Indirect detection of WIMP dark matter

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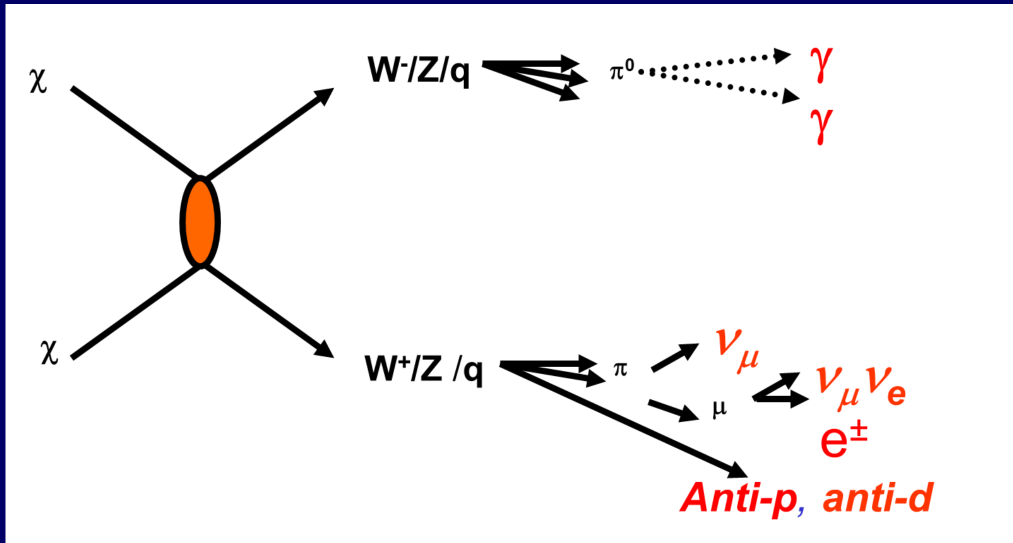
Indirect detection of Dark Matter



Particle Physics

$$\frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\Sigma_f\frac{dN}{dE}B_f$$

ν,γ: rate = PPP × Astrophysical part (APP)

$$APP = "J - factor" = \iint d\Omega dl \rho^2(l)$$

cosmic rays PPP = q(r,p,t)

$$\frac{\partial F(\mathbf{r},p,t)}{\partial t} - \nabla(\mathbf{D}_{xx}\nabla F) + \nabla(\mathbf{u}F) - \frac{\partial}{\partial p}\left(p^2 D_{pp}\frac{\partial}{\partial p}\frac{F}{p^2}\right) + \frac{\partial}{\partial p}\left[\dot{p}F - \frac{p}{3}(\nabla\mathbf{u})F\right] + \frac{F}{\tau_f} + \frac{F}{\tau_d} = q(\mathbf{r},p,t),$$

B-field, radiation field, gas, E-field:

