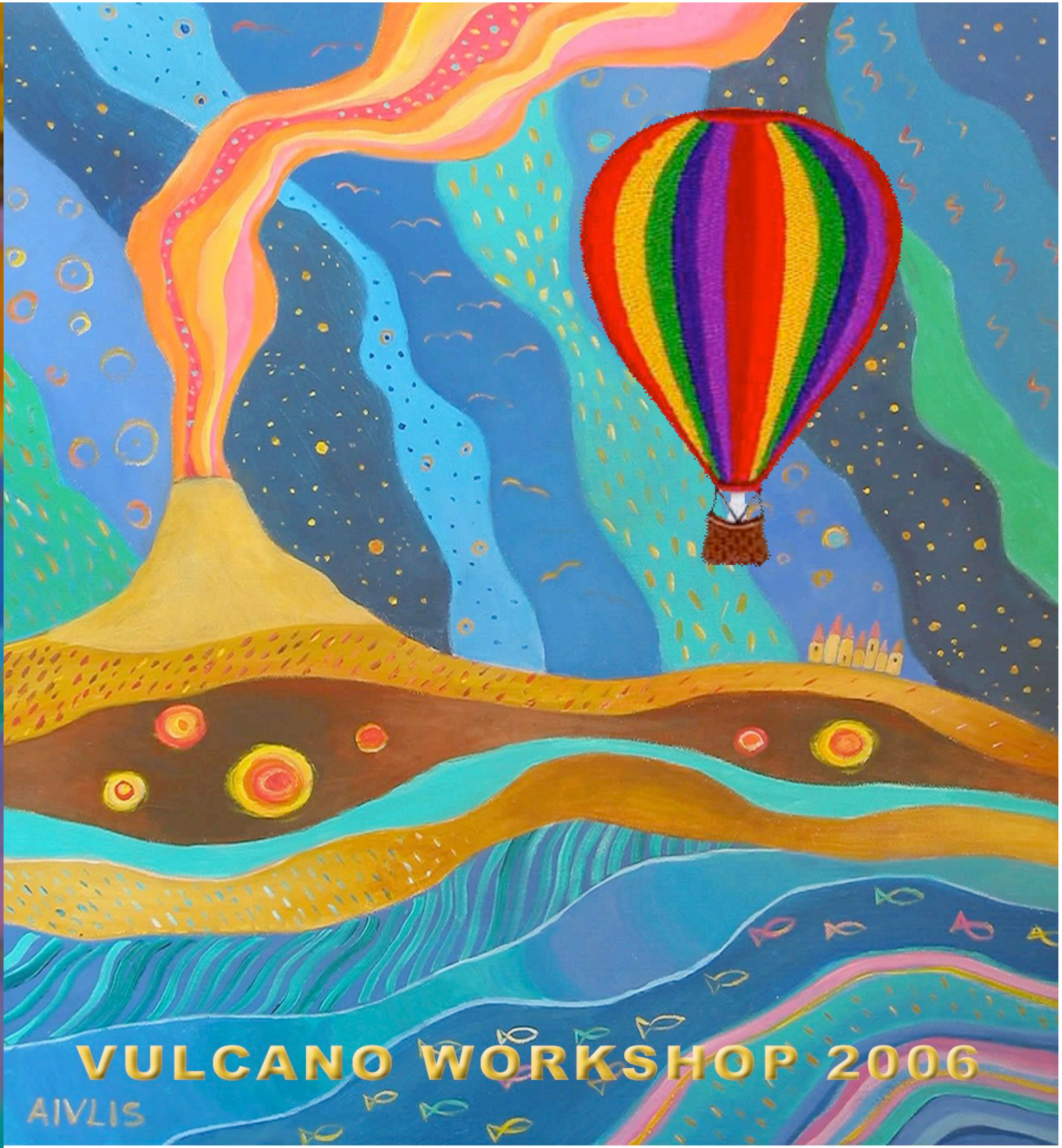
High-Energy Deuteron Measurement with the CAPRICE98 Experiment

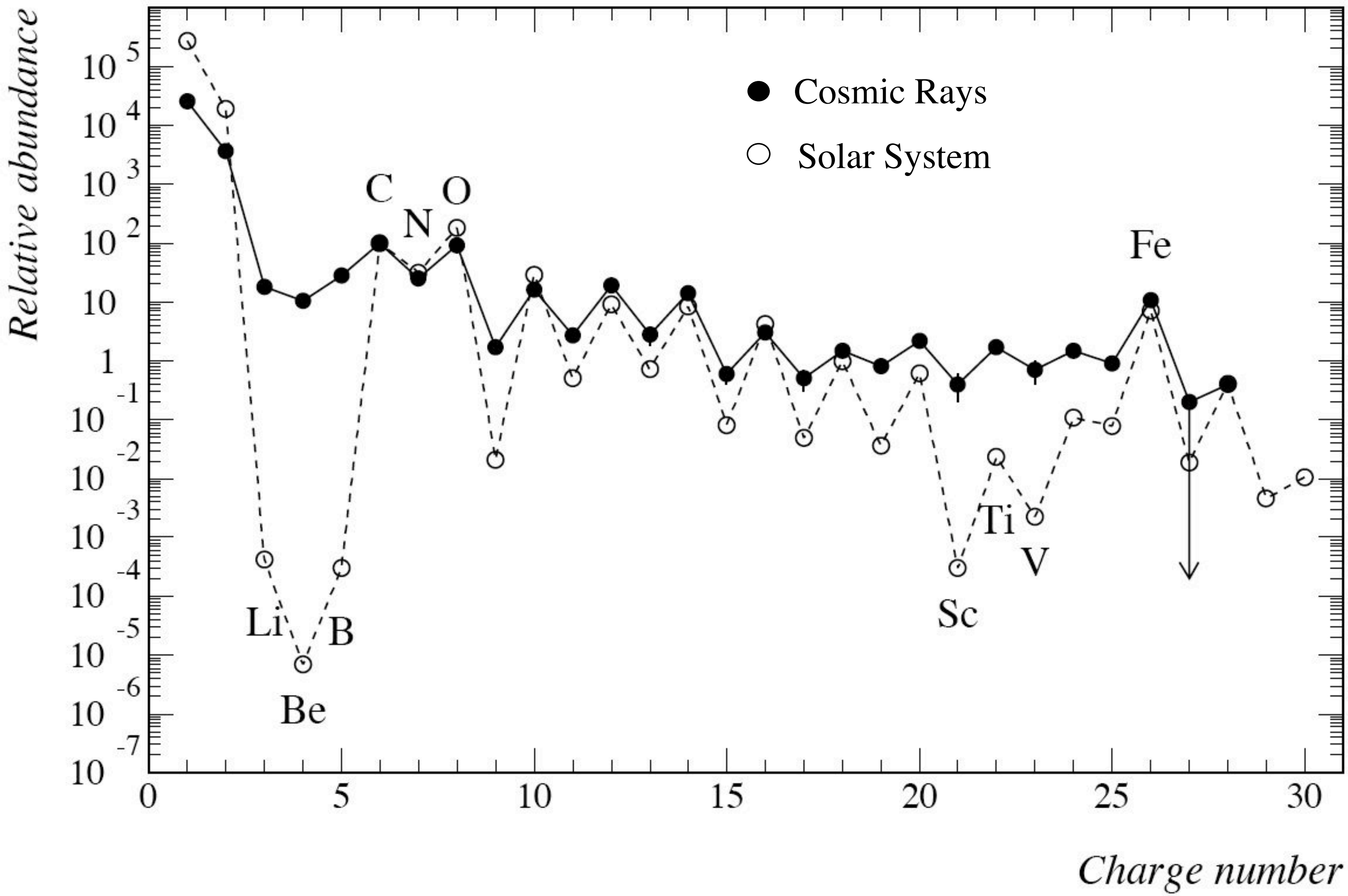
Aldo Morselli

INFN &
Università di Roma Tor Vergata

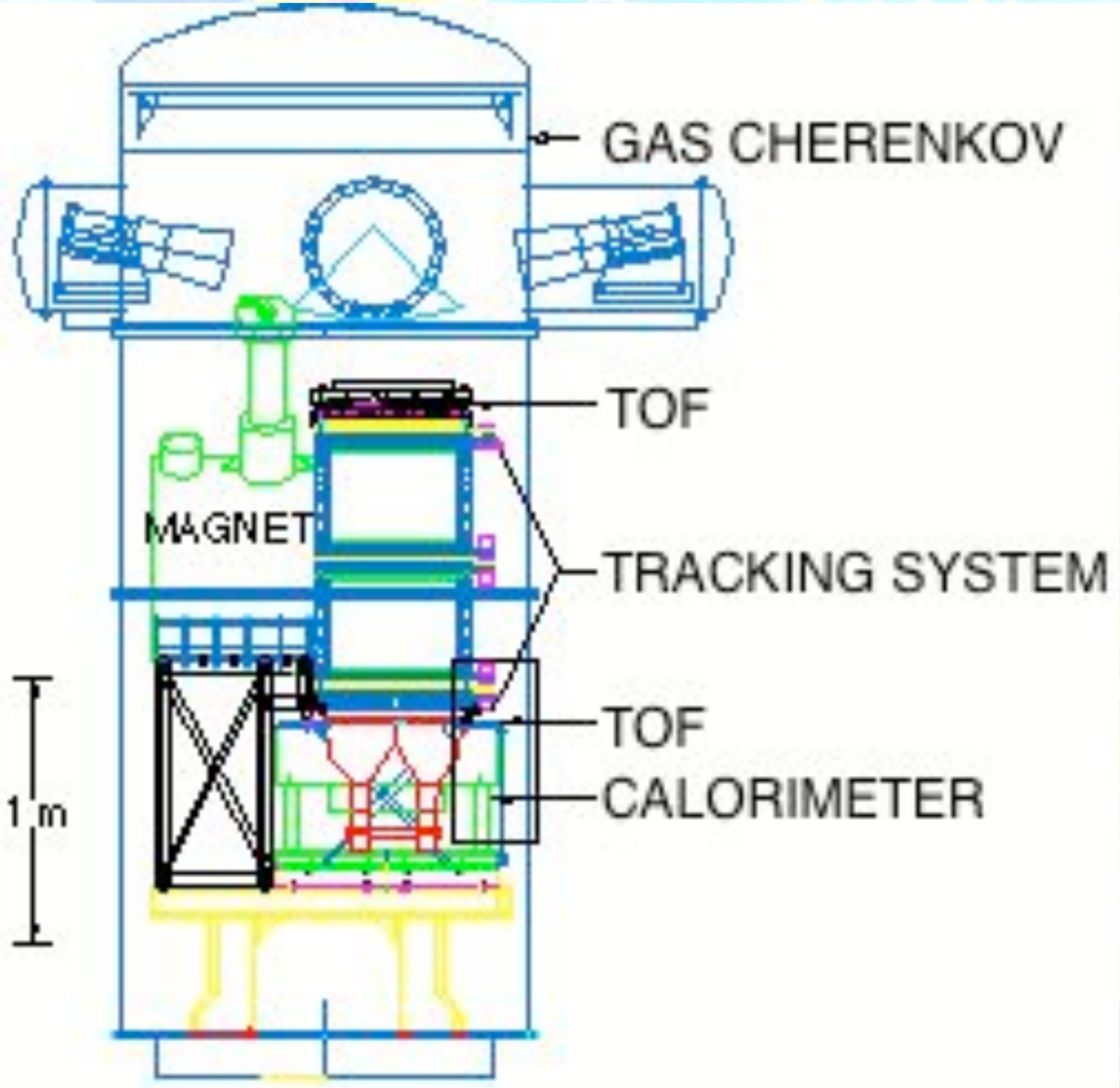
25 - May 2004

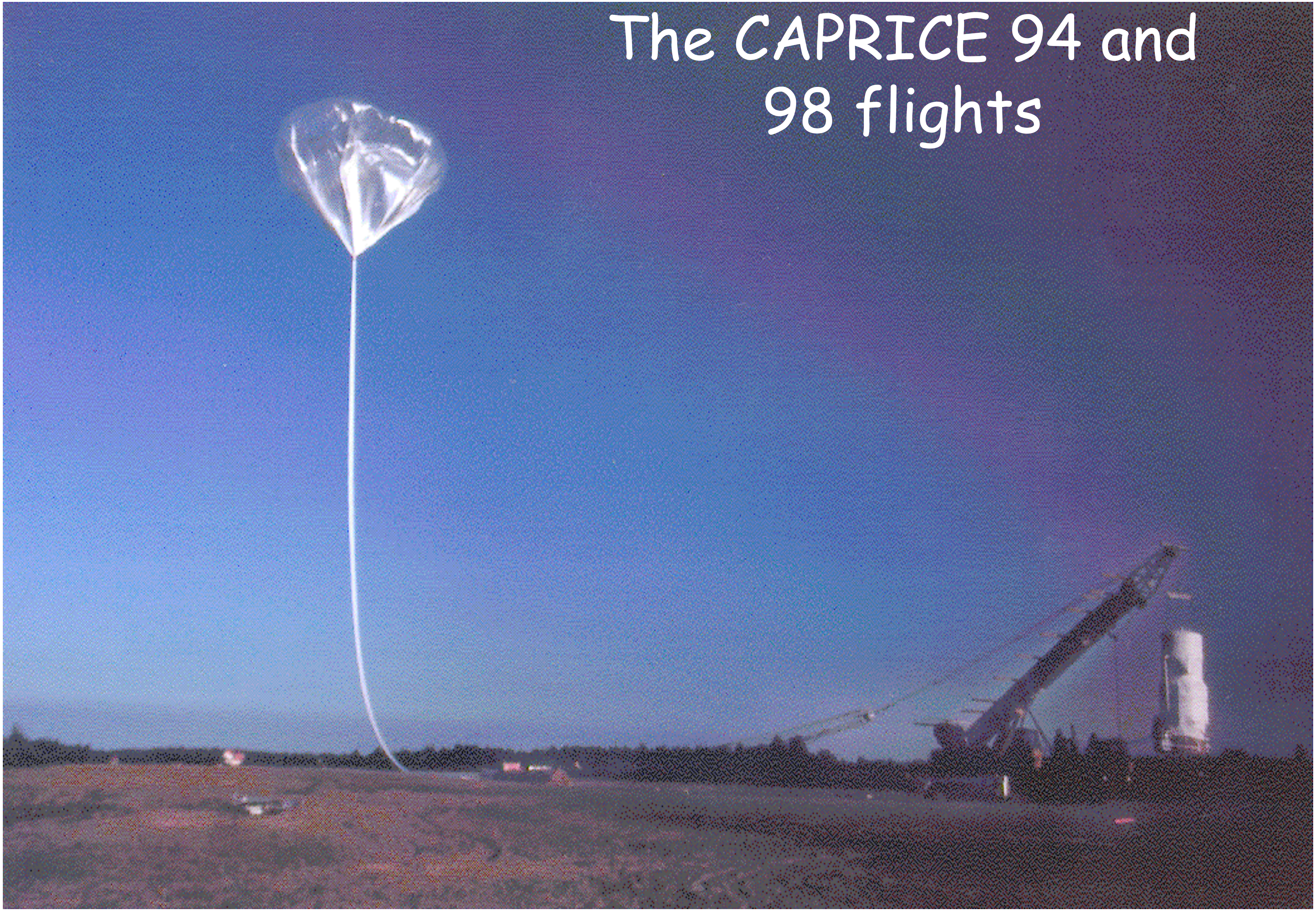


Comparison between the cosmic rays and the Solar System element composition, both relative to Carbon



MASS Matter Antimatter Space Spectrometer




The CAPRICE 94 and
98 flights

The WiZard/CAPRICE collaboration

M. Ambriola[2], S. Bartalucci[3], R. Bellotti[2], D. Bergström[4], M. Boezio[5], V. Bonvicini[5], U. Bravar[6], F. Cafagna[2], P.Carlson[4], M. Casolino[7], F. Ciacio[2], M. Circella[2], C. N. De Marzo[2], M. P. De Pascale[6], N. Finetti[1], T. Francke[4], P. Hansen[4], M. Hof[8], J. Kremer[8], W. Menn[8], J. W. Mitchell[9], E. Mocchiutti[4], A. Morselli[7], J. F. Ormes[9], P. Papini[1], S. Piccardi[1], P. Picozza[7], M. Ricci[3], P. Schiavon[5], M. Simon[8], R. Sparvoli[7], P. Spillantini[1], S. A. Stephens[9], S. J. Stochaj[6], R. E. Streitmatter[9], M. Suffert[10], A. Vacchi[5], E. Vannuccini[1] and N. Zampa[5]

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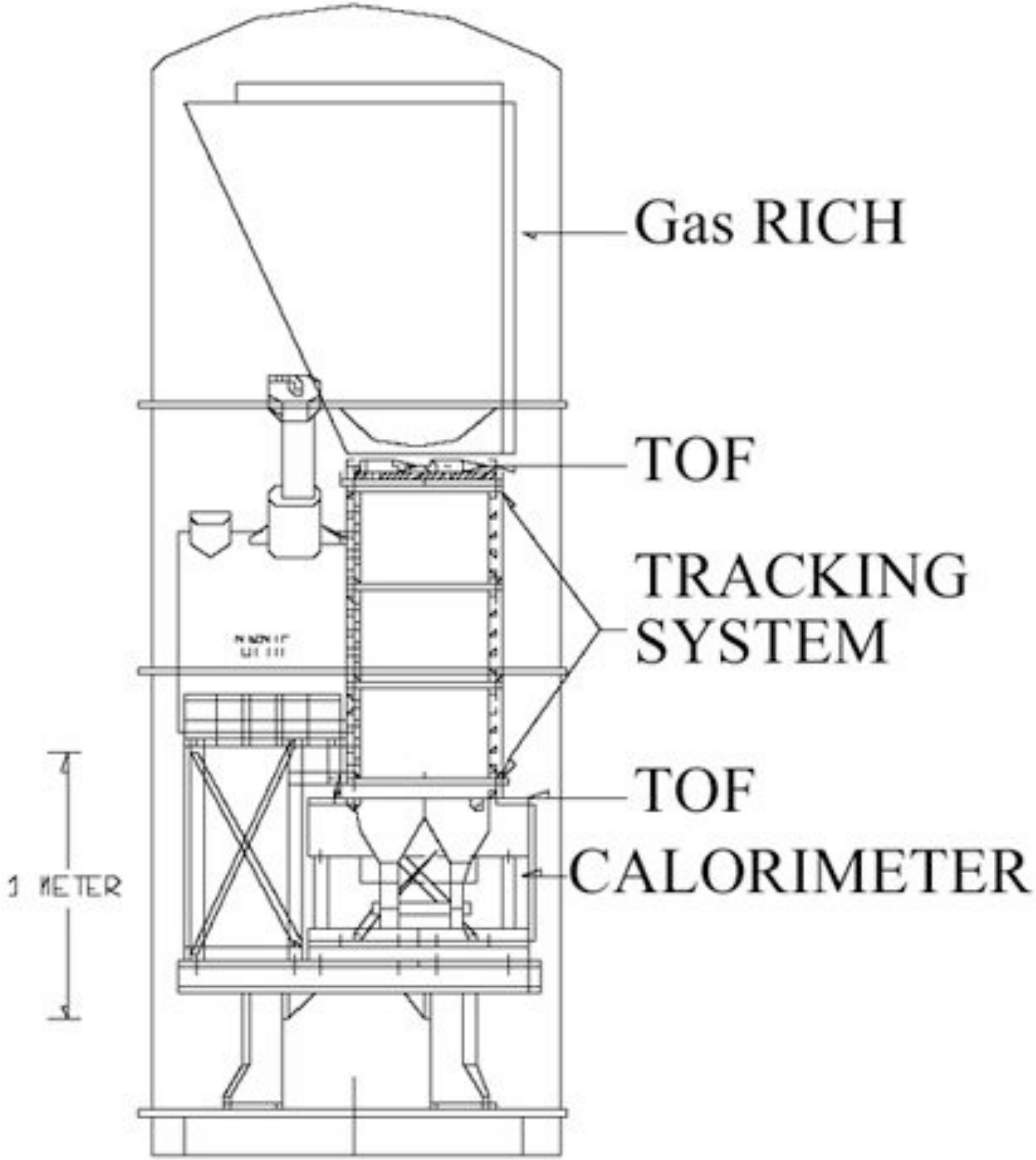

CAPRICE 98

(Cosmic AntiProton Ring-Imaging Cherenkov Experiment)

- Charge sign and momentum
- Beta selection
- Z selection
- hadron – electron discrimination

