New Physics & its Experimental Probes

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Open Questions beyond the Standard Model

- What is the origin of particle masses? due to a Higgs boson?
- Why so many types of matter particles?
- What is the dark matter in the Univers
- Unification of fundamental forces?
- Quantum theory of gravity?

SUSY

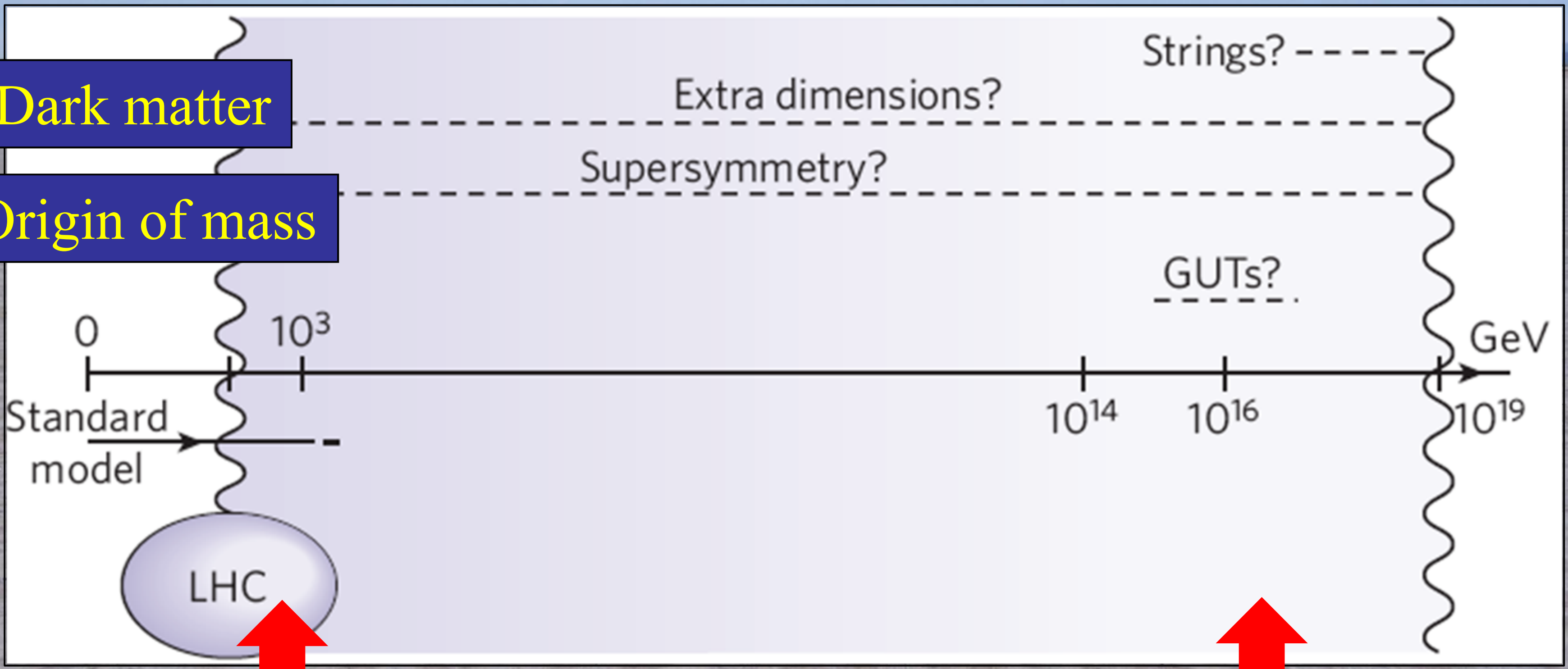
LHC

SUSY

SUSY

String

At what Energy is the New Physics?



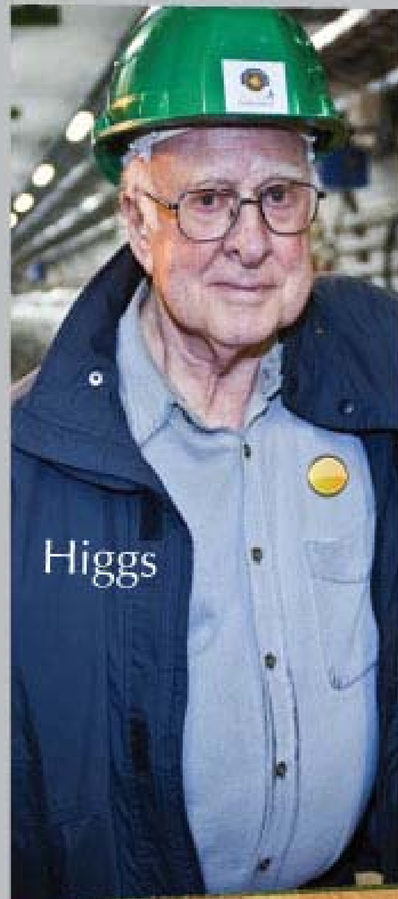
Dark matter

Origin of mass

A lot accessible to the LHC

Some accessible only via astrophysics & cosmology

What lies Beyond?



… Open The Door

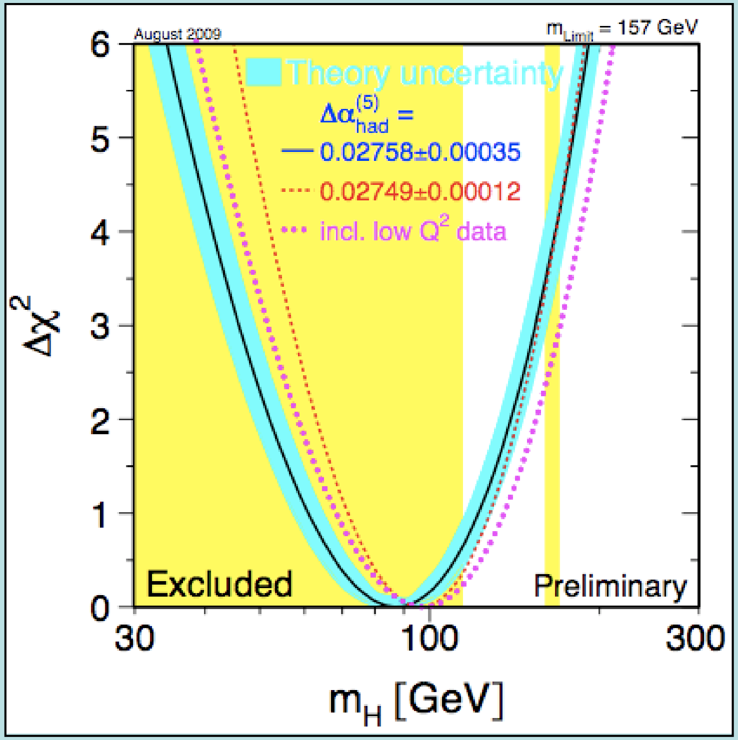
The State of the Higgs: May 2011

- High-energy search:
  - Limit from LEP:

$$m_H > 114.4\ \text{GeV}$$

- High-precision electroweak data:
  - Sensitive to Higgs mass:

$$m_H = 96^{+30}_{-24}\ \text{GeV}$$



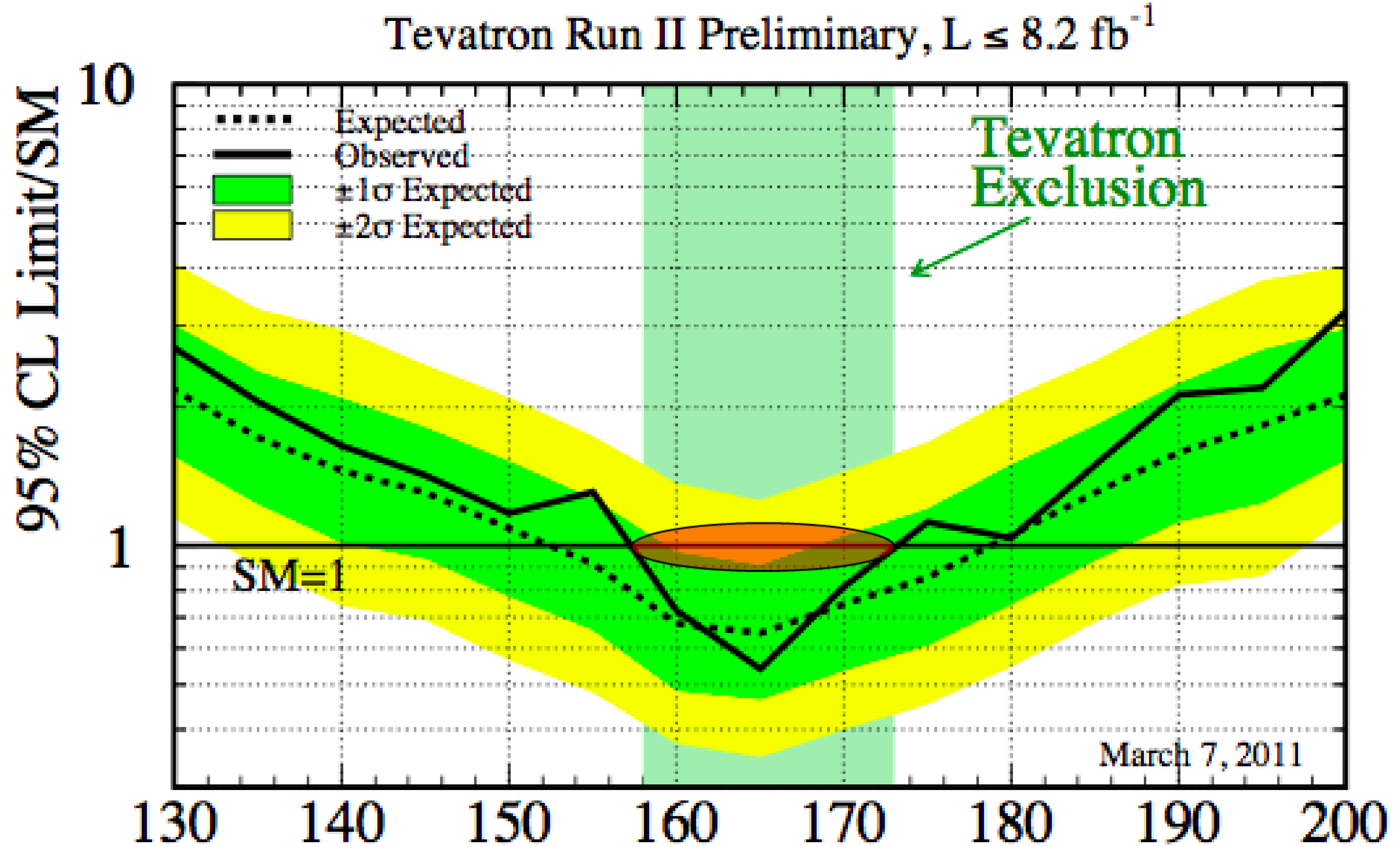
- Combined upper limit:

$$m_H < 157\ \text{GeV, or } 186\ \text{GeV including direct limit}$$

- Exclusion from high-energy search at Tevatron:

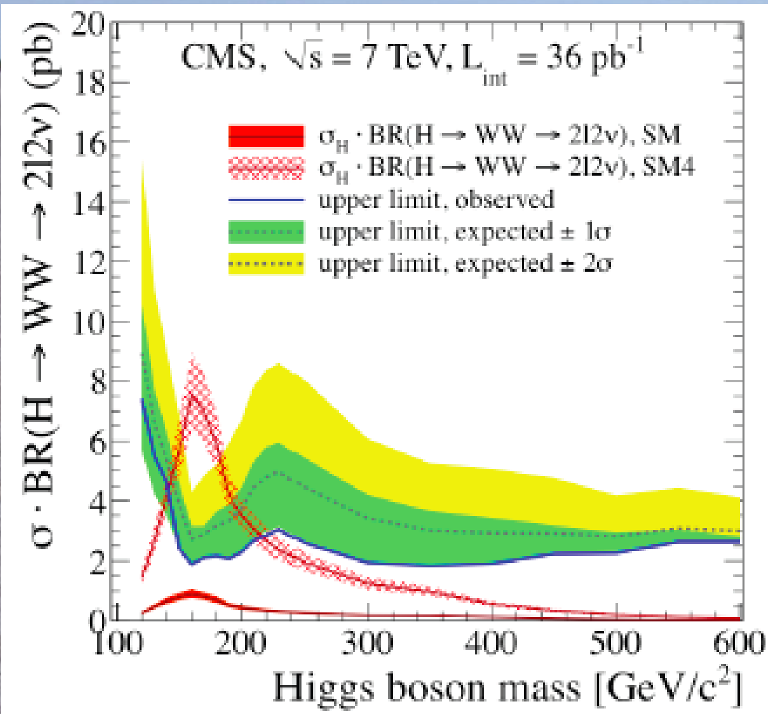
$$m_H < 158\ \text{GeV or } > 173\ \text{GeV}$$

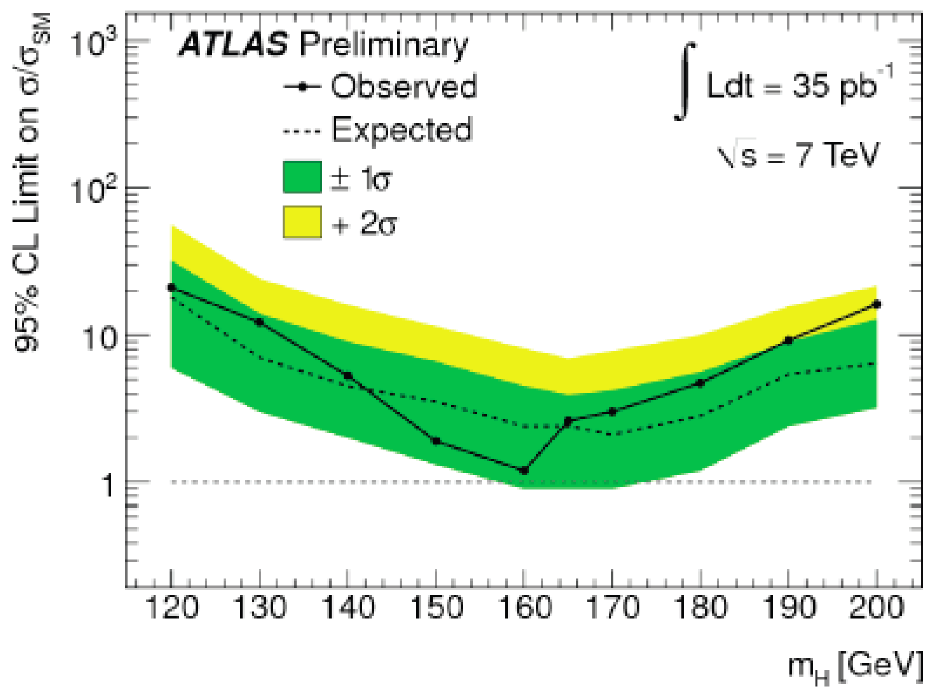
Higgs Search @ Tevatron



Tevatron excludes Higgs between 158 & 173 GeV

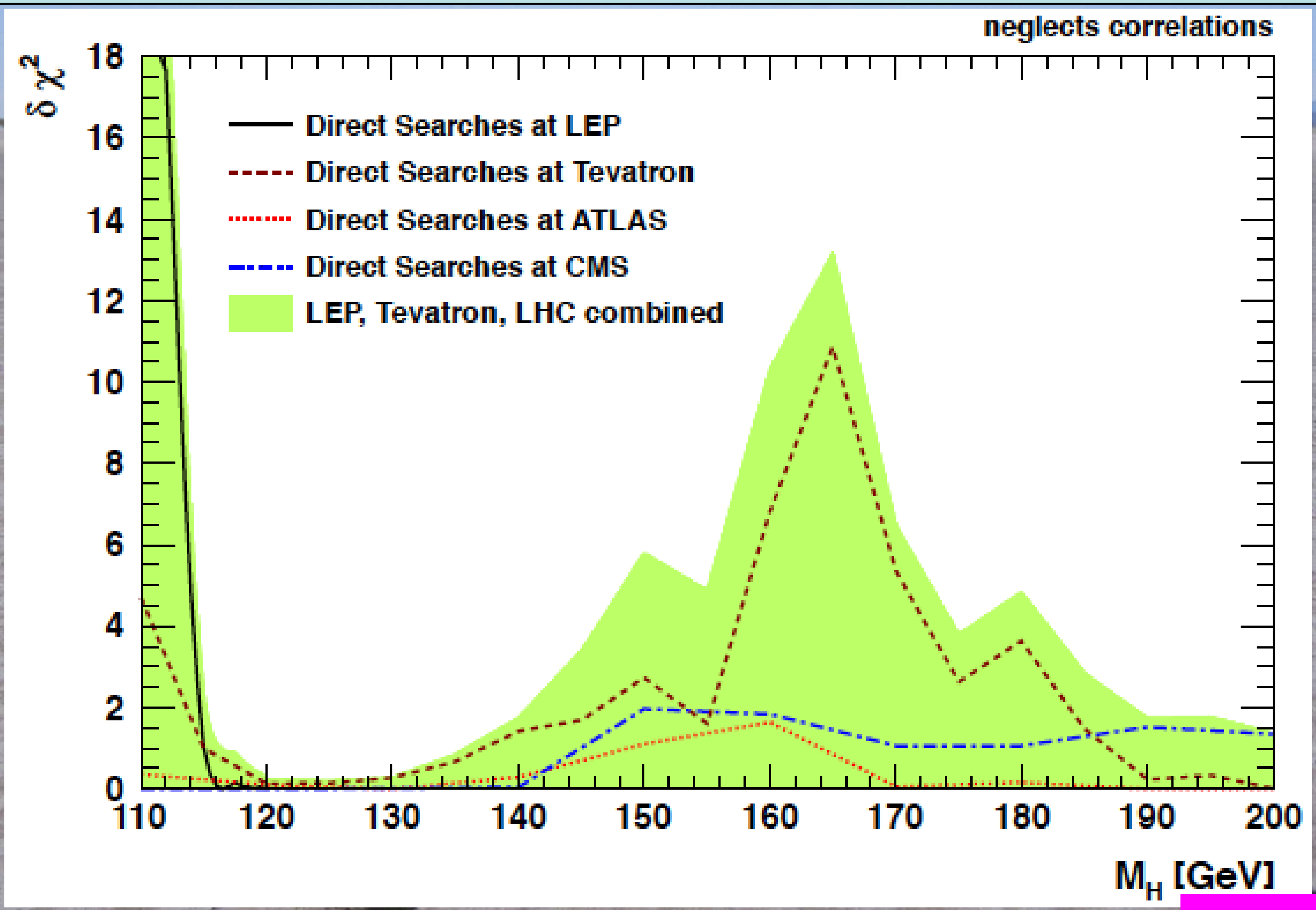
First Higgs Searches @ LHC





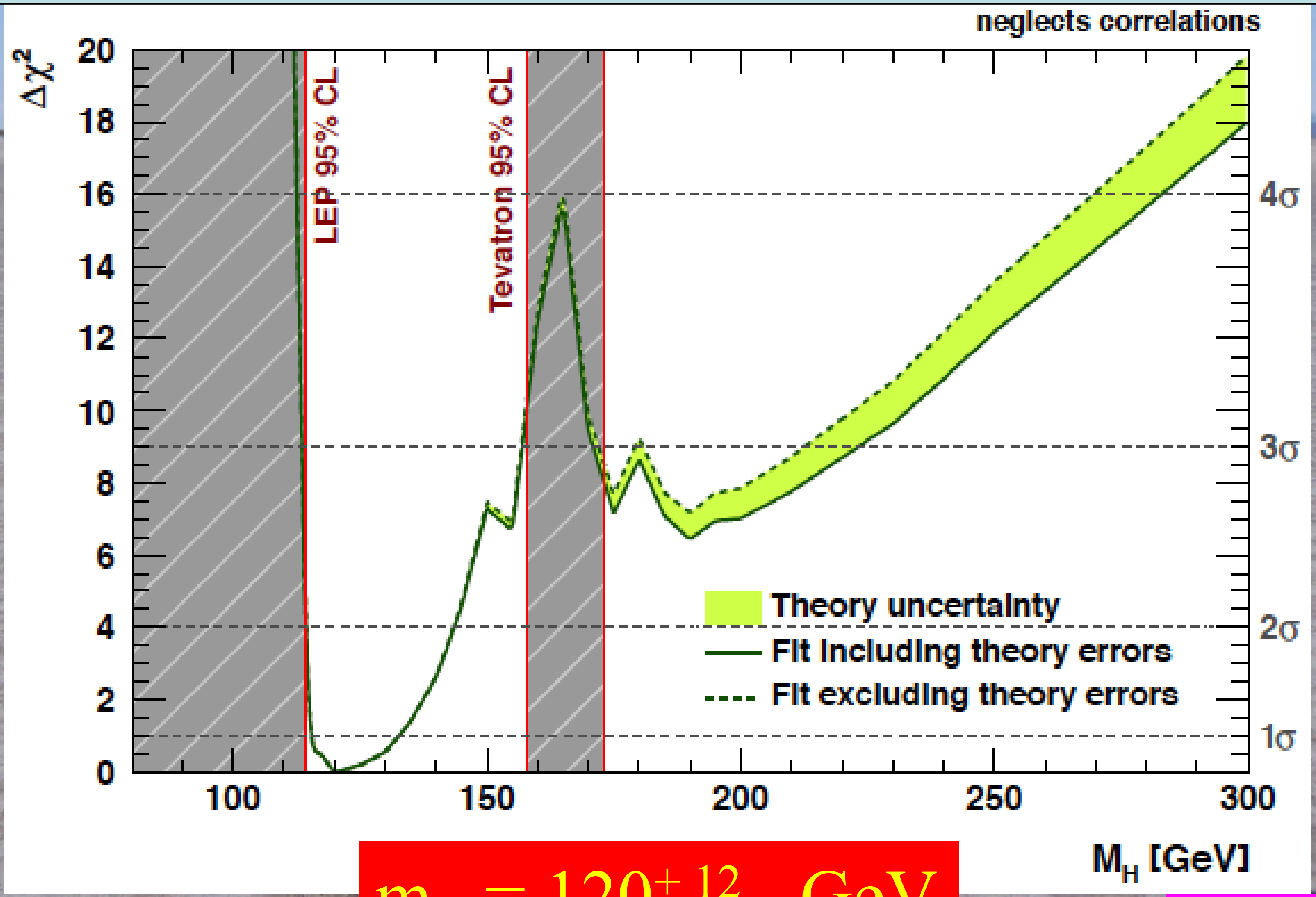
No exclusion yet, but significant contribution to global fit

Information from Direct Higgs Searches



Gfitter collaboration

Combining the Information from Direct Searches and Indirect Data

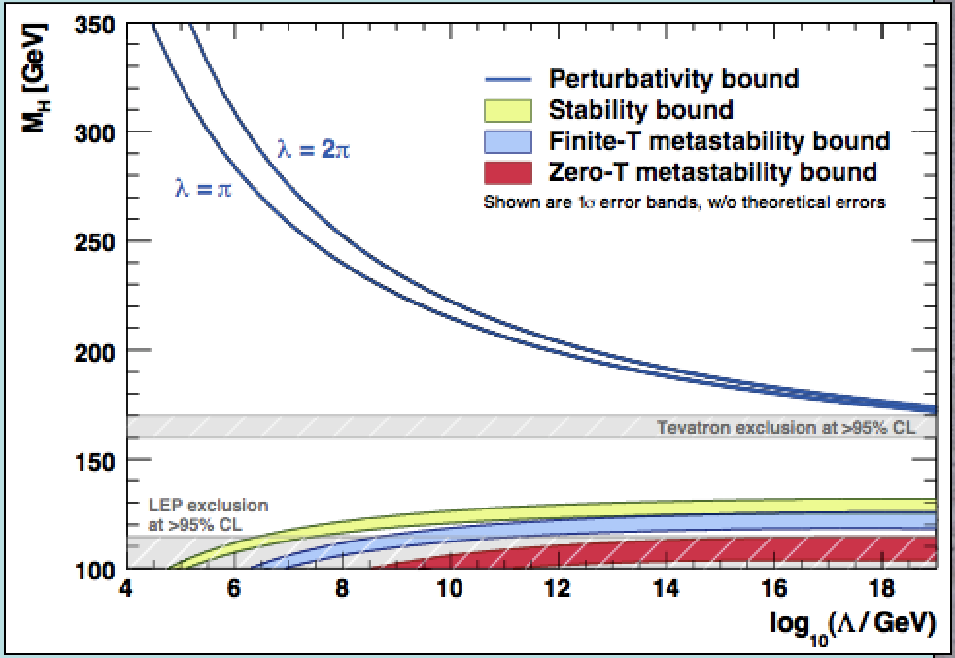


$m_H = 120^{+12}_{-5}$ GeV

Gfitter collaboration

Theoretical Constraints on Higgs Mass

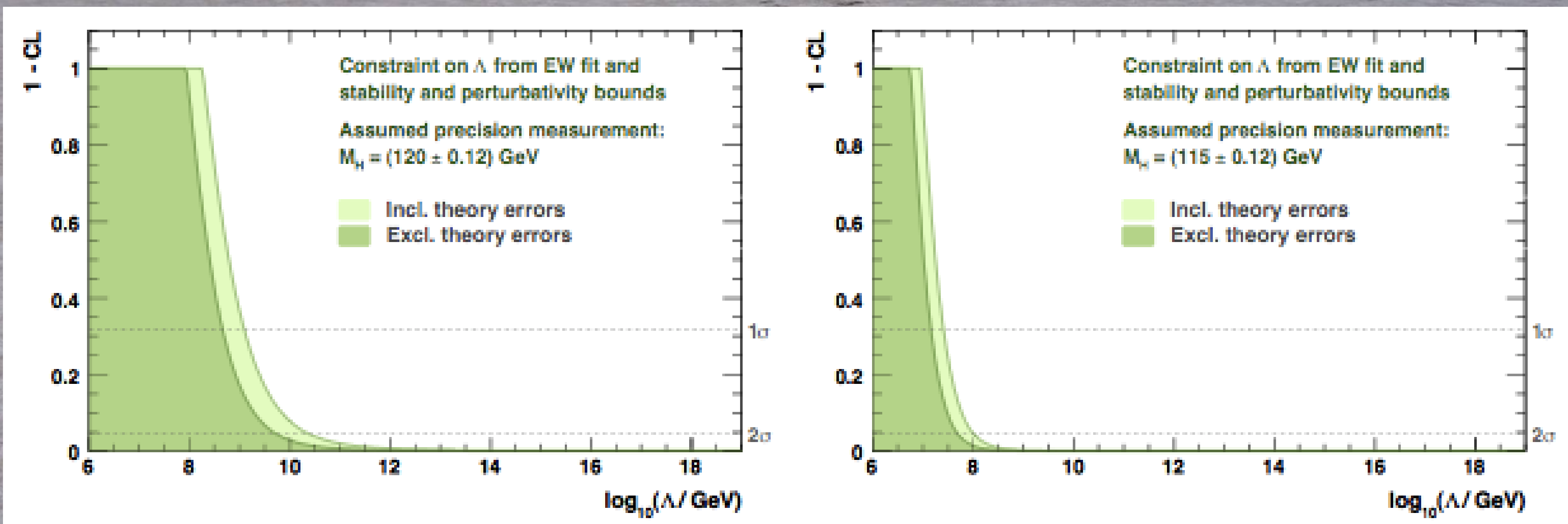
- Large → large self-coupling → blow up at low energy scale Λ due to renormalization
- Small: renormalization due to t quark drives quartic coupling < 0 at some scale Λ → vacuum unstable



- Bounds on Higgs mass depend on Λ

The LHC will Tell the Fate of the SM

Examples with LHC measurement of m_H = 120 or 115 GeV



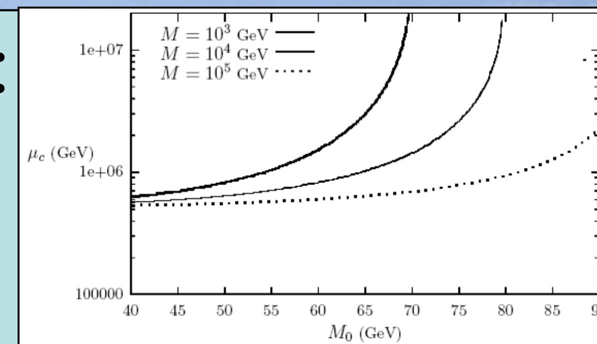
Espinosa, JE, Giudice, Hoecker, Riotto

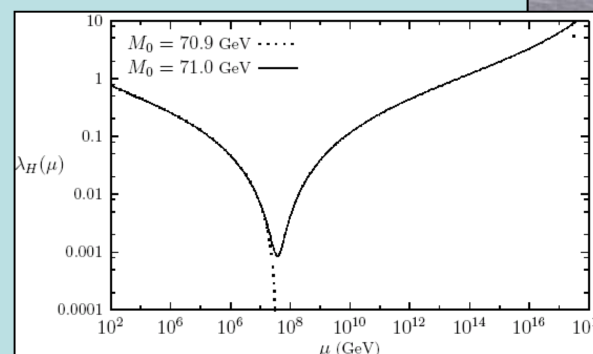
How to Stabilize a Light Higgs Boson?

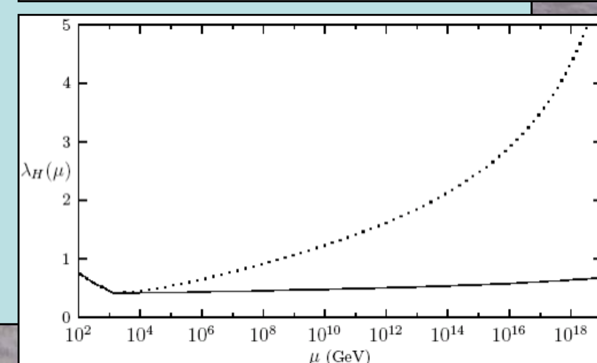
- Top quark destabilizes potential: introduce stop-like scalar:

$$\mathcal{L} \supset \ M^2|\phi|^2 + \frac{M_0}{v^2}|H|^2\,|\phi|^2$$

- Can delay collapse of potential:
- But new coupling must be fine-tuned to avoid blow-up:
- Stabilize with new fermions:
  – just like Higgsinos
- Very like **Supersymmetry!**







JE & D. Ross

The Stakes in the Higgs Search

- How is particle symmetry broken?
- Is there an elementary scalar field?
- What is the fate of the Standard Model?
- Did mass appear when the Universe was a picosecond old?
- Did Higgs help create the matter in the Universe?
- Did a related inflaton make the Universe so big and old?
- Why is there so little dark energy?

What lies Beyond?

Supersymmetry?

