Dark Matter

A Particle Theorist's Perspective

Lecture 2

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Outline

Lecture 1:

- evidence for DM
- DM candidates and particle physics models
- strategies for DM detection: direct, indirect, LHC
- prospects for direct detection
    - new results from CDMS

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  - indirect detection (PAMELA, Fermi/GLAST, the LHC)
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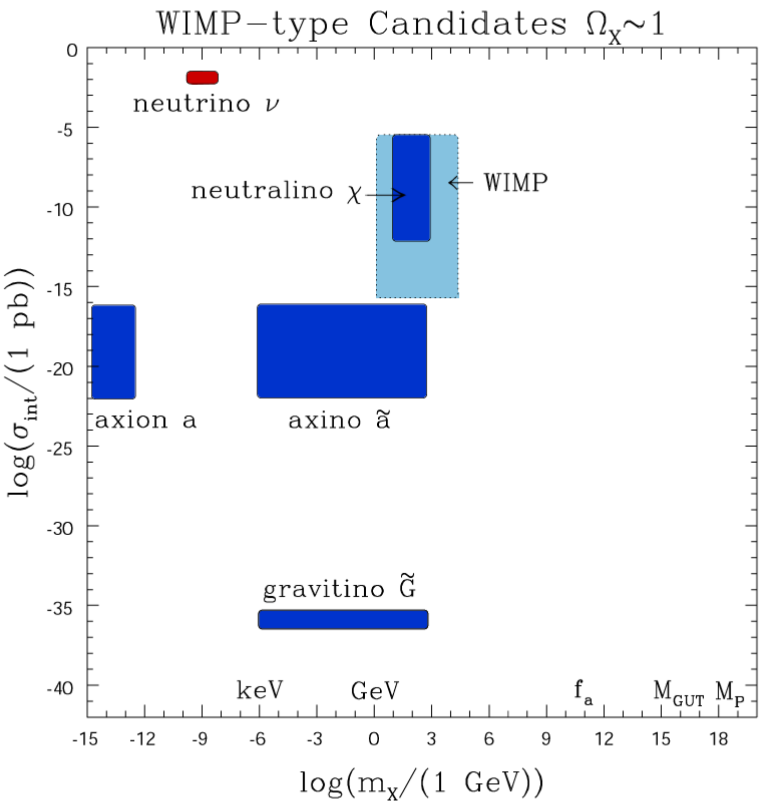
- axion
- summary

The Big Picture

well–motivated particle candidates such that $\Omega \sim 0.1$



- neutrino ν – hot DM
- neutralino χ
- “generic” WIMP
- axion a
- axino $\tilde{a}$
- gravitino $\tilde{G}$
- ????

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- (the LHC)

Go underground/–ice/–water

... or to space

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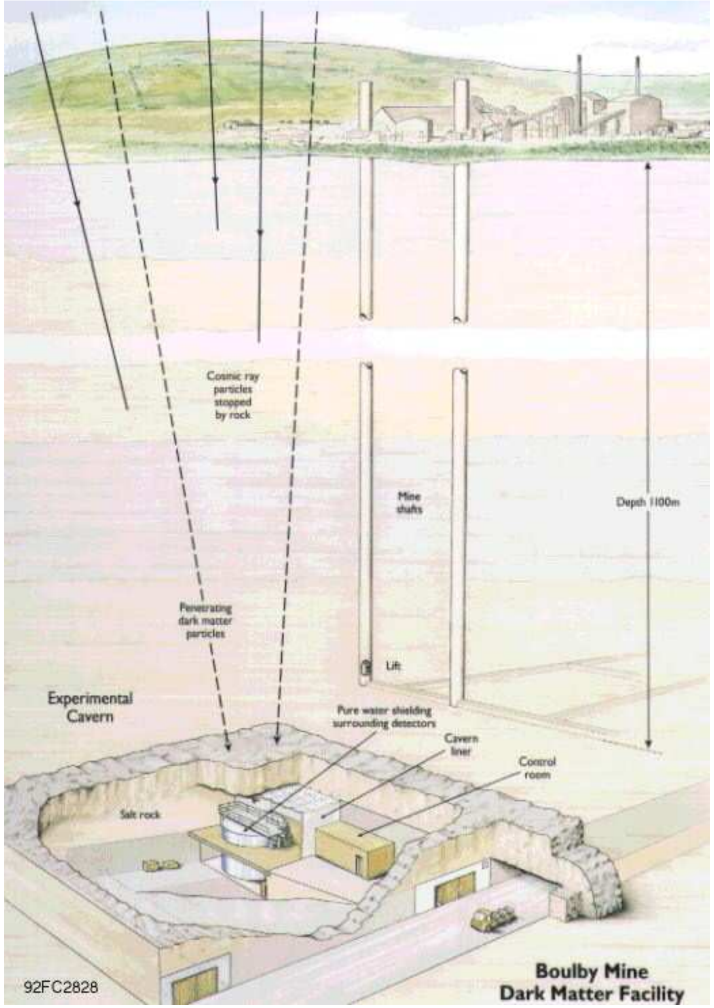

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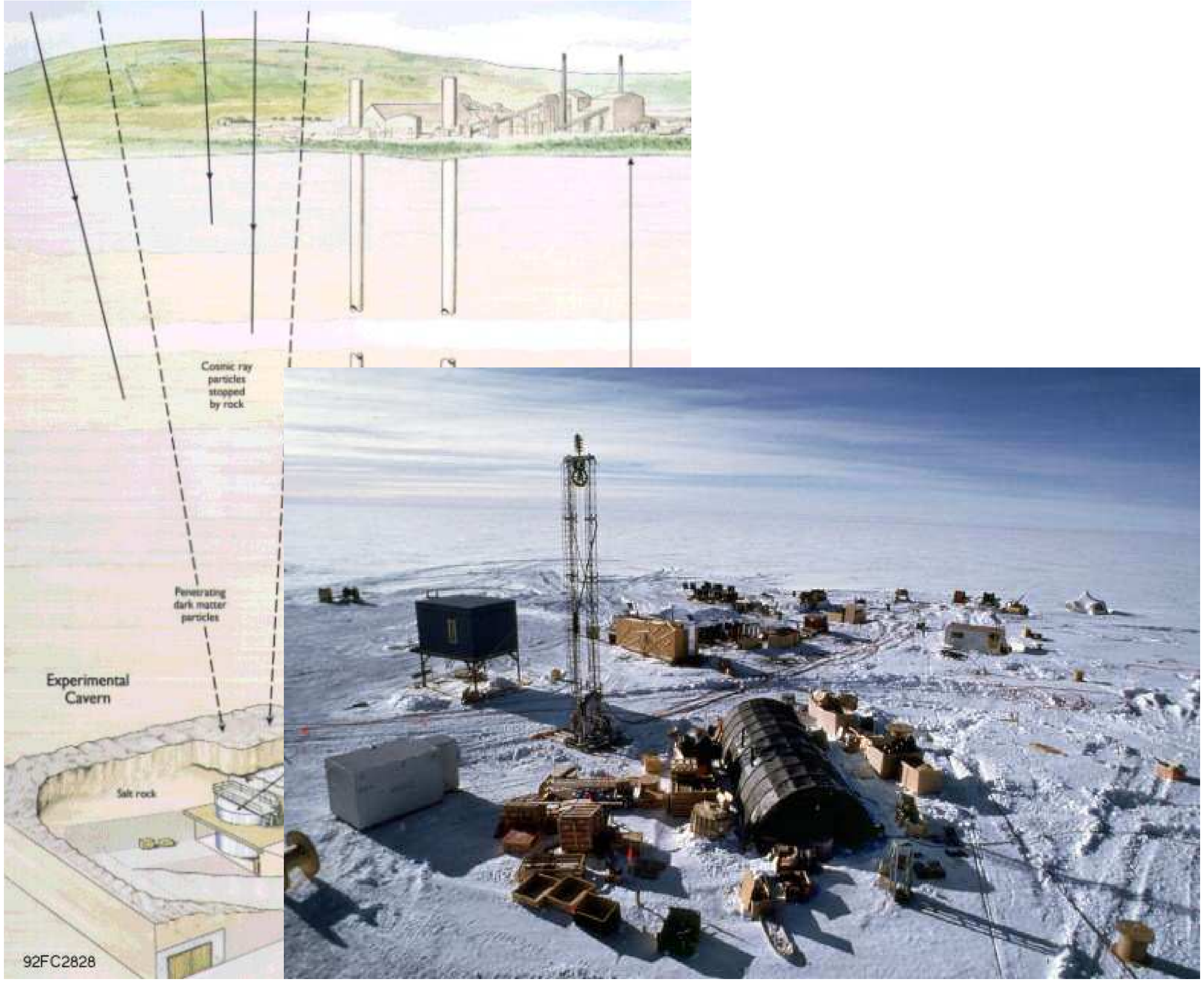

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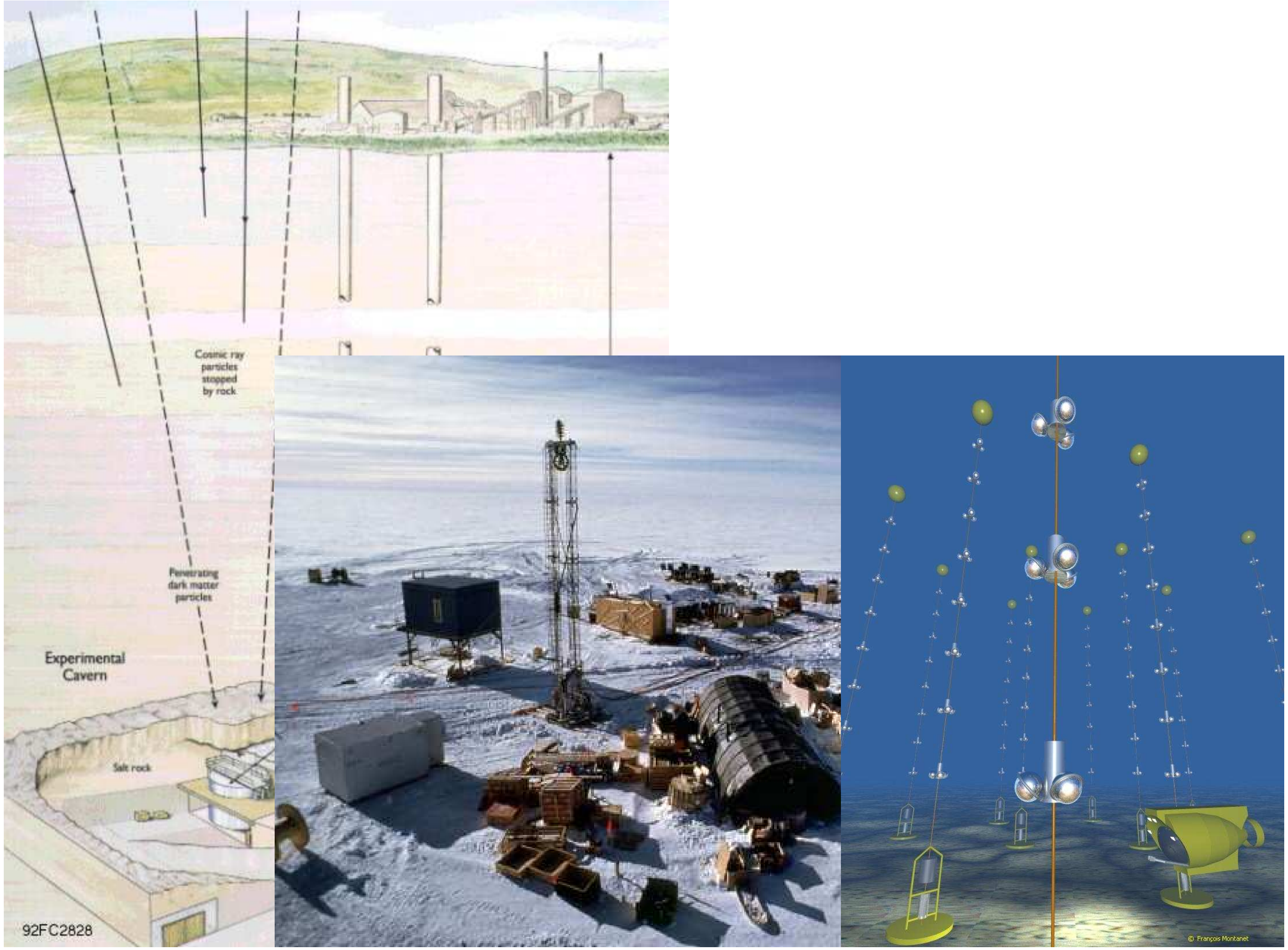

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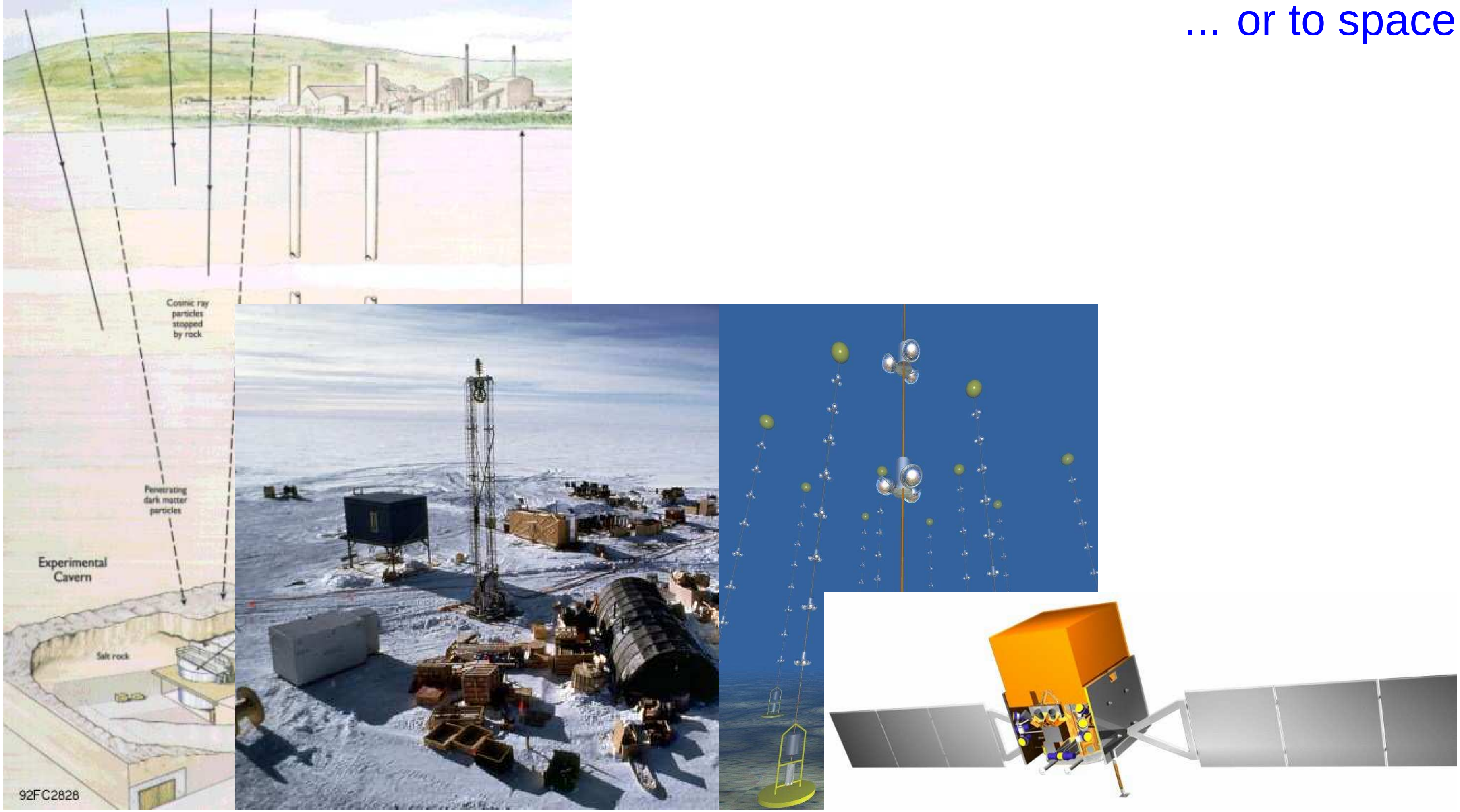

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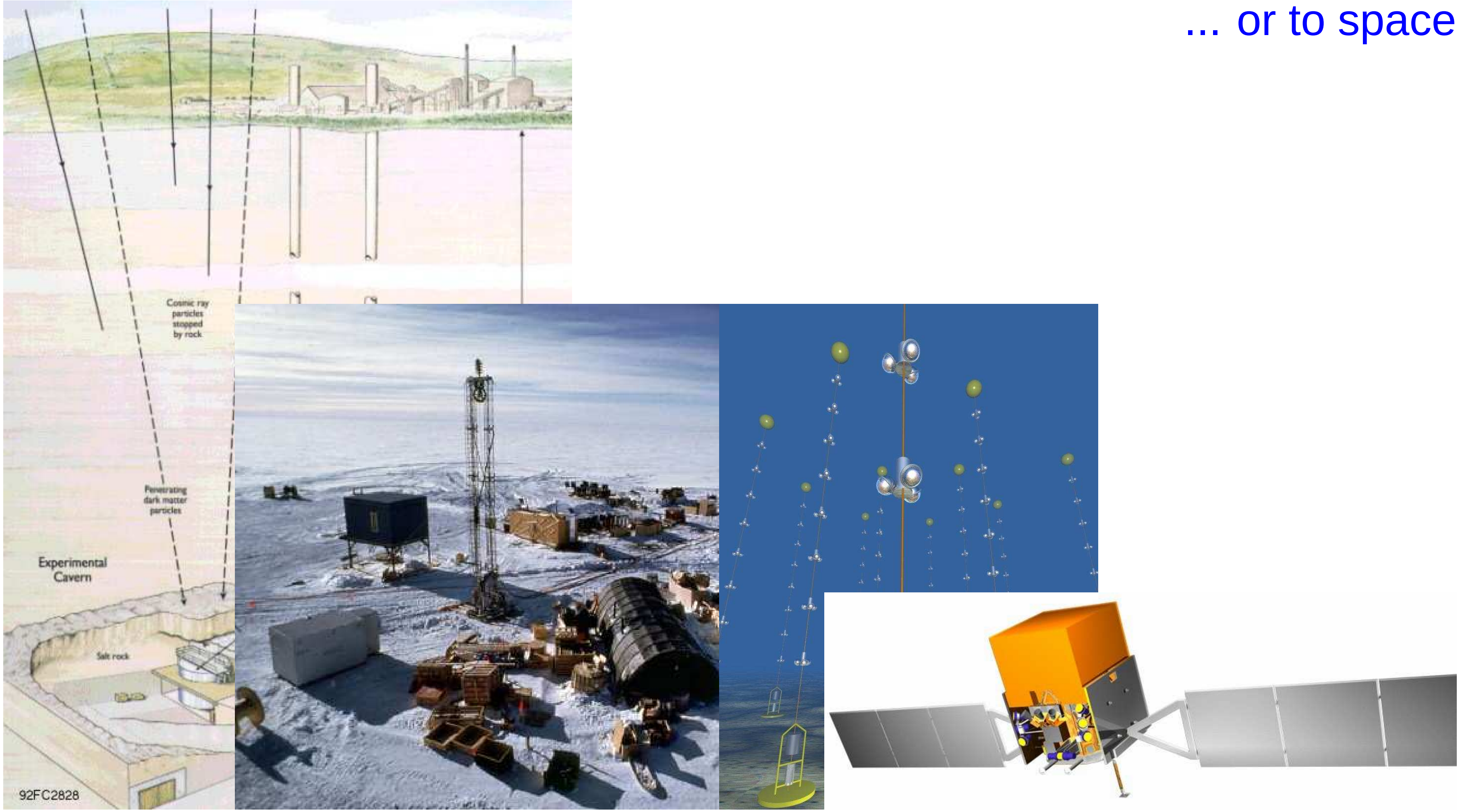

impressive experimental effort

Neutralino of SUSY – Prime Suspect

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neutralino $\chi =$ lightest mass eigenstate
of neutral gauginos $\widetilde{B}$ (bino), $\widetilde{W}_3^0$ (wino) and neutral higgsinos $\widetilde{H}_t^0$, $\widetilde{H}_b^0$
Majorana fermion ($\chi^c = \chi$)

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- part of a well-defined and well-motivated framework of SUSY
- calculable
- relic density: $\Omega_\chi h^2 \sim 0.1$ from freeze-out (...more like $10^{-4} - 10^3$)
- stable with some discrete symmetry (e.g., R-parity or baryon parity)
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- multitude of SUSY-based models: general MSSM, CMSSM, split SUSY, MNMSSM, $SO(10)$ GUTs, string inspired models, etc, etc
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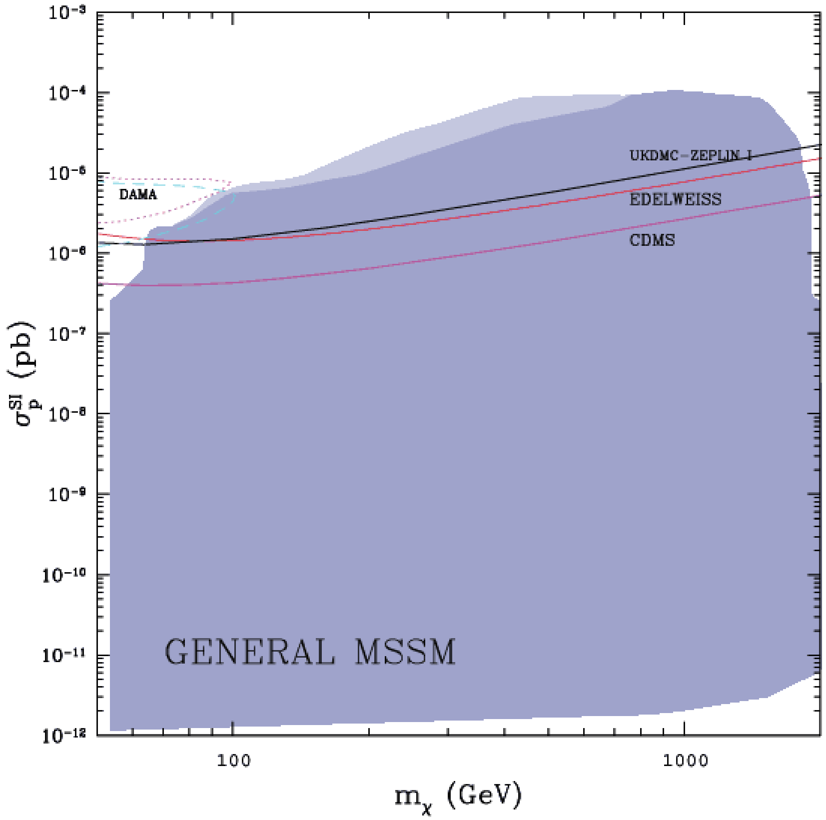
neutralino = stable, weakly interacting, massive ⇒ WIMP

General MSSM: Expectations for σ_p^{SI}

$\mu > 0$

Kim, Nihei, LR & Ruiz de Austri (02)



σ_p^{SI}– WIMP–proton SI elastic scatt. c.s.

(elastic c.s. for $\chi p \longrightarrow \chi p$ at zero momentum transfer)

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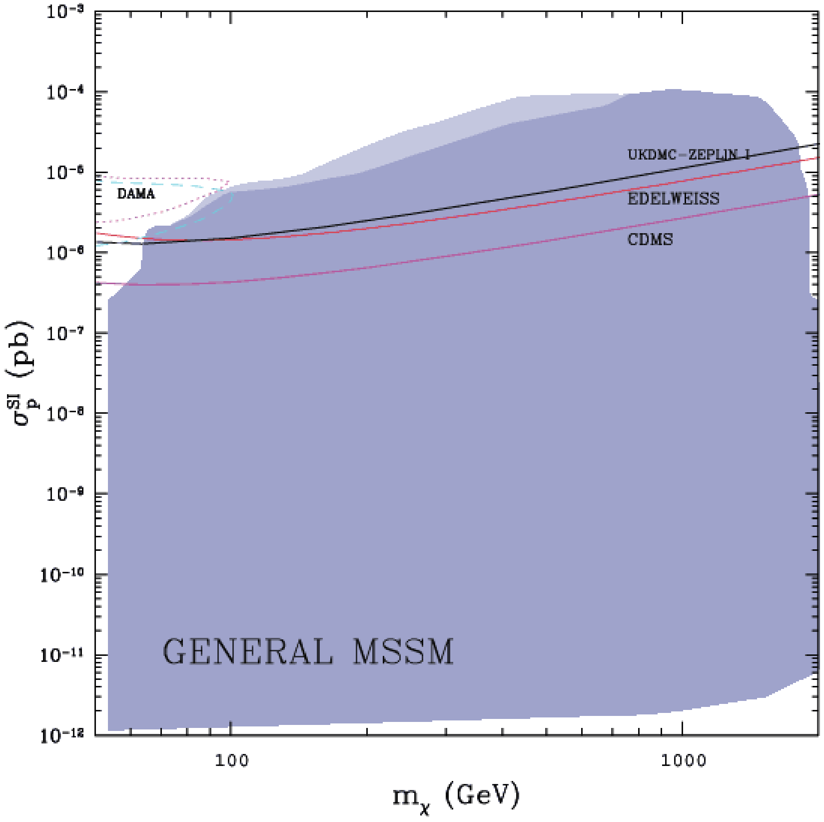

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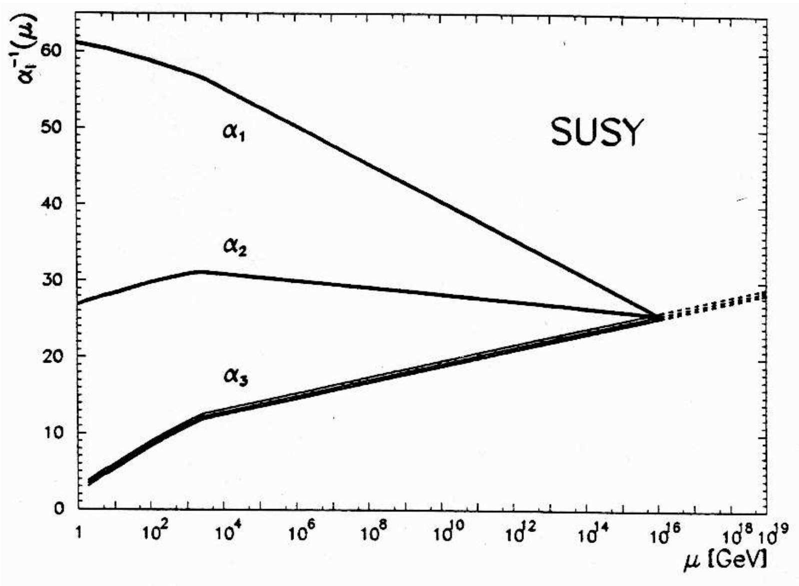
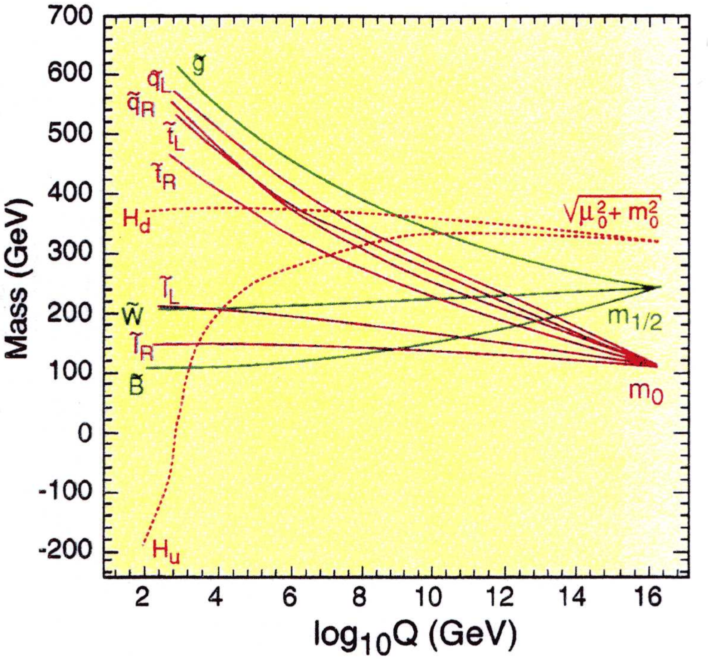
$\Rightarrow$ MSSM: vast ranges! Lacks real predictive power!

Add grand unification...



