Fermi

Gamma-ray Space Telescope

Dark Matter Observations and Fermi

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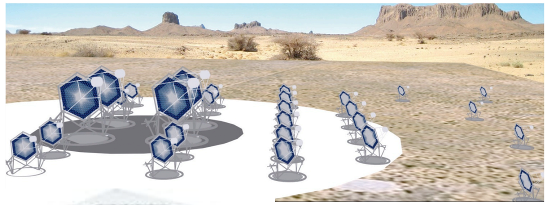
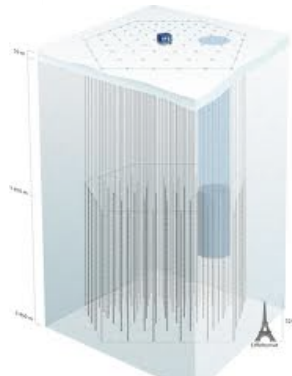
I – Basics of Indirect DM Searches

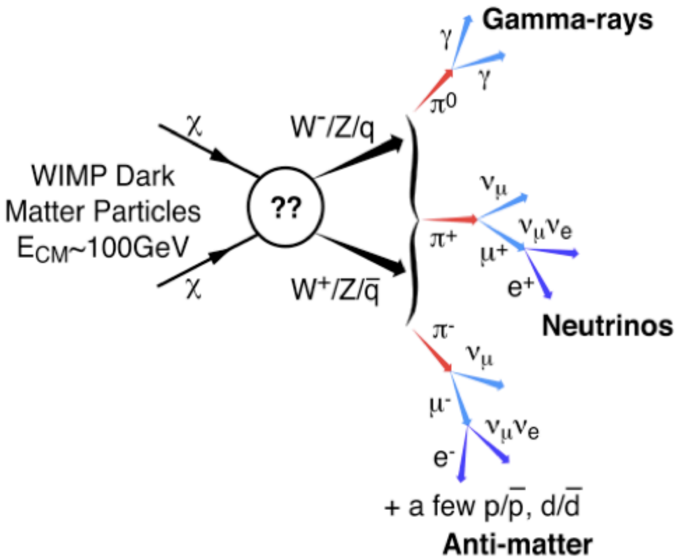
Spectra
Fluxes
Targets

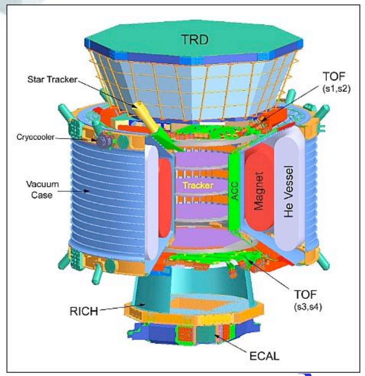
Basics - Dark Matter tracers

- The so-called WIMP *miracle*
  - most natural extension of particle physics Standard Model provide a natural DM candidate with correct relic density from cosmology
- Thermal freeze-out gives benchmark annihilation cross-section $<\sigma v> \sim 3\times10^{-26}$ cm^3s^{-1}



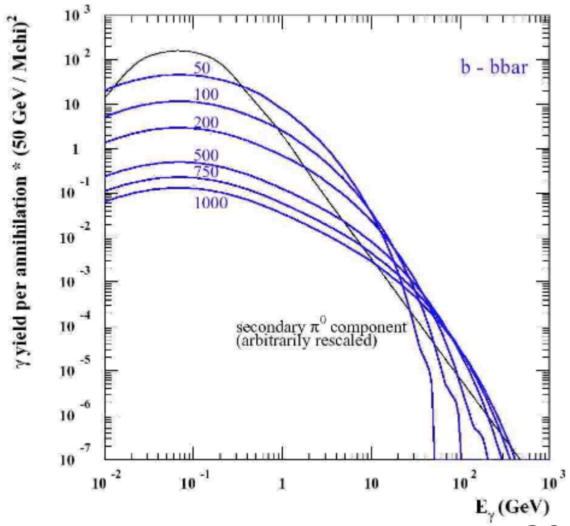


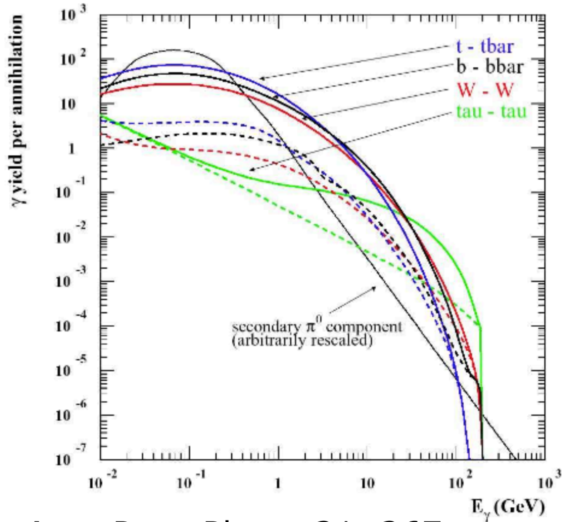




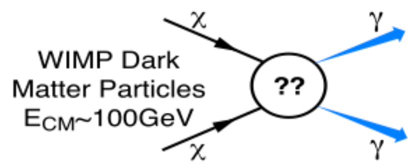
Basics - WIMP Dark Matter Spectra

- Choice of the particle physics model fixes final states and spectrum, but in general
  - Non simple power law spectra
  - b-bbar spetrum good proxy for hadronic channels (quarks and gauge bosons)
  - Leptonic channels in conjunction with CRE excesses
  - Inclusive photon spectra





2004, AstroPart. Phys., 21, 267



Smoking-gun signature, but $O(10^{-3} / 10^{-4})$ suppressed

Basics – Indirect Dark Matter fluxes

- ❑ Measured flux (from the instrument)
  - Instrument related systematics
- ❑ Expected flux typically factorized as

particle physics

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\phi,\theta) = \boxed{\frac{1}{4\pi}\frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f} \times \boxed{\int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los} \rho^2(r(l,\phi'))dl(r,\phi')}$$

DM distribution

  - Particle Physics factor (from theorists)
    - Model-dependent
  - DM density (from measurements and simulations)
    - Large uncertainties
    - folds with instrument resolution (source extension)

Basics – DM targets in the sky

Galactic Center

Good Statistics but source confusion/diffuse background

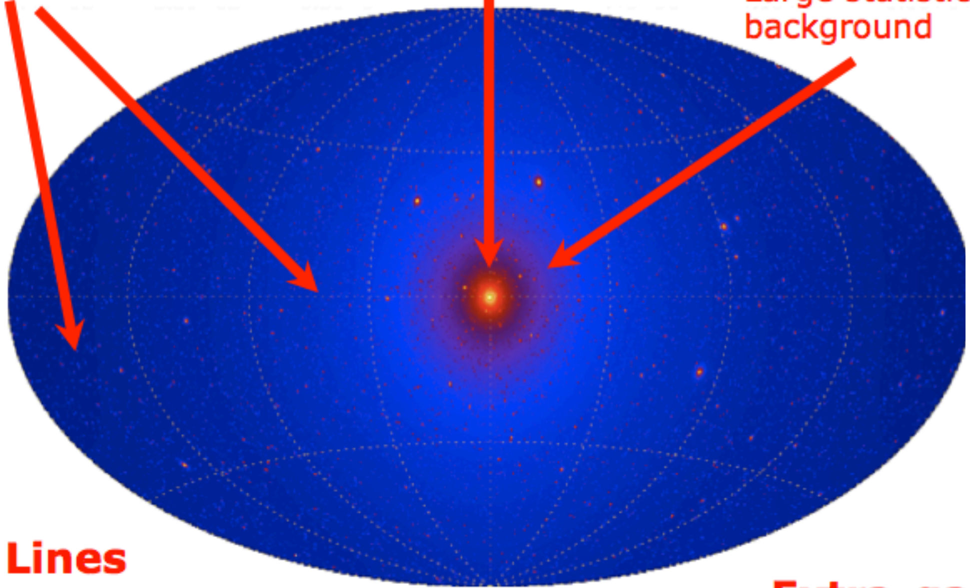
Satellites

Low background and good source id, but low statistics, in some cases astrophysical background

