Search for New Particles or Physics Beyond the Standard Model at the LHC

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OUTLINE

1. **Success of the Standard Model**
2. **Need for deeper theory: Beyond the Standard Model**
   - Dark matter and small neutrino masses suggest BSM
3. **Many theoretical alternatives (scenarios)**
   - Two examples: 3.1 Supersymmetry and 3.2 Extra Dimensions
4. **Search strategies and experimental signatures**
5. **Sensitivities of the LHC experiments to the BSM signals**
   - Detectors ATLAS and CMS
   - Some examples

1. Success of the Standard Model

Many experimentally measured quantities agree very well (at $O(10^{-4}$ -$10^{-5})$ level) with the theoretical predictions of the Standard Model.

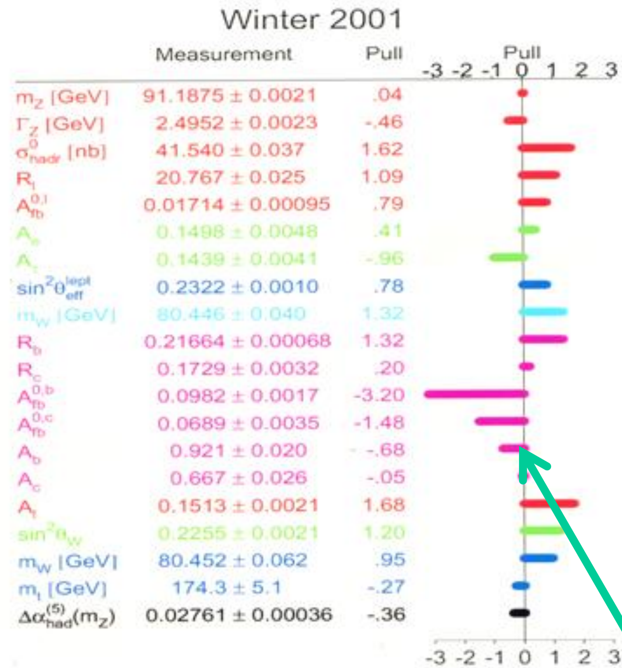
There are no disagreements known, up to presently accessible energies.

This means that both the leading order and the loop (quantum) corrections in the SM are well understood.

STANDARD MODEL IS A VERY WELL TESTED THEORY UP TO THE ENERGIES OF O(100 GEV).

LEP, SLD and TeVatron data 2001

Experimetally measured electroweak quantities compared to the best predictions of the SM



SM prediction

COMPILATION BY THE ELECTROWEAK WORKING GROUP 2001

2. Need for deeper theory: Beyond the Standard Model

On the theoretical side, the arguments for deeper theory, encompasing the SM, were summarized by Stefan Pokorski.

On the experimental/ observational side I would like to offer 3 arguments for BSM physics:

1. Dark Matter contents of the Universe and Dark Matter Particles,
2. Very low values of neutrino masses,
3. Existence of 3 generations of elementary fermions, with wildly different masses. $\Rightarrow$ GUT

2.1 Dark Matter Particles- weakly interacting, neutral, massive particles (WIMPs)

Dark matter density in the Universe is high, and most of the DM is non baryonic:

$$\Omega_{\mathrm{NonBaryonicDarkMatter}} h^2 = 0.111 \pm 0.006$$

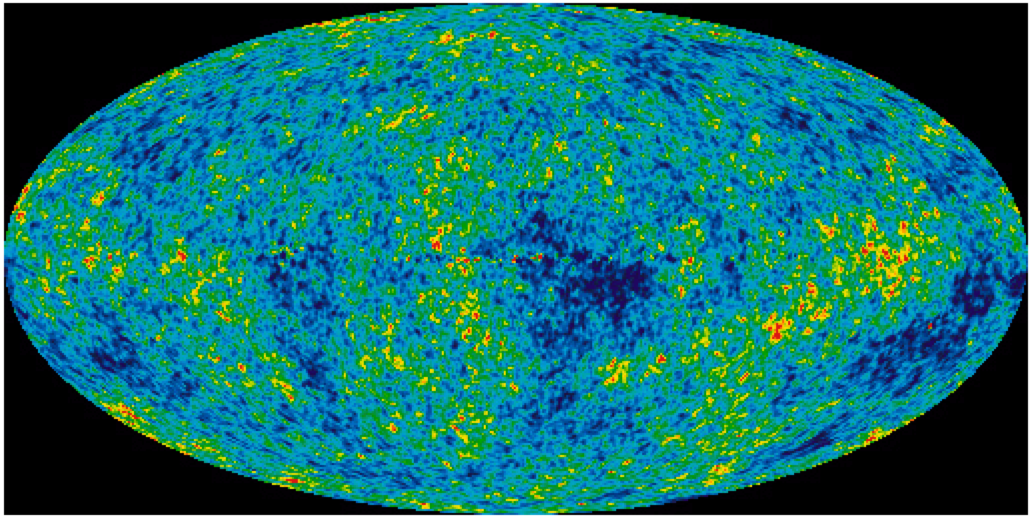
$$\Omega_{\mathrm{BaryonicDarkMatter}} h^2 \simeq 0.023 \pm 0.001$$