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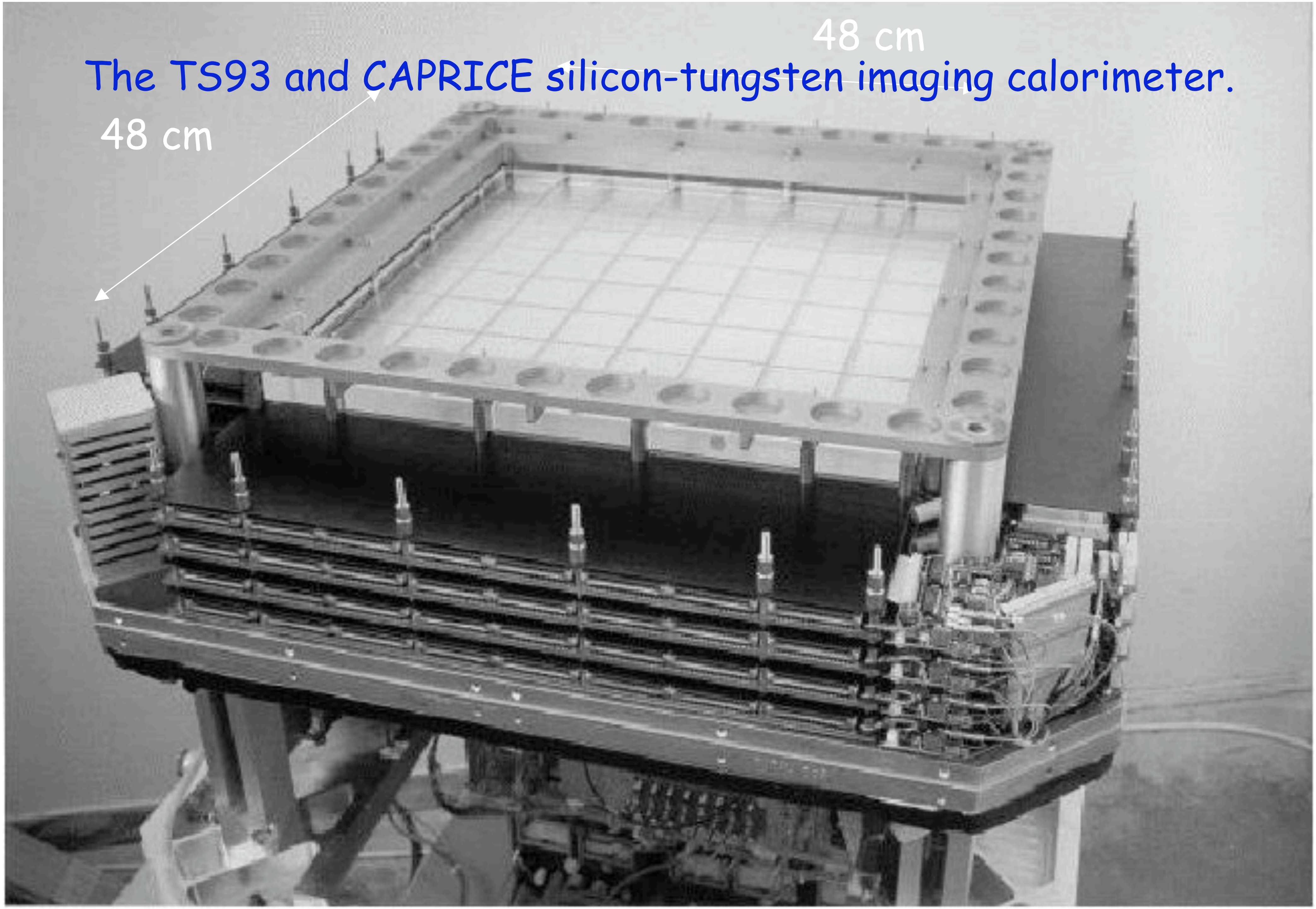
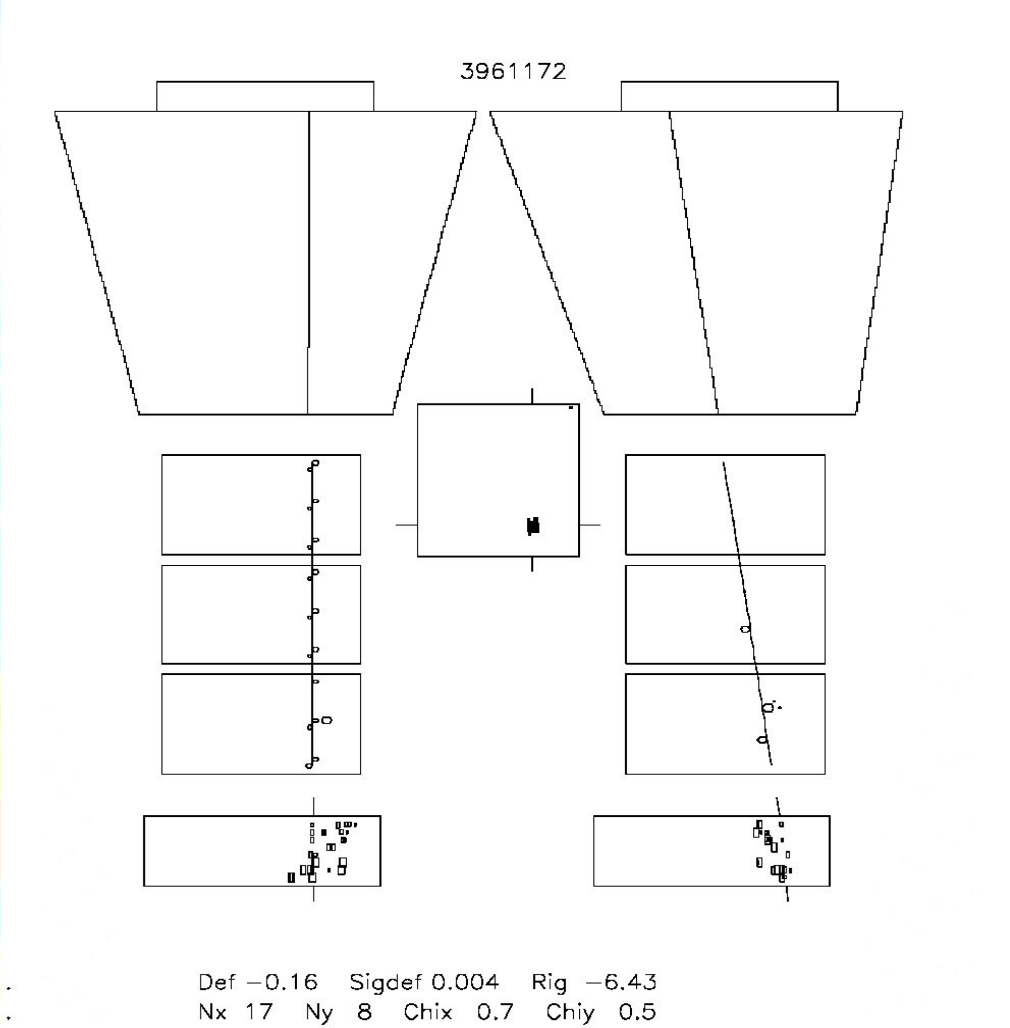
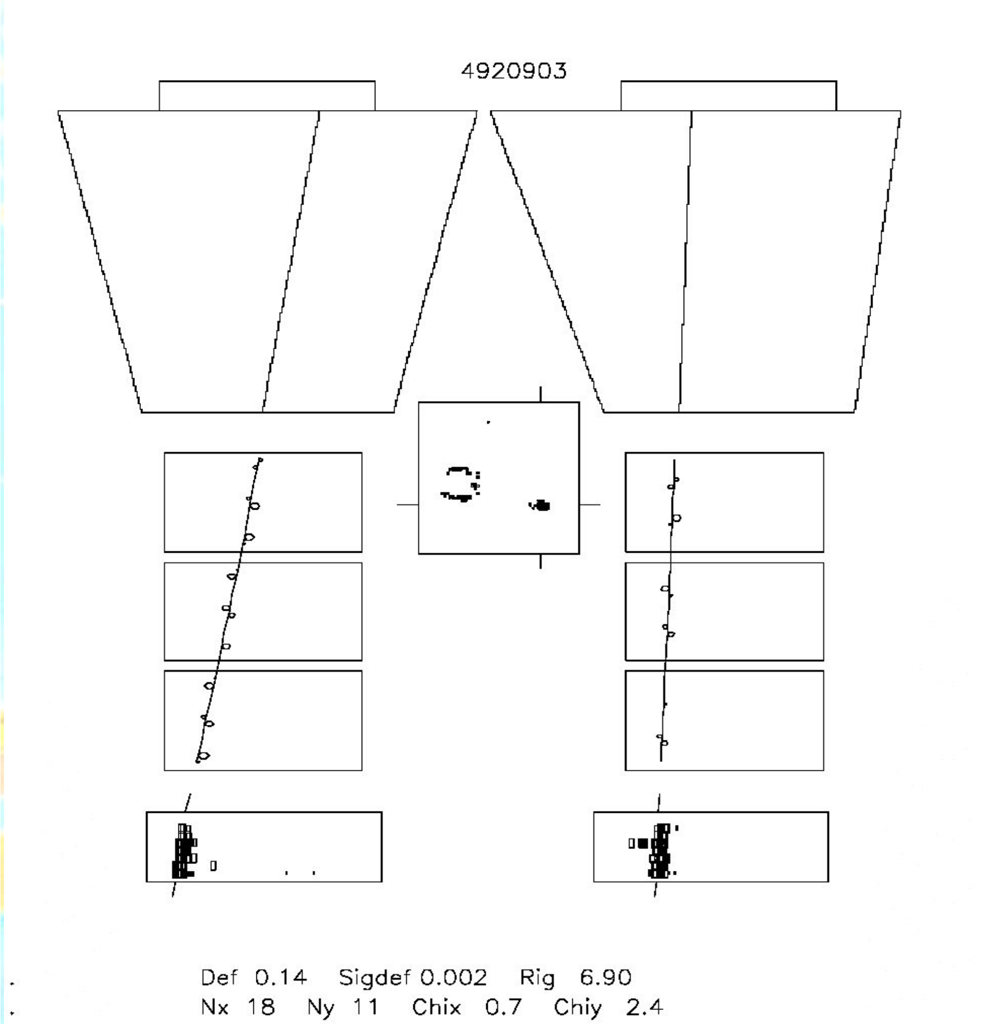
The TS93 and CAPRICE silicon-tungsten imaging calorimeter.



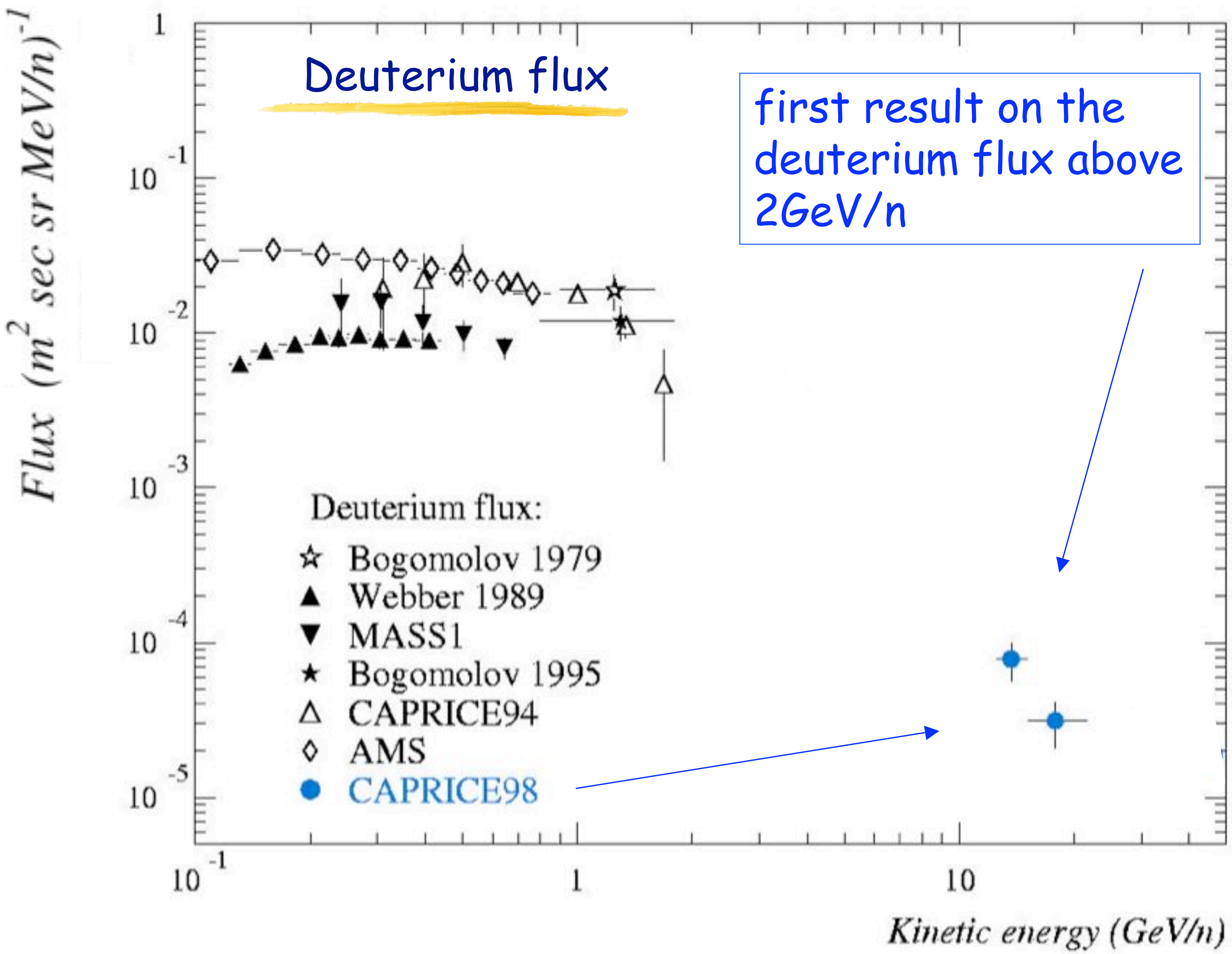
Antiproton



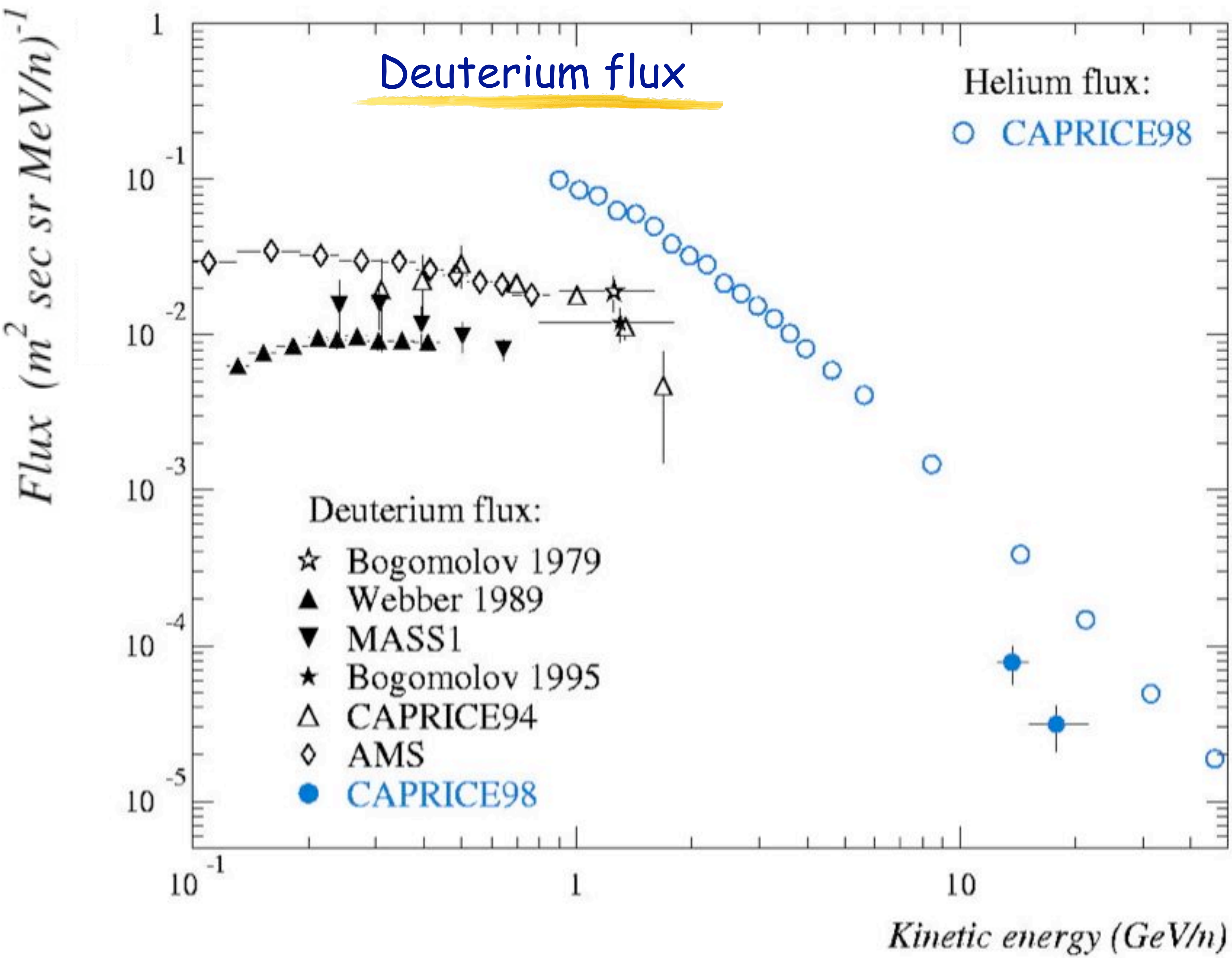
Positron



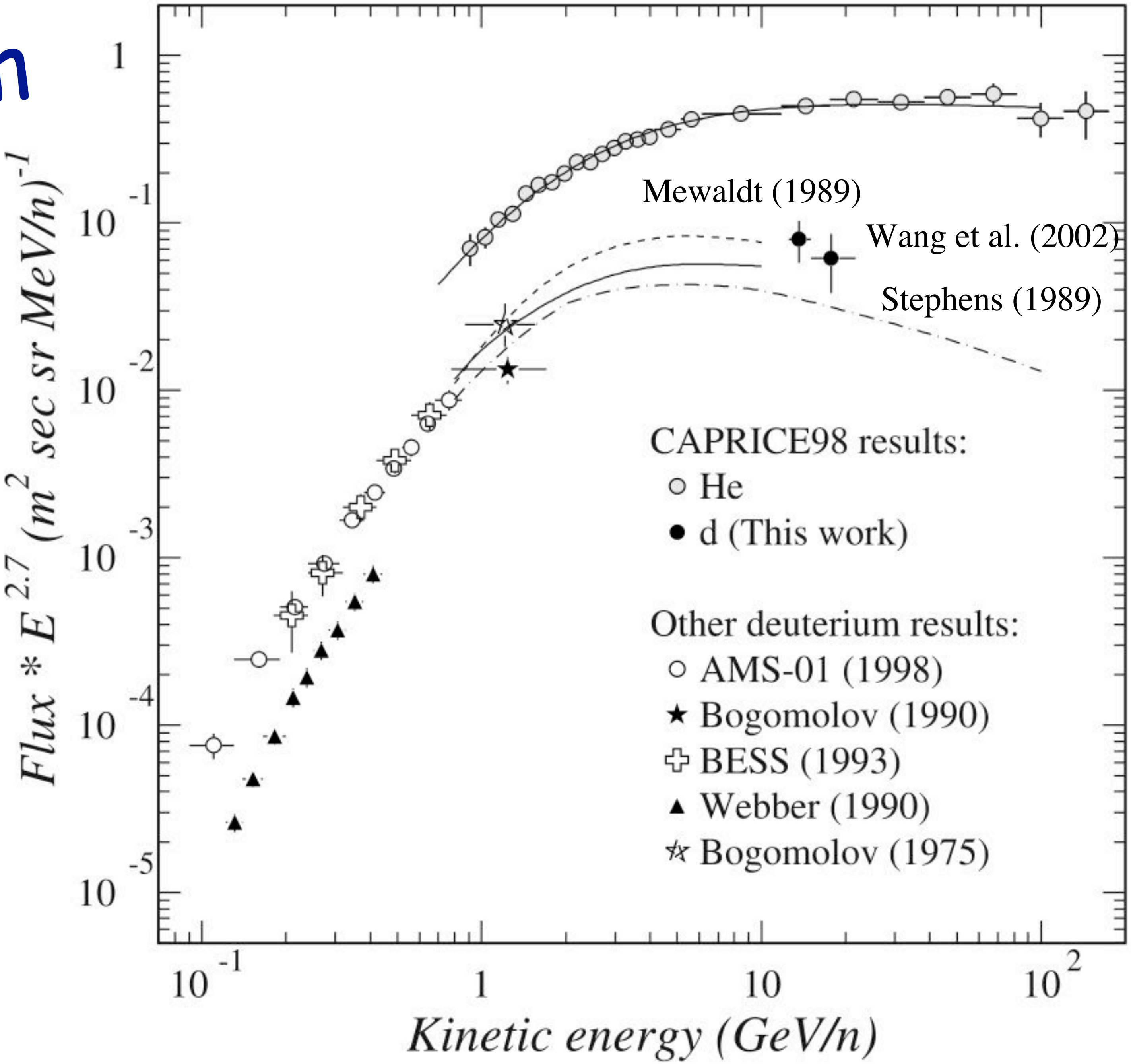
In the CAPRICE98 experiment, a gas RICH detector was flown for the first time with a magnet spectrometer. This allowed to separate 2H from 1H in the energy range from 12 to 22 GeV/n.