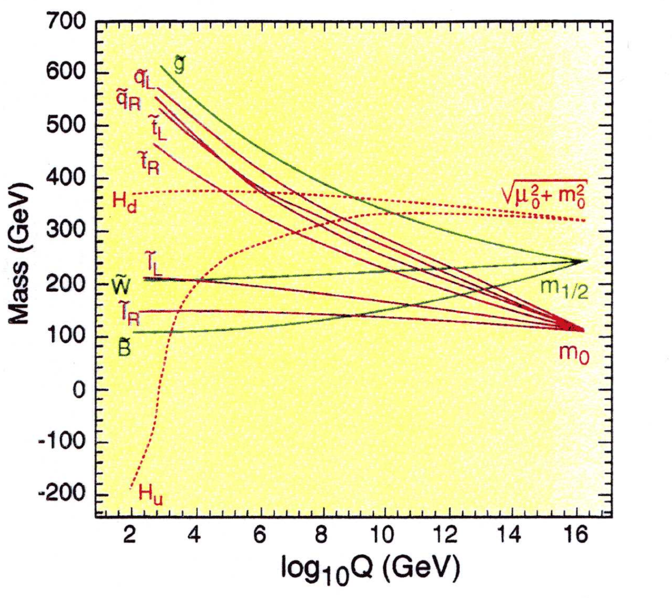


Constrained MSSM (CMSSM)

Kane, Kolda, LR, Wells (1993)

...“benchmark framework” for the LHC

(...e.g., mSUGRA)



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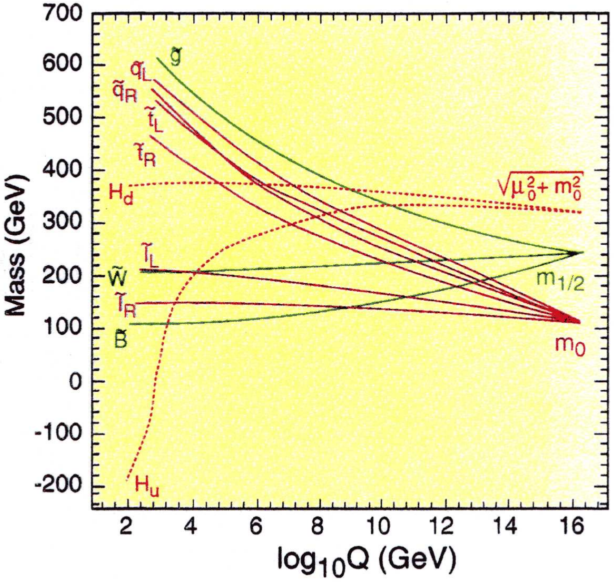

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- scalars
  $m^2_{\tilde{q}_i} = m^2_{\tilde{l}_i} = m^2_{H_b} = m^2_{H_t} = m^2_0$
- 3–linear soft terms $A_b = A_t = A_0$

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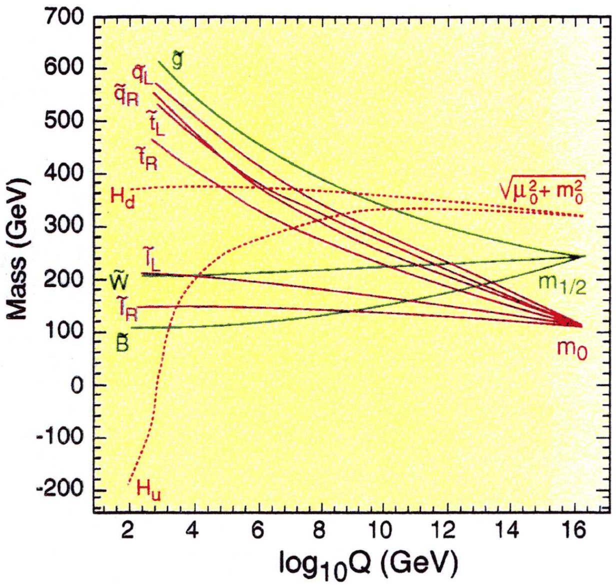

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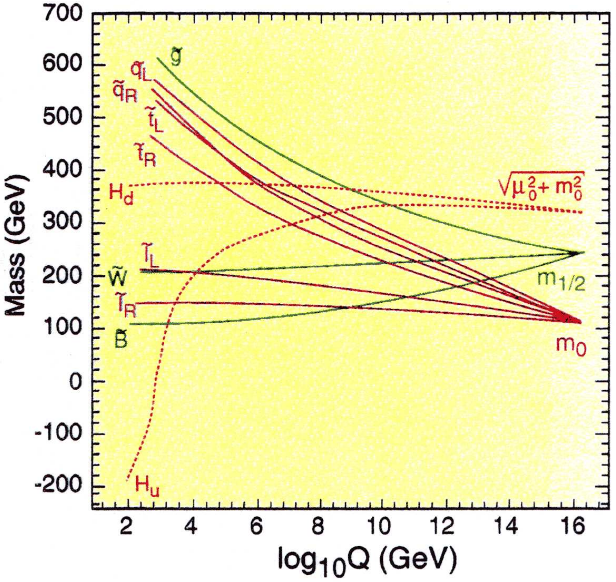

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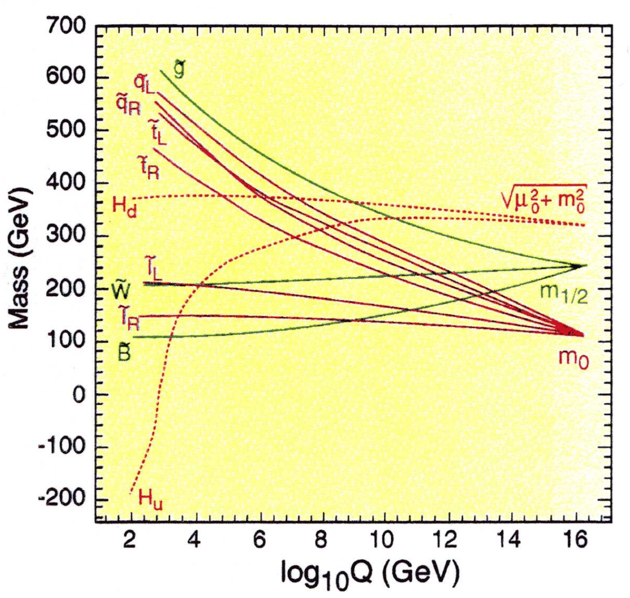

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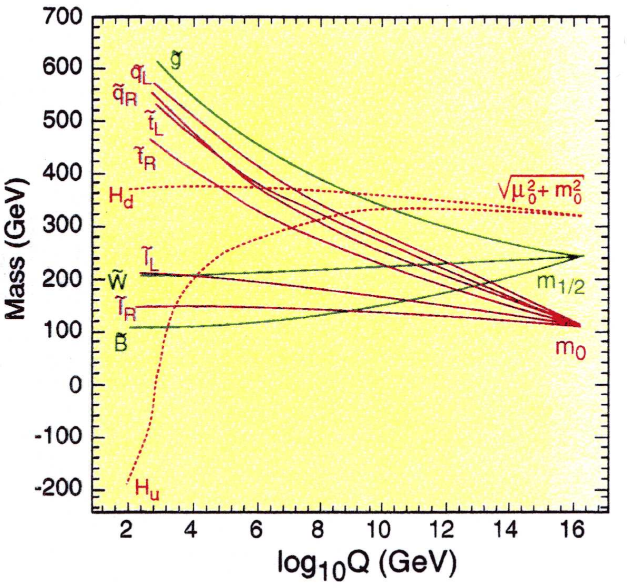

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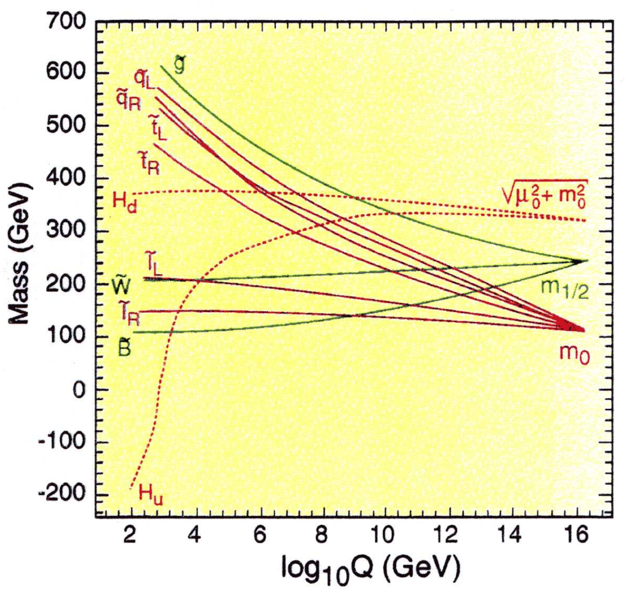

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some useful mass relations:

- bino: $m_\chi \simeq 0.4 m_{1/2}$
- gluino $\tilde g$: $m_{\tilde g} \simeq 2.7 m_{1/2}$
- supersymmetric tau (stau) $\tilde\tau_1$: $m_{\tilde\tau_1} \simeq \sqrt{0.15 m^2_{1/2} + m_0^2}$

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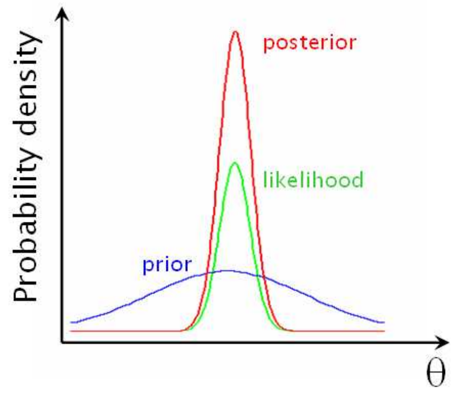

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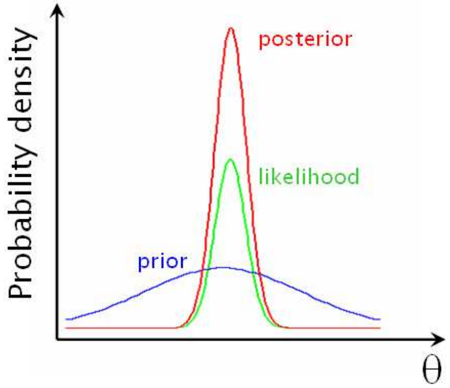
- Bayes' theorem: posterior pdf

$$\boxed{p(\theta, \psi | d) = \frac{p(d|\xi)\pi(\theta,\psi)}{p(d)}}$$

- $p(d|\xi) = \mathcal{L}$: likelihood
- $\pi(\theta, \psi)$: prior pdf
- $p(d)$: evidence (normalization factor)



$$\text{posterior} = \frac{\text{likelihood} \times \text{prior}}{\text{normalization factor}}$$

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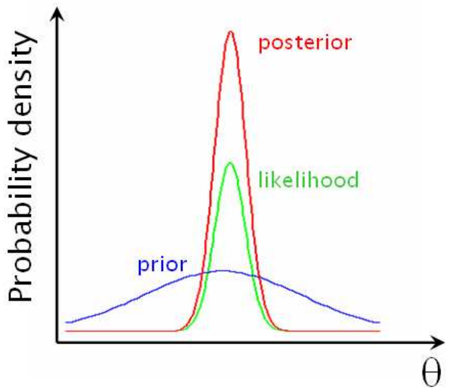

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- $p(d|\xi) = \mathcal{L}$: likelihood
- $\pi(\theta, \psi)$: prior pdf
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- usually marginalize over SM (nuisance) parameters $\psi \Rightarrow \boxed{p(\theta|d)}$

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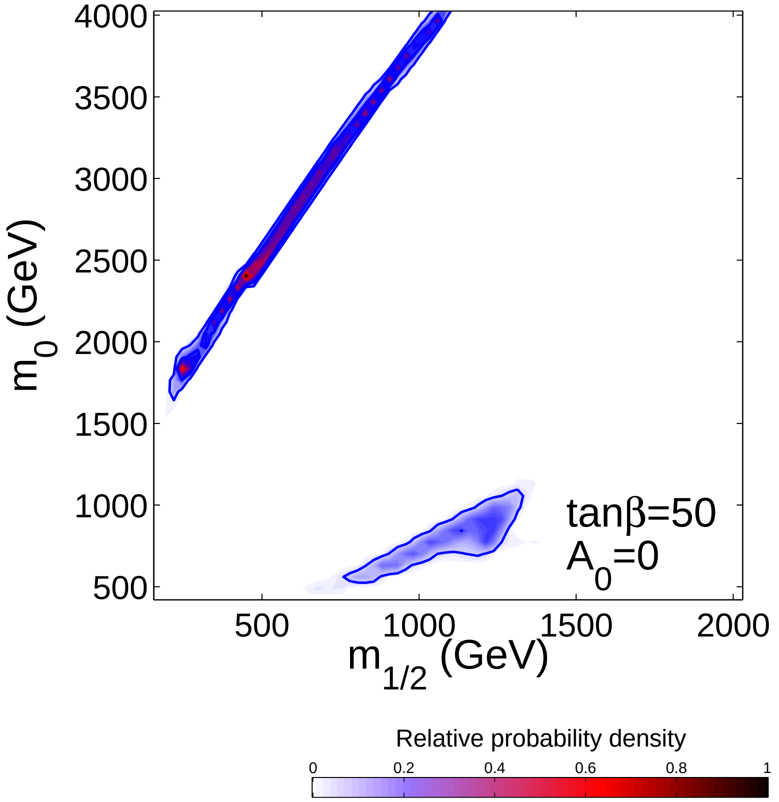
fix $\tan\beta$, A_0 + all SM param's



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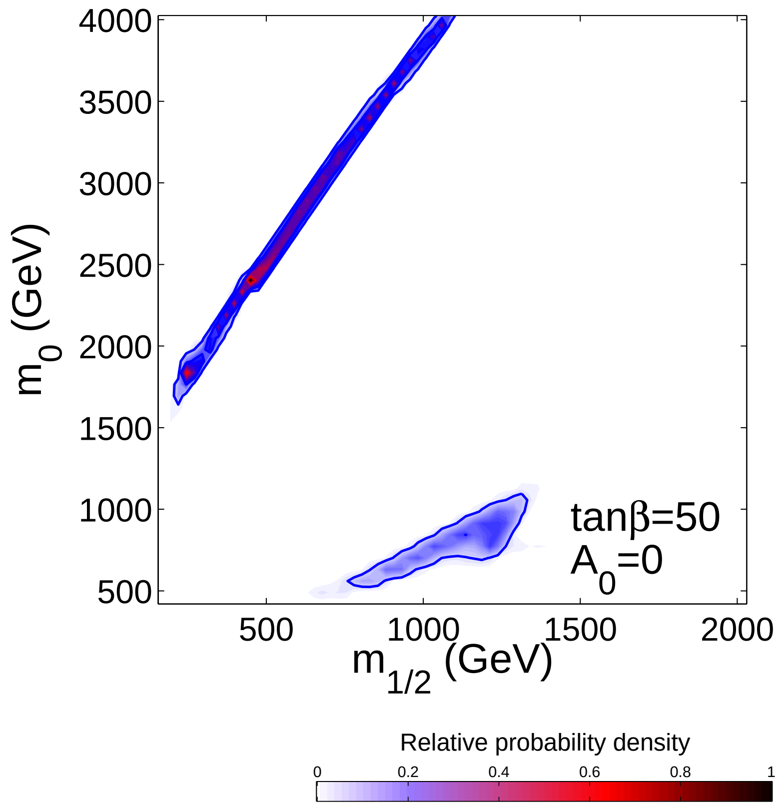
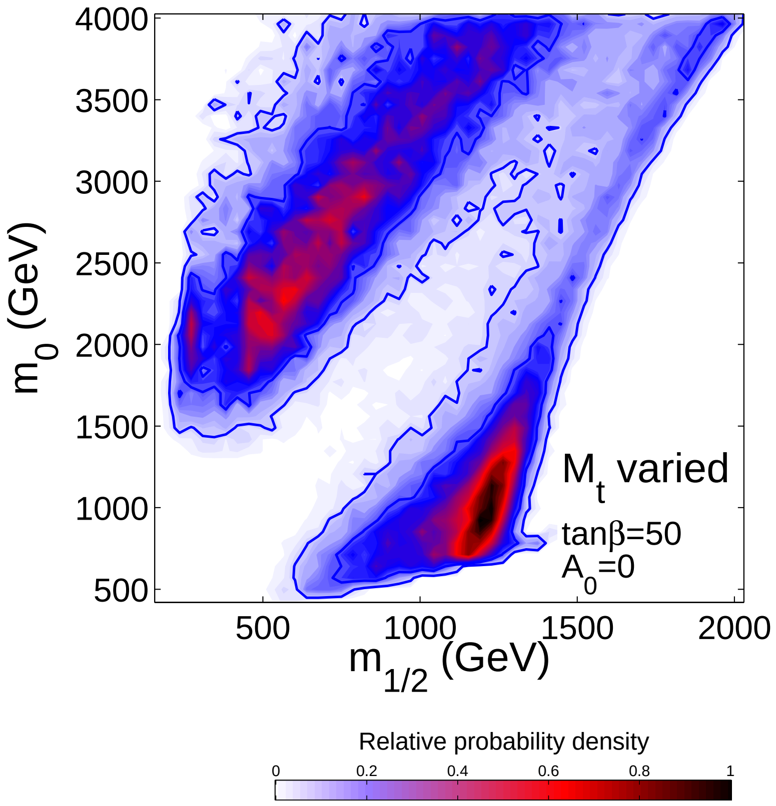


vary M_t



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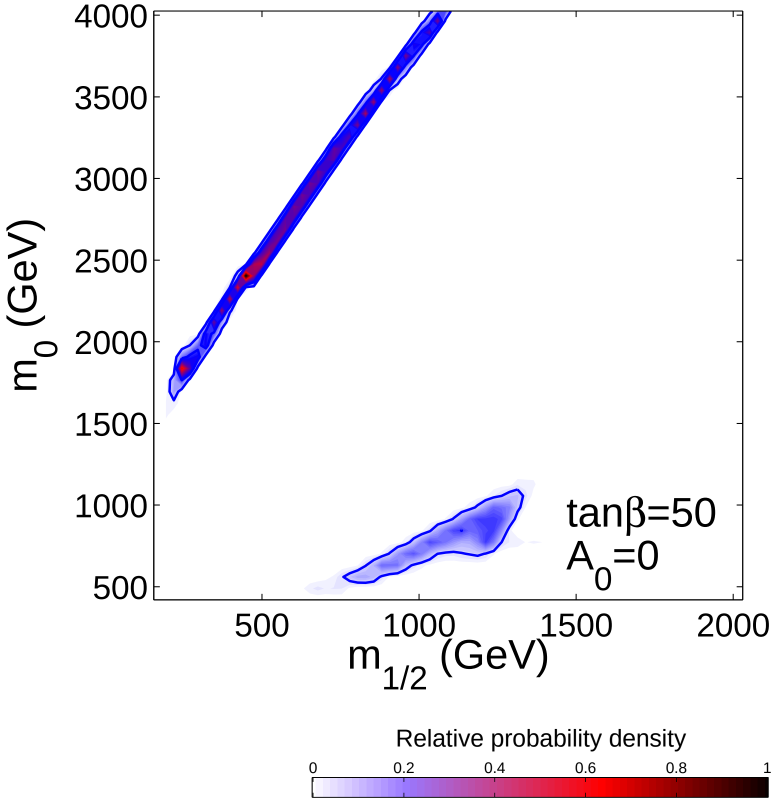
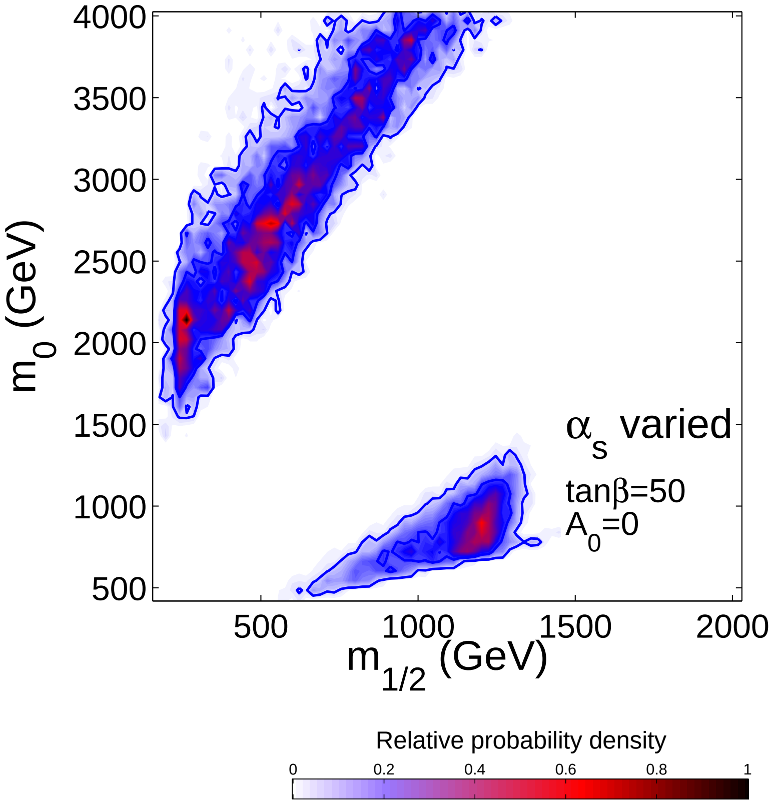
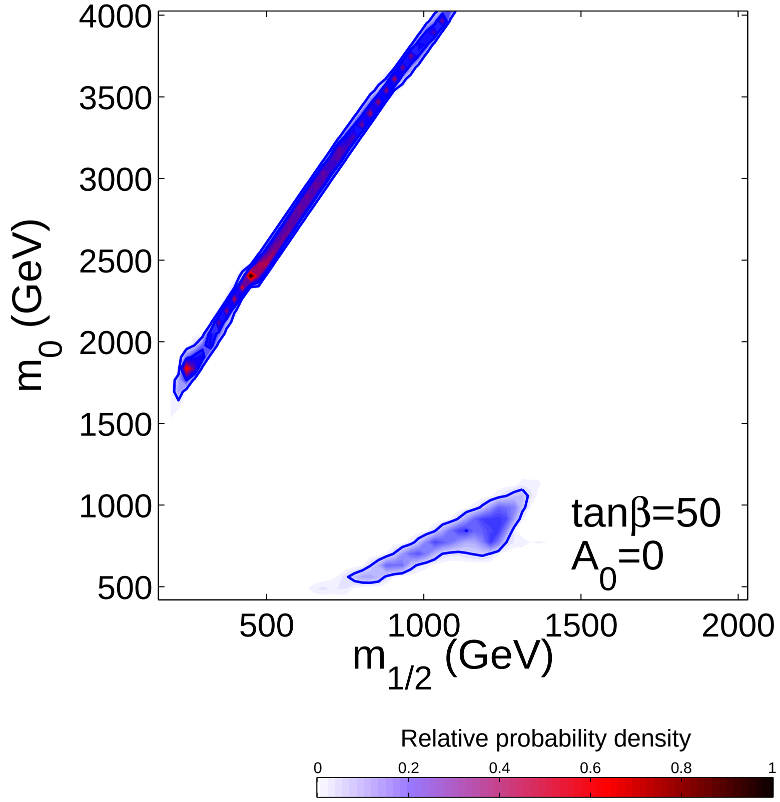


vary α_s



Impact of varying SM parameters

fix $\tan\beta$, A_0 + all SM param's



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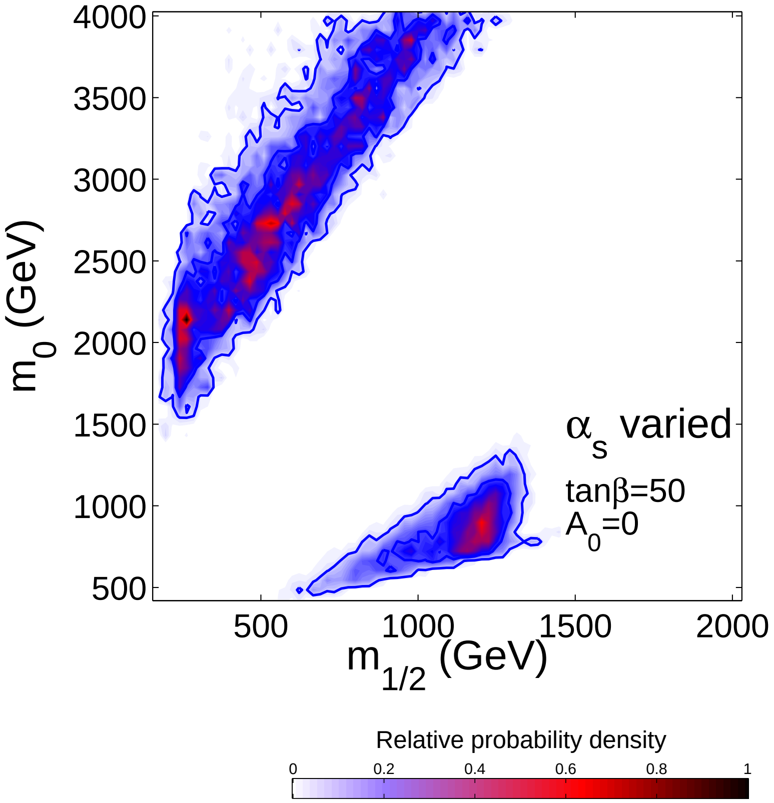

residual errors in SM parameters ⇒ strong impact on favoured SUSY ranges

effect of varying A_0, $\tan\beta$ also substantial

Bayesian Analysis of the CMSSM

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- $\theta = (m_0, m_{1/2}, A_0, \tan\beta)$: CMSSM parameters
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CMSSM parameters θ
$50\,\mathrm{GeV} < m_0 < 4\,\mathrm{TeV}$
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$\lvert A_0\rvert < 7\,\mathrm{TeV}$
$2 < \tan\beta < 62$

flat priors: SM (nuisance) parameters ψ
$160\,\mathrm{GeV} < M_t < 190\,\mathrm{GeV}$
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- vary all 8 (CMSSM+SM) parameters simultaneously, apply MCMC
- include all relevant theoretical and experimental errors

Experimental Measurements

(assume Gaussian distributions)

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SM (nuisance) parameter	Mean μ	Error σ (expt)
M_t	172.6 GeV	1.4 GeV
$m_b(m_b)^{\overline{MS}}$	4.20 GeV	0.07 GeV
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Derived observable	Mean	Errors	
	μ	σ (expt)	τ (th)
M_W	$\mathbf{80.398\,GeV}$	$\mathbf{25\,MeV}$	$\mathbf{15\,MeV}$
$\sin^2\theta_{\rm eff}$	$\mathbf{0.23153}$	$\mathbf{16 \times 10^{-5}}$	$\mathbf{15 \times 10^{-5}}$
$\delta a_\mu^{\rm SUSY} \times 10^{10}$	$\mathbf{29.5}$	$\mathbf{8.8}$	$\mathbf{1}$
$\mathrm{BR}(\bar{B} \to X_s\gamma) \times 10^4$	$\mathbf{3.55}$	$\mathbf{0.26}$	$\mathbf{0.21}$
ΔM_{B_s}	17.33	0.12	4.8
$\Omega_\chi h^2$	0.1099	0.0062	$0.1\,\Omega_\chi h^2$

take w/o error: $M_Z = 91.1876(21)\,\mathrm{GeV}$, $G_F = 1.16637(1) \times 10^{-5}\,\mathrm{GeV}^{-2}$

Experimental Limits

Derived observable	upper/lower limit	Constraints	
		ξ_{lim}	τ (theor.)
$\mathrm{BR}(\mathrm{B_s} \to \mu^+\mu^-)$	UL	1.5×10^{-7}	14%
m_h	LL	$114.4\,\mathrm{GeV}\ (91.0\,\mathrm{GeV})$	$3\,\mathrm{GeV}$
$\zeta_h^2 \equiv g_{ZZh}^2/g_{ZZH_{\mathrm{SM}}}^2$	UL	$f(m_h)$	3%
m_χ	LL	$50\,\mathrm{GeV}$	5%
$m_{\chi_1^\pm}$	LL	$103.5\,\mathrm{GeV}\ (92.4\,\mathrm{GeV})$	5%
$m_{\tilde{e}_R}$	LL	$100\,\mathrm{GeV}\ (73\,\mathrm{GeV})$	5%
$m_{\tilde{\mu}_R}$	LL	$95\,\mathrm{GeV}\ (73\,\mathrm{GeV})$	5%
$m_{\tilde{\tau}_1}$	LL	$87\,\mathrm{GeV}\ (73\,\mathrm{GeV})$	5%
$m_{\tilde{\nu}}$	LL	$94\,\mathrm{GeV}\ (43\,\mathrm{GeV})$	5%
$m_{\tilde{t}_1}$	LL	$95\,\mathrm{GeV}\ (65\,\mathrm{GeV})$	5%
$m_{\tilde{b}_1}$	LL	$95\,\mathrm{GeV}\ (59\,\mathrm{GeV})$	5%
$m_{\tilde{q}}$	LL	$318\,\mathrm{GeV}$	5%
$m_{\tilde{g}}$	LL	$233\,\mathrm{GeV}$	5%
$(\sigma_p^{\mathrm{SI}}$	UL	WIMP mass dependent	$\sim 100\%)$

Note: DM direct detection σ_p^{SI} not applied due to astroph’l uncertainties (eg, local DM density)

