MSSM Neutralino signature

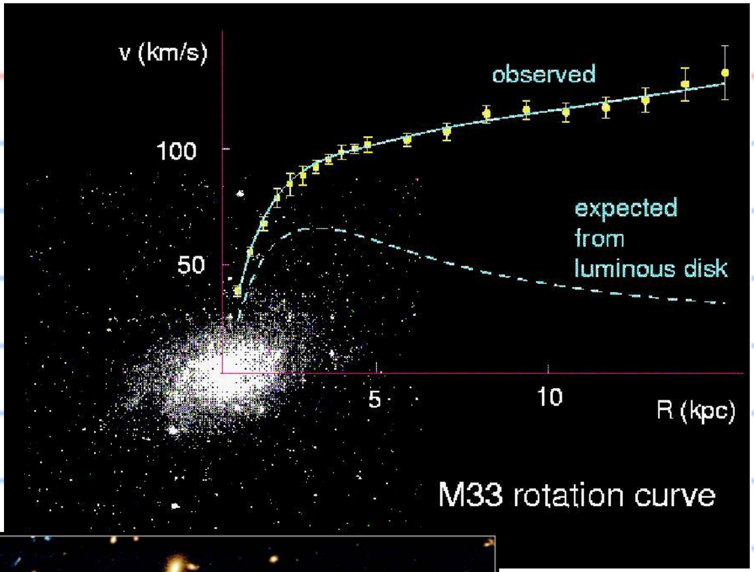
IPMU

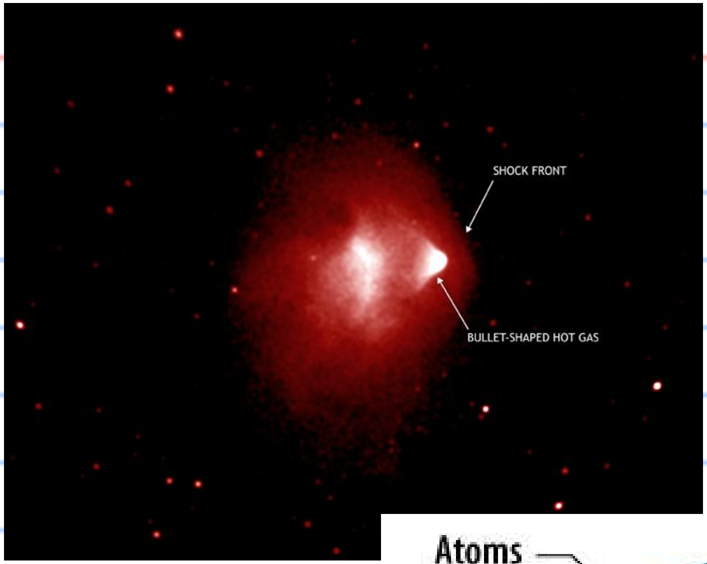
1 November 2013

Y-L Sming Tsai (蔡岳霖.馴名)

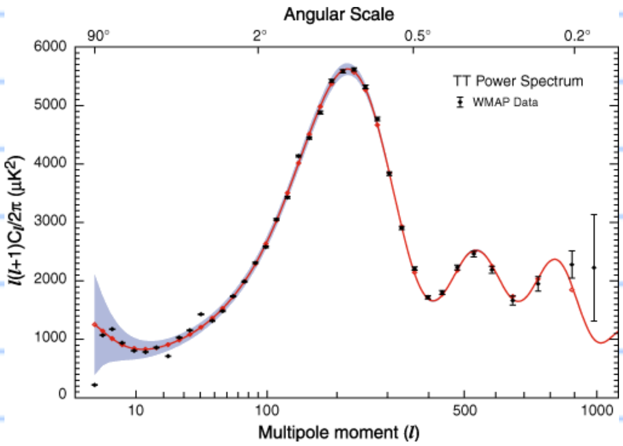
Based on 1306.1567
Phys.Rev. D88 (2013) 055012
in Collaboration with BayesFITS group

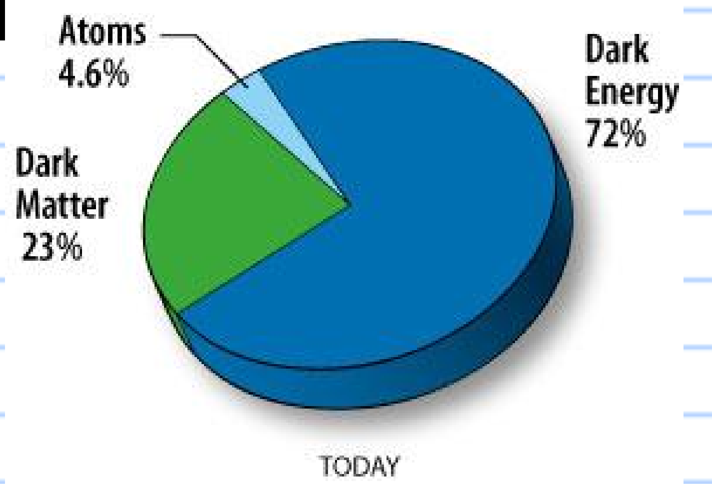
Dark Matter evidence



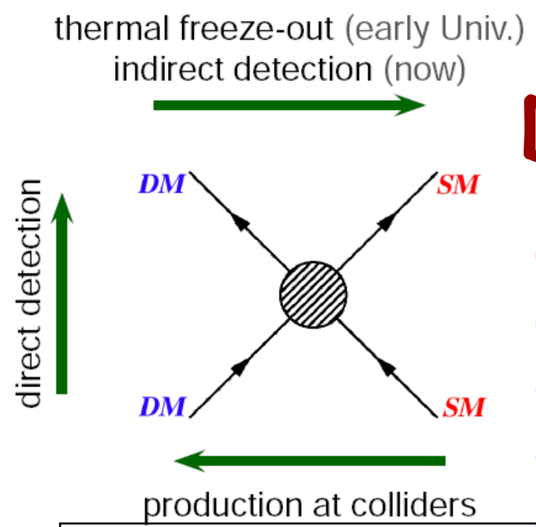


Gravitational Lens HST • WFPC2
Galaxy Cluster 0024+1654
PRC96-10 • ST ScI OPO • April 24, 1996
W.N. Colley (Princeton University), E. Turner (Princeton University), J.A. Tyson (AT&T Bell Labs) and NASA





It will be difficult to explain the universe without dark matter assumption.



Dark Matter search

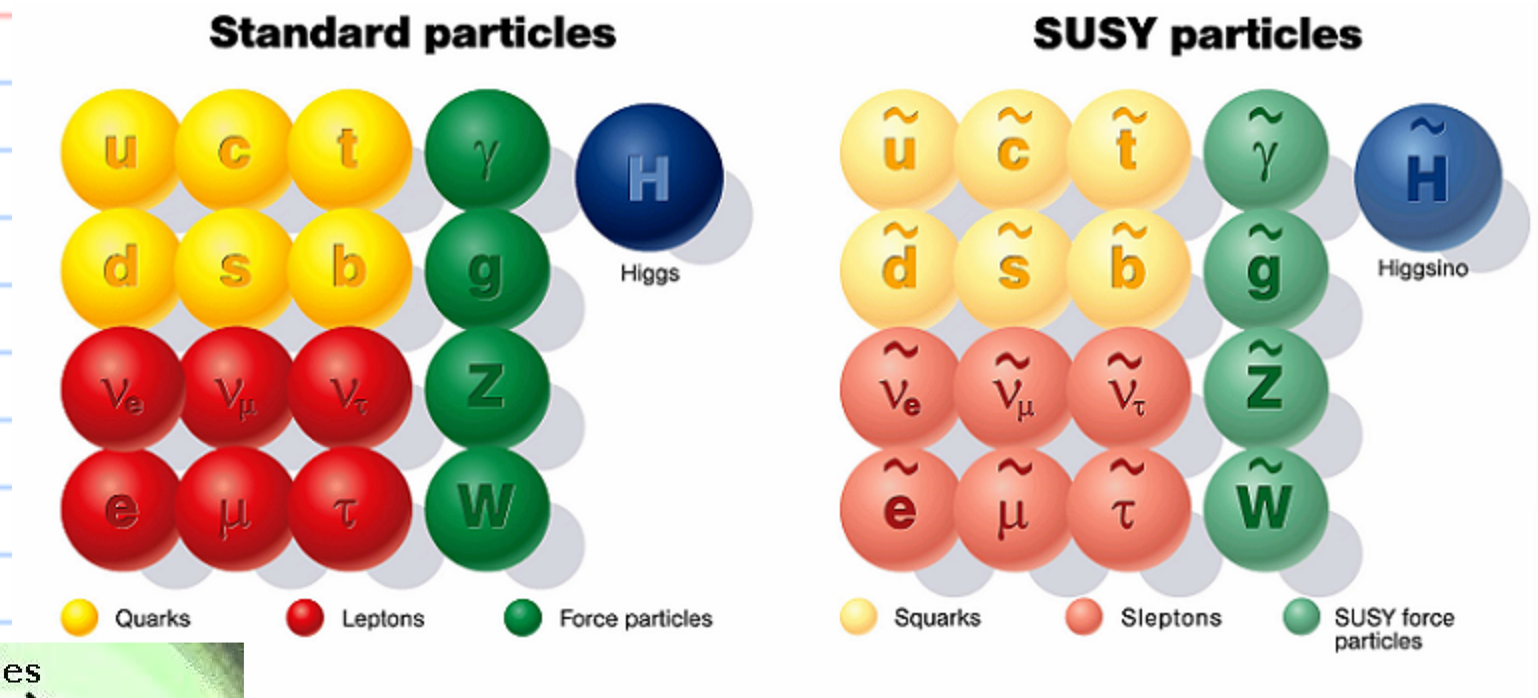
Signals at	Experiments	DM Hints
Coillders	LHC, LEP, Tevatron, …	None
Direct detection	XENON100, CDMS, LUX …	DAMA, CoGeNT, CRESST at low DM mass region.
Cosmic rays 1. Positrons 2. antiprotons 3. neutrinos	1. PAMELA, Fermi-LAT, AMS02… 2. PAMELA… 3. IceCube…	1. High energy positron excess 2. None 3. PeV neutrinos
Gamma rays	Fermi-LAT, …	FERMI bubbles, Fermi Gamma ray line at 130 GeV…
Radio	WMAP, Planck	WMAP (Planck) haze

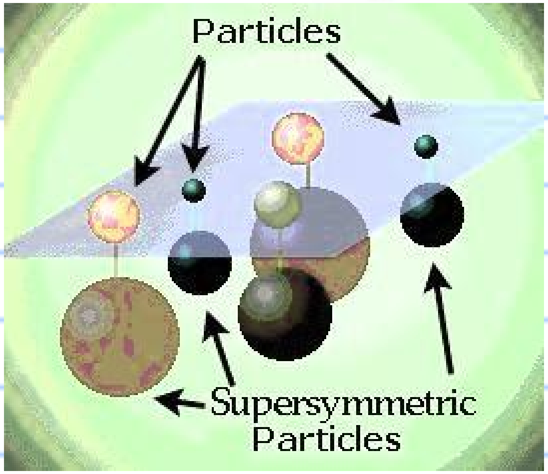
Outline

1. MSSM neutralino dark matter
2. SUSY Dark Matter search at the LHC
3. Impact of the XENON100 (2012) result
4. Neutralino indirect detection
5. Summary

Neutralino Dark Matter

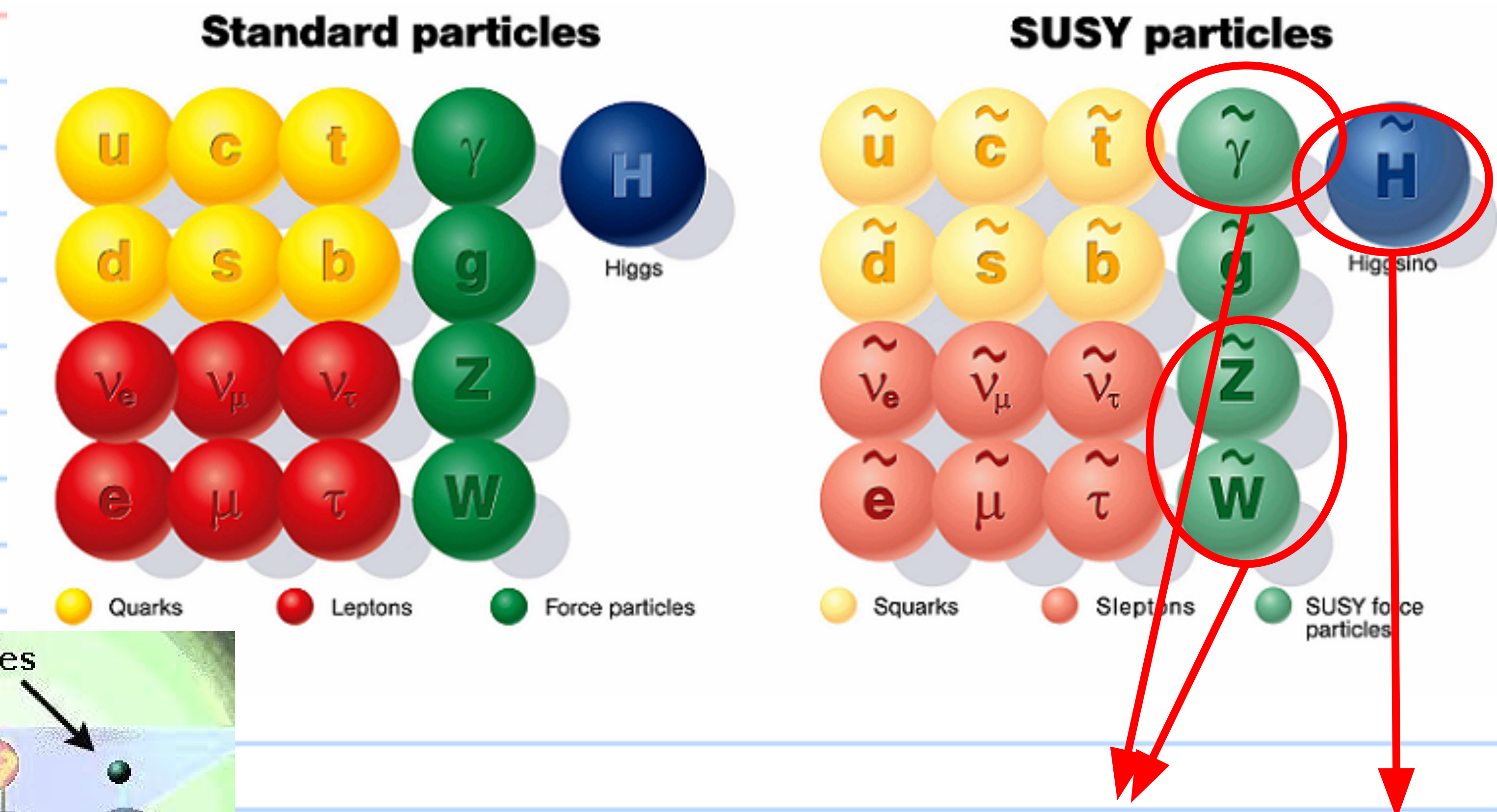
Supersymmetry

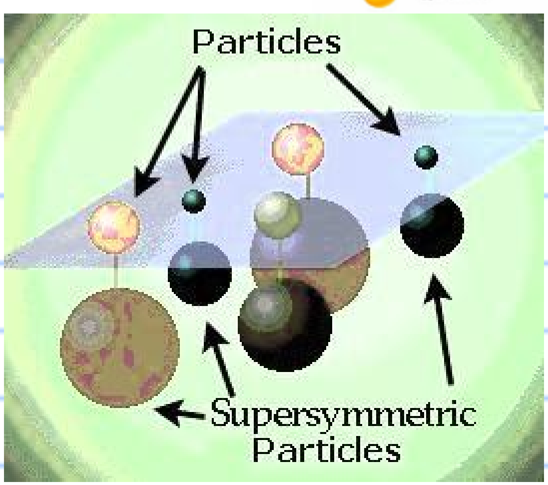




Supersymmetry

No DM candidate !!