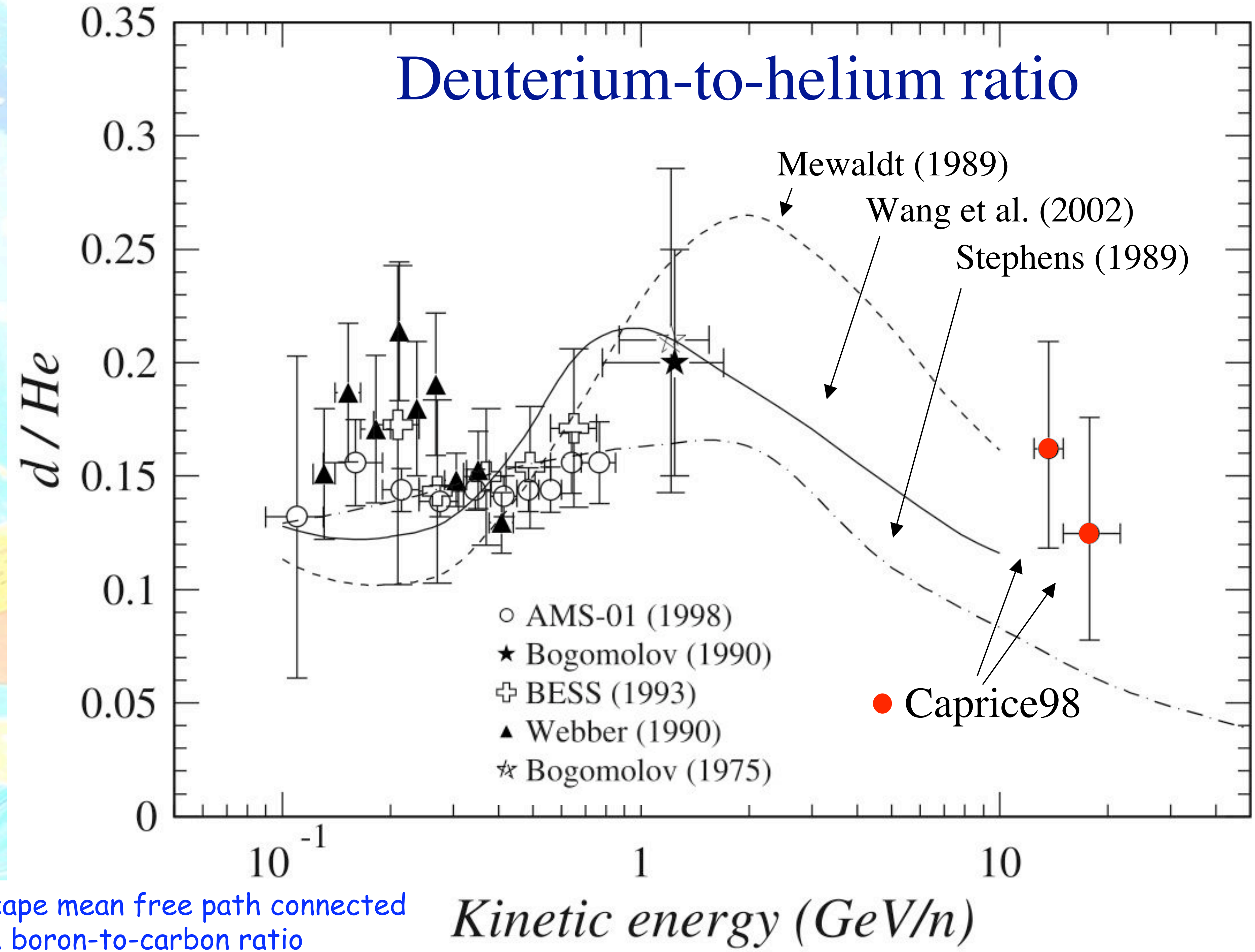


Deuterium flux
first result on the deuterium flux above 2GeV/n
Flux (m^2 sec sr MeV/n)^-1
1
10^-1
10^-2
10^-3
10^-4
10^-5
Deuterium flux:
Bogomolov 1979
Webber 1989
MASS1
Bogomolov 1995
CAPRICE94
AMS
CAPRICE98
10^-1
1
10
Kinetic energy (GeV/n)


Deuterium flux
Helium flux:
CAPRICE98
Deuterium flux:
Bogomolov 1979
Webber 1989
MASS1
Bogomolov 1995
CAPRICE94
AMS
CAPRICE98
Flux (m^2 sec sr MeV/n)^-1
Kinetic energy (GeV/n)
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-1
1
10

Deuterium flux





•Escape mean free path connected with boron-to-carbon ratio

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

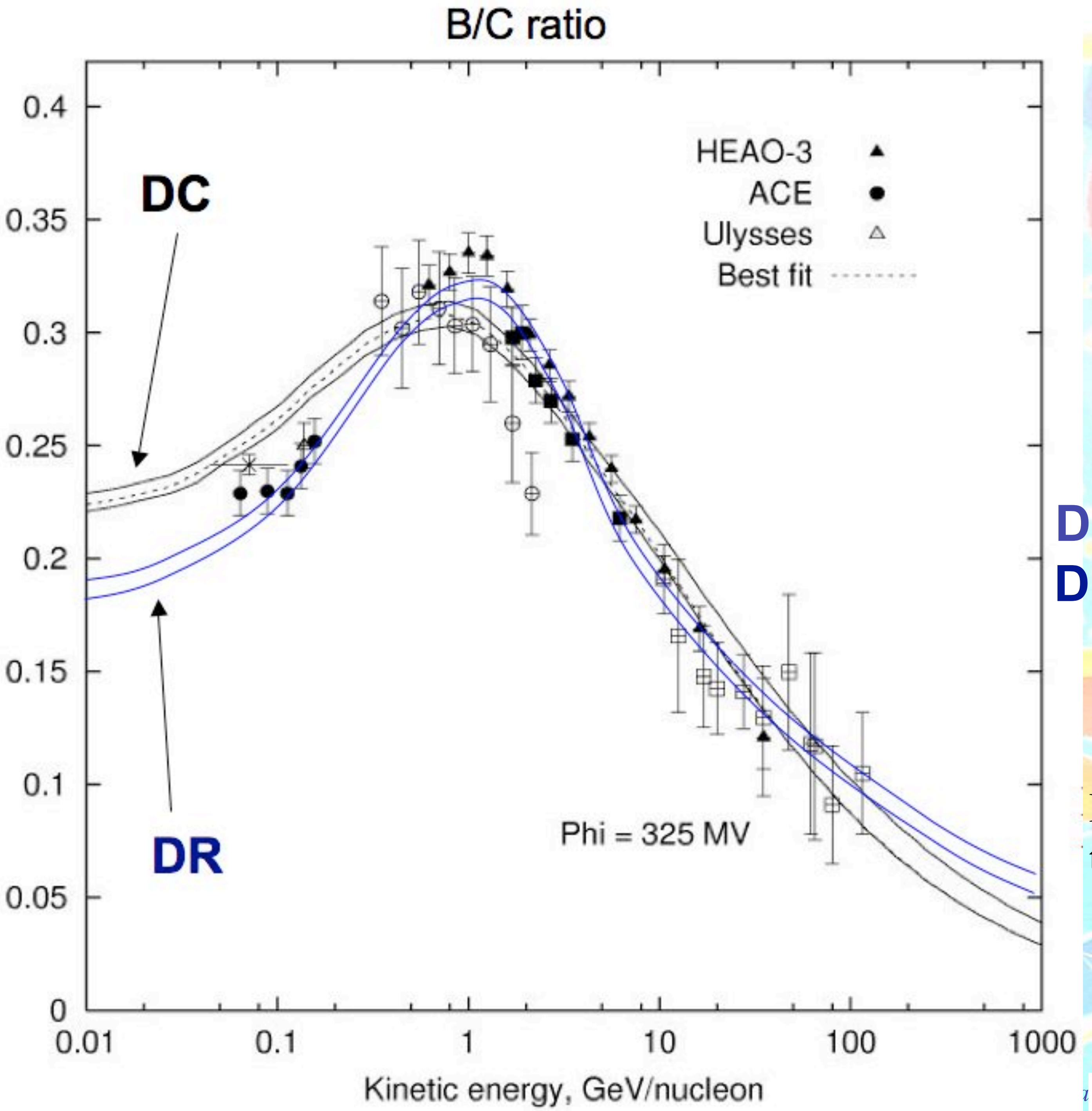
diffusion coefficient is function of rigidity

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

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

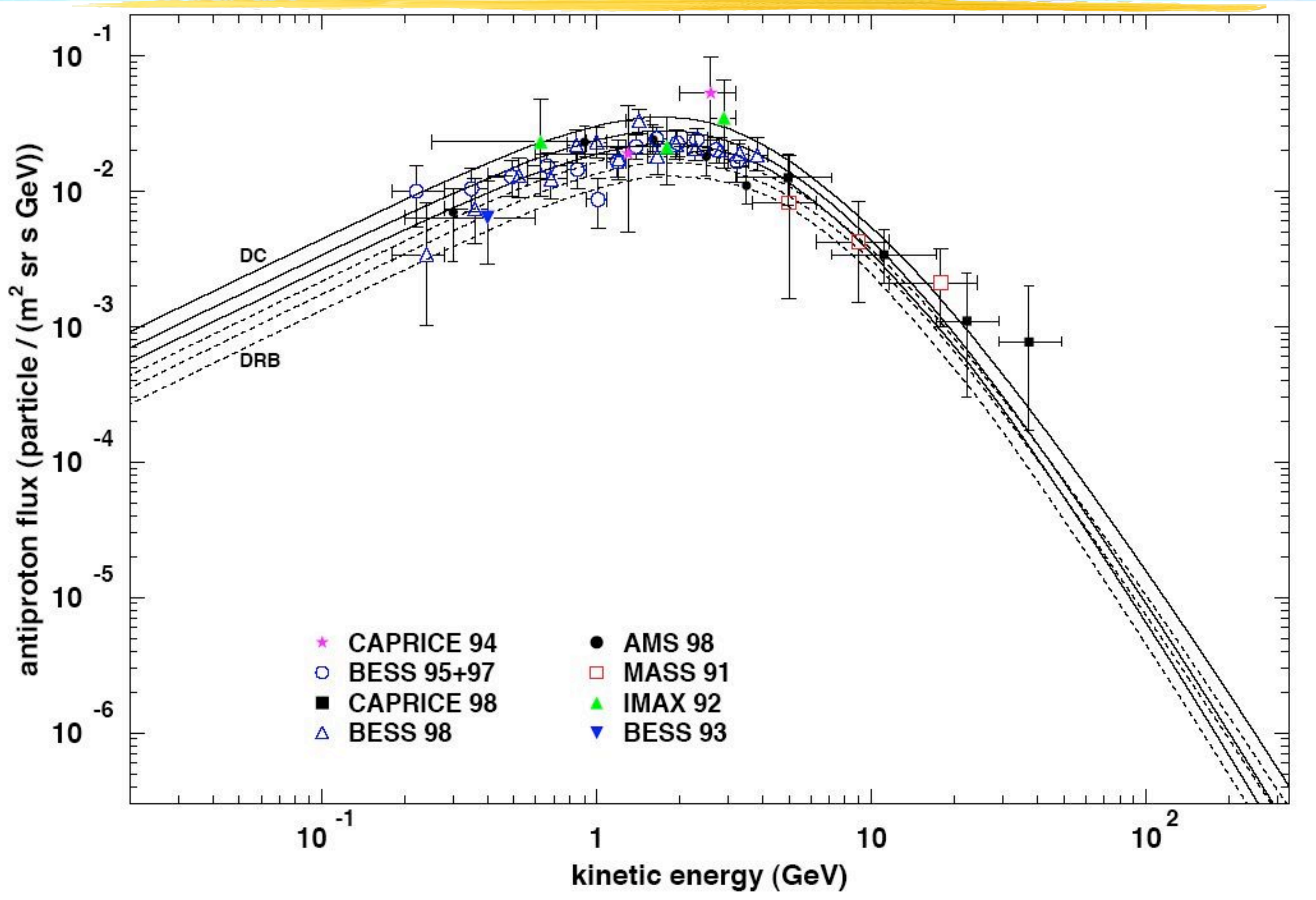
DC: diffusion+convection

In DC model problem with the ACE data at low energy

A.Lionetto, A.Morselli, V.Zdravkovic

JCAP09(2005)010 astro-ph/0502406

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



the future

PAMELA scientific program

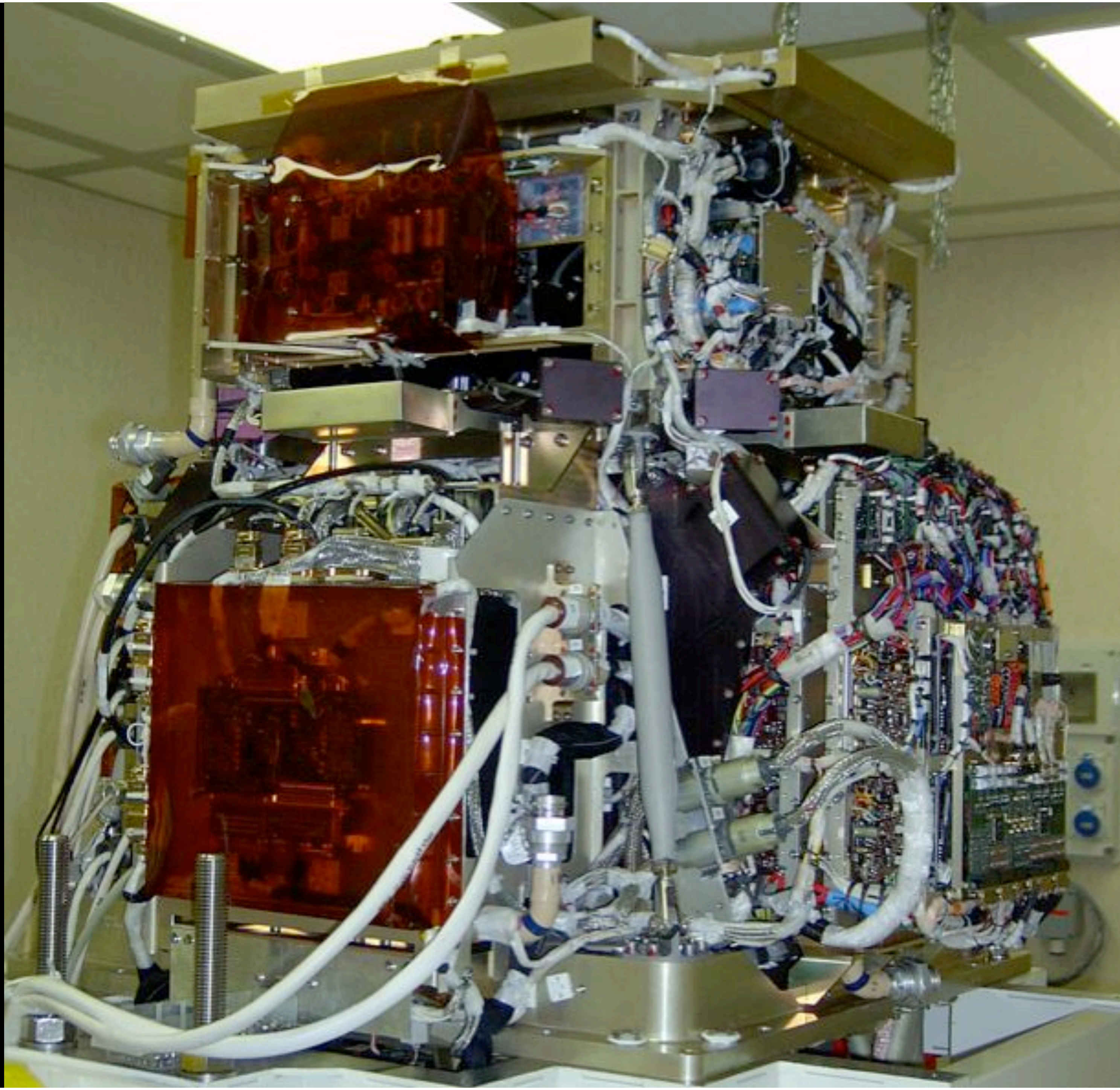
PAMELA is a magnetic spectrometer which will fly on a Russian satellite by Fall 2005. Its scientific scope is the measurement of the antiproton and positron spectra up to few hundred GeV, of the proton and electron spectra up to 700 GeV and that of light nuclei.

	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 He/He)	

