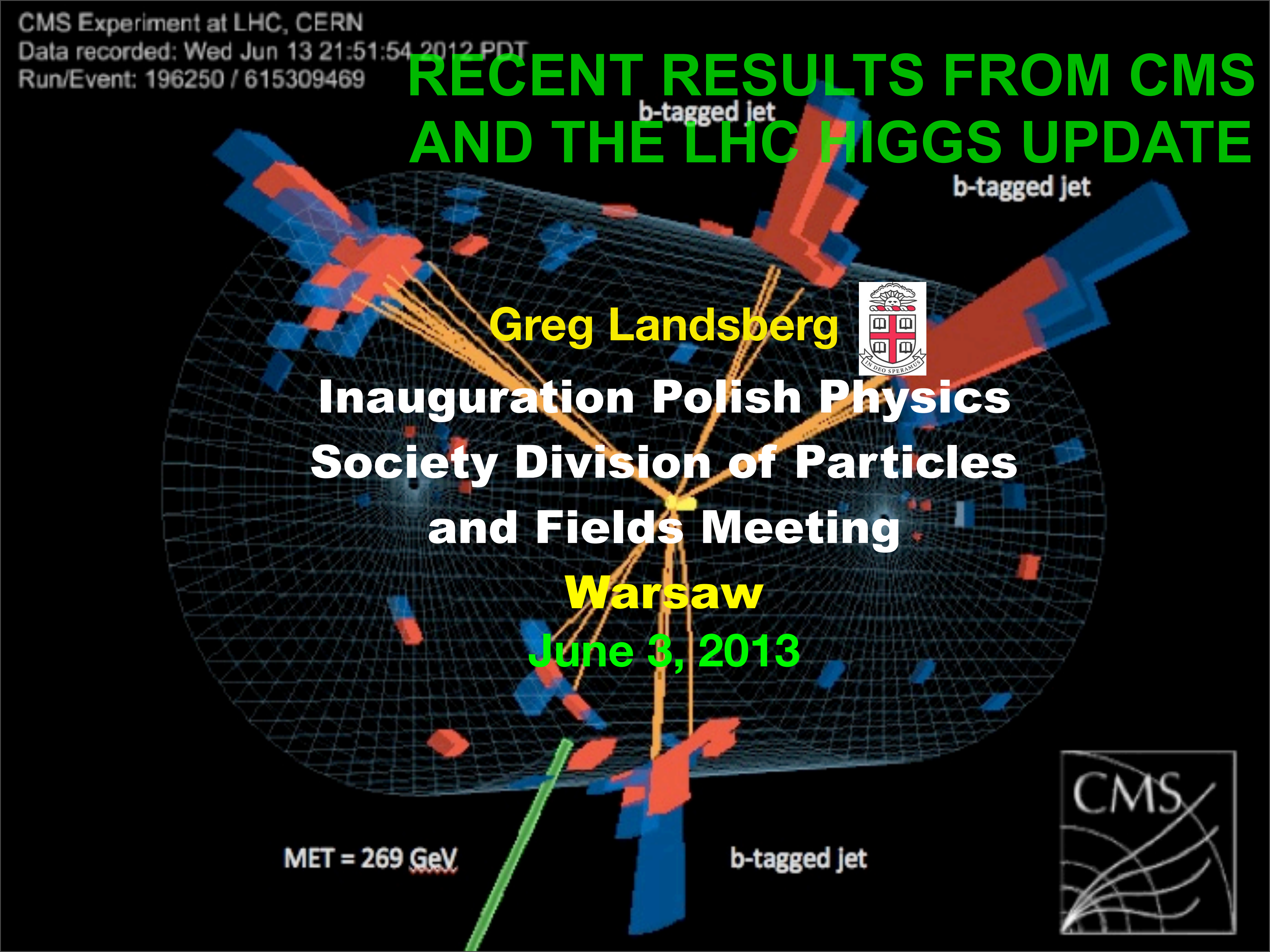
RECENT RESULTS FROM CMS AND THE LHC HIGGS UPDATE

Greg Landsberg

Inauguration Polish Physics Society Division of Particles and Fields Meeting

Warsaw

June 3, 2013



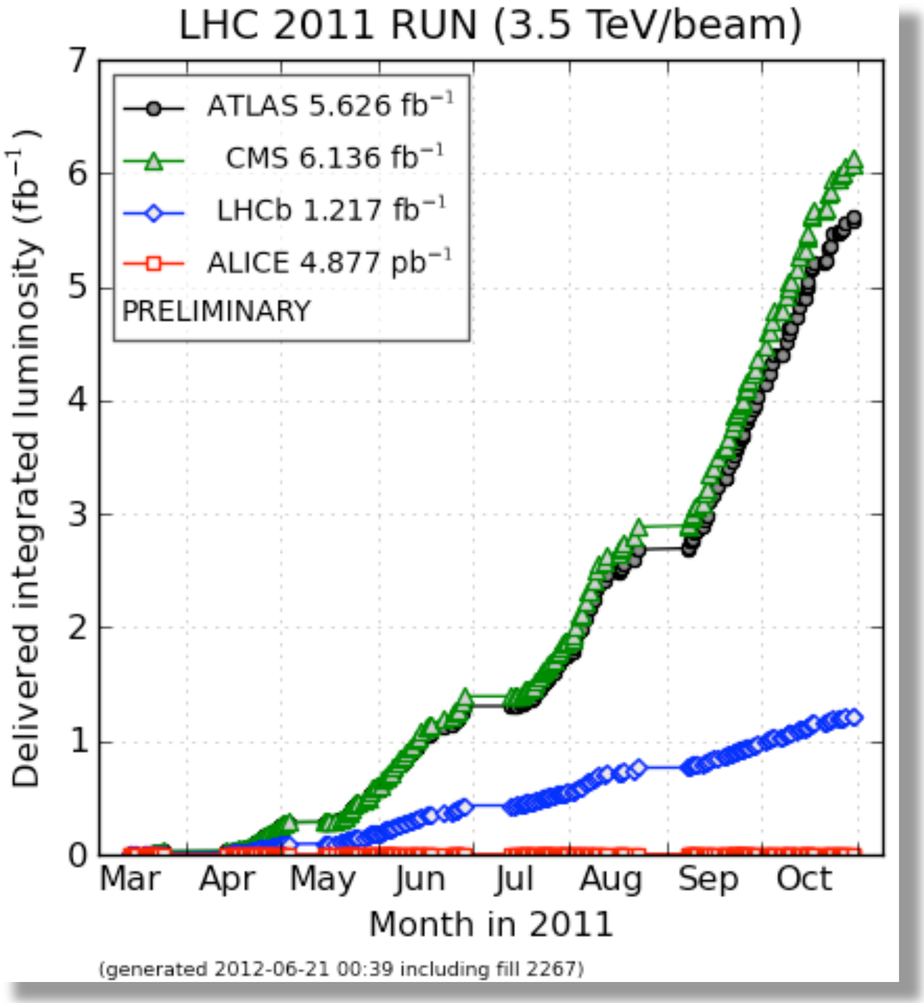
Outline

- LHC and CMS Performance
- The LHC: Three Machines in One
- B-Physics Measurements
- Heavy Ion Results
- Standard Model Measurements
- The Higgs Story
- Highlights from Searches
    - Lessons from the Higgs discovery
    - Naturalness, as a guiding light
- Conclusions

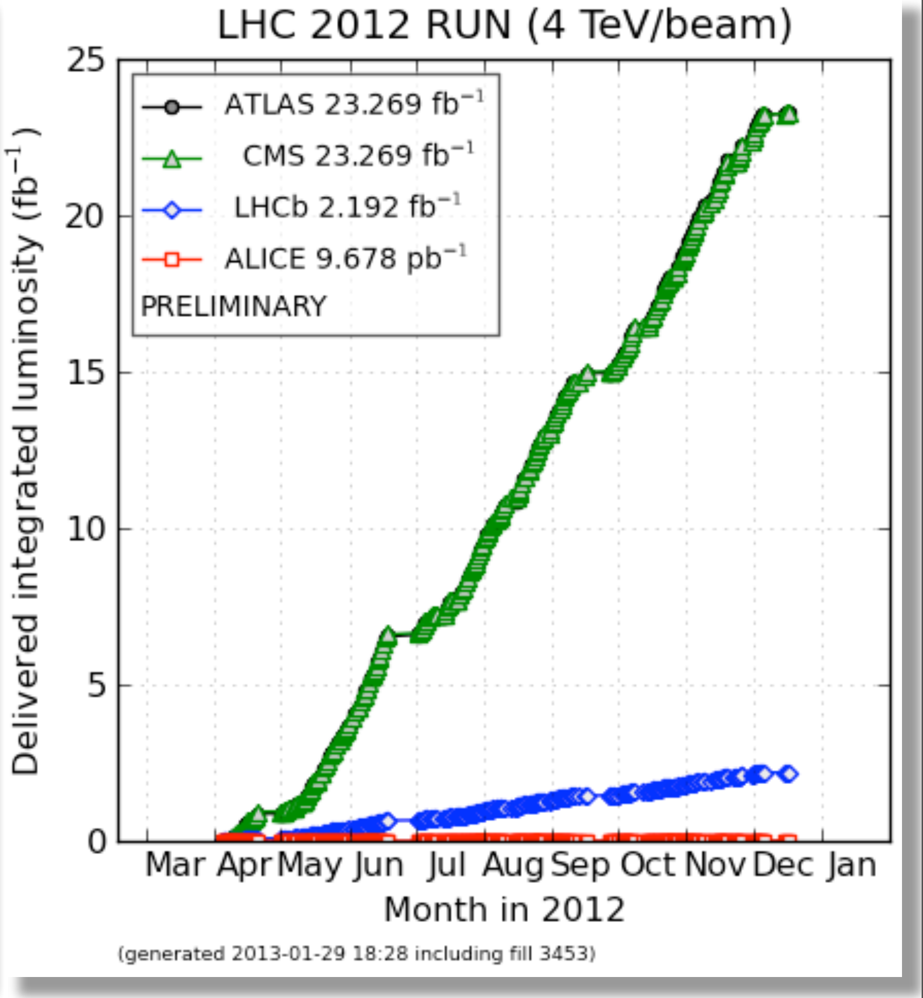
The LHC Playground

Measure of Our Success

- ✦ Thank you, the LHC, for spectacular 3 years and ~30/fb delivered!



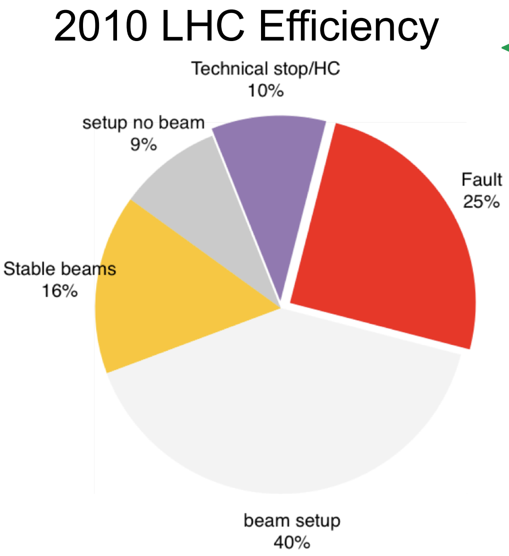
(generated 2012-06-21 00:39 including fill 2267)

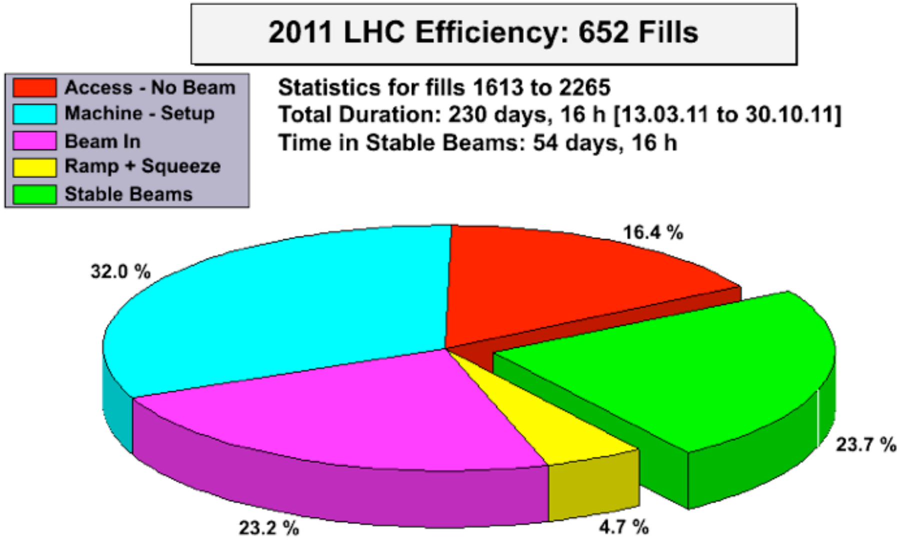


(generated 2013-01-29 18:28 including fill 3453)

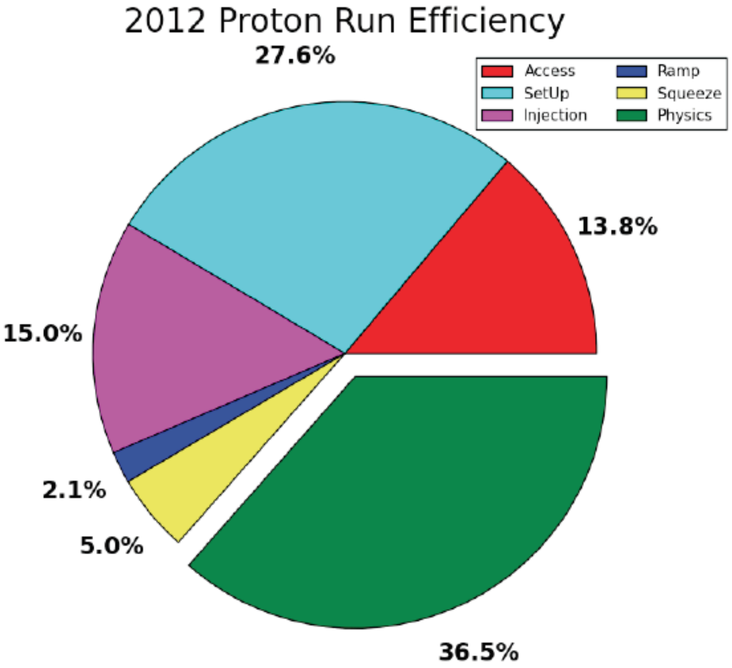
Great Running Efficiency

- Fraction of the LHC operations used for physics:
  - 2010: 16%
  - 2011: 23.7%
  - 2012: 36.5%





Statistics for fills 1613 to 2265
Total Duration: 230 days, 16 h [13.03.11 to 30.10.11]
Time in Stable Beams: 54 days, 16 h

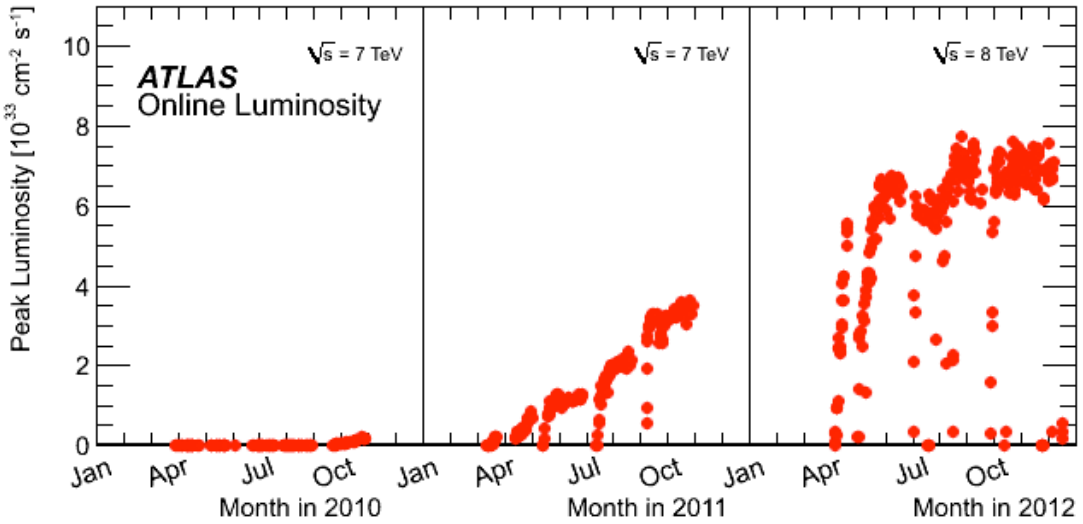


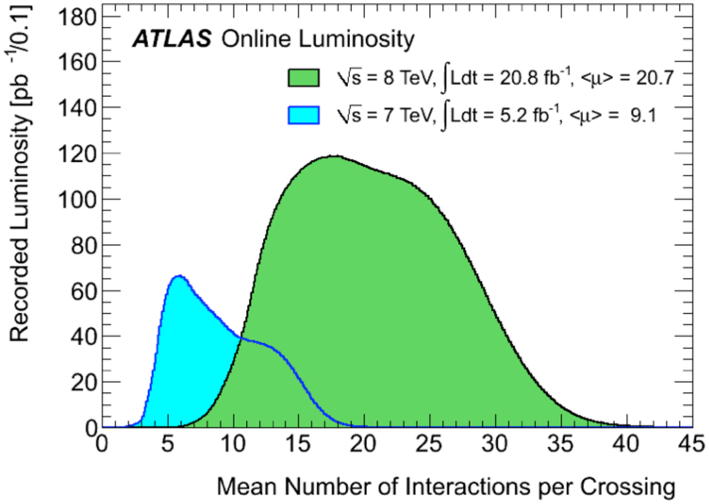
SB Time: 73.2 days Total Time: 200.5 days

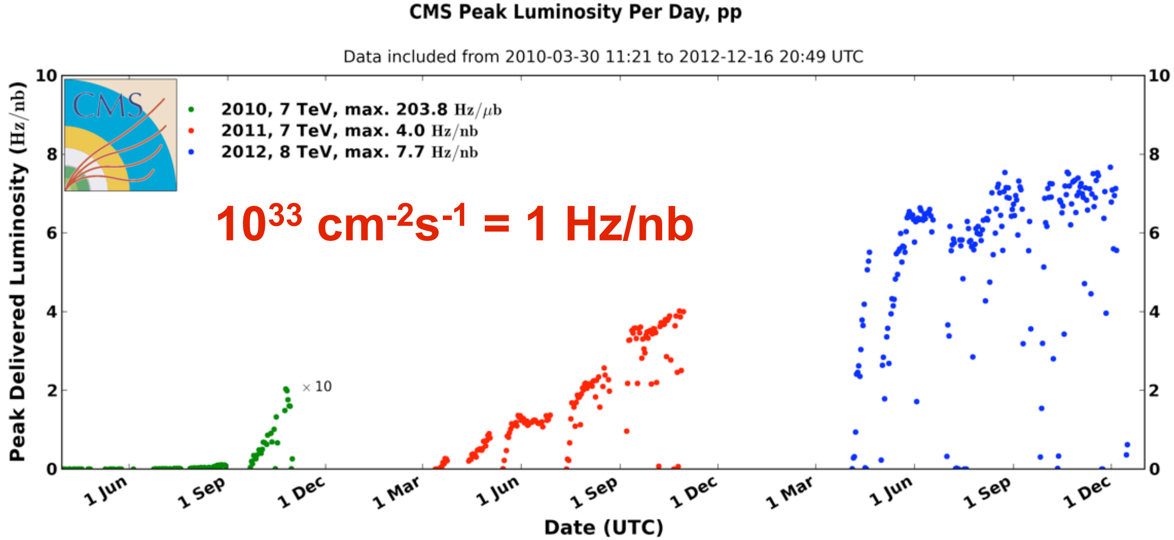
Alick Macpherson

Ever-Increasing Luminosity

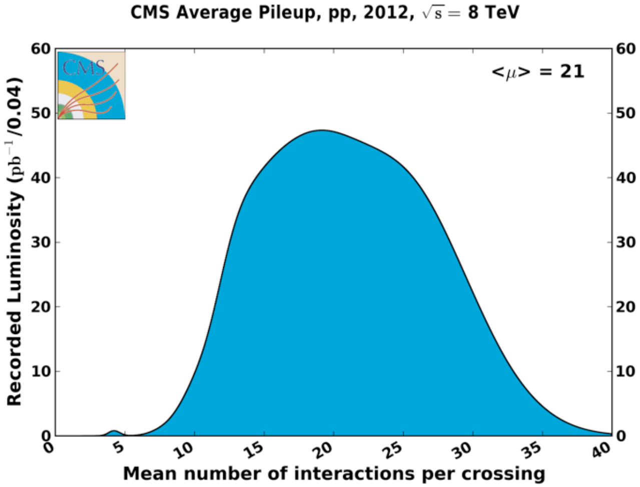
- Luminosity records were set monthly, often weekly!







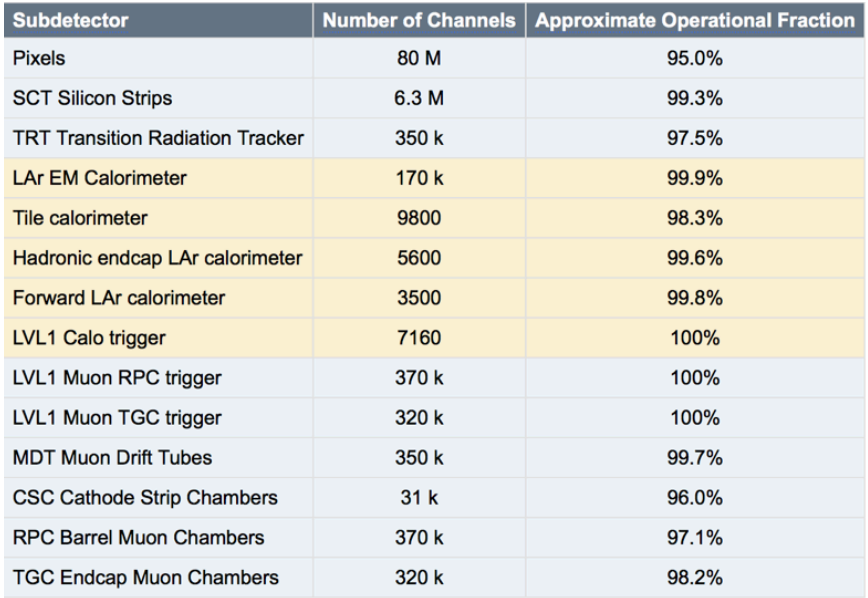
10^{33} cm^{-2}s^{-1} = 1 Hz/nb



Excellent Detector Performance

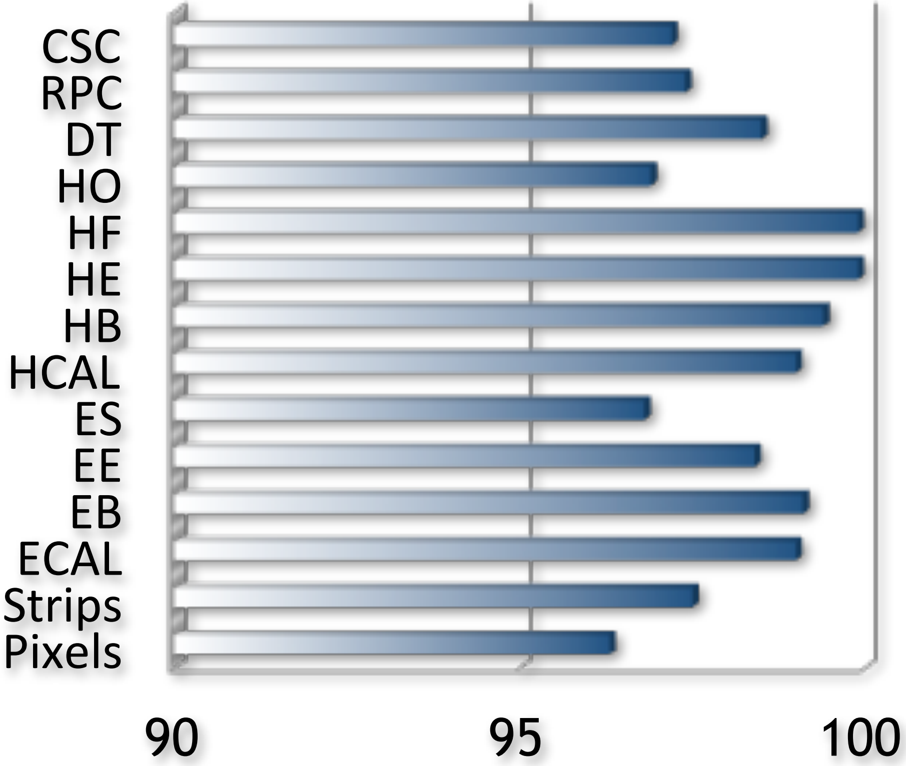
- The LHC detectors have been working spectacularly with virtually no degradation in performance over the three years of LHC Run 1
  - In some cases, original losses in performance was recovered

ATLAS Performance in 2012



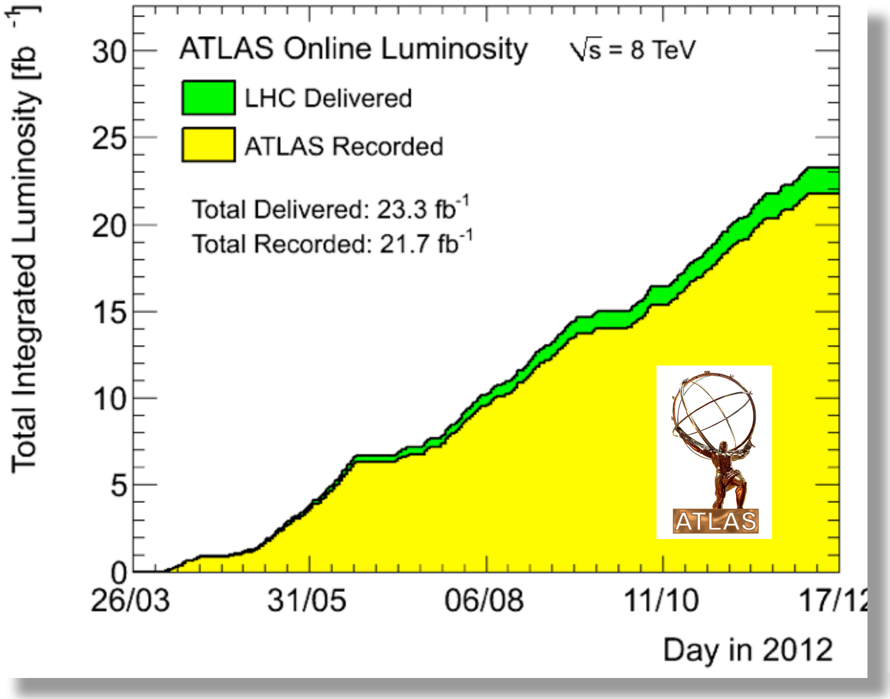
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

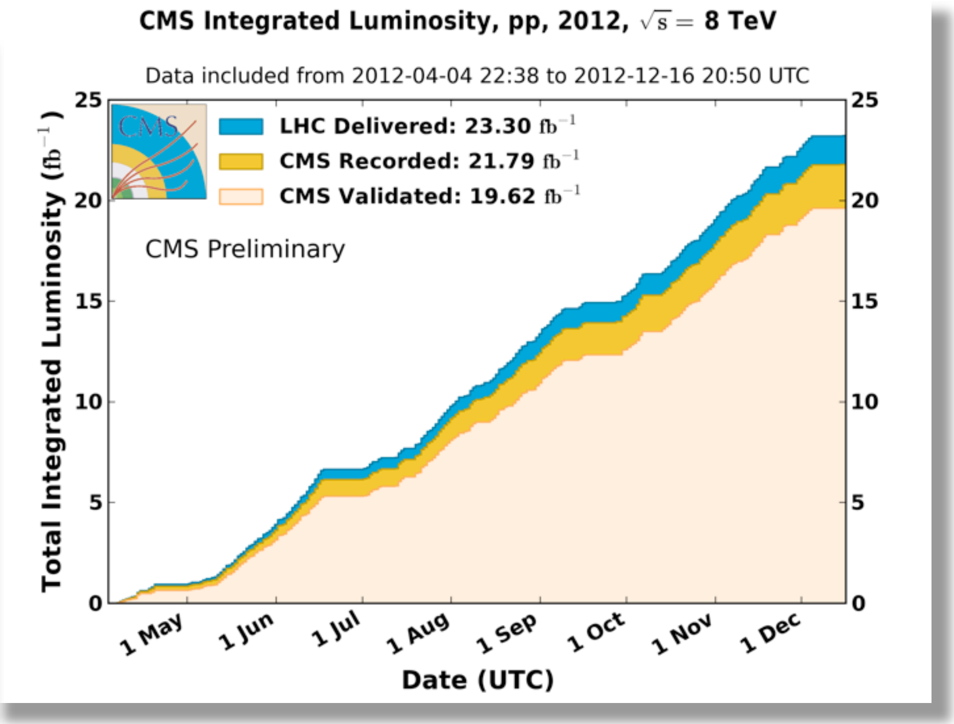
CMS Status in Feb 2013 (%)



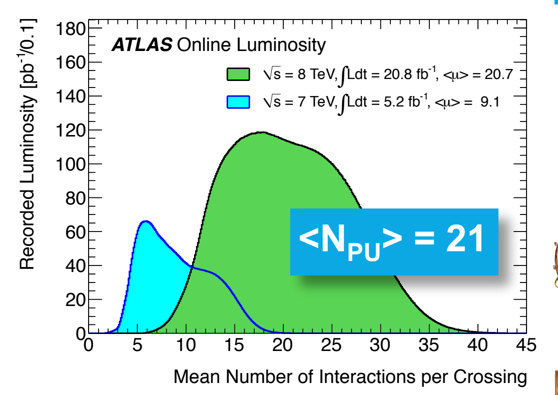
High-Quality Data

- Excellent detector performance resulted in very high data quality: ~95% of delivered data are recorded, and ~95% of those are certified and used in physics publications!
  - We publish based on ~90% of all the bunch collisions that took place in the LHC!



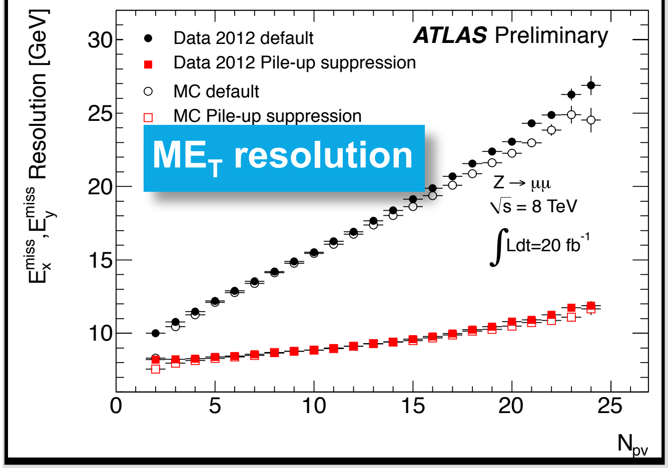


Successful Pileup Mitigation

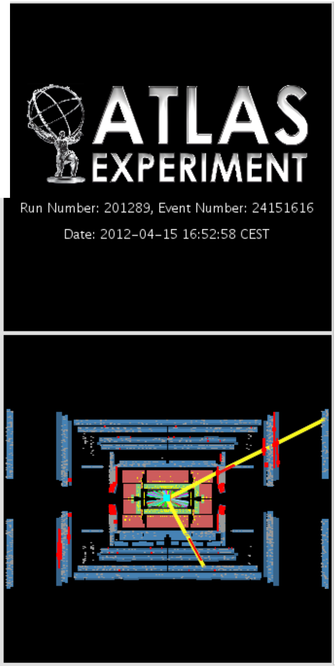


$<N_{PU}> = 21$

LHC already reached nominal pileup rate; experiments cope well!

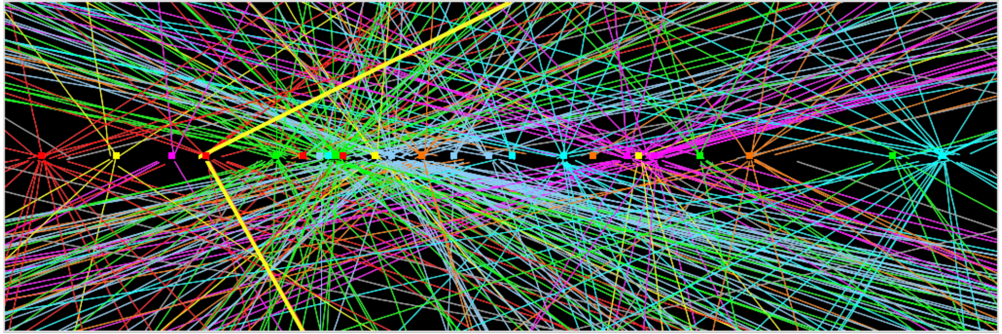


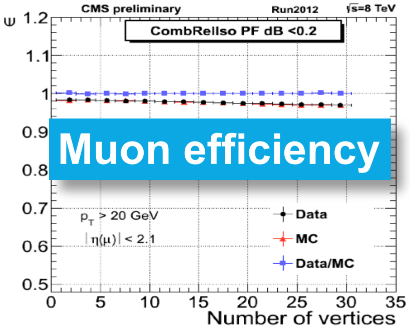
ME_T resolution



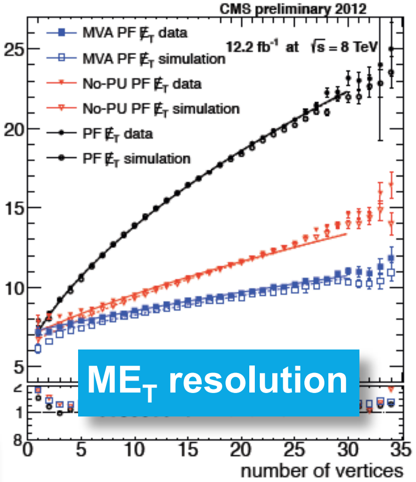
Run Number: 201289, Event Number: 24151616

Date: 2012-04-15 16:52:58 CEST





Muon efficiency



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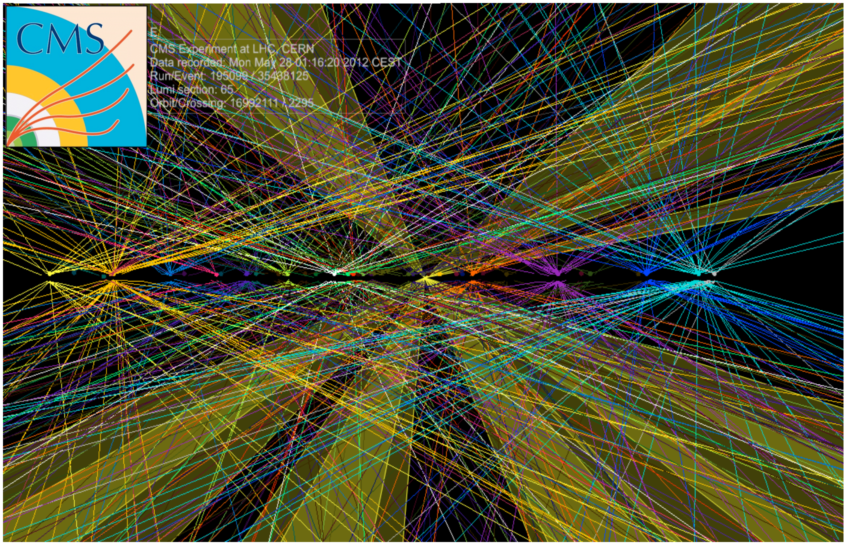


CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295

Three Machines in One!

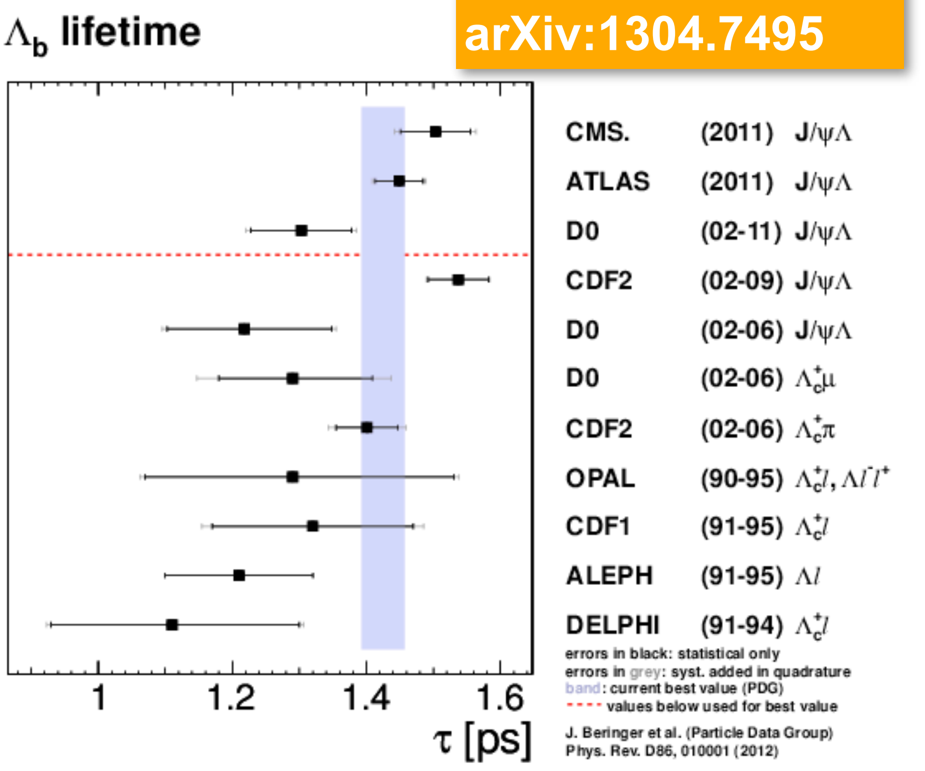
The LHC Legacy

- The LHC has in fact (allegorically) replaced three machines in one go:
  - Tevatron (Higgs, BSM searches, top physics, and precision EW measurements)
  - Belle (precision B-physics)
  - RHIC (heavy-ion physics)
- The LHC experiments are very successful in all these three areas
- Would not be possible without theoretical and phenomenological breakthroughs of the past decade:
  - Higher-order calculations, modern Monte Carlo generators, reduced PDF uncertainties
- I'll present a few CMS highlights from the first three years of the LHC operations in flavor physics, heavy-ion physics, and the discovery program, with the focus on the latter
  - In addition, when talking about the Higgs physics, I'll show the latest ATLAS results as well (per organizers' request)

B-Physics Highlights

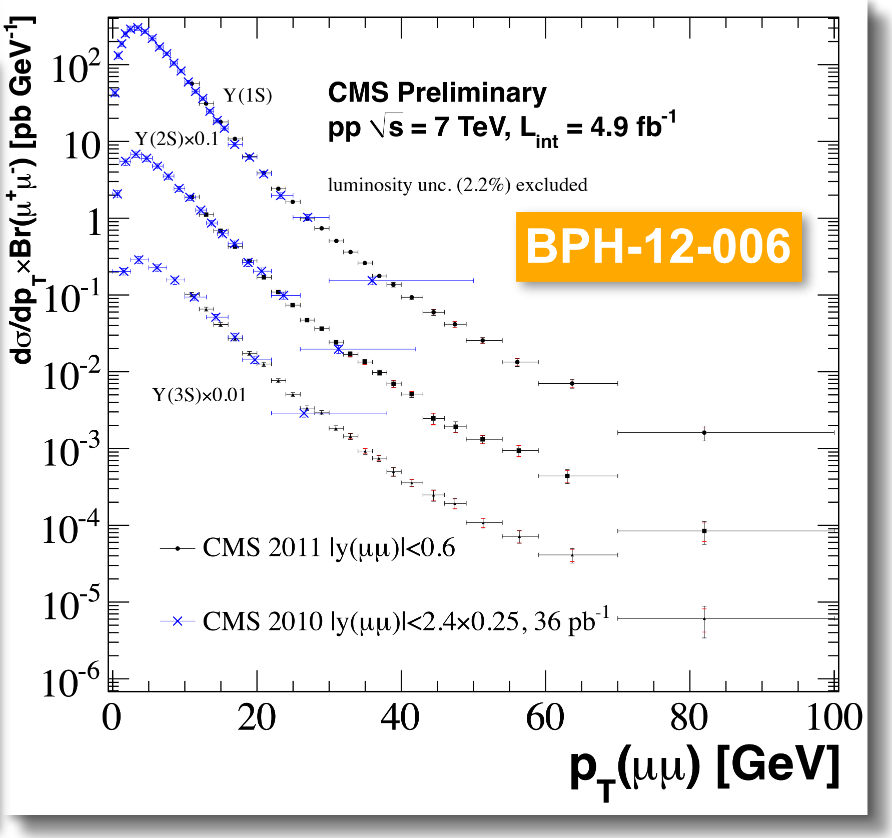
B-Physics: Production

- New measurement of Λ_b lifetime in 7 TeV data
  - τ = 1.503 ± 0.052 (stat.) ± 0.031 (syst.) ps



CMS Collaboration arXiv:1304.7495

- Measurement of differential $d\sigma/dp_T$ Υ(nS) production cross section with full 7 TeV data sample

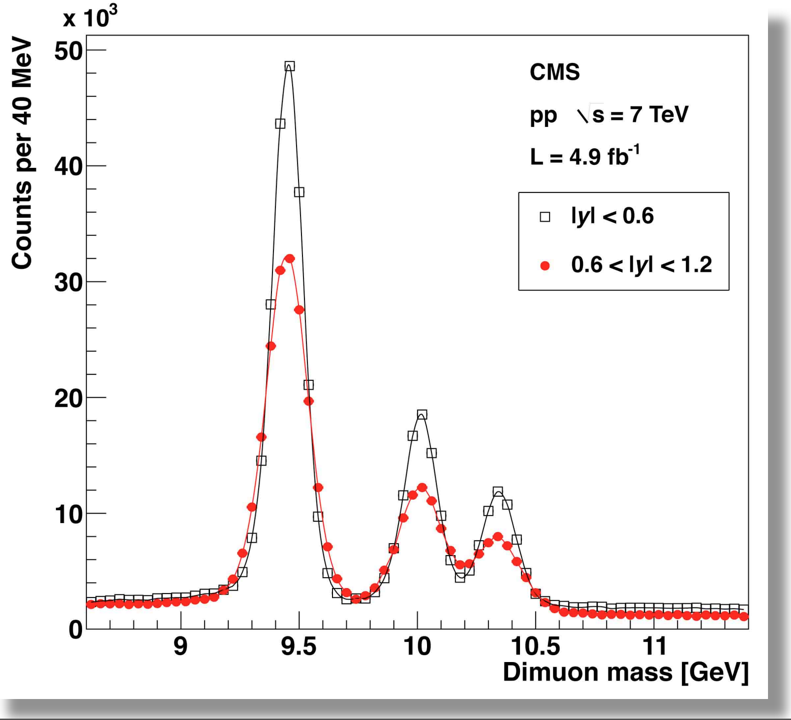


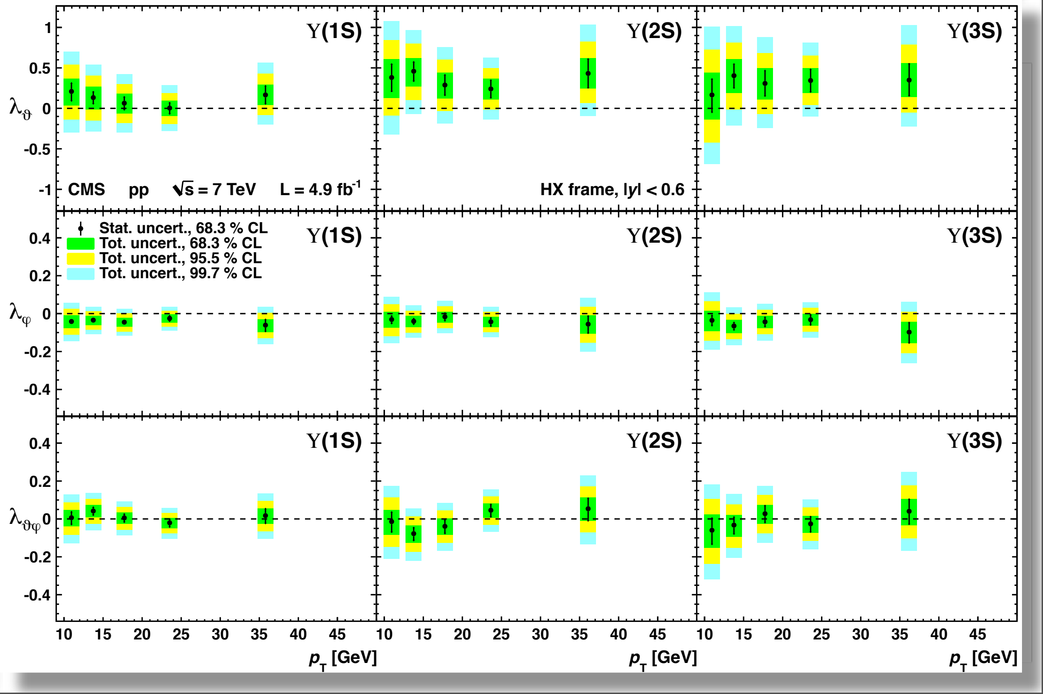
BPH-12-006

Measurement of Υ/Ψ Polarization

- First measurement of Υ(1S-3S) polarization at the LHC
- Now extended to Ψ(2S) polarization measurement **BPH-13-003**
- No evidence for large transverse or longitudinal polarization in the explored kinematic range, in contradiction with theoretical predictions
  - A bit of a crisis in NRQCD - needs to be resolved!

