Indirect detection of dark matter

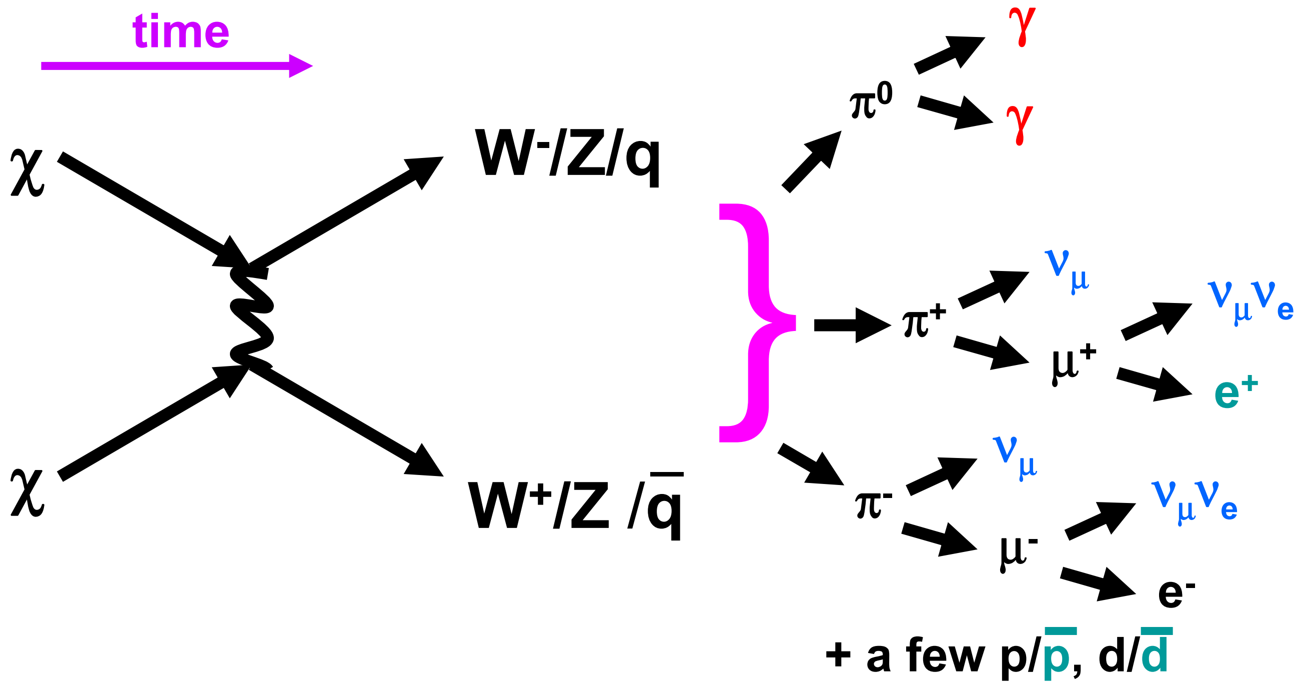
Larry Wai
SLAC

Indirect detection – a complementary way to observe dark matter signals!

DM Experiment Class	***Dark matter source location***	***Dark matter interaction***
Direct Detection	**Earth's Surface**	**WIMP-nucleus scattering**
Particle Beam Collider	**Irrelevant**	**WIMP pair production**
Indirect Detection	**Earth, Sun, Galaxy, extragalactic**	**WIMP pair annihilation**

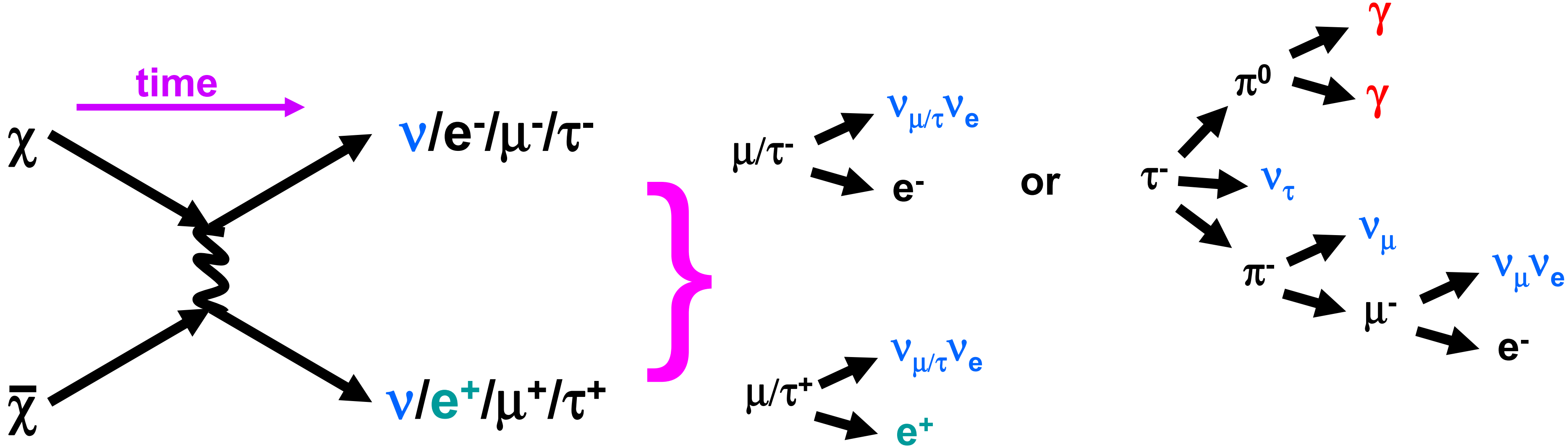
Particles used for indirect detection of dark matter

WIMP pair annihilation
hadronic final states

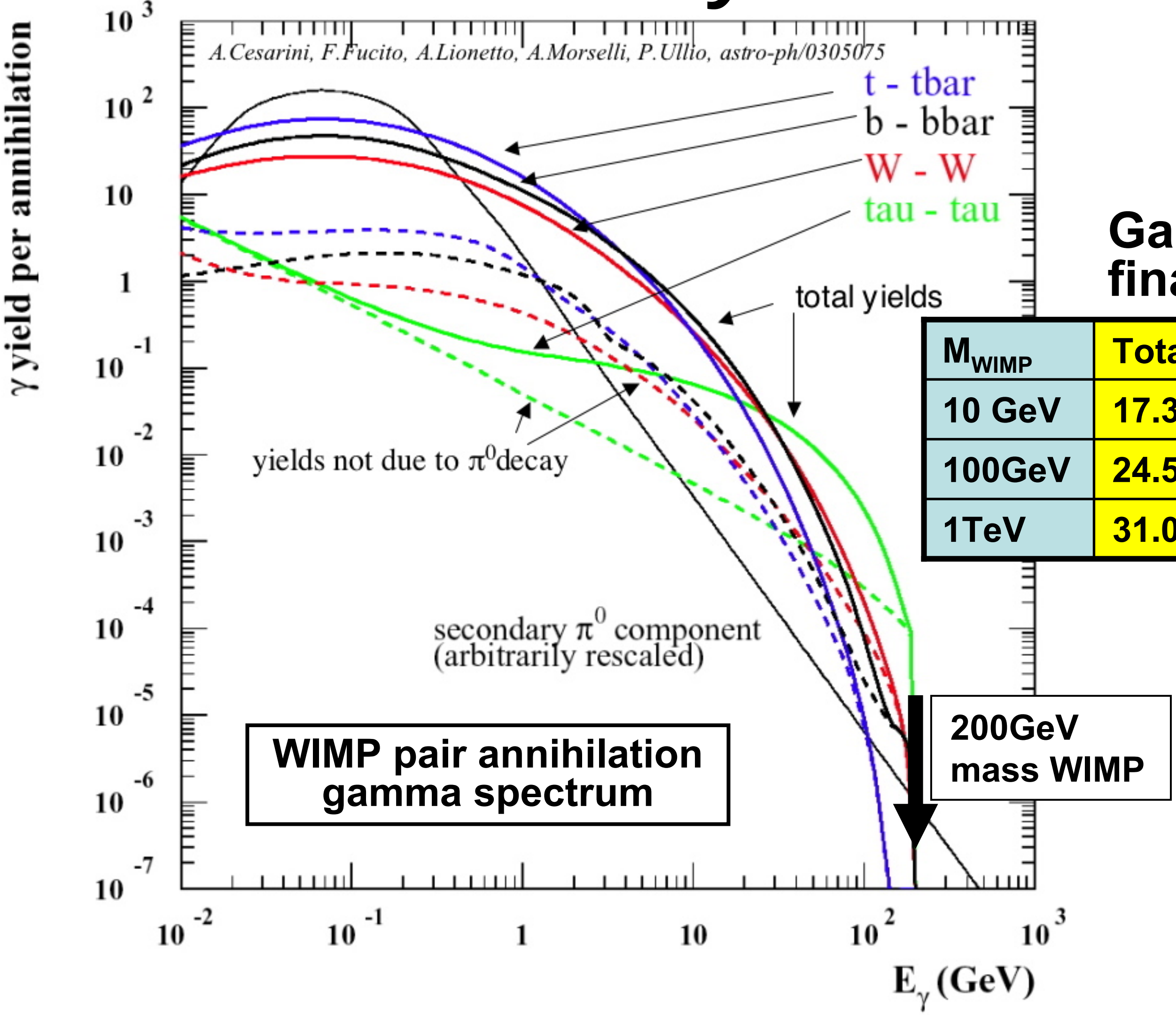


Particles used for indirect detection of dark matter

WIMP pair annihilation
leptonic final states



Particle yields & spectra



Gamma ray yield per final state $b\bar{b}$

M_{WIMP}	Total# γ	>100MeV	>1GeV	>10GeV
10 GeV	17.3	12.6	1.0	0
100GeV	24.5	22.5	12.4	1.0
1TeV	31.0	29.3	22.4	12.3

