Title: Indirect Searches for Dark Matter with the Fermi Large Area Telescope

Date: Jan 18, 2013 01:00 PM

URL: http://www.pirsa.org/13010102

Abstract: There is overwhelming evidence that non-baryonic dark
matter constitutes ~23% of the energy density of the universe. Weakly Interacting Massive Particles (WIMPs)
are promising dark matter candidates that may produce gamma rays via
annihilation or decay detectable by the Fermi Large Area Telescope (Fermi
LAT). A detection of WIMPs would also
indicate the existence of physics beyond the Standard Model. I will present recent results from indirect
WIMP searches by the Fermi LAT Collaboration.
I will focus on our recent search for gamma-ray spectral lines from WIMP
annihilations with 4 years of data.
There has been recent excitement with the report of a line-like feature
localized in the galactic center around 130 GeV. I will be discussing what our search finds
and the systematic checks we've performed on potential signals.

Indirect Searches for Dark Matter with the Fermi Large Area Telescope

Andrea Albert
(The Ohio State University)
on behalf of
The Fermi LAT Collaboration

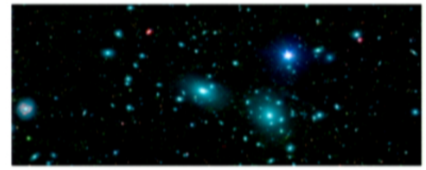
Particle Physics Seminar
Perimeter Institute for Theoretical Physics
January 18th, 2013

Outline

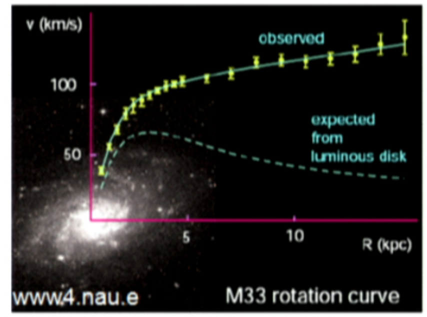
- Dark Matter Overview
- The Fermi Large Area Telescope
- The Gamma-ray Sky
- Recent Dark Matter Results
  - Focus on spectral line search

Astrophysical Evidence for Dark Matter

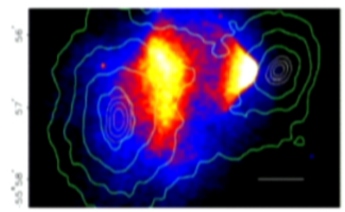
- Majority of mass in galaxies is ***dark***
  - Coma Cluster + Virial Theorem
    F. Zwicky (1937)



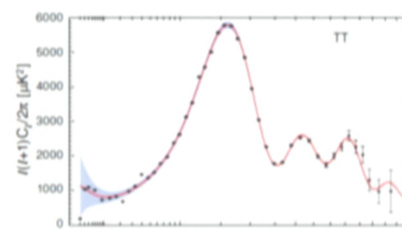
- Dark Matter clumps in large ***halos*** around galaxies
  - Galactic Rotation Curves
    V. Rubin et al (1980)



- Dark Matter is virtually ***collisionless***
  - The Bullet Cluster
    D. Clowe et al (2006)



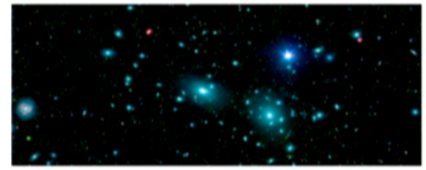
- Dark Matter is ***non-baryonic***
  - CMB Acoustic Oscillations
    WMAP (2010)



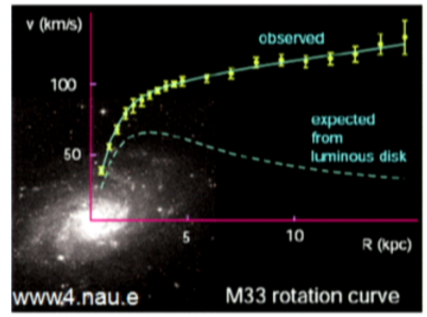
Astrophysical Evidence for Dark Matter

Fermi Gamma-ray Space Telescope

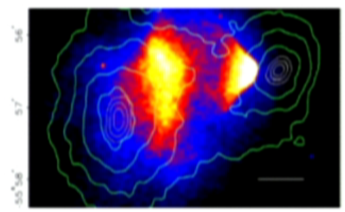
- Majority of mass in galaxies is ***dark***
  - Coma Cluster + Virial Theorem
    F. Zwicky (1937)



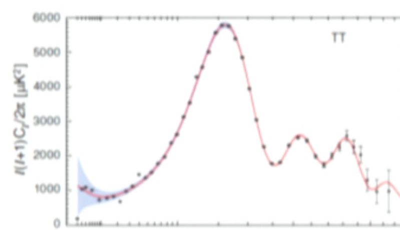
- Dark Matter clumps in large ***halos*** around galaxies
  - Galactic Rotation Curves
    V. Rubin et al (1980)



- Dark Matter is virtually ***collisionless***
  - The Bullet Cluster
    D. Clowe et al (2006)

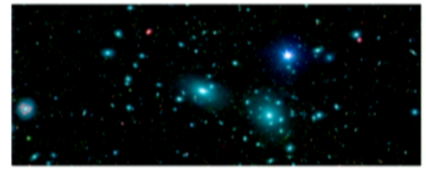


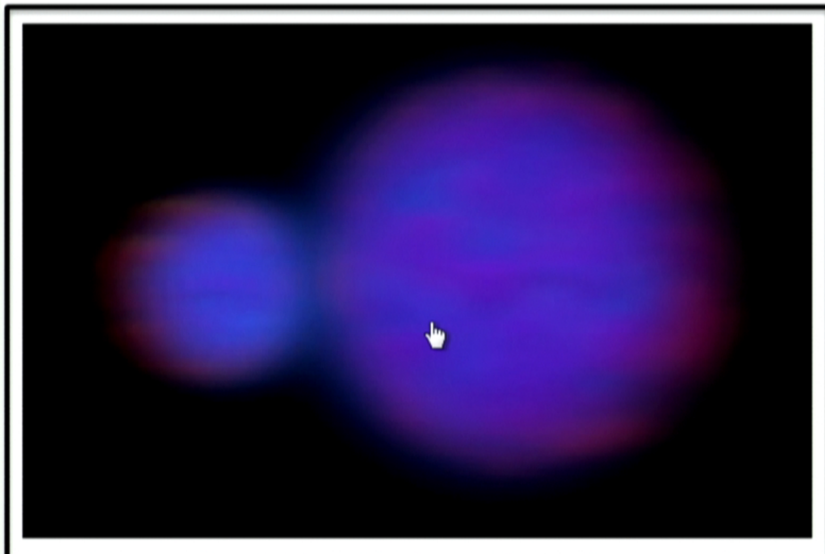
- Dark Matter is ***non-baryonic***
  - CMB Acoustic Oscillations
    WMAP (2010)

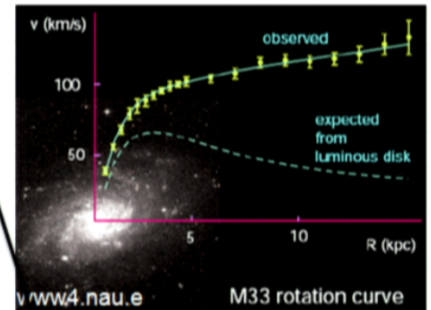


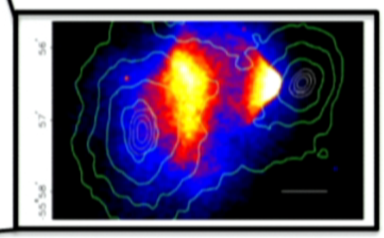
Astrophysical Evidence for Dark Matter

- Majority of mass in galaxies is ***dark***
  - Coma Cluster + Virial Theorem
    F. Zwicky (1937)

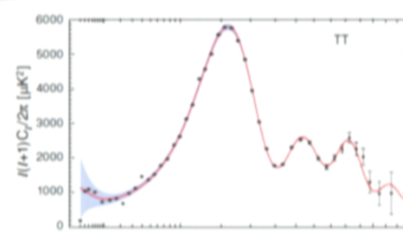








- Dark Matter is ***non-baryonic***
  - CMB Acoustic Oscillations
    WMAP (2010)

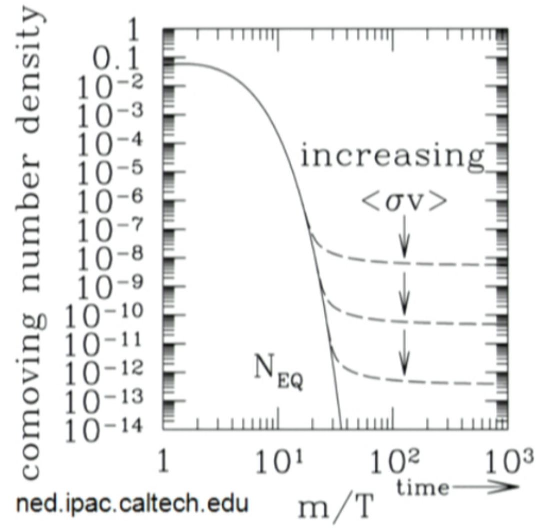


WIMPs detectable by Fermi LAT

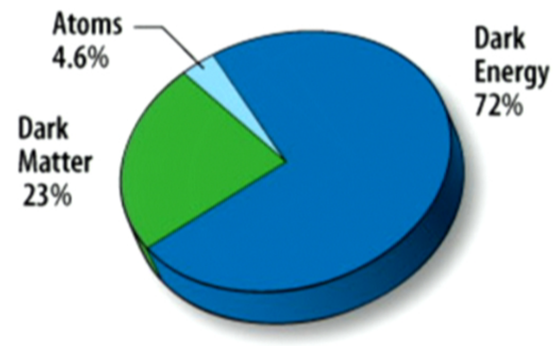
- Weakly Interacting Massive Particle (WIMP)
- GeV-TeV mass scale
- *Assume*: Can annihilate or decay into SM particles
- *Assume*: Accounts for measured DM density
- Ex) Neutralino
  - Predicted by many SUSY models
    - LHC experiments starting to put strong constraints on SUSY
  - Electrically neutral
  - LSP $\rightarrow$ stable particles
  - GeV-TeV mass

WIMPs as a Thermal Relic

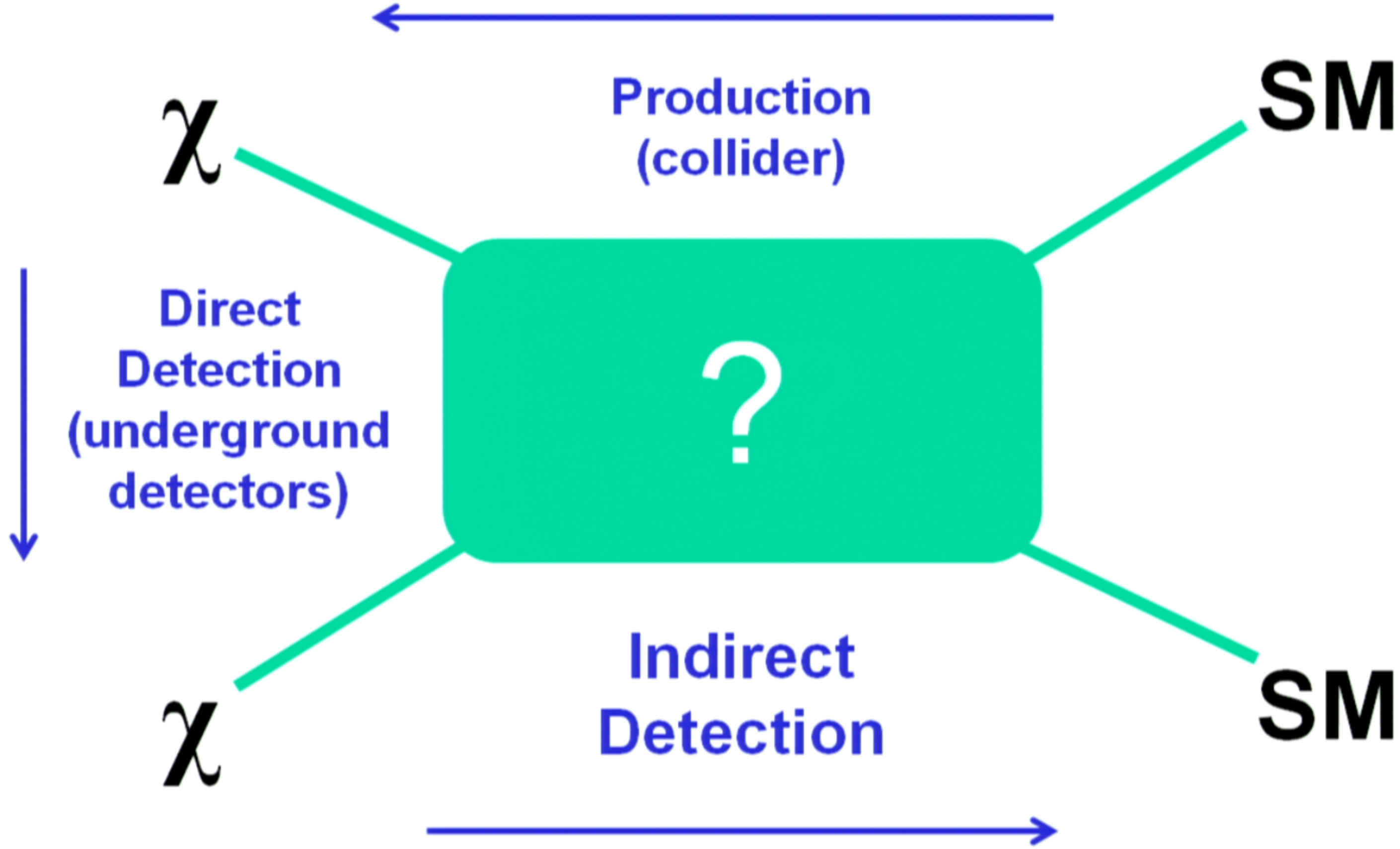
- If WIMP was a thermal relic, then it was in creation/annihilation equilibrium in early universe
- Once universe cools enough, amount of dark matter freezes out
  - No longer created, and expansion causes annihilation rate to drop to ~0
- Assume *weak scale* $\sigma_{ann} \rightarrow$ observed abundance (~23%)
  - $<\sigma v>_{ann} \sim 3e\text{-}26\ cm^3/s$ ($\sigma_{ann} \sim 3$ pb)
  - $v_{CDM} \sim 0.3c$
    - Virial theorem -> to form stable halos around galaxies, DM particle should be non-relativistic (cold dark matter)



