(Estimated) Optimized conservative constraints on Dark Matter models using Fermi Diffuse Spectrum

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(Stony Brook University)
on behalf of The Fermi-LAT Collaboration
with
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Andrea Albert (KIPAC-SLAC)

Pheno 2014 - University of Pittsburgh
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Fermi *Gamma-ray Space Telescope*

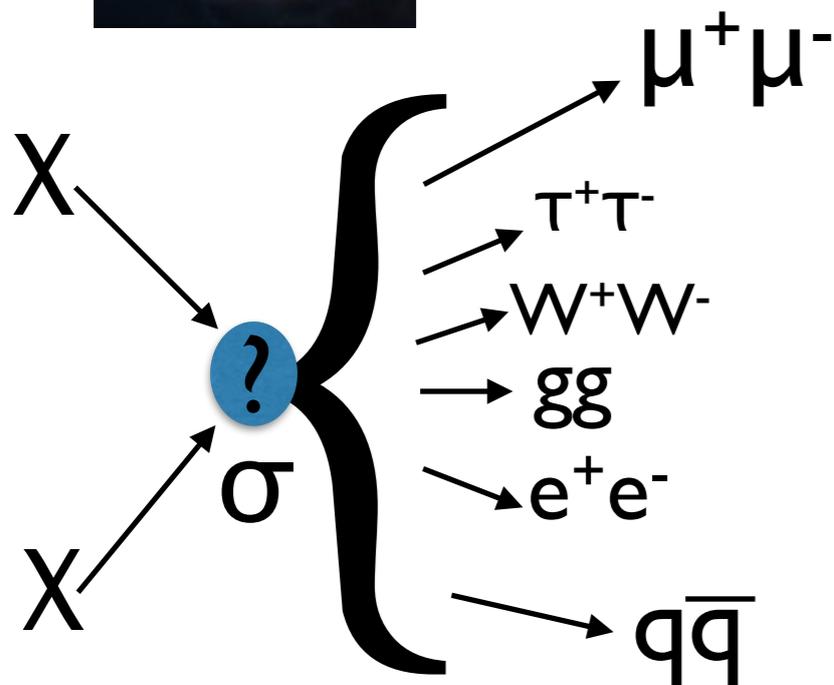National Aeronautics and Space Administration

www.nasa.gov/fermi

Outline

- Constraining DM models

- Optimizing Regions of Interest in the gamma-ray Sky
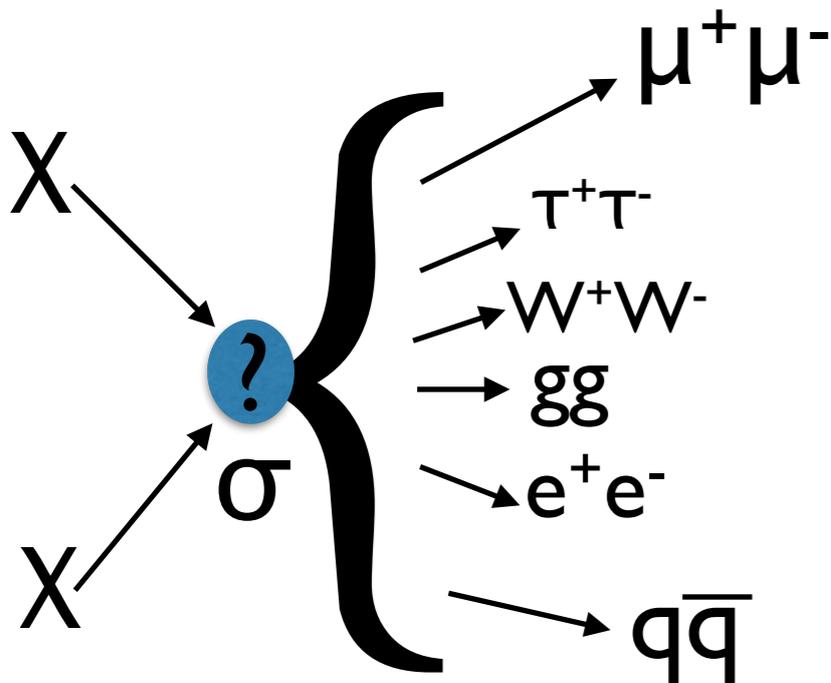
- Prospective results overview

Introduction

Dark Matter models (such as WIMPs) can feature DM annihilating into Standard Model particles.

$$\chi\chi \xrightarrow{\sigma} \begin{cases} \mu^+\mu^- \\ \tau^+\tau^- \\ W^+W^- \\ gg \\ e^+e^- \\ q\bar{q} \end{cases}$$

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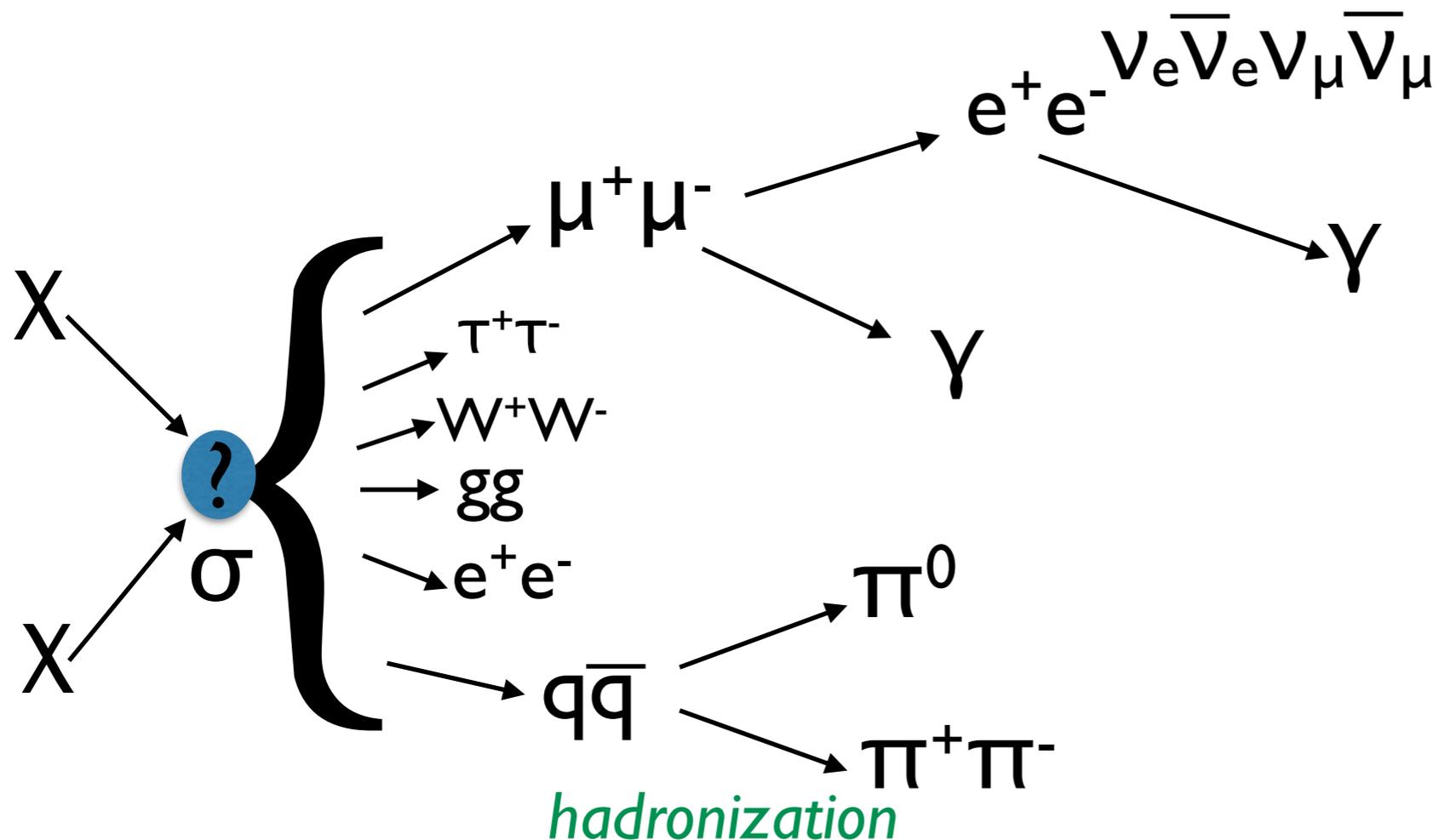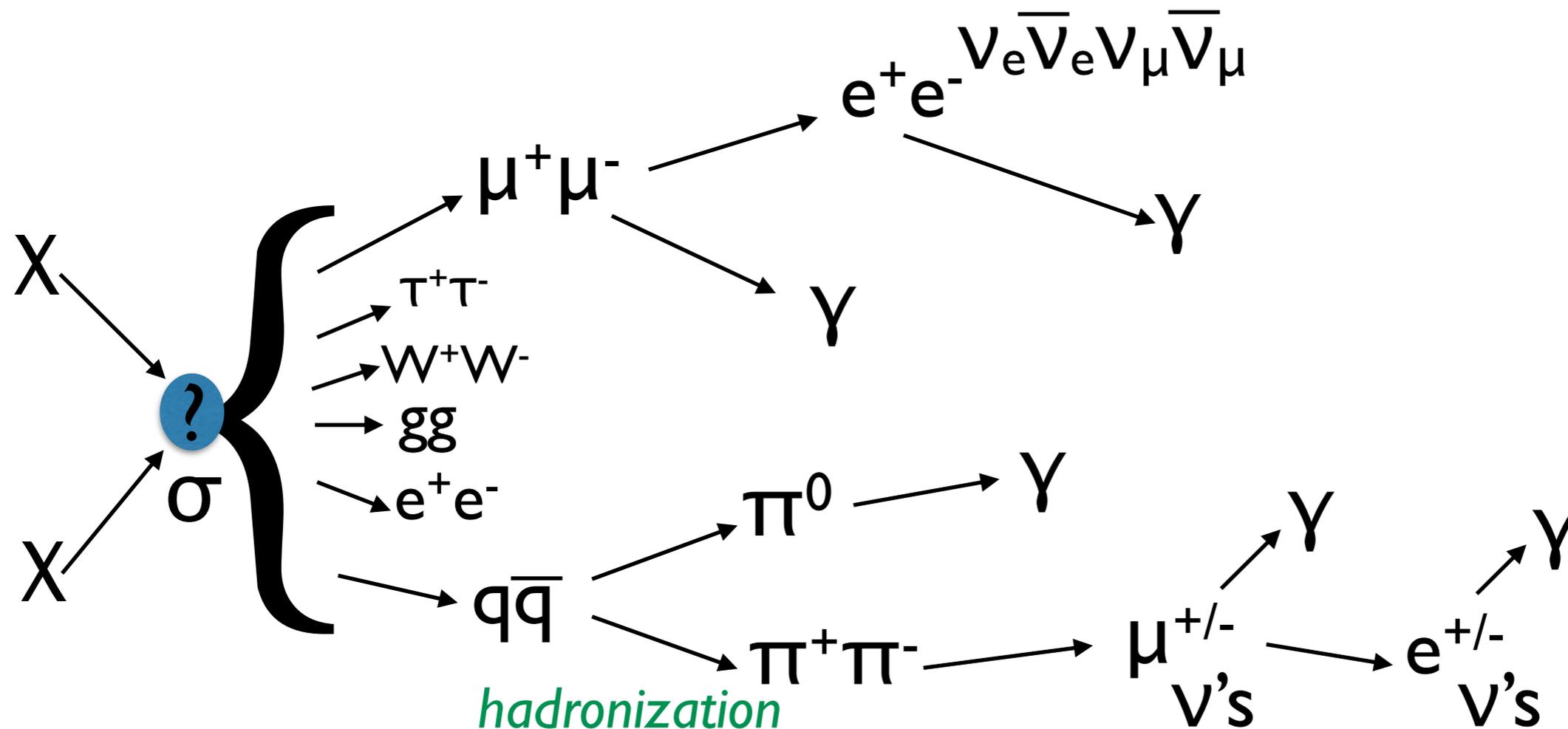SM particles decay/propagate and final products are detectable.