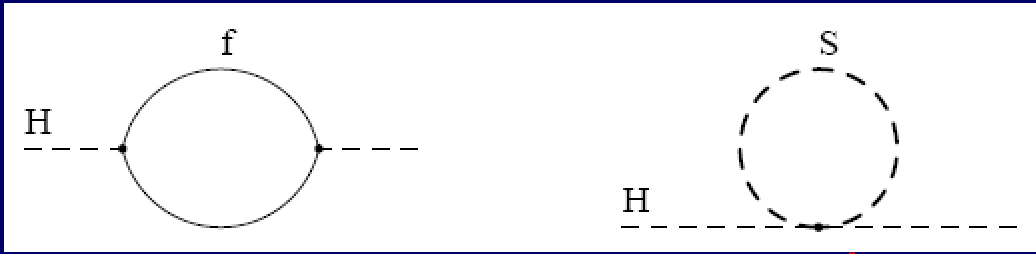
- Would unify matter particles and force particles
- Related particles spinning at different rates

  0 - ½ - 1 - 3/2 - 2

  Higgs - Electron - Photon - Gravitino – Graviton
- Many phenomenological motivations
  - Would help fix particle masses
  - Would help unify forces
  - Predicts light Higgs boson
  - Could fix discrepancy in $g_{\mu} - 2$
- **Could provide dark matter for the astrophysicists and cosmologists**

Loop Corrections to Higgs Mass^2

- Consider generic fermion and boson loops:



- Each is quadratically divergent: $\int^{\Lambda} d^4k/k^2$

$$\Delta m_H^2 = -\frac{y_f^2}{16\pi^2}[2\Lambda^2 + 6m_f^2 \ln(\Lambda/m_f) + ...]$$

$$\Delta m_H^2 = \frac{\lambda_S}{16\pi^2}[\Lambda^2 - 2m_S^2 \ln(\Lambda/m_S) + ...]$$

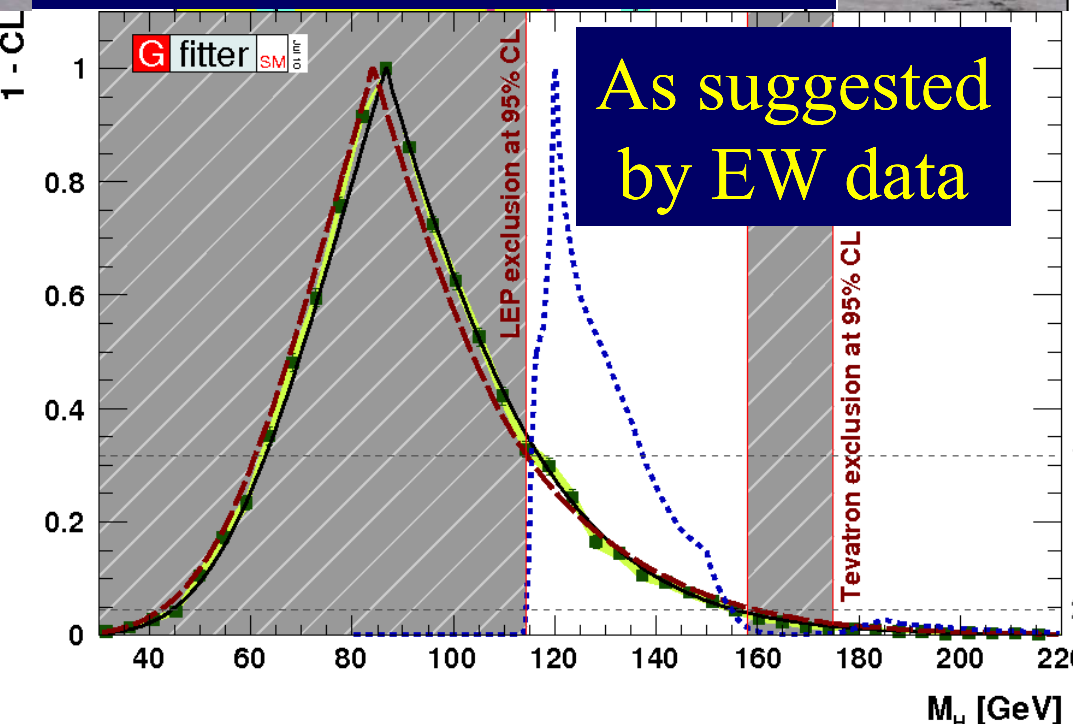
- Leading divergence cancelled if

$\lambda_S = y_f^2$ x 2 **Supersymmetry!**

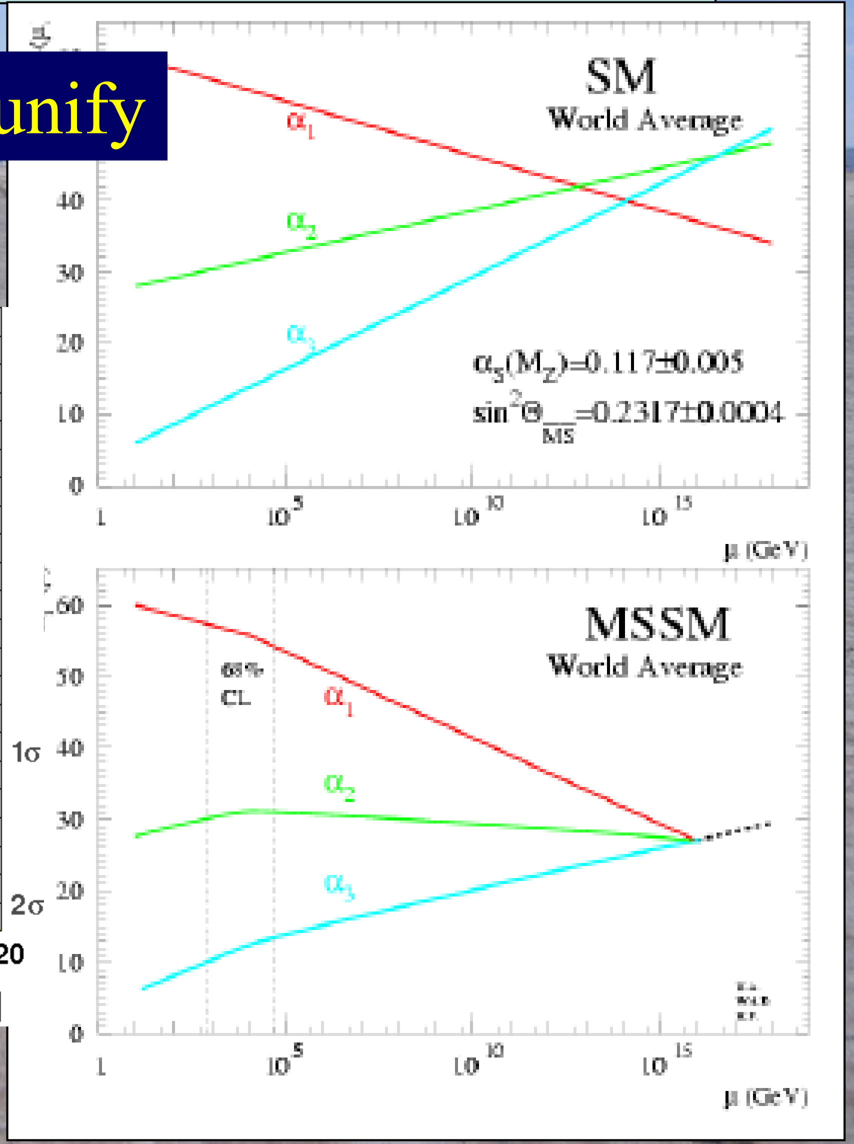
Reasons to like Supersymmetry

It enables the gauge couplings to unify

It predicts $m_H < 150$ GeV



As suggested by EW data



Minimal Supersymmetric Extension of Standard Model (MSSM)

- Particles + spartners

$$\begin{pmatrix}\frac{1}{2}\\0\end{pmatrix} \; e.g., \; \begin{pmatrix}\ell\ (lepton)\\ \tilde{\ell}\ (slepton)\end{pmatrix} \; or \; \begin{pmatrix}q\ (quark)\\ \tilde{q}\ (squark)\end{pmatrix} \quad \begin{pmatrix}1\\ \frac{1}{2}\end{pmatrix} \; e.g., \; \begin{pmatrix}\gamma\ (photon)\\ \tilde{\gamma}\ (photino)\end{pmatrix} \; or \; \begin{pmatrix}g\ (gluon)\\ \tilde{g}\ (gluino)\end{pmatrix}$$

- 2 Higgs doublets, coupling μ, ratio of v.e.v.'s = $\tan\beta$
- Unknown supersymmetry-breaking parameters:

  Scalar masses m_0, gaugino masses $m_{1/2}$,
  trilinear soft couplings A_λ, bilinear soft coupling B_μ
- Often assume universality:

  Single m_0, single $m_{1/2}$, single A_λ, B_μ: not string?
- Called constrained* MSSM = CMSSM (* at what scale?)
- Minimal supergravity (mSUGRA) predicts gravitino mass: $m_{3/2} = m_0$ and relation: $B_\mu = A_\lambda - m_0$

Lightest Sparticle as Dark Matter

Fayet

- Stable in many models because of conservation of R parity:

  $R = (-1)^{2S - L + 3B}$

  where S = spin, L = lepton #, B = baryon #

- Particles have R = +1, sparticles R = -1:

  Sparticles produced in pairs

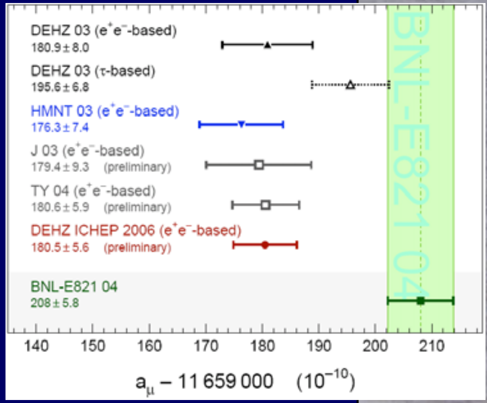
  Heavier sparticles → lighter sparticles

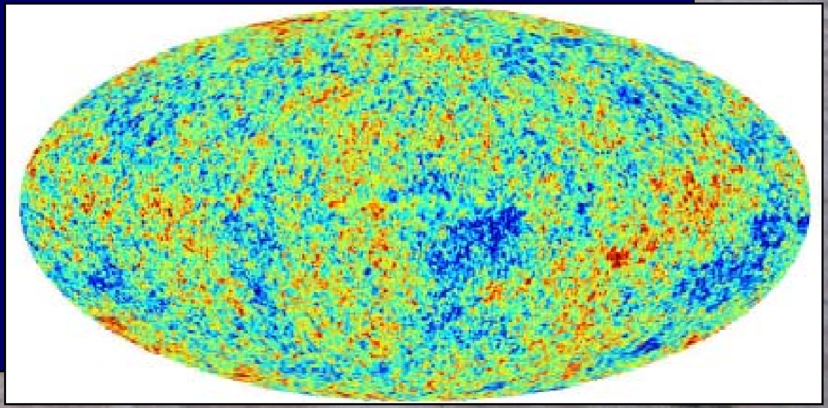
- Lightest supersymmetric particle (LSP) stable
- Present in Universe today as relic from Big Bang

Constraints on Supersymmetry

- Absence of sparticles at LEP, Tevatron
  - selectron, chargino > 100 GeV
  - squarks, gluino > 400 GeV
- Indirect constraints
  - Higgs > 114 GeV, $b \to s\,\gamma$
- Density of dark matter
  - lightest sparticle χ:
  - $0.094 < \Omega_\chi h^2 < 0.124$

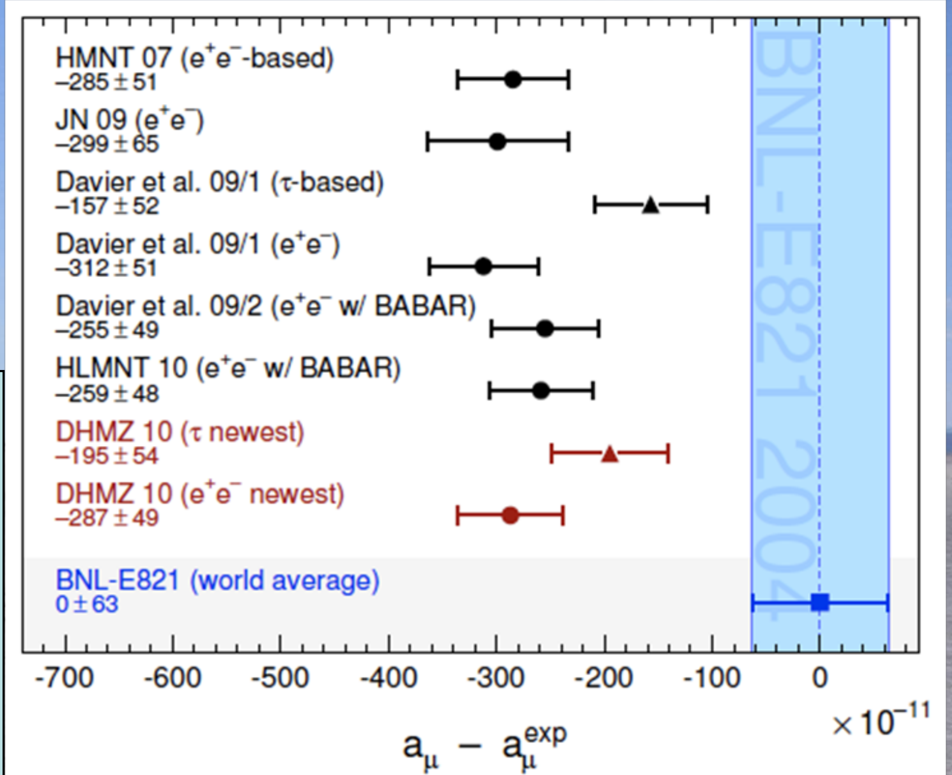
3 σ effect in $g_\mu - 2$?

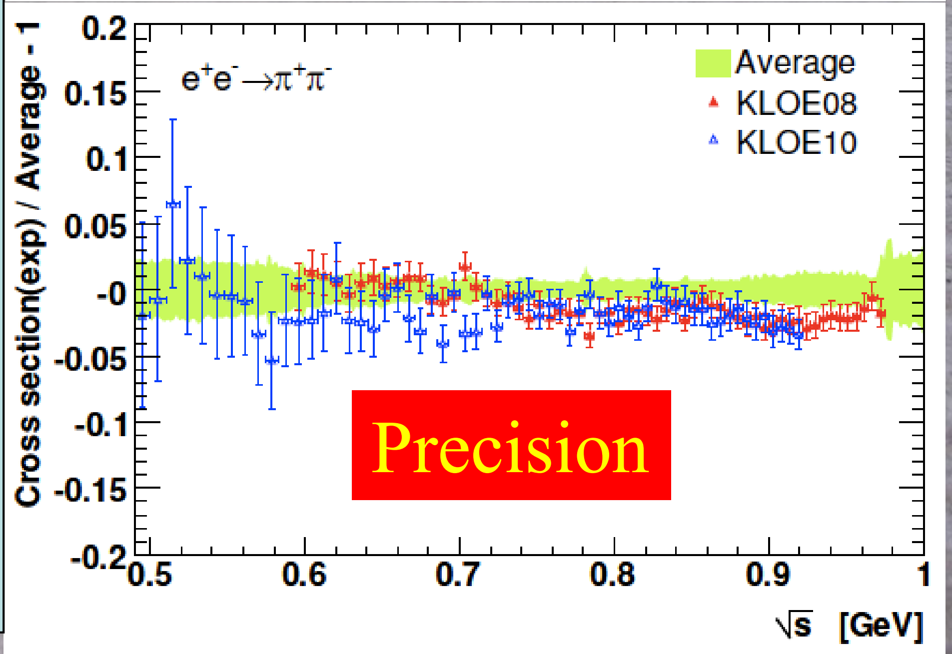




Quo Vadis g_μ - 2?

- Strong discrepancy between BNL experiment and e^+e^- data:
  - now ~ 3.6 σ
- Decent agreement between e^+e^- experiments
- Increased discrepancy between BNL experiment and τ decay data
  - now ~ 2.4 σ
- Convergence between e^+e^- experiments and τ decay data?
- **More credibility?**





Precision

Pre-LHC Constraints on CMSSM

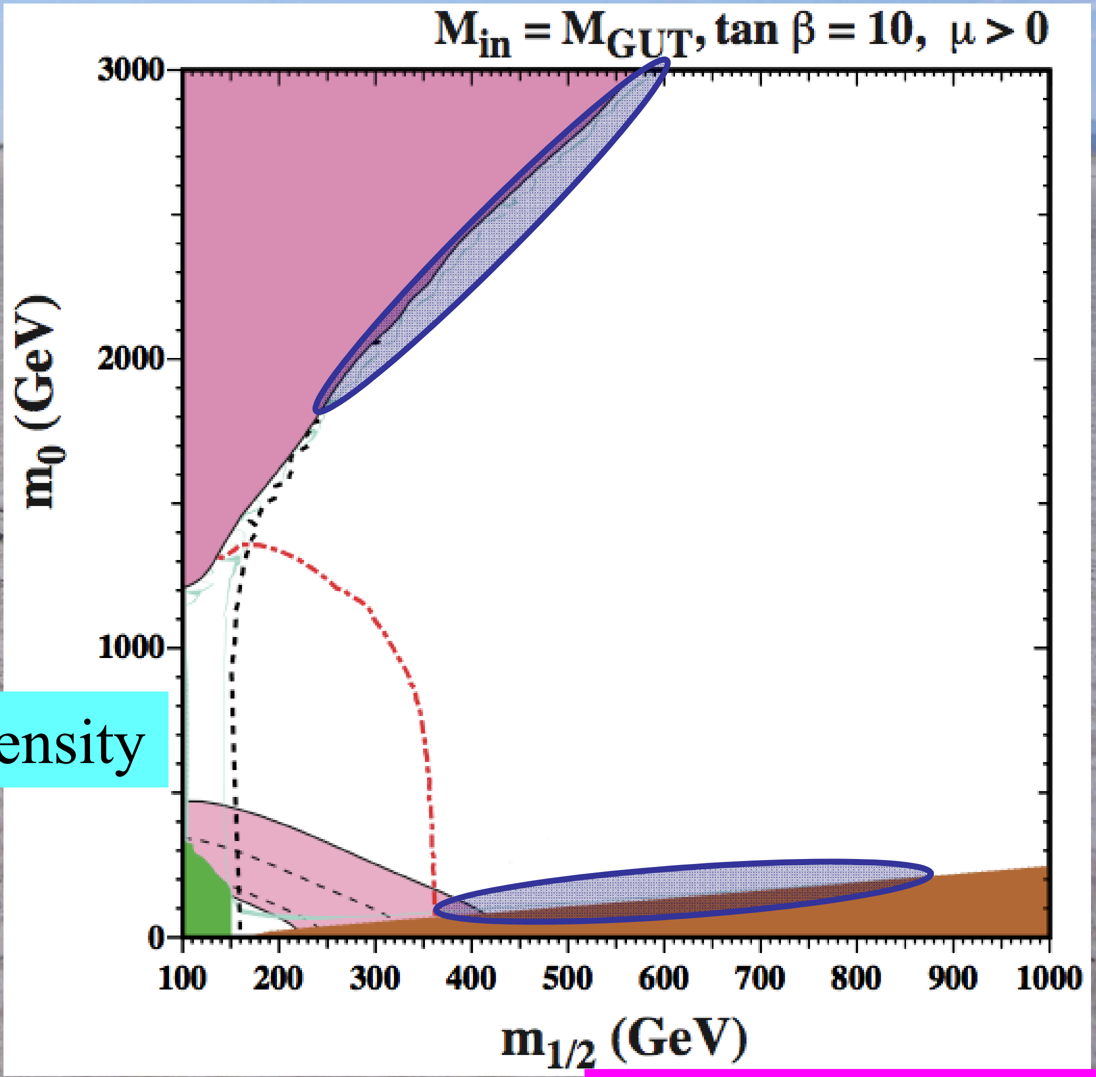
Assuming the lightest sparticle is a neutralino

Excluded because stau LSP

Excluded by b → s gamma

WMAP constraint on relic density

Preferred (?) by latest g - 2



JE + Olive + Santoso + Spanos

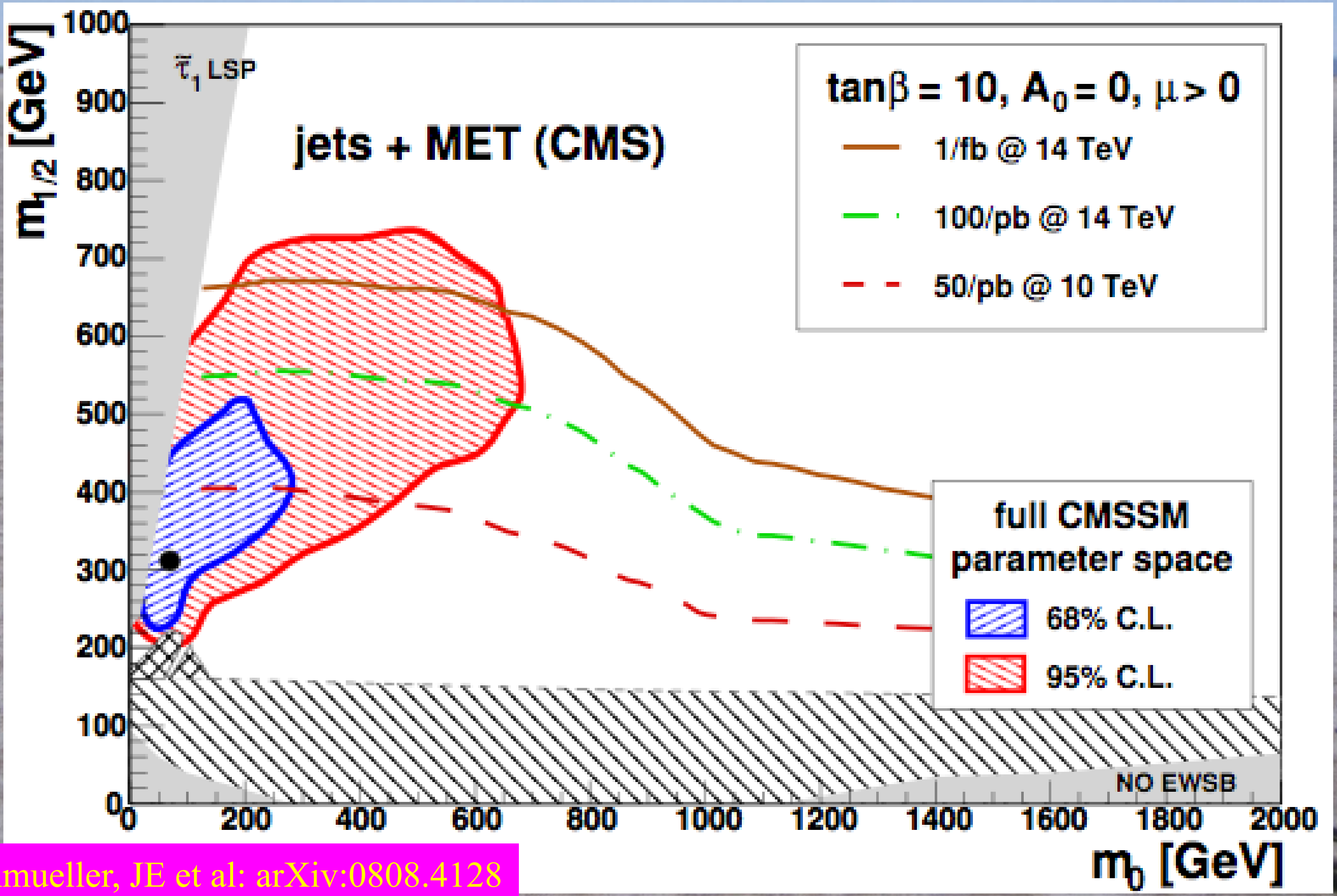
Global Supersymmetric Fits

- Frequentist approach
- Data used:
  - Precision electroweak data
  - Higgs mass limit
  - cold dark matter density
  - B decay data ($b \rightarrow s \gamma$, $B_s \rightarrow \mu^+\mu^-$)
  - g_μ - 2 (optional)
- Combine likelihood functions pre/post-LHC
- Analyze CMSSM, NUHM1 (VCMSSM, mSUGRA)

O.Buchmueller, JE et al: arXiv:0808.4128, 0907.5568, 0912.1036, 1011.6118, 1102.4585

Pre-LHC

How Soon Might the CMSSM be Detected?



O.Buchmueller, JE et al: arXiv:0808.4128

Strategies for Detecting Supersymmetric Dark Matter

- Scattering on nucleus in laboratory

  $\chi + A \rightarrow \chi + A$
- Annihilation in core of Sun or Earth

  $\chi - \chi \rightarrow \nu + \ldots \rightarrow \mu + \ldots$
- Annihilation in galactic centre

  $\chi - \chi \rightarrow \gamma + \ldots ?$
- Annihilation in galactic halo

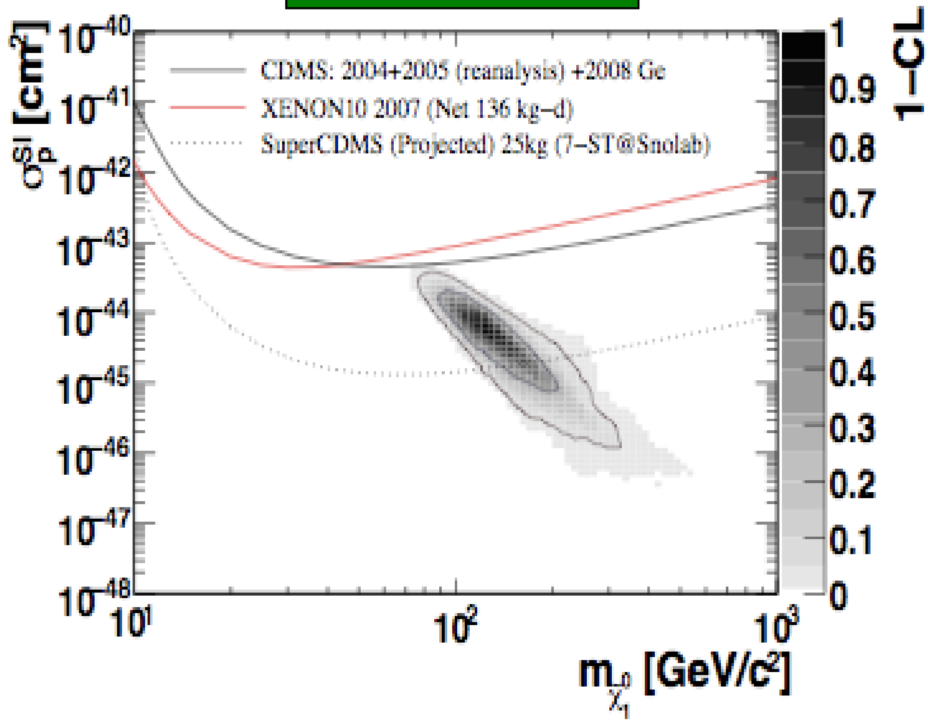
  $\chi - \chi \rightarrow$ antiprotons, positrons, …?

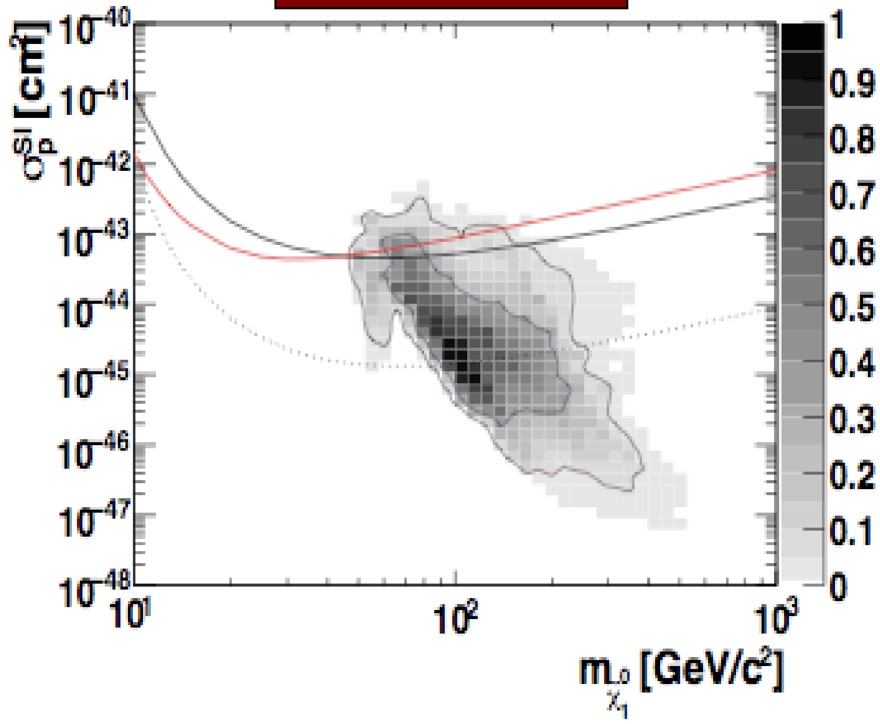
Pre-LHC

Elastic Scattering Cross Sections

CMSSM

NUHM1





O.Buchmueller, JE et al: arXiv:0907.5568

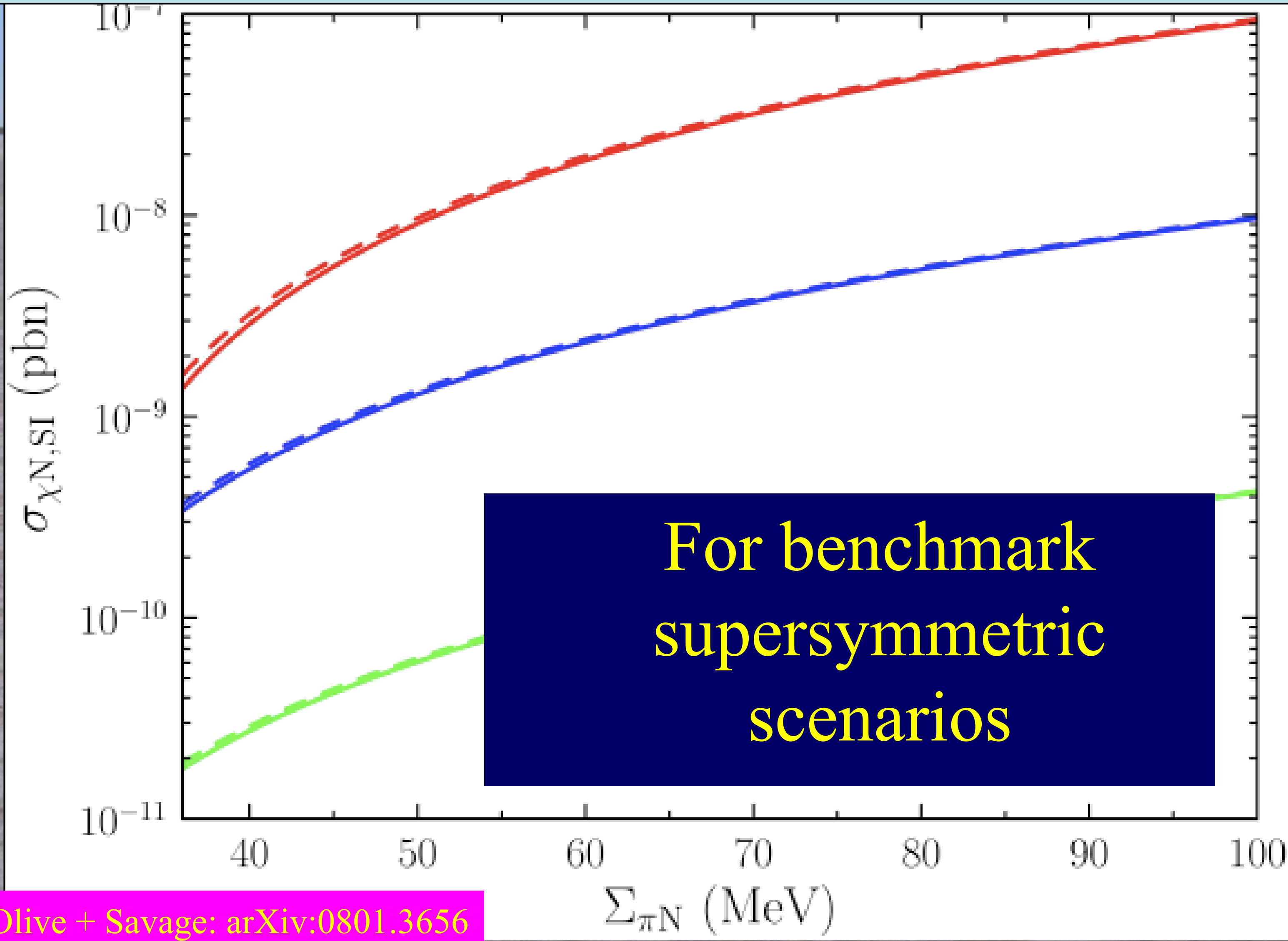
Importance of the π-N σ Term ($\Sigma_{\pi N}$)