→ Unprecedented Statistics and new Energy Range in Cosmic Rays

Actual limits: antip&positrons ≈ 40 GeV

Pamela
in Samara,
Russia
4/09/05



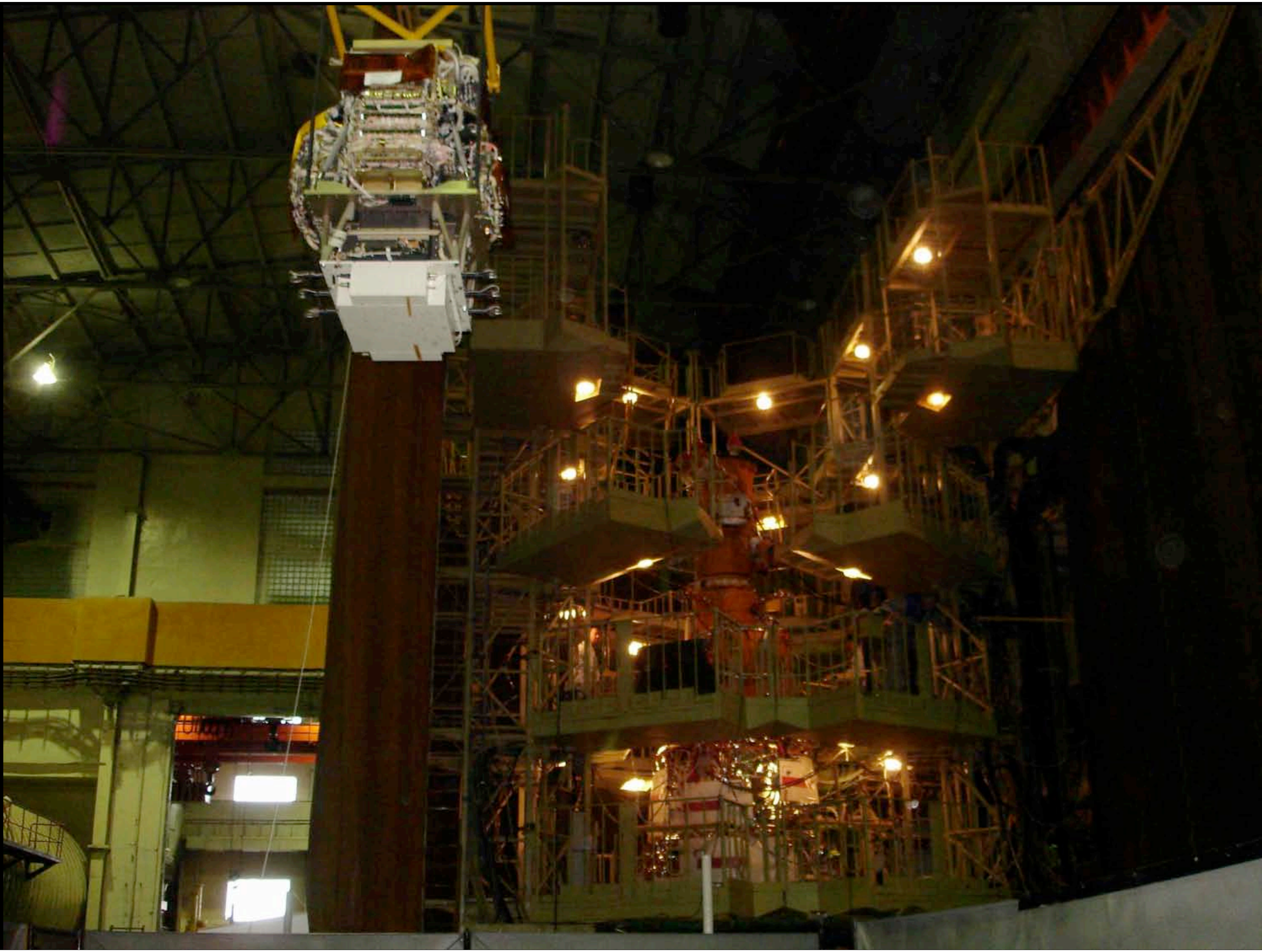
PAMELA @ Baikonur

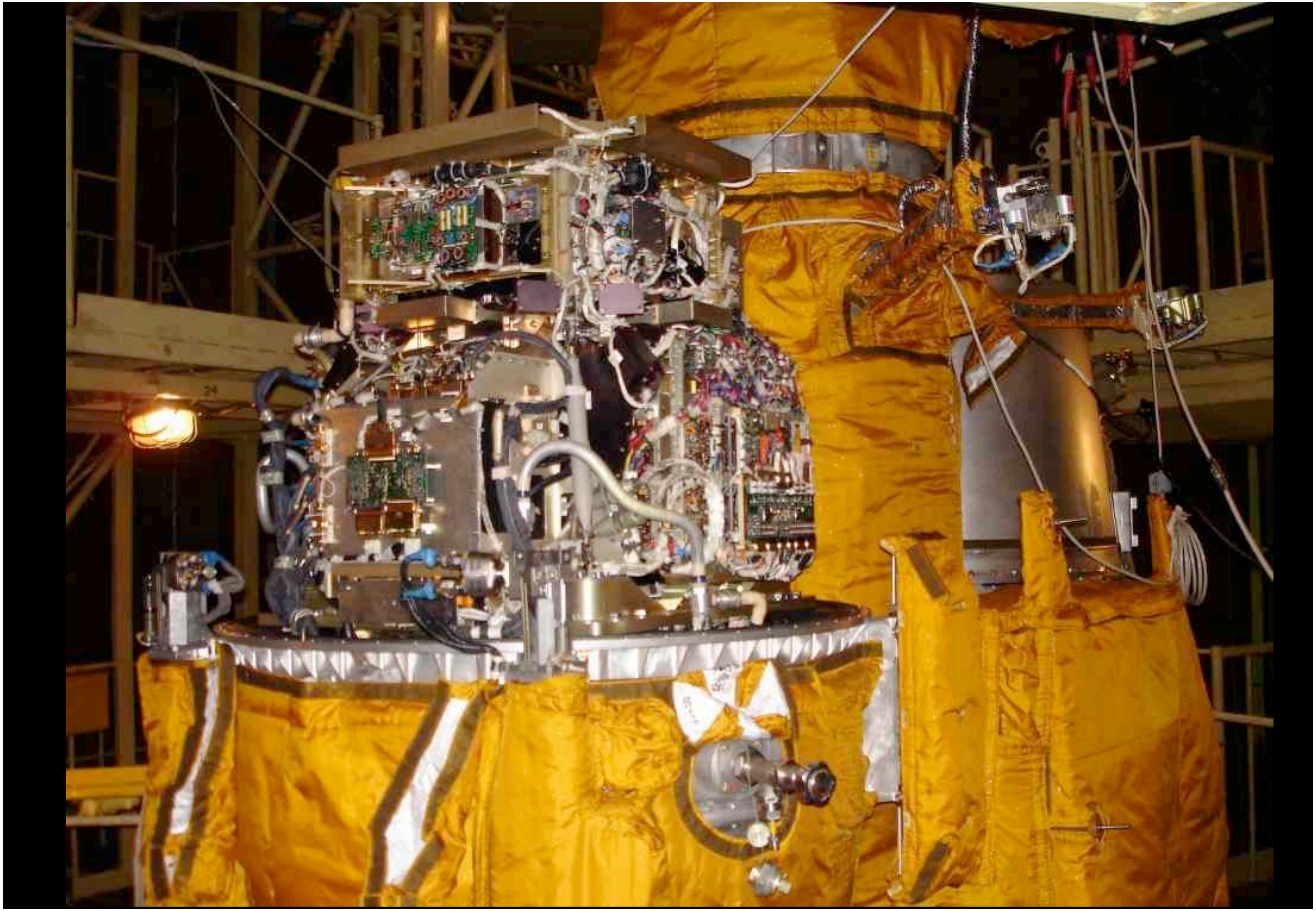
28/03/06

28/03/06

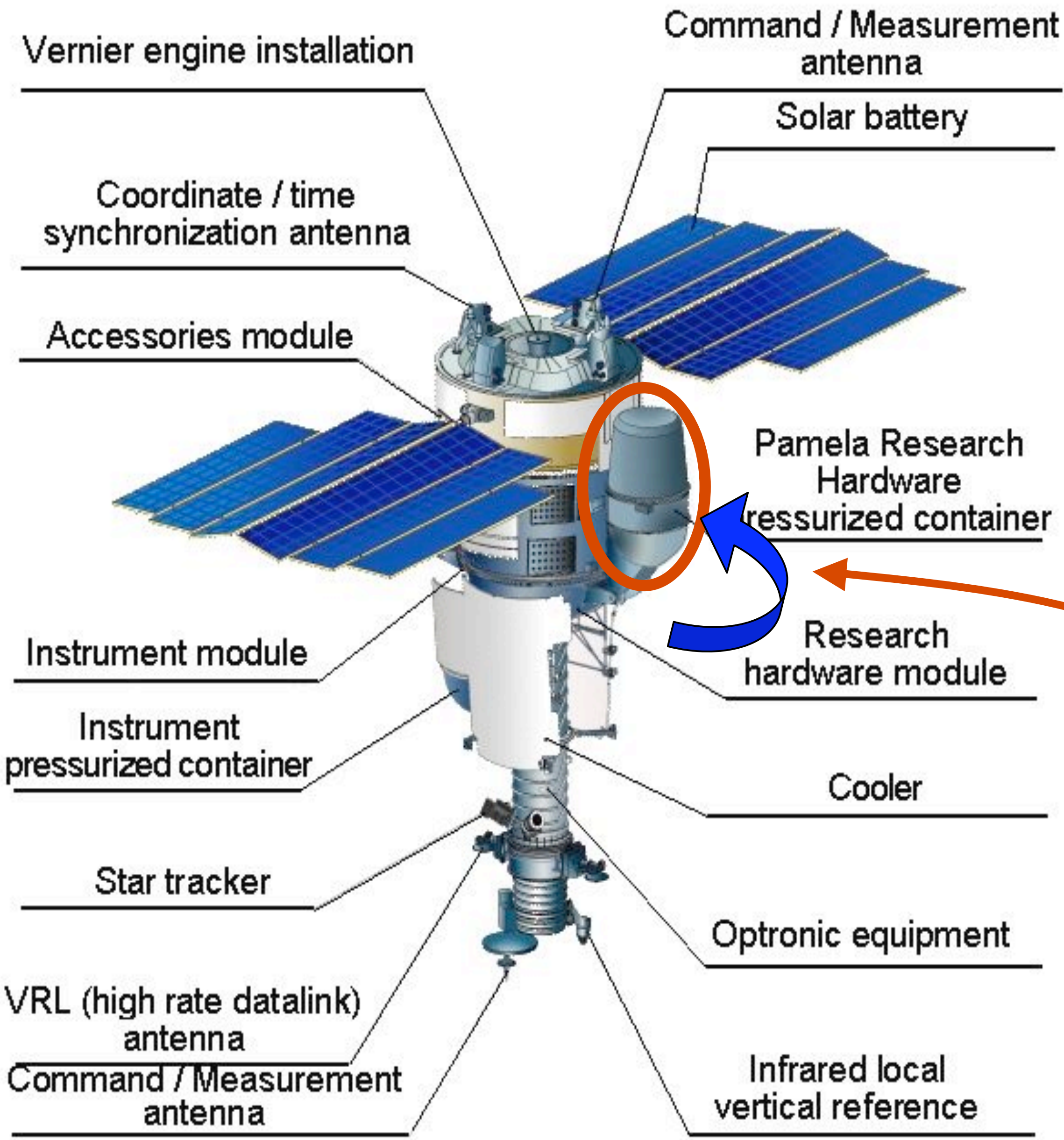
PAMELA @ Baikonur

RESURS DK1 Satellite

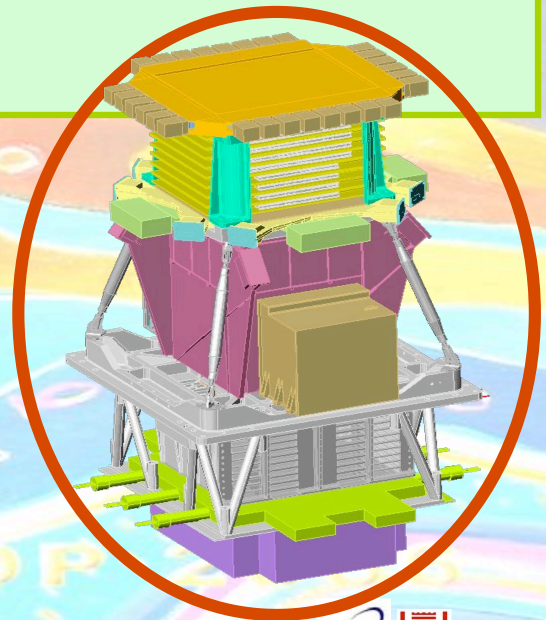




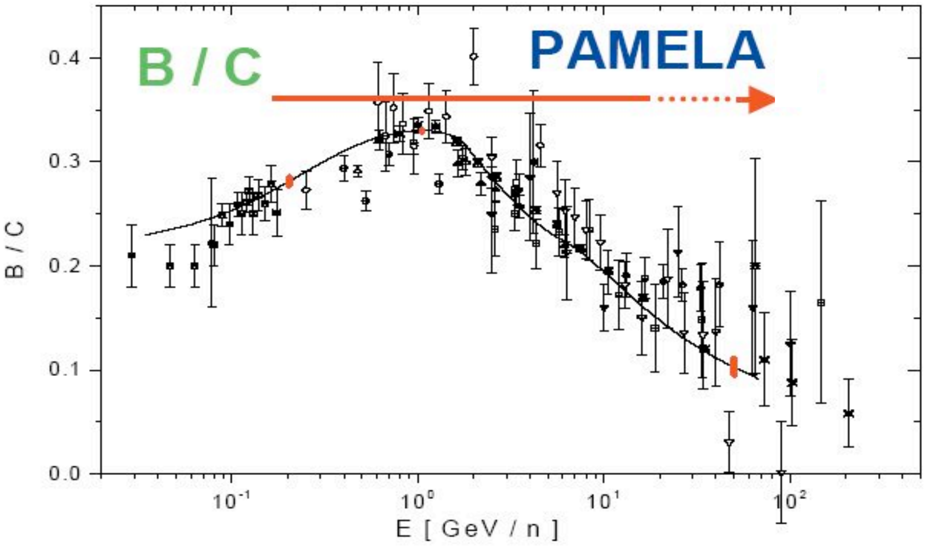
The Satellite: Resurs DK1

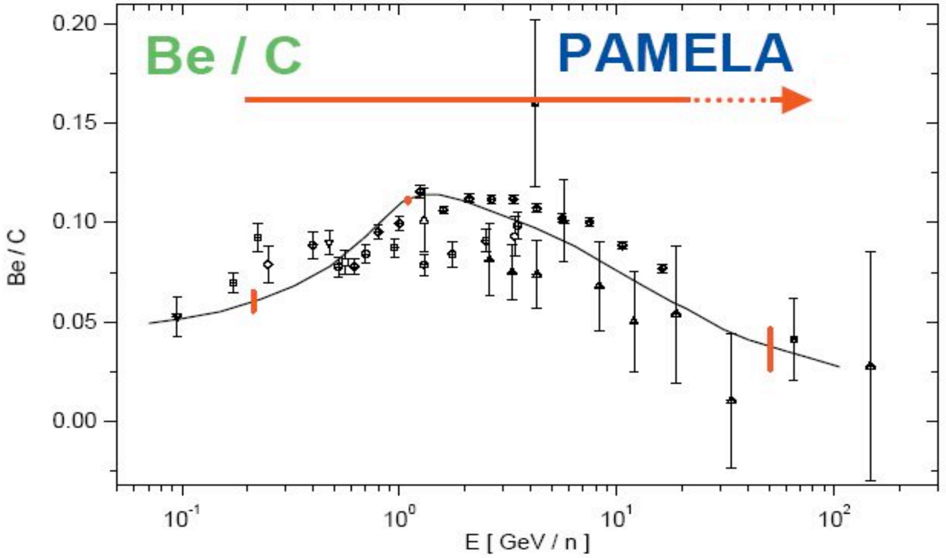


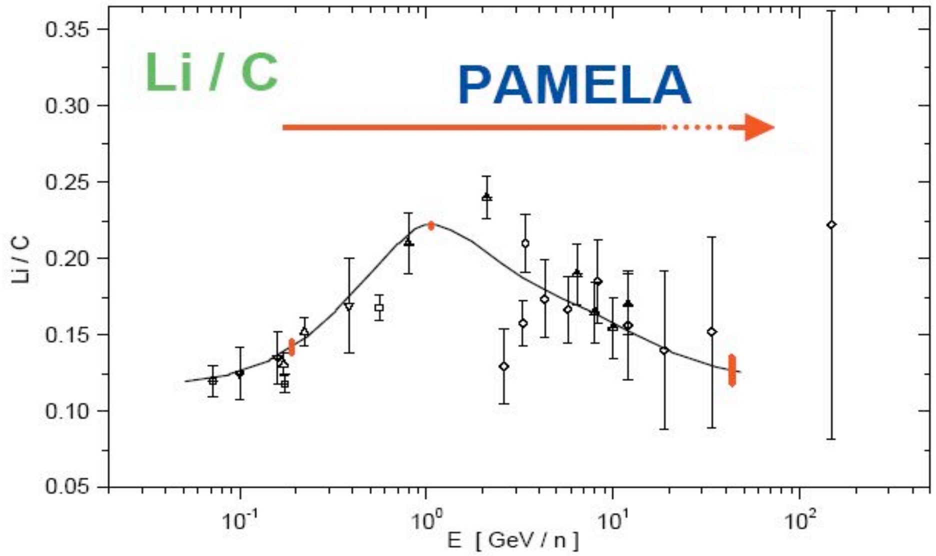
- Soyuz-TM Launcher from Baikonur
- Launch 14 June 2006
- Lifetime >3 years
- PAMELA mounted inside a Pressurized Container, attached to Satellite
- Earth-Observation-Satellite



