Status of Indirect Dark Matter Detection

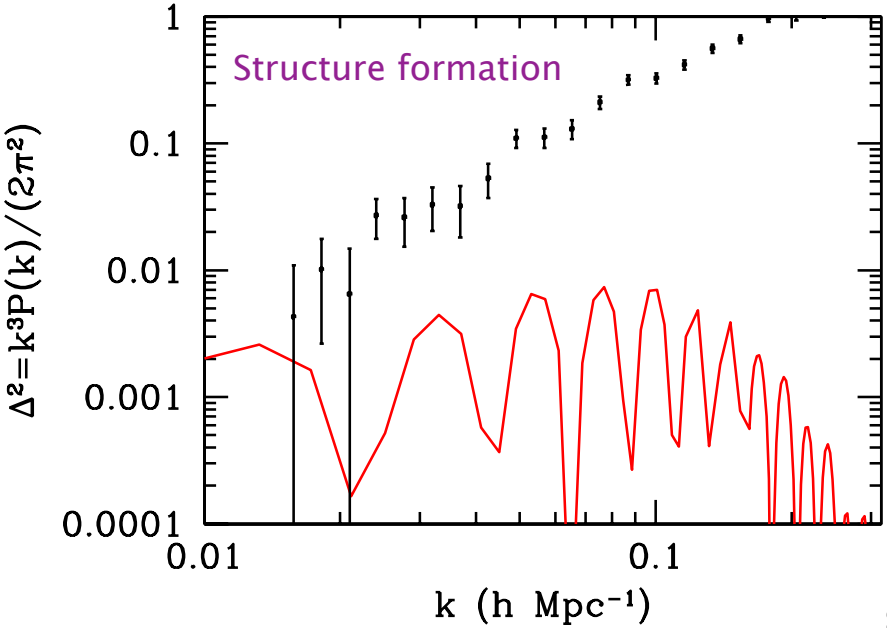
Pasquale D. Serpico

TAUP 2011 Munich - 5-9 September 2011

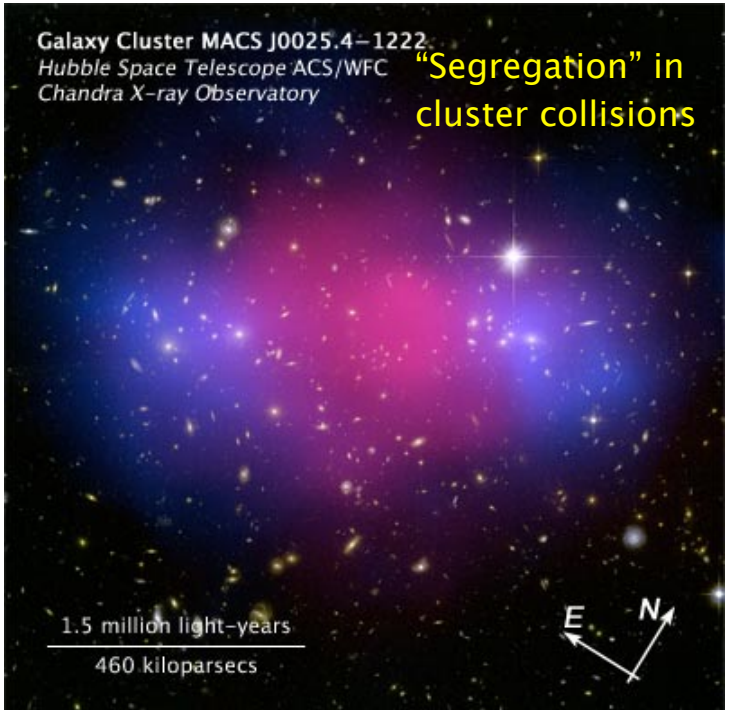
Outline of the talk

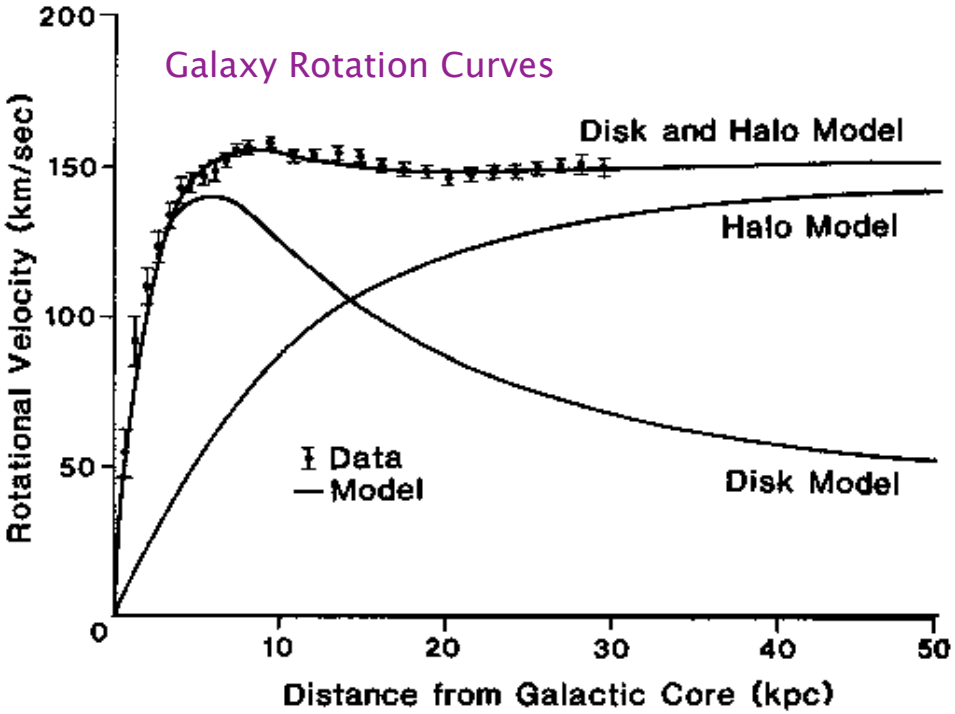
- DM does exist. Why do we want to “(re)detect” it, additionally indirectly?
- Present constraints on the WIMP paradigm from photons, neutrinos, charged cosmic rays
- Lessons learned: Moving from constraints to a detection strategy

DM already detected indirectly: gravity!



But gravity is "universal", does not permit particle identification: a discovery via other channels is needed to clarify the particle physics framework





What does indirect particle identification mean?

That one looks for consequences of DM interactions elsewhere (not in the Lab lab!), such as decays, annihilations, energy transfer to baryons.

- ★ *It's a natural thing to do (DM is seen "elsewhere"!)*
- ★ *these features may imply an impact on cosmology or astrophysics.*
- ★ *It is an additional handle on properties one cannot probe otherwise in the Lab.*

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- ✓ **The presence of indirect signatures is by no means guaranteed (model-dependent)**
- ✓ **It needs not to be a GeV-TeV-scale signature, neither necessarily an annihilation one (notable example: ~ keV sterile neutrino X-ray decay line)**
- ✓ **There is no <u>astrophysical or cosmological</u> evidence whatsoever for the electroweak scale being the right one for explaining the DM problem.**

Most people bet on WIMPs (...but science≠democracy!)

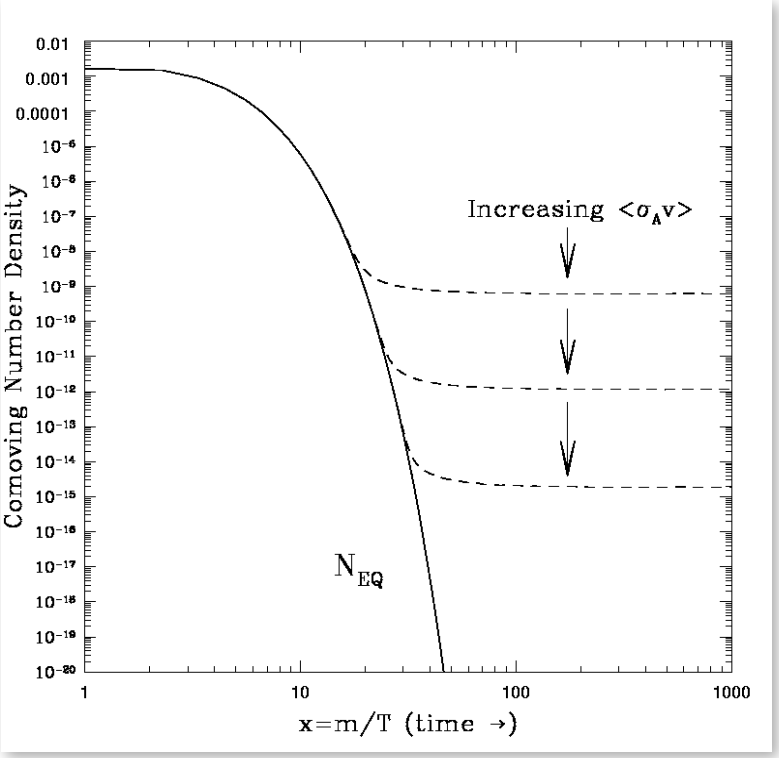
Weakly Interacting Massive Particle "miracle" (?)

thermal relic with α_{ew} & $m_\chi \approx 0.01 - 1$ TeV matches cosmological measurement, $\Omega_\chi \approx 0.25$

$$\Omega_{wimp} \sim 0.3 / \langle \sigma v \rangle (pb)$$

EW scale BSM physics may be related to DM!

Stability↔Discrete Symmetry↔Pair produced@ Collider (SUSY R-parity, K-parity in ED, T-parity in Little Higgs)
Also would ease agreement with EW observables, Proton stability…



EW-scale candidates have a rich phenomenology

(more room for creativity/entertainment) more detection strategies via collider, direct, and indirect techniques

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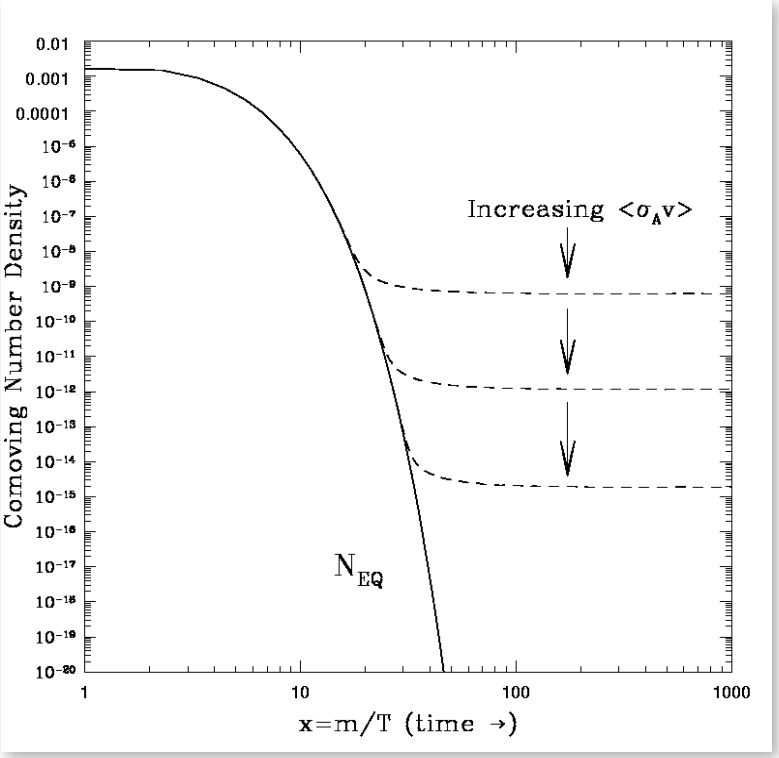

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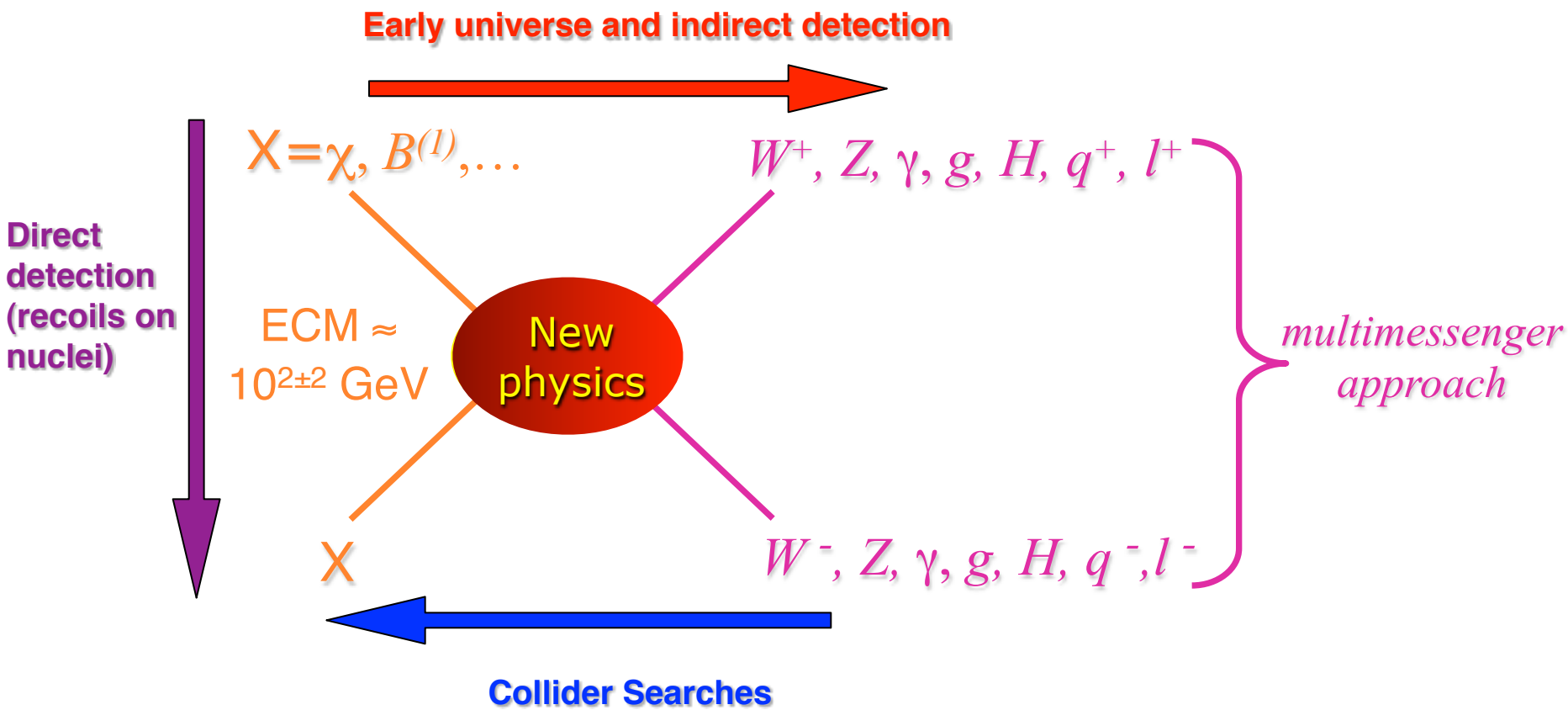
(more room for creativity/entertainment) more detection strategies via collider, direct, and indirect techniques