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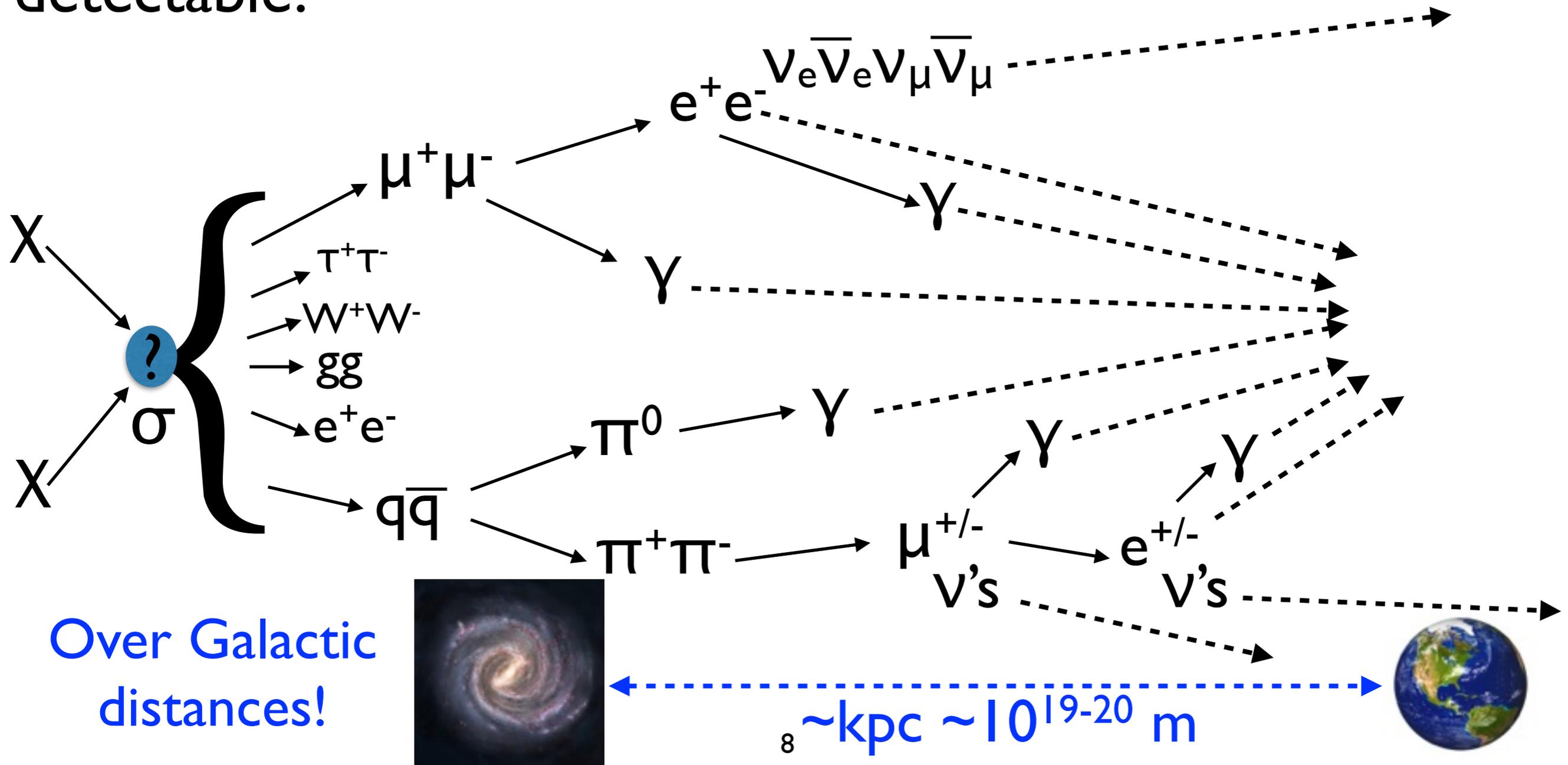Dark Matter models (such as WIMPs) can feature DM annihilating into Standard Model particles. SM particles decay/propagate and final products are detectable.
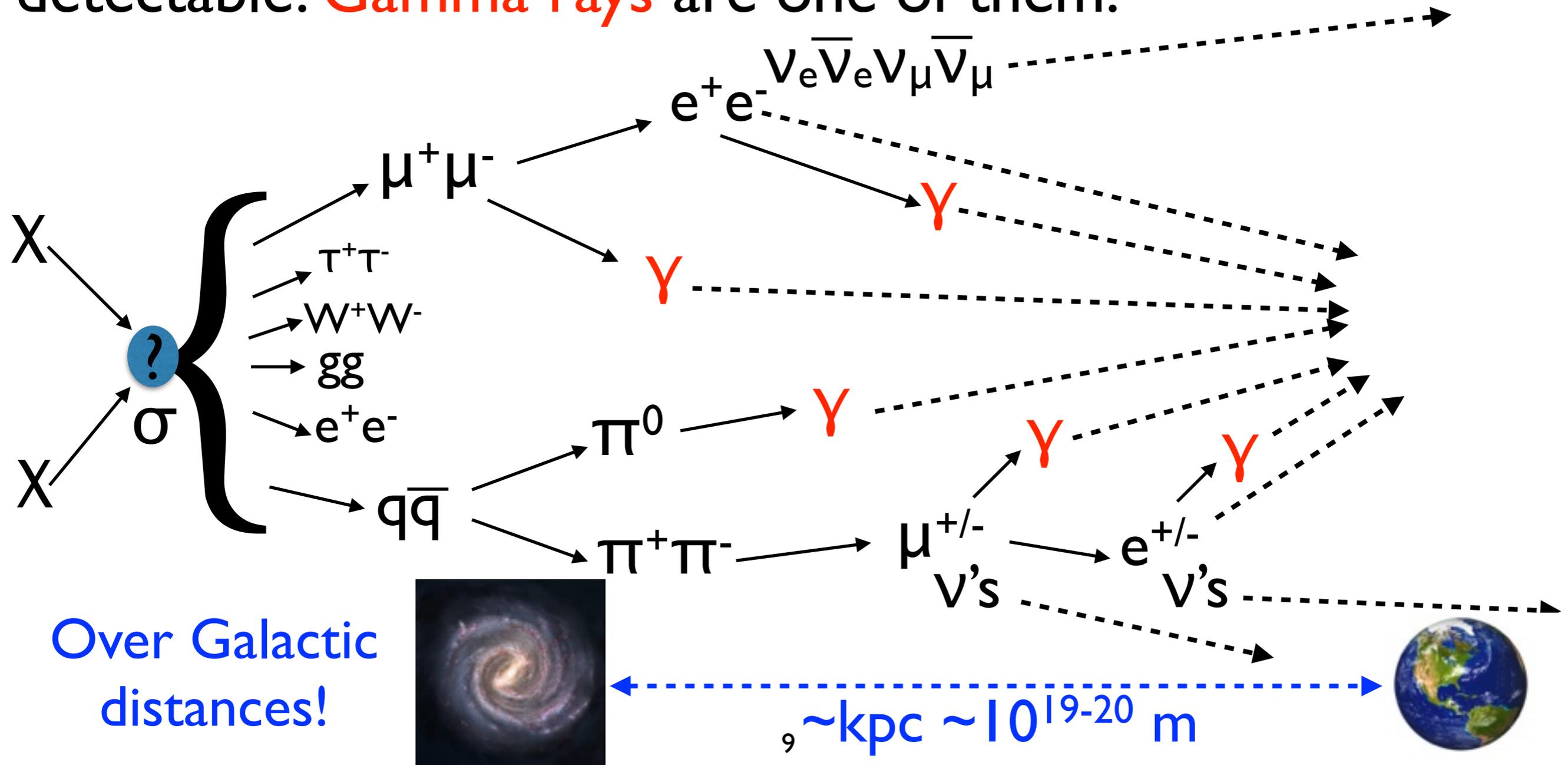
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Over Galactic distances!
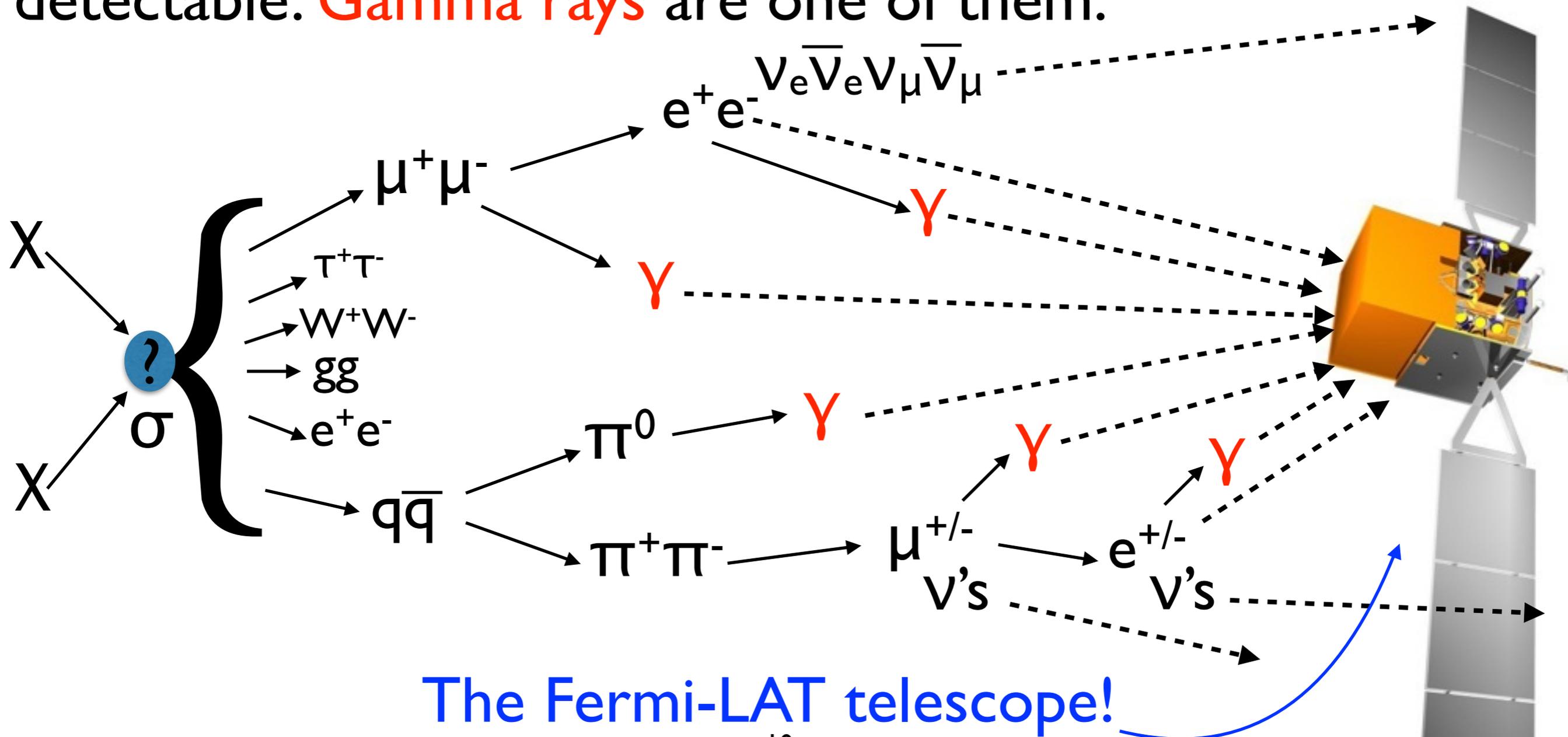
~kpc ~$10^{19\text{-}20}$ m

Introduction

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χ
χ
σ
?

$\mu^+\mu^-$
$\tau^+\tau^-$
W^+W^-
gg
e^+e^-
$q\overline{q}$

e^+e^-
$\nu_e\overline{\nu}_e\nu_\mu\overline{\nu}_\mu$

γ

π^0
$\pi^+\pi^-$

γ

γ
$\mu^{+/-}$
ν's
γ
$e^{+/-}$
ν's
γ

Over Galactic distances!

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9

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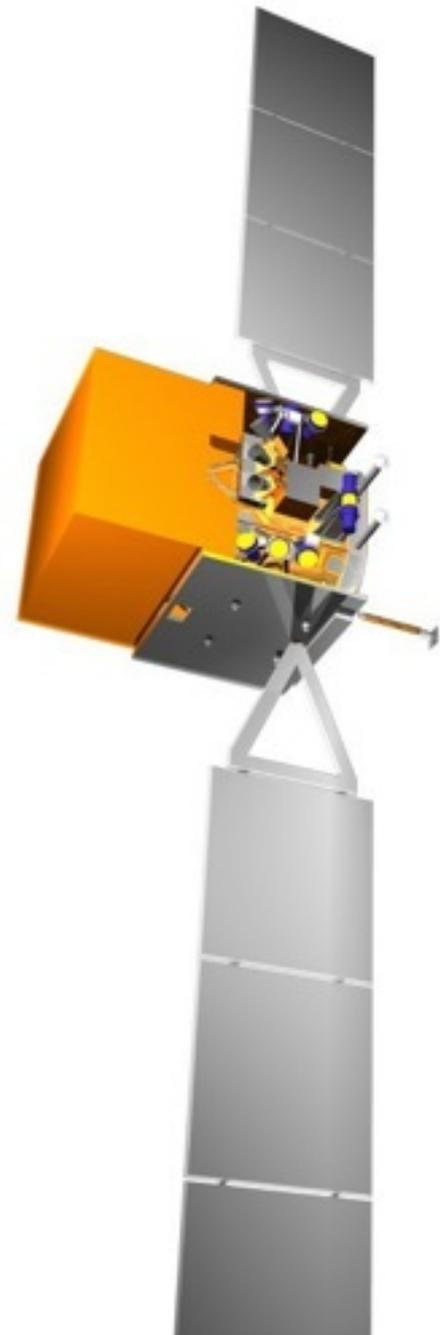SM particles decay/propagate and final products are detectable. Gamma rays are one of them.