- Higgs exchange important for spin-independent DM scattering
- **Sensitive to $\langle N|\bar{s}s|N\rangle$**
- Baryon masses: $\sigma_0 = ½(m_u + m_d)\langle N|\bar{u}u + \bar{d}d - 2\bar{s}s|N\rangle$

  $= 36 \pm 7$ MeV
- Cf, $\Sigma_{\pi N} = ½(m_u + m_d)\langle N|\bar{u}u + \bar{d}d|N\rangle$
- Strangeness ratio $y = \langle N|2\bar{s}s|N\rangle / \langle N|\bar{u}u + \bar{d}d|N\rangle$

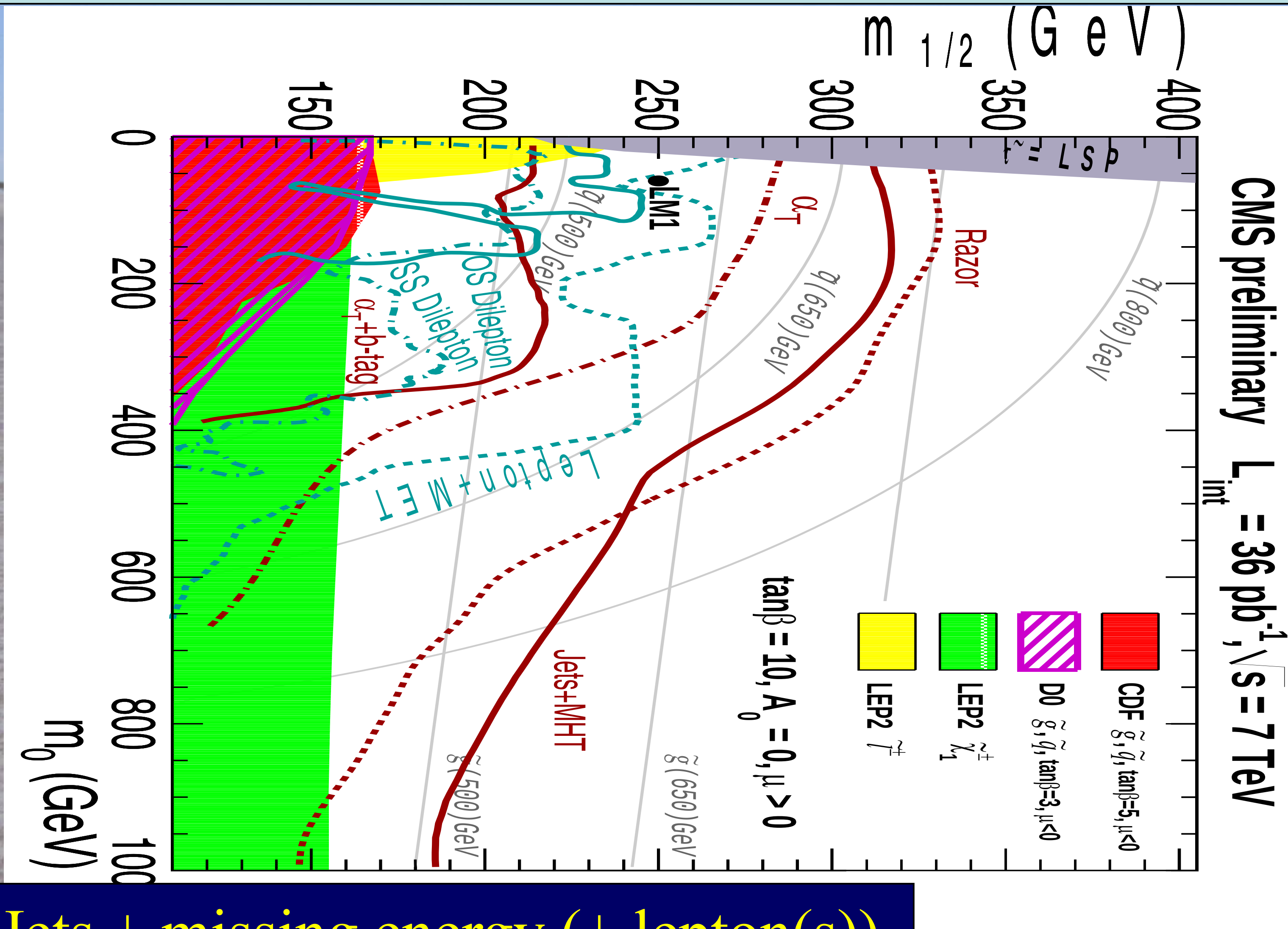
  $= 1 - \sigma_0/\Sigma_{\pi N}$
- Some experiments suggest large value of $\Sigma_{\pi N} = 64 \pm 8$ MeV, hence y large
- Some lattice calculations suggest y small

Sensitivity to π-N Scattering σ Term



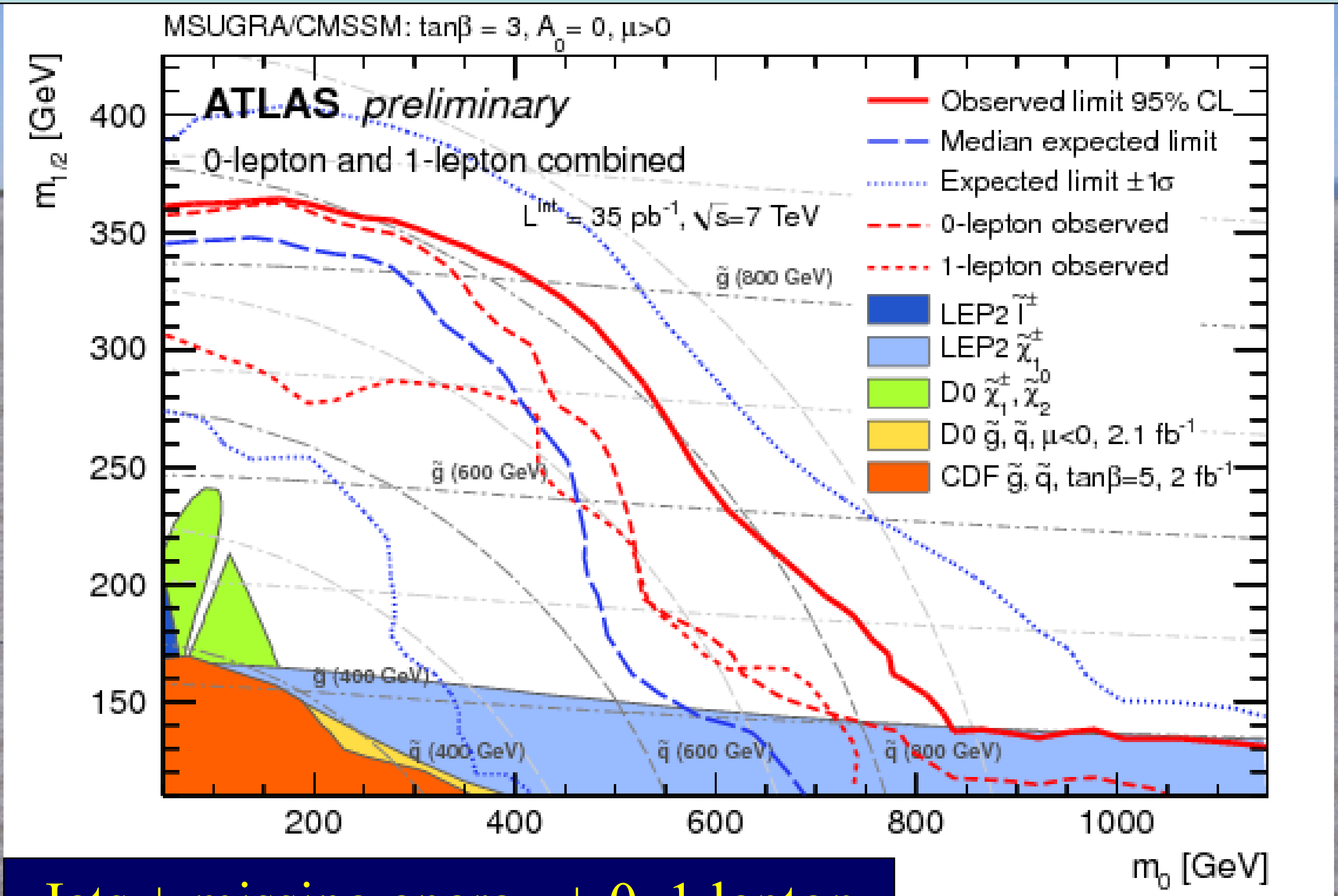
JE + Olive + Savage: arXiv:0801.3656

Supersymmetry Searches in CMS



Jets + missing energy (+ lepton(s))

Supersymmetry Searches in ATLAS



Jets + missing energy + 0, 1 lepton

Impact of LHC on the CMSSM

Assuming the lightest sparticle is a neutralino

CMS MHT

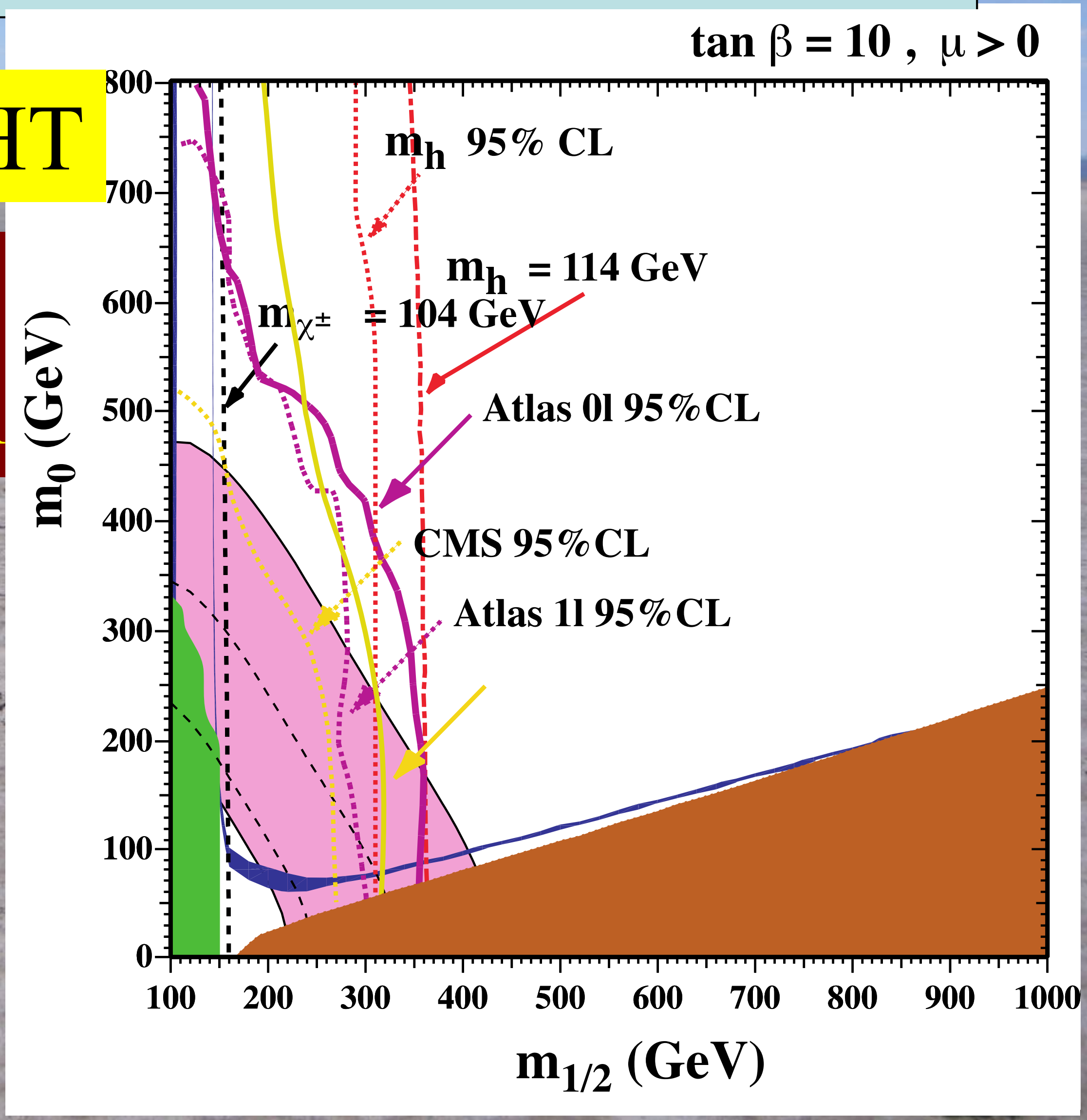
ATLAS 0 Lepton

Excluded because stau LSP

Excluded by b → s gamma

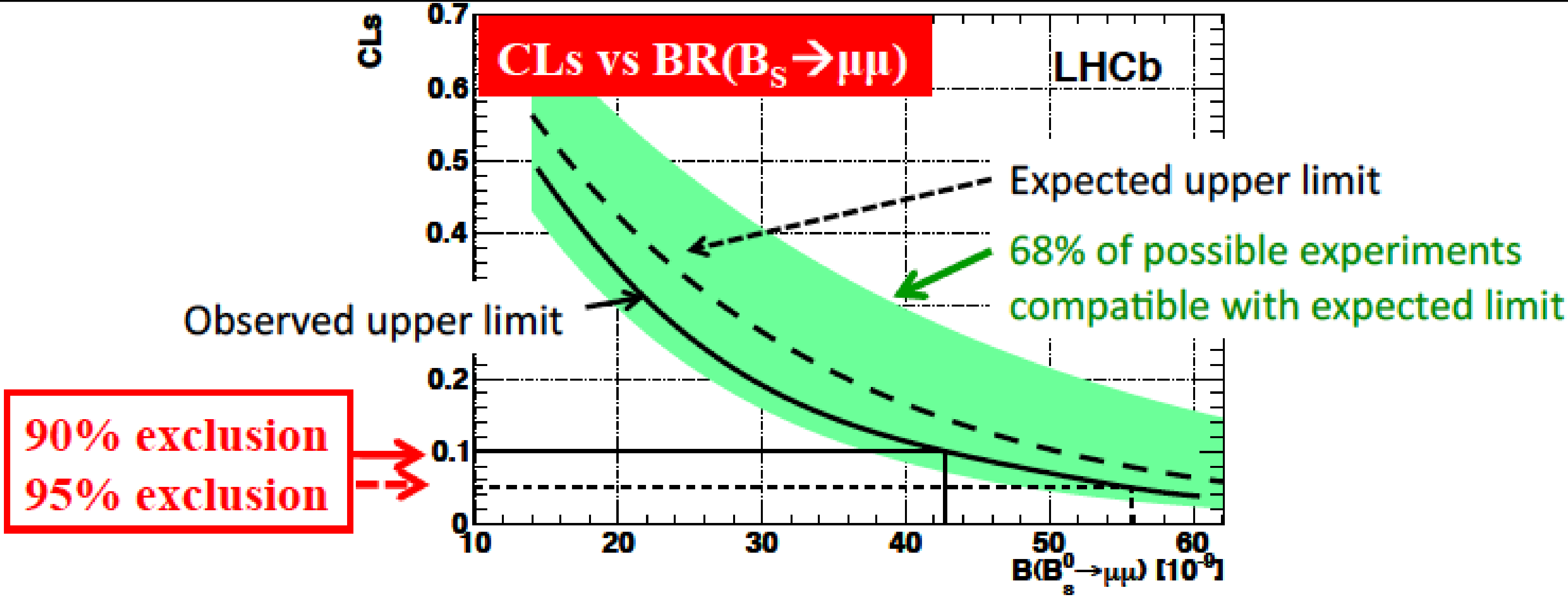
WMAP constraint on CDM density

Preferred (?) by latest g - 2



Rare decay

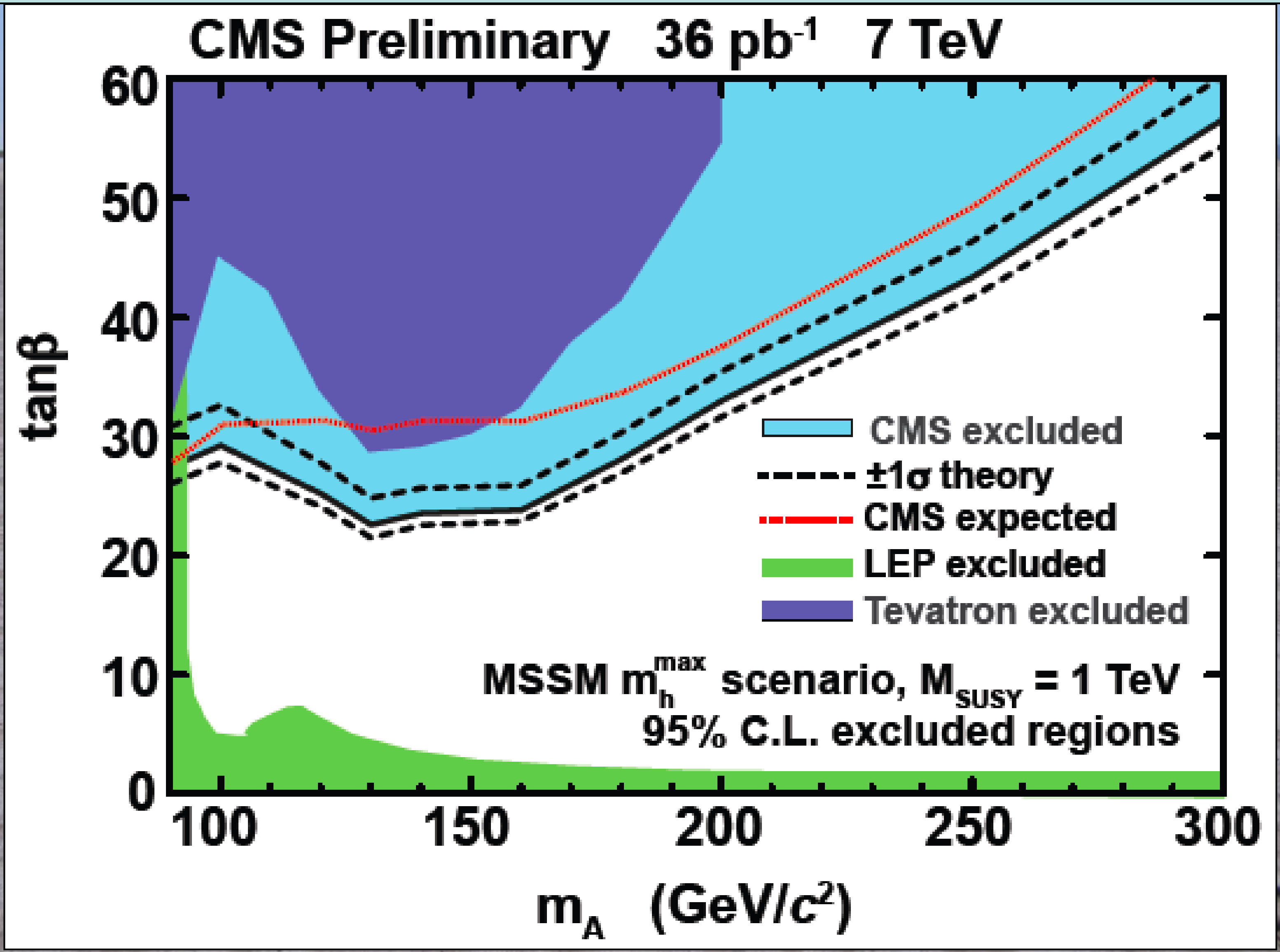
LHCb Upper Limit on BR($B_s \rightarrow \mu^+\mu^-$)



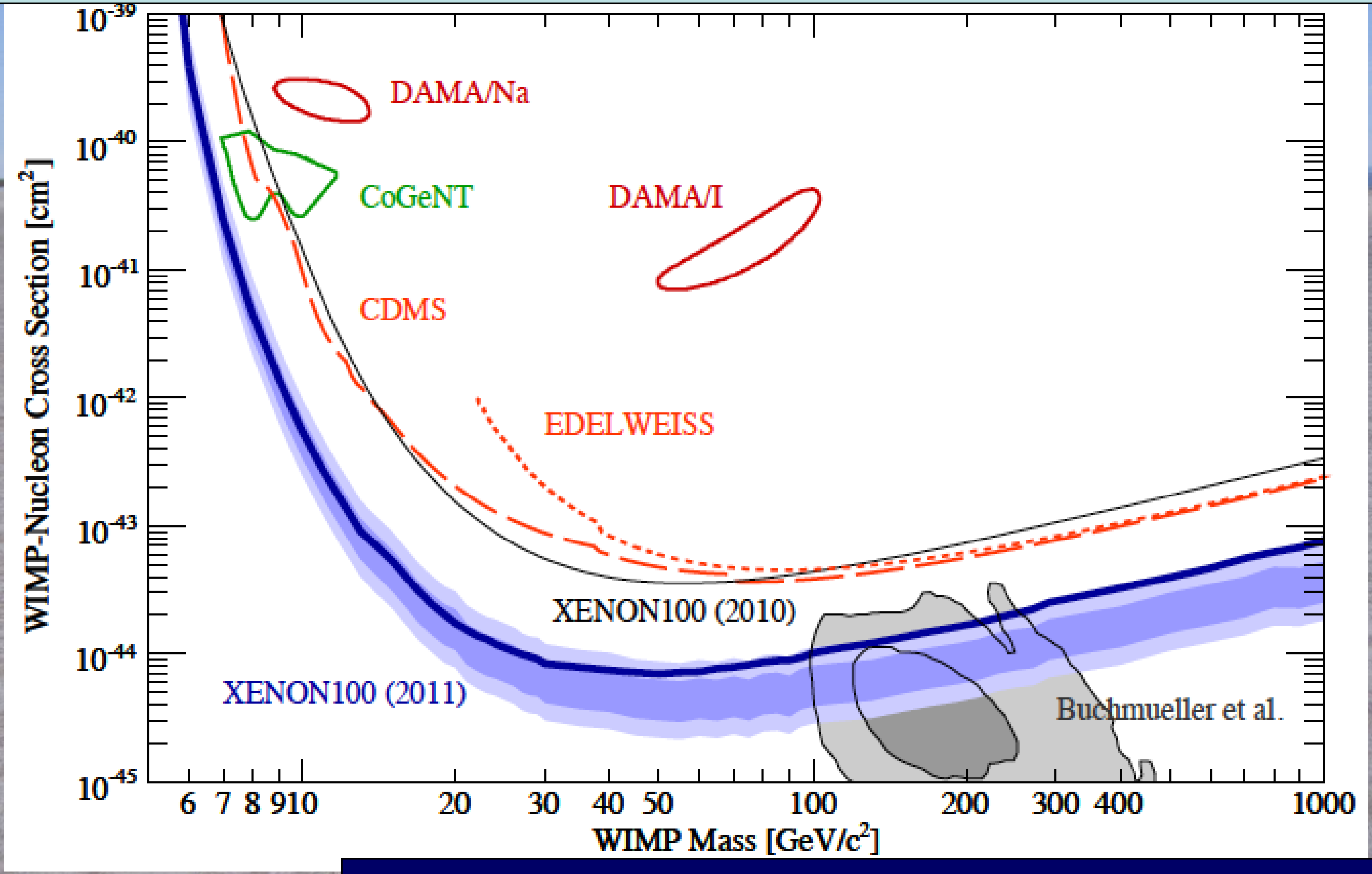
		@ 90% CL	@ 95% CL
LHCb	Observed (expected), **37 pb^{-1}**	< 43 (51) $\times 10^{-9}$	< 56 (65) $\times 10^{-9}$
D0	World best published, **6.1 fb^{-1}** PLB 693 539 (2010)	< 42 $\times 10^{-9}$	< 51 $\times 10^{-9}$
CDF	Preliminary, **3.7 fb^{-1}** Note 9892	< 36 $\times 10^{-9}$	< 43 $\times 10^{-9}$

Potential impact of LHCb, CDF and D0

Limits on Heavy MSSM Higgses



Xenon100 Experiment

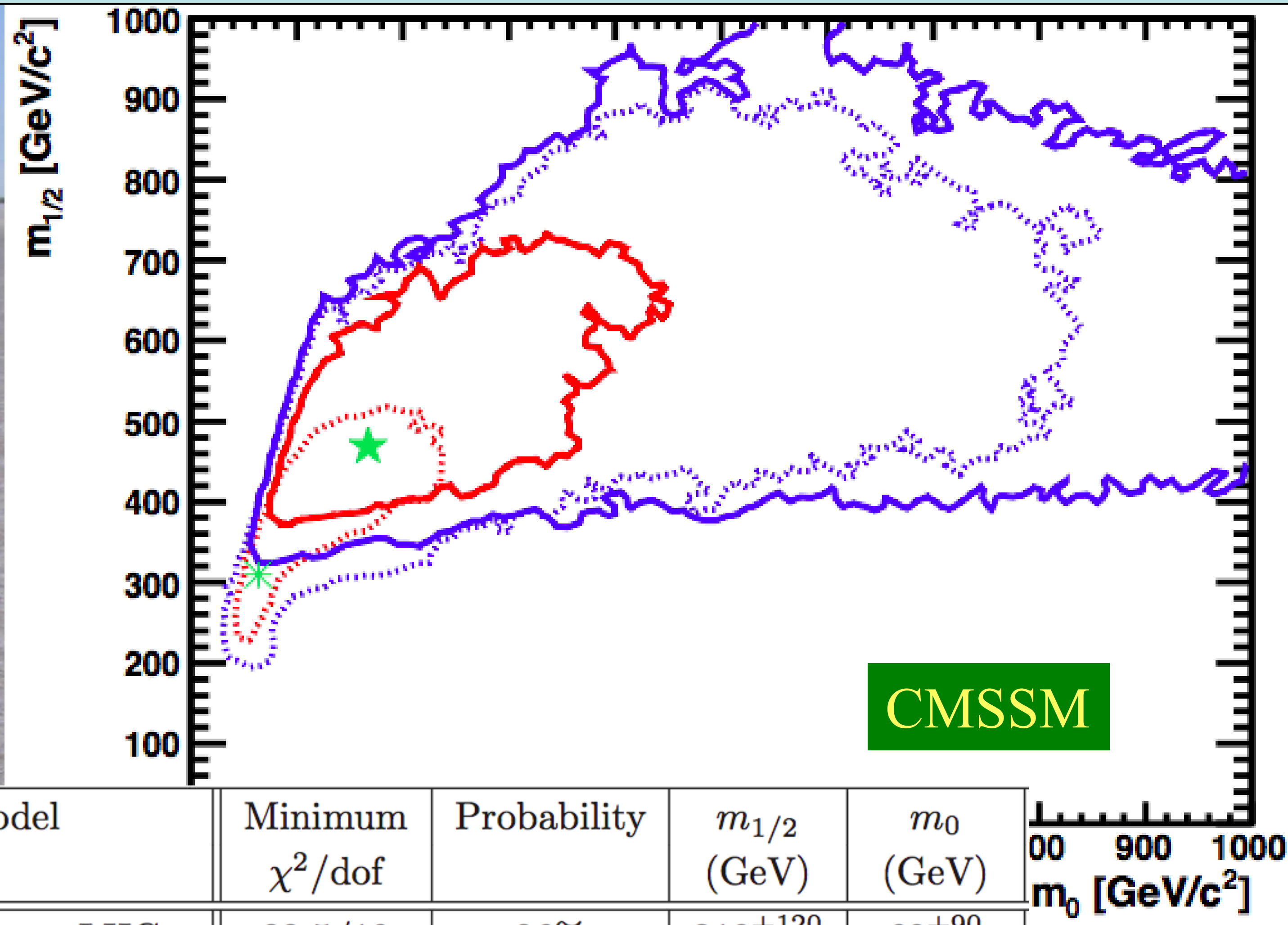


Best available limit with 100 days of data

Aprile et al: arXiv:1104.2549

Full LHC 2010 data

CMSSM (m_0, $m_{1/2}$) Plane Revisited

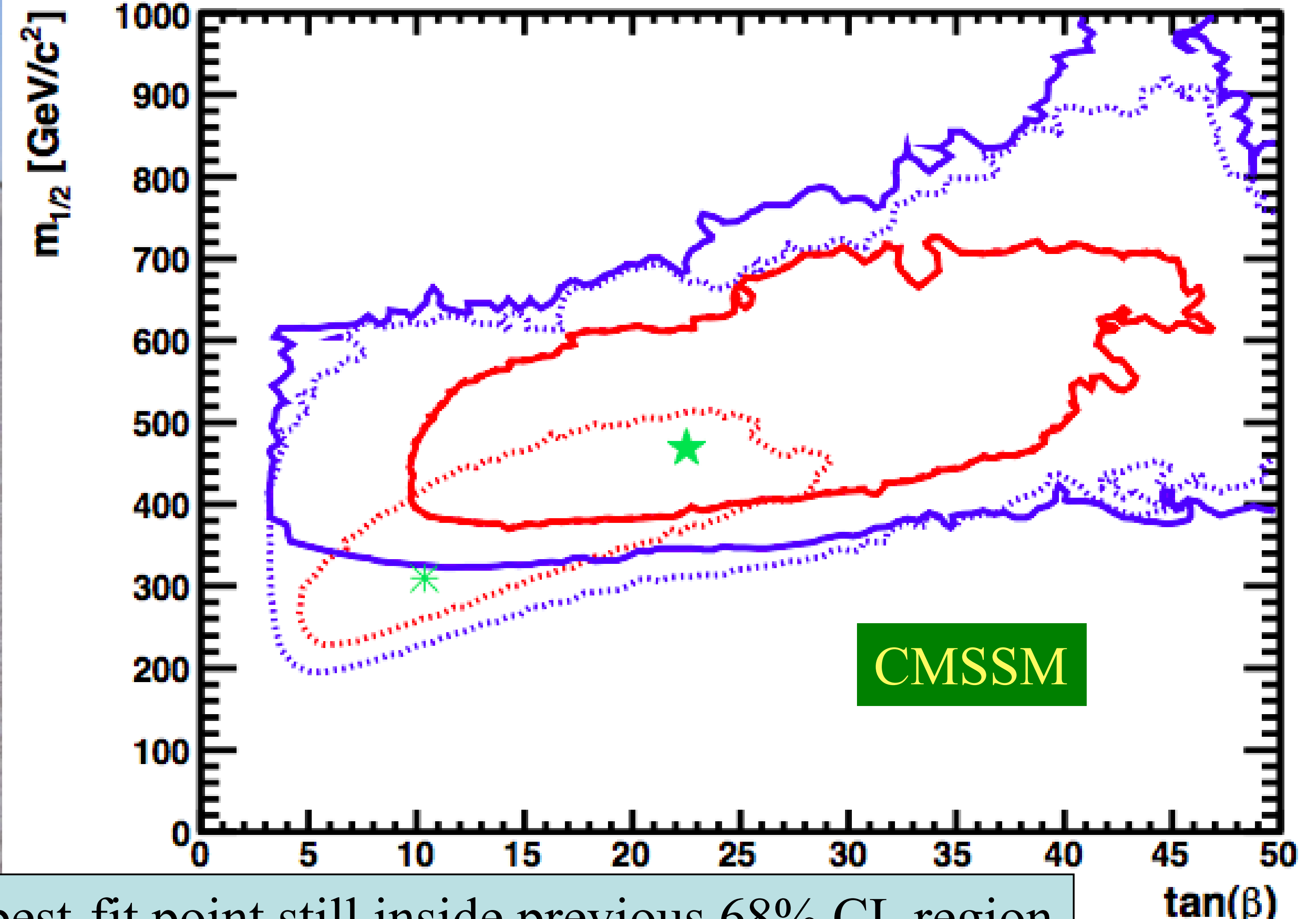


Model	Minimum χ^2/dof	Probability	$m_{1/2}$ (GeV)	m_0 (GeV)
CMSSM pre-LHC	22.5/19	26%	310^{+120}_{-50}	60^{+90}_{-10}
post-2010-LHC	26.1/19	13%	470^{+140}_{-70}	170^{+330}
post-Xenon (50 ± 14)	26.2/20	16%	470^{+140}_{-70}	1