BPH-11-023
PRL 110 (2013) 081802





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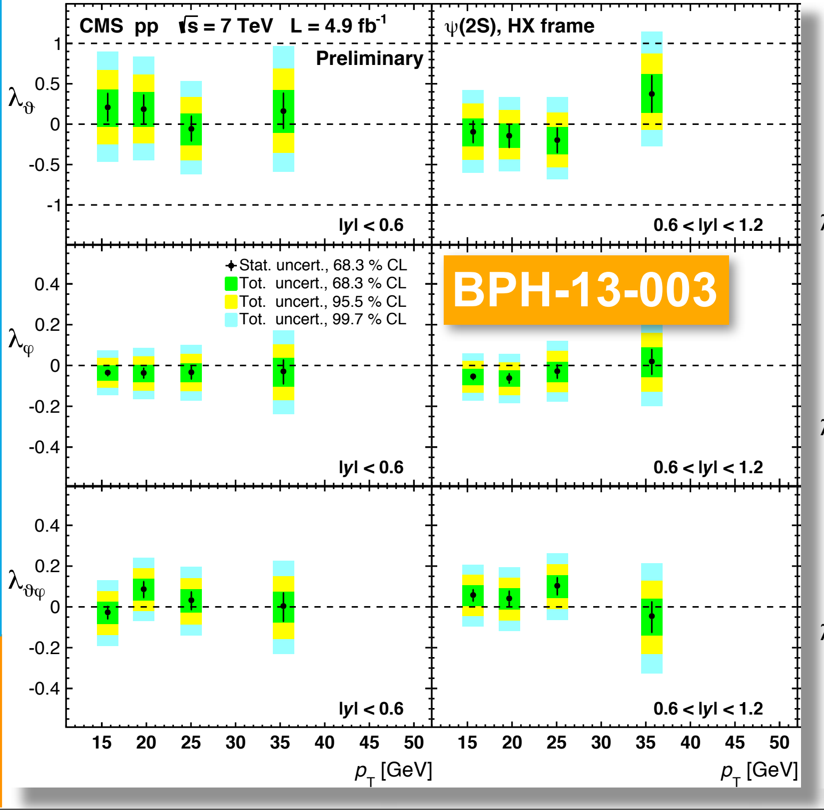

BPH-13-003

BPH-11-023
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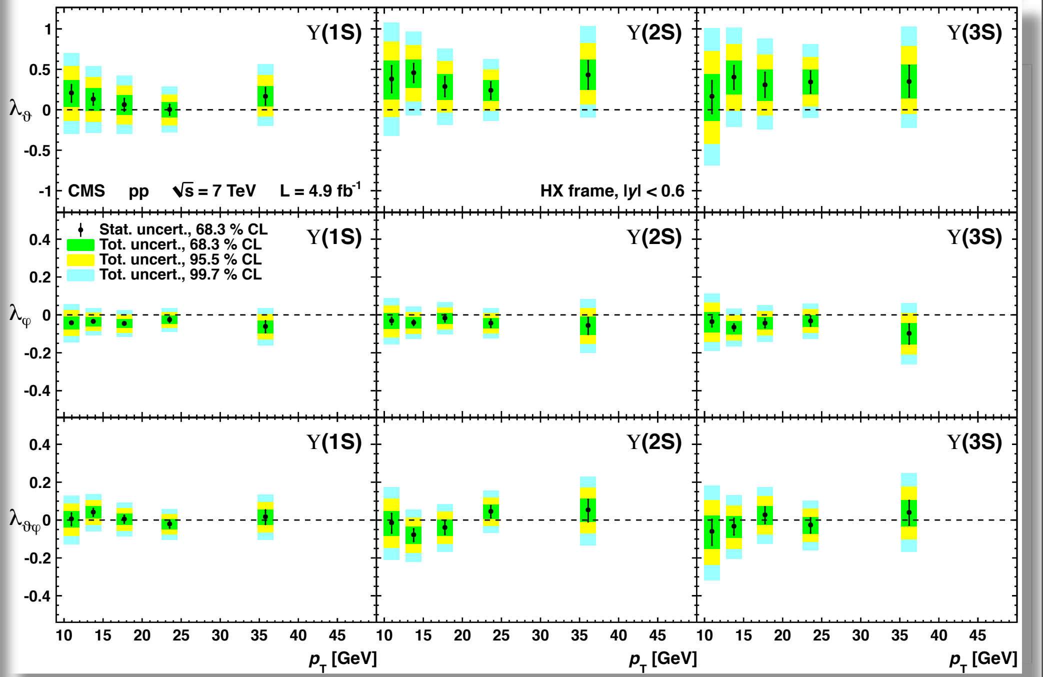
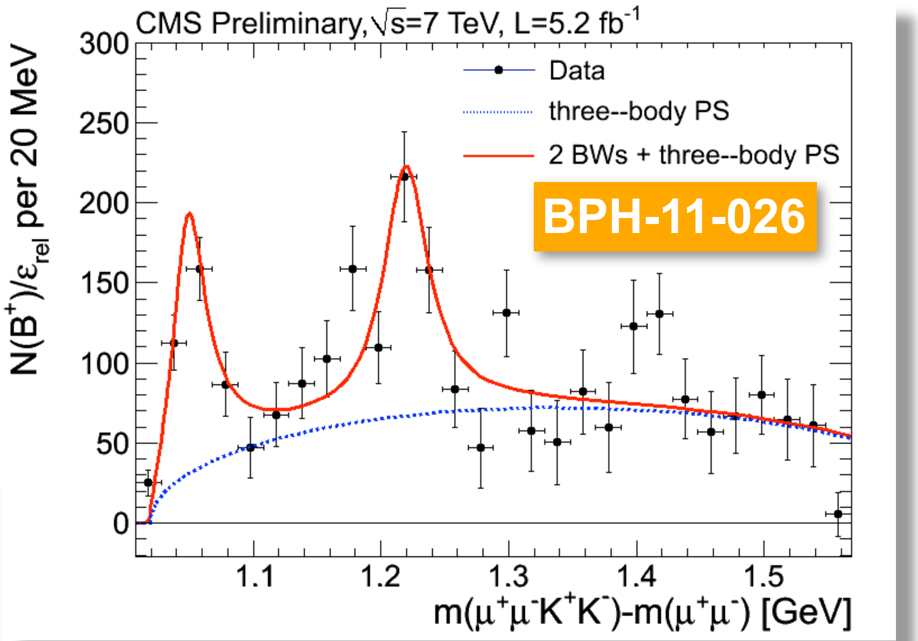
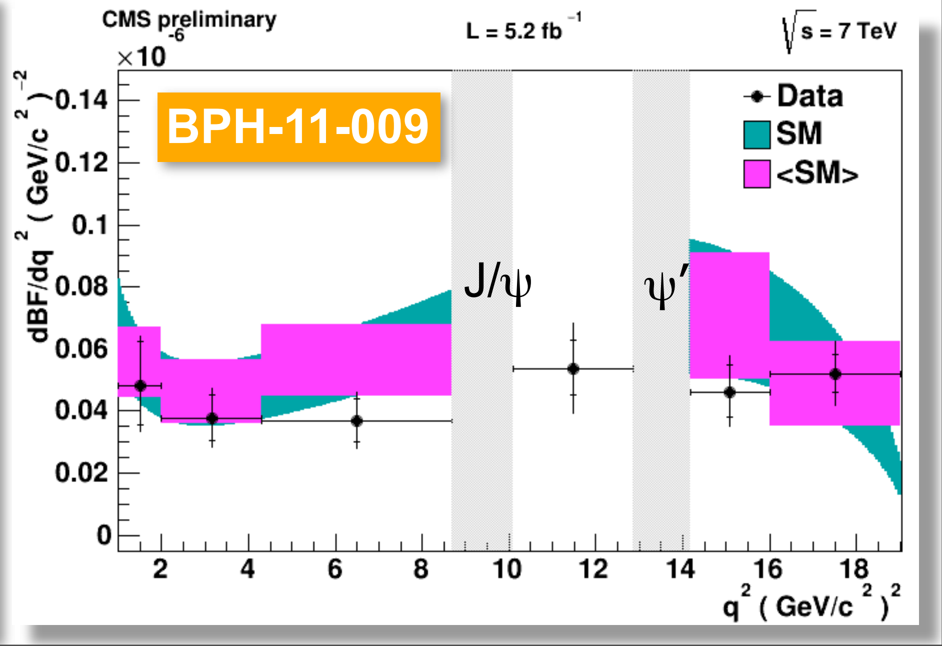


B-Physics: Rare Decays

- Confirmation of a structure earlier observed by CDF and observation of a second structure in the J/ψϕ spectrum from B^+ decays
- Full angular analysis of the $B^0 \rightarrow \mu^+\mu^-K^0$ decay and determination of differential branching fraction as a function of dimuon invariant mass squared

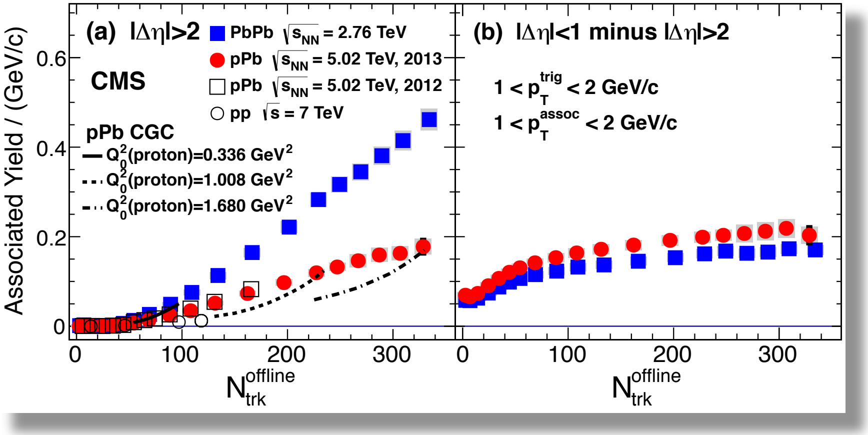




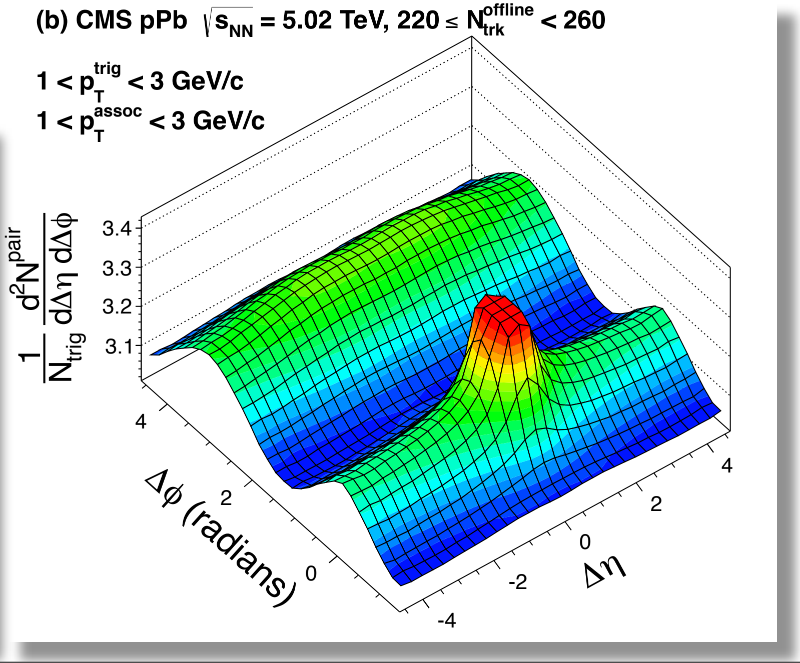
Heavy-Ion Highlights

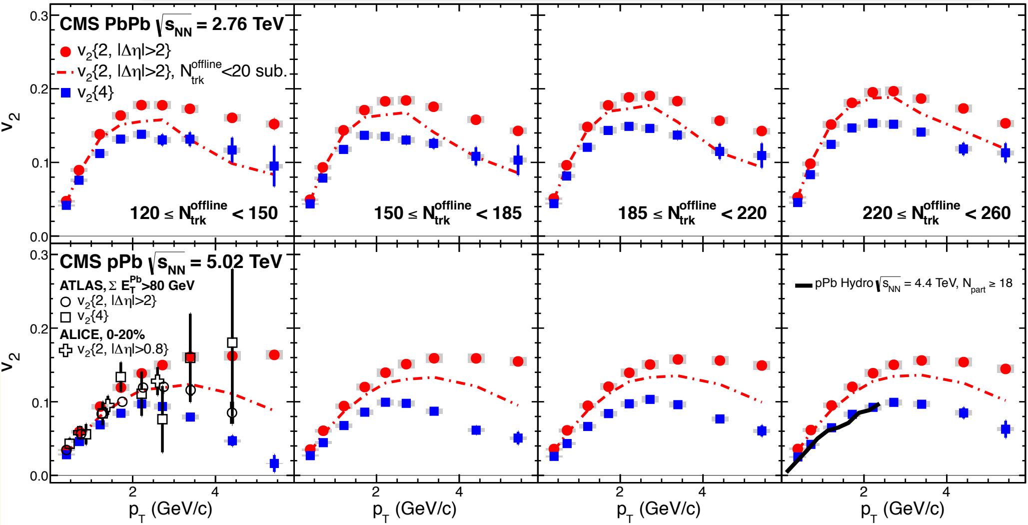
Ridge in high-multiplicity pPb

- ✦ Ridge yield measurement is now extended to much larger multiplicities in pPb collisions
- ✦ Determination of 4-particle correlations and elliptic flow in the ridge region



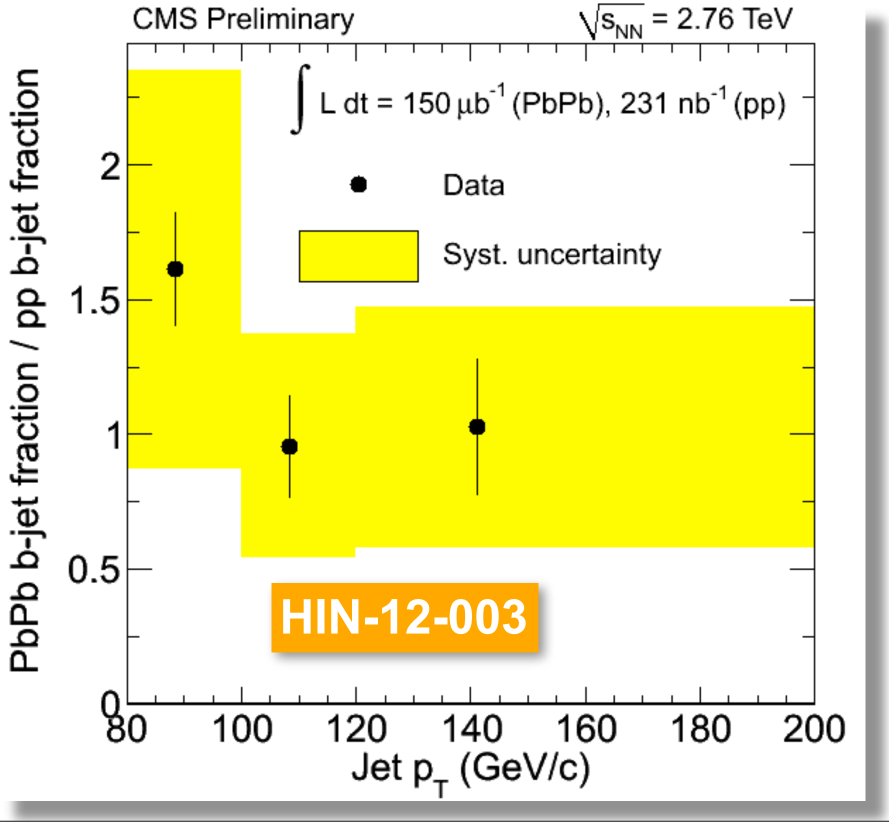
CMS Collaboration
arXiv:1305.0609



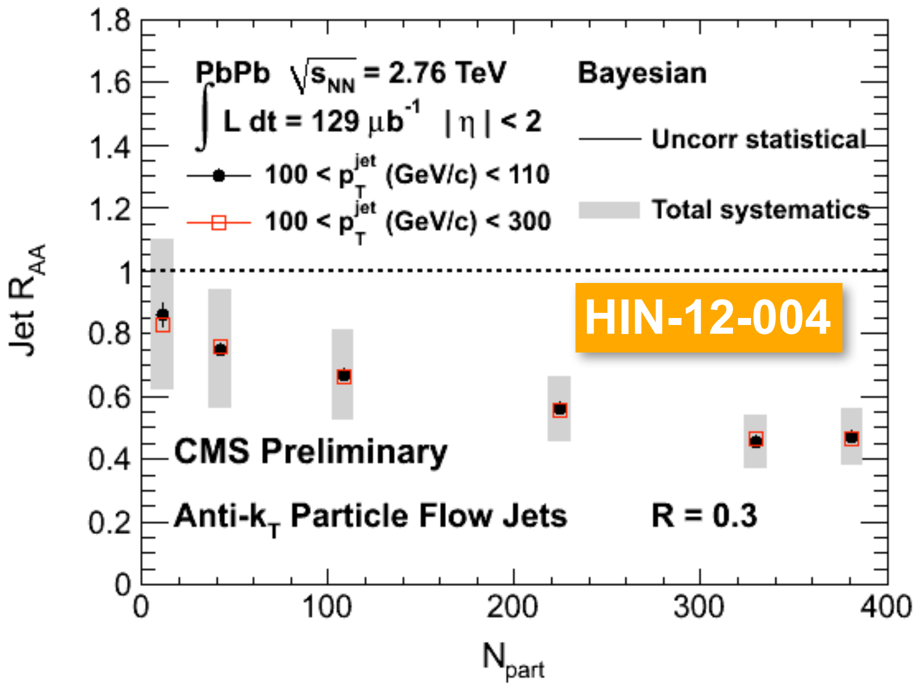


Nuclear Modification Factors

- First measurement of the b-jet yield in PbPb collisions using secondary-vertex reconstruction
- Measurement of the nuclear modification factor for high-p_T jets in PbPb collisions (compared to that in pp collisions)



HIN-12-003

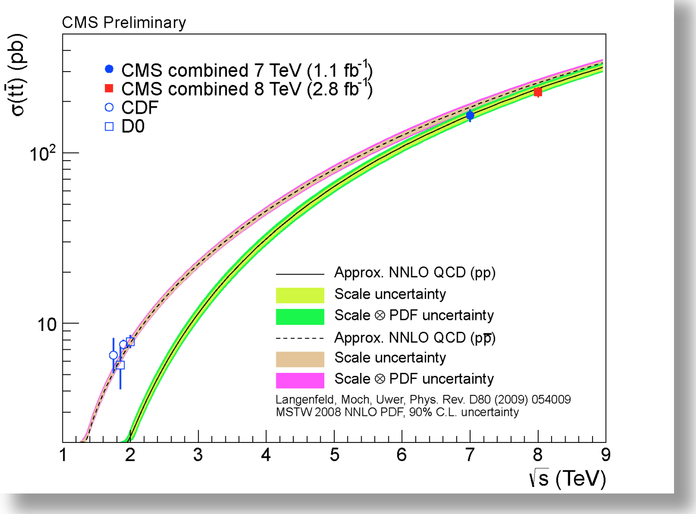


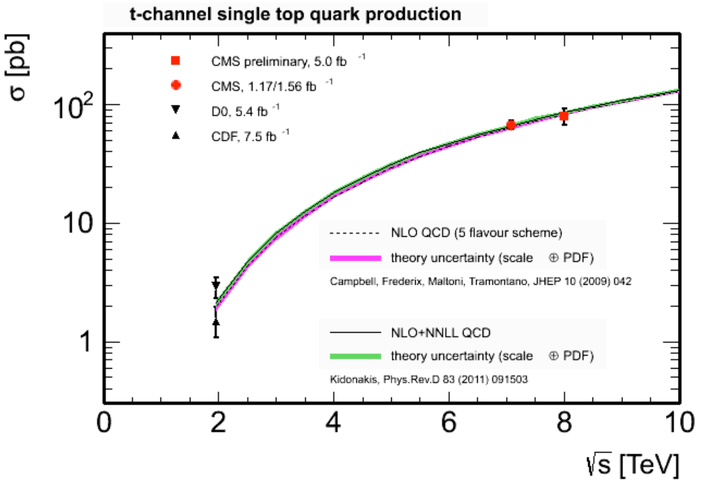
HIN-12-004

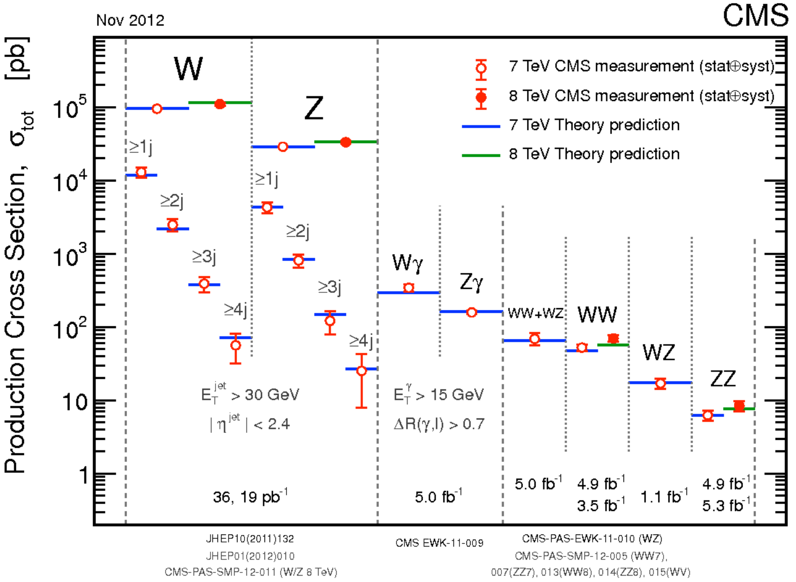
Standard Model Highlights

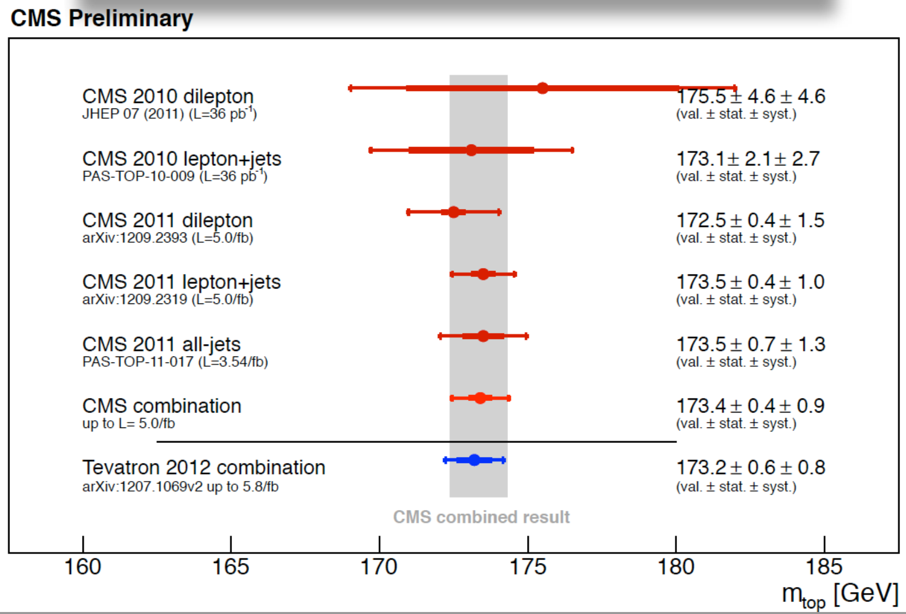
The Big Picture

- CMS has measured most of the SM processes with unprecedented precision



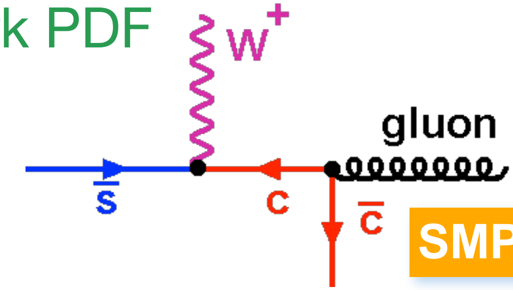






V+jets Highlights

- W+c production with exclusive charm tagging via full reconstruction of D±, D*, and semileptonic decays
- Direct access to the strange-quark PDF

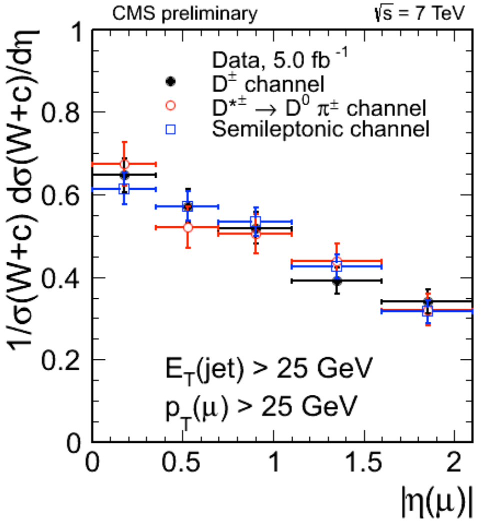


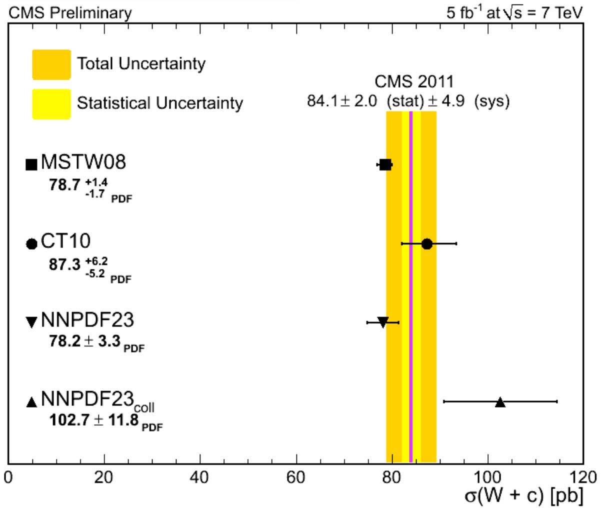
SMP-12-002

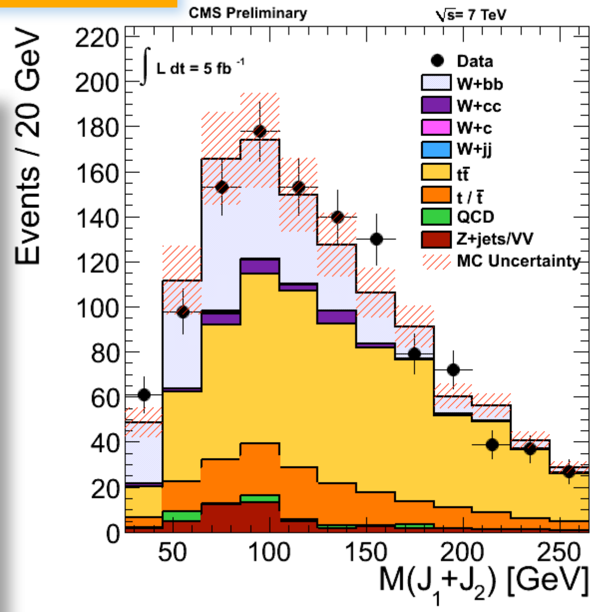
- W+bb/Z+bb cross section measurement
- σ x $Br(W\to\mu\nu) = 0.53 \pm 0.12$ pb @ 7 TeV ($p_T^{b,\mu} > 25$ GeV), in good agreement with the NLO prediction of 0.52 ± 0.03 pb
- σ x $Br(Z\to ll) = 0.36 \pm 0.07$ pb @ 7 TeV ($p_T^{b} > 25$ GeV)

SMP-13-004

SMP-12-026



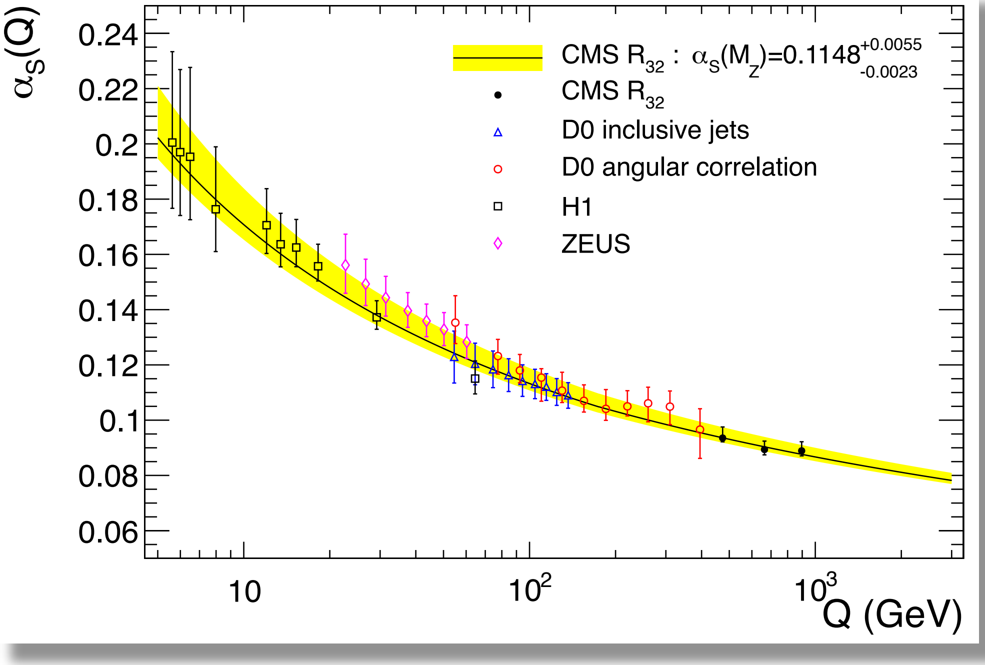




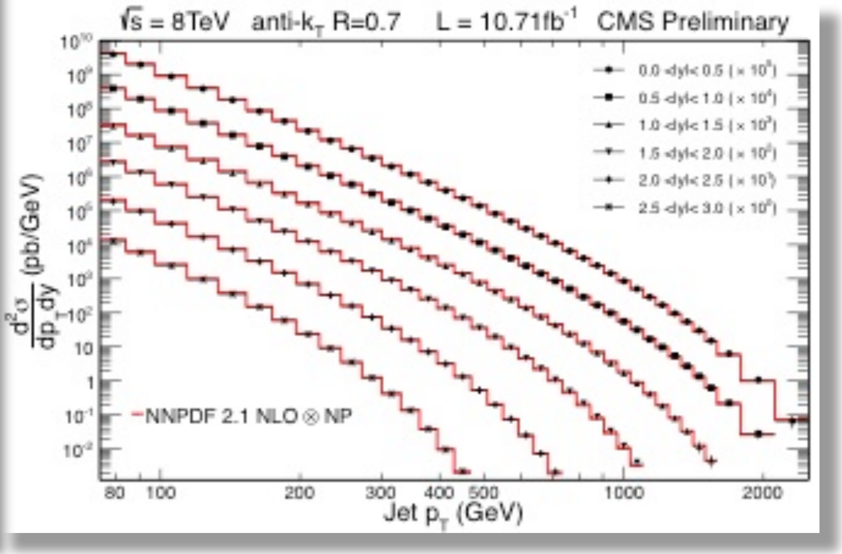
Jet Physics Highlights

- New measurement of the α_S via the ratio of 3 to 2 jet events:
  - $\alpha_S(M_Z) = 0.1148 \pm 0.0014$ (exp.) ± 0.0018 (PDF) $^{+0.0050}_{-0.0000}$ (scale)
- First differential inclusive jet cross section measurement at 8 TeV – important input to PDF fits

QCD-11-003
arXiv:1304.7498



SMP-12-012



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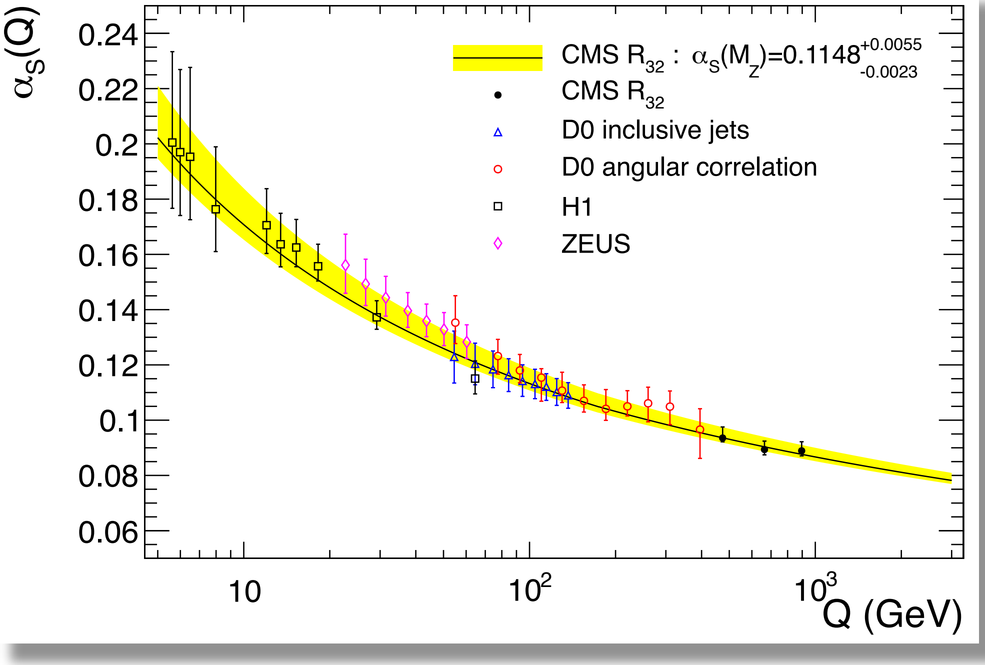
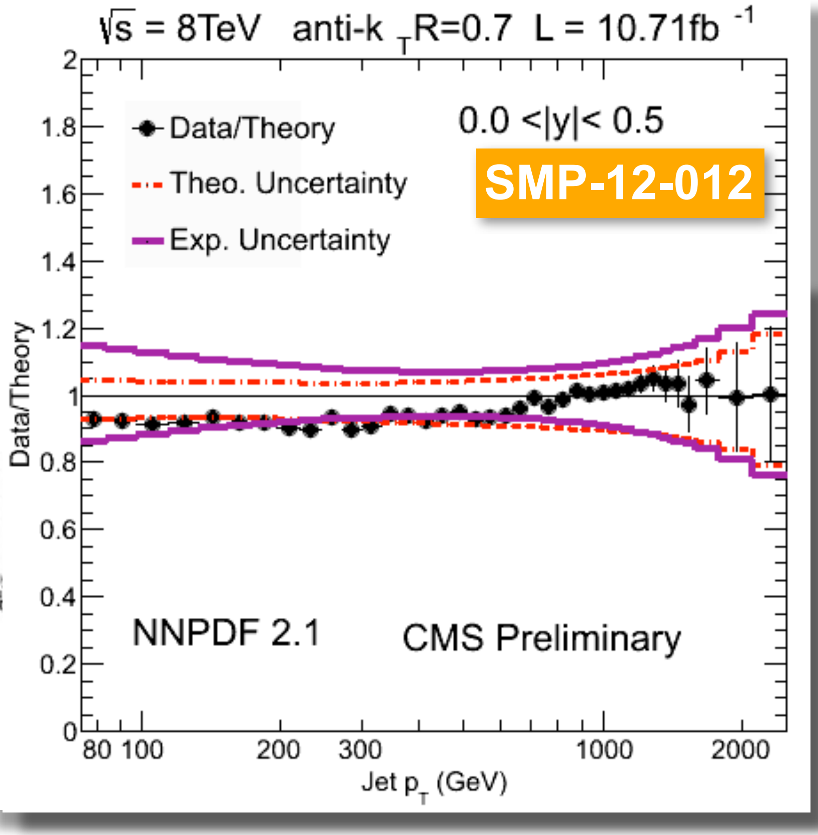
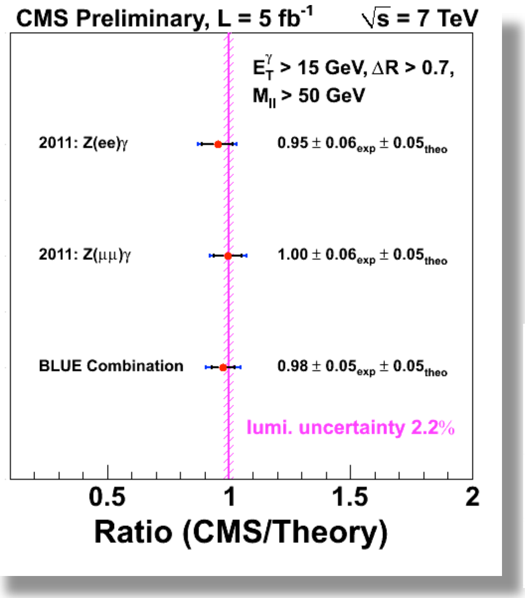
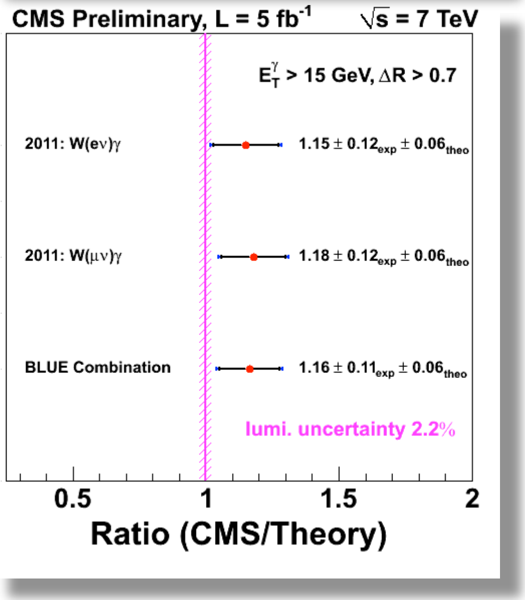


SMP-12-012



Triple Gauge Couplings

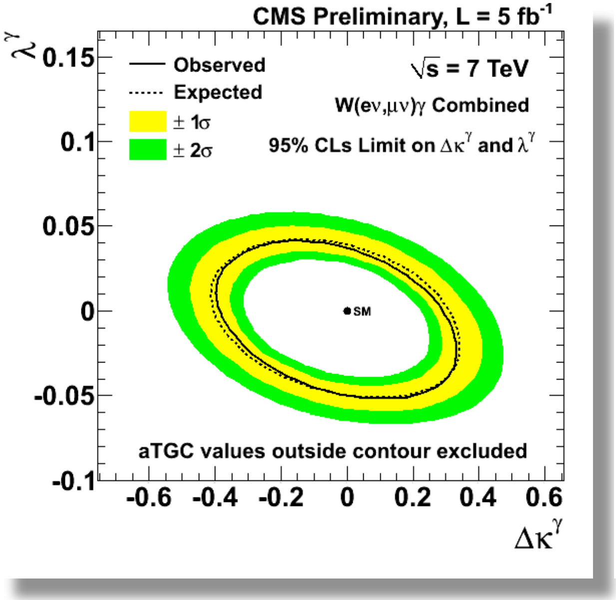


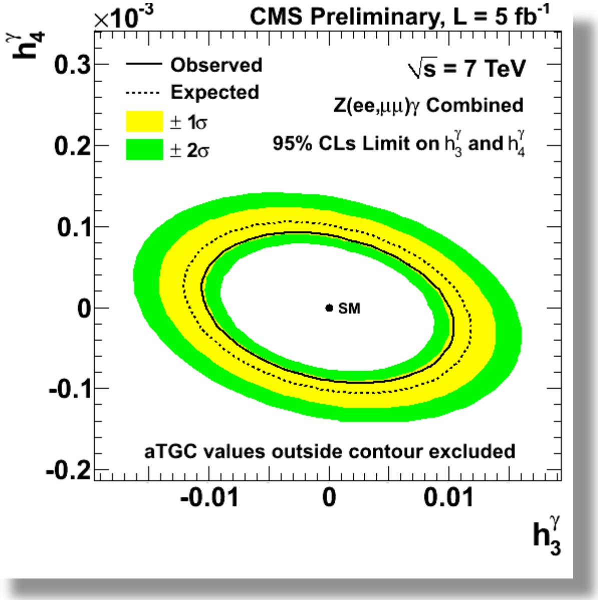


- ✦ Precision measurement of Wγ and Zγ production cross sections and most stringent limits on anomalous Zγγ couplings to date

EWK-11-009

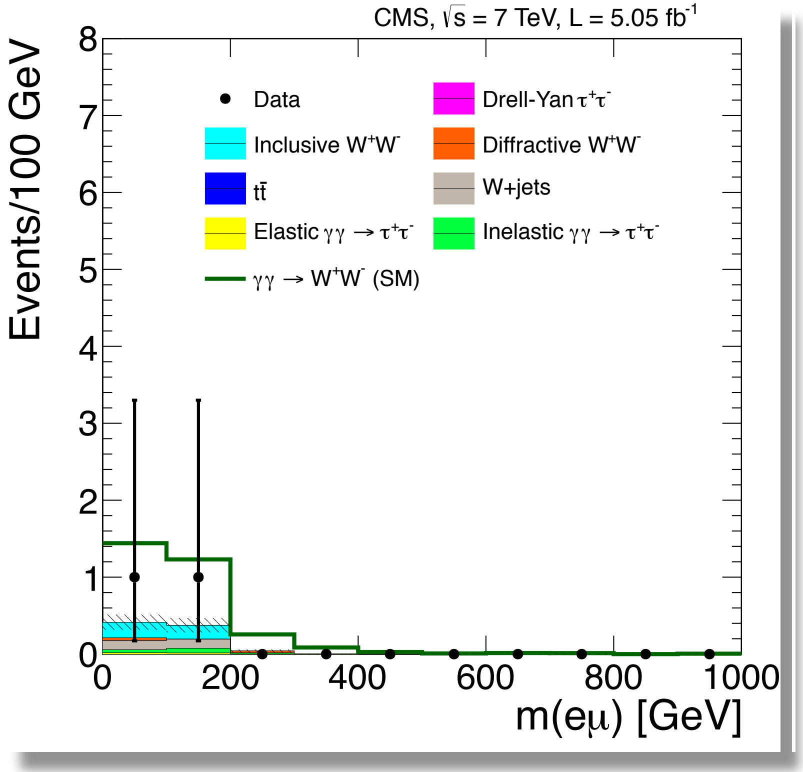
Coupling	95% CL Limit	95% CL Limit
WWγ	$-0.38 < \kappa_\gamma < 0.29$	$-0.050 < \lambda_\gamma < 0.037$
Zγγ	$-0.010 < h_3^\gamma < 0.010$	$\|h_4^\gamma\| < 8.8\text{x}10^{-5}$
ZZγ	$-0.0086 < h_3^Z < 0.0084$	$-8.0\text{x}10^{-5} < h_4^Z < 7.9\text{x}10^{-5}$



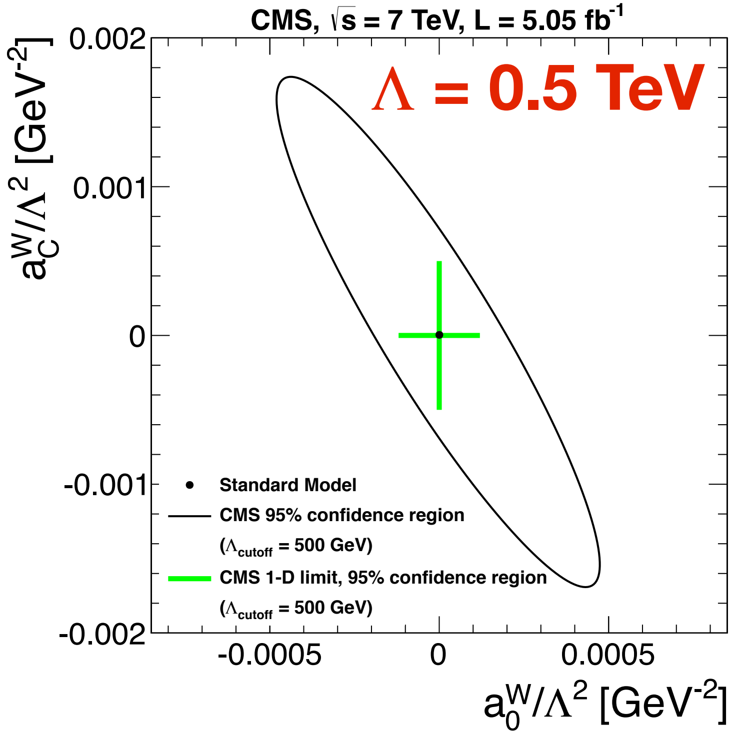


Exclusive WW Production

- Exclusive $\gamma\gamma \rightarrow WW(e\mu + ME_T)$ at 7 TeV
- 2 events observed with 2.2 ± 0.4 signal and 0.84 ± 0.15 background events expected
- Set stringent limits on anomalous quartic $\gamma\gamma WW$ couplings two orders of magnitude beyond beyond LEP (Λ = 0.5 TeV) and the Tevatron (no form-factor): $a_0{}^W/\Lambda^2 < 7.5 \times 10^{-6}$ GeV^{-2}; $a_C{}^W/\Lambda^2 < 2.5 \times 10^{-5}$ GeV^{-2} at 95% CL

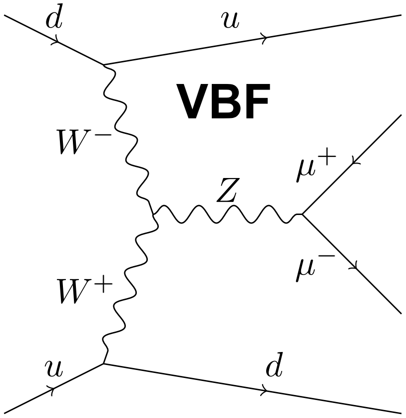


CMS Collaboration
arXiv:1305.5596

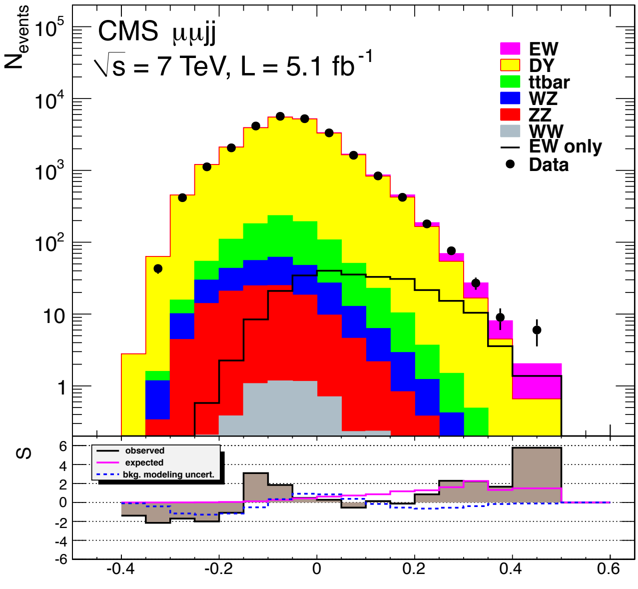


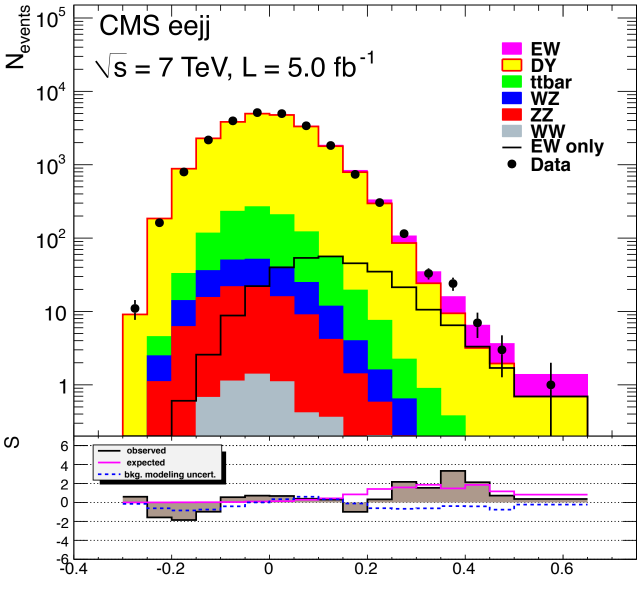
VBF Z Production

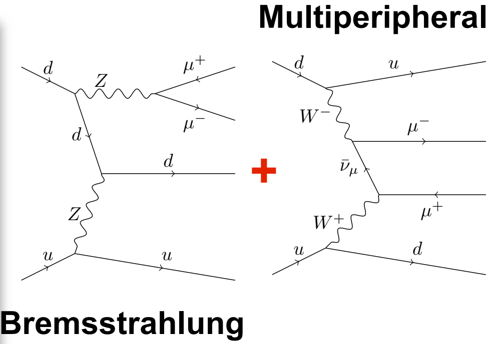
- Evidence for a VBF Z boson production – a crucial measurement for the Higgs VBF studies (paper to be submitted)
  - Thought to be very hard due to dominant channel background
- Require large rapidity gap between the tag jets and use advanced multivariate techniques (BDT) to extract signal
- See ~3σ evidence for EW production of the Z
- Measured cross section:
  - σ(μμ+ee) = 154 ± 24 (stat.) ± 46 (syst.) ± 27 (th.) ± 3 (lum.) fb
  - Theoretical NLO cross section: 166 fb



Negative interference with:

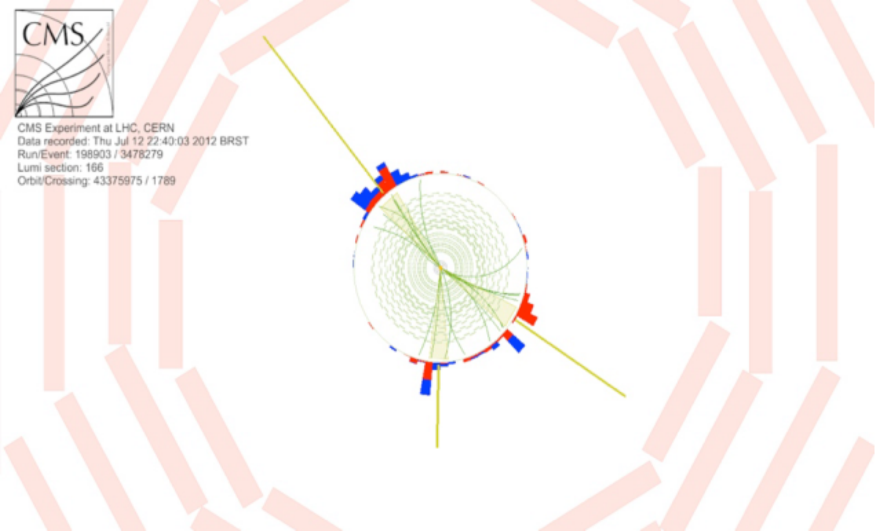


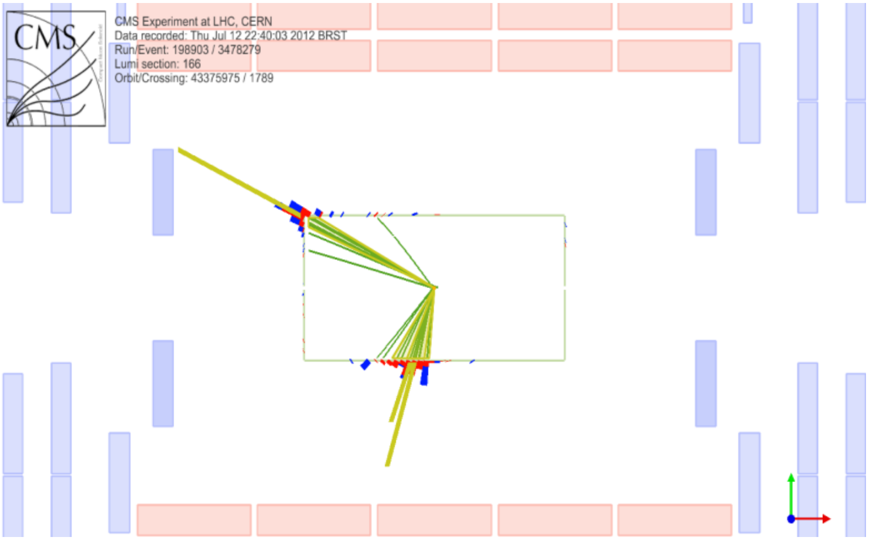




CMS Collaboration arXiv:1305.7389

Newlywed: CMS+TOTEM



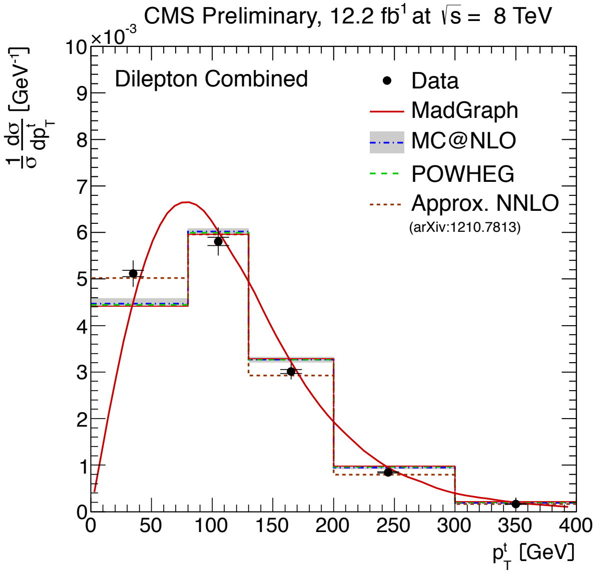


- First event displays of high-p_T jets with leading protons at 8 TeV
- Based on β*=90m data, taken using common triggers with TOTEM
  - 3 jets with pT >20 GeV
  - Protons tagged in TOTEM Roman Pots in both directions
  - No hits in CMS Forward Shower Counters (|η| ~ 6-8)
- Kinematics of activity reconstructed by CMS and TOTEM are compatible
  - m(CMS,jj) = 219 GeV
  - m(TOTEM, pp recoil) = 244 GeV
- Further analysis of common data ongoing
- Working toward joint CMS+TOTEM publication of activity reconstructed by CMS and TOTEM are compatible

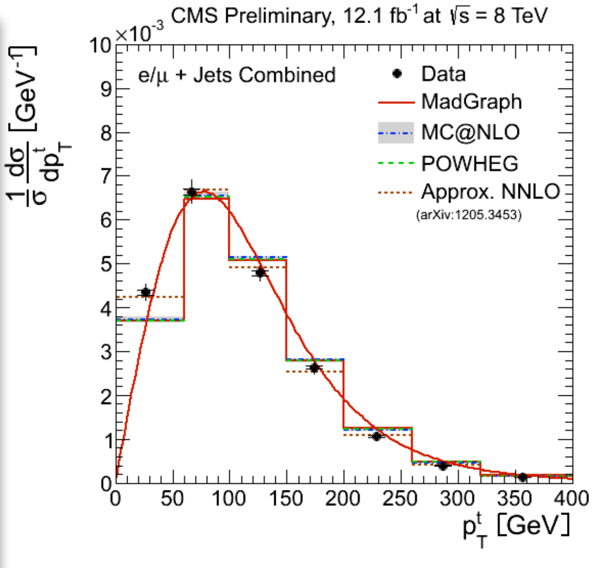
TOP Highlights: Production

- Moving toward studies of a number of differential distributions, thanks to the high integrated luminosity
  - Testing up to approximate NNLO QCD predictions
  - Some discrepancy in the top p_T at NLO seems to disappear with higher accuracy calculations

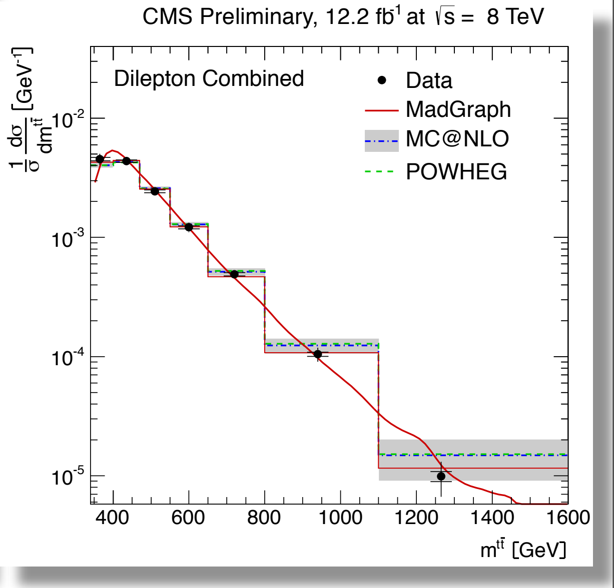
TOP-12-028



TOP-12-027

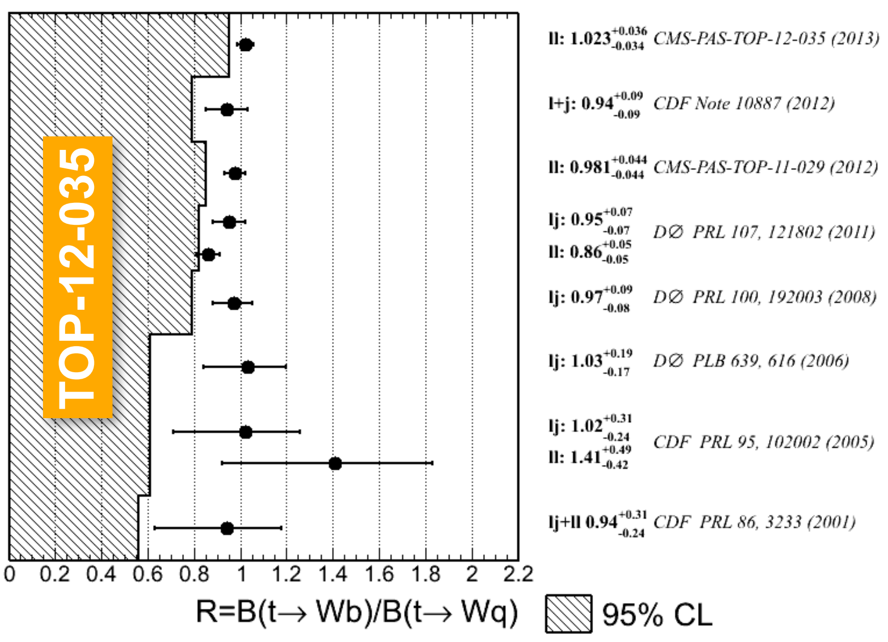


TOP-12-028



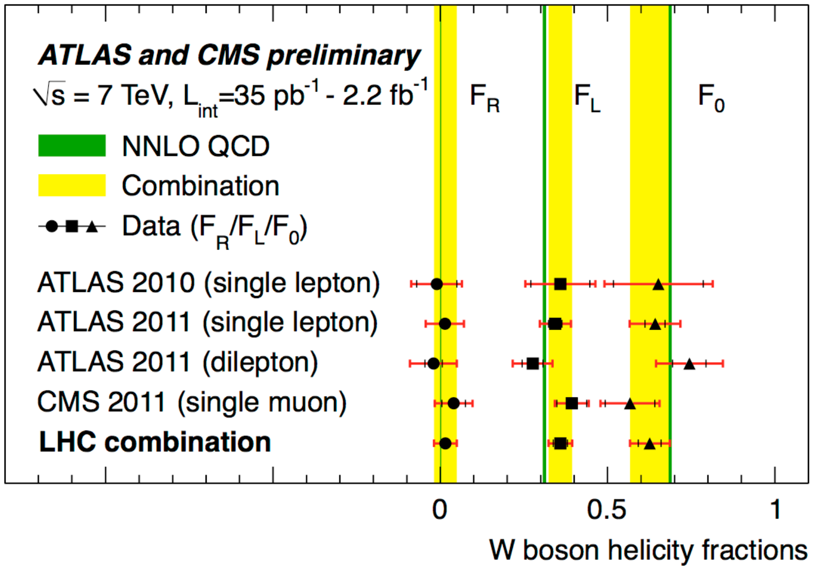
TOP Highlights:Properties

- Most precise measurement of R=B(t→Wb)/B(t→Wq)
  - $R = 1.023^{+0.036}_{-0.034}$ **TOP-12-035**
- Search for FCNC top decay t→Zq:
  $Br(t \to Zq) < 0.07\%$ @ 95% CL **TOP-12-037**
- First LHC combination of W helicity measurements in top decays
  - New CMS W helicity measurements in single-top and dilepton channels