Milky Way Halo

Large statistics but diffuse background

All-sky map of gamma rays from DM annihilation arXiv:0908.0195 (based on Via Lactea II simulation)



Spectral Lines

No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Extra-galactic

Large statistics, but astrophysics, galactic diffuse background

Galaxy Clusters

Low background, but low statistics

II – Observation techniques and example results

Cosmic Rays

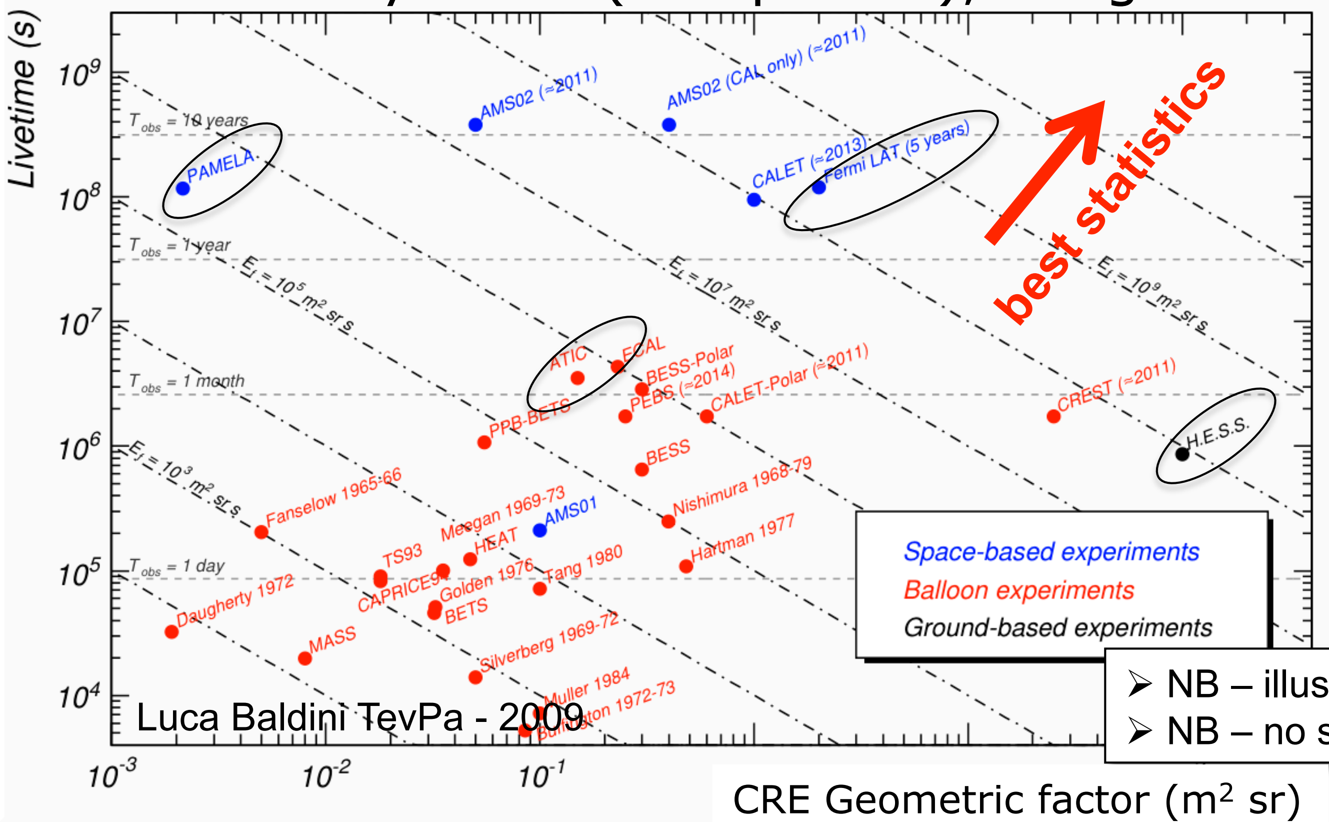
Neutrinos

Gamma-rays from the ground

Gamma-rays from space

Cosmic Rays – techniques

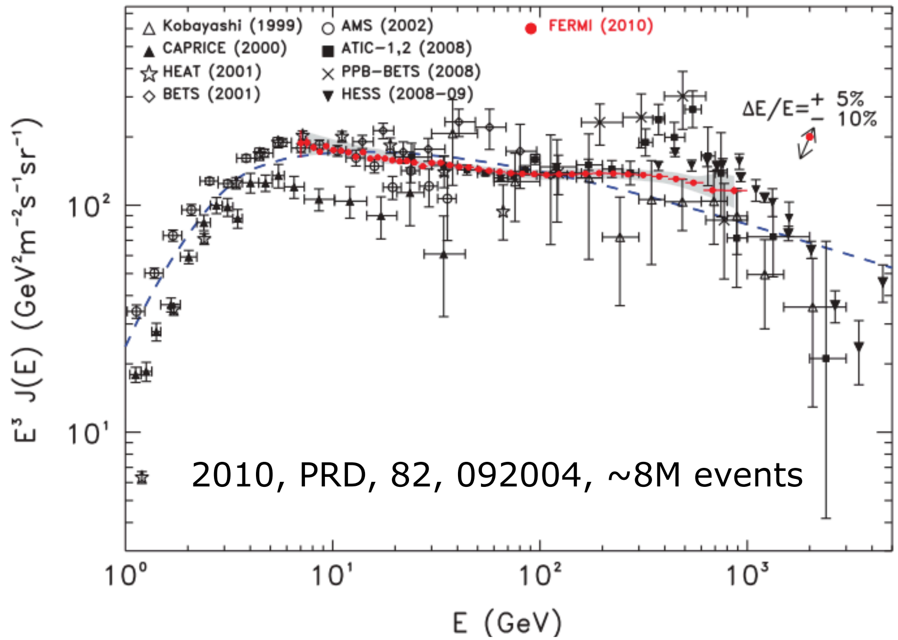
- Spectrometers (PAMELA, AMS, balloons)
  - Measure particle ID, charge
- Calorimeters (ATIC, Fermi, HESS, balloons)
  - Separate EM from hadronic signals via shower topology
- Statistics driven by ~size (acceptance), integrated livetime

