Dark Matter Searches with the Fermi Large Area Telescope

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on behalf of the Fermi-LAT Collaboration

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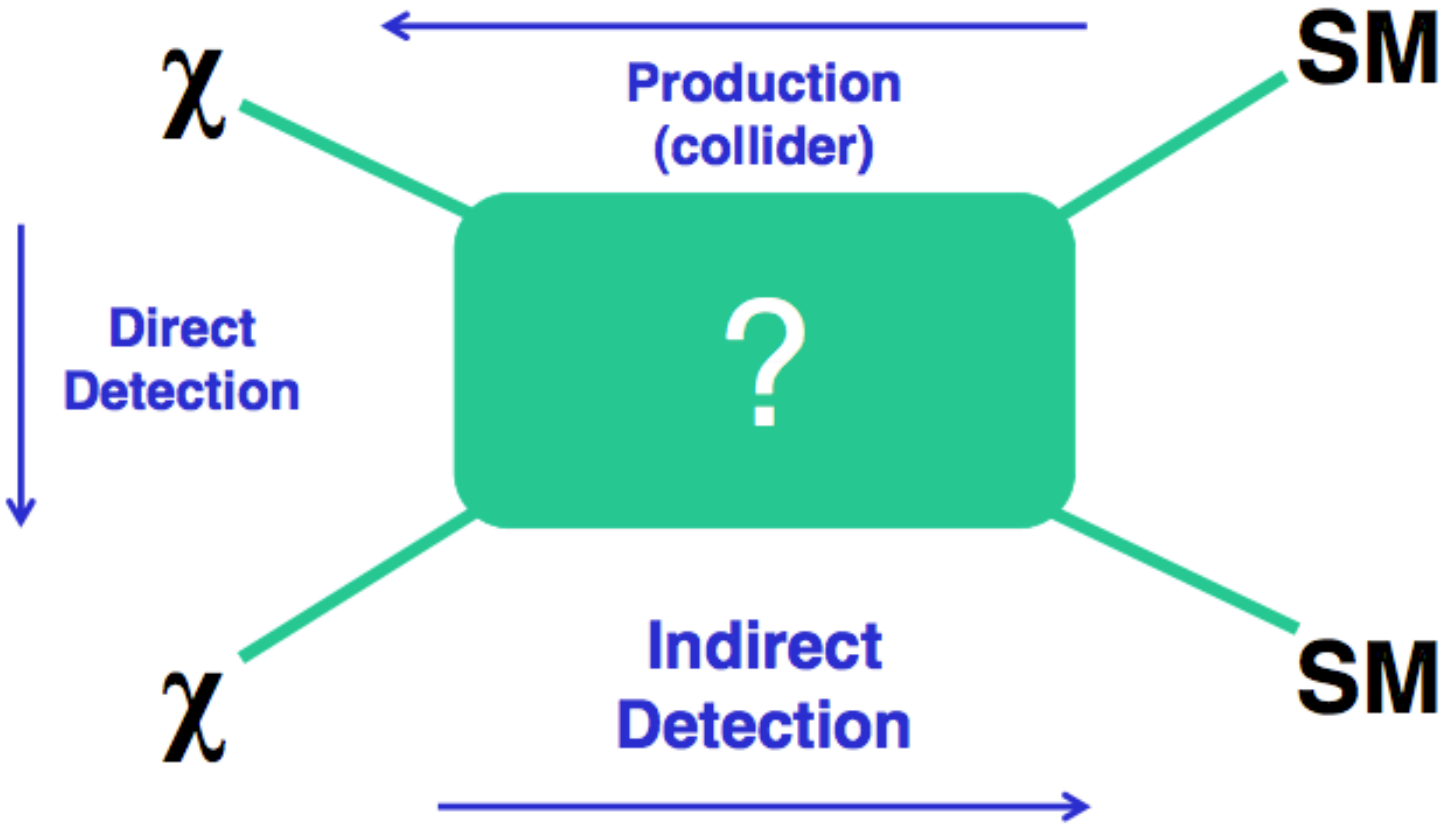
SLAC NATIONAL ACCELERATOR LABORATORY

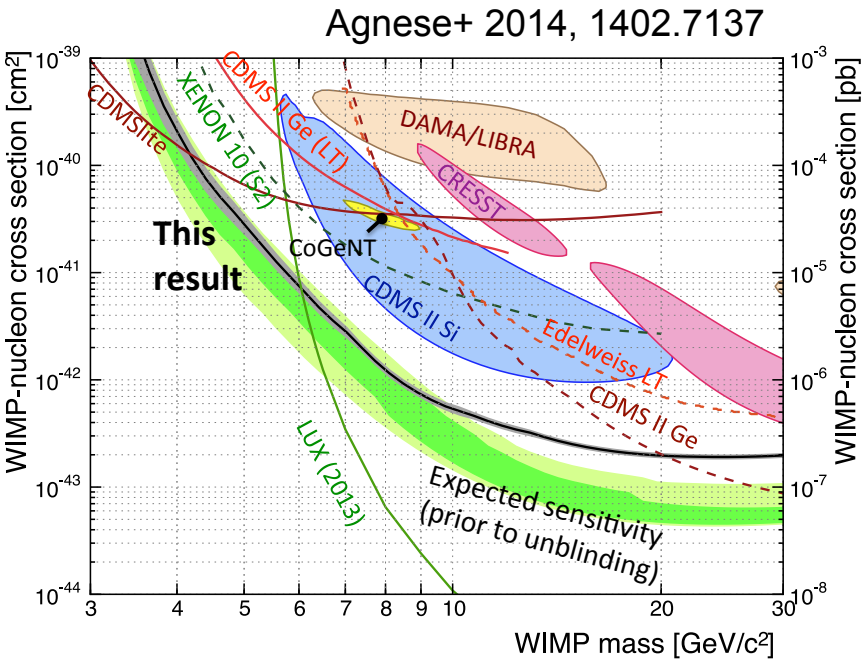
KIPAC

Dark Matter Searches

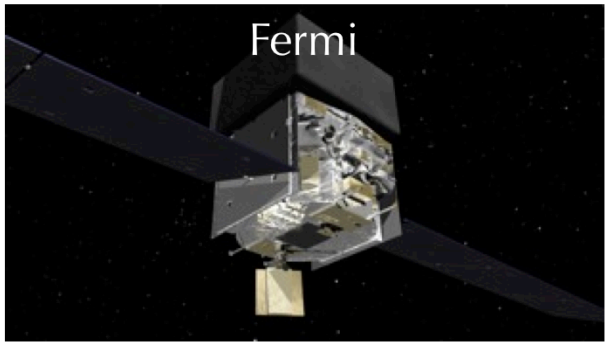


Direct and Collider DM Searches

- No evidence for DM in either direct or collider searches
- Latest upper limits from Super-CDMS and LUX disfavor DM interpretations of some previously reported low mass signals (COGENT,DAMA)
- ATLAS and CMS have reported limits on the existence of new SUSY particles using data collected from 7/8 TeV runs with ~20 fb^{-1}
- Current experimental status emphasizes the importance of **indirect detection**

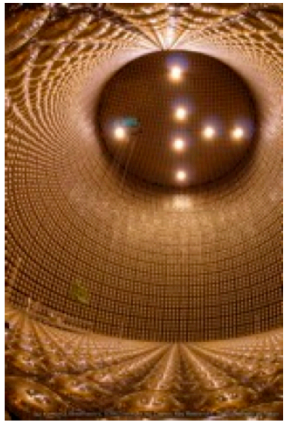


Indirect Dark Matter Searches

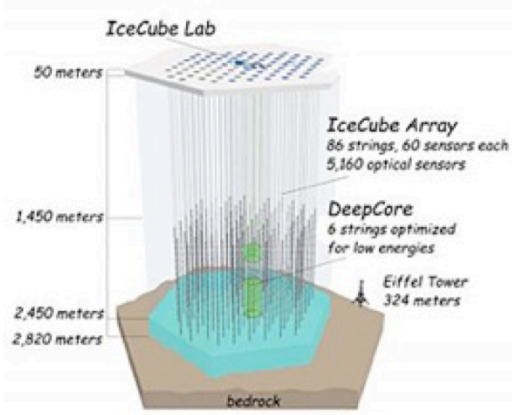


γ

Super-K

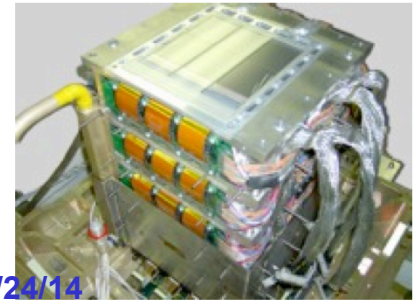


ν



ICECUBE

PAMELA



$e^-, e^+, p, \bar{p}$

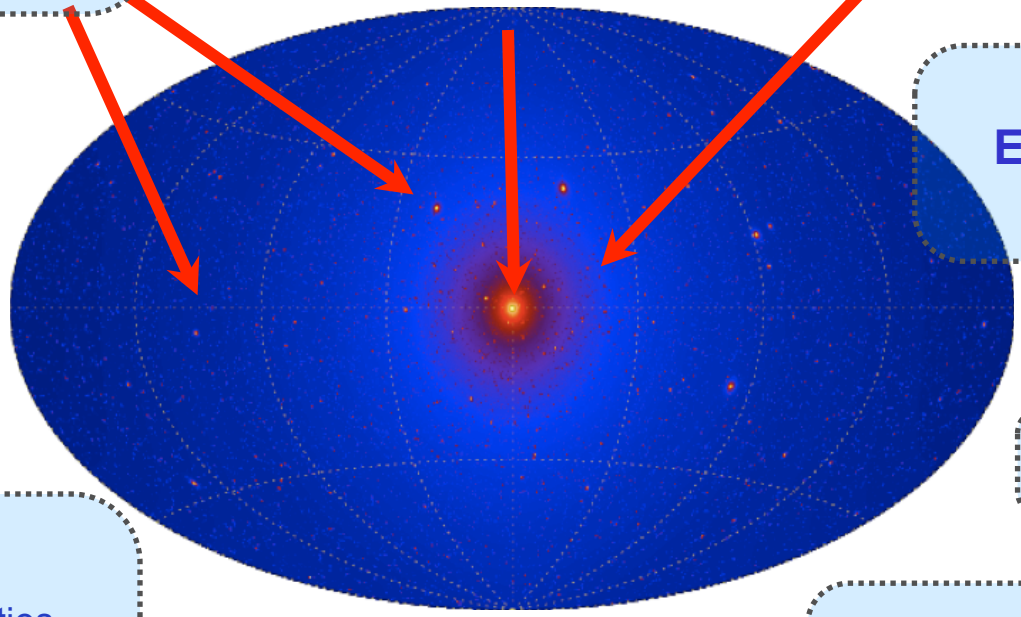
AMS

Fermi-LAT DM Search Targets

Satellites
Low background and good source id, but low statistics, astrophysical background

