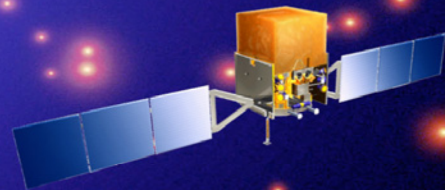
Observation of Antimatter in Our Galaxy



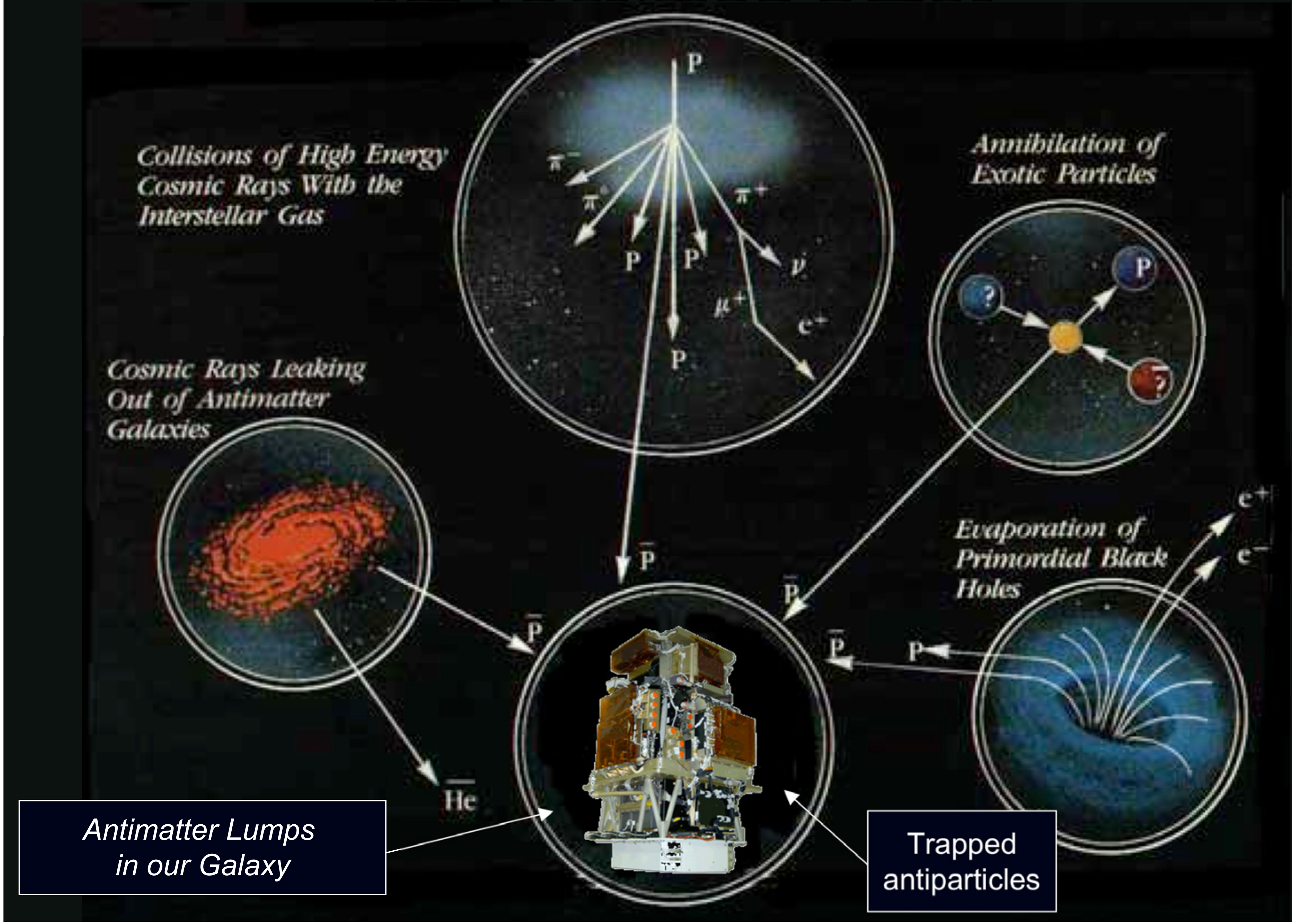
Piergiorgio Picozza

INFN & University of Rome " Tor Vergata"

TAUP 2007 September 11-15, 2007

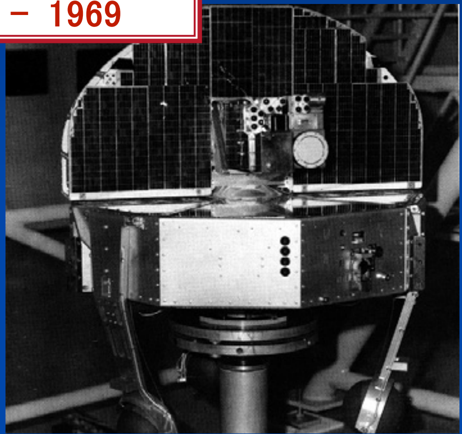
Sendai, Japan

ANTIMATTER

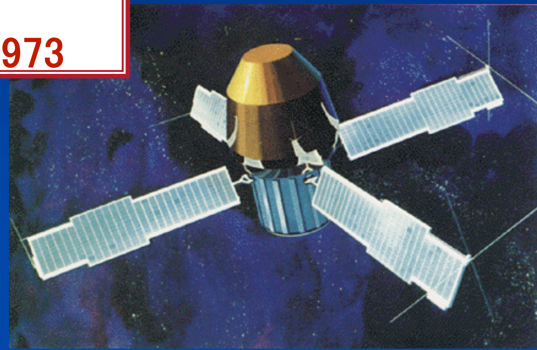

Collisions of High Energy Cosmic Rays With the Interstellar Gas
Annihilation of Exotic Particles
Cosmic Rays Leaking Out of Antimatter Galaxies
Evaporation of Primordial Black Holes
Antimatter Lumps in our Galaxy
Trapped antiparticles
P
P
P
P
π^-
π^+
ν
μ^+
e^+
e^-
$\bar{P}$
$\overline{He}$

Gamma Evidence for Cosmic Antimatter?

OSO-3
1967 – 1969



SAS-2
1972 – 1973

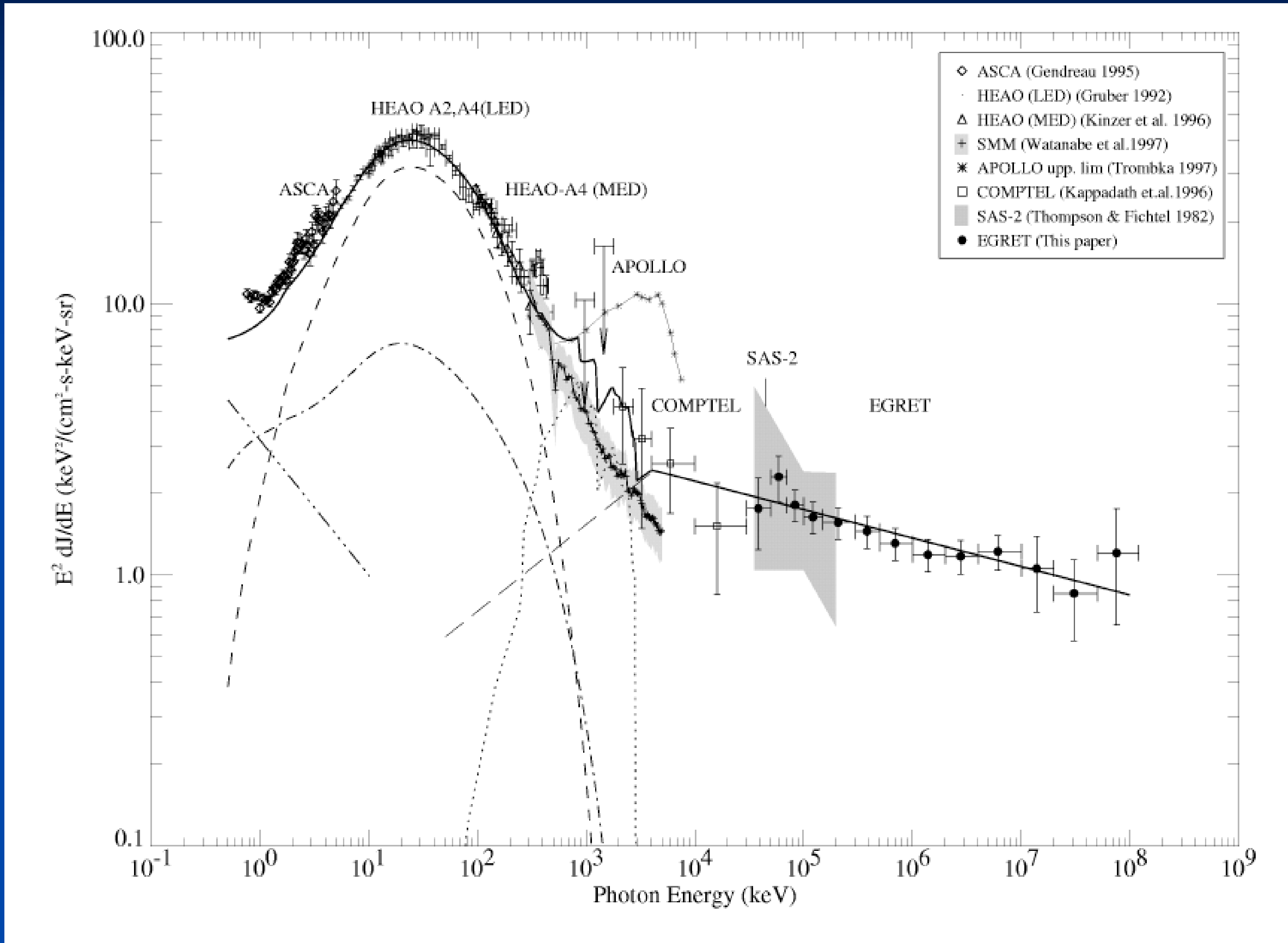


COS-B
1975 – 1982

GRO: Comptel and EGRET
1991 – 2000

INTEGRAL/SPI
2002

Cosmic Diffuse Gamma Spectrum



P. Sreekumar et al, astroph/9709257

Gamma Evidence for Cosmic Antimatter?

Steigman 1976, De Rujula 1996, Dolgov 2007

- Osservation in the 100 MeV gamma range

Leading process:

$$p\bar{p} \rightarrow \pi^0 + \ldots\ldots\ldots$$
$$\pi^0 \rightarrow \gamma\gamma$$

Other processes:

$$p\bar{p} \longrightarrow \pi^+ \cdots\cdots\cdots \longrightarrow \mu^+ \cdots\cdots\cdots \longrightarrow e^+ \cdots\cdots\cdots \longrightarrow \gamma \quad 1\text{–}10 \text{ MeV}$$

$$e^+e^- \longrightarrow \gamma\ \gamma \qquad 0.511 \text{ MeV}$$

Globally B-Symmetric Universe

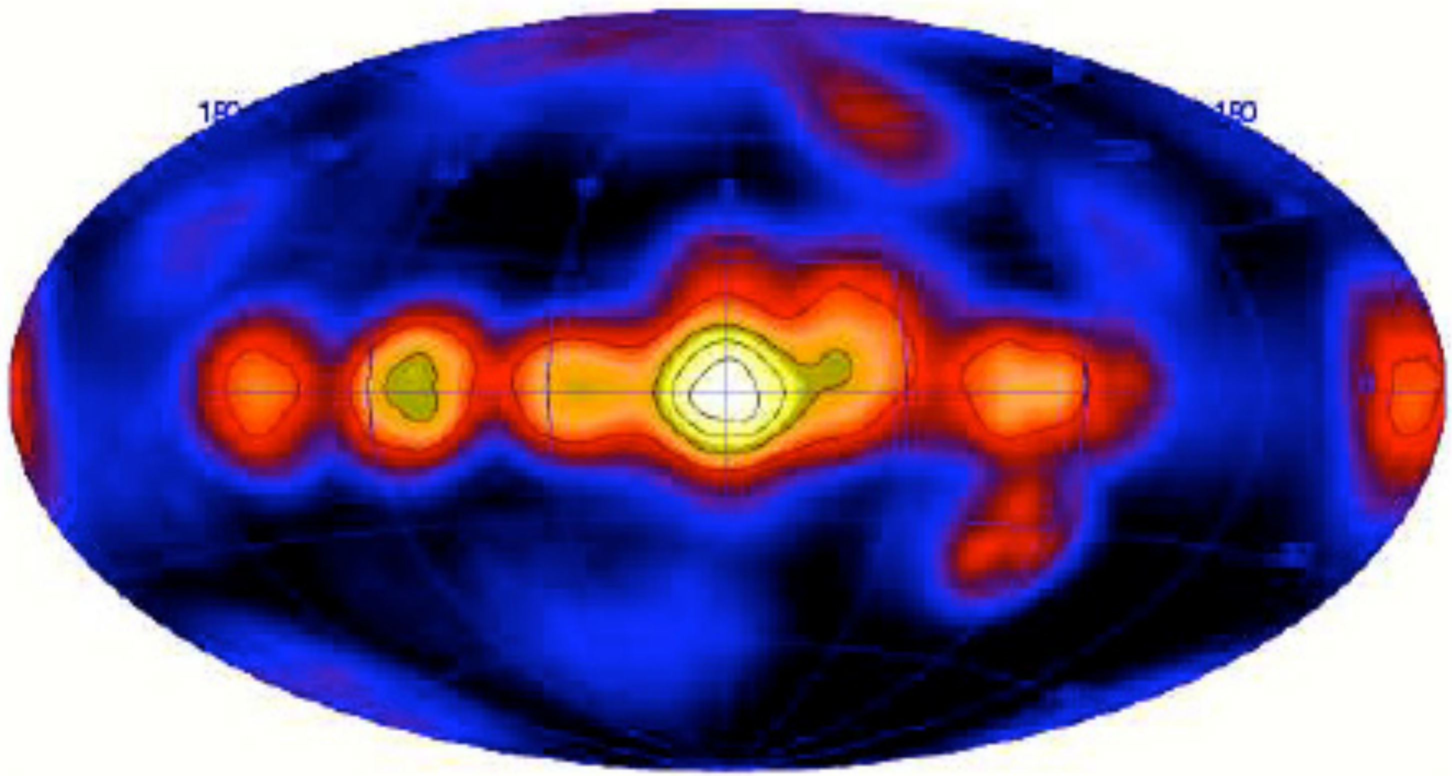
- This possibility seems observationally excluded

- A.G. Cohen, A. De Rujula and S.L. Glashow, Astrophys. J. 495, 539, 1998

Lumps of Antimatter in our Galaxy?

C. Bambi and A. D. Dolgov, arXiv: astro-ph/0702350 **and therein enclosed references**

0.511 MeV positron annihilation-Integral/SPI



G. Weidenspointner *et al.*, astro-ph/070261

New Gamma Space Experiments

AGILE
23-04-2007

GLAST
2008

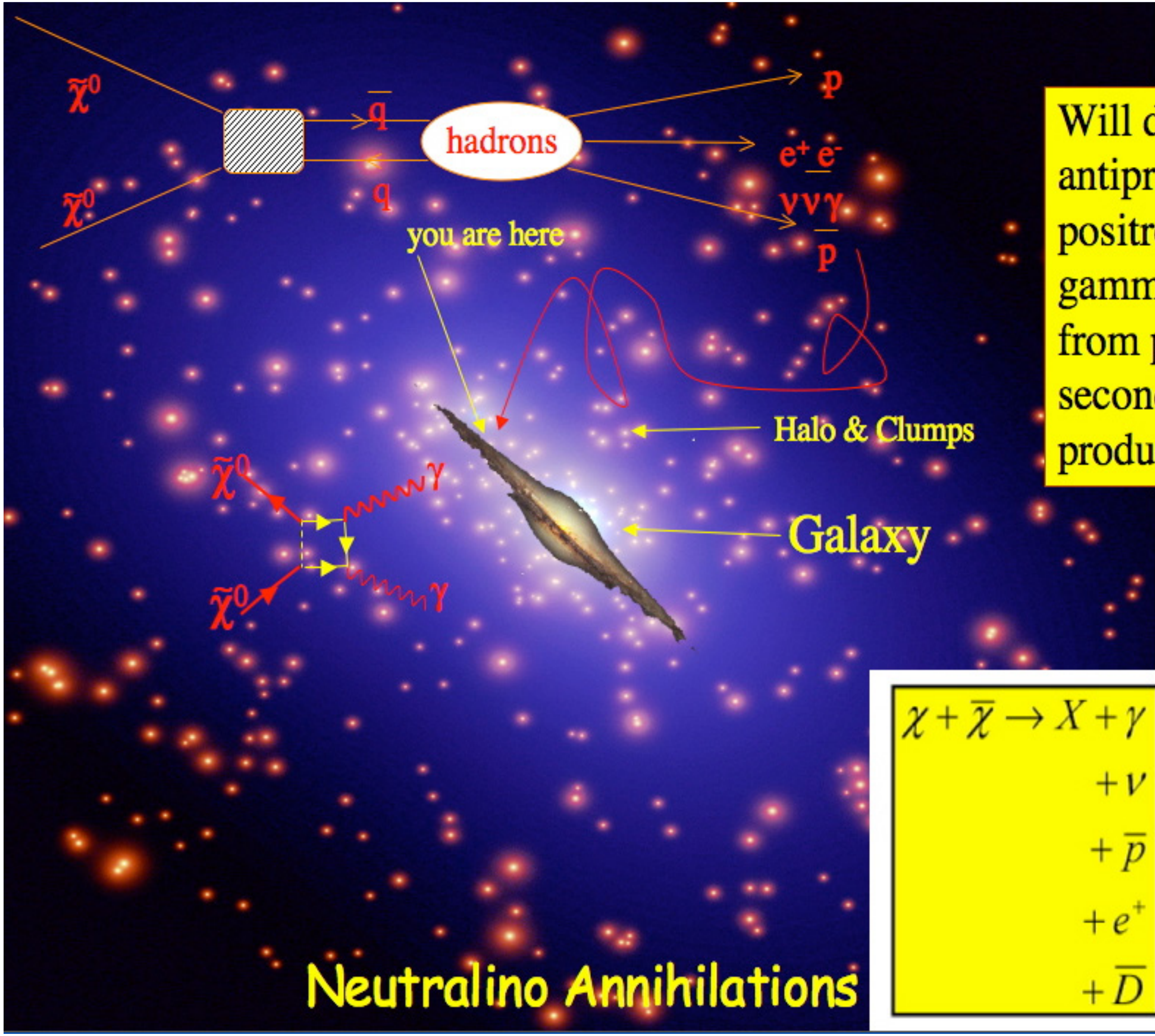
Antimatter Direct research

- **Antimatter** which has escaped as a cosmic ray from a distant antigalaxy

  Sreitmatter, R. E., Nuovo Cimento, 19, 835 (1996)

- **Antimatter** from globular clusters of antistars in our Galaxy as antistellar wind or anti-supernovae explosion

  K. M. Belotsky et al., Phys. Atom. Nucl. 63, 233 (2000), astro-ph/9807027



Will distort the antiproton positron and gamma spectra from purely secondary production

$$\chi + \bar{\chi} \to X + \gamma$$ (GLAST AMS-02)

$$+ \nu$$ (AMANDA / IceCube)

$$+ \bar{p}$$

$$+ e^+$$

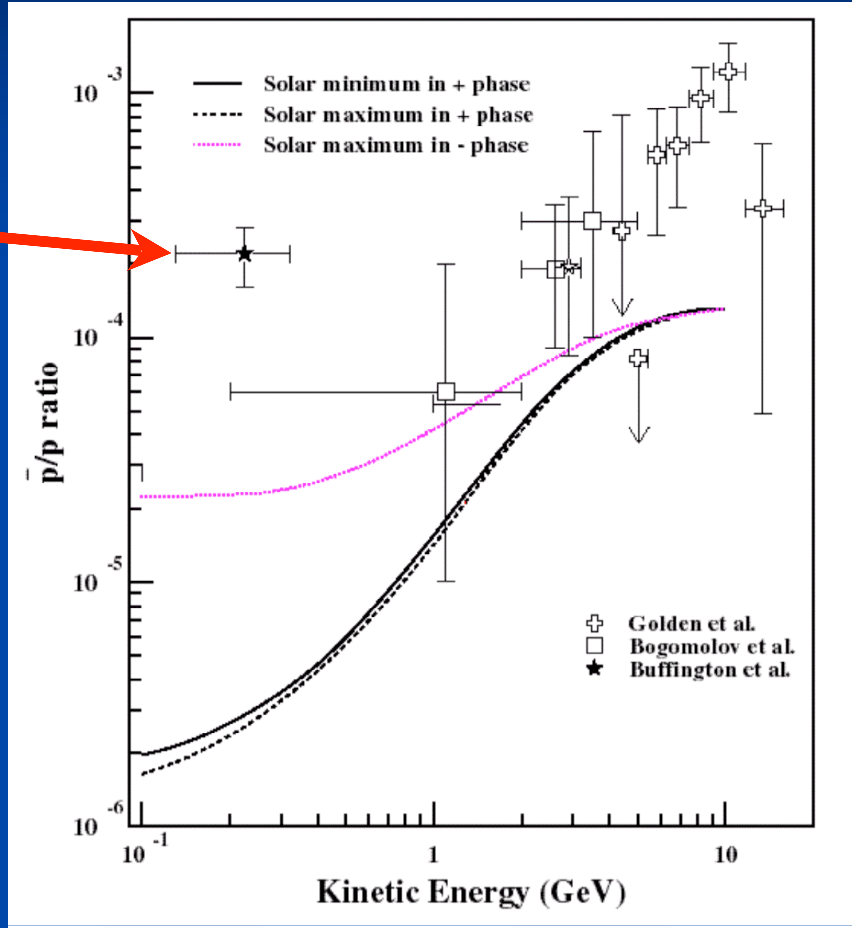
$$+ \bar{D}$$

PAMELA (and Bess, HEAT, AMS etc.)