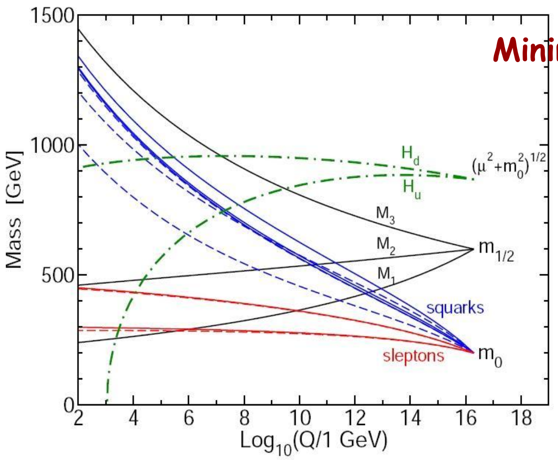




"neutralino" χ: lightest mass state of neutral gauginos and higgsinos

stable WIMP: excellent DM candidate

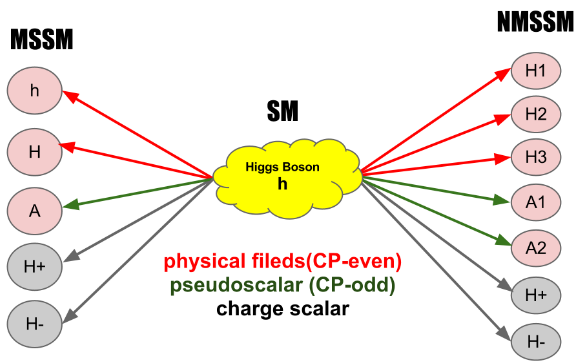
Some popular supersymmetric models:



Minimal and Next Minimal Supersymmetric Standard Model

G. L. Kane, C. F. Kolda, L. Roszkowski and J. D. Wells, Phys. Rev. D 49 (1994) 6173

Higgs sector



Models	Input parameters	Boundary conditions
CMSSM	**m_0, m_{1/2}, tanb, A_0, sgn(mu)**	GUT (Q/GeV ~2 X 10^16)
CMSSM +non-universal Higgs mass	**CMSSM+**(m_Hu,m_Hd)	GUT (Q/GeV ~2 X 10^16)
MSSM	all trilinear couplings, masses, and Higgs parameters	SUSY (Q~stop mass)
CNMSSM	**CMSSM+** Singlet higgs mass	GUT (Q/GeV ~2 X 10^16)
NMSSM	all trilinear couplings, masses, and Higgs parameters	SUSY (Q~stop mass)

Choice of parameters (p9MSSM)

All ranges in TeV

Parameter	Range
gluino mass	$0.7 < M_3 < 8$
wino mass	$0.01 < M_2 < 4$
bino mass	$M_1 = 0.5 M_2$
stop trilinear coupl.	$-7 < A_t < 7$
τ trilinear coupl.	$-7 < A_\tau < 7$
sbottom trilinear coupl.	$A_b = -0.5$
pseudoscalar mass	$0.2 < m_A < 4$
μ parameter	$0.01 < \mu < 4$
3rd gen. soft squark mass	$0.3 < m_{\tilde{Q}_3} < 4$
3rd gen. soft slepton mass	$0.1 < m_{\tilde{L}_3} < 2$
1st/2nd gen. soft slepton mass	$m_{\tilde{L}_{1,2}} = M_1 + 50\,\mathrm{GeV}$
1st/2nd gen. soft squark mass	$m_{\tilde{Q}_{1,2}} = 2.5$
ratio of Higgs doublet VEVs	$3 < \tan\beta < 62$
Nuisance parameter	**Central value, error**
Bottom mass $m_b(m_b)^{\overline{MS}}$ (GeV)	(4.18, 0.03)
Top mass at pole M_t (GeV)	(173.5, 1.0)

Bino DM candidate
(Fit relic density and ID)

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Bino DM candidate
(Fit relic density and ID)

SMUON light
(Fit g-2)

1st 2nd gen squarks heavy
(LHC disfavored)

Choice of parameters (p9MSSM)

All ranges in TeV

$M_2,\ M_3,\ m_{\tilde{Q}_3},\ m_{\tilde{L}_3},\ A_t,\ A_\tau,\ m_A,\ \mu,\ \tan\beta$

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1.8×10^6 points collected subject to constraints

$$\mathrm{BR}(\bar{\mathrm{B}}_s \to \mu^+\mu^-) \propto \frac{\tan^6\beta}{\mathrm{m}_\mathrm{A}^4}$$

Constraints in Likelihood

Measurement	Mean or Range	Error: (Exp., Th.)	Distribution
CMS α_T 11.7/fb , $\sqrt{s} = 8\,\mathrm{TeV}$	See text	See text	Poisson
m_h by CMS	$125.8\,\mathrm{GeV}$	$0.6\,\mathrm{GeV}, 3\,\mathrm{GeV}$	Gaussian
$\Omega_\chi h^2$	0.1199	0.0027, 10%	Gaussian
$\mathrm{BR}\,(\overline{B} \to X_s\gamma)\times 10^4$	3.43	0.22, 0.21	Gaussian
$\mathrm{BR}\,(B_u \to \tau\nu)\times 10^4$	1.66	0.33, 0.38	Gaussian
ΔM_{B_s}	$17.719\,\mathrm{ps}^{-1}$	$0.043\,\mathrm{ps}^{-1}$, $2.400\,\mathrm{ps}^{-1}$	Gaussian
$\sin^2\theta_{\mathrm{eff}}$	0.23146	0.00012, 0.00015	Gaussian
M_W	$80.399\,\mathrm{GeV}$	$0.023\,\mathrm{GeV}$, $0.015\,\mathrm{GeV}$	Gaussian
$\mathrm{BR}\,(B_s \to \mu^+\mu^-) \times 10^9$	3.2	$+1.5 - 1.2$, 10%	Gaussian
$m_b(m_b)^{\overline{MS}}$	$4.18\,\mathrm{GeV}$	$0.03\,\mathrm{GeV}$, 0	Gaussian
M_t	$173.5\,\mathrm{GeV}$	$1.0\,\mathrm{GeV}$, 0	Gaussian
$\delta\,(g-2)_\mu^{\mathrm{SUSY}}\times 10^{10}$	28.7	8.0, 1.0	Gaussian
XENON100 (2012)	See text	See text	Poisson
CMS $3l + E_T^{\mathrm{miss}}$ 9.2/fb, $\sqrt{s} = 8\,\mathrm{TeV}$	See text	See text	Poisson

PLUS LEP CONSTRAINTS:

$$
\begin{aligned}
m_\chi &> 46\,\mathrm{GeV}\,, \\
m_{\tilde{e}} &> 107\,\mathrm{GeV}\,, \\
m_{\chi_1^\pm} &> 94\,\mathrm{GeV}\ \text{if}\ m_{\chi_1^\pm} - m_\chi > 3\,\mathrm{GeV}\ \text{and}\ \tan\beta < 40\,, \\
m_{\tilde{\mu}} &> 94\,\mathrm{GeV}\ \text{if}\ m_{\tilde{\mu}} - m_\chi > 10\,\mathrm{GeV}\ \text{and}\ \tan\beta < 40\,, \\
m_{\tilde{\tau}} &> 81.9\,\mathrm{GeV}\ \text{if}\ m_{\tilde{\tau}_1} - m_\chi > 15\,\mathrm{GeV}\,, \\
m_{\tilde{b}_1} &> 89\,\mathrm{GeV}\ \text{if}\ m_{\tilde{b}_1} - m_\chi > 8\,\mathrm{GeV}\,, \\
m_{\tilde{t}_1} &> 95.7\,\mathrm{GeV}\ \text{if}\ m_{\tilde{t}_1} - m_\chi > 10\,\mathrm{GeV}\,.
\end{aligned}
$$

NEW!!! XENON100 (2012) included.

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Basic set

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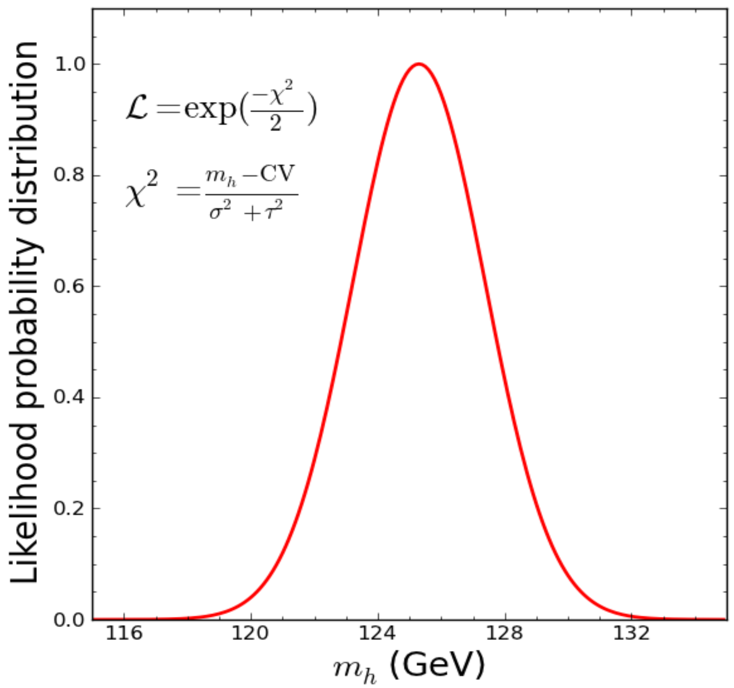
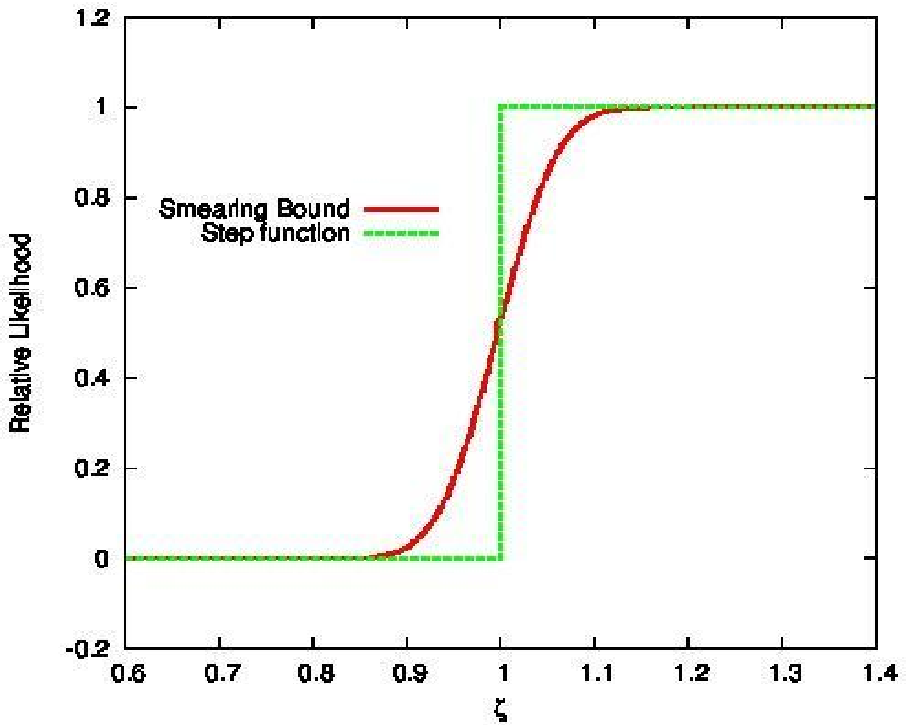
Likelihood types



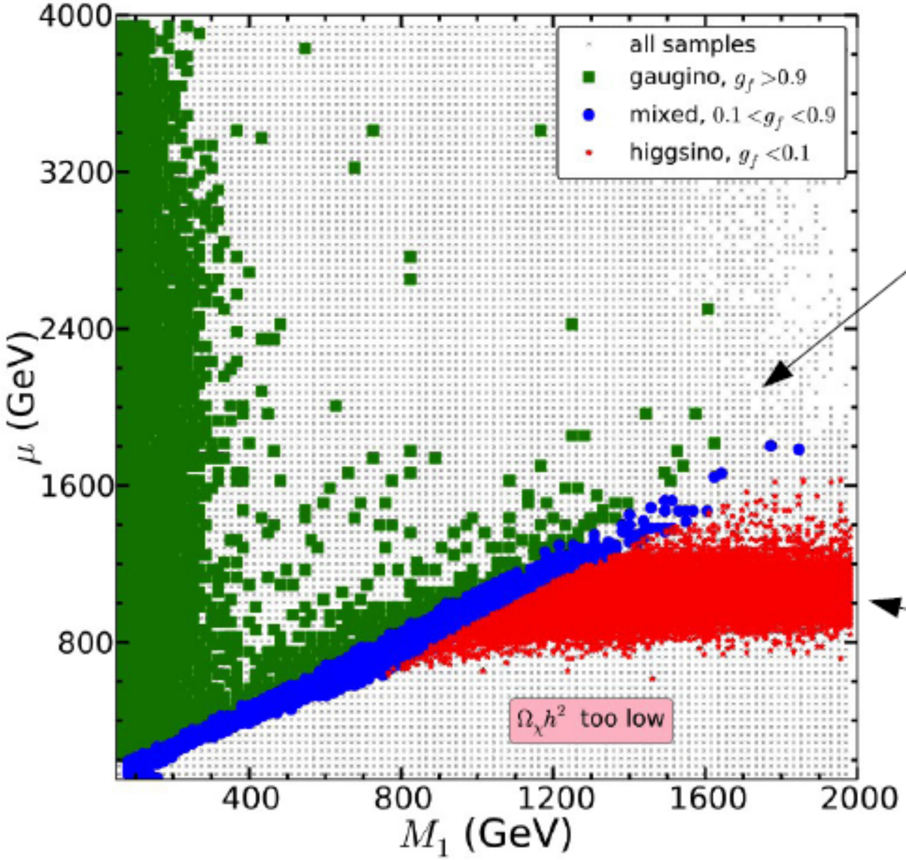


Gaussian Likelihood distribution

Lower-limit Likelihood distribution

Poisson Likelihood distribution will be shown later…

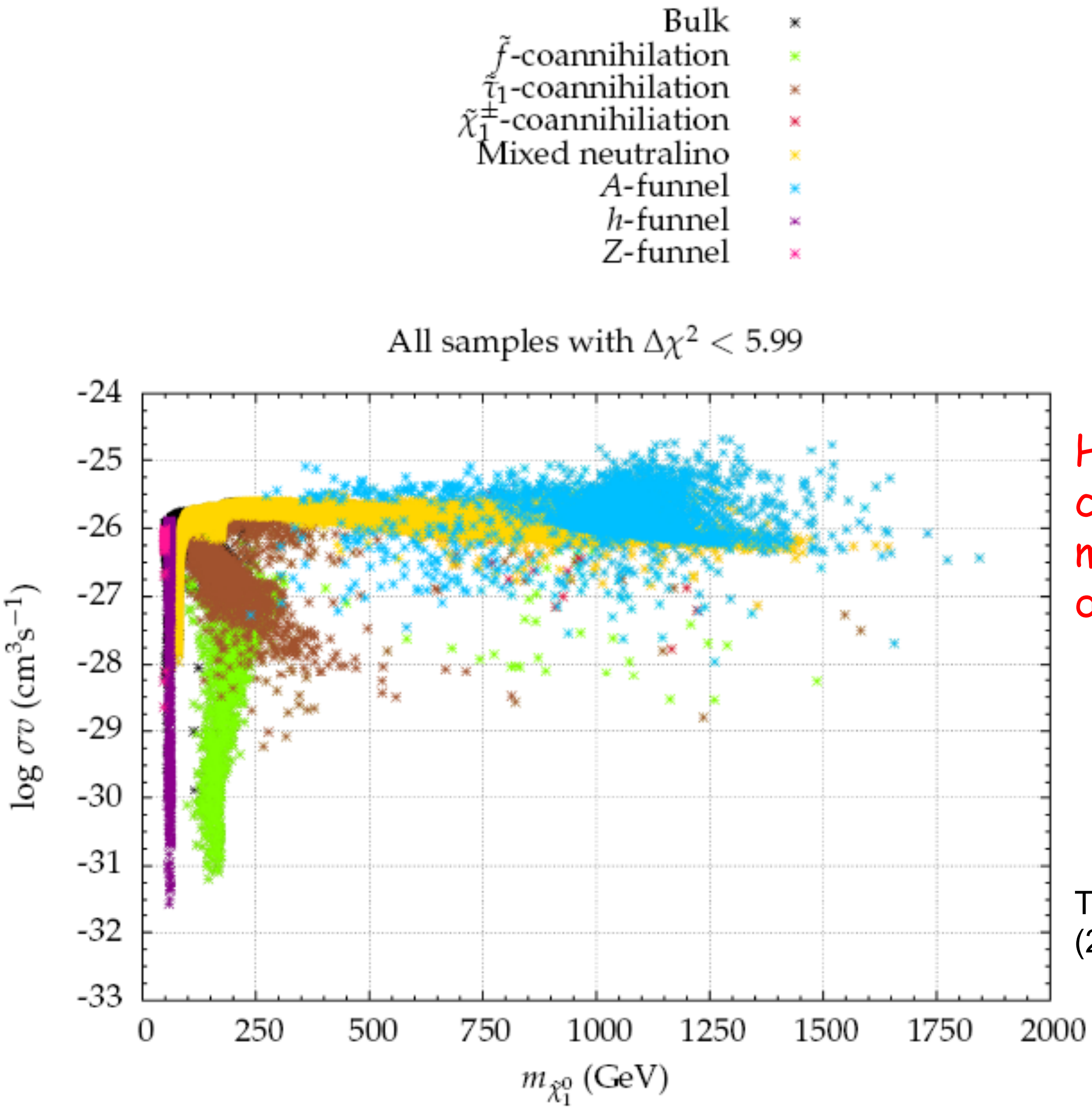
Impact of the relic density



95% conf dence region
No g-2, No Xenon 30% of all points

- Gaugino-like LSP: $m_\chi = M_1$
- Higgsino-like LSP: $m_\chi = \mu$

Large higgsino-like region at $m_\chi \simeq 1$ TeV

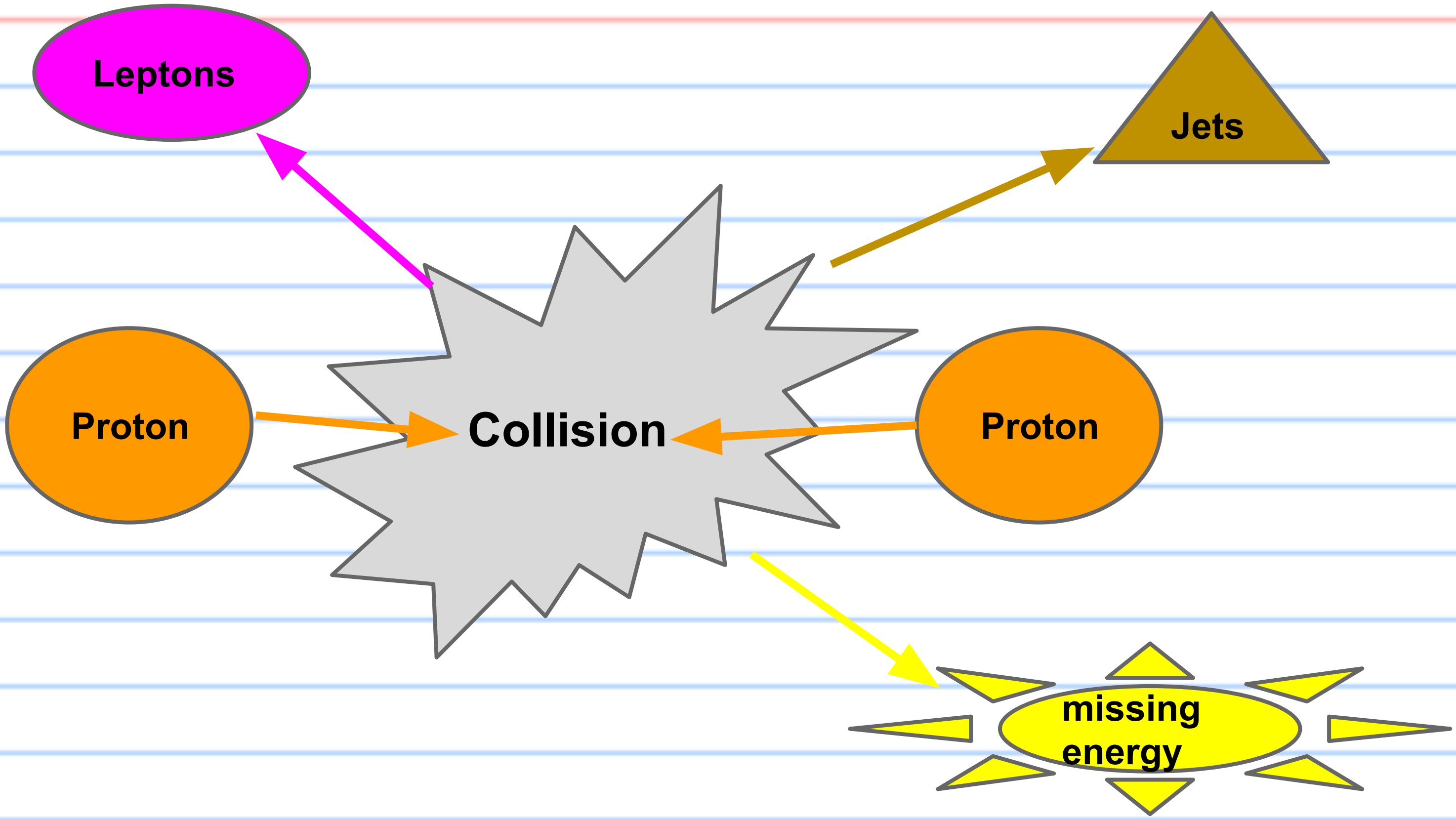


High probability region can be grouped by their main contribution to relic density reduction.