Diffusion

reacceleration

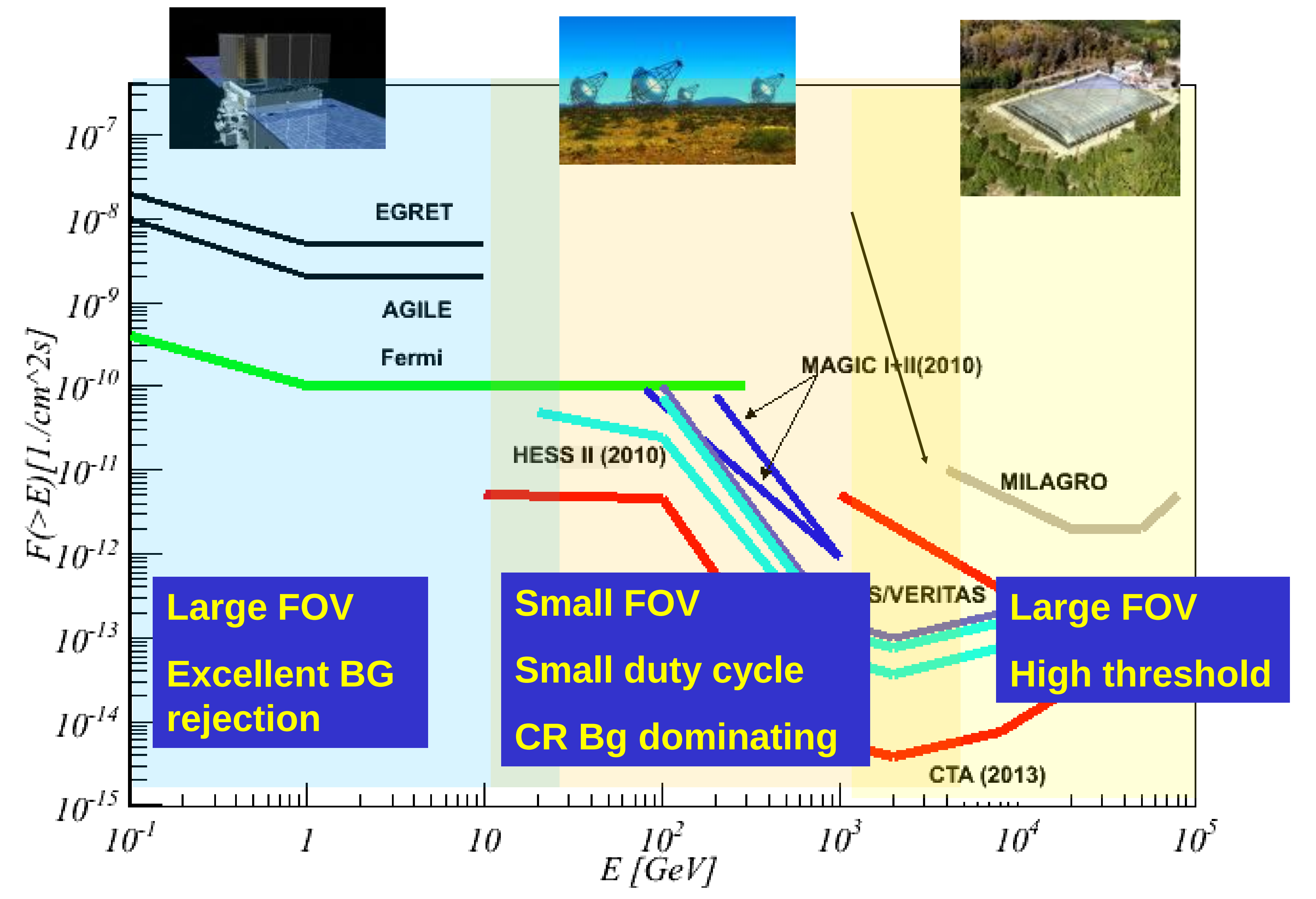
convection

energy loss

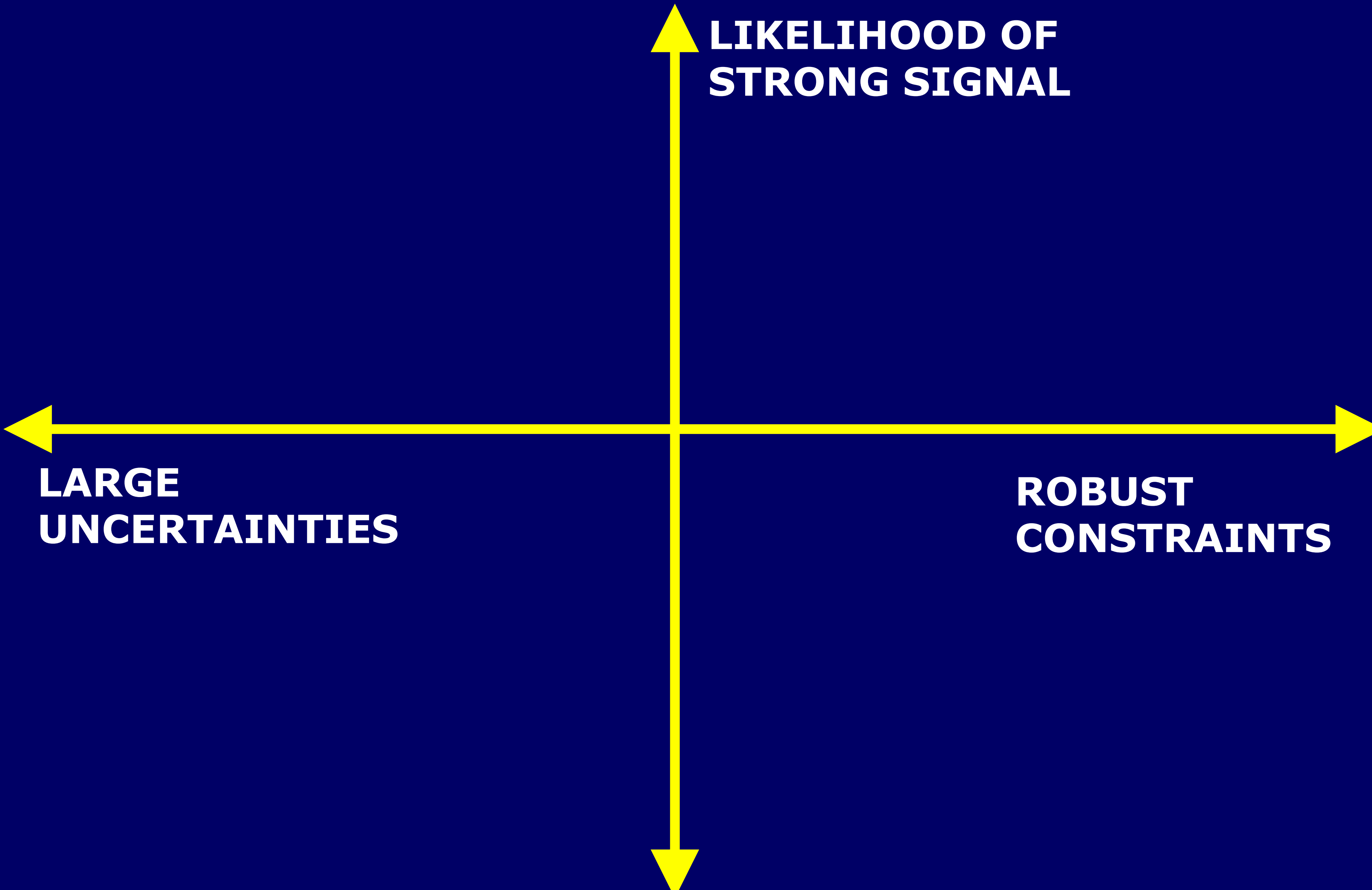
Spallation, decay

gamma rays: the golden channel

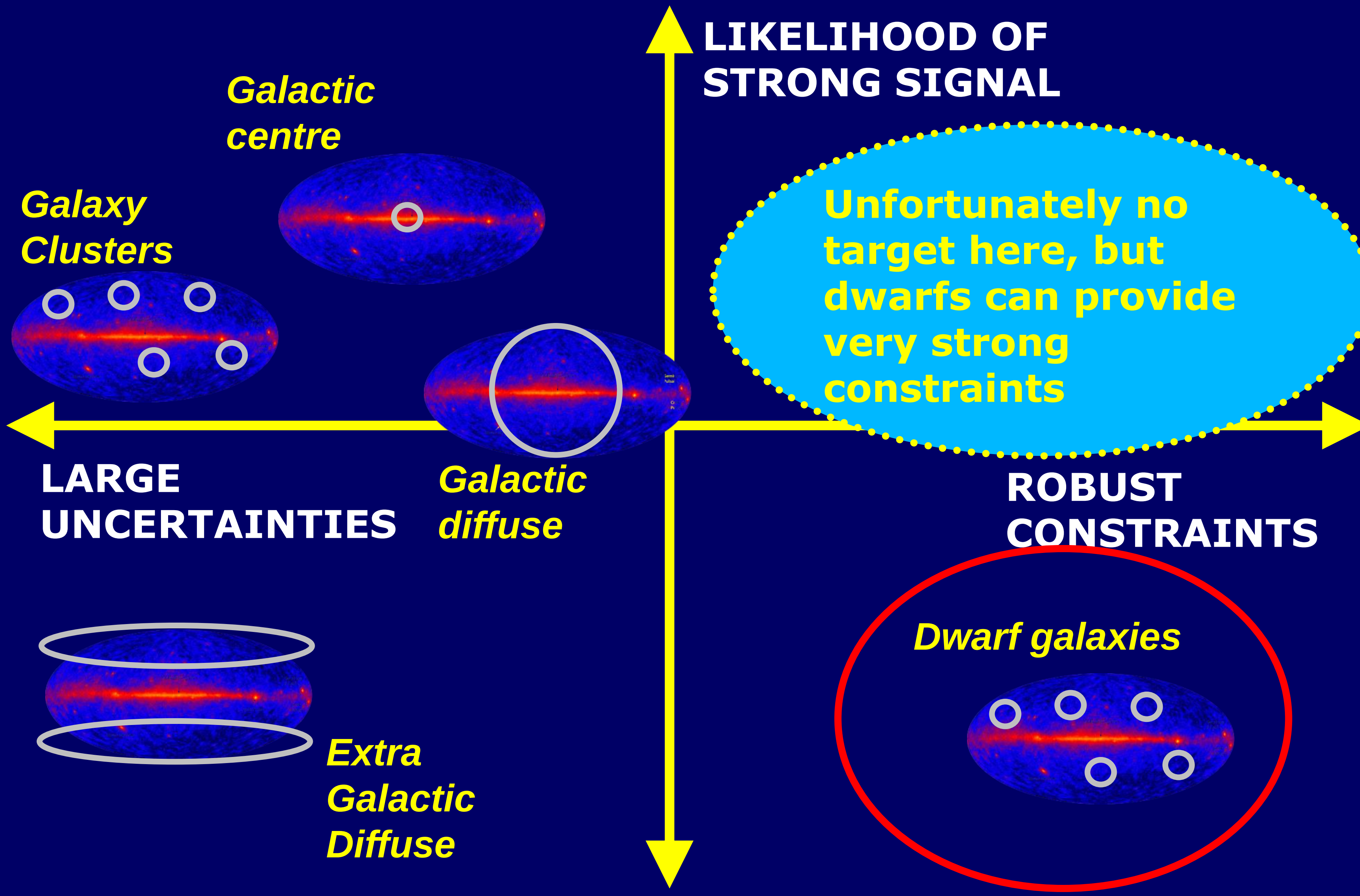
Gamma-rays: sensitivity illustration



Targets and Challenges - Satellites

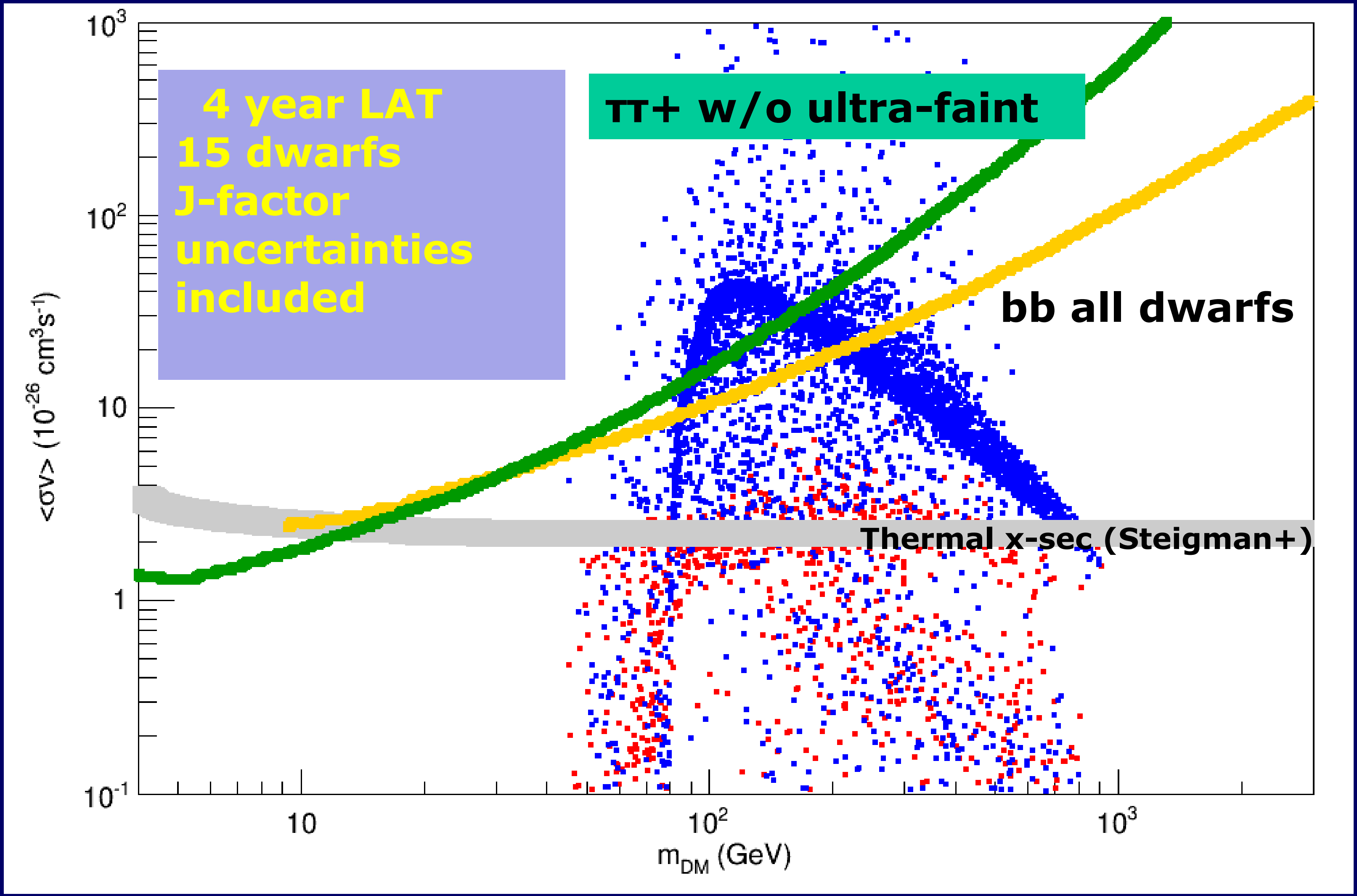


Targets and Challenges - Satellites

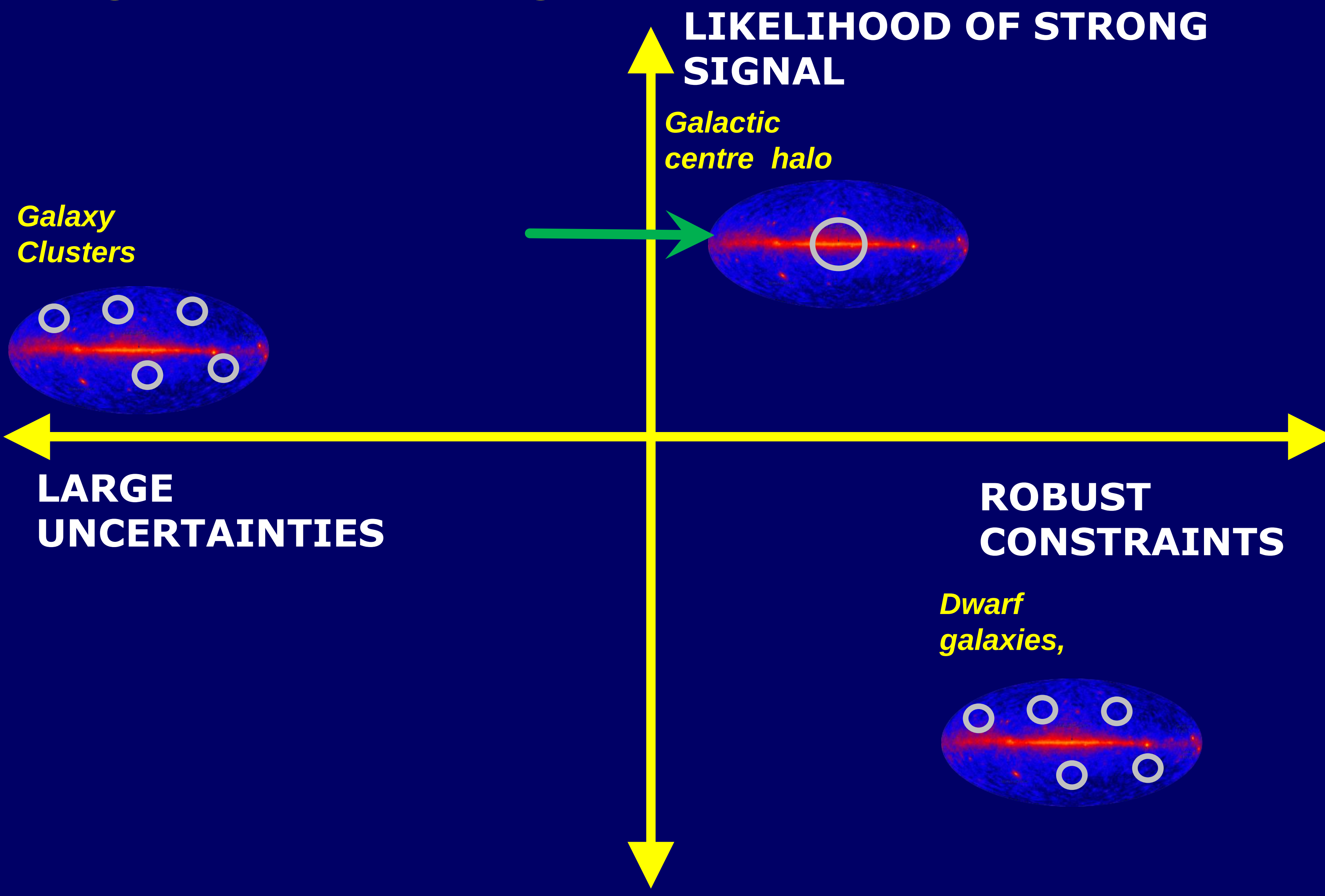


Constraints from likelihood combination of dwarf galaxies

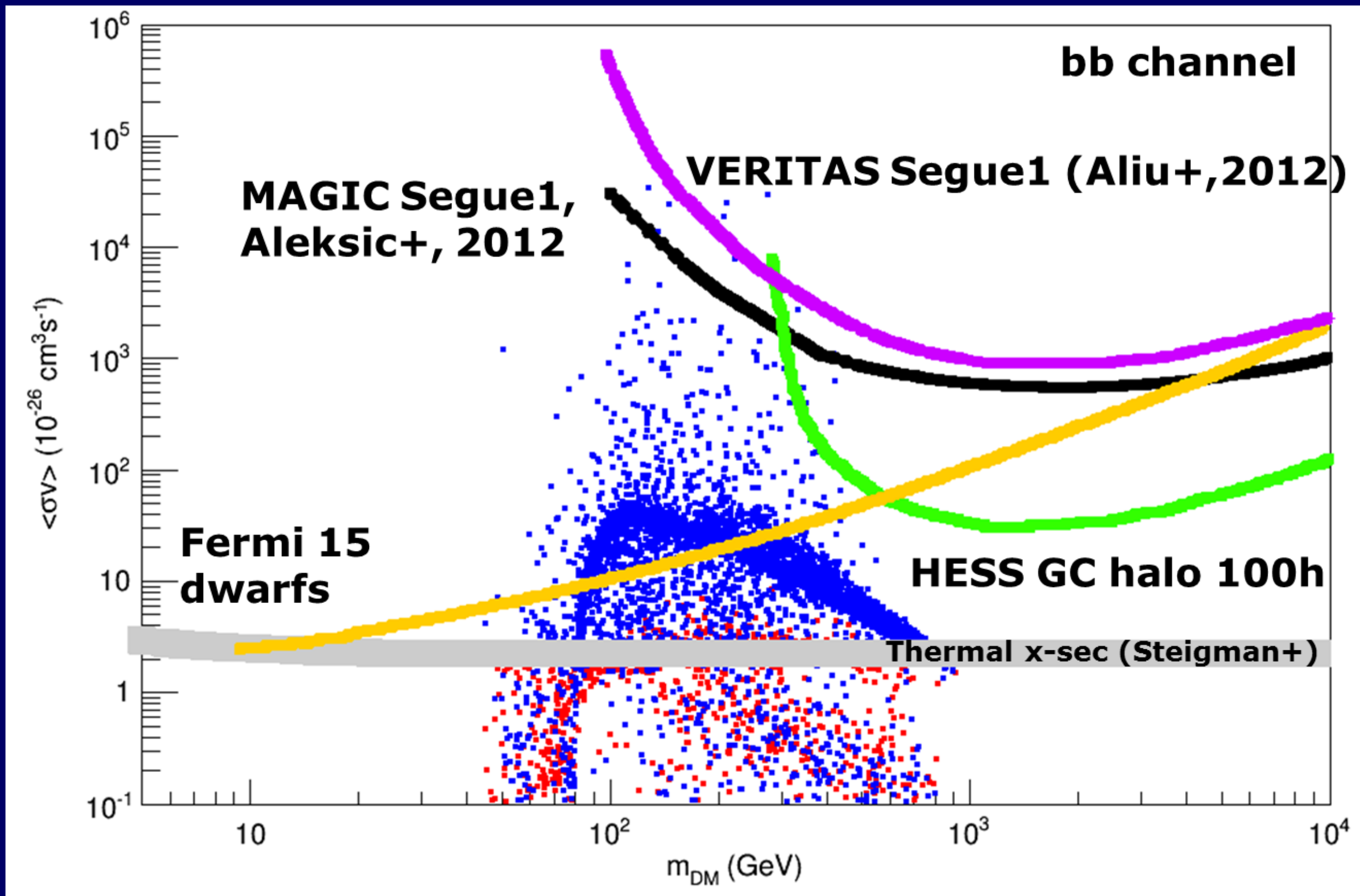
Fermi-LAT: Phys. Rev. Lett. 107, 241302 (2011)
Fermi-LAT: Phys. Rev. D . 89 , 042001, (2014)

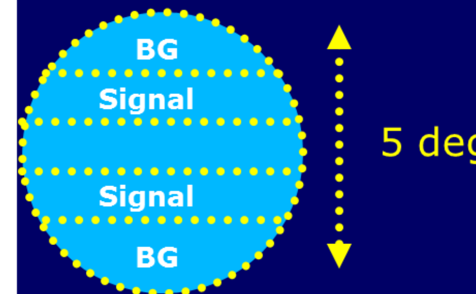


Targets and Challenges – IACT



Most important gamma–ray constraints - summary





What about discovery?

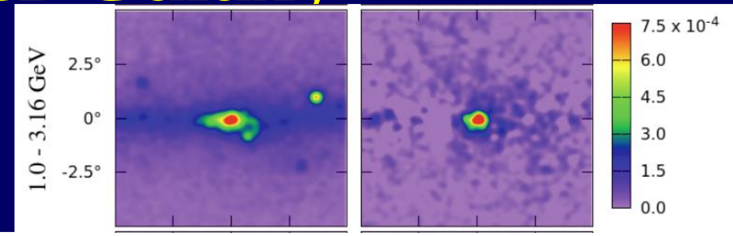
Extended emission in the Inner Galaxy consistent with dark matter?

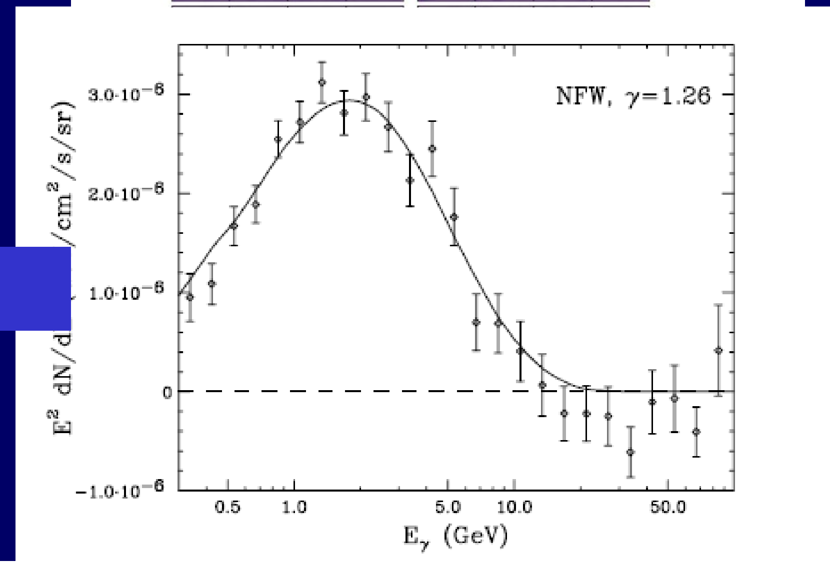
T. Daylan+ (2014)

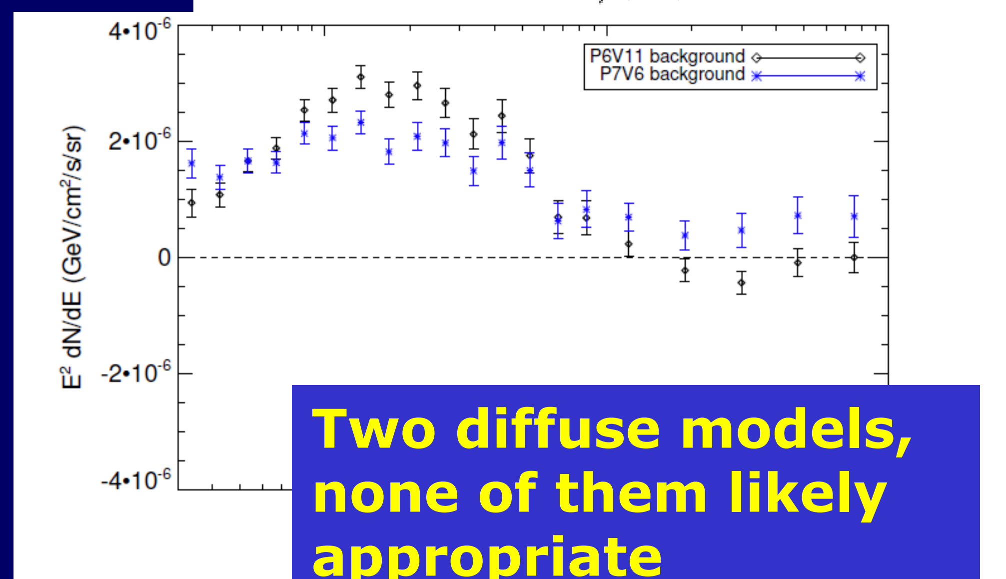
- Excess exhibits spatial and spectral features consistent with dark matter (quark annihilation, 30-40 GeV, thermal cross-section)

Horiuchi talk

- Potential problems arise from the custom made event selection and corresponding diffuse modelling. Whether these aspects invalidate the conclusion, I don’t know.
- Can this be resolved in the Galactic Centre? I doubt it ….

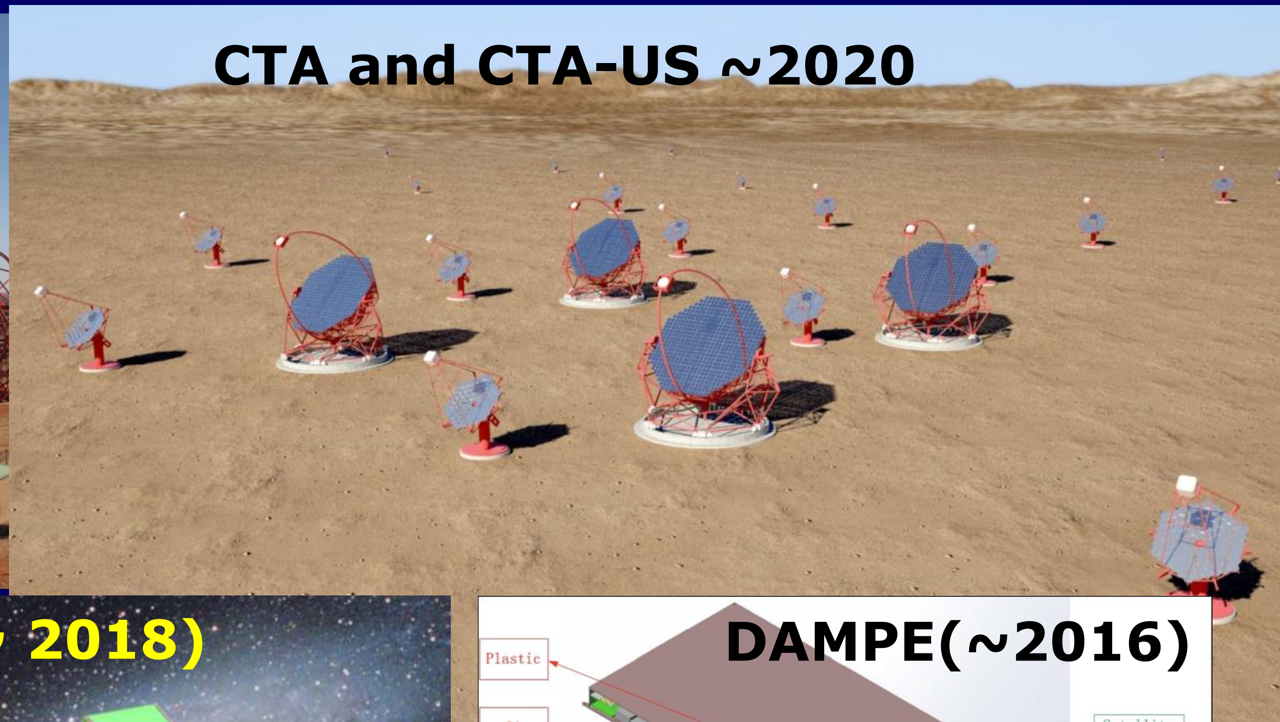


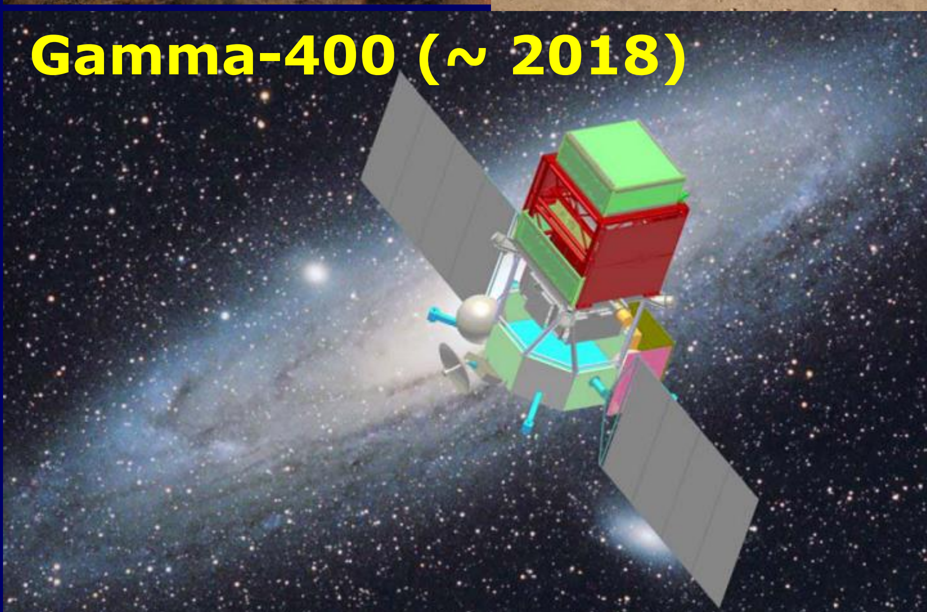


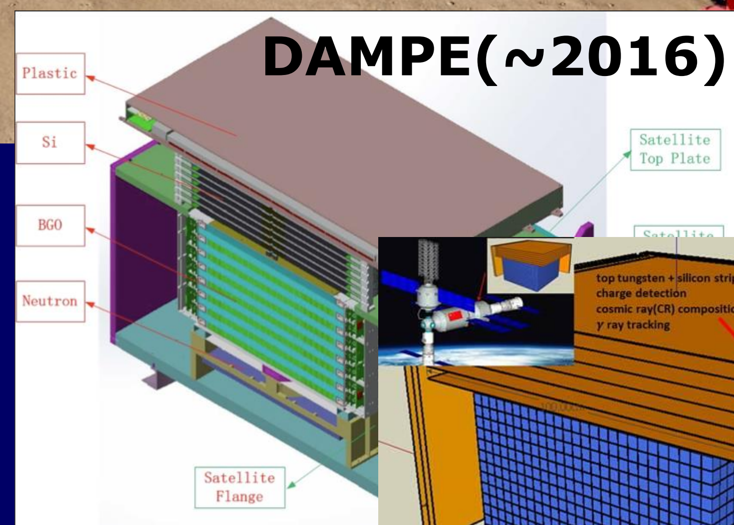


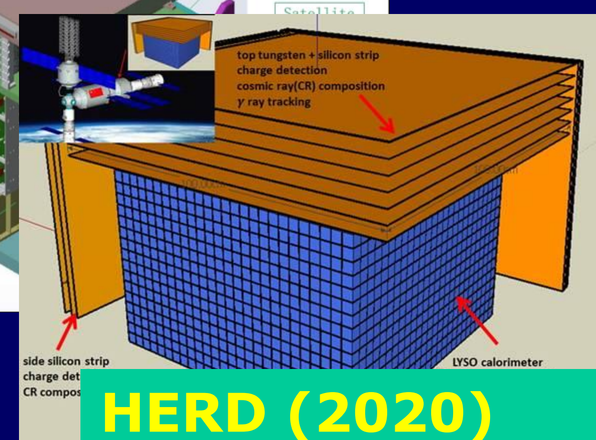
Two diffuse models, none of them likely appropriate