Warning: keep in mind other possibilities (just heard M. Pospelov)!
(Axions, SuperHeavy DM, SuperWIMPs, MeV DM, sterile neutrinos…)
They have peculiar signatures and require ad hoc searches

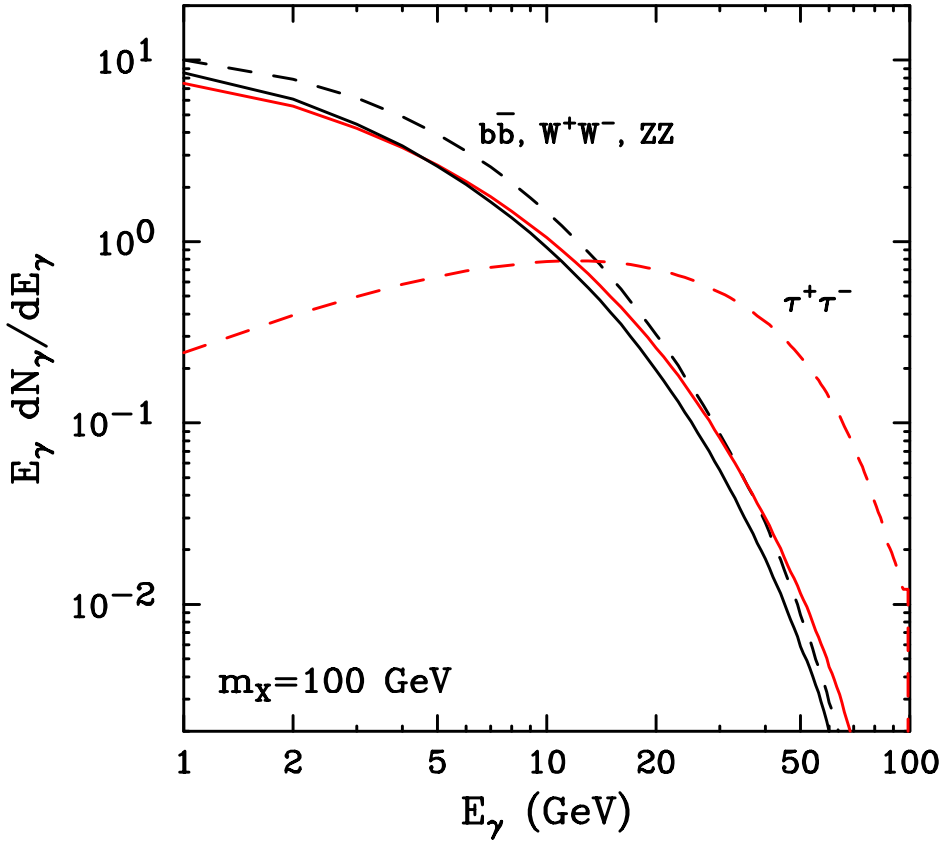
one example, decaying gravitinos, discussed in the talk by M. Grefe @ 15:55

A benchmark diagram & the discovery program



- ✓ demonstrate that astrophysical DM is made of particles (locally, via DD; remotely, via ID)
- ✓ Possibly, create DM candidates in the controlled environments of accelerators
- ✓ Find a consistency between properties of the two classes of particles. Ideally, we would like to calculate abundance and DD/ID signatures → link with cosmology/test of production

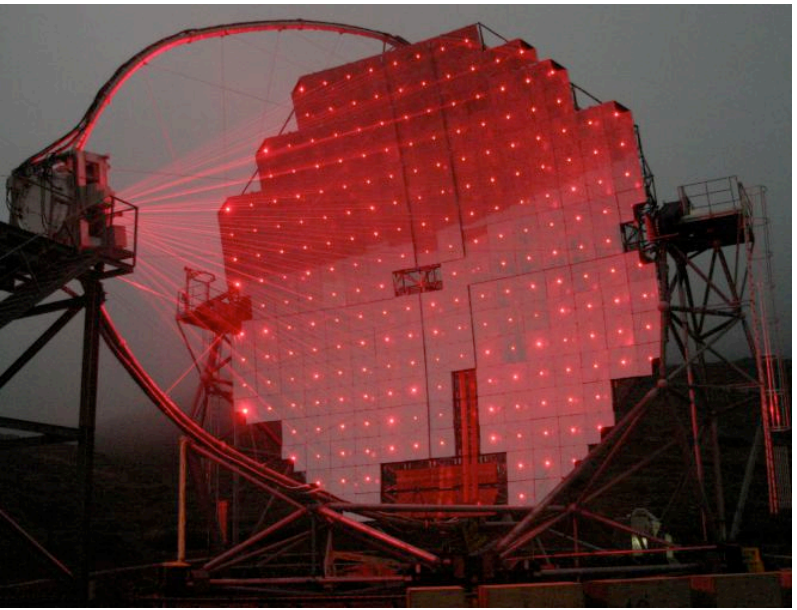
Theoretical Predictions of Spectra

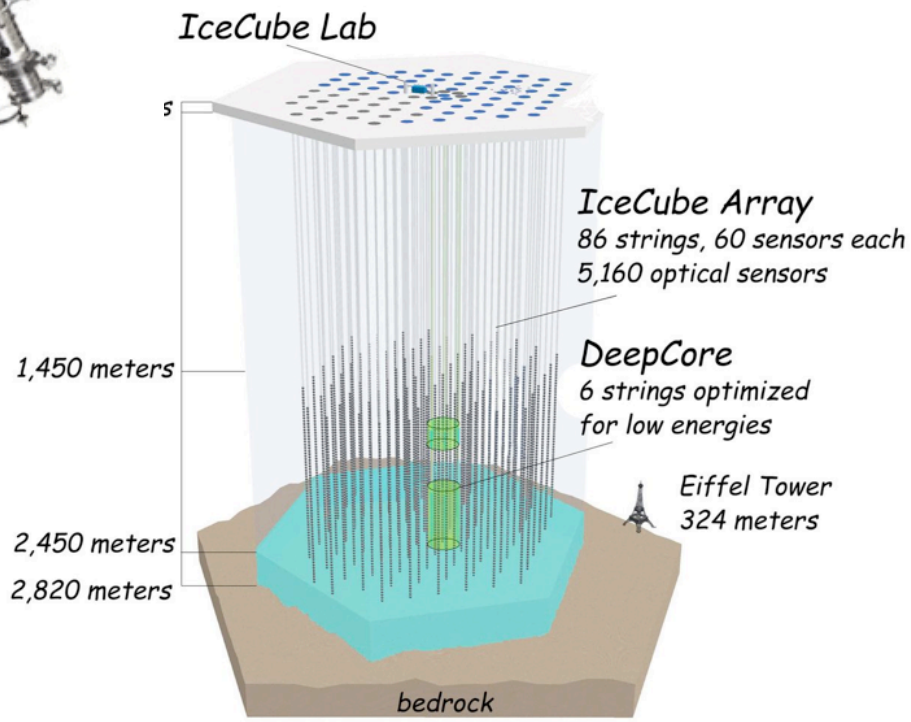


- ✓ in the "vanilla case", DM annihilates into the heaviest SM stuff allowed: modulo some br's variations, quasi-universal spectra as a result of decays/fragmentations
- ✓ "Prompt" production dominates (= forget propagation for now)
- ✓ Notable exceptions are present, later on I shall briefly comment on some....

Go to your exper. friends and tell them to find DM

(some millions to billions $/€ later)





At the moment no confirmed detection: Constraints

- ✓ γ signatures (dwarfs, halo) & Galactic Center
- ✓ CMB
- ✓ Neutrinos
- ✓ Charged particles

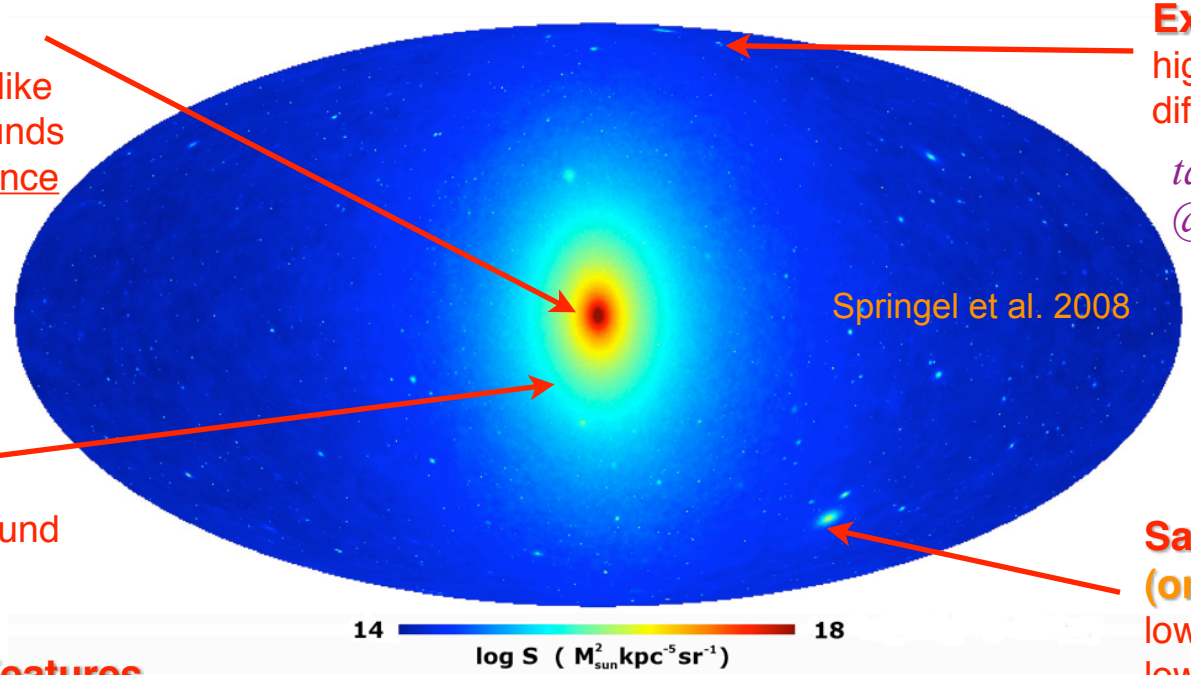
Emphasis on most recent/updated/stringent results I am aware of, apologies if your favourite paper is missing...

Where to look for Gamma rays

Galactic Center
high statistics, point-like
and diffuse backgrounds
halo-model dependence

Extragalactic
high statistics, lot of
diffuse backgrounds

talk by F. Donato
@ 14:30



Springel et al. 2008

MW Halo
high statistics,
high diffuse background

Satellites
(or Clusters)
low background (?),
low statistics

Lines/Spectral Features
talk by Christoph Weniger @ 14:50

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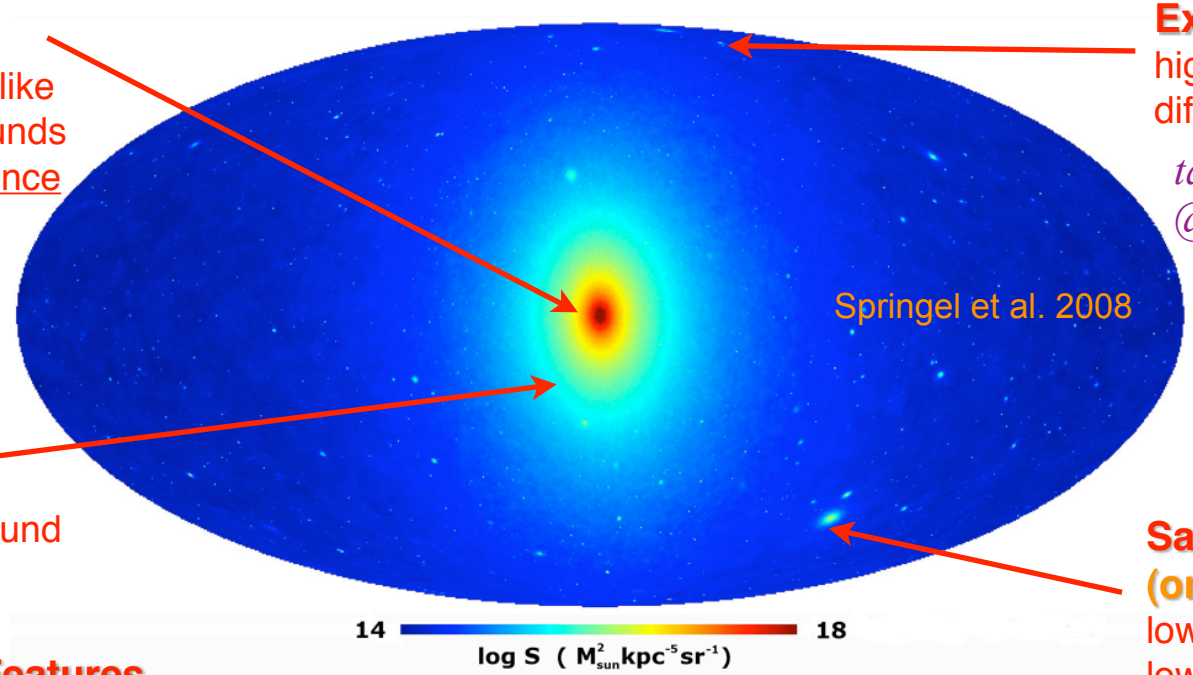