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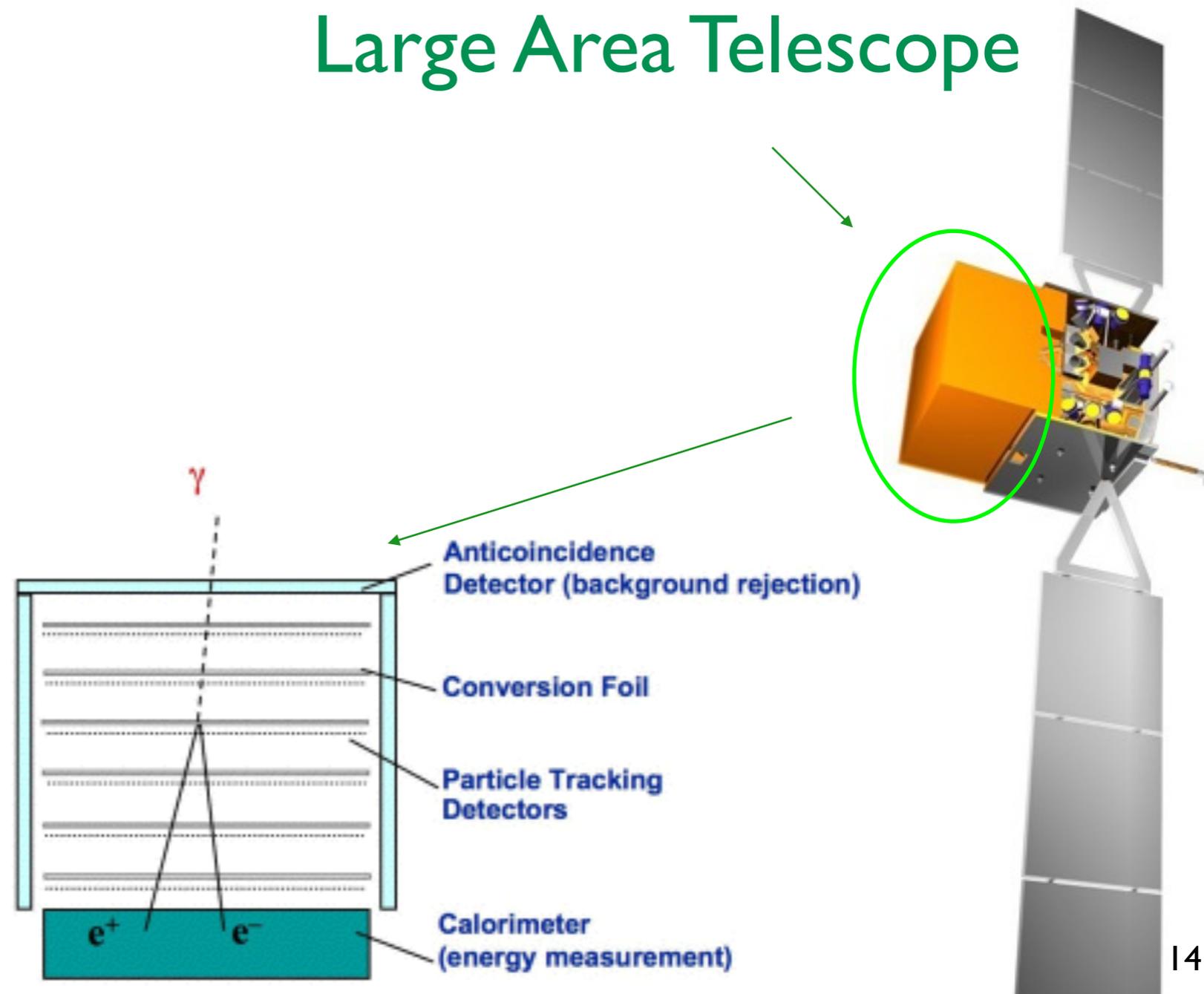ν's
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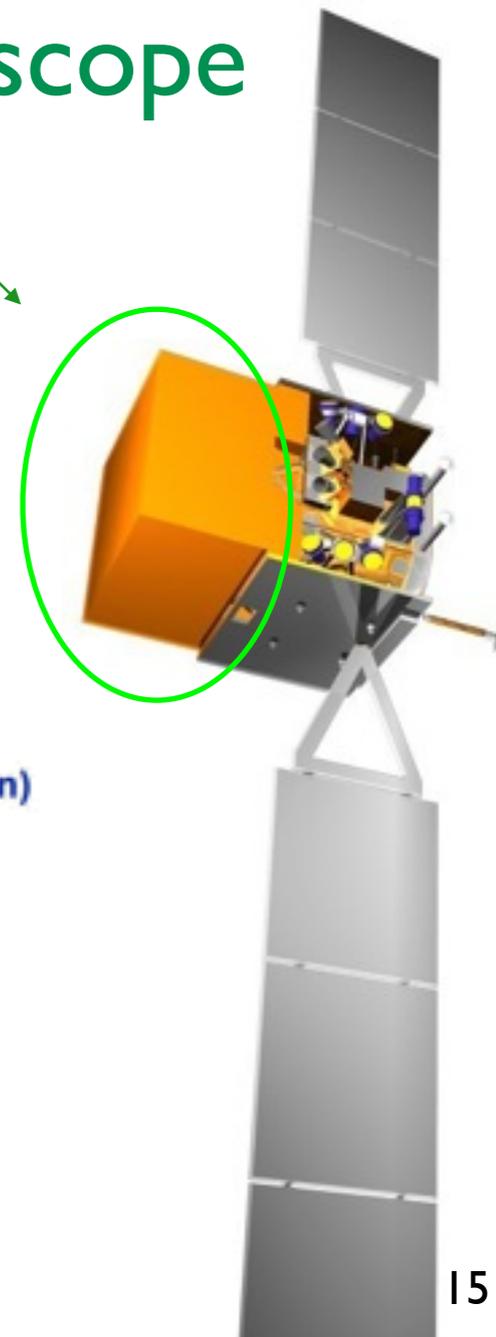
The Fermi-LAT telescope!

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The Fermi-Large Area Telescope

The Fermi-Large Area Telescope

- In orbit since June, 11th 2008
- Photons from ~20 MeV to over 300 GeV
- Surveys entire sky every 3 hours

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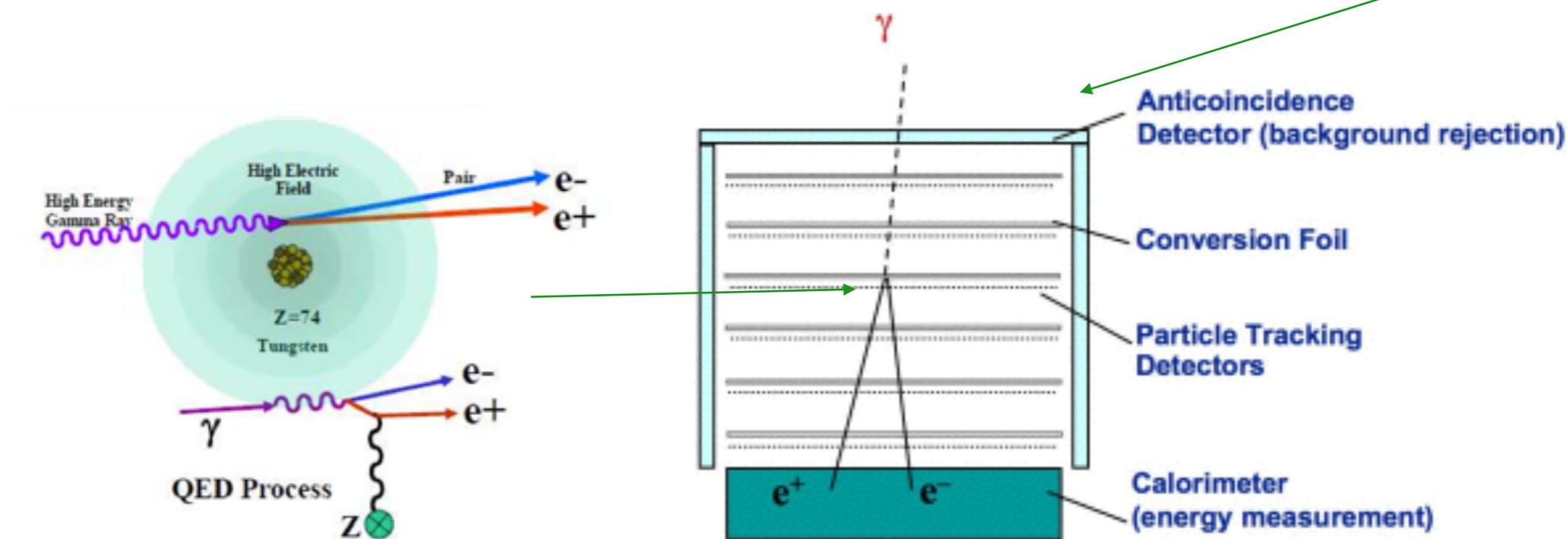- Surveys entire sky every 3 hours
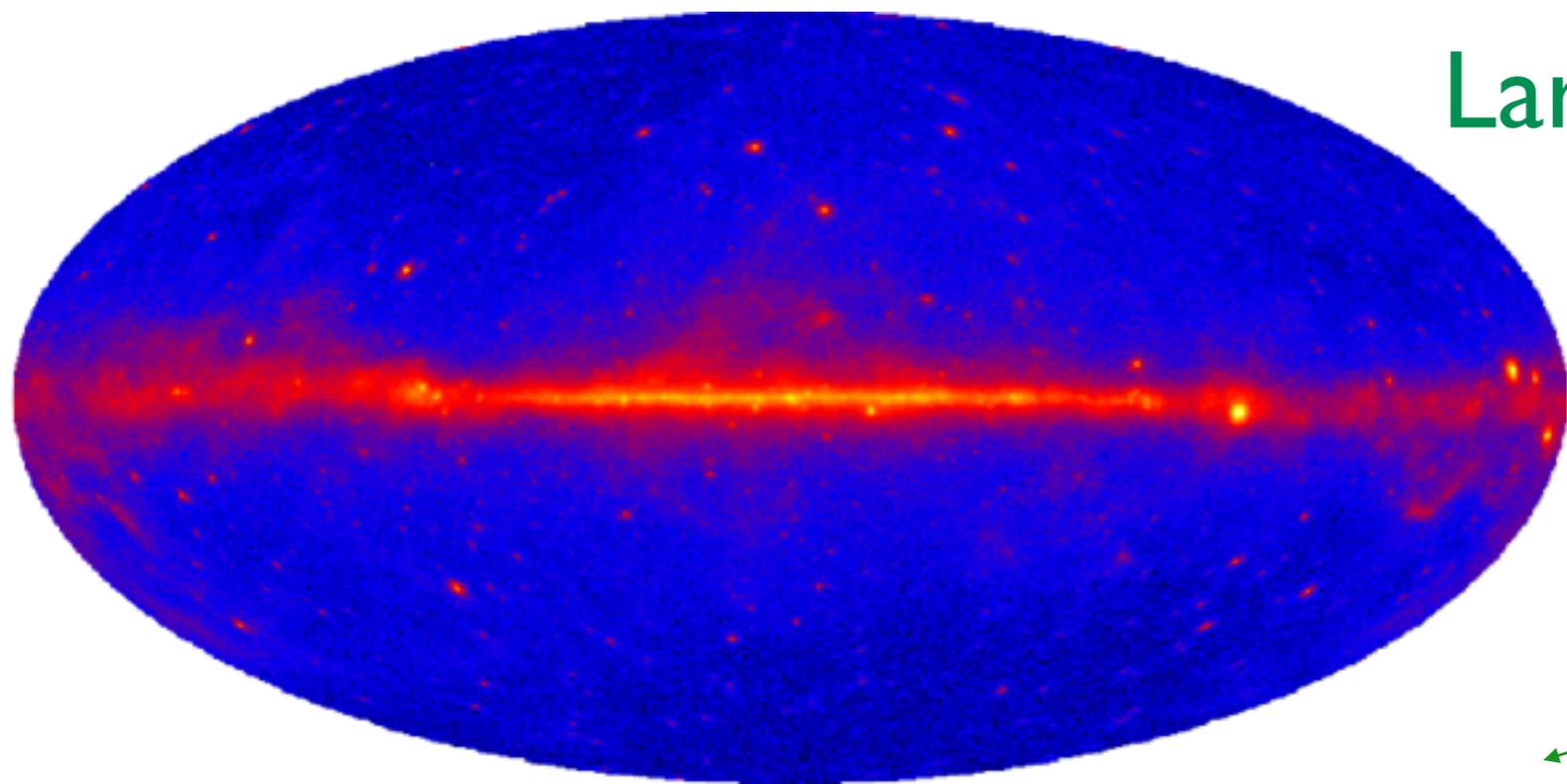
Large Area Telescope