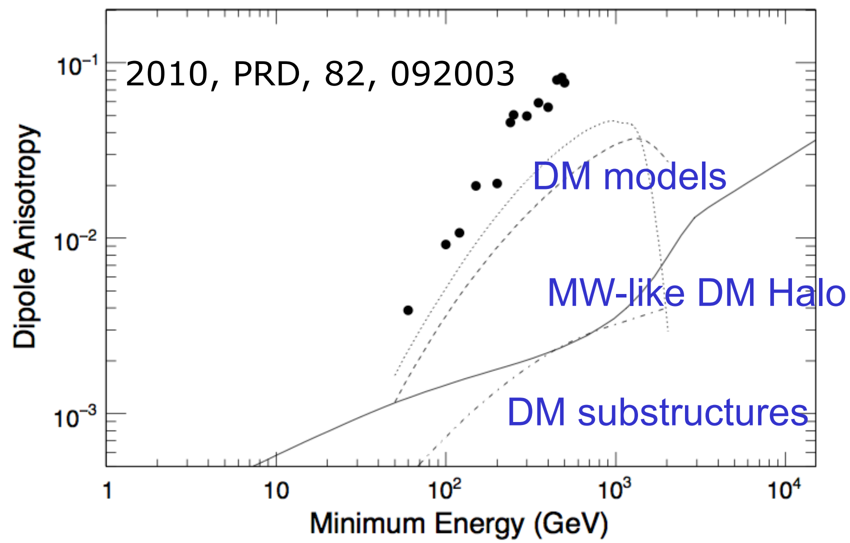


- NB – illustrative
- NB – no systematics

Cosmic Ray Electrons - Results

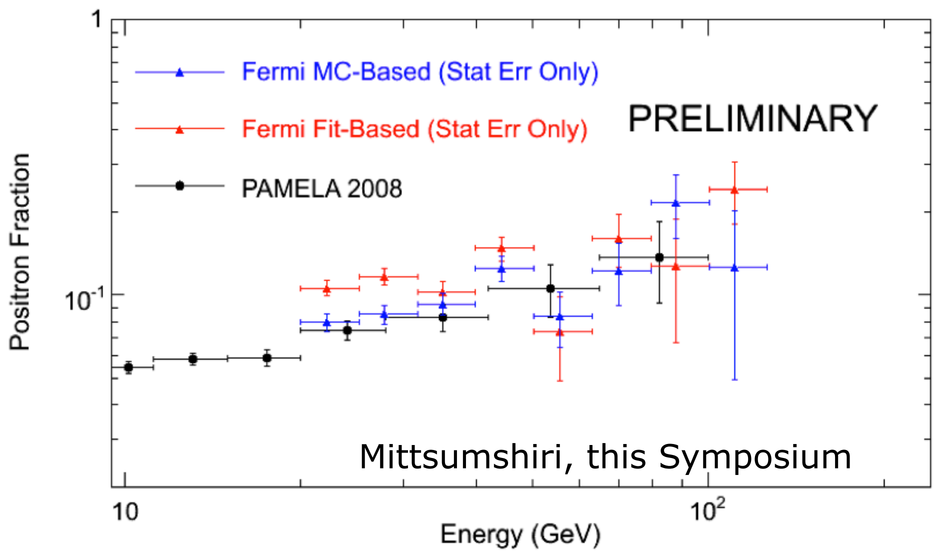
- Inclusive spectrum
  - Hard with no strong features (Fermi)
  - ~>TeV cutoff (HESS)
- CRE Anisotropies (Fermi)
  - ~Exclude single local astrophysical source (dipole)
  - Leave room for DM (expected more symmetrical halo)
  - Same technique used to constrain CREs from the Sun and derive DM limits (see poster DMNP.S1.N8)

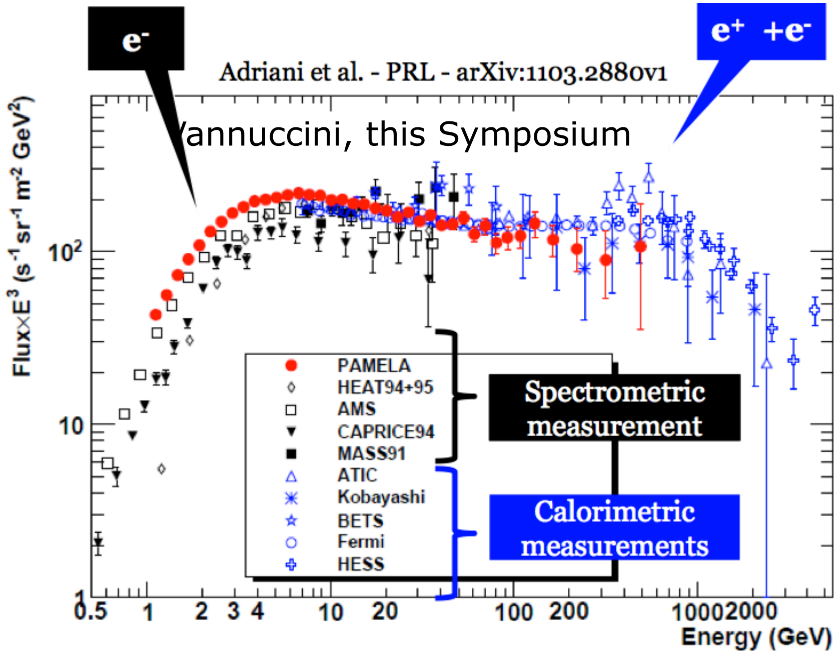




Cosmic Ray Electrons - Results

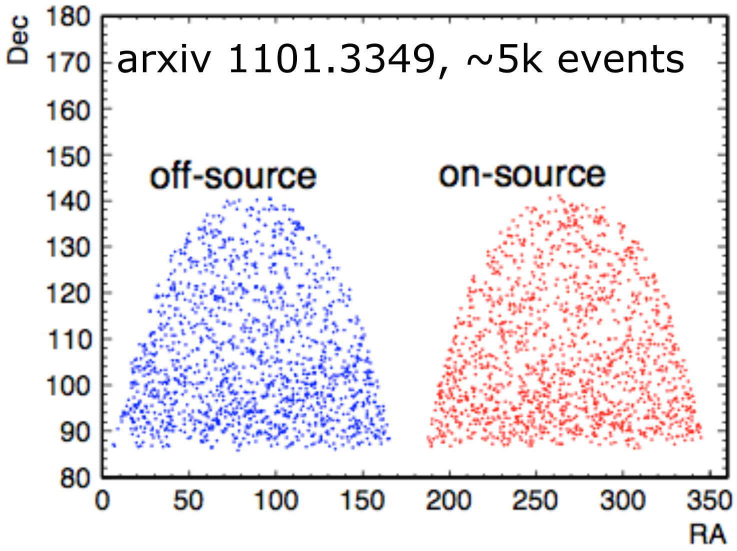
- Positron fraction (Pamela, Fermi)
  - Rising
  - At odd with standard production of secondaries (and anti-proton spectrum from Pamela)
- Electron spectrum (Pamela)
  - Consistent with Fermi
- Leptophilic DM ?
  - Test with gamma-rays!





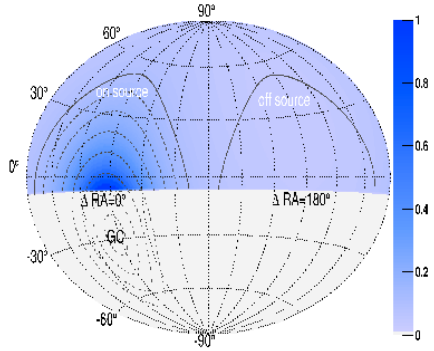
Neutrinos - IceCube technique

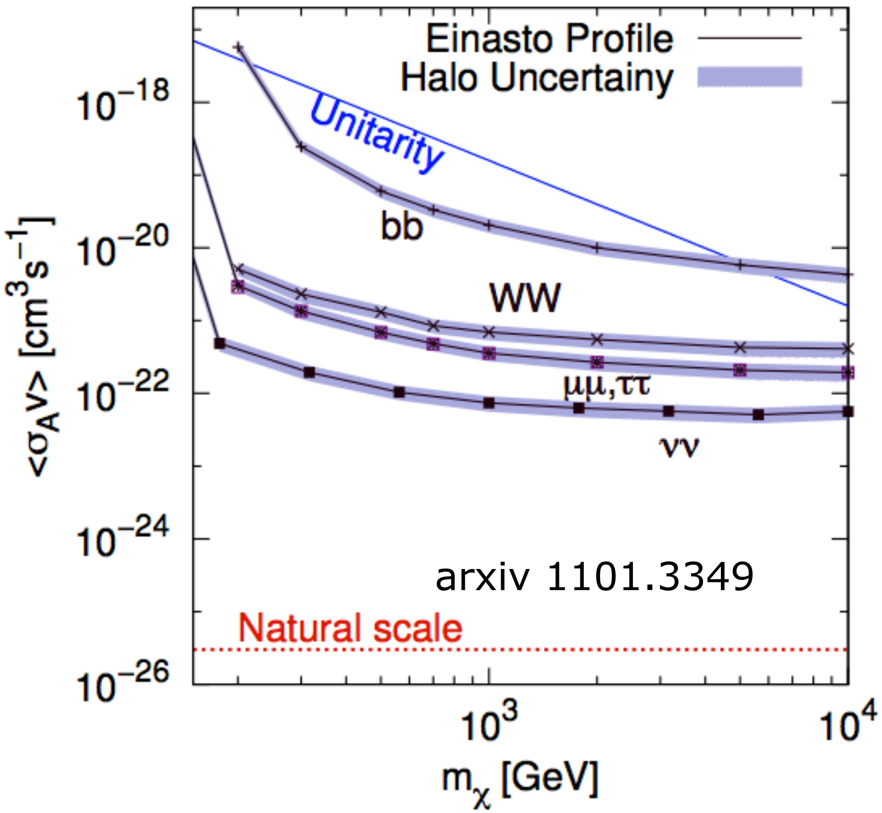
- Workhorse IC muon neutrino tracking
  - ~degree resolution
- Search for large scale anisotropy form DM in the Galactic Halo
  - ON-region (signal) centered around GC
  - OFF-region (background) anti-centered on the GC
  - Galactic center outside FOV (looks at events below horizon from Northern sky)



