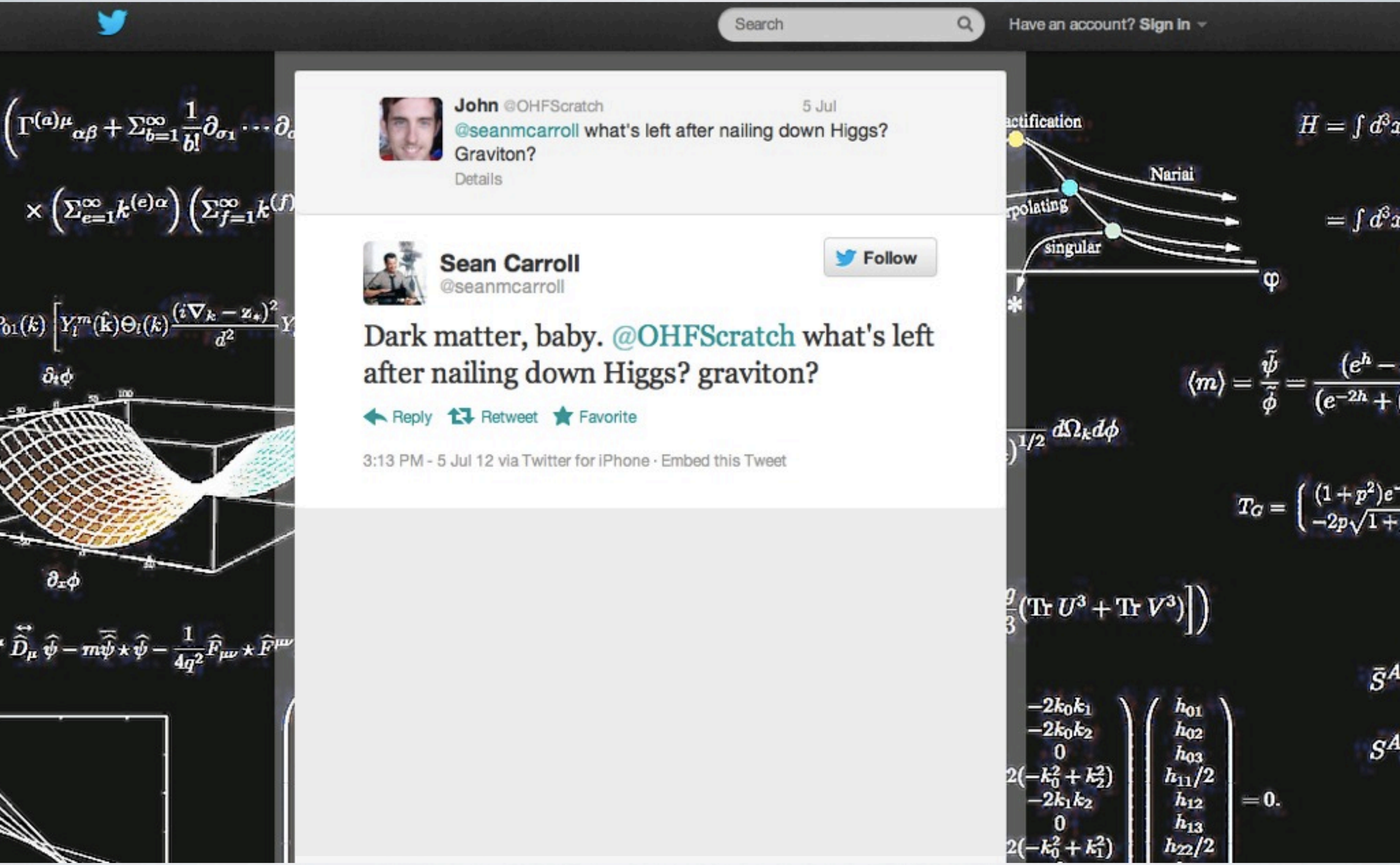
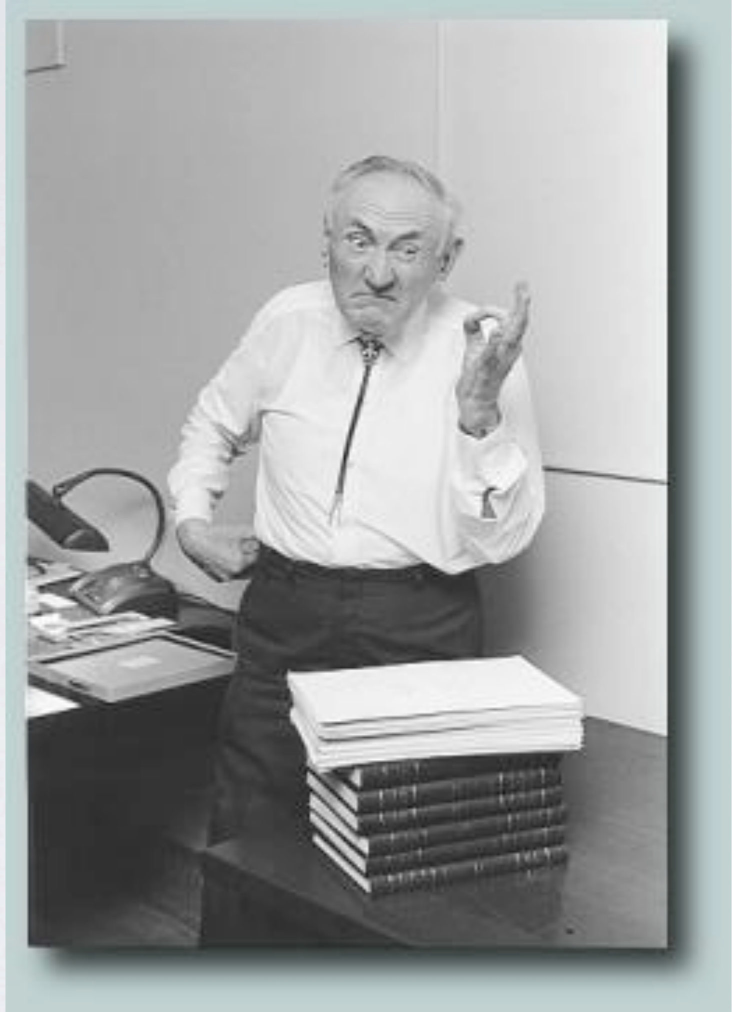
DARK MATTER AND NEW PHYSICS IN 30’

Neal Weiner
ICHEP Melbourne 2012
CCPP - NYU
July 11, 2012


Search
Have an account? Sign in
John @OHFScratch 5 Jul
@seanmcarroll what's left after nailing down Higgs? Graviton?
Details
Sean Carroll
@seanmcarroll
Follow
Dark matter, baby. @OHFScratch what's left after nailing down Higgs? graviton?
Reply Retweet Favorite
3:13 PM - 5 Jul 12 via Twitter for iPhone · Embed this Tweet

- Higgs took 45 years!



DM: 80 years?

Or at least 40 years?

WHERE TO LOOK?

- Unlike the Higgs, for DM at best we have guesses

NEW IDEAS

Dynamical Dark Matter

K. Dienes; B. Thomas

Pangenesis

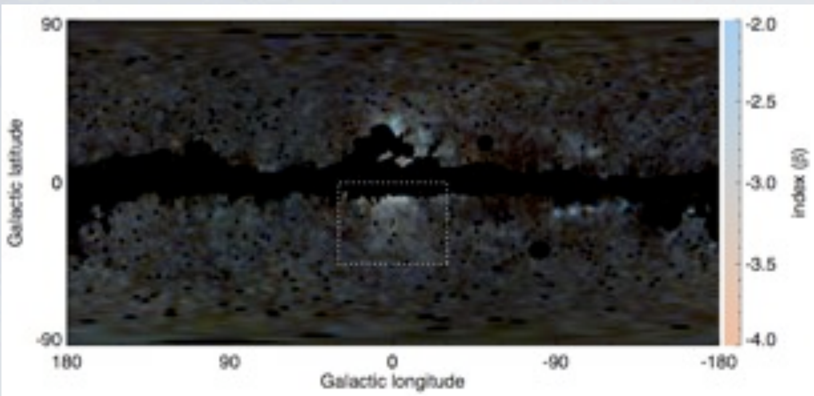
B. von Harling; K. Petraki

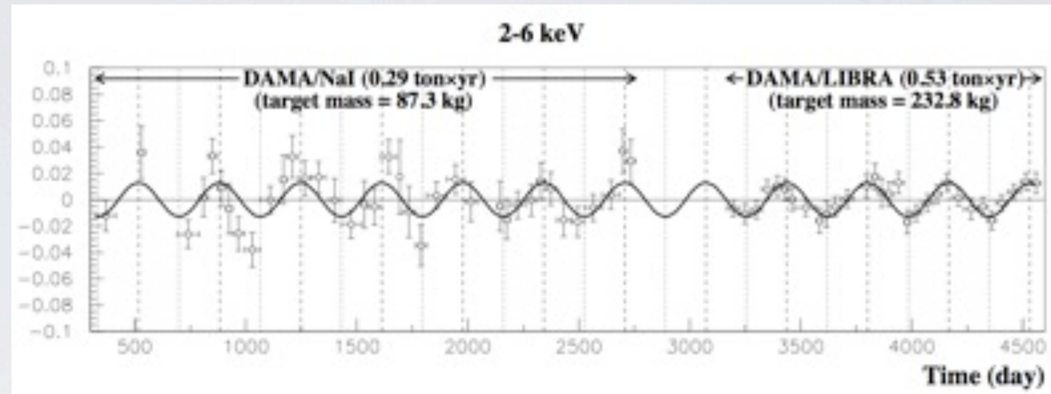
Mirror Matter

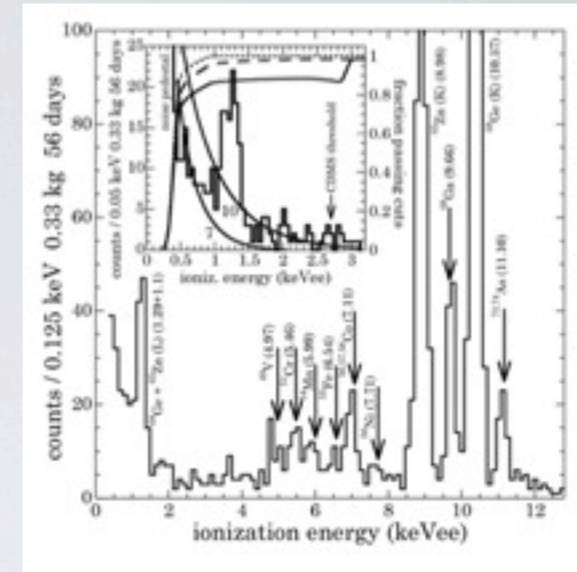
R. Foot

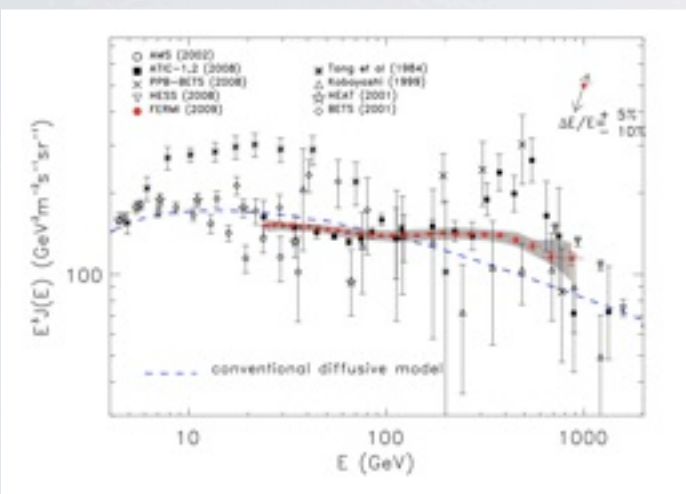
Our ideas of what dark matter is gives us ideas on how to find it

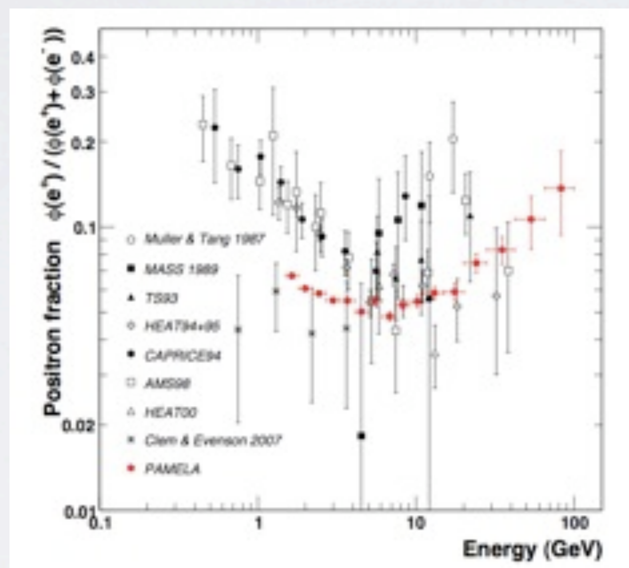
- Unlike the Higgs DM has been discovered many times

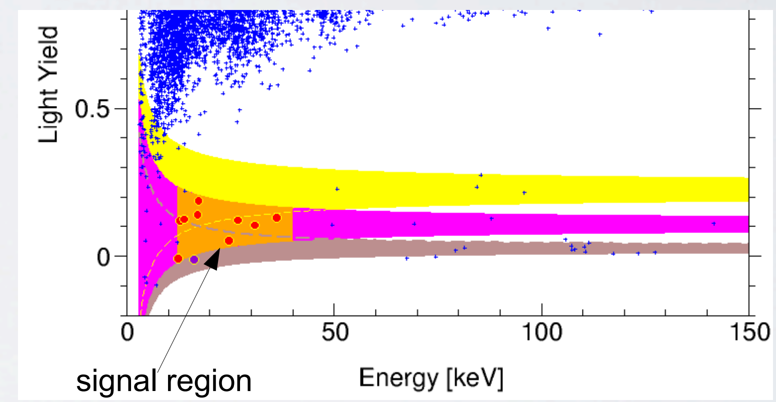


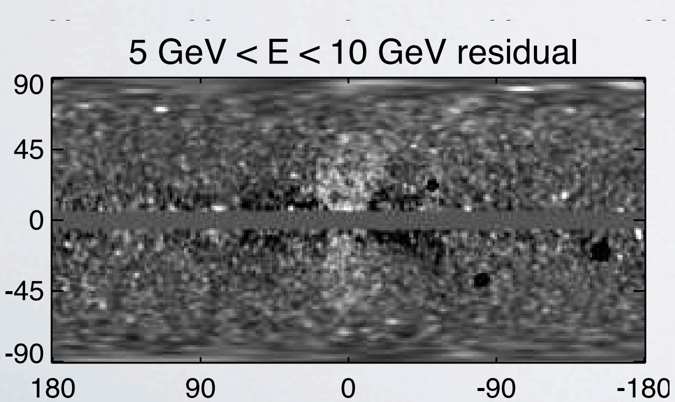


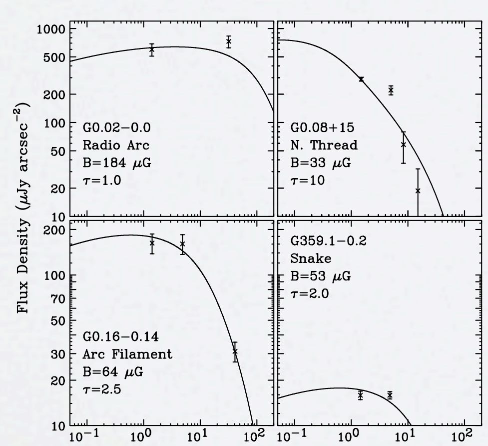


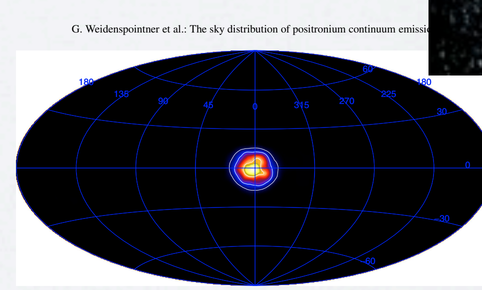


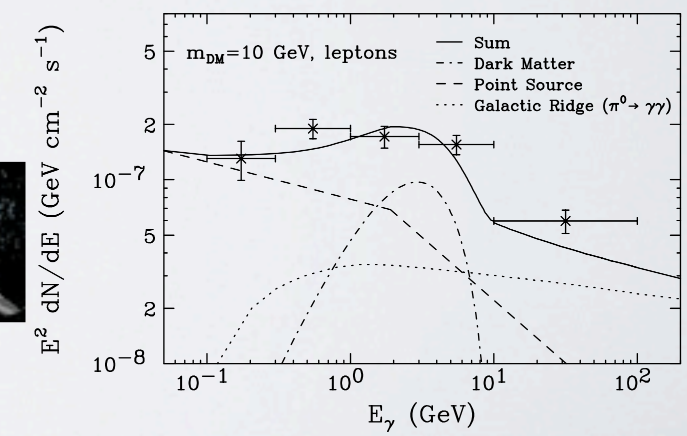












INDIRECT DETECTION

DIRECT DETECTION

JETS + MET

INDIRECT DETECTION

DIRECT DETECTION

JETS + MET

INDIRECT DETECTION

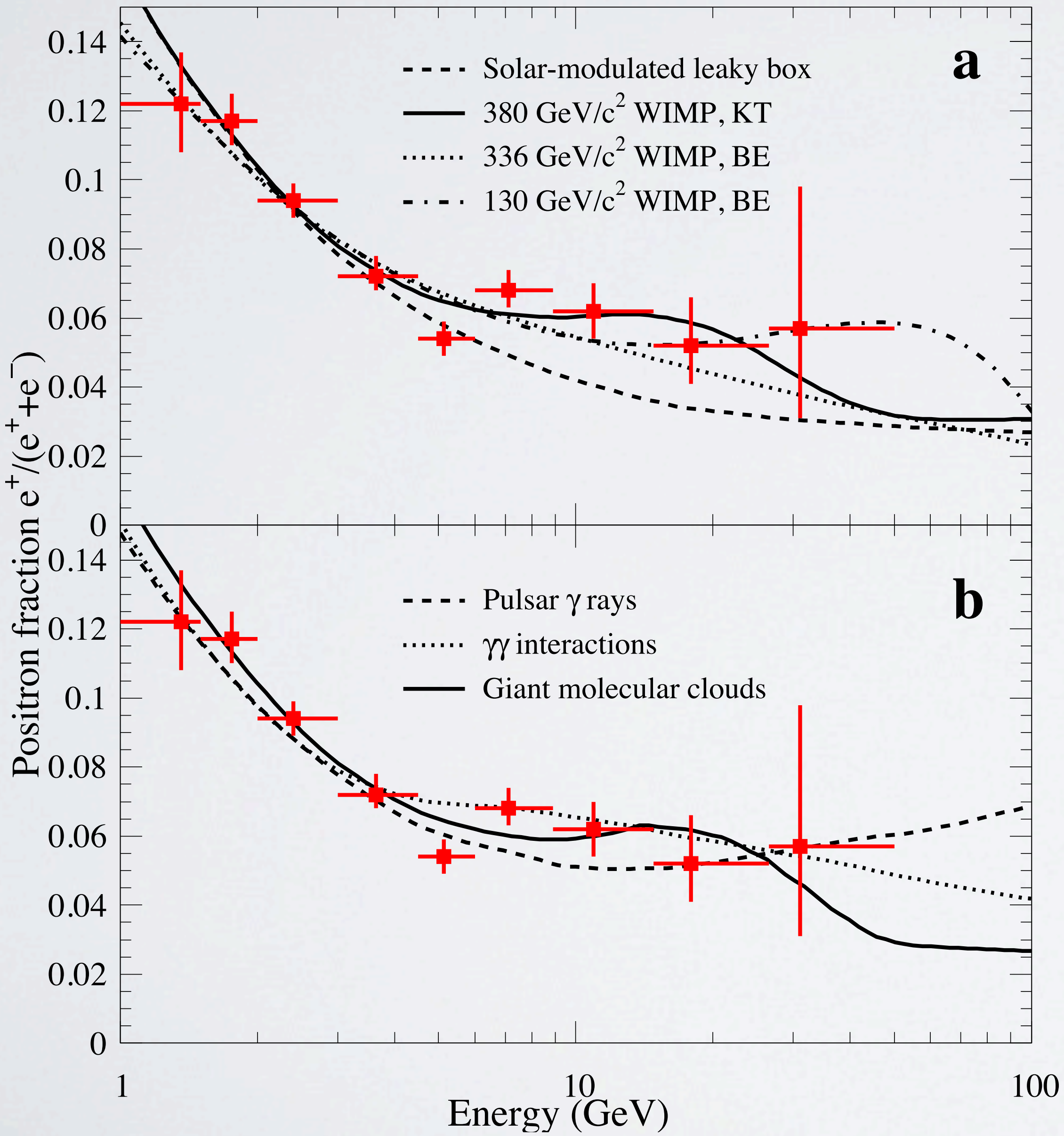
DIRECT DETECTION

JETS + MET

NB: I won't discuss the axion for time, but it is a great DM candidate

INDIRECT DETECTION

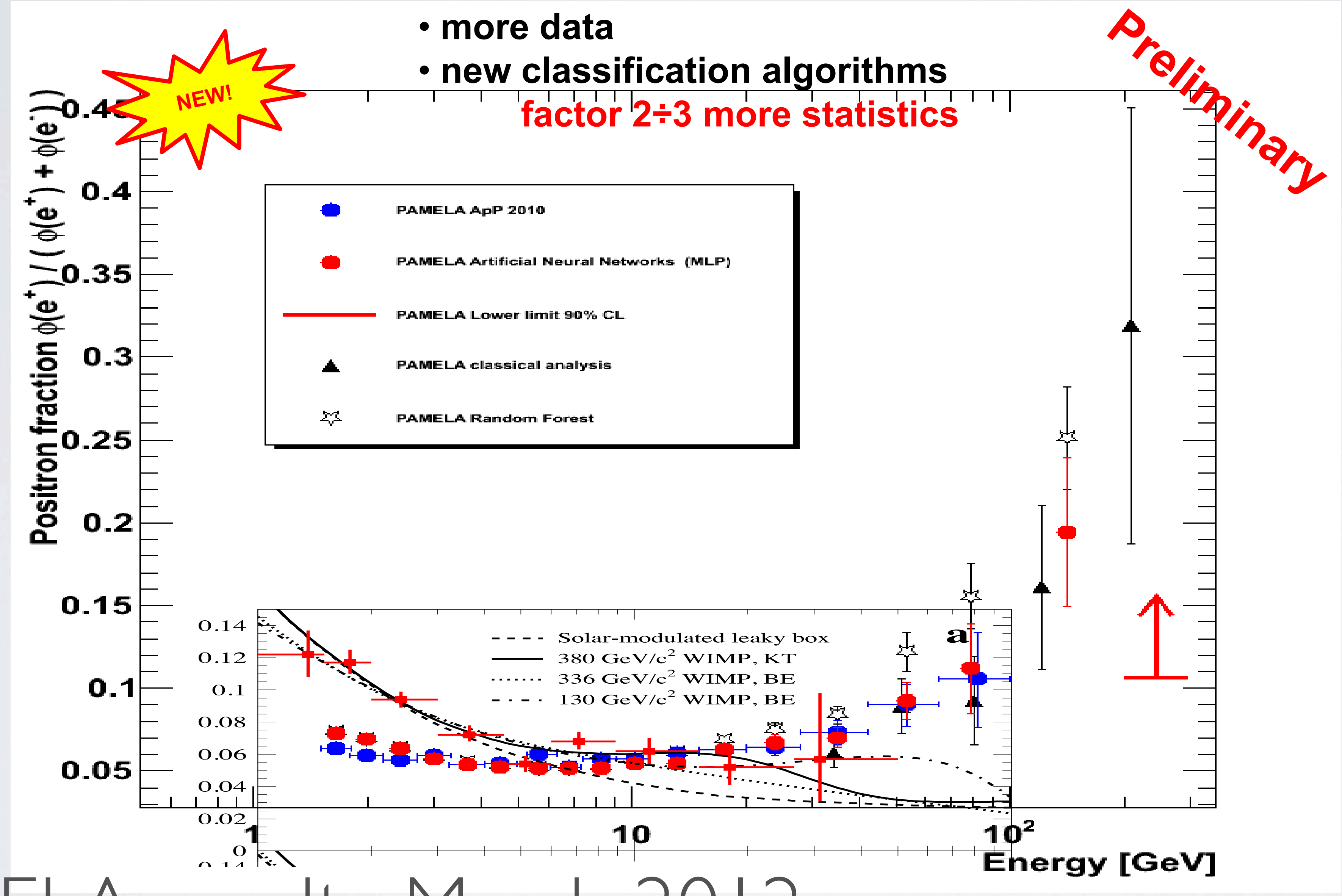
DM annihilation => positrons [antimatter]



Coutu et al, '99

1999 - HEAT results

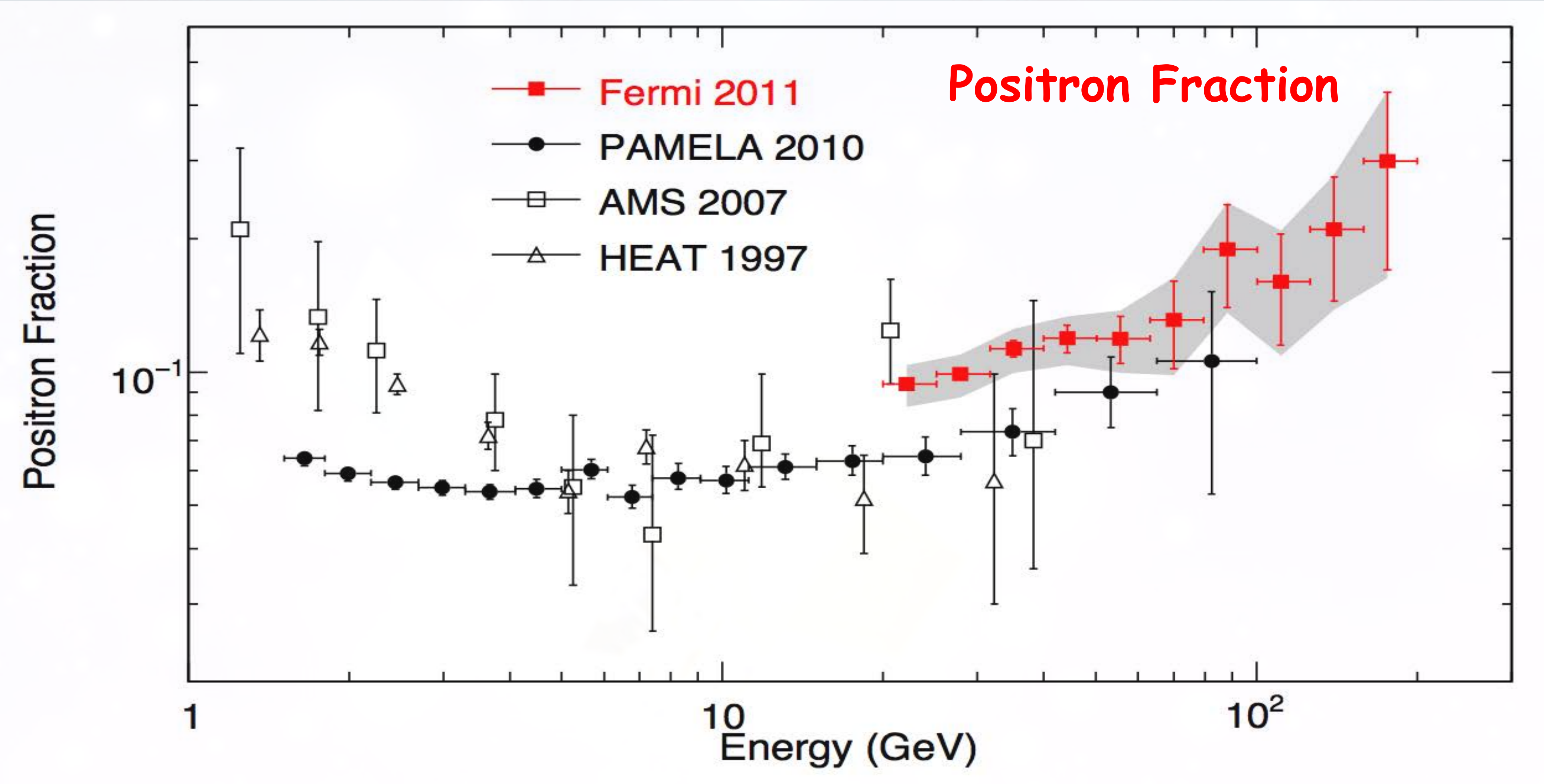
NOW THAT'S A SIGNAL



PAMELA results, March 2012

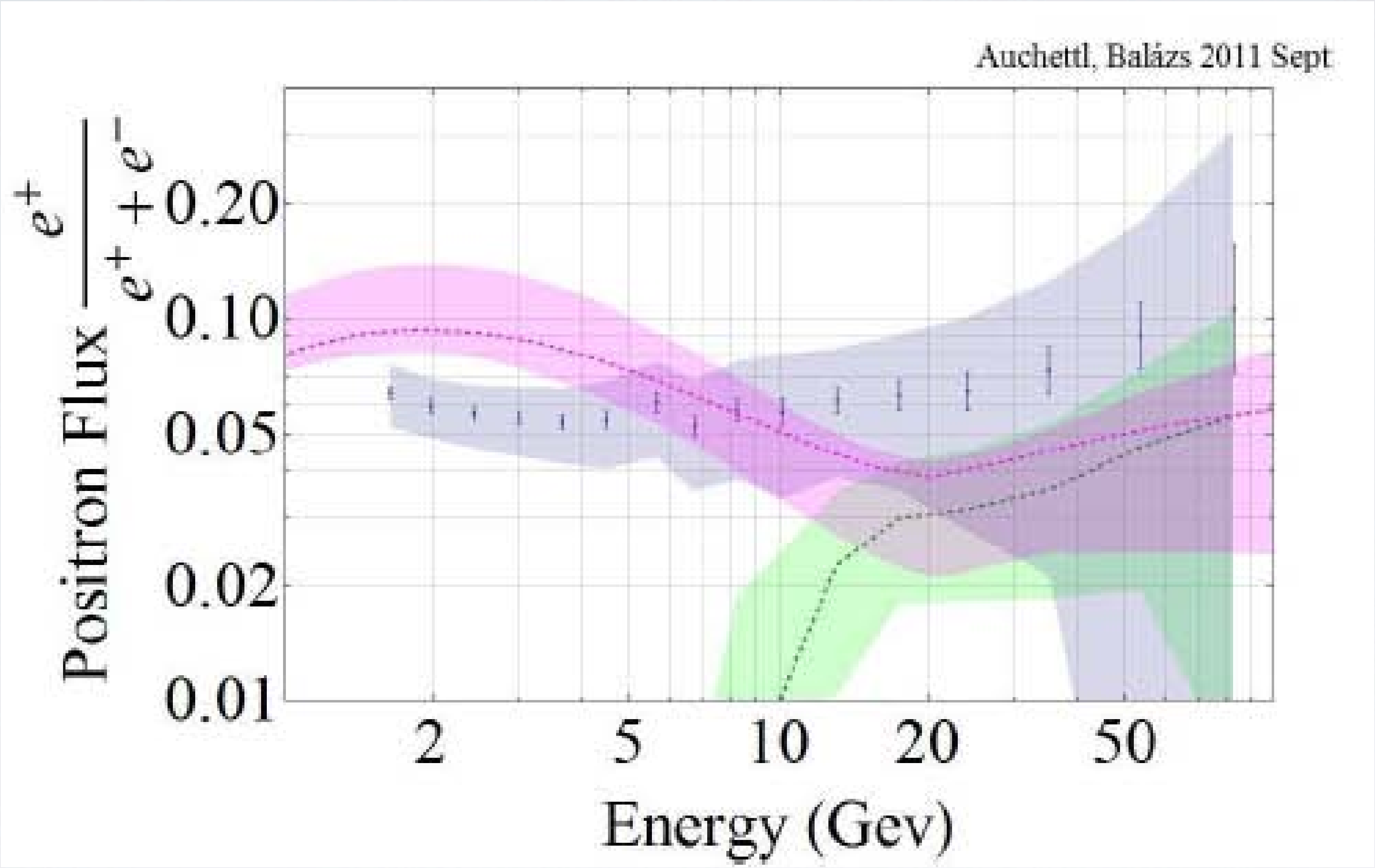
It's too great to be dark matter!