Antimatter in Cosmic Rays

1979: First observation (Golden et al)
1979: Russian PM (Bogomolov et al)
1981: Excess reported (Buffington et al)
1985: ASTROMAG Study Started
1987: LEAP, PBAR (upper limits)

1991: MASS
1992: IMAX
1993: TS93, BESS
1994: CAPRICE94, HEAT-e±
1996: Solar minimum
1997: BESS
1998: CAPRICE98, AMS-01
1999: BESS
2000: HEAT-pbar, BESS
2004: BESS Polar I

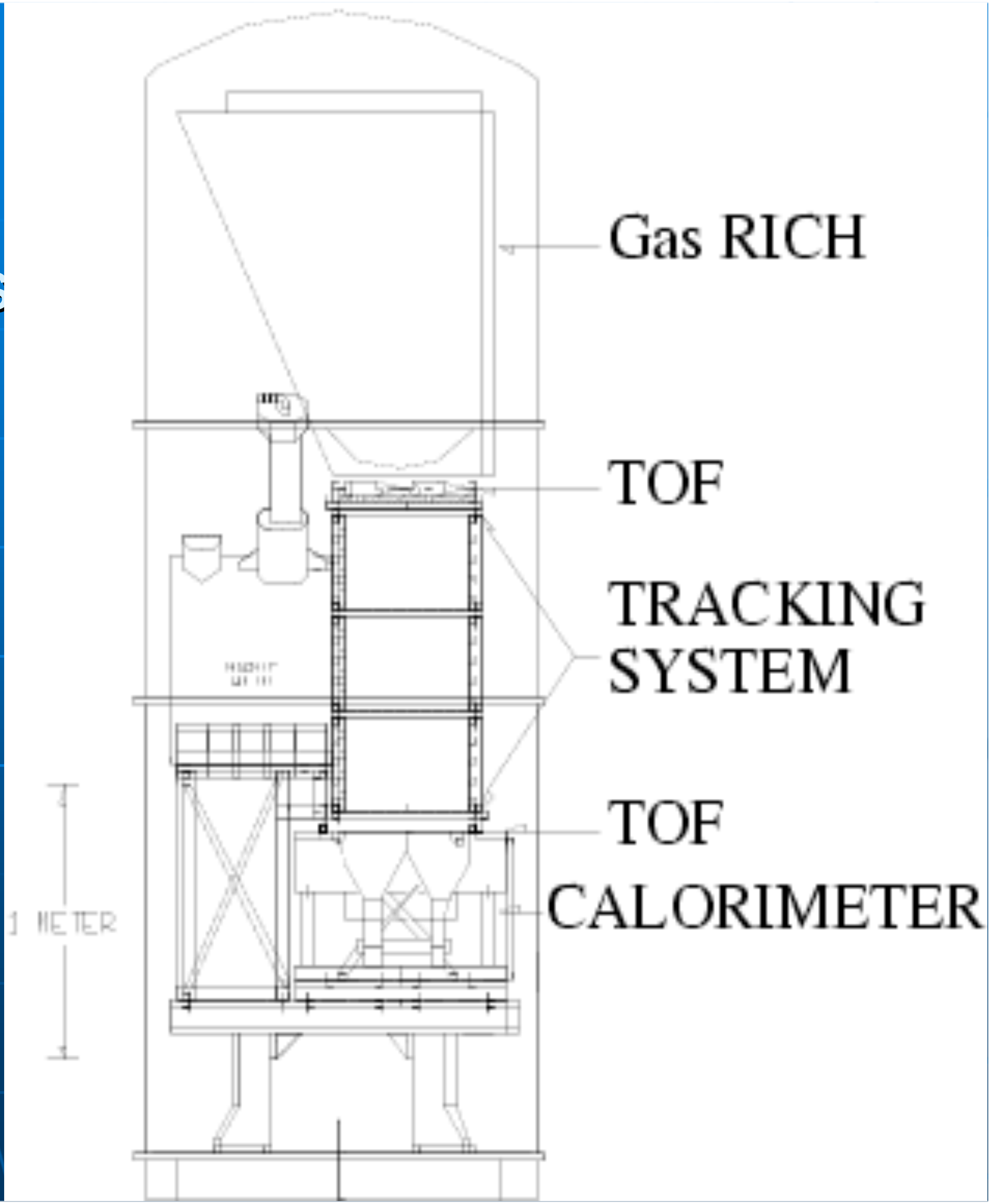


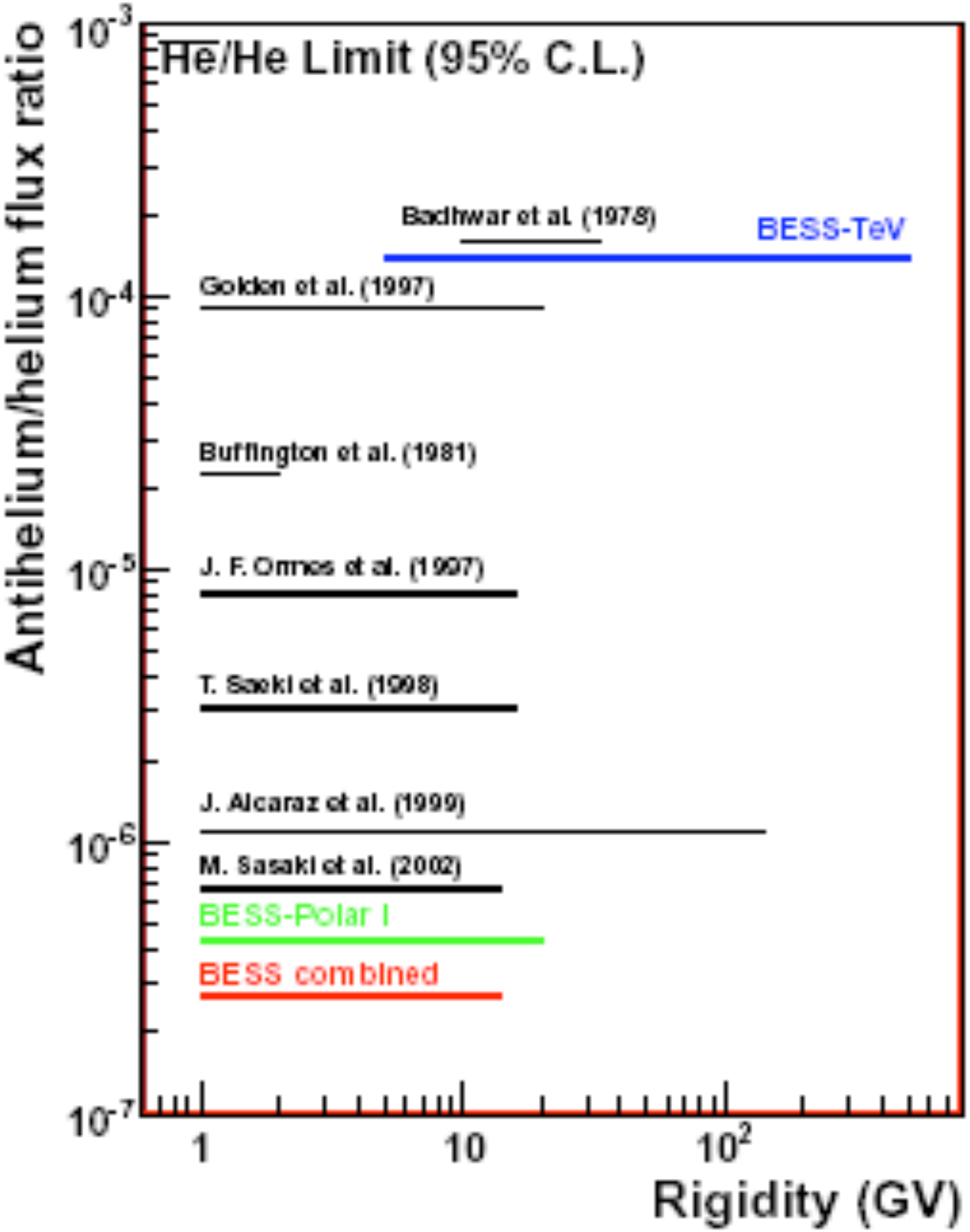
Before MASS Flight

Caprice

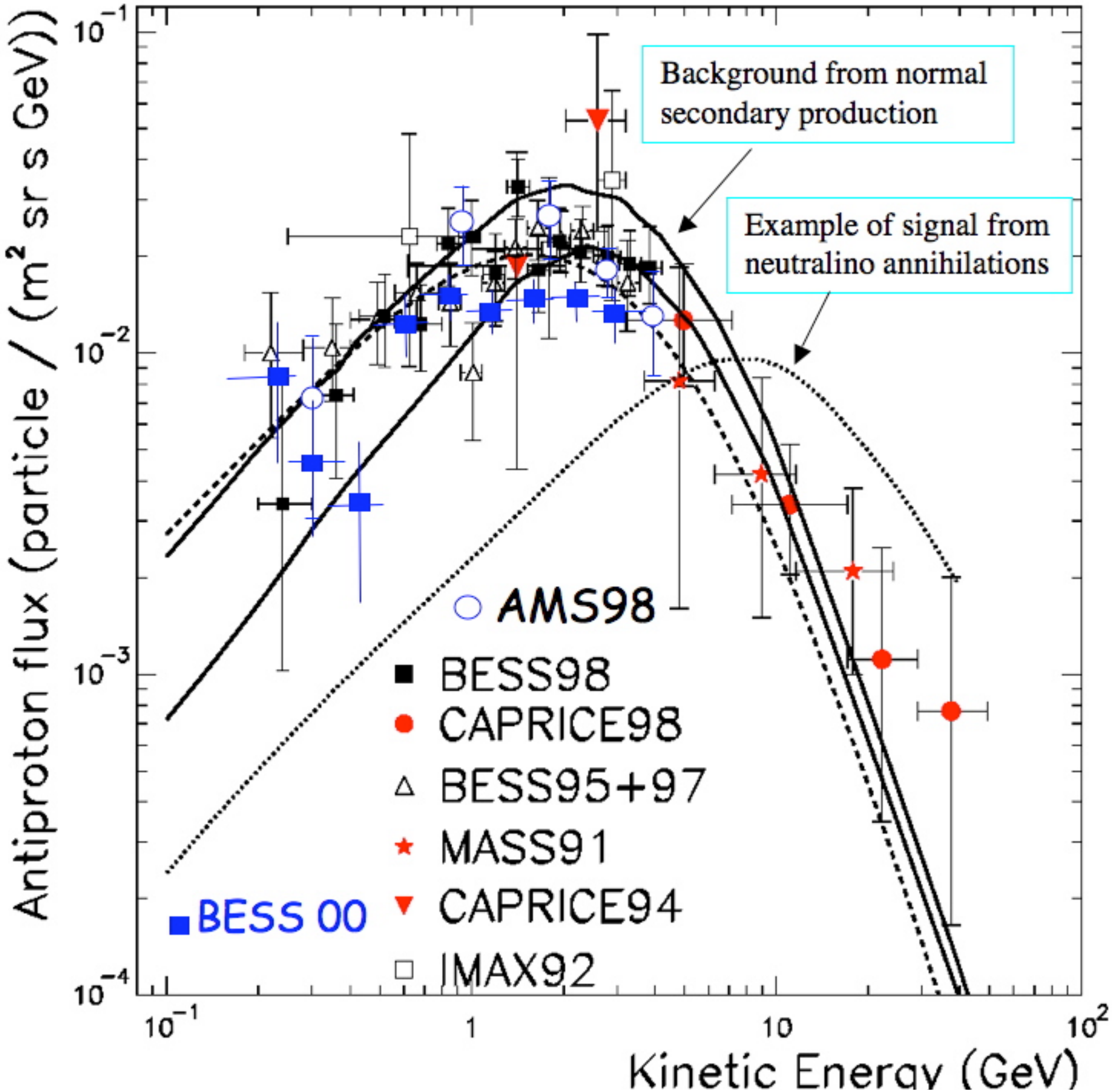
Subnuclear physics techniques in space experiments

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

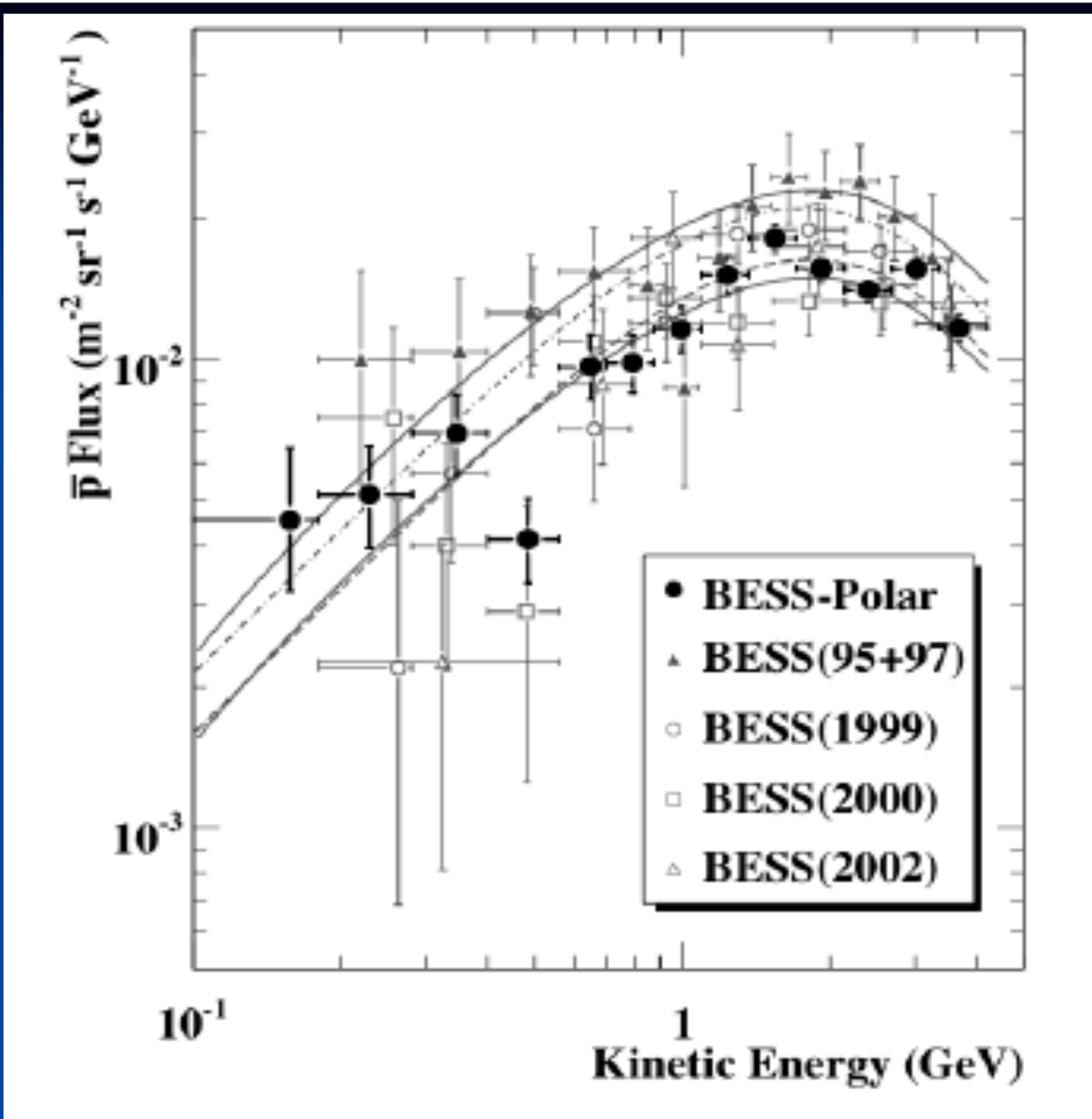




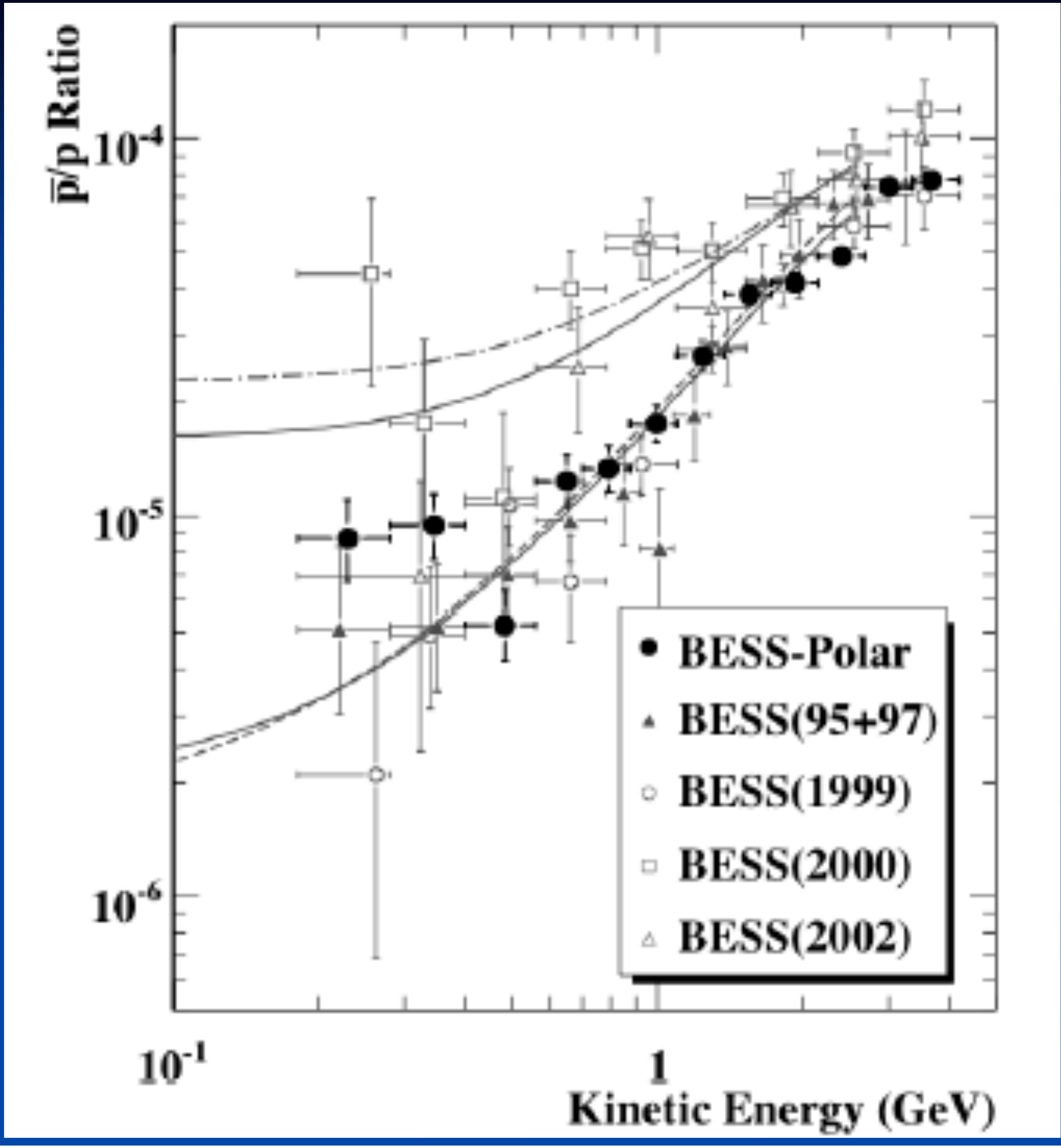
He/He Limit (95% C.L.)
Antihelium/helium flux ratio
Badhwar et al. (1978)
BESS-TeV
Golden et al. (1997)
Buffington et al. (1981)
J. F. Ormes et al. (1997)
T. Saeki et al. (1998)
J. Alcaraz et al. (1999)
M. Sasaki et al. (2002)
BESS-Polar I
BESS combined
Rigidity (GV)



Antiproton flux (particle / (m² sr s GeV))
Kinetic Energy (GeV)
Background from normal secondary production
Example of signal from neutralino annihilations
AMS98
BESS98
CAPRICE98
BESS95+97
MASS91
CAPRICE94
IMAX92
BESS 00



BESS Coll.
30th ICRC 2007



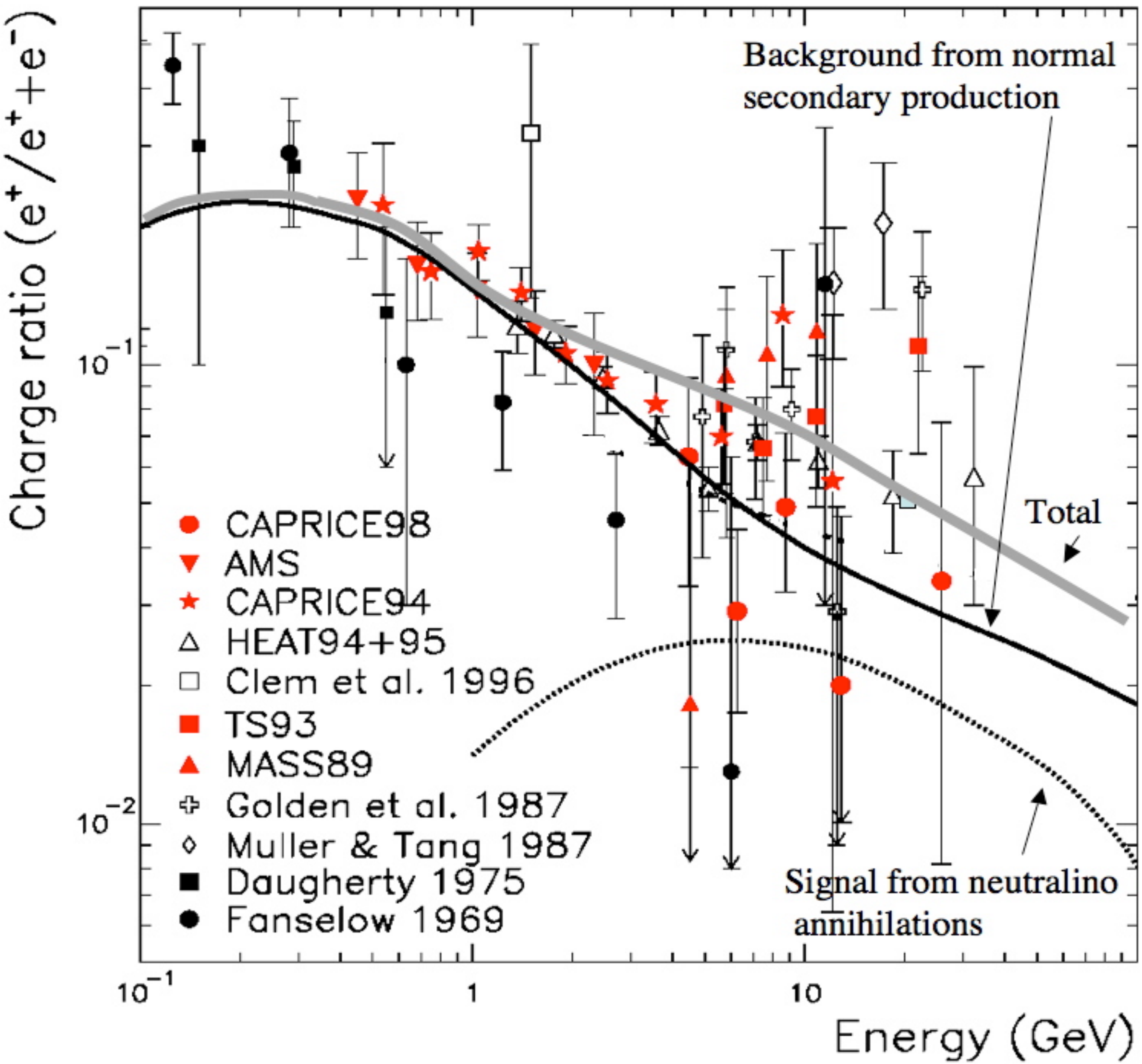
BESS Coll.
30th ICRC 2007

Antistars in our Galaxy?

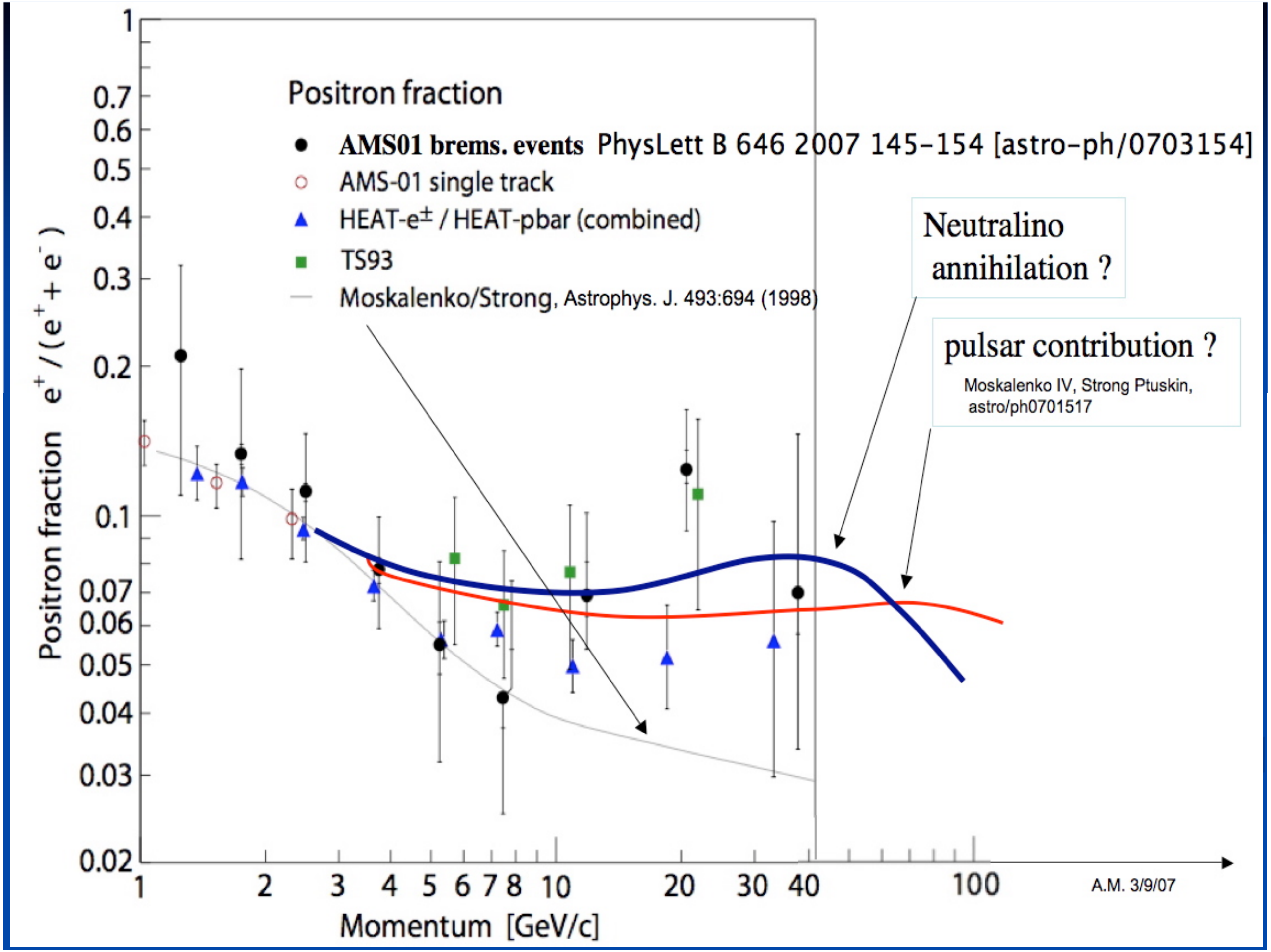
- Abundance of elements in CR reflects relative abundances in the Galaxy

$$\frac{N_{\bar{S}}}{N_S} \lesssim \left(\frac{\bar{p}}{p}\right)_{\mathrm{ES}} \lesssim 10^{-5} \quad \Rightarrow \quad N_{\bar{S}} \lesssim 10^{6}$$

$$\frac{N_{\bar{S}}}{N_S} \lesssim \left(\frac{\bar{He}}{He}\right)_{\mathrm{ES}} \lesssim 10^{-6} \quad \Rightarrow \quad N_{\bar{S}} \lesssim 10^{5}$$



Charge ratio (e+/e++e-)
Energy (GeV)
Background from normal secondary production
Total
Signal from neutralino annihilations
CAPRICE98
AMS
CAPRICE94
HEAT94+95
Clem et al. 1996
TS93
MASS89
Golden et al. 1987
Muller & Tang 1987
Daugherty 1975
Fanselow 1969