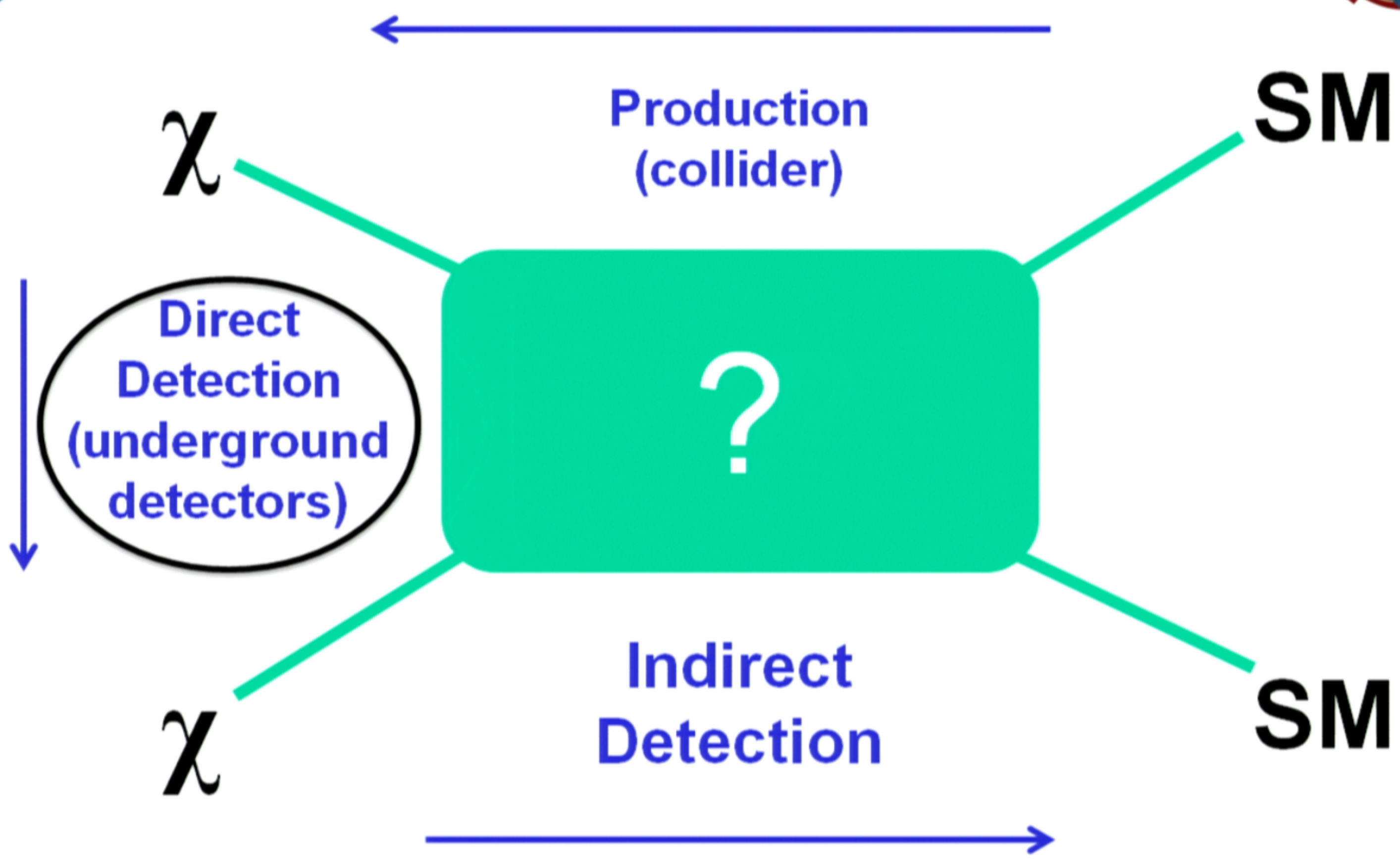
ned.ipac.caltech.edu



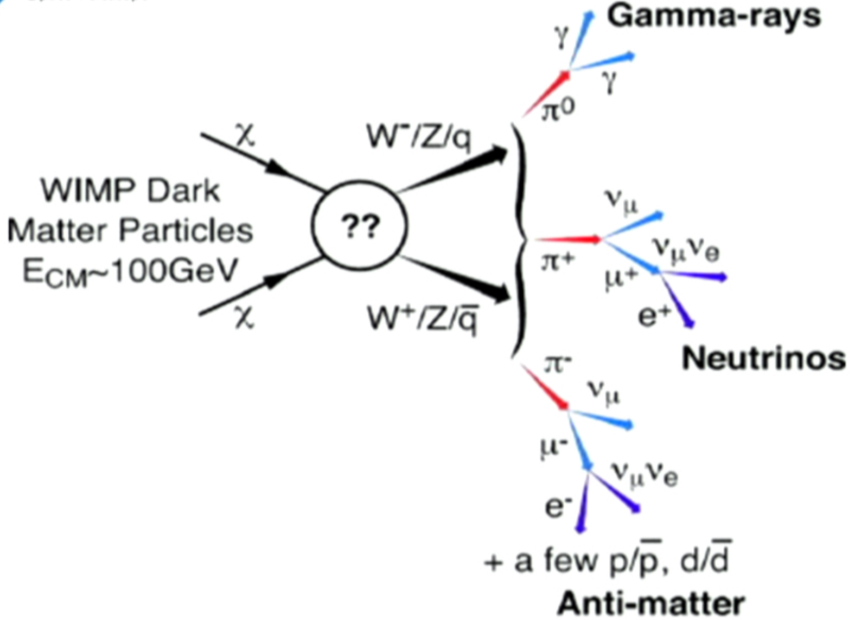
How to Detect WIMPs

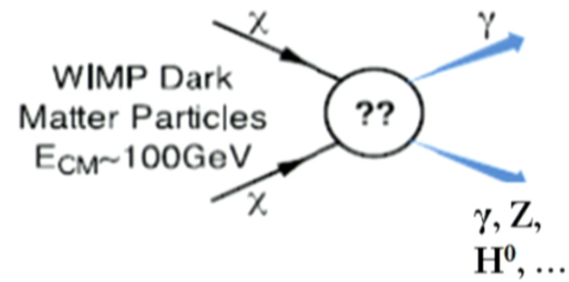


How to Detect WIMPs



WIMP Signatures (1)





- WIMP annihilation or decay may produce a variety of detectable SM particles

- Goal is to detect these particles and disentangle intrinsic WIMP properties

WIMP Signatures (2)

What we observe

$$\Phi_\chi(E,\psi) = \frac{\langle\sigma_\chi v\rangle}{4\pi}\sum_f \frac{dN_f}{dE}B_f \int_{LOS} dl(\psi)\frac{1}{2}\frac{\rho(l)^2}{m_\chi^2}$$

DM Flux (events/cm²/s)

Region of Interest (ROI)
(dwarf galaxy, the whole sky, etc)

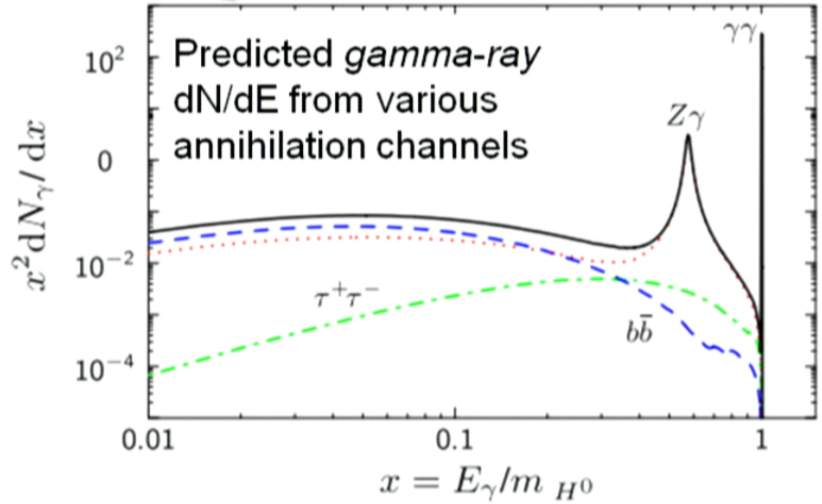
WIMP Signatures (2)

Intrinsic Particle Properties

$$\Phi_\chi(E,\psi) = \frac{\langle \sigma_\chi v \rangle}{4\pi} \sum_f \frac{dN_f}{dE} B_f \int_{LOS} dl(\psi) \frac{1}{2} \frac{\rho(l)^2}{m_\chi^2}$$

Annihilation Cross Section * velocity
($v \sim 0.3c$)
$\langle\sigma v\rangle_{ann} \sim$ 3e-26 cm^3/s ($\sigma_{ann} \sim$ 3 pb)

Note: large fraction of predicted gamma's have $E_\gamma < m_{DM}$



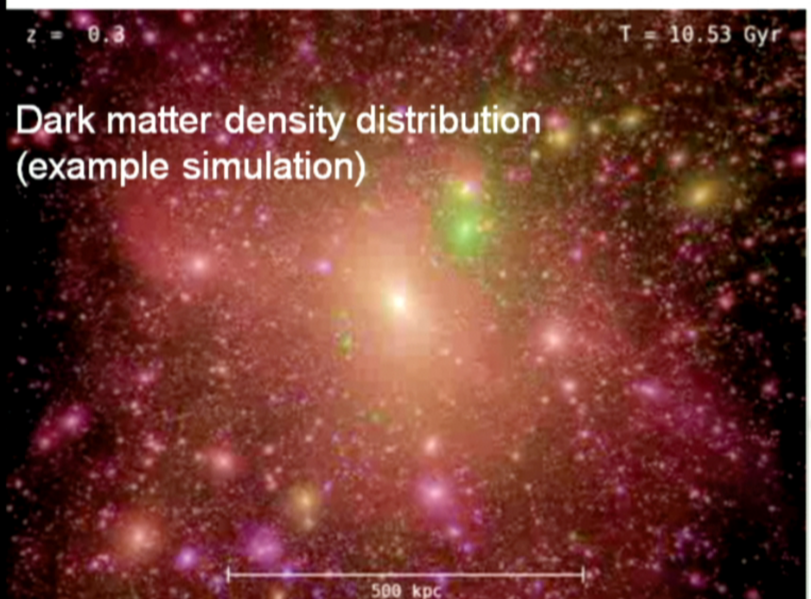
Gustafsson et al. PRL 99.041301

WIMP Signatures (2)

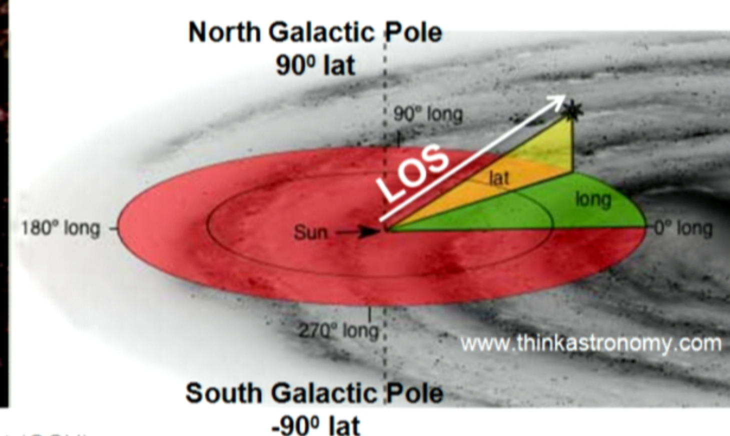
Astrophysics

$$\Phi_\chi(E,\psi) = \frac{\langle \sigma_\chi v\rangle}{4\pi} \sum_f \frac{dN_f}{dE} B_f \int_{LOS} dl(\psi) \frac{1}{2} \frac{\rho(l)^2}{m_\chi^2}$$

J-factor – Line of sight integral over a ROI



Credit: Springel et al. (Virgo Consortium)



Outline

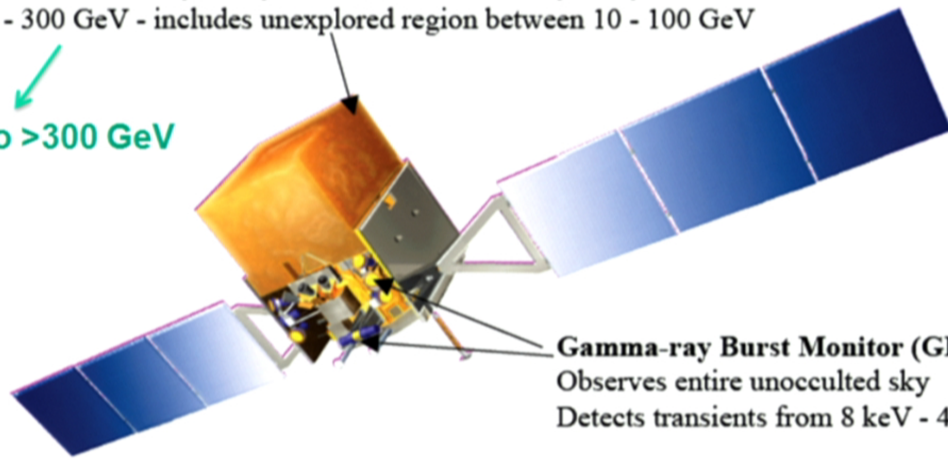
- Dark Matter Overview
- **The Fermi Large Area Telescope**
- The Gamma-ray Sky
- Recent Dark Matter Results
  - Focus on spectral line search

Fermi Large Area Telescope (LAT)

- On board the Fermi Gamma-ray Space Telescope
  - Launched June 11, 2008
    - Started taking data Aug 2008
  - 5 year mission
    - Mission extended at least through 2016

Large Area Telescope (LAT)
Observes 20% of the sky at any instant, views entire sky every 3 hrs
20 MeV - 300 GeV - includes unexplored region between 10 - 100 GeV

Can go >300 GeV



Gamma-ray Burst Monitor (GBM)
Observes entire unocculted sky
Detects transients from 8 keV - 40 MeV

Gamma Ray Pair Conversion

Energy loss mechanisms

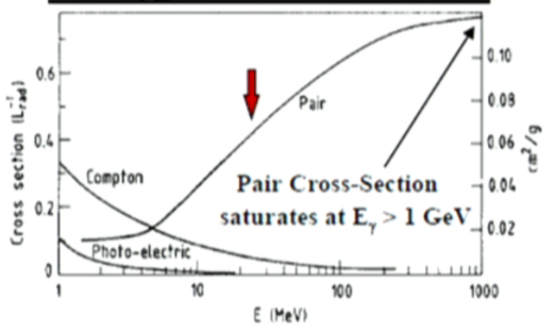
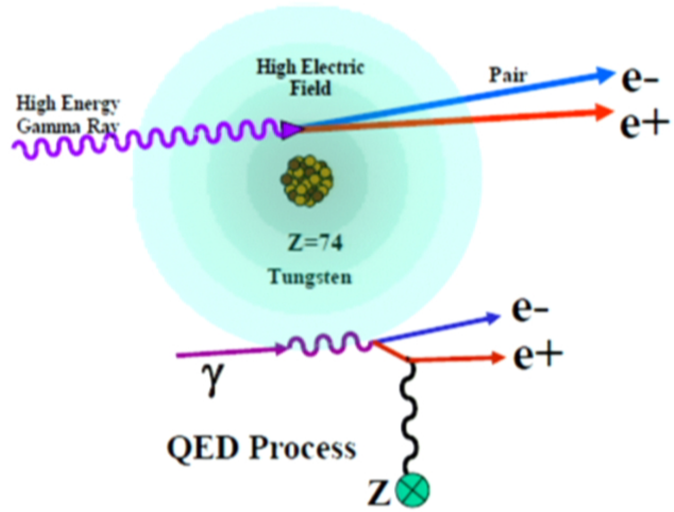


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

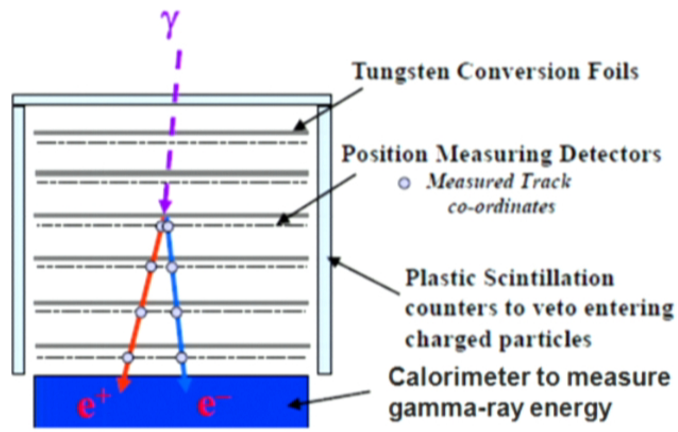


Opening Angle

$$\theta_{Open} \approx \frac{4m_e}{E_\gamma}$$

At 100 MeV

$\theta_{Open} \sim 1^o$



Gamma Ray Pair Conversion

Energy loss mechanisms

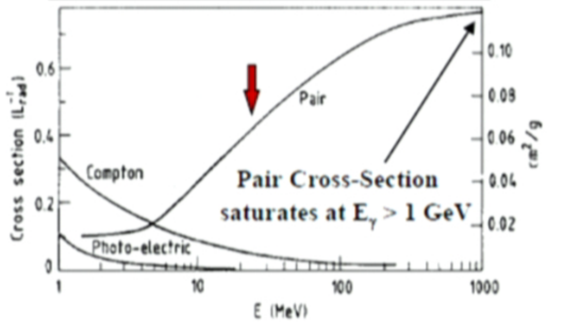
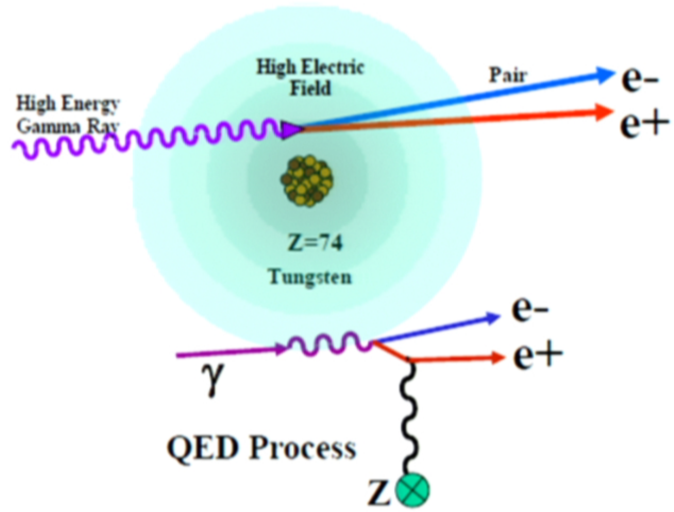