O.Buchmueller, JE et al: in preparation

Full LHC 2010 data

CMSSM (tan β, $m_{1/2}$) Plane



New best-fit point still inside previous 68% CL region

➔ No significant tension or conflict

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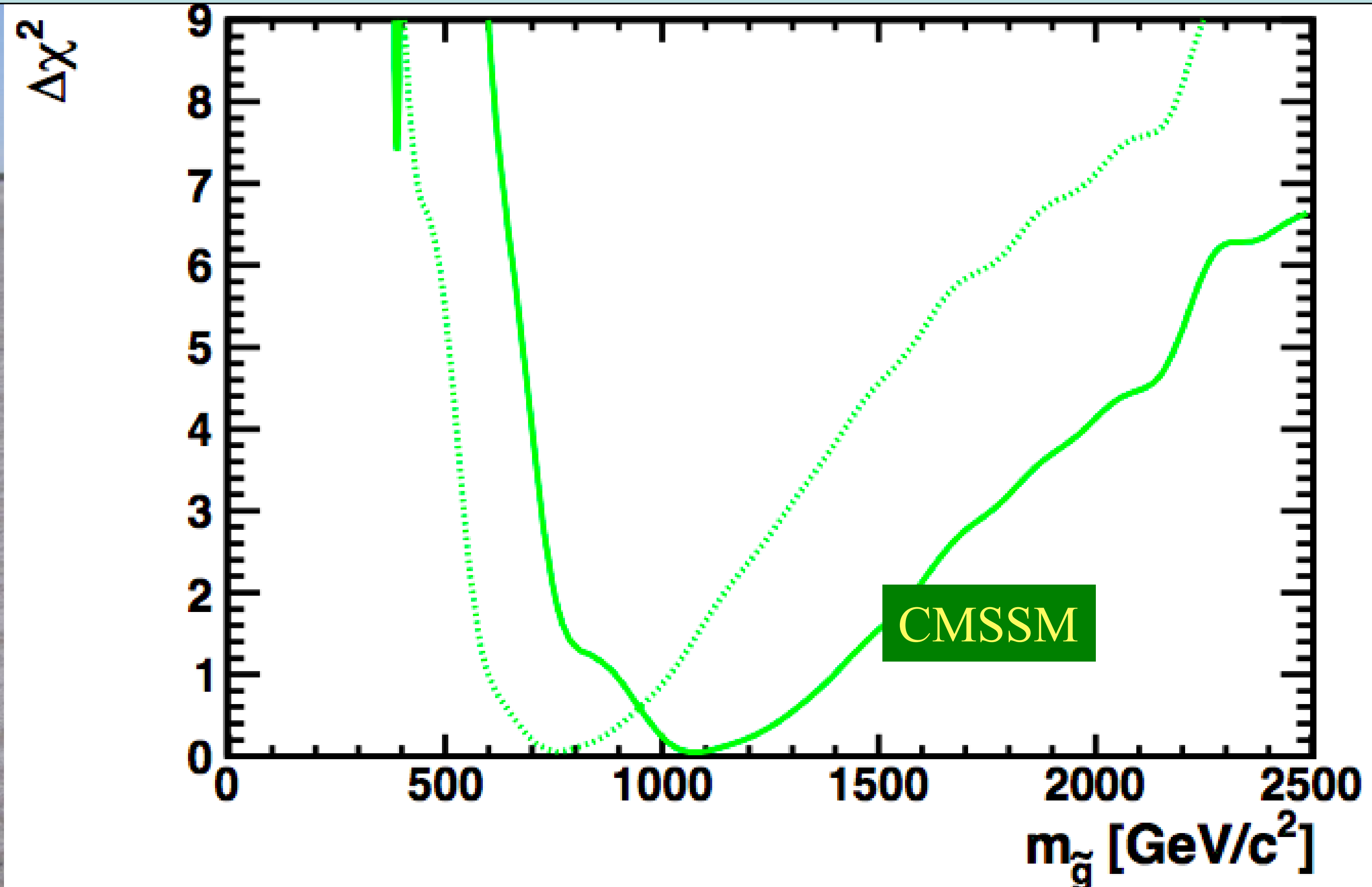
CMSSM Gluino Mass



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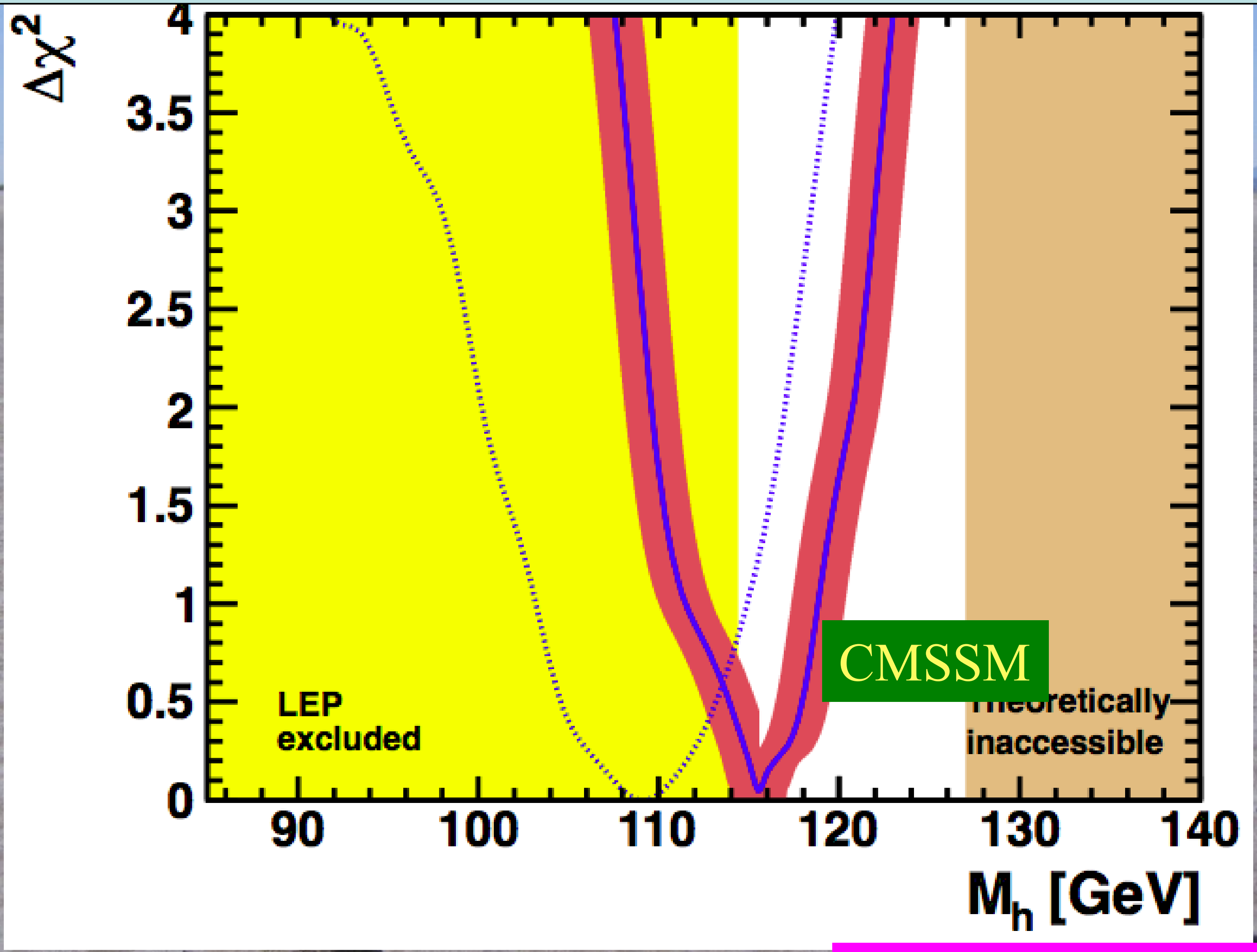
Full LHC 2010 data

CMSSM HiggsMass



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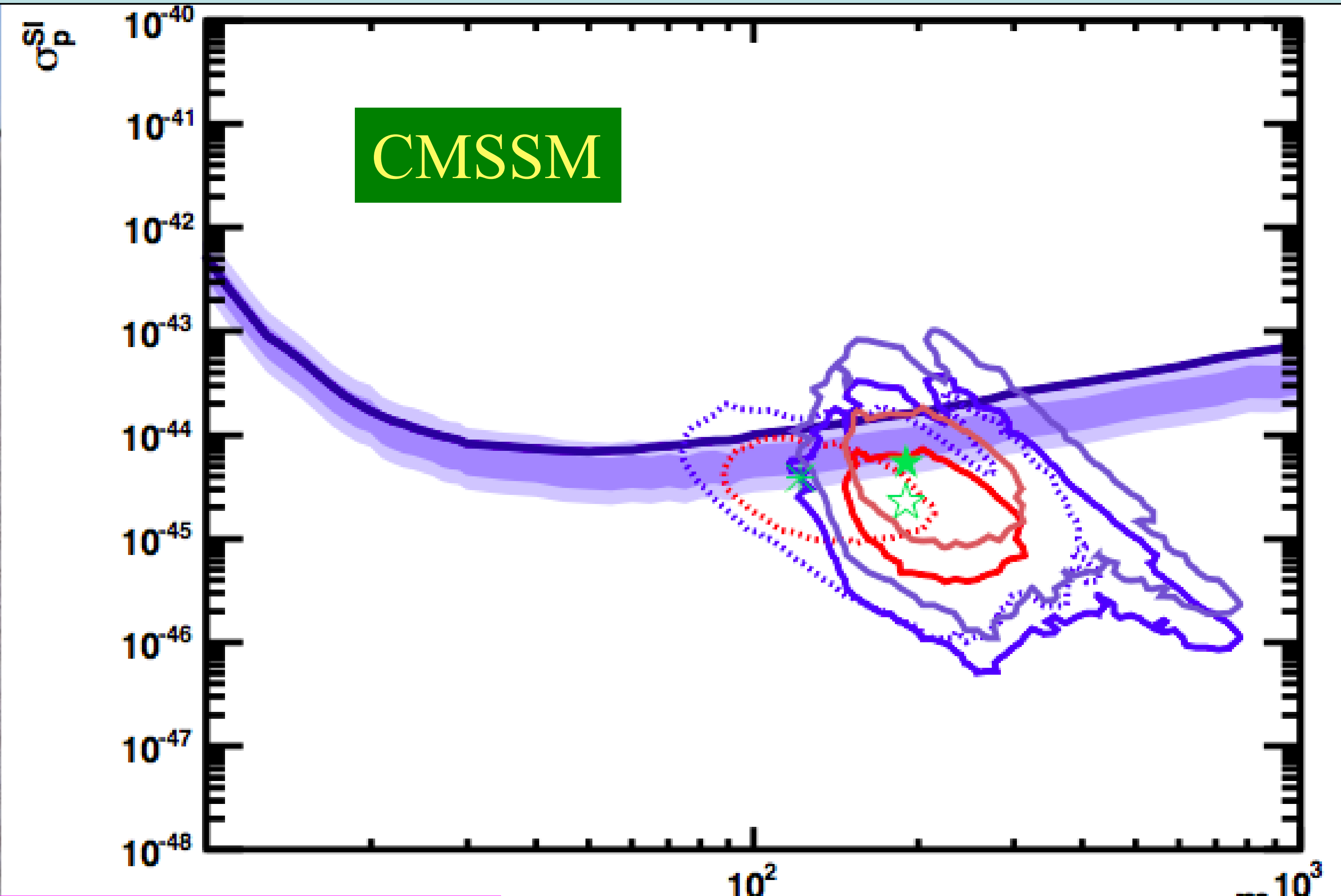
Impact of Xenon100 on LHC Fit



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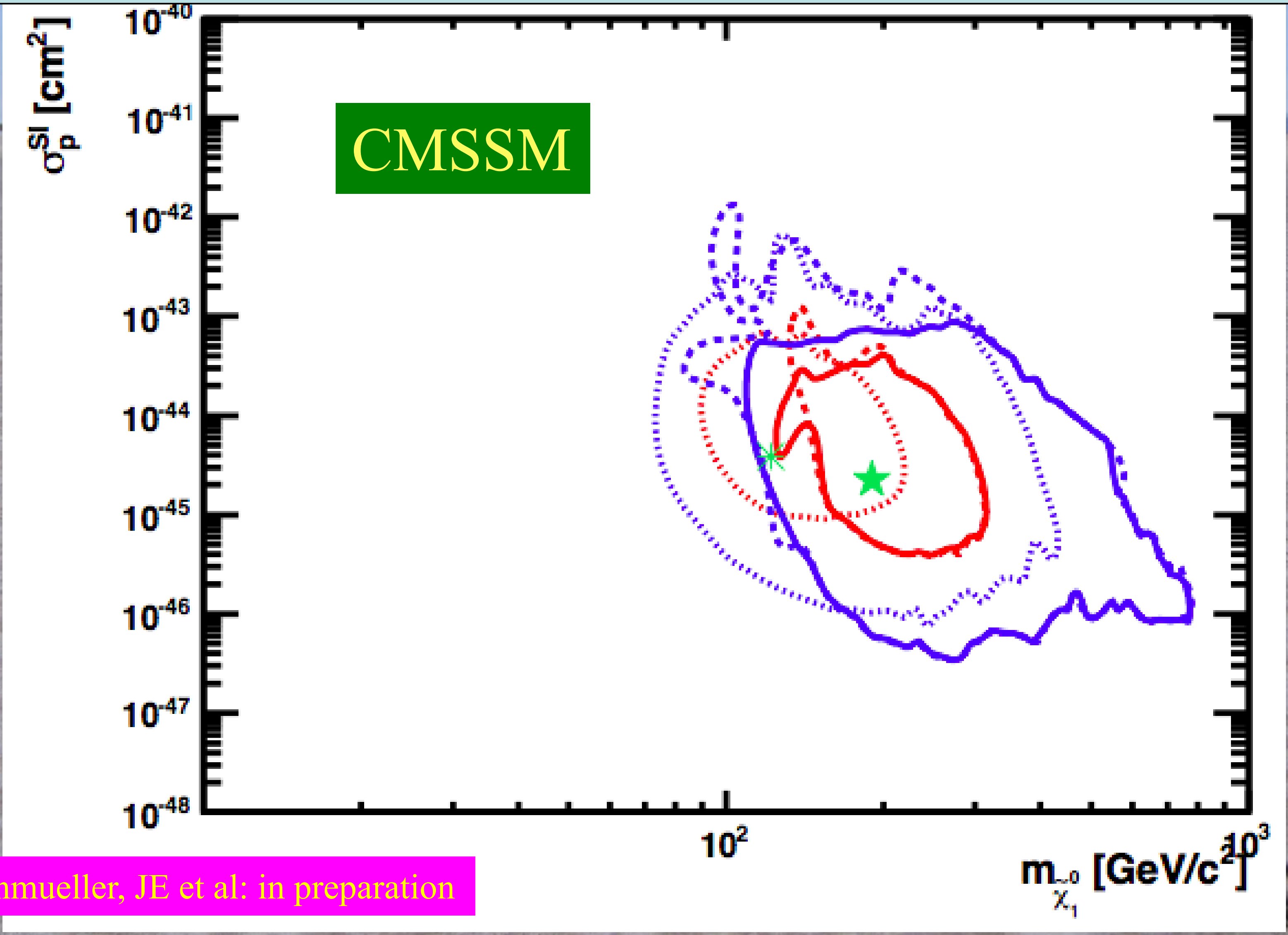

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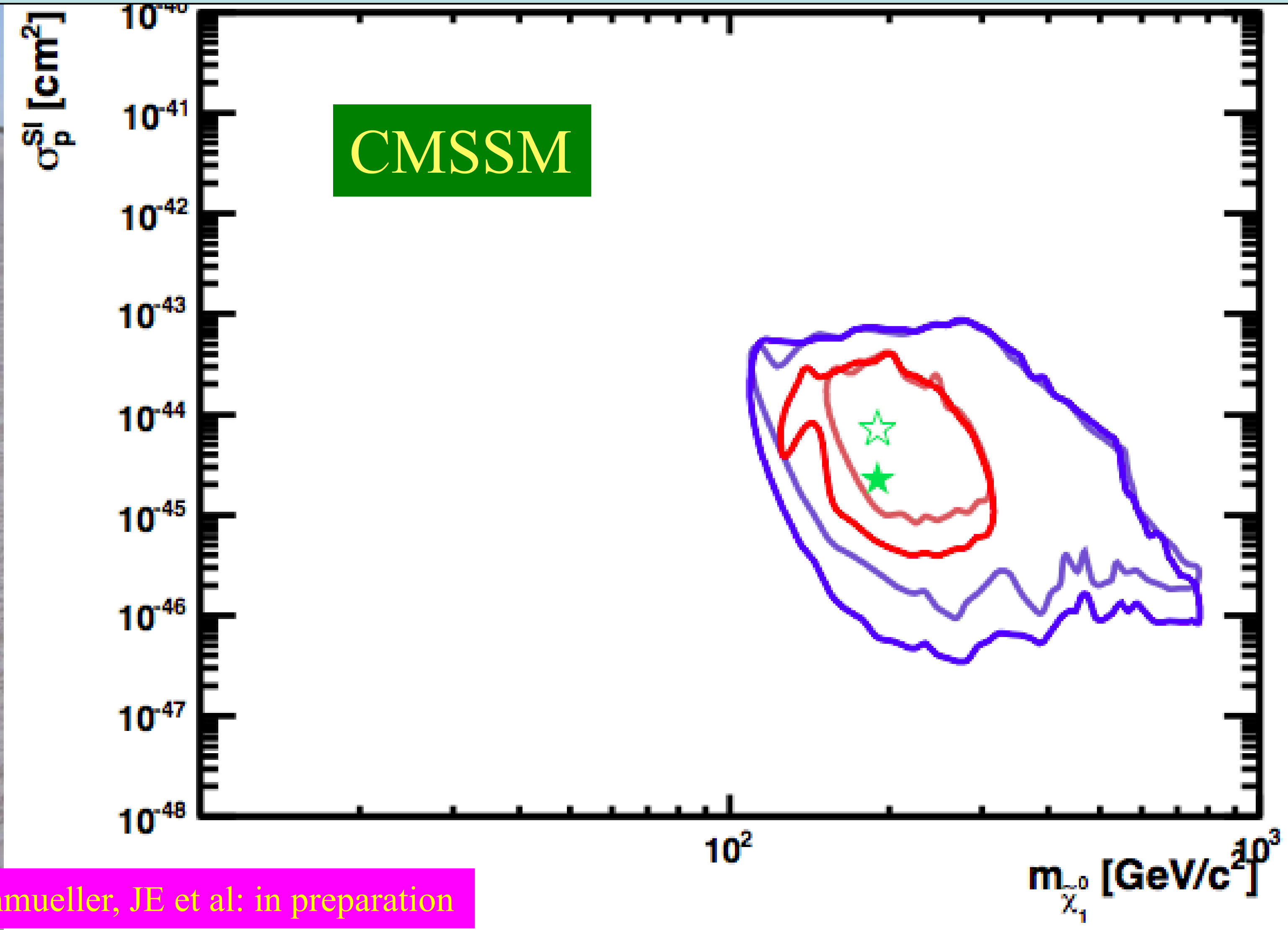
Impact of Xenon100 on LHC Fit



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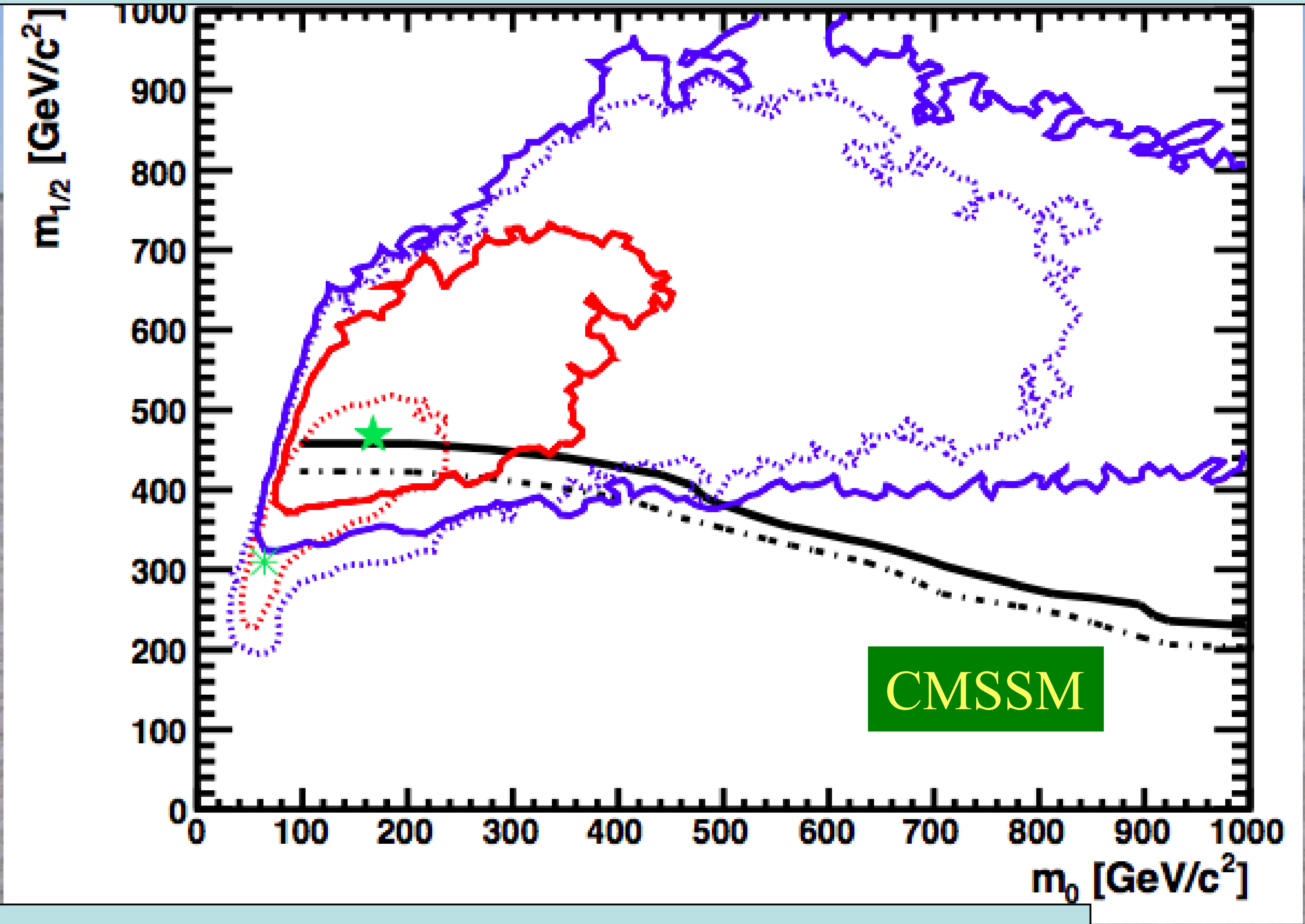
Caveat LHC 2011 data

CMSSM (m_0, $m_{1/2}$) Plane Revisited



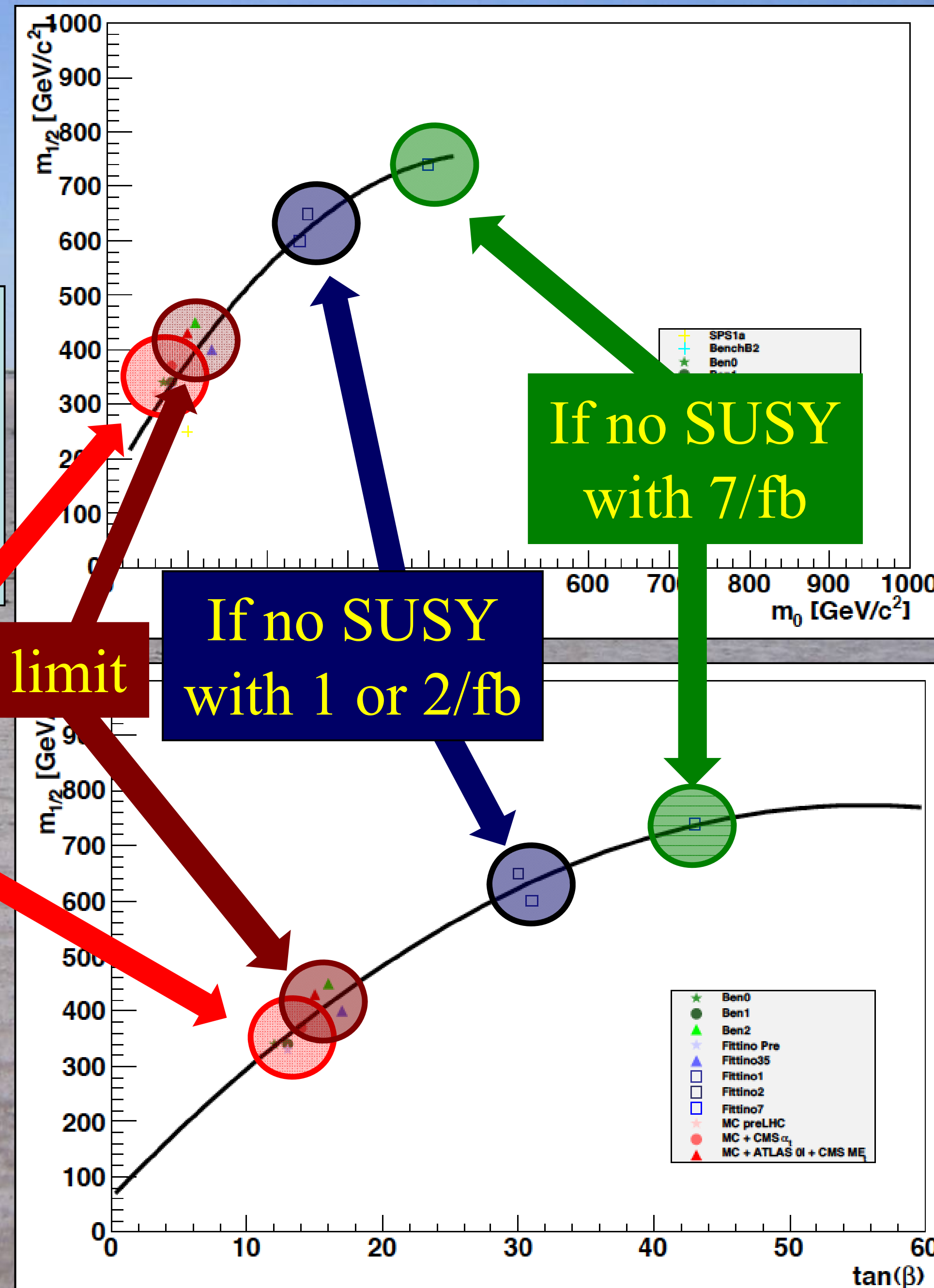
New best-fit point still inside previous 68% CL region

➔ No significant tension or conflict

O.Buchmueller, JE et al: in preparation

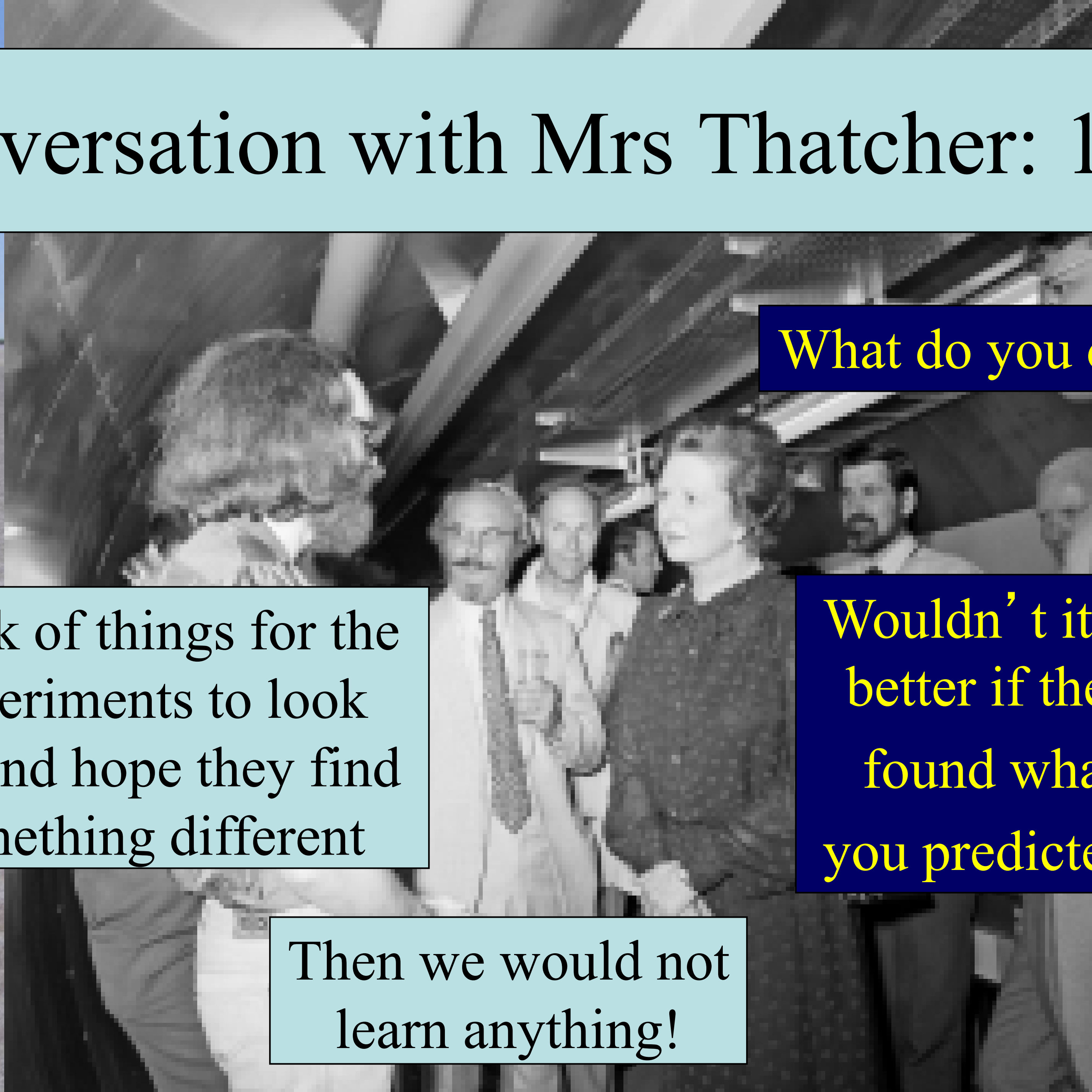
Trajectory of CMSSM Fits

How have best-fit CMSSM points evolved?
How would they evolve if SUSY is not discovered in 2011/2?