FERMI POSITRONS

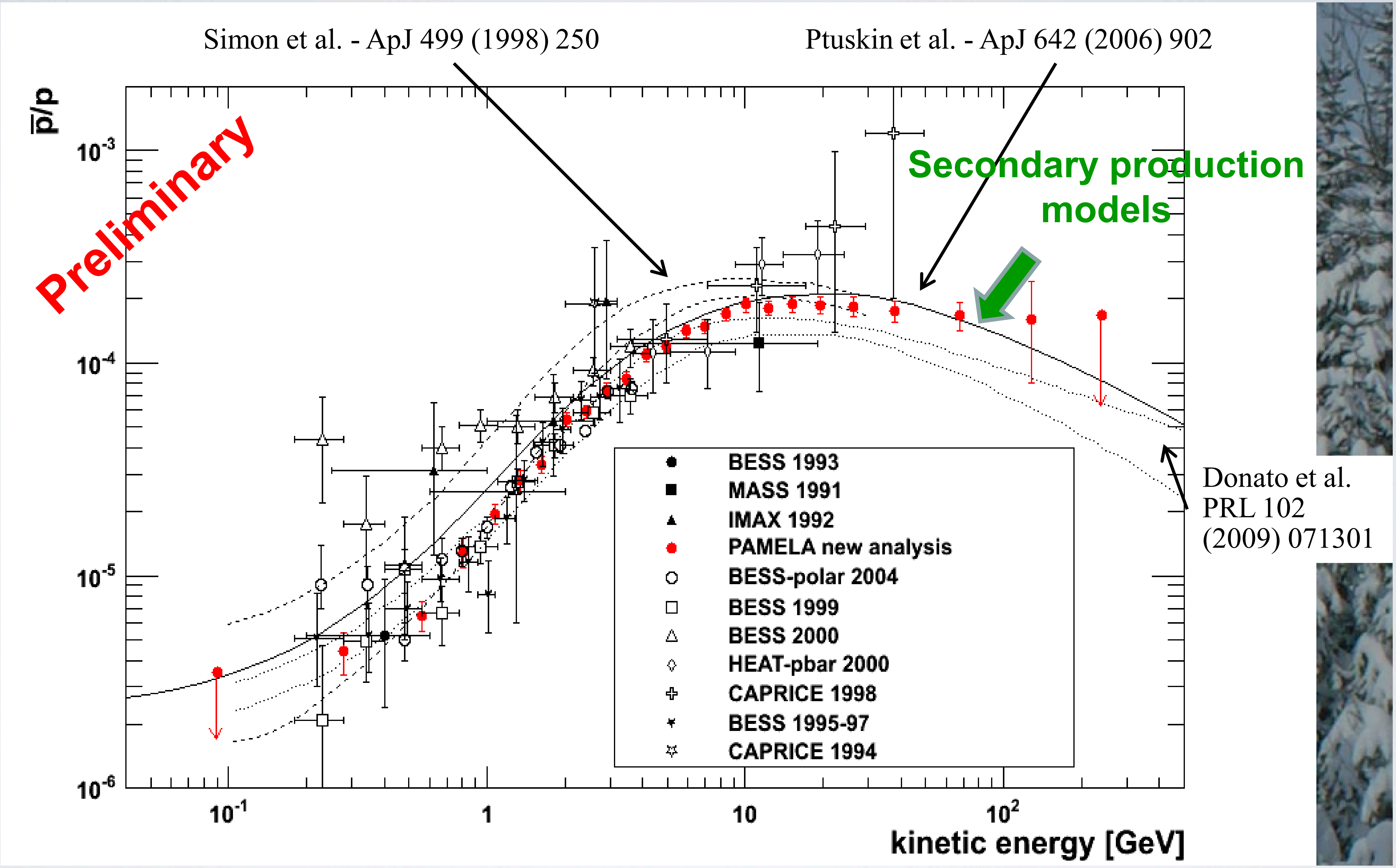


Signal is confirmed

IS THERE AN "ANOMALY"?

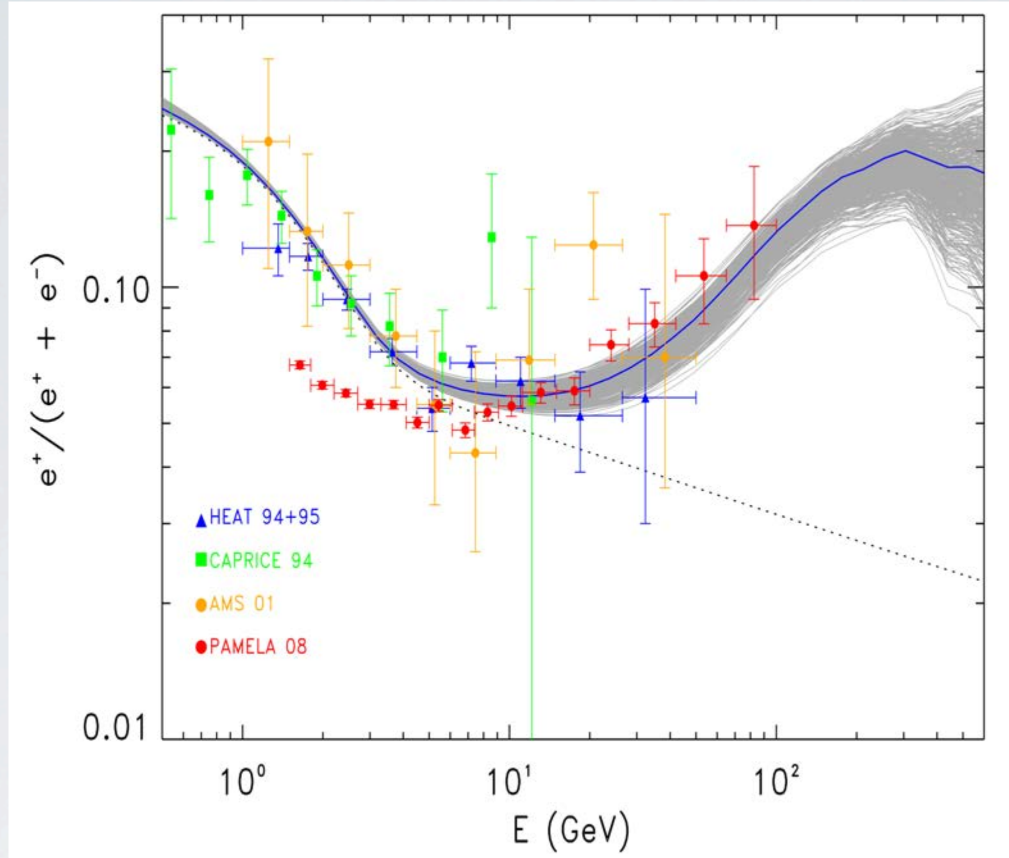


SO WHAT IS IT?

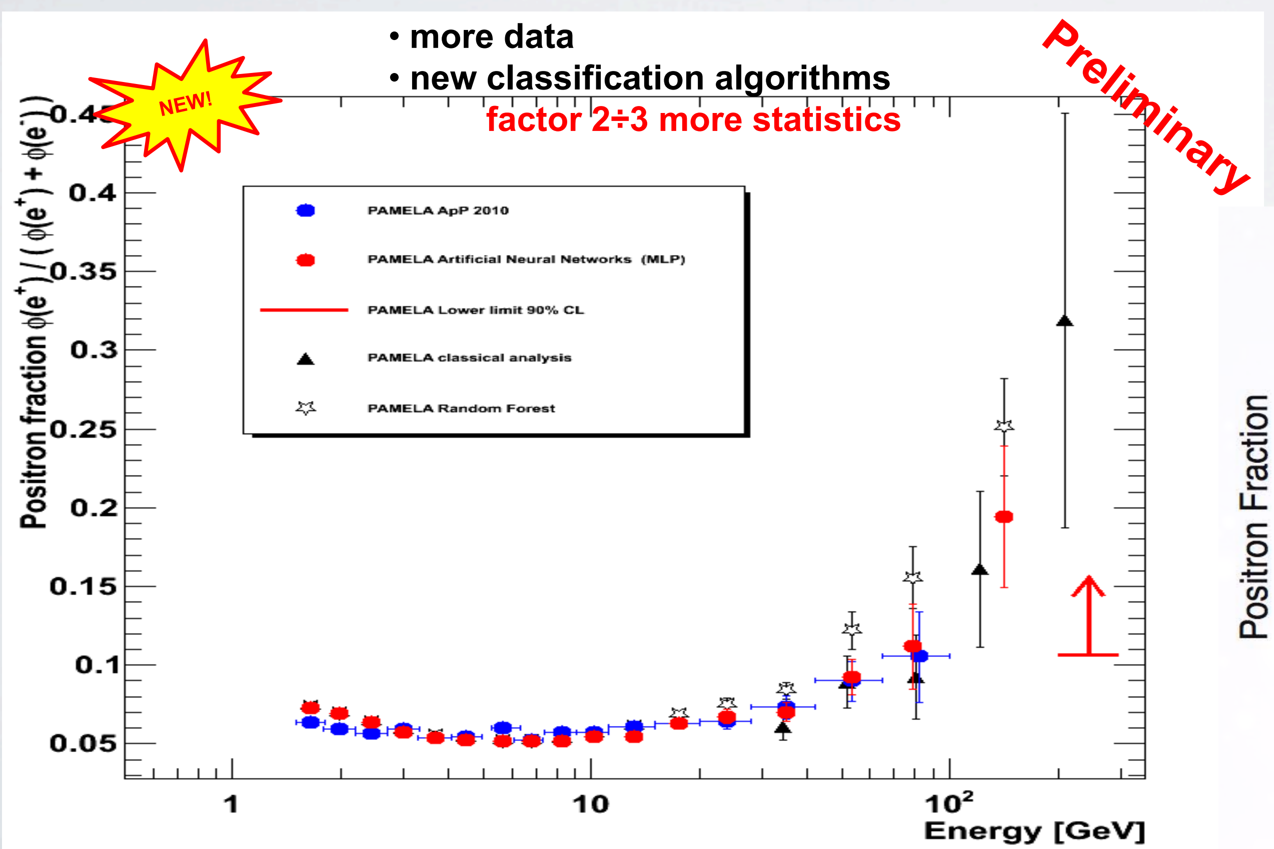


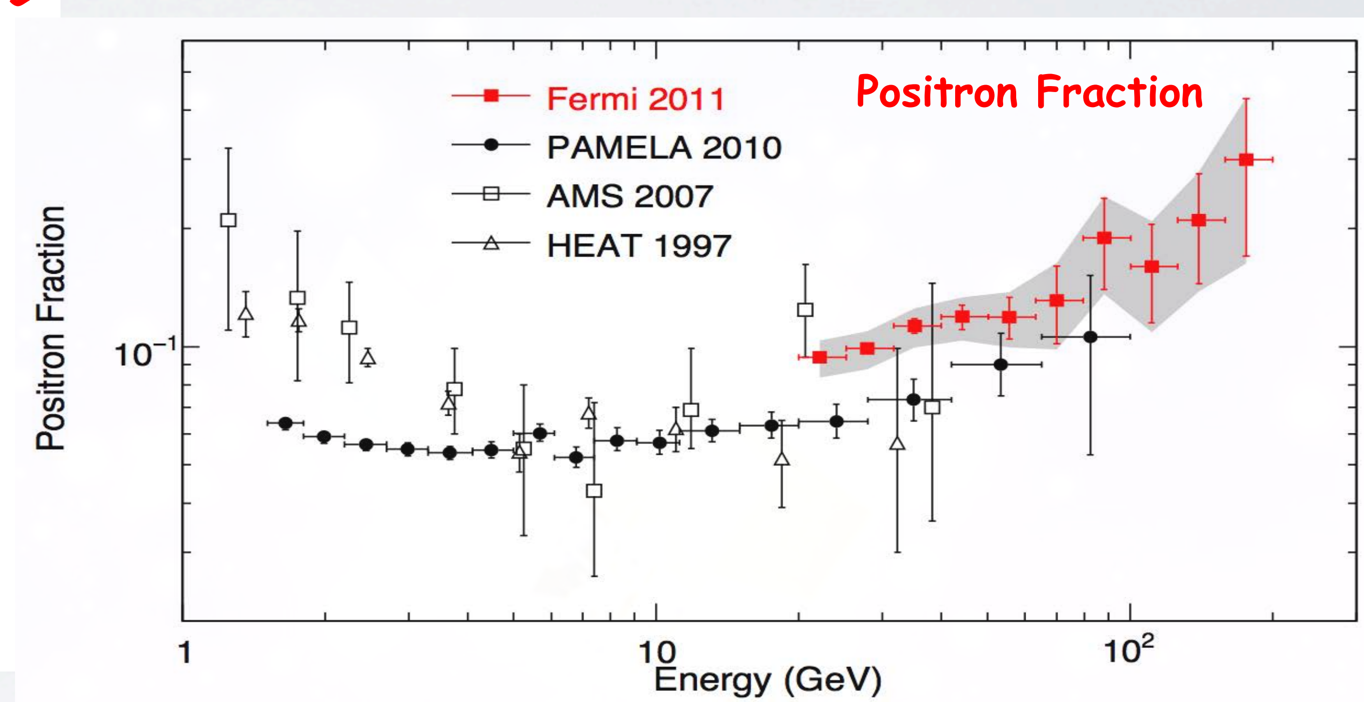
No associated anti-proton signal

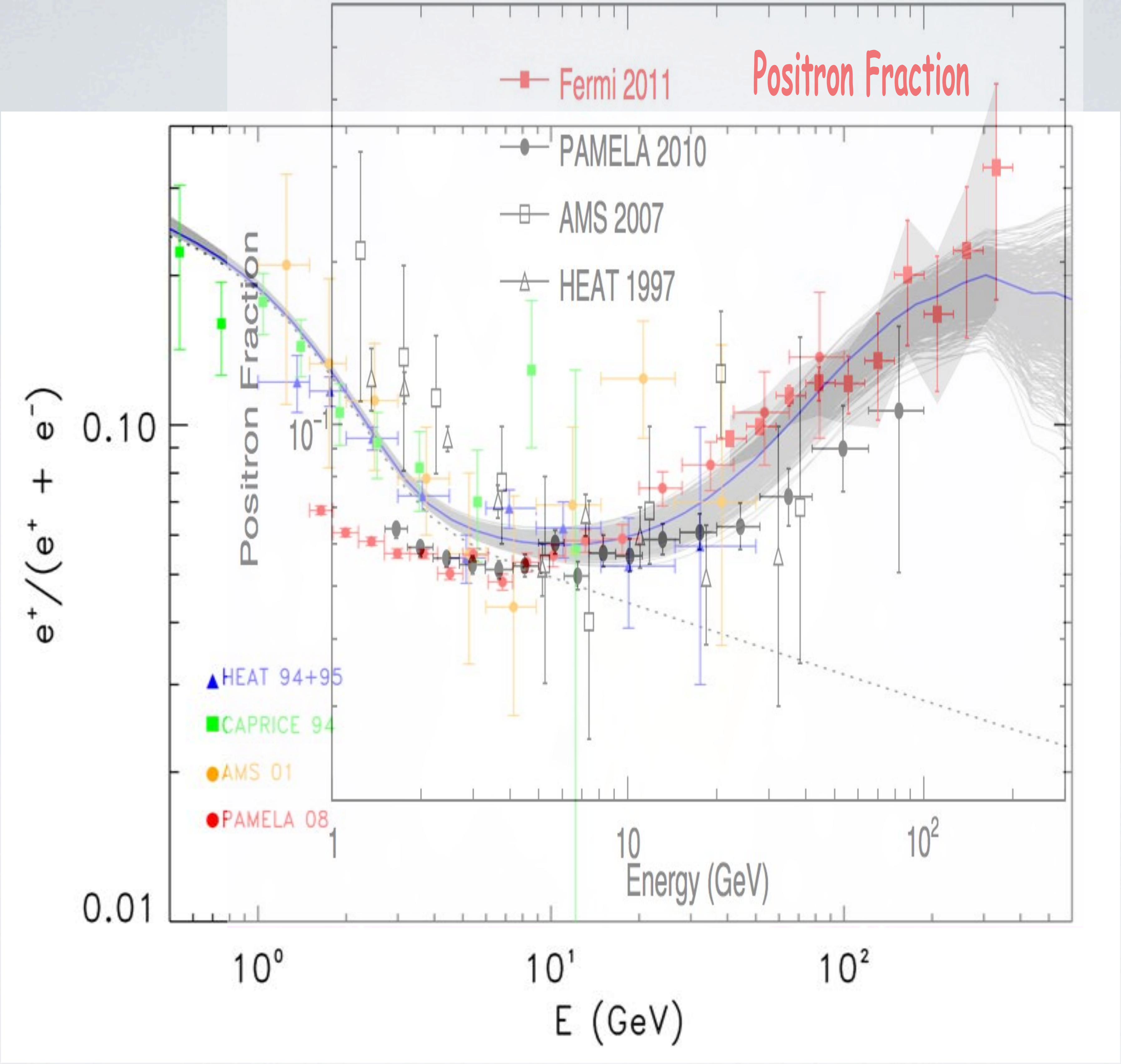
Pulsars? [Blasi, Hooper, Serpico; Profumo; Cholis, Gelfand, Malyshev...]



D.Grasso et al. Astropart. Phys. 32 (2009), pp.140 [arXiv:0905.0636]

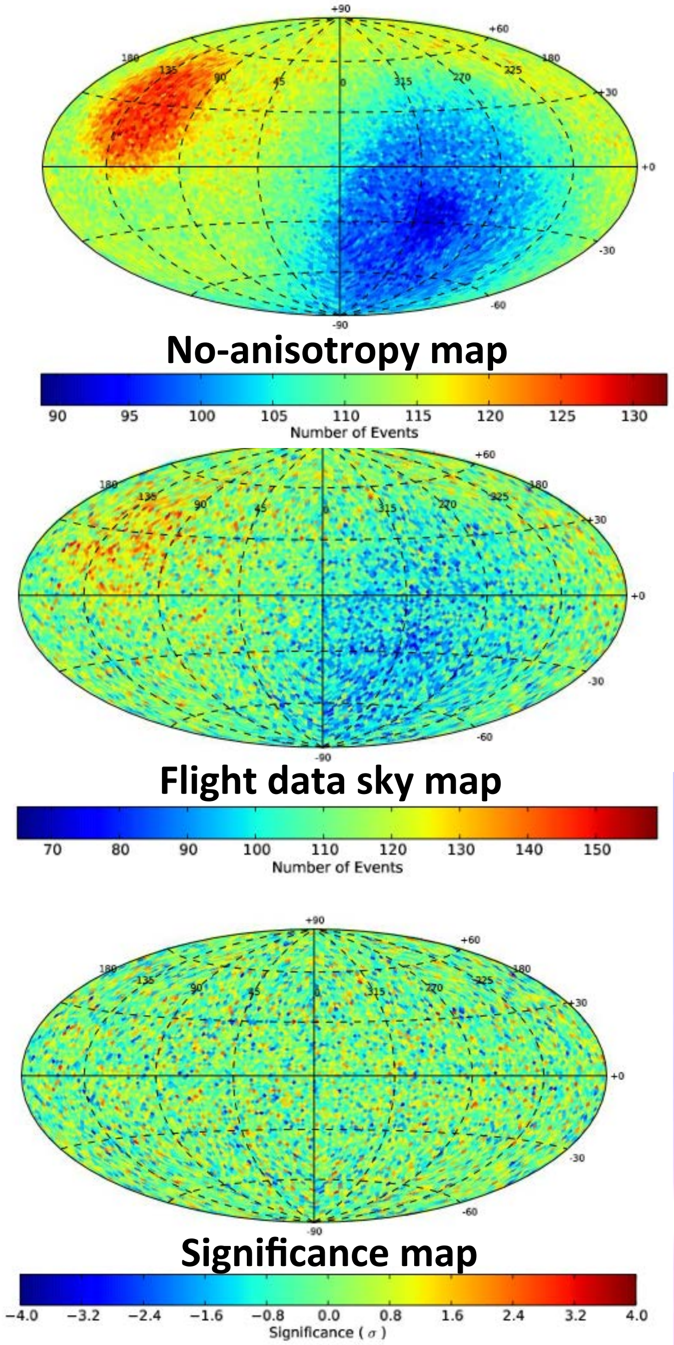




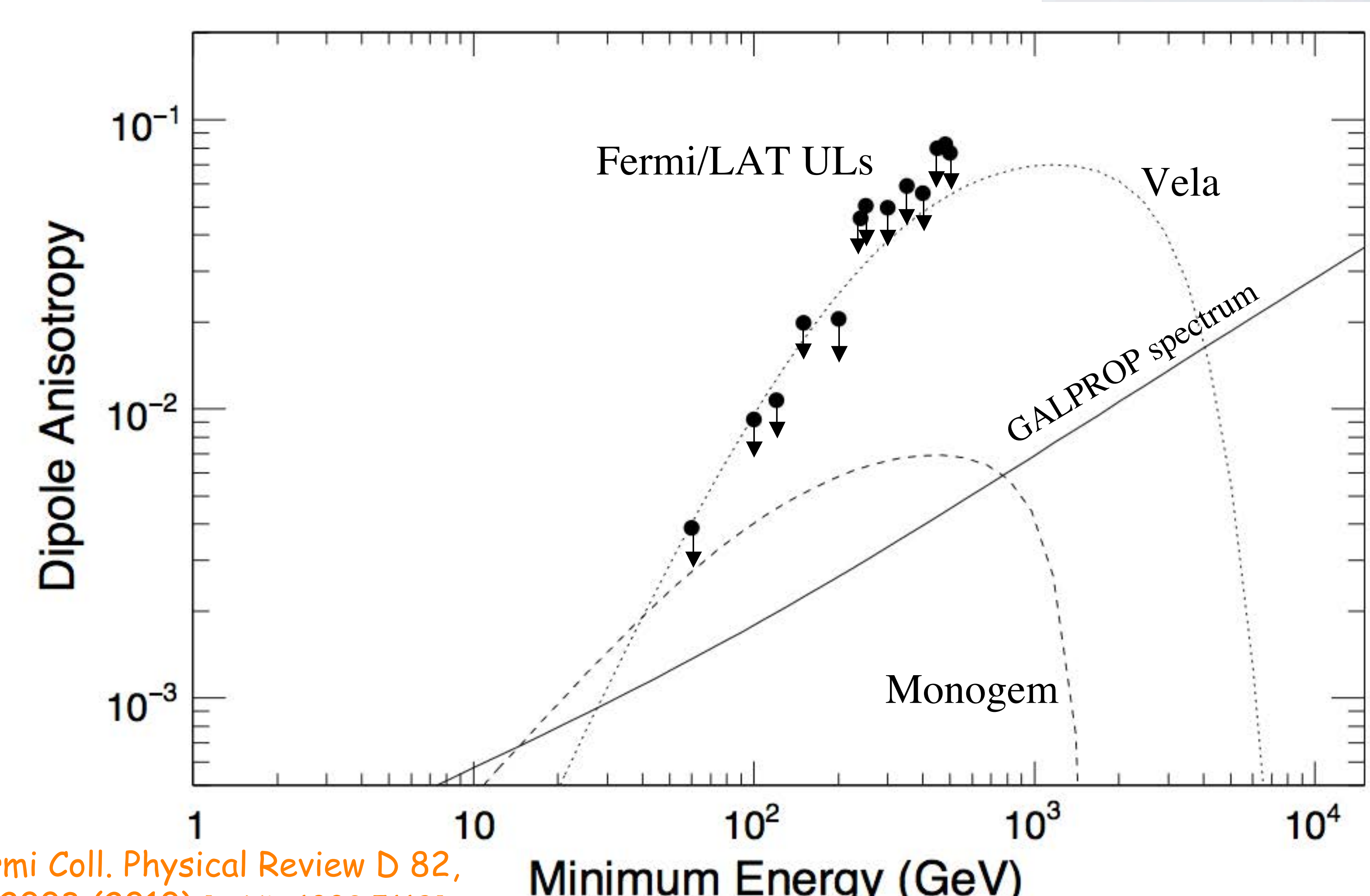


Are we turning everything to 11?

