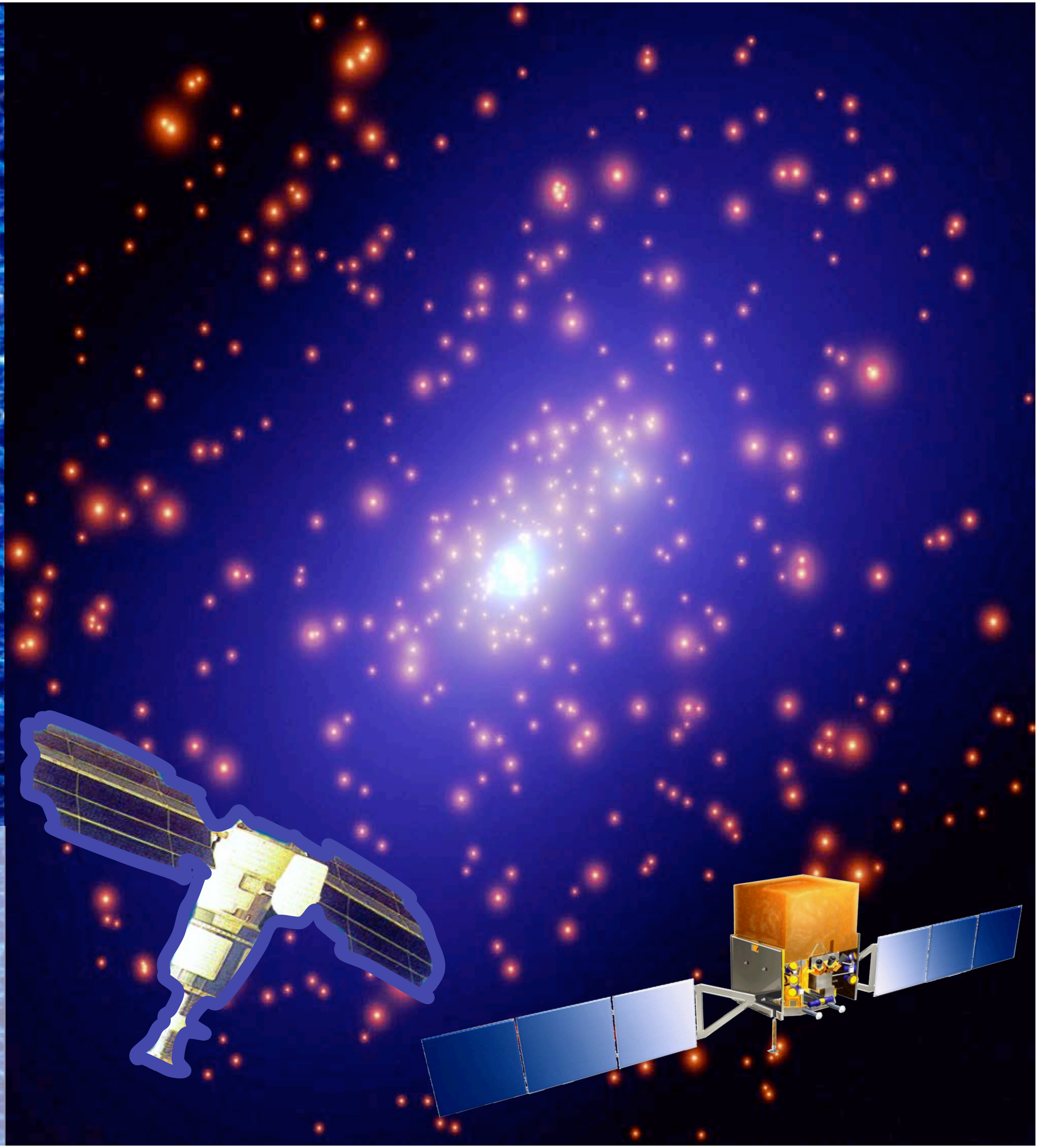
Search for Dark Matter with space experiments

Aldo Morselli

INFN &
Università di Roma Tor Vergata

22 - June 2006

International Workshop
The Dark Side of the Universe
Madrid,
June 20-24, **2006**



Neutralino WIMPs

Assume χ present in the galactic halo

- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** $\bar{p}$ + X)
- So, any extra contribution from exotic sources ($\chi\,\chi$ annihilation) is an interesting signature
- ie: $\chi\,\chi$ --> $\bar{p}$ + X
- Produced from (e. g.) $\chi\,\chi$ **-->** q / g / gauge boson / Higgs boson and subsequent decay and/ or hadronisation.

Propagation Equation for Cosmic Rays in the Milky Way

$$\frac{\partial \psi(\mathbf{r},p,t)}{\partial t} = q(\mathbf{r},p) + \nabla \cdot (D_{xx}\nabla\psi - \mathbf{V}\psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi$$

$$- \frac{\partial}{\partial p}\left[\dot{p}\psi - \frac{p}{3}(\nabla \cdot \mathbf{V})\psi\right] - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

diffusion coefficient in the impulse space, quasi-linear MHD:

$D_{pp}(D_{xx}, v_A)$

convection velocity field that corresponds to galactic wind and it has a cylindrical symmetry, as the geometry of the galaxy. It's z-component is the only one different from zero and increases linearly with the distance from the galactic plane

loss term: fragmentation

loss term: radioactive decay

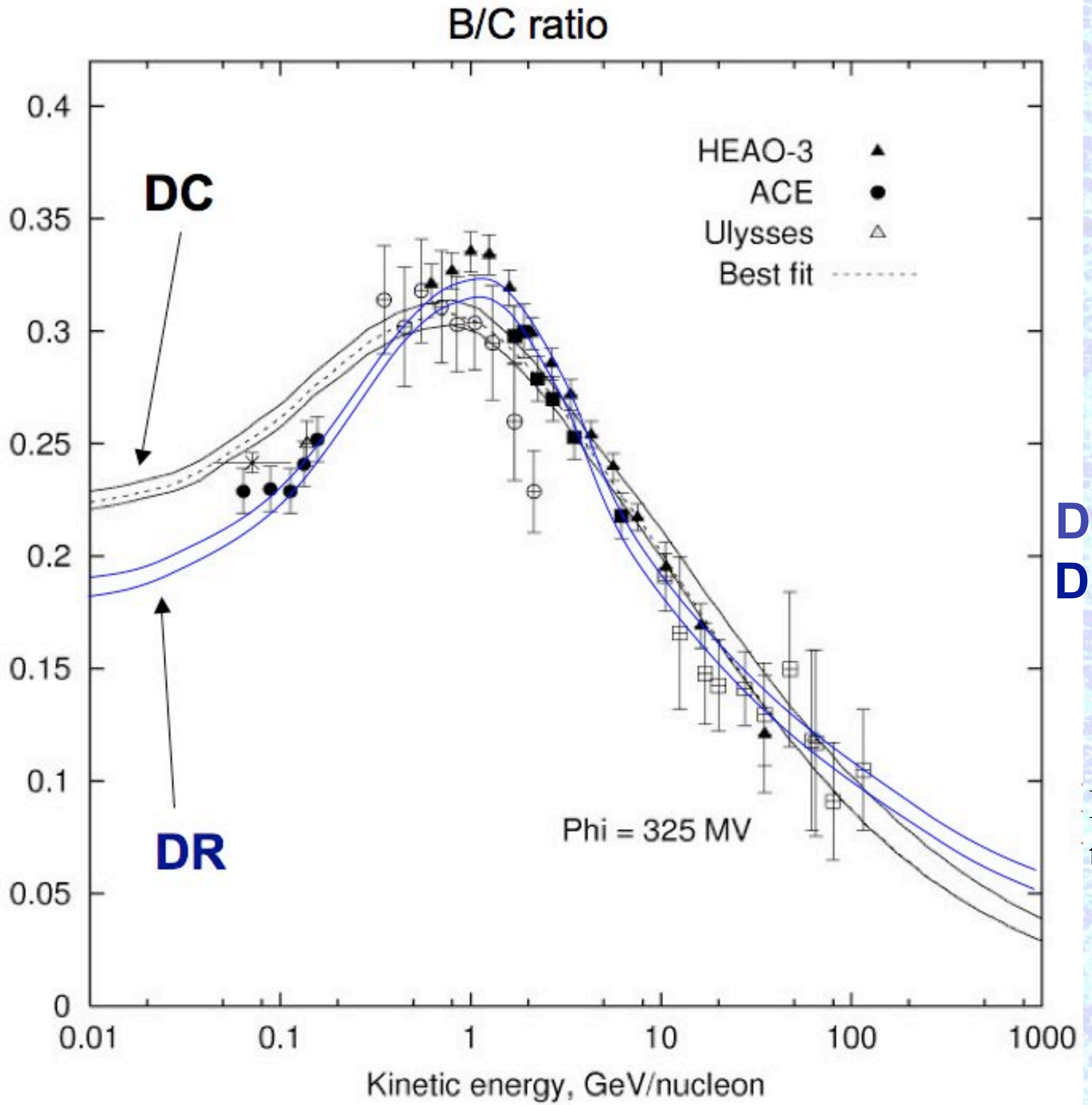
diffusion coefficient is function of rigidity

$$D_{xx} = \beta D_0 (\rho/\rho_0)^{\delta}$$

primary spectra injection index

$$dq(p)/dp \propto p^{-\gamma}$$

implemented in Galprop (Strong & Moskalenko, available on the Web)



Enveloping curves of all the good fits of the experimental B/C data

Dashed line: Best fit

DR: diffusion+ reacceleration

DC: diffusion+convection

In DC model problem with the ACE data at low energy

A.Lionetto, A.Morselli, V.Zdravkovic

JCAP09(2005)010 astro-ph/0502406

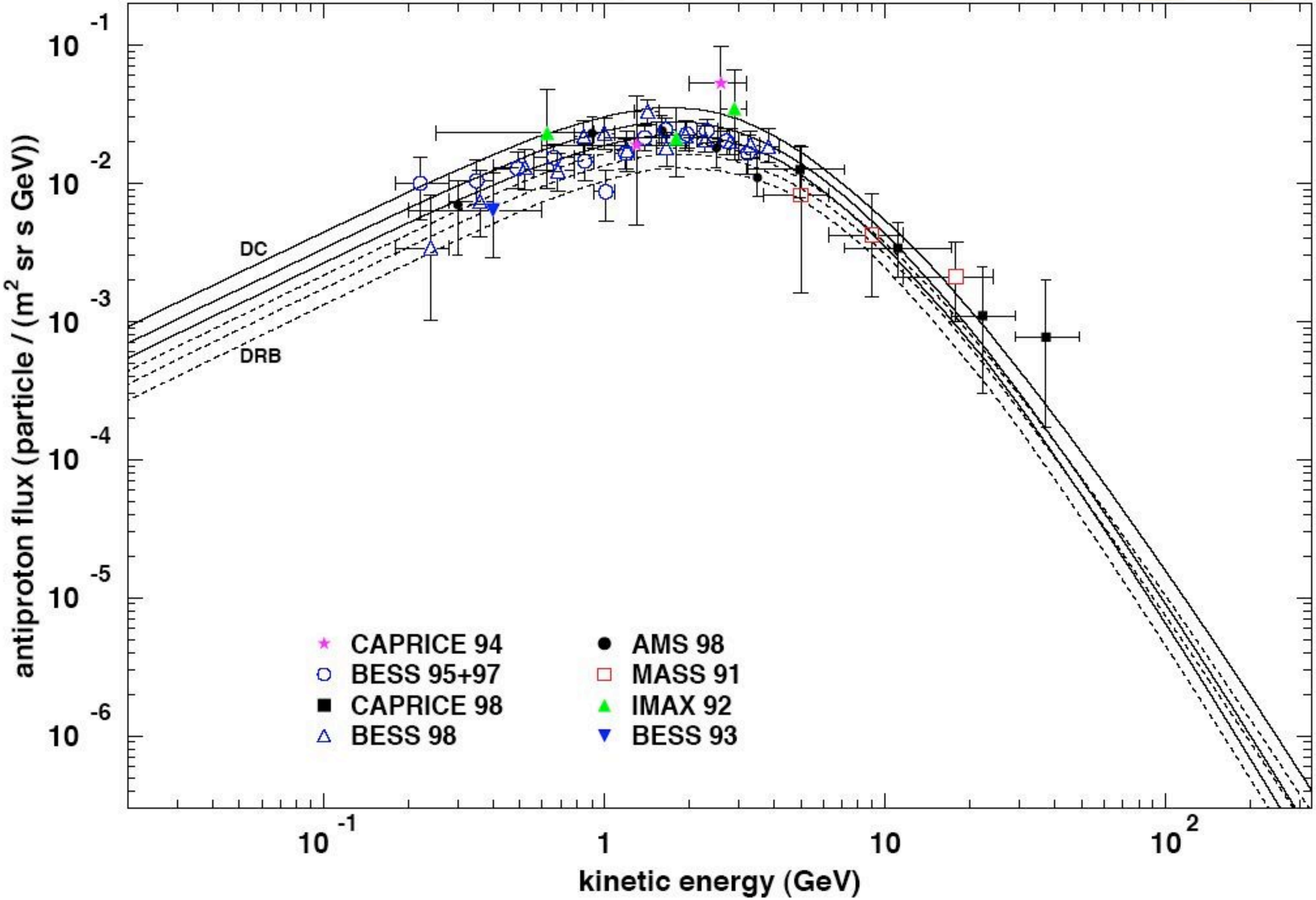
Allowed values for the propagation parameters for DR propagation

	halo size	diffusion constant	diff index	prim spec injection index	Alfven velocity
par./val.	$z[kpc]$	$D_0[cm^2 s^{-1}]$	δ	γ	$v_A[kms^{-1}]$
minimal	3.0	$5.2\ 10^{28}$	0.25	2.35	22
best fit	4.0	$5.8\ 10^{28}$	0.29	2.47	26
maximal	5.0	$6.7\ 10^{28}$	0.36	2.52	35

Allowed values for the propagation parameters for DC propagation

	halo size	diff constant	diff index	V_c gradient	injection indexes	
par./val.	$z[kpc]$	$D_0[\frac{cm^2}{s}]$	δ_2	$\frac{dV_C}{dz}[\frac{km}{skpc}]$	γ_1	γ_2
minimal	3.0	$2.3\ 10^{28}$	0.48	5.0	2.42	2.14
best fit	4.0	$2.5\ 10^{28}$	0.55	6.0	2.48	2.20
maximal	5.0	$2.7\ 10^{28}$	0.62	7.0	2.50	2.22

Antiproton spectra: Upper and lower bounds of due to the uncertainties of propagation parameters



PAMELA scientific program

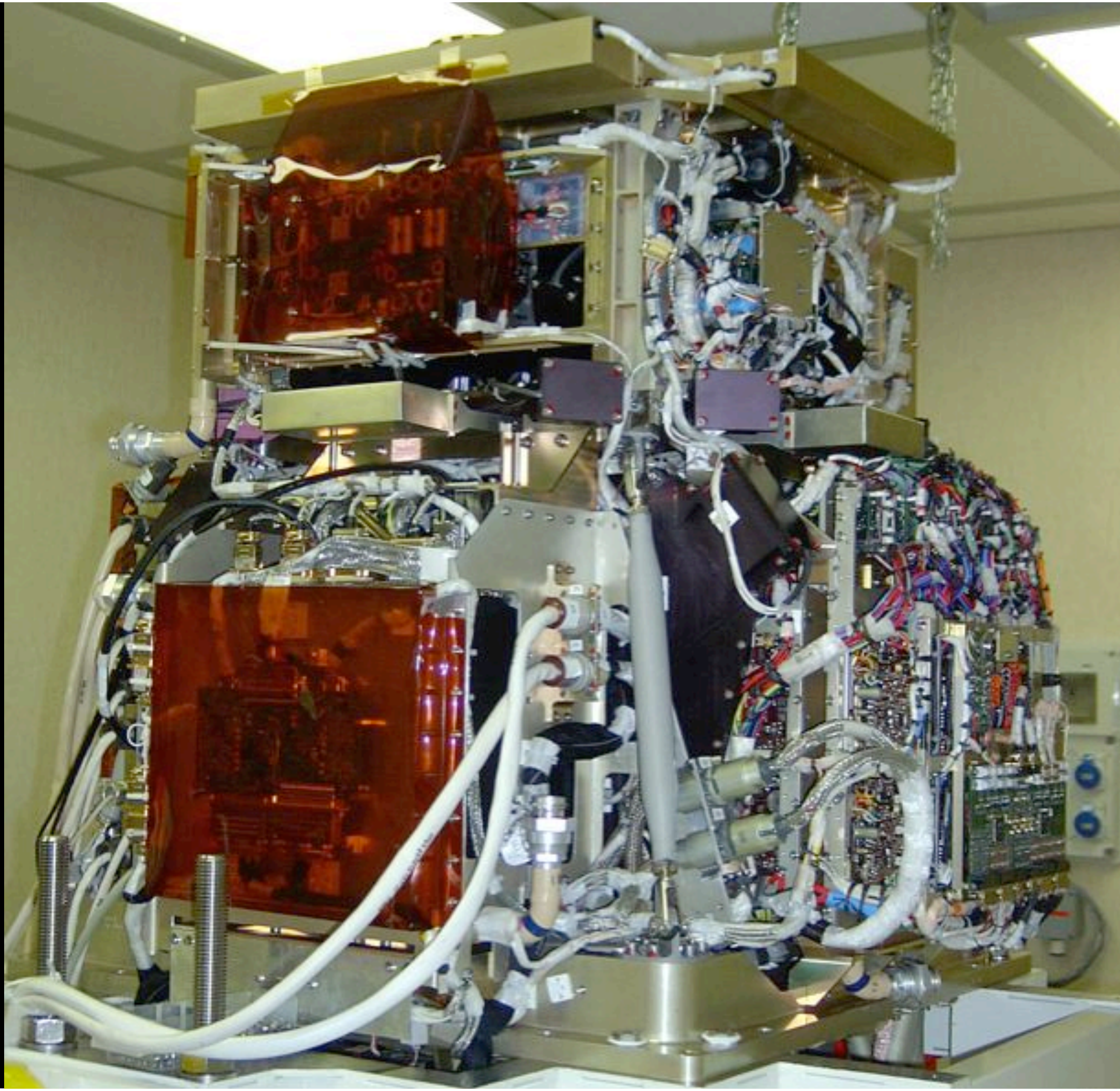
PAMELA is a magnetic spectrometer which will fly on a Russian satellite by Fall 2005. Its scientific scope is the measurement of the antiproton and positron spectra up to few hundred GeV, of the proton and electron spectra up to 700 GeV and that of light nuclei.

	energy range	particles/3 years
Antiproton flux	80 MeV - 190 GeV	>3 10^{4}
Positron flux	50 MeV – 270 GeV	>3 10^{5}
Electron flux	up to 400 GeV	6 10^{6}
Proton flux	up to 700 GeV	3 10^{8}
Electron/positron flux	up to 2 TeV	
Light Nuclei (up to Z=6)	up to 200 GeV/n	He/Be/C: 4 $10^{7/4/5}$
AntiNuclei search	(sensitivity of 3 10^{-8} in $\overline{He}$/He)	