TOP-12-035

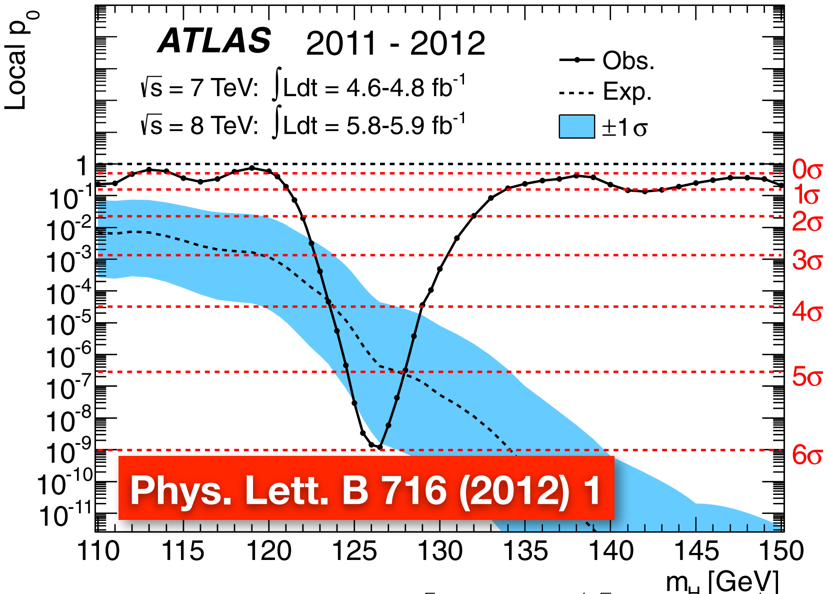
TOP-12-025



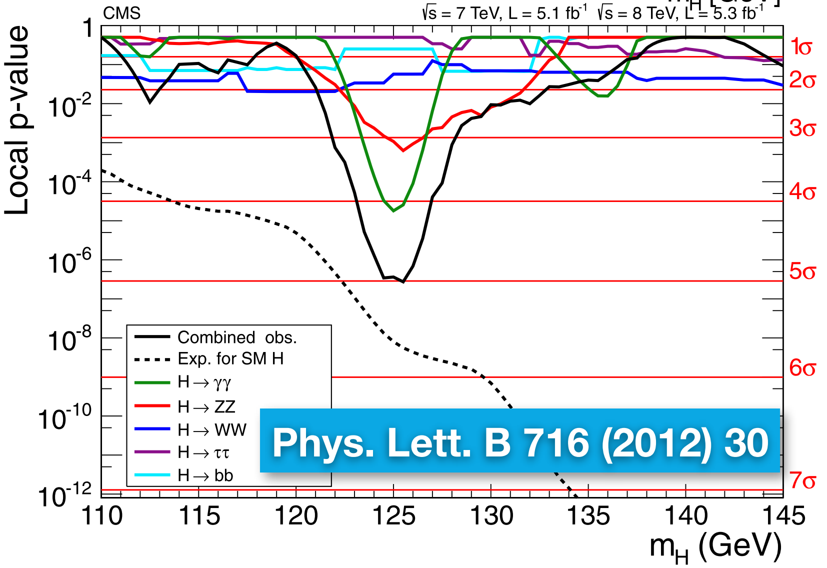
The Higgs Story

4th of July Fireworks

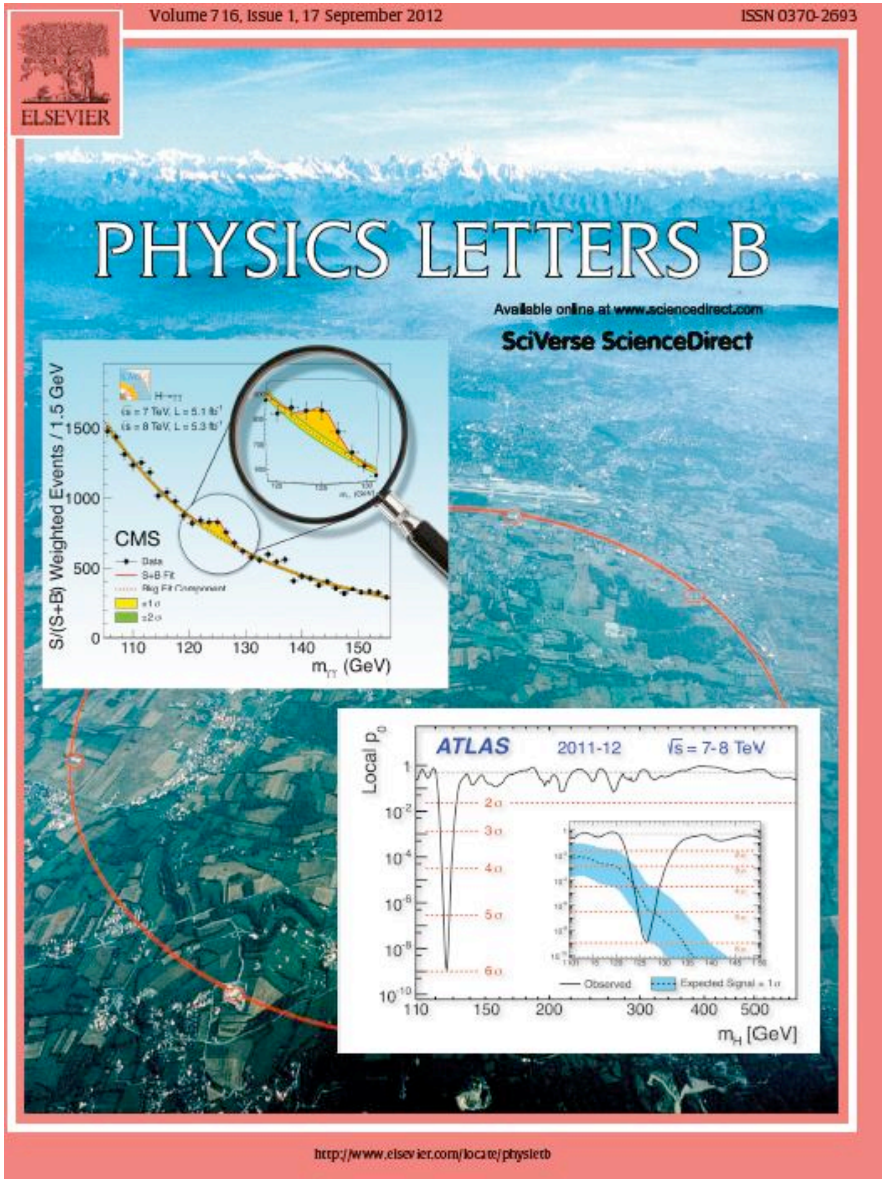
A New Boson Discovery



Phys. Lett. B 716 (2012) 1



Phys. Lett. B 716 (2012) 30



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Moriond 2013 - What a Week!

New results indicate that new particle is a Higgs boson

ISSUES AND EXPERTS

Higgs boson and new pope confirmed

March 14, 2013

Is the Higgs boson the key that will unlock the secrets of the universe?

Find out on an all new Through the Wormhole

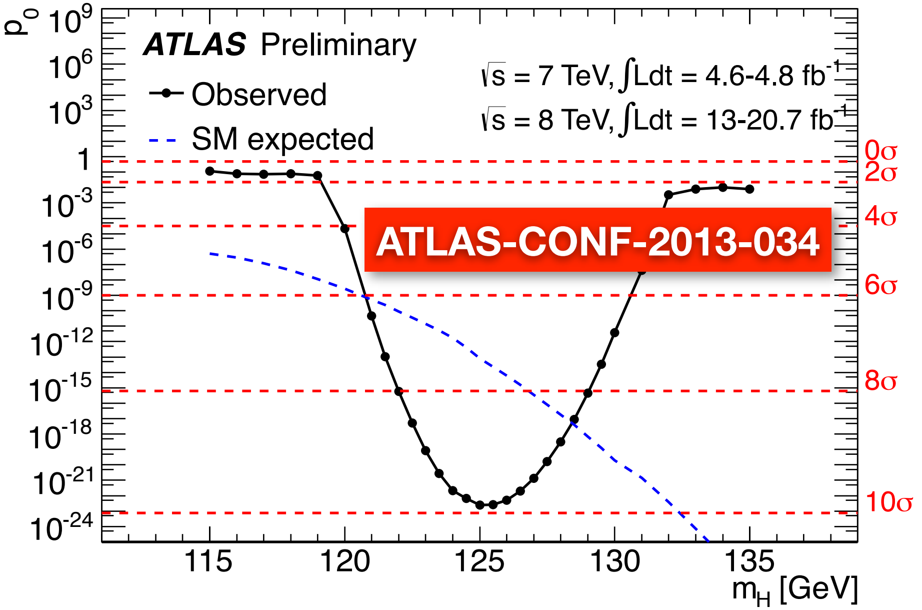
March 20th at 9pm

Only on Science

White smoke rises from the chimney on the roof of the Sistine Chapel meaning that cardinals elected a new pope on March 13, 2013.

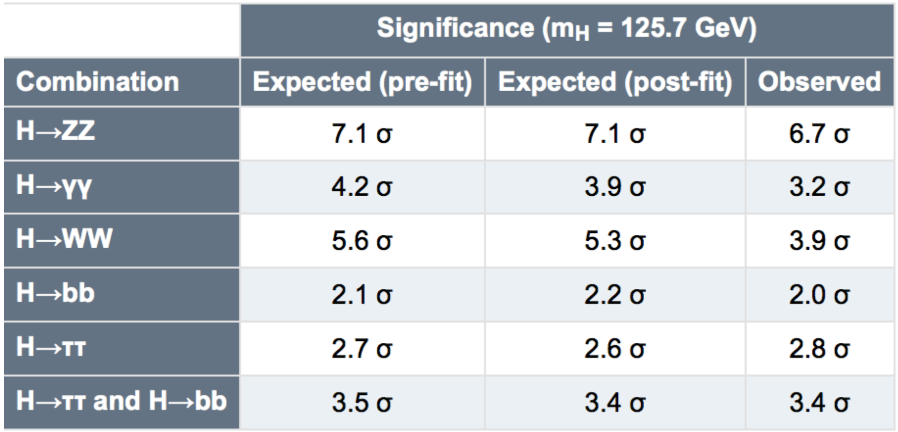
Higgs: 10 Months After

- The existence of new particle has been established beyond any doubts; it is a 0^{++} boson responsible for EWSB, as evident from its relative couplings to W/Z vs. γ
  - It’s properties are consistent with those of the SM Higgs boson within (sizable) uncertainties
  - There is mounting evidence (Tevatron, CMS), that it is couples to at least third generation fermions



ATLAS-CONF-2013-034

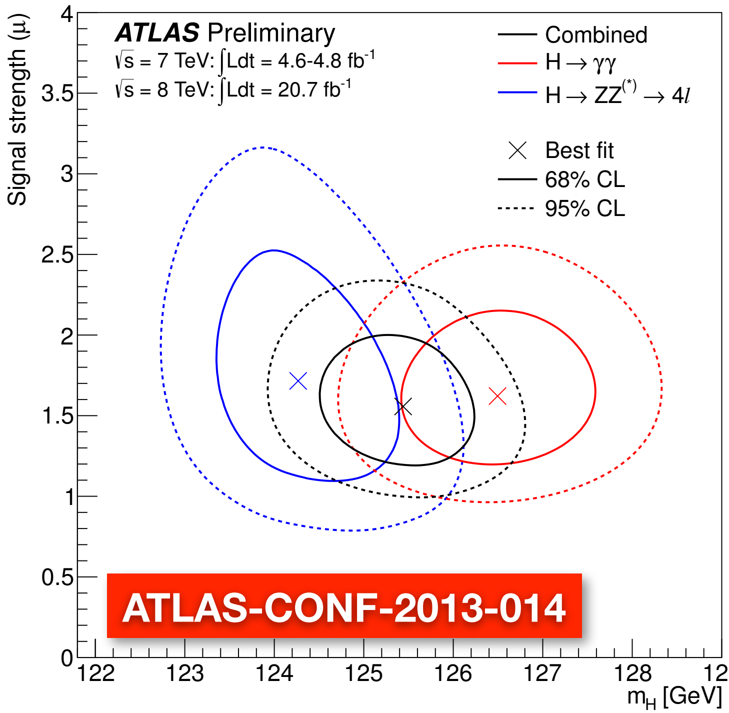
CMS PAS HIG-13-005



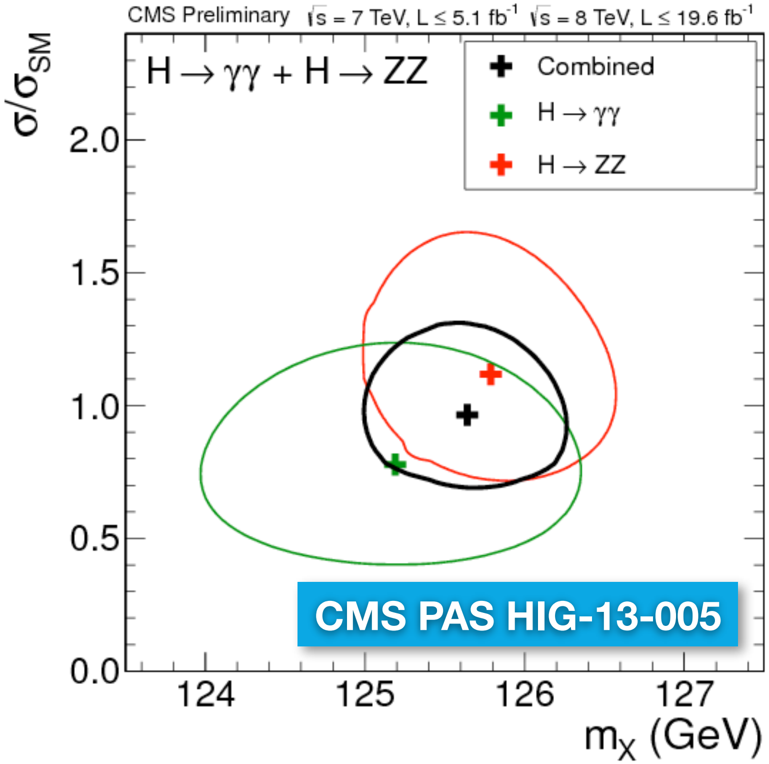
	Significance (m_H = 125.7 GeV)		
Combination	**Expected (pre-fit)**	**Expected (post-fit)**	**Observed**
H→ZZ	7.1 σ	7.1 σ	6.7 σ
H→γγ	4.2 σ	3.9 σ	3.2 σ
H→WW	5.6 σ	5.3 σ	3.9 σ
H→bb	2.1 σ	2.2 σ	2.0 σ
H→ττ	2.7 σ	2.6 σ	2.8 σ
H→ττ and H→bb	3.5 σ	3.4 σ	3.4 σ

Higgs Boson Mass

- Higgs boson mass:
  - ATLAS: $M_H = 125.5 \pm 0.2\ ^{+0.5}_{-0.6}$ GeV (0.43% precision)
  - CMS: $M_H = 125.7 \pm 0.3 \pm 0.3$ GeV (0.34% precision)
- The Higgs boson mass has been already measured to a better precision than the top (or any other quark!) mass (0.50%)



ATLAS-CONF-2013-014

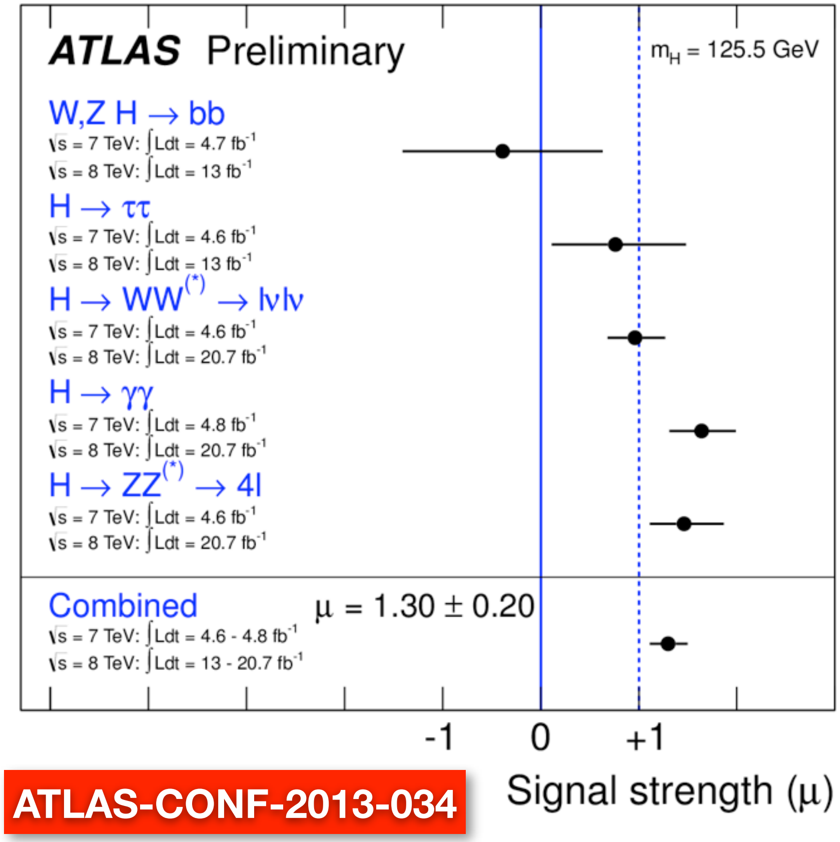


CMS PAS HIG-13-005

Higgs Boson Signal Strength

- Consistency with the SM Higgs boson:
  - ATLAS: $\mu = 1.30 \pm 0.20$ @ 125.5 GeV
  - CMS: $\mu = 0.80 \pm 0.14$ @ 125.7 GeV

CMS PAS HIG-13-005



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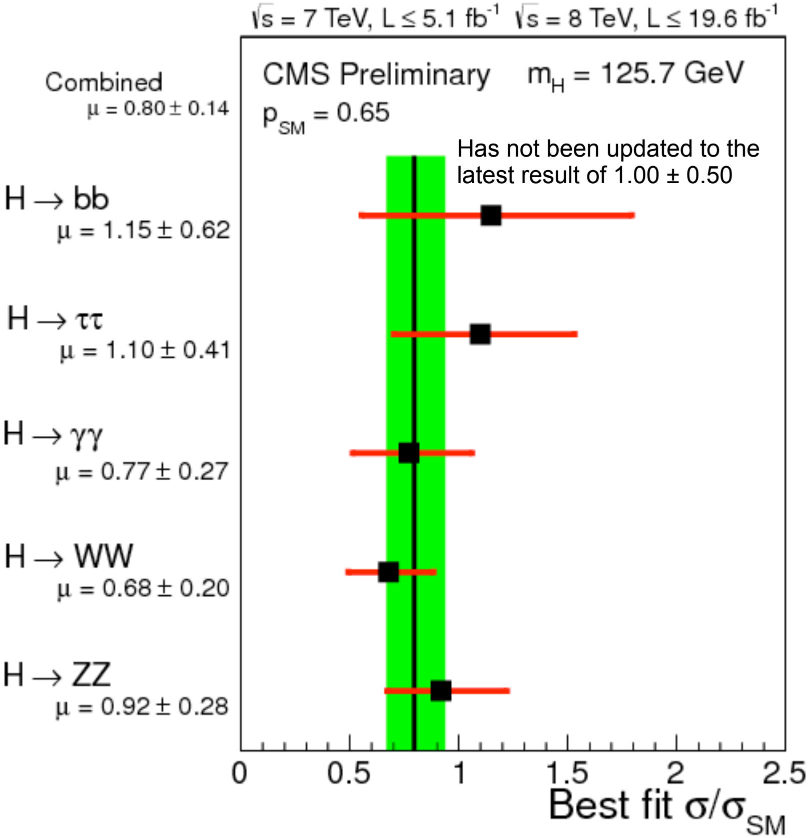

Has not been updated to the latest result of 1.00 ± 0.50

Higgs Boson Signal Strength

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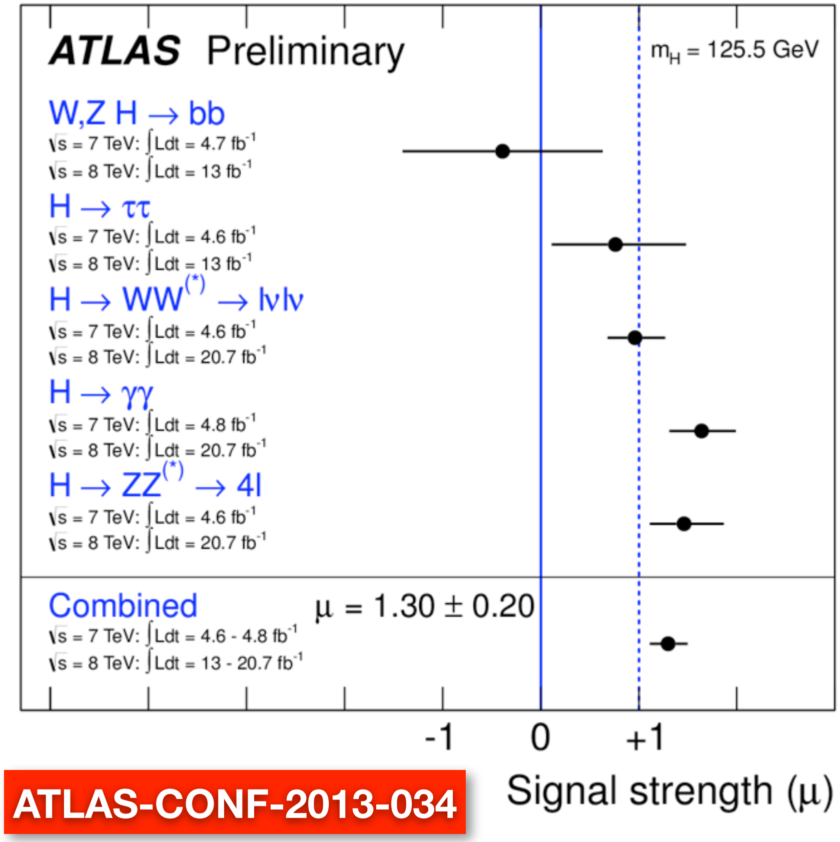
CMS PAS HIG-13-005



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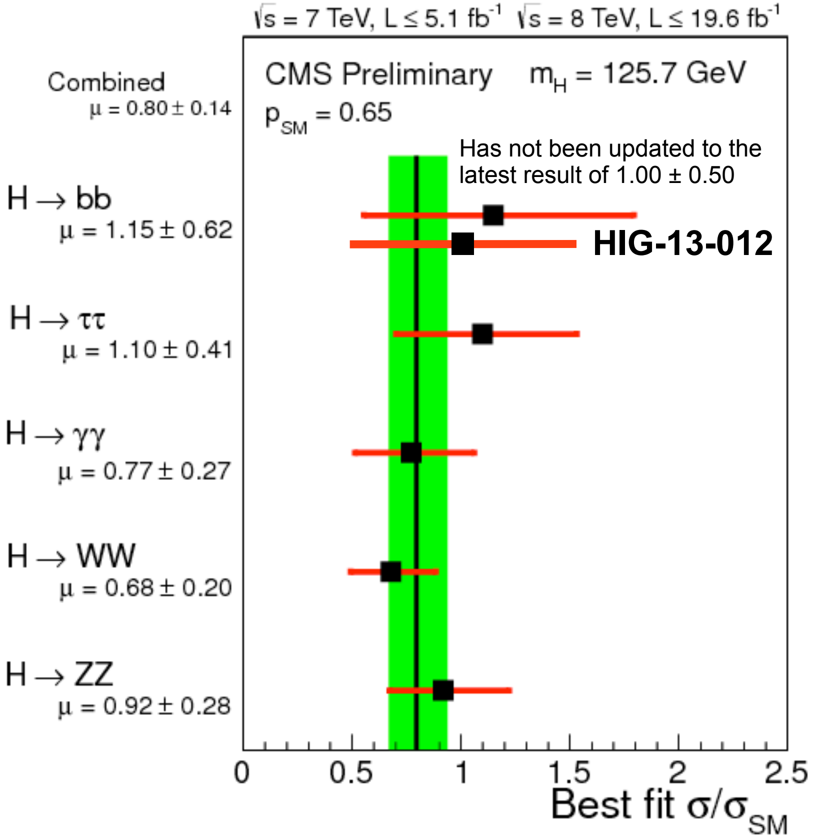


Has not been updated to the latest result of 1.00 ± 0.50

HIG-13-012

Higgs Boson Spin

- Both ATLAS and CMS strongly prefer $J^{PC} = 0^{++}$ over the alternatives
  - Pseudoscalar 0^{-+} and tensor 2^{++} hypotheses have been excluded at ~3σ level by each experiment

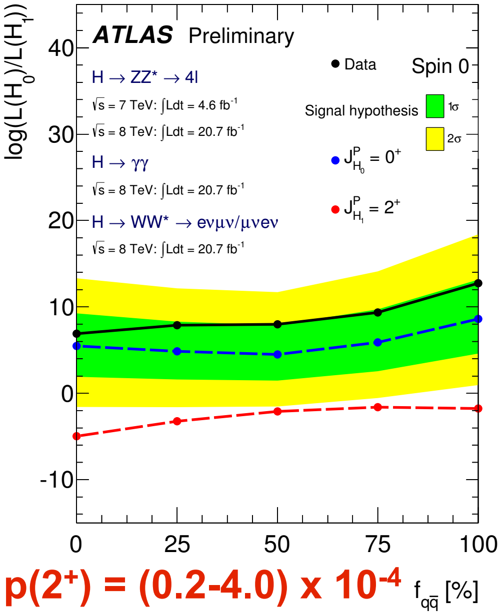
ATLAS-CONF-2013-013

		BDT analysis			
		tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	$\mathrm{CL_s}$
		expected	observed	observed*	
0^-	p_0	0.0037	0.015	0.31	0.022
1^+	p_0	0.0016	0.001	0.55	0.002
1^-	p_0	0.0038	0.051	0.15	0.060
2^+_m	p_0	0.092	0.079	0.53	0.168
2^-	p_0	0.0053	0.25	0.034	0.258

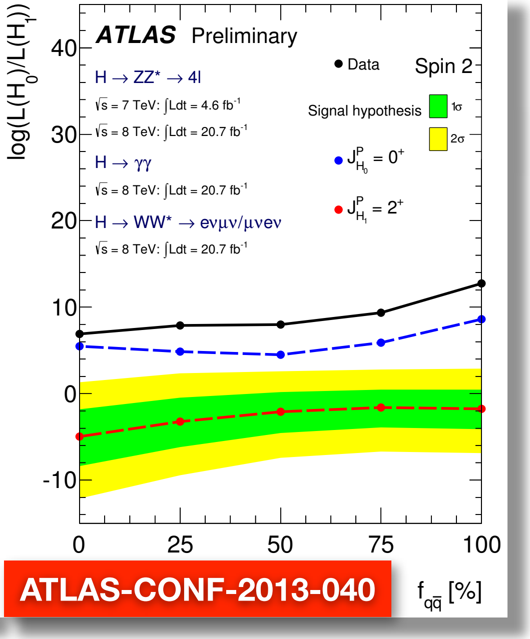
H(ZZ) alone

CMS PAS HIG-13-002

J^P	production	comment	expect (μ=1)	obs. 0^+	obs. J^P	CL_s
0^-	$gg \to X$	pseudoscalar	2.6σ (2.8σ)	0.5σ	3.3σ	0.16%
0^+_h	$gg \to X$	higher dim operators	1.7σ (1.8σ)	0.0σ	1.7σ	8.1%
2^+_{mgg}	$gg \to X$	minimal couplings	1.8σ (1.9σ)	0.8σ	2.7σ	1.5%
$2^+_{mq\bar{q}}$	$q\bar{q} \to X$	minimal couplings	1.7σ (1.9σ)	1.8σ	4.0σ	<0.1%
1^-	$q\bar{q} \to X$	exotic vector	2.8σ (3.1σ)	1.4σ	$>4.0\sigma$	<0.1%
1^+	$q\bar{q} \to X$	exotic pseudovector	2.3σ (2.6σ)	1.7σ	$>4.0\sigma$	<0.1%

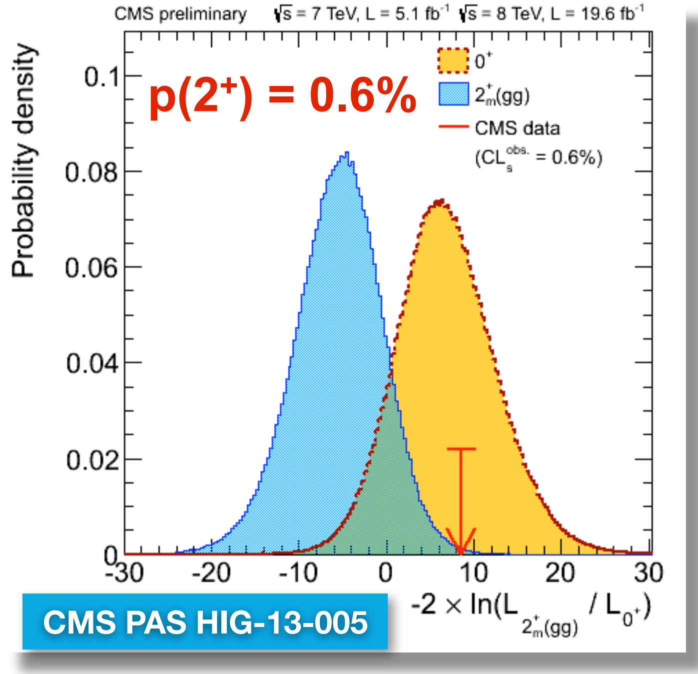


$p(2^+) = (0.2\text{-}4.0) \times 10^{-4}$



ATLAS-CONF-2013-040

Combination



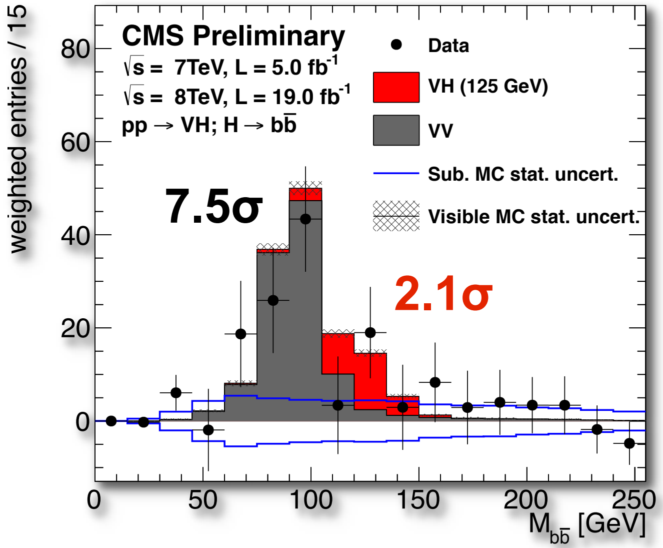
CMS PAS HIG-13-005

CMS Updates Since the Moriond

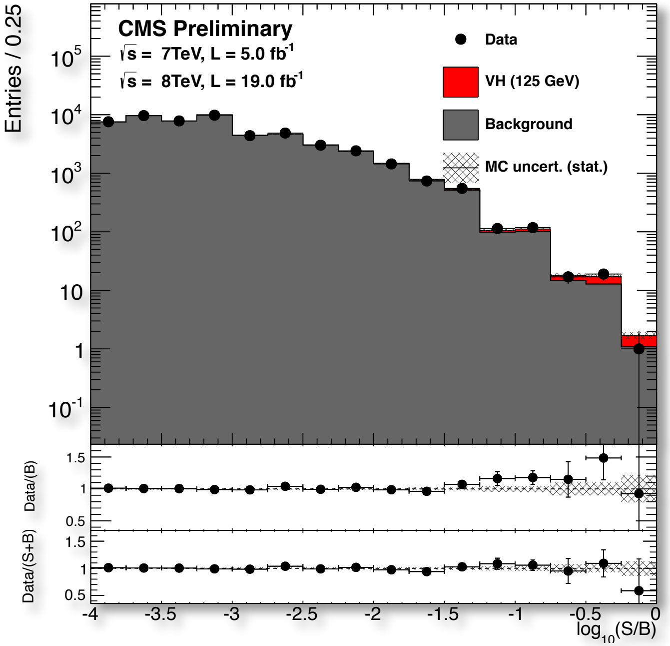
- It looks more and more like the Standard Model Higgs Boson…
- Five new results have been approved since the Moriond
  - The last of five main channels was updated with full statistics: VH(bb) **HIG-13-012**
  - New H(bb) search in VBF production **HIG-13-011**
  - ttH($\gamma\gamma$) **HIG-13-015**
  - Two new high-mass Higgs analyses: ZZ($ll\nu\nu$) and WW($l\nu$jj) with jet substructure **HIG-13-014/008**
- ATLAS is working on the updates for summer conferences

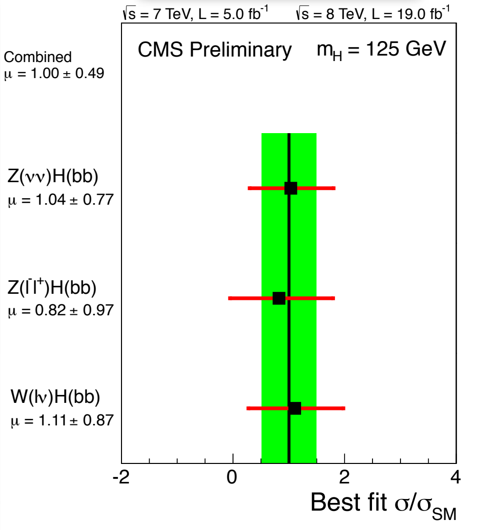
VH(bb) Update

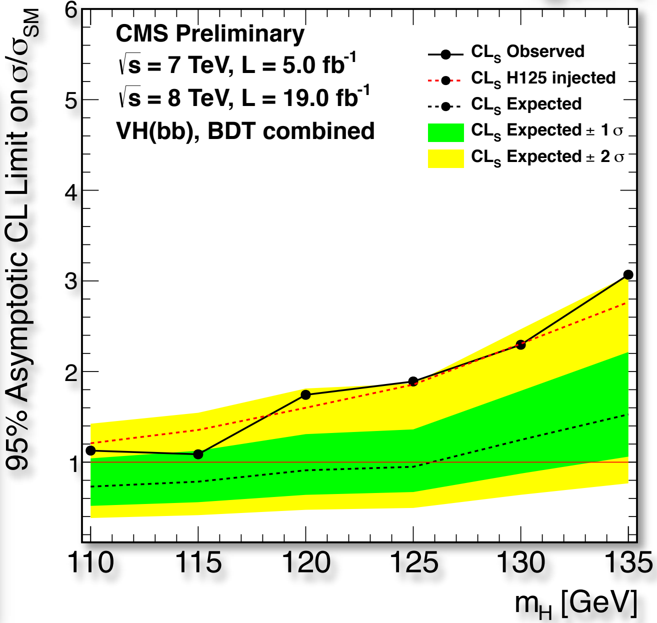
- Observed a 2.1σ excess over the SM expectations
- Corresponding signal strength: 1.0 ± 0.5
- Increased theory systematics (due to NLO EW + NNLO QCD) leading to a bit lower cross section compared to the previous (HCP 2012) analysis



HIG-13-012

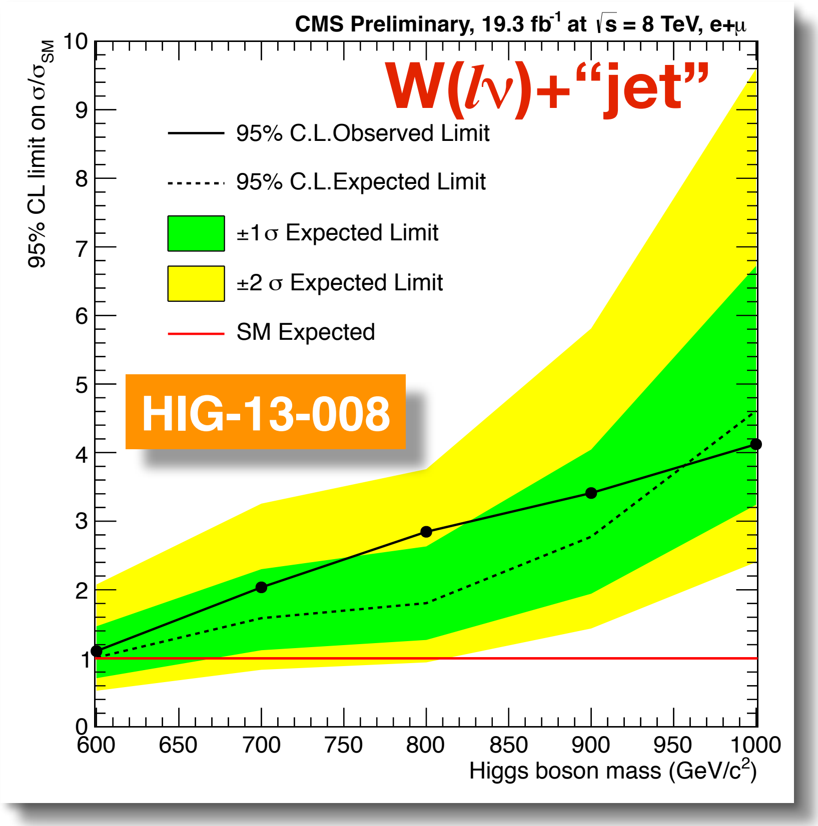


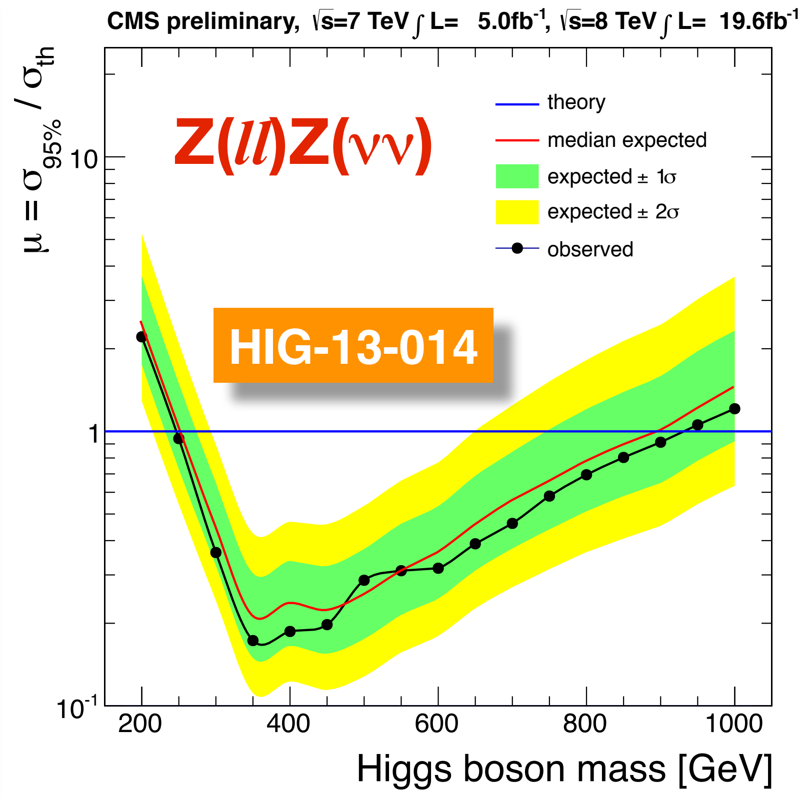




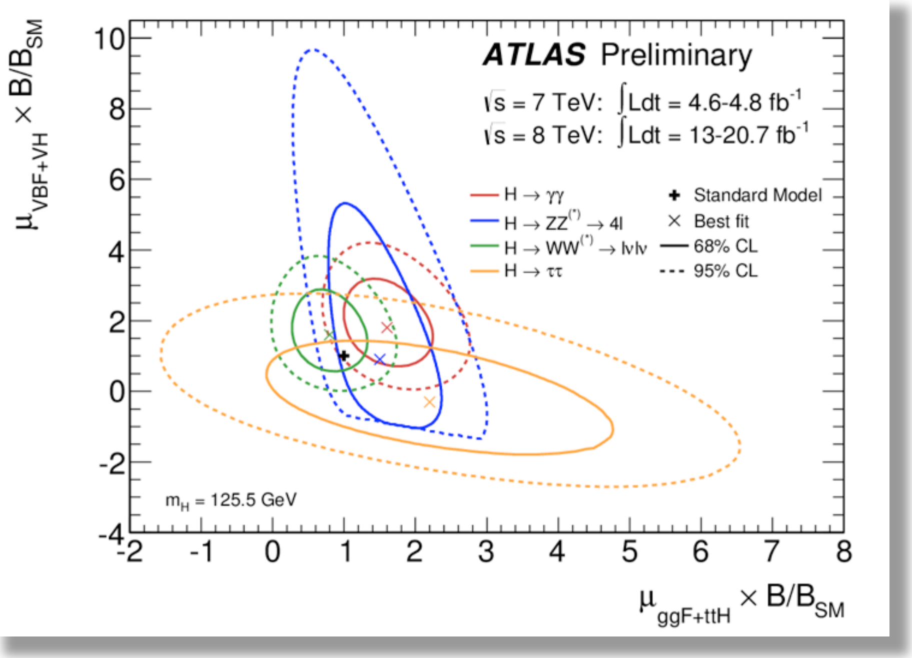
High-Mass Higgs Boson

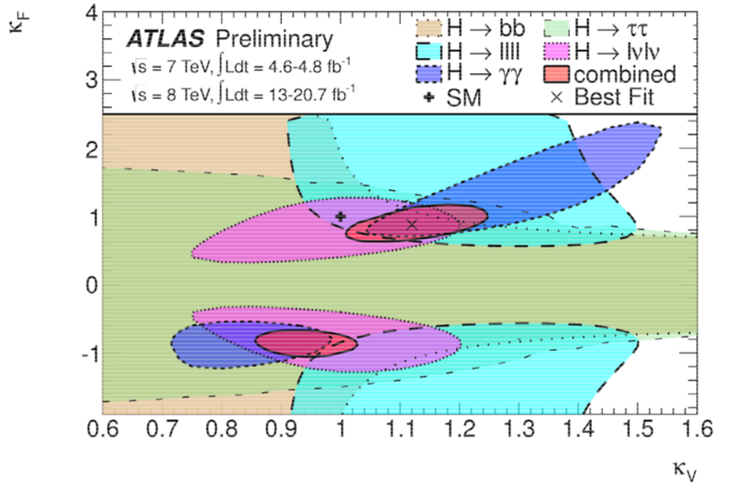
- New search in the W(lν)W(“j”) channel in a boosted regime
  - Sensitive to Higgs masses above ~600 GeV
- An update of the high-mass Z(ll)Z(νν) search to full statistics
  - Probes SM-like heavy Higgs up to ~900 GeV



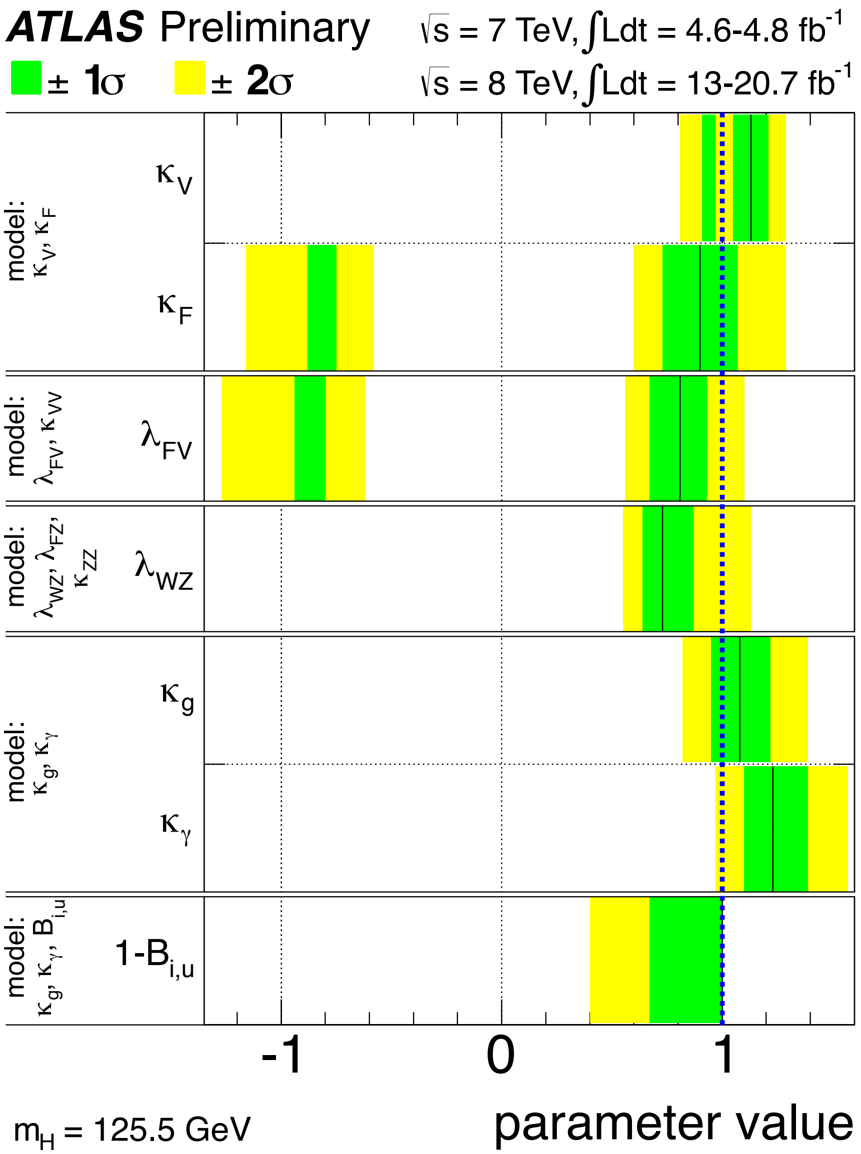


Higgs Properties: ATLAS

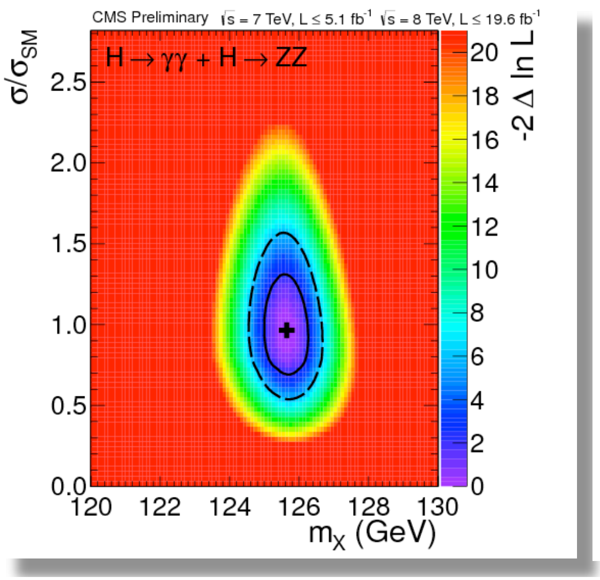


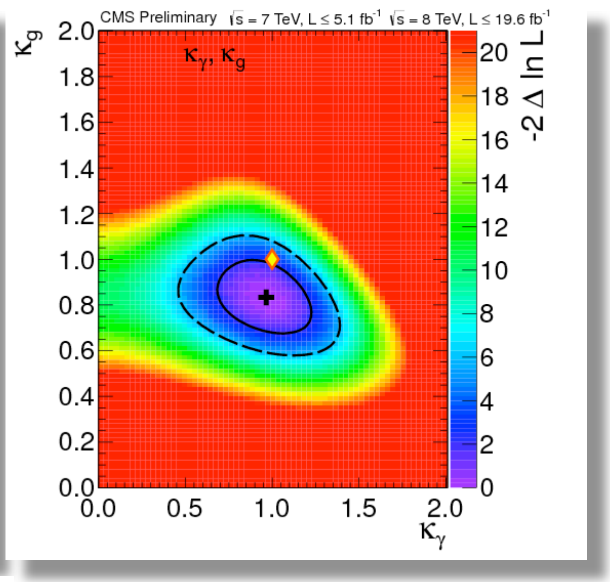


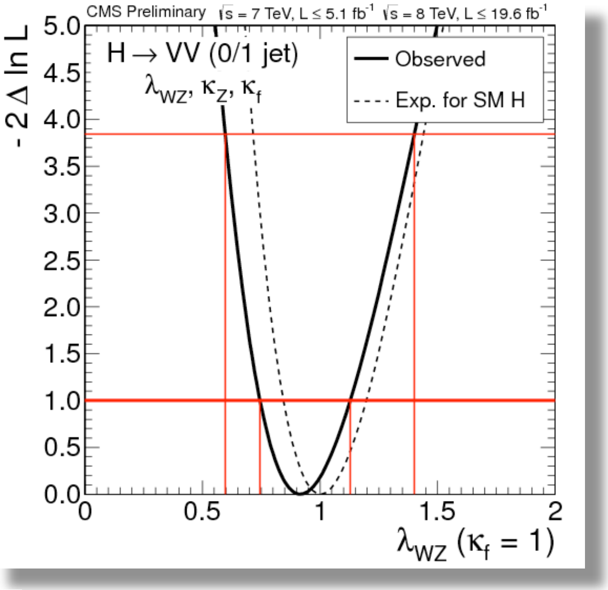
ATLAS-CONF-2013-034

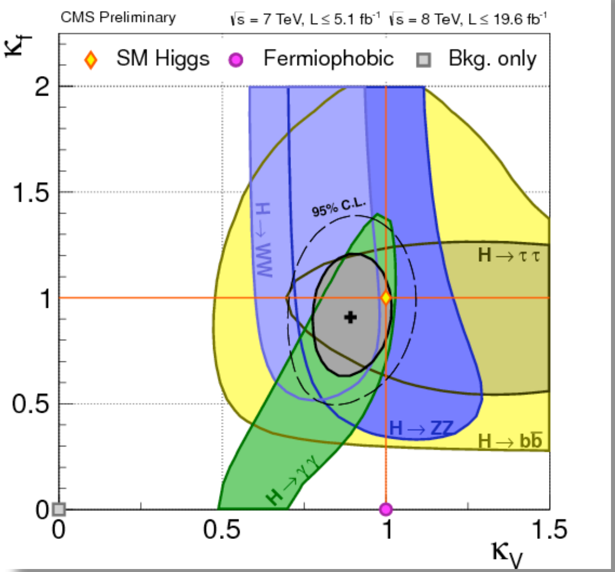


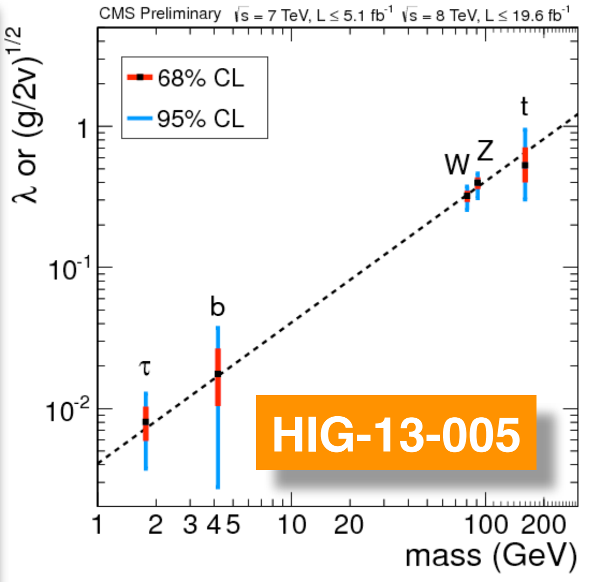
Higgs Boson Properties: CMS



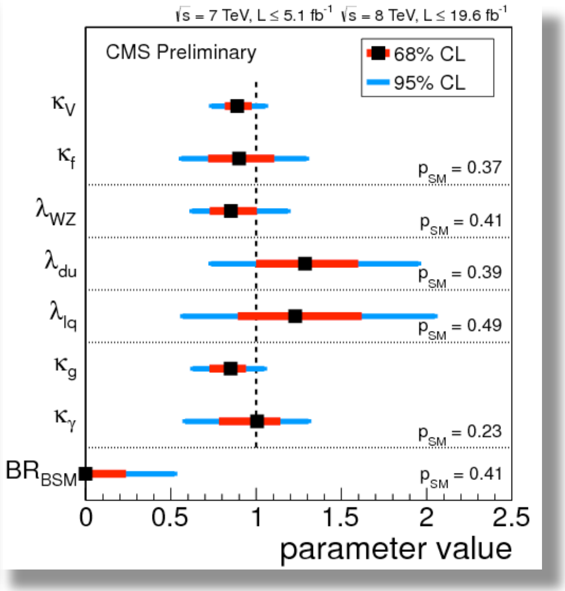






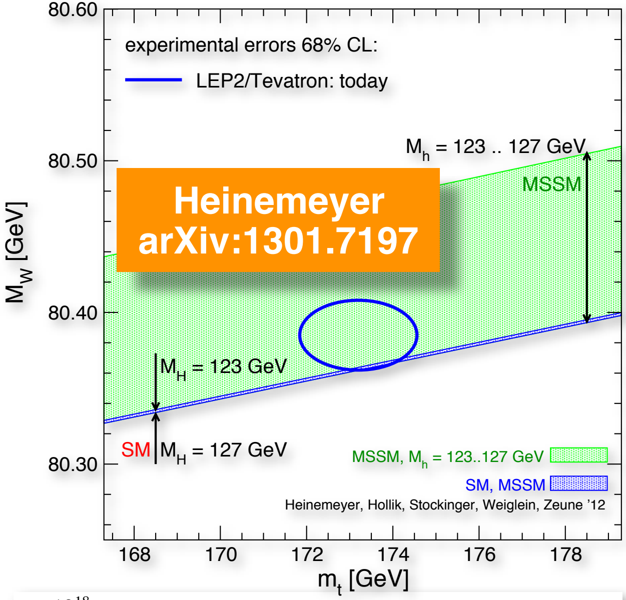


HIG-13-005

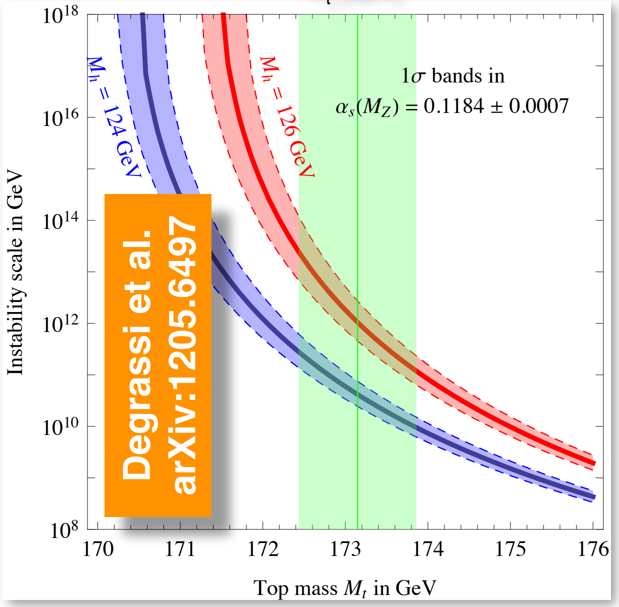


Higgs Discovery Implications

- Light Higgs boson discovery implies that the SM can not be a complete theory up to the Planck scale
- It's light enough to be a MSSM Higgs, but yet too heavy to obviously prefer MSSM vs. SM!
    - Had it been just 10% heavier we would probably stop talking about low-scale SUSY!
- If we found the SM Higgs boson, we now need to explain the EWSB mechanism, i.e. what makes the Higgs potential what it is (explain the origin of the λ term in the Lagrangian)
    - It looks more and more like the SM Higgs boson, but there is still room for surprises!
- Vacuum stability arguments require new physics to come at a scale ~10^{11} GeV or less
    - Curiously points to a similar scale as suggested by the neutrino mass hierarchy via see-saw mechanism
- Nevertheless, a metastable vacuum could survive w/o new physics
- In a sense, a 125 GeV Higgs boson is maximally challenging and rich experimentally, but also inflicts "maximum pain" theoretically, as it is not so easy to accommodate