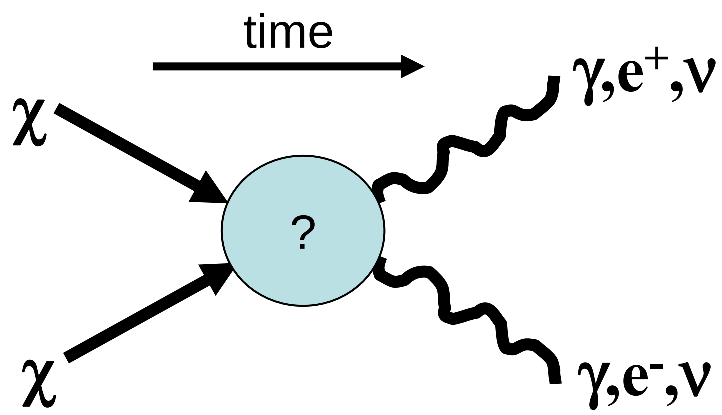
Spectral lines

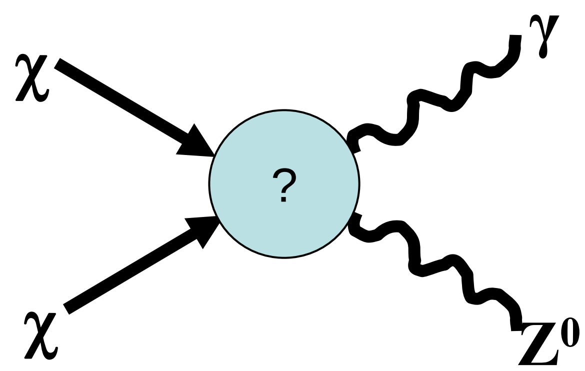
- **For γγ lines, energy = WIMP mass; branching fraction is suppressed**

- **e^+e^-, νν lines are possible at tree level (especially for Dirac fermion or boson WIMPs)**

- **For WIMP masses > M_Z /2 can also have γZ^0 line**

- ***Measurement of line branching fractions would constrain particle theory***



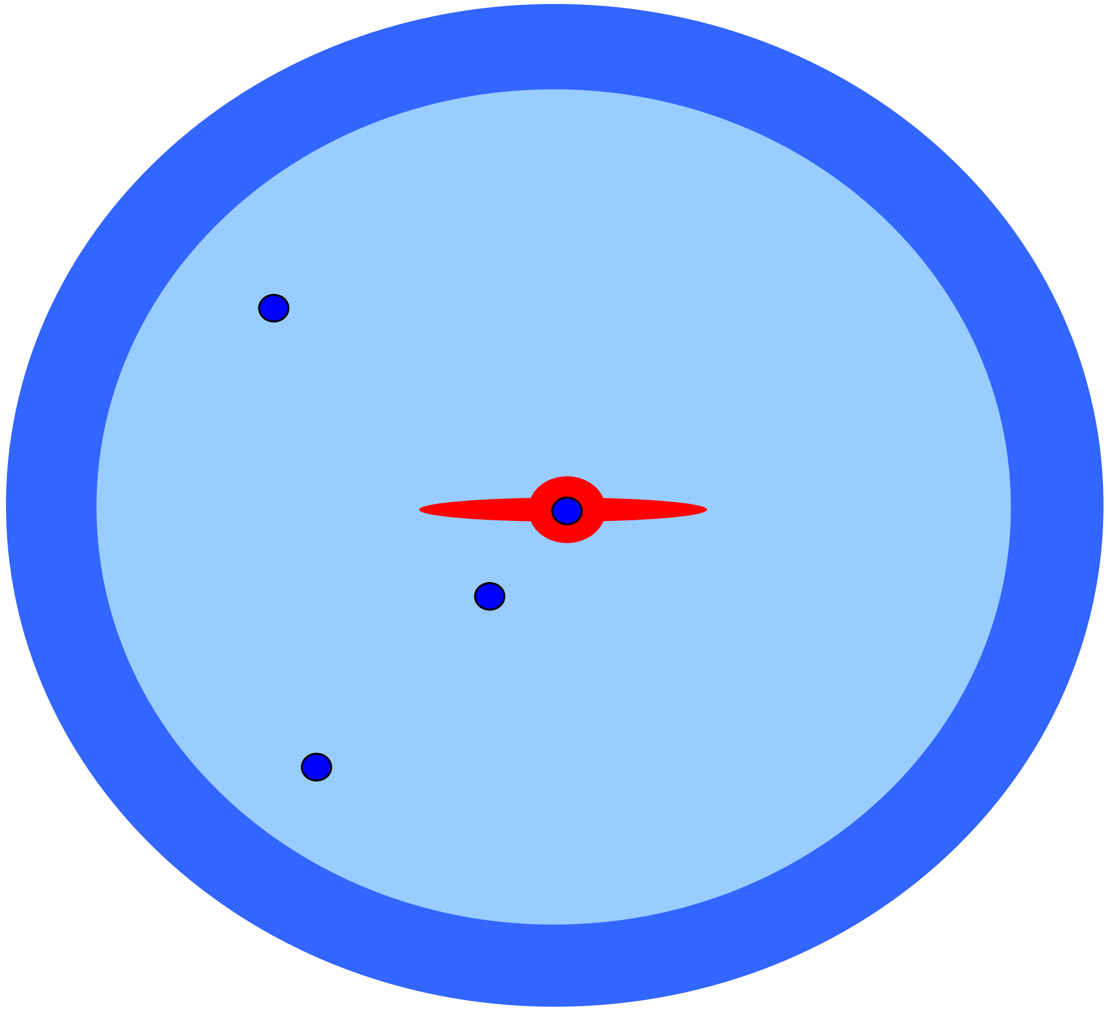


Annihilation flux

$\int(\sum_i dN/dE\ B_i)dE$	spectrum (particle physics)
x	x
$4\pi \int\rho^2(r)r^2dr\ /\ M^2_{WIMP}$	number density^2 (astrophysics)
x	x
$<\sigma v>\ /\ 2$	ann. cross-section (cosmology, particle physics)
x	x
$1/4\pi d^2$	distance^{-2}

Where should we look for indirect signals?

- Galactic satellites
- Galactic halo
- Extra-galactic
- Galactic center
- Stars



Current experiments

Gamma ray detectors

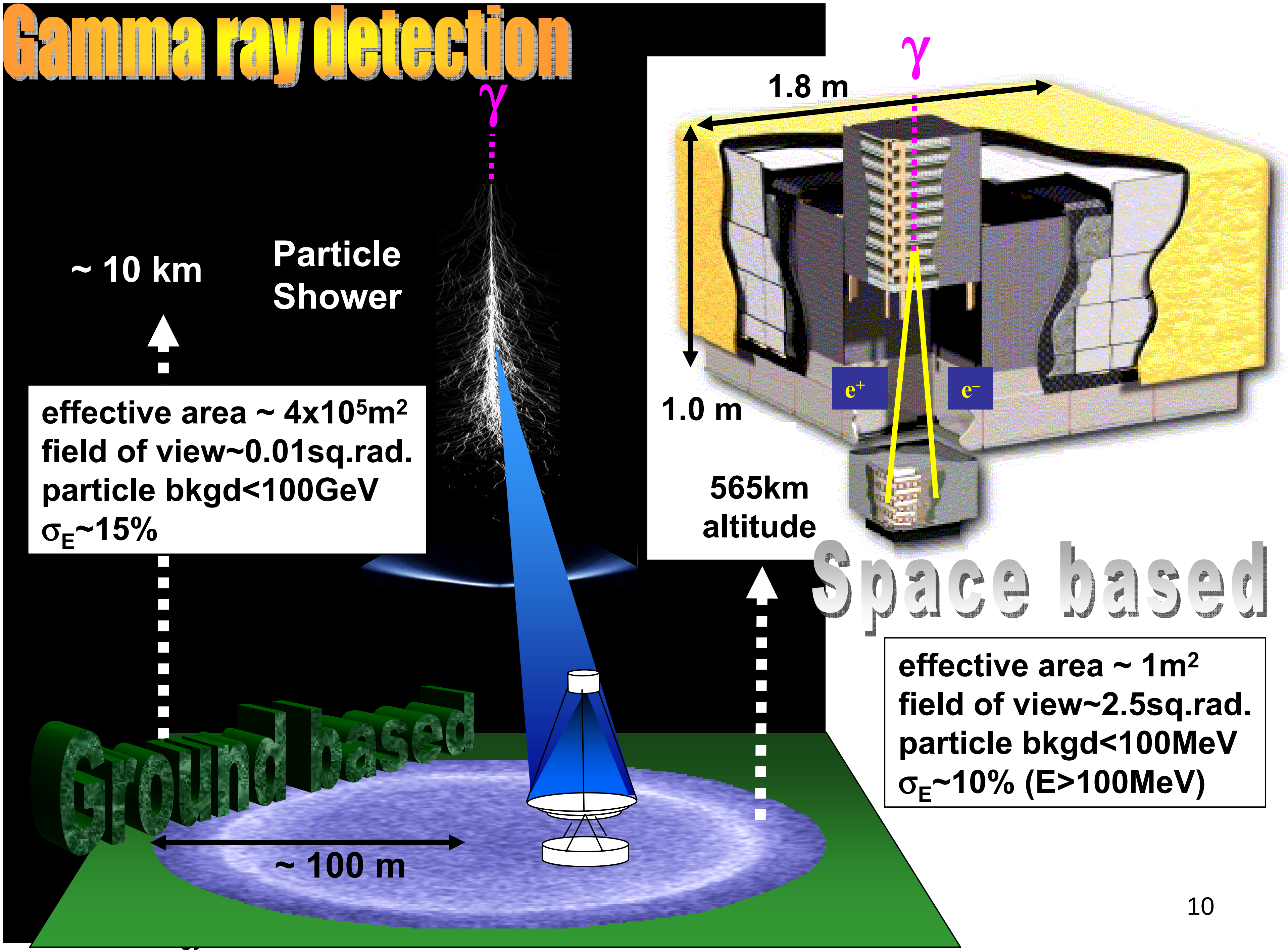
- Space (20MeV-300GeV)
  - GLAST
- Ground (>100GeV)
  - VERITAS
  - HESS
  - MAGIC

Neutrino detectors

- Underground (>5MeV)
  - Super-Kamiokande
- Undersea / ice (>5GeV)
  - AMANDA/ ICECUBE
  - ANTARES