Cosmic Ray Electrons Anisotropy



<u>the levels of anisotropy expected for Geminga-like and Monogem-like sources</u> (i.e. sources with similar distances and ages) <u>seem to be higher than the scale of anisotropies excluded by the results</u>
However, it is worth to point out that the model results are affected by large uncertainties related to the choice of the free parameters



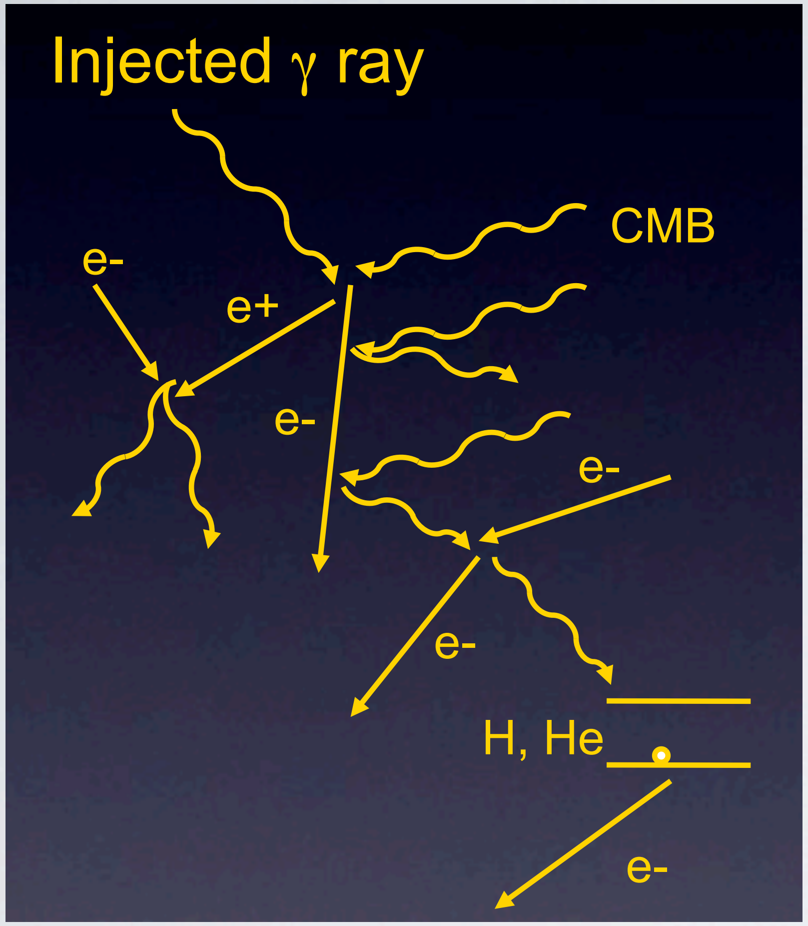
Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

PULSARS & POSITRONS

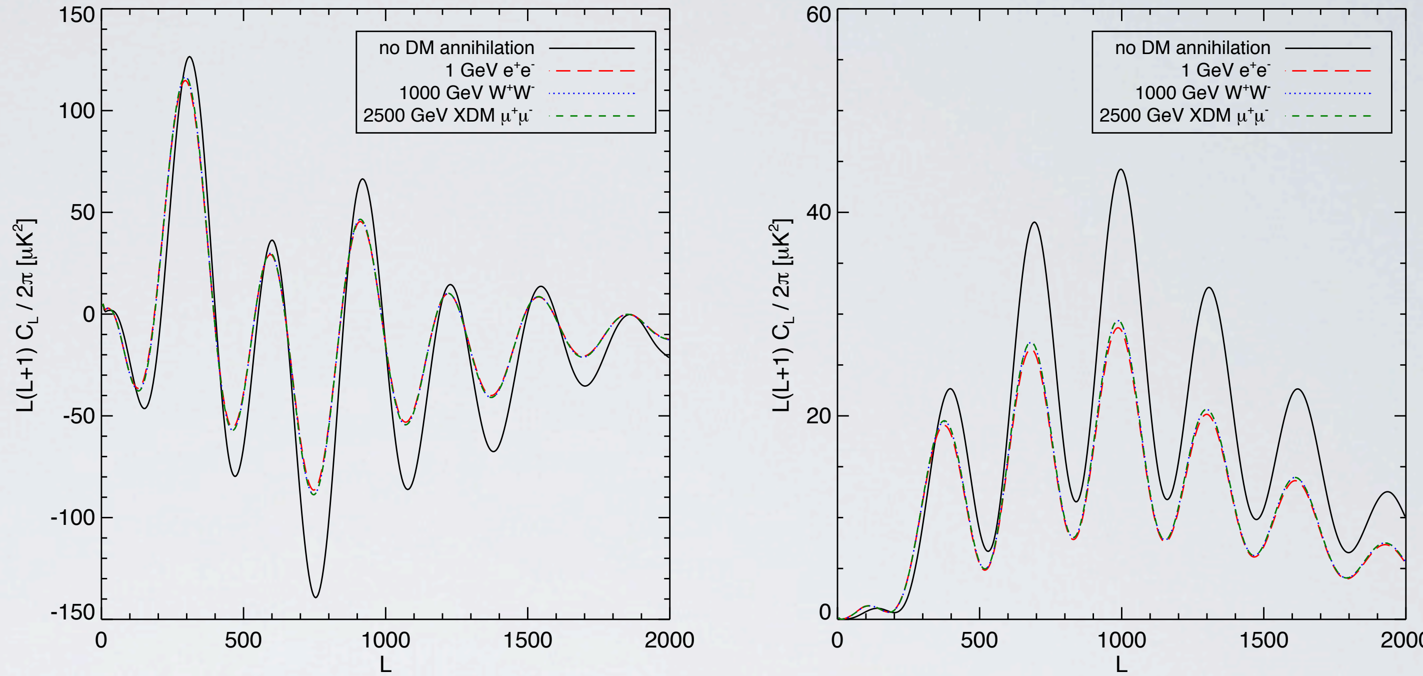
- Pulsars remain the best explanation of the PAMELA/ Fermi excess (i.e., we know there are pulsars and they make e+e-)
- They have not taken it upon themselves to demonstrate that they are, in fact, the origin (spectral breaks, anisotropies)

GIVE UP?

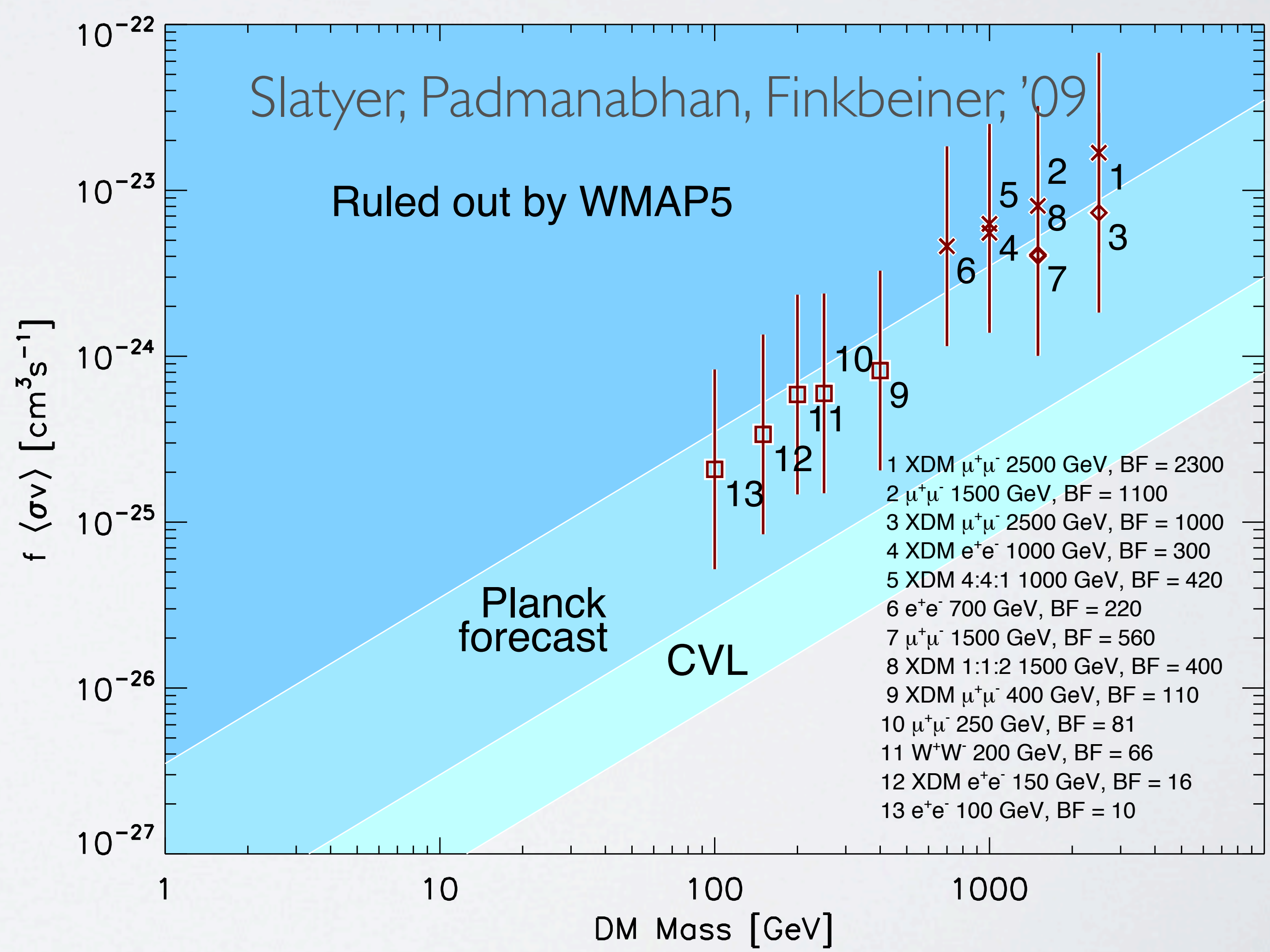
- Pulsars leading candidate - tough to prove
- Could still be DM - too important not to check
- Has *also* not taken advantage of opportunities to present itself (galactic center, diffuse background...)
- how do we test?



talk by T. Slatyer



Padmanabhan + Finkbeiner, '05; Galli, Bertone, Iocco, Melchiorri, '09; Slatyer, Padmanabhan, Finkbeiner, '09



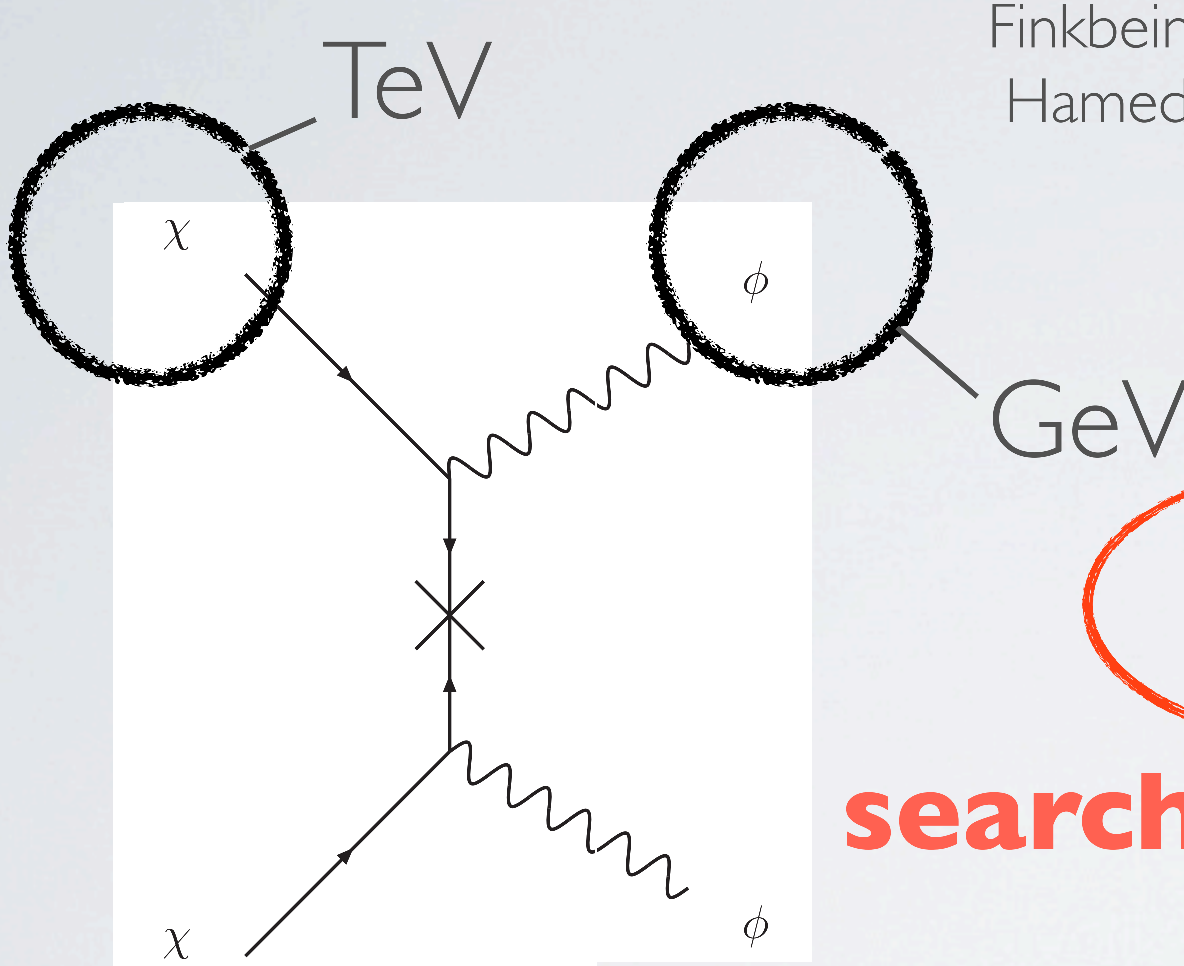
should have some result in 2013...

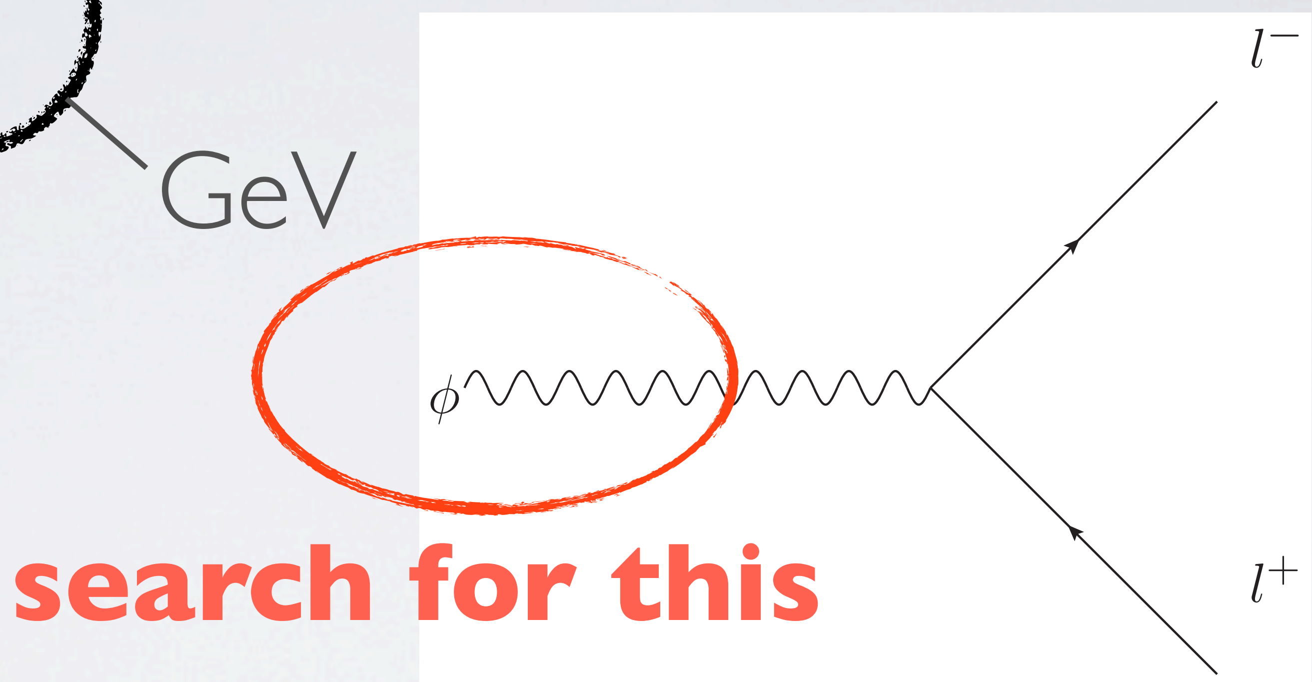
MODELS FOR PAMELA

- Dark Matter Explanations for PAMELA are tough
  - Large rates
  - Large rates *into e+e-*
  - *Low* rates into antiprotons

DARK FORCE MODELS

Finkbeiner+NW '07; Pospelov, Ritz, Voloshin '08; Arkani-Hamed, Finkbeiner, Slatyer, NW '09; Pospelov+Ritz '09; Nomura+Thaler '09

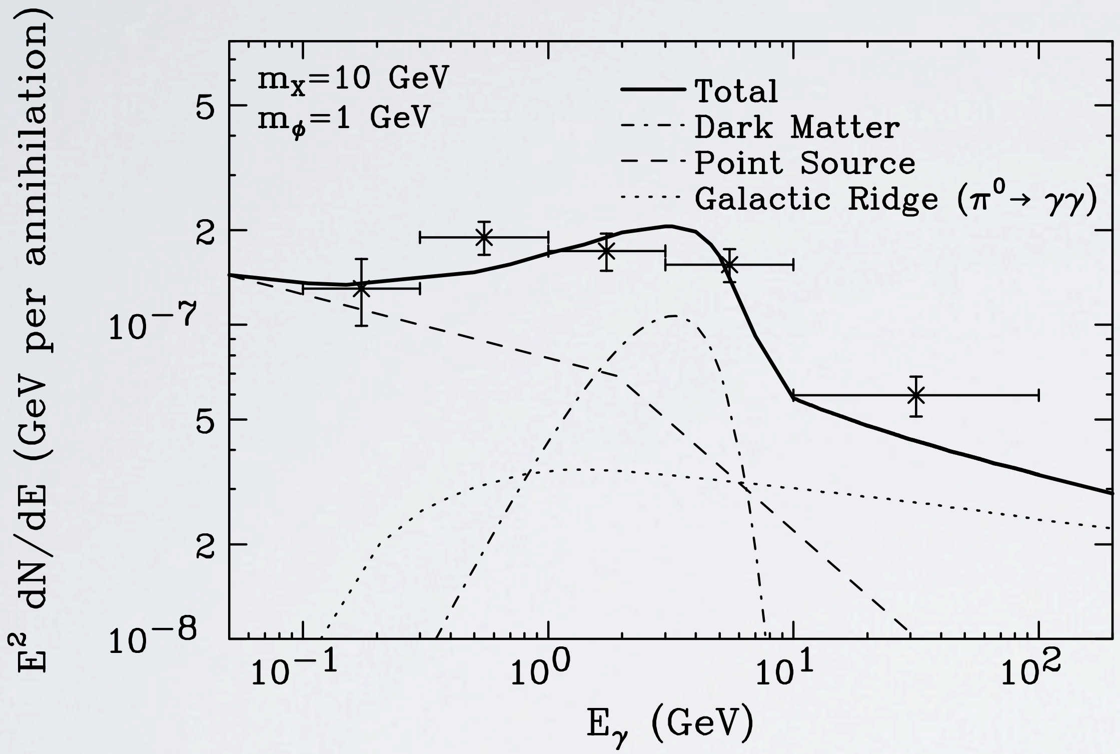


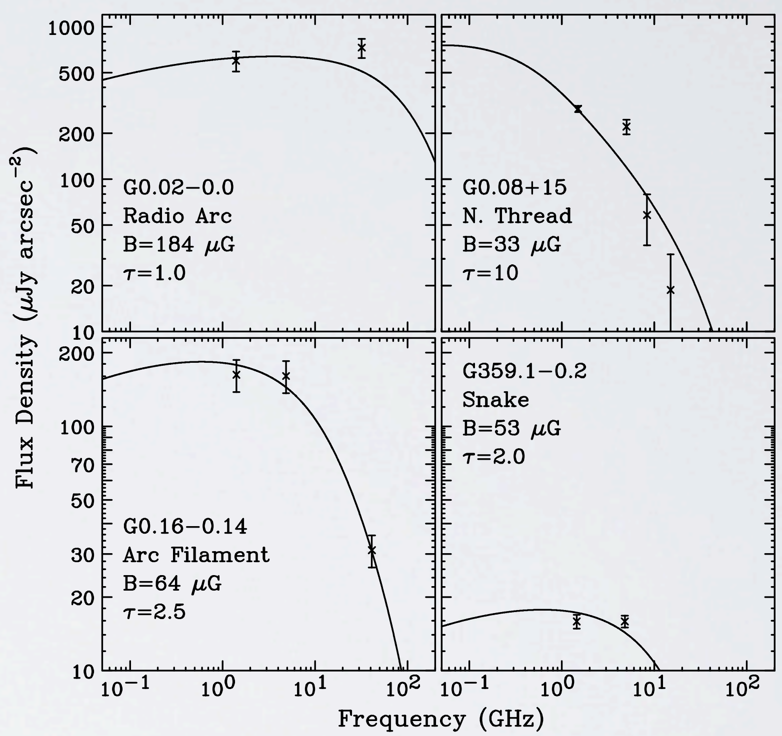


generates hard leptons by annihilations into a light mediator, no anti-protons

Realization: We are amazingly ignorant of weakly coupled GeV scale physics!

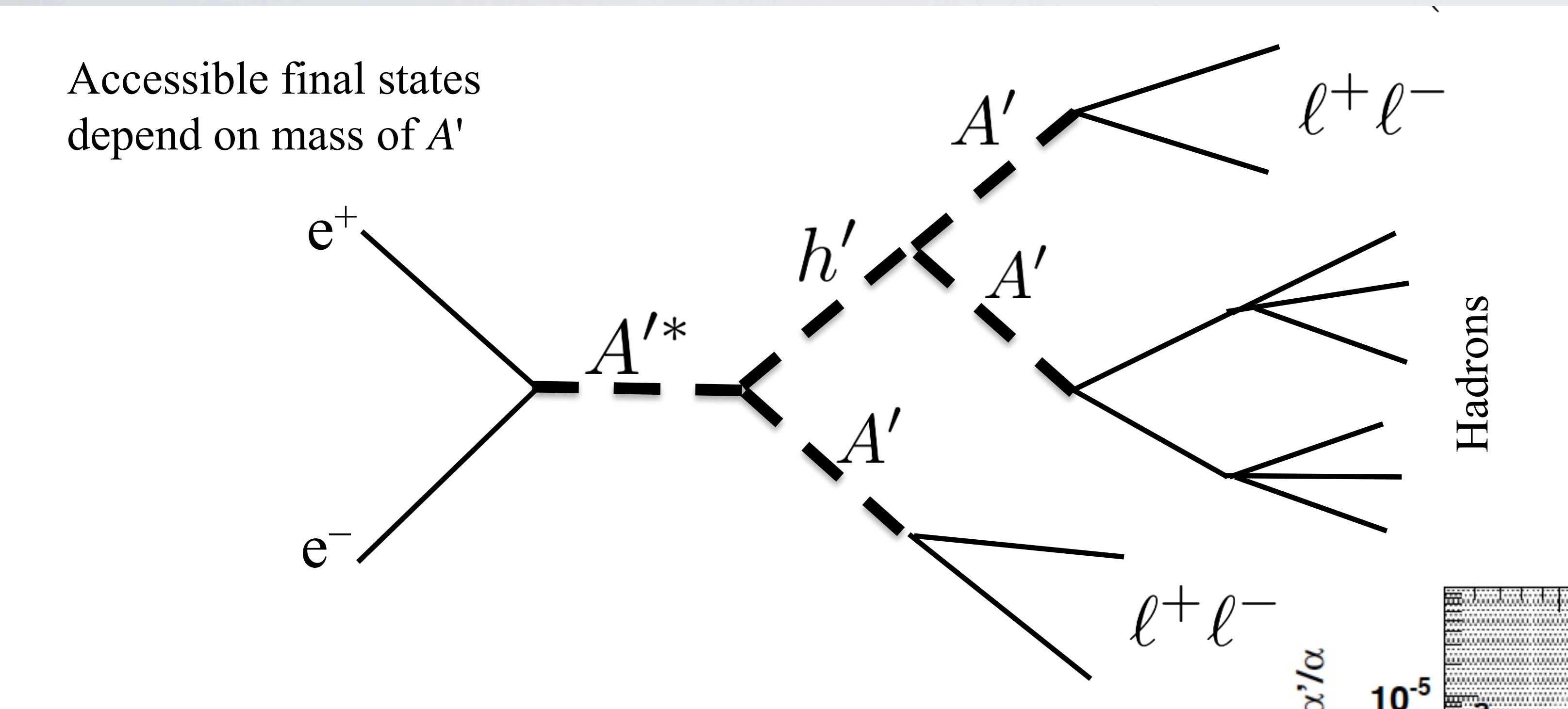
OTHER MOTIVATIONS FOR LIGHT DARK FORCES



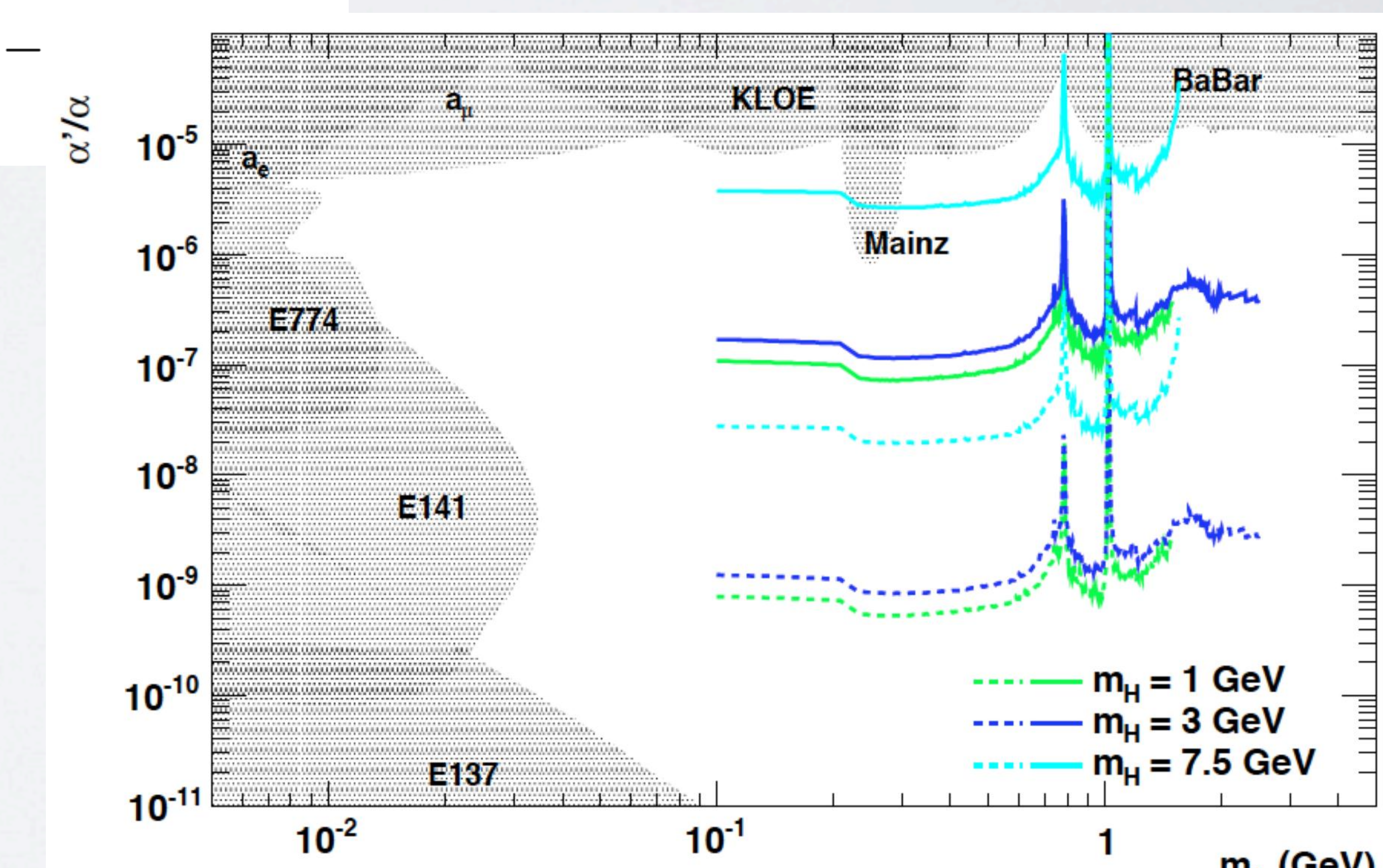


Goodenough, Hooper; Hooper + Linden;...