→ **Unprecedented Statistics and new Energy Range in Cosmic Rays**

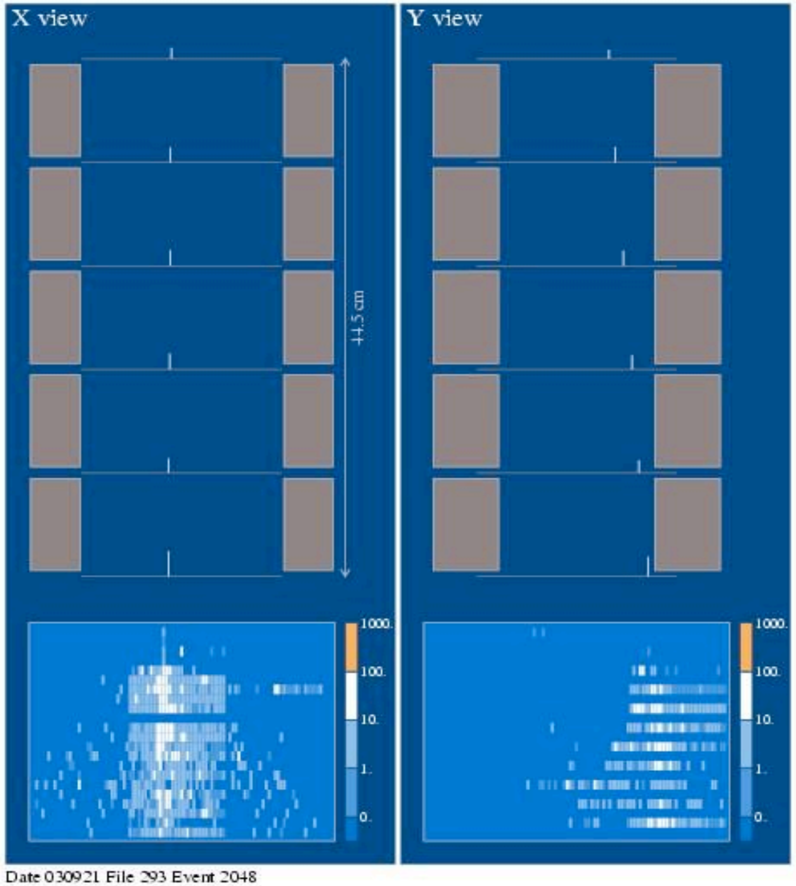
Actual limits: antip&positrons ≈ 40 GeV

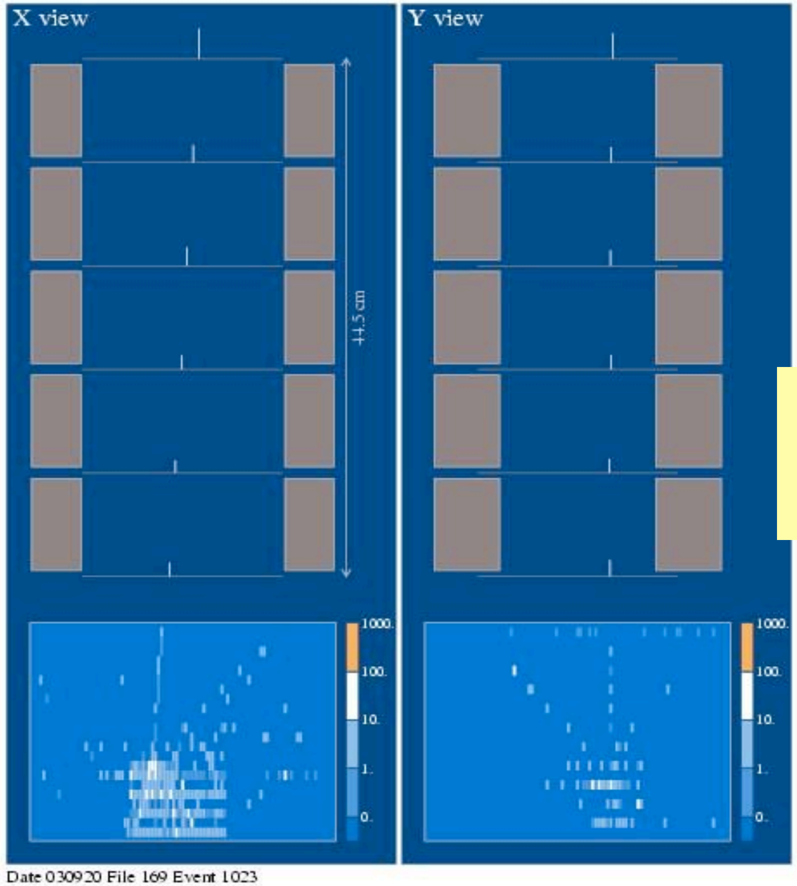
Pamela
in Samara,
Russia
4/09/05



Pamela Calibration

SPS Test Beam Data: p 50 GeV/c

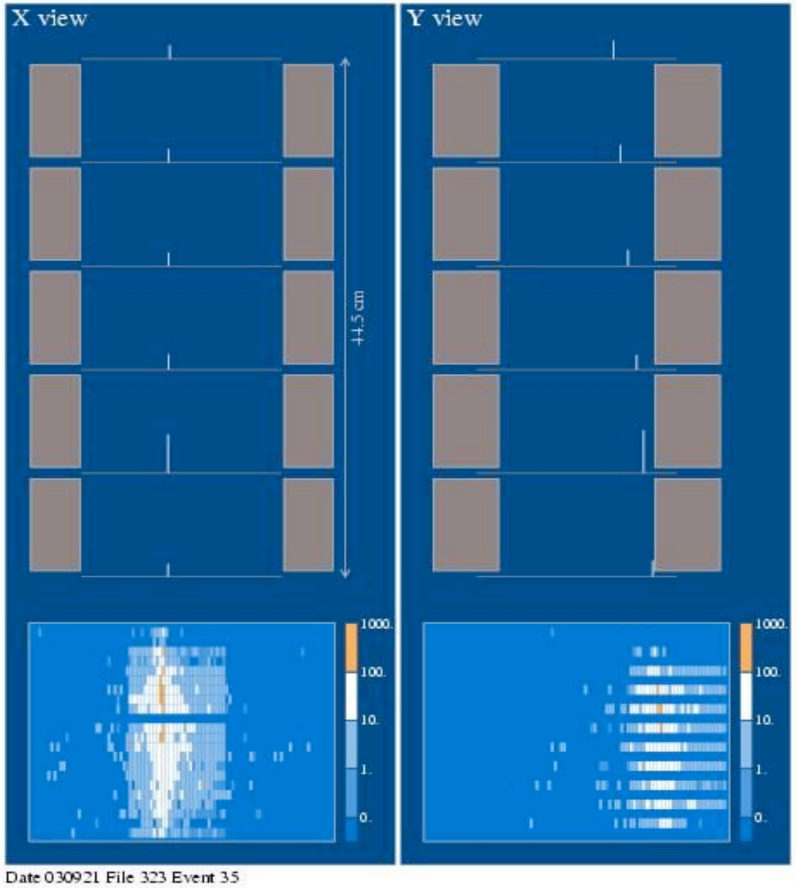


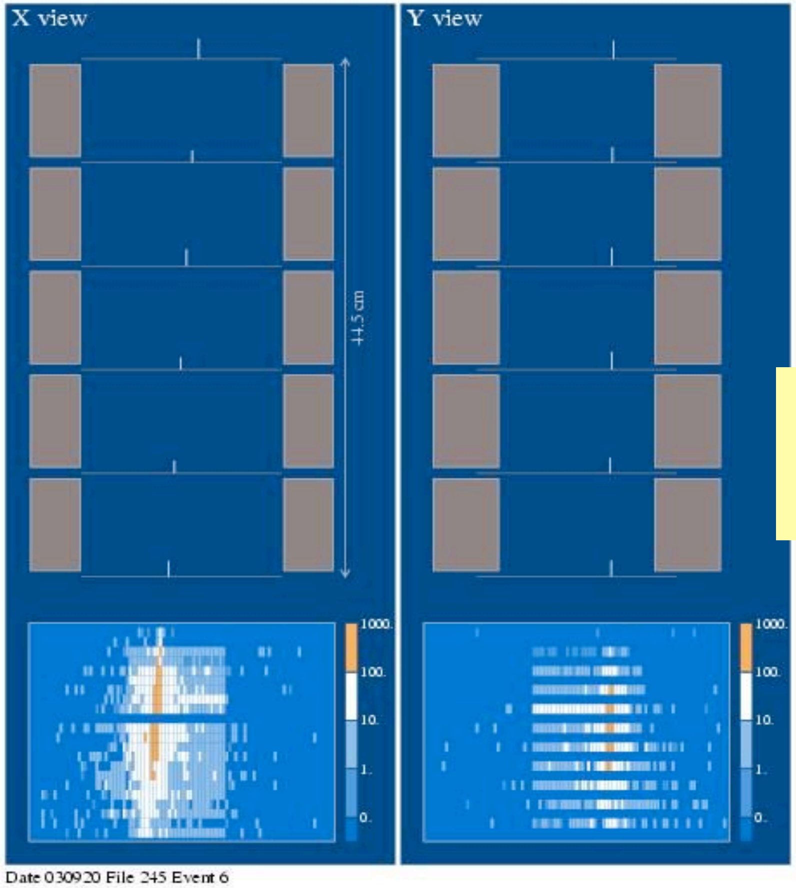


SPS Test Beam Data: p 100 GeV/c

Pamela Calibration

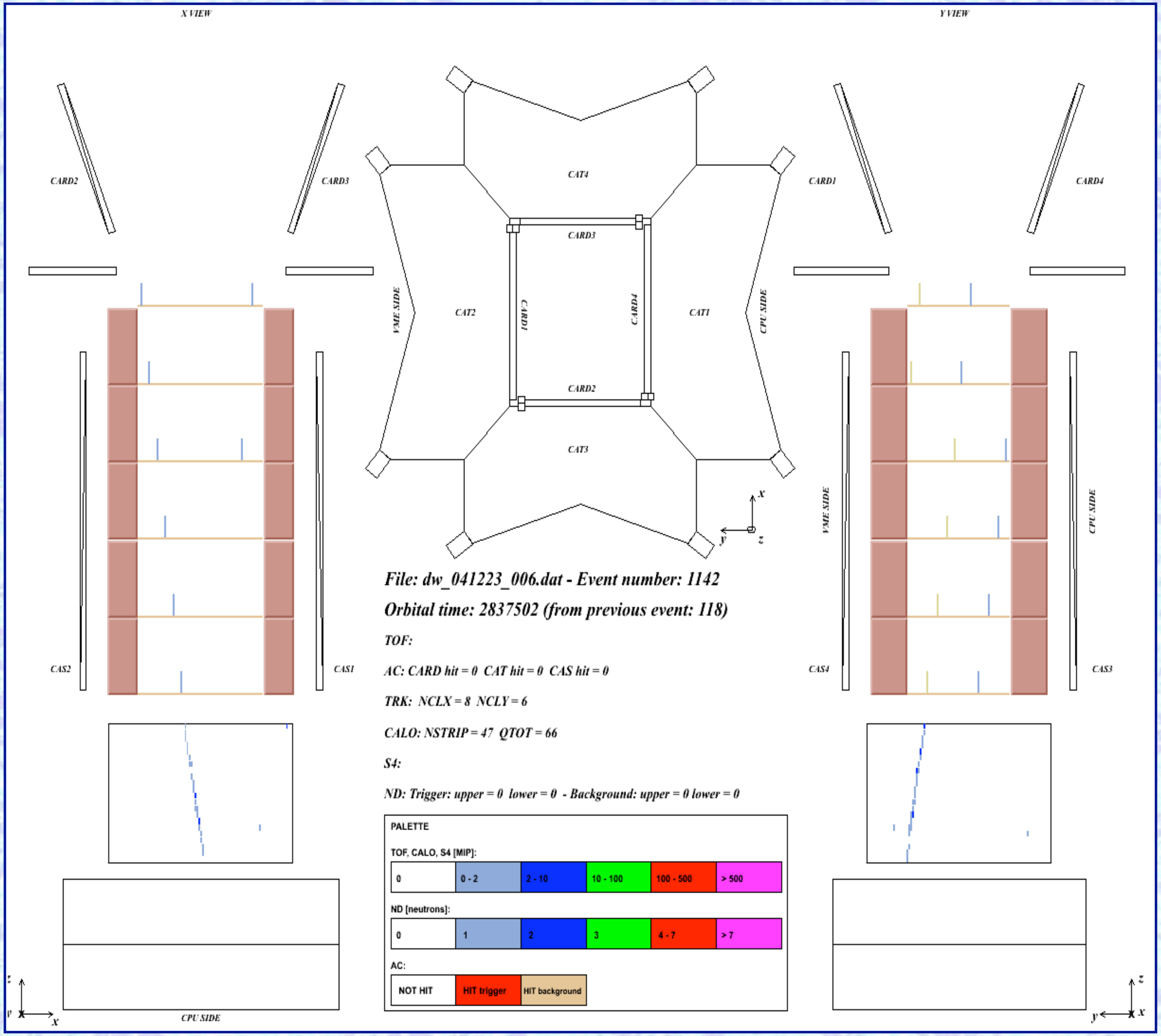
SPS Test Beam Data: e^- 50 GeV/c





SPS Test Beam Data: e^- 100 GeV/c

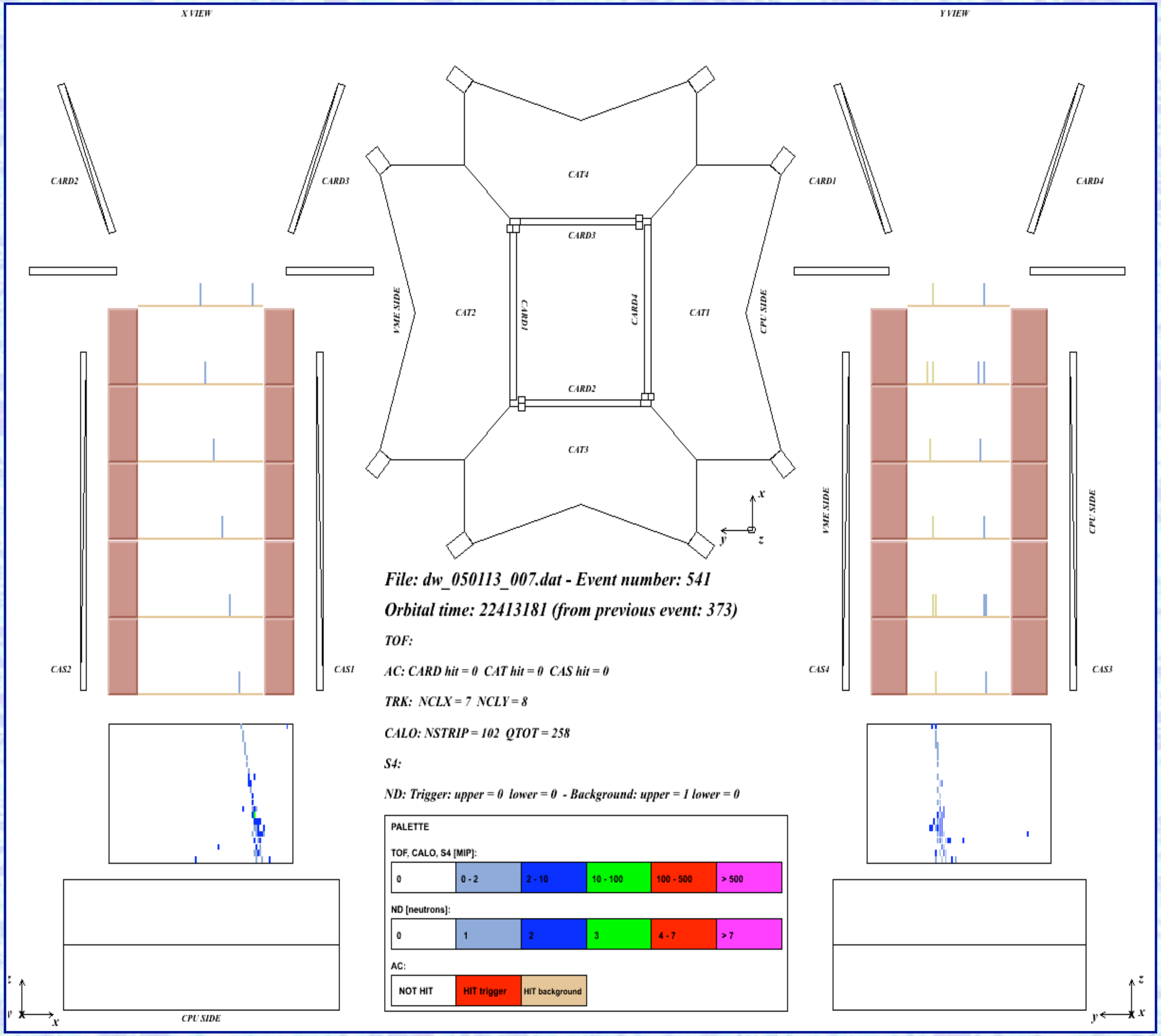
PAMELA Cosmic ray tracks (Dec. 2005)



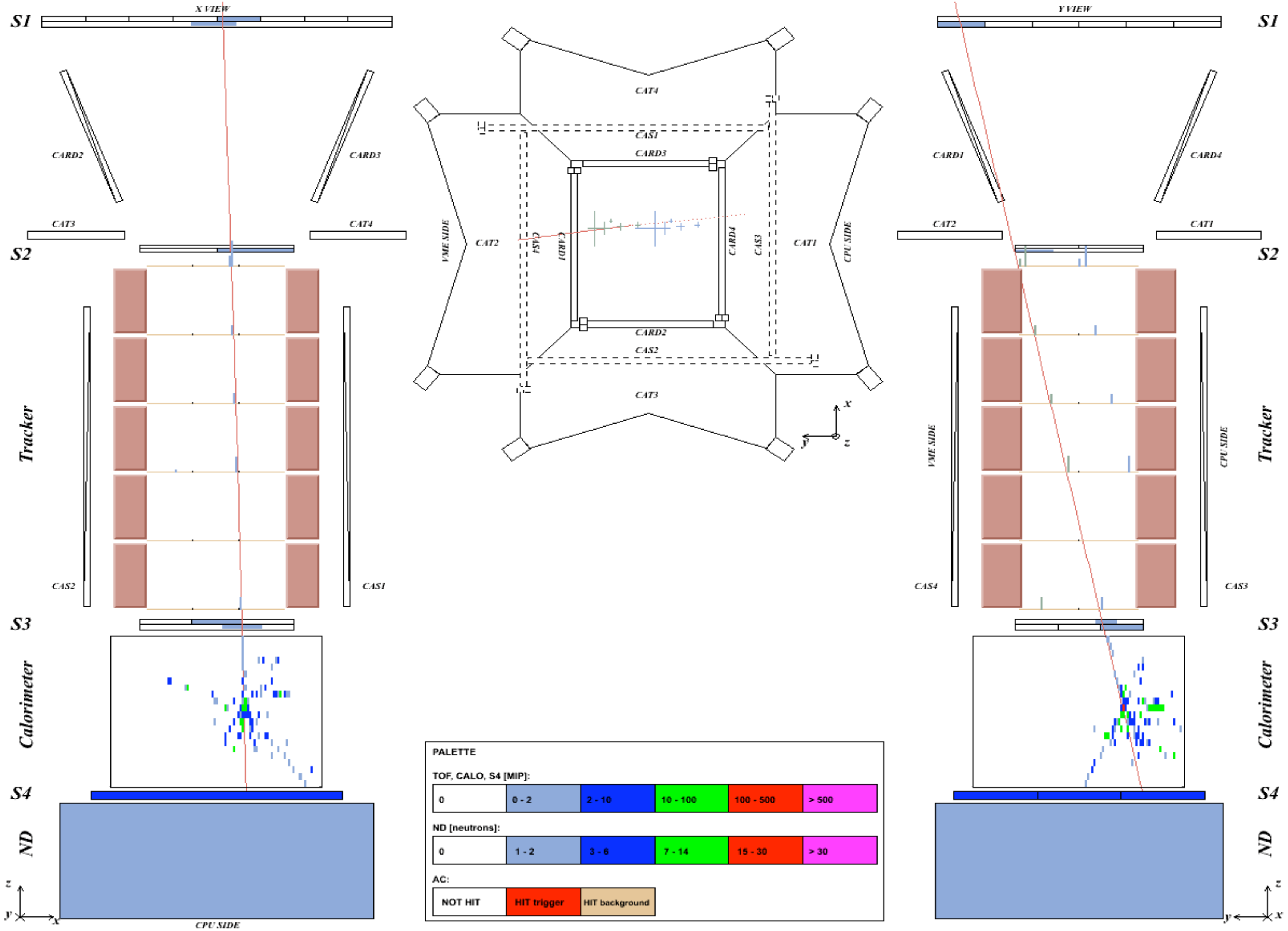
Since November 2004 PAMELA is set in cosmic-ray acquisition during night shifts.

PAMELA
Cosmic ray tracks
(Dec. 2005)

Since November 2004 PAMELA is set in cosmic-ray acquisition during night shifts.



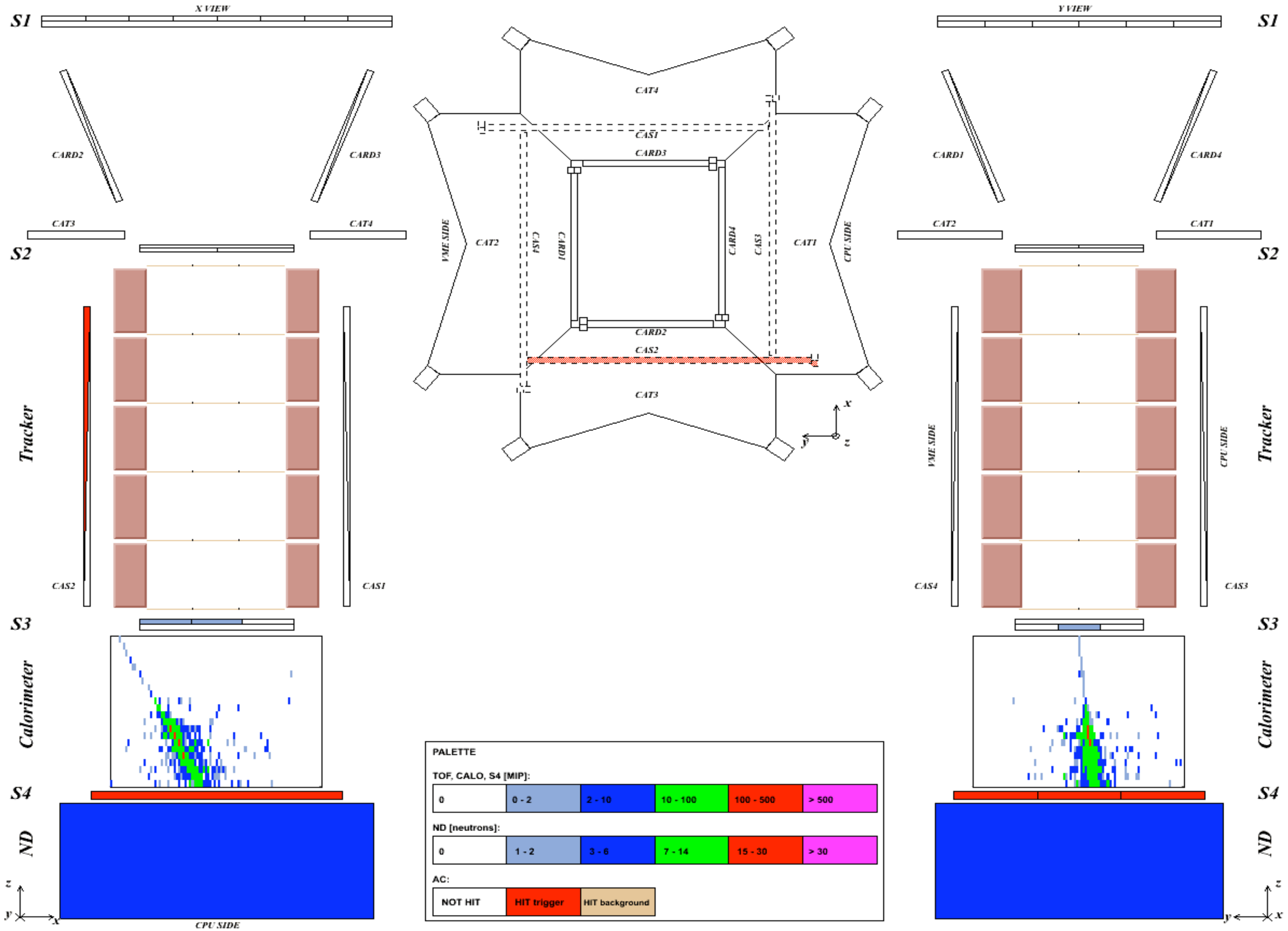
PAMELA Event



Ground Data
Hadron:
6.6 GV

PAMELA Event

Calorimeter Self Trigger



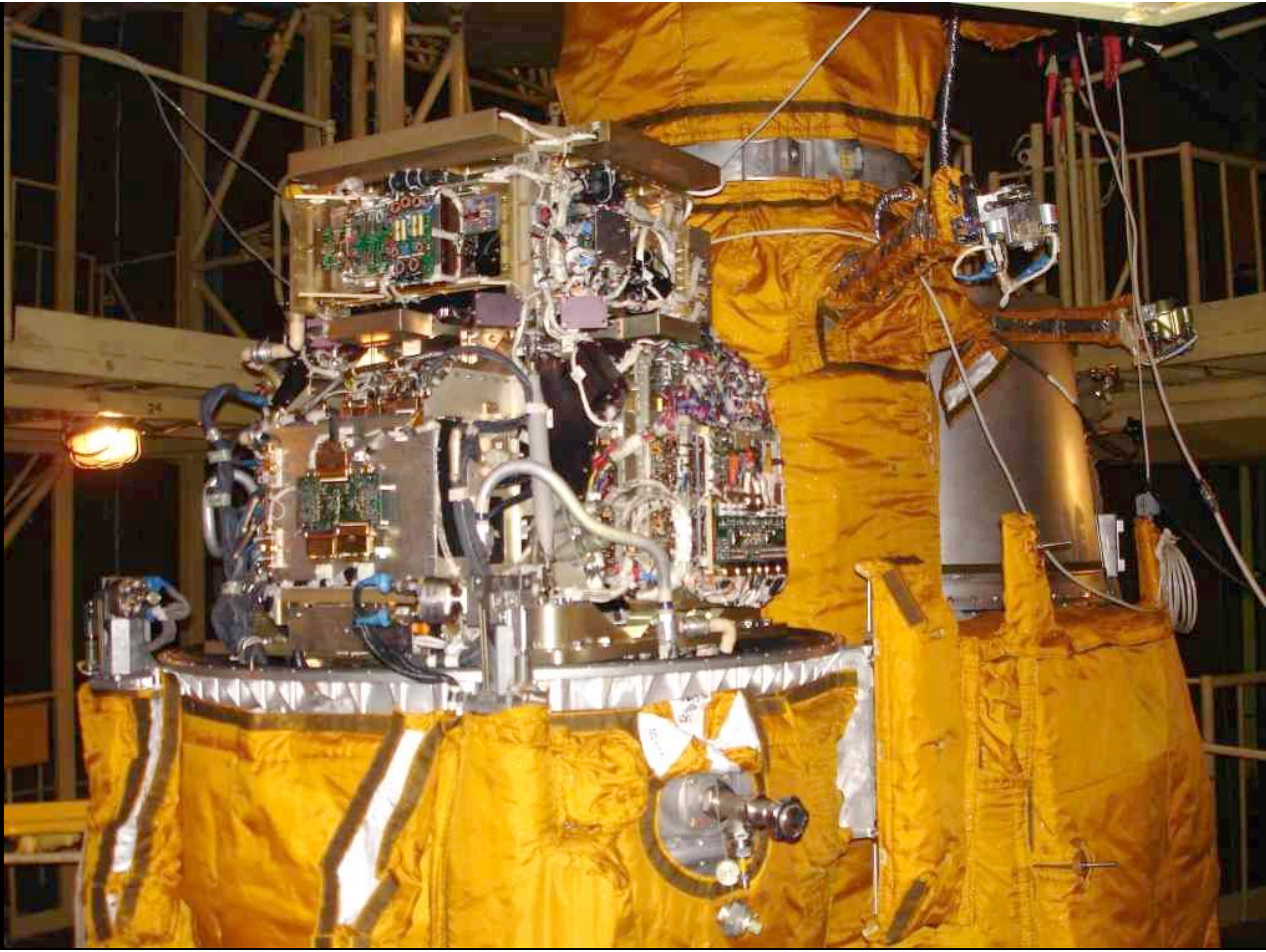
PAMELA @ Baikonur

28/03/06

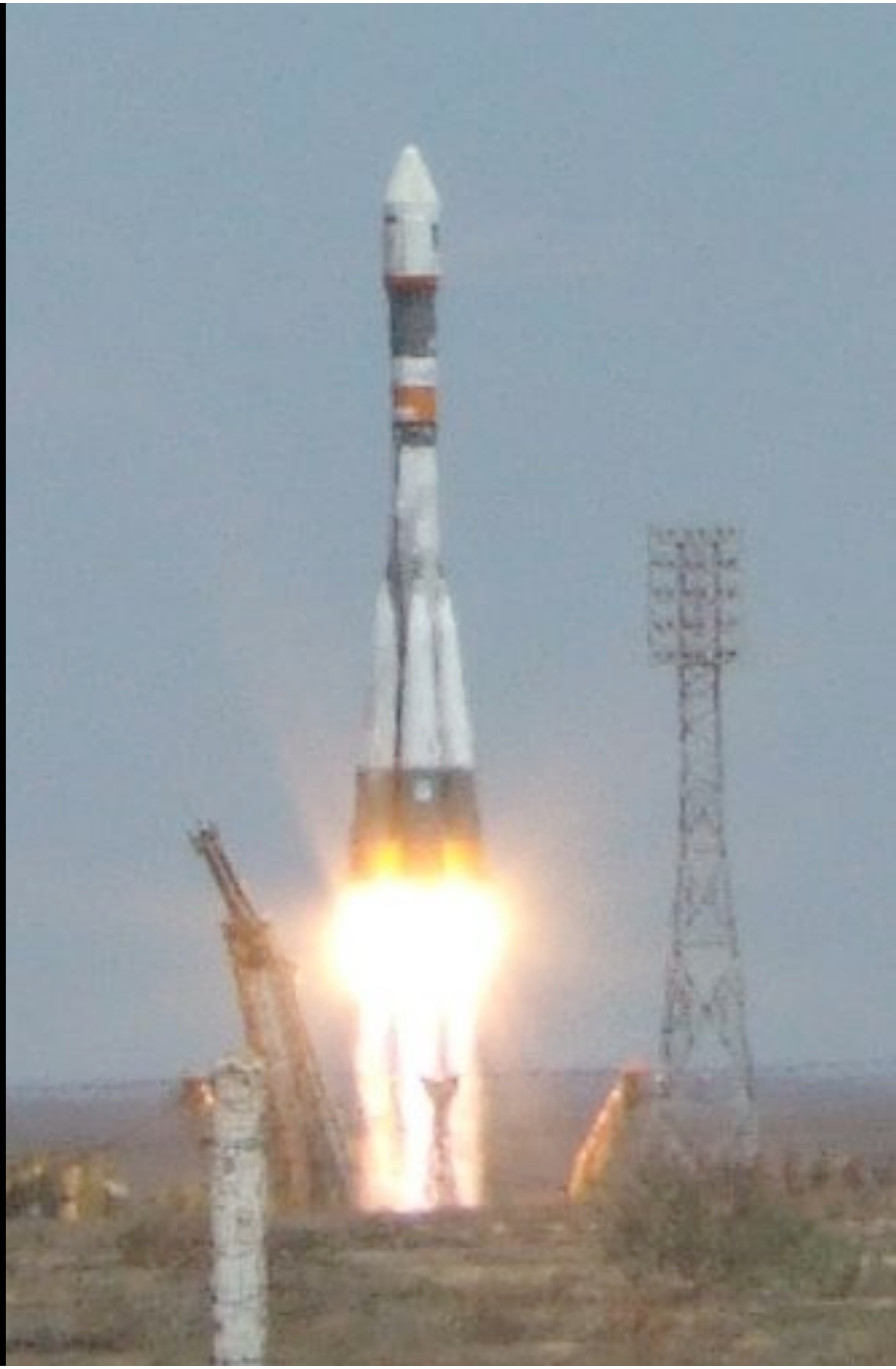
28/03/06

PAMELA @ Baikonur

RESURS DK1 Satellite



PAMELA Launch
15/06/06



PAMELA Launch
15/06/06

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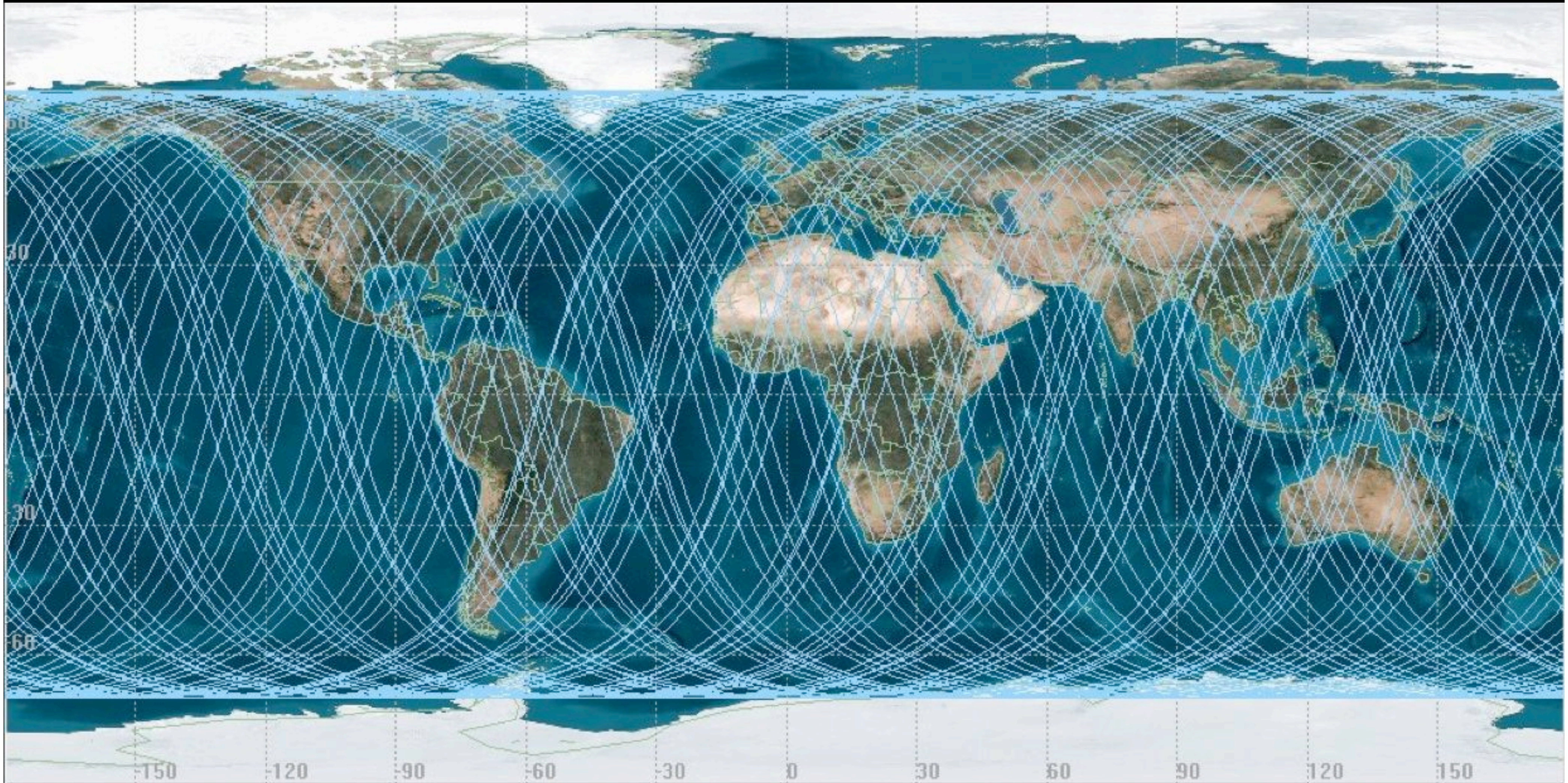
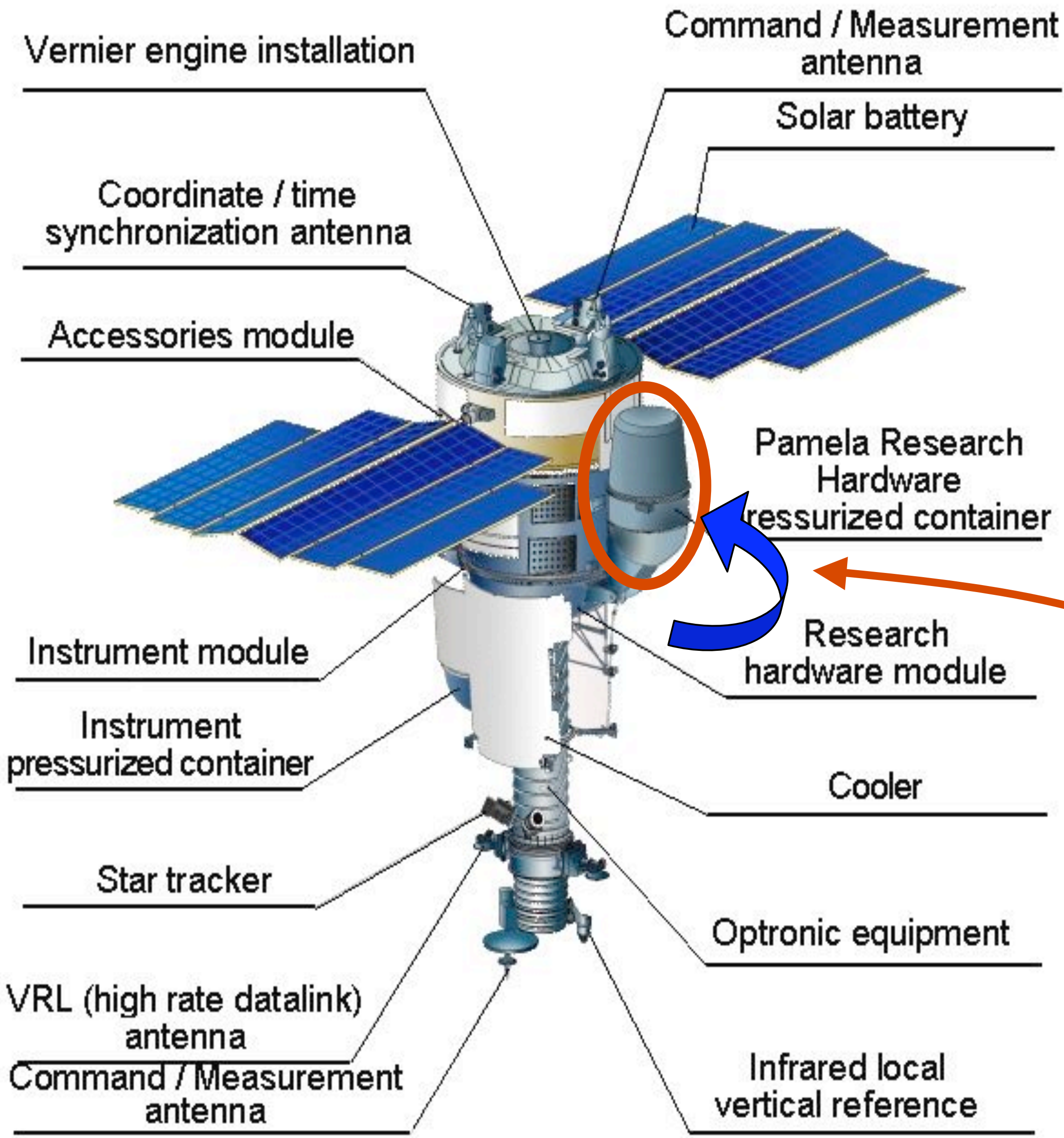


PAMELA Orbit : Current altitude 596-353 km

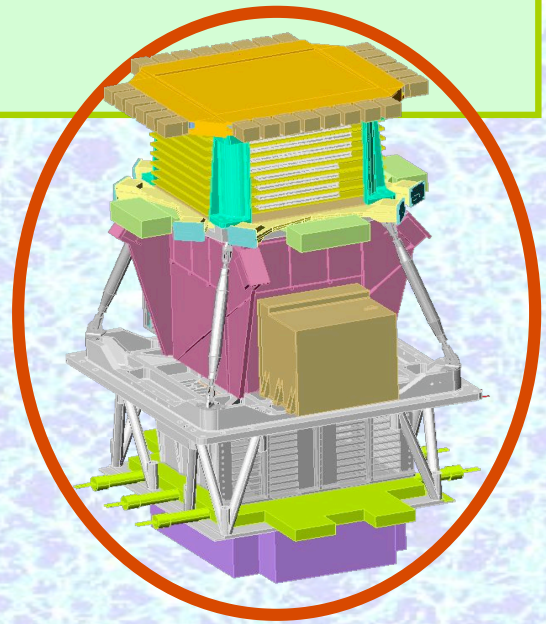
PAMELA was turned on yesterday at 10:00 Moscow local time and was operated for 4 hours. The mass memory was filled with 2 Gbyte of data (ie: the maximum possible).
Log information is available for the first 1.5 hours and showed one calibration and 5 acquisition runs. According to this information, all systems are functioning as expected.
Moreover, the maximum DC/DC and VME temperatures were stable at 26C indicating that the cooling system is working well.

