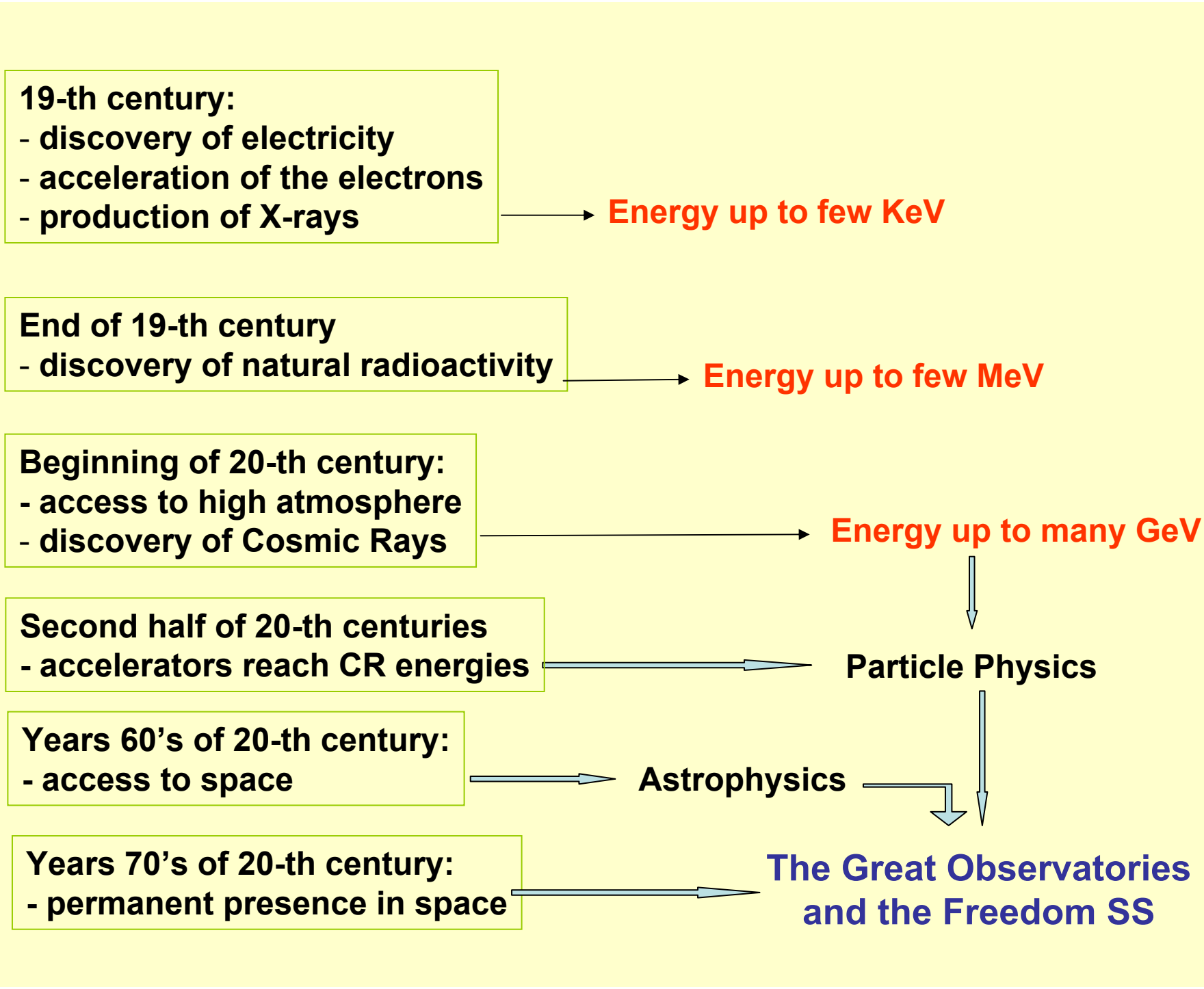
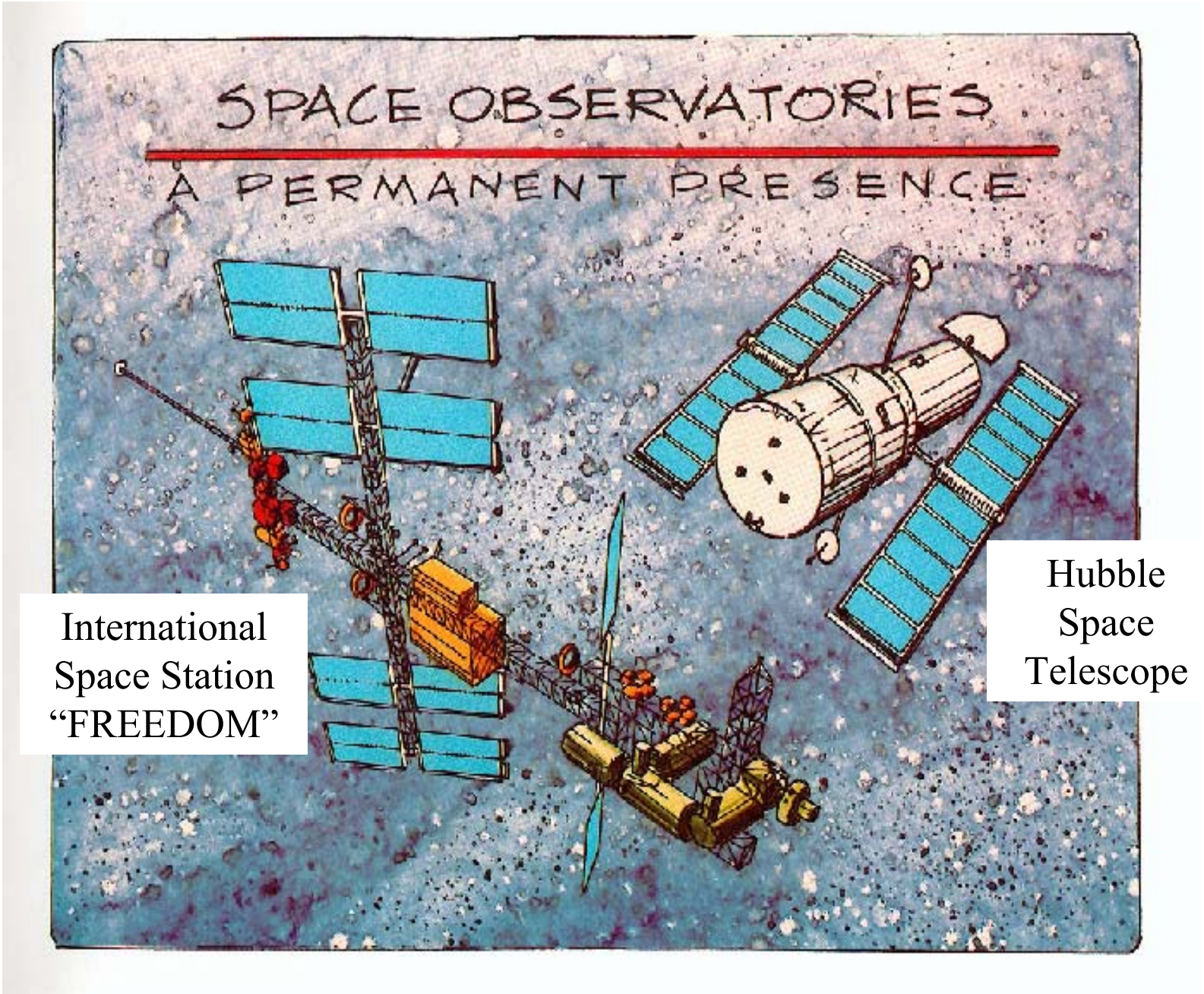
CR from space based observatories

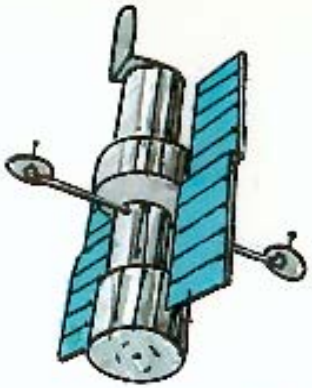
Piero Spillantini
University and INFN, Florence, Italy

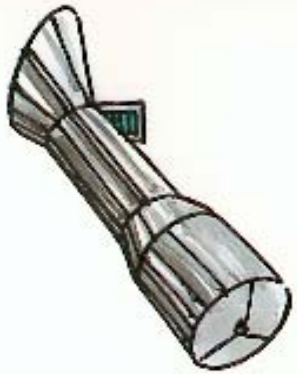
Physics in collisions

Perugia, 26 june 2008


19-th century:
- discovery of electricity
- acceleration of the electrons
- production of X-rays
Energy up to few KeV
End of 19-th century
- discovery of natural radioactivity
Energy up to few MeV
Beginning of 20-th century:
- access to high atmosphere
- discovery of Cosmic Rays
Energy up to many GeV
Second half of 20-th centuries
- accelerators reach CR energies
Particle Physics
Years 60's of 20-th century:
- access to space
Astrophysics
Years 70's of 20-th century:
- permanent presence in space
The Great Observatories
and the Freedom SS


SPACE OBSERVATORIES
A PERMANENT PRESENCE
International Space Station "FREEDOM"
Hubble Space Telescope





CGRO

AXAF (CXO)

HST

SIRTF

THE GREAT OBSERVATORIES

FOR SPACE ASTROPHYSICS

\+

Advanced Composition Explorer (ACE)

Heavy Nuclei Collector (HNC)
and
Particle-Antiparticle Superconducting Magnet (ASTROMAG)

facilities

on board of the Freedom SS

\+

Very Long Base Interferometer (VLBI)

CR open problems were divided in five main typical ‘categories’:

(1) high Z,
(2) isotopes and rare elements,
(3) antiparticles and antinuclei,
(4) chemical composition at the knee,
(5) UHECR.

The problems of that time are still open, and the subdivision in the above categories still valid.

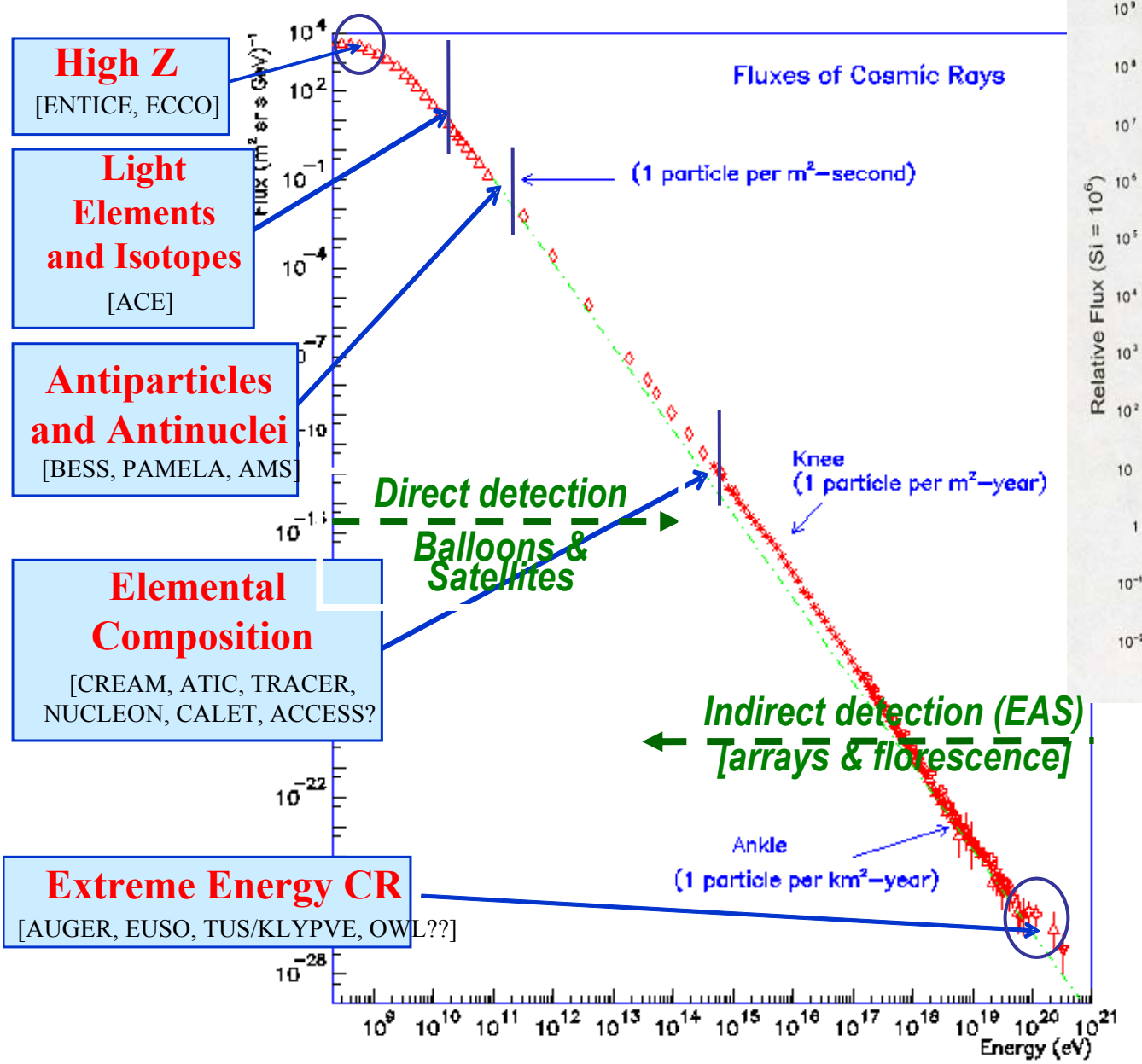
High Z
[ENTICE, ECCO]

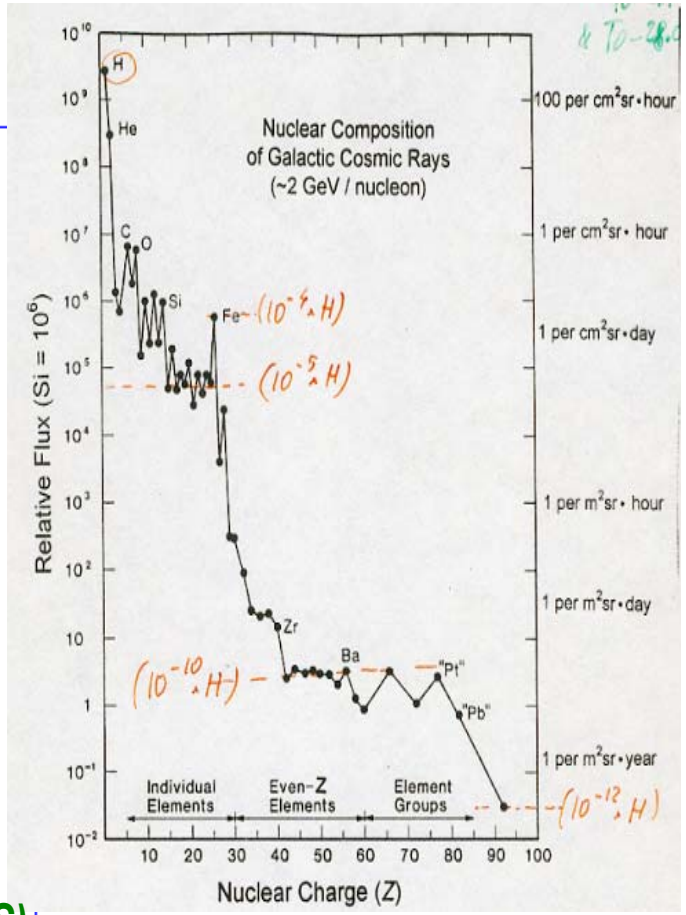
Light Elements and Isotopes
[ACE]

Antiparticles and Antinuclei
[BESS, PAMELA, AMS]

Elemental Composition
[CREAM, ATIC, TRACER, NUCLEON, CALET, ACCESS?

Extreme Energy CR
[AUGER, EUSO, TUS/KLYPVE, OWL??]





CR from space based observatories: *What happened in the last 20 years?*

- Loss of Challenger Shuttle (1986)
- Freedom Space Station cancelled (beginning of 1991)
- Consequently: HNC and ASTROMAG facilities cancelled

for **HNC**:

High Z → precursors on LDEF and MIR, but ENTICE + ECCO not funded

for **ASTROMAG**:

Isotopes → - ***LISA*** collaboration (USA) for isotopes studies continued by ballooning, but it was stopped by the ISOMAX accident.

CR @ Knee → - ***MAGIC-SCINATT*** collaboration (USA+Japan) continued by ballooning, but with limited results, ACCESS on ISS never funded .