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- for several uncorrelated observables (assumed Gaussian):

$$\mathcal{L} = \exp\left[-\sum_i \frac{\chi_i^2}{2}\right]$$

Probability maps of the CMSSM

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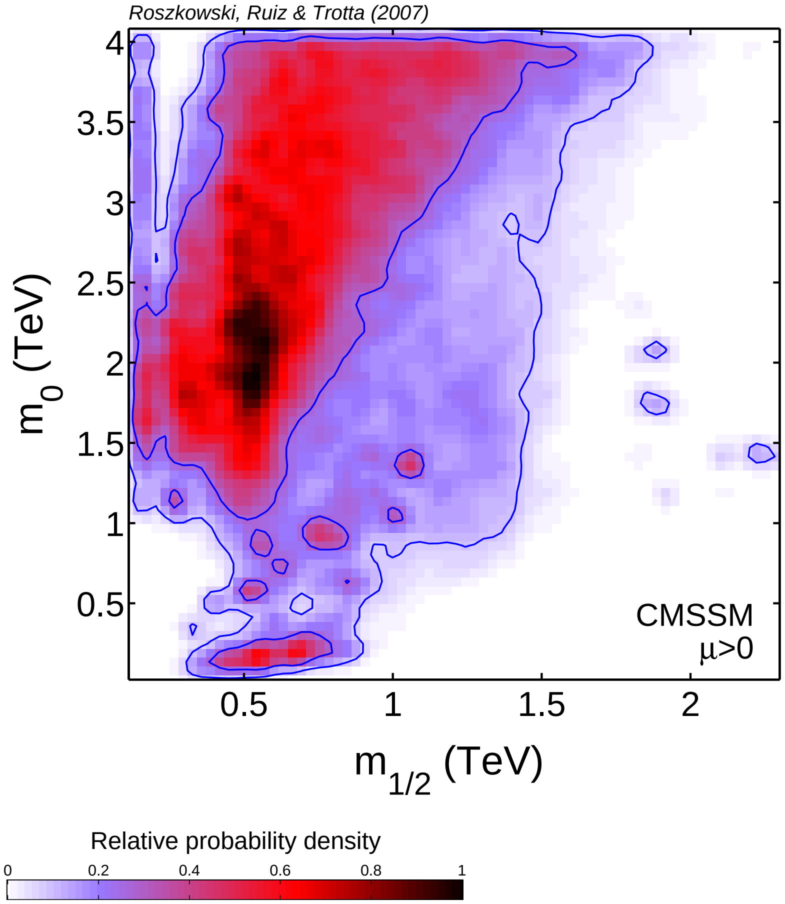
arXiv:0705.2012



- MCMC scan
- Bayesian analysis
- relative probability density fn
- flat priors
- 68% total prob. – inner contours
- 95% total prob. – outer contours

- 2-dim pdf $p(m_0, m_{1/2}|d)$
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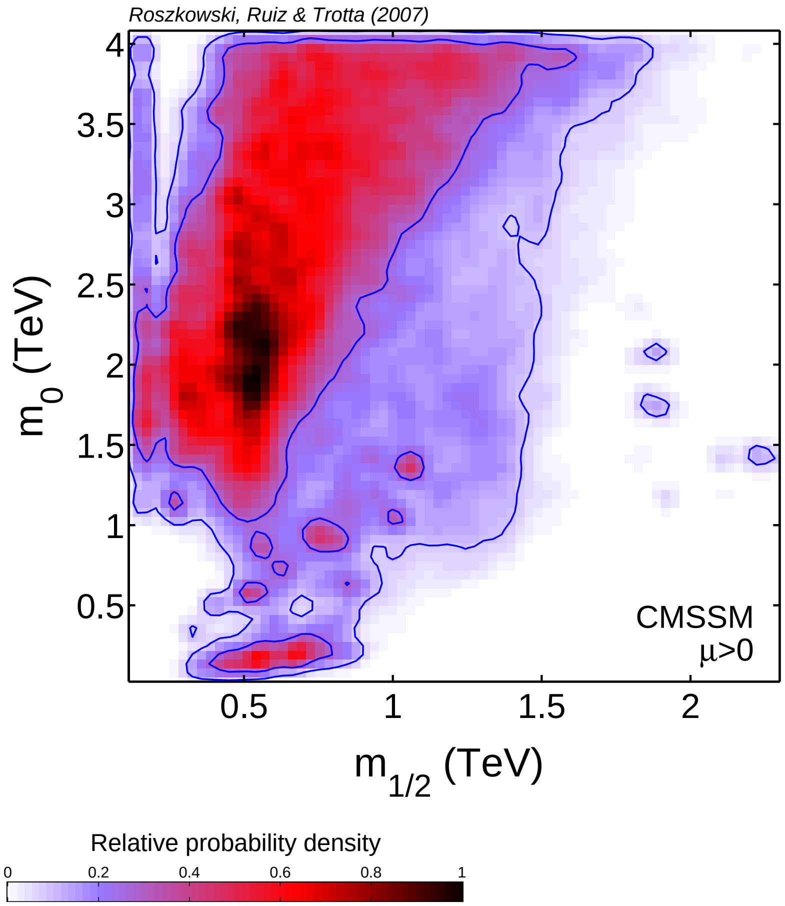

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similar study by Allanach+Lester(+Weber)

see also, Ellis et al (EHOW, χ^2 approach, no MCMC, they fix SM parameters!)

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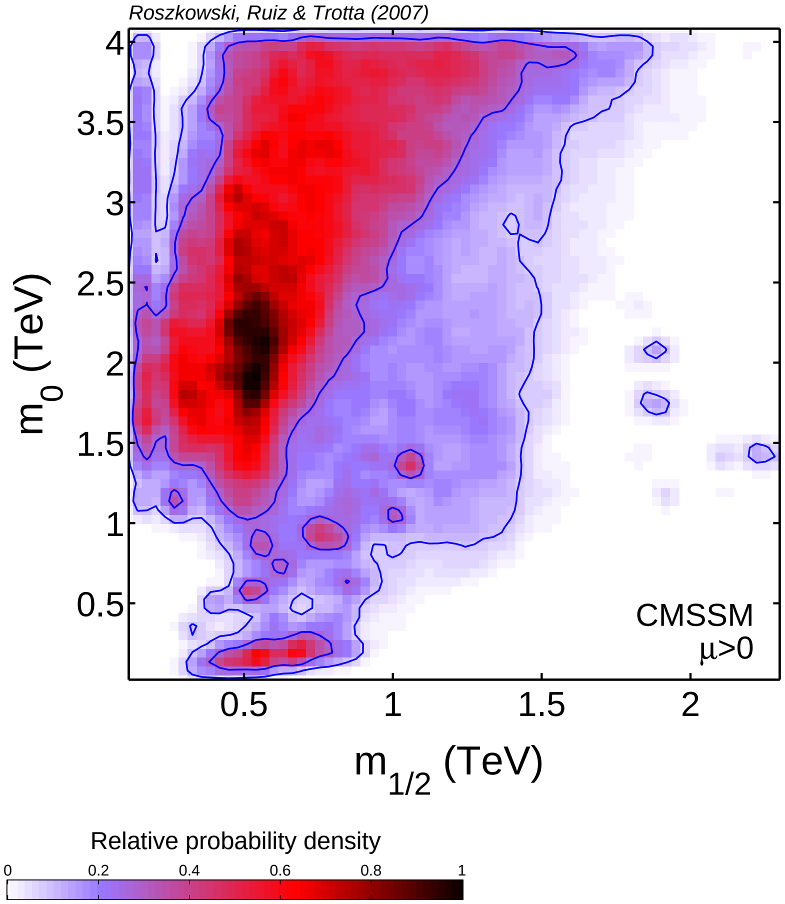

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unlike others (except for A+L), we vary also SM parameters

Light Higgs in the CMSSM

Bayesian analysis, relative probability density fn (pdf), flat priors, $\mu > 0$

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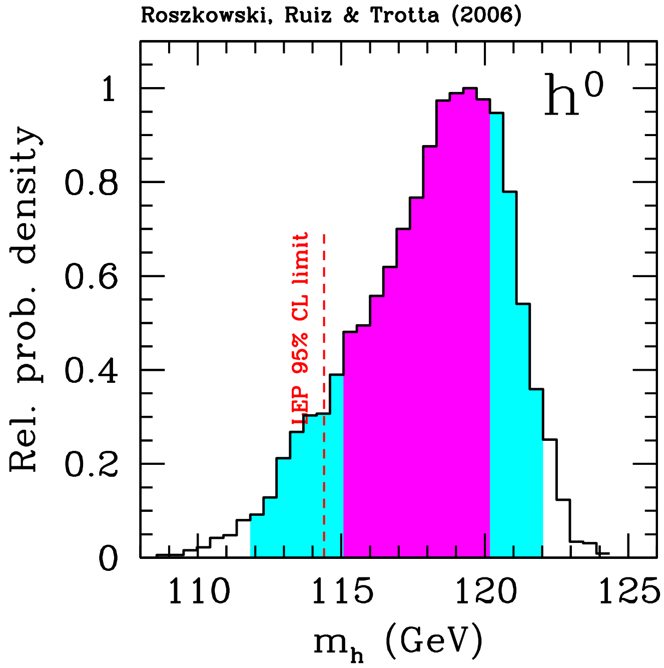
posterior pdf

relative pdf $p(m_h|d)$



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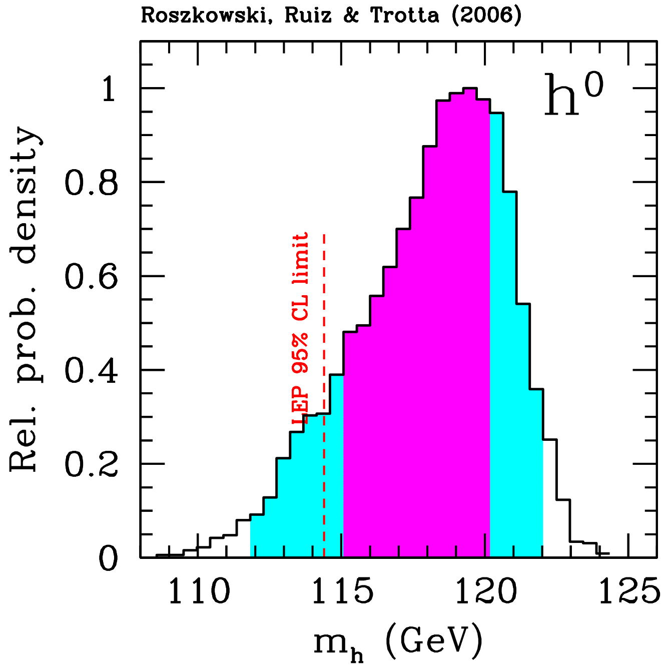

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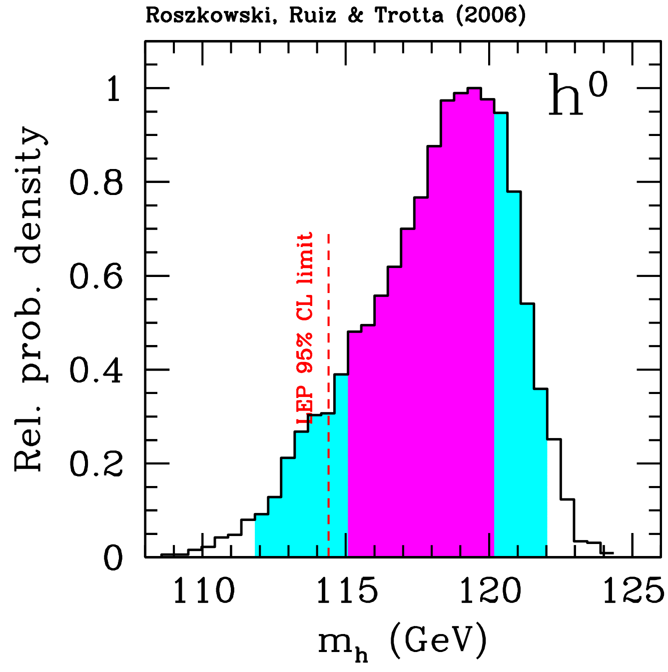

sharp drop-off on rhs from no solutions at large $m_{1/2}$ and/or cutoff at $m_0 < 4\,\mathrm{TeV}$

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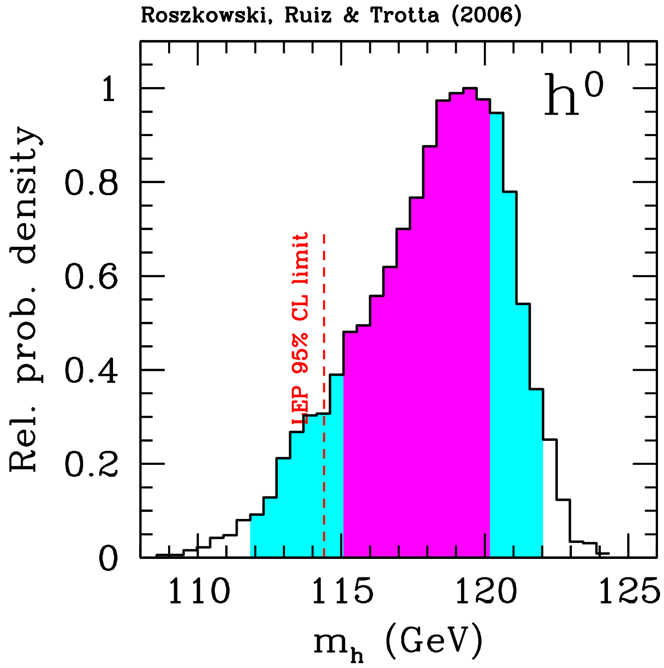

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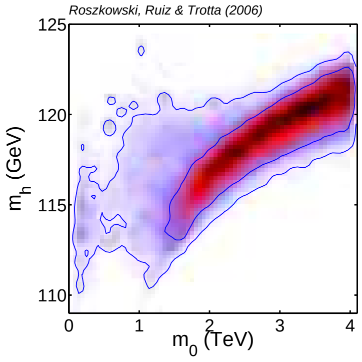
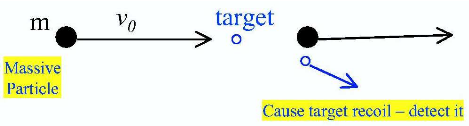


if $m_0 < 8\,\mathrm{TeV}$ then $m_h \lesssim 125.6\,\mathrm{GeV}$ (95% CL)

SUSY: Prospects for direct detection

global Bayesian analysis, MCMC scan of 8 params (4 SUSY+4 SM)



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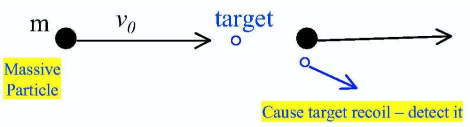
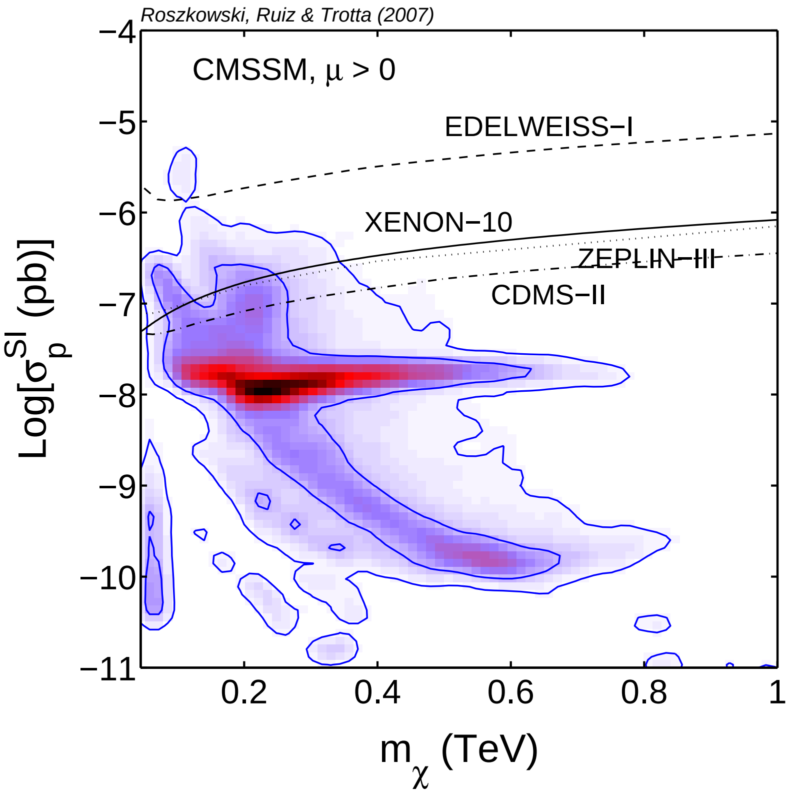


Constrained MSSM (mSUGRA)



internal (external): $\mathbf{68\%}$ ($\mathbf{95\%}$) region

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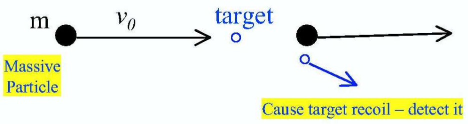

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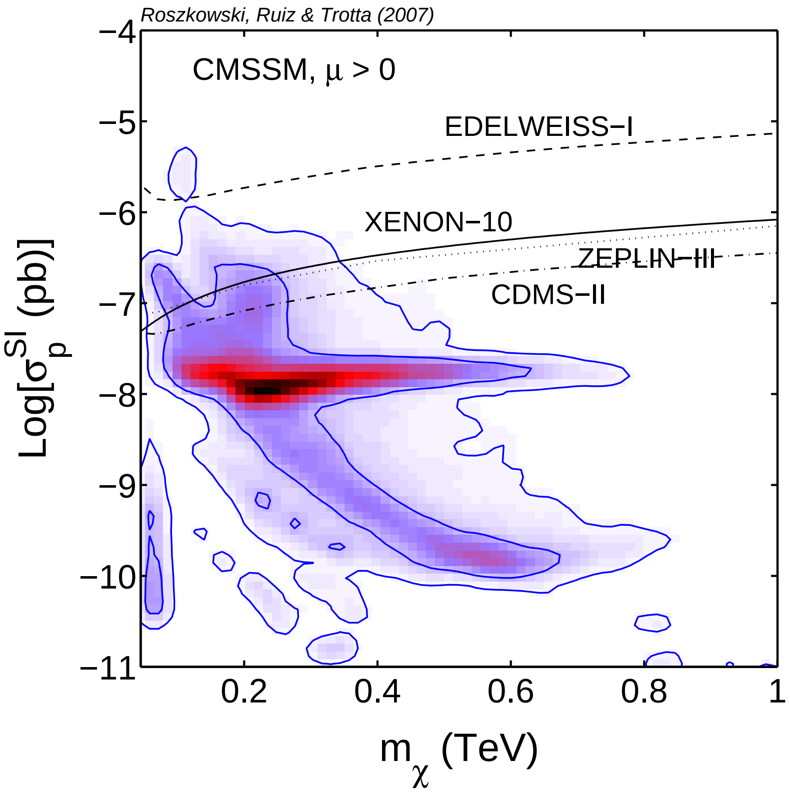

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$\sigma_p^{\mathrm{SI}} \lesssim 10^{-7}$ pb:

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$\Rightarrow$ already explore 68% region

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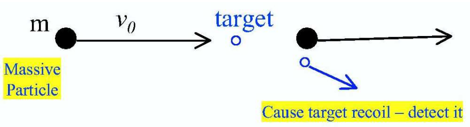

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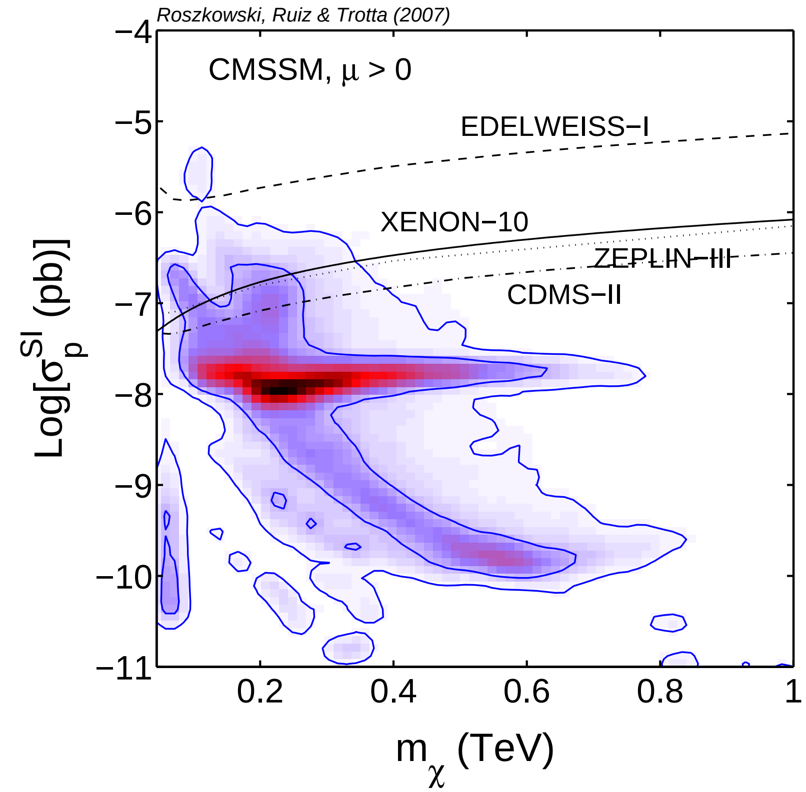

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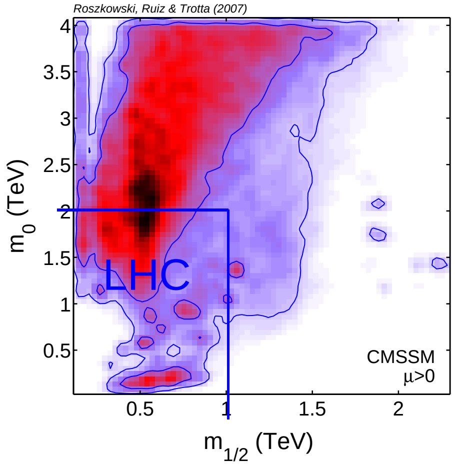

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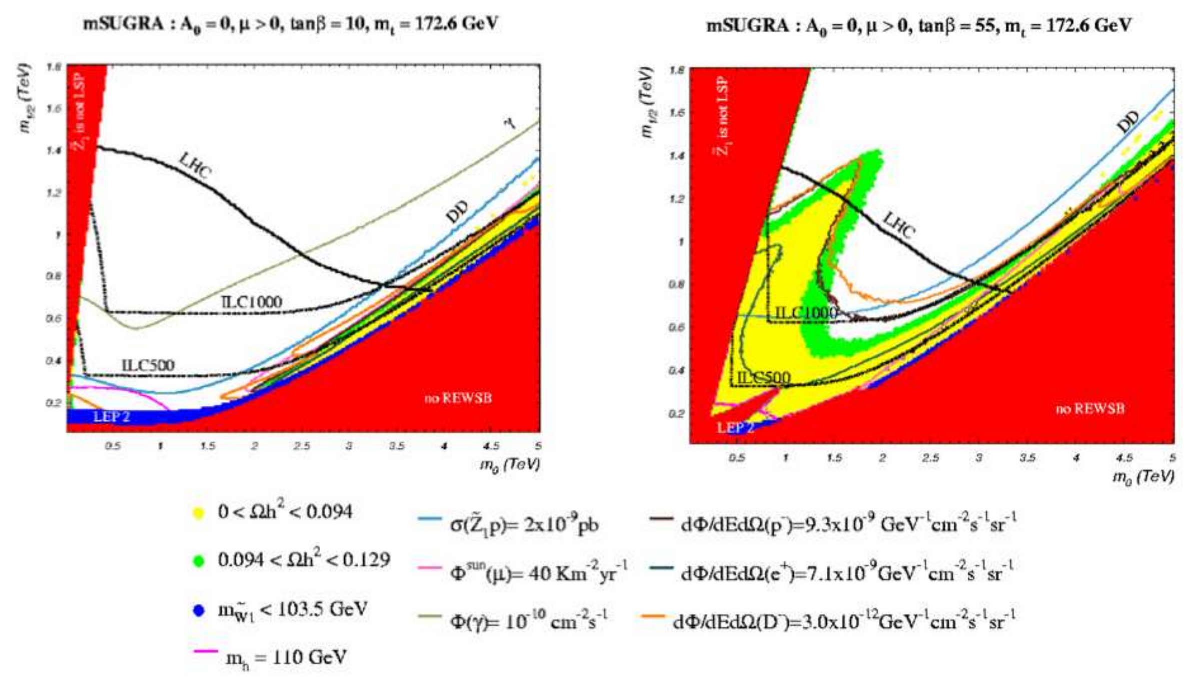

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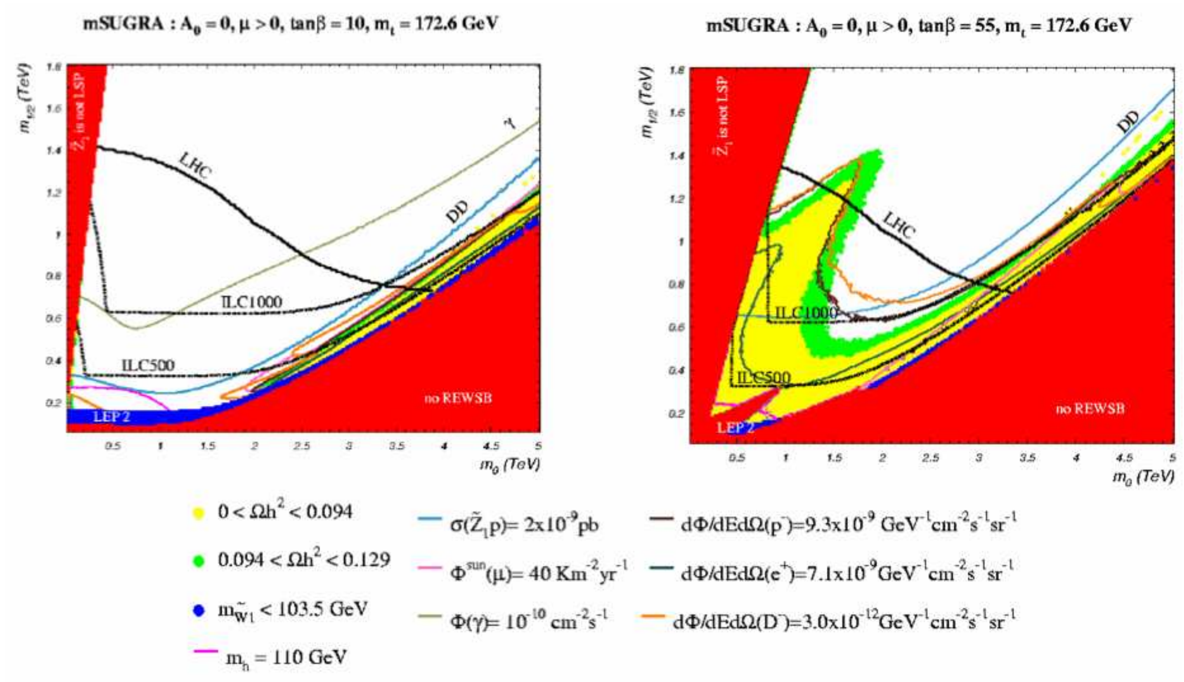

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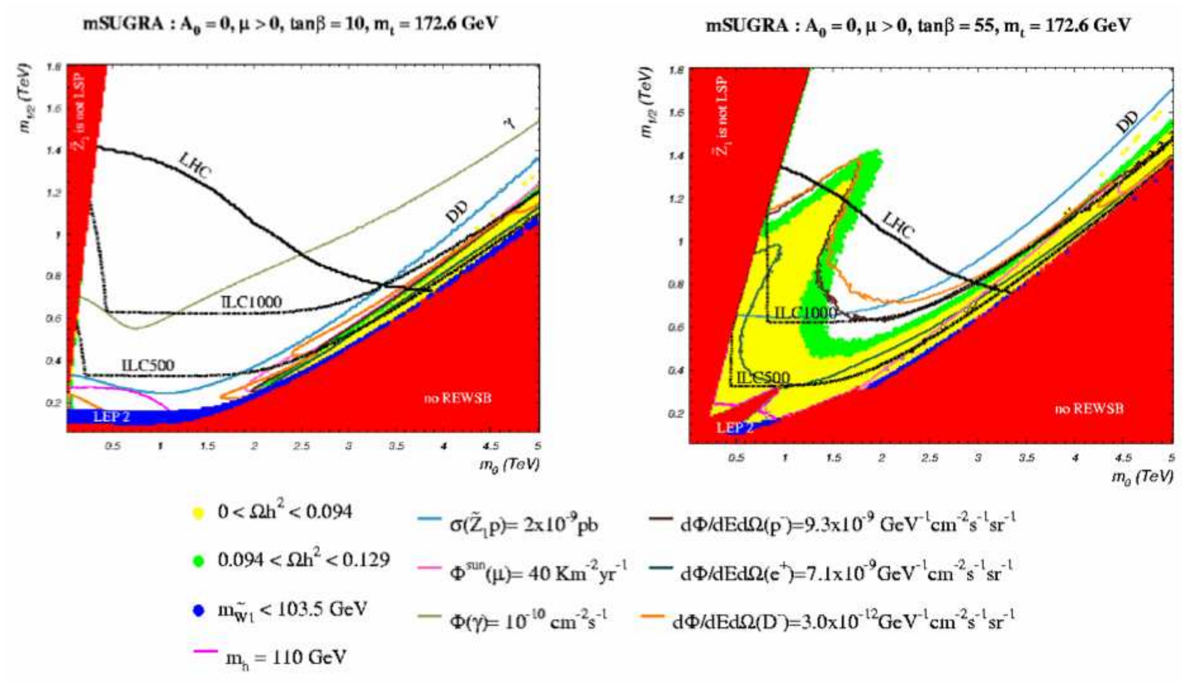