Anti-Matter detectors

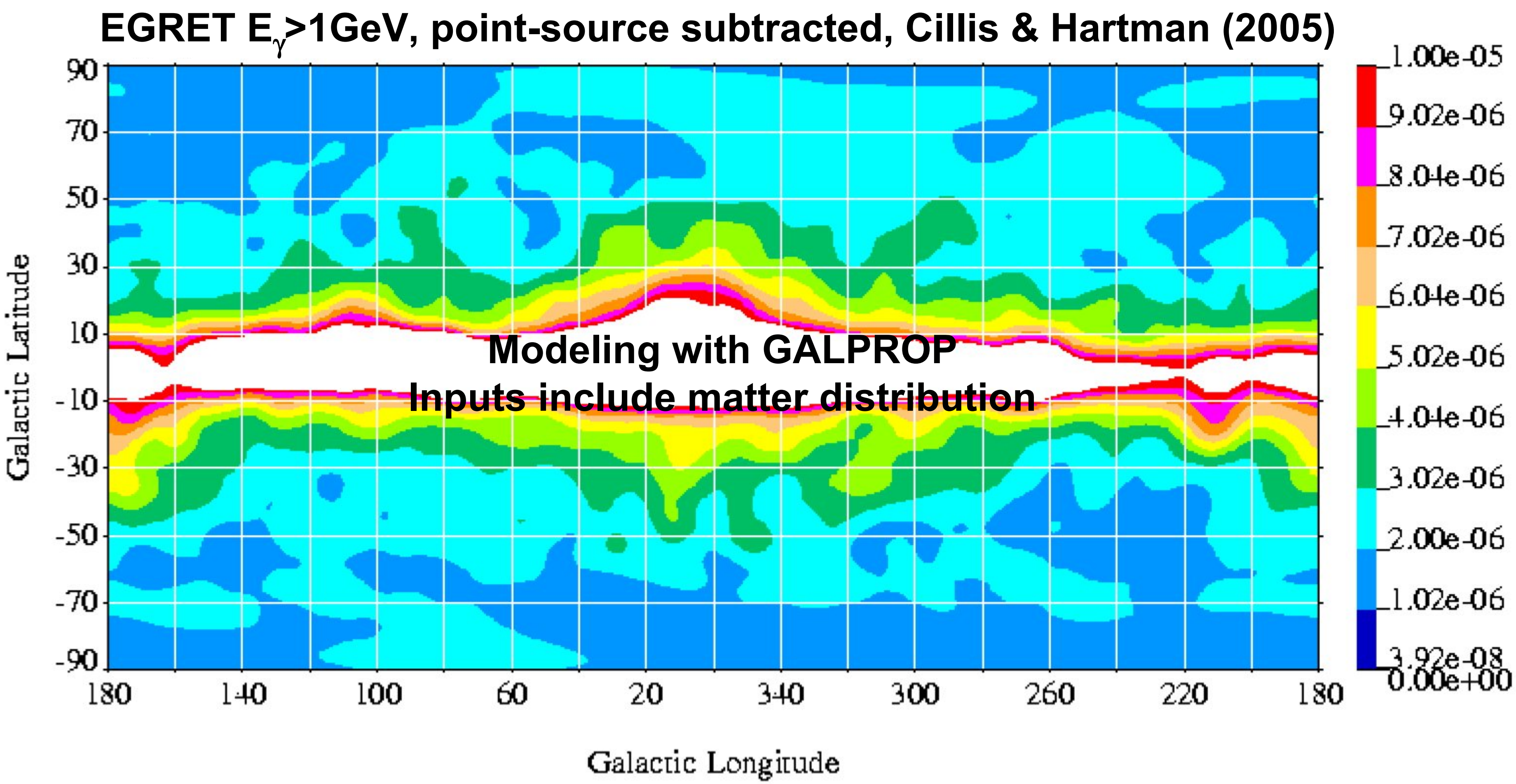
- Space
  - PAMELA
  - AMS



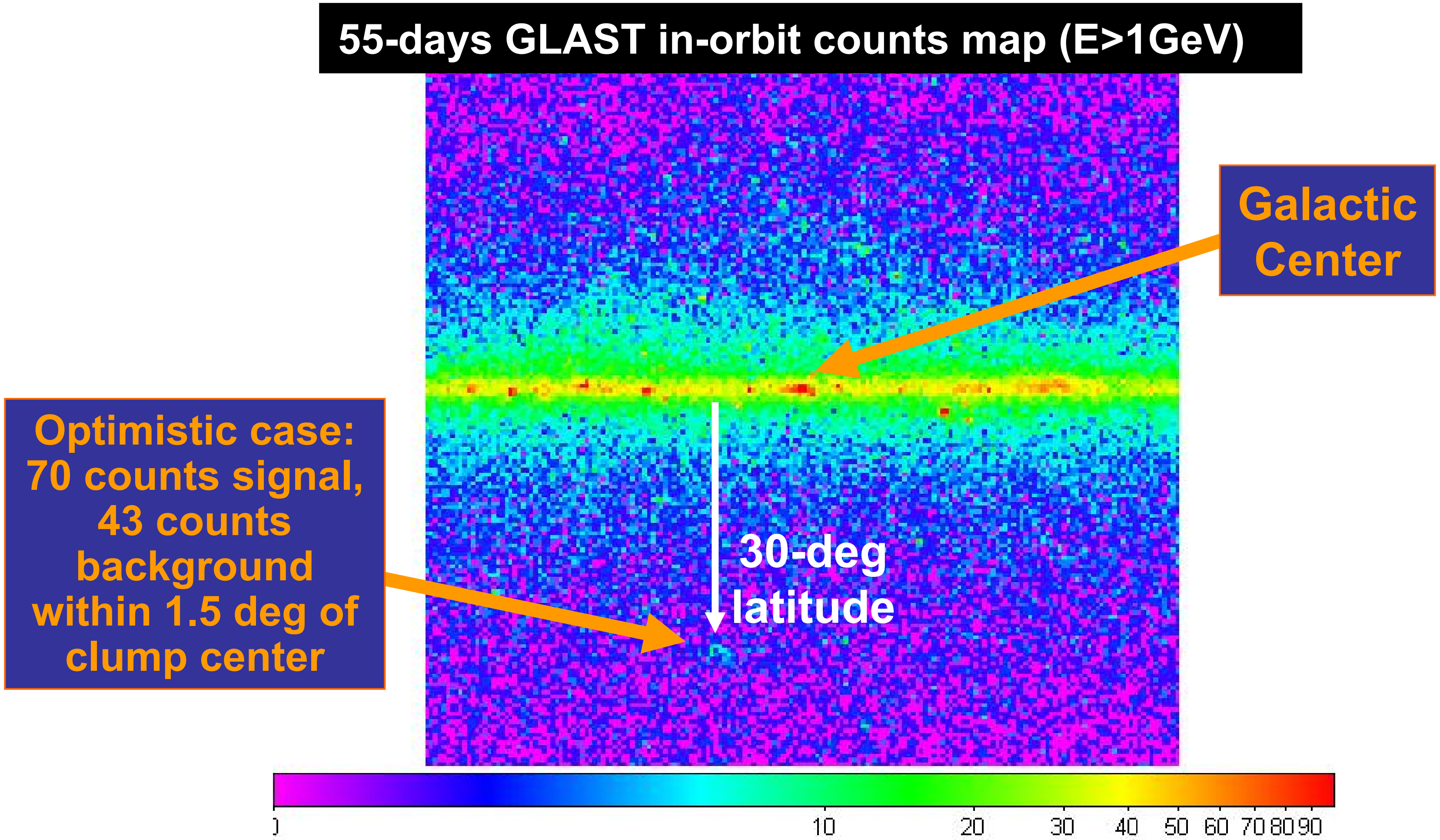
Gamma ray detection
γ
~ 10 km
Particle Shower
effective area ~ 4x10⁵m²
field of view~0.01sq.rad.
particle bkgd<100GeV
σE~15%
Ground based
~ 100 m
γ
1.8 m
1.0 m
e+
e−
565km altitude
Space based
effective area ~ 1m²
field of view~2.5sq.rad.
particle bkgd<100MeV
σE~10% (E>100MeV)