Galactic Center
Good Statistics but source confusion/diffuse 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)

Cosmic-ray Electrons and Positrons

The Sun

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

Galaxy Clusters
Low background, but low statistics

Extragalactic
Large statistics, but astrophysics, galactic diffuse background

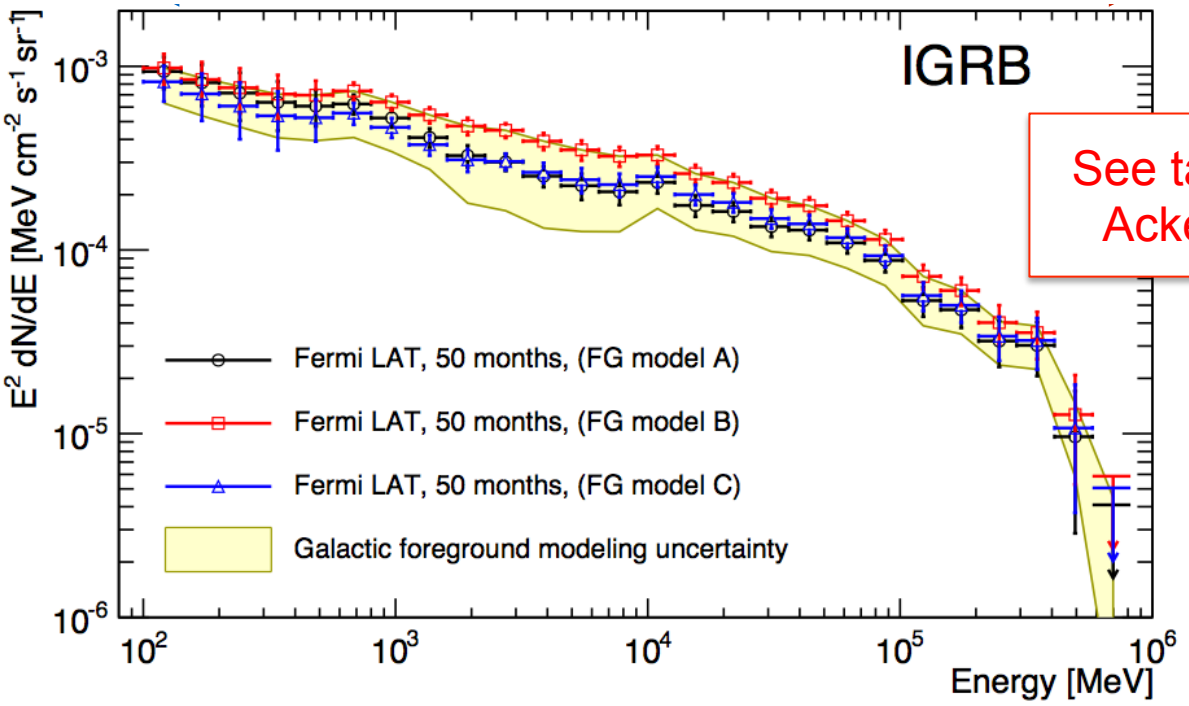
DM Related Symposium Contributions

Non-detections of Gamma-rays from Galaxy Clusters with the Fermi-LAT: status and implications for cosmic ray and dark matter physics (**S. Zimmer**)	Galaxy Clusters
A modified likelihood procedure for dark matter searches (**A. Drlica-Wagner**)	Milky Way Satellites
A Search for Dark Matter Annihilation in Dwarf Spheroidal Galaxies with Pass 8 Data (**B. Anderson**)	
Searching for Dark Matter Annihilation in the Smith High-Velocity Cloud (**G. Gómez-Vargas**)	
Updated Spectral Line Search and Status of 135 GeV Feature with Pass 8 Data (**A. Albert**)	Gamma-ray Lines
Detailed Look at the 133 GeV Feature Comparing Pass 7 and Pass 8 Event Reconstructions (**R. Caputo**)	
Fermi LAT limit on evaporation of primordial black holes (**D. Malyshev**)	Isotropic Gamma-ray Background
Dark Matter Annihilation Cross Section Constraints from the Cross-correlation of Cosmic Shear and Extragalactic Gamma-ray Background (**M. Shirasaki**)	
Anisotropies in the Gamma-ray Sky (**F. Donato**)	
Composition of the Isotropic Diffuse Gamma-ray Background and Dark Matter Constraints (**M. Di Mauro**)	
Observations of High-Energy Gamma-Ray Emission Toward the Galactic Center (**S. Murgia**)	Inner Galaxy/ Galactic Center
The Characterization of the Gamma-Ray Signal from the Central Milky Way (**T. Linden**)	
Dark Matter Annihilation in the Galactic Center (**D. Hooper**)	
The GeV Excess Shining Through: Background Systematics for the Inner Galaxy Analysis (**F. Calore**)	
Robust Identification of the GeV Galactic Center Excess at Higher Latitudes (**C. Weniger**)	
The Inner Milky Way's Extended Gamma-ray Excess: Evidence of Self-annihilating Dark Matter? (**A. Kwa**)	
GeV Excess Electrons Upscattering the CMB: A Possible Resolution to the "Photon Underproduction Crisis" (**T. Daylan**)	

New 4-year IGRB Measurement

Ackermann+ ApJ accepted, arXiv:1410.3696

- New LAT collaboration measurement based on 4 years of P7REP data extends energy range to 100 MeV – 820 GeV
- Careful analysis of systematics including uncertainties from galactic foreground modeling
- A high-energy cutoff is significantly detected at ~250 GeV



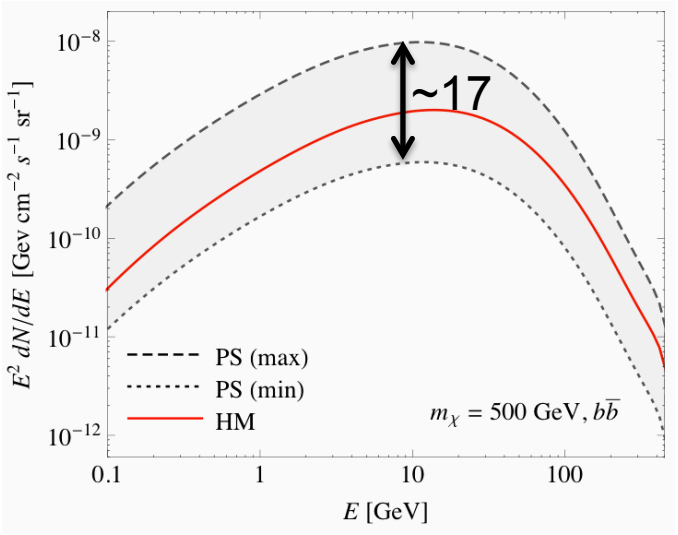
See talk by M. Ackermann

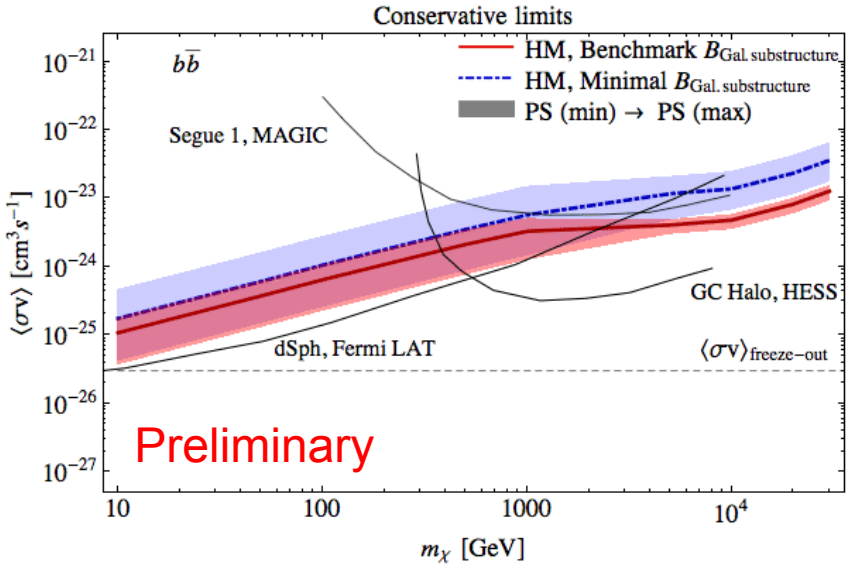
DM Limits from the IGRB

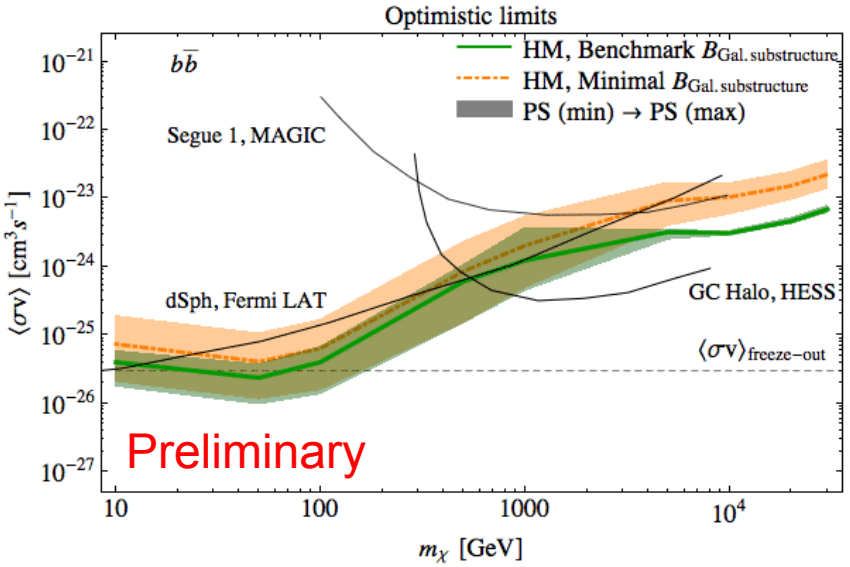
Use two independent approaches (Halo Model and Power Spectrum) to estimate the cosmological flux multiplier → **theoretical uncertainty reduced from ~10^3 to ~17**