→ Old benchmarks
★ Pre-LHC fits
♦ After LHC 2010
■ After LHC 2011?

Conversation with Mrs Thatcher: 1982



What do you do?

Think of things for the experiments to look for, and hope they find something different

Wouldn't it be better if they found what you predicted?

Then we would not learn anything!

Strategies for Detecting Supersymmetric Dark Matter

- Scattering on nucleus in laboratory

$$\chi + A \rightarrow \chi + A$$

- Annihilation in core of Sun or Earth

$$\chi - \chi \rightarrow \nu + \ldots \rightarrow \mu + \ldots$$

- Annihilation in galactic centre

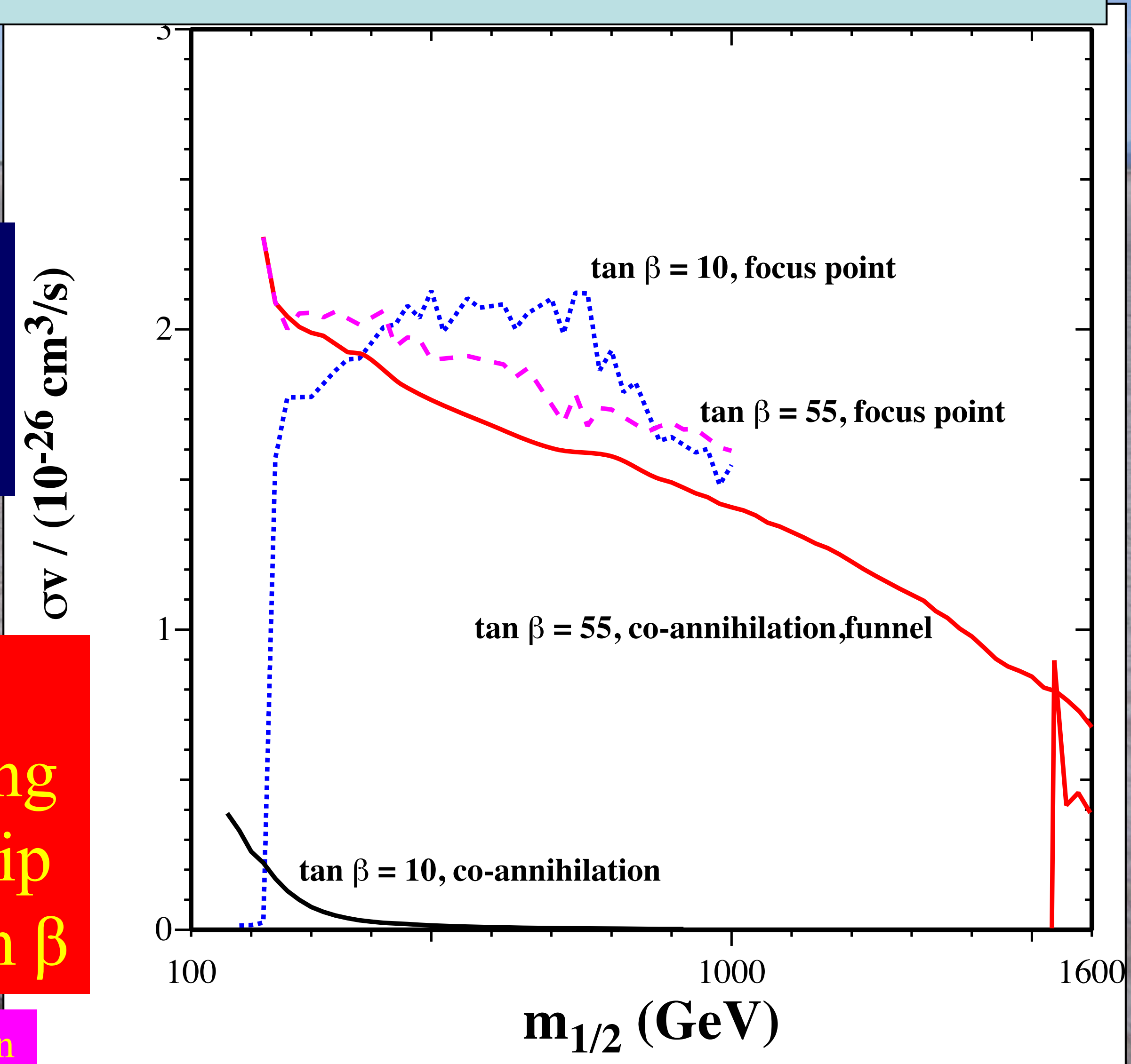
$$\chi - \chi \rightarrow \gamma + \ldots ?$$

- Annihilation in galactic halo

$$\chi - \chi \rightarrow \text{antiprotons, positrons, } \ldots ?$$

Neutralino Annihilation Rates

Small in coannihilation strip @ small tan β

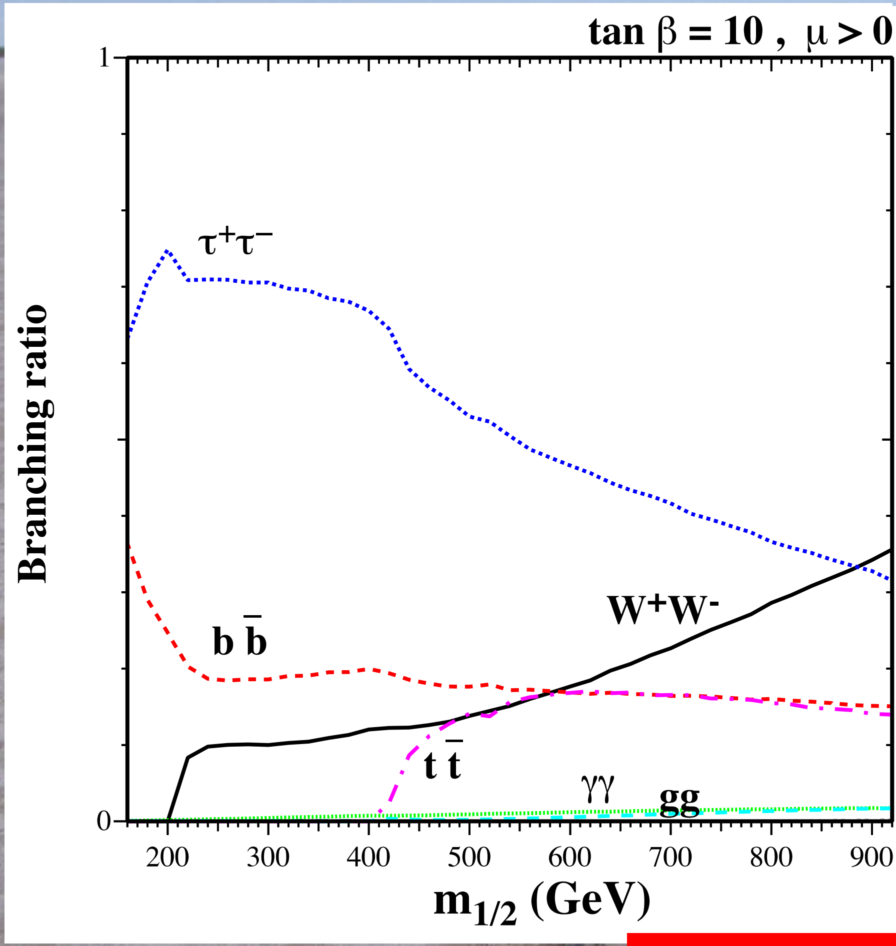


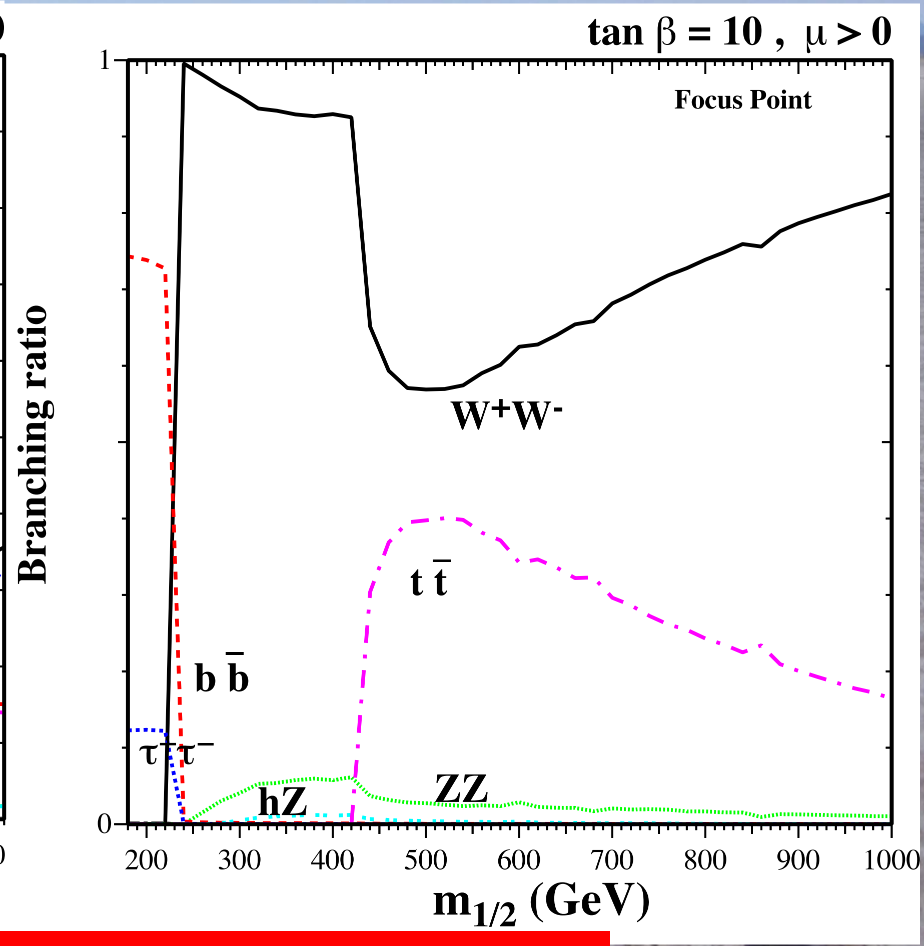
Constraints potentially along focus-point strip and @ large tan β

JE, Olive & Spanos: in preparation

Annihilation Branching Fractions

Vary in different regions of parameter space



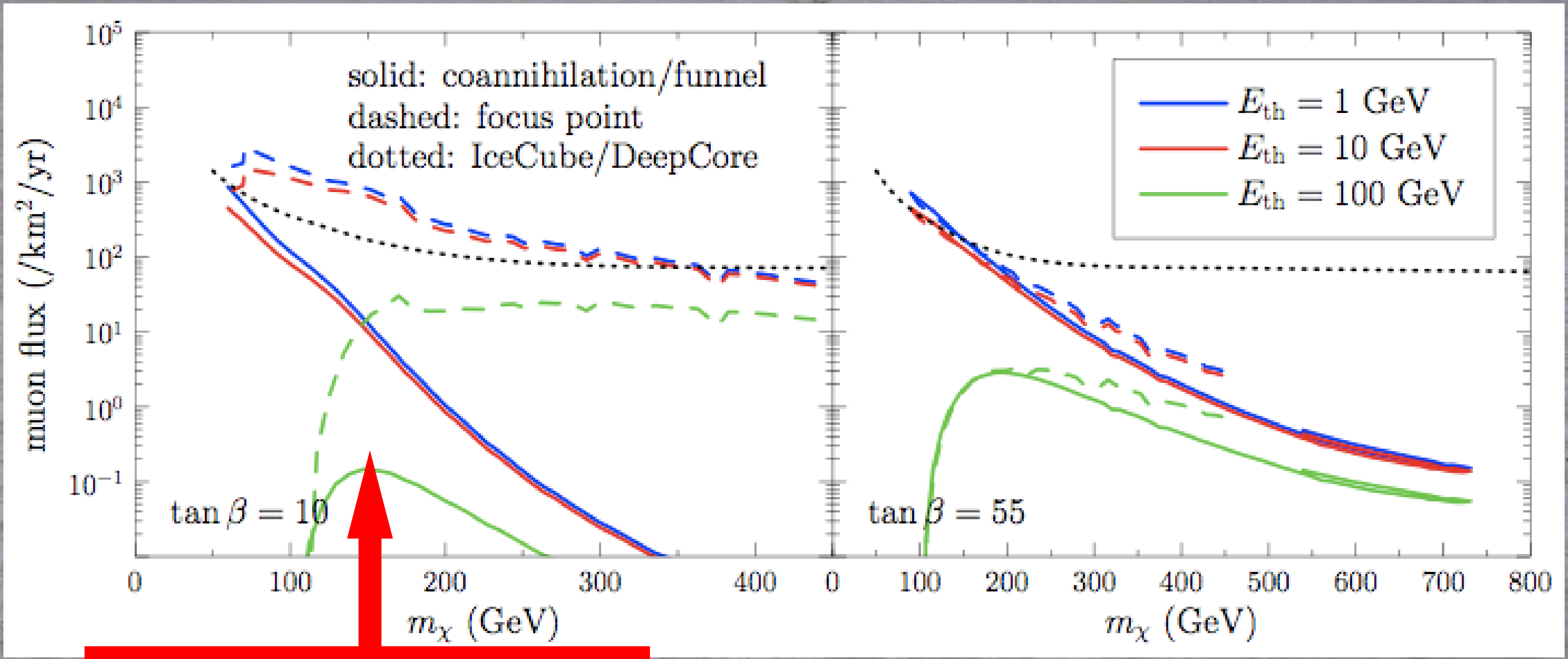


JE, Olive & Spanos: in preparation

Must be modelled correctly

Neutrino Fluxes from CMSSM Dark Matter Annihilation in Sun

Fluxes along WMAP strips

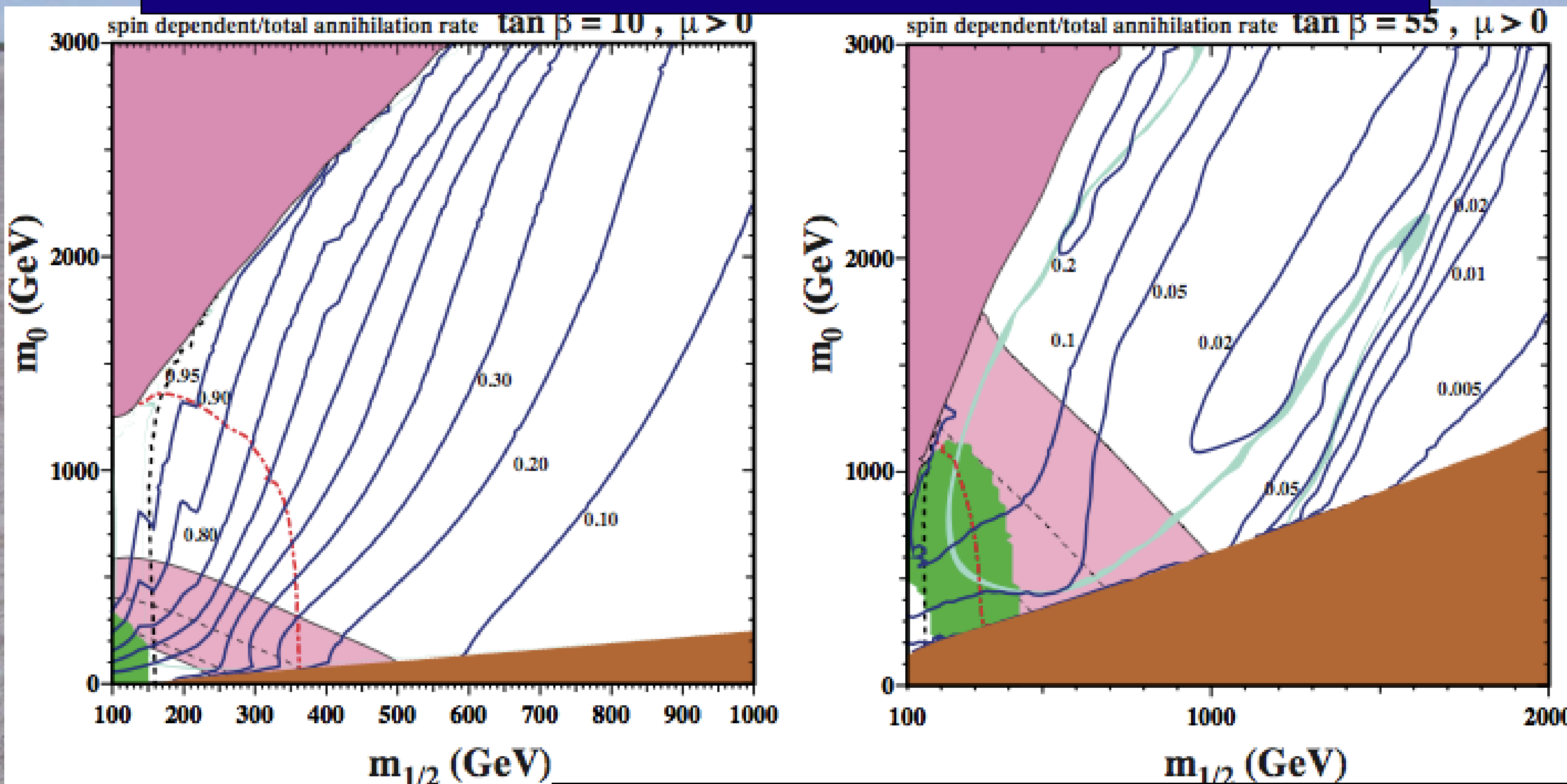


LHC mass limit

JE, Olive & Savage: arXiv:0912.3137

Neutrino Fluxes from CMSSM Dark Matter Annihilation in Sun

Spin-dependent scattering not dominant

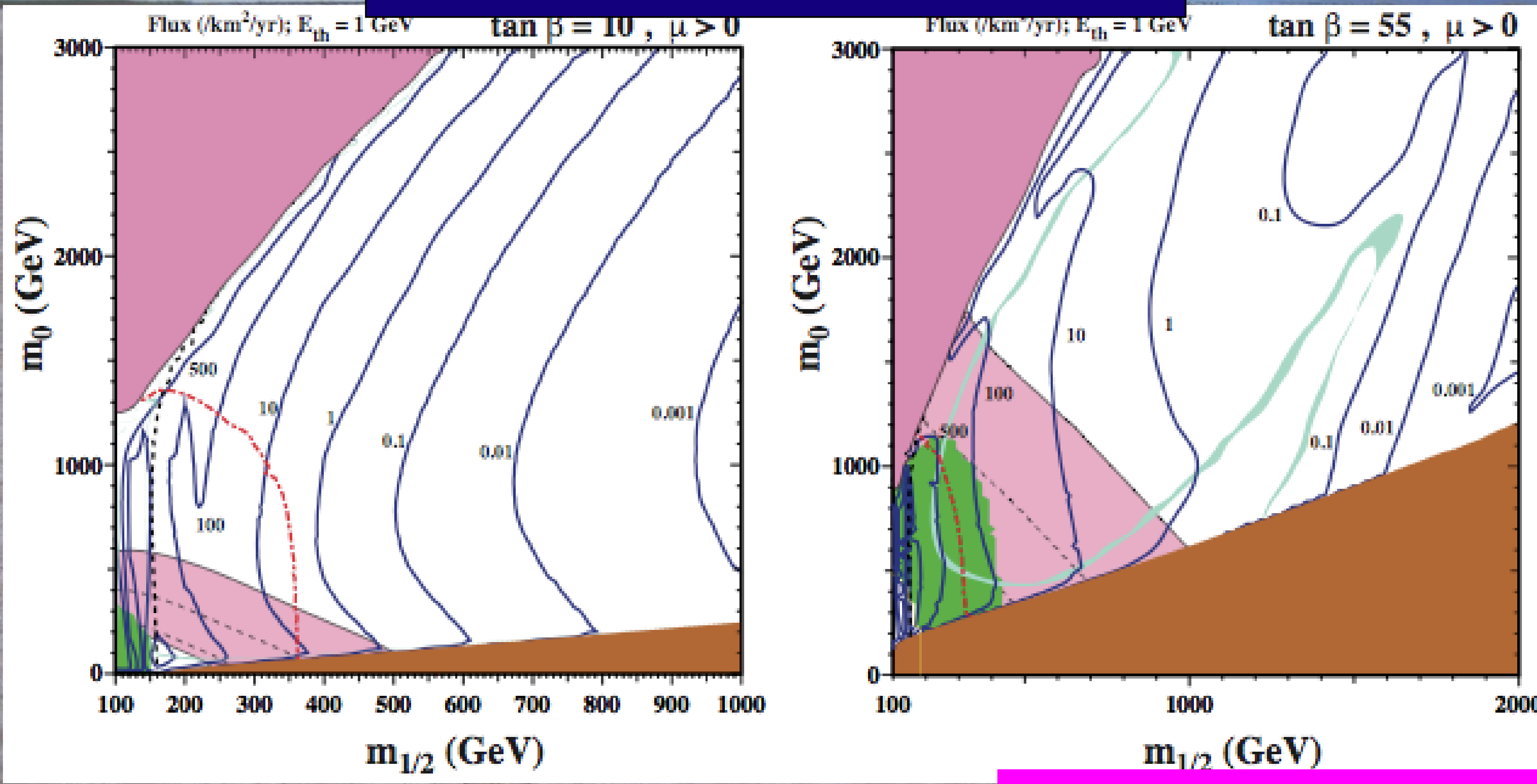


JE, Olive & Savage: arXiv:0912.3137

Spin-independent scattering: $\Sigma_{\pi N}$!

Neutrino Fluxes from CMSSM Dark Matter Annihilation in Sun

Neutrino flux above 1 GeV

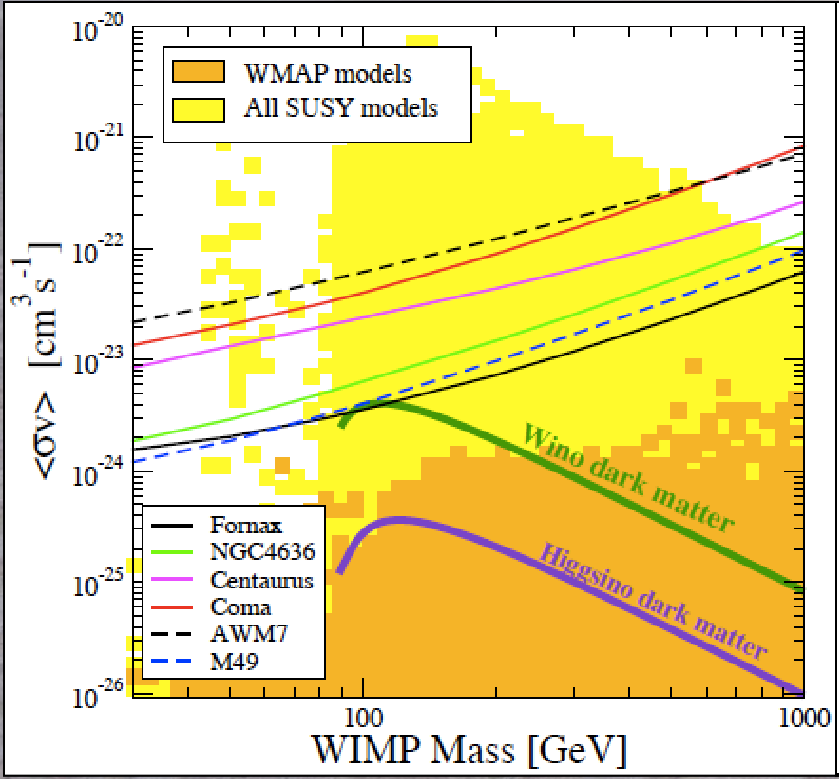


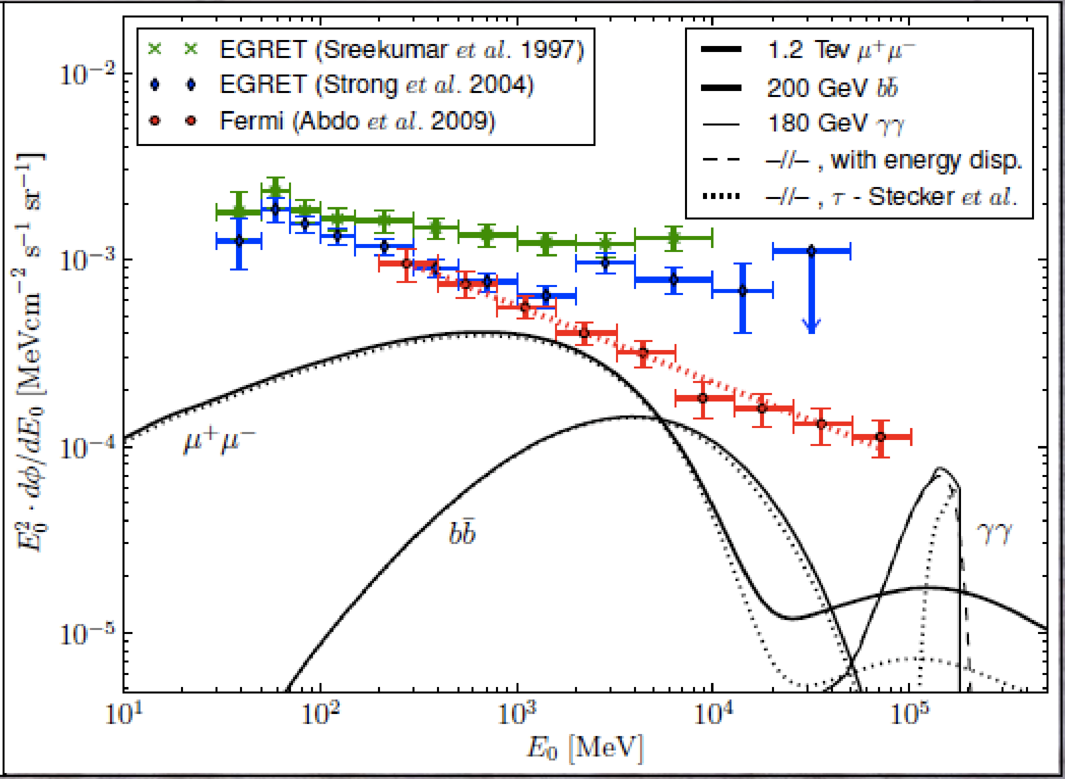
JE, Olive & Savage: arXiv:0912.3137

Fermi Satellite Searches for Gammas

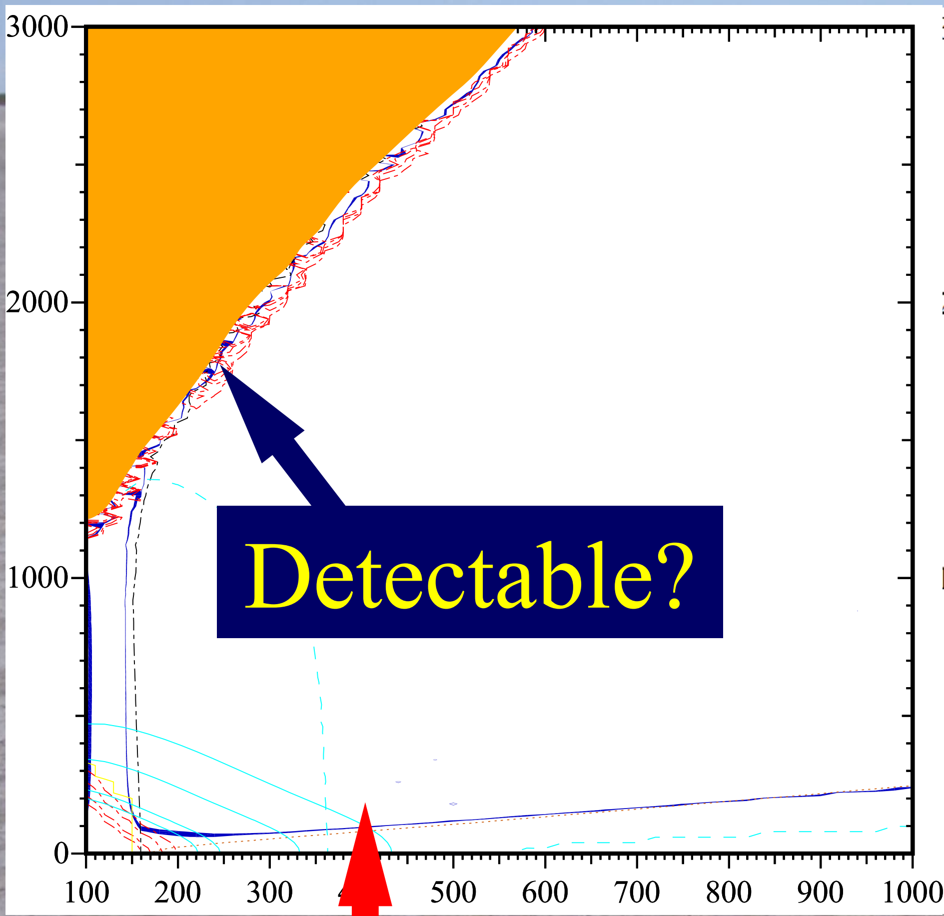
- From clusters?