Gamma Ray Detectors

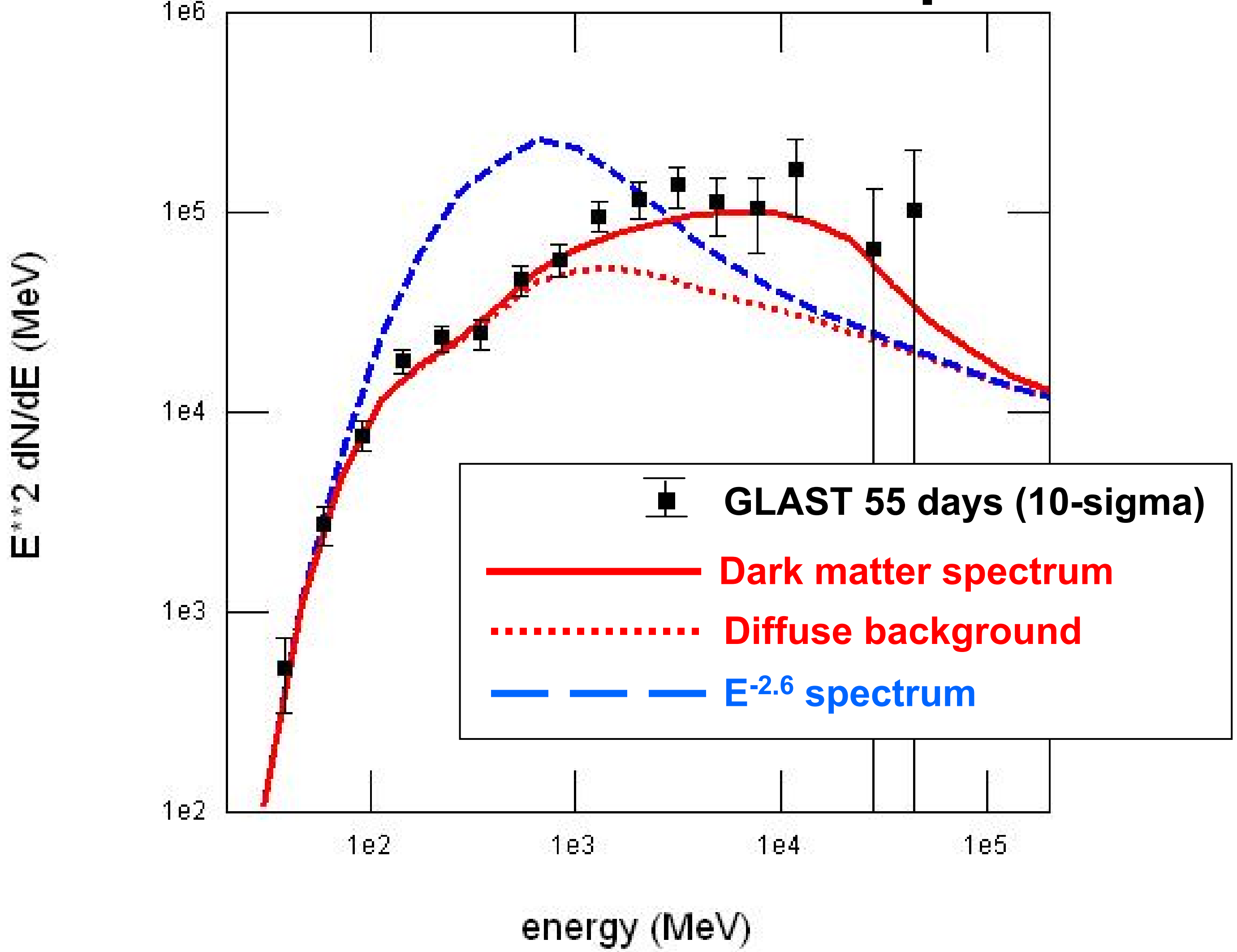
Diffuse gamma ray background



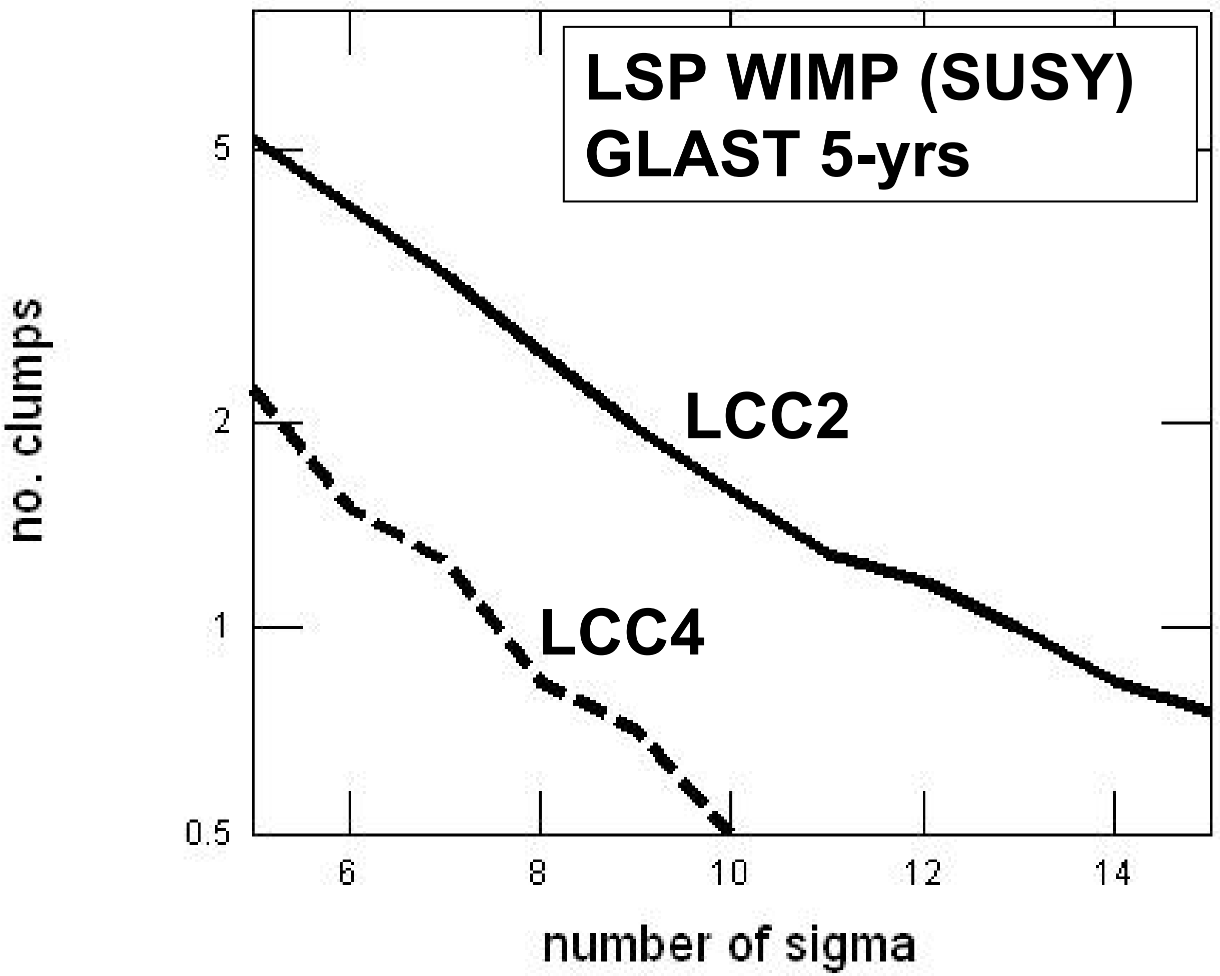
Example A. dark matter satellite



Dark matter source spectrum



How many observable dark matter sources?



Simulation of Milky Way dark matter satellites from Taylor & Babul (2004,2005)

SUSY model definitions from Baltz, et.al. (2006); LCC2 and LCC4 are favorable to GLAST compared to LCC1 and LCC3.

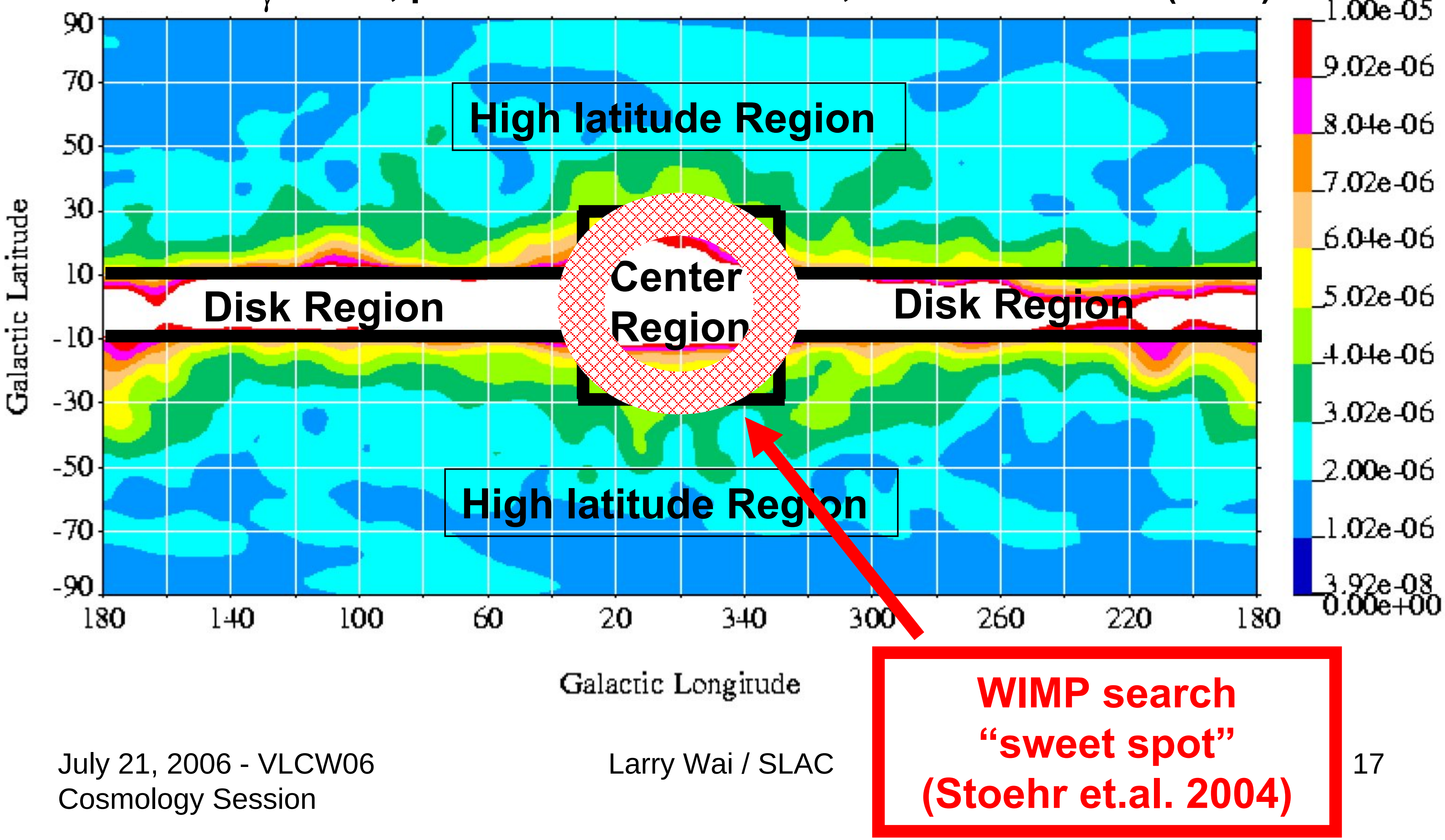
Example: GLAST-IACT search strategy

- ***Assume GLAST finds some high latitude dark matter point sources consistent with WIMP mass ~100GeV***
- ***Assume IACTs learn how to eliminate all of the charged particle background <150 GeV while retaining 20% gamma efficiency***

➢ ***Example: 10-sigma high latitude GLAST WIMP source (5-yr exposure) would have ~100 counts background (0.5-deg radius circle, E>1GeV), ~100 counts signal; follow-up by IACT would have ~40 line gammas for a line branching fraction ~.003. The IACT extragalactic gamma background would be ~60 (100GeV mass WIMP).***