Downlink of data to ground will happen sometime today (best vertical orbit)

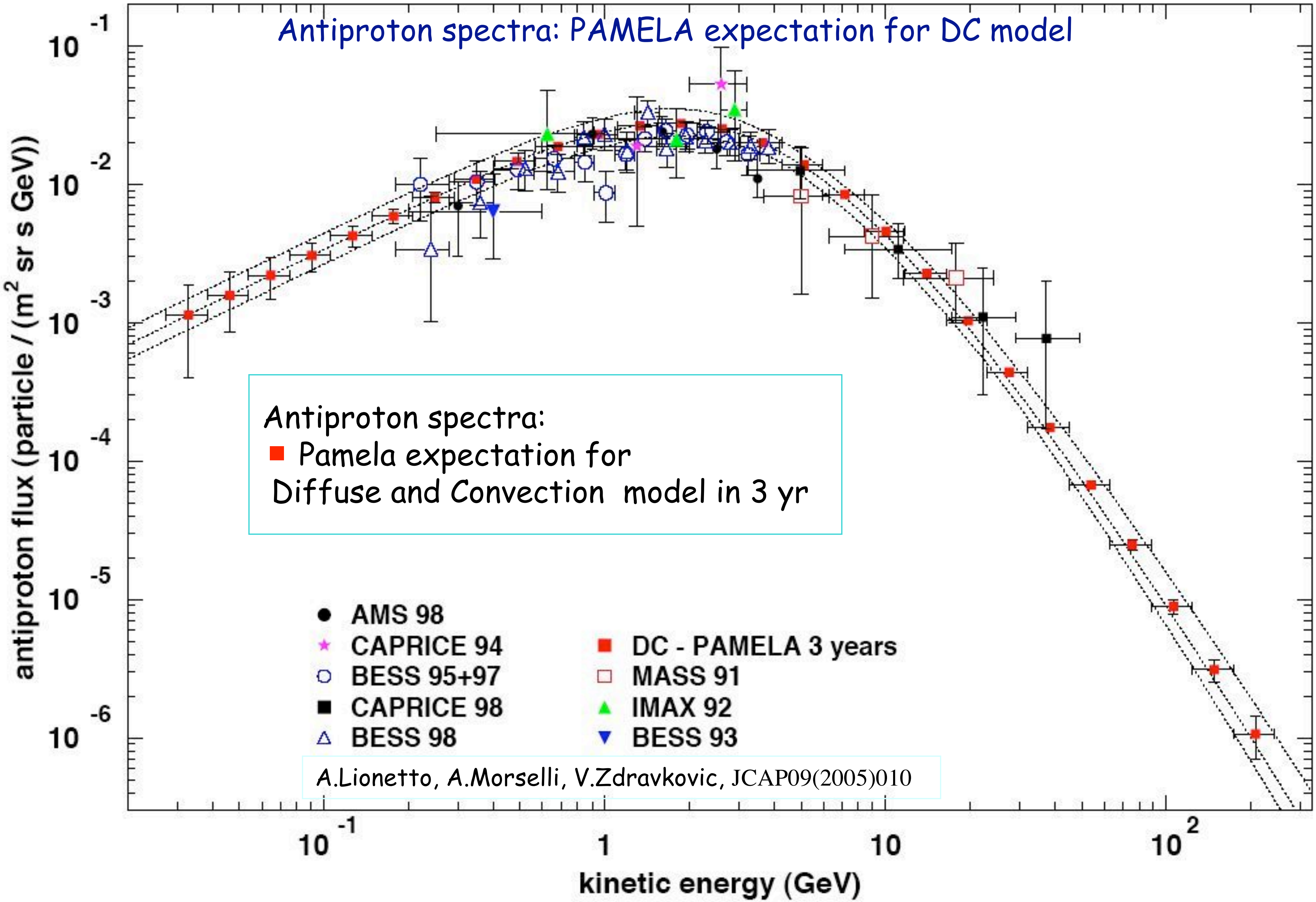
The Satellite: Resurs DK1



- Soyuz-TM Launcher from Baikonur
- Launch 14 June 2006
- Lifetime >3 years
- PAMELA mounted inside a Pressurized Container, attached to Satellite
- Earth-Observation-Satellite



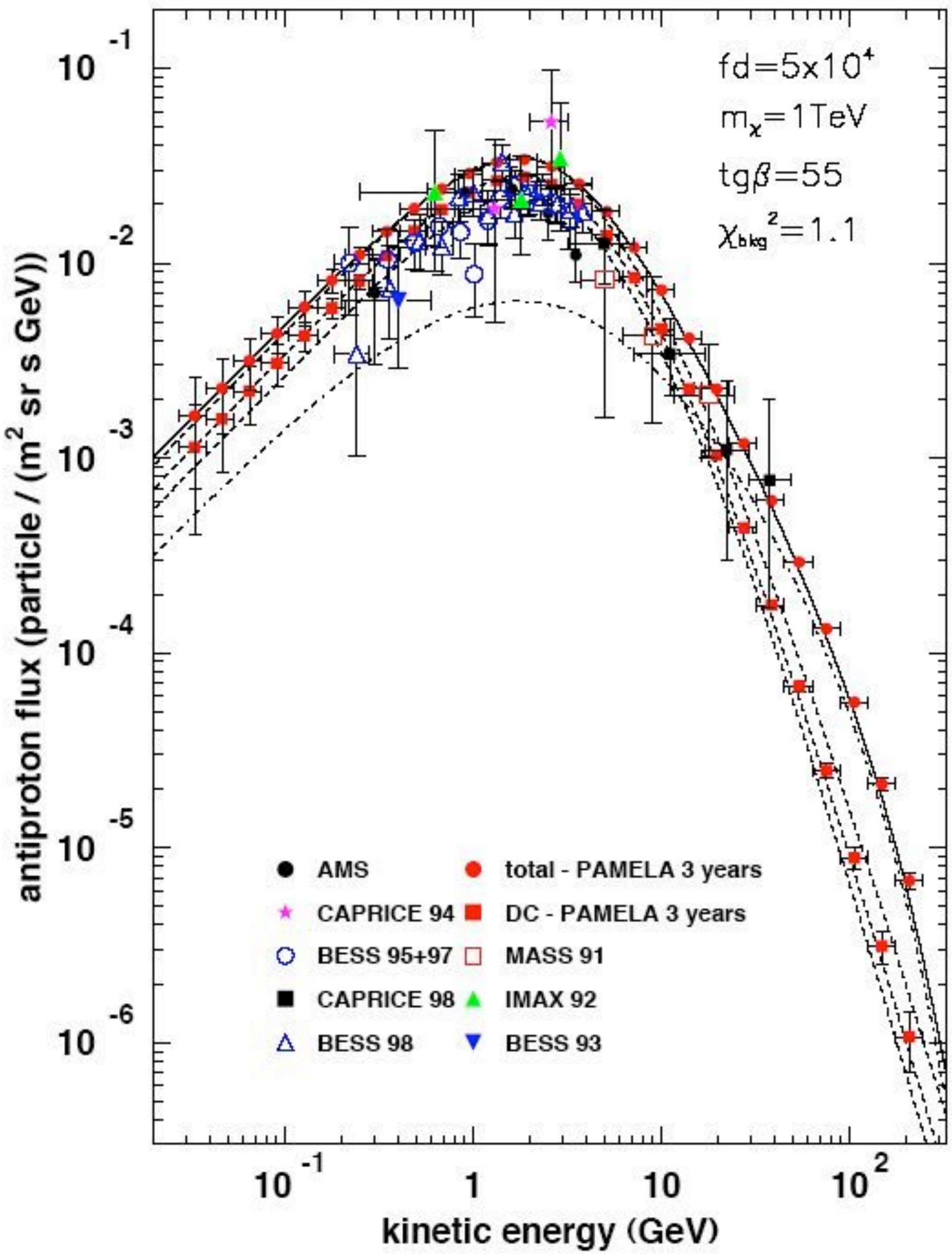
Antiproton spectra: PAMELA expectation for DC model



PAMELA:

Cosmic-Ray Antiparticle Measurements: Antiprotons

cMSSM

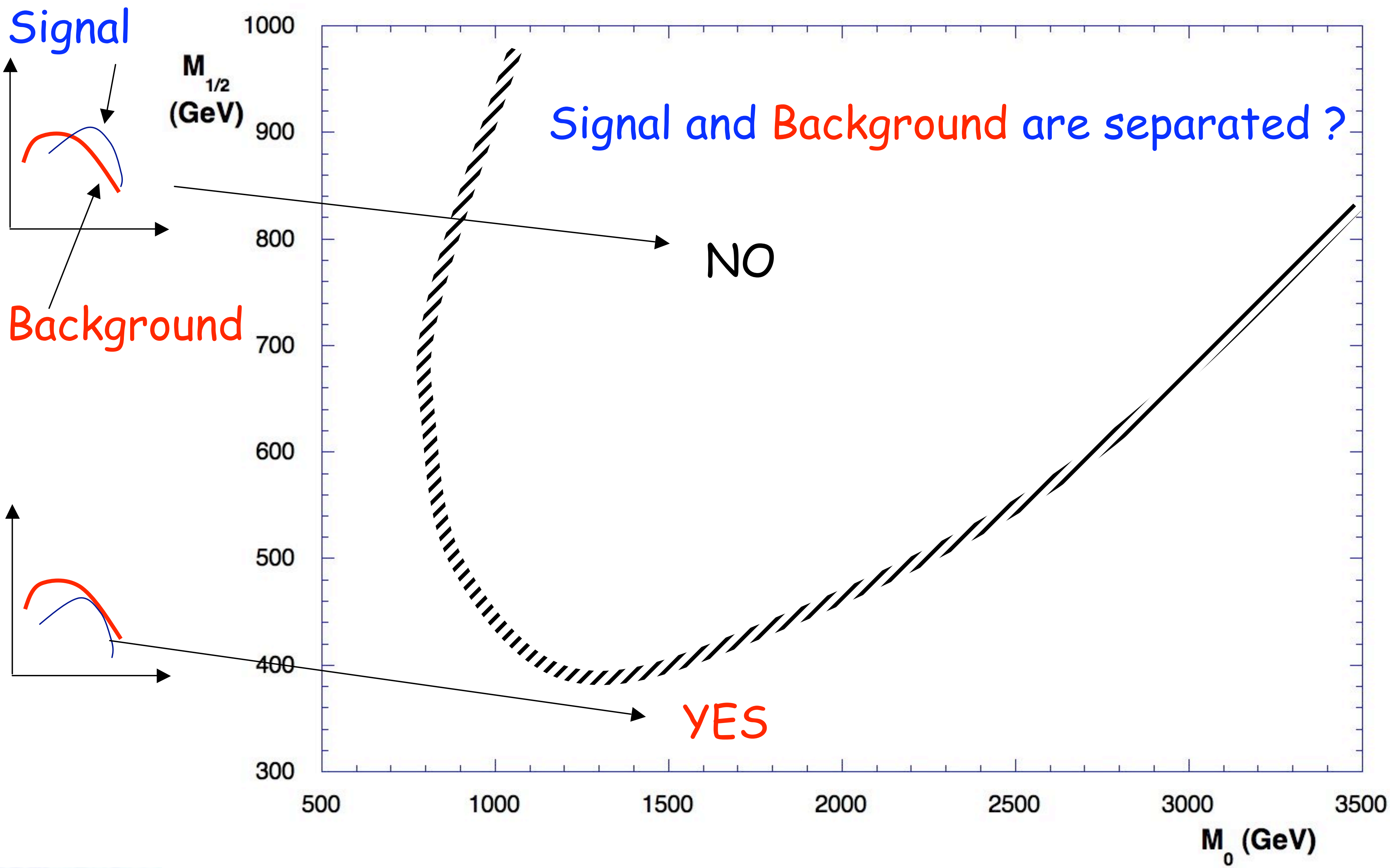


fd: Clumpiness factors needed to disentangle a neutralino induced component in the antiproton flux

A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]

cMSSM

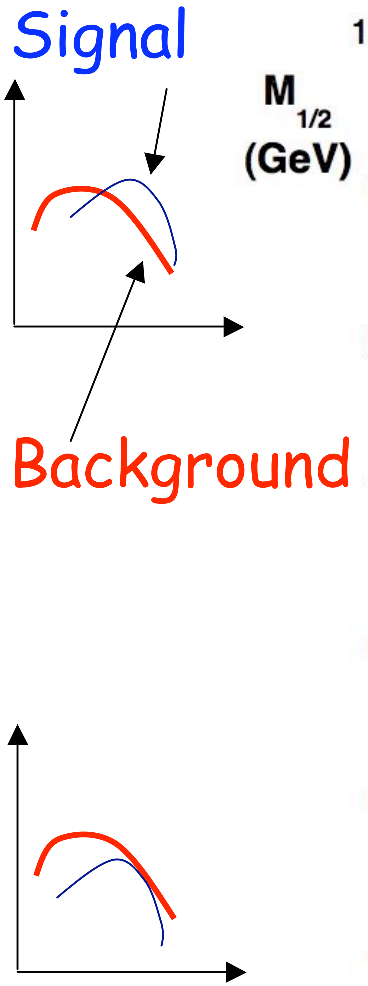
tg(β)=55, sign(μ)=+1

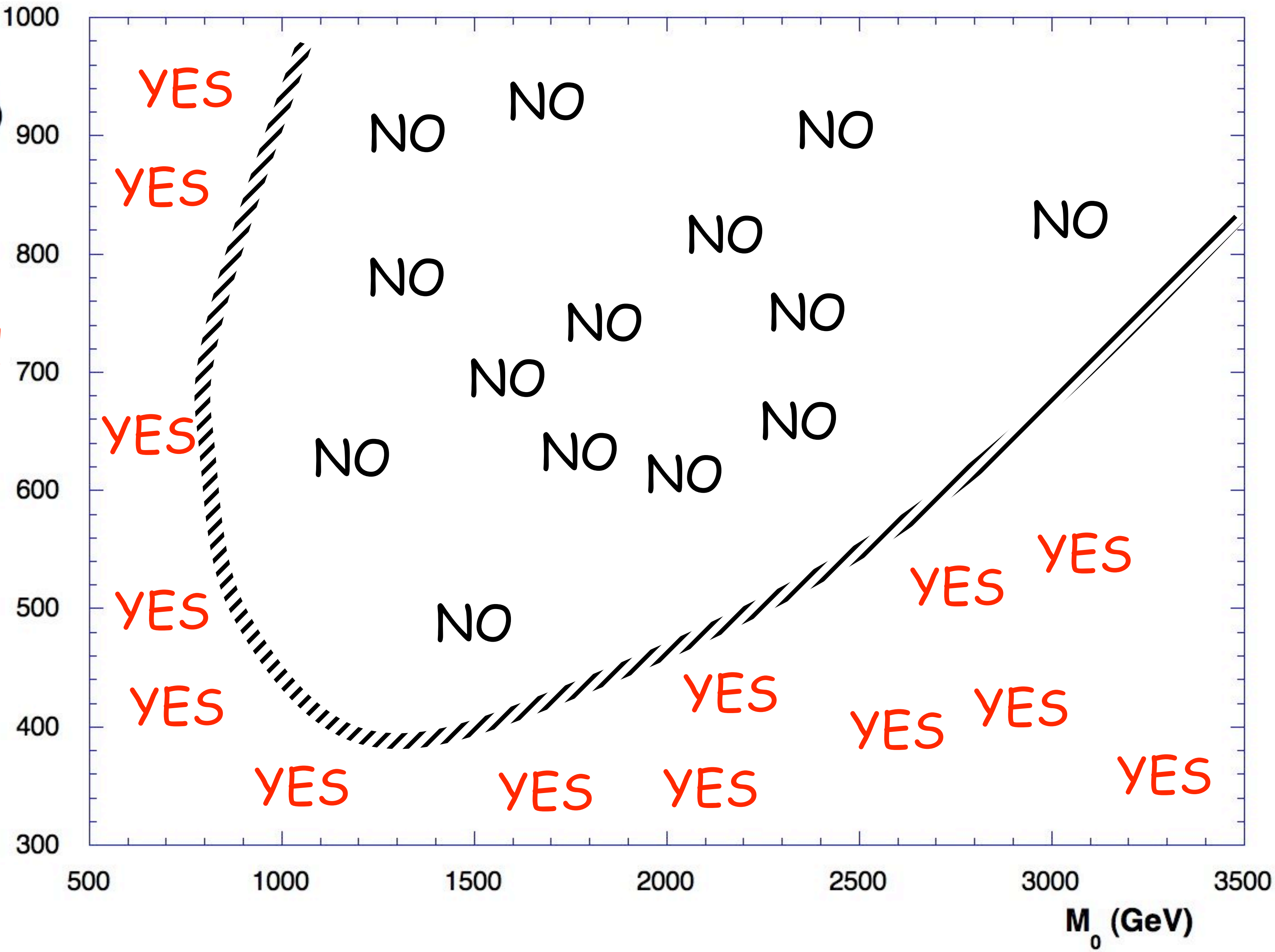


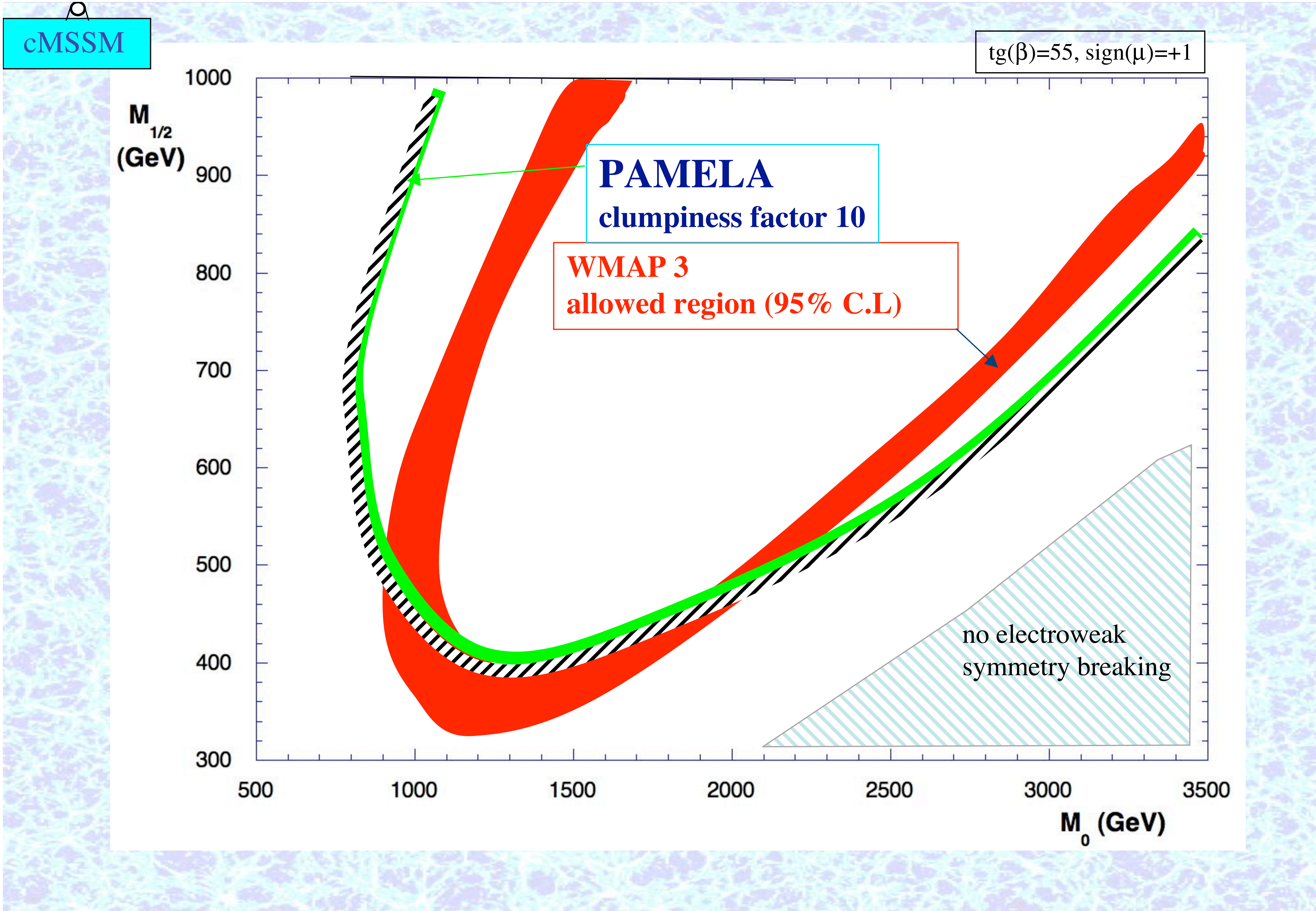
cMSSM

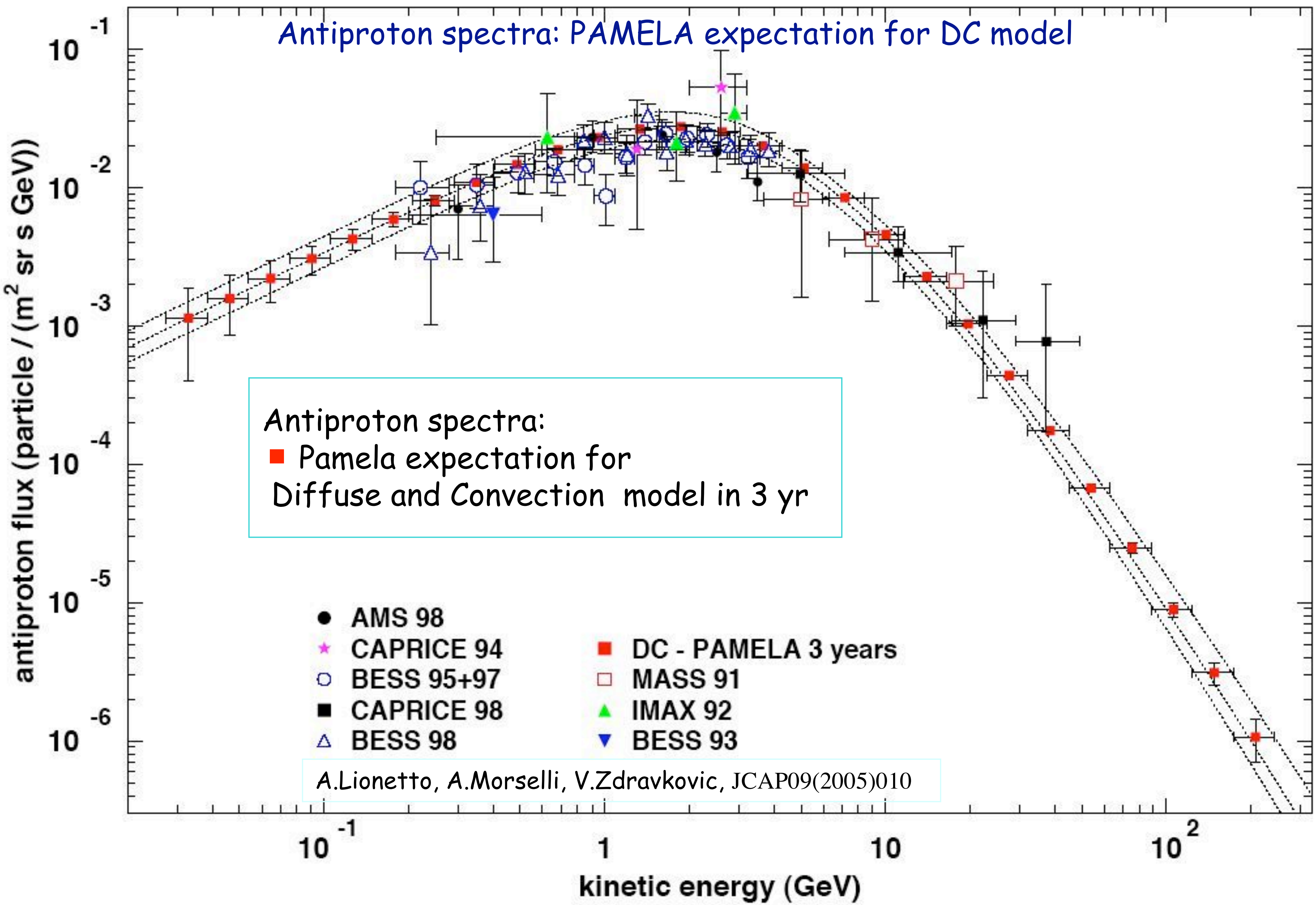
Signal and Background are separated ?

tg(β)=55, sign(μ)=+1

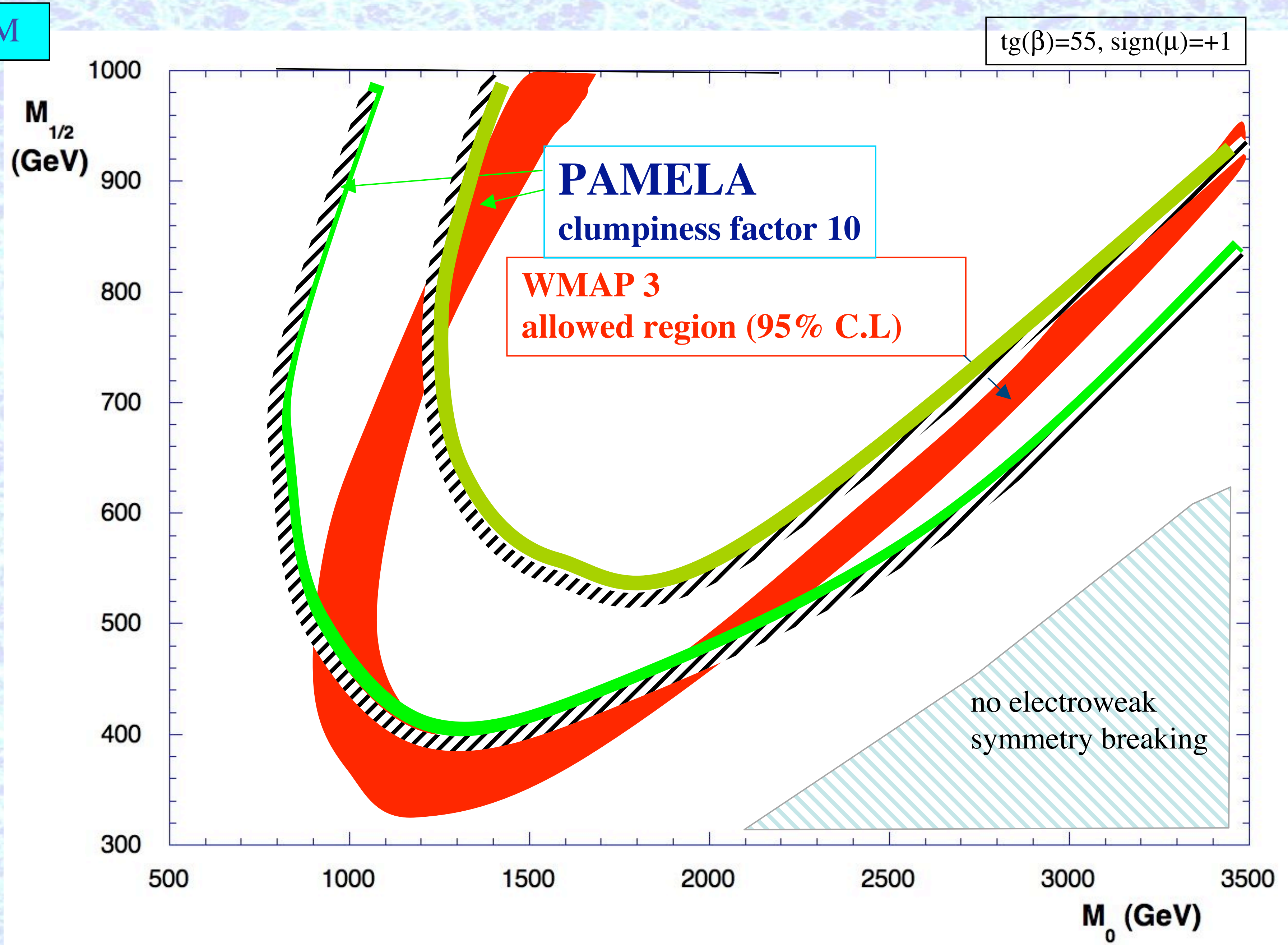





cMSSM
tg(β)=55, sign(μ)=+1
M 1/2 (GeV)
1000
900
800
700
600
500
400
300
500
1000
1500
2000
2500
3000
3500
M 0 (GeV)
PAMELA
clumpiness factor 10
WMAP 3
allowed region (95% C.L)
no electroweak
symmetry breaking