Conservative Limits: No background subtraction

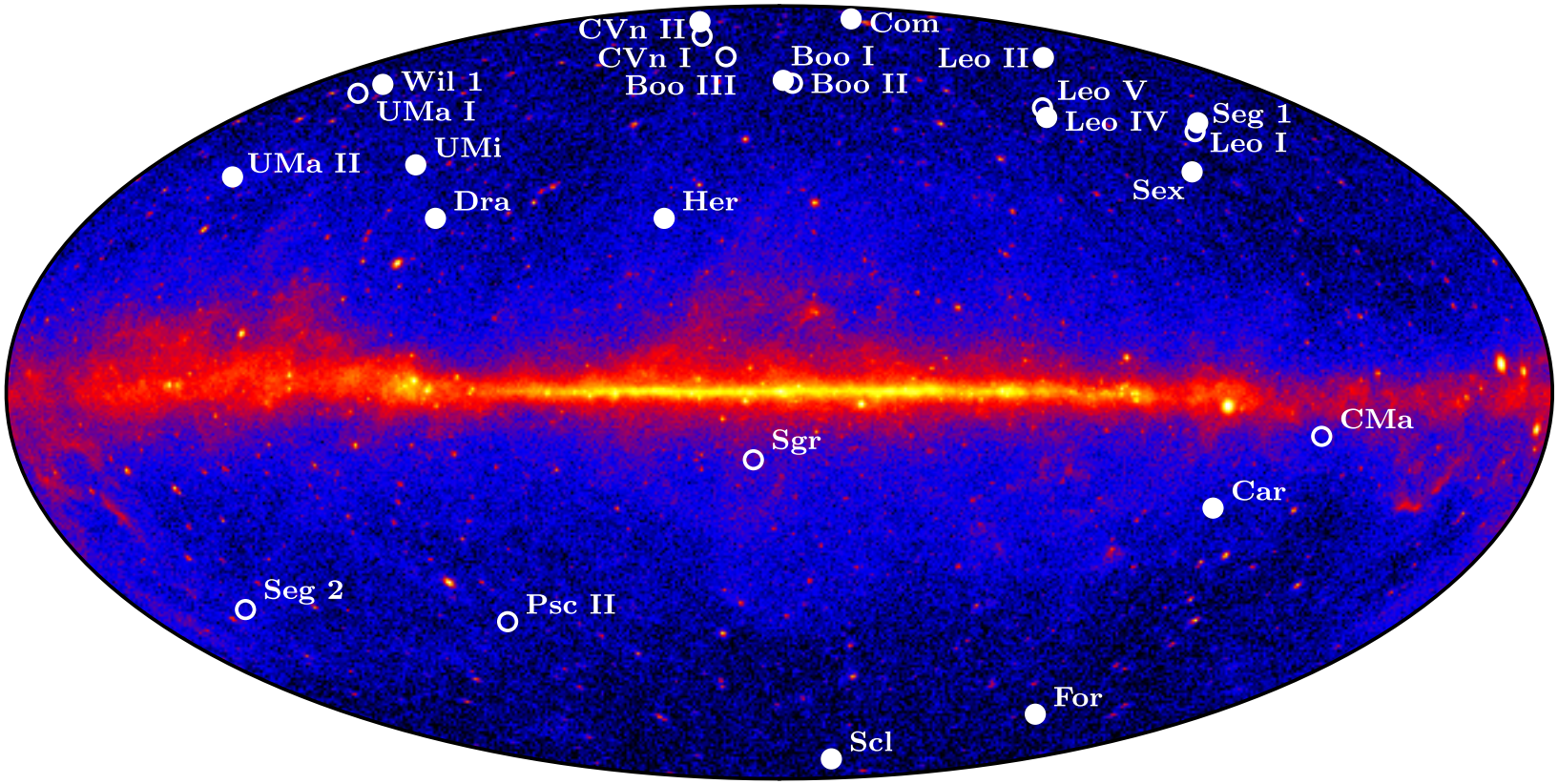
Optimistic Limits: Assume that all galactic and extragalactic astrophysical contributions can be accurately modeled







Dwarf Spheroidal Galaxies



Dwarf spheroidal galaxies (dSphs) are highly **DM-dominated** systems orbiting the MW at typical distances of 25-100 kpc

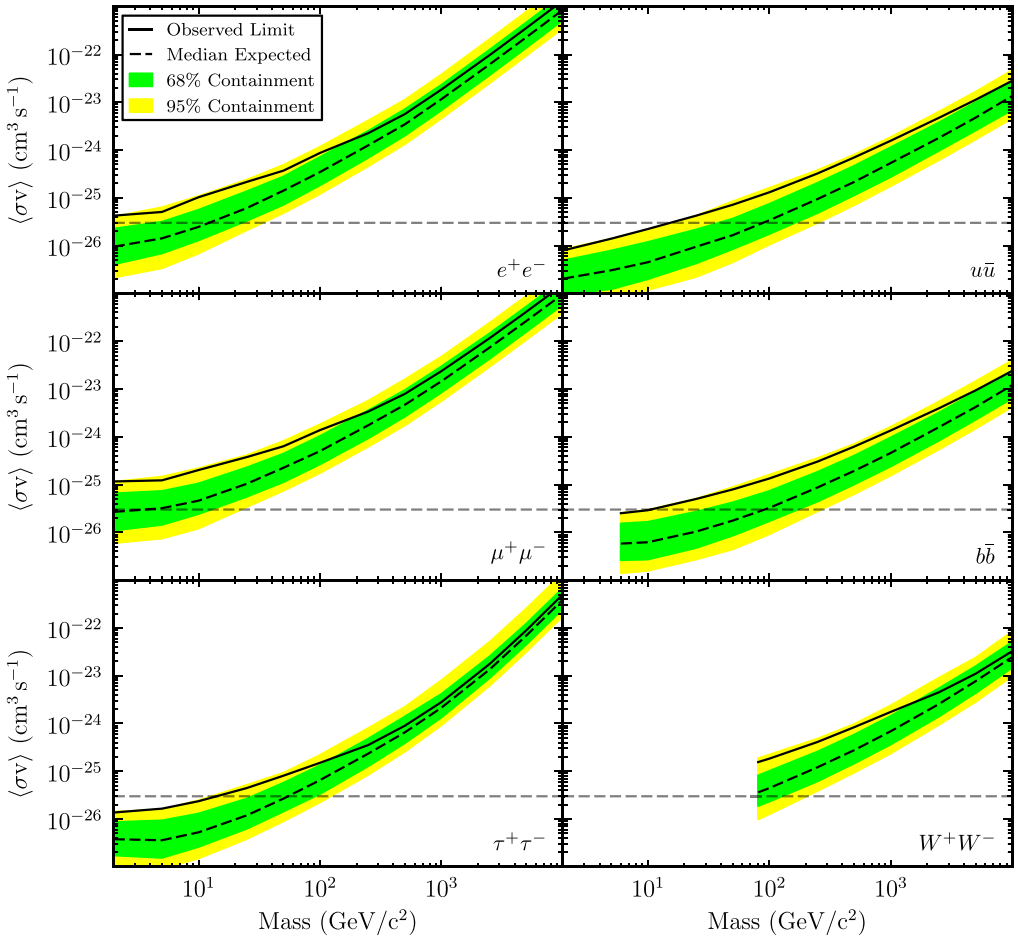
There are **18 dwarf galaxies** for which the astrophysical factor is well determined

P7REP Dwarf Stacking Analysis

Ackermann et al. PRD 89 042001 (2014), arXiv: 1310.0828

- Dwarf galaxies remain one of the cleanest targets for indirect DM searches
  - Low astrophysical backgrounds
  - Robust measurements of the astrophysical factors
- Most recent LAT collaboration based on four years of P7REP data (Ackermann+ 2014)
  - No detection (global significance of 1.4σ)
  - WIMPs with thermal relic cross section excluded for M < 10 GeV

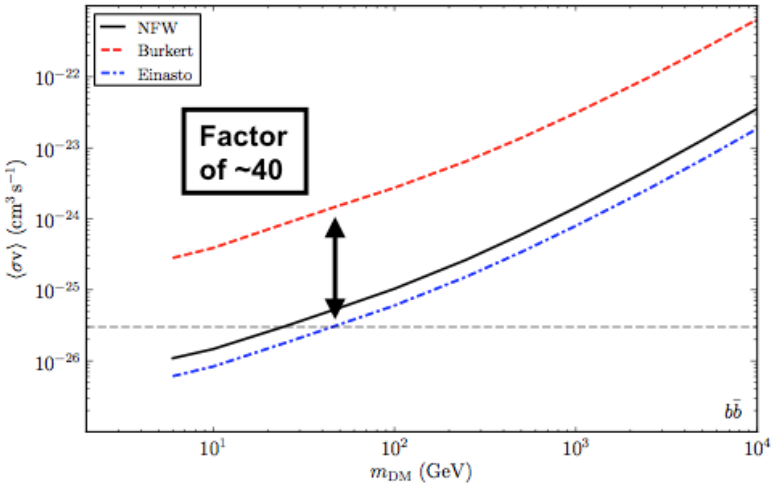
See next talk by B. Anderson for results of new dwarf analysis with Pass 8

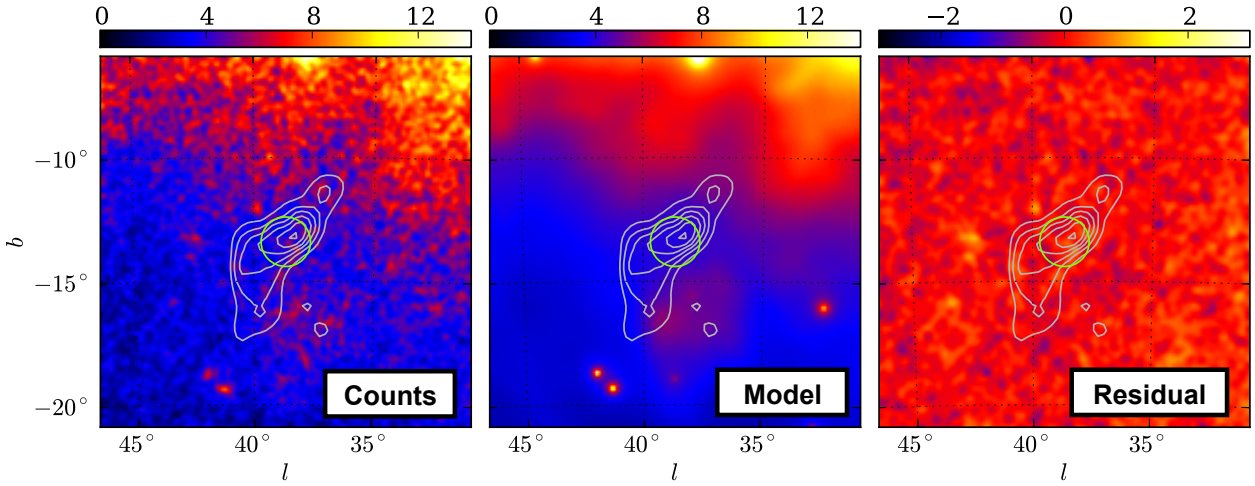


High Velocity Clouds: Smith Cloud

Drlica-Wagner et al. ApJ, 790, 24 (2014) [astro-ph/1405.1030]