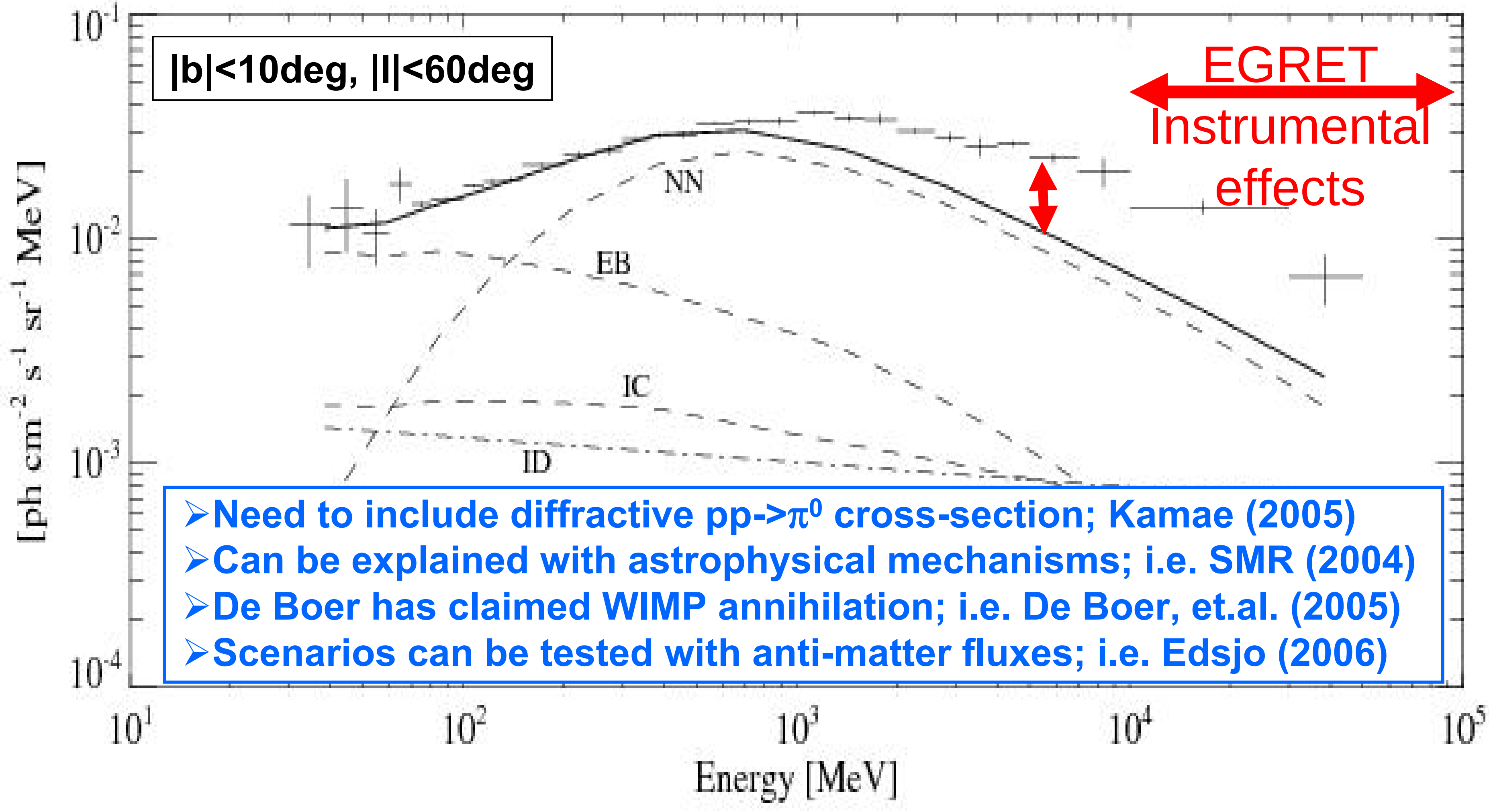
Example B. Milky Way dark matter halo

EGRET E_γ>1GeV, point-source subtracted, Cillis & Hartman (2005)



EGRET diffuse "GeV excess" -still up for grabs!

Hunter et al (1997); similar "GeV excess" in all sky regions



- **Need to include diffractive pp->π^0 cross-section; Kamae (2005)**
- **Can be explained with astrophysical mechanisms; i.e. SMR (2004)**
- **De Boer has claimed WIMP annihilation; i.e. De Boer, et.al. (2005)**
- **Scenarios can be tested with anti-matter fluxes; i.e. Edsjo (2006)**

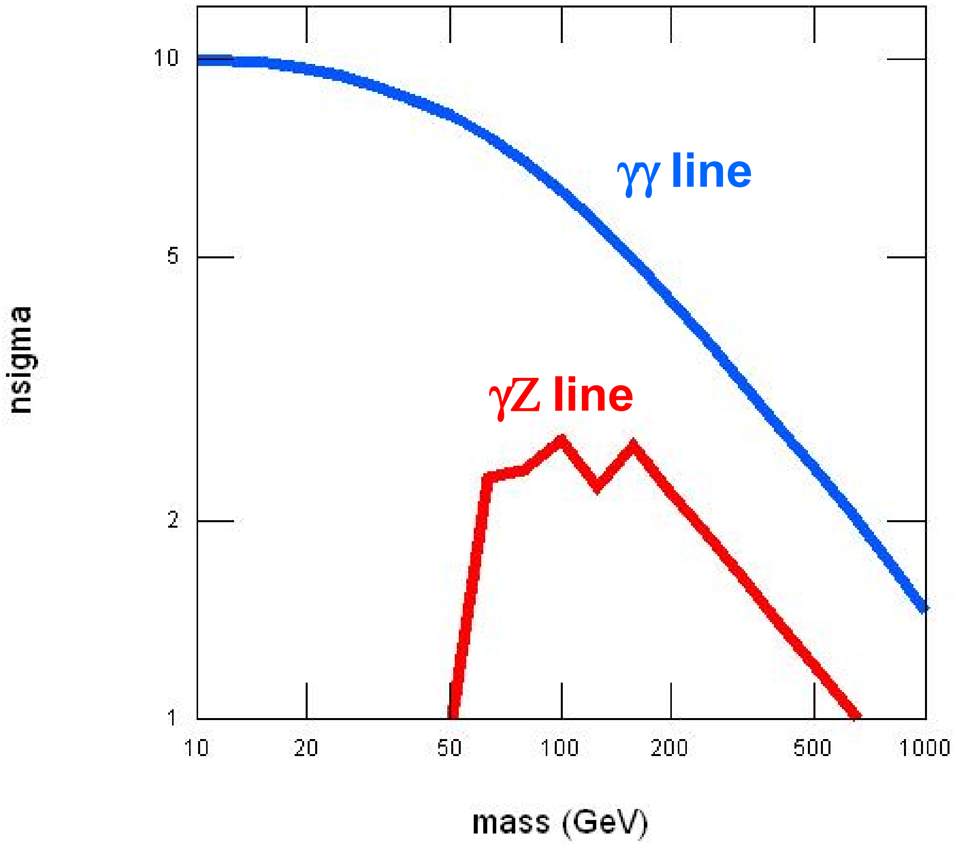
Back-of-the-envelope line significance

- **Consider high latitude region |b|>10deg (|b|>30deg for |l|<30deg), 5 years GLAST on-orbit**
- **line background is flux within $\Delta E/E=0.235$ at M_{WIMP}, γZ line**

➢ **Assume WIMP continuum is 30% of galactic diffuse flux for $E>.01M_{WIMP}$**

➢ **Assume 0.1% branching fraction to line**

➢ **# sigma is no. line counts/sqrt(no. bkgd counts)**



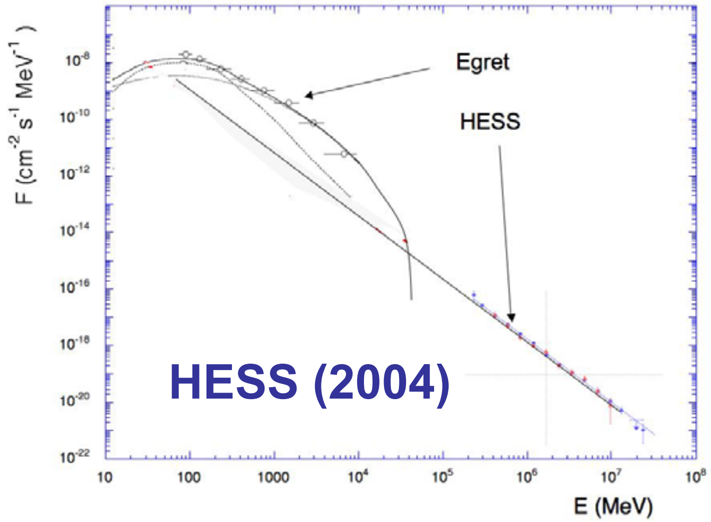
Example C: Galactic Center

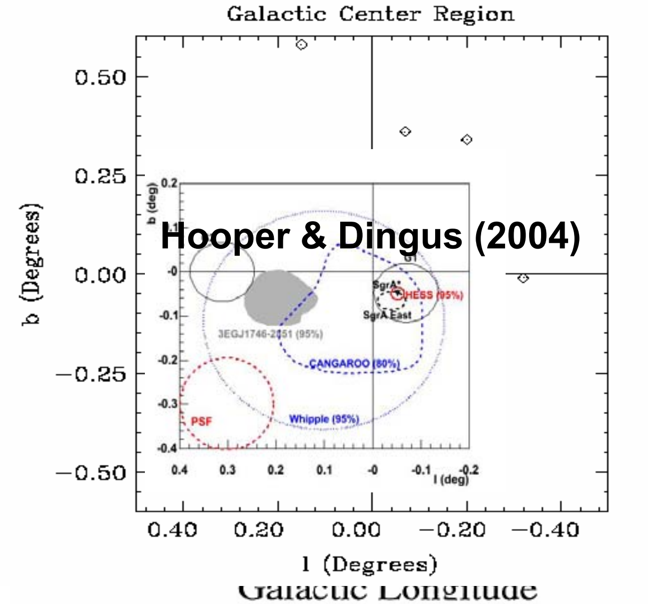
Mayer-Hasselwander (1998) - EGRET point source

Spatial analysis

- **100MeV-300MeV (l ~ -0.75deg)**
- **300MeV-1GeV (l ~ -0.30deg)**
- **> 1GeV (l ~ 0.05deg)**
- **> 5GeV (l ~ 0.20deg)**