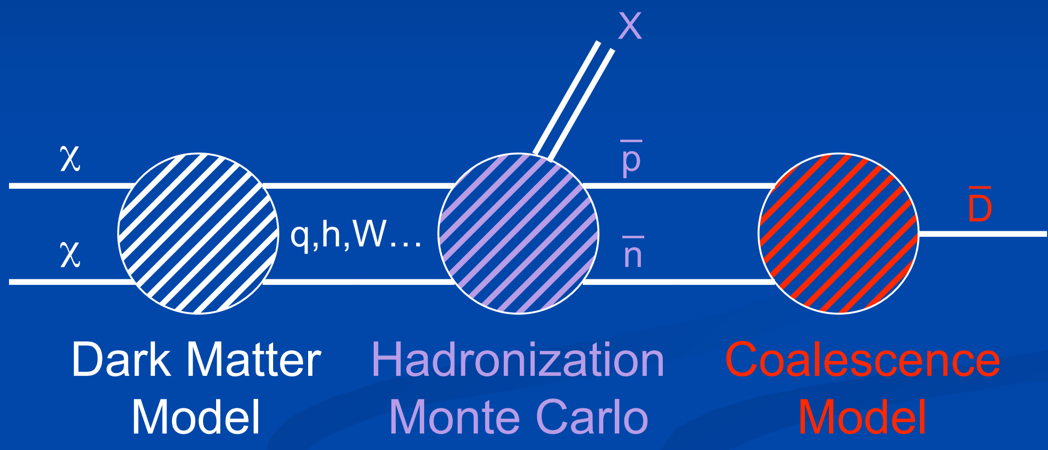


Positron fraction
AMS01 brems. events PhysLett B 646 2007 145-154 [astro-ph/0703154]
AMS-01 single track
HEAT-e± / HEAT-pbar (combined)
TS93
Moskalenko/Strong, Astrophys. J. 493:694 (1998)
Neutralino annihilation ?
pulsar contribution ?
Moskalenko IV, Strong Ptuskin, astro/ph0701517
Positron fraction e+/(e+ + e-)
Momentum [GeV/c]
A.M. 3/9/07

Antideuterons

- Pair annihilating WIMPS produce:

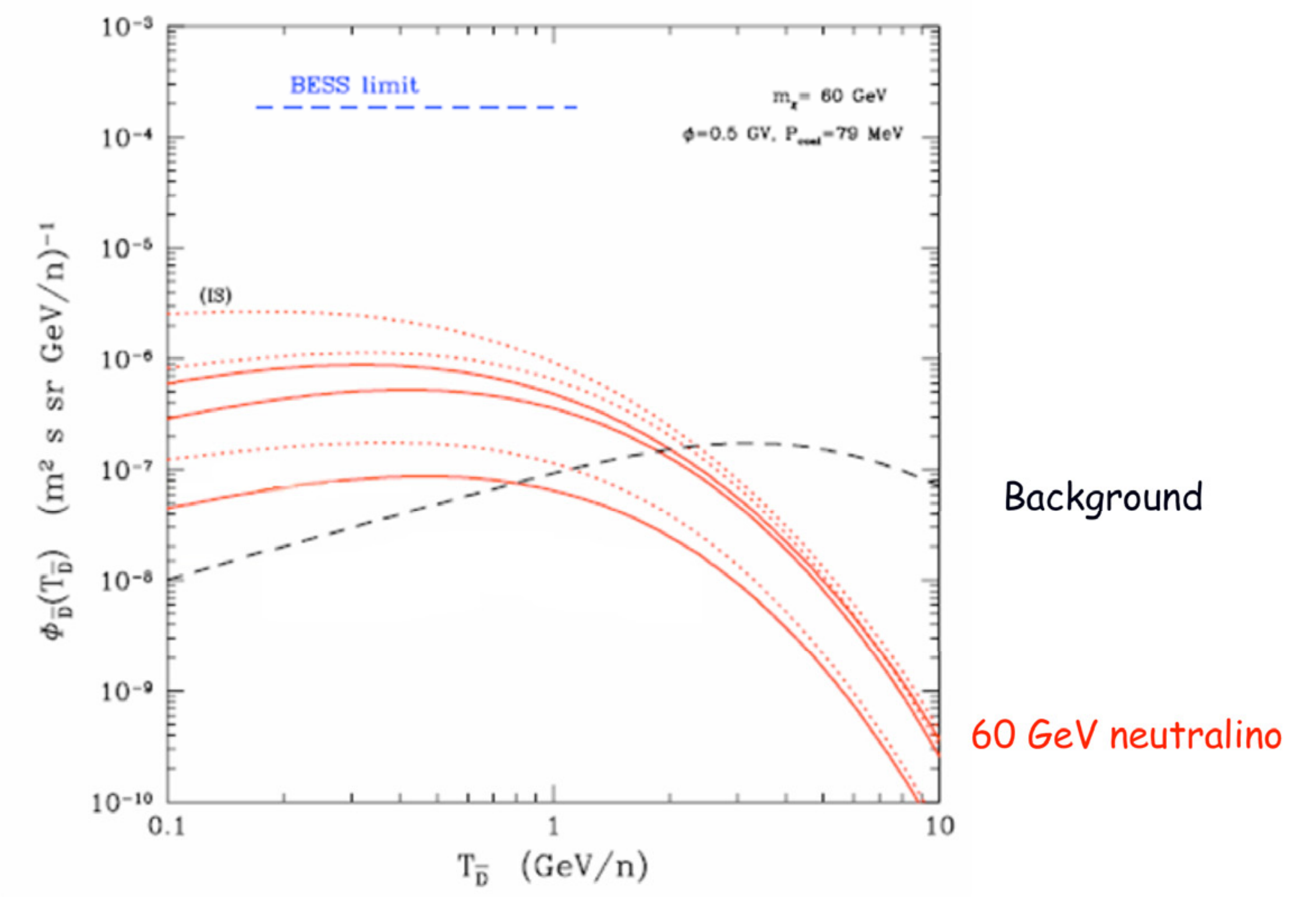
  γ, ν, e^+… $\bar{p}$…



F. Donato *et al.* Antideuterons as a signature of supersymmetric dark matter. *Phys. Rev D*, 62(4):043003

Antideuterons

F. Donato et al. – 30th ICRC 2007



What do we need?

- Measurements at higher energies
- Better knowledge of background
- High statistic
- Continuous monitoring of solar modulation

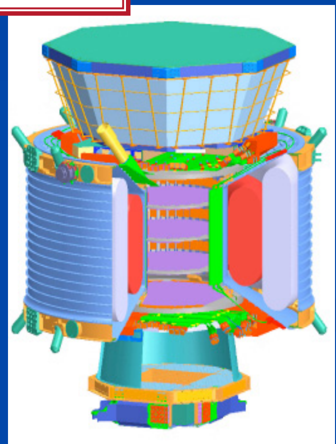
Long Duration Flights

Antimatter Dark Matter Space Missions

PAMELA
15-06-2006

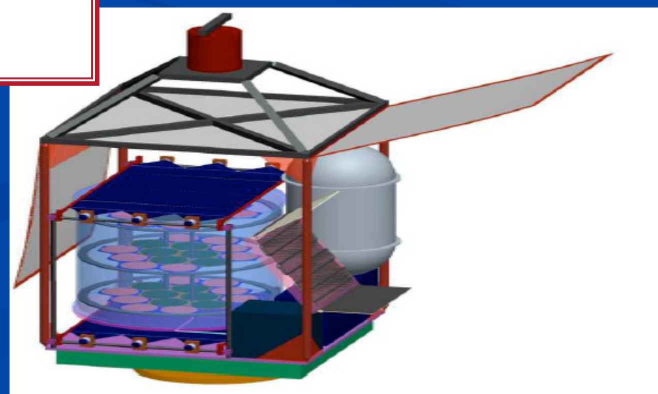
BESS
2007

AMS-02
2009

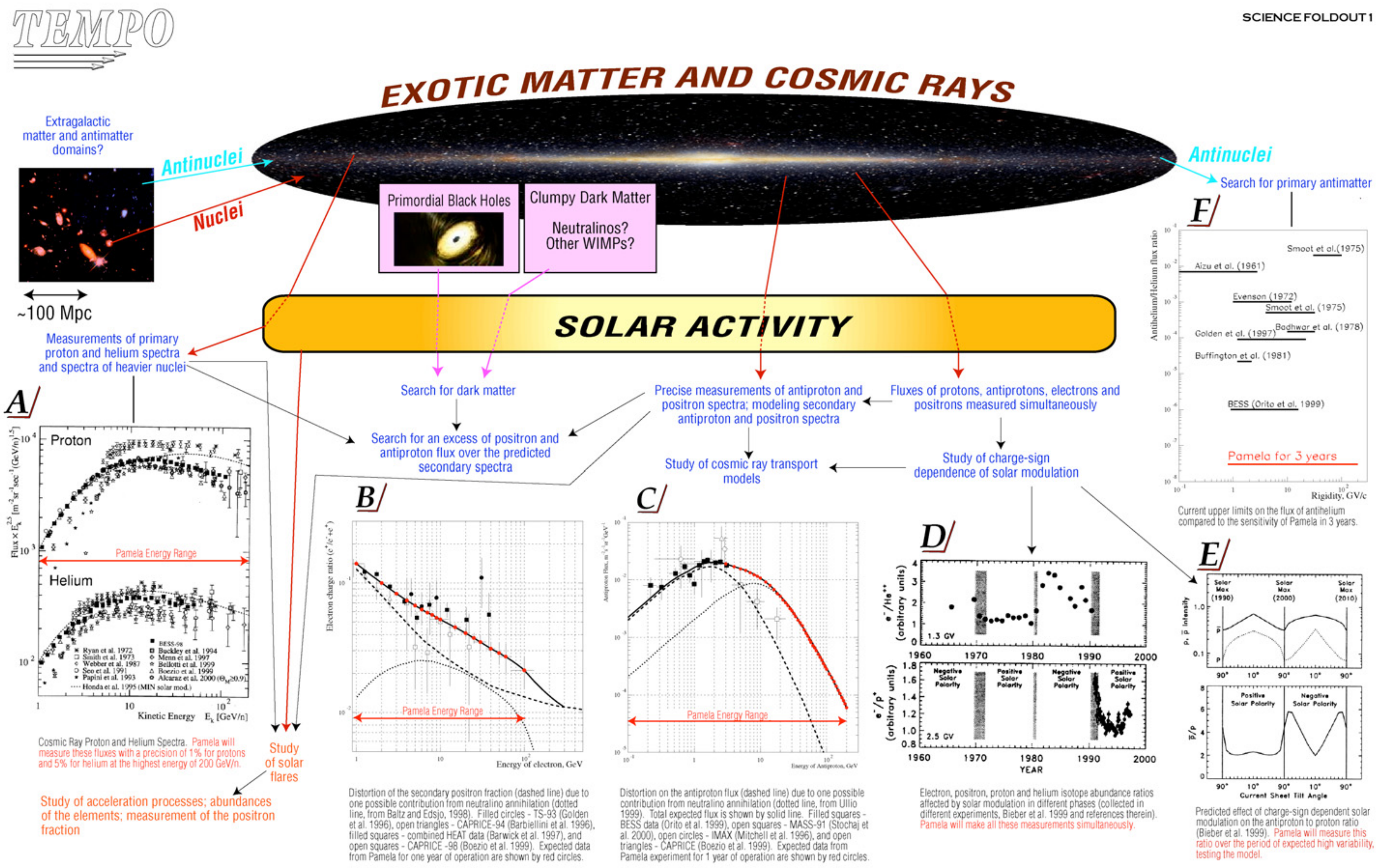


PEBS
2010

GAPS
2013



PAMELA and AMS-02: Observatories at 1 AU



PAMELA

Launched in orbit on June 15, 2006, on board of the DK1 satellite by a Soyuz rocket from the Bajkonour launch site.

Since July 11, 2006, Pamela is in continuous data taking mode

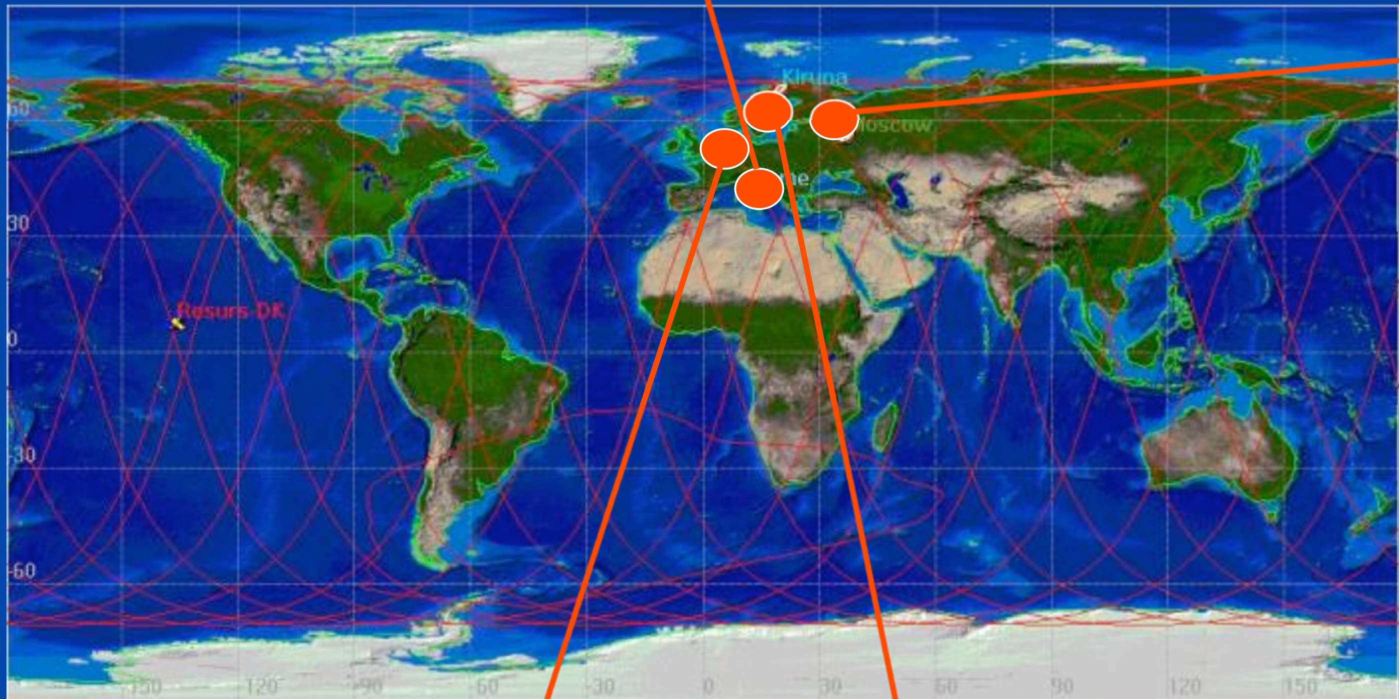
16 Gigabytes data/day

The amount of data collected is ~5.8TB, corresponding to more than 7×10^8 events.

PAMELA Collaboration

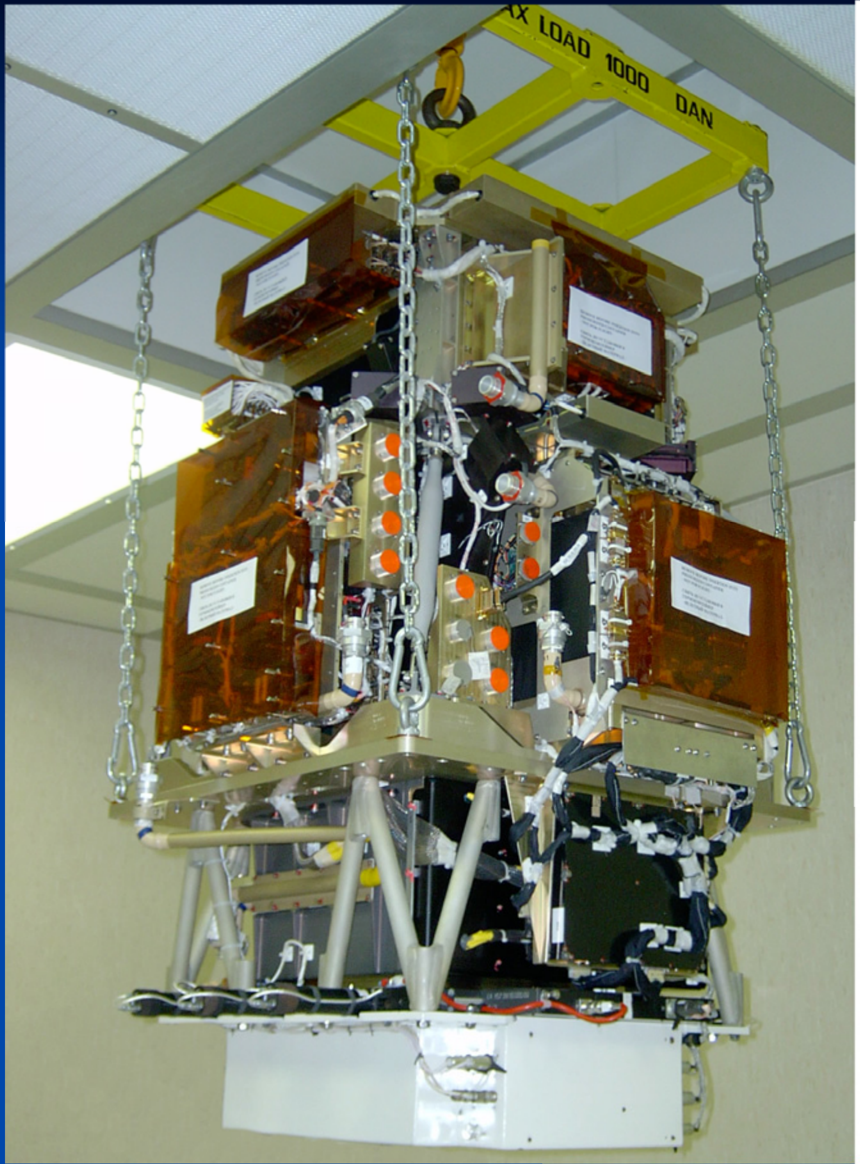
Italy: Bari, Florence, Frascati (LNF), Naples, Rome (Tor Vergata), Trieste, CNR, Florence

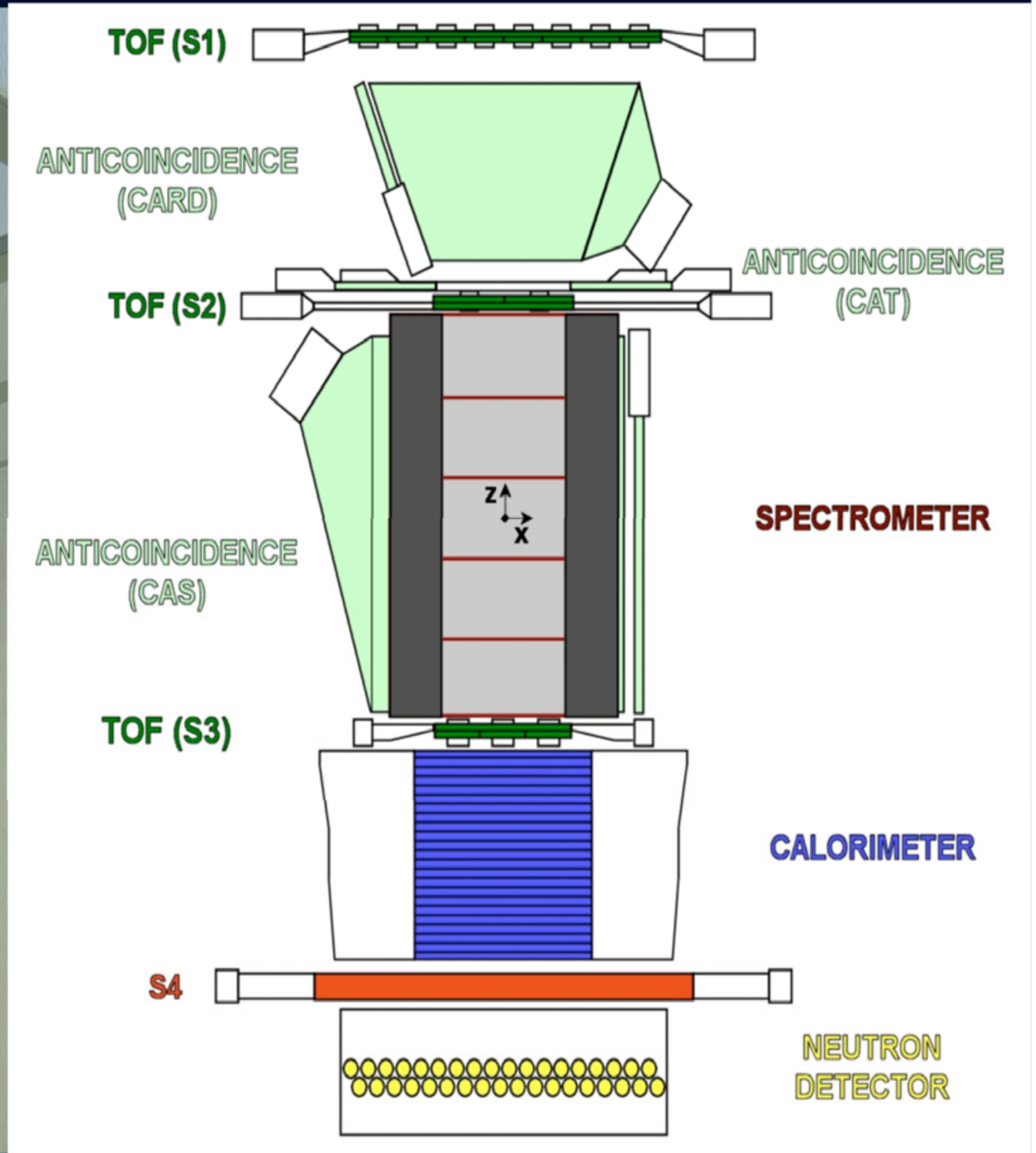
Russia: Moscow, St. Petersburg (Ioffe Physico-Technical Institute)