Dark Matter is cold, i.e was non-relativistic when it decoupled from the rest of the Universe.

Dark Matter Particles are most likely massive with

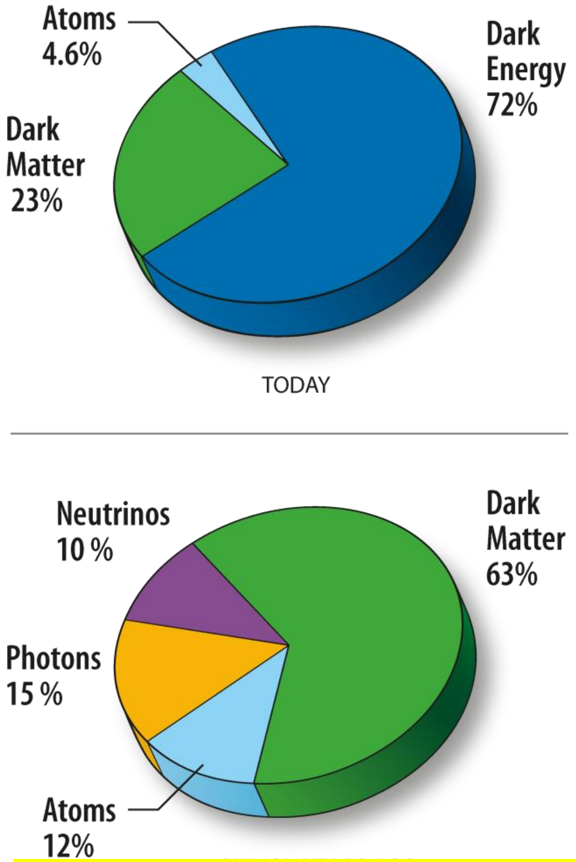
$$10\,\mathrm{GeV}/c^2 < m_{\mathrm{DM}} < \text{a few TeV}/c^2$$

2008 WMAP results after 5 years of data taking



Anisotropy of the CMB

Universe now



Universe 380 000 years old

2.2. Very small neutrino masses suggest BSM

- **Neutrino masses are not yet directly measured.**
- **The non zero values of their mass differences suggest their masses of order of 10^{-2}-1 eV/c^2, which are much smaller than the mass of the electron- 511 000 eV/c^2.**
- **The SEE-SAW mechanism, which is the most likely explanation for this phenomenon requires existence of the large mass scale of $O(10^{14\text{-}16}$ GeV), and many more massive particles.**

3. Many theoretical alternatives. Two examples: Supersymmetry and Extra Dimensions

There were many extensions of the SM postulated, and quite a number of these SCENARIOS is consistent with the electroweak data at LEP, SLC and TeVatron.

In these extensions a number of <u>new, heavy particles</u> with masses above the achieved experimental reach were invariably postulated to exist.

The values of masses themselves depend on the scenario and model parameters.

Search for these new particles is an important part of the LHC physics programme.

3.1 SuperSymmetry

Supersymmetric extensions of the SM are very attractive. Their main properties, common to most SUSY extensions, are summarized below:

In SUSY, every known elementary fermion and boson has its bosonic or fermionic partner.

These partners, unseen up to the presently available energies are heavy new particles, waiting to be discovered.

Because of the conservation law of R-parity, in collisions of ordinary particles such as quarks and gluons in LHC, the superpartners are produced in pairs of particle- antiparticle.

In the decays of superpartners, the lightest supersymmetric particle (LSP) remains stable. The LSP is neutral, weakly interacting particle, hard to detect, and a good Dark Matter candidate.

SUSY contd.

