COSMOLOGY AND THE LHC

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THE GREATEST EXPERIMENTS ON EARTH

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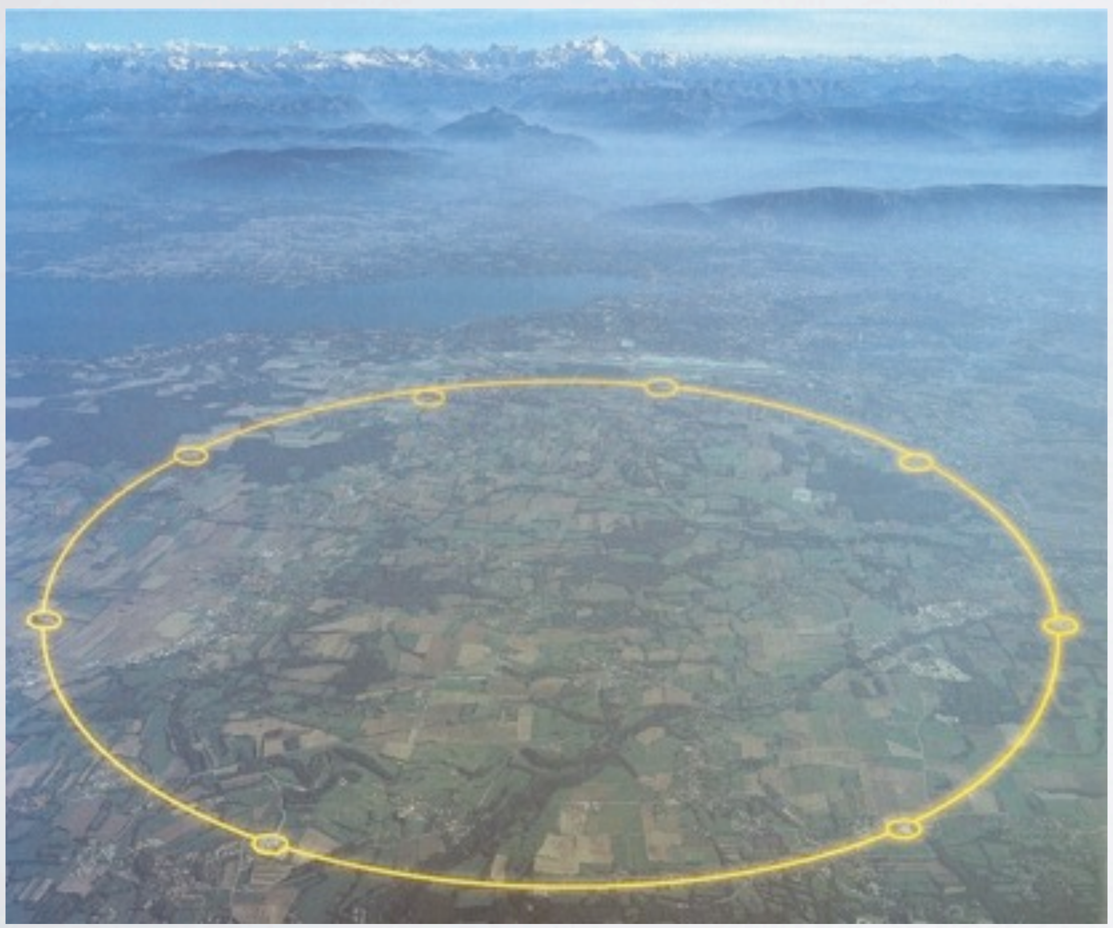

The LHC

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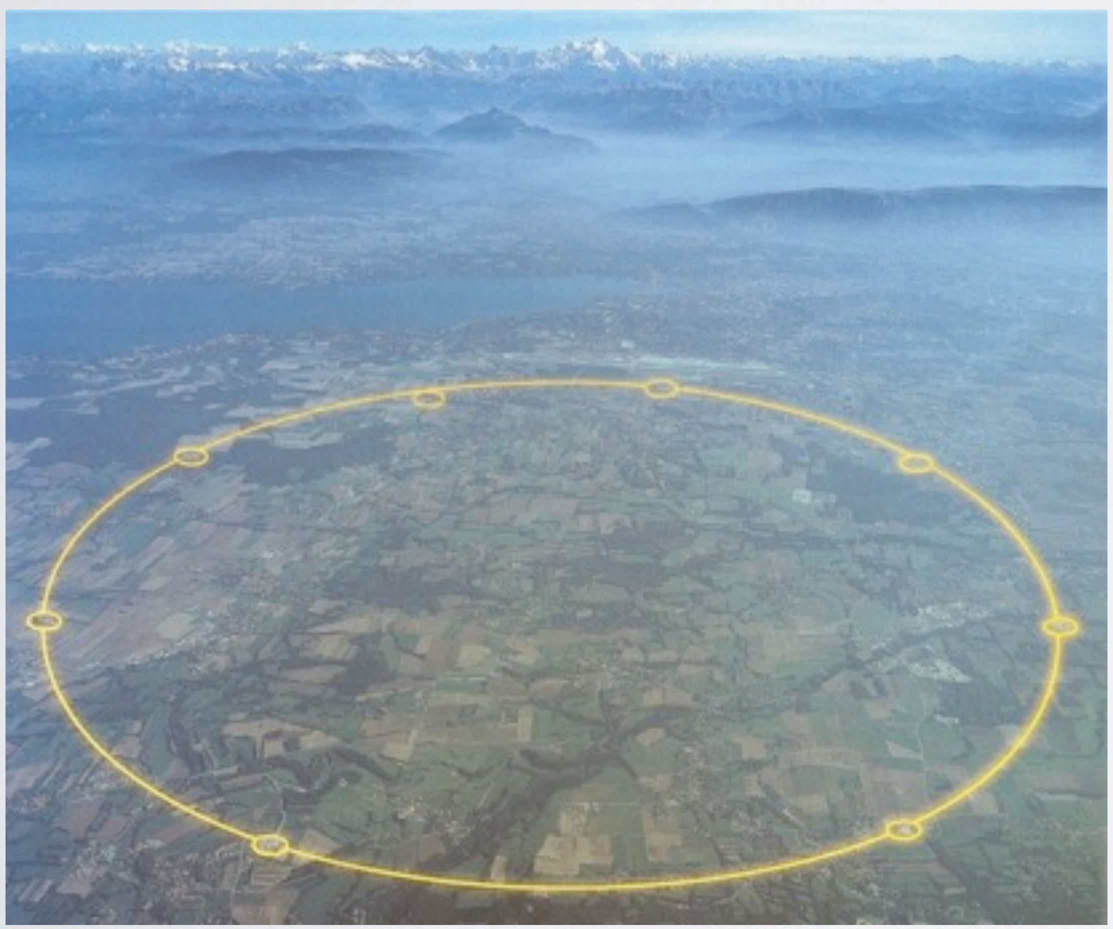
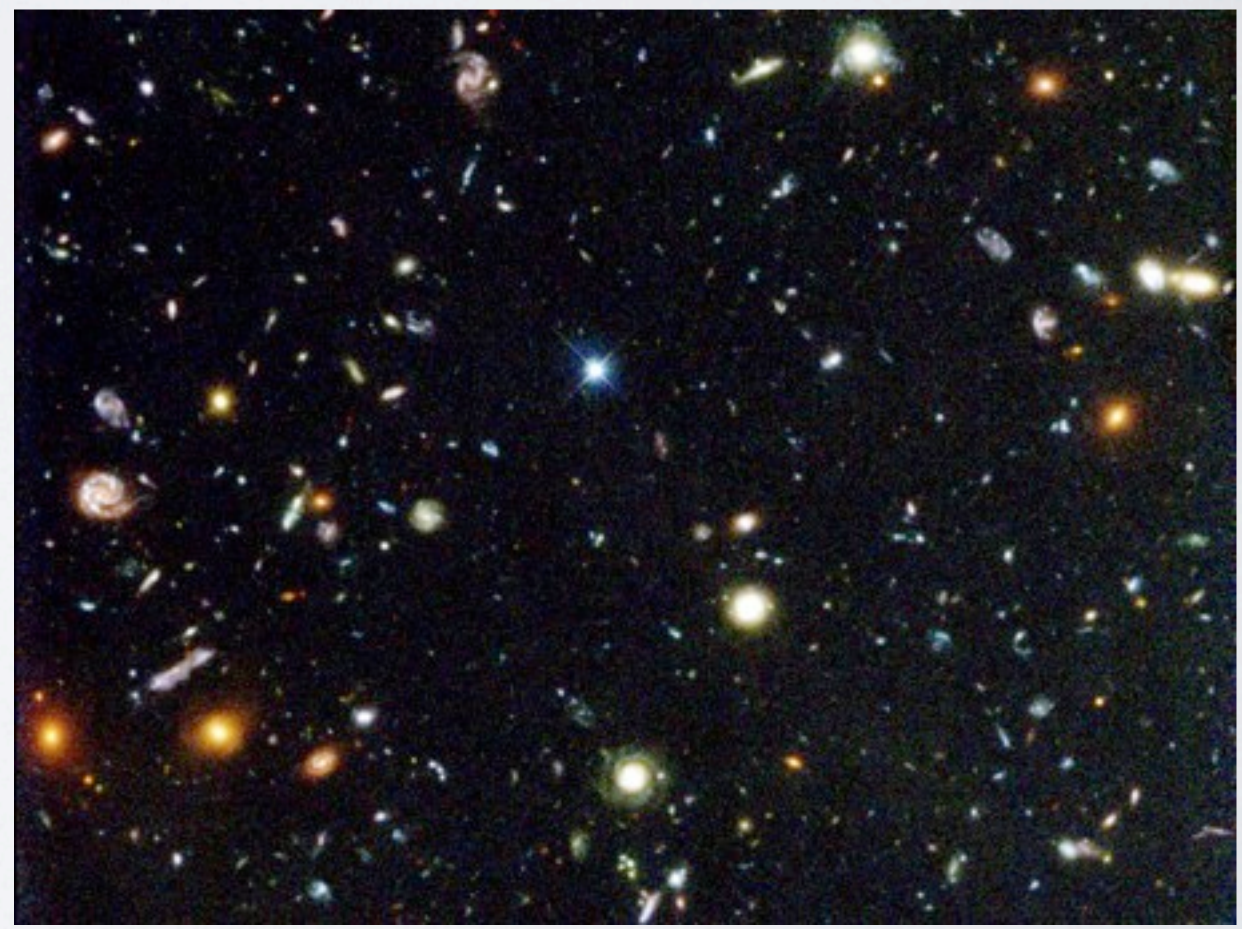