- HVCs are coherent over-densities of **HI gas** covering 40% of the sky.
- Smith cloud is one of the best studied HVCs and may be bounded by a **DM halo of ~10^8 solar masses** (Nichols & Bland-Hawthorn 09)
- No signal observed in LAT analysis of the Smith Cloud with 5.2 years of data, Pass7 reprocessed, 500 MeV – 500 GeV
- Assuming an NFW profile the derived limits are on the level of the thermal annihilation cross section for masses 20-30 GeV

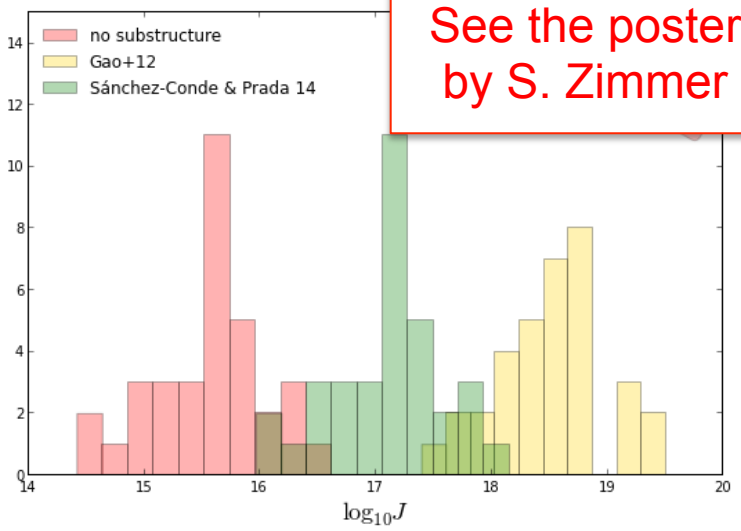




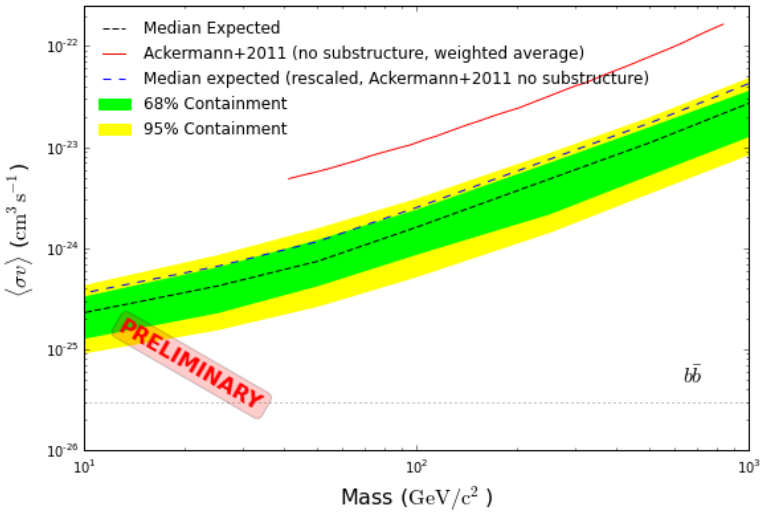
See poster by G. Gómez-Vargas

Galaxy Clusters

- Galaxy clusters may be a compelling target if the boost factor from DM substructure is sufficiently large
- Recent theoretical work (Sánchez-Conde+ 2011, Sánchez-Conde & Prada 2014) has led to a reevaluation of cluster boost factors
  - Concentrations of low mass halos were overestimated in previous works
  - New models for c(M) relation predict typical boost factors of 30-50 for galaxy clusters and 1-2 for dwarfs
  - "Best" Cluster astrophysical factors with substructure boost are ~10x lower than astrophysical factors of the best MW dwarf galaxy candidates
- New LAT cluster stacking analysis is currently in development



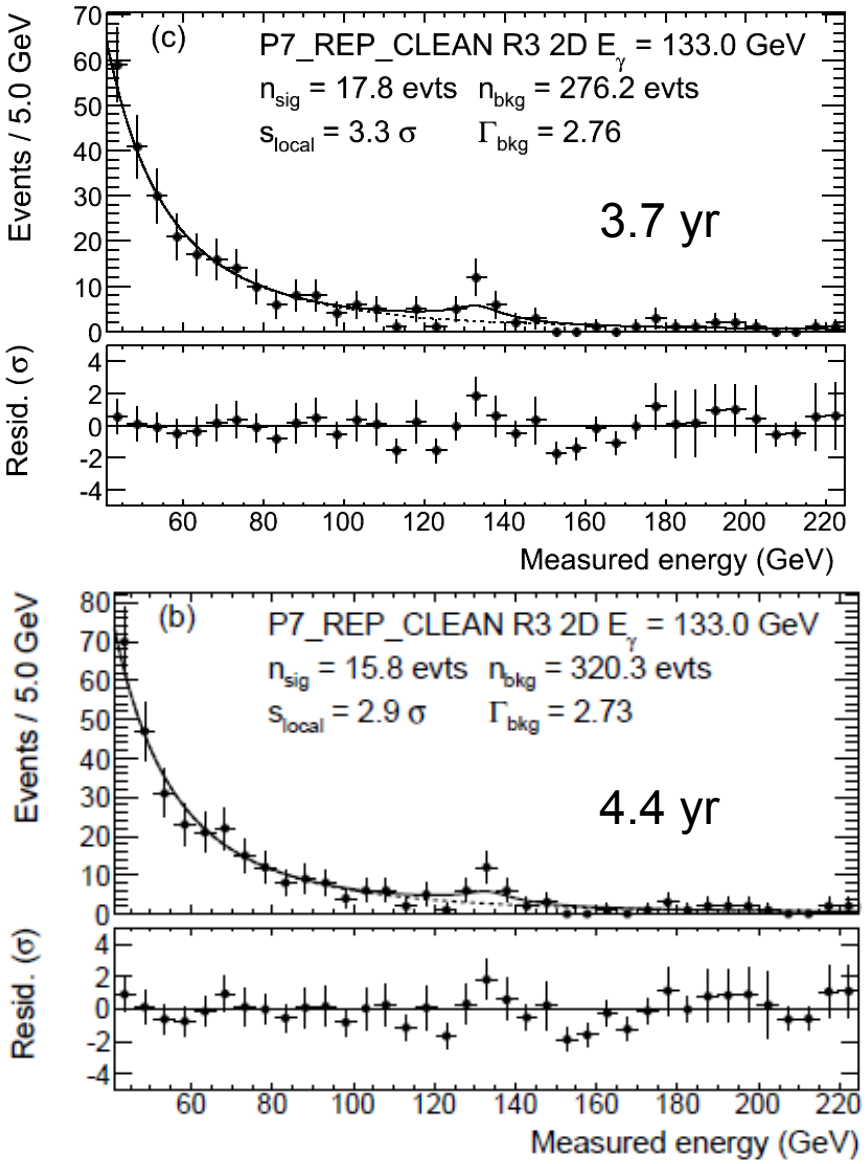
See the poster by S. Zimmer



Line Searches

- Only “smoking gun” signature but low expected signal amplitude relative to continuum searches
- Significant interest in gamma-ray lines circa 2012-2013 due to reports of a significant gamma-ray feature at ~133 GeV in LAT data (Bringmann+ 2012, Weniger 2012)
- LAT collaboration analysis with 3.7 years P7REP data (Ackermann+ 2013 PRD 88, 082002)
  - No globally significant lines (<2σ)
  - Feature observed at 133 GeV with 3.3σ local significance
  - Width of 133 GeV feature found to be narrower than expected from LAT energy resolution
  - Feature at 133 GeV also observed in the Earth limb
- Significance of the 133 GeV feature has subsequently declined with 4+ years of data

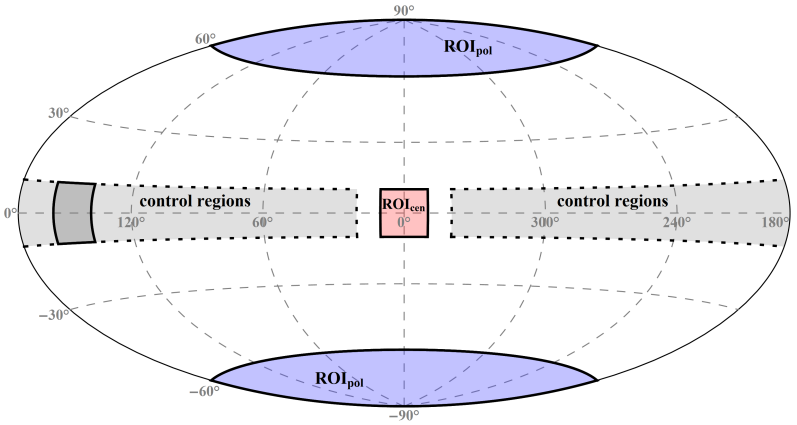
See next talk by A. Albert and poster by R. Caputo for results from Pass 8 line analysis

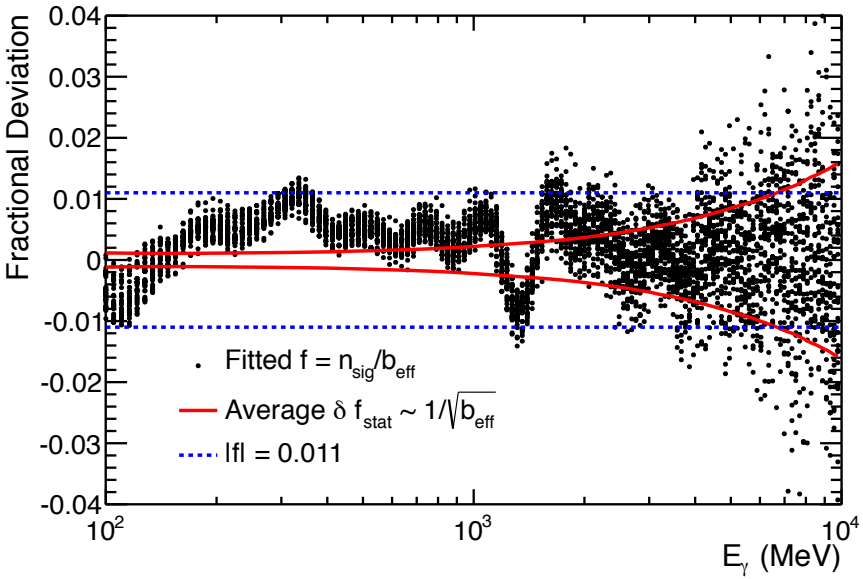


Low-energy Line Search

Albert+ JCAP 1410 (2014) 10, 023, astro-ph/1406.3430

- Search **between 100 MeV up to 10 GeV** (previously unexplored energy range!).
- **Data**: 5.2 years, P7 reprocessed Clean.
- Regions of Interest optimized for annihilation and decay.
  → for decay, it constrains e.g. models of **gravitino** decay.
- At low energies, statistical uncertainties get very small (<1%)
  → **systematics dominate**
  → important to model them properly!