Future experiments

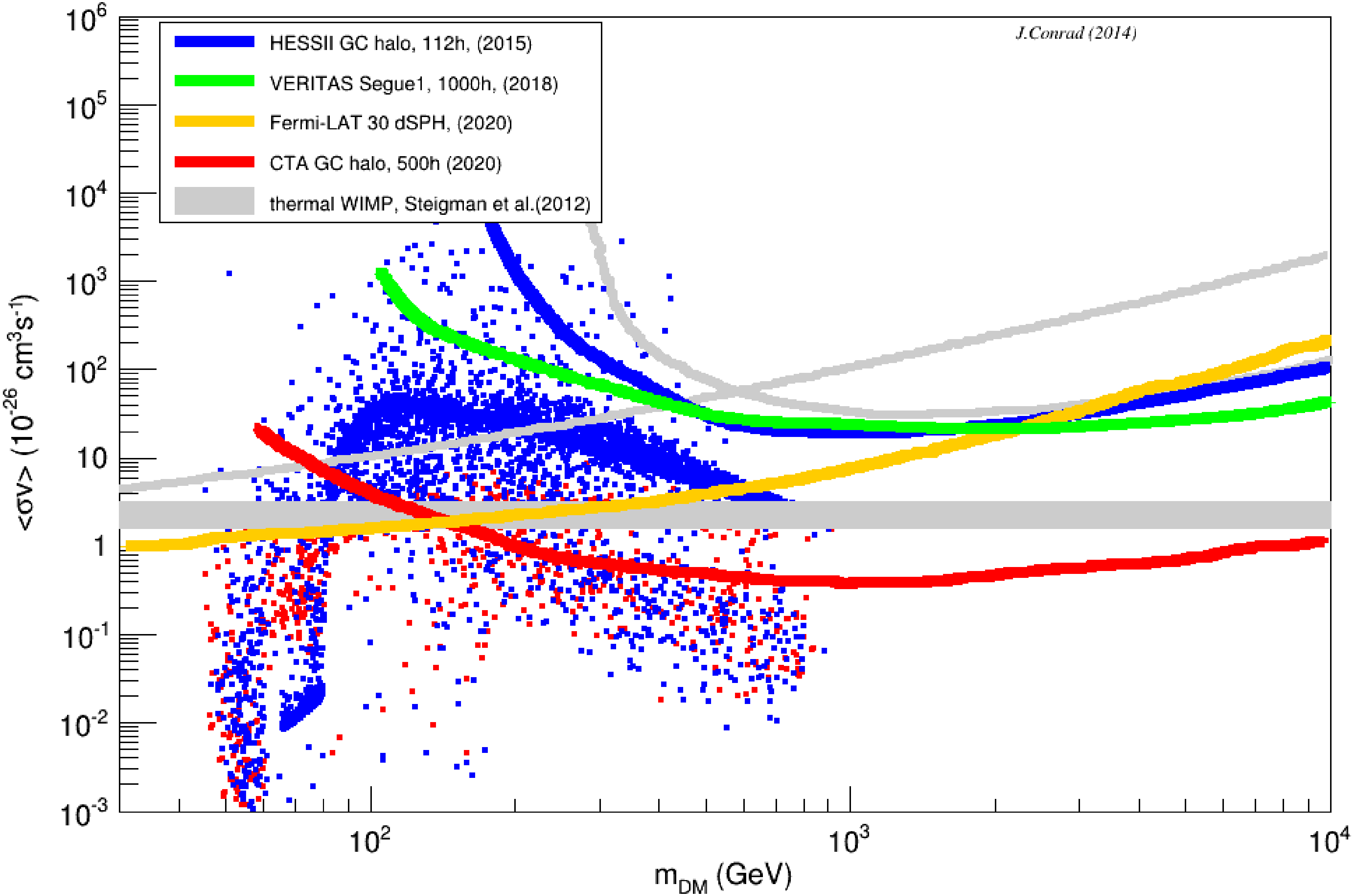








Future Gamma-ray constraints – from now to 2020

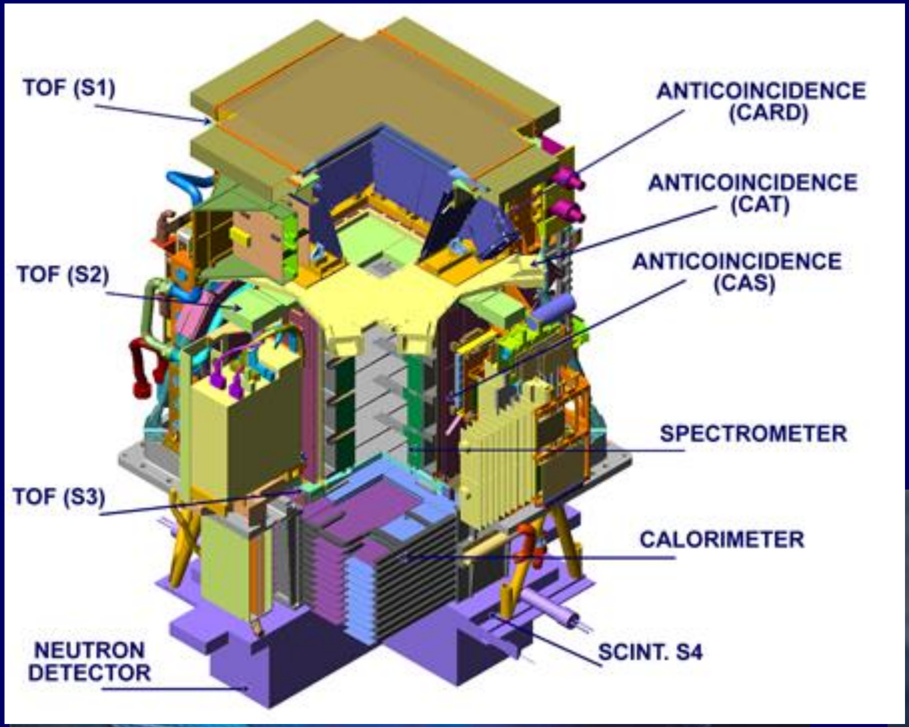


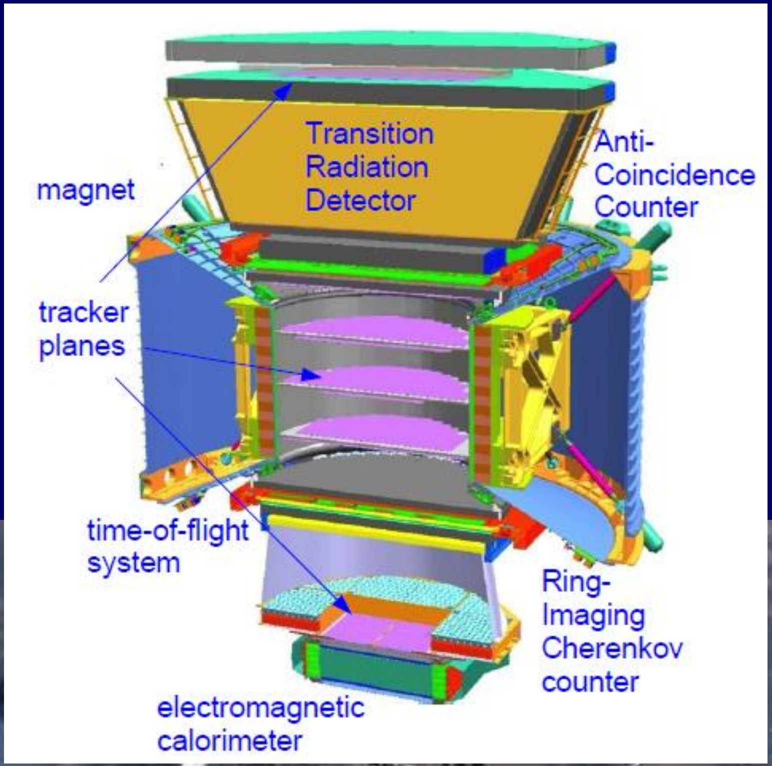
Summary (gamma rays):

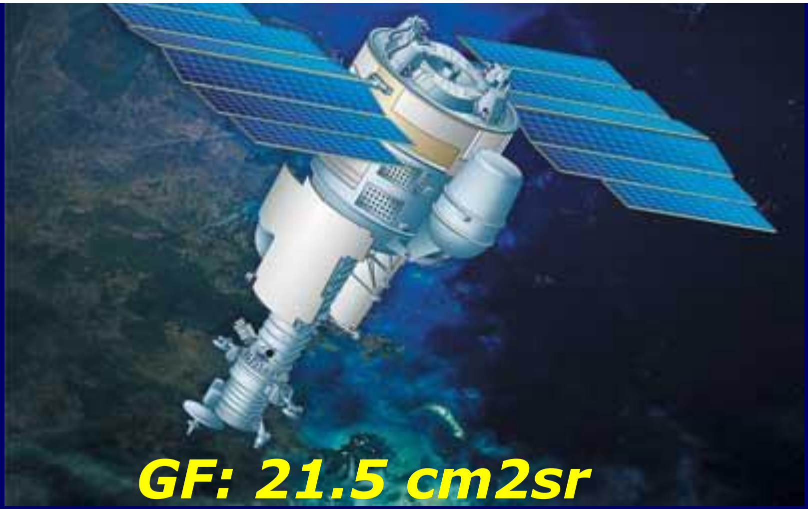
- General:
  - Gamma rays are the golden channel for indirect detection of dark matter, due to the wealth of information they carry and simple propagation
- Status:
  - The most robust constraints (and stringent) are obtained from dwarf galaxies (Fermi-LAT) and the vicinity of the galactic center (HESS)
  - Gamma ray searches provide the most stringent, robust constraints to WIMP dark matter, excluding thermal WIMPS below masses of about 20-30 GeV.
  - An excess at the Galactic Center with respect to simple diffuse emssion models can be interpreted as dark matter →solution in the next iteration of the combined dwarf analysis?
- Outlook:
  - Fermi-LAT/CTA will be able to exclude thermal WIMPS from a few GeV upto several TeV within the next decade → we are entering the endgame for the WIMP paradigm

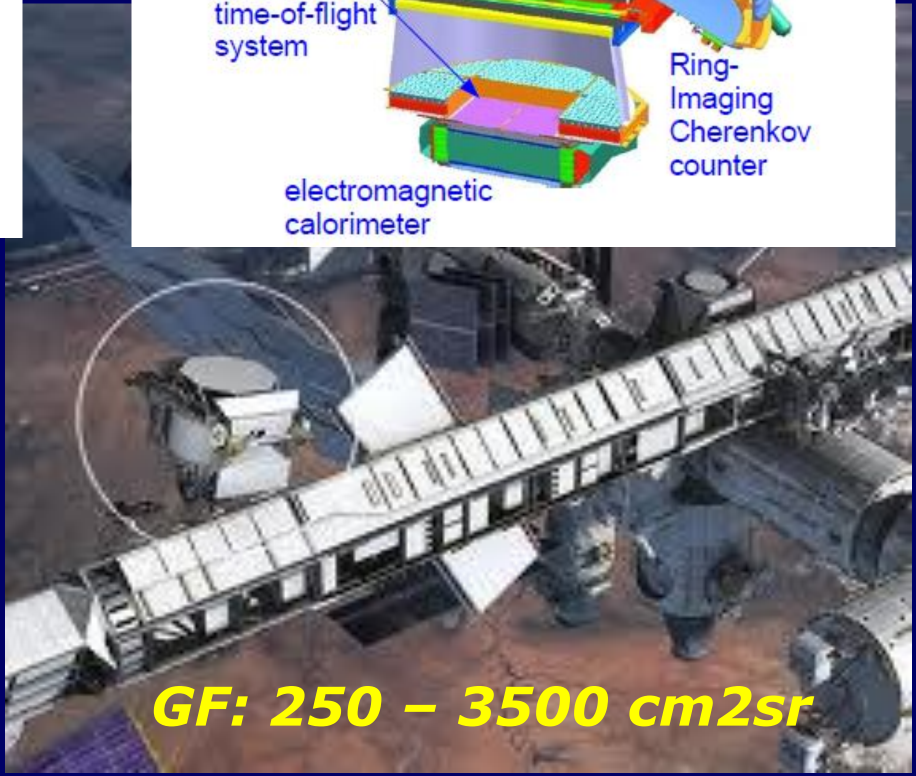
Cosmic rays: a clear signal – but of what?

PAMELA/AMS

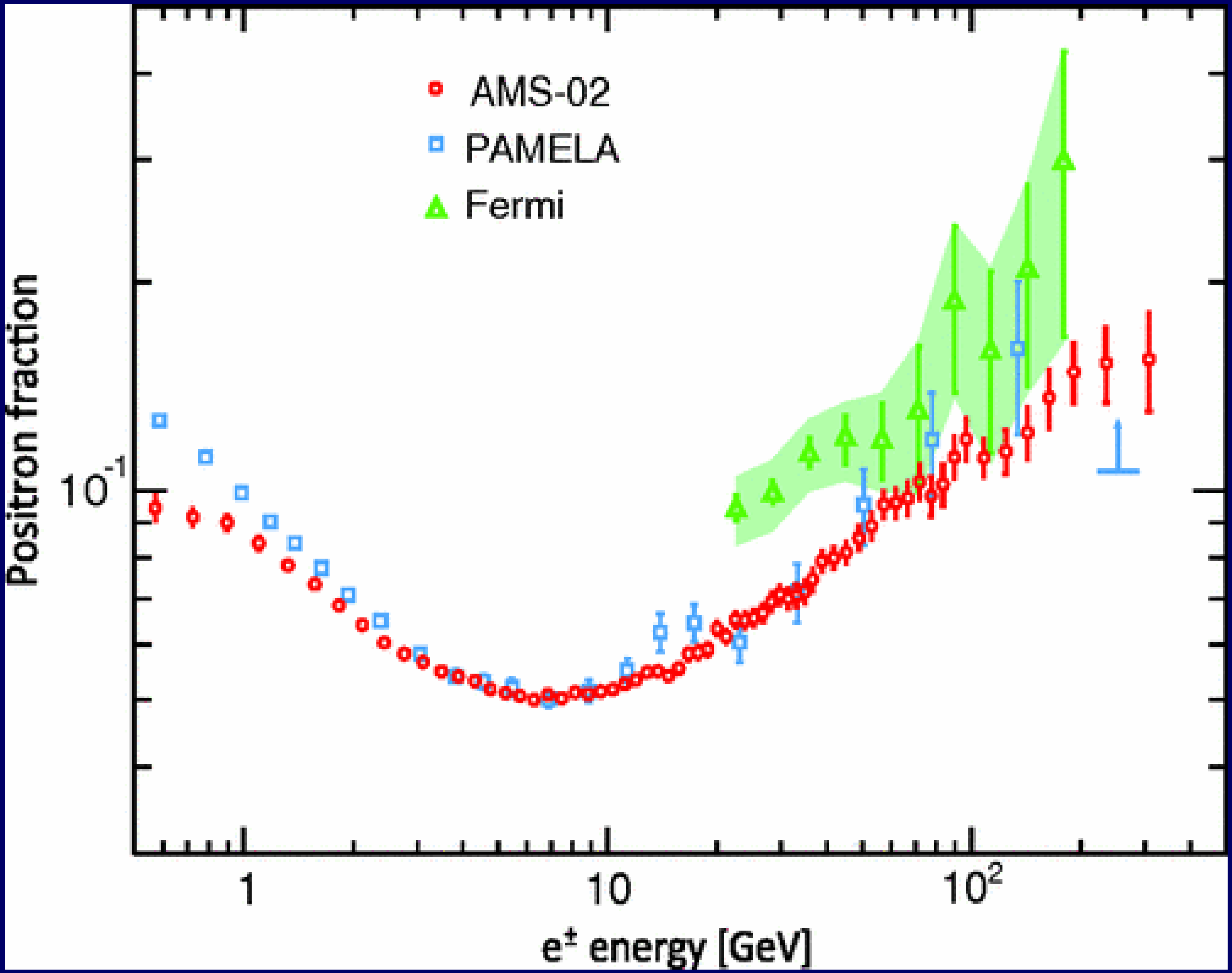

TOF (S1)
ANTICOINCIDENCE (CARD)
ANTICOINCIDENCE (CAT)
ANTICOINCIDENCE (CAS)
TOF (S2)
SPECTROMETER
TOF (S3)
CALORIMETER
NEUTRON DETECTOR
SCINT. S4


magnet
Transition Radiation Detector
Anti-Coincidence Counter
tracker planes
time-of-flight system
Ring-Imaging Cherenkov counter
electromagnetic calorimeter


GF: 21.5 cm2sr


GF: 250 – 3500 cm2sr

Positron fraction



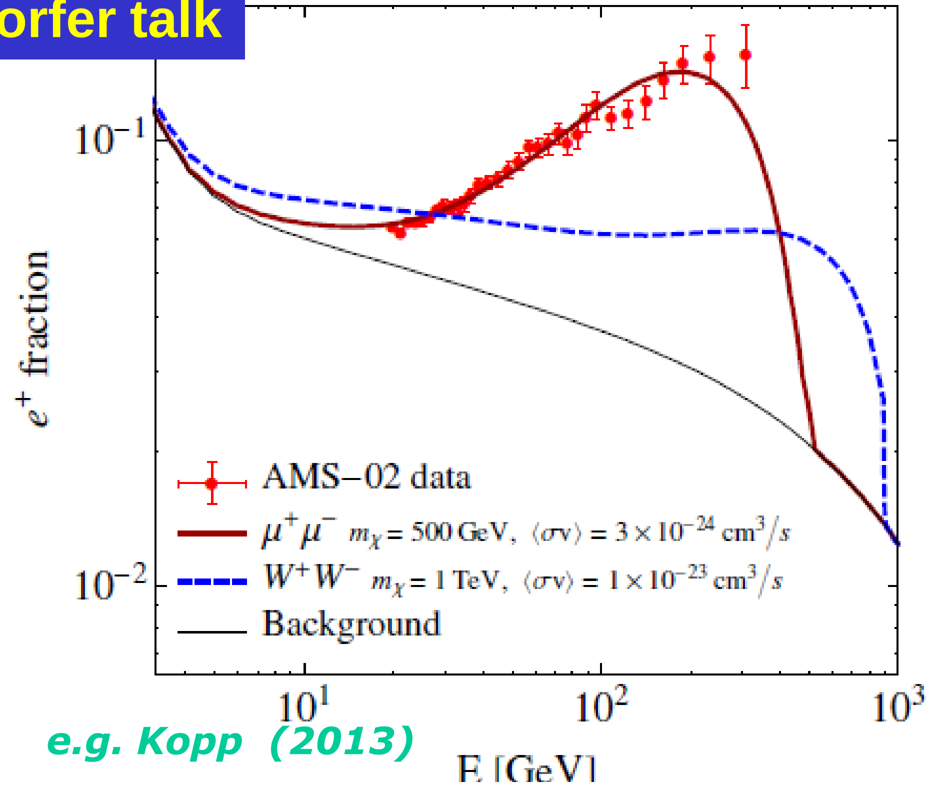
Requires non-standard source of positrons but what?

Dark Matter

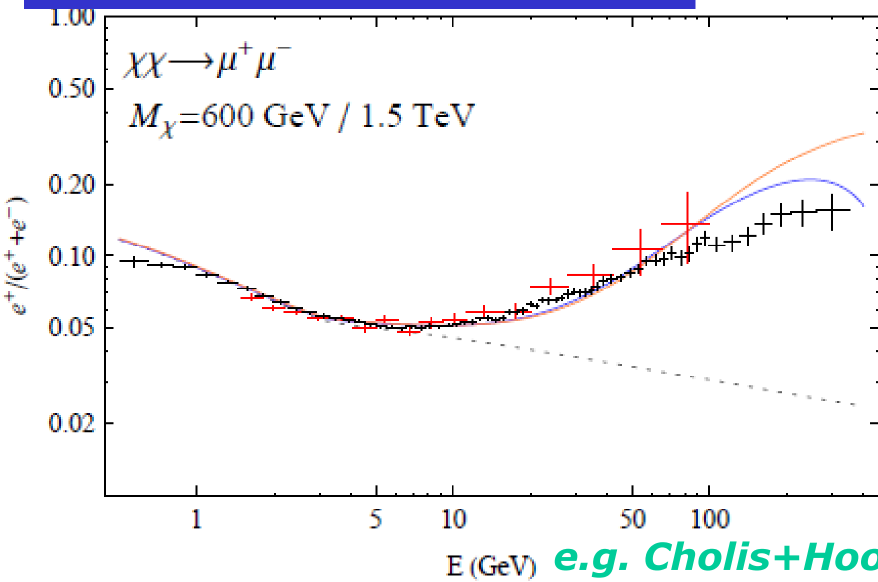
Lamperstorfer talk

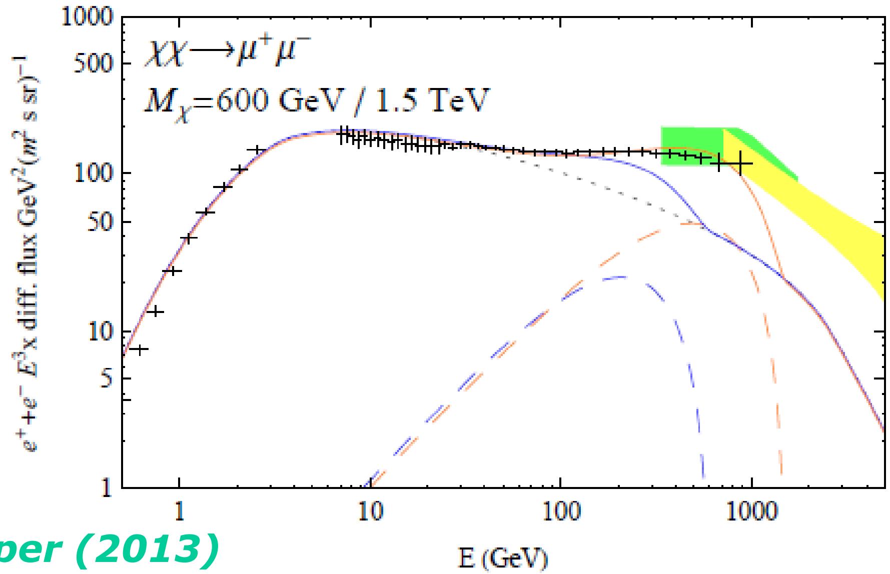
- Data prefers models with leptonic annihilation, largish masses (~ TeV), large x-sec or boost
- Difficult to accomdate both the positron fraction and the hard Fermi-LAT electron spectrum (decay via light mediator states)

See also Pospelov talk



e.g. Kopp (2013)





e.g. Cholis+Hooper (2013)

Pulsars or SNRs?