Taken from Fowlie's PhD thesis (2013)

SUSY Dark Matter search at the LHC

Dark Matter production at the LHC



Dark Matter studies at the LHC are highly model-dependent: one can identify DM candidate.

This will need a confirmation from DM DD and ID search.

315 Physicists Report Failure In Search for Supersymmetry

The negative result illustrates the risks of Big Science, and its often sparse pickings.

By MALCOLM W. BROWNE

Three hundred and fifteen physicists worked on the experiment.

Their apparatus included the Tevatron, the world's most powerful particle accelerator, as well as a $65 million detector weighing as much as a warship, an advanced new computing system and a host of other innovative gadgets.

But despite this arsenal of brains and technological brawn assembled at the Fermilab accelerator laboratory, the participants have failed to find their quarry, a disagreeable reminder that as science gets harder, even Herculean efforts do not guarantee success.

That was reported 10 years ago about Tevatron...

What has been changed since then?

315 Physicists Report Failure

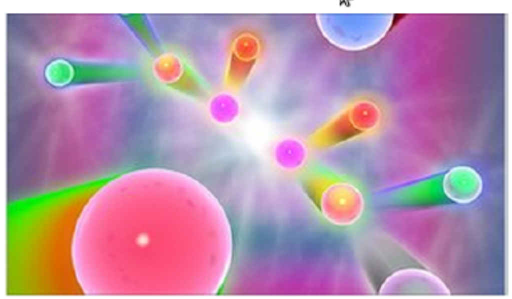
NEWS SCIENCE & ENVIRONMENT

27 August 2011 Last updated at 06:41 GMT

LHC results put supersymmetry theory 'on the spot'

By Pallab Ghosh
Science correspondent, BBC News

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.



Supersymmetry predicts the existence of mysterious super particles.

Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had hoped would plug holes in the current theory.

Theorists working in the field have told BBC News that they may have to come up with a completely new idea.

Data were presented at the Lepton Photon science meeting in Mumbai.

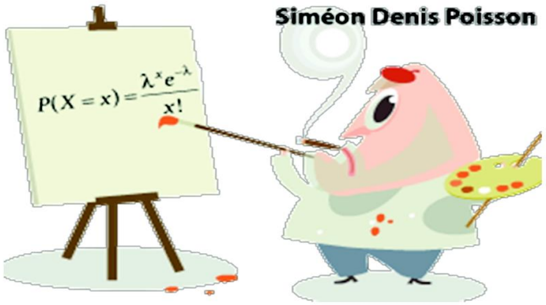
Related Stories

Herculean efforts do not guarantee success.

Increasing energy, luminosity and number of physicist failed to find SUSY have increased by factor of 10...

Let's look at the situation in the MSSM.

LHC likelihood



Poisson likelihood
$p(o\,|\,s;b)$

CMS boxes for **Observed** and **BG** yields

$$\mathcal{L}(s) = \int p(o|s;b')\exp\left[-\frac{(b-b')^2}{2\delta b^2}\right]db'$$

Simulate "signal"

Table 1: CMS preliminary 2012, $L_{int} = 11.7$ fb^{-1}, $\sqrt{s} = 8$ TeV. Comparison of the observed yields in the different H_T bins when requiring $2 \le n_{jet} \le 3$ and $n_b^{reco} = 0$ for the signal region and data control samples with the SM expectations and combined statistical and systematic uncertainties given by the simultaneous fit.

H_T Bin (GeV)	275–325	325–375	375–475	475–575	575–675	675–775	775–875	875–∞
SM hadronic	6235^{+100}_{-67}	2900^{+60}_{-54}	1955^{+34}_{-39}	558^{+14}_{-15}	186^{+11}_{-10}	$51.3^{+3.4}_{-3.8}$	$21.2^{+2.3}_{-2.2}$	$16.1^{+1.7}_{-1.7}$
Data hadronic	6232	2904	1965	552	177	58	16	25
SM μ+jets	9696^{+102}_{-83}	5044^{+69}_{-81}	4655^{+57}_{-73}	1806^{+43}_{-34}	766^{+27}_{-24}	307^{+14}_{-16}	147^{+10}_{-11}	195^{+13}_{-13}
Data μ+jets	9698	5039	4653	1808	779	294	150	193
SM $\mu\mu$+jets	1334^{+28}_{-37}	707^{+26}_{-27}	594^{+18}_{-22}	238^{+10}_{-10}	116^{+9}_{-10}	$46.2^{+3.8}_{-4.8}$	$22.4^{+3.0}_{-2.7}$	$28.6^{+4.3}_{-4.0}$
Data $\mu\mu$+jets	1336	708	623	205	120	44	21	26
SM γ+jets	–	–	2637^{+48}_{-42}	818^{+24}_{-20}	261^{+16}_{-15}	$85.1^{+5.3}_{-5.7}$	$31.3^{+4.0}_{-4.0}$	$25.4^{+3.3}_{-3.4}$
Data γ+jets	–	–	2601	854	252	94	35	21

SUSY Spectrum (model)	Decay BR's	Event generation, X-sec storage, Hadronization	Detector simulation, Object reconstruction, Cards, *b*-tagging	Kinematical cuts
SoftSUSY	SUSYHIT	PYTHIA	PGS4	Follow CMS

In our scan:

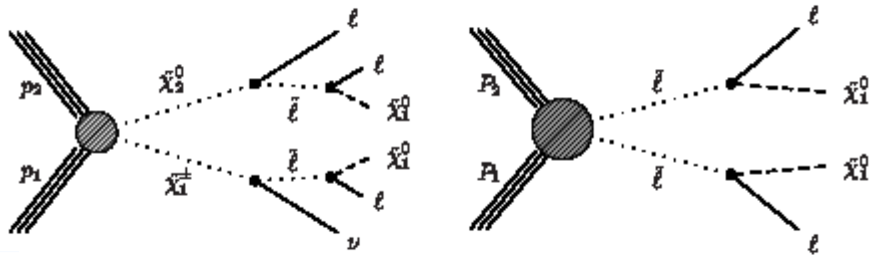
Inclusive prod. for squarks + gluinos — $\alpha_T\,,\sqrt{s} = 8\ \text{TeV}\,,11.7/\text{fb}$

EW production — $3l + E_T^{\text{miss}}\,,\sqrt{s} = 8\ \text{TeV}\,,9.2/\text{fb}$

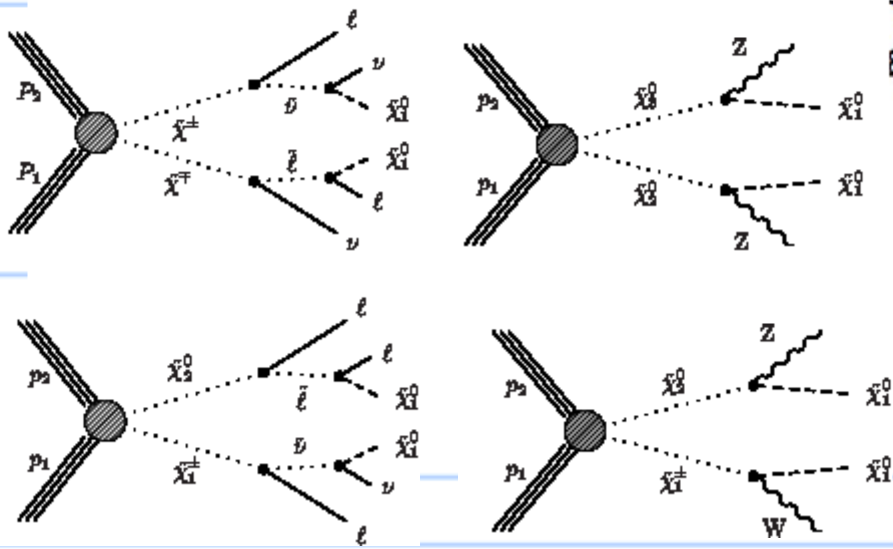
chargino-neutralino pair production (EW production)

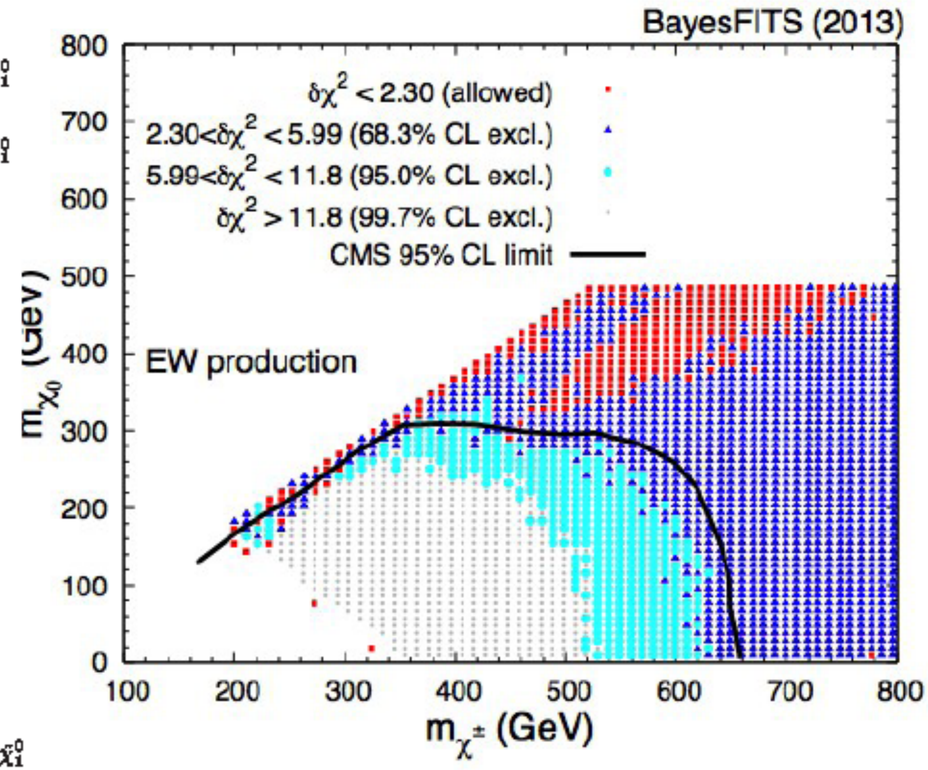
$3l + E_T^{\mathrm{miss}}\,, \sqrt{s} = 8\ \mathrm{TeV}\,, 9.2/\mathrm{fb}$

$(\mathrm{SMS:}\ m_{\tilde{l}} = 0.5 m_{\chi_1^0} + 0.5 m_{\chi_1^\pm})$



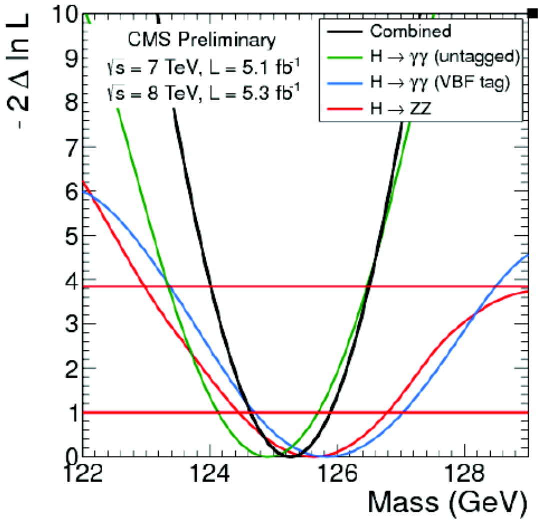
Very Good!





The impact of 125 GeV Higgs mass

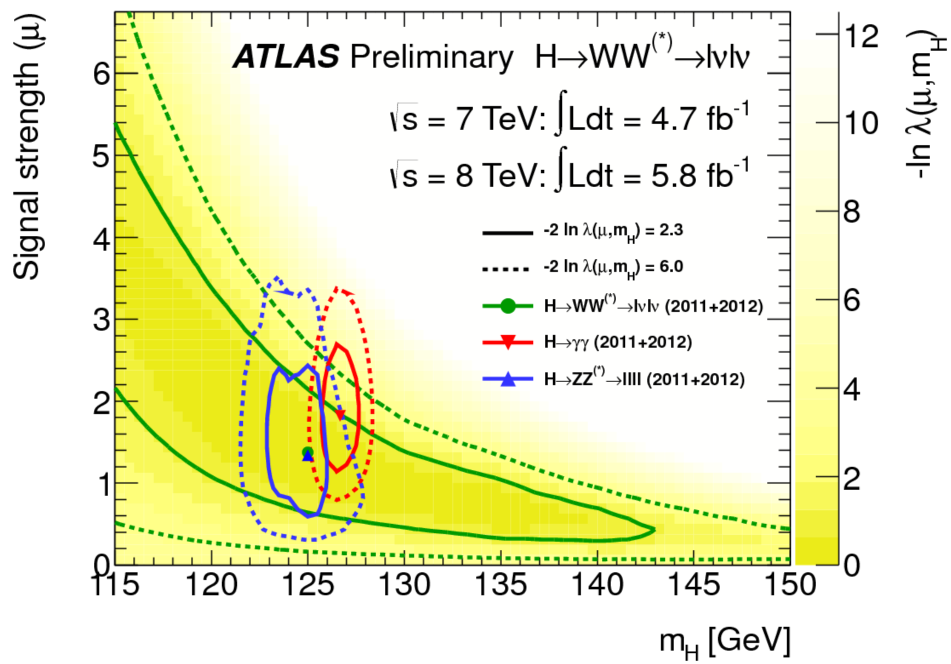
Characterization of the excess: mass



To reduce model dependence, allow for free cross sections in three channels and fit for the common mass:

$m_X = 125.3 \pm 0.6$ GeV

04th July 2012, CMS and ATLAS



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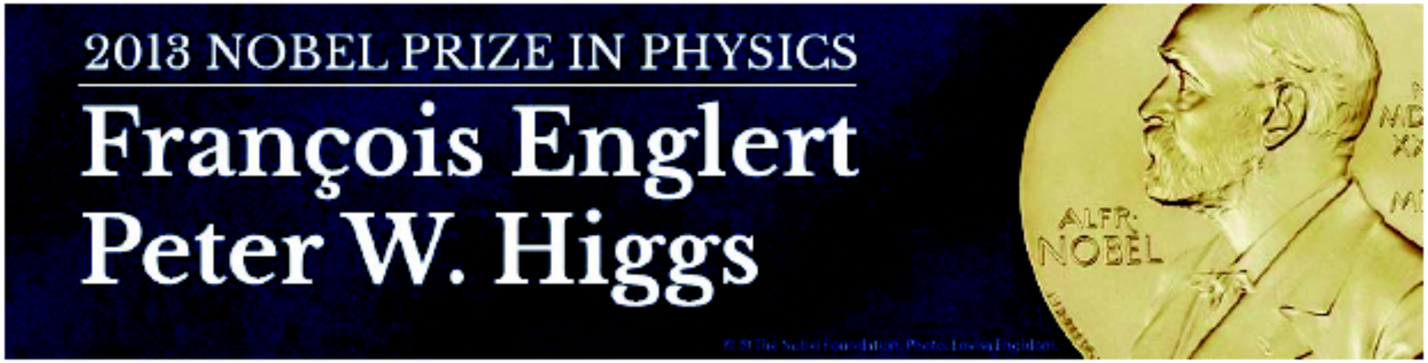
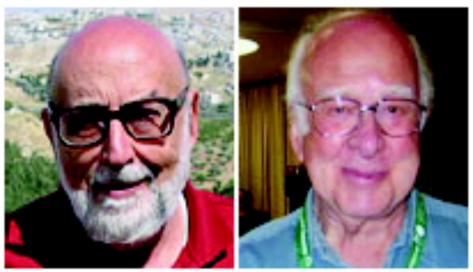