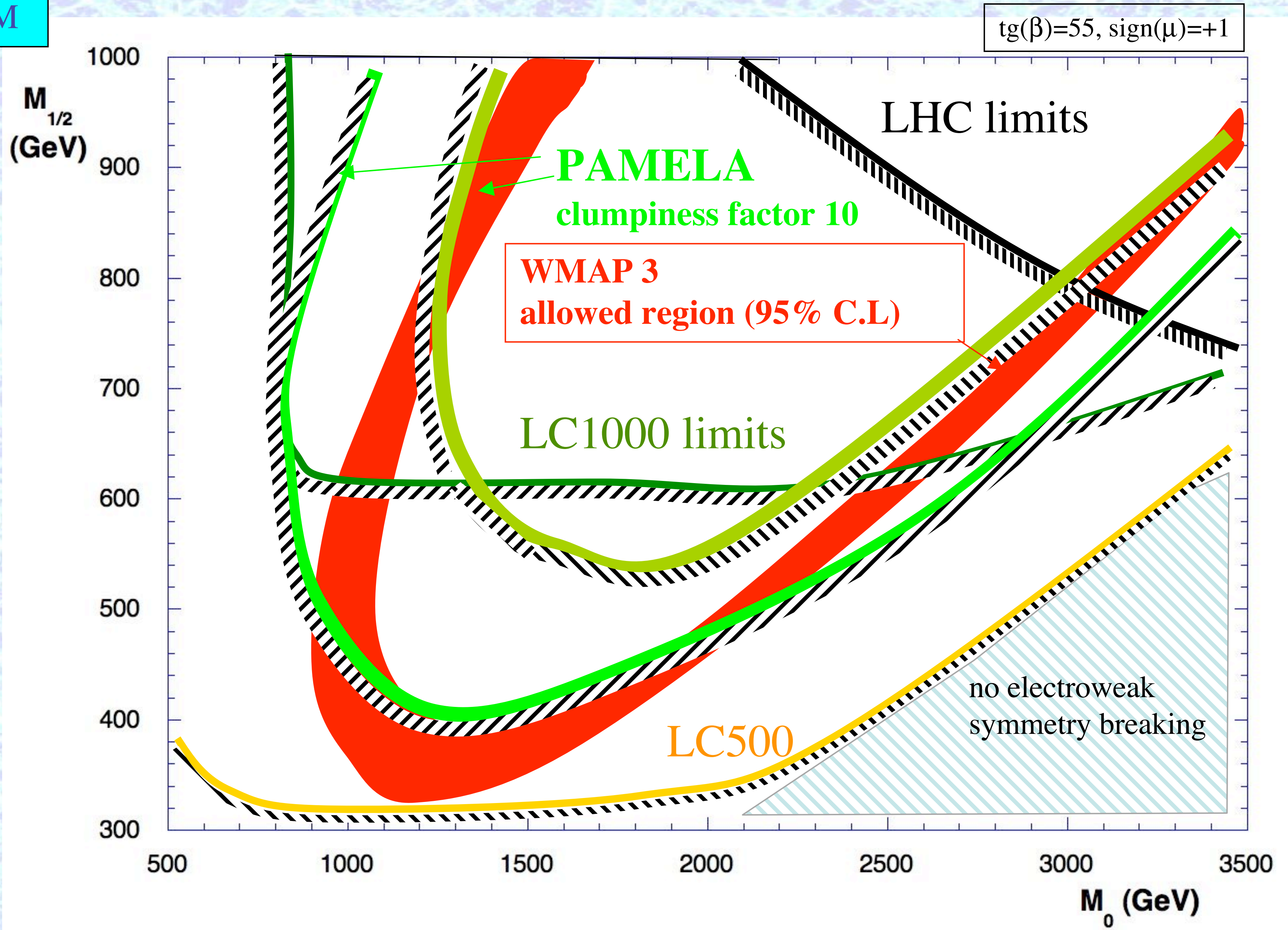

Antiproton spectra: PAMELA expectation for DC model
antiproton flux (particle / (m^2 sr s GeV))
kinetic energy (GeV)
Antiproton spectra:
Pamela expectation for
Diffuse and Convection model in 3 yr
AMS 98
CAPRICE 94
BESS 95+97
CAPRICE 98
BESS 98
DC - PAMELA 3 years
MASS 91
IMAX 92
BESS 93
A.Lionetto, A.Morselli, V.Zdravkovic, JCAP09(2005)010

cMSSM



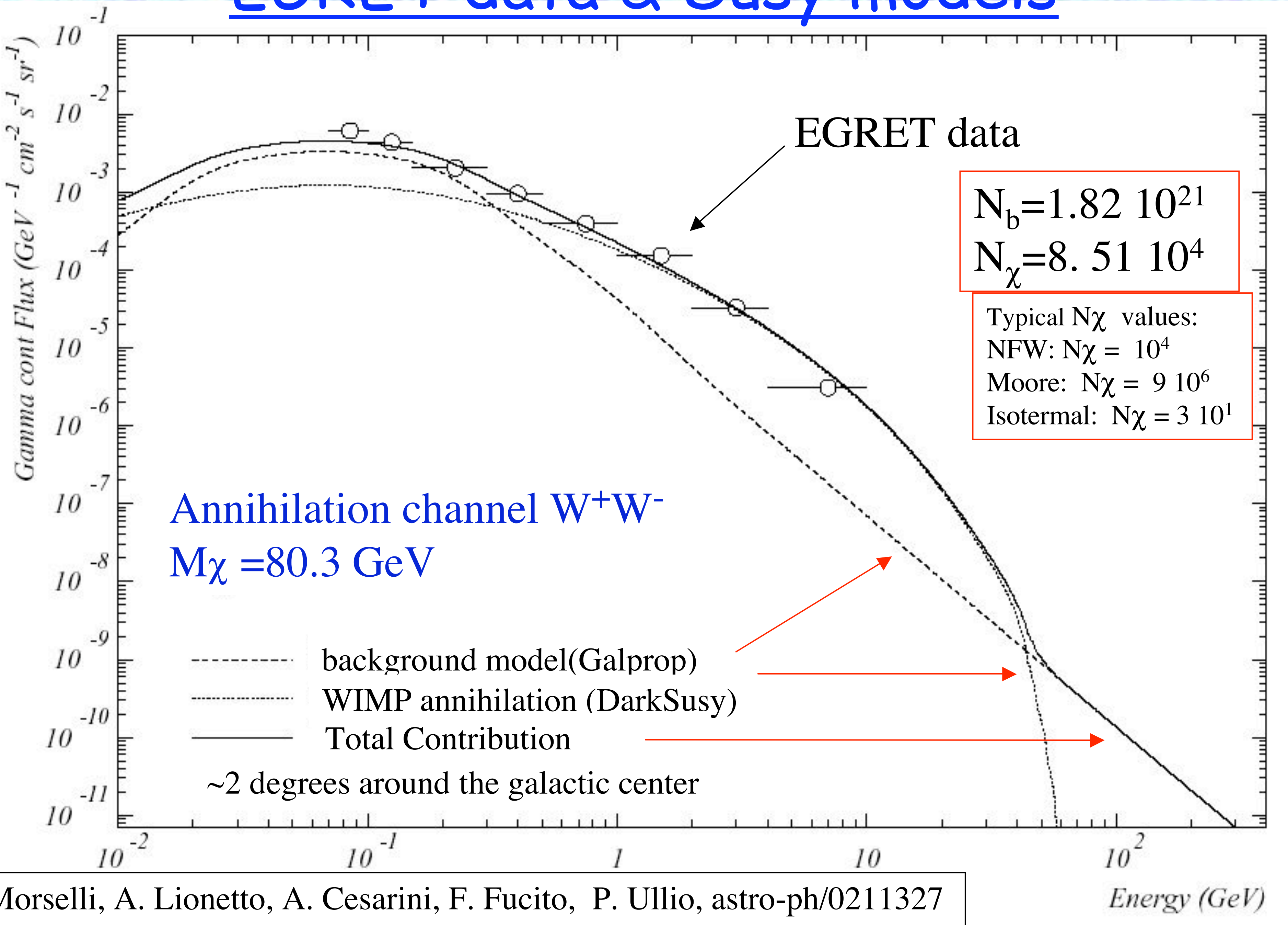
tg(β)=55, sign(μ)=+1
M 1/2 (GeV)
1000
900
800
700
600
500
400
300
500
1000
1500
2000
2500
3000
3500
M 0 (GeV)
PAMELA
clumpiness factor 10
WMAP 3
allowed region (95% C.L)
no electroweak
symmetry breaking

cMSSM



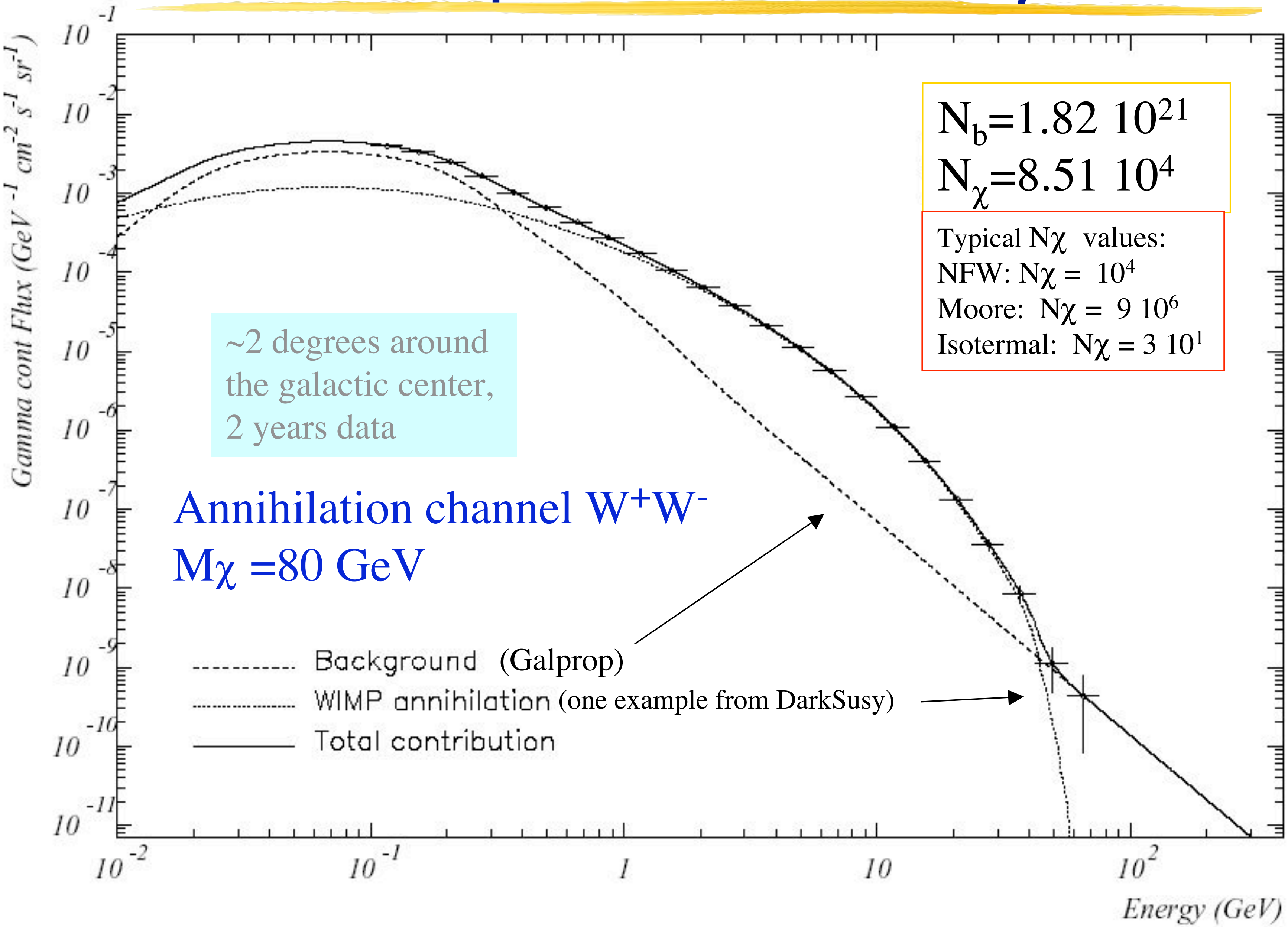
tg(β)=55, sign(μ)=+1
M 1/2 (GeV)
M 0 (GeV)
LHC limits
PAMELA
clumpiness factor 10
WMAP 3
allowed region (95% C.L)
LC1000 limits
LC500
no electroweak
symmetry breaking

EGRET data & Susy models

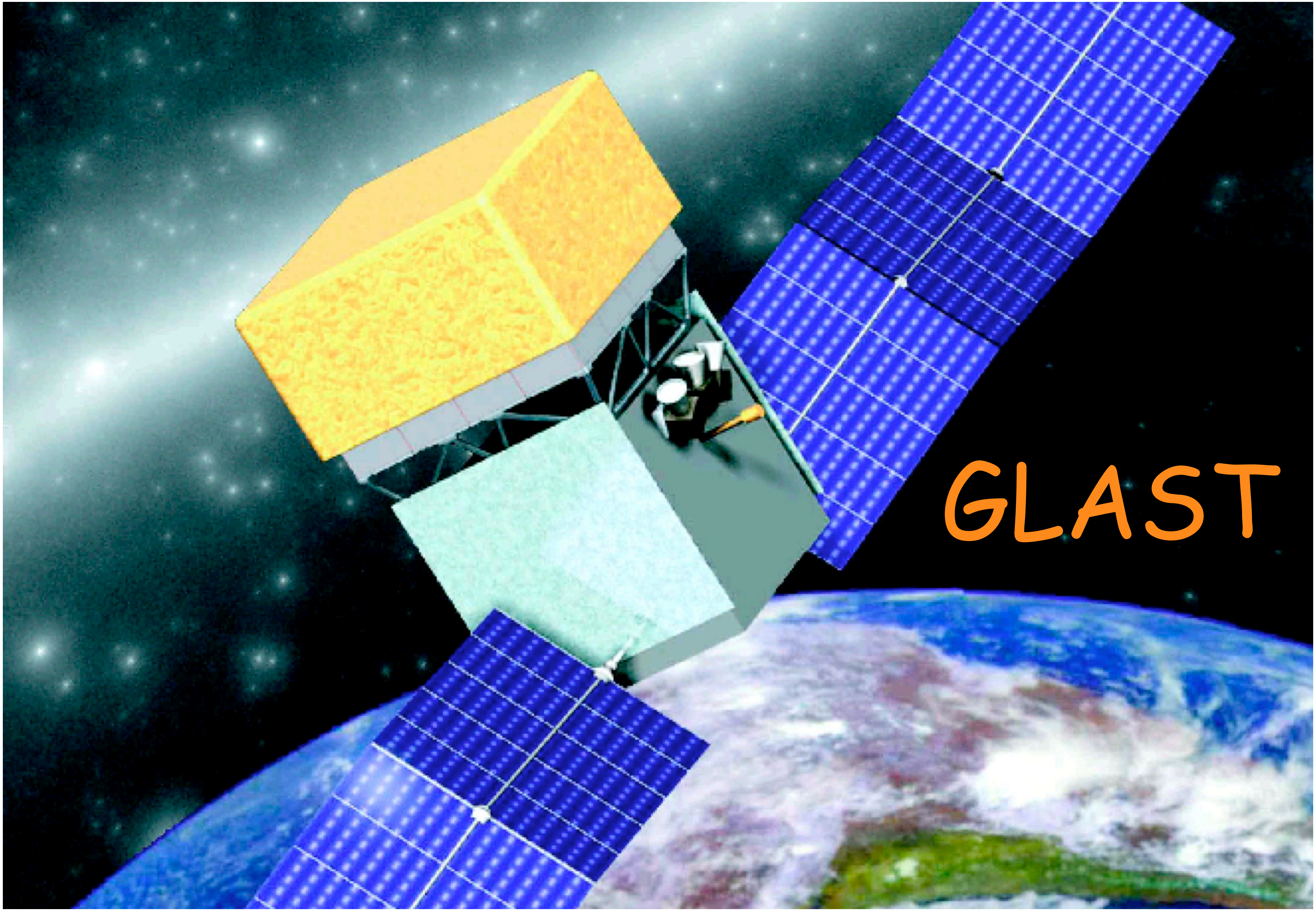


A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, astro-ph/0211327

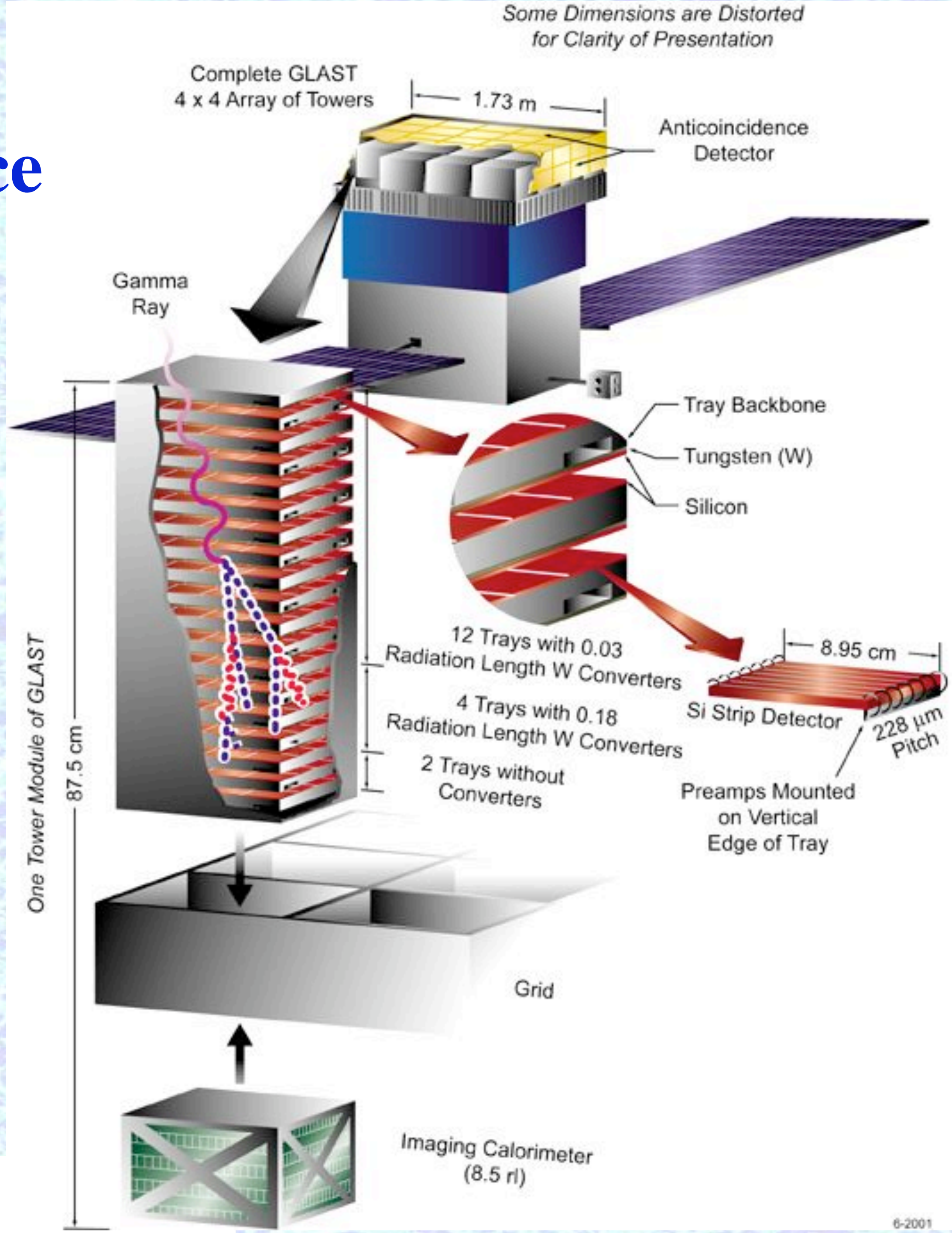
GLAST Expectation & Susy models



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, June 2004 [astro-ph/0305075]


GLAST

Gamma-Ray Large Area Space Telescope



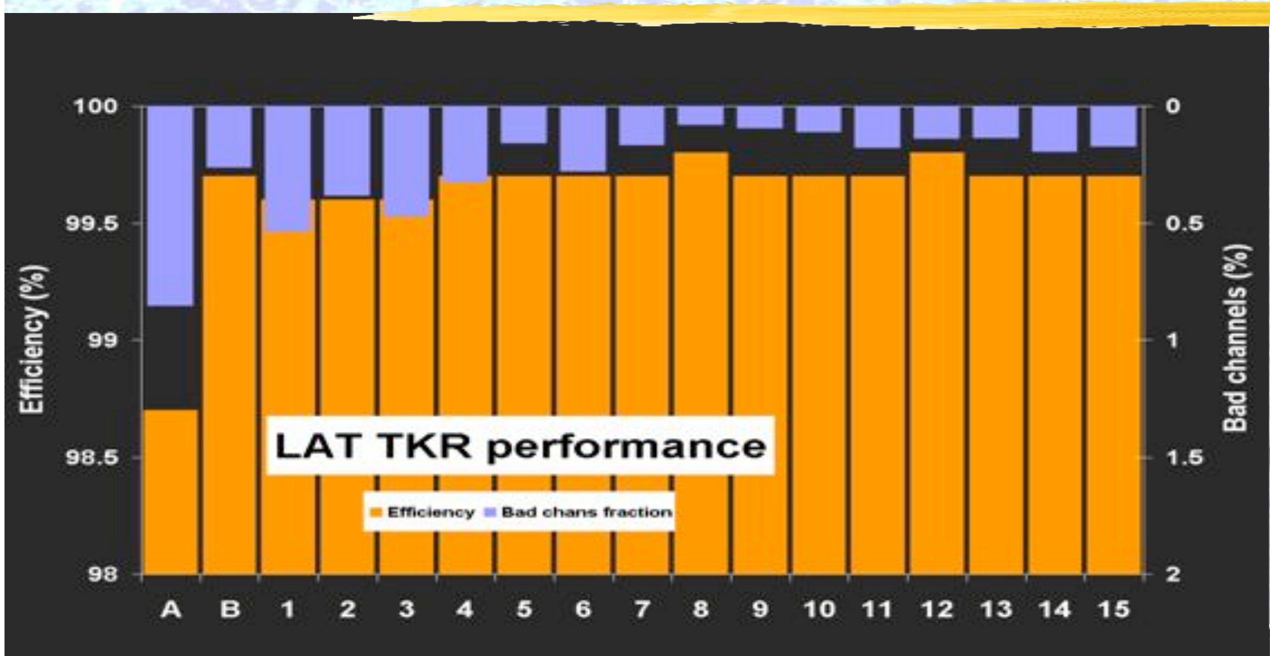
GLAST @ SLAC

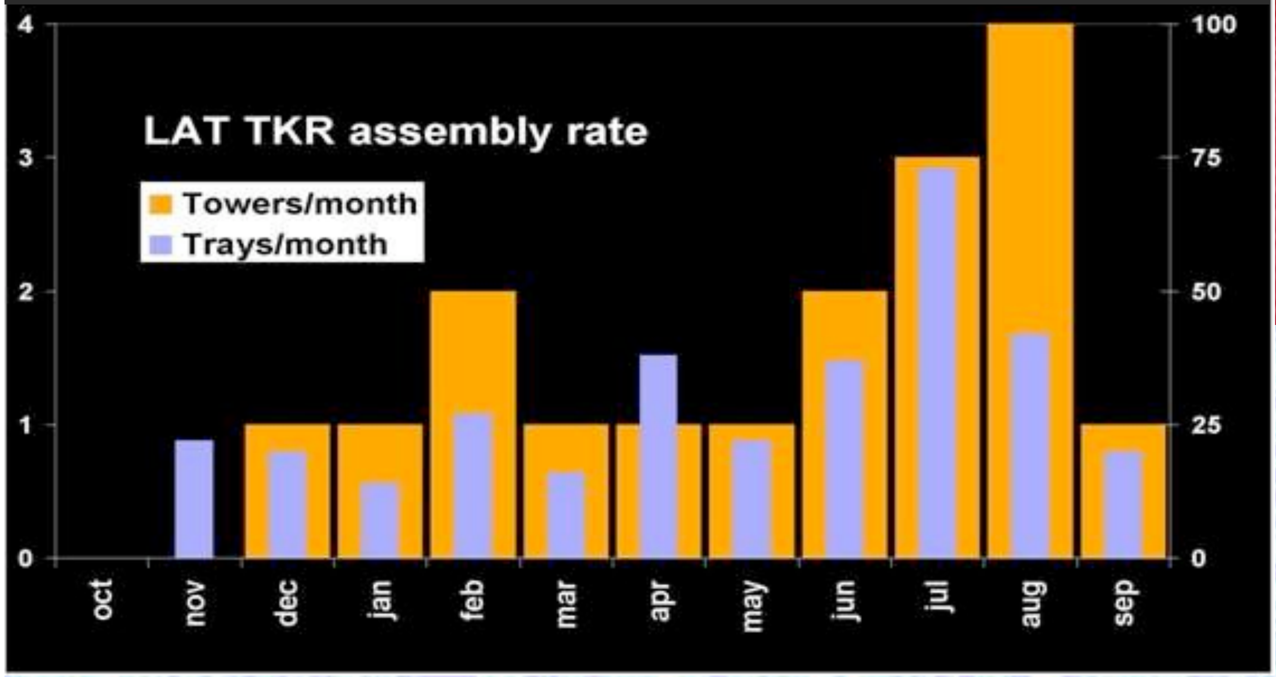
12/16 Towers in the GRID on 7/10/05

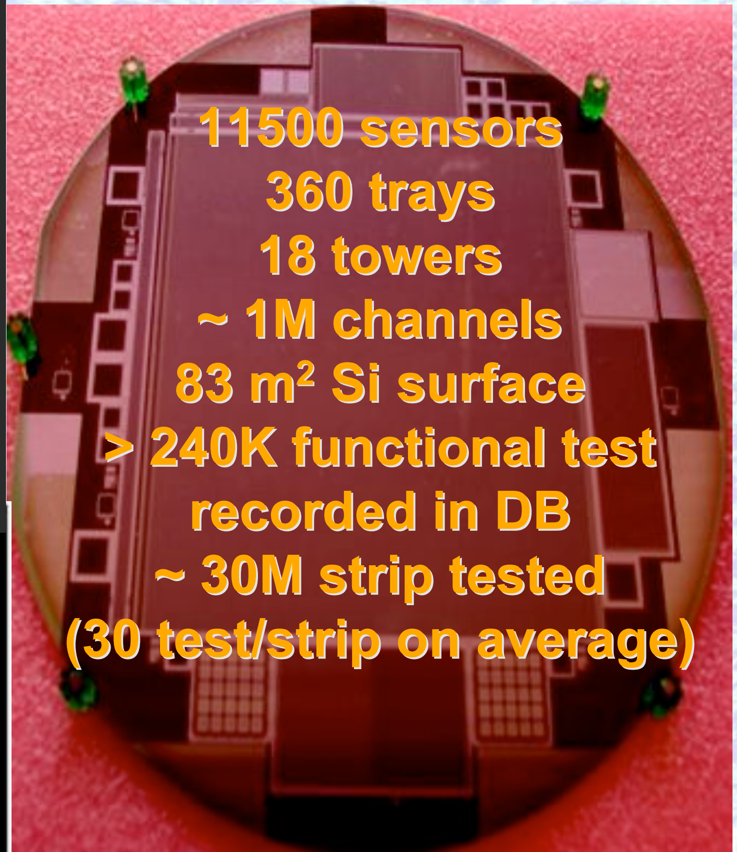
GLAST @ SLAC

16/16 Towers in the GRID on 20/10/05

The LAT Tracker numbers







11500 sensors
360 trays
18 towers
~ 1M channels
83 m^2 Si surface
> 240K functional test
recorded in DB
~ 30M strip tested
(30 test/strip on average)

> 60 physicist and engineers involved in the italian teams from INFN (Trieste, Udine, Padova, Pisa, Perugia, Roma2, Bari) in partnership with ASI

Celebrations for the end of Tracker construction

52 attendees from INFN, ASI, SLAC, NASA, italian industrial partners

Current Collaboration Science Groups

1a. **Catalog**

Seth Digel (SU-SLAC); Isabelle Grenier (CEA/ Saclay)

1b. **Diffuse (Galactic and Extragalactic) and Molecular Clouds**

Seth Digel (SU-SLAC); Isabelle Grenier (CEA/ Saclay)

2. **Blazars and Other AGNs** –Paolo Giommi (ASI), Benoit Lott (Bordeaux)

3. **Pulsars, SNRs, and Plerions** - Roger Romani (Stanford); David Thompson (GSFC)

4. **Unidentified Sources, Population Studies, and Other Galaxies**
   Patrizia Caraveo (IASF); Olaf Reimer (Stanford)

5. **Dark Matter and New Physics** - Elliott Bloom (SU-SLAC); Aldo Morselli (INFN–Rome)

6. **Gamma-Ray Bursts** - Jay Norris (GSFC); Nicola Omodei (INFN-Pisa)

7. **Solar System Sources** - Gerry Share (NRL)

8. **Calibration and Analysis Methods** - William Atwood (UCSC); Steve Ritz (GSFC)

9. **Multiwavelength Coordination Group** – Roger Blandford (SU – KIPAC); David Thompson (GSFC)

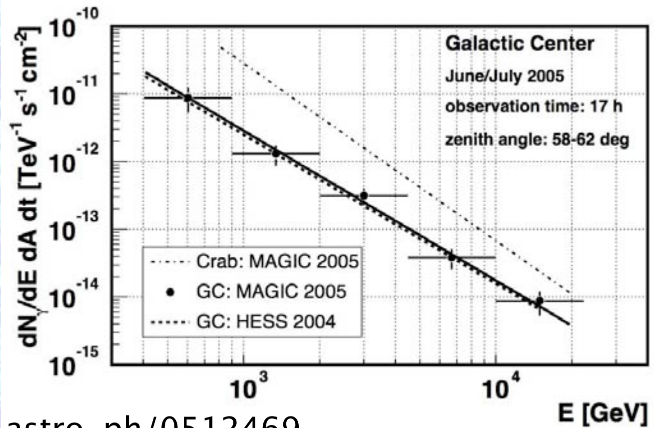
Galactic Center

HESS Spectrum

Unbroken power-law.

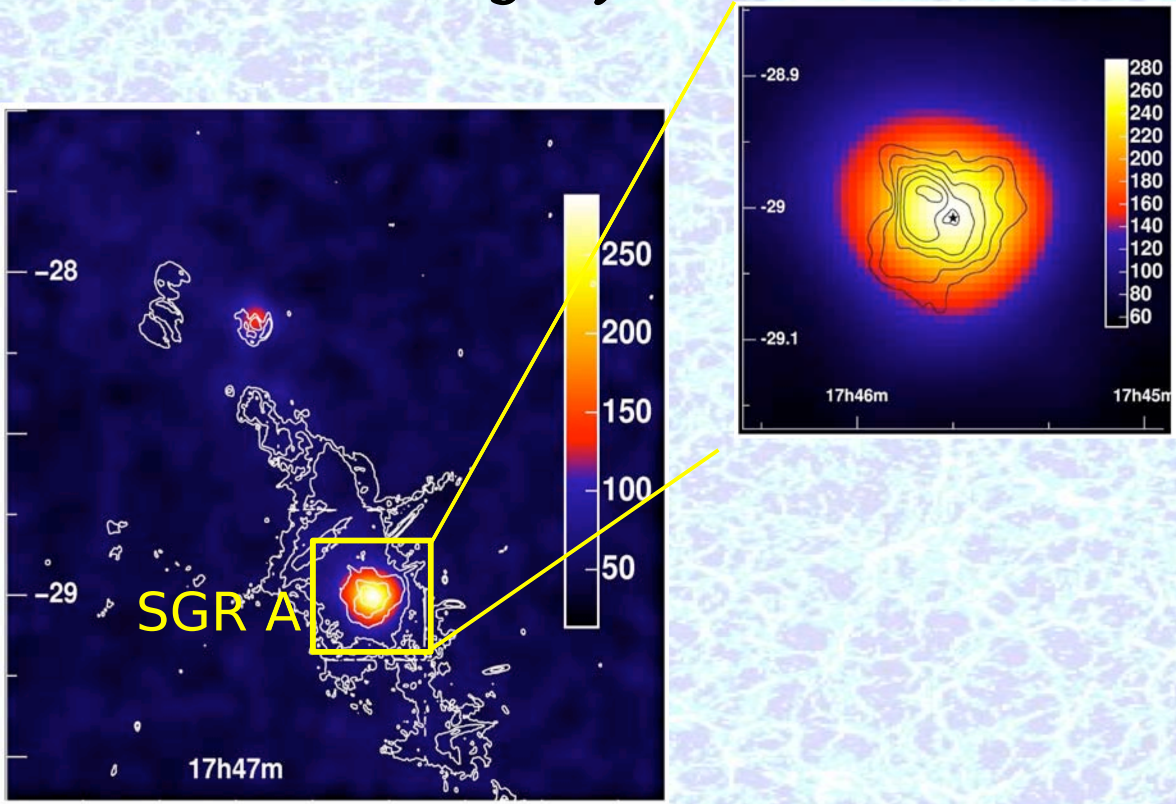
- ***Hard spectrum*** Γ ***= 2.2.***
- ***No evidence for variability on a variety of time scales.***

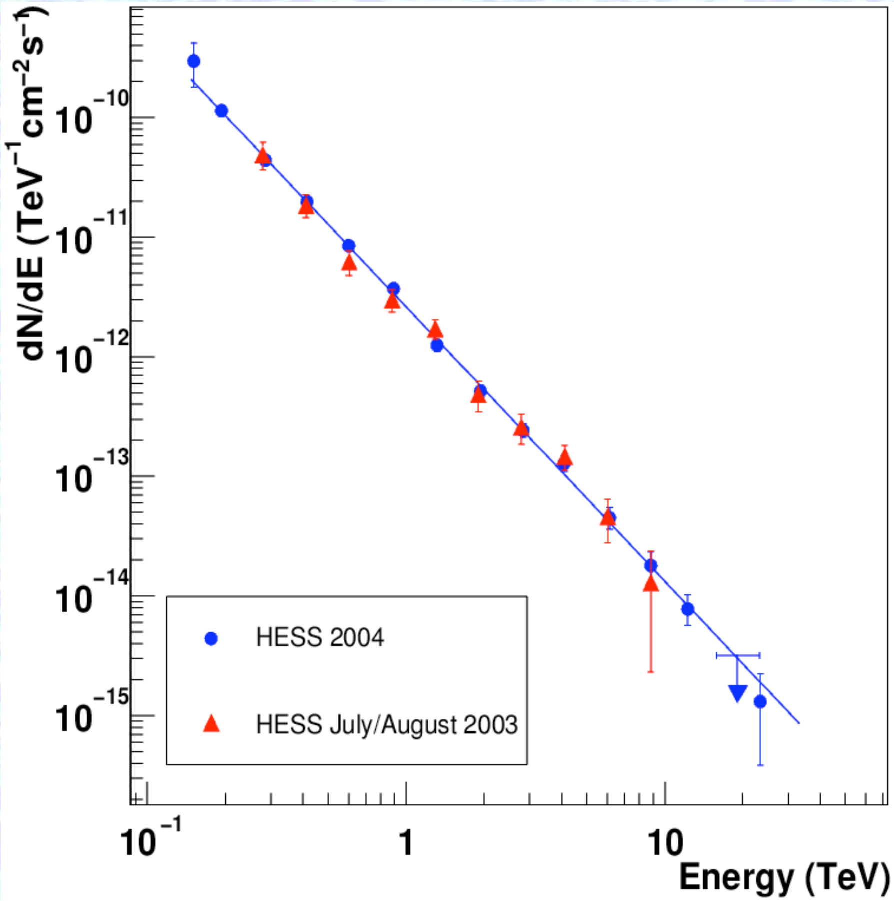
Good agreement between HESS and MAGIC (large zenith angle observation).