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

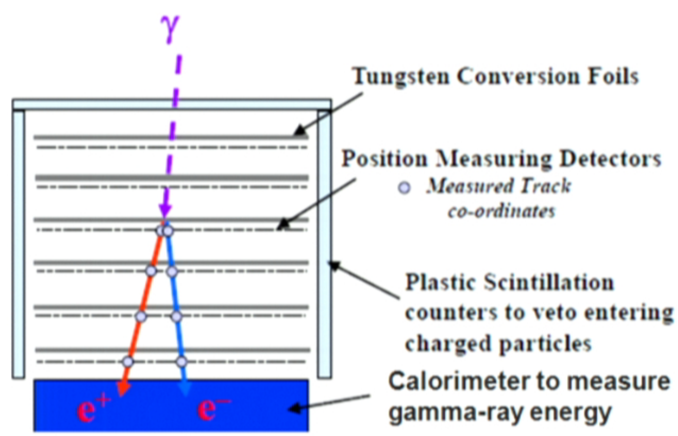


Opening Angle

$$\theta_{Open} \approx \frac{4m_e}{E_\gamma}$$

At 100 MeV

$\theta_{Open} \sim 1^o$



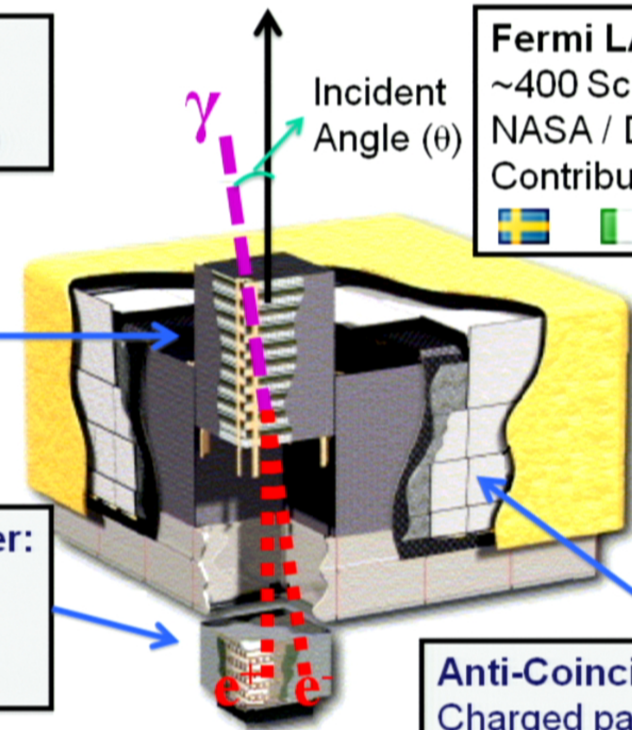
Fermi LAT

Public Data Release:
All γ-ray data made public within 24 hours (usually less)

Si-Strip Tracker:
convert $\gamma \rightarrow e^+e^-$
reconstruct γ direction
EM v. hadron separation

Hodoscopic CsI Calorimeter:
measure γ energy
image EM shower
EM v. hadron separation

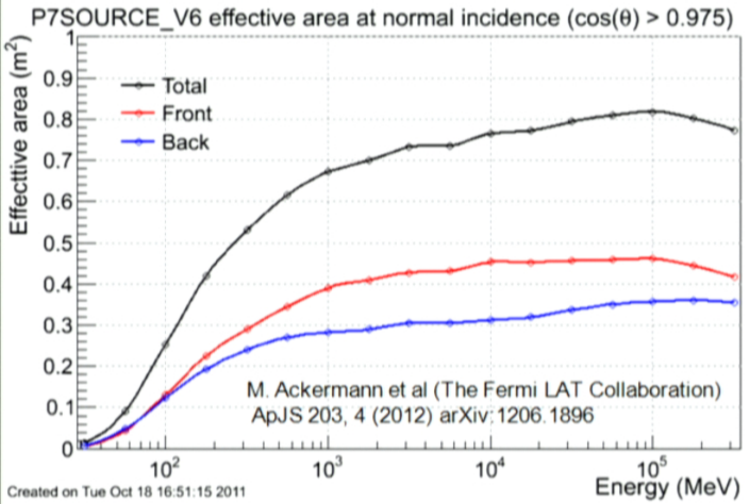
Trigger and Filter:
Reduce data rate from ~10kHz to 300-500 Hz

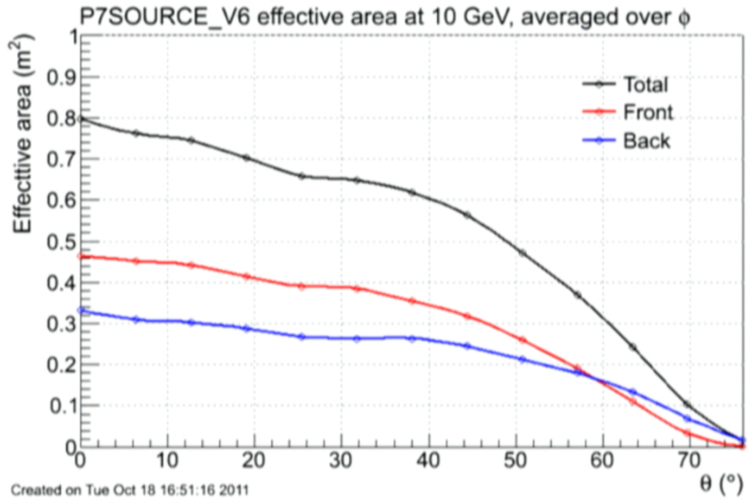


Fermi LAT Collaboration:
~400 Scientific Members, NASA / DOE & International Contributions

Anti-Coincidence Detector:
Charged particle separation

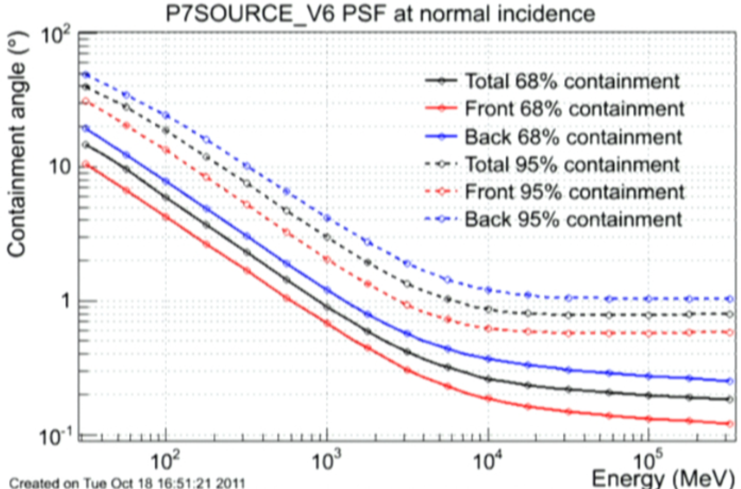
Fermi LAT Effective Area





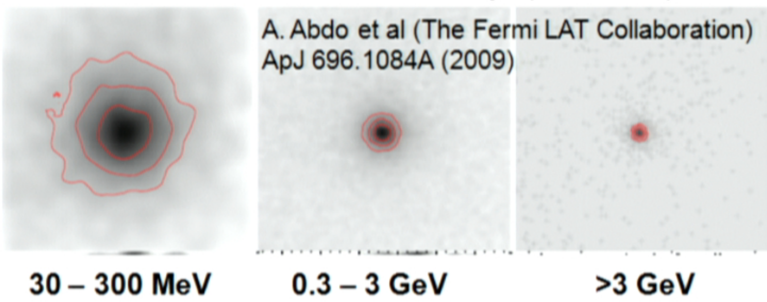
- < 100 MeV limited by 3 in-a-row trigger requirement & drop in pair production cross section (see slide 16)
- > 100 GeV limited by backsplash
- See arXiv:1206.1896 for more info on Fermi LAT performance/validation

Fermi LAT Point Spread Function (PSF)



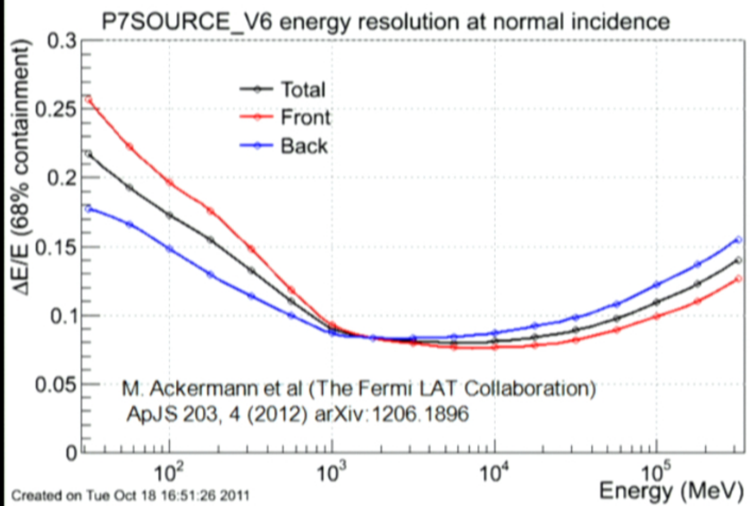
M. Ackermann et al (The Fermi LAT Collaboration)
ApJS 203, 4 (2012) arXiv:1206.1896

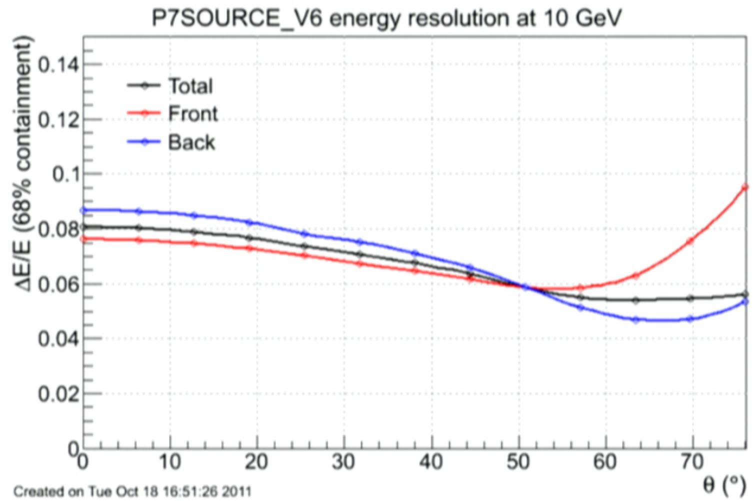
Vela Pulsar Counts Map (10^0x10^0)



- **Limited by multiple scattering at low E**
- **Limited by strip pitch at high E (pitch = 228 μm)**
- **See arXiv:1206.1896 for more info on Fermi LAT performance/validation**

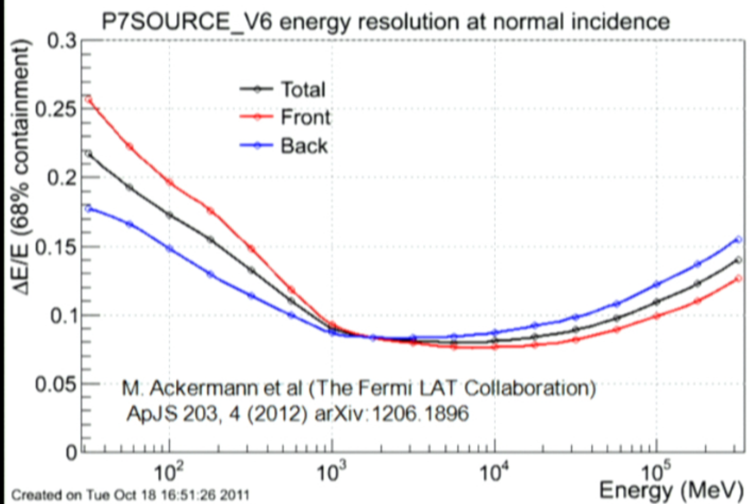
Fermi LAT Energy Dispersion

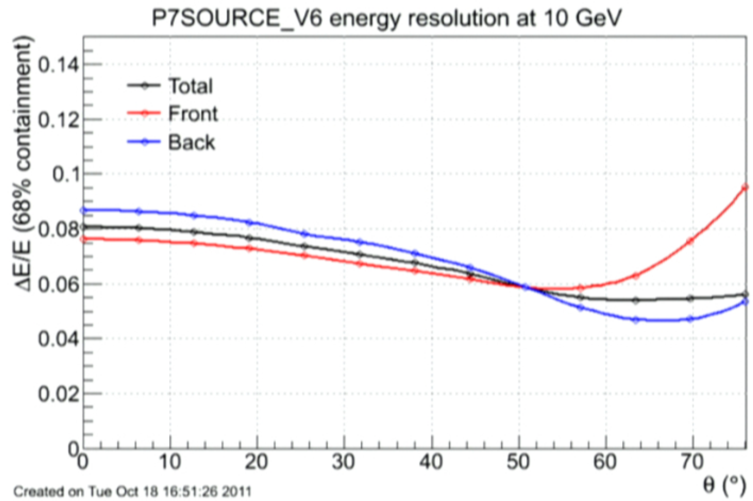




- **Limited by energy loss in tracker at low E**
- **Limited by leakage and CAL saturation at high E**
- **See arXiv:1206.1896 for more info on Fermi LAT performance/validation**