Neutrinos - IceCube GH results

- Sensitive to high energy
- Limits to WIMP annihilation cross-section derived similarly to gamma-ray analysis
- ~O(10^4) from thermal limit, expected improvements from
  - Increased acceptance (IceCube40)
  - other targets (dwarfs, GC with IceCube core)

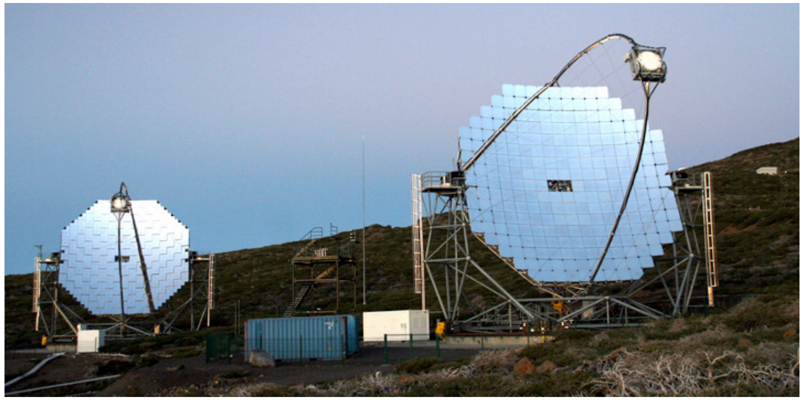




arxiv 1101.3349

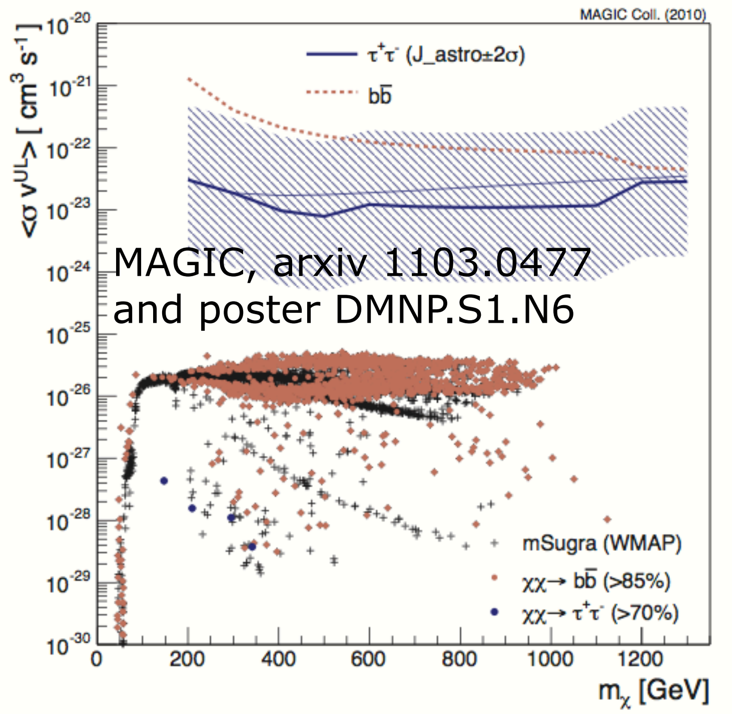
Gamma-rays from ground - IACT

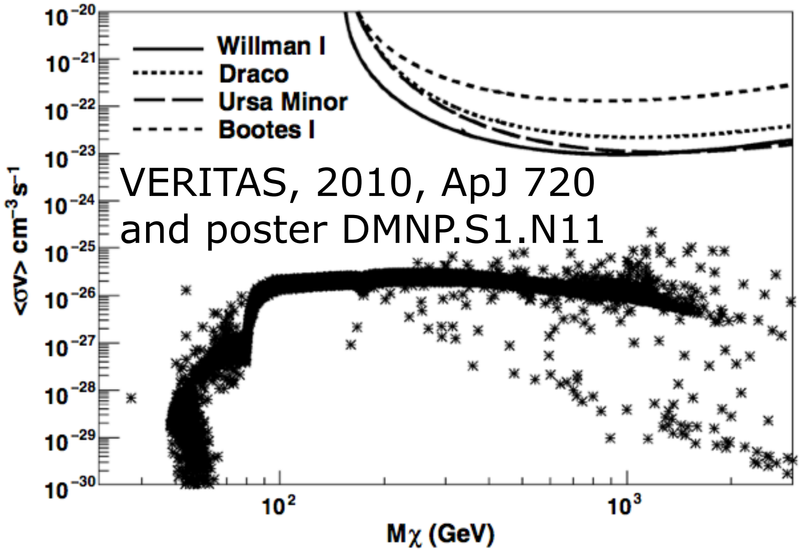
- ~10^4 m^2 effective area
  - atmosphere, wide mirrors
- ~0.1^o angular resolution
- ~100 GeV current WIMP threshold
- Field of view (few degrees) and duty cycle current challenge
  - Competition with astrophysical targets
  - Typical observing time for DM targets ~30 hrs



γ-rays from ground – some results

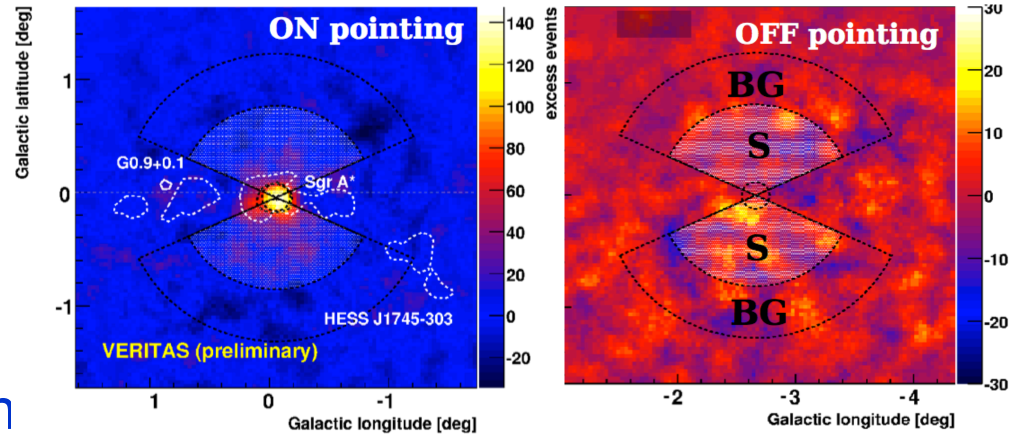
- Limits on single dwarfs
  - ~O(10^4) above thermal limit
  - significant improvement could come from much improved sensitivity of CTA
- Extended regions (Galactic Halo)
  - Work in progress at HESS