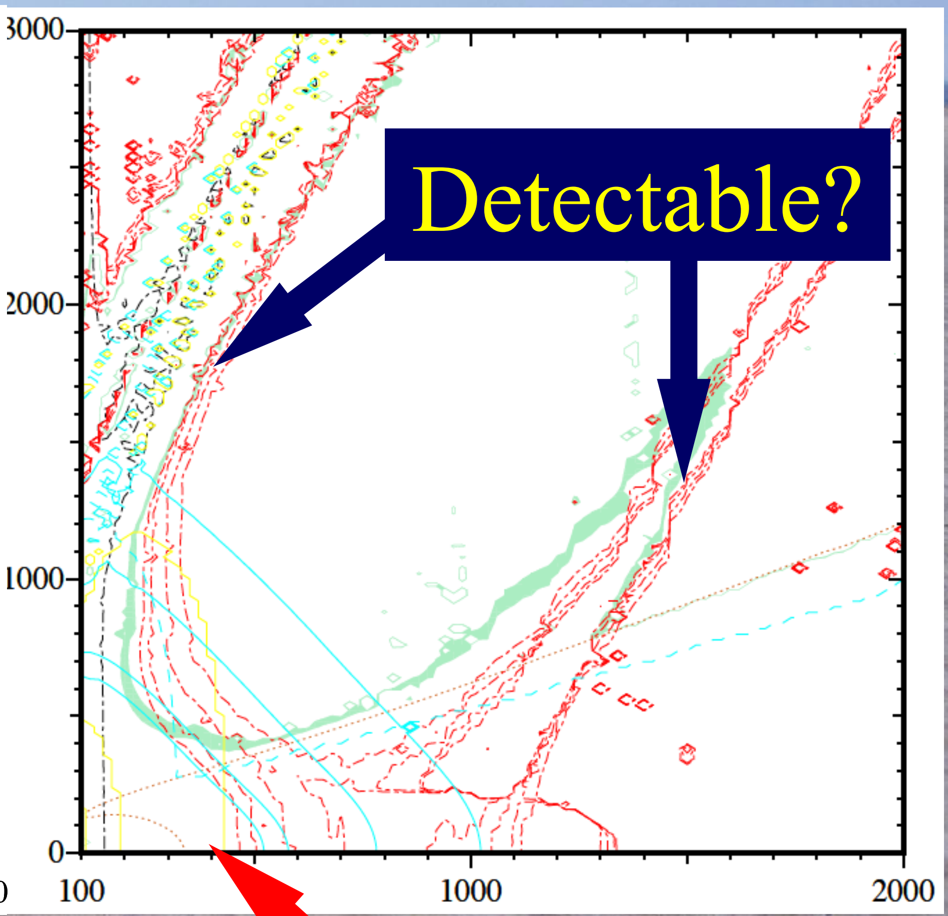
- Diffuse background





Gamma Fluxes from Dark Matter Annihilation in the Galactic Centre





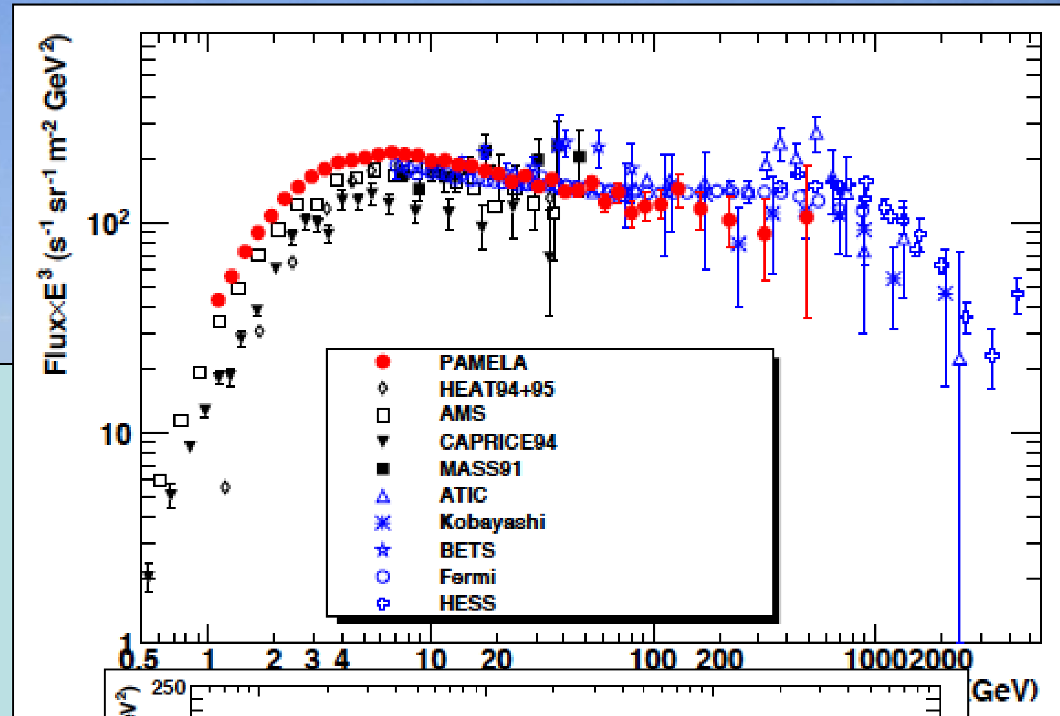
LHC mass limit

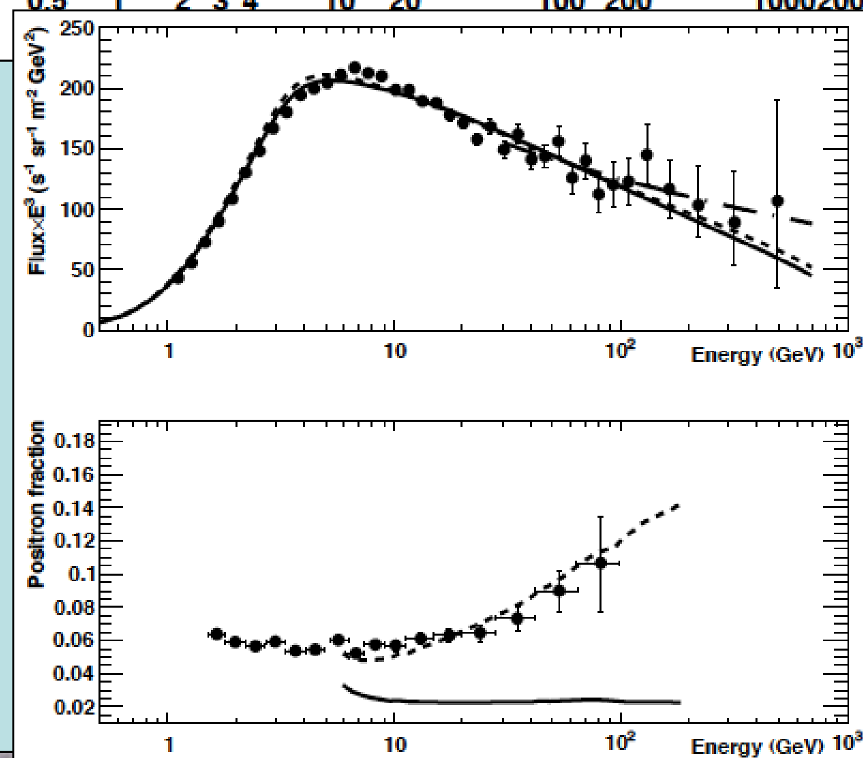
LHC mass limit

JE, Olive & Spanos: in prep'n

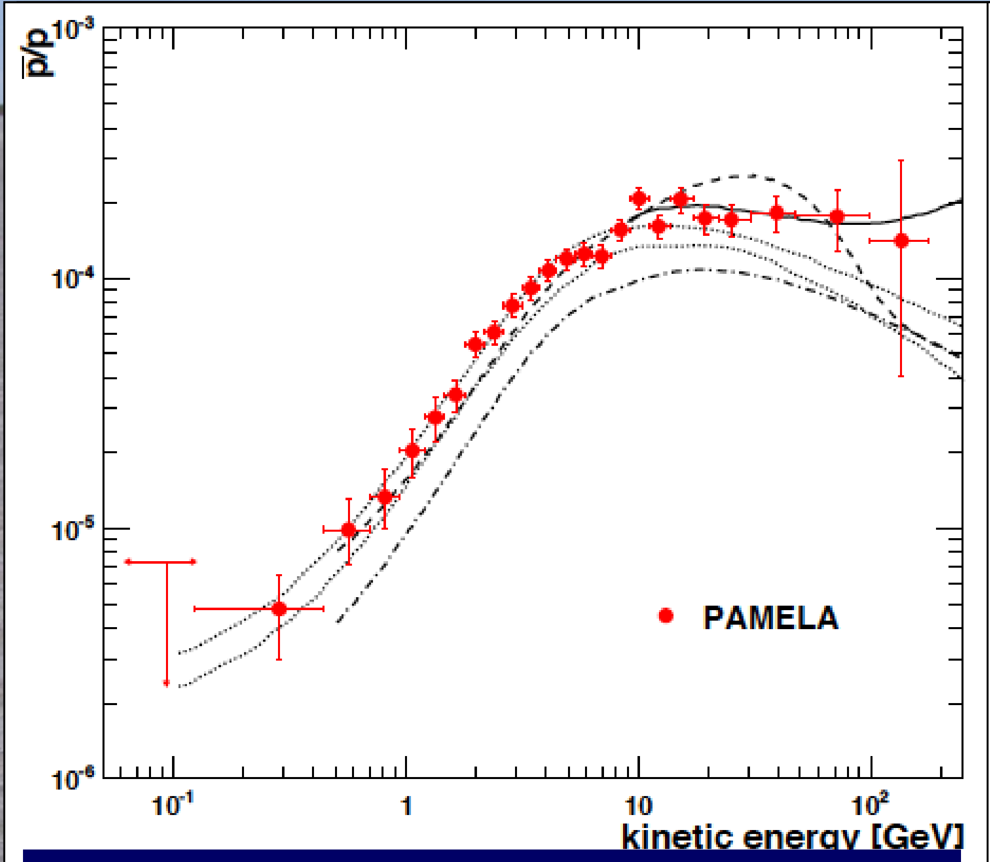
Anomalies in e^+/e^- Spectra?

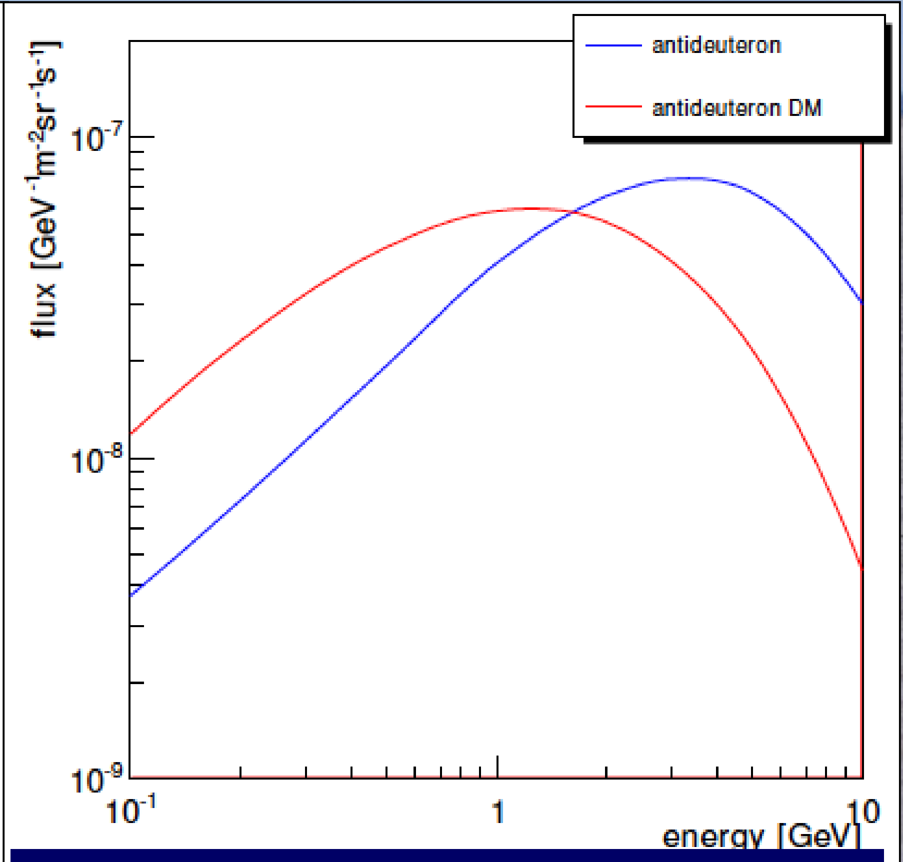
- Shoulder in $e^+ + e^-$ spectrum?
- Rising e^+/e^- ratio
- Uncertainties in cosmic-ray production, propagation?
- Nearby sources?
- SUSY interpretation difficult, unnecessary?





Antiprotons and Antideuterons from Dark Matter Annihilation?

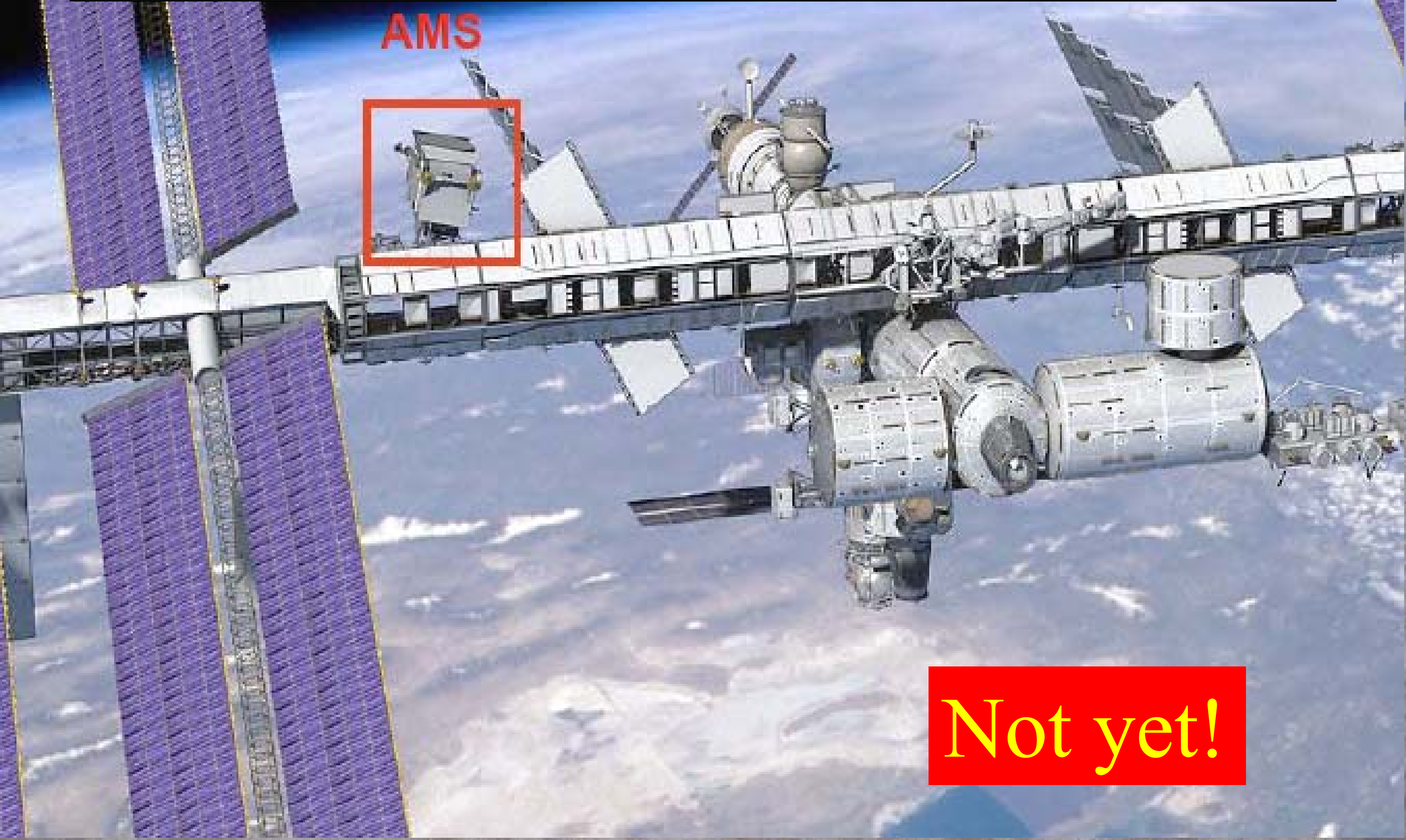




··· standard cosmic rays
--- possible supersymmetric model
— including production at source

Antideuterons could provide another window of opportunity?

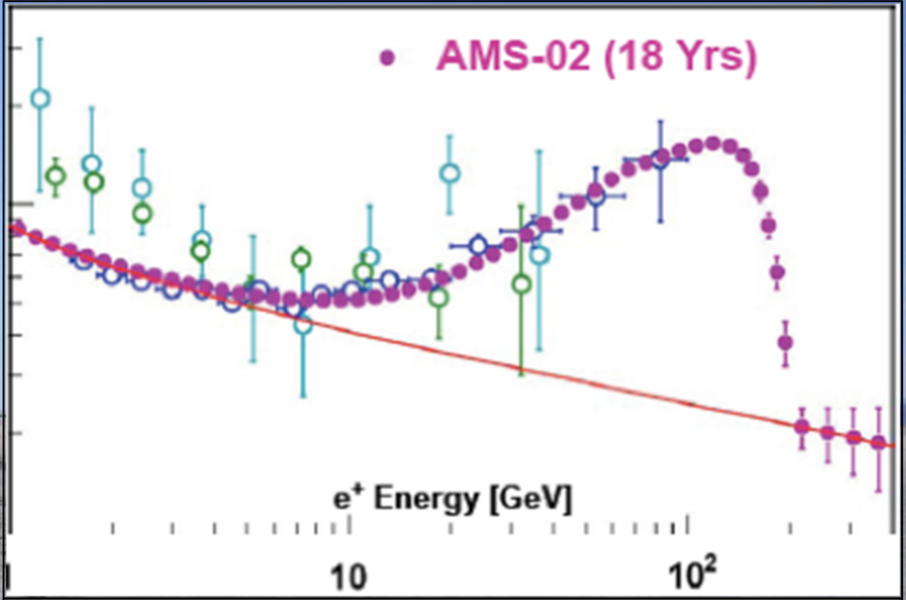
AMS-02 on the International Space Station (ISS)

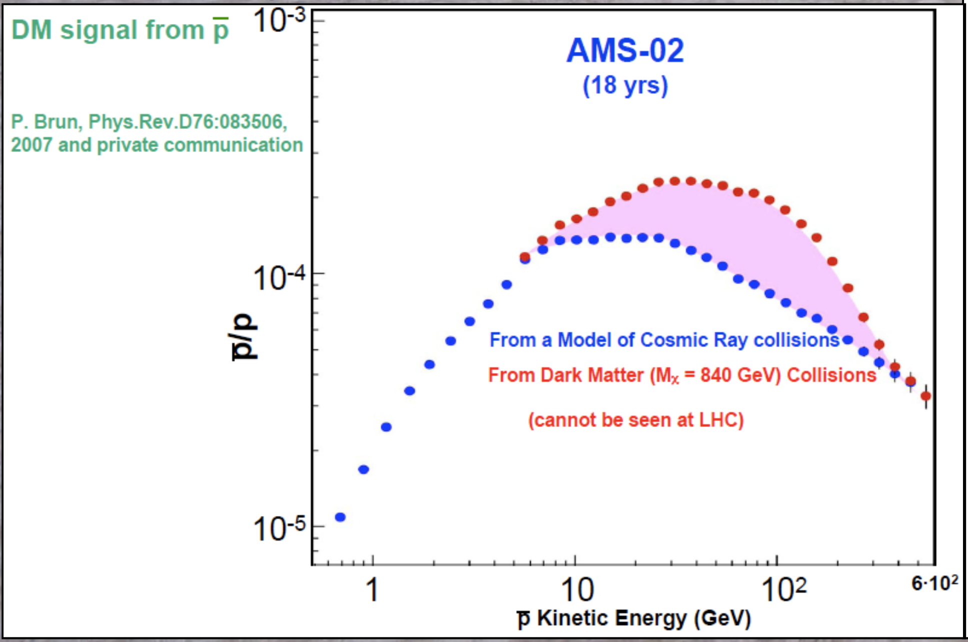


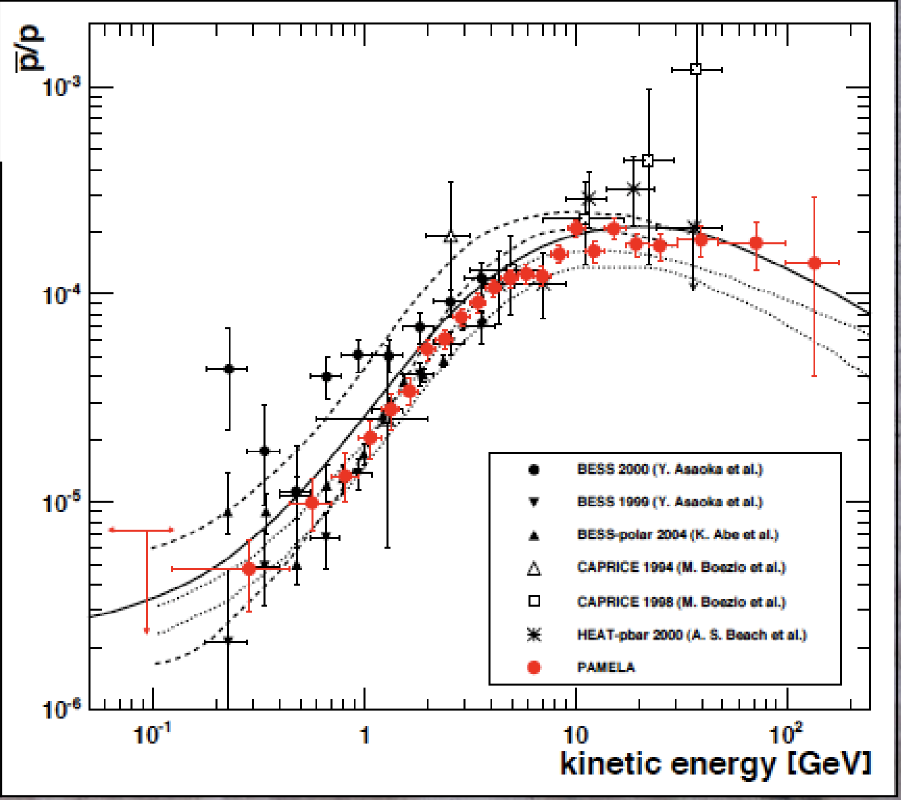
Not yet!

AMS-02 and Dark Matter

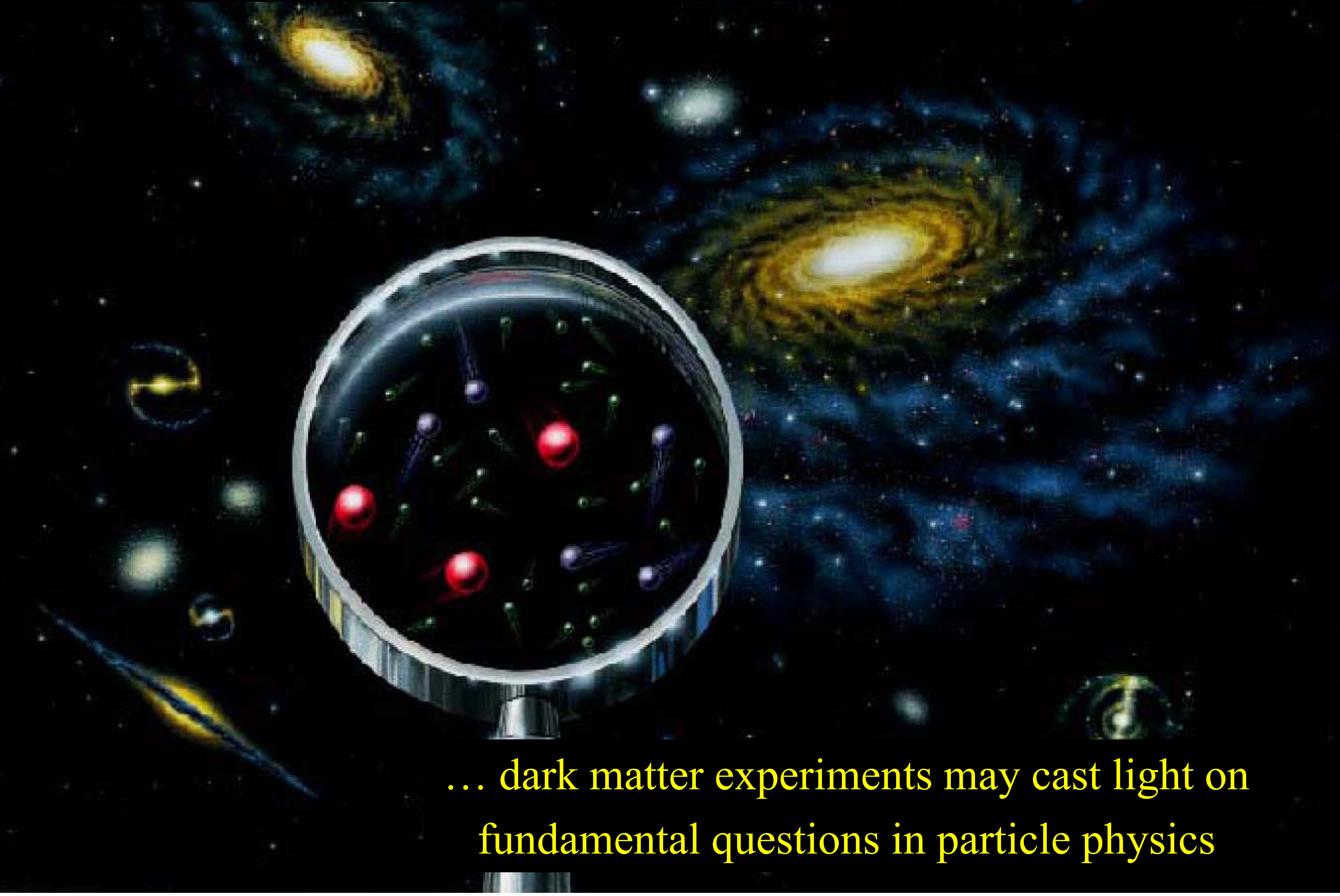
- Measurement of e^+ spectrum to higher E
- Precision measurement of antiproton spectrum







The LHC may cast light on dark matter…



… dark matter experiments may cast light on fundamental questions in particle physics

Non-Universal Scalar Masses

- Different sfermions with same quantum #s?

  e.g., d, s squarks?

  disfavoured by upper limits on flavour-changing neutral interactions

- Squarks with different #s, squarks and sleptons?

  disfavoured in various GUT models

  e.g., $d_R = e_L$, $d_L = u_L = u_R = e_R$ in SU(5), all in SO(10)

- Non-universal susy-breaking masses for Higgses?

  No reason why not! NUHM

Lightest Supersymmetric Particle

- Stable in many models because of conservation of R parity:

  $R = (-1)^{2S - L + 3B}$

  where S = spin, L = lepton #, B = baryon #

- Particles have R = +1, sparticles R = -1:

  Sparticles produced in pairs

  Heavier sparticles → lighter sparticles

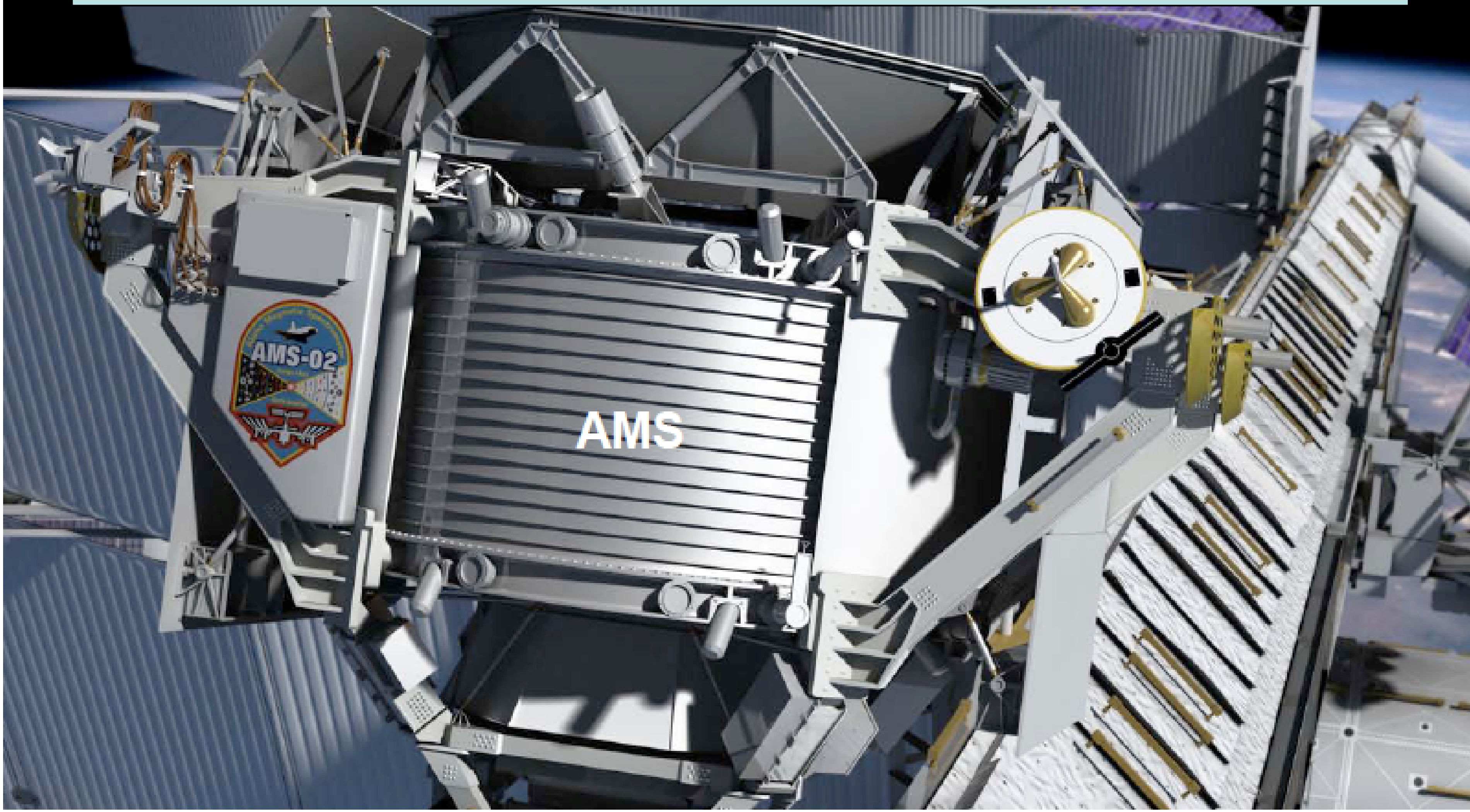
- Lightest supersymmetric particle (LSP) stable

Fayet

Possible Nature of LSP

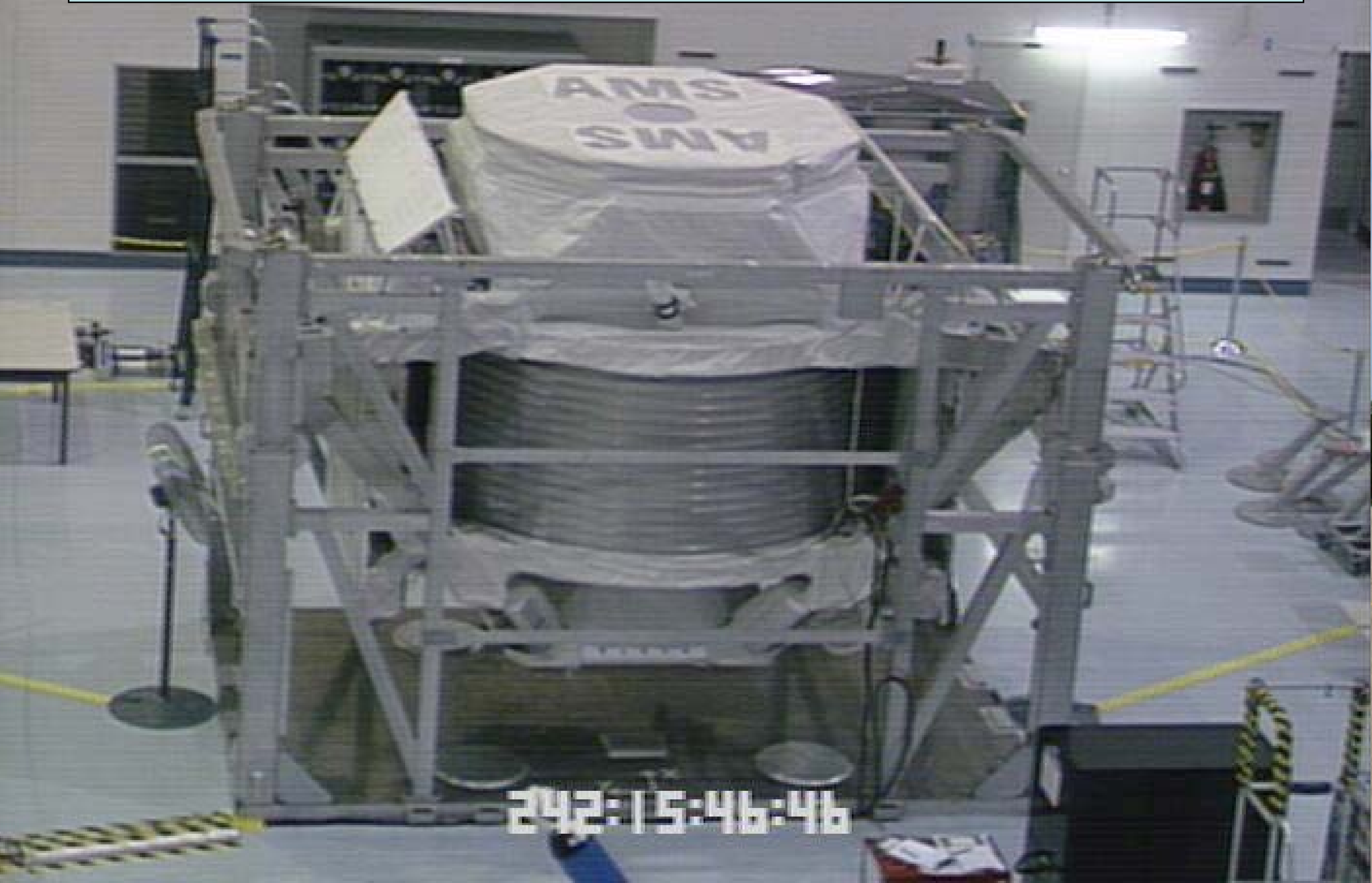
- No strong or electromagnetic interactions
  - Otherwise would bind to matter
  - Detectable as anomalous heavy nucleus
- Possible weakly-interacting scandidates
  - Sneutrino
    - (Excluded by LEP, direct searches)
  - Lightest neutralino χ (partner of Z, H, γ)
  - Gravitino
    - (nightmare for astrophysical detection)