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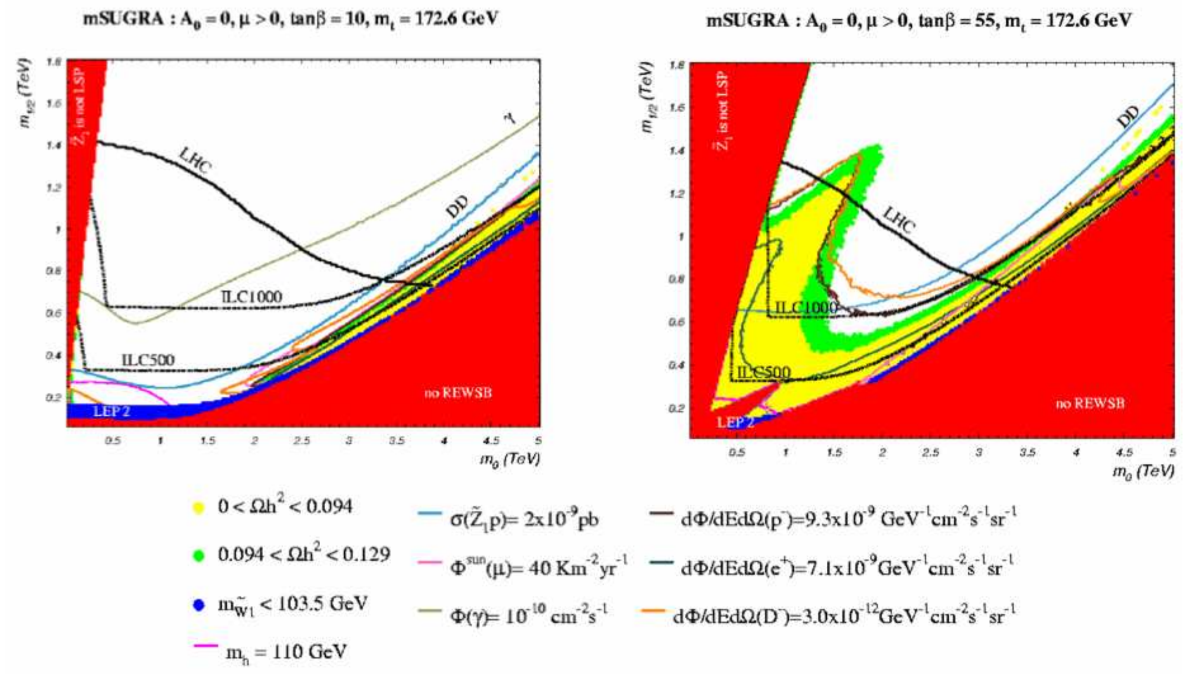

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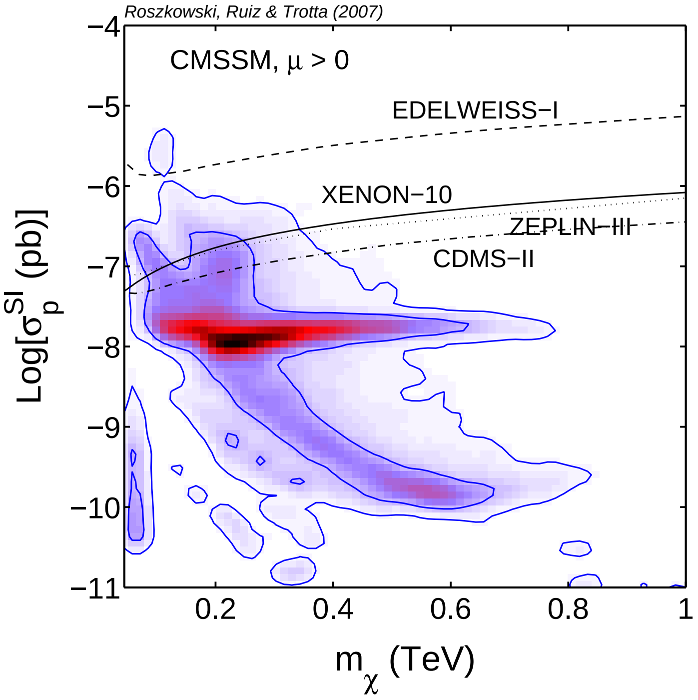

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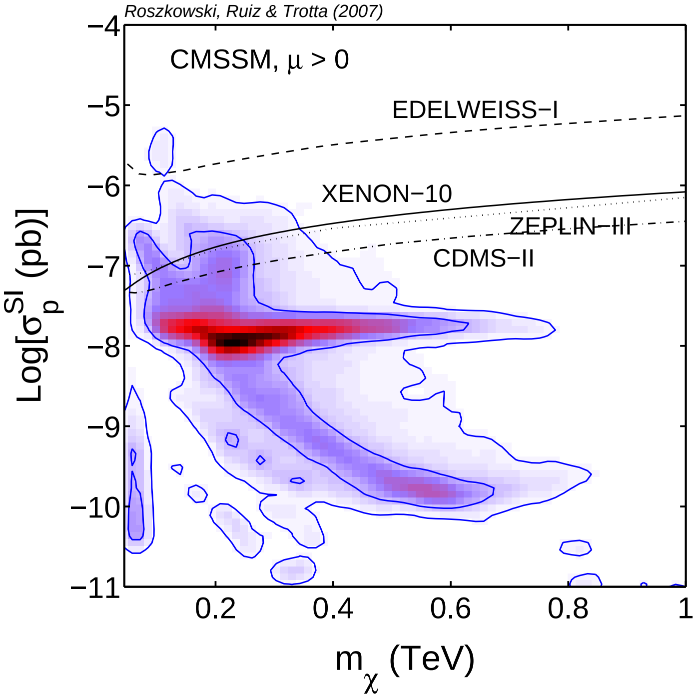

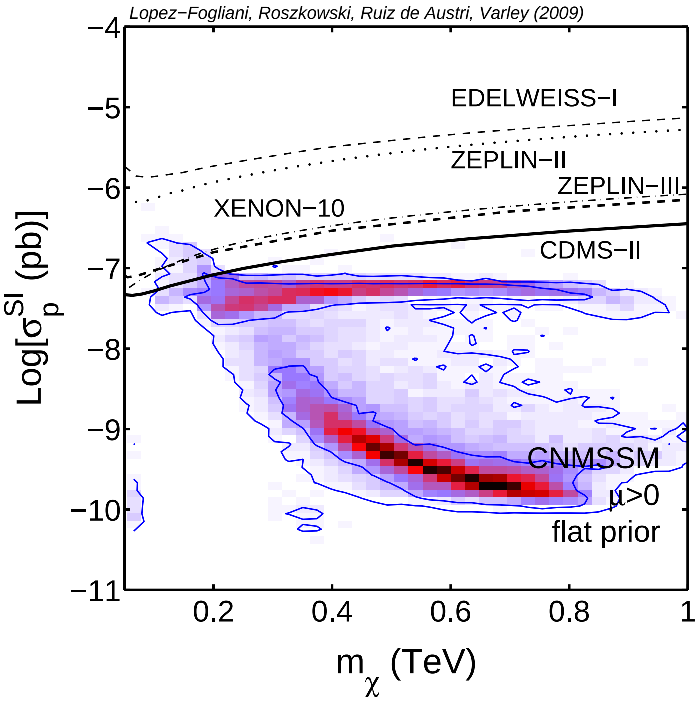

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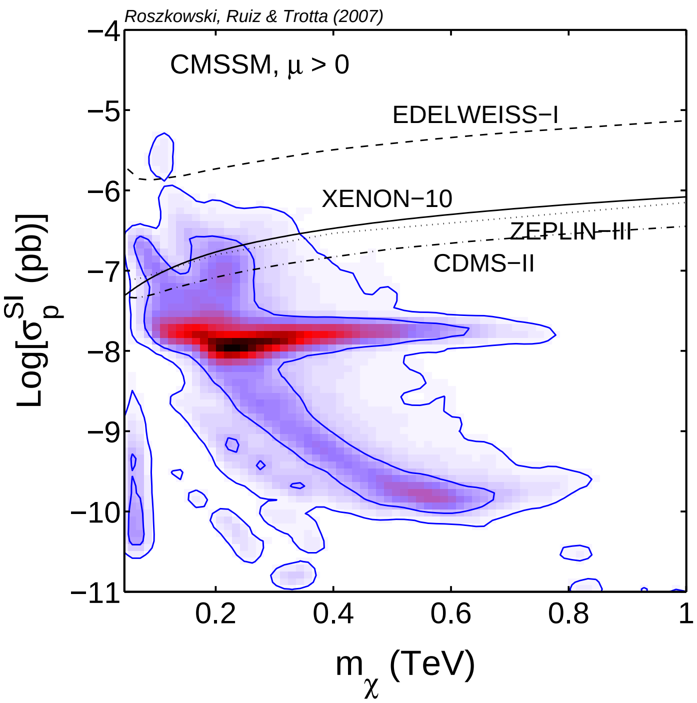

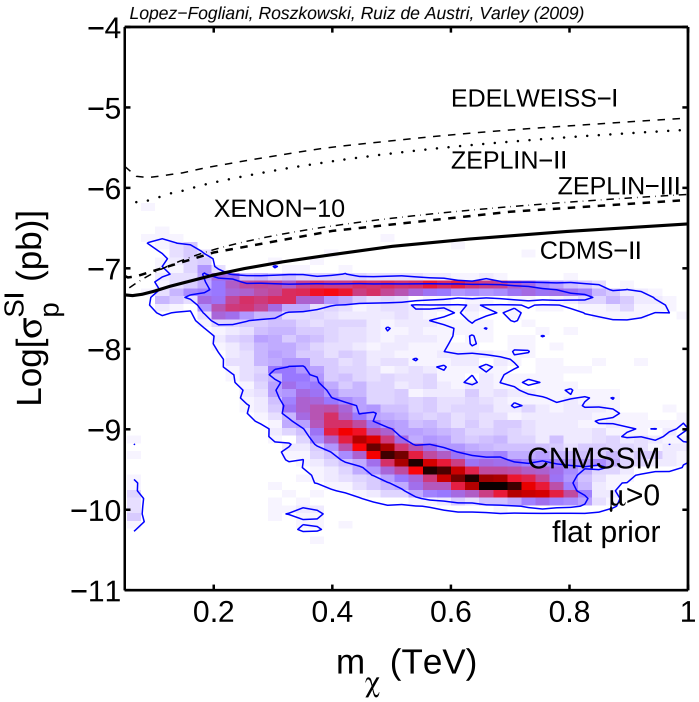

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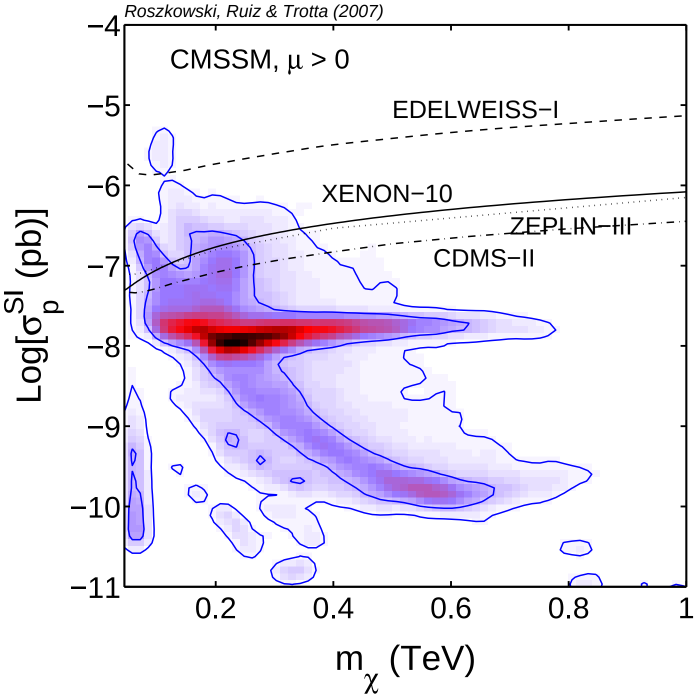

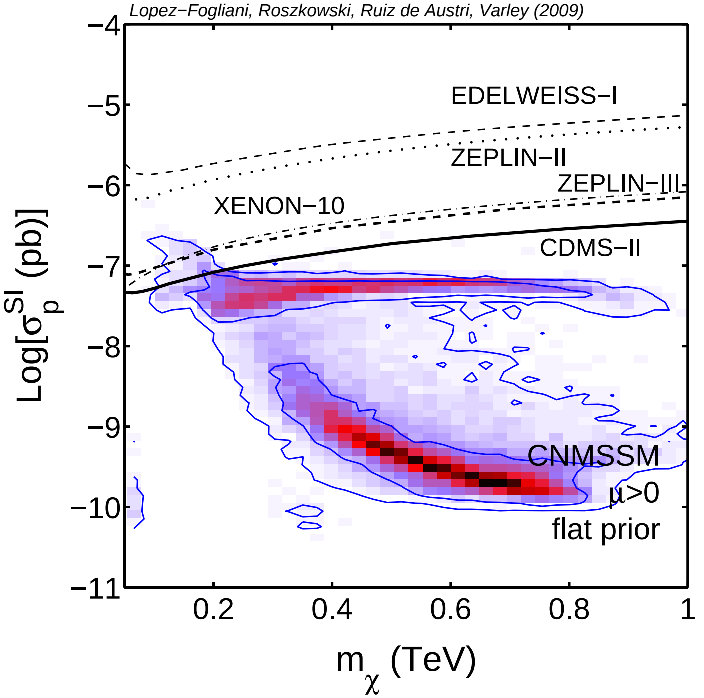

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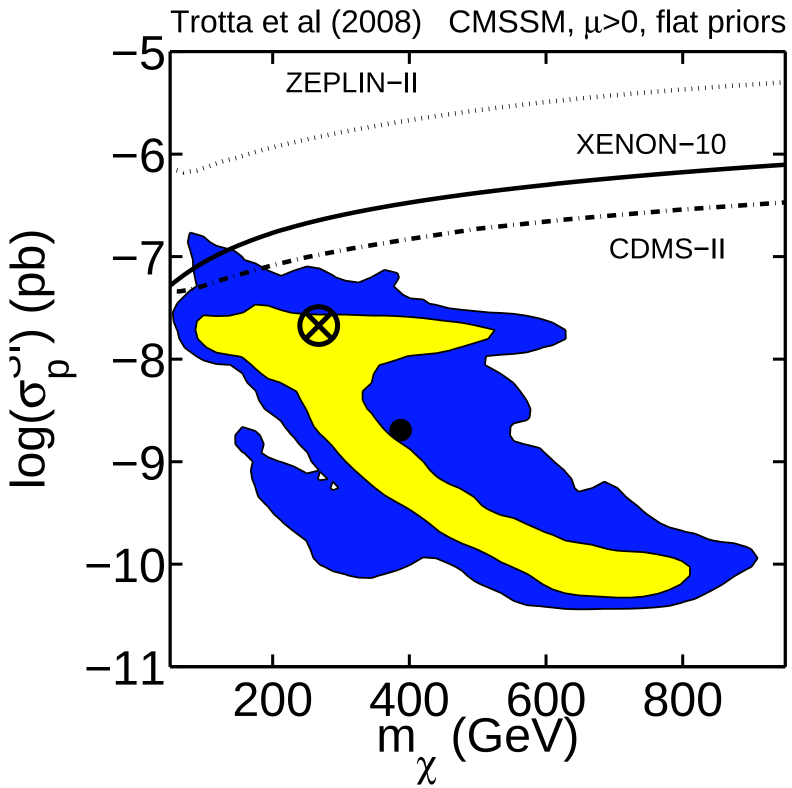
flat in $m_0, m_{1/2}$



Impact of priors

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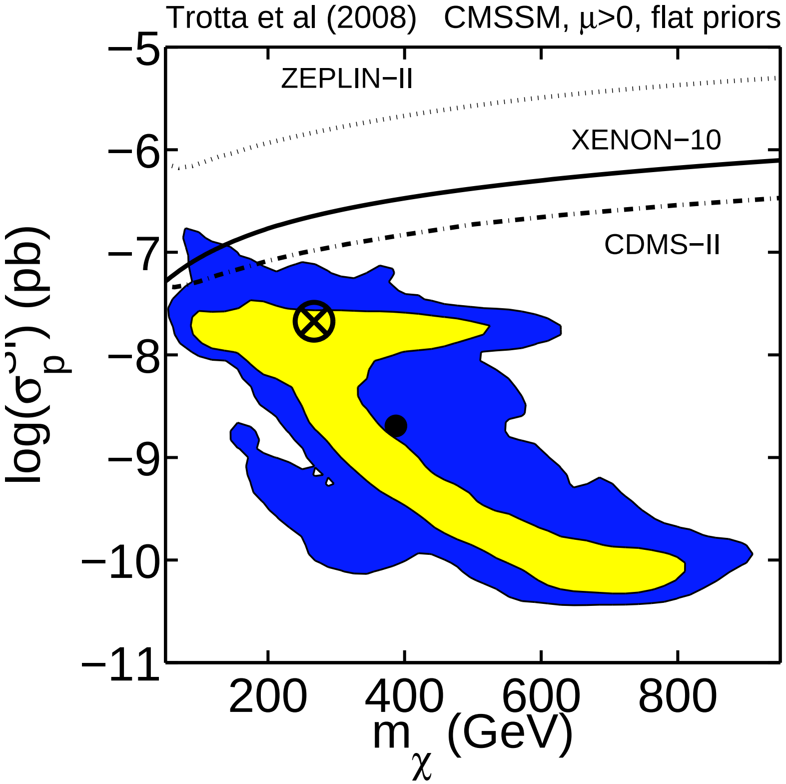
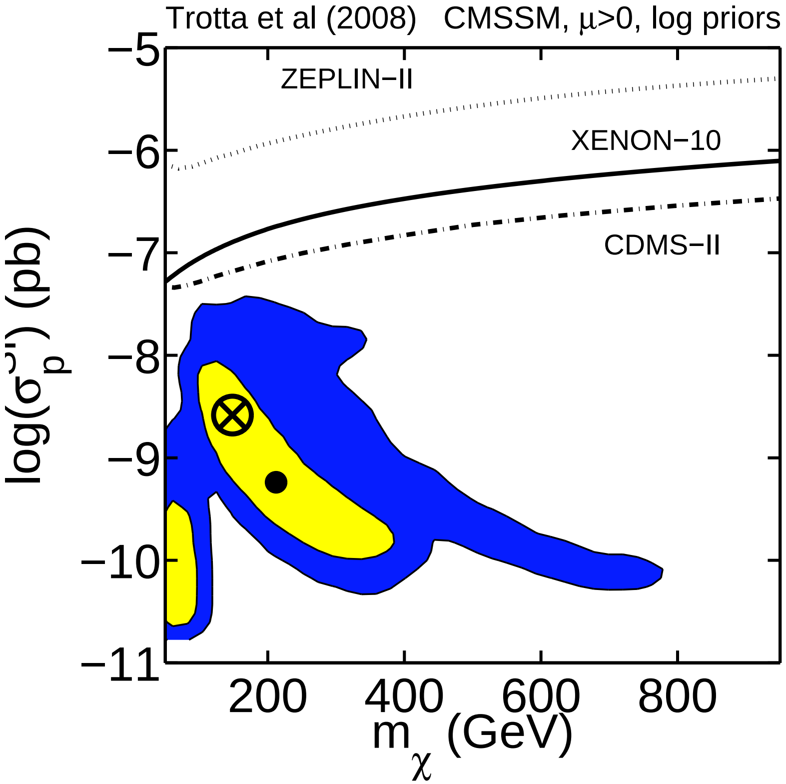
flat in $\log(m_0)$, $\log(m_{1/2})$





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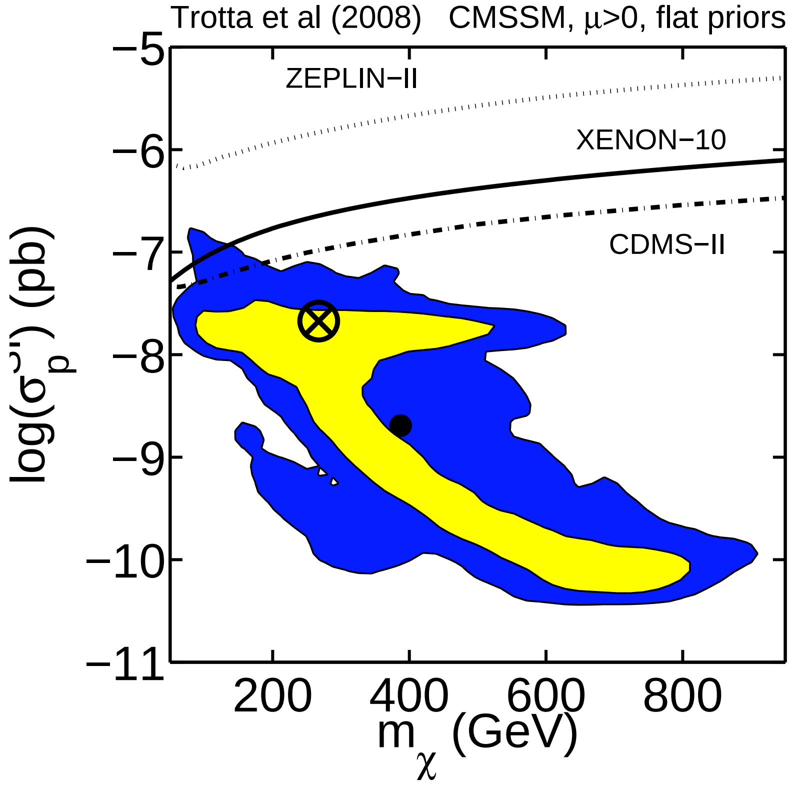

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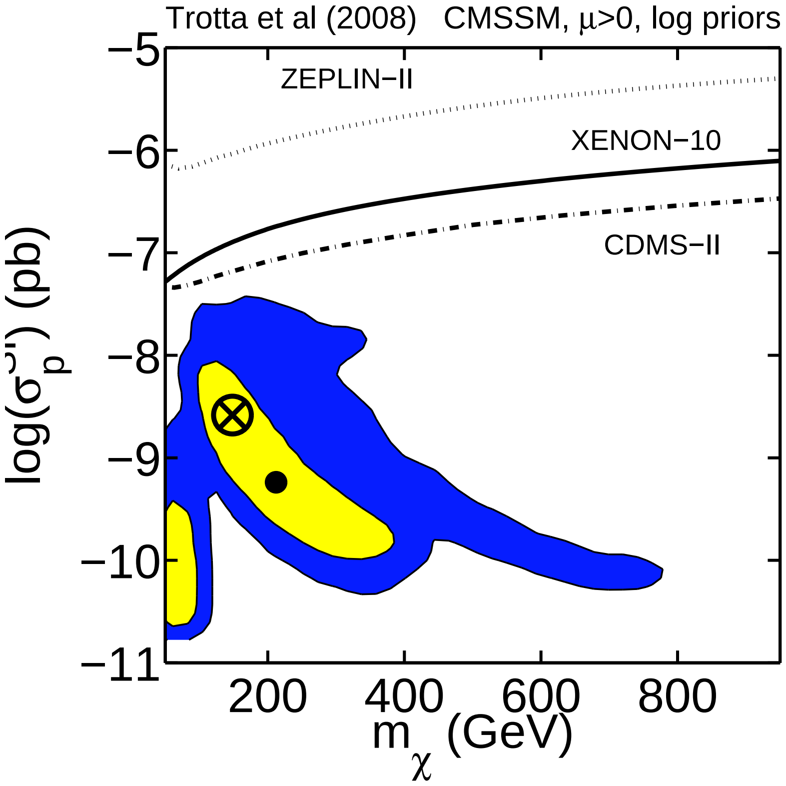

- still strong prior dependence (data not yet constraining enough)
- both priors: most regions above some 10^{-10} pb ⇒ good news for DM expt
- LHC reach: $m_\chi \lesssim 400-500\,\mathrm{GeV}$ ⇒ additional vital info

Bayesian vs frequentist

CMSSM:

Bayesian vs frequentist

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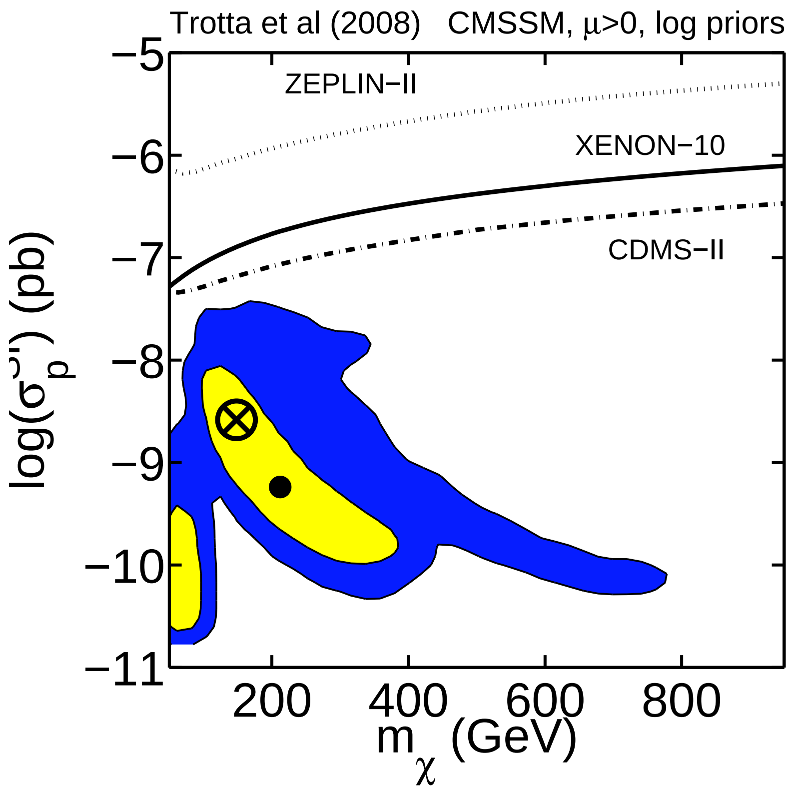
log prior



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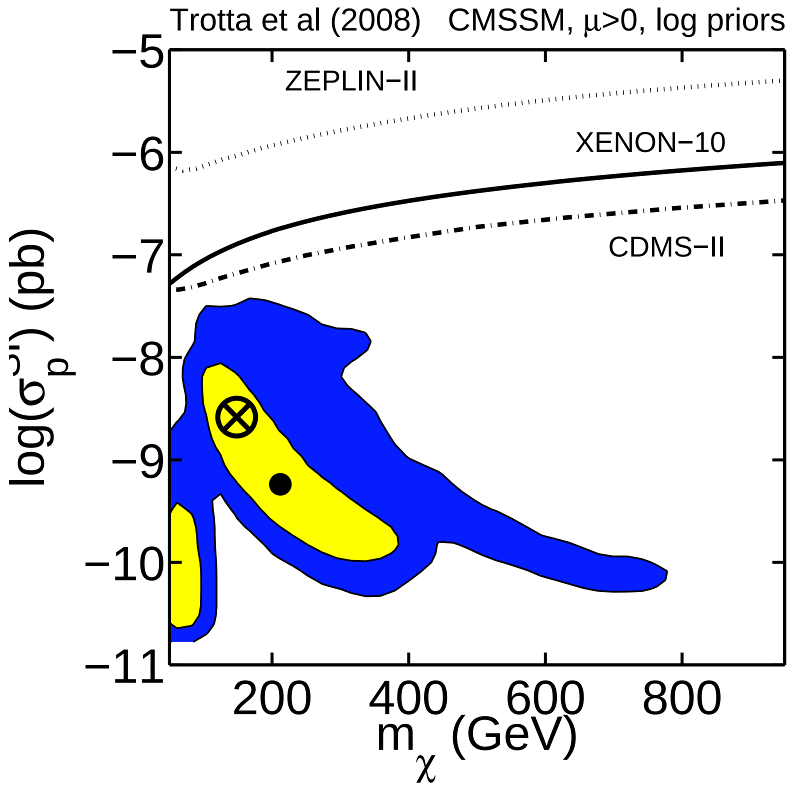
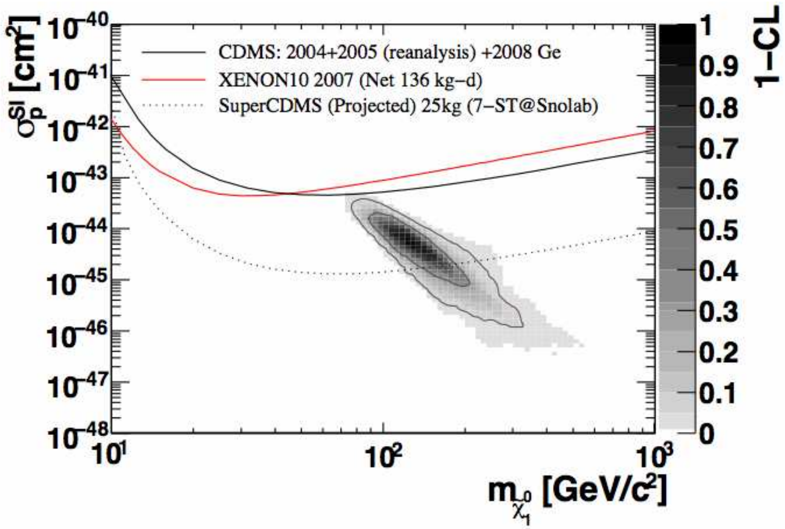