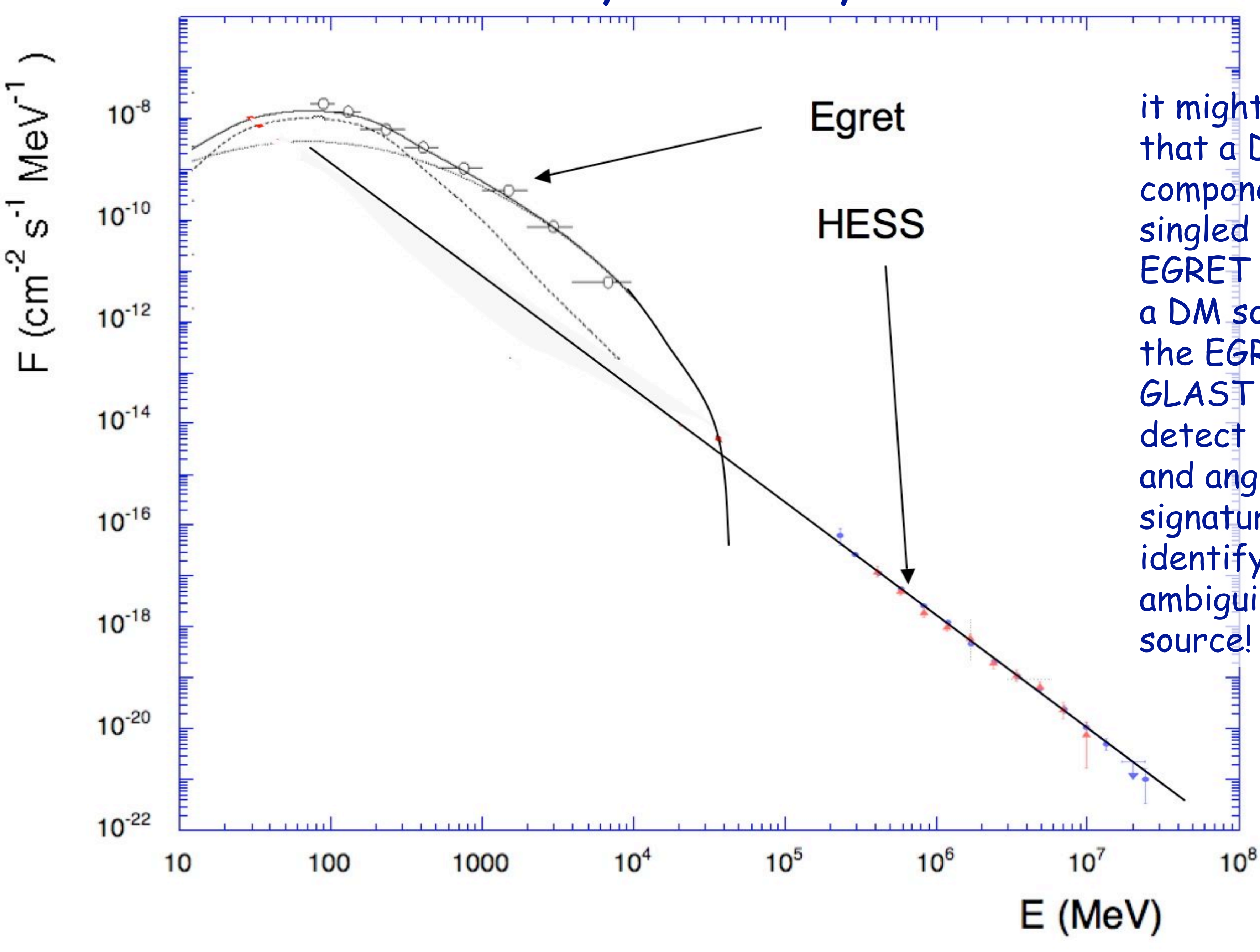
astro-ph/0512469

Consistent with
SGR A* to 6″ and ***slightly extended.***

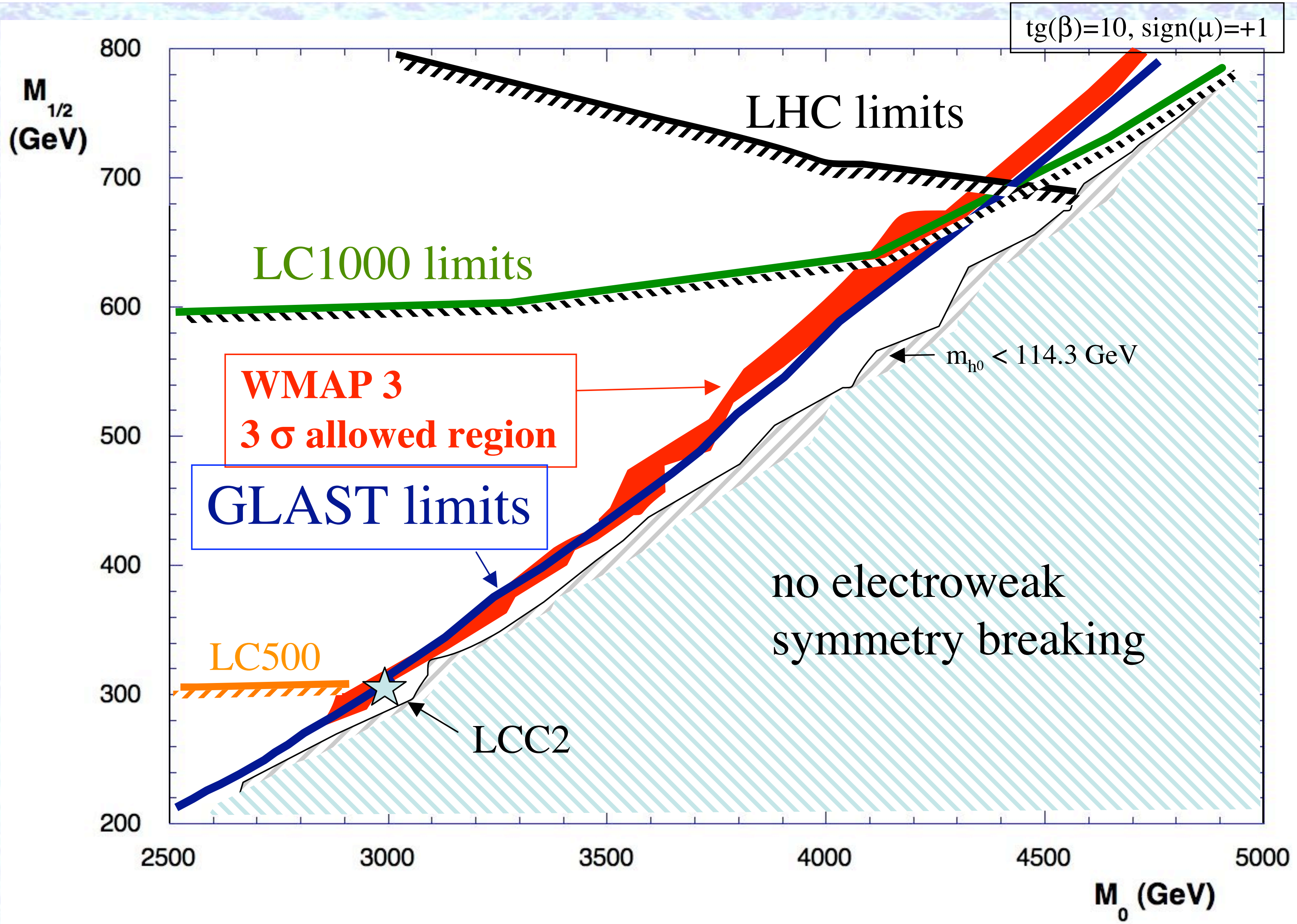




EGRET, GLAST, HESS



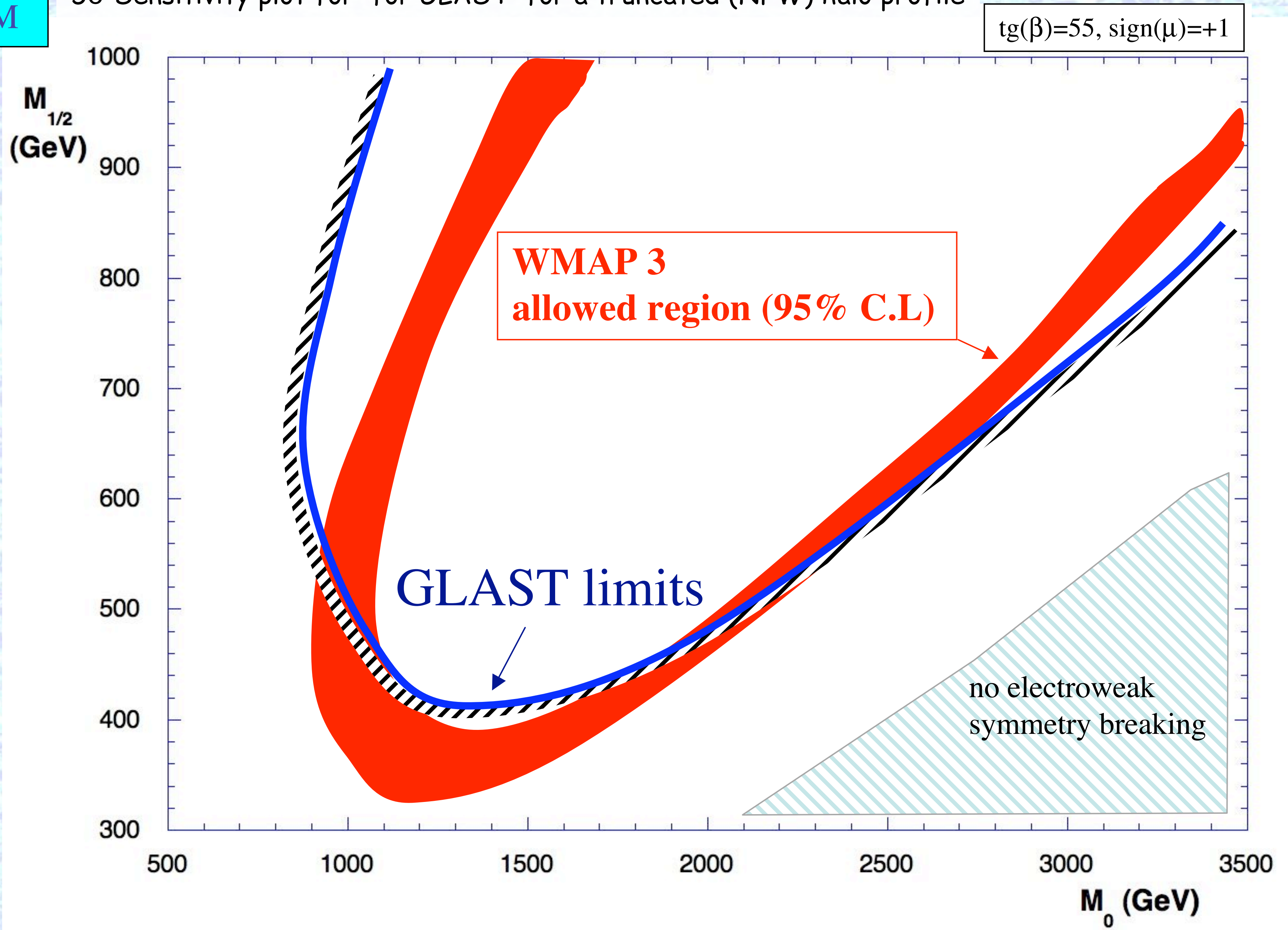
it might still be that a DM component could be singled out, e.g. the EGRET source (?): a DM source can fit the EGRET data; GLAST would detect its spectral and angular signatures and identify without ambiguity such DM source!



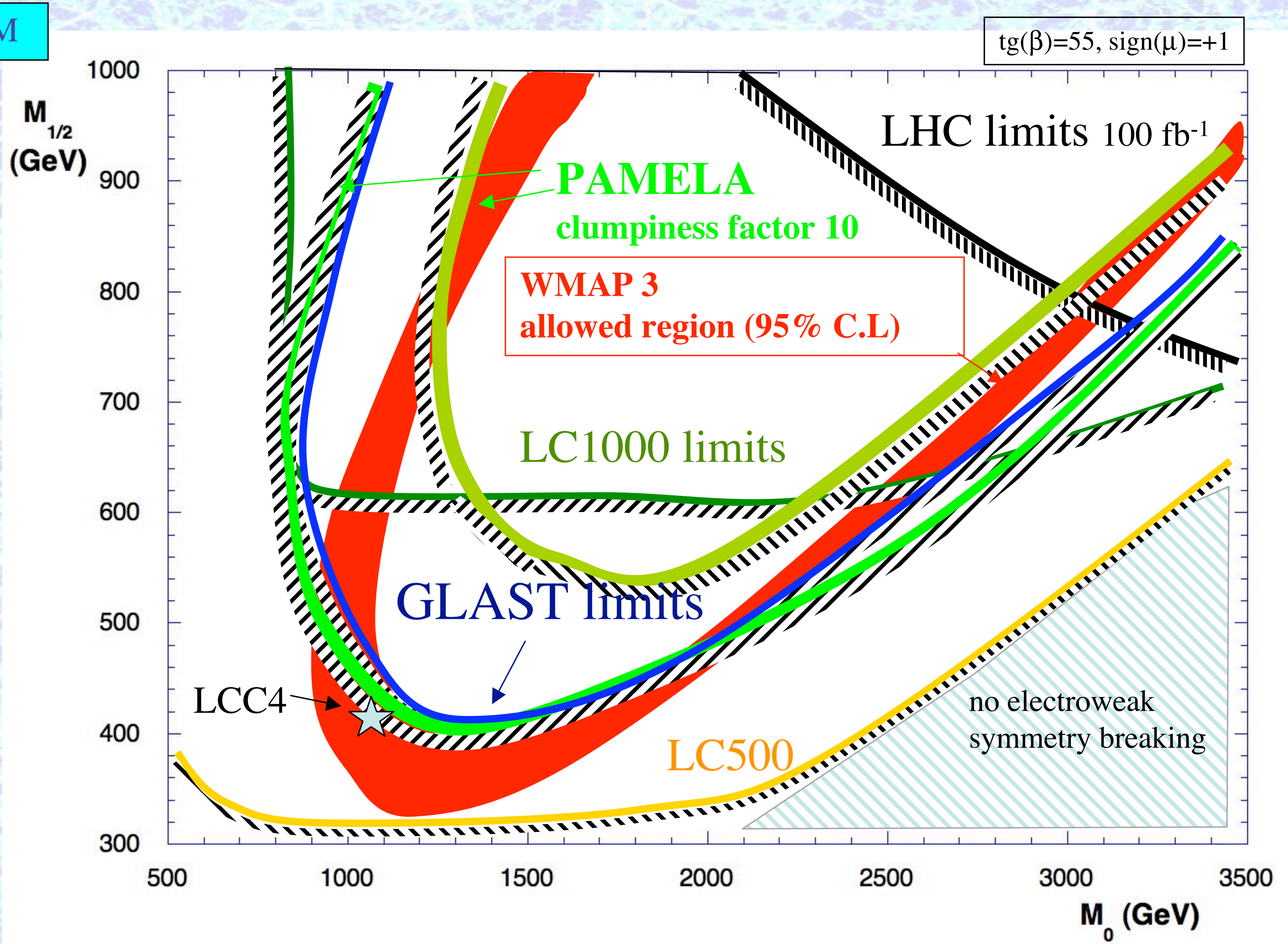
Sensitivity plot for observation of mSUGRA for a number of accelerator experiments and GLAST for tg(β)=10. GLAST 5σ sensitivity is shown at the blue line and below a for truncated Navarro Frank and White (NFW) halo profile

cMSSM

5σ Sensitivity plot for for GLAST for a truncated (NFW) halo profile



cMSSM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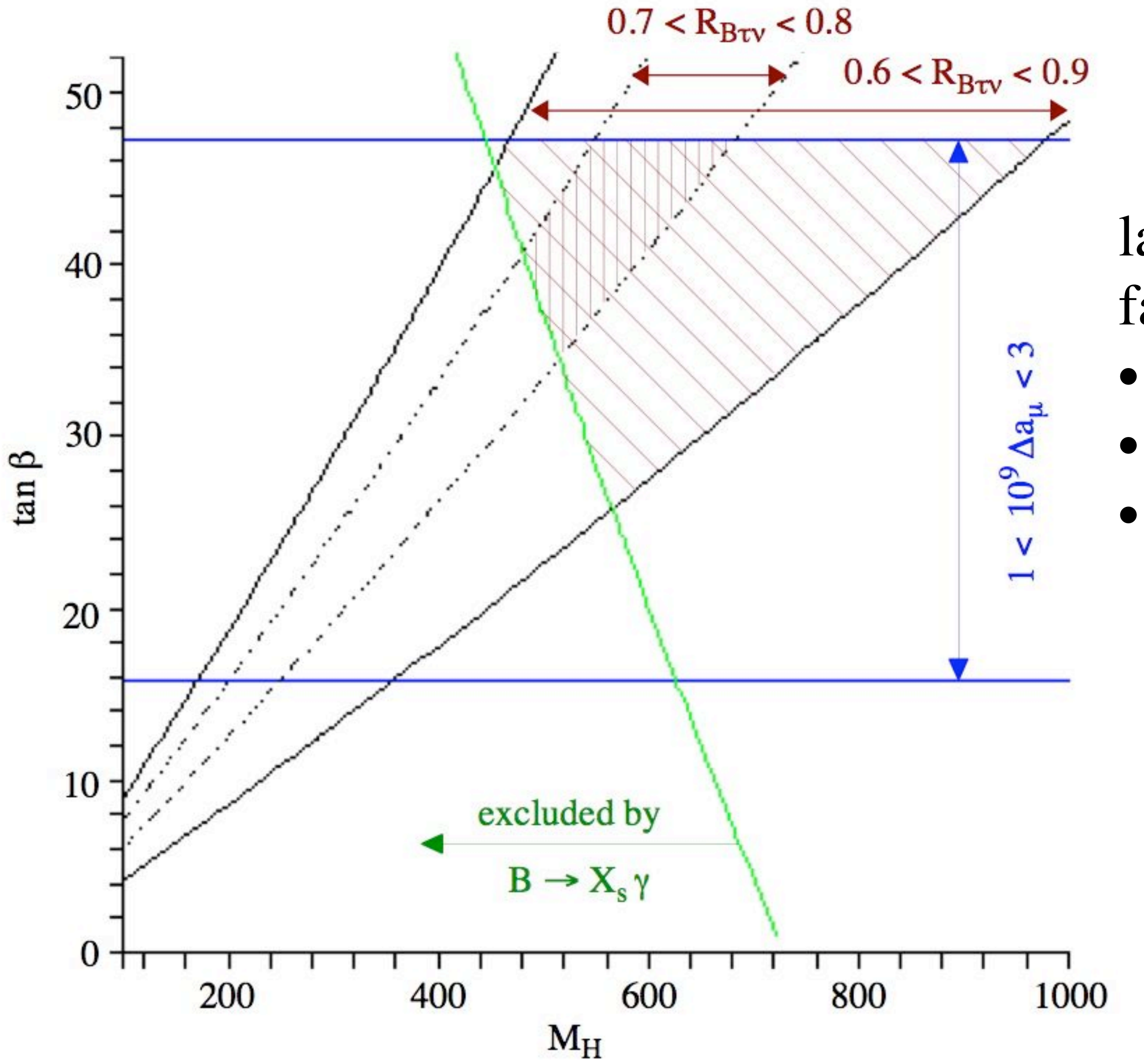


large tgβ regions favoured in flavour physics:

- suppression of B -> τν
- sizable enhancement of $(g-2)_\mu$
- small non-standard effects in ΔM_{Bs} and $B(B\rightarrow X_s\gamma)$

G.Isidoria and P.Paradisi hep-ph/0605012

Conclusion

PAMELA is in the sky !!!!

- Will give strong constraints on propagation parameters.

Discovery Potential for Supersymmetry

on line news in

http://wizard.roma2.infn.it/

GLAST Schedule

PAMELA will be very useful for the background model of GLAST

- **August 2004**

Assembling of first tower completed

- **Middle of October 2005**

Completion of the LAT – *Environmental testing*

- **May 2006**

Delivery to NRL–

- **August 2007**

Kennedy Space Flight Center

thank you !!

LAUNCH

•November 2007

Science operation begins!

more info : http://people.roma2.infn.it/glast/

extra slides

Estimated reaches with Pamela

cMSSM

Clumpiness factors fd needed to disentangle a neutralino induced component in the antiproton flux with PAMELA

region where

$0.13 < \Omega_{CDM.} h^2 < 0.3$

region where

$0.09 < \Omega_{CDM.} h^2 < 0.13$

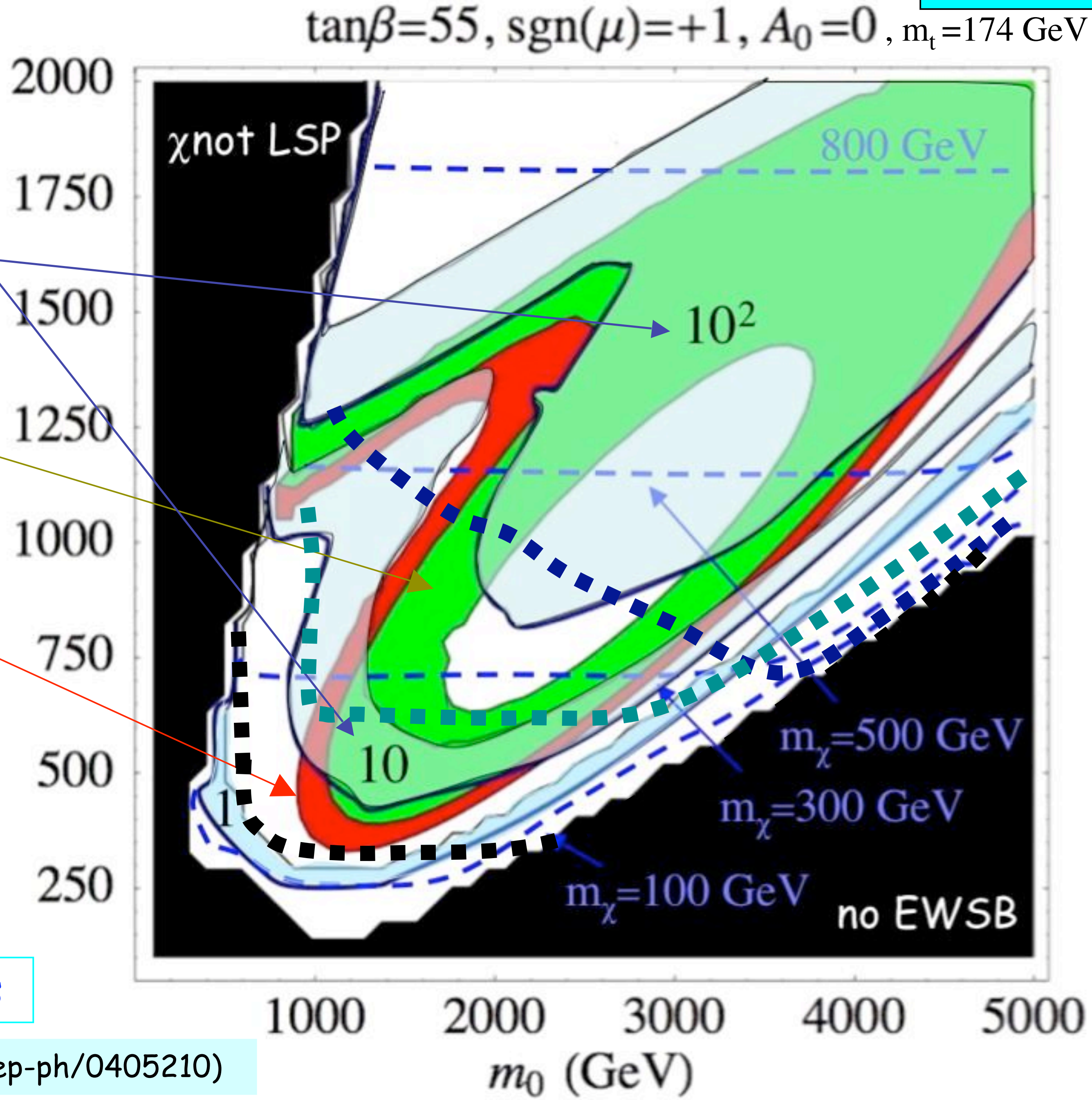
Equi-clumpiness factor density in respect to a NFW

LHC 100 fb^{-1}

LC1000 100 fb^{-1}

LC500 100 fb^{-1}

Equi-neutralino mass lines



A.Morselli (from astro-ph/0502406 +hep-ph/0405210)

Estimated reaches with GLAST and Pamela

MSSM

Clumpiness factors fd needed to disentangle a neutralino induced component in the antiproton flux with PAMELA (χ^2>1.8) that still give a good fit of the present data.