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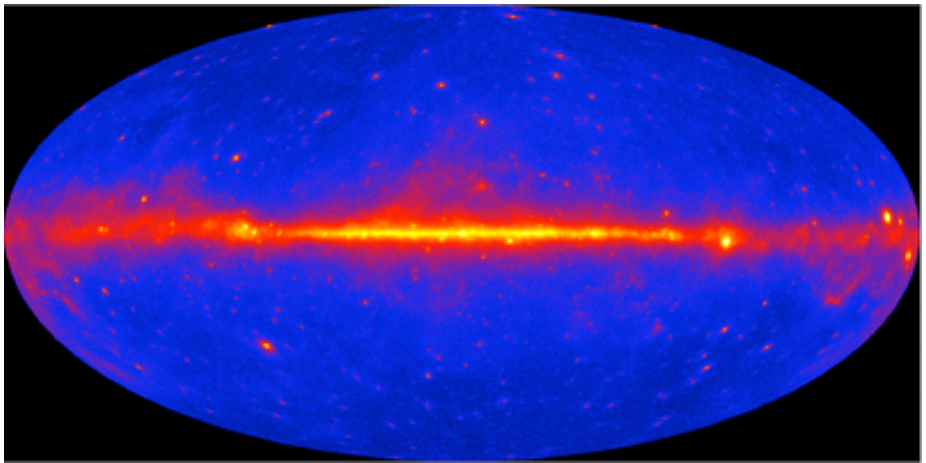
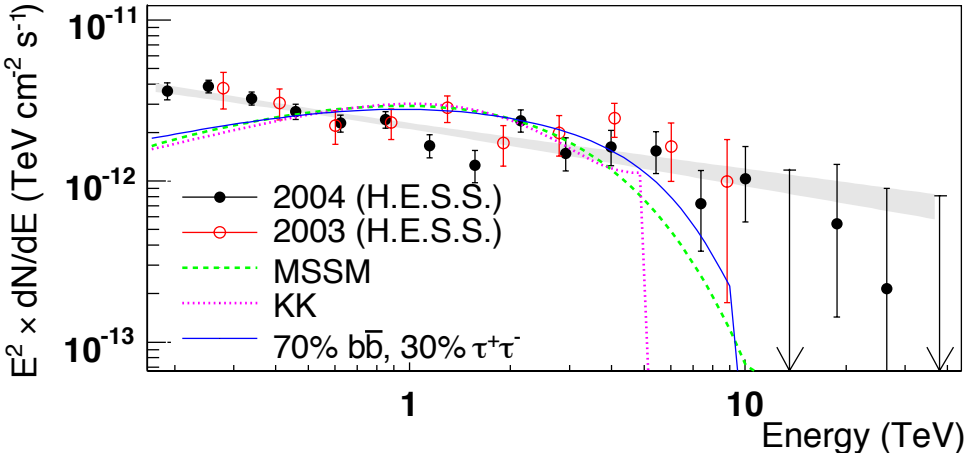
What Fermi or ACTs see looks nothing like DM expectations: backgrounds are often important!

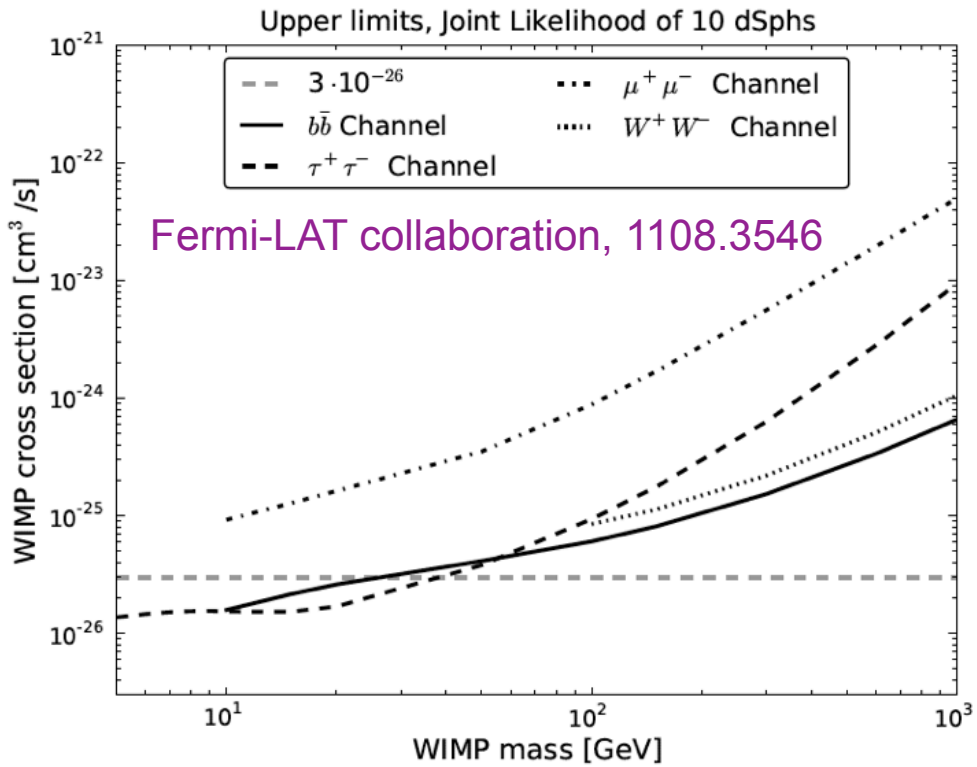




Fermi: stacked dwarf analysis

✦ Depends on distance and volume average of DM density^2 (hence DM distribution & normalization) The bounds are as robust as these are.

✦ Nominally excludes "generic thermal" S-wave relics annihilating into b's up to 27 GeV, τ's up to 37 GeV



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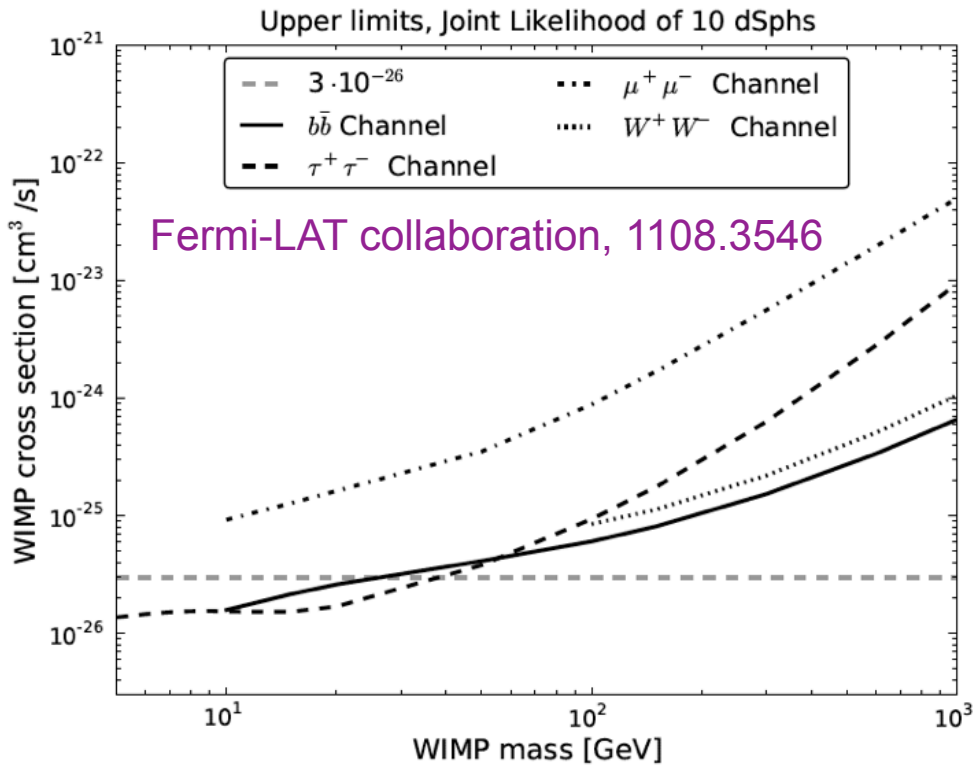
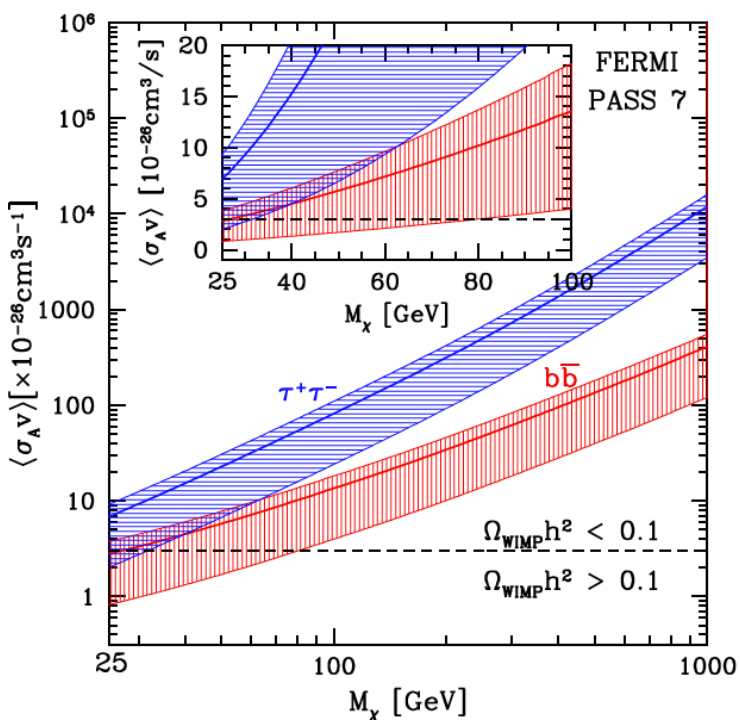
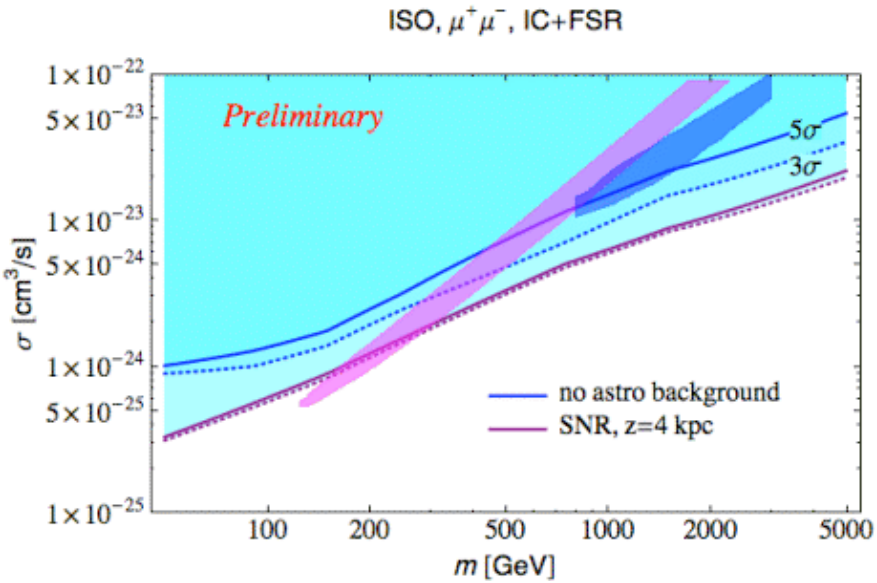
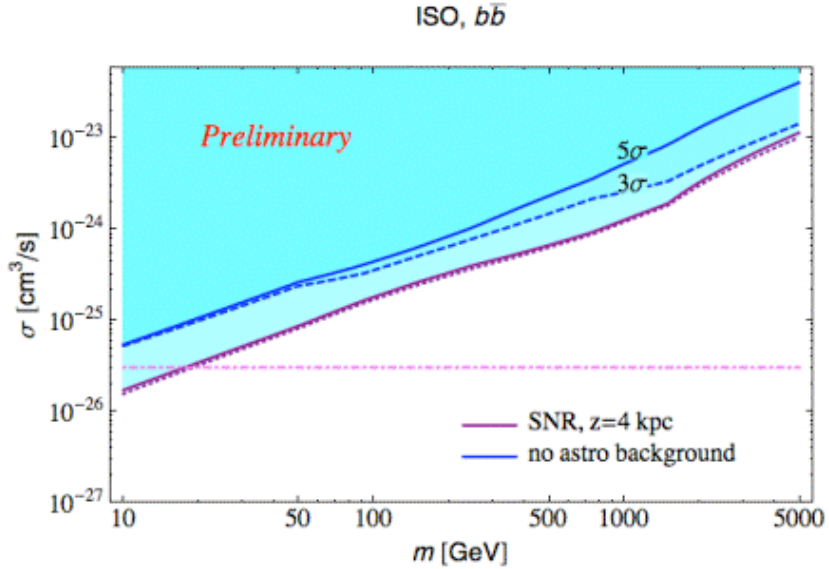