- Single mature pulsar or sum of pulsars
  - Monogem
    Geminga

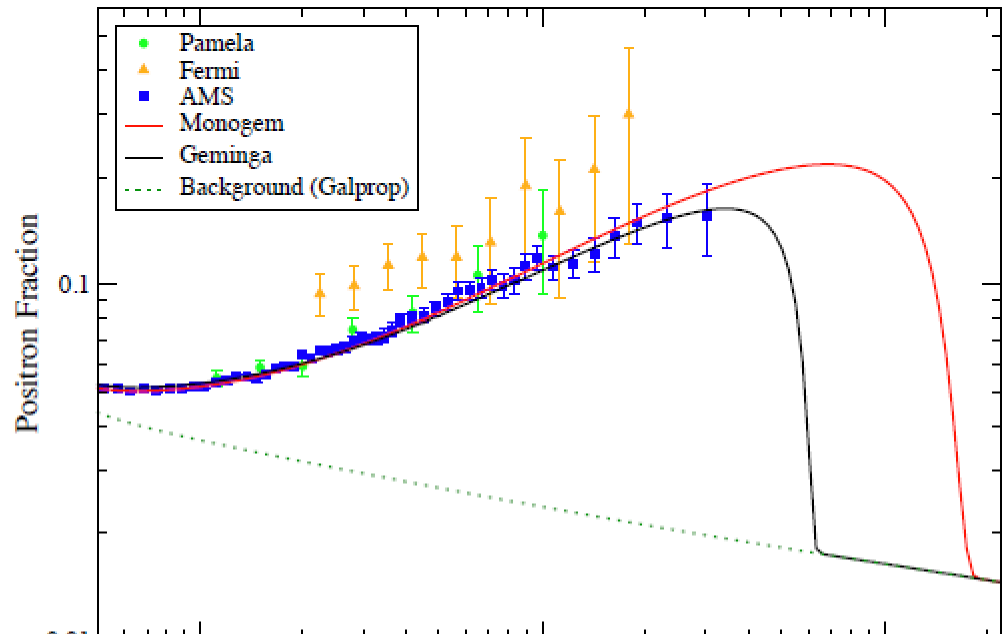
- SNR

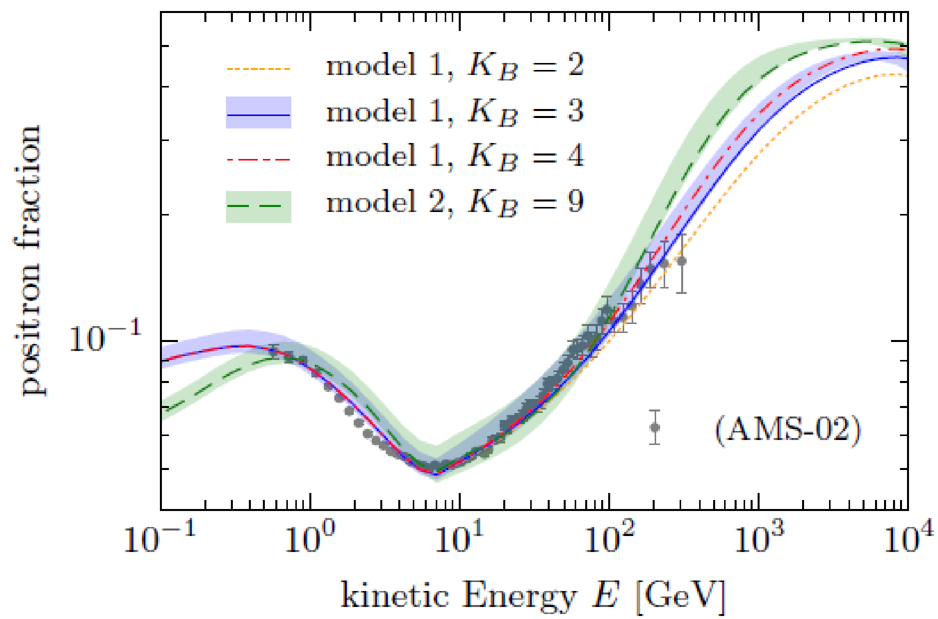
e^+ produced inside SNR → harder positron spectrum

Blasi+ (2009), Ahlers+ 2009

Mertsch+Sarkar (2014)

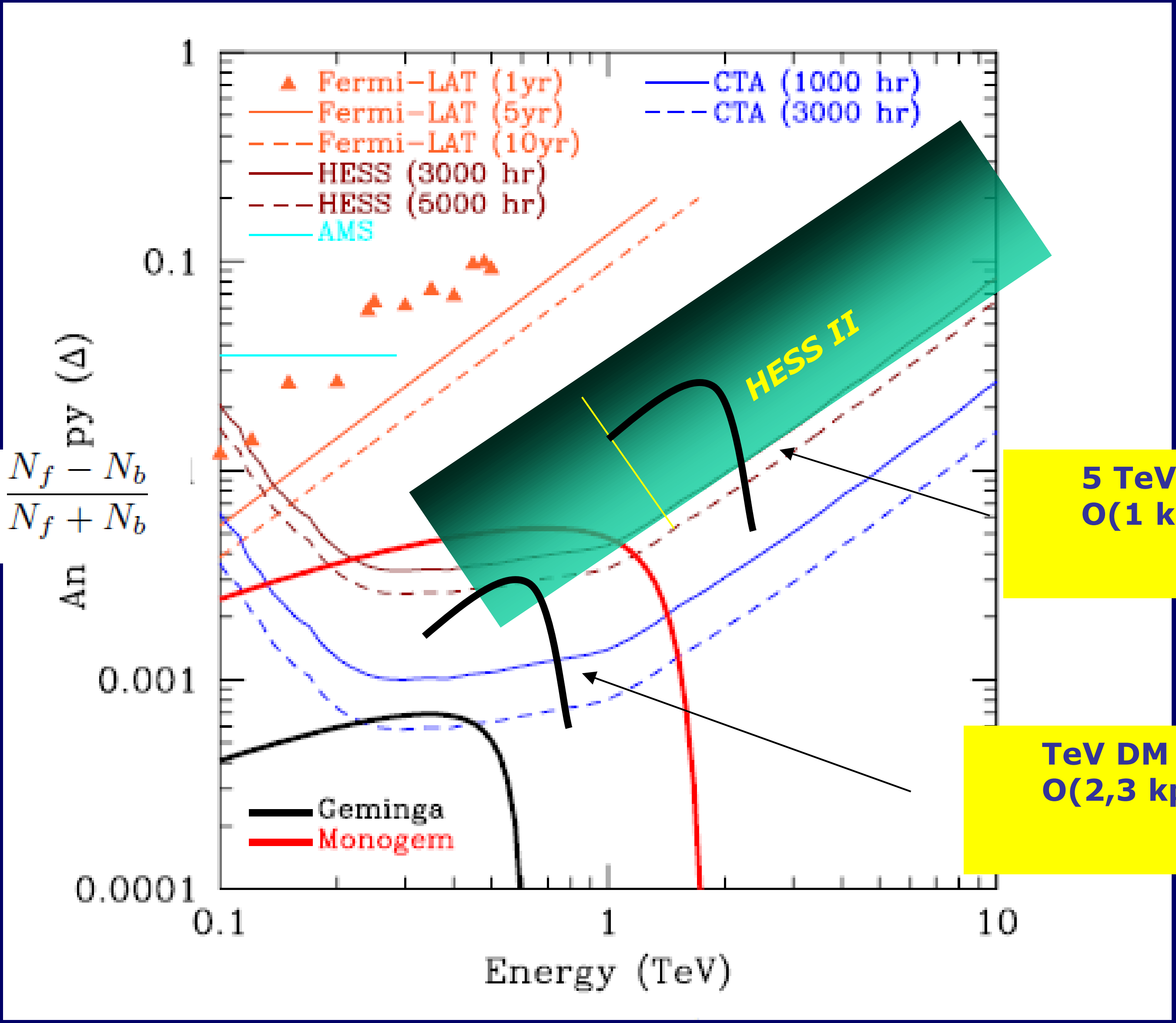
e.g. Linden+Profumo (2013)





e.g. Cholis

Can air cherenkov telescopes help?



$$\Delta = \frac{N_f - N_b}{N_f + N_b}$$

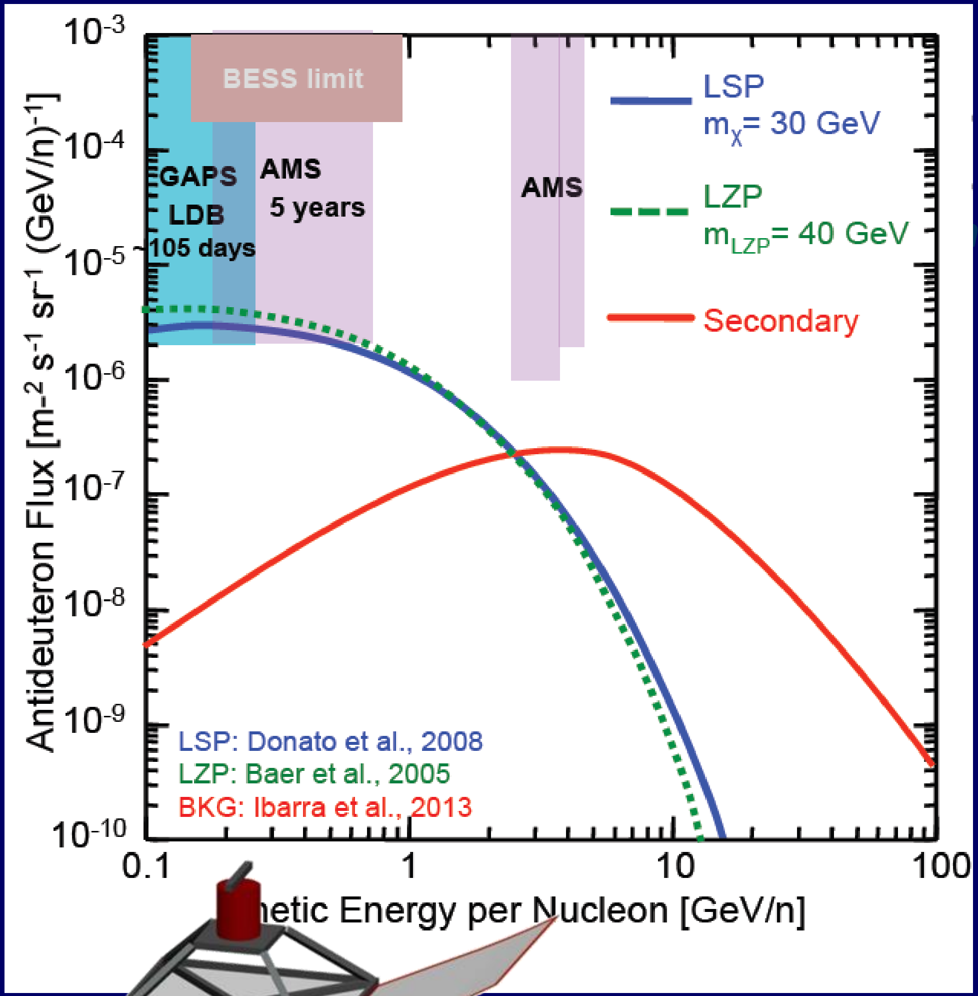
5 TeV DM clump at O(1 kpc)

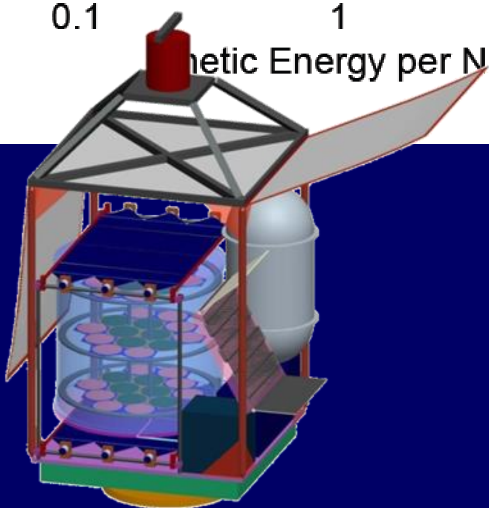
TeV DM clump at O(2,3 kpc)

Linden,Profumo (2013)

See also Regis, Ullio (2009)

Anti-deuteron: GAPS





Vittino talk

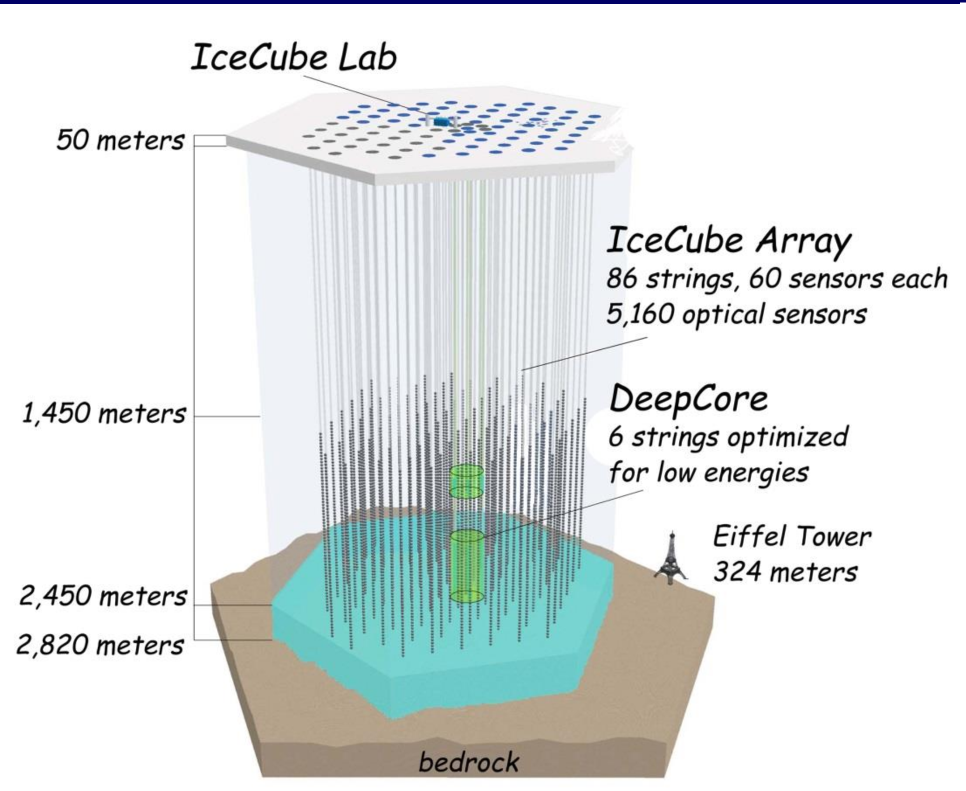
- TOF and Si(Li) strip detector , signature: x-rays from deexcitation of exotic atom and tracks of decay products (p, pions)
- Successful prototype flight in 2012
- First flight 2018/2019
- Full sensitivity achieved: 2020/21 (?), (AMS 5 year reached by 2017)

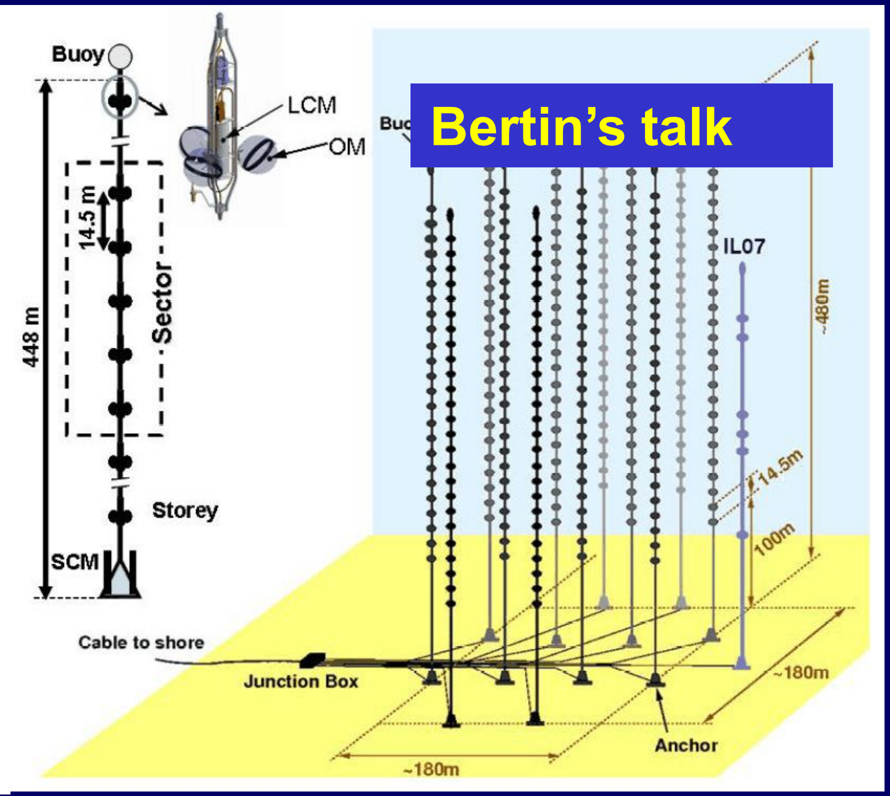
Summary (cosmic rays):

- General:
  - Cosmic (anti-) rays can provide convincing signals of Dark Matter
  - Competetive constraints for leptonic channels
- Status: *e.g. Bergström+(2013)*
  - AMS has spectacularly confirmed the existence of a new source of positrons.
  - DM IMHO even less likely than after PAMELA.
- Outlook:
  - Anti-proton/spectra and B/C measurements highly anticipated to rule out or confirm proposal of SN production
  - Can IACTs provide sensitive anisotropy measurement?

