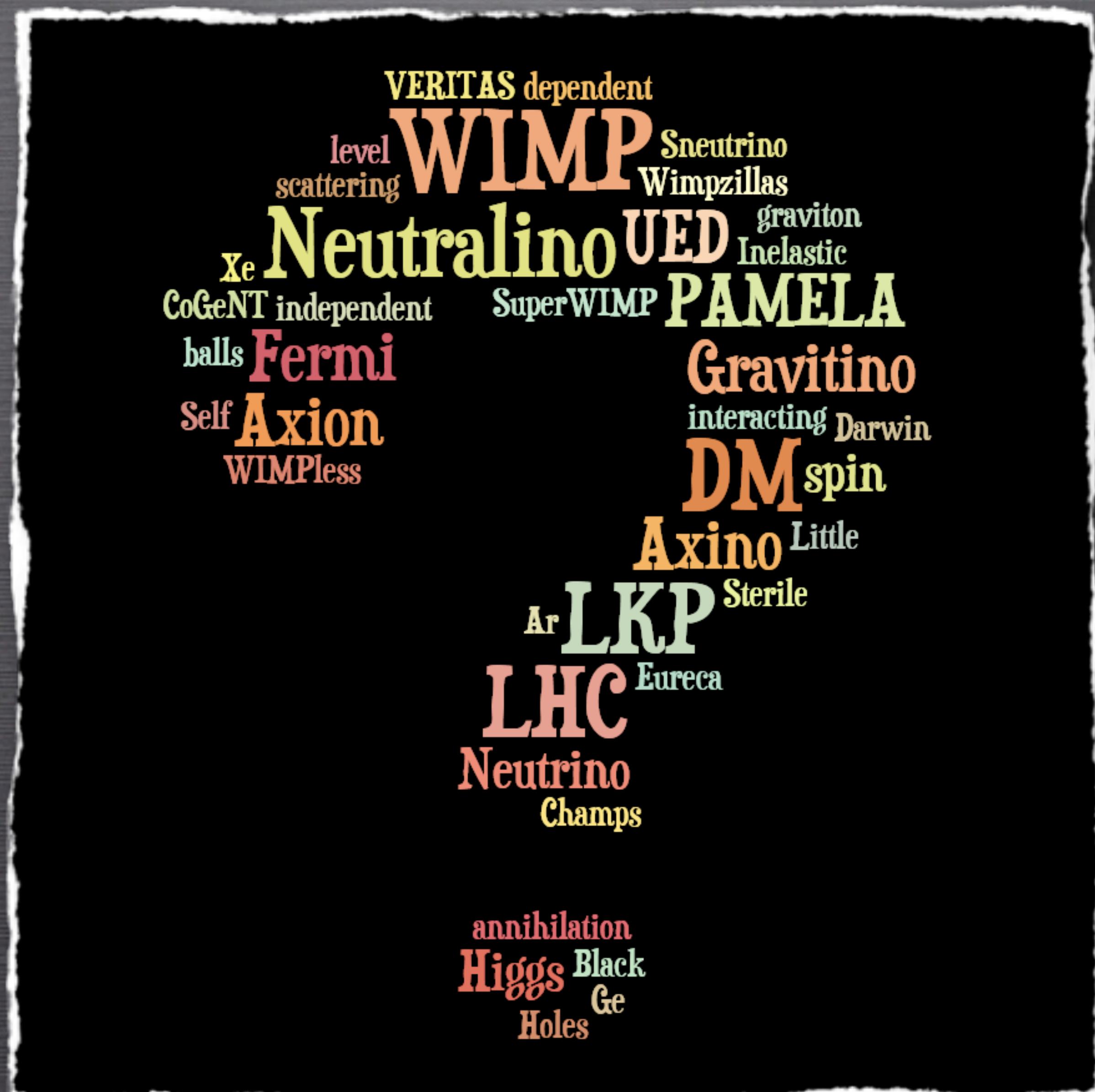
Identification of Dark Matter Candidates

Gianfranco Bertone



Institut d'Astrophysique de Paris
Unité mixte de recherche 7095 — CNRS - Université Pierre et Marie Curie
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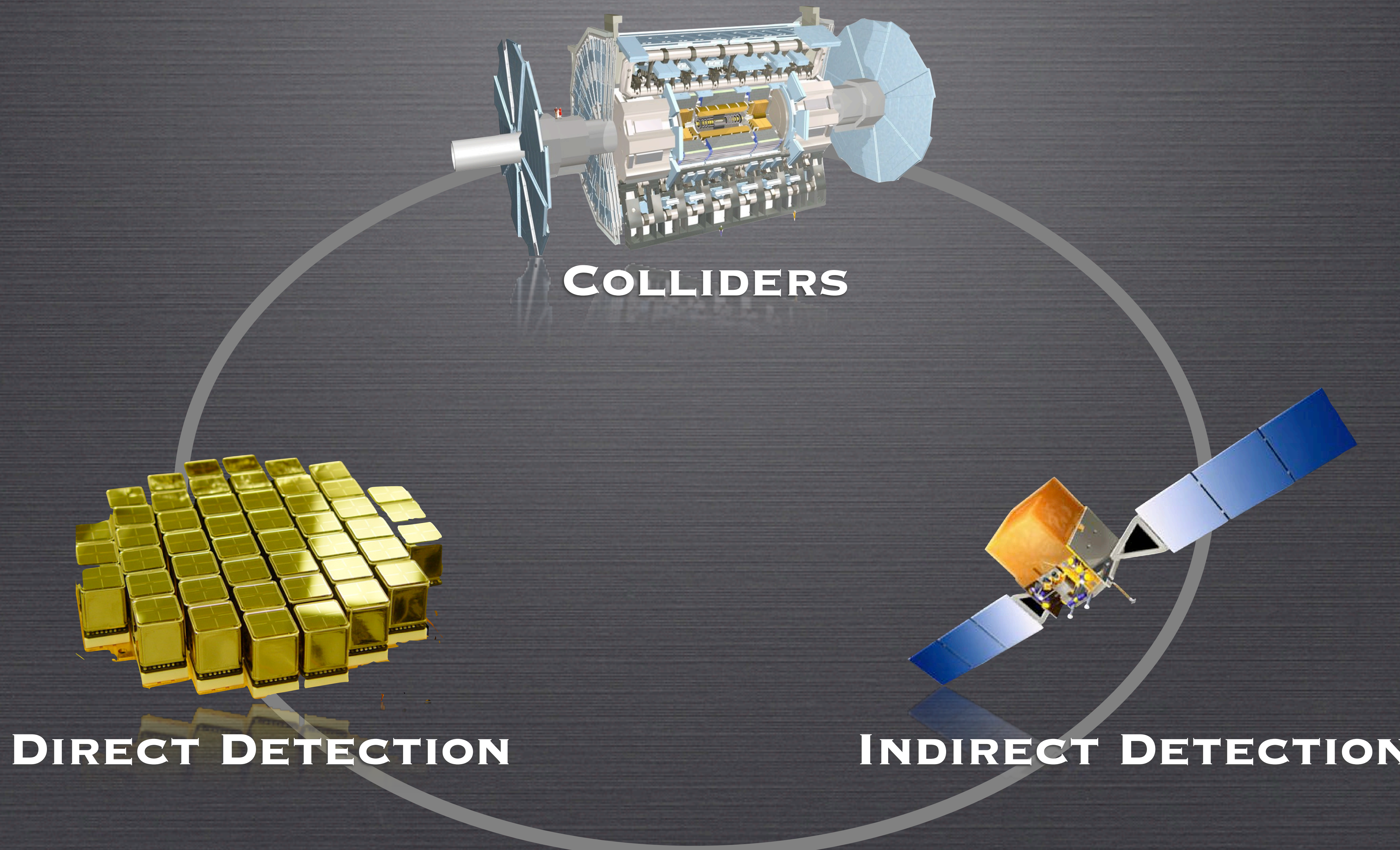
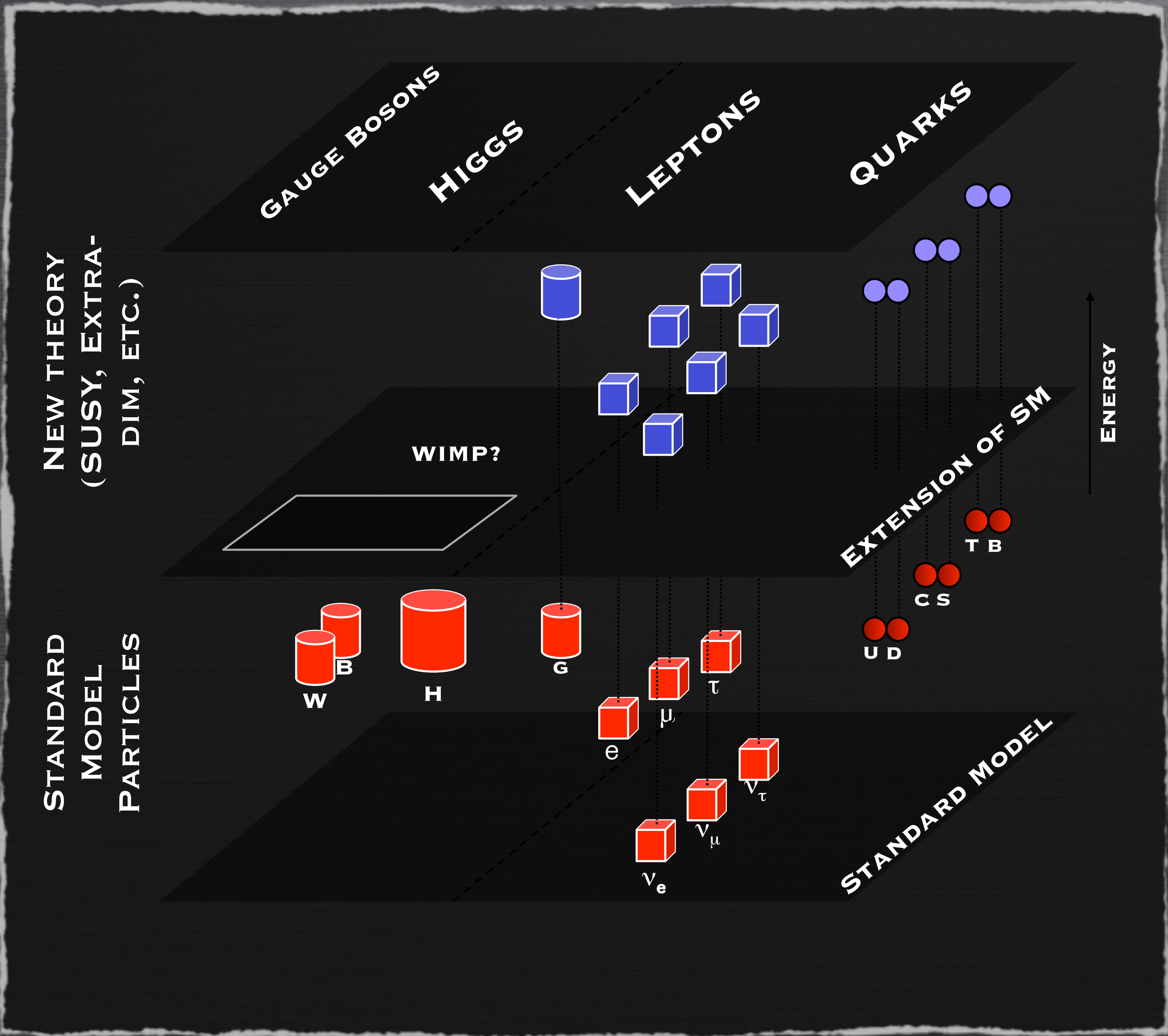
Particle Dark Matter: Search Strategies



Beyond the Standard Model

The Standard Model provides an accurate description of all known particles and interactions, however there are good reasons to believe that the Standard model is a low-energy limit of a more fundamental theory



To explain the origin of the weak scale, extensions of the standard model often postulate the existence of new physics at ~100 GeV

On the left, schematic view of the structure of possible extensions of the standard model

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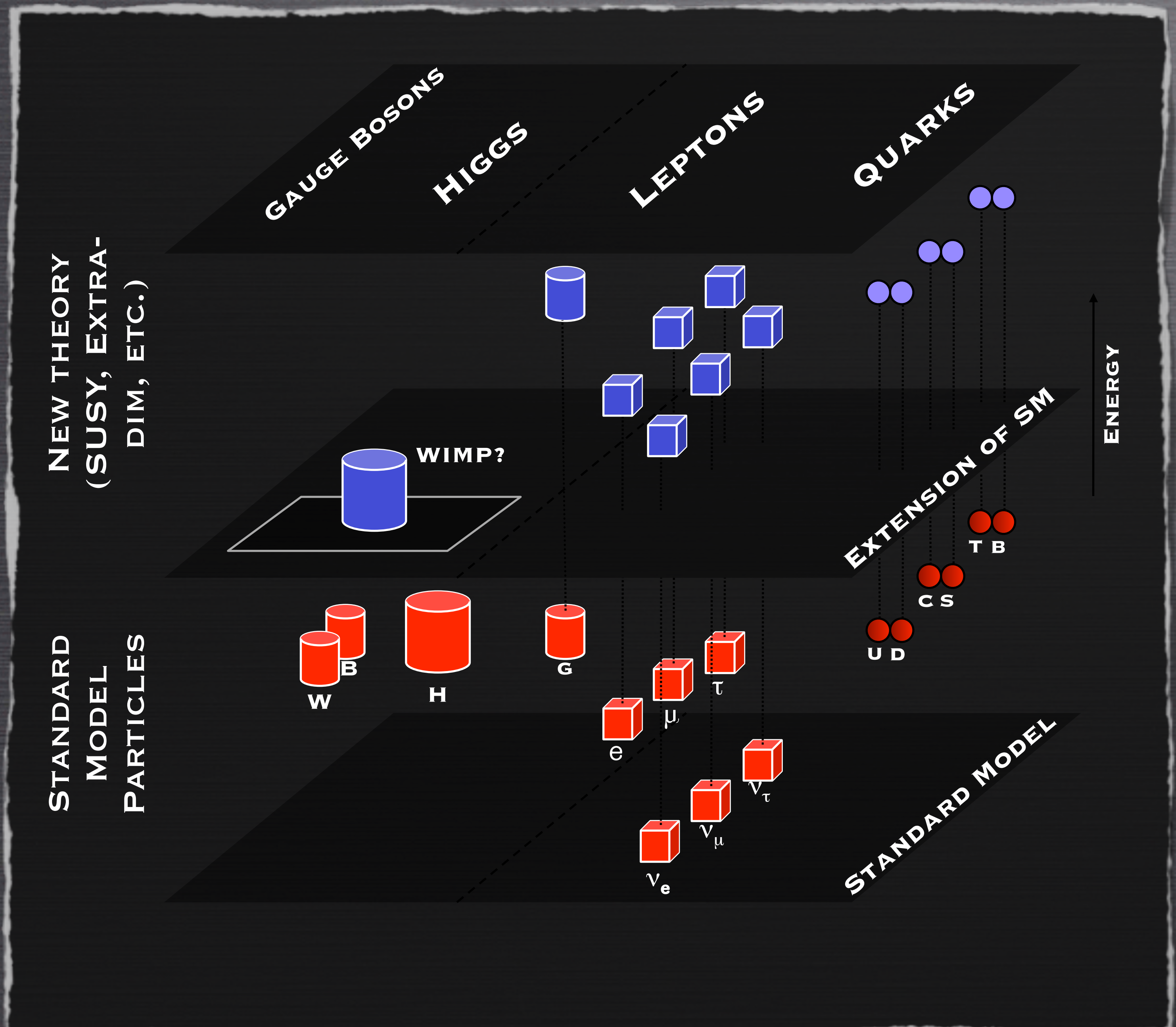