AMS-02 on the ISS

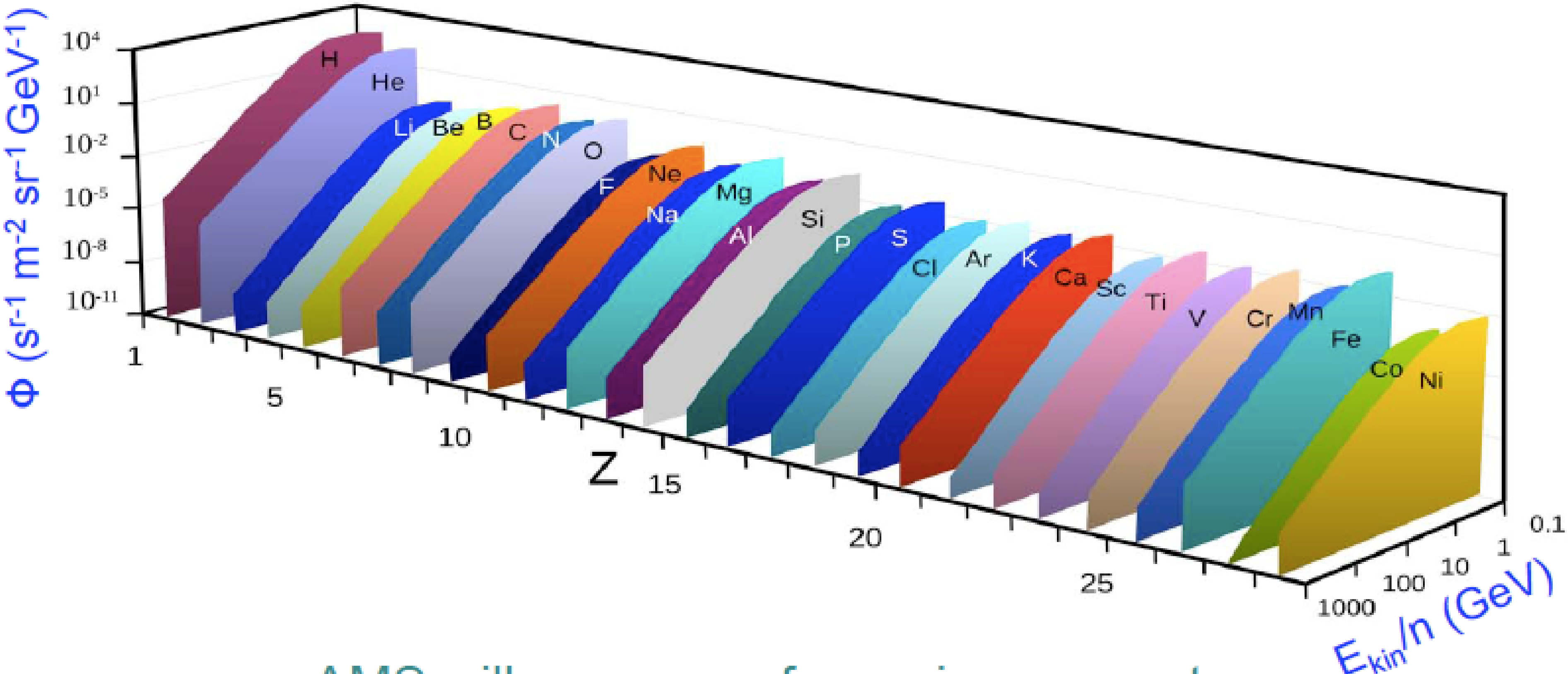


AMS on ISS for the lifetime of ISS:
18 or more years

AMS-02 on its way to the ISS



AMS Capability for Element Abundances



AMS will measure of cosmic ray spectra for nuclei, for energies from 100 MeV to 2 TeV with 1% accuracy over the 11-year solar cycle.

- Useful for calculations of spallation, antiprotons

Long-Lived Gravitino & BBN

- Conventional Big-Bang Nucleosynthesis calculations agree well with D, 3He, 4He data
- Constraints on abundance of long-lived relic
  - Apparent discrepancy for Lithium:

$$\left(\frac{\mathrm{Li}}{\mathrm{H}}\right)_{\mathrm{halo}\star} = \left(1.23^{+0.34}_{-0.16}\right) \times 10^{-10}$$

  - Globular clusters: $(2.34 \pm 0.05) \times 10^{-10}$
  - BBN calculation: $\left(5.12^{+0.71}_{-0.62}\right) \times 10^{-10}$
- **Can discrepancy be removed by decays of long-lived relic, e.g., gravitino?**

Cyburt, JE, Fields, Luo, Olive & Spanos: arXiv:1007.4173

Nuclear Reactions

- Relevant interactions of non-thermal particles from relic decay showers
- Incorporate errors in measurements
- Make global likelihood analysis

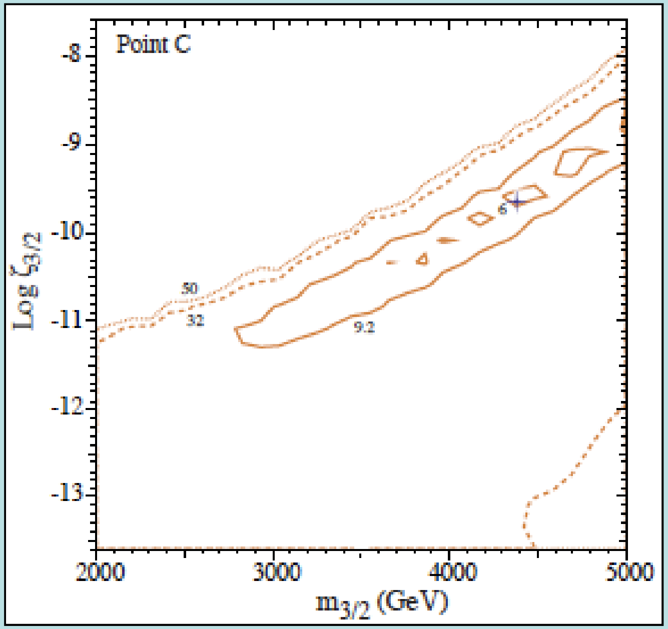
Table 1: Nuclear reactions of non-thermal particles, including the most important of the estimated uncertainties in the cross sections.

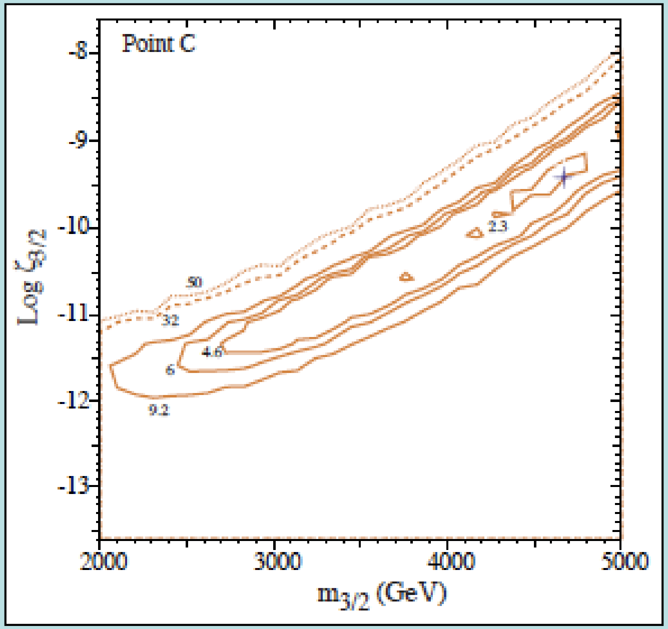
Code	Reaction	Uncertainty ϵ	Reference
1	$p^4\mathrm{He} \to d^3\mathrm{He}$		Meyer [34]
2	$p^4\mathrm{He} \to np^3\mathrm{He}$	20%	Meyer [34]
3	$p^4\mathrm{He} \to ddp$	40%	Meyer [34]
4	$p^4\mathrm{He} \to dnpp$	40%	Meyer [34]
5	$d^4\mathrm{He} \to {}^6\mathrm{Li}\gamma$		Mohr [35]
6	$t^4\mathrm{He} \to {}^6\mathrm{Li}n$	20%	Cyburt et al. [14]
7	${}^3\mathrm{He}^4\mathrm{He} \to {}^6\mathrm{Li}p$	20%	Cyburt et al. [14]
8	$t^4\mathrm{He} \to {}^7\mathrm{Li}\gamma$		Cyburt [27]
9	${}^3\mathrm{He}^4\mathrm{He} \to {}^7\mathrm{Be}\gamma$		Cyburt and Davids [36]
10	$p^6\mathrm{Li} \to {}^3\mathrm{He}^4\mathrm{He}$		Cyburt et al. [14]
11	$n^6\mathrm{Li} \to t^4\mathrm{He}$		Cyburt et al. [14]
12	$pn \to d\gamma$		Ando, Cyburt, Hong, and Hyun [37]
13	$pd \to {}^3\mathrm{He}\gamma$		Cyburt et al. [14]
14	$pt \to n^3\mathrm{He}$		Cyburt [27]
15	$p^6\mathrm{Li} \to {}^7\mathrm{Be}\gamma$		Cyburt et al. [14]
16	$p^7\mathrm{Li} \to {}^8\mathrm{Be}\gamma$		Cyburt et al. [14]
17	$p^7\mathrm{Be} \to {}^8\mathrm{B}\gamma$		Cyburt et al. [32]
18	$np \to d\gamma$		Ando, Cyburt, Hong, and Hyun [37]
19	$nd \to t\gamma$		Cyburt et al. [14]
20	$n^4\mathrm{He} \to dt$		Meyer [34]
21	$n^4\mathrm{He} \to npt$	20%	Meyer [34]
22	$n^4\mathrm{He} \to ddn$	40%	Meyer [34]
23	$n^4\mathrm{He} \to dnnp$	40%	Meyer [34]
24	$n^6\mathrm{Li} \to {}^7\mathrm{Li}\gamma$		Cyburt et al. [14]
25	n (thermal)		—
26	$n^7\mathrm{Be} \to p^7\mathrm{Li}$		Cyburt et al. [14]
27	$n^7\mathrm{Be} \to {}^4\mathrm{He}^4\mathrm{He}$		Cyburt et al. [32]
28	$p^7\mathrm{Li} \to {}^4\mathrm{He}^4\mathrm{He}$		Cyburt et al. [14]
29	$n\pi^+ \to p\pi^0$		Meyer [34]
30	$p\pi^- \to n\pi^0$		Meyer [34]
31	$p^4\mathrm{He} \to ppt$	20%	Meyer [34]
32	$n^4\mathrm{He} \to nn^3\mathrm{He}$	20%	Meyer [34]
33	$n^4\mathrm{He} \to nnnpp$		Meyer [34]
34	$p^4\mathrm{He} \to nnppp$		Meyer [34]
35	$p^4\mathrm{He} \to N^4\mathrm{He}\pi$		Meyer [34]
36	$n^4\mathrm{He} \to N^4\mathrm{He}\pi$		Meyer [34]

Cyburt, JE, Fields, Luo, Olive & Spanos: arXiv:1007.4173

Improvements in Fit to BBN Data

- Standard BBN: $\chi^2 = 31.7$
- Best fit to halo Li data: $\chi^2 \sim 5.5$



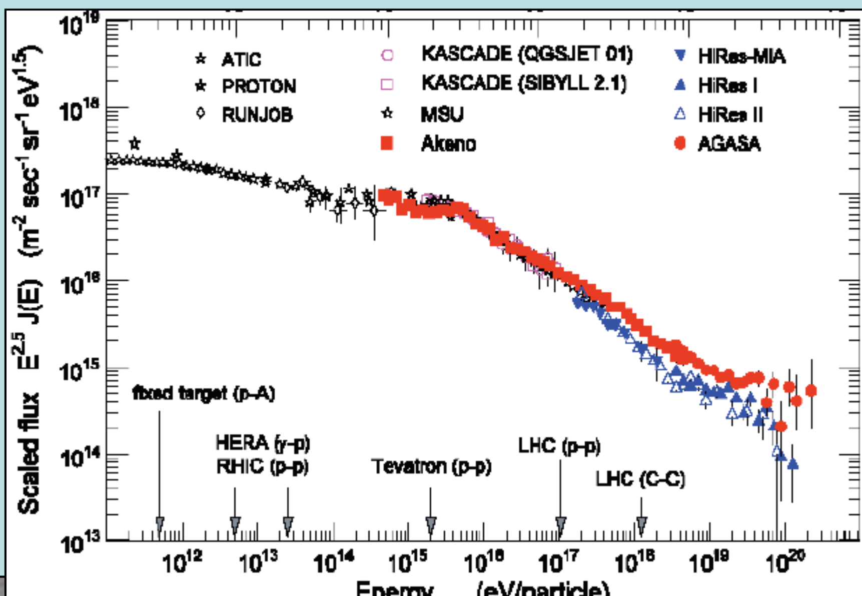


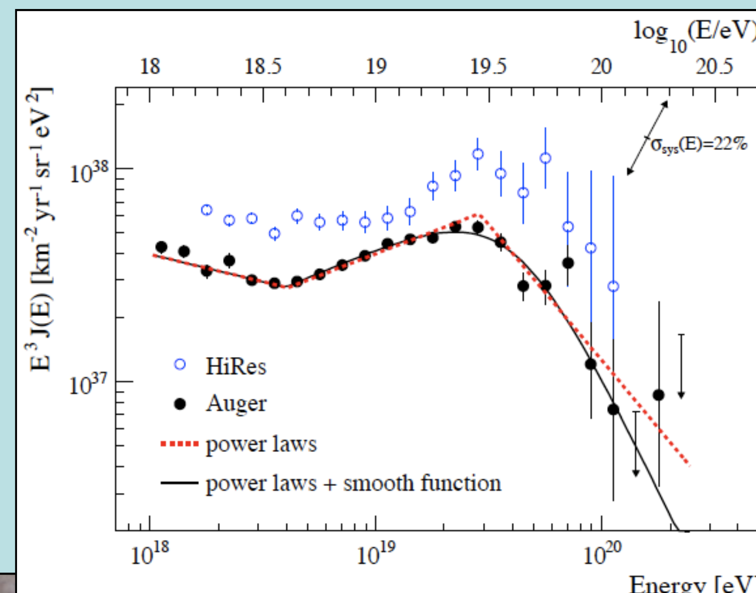
- Best fit to globular cluster Li data: $\chi^2 \sim 2.7$
- Allowing for higher D/H error: $\chi^2 \sim 1.1$

Cyburt, JE, Fields, Luo, Olive & Spanos: arXiv:1007.4173

Energy Spectrum of Cosmic Rays

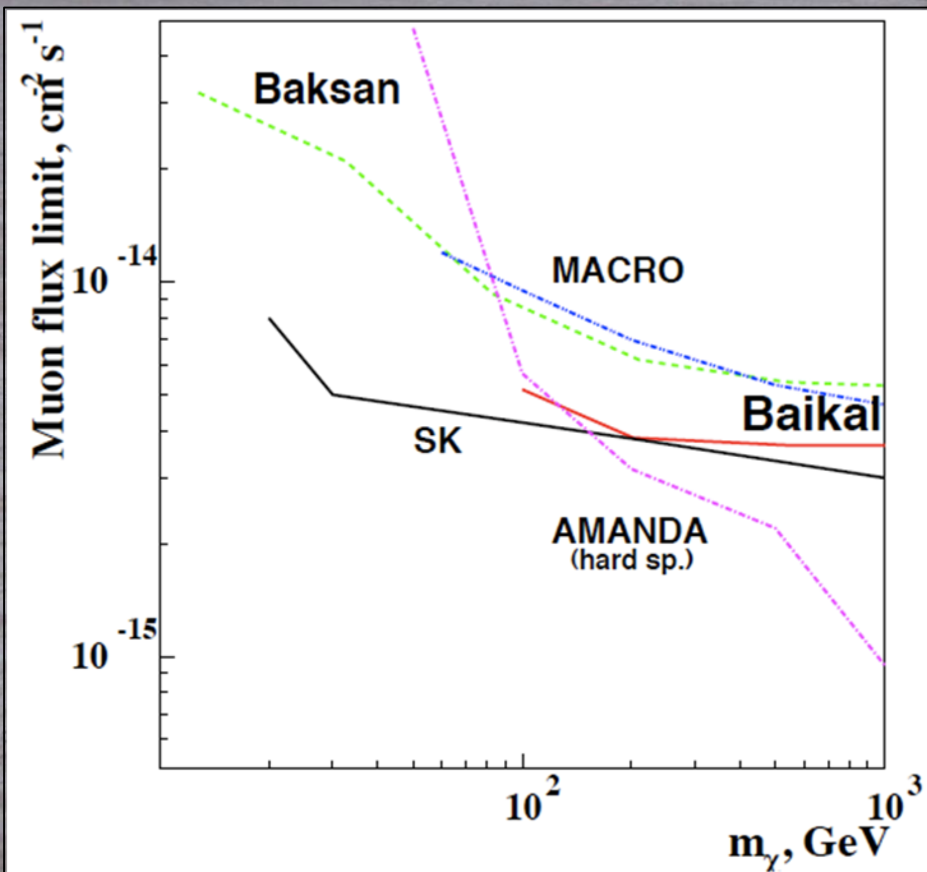
- Fall ~ $1/E^3$ over many decades
  - Change of slope @ 10^{15} to 10^{16} eV "knee"
- Extends to > LHC equivalent energy ~ 10^{17} eV
  - Change of slope @ 10^{18} to 10^{19} eV "ankle"
- Expect GZK cutoff ~ 10^{20} eV: $p+\gamma \rightarrow \Delta \rightarrow N+\pi$