Buchmueller, et al (09)



$(10^{-44}\mathrm{cm}^2 = 10^{-8}$ pb)

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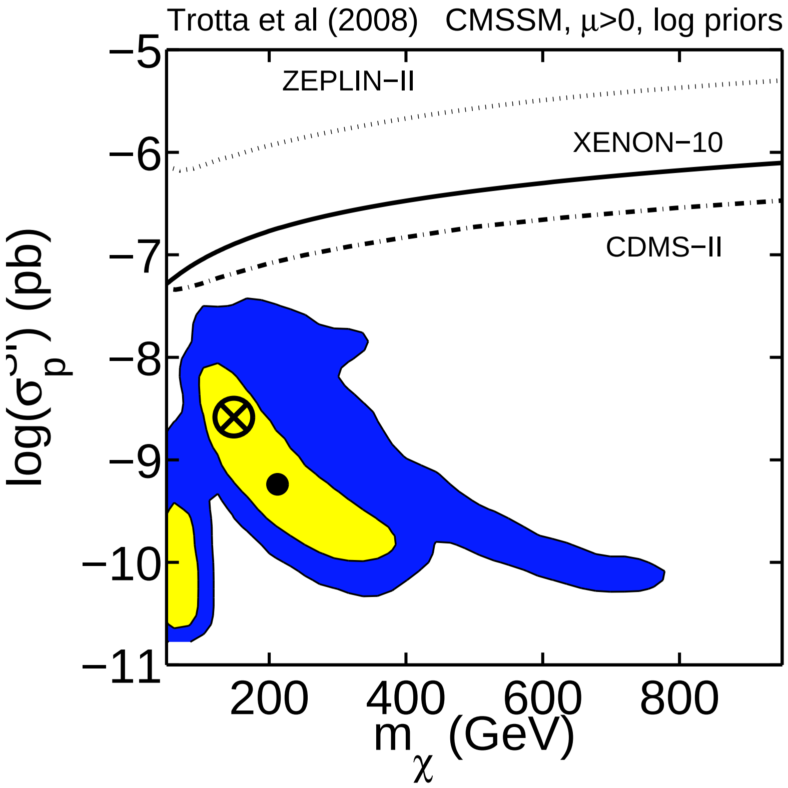

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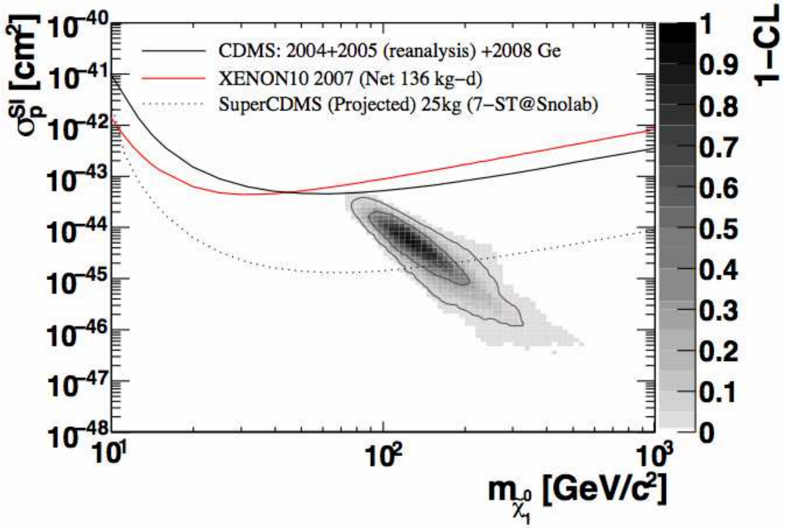
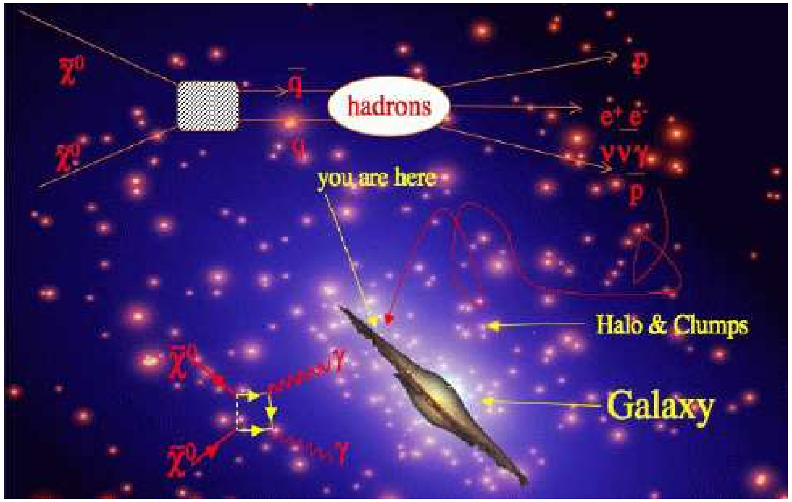


$(\mathbf{10^{-44}cm^2 = 10^{-8}}$ pb)

- reasonable agreement

Indirect detection

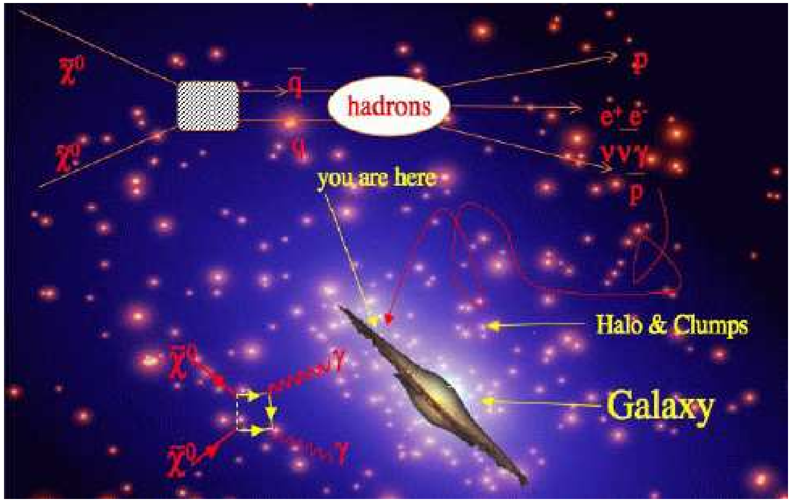
Indirect detection



- look for traces of WIMP annihilation in the MW halo (γ's, e^+'s, $\bar{p}$, ...)
- detection prospects often strongly depend on astrophysical uncertainties (halo models, astro bgnd, ...)

Much activity in connection with:

Indirect detection



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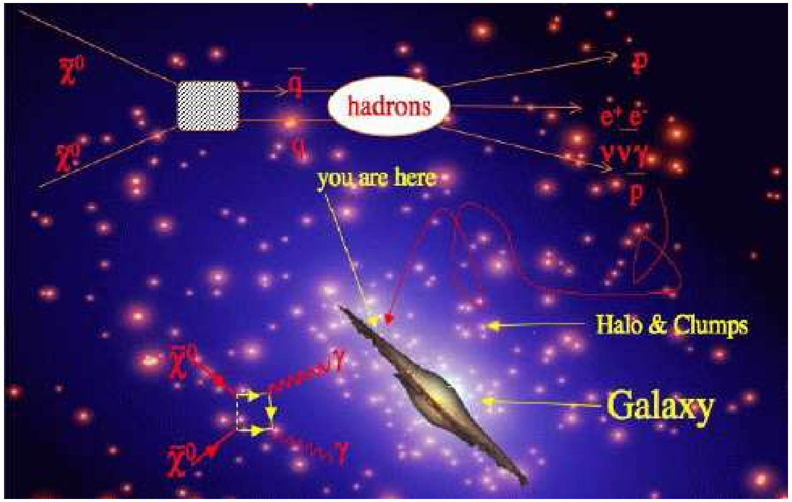

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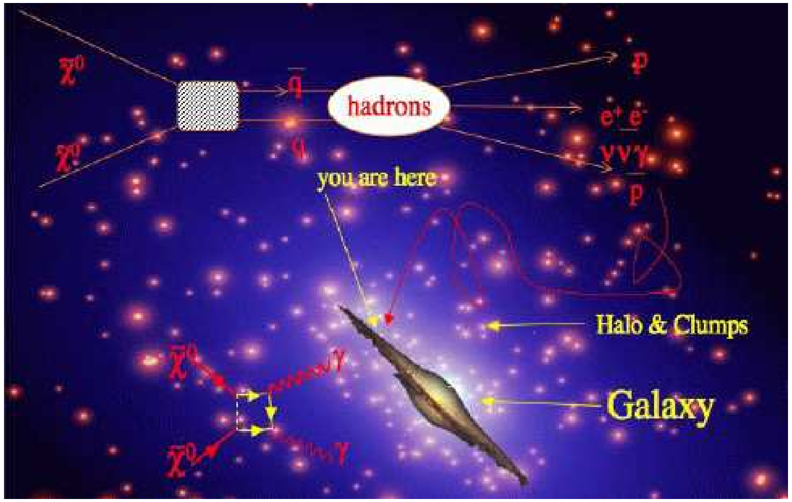

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- H.E.S.S, ATCs, ...

Fermi

in orbit since 2008

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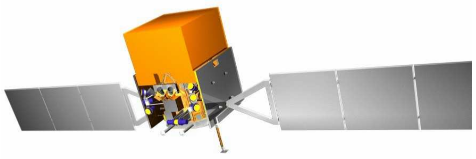

in orbit since 2008

- full sky map in γ-ray spectrum, $\sim \mathbf{20\,MeV}$ to $\sim \mathbf{300\,GeV}$
- superior energy and angular resolution
- improve accuracy/energy range of EGRET by an order of magnitute
- preliminary mid-latitude LAT data on diffuse γ-radiation presented in Spring 09
- 1st year LAT data released in August 09, more to come

Gamma Rays From DM Annihilation

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- WIMP pair-annihilation $\longrightarrow \boldsymbol{WW}, \boldsymbol{ZZ}, \boldsymbol{\bar{q}q}, \ldots \longrightarrow$ diffuse γ radiation (+ $\gamma\gamma$, γZ lines)

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l.o.s - line of sight

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$\Delta\Omega$ - finite point spread function (resolution) of GR detector,
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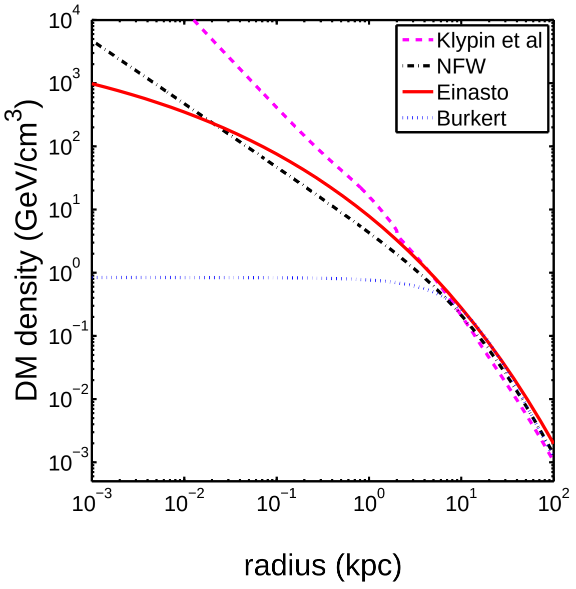

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some representative halo profiles

Diffuse GRs from the GC

use Fermi/GLAST parameters

Bayesian posterior probability maps

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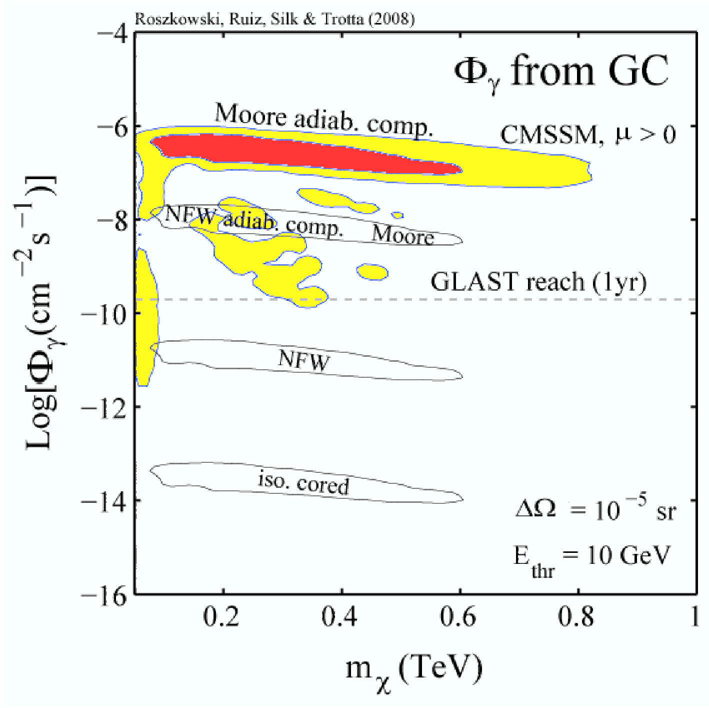
CMSSM, flat priors



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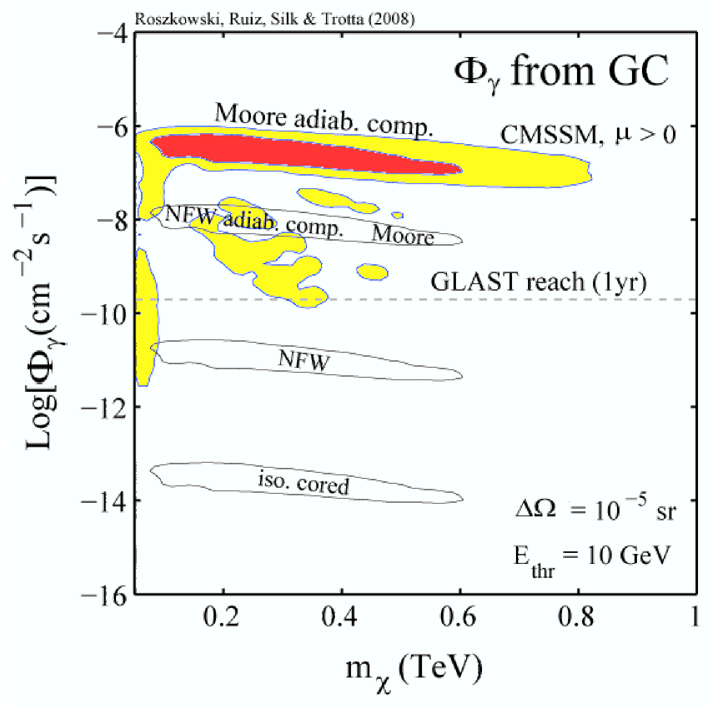

Roszkowski, Ruiz, Silk & Trotta (2008)

Bayesian posterior probability maps

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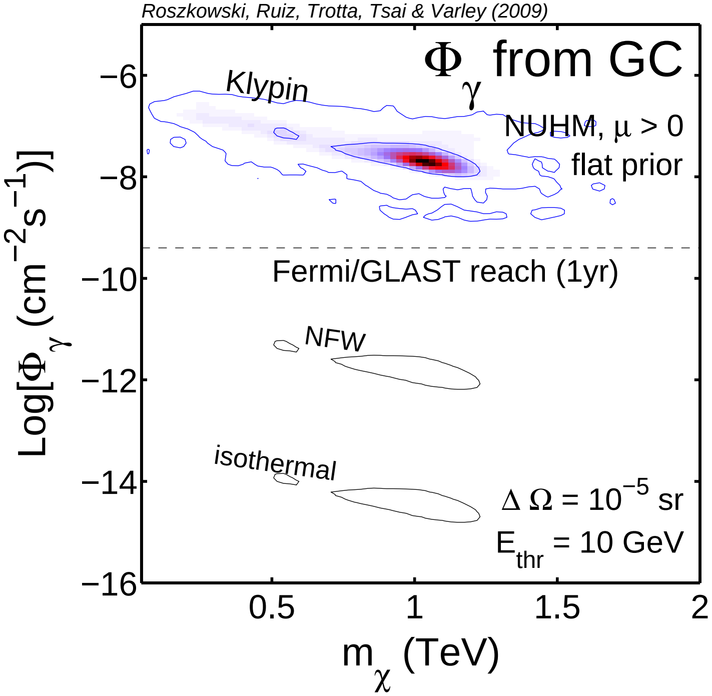

Roszkowski, Ruiz, Trotta, Tsai & Varley (2009)

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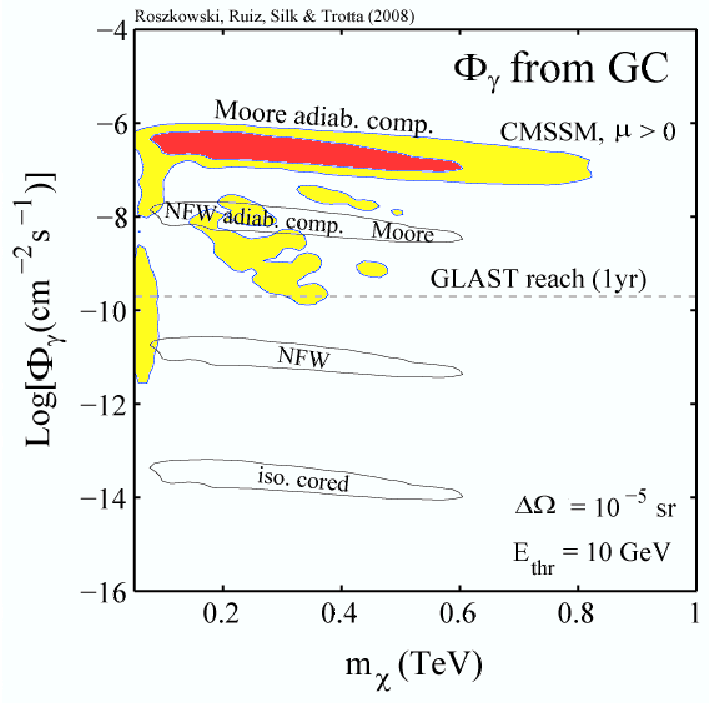

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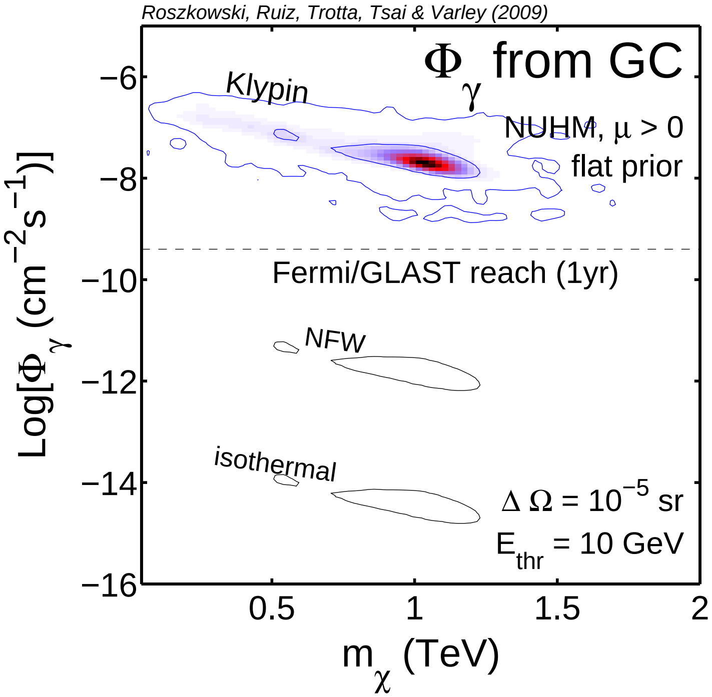

⇒ WIMP signal at Fermi/GLAST: outcome depends on halo cuspiness at GC

a conclusion of several different studies

Tests of DM in the Galactic Center

ratio of fluxes is independent of particle physics input

$$R^{\mathrm{GC}}_{d\Phi_\gamma/dE_\gamma} = \frac{\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\psi)}{\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\psi=0)} = \frac{\langle J(\psi)\rangle_{\Delta\Omega}}{\langle J(\psi=0)\rangle_{\Delta\Omega}} = \frac{\int_{\mathrm{l.o.s.}} dl'\,\rho_\chi^2(r(l',\psi))}{\int_{\mathrm{l.o.s.}} dl'\,\rho_\chi^2(r(l',\psi=0))}$$

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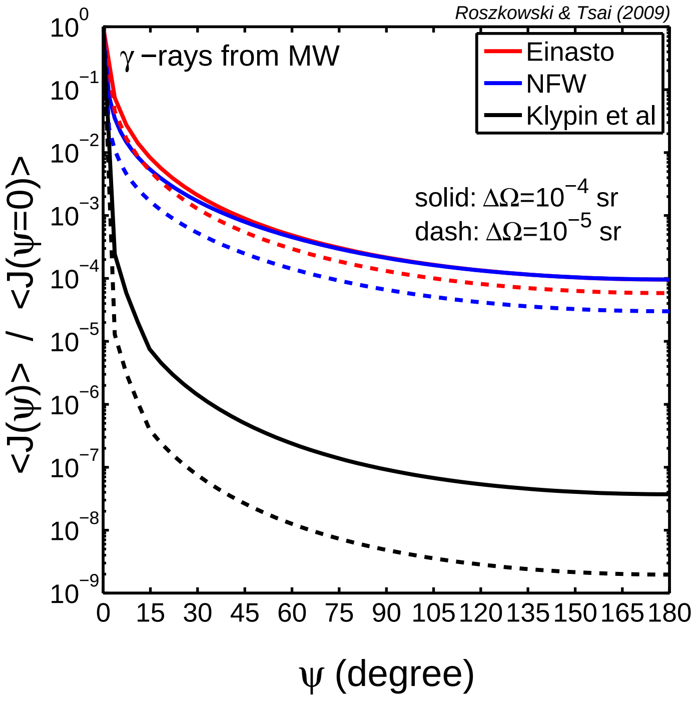
arXiv:0909.1529



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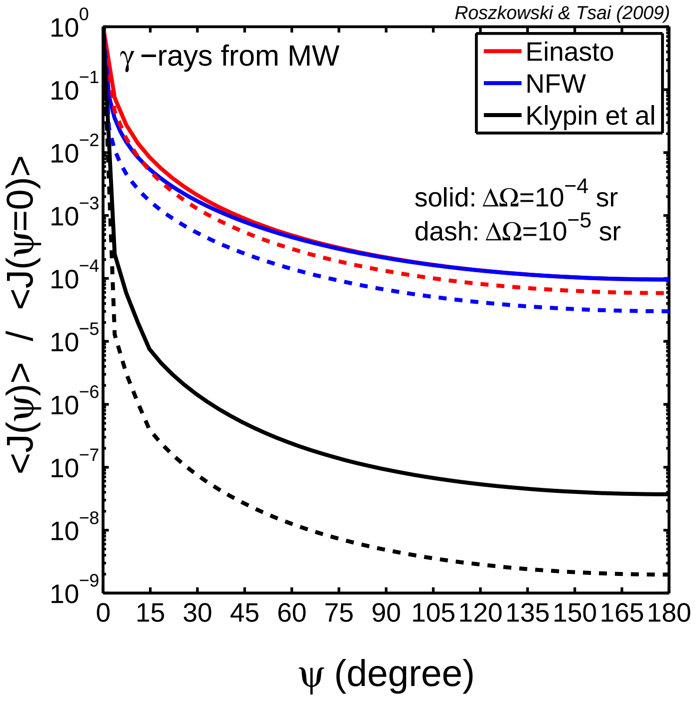

Signal of DM if:

- data follows one of the curves
- measured ratio *remains the same* in the Galactic plane *and* the plane normal to the Galactic plane
- astro sources (bgnd): bigger contribution from the MW disk

DM can possibly dominate within $2-3^\circ$ of the GC

- data $\Rightarrow$ can get handle on DM halo density slope in the GC

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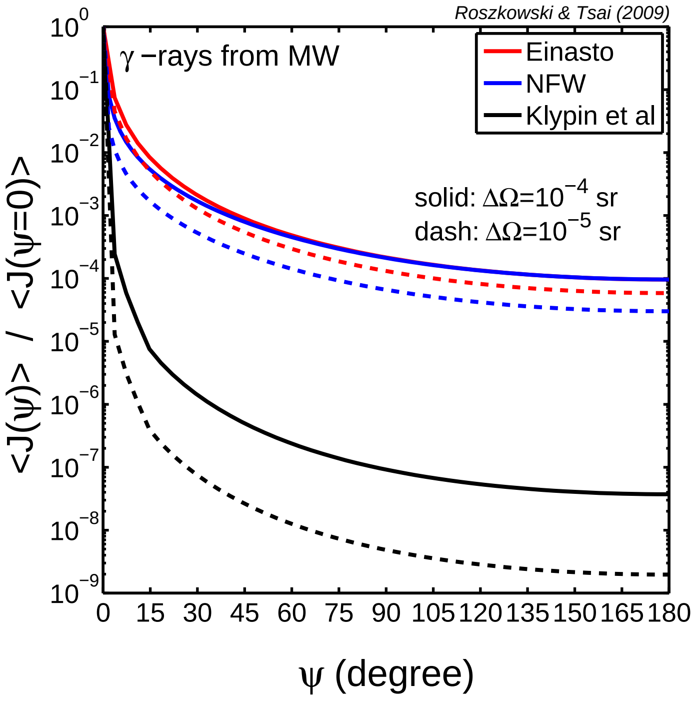

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$\Rightarrow$ $\boxed{\text{would provide an unambiguous signal of DM origin}}$

reason: only DM distribution around GC is (likely to be) spherical and $\propto \rho_\chi^2$

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enhance signal by integrating over energy and solid angle

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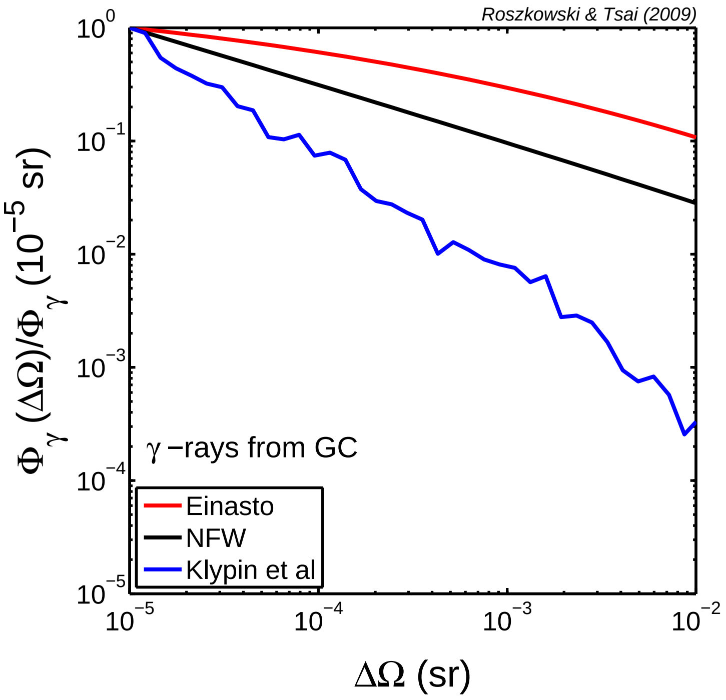

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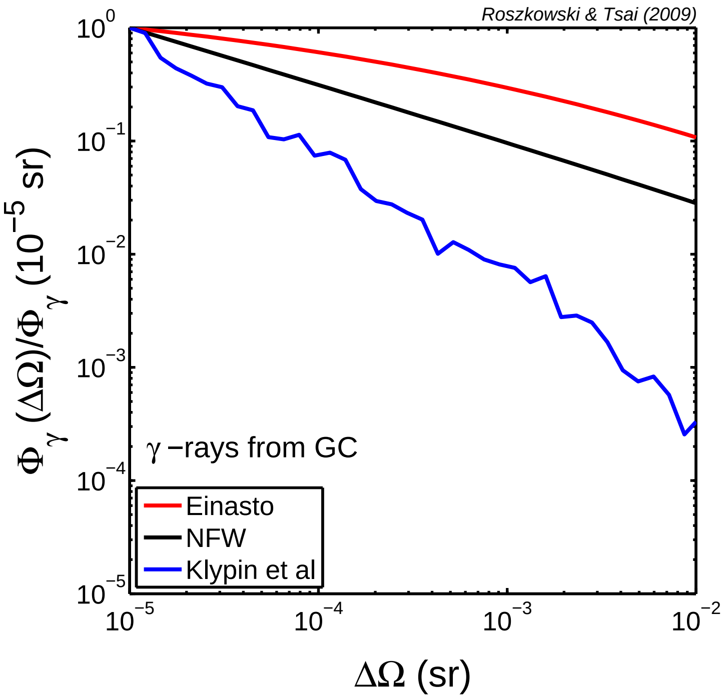