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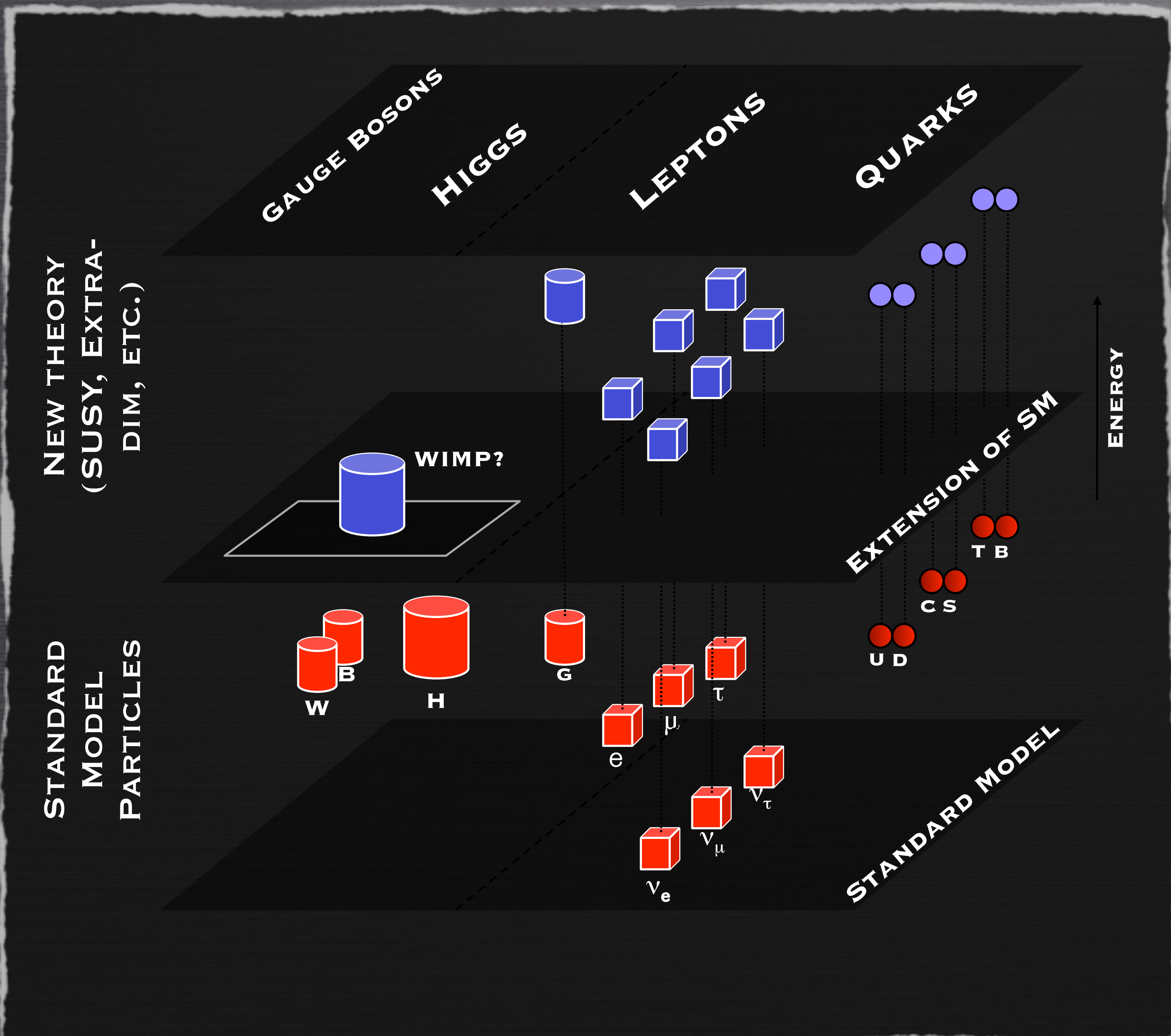
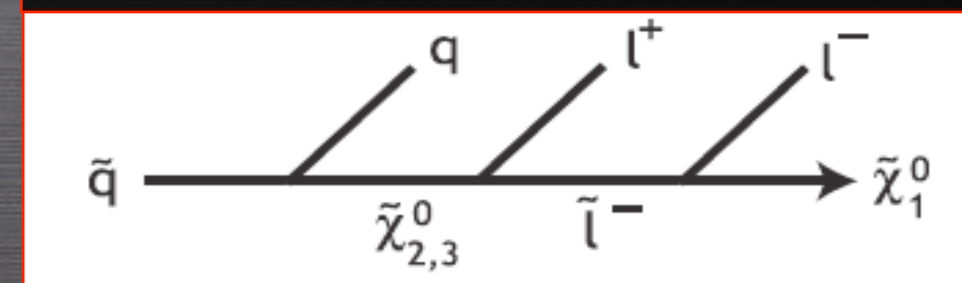
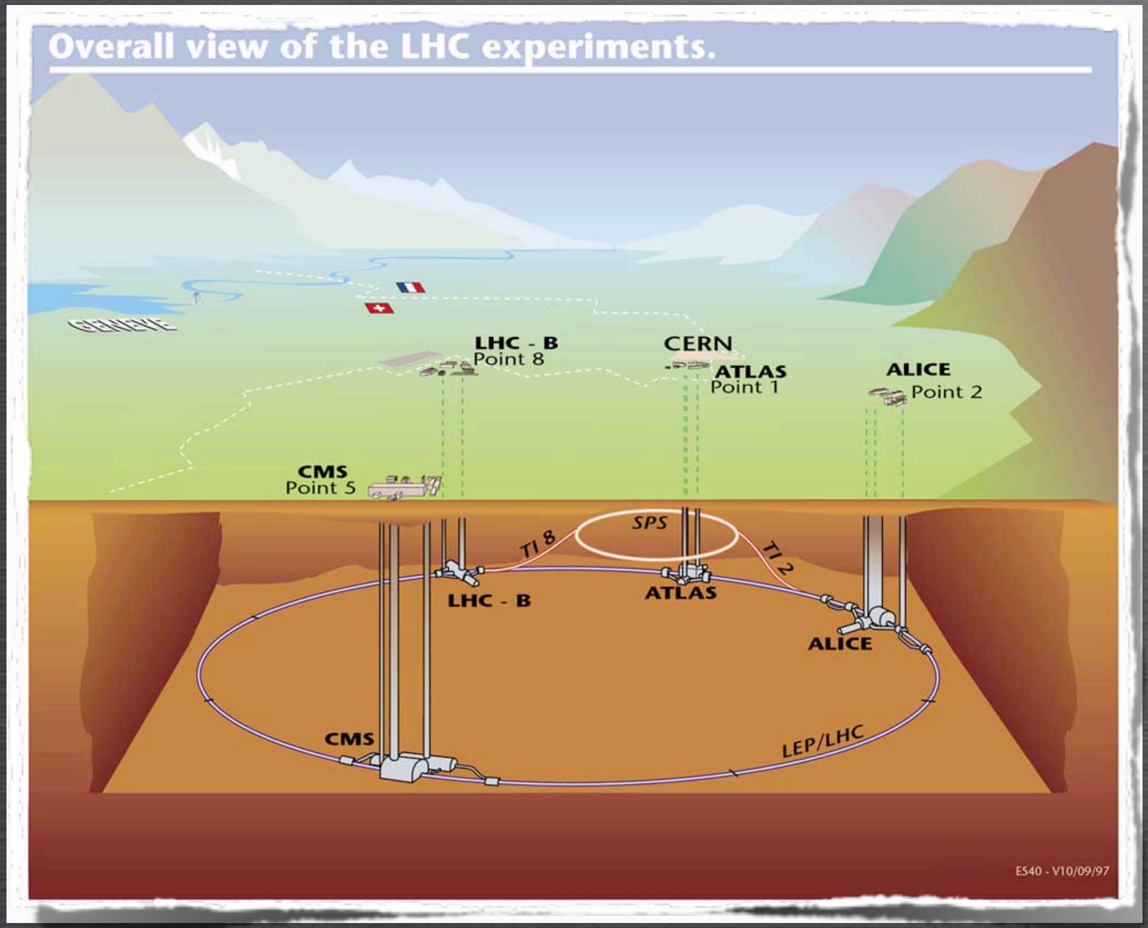
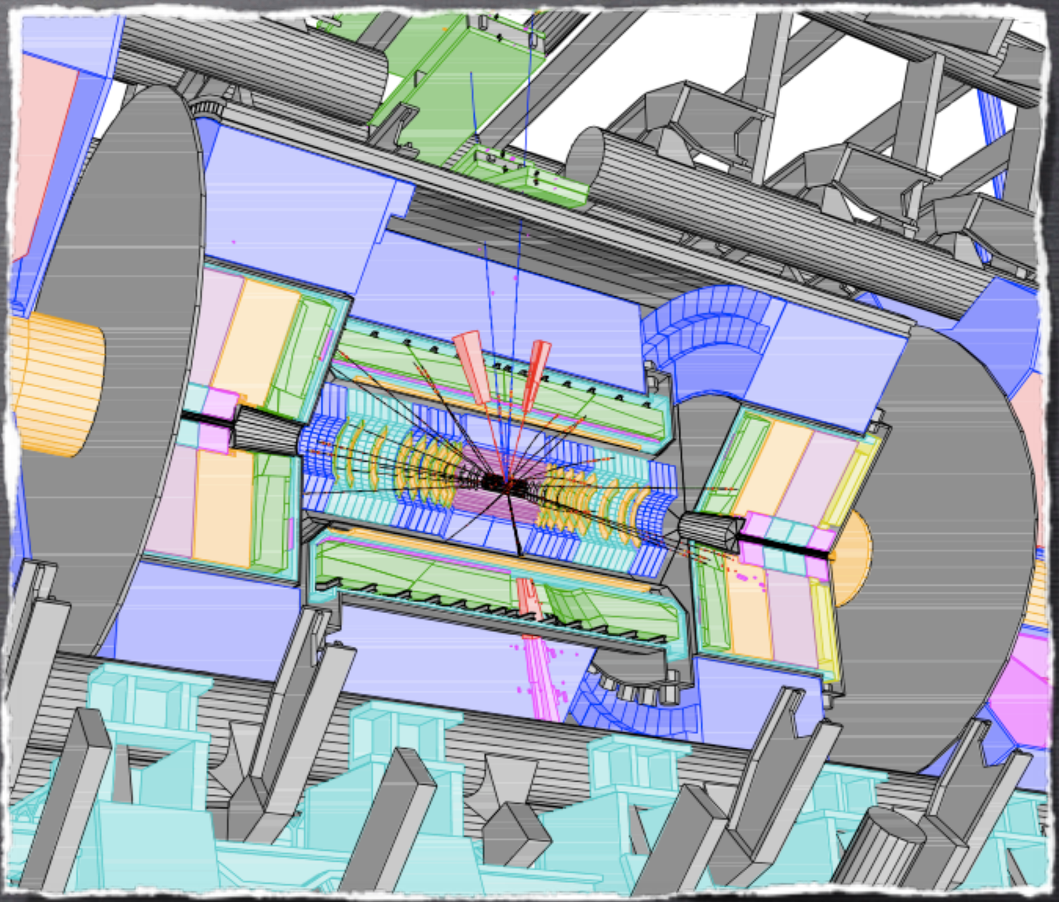


Search at LHC for processes like e.g.



Searching for New Physics at the LHC





Example of Inverse problem at LHC

Inferring the relic density (thus the DM nature) of newly discovered particles from LHC data... What we would like:

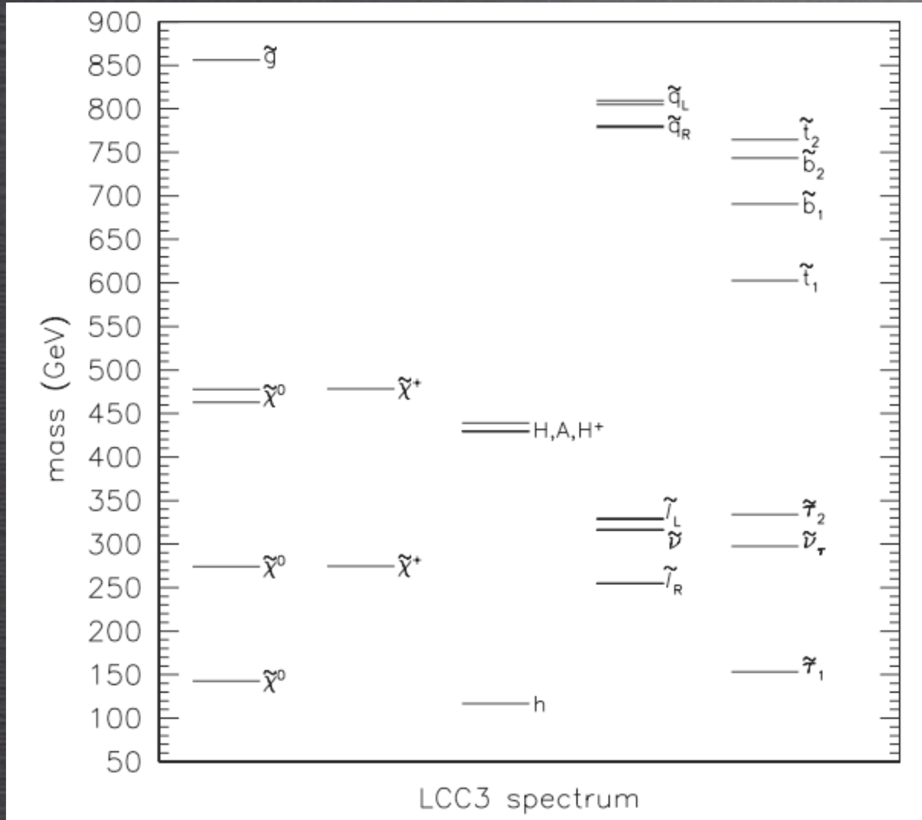
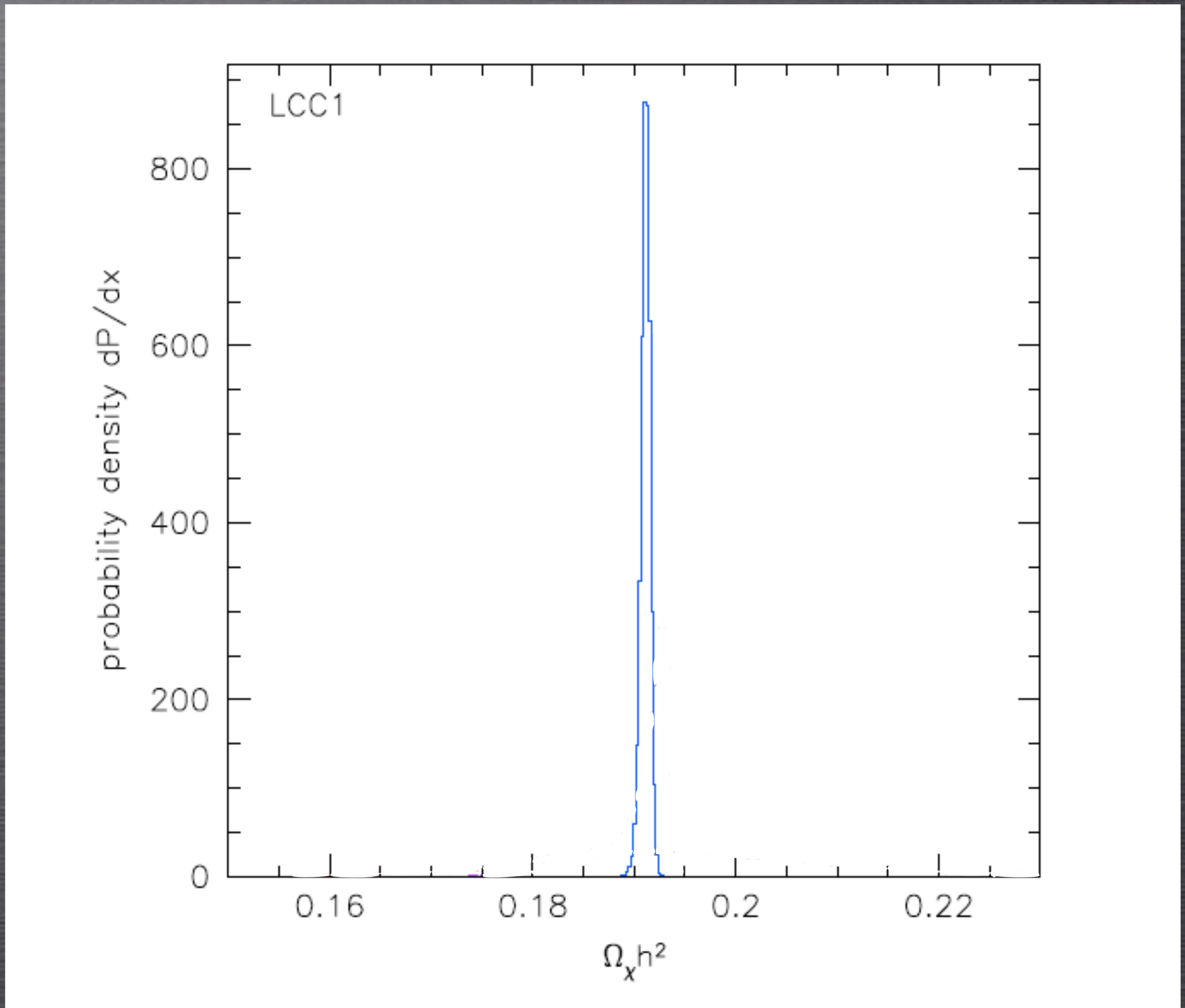
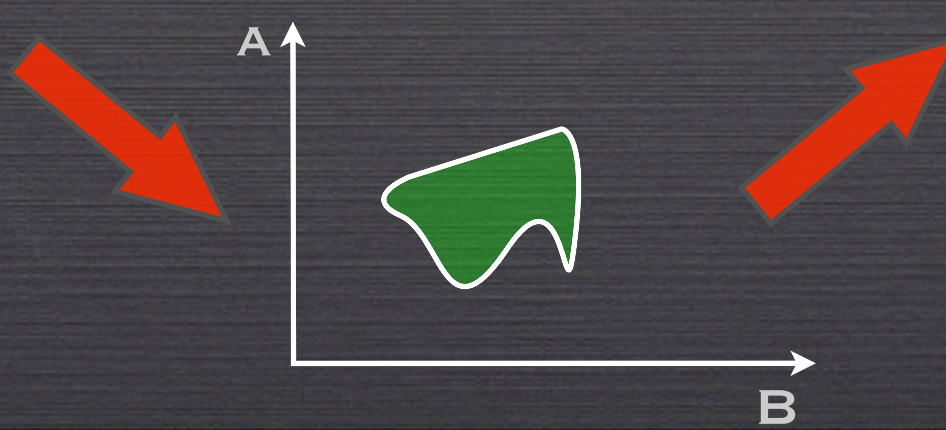


FIG. 34. Particle spectrum for point LCC3. The stau-neutralino mass splitting is 10.8 GeV. The lightest neutralino is predominantly b-ino, the second neutralino and light chargino are predominantly W-ino, and the heavy neutralinos and chargino are predominantly Higgsino.