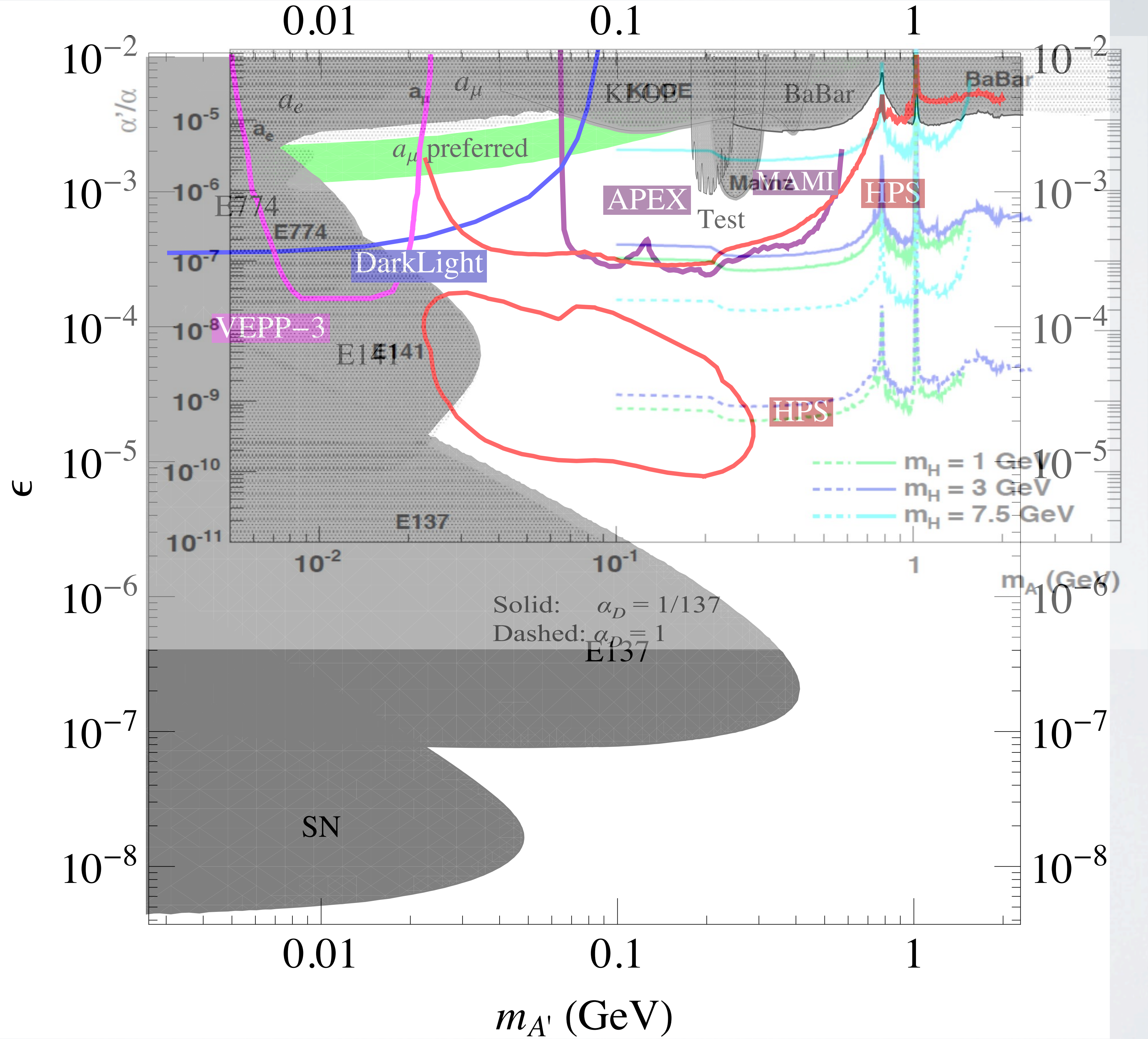
A NEW CONNECTION TO DARK MATTER: DARK FORCES



Talk by Bevan
BaBar searches

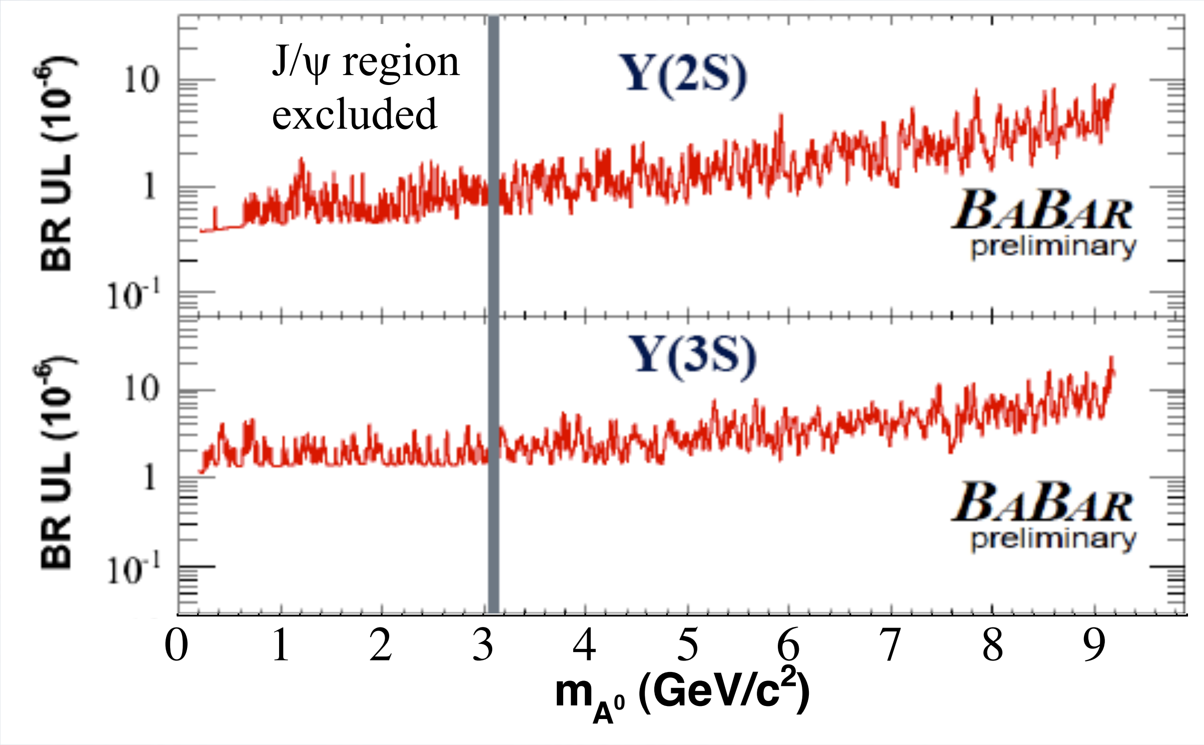


Solid: $\alpha_D = 1/137$
Dashed: $\alpha_D = 1$



a_e
a_μ
a_μ preferred
KLOE
BaBar
APEX
MAMI
Mainz
Test
HPS
DarkLight
VEPP−3
E774
E141
E137
HPS
m_H = 1 GeV
m_H = 3 GeV
m_H = 7.5 GeV
Solid: $\alpha_D = 1/137$
Dashed: $\alpha_D = 1$
E137
SN
ϵ
α'/α
$m_{A'}$ (GeV)
$m_{A'}$ (GeV)

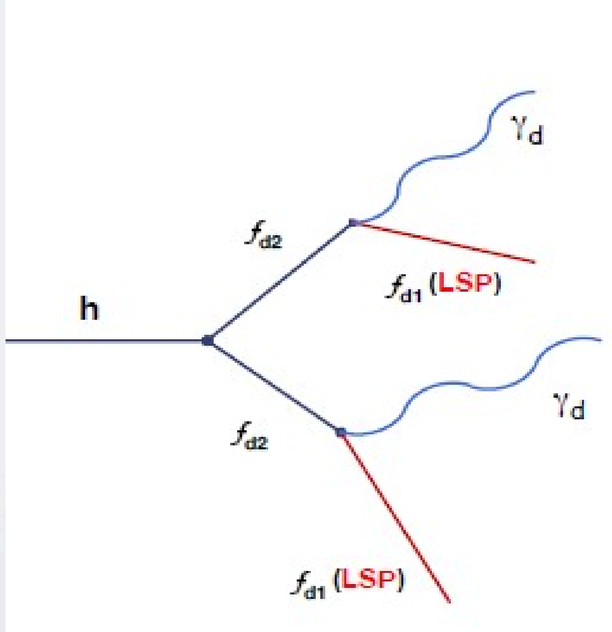
$BF(\Upsilon(1S)\to\gamma A^0)*BF(A^0\to\mu\mu) < (0.3\text{–}10)*10^{-6}$ for $0.2<m_{A0}<9.2$ GeV

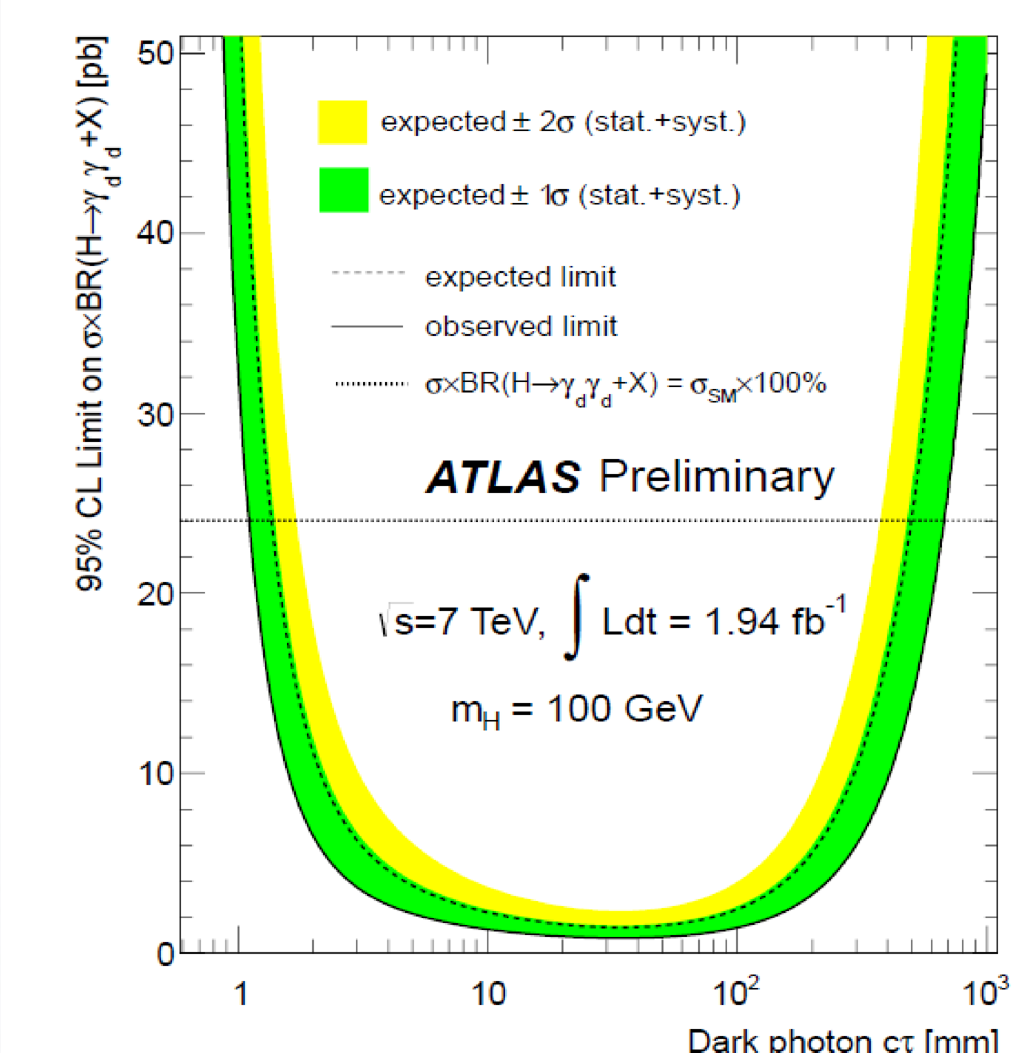


Talk by Y Kolomensky

Talk by A. Haas

“Lepton-jet”:
collimated group of electrons, muons, pions from decay to a new, light hidden-sector particles (“dark-photon”)





POSITRONS AND DARK FORCES

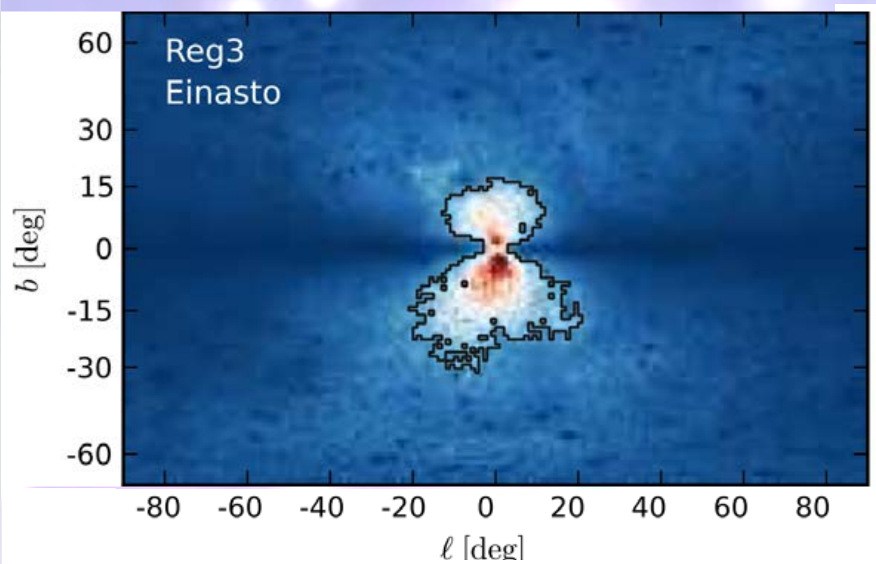
- the PAMELA excess is challenging to achieve with dark matter, but viable scenarios exist
- hasn’t shown up elsewhere yet
- CMB test (hopefully) in 2013
- Dark forces easy to come by, esp in SUSY theories => should keep looking regardless

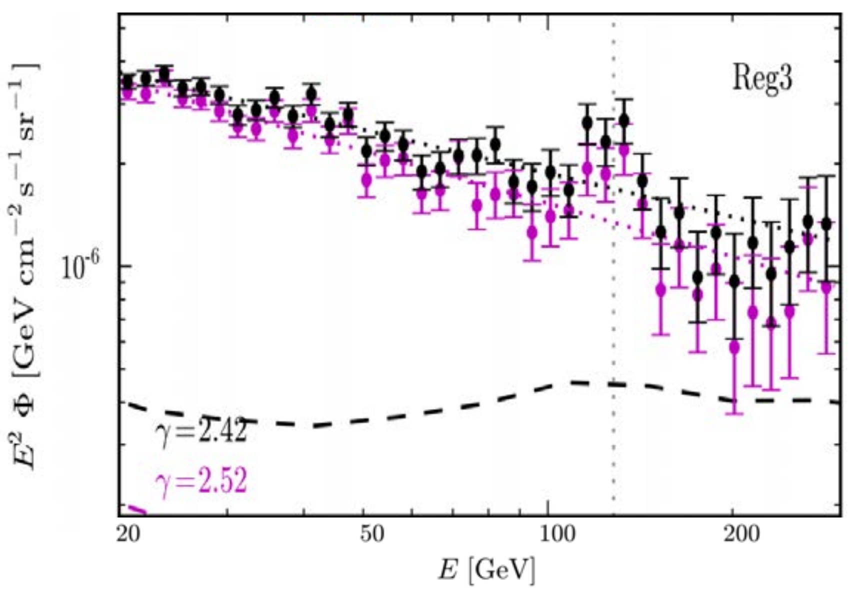
POSITRONS ARE TOO MESSY

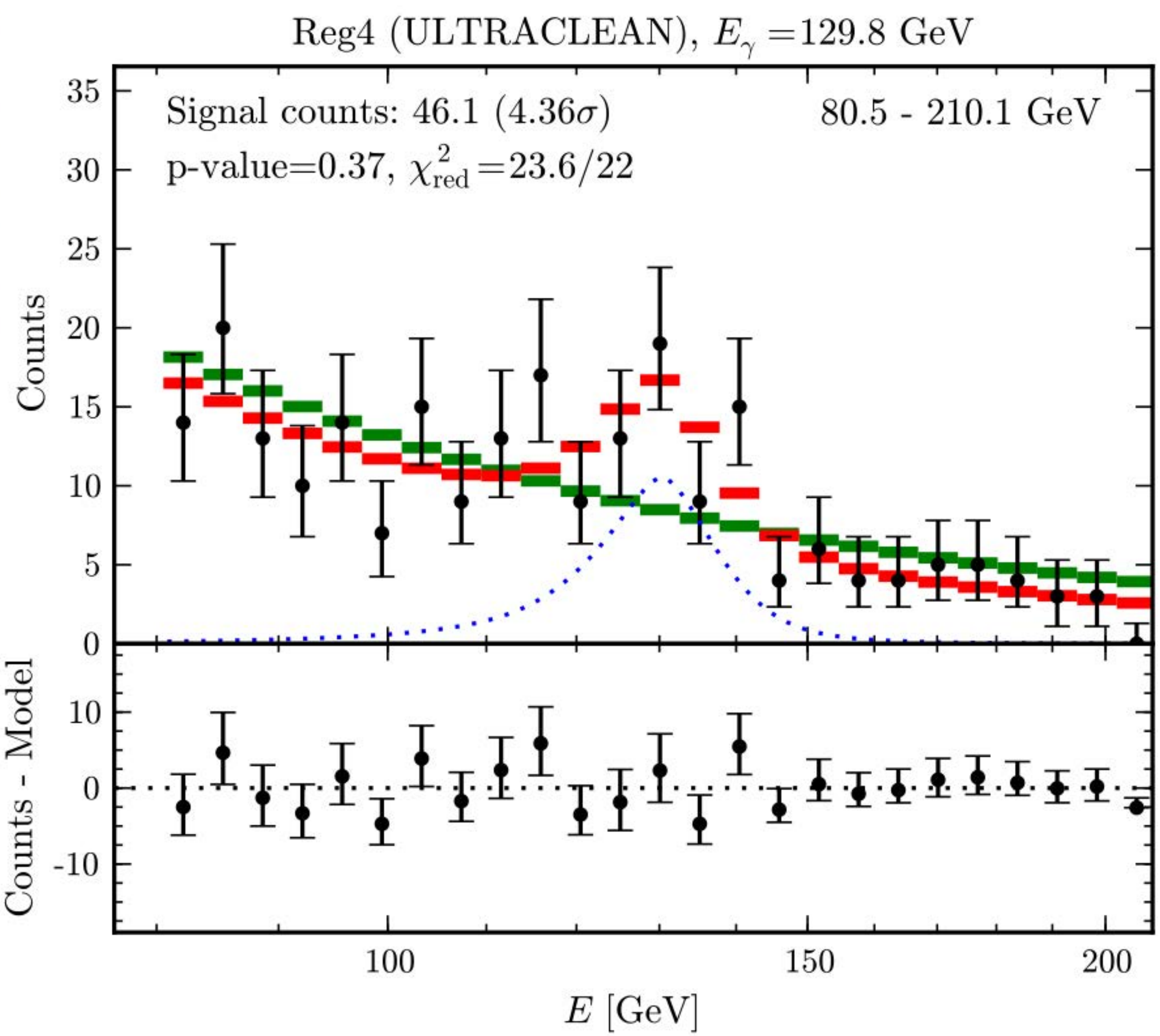
“The only really convincing signal of DM would be a monoenergetic line. Nothing can fake that.”

- Almost everyone

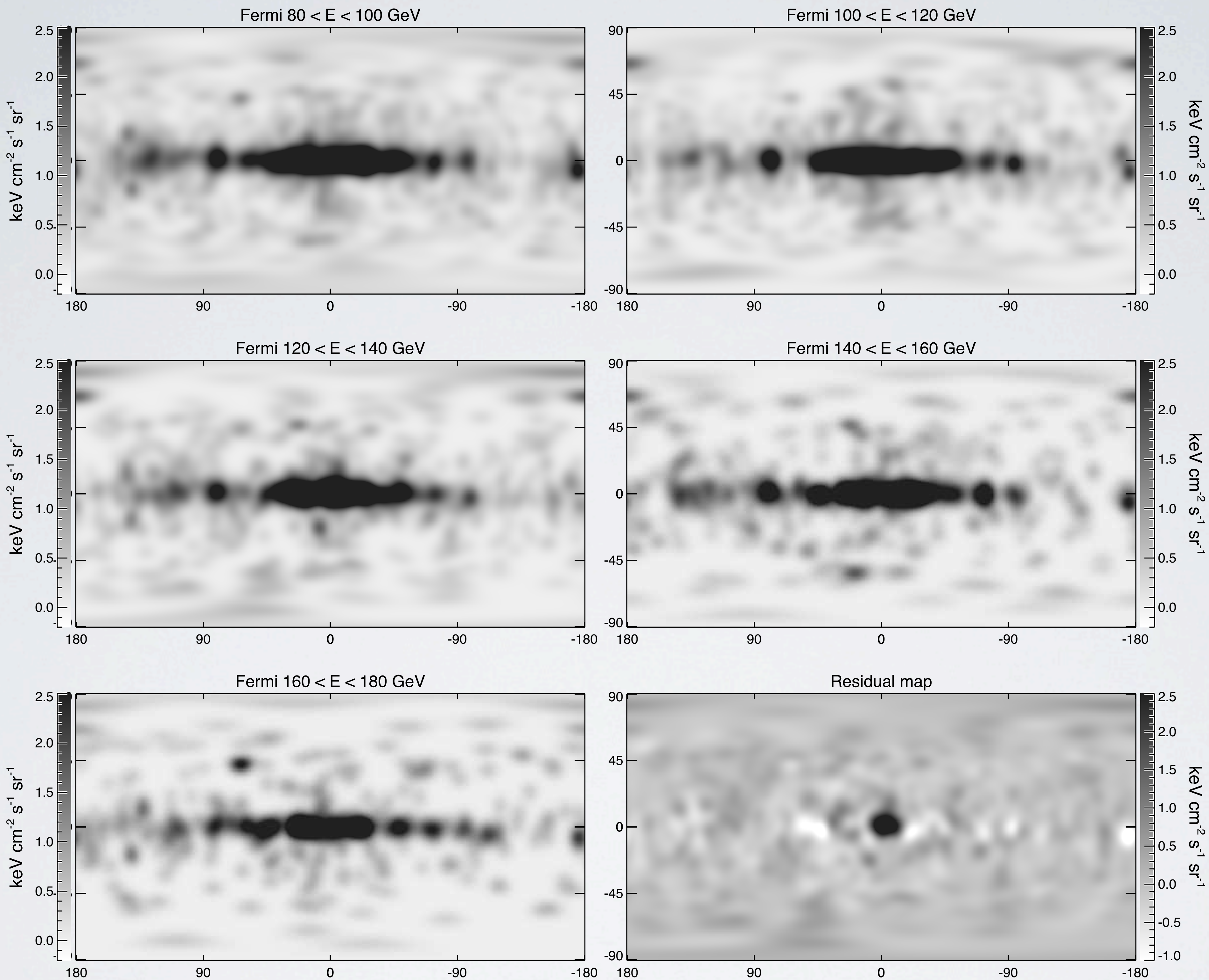
A line at ~ 130 GeV ?





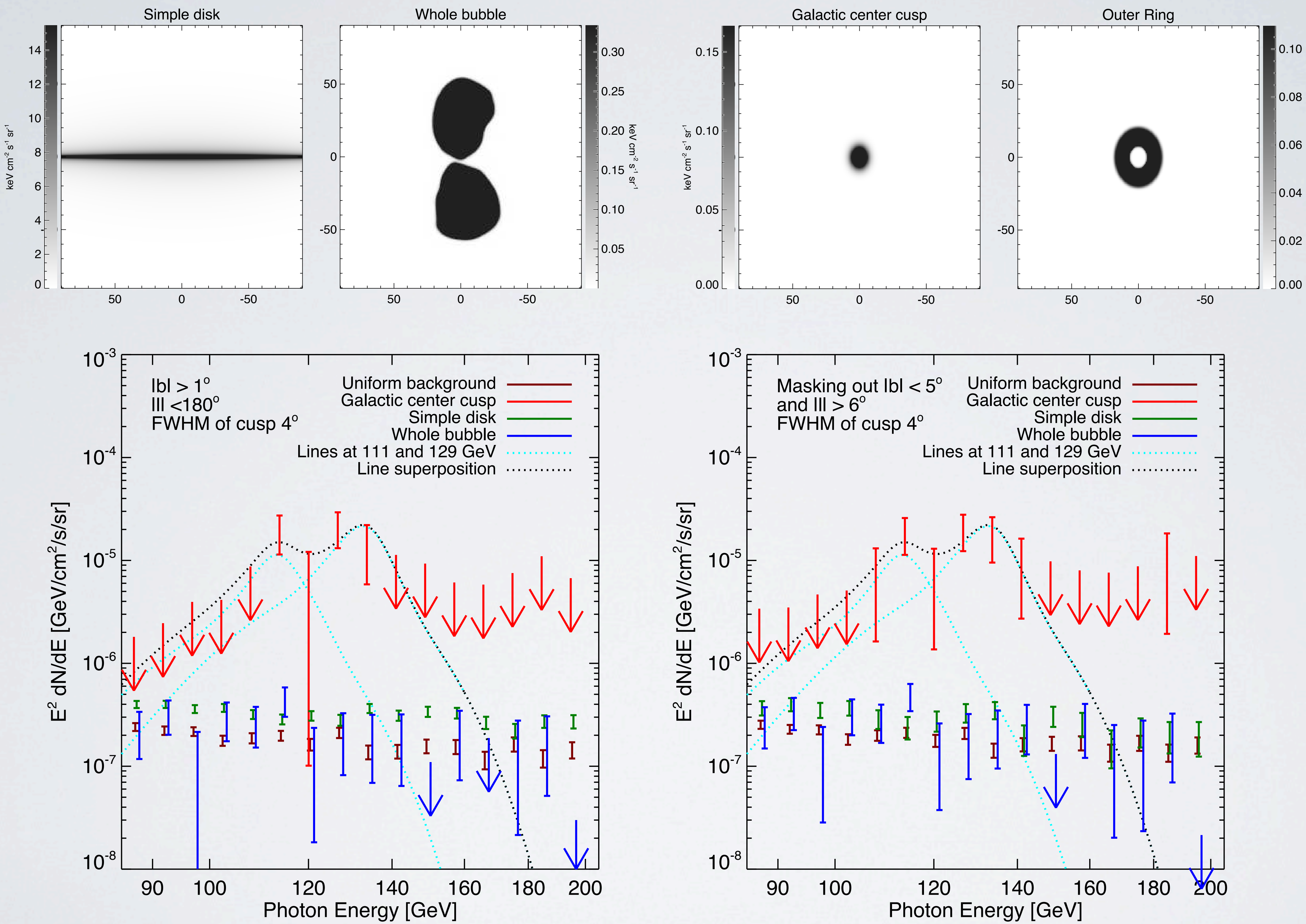


Bringmann et al '12; Weniger '12; Tempel, Hektor, Raidal '12; Linden + Profumo '12; Boyarsky, Malyshev, Ruchayski '12; Finkbeiner + Su '12



Finkbeiner + Su '12

Template Analysis



Two lines?

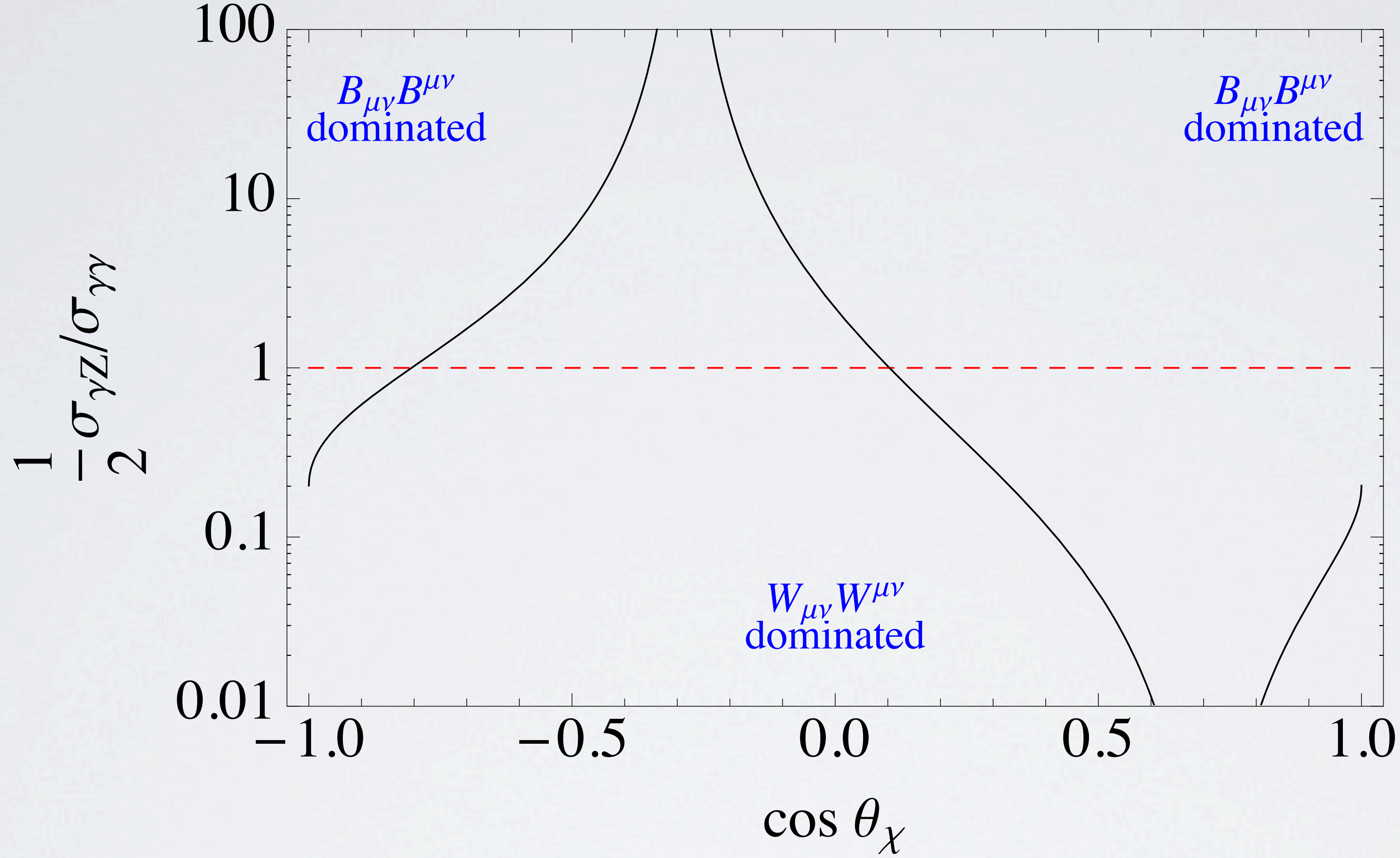
YOU ACTUALLY EXPECT TWO LINES

$$\mathcal{L} = \frac{1}{4\Lambda_R^3} \Big\{ \bar{\chi}\chi \left(\cos\theta_\chi B_{\mu\nu}B^{\mu\nu} + \sin\theta_\chi \mathrm{Tr}W_{\mu\nu}W^{\mu\nu}\right) + i\,\bar{\chi}\gamma_5\chi \left(\cos\theta_\chi B_{\mu\nu}\tilde{B}^{\mu\nu} + \sin\theta_\chi \mathrm{Tr}W_{\mu\nu}\tilde{W}^{\mu\nu}\right)\Big\}$$