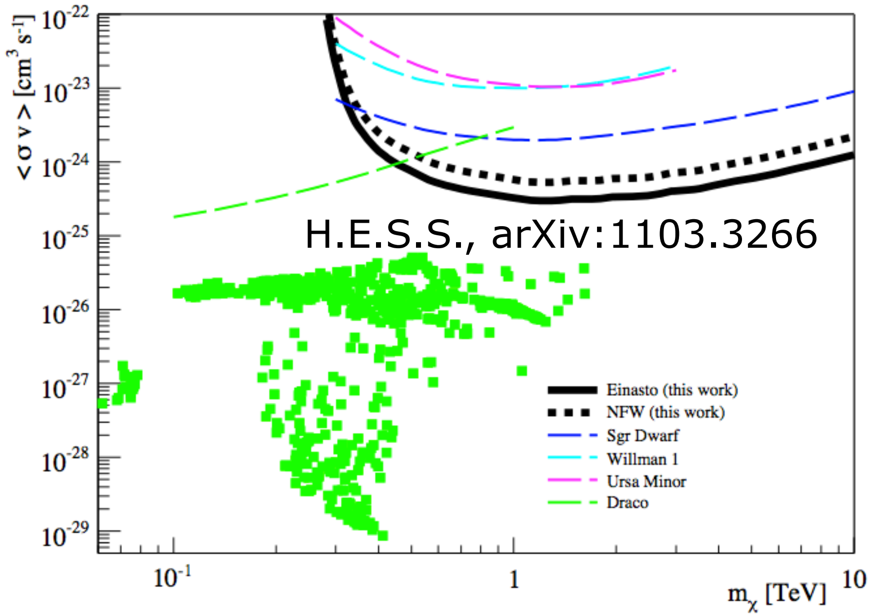


γ-rays from ground – Galactic Centre

- Galactic center analyses
  - help resolving sources in the region
  - VERITAS detects GC (confirms HESS/MAGIC spectra) with large zenith angle observations
  - DM constraints requires careful definition of ON and OFF regions
  - HESS constraints ~O(10) x$<\sigma v>_{thermal}$ but insensitive to isothermal DM profiles



Beilike, this Symposium

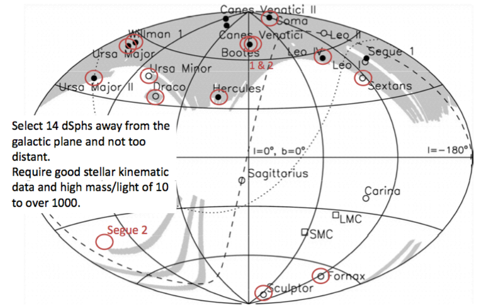


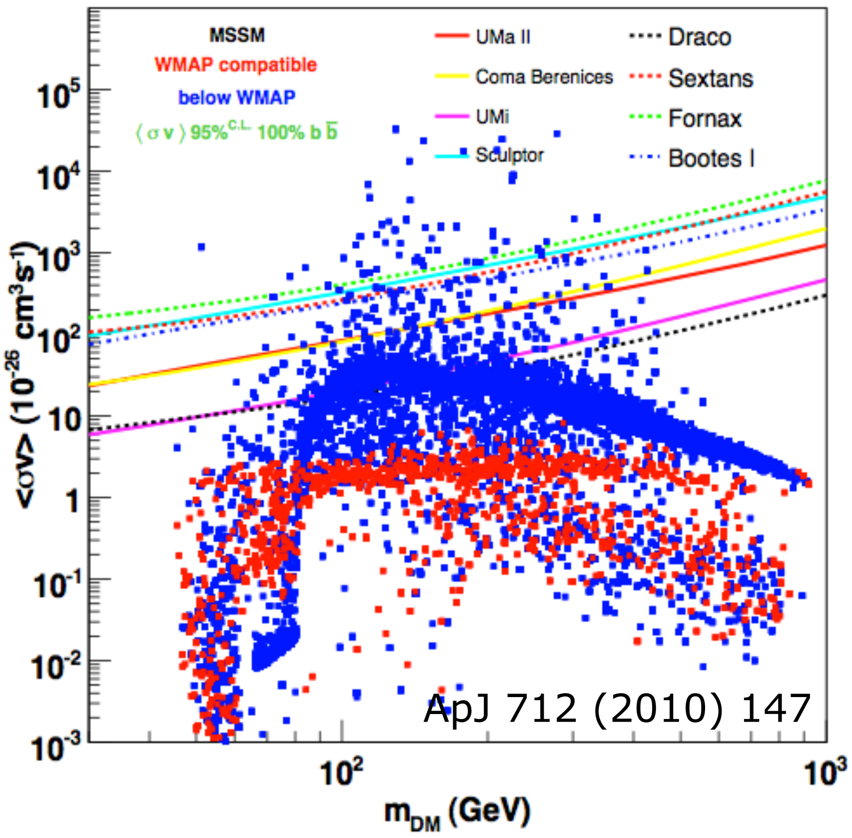
Gamma Rays from space - Fermi LAT

- Key features for DM searches
  - Energy range and resolution
    - probe ~GeV – 1 TeV WIMPs with $7<\sigma_E<15\%$
  - ~0.1^{o} angular resolution
    - From point source to diffuse emission
  - Full-sky coverage
    - All targets at same time
      - Synergy with astrophysics (e.g. diffuse gamma-rays)
      - No competition for observing time with astrophysical program
  - Large photon statistics

Example LAT results – point sources

- ❑ Search for gamma-ray emission from dwarf spheroidals
  - No astrophysical emission expected
- ❑ Conventional Fermi-LAT point source analysis
  - uses LAT experience in handling instrument response and background
- ❑ Convert flux Upper Limits to model-dependent UL on DM annihilation cross section
  - Uncertainties on J factor
- ❑ Updated results from stacked dwarfs reach ~ $\langle\sigma v\rangle_{thermal}$
  - See talk by Llena-Garde

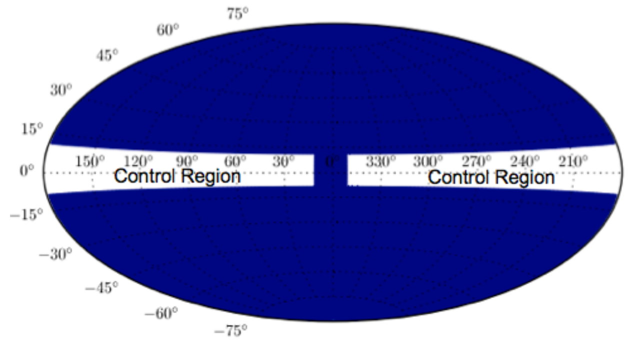


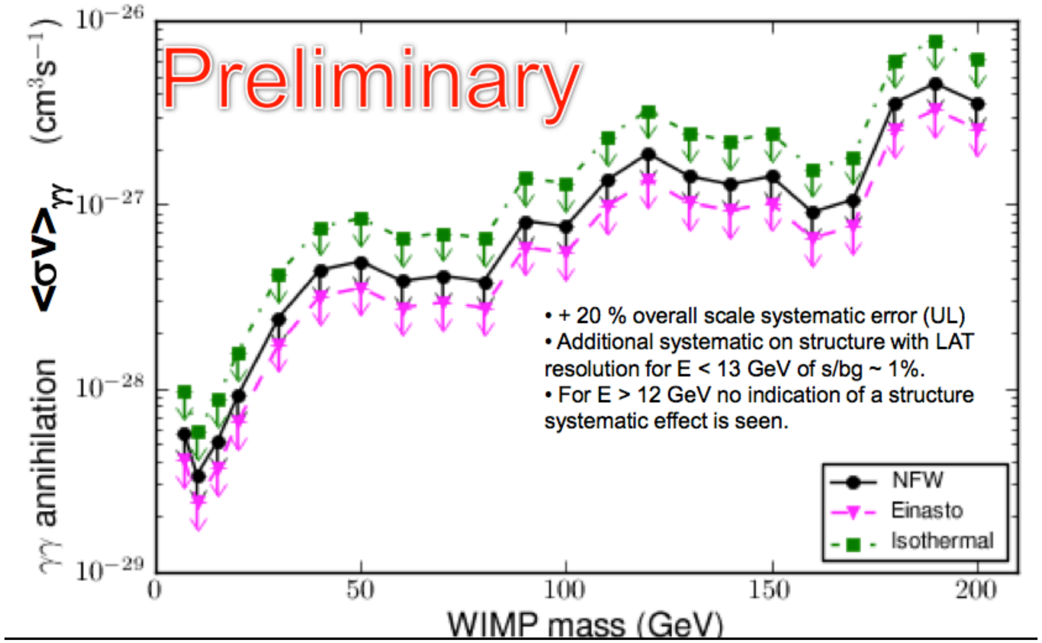


ApJ 712 (2010) 147

Example LAT result – all sky spectrum

- Search for gamma-ray lines in inclusive, all-sky spectrum
  - No astrophysical background
- Suppressed signal
  - limits still some ~O(1) X thermal WIMPs
  - Some scenarios constrained (non thermal WIMPs)
- Require good and well-known energy resolution
  - See talk by Bloom