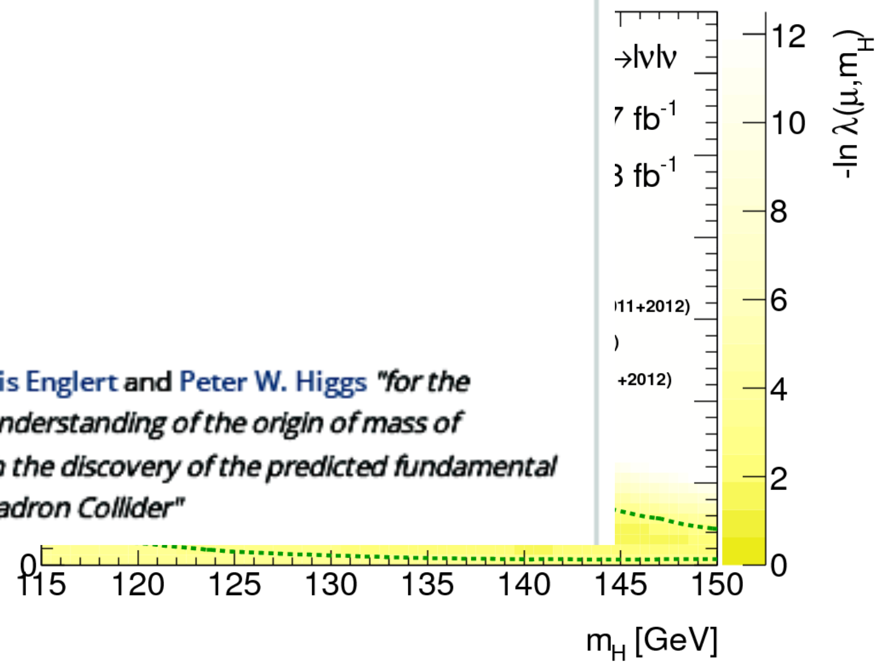


F. Englert and P. Higgs
Photo: Wikimedia Commons

2013 Nobel Prize in Physics

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

s and



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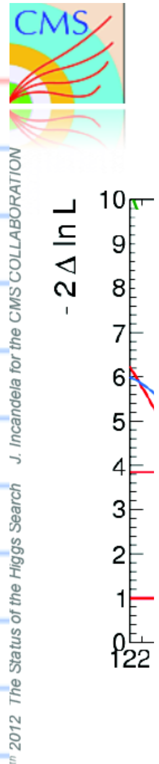
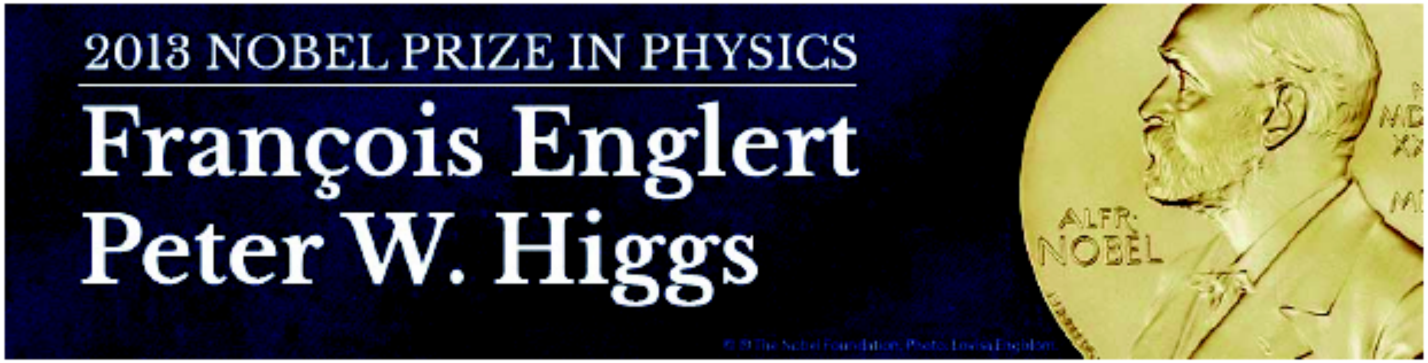
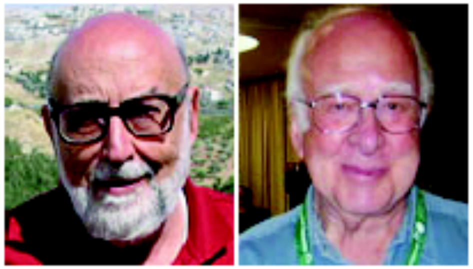
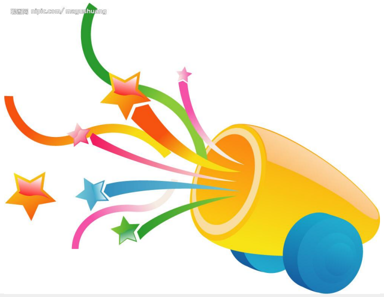
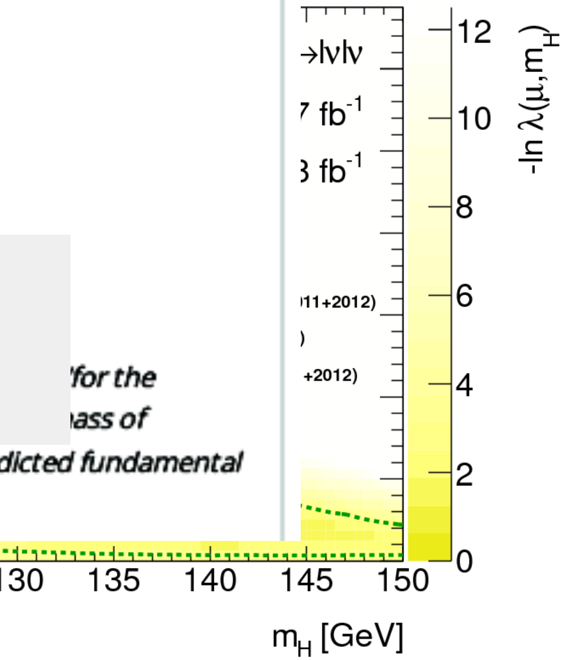








and



Time to celebrate?

Hold on a moment, is Higgs Standard Model like?

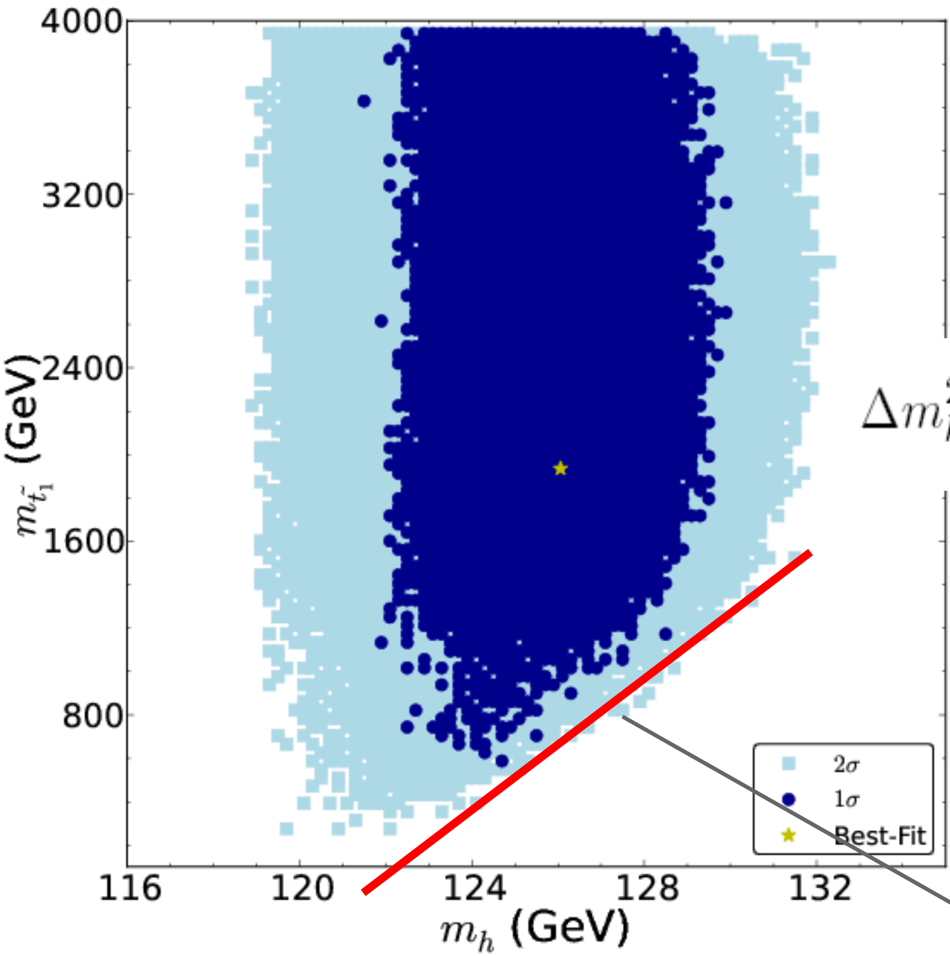
for the

ass of

ecently was confirmed through the discovery of the predicted fundamental

xperiments at CERN's Large Hadron Collider"

The impact of 126 GeV Higgs mass



M_SUSY Scale

input parameters

$$X_t = A_t - \mu \cot\beta$$

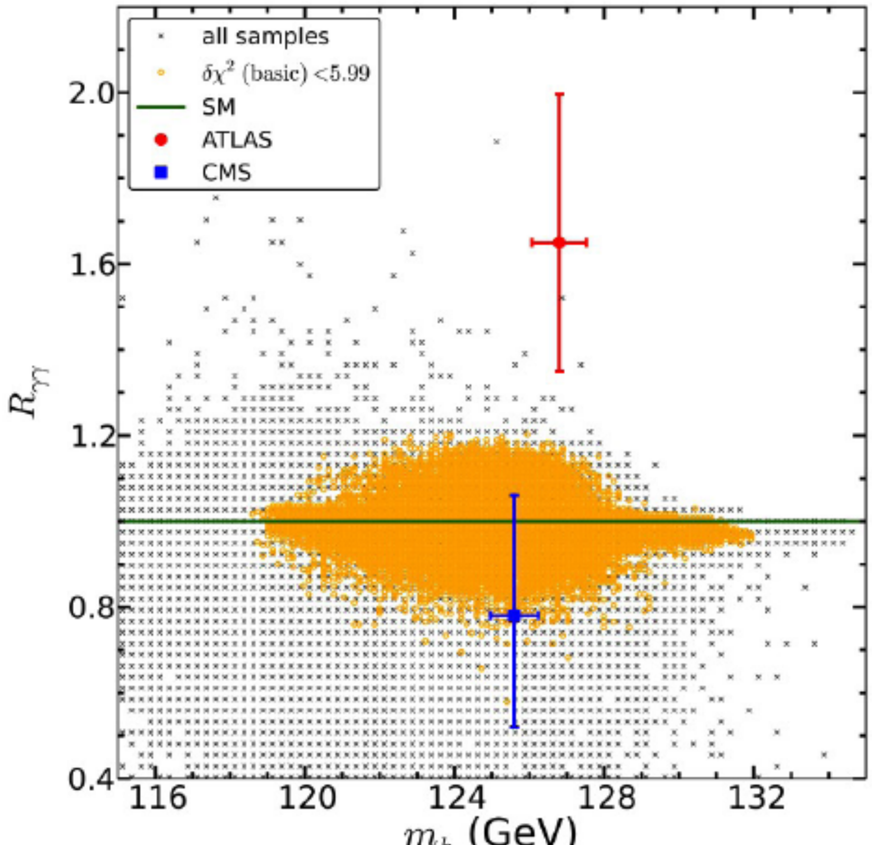
$$\Delta m_h^2 \propto \ln \frac{M_{\rm SUSY}^2}{m_t^2} + \frac{X_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{\rm SUSY}^2}\right)$$

No difficulty to fit Higgs mass at 126 GeV!!!

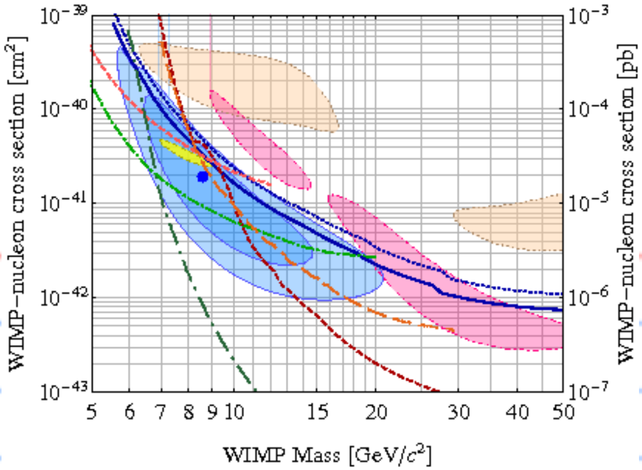
The impact of 126 GeV Higgs mass

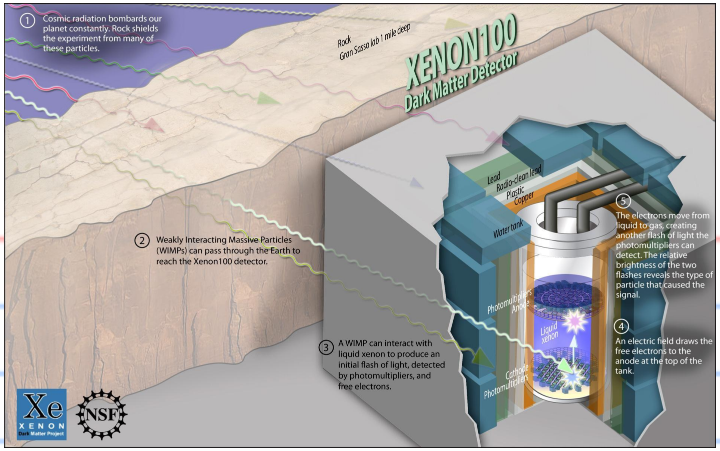
Gamma-gamma rate

$$R_h(\gamma\gamma) = \frac{\sigma(pp \to h)}{\sigma(pp \to h_{\rm SM})} \times \frac{BR(h \to \gamma\gamma)}{BR(h_{\rm SM} \to \gamma\gamma)} \qquad \frac{\sigma(pp \to h)}{\sigma(pp \to h_{\rm SM})} = \sum_{Y \in \text{prod}} \frac{\sigma(pp \to Y \to h_{\rm SM})}{\sigma(pp \to h_{\rm SM})} \times \frac{\sigma(Y \to h)}{\sigma(Y \to h_{\rm SM})}$$

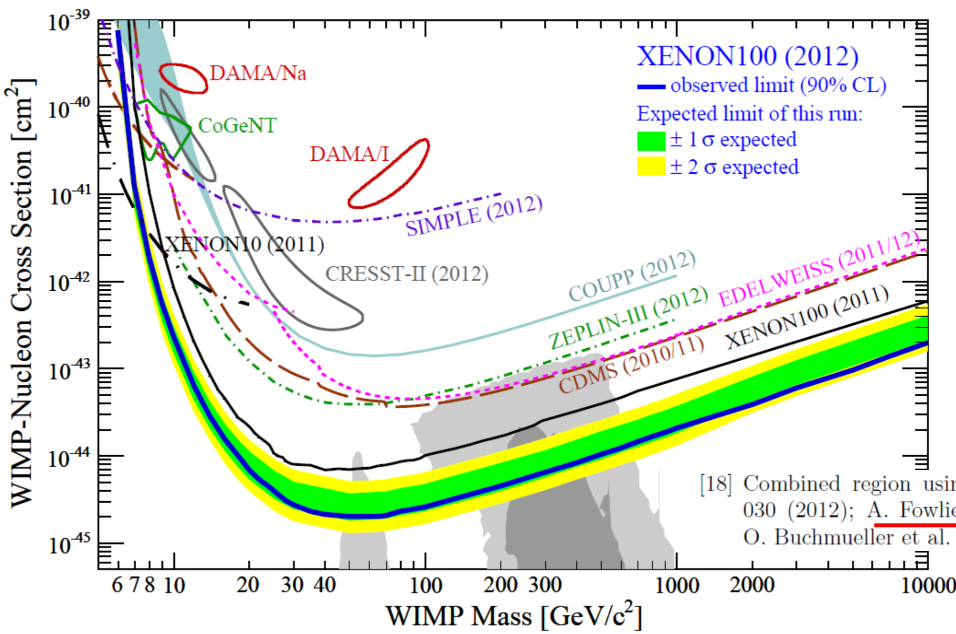


Agree with SM !