Neutrinos: direct detection in disguise

IceCube and ANTARES





~ 5000 channels

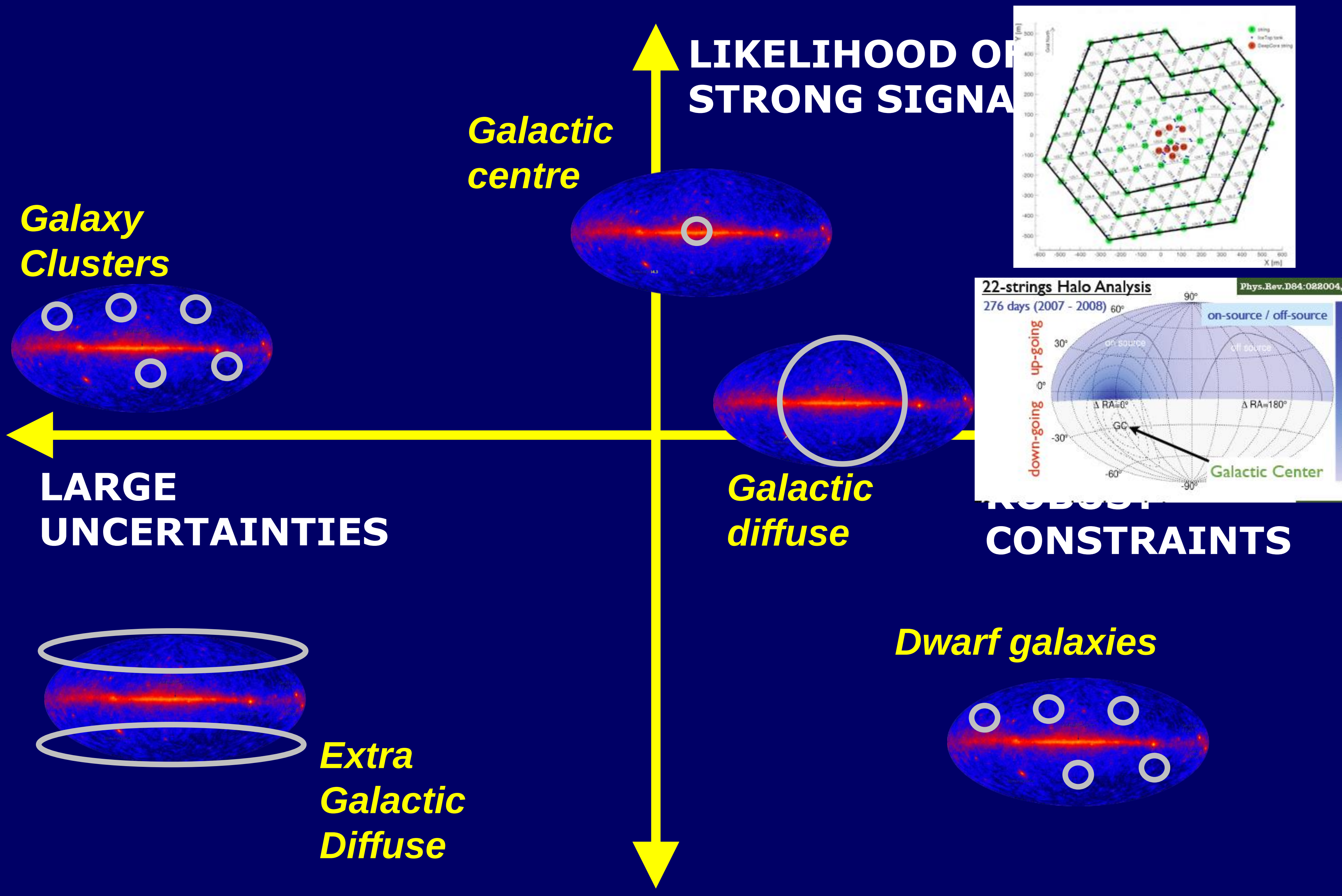
Mainly northern hemisphere

~ 900 channels

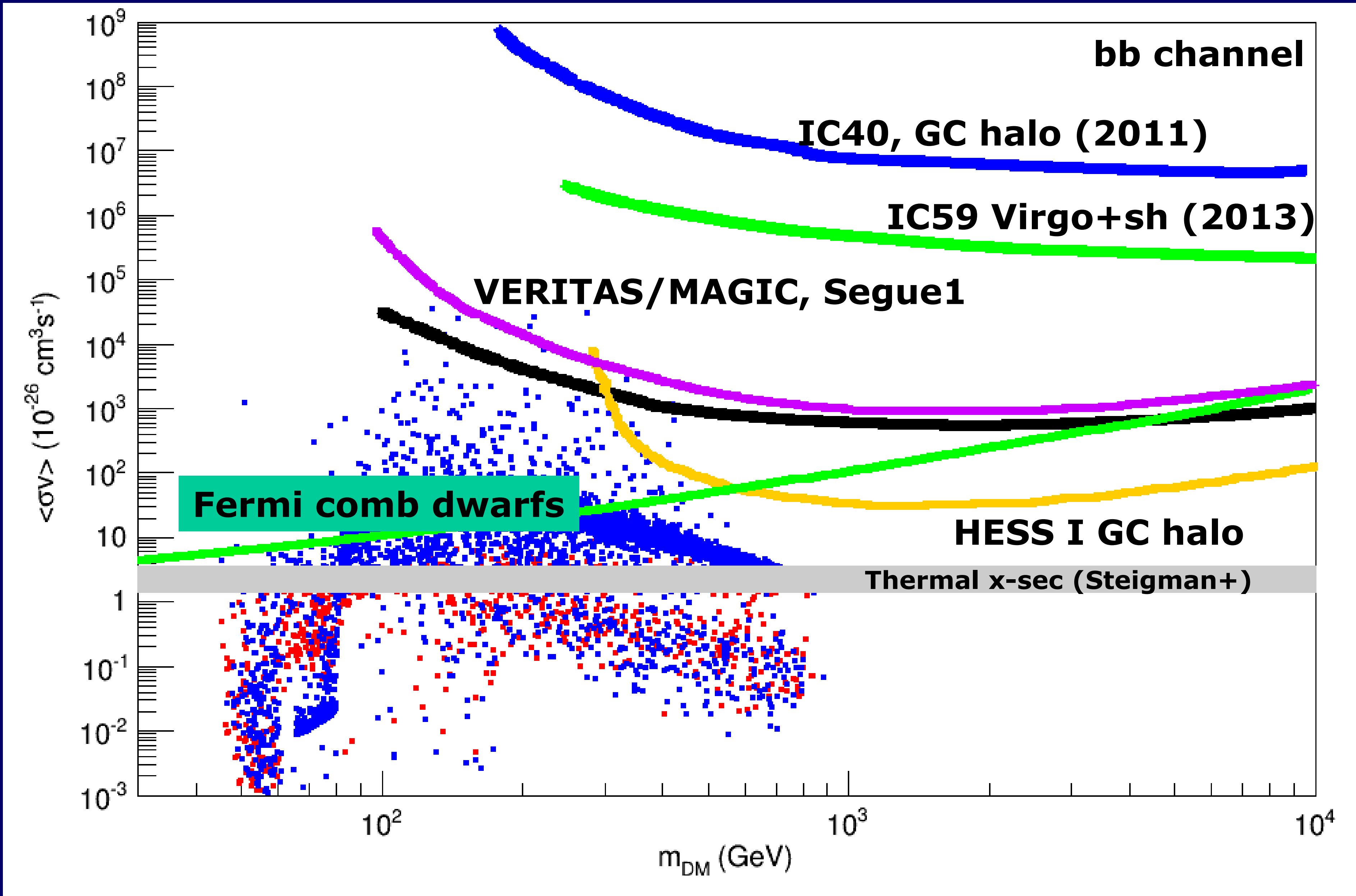
Mainly southern hemisphere

First, constraints on annihilation cross-sections ….

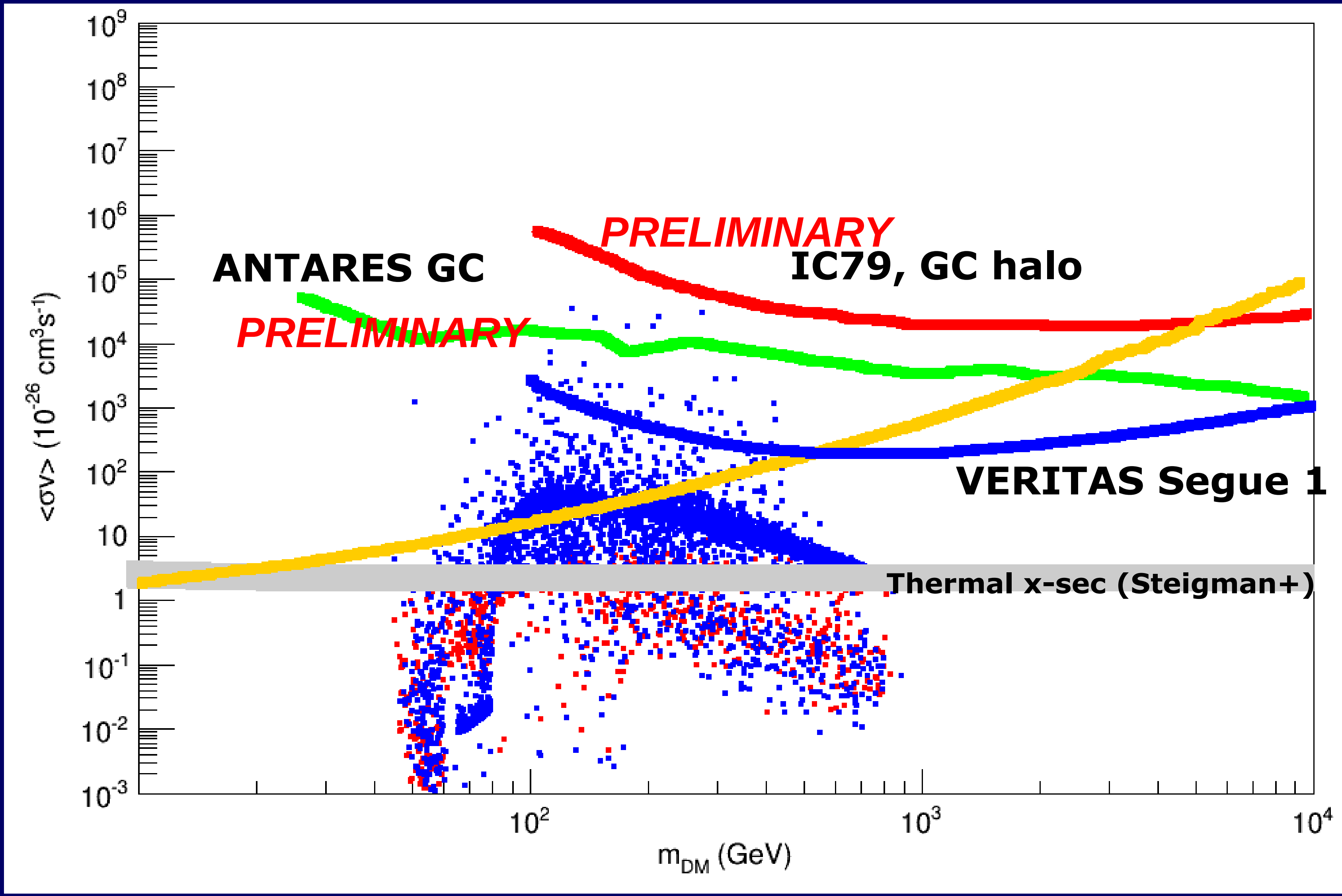
Targets and Challenges – neutrino telescopes



Indirect limits ICE3 compared to gamma rays



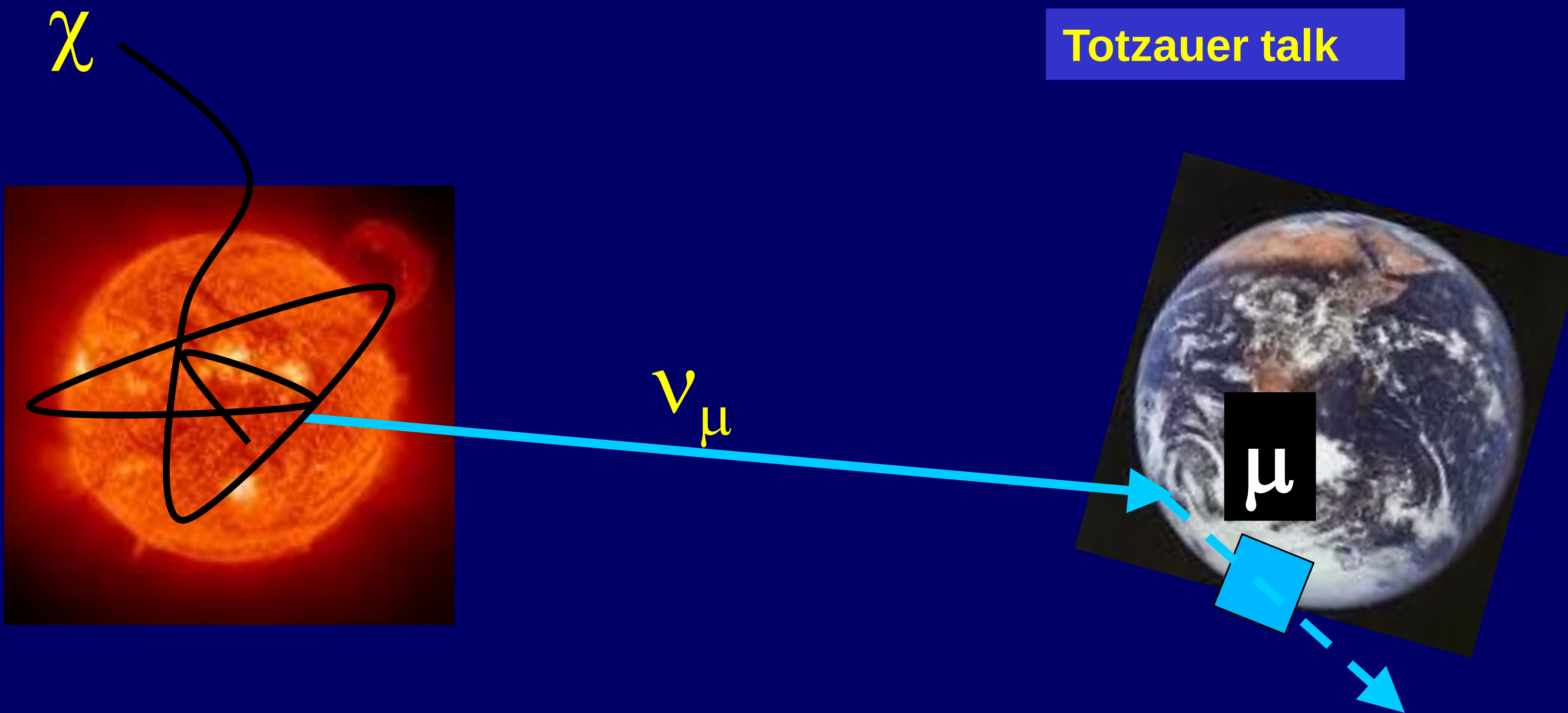
τ channel



PRELIMINARY
ANTARES GC
IC79, GC halo
PRELIMINARY
VERITAS Segue 1
Thermal x-sec (Steigman+)
$\langle\sigma v\rangle$ (10^{-26} cm^{3}s^{-1})
m_{DM} (GeV)

Neutrinos: detection from the Sun

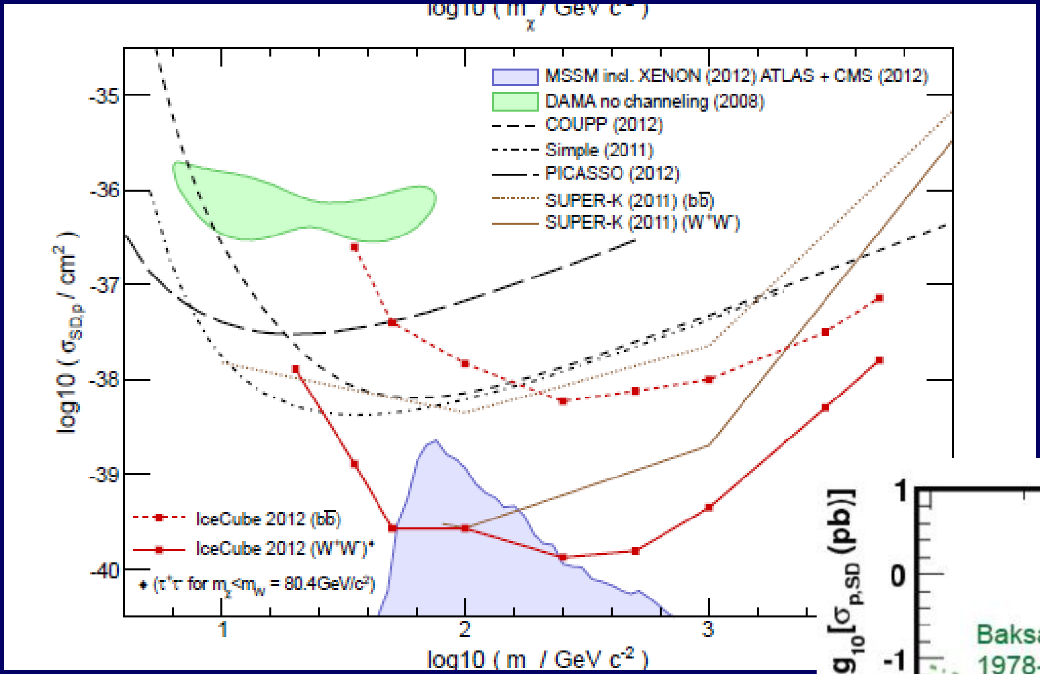
Totzauer talk



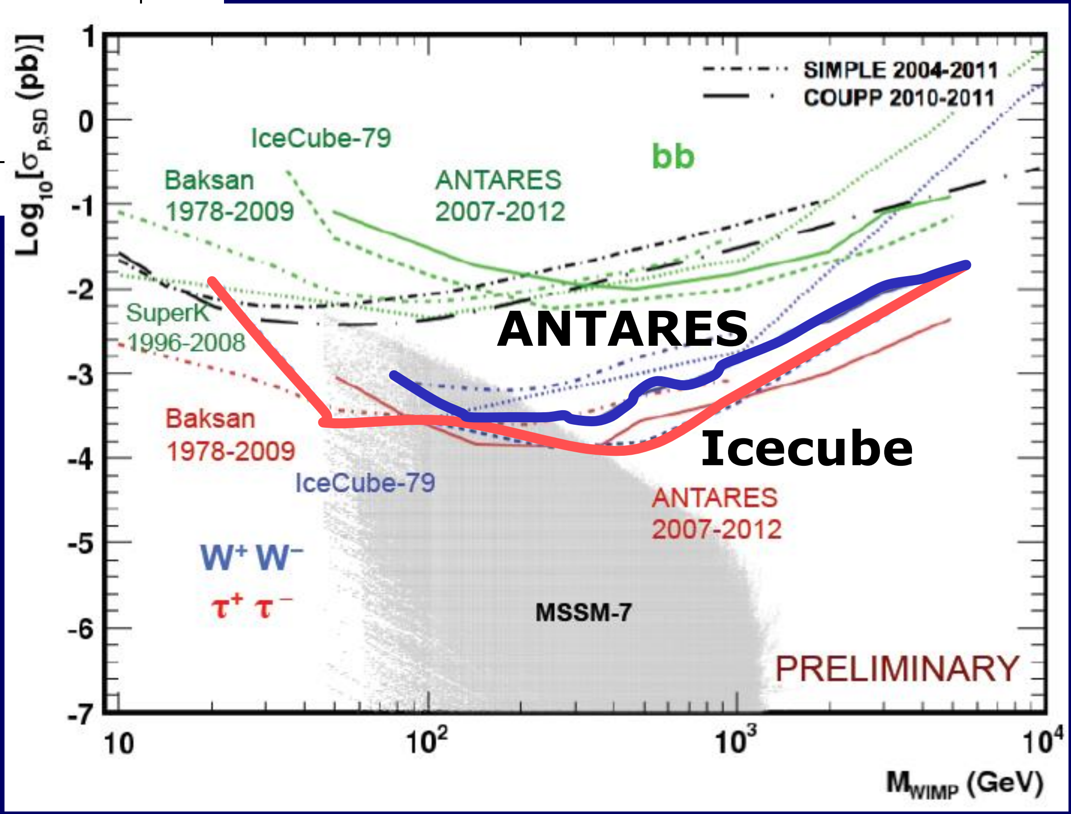
$$\Gamma_{\text{Capture}} \; (\propto \; \sigma_{SD}) \; = 2 \; \Gamma_{\text{annihilation}}$$

→ Hydrogen dominated target → excellent sensitivity SD cross section

Icecube 79 and ANTARES



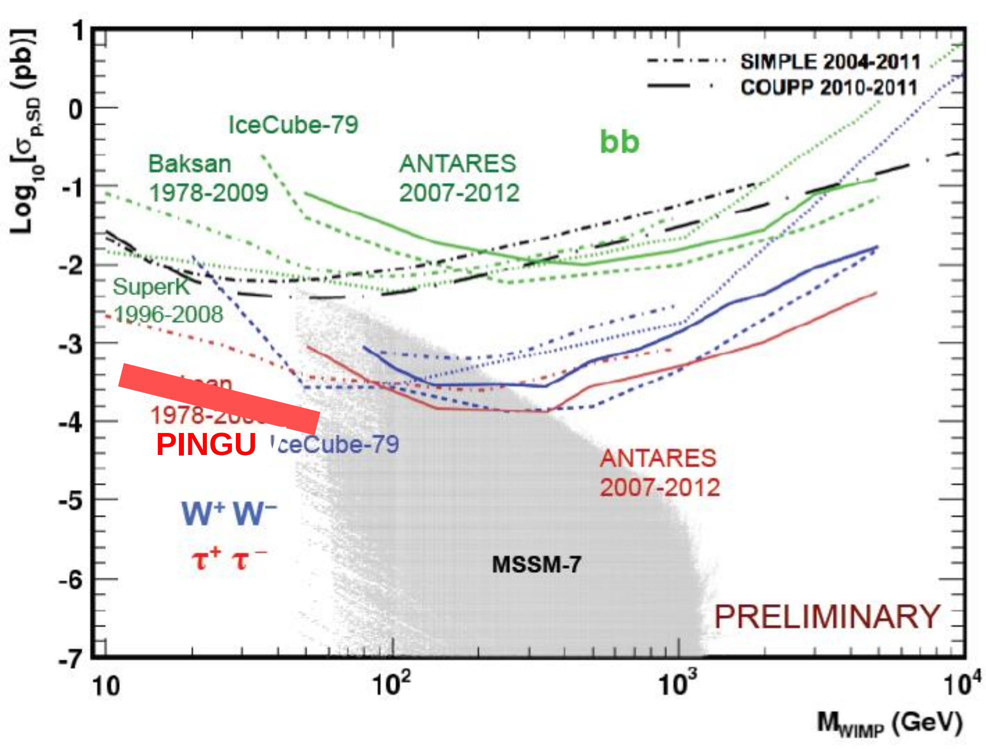
[Aartsen+ (IceCube), (2012)]