effective theory of DM-> photons   Yavin+NW

contain both Z and photon;
expect ***γγ*** and ***γ***Z

YOU ACTUALLY EXPECT TWO LINES

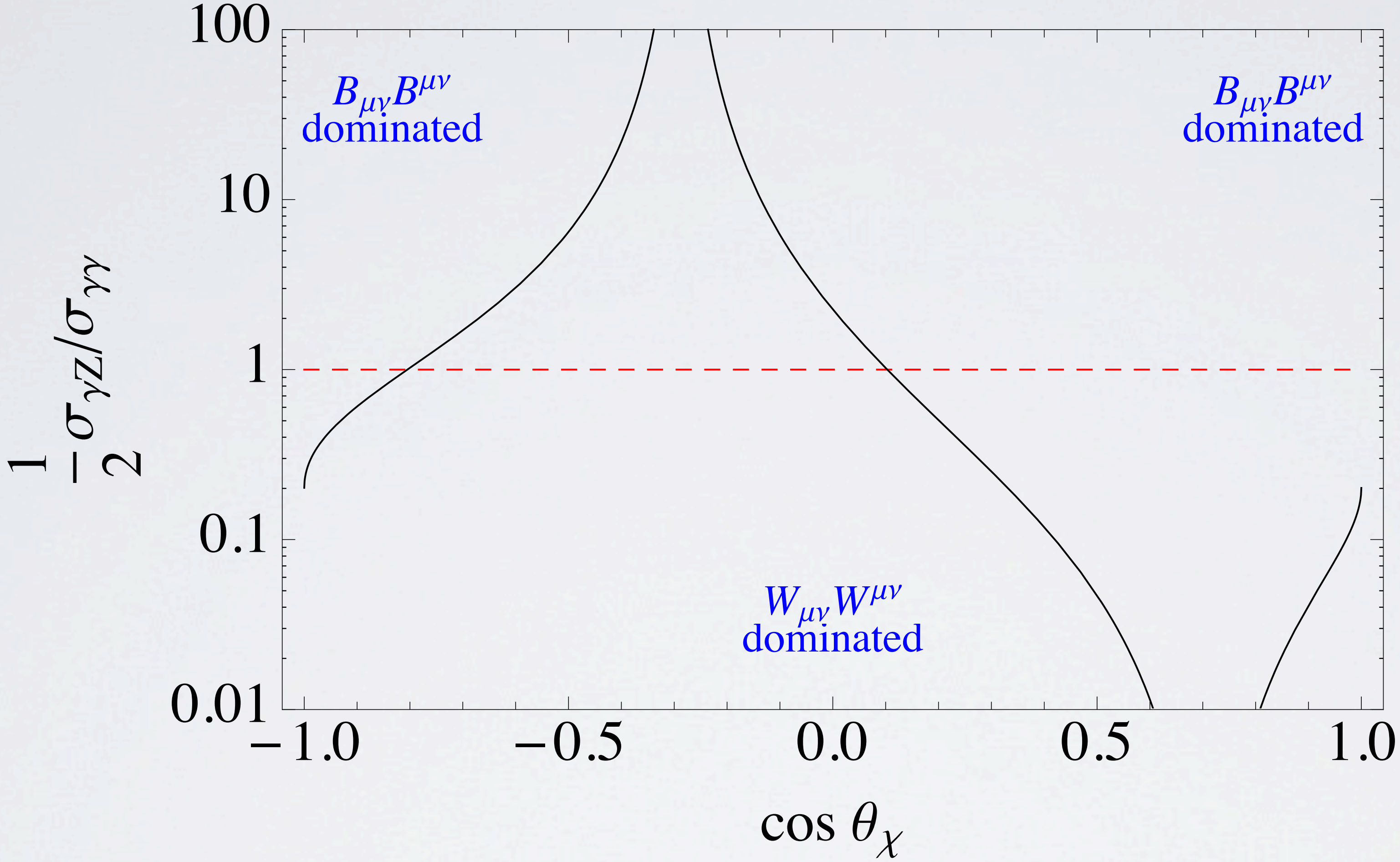


Yavin+NW

$$\mathcal{L} = \frac{1}{4\Lambda_R^3} \left\{ \bar{\chi}\chi \left(\cos\theta_\chi B_{\mu\nu}B^{\mu\nu} + \sin\theta_\chi \mathrm{Tr} W_{\mu\nu}W^{\mu\nu}\right) + i\,\bar{\chi}\gamma_5\chi \left(\cos\theta_\chi B_{\mu\nu}\tilde{B}^{\mu\nu} + \sin\theta_\chi \mathrm{Tr} W_{\mu\nu}\tilde{W}^{\mu\nu}\right)\right\}$$

effective theory of DM-> photons

YOU ACTUALLY EXPECT TWO LINES

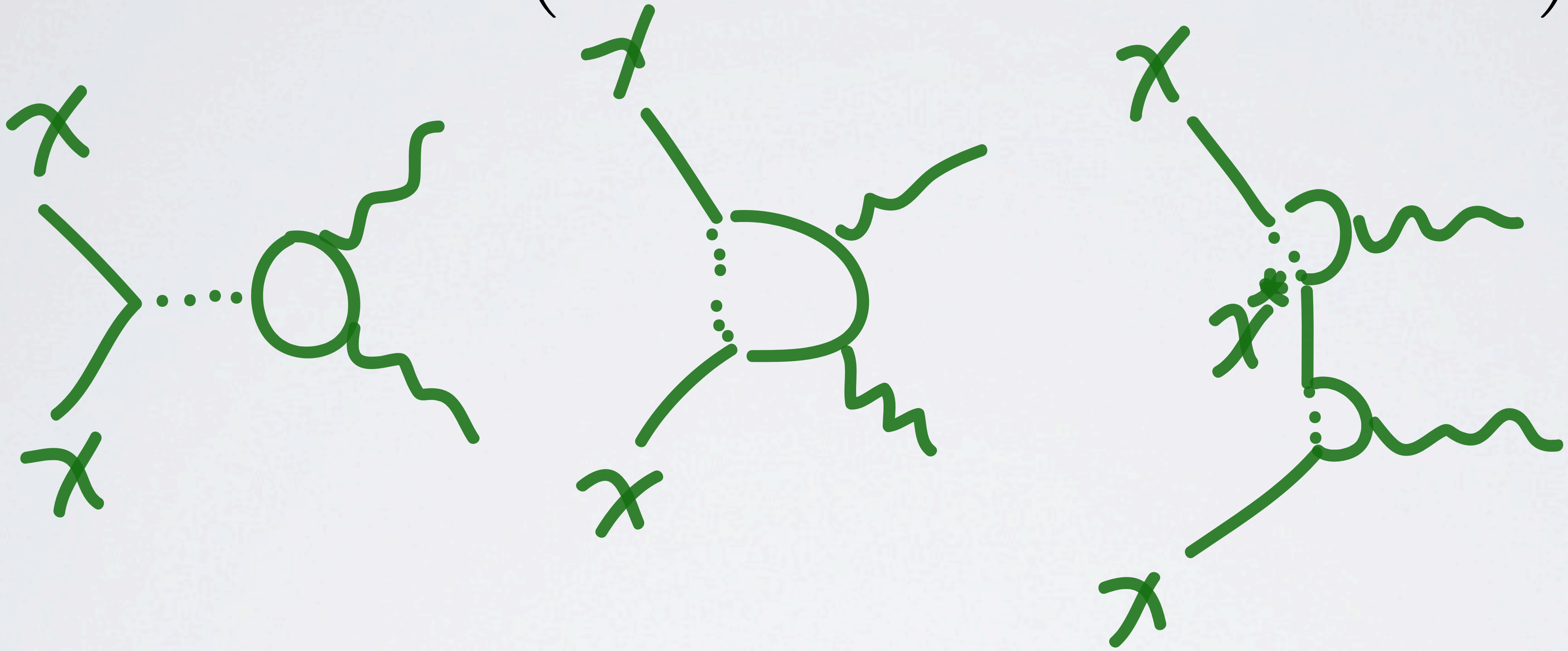


Yavin+NW

$$\mathcal{L} = \frac{1}{4\Lambda_R^3} \left\{\bar{\chi}\chi\left(\cos\theta_\chi B_{\mu\nu}B^{\mu\nu} + \sin\theta_\chi \mathrm{Tr}W_{\mu\nu}W^{\mu\nu}\right) + i\,\bar{\chi}\gamma_5\chi\left(\cos\theta_\chi B_{\mu\nu}\tilde{B}^{\mu\nu} + \sin\theta_\chi \mathrm{Tr}W_{\mu\nu}\tilde{W}^{\mu\nu}\right)\right\}$$

effective theory of DM-> photons

$$\mathcal{L} = \frac{1}{4\Lambda_R^3} \left\{ \bar{\chi}\chi \left(\cos\theta_\chi B_{\mu\nu}B^{\mu\nu} + \sin\theta_\chi \mathrm{Tr}W_{\mu\nu}W^{\mu\nu} \right) + i\,\bar{\chi}\gamma_5\chi \left(\cos\theta_\chi B_{\mu\nu}\tilde{B}^{\mu\nu} + \sin\theta_\chi \mathrm{Tr}W_{\mu\nu}\tilde{W}^{\mu\nu} \right) \right\}$$



Yavin+NW

New physics scale of 400-500 GeV =>
should be weakly coupled ~ 100 GeV/
Strongly coupled ~ 500 GeV

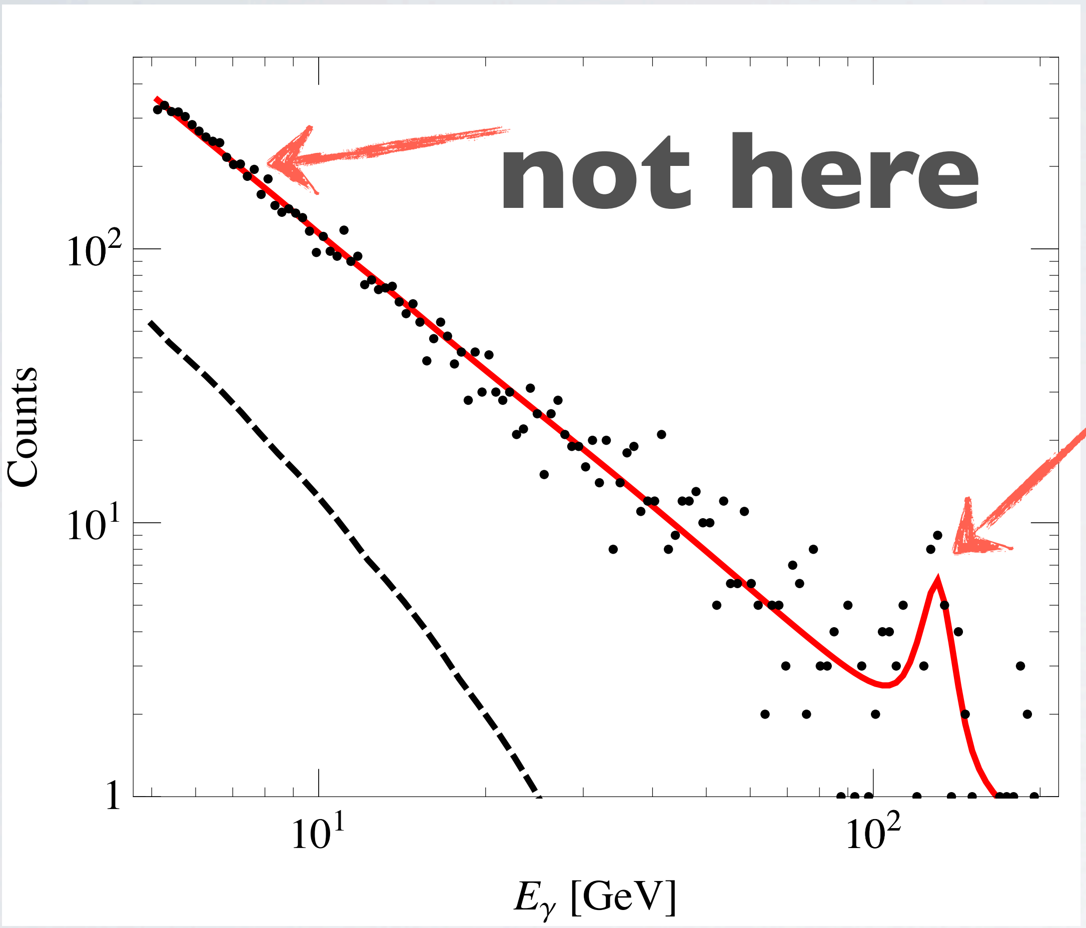
effective theory of DM-> photons

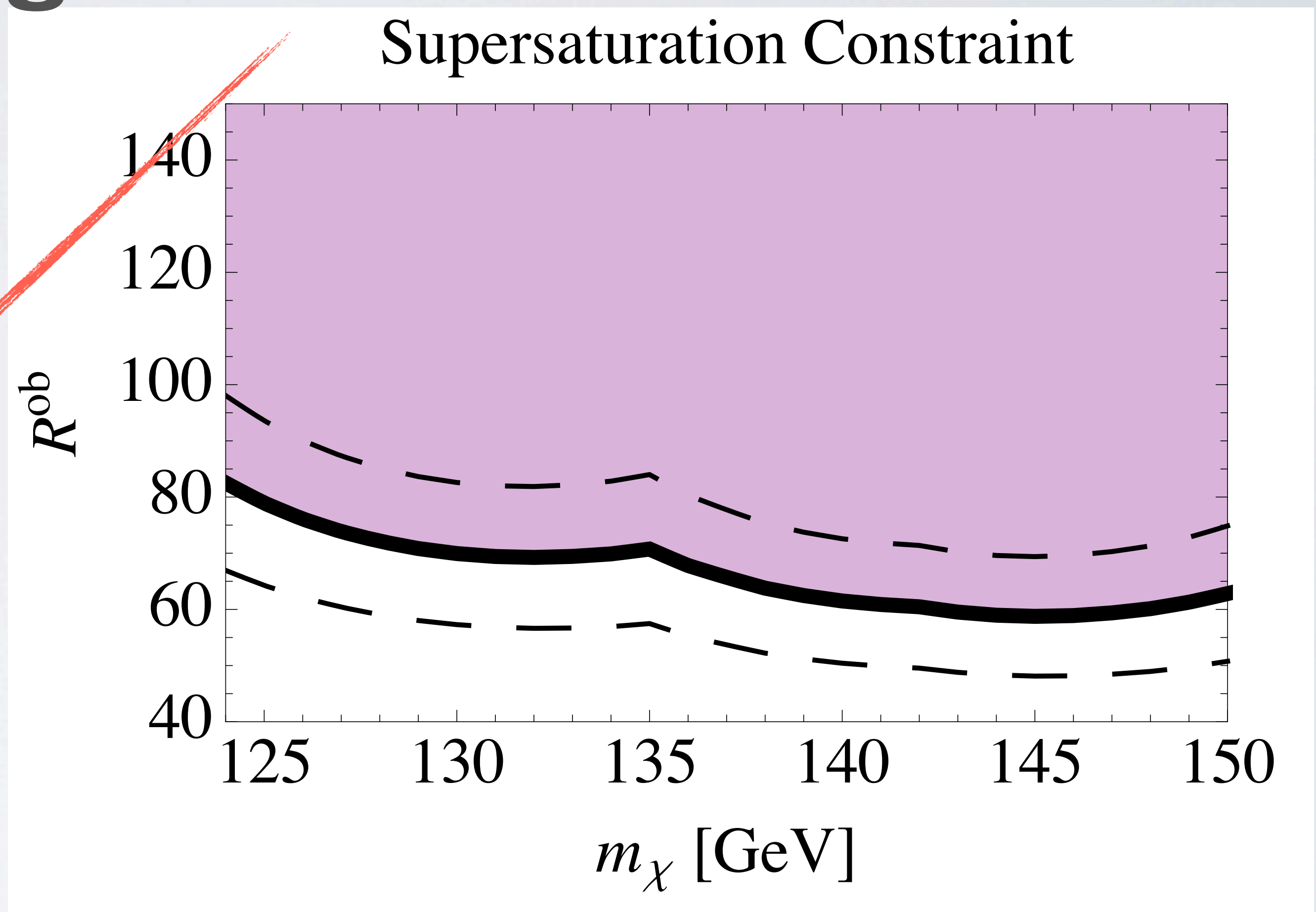
CONSTRAINTS

$$R^{\rm th} \equiv \frac{\sigma_{\rm ann}}{2\,\sigma_{\gamma\gamma} + \sigma_{\gamma Z}},$$

Cohen, Lisanti, Slatyer & Wacker; Buchmuller + Garney; Cholis, Tavakoli, Ulio;

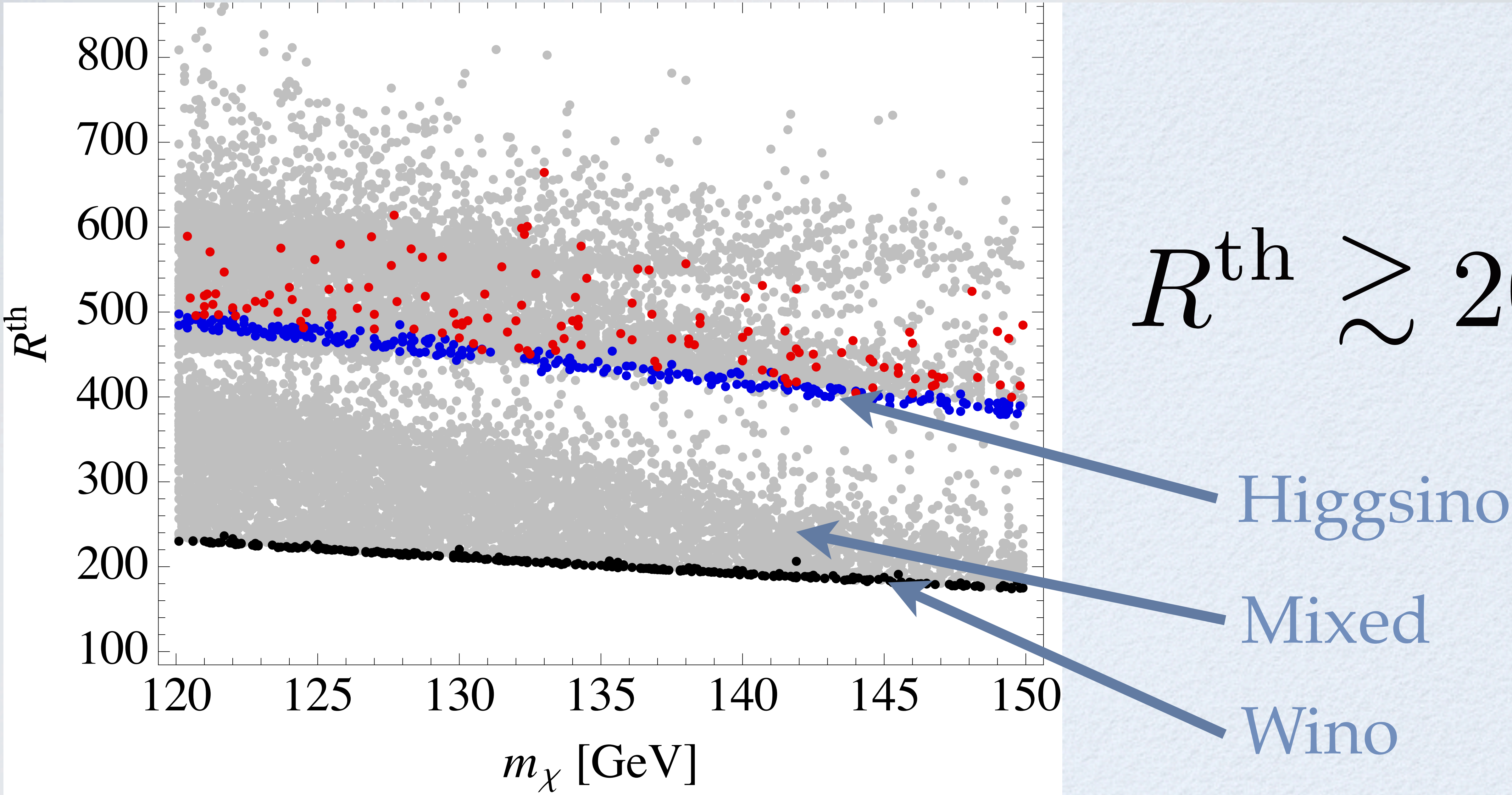
want a signal here





No astrophysical uncertainties!

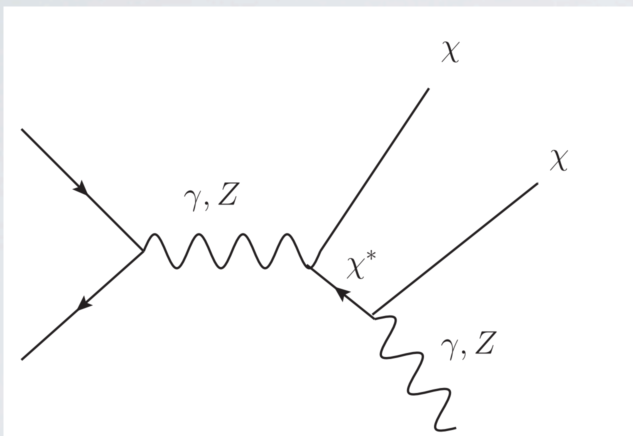
Models with sizable tree-level annihilation cannot yield this signal