Equi-clumpiness factor density in respect to a NFW

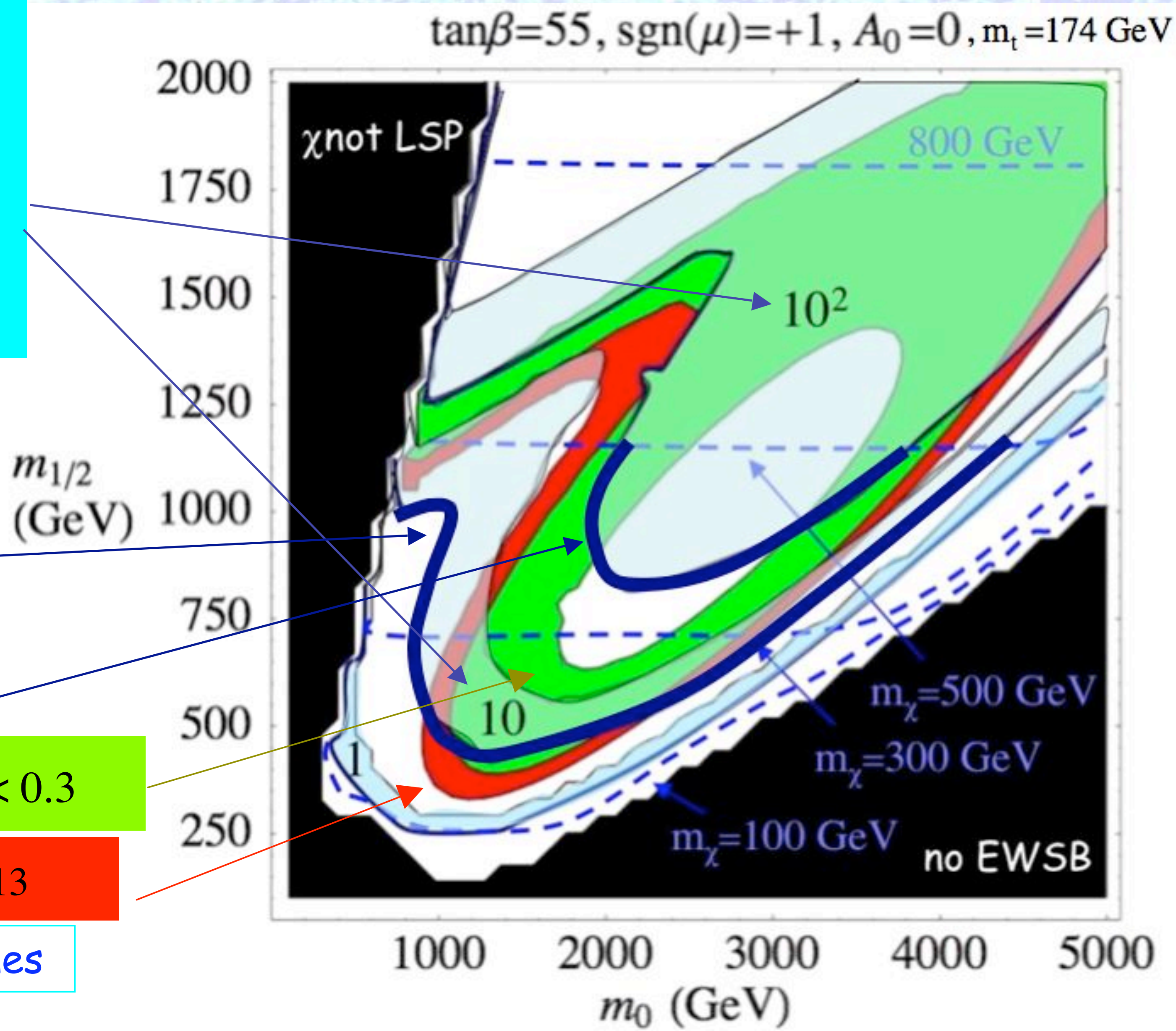
GLAST sensitivity (5 σ) for a neutralino density Nχ of 10^4 NFW in a $\Delta\Omega=10^{-5}$ sr region around the galactic center

same but for Nχ of 10^5 (clumpines factor 10)

region where $0.13 < \Omega_{CDM.}h^2 < 0.3$

region where $0.09 < \Omega_{CDM.}h^2 < 0.13$

- - . Equi-neutralino mass lines



astro-ph/0502406 and astro-ph/0305075

Estimated reaches with Pamela

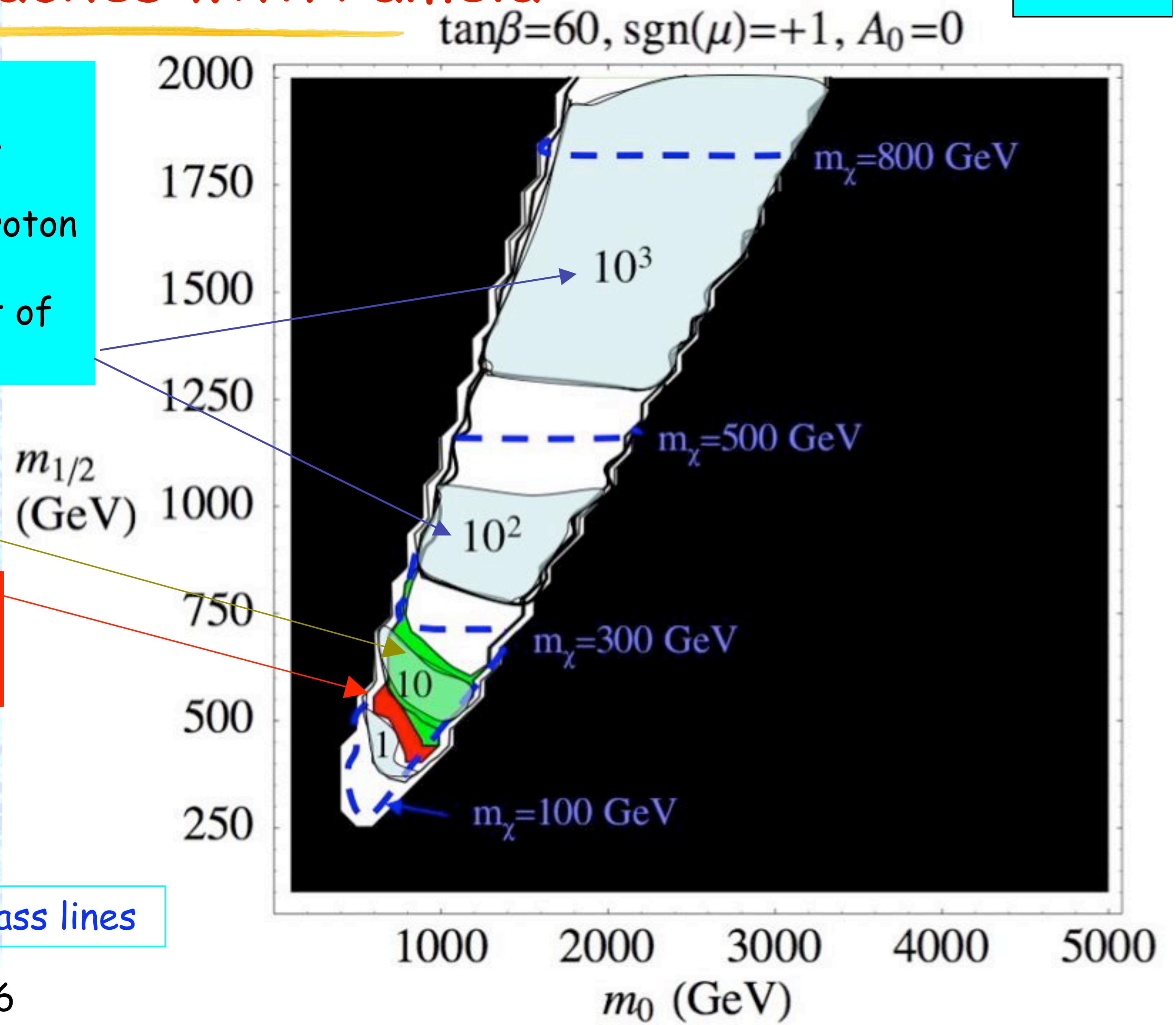
MSSM

Clumpiness factors fd needed to disentangle a neutralino induced component in the antiproton flux with PAMELA
that still give a good fit of the present data

region where
$0.13 < \Omega_{CDM.}h^2 < 0.3$

region where
$0.09 < \Omega_{CDM.}h^2 < 0.13$

Equi-clumpiness
factor density
in respect to a NFW



- - · Equi-neutralino mass lines

astro-ph/0502406

Estimated reaches with Pamela

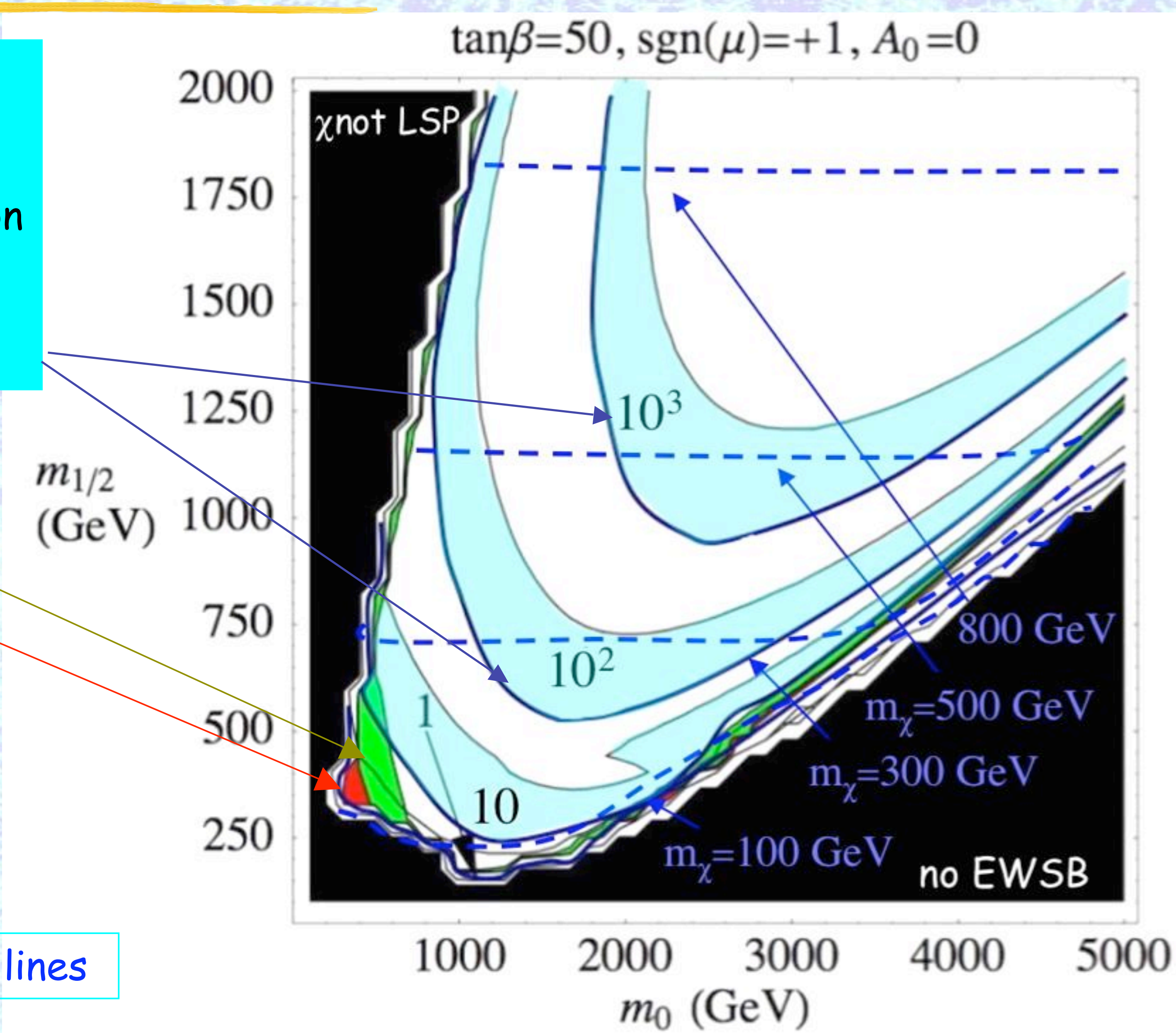
MSSM

Clumpiness factors fd needed to disentangle a neutralino induced component in the antiproton flux with PAMELA that still give a good fit of the present data

region where $0.13 < \Omega_{CDM.} h^2 < 0.3$

region where $0.09 < \Omega_{CDM.} h^2 < 0.13$

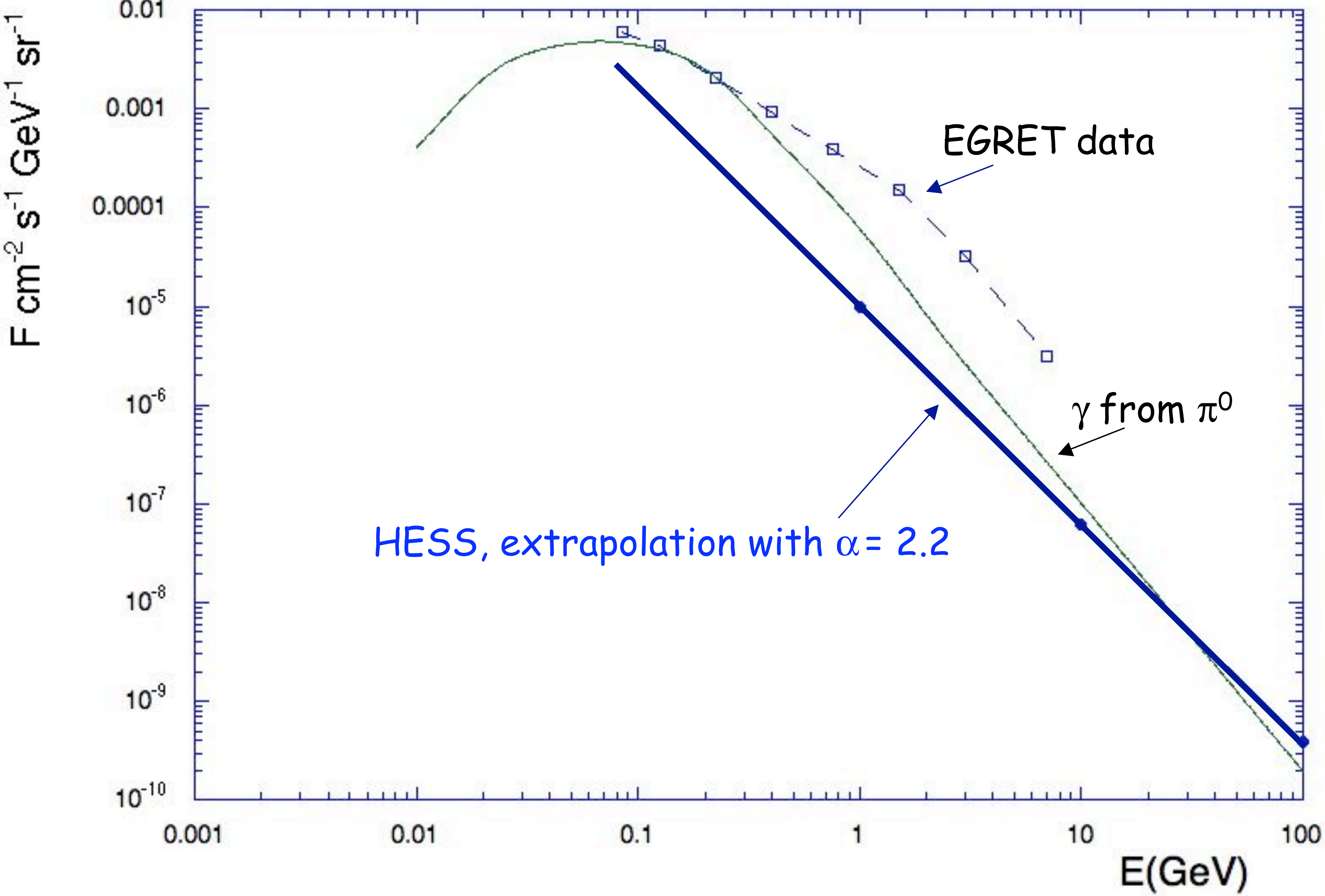
Equi-clumpiness factor density in respect to a NFW



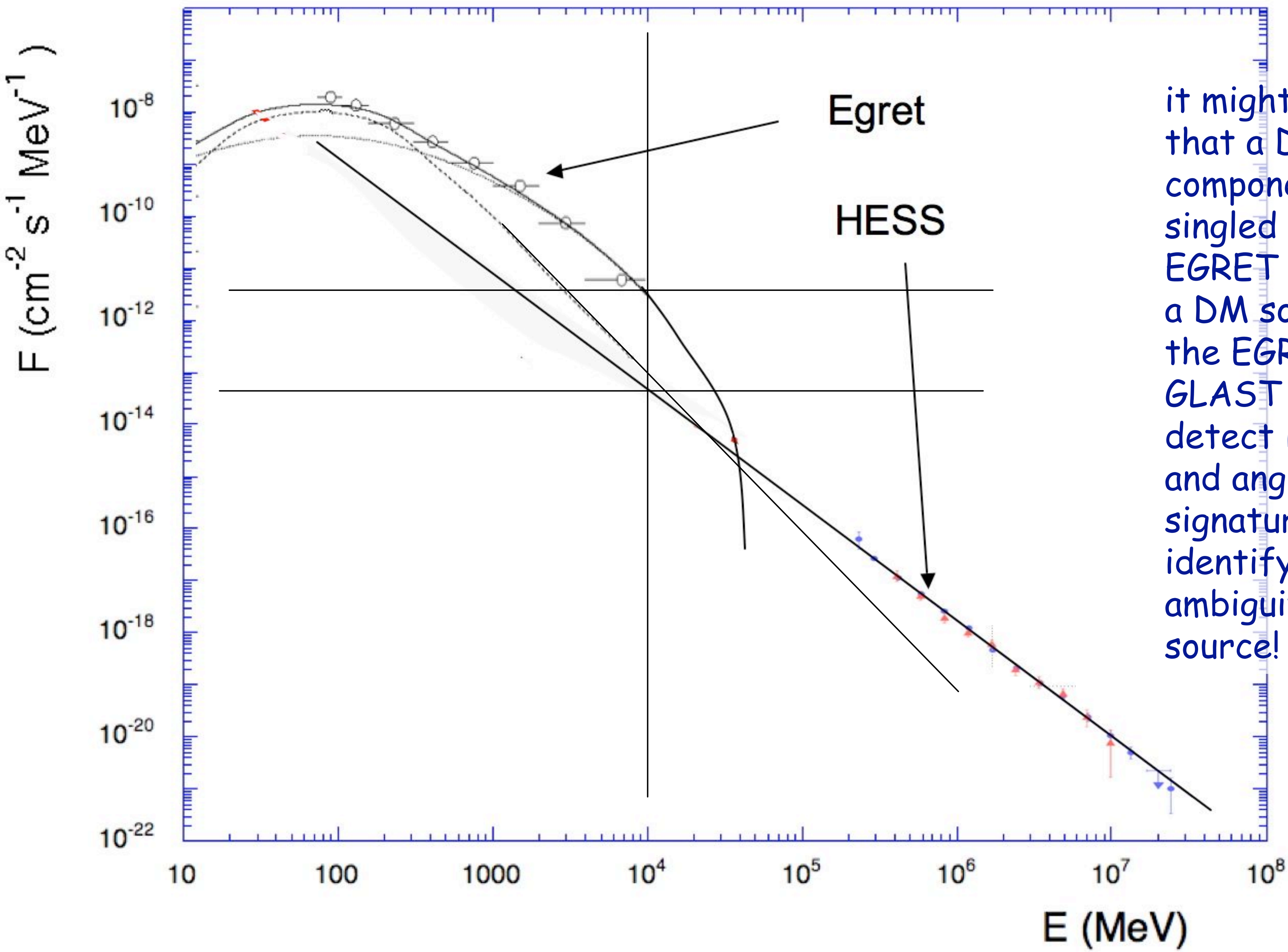
- - · Equi-neutralino mass lines

astro-ph/0502406

EGRET, GLAST, HESS



EGRET, GLAST, HESS



it might still be that a DM component could be singled out, e.g. the EGRET source (?): a DM source can fit the EGRET data; GLAST would detect its spectral and angular signatures and identify without ambiguity such DM source!

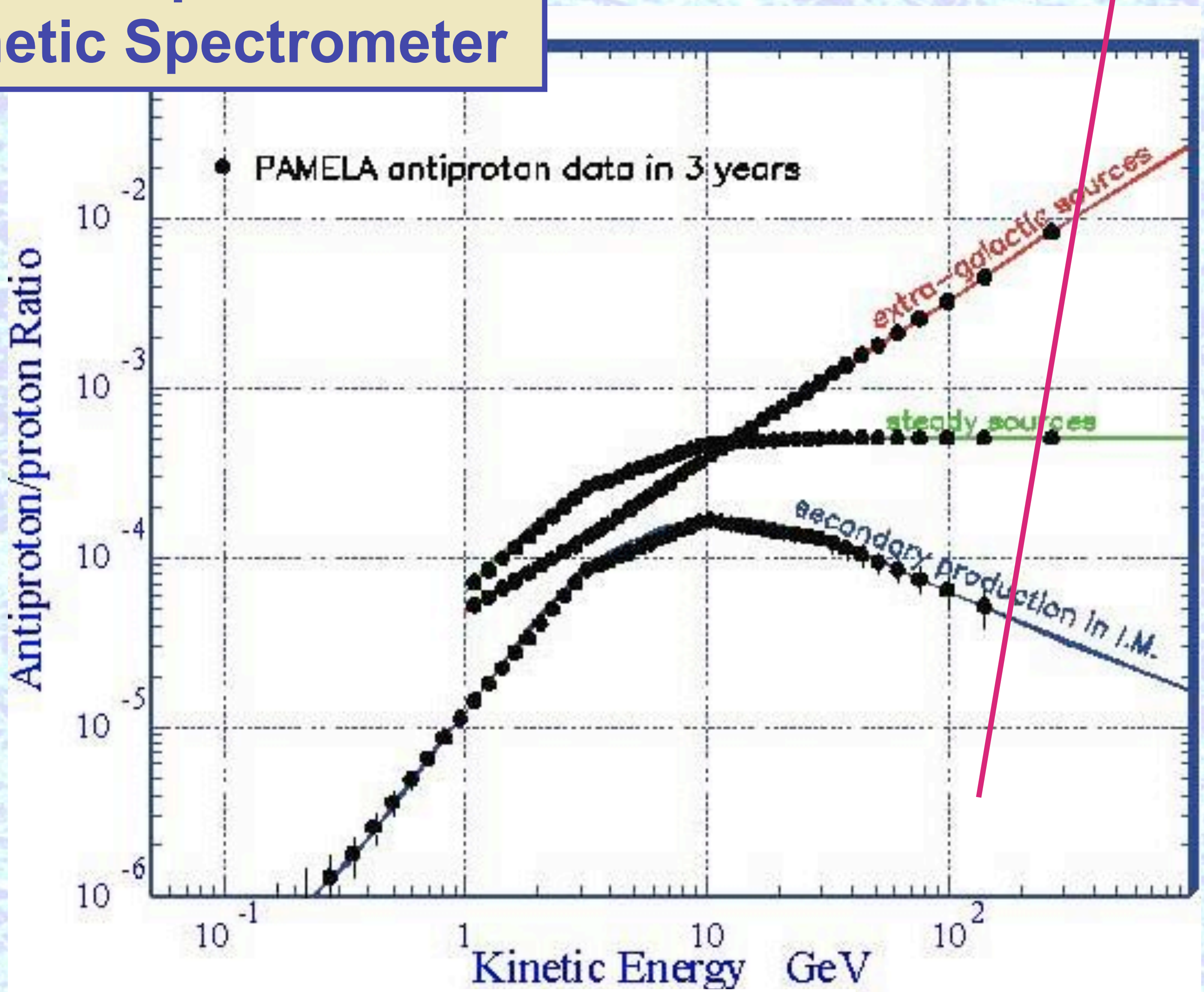
The figures show sensitivity plots in the $M\frac{1}{2}$ and M0 mSUGRA parameter plane. The other important parameter in mSUGRA is tg(β) and the two figures show the different limits for two different values of tg(β).
We also show the two points LCC2 and LCC4 that are the best for GLAST of the four “benchmark” points presented in reference 3. The accelerator limits are from reference 6. The dark matter halo used for the GLAST indirect search sensitivity estimate is a truncated Navarro Frank and White (NFW) halo profile as used in references 3 and 4. Figure 2 shows that for a small region of the phase space GLAST sensitivity actually exceeds that for the LHC (100 fb-1).
For steeper halo profiles (like the Moore profile) the GLAST limits move up, covering a wider WMAP allowed region, while for less steep profile (like the isothermal profile) the GLAST limits move down, covering less WMAP allowed region (see reference 4).

References

1. To find out about more about GLAST go to http://www-glast.stanford.edu .
2. D. N. Spergel, et al. , Wilkinson Microwave Anisotropy Probe (WMAP) Three Year Results: Implications for Cosmology, astro-ph/0603449 v1, March 19, 2006.
3. E. Baltz, M Battaglia, M. Peskin, and T. Wizansky, Determination of Dark Matter Properties at High Energy Colliders, hep-ph/0602187, March 2006.
4. A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics 21, 267-285, 2004 [astro-ph0305075]. This reference presents the methodology for deriving the various curves shown in figure 2a,b .
5. Taylor & Babul (2004, 2005)
6. H. Baer, et al., JCAP 0408 (2004) 005
7. P.Papini et al. High-energy deuteron measurement with the CAPRICE98 experiment, The Astrophysical Journal 615 (2004) 259

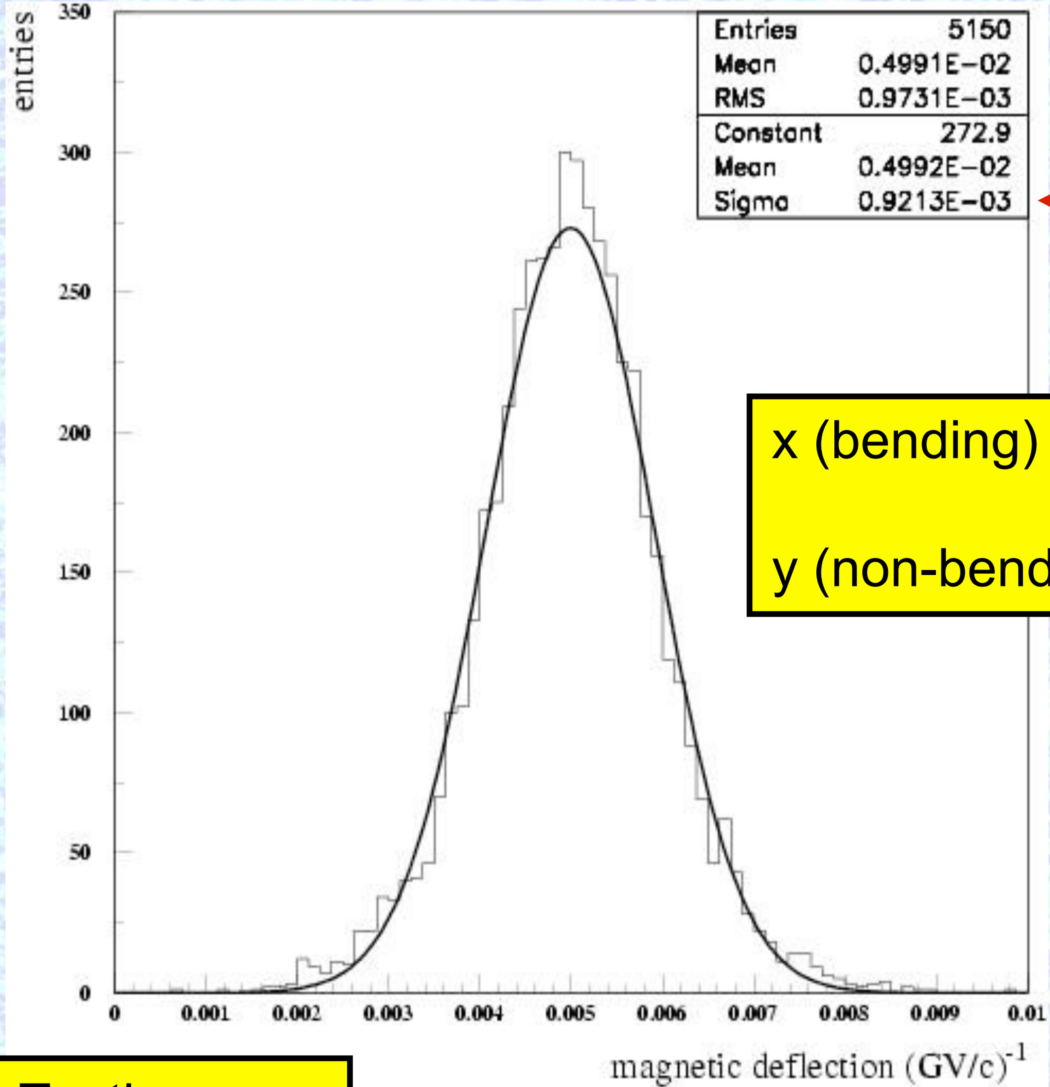
To go up in Energy needed to improve the precision of the Magnetic Spectrometer

Spillover of p on antip = 0.2 of the antip flux



Antip (3 andamenti)