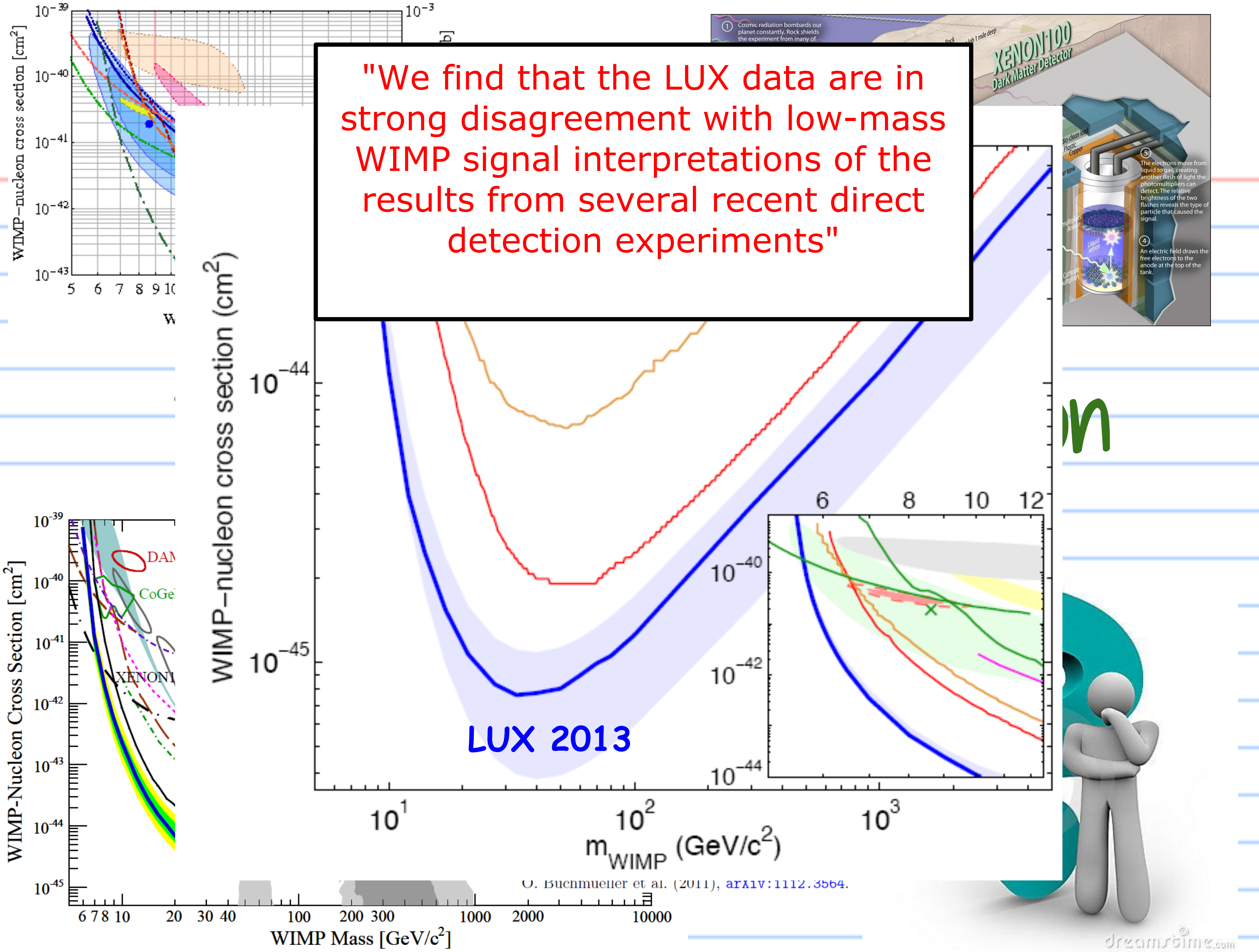


Dark matter direct detection

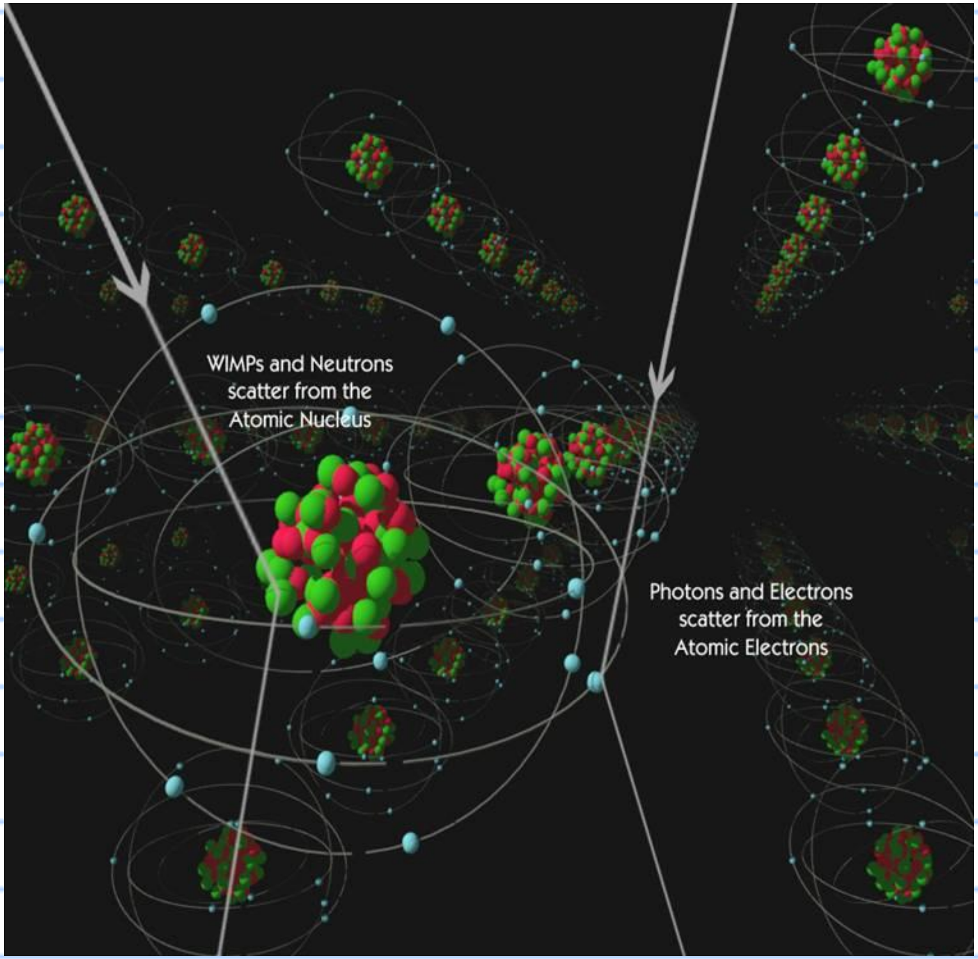


[18] Combined region using C. Strege et al., JCAP **1203**, 030 (2012); A. Fowlie et al. (2012), arXiv:1206.0264; O. Buchmueller et al. (2011), arXiv:1112.3564.

"We find that the LUX data are in strong disagreement with low-mass WIMP signal interpretations of the results from several recent direct detection experiments"



Detect Dark Matter elastic scattering



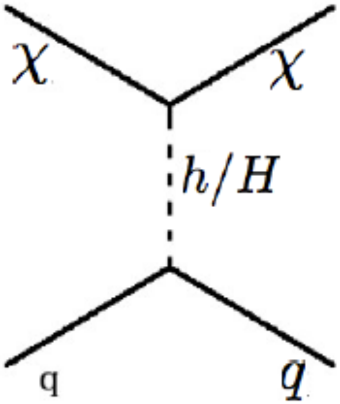
Undetermined direct detection parameters:

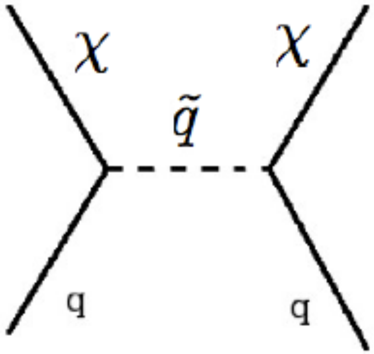
- Local dark matter density
- Dark matter velocity distribution
- Dark matter mass
- Form Factor
- effective couplings of DM to protons and neutrons.

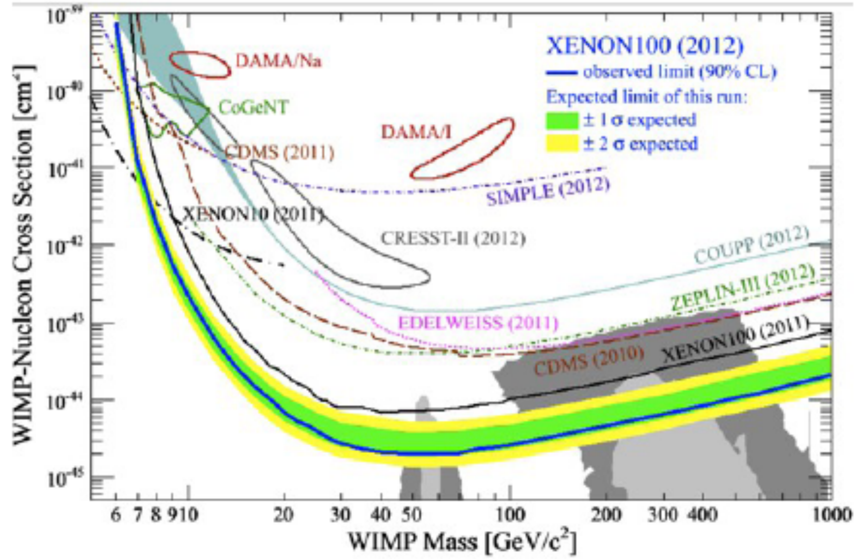
Large theoretical uncertainties from lattice physics

Astrophysical uncertainties ~2 (1111.0292, 1012.3458)
Form Factor uncertainties ~1.2 (hep-ph/0608035v2)

XENON100 likelihood







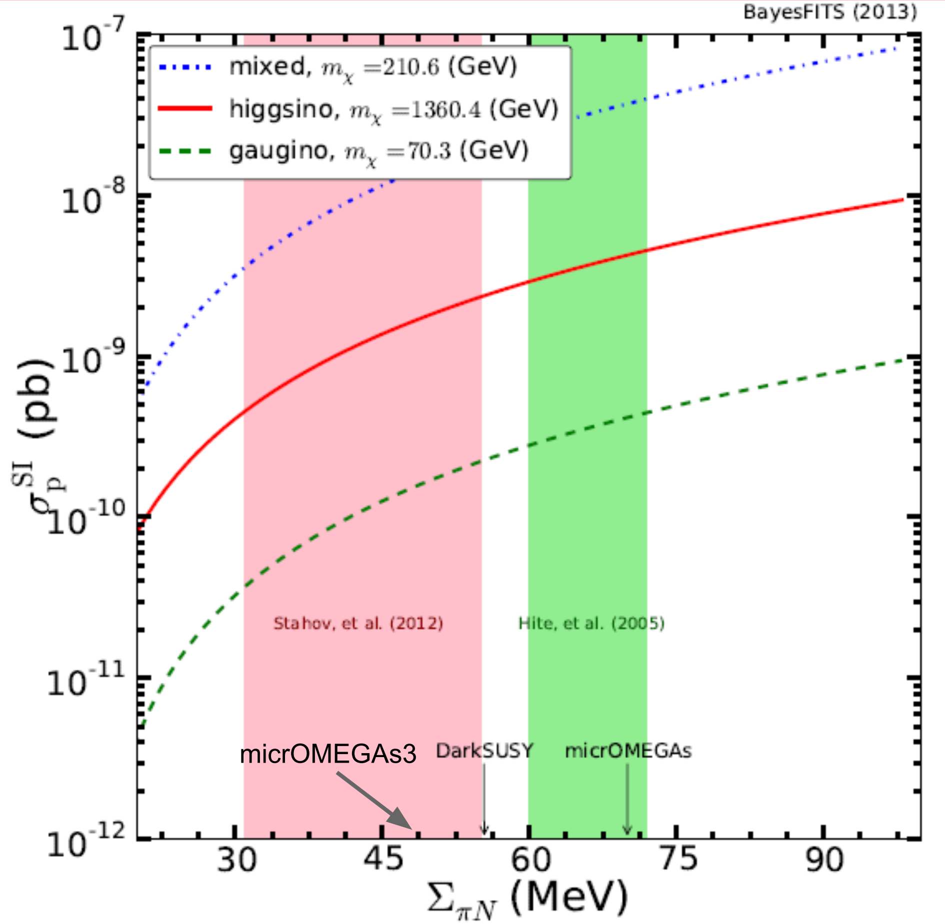
<u>Experimental part:</u>

$o = 2,\ b = 1,\ \delta b = 0.2$ ⟶ Simulate signal with micrOMEGAs

$$\mathcal{P}(s+b|o) = \int_0^\infty \frac{e^{-(s+b')}\,(s+b')^o}{o!} \exp\left[-\frac{(b'-b)^2}{2\delta b^2}\right] db'$$

Kingman Cheung, Yue-Lin Sming Tsai, Po-Yan Tseng, Tzu-Chiang Yuan, A. Zee
Published in JCAP 1210 (2012) 042
e-Print: arXiv:1207.4930

Large theoretical error from lattice calculations



$$\sigma_0 = \frac{m_u + m_d}{2}\langle N|\bar{u}u + \bar{d}d - 2\bar{s}s|N\rangle,$$

$$\Sigma_{\pi N} = \frac{m_u + m_d}{2}\langle N|\bar{u}u + \bar{d}d|N\rangle\,.$$

From quark level to parton level

Varying sigma-term between two scenarios (30 MeV and 80 MeV), spin-independent cross-section can vary by ~one order of magnitude .

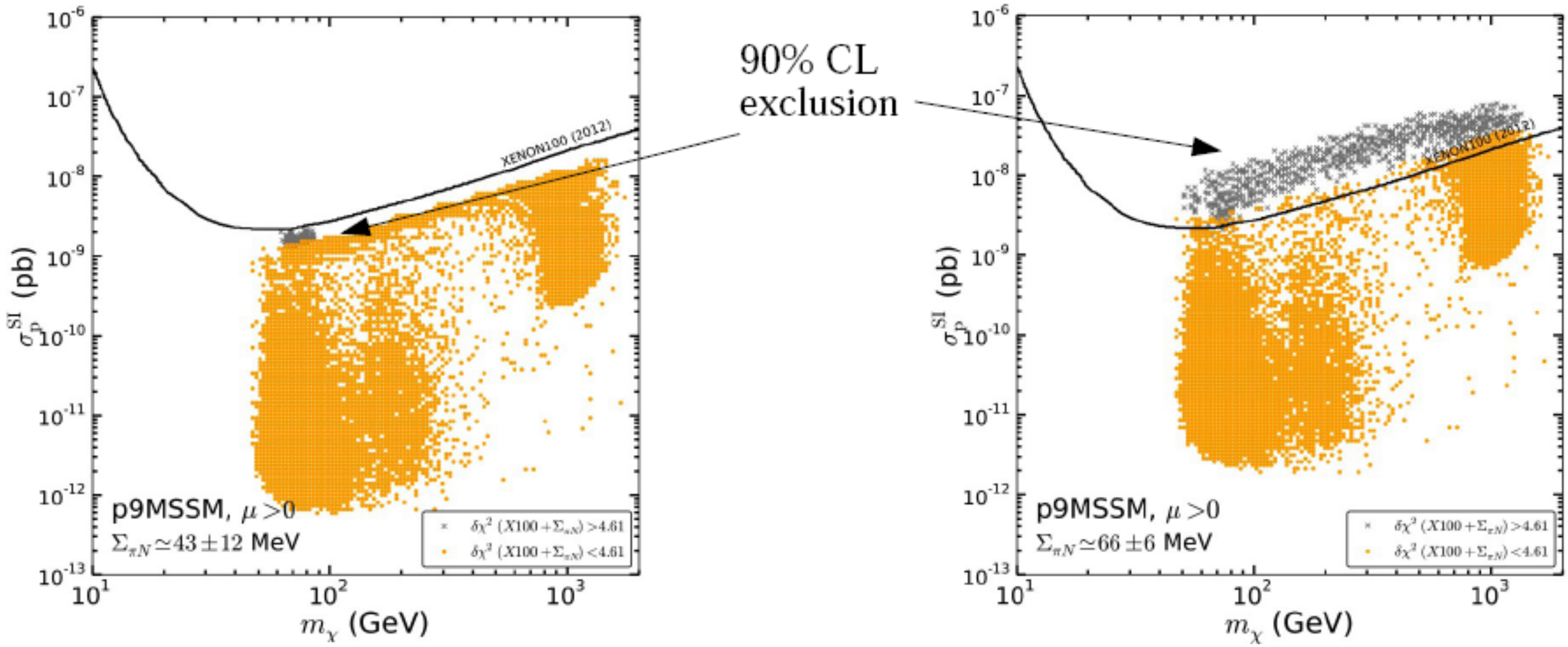
The effect of theoretical error

Our likelihood:

$$\mathcal{L}[m_\chi, \sigma_p^{\rm SI}(\Sigma_{\pi N})] = \max_{\Sigma'_{\pi N}} \mathcal{P}[\varepsilon s_{\rm mo}(m_\chi, \sigma_p^{\rm SI}(\Sigma'_{\pi N})) + b|o] \cdot \exp\left[-\frac{(\Sigma'_{\pi N} - \Sigma_{\pi N})^2}{2\sigma^2_{\Sigma_{\pi N}}}\right]$$