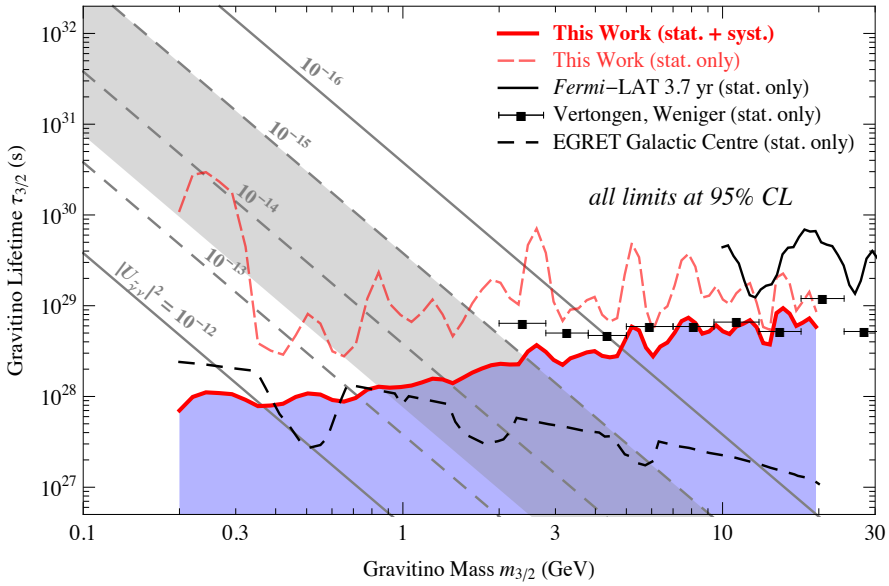


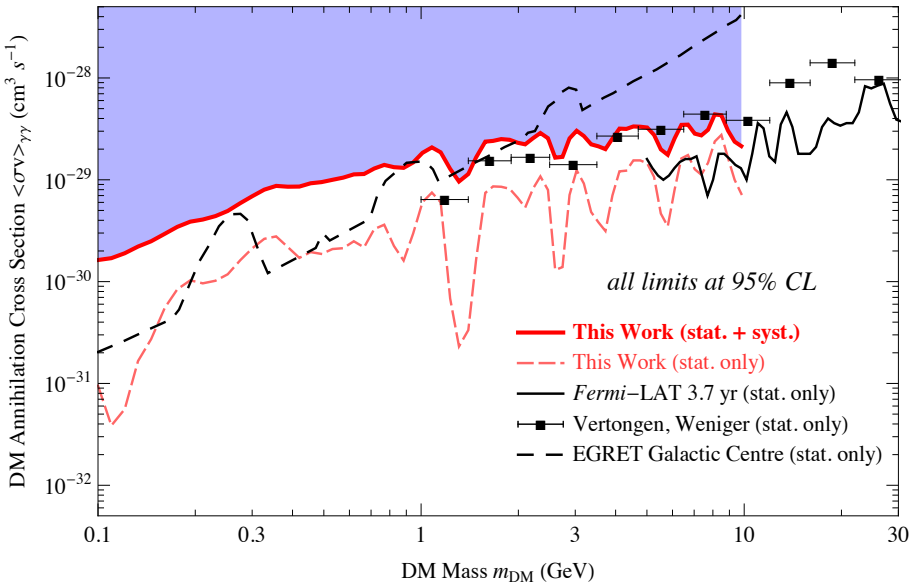
Low-energy Line Search: Limits

Albert+ JCAP 1410 (2014) 10, 023, astro-ph/1406.3430

No globally significant lines detected:

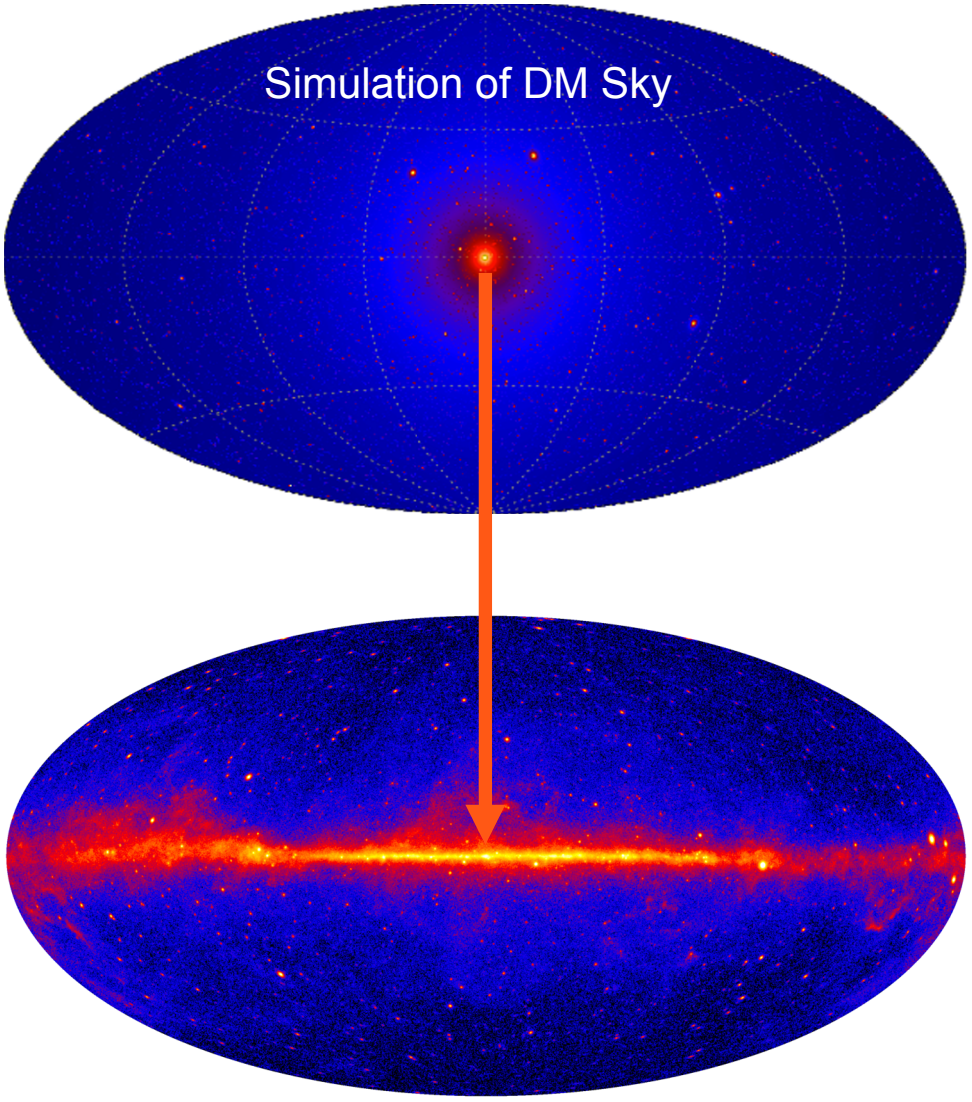
→ flux upper limits in annihilation and decay ROIs





LAT data exclude μvSSM gravitinos with masses larger than ~5 GeV or lifetimes smaller than ~10^{28} s as DM candidates.

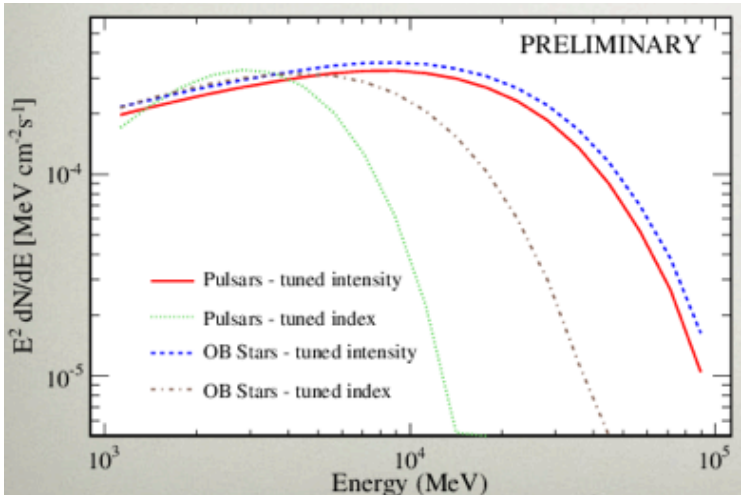
The Inner Galaxy

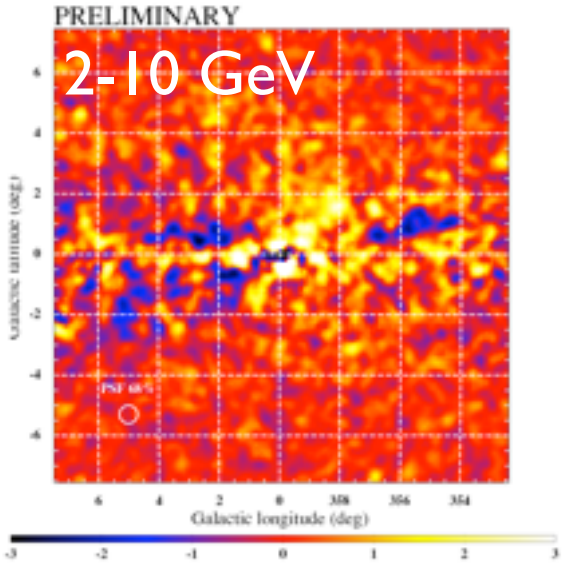


- **The center of the Galactic dark matter halo is a promising target**
  - **Deep gravitational potential**
  - **Relatively nearby**
- **However, it is extremely complicated**
  - **Diffuse emission from cosmic-ray interactions with Galactic gas and dust**
  - **Densely populated by astrophysical sources (e.g., pulsars, SNR)**
  - **Detected in other wavelengths (e.g., radio, X-ray, TeV)**
- **Topic of much study, both inside and outside the collaboration...**
  - **Hooper & Linden (2011)**
  - **Boyarski et al. (2011)**
  - **Abazajian & Kaplinghat (2012)**
  - **Gordon & Macias (2013)**
  - **Abazajian et al. (2014)**
  - **Daylan et al. (2014)**
  - **etc.**