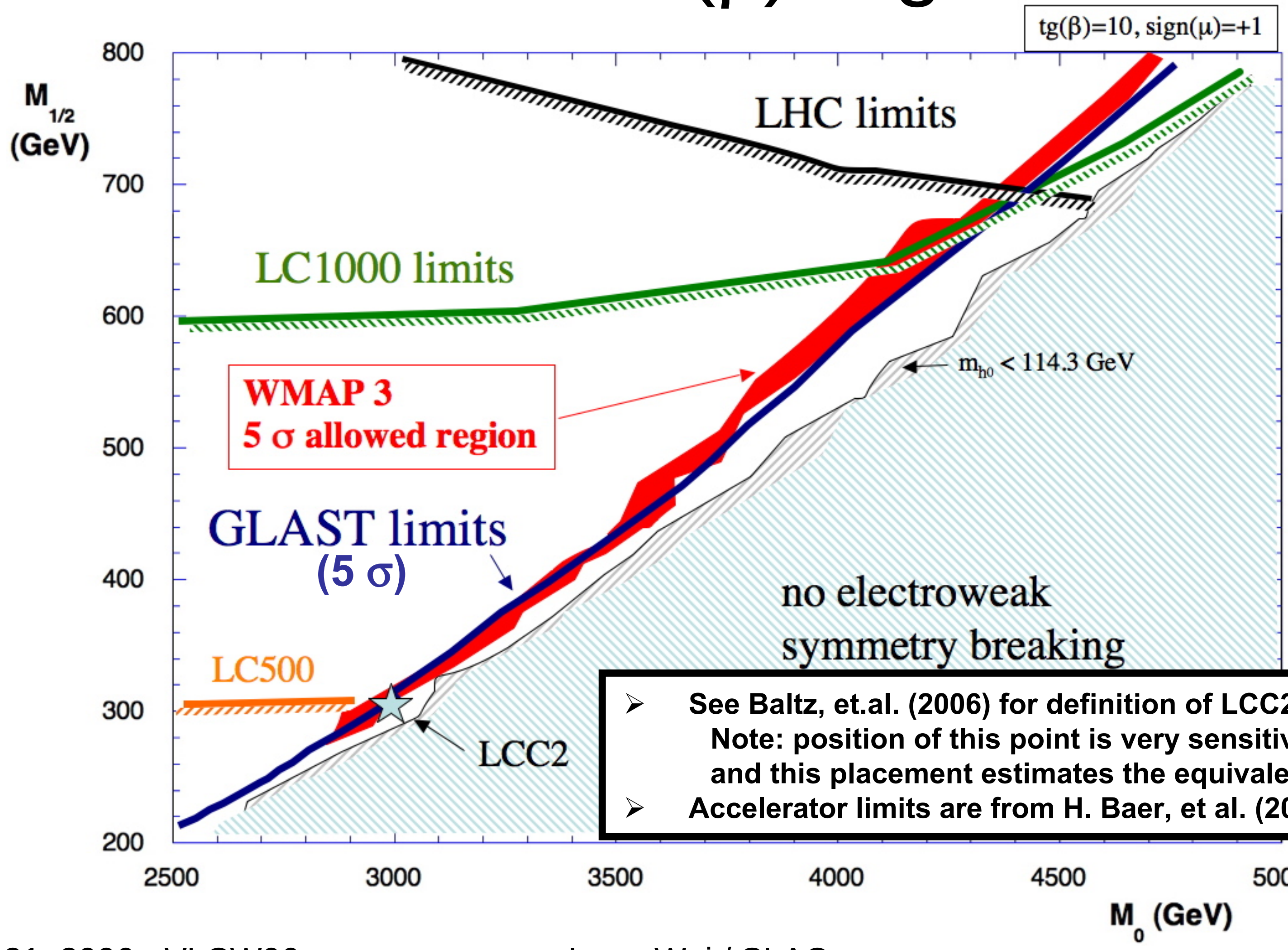
New diffuse component in the galactic center region, HESS (2006)





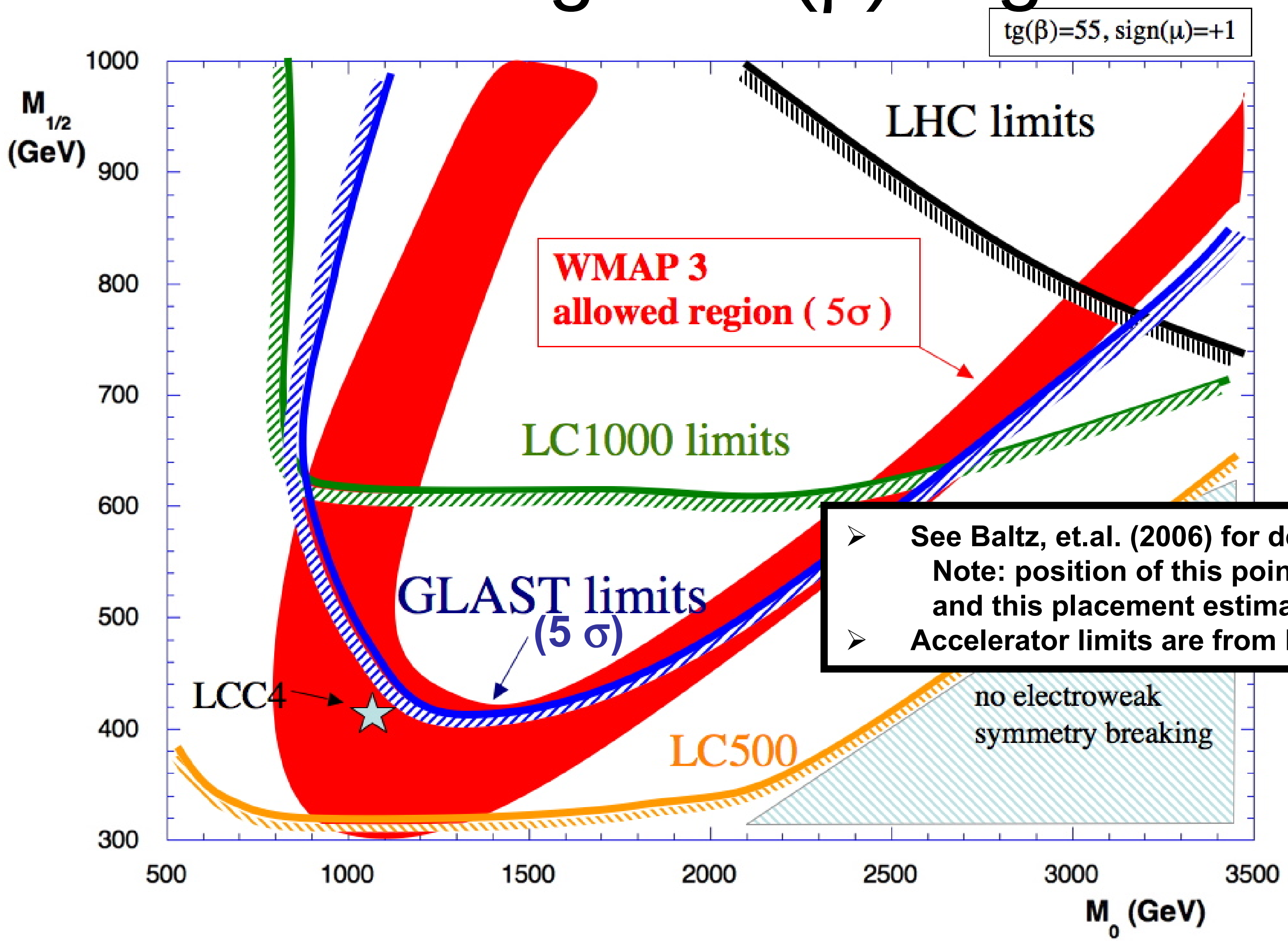
Mayer-Hasselwander et.al. (1998)

Galactic center mSUGRA sensitivity: small tan(β) regime



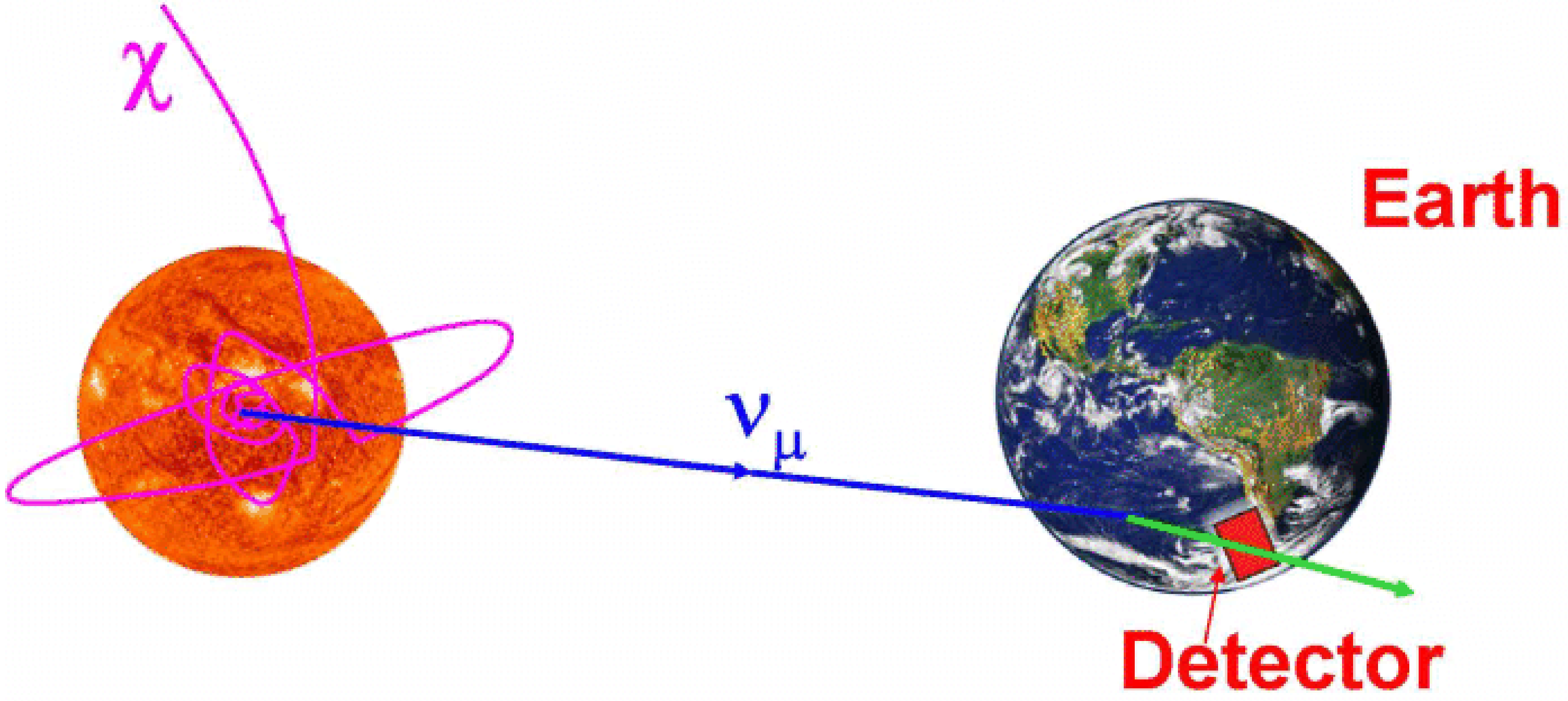
- See Baltz, et.al. (2006) for definition of LCC2.
  Note: position of this point is very sensitive to m_t and this placement estimates the equivalent LCC2.
- Accelerator limits are from H. Baer, et al. (2004)