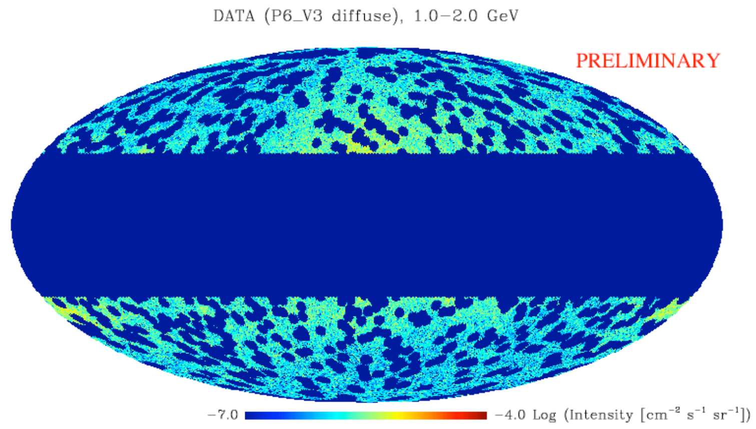


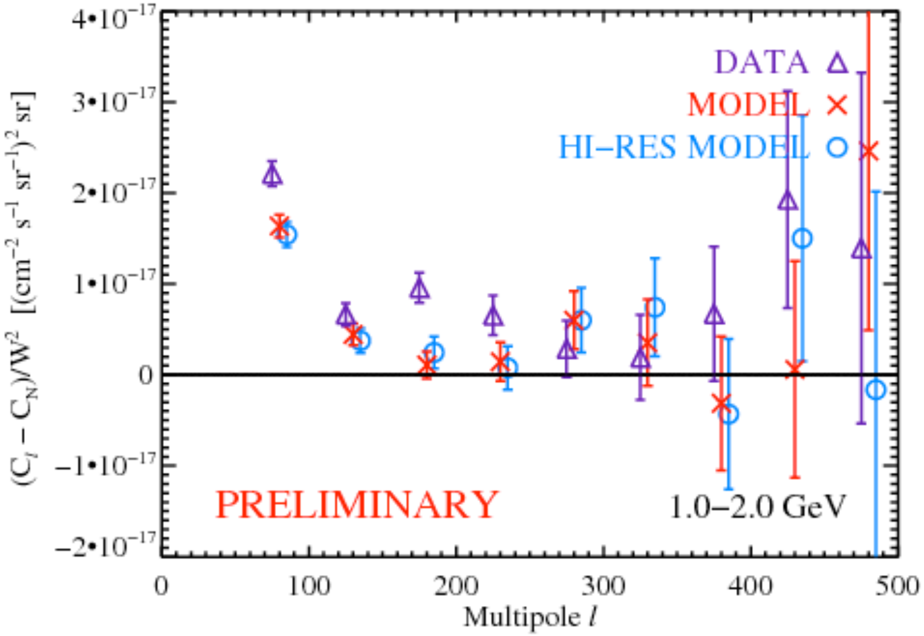


update to PRL 104, 091302, 2010

Example LAT results – spatial domain

- Search for anisotropies of diffuse gammas through Angular Power Spectrum
- Benefits from LAT full sky coverage, uniform exposure, angular resolution
- Potential to reveal un-modeled source classes, including Dark Matter
  - See talk by Siegal-Gaskins
  - See poster by Fornasa (DMNP.S1.N5)