Some SUSY partners:

- quarks (j=1/2) ←------------ ---------→ squarks (j=0)
- leptons (e, μ, τ) ←-----------------------→ sleptons
- neutrinos (ν) ←-----------------------→ sneutrinos
- W, Z, γ (j=1), ←----------------------→ wino, zino, photino (j=1/2)
- gluon (j=1) ←-----------------------→ gluino (j=1/2)
- Higgs h0 (j=0) ←----------------------→ higgsino (j=1/2)

All neutral and charged superparticles may mix, i.e. the physical states of definite mass will be superpositions of several superparticles .

Neutralinos- a superposition of neutral superparticles – are very good candidates for the Dark Matter Particles

3.2 Extra dimensions

A conjecture that the space-time is not 4-dimesional but of 4+n dimensions, extra dimensions being compactified , leads to another popular class of SM extensions.

In these models there are so called Kaluza-Klein excitations- massive states with typical masses in excess of 1 TeV/c^2. The exact masses, couplings and other properties depend on the details of the model.

4. Search strategies and experimental signatures

- In all scenarios, the crossections for new, massive particles are small – *O(1-100 fb)*.
- The number of produced new particles at the LHC at maximum luminosity would be *O*(10-100)/ year of data taking.
- The production of SM light particles is many orders of magnitute stronger, and may mimic heavy particle production.
- The clever search strategies leading to the efficient background reduction are, thus, of primary importance.

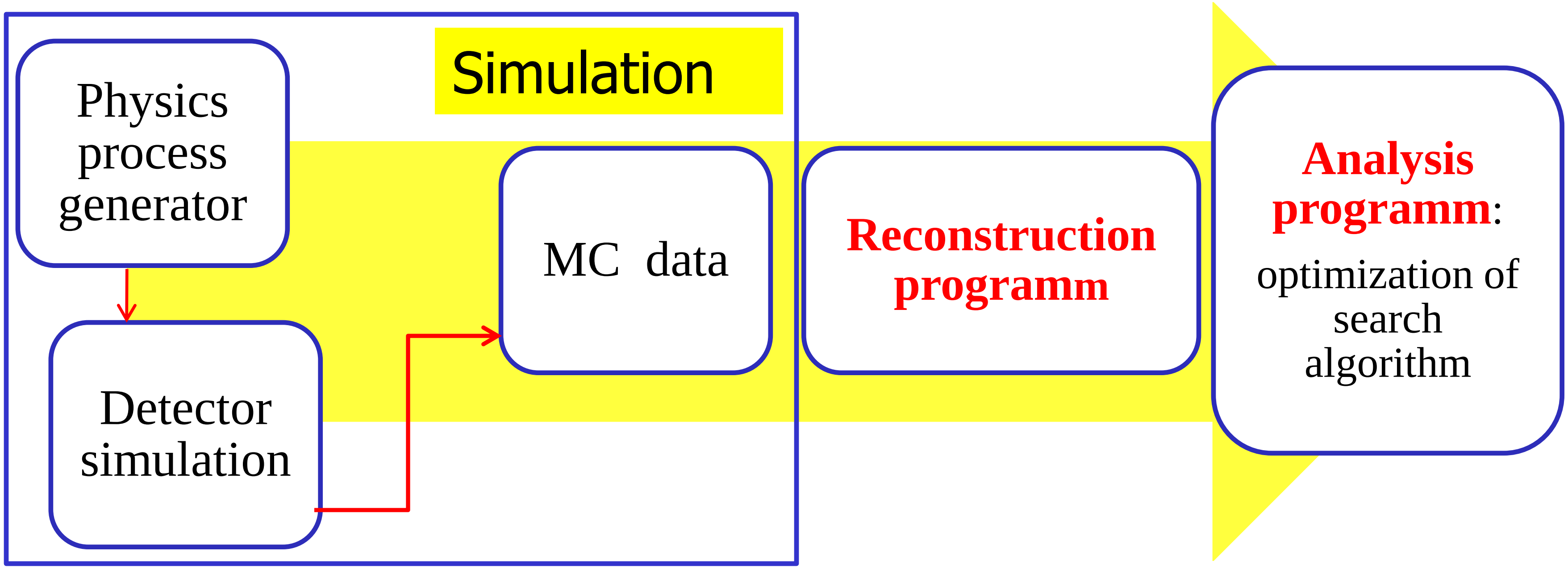
Search strategies contd.