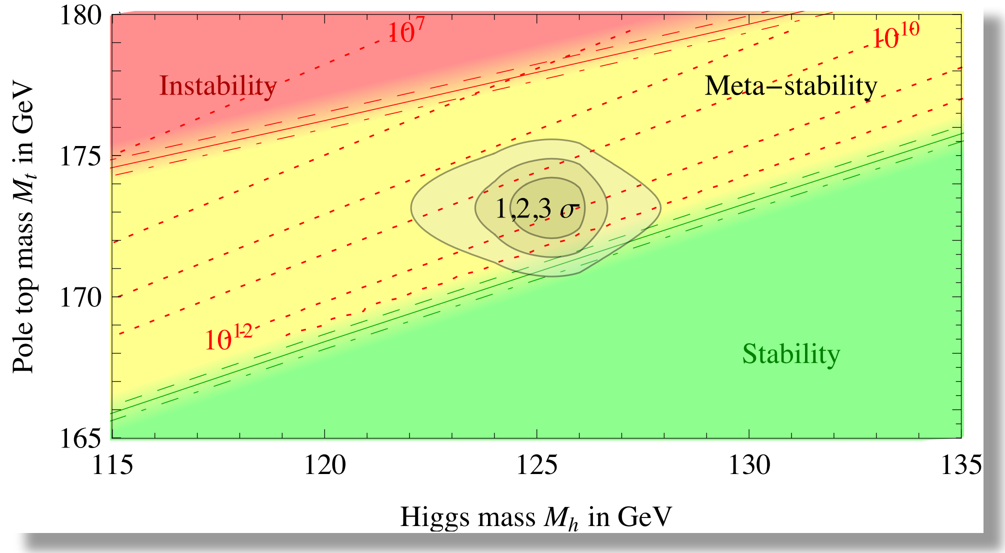
Heinemeyer arXiv:1301.7197



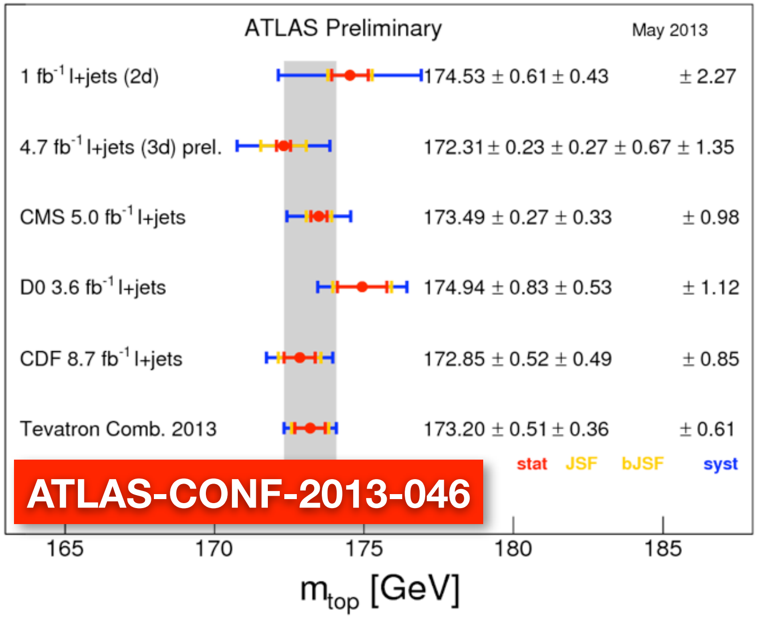
Degrassi et al. arXiv:1205.6497

Just-So Higgs?

- The simultaneous measurement of the Higgs boson and top quark masses allowed for the first time to infer properties of the very vacuum we leave in!
    - We are in a highly fine-tuned situation: the vacuum is at the verge of being either stable or metastable!
    - ~1 GeV in either the top-quark or the Higgs boson mass is all it takes to tip the scales!
- Perhaps Nature is trying to tell us something here?
    - Very important to improve on the precision of top quark mass measurements, including various complementary methods and reduction of theoretical uncertainties
    - Tevatron is still leading with the new combined M_t result, but LHC is catching up quickly!



Degrassi et al, arXiv:1205.6497



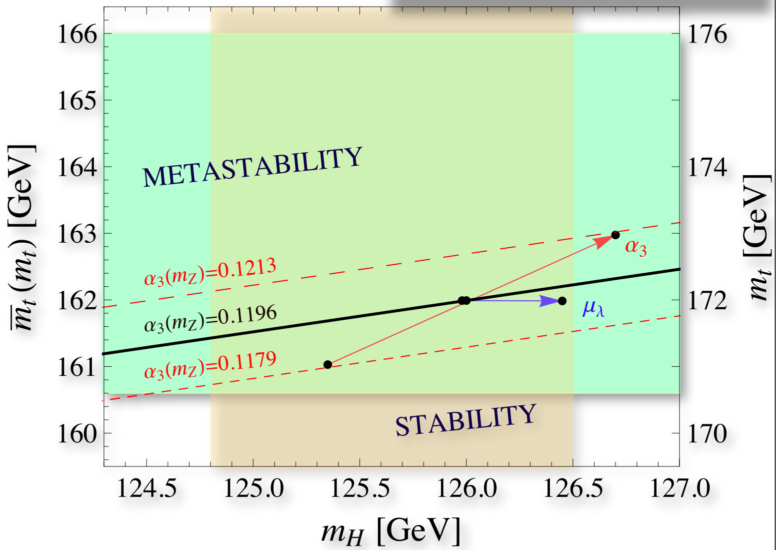
ATLAS-CONF-2013-046

What Vacuum Do We Live In?

- Stable vacuum?

- Metastable vacuum?

Masina
arXiv:1301.2175

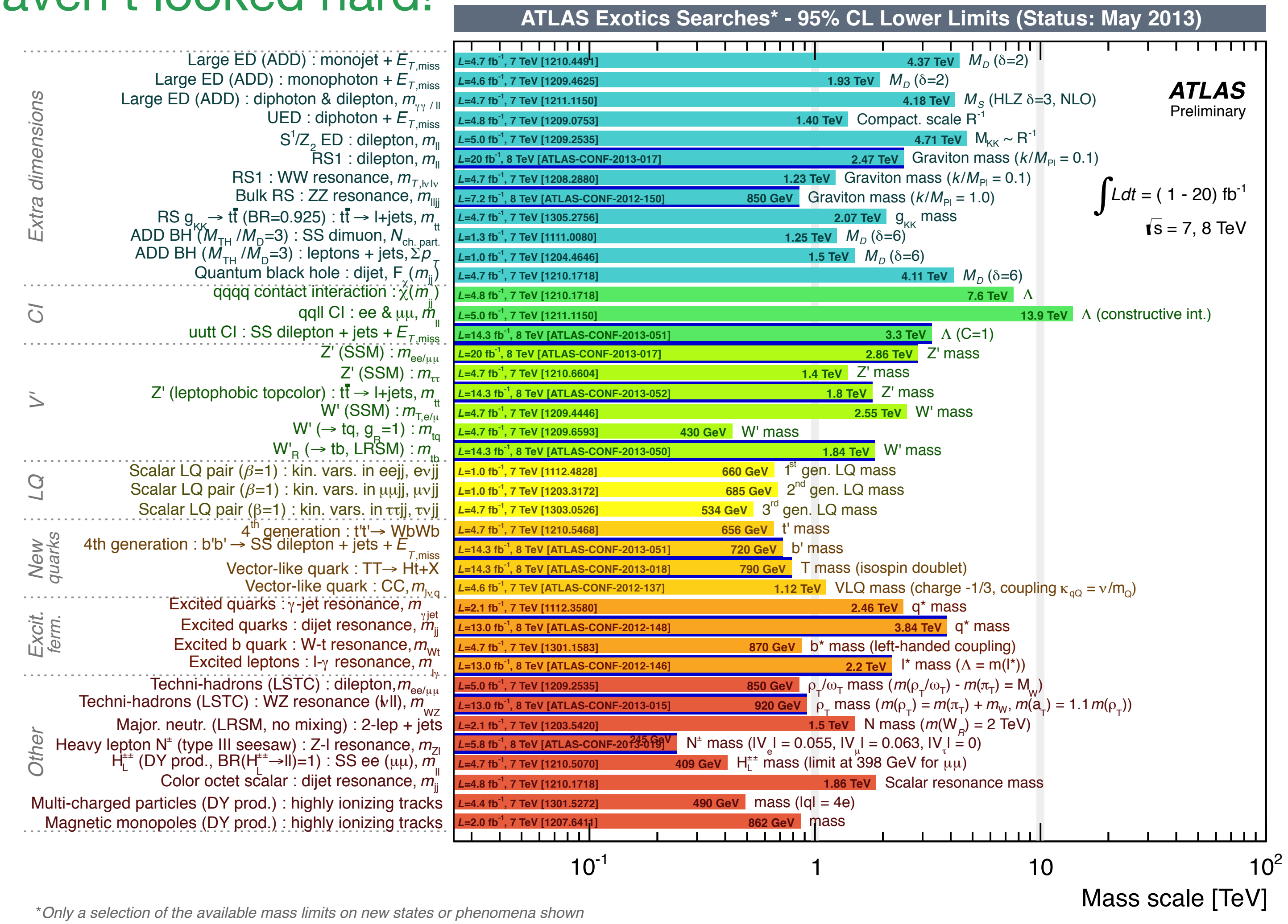


- Unstable vacuum?

Searches Beyond the SM

And What About New Physics?

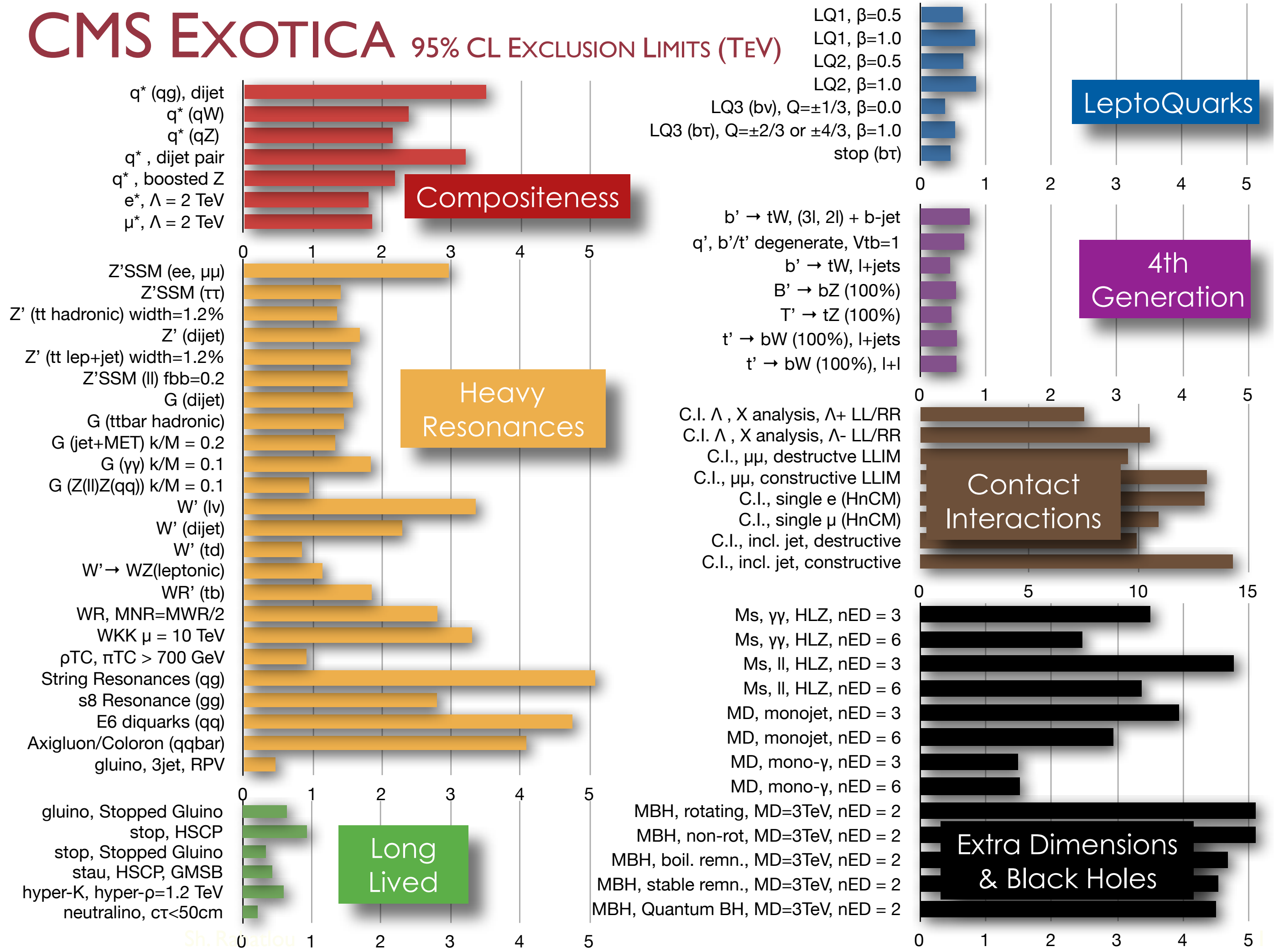
- The Higgs is there, but so far, no sign of new physics, and it’s not like we haven’t looked hard!



*Only a selection of the available mass limits on new states or phenomena shown

And What About New Physics?

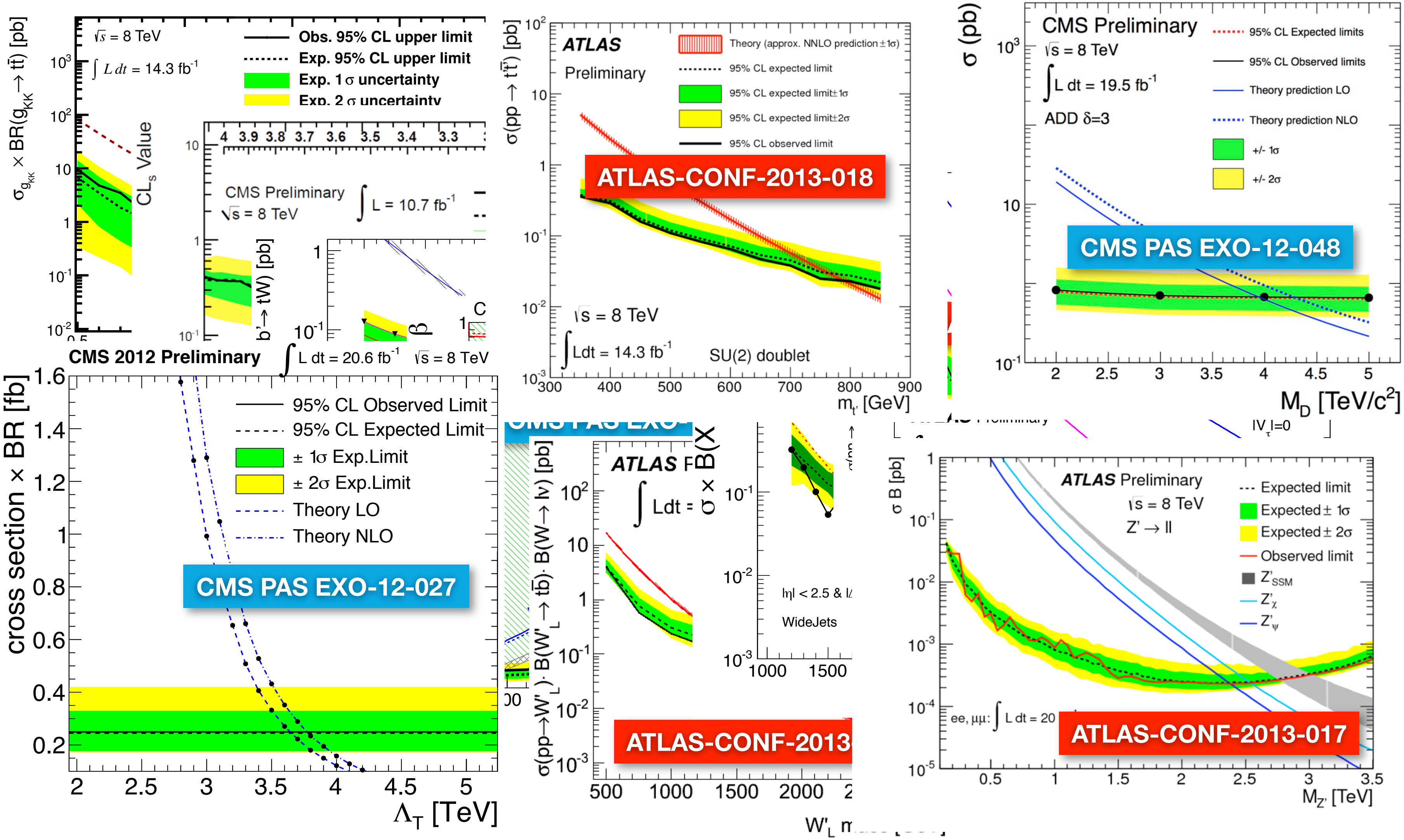
- ✦ The Higgs is there, but so far, no sign of new physics, and it's not like we haven't looked hard!



Limits, Limits, Limits...

Limits, Limits, Limits…

- Yet, we could cover Brazil with “Brazilian-flag” plots!



ATLAS-CONF-2013-018

CMS PAS EXO-12-048

CMS PAS EXO-12-027

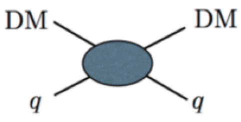
ATLAS-CONF-2013-

ATLAS-CONF-2013-017

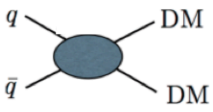
A few non-SUSY Highlights

Search for Dark Matter

- Search for Dark Matter in monojet and monophoton final states a la the direct detection experiments:
  - Limits are somewhat model-dependent as they are sensitive to the mass of the mediator; yet competitive
  - Offer unique sensitivity to DM-gluon couplings
- Increased interest since the recent CDMS result (arXiv:1304.4279)!

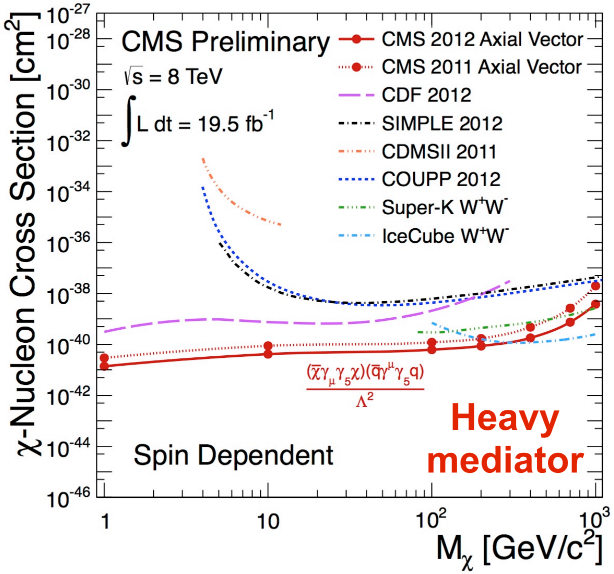


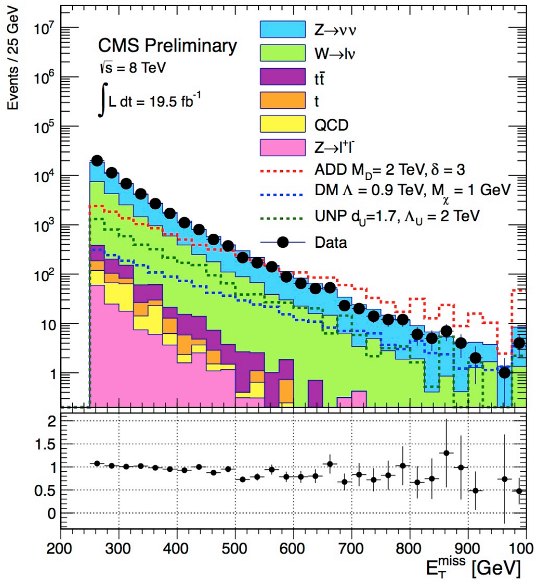
Direct Detection (t-channel)

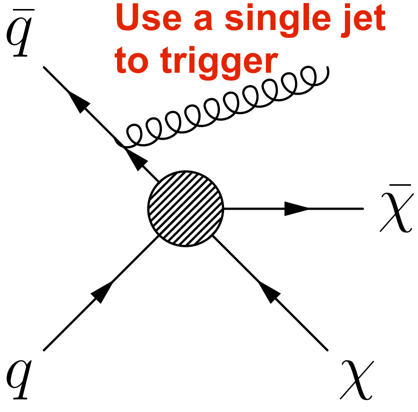


Collider Searches (s-channel)

EXO-12-048

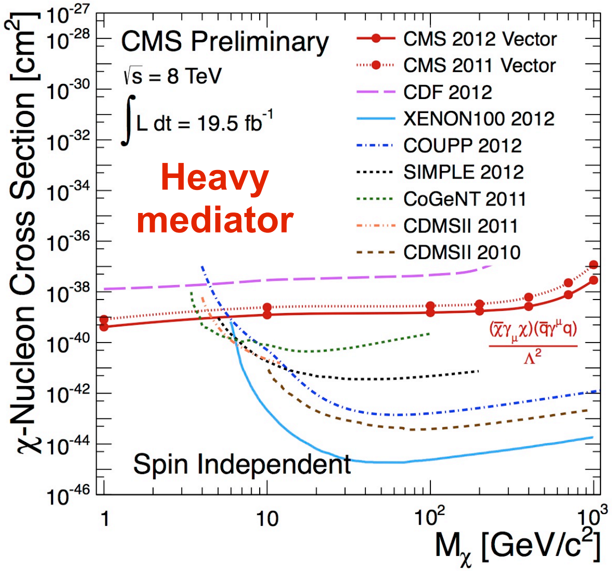






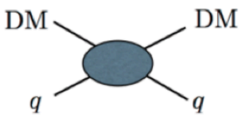
Use a single jet to trigger

Monojet + MET

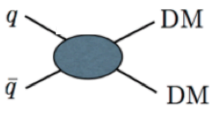


Search for Dark Matter

- Search for Dark Matter in monojet and monophoton final states a la the direct detection experiments:
  - Limits are somewhat model-dependent as they are sensitive to the mass of the mediator; yet competitive
  - Offer unique sensitivity to DM-gluon couplings
- Increased interest since the recent CDMS result (arXiv:1304.4279)!

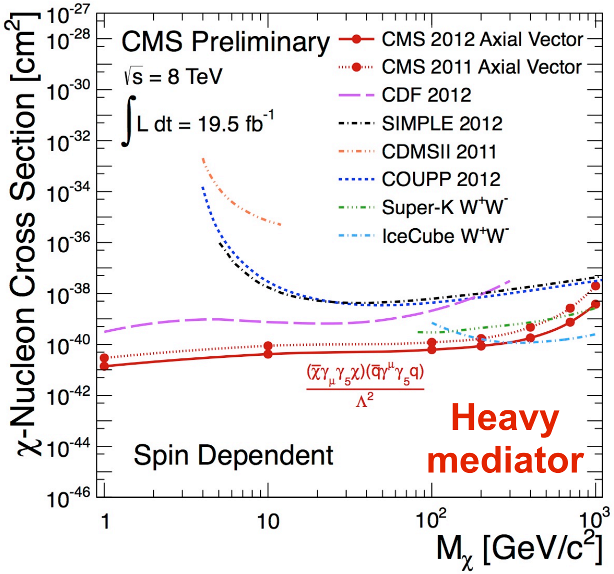


Direct Detection (t-channel)

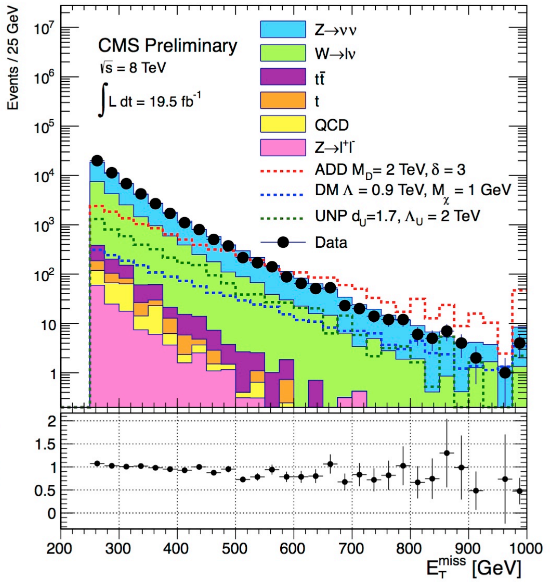


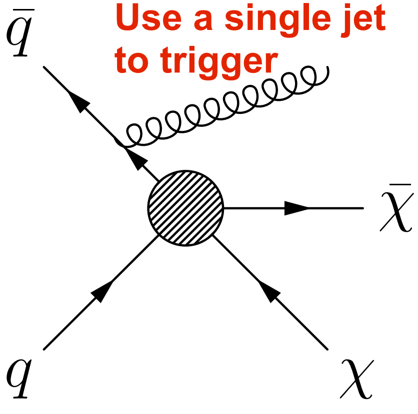
Collider Searches (s-channel)

EXO-12-048



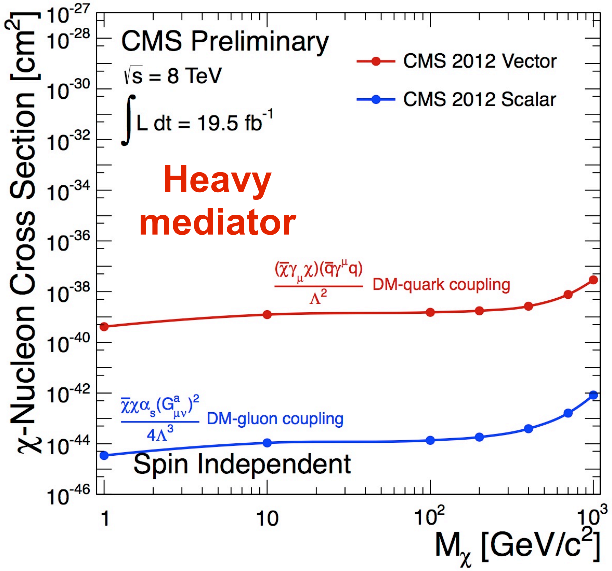
Heavy mediator





Use a single jet to trigger

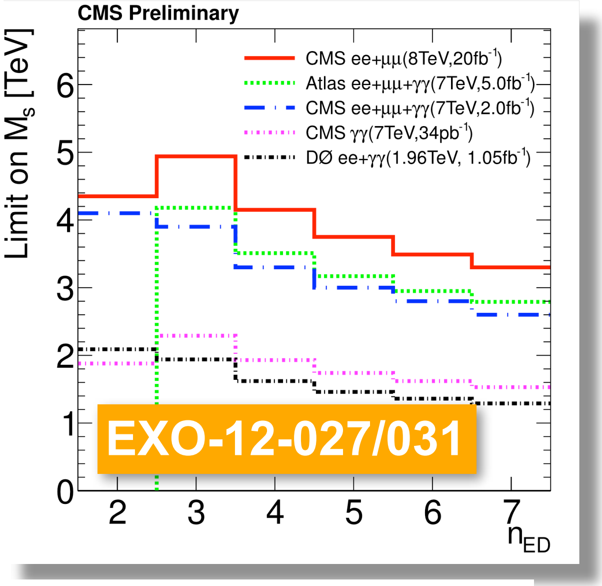
Monojet + MET



Heavy mediator

BSM Searches: W′ and Z′

- Search for W′ and Z′ in leptonic decay channels
  - M(W′) > 3.2 (W'_{SSM}) TeV; also limits on UED and compositeness
  - M(Z′) > 2.6 (Z'_{ψ})–3.0 (Z'_{SSM}) TeV
  - Also interpreted in terms of limits on large ED (M_S ~ 4 TeV)



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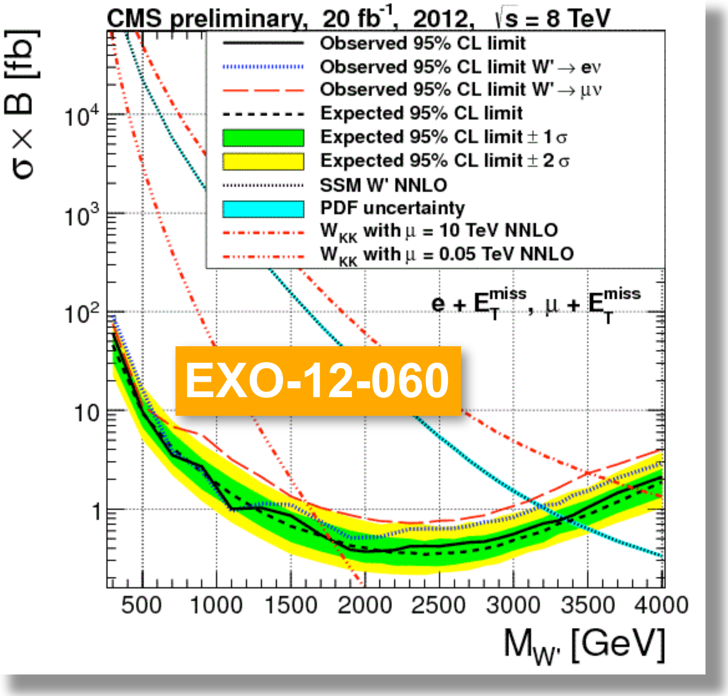
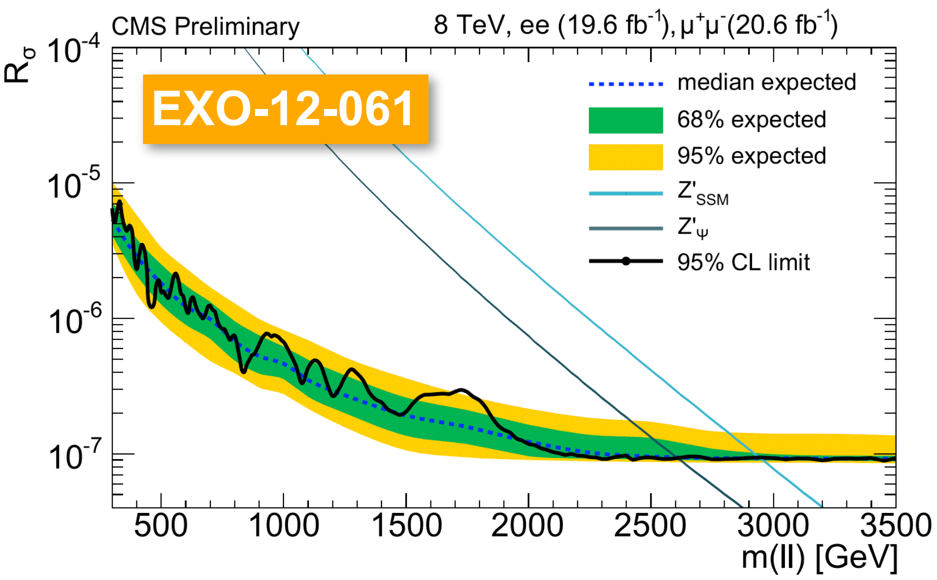
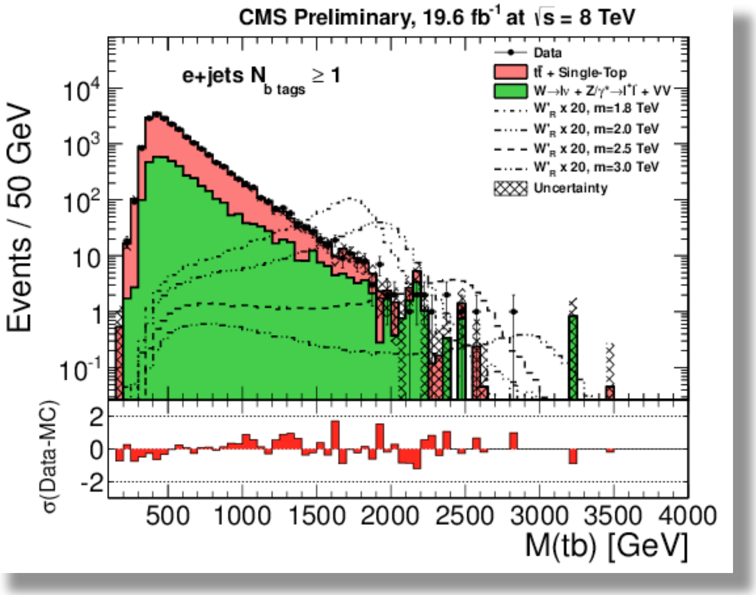


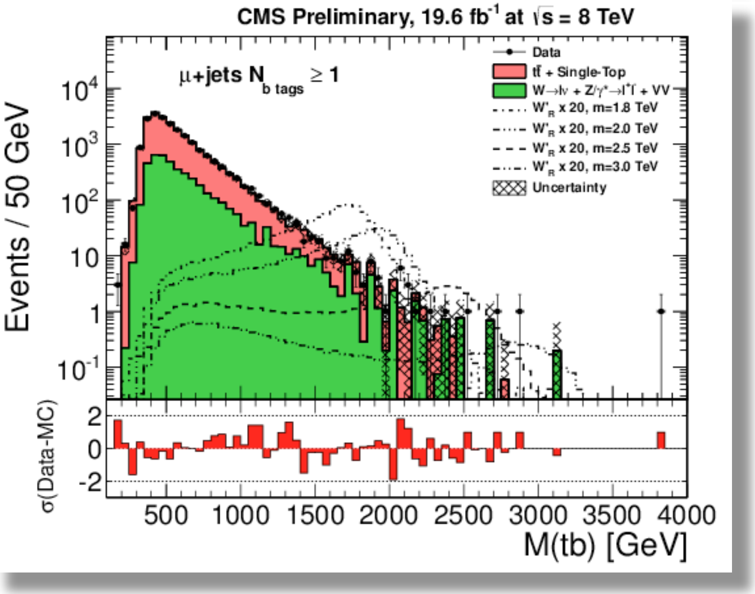
EXO-12-060



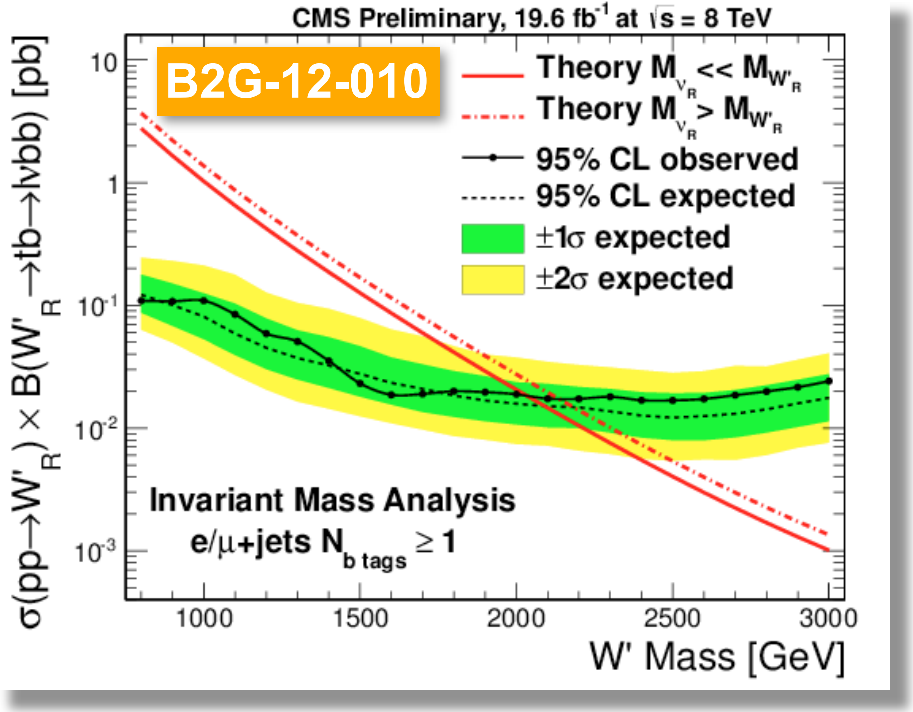
EXO-12-061

BSM Searches: W’(tb)

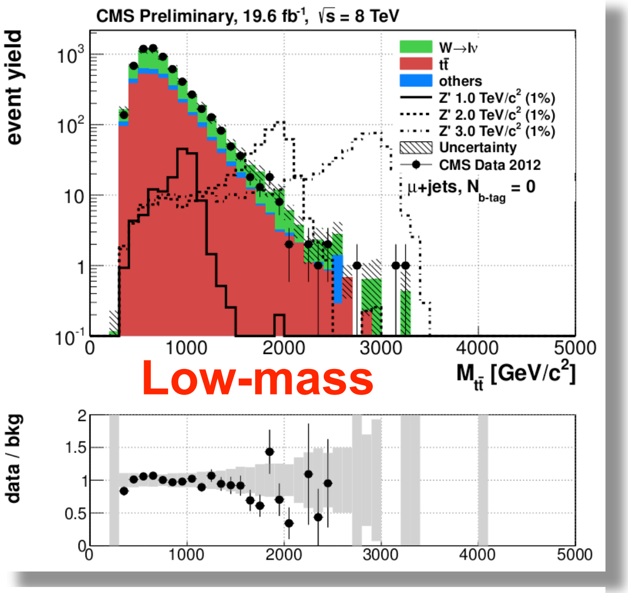




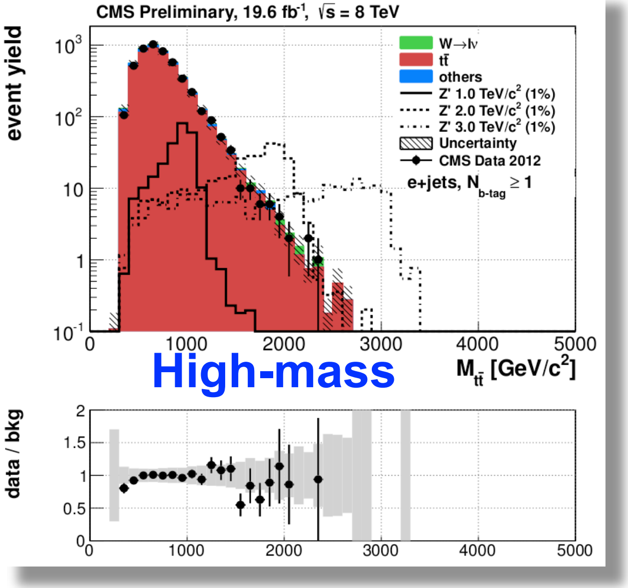
- Extension of the W′(tb) search with full 8 TeV statistics
- Probing $W_{R,L}$ as well as arbitrary couplings
    - Limits as high as 2.1 TeV are set for W_R and W_L w/o interference
    - Also set limits for arbitrary left/right W mixture



BSM Searches: tt Resonances

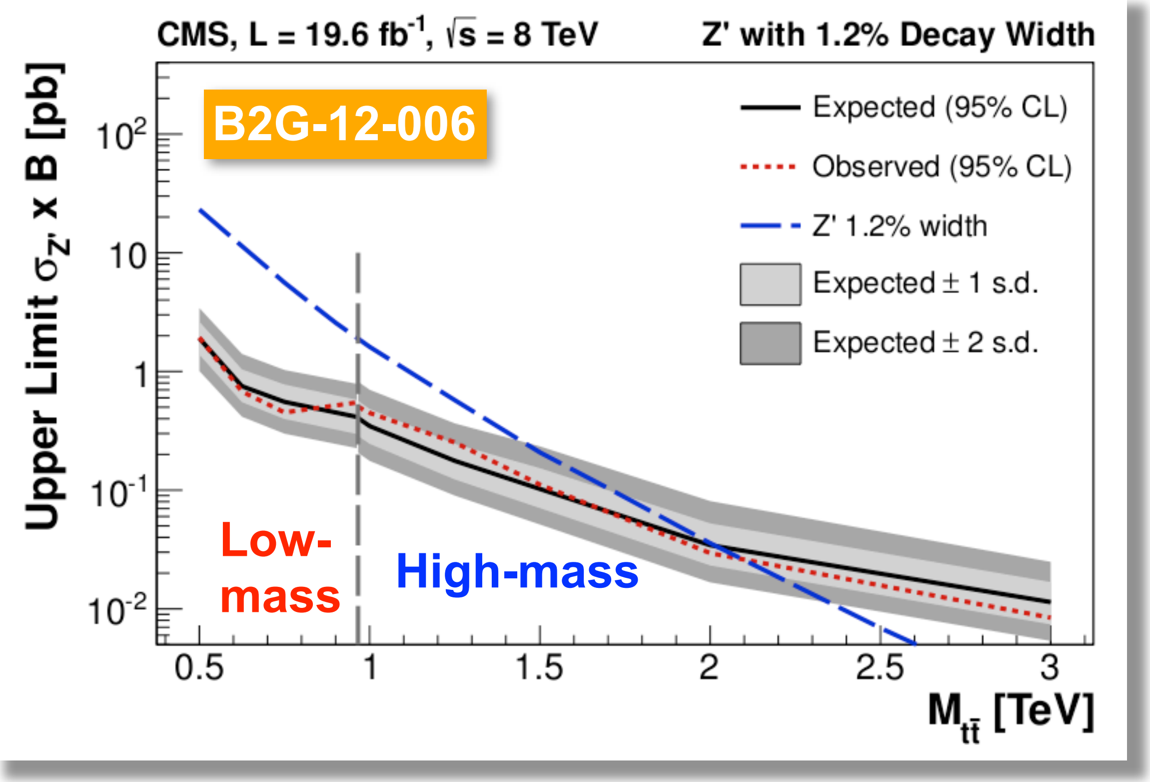


Low-mass



High-mass

- New search for tt-resonances in the l+jets+MET channel with full Run 1 data
  - Optimized separately for low-mass (non-boosted, $M_{tt} < 1$ TeV) and high-mass (boosted) regimes
  - Sets most stringent limits today



B2G-12-006

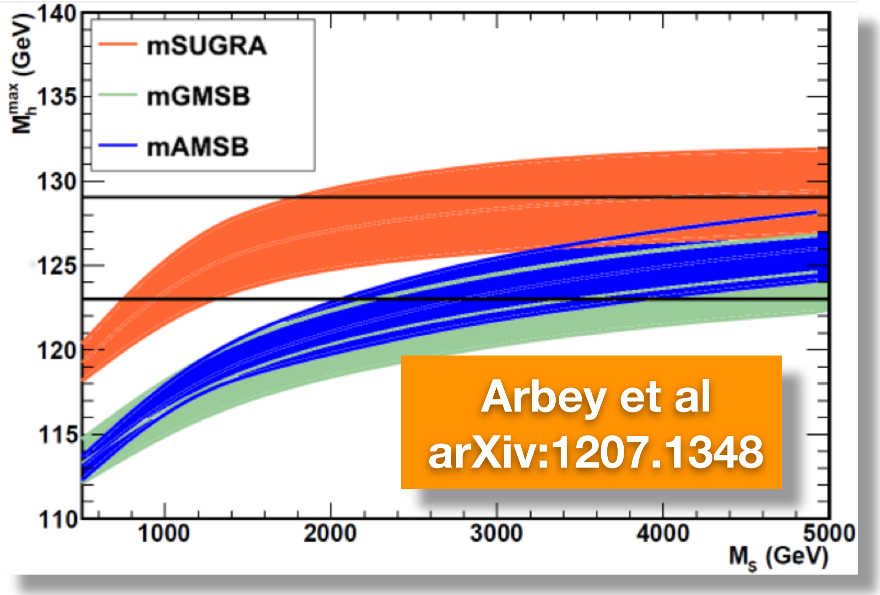
Low-mass

High-mass

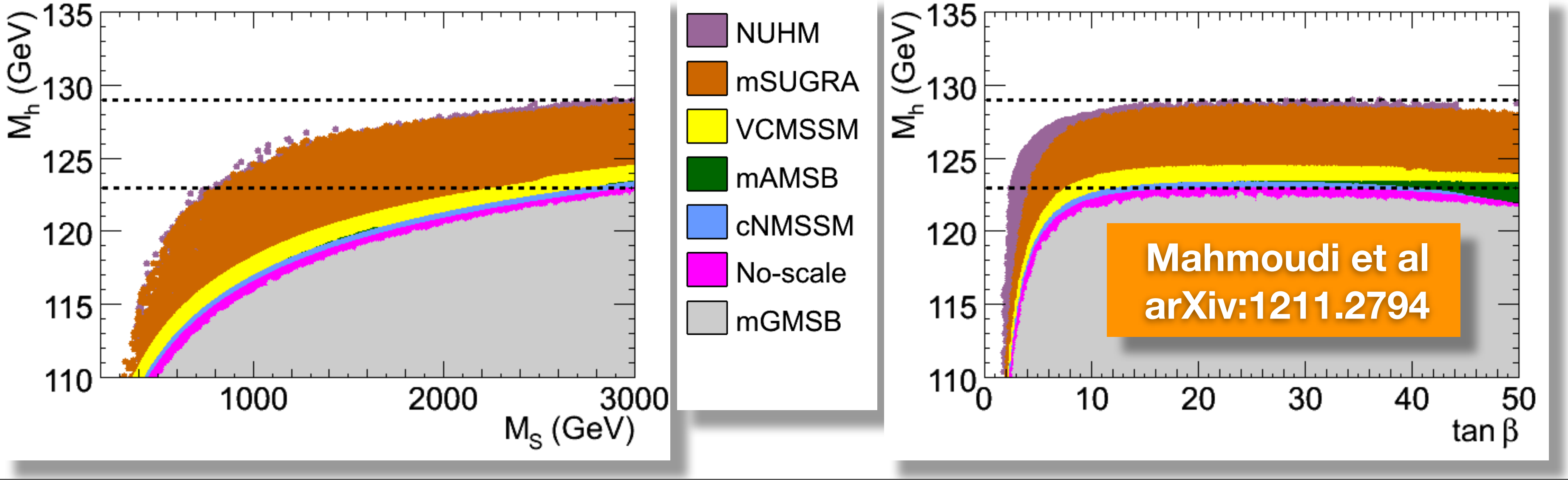
Searches for SUSY

SUSY: the Higgs Aftermath

- A 125 GeV Higgs boson is challenging to accommodate in (over)constrained versions of SUSY, particularly for “natural” values of superpartner masses
  - Started to constrain some of the simpler models
- Big question: if SUSY exists, can it still be “natural”, i.e. offer a non-fine-tuned solution to the hierarchy problem
  - If not, we would be giving up at least one of the three SUSY “miracles”



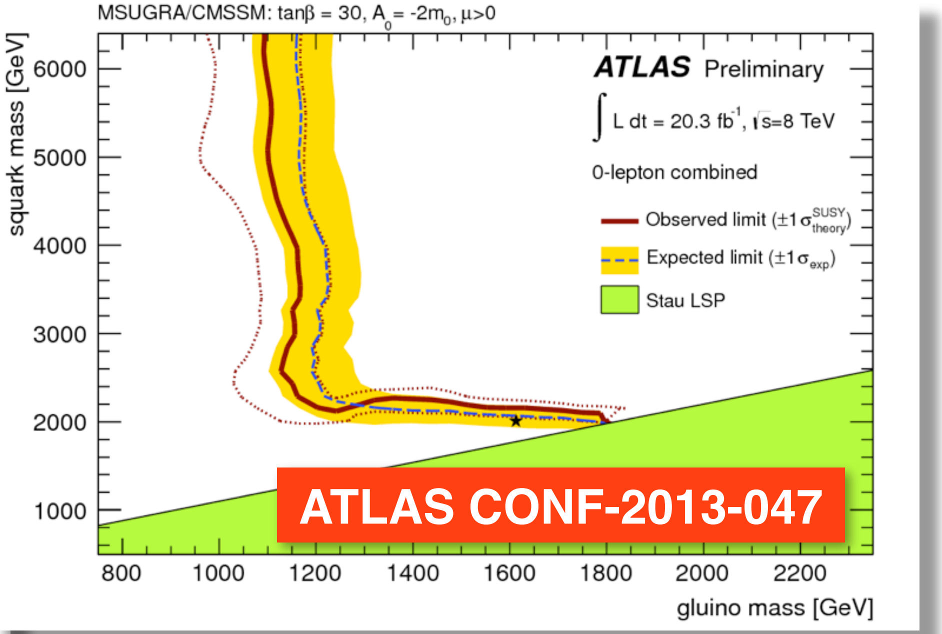
Arbey et al arXiv:1207.1348



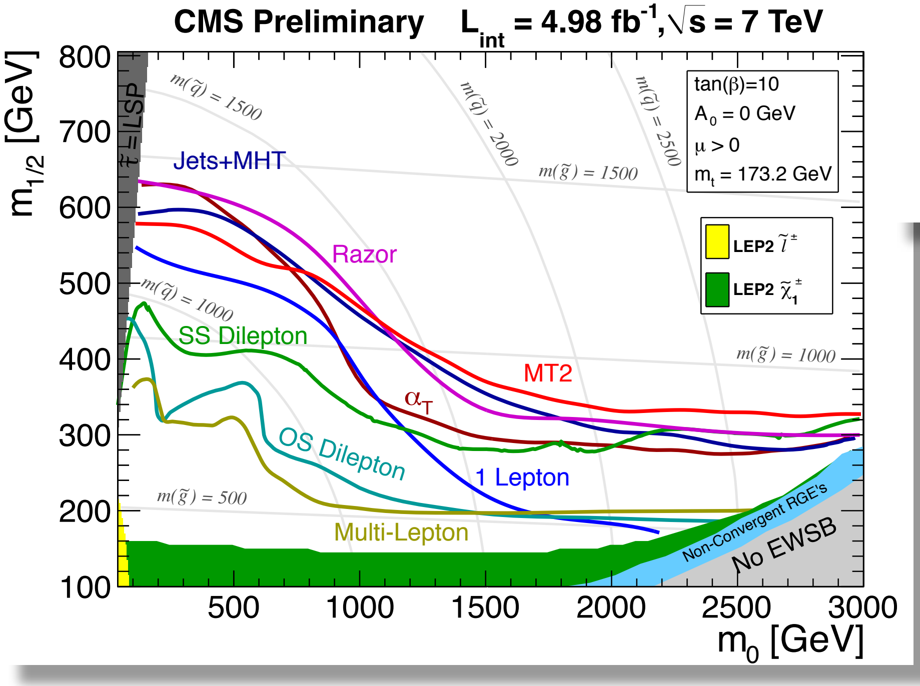
Mahmoudi et al arXiv:1211.2794

SuperSymmetry or SuperCemetery?