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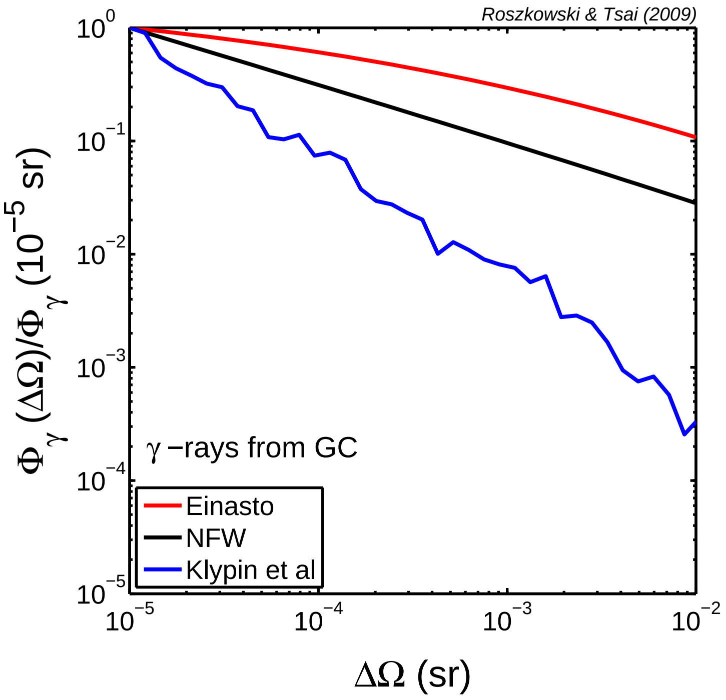

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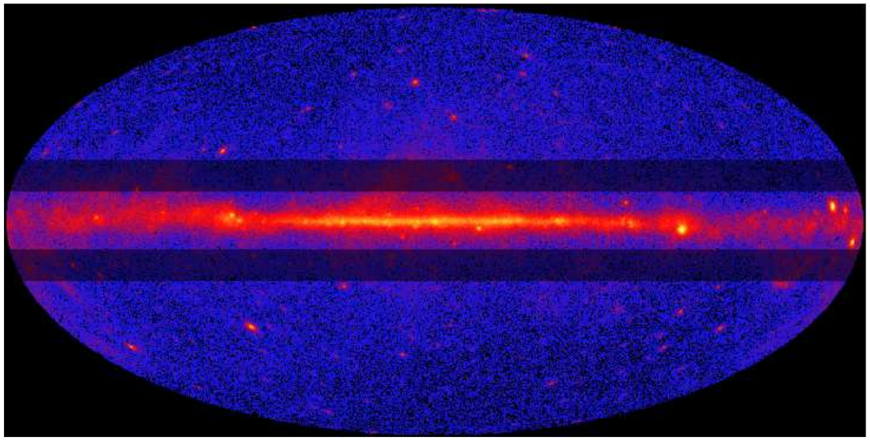
Fermi LAT mid-latitude data

diffuse γ-rays from $10^\circ \le |b| \le 20^\circ$ and $0 \le l < 360^\circ$, $0.1\,\mathrm{GeV} \le E_\gamma \le 10\,\mathrm{GeV}$

Porter, ICRC, 0907.0294



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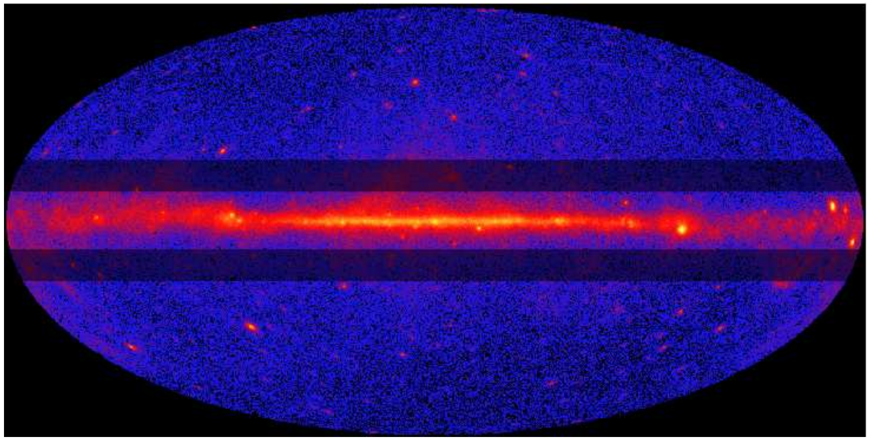

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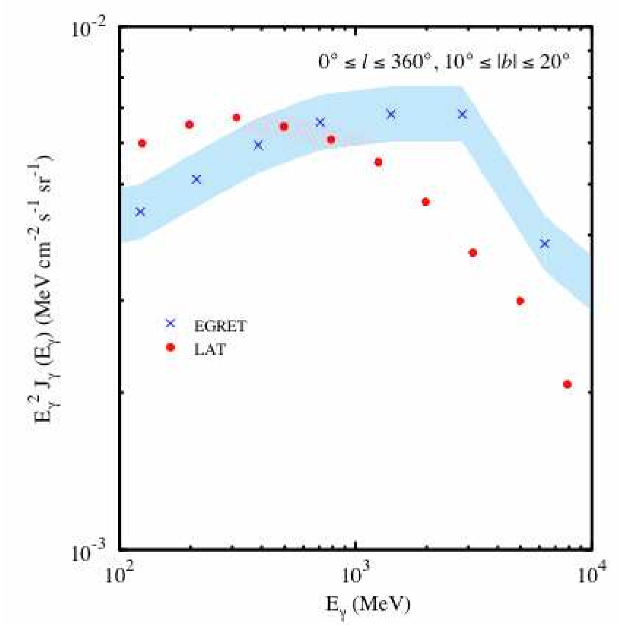

- LAT data: spectrum softer than claimed by EGRET

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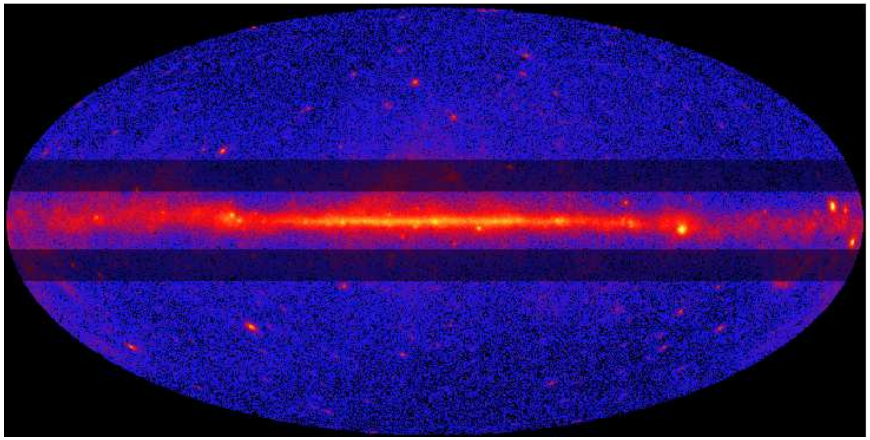

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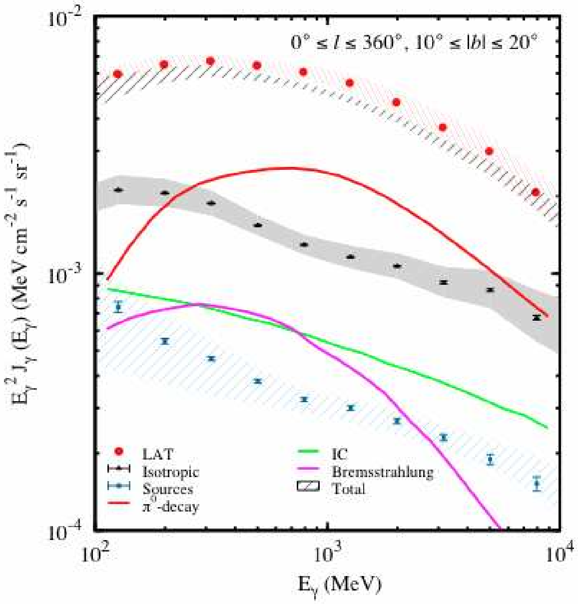

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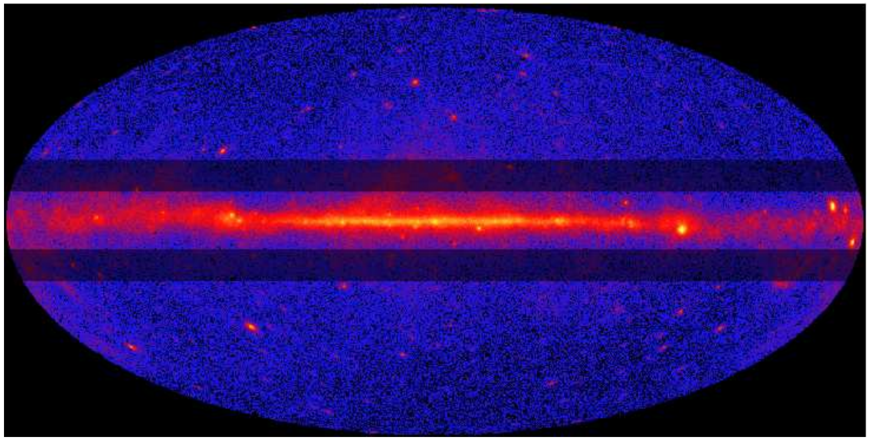

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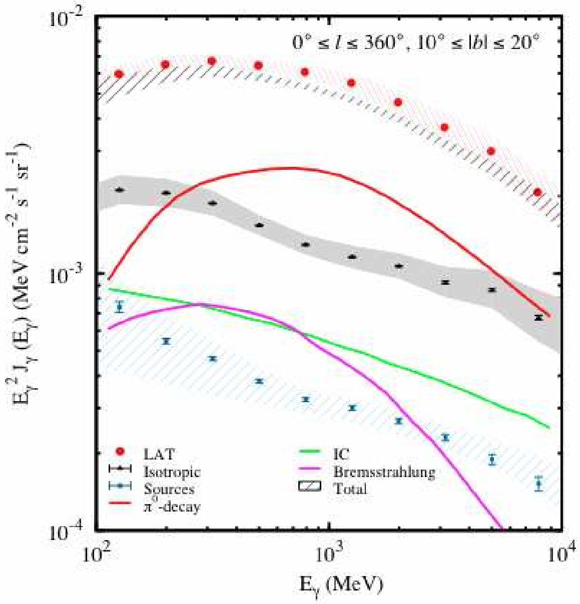

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Upper bound on DM halo slope

Fermi LAT mid-latitude diffuse γ-radiation $\Rightarrow$ little room for DM contribution

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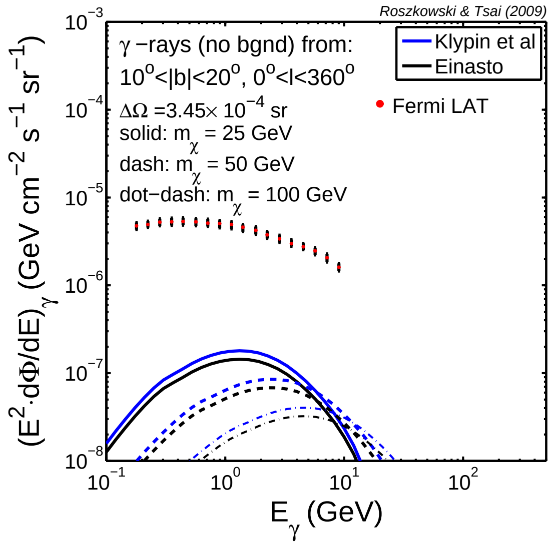

χ: neutralino of minimal SUSY

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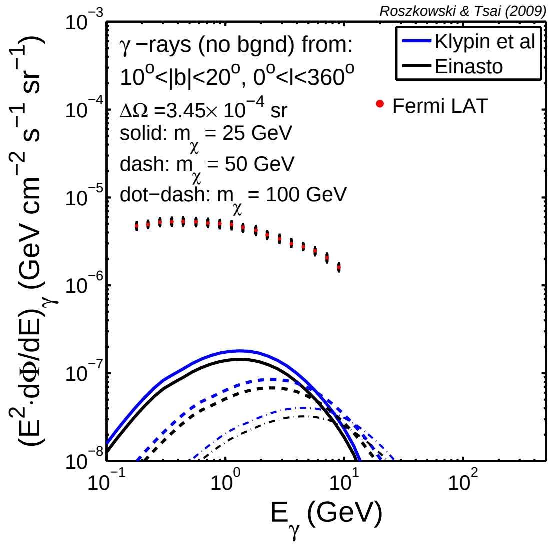

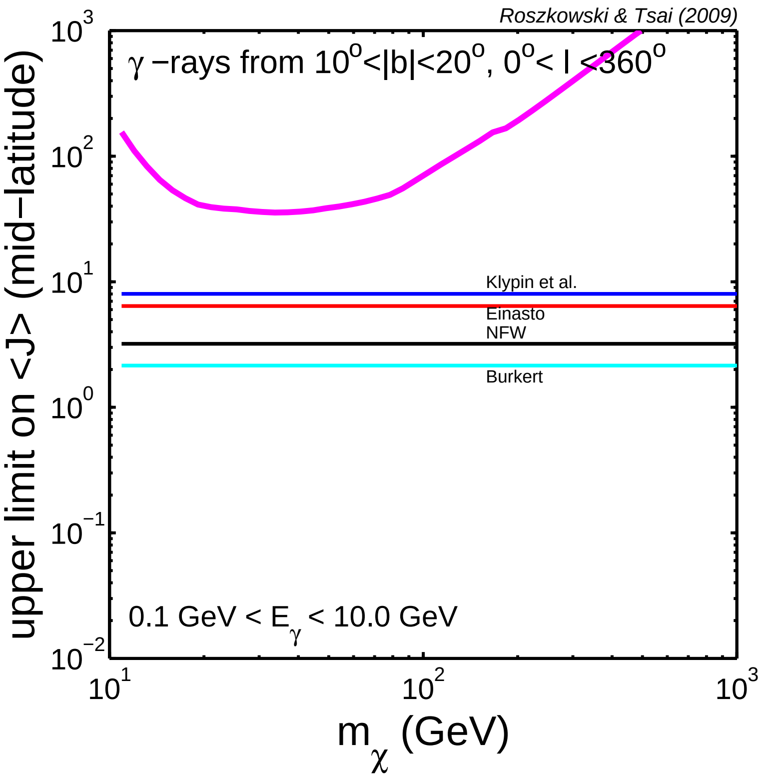

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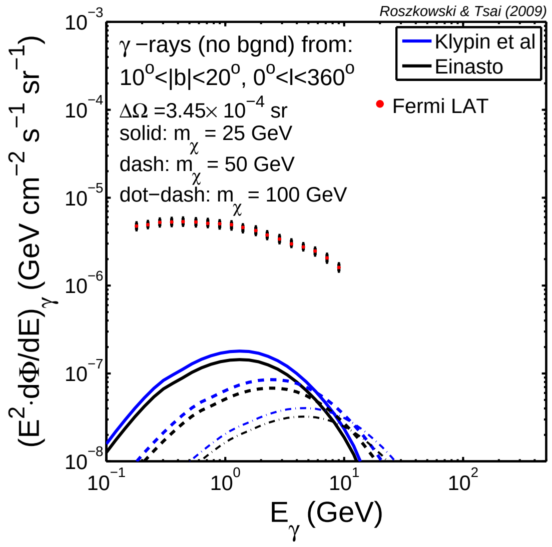

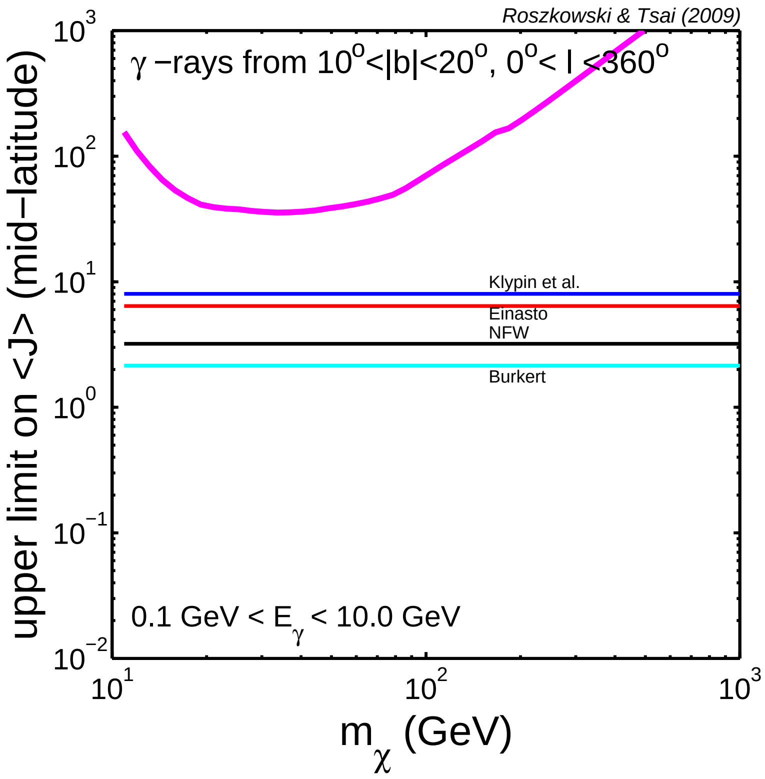

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$\Rightarrow$ upper limit on DM halo slope

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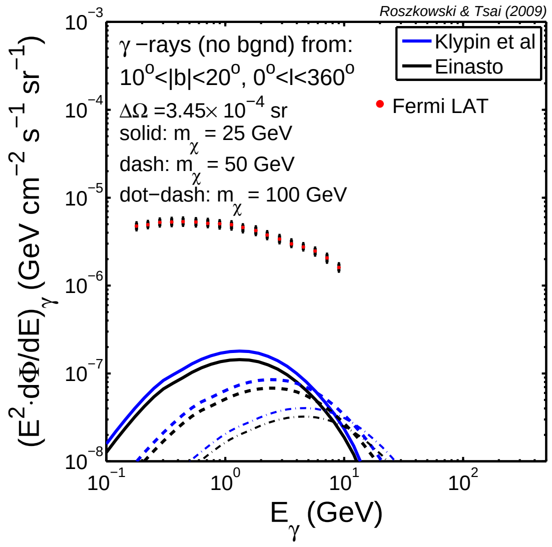

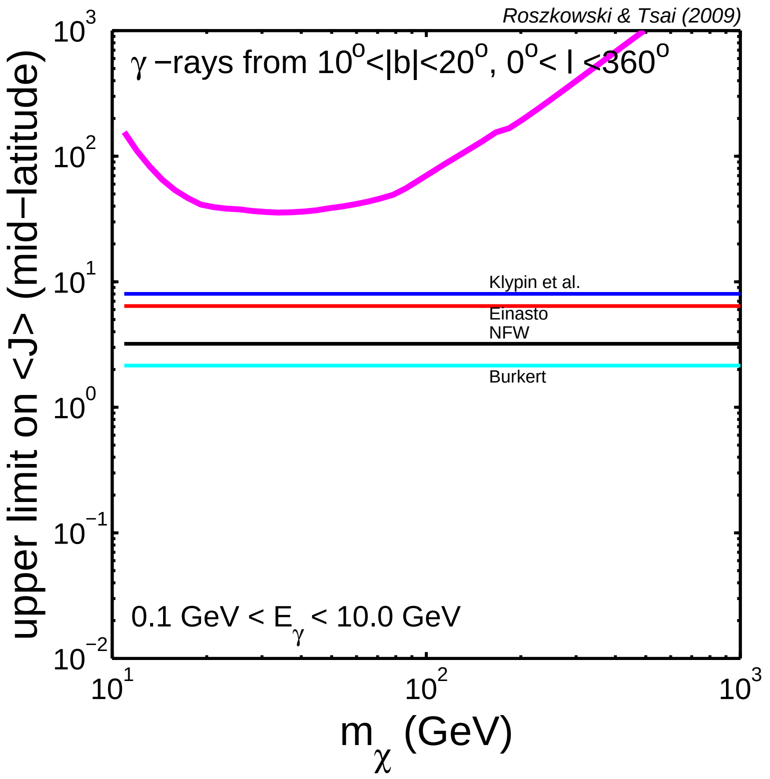

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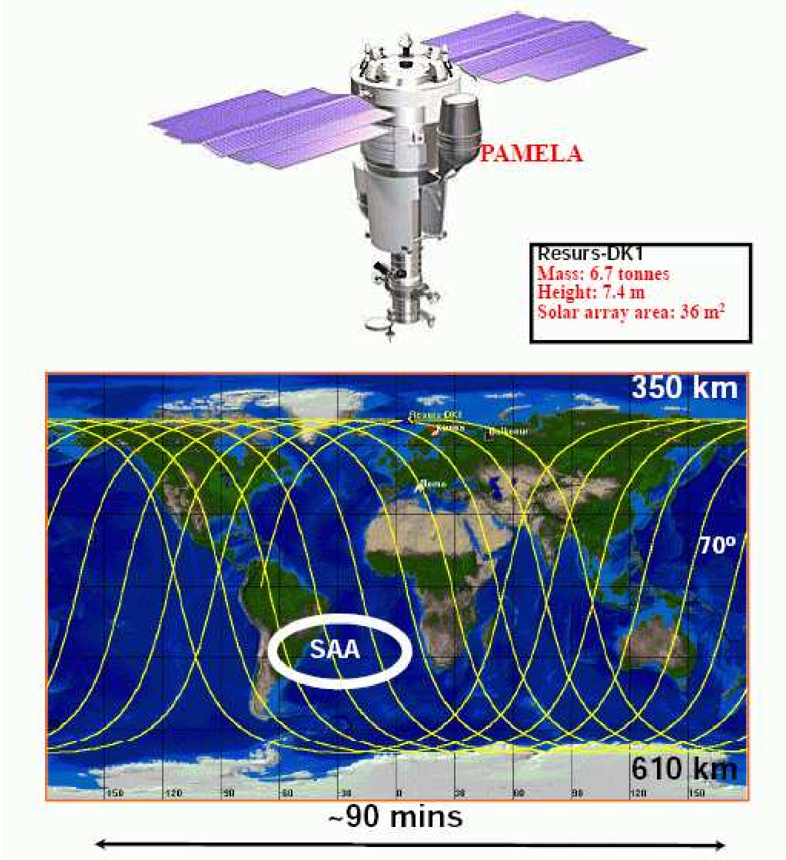
still weak. Can be improved with GC data?

e^+ data from PAMELA & DM

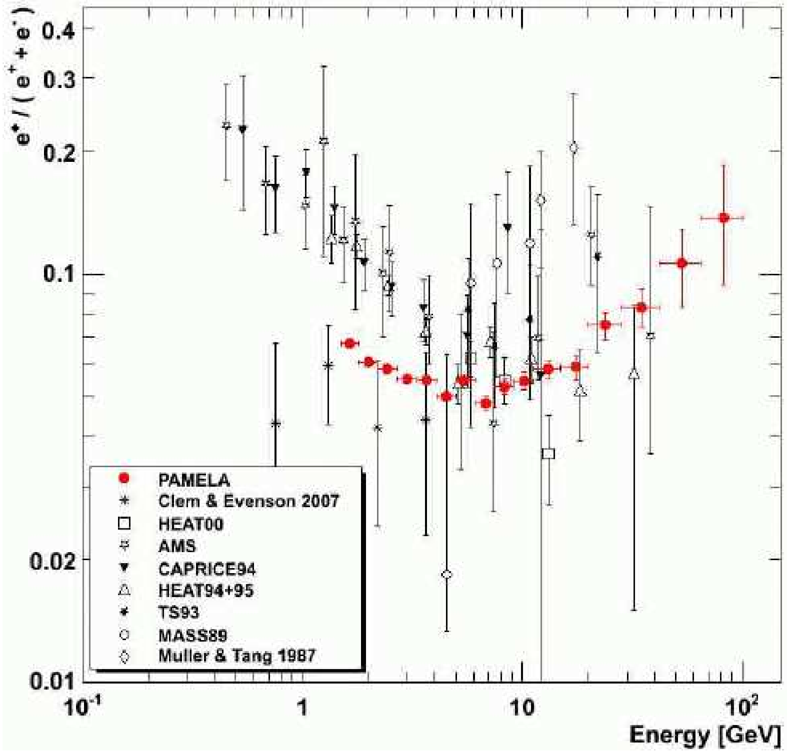
e^+ data from PAMELA & DM

PAMELA satelite (since 2007)



e^+ data from PAMELA & DM

$e^+/(e^+ + e^-)$ ratio, $\bar{p}$ flux, ...



O. Adriani et al., arXiv:0810.4995

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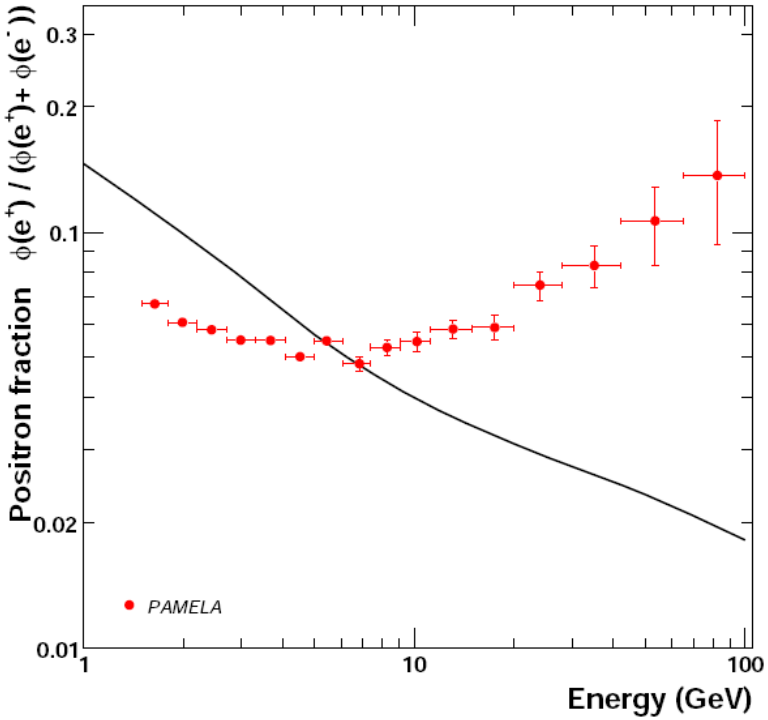
- no excess in $\bar{p}$ flux
- puzzling: growth at large e^+ energy



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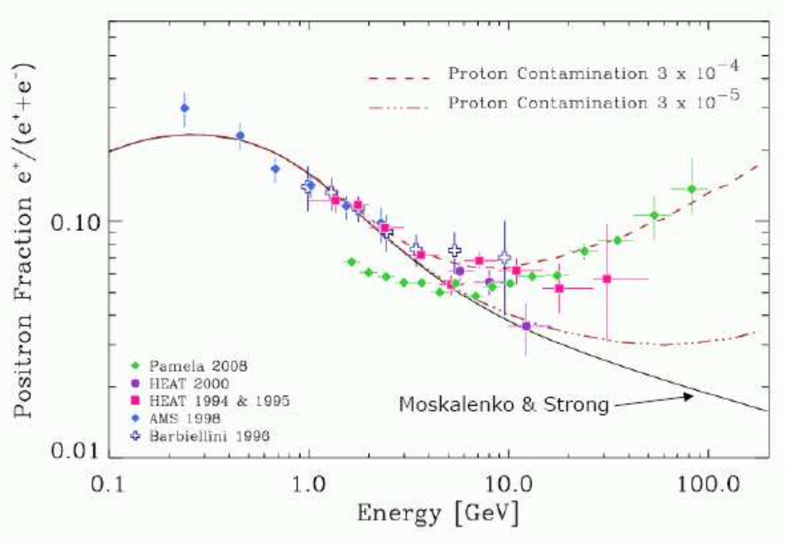
e^+: difficult measurement



p contamination of 3×10^{-5} sufficient?

Schubnell, Feb. 09

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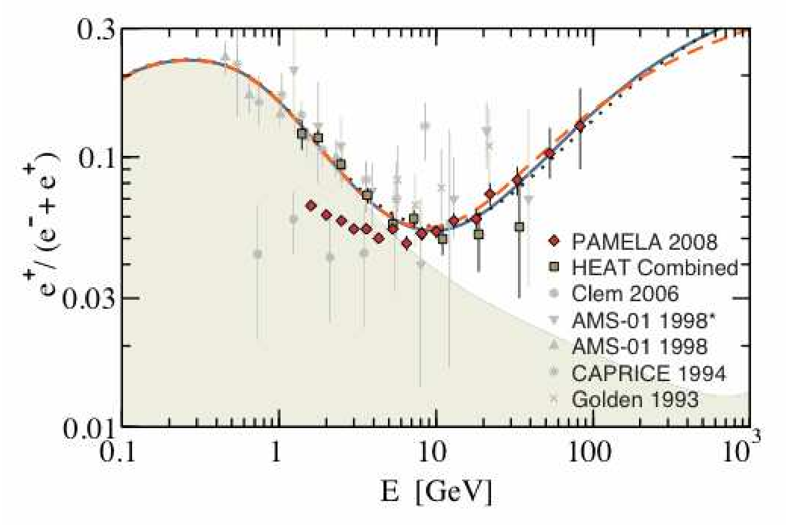
If excess genuine, explanations:

- pulsars

Hooper+Serpico, Profumo, ...