Germany: Universität Gesamthochschule Siegen, Siegen

Sweden: Kungl Tekniska Högskolan, KTH, Stockholm

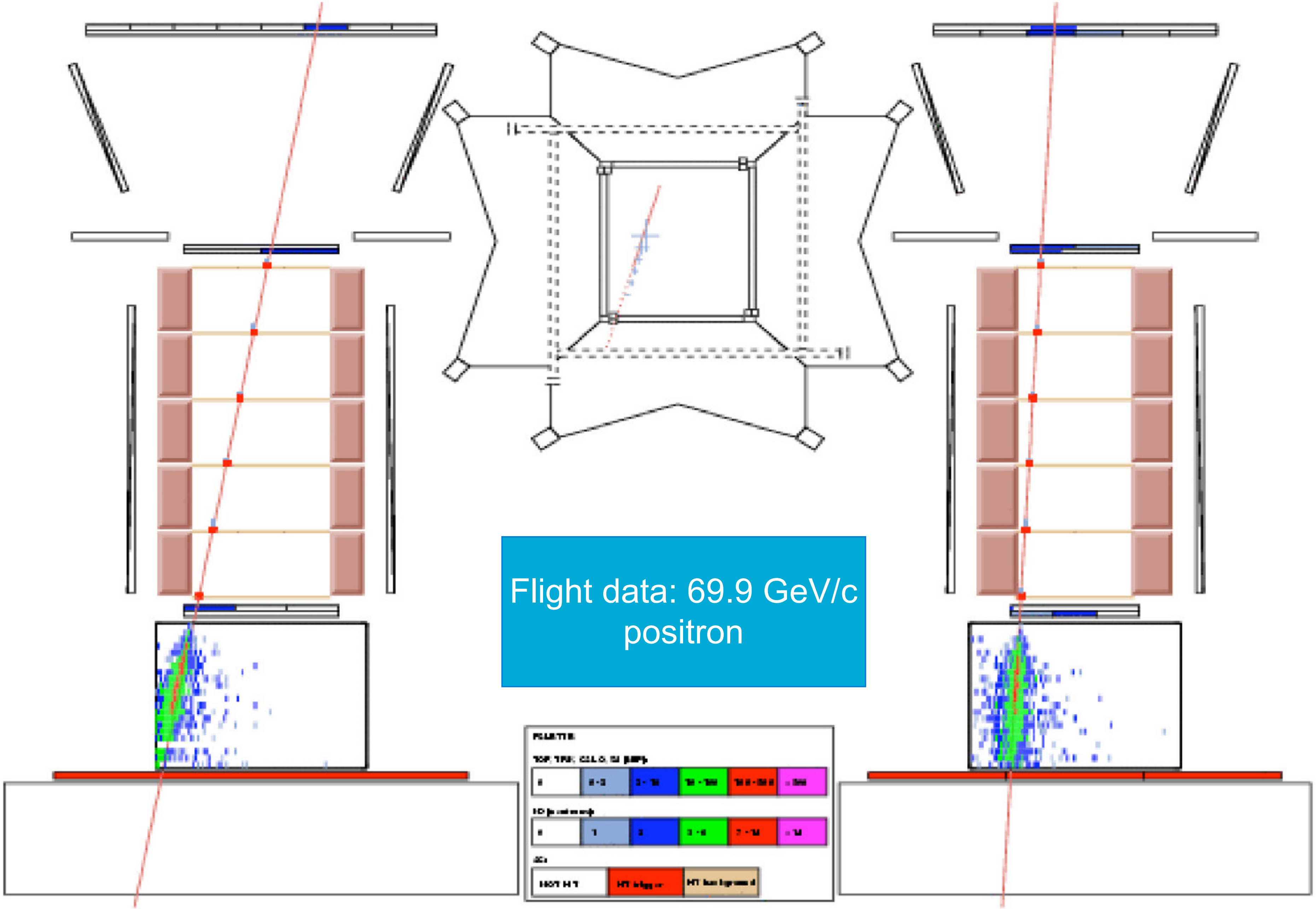


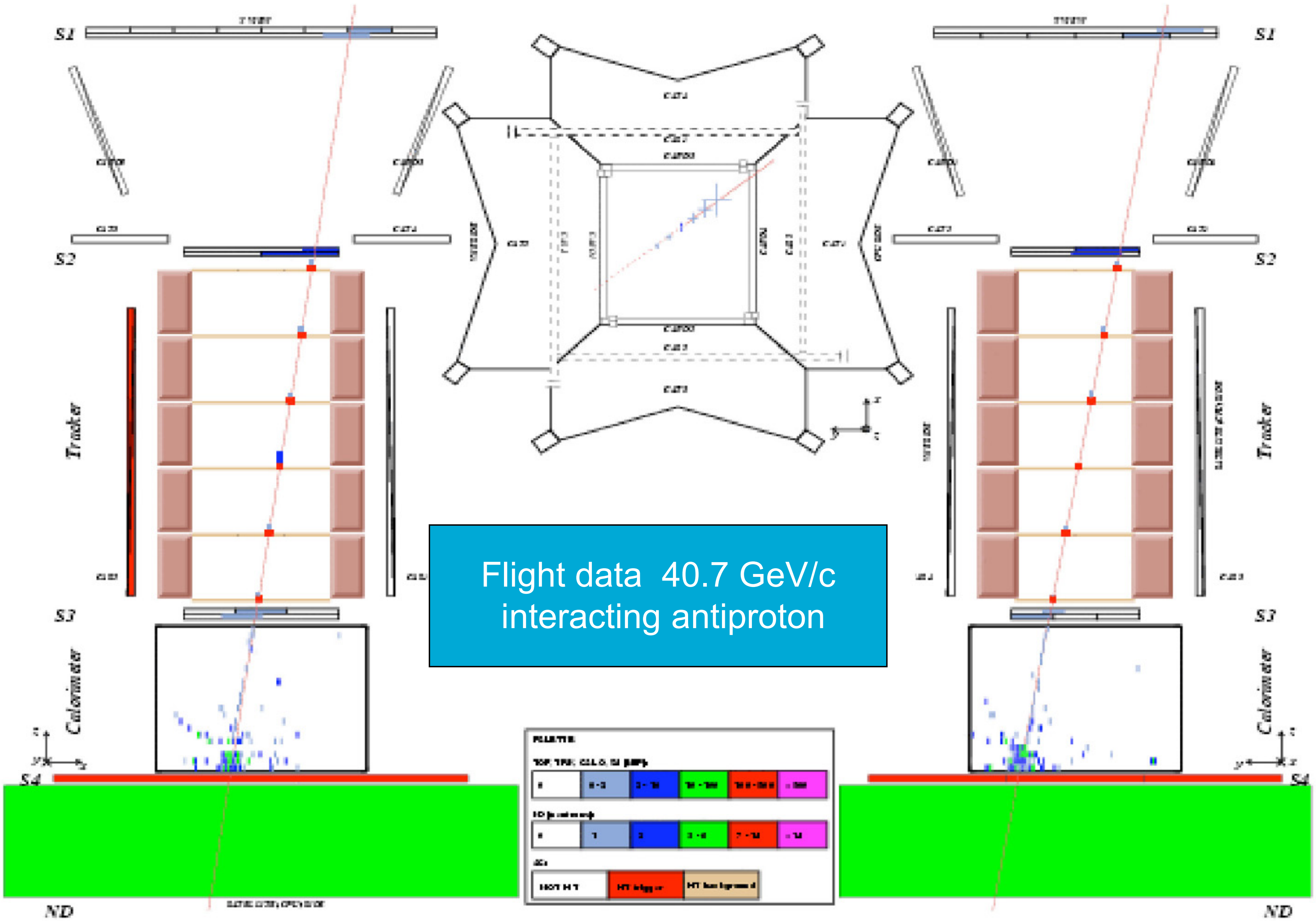


GF ~21.5 cm^{2}sr Mass: 470 kg Size: 130x70x70 cm^3

PAMELA nominal capabilities

	energy range	particles in 3 years
Antiprotons	80 MeV - 190 GeV	$\sim 10^4$
Positrons	50 MeV – 270 GeV	$\sim 10^5$
Electrons	up to 400 GeV	$\sim 10^6$
Protons	up to 700 GeV	$\sim 10^8$
Electrons+positrons	up to 2 TeV (from calorimeter)	
Light Nuclei	up to 200 GeV/n He/Be/C:	$\sim 10^{7/4/5}$
AntiNuclei search	sensitivity of 3×10^{-8} in antiHe/He	


Flight data: 69.9 GeV/c
positron

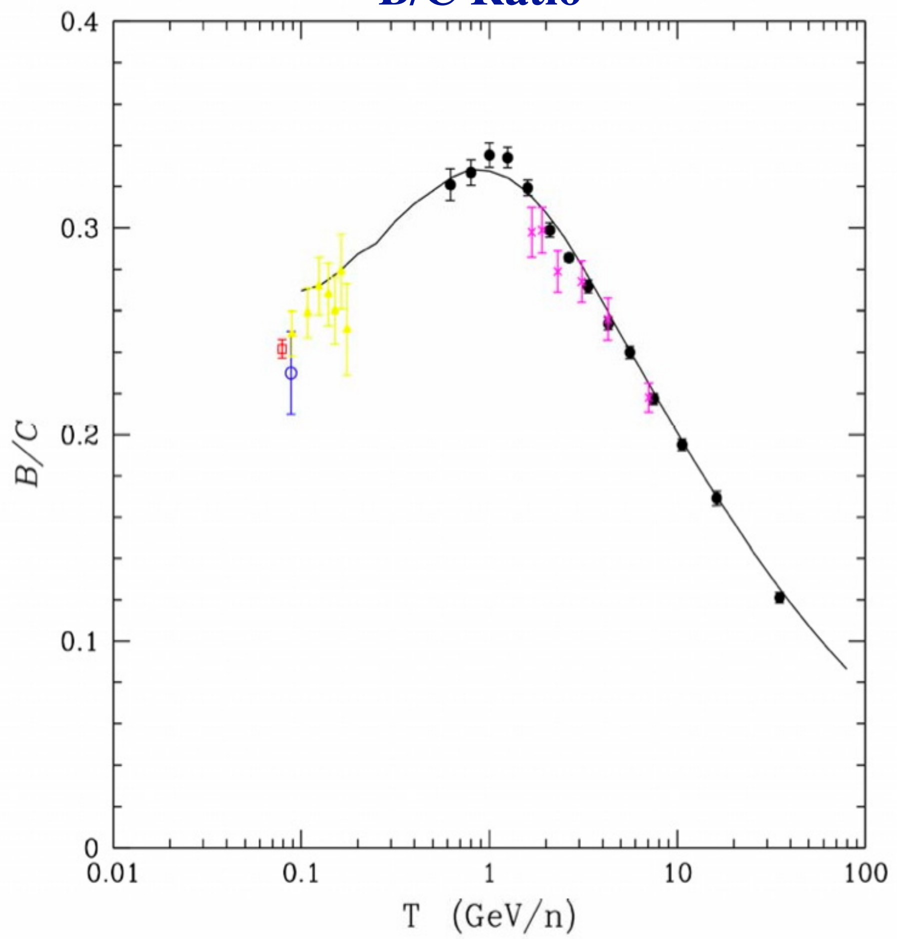

S1
S2
S3
S4
ND
Tracker
Calorimeter
Flight data 40.7 GeV/c
interacting antiproton

Secondaries / primaries
i.e. Boron/ Carbon to constrain propagation parameters

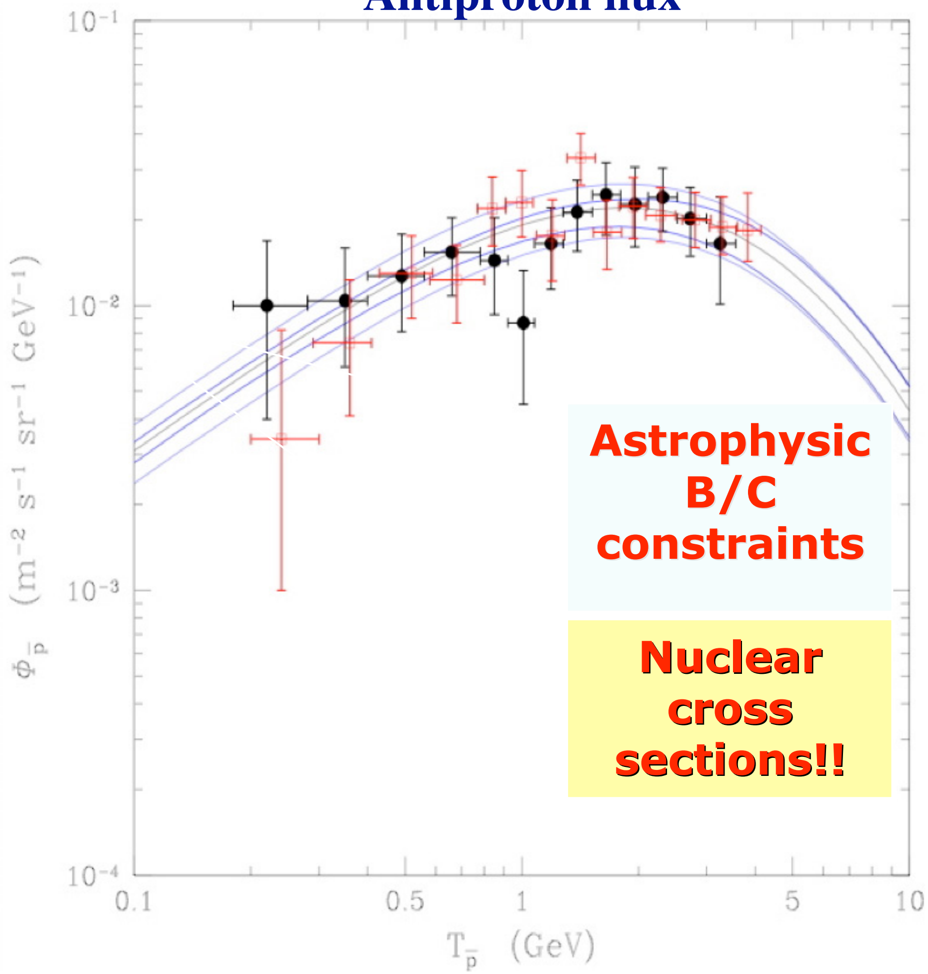
D. Maurin, F. Donato R. Taillet and P.Salati ApJ, 555, 585, 2001 *[astro-ph/0101231]*

F. Donato *et.al*, ApJ, 563, 172, 2001 *[astro-ph/0103150]*

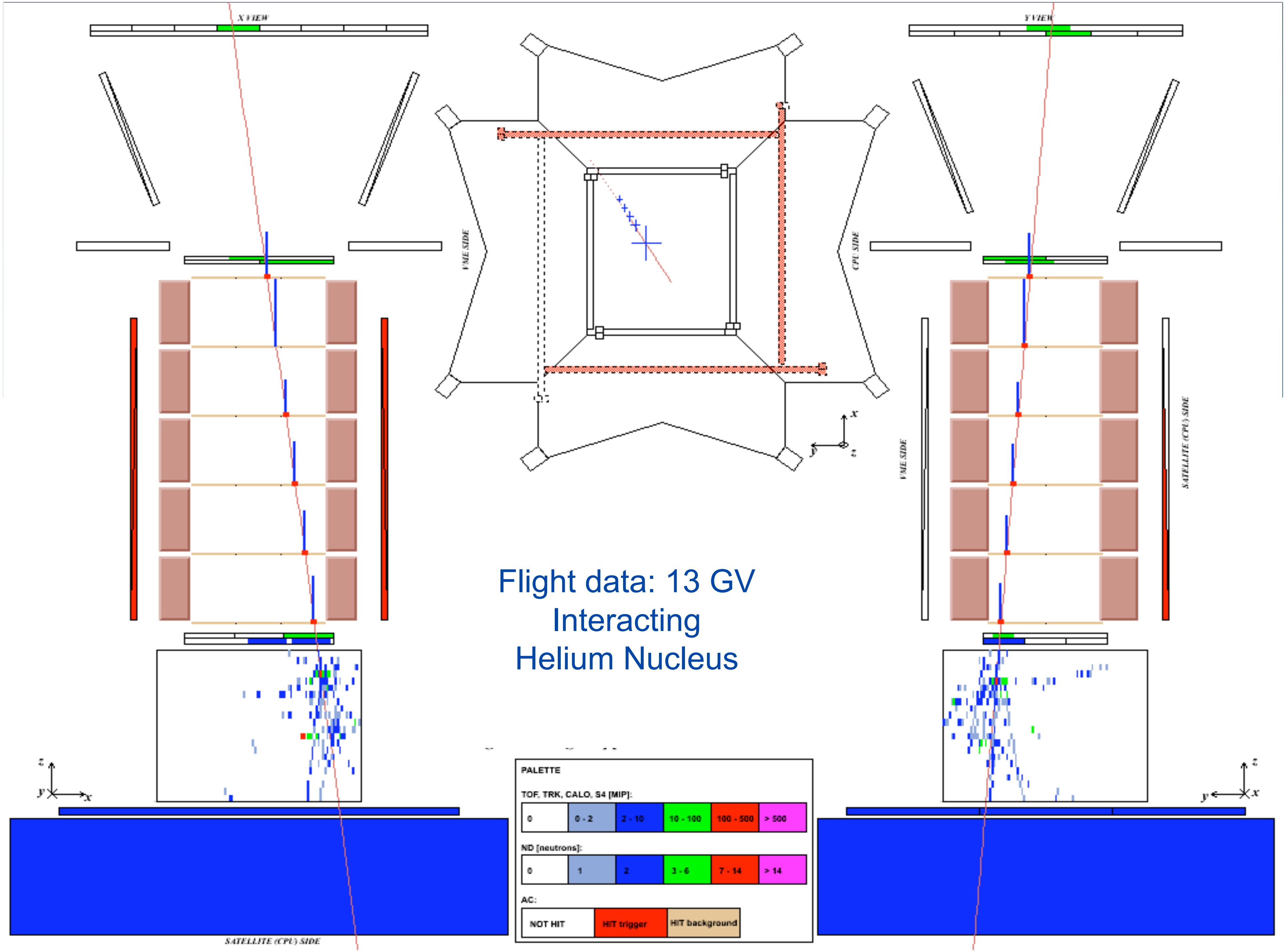
B/C Ratio



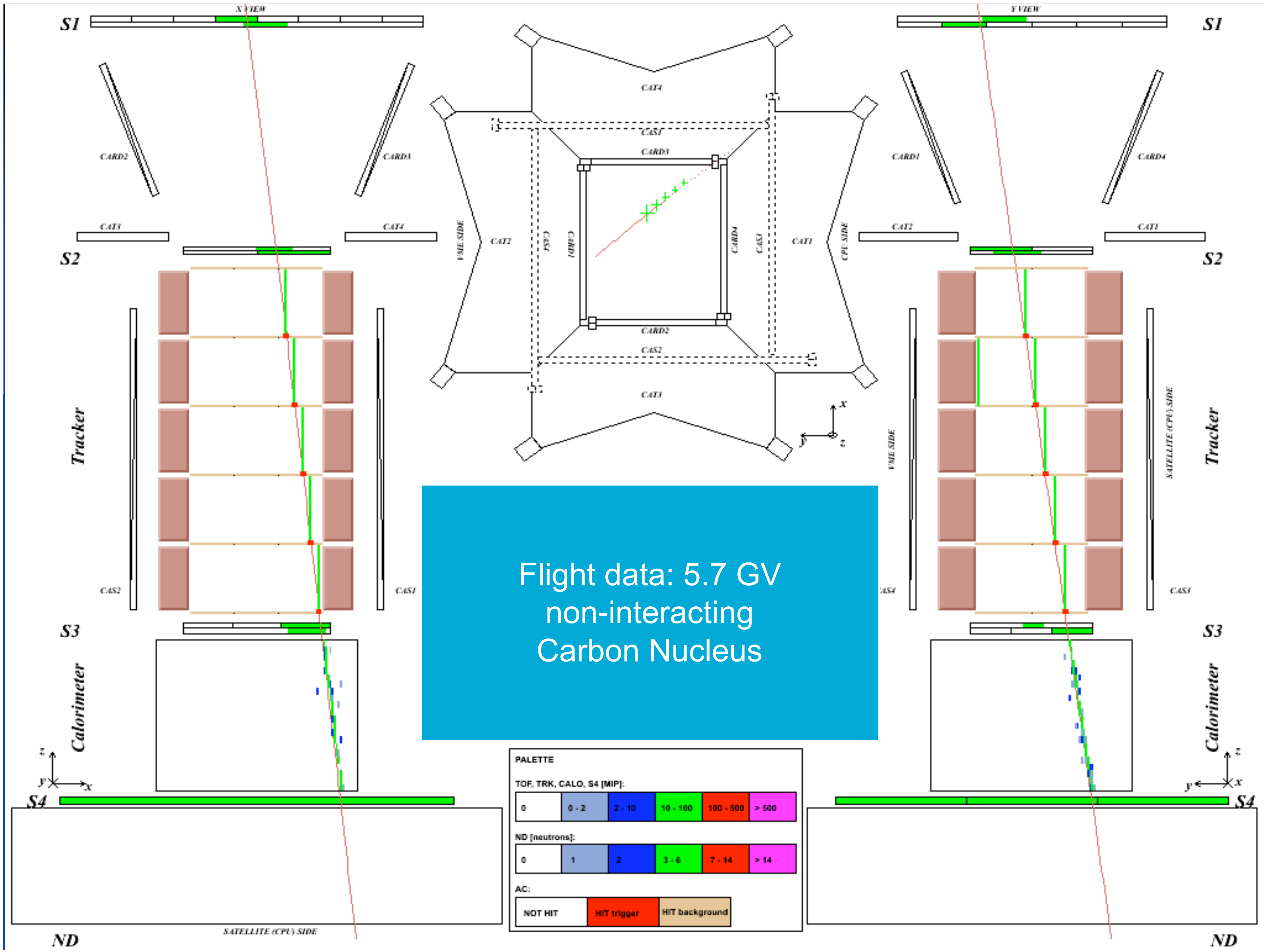
Antiproton flux



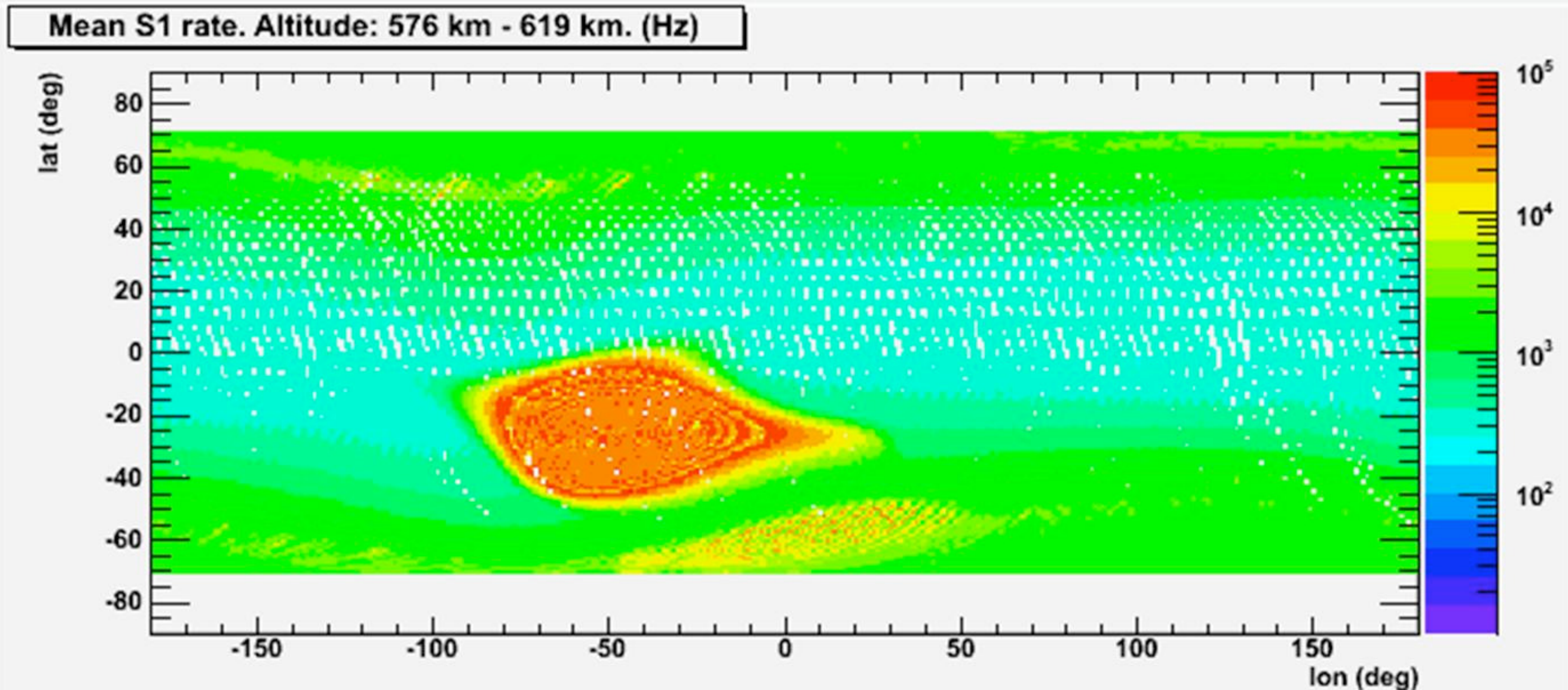
Flight data: 13 GV
Interacting
Helium Nucleus