- Excluded squarks to ~2.0 TeV and gluinos to ~1.2 TeV - or did we?



ATLAS CONF-2013-047



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Read the fine print!

What SUSY Have We Excluded?

- We set strong limits on squarks and gluinos, and yet we have not excluded SUSY
  - Moreover, we basically excluded VERY LITTLE!
- We ventured for an "easy-SUSY" or "lazy-SUSY" and we basically failed to find it
  - So what? - Nature could be tough!
- What we probed is a tiny sliver of multidimensional SUSY space, simply most "convenient" from the point of view of theory

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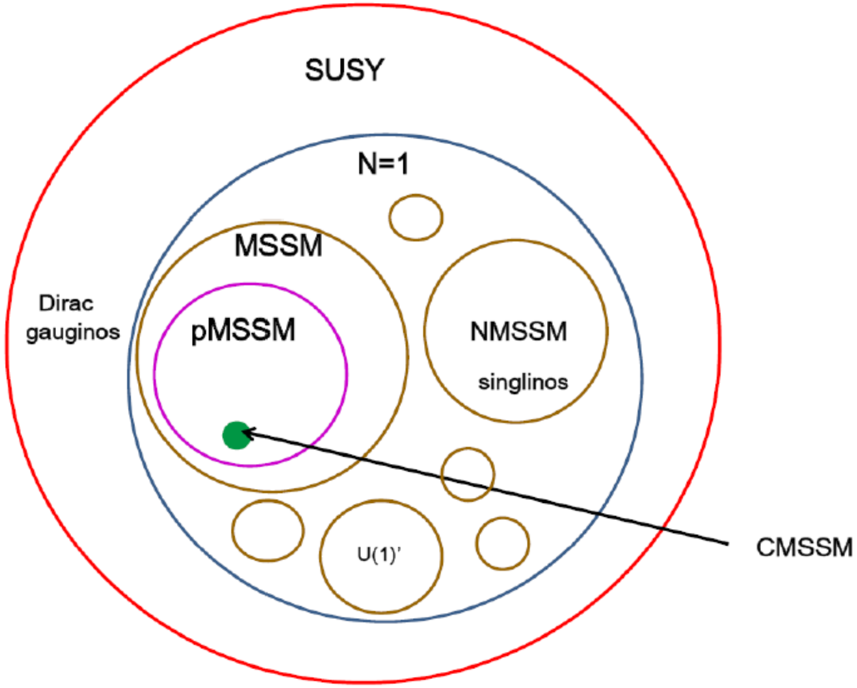
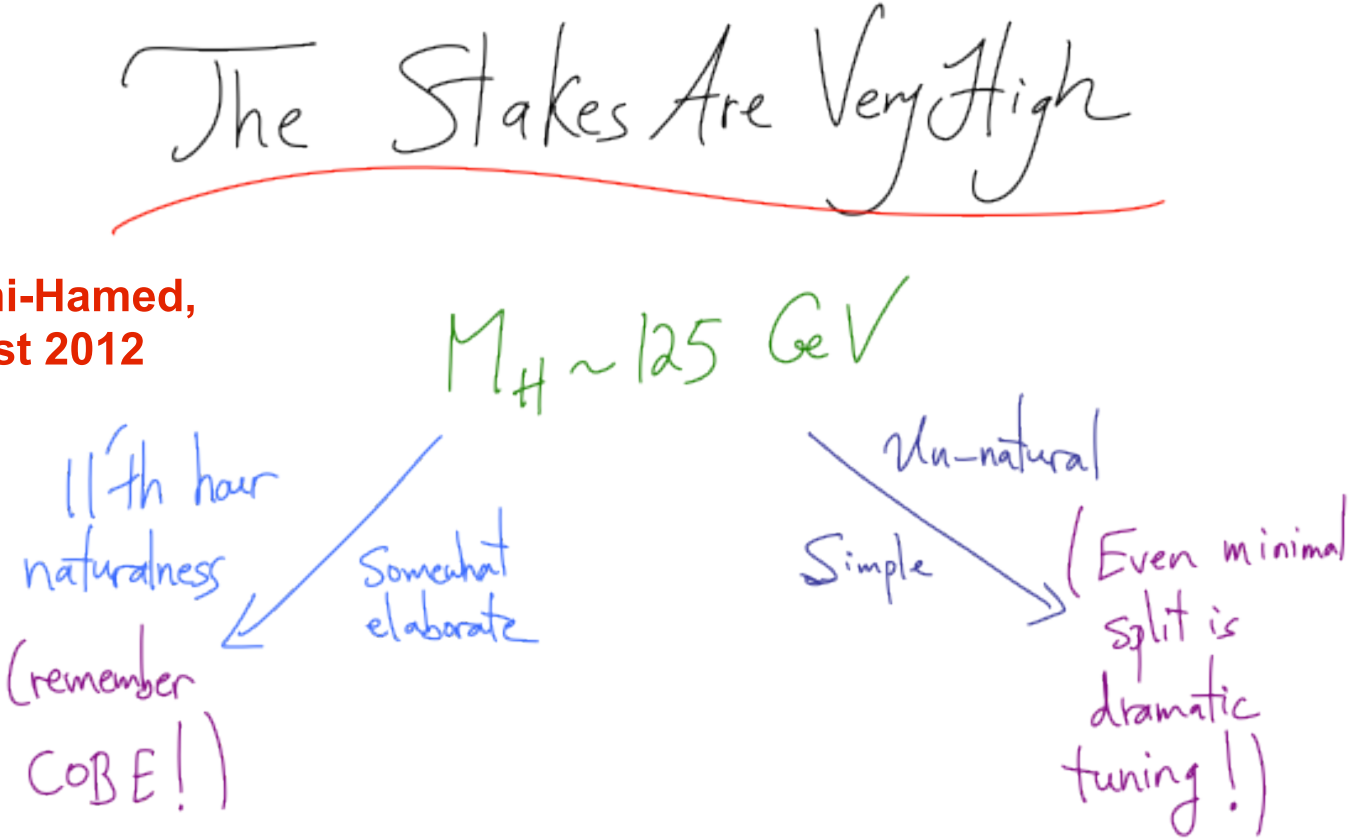
SUSY Theory phase space



T. Rizzo (SLAC Summer Institute, 01-Aug-12)

We are at a SUSY Crossroad

- Light 125 GeV Higgs boson strongly prefers SUSY as the fundamental explanation of the EWSB mechanism (via soft SUSY-breaking terms and radiative corrections)
- But what kind of SUSY?



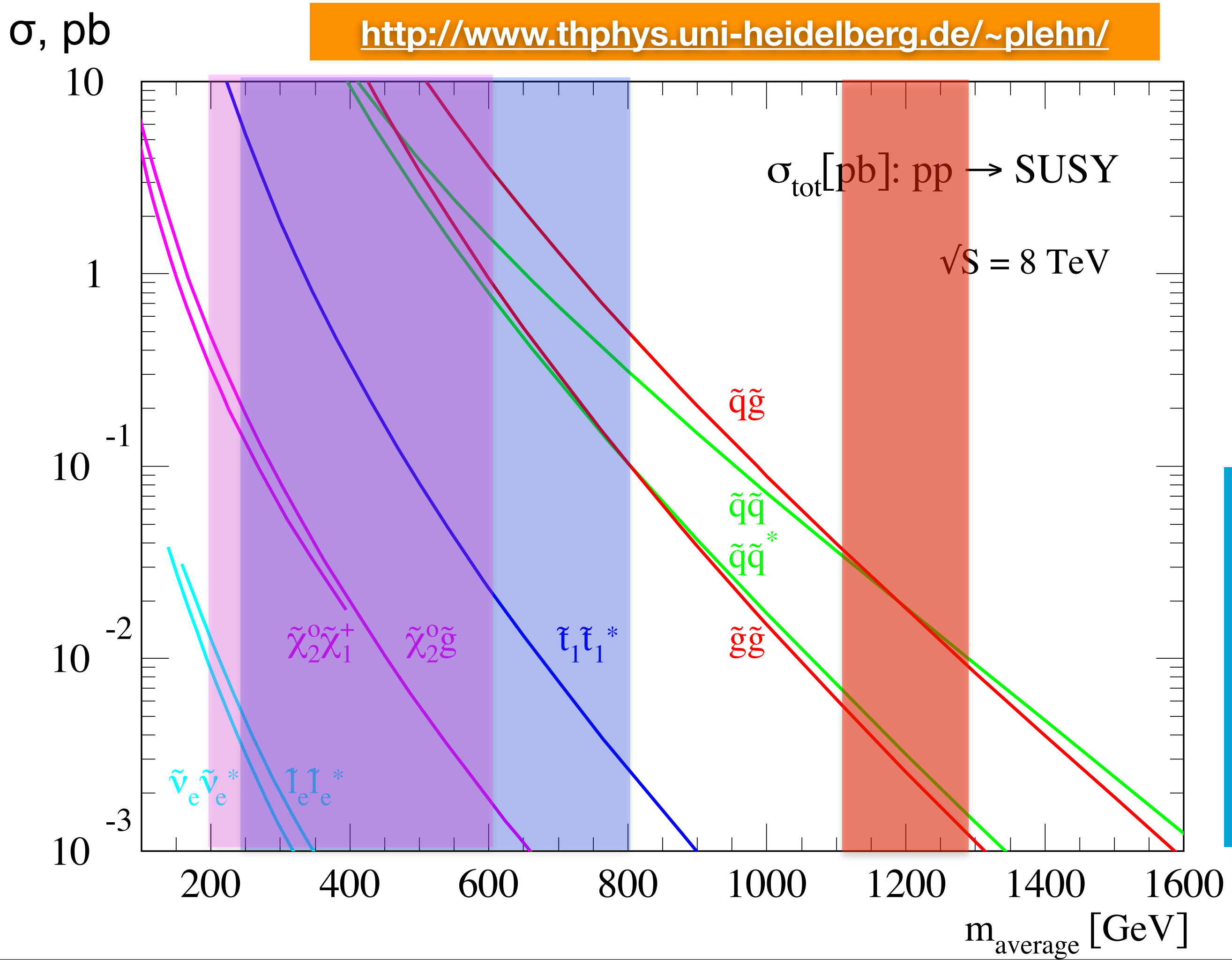
Nima Arkani-Hamed, SavasFest 2012

Implies: light stops/sbottom, reasonably light gluinos and charginos/neutralinos

Likely: long-lived particles, light neutralino, multi-TeV Z′, ...

Natural SUSY Reach

- With ∫Ldt ~ $25/\text{fb}^{-1}$ and 1 fb cross section produce 25 events; typically 1-10 events observed after acceptance/efficiencies



http://www.thphys.uni-heidelberg.de/~plehn/

$\tilde{g}\tilde{g}$: $M(\tilde{g}) \lesssim$ 1.3 TeV

$\tilde{t}_1\tilde{t}_1$: $M(\tilde{t}_1) \lesssim$ 0.8 TeV

$\tilde{\chi}\tilde{\chi}$: $M(\tilde{\chi}) \lesssim$ 0.6 TeV

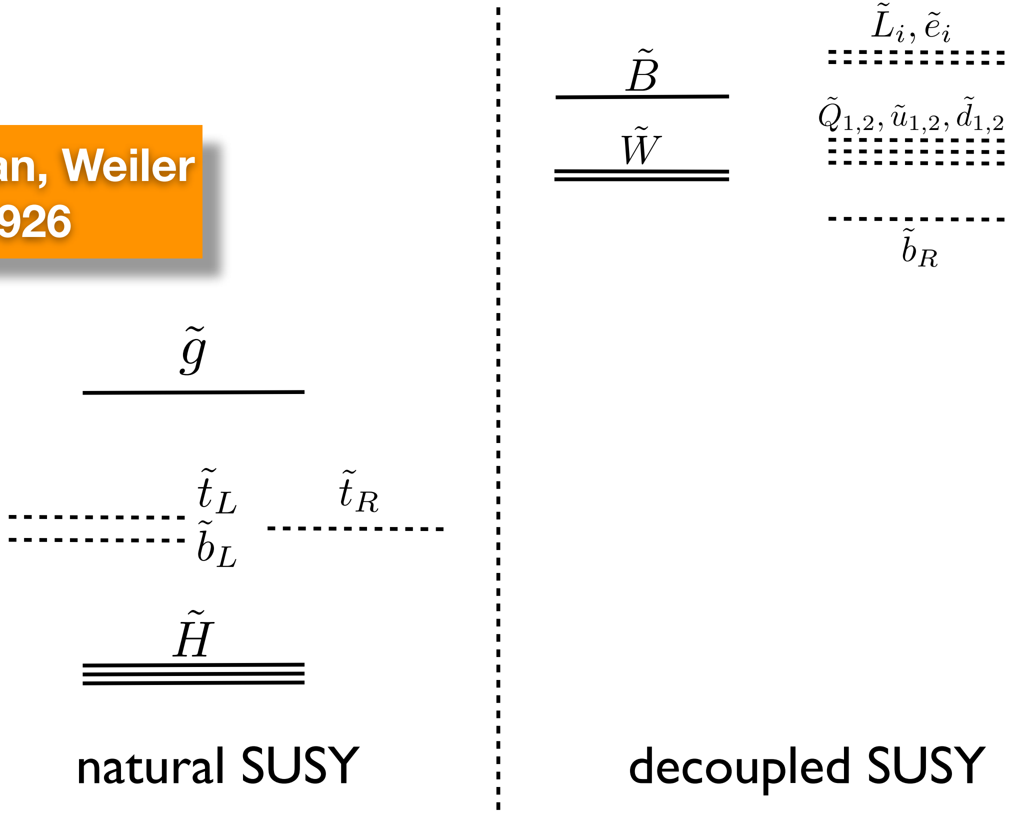
In combination, we could cover most of the natural SUSY space!

Can't do this with gluinos alone!

Natural SUSY

- If SUSY is natural, we should find it soon:
  - And we most likely will find it by observing 3rd generation SUSY particles first!
- Requires shifting of the SUSY search paradigm: going for the third generation partners, push gluino reach, and look for EW boson partners

Papucci, Ruderman, Weiler
arXiv:1110.6926



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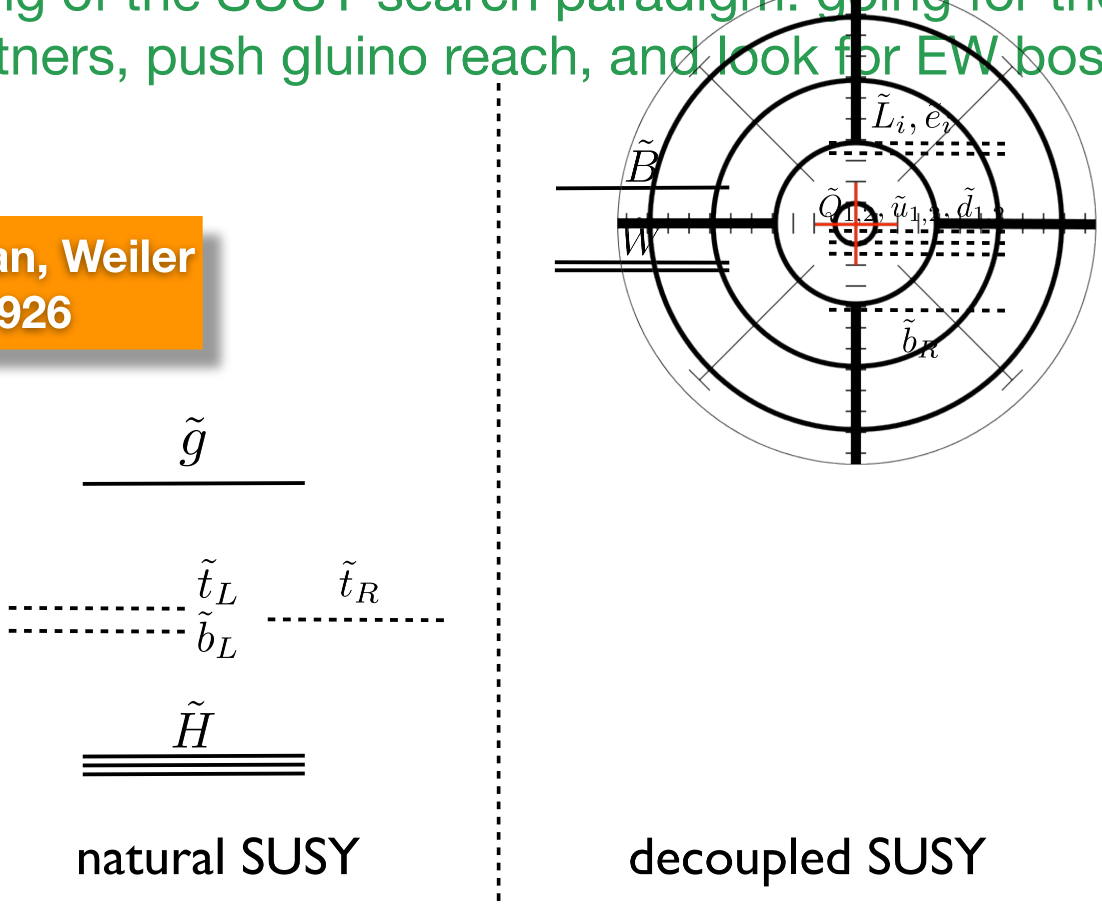

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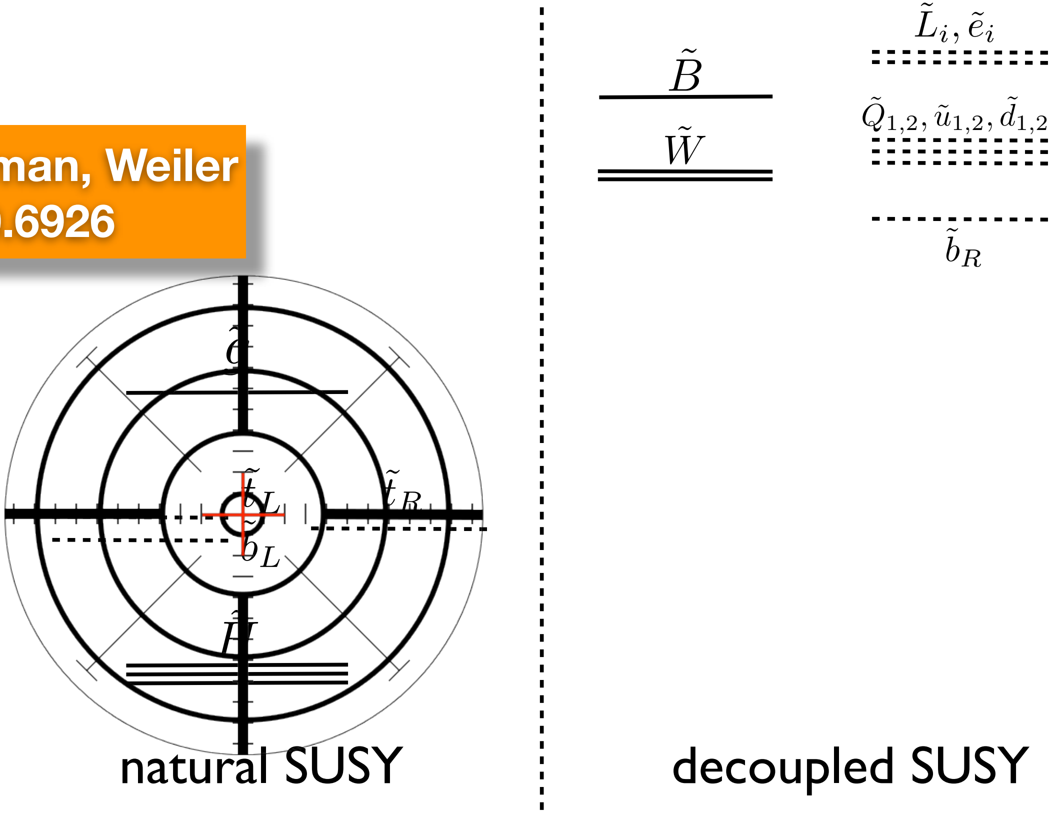
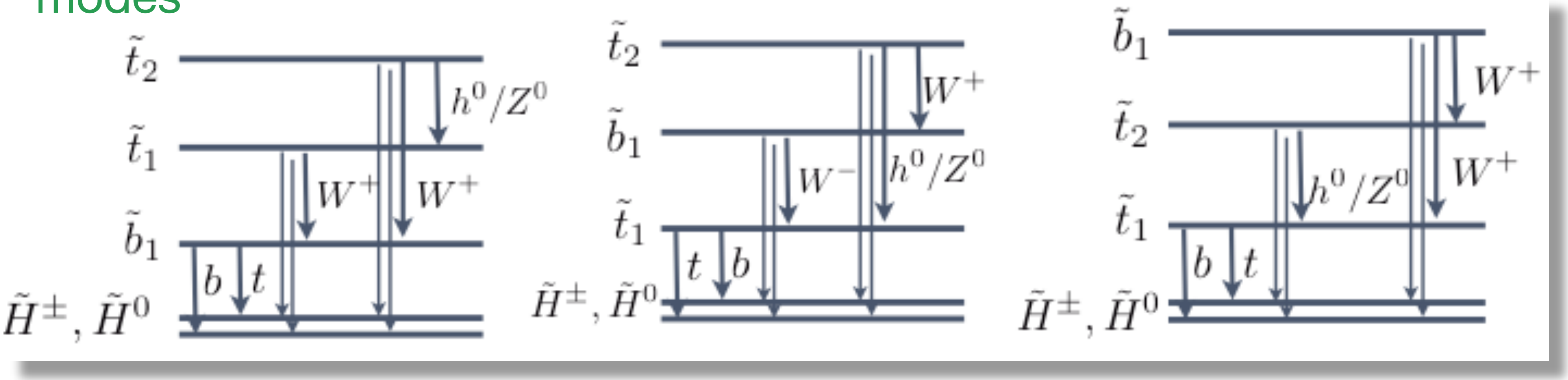


Natural SUSY Spectra

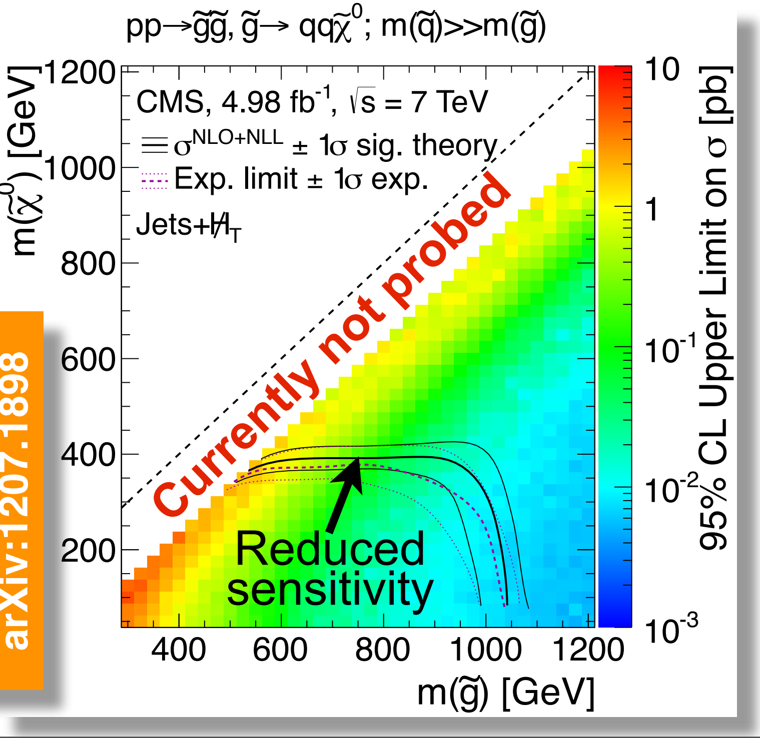
- Once we focus on natural SUSY, the spectra and the signatures become rather simple – almost like SMS
- Basically have to consider three types of spectra and related decay modes



Abbreviation	Decay mode	Conditions
T_t	$\tilde{t} \to t\chi^0$	$m_{\tilde{t}} > m_t + m_{\chi^0}$
T_b	$\tilde{t} \to b\chi^+ \to bW^+\chi^0$	$m_{\tilde{t}} > m_b + m_{\chi^+}, \quad m_{\chi^+} > m_{\chi^0} + m_W$
$T_{b'}$	$\tilde{t} \to b\chi^+ \to bW^{+*}\chi^0$	$m_{\tilde{t}} > m_b + m_{\chi^+}, \quad m_{\chi^+} < m_{\chi^0} + m_W$
$T_{t'}$	$\tilde{t} \to t^*\chi^0 \to bW^+\chi^0$	$m_{\tilde{t}} < m_t + m_{\chi^0}, \quad m_{\tilde{t}} < m_{\chi^+} + m_b$
T_c	$\tilde{t} \to c\chi^0$	$m_{\tilde{t}} < m_t + m_{\chi^0}, \quad m_{\tilde{t}} < m_{\chi^+} + m_b$
B_b	$\tilde{b} \to b\chi^0$	
B_t	$\tilde{b} \to t\chi^- \to tW^-\chi^0$	$m_{\tilde{b}} > m_t + m_{\chi^-}, \quad m_{\chi^-} > m_{\chi^0} + m_W$
$B_{t'}$	$\tilde{b} \to t\chi^- \to tW^{-*}\chi^0$	$m_{\tilde{b}} > m_t + m_{\chi^-}, \quad m_{\chi^-} < m_{\chi^0} + m_W$

Compressed Spectrum?

- If t_1 is NLSP and its mass is close to the top mass, the main decay mode becomes 3-body and hard to reconstruct
- It is still possible to handle this case experimentally:
    - Take a cross section hit and look for t_2 and sbottom decays
    - Look for modifications of the tt differential cross sections and asymmetries due to the stop contamination in tt
- Another possibility is nearly degenerate gluino and neutralino
    - In CMS, we “parked” a lot of datain 2012 corresponding to low-threshold triggers targeting compressed scenarios - first results are expected this summer!

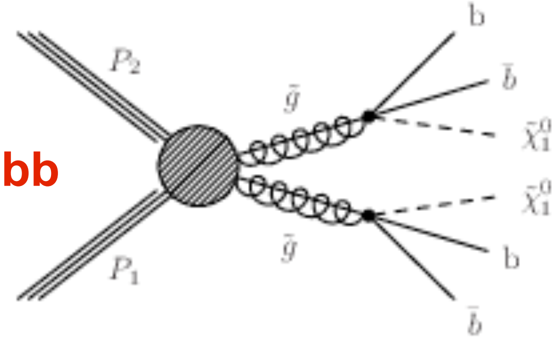


CMS Collaboration
arXiv:1207.1898

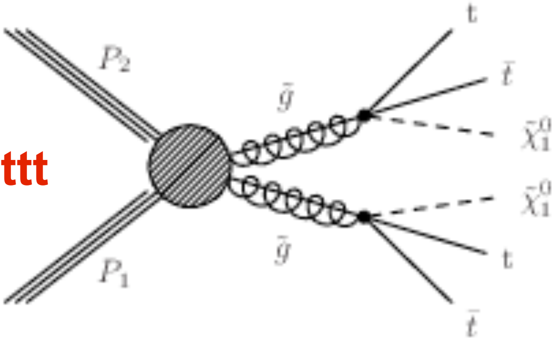
Natural SUSY: Gluino-Induced

- Repeat the entire host of all-hadronic, single-lepton, dilepton, and multilepton searches in the bins of b-jet multiplicity
  - Expect up to 4 b-jets in the following SMS targeting gluino decays via virtual stop or sbottom:

T1bbbb



T1tttt

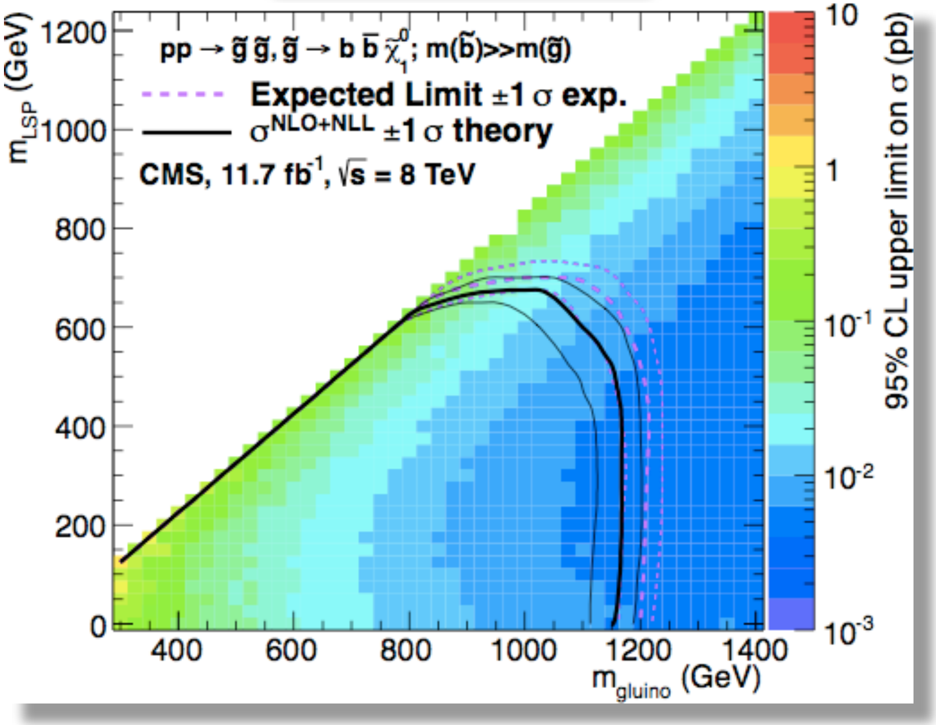


  - T1bbbb can be probed in all-hadronic searches with b-jets
  - Depending on the decay mode of the tops, could look for the T1tttt production in all-hadronic, single-lepton, dilepton, and multilepton final states
  - Next in line: T1ttbb, with two gluinos decaying differently

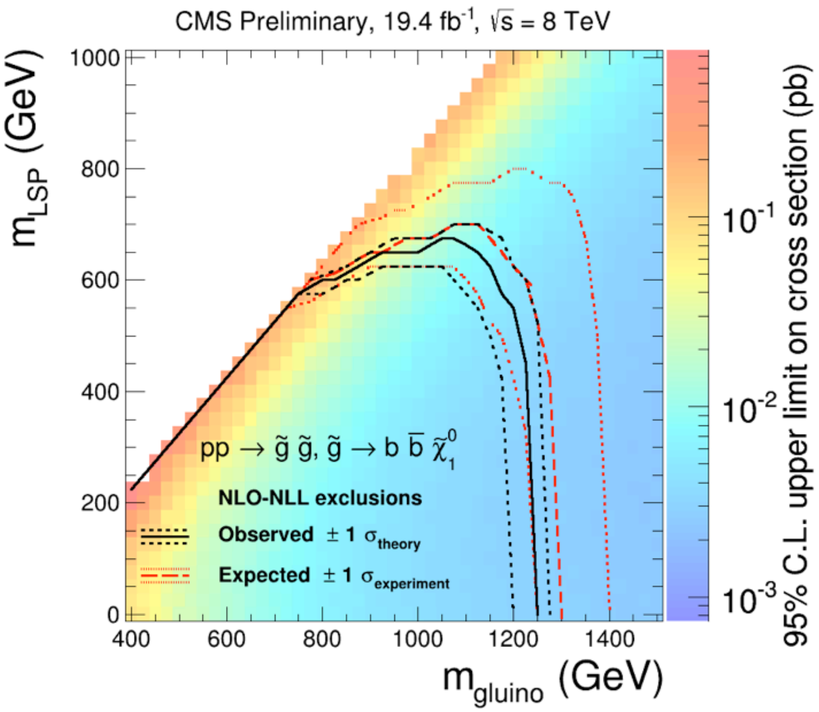
T1bbbb Limits @ 8 TeV

- Two all-hadronic analyses binned in b-jet content, up to 4 or more: α_T and H_T+ME_T

CMS Collaboration arXiv:1303.2985

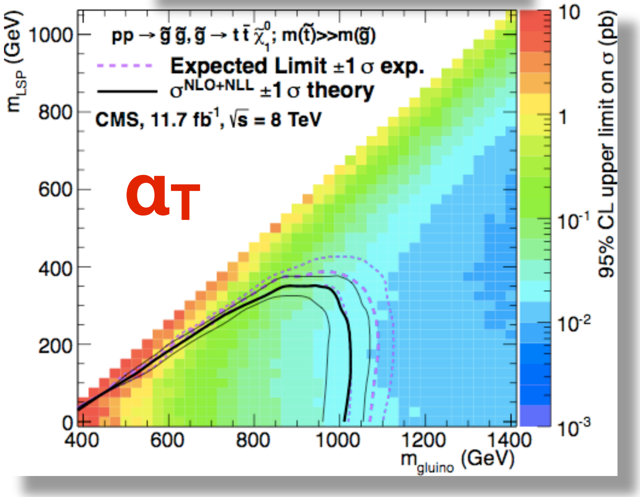


CMS SUS-12-024



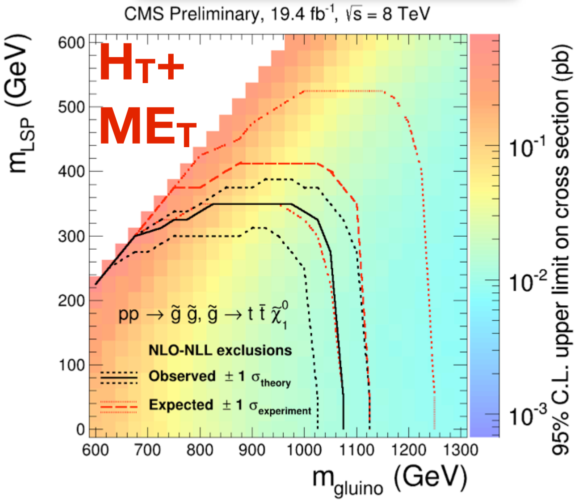
T1tttt Limits @ 8 TeV

CMS Collaboration
arXiv:1303.2985

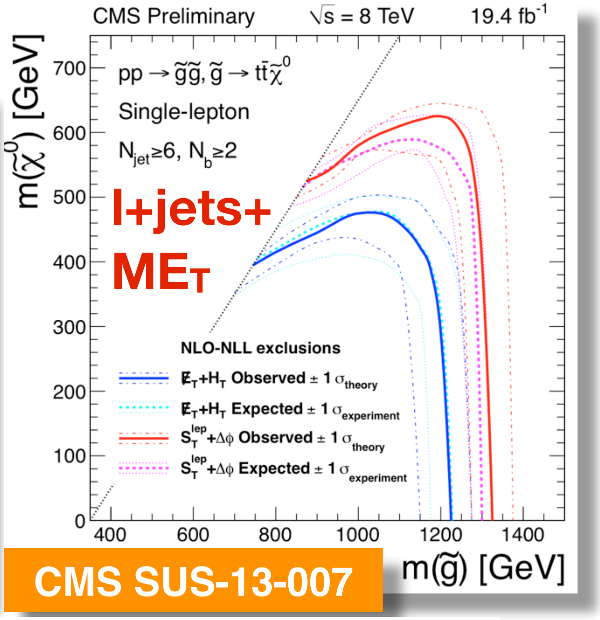


α_T

CMS SUS-12-024

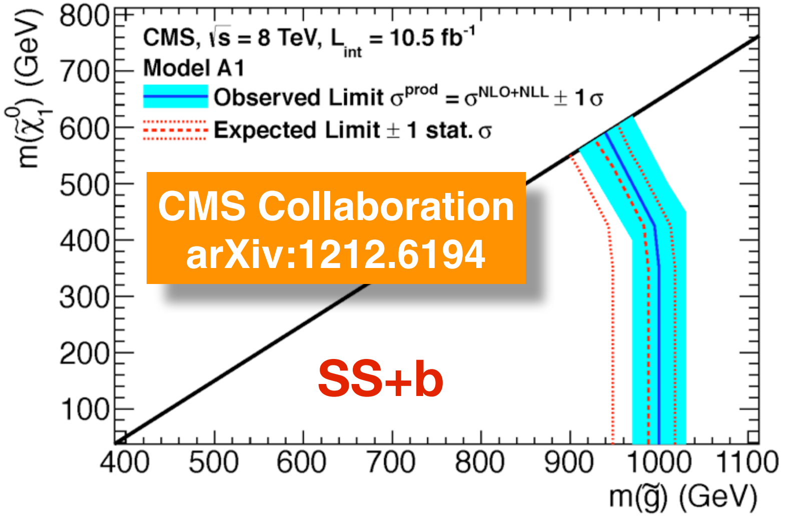


H_T+
ME_T



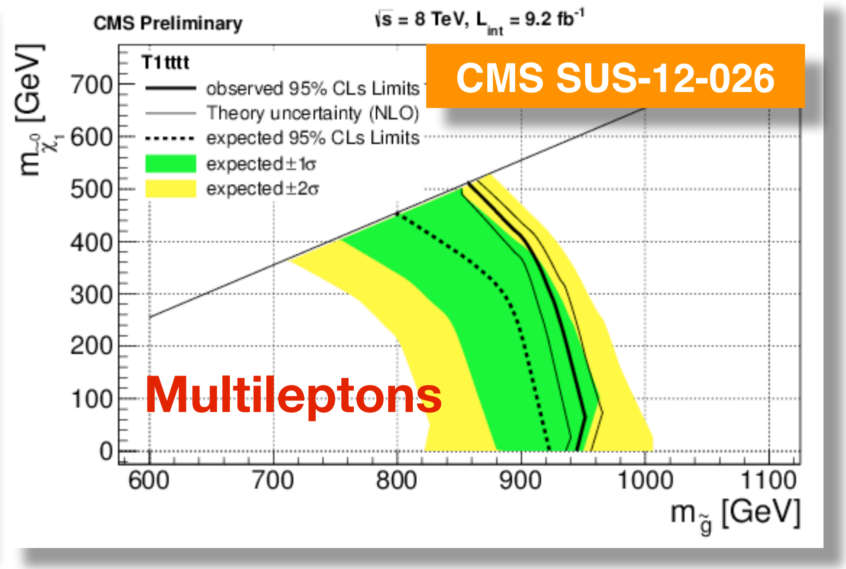
l+jets+
ME_T

CMS SUS-13-007



CMS Collaboration
arXiv:1212.6194

SS+b



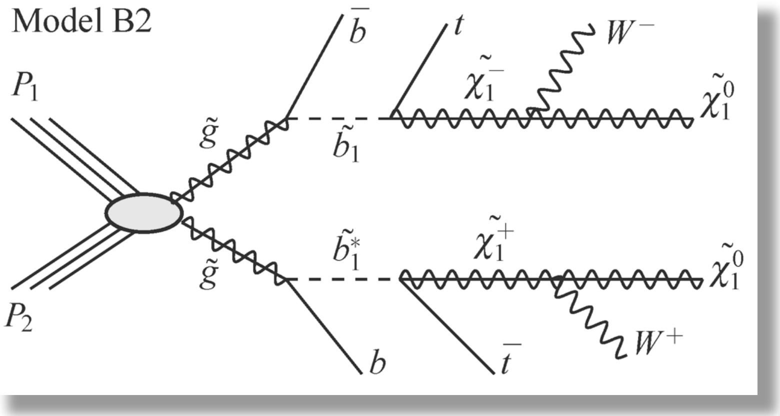
CMS SUS-12-026

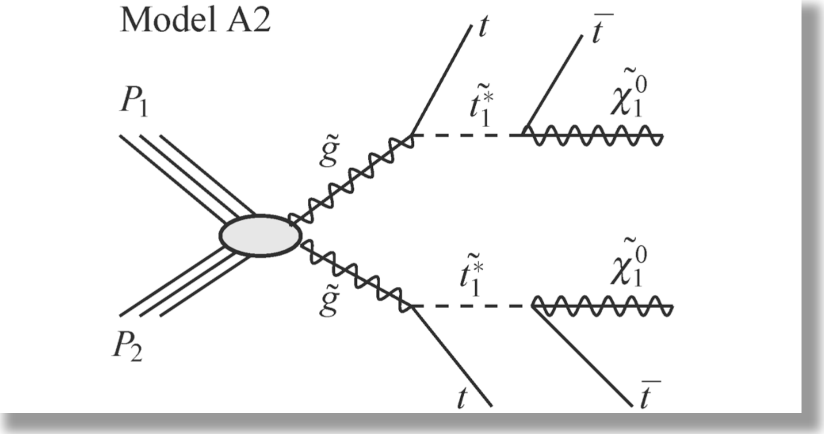
Multileptons

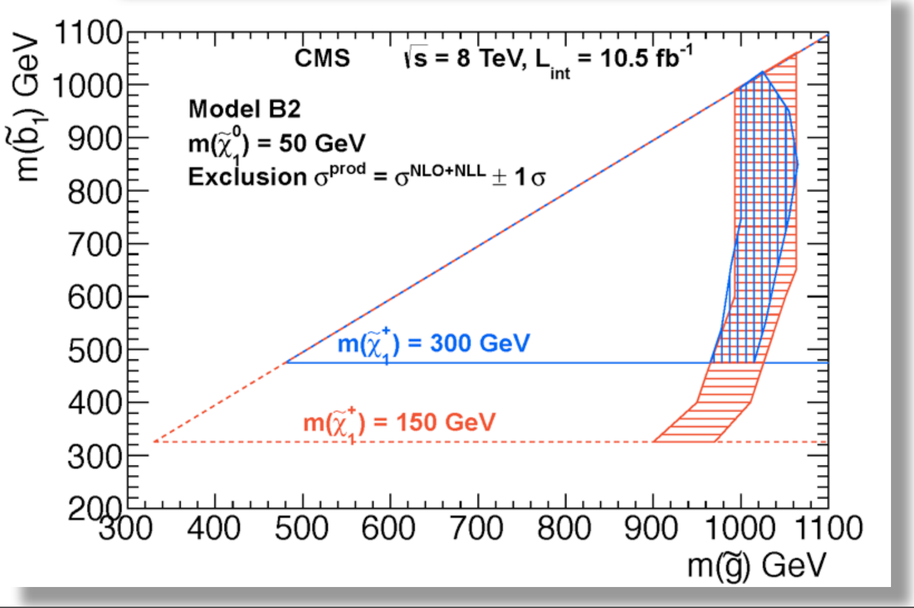
On-Shell Sbottoms/Stops

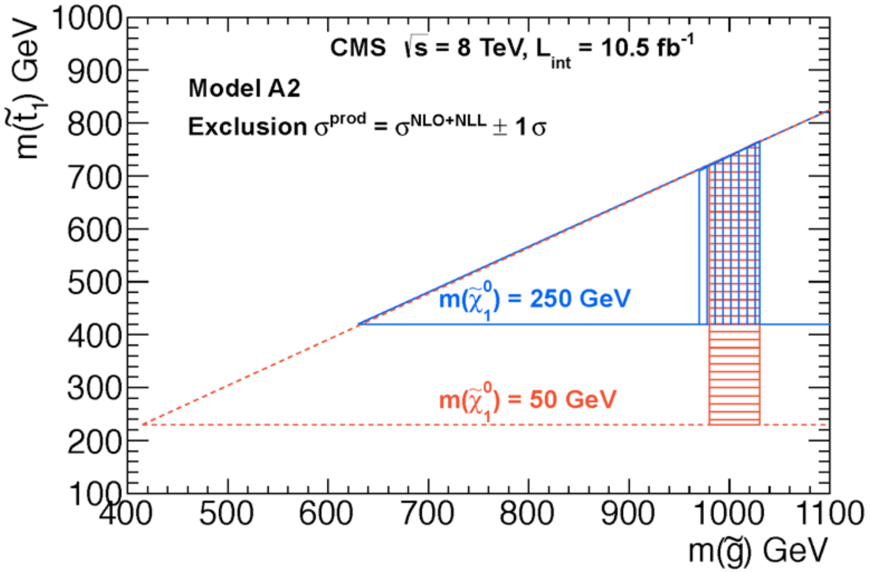
- ✦ SS+b dilepton analysis also looks for on-shell production:

CMS Collaboration arXiv:1212.6194



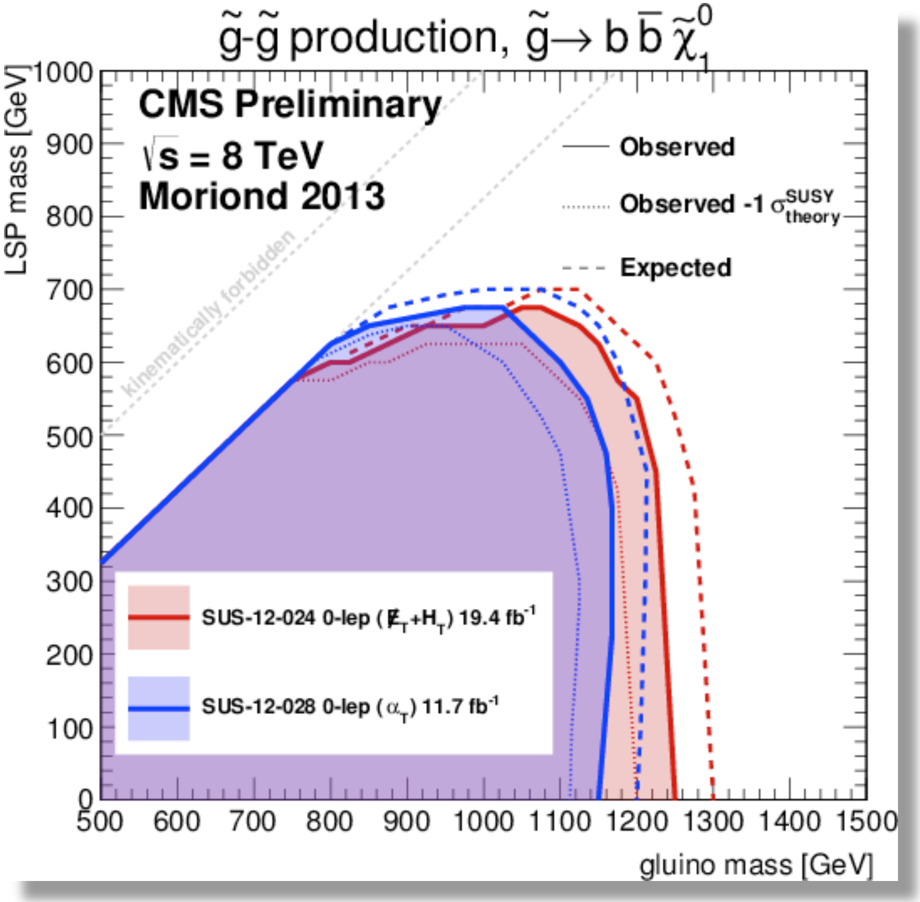


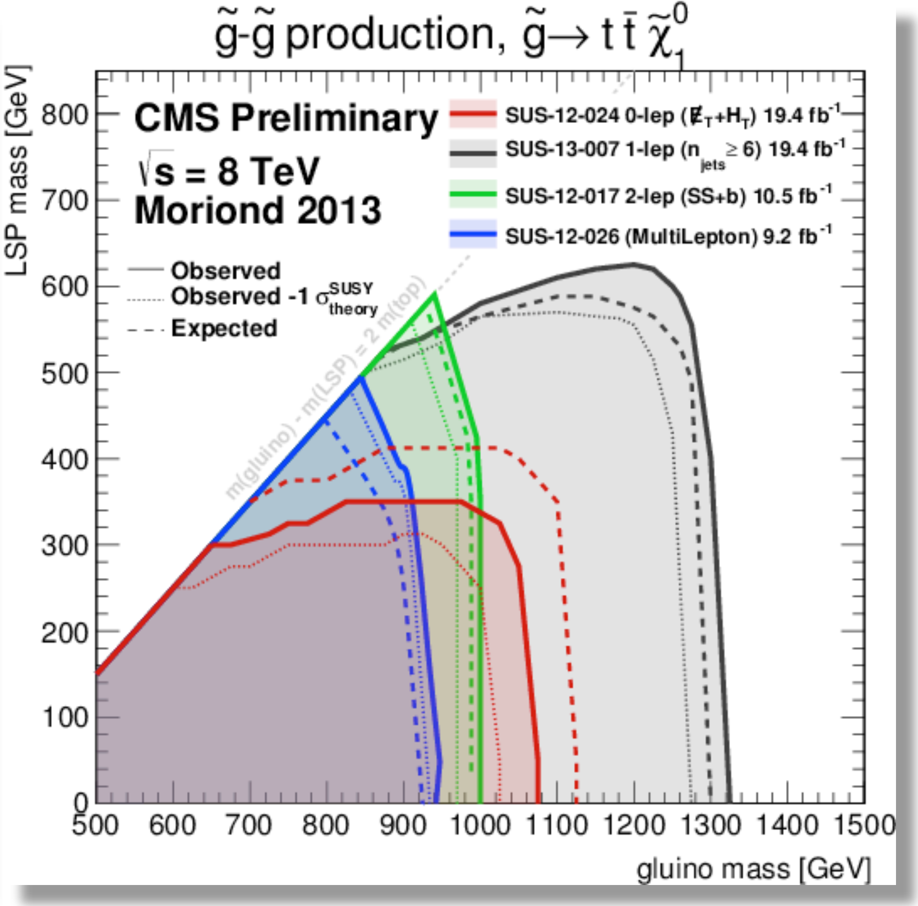




Gluino-Induced: Summary

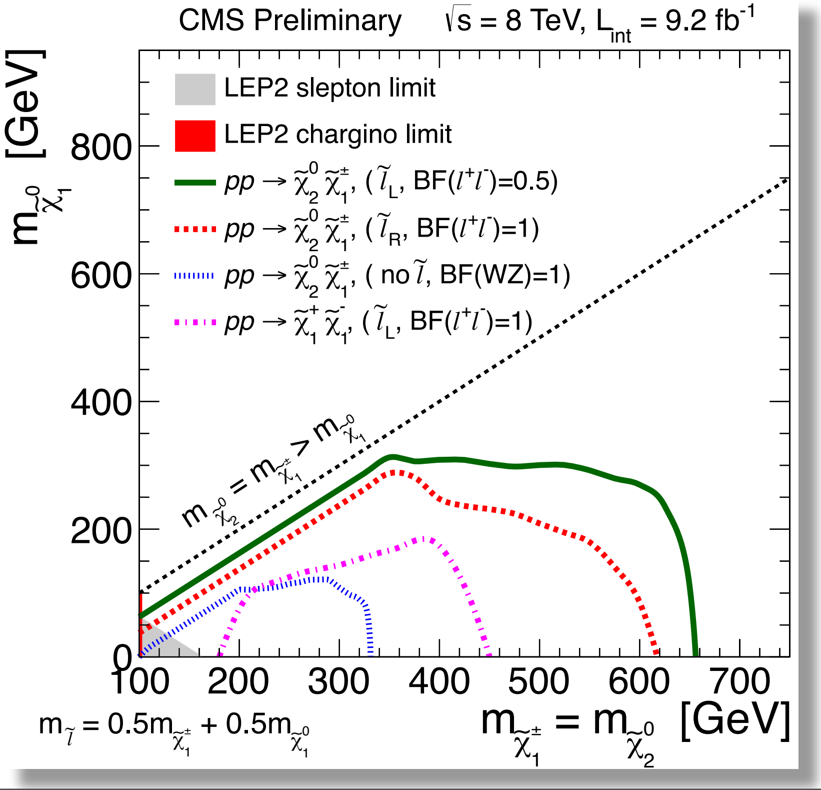
- Summary of current limits on sbottoms and stops from gluino-induced production
  - Pretty much reached the kinematic limit of ~1.3 TeV on gluino production for large fraction of the parameter space