$\Sigma_{\pi N} = 43 \pm 12$ MeV

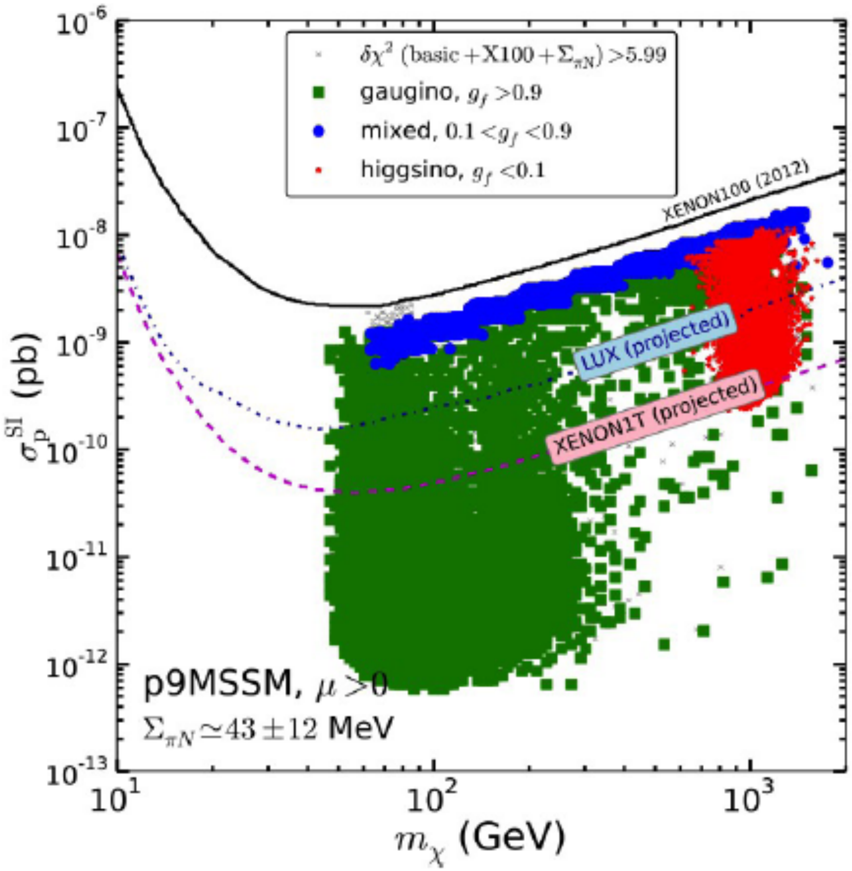
$\Sigma_{\pi N} = 66 \pm 6$ MeV

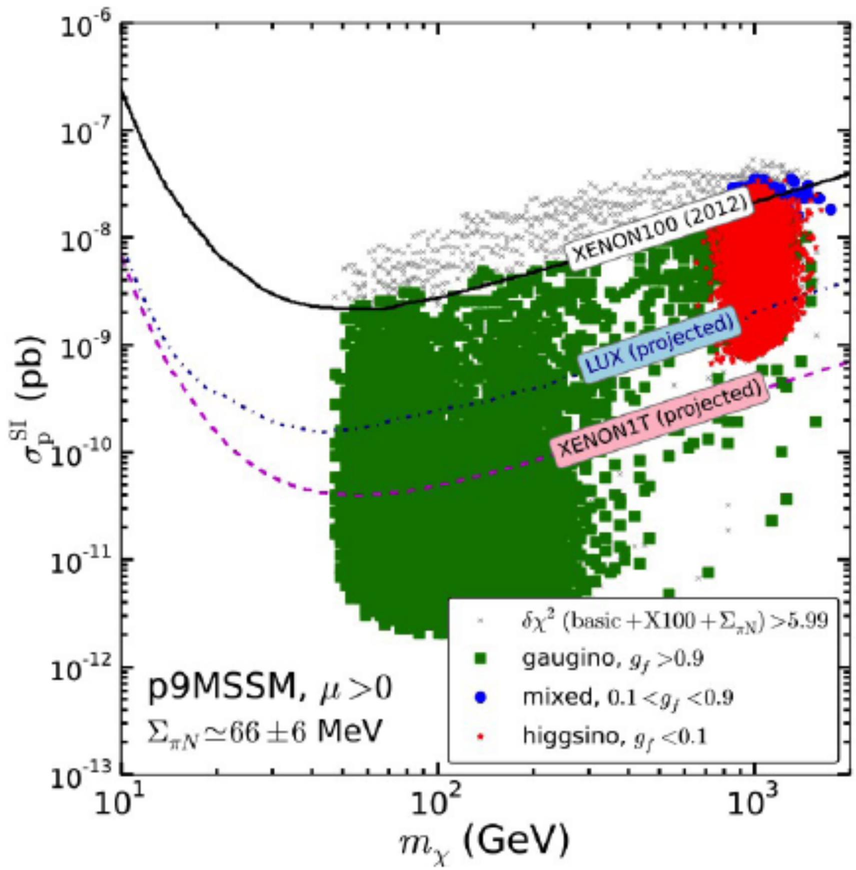


Impact of the XENON100

Impact of the XENON100 and future sensitivities at LUX and XENON1T

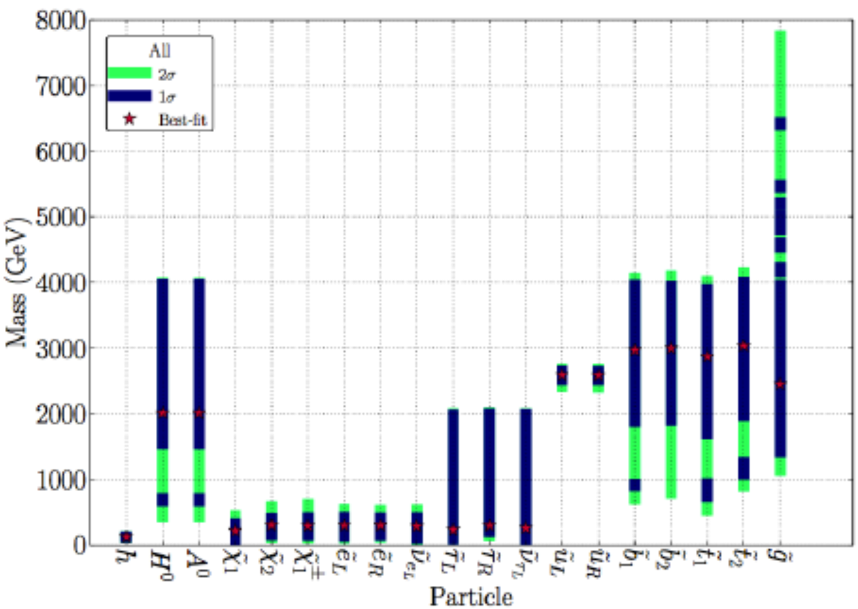
95% conf dence region
No g-2





Results

Mass spectrum and BF points



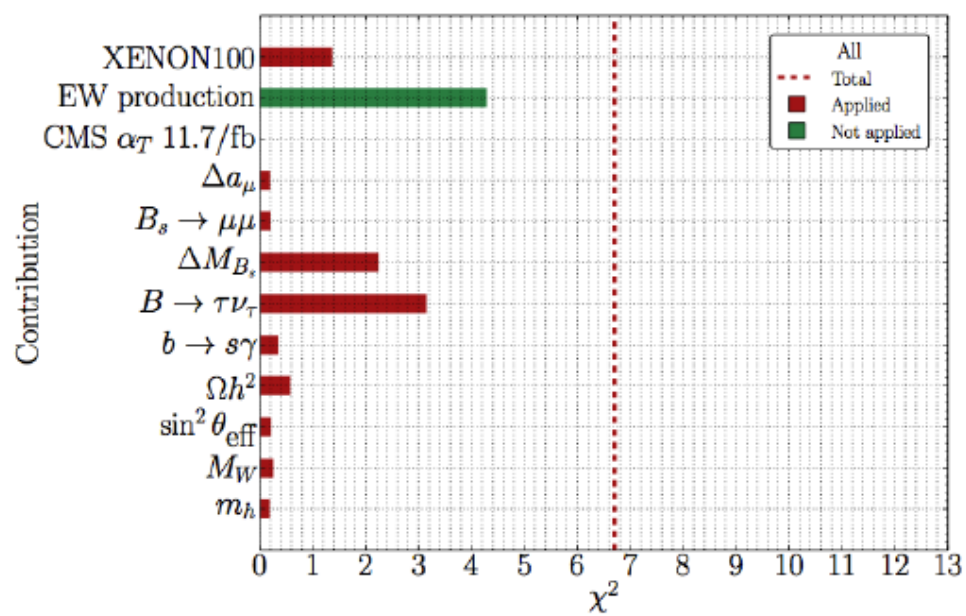
200 GeV <mx< 500 GeV

Constraints

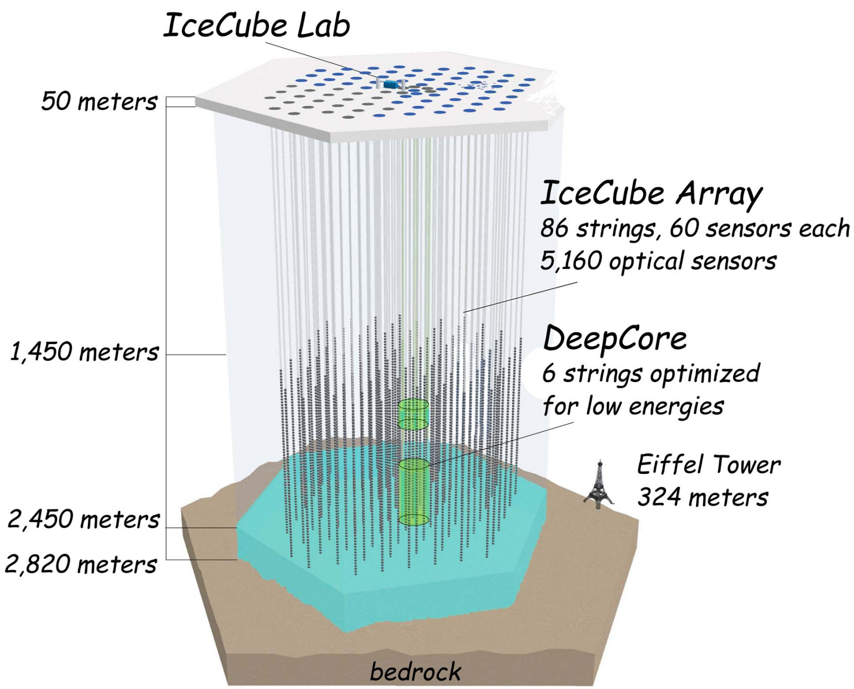
Measurement	Mean or Range	Error: (Exp., Th.)	Distribution
CMS α_T 11.7/fb , $\sqrt{s} = 8\,\text{TeV}$	See text	See text	Poisson
m_h by CMS	125.8 GeV	0.6 GeV, 3 GeV	Gaussian
$\Omega_\chi h^2$	0.1199	0.0027, 10%	Gaussian
BR $(\overline{B} \to X_s\gamma)\times 10^4$	3.43	0.22, 0.21	Gaussian
BR $(B_u \to \tau\nu)\times 10^4$	1.66	0.33, 0.38	Gaussian
ΔM_{B_s}	17.719 ps^{-1}	0.043 ps^{-1}, 2.400 ps^{-1}	Gaussian
$\sin^2\theta_{\text{eff}}$	0.23146	0.00012, 0.00015	Gaussian
M_W	80.399 GeV	0.023 GeV, 0.015 GeV	Gaussian
BR $(B_s \to \mu^+\mu^-) \times 10^9$	3.2	$+1.5 - 1.2$, 10%	Gaussian
$m_b(m_b)^{\overline{MS}}$	4.18 GeV	0.03 GeV, 0	Gaussian
M_t	173.5 GeV	1.0 GeV, 0	Gaussian
$\delta\,(g-2)_\mu^{\text{SUSY}}\times 10^{10}$	28.7	8.0, 1.0	Gaussian
XENON100 (2012)	See text	See text	Poisson
CMS $3l + E_T^{\text{miss}}$ 9.2/fb, $\sqrt{s} = 8\,\text{TeV}$	See text	See text	Poisson

PLUS LEP CONSTRAINTS:

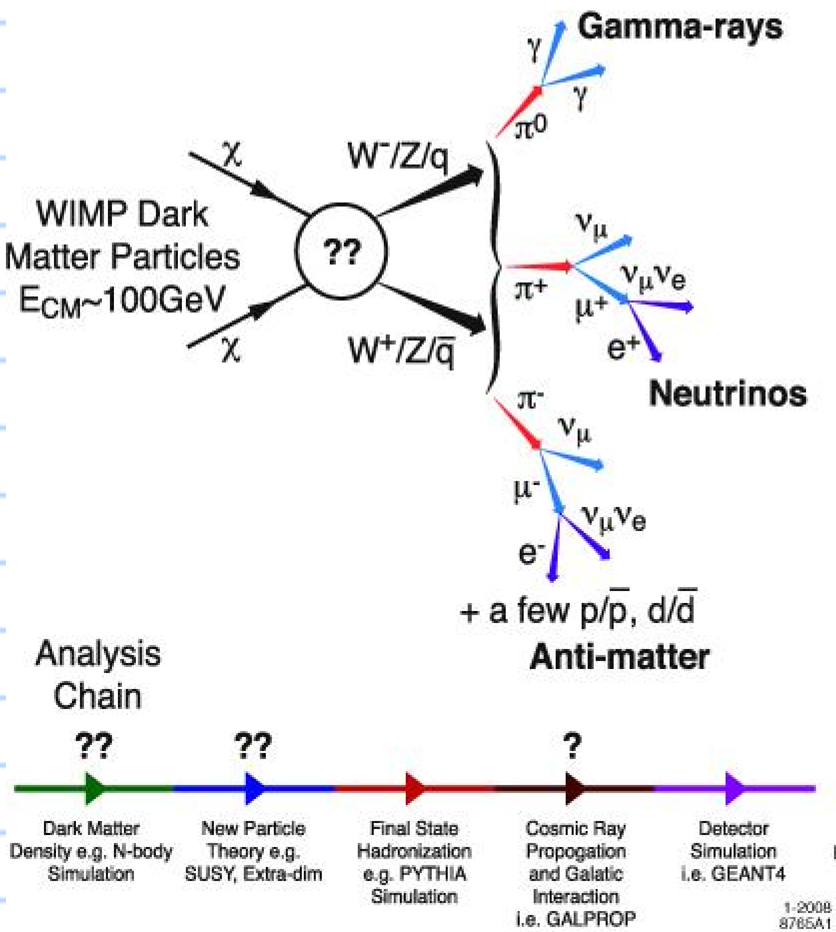
$$
\begin{aligned}
m_\chi &> 46\,\text{GeV}\,,\\
m_{\tilde{e}} &> 107\,\text{GeV}\,,\\
m_{\chi_1^\pm} &> 94\,\text{GeV if } m_{\chi_1^\pm} - m_\chi > 3\,\text{GeV and } \tan\beta < 40\,,\\
m_{\tilde{\mu}} &> 94\,\text{GeV if } m_{\tilde{\mu}} - m_\chi > 10\,\text{GeV and } \tan\beta < 40\,,\\
m_{\tilde{\tau}} &> 81.9\,\text{GeV if } m_{\tilde{\tau}_1} - m_\chi > 15\,\text{GeV}\,,\\
m_{\tilde{b}_1} &> 89\,\text{GeV if } m_{\tilde{b}_1} - m_\chi > 8\,\text{GeV}\,,\\
m_{\tilde{t}_1} &> 95.7\,\text{GeV if } m_{\tilde{t}_1} - m_\chi > 10\,\text{GeV}\,.
\end{aligned}
$$



Neutralino indirect detection

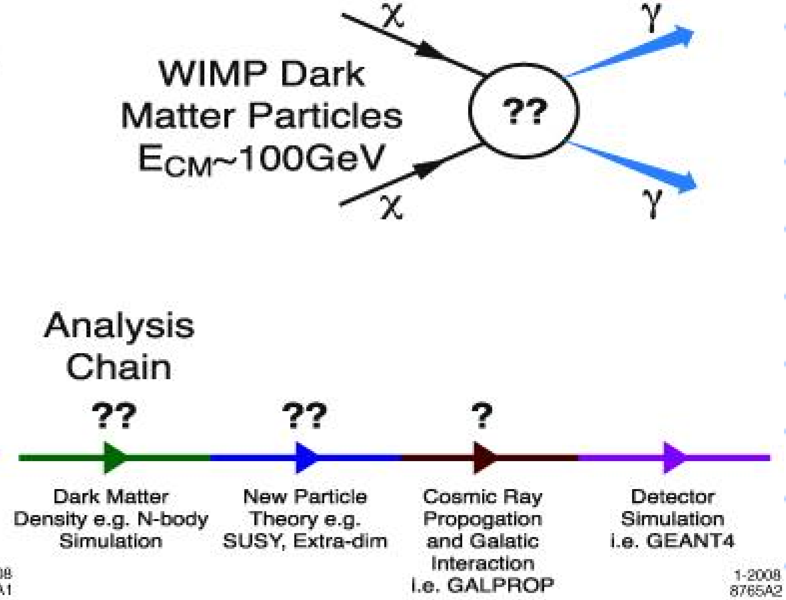


Detect Dark Matter annihilation



Undetermined indirection detection inputs:

- Astrophysics background
- Halo model
- Dark matter mass
- annihilation cross-sections



E. A. Baltz et. al., JCAP 0807 (2008) 013, [arXiv:0806.2911]

Fermi DM gamma ray search

Source	Advantage	Disadvantage
Galactic Center	Strong DM signal, good statistics	High astrophysics background, unclear source
Milky Way Halo	Large statistics	High astrophysics background
dSphs	Low astrophysics background	Low statistics
Gamma-ray line	No similar astrophysical signal	Low statistics
Extragalactic gamma-ray background	Large statistics	Huge astrophysical uncertainties
Galaxy Clusters	Low astrophysics background	Low statistics and astrophysical uncertainties

neutralino DM gamma ray search

Fermi dSphs data can provide sensitive bound for CMSSM.
See: Roszkowski, Sessolo, Tsai (1202.1503)

Source	Advantage	Disadvantage
Galactic Center	Strong DM signal, good statistics	High astrophysics background, unclear source
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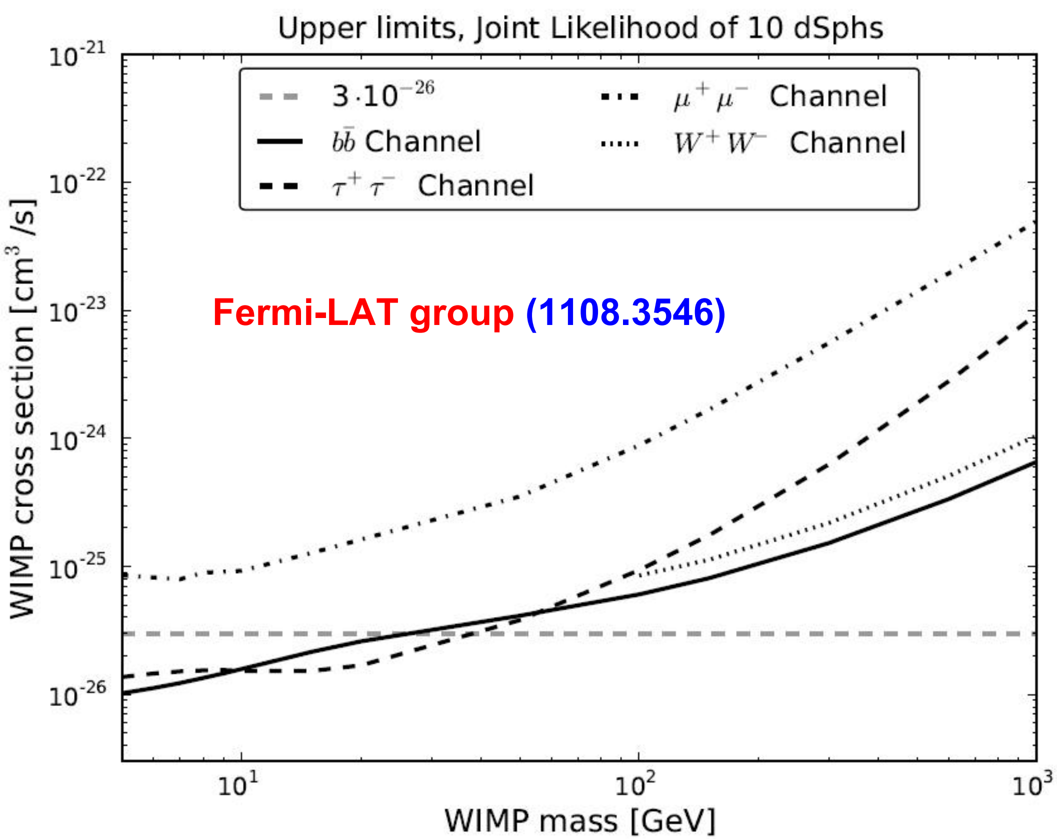
Extragalactic gamma-ray background	Large statistics	Huge astrophysical uncertainties
Galaxy Clusters	Low astrophysics background	Low statistics and astrophysical uncertainties