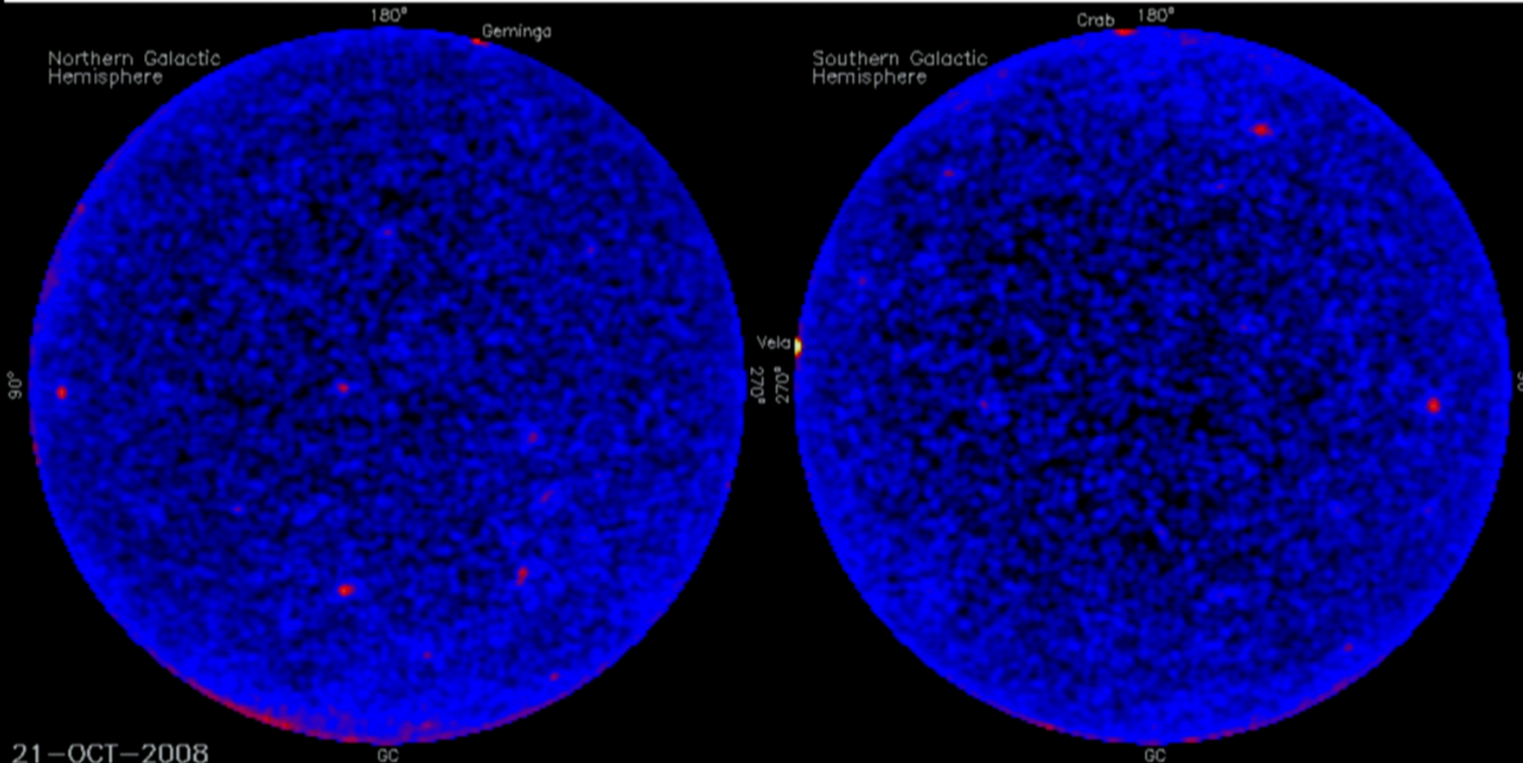
Fermi LAT Energy Dispersion





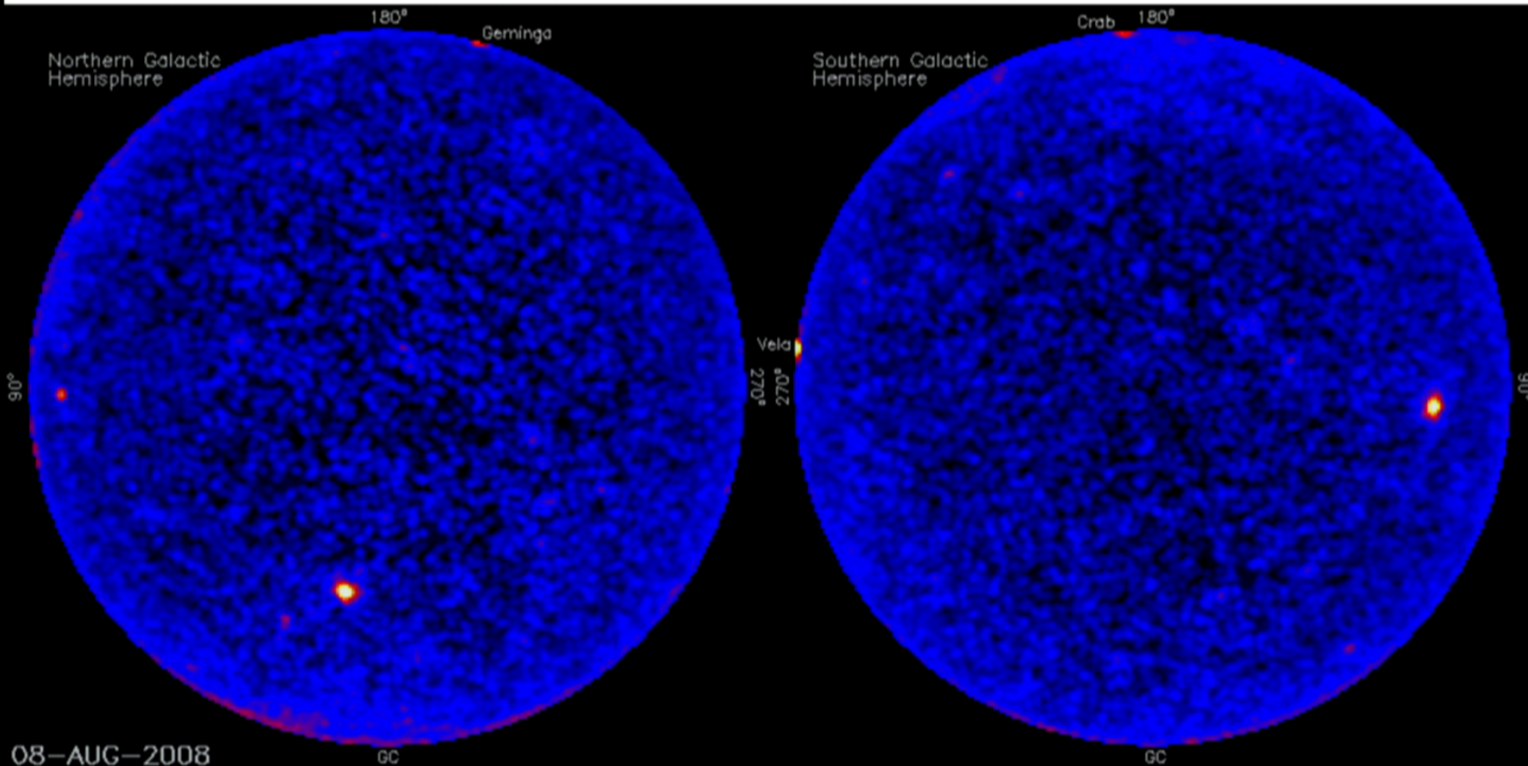
- **Limited by energy loss in tracker at low E**
- **Limited by leakage and CAL saturation at high E**
- **See arXiv:1206.1896 for more info on Fermi LAT performance/validation**

Daily Gamma-ray Sky



Andrea Albert (OSU)

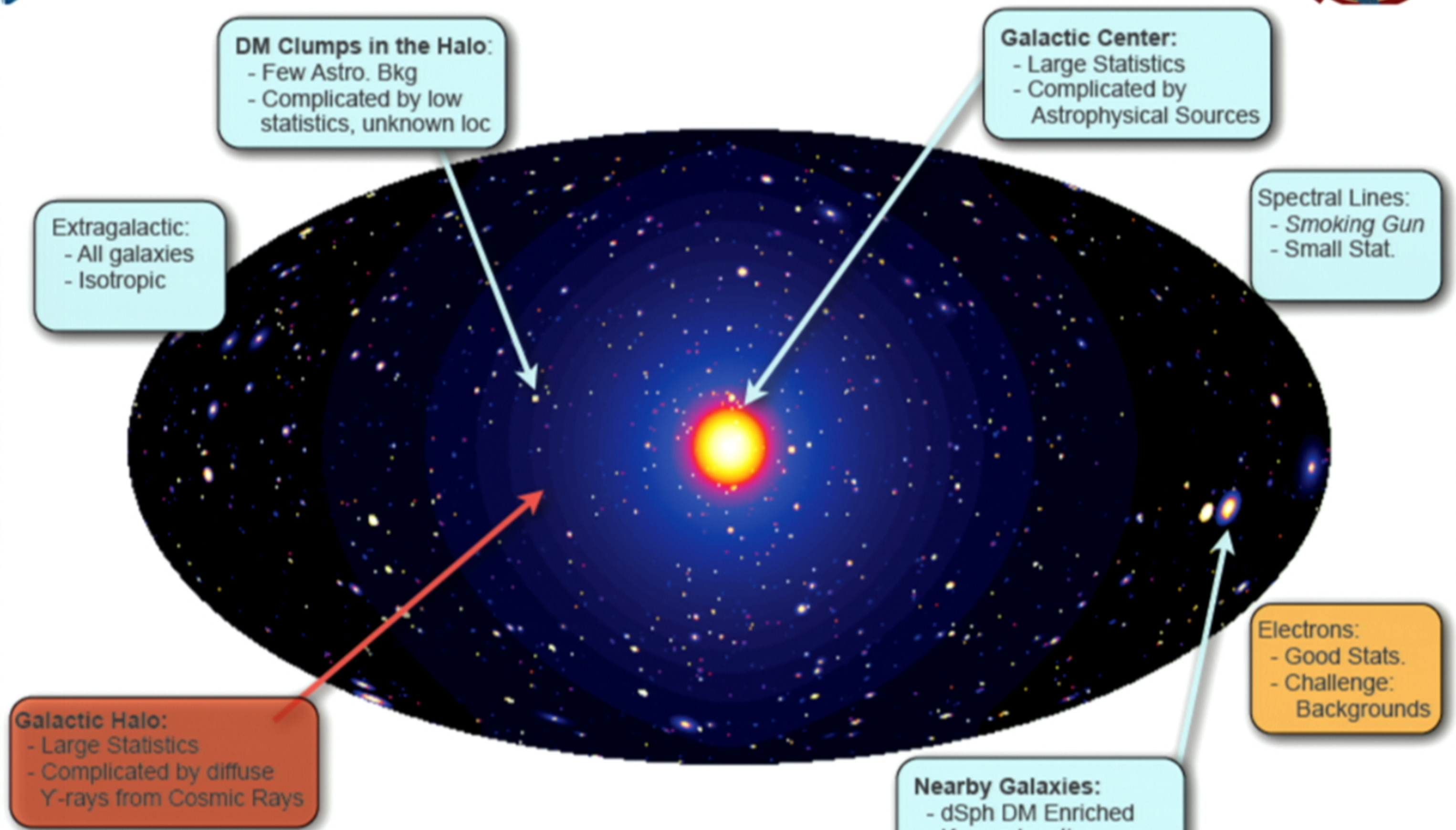
Daily Gamma-ray Sky



11/26/2012

Andrea Albert (OSU)

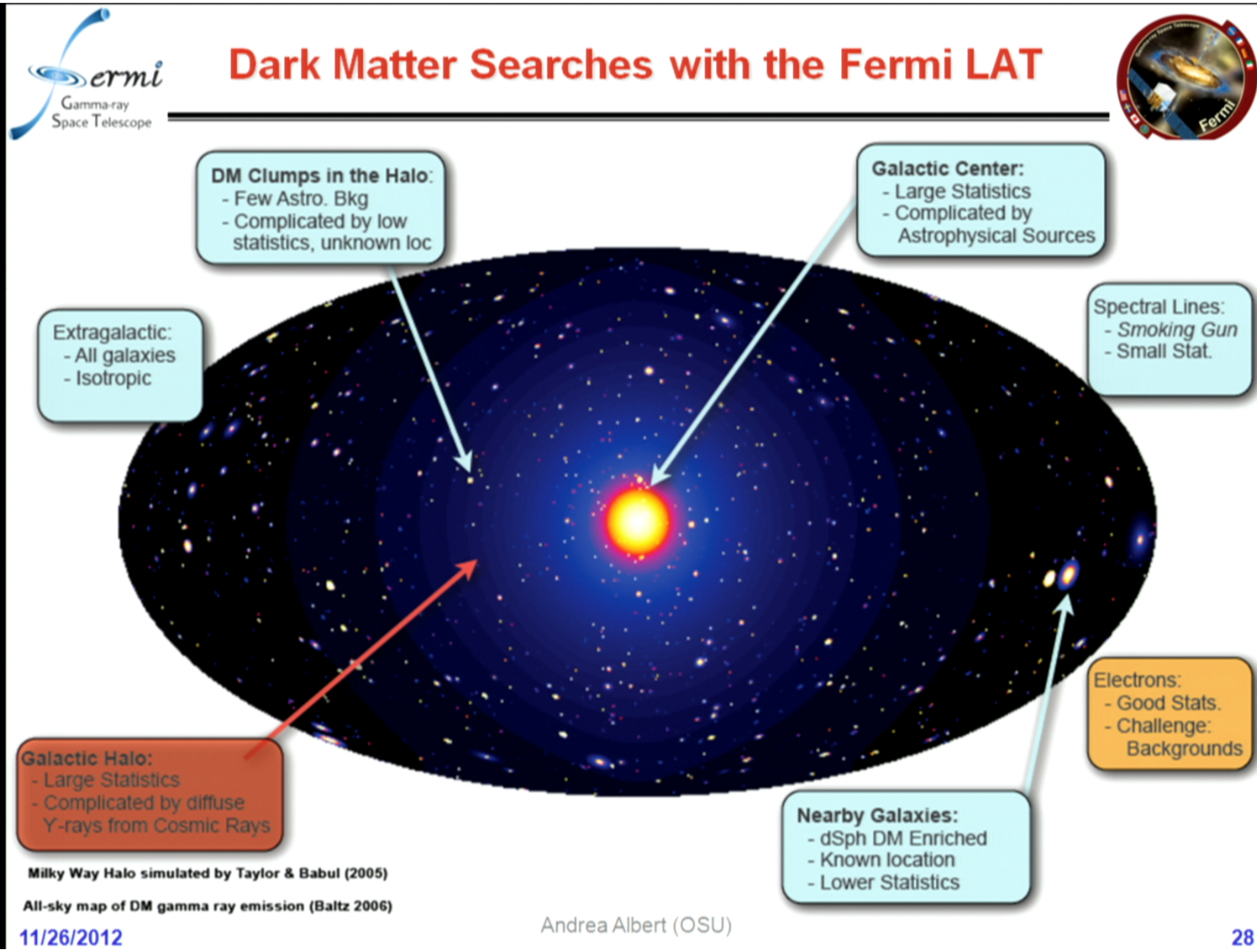
Dark Matter Searches with the Fermi LAT



Milky Way Halo simulated by Taylor & Babul (2005)

All-sky map of DM gamma ray emission (Baltz 2006)

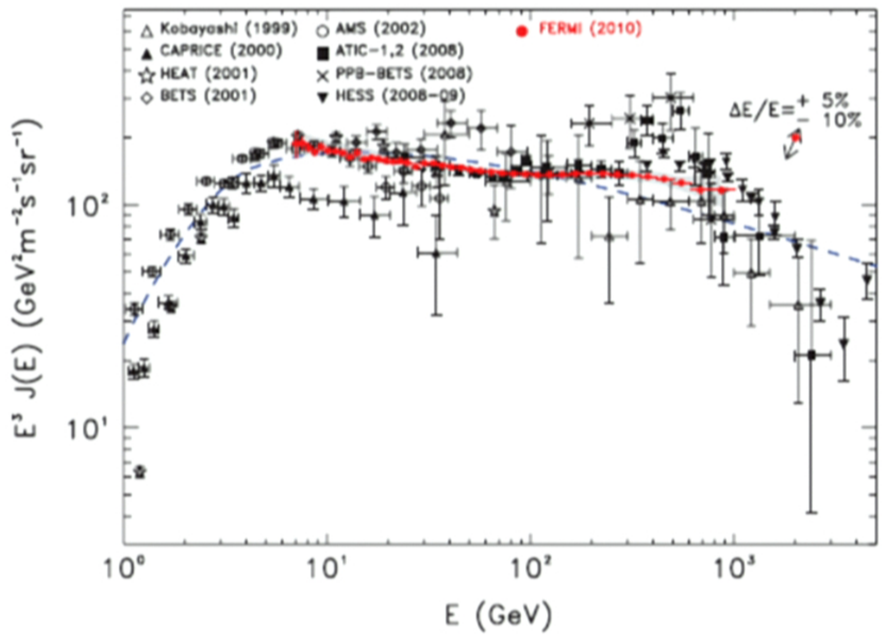
11/26/2012 Andrea Albert (OSU) 28


Fermi Gamma-ray Space Telescope
Dark Matter Searches with the Fermi LAT
DM Clumps in the Halo:
- Few Astro. Bkg
- Complicated by low statistics, unknown loc
Galactic Center:
- Large Statistics
- Complicated by Astrophysical Sources
Extragalactic:
- All galaxies
- Isotropic
Spectral Lines:
- Smoking Gun
- Small Stat.
Electrons:
- Good Stats.
- Challenge: Backgrounds
Galactic Halo:
- Large Statistics
- Complicated by diffuse γ-rays from Cosmic Rays
Nearby Galaxies:
- dSph DM Enriched
- Known location
- Lower Statistics
Milky Way Halo simulated by Taylor & Babul (2005)
All-sky map of DM gamma ray emission (Baltz 2006)
11/26/2012
Andrea Albert (OSU)
28