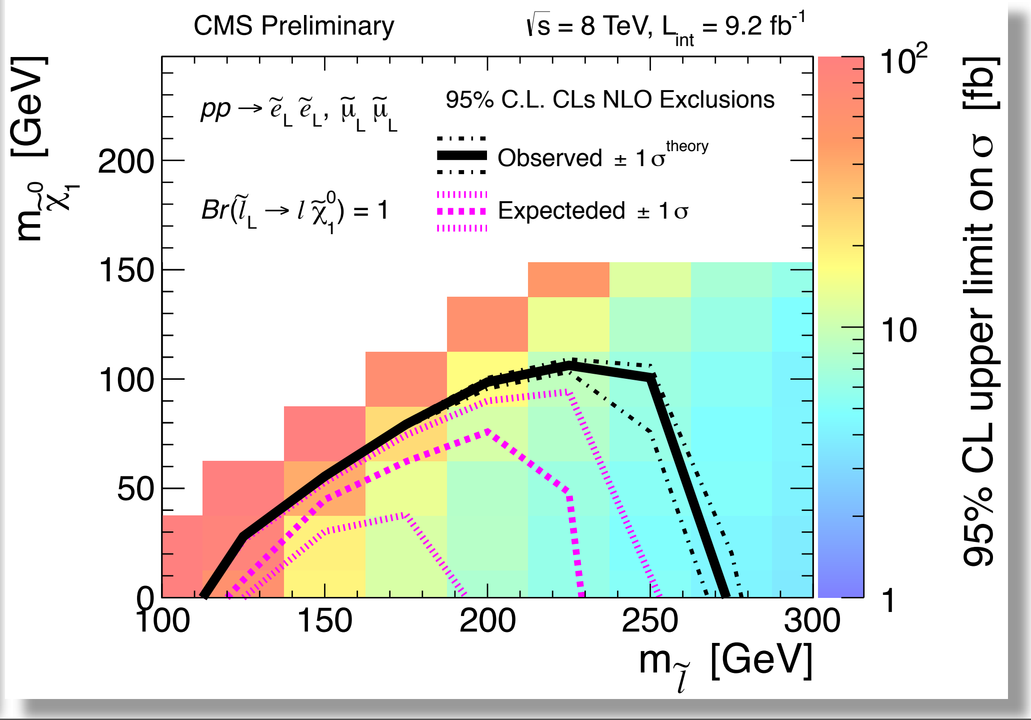




Direct EW Pair-Production

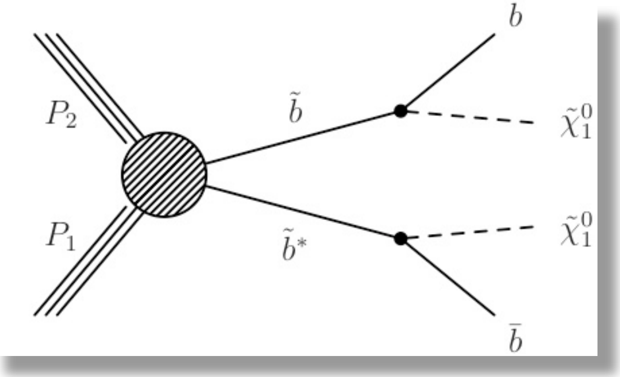
- Also look for direct EW pair-production of charginos/neutralinos and sleptons in multilepton and dileptons final states
- Set stringent limits on neutralinos for non-degenerate chargino/ neutralino cases
  - Drops from ~200 GeV to ~100 GeV in case of heavy sleptons

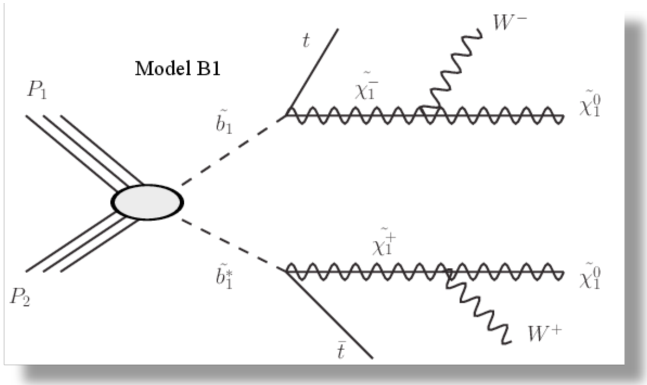


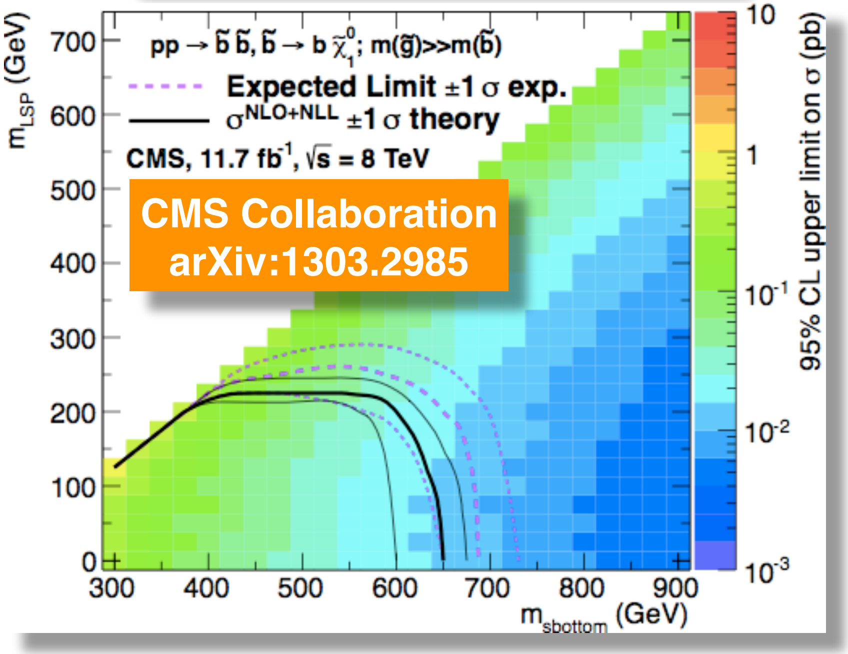


Direct Sbottom Production

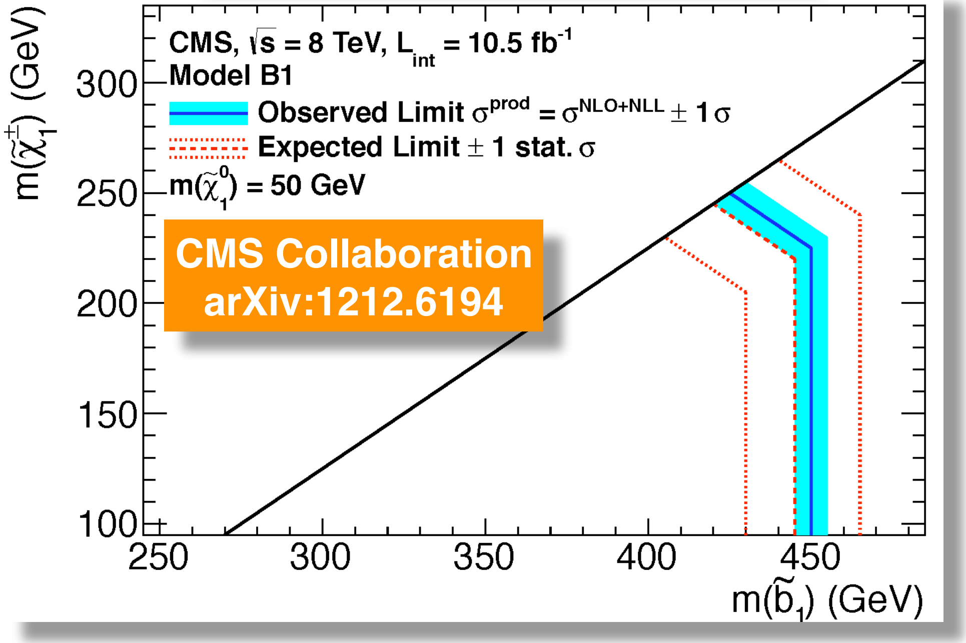
- Direct sbottom pair production was looked at in the all-hadronic α_T + b-jets and same-sign dilepton + b-jets channels:







CMS Collaboration arXiv:1303.2985

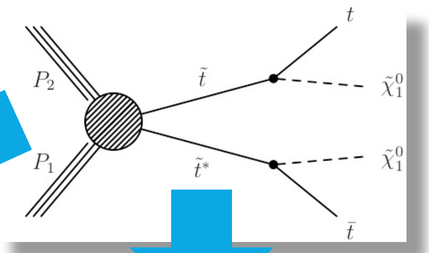


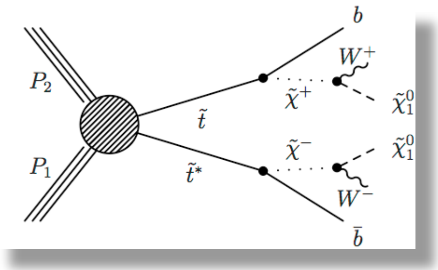
CMS Collaboration arXiv:1212.6194

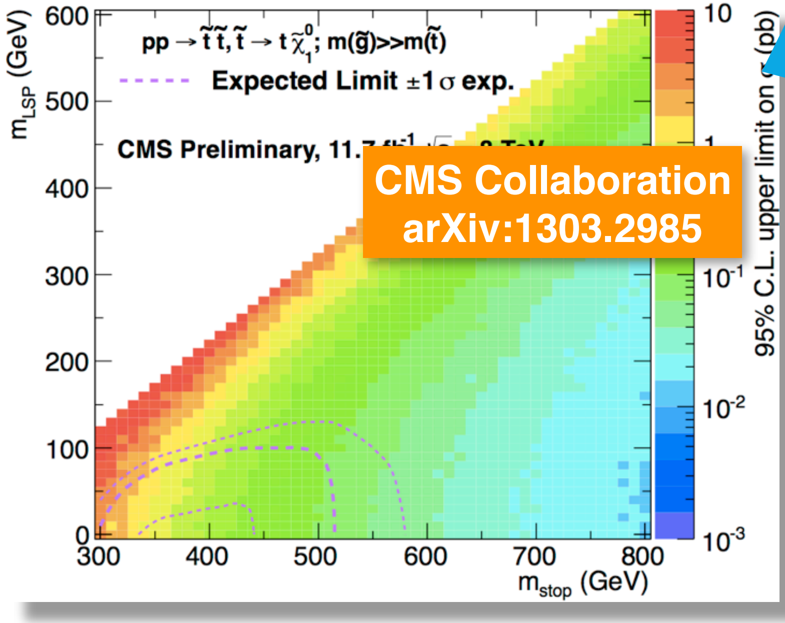
Direct Stop Production

- ✦ This is the most hopeful, and yet the toughest channel at the LHC
- ✦ Simple reinterpretation of the existing analyses is not sensitive enough
- ✦ Requires a dedicated optimized tour-de-force analysis:
    - W+jets and tt with τ_h and lost leptons (from W(μν)+jets with embedded τ_h), invisible Z decays (from Z(μμ)), and multijets (reweighted MC with kinematics and resolutions reweighted to match multijet data)
    - The 8 TeV analysis is ongoing

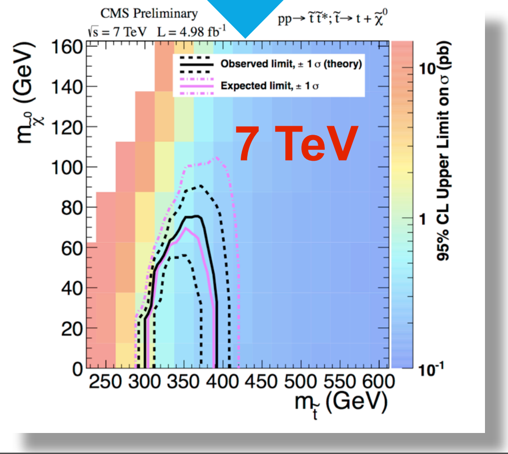
CMS SUS-11-030

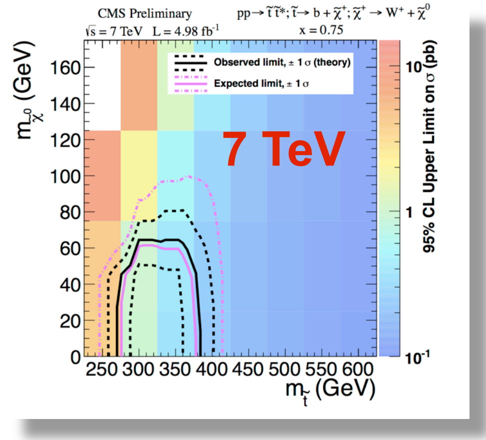






CMS Collaboration
arXiv:1303.2985





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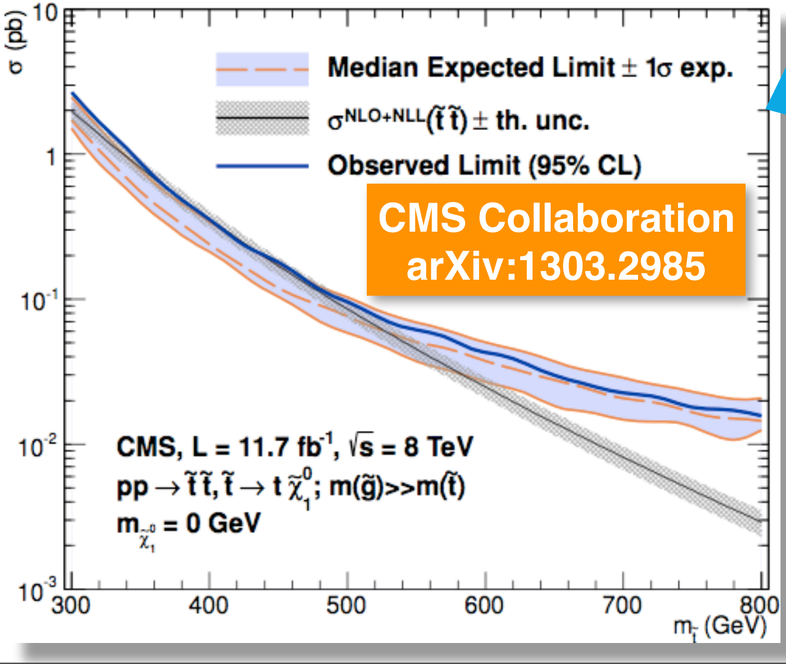
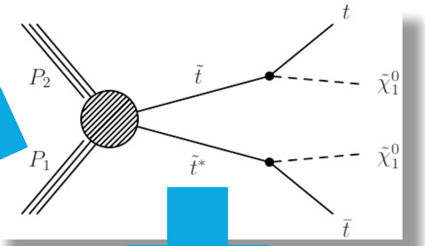
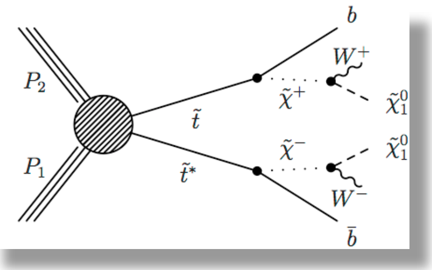
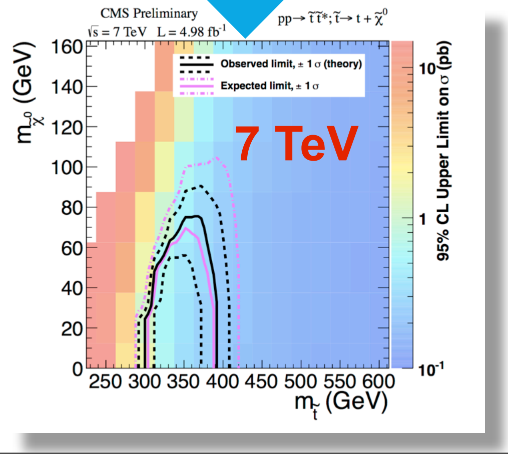
CMS SUS-11-030

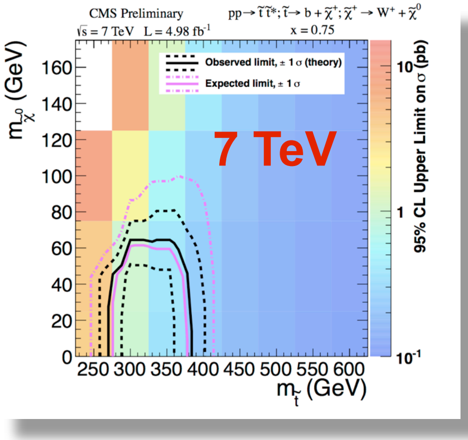


CMS Collaboration arXiv:1303.2985





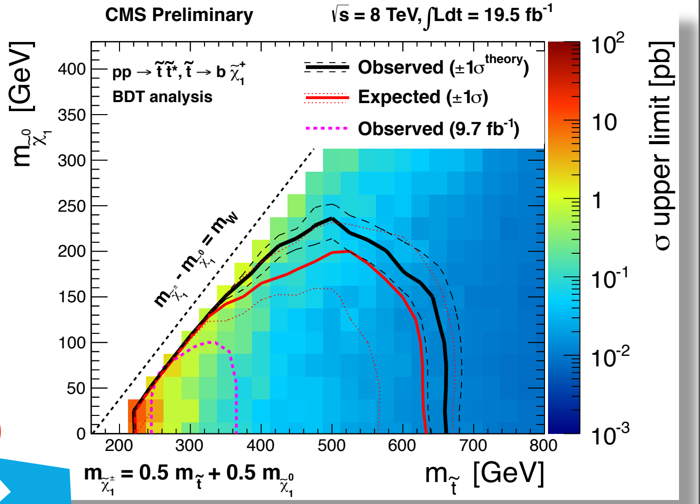


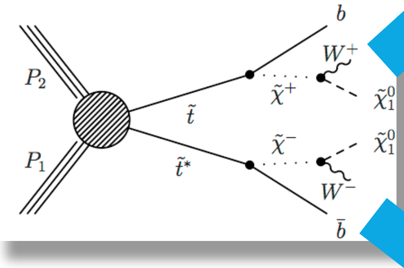


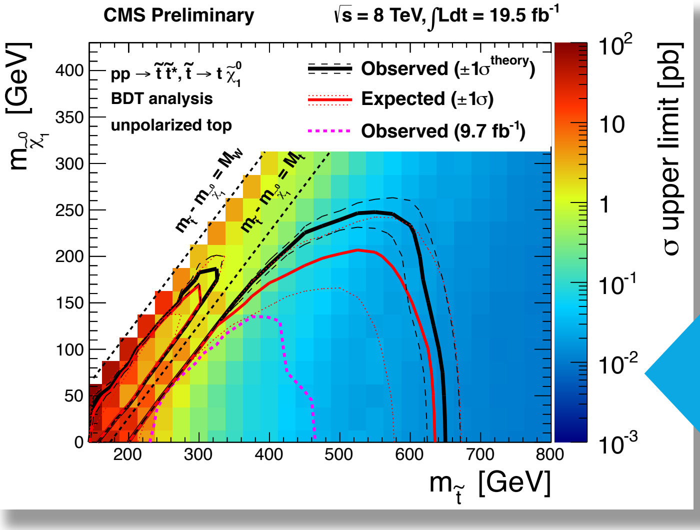
Direct Stop: l+jets+$\mathrm{ME_T}$

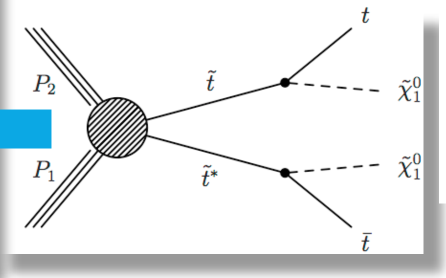
- Another important channel for direct stop production is single-lepton channel
  - Dedicated optimized multivariate analysis, cross checked with cut-based analysis
  - Main background is from tt to dileptons with a lost lepton or τ_h, followed by W+jets and semileptonic tt
  - Backgrounds estimated from MC corrected to match data in several control regions
  - Some dependence on top polarization (~40 GeV)

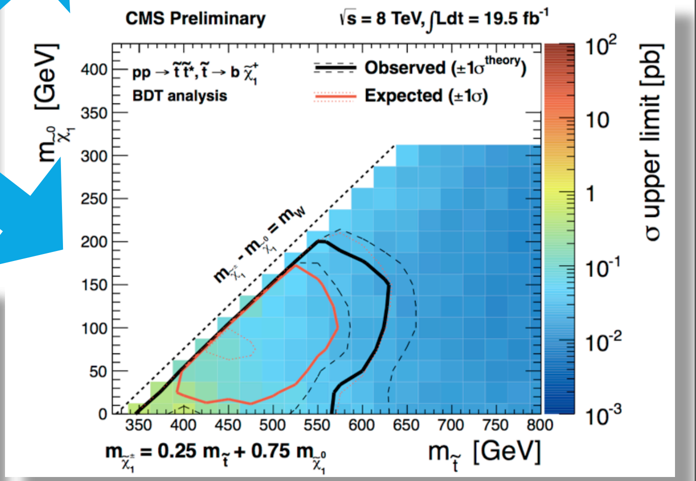
CMS SUS-13-011







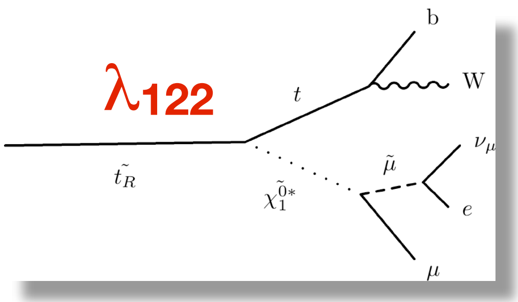


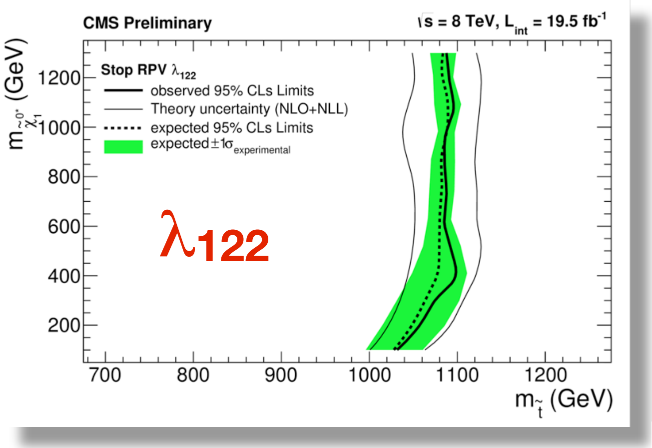


Compressed chargino-neutralino spectrum

RPV Stop Search

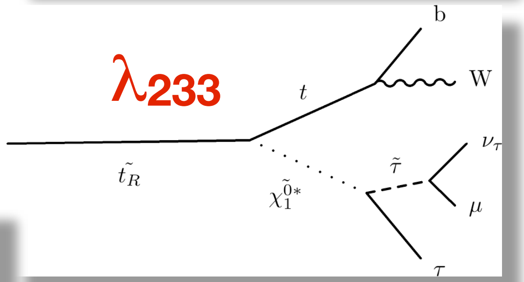
- Natural SUSY could still be RPV!
- Can look for stop decays into top and neutralino, with neutralino decaying via RPV couplings to two leptons and neutrino (λ_{ijk}) or a lepton, bottom, and top quarks (λ'_{223})
- Reinterpret multilepton search with b-jets within these scenarios

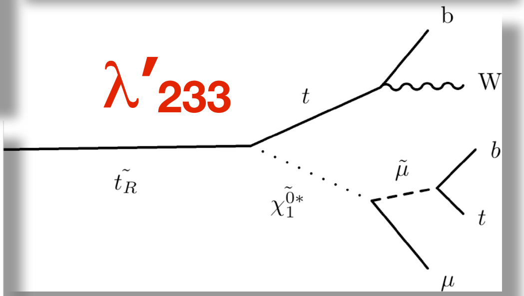


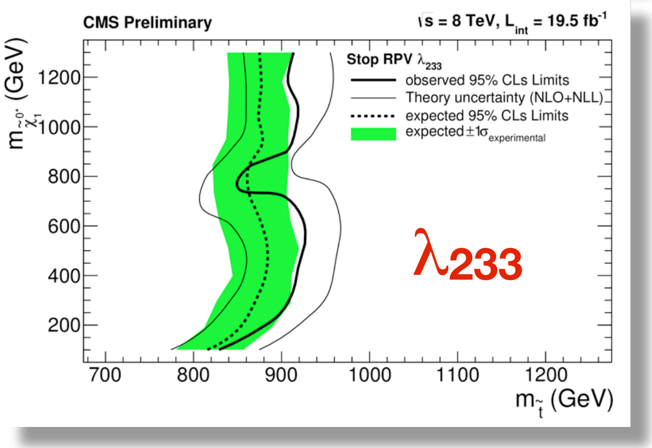


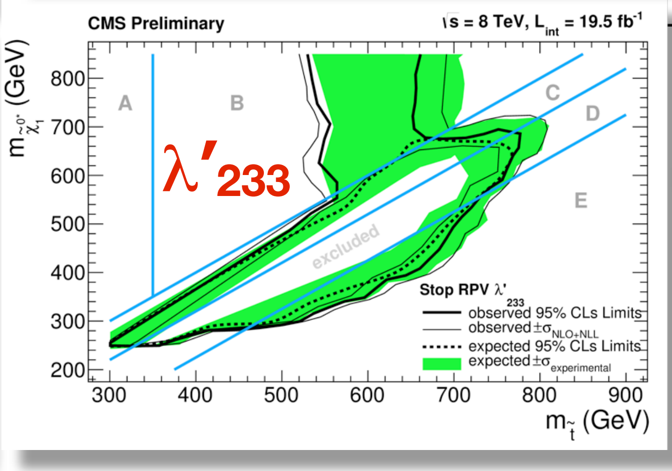
CMS SUS-13-003

region label	kinematic region	stop decay mode(s)
A	$m_t < m_{\tilde t} < 2m_t, m_{\tilde\chi_1^0}$	$\tilde t \to t\nu b\bar b$
B	$2m_t < m_{\tilde t} < m_{\tilde\chi_1^0}$	$\tilde t \to t\mu t\bar b + t\nu b\bar b$
C	$m_{\tilde\chi_1^0} < m_{\tilde t} < m_W + m_{\tilde\chi_1^0}$	$\tilde t \to \ell\nu b\tilde\chi_1^0 + jjb\tilde\chi_1^0$
D	$m_W + m_{\tilde\chi_1^0} < m_{\tilde t} < m_t + m_{\tilde\chi_1^0}$	$\tilde t \to Wb\tilde\chi_1^0$
E	$m_t + m_{\tilde\chi_1^0} < m_{\tilde t}$	$\tilde t \to t\tilde\chi_1^0$





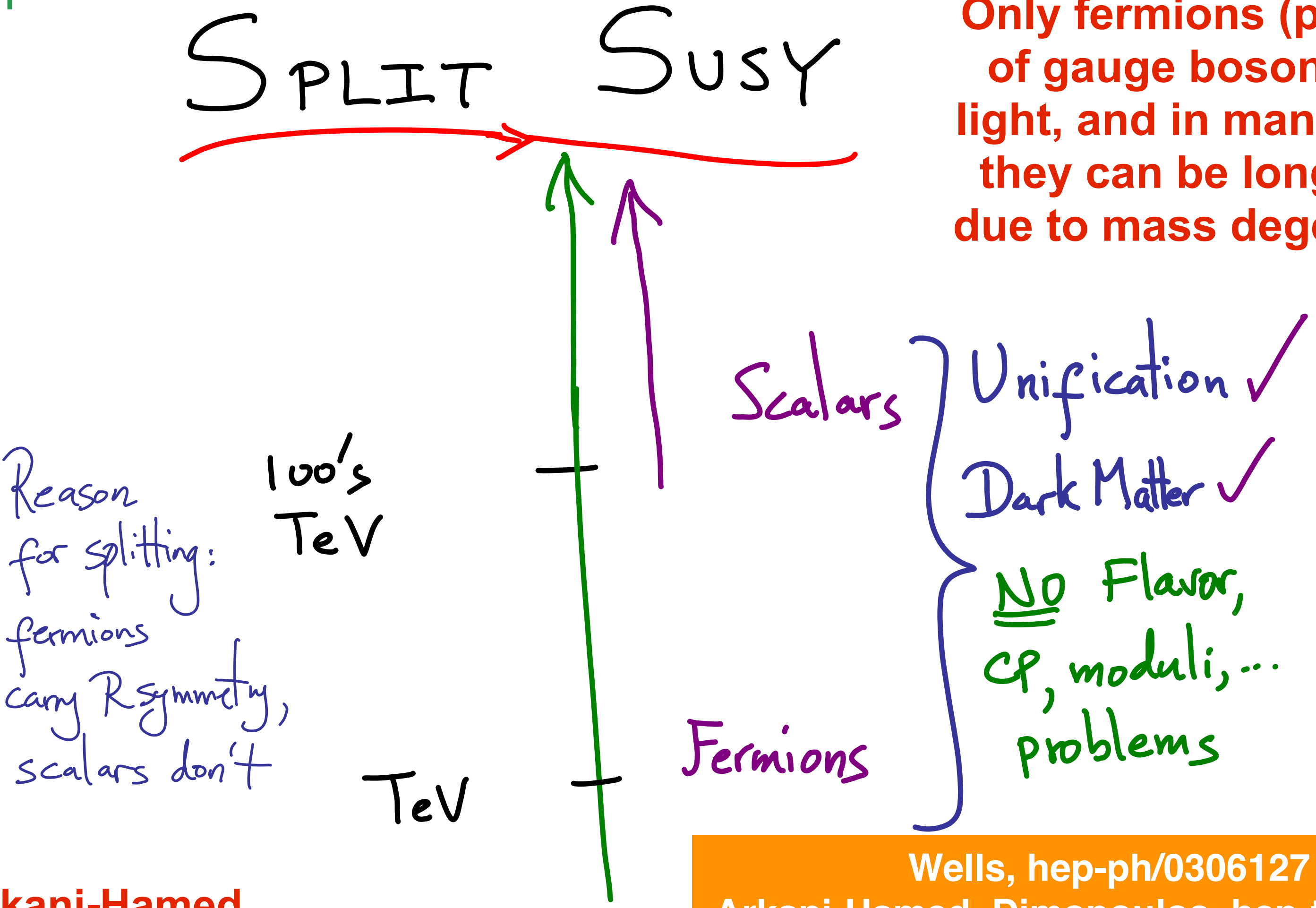




First limits on stop in the RPV models!

Unnatural SUSY

- Yet, SUSY may still be a solution to EWSB, albeit we would have to give up the first “miracle”



Reason for splitting: fermions carry R symmetry, scalars don't

Only fermions (partners of gauge bosons) are light, and in many cases they can be long-lived due to mass degeneracy

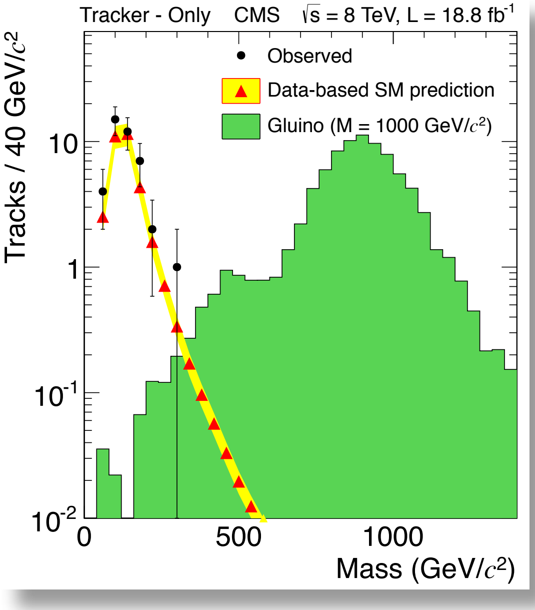
Nima Arkani-Hamed, SavasFest 2012

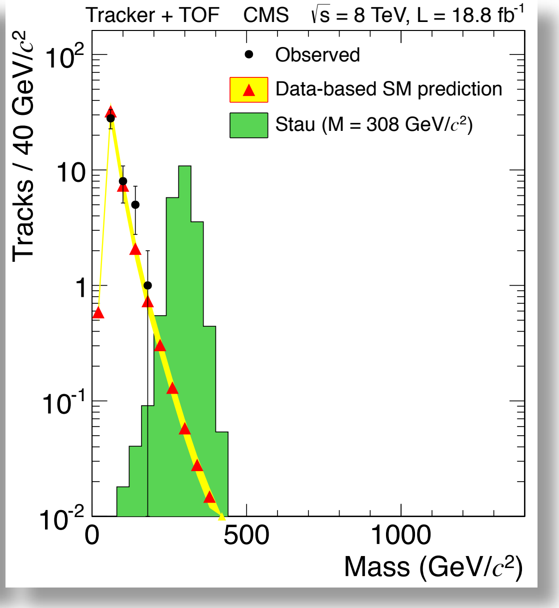
Wells, hep-ph/0306127
Arkani-Hamed, Dimopoulos, hep-th/0405159
Giudice, Romanino, hep-ph/0406088

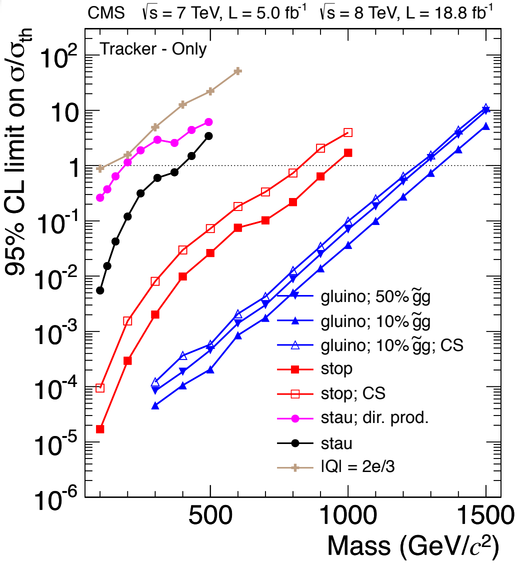
Searches for Long-Lived SUSY

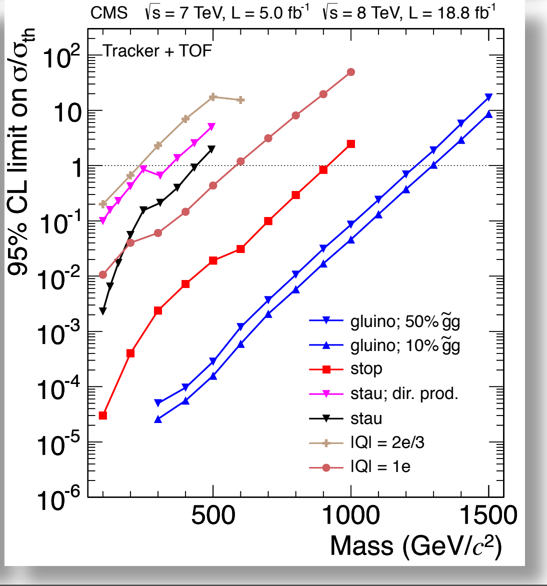
- ✦ An extension of the HSCP search to full 8 TeV statistics + 7 TeV reanalysis
- ✦ Background prediction based on the lack of correlation between pT spectrum and the mass, as determined from the ionization
- ✦ Strong limits on gluinos, stops, and staus from the combination of tracker +TOF and tracker-only analyses

CMS Collaboration arXiv:1305.0491



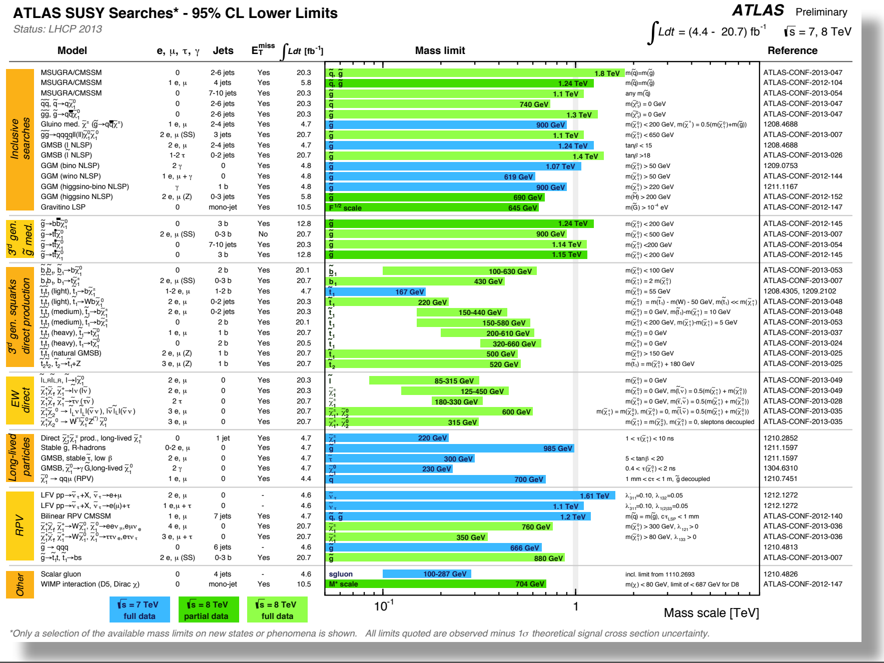


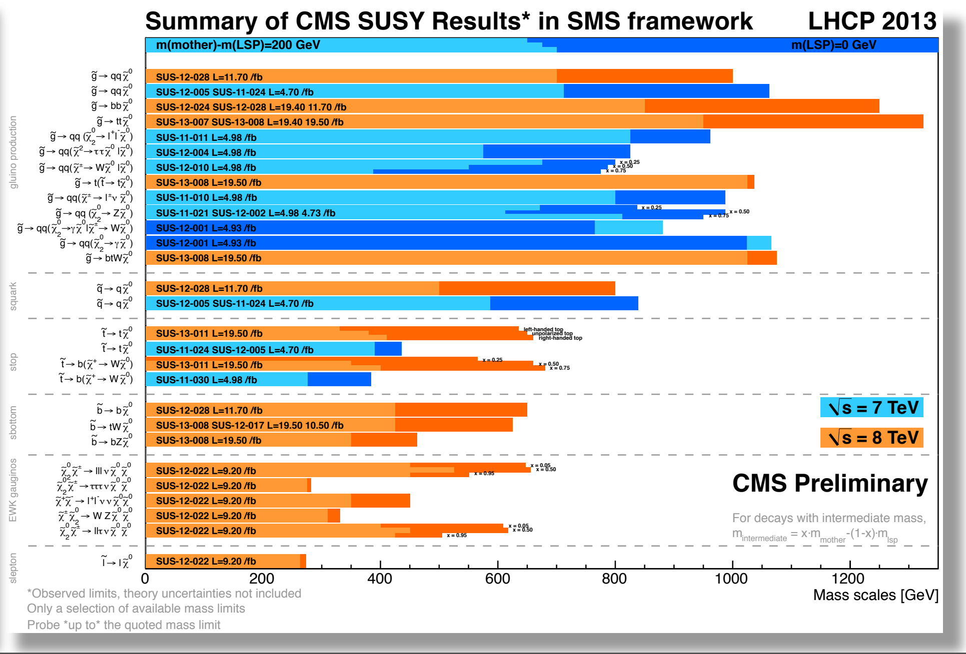




SUSY Grand Summary

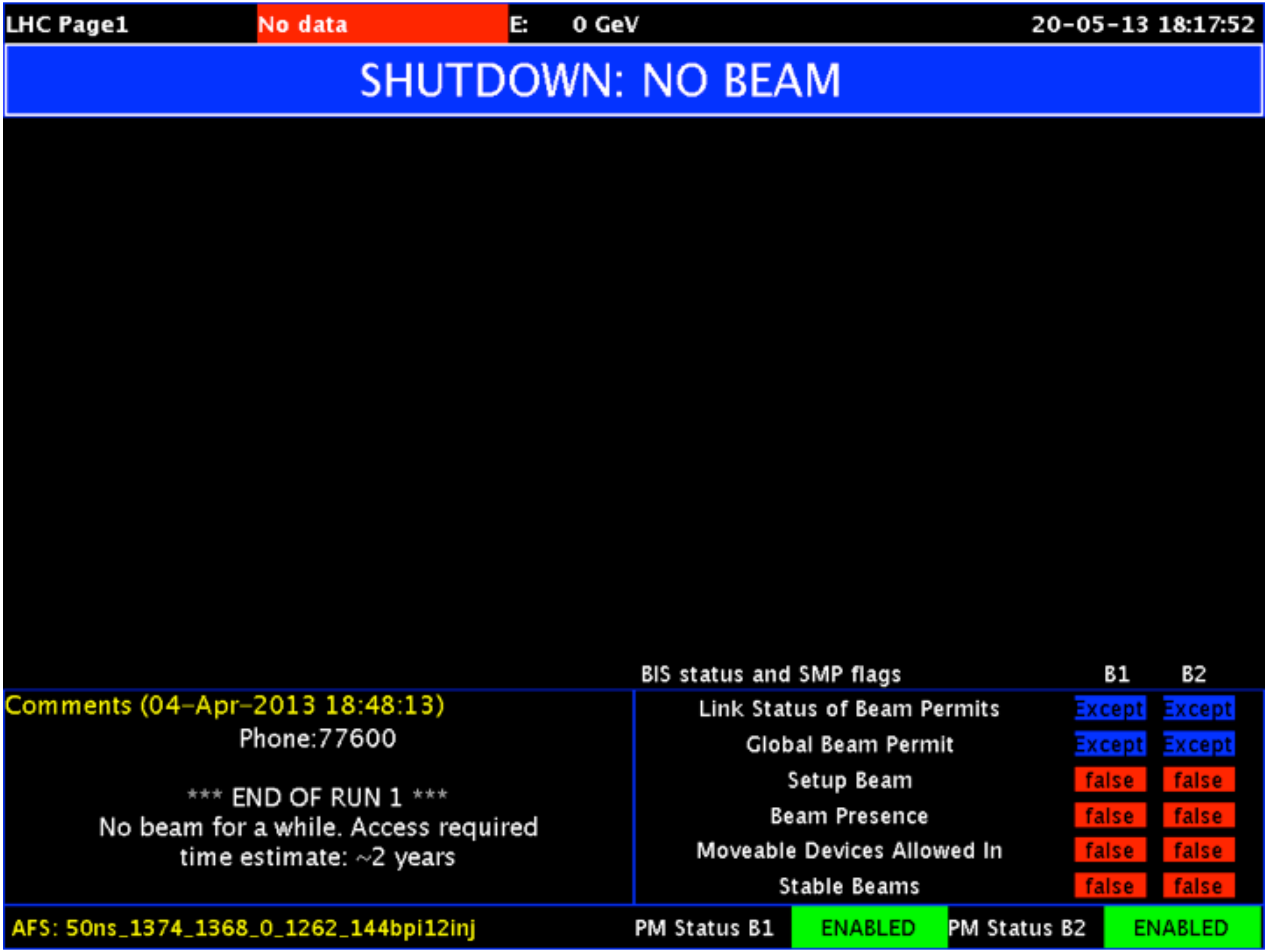
- Closing in on the “natural” SUSY, but may be just short the reach
- Can we either find natural new physics or rule out naturalness as the guiding light to our quest for the origin of EWSB, dark matter, etc.?
- Very important to continue the quest for naturalness in SUSY and other BSM, which requires to explore the full energy potential of the LHC
- What would it take?