Flight data: 5.7 GV non-interacting Carbon Nucleus

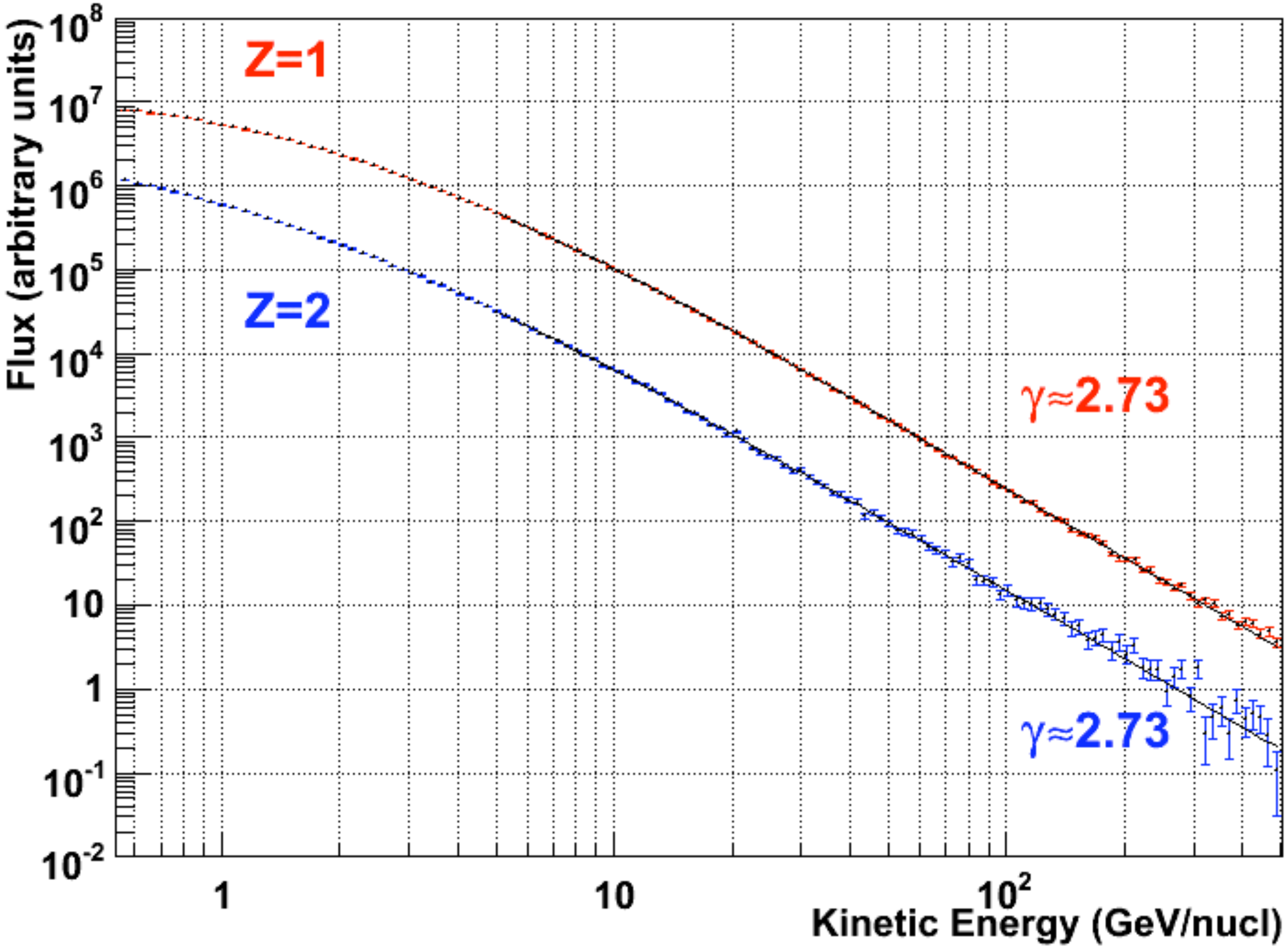


Pamela maps at various altitudes

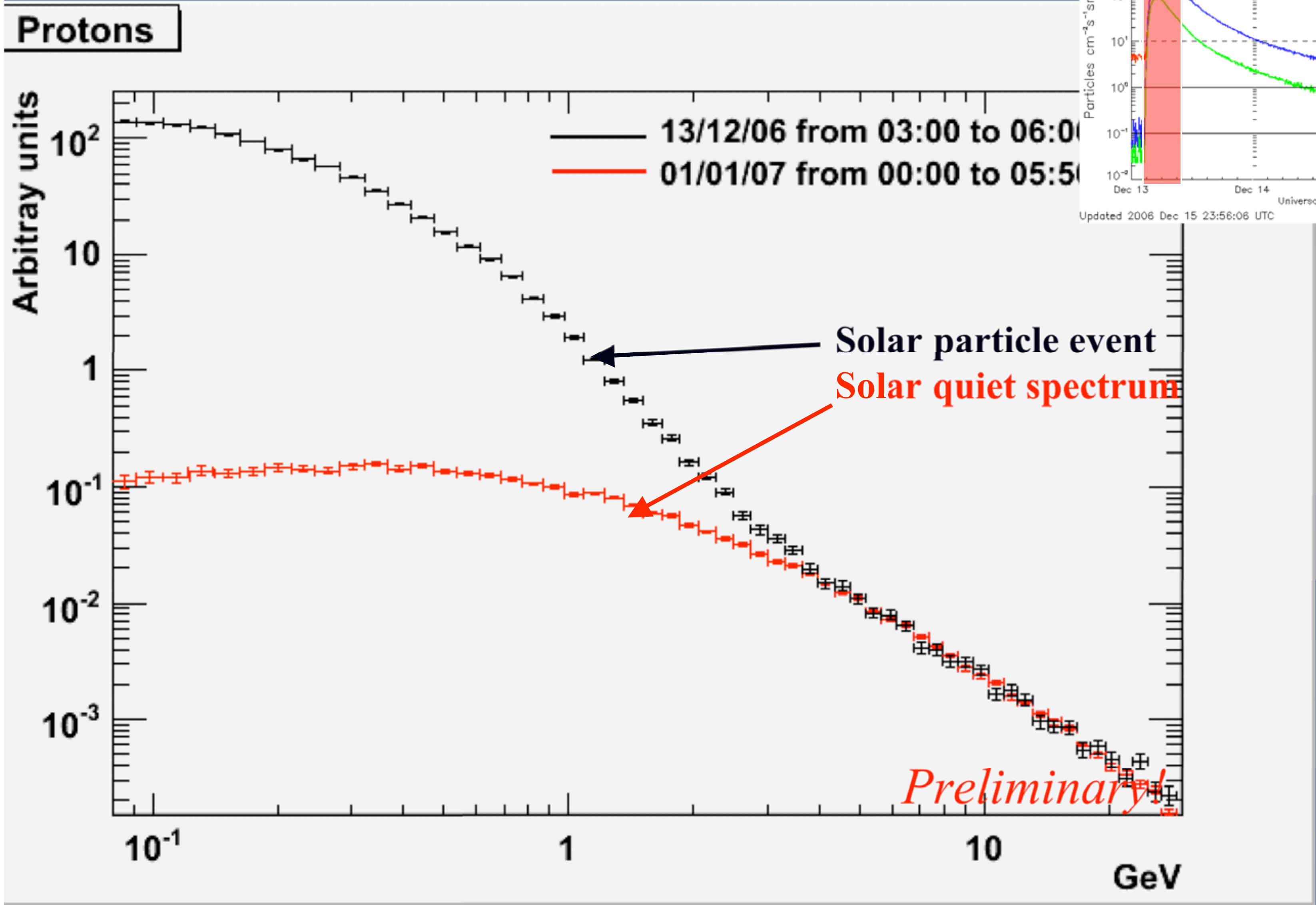


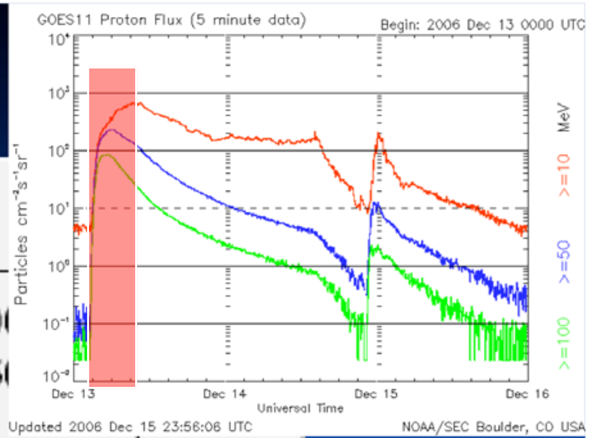
Galactic H and He spectra

Preliminary !!!

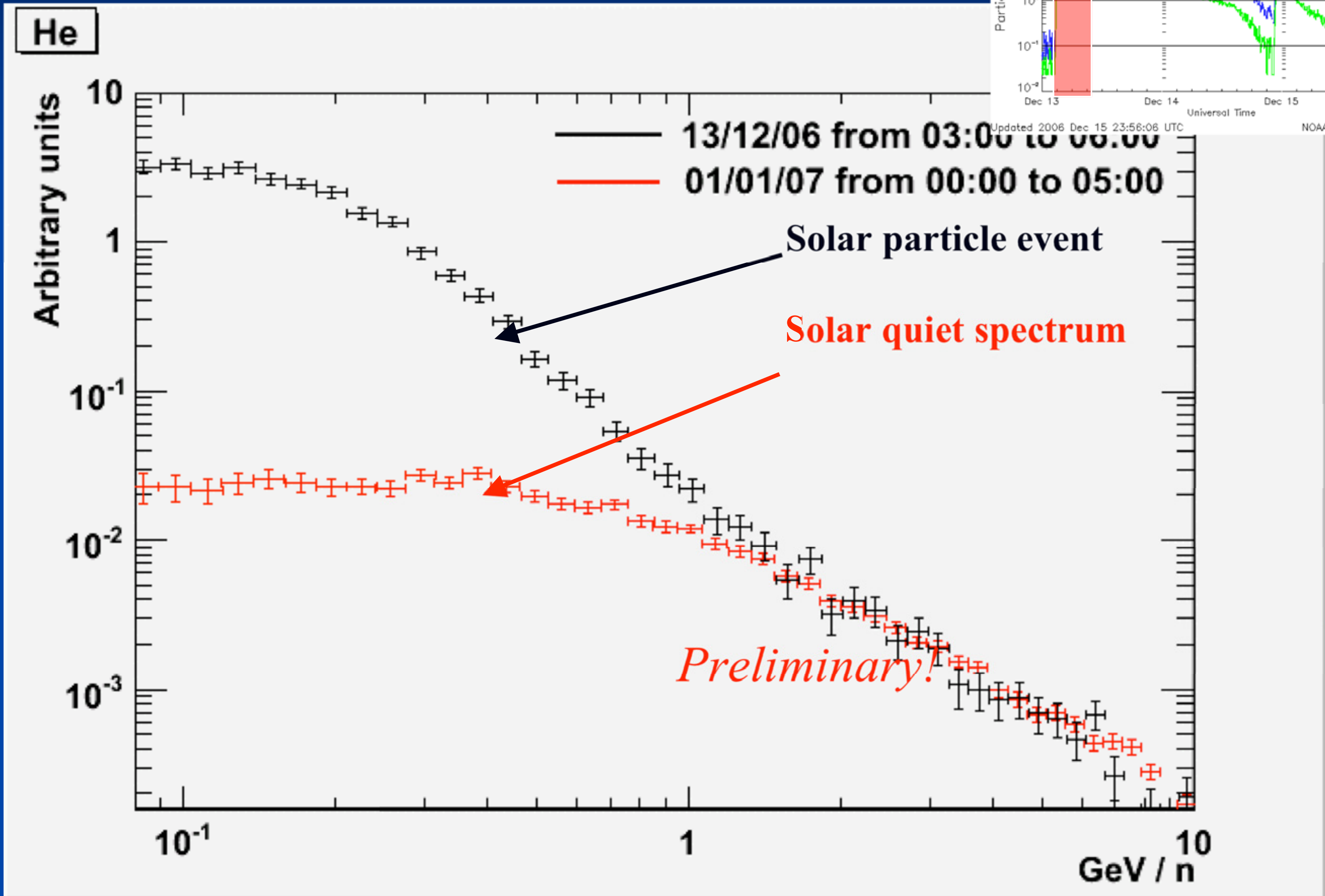


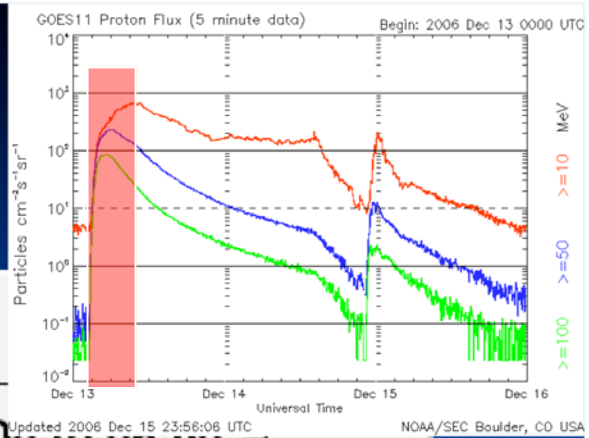
13 december 2006 solar impulsive event



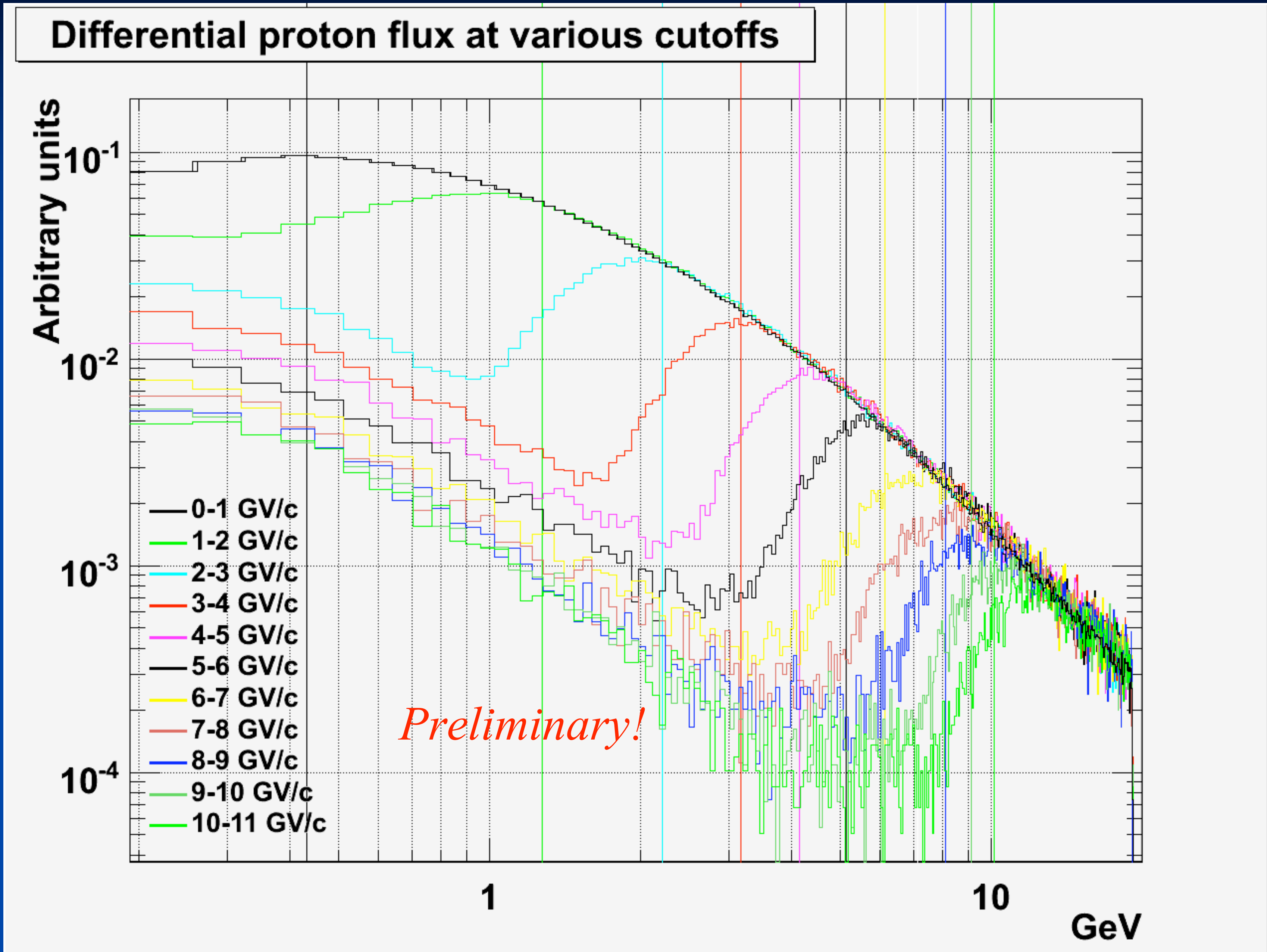


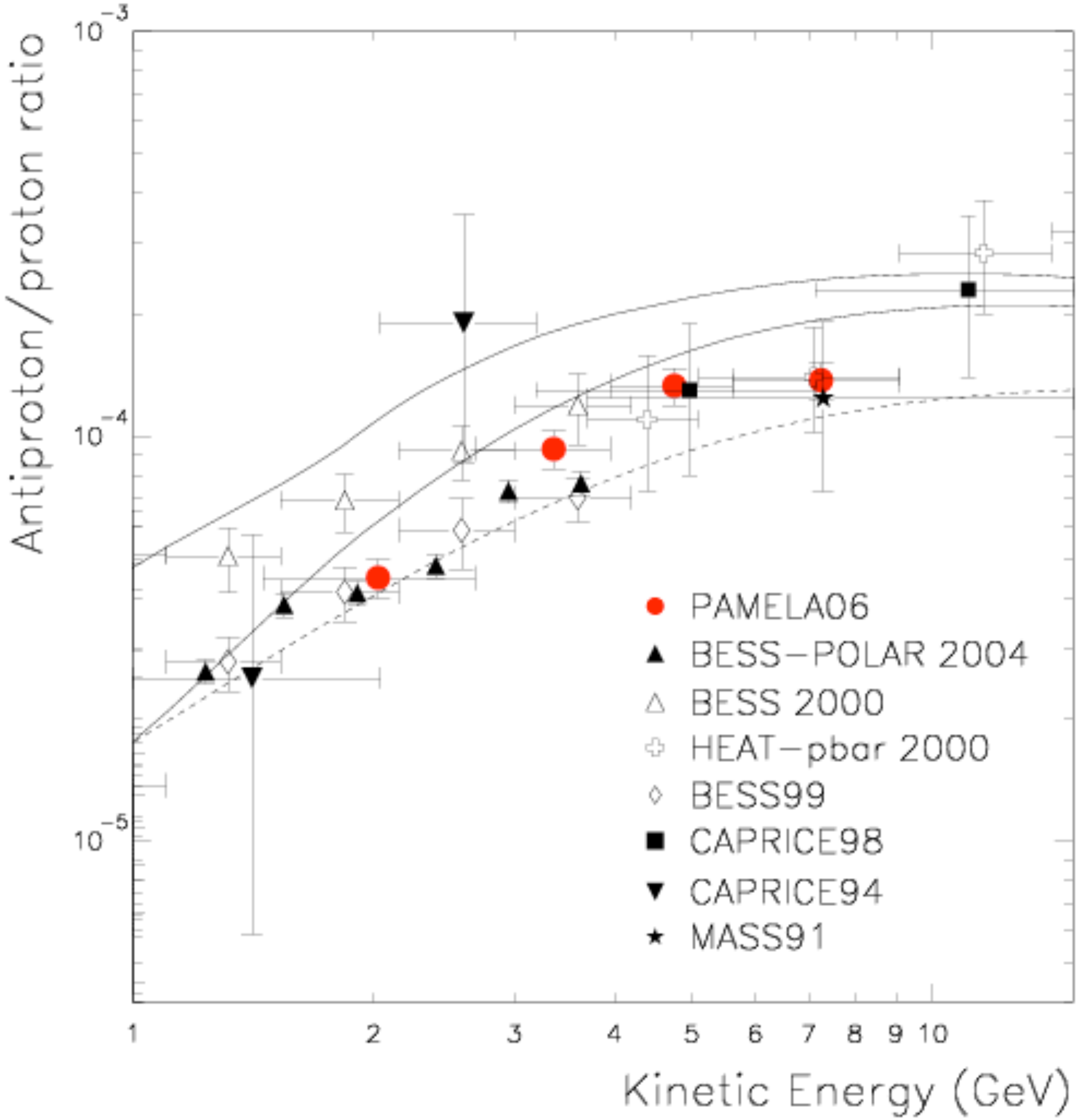
13 december 2006 solar impulsive event



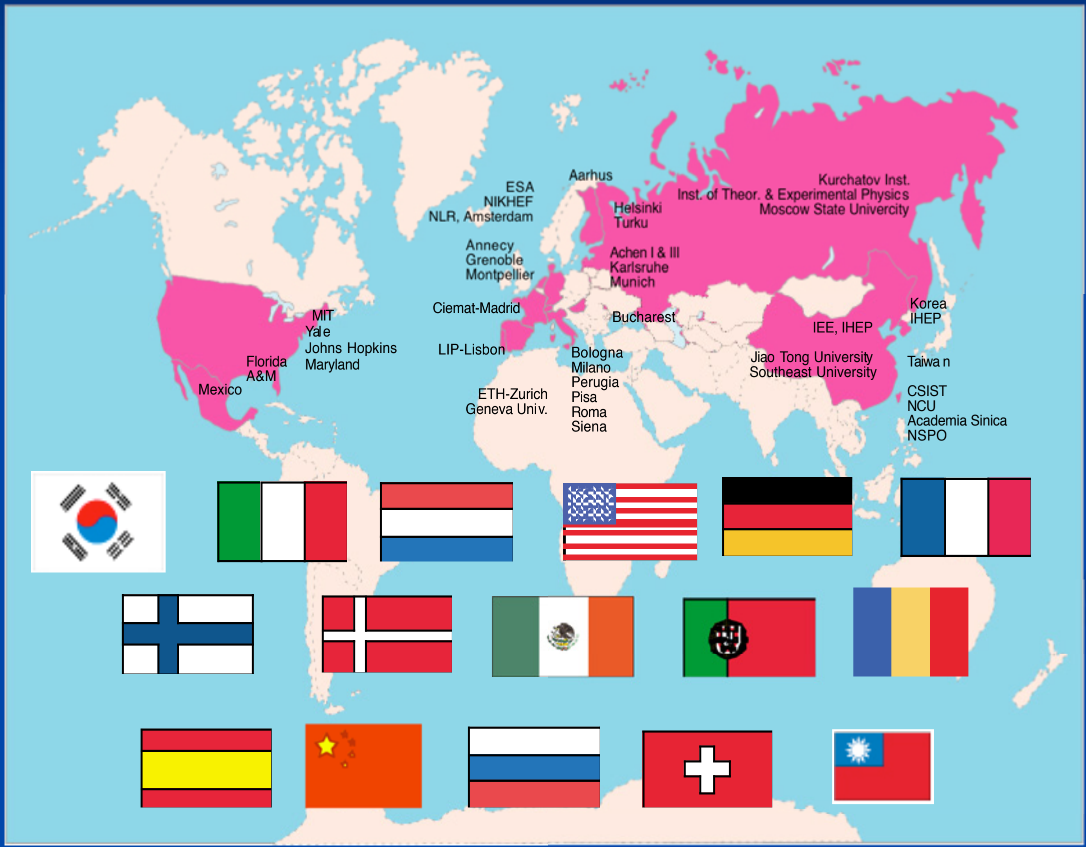


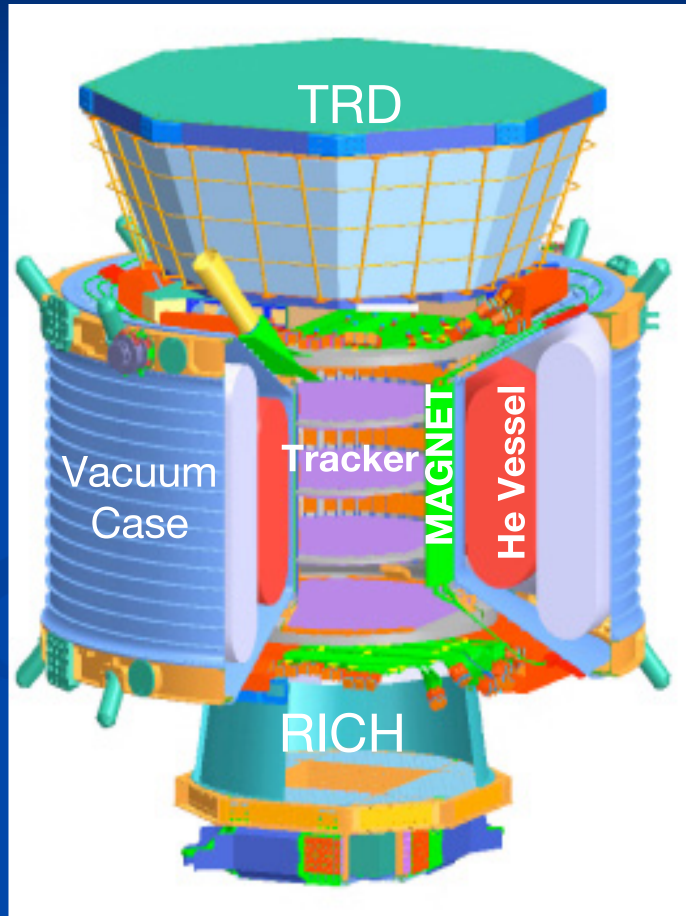
Primary and Albedo (sub-cutoff measurements)




Antiproton/proton ratio
10^{-3}
10^{-4}
10^{-5}
1
2
3
4
5
6
7
8
9
10
Kinetic Energy (GeV)
PAMELA06
BESS−POLAR 2004
BESS 2000
HEAT−pbar 2000
BESS99
CAPRICE98
CAPRICE94
MASS91

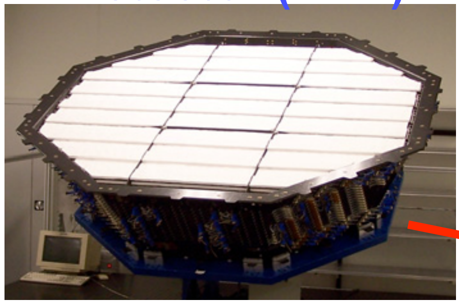
AMS-02 on ISS
In Orbit 2009



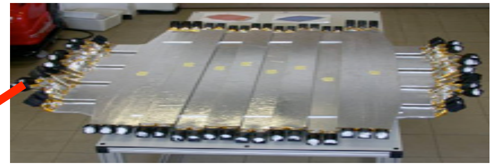


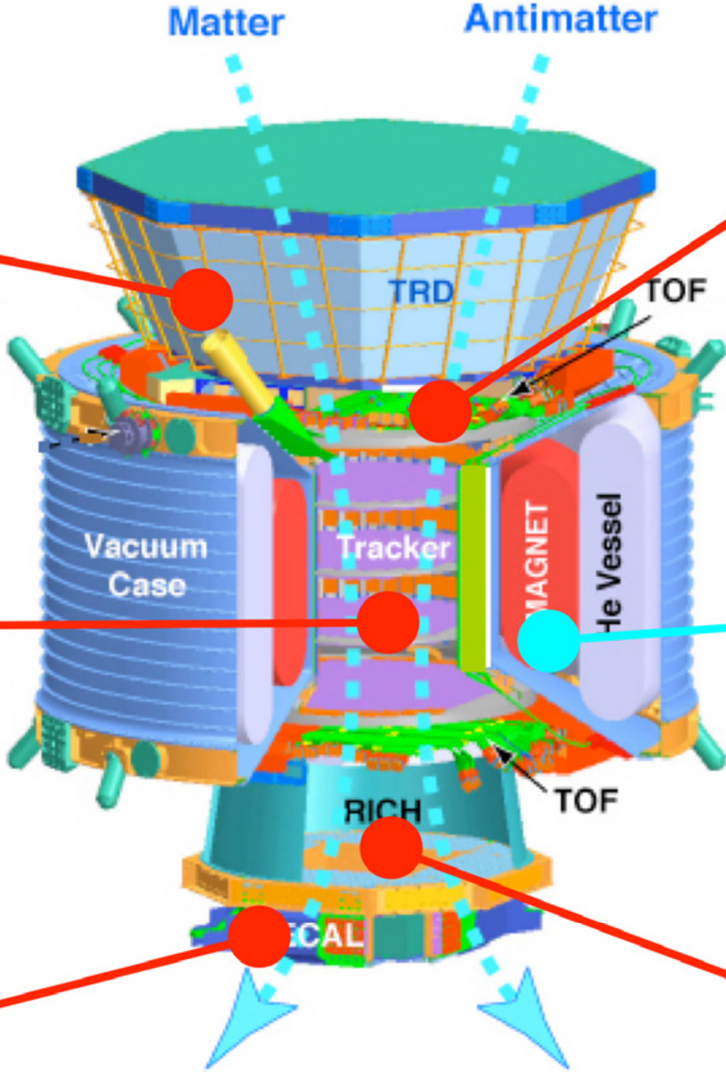
The Completed AMS Detector on ISS

Transition Radiation Detector (TRD)