Ad. from Baltz, Battaglia, Peskin, Wizansky (2005)



Example of Inverse problem at LHC

(example in the stau coannihilation region, 24 parms pMSSM)

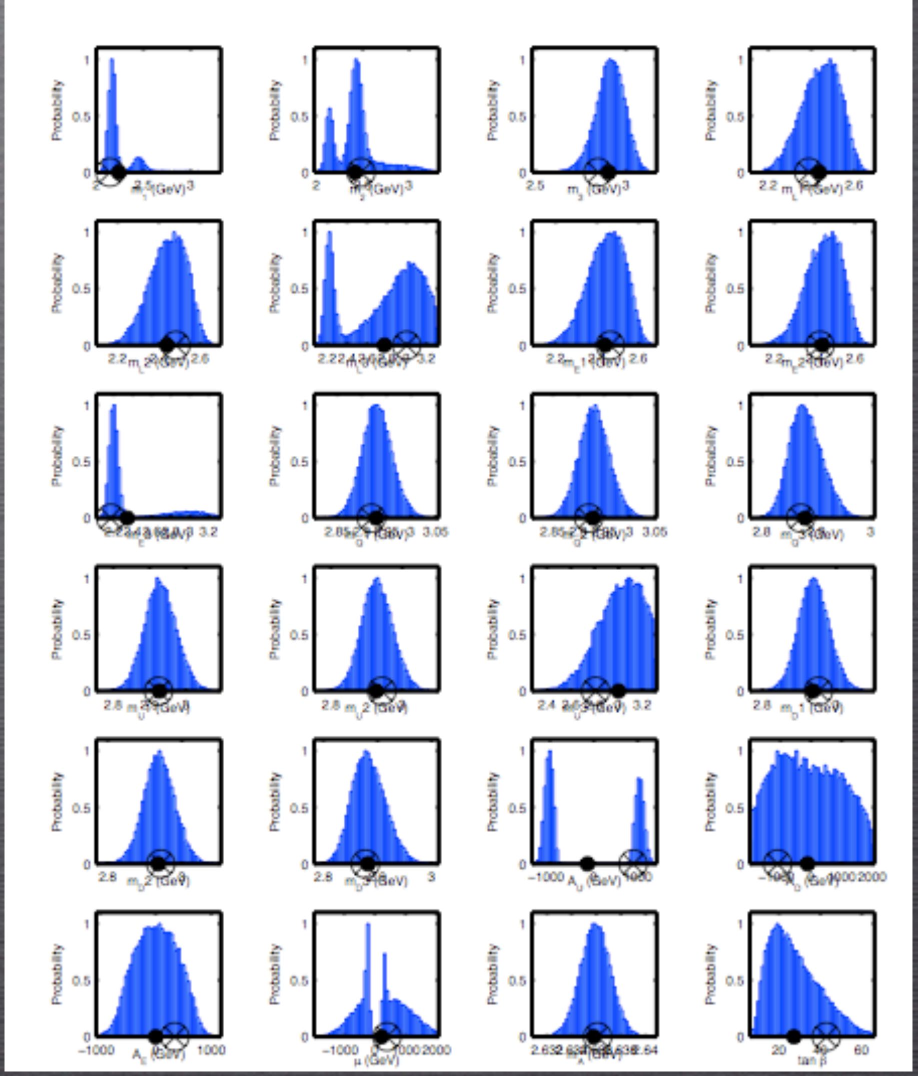
Mass	Benchmark value, μ	LHC error, σ
$m(\tilde{\chi}^0_1)$	139.3	14.0
$m(\tilde{\chi}^0_2)$	269.4	41.0
$m(\tilde{e}_R)$	257.3	50.0
$m(\tilde{\mu}_R)$	257.2	50.0
$m(h)$	118.50	0.25
$m(A)$	432.4	1.5
$m(\tilde{\tau}_1) - m(\tilde{\chi}^0_1)$	16.4	2.0
$m(\tilde{u}_R)$	859.4	78.0
$m(\tilde{d}_R)$	882.5	78.0
$m(\tilde{s}_R)$	882.5	78.0
$m(\tilde{c}_R)$	859.4	78.0
$m(\tilde{u}_L)$	876.6	121.0
$m(\tilde{d}_L)$	884.6	121.0
$m(\tilde{s}_L)$	884.6	121.0
$m(\tilde{c}_L)$	876.6	121.0
$m(\tilde{b}_1)$	745.1	35.0
$m(\tilde{b}_2)$	800.7	74.0
$m(\tilde{t}_1)$	624.9	315.0
$m(\tilde{g})$	894.6	171.0
$m(\tilde{e}_L)$	328.9	50.0
$m(\tilde{\mu}_L)$	228.8	50.0

TABLE I: Sparticle spectrum (in GeV) for our benchmark SUSY point and relative estimated measurements errors at the LHC (standard deviation σ).

Benchmark in the co-anihilation region (similar to LCC3 in Baltz et al.). Errors correspond to 300 fb-1. Error on mass difference with the stau ~10% for this model can be achieved with 10 fb-1

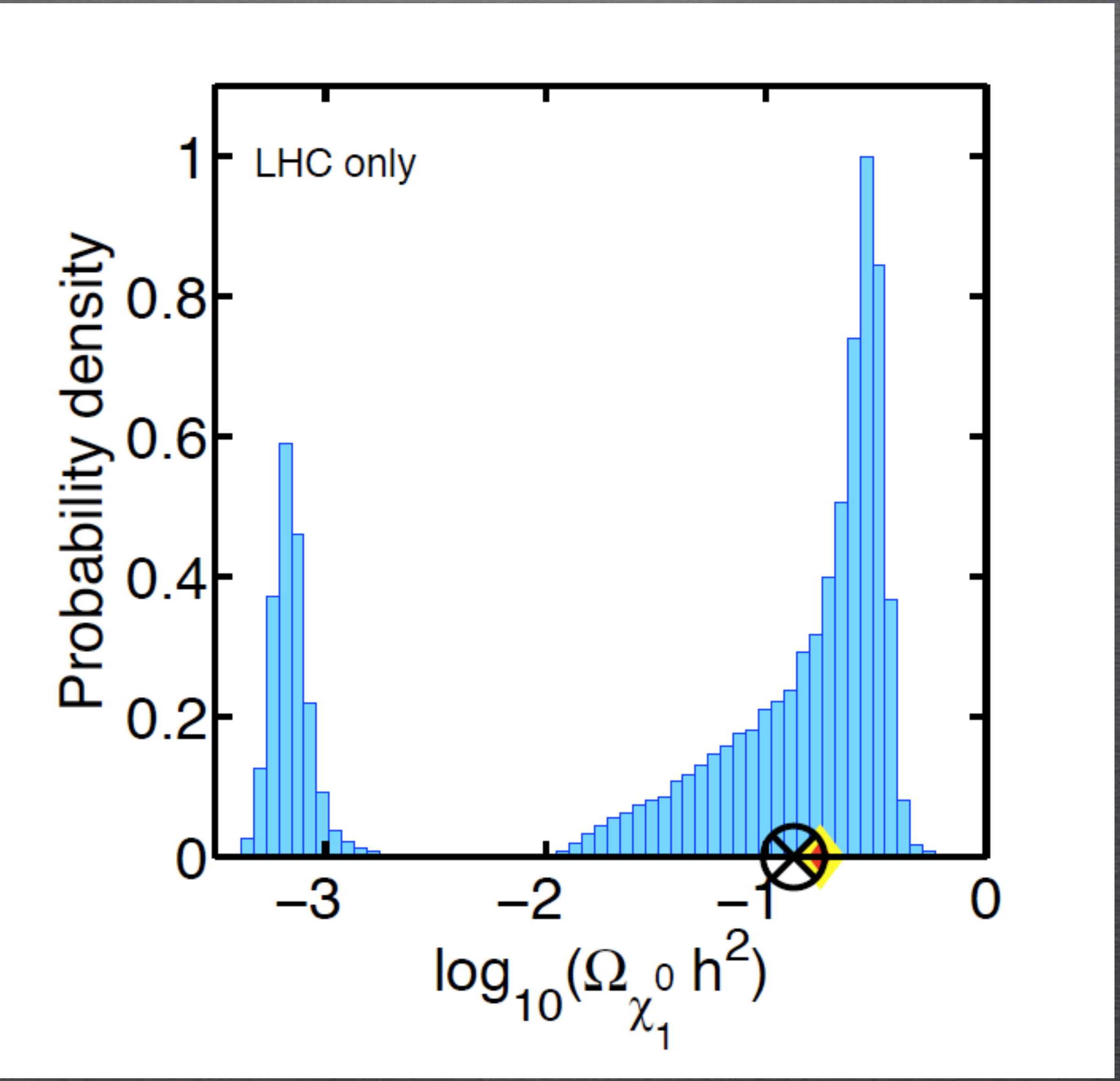
$$p(\mathbf{x}|\mathbf{d}) = \frac{p(\mathbf{d}|\mathbf{x})p(\mathbf{x})}{p(\mathbf{d})},$$

MCMC as implemented in the SuperBayes code



Example of Inverse problem at LHC

what we will most probably get
(example in the stau coannihilation region, 24 parms MSSM)



GB, Cerdeno, Fornasa, Ruiz de Austri & Trotta, 2010

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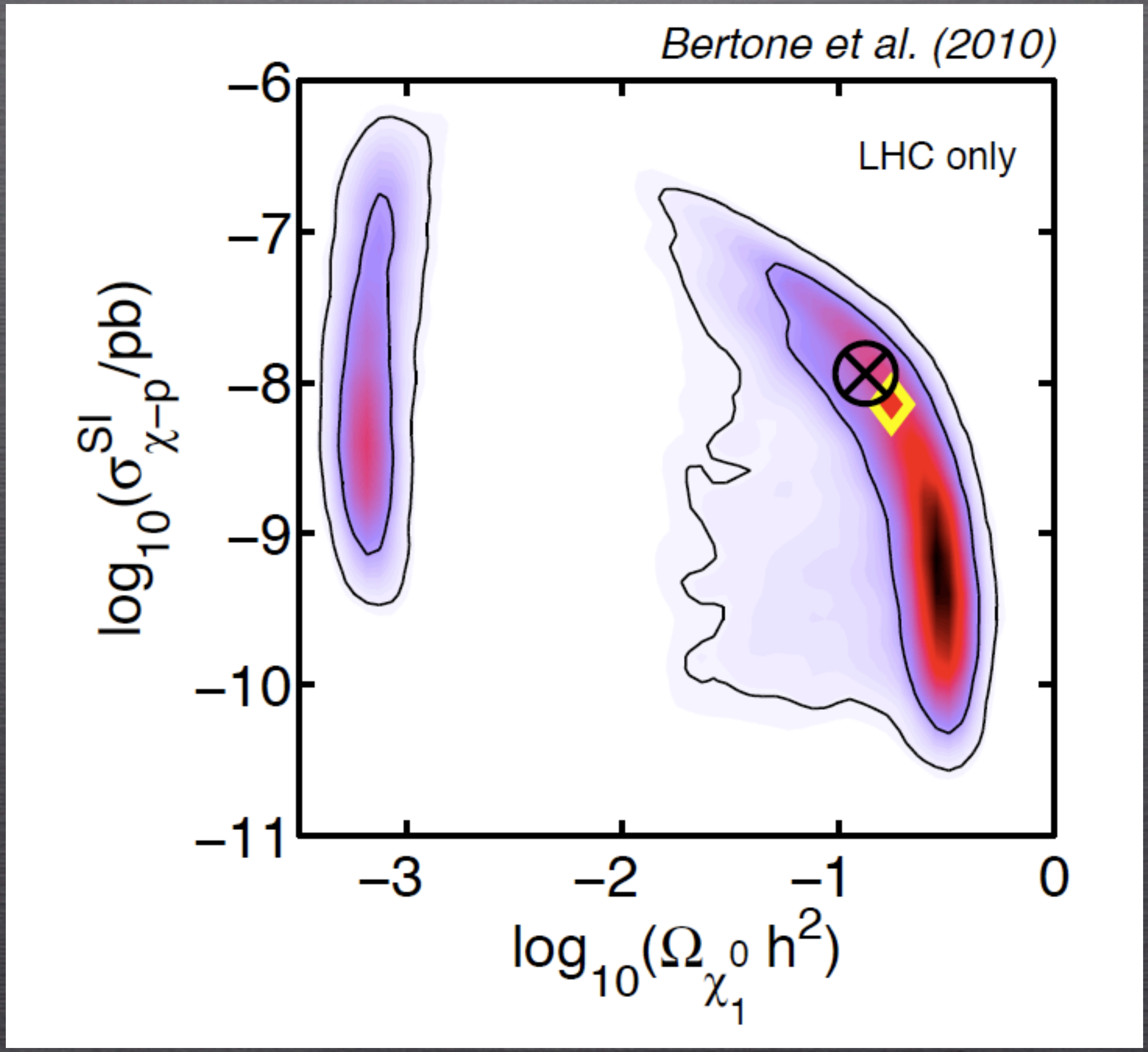

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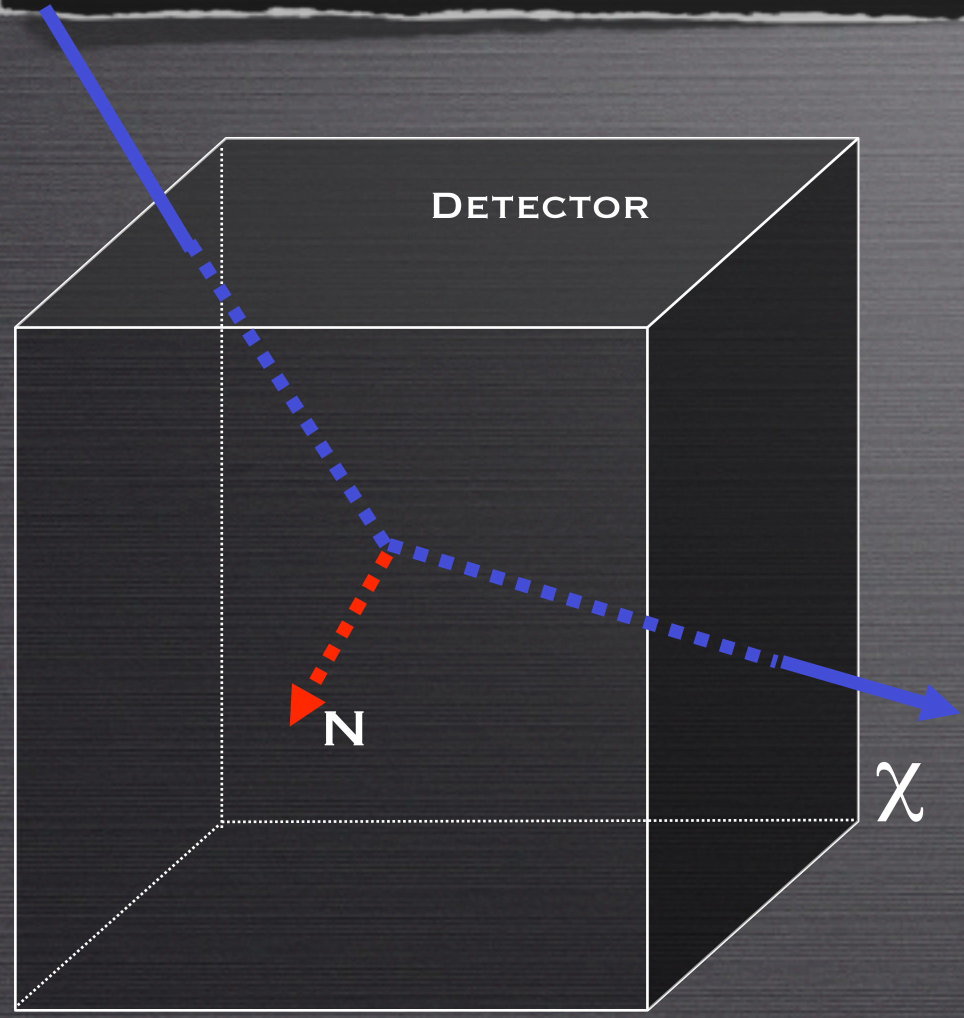
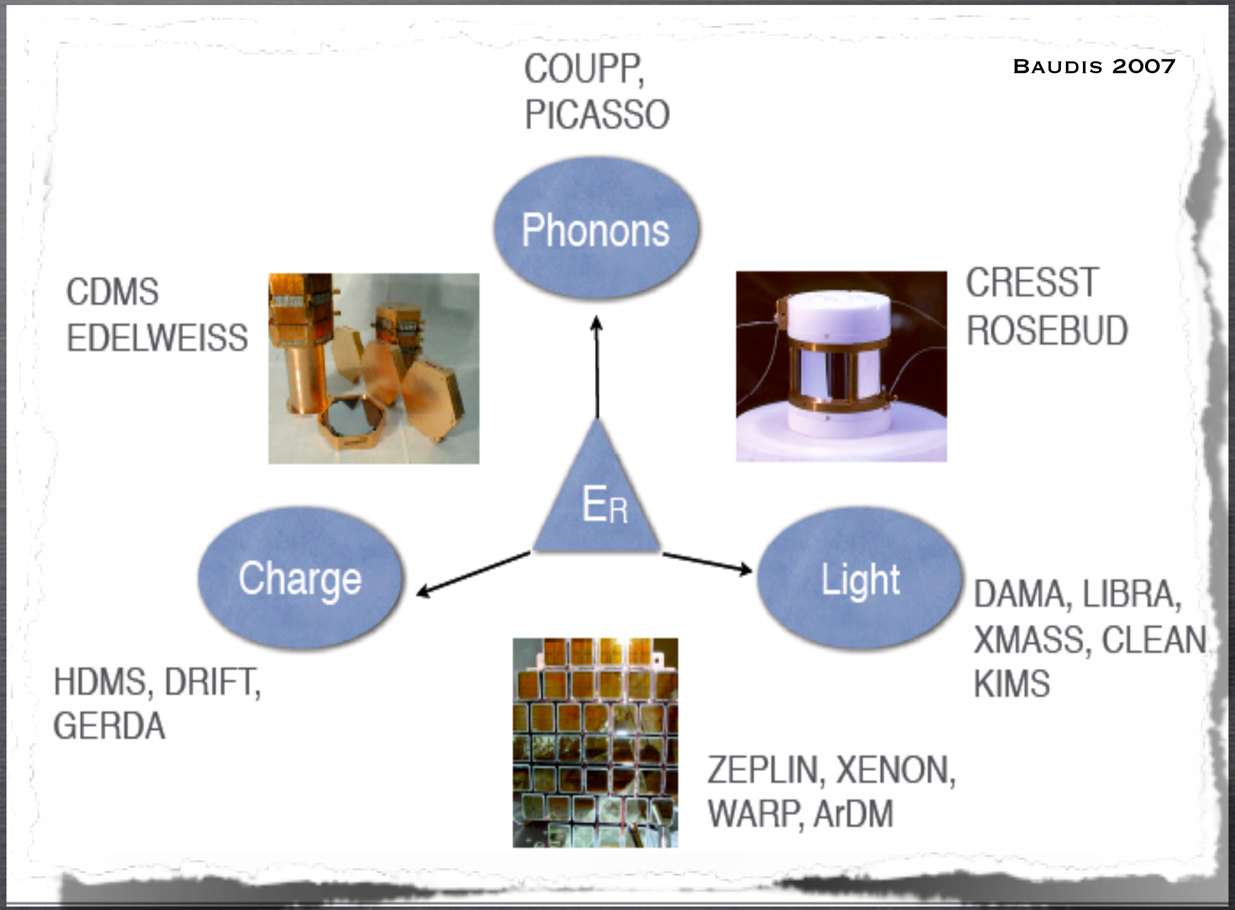
Direct Detection