Secondary to Primary ratios

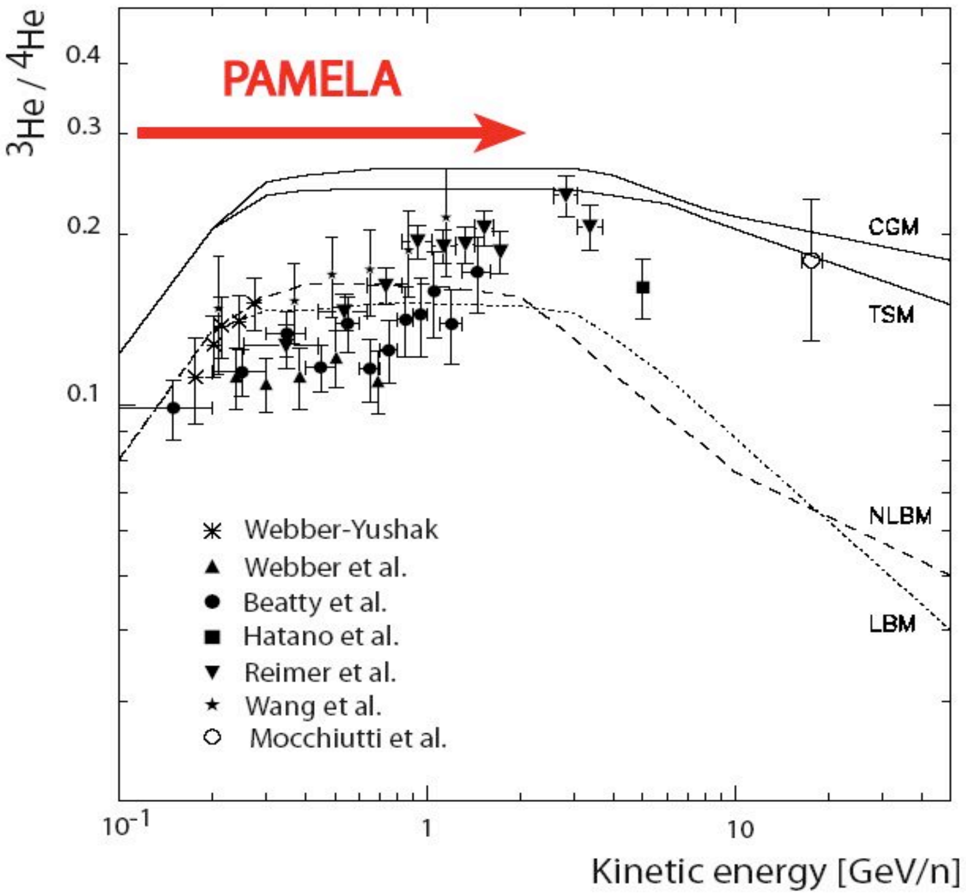




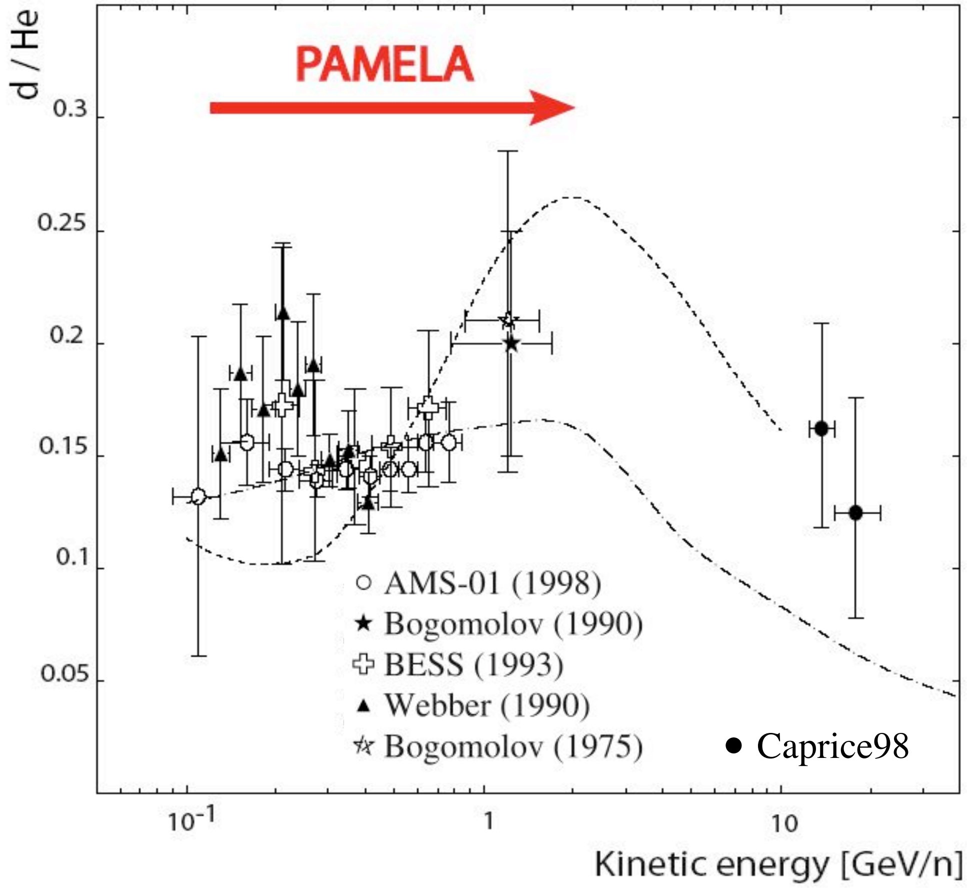


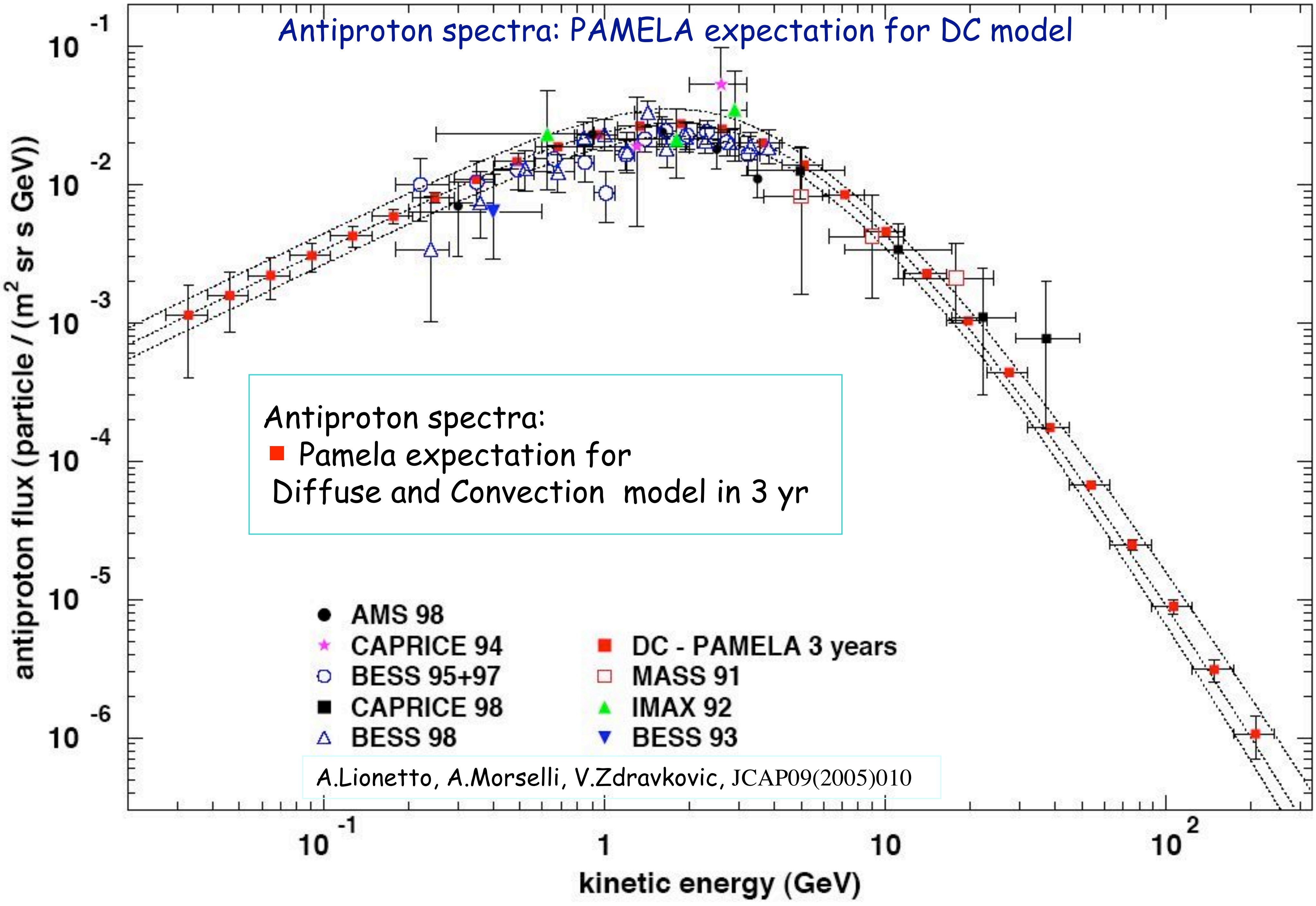
Helium and Hydrogen Isotopes

The current situation of the ^3He / ^4He ratio



The current situation of the d / He ratio

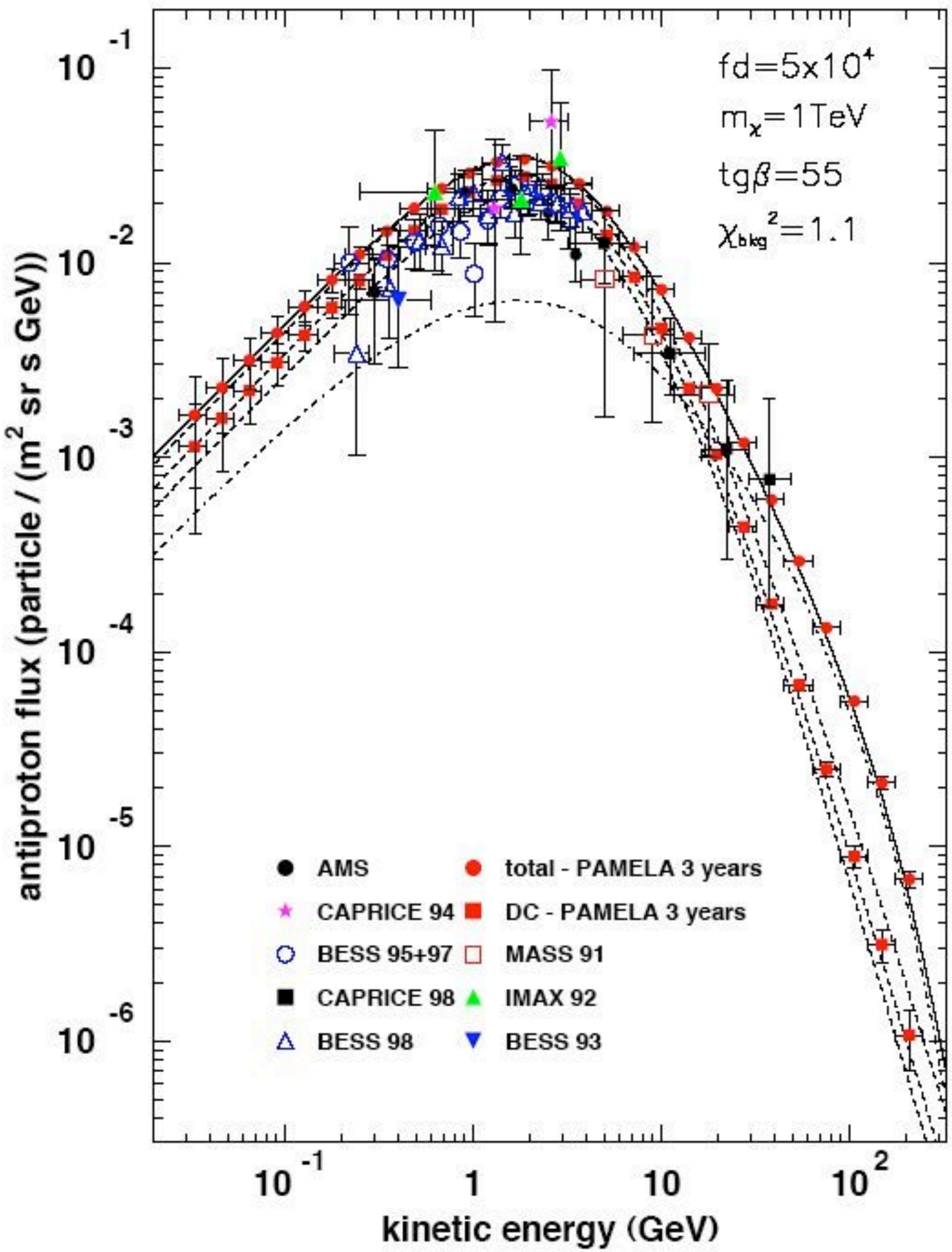




Antiproton spectra: PAMELA expectation for DC model
Antiproton spectra:
Pamela expectation for
Diffuse and Convection model in 3 yr
AMS 98
CAPRICE 94
BESS 95+97
CAPRICE 98
BESS 98
DC - PAMELA 3 years
MASS 91
IMAX 92
BESS 93
A.Lionetto, A.Morselli, V.Zdravkovic, JCAP09(2005)010
antiproton flux (particle / (m² sr s GeV))
kinetic energy (GeV)

PAMELA:

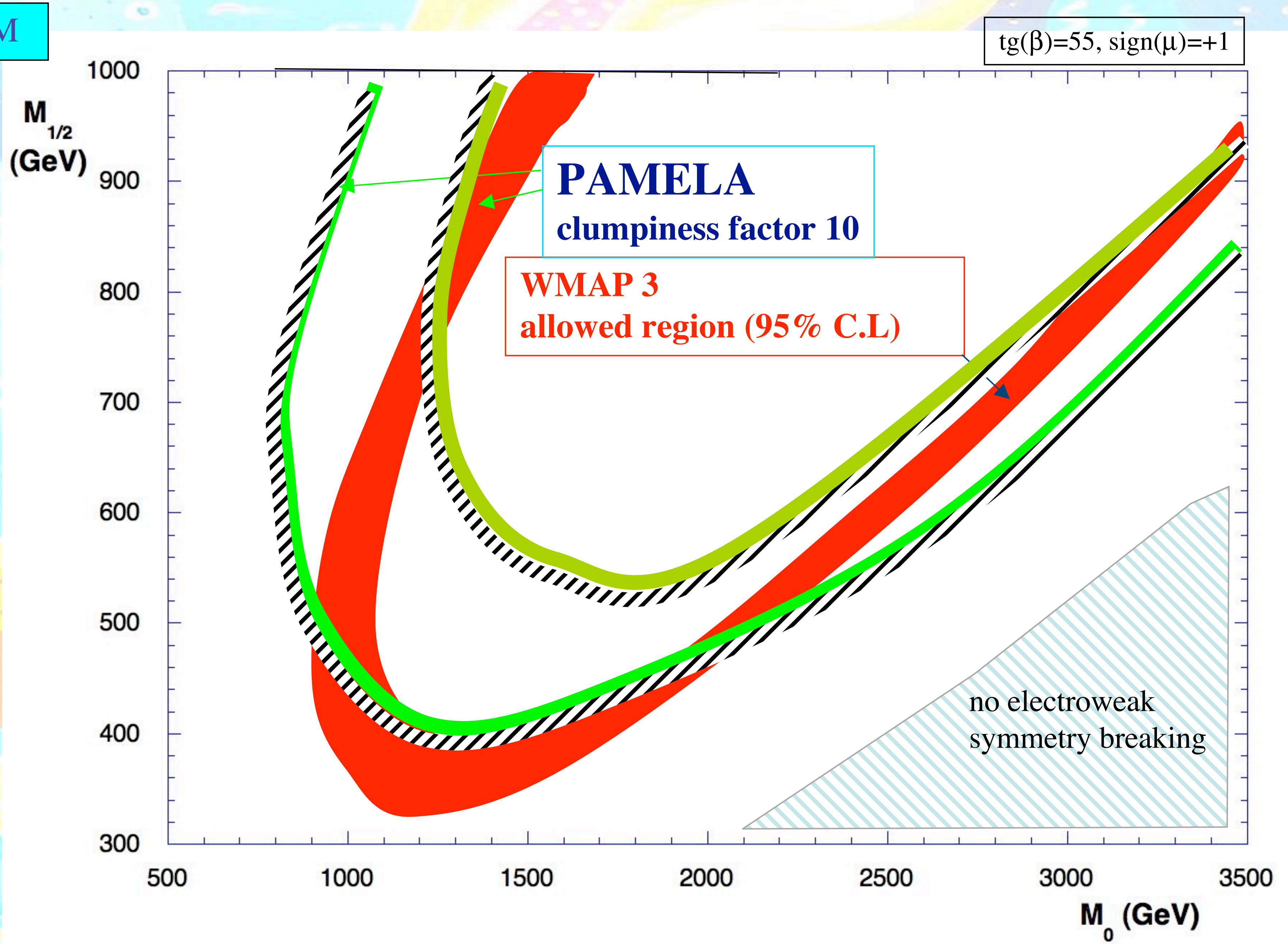
Cosmic-Ray Antiparticle Measurements: Antiprotons



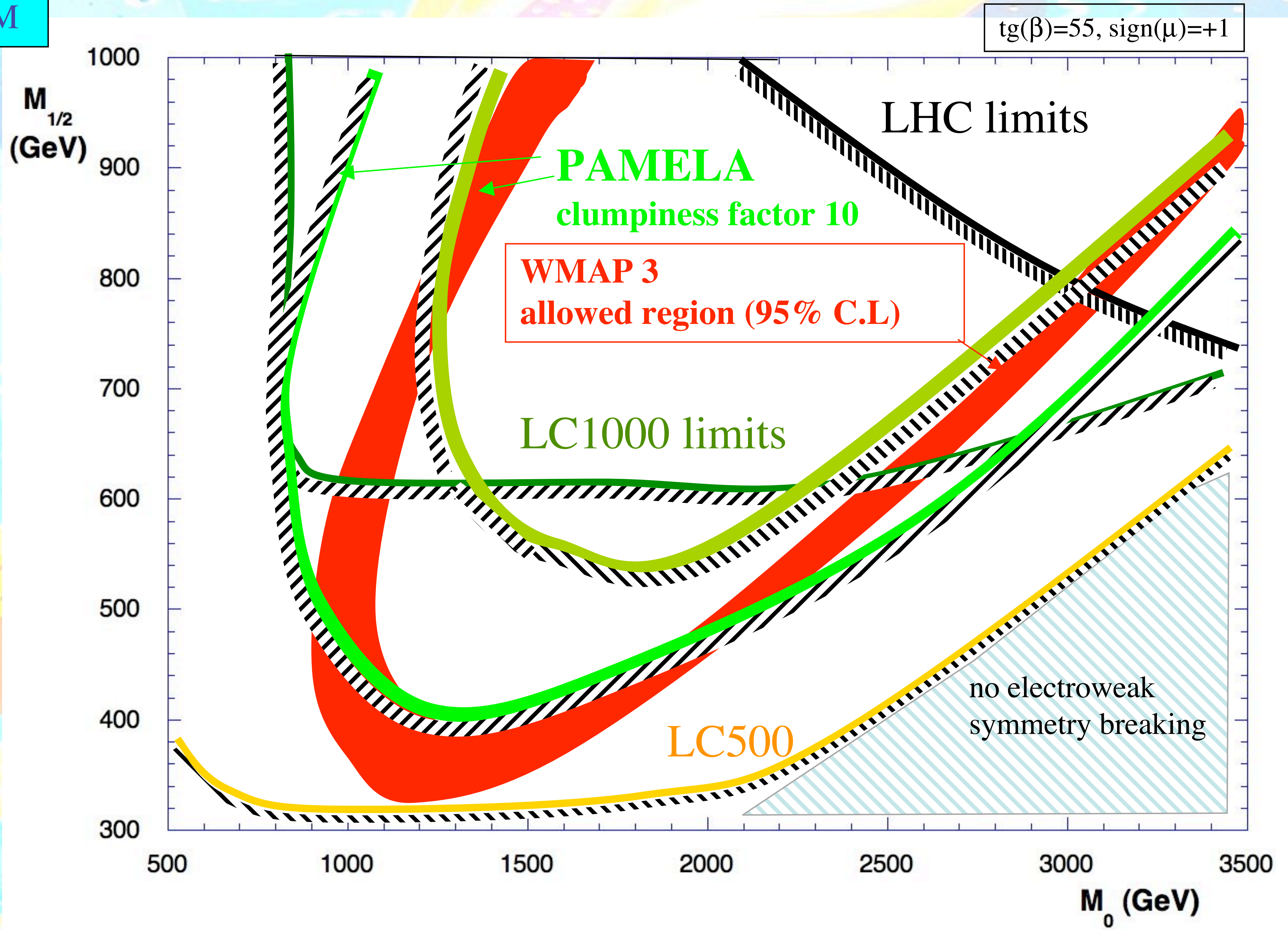
fd: Clumpiness factors needed to disentangle a neutralino induced component in the antiproton flux

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

cMSSM


tg(β)=55, sign(μ)=+1
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

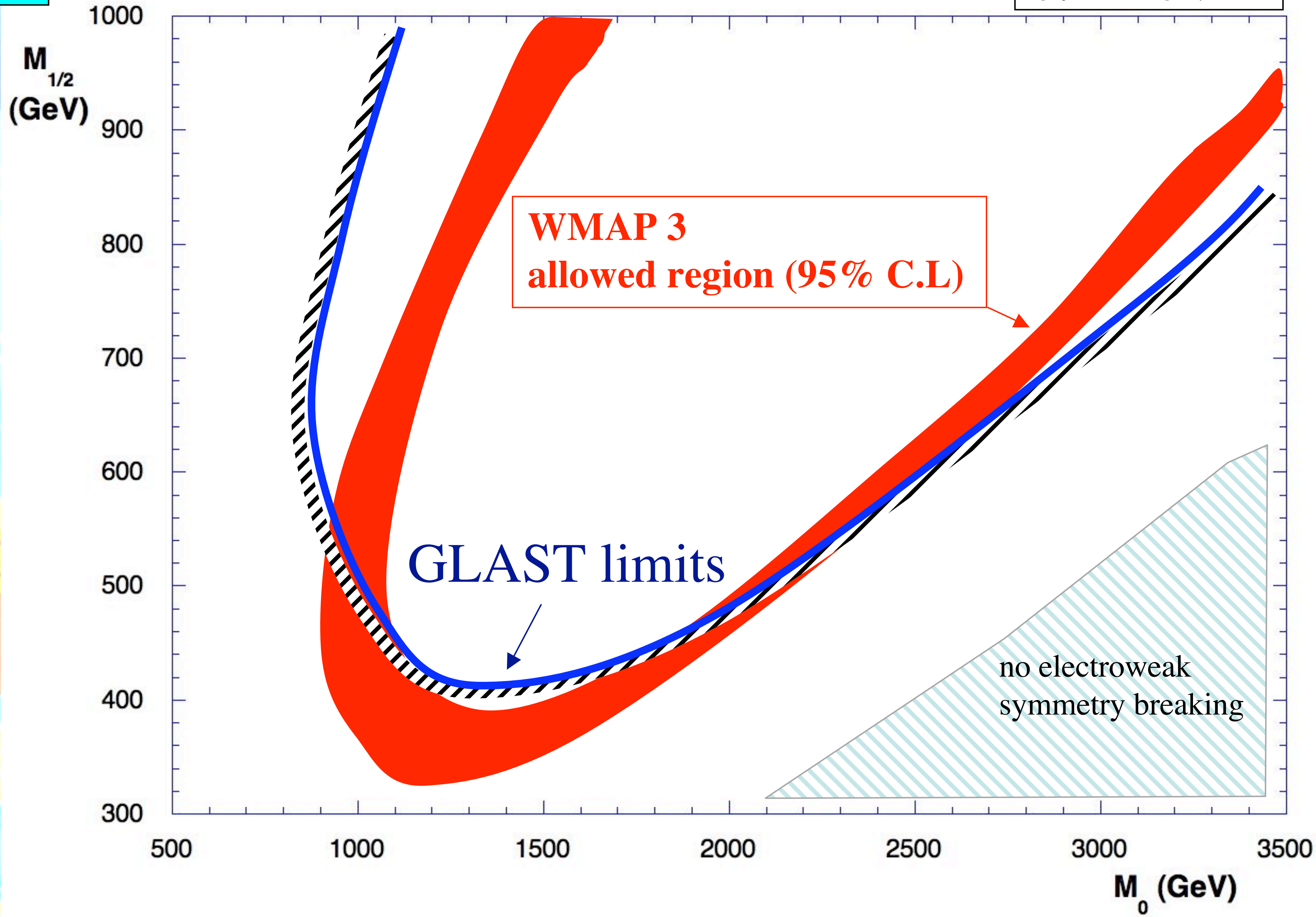
cMSSM


tg(β)=55, sign(μ)=+1
M1/2 (GeV)
1000
900
800
700
600
500
400
300
500
1000
1500
2000
2500
3000
3500
M0 (GeV)
LHC limits
PAMELA
clumpiness factor 10
WMAP 3
allowed region (95% C.L)
LC1000 limits
LC500
no electroweak
symmetry breaking