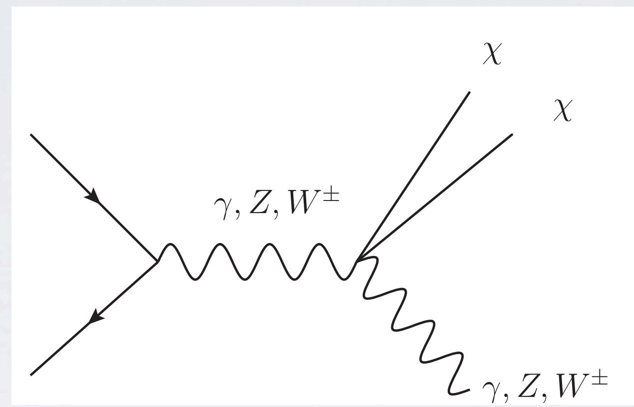
$$R^{\rm th} \gtrsim 200$$

Models with sizable tree-level annihilation cannot yield this signal

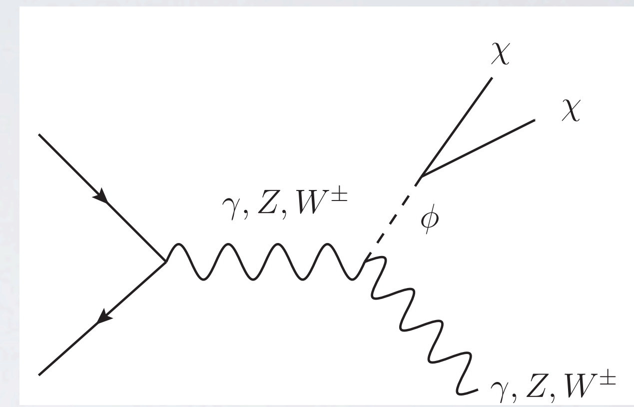
MONOPHOTON/JET SEARCHES



(a) MiDM



(b) RayDM



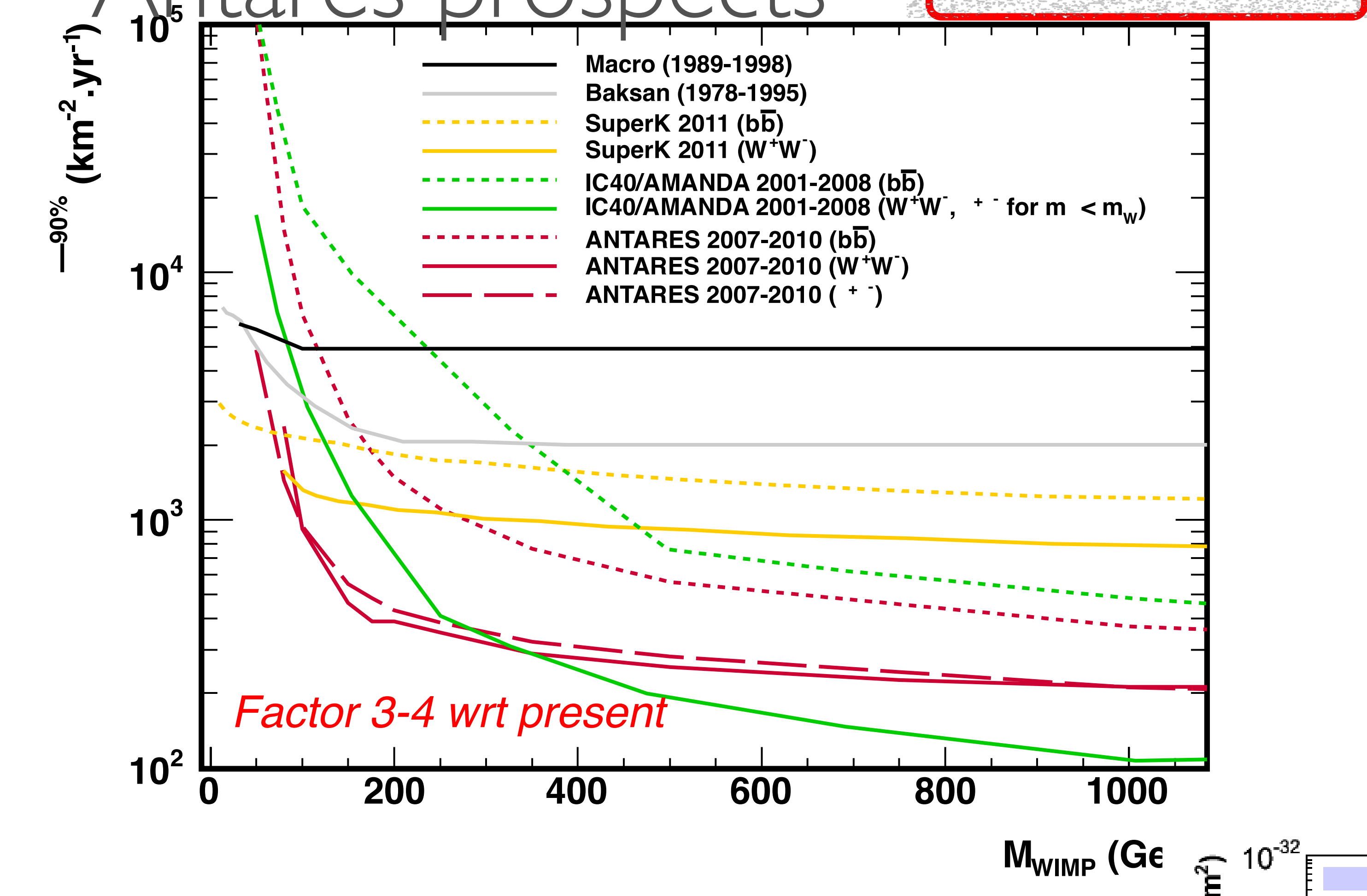
(c) ϕFF

Yavin+NW

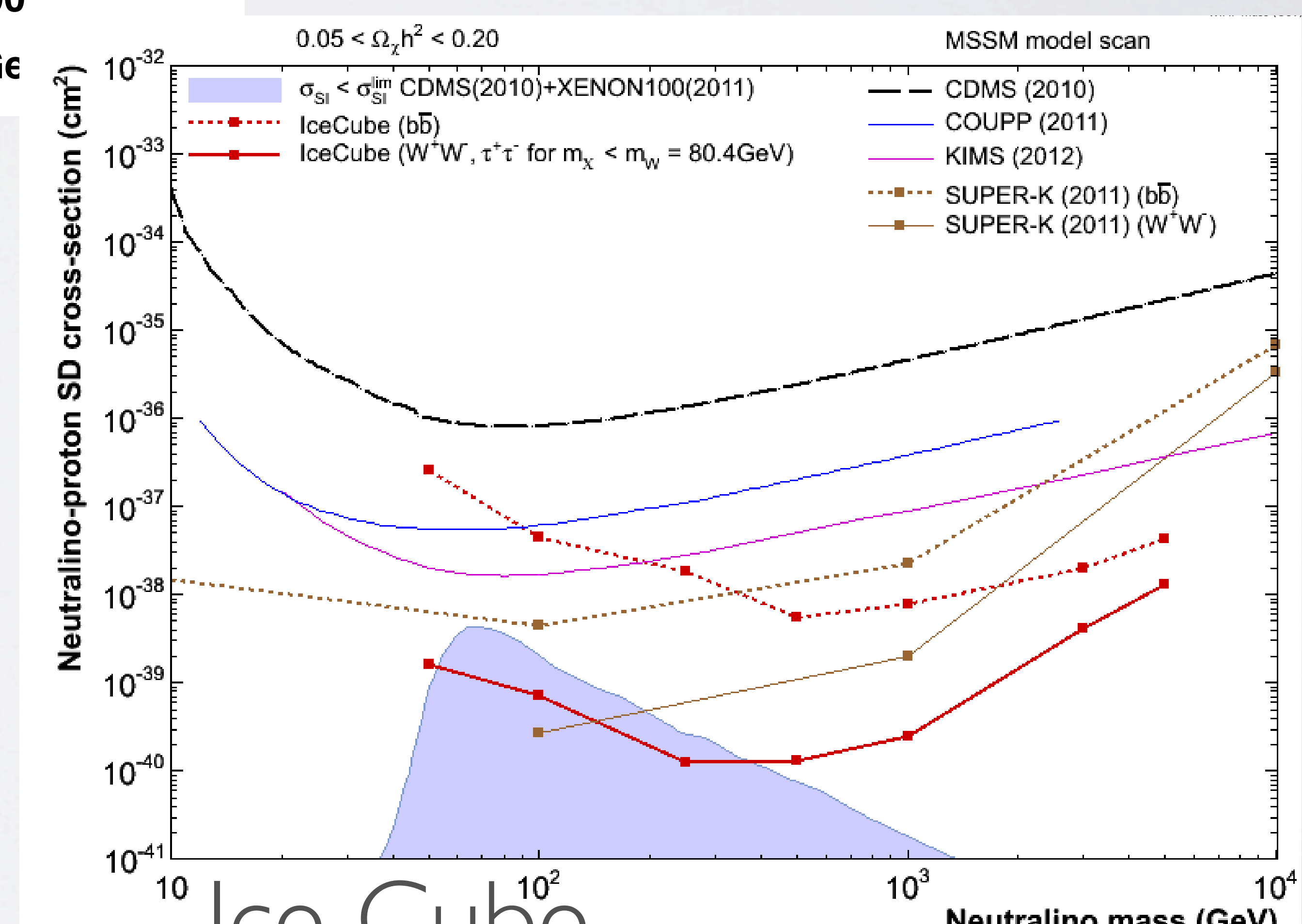
detection is model dependent

YOU DON'T HAVE TO BELIEVE IN ANOMALIES TO BE EXCITED ABOUT INDIRECT SEARCHES

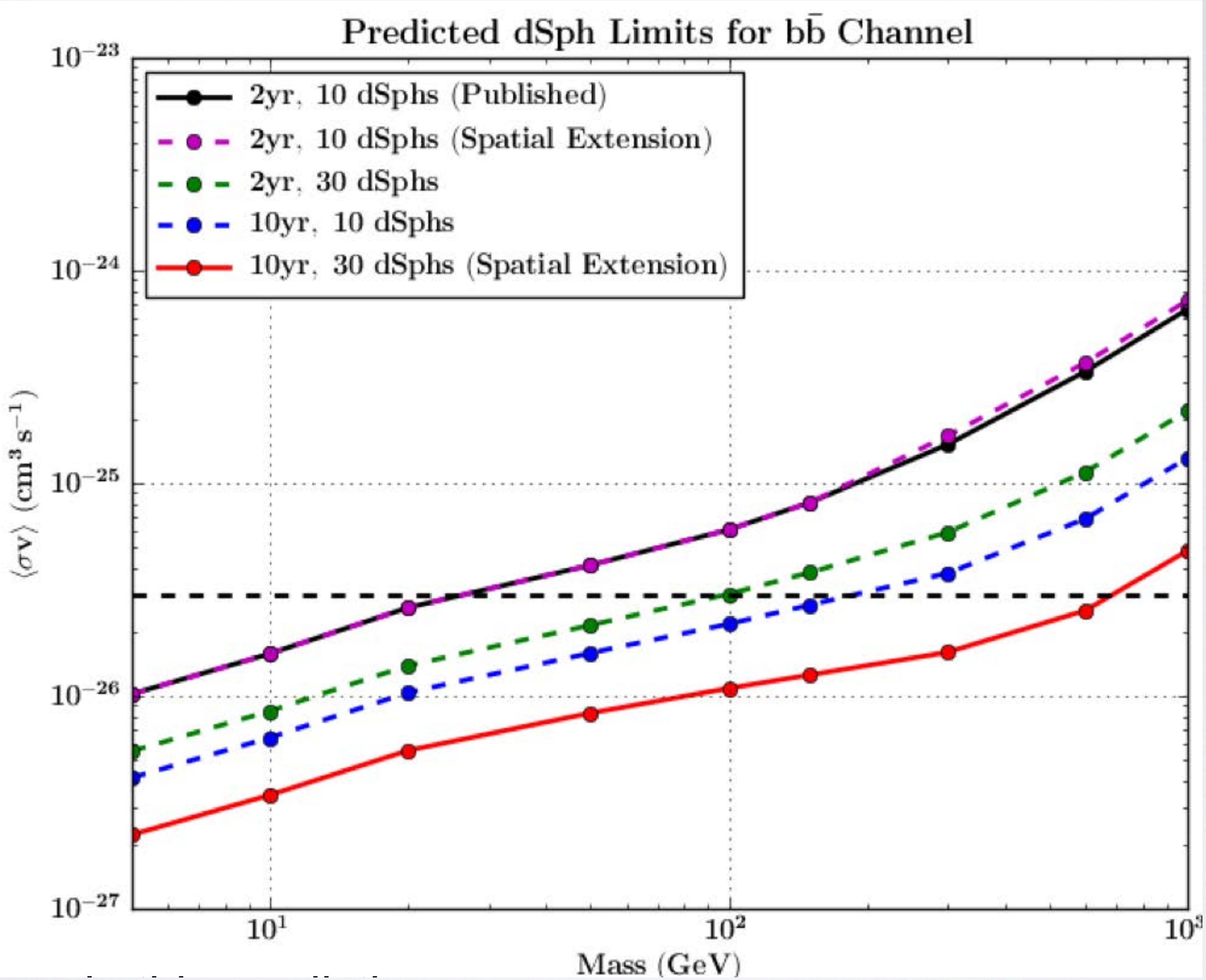
Antares prospects



Strong constraints on models with smaller SI couplings



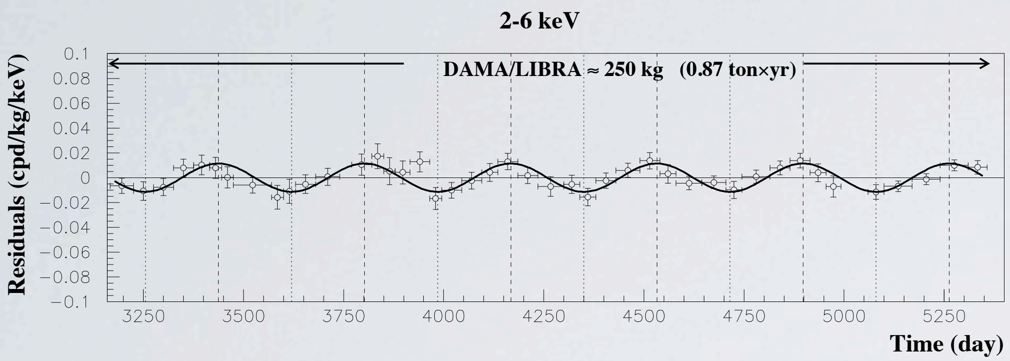
Ice Cube

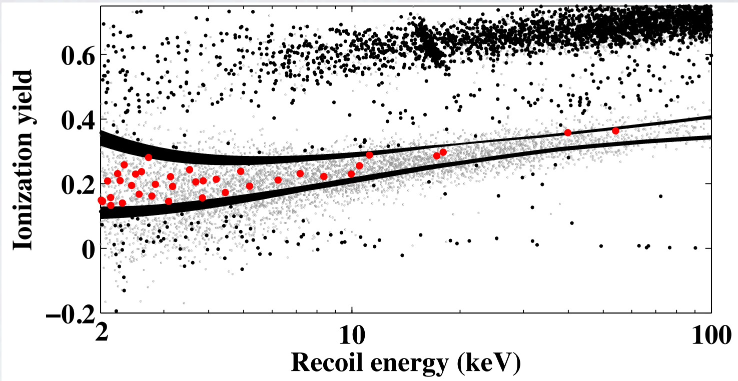


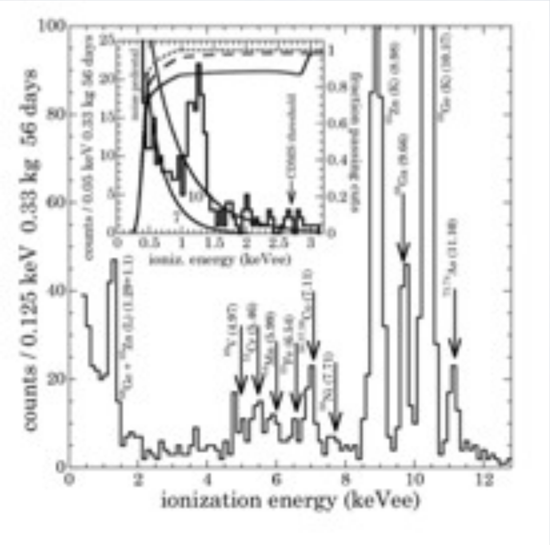
Dwarf searches already probing interesting models

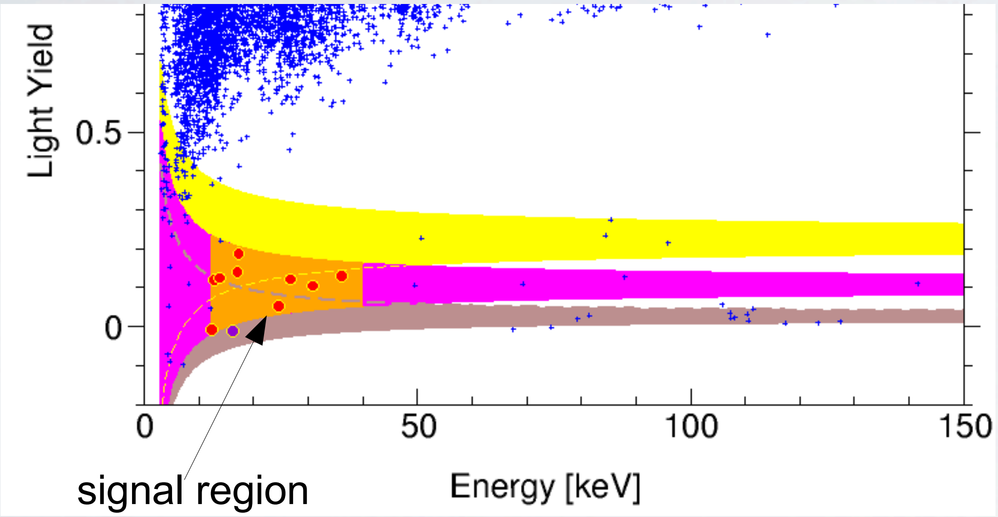
DIRECT DETECTION

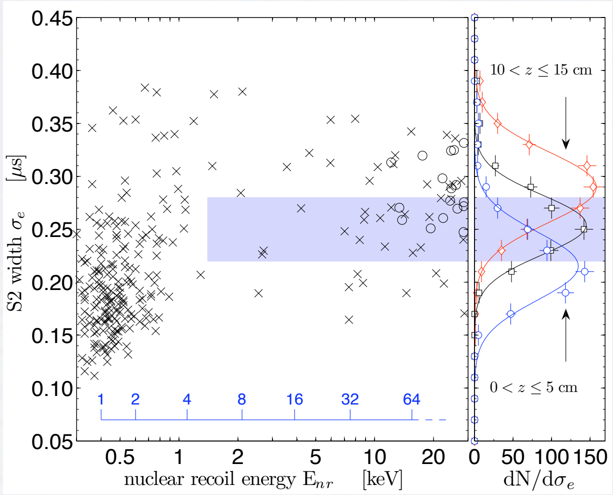
ANOMALIES AND CONSTRAINTS

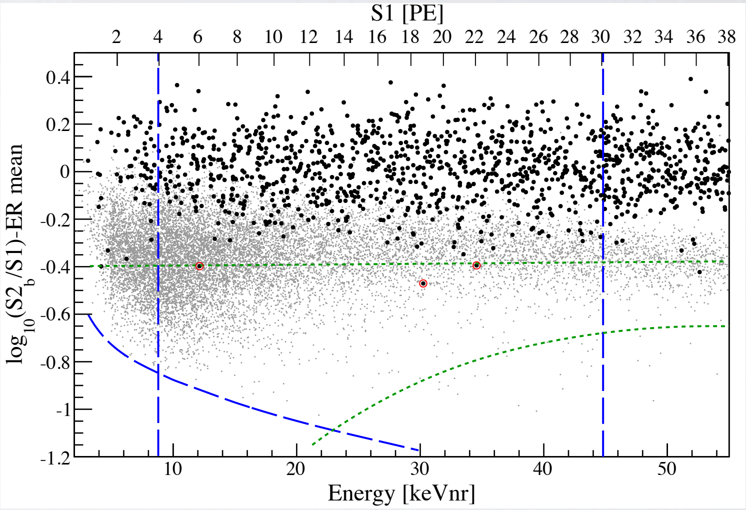


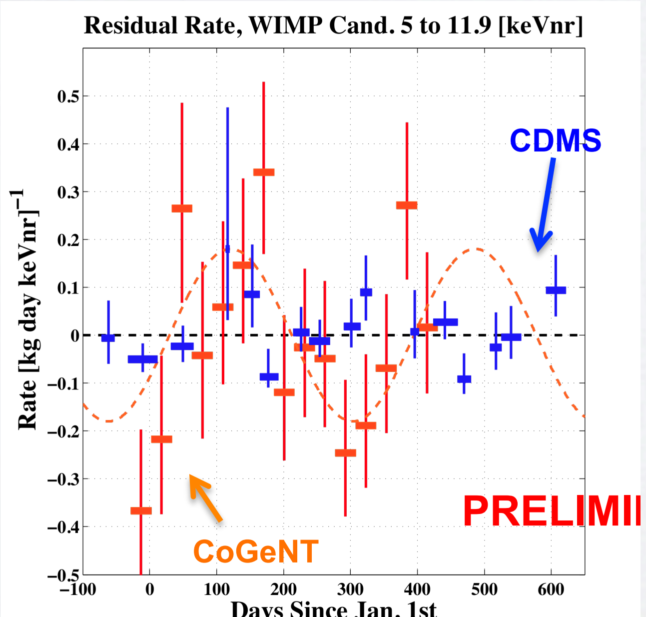


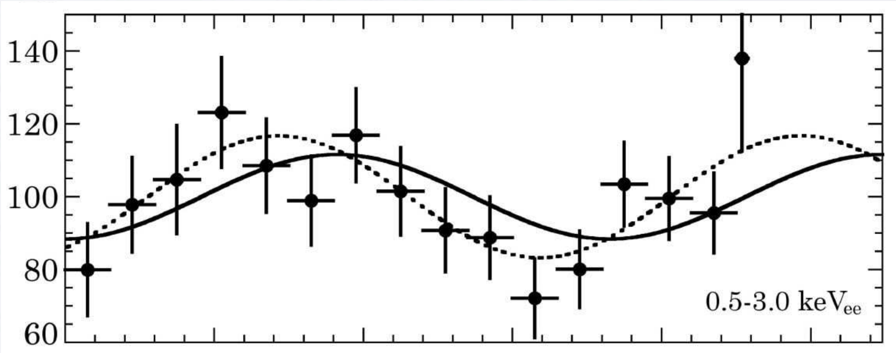


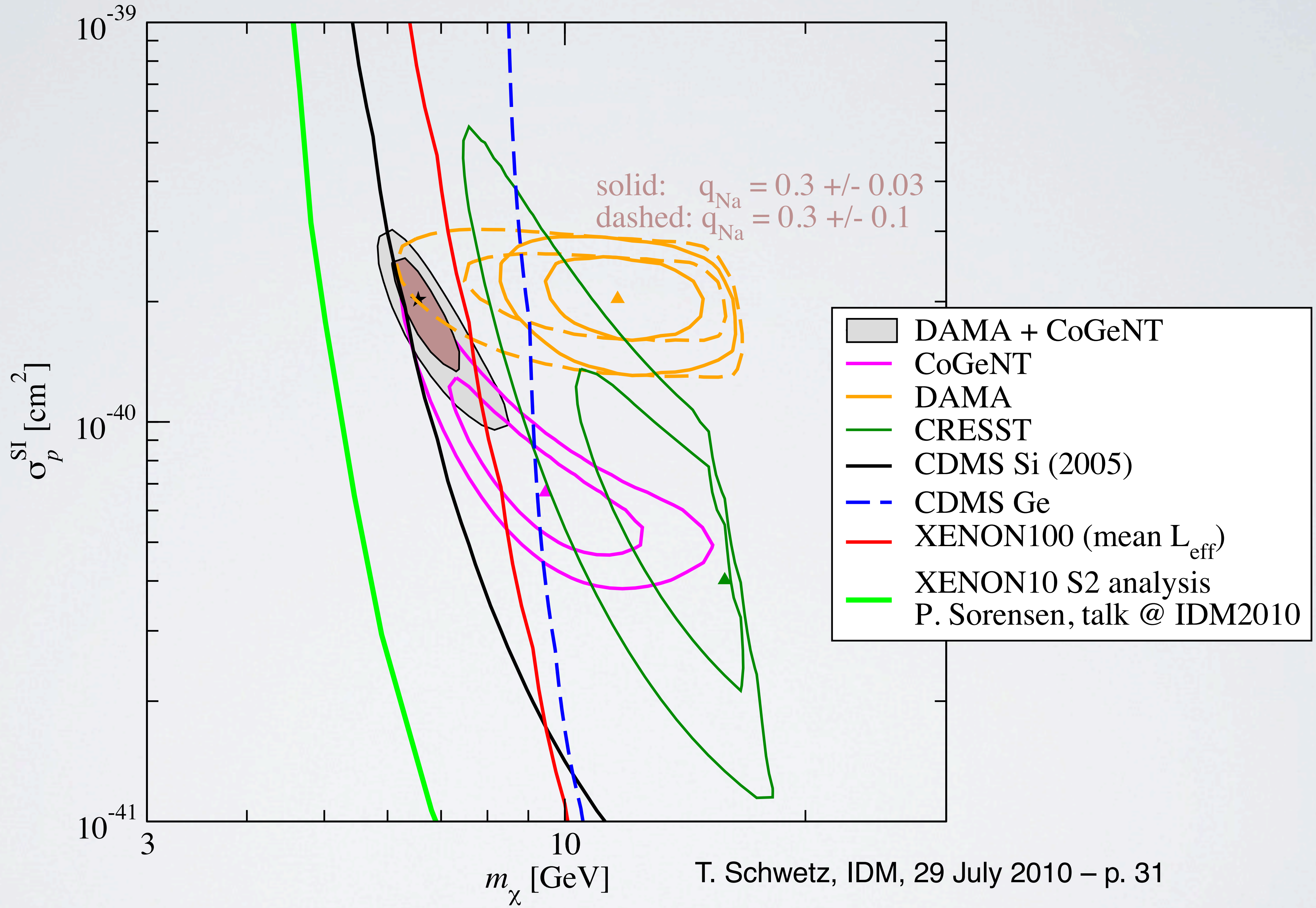












solid: q_{Na} = 0.3 +/- 0.03
dashed: q_{Na} = 0.3 +/- 0.1
DAMA + CoGeNT
CoGeNT
DAMA
CRESST
CDMS Si (2005)
CDMS Ge
XENON100 (mean L_{eff})
XENON10 S2 analysis
P. Sorensen, talk @ IDM2010
10^{-39}
10^{-40}
10^{-41}
σ_p^{SI} [cm^2]
3
10
m_χ [GeV]

THE CONTROVERSY

3) **Comments on arXiv:1006.0972 'XENON10/100 dark matter constraints in comparison with CoGeNT and DAMA: examining th**
J.I. Collar, . Jun 2010. 2pp. Temporary entry
e-Print: **arXiv:1006.2031** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 10 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

4) **Response to arXiv:1005.2615.**
J.I. Collar, D.N. McKinsey, . May 2010. Temporary entry
e-Print: **arXiv:1005.3723** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Cited 15 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

5) **Reply to the Comments on the XENON100 First Dark Matter Results.**
The XENON100 Collaboration, . May 2010. Temporary entry
e-Print: **arXiv:1005.2615** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 14 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

6) **Comments on 'First Dark Matter Results from the XENON100 Experiment'.**
J.I. Collar, D.N. McKinsey, . May 2010. Temporary entry
e-Print: **arXiv:1005.0838** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 22 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

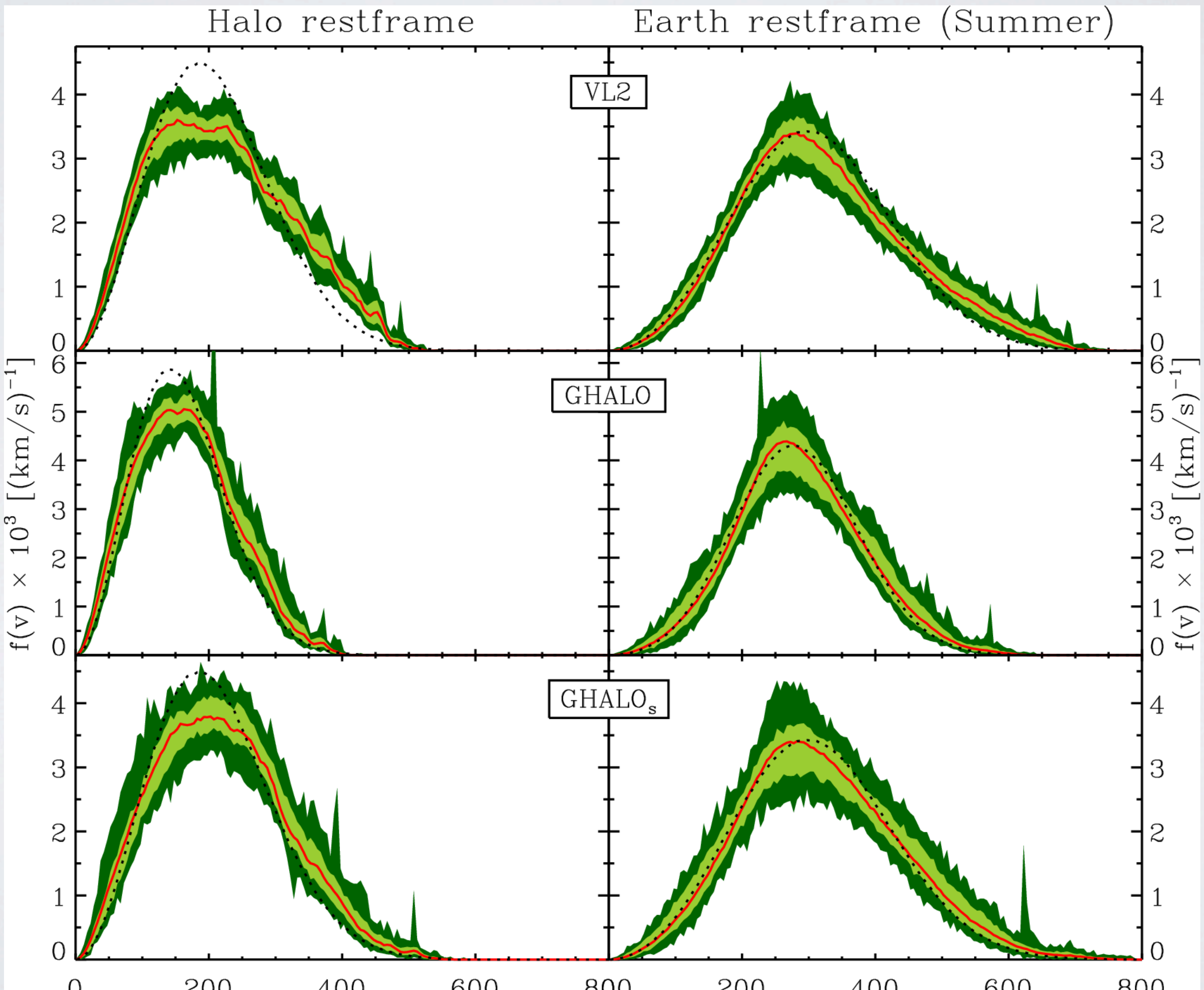
7) **First Dark Matter Results from the XENON100 Experiment.**
By XENON100 Collaboration (E. Aprile *et al.*). May 2010. (Published Sep 24, 2010). 4pp.
Published in **Phys.Rev.Lett.105:131302,2010**.
e-Print: **arXiv:1005.0380** [astro-ph.CO]

TOPCITE = 50+
References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 103 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Journal Server [doi:10.1103/PhysRevLett.105.131302]
EXP XENON
Bookmarkable link to this information

FIND KEYWORD BIG TIZZY

WANT MODEL INDEPENDENT CONSTRAINTS

Kuhlen, et al



WANT MODEL INDEPENDENT CONSTRAINTS

Usual: make assumptions on this

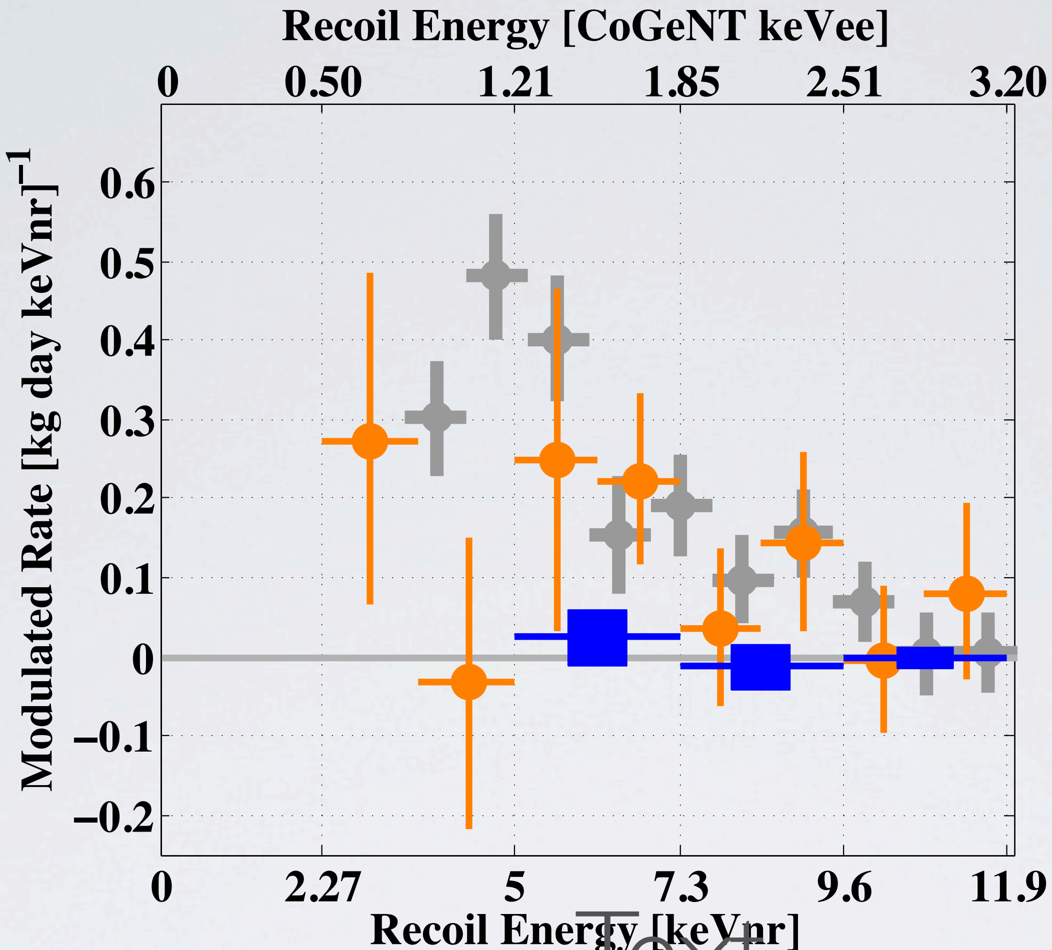
set limits on this

$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2 m_\chi \mu^2} \sigma(E_R) \int_{v_{min(E_R)}}^{\infty} \frac{f(v)}{v} d^3 v$$

Alternative: set limits on this

Fox, Liu, NW

10 GeV

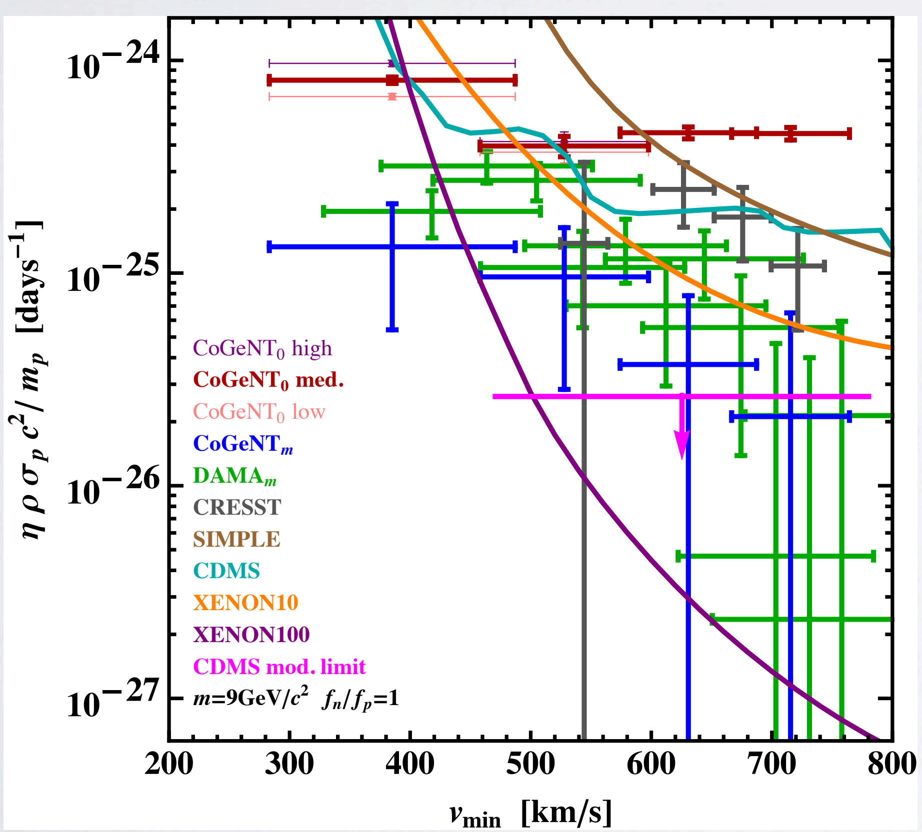


DAMA

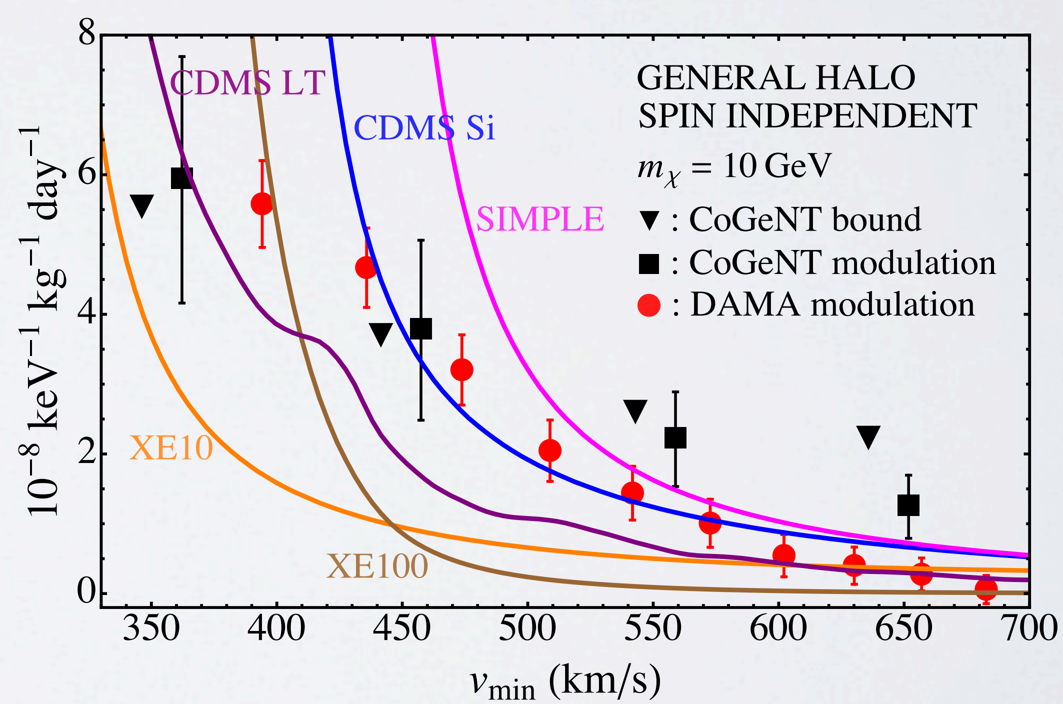
CoGeNT Mod

CDMS Mod

Text



Gondolo+Gelmini



Herrero-Garcia, Schwetz, Zupan

also Frandsen et al

IF IT'S NOT A LIGHT WIMP?