GeV Excess in the Galactic Center

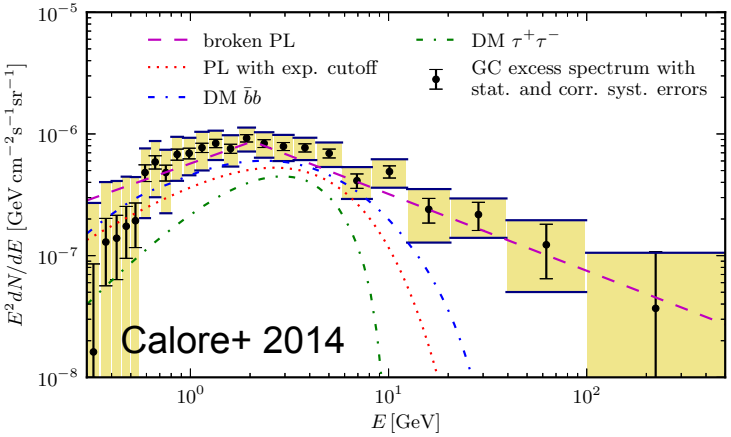
- Many recent papers report the detection of a diffuse gamma-ray excess in the Galactic Center (GCE) in LAT data; see e.g. Goodenough & Hooper 2009, Abazajian & Kaplinghat 2012, Gordon & Macias 2013, Daylan+ 2014, Abazajian+ 2014, Calore+ 2014
- A consistent picture has begun to emerge for the properties of the GCE
  - SED with peak at 1-3 GeV but with large systematic uncertainties on its precise shape (Abazajian+ 2014, Calore+ 2014)
  - Spherically symmetric spatial distribution extending at least 10-20 degrees from the GC (Daylan+ 2014, Calore+ 2014)
- LAT collaboration analysis finds that the spectrum of the excess emission varies widely depending on modeling of the interstellar emission (see talk by Simona Murgia)



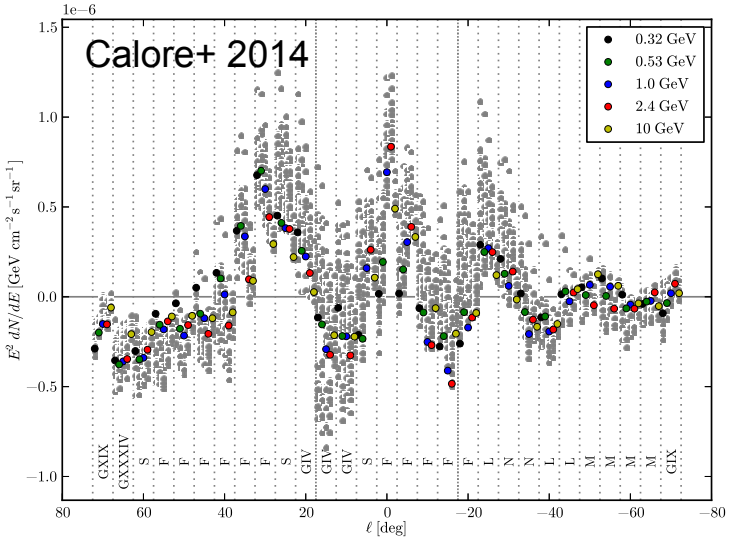


Diffuse Modeling Systematics in the Inner Galaxy

- Improved understanding of the systematic uncertainties in the galactic diffuse emission is needed before the nature of the GCE can be conclusively determined
  - Many uncertainties are unique to the Galactic Center
  - Impact of simplifications made in CR propagation models (e.g. GALPROP) are difficult to quantify



- Currently even diffuse emission models tuned to fit LAT data produce residuals along the galactic plane that are comparable in magnitude to the GCE

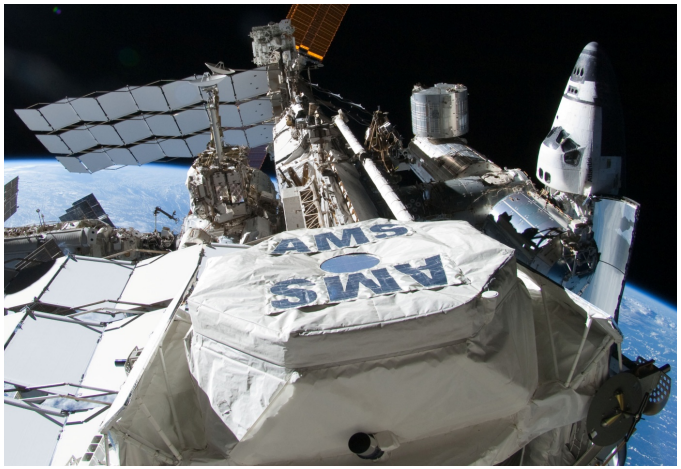


- Paths for future investigation
  - Radial distribution of gas along the line of sight
  - Non axisymmetric models of CR propagation (see talk by G. Johannesson)

Multi-messenger Constraints

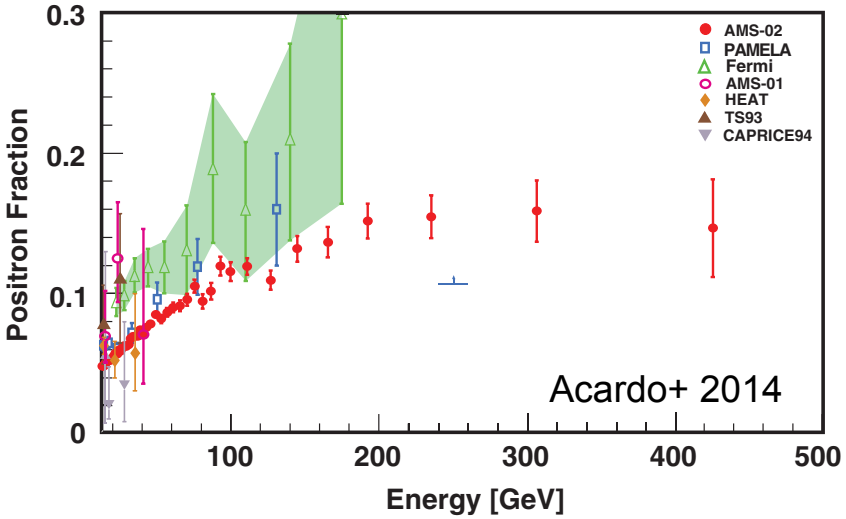
- Multi-messenger and multi-wavelength data are an important ingredient in a comprehensive DM search strategy
  - Positrons
  - Antiprotons
  - Neutrinos
  - Radio
  - X-ray

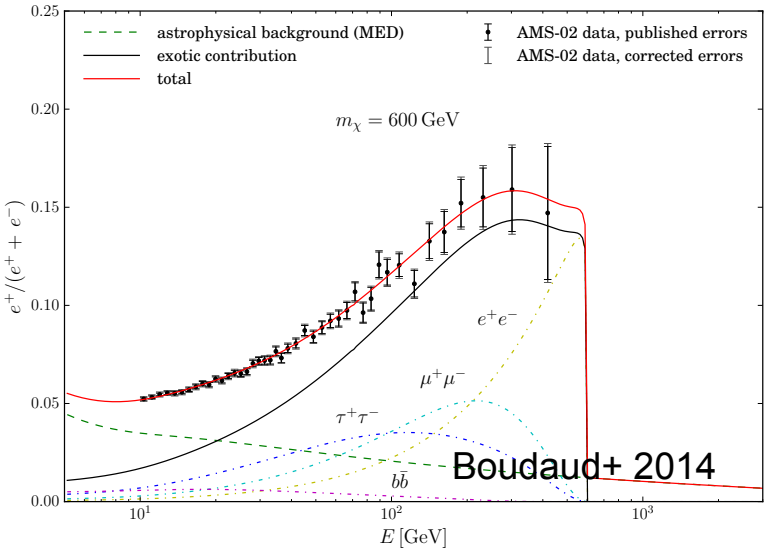
- These data also provide an additional avenue for confirming or disproving gamma-ray signals



Positrons

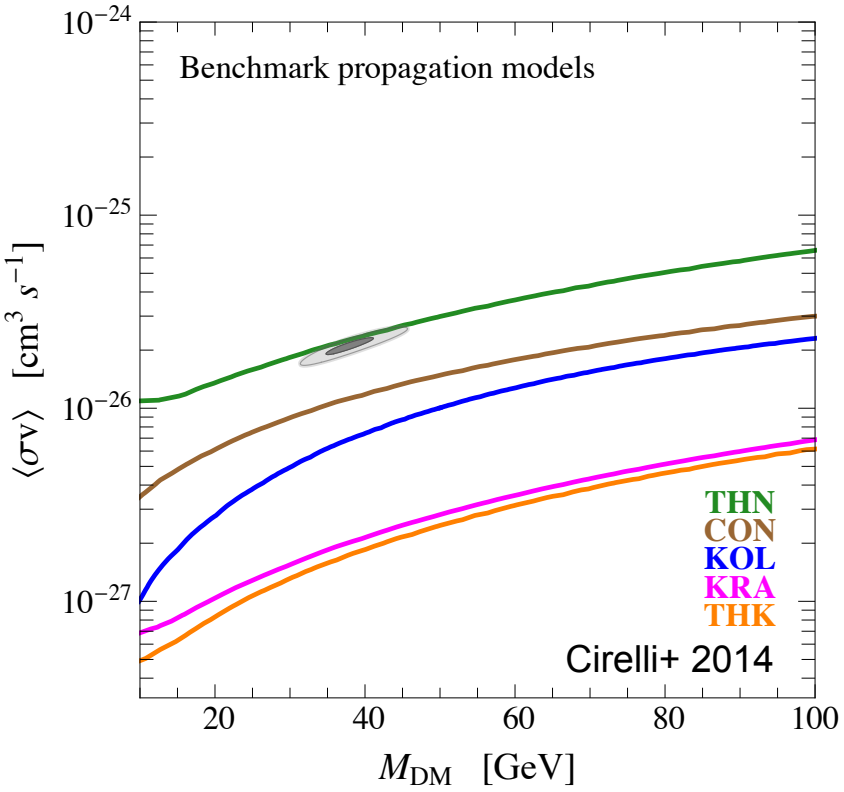
- AMS-02 beautifully confirms the rise in the positron fraction first measured by PAMELA and Fermi-LAT
- However there are several challenges for a DM interpretation
  - Require Leptophilic models
  - Large non-thermal cross sections
  - Strong tension with gamma-ray constraints
- Many astrophysical models which can easily explain a rising fraction
  - Local pulsar sources
  - Acceleration of secondaries in SNR
- Sharp feature or edge would be needed to conclusively connect the rising positron fraction to DM