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Large Area Telescope

γ

Anticoincidence
Detector (background rejection)

Conversion Foil

Particle Tracking
Detectors

e⁺   e⁻

Calorimeter
(energy measurement)

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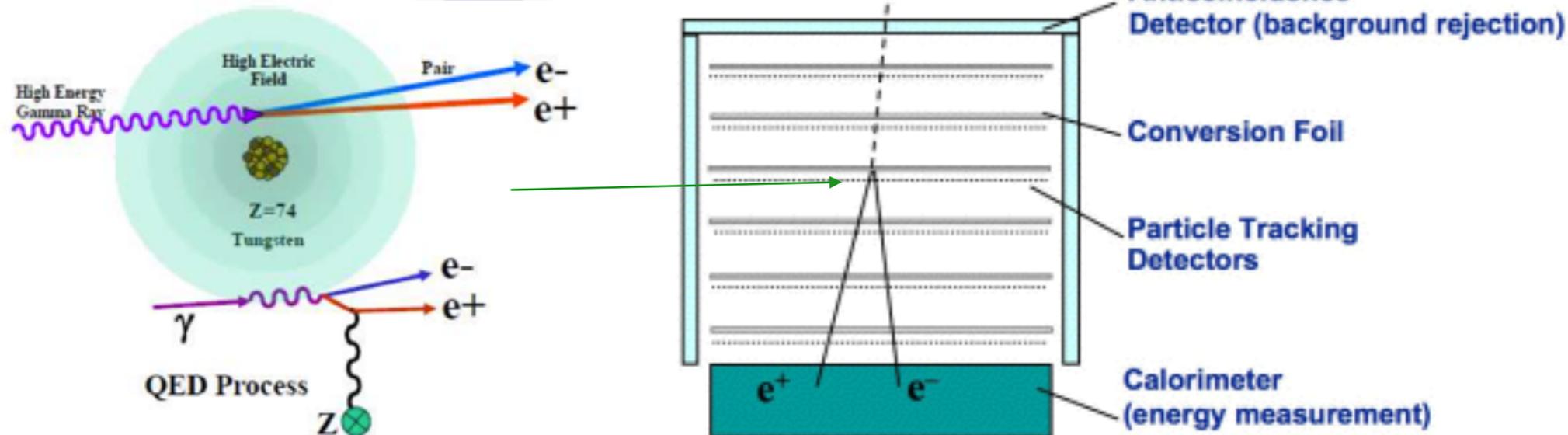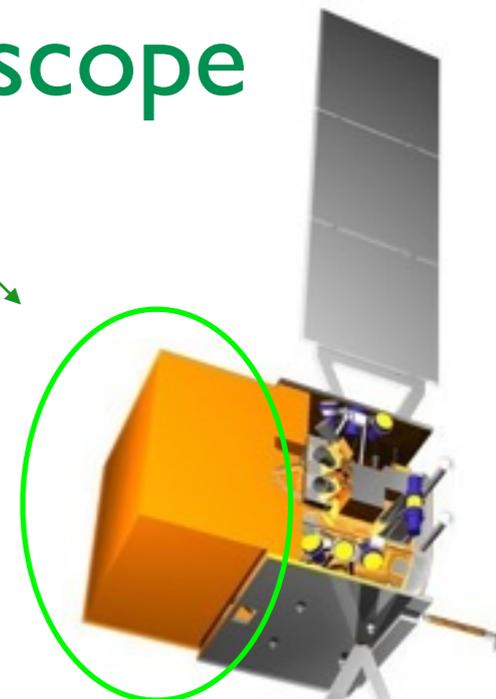- Surveys entire sky every 3 hours

Large Area Telescope

High Electric Field

Pair

e−

High Energy Gamma Ray

e+

Z=74
Tungsten

e−
e+

γ

QED Process

Z

γ

Anticoincidence Detector (background rejection)

Conversion Foil

Particle Tracking Detectors

e+   e−

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Calorimeter (energy measurement)

e+   e−

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Setting the constraints on DM models

Similar recent analyses by Fermi collaboration:

1205.2739 Ackermann et al. "Pass 6 paper"

1205.6474 Ackermann et al. "Halo paper"

1308.3515 Gómez-Vargas et al. "Inner Galaxy paper"

Comparison with our work:
- ~same way of setting constraint (but different c.l.)
- different model choices (e.g. DM profiles)
- new: ROI optimization method

Setting the constraints on DM models

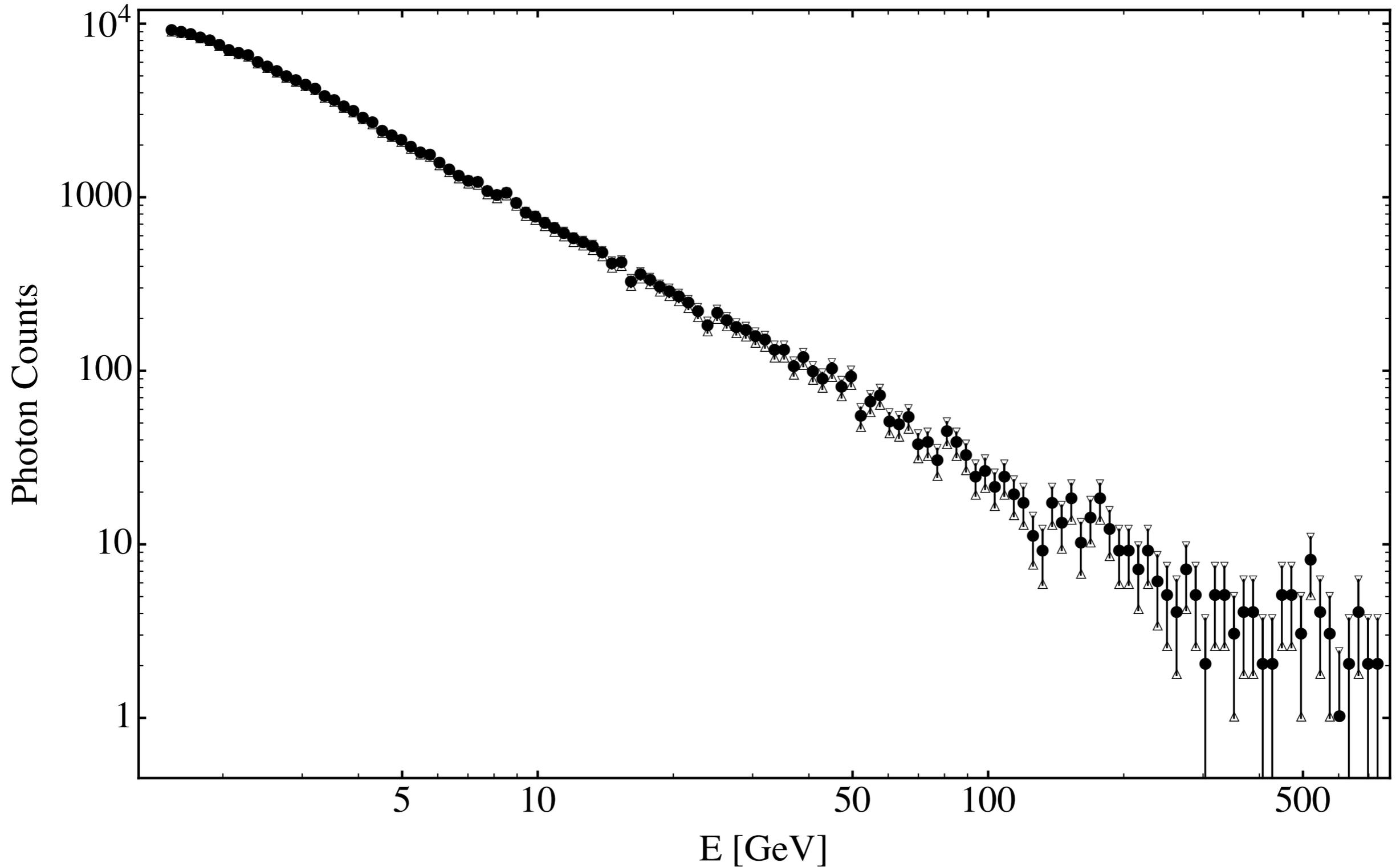Here is the gamma-ray spectrum with statistical error bars

[from a Monte Carlo simulation!]

Setting the constraints on DM models

For annihilating DM, photon counts $\propto \langle \sigma v \rangle$

Setting the constraints on DM models

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e.g. for Prompt radiation

$$N^{\Omega,k}_{\chi\chi \to X \to \gamma} = \frac{1}{8\pi} \frac{r_\odot \rho^2_\odot}{m^2_\chi} \langle \sigma v \rangle \int_{E_k}^{E_{k+1}} dE_\gamma \frac{dN_{X \to \gamma}}{dE_\gamma} J_{\Omega,ann} \exp^{\Omega,k}$$

Setting the constraints on DM models

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Require expected counts < observed counts
(at, e.g., 95% c.l.)

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$\Longrightarrow$ (95%) upper limit on $\langle \sigma v \rangle$