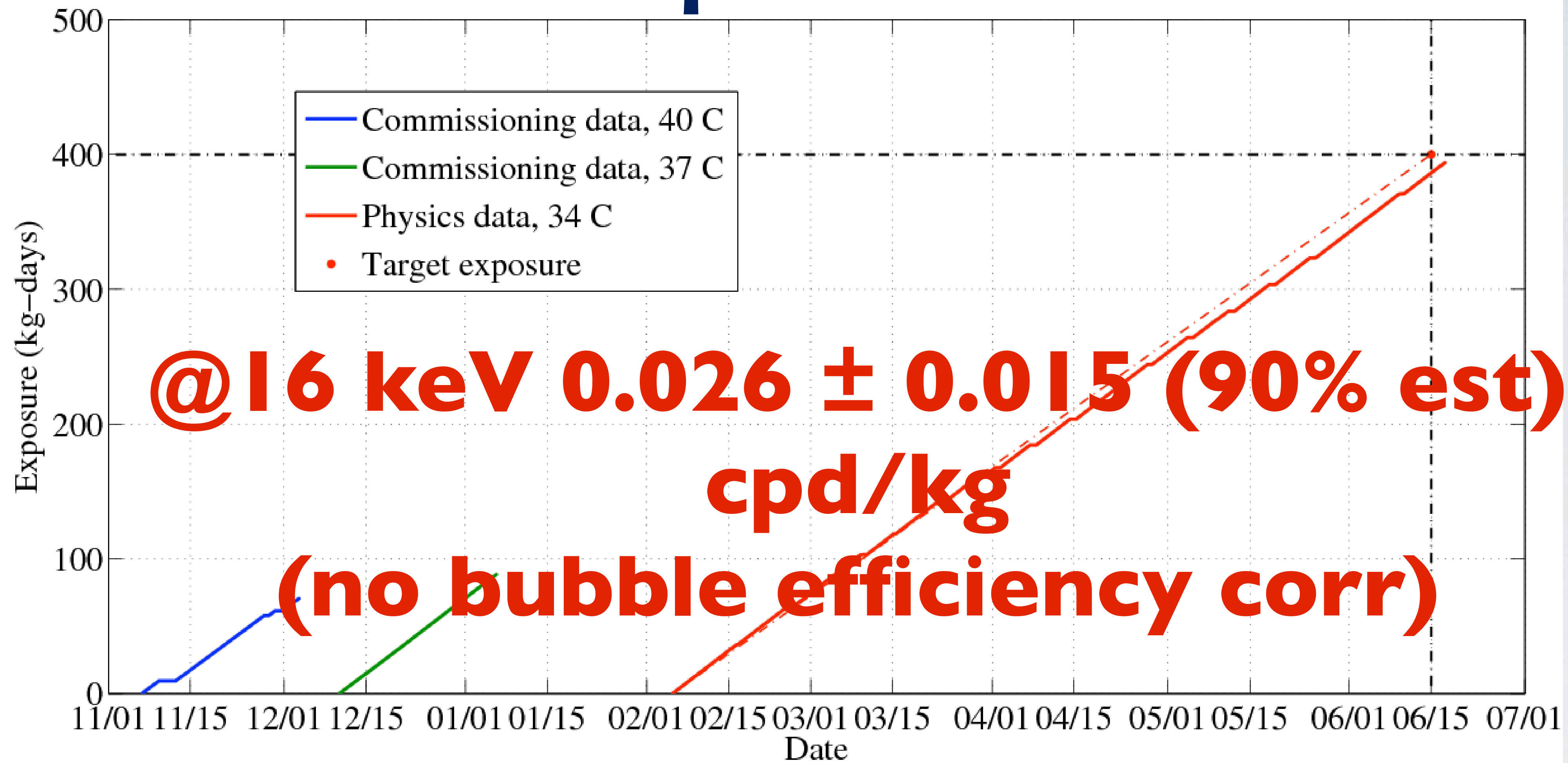
- DAMA: NaI(Tl) => What about iodine scattering?
- Some models (Magnetic Inelastic DM) can have dominant signals on Iodine
- Other models we haven't thought of

Want direct comparisons to iodine targets - COUPP (CF_3I) and KIMS (CsI)

COUPP

(talk by R. Neilson)

Exposure



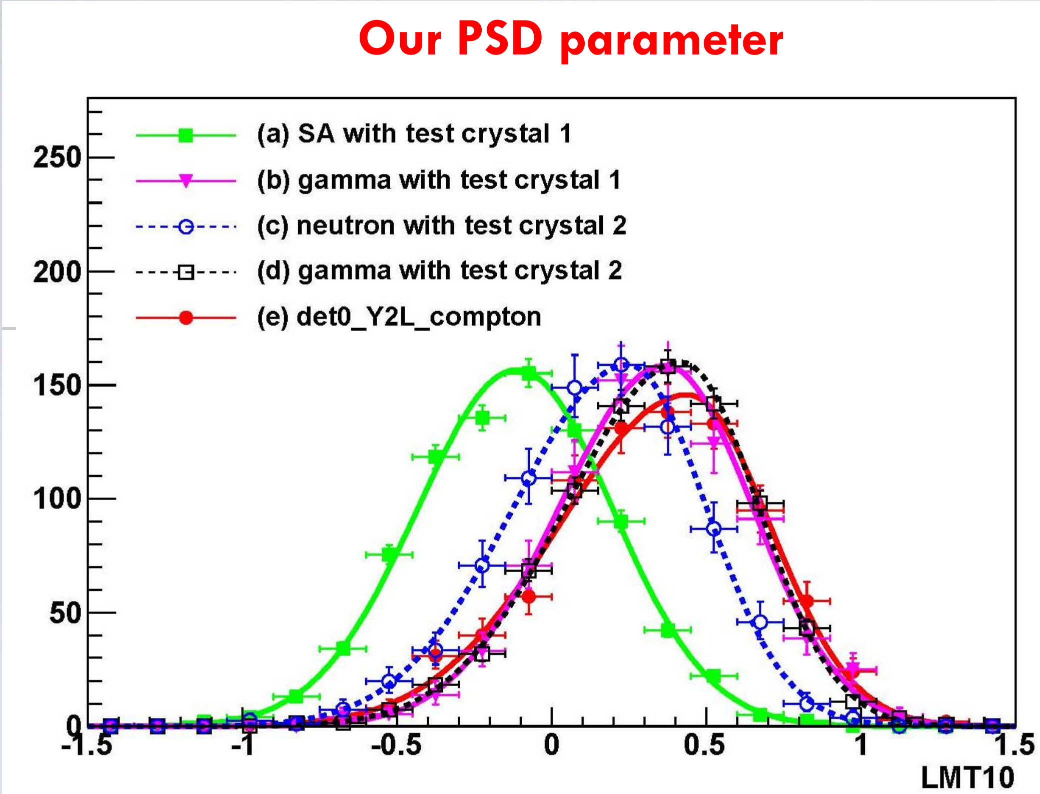
@16 keV 0.026 ± 0.015 (90% est) cpd/kg

(no bubble efficiency corr)

- 17.4, 21.9, 97.3 live-days at 8, 11, 16 keV thresholds
- 4.048 kg target, 79% cut-efficiency for nuclear recoils

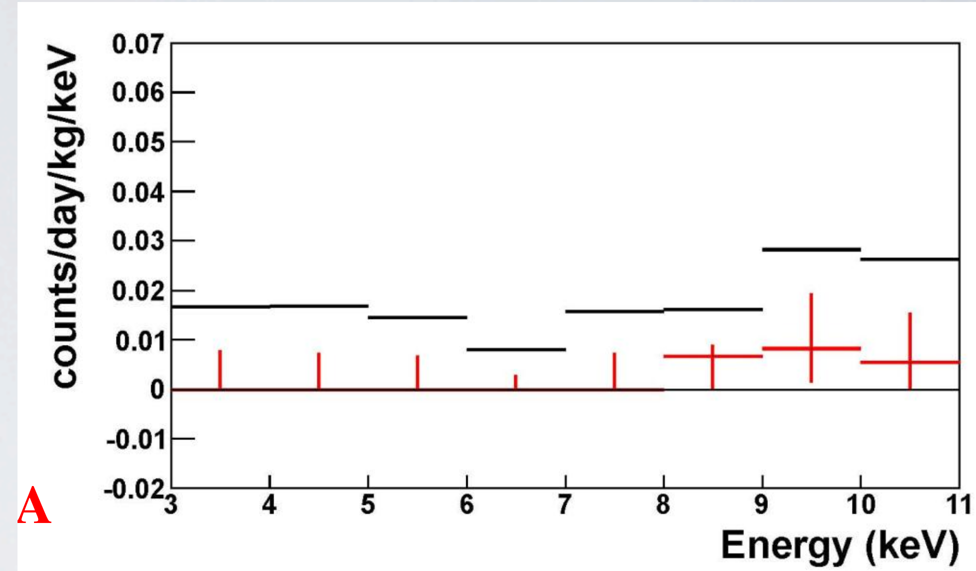
For 100% DAMA modulation expect .

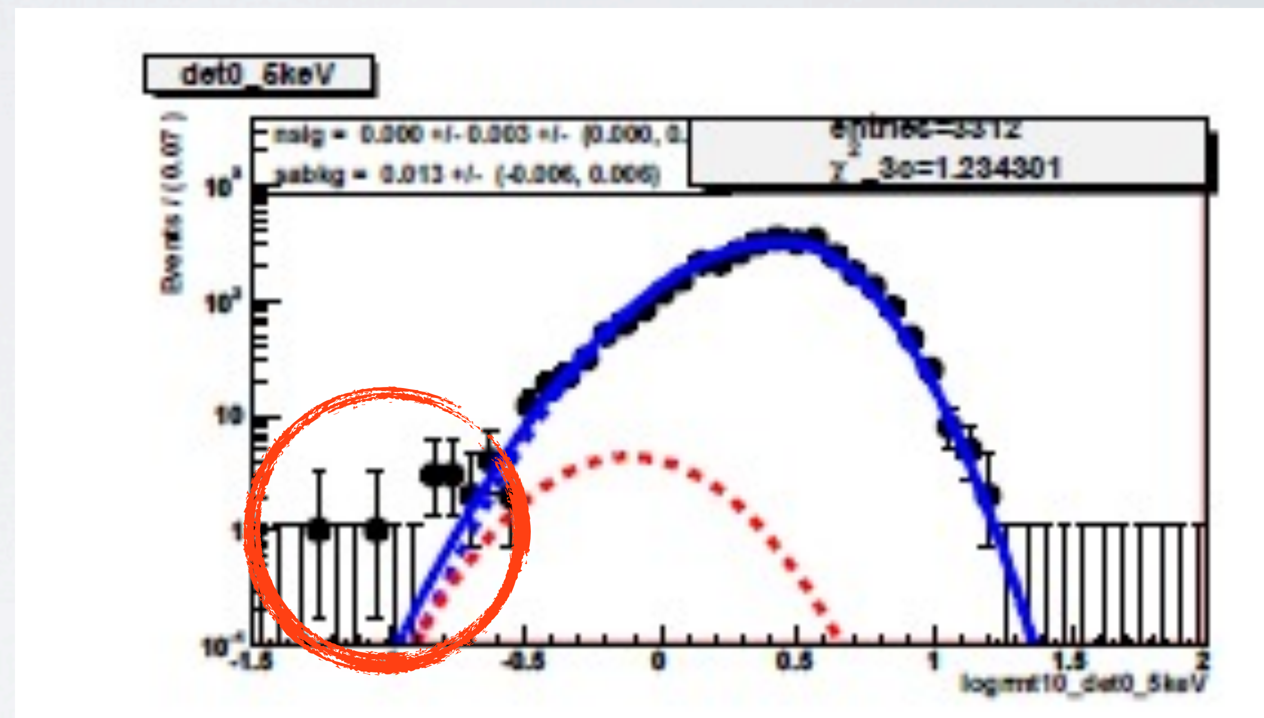
0.037±.007 (90%)



KIMS

talk by Y. Kim





Claim: exclude Iodine interpretation at O(1)

Strong limit, but...
energy scale uncertainties? energy resolution comparison?
does the model describe the data?

DIRECT ANOMALIES

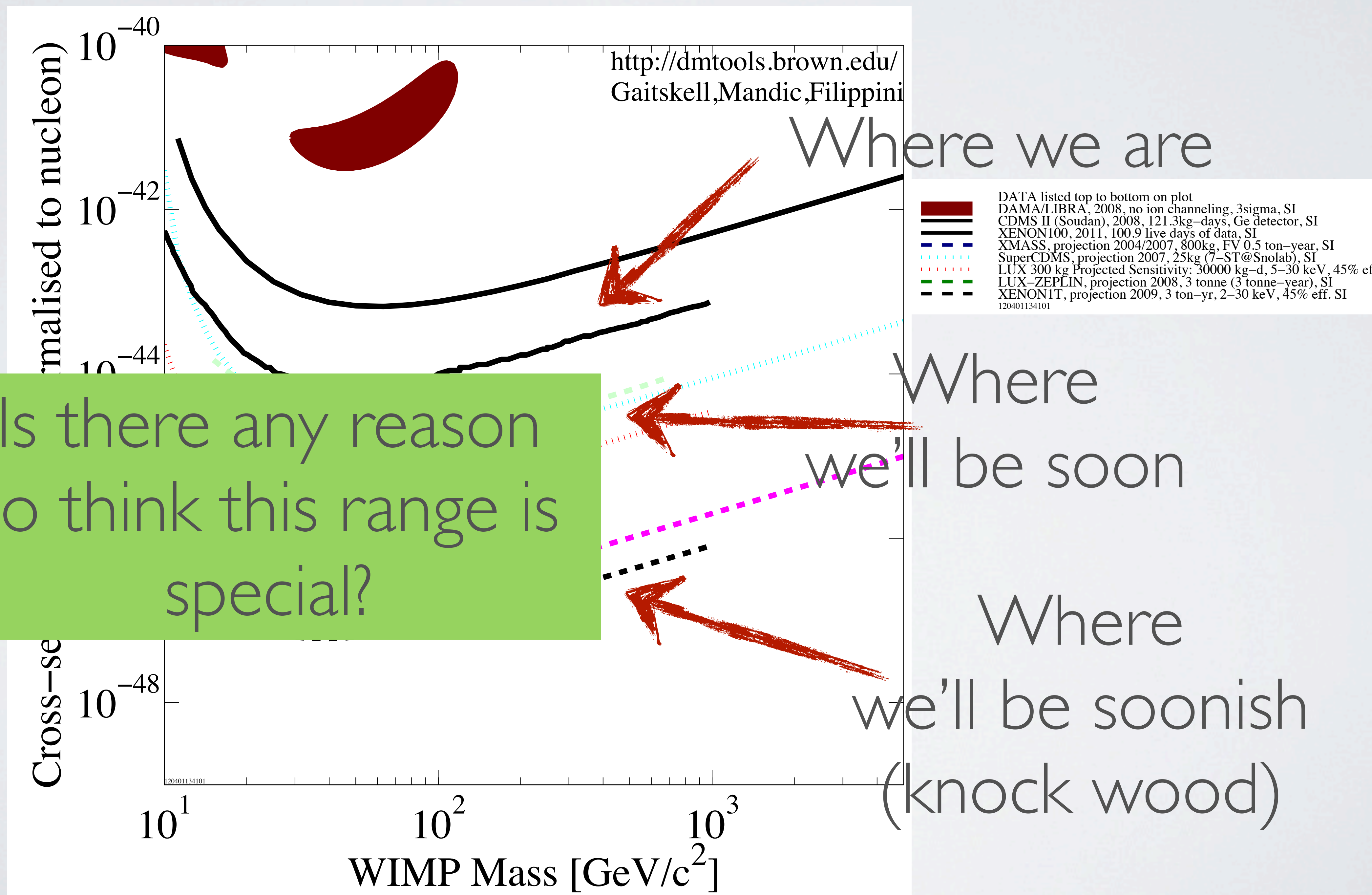
- Light WIMPs seem really constrained
  - Someone has to be quite wrong
- Iodine scattering must be very highly modulated
  - Models exist - but at the edge
  - XENON100 could see rates at high (30-60 keV) energy
  - Nuclear recoil+nuclear excitation of Xe (40 keV photon) would be striking signature

XENON100?

- Upcoming XENON100 results - already strong
- Lower threshold
- Higher exposure in “iodine” range (30-60 keV)
- Could see strange signals (e.g., nuclear recoil + ^{129}Xe 40 keV excitation)...

YOU DON'T HAVE TO BE EXCITED ABOUT ANOMALIES TO BE EXCITED ABOUT DIRECT DETECTION

THE IMPROVEMENT OF DARK MATTER EXPERIMENT



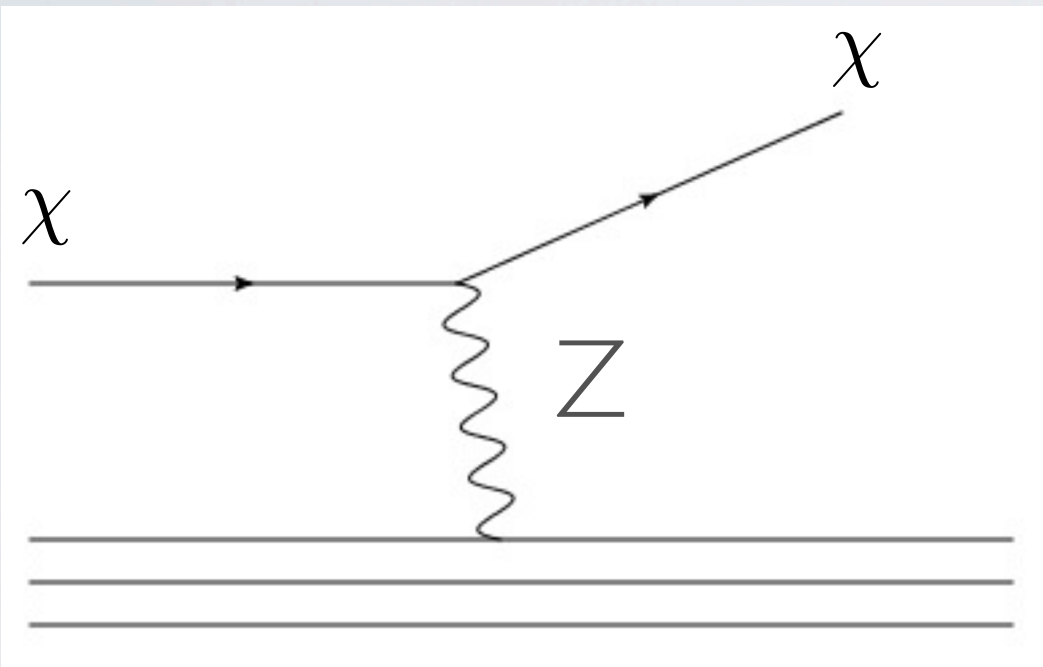
Where we are

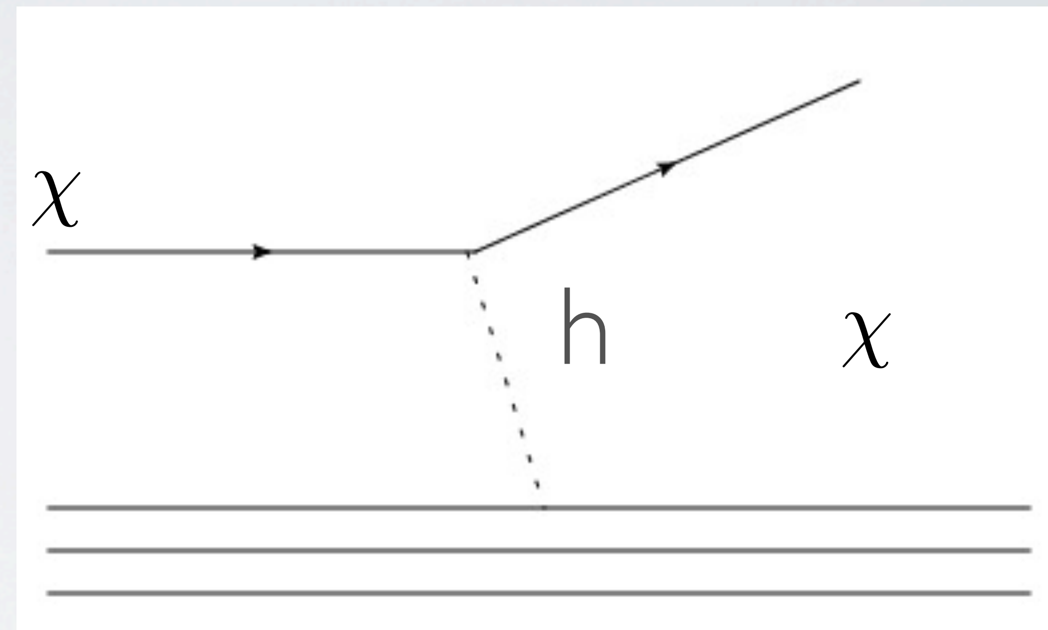
Where we'll be soon

Where we'll be soonish (knock wood)

Is there any reason to think this range is special?

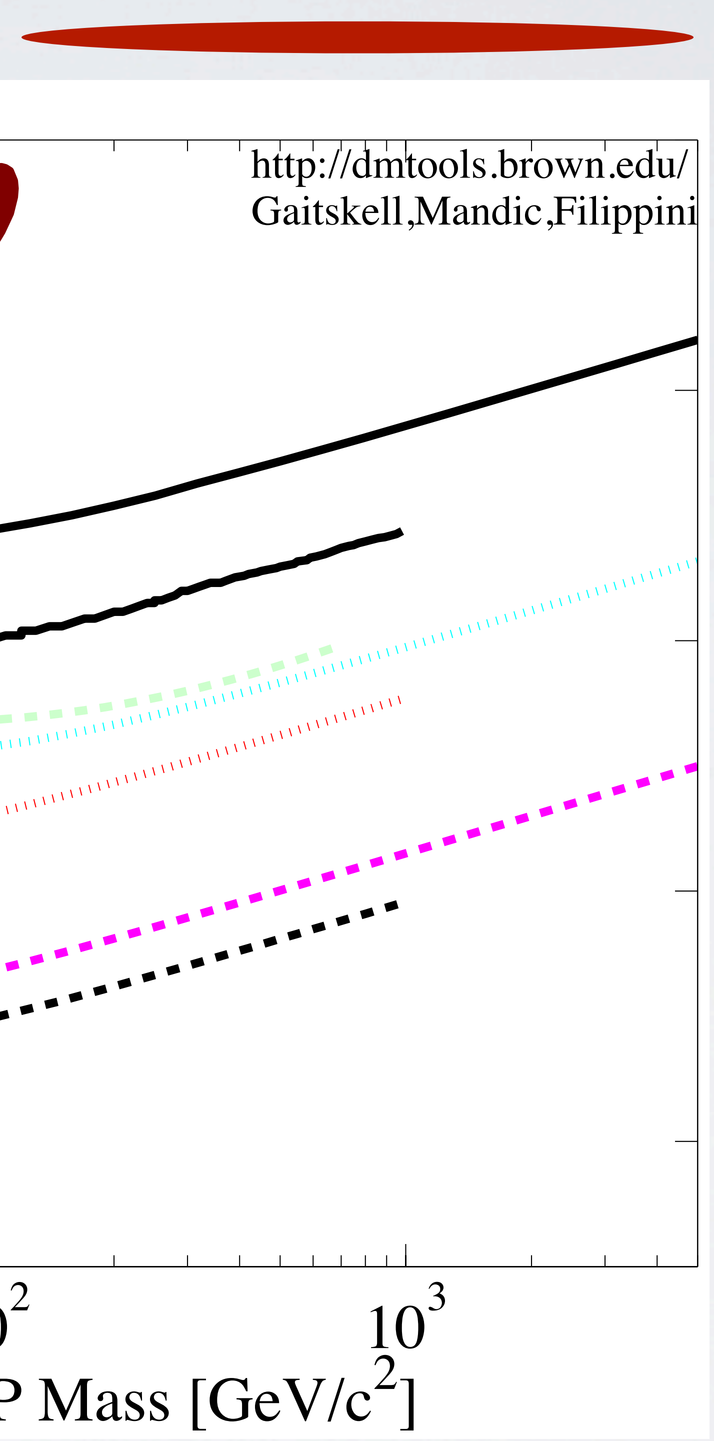
THE TWO CROSS SECTIONS TO THINK ABOUT



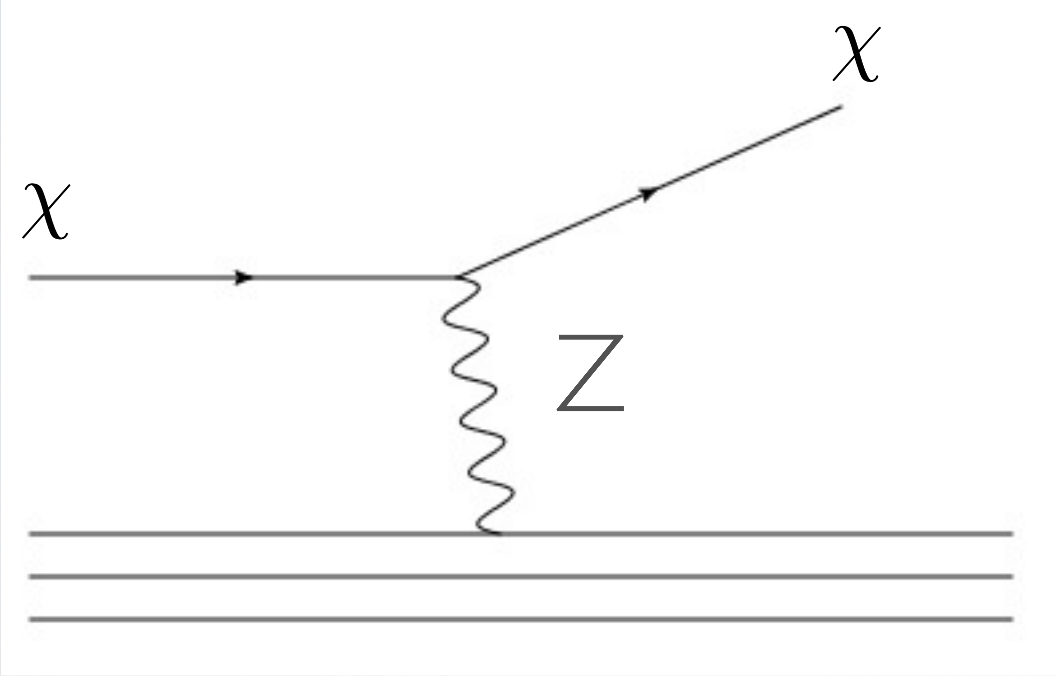


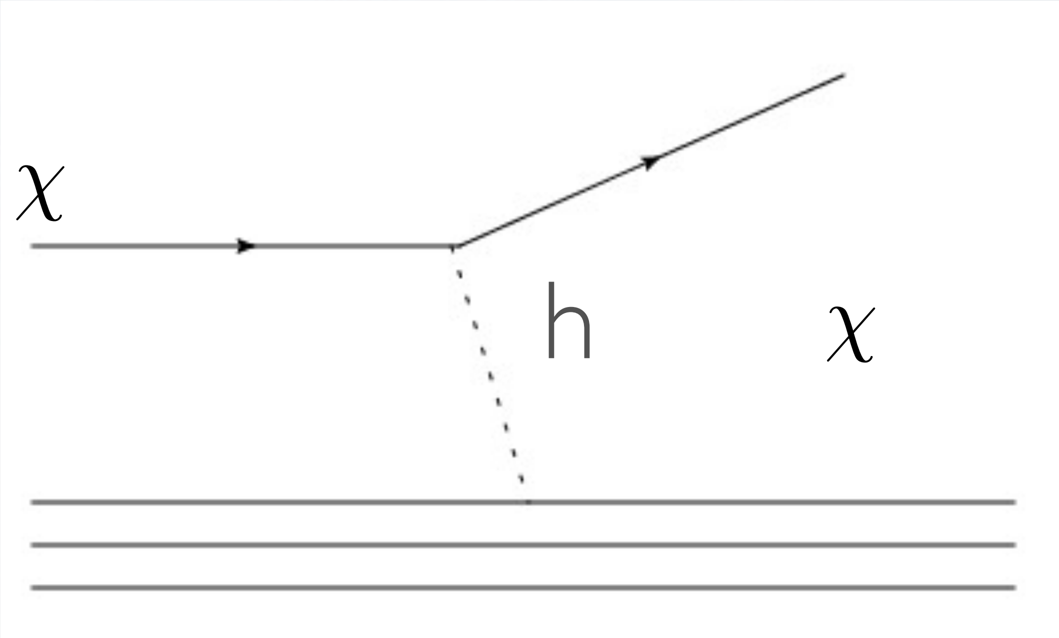
$$\sigma_0 \approx \frac{G_f^2 \mu^2}{2\pi} \sim 10^{-39} \mathrm{cm}^2$$