Unexpected Excess in the Cosmic Ray e± Spectrum

- **ATIC observed an unexpected bump in the CR e± spectrum**
- **Fermi observes a broader excess around the same energy**
- **This feature can be accounted for by adjusting the CR injection spectrum or nearby pulsars**
- **Can also be explained with leptophillic DM annihilation models**
  - **Requires large $\langle\sigma v\rangle_{ann}$ to explain excess**

Fermi electron + positron spectrum

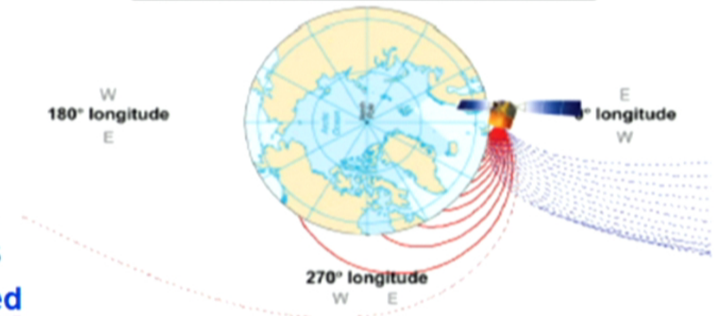


Ackermann et al. [Fermi LAT Collaboration] 2010

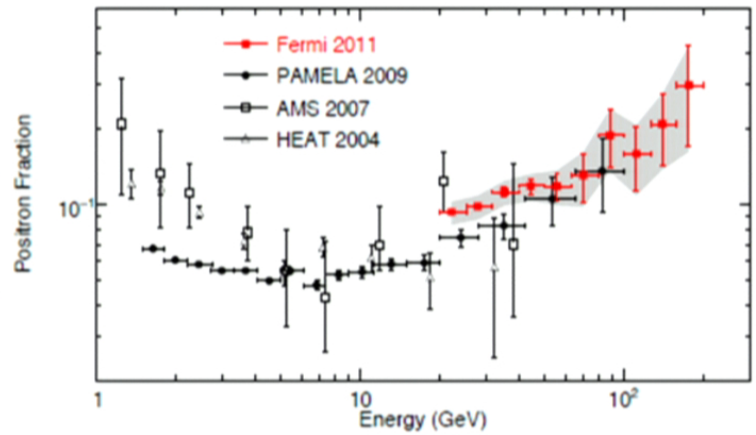
Unexpected Rise in local CR Positron Fraction

- **Fermi measures a rise in the local high-energy CR positron fraction, consistent with the PAMELA results**
- **No magnet on-board, so use Earth's magnetic field**
- **Rise in local positron fraction disagrees with conventional model for cosmic rays**
  - **Local positrons are secondaries created by CR nuclei interactions (this should cause fraction to *decrease*)**
- **This can be explained with leptophilic annihilating/decaying DM**
  - **Requires large $\langle\sigma v\rangle_{ann}$ to explain excess**
  - **Antiproton fraction does *not* rise; need to suppress hadronic modes**
  - **see T. A. Porter et al. (2011) arXiv:1104.2836v1; D. Grasso et al. (2009) arXiv:0905.0636v3 for more**

events arriving from West: e^+ allowed, e^- blocked



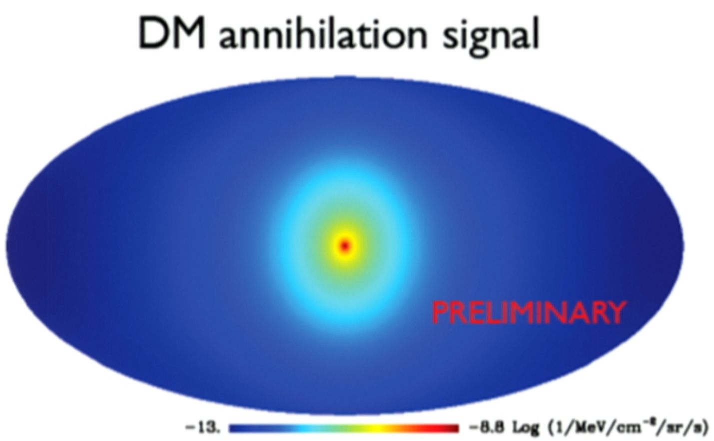
Fermi positron fraction

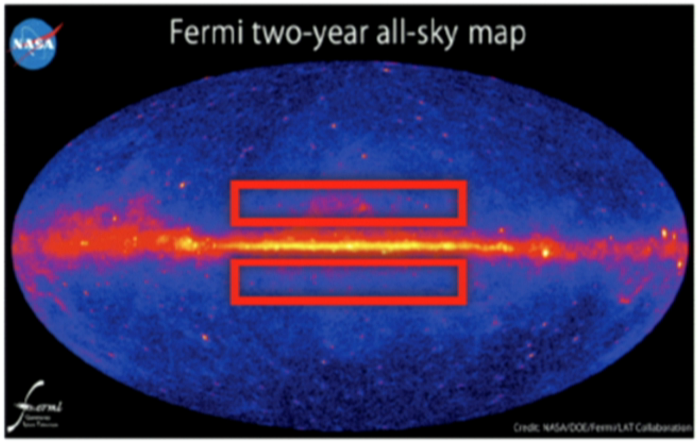


Ackermann et al. [Fermi LAT Collaboration] 2011

DM Constraints from the Milky Way Halo

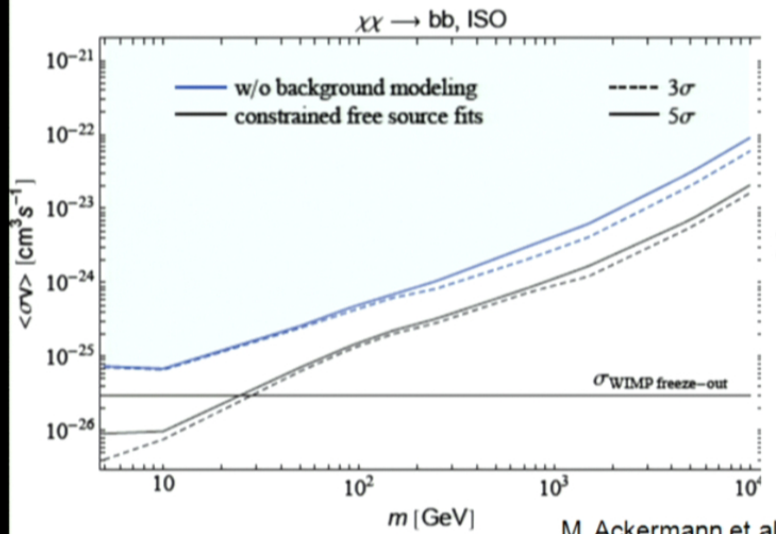
- Look in 2 year diffuse from 1 – 100 GeV
  - Mask out known gamma-ray sources
- Region of Interest: two off-plane rectangles ($5^0<|b|<15^0$ & $|l|<80^0$)
  - Minimizes DM profile uncertainties (central cuspiness varies)
  - Limits astrophysical uncertainties (mask bright plane, avoid high latitude Fermi lobes and Loop I)
- This analysis focuses on setting limits on possible DM signals
  - See non-DM like residuals (e.g. not centrally peaked)



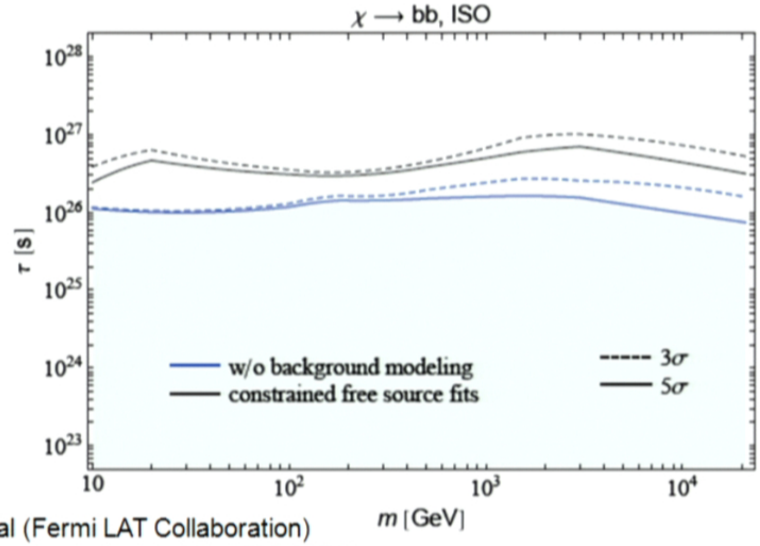


MW Halo Results- b$\bar{b}$

Annihilation



Decay

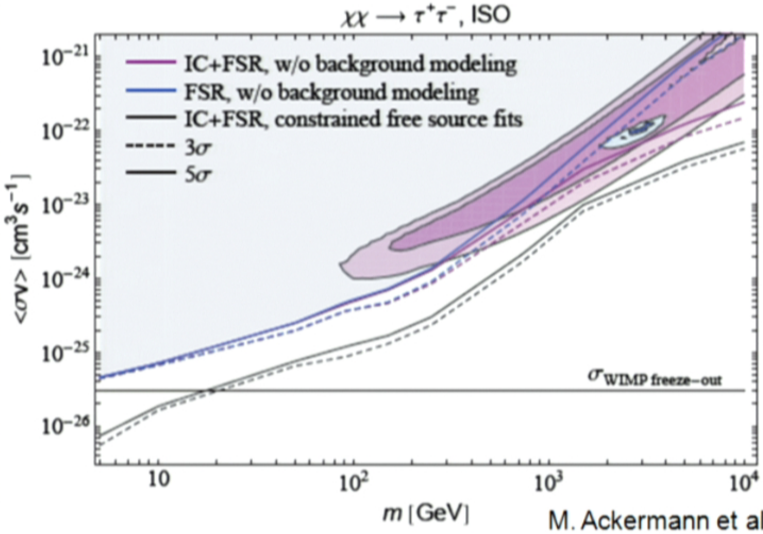


M. Ackermann et al (Fermi LAT Collaboration)
Accepted for publication in ApJ (arXiv:1205.6474)

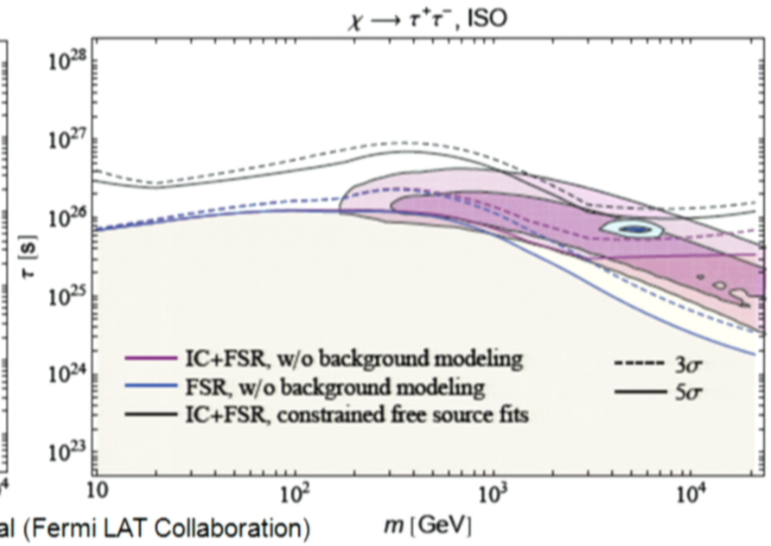
- b$\bar{b}$ annihilation spectrum is similar in shape to DM annihilations/decays producing heavy quarks and gauge bosons in this energy range
- Exclude canonical thermal relic WIMPs for masses below ~30 GeV in b$\bar{b}$

MW Halo Results- τ⁺ τ ⁻

Annihilation



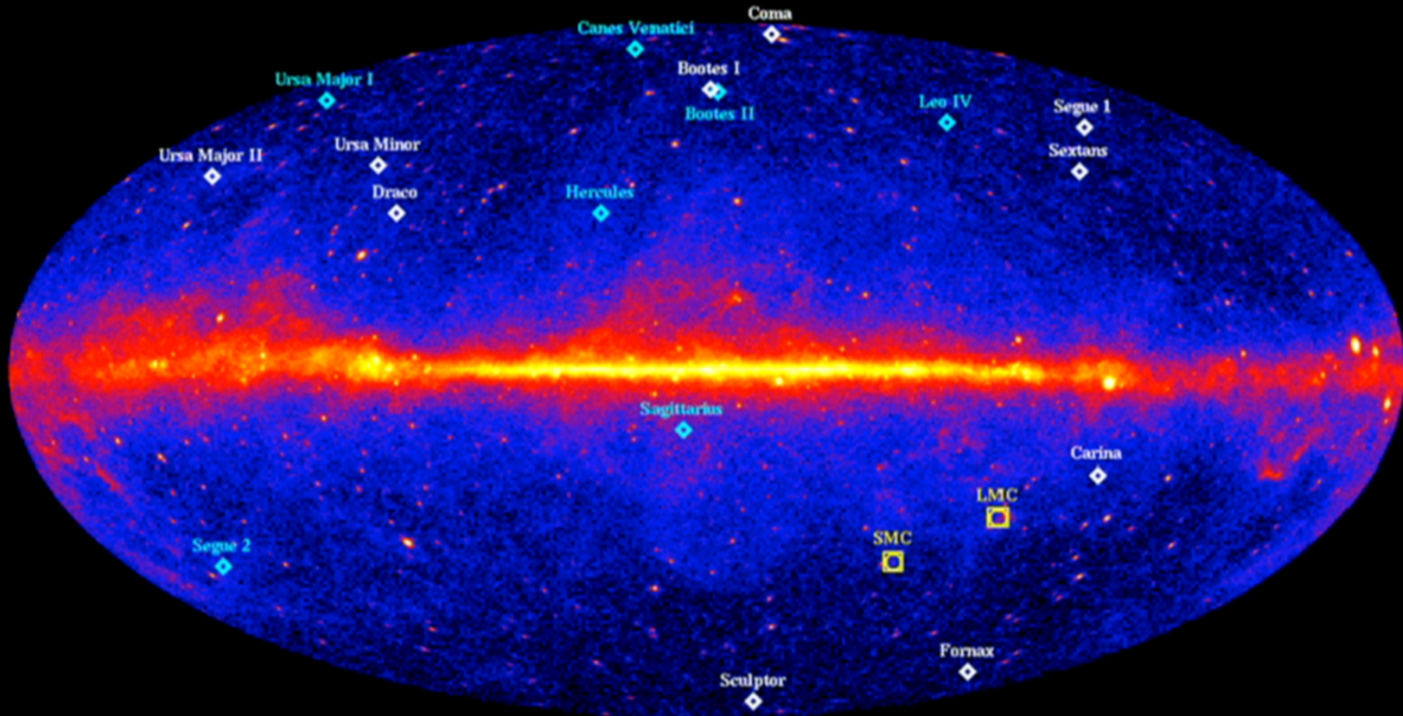
Decay



M. Ackermann et al (Fermi LAT Collaboration)
Accepted for publication in ApJ (arXiv:1205.6474)

- **Set limits assuming only Final State Radiation and FSR + Inverse Compton**
  - **Only FSR = only photons produced by taus (no electrons)**
  - **"FSR + IC" includes IC gamma rays from electrons produced via DM annihilation/decay**
- **Contours show 2σ and 3σ CL fits to PAMELA (purple) and Fermi (blue) positron fraction**
  - **DM interpretation of positron fraction strongly disfavored (for annihilating DM)**