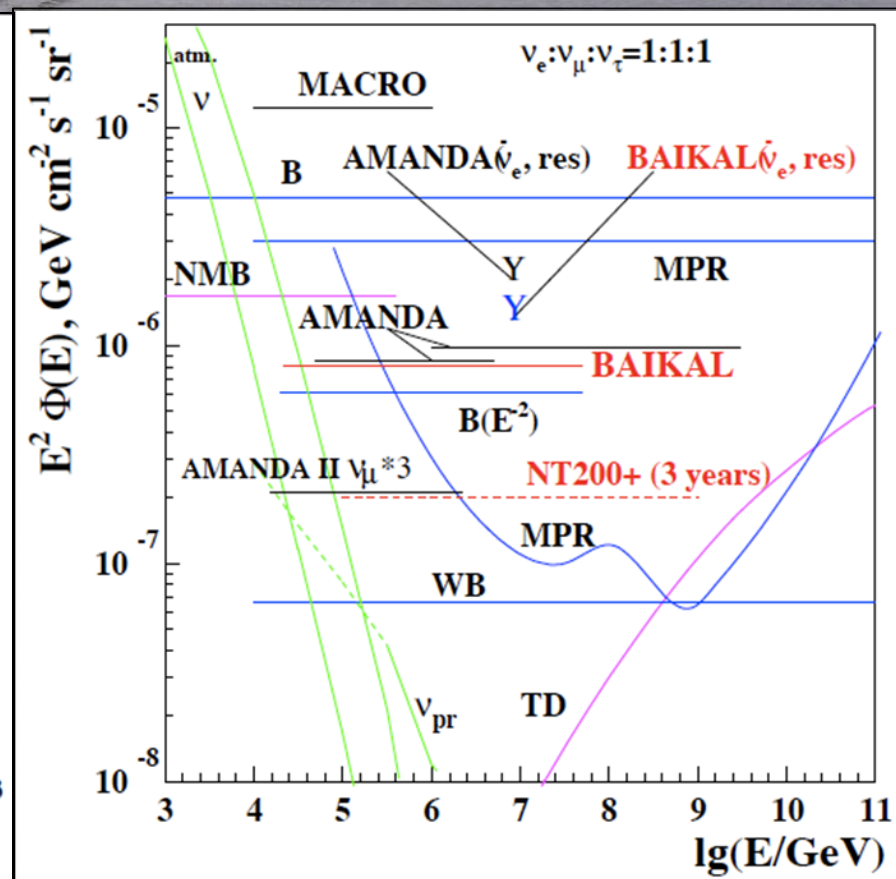


Searches with Baikal Neutrino Telescope

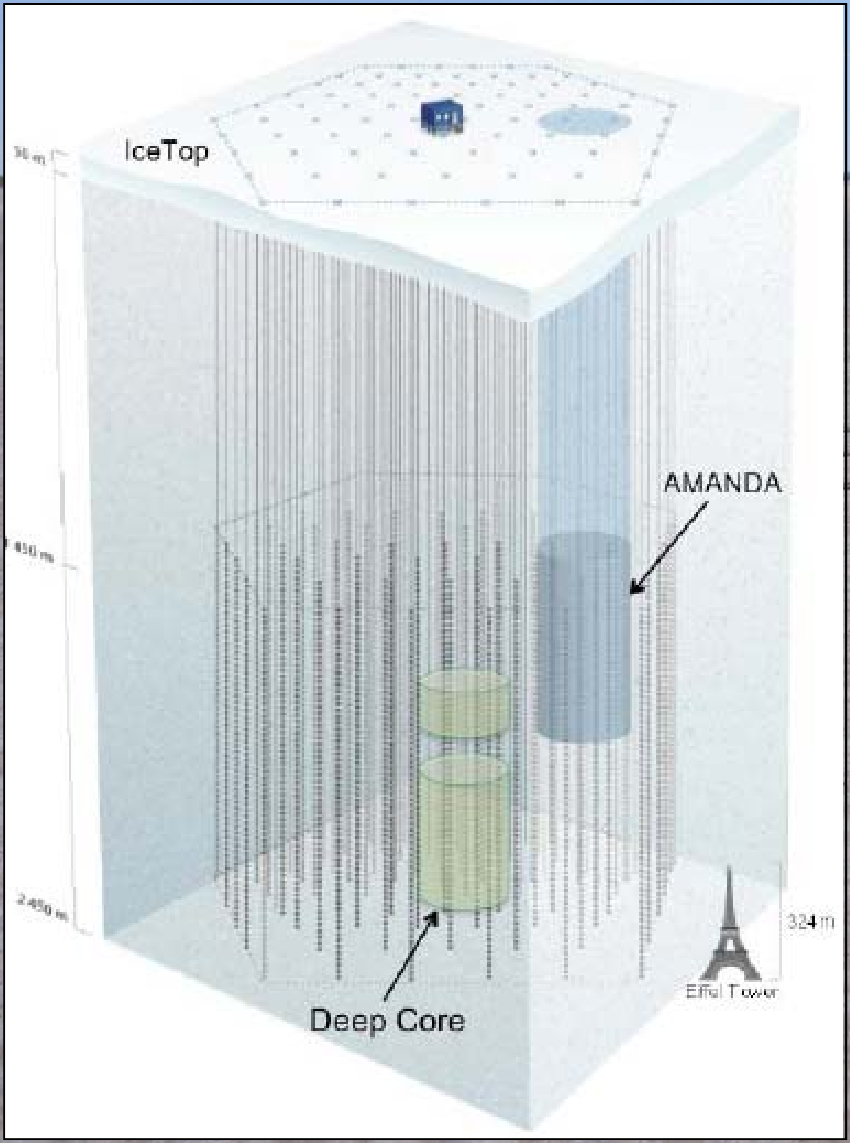
- Muons from centre of Earth



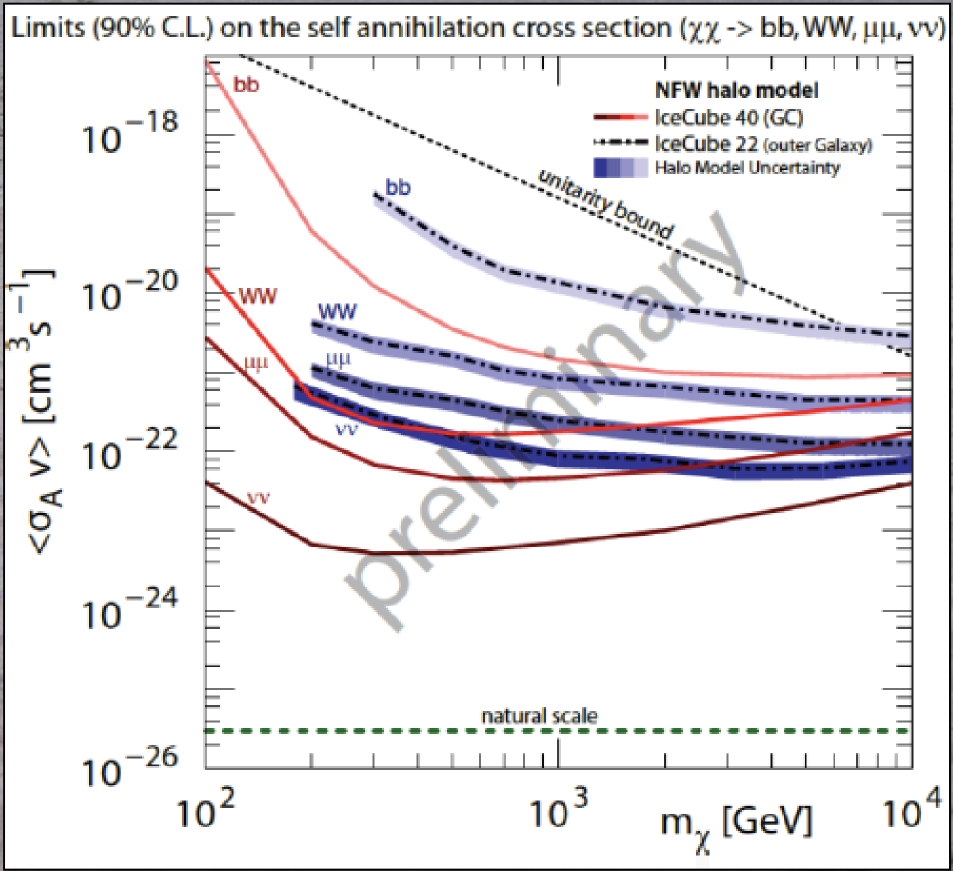
- Diffuse neutrino background



IceCube Neutrino Telescope

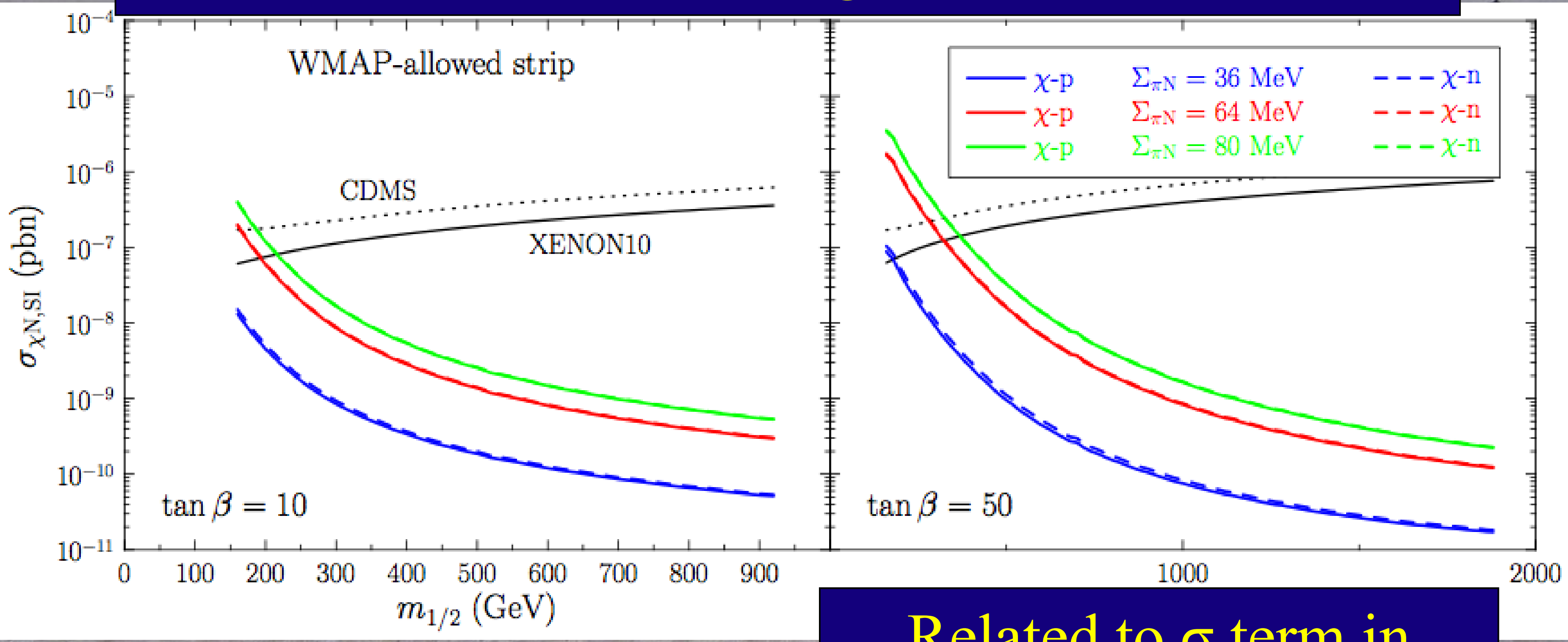


- Limit on diffuse neutrino flux



Elastic Scattering Cross Sections

Significant uncertainty in spin-independent hadronic scattering matrix element

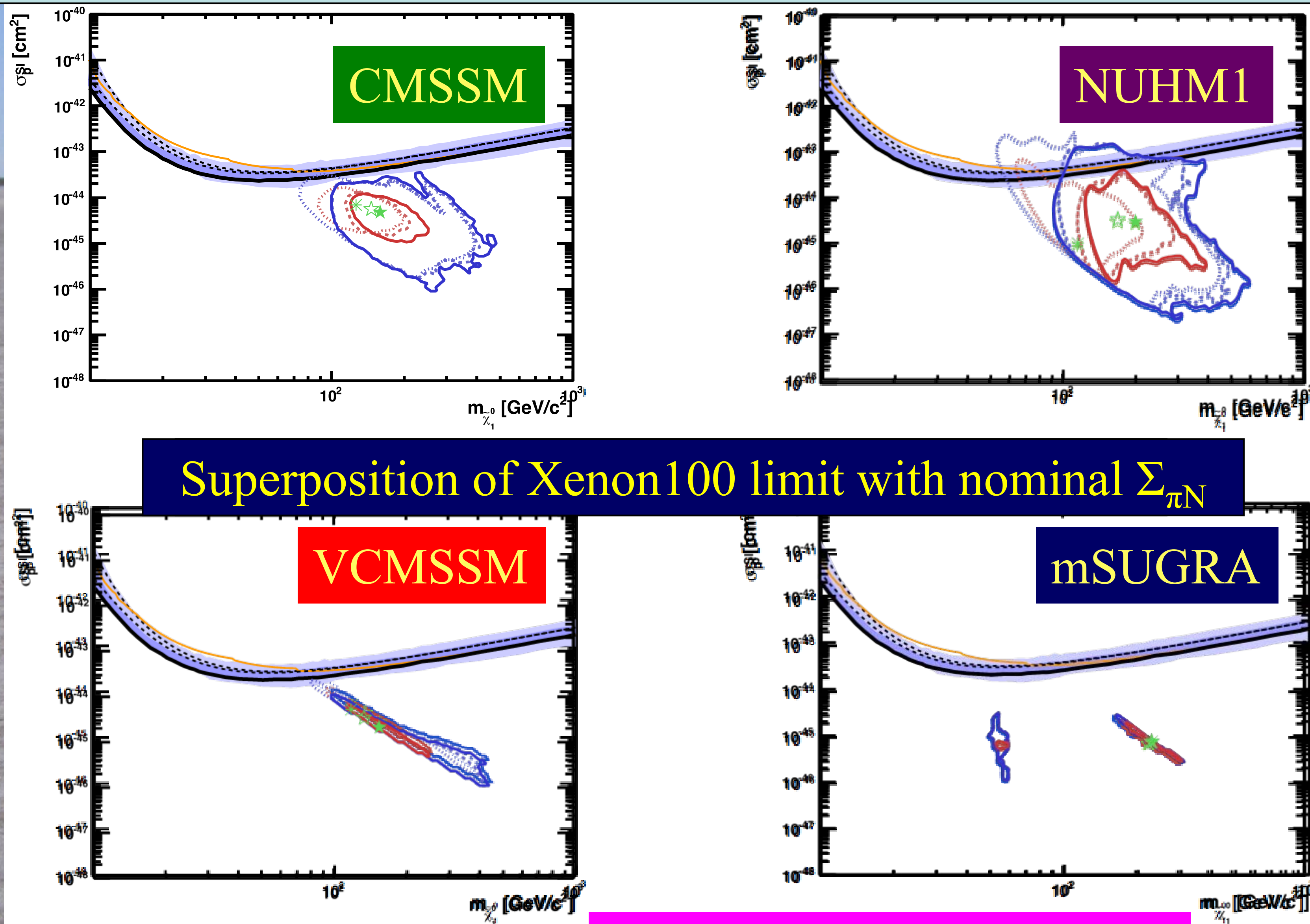


Related to σ term in π-nucleon scattering: $\Sigma_{\pi N}$

JE, Olive & Savage: arXiv:0801.3656

Post-LHC

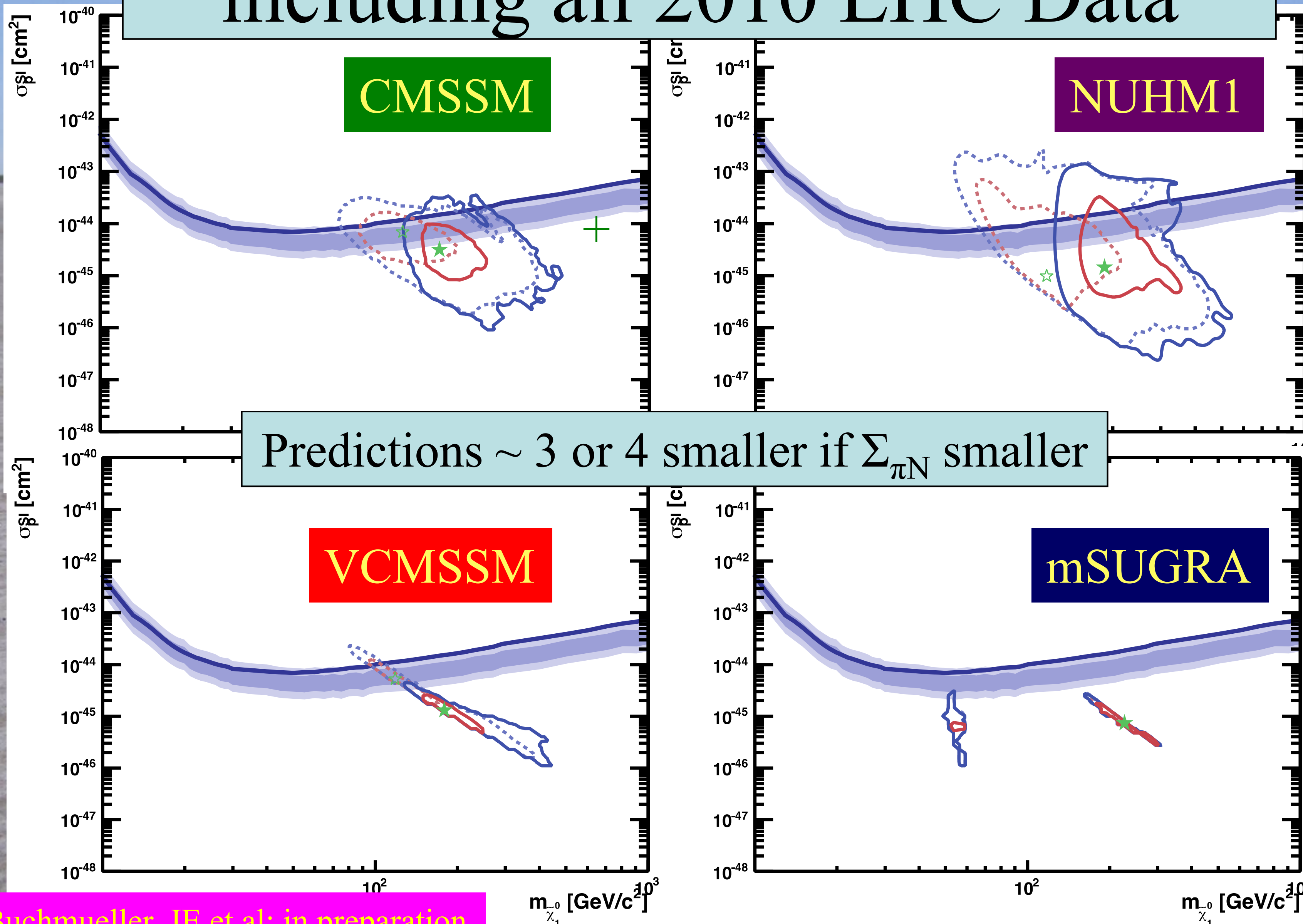
Dark Matter Scattering Revisited



Superposition of Xenon100 limit with nominal $\Sigma_{\pi N}$

O.Buchmueller, JE et al: arXiv:1102.4585

Dark Matter Scattering including all 2010 LHC Data



Predictions ~ 3 or 4 smaller if $\Sigma_{\pi N}$ smaller

O.Buchmueller, JE et al: in preparation

Constraints on Supersymmetry

- Absence of sparticles at LEP, Tevatron

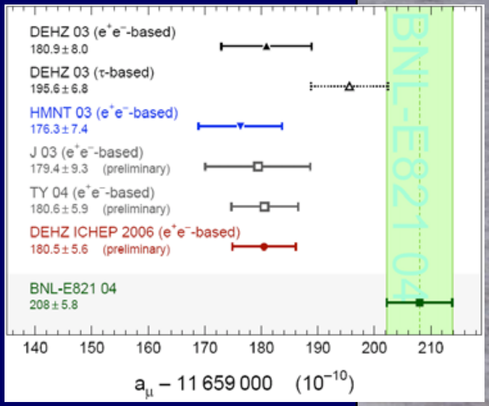
  selectron, chargino > 100 GeV

  squarks, gluino > 400 GeV

- Indirect constraints

  Higgs > 114 GeV, $b \to s\,\gamma$

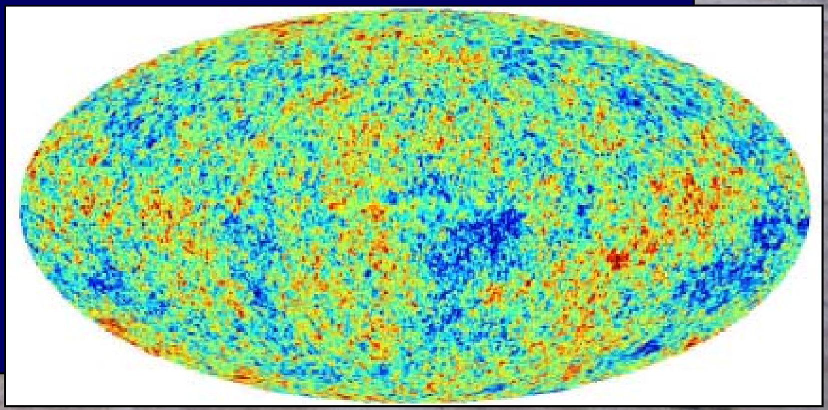
  3.3 σ effect in $g_\mu - 2$?



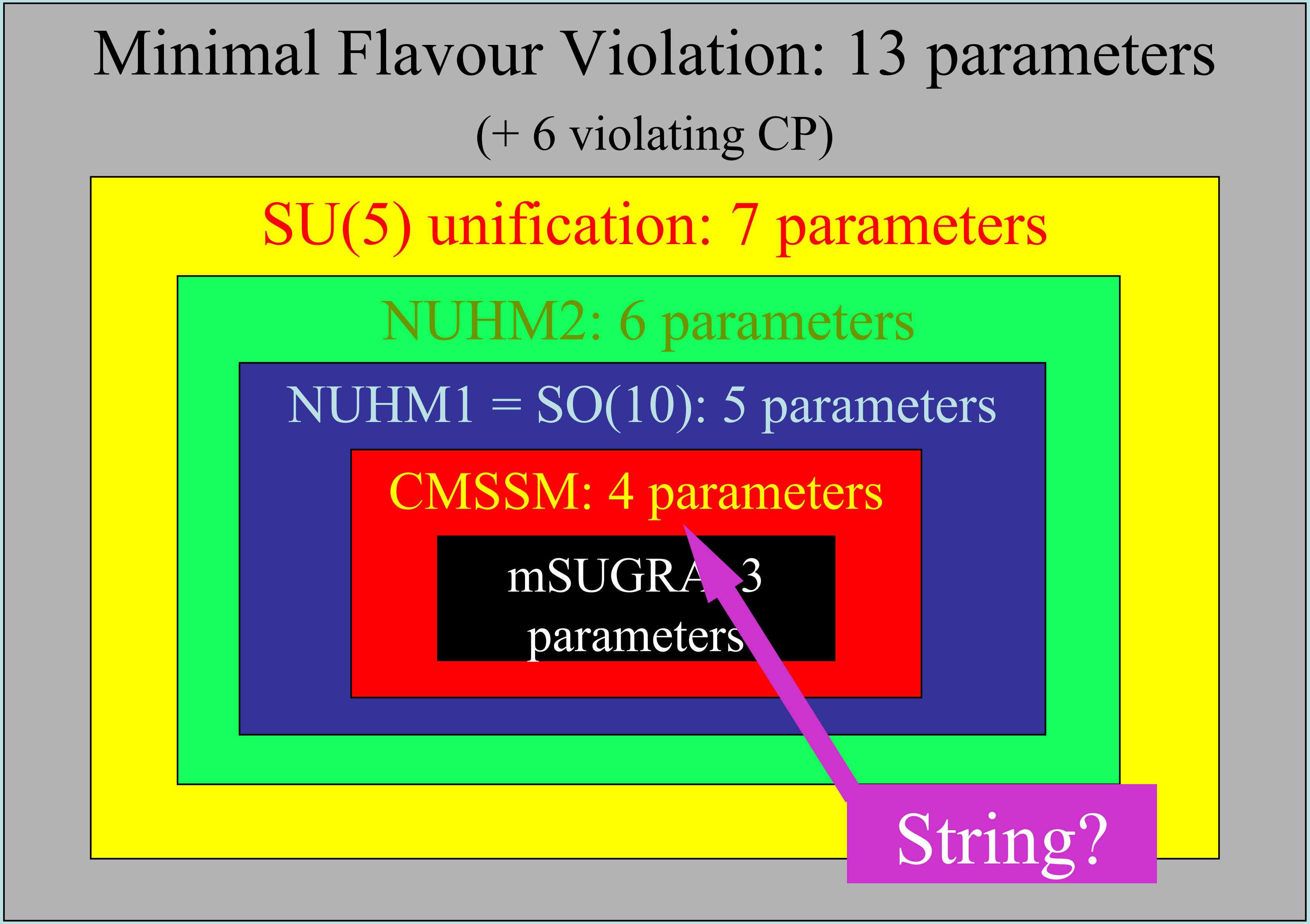
- Density of dark matter

  lightest sparticle χ:

  $0.094 < \Omega_\chi h^2 < 0.124$

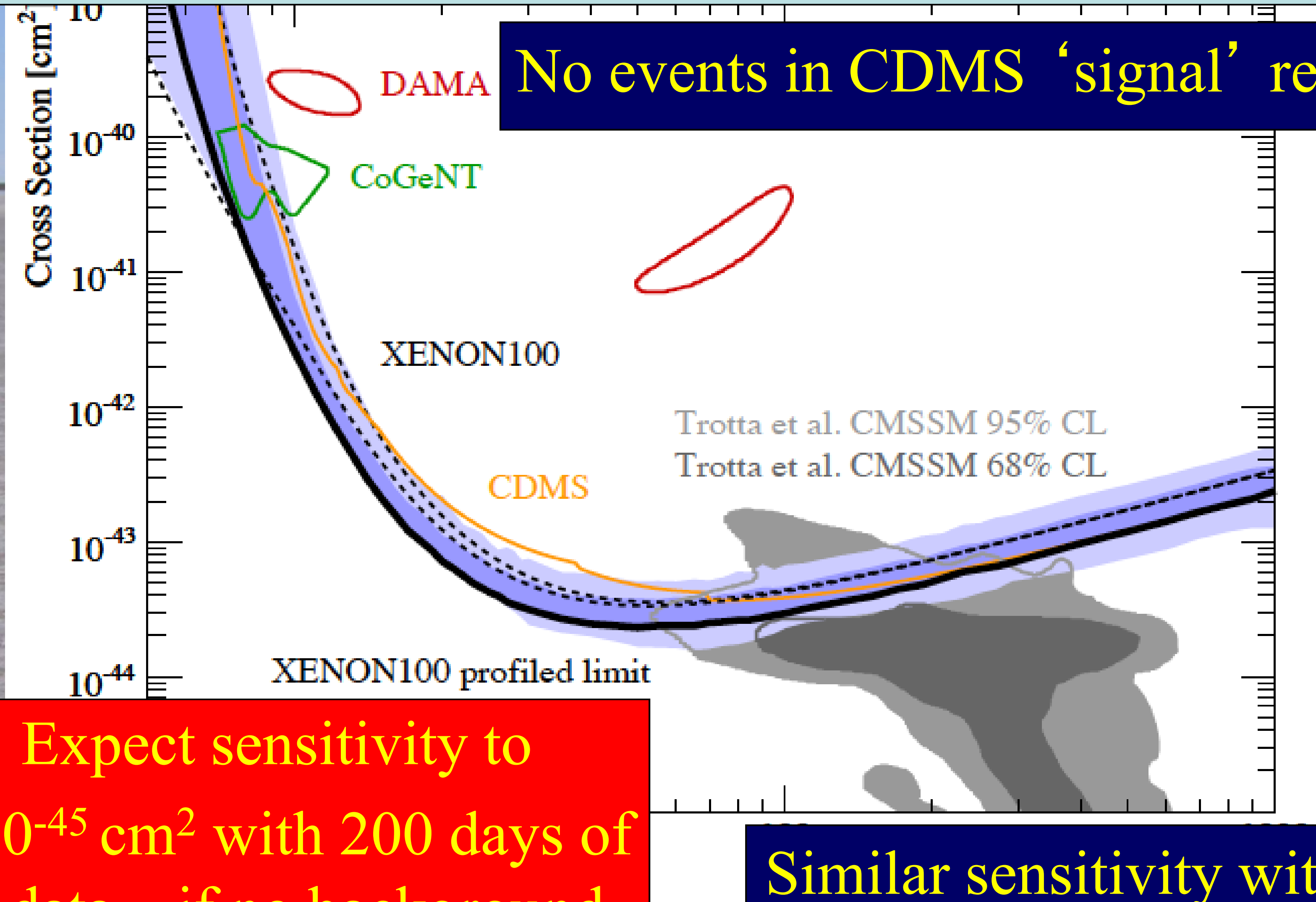


MSSM: > 100 parameters



Xenon100 Experiment

No events in CDMS ‘signal’ region

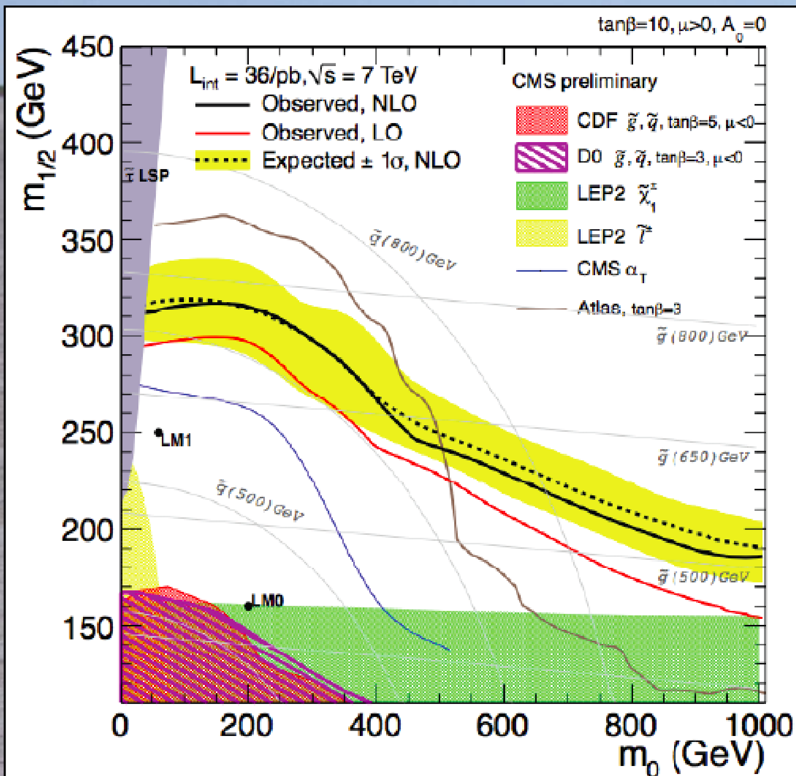


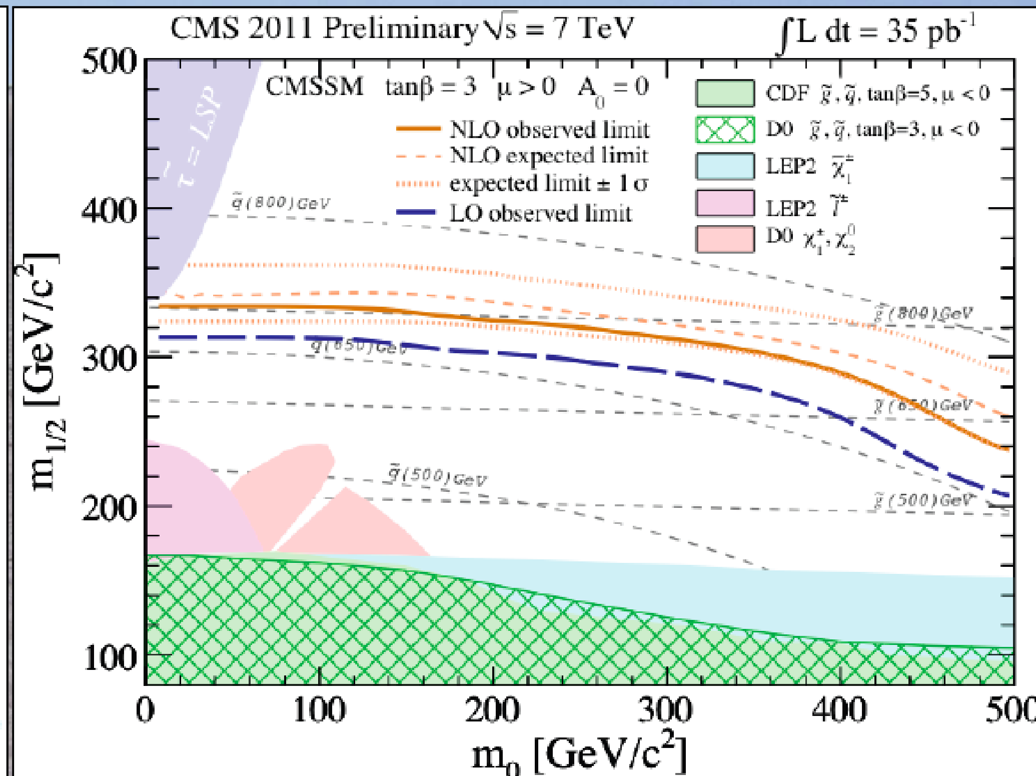
Expect sensitivity to $\sim 10^{-45}$ cm^2 with 200 days of data – if no background

Similar sensitivity with 11 days of data

Aprile et al: arXiv:1103.0303

New CMS Jet + MET Analyses





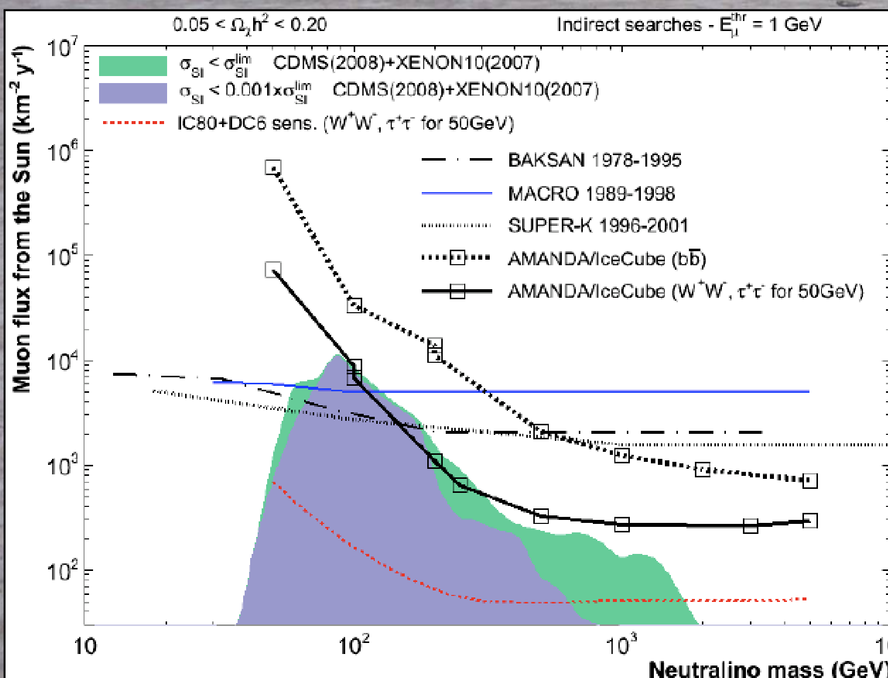
Jets + missing energy + 0 lepton (CMS MHT)

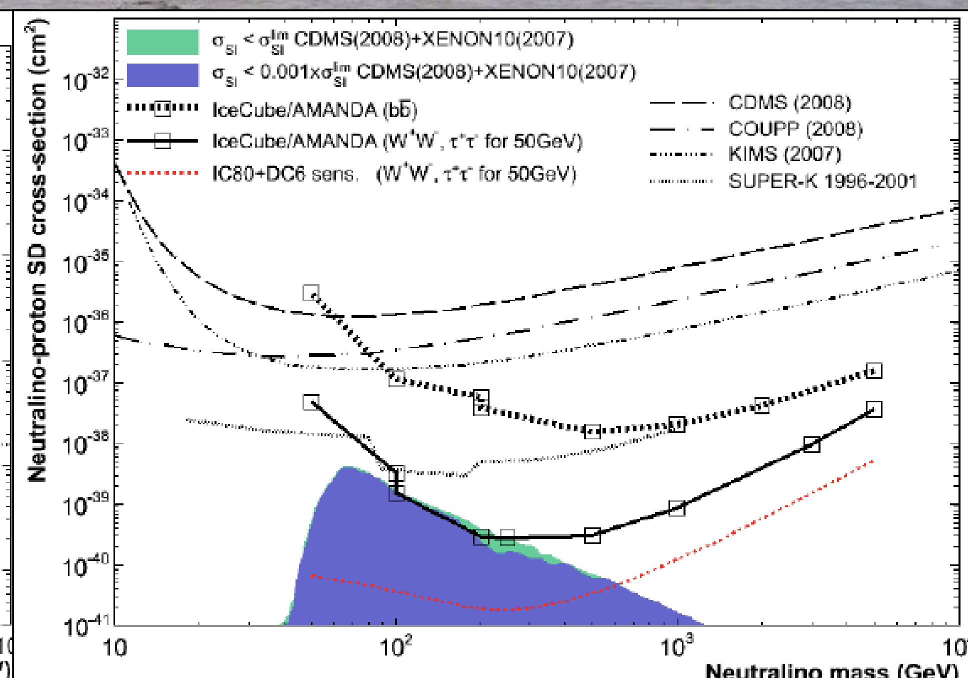
Less robust for discovery: greater exclusion reach

IceCube Neutrino Telescope

- Muons from neutrinos from dark matter annihilations inside Sun

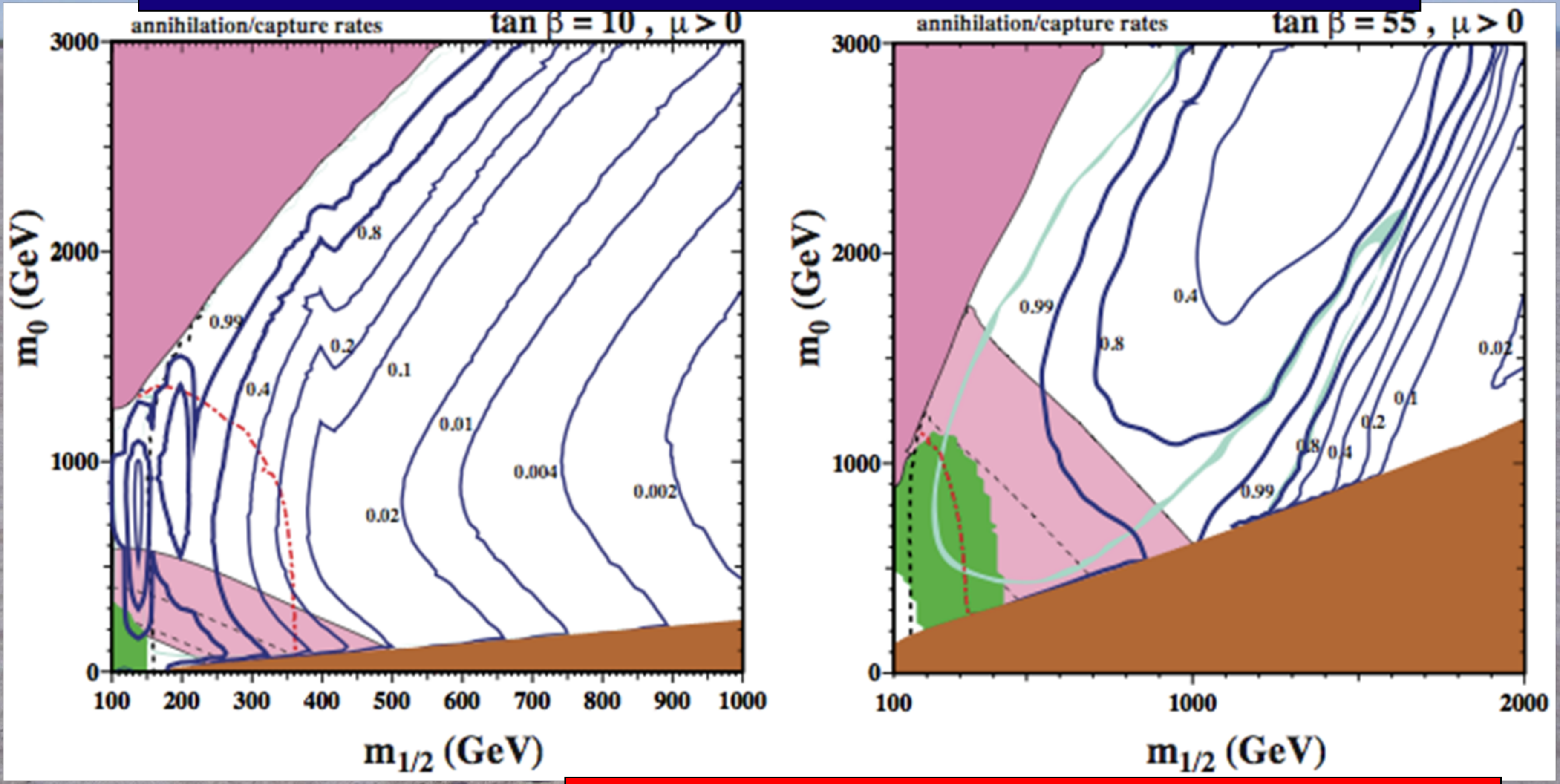
- Inferred ‘limit’ on dark matter scattering inside Sun **(assuming equilibrium)**





Neutrino Fluxes from CMSSM Dark Matter Annihilation in Sun

Annihilation rate < capture rate in general



JE, Olive & Savage: arXiv:0912.3137

Dark matter not in equilibrium

Minimal Supersymmetric Extension of Standard Model (MSSM)

- Particles + spartners

$$\begin{pmatrix} \frac{1}{2} \\ 0 \end{pmatrix} \; e.g., \; \begin{pmatrix} \ell \; (lepton) \\ \tilde{\ell} \; (slepton) \end{pmatrix} \; or \; \begin{pmatrix} q \; (quark) \\ \tilde{q} \; (squark) \end{pmatrix} \begin{pmatrix} 1 \\ \frac{1}{2} \end{pmatrix} \; e.g., \; \begin{pmatrix} \gamma \; (photon) \\ \tilde{\gamma} \; (photino) \end{pmatrix} \; or \; \begin{pmatrix} g \; (gluon) \\ \tilde{g} \; (gluino) \end{pmatrix}$$

- 2 Higgs doublets, coupling μ, ratio of v.e.v.'s = $\tan\beta$
- Unknown supersymmetry-breaking parameters:
  - Scalar masses m_0, gaugino masses $m_{1/2}$,
  - trilinear soft couplings A_{λ}, bilinear soft coupling B_{μ}
- Often assume universality:
  - Single m_0, single $m_{1/2}$, single A_{λ}, B_{μ}: not string?
- Called constrained* MSSM = CMSSM (* at what scale?)
- Minimal supergravity (mSUGRA) predicts gravitino mass: $m_{3/2} = m_0$ and relation: $B_{\mu} = A_{\lambda} - m_0$