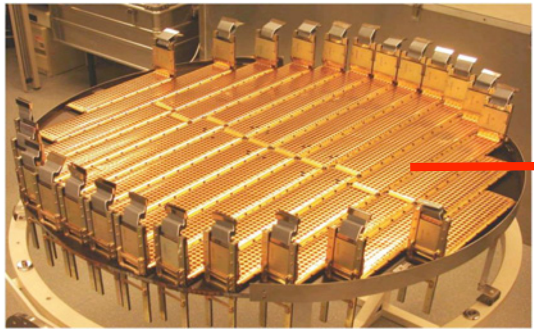


Time of Flight Detector (TOF)

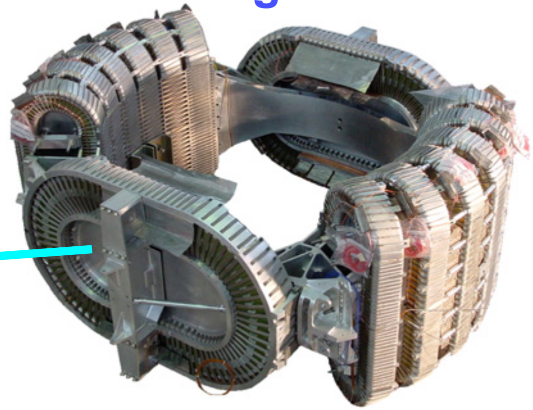




Silicon Tracker

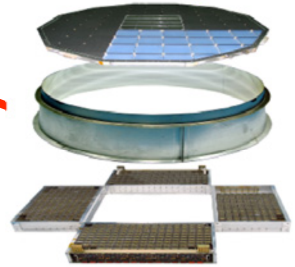


Magnet



Electromagnetic Calorimeter (ECAL)

Ring Image Cerenkov Counter (RICH)



Size: 3m x 3m x 3m
Weight: 7 tons

AMS-02 goals and capabilities

Cosmic rays spectra and chemical composition up to 1 TeV

Search for Antimatter in Space

Search for Dark Matter

Gamma Rays

↓

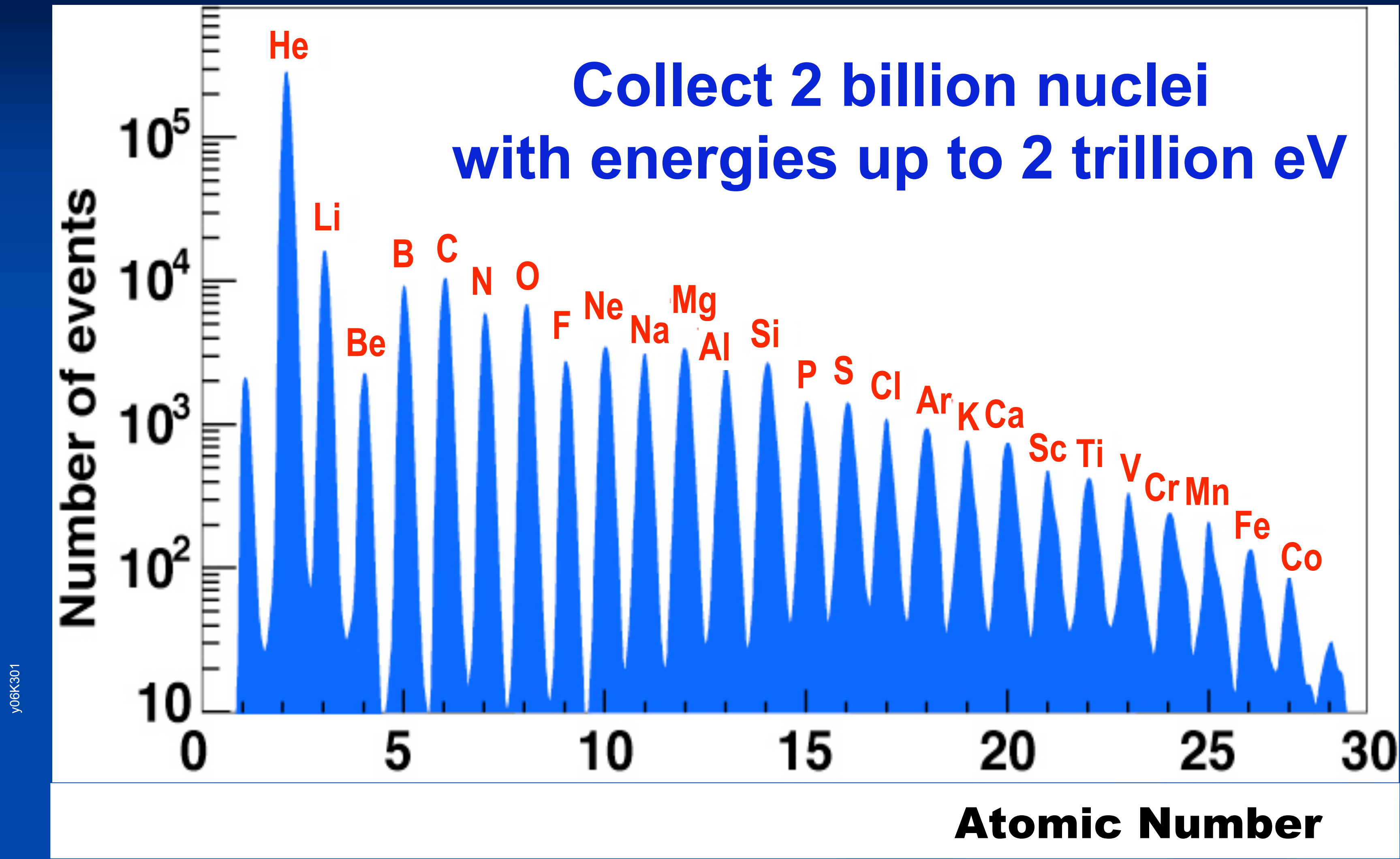
AMS will identify and measure the fluxes for:

- **p for E < 1 TeV with unprecedented precision**
- **e+ for E < 300 GeV and e– for E < 1 TeV (unprecedented precision)**
- **Light Isotopes for E < 10 GeV/n**
- **Individual elements up to Z = 26 for E < 1 TeV/n**

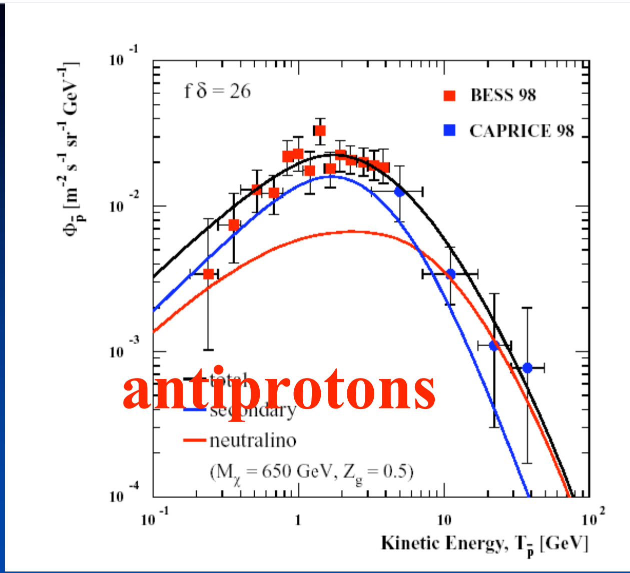
Absolute fluxes and spectrum shapes of protons and helium are important for calculation of atmospheric neutrino fluxes

Composition and spectra are important to constraint propagation, confinement, ISM density

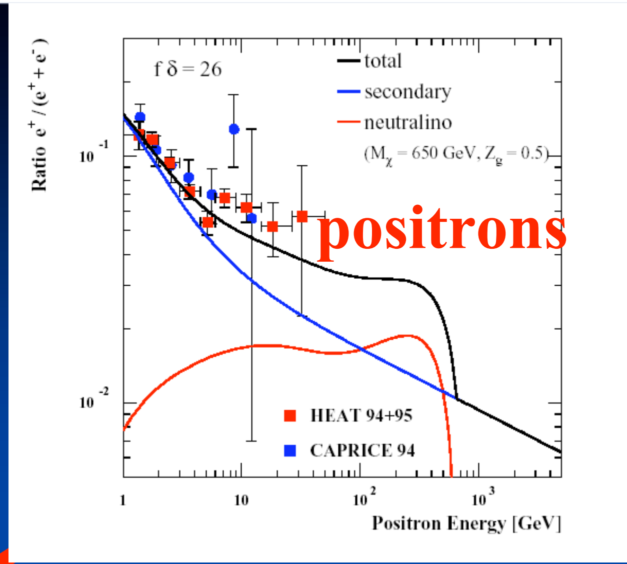
Direct search for antimatter: AMS on ISS



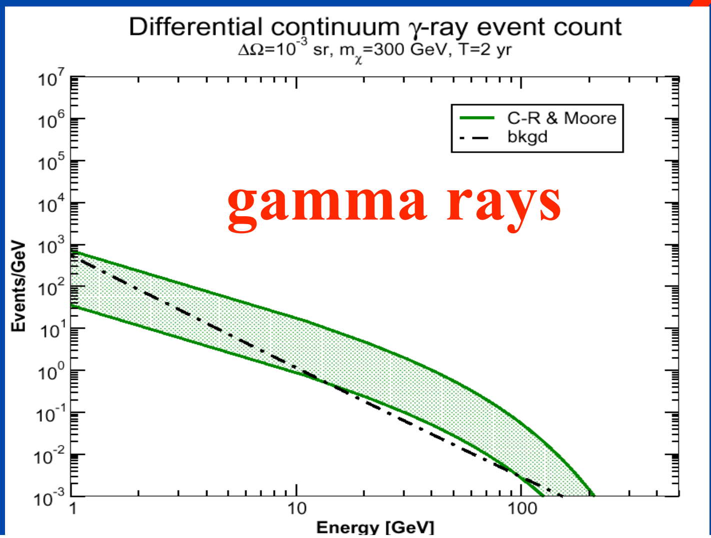
Sensitivity of AMS: **If no antimatter is found => there is no antimatter to the edge of the observable universe (~ 1000 Mpc).**

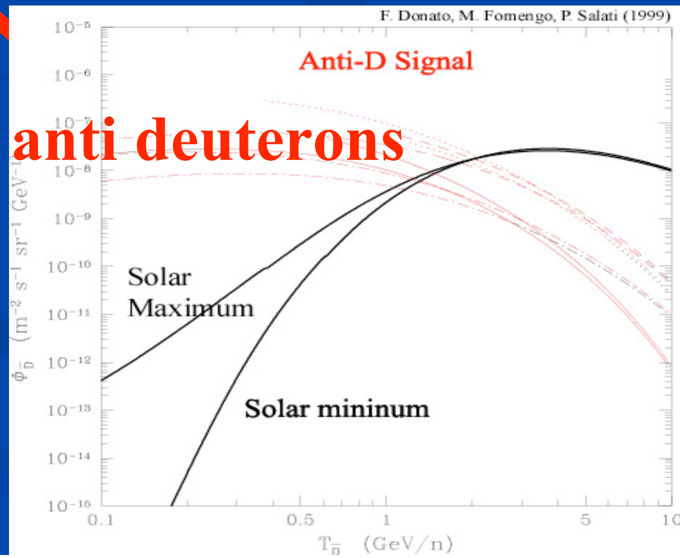


Unique Feature Of AMS



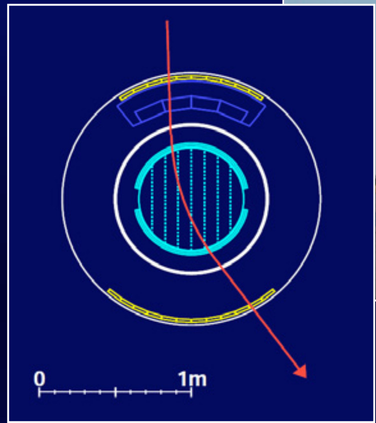
Combining searches in different channels could give (much) higher sensitiviy to SUSY DM signals





BESS

***B**alloon-borne*
***E**xperiment with a*
***S**uperconducting*
***S**pectrometer*



Search for
Primordial Antiparticle

antiproton: Novel primary origins (PBH,DM)
antihelium: Asymmetry of matter/antimatter

Precise Measurement of Cosmic-ray flux:

highly precise measurement at < 1 TeV

BESS Collaboration

As of April, 2006

High Energy Accelerator Research Organization(KEK)

National Aeronautical and Space Administration Goddard Space Flight Center

The University of Tokyo

BESS Collaboration

University of Maryland

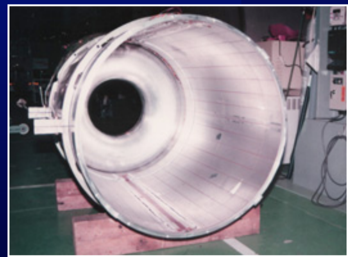
Kobe University

University of Denver (Since June 2005)

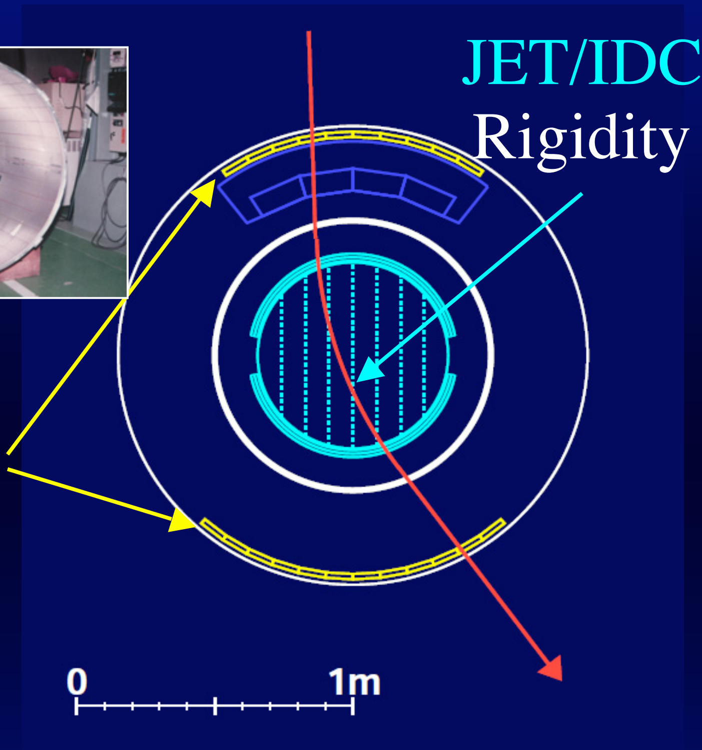
Institute of Space and Astronautical Science/JAXA

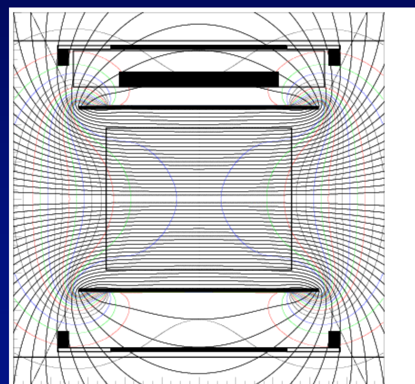
BESS Detector

- **Rigidity measurement**
  - SC Solenoid (L=1m, B=1T)
  - Min. material (4.7g/cm^2)
  - Uniform field
  - Large acceptance
- Central tracker
  - (Drift chamber
  - $\delta \sim 200\,\mu\mathrm{m}$
- ***Z, m* measurement**
  - R,β --> $m = ZeR\sqrt{1/\beta^2-1}$
  - dE/dx --> Z



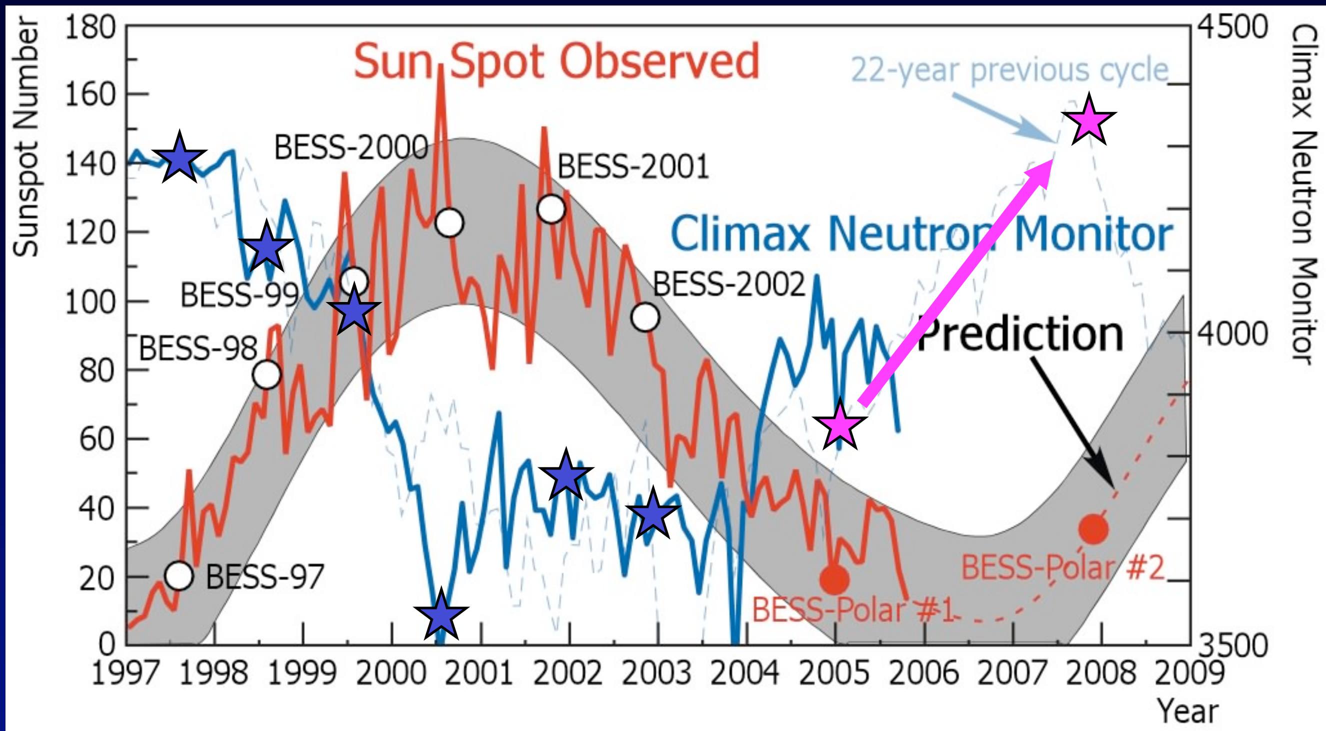
TOF
β, dE/dx



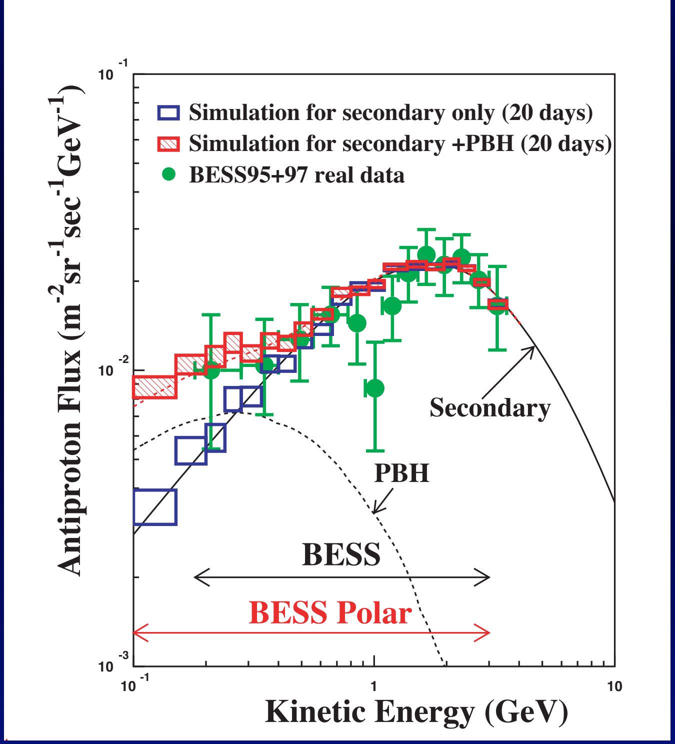


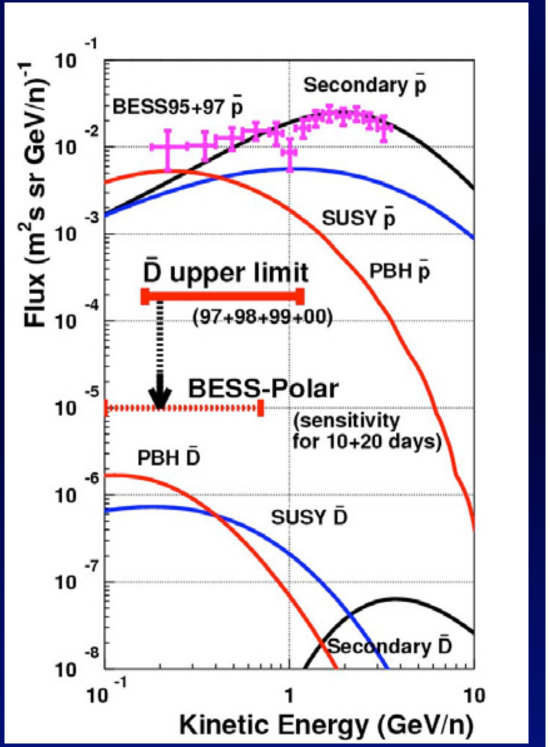
BESS-Polar II December 2007

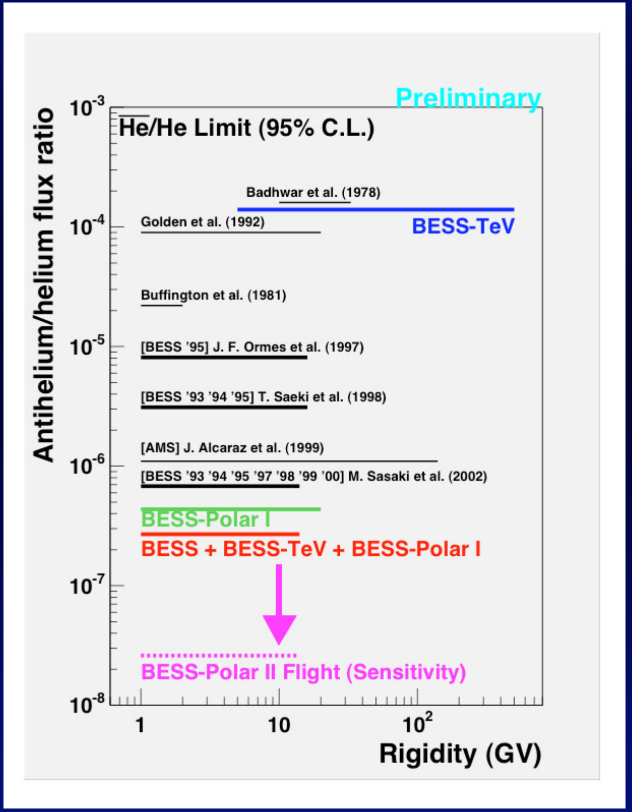
- Long duration flight of **20 days** with two circle around the pole, **4~5 x BESS-Polar I statistics**
- Combined measurements with PAMELA



BESS Polar II Observation (Expected)