MSSM neutralino flux has O(1~2) lower than Fermi data.
NMSSM: one can have larger fluxes.
See: Guillaume Chalons (1204.4591) and
Das, Ellwanger, Mitropoulos (1206.2639)

DM gamma rays from dSphs



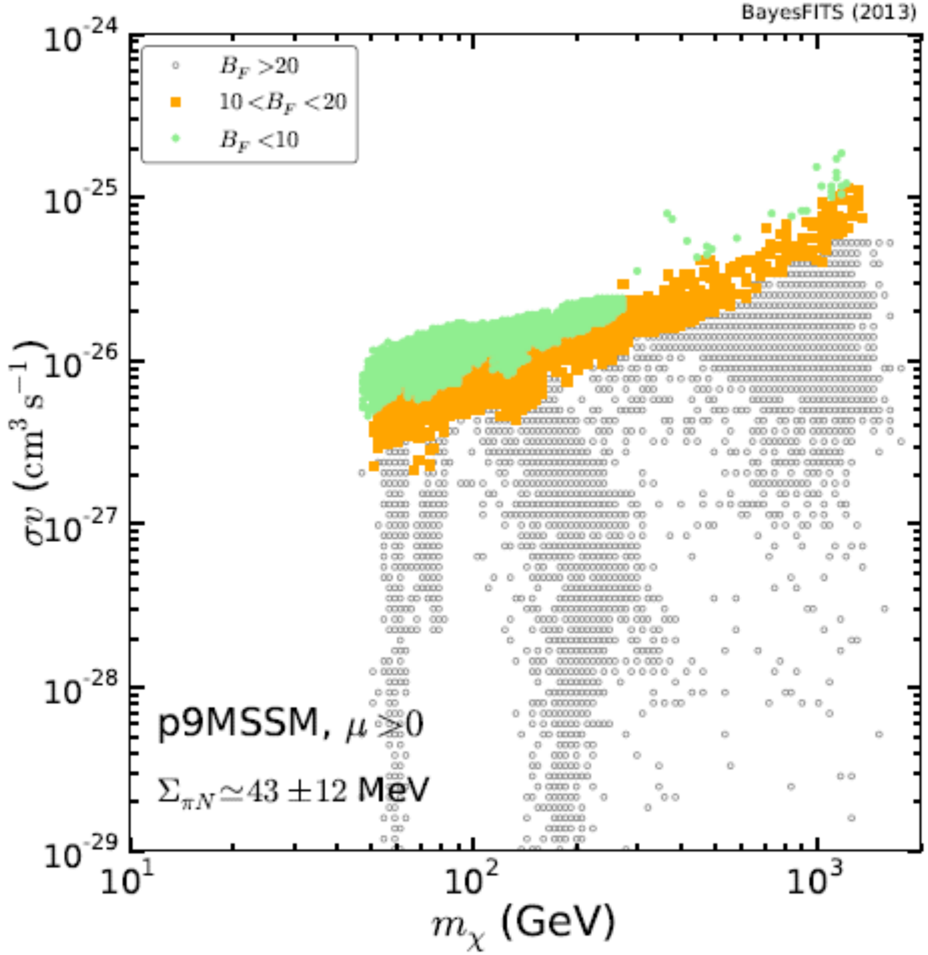
$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\psi)=\sum_i \frac{\sigma_i v}{8\pi m_\chi^2}\frac{dN_\gamma^i}{dE_\gamma}\int_{\rm l.o.s.} dl\, \rho_\chi^2(r(l,\psi))$$

TABLE I. Position, distance, and J factor (under assumption of a Navarro-Frenk-White profile) of each dSph. The 4th column shows the mode of the posterior distribution of $\log_{10} J$, and the 5th column indicates its 68% C.L. error. See the text for further details. The J factors correspond to the pair annihilation flux coming from a cone of solid angle $\Delta\Omega = 2.4\cdot10^{-4}$ sr. The final column indicates the reference for the kinematic dataset used.

Name	l deg.	b deg.	d kpc	$\overline{\log_{10}(J)}$	σ $\log_{10}[\mathrm{GeV}^2\mathrm{cm}^{-5}]$	ref.
Bootes I	358.08	69.62	60	17.7	0.34	[15]
Carina	260.11	−22.22	101	18.0	0.13	[16]
Coma Berenices	241.9	83.6	44	19.0	0.37	[17]
Draco	86.37	34.72	80	18.8	0.13	[16]
Fornax	237.1	−65.7	138	17.7	0.23	[16]
Sculptor	287.15	−83.16	80	18.4	0.13	[16]
Segue 1	220.48	50.42	23	19.6	0.53	[18]
Sextans	243.4	42.2	86	17.8	0.23	[16]
Ursa Major II	152.46	37.44	32	19.6	0.40	[17]
Ursa Minor	104.95	44.80	66	18.5	0.18	[16]

Fermi -LAT put the upper limit on WIMP annihilation cross section.

DM gamma rays from dSphs



Parameter	gaugino	mixed	higgsino
$\tan\beta$	7.94	52.63	4.76
M_2 (GeV)	148.56	457.82	3810.98
M_3 (GeV)	1847.66	2785.12	2281.29
μ (GeV)	620.95	275.72	1345.21
m_A (GeV)	1454.49	3648.84	2716.89
A_t (GeV)	2086.52	3607.58	5277.32
A_τ (GeV)	-2786.17	5256.12	-4519.05
$m_{\tilde{Q}_3}$ (GeV)	3335.38	2330.03	3577.35
$m_{\tilde{L}_3}$ (GeV)	144.74	1613.40	1500.82
m_χ (GeV)	70.29	210.61	1360.36
σv (cm^{3}s^{-1})	1.33×10^{-26}	2.64×10^{-26}	3.75×10^{-25}
B_F	4.49	6.11	3.14

Fermi LAT data taken from 4 August 2008 to 2 August 2012 with the pass 7 photon selection, and energy from 200 MeV to 500 GeV.

Fermi-dSphs data is more sensitive to low neutralino mass region.

Uncertainties of DM annihilation to gamma rays

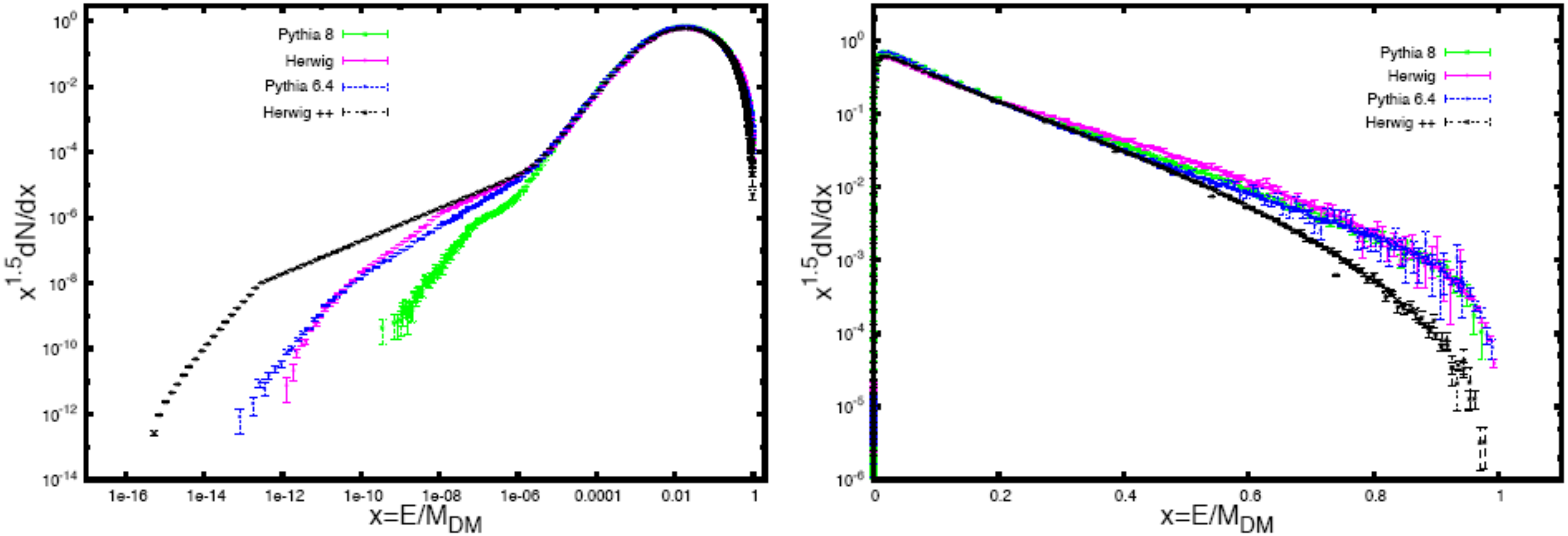
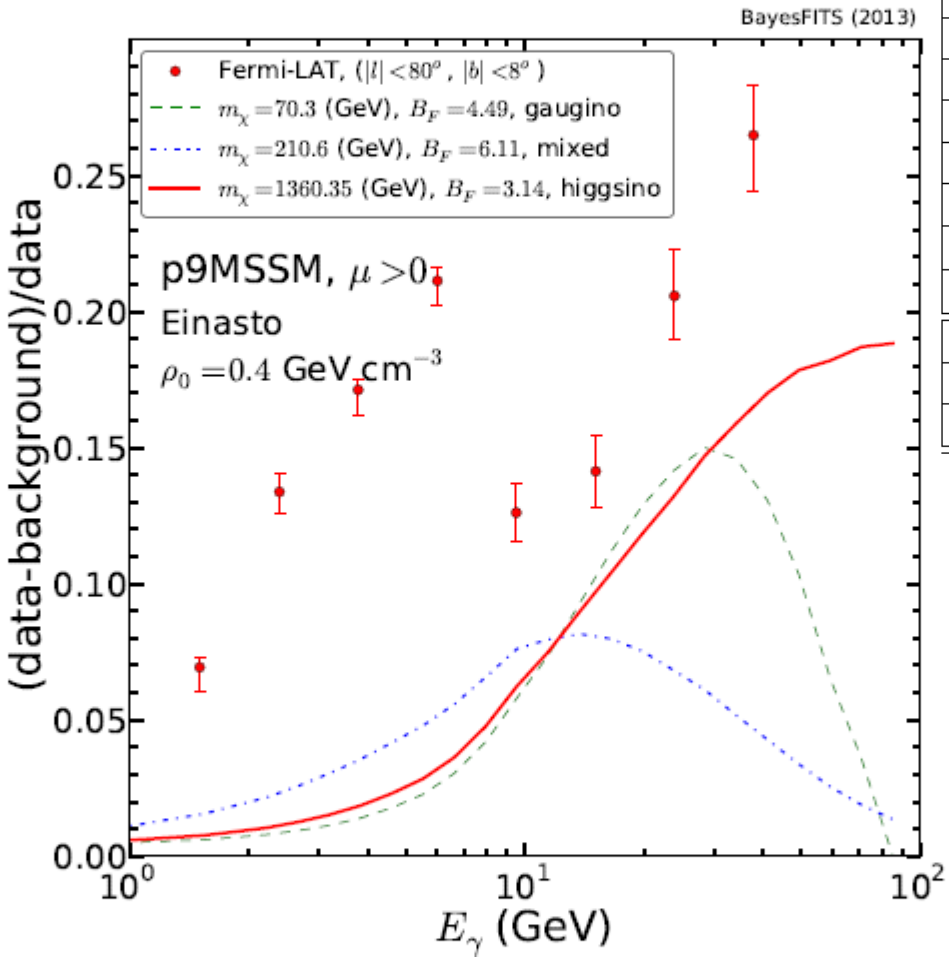


Figure 2. *(Left–panel)* W^+W^- annihilation channel with $M_{\rm DM} = 1$ TeV in logarithmic scale. As in Fig. 1, the simulations are consistent down to a value of x, that is 10^{-6} in the case of $M_{\rm DM} = 1$ TeV (a factor ten lower in x with respect to the case with $M_{\rm DM} = 100$ GeV). Similar behaviors of the lower energy cuts-off are also observed, with a general shift of x cut-off value of order 10^{-2}. *(Right–panel)* W^+W^- annihilation channel with $M_{\rm DM} = 1$ TeV in linear scale. All the simulations except for HERWIG++ exhibit the same behavior as in Fig. 1, but within $x \simeq 0.3$ and $x \simeq 0.7$ and a maximum discrepancy at $x \simeq 0.5$. The shift with respect to Fig. 1 can be simply explained by the increment of the WIMP mass.

Can be more than one order of magnitude

Taken from 1305.2124

DM gamma rays from GC



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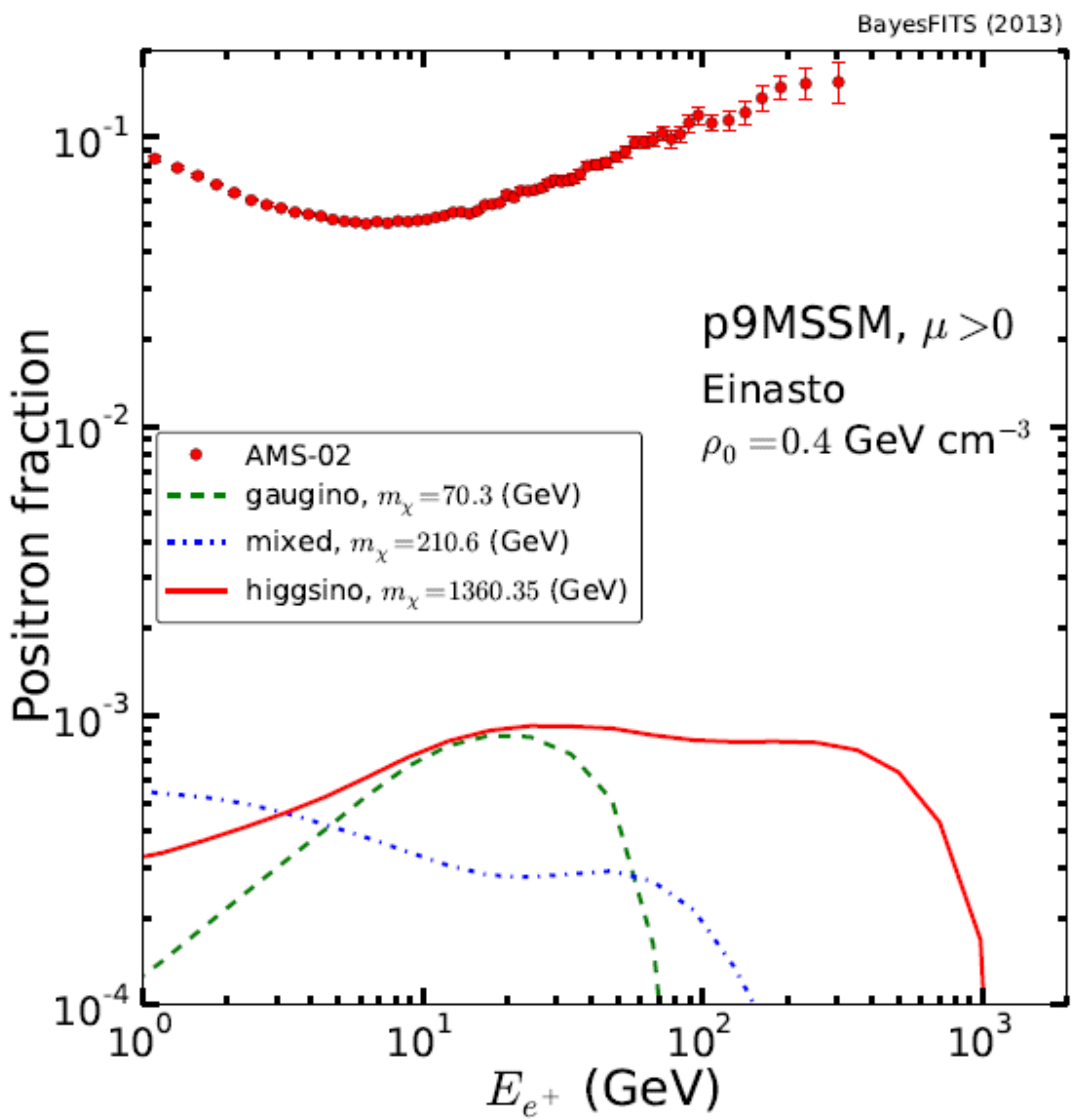
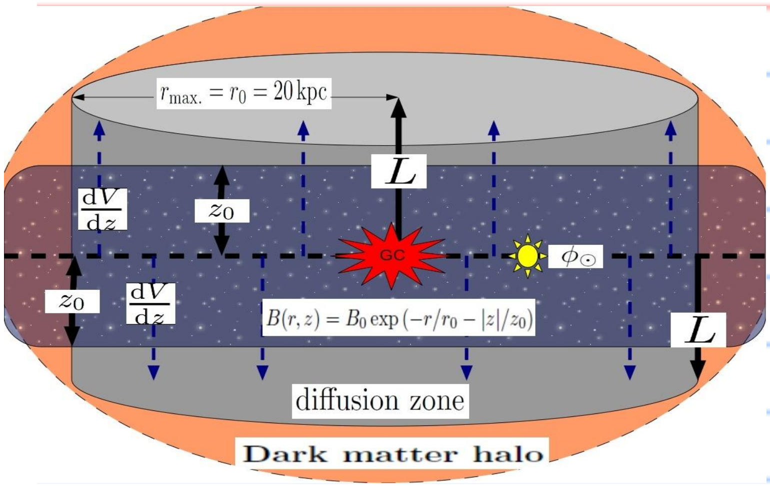
B_F	4.49	6.11	3.14

1. Dark matter pi^0-decay
2. Inverse Compton
3. bremsstrahlung

SUSY can be also testable in Fermi-GC search.