Ruled out
(just a little bit)



THE TWO CROSS SECTIONS TO THINK ABOUT



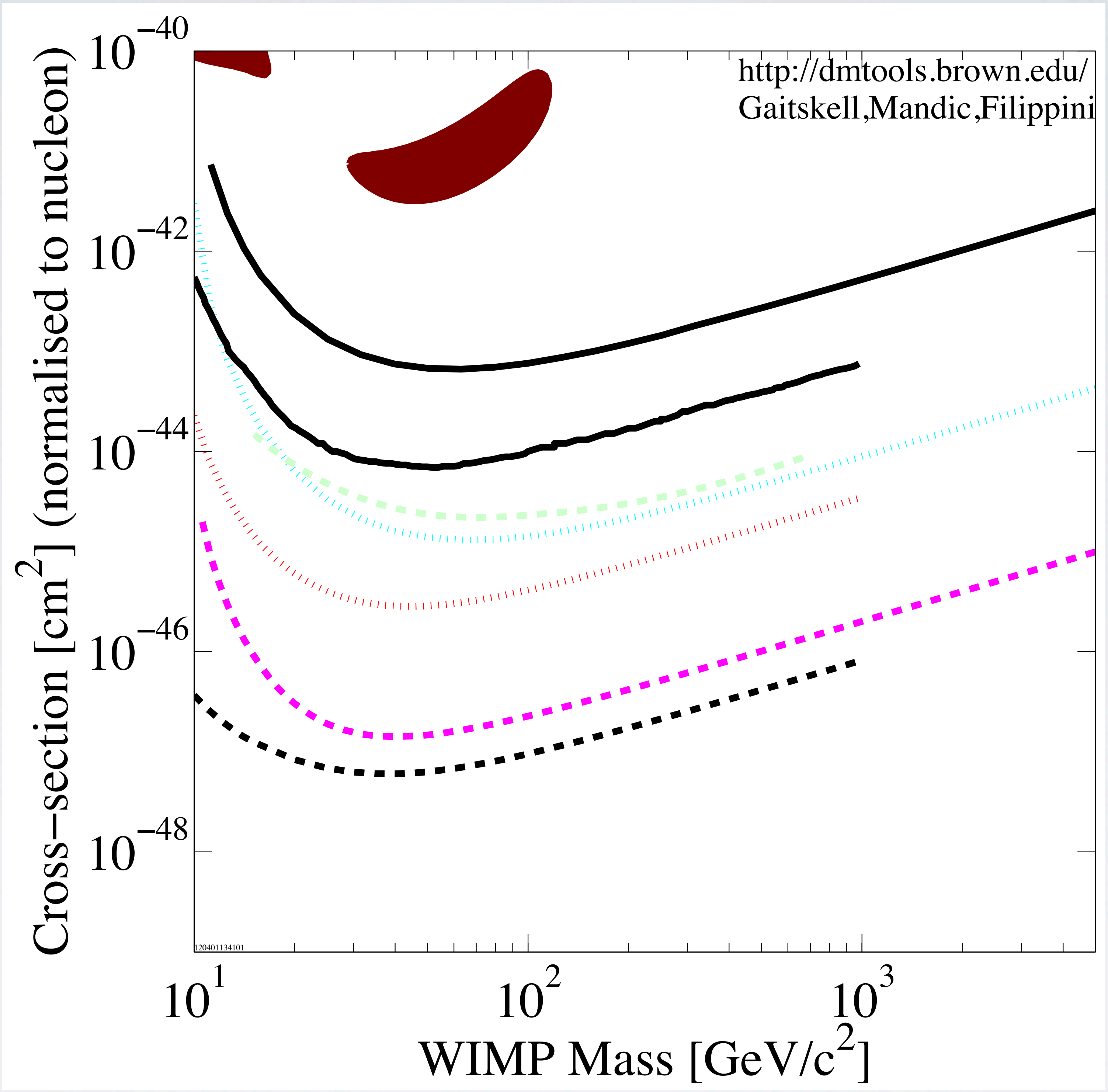


$$\sigma_0 \approx \frac{G_f^2 \mu^2}{2\pi} \sim 10^{-39} \mathrm{cm}^2$$

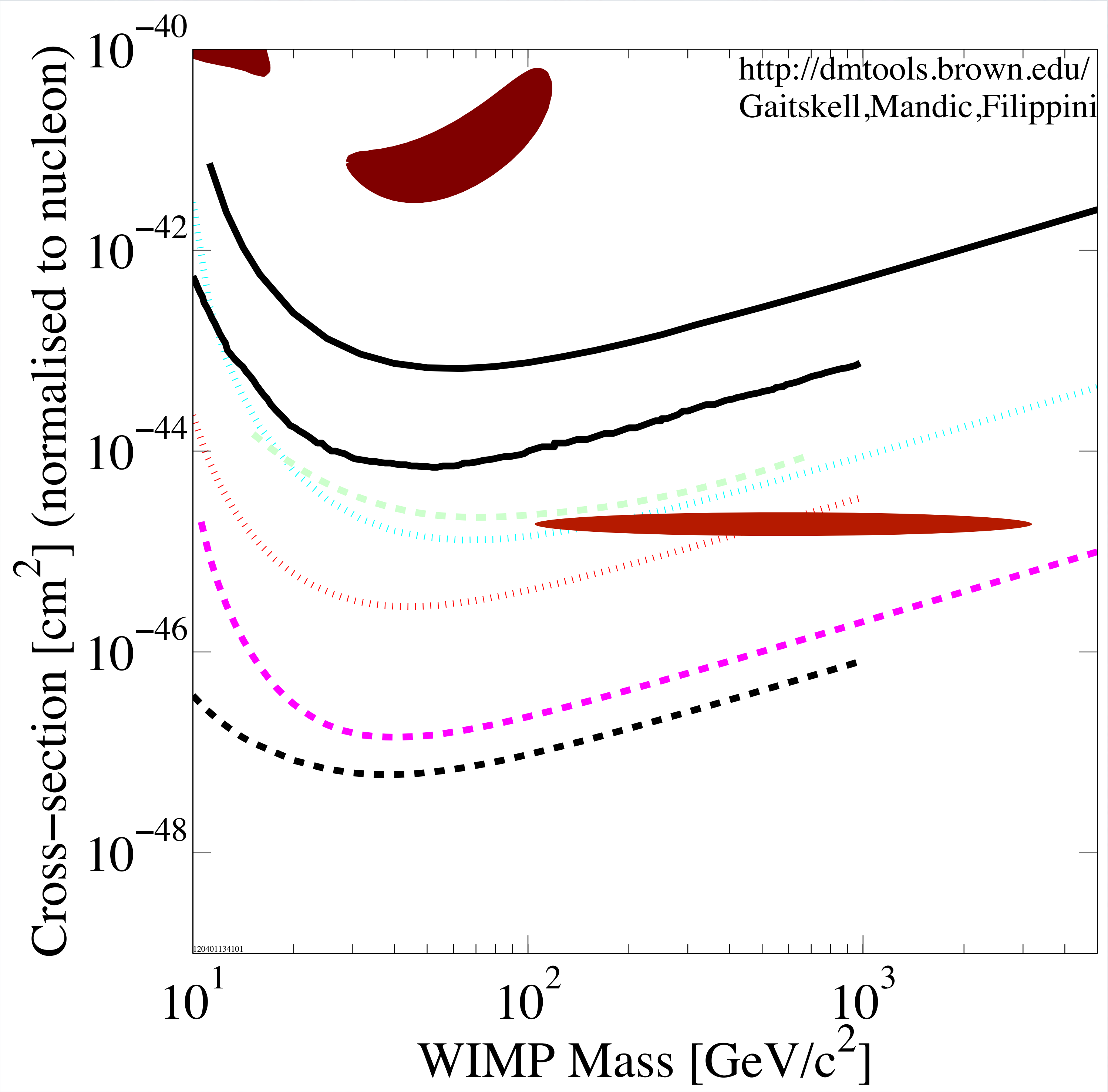
$$g \sim 1 \Rightarrow y_p \sim \frac{1}{\mathrm{few}} \frac{m_p}{v}$$

$$\sigma_0 \sim 10^{-39} \mathrm{cm}^2 \times 10^{-6}$$

$$\sim 10^{-45} \mathrm{cm}^2$$



http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini
Cross-section [cm^2] (normalised to nucleon)
10^{-40}
10^{-42}
10^{-44}
10^{-46}
10^{-48}
10^1
10^2
10^3
WIMP Mass [GeV/c^2]



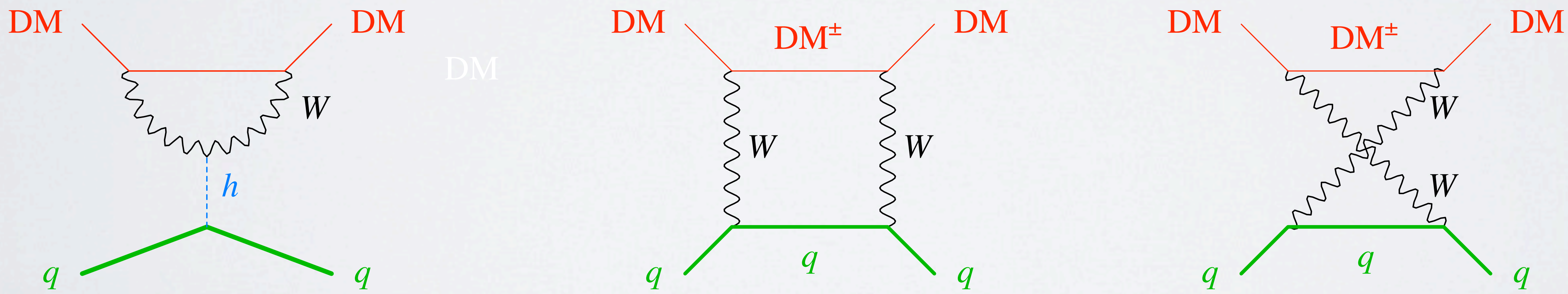
Various physics can move it up or down - but this is a natural starting point

Farina, Kadastik, Pappadopulo, Pata, Raidal, Strumia ’11

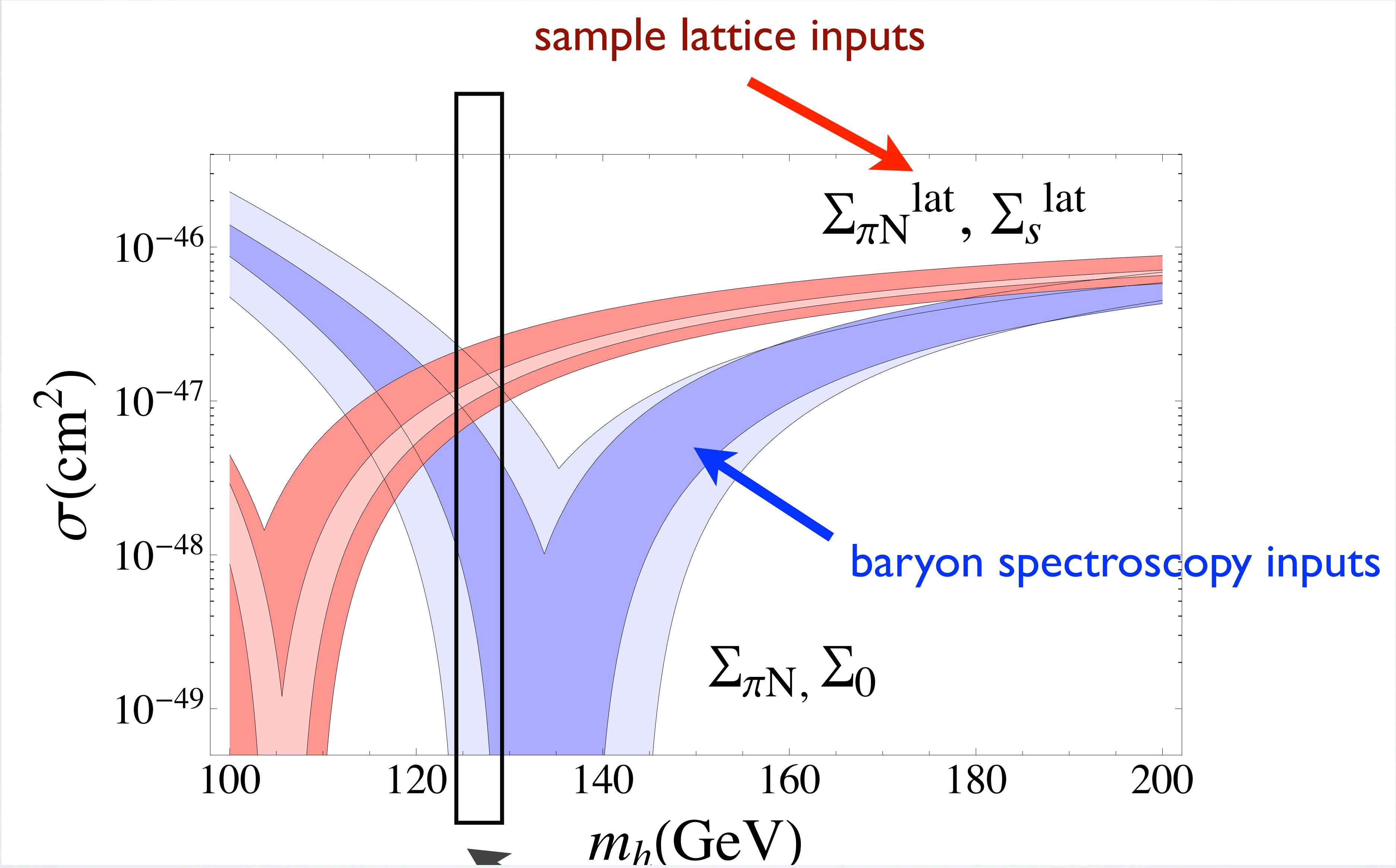
IF XENON SEES NOTHING, THEN WHAT?

WHITHER NO XENON100 DETECTION

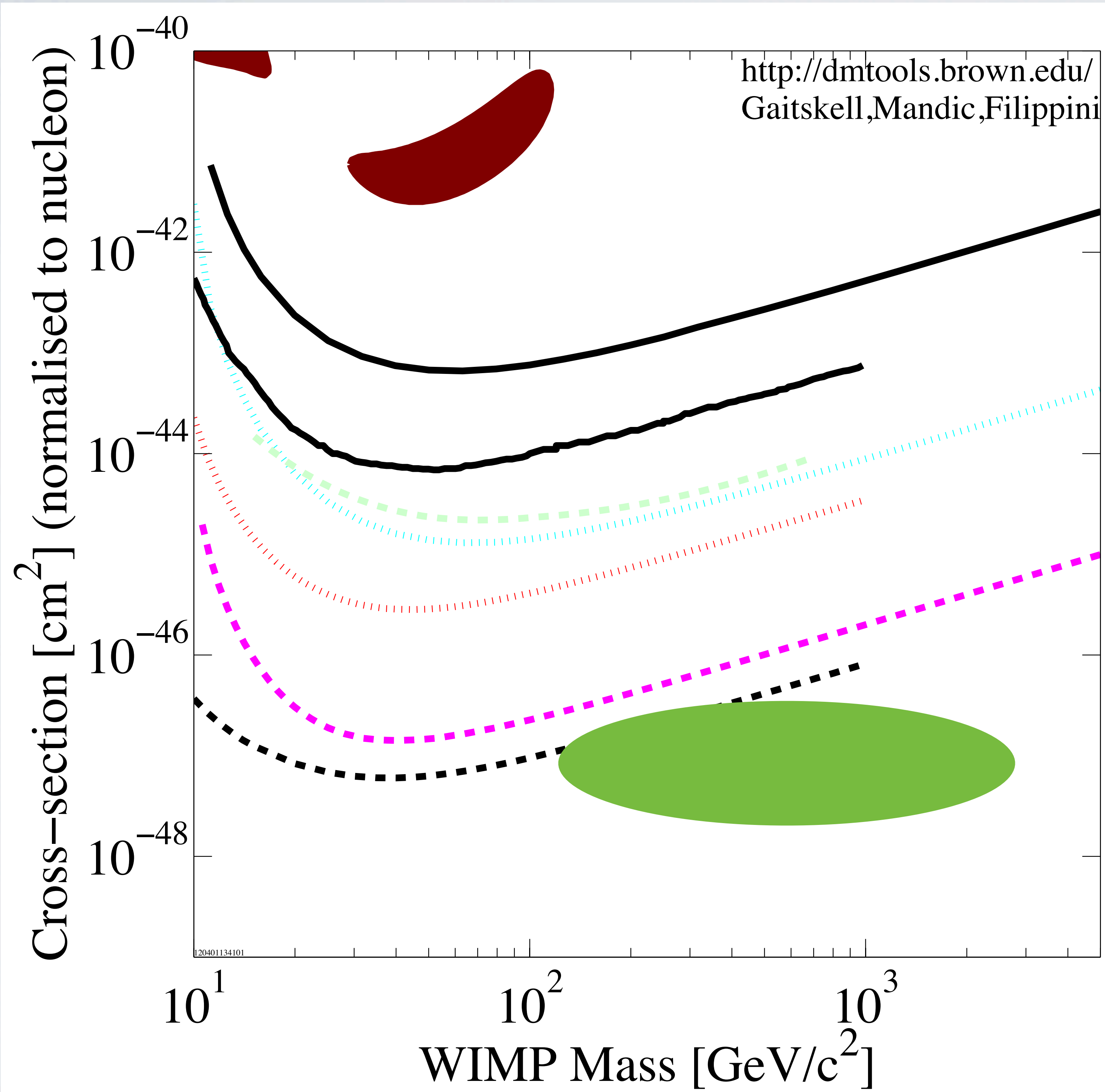
- Are WIMPs dead? No!
- Consider an SU(2) triplet (aka a "pure Wino")
  - no Z-boson coupling; no (tree level) Higgs boson coupling

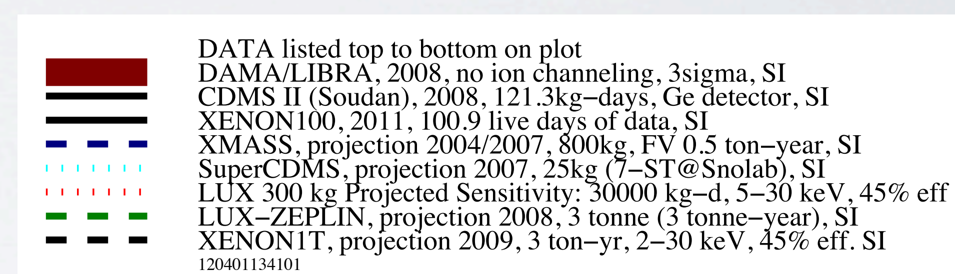


talk by R. Hill



talk by R. Hill





may be hard to find

TWO CROSS SECTIONS

- If I had to pick two numbers for the cross section that a WIMP would scatter with, they'd be 10^{-39} cm^2 and 10^{-45} cm^2.
- It's not the former.
- The latter is nigh
- But that's no guarantee

A FINAL THOUGHT GIVEN THAT IT APPEARS THE HIGGS HAS BEEN DISCOVERED

THE HIGGS AND DM IN SUSY

In SUSY the
Higgs is light
for no good
reason!

"X" may
Keep other
things light,
too

THE HIGGS AND DM

- Maybe the Higgs couplings are non-standard=> new electroweak states?
- What if there is a sister partner to the Higgs, which has some symmetry group G_s that keeps it from coupling to fermions?
- But what if this sister Higgs field gets a vev and participates in EWSB? (SUSY generalization of Type I 2HDM)

H_u $\quad$ H_d $\quad\Rightarrow$ χ is combination of H, Σ

$G_s \Rightarrow$ Σ_u $\quad$ Σ_d

More "well-tempered"

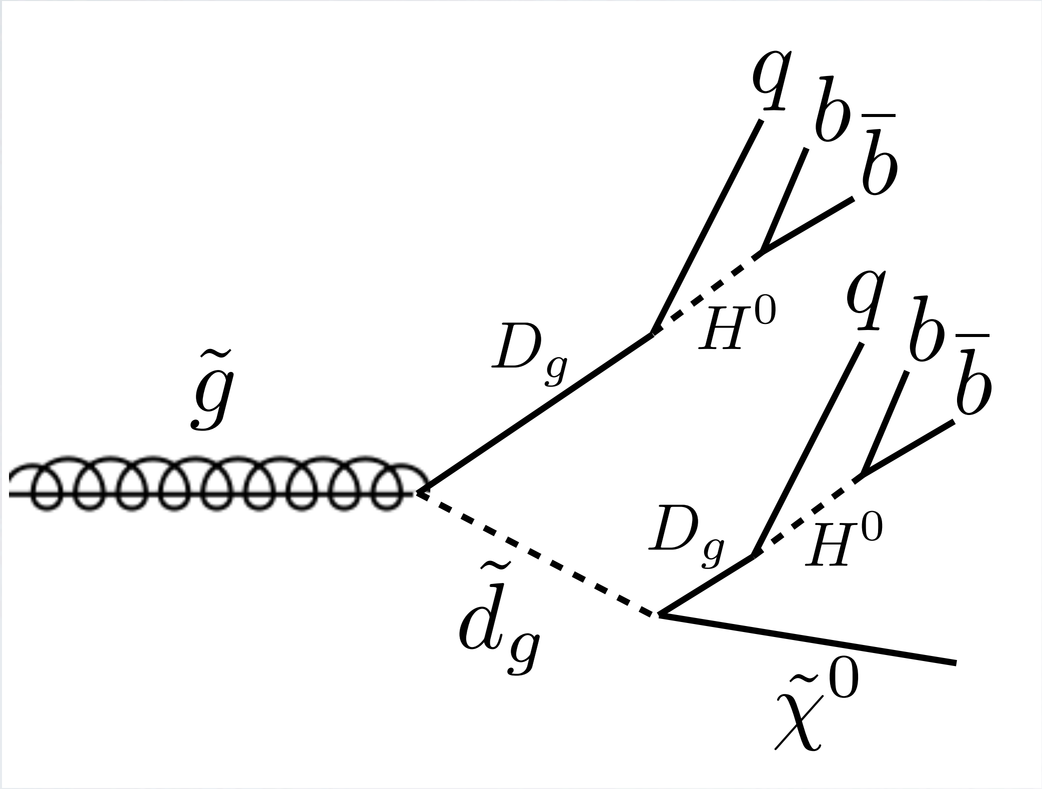
Arkani-Hamed, Delgado, Giudice

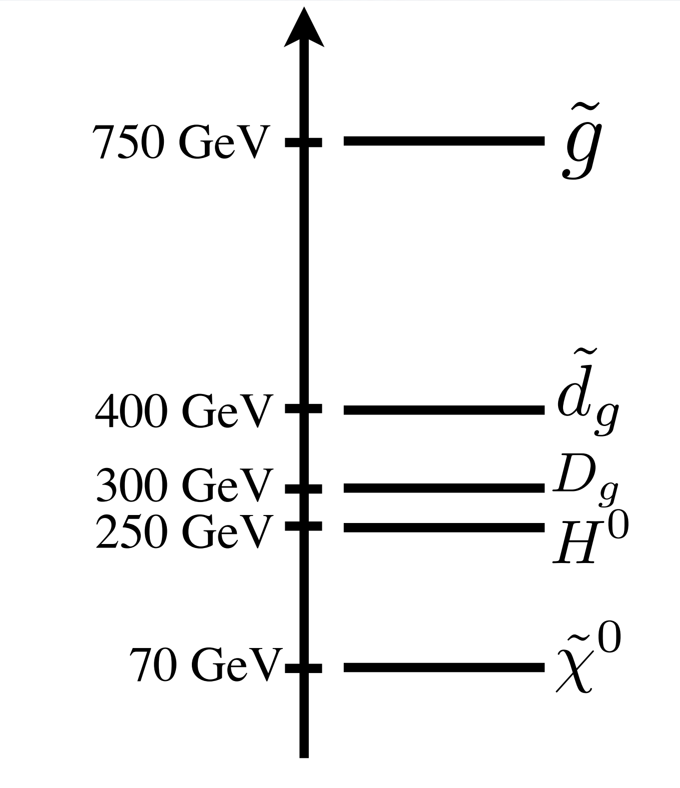
THE HIGGS AND DM

- Grand Unification implies GUT-related colored fields ("G-quarks" D_g)

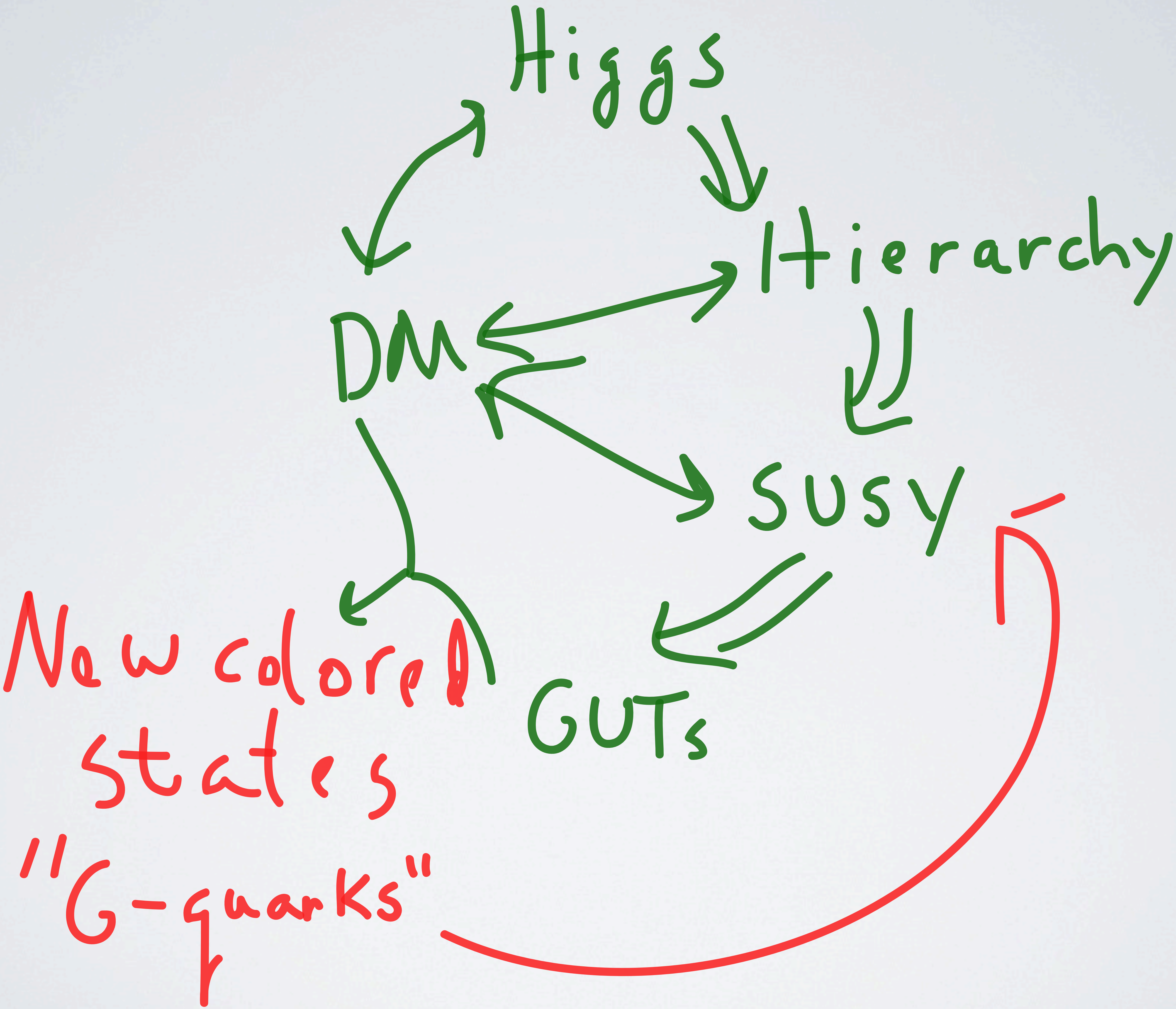
H_u H_d GUT

$G_s \Rightarrow \Sigma_u$ $\Sigma_d \Rightarrow D_g$ D_g^c





New opportunities for "stealth" or squeezed SUSY


Higgs
Hierarchy
DM
SUSY
GUTs
New colored states
"G-quarks"

CONCLUSIONS

- After the Higgs, it’s time for new physics discoveries
- Dark matter is due: data from LHC, direct, indirect
- Rate of anomalies in > rate of anomalies out
- Slowly, we may be able to exclude the old ones
  - CMB tests for PAMELA
  - Iodine tests for DAMA
  - More Fermi data from the GC

CONCLUSIONS

- But DM models also provide us great motivations for new searches
  - jets+MET
  - dark forces/rare GeV decays
  - monophoton/monojet
- More complicated electroweak sectors => new colored states
- “G-quarks” could play a role in SUSY signals

CONCLUSIONS

- Hopefully, it’s not another 40 years!