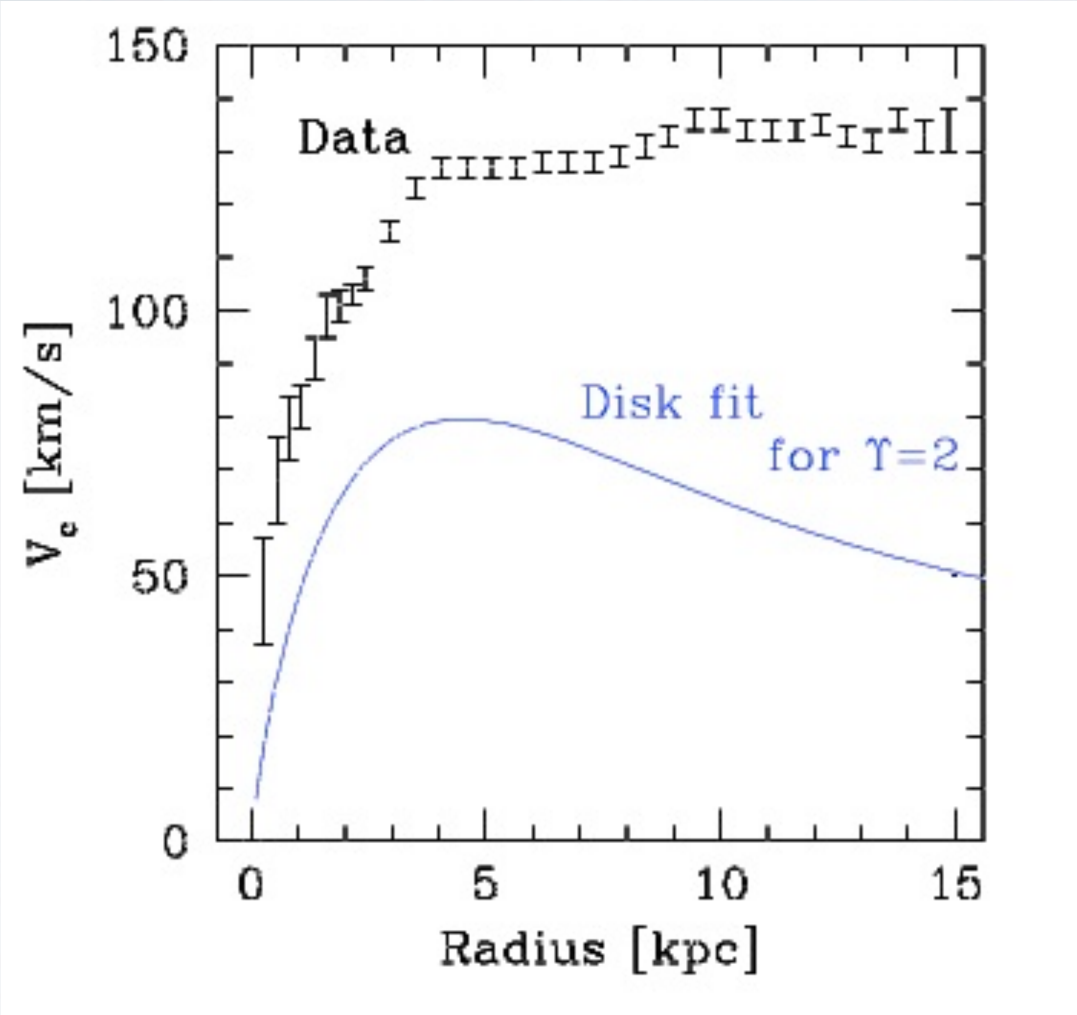
The LHC

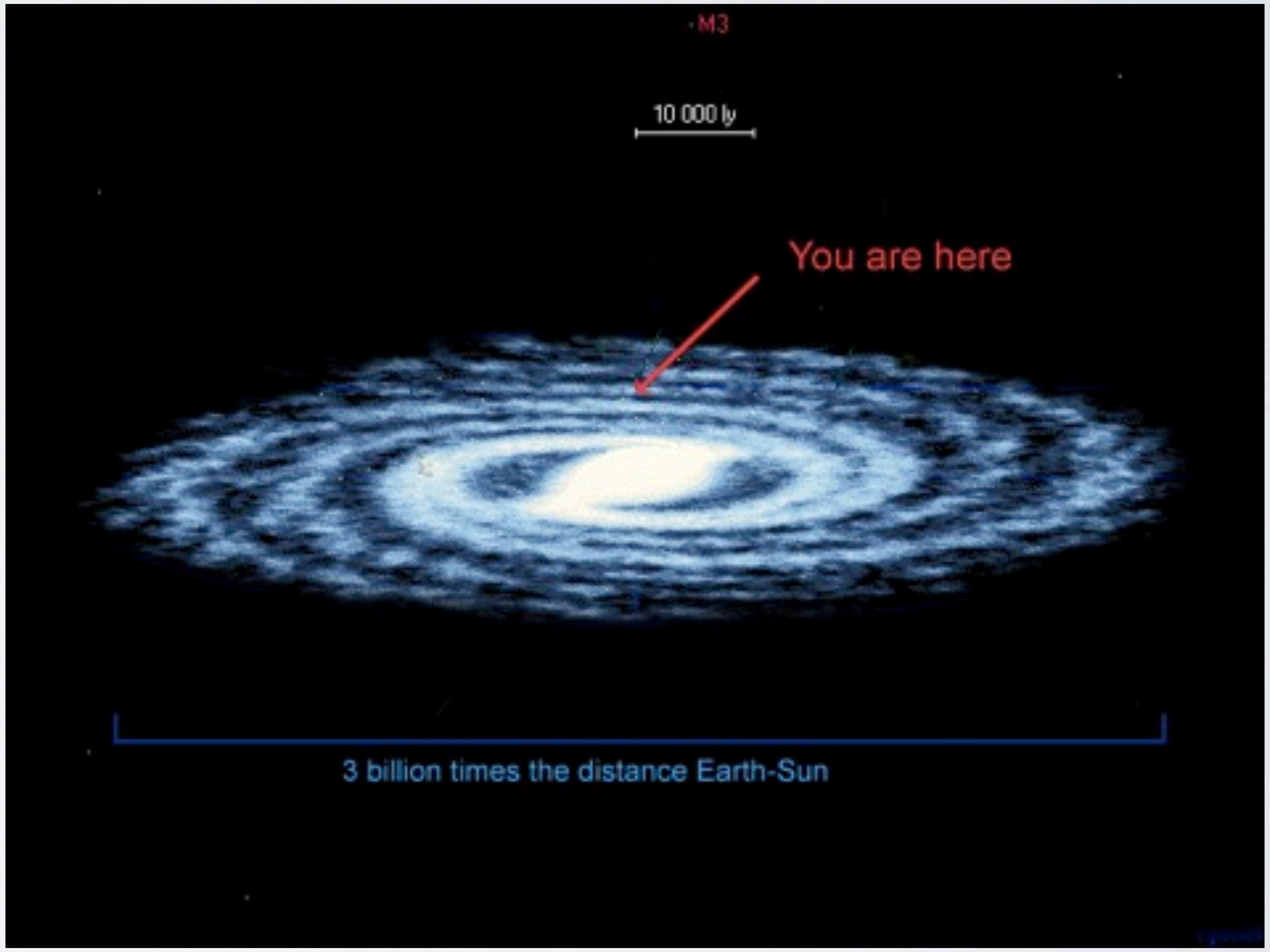


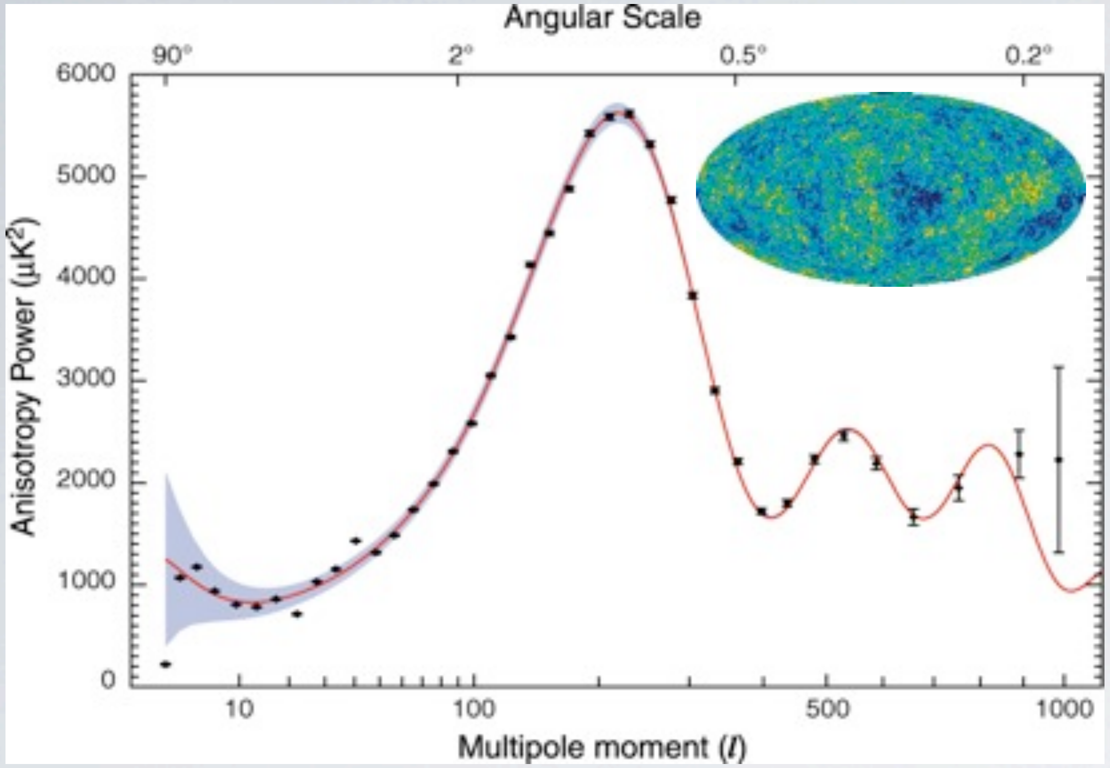
The Universe

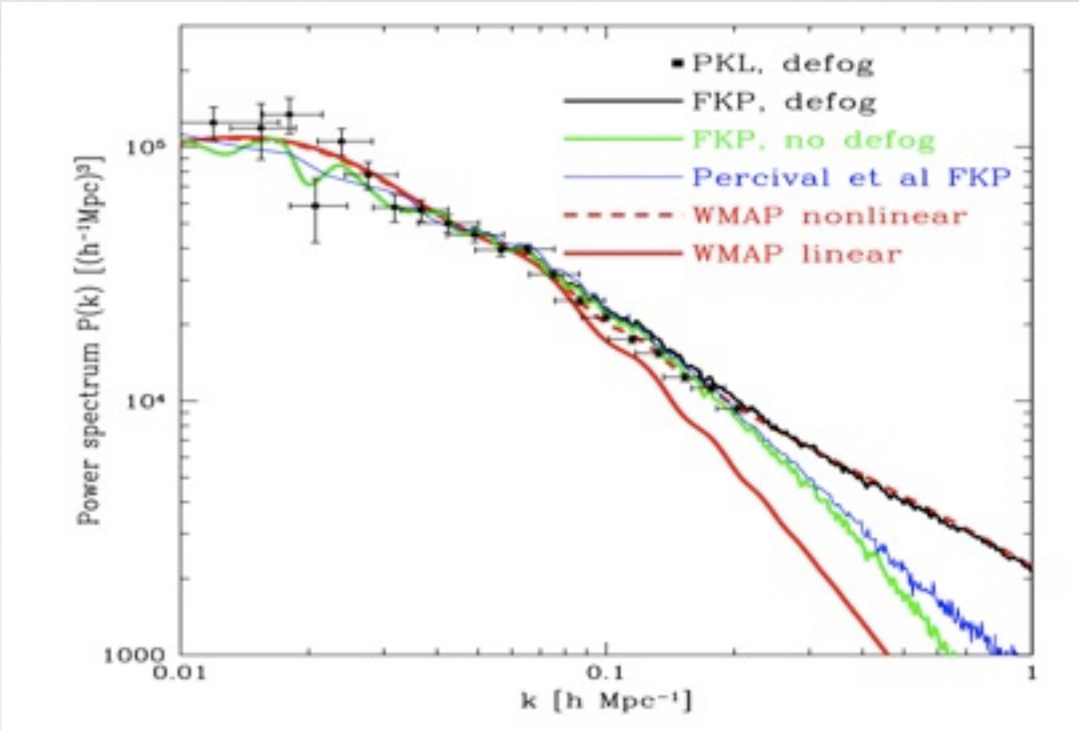
cosmology can tell us about high energy physics can tell us about cosmology

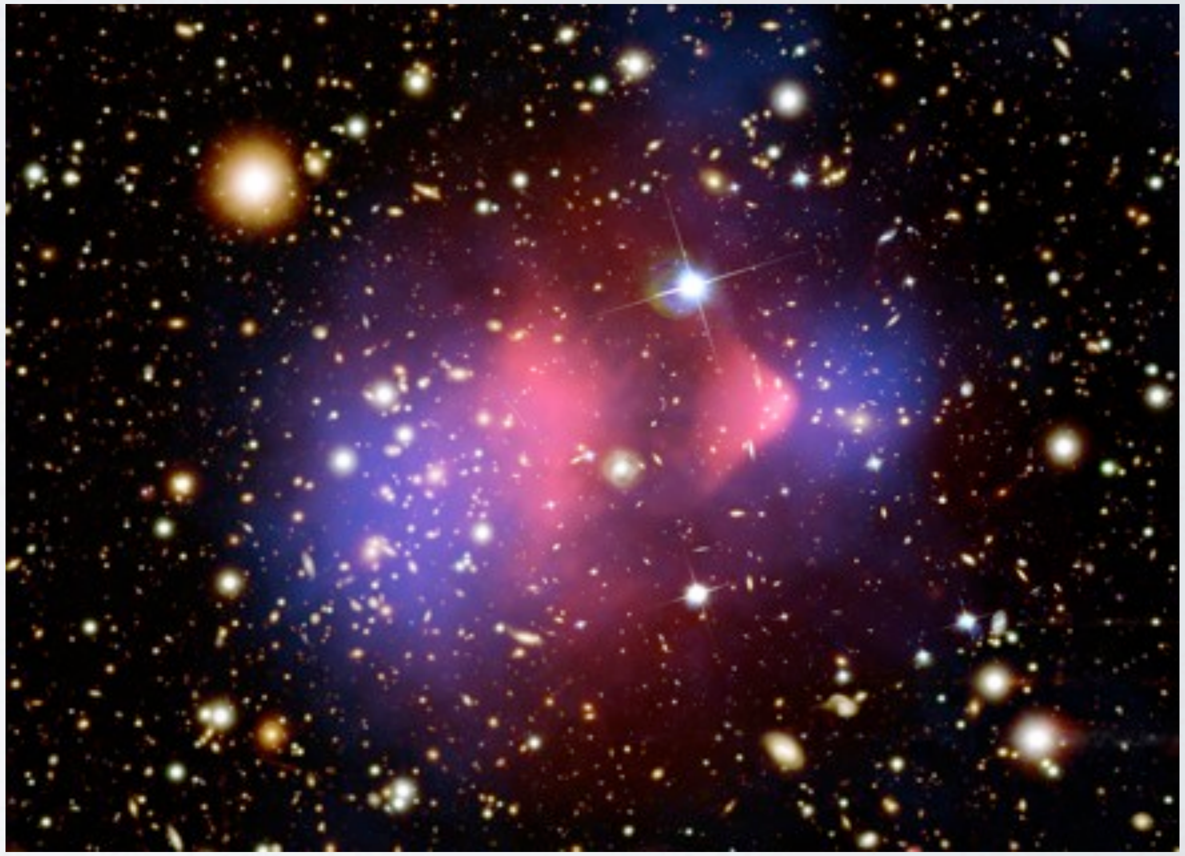
DARK MATTER


150
100
50
0
Data
Disk fit
for Υ=2
V_c [km/s]
0
5
10
15
Radius [kpc]


M3
10 000 ly
You are here
3 billion times the distance Earth-Sun







dark matter now robustly tested

so there ***is*** physics beyond the standard model...

but does it have anything to do with the TeV scale?

A classic tale...

SUSY + B + L

$\simeq$ SUSY + R-parity

A classic tale...

SUSY + B + L

= SUSY + R-parity

SUSY + R-Parity

= Dark matter!!!

(often)

A classic tale...

SUSY + B + L
= SUSY + R-parity

SUSY + R-Parity
= Dark matter!!!
(often)

is there more to the story?

- Precision and the standard model

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Quantity	Value	Standard Model	Pull
m_t [GeV]	$172.7 \pm 2.9 \pm 0.6$	172.7 ± 2.8	0.0
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M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1
Γ_Z [GeV]	2.4952 ± 0.0023	2.4968 ± 0.0011	−0.7
$\Gamma(\text{had})$ [GeV]	1.7444 ± 0.0020	1.7434 ± 0.0010	—
$\Gamma(\text{inv})$ [MeV]	499.0 ± 1.5	501.65 ± 0.11	—
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	83.996 ± 0.021	—
σ_{had} [nb]	41.541 ± 0.037	41.467 ± 0.009	2.0
R_e	20.804 ± 0.050	20.756 ± 0.011	1.0
R_μ	20.785 ± 0.033	20.756 ± 0.011	0.9
R_τ	20.764 ± 0.045	20.801 ± 0.011	−0.8
R_b	0.21629 ± 0.00066	0.21578 ± 0.00010	0.8
R_c	0.1721 ± 0.0030	0.17230 ± 0.00004	−0.1
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01622 ± 0.00025	−0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.5
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$A_{FB}^{(0,b)}$	0.0992 ± 0.0016	0.1031 ± 0.0008	−2.4
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A_e	0.15138 ± 0.00216	0.1471 ± 0.0011	2.0
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A_μ	0.142 ± 0.015		−0.3
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g_L^2	0.30005 ± 0.00137	0.30378 ± 0.00021	−2.7
g_R^2	0.03076 ± 0.00110	0.03006 ± 0.00003	0.6
$g_V^{\nu e}$	-0.040 ± 0.015	-0.0396 ± 0.0003	0.0
$g_A^{\nu e}$	-0.507 ± 0.014	-0.5064 ± 0.0001	0.0
A_{PV}	-1.31 ± 0.17	-1.53 ± 0.02	1.3
$Q_W(\text{Cs})$	-72.62 ± 0.46	-73.17 ± 0.03	1.2
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$\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to X e\nu)}$	$3.35^{+0.50}_{-0.44} \times 10^{-3}$	$(3.22 \pm 0.09) \times 10^{-3}$	0.3
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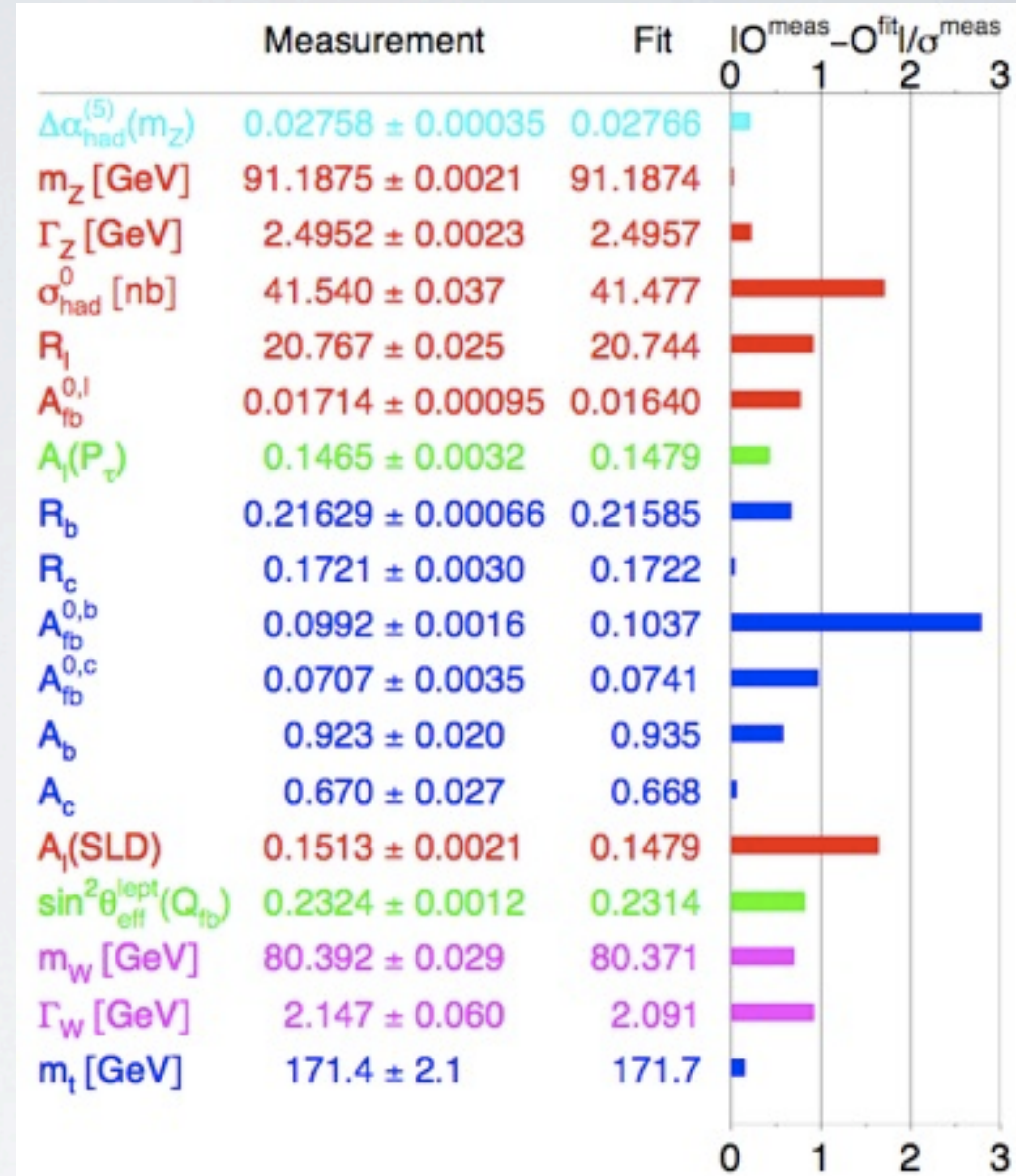

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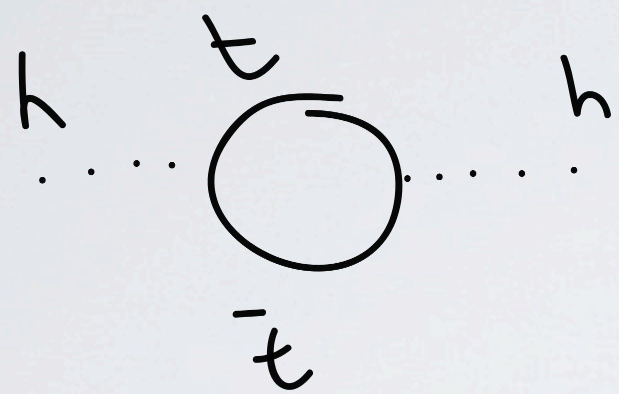
The "LEP Paradox" (Barbieri+Strumia '00)
or "Little Hierarchy Problem"

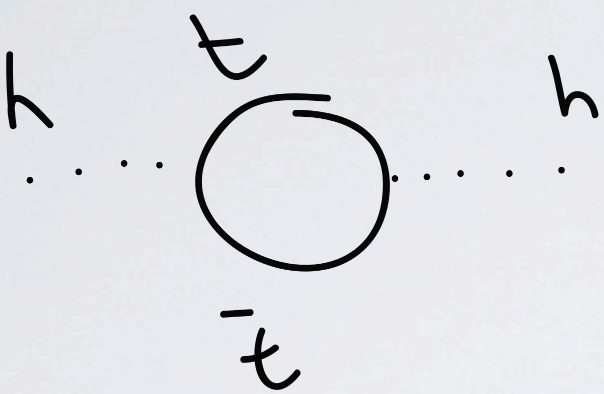
The hierarchy problem

The hierarchy problem



$$\delta m_h^2 = \frac{3\lambda_t^2}{16\pi^2}\Lambda^2$$

The hierarchy problem

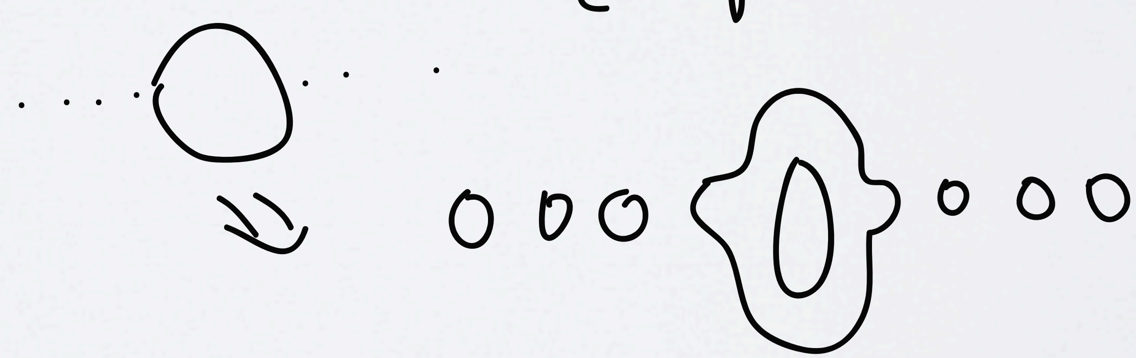


$$\delta m_h^2 = \frac{3\lambda_t^2}{16\pi^2}\Lambda^2$$

susy

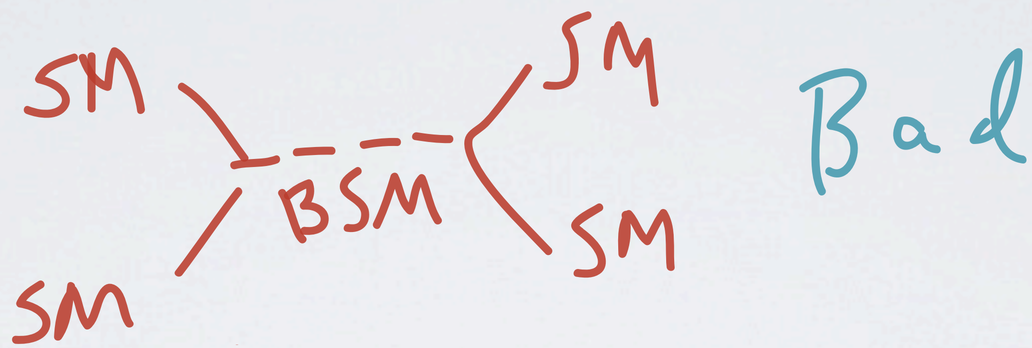
or

compositeness



T-Parity (Cheng and Low)