Setting the constraints on DM models

Setting the constraints on DM models

compute 95% Poisson UL on the counts
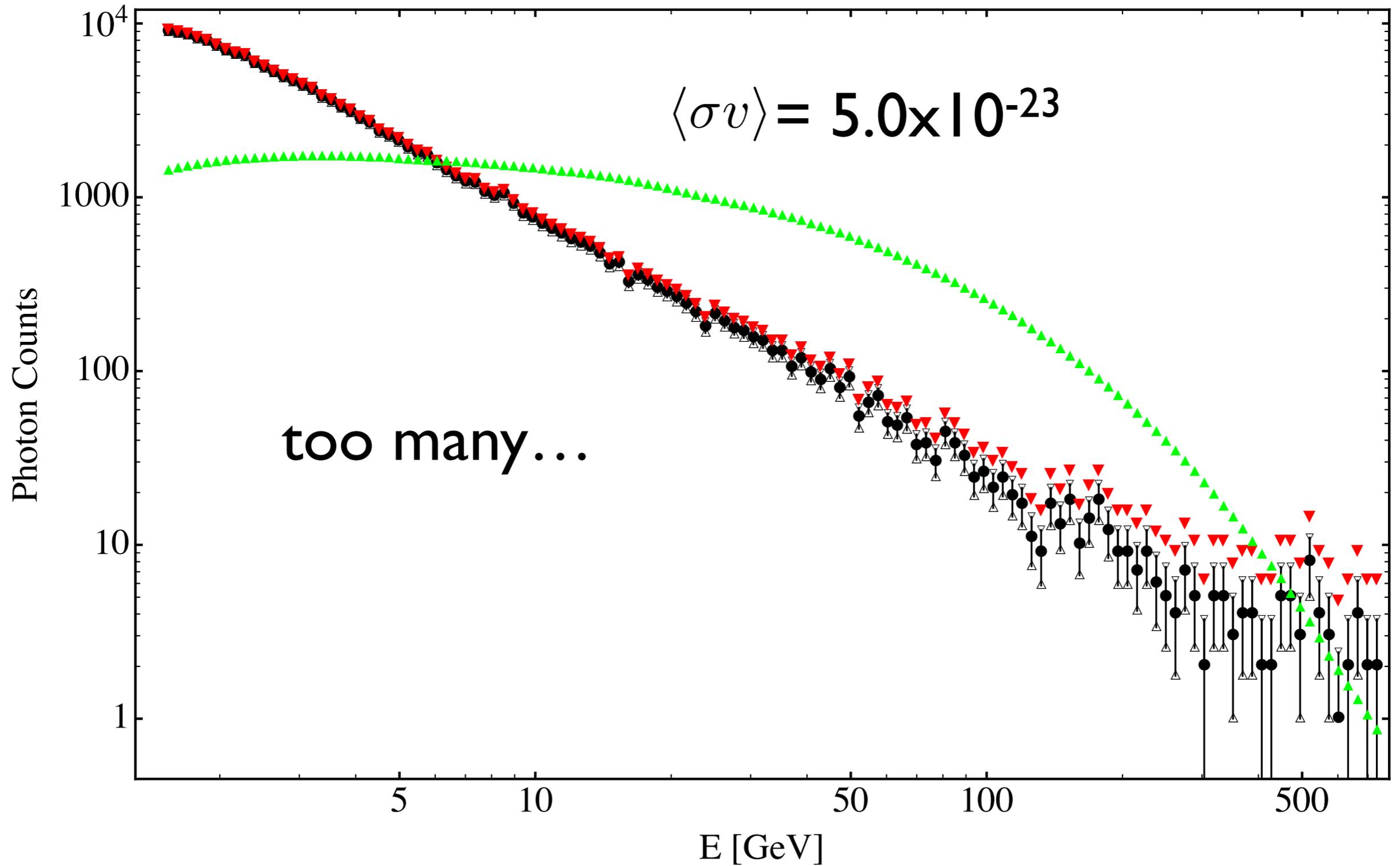
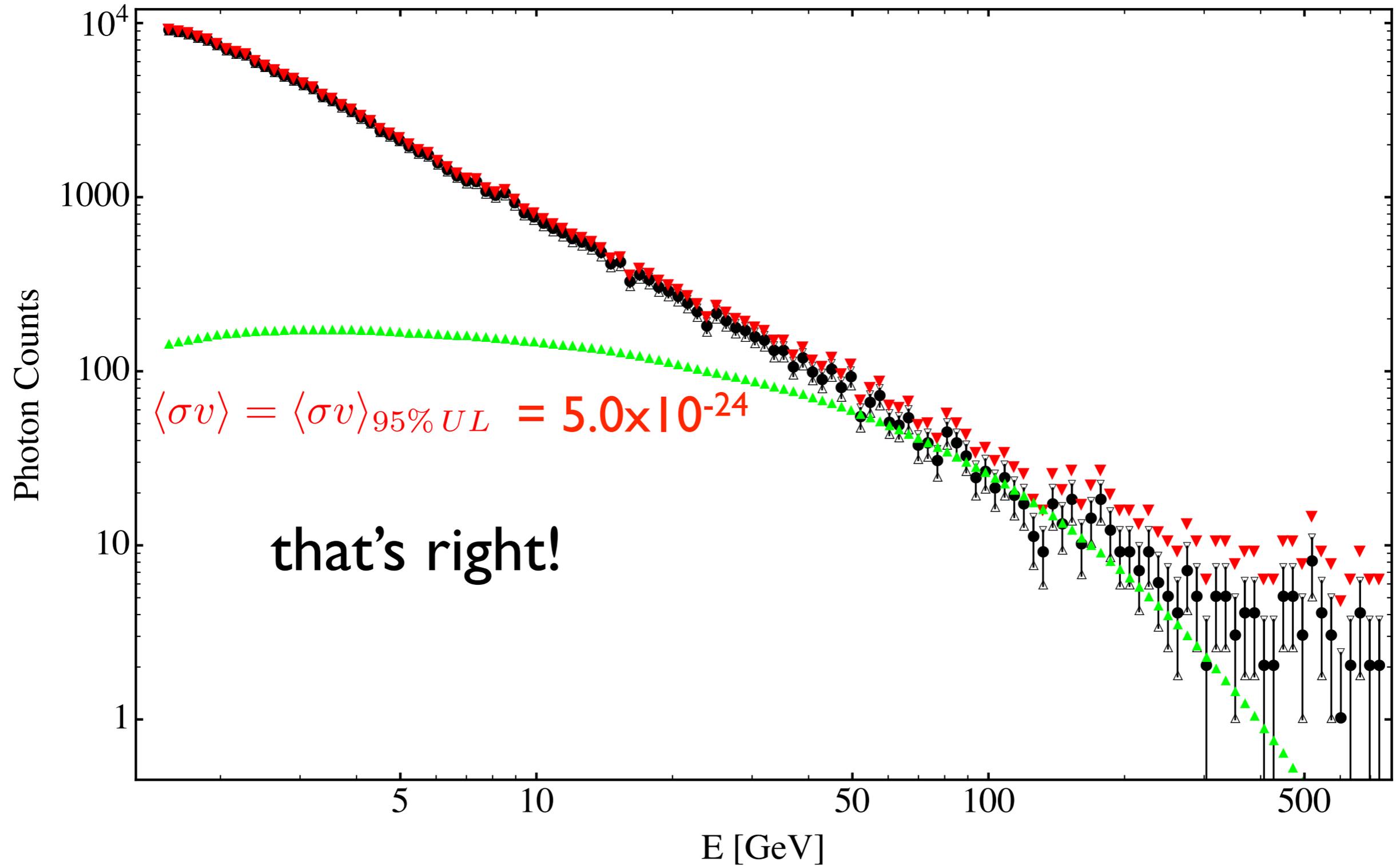# Setting the constraints on DM models

compute 95% Poisson UL on the counts

now add the DM
expected counts

Setting the constraints on DM models

too few…

$\langle \sigma v \rangle = 5.0 \times 10^{-25}$

Photon Counts

E [GeV]

Setting the constraints on DM models

$\langle \sigma v \rangle = 5.0 \times 10^{-23}$

too many…

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Setting the constraints on DM models

$\langle \sigma v \rangle = \langle \sigma v \rangle_{95\% UL} = 5.0 \times 10^{-24}$

that's right!

Setting the constraints on DM models

most constraining
data point

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Photon Counts

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most constraining
data point

$\langle \sigma v \rangle = \langle \sigma v \rangle_{95\% UL} = 5.0 \times 10^{-24}$

Photon Counts

E [GeV]

30

Setting the constraints on DM models

I might get a stricter bound...

$\langle \sigma v \rangle = \langle \sigma v \rangle_{95\% \, UL} = 5.0 \times 10^{-24}$

Photon Counts

E [GeV]

Setting the constraints on DM models
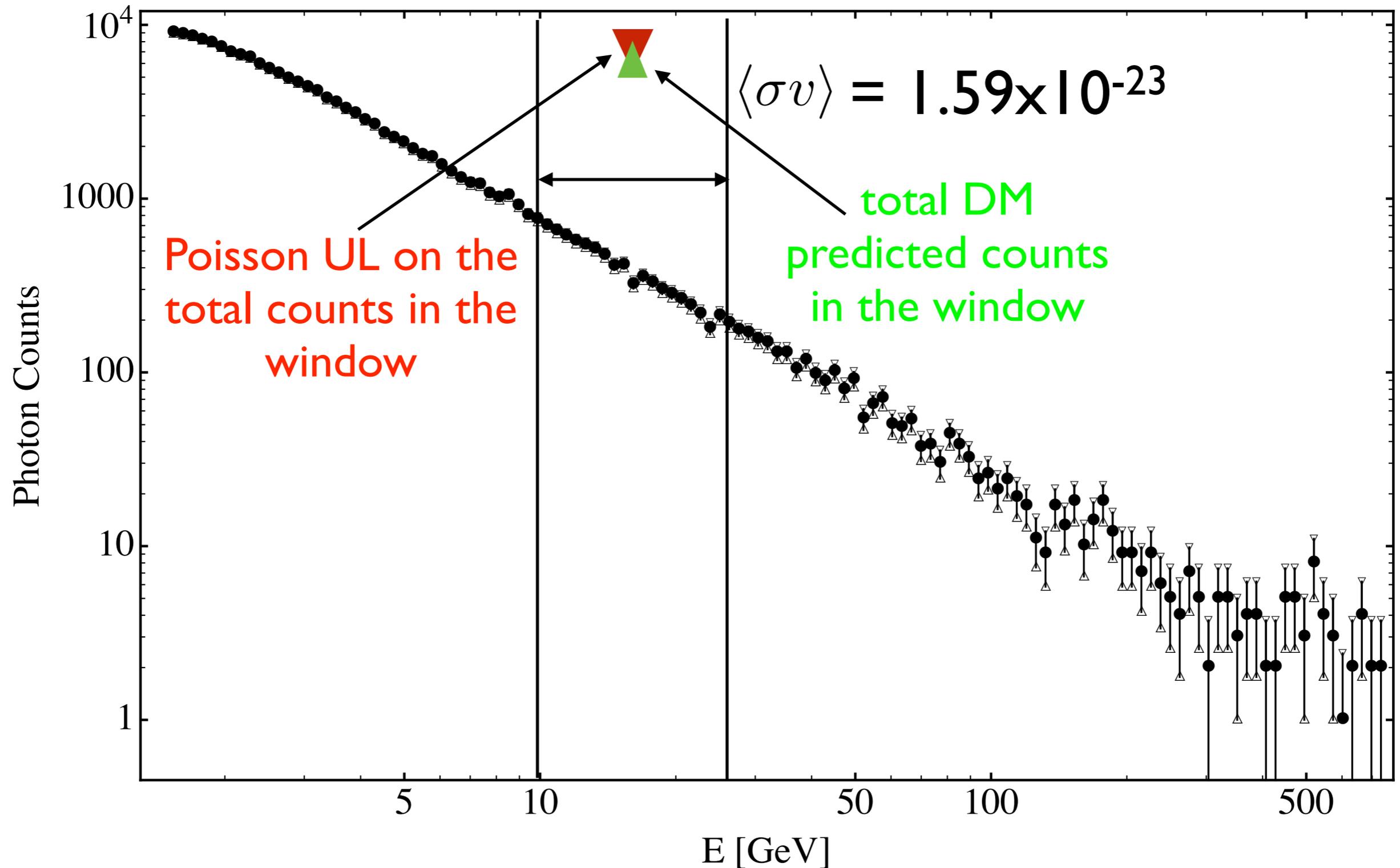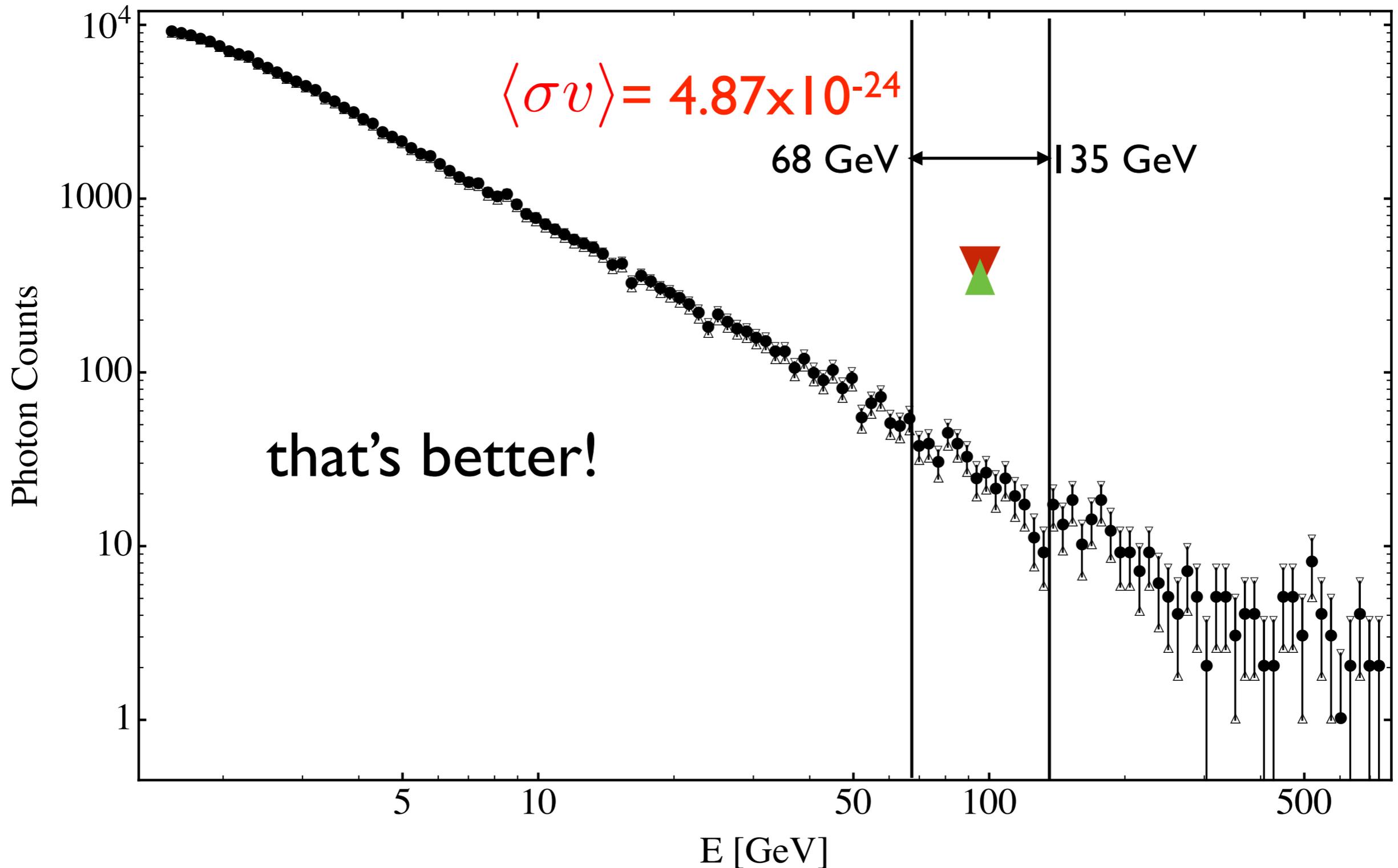
Idea: use a sliding window of variable width in energy

Setting the constraints on DM models

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Poisson UL on the total counts in the window

Setting the constraints on DM models

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$\langle \sigma v \rangle = 4.87 \times 10^{-24}$

68 GeV 135 GeV

that's better!