Positron signatures of neutralino DM

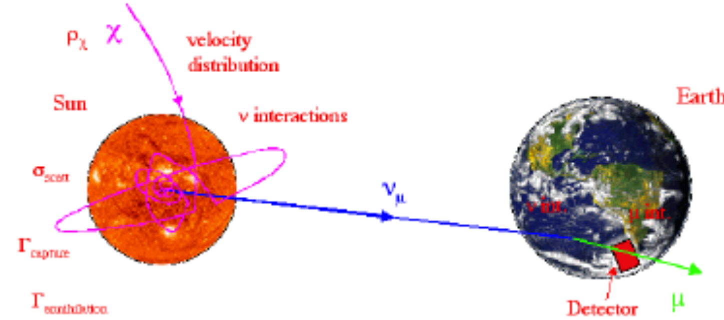


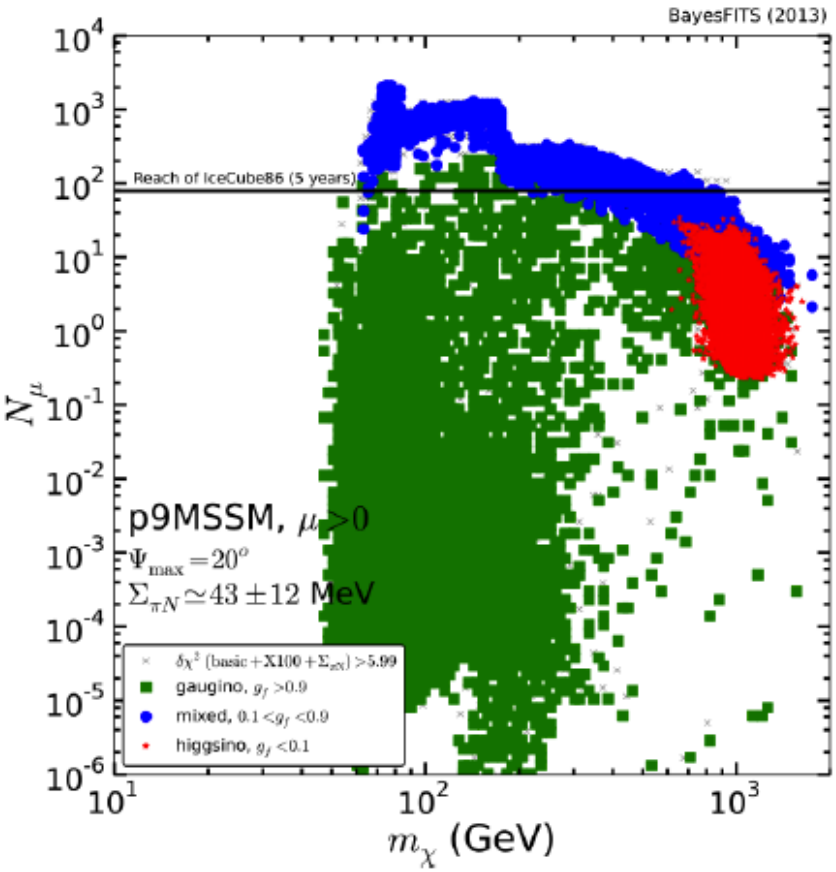


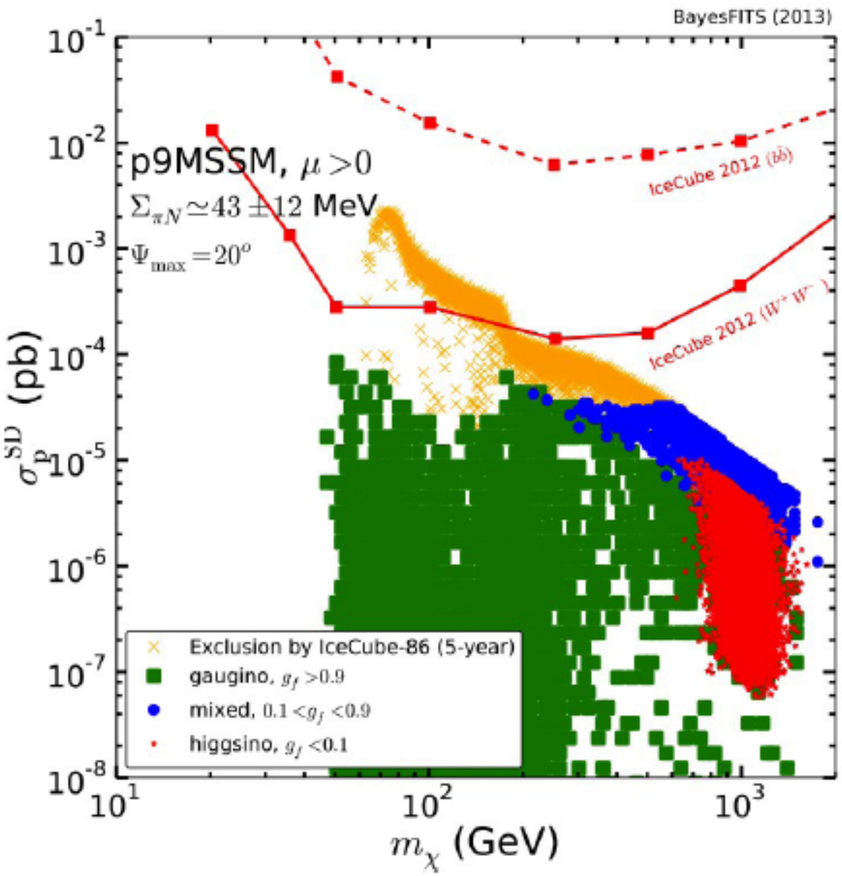
SUSY does not reproduce AMS-02 e+ fluxes (pulsars).

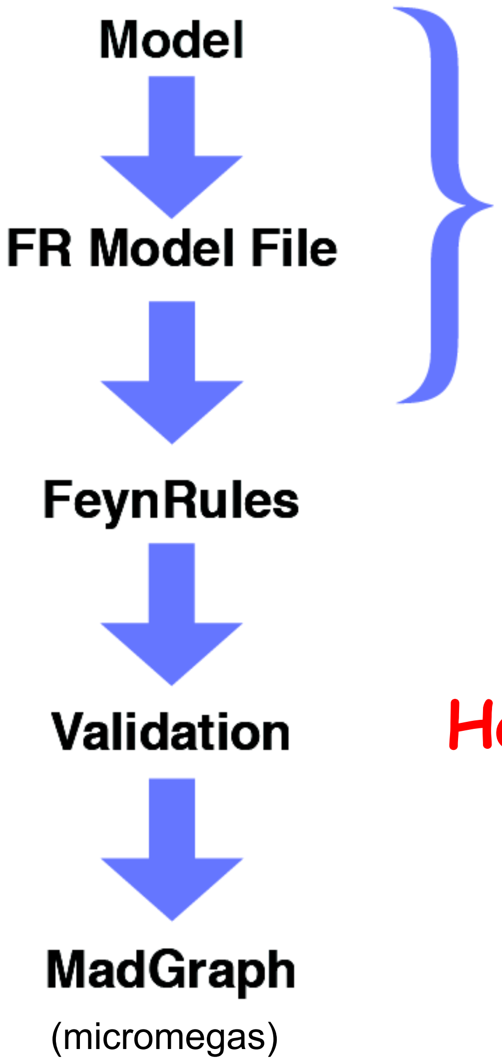
Impact of DM indirect detection

Fermi-LAT, AMS02, **IceCube**
(see arXiv:1306.1567)









Galileo

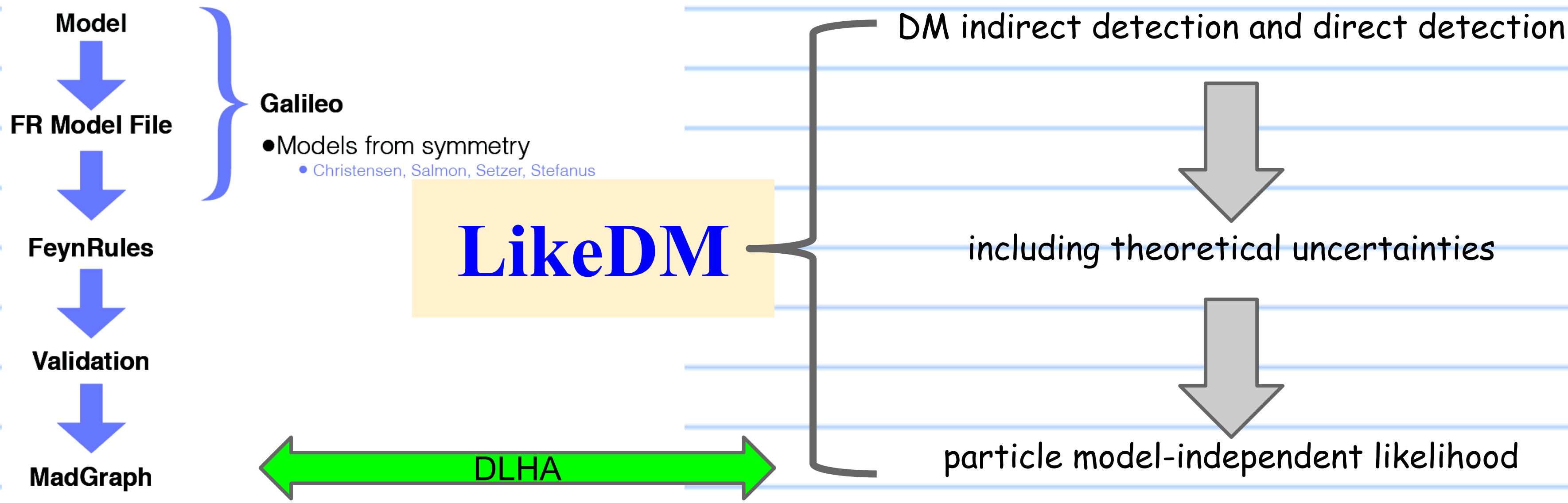
- Models from symmetry
  - Christensen, Salmon, Setzer, Stefanus

How about the experimental constraints?

Slide taken from MadGraph School 2013 Taipei, Neil Christensen

LikeDM code

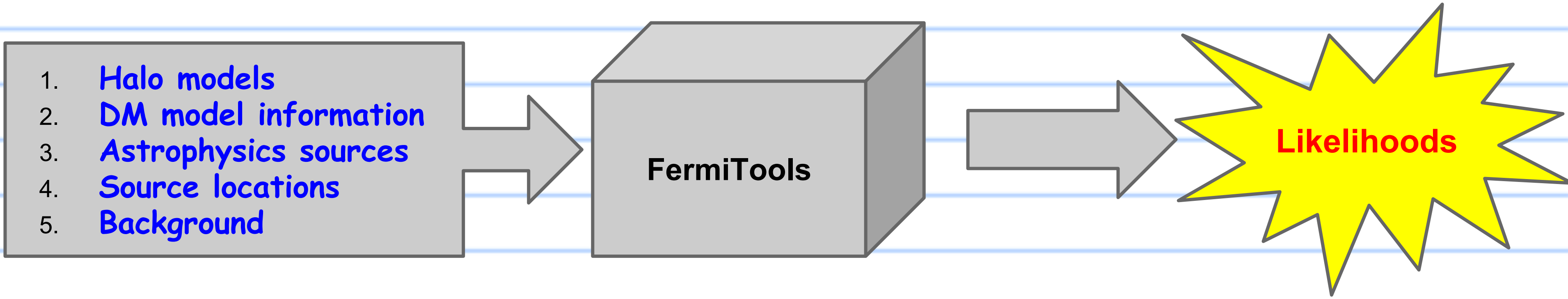
in Collaboration with Q. Yuan and X. Huang



- We can more confidently and efficiently check every dark matter model.
- Can be extend to cosmology constraints.
- Similar to “DMFIT“ but starting from data level

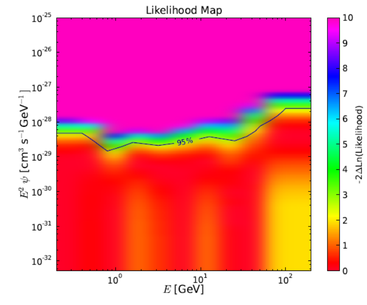
(Tesla E. Jeltema, Stefano Profumo)

Fitting DM gamma rays by using FermiTools



Too much CPU time consuming to do particle model fitting

Fitting DM gamma rays by using LikeDM



1. Halo models
2. Astrophysics sources
3. Source locations
4. Background

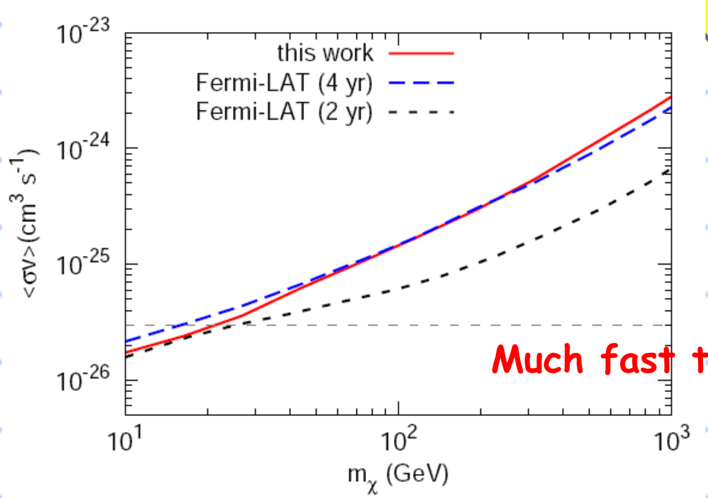
FermiTools

Energy-Residual likelihood map

Y-L Sming Tsai, Qiang Yuan, Xiaoyuan Huang
Published in JCAP 1303 (2013) 018
e-Print: arXiv:1212.3990

Likelihoods

DM particle model information



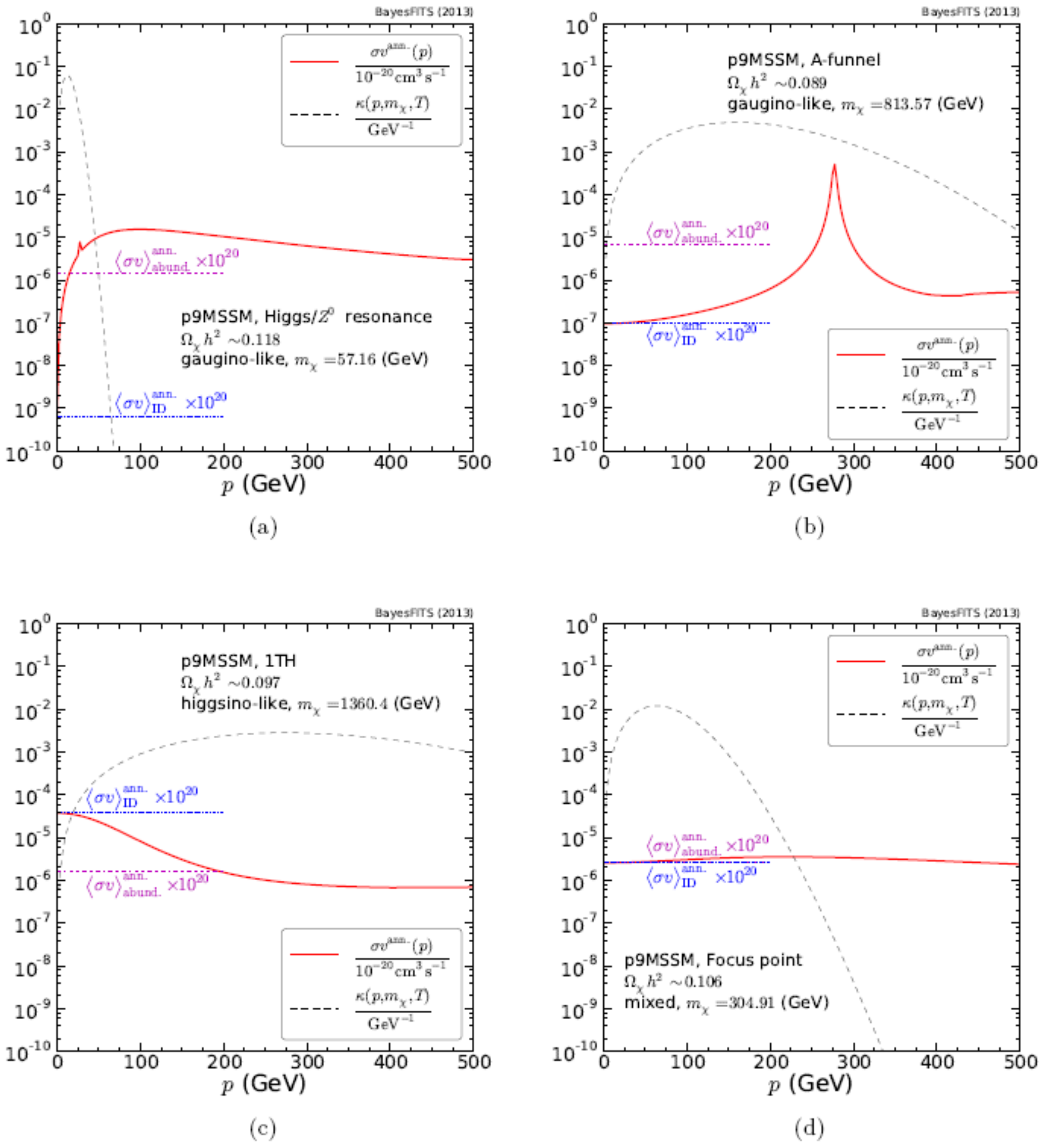
Much fast to do particle model fitting

Summary

1. A global Statistical Analysis of the MSSM with a minimum set of 9 parameters.
2. Better numerical simulation of LHC, XENON100, and Fermi gamma-ray likelihoods.
3. Theoretical error strongly limits power of XENON100 on MSSM (Not so for XENON1T)
4. With all the constraints, especial g-2 and LHC, the limit 200 GeV < m_χ < 500 GeV.
5. Interesting prospects for indirect detection
6. Our method is completely general. It can be applied to other models (SUSY or not).

Thank you very much for your attention.

Backup



$$\langle\sigma v\rangle^{\rm ann+co}_{\rm abund} \sim \int \sigma v^{\rm ann+co}(p)\kappa(p, m_\chi, T)dp\,.$$

Boltzmann distribution