Galactic center mSUGRA sensitivity: large tan(β) regime

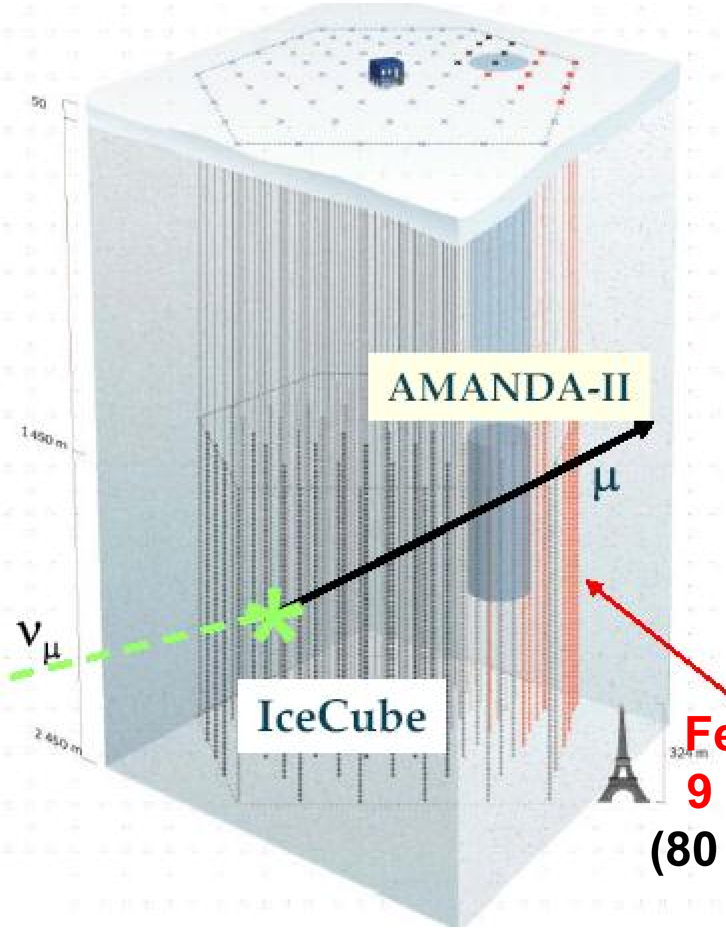


- See Baltz, et.al. (2006) for definition of LCC4. Note: position of this point is very sensitive to m_t and this placement estimates the equivalent LCC4.
- Accelerator limits are from H. Baer, et al. (2004)

Dark matter neutrino detection technique

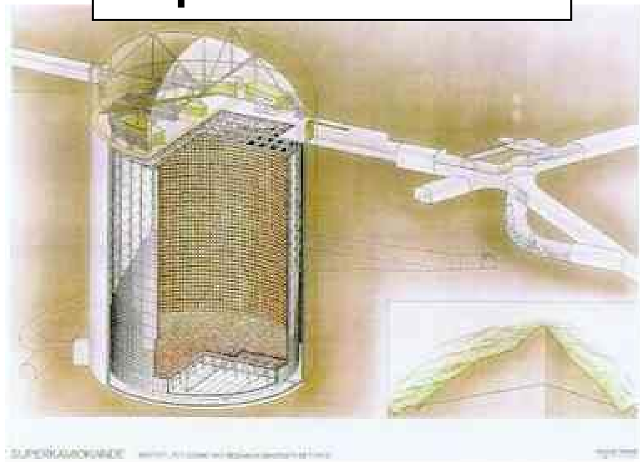


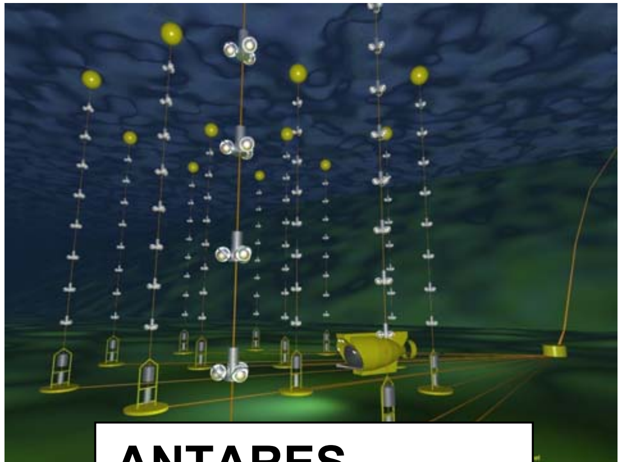
Neutrino detectors



Feb.2006
9 strings
(80 by 2011)