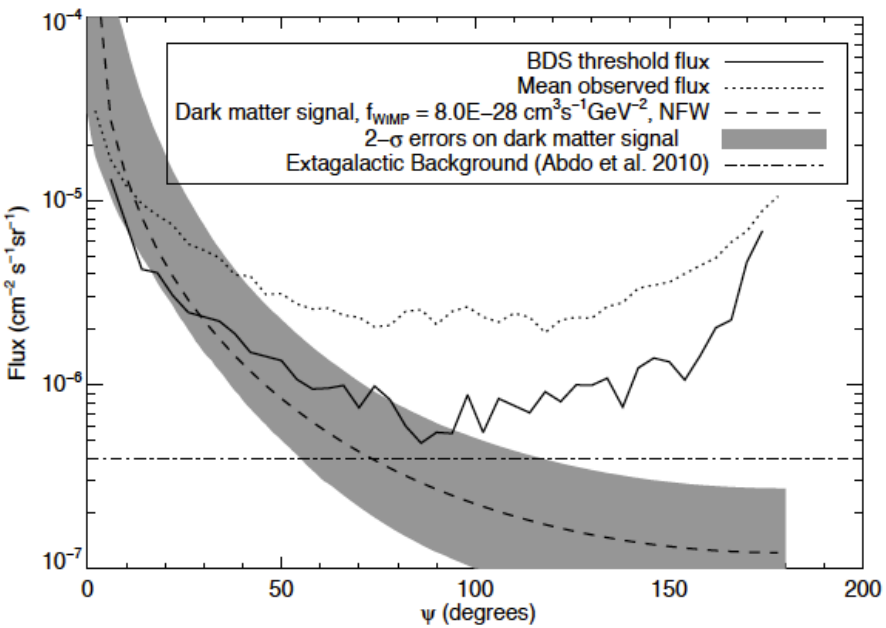
A few days earlier, similar (but not identical) results in Geringer-Sameth & Koushiappas, 1108.2914

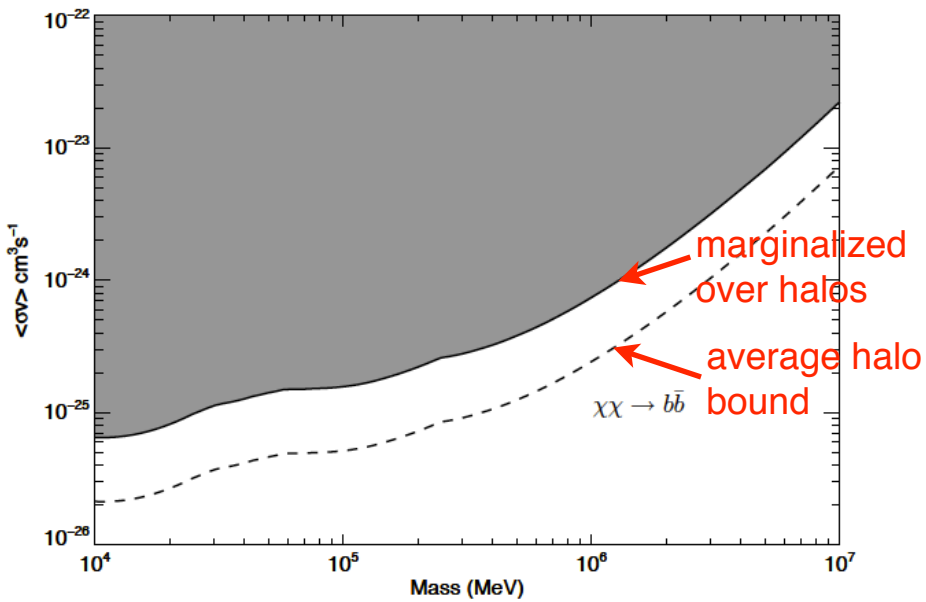
Diffuse Galactic Emission: dealing with backgrounds





Zaharijas et al. [Fermi-LAT], 1012.0588 & Fermi Symposium 2011 (no or conservative astro background)

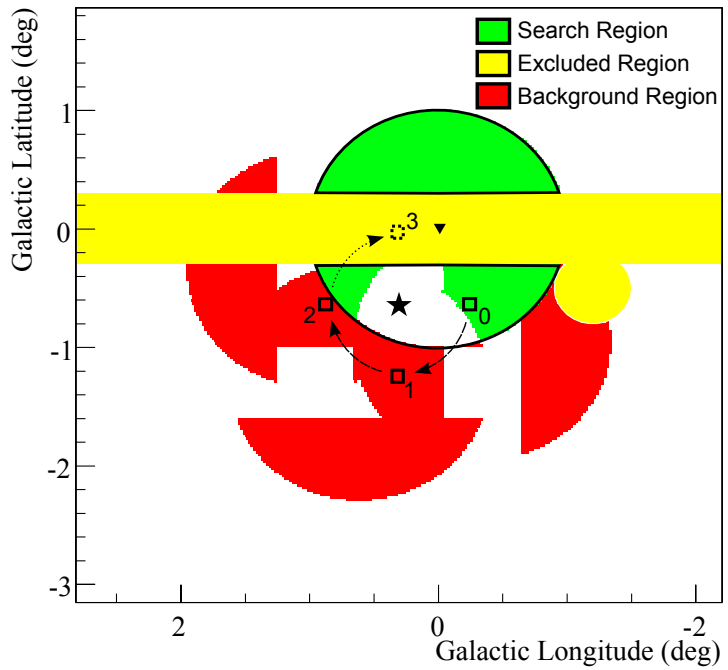


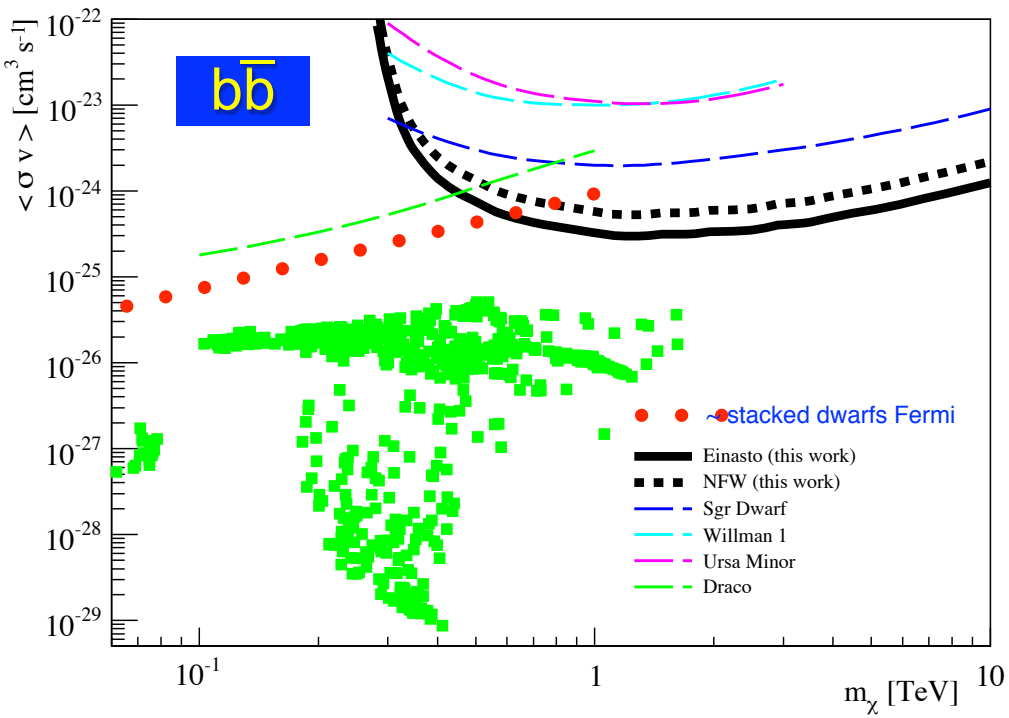


Baxter and Dodelson, 1103.5779 (assume cylindrical symmetry of signal & uncorrelated pixels)

H.E.S.S. inner galaxy bound (arxiv:1103.3266)

- GC has complex astrophysics, look away!
- Select signal region close to GC but as much as possible free from backgrounds
- Select "similar geometry" region where signal is expected to be smaller for background subtraction





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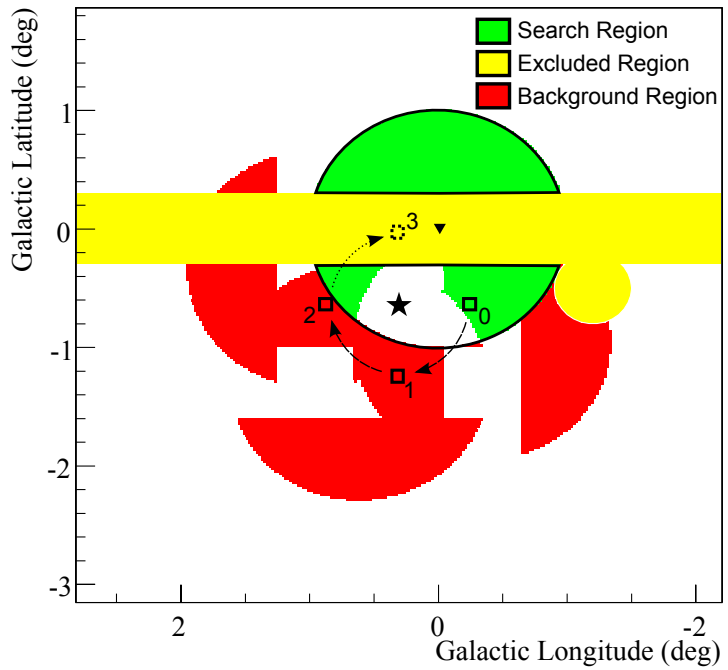
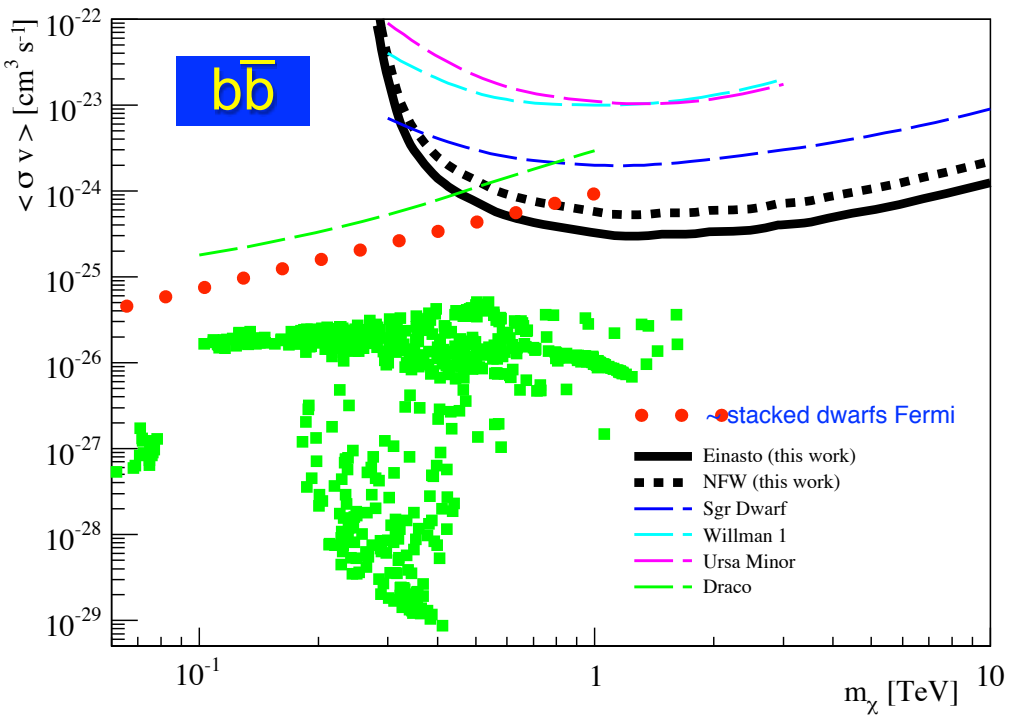


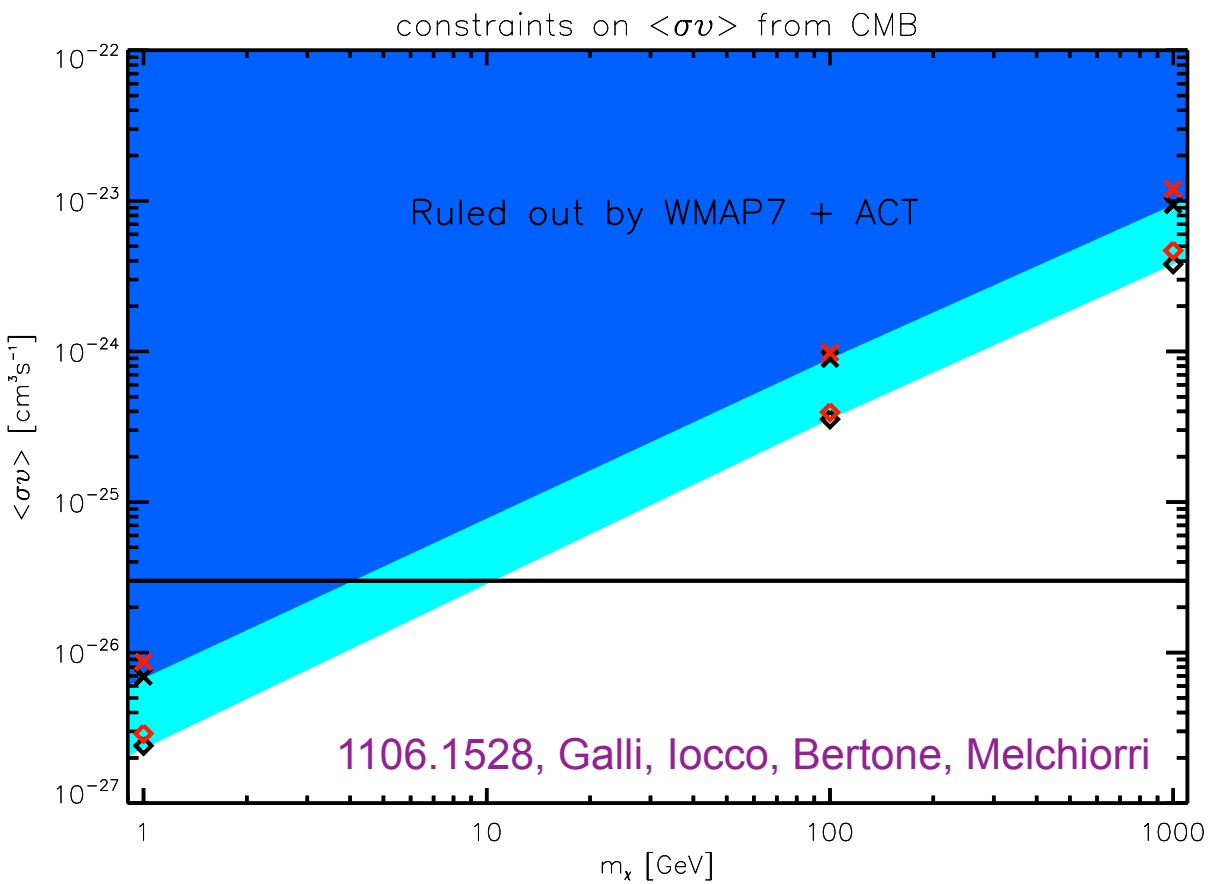


most stringent bound on DM from IACTs I'm aware of (but <u>halo-model dependent)</u>