Photon Counts

E [GeV]

DM density profiles

Remember:

$$N^{\Omega,k}_{\chi\chi\to X\to\gamma} = \frac{1}{8\pi}\frac{r_\odot\rho_\odot^2}{m_\chi^2}\langle\sigma v\rangle \int_{E_k}^{E_{k+1}} \mathrm{d}E_\gamma \frac{\mathrm{d}N_{X\to\gamma}}{\mathrm{d}E_\gamma} J_{\Omega,ann} \exp^{\Omega,k}$$

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$$J_{\Omega,ann} = \iint_\Omega \mathrm{d}b\,\mathrm{d}l \int \frac{\mathrm{d}s}{r_\odot}\left[\cos b\,\frac{\rho(r(s,b,l))}{\rho_\odot}\right]^2$$

DM density profiles

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DM density profiles

DM density profiles

DM density profiles

Isothermal $\propto$ const
NFW $\propto r^{-1}$
Einasto $\propto \exp(\text{const } r^{0.17})$
for $r \sim 0$

$\rho_\odot = 0.4 \text{ GeVcm}^{-3}$

$r_\odot = 8.5 \text{ kpc}$

ρ_{DM} [GeV cm^{-3}]

r [kpc]

normalization at Sun's galactocentric radius

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Choosing Regions Of Interest (ROIs)

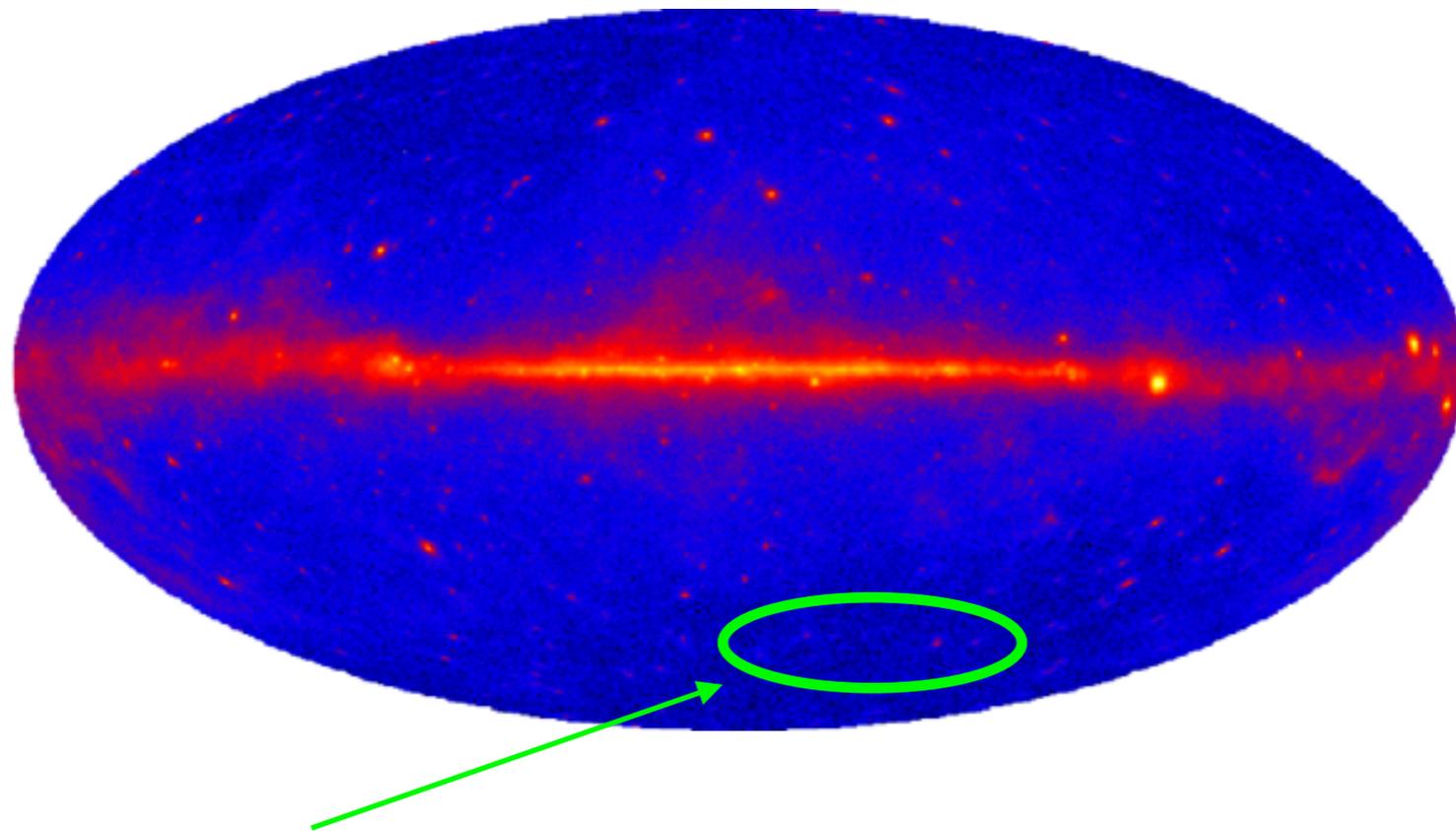Some sky patches are different…

Choosing Regions Of Interest (ROIs)

Some sky patches are different…

e.g. GC = lots of DM 😊 <u>but</u> lots of foreground 😞

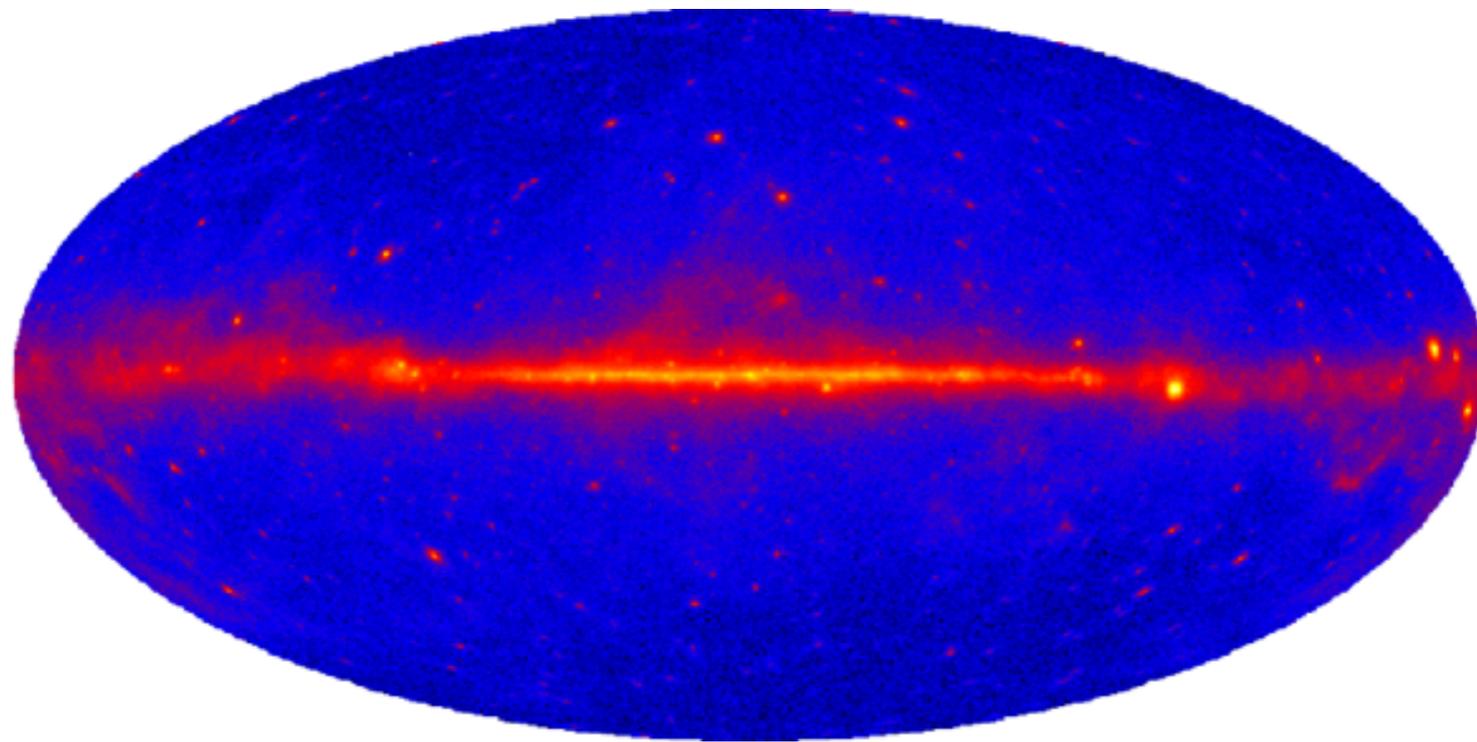# Choosing Regions Of Interest (ROIs)

Some sky patches are different…

high latitudes = little foreground 😊 <u>but</u> little DM 😞
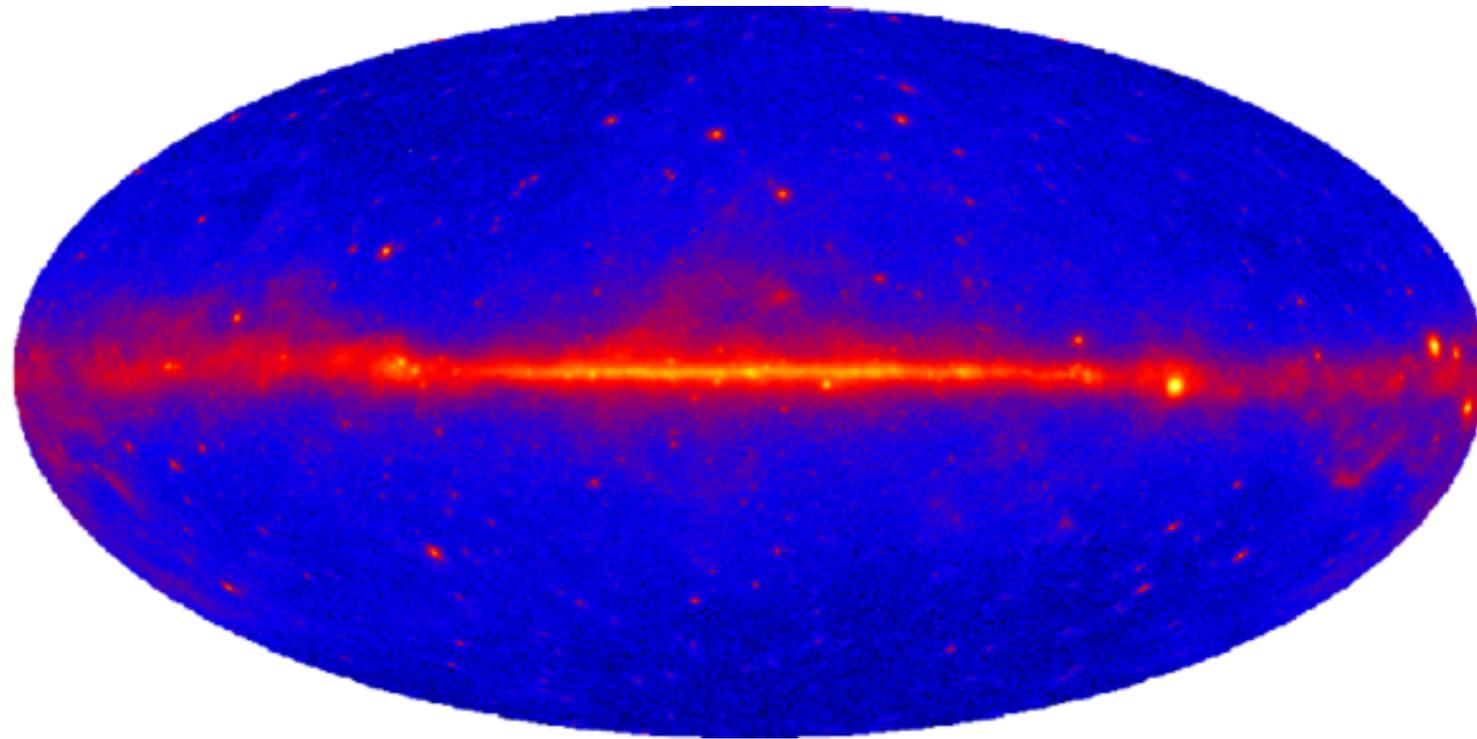
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Some sky patches are different…

Optimize ROI!