Antiprotons

- Several papers report limits from antiprotons that exclude or are in strong tension with the GCE WIMP interpretation (Cirelli+ 2014, Bringmann+ 2014)
- **However**, there are large uncertainties in modeling both expected signal and background fluxes
  - Galactic Propagation model
  - Solar modulation
- For other choices of propagation models one can arrive at substantially weaker constraints (Hooper+ 2014)
- New measurements from AMS-02 may help reduce some of the current uncertainties on propagation modeling



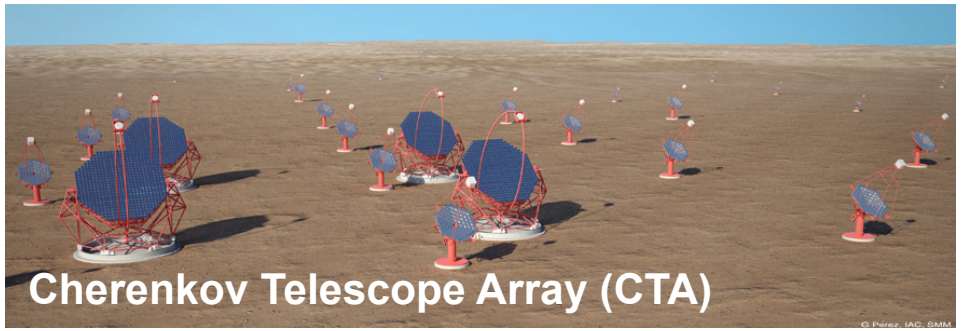
Status of Indirect DM Searches

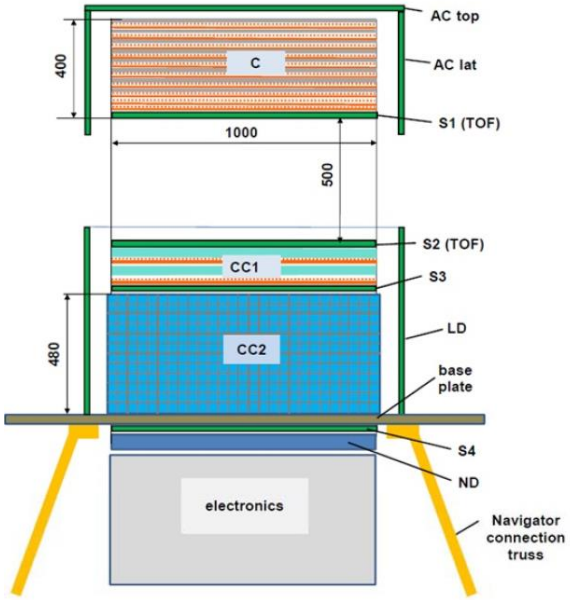
	Experimental Status	Discovery Potential	Astrophysical Uncertainties
Positrons	?	Low	High
Antiprotons	?	Low	High
Galactic Center	?	High	Medium
Dwarf Spheroidal Galaxies	No Signal	High	Low
Gamma-ray Lines	No Signal	Medium	Low
IGRB	No Signal	Low	High
Galaxy Clusters	No Signal	Medium	Medium

Future for Indirect Searches

- **New Data**
  - Fermi-LAT Pass 8 Data Release (mid-2015)
  - AMS Measurements of B/C Ratio and Antiprotons

- **New and Future Instruments**
  - HESS II
  - Cherenkov Telescope Array
  - GAPS (Antideuteron Search)
  - DAMPE (Gamma-ray Space Telescope)
  - GAMMA-400 (Gamma-ray Space Telescope)

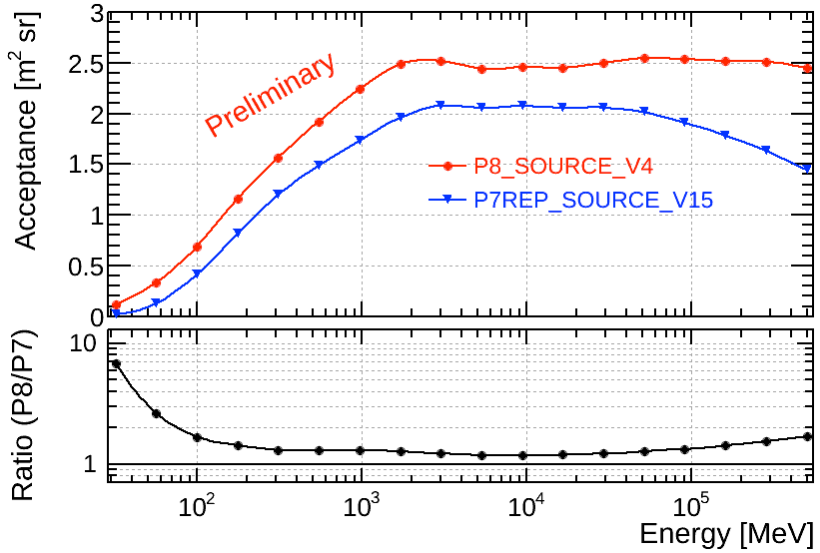


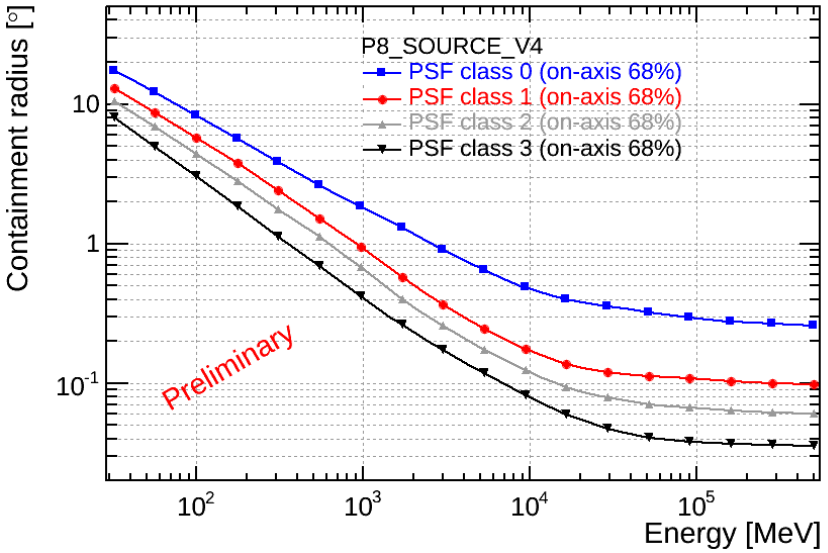


GAMMA-400

Pass 8: Improving the LAT Performance

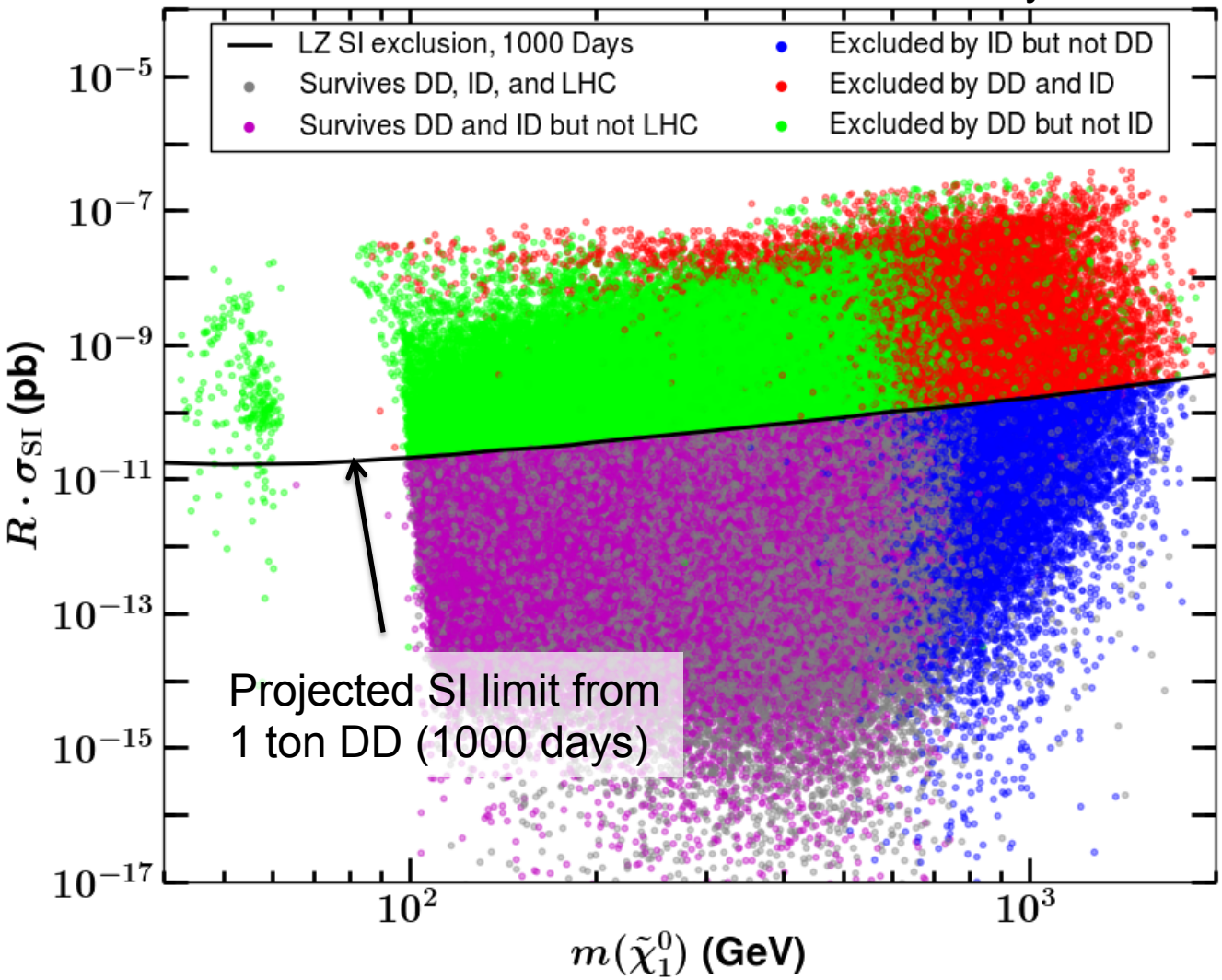
- **Pass 8** is a complete revision of the LAT event-level reconstruction and classification (see talk by P. Bruel for more details)
- Many improvements relative to Pass 7
  - Increased point-source sensitivity at all energies (30-40% at 1-10 GeV)
  - Large increase in acceptance at very low and very high energies (< 100 MeV and > 100 GeV)
  - PSF event classes (ala CTBCORE)
- Impact on dark matter searches
  - Energy Range: Extend reach to lower and higher masses
  - Angular Resolution: Better sensitivity to angular extension
  - Improved sensitivity for all DM channels