Toward the Future

Long Shutdown One



LHC Page1 | No data | E: 0 GeV | 20-05-13 18:17:52

SHUTDOWN: NO BEAM

Comments (04-Apr-2013 18:48:13)

Phone:77600

*** END OF RUN 1 ***

No beam for a while. Access required

time estimate: ~2 years

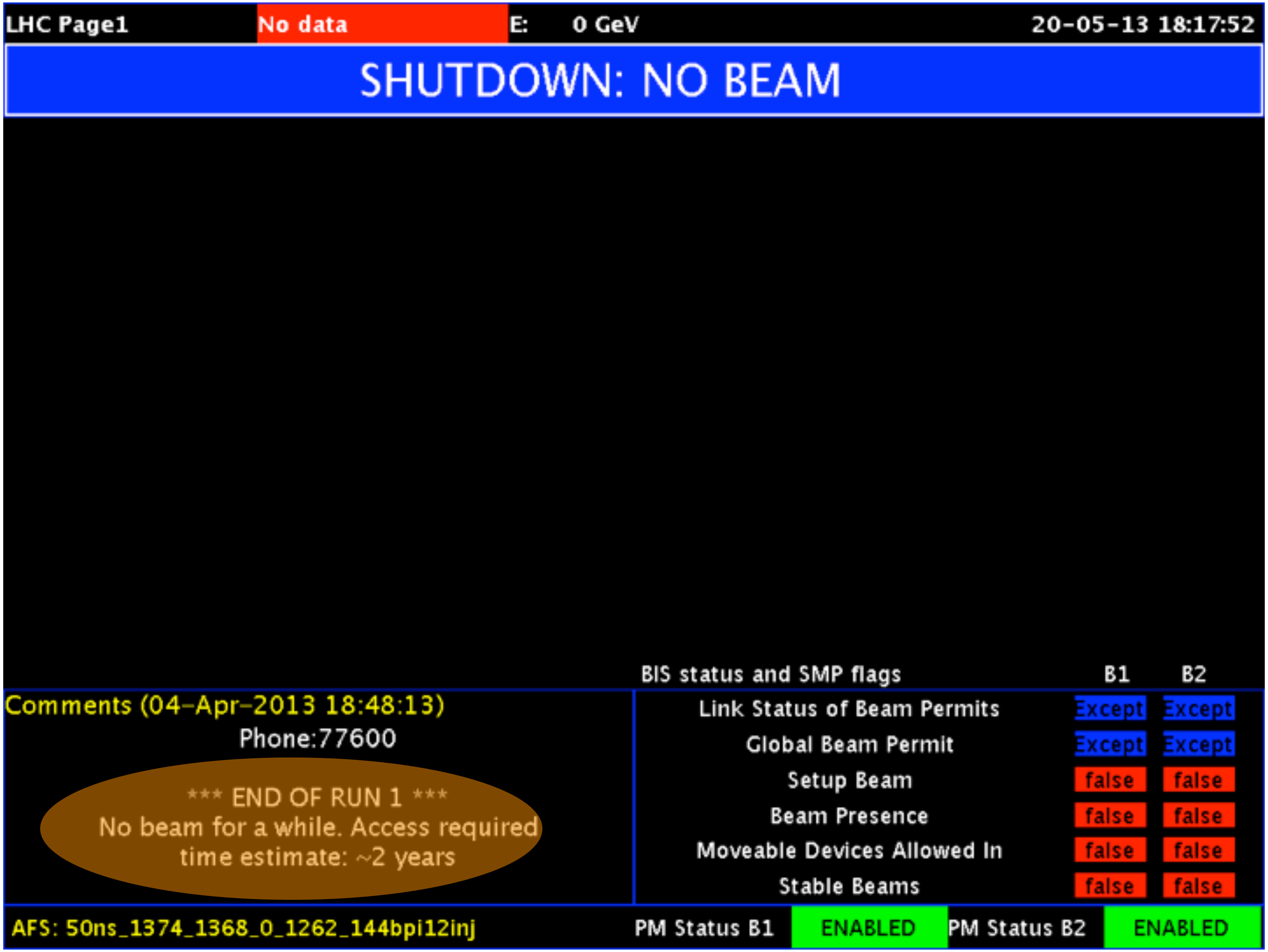
BIS status and SMP flags	B1	B2
Link Status of Beam Permits	Except	Except
Global Beam Permit	Except	Except
Setup Beam	false	false
Beam Presence	false	false
Moveable Devices Allowed In	false	false
Stable Beams	false	false

AFS: 50ns_1374_1368_0_1262_144bpi12inj

PM Status B1 ENABLED

PM Status B2 ENABLED

Long Shutdown One



LHC Page1 No data E: 0 GeV 20-05-13 18:17:52

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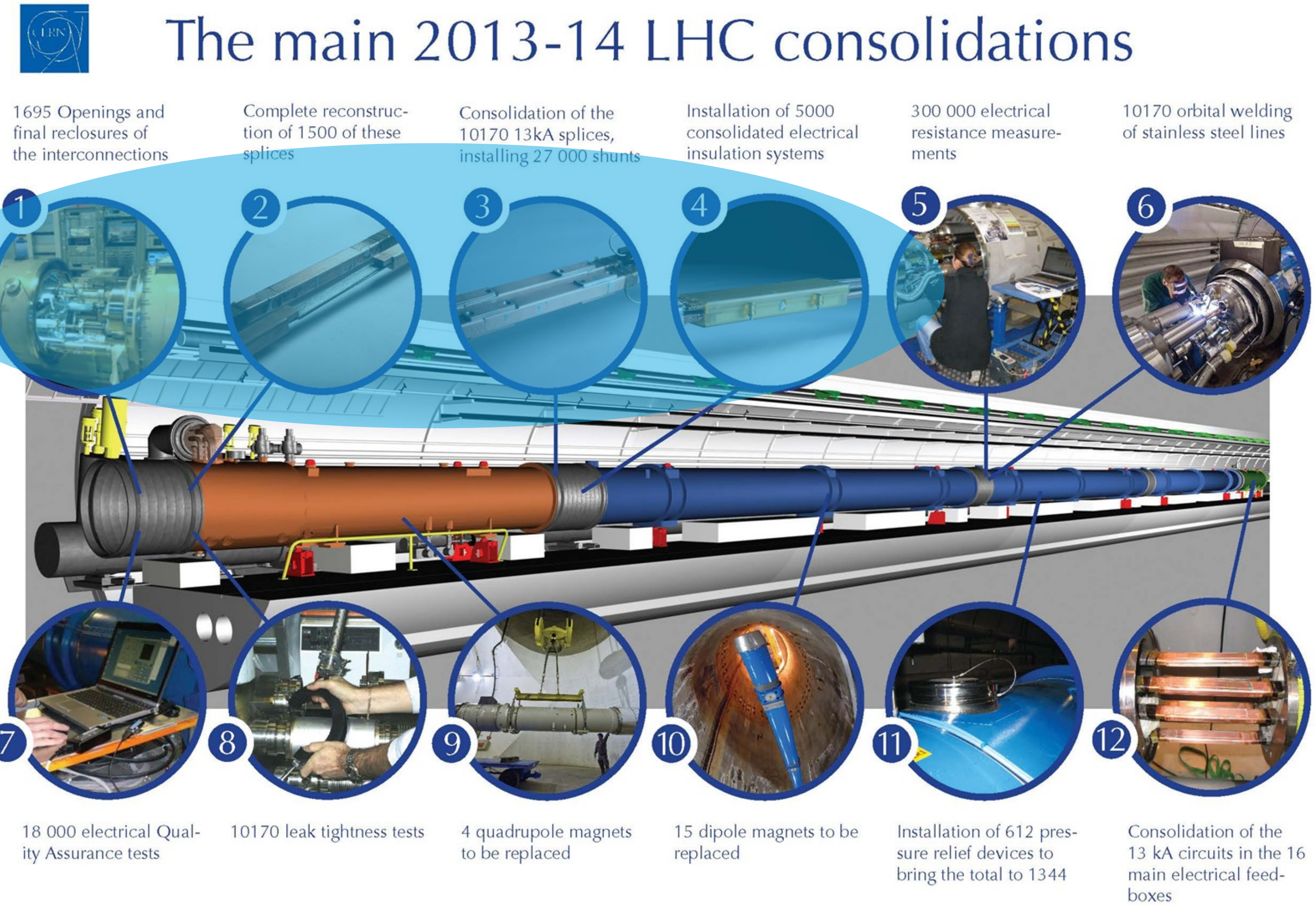
LS1 Consolidations

The main 2013-14 LHC consolidations

1. 1695 Openings and final reclosures of the interconnections
2. Complete reconstruction of 1500 of these splices
3. Consolidation of the 10170 13kA splices, installing 27 000 shunts
4. Installation of 5000 consolidated electrical insulation systems
5. 300 000 electrical resistance measurements
6. 10170 orbital welding of stainless steel lines
7. 18 000 electrical Quality Assurance tests
8. 10170 leak tightness tests
9. 4 quadrupole magnets to be replaced
10. 15 dipole magnets to be replaced
11. Installation of 612 pressure relief devices to bring the total to 1344
12. Consolidation of the 13 kA circuits in the 16 main electrical feedboxes

LS1 Consolidations



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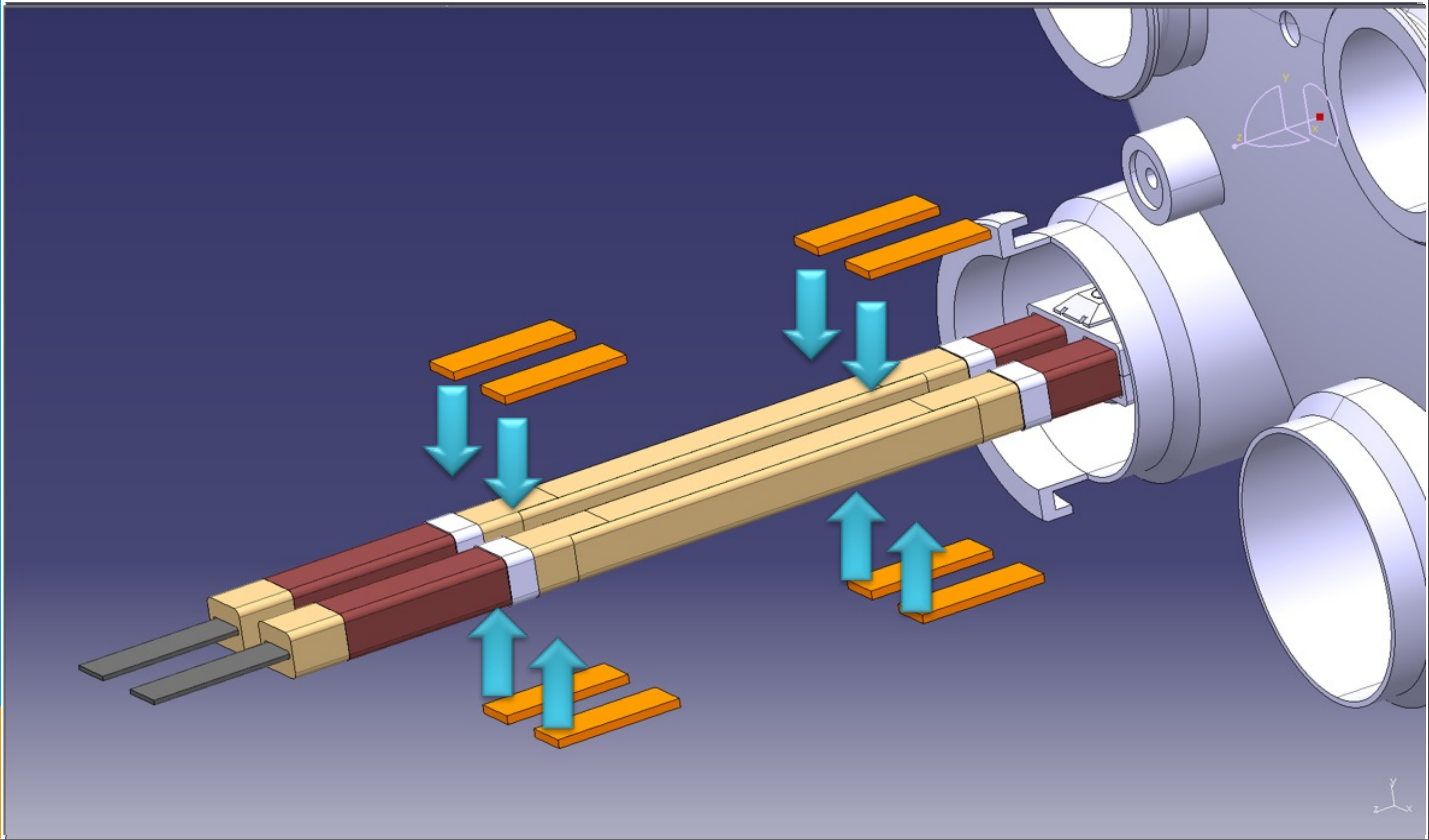
LHC Dipole Interconnects

- Welding, shunting, installation of spacer and shield



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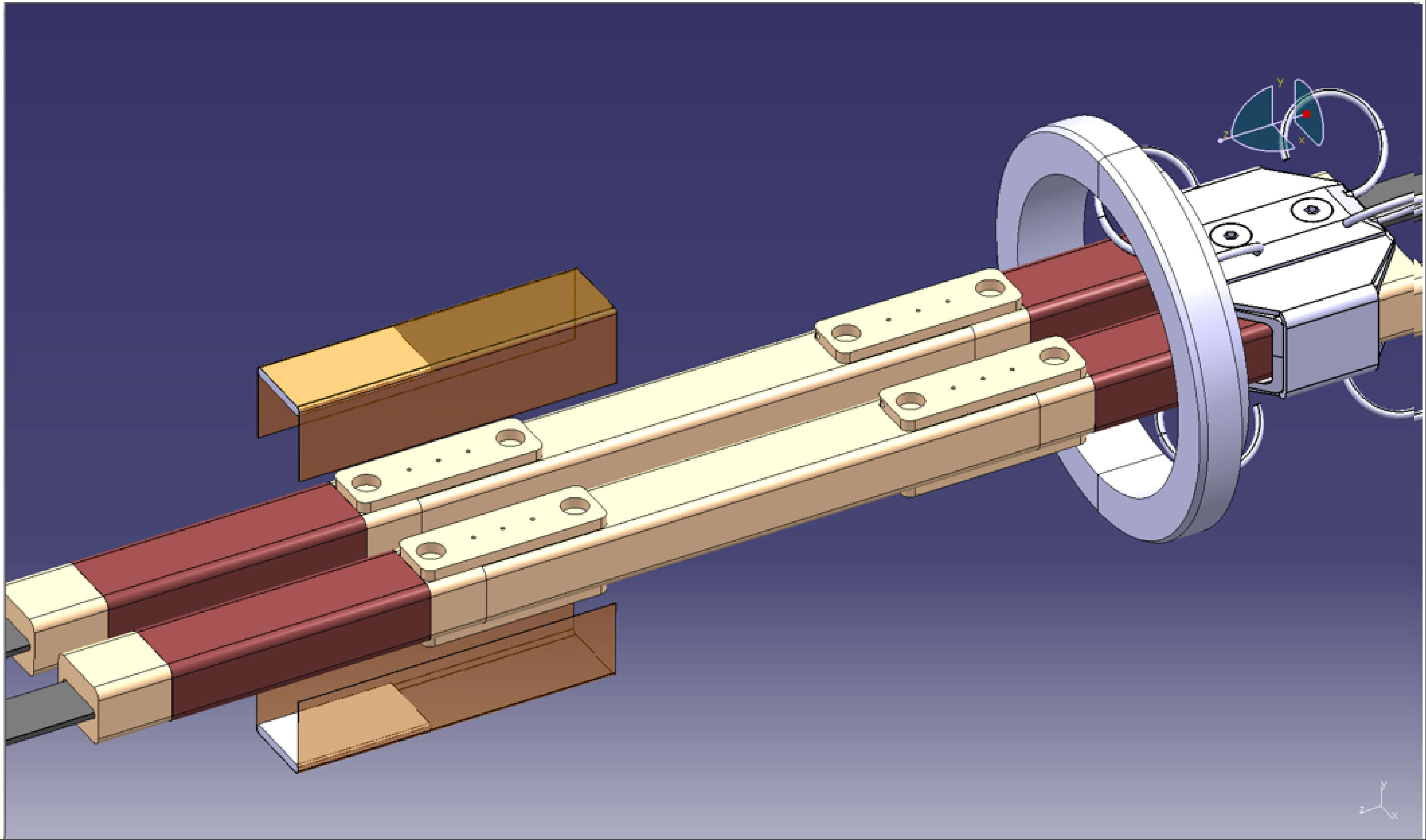

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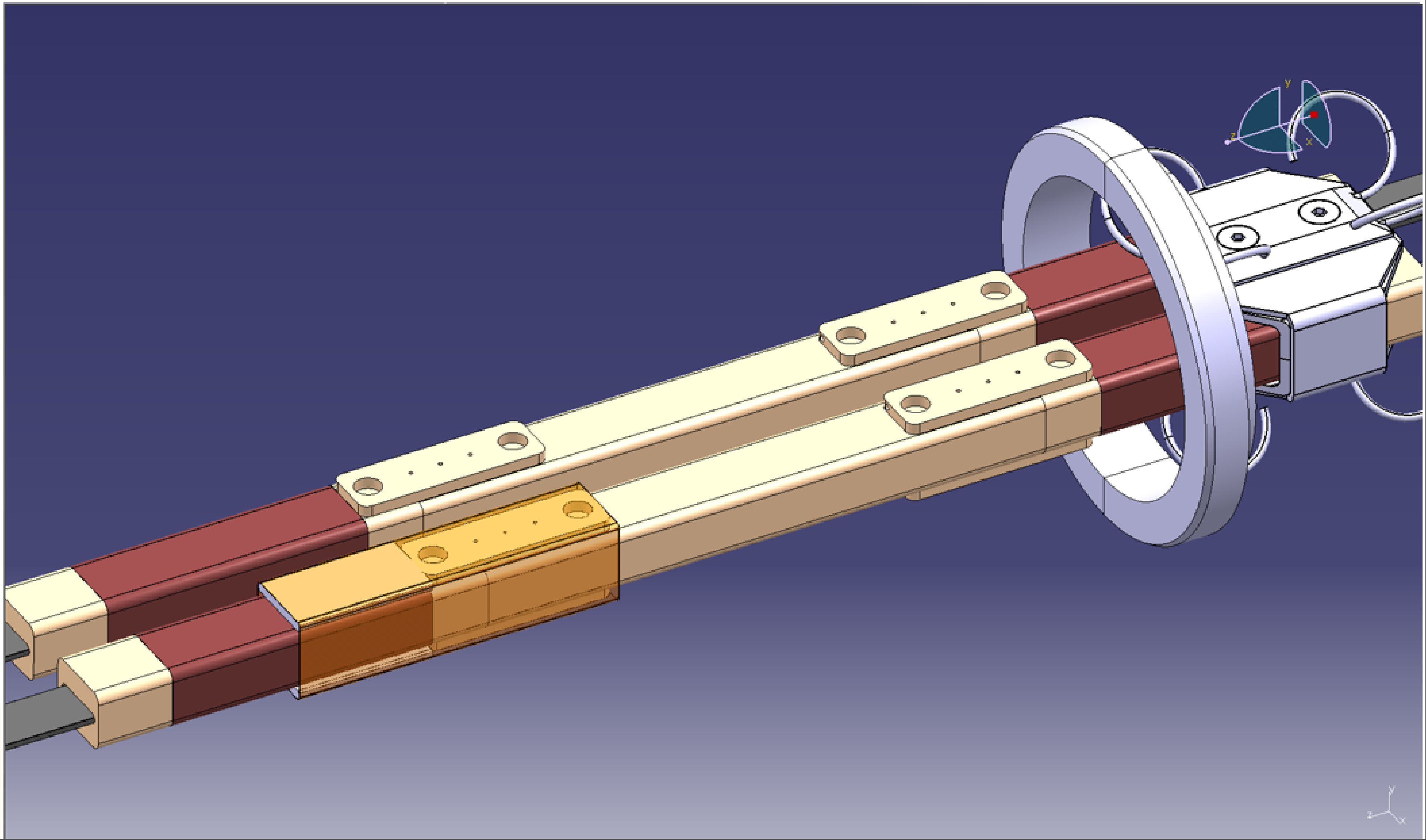

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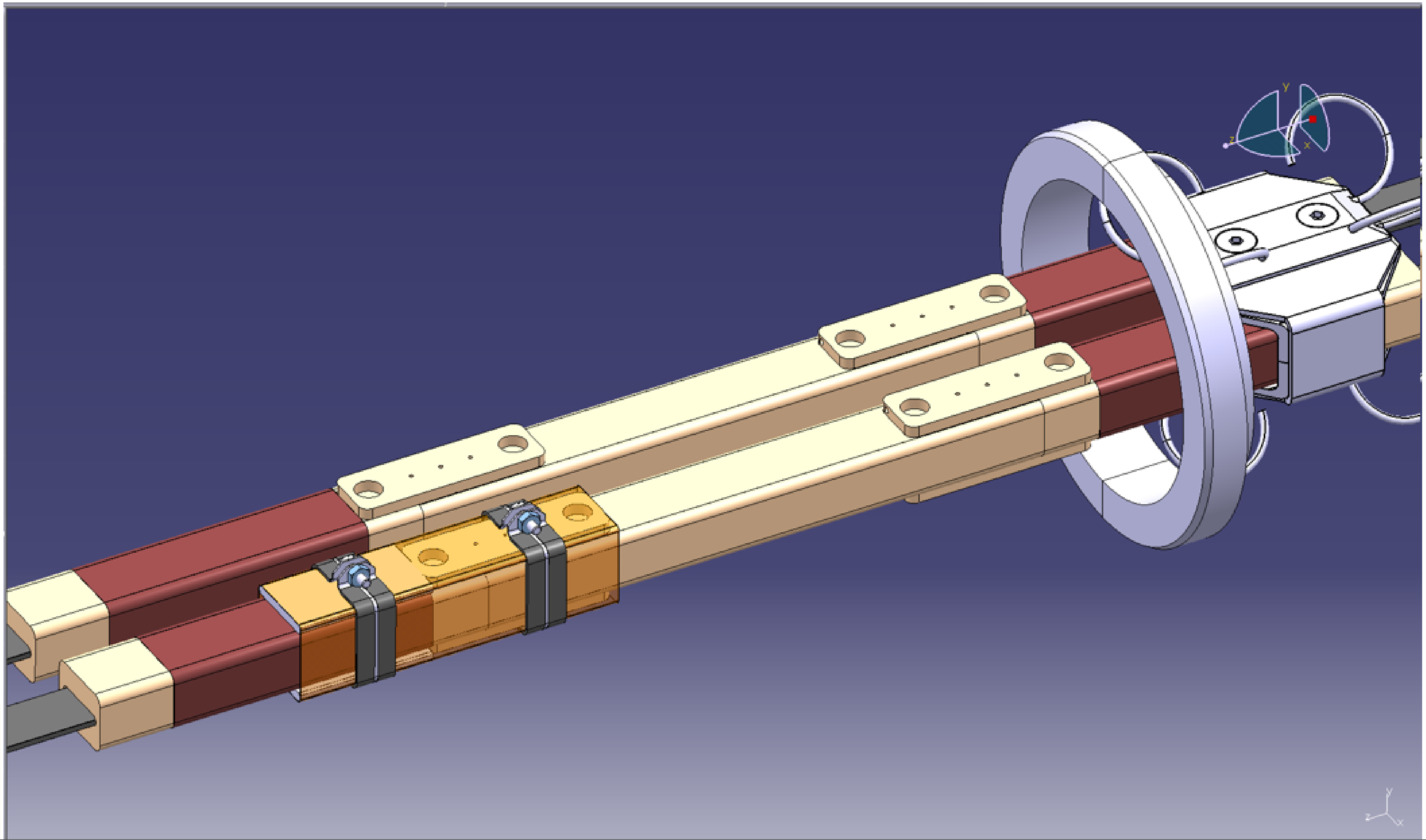

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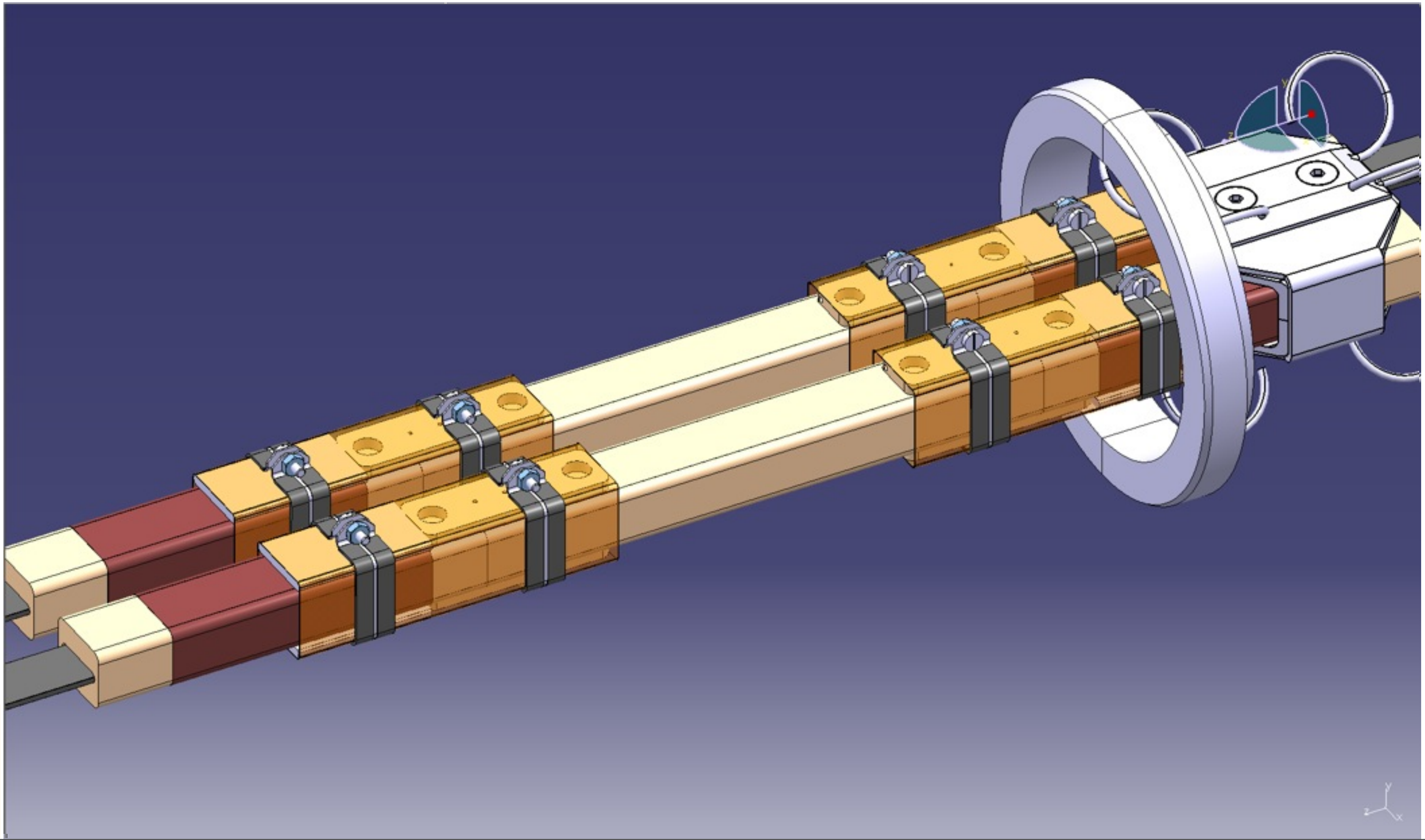

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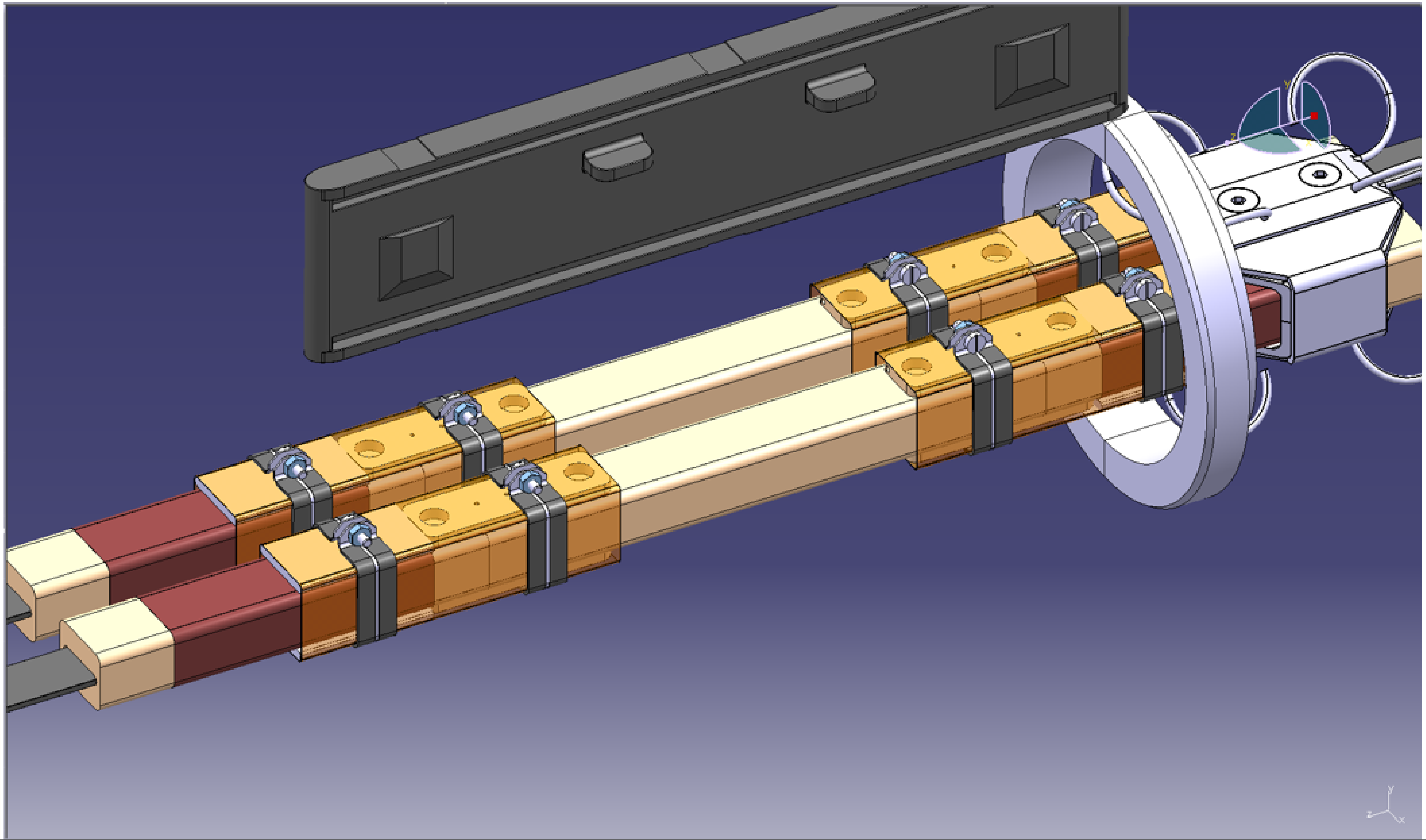

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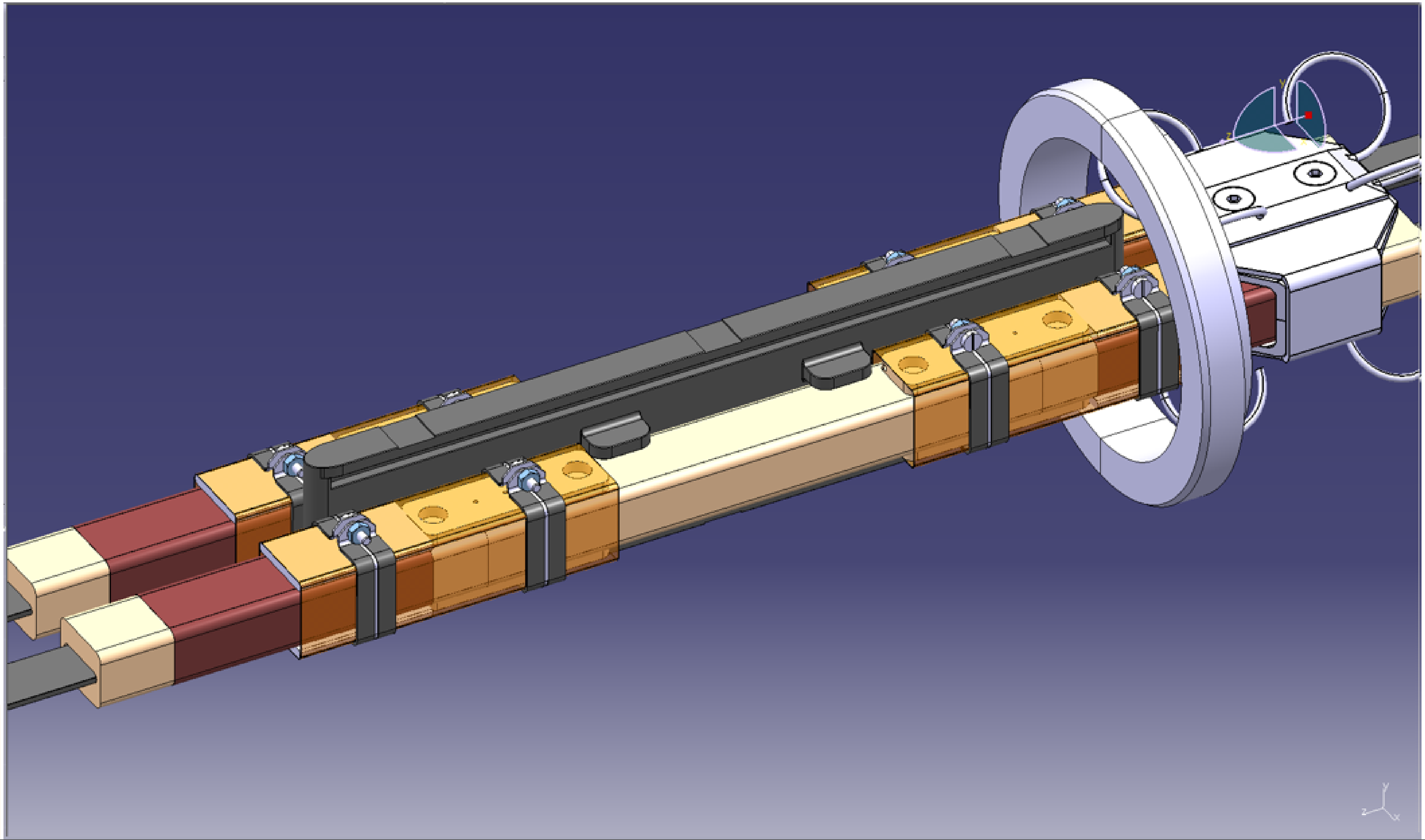

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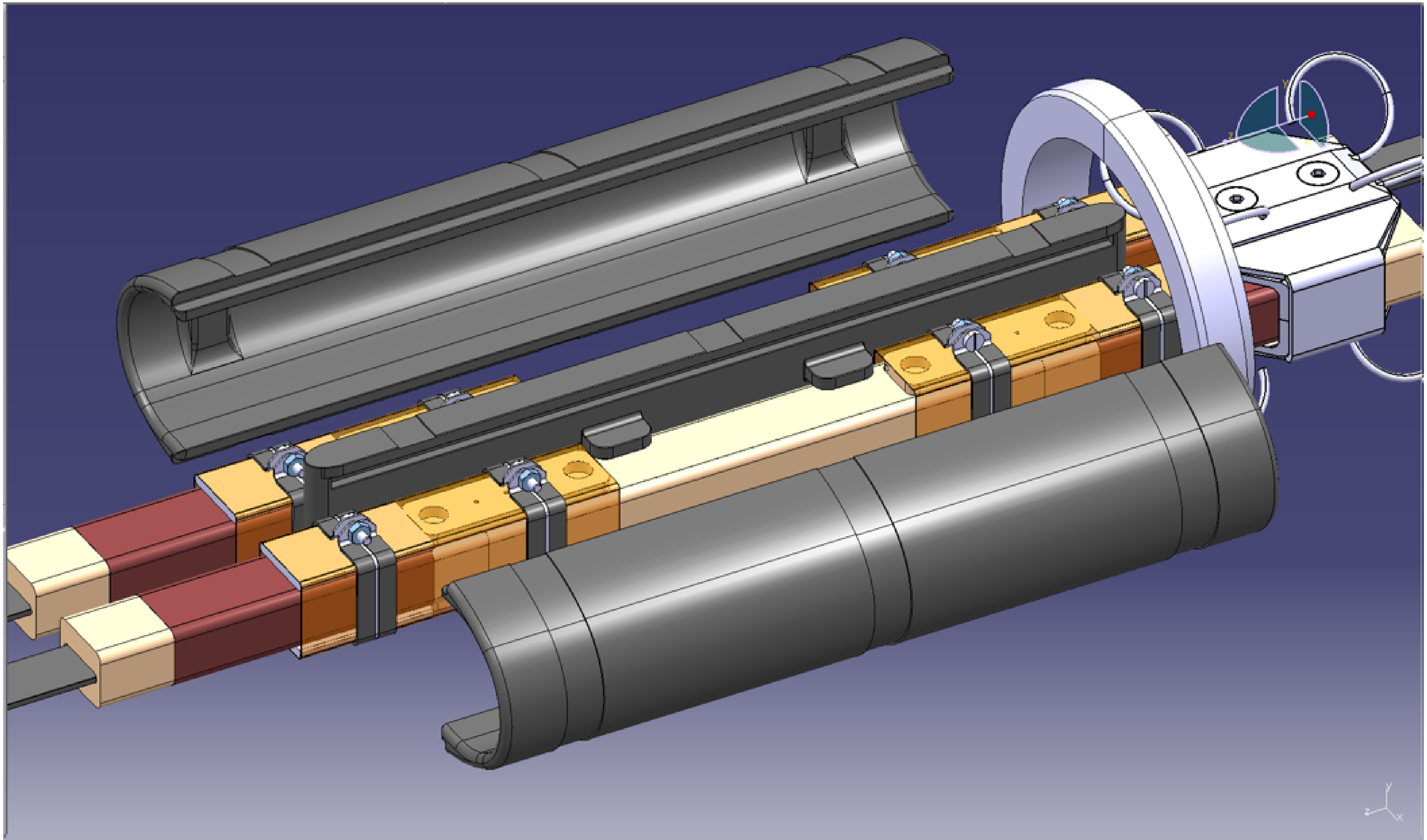

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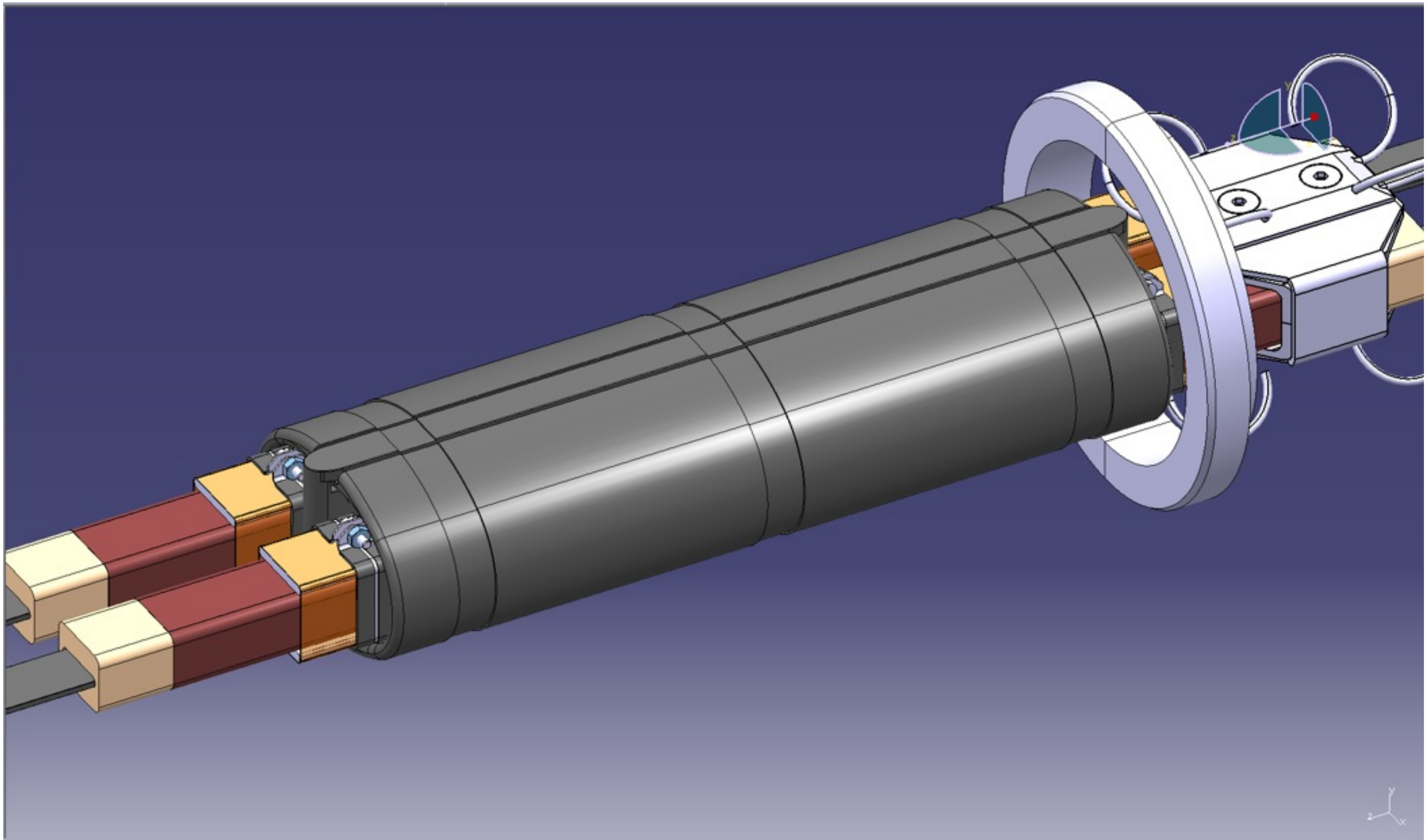

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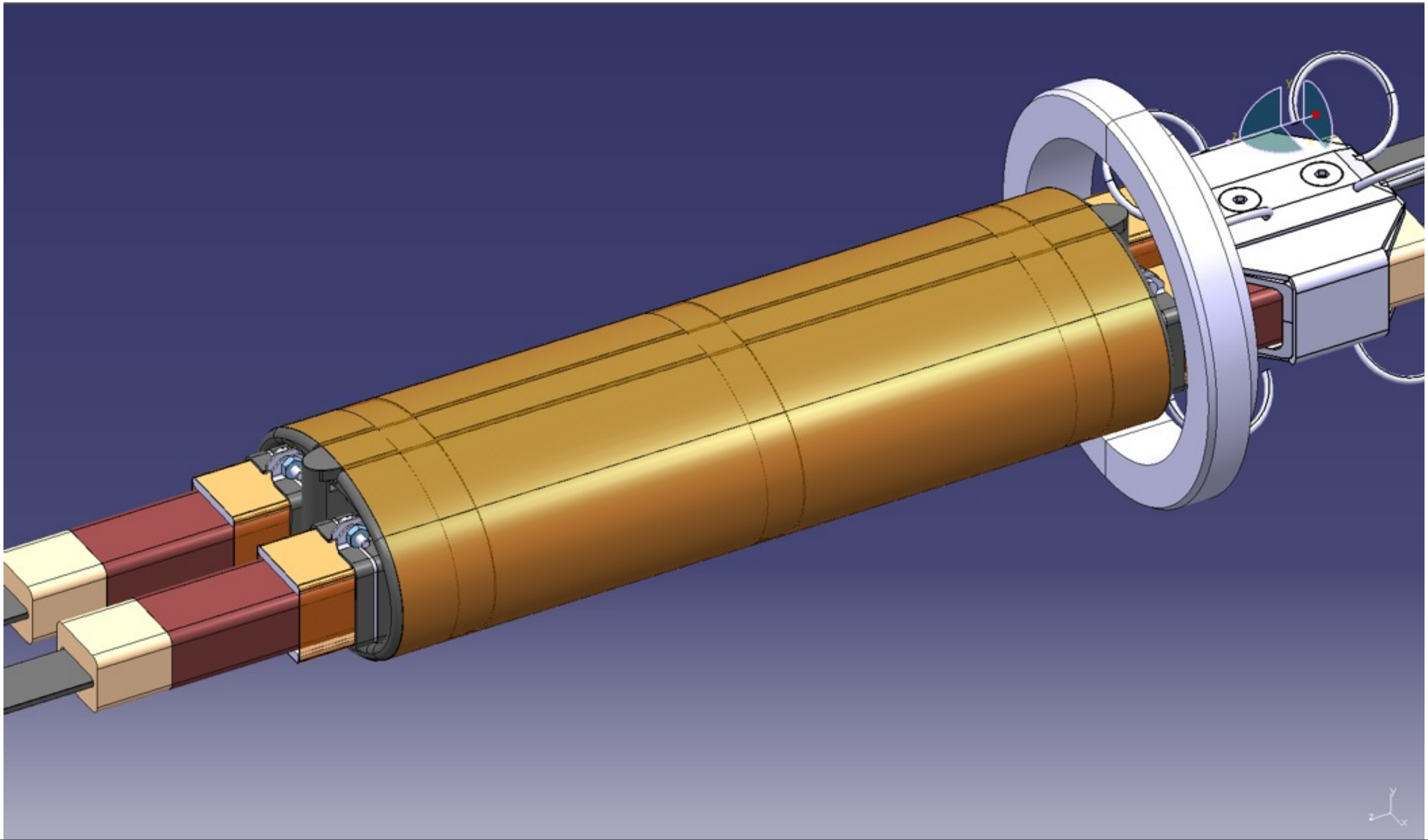
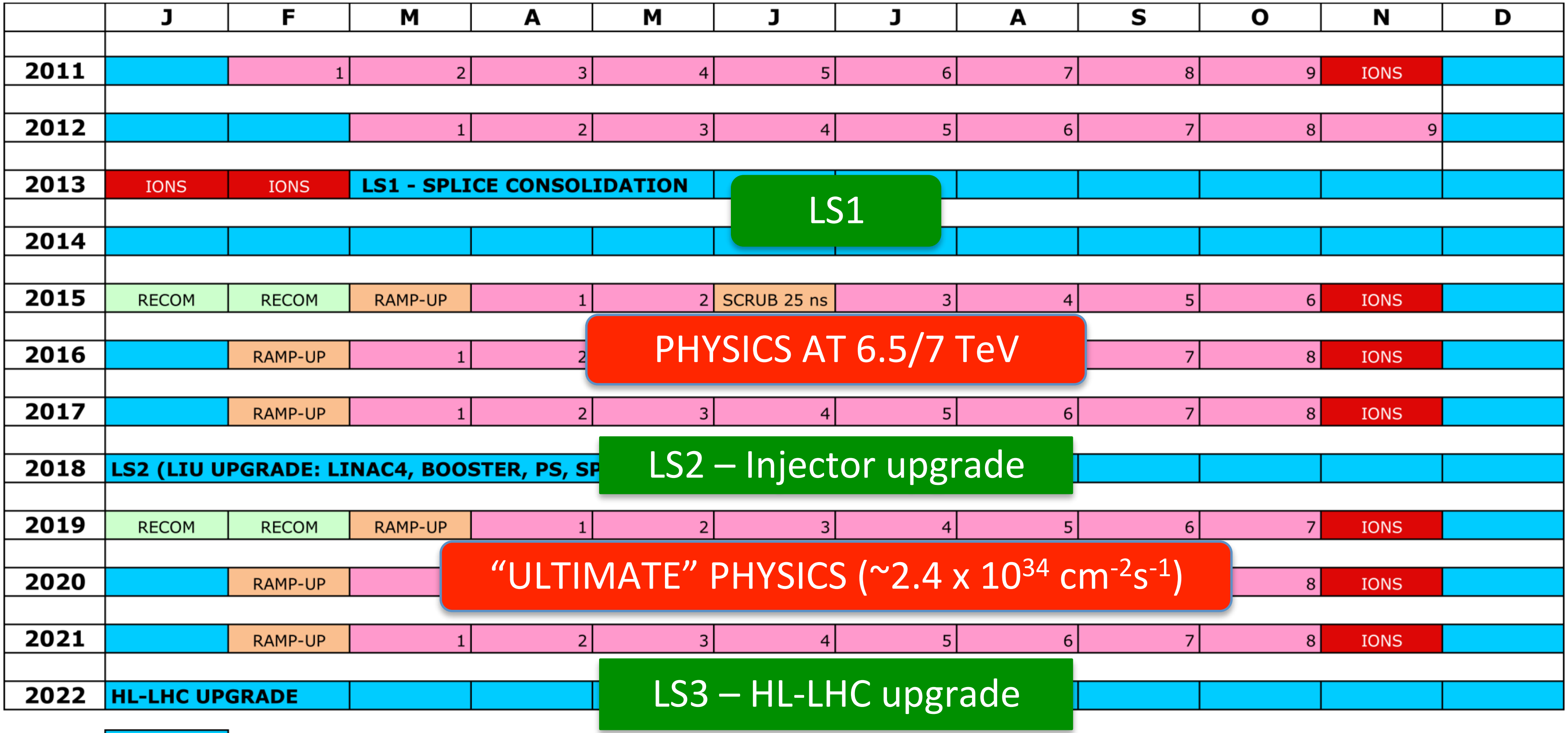


The Ten-Year Plan



	J	F	M	A	M	J	J	A	S	O	N	D
2011	🟦	1	2	3	4	5	6	7	8	9	IONS	🟦
2012	🟦	🟦	1	2	3	4	5	6	7	8	9	🟦
2013	IONS	IONS	**LS1 - SPLICE CONSOLIDATION**					🟦	🟦	🟦	🟦	🟦
2014	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
2015	RECOM	RECOM	RAMP-UP	1	2	SCRUB 25 ns	3	4	5	6	IONS	🟦
2016	🟦	RAMP-UP	1	2					7	8	IONS	🟦
2017	🟦	RAMP-UP	1	2	3	4	5	6	7	8	IONS	🟦
2018	**LS2 (LIU UPGRADE: LINAC4, BOOSTER, PS, SP**								🟦	🟦	🟦	🟦
2019	RECOM	RECOM	RAMP-UP	1	2	3	4	5	6	7	IONS	🟦
2020	🟦	RAMP-UP								8	IONS	🟦
2021	🟦	RAMP-UP	1	2	3	4	5	6	7	8	IONS	🟦
2022	**HL-LHC UPGRADE**		🟦	🟦					🟦	🟦	🟦	🟦

LS1

PHYSICS AT 6.5/7 TeV

LS2 – Injector upgrade

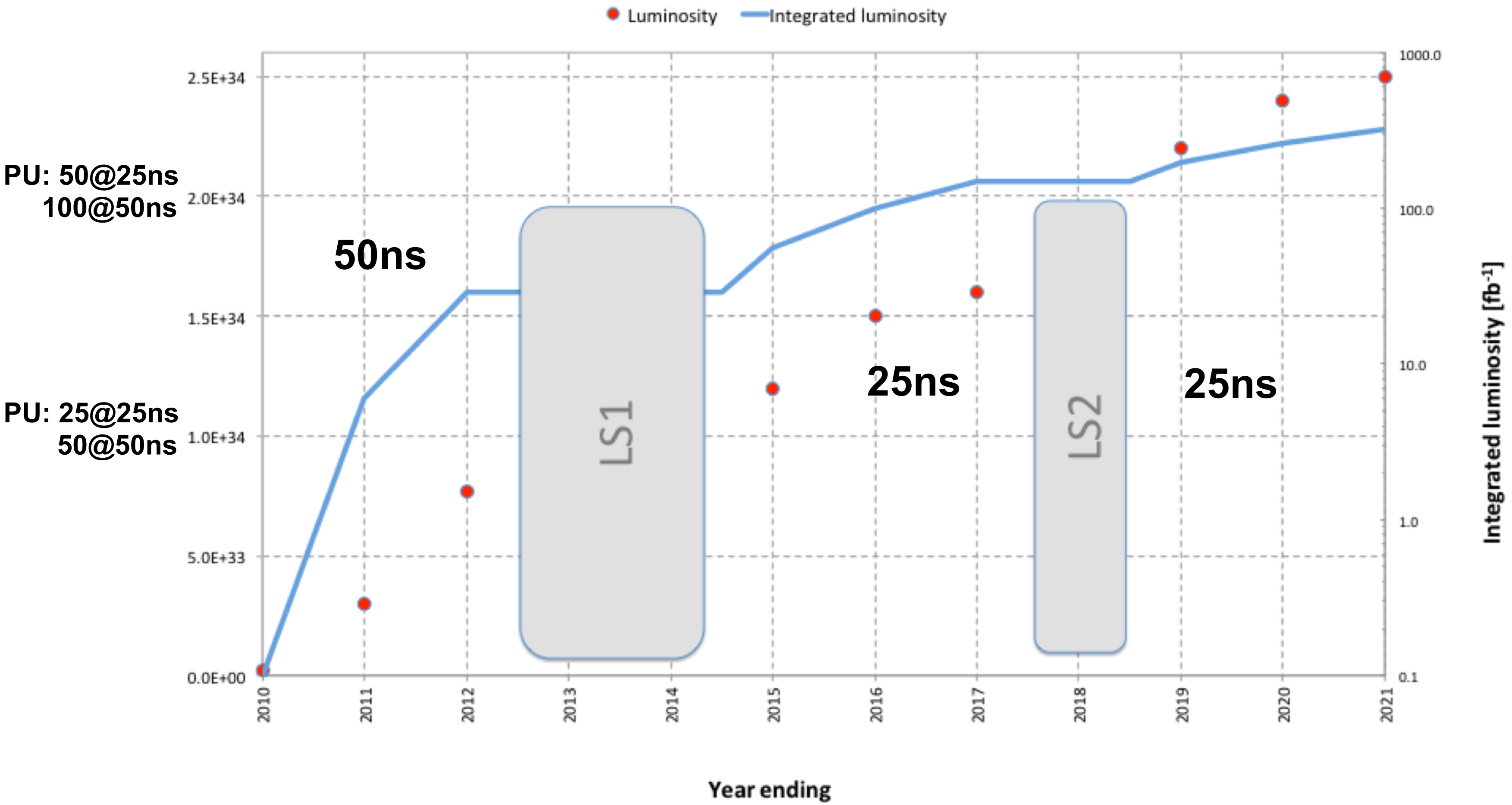
“ULTIMATE” PHYSICS (~2.4 x 10^{34} cm^{-2}s^{-1})

LS3 – HL-LHC upgrade

🟦 Technical stop or shutdown
🟪 Proton physics
🟥 Ion Physics
🟩 Recommissioning
🟧 Intensity ramp-up

Luminosity vs. Time

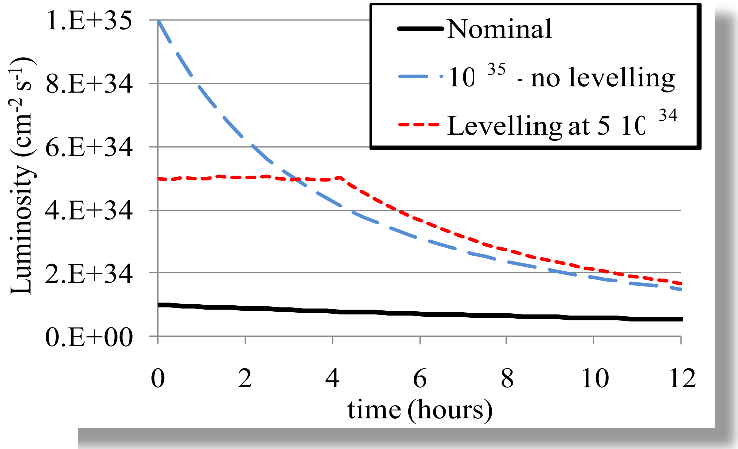
From Mike Lamont, CMS Upgrade Workshop, January 17, 2013



- ✦ 2013-2022: 300-400/fb by 2022
- ✦ 2023-2033: HL-LHC upgrade with leveling at ~5x10^{34} cm^{-2}s^{-1}?