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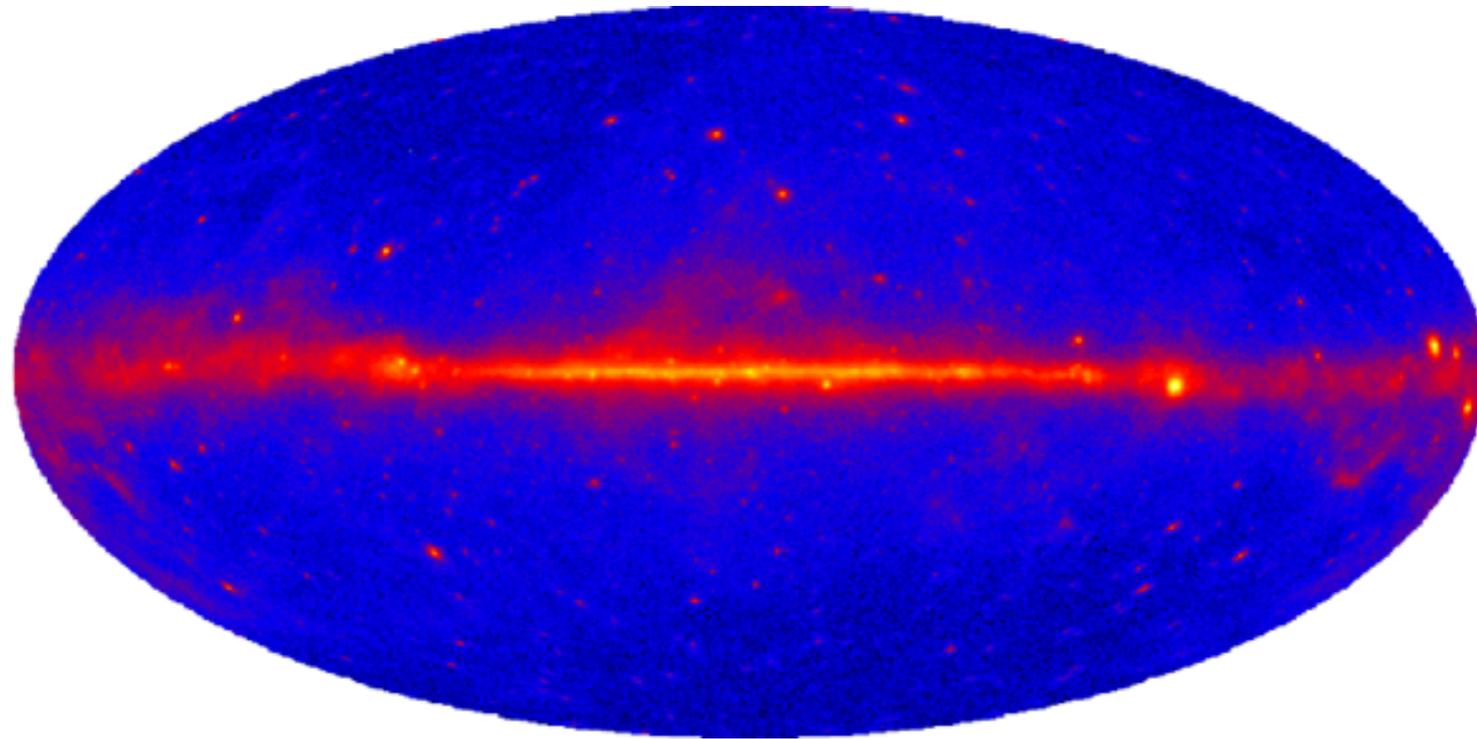

Optimize ROI!

If use data $\implies$ sensitive to fluctuations!

Choosing Regions Of Interest (ROIs)

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Optimize ROI!

If use data $\Longrightarrow$ sensitive to fluctuations!
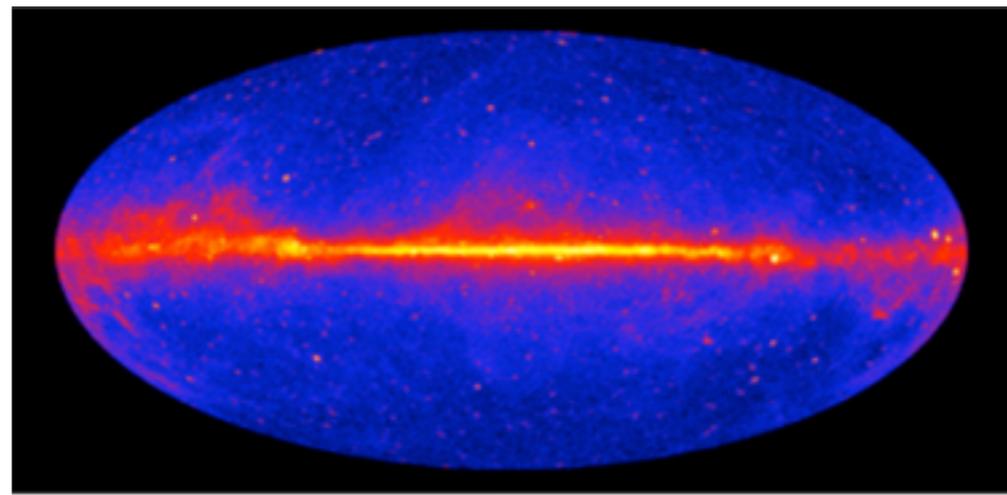
Use Monte Carlo simulations!

Optimization on Monte Carlo simulations

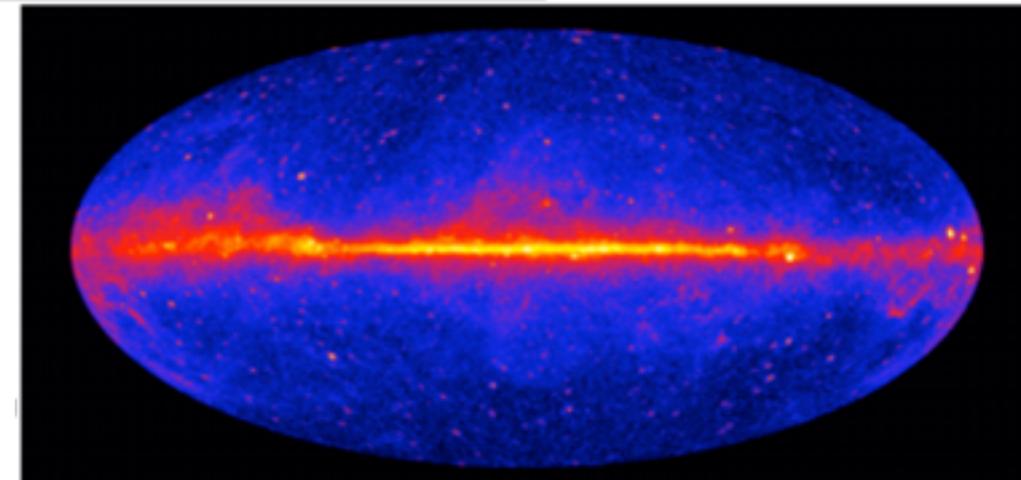- We generate 10 MC simulations based on 2FGL catalog and Public diffuse model;

Optimization on Monte Carlo simulations

- We generate 10 MC simulations based on 2FGL catalog and Public diffuse model;
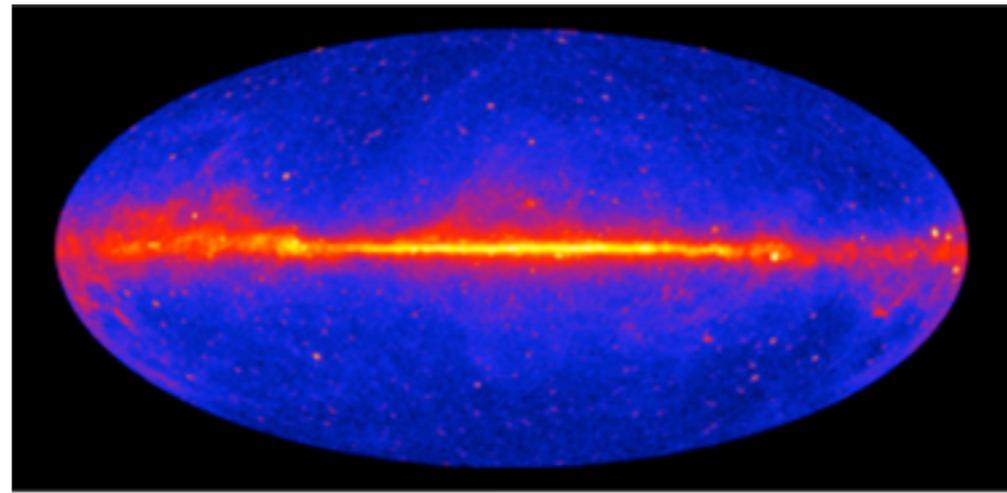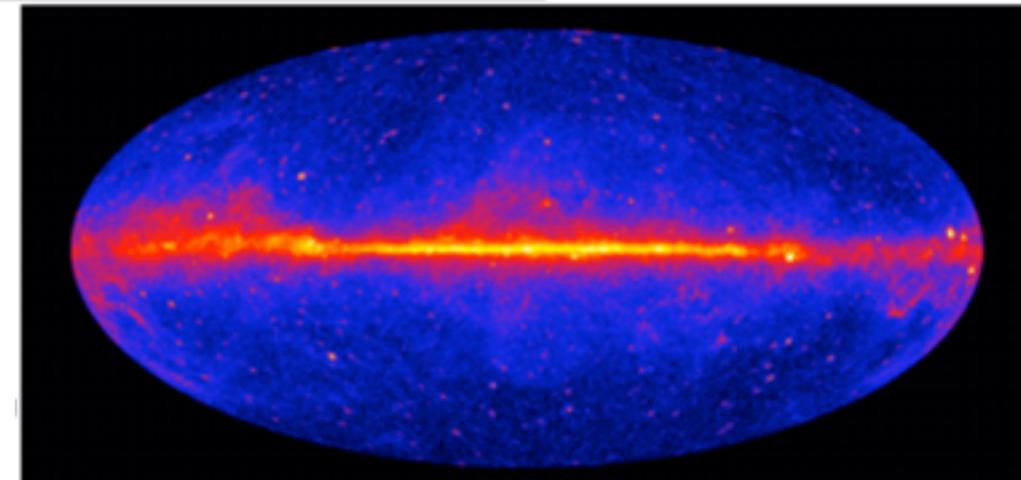

52 months of MC

E > 1 GeV

48 months of real data

Optimization on Monte Carlo simulations

- We generate 10 MC simulations based on 2FGL catalog and Public diffuse model;

52 months of MC

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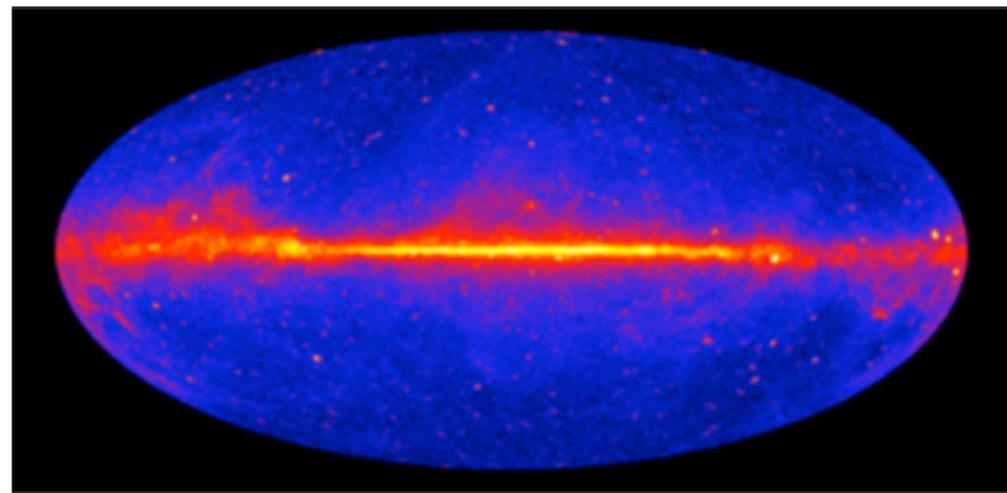- For a given, channel, m_χ, $\rho(r)$, ROI, compute 95% upper limit on $\langle \sigma v \rangle$ for each MC;