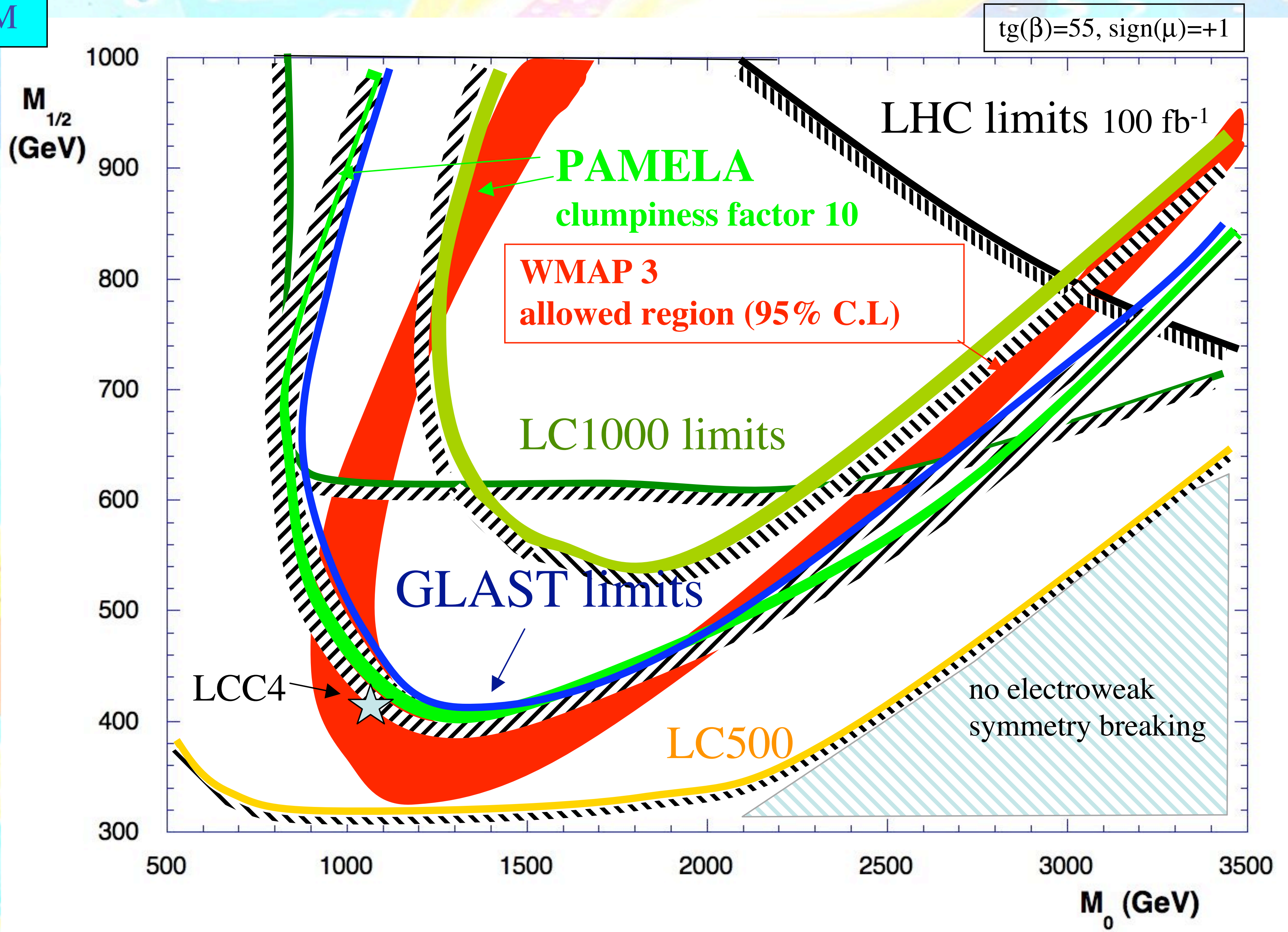
cMSSM

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

tg(β)=55, sign(μ)=+1



cMSSM



tg(β)=55, sign(μ)=+1
LHC limits 100 fb-1
PAMELA
clumpiness factor 10
WMAP 3
allowed region (95% C.L)
LC1000 limits
GLAST limits
LCC4
LC500
no electroweak
symmetry breaking
M1/2 (GeV)
M0 (GeV)
1000
900
800
700
600
500
400
300
500
1000
1500
2000
2500
3000
3500

Conclusion

Caprice98: **first result on the deuterium flux above 2 GeV/n**

- PAMELA : much more precise measurements.
- Will give strong constraints on propagation parameters.

Discovery Potential for Supersymmetry

PAMELA : **Launch 14 June 2006**

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GLAST Schedule

- **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

PAMELA will be very useful for the background model of GLAST

thank you !!

LAUNCH

•November 2007

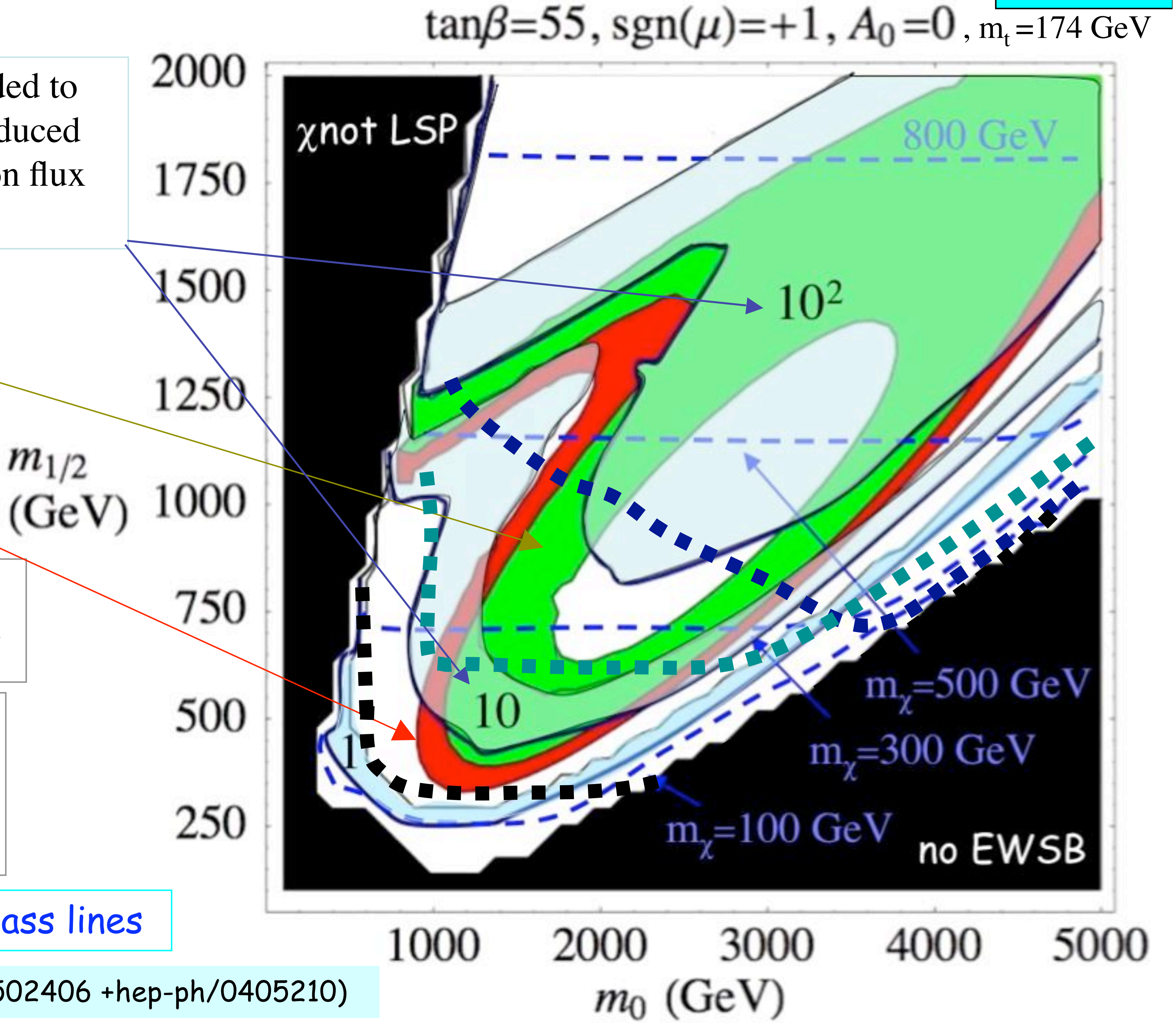
Science operation begins!

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

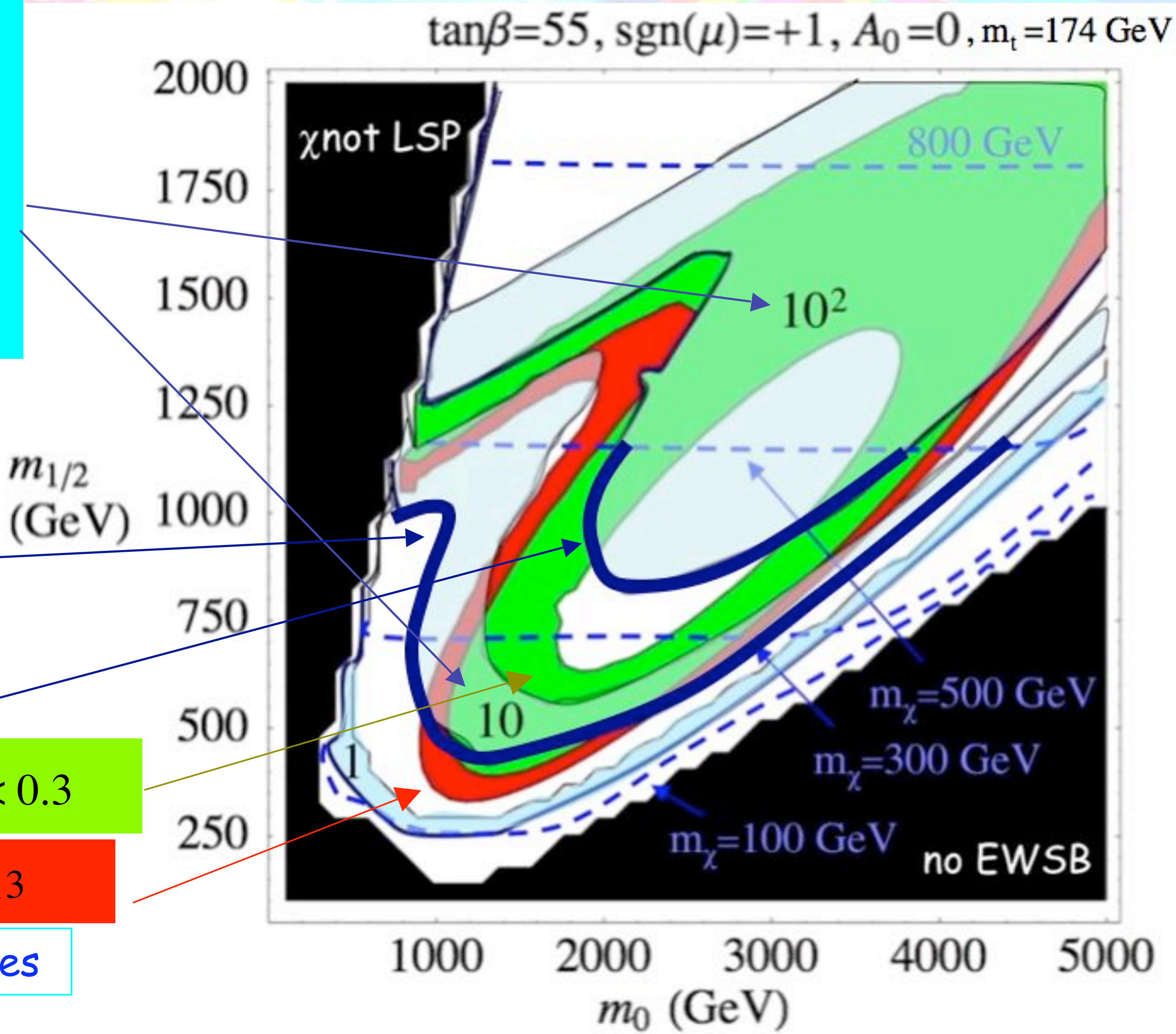
GLAST sensitivity (5 σ) for a neutralino density Nχ of 10^4 NFW in a $\Delta\Omega=10^{-5}$ sr region around the galactic center

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

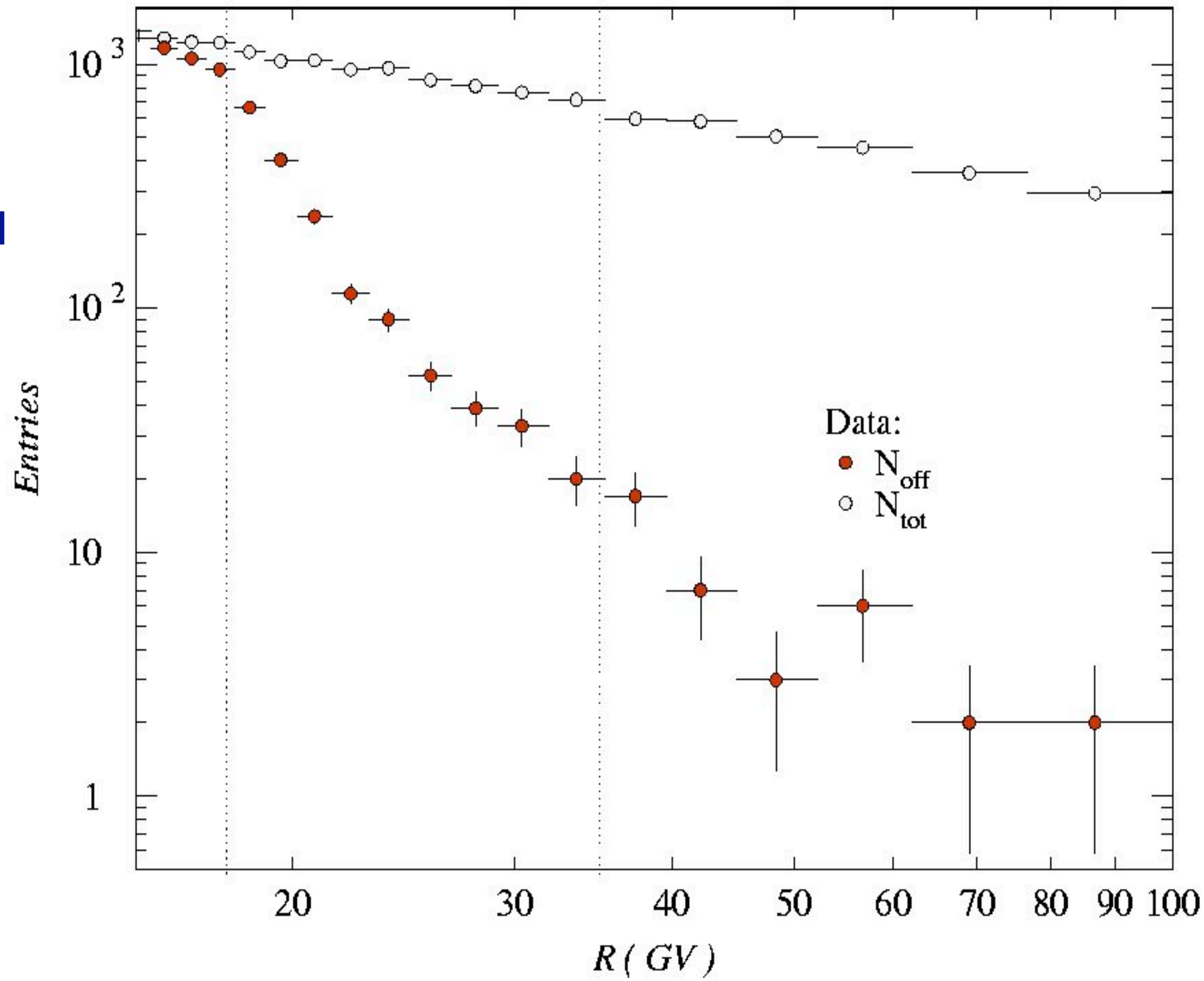


astro-ph/0502406 and astro-ph/0305075

Deuteron selection

Deuterons selected out of singly charged particles by requiring:

- **No Cherenkov signal in the RICH**



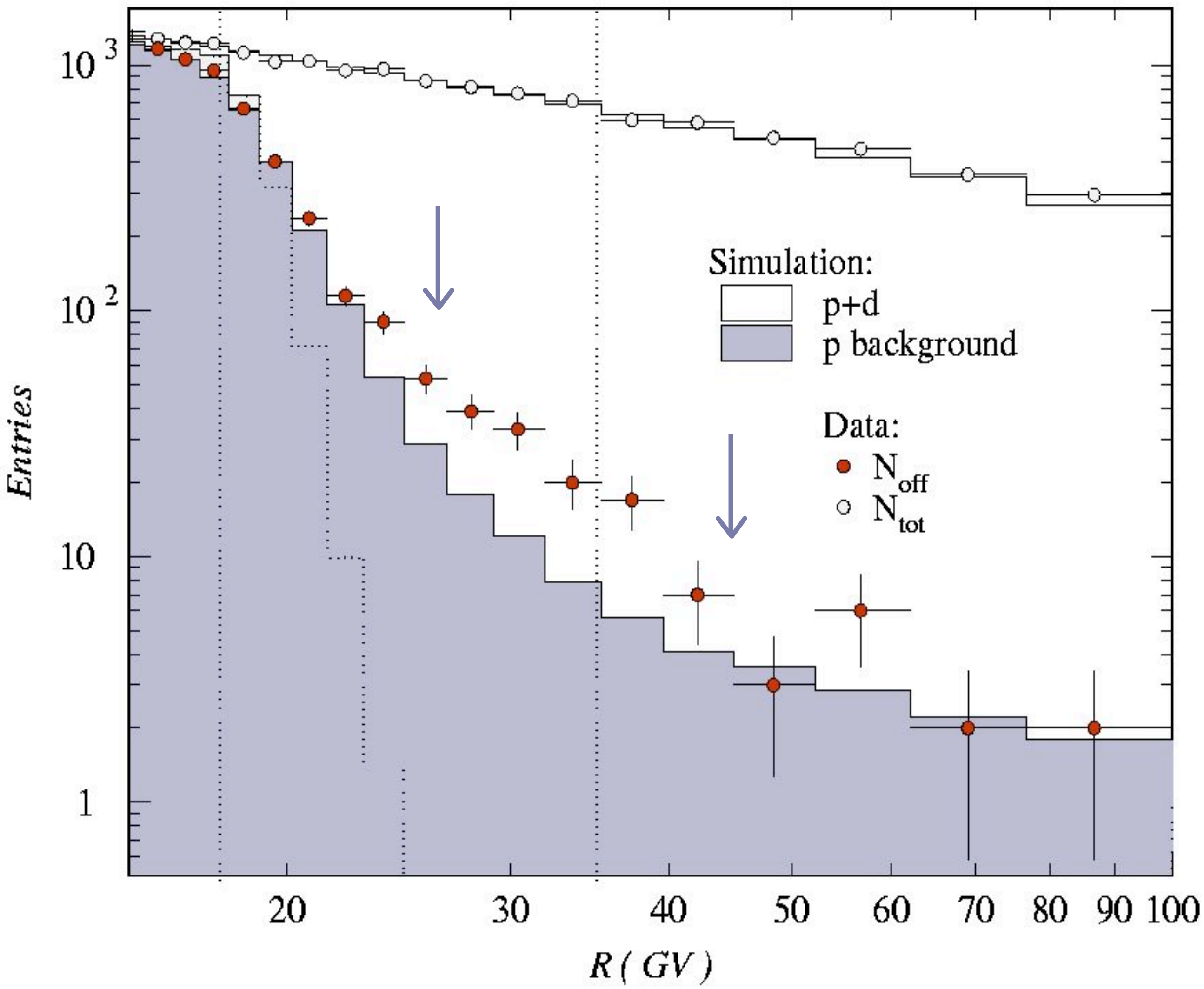
Deuteron selection

Proton background distribution and deuteron selection efficiency estimated with Monte Carlo technique.