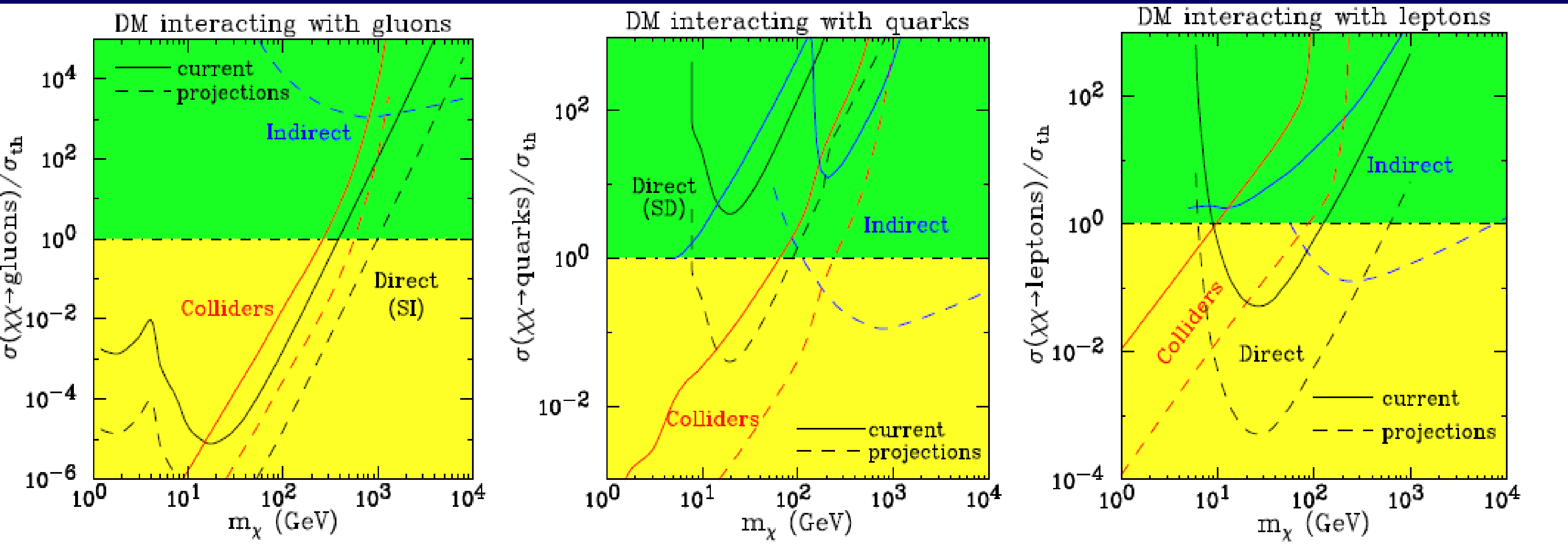
Summary (neutrinos):

- General:
  - The main niche for neutrino telescopes are models with large SD cross section (solar WIMPs)
  - Annihilations: hard to compete with IACT, maybe at very high masses (~10s of TeV …?), where neutrino x-sec/muon range can compensate 1/m**2 scaling of the sensitivity and for leptophillic models
- Status:

  Ice3 and Antares in full swing
- Outlook:
  - PINGU: 1-2 dex improvement at low masses (below 100 GeV), ~factor 2 at large masses …



Last slide: complementarity in effective theory approach



Arrenberg+. Snowmass (2013)

BACKUP

APP- smooth Dark matter halo density profile

Cosmological N-body simulations:

Navarro-Frenk-White

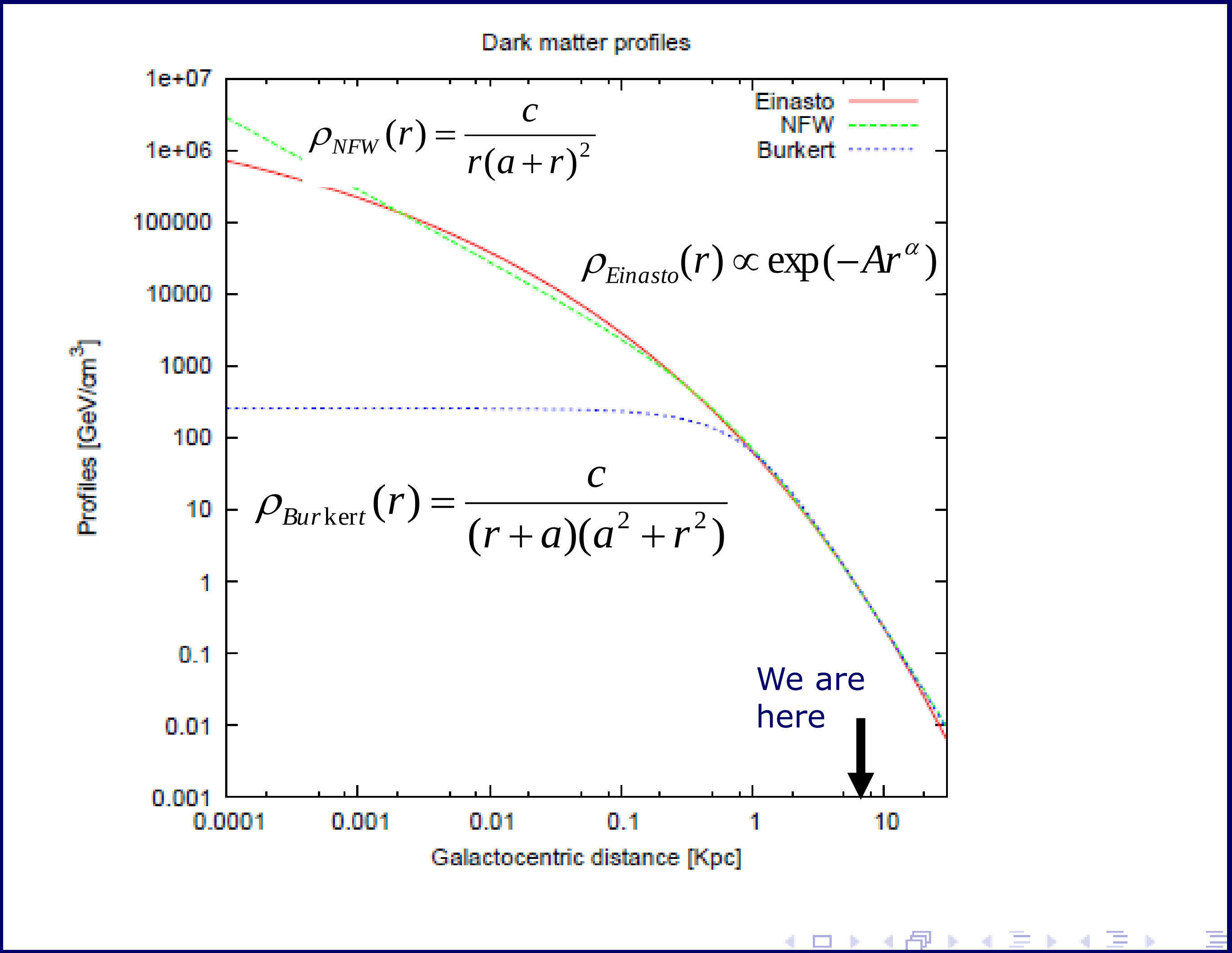
Einasto

→ "Cuspy"

Stellar dynamics:

e.g. Burkert.

→ "Cored"



R. Catena

Strongest signal from the Galactic Center !

Excess continued:

- The spectrum is consistent with a DM particle of mass (30 - 40 GeV) annihilating to quarks and thermal annihilation x-sec
  - → Smack on the current paradigm

- Excess is spherically symmetric

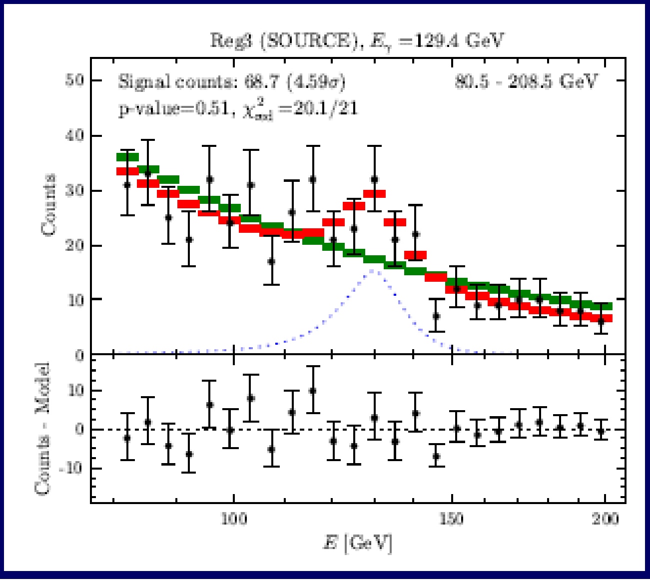
- The emission profile is consistent with what a Dark Matter distribution predicts, and less so with the prime candidate for source confusion (pulsars).

- Potential problems arise from the custom made event selection and corresponding diffuse modelling. Whether these aspects invalidate the conclusion can not be concluded from the paper

A line in Fermi-LAT data?

- 3.3σ LEE corrected (~50 events)

  Bringmann+ (2012)
  Weniger (2012)



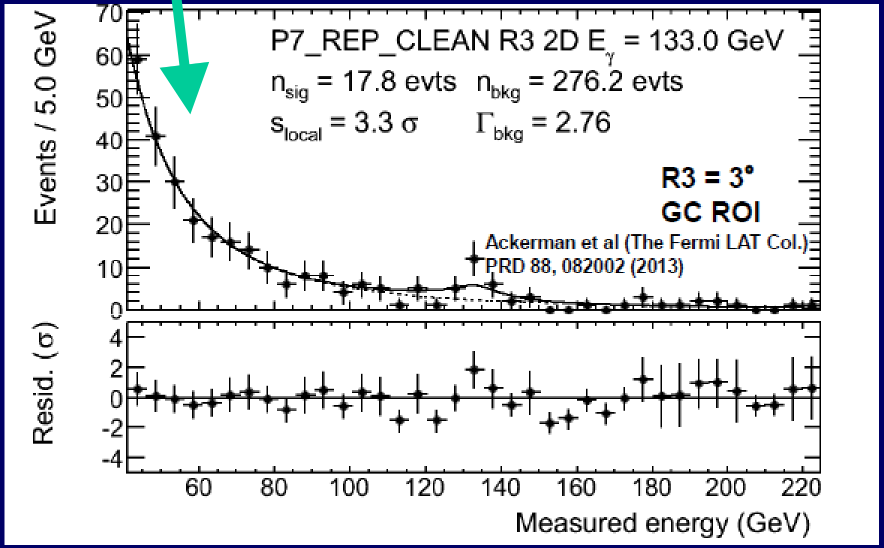
- 5σ LEE corrected, and two lines?

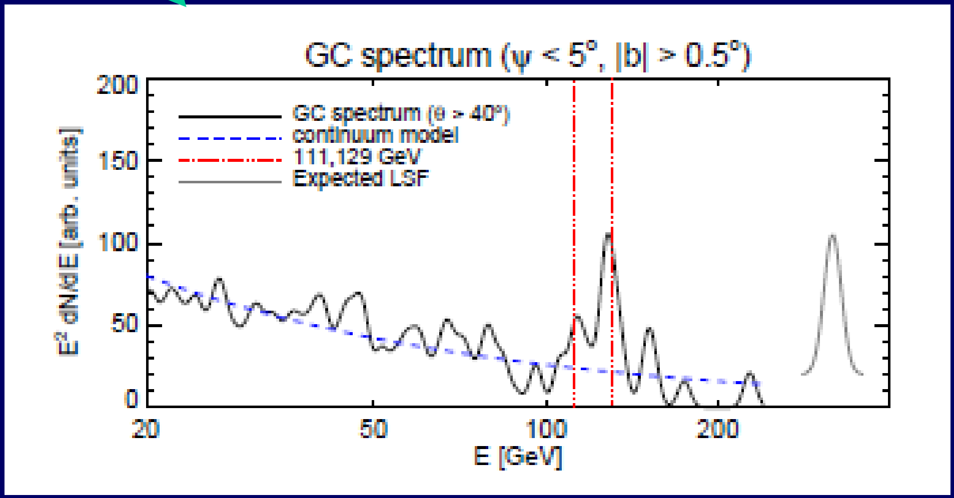
  Su&Finkbeiner (2012)
  Tempel+ (2012) (4.5σ)

-

- 2σ LEE corrected
  and signal in Earth Limb

  Ackermann+ (Fermi-LAT) (2013)





Signal 1.5 deg offset

Significance until September 2013

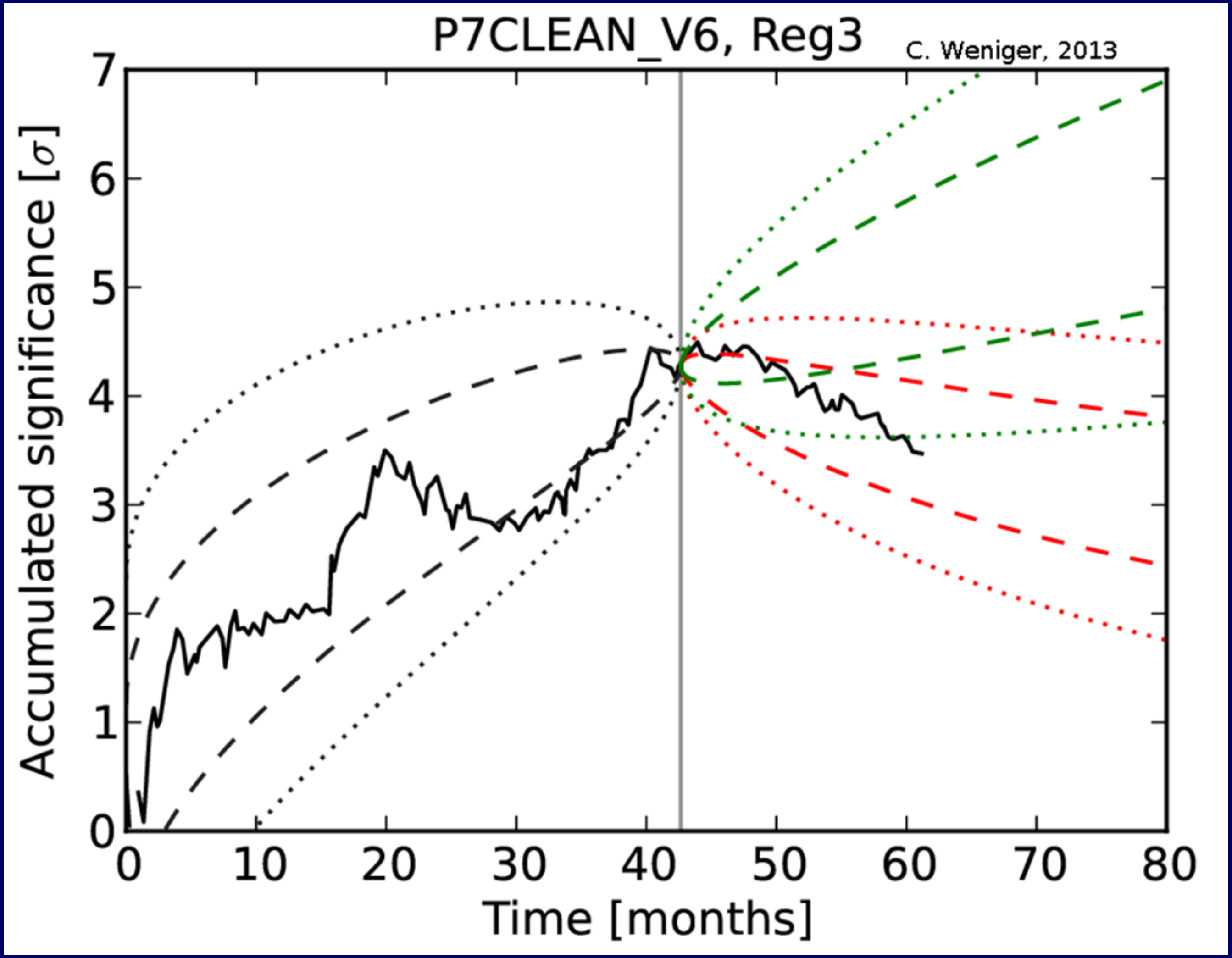
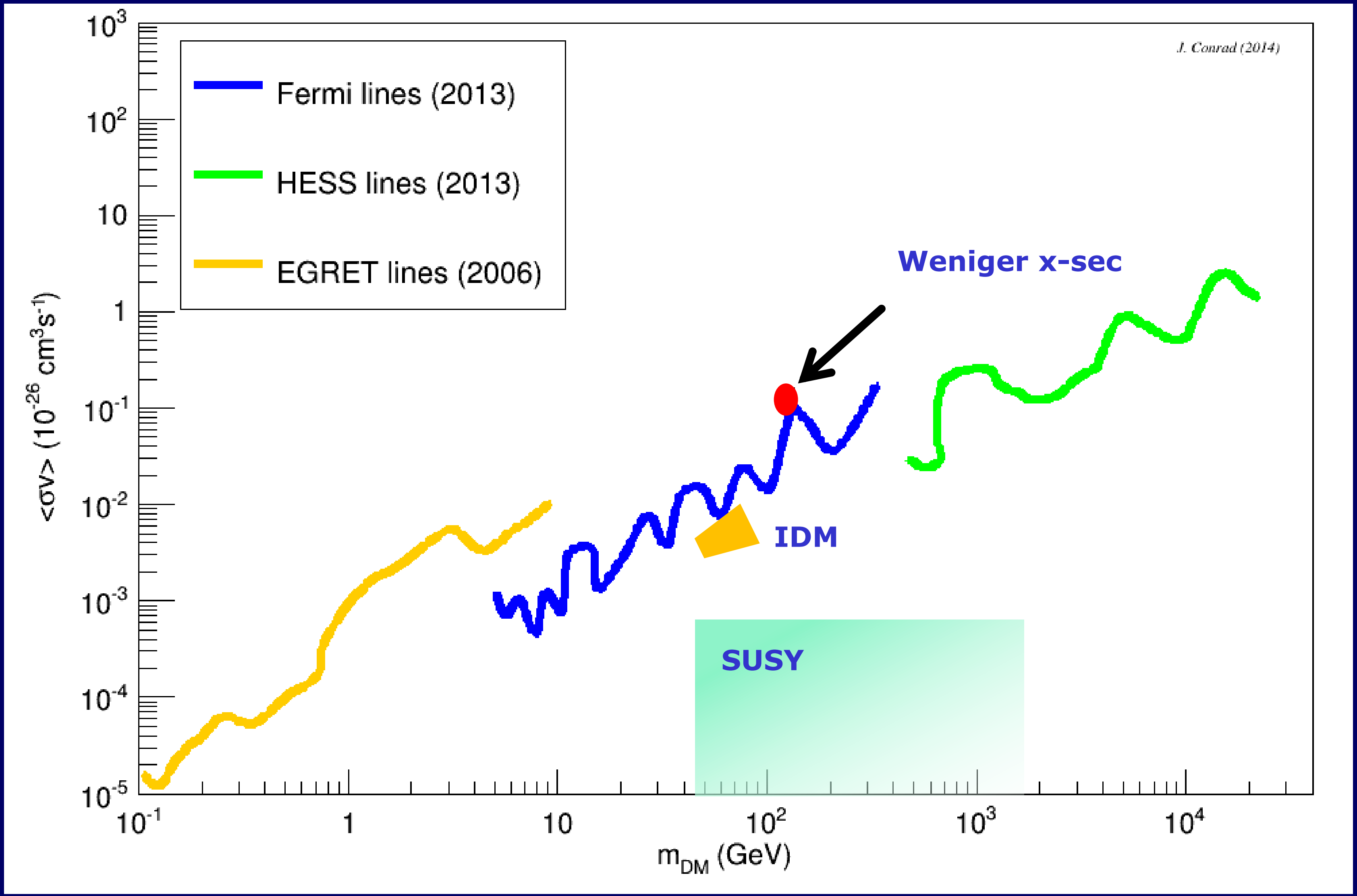
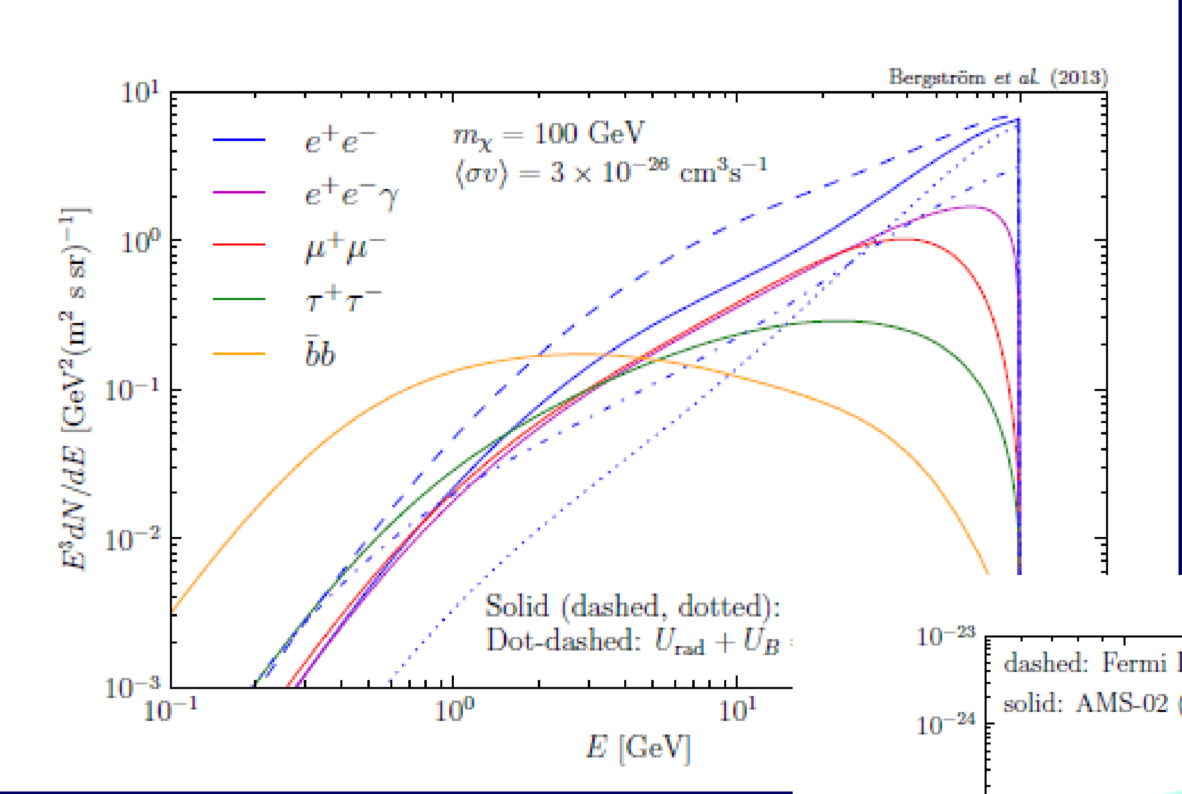