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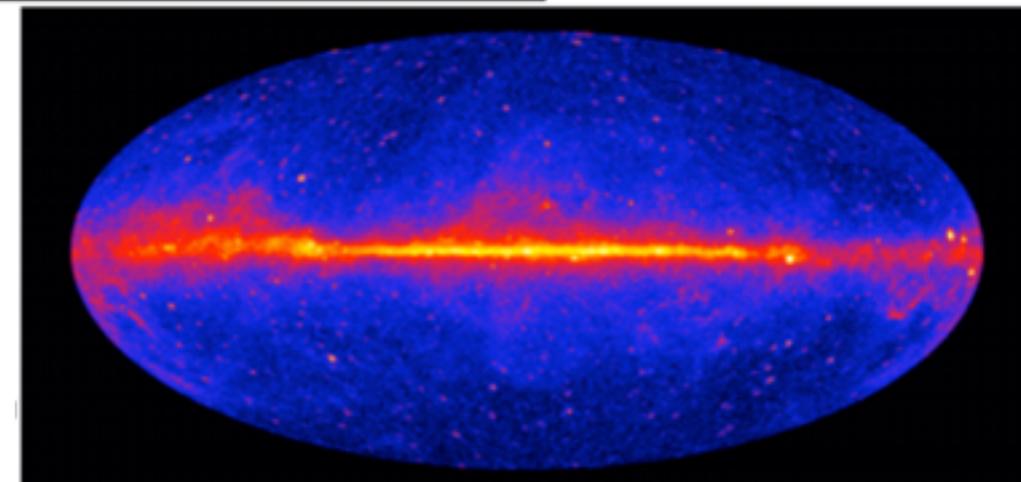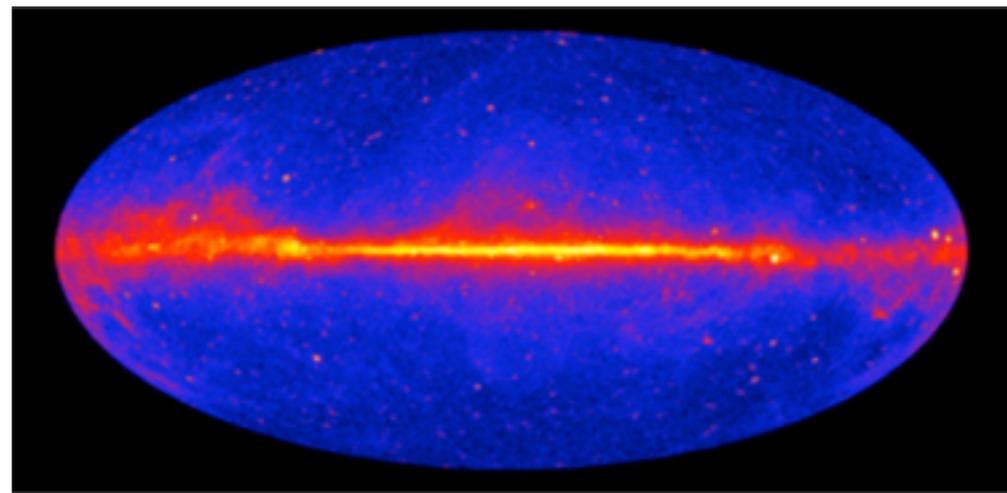

48 months of real data

- Average the limits over 10 MC;

Optimization on Monte Carlo simulations

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48 months of real data

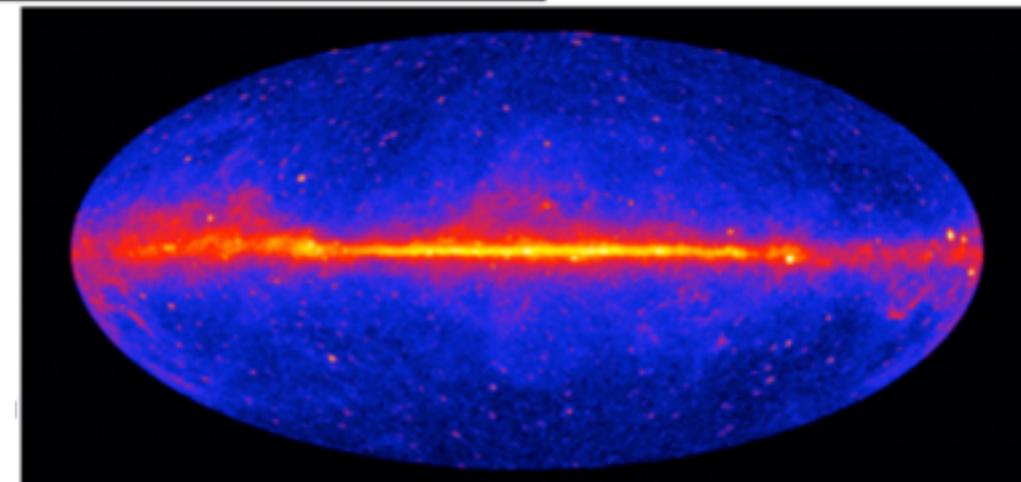- Average the limits over 10 MC;

- Optimize the ROI w.r.t. this average limit.

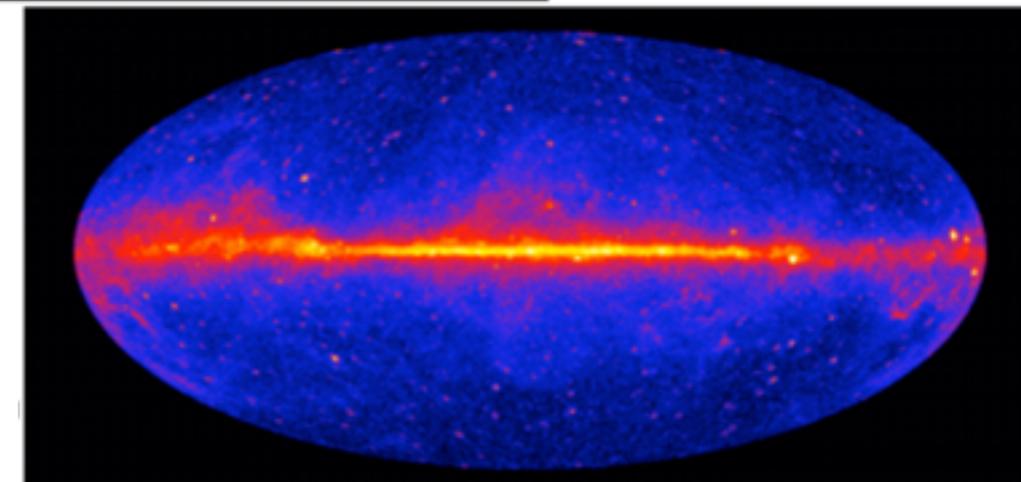# Optimization on Monte Carlo simulations

- We generate 10 MC simulations based on 2FGL catalog and Public diffuse model;

52 months of MC

E > 1 GeV

- For a given, channel, m_X, $\rho(r)$, ROI, compute 95% upper limit on $\langle \sigma v \rangle$ for each MC;

48 months of real data

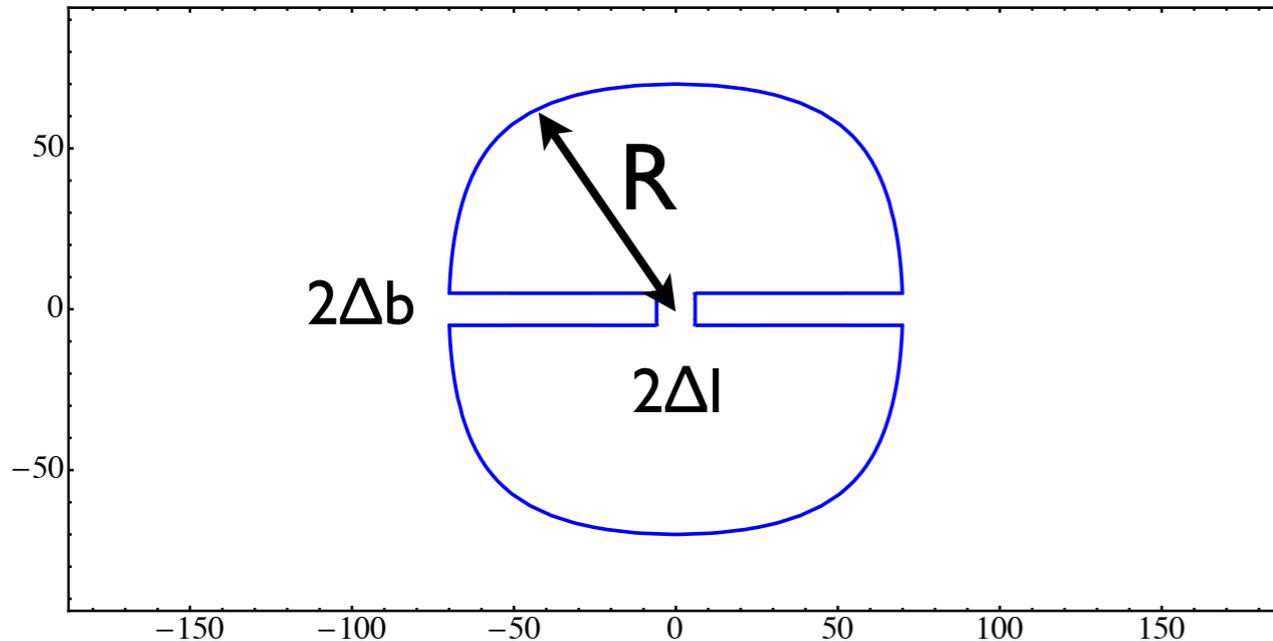- Average the limits over 10 MC;

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How to choose the ROI shapes?

ROI shapes

We parametrize the ROI shapes in this way

For annihilations

For decays

Shapes found by trial and error
and inspired by other works

(Ackermann et al. 1305.5597)

and now…

Results

(expected estimated limits from MC)

(for b$\bar{\text{b}}$ channel only)

$\chi\chi\rightarrow b\bar{b}$, NFW, Prompt only

Optimized bounds
dashed = MC average over 10 MC

thermal relic

preliminary

$\langle\sigma v\rangle$ $[cm^3\,s^{-1}]$

m_{DM} [GeV]

χχ→b̄b, NFW, Prompt only

Optimized bounds
   dashed = MC average
   shading = 1 standard deviation over 10 MC

thermal relic

preliminary

$\langle \sigma v \rangle$ [cm³ s⁻¹]

m_{DM} [GeV]

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   dashed = MC average
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width of the band ~ $\sqrt{\text{counts in ROI}}$

thermal relic

preliminary

$\langle \sigma v \rangle$ [cm^3 s^{-1}]

m_{DM} [GeV]

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Optimal ROIs

Optimized bounds
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shading = 1 st. dev.

thermal relic

$\langle \sigma v \rangle$ [cm^3 s^{-1}]

m_{DM} [GeV]

preliminary

61

$\chi\chi \rightarrow b\bar{b}$, NFW, Prompt only

Optimal ROIs

Optimized bounds
dashed = MC average
shading = 1 st. dev.

7.5 sqdeg

19.1 sqdeg

11.7 sqdeg

thermal relic

13.6 sqdeg

34.1 sqdeg

6.4 sqdeg

preliminary

$\langle\sigma v\rangle$ [cm^3 s^{-1}]

m_{DM} [GeV]

62

χχ→bb̄, NFW, Prompt only

Optimal Energy Ranges

$\chi\chi \rightarrow b\bar{b}$, 3 density profiles, Prompt only

Optimized bounds
dashed = MC average
shading = 1 st. dev.

Isothermal

NFW

Einasto

thermal relic

preliminary

$\langle\sigma v\rangle \ [\mathrm{cm}^3 \, s^{-1}]$

$m_{\mathrm{DM}} \ [\mathrm{GeV}]$

Conclusions

- **ROI & Energy Range** optimization;

- **MC-based**;

- **No foreground** modeling;

$\Rightarrow$ Very promising prospective limits

data results very soon!

Publication is in progress

Thank you!

Back-Up Slides

Data Selection

- Data version: Pass 7 reprocessed

- 08/2008-12/2013 ~5.3 years ~1980 days

- Class CLEAN, z < 100°, rocking angle < 52°

- Energies: 1.5-750 GeV (127 log-uniform bins)

- Exposures computed with P7REP_CLEAN_V15 IRFs