Principle and Detection Techniques



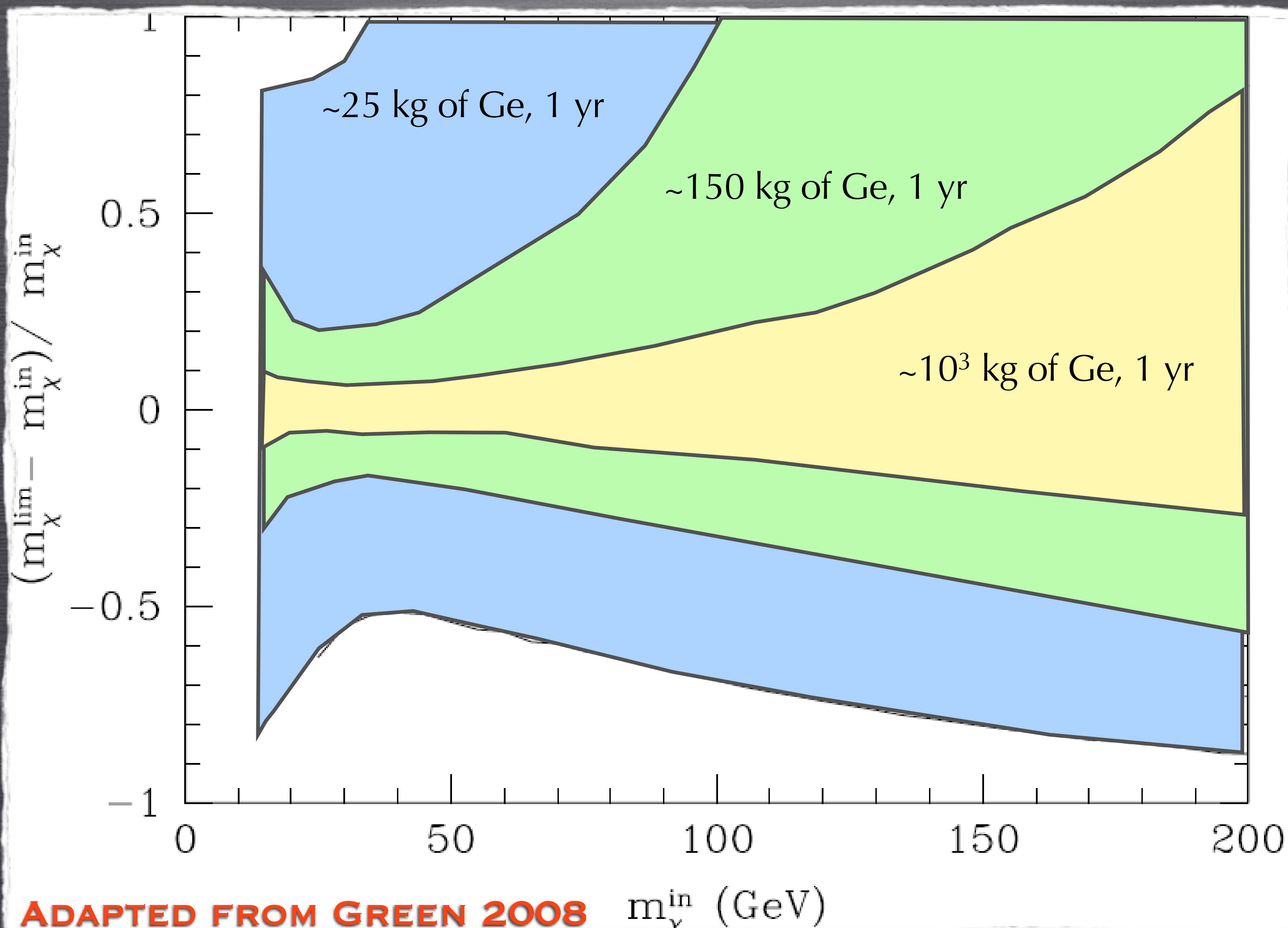


DM scatters off nuclei in the detector

Detection of recoil energy via ionization (charges), scintillation (light) and heat (phonons)

Direct Detection

95% C.L. constraint on the reconstructed DM mass



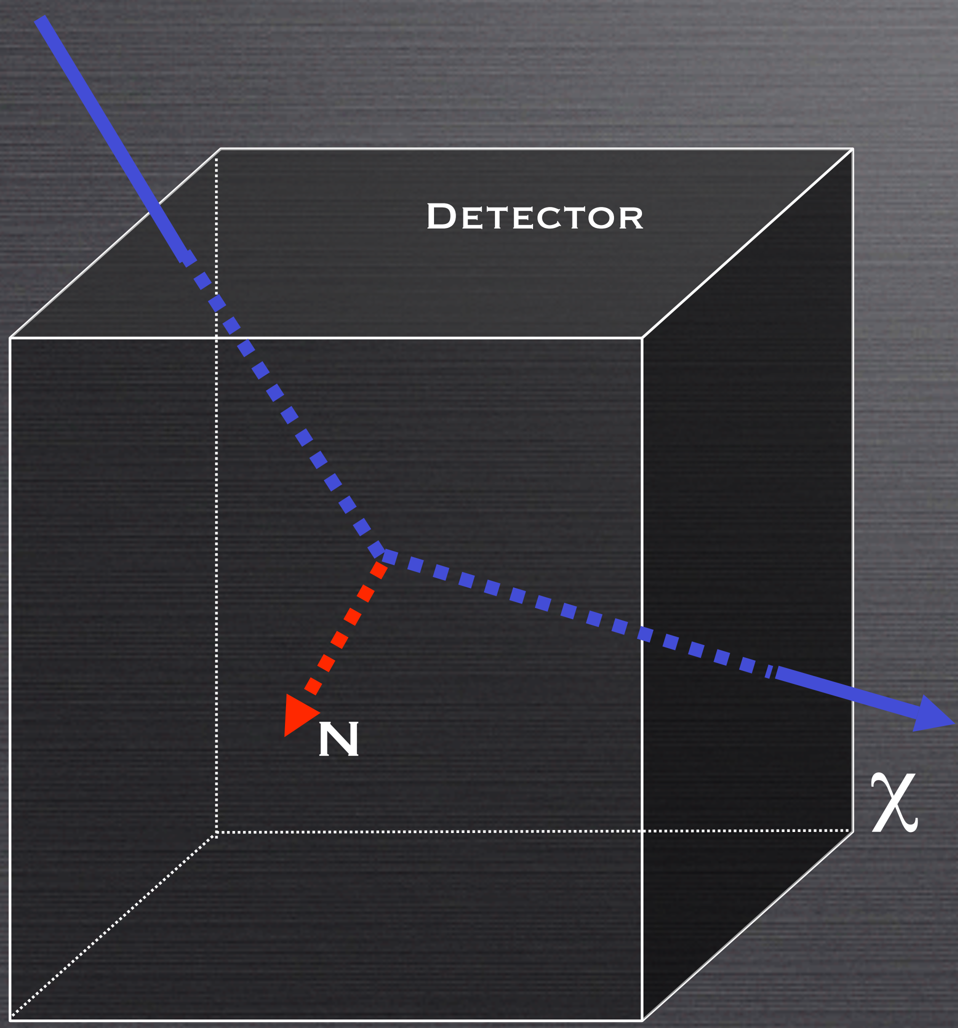
Adapted from Green 2008

$\sigma_{\chi N} = 10^{-8}$ pb; $N_{ev} \sim 20, 120, 800$ at $m_\chi = 50$ GeV

Direct Detection

Basics

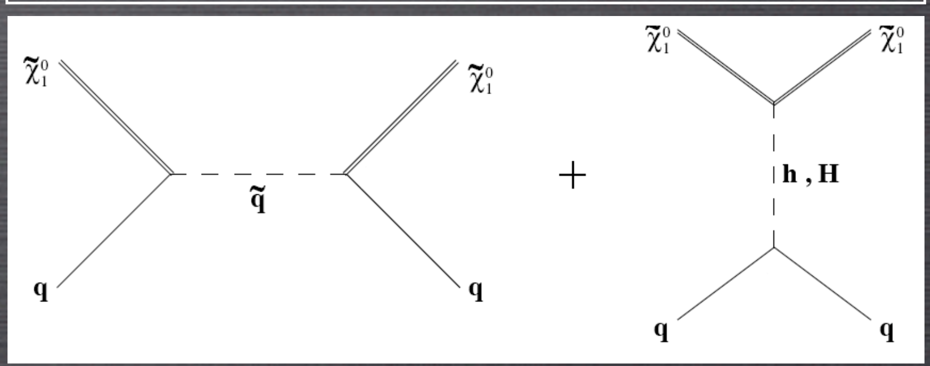
DM Scatters off nuclei in the detector



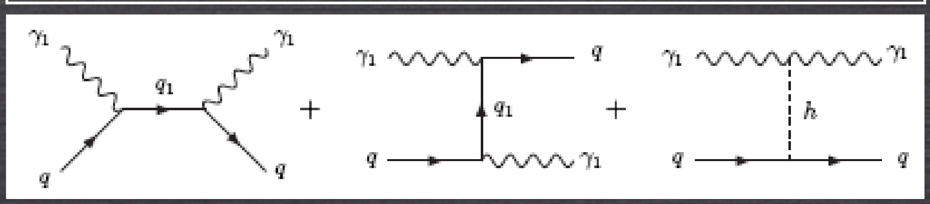
Differential Event Rate

$$\frac{\mathrm{d}R}{\mathrm{d}E}(E) = \frac{\sigma_{\mathrm{p}}\rho_{\chi}}{2\mu_{\mathrm{p}\chi}^2 m_{\chi}} A^2 F^2(E) \langle \int_{v_{\min}}^{\infty} \frac{f^{\mathrm{E}}(v,t)}{v} \mathrm{d}v \rangle$$

SUSY: squarks and Higgs exchange



UED: 1st level quarks and Higgs exchange



Direct Detection

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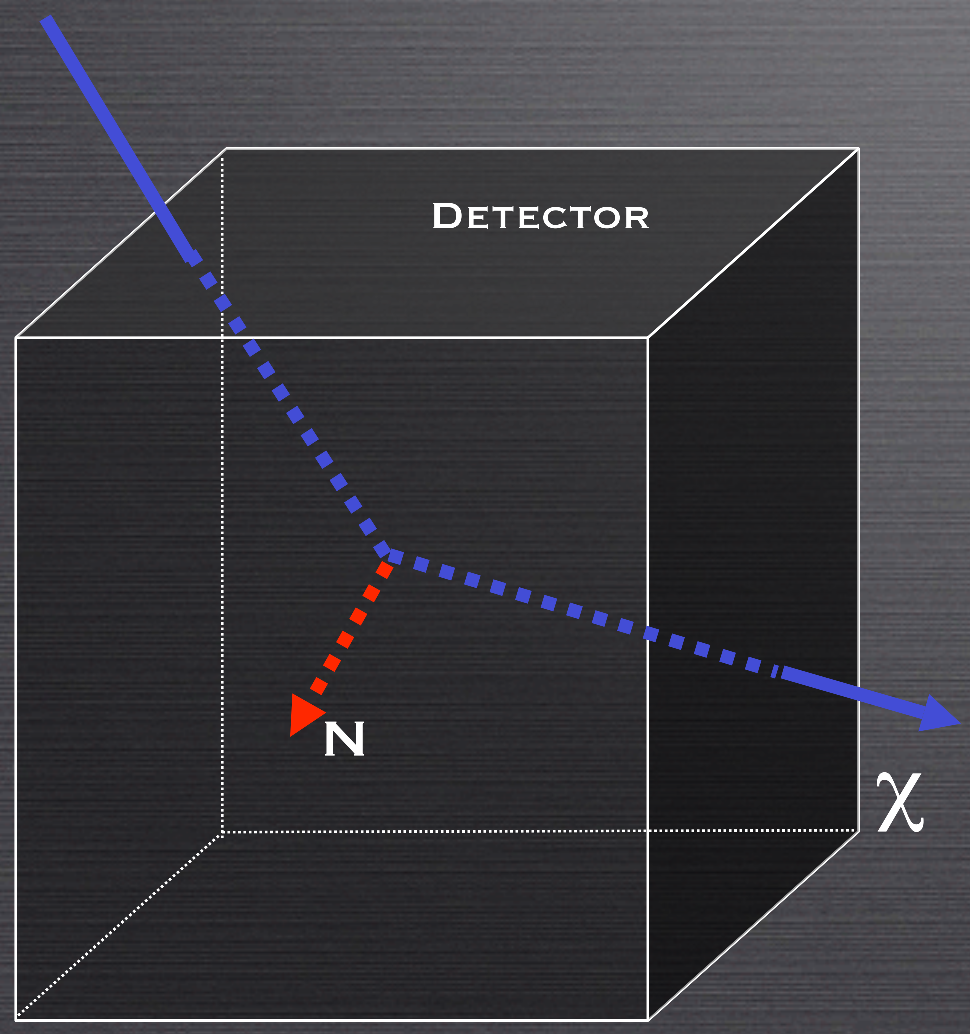

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Theoretical Uncertainties

Ellis, Olive & Savage 2008; Bottino et al. 2000; etc.

Uncertainties on f(v)

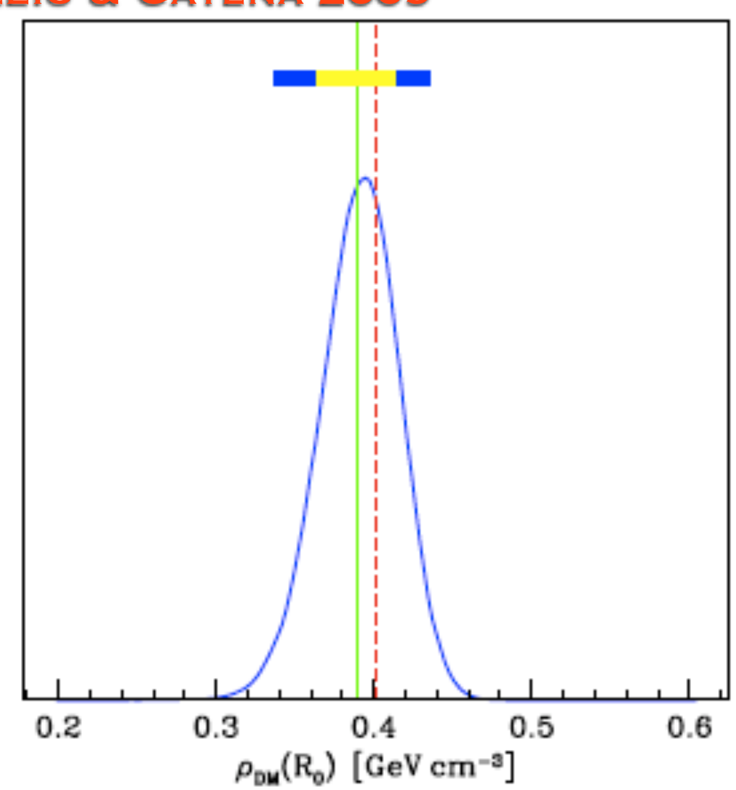
Ling et al. 2009; Widrow et al. 2000; Helmi et al 2002

Direct Detection

Uncertainties on the Local Density

"Statistical"

Ullio & Catena 2009

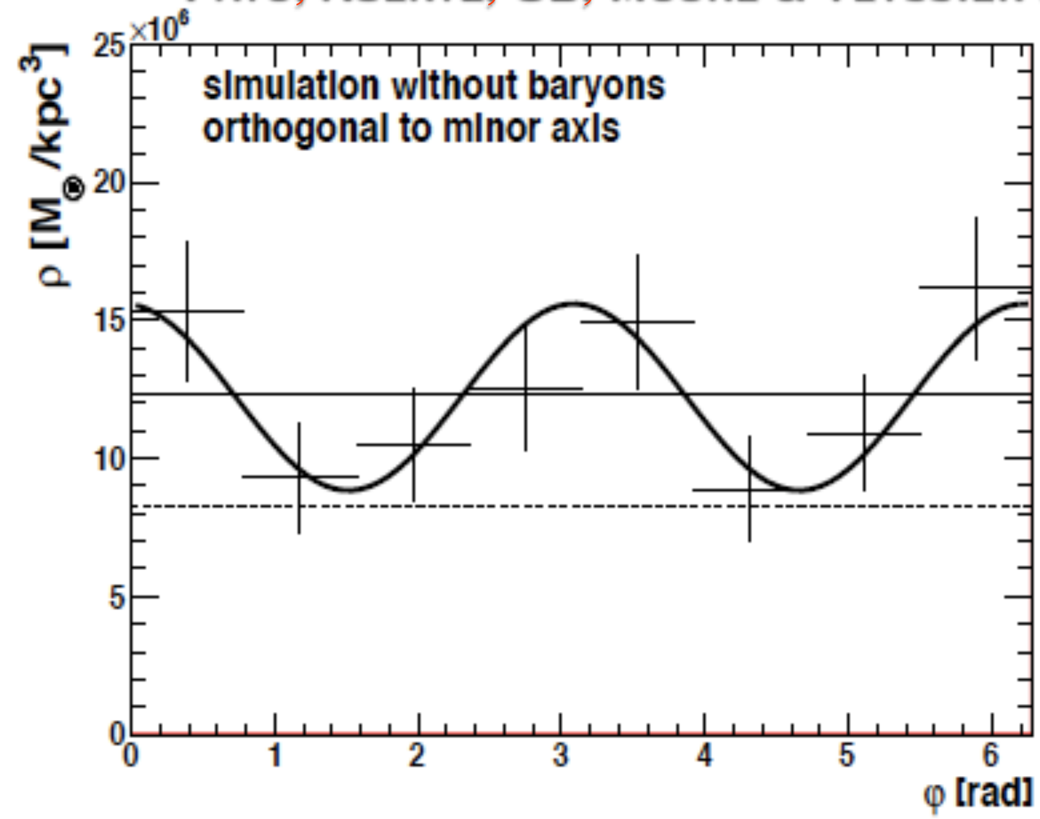


$$\rho_{DM}(R_0) = 0.389 \pm 0.025\,\mathrm{GeV\ cm}^{-3}$$

From dynamical Observables (see also Strigari & Trotta 2009)