- The problem arises from



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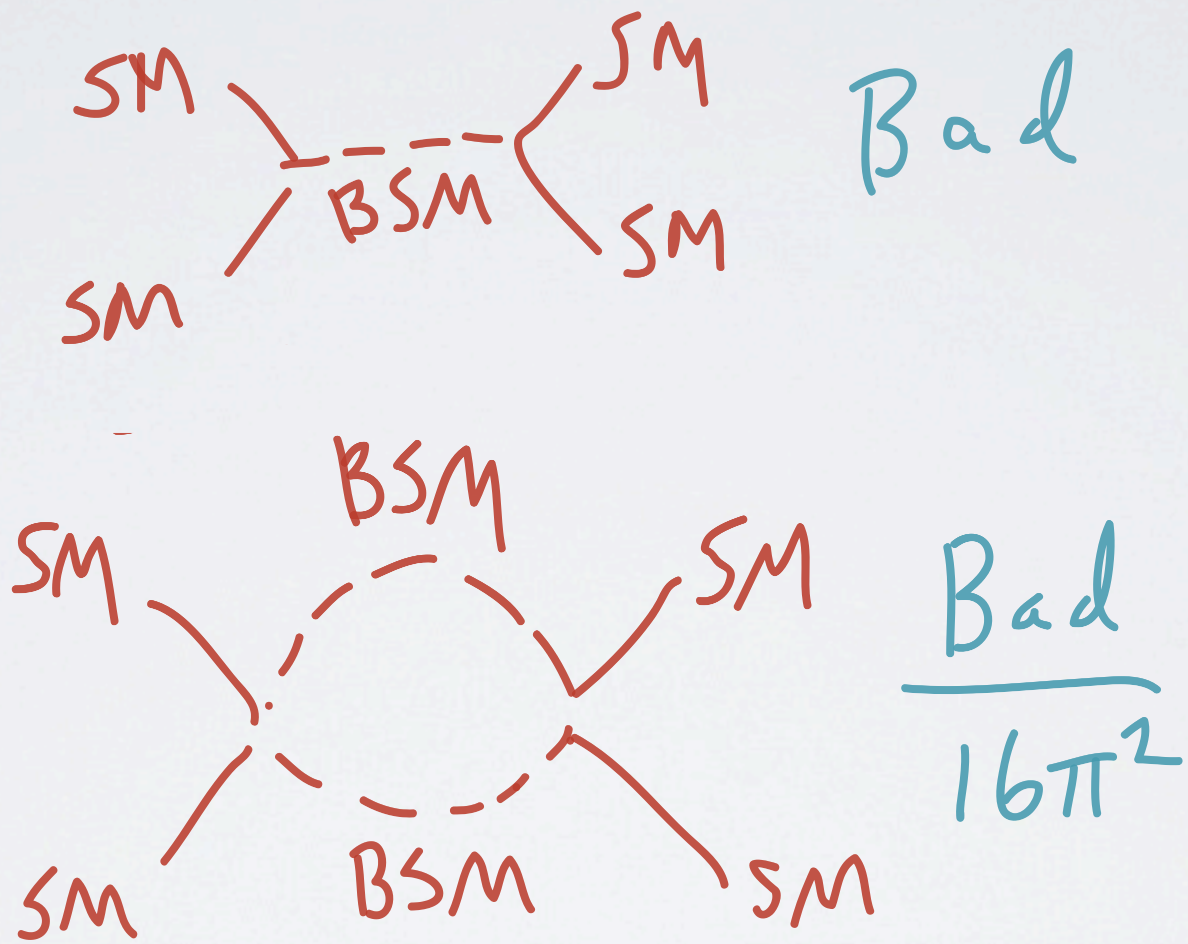

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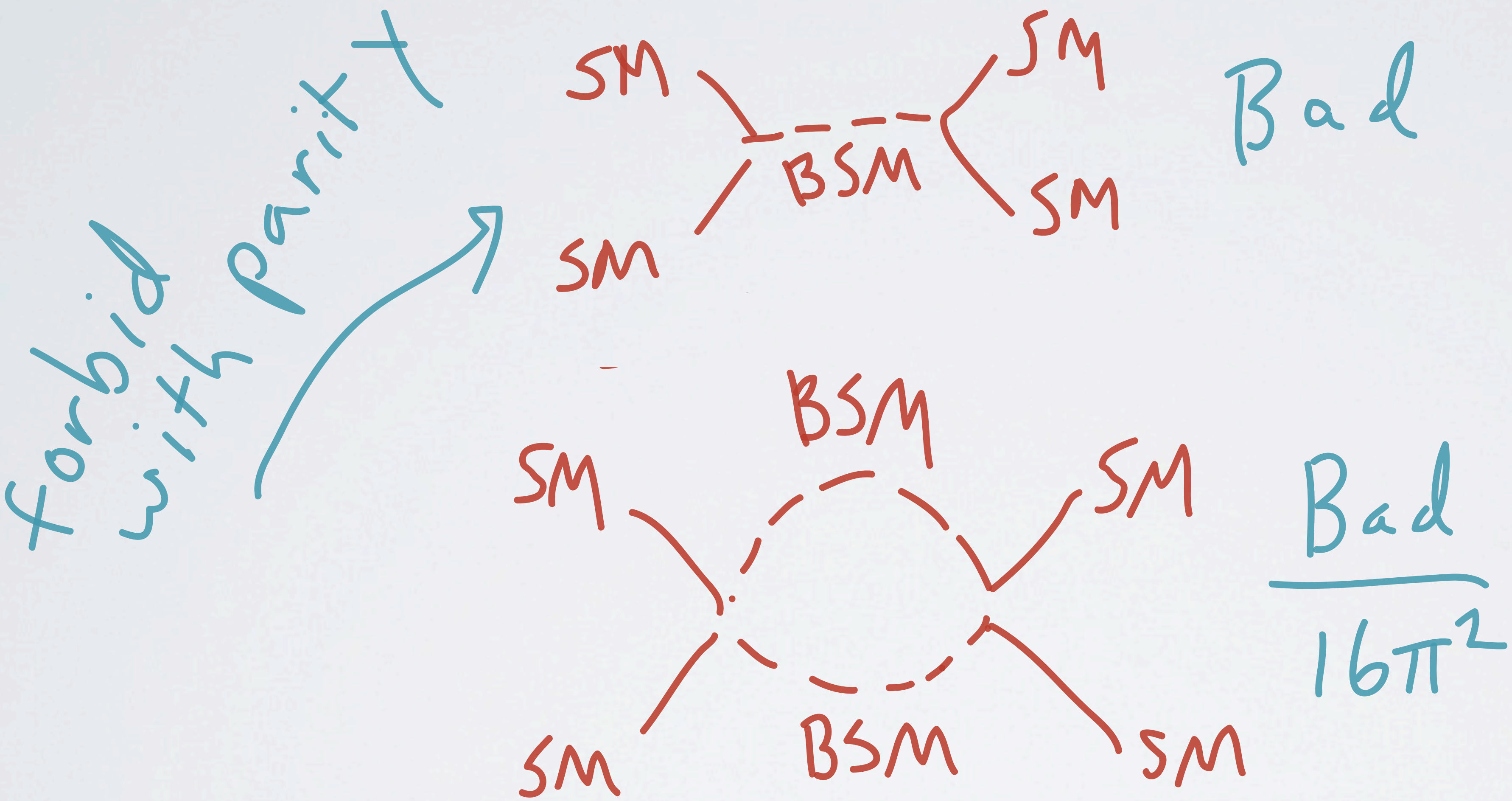


I.e., problem is presence of single BSM field

If only even numbers of BSM fields were allowed, this term is forbidden!

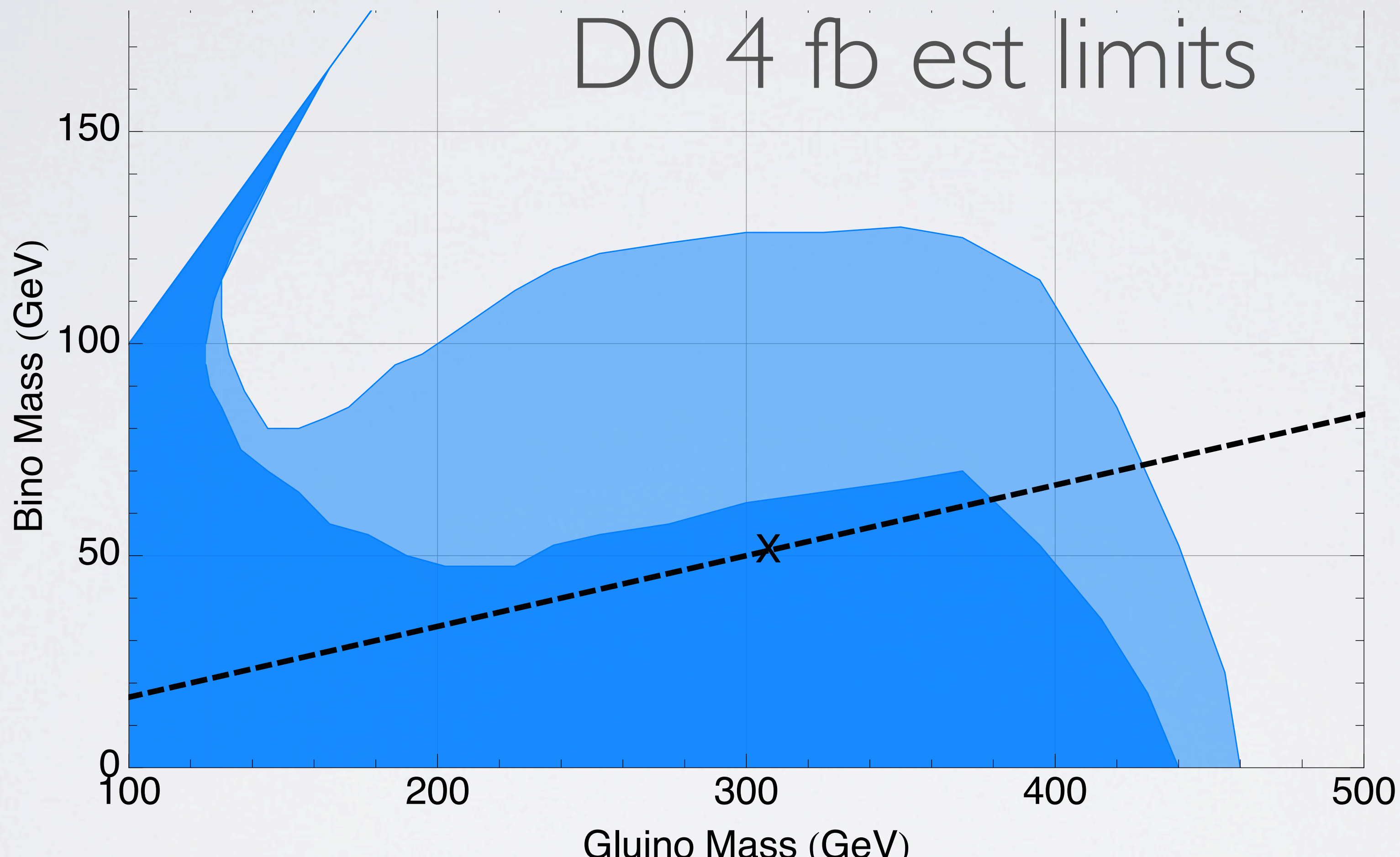
a parity is a natural/expected element of weak scale physics

Lightest stable new particle should be present! (LSNP) a parity is a natural/expected element of weak scale physics

Lightest stable new particle should be present! (LSNP)

so how much should we expect from MET?

HOW ROBUST IS MET?



Alves, Lisanti, Wacker, '08

Squeezed spectra a challenging - but not impossible

HOW ROBUST IS MET?

Is a squeezed spectrum even natural?

Maybe: accident in extended anomaly mediation

$m^i_1 \sim \alpha_i \beta_i$

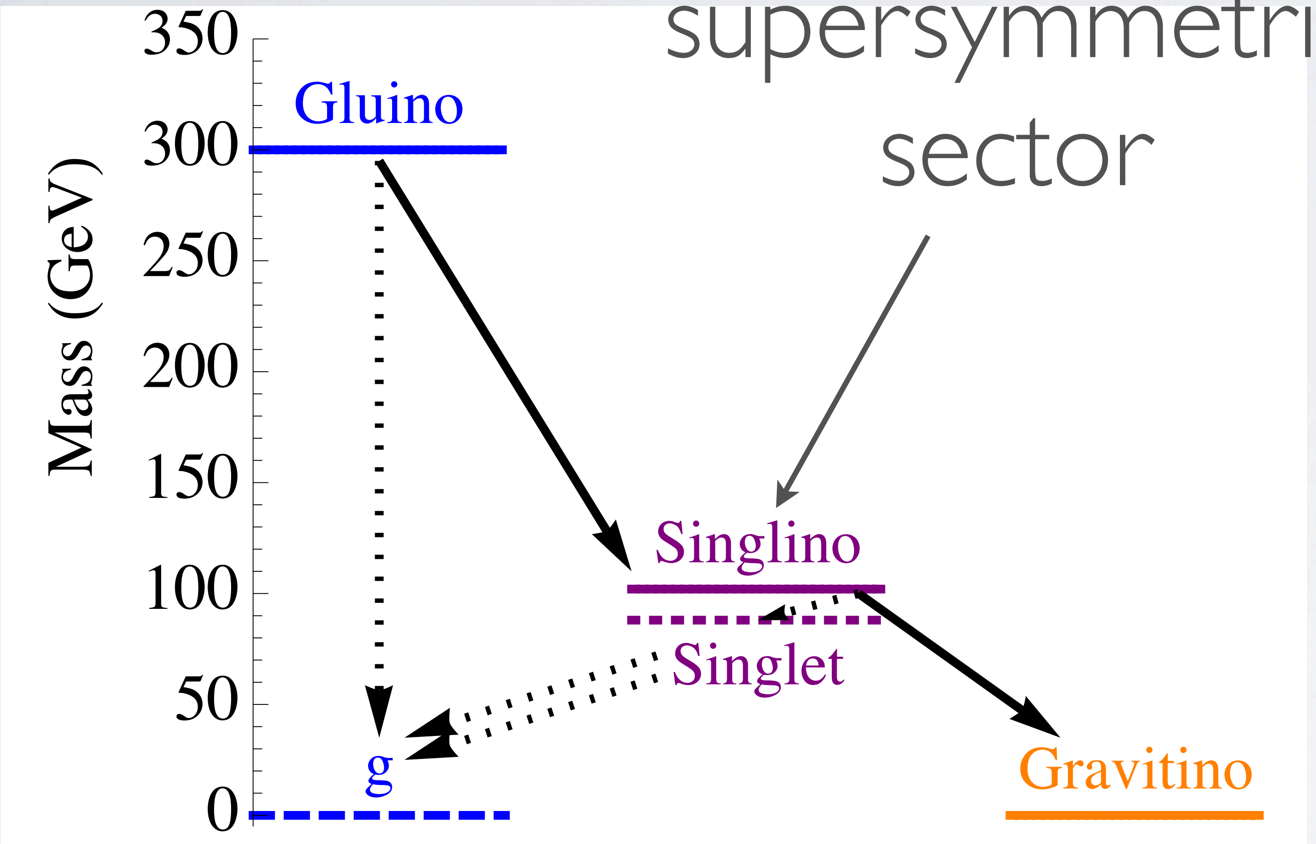
$m^i_{1/2} \quad \alpha_i [\beta_i + 2 N_{mess}]$ (Nelson, NW '02)

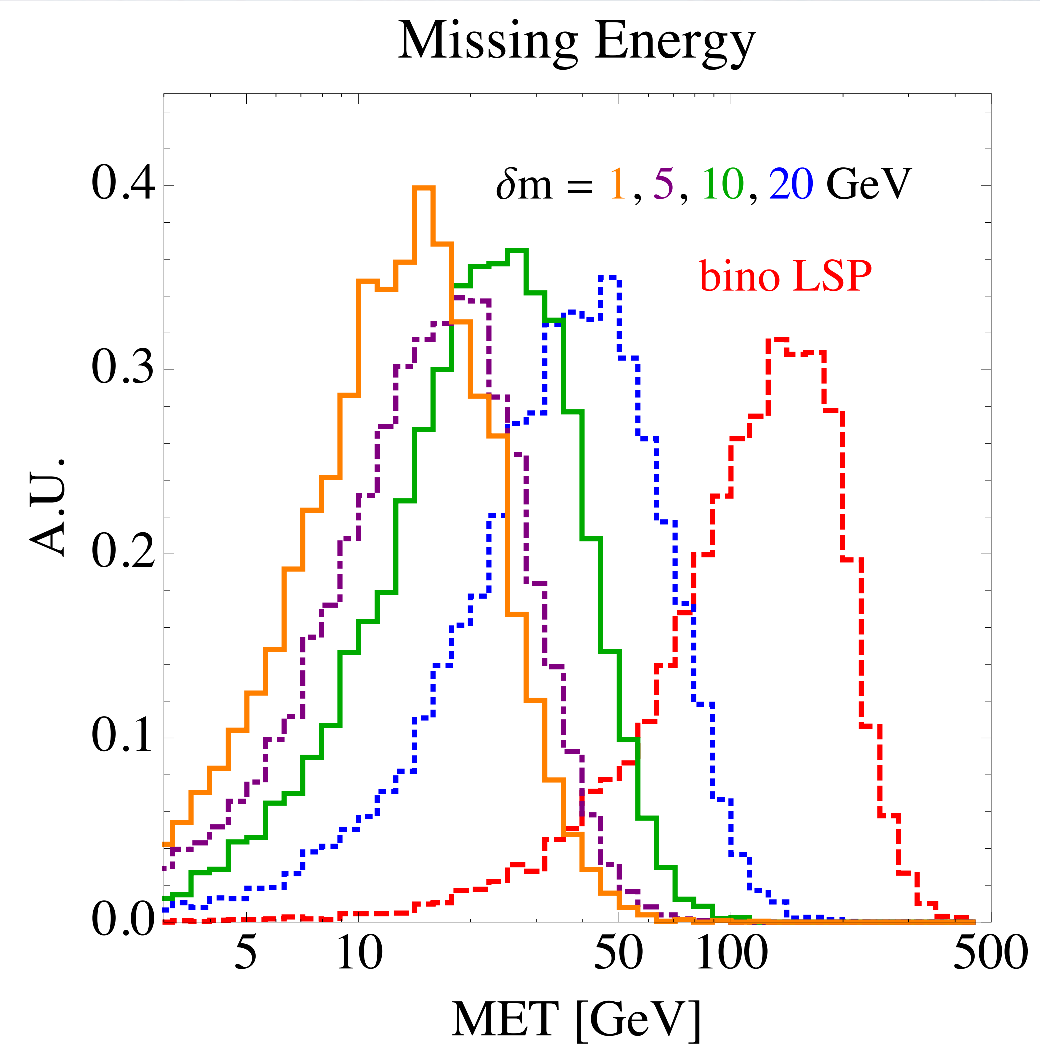
$m_1 : m_2 : m_3 \sim 1 : 1 : 1.4$

(Kaplan, NW in progress)

SUSY WITH (ALMOST) NO MET

approximately supersymmetric sector





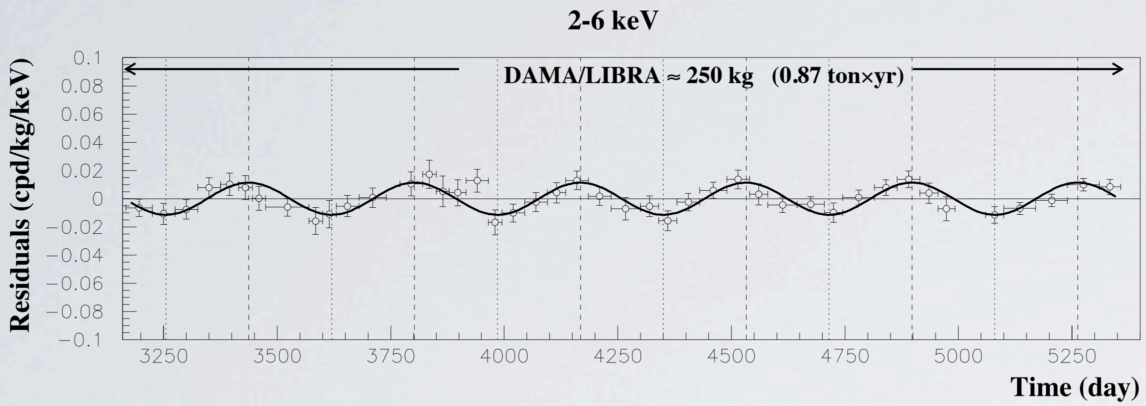
Fan, Reece, Ruderman '11

MET AND COSMOLOGY

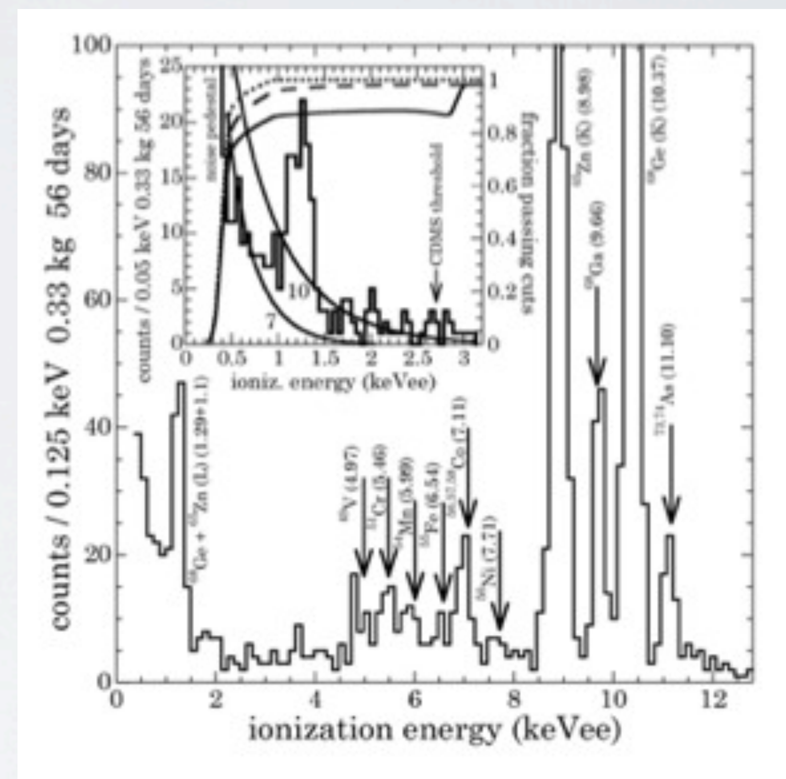
- Parities are strongly motivated, and so MET is a likely scenario
- But MET can be lost, or suppressed!