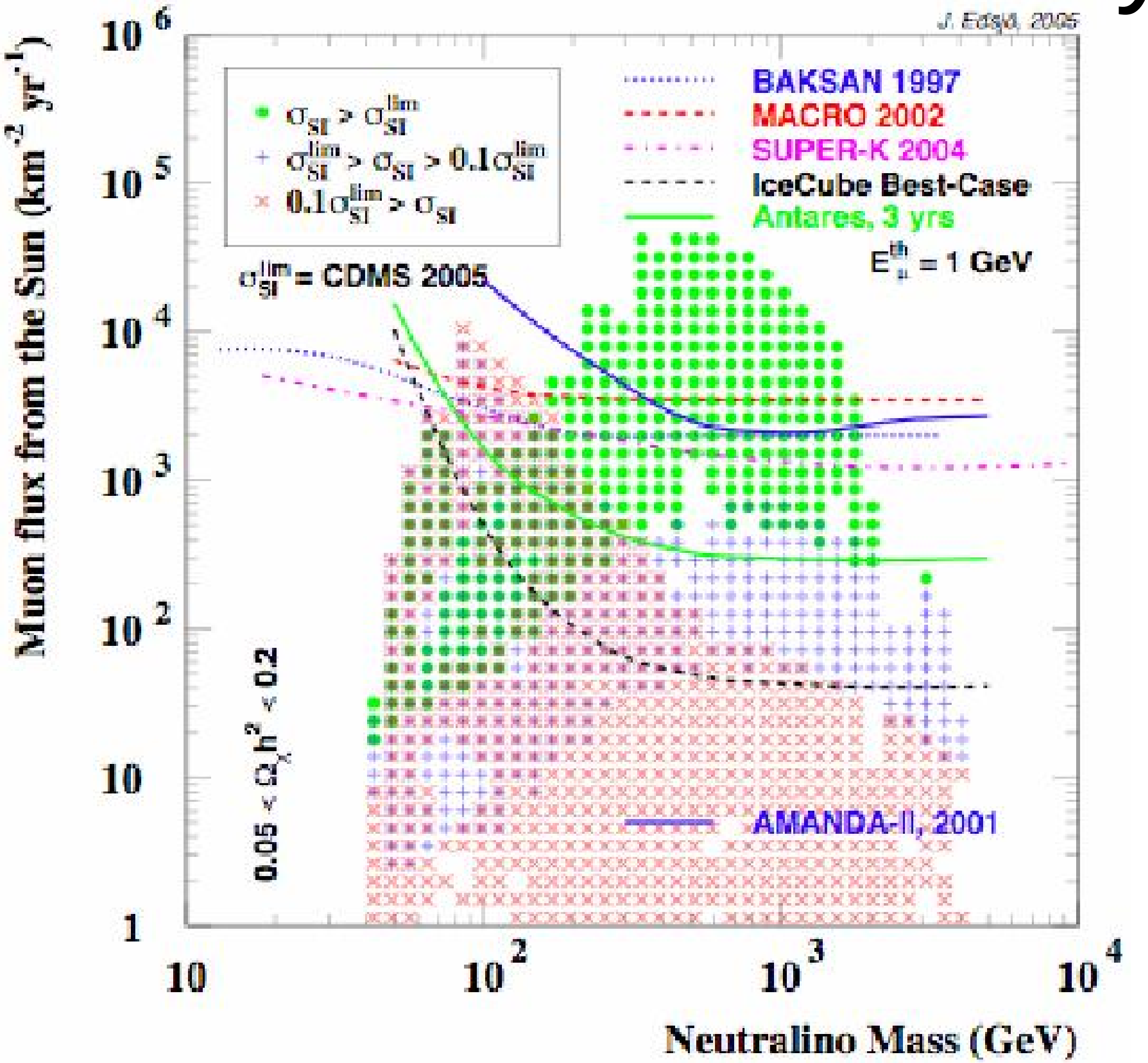
Super-Kamiokande



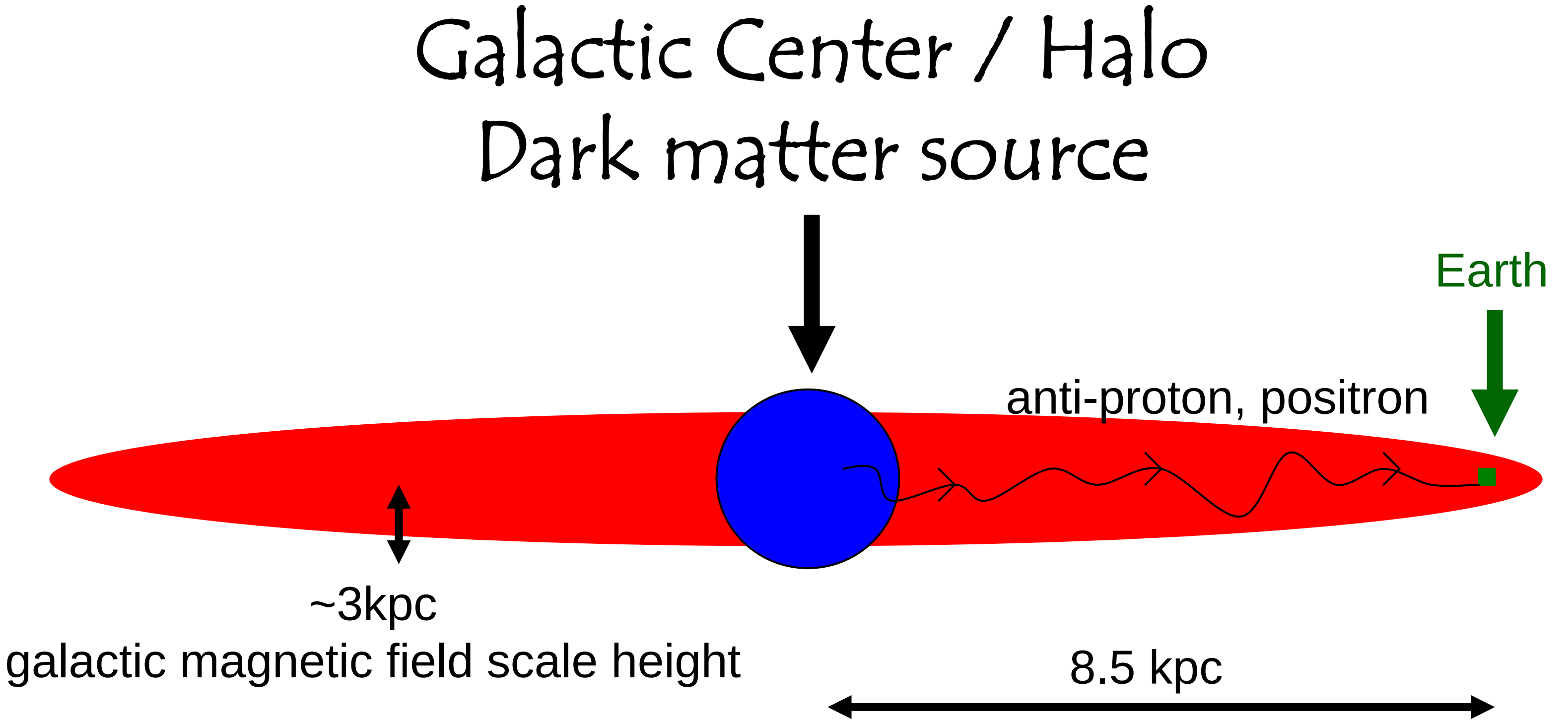


ANTARES
Feb.2006 – 1 line
(12 lines by 2007)

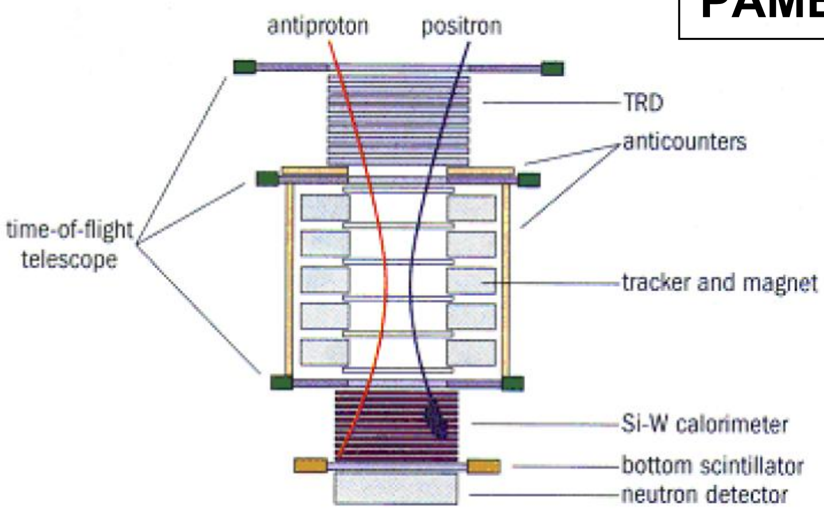
Solar WIMP sensitivity



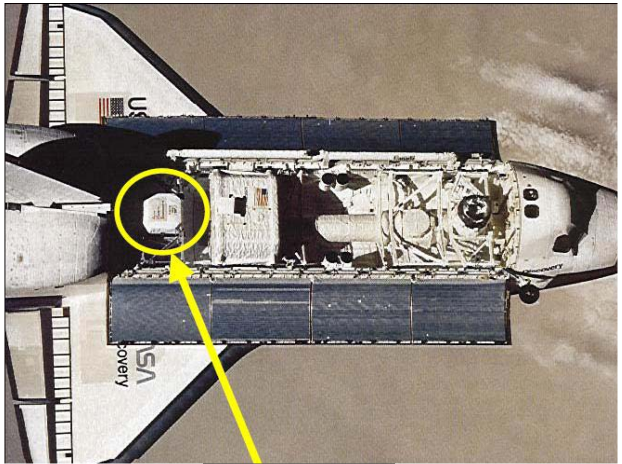
dark matter anti-matter sources



Anti-matter detectors

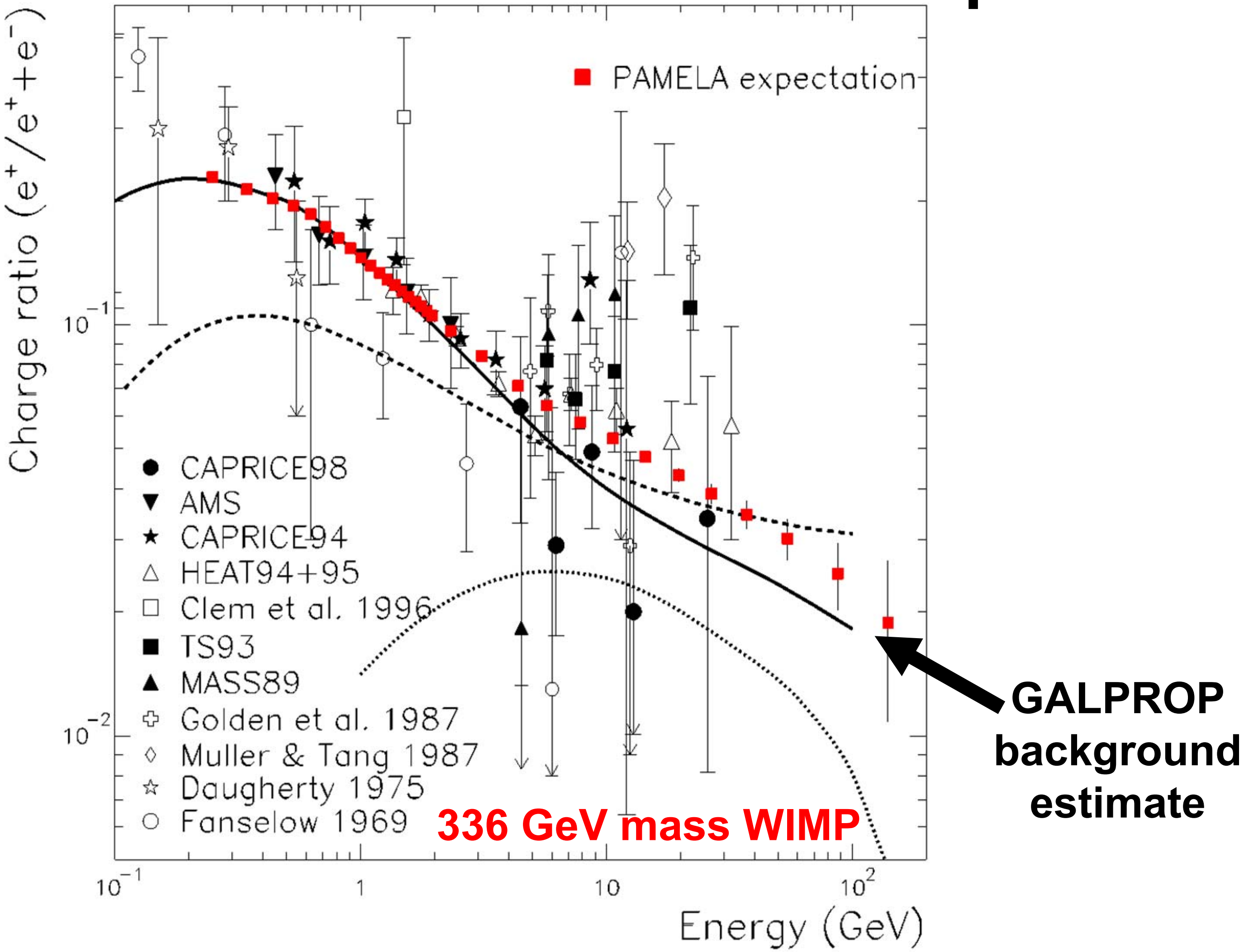


PAMELA



AMS-1

Dark matter anti-matter spectra



Future of indirect detection

Impact of new information

- ***Direct detection results on cross-section will impact expected neutrino flux from solar WIMP accumulation***
- ***WIMP mass measurements (from direct, LHC, GLAST?) will impact expected annihilation spectrum; i.e. what threshold do we need for IACT line measurements?***
- ***Location of WIMP annihilation sources by GLAST would dramatically alter the landscape; i.e. tell IACTs where to look!***

Indirect experiments

- ***ICECUBE, PAMELA, AMS-2 – discovery potential for large mass, large lepton branching fraction scenarios***
- ***GLAST, IACTs, & Beyond VERITAS – accurate line branching fraction measurements would constrain particle theory***

Indirect detection summary