Modulo comparatively small differences (dedicated time, latitute, E-threshold, field of view) this also applies to VERITAS and MAGIC: hardly much better can be achieved with present generation IACTs

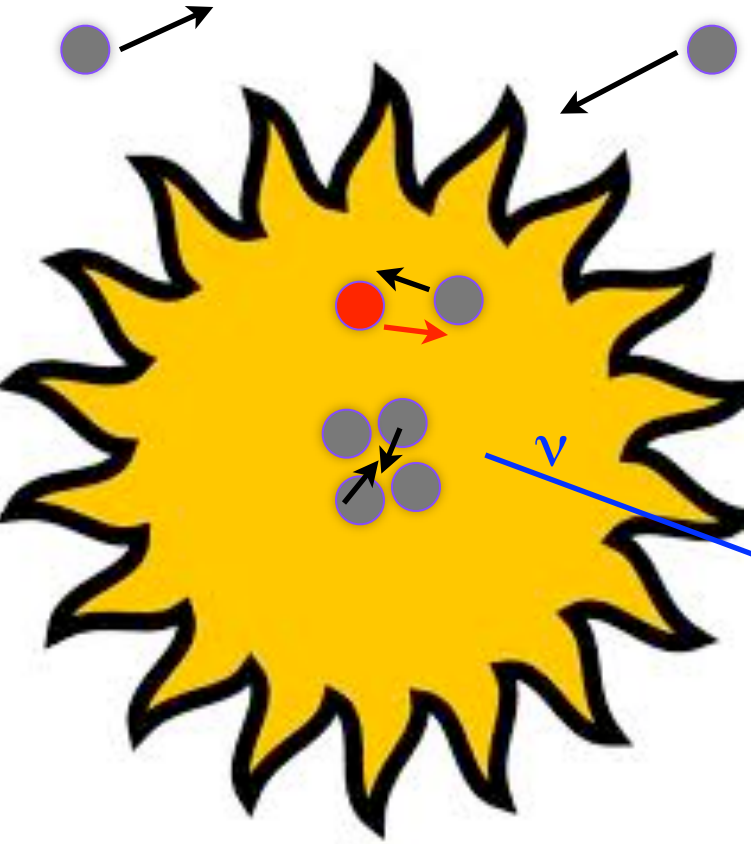
Bound from CMB

Annihilating "dark mass" into visible energy heats and ionizes baryons during the "Dark Ages" (z~100-1000), which can be constrained by CMB (especially via optical depth τ)



Particles lighter than 5 (10) GeV going into mu (e) are disfavoured/excluded: good perspectives for Planck as well!

Neutrinos from the Sun



$$\dot{N} = C - C_A N^2$$

If equilibrium is reached btw the two, the annihilation signal rate writes:

$$\Gamma_A = \frac{C_A}{2} {N_{\rm eq}}^2 = \frac{C}{2}$$

ν

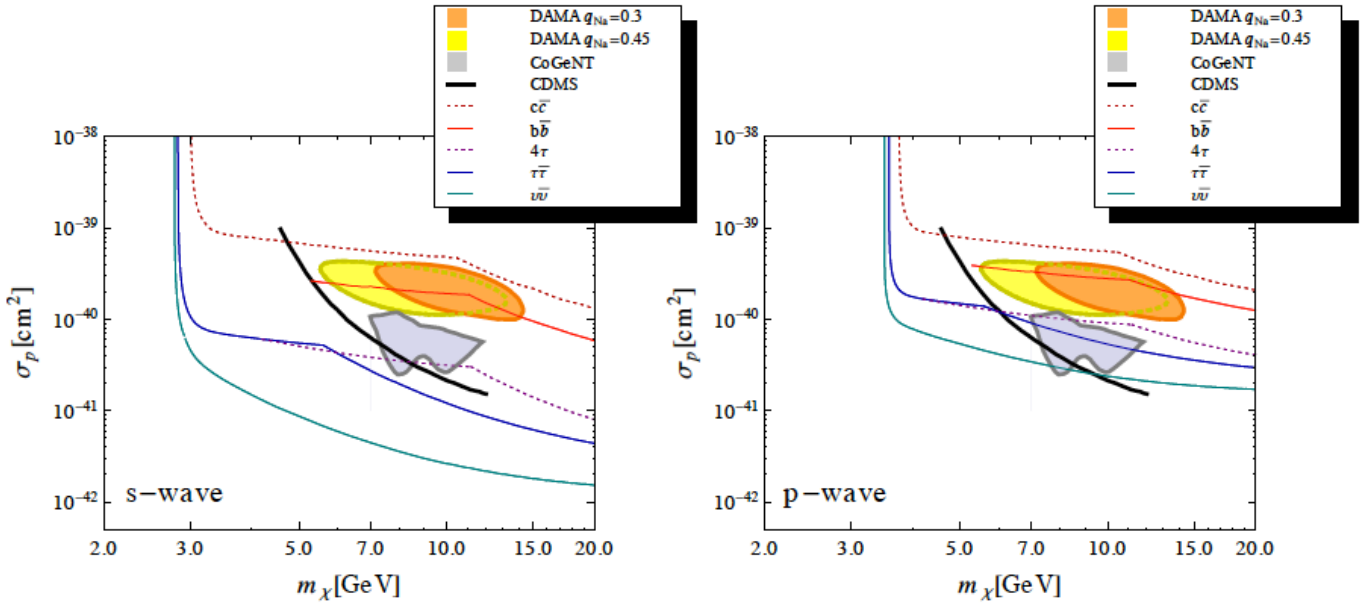
$$C \propto \sigma \, \rho_{\rm DM}$$

"just like" (although not exactly) DD experiments!

more on that in talks by
Chitta Ranjan Das @ 15:10
Viviana Niro @ 15:30

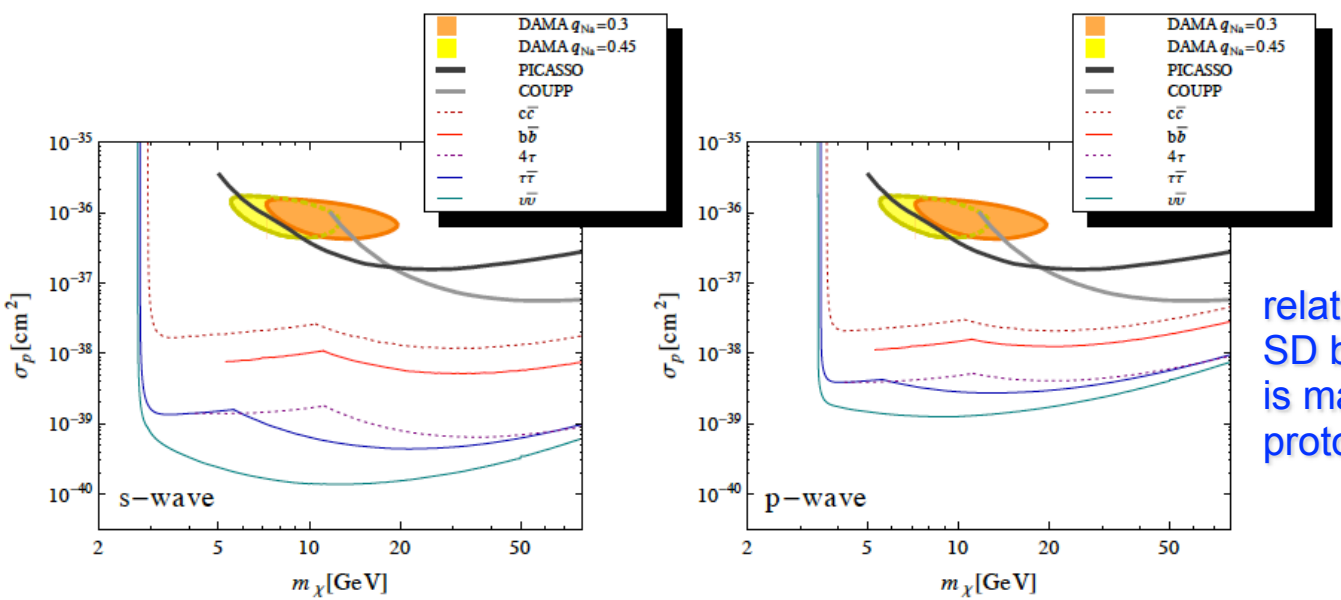
Recent neutrino bounds (from SK data)

SI



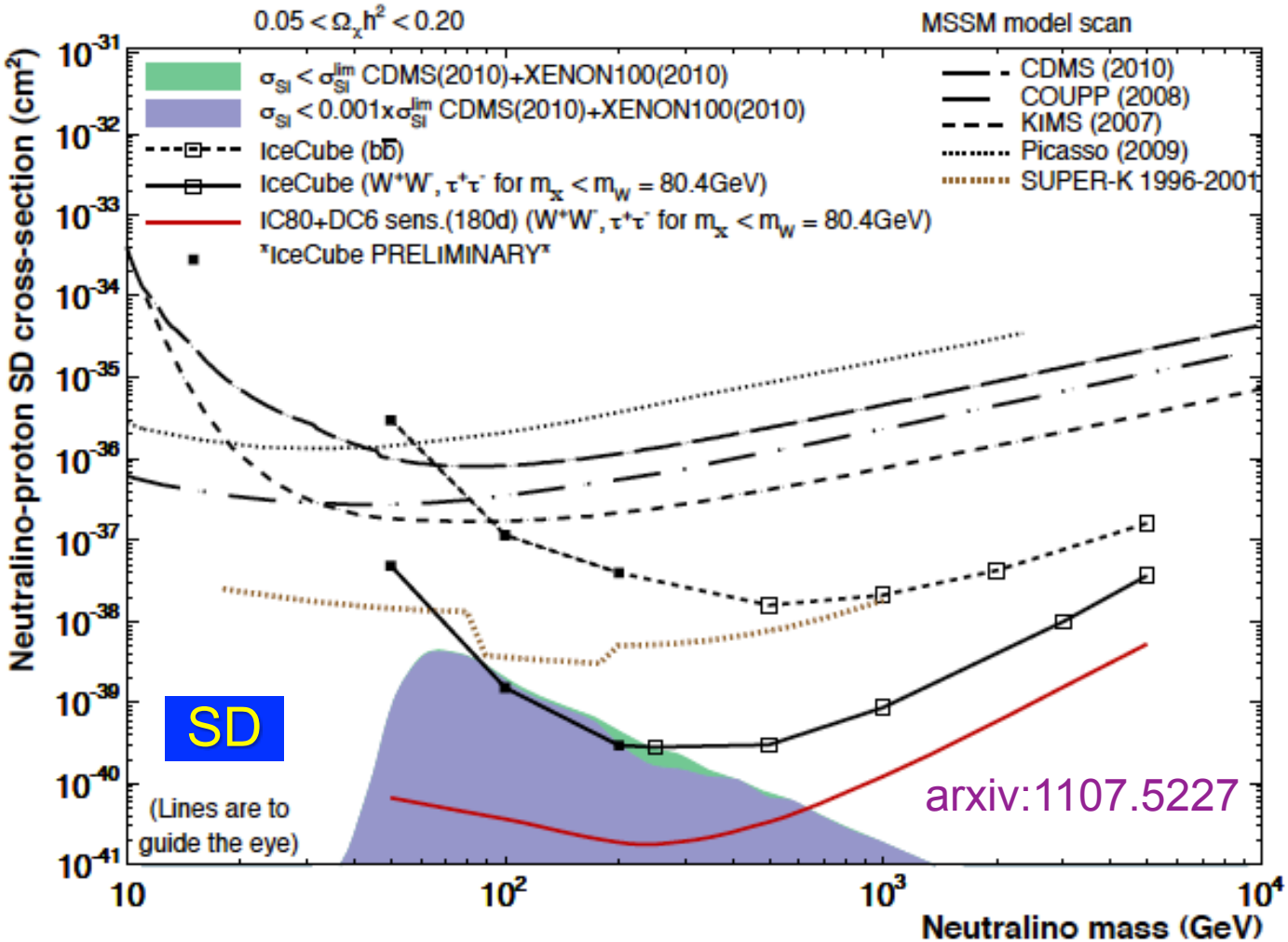
Kappl & Winkler 1104.0679

SD



relatively stronger SD bounds (Sun is made mostly of protons)!