Geminga pulsar

Yuksel+Kistler+Stanev, 0810.2784

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$\Rightarrow$ case for DM origin of PAMELA e^+ excess is weak

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$\Rightarrow$ $\boxed{\text{case for DM origin of PAMELA } e^+ \text{ excess is weak}}$

...pulsar explanation seems sufficient

SUSY and positron flux

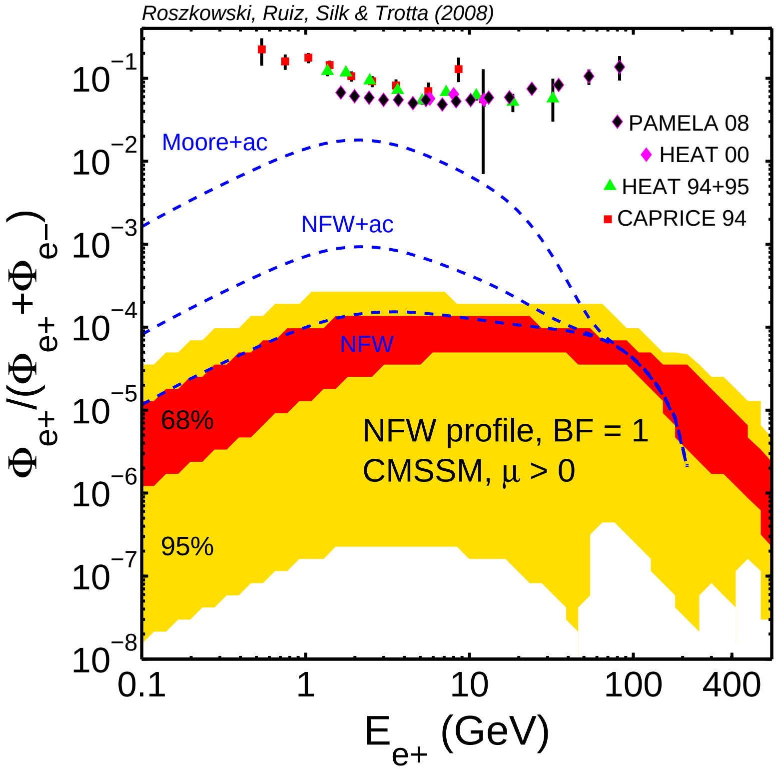
Bayesian posterior probability maps BF=1

SUSY and positron flux

Bayesian posterior probability maps

BF=1

CMSSM, flat priors, NFW



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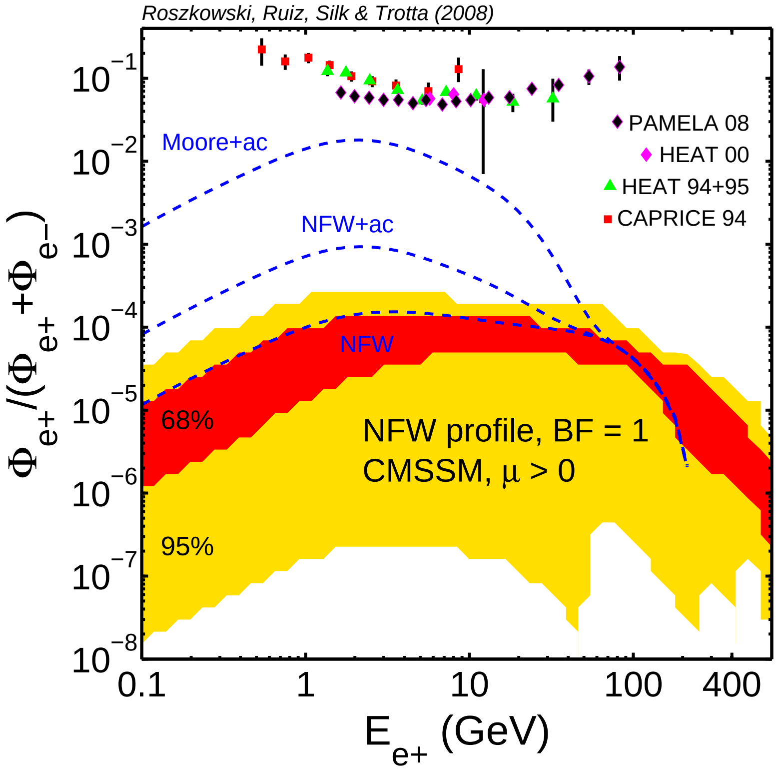

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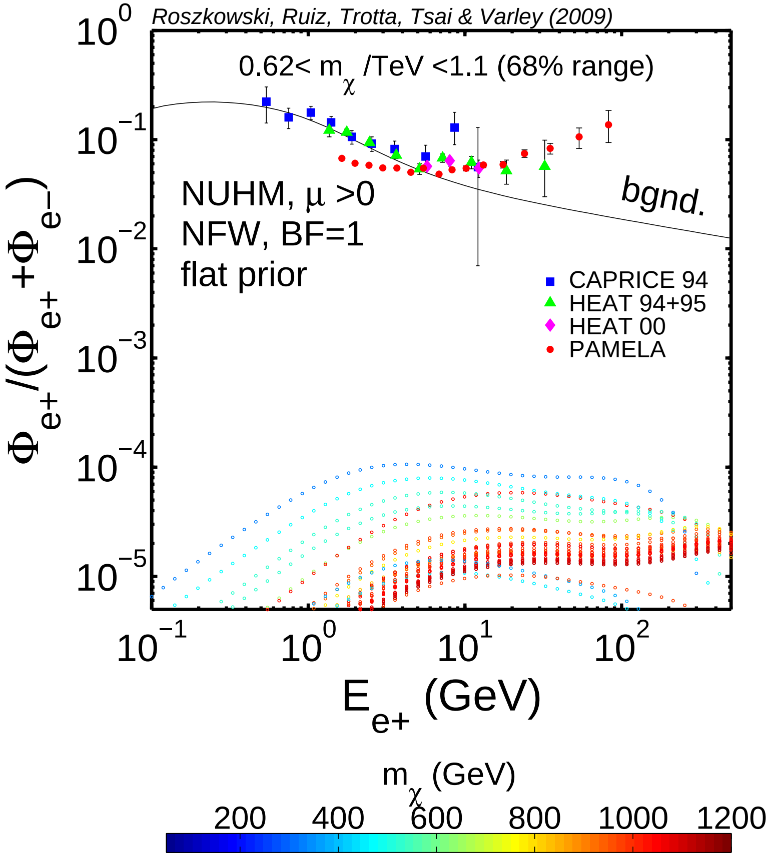

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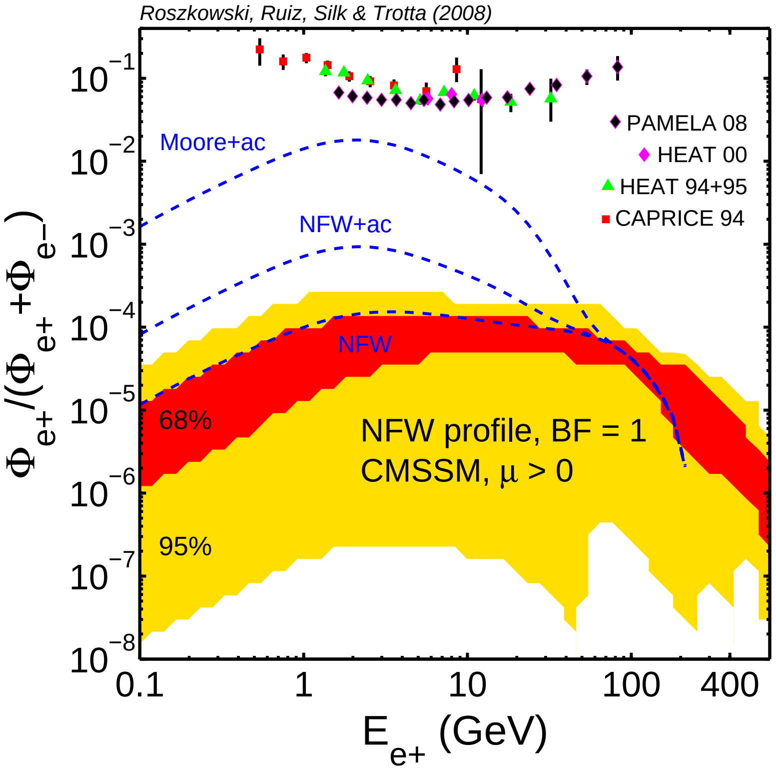

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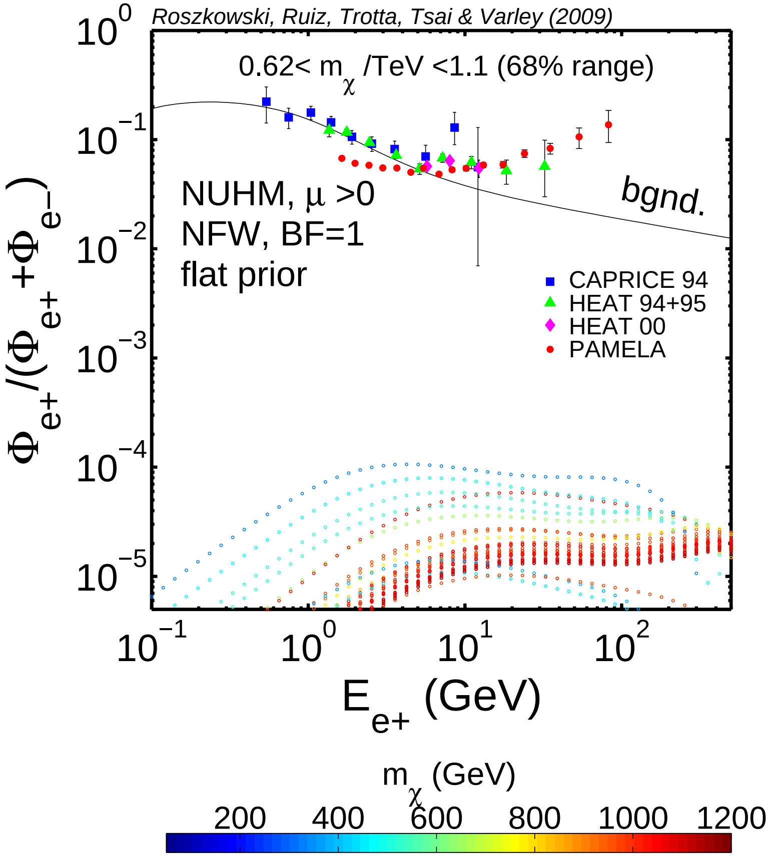

simple unified SUSY models are inconsistent with PAMELA's e^+ result

...even for unrealistically large boost factors

(flux scales linearly with boost factor)

The great tragedy of Science – the slying of a beautiful hypothesis by an ugly fact

T.H. Huxley

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One should never believe any experiment until it has been confirmed by theory

A. Eddington

Dark matter and the LHC

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  champagne, Stockholm, SUSY model reconstruction, WIMP astronomy, the ILC...

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Determining m_χ and $\Omega_\chi h^2$ at LHC

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- mass m_χ: up to some $400 - 500\,\mathrm{GeV}$ (from missing mass and missing energy)
- relic abundance $\Omega_\chi h^2$ (assuming stable neutralino): need to measure m_χ, Higgs, gluino and lightest squark masses, several BRs and $\tan\beta$ (depending on SUSY framework):

Nojiri, Polesello, Tovey ’04: SPA point: 5-10% error achievable

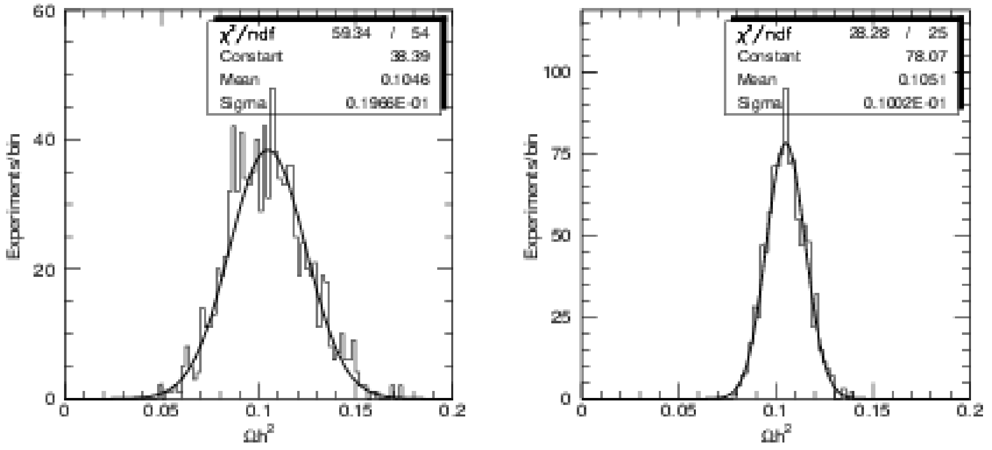

Figure 7: *Distributions of the predicted relic density $\Omega_\chi h^2$ incorporating the experimental errors. The distributions are shown for an assumed error on the $\tau\tau$ edge respectively of 5 GeV (left) and 0.5 GeV (right).*

Add info about DM abundance

assume Planck-like error: reduce WMAP error on $\boldsymbol{\Omega_\chi h^2}$ by $\sim \mathbf{5}$ ($\lesssim \mathbf{0.0016}$)

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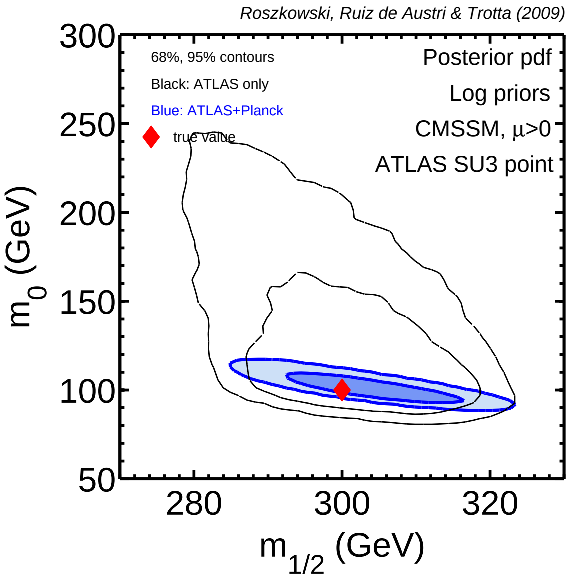

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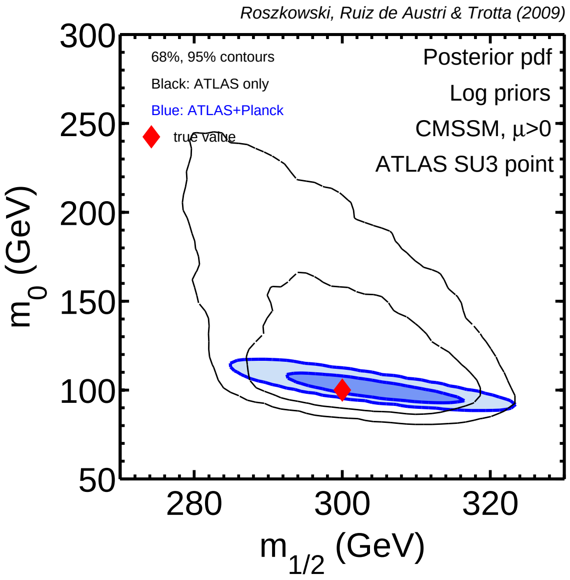

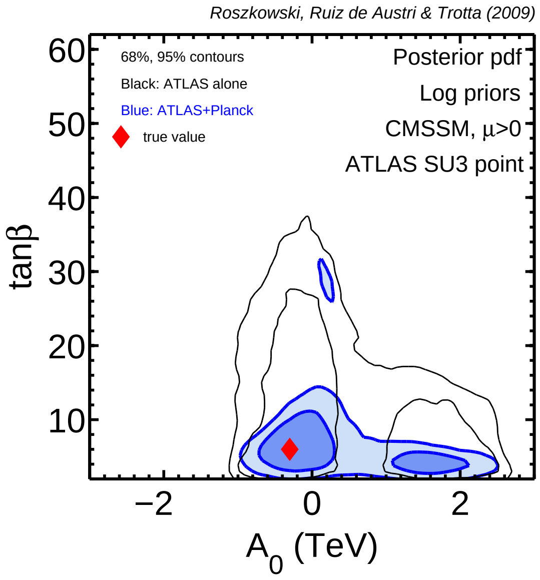

similar result for flat prior and profile likelihood

- determination of $m_{1/2}, m_0$ spot on!
- $\tan\beta$ resolved reasonably well
- determination of A_0 remains poor
- still cannot resolve sign of A_0

Determination of the relic abundance

ATLAS SU3 point

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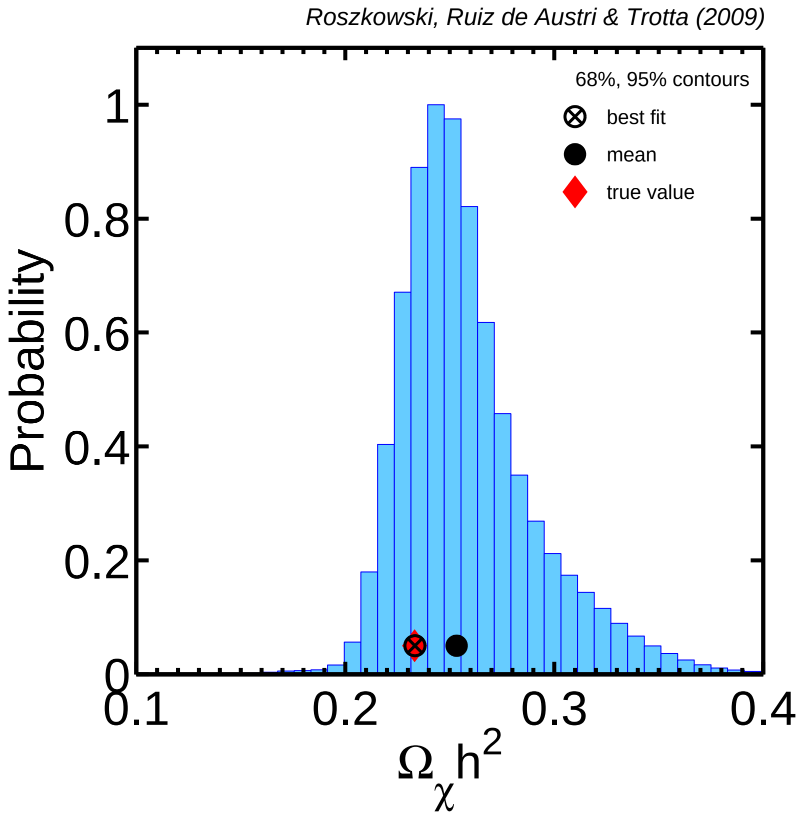

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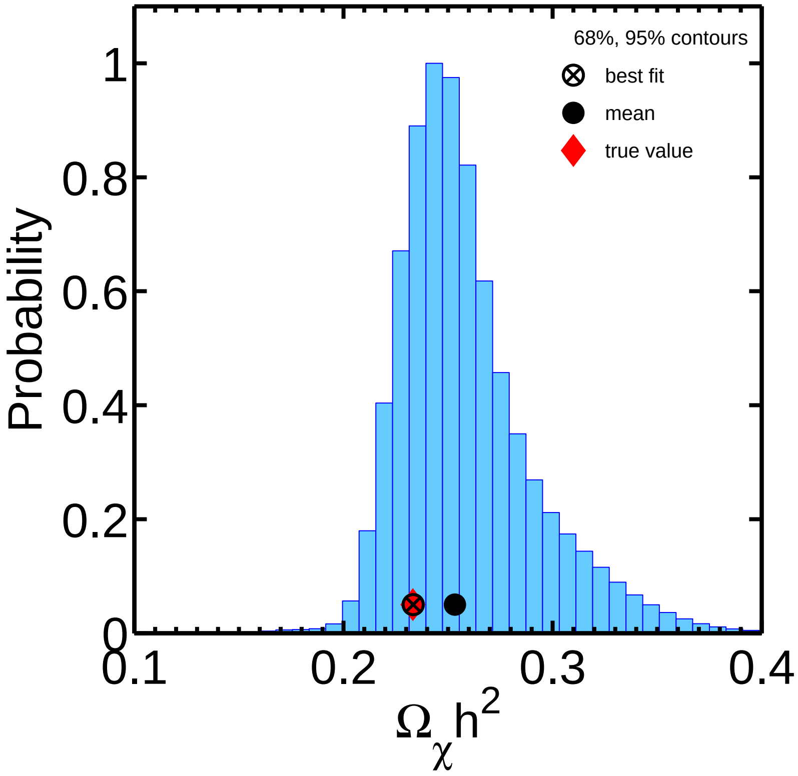
Roszkowski, Ruiz de Austri & Trotta (2009)



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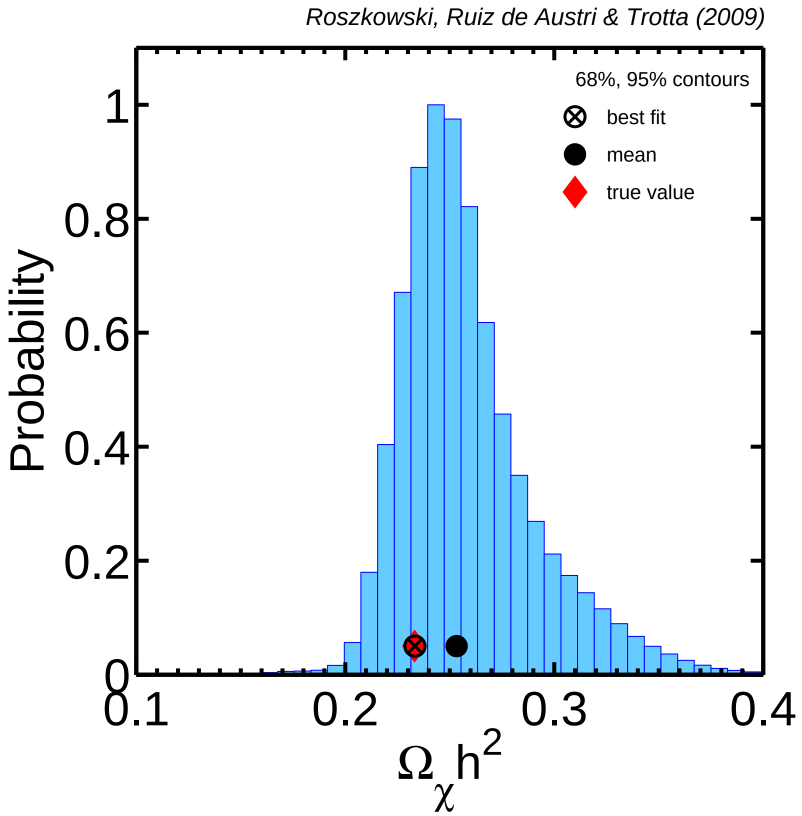

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$$\Rightarrow \ \Omega_\chi h^2 = 0.253 \pm 0.034$$

relative accuracy of $\sim 10\%$

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  even reconstructed density (neutralino or even stau!) can give $\Omega h^2 \sim 0.1$

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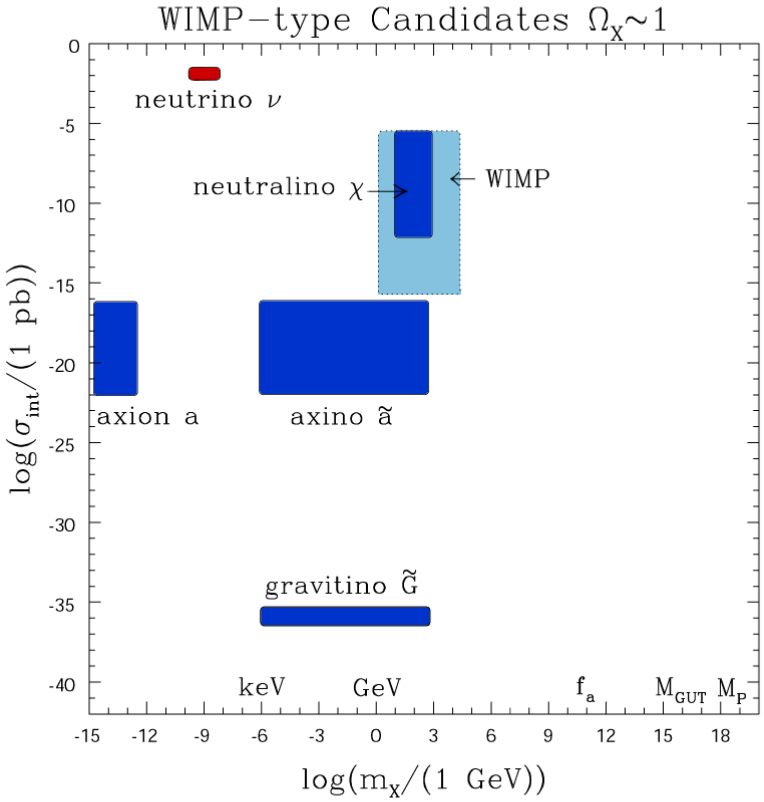
The LHC will be crucial in clarifying the nature of DM.

The Big Picture

well–motivated particle candidates such that $\mathbf{\Omega \sim 0.1}$



- neutrino $\boldsymbol{\nu}$ – hot DM
- neutralino $\boldsymbol{\chi}$
- “generic” WIMP
- axion $\boldsymbol{a}$
- axino $\boldsymbol{\widetilde{a}}$
- gravitino $\boldsymbol{\widetilde{G}}$

- WIMP (neutralino, weakly int’ing states, ...): discoverable now
- EWIMP/superWIMP (axino, gravitino, super-weakly int’ing states, ...): hopeless in direct detection, but hints possible at LHC

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(extremely weakly interacting massive particles)

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	axino $\widetilde{a}$	gravitino $\widetilde{G}$
spin	1/2	3/2
interaction	$\sim 1/f_a^2$	$\sim 1/M_P^2$
mass	$\not\propto M_{\rm SUSY}$	$\propto M_{\rm SUSY}$

- mass model dependent

  take it as free parameter

$f_a \sim 10^{9-12}\,\mathrm{GeV}$ – PQ scale
$M_P = 2.4 \times 10^{18}\,\mathrm{GeV}$ – reduced Planck mass
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- R-parity can but does not have to be conserved

cf. recent work by Buchmuller et al; Ibarra; Bomark, et al, , ...

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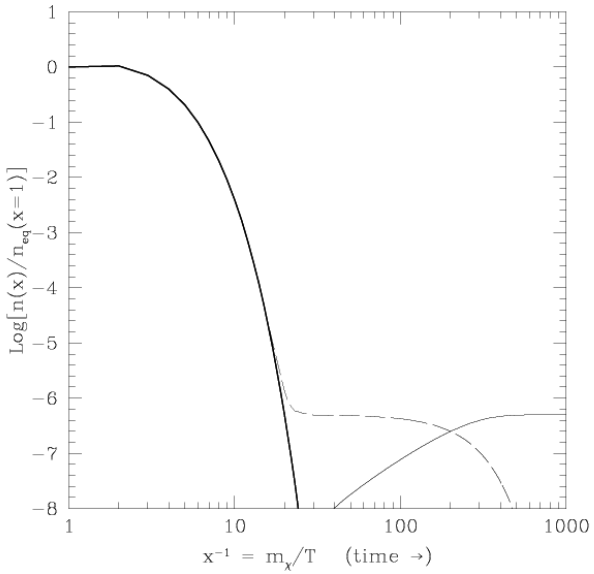

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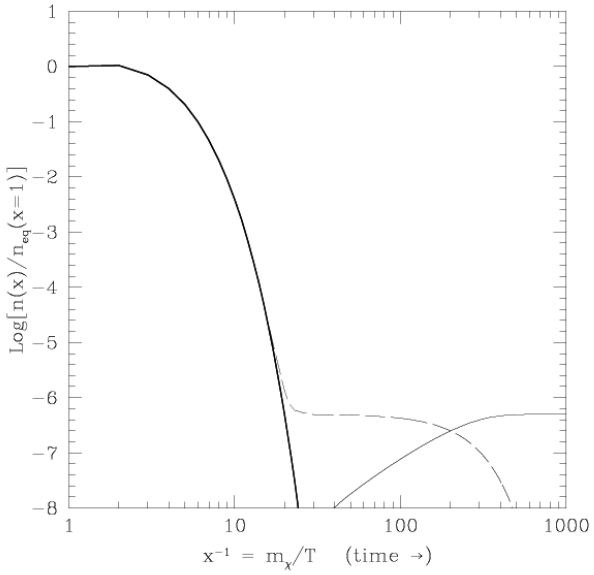
$$\boxed{\tau(\chi \to \widetilde{a}\,\gamma) \simeq 0.3\,\mathrm{sec}\left(\frac{100\,\mathrm{GeV}}{m_\chi}\right)^3 \ldots}$$

(for χ $\simeq$bino)

...before BBN!