COSMOLOGY UNDERGROUND

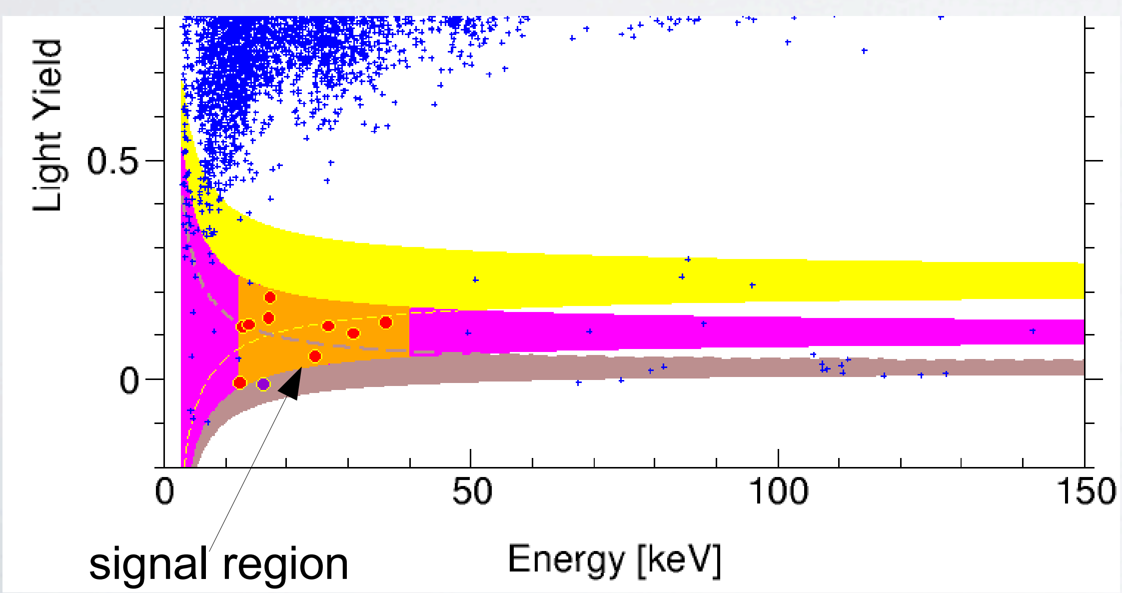
LIGHT WIMP ANOMALIES



DAMA

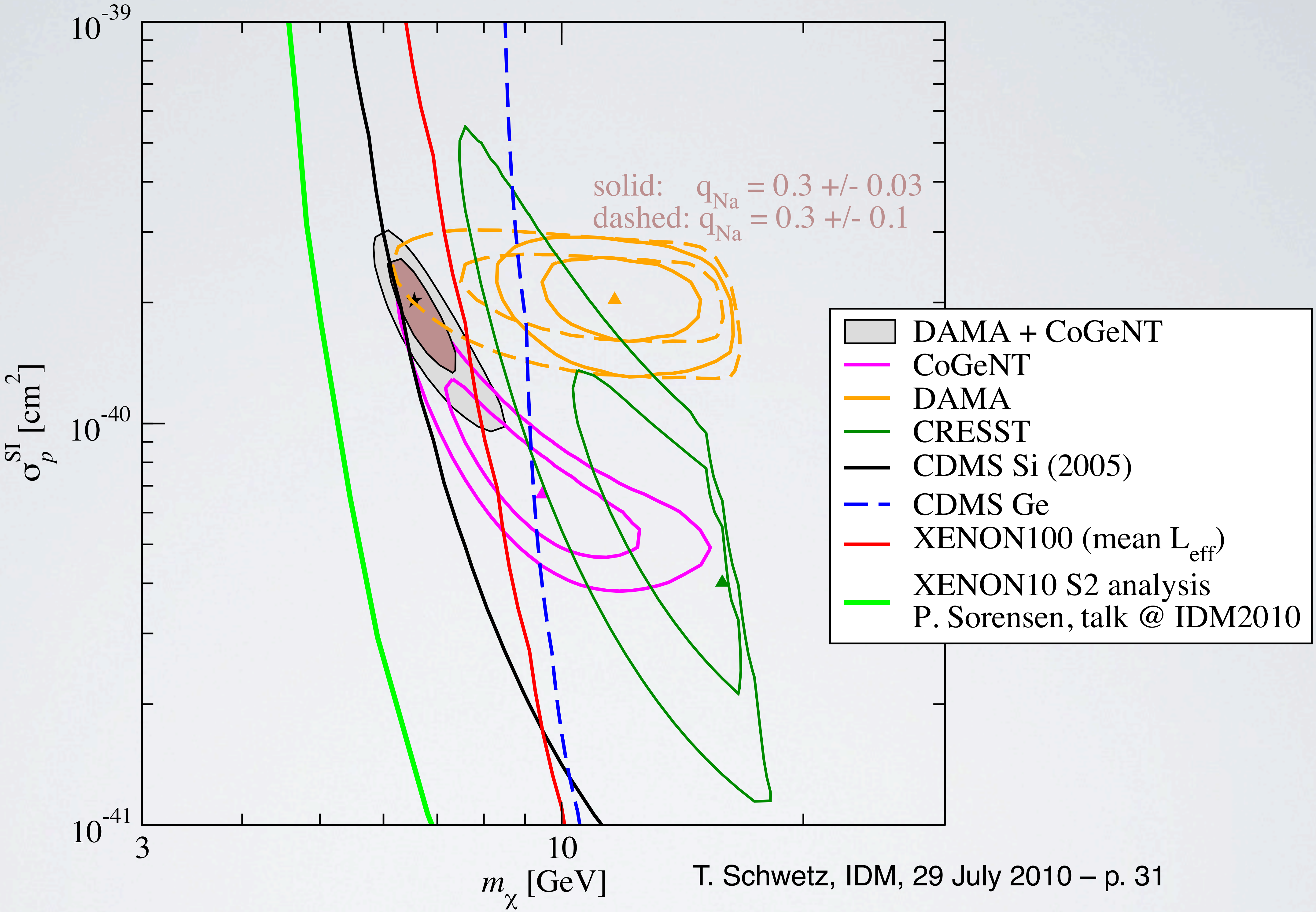


CoGeNT



CRESST

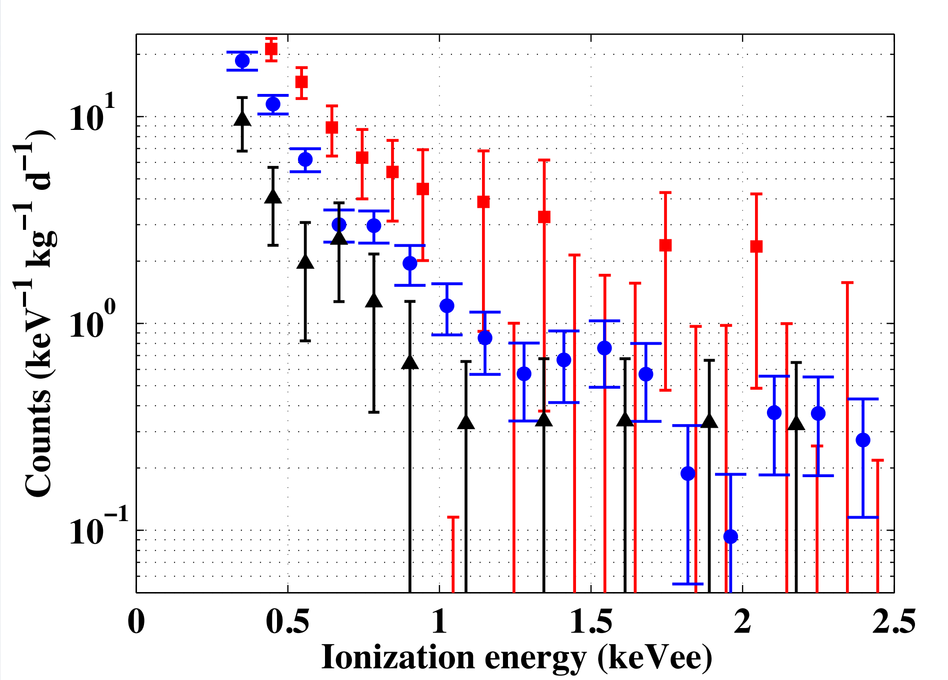
• The same beast?

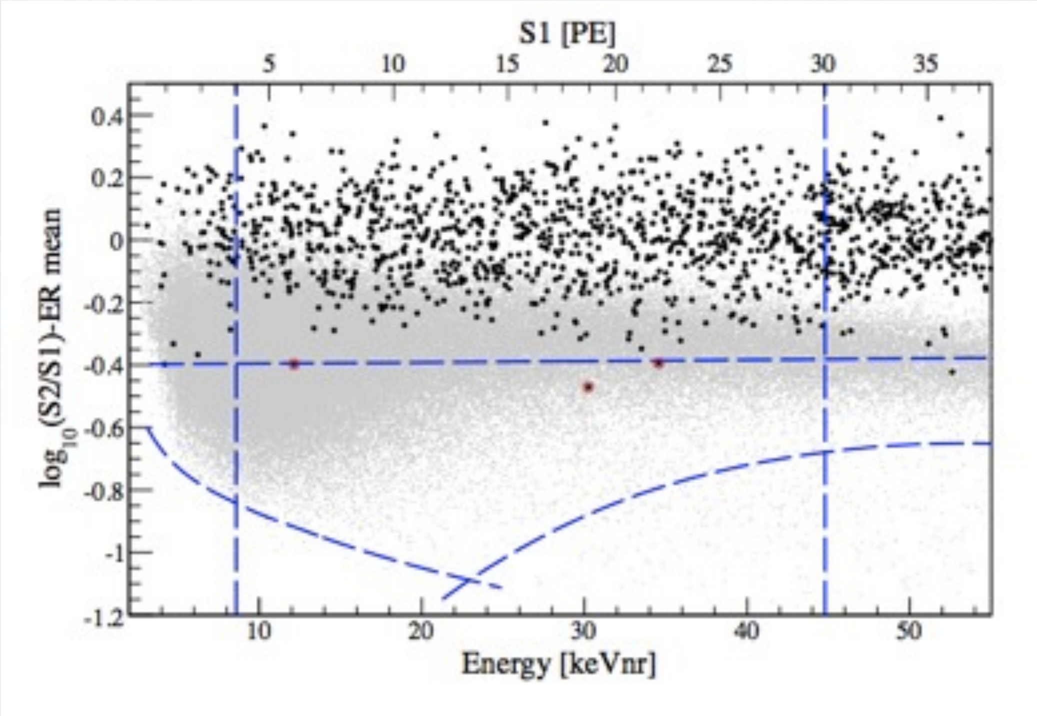


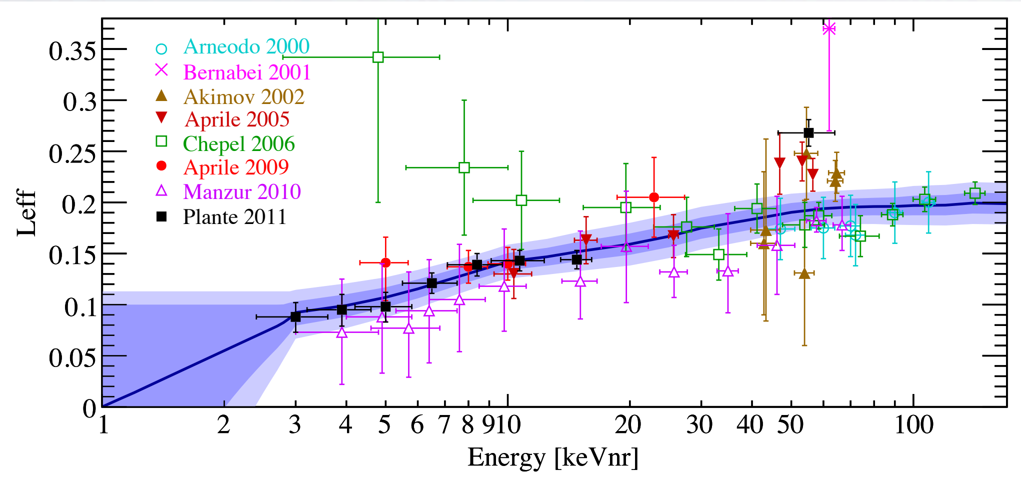
T. Schwetz, IDM, 29 July 2010 – p. 31

don't *really* line up, but within spitting distance

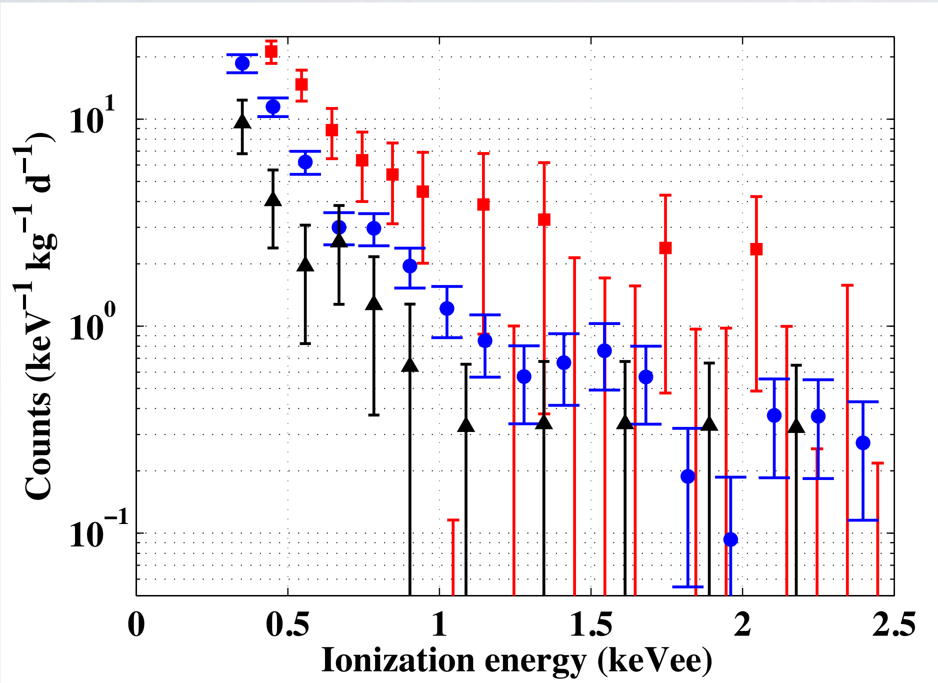
TENSIONS? EXCLUSIONS?