IceCube bounds



more in talks by

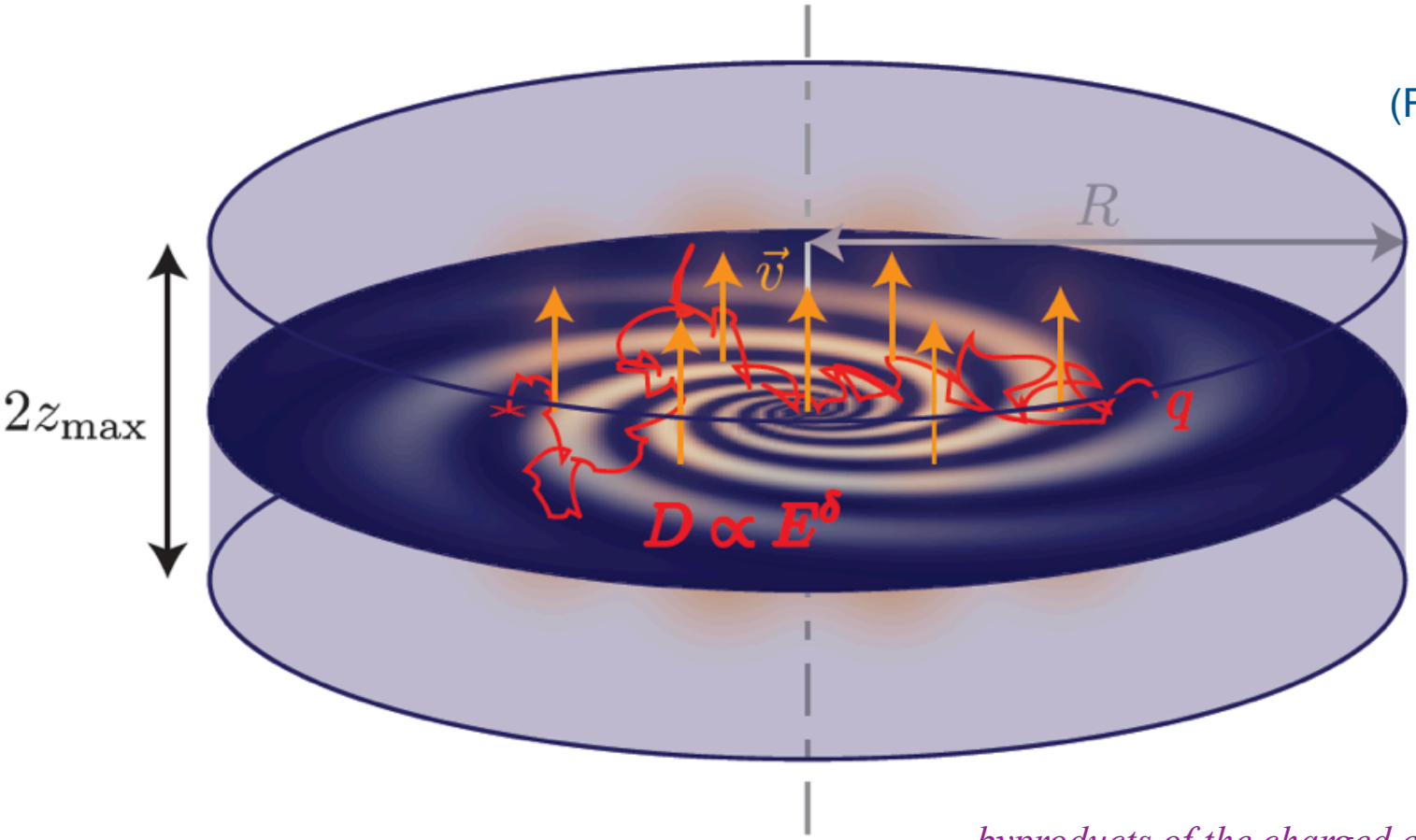
Mattias Danninger @ 16:50 (Icecube)

Vincent Bertin @ 17:05 (Antares)

some (weaker than γ) bounds also from Galactic Center in 1101.3349

Charged Particles

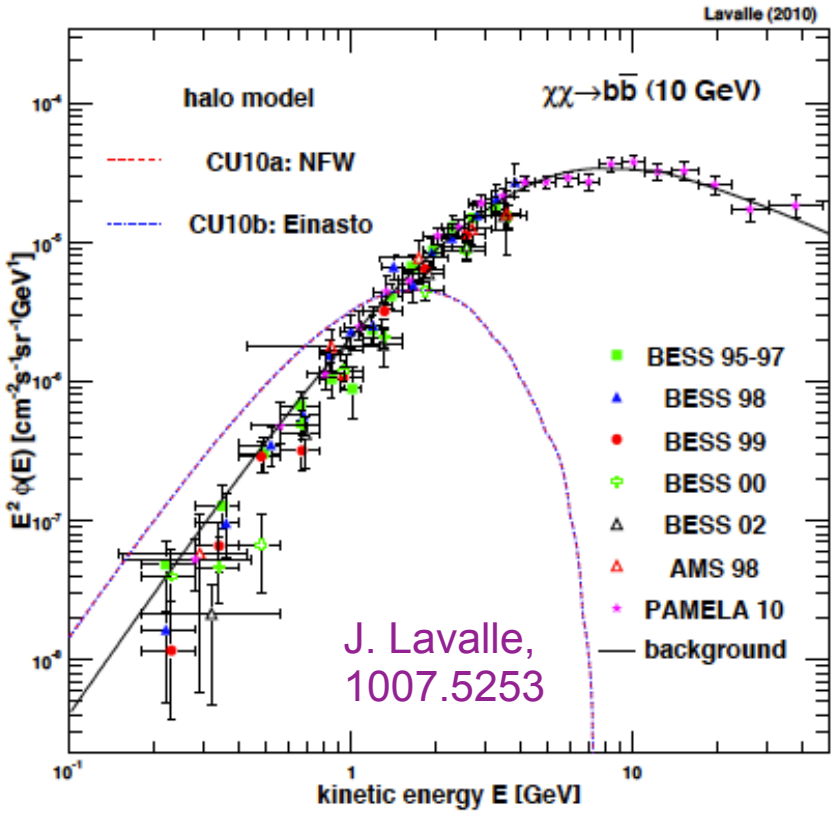
Not only DM physics (sigma's, b.r.) and astrophysics (halo distribution) matter, but also plasma astrophysics (diffusion in the Galaxy)
Antimatter is preferred due to lower astro background

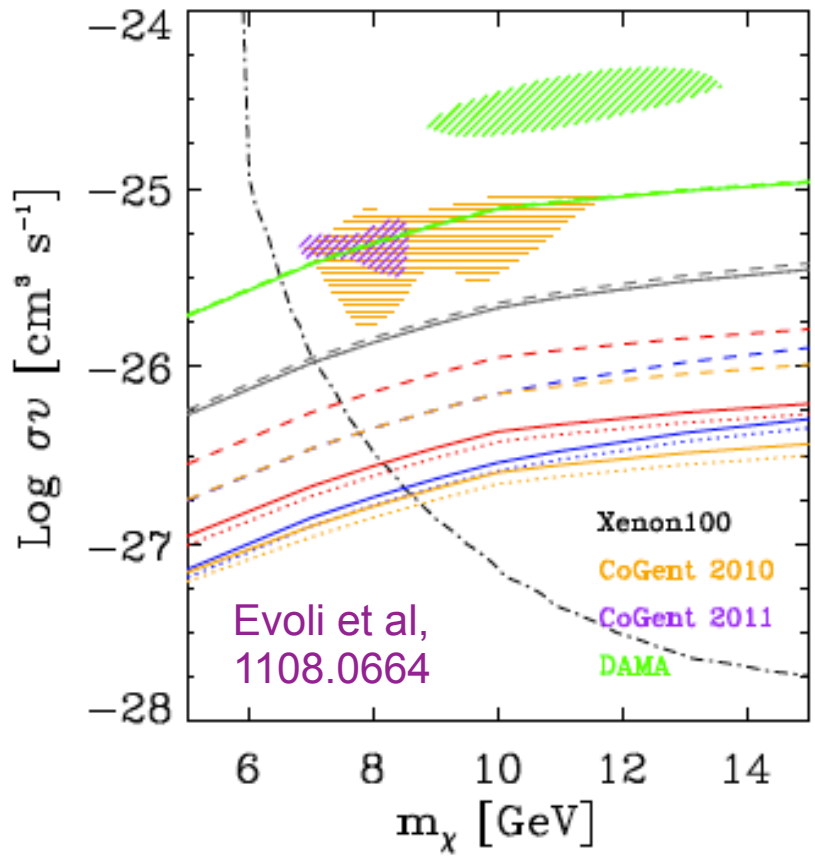


(P. Mertsch)

byproducts of the charged e^- and e^+ are synchroton/radio signals; see talks by Roberto Lineros @ 17:10 (tomorrow) Marco Taoso @ 17:30 (tomorrow)

Antiprotons: Light DM mass range

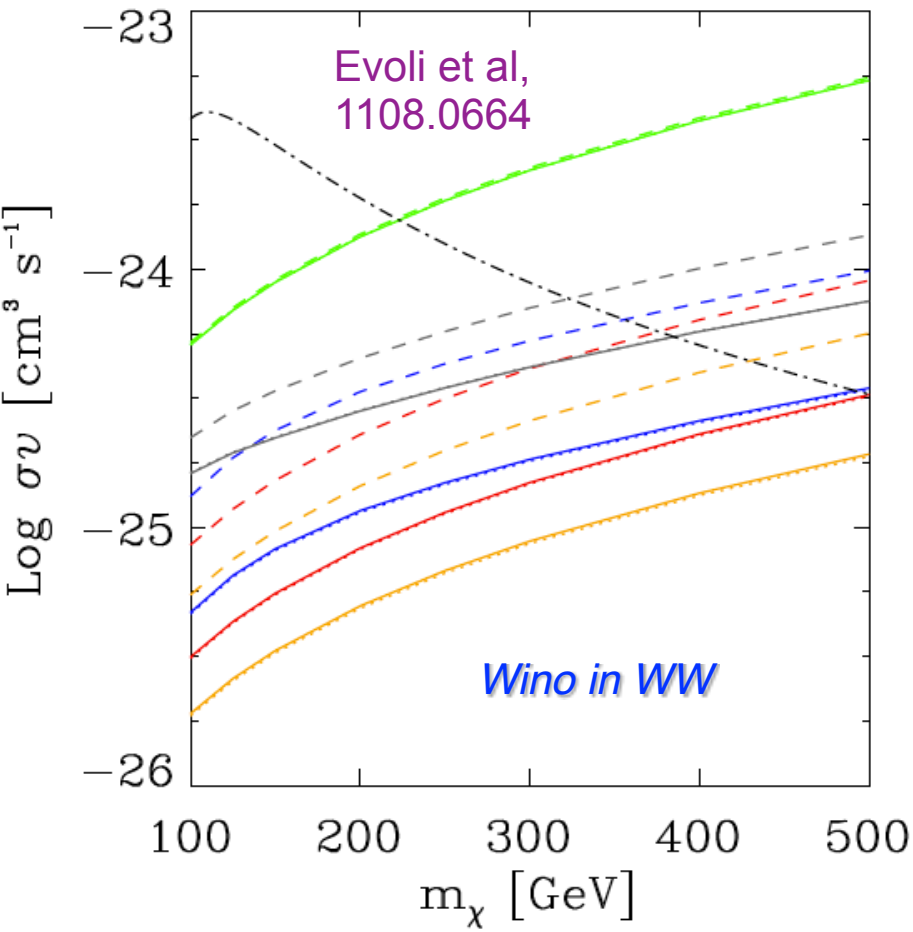




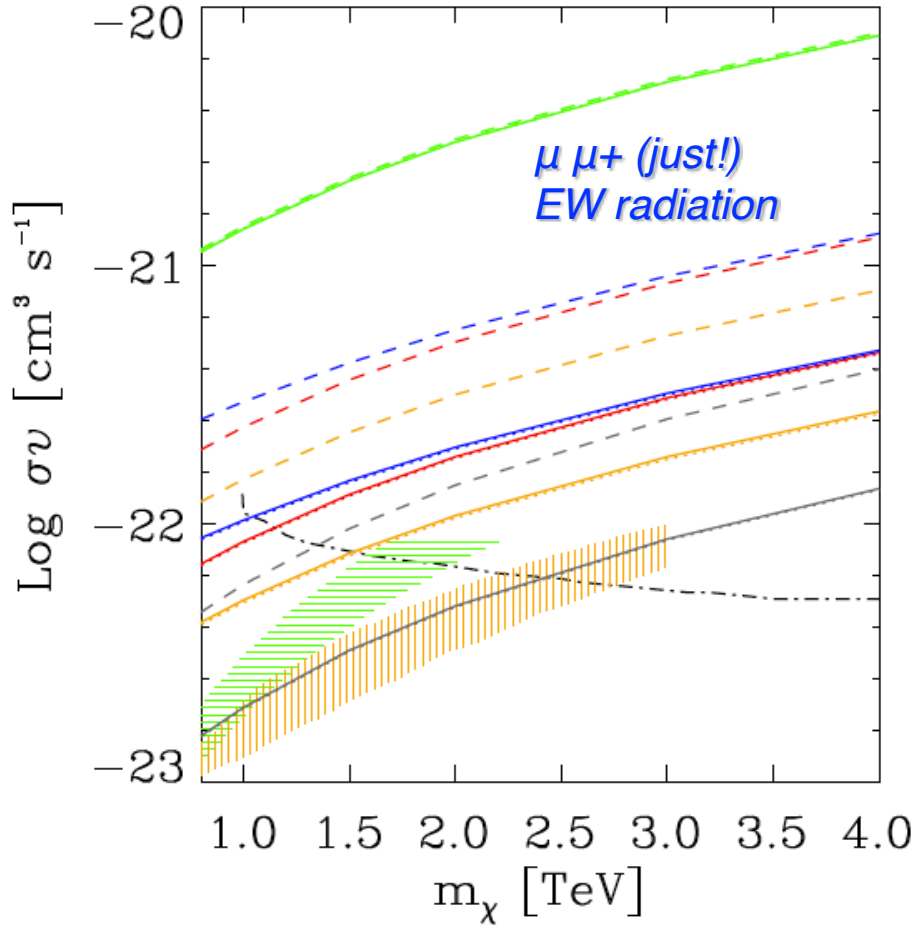
see also talk by J. Lavalle @ 17:50 (tomorrow)

Suggest that if light DM explanations of Direct Detection anomalies are correct, probably not a S-wave annihilating thermal relic candidate

Antiprotons: high masses



Different colors: different propagation parameters



Different linestyles: different halo shapes

Constraints interesting for candidates with sufficiently enhanced <σv> wrt naive expectations (e.g. excludes benchmark Wino explanations of PAMELA, like γ's from Fermi)

Charged leptons: a relatively bad channel for DM

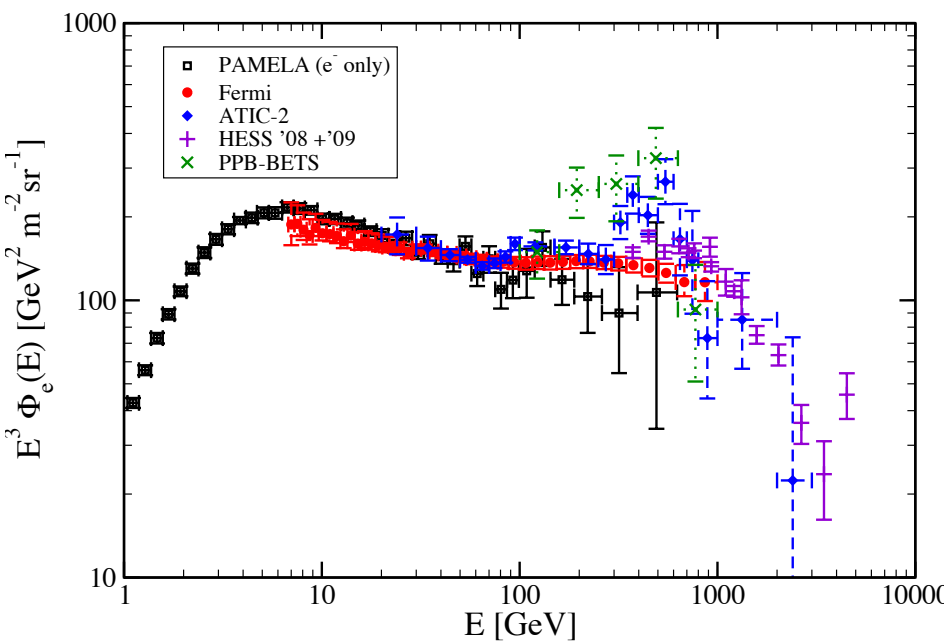
More sensitive to inhomogeneities, to energy losses... and to many more potential astrophysical backgrounds (more lepton accelerators known!), for a review: PS 1108.4827

Would you start looking for new physics at LHC in soft jets?