Spectrometer Resolution



MDR ≅ 1080 GV (Δp/p = 1)

x (bending) resolution = 2.7 μm

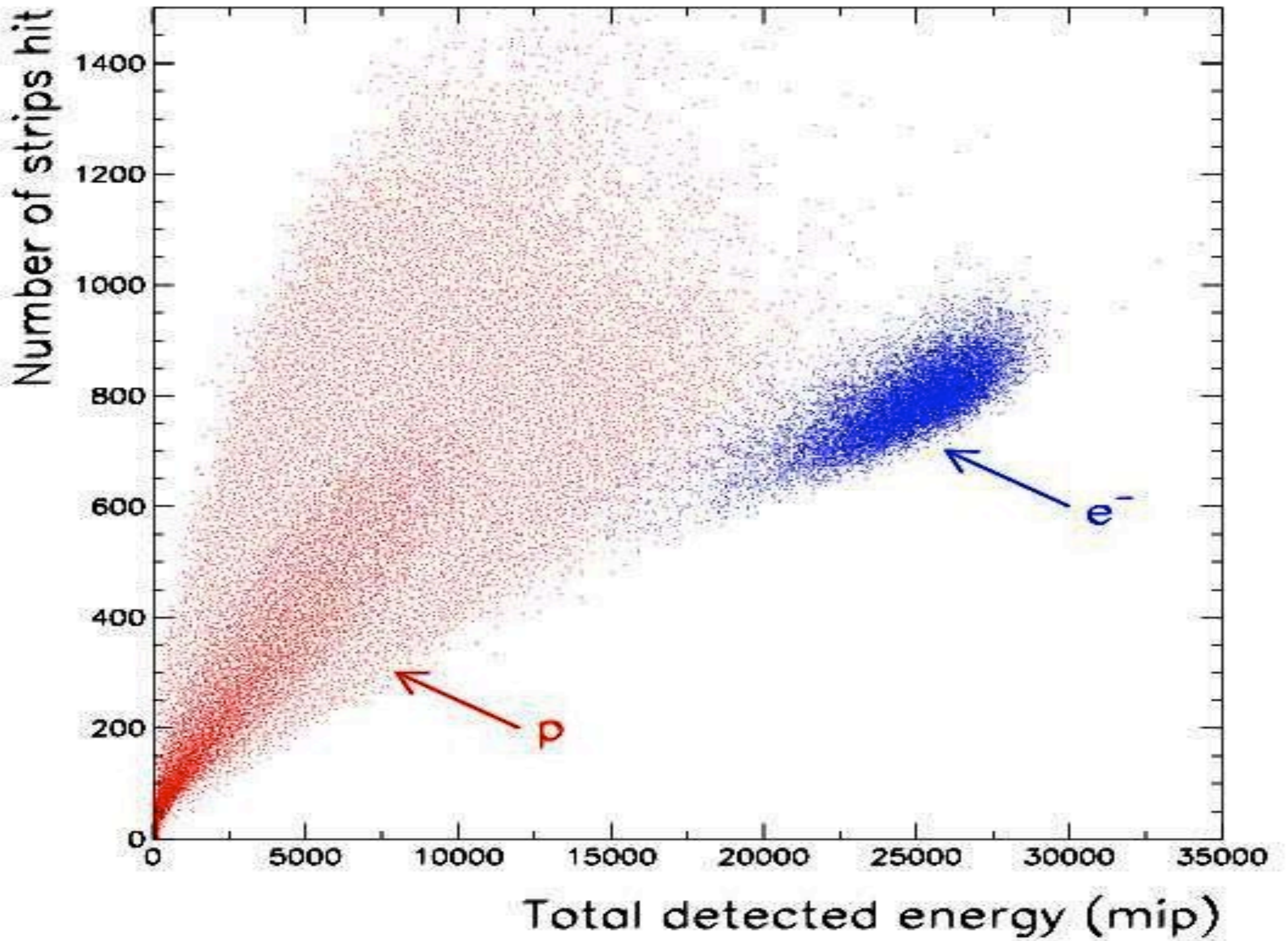
y (non-bending) resolution = 12 μm

SPS Testbeam
data: p 200 GeV/c

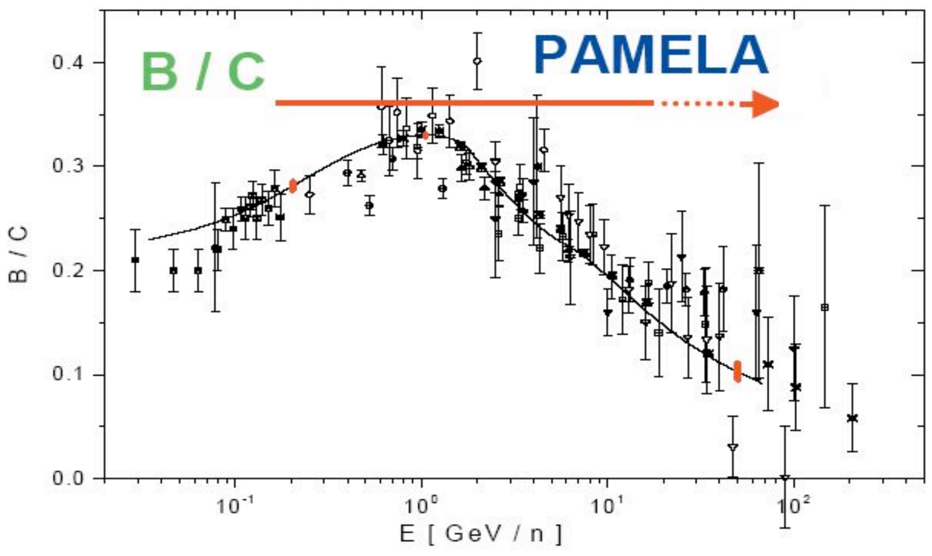
e-p Separation with the Calorimeter

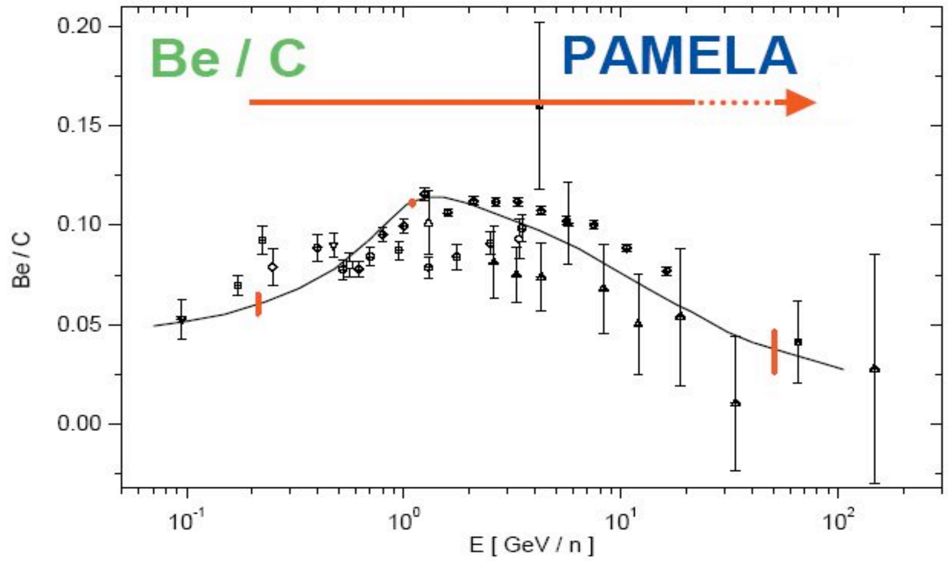
SPS Test Beam Data:
p & e^-
200 GeV/c

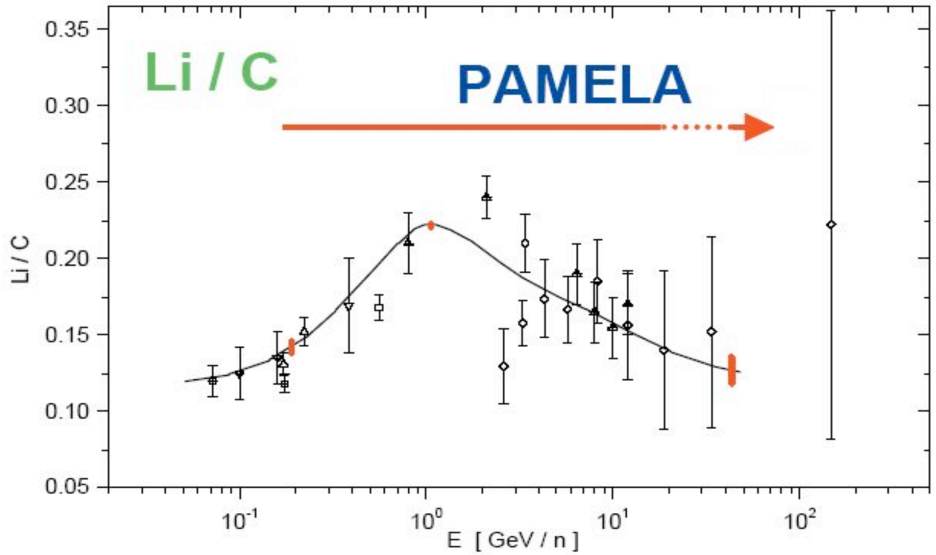
Rejection: 1:30000



Secondary to Primary ratios

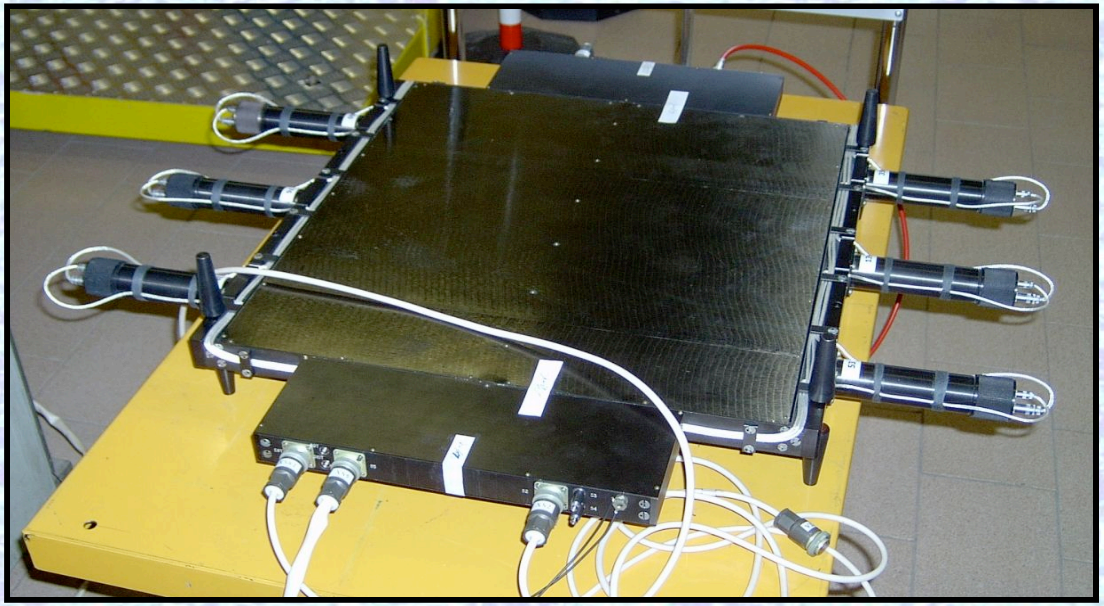




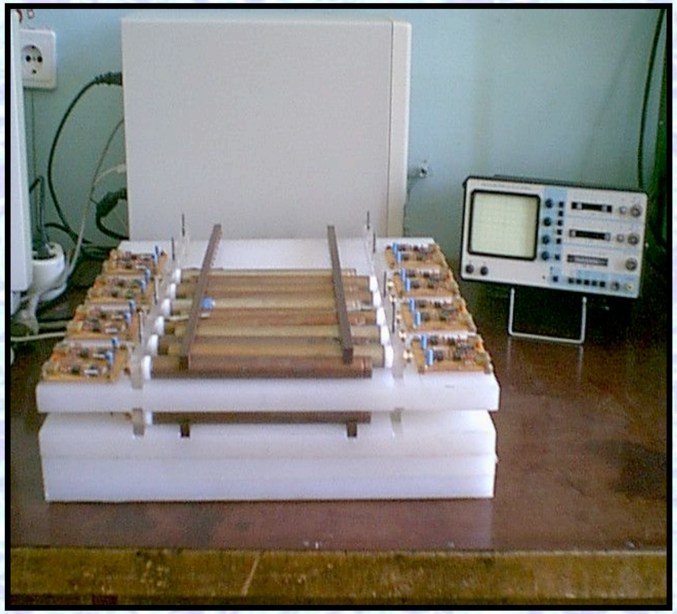


Shower Scintillator Neutron Counter

- Plastic scintillator: 482 mm x 482 mm x 10 mm
- 6 PMT read-out
- Dynamic range: 1 - 1000 MIP

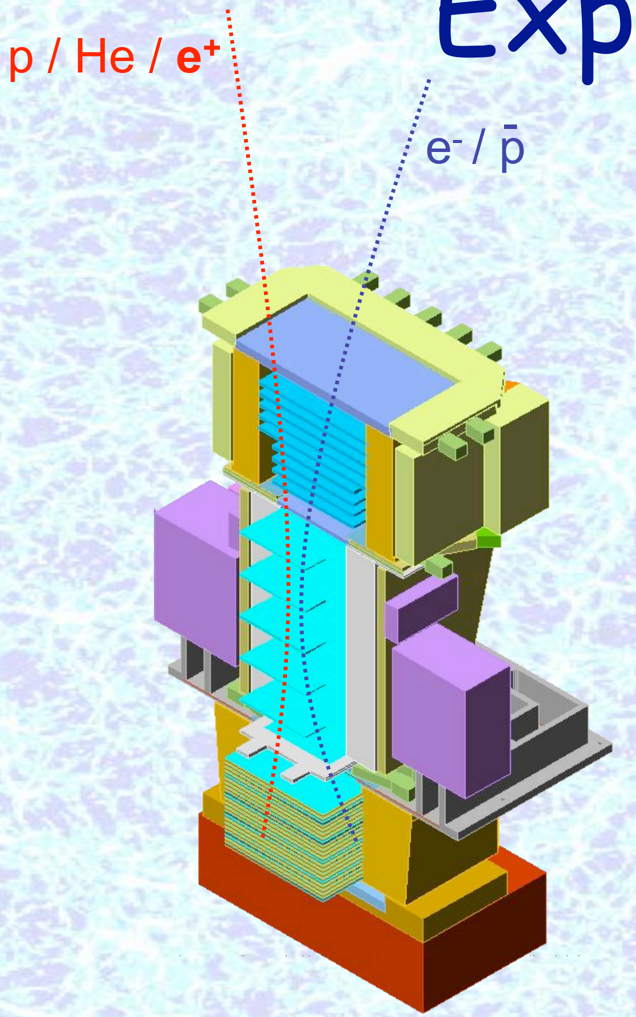


Trigger



- 2 x 18 ^3He proportional counters (polyethylene / Cd envelope)
- 600 × 550 × 150 mm^3
- n + ^3He → p + ^3H + 765 keV
- O(10) more n in hadronic cascades than EM

Expected Statistics

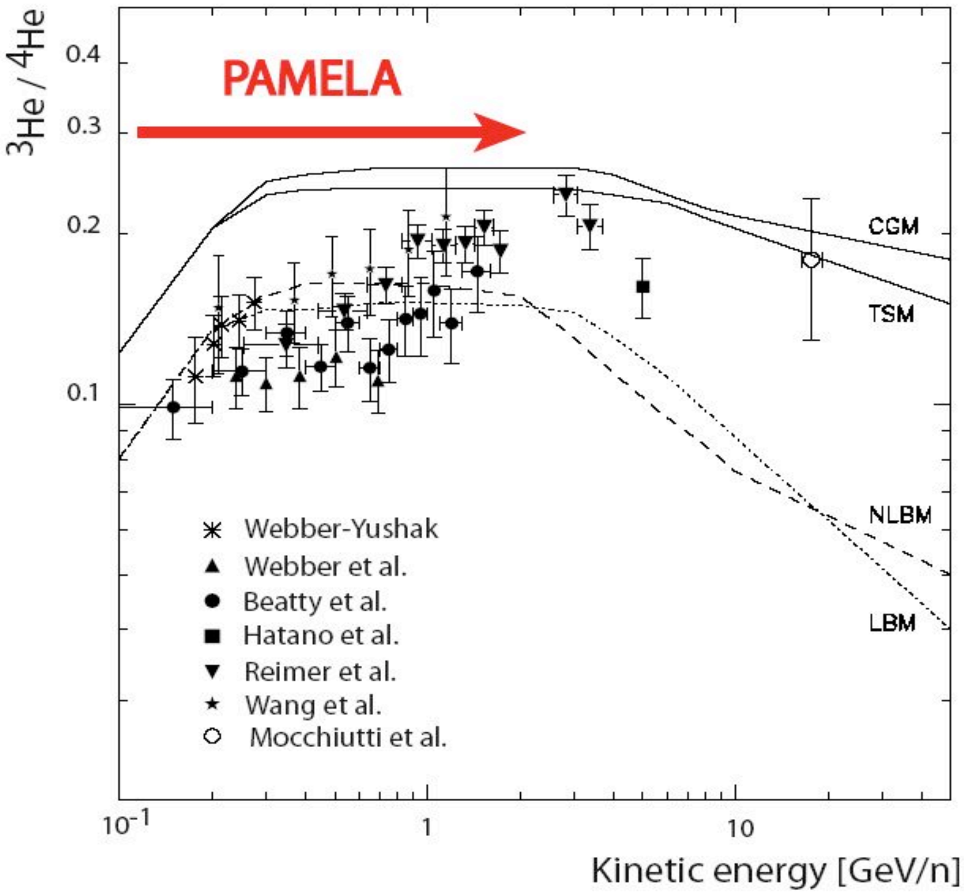


Particle	Number (3 yrs)	Energy Range
Protons	3.10^{8}	80 MeV - 700 GeV
Antiprotons	**$>3.10^{4}$**	**80 MeV - 190 GeV**
Electrons	6.10^{6}	50 MeV - 2 TeV
Positrons	**$>3.10^{5}$**	**50 MeV - 270 GeV**
He	4.10^{7}	80 MeV/n - 300 GeV/n
Be	4.10^{4}	80 MeV/n - 300 GeV/n
C	4.10^{5}	80 MeV/n - 300 GeV/n
Antihelium Limit (90% C.L.)	**7.10^{-8}**	**80 MeV/n - 30 GeV/n**

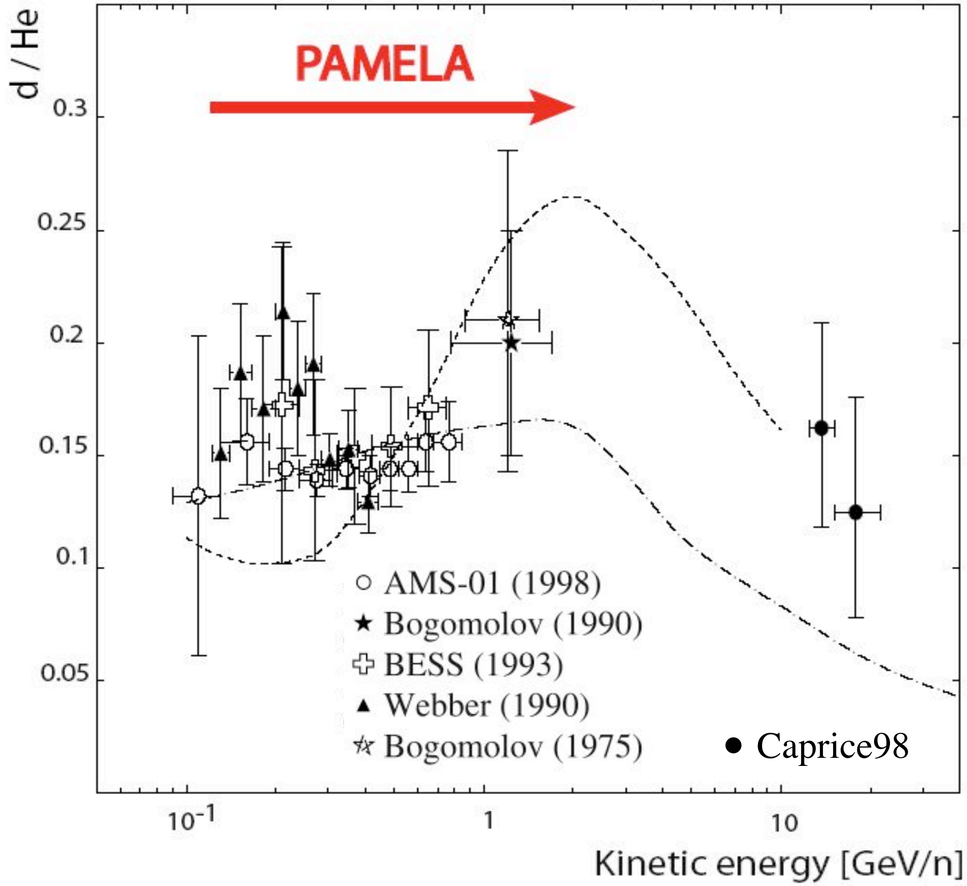
- Semi-polar orbit (70.4°) ⇒ access to low energy regime
- 3 year mission ⇒ large data sets

Helium and Hydrogen Isotopes

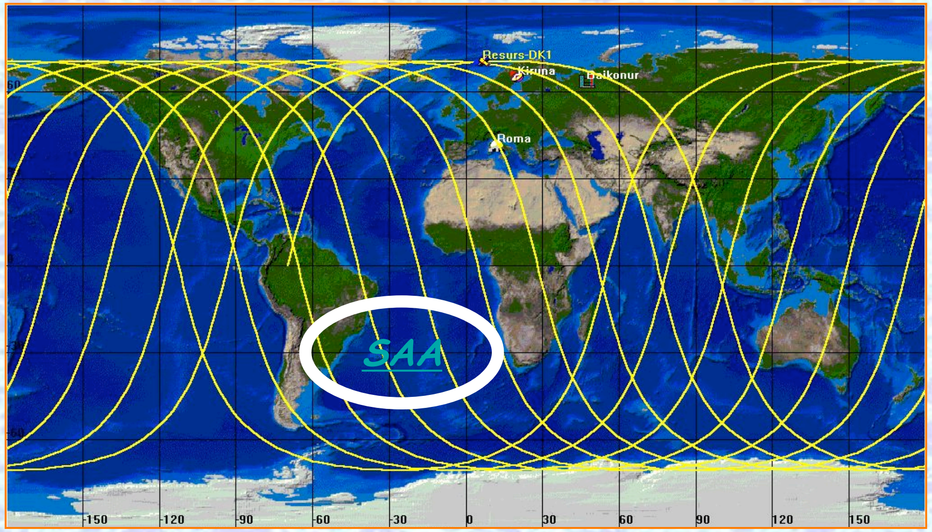
The current situation of the 3He / 4He ratio

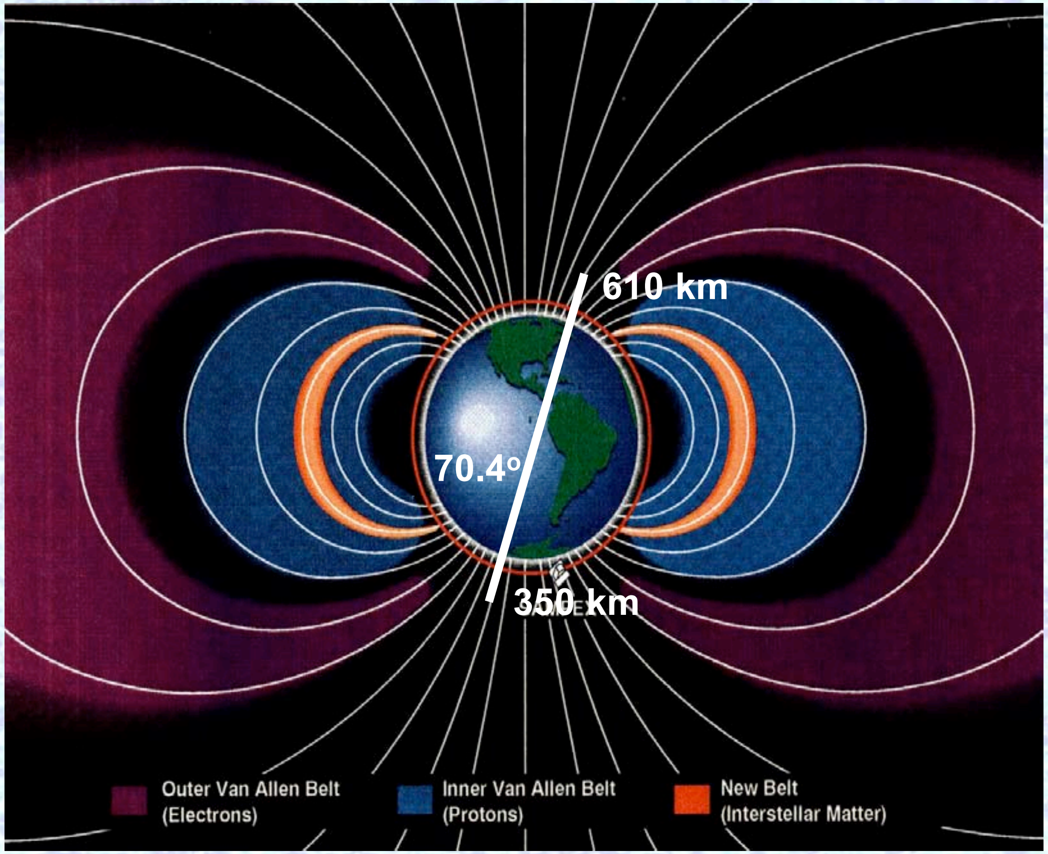


The current situation of the d / He ratio



Orbit Characteristics



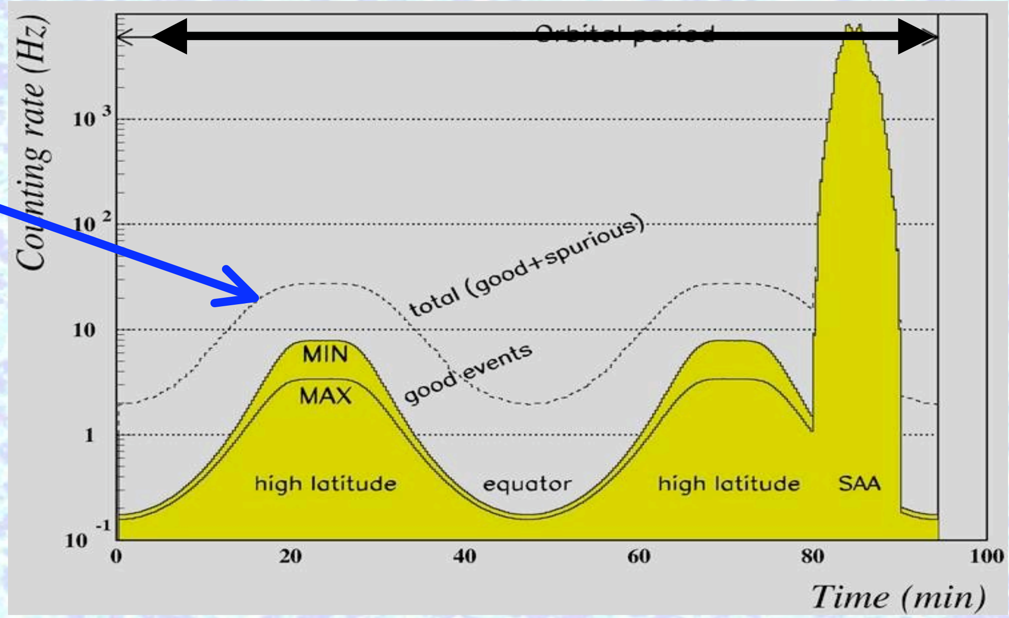


- Low-earth elliptical orbit
- 350 – 610 km
- Quasi-polar (70.4° inclination)
- Lifetime >3 years (assisted)
- Electronics receive ~3 krad (qualify commercial parts)

Trigger and Data Rate

Level 1 Trigger

One orbit



TOF Scintillator Coincidence

- S1 x S2 x S3
- S2 x S3

12 Hz / G.F. = 20.5 cm^2sr + background

Calorimeter Self-trigger (E_e>0.3TeV)

10 mHz / G.F. = 600 cm^2sr

Data Rate / Storage / Downlink

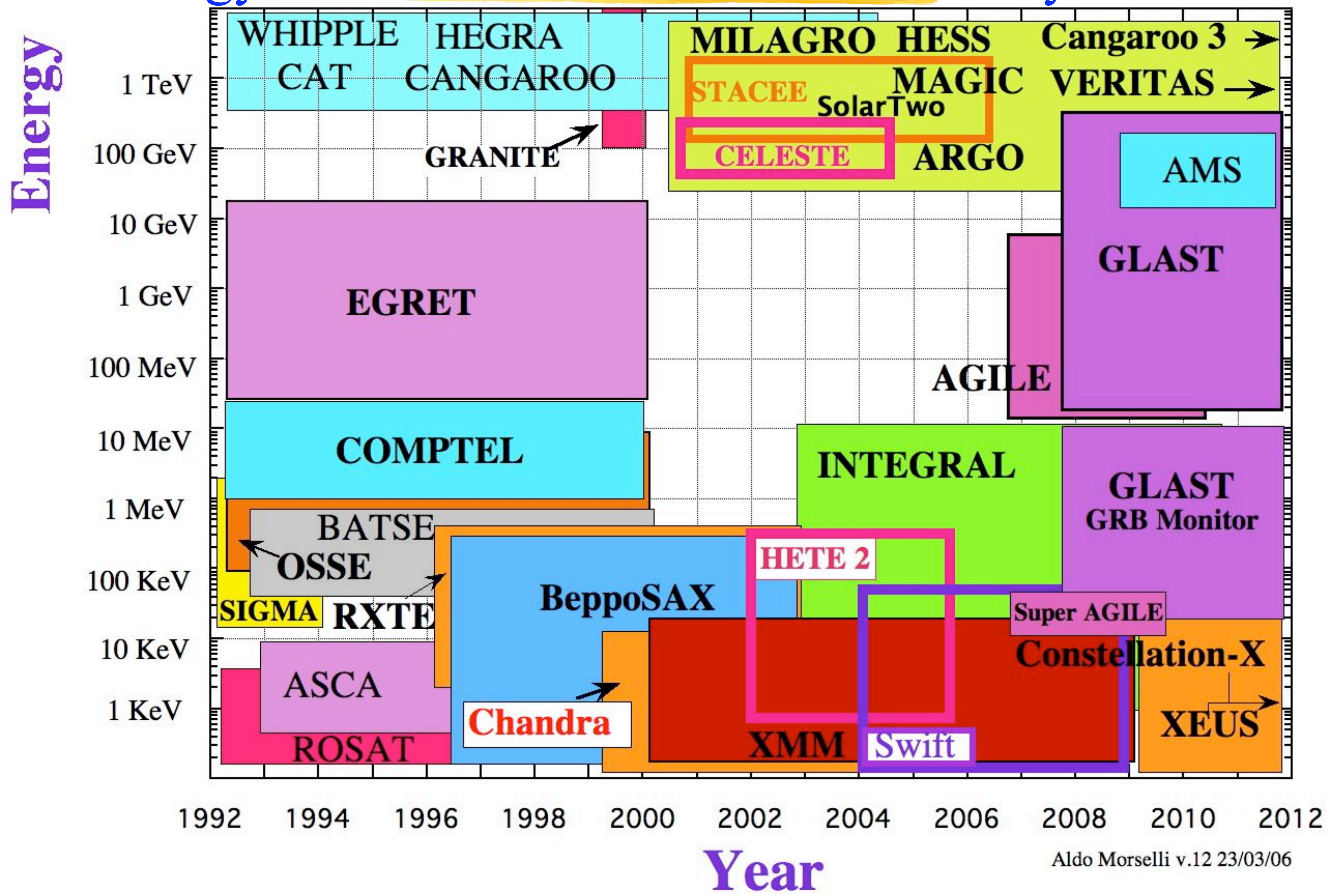
12 Hz x 5 kByte / event ~ **5 GB/day**

Up to 20 GB daily accumulation on-board

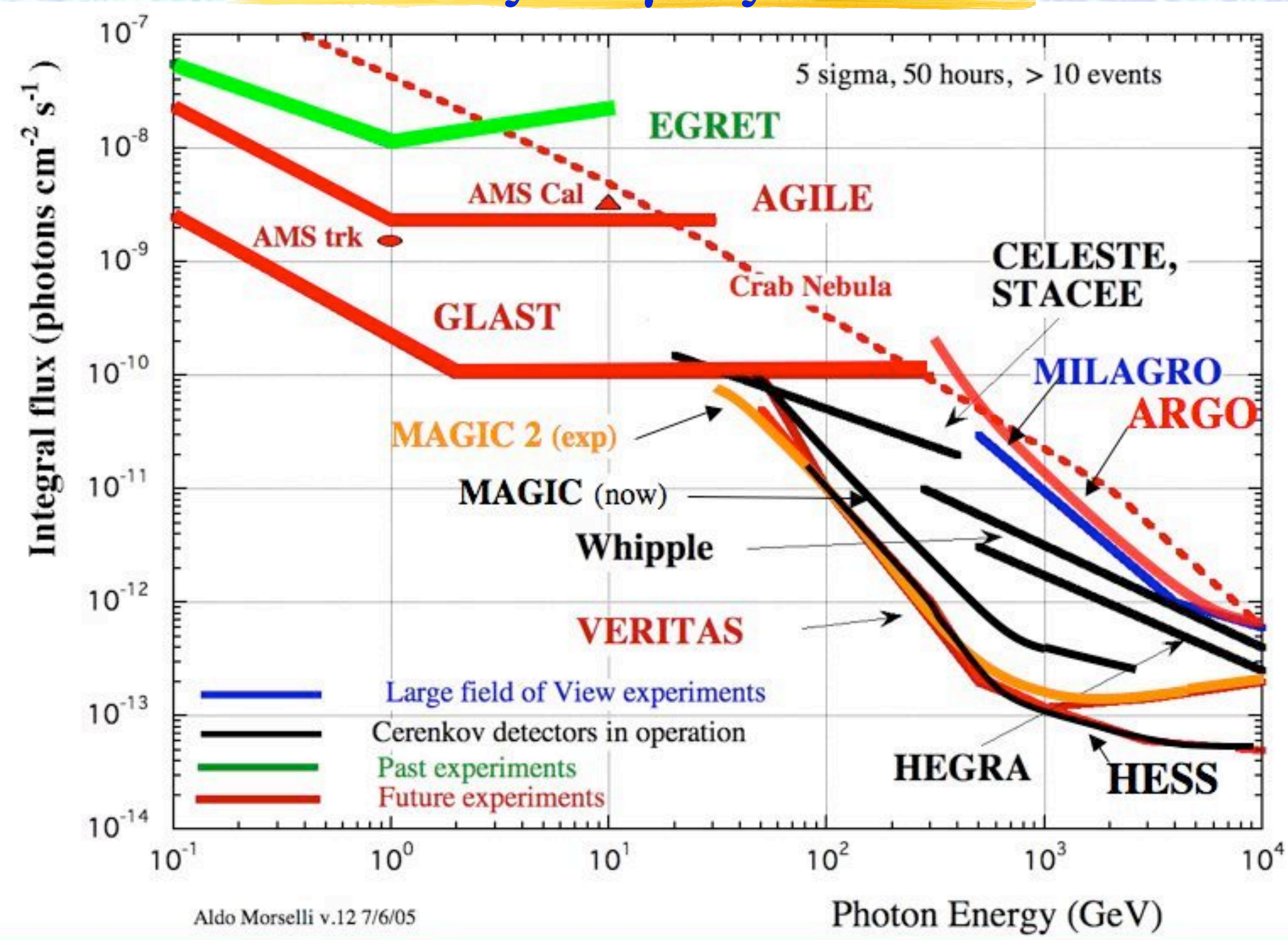
Downlinked with a few ground-connections per day

[PAMELA DAQ ~10% dead-time (10 ms)]

Energy versus time for X and Gamma ray detectors



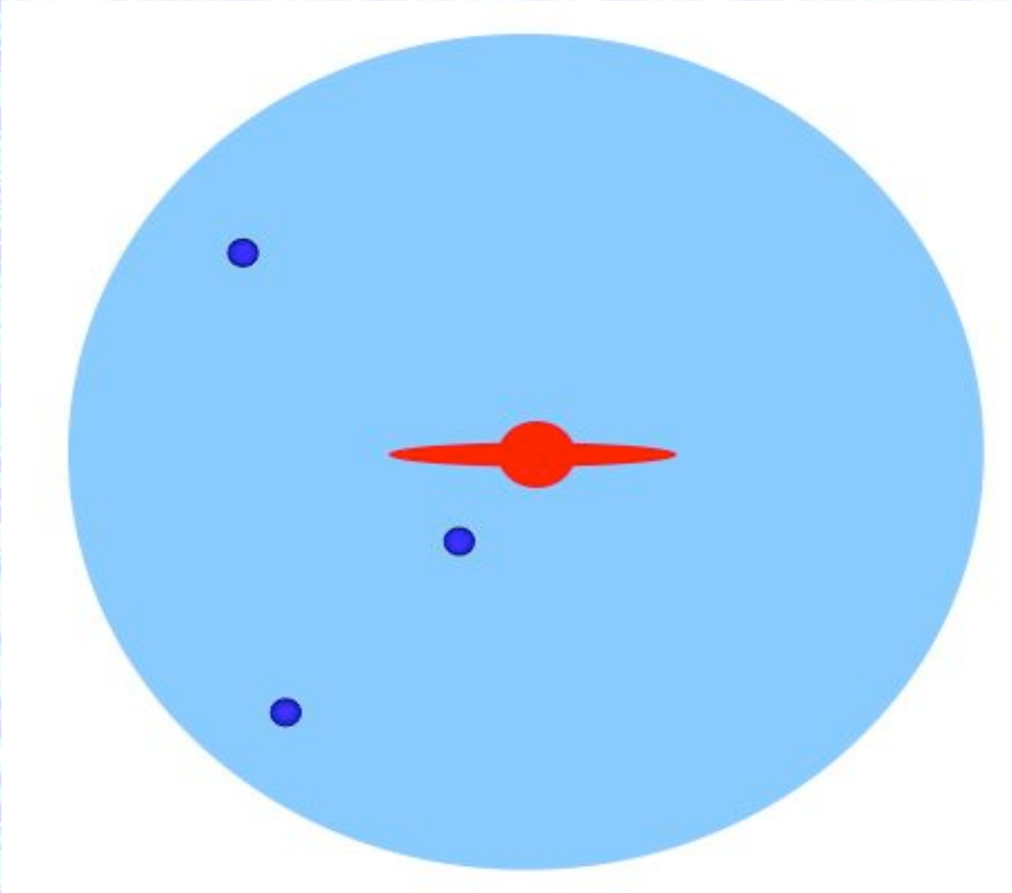
Sensitivity of γ-ray detectors



High galactic latitudes(Φ_b=2 10^{-5} γ cm^{-2} s^{-1} sr $^{-1}$ (100 MeV/E)$^{1.1}$). Cerenkov telescopes sensitivities (Veritas, MAGIC, Whipple, Hess, Celeste, Stacee, Hegra) are for 50 hours of observations.Large field of view detectors sensitivities (AGILE, GLAST, Milagro, ARGO, AMS) are for 1 year of observation.