"Systematic"

Pato, Agertz, GB, Moore & Teyssier 2010

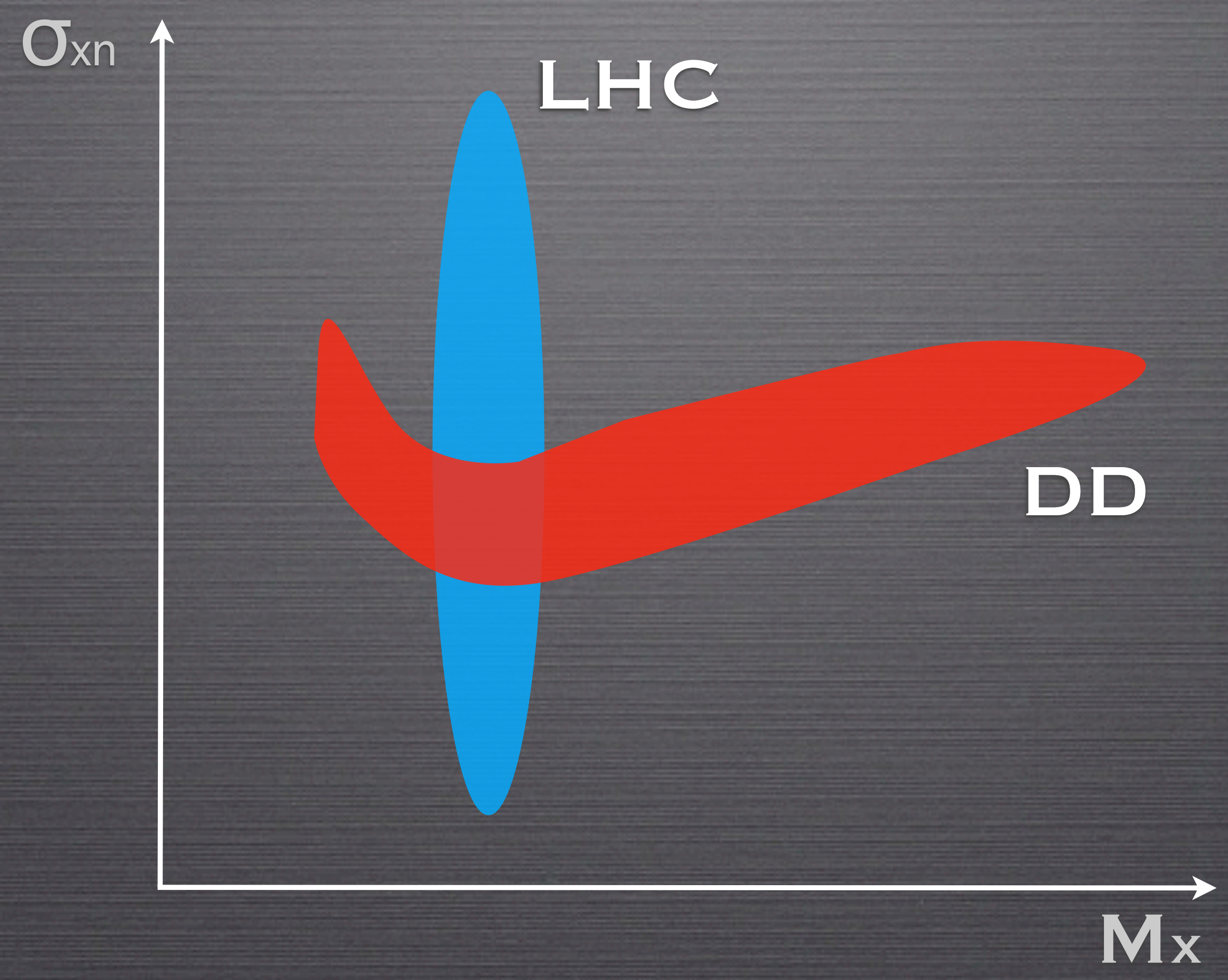


$$\rho_0/\bar{\rho}_0 = 1.01 - 1.41$$ w/ Baryons

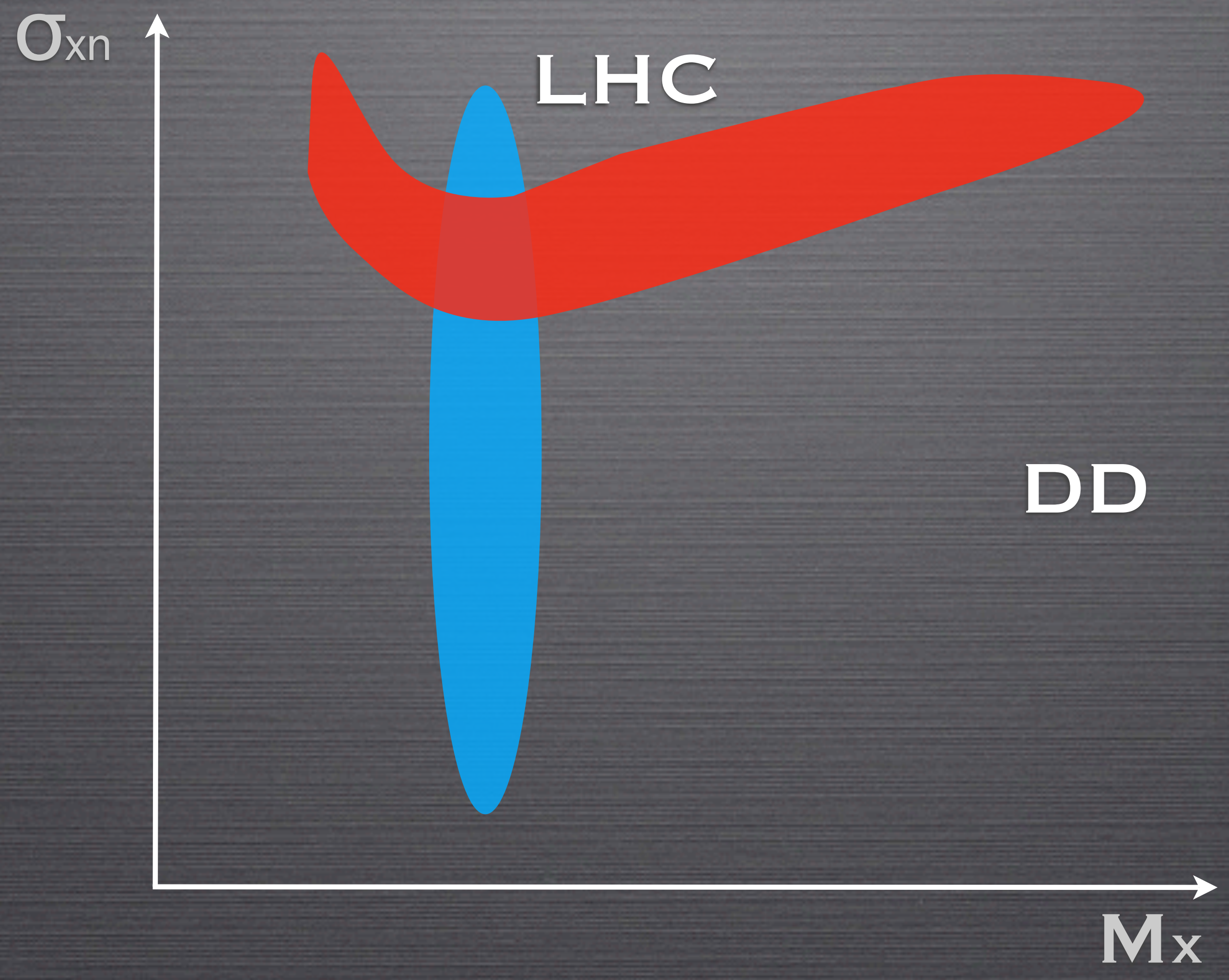
$$\rho_0/\bar{\rho}_0 = 0.39 - 1.94$$ DM only

$$\rho_0 = 0.466 \pm 0.033(\mathrm{stat}) \pm 0.077(\mathrm{syst})\ \mathrm{GeV\ cm}^{-3}$$

LHC+DD

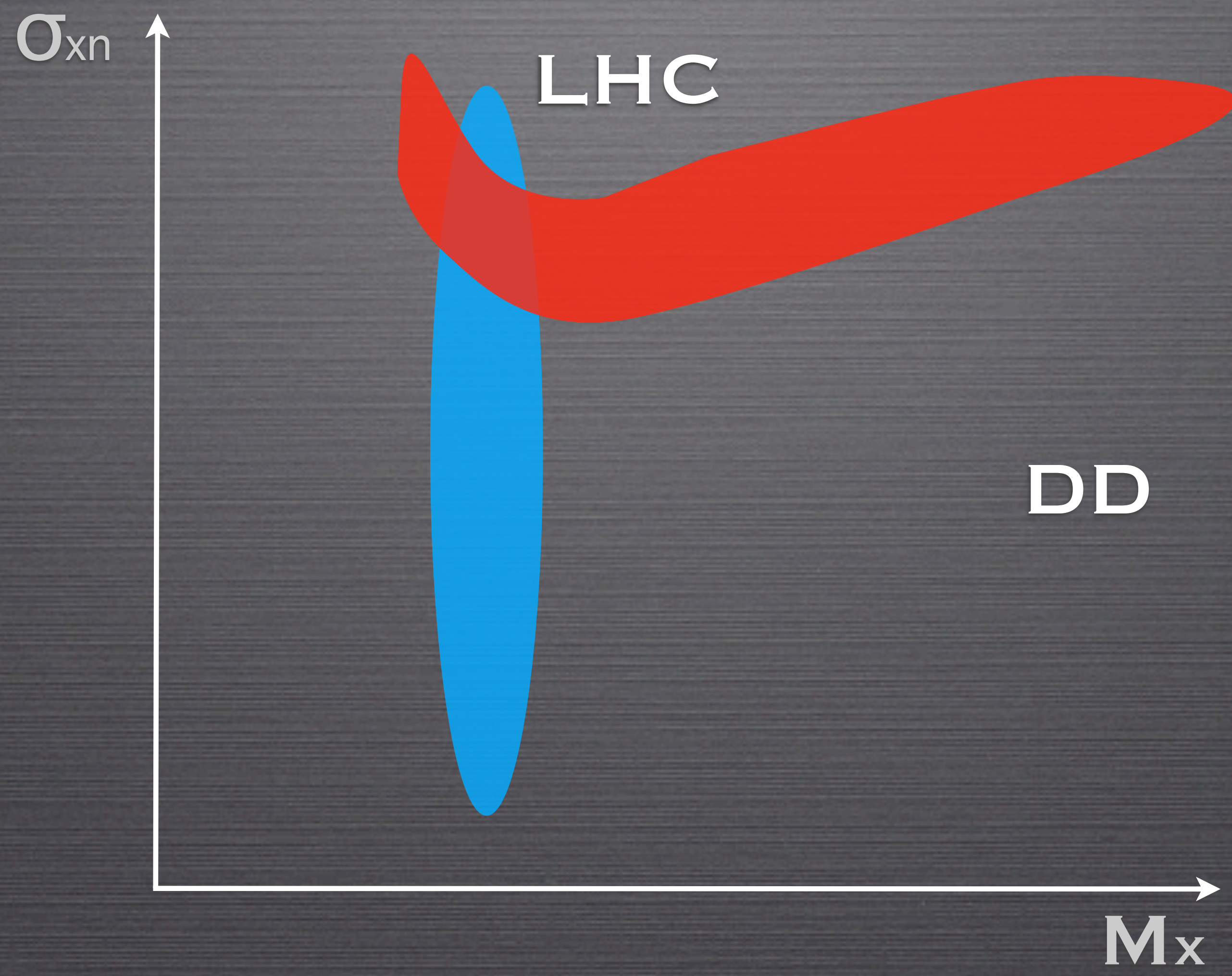


LHC+DD



$$\rho_\chi < \rho_{dm}$$

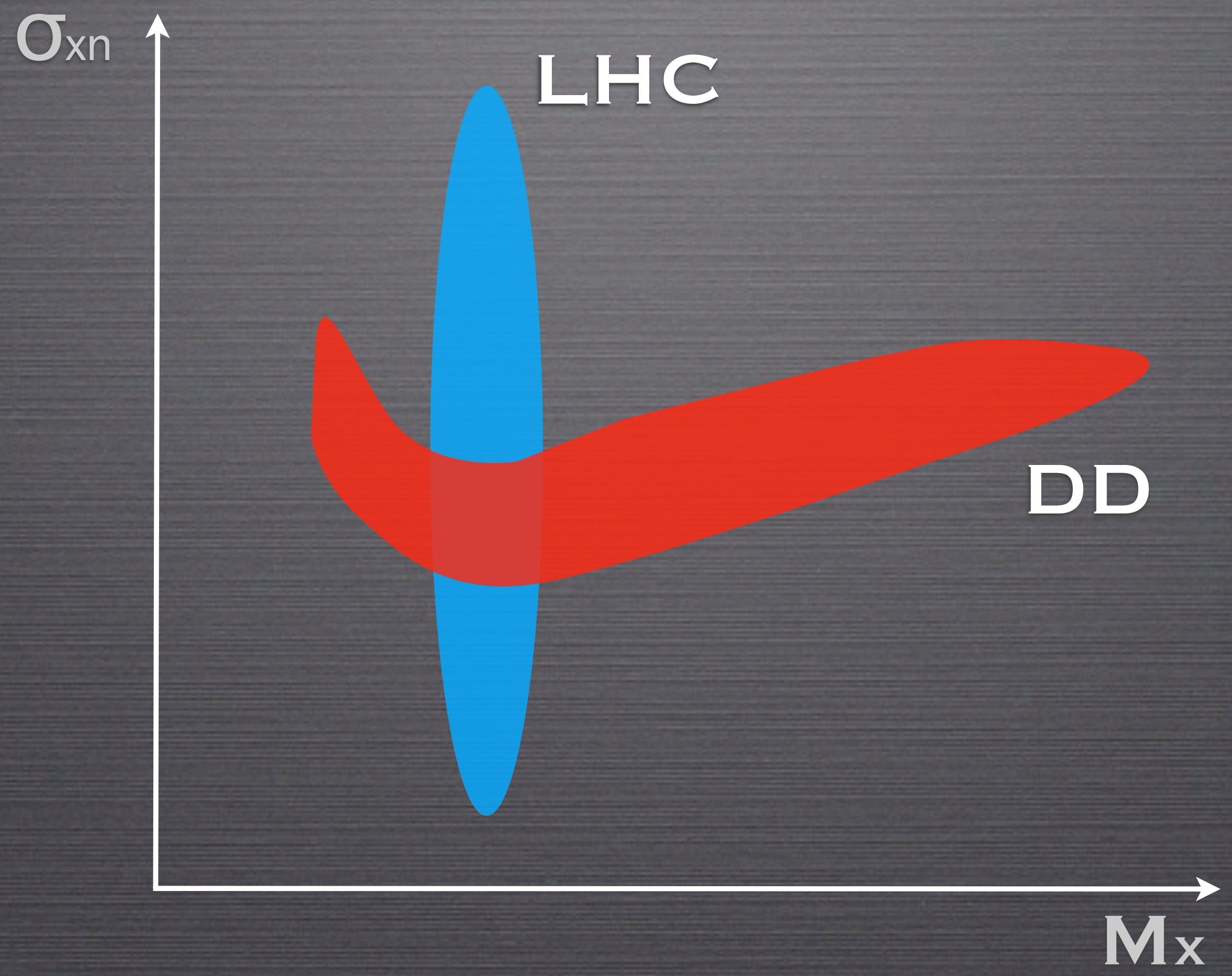
LHC+DD



$\rho_\chi < \rho_{dm}$

$f(v)$

LHC+DD



$$\rho_\chi < \rho_{dm}$$

$$f(v)$$

LHC+DD

To combine LHC and DD:

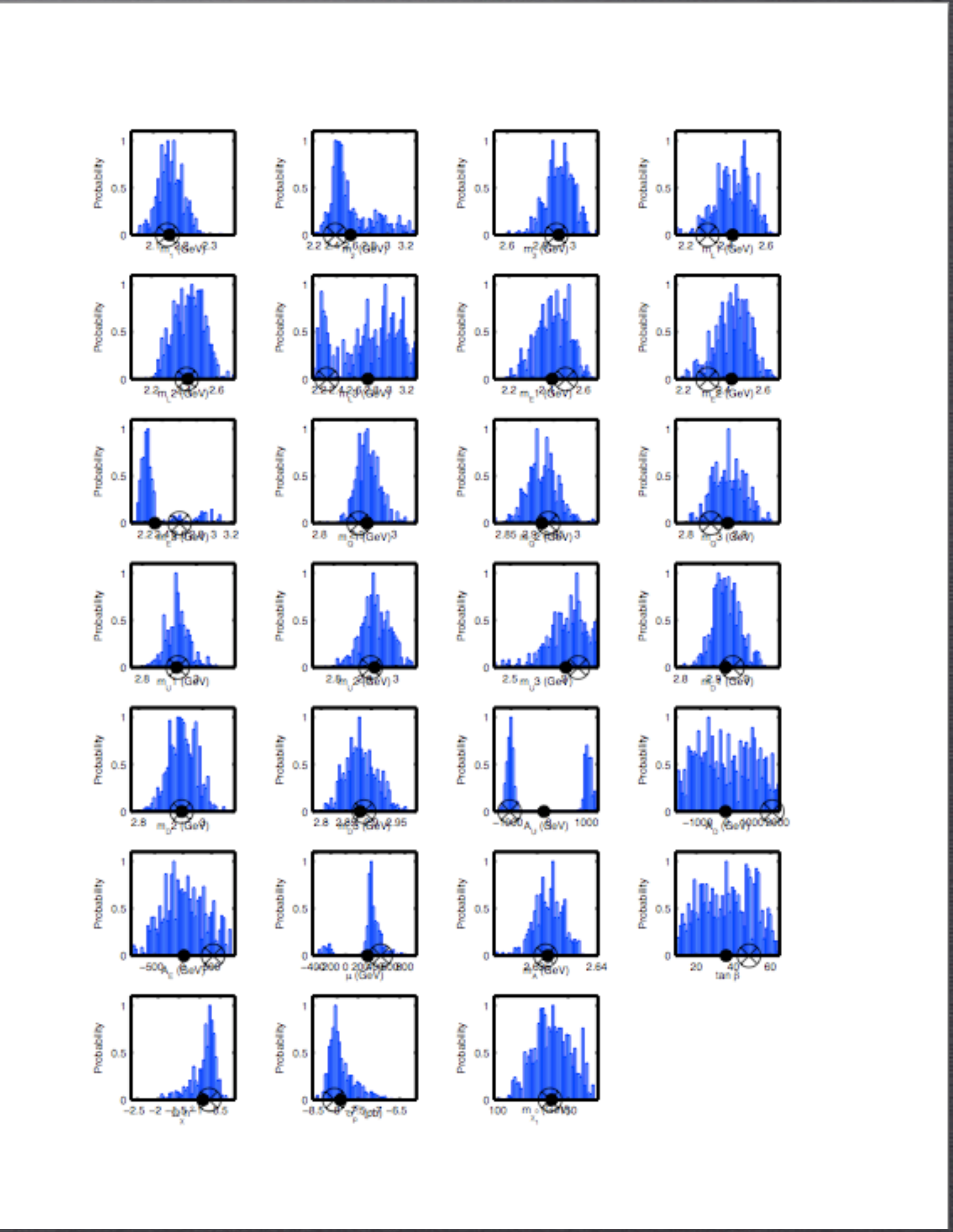
- Specify DM experiment

Target	A	ϵ	$E_{\rm th}$	$E_{\rm max}$	ρ_χ	λ
Ge	73	300 ton day	10 keV	100 keV	0.385 GeV cm^{-3}	638

- add new likelihood built on the number of events

- re-run the chains

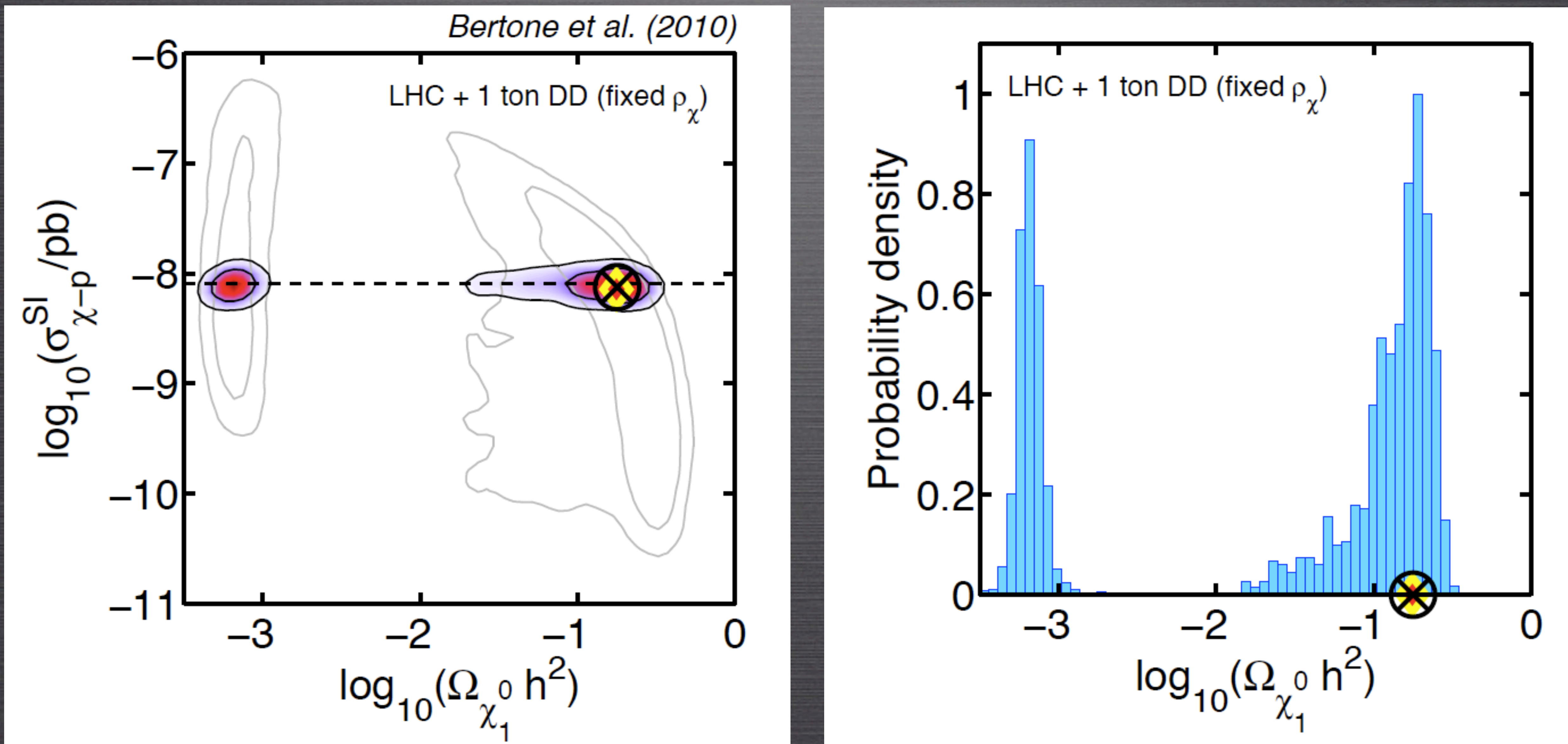
- (note that Fixing the number of events = fixing the product of cross section times local density)



GB, Cerdeno, Fornasa, Ruiz de Austri & Trotta (2010)

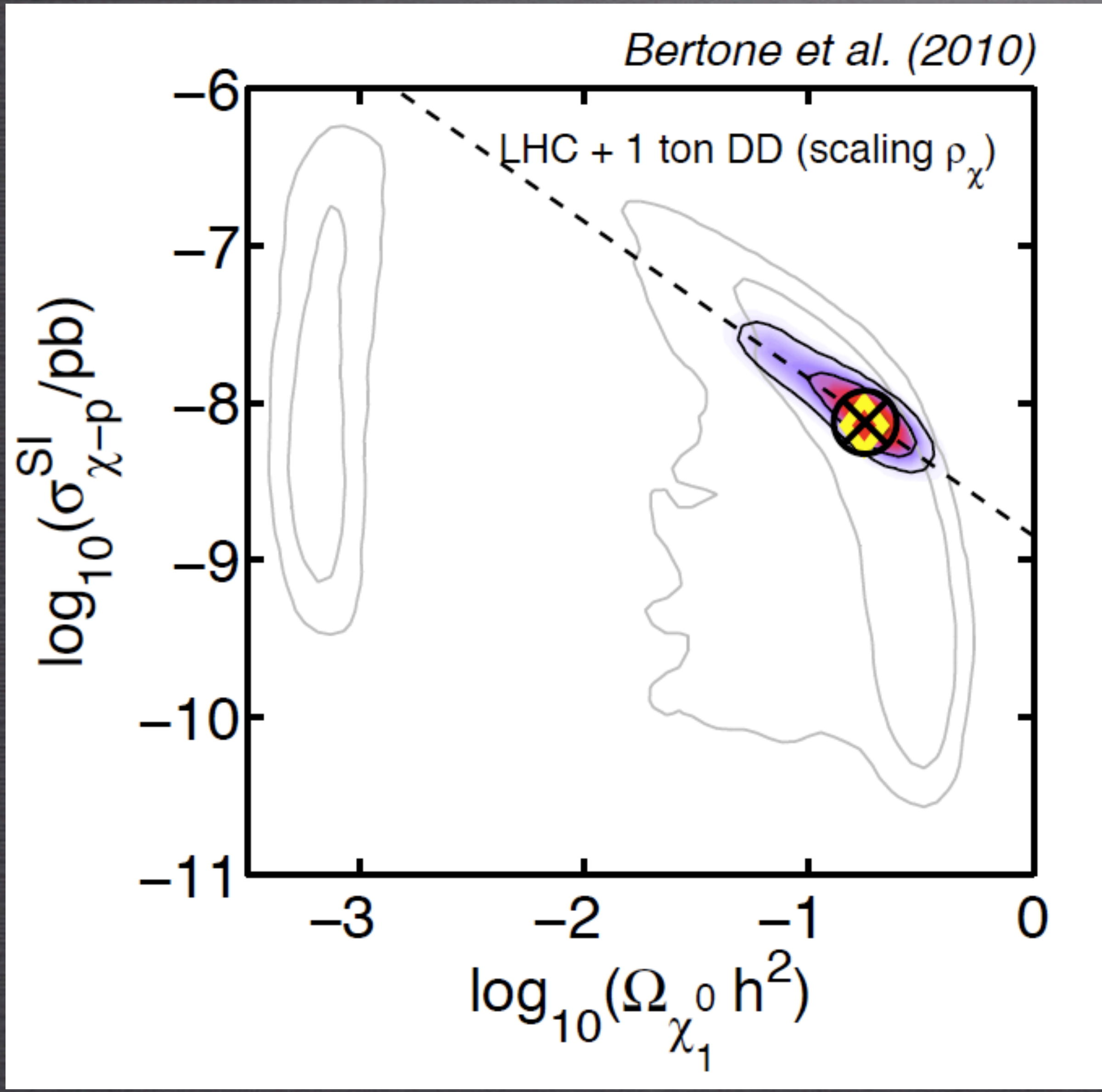
1st possibility: "consistency check"

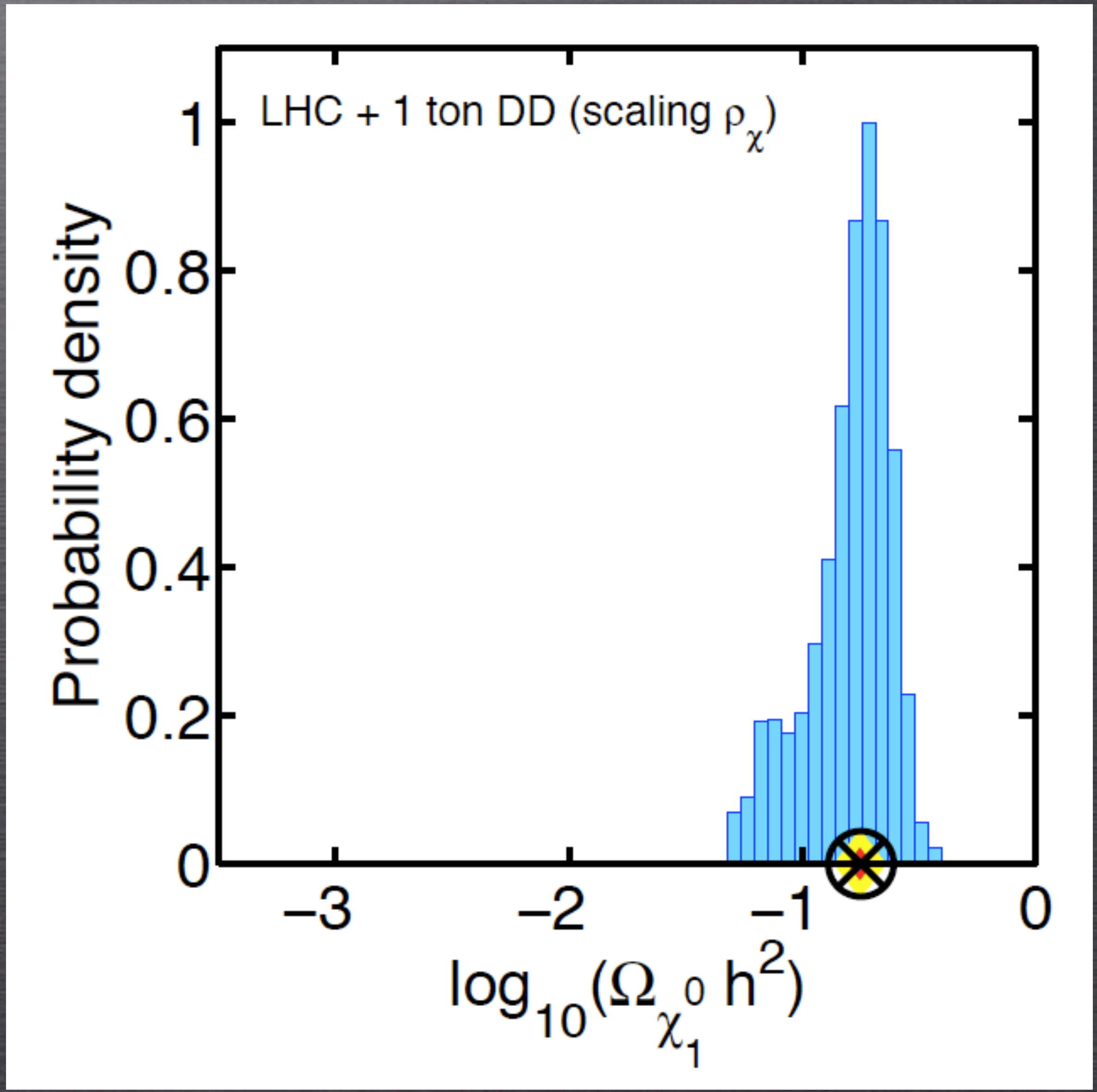
$$\rho_\chi = \rho_{\rm DM}$$



2nd (more physical) possibility: "Scaling" Ansatz

$$\frac{\rho_\chi}{\rho_{dm}} = \frac{\Omega_\chi}{\Omega_{dm}}$$

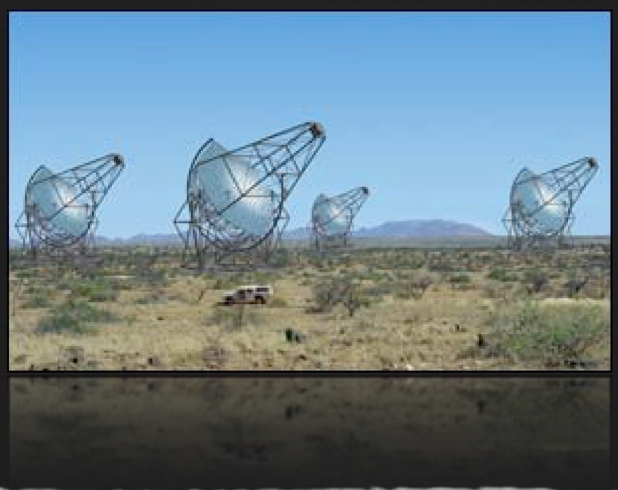


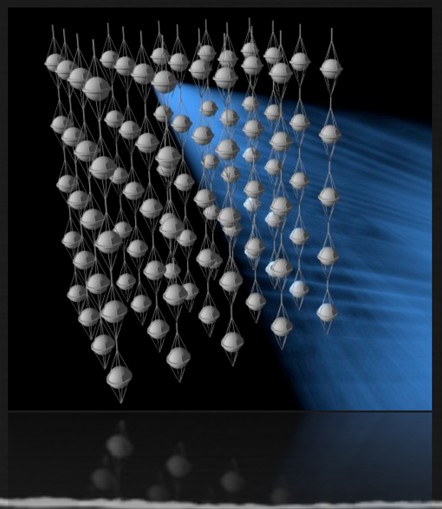


$$\sigma^{\mathrm{SI}}_{\chi-\mathrm{p}} \propto \Omega^{-1}_{\tilde{\chi}^0_1}$$

Indirect Detection







Gamma-ray telescopes

- Ground Based (CANGAROO, HESS, MAGIC, MILAGRO, VERITAS)
- Space satellite FERMI
- Plans for a future Cherenkov Telescope Array