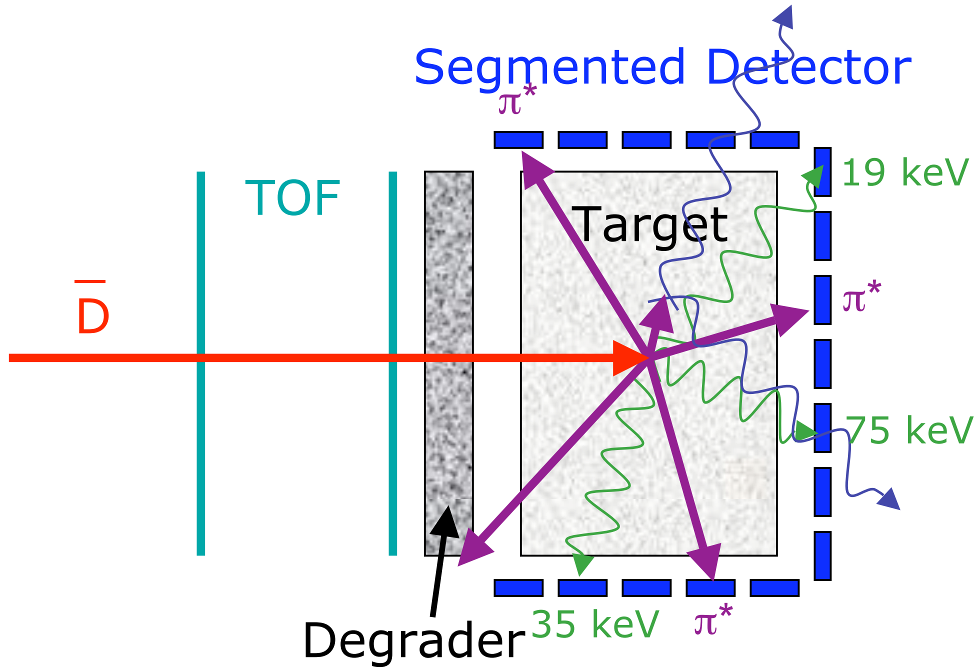


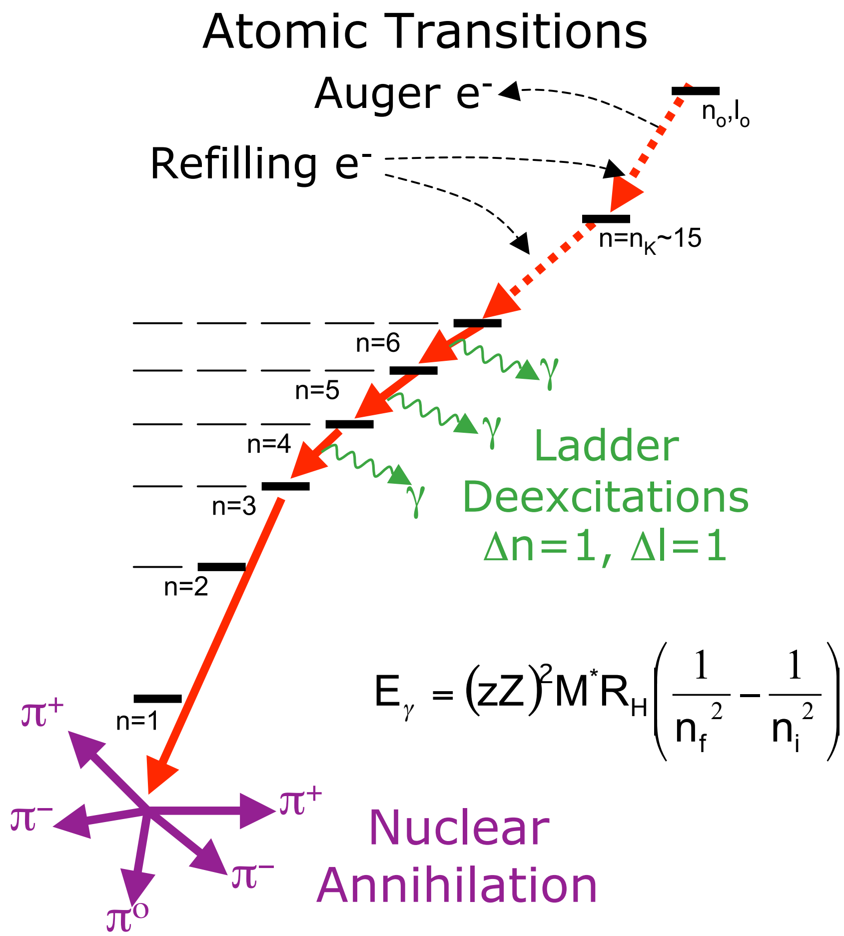


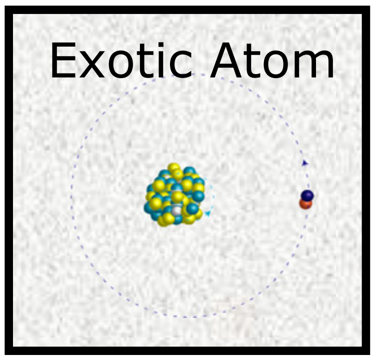
Antiproton Spectrum **Search for Antideuteron and AntiHelium**

(Search for PBH)

General Antiparticle Spectrometer (GAPS)



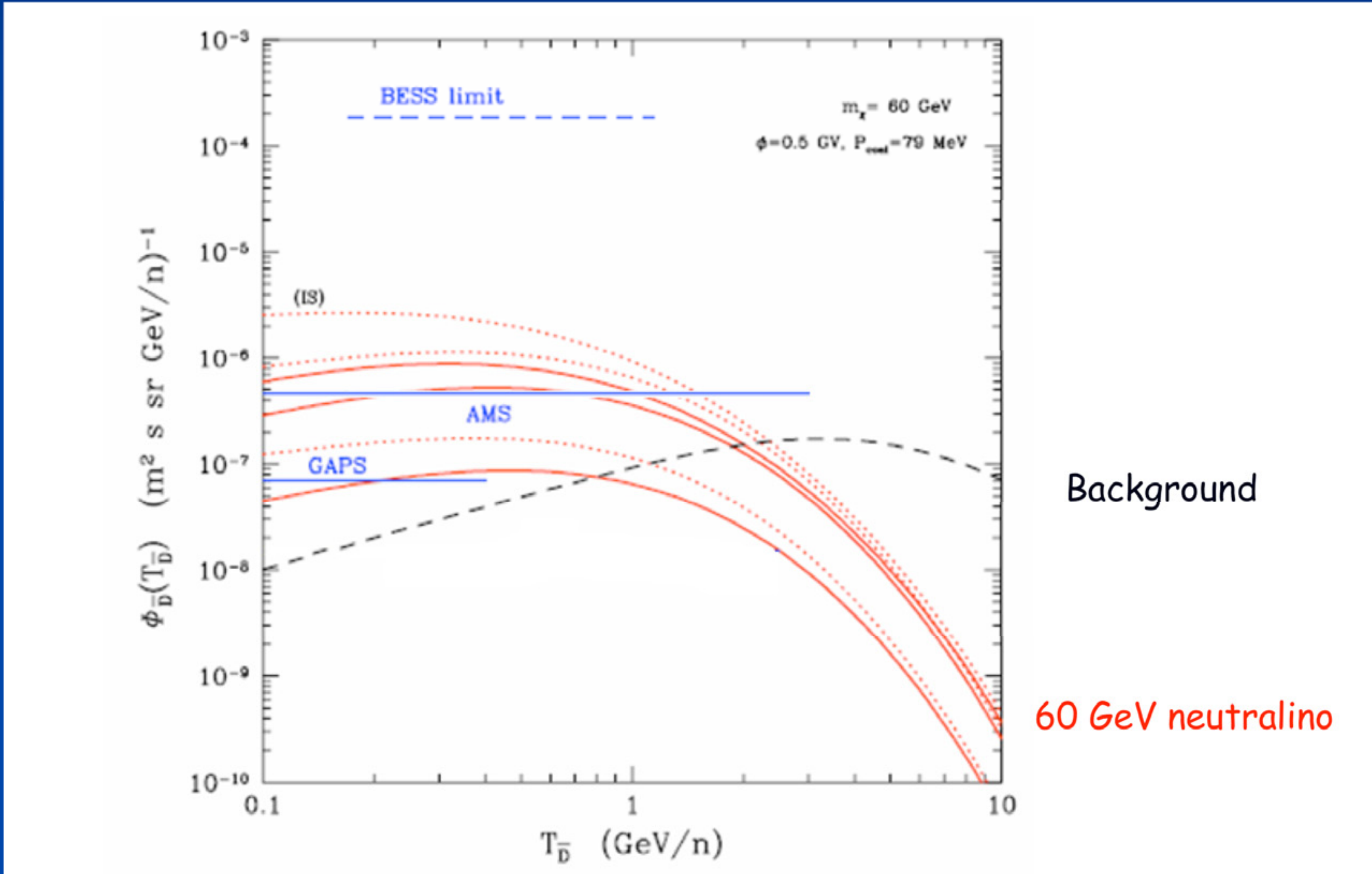




K.Mori *et al.* APJ 566 604-616 2002

Antideuterons

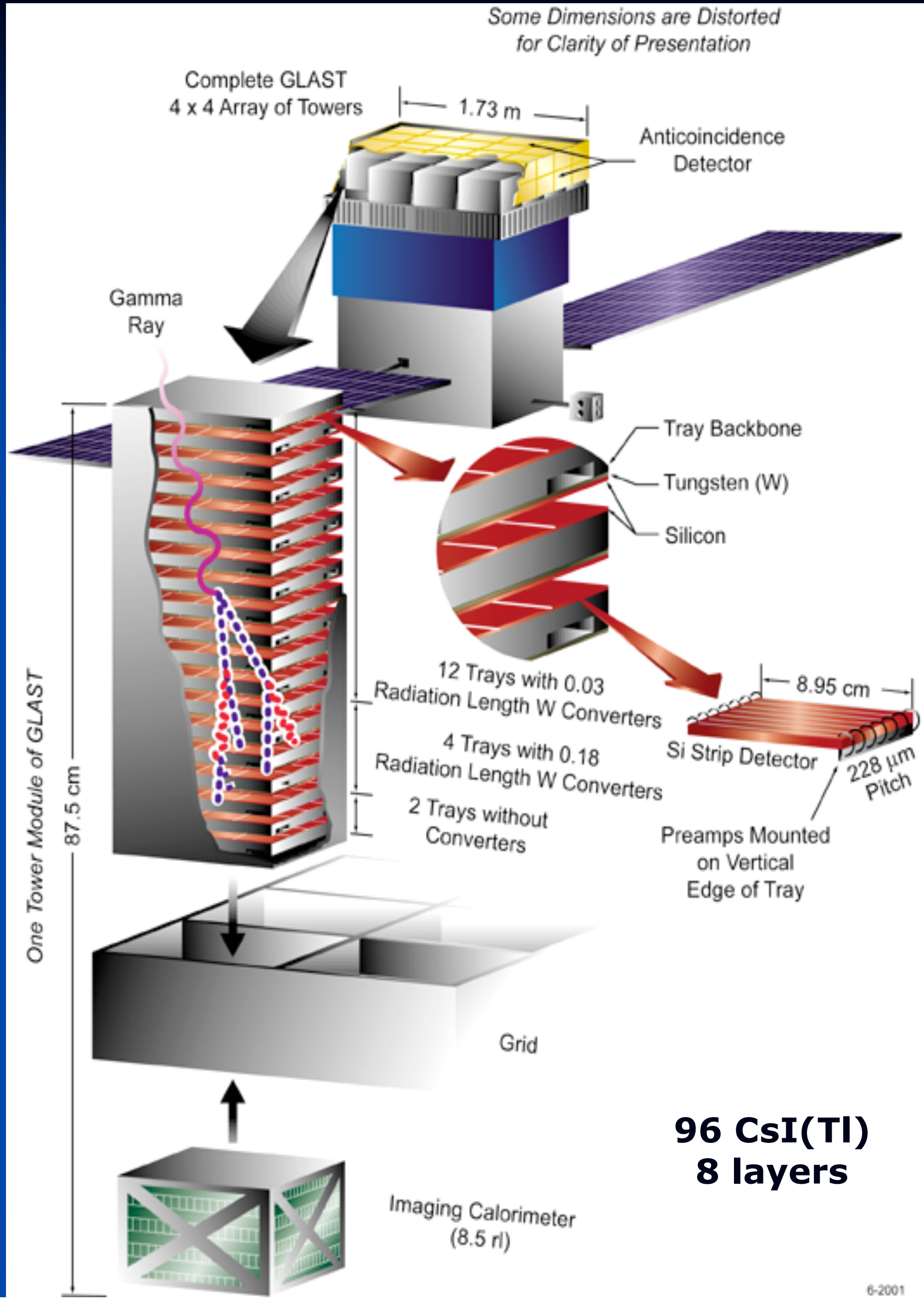
F. Donato et al. – 30th ICRC 2007



GLAST

Gamma-Ray
Large Area Space
Telescope

3000 kg, 650 W
1.8 m x 1.8 m x 1 m
20 MeV – 300 GeV



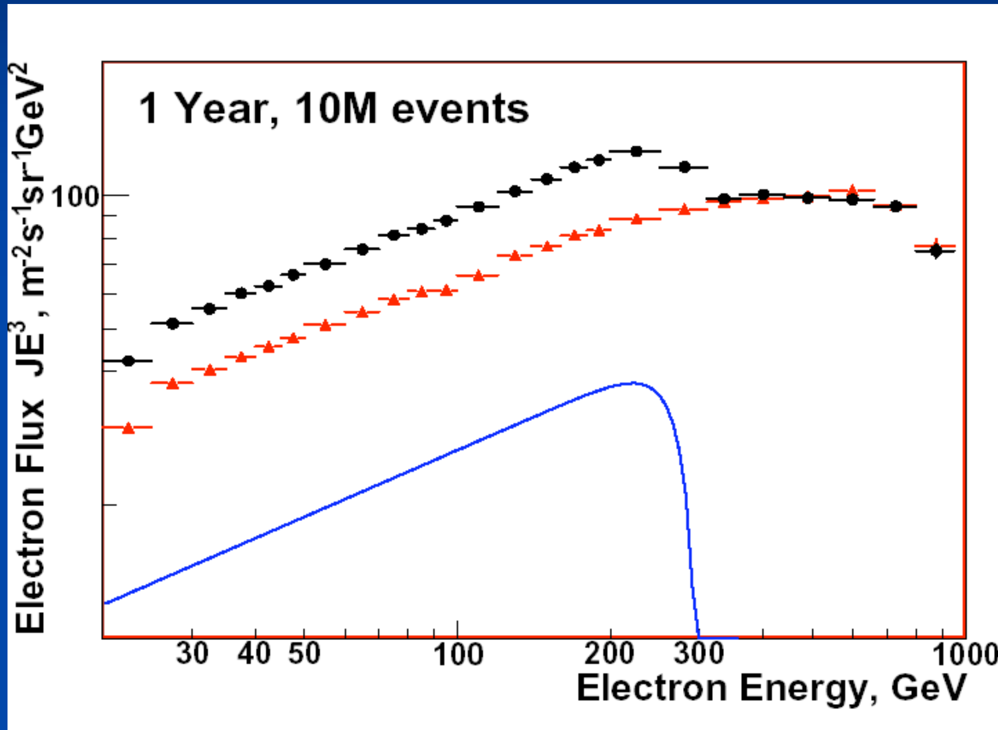
LKP Detection by LAT

Very, very favorable situation:

- LKP mass = 300 GeV
- e^- + e^+ yield direct annihilation ~20% of the total
- Single (closest) clump
- 1 year observation

Moiseev et al. – 30th ICRC 2007

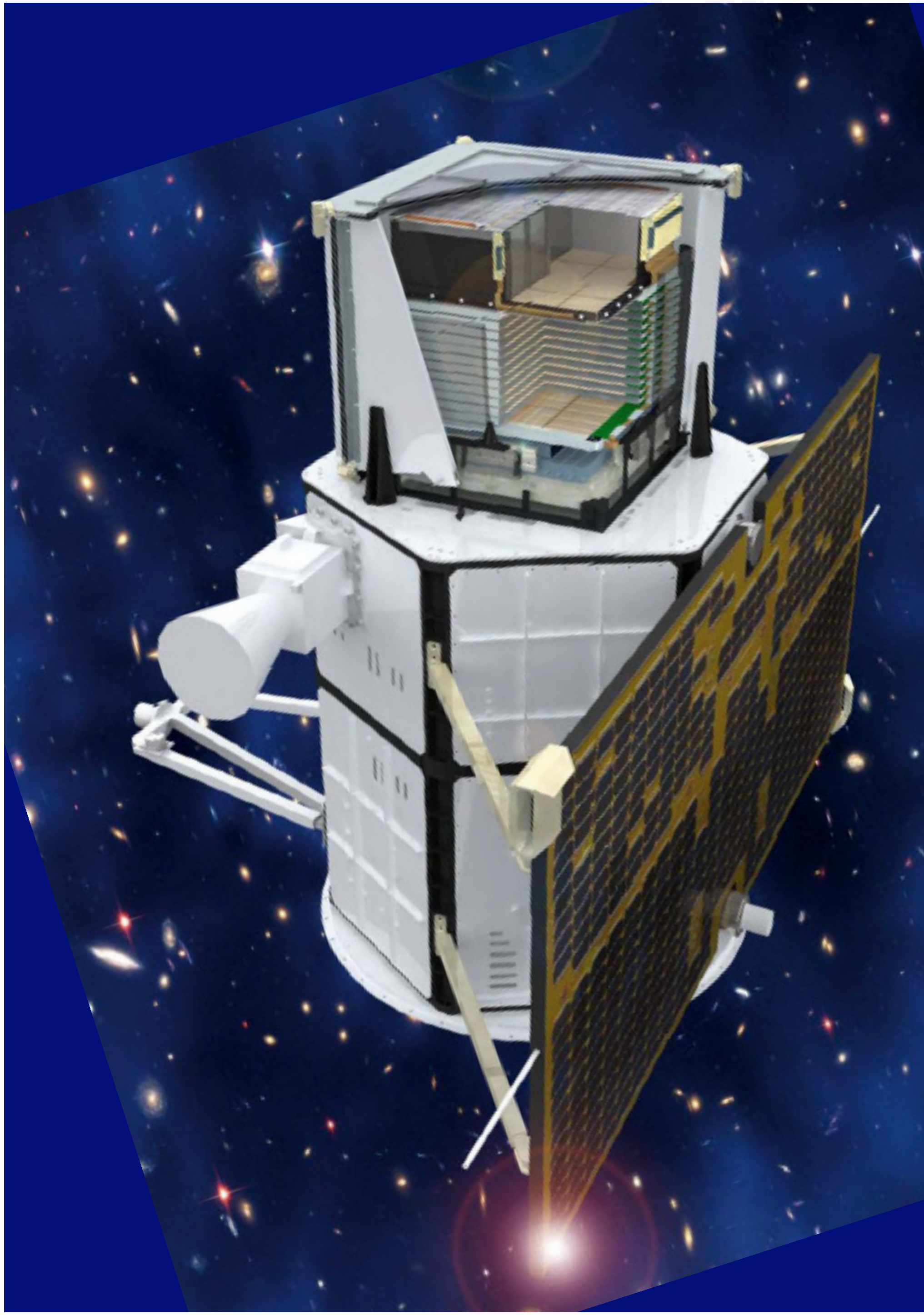
Reconstructed LAT electron spectrum



Red points – "conventional" electron flux

Blue line – LKP annihilation in electrons

Black points – reconstructed LAT electron spectrum with LKP



AGILE

the most compact instrument for high-energy astrophysics

It combines for the first time a gamma-ray imager (30 MeV- 30 GeV) with a hard X-ray imager (18-60 keV) with large FOVs (1-2.5 sr) and optimal angular resolution