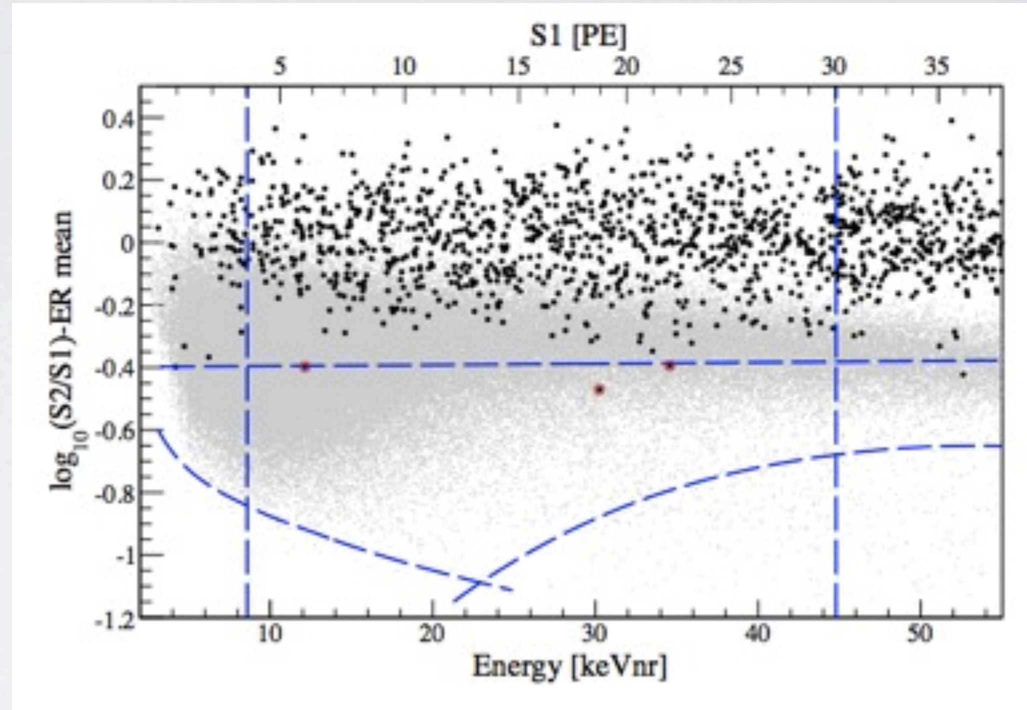


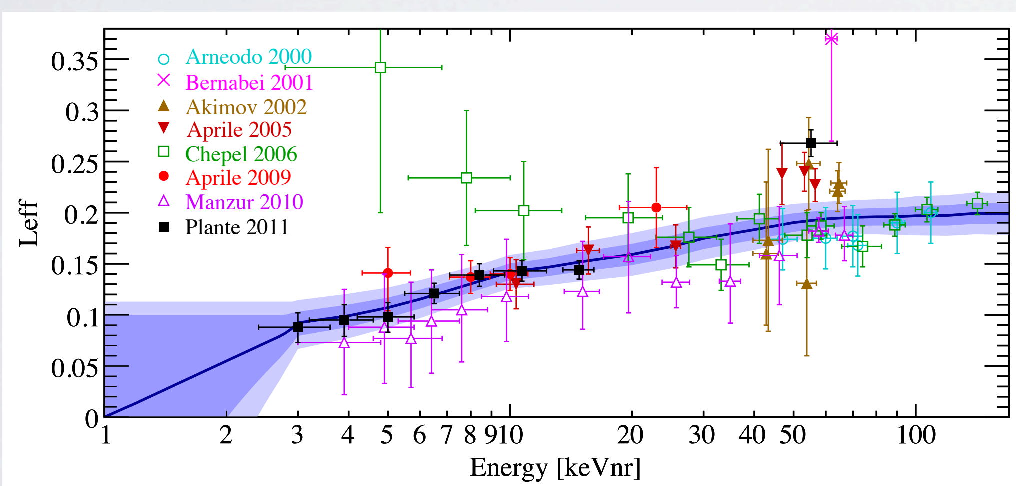


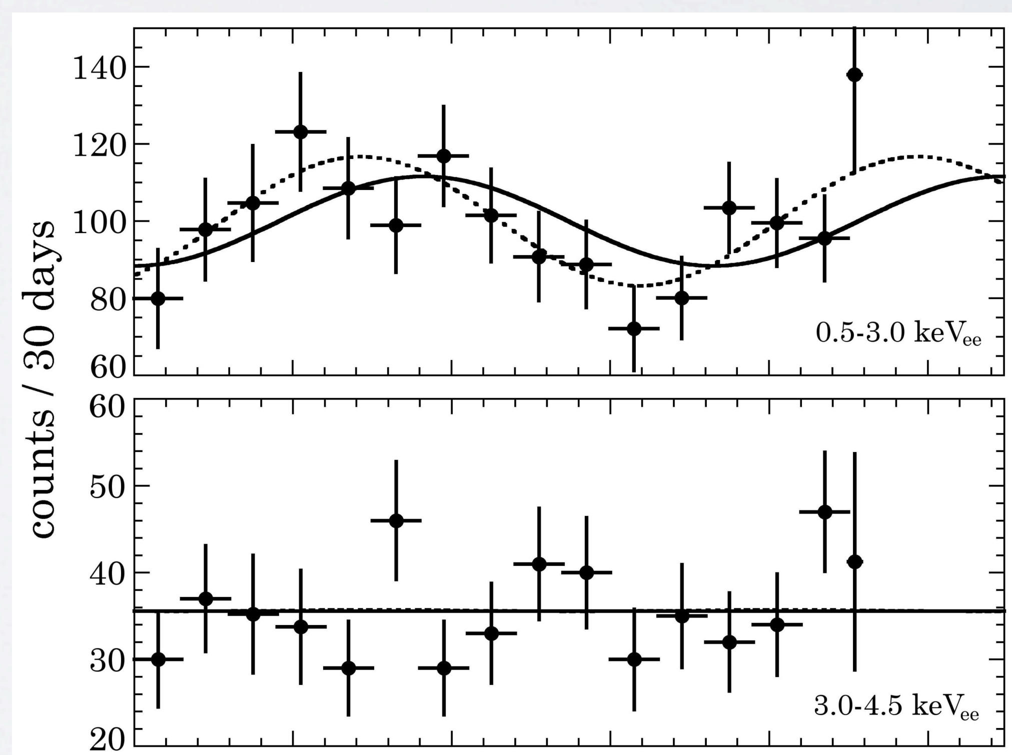


TENSIONS? EXCLUSIONS?









modulation?

WHAT WOULD IT BE?

Light neutralinos with large scattering cross sections in the minimal supersymmetric standard model

Eric Kuflik, Aaron Pierce, and Kathryn M. Zurek
Michigan Center for Theoretical Physics, University of Michigan, Ann Arbor, MI 48109
(Dated: July 20, 2010)

Motivated by recent data from CoGeNT and the DAMA annual modulation signal, we discuss collider constraints on minimal supersymmetric standard model neutralino dark matter with mass in the 5-15 GeV range. The lightest superpartner (LSP) would be a bino with a small Higgsino admixture. Maximization of the dark matter-nucleon scattering cross section for such a weakly interacting massive particle requires a light Higgs boson with $\tan\beta$ enhanced couplings. Limits on the invisible width of the Z boson, combined with the rare decays $B^{\pm} \to \tau\nu$, and the ratio $B \to D\tau\nu/B \to D\ell\nu$, constrain cross sections to be below $\sigma_n \lesssim 5 \times 10^{-42}$ cm^2. This indicates a higher local Dark Matter density than is usually assumed by a factor of roughly six would be necessary to explain the CoGeNT excess. This scenario also requires a light charged Higgs boson, which can give substantial contributions to rare decays such as $b \to s\gamma$ and $t \to bH^{+}$. We also discuss the impact of Tevatron searches for Higgs bosons at large $\tan\beta$.

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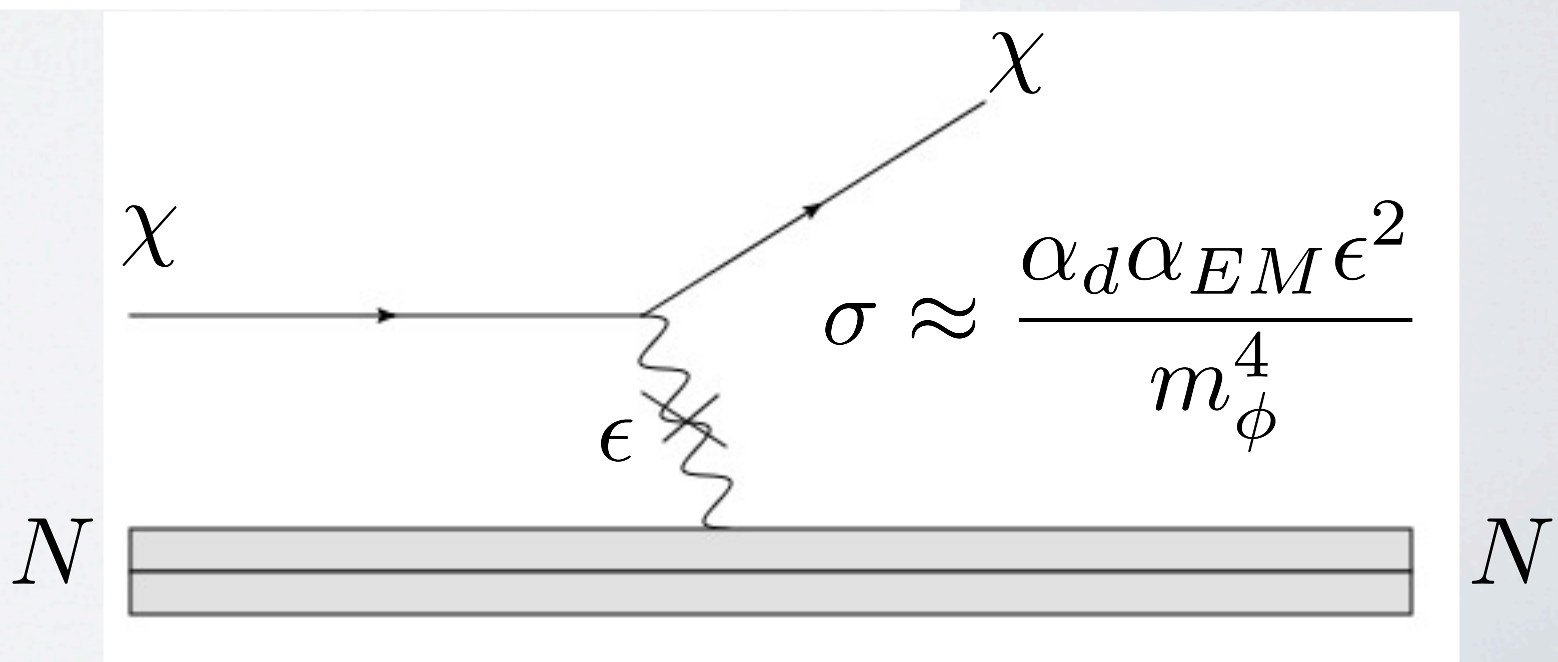
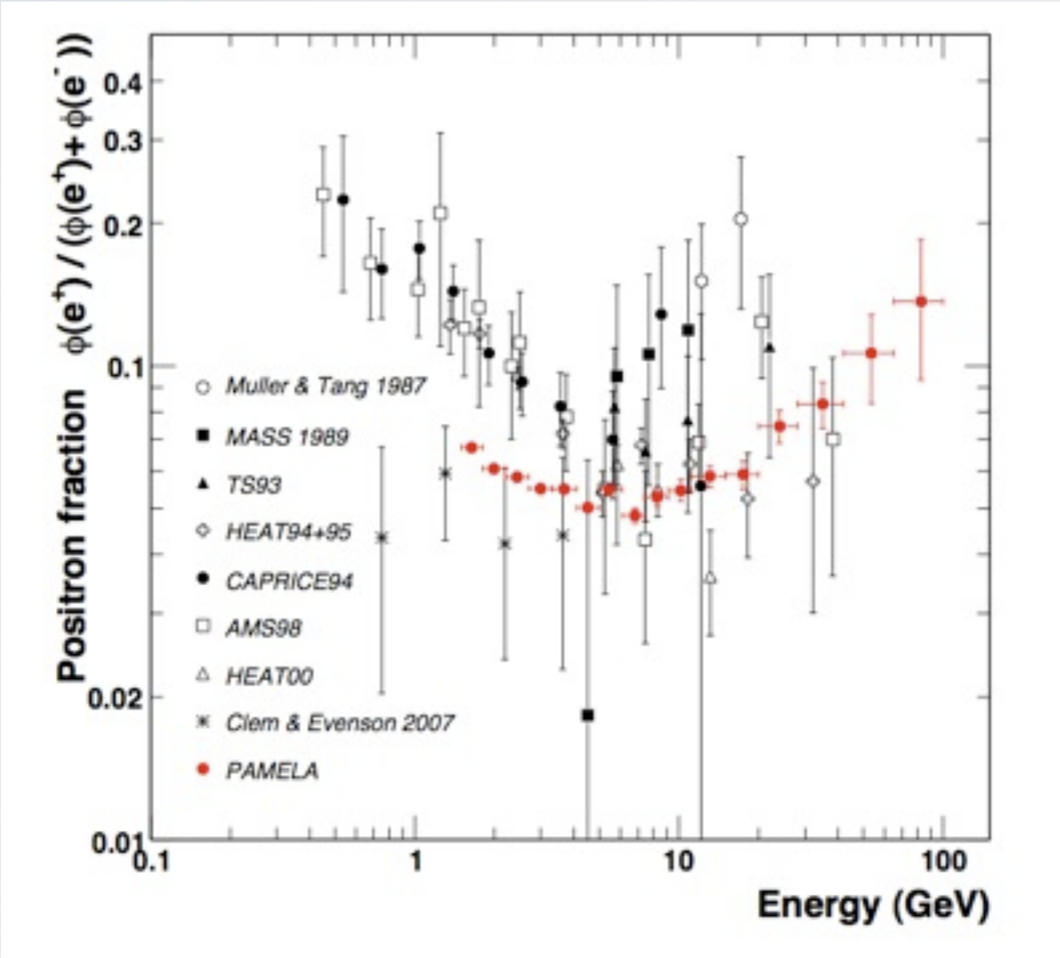
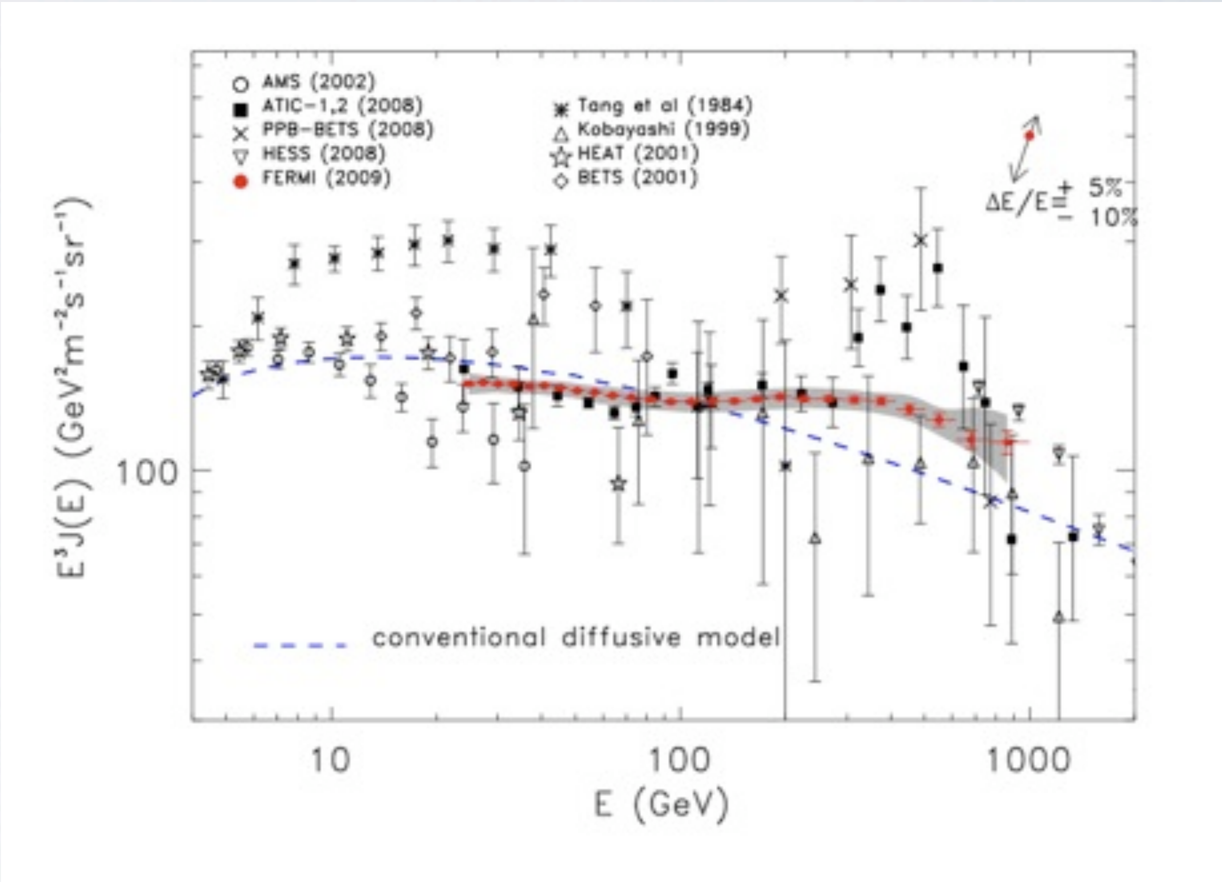
interaction through
a light sector?



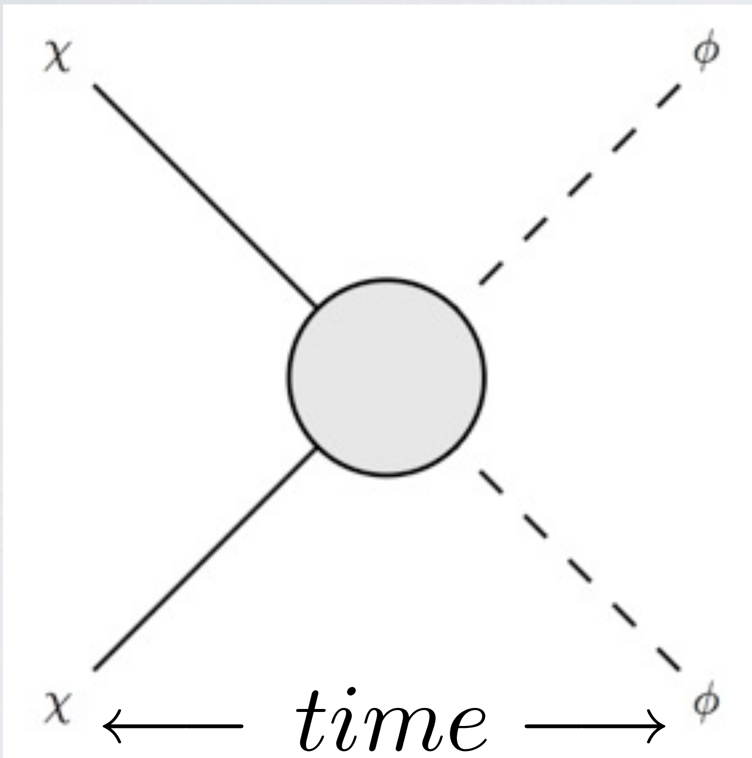
$$\sigma \approx \frac{\alpha_d \alpha_{EM} \epsilon^2}{m_\phi^4}$$

COSMOLOGY OUTSIDE THE BOX





A LIGHT SECTOR TAKE 2



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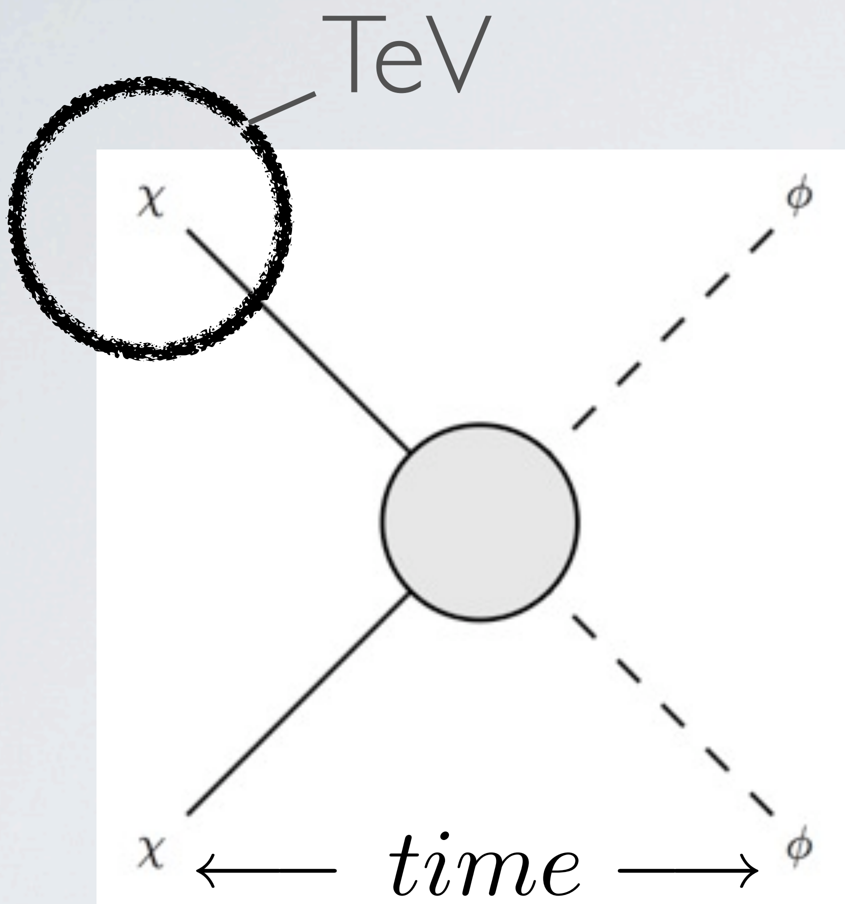