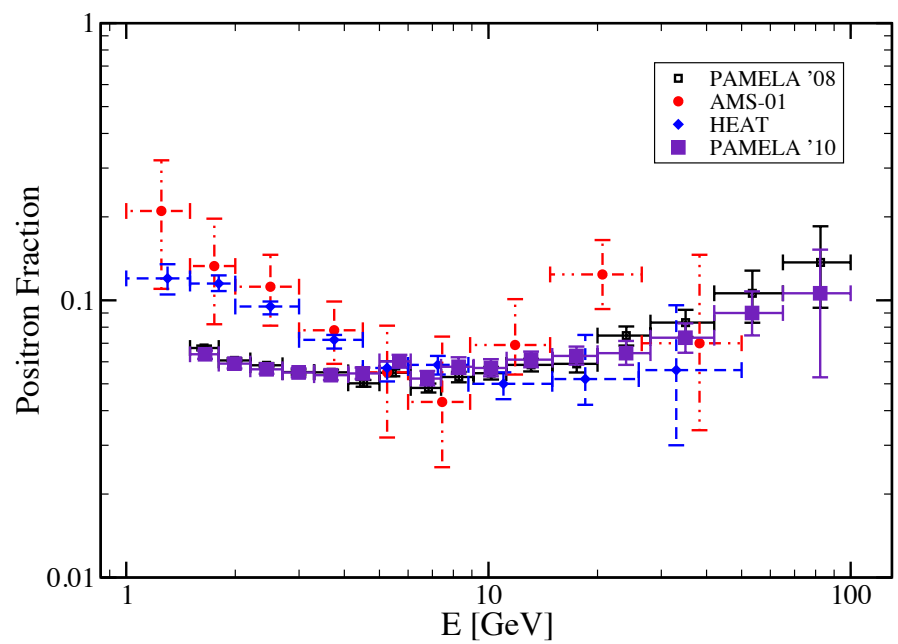
Nonetheless, no need to remind you the excitement following many data releases (perhaps major scientific impact of the LHC accident on particle theorists!) which also stimulated some interesting questions...

a talk on signal/background diagnostics via anisotropies by Enrico Borriello @ 16:50 (tomorrow)

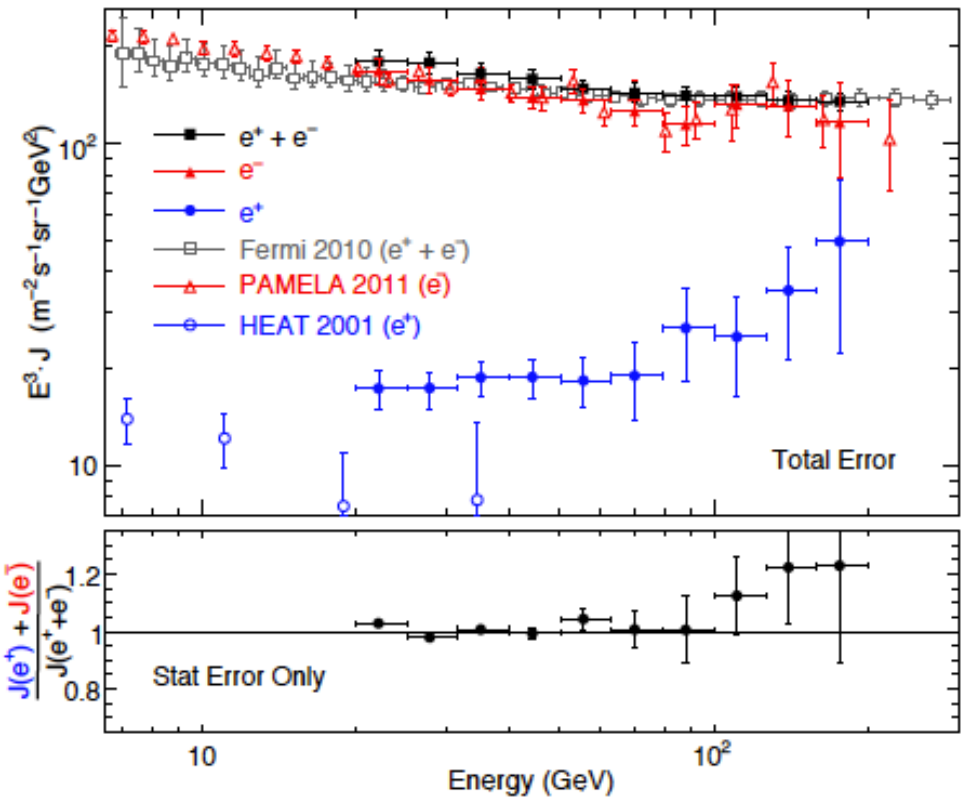
Total $e^- + e^+$ Spectrum

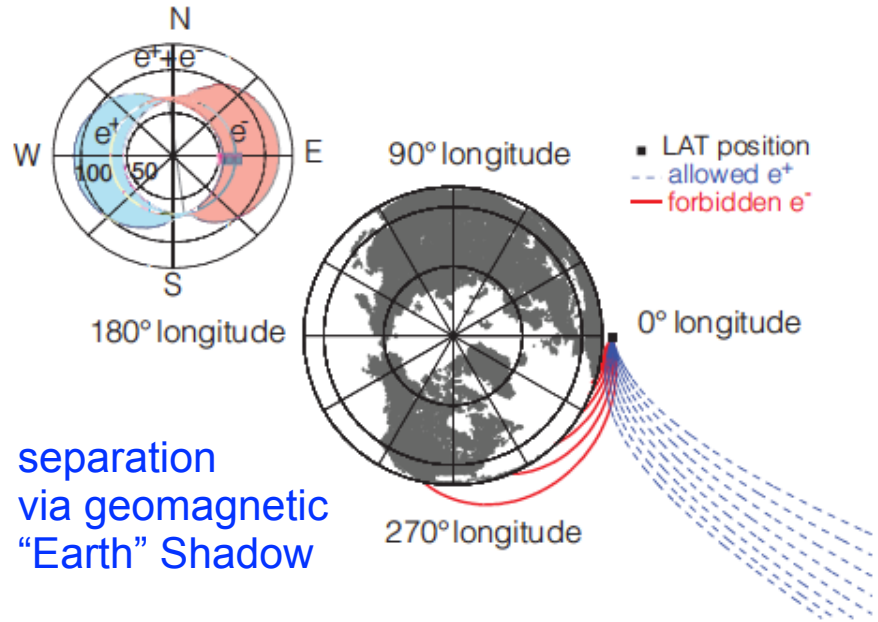


Positron Fraction data



Breaking news: Fermi confirms & extends PAMELA

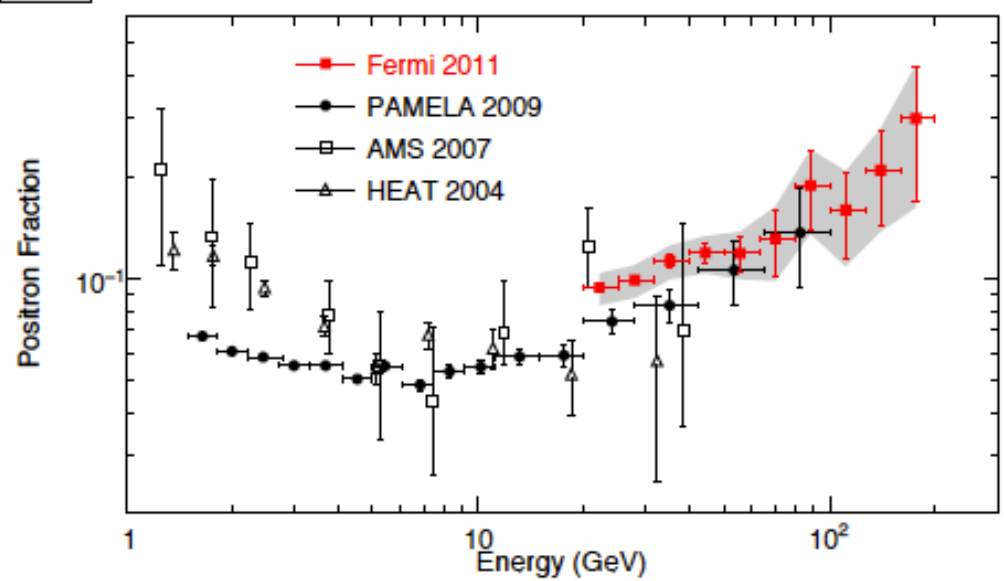




separation
via geomagnetic
"Earth" Shadow

Fermi-LAT, 1109.0521 (TODAY)

Death Bell for residual DM interpretations?



Are “standard” calculations of IDM signatures reliable?

Heavy, leptophilic DM candidates imply that most indirect signatures in CRs are at $E \ll m$.
It’s important to consider “tertiary” signatures (e.g. Inverse Compton γ’s from $e^{\pm}$ originating from DM) and/or multi-body final states (W,Z-strahlung, 3-body from sub-threshold virtual states...)

Need to go beyond mere “one step production” (need propagation!) and 2-body final states

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- ✓ γ signatures are present at high latitudes.
- ✓ Leptophilic models do have b.r. in other channels
- ✓ $e^{\pm}$ spectra are softer and fits typically worsen

Kachelriess, PS 0707.0209
Bell, Jacques, Dent, Weiler '08-'11
Kachelriess, PS, Solberg 0911.0001
Yaguna,1003.2730
Ciafaloni et al. 1009.0224, 1104.2996
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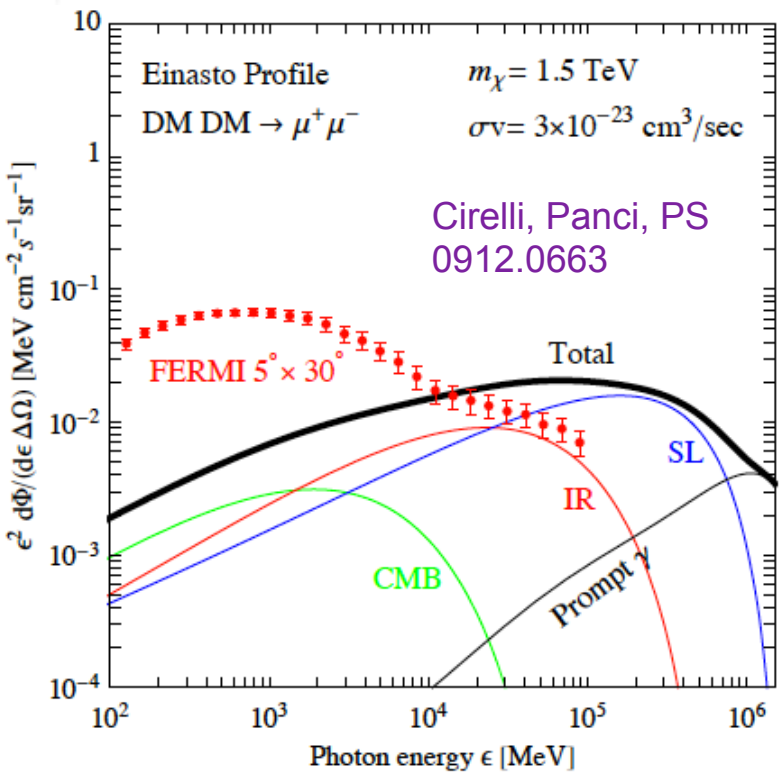
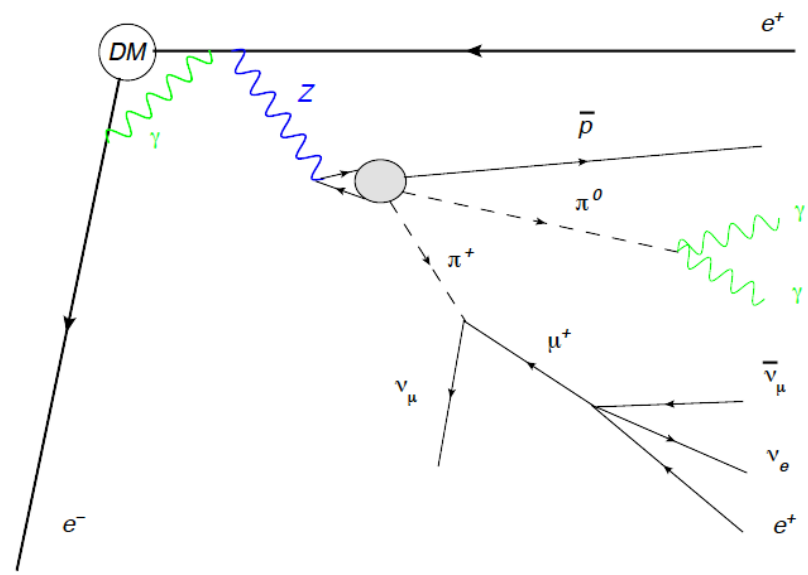




related to EW effects, see talk by A. De Simone @ 18:10 (tomorrow)

Moving from “constraints” to detection

How? Either looking for robust signatures...