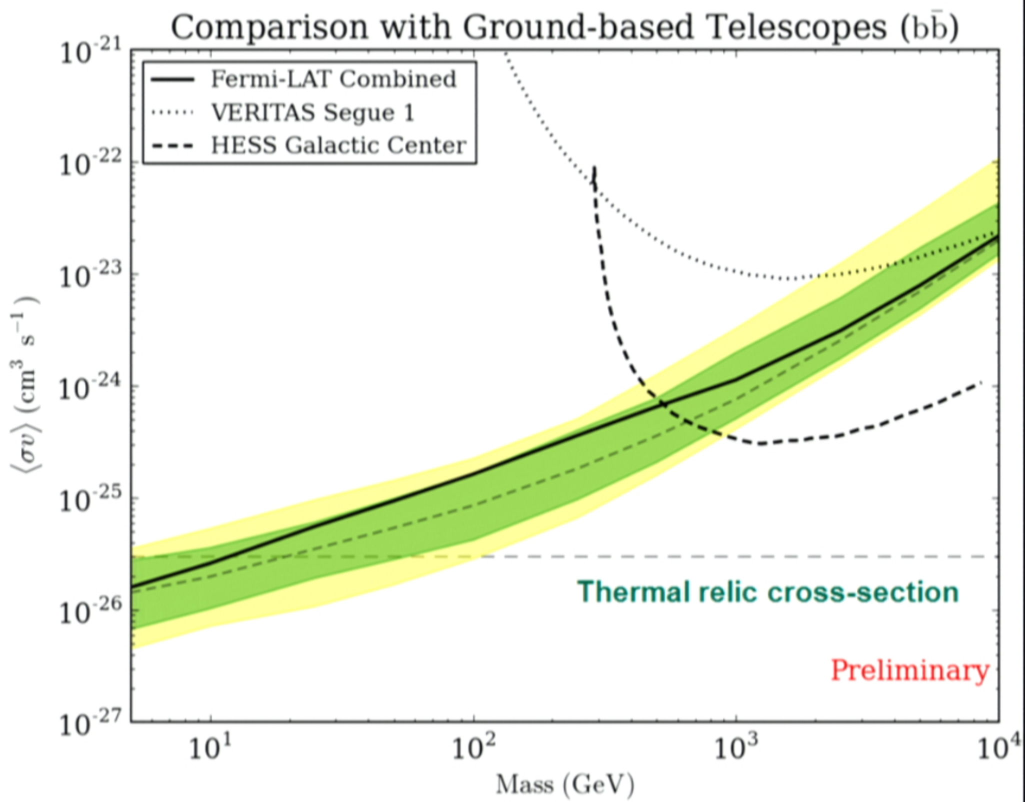
Constraints from dwarf galaxies



- **Dwarf galaxies have a large mass-to-light ratio**
- **Good signal-to-noise for a DM search**

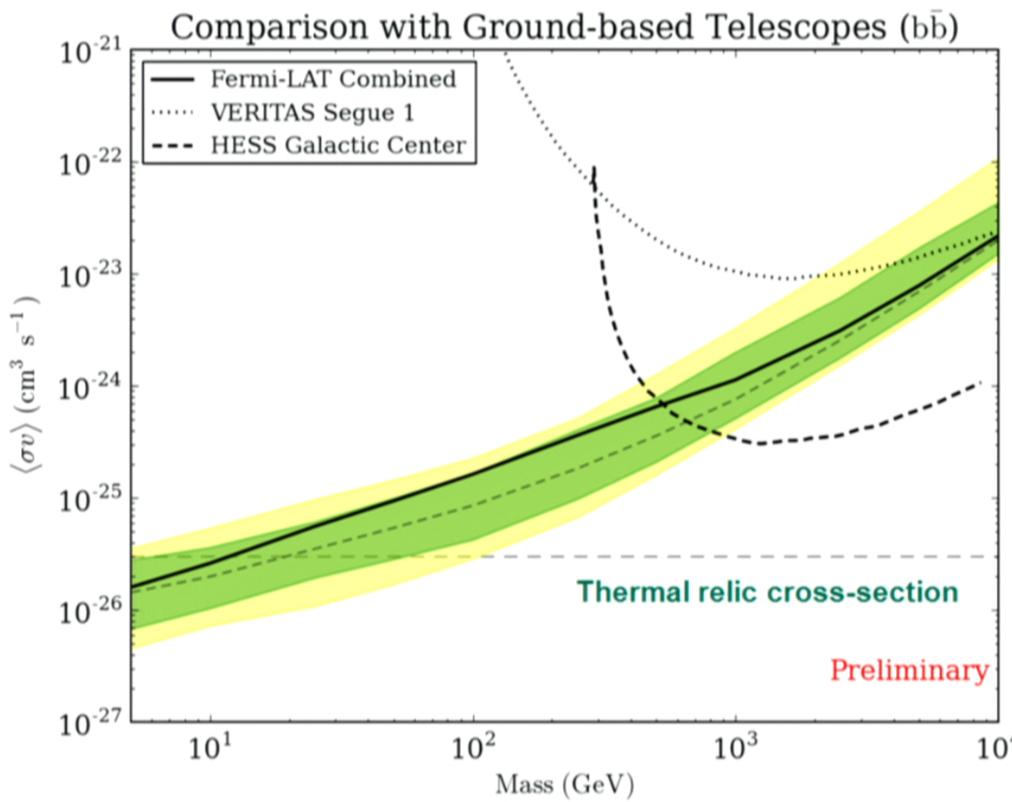
Combined dSphs Results

- **Joint likelihood analysis of 10 dwarf galaxies**
- **4 years of data in energy range 100 MeV – 500 GeV**
- **Account for uncertainties in J-factor**
  - **DM distribution determined using observed stellar velocities**
- **4 annihilation channels considered**
- **No DM seen**
  - **Exclude canonical thermal relic cross-section for masses less than ~10 GeV (in bb̄ and tau's)**



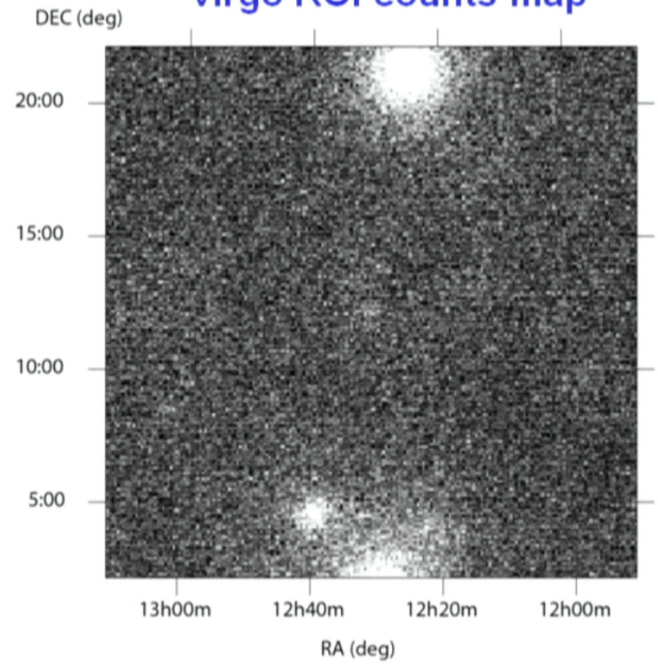
Combined dSphs Results

- Joint likelihood analysis of 10 dwarf galaxies
- 4 years of data in energy range 100 MeV – 500 GeV
- Account for uncertainties in J-factor
  - DM distribution determined using observed stellar velocities
- 4 annihilation channels considered
- No DM seen
  - Exclude canonical thermal relic cross-section for masses less than ~10 GeV (in $b\bar{b}$ and tau's)



Virgo Galaxy Cluster (1)

Virgo ROI counts map



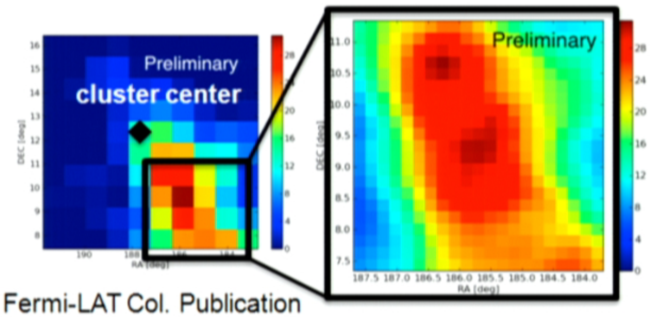
DM annihilation profile

Han et al. 2012

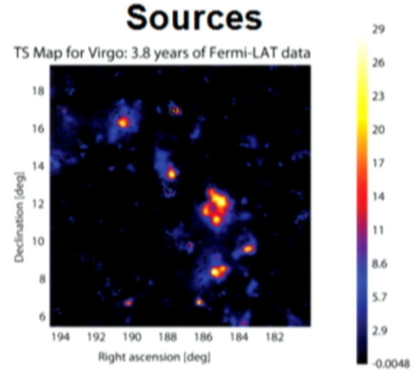
- Han et al 2012 (arXiv 1201.1003) claimed ~4 sigma evidence from dark matter annihilation in the Virgo galaxy cluster
- Very extended DM annihilation profile (from substructure), majority of excess comes from inner 3 deg of the profile

Virgo Galaxy Cluster (2)

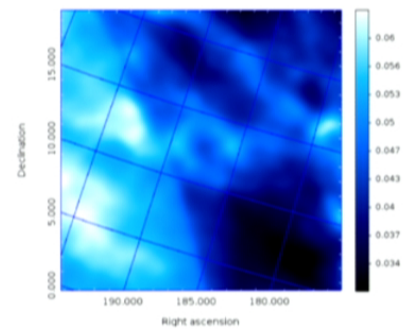
TS map with 0.5 deg bins | **TS map with 0.2 deg bins** | **New Point Sources** | **Interstellar Emission Model**



Fermi-LAT Col. Publication in preparation



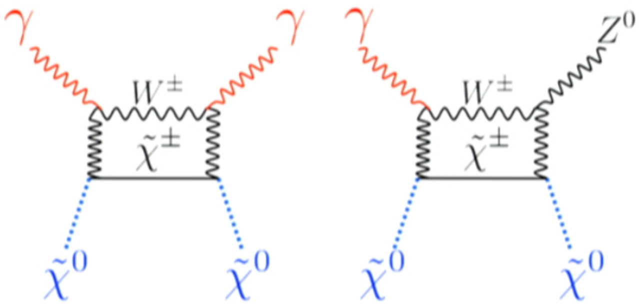
Macias-Ramirez et al. (2012)

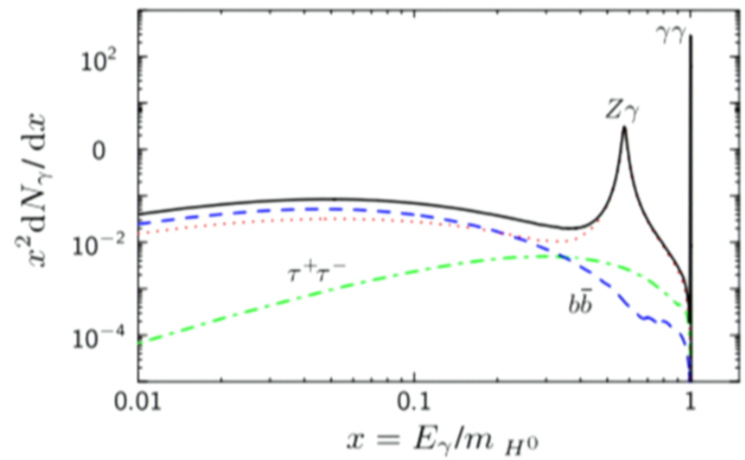


Fermi-LAT Col. Publication in preparation

- **Excess is not in the cluster center (as expected from DM)**
- **Macias-Ramirez find 7 new candidate point sources that could explain excess**
  - **Han et al 2012 (arXiv 1207.6749) find 4 new candidate point sources**
- **Significance depends strongly on the interstellar emission model**
  - **Requires a detailed study of systematic uncertainties especially of the interstellar emission model even for extragalactic regions**
  - **Virgo is at fairly low galactic latitude and in a challenging region for diffuse emission modeling.**

Search for Gamma-ray Spectral Lines



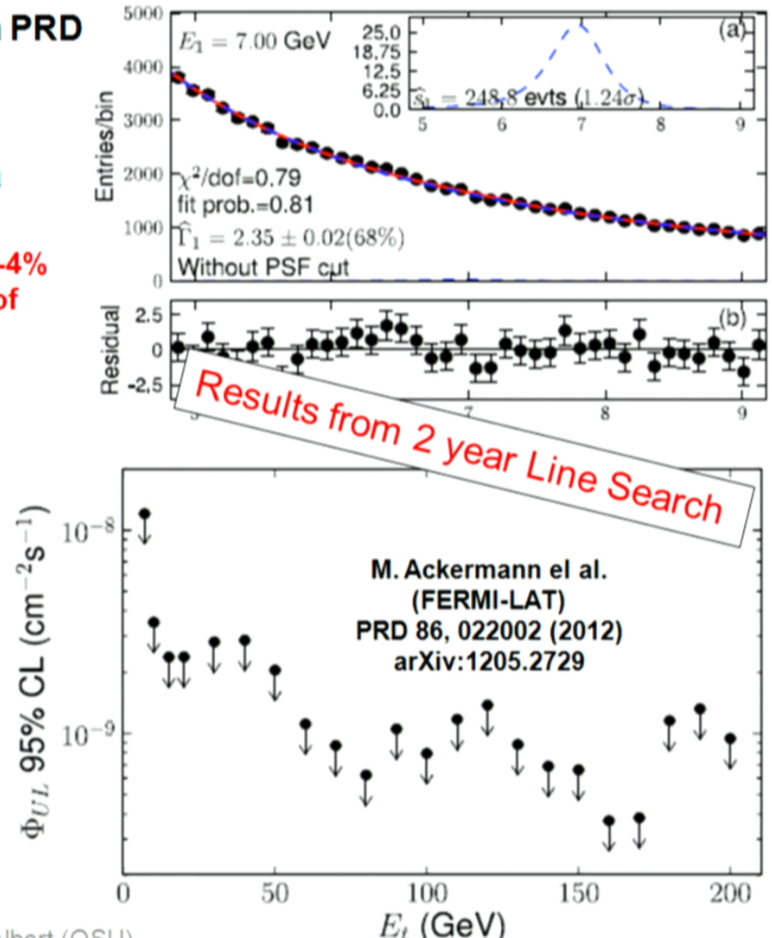


Gustafsson et al. PRL 99.041301

- **Annihilation/decay directly into γγ or Xγ (X = Z^0, H^0, …)**
- **"Smoking Gun" channel**
- **Advantage: sharp, distinct feature**
- **Disadvantage: low predicted counts**

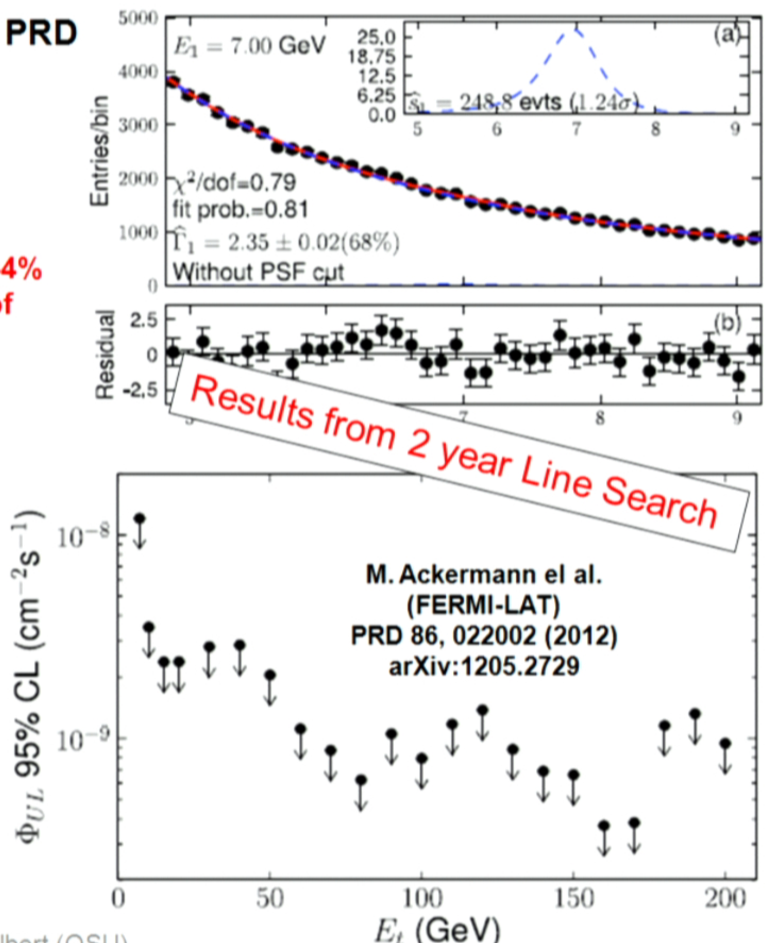
The Fermi LAT Line Search

- 2 year analysis accepted for publication in PRD
  - Current analysis uses similar method
- 4 year analysis mostly complete
  - Use Reprocessed "Pass 7 Clean" data
    - Low cosmic-ray contamination
    - Reprocessing shifts energy scale by 1-4% to account for expected accumulation of radiation damage to calorimeter
  - Paper is under construction
- Search for lines from 5 to 300 GeV
  - Maximum Likelihood Fit
  - Use sliding $\pm 6\sigma_E$ windows
  - Fit for energies in σ_E steps
    - Perform finer $0.5\sigma_E$ scan near significant energies
  - Model bkg as single powerlaw
  - Γ_{bkg} and f_{sig} free in fit