III – Updates from Fermi and caveats

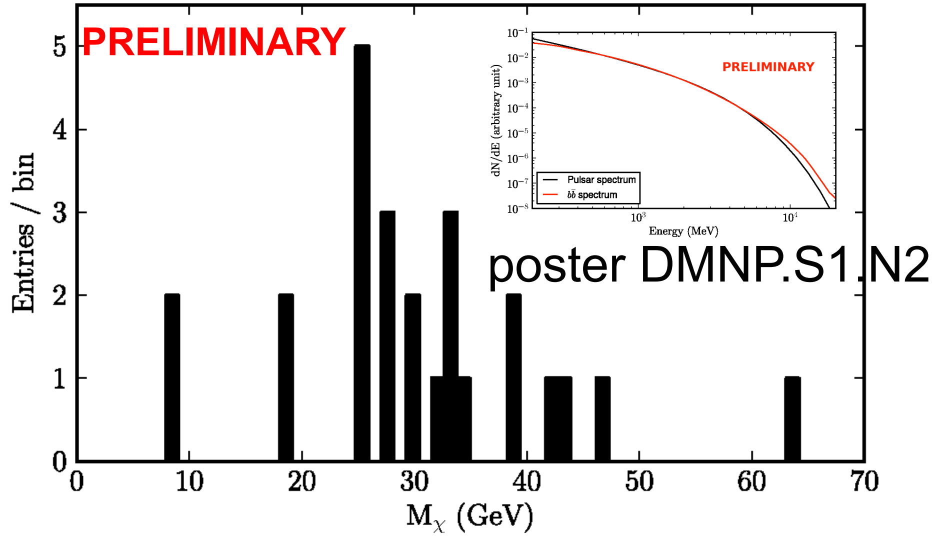
Point sources and DM distribution

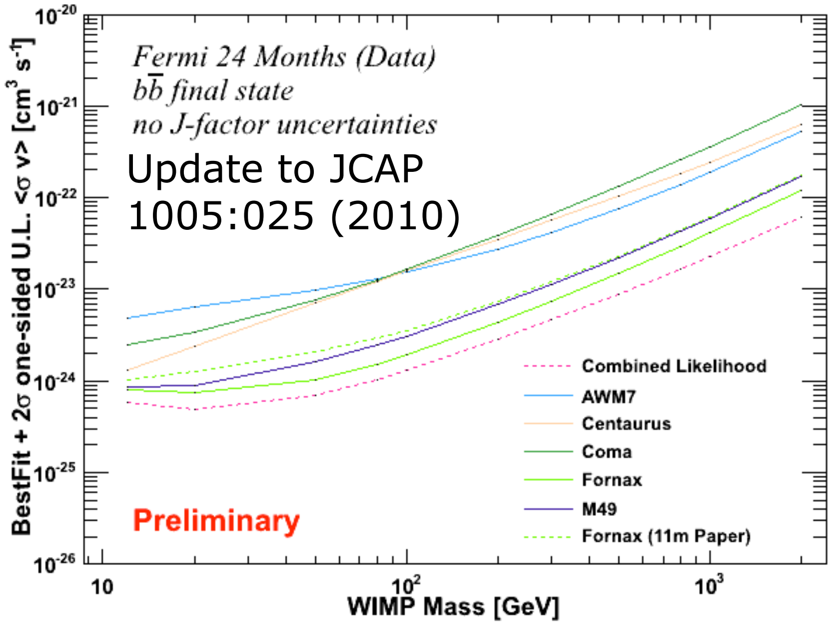
Extended regions and diffuse emission

Isotropic and astrophysical contributions

Fermi updates on sources

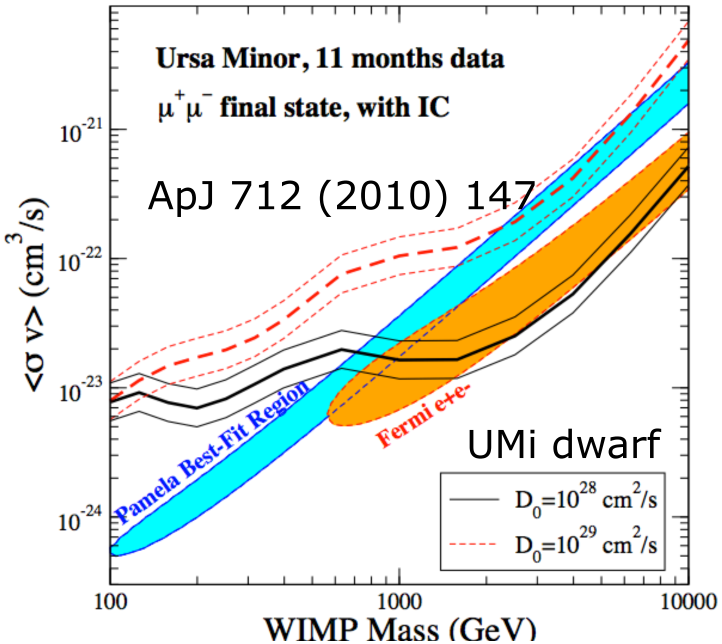
- No DM satellites found in 1 year of data when requiring
  - Spectrum inconsistent with conventional power law
  - source extension (almost all pulsars pass simple spectral tests)
- Galaxy Clusters
  - Stacking method improved limits
  - Guaranteed gamma-ray from CR interactions
  - See talk by Zimmer

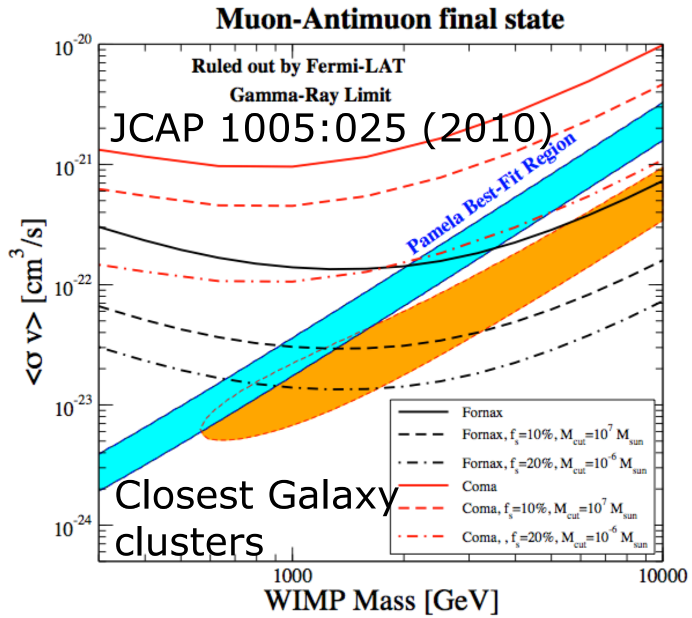




Caveats – Astrophysical uncertainties

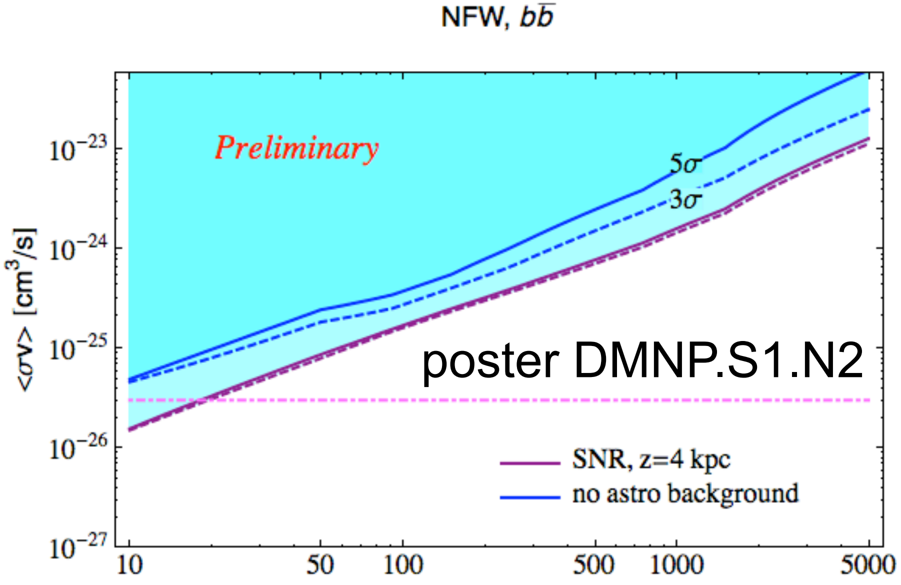
- ❑ Important for converting flux UL into cross-section limits
- ❑ J factor
  - – Important for dSph
- ❑ Diffusion
  - – Impact IC component for leptonic final states
- ❑ Role of substructures
  - – Expected from theoretical arguments
  - – can be used to boost signal and improve limits

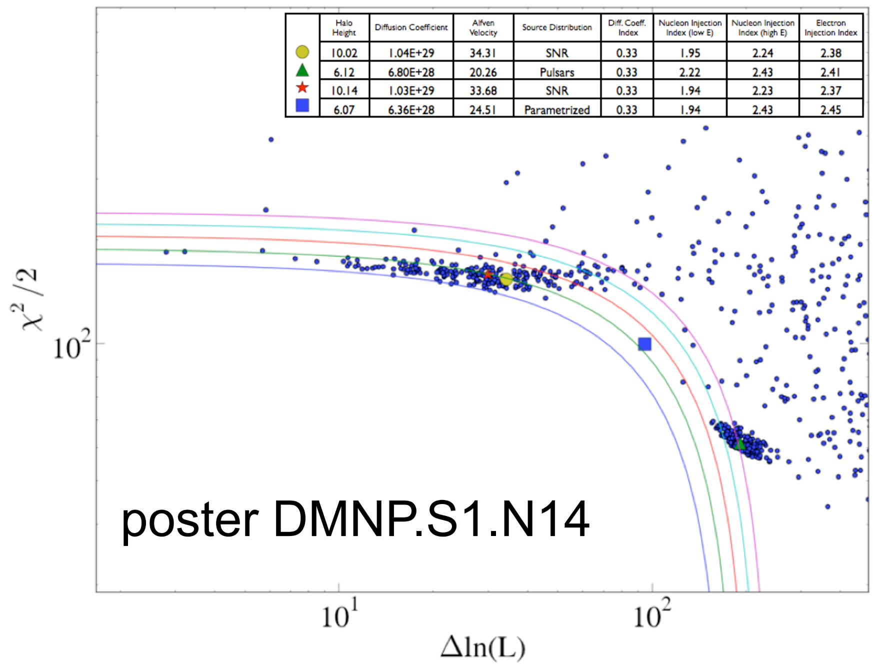




Fermi updates on Galactic Halo

- Exploits both spectral and spatial information
  - Data binned in E and angle
- Large residuals in the fit favor a DM component
  - scan model parameters of diffuse emission that affect more significantly DM limits
  - Compute limits assuming all diffuse emission is DM
- Simultaneously fit CR and gamma-ray data scanning full phase space of CR models