Neutrino Telescopes

- Amanda, IceCube
- Antares, Nemo, Nestor
- Km3

Anti-matter Satellites

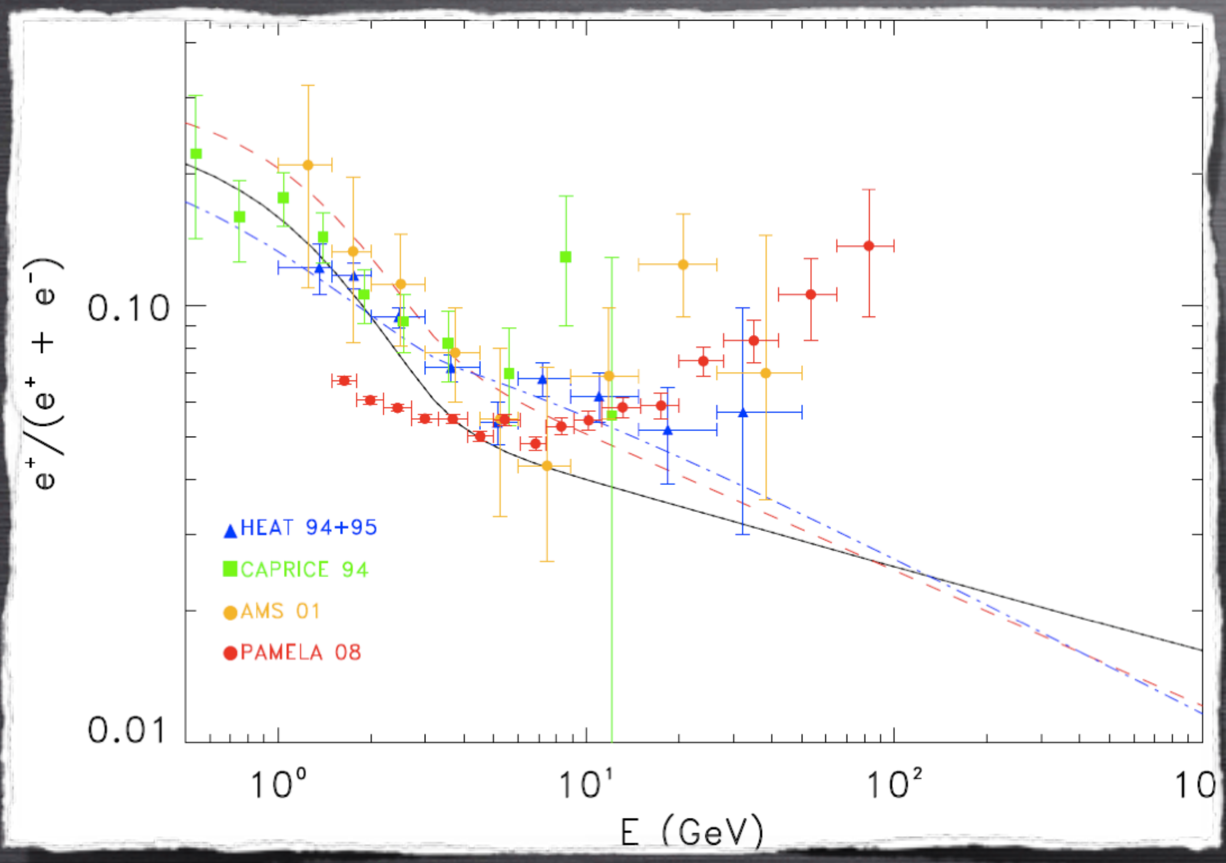
- PAMELA
- ATIC,PPB-BETS
- AMS-02

Other

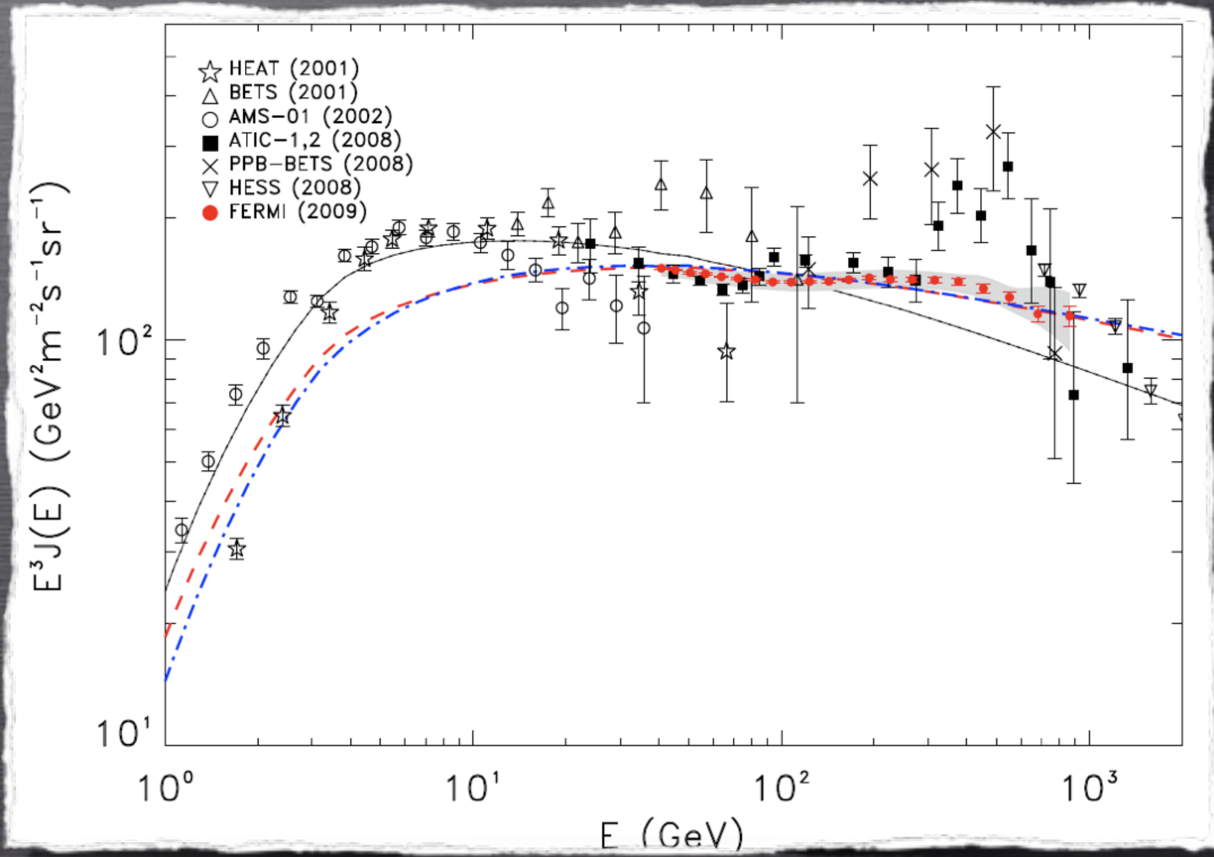
- Synchrotron Emission
- SZ effect
- Effect on Stars

Cosmic e^+e^-

PAMELA, HESS, Fermi, ATIC, PPB-BETS, HEAT, AMS, Caprice...

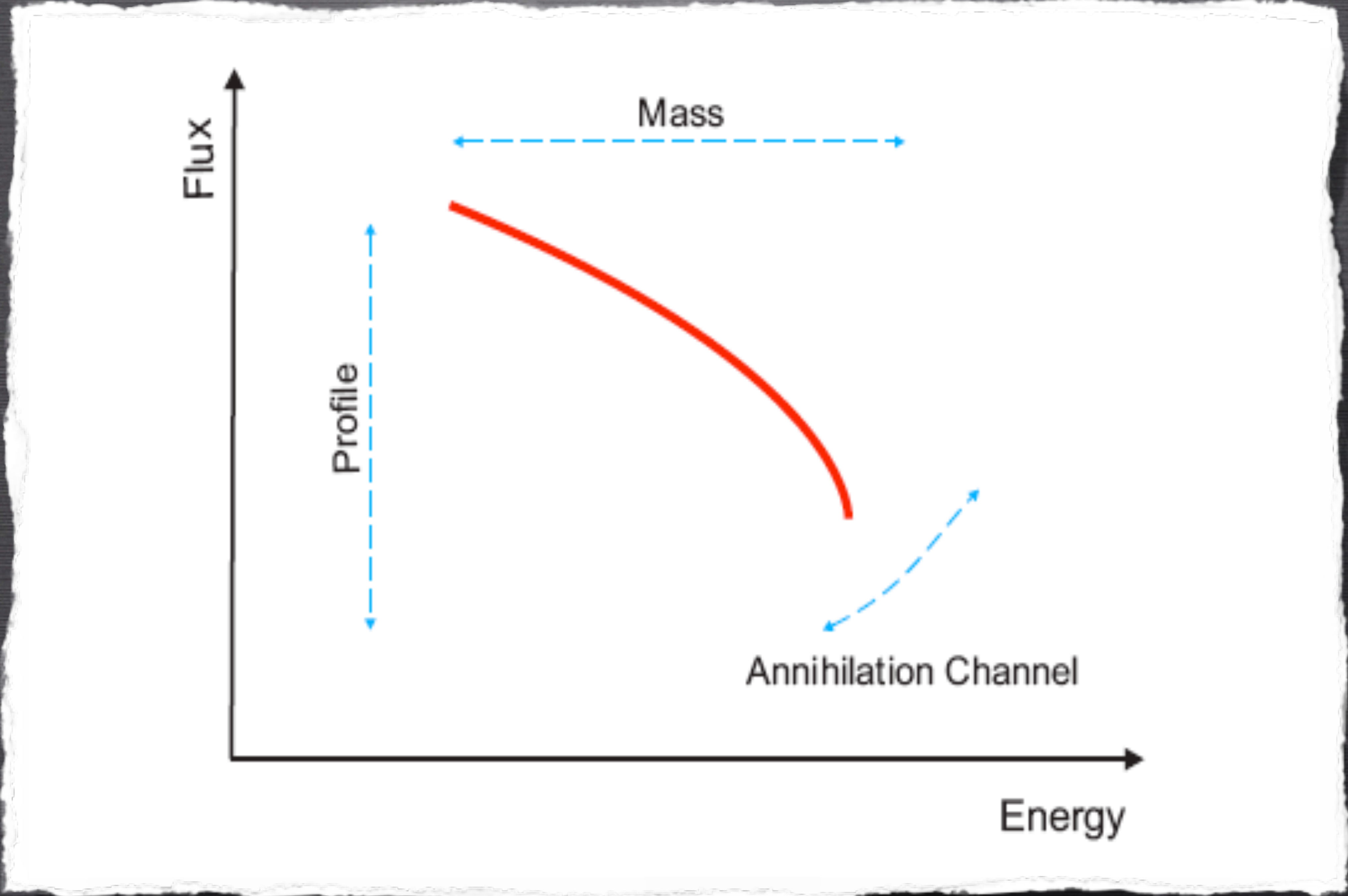


Grasso et al. 2009



Grasso et al. 2009

The trouble with indirect searches



...which means that the "inverse problem" always admits a solution, even when the data have nothing to do with DM!

The quest for the smoking-gun

or

"How to convince a particle physicist?"

The quest for the smoking-gun or "How to convince a particle physicist?"

Claims of discovery have been made over the years (EGRET source, HEAT excess, INTEGRAL 511 keV line, WMAP Haze). The footprint of DM could be anywhere, but how do we go from "hints" to "discovery"?

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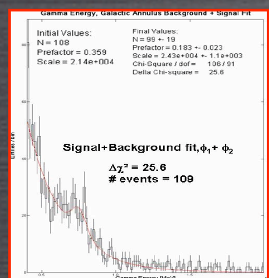

1) Annihilation Lines (or other unmistakable spectral features)

Neutralinos (e.g. Bergstrom and Ullio 1997)
KK Dark Matter in UED (Bringmann et al. 2005)
Inert Higgs DM (Gustafsson et al. 2007)
gravitinos in SUSY with R-parity violation (GB, Buchmueller, Covi & Ibarra 2008)
WIMP FOREST! GB, Jackson, Tait & Vallinotto 2009

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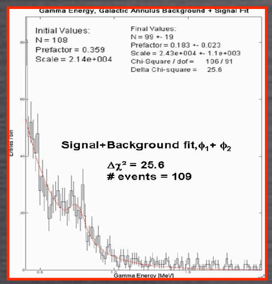

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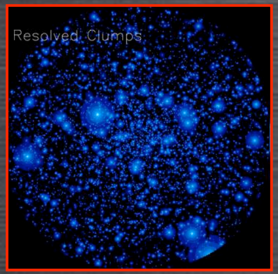

2) Multiple Sources with Identical spectra

e.g. DM clumps or IMBHs

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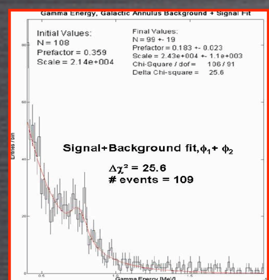

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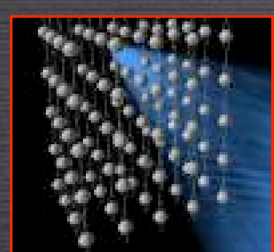

3) High-Energy Neutrinos from the Sun

Icecube, Antares, km3
Fluxes proportional to SCATTERING not annihilation cross section

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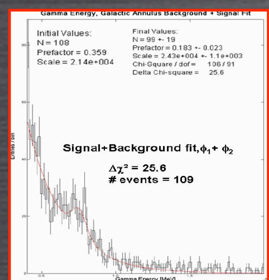

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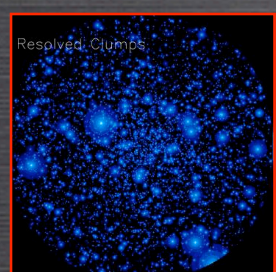

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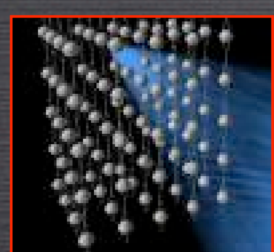

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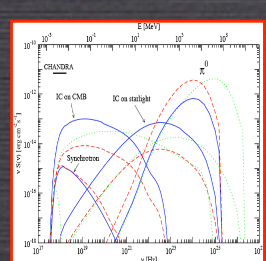
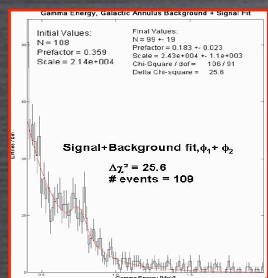


4) Multi-wavelength / multi-messenger approach

Bertone, Sigl & Silk 2001; Aloisio, Blasi & Olinto 2004; Colafrancesco, Profumo & Ullio 2005; Regis & Ullio 2007, Jeltema and Profumo 2008 etc.

The quest for the smoking-gun or "How to convince a particle physicist?"

Claims of discovery have been made over the years (EGRET source, HEAT excess, INTEGRAL 511 keV line, WMAP Haze). The footprint of DM could be anywhere, but how do we go from "hints" to "discovery"?

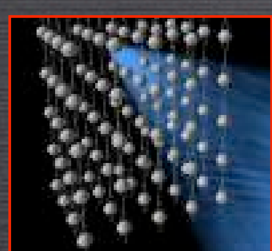


1) Annihilation Lines (or other unmistakable spectral features)

Neutralinos (e.g. Bergstrom and Ullio 1997)
KK Dark Matter in UED (Bringmann et al. 2005)
Inert Higgs DM (Gustafsson et al. 2007)
gravitinos in SUSY with R-parity violation (GB, Buchmueller, Covi & Ibarra 2008)
WIMP FOREST! GB, Jackson, Tait & Vallinotto 2009

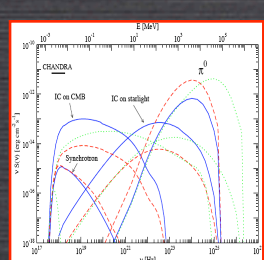
2) Multiple Sources with Identical spectra

e.g. DM clumps or IMBHs



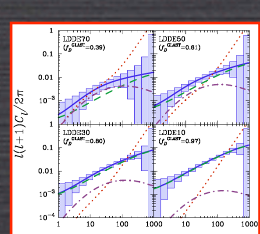
3) High-Energy Neutrinos from the Sun

Icecube, Antares, km3
Fluxes proportional to SCATTERING not annihilation cross section



4) Multi-wavelength / multi-messenger approach

Bertone, Sigl & Silk 2001; Aloisio, Blasi & Olinto 2004; Colafrancesco, Profumo & Ullio 2005; Regis & Ullio 2007, Jeltema and Profumo 2008 etc.

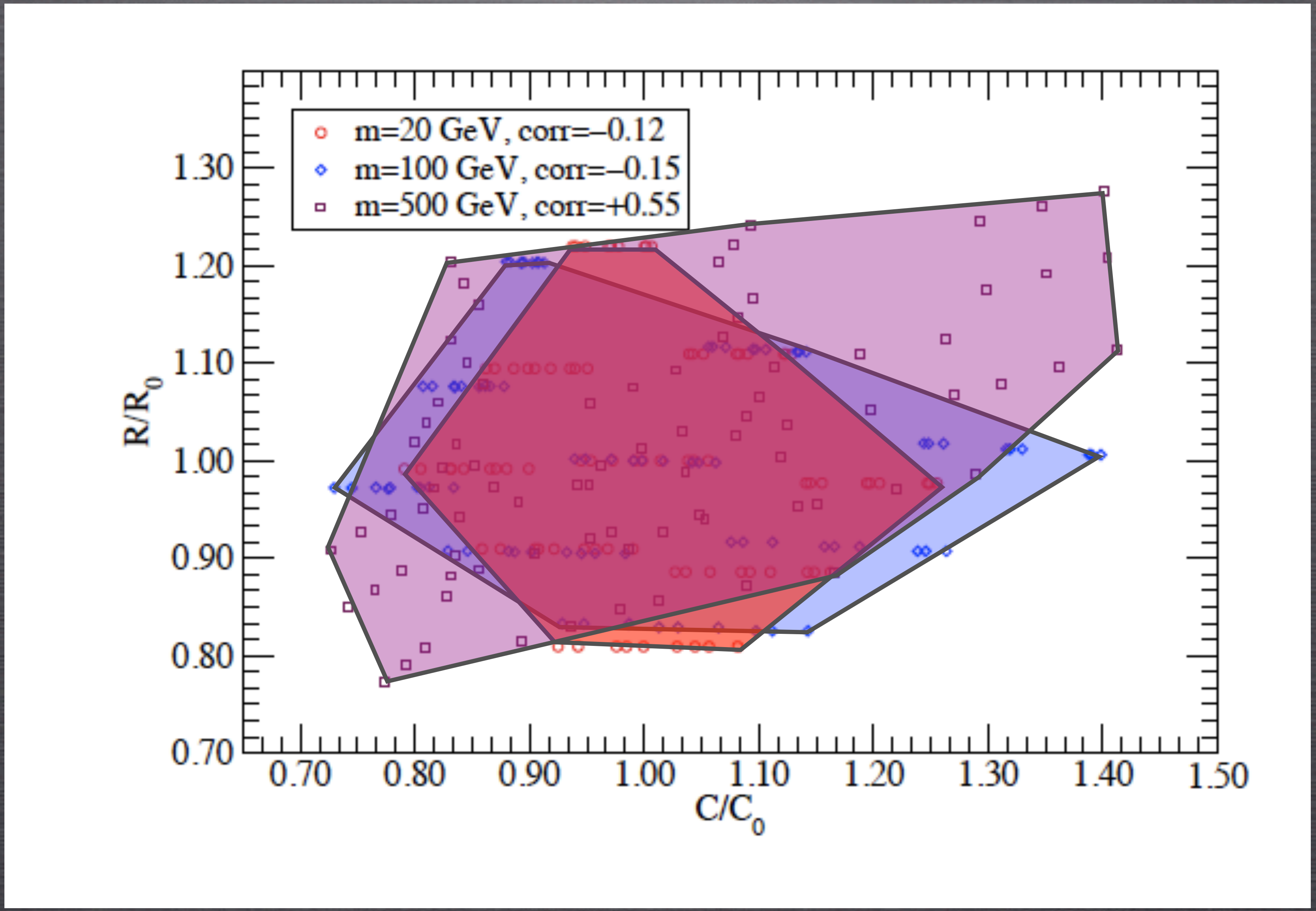


5) Angular power Spectrum of EG Background

Ando & Komatsu 2006, Ando et al. 2007; Siegal-Gaskins 2008; Fornasa, GB et al. 2008
Fermi Guest Investigator Grant!