★ Gamma-ray lines?

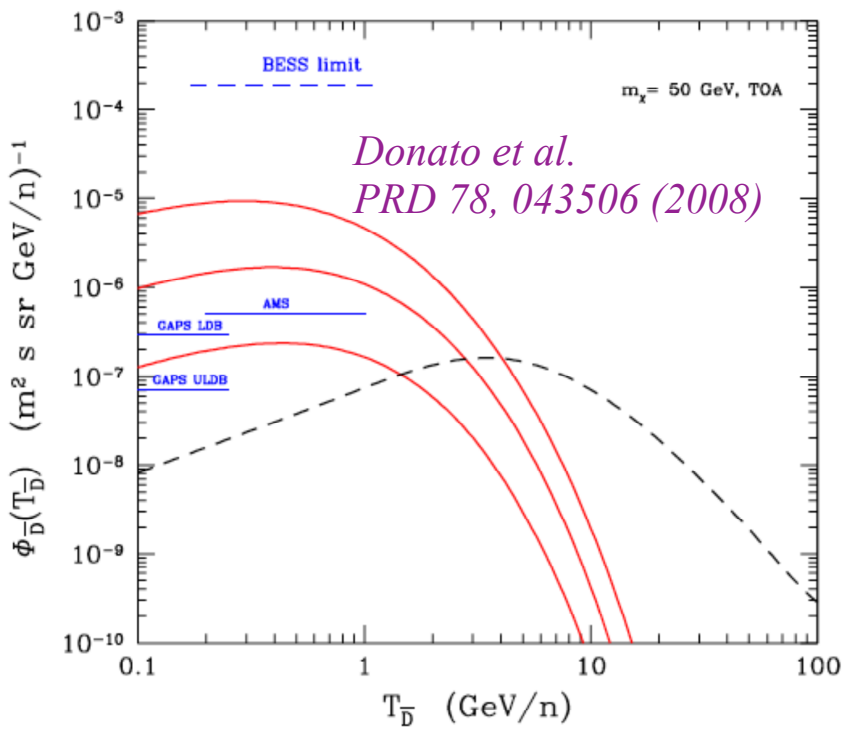
Theoretically challenging to have strong signals, usually orders of magnitude below Fermi bound (arxiv:1001.4836)... hard to do much better.

for some hope on "conceptually similar" but more likely (?) detectable spectral features at future IACTs, see talk by Christoph Weniger

★ Neutrinos from the Sun/Earth Core?

Only a small portion of typical parameter space accessible, only works until limited by atmospheric background or, ultimately, by "solar atmospheric background"

★ Perhaps "large" fluxes of antideuterons?!?

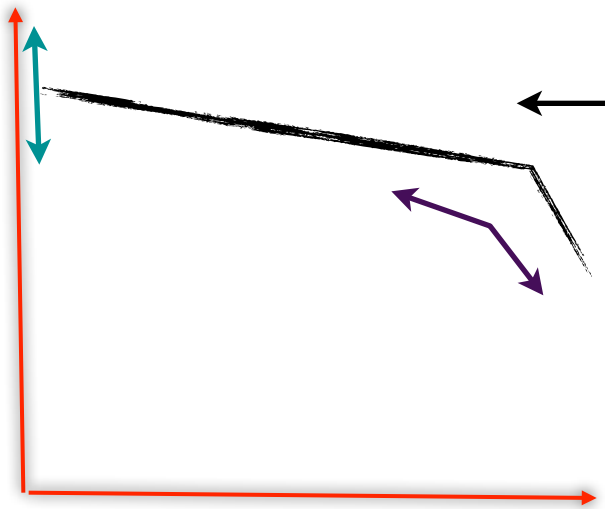


need to be lucky: not generically large enough & often "special" detector requirement needed...

or else: Can a CR feature be fitted with a DM model?

Almost a trivial question. The generic answer is "Yes", rather than "No"!
In fact, one has enough handles to control:
a) spectral shape **b)** endpoint/Energy scale **c)** normalization...

adjust σ or Γ, or DM profile
(also controls ang. shape!)



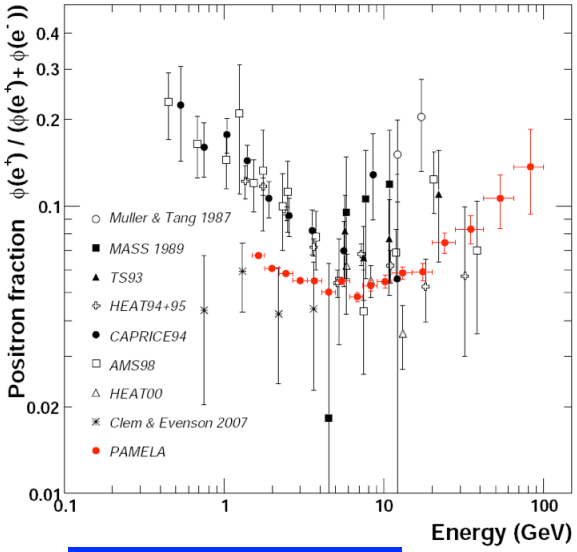
adjust mass

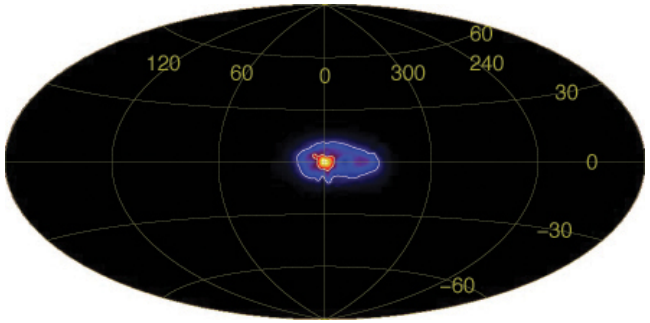
for the shape, adjust final state and/or propagation parameters

The real issues for "claiming indirect detection" are:

- to find an explanation of <u>many</u> phenomena with PP motivated models
- to predict ID features which cannot be understood by known astrophysics
- to have links with direct or collider signatures

Lessons from the past:





e^+ fraction

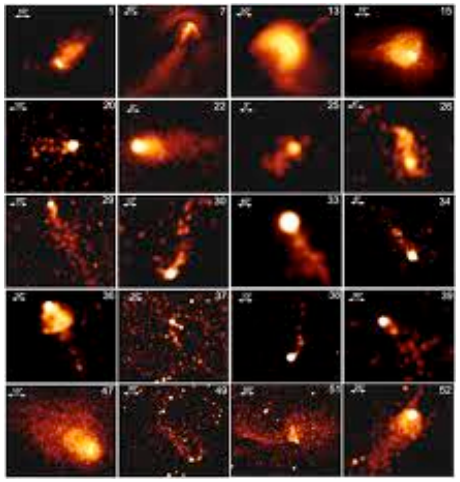
GC source(s)

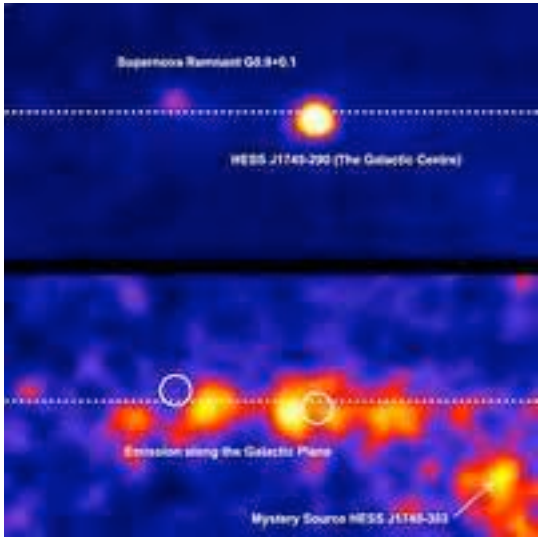
511 keV radiation

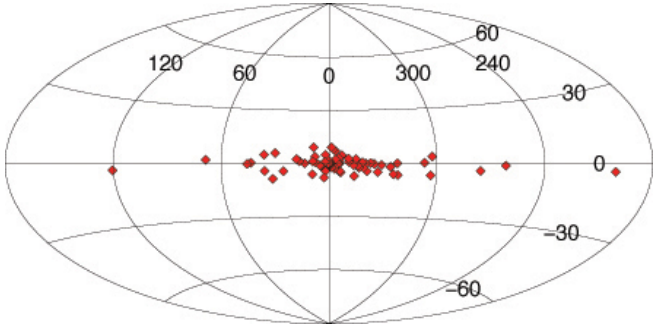
PWNe? SNRs?

BH, SNRs, PWNe, Diffuse...

X-ray binaries?







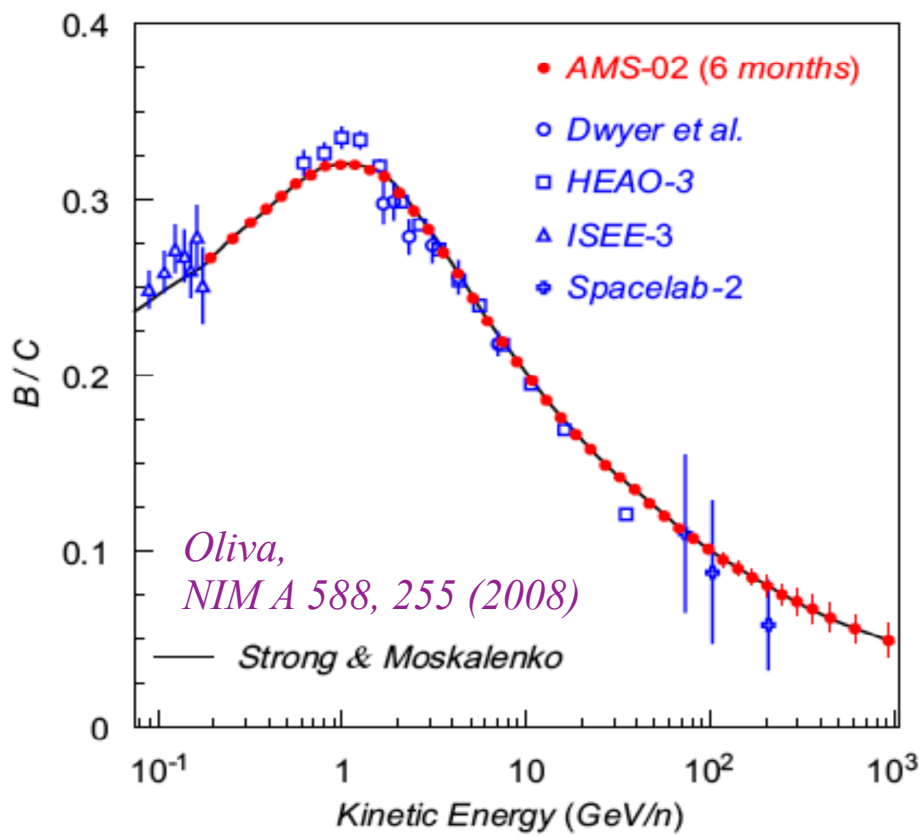
ID, what have we learned?

➡ With a few "hints" still debated, most indirect signatures told us that DM signals are not dominant, rather at or below the level of "astrophysical systematics". New "backgrounds" have been discovered/discussed

➡ A few years ago, the attitude was that the major uncertainties in ID was due to ISM and propagation parameters. A large(r) community now appreciates that a more challenging limitation to overcome is the lack of detailed knowledge of the sources

➡ Experiments like AMS-02 & current/ future gamma-ray detectors will provide further checks of the internal consistency of simple models of CRs. The field is being re-defined by high-quality data, extending over a larger dynamical range.

Wonderful time to do good high-energy astrophysics!



Outlook

Indirect probes (astrophysics & cosmology) tell us a lot: BSM physics is there!
However, they do not tell us its scale, and blind searches are more and more challenging, facing little known astrophysics.

This is the "golden age" for direct searches and colliders!
It's advisable to go back to the "standard practice": experiments must guide us to BSM physics, following the good old pipeline:
Particle Physics progress→Theory Framework→Prediction for ID→a priori searches (avoid "look elsewhere effect"!)

If a signal is found in other channels (collider/DD) We still *need* ID:

- To confirm that whatever we find in the Lab is the same "dark stuff" responsible for astrophysical and cosmological observations.
- To access particle information not otherwise available in the Lab (annihilation cross section or decay time, b.r.'s)
- to infer cosmological properties of DM (e.g. power spectrum of DM at very small scales) not accessible otherwise.

Consistency checks/constrained searches more promising than blind ones!
ongoing/near future ID experiments will help with more sensitivity and precision as well as better understanding of astrophysical sources & propagation parameters

In the meanwhile: Take Home Messages

- Current experiments are excluding the < O(10) GeV mass scale for “vanilla” S-wave thermal relics and are probing the O(100) GeV scale
- Most TeV scale-models proposed for “PAMELA-Fermi” data have been ruled out, more importantly no evidence/prediction of these models has shown up.

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For now, not a bad idea to stick to the lesson of a XIV century franciscan friar (at the time, known also in Munich to be guys aware of what's important in life):

"Frustra fit per plura quod potest fieri per pauciora"

"It is futile to do with more things what can be done with fewer"

W. of Ockham, Summa Totius Logicae

*"**Numquam** ponenda est pluralitas sine necessitate"*

"Plurality must **never** be posited without necessity"

Quaestiones et decisiones in quattuor libros Sententiarum Petri Lombardi

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but, evidently, phenomenologists have their kind of needs...

(Btw, only a few know how Ockham got the idea...)

Thanks for Your Attention!

Ockham chooses a razor