Complementarity of DM Searches

Cahill-Rowley+ 2014

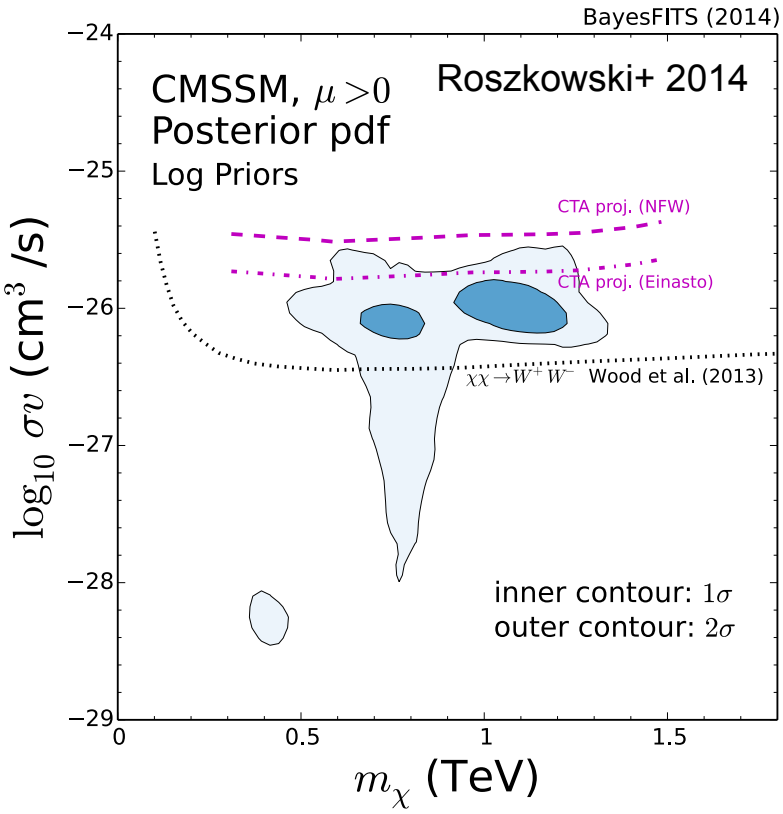


Conclusions

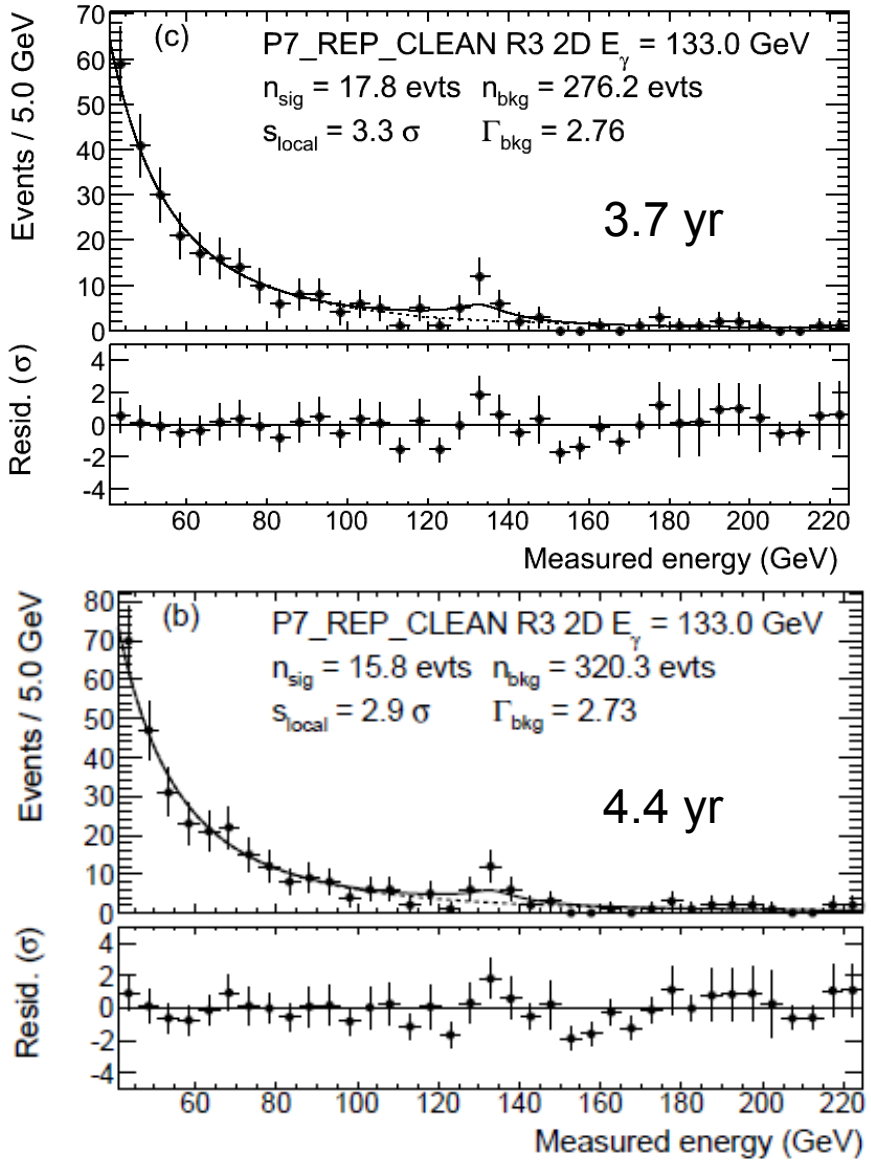
- This is an exciting period for LAT DM searches
  - Many targets are now probing the preferred phase space of thermal relic WIMP models
  - Conclusive evidence will probably require confirmation with multiple targets and/or messengers
- Interpretation of the GCE remains challenging
  - WIMP interpretation in mild tension with dwarf galaxy limits and antiproton measurements
  - Further progress will require more accurate models for the galactic diffuse emission and quantification of its uncertainties
- Pass 8 data release will provide a new window for future studies with LAT data
  - Improved performance and new capabilities
  - Reduced instrumental systematics
- Indirect Detection will continue to play a complementary role in the hunt for DM with direct and collider searches

Reach of CTA for DM Searches

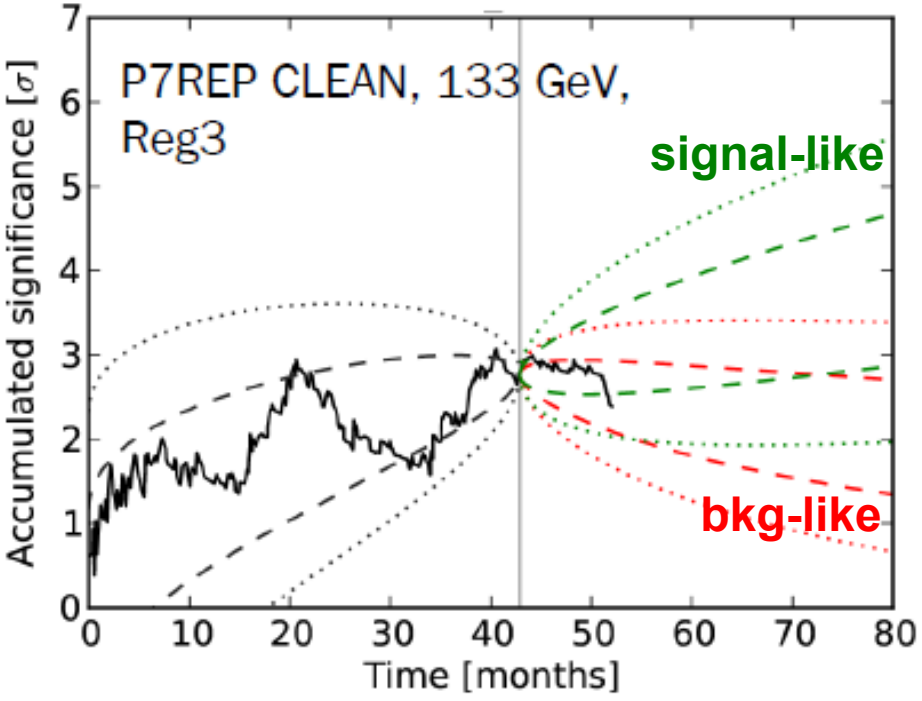
- CTA observations of the Galactic Center will be an excellent probe for WIMP models with mass greater than 100 GeV
- Sensitivity of CTA complements the parameter space explored by the Fermi-LAT
- Higgsino models with WIMP masses near 1 TeV are a particular interesting part of the WIMP phase space from the standpoint of SUSY model scans (CMSSM, pMSSM)



133 GeV Feature in 4.4 year dataset



Weniger et al (2013)
http://fermi.gsfc.nasa.gov/ssc/proposals/alt_obs/white_papers_eval.html



- **s_{local} decreased in 4.4 yr data by ~10% compared to 3.7 yr data**
- **Since spring 2012, feature has decreased**
  - **More "background-like"**