Where should we look for WIMPs with GLAST?

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



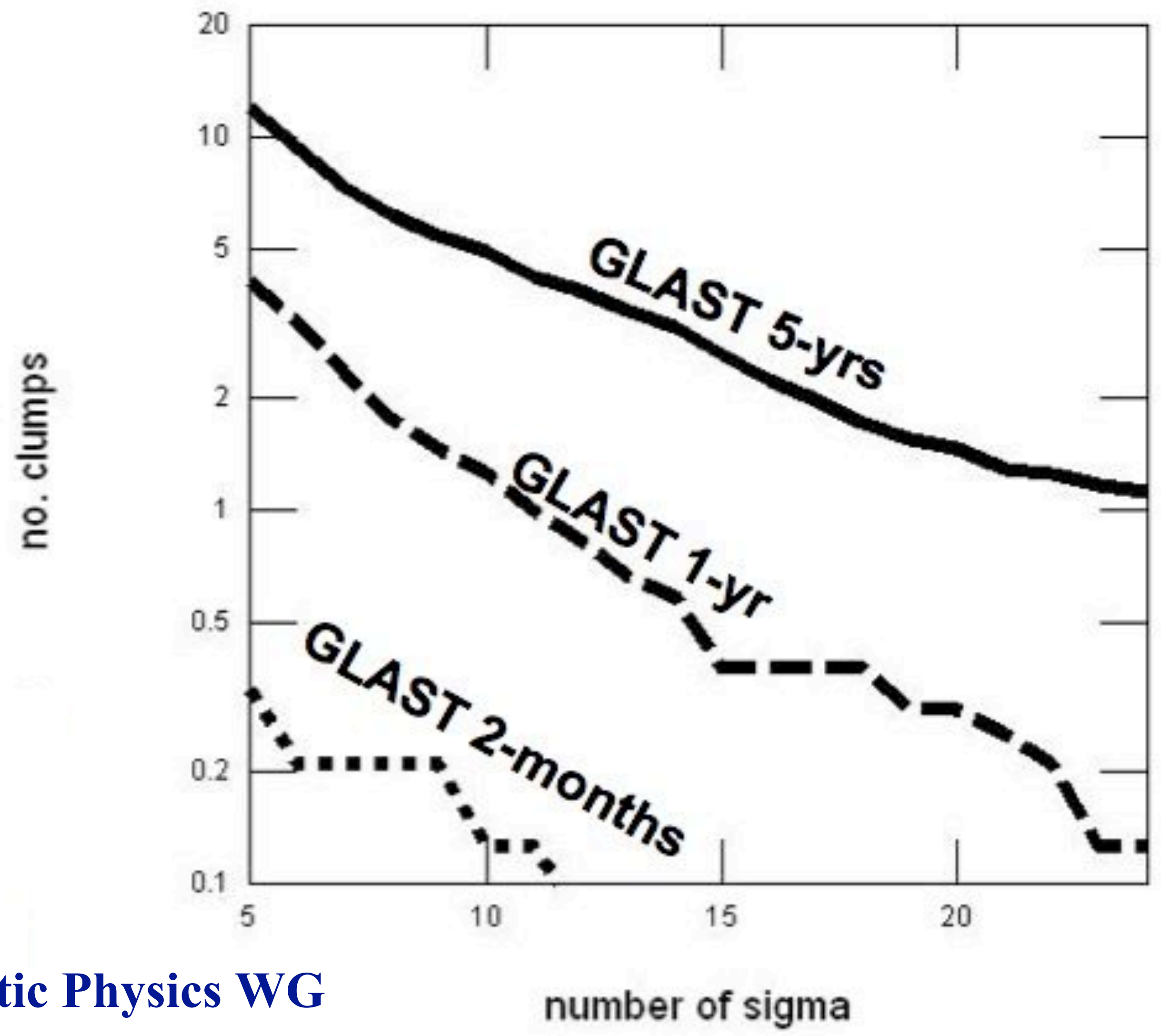
The search for milky way halo substructure WIMP annihilations using the GLAST LAT

Dark matter calculation with semi-analytic method of Taylor & Babul 2004, 2005

Background estimate using EGRET above 1GeV (source subtracted)

M=100GeV

$\langle \sigma v \rangle = 2.3\times10^{-26} cm^3 s^{-1}$

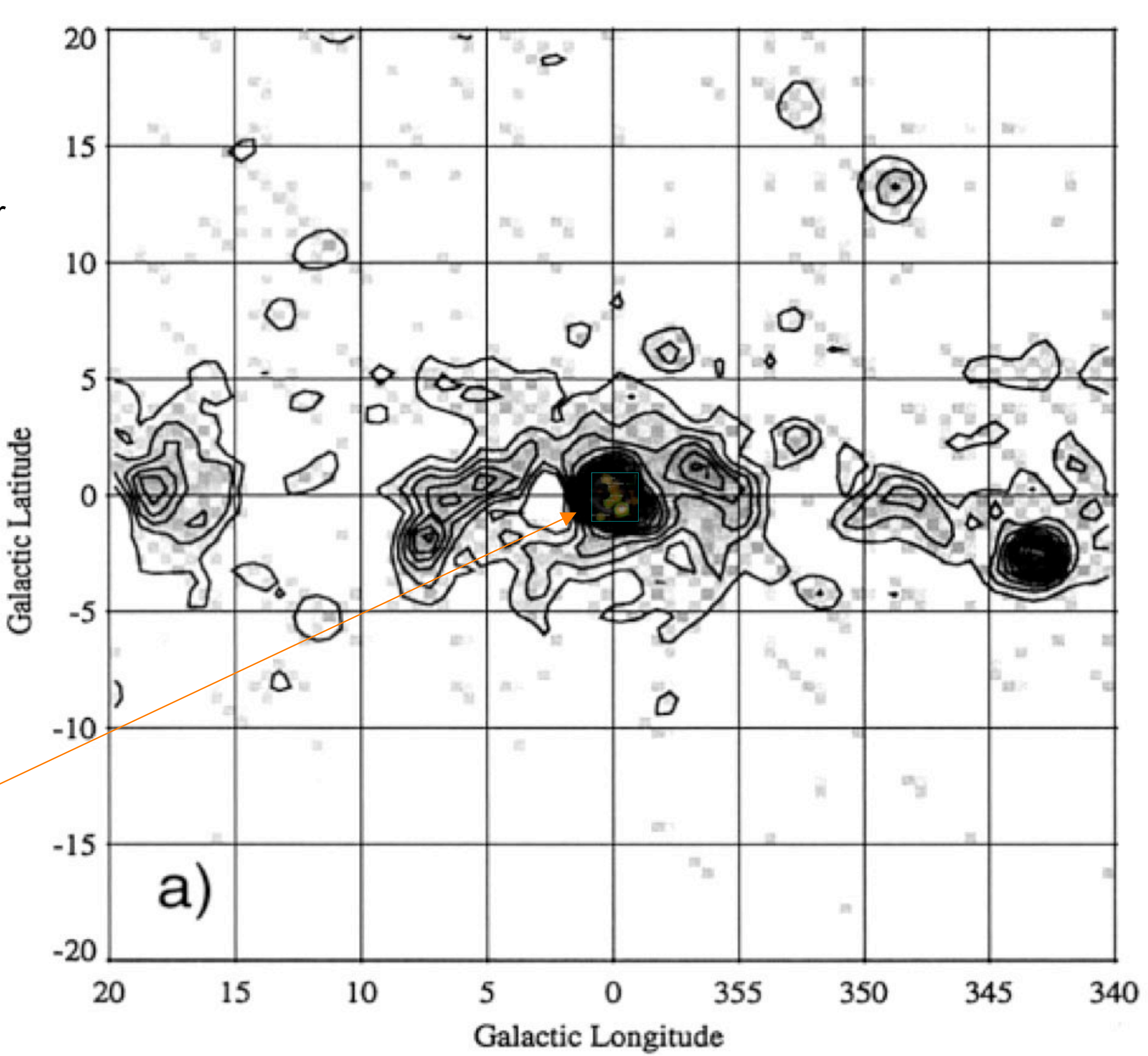


Larry Wai and Ping Wang

on behalf of GLAST DM & Exotic Physics WG

EGRET, E > 1GeV

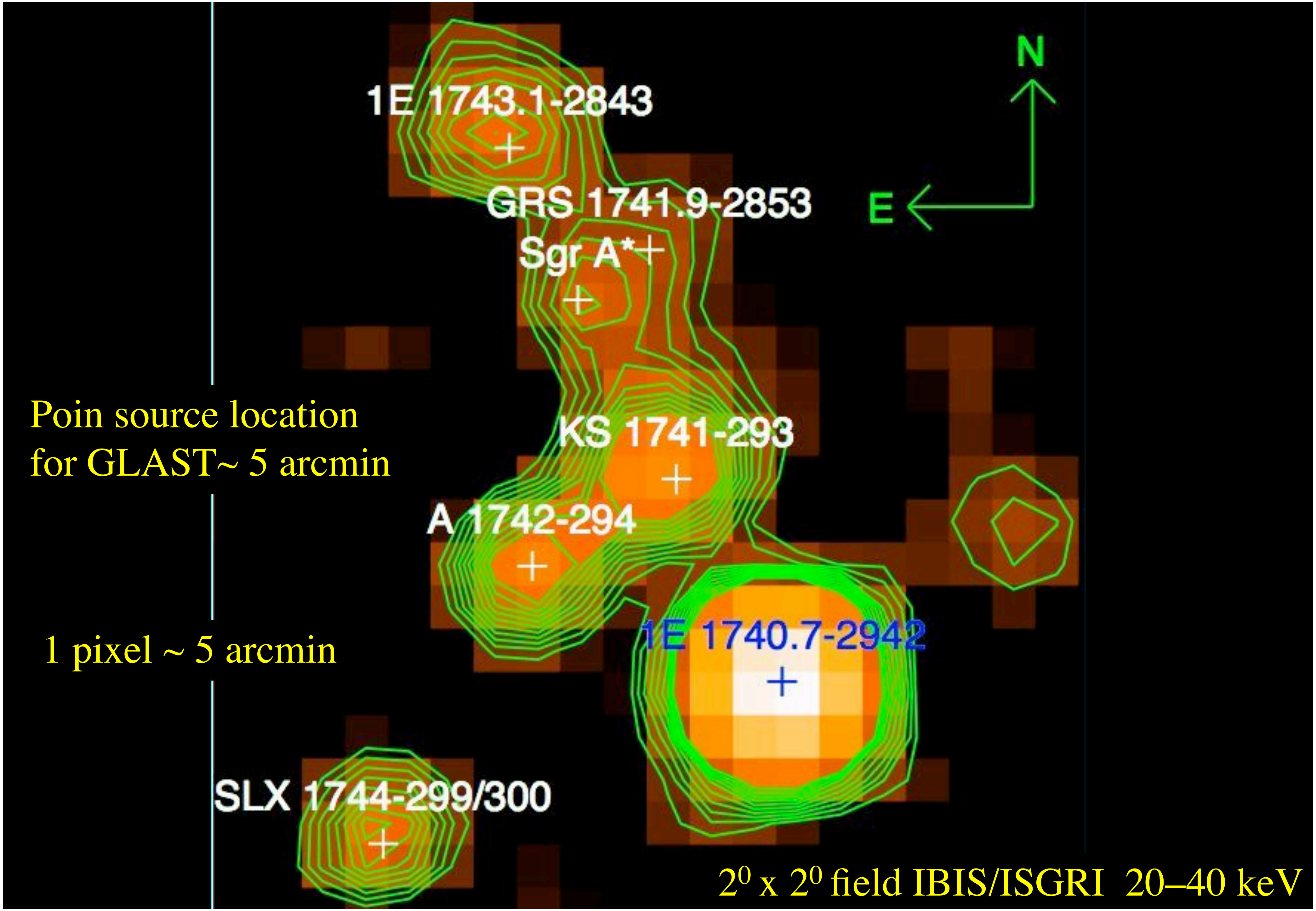
Mayer-Hasselwander et al, 1998

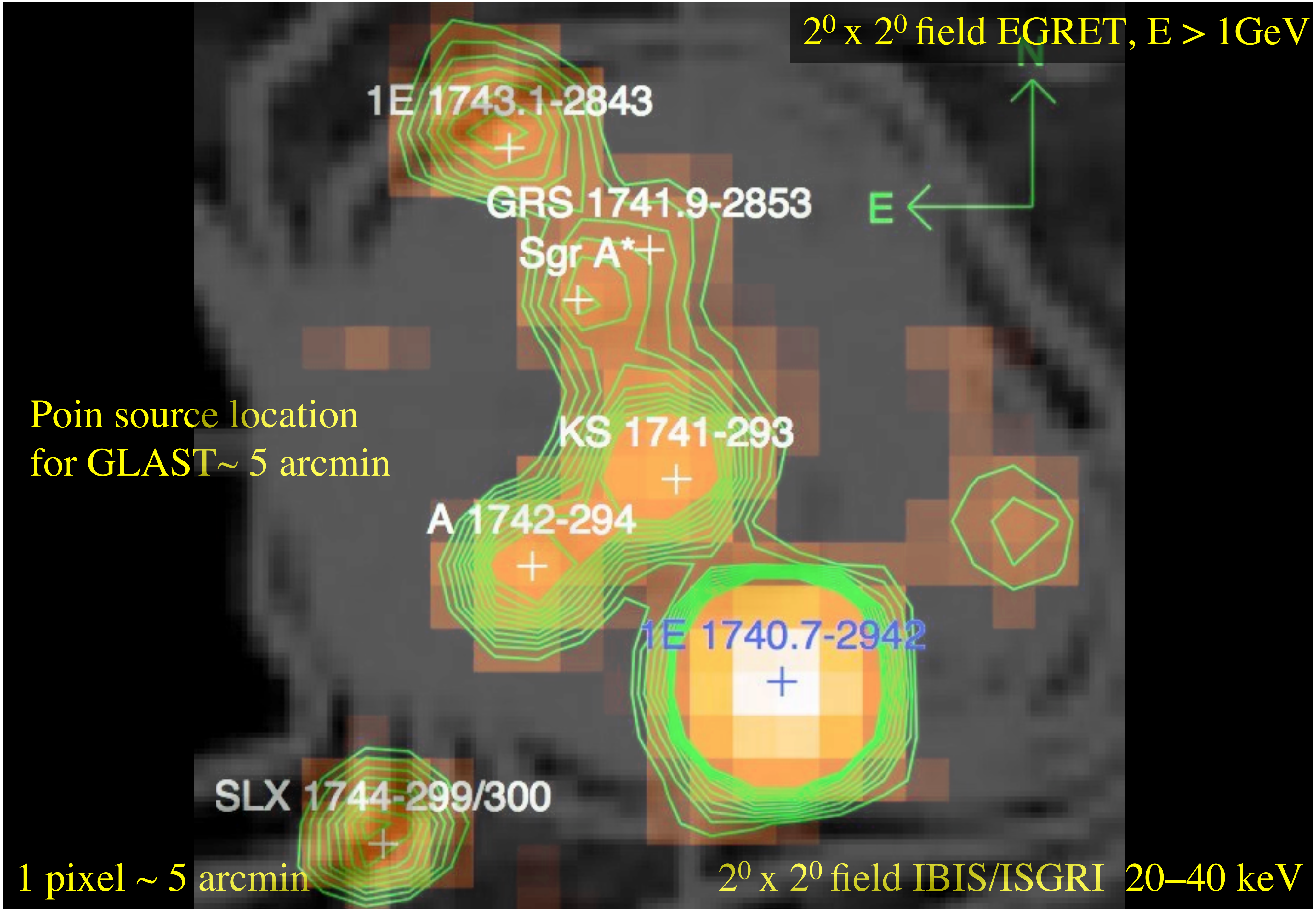


Integral data

2^0 x 2^0 field IBIS/ISGRI

20–40 keV


1E 1743.1-2843
GRS 1741.9-2853
Sgr A*
N
E
Poin source location
for GLAST~ 5 arcmin
KS 1741-293
A 1742-294
1 pixel ~ 5 arcmin
1E 1740.7-2942
SLX 1744-299/300
2^0 x 2^0 field IBIS/ISGRI 20–40 keV

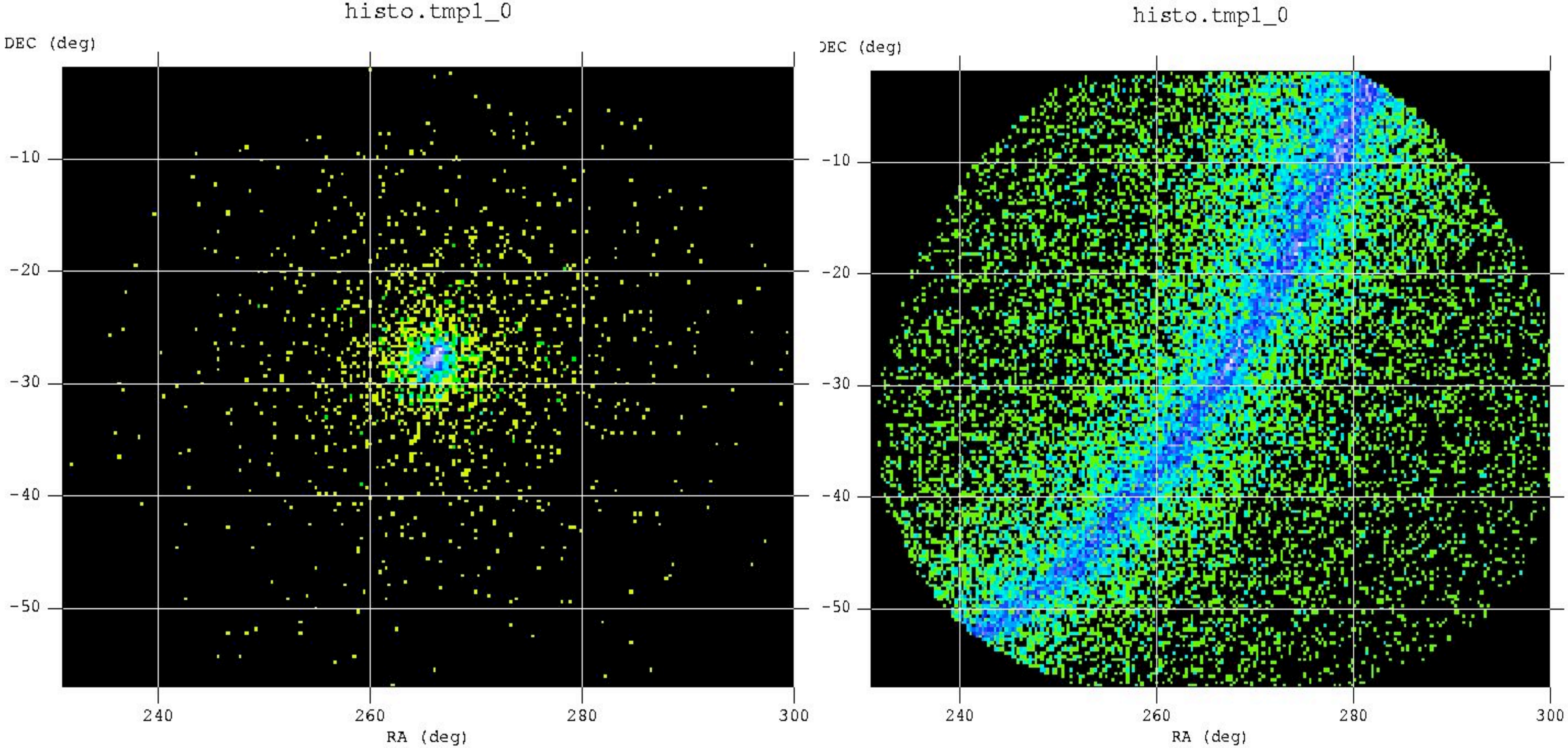

2^0 x 2^0 field EGRET, E > 1GeV
N
E
1E 1743.1-2843
GRS 1741.9-2853
Sgr A*
KS 1741-293
A 1742-294
1E 1740.7-2942
SLX 1744-299/300
Poin source location
for GLAST~ 5 arcmin
1 pixel ~ 5 arcmin
2^0 x 2^0 field IBIS/ISGRI 20–40 keV

GLAST simulations

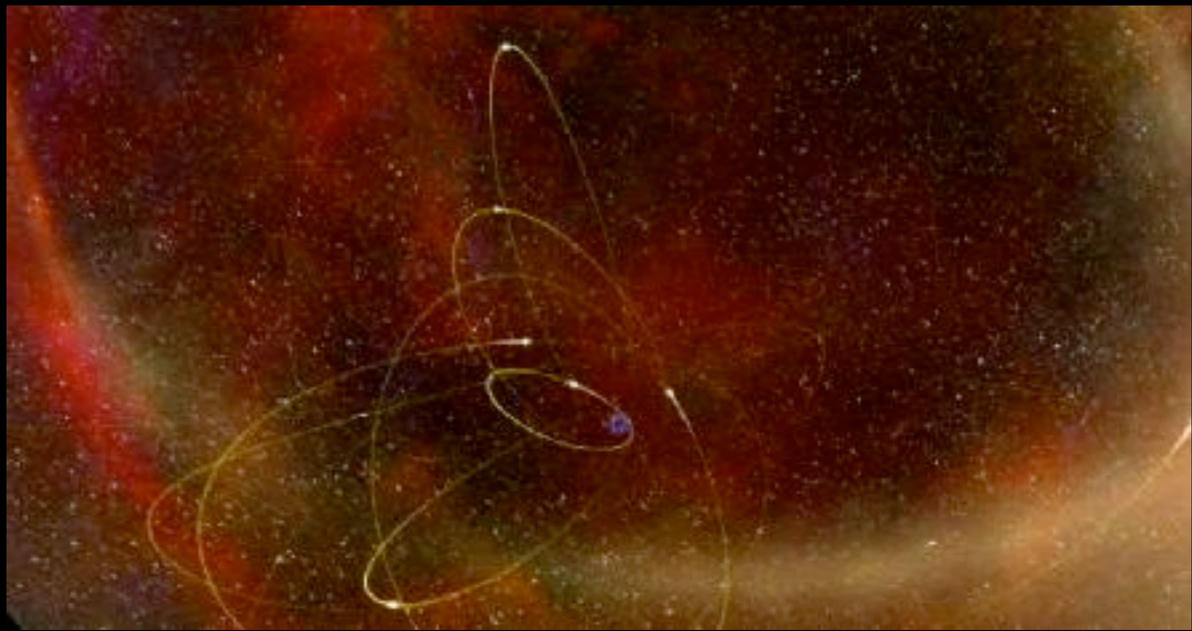
> Whole sky 'realistic' simulation (Data Challenge2 Instrument Response Function)
> One Year observations, 30 deg radius FOV Galactic Center centered

Dark Matter NFW profile,
$m_{B(1)} \sim 500$ GeV

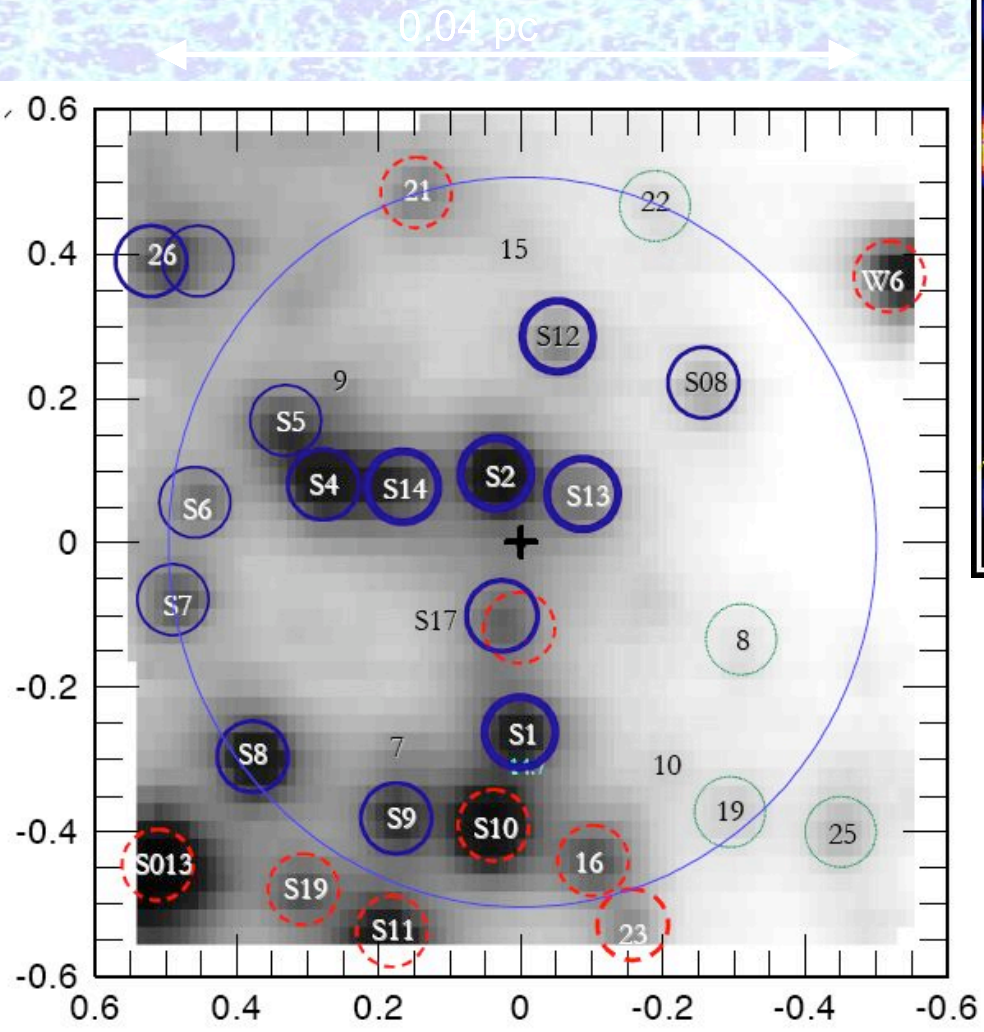
Diffuse background based on GALPROP code
(Point source substracted)



The Galactic center



The Central Cusp of Stars
-- mostly B stars
DM < 5% M_black hole
inside S2 orbit



Eisenhauer et al. 2005