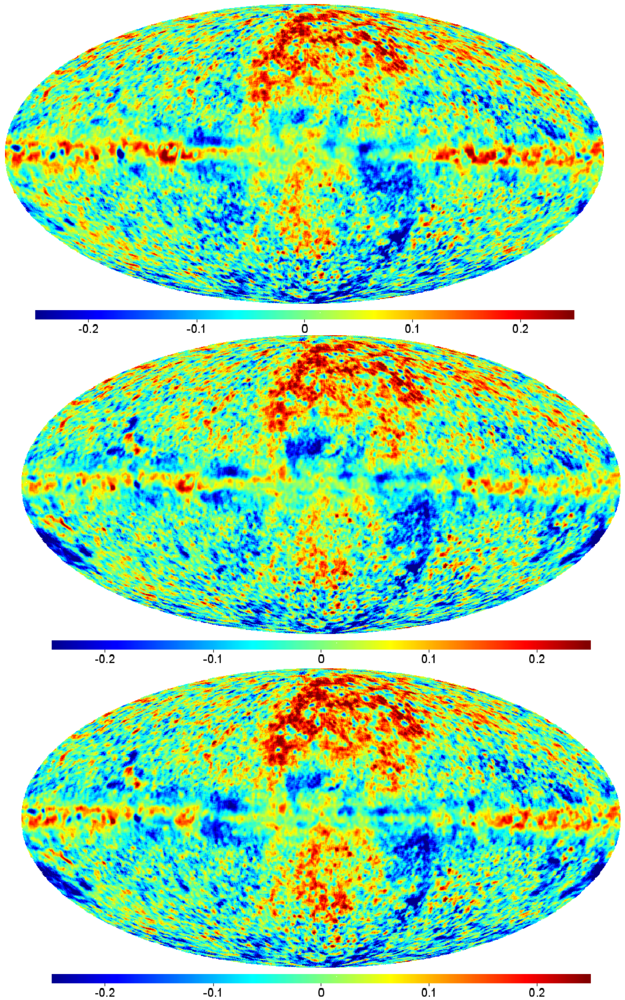


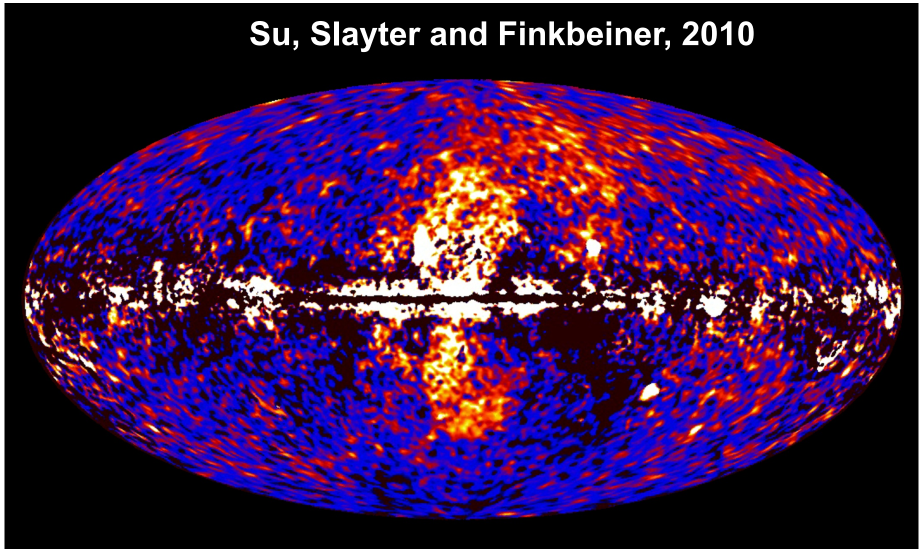


	Halo Height	Diffusion Coefficient	Alfven Velocity	Source Distribution	Diff. Coeff. Index	Nucleon Injection Index (low E)	Nucleon Injection Index (high E)	Electron Injection Index
●	10.02	1.04E+29	34.31	SNR	0.33	1.95	2.24	2.38
▲	6.12	6.80E+28	20.26	Pulsars	0.33	2.22	2.43	2.41
★	10.14	1.03E+29	33.68	SNR	0.33	1.94	2.23	2.37
■	6.07	6.36E+28	24.51	Parametrized	0.33	1.94	2.43	2.45

Challenge with Halo Analysis

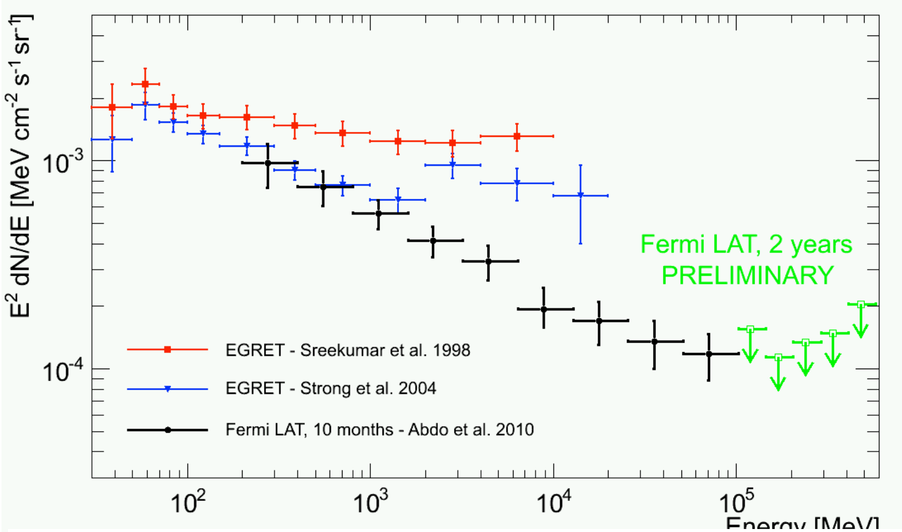
- Residual maps from a selection of GALPROP models show considerable large scale structures
  - Fermi lobes, Loop I, bubbles … see talk by JM Casandjian

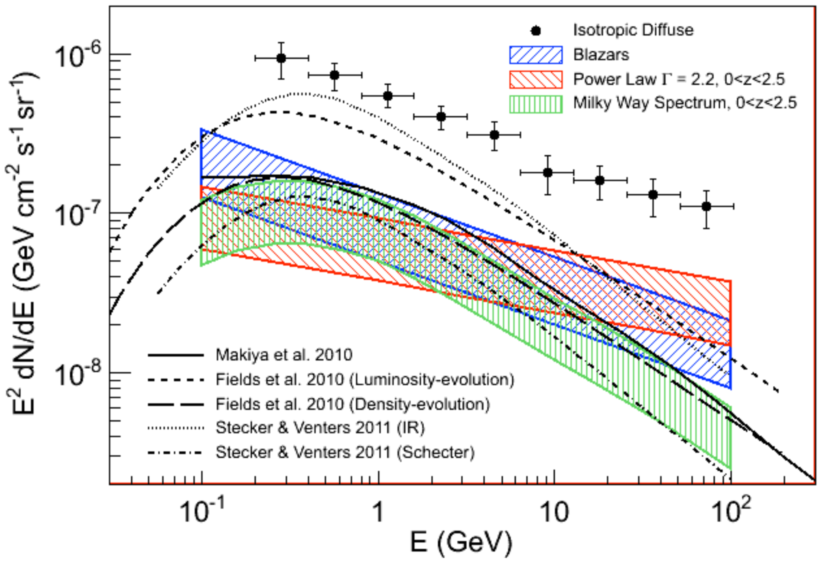




Fermi updates – Isotropic gamma-ray Background

- All sky spectrum
  - Clean sample to extend beyond 100 GeV and prob higher energy WIMPs
  - Major contribution from galactic diffuse emission
- Caveats for constraining DM
  - modeling astrophysical contribution
  - Effects from cosmological DM distribution and photon propagation effects (EBL)
  - See 2010, JCAP, 04, 014





Conclusions

- Wealth of results from Indirect Dark Matter searches
  - Cosmic Rays
    - Fermi and Pamela provide coherent observational picture
  - Neutrinos
    - Initial results, comprehensive observational program
  - Gamma-rays
    - Fermi and IACT complementary in energy range
- Important synergies
  - Gamma-ray results disfavor lepto-philic DM from CRE excesses
  - Hints from direct or accelerator searches reduce models phase space for cross-checks

Conclusions

- Gamma-ray results
  - Point sources cleanest target
    - Fermi limits from dwarfs scratching WIMP benchmark thermal cross section at ~10 GeV
  - All sky (EGB, line, anisotropies) accessible to Fermi only
    - Focus on instrument performance
  - Extended regions (halo, Inner Galaxy) promising but hard
    - Diffuse emission is the maximal uncertainty, need input from Fermi and other missions to improve modeling