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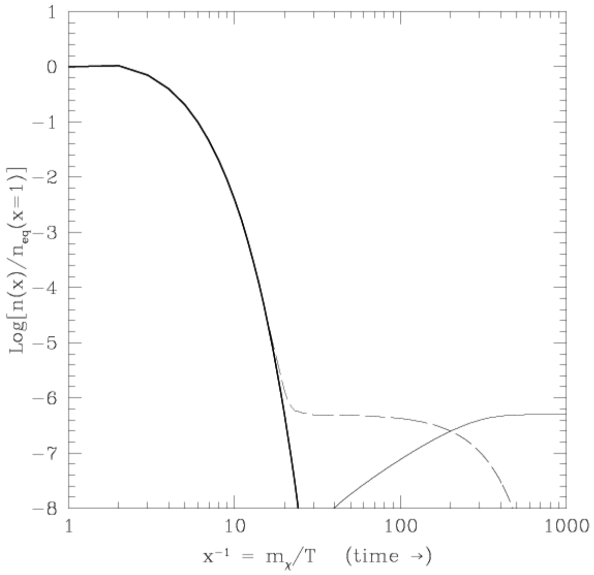

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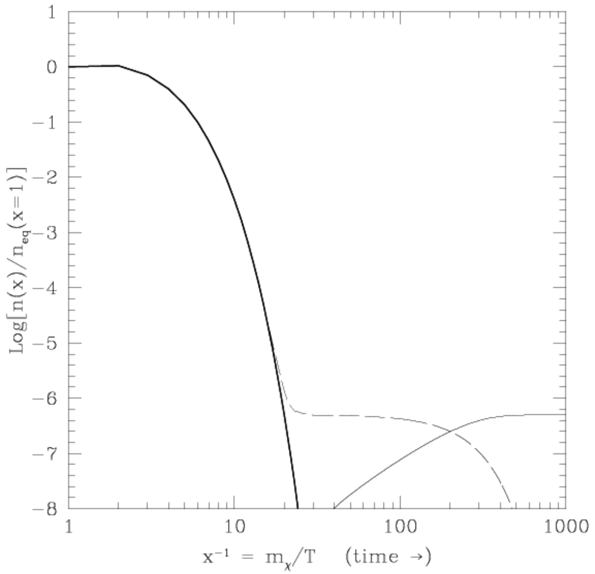

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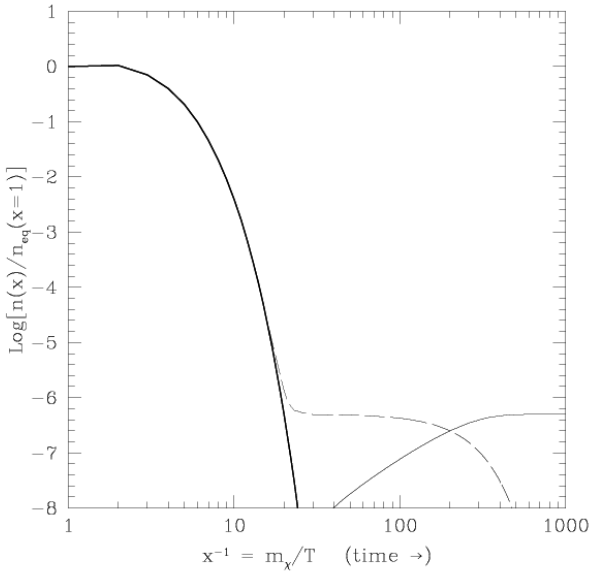

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- plus TP processes: $q\,q \to \widetilde{a}\,\widetilde{g},\quad \widetilde{q} \to \widetilde{a}\,q,\ \ldots$ (TP: thermal production)

$$\boxed{\Omega_{\widetilde{a}}^{\mathrm{TP}} h^2 \simeq 5.5\, g_s^6 \ln\left(\frac{1.108}{g_s}\right)\left(\frac{m_{\widetilde{a}}}{0.1\,\mathrm{GeV}}\right)\left(\frac{10^{11}\,\mathrm{GeV}}{f_a}\right)^2\left(\frac{T_R}{10^4\,\mathrm{GeV}}\right)}$$

TP dominance $\Rightarrow$ $\boxed{T_R \propto f_a^2 / m_{\widetilde{a}}}$

Covi+J.E. Kim+H.-B. Kim+LR, JHEP'01
Brandenburg and Steffen ('04)

Hints for axino DM from LHC?

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but LHC measurements may point to $\widetilde{a}$ LSP and DM

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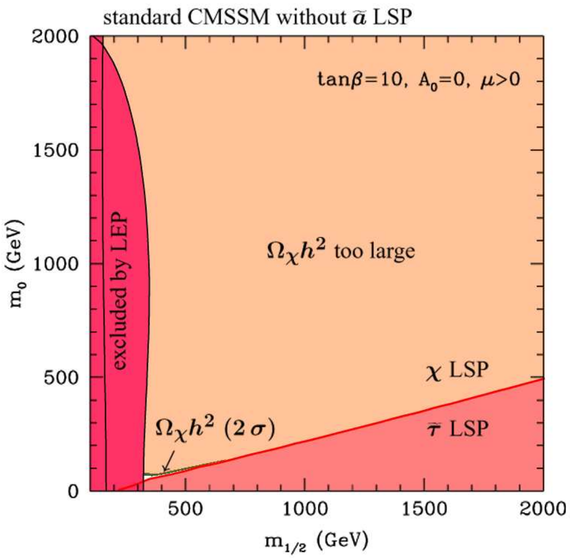

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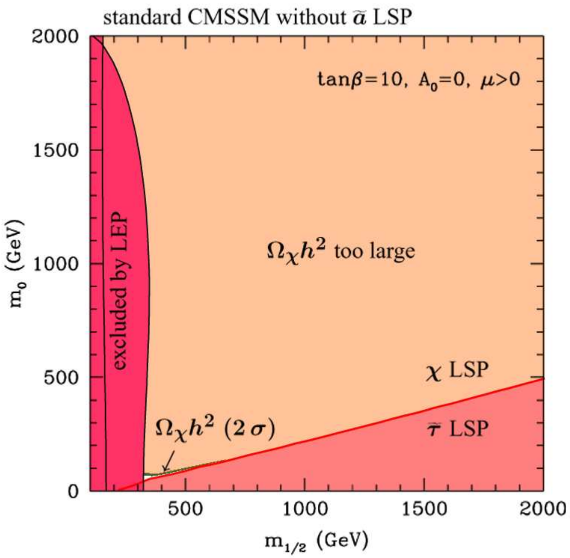
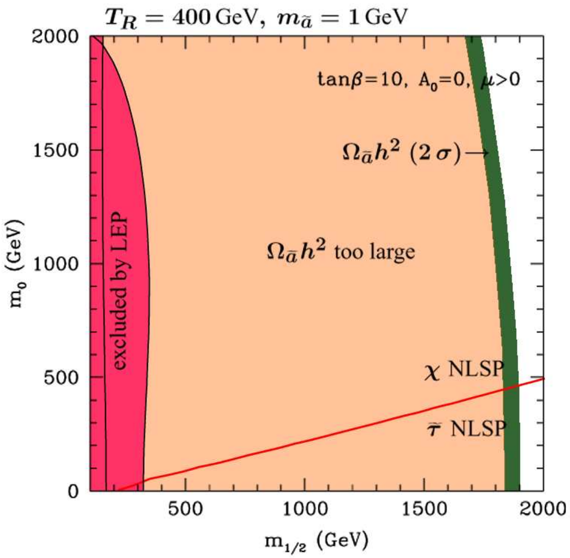


CMSSM, $\widetilde{a}$ LSP, $m_{\widetilde{a}} \simeq m_\chi$



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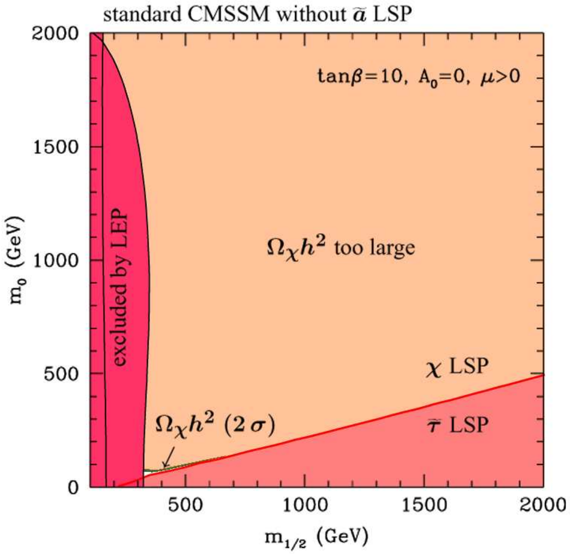
$\widetilde{a}$ is too feebly interacting for any DM searches

but LHC measurements may point to $\widetilde{a}$ LSP and DM

CMSSM, (standard) χ LSP



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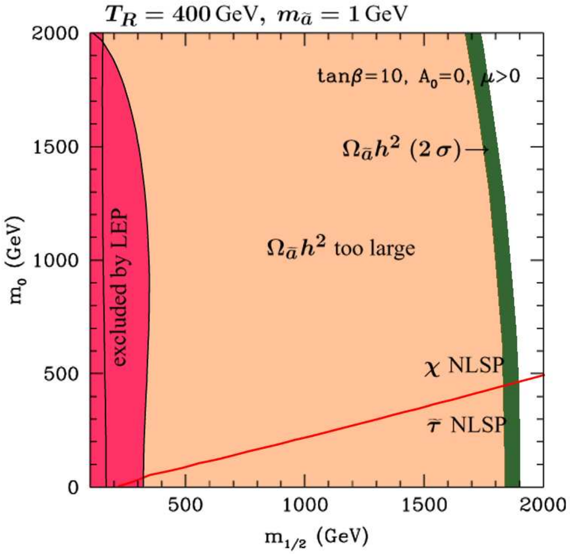

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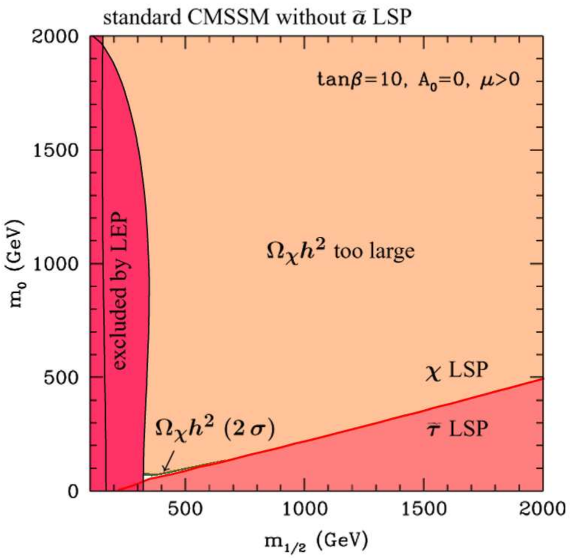

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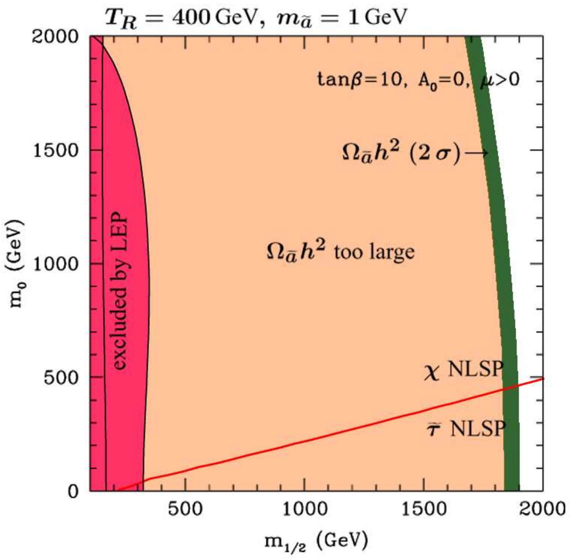

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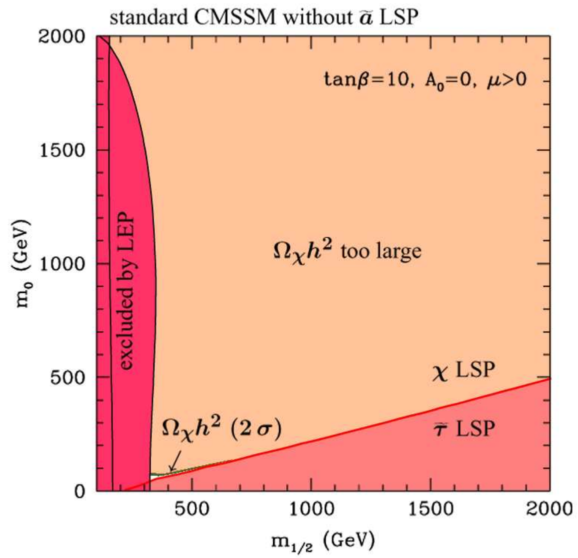

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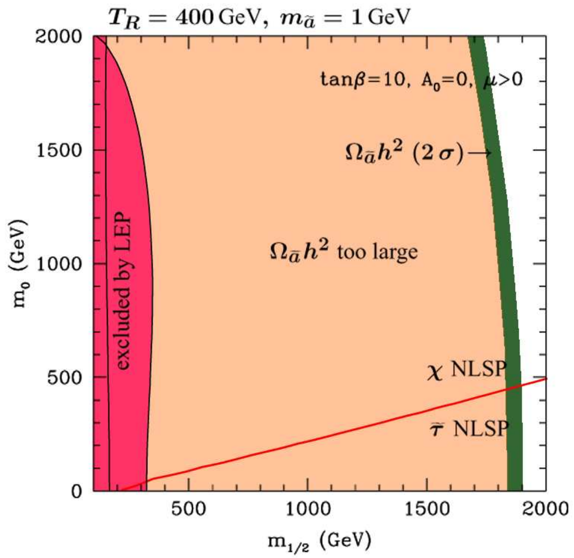

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- if $\widetilde{\tau}_1$–NLSP: charged, apparently stable $\Rightarrow$ striking signature at LHC

The Gravitino $\widetilde{G}$

spin–$\mathbf{3/2}$ partner of the graviton

- in gravity–mediated SUSY breaking models

$$m_{\widetilde{G}} = \frac{F}{\sqrt{3}M_{\mathrm{P}}}$$

$F \sim 10^{11}\,\mathrm{GeV}$ – SUSY breaking scale

$M_{\mathrm{P}} = 2.4 \times 10^{18}\,\mathrm{GeV}$ – reduced Planck mass

soft masses $\sim F/M_{\mathrm{P}}$

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- if it is the LSP…

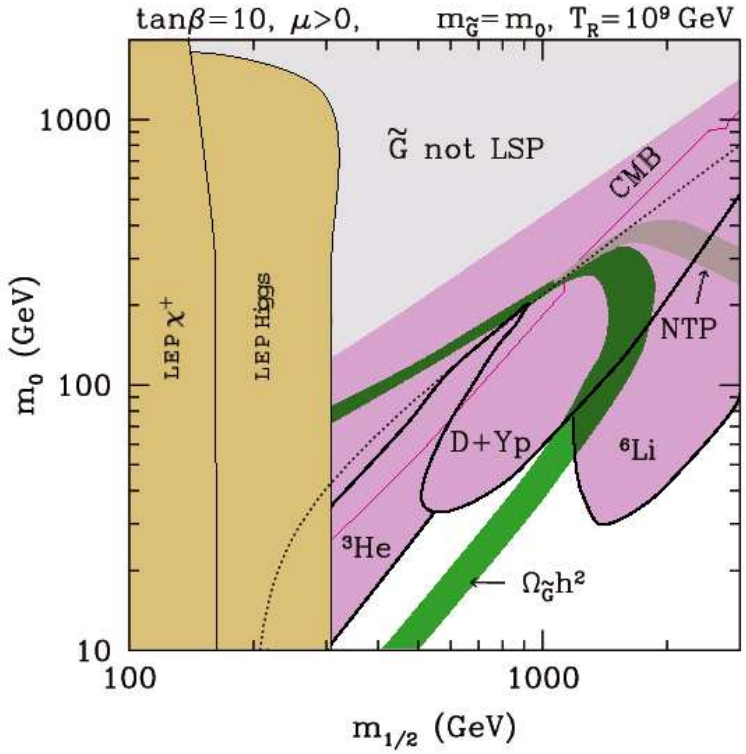
can $\widetilde{G}$ give $\Omega_{\rm CDM}h^2 \sim 0.1$?

$\widetilde{G}$: cold (not warm) DM

Example: $m_{\widetilde{G}} = m_0$

Cerdeño+K.-Y. Choi+Jedamzik+L.R.+Ruiz de Austri

apply all BBN: $D/H + Y_p + {}^7Li/H + {}^3He/D + {}^6Li/{}^7Li$



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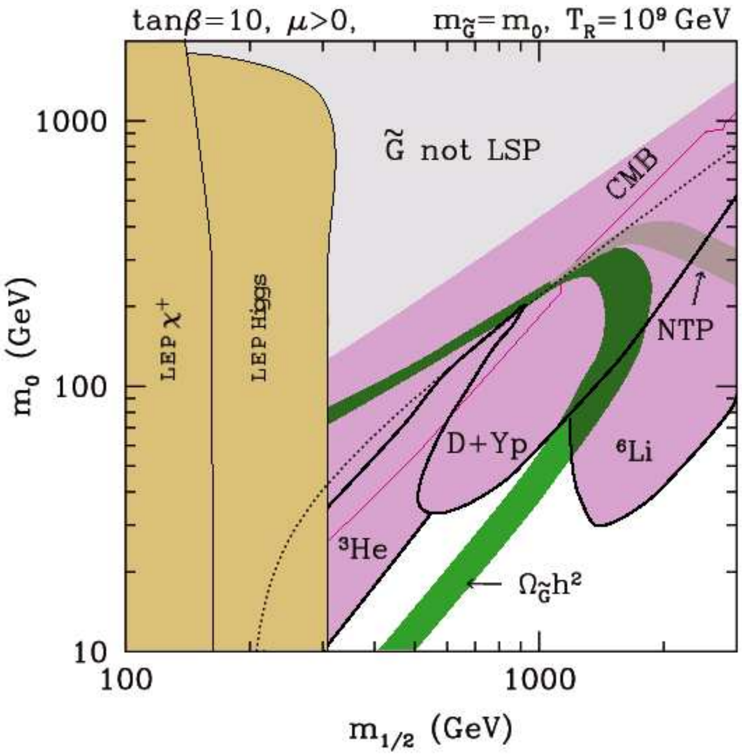

- only $\widetilde{\tau}_1$–NLSP region remains allowed

$\Rightarrow$ at LHC see charged "stable" LOSP $\widetilde{\tau}_1$ (instead of "expected" neutral χ)

confirmed Feng, et al (Apr 04)

- low T_R basically excluded (NTP part only), must include TP contribution to $\Omega_{\widetilde{G}}h^2$

$\Rightarrow$ $m_{\widetilde{G}} = \mathcal{O}(100\,\mathrm{GeV})$: (typically) need high $T_R \sim 10^9\,\mathrm{GeV}$

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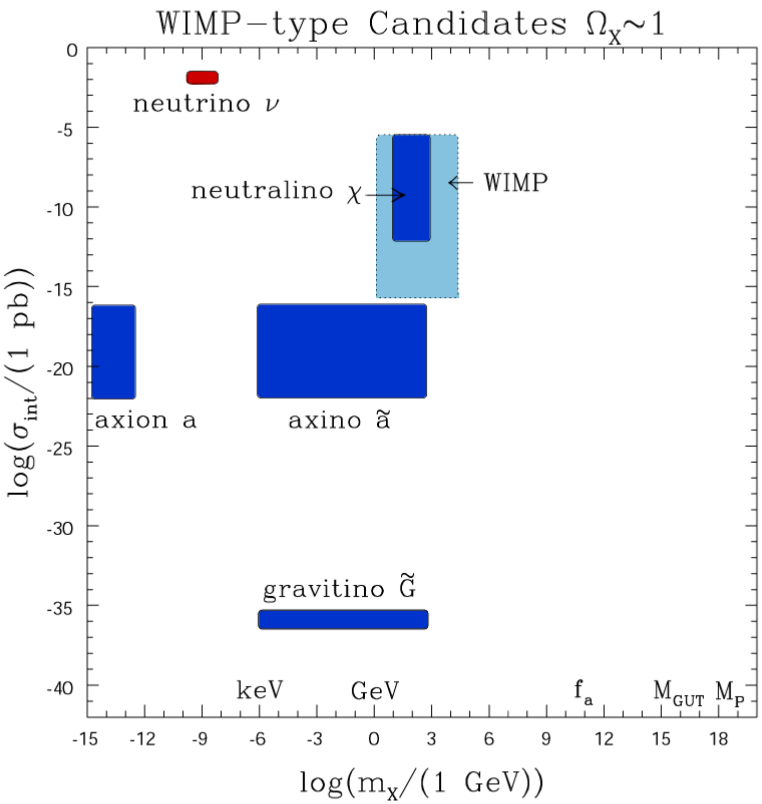
$\Rightarrow$ $\boxed{\text{LHC can give strong indications for EWIMP DM possible}}$

The Big Picture

well–motivated particle candidates such that $\Omega \sim 0.1$



- neutrino ν – hot DM
- neutralino χ
- “generic” WIMP
- axion a
- axino $\widetilde{a}$
- gravitino $\widetilde{G}$
- ????

Dark matter and the LHC

Assume SUSY as a popular and well-motivated framework...

- DM detected in DD/ID expts, SUSY found at the LHC
- DM detected in DD/ID expts, but no SUSY at the LHC

  $\Rightarrow$ The nature of DM WIMP would remain a mystery
- a stable state (χ or charged $\widetilde{\tau}_1$) found at the LHC...
  ... but no signal in DM DD/ID searches

  $\Rightarrow$ a particle lighter than χ (and for sure $\widetilde{\tau}_1$) is the DM?
- LHC may (indirectly) point to E-WIMPs as DM

The LHC will be crucial in clarifying the nature of DM.

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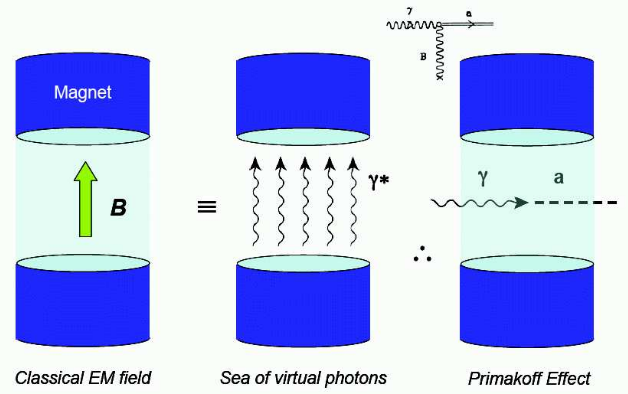
(detection scheme)



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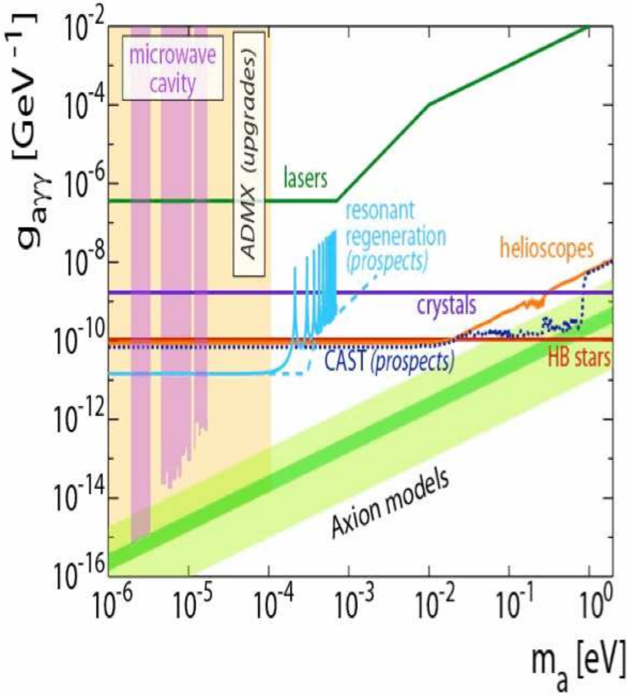
current status



expt sensitive to cosmologically subdominant a

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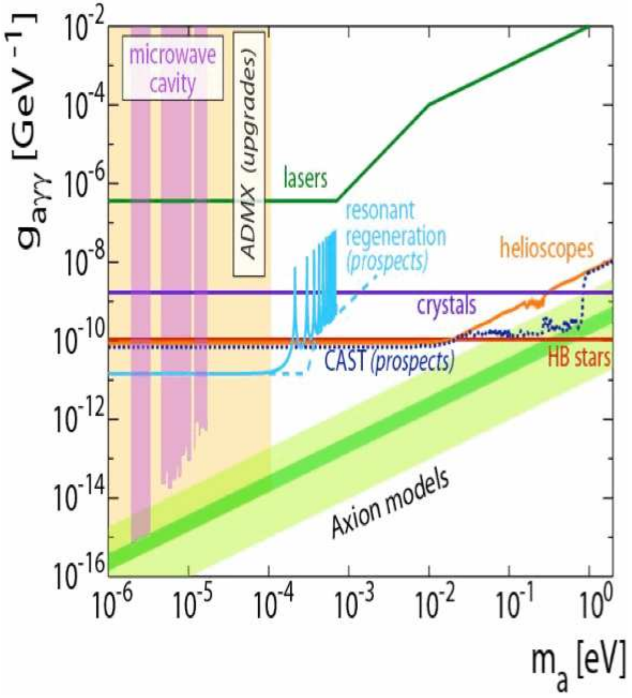

expt sensitive to cosmologically subdominant a

search continues, a possibly cosmologically subdominant?

The bottom line:

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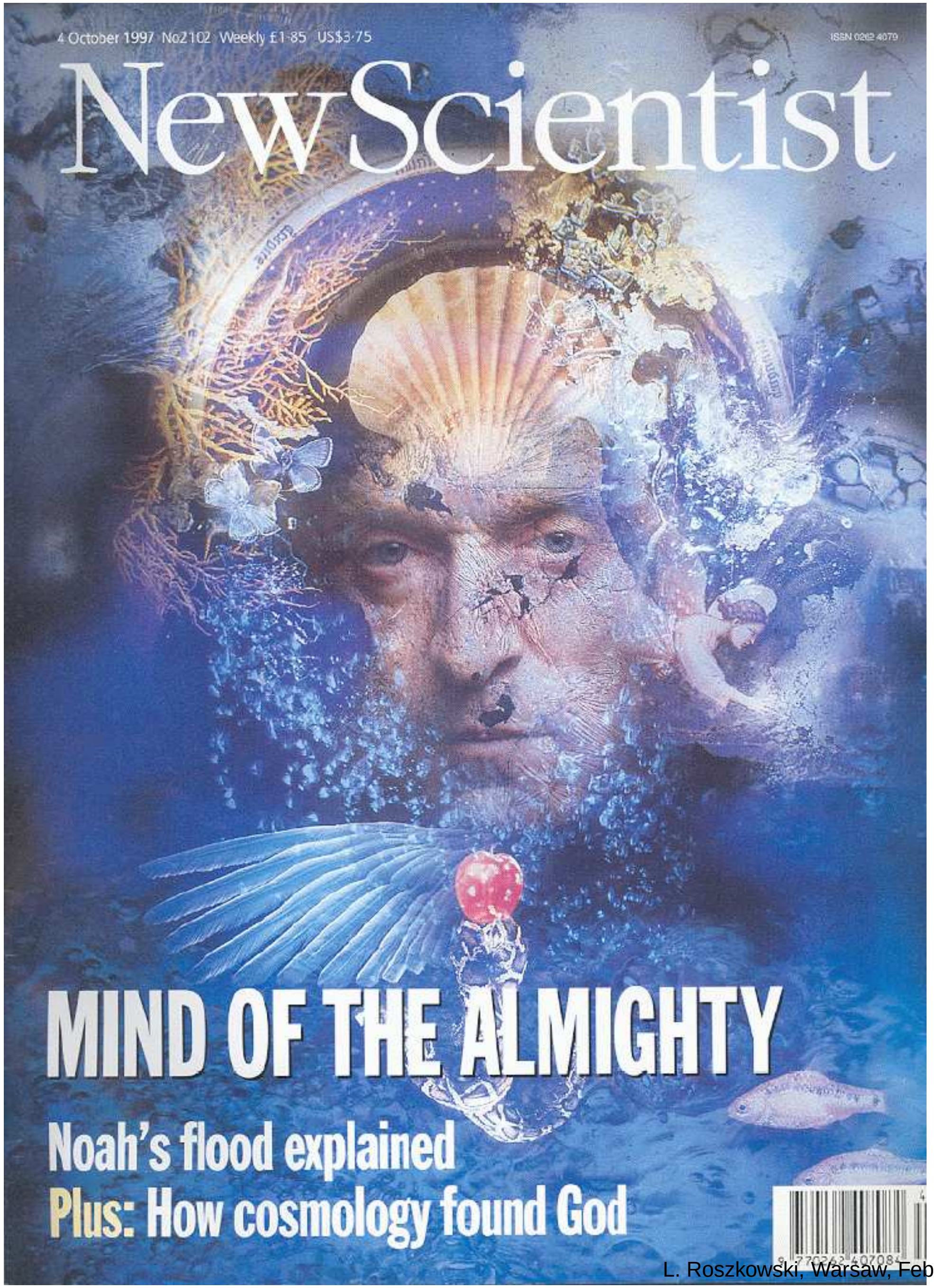

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