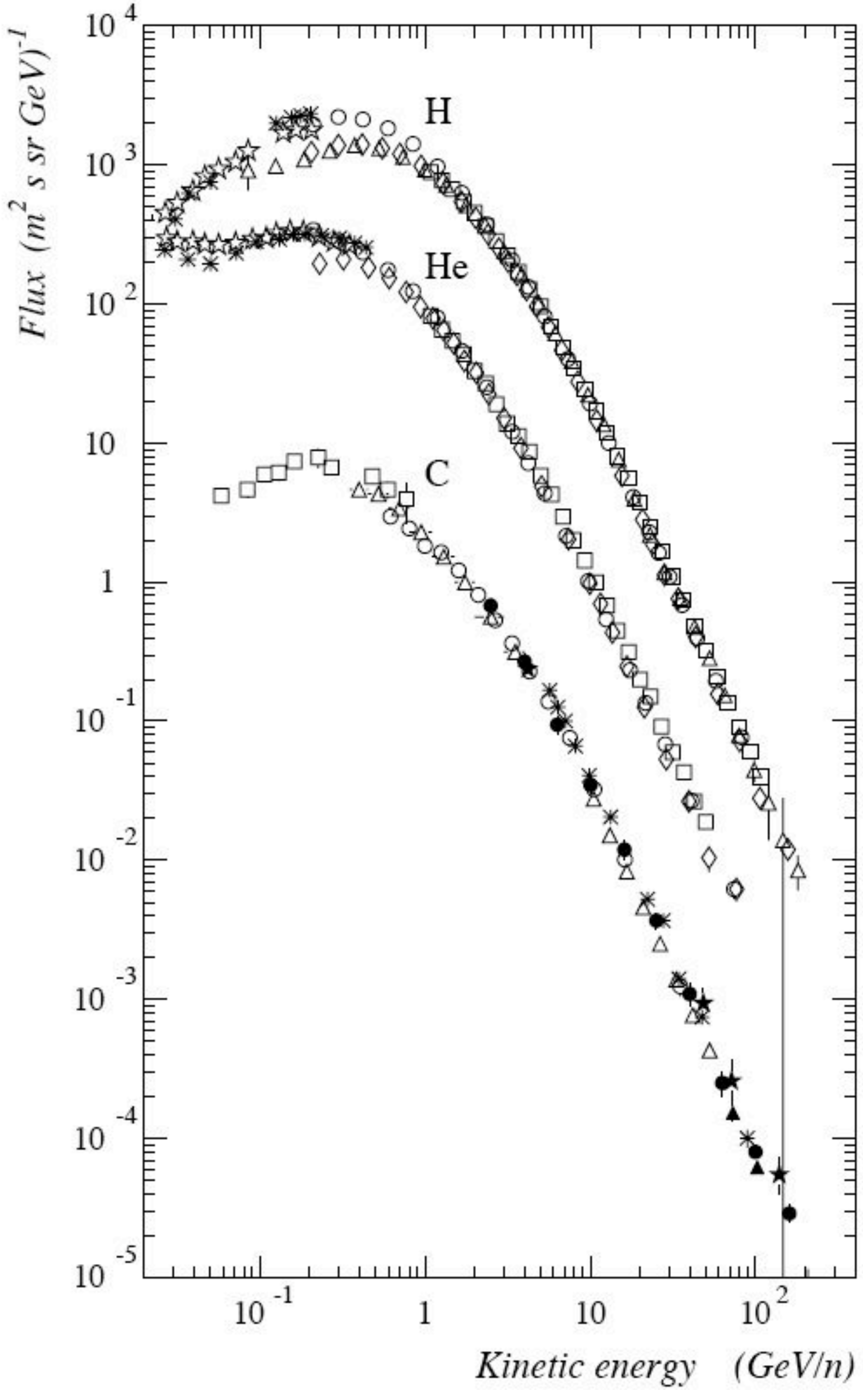
Simulation based on characteristic functions derived form experimental data:

High-energy Spectrometer Resolution Function → SRF

Probability of having no Cherenkov signal → P_{0ff} (β)



the differential energy spectra of cosmic-ray proton, helium and carbon as measured on Earth at the minimum solar modulation level



The WiZard/CAPRICE98 experiment

(Cosmic AntiProton Ring-Imaging Cherenkov Experiment)

- Launched on May 28 1998

  Fort Sumner (New Mexico) → Holbroke (Arizona)
- Flight duration: 24h @ 36Km (~5.5g/cm^2)
- Geomagnetic cutoff ~4.3 GV

Number of detected deuterons

Rigidity (GV)	28-32	32-45
N_{tot}	1578	1894
N_{off}	72	44
BK	~30	~18
N_d	~46	~47
N_d/N_p	~2.75%	

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The CAPRICE98 apparatus

- **Time-Of-Flight system**

  (230 ps)

- **Spectrometer**

  * Drift chamber tracking system

  (18+12 position measurements
  with ~100 μm resolution)

  * Superconducting magnet

  (0.1-1.8 T)

  →MDR ~ 400GV

- **Silicon-Tungsten calorimeter**

  (7.2 X_0 and 0.33 λ_0)

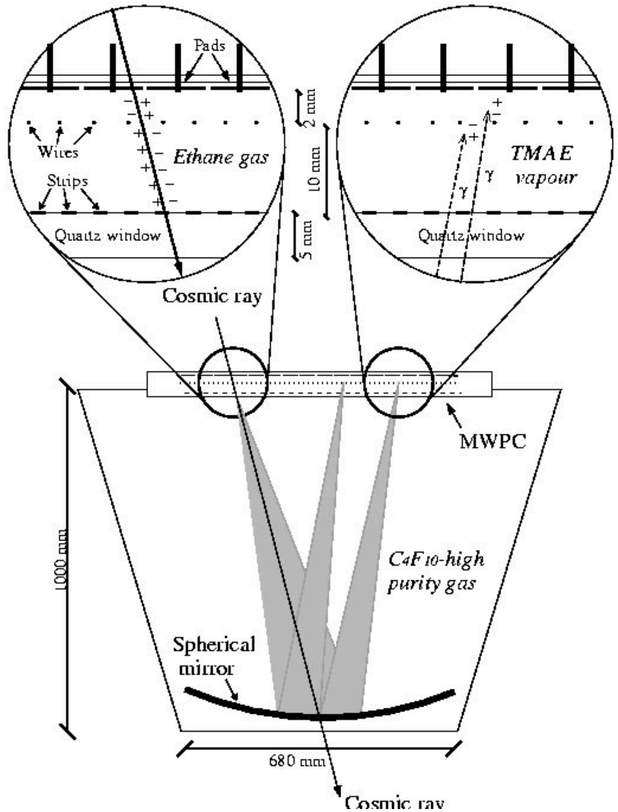
- **Gas-RICH detector**

  * C_4F_{10} radiator ~1m

  (n~1.0014 @ flight)

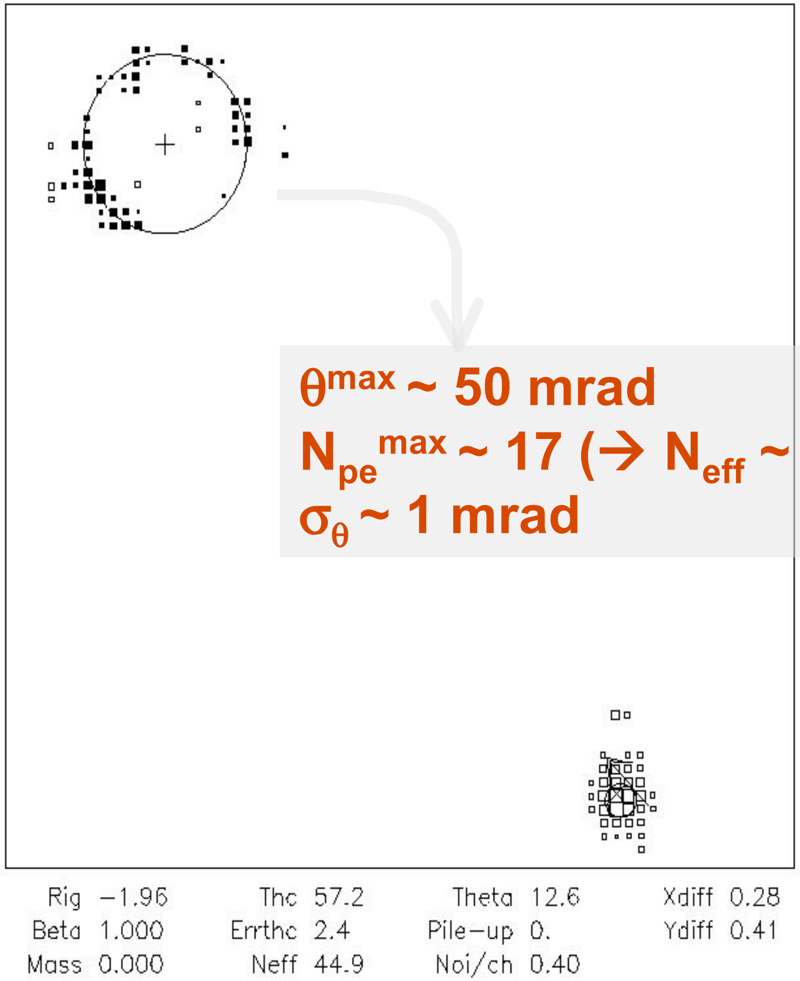
  * MWPC ethane + TMAE

  (N_0~60 cm^{-1} @ flight)

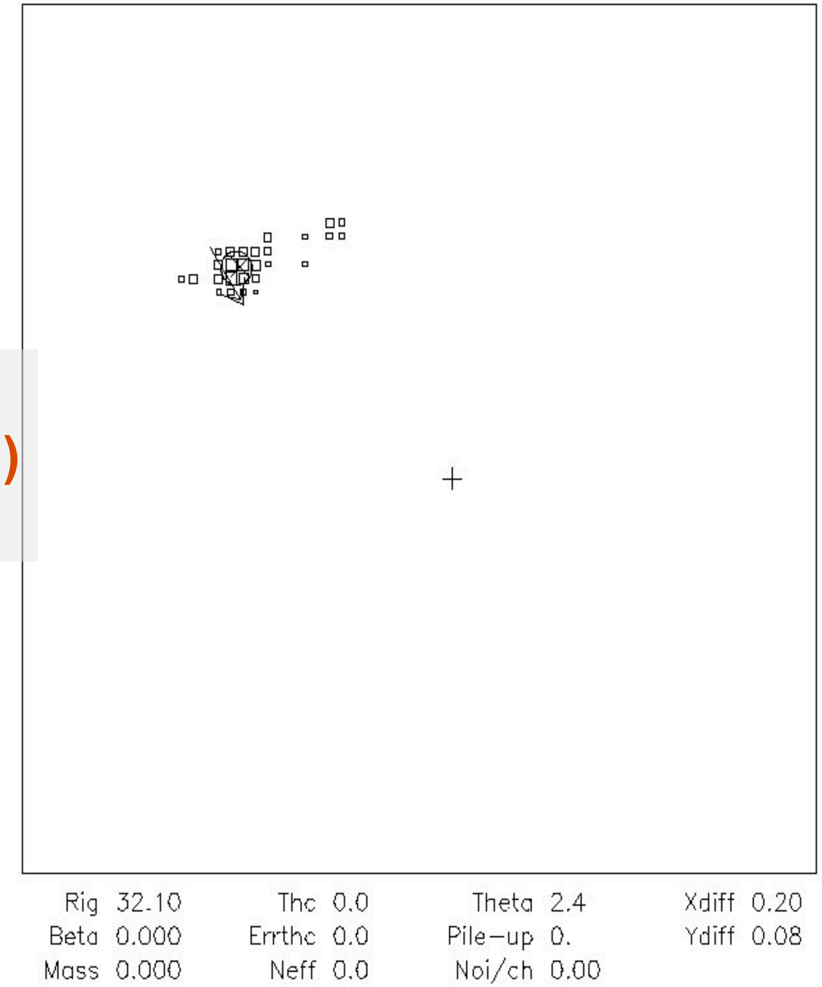


Cherenkov threshold rigidity:
- Muons → ~2 GV
- Protons → ~18 GV
- Deuterons → ~35 GV

Event topology in the RICH



θ^{max} ~ 50 mrad
N_{pe}^{max} ~ 17 (→ N_{eff} ~ 41)
σ_θ ~ 1 mrad



Relativistic electron (R~2 GV)

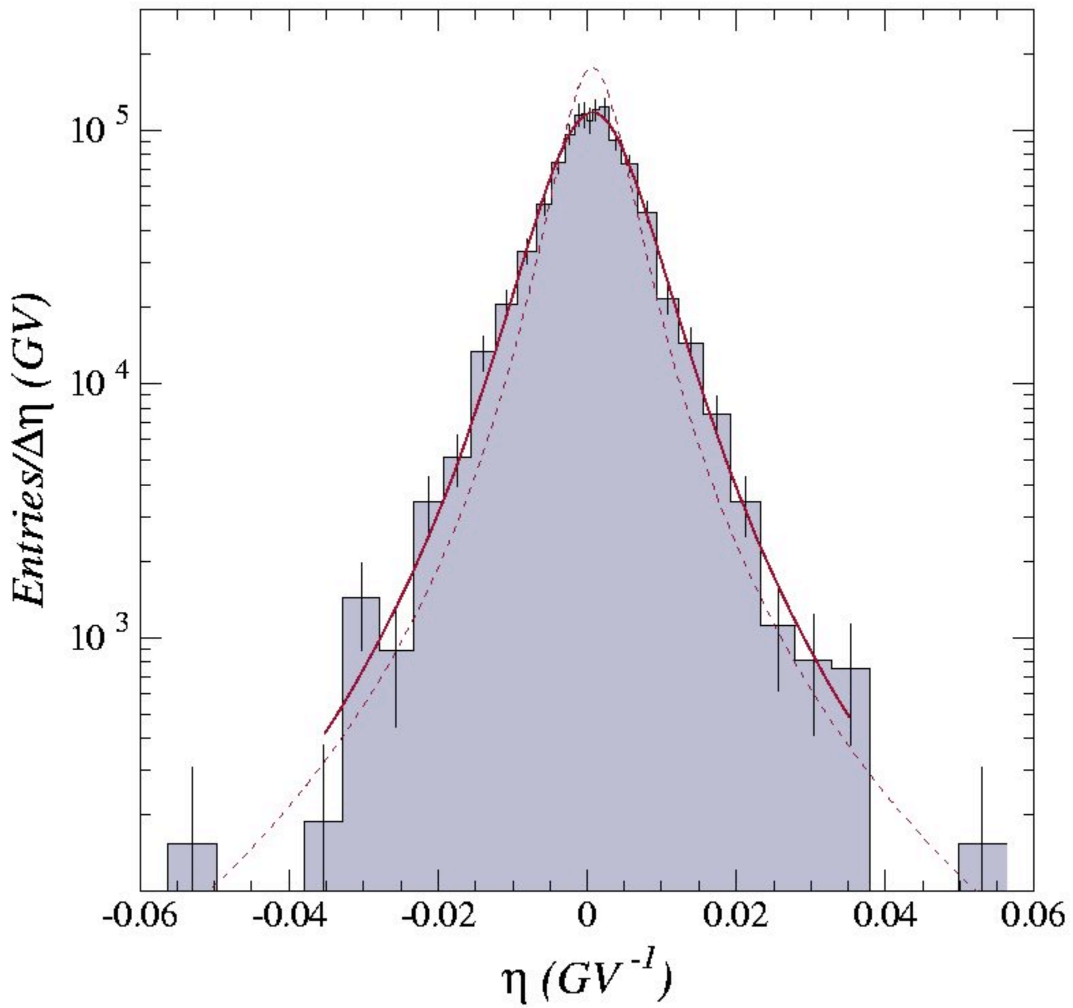
Z=1 particle (R~32 GV)
→ candidate deuteron

SRF → Magnet-off method

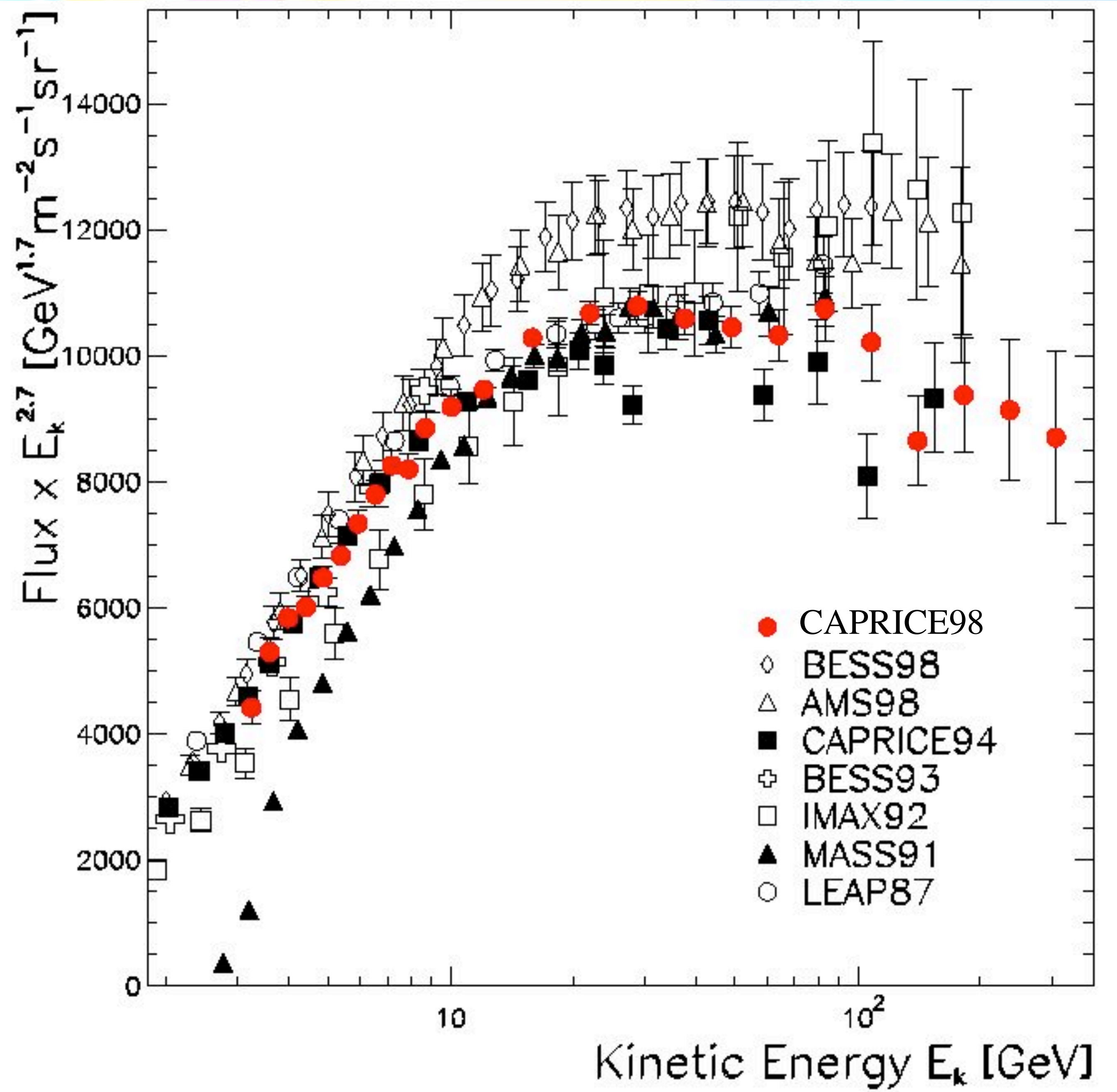
- SRF evaluated from relativistic (R>5 GV) ground muons collected with magnet off
→ straight tracks (η=0)

***

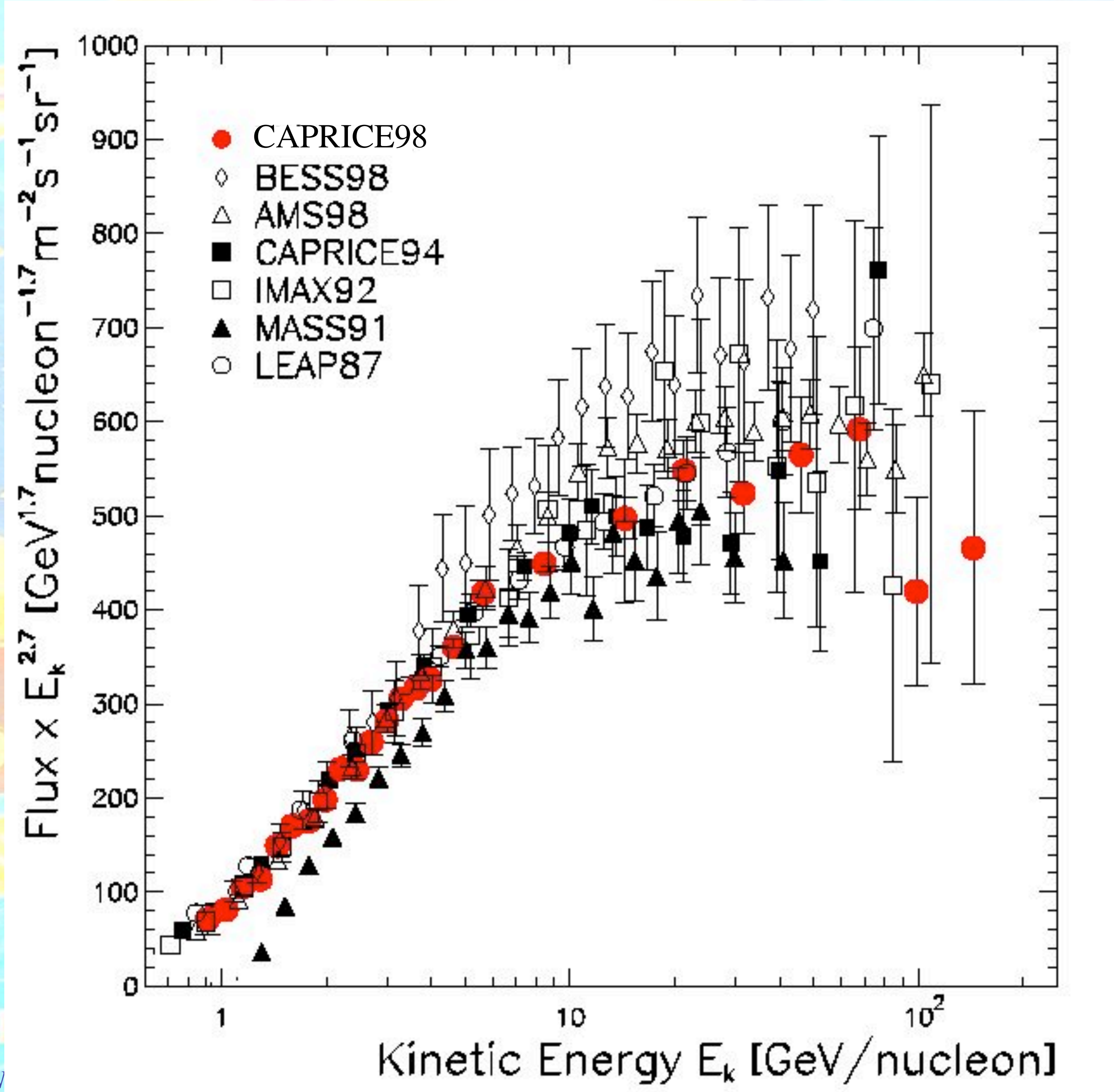
Deflection distribution corrected for the residual multiple-scattering effect