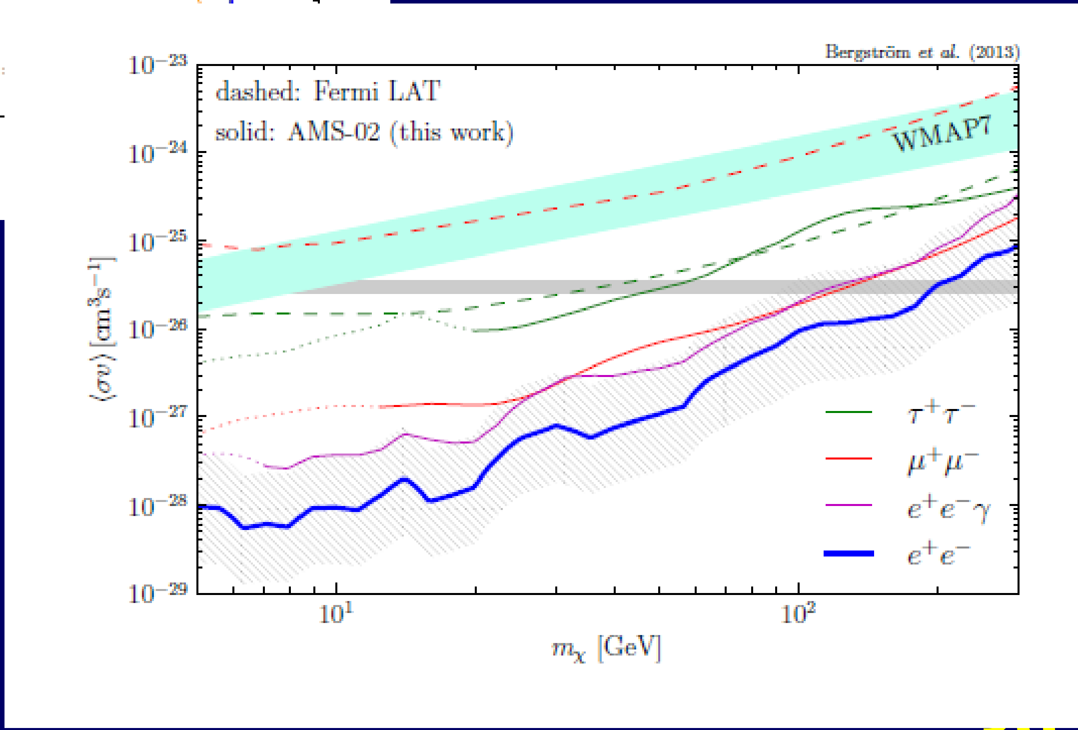
Figure courtesy of C. Weniger

Line results summary:

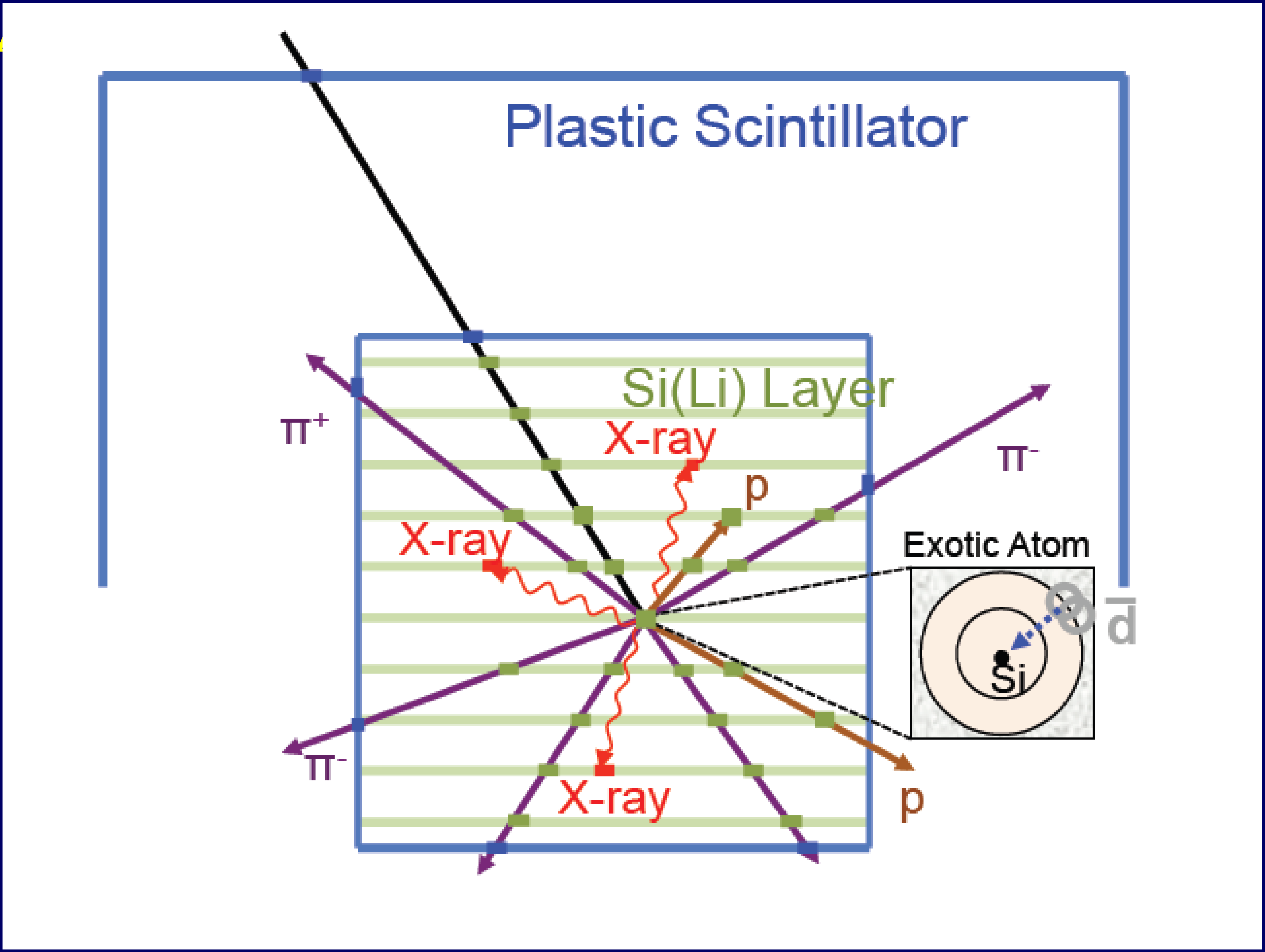


Constraints on leptonic channels





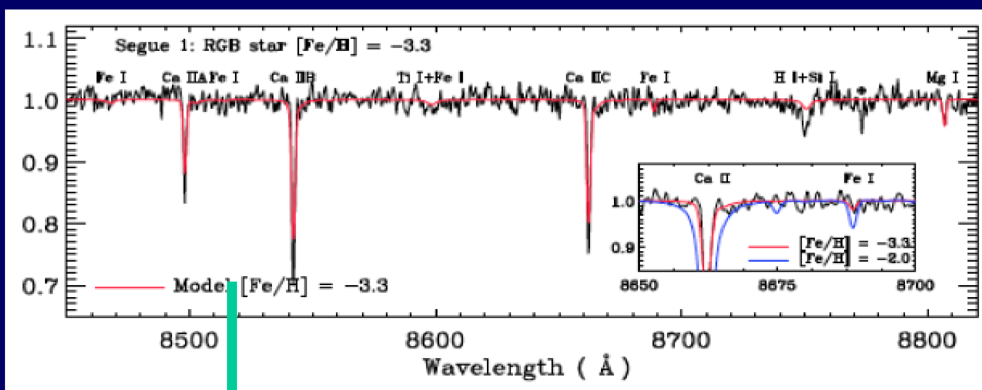
e.g. Bergström+ (2013)

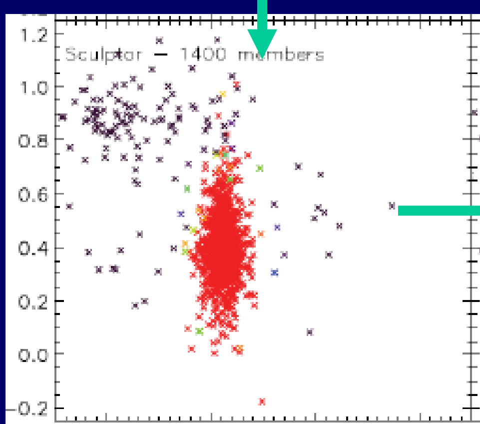


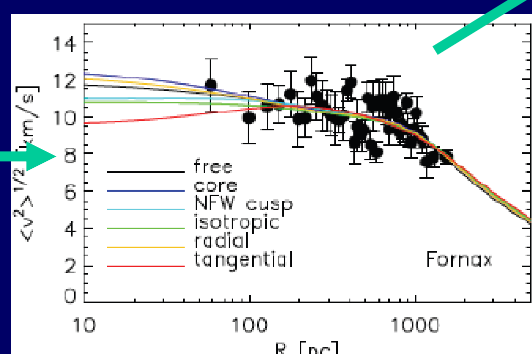
Plastic Scintillator
Si(Li) Layer
π+
π-
π-
X-ray
X-ray
X-ray
p
p
Exotic Atom
Si
d

Dwarfs galaxies – cleanest target

- DM dominated (M/L ~10--1000).
- Nearby (~ **100 kpc**)
- Stellar velocities can be used to measure DM density (error can be propagated to particle constraints) → propagated to constraints



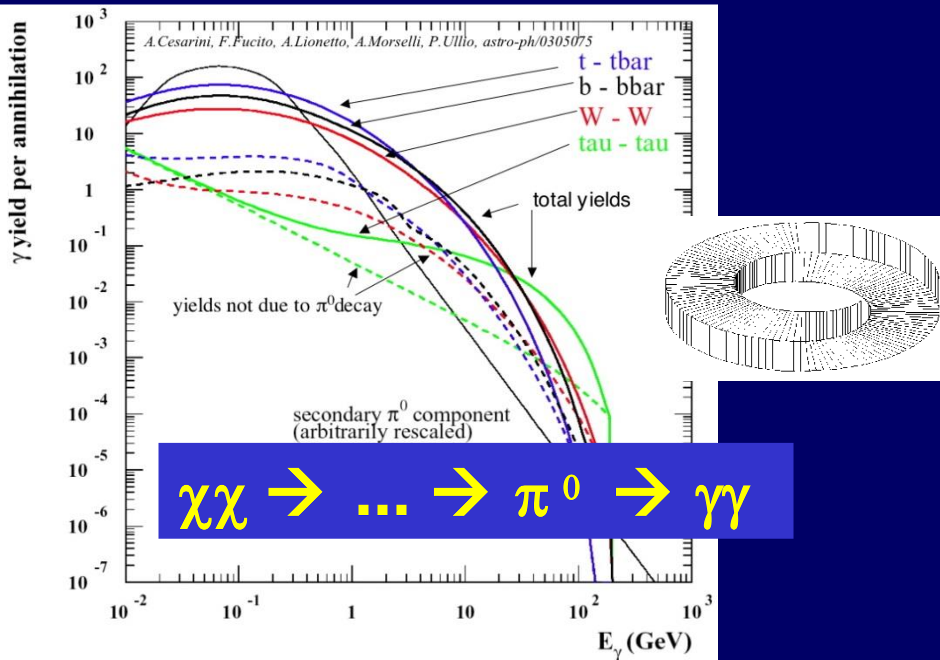




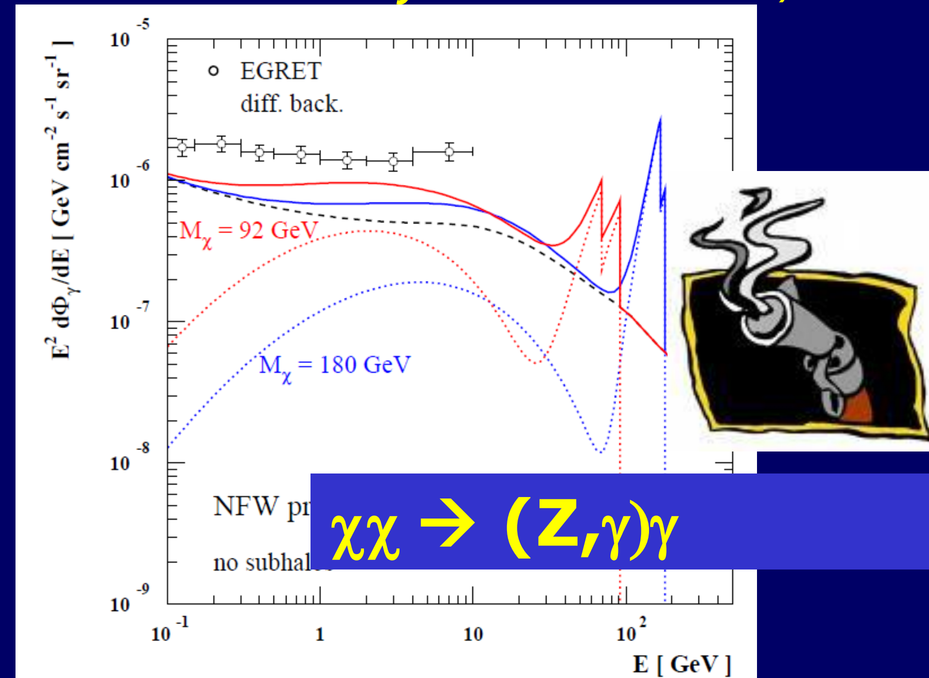
Name	l deg.	b deg.	d kpc	$\overline{\log_{10}(J)}$ $\log_{10}[\mathrm{GeV^2cm^{-5}}]$	σ	ref.
Bootes I	358.08	69.62	60	17.7	0.34	[15]
Carina	260.11	−22.22	101	18.0	0.13	[16]
Coma Berenices	241.9	83.6	44	19.0	0.37	[17]
Draco	86.37	34.72	80	18.8	0.13	[16]
Fornax	237.1	−65.7	138	17.7	0.23	[16]
Sculptor	287.15	−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]

e.g:
Charbonnier+, MNRAS 418 (2011) 1526
Strigari+,Phys. Rev. D, 75, 083526
Evans+, Phys. Rev., D69, 123501, (2004)