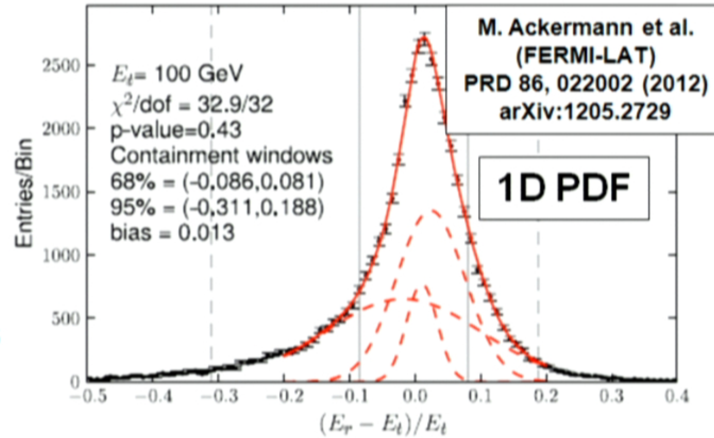
The Fermi LAT Line Search

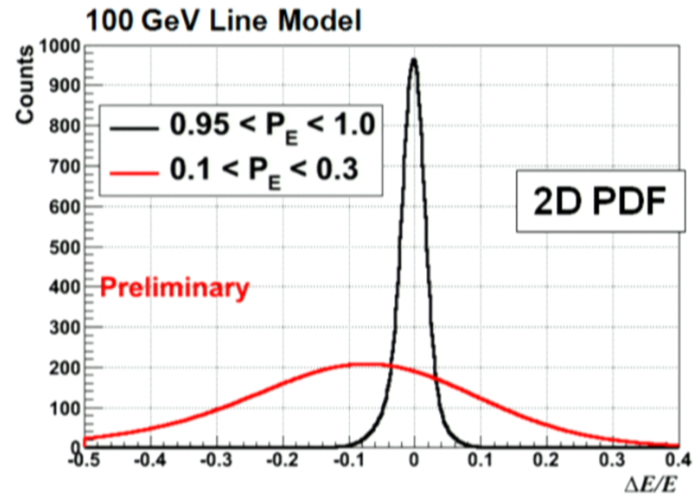
- 2 year analysis accepted for publication in PRD
  - Current analysis uses similar method
- 4 year analysis mostly complete
  - Use Reprocessed "Pass 7 Clean" data
    - Low cosmic-ray contamination
    - Reprocessing shifts energy scale by 1-4% to account for expected accumulation of radiation damage to calorimeter
  - Paper is under construction
- Search for lines from 5 to 300 GeV
  - Maximum Likelihood Fit
  - Use sliding $\pm 6\sigma_E$ windows
  - Fit for energies in σ_E steps
    - Perform finer $0.5\sigma_E$ scan near significant energies
  - Model bkg as single powerlaw
  - Γ_{bkg} and f_{sig} free in fit



Improved Model for LAT Response to a Line

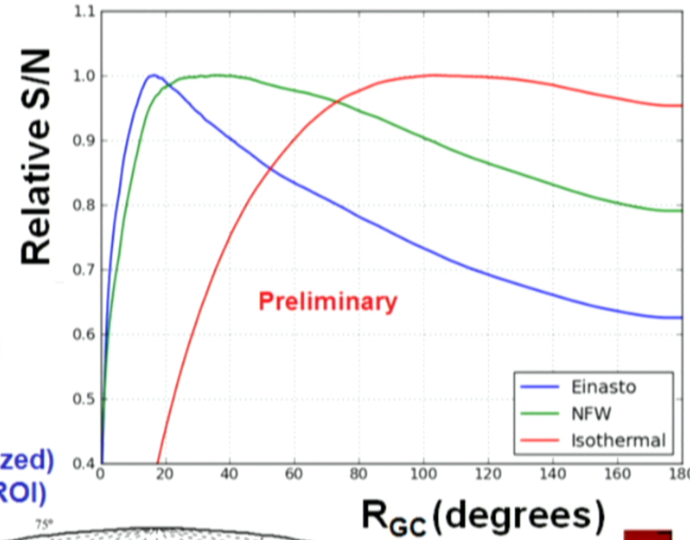
- Use full detector simulation to get Fermi LAT energy dispersion
- Previously modeled line with a triple gaussian fit ("1D PDF")
- This analysis adds a 2nd dimension to line model: P_E
  - P_E is the probability that measured energy is true energy
    - Labeled "CTBBestEnergyProb" in our extended data
  - "2D PDF" (a function of both energy and P_E)
- Break Line into 10 P_E slices and do triple gaussian fit in each slice separately
  - Fit explicitly at 9 energies and interpolate parameters in each slice to produce lines at other energies
- Including $P_E \rightarrow$ ~15% improvement to signal sensitivity (when there is signal) and counts upper limit (when there is no signal)

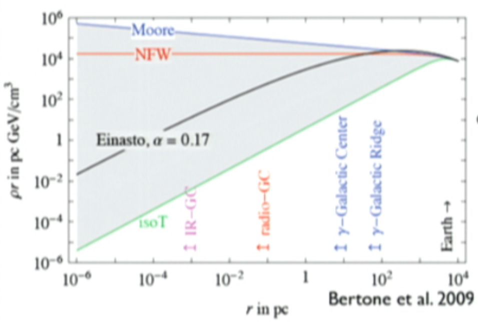


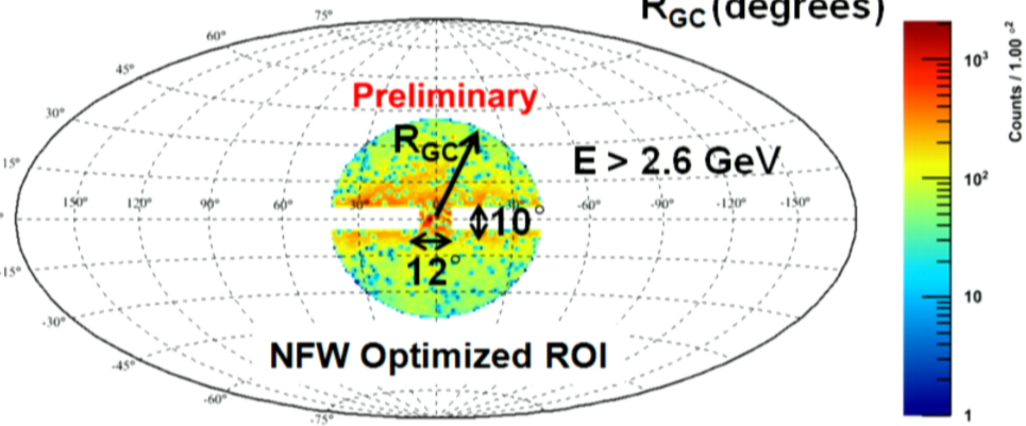


Region of Interest (ROI) Optimization

- Many have shown ROI optimization importance in line searches
  - e.g. C. Weniger JCAP 1208 (2012) 007
- Find R_{GC} that optimizes sig/sqrt(bkg)
  - ROI choices made a priori using MC
  - sig from J factor in that ROI
  - bkg from MC simulation of galactic diffuse model
    - http://fermi.gsfc.nasa.gov/ssc/data/access/lat/Model_details/Pass7_galactic.html
- Search in 5 ROIs
  - R0 (10^0x12^0 GC box)
  - R16 (Einasto Optimized)
  - R41 (NFW Optimized)
  - R90 (Isothermal Optimized)
  - R180 (2 year Analysis ROI)

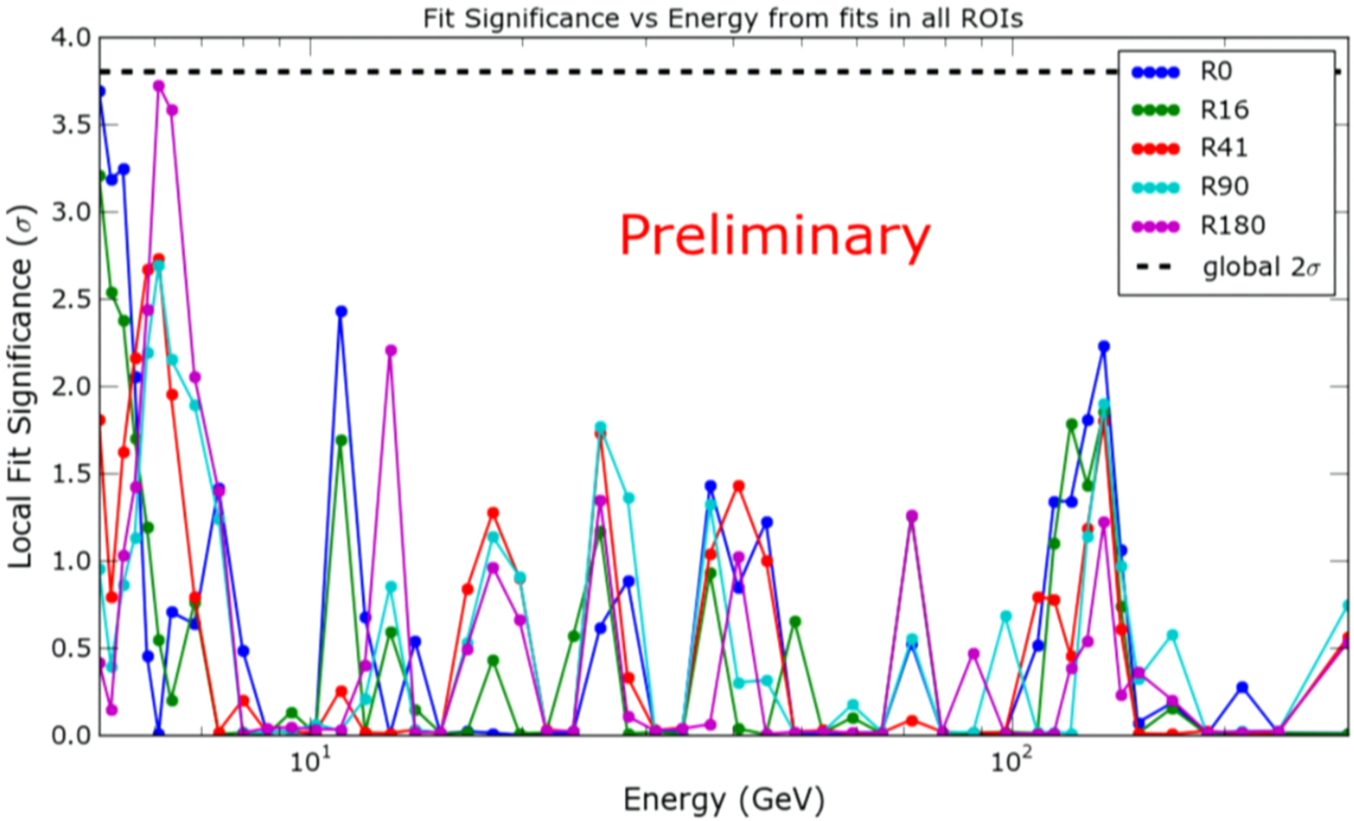






4 year Fermi-LAT Line Search Results

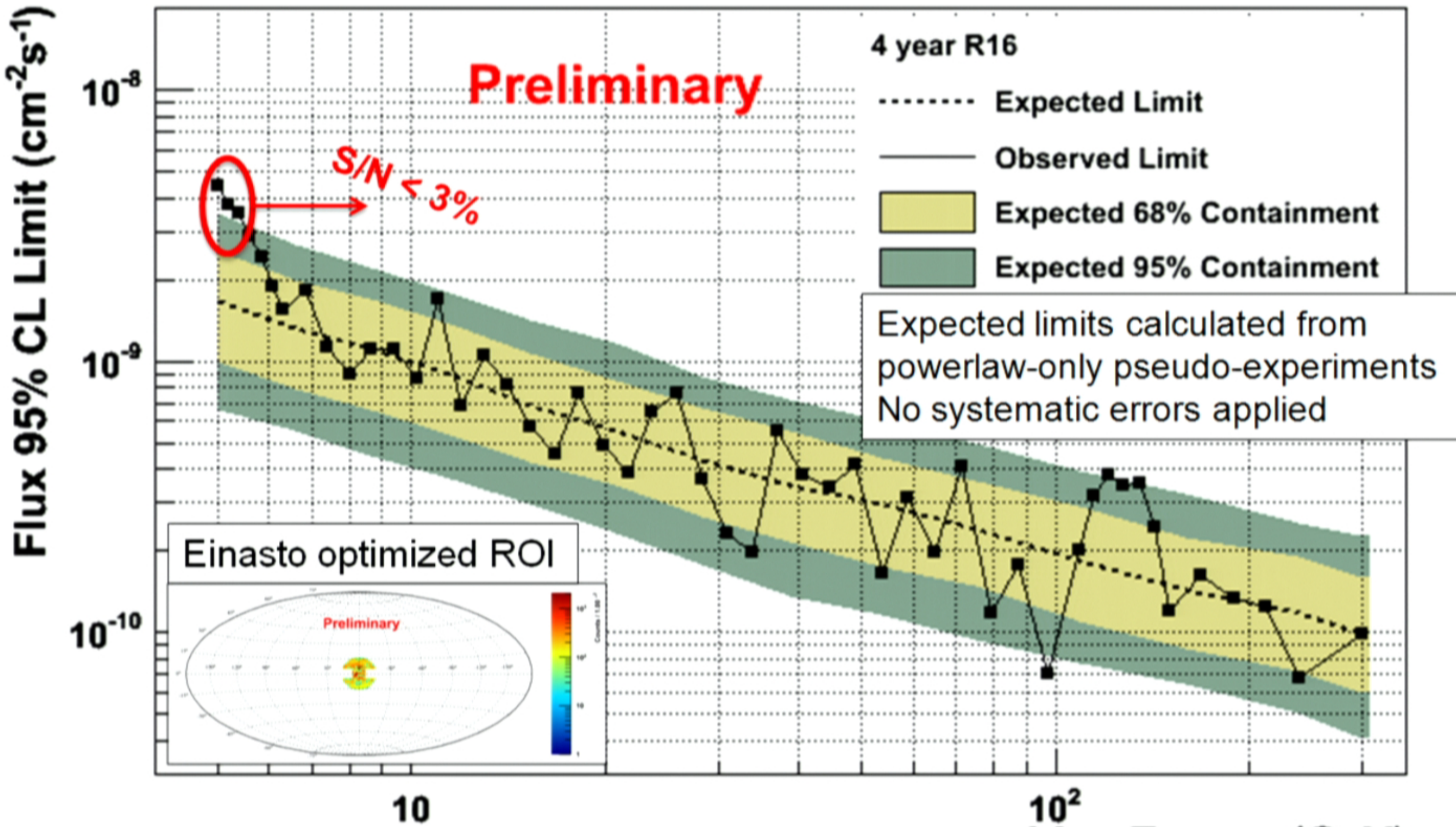
- **No globally significant lines found**
  - **Most significant fit was in R180 at 5 GeV, ~2σ (3.7σ local)**



Andrea Albert (OSU)