Antimatter

- ***WIZARD*** collab. (It,USA,S,D) continued by ballooning, constructed with Russia the Russian-Italian Mission (RIM) program, flew **PAMELA** [and other missions: SilEye-1-2-3, NINA, NINA-2, ALTEINO, ALTEA]
  - Japanese-USA built up the **BESS** ballooning program
  - a new Elementary Particle physicist collaboration (**AMS**) joined in studing the same thematic
- ***ASTROGAM*** collab. disbanded, AGILE and GLAST collab. formed

UHECR

UHECR space based undertaking:
- Linsley and Scarsi created the EUSO program, now continuing in different scenarios (**JEM-EUSO**, **S-EUSO**)
- Russians are testing new methods with the Lunar Orbiter Radio Detector (**LORD**) on board of the Luna-Glob Moon satellite)

Antimatter in the Cosmic Radiation

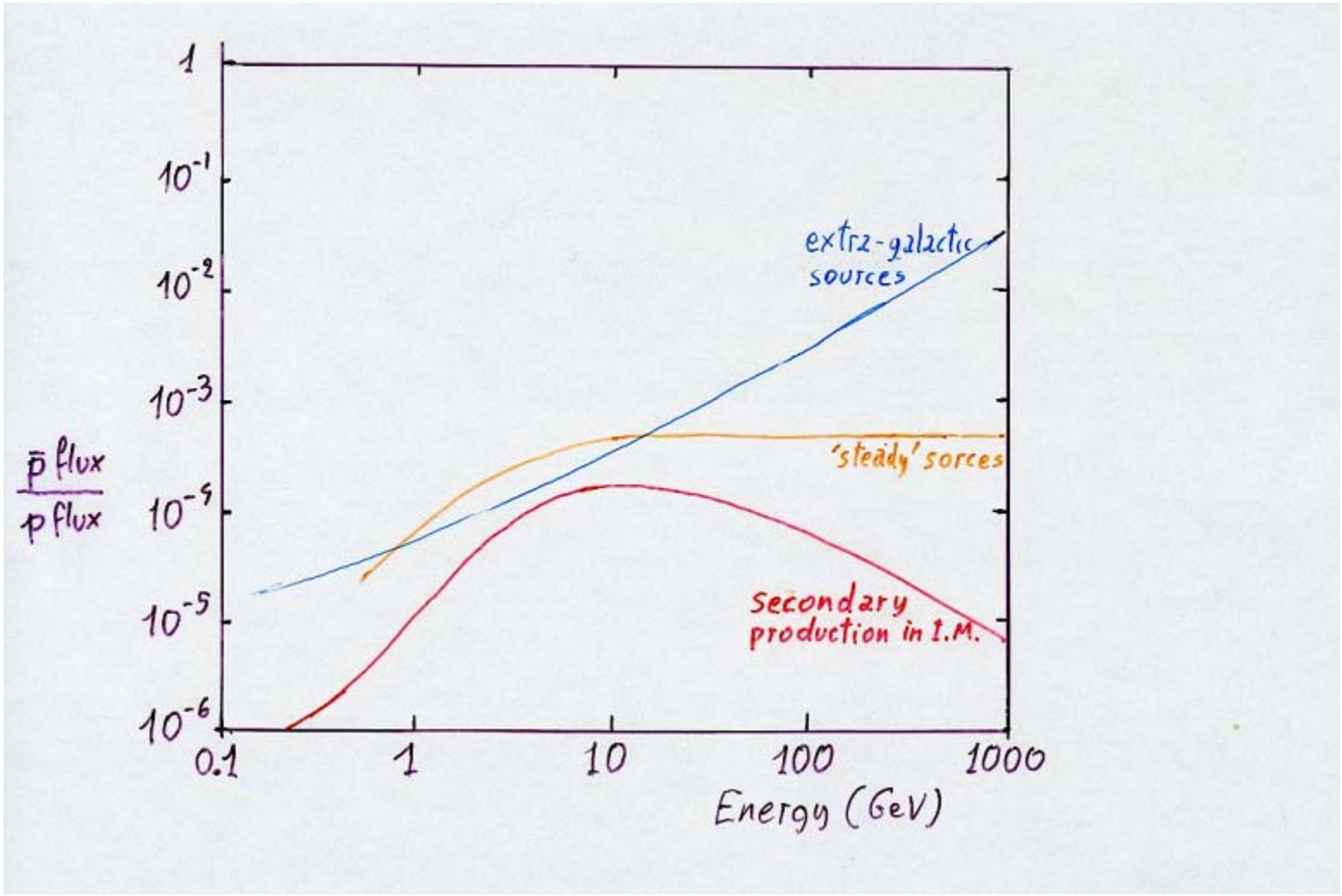
e^+
- Large background from many secondary sources

$\bar{p}$
- Relatively abundant
- Large background (from p+ISM) up to ~10 GeV
- Sensible probe at very high energies ($\gtrsim$100 GeV)

→ high energy (→ 1 TeV)

$\bar{N}$
- NO idea of their abundance
- NO background
- however
  - 'diffusive' long travel
  - Galactic modulation

→ high energy (→ 100 GeV/n)


1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$\frac{\bar{p}\ \text{flux}}{p\ \text{flux}}$
extra-galactic sources
'steady' sorces
secondary production in I.M.
0.1
1
10
100
1000
Energy (GeV)

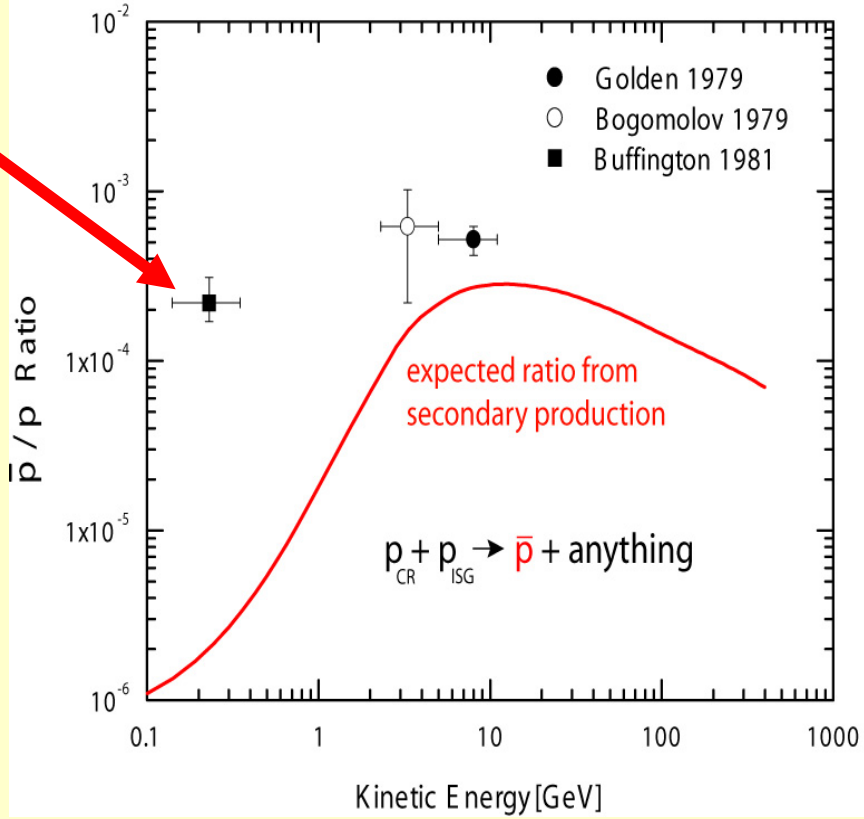
Antimatter in Cosmic Rays

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)

1990: MASS
1991: MASS1
1992: IMAX
1993: TS93, BESS
1994: CAPRICE94, HEAT-$e^{\pm}$
1997: CAPRICE97, BESS
1998: CAPRICE98, AMS-01
1999: BESS
2000: HEAT-pbar, BESS
2004: BESS Polar I
2007: BESS Polar II

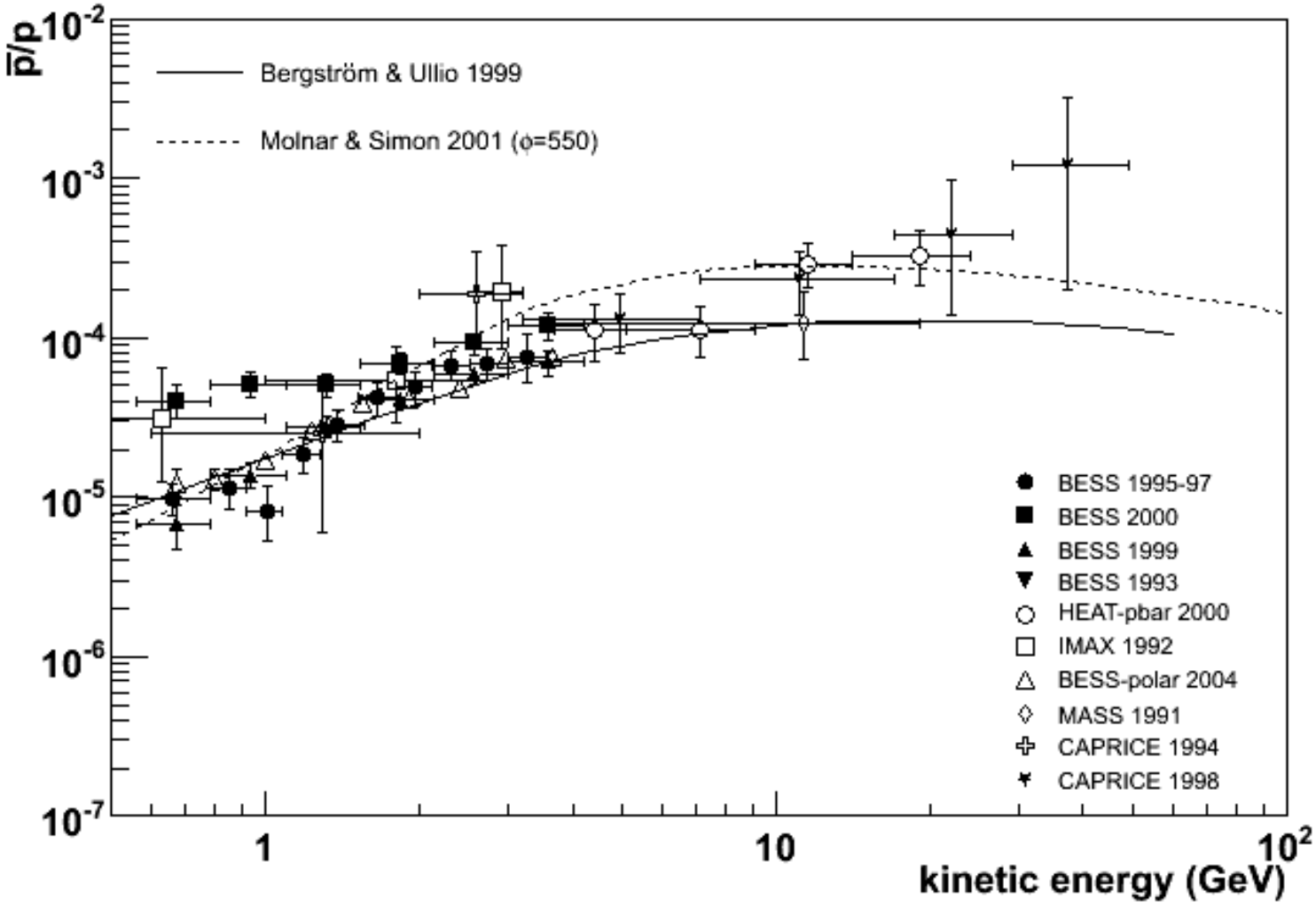
In RED
Wizard collab.

The first historical measurements on galactic antiprotons



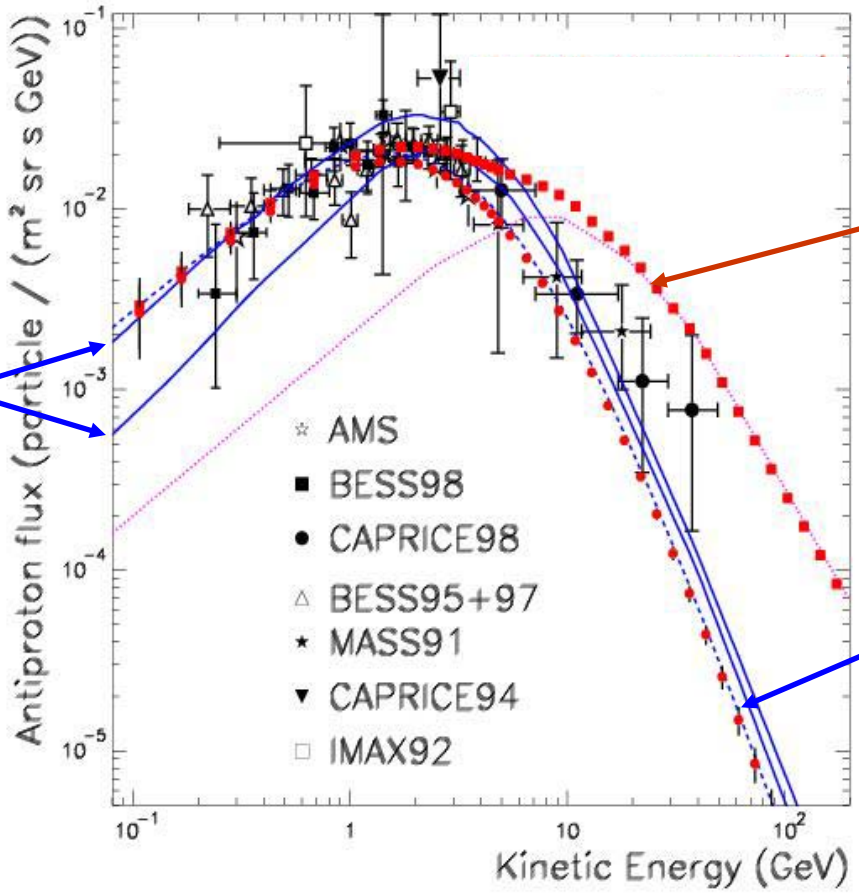
Before MASS Flights

Antiproton-Proton Ratio



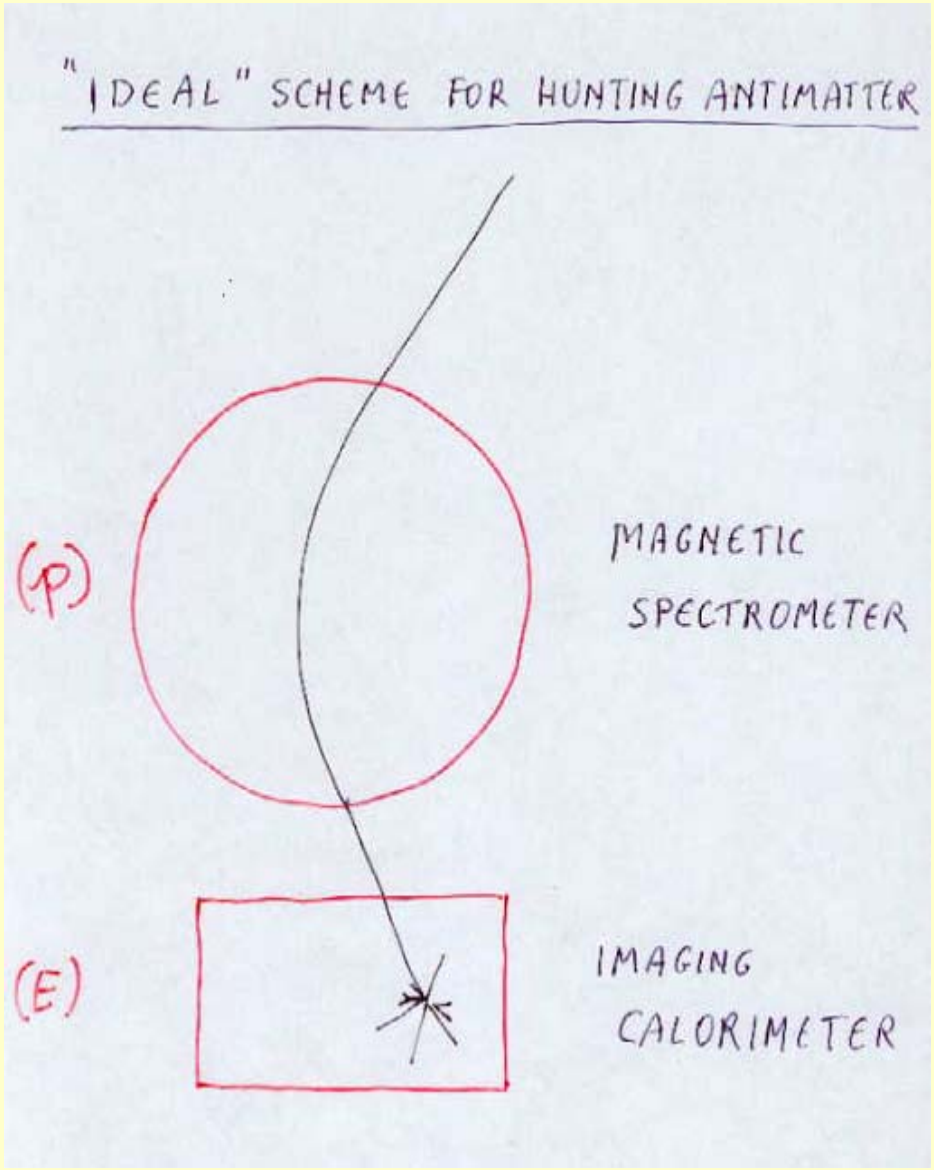
Search of structures in antiproton spectrum

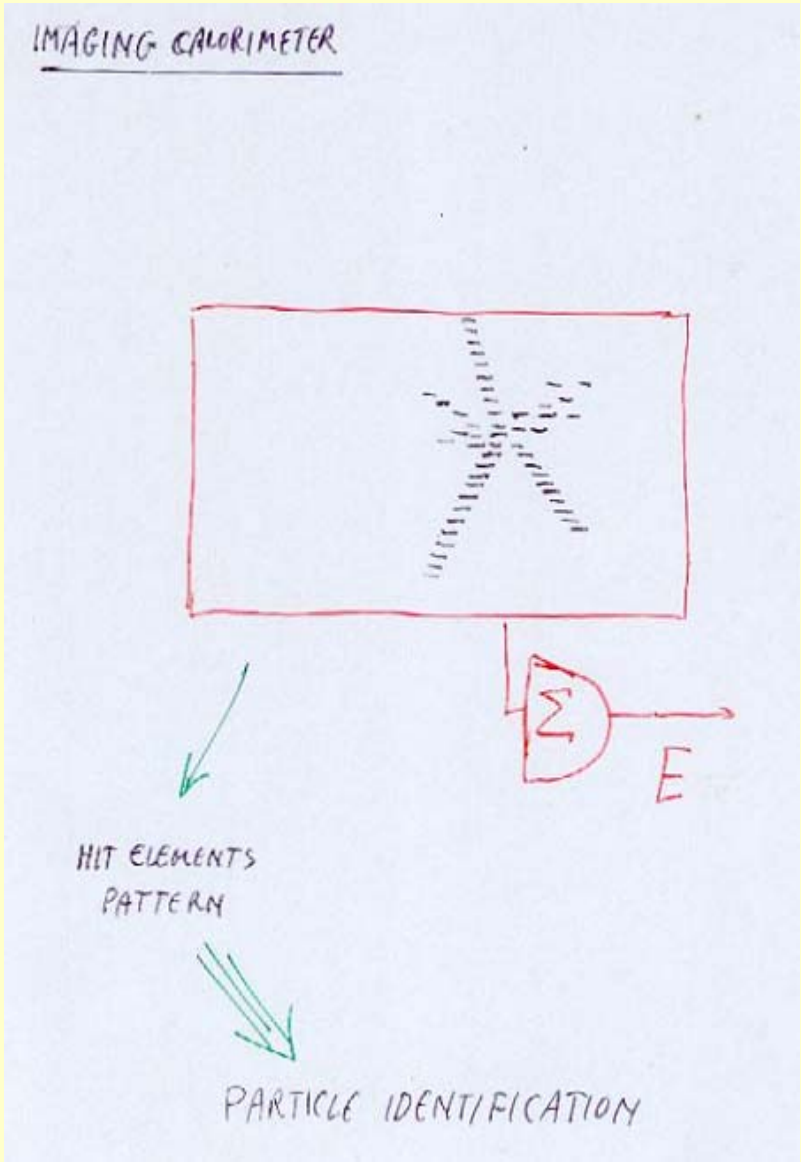
Secondary production
(upper and lower limits)
Simon et al.



Primary production from
$\chi\chi$ annihilation
($m(\chi)$ = ~ 1 TeV)
(astro-ph 9904086)

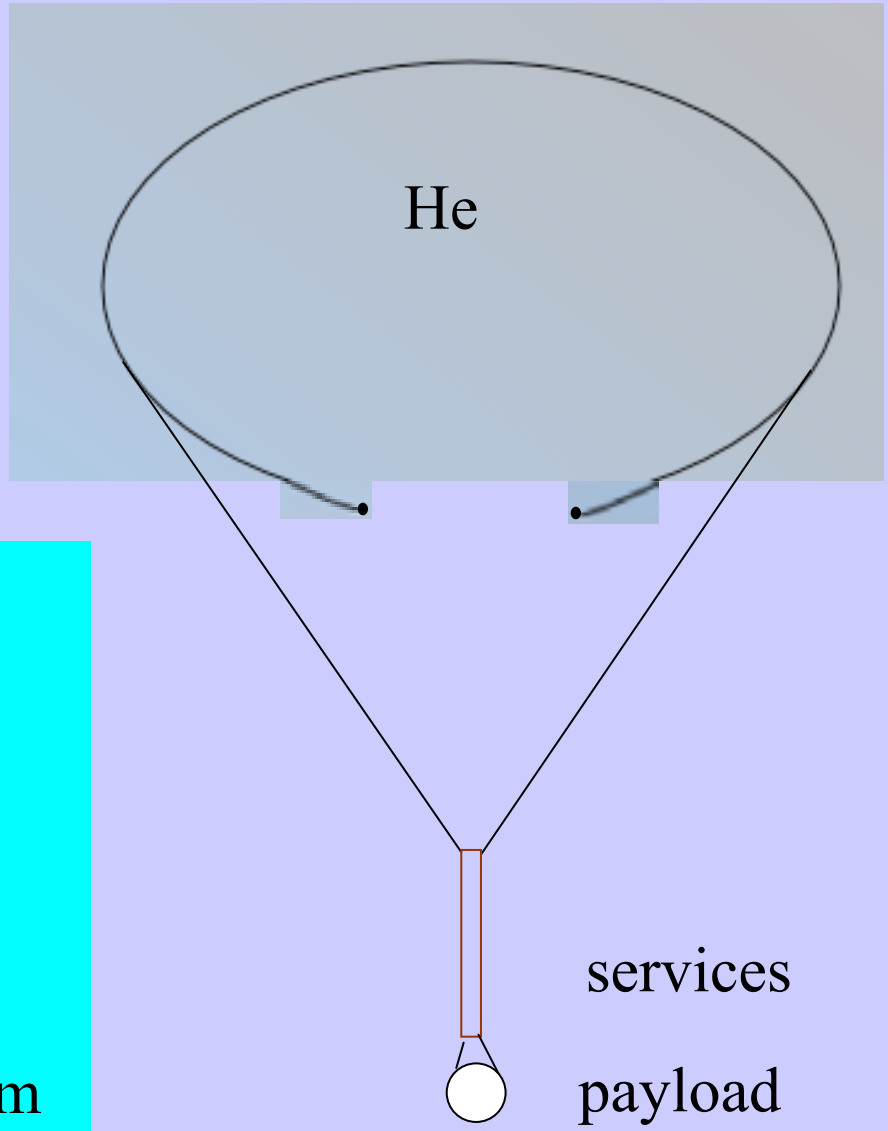
Secondary production
(CAPRICE94-based)
Bergström et al.





AntiM. 'ideal scheme'

Open balloons



Class A balloons
2.8 Mm^3 @ 5 g/cm^2

Lifting power ~ 11t

Balloon 5 t
services 3 t
payload 3 t @ 38÷40km
(5g/cm^2 residual atm.)

‘open’ balloons:

Volume @ 5g/cm^2 > 1 Mm^3

Very thin material (20μm),

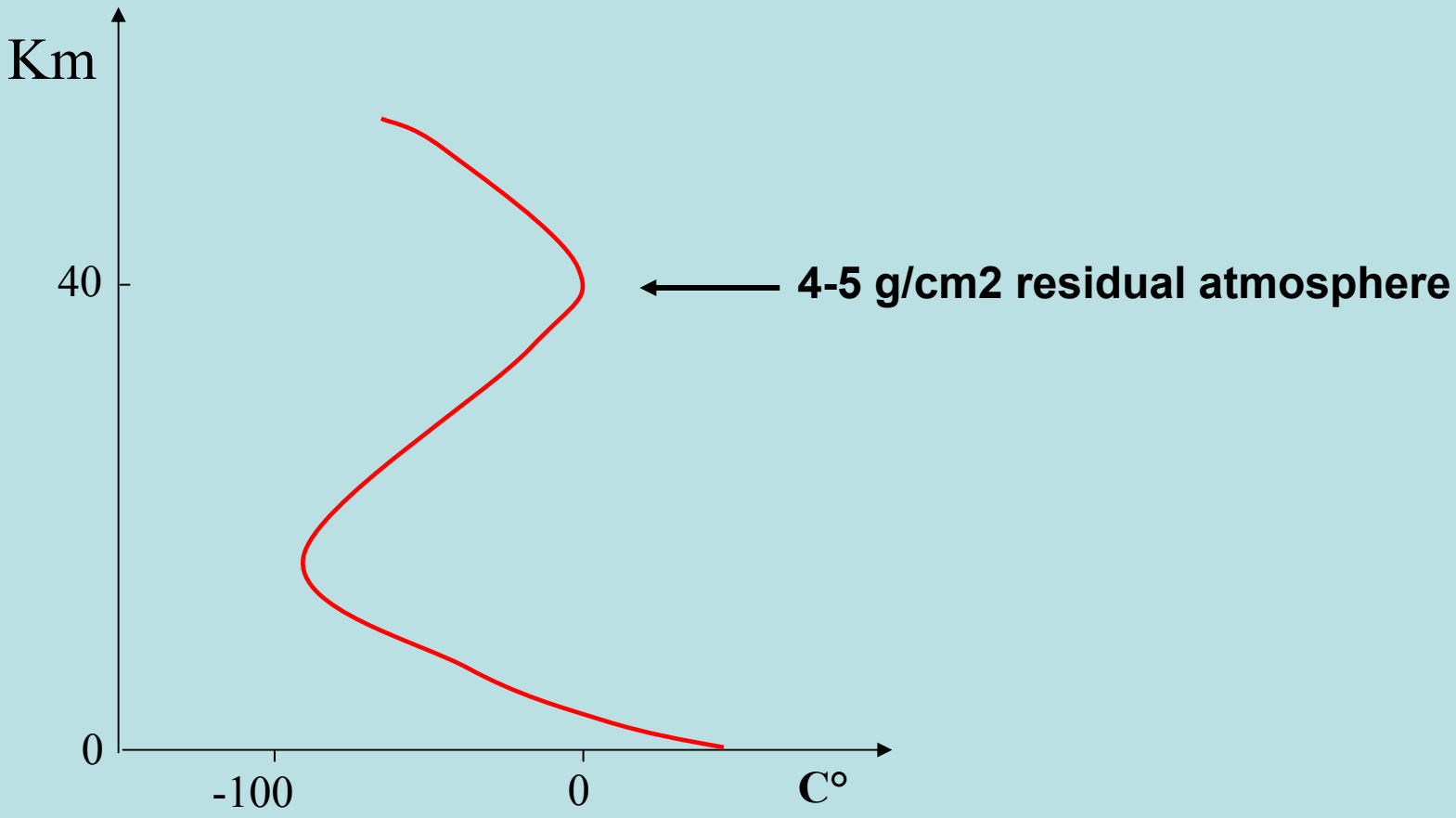
does not support pressure differences

Maximum load ≈ 3 t

Line of sight (LOS) ≈ 800 km

Tipical duration of the flight 20 hours

Atmospheric temperature versus Altitude



It is necessary a:

New Generation of Antimatter Researches in Cosmic Rays

[BESS + PAMELA + AMS]

BESS – Long Duration Ballooning in Antarctica

Antiproton at low energy (dark matter etc...)
Antinuclei at low energy

PAMELA – Satellite borne permanent magnet spectrometer

Antiproton and positrons up to highest energies
Antinuclei up to highest energies
Dark matter searches
Solar Physics

AMS-2 – ISS borne superconducting magnet spectrometer

Antiproton and positrons up to highest energies
Antinuclei up to highest energies
Dark matter searches

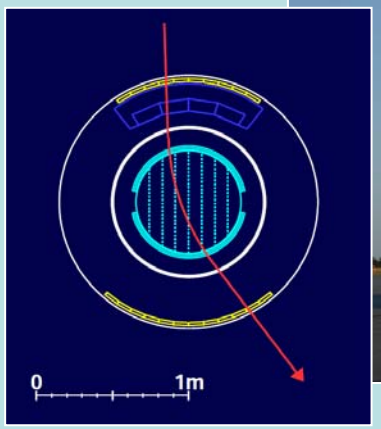
BESS

***B*alloon-borne**

***E*xperiment with a**

***S*uperconducting**

***S*pectrometer**



Search for

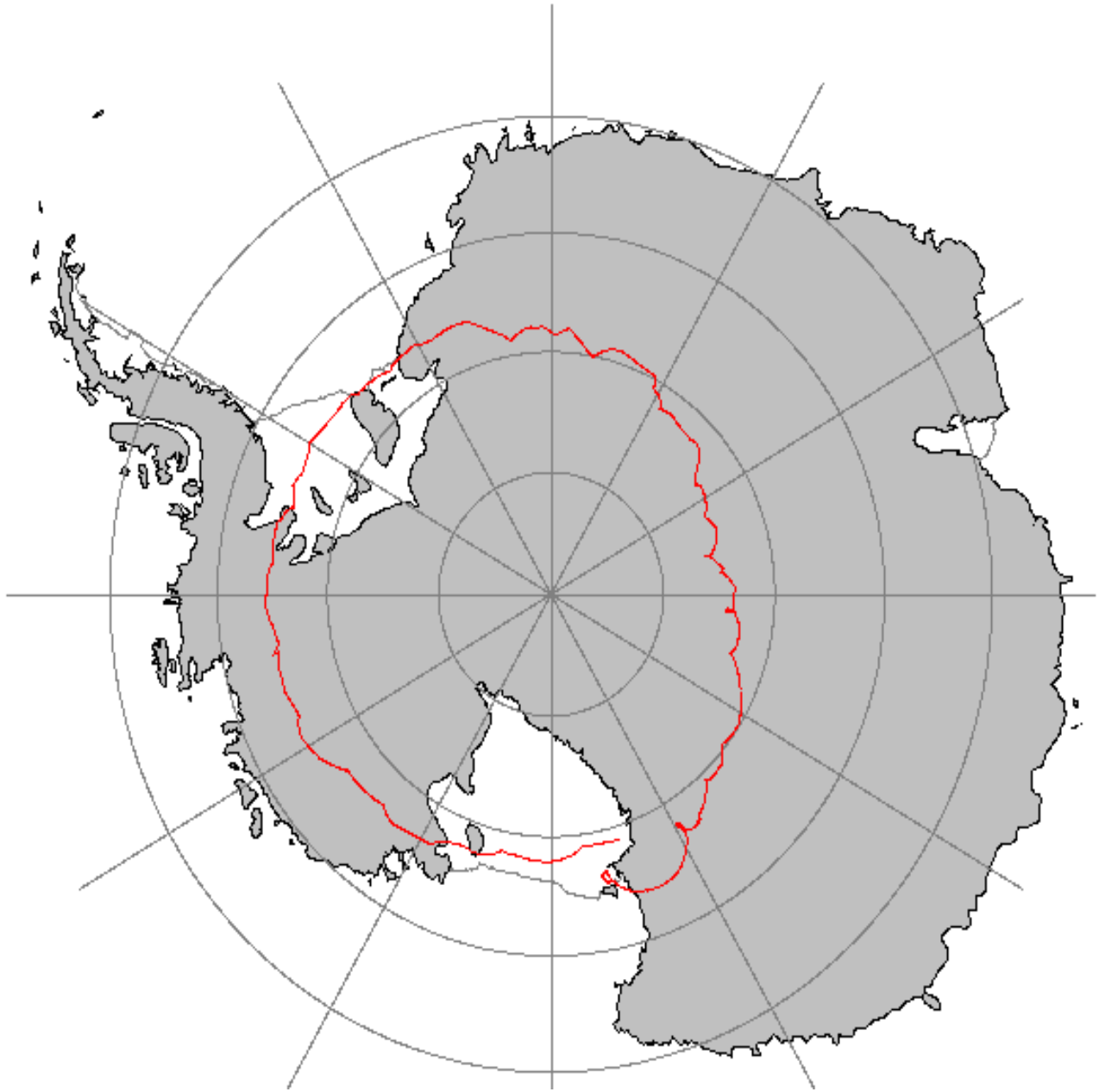
Primordial Antiparticle

antiproton: Novel primary origins (PBH,DM)

antihelium: Asymmetry of matter/antimatter

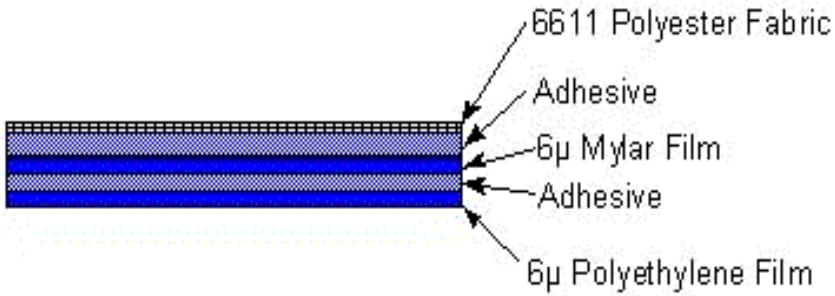
Precise Measurement of Cosmic-ray flux:

highly precise measurement at < 1 TeV



Balloon Material

- **Composite material (62 g/m^2 approximately)**
  - Polyester fabric (30 g/m^2)
    - Yarn denier 30g/9000m (warp and fill)
    - Yarn tenacity 6.1g/denier (warp and fill)
    - Yarns per meter 4724/m (warp) and 4252/m (fill)
  - Polyester film (8.8 g/m^2 , 6x10^{-6} m thick)
  - Polyethylene film (5.8 g/m^2 , 6x10^{-6} m thick)
  - Two adhesive layers
- **Strength requirement - 600 N/m**



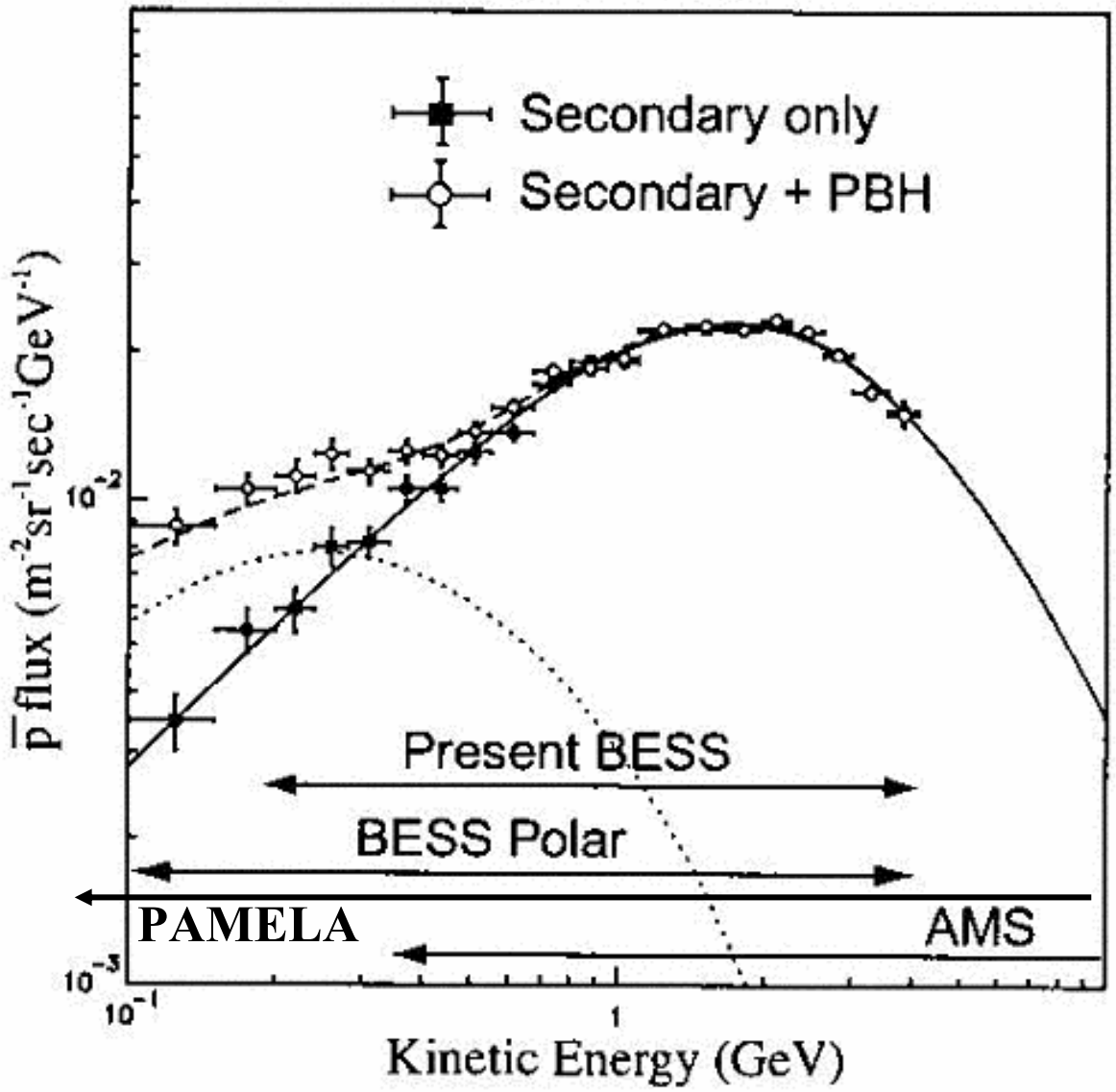
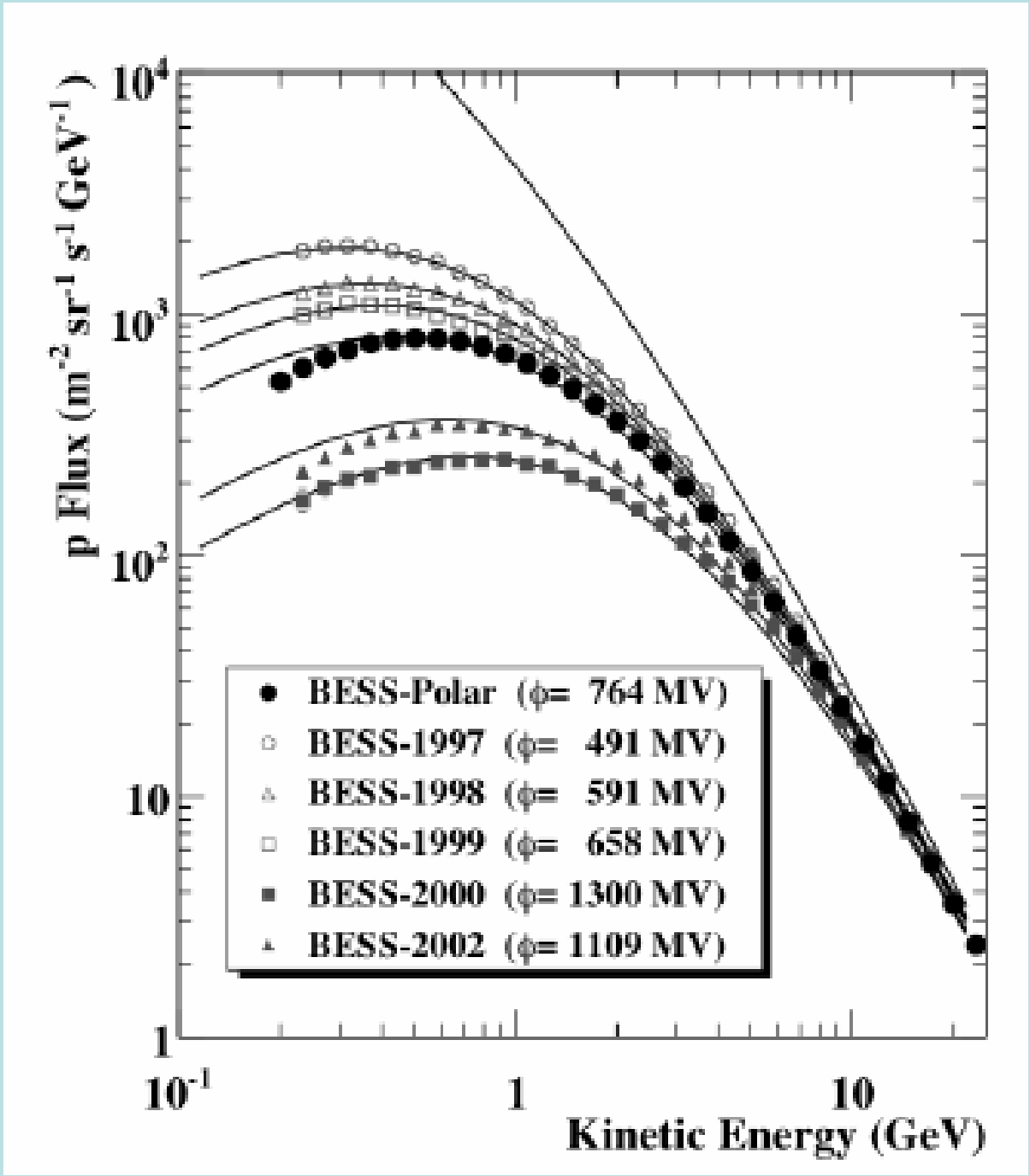
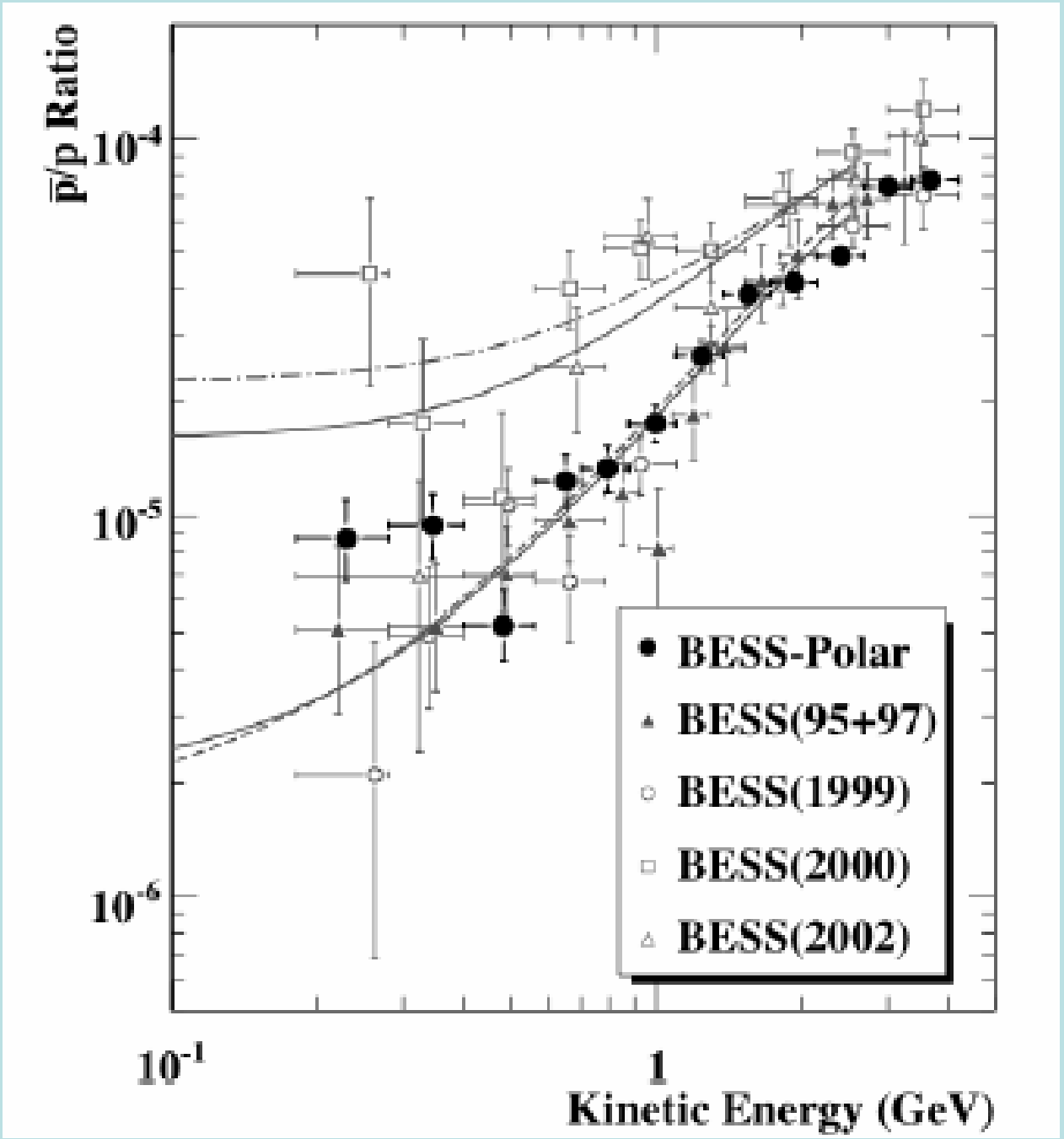


Fig. 3. Antiproton spectra in a simulation expected in a 20 days flight in Antarctica with and without primary origin of PBH.



BESS Coll.
30th ICRC 2007



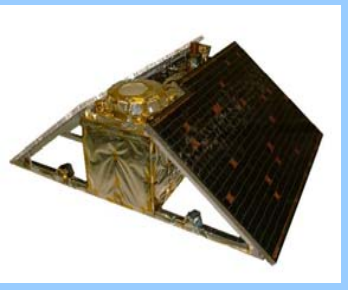
BESS Coll.
30th ICRC 2007

WiZard: Russian Italian Missions (RIM)

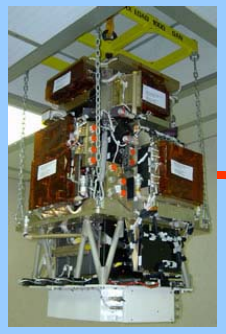
MASS-89, 91, TS-93, CAPRICE 94-97-98

NINA-1

NINA-2



PAMELA



M 89 · M 91 · TS 93 · C 94 · C 97 · C 98 · ←Antimatter search → PAMELA

…1989 · 1990 · 1991 · 1992 · 1993 · 1994 · 1995 · 1996 · 1997 · 1998 · 1999 · 2000 · 2001 · 2002 · 2003 · 2004 · 2005 · 2006 · 2007..

Life Science
Solar physics

SILEYE-1

NINA-1

NINA-2

Alteino-SILEYE-3

LAZIO-SIRAD

SILEYE-2

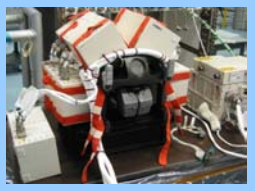
ALTEA-SILEYE-4

SILEYE-1

SILEYE-2

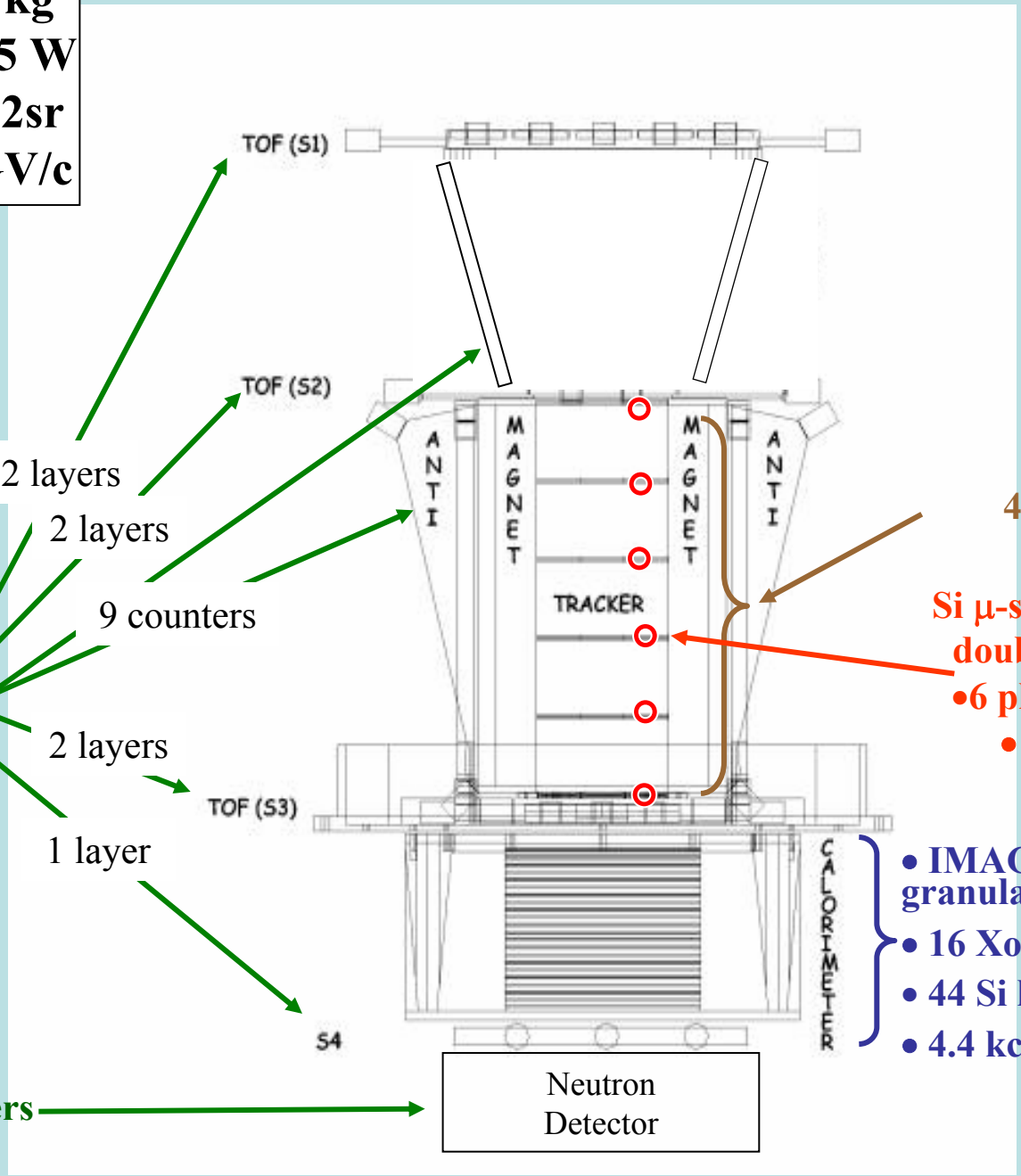
ALTEINO: SILEYE-3

LAZIO SIRAD



ALTEA: SILEYE-4

MASS = 480 kg
POWER = 345 W
GF = 20.5 cm2sr
MDR = 740 GV/c



2 layers
2 layers
9 counters
2 layers
1 layer

Scintillation Counters Hodoscopes

36 He3 counters

5 magnets, 4.8 kG @ center

Si μ-strip, double side, double metallization
- **6 planes x 6 sensors**
- **37 kchannels**

- **IMAGING (2.4mm granularity)**
- **16 Xo deep**
- **44 Si layers + W**
- **4.4 kchannels**

PAMELA

GF	20.5 cm^2 sr
Mass	480 Kg
Dimensions	120 x 40x45 cm^3
Power Budget	345W

- Positrons 50 MeV - 270 GeV
- Antiprotons 80 MeV – 190 GeV
- Limit on antinuclei ~7 10^{-8} ($\bar{He}$ /He)

- Electrons 50 MeV – 2TeV
- Protons 80 MeV – 700 GeV
- Nuclei < 300 GeV/n ($Z \leq 8$)
- study of the solar modulation after the 23rd solar cycle maximum.

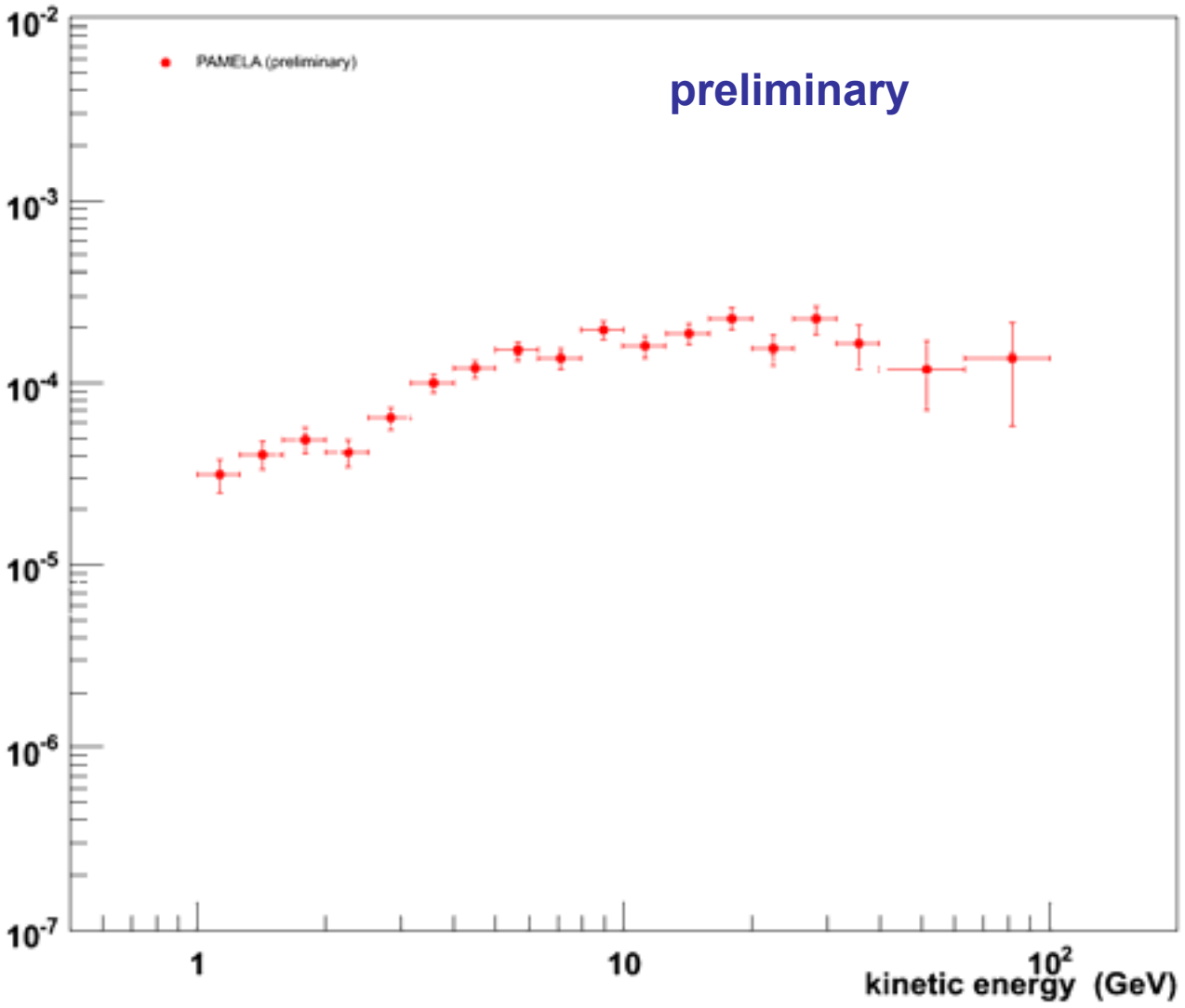
PAMELA

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

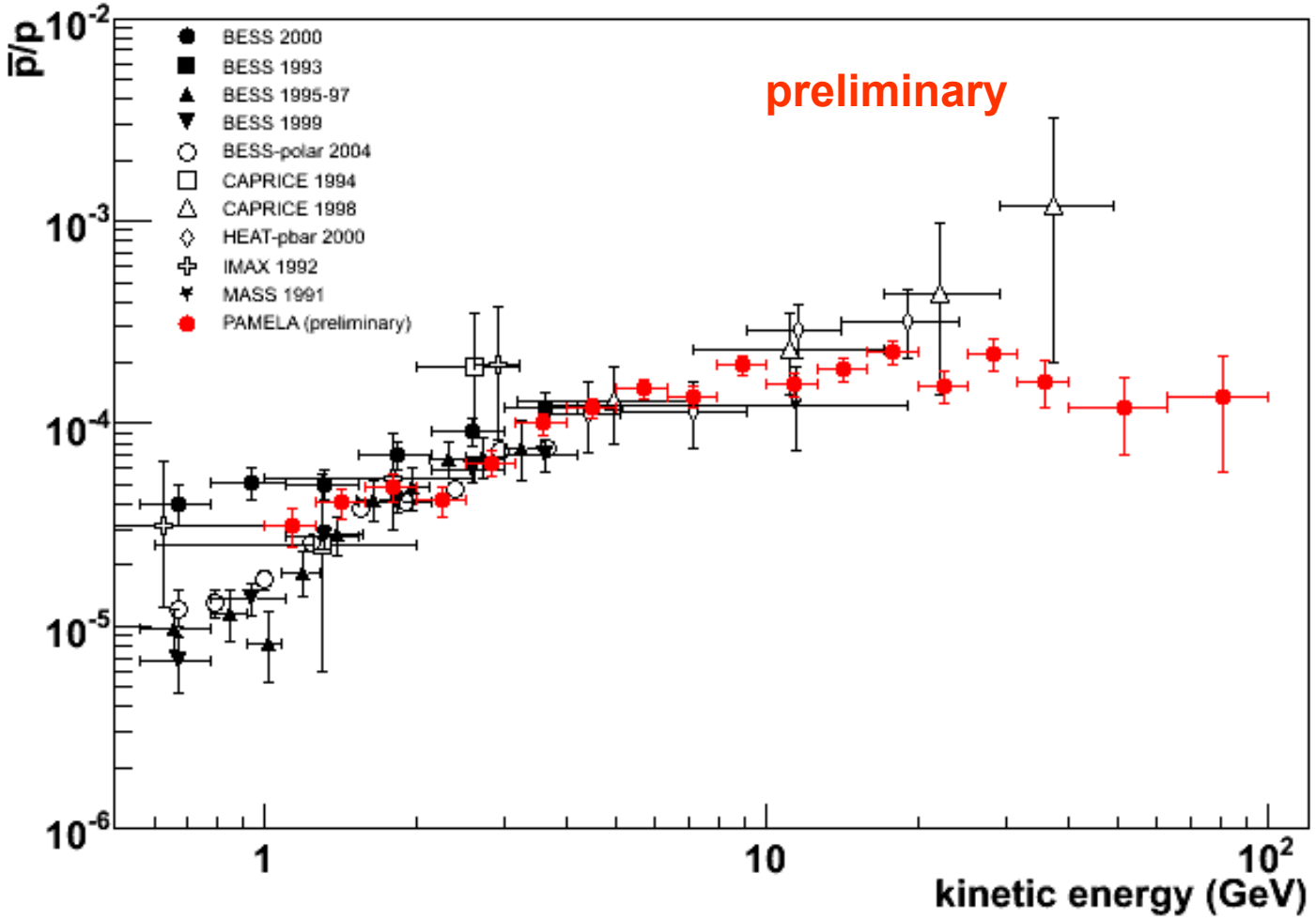
16 Gigabytes data/day

Till 2nd of March 2008 PAMELA has collected ~ 8.8TB of data, corresponding to ~ 10.6×10^8 triggers

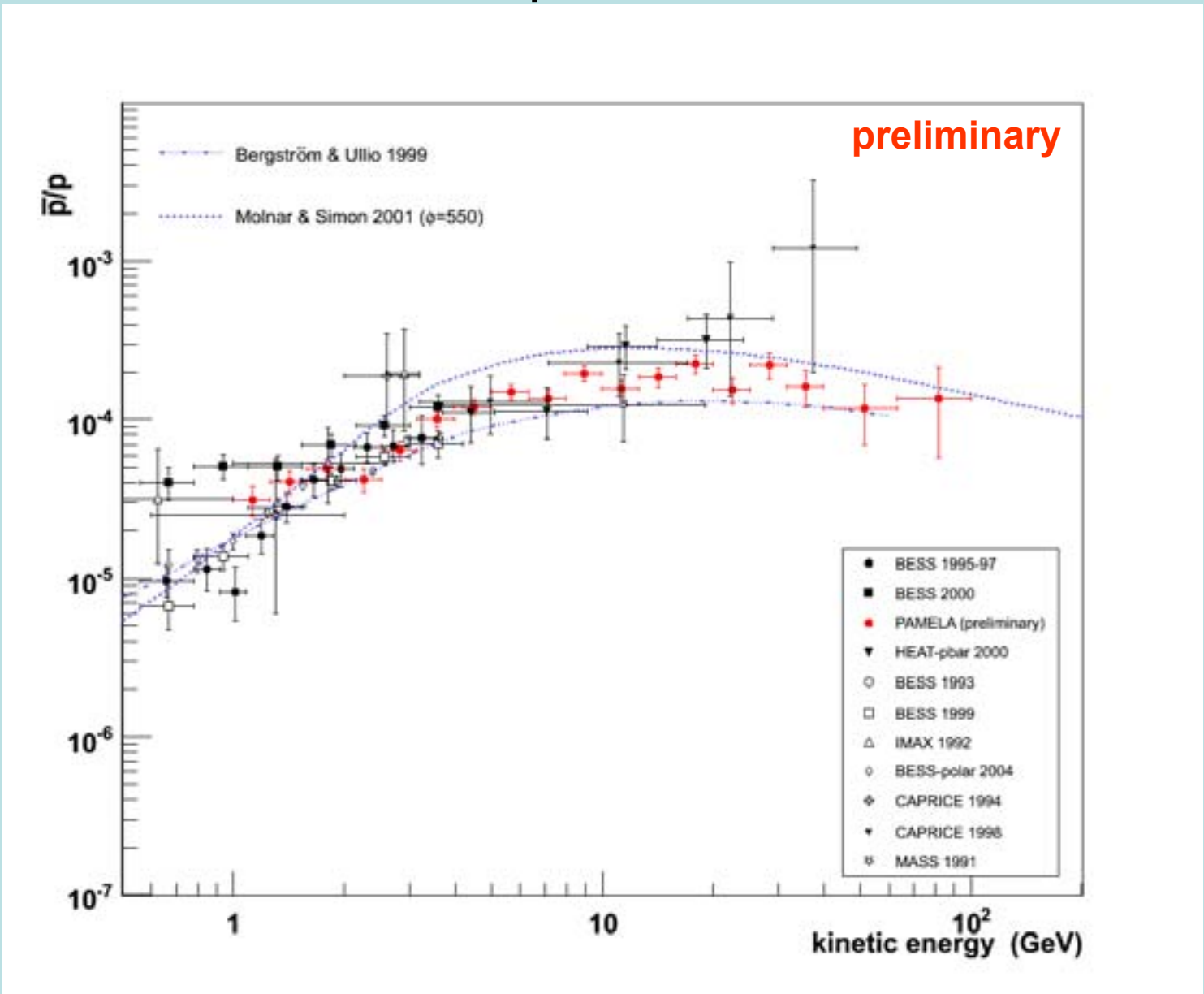
PAMELA: Antiproton-Proton Ratio



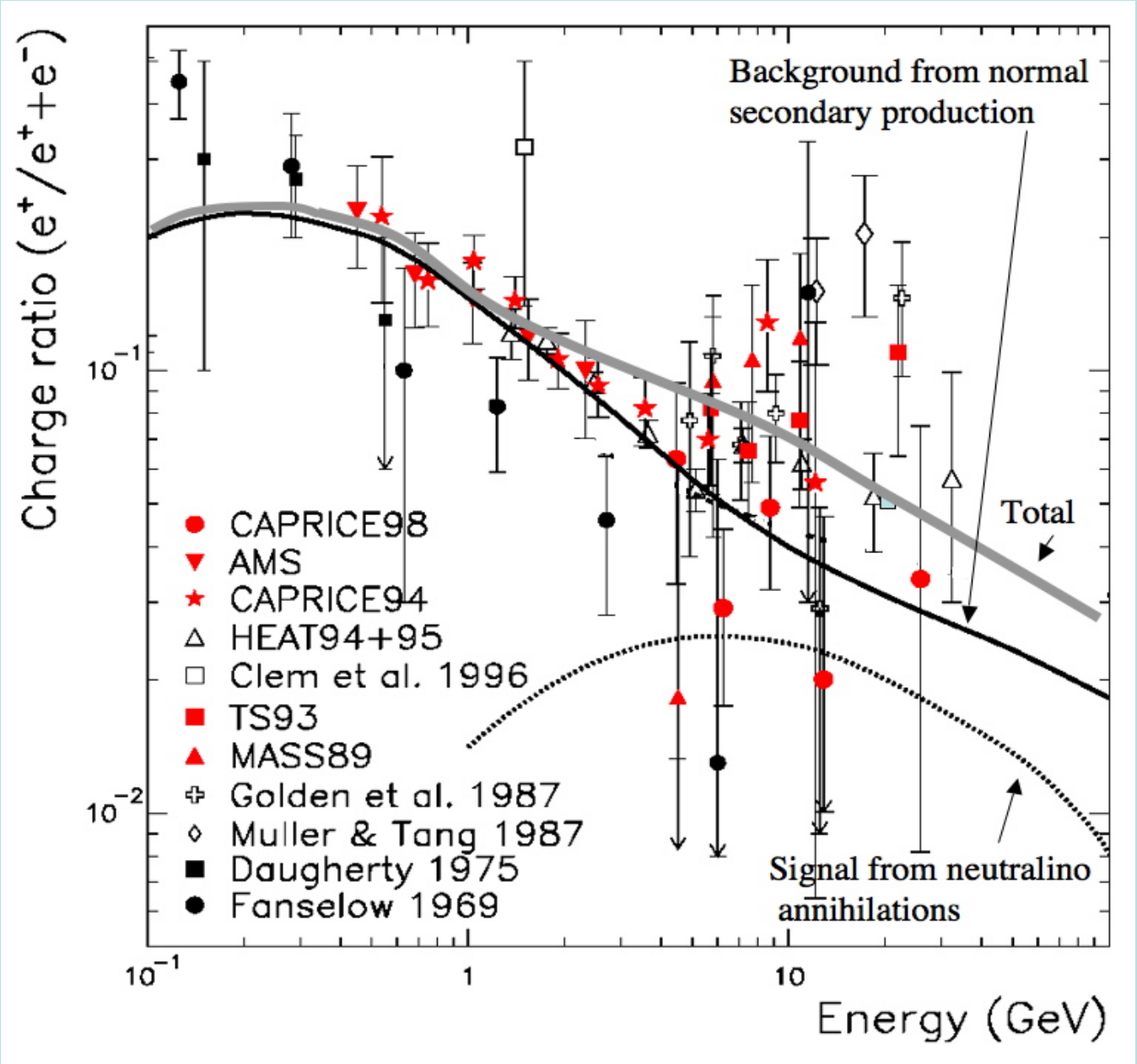
PAMELA: Antiproton-Proton Ratio



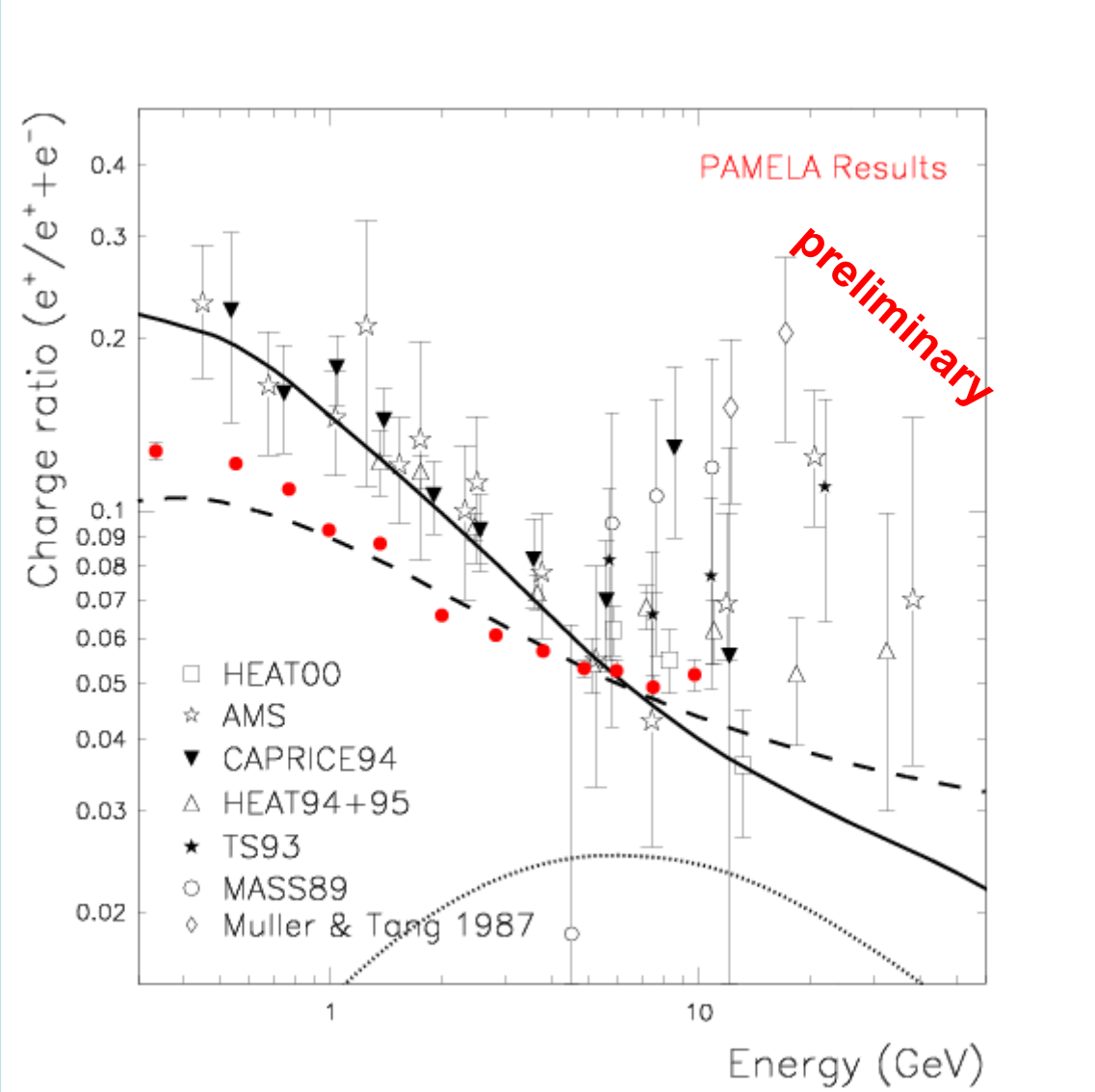
PAMELA: Antiproton-Proton Ratio



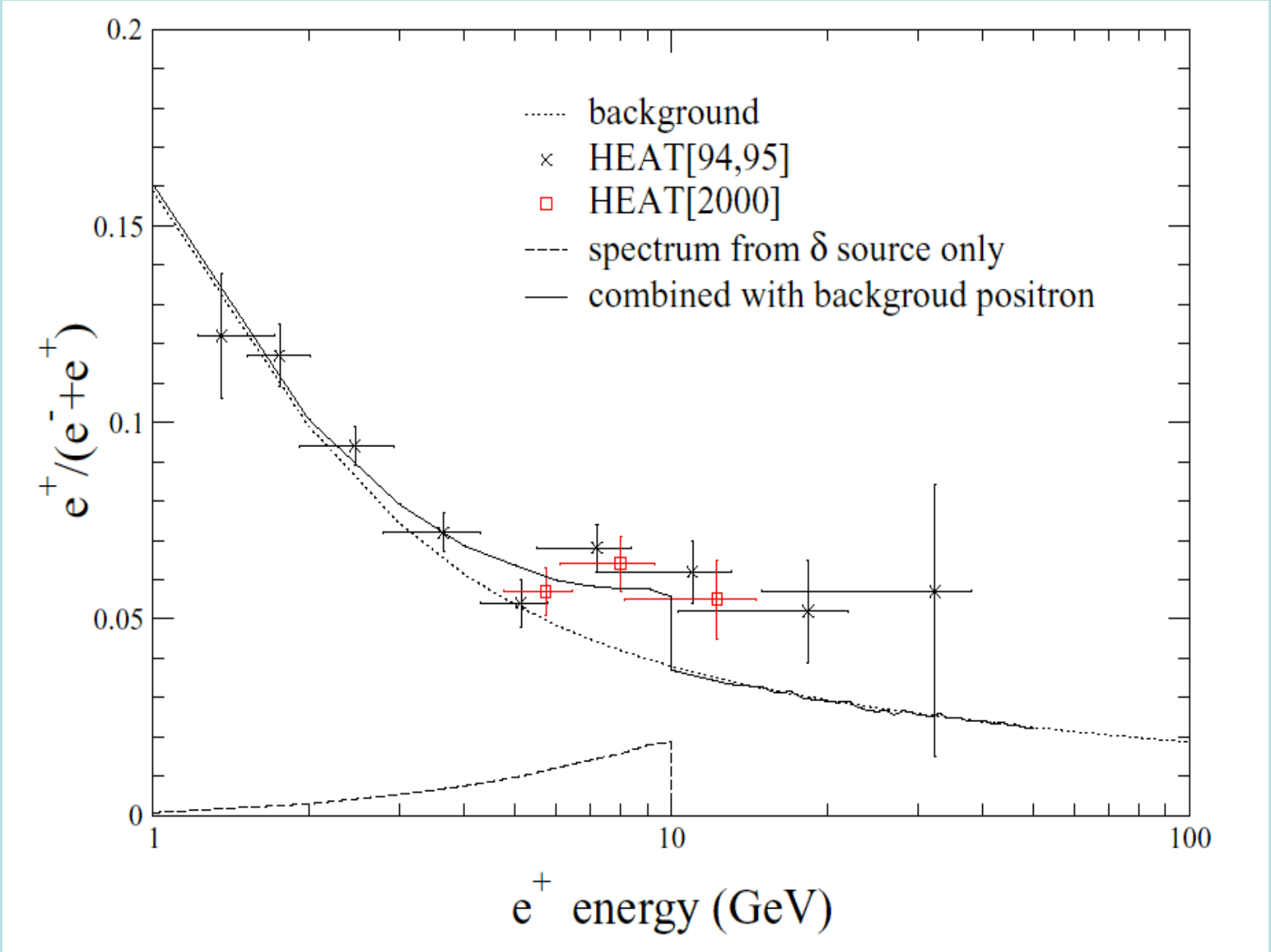
Positron - Electron ratio



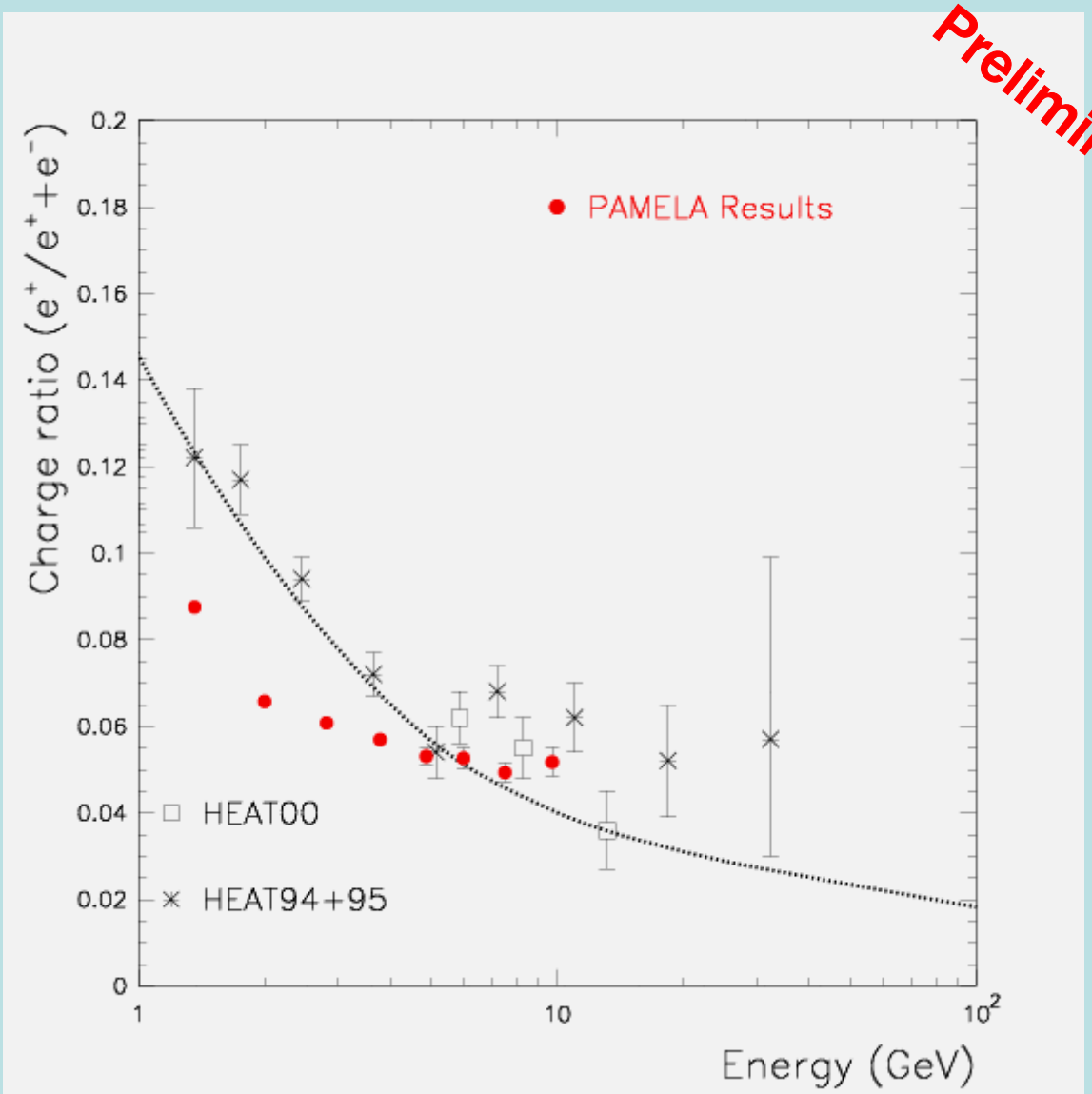
PAMELA: Positron - Electron ratio



Positrons with HEAT



Positrons with HEAT & PAMELA



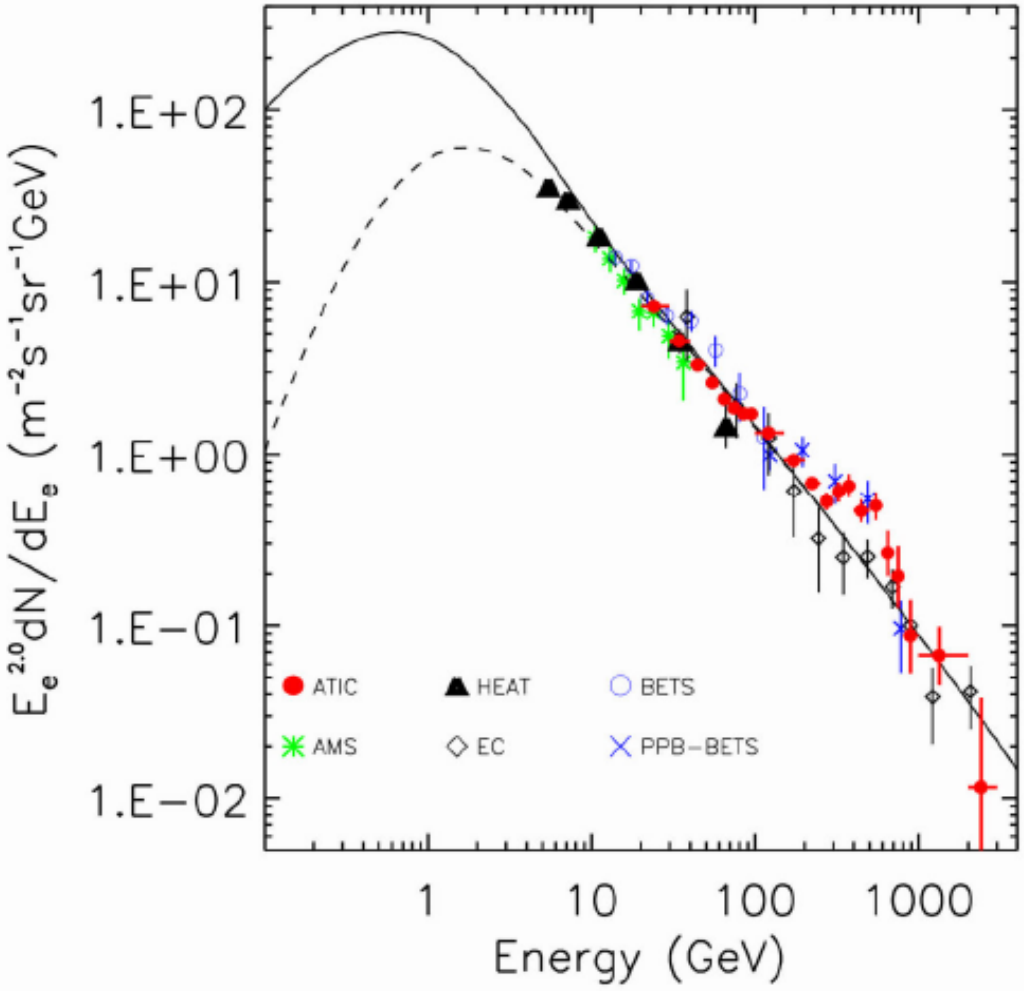
The ATIC electron results exhibits a feature

Curves are from GALPROP diffusion propagation simulation code

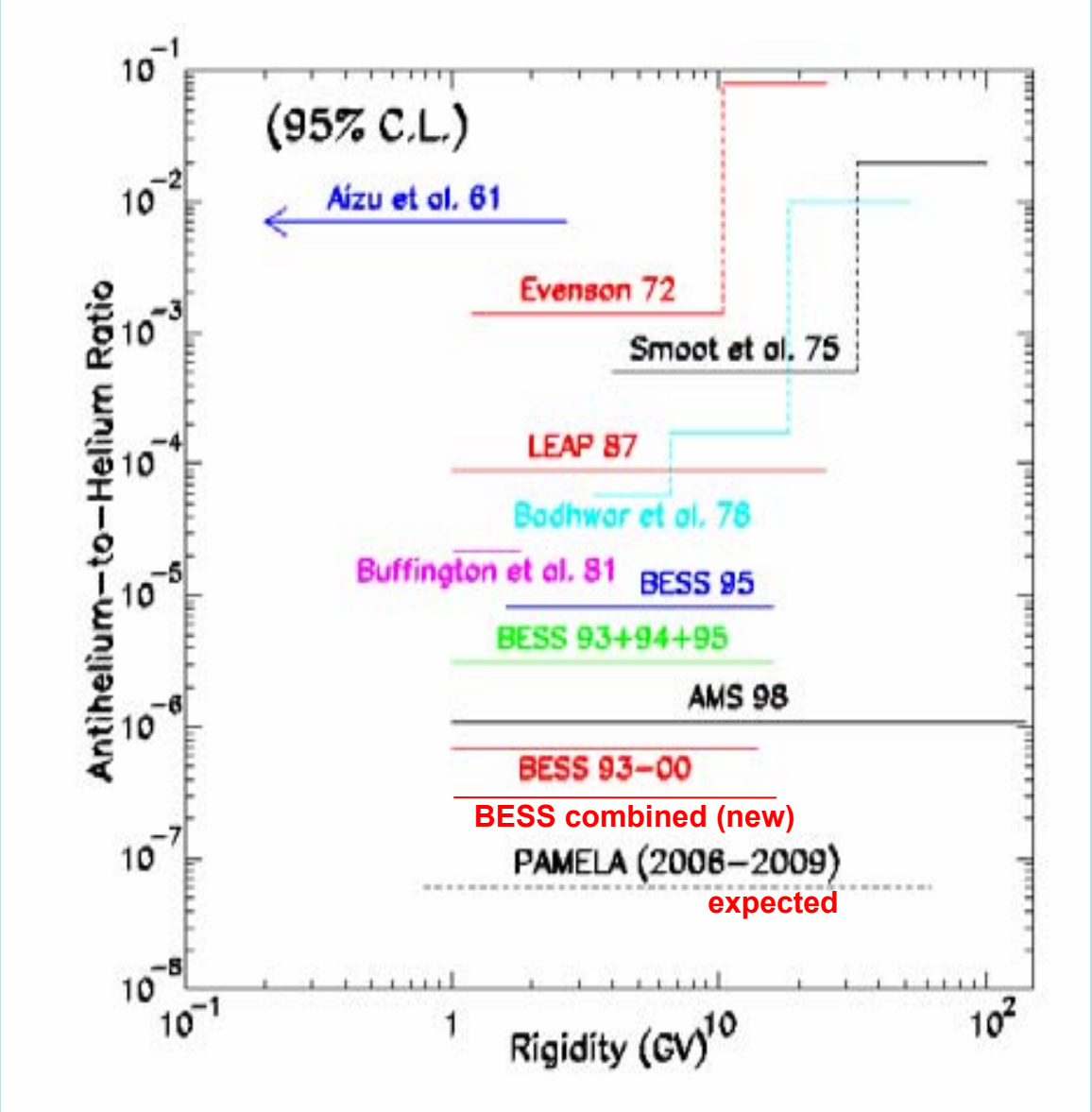
- Solid curve is local interstellar space
- Dashed curve is with solar modulation (500 MV)

"Excess" at about 300 – 600 GeV

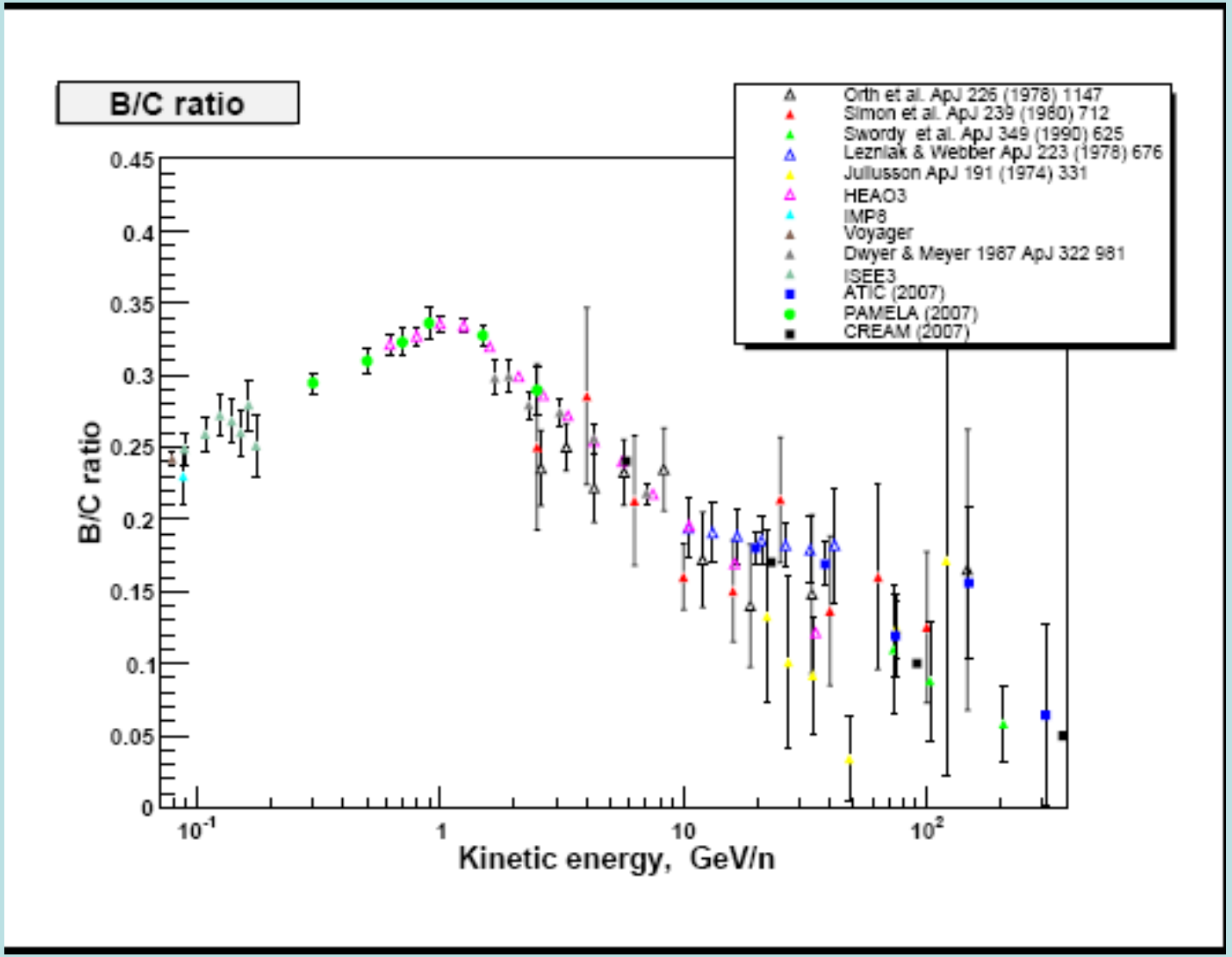
Also seen by recent PPB-BETS



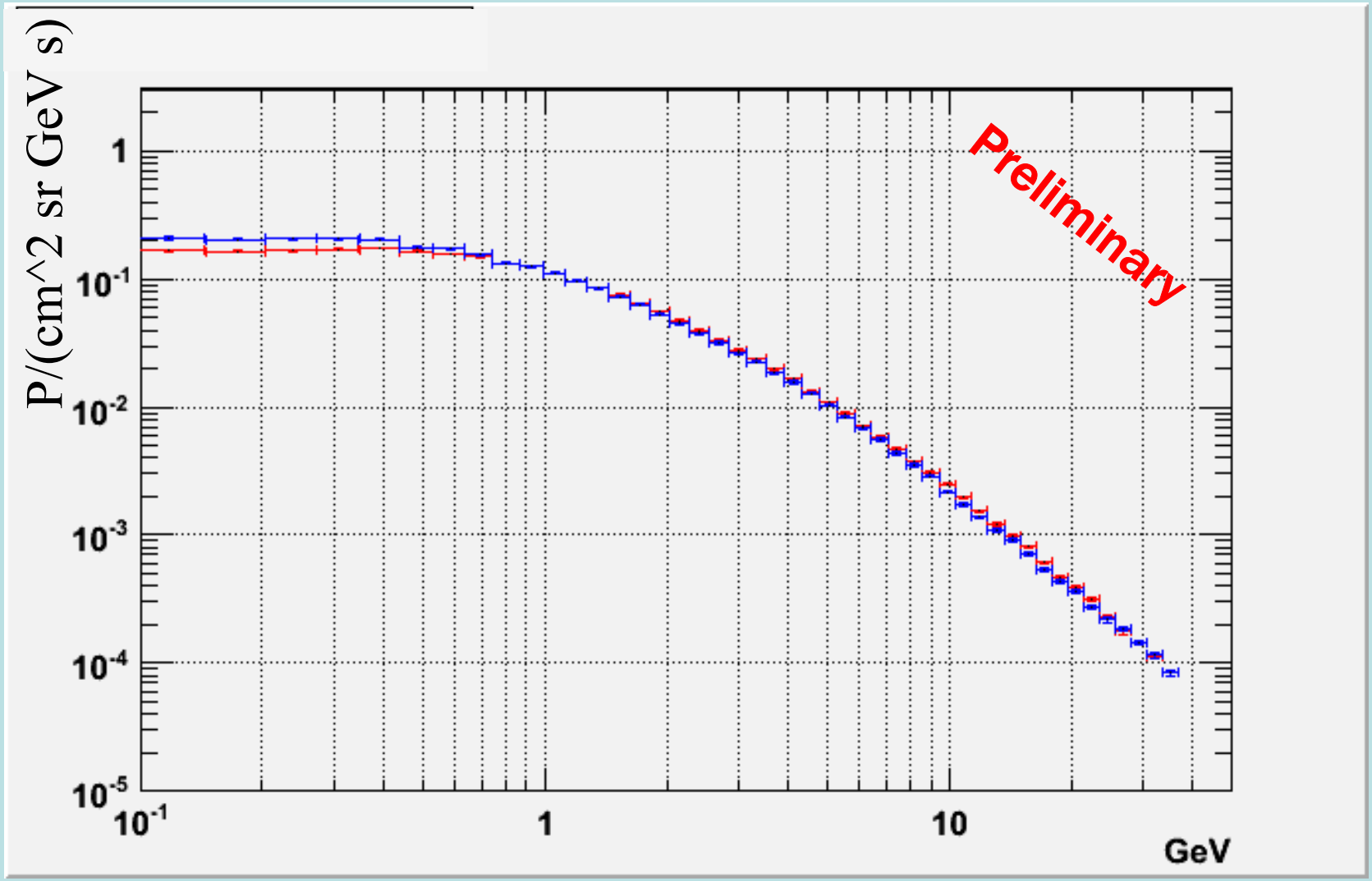
Cosmic-ray antimatter search



PAMELA: Preliminary Results B/C

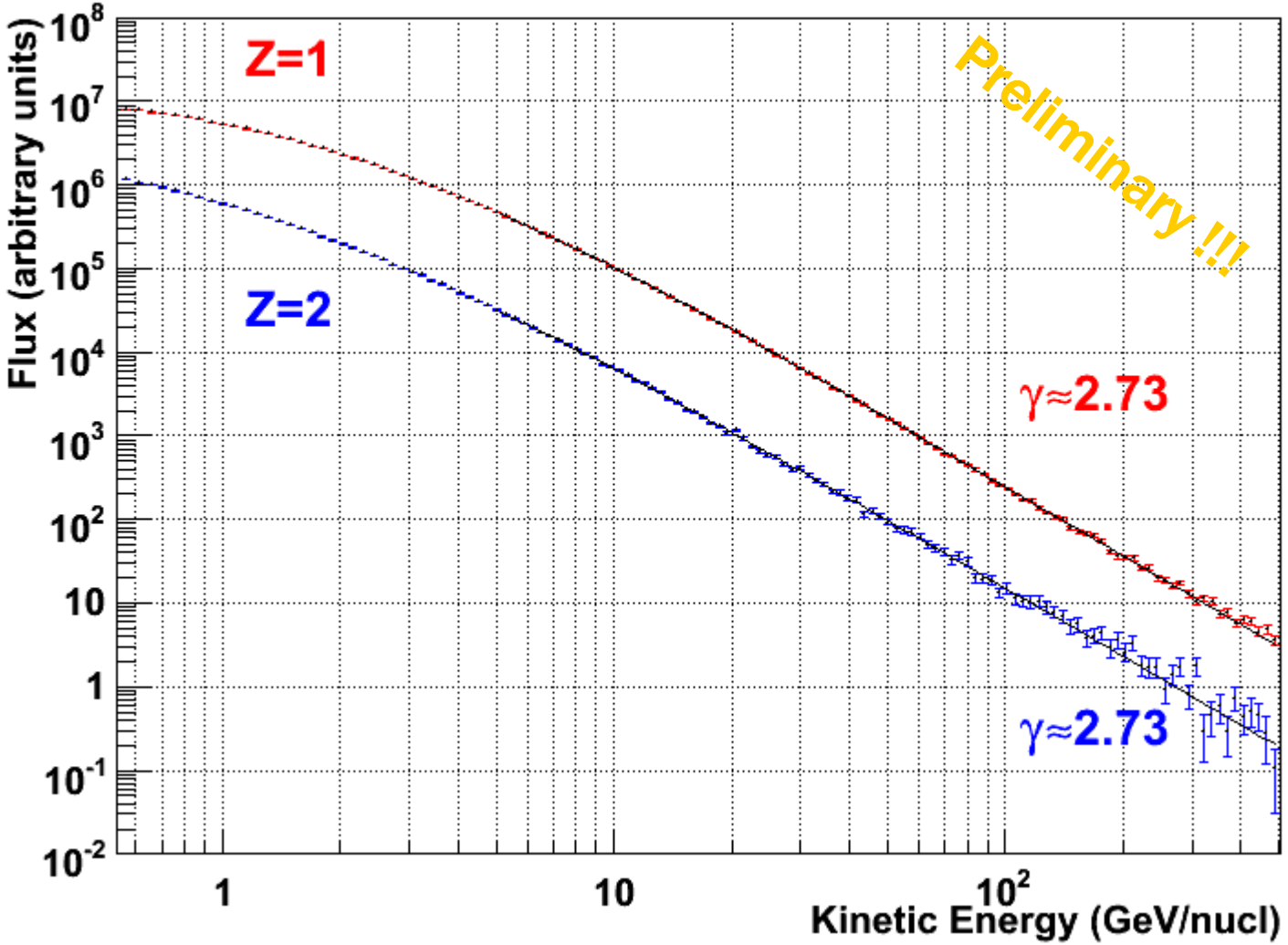


PAMELA: Proton Spectra

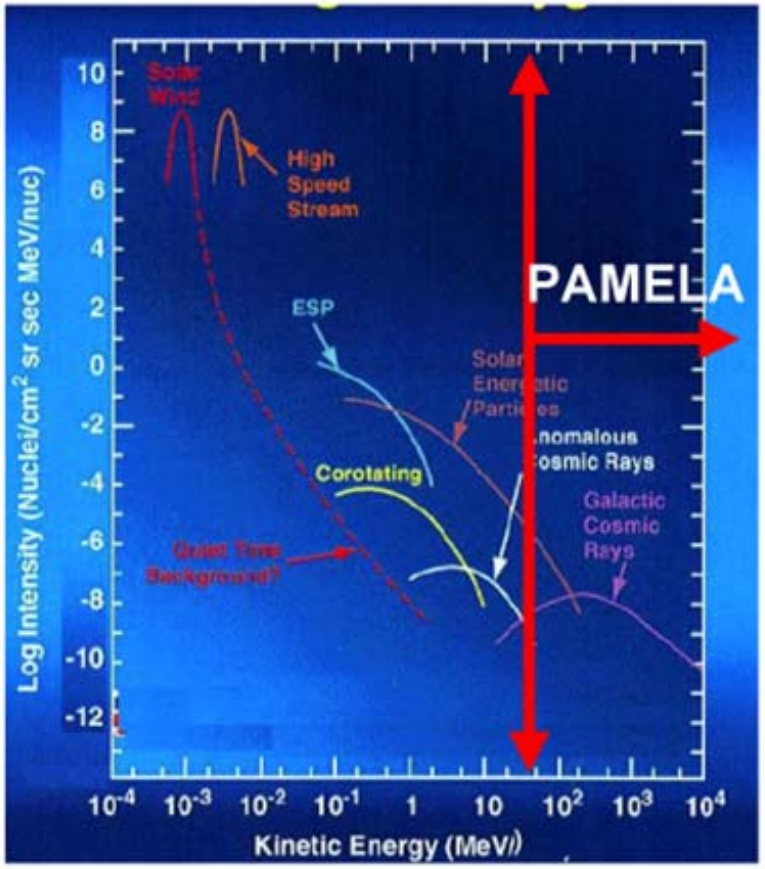


RED: JULY 2006
BLUE: AUGUST 2007

PAMELA: Galactic H and He spectra

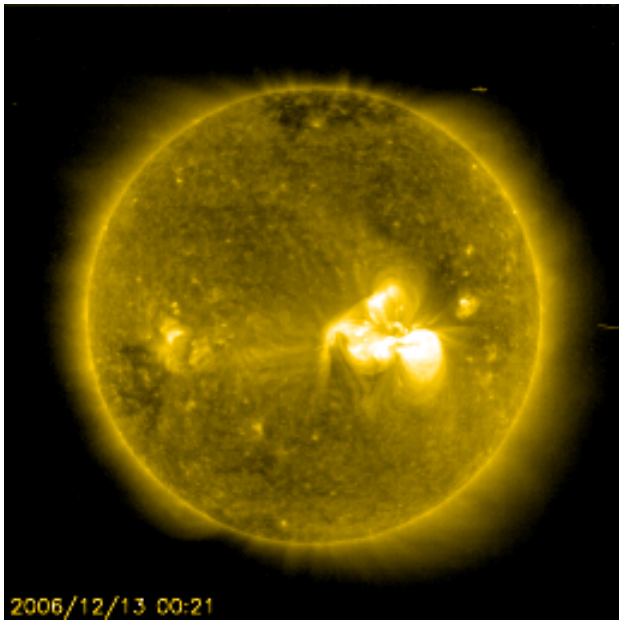


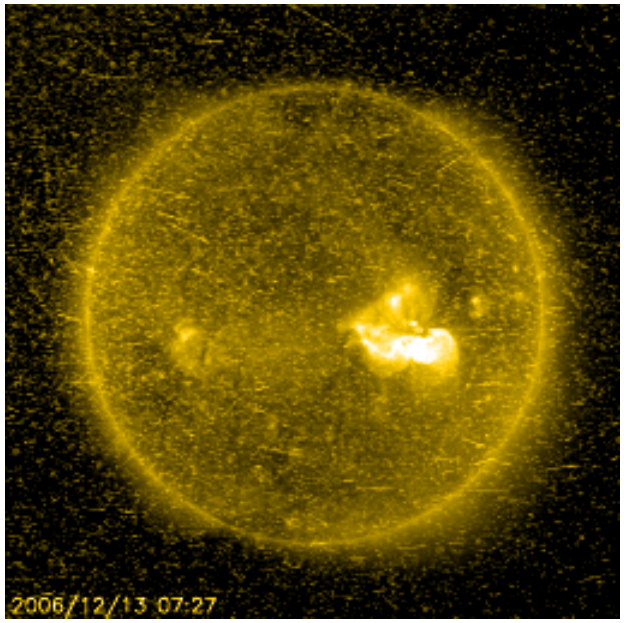
Solar Physics with PAMELA

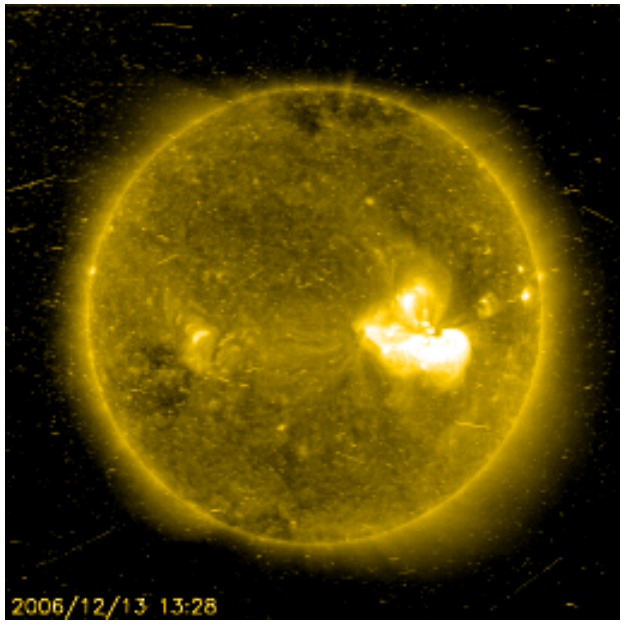


- Solar Modulation effects
- High energy component of Solar Proton Events (from 80 MeV to 10 GeV) — ***80 MeV***
- High energy component of electrons and positrons in Solar Proton Events (from 50 MeV) — ***50 MeV***
- Nuclear composition of Gradual and Impulsive events
- ^{3}He and ^{4}He isotopic composition

December 2006 Solar particle events

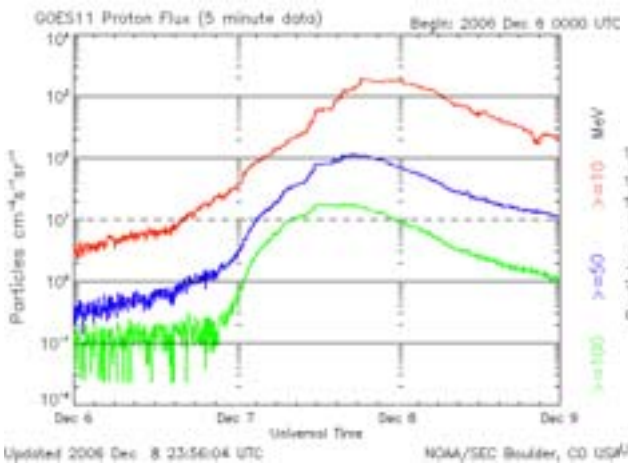


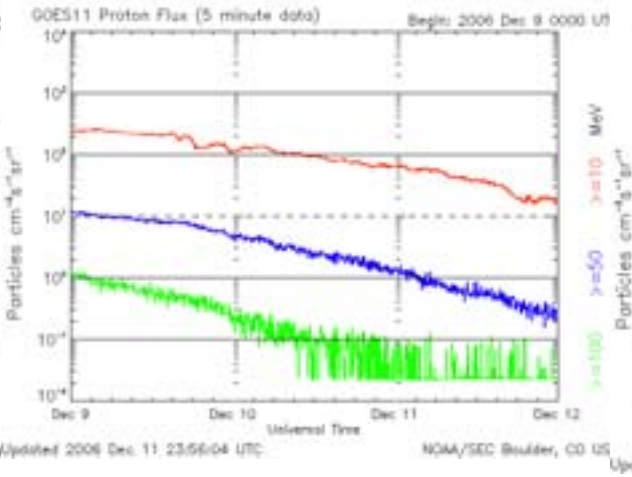


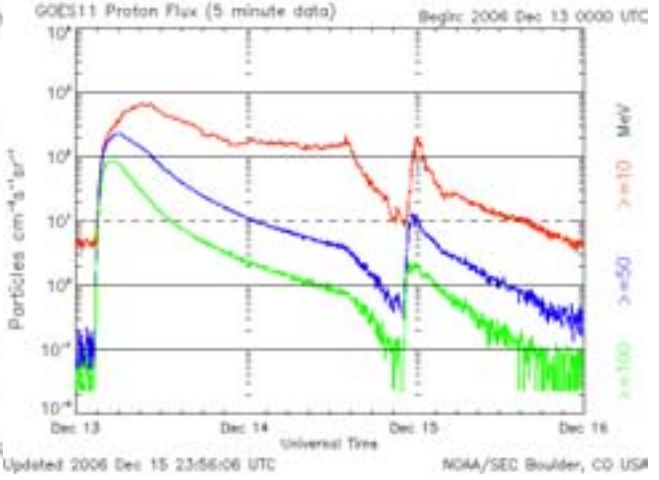


X3.4 solar flare

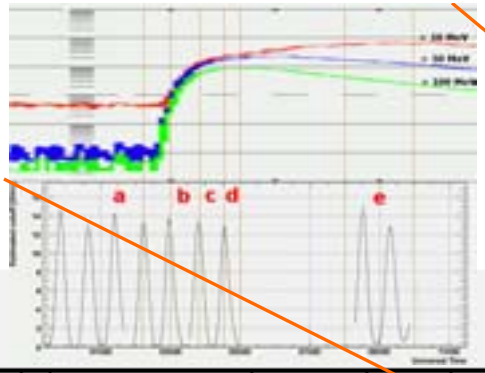
Dec 13th largest CME since 2003, anomalous at sol min

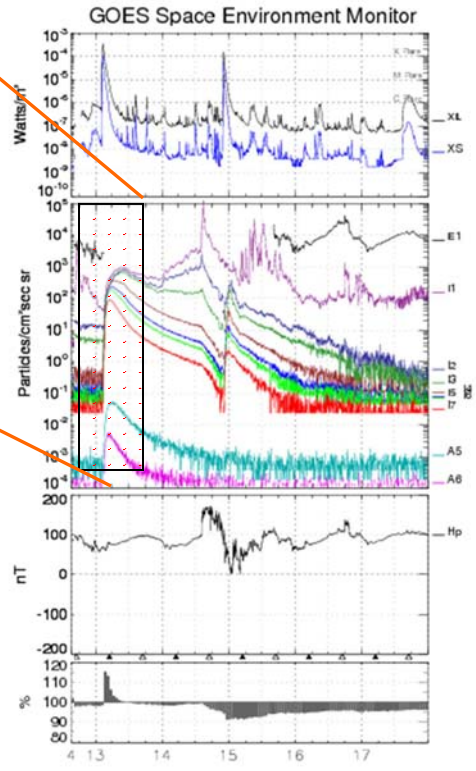


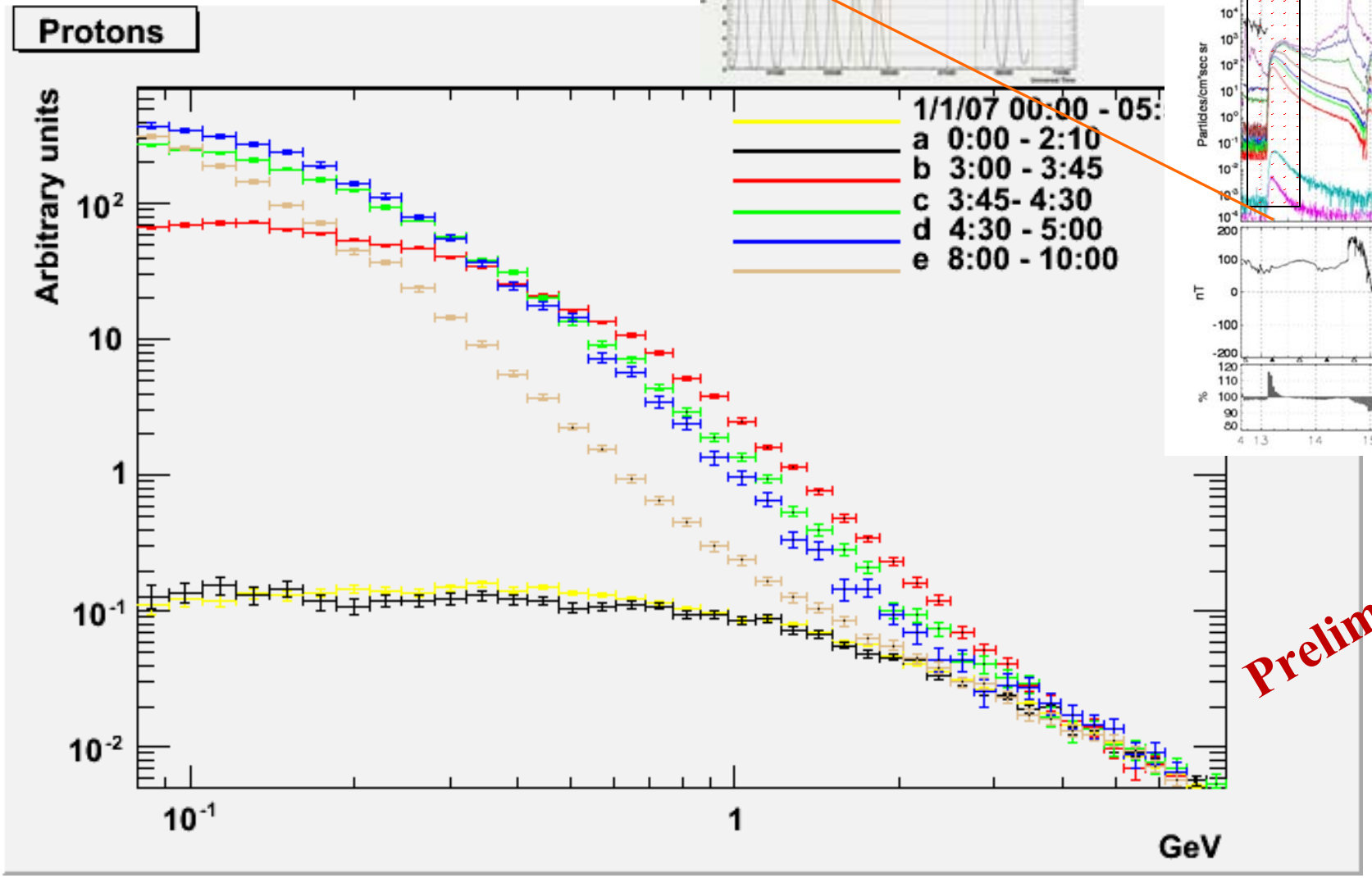




December 13th 2006 event

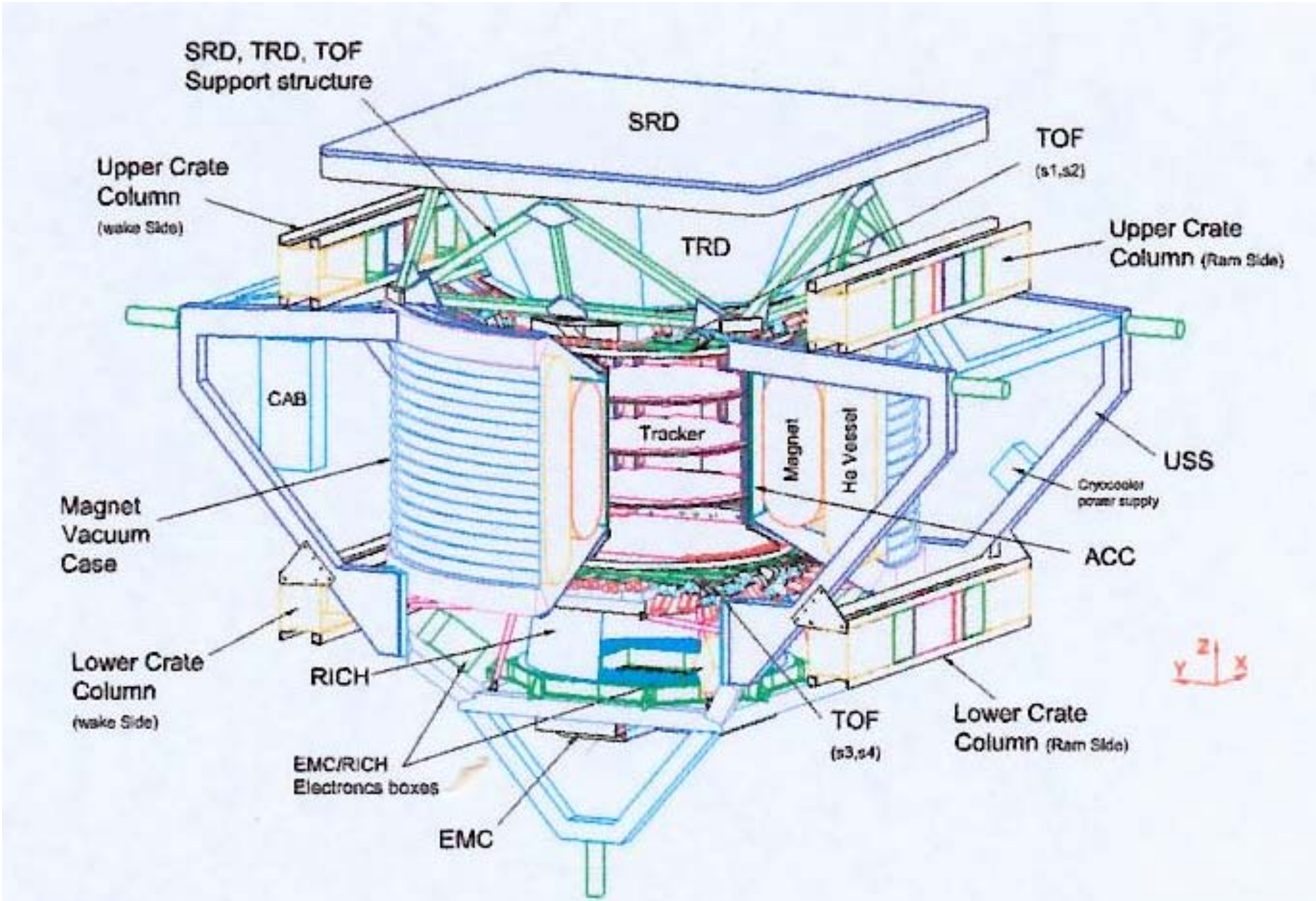




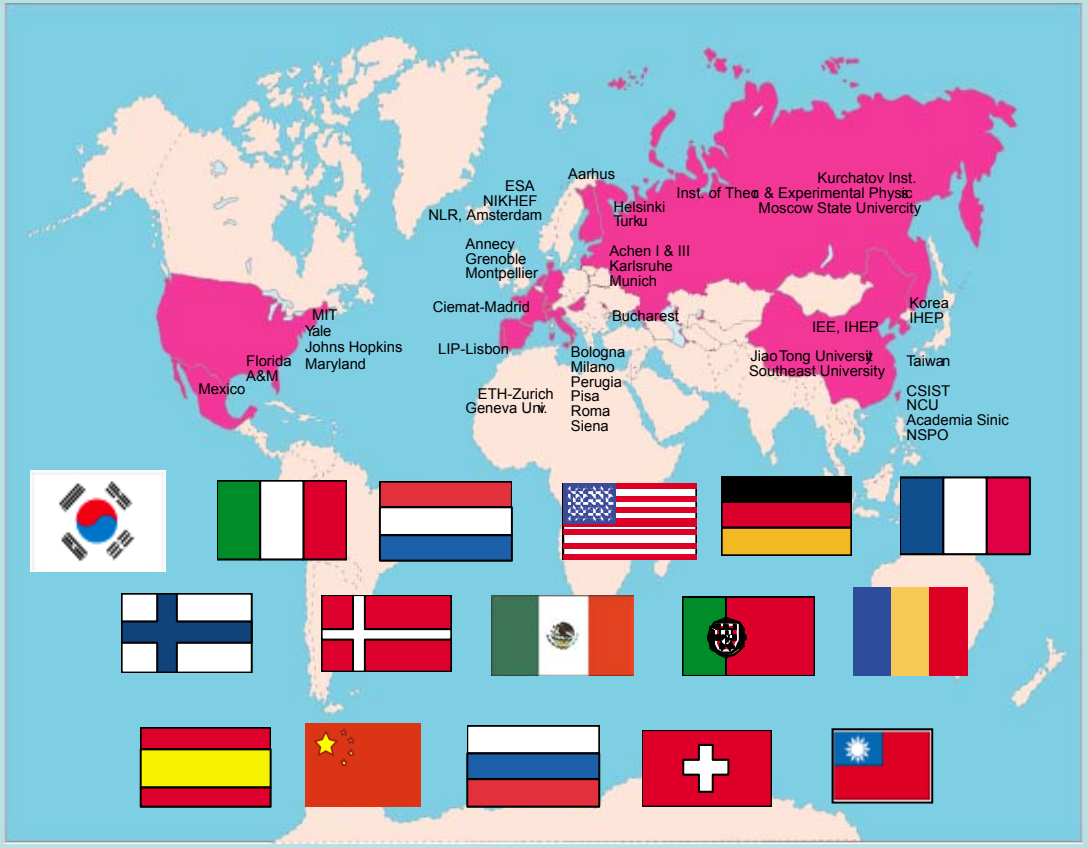