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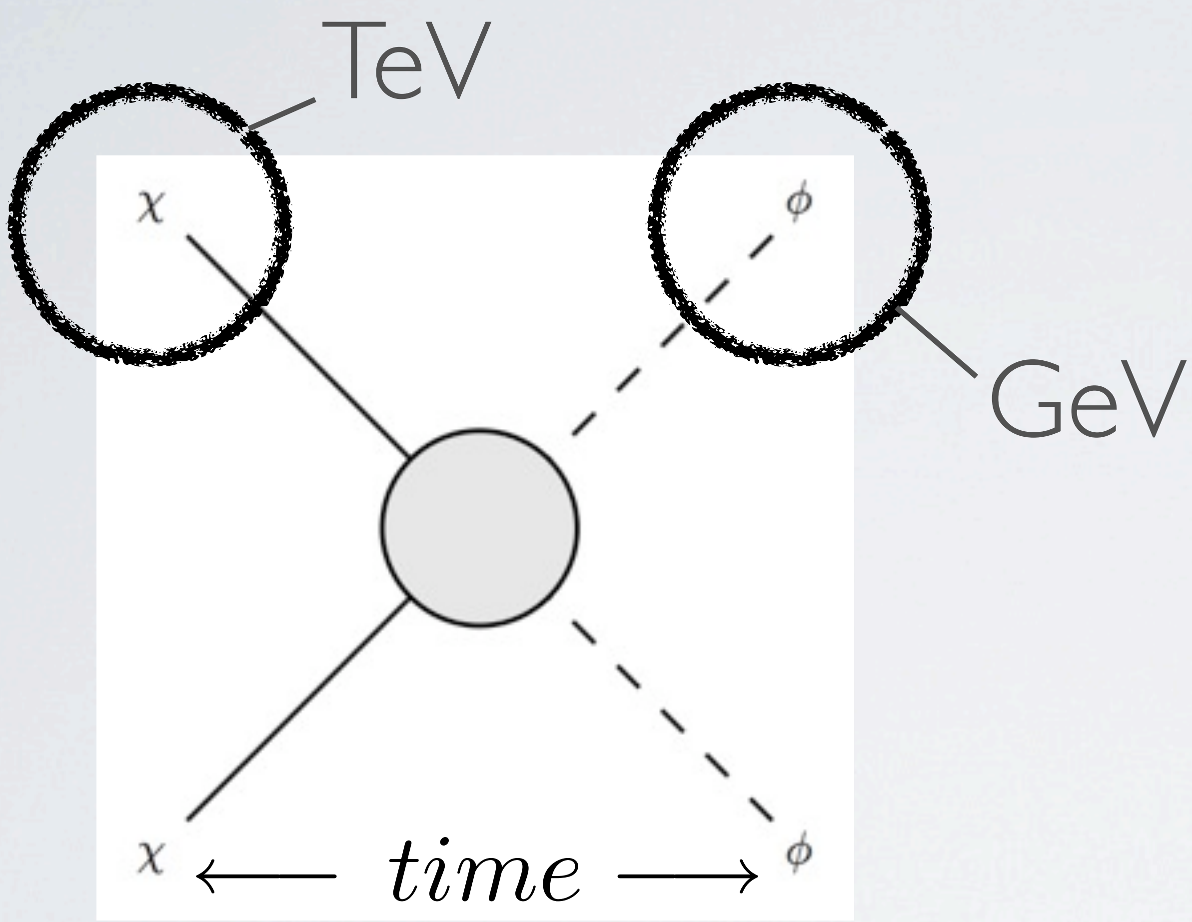

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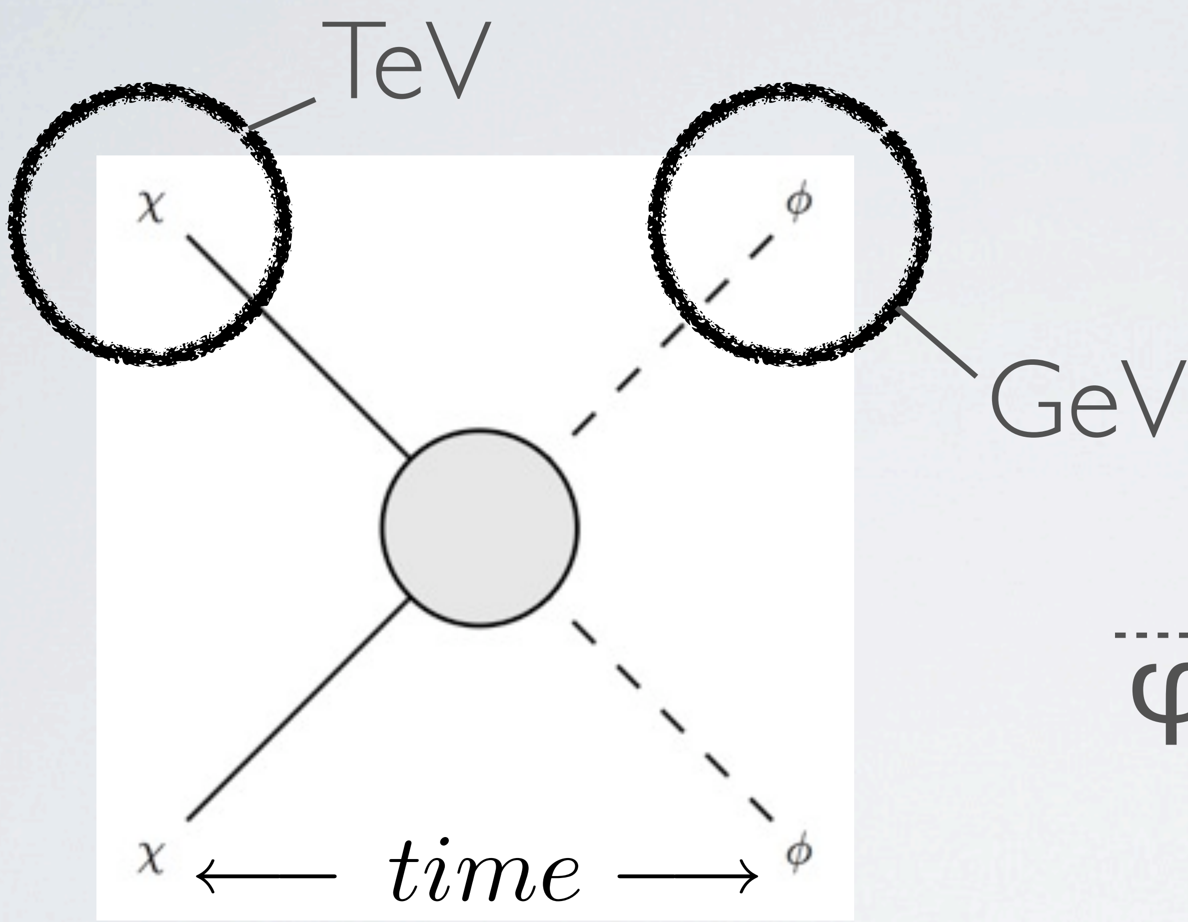

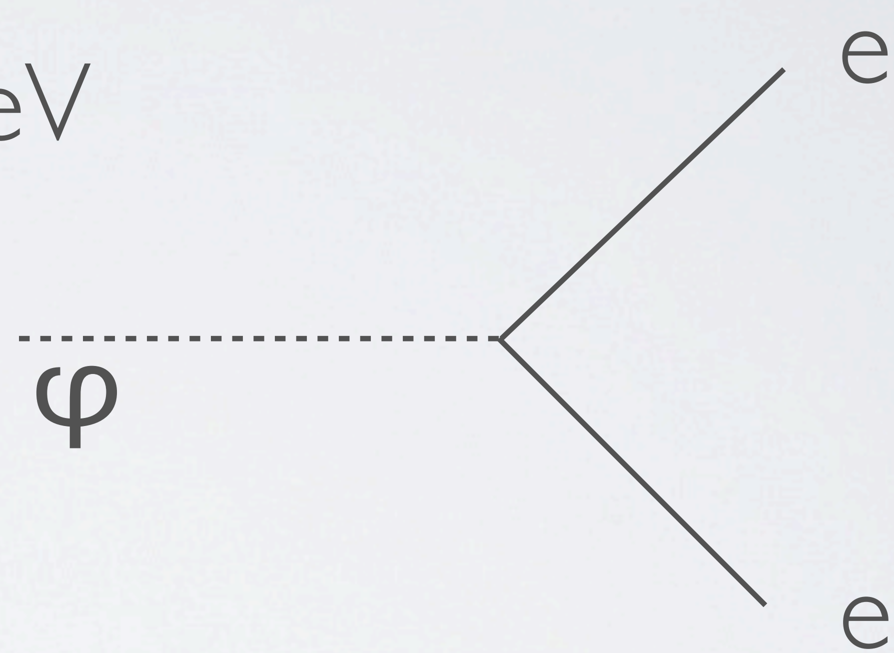

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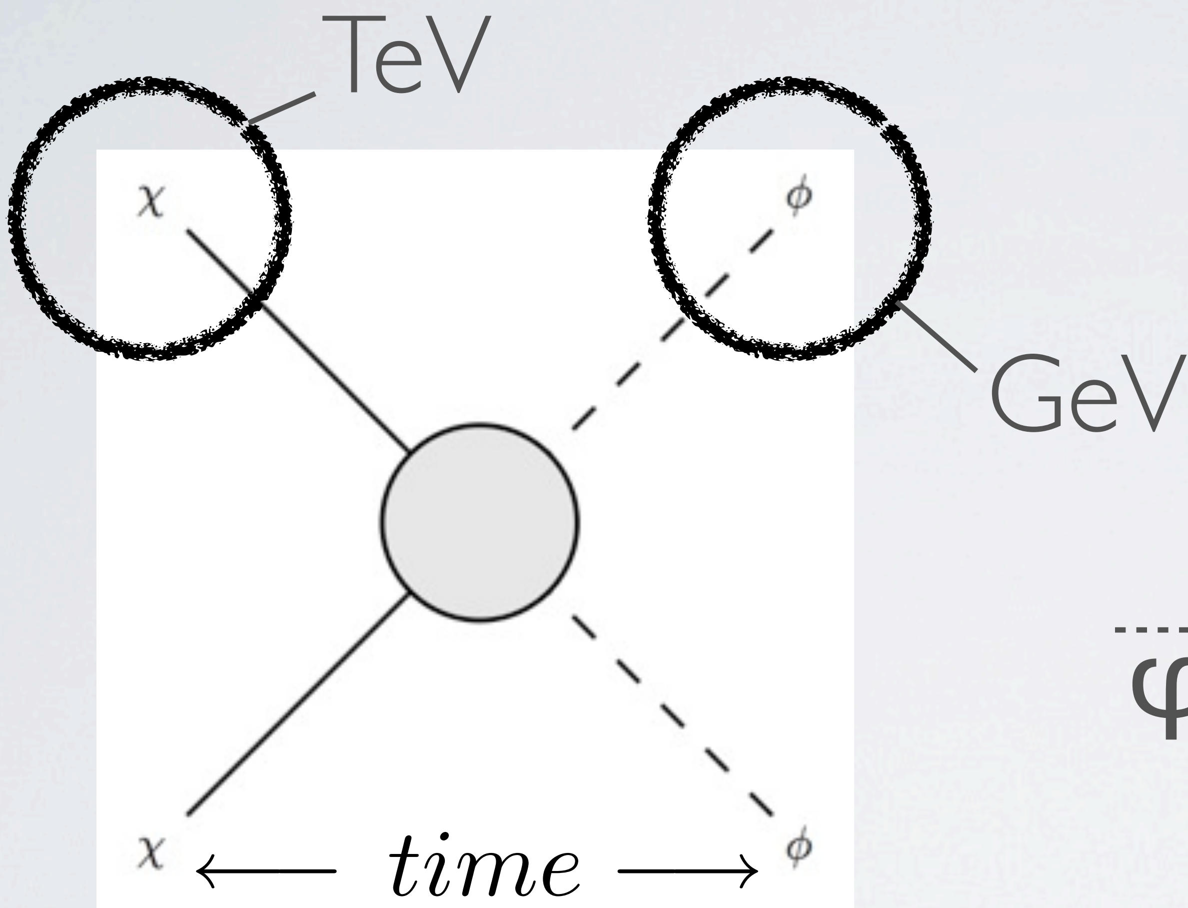
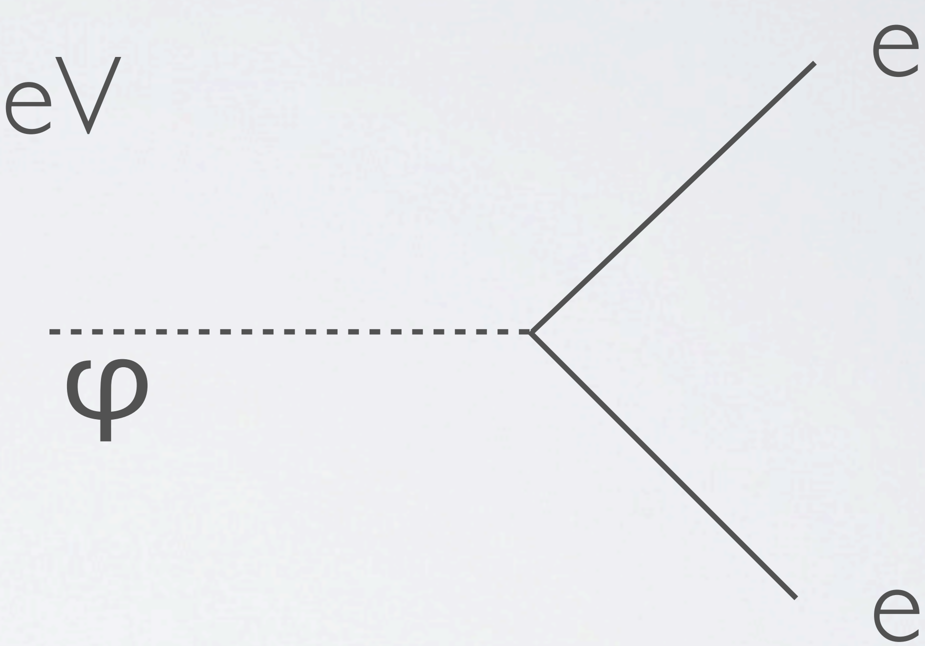
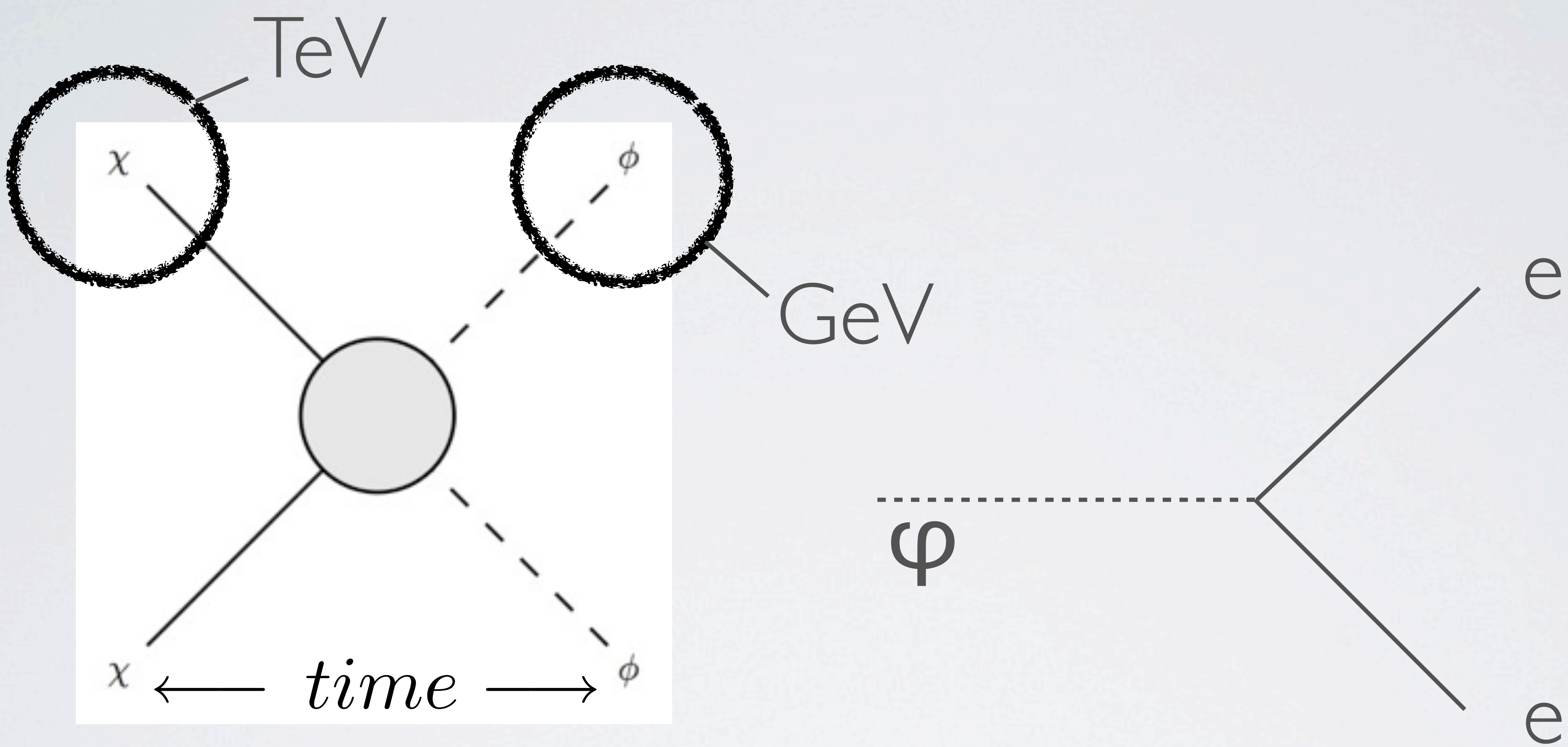




generates hard leptons by annihilations into a light mediator

A LIGHT SECTOR TAKE 2



generates hard leptons by annihilations into a light mediator

New GeV particles and GeV ‘inos

NEW COLLIDER PHENO:

Production of light, dark states, yield boosted, highly collimated leptons ("lepton jets")

Arkani-Hamed, NW, '08; Baumgart, Cheung, Ruderman, Wang, Yavin, ' 09; Bai, Han '09

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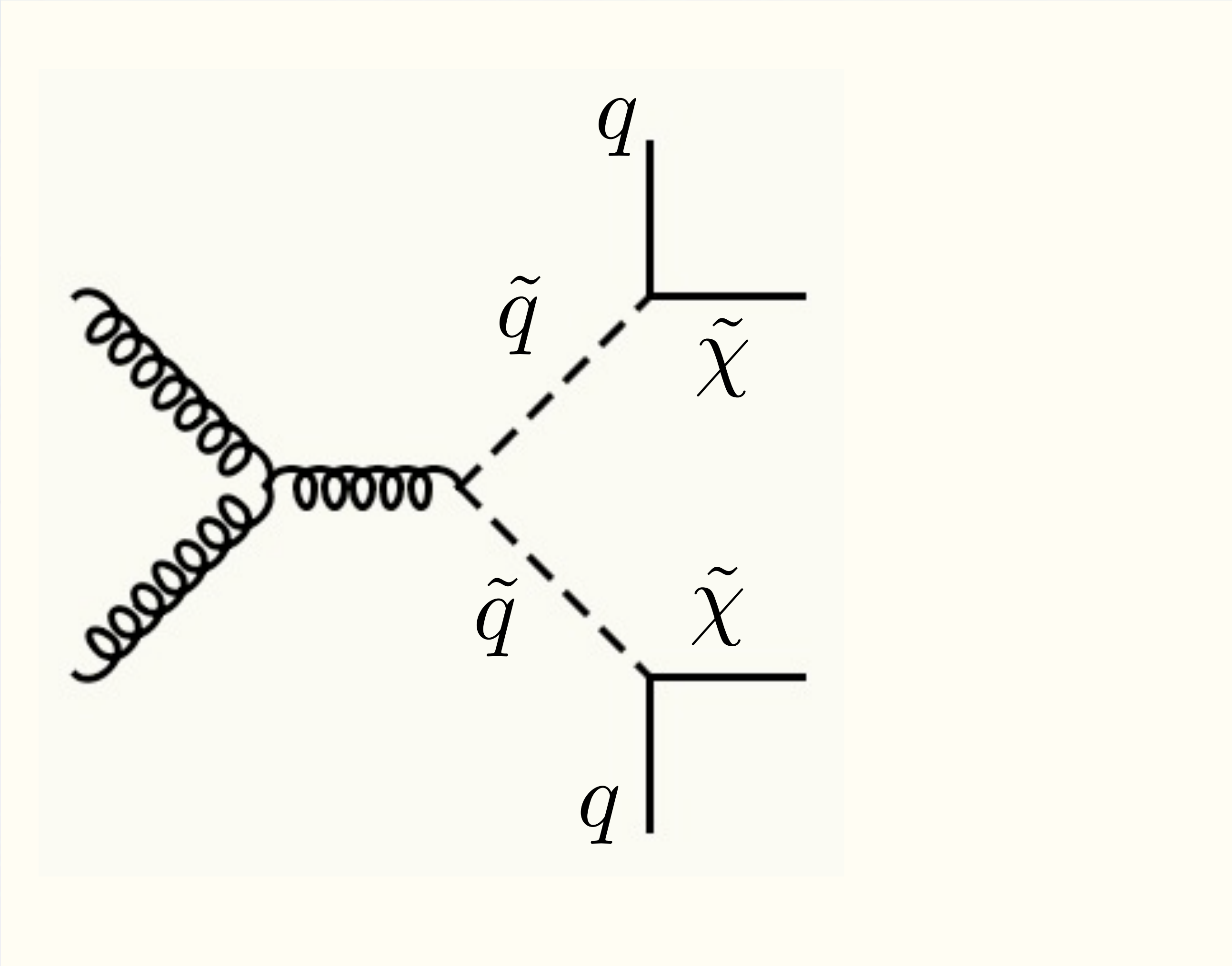

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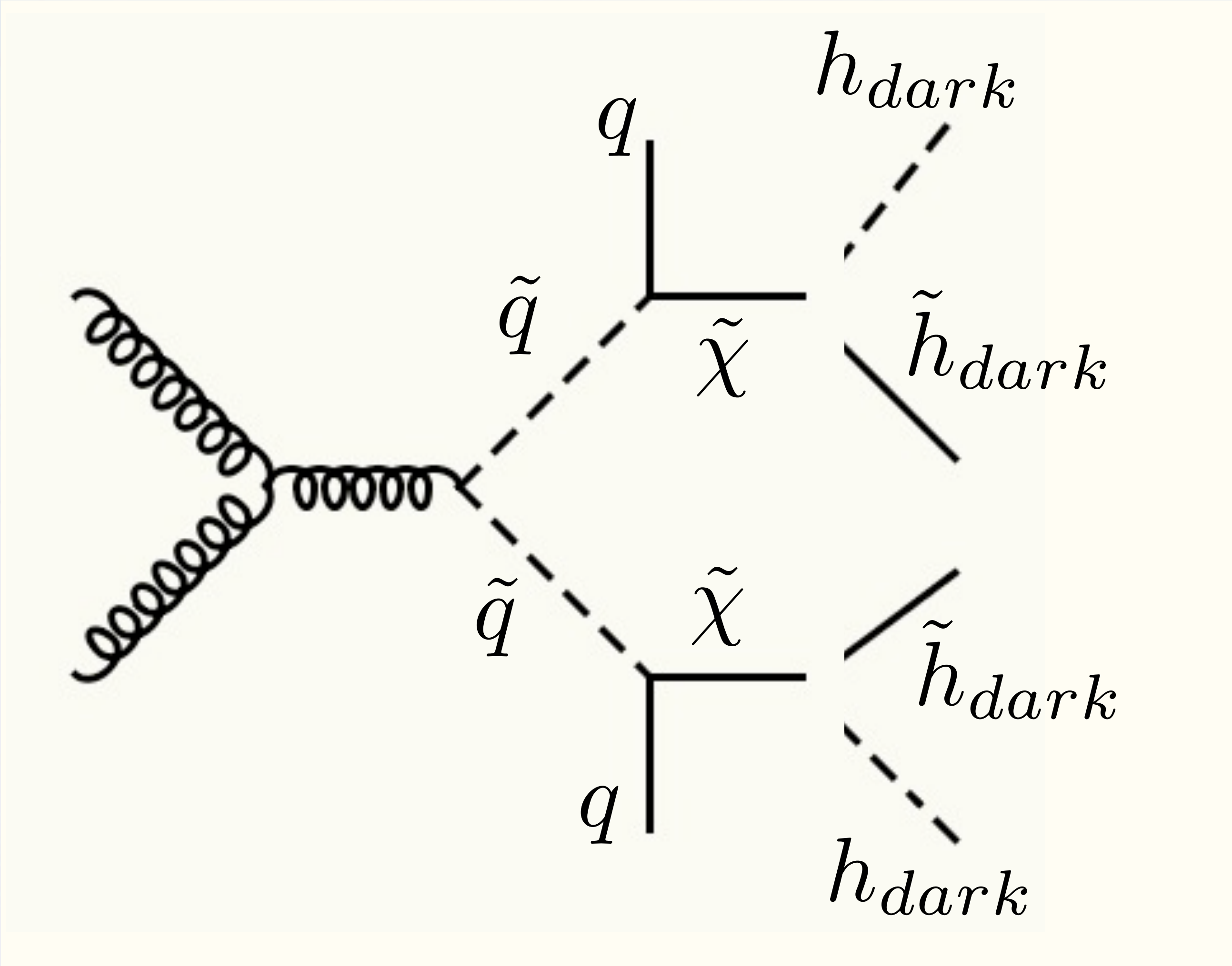
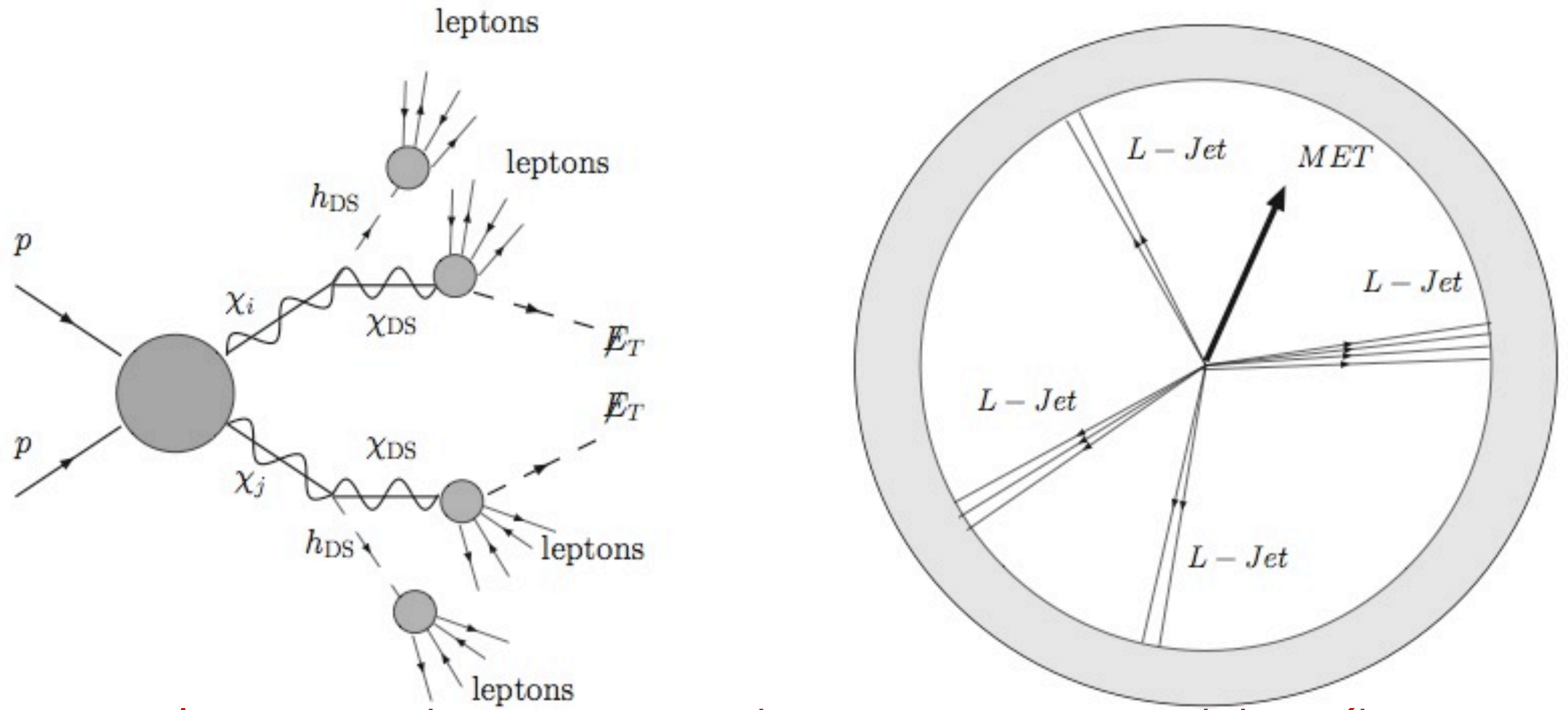
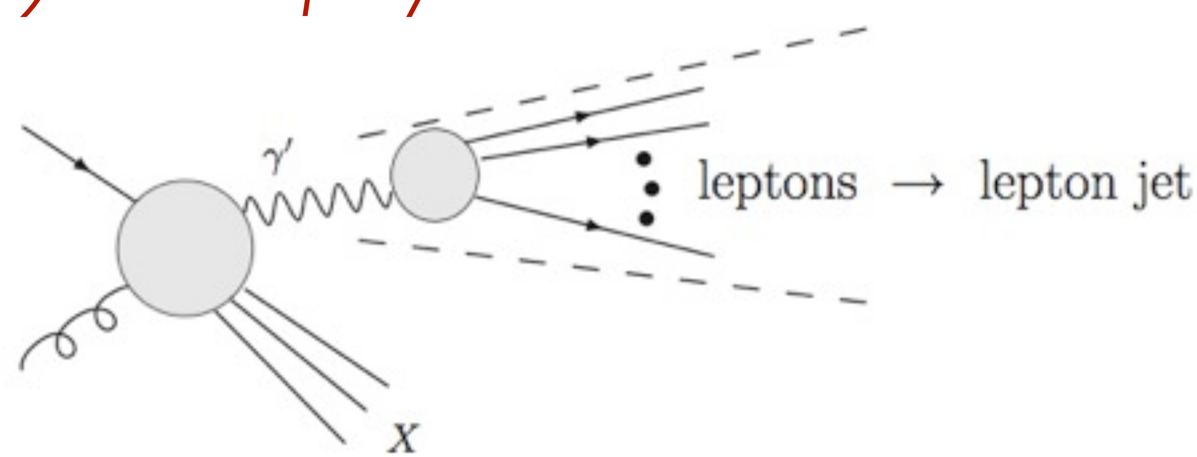


cf "Hidden Valley" models, Strassler and Zurek '06



A new phenomenology, motivated by (but not limited to) astrophysics



Baumgart, Cheung, Ruderman, Wang, Yavin, '09

THINKING ABOUT THE LATE EARLY UNIVERSE

Moduli in Supergravity

(in particular Acharya, Kane et al)

$$\int d^4\theta \, \frac{X^\dagger X}{M_{pl}^2} \phi^\dagger \phi \qquad \langle X \rangle = \theta^2 F \Rightarrow \tilde{m}^2 \phi^\dagger \phi$$

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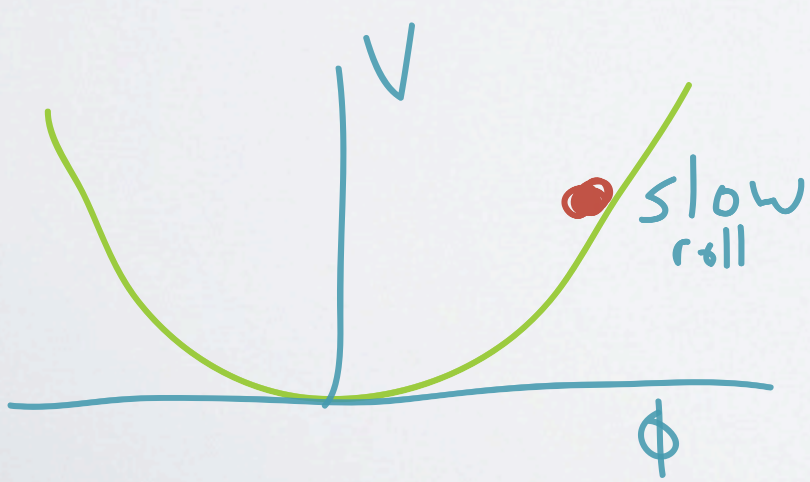
$$\int d^4\theta \, \frac{X^\dagger X}{M_{pl}^2} \phi^\dagger \phi \qquad \langle X \rangle = \theta^2 F \Rightarrow \tilde{m}^2 \phi^\dagger \phi$$

What happens to ϕ?



until $H \sim m \Rightarrow$

THINKING ABOUT THE LATE EARLY UNIVERSE

So ϕ evolves like matter until it decays at time

$$t \sim \left(\frac{m_\phi^3}{M_{pl}^2}\right)^{-1}$$

at temperature

$$T \sim 10\,\text{MeV} \times \left(\frac{m_\phi}{\text{TeV}}\right)^{3/2}$$

Yikes!

$$\Longrightarrow m_\phi \sim 30\,\text{TeV}$$

THINKING ABOUT THE LATE EARLY UNIVERSE

$$\frac{X^\dagger X \phi^\dagger \phi}{M_{Pl}^2} \longleftrightarrow \frac{X^\dagger X Q^\dagger Q}{M_{Pl}^2}$$

Squarks at 30 TeV?!?!

(except for "light" stops at ~10 TeV)

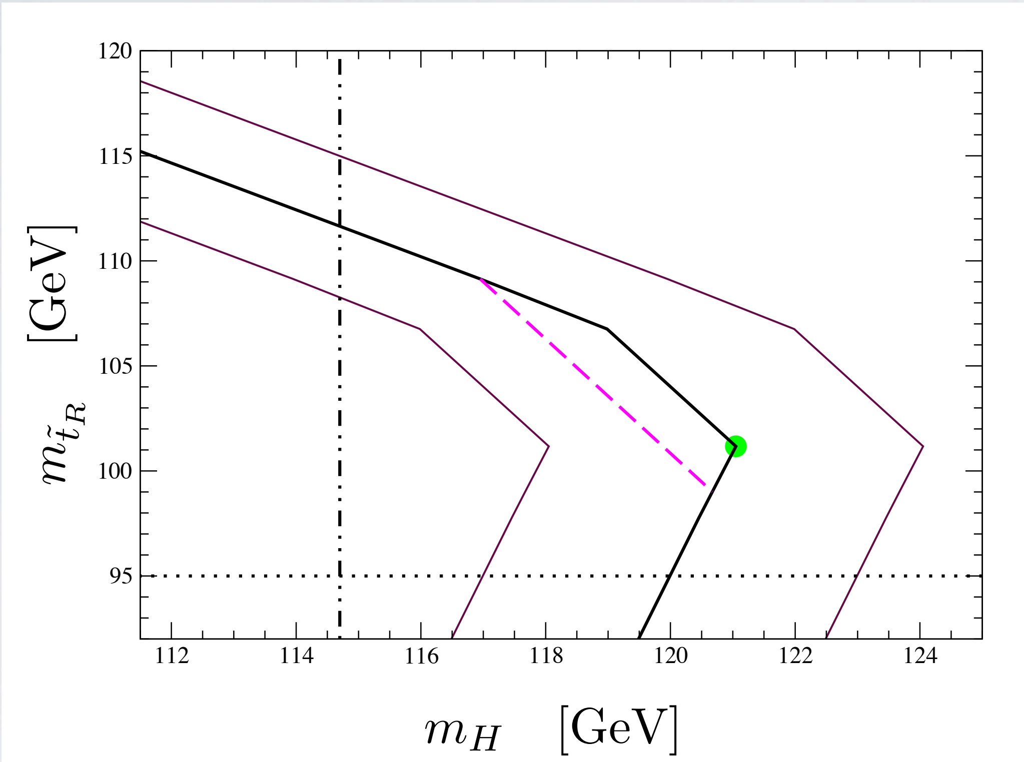
Gauginos still light

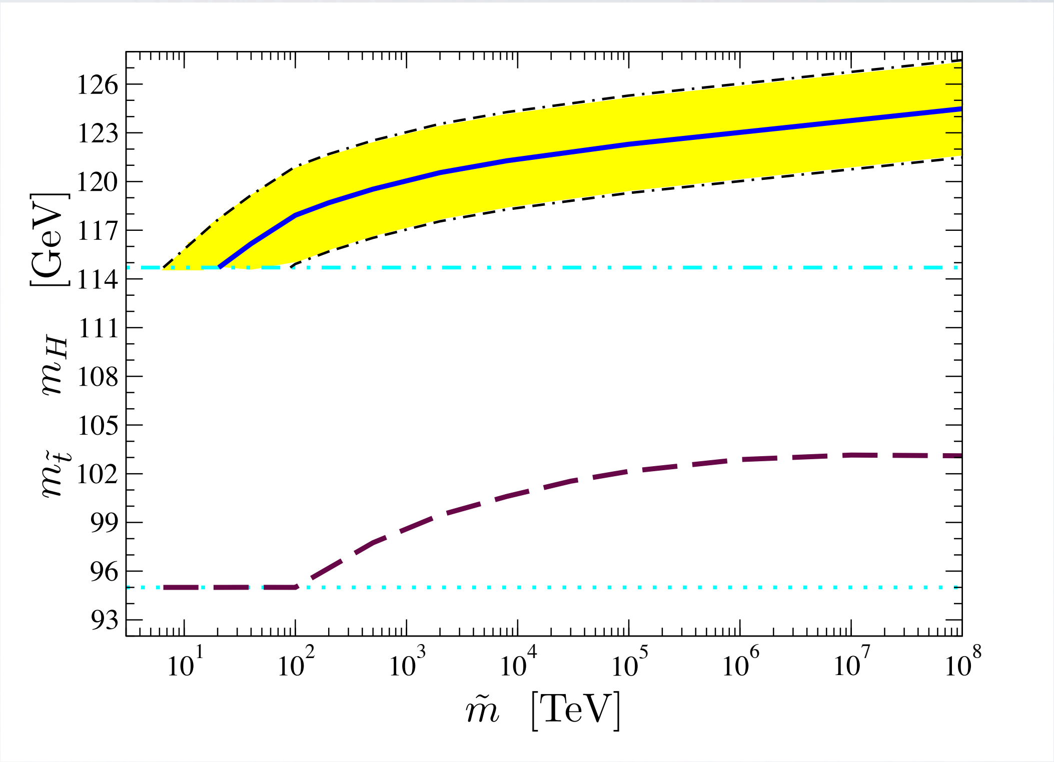
(anomaly mediation)

WHY ARE WE HERE?