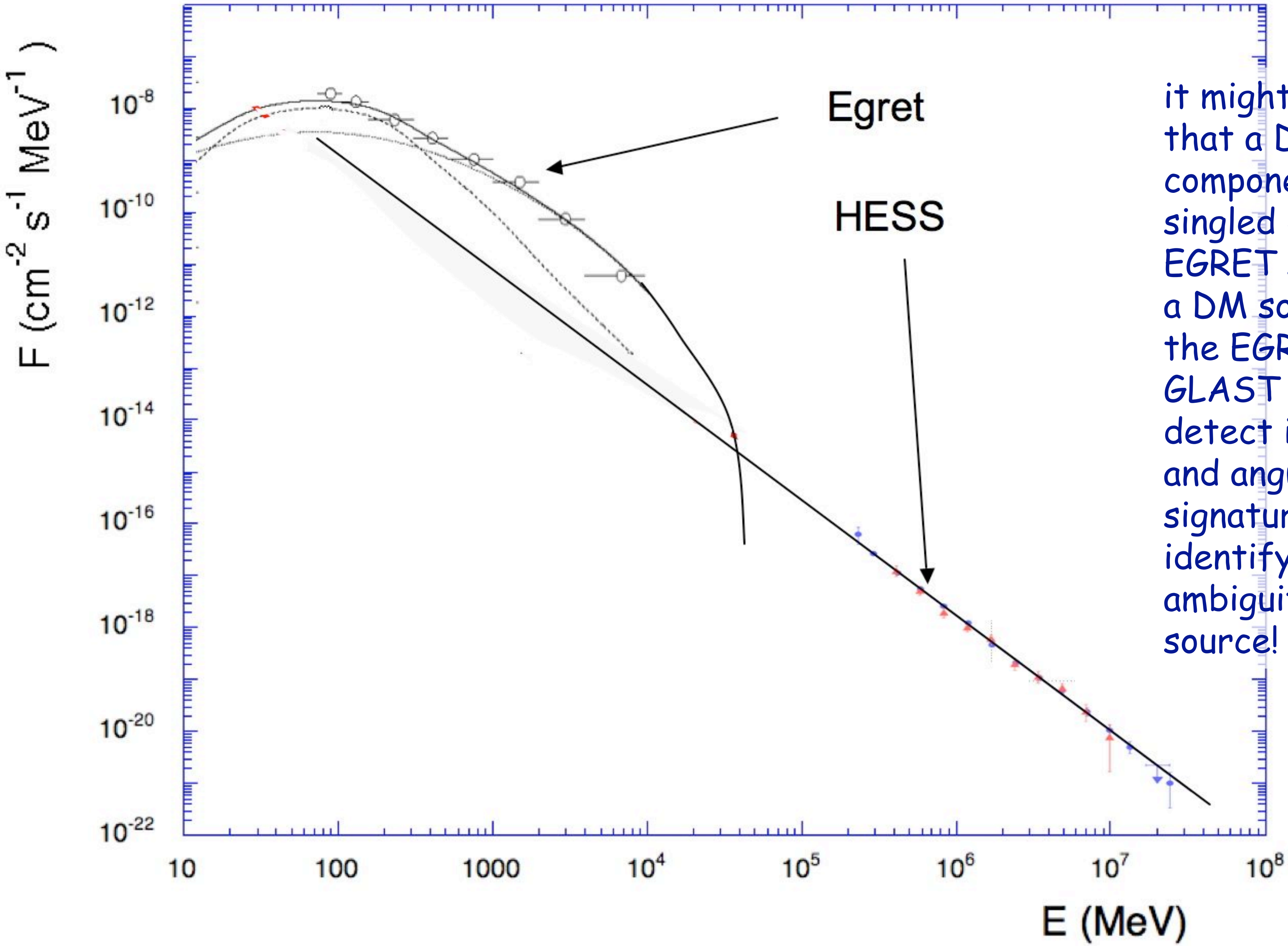
Proton energy spectrum at the top of atmosphere



The helium energy spectrum at the top of atmosphere

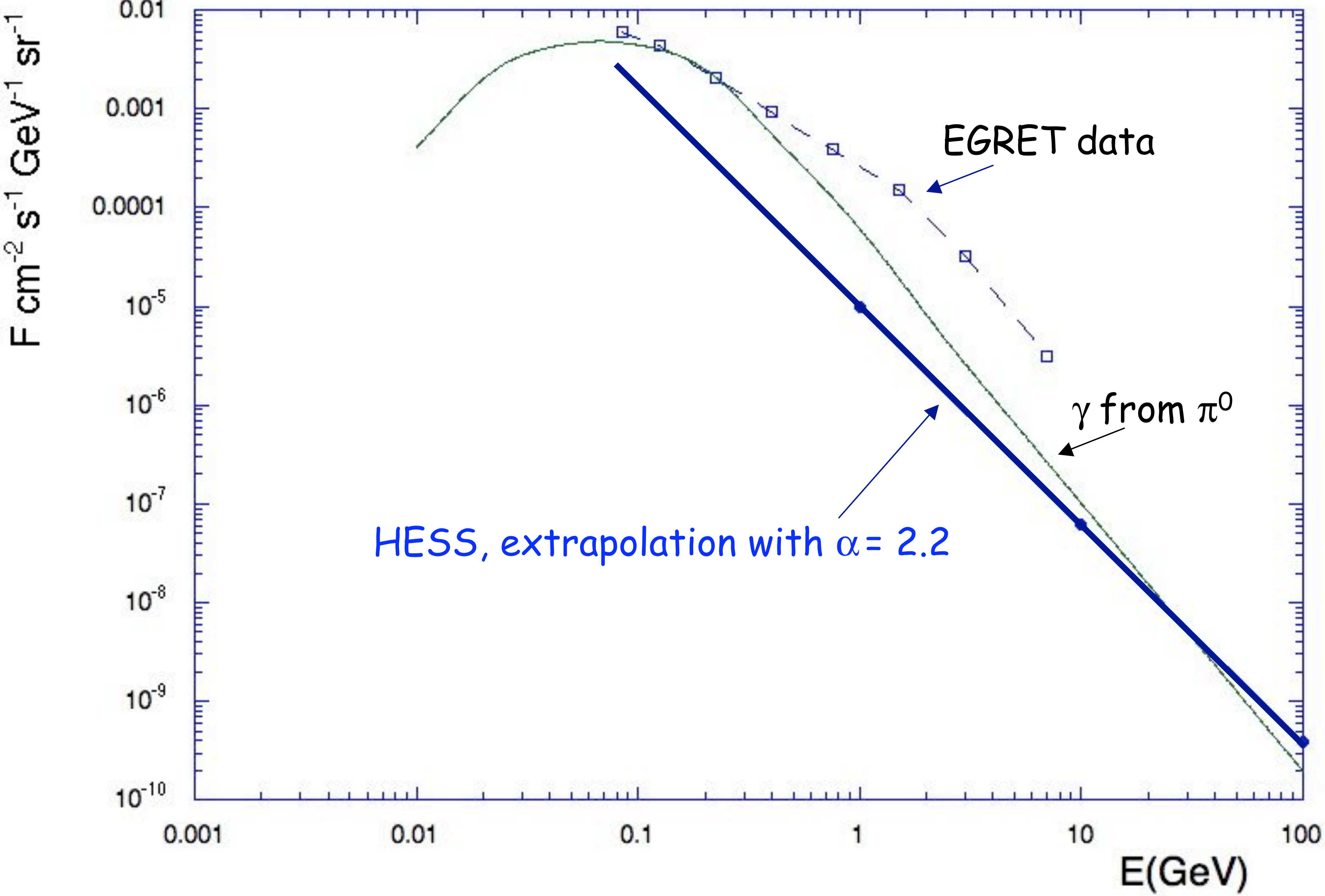


EGRET, GLAST, HESS



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!

EGRET, GLAST, HESS



Estimated reaches with Pamela

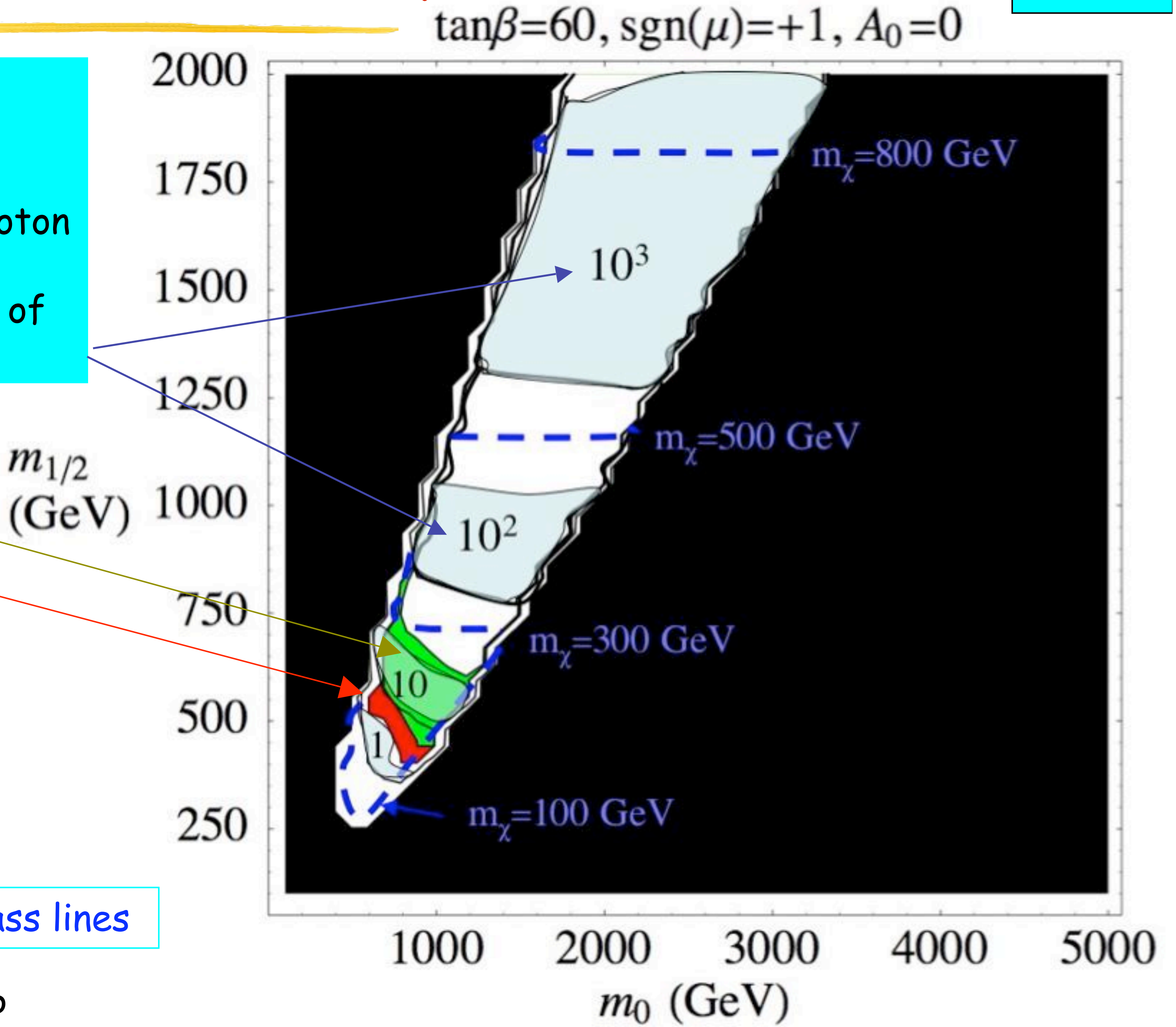
MSSM

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

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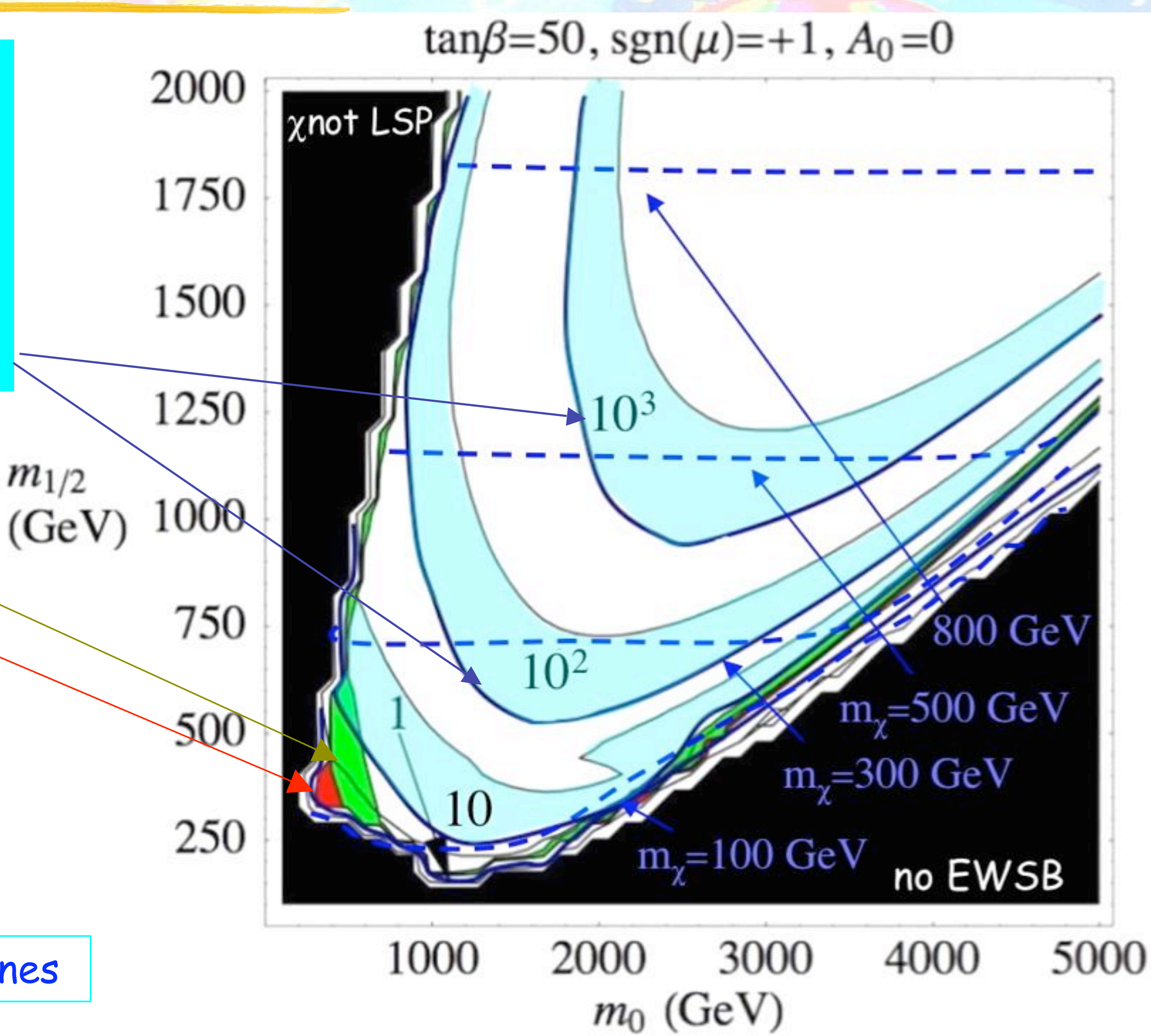
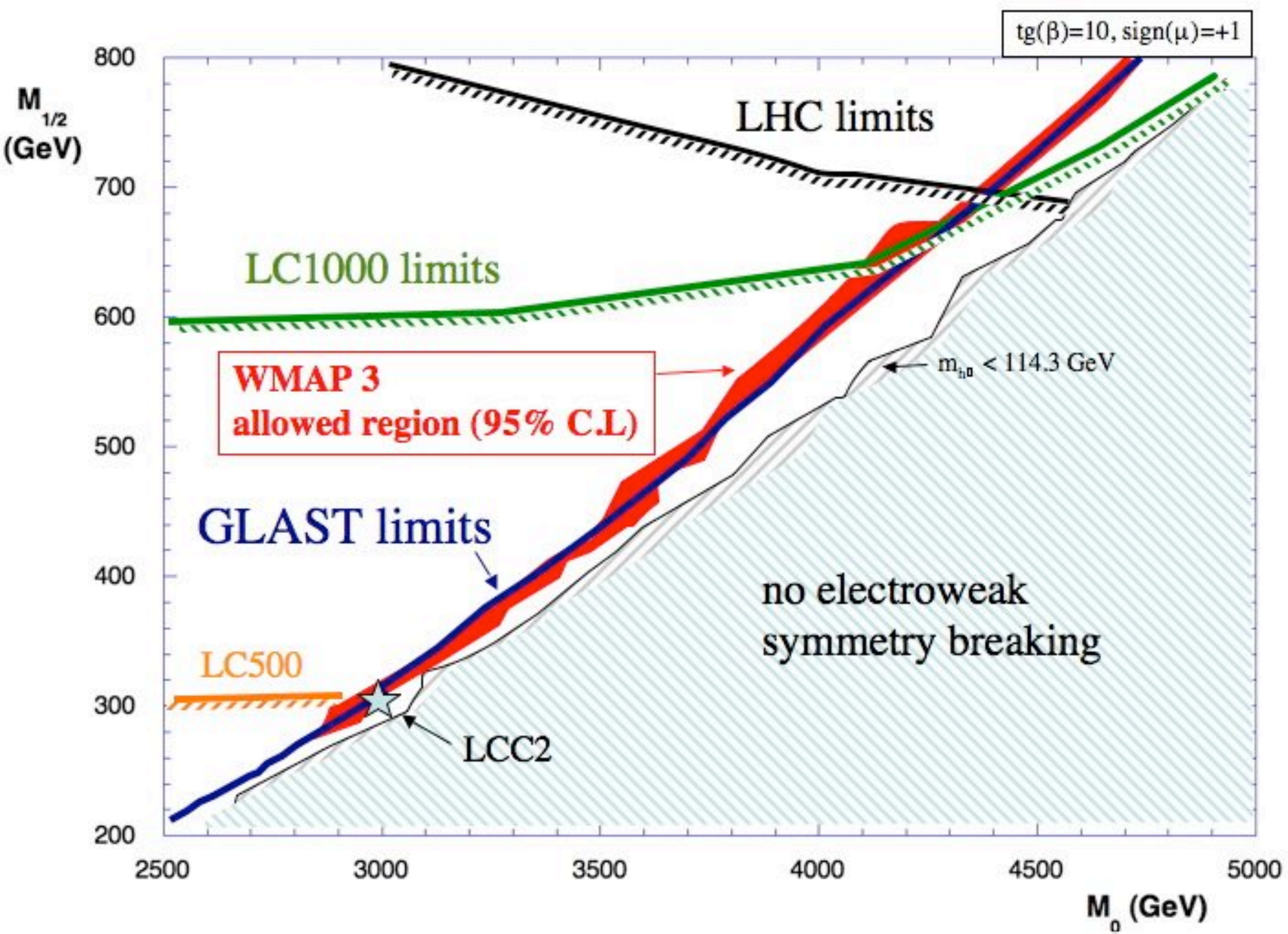


astro-ph/0502406



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

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

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3. E. Baltz, M Battaglia, M. Peskin, and T. Wizansky, Determination of Dark Matter Properties at High Energy Colliders, hep-ph/0602187, March 2006.
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6. H. Baer, et al., JCAP 0408 (2004) 005

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