Spectral Line 95% CL Flux Upper Limit R16

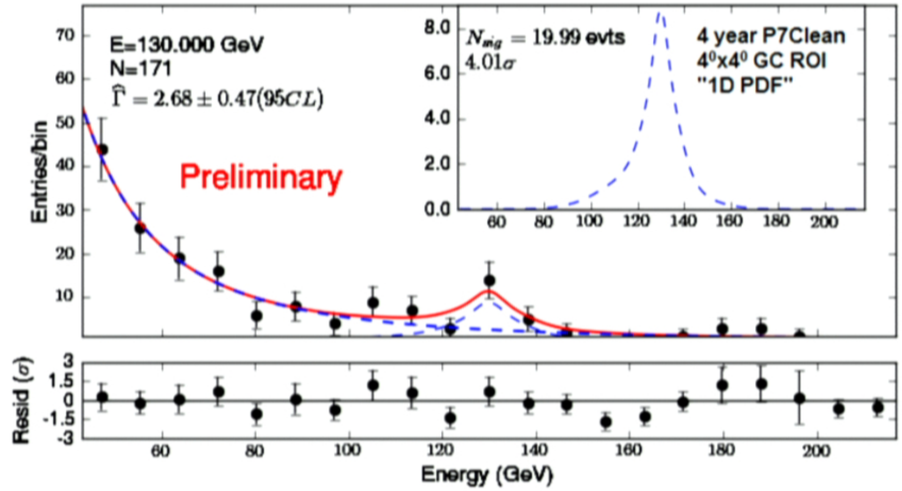
- No globally significant lines found
  - Most significant fit was in R180 at 5 GeV, ~2σ (3.7σ local)



11/26/2012 Andrea Albert (OSU) 45

Line-like Feature near 135 GeV

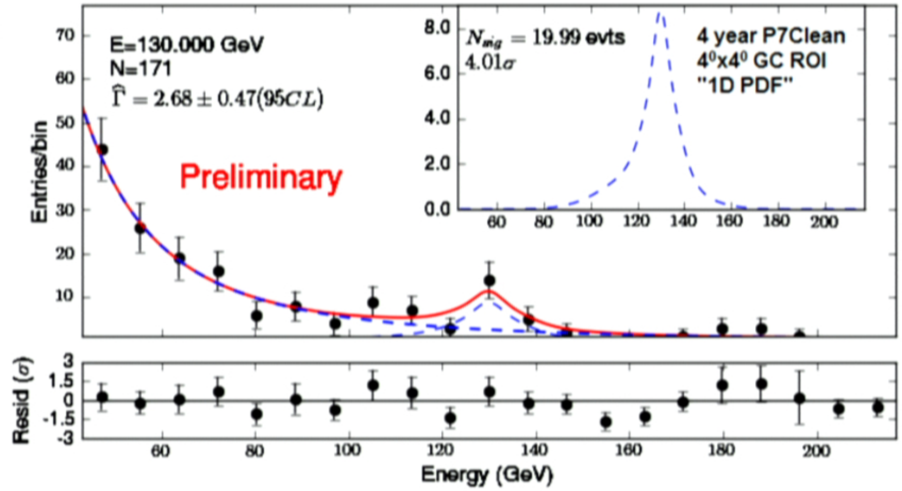
- **Our blind search does not find globally significant feature near 135 GeV**
  - Reprocessing shifts feature from 130 GeV to 135 GeV
  - Most significant fit was in R0, 2.23σ local (<0.5σ global)
- **Much interest after detection of line-like feature localized in the Galactic center at 130 GeV**
  - See C. Weniger JCAP 1208 (2012) 007 arXiv:1204.2797
- **4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data**
  - Look in 4°x4° GC ROI
  - Use 1D PDF (no use of P_E)



Andrea Albert (OSU)

Line-like Feature near 135 GeV

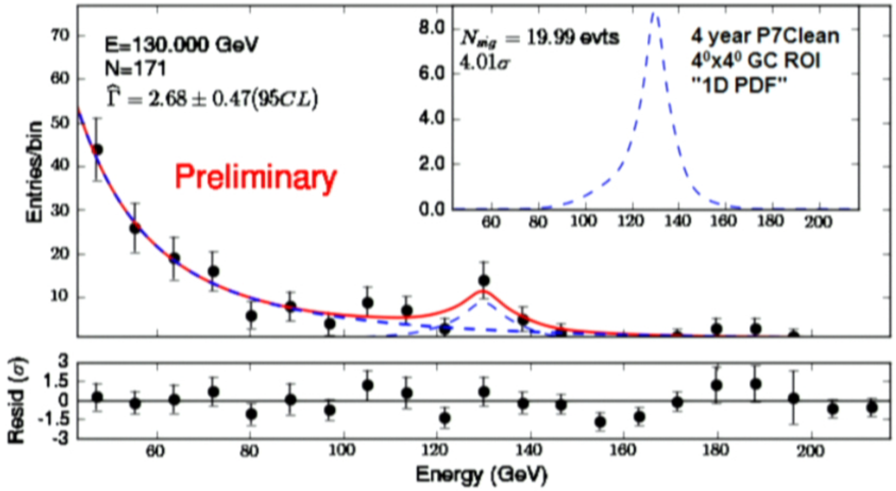
- Our blind search does not find globally significant feature near 135 GeV
  - Reprocessing shifts feature from 130 GeV to 135 GeV
  - Most significant fit was in R0, 2.23σ local (<0.5σ global)
- Much interest after detection of line-like feature localized in the Galactic center at 130 GeV
  - See C. Weniger JCAP 1208 (2012) 007 arXiv:1204.2797
- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in 4°x4° GC ROI
  - Use 1D PDF (no use of P_E)



Andrea Albert (OSU)

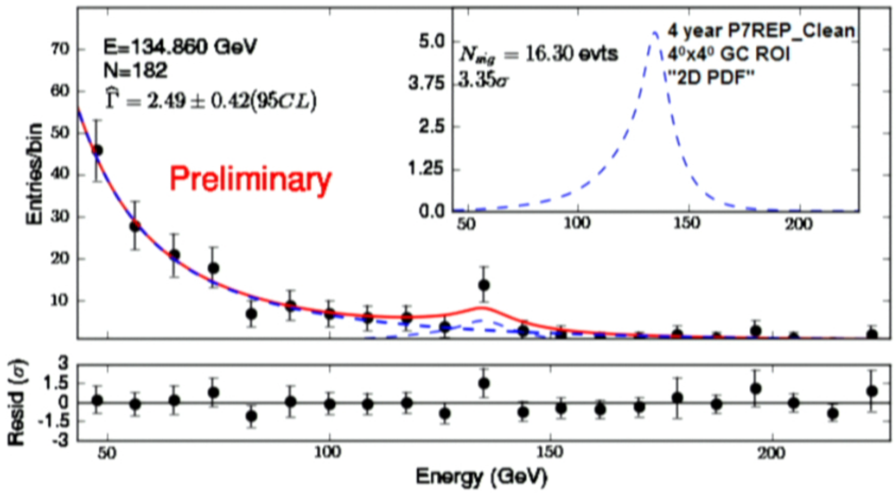
Line-like Feature near 135 GeV

- Our blind search does not find globally significant feature near 135 GeV
  - Reprocessing shifts feature from 130 GeV to 135 GeV
  - Most significant fit was in R0, 2.23σ local (<0.5σ global)
- Much interest after detection of line-like feature localized in the Galactic center at 130 GeV
  - See C. Weniger JCAP 1208 (2012) 007 arXiv:1204.2797
- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in 4°x4° GC ROI
  - Use 1D PDF (no use of P_E)



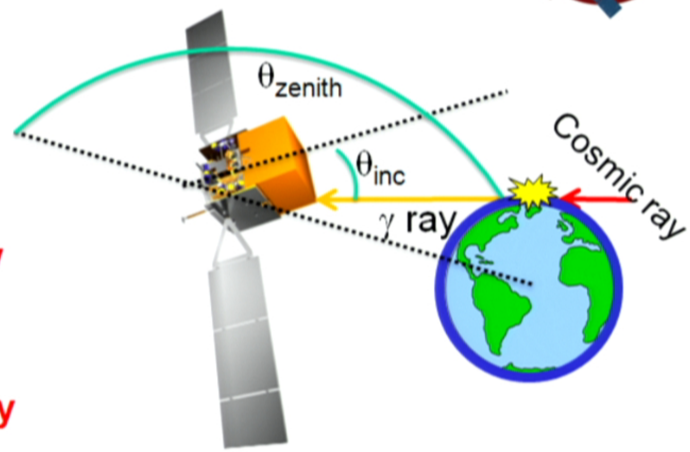
Line-like Feature near 135 GeV

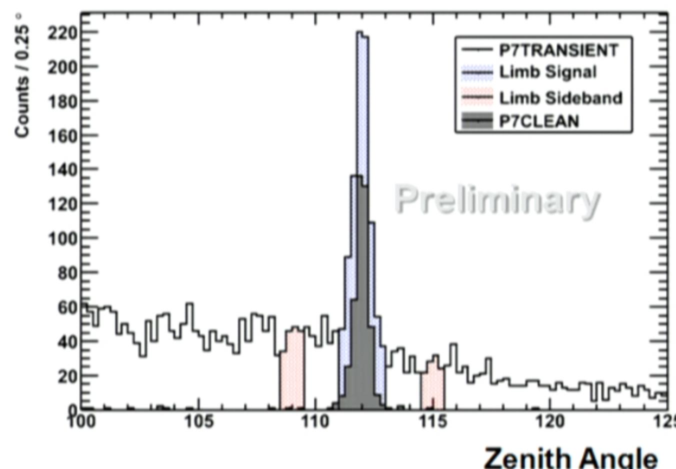
- **Our blind search does not find globally significant feature near 135 GeV**
  - Reprocessing shifts feature from 130 GeV to 135 GeV
  - Most significant fit was in R0, 2.23σ local (<0.5σ global)
- **Much interest after detection of line-like feature localized in the Galactic center at 130 GeV**
  - See C. Weniger JCAP 1208 (2012) 007 arXiv:1204.2797
- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in 4°x4° GC ROI
  - Use 1D PDF (no use of P_E)
- 3.73σ (local) 1D fit at 135 GeV with 4 year reprocessed data
  - Look in 4°x4° GC ROI
  - Use 1D PDF (no use of P_E)
- **3.35σ (local) 2D fit at 135 GeV with 4 year reprocessed data**
  - Look in 4°x4° GC ROI
  - Use 2D PDF
    - P_E in data → feature is slightly narrower than expected
  - <2σ global



135 GeV in the Earth Limb spectrum (1)

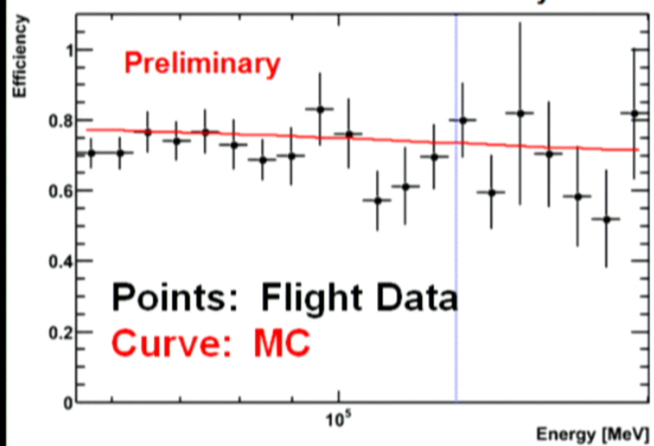
- Earth Limb is a bright, well understood source
  - γ rays from CR interactions in the atmosphere
    - Expected to be a smooth power-law
  - Can be used to study instrumental effects
    - Can see in loosest cuts → can study cut efficiencies
- Need to cut on times when the LAT was pointing at the limb
- Have made changes to increase our Limb dataset
  - Pole-pointed observations each week
  - Extended "targets of opportunity"
    - Trace limb while target is occulted



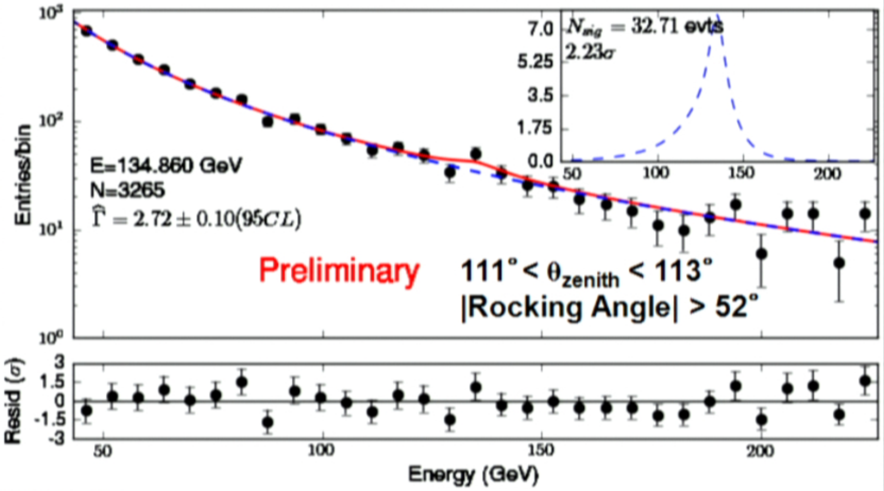


135 GeV in the Earth Limb spectrum (2)

P7Transient to P7Clean Efficiency

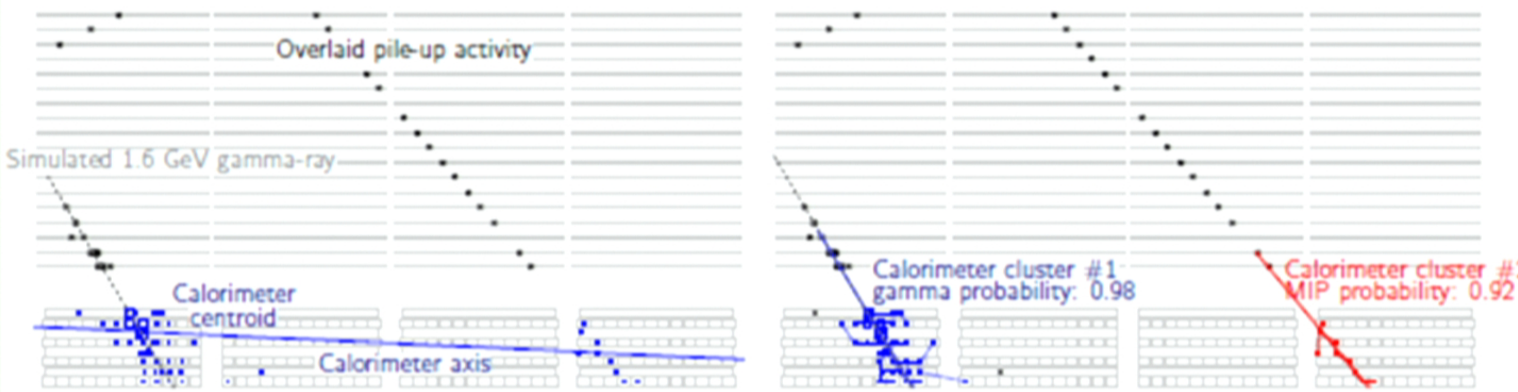


Fit to Limb data



- Dips in efficiency below and above 135 GeV
  - Appear to be related to CAL-TKR agreement
  - Could be artificially sculpting the energy spectrum
- Line-like feature in the limb at 135 GeV
  - Appears when LAT is pointing at the Limb
  - Surprising since limb should be smooth
  - S/N_{limb} ~15%, while S/N_{GC} ~30% - 66% (depending on ROI choice)
    - Limb feature not large enough to explain all the GC signal

Pass 8



- **Better event selection (higher signal efficiency at the same bkg level)**
  - **Expect a ~25% increase in high-energy effective area in the "standard" photon classes**
- **Better control over systematic uncertainties**
- **Extend both low and high energy reach**
- **Include calorimeter-only events (substantial effective area increase above 40 GeV)**
- **Better high-energy point spread function**

Summary

- The Fermi LAT team has looked for indirect DM signals using a wide variety of different methods
  - So far no signals have been detected and strong constraints have been set
- Observed deviations from conventional models in e^+e^- spectrum
  - Confirm PAMELA e^+ fraction increase
- We do not see any globally significant spectral lines
- Uncovered some aspects of the 135 GeV line that require more study
  - Significance decreases with analysis improvements
  - Also present in the Earth limb
  - Too soon to draw firm conclusions, more data needed
    - More data + Pass 8 will give a more definitive answer in 1 year
- Current searches are already exploring interesting parts of WIMP phase space and will just keep getting more sensitive; stay tuned for more exciting Dark Matter results from the Fermi LAT!