Even in case of detection, the precise determination of DM will be a tricky issue

indirect neutrino signals vis-a-vis direct detection recoil rates



Serpico & GB, 2010

Conclusions

- Huge Theoretical and experimental effort towards the identification of DM

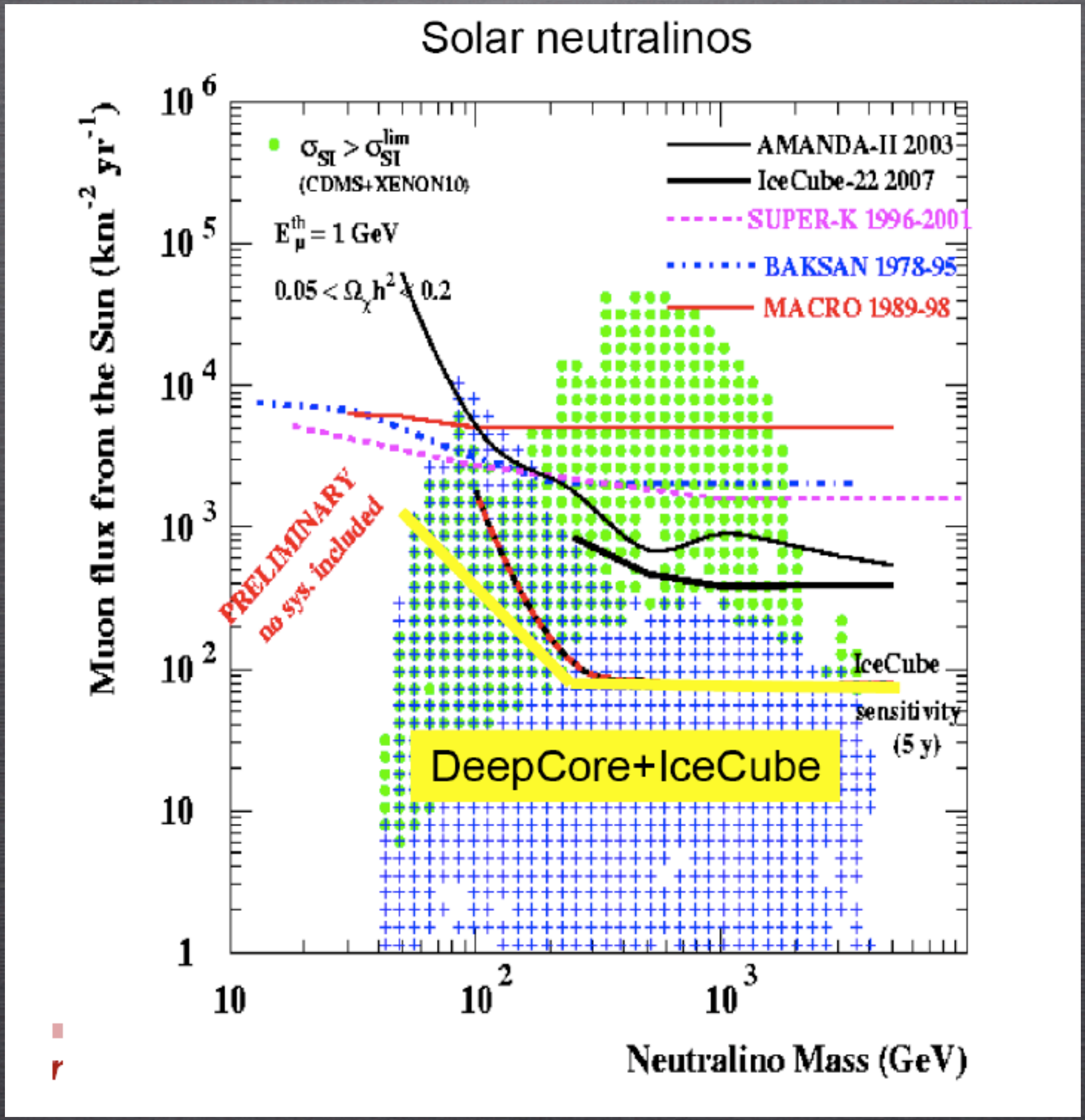
- LHC is running! Exciting times ahead, but direct and indirect searches likely necessary to identify DM

- DM Direct Detection looks promising, but info from other exps. is needed to determine DM parameters

- DM Indirect Detection more and more constrained, but detection still possible

- We Need Data! In ~5 Yrs. discovery of Wimps or Paradigm shift..

Prospects for detecting neutrinos from SUSY DM annihilations in the Sun



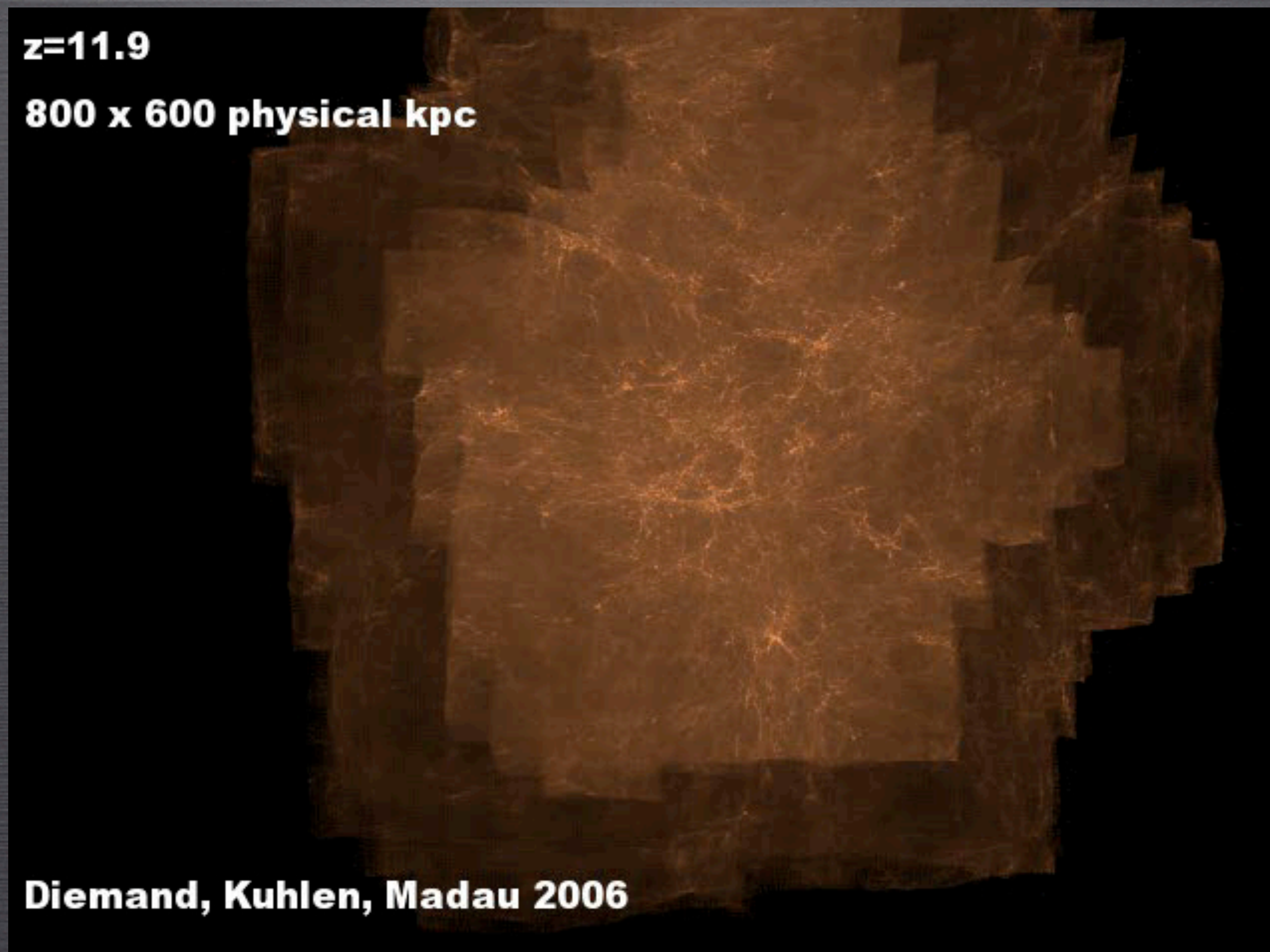
Halzen & Hooper 2009

Deriving Exclusion Plots

1. Take a numerical simulation

Deriving Exclusion Plots

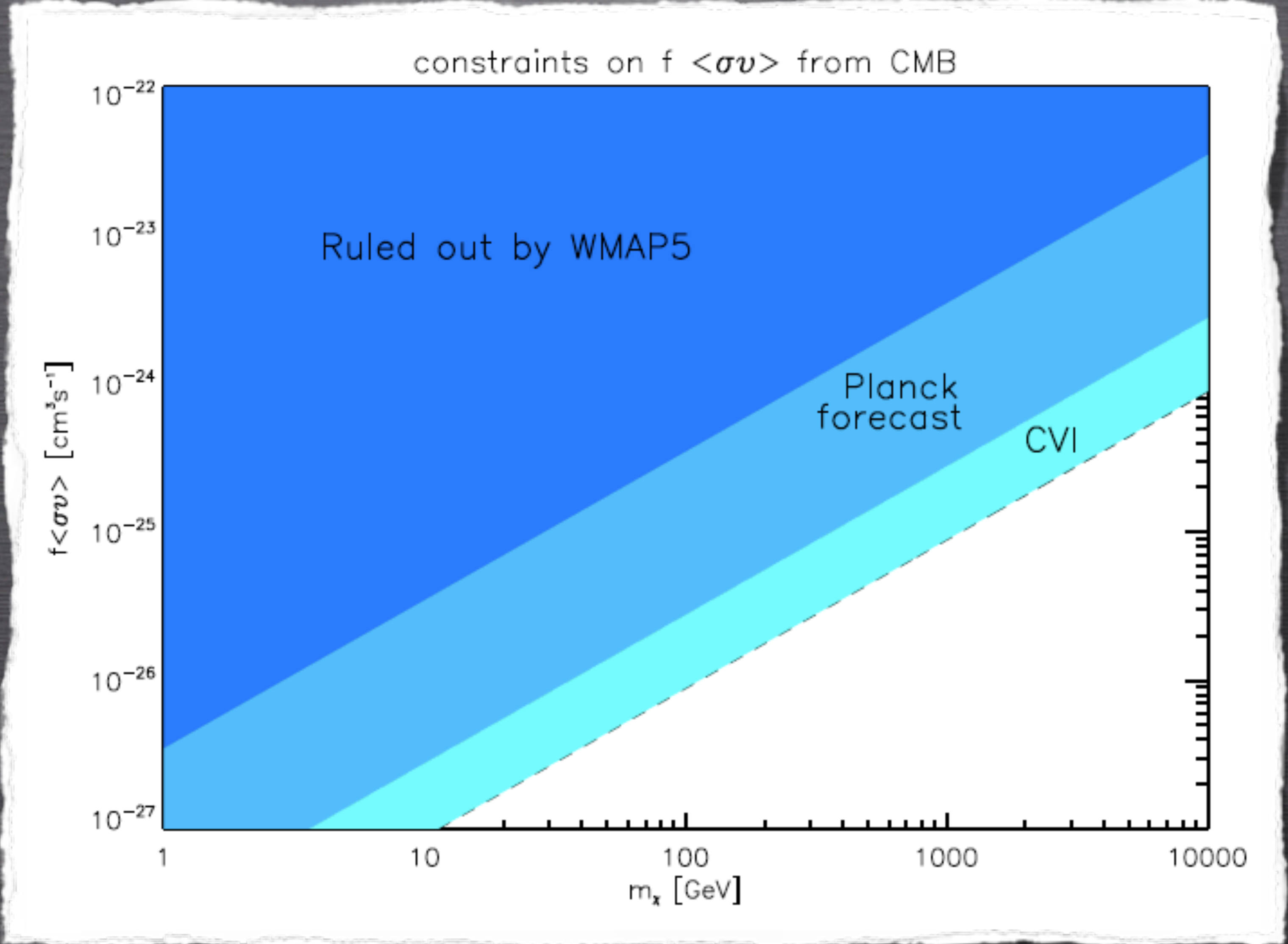
I. Take a numerical simulation



Constraints from CMB

on the ann. cross section at recombination, i.e. $v/c \sim 10^{-8}$

(cfr. Talks by Iocco and Hector on Monday)



Galli, Iocco, GB, Melchiorri 2009

The interaction of secondary particle from DM annihilation with the thermal gas can 1: ionize it, 2: induce Ly–α excitation of the hydrogen and 3: heat the plasma. The first two modify the evolution of the free electron fraction xe, the third affects the temperature of baryons.

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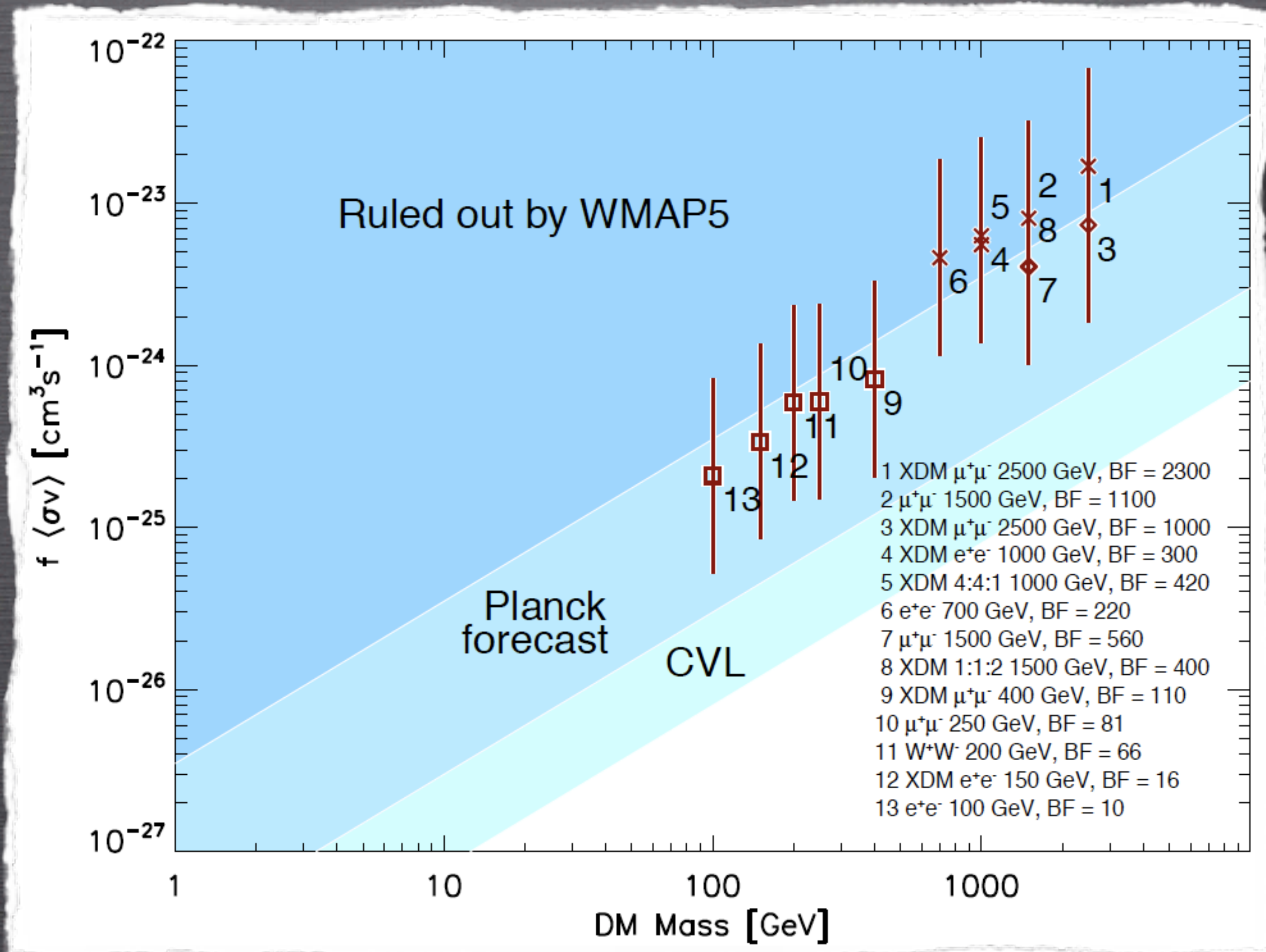

Slatyer, Padmanabhan, Finkbeiner 2009

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