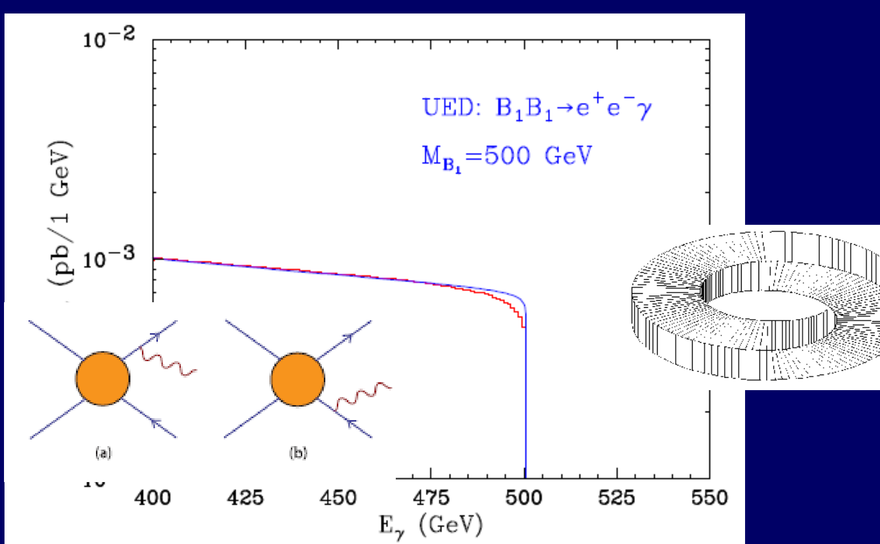
Universal spectral signatures



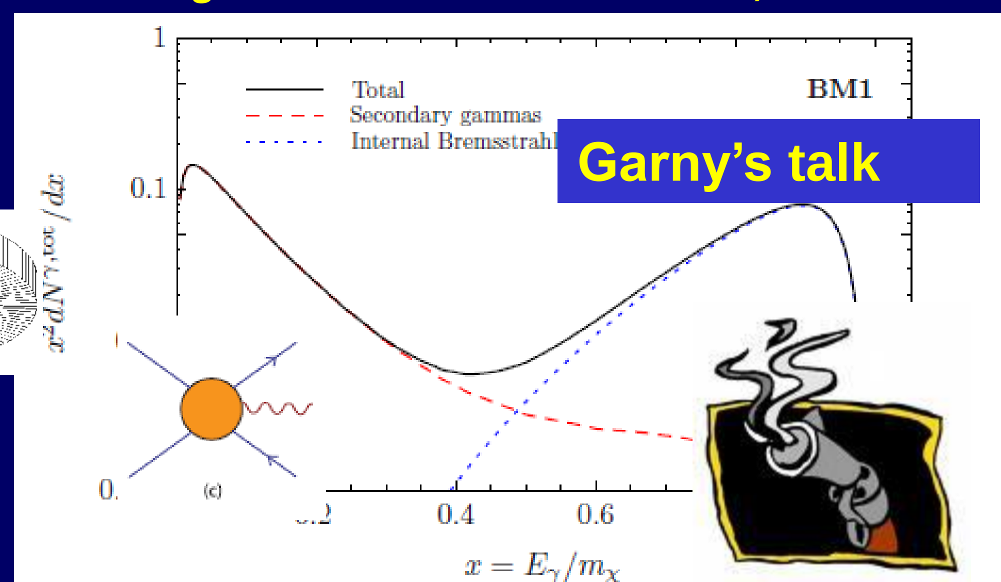
Ullio et al. Phys.Rev.D66:123502,2002



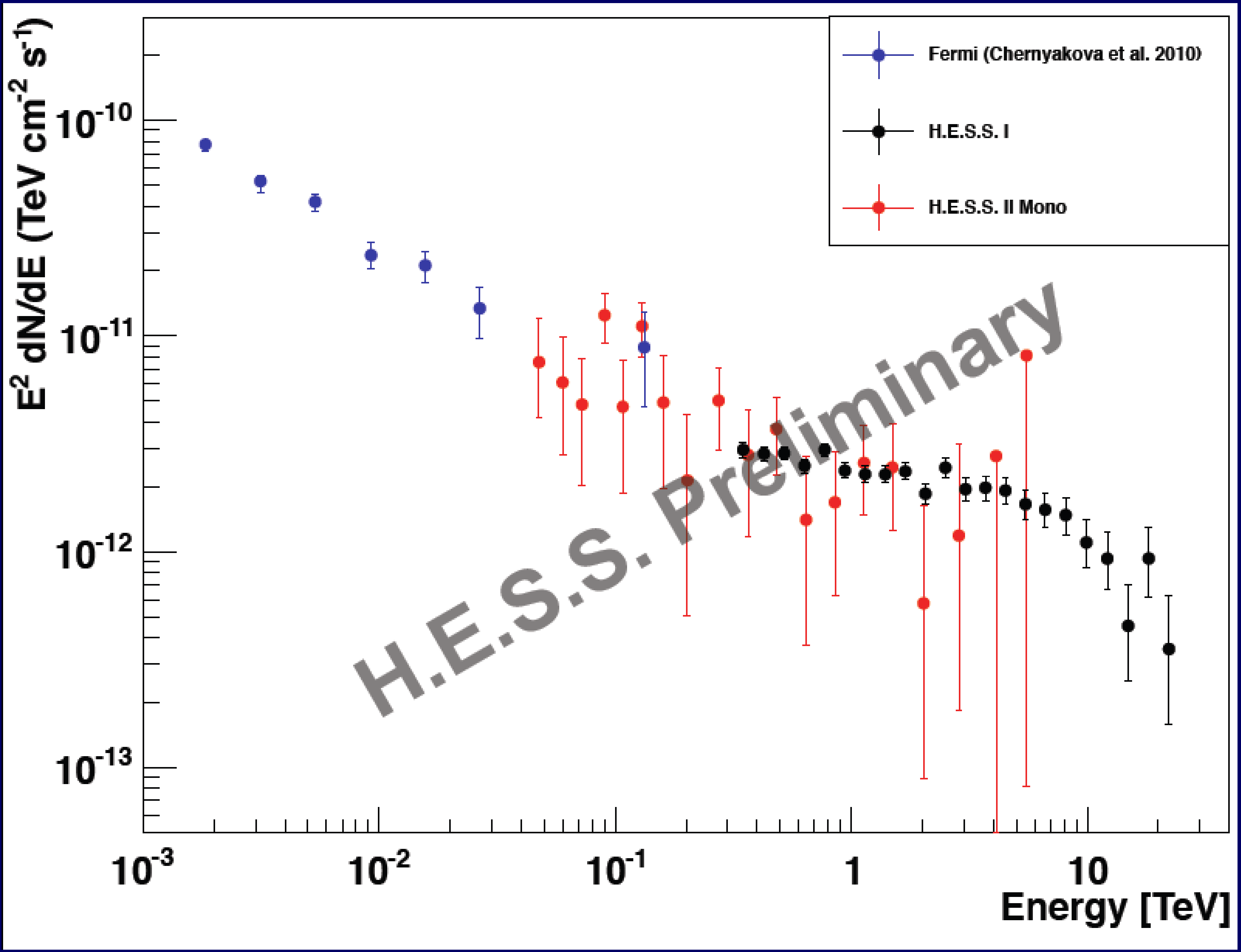
Birkedal et al.,



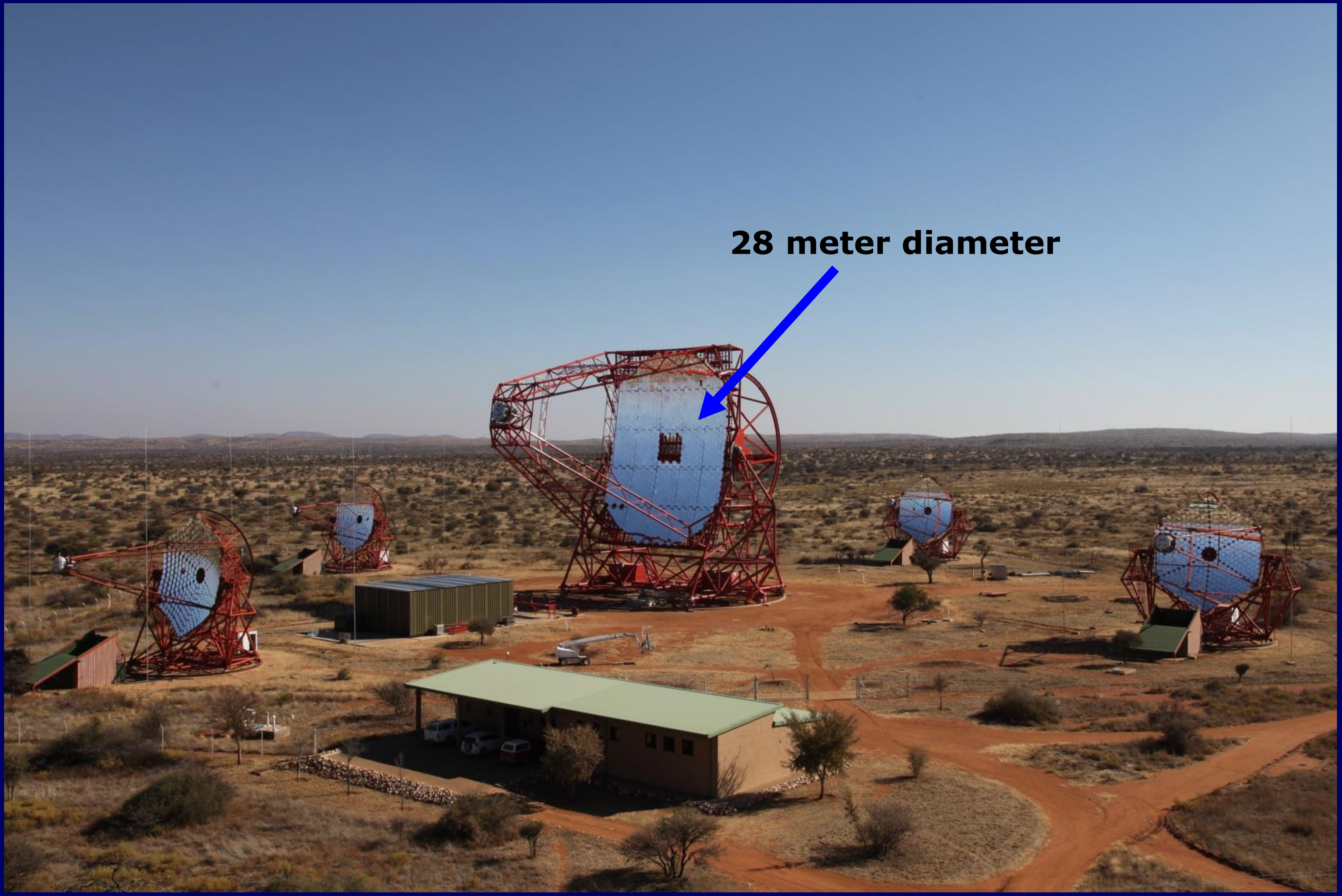
Bringmann et al. JHEP 0801:049,2008



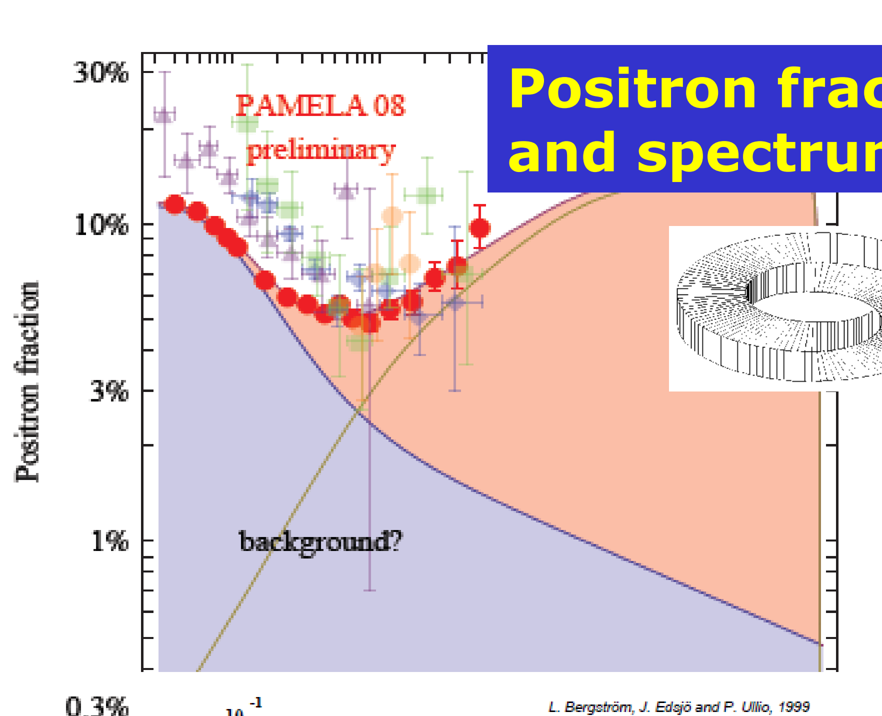
Spectrum for Galactic Centre source Sag A*



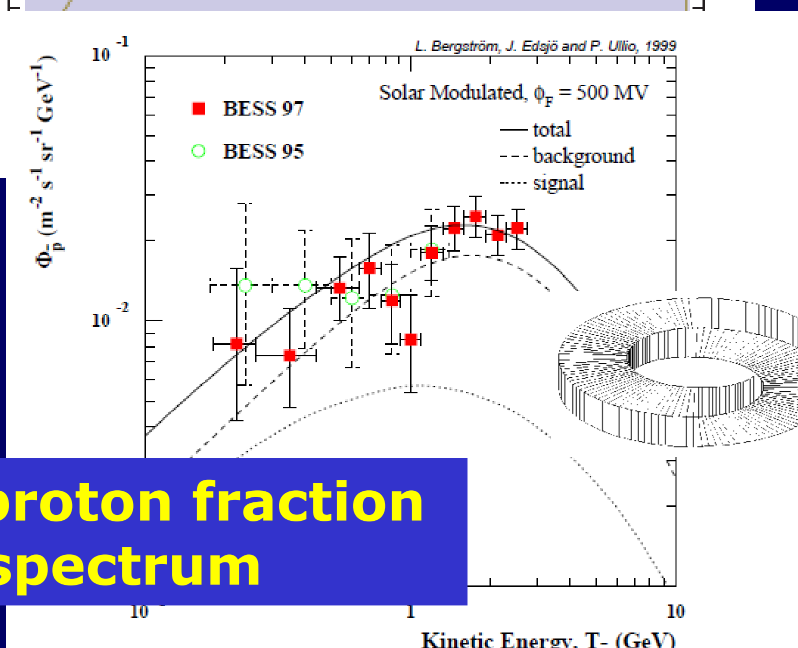
First light for worlds largest Cherenkov Telescope: HESS II, Summer 2012



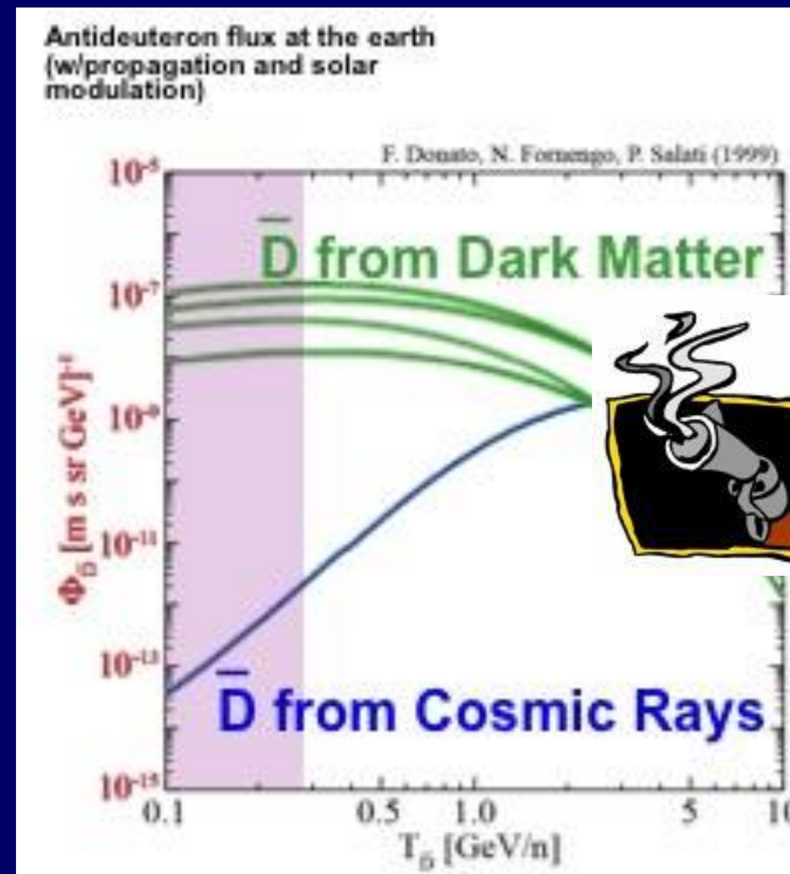
Cosmic rays: signatures



Positron fraction and spectrum



Antiproton fraction and spectrum



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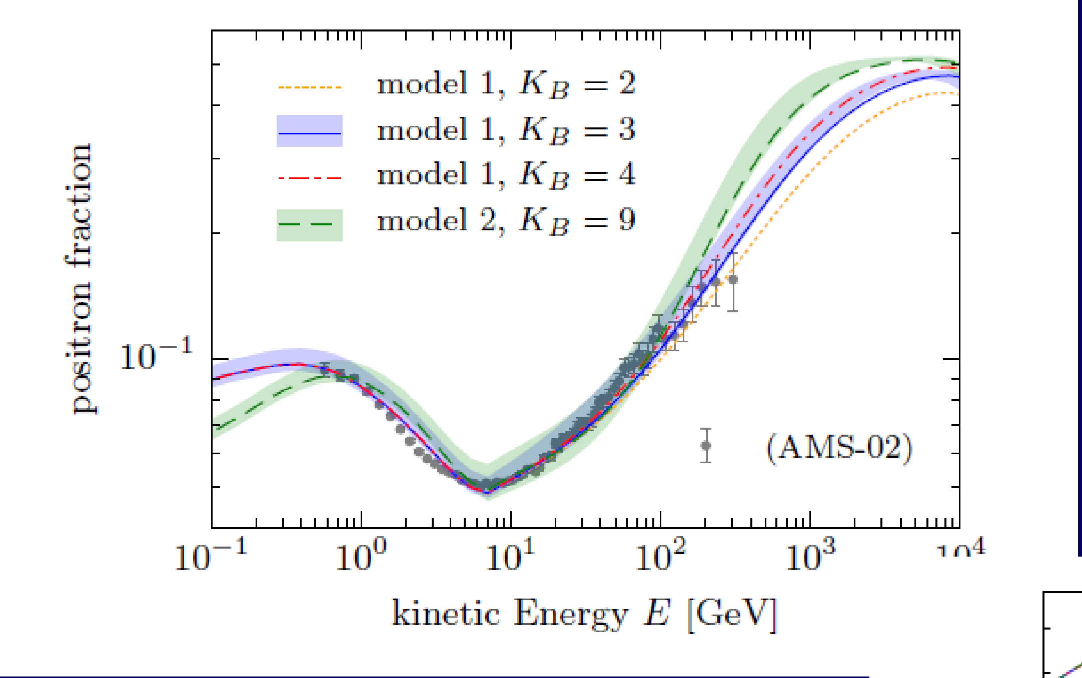
Anti-deuteron spectrum

Can it be secondary? E.g by close by SNRs?

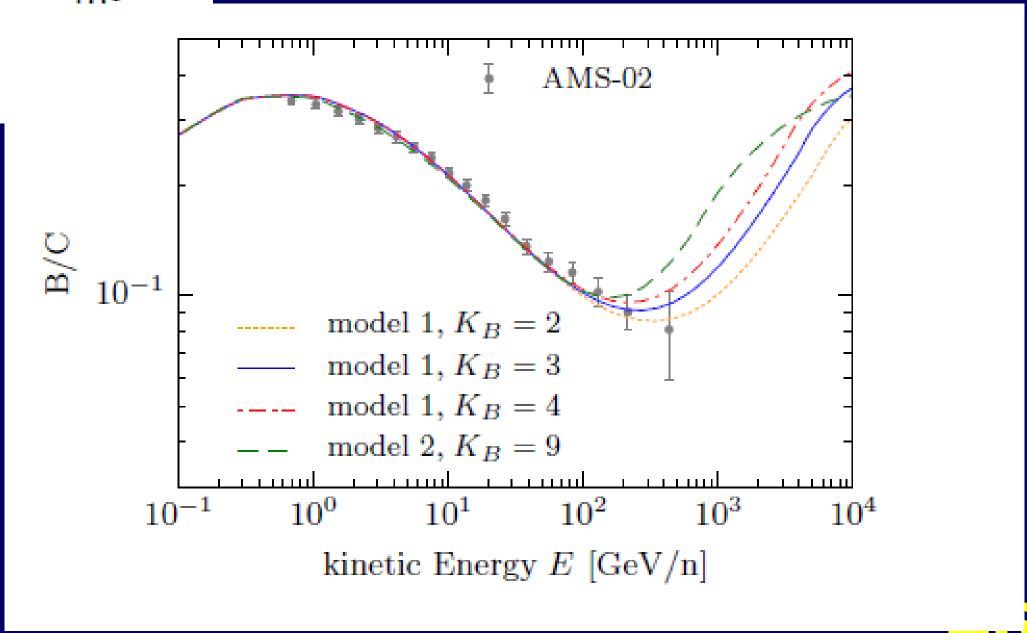


e^+ produced inside SNR → harder positron spectrum

Blasi+ (2009), Ahlers+ 2009

Mertsch+Sarkar (2014)

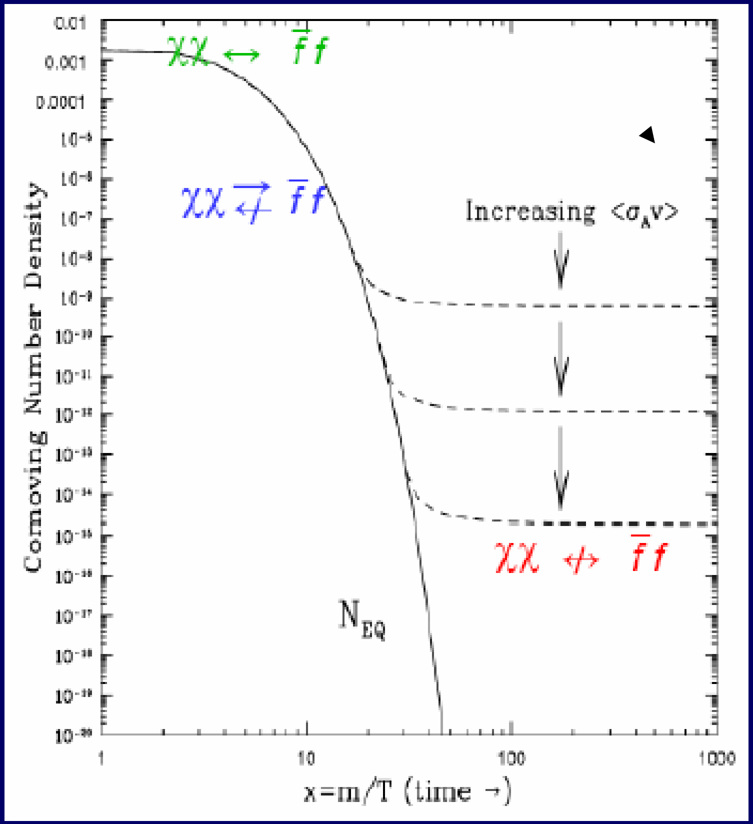
Prediction: rise in p/anti-p and B/C ratio



Marginally consistent with current AMS data, if you ask me.

Weakly Interacting Massive Particles (WIMPs)

The weak interaction mass scale and ordinary gauge couplings give right relic DM density without fine-tuning. Mass scale O(GeV)-O(TeV), makes them Cold Dark Matter



Jungman+, Phys. Rept. (1996)

$$\Omega_{Wimp} \approx \frac{10^{-26} cm^{-3} s^{-1}}{\langle \sigma v \rangle}$$

$$\langle \sigma v \rangle_{\sim weak} \sim \frac{\alpha^2}{m_{WIMP}^2} \sim 10^{-25} cm^{-3} s^{-1}$$

Provides benchmark for indirect detection: thermally produced WIMPs