HL-LHC: Need for an Upgrade

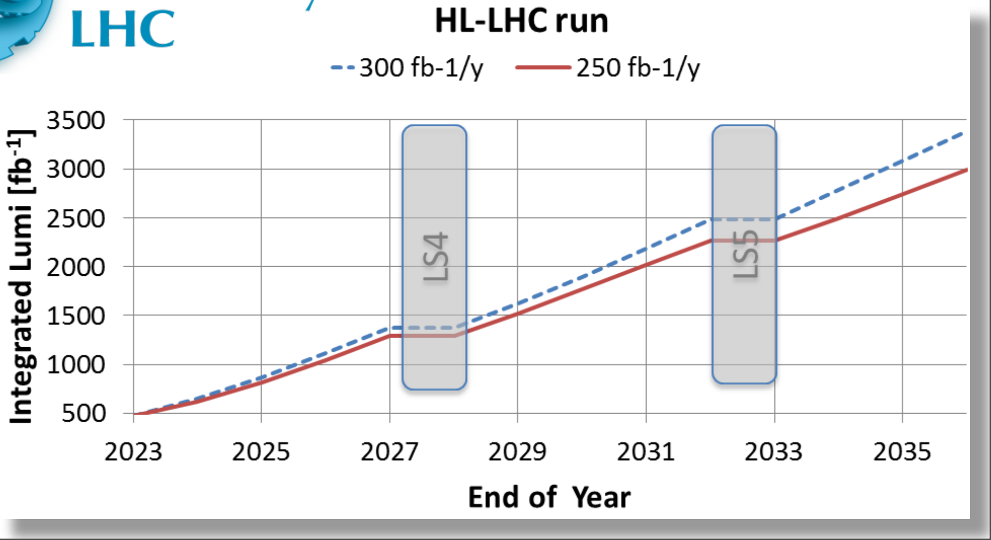
- By 2022, several machine elements will need to be replaced, including triplets
- In addition, the LHC luminosity will saturate by then and doubling time becomes too long
- Detectors will suffer significant radiation damage
- Time to upgrade to reach $L = 10^{35}$ $cm^{-2}s^{-1}$ (but run with the luminosity leveling at 5×10^{34} $cm^{-2}s^{-1}$)



Parameter	Nom. 25 ns	Target 25 ns	Target 50 ns
N_b [10^{11}]	1.15	2.0	**3.3**
n_b	2808	2808	1404
I [A]	0.56	**1.02**	0.84
θc [μrad]	300	475	445
β* [m]	0.55	**0.15**	**0.15**
ε_n [μm]	3.75	**2.5**	**2.0**
ε_s [eV s]	2.5	2.5	2.5
IBS h [h]	111	25	**17**
IBS l[h]	65	21	**16**
Piwinski	0.68	2.5	2.5
F red.fact.	0.81	0.37	0.37
b-b/IP[10^{-3}]	3.1	3.9	**5**
L_{peak}	1	7.4	8.4
Crabbing	no	**yes**	**yes**
$L_{peak\ virtual}$	1	20	22.7
Pileup L_{lev}=$5L_0$	19	95	190
Eff.†150 days	=	0.62	0.61

baseline

High Luminosity LHC

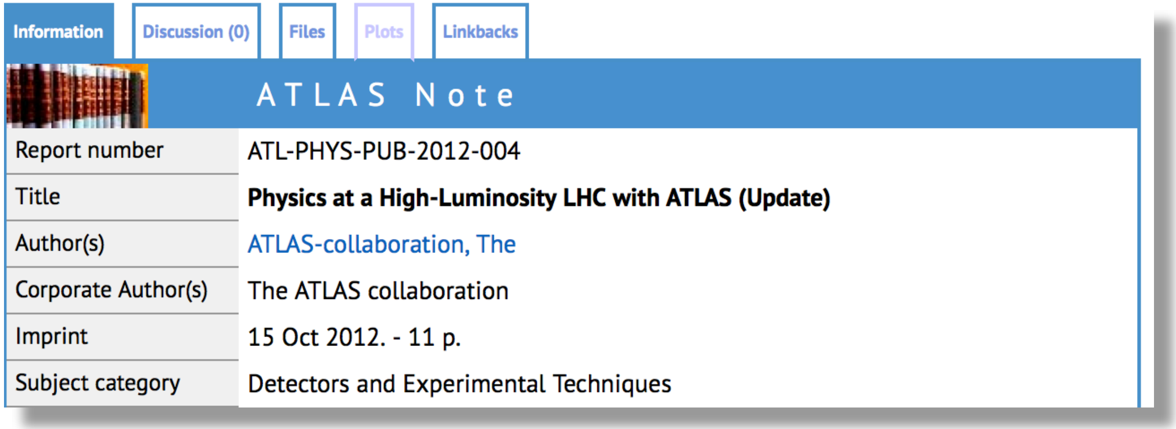


HL-LHC: Detector Upgrades

- Both ATLAS and CMS are planning major "Phase 2" upgrades for the HL-LHC era
  - Replace components of the detector, which will reach the end of the life-cycle due to radiation damage
    - Entire central tracking systems
    - Forward calorimetry
  - Prepare the detectors for much harsher running conditions at the HL-LHC (up to x5 higher pileup)
    - Redesigned trigger and DAQ
    - Possibly use of fast timing for pileup mitigation
    - Level-1 tracking trigger
    - Improved forward detectors for VBF tagging
  - The goal is to achieve the same or better performance as in Run 1 under the HL-LHC conditions

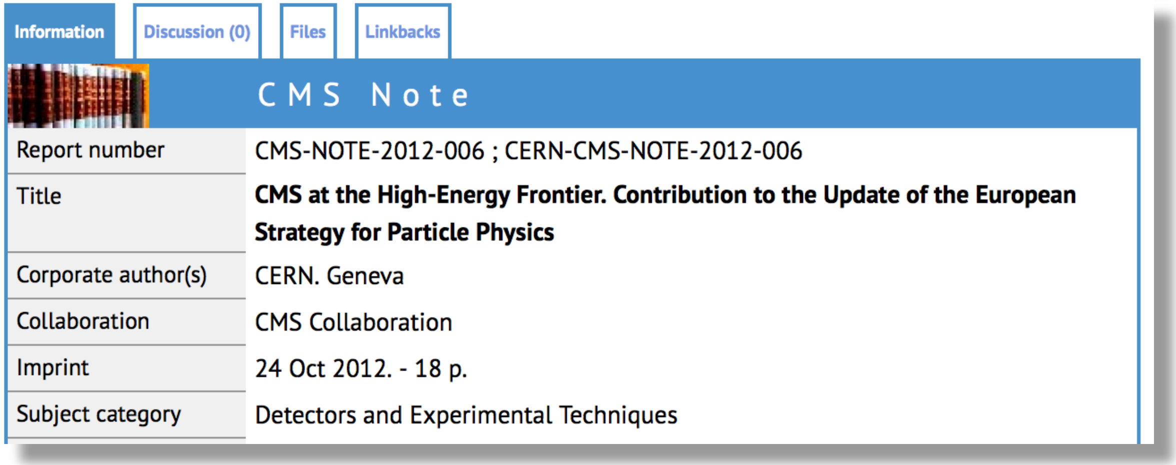
From LHC-14 to HL-LHC

- These projections were made as a part of the ESPG report, ATL-PHYS-PUB-2012-004 and CMS Note 2012-006
- Also LHCb report and Heavy-Ion reports from the experiments
- Will focus on the energy frontier in this talk (apologies to others!)
- The projections are mainly based on extrapolation of the existing analyses to the conditions expected up to the HL-LHC
- These studies are being repeated with more realistic detector simulation and will be updated this Fall



ATLAS Note

Report number	ATL-PHYS-PUB-2012-004
Title	**Physics at a High-Luminosity LHC with ATLAS (Update)**
Author(s)	ATLAS-collaboration, The
Corporate Author(s)	The ATLAS collaboration
Imprint	15 Oct 2012. - 11 p.
Subject category	Detectors and Experimental Techniques

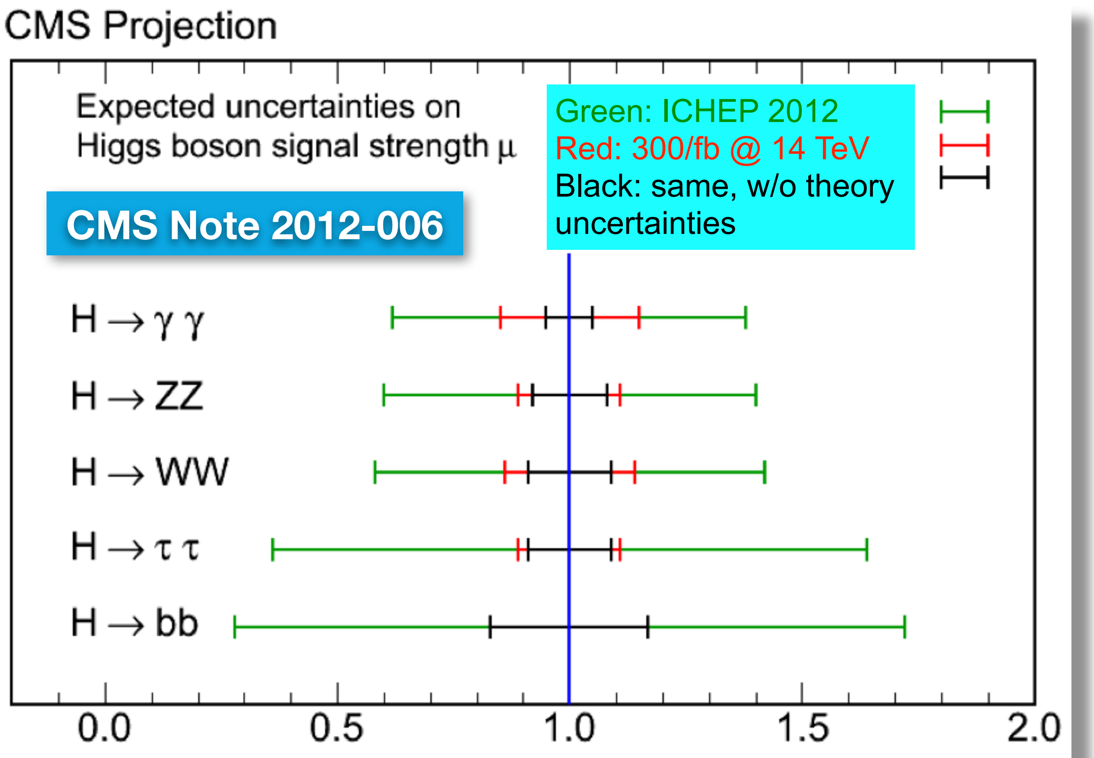


CMS Note

Report number	CMS-NOTE-2012-006 ; CERN-CMS-NOTE-2012-006
Title	**CMS at the High-Energy Frontier. Contribution to the Update of the European Strategy for Particle Physics**
Corporate author(s)	CERN. Geneva
Collaboration	CMS Collaboration
Imprint	24 Oct 2012. - 18 p.
Subject category	Detectors and Experimental Techniques

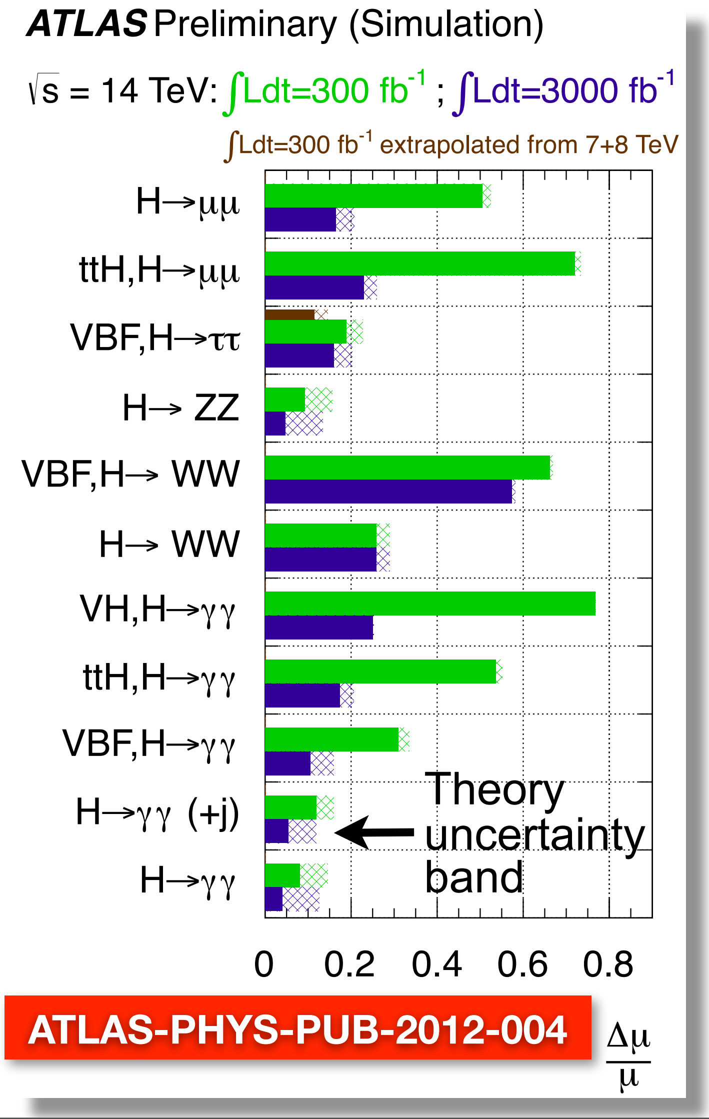
Higgs Signal Strength

- 15% precision has been already achieved in the combination
- 10-15% precision per channel is achievable w/ 300/fb
    - Effect of theory uncertainties is mostly important in the H(γγ) and H(ZZ) channels



CMS Note 2012-006

Green: ICHEP 2012
Red: 300/fb @ 14 TeV
Black: same, w/o theory uncertainties



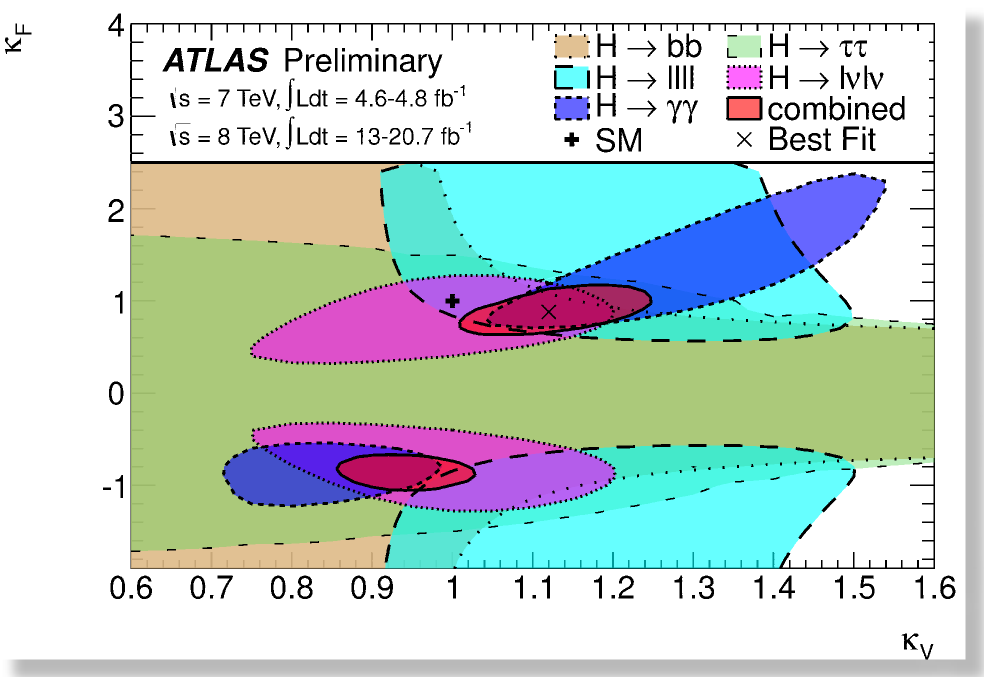
Theory uncertainty band

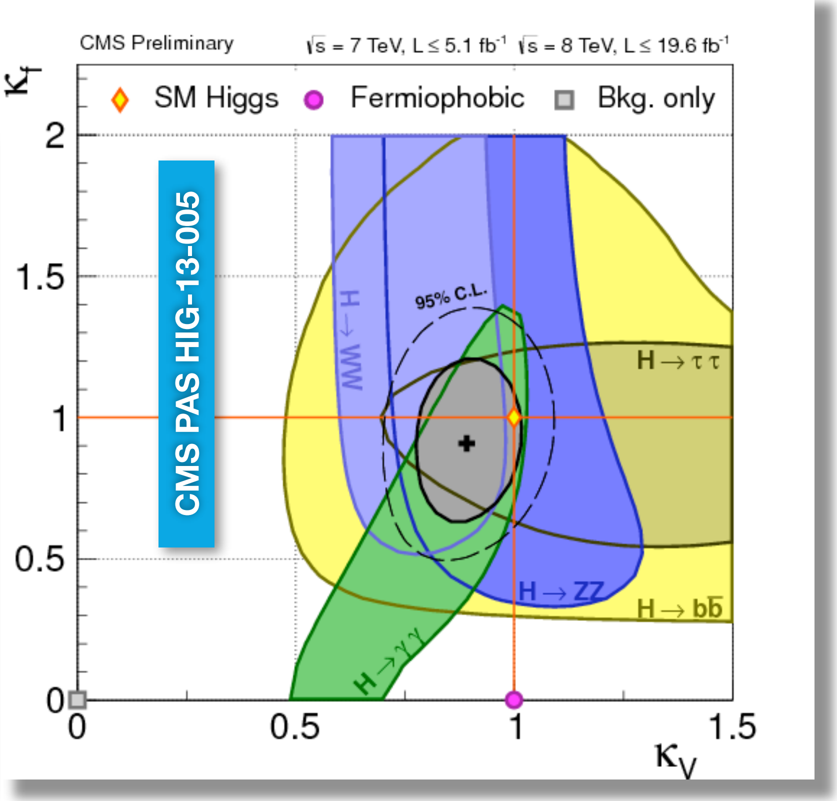
ATLAS-PHYS-PUB-2012-004

Couplings: Where are we Now?

- 2013: couplings consistent with the SM within 1σ
  - Typical uncertainty: 15% (κ_V) – 40% (κ_F)
- Crucial to improve this precision to ~5% level or better
  - Many BSM Higgs scenarios predict coupling modification at that level

ATLAS-CONF-2013-034

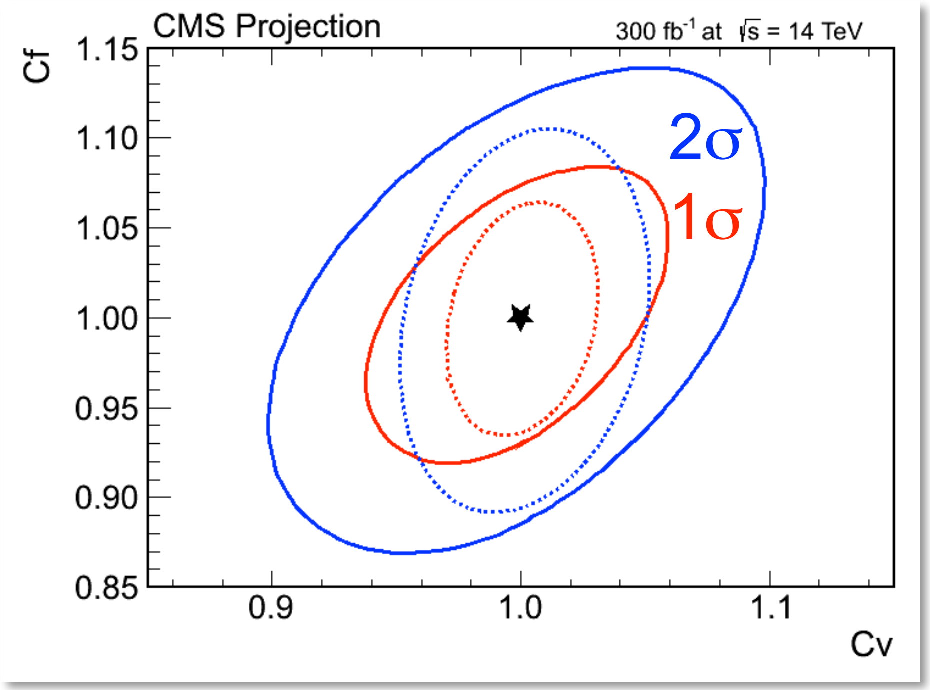


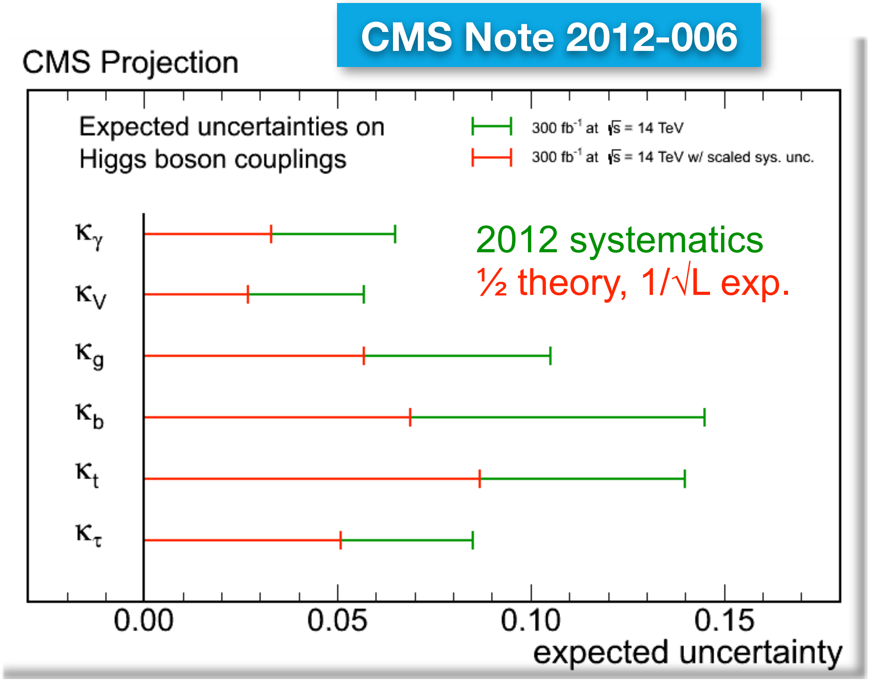


CMS PAS HIG-13-005

Couplings at the LHC-14

- ✦ Projections up to ~300/fb (~2022) are reasonably straightforward
- ✦ Two scenarios considered in CMS:
  - ◉ Scenario 1: same systematics as in 2012 - pessimistic
  - ◉ Scenario 2: theory systematics are halved; the rest scale as 1/√L – somewhat optimistic





CMS Note 2012-006

2012 systematics

½ theory, 1/√L exp.

Solid: nominal; dashed: no theory systematics

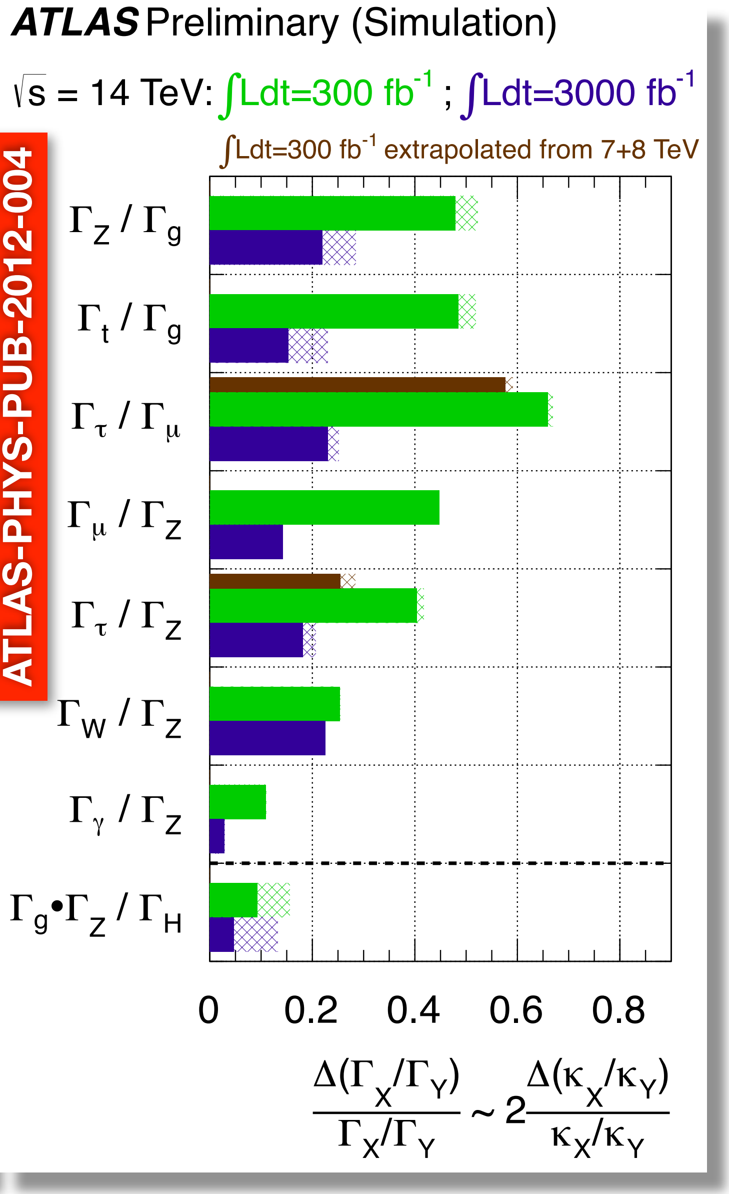
Couplings: Beyond 300 fb^{-1}

- Projections further out are subject of large uncertainties
    - The exact detector configurations & even the technology are not quite known yet
    - The running conditions have not been defined yet
    - Theoretical progress in the next decade is hard to gauge
- Still, in an optimistic “Scenario 2” the HL-LHC would allow to do precision Higgs physics with individual couplings measured up to 1-3% precision
- Also: searches for exotic/invisible Higgs decay as a window on new physics

CMS Note 2012-006

Coupling	Uncertainty (%)			
	300 fb^{-1}		3000 fb^{-1}	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
κ_γ	6.5	5.1	5.4	1.5
κ_V	5.7	2.7	4.5	1.0
κ_g	11	5.7	7.5	2.7
κ_b	15	6.9	11	2.7
κ_t	14	8.7	8.0	3.9
κ_τ	8.5	5.1	5.4	2.0

ATLAS-PHYS-PUB-2012-004



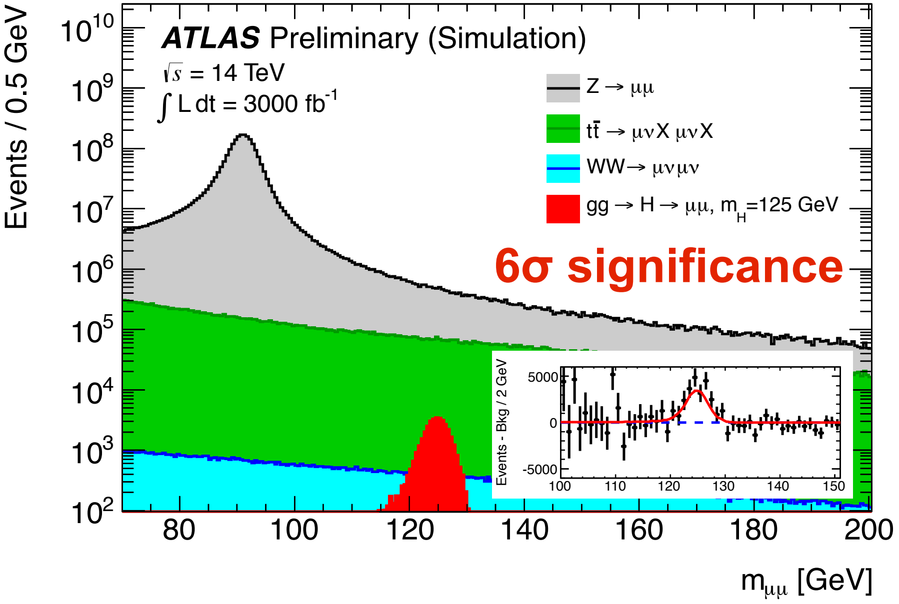
Beyond 300 fb^{-1}: More

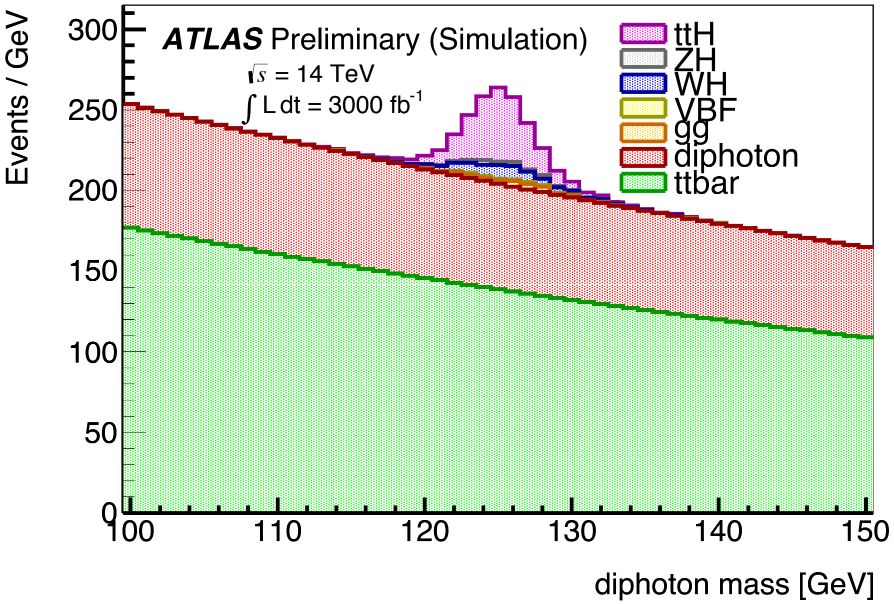
- Need to go significantly beyond 300 fb^{-1} to study Higgs couplings to the muons and top quarks
  - Muon is the second-generation fermion: are the Higgs couplings flavor-universal?
    - Muons offer a possibly unique measurement (charm tagging is hard!)
  - Are couplings to the up- and down-type quarks have the same structure?

H → μμ

ATLAS-PHYS-PUB-2012-004

ttH(γγ)





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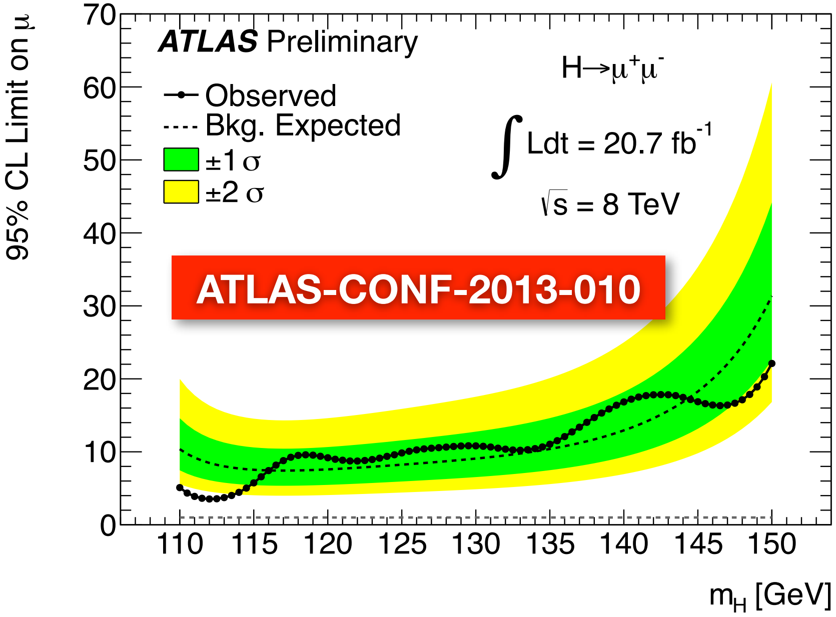
    - Muons offer a possibly unique measurement (charm tagging is hard!)
  - Are couplings to the up- and down-type quarks have the same structure?

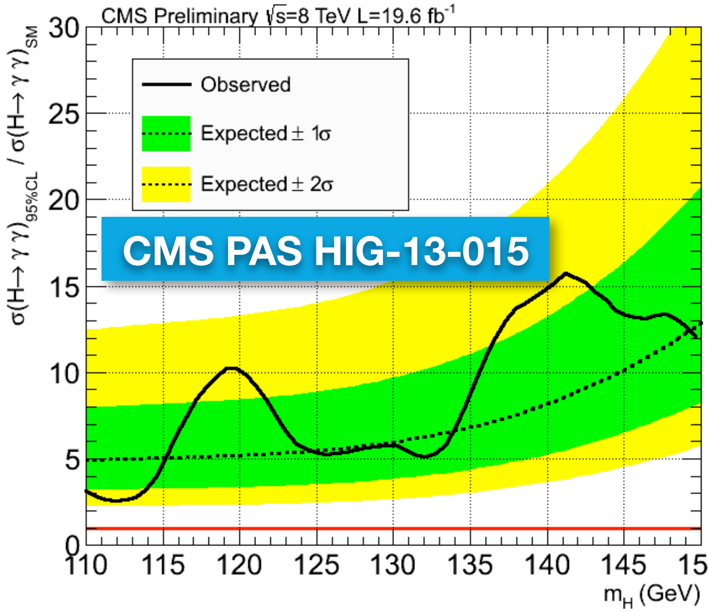
First 8 TeV studies are already under way!

H → μμ



ATLAS-CONF-2013-010

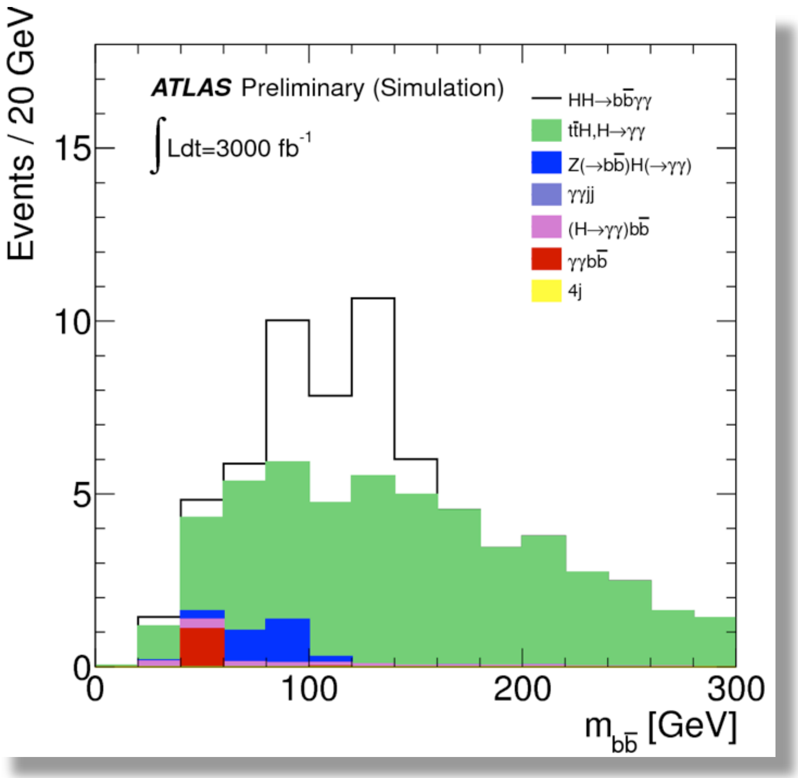
ttH(γγ)



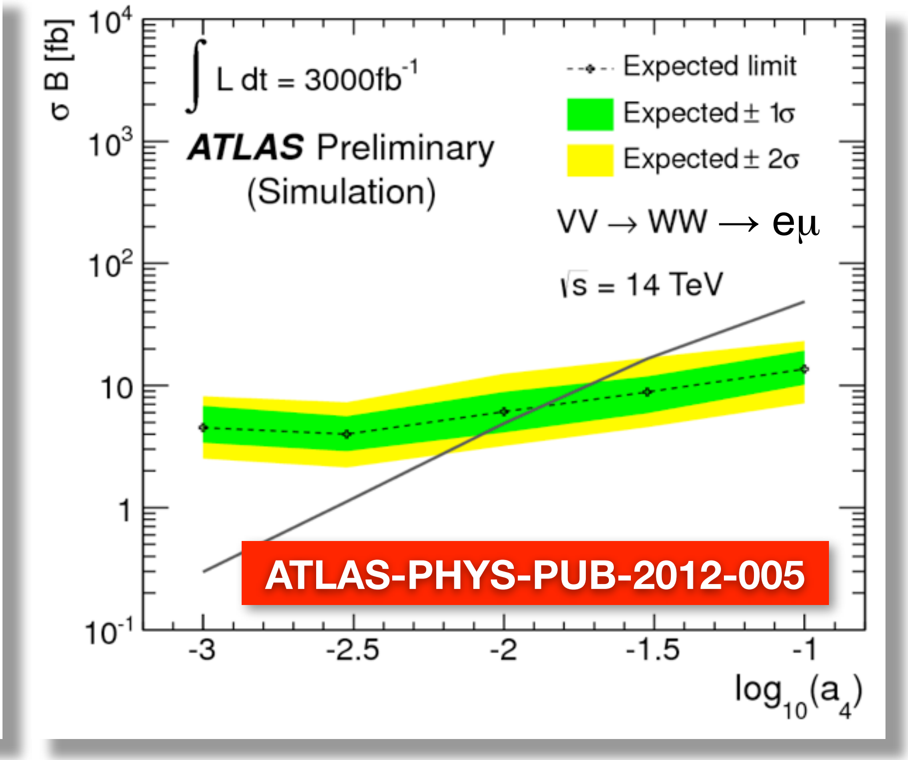
CMS PAS HIG-13-015

VV Scattering & Higgs Self-Coupling

- Higgs self-coupling measurement is an ultimate challenge for the LHC, and 3/ab are crucial given small cross section for HH production
  - σ is only 33 fb @ 14 TeV
- Another important case for LH-LHC is unitarization of VV scattering and searches for additional particles that may change the unitarization behavior
  - This is done via obtaining limits on anomalous quartic couplings a_4 and a_5



ATLAS-PHYS-PUB-2013-001



ATLAS-PHYS-PUB-2012-005

VV Scattering & Higgs Self-Coupling

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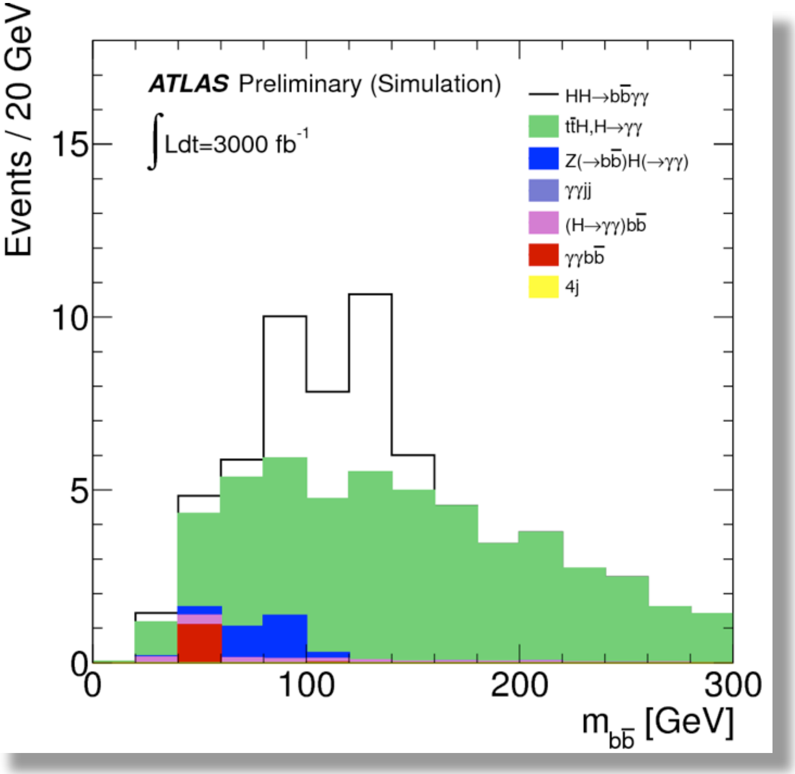

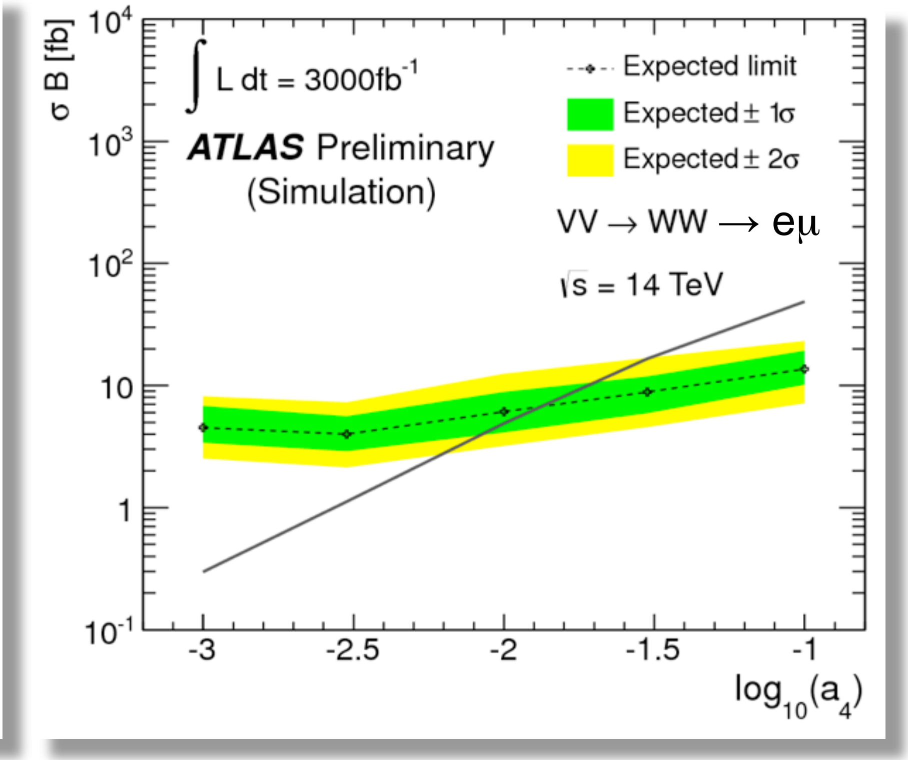

ATLAS-PHYS-PUB-2013-001

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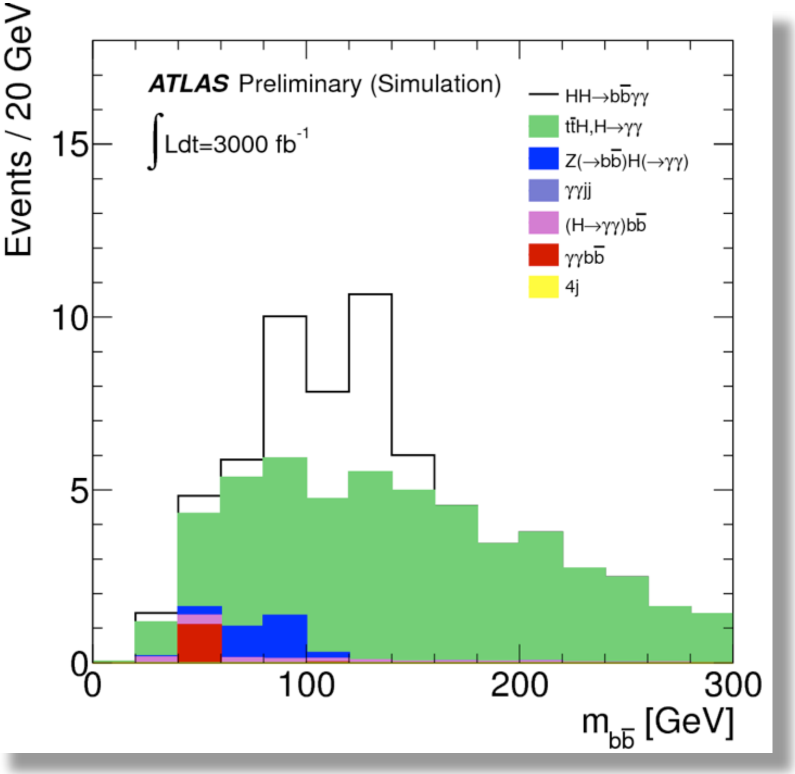
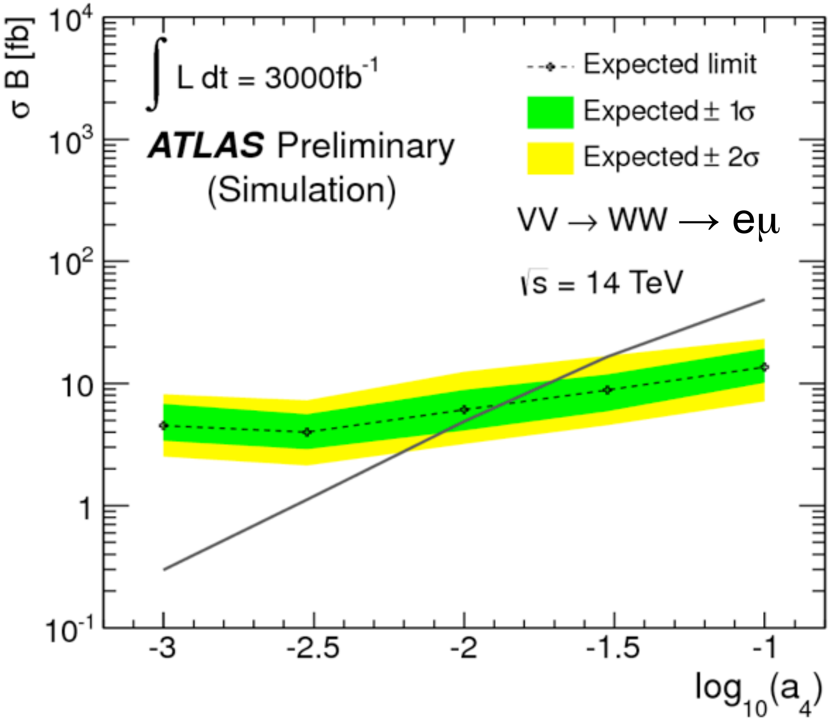




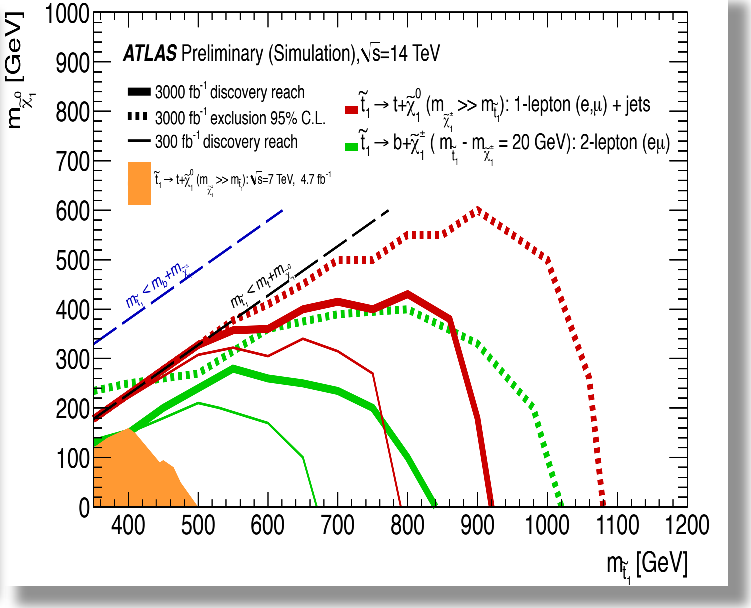
Strong Case for the HL-LHC

- There are unique measurements, which require to go far beyond 300 fb^{-1}:
  - Establishing H(μμ) decay at >5σ significance and measurement of the Hμμ coupling to ~15% level
  - Measurement of the Higgs self-coupling
  - Observing how the VV scattering amplitudes unitarize in the presence of the Higgs boson
- Higgs is not the only case for the HL-LHC
  - Finding massive new physics or ruling out broad class of “natural” new physics model and demonstrating that SM is fine tuned
  - Answering the major question if we have entered the “desert” and there are no new weakly or strongly interacting states below a few TeV
  - Probing higher energy scales via precision measurements

SUSY beyond LHC-14

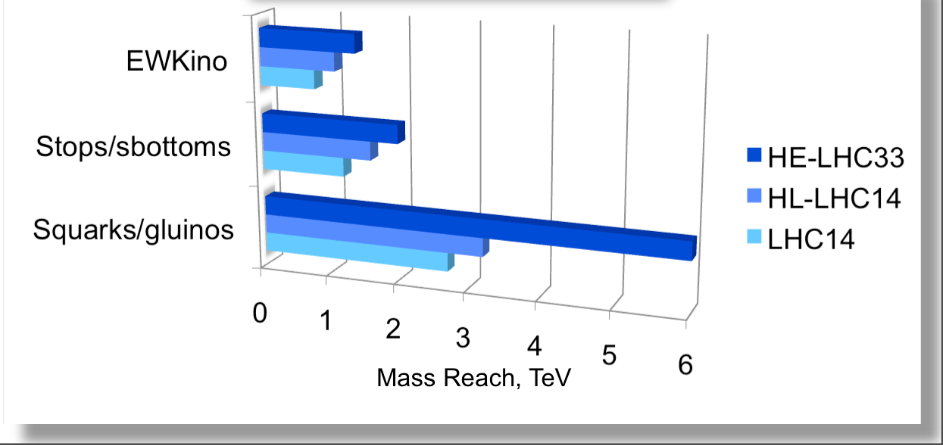
- If we find new physics (e.g., SUSY) at the LHC-14, we will need to measure masses and decay rates precisely to shed light on:
  - Gaugino mass unification
  - Squark/slepton unification
  - SUSY flavor and CP violation
  - Baryogenesis
  - Neutrinos and leptogenesis
  - String compactification
  - …

ATLAS-PHYS-PUB-2012-002



- If SUSY is not found at the LHC-14, how far should we push?
  - Important to test naturalness to the limit
  - Need to go up to ~1 TeV for stops and sbottoms
  - Also target chargino-neutralino pair production up to high masses
    - The latter is not possible at any of the foreseen e^+e^- colliders

CMS Note 2012-006



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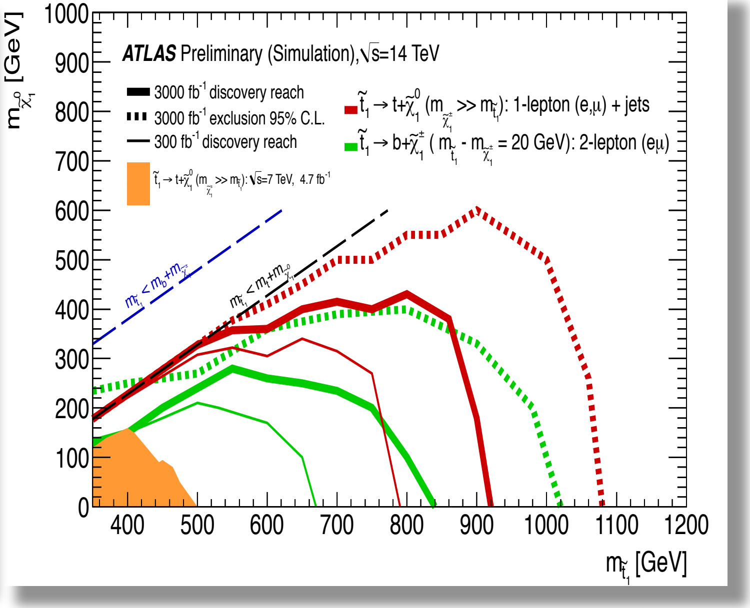
ATLAS-PHYS-PUB-2012-002



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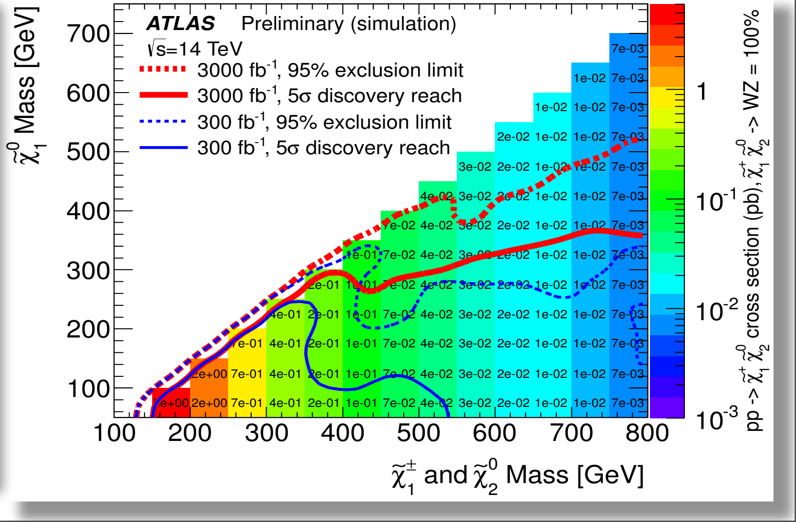
ATLAS-PHYS-PUB-2012-002



Conclusions

- The LHC is the most successful and amazing particle accelerator built so far
- The first three years of spectacular performance of the machine and the detectors brought in the first major discovery and a whole new program of precision measurements and searches
- The LHC is taking a short break till 2015 to come back at the ~13 TeV energy to explore the Terascale with a full potential
- Running beyond 2022 with much x10 higher integrated luminosity (HL-LHC) will be needed for detailed studies of the Higgs sector and any new physics to be found beforehand
- The LHC is a very young machine, and it has a 20+ year long exciting program ahead, which is what we need to fully explore the properties and the consequences of the new particle the LHC has delivered so far!

Thank You!