Choice of background reducing signatures depend on the scenario, but there are some general rules good for many of scenarios. Some examples:

- Usually, the new particles decay in cascade chains, with undetectable neutrinos and other weakly interacting neutral particles escaping detection.
- Missing transverse energy $E_{T\ miss}$ sensitive to escaping energy, is a good variable to use,
- Multiobject final states (several charged leptons, jets, photos etc.) enhance the new particle decay signal,
- Clever background subtraction techniques like (opposite sign dileptons – same sign ones) may enhance the signal.
- Heavy stable particles may travel with the velocity lower than c. Measuring particle velocity may be useful, but is technically difficult.

The Tools: Monte Carlo simulations, detector and analysis design

The method of Monte Carlo simulation of the physics and detector response, followed by the reconstruction is used to optimize the detector, trigger and future analyses .

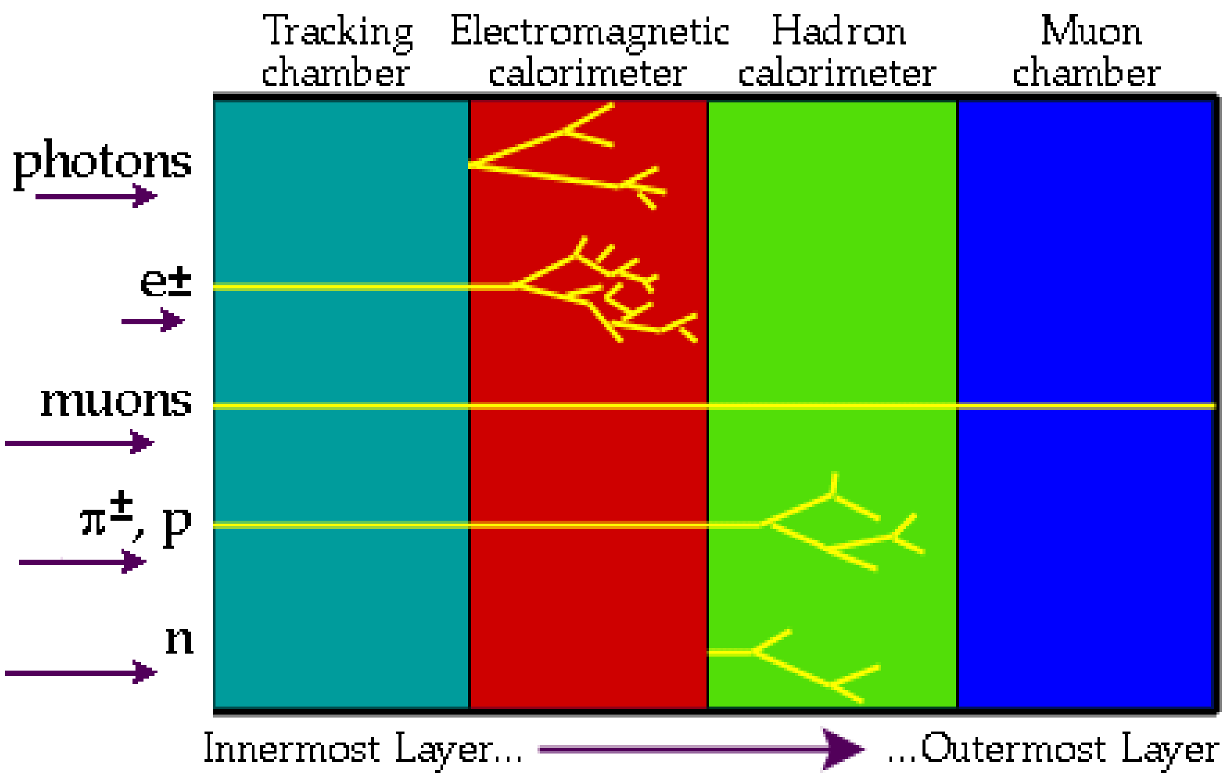


5. Sensitivities of the LHC experiments to the BSM signals

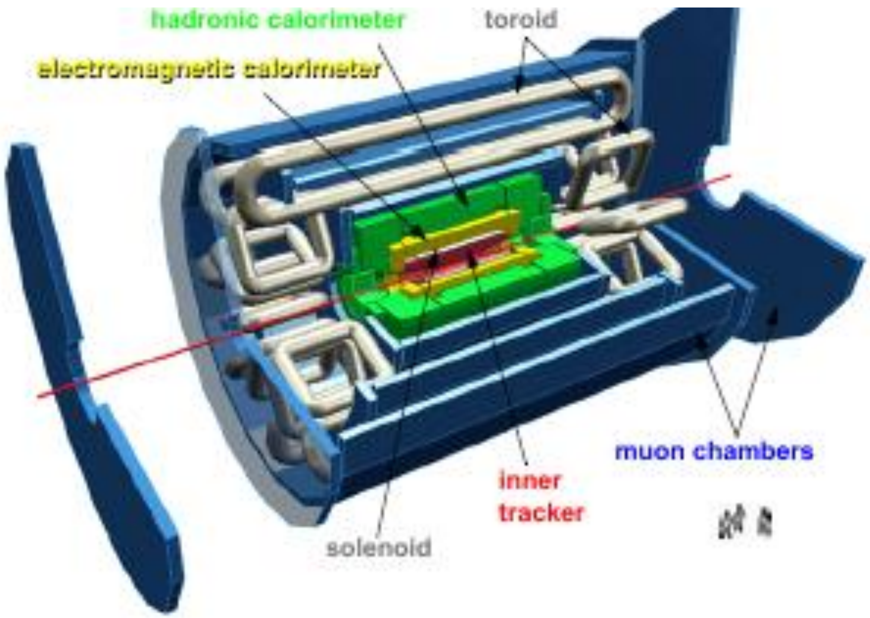
ATLAS and CMS are multipurpose detectors, built out of several heavily segmented layers with different functionalities.

Each layer identifies and measures different object:

- Charged track,
- Photon and electron,
- Hadrons nad jet,
- Muon,
- Missing energy

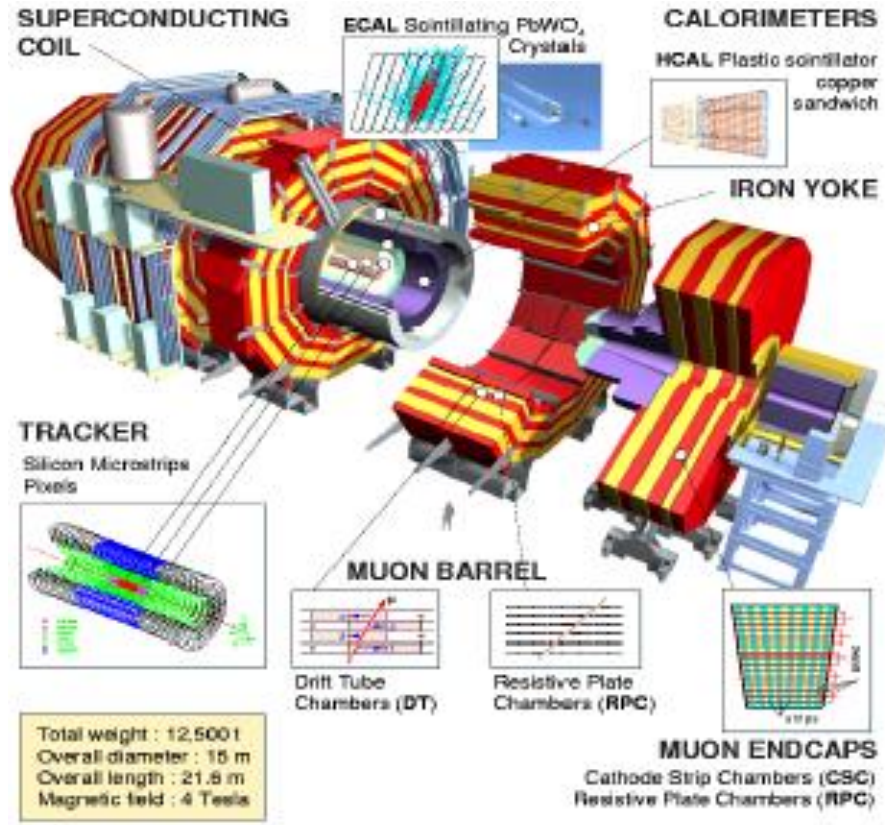


ATLAS and CMS detectors



ATLAS

CMS



Search for SUSY

Typical hadronic signature:

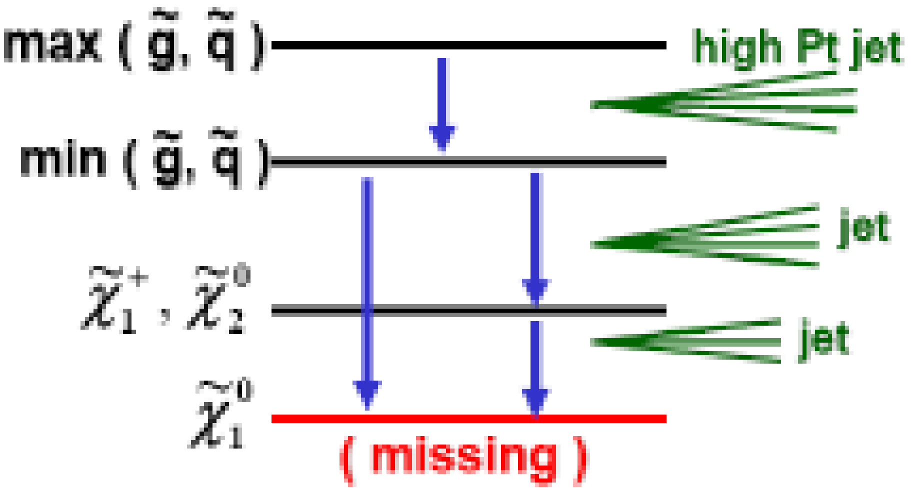
- large missing E_T ($\geq$ 200 GeV)
- Jets (N$\geq$ 3)

Typical leptonic signature:

- Charged leptons (N =1,2,34)
- Missing E_T

Background:

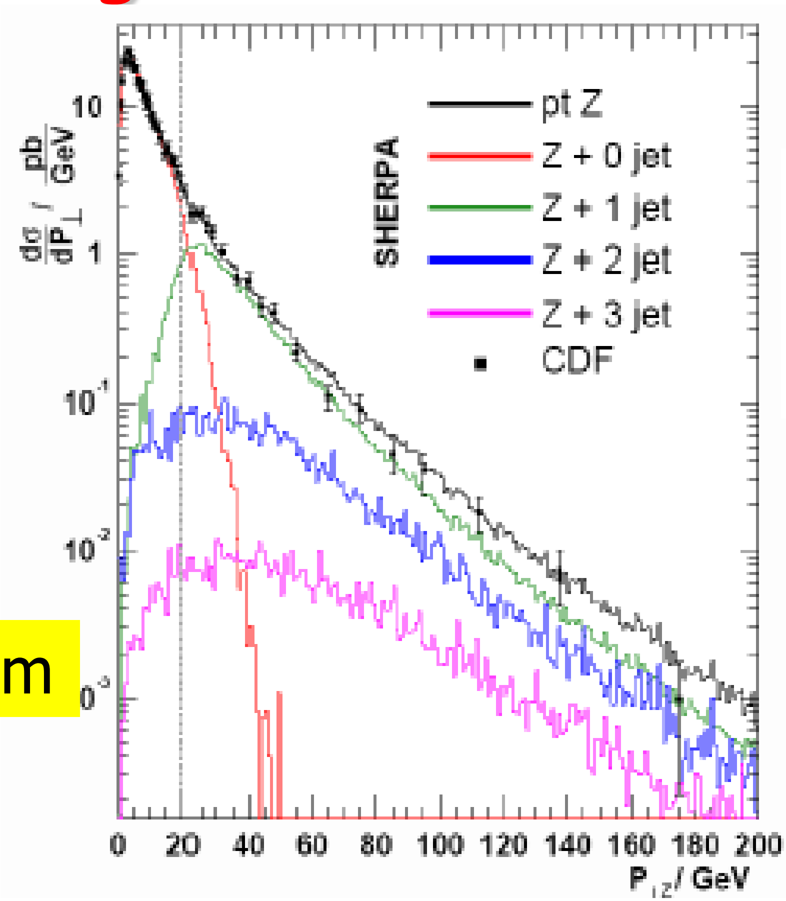
- QCD jets (hadronic)
- Top/ W/Z + Jets (hadronic and leptonic)