- Baryogenesis requires
  - C/CP Violation
  - Baryon number violation
  - First order phase transition
- Do these (esp FO EWPT) appear in our theories?

WHY ARE WE HERE?



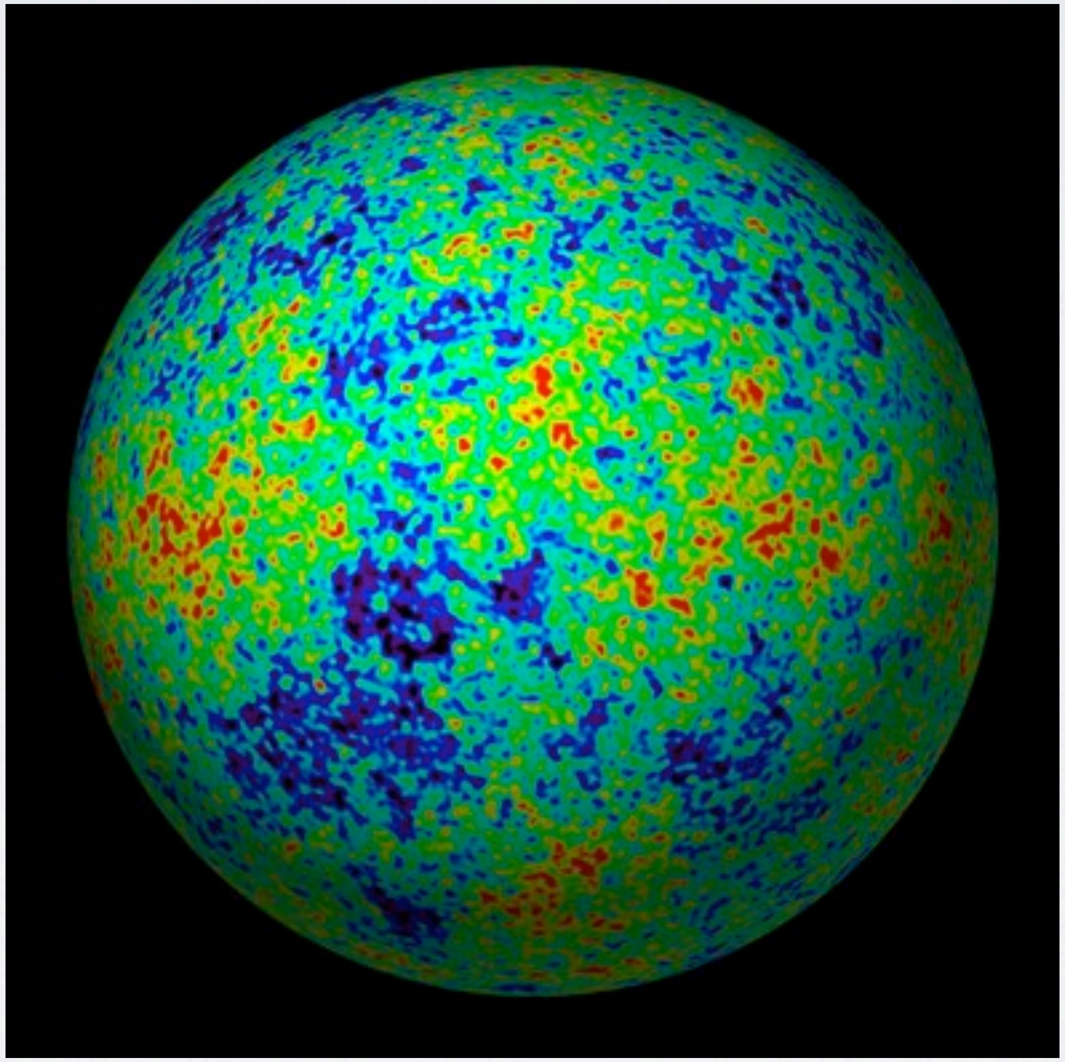


Carena, Nardini, Quiros, Wagner '08

Light stops -> First order phase transition
-> the origin of matter?

PLANCK AND THE LHC

What if you see hints of new physics before the shutdown, and Planck sees tensor modes?



Tensor modes => inflation scale = MGUT!

WHAT CAN THE LHC TELL US ABOUT COSMOLOGY?

Cosmology tells us

WHAT CAN THE LHC TELL US ABOUT COSMOLOGY?

Cosmology tells us

MET!

WHAT CAN THE LHC TELL US ABOUT COSMOLOGY?

Cosmology tells us

MET!

(maybe not much MET)

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TeV WIMPs

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Prompt spartícle decays

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Displaced vertices

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Displaced vertices

Very very light stops

Prompt spartickle decays

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Very very heavy stops!

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Cosmology tells us

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TeV WIMPs

Light WIMPs

lepton jets

Displaced vertices

Very very light stops

Prompt spartick decays

Very very heavy stops!

WHAT CAN THE LHC TELL US ABOUT COSMOLOGY?

Cosmology tells us

MET!

(maybe not much MET)

lepton jets

Very very light stops

SUSY + Grand unification

(if we're lucky)

Displaced vertices

Prompt spartick decays

TeV WIMPs

Light WIMPs

Very very heavy stops!

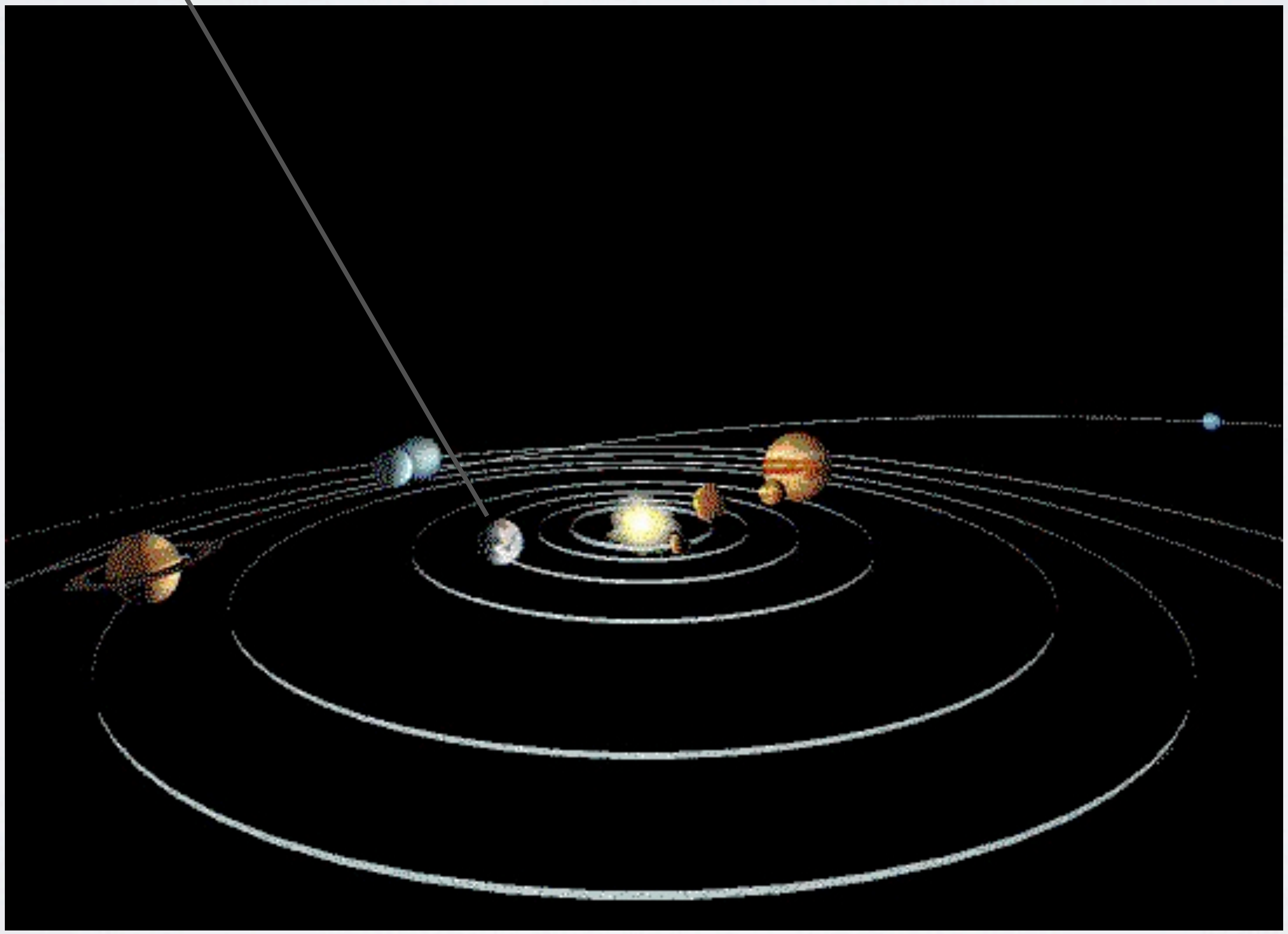
- a lot of predictions, but it’s a big universe

THE COPERNICAN EVOLUTION

You are here

THE COPERNICAN EVOLUTION

You are here



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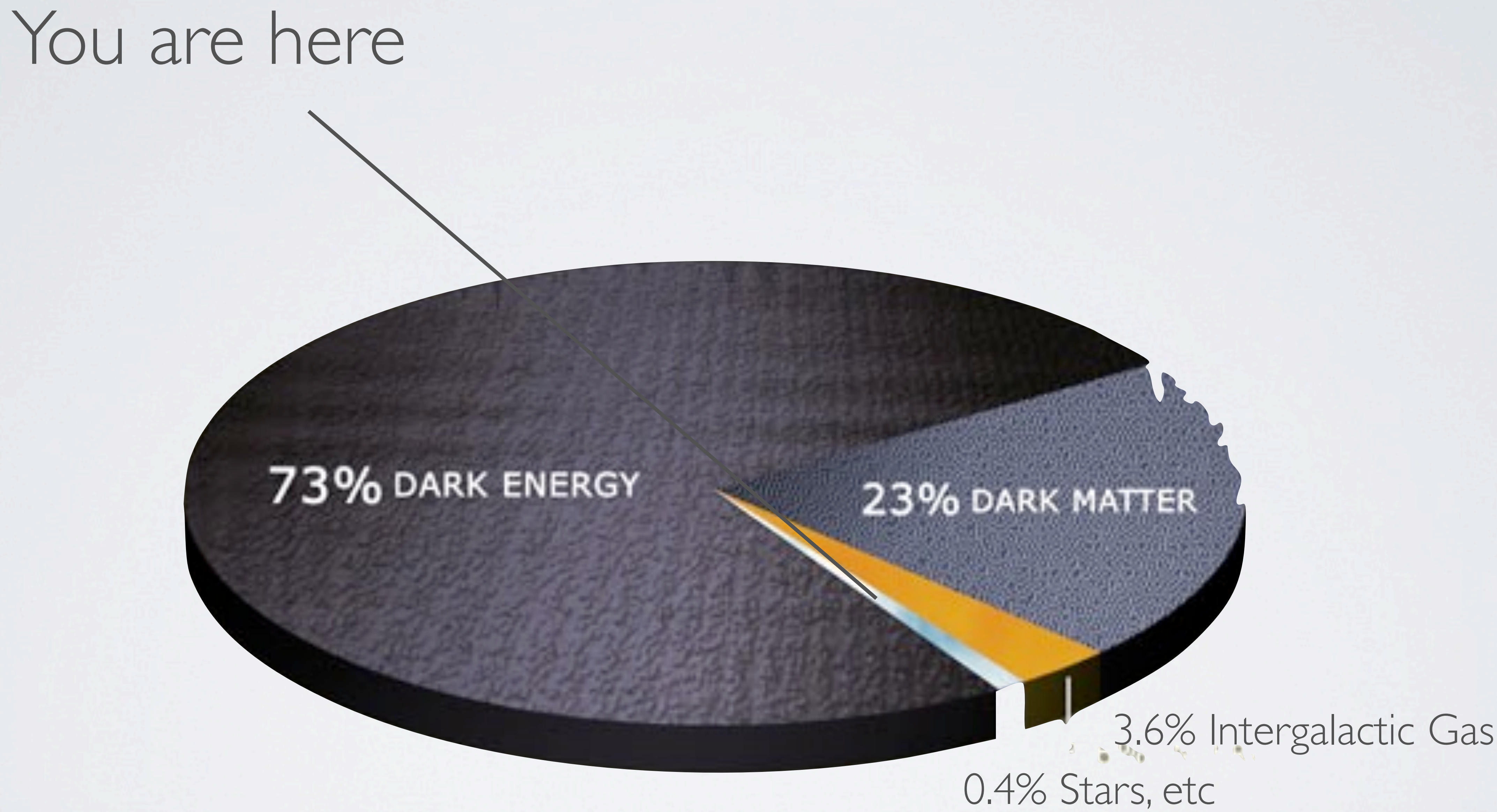

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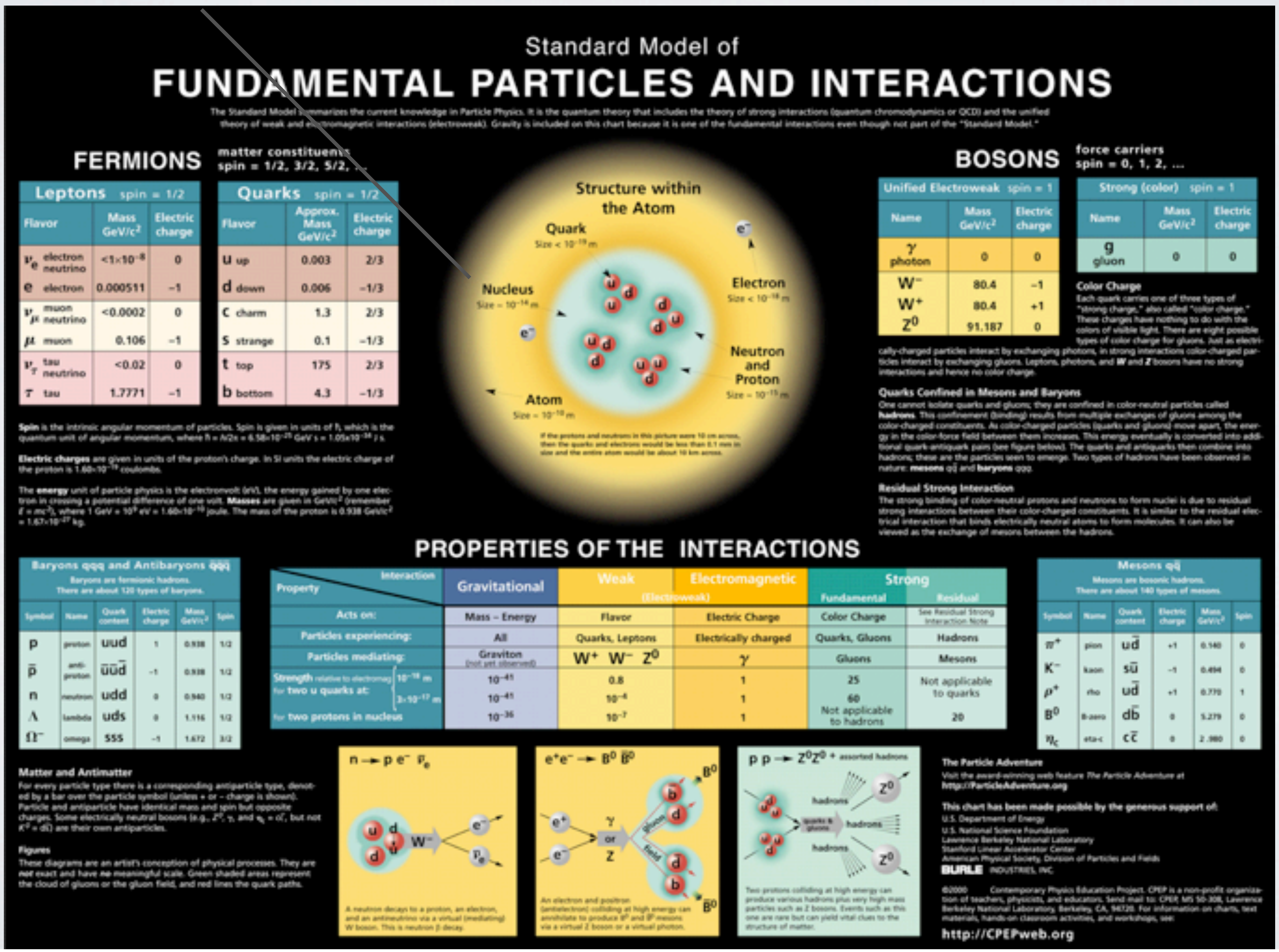
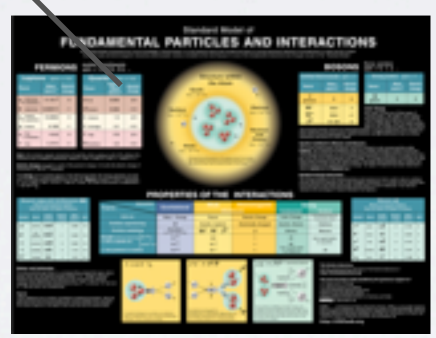


THE COPERNICAN EVOLUTION

You are here

SUSY?

Large extra dimensions?



Hidden sectors?

Conformal dynamics?

Dark forces?

Strong dynamics?