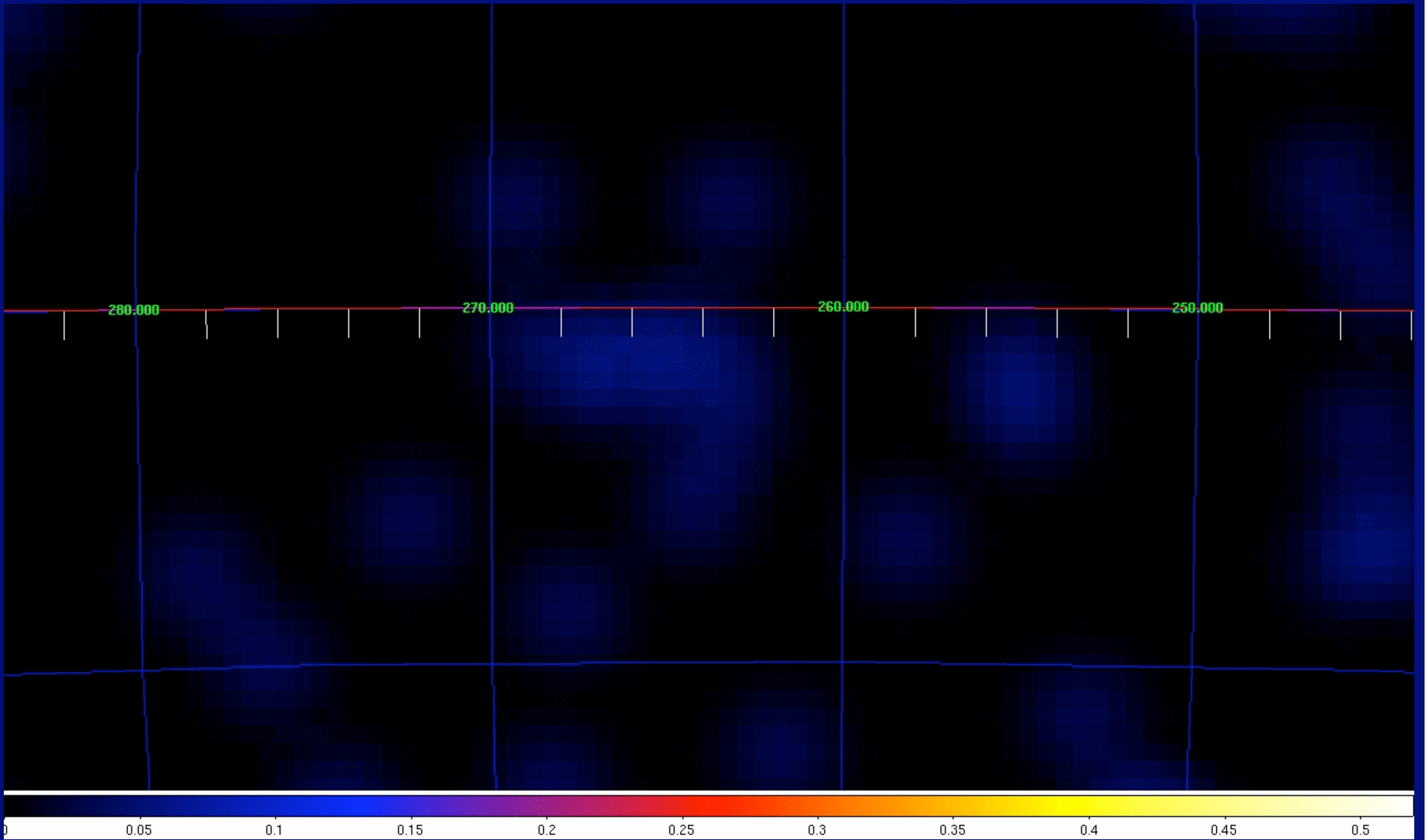
AGILE in orbit

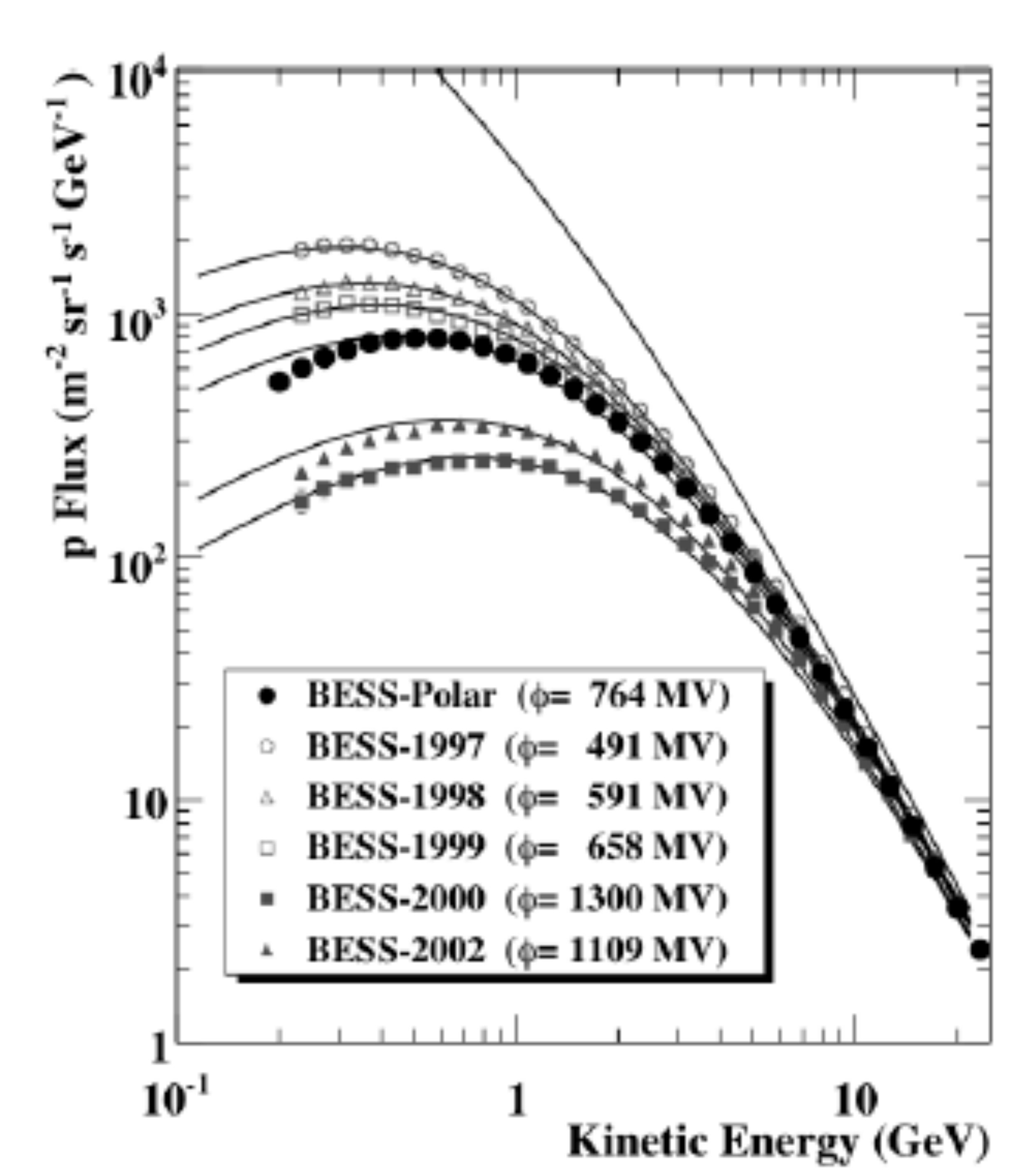
April 23, 2007

ISRO Sriharikota base,
PSLV-C8

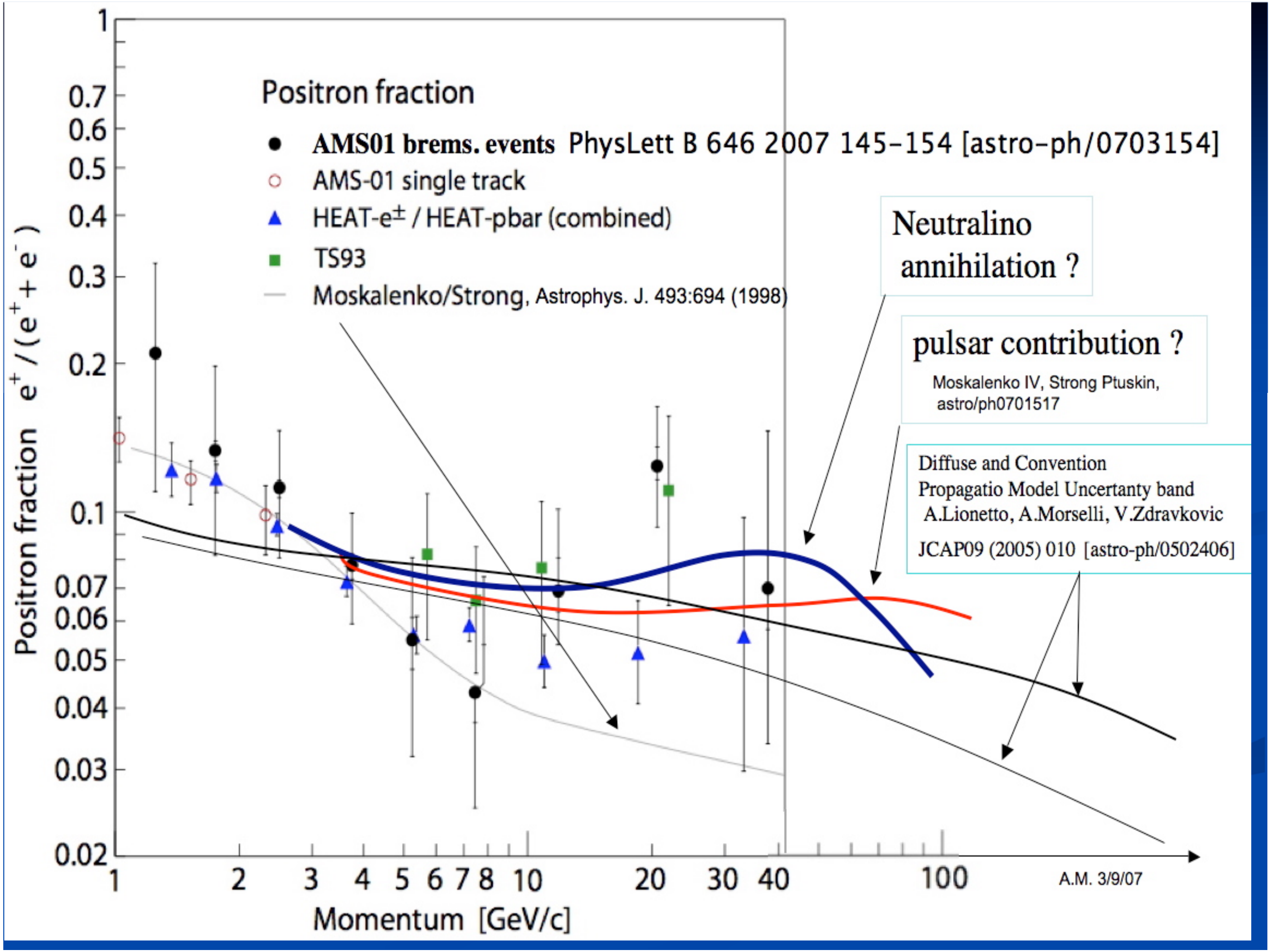
AGILE gamma-ray detection of the Vela PSR

12 orbits data accumulation of the Vela PSR region

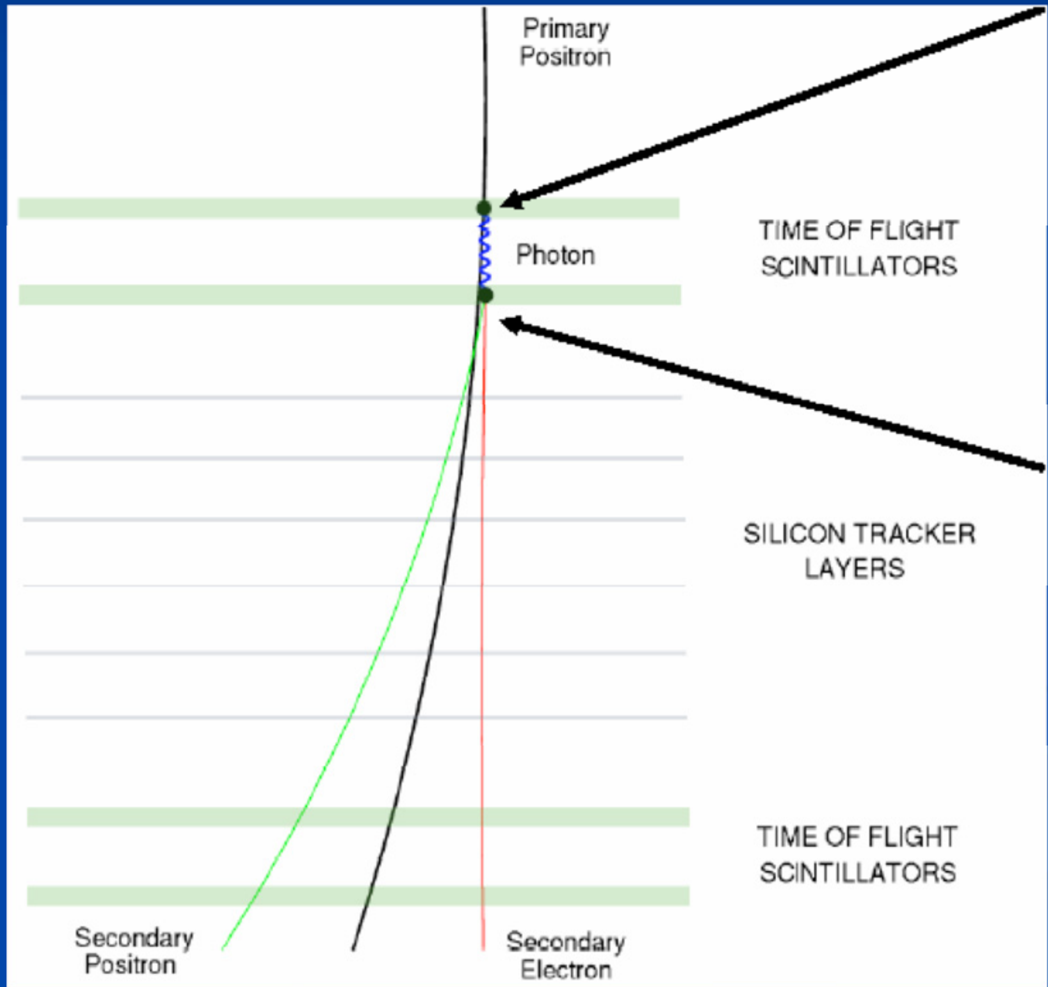


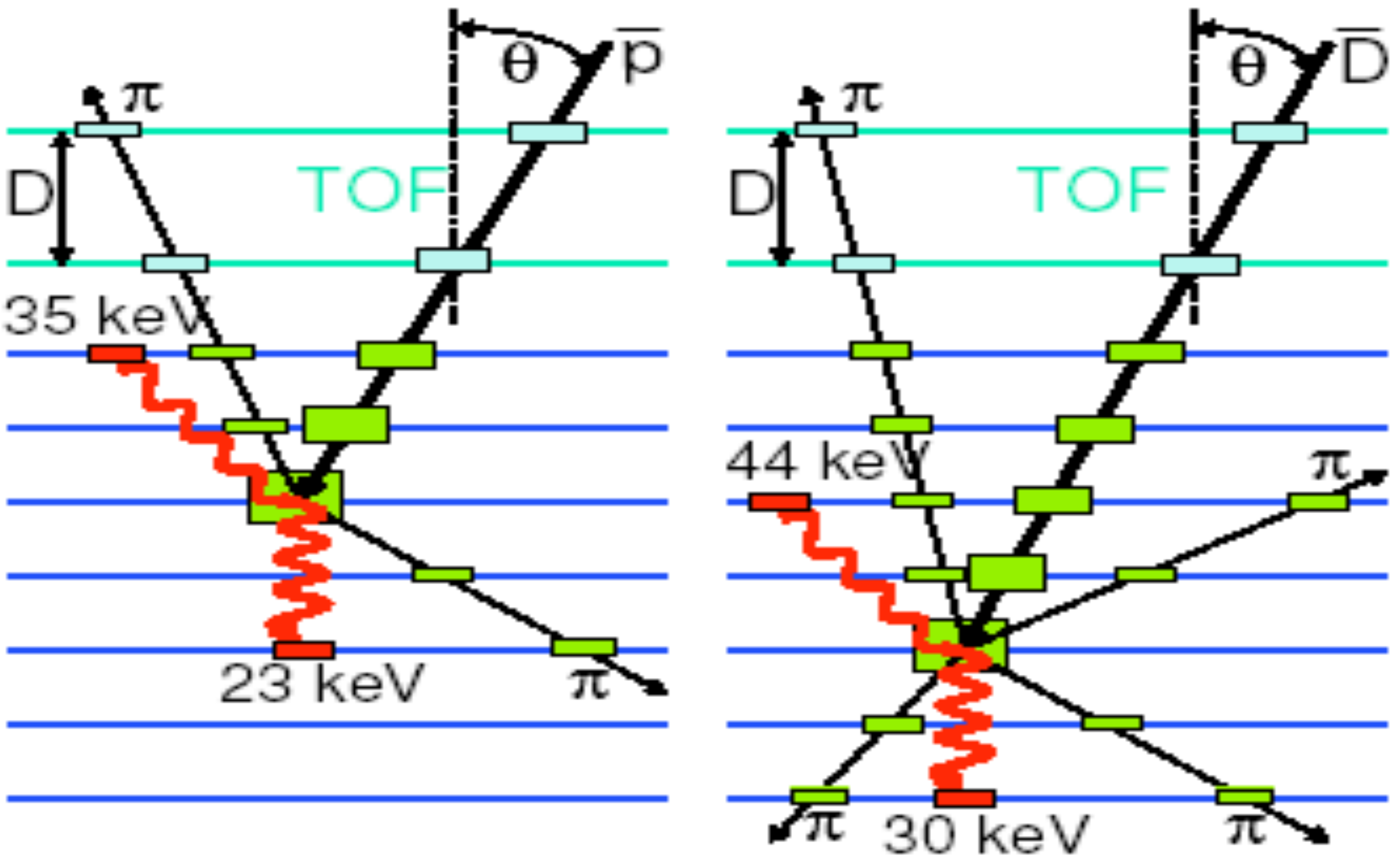


BESS Coll.
30th ICRC 2007


Positron fraction
AMS01 brems. events PhysLett B 646 2007 145-154 [astro-ph/0703154]
AMS-01 single track
HEAT-e± / HEAT-pbar (combined)
TS93
Moskalenko/Strong, Astrophys. J. 493:694 (1998)
Neutralino annihilation ?
pulsar contribution ?
Moskalenko IV, Strong Ptuskin, astro/ph0701517
Diffuse and Convention Propagatio Model Uncertanty band
A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09 (2005) 010 [astro-ph/0502406]
Positron fraction e+/(e+ + e-)
Momentum [GeV/c]
A.M. 3/9/07

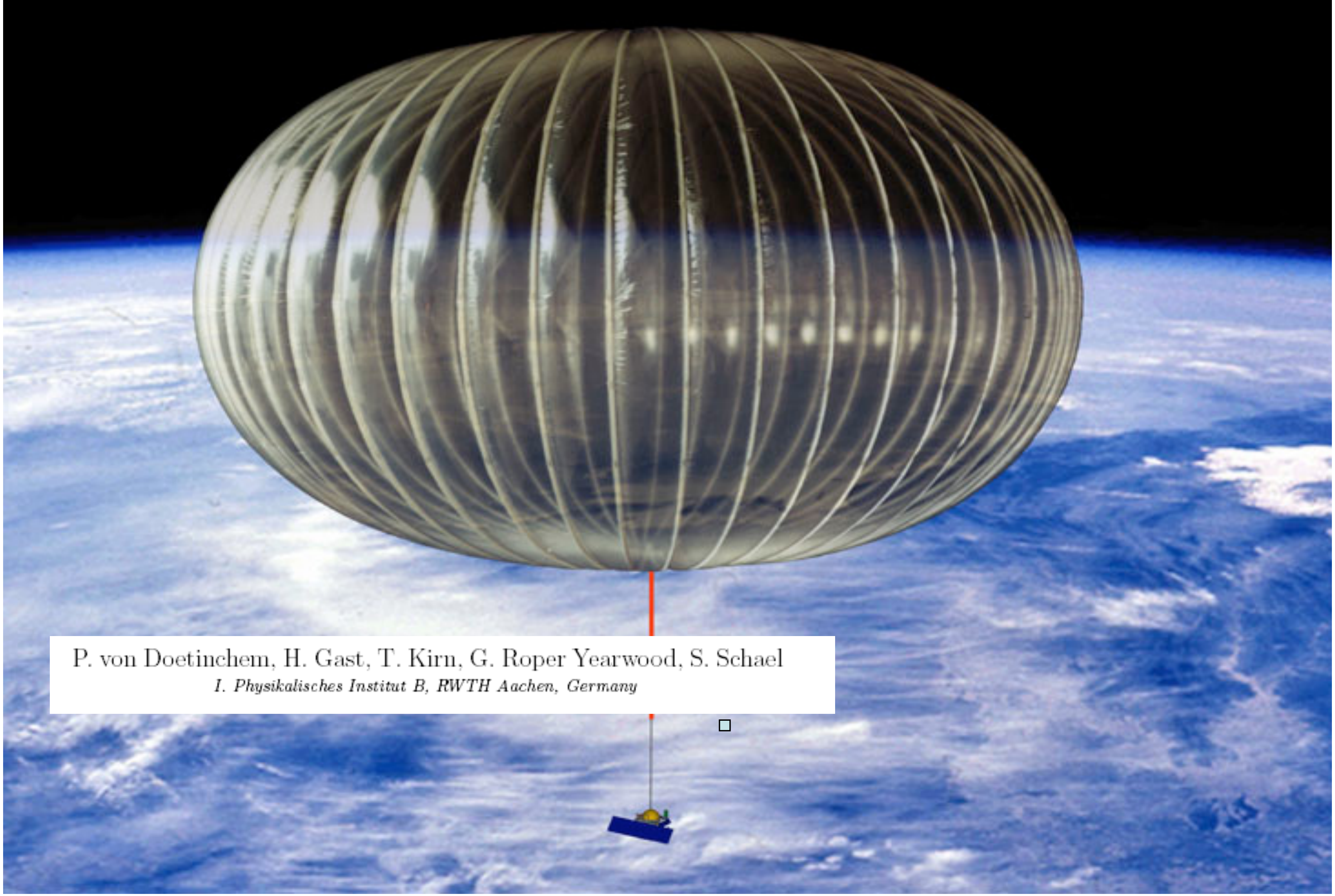
AMS-01 Bremstrahlung event



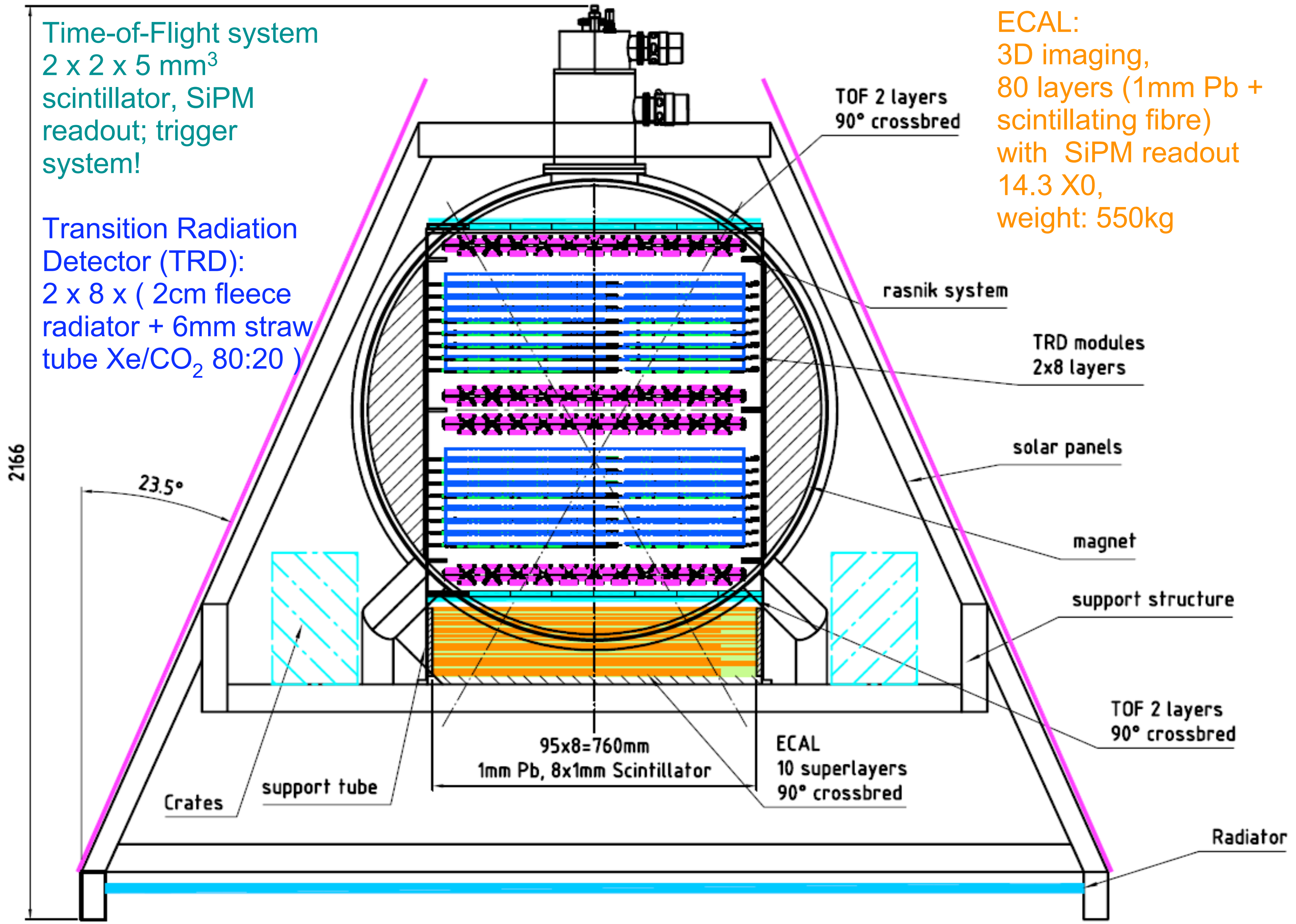


J.E. Koglin *et al*. 30th ICRC 2007

PEBS - Positron Electron Balloon Spectrometer

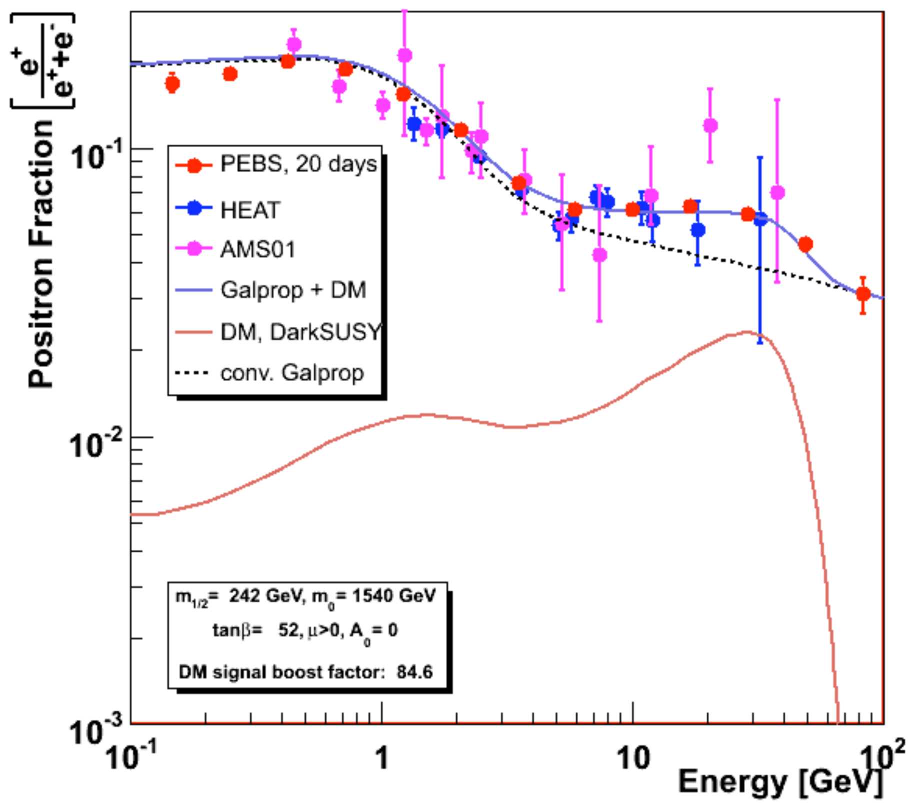


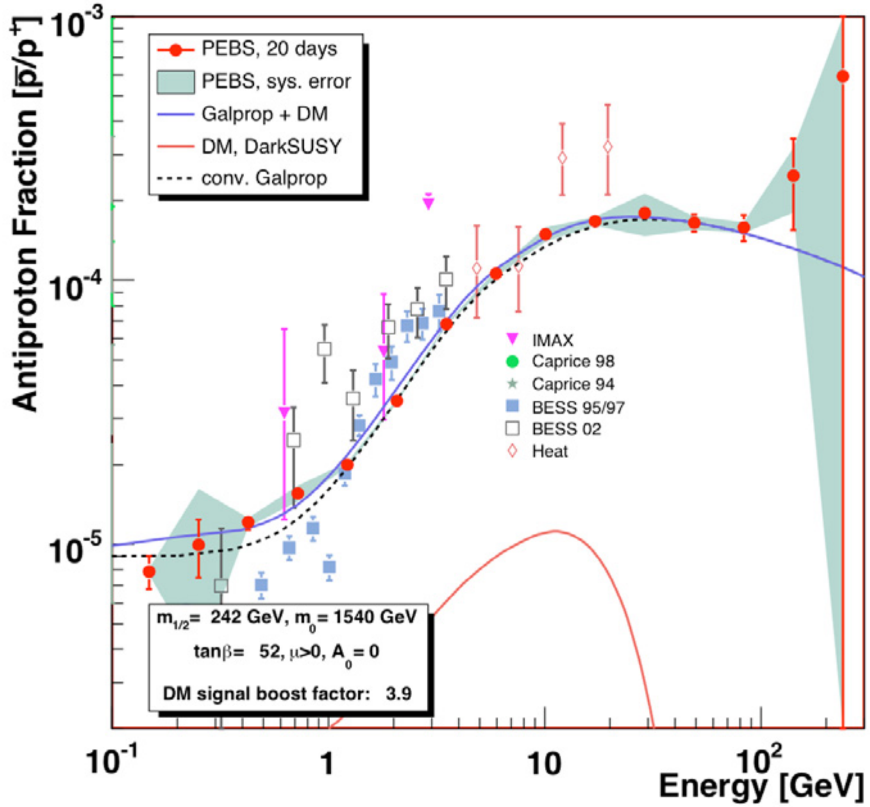
P. von Doetinchem, H. Gast, T. Kirn, G. Roper Yearwood, S. Schael
I. Physikalisches Institut B, RWTH Aachen, Germany



Time-of-Flight system
2 x 2 x 5 mm^3
scintillator, SiPM
readout; trigger
system!
Transition Radiation
Detector (TRD):
2 x 8 x (2cm fleece
radiator + 6mm straw
tube Xe/CO_2 80:20)
ECAL:
3D imaging,
80 layers (1mm Pb +
scintillating fibre)
with SiPM readout
14.3 X0,
weight: 550kg
TOF 2 layers
90° crossbred
rasnik system
TRD modules
2x8 layers
solar panels
magnet
support structure
TOF 2 layers
90° crossbred
Radiator
ECAL
10 superlayers
90° crossbred
95x8=760mm
1mm Pb, 8x1mm Scintillator
support tube
Crates
23.5°
2166

What could be measured with a 2500 cm² sr Experiment ?





PAMELA: 20 cm² sr
AMS-02: 500 cm² sr

20 days PEBS = 7 years PAMELA
= 100 days AMS-02

What ever PAMELA or AMS-02 might discover in the positron fraction, we need an independent verification.

GLAST

Large Area Telescope (LAT)
Gamma Ray Burst Monitor (GBM)

(Gamma Ray Burst Monitor) GBM:

correlative transient observations