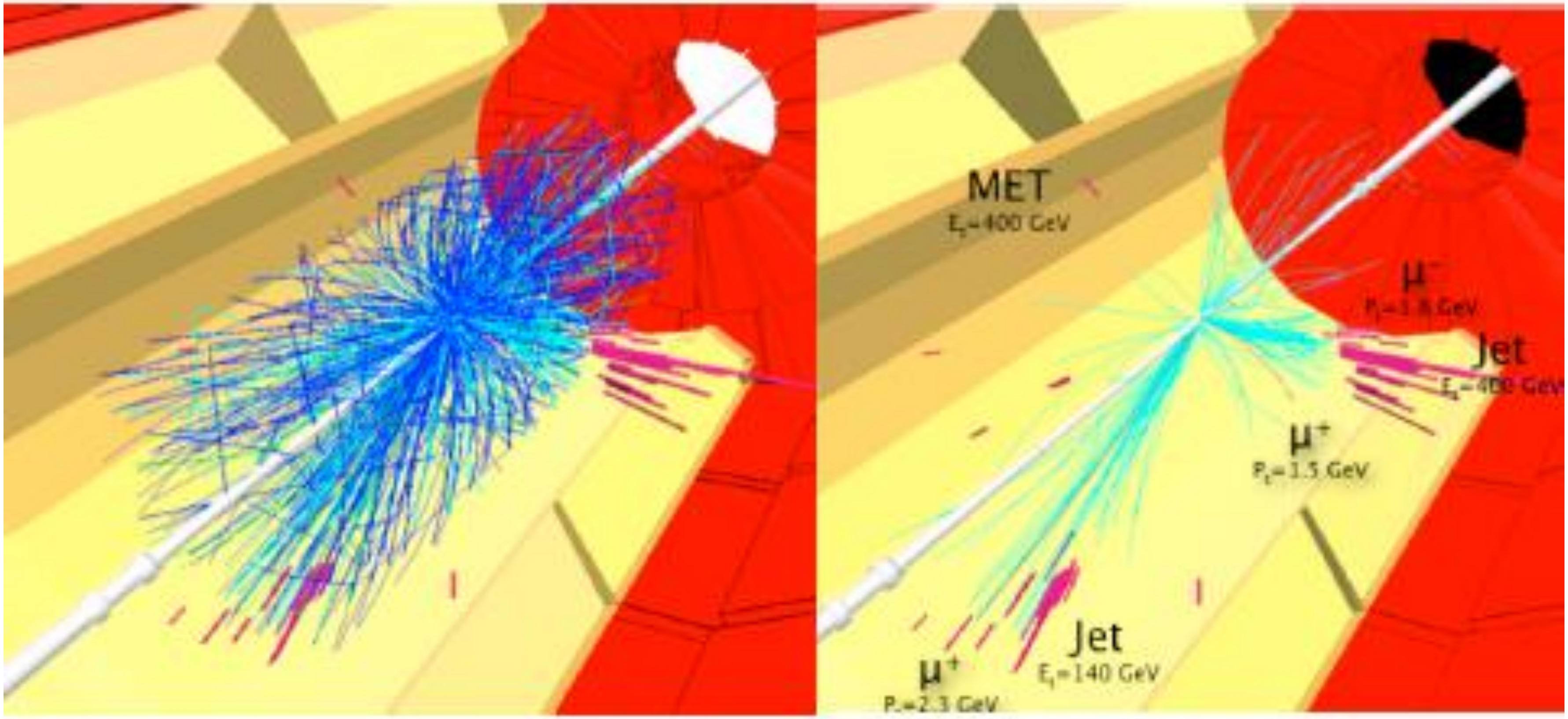
SUSY search: example of CMS MC tuning

MC is tuned to the existing CDF data from p-pbar at 1.8 TeV

Z^0 transverse momentum



Example: 1.9 TeV gluino in the CMS detector



All charged tracks+E **After reconstruction**

List of searches being prepared

List of searches being prepared:

• SUSY: mSUGRA, nMSSM, GMSB, AMSB,

• MSSM and SM Higgs

• Extra dimensions: RS, ADD, UED,

• Extra gauge bosons: Z’, W’,

• Microscopic strings- Quirks,

• Antiparticles,

•Black Holes,

•…….

Signatutes- objects to look at:

• Missing E_T +jets,

• Charged leptons + jets+ Missing E_T ,

• Dileptons (same and opposite sign),

• Long-lived particles (secondary vertices),

• Particles not pointing to the IP,

• Doubly charged particles,

• Particles changing charge in flight,

• Low velocity particles,

….

List of searches contd.

In all the cases we establish :

- the analysis algorithms,
- the sensitivity to new particles as a function of integrated luminosity,
- trigger conditions for different searches,
- search strategies for given luminosity estimate.

In autumn 2008 we start taking data at the LHC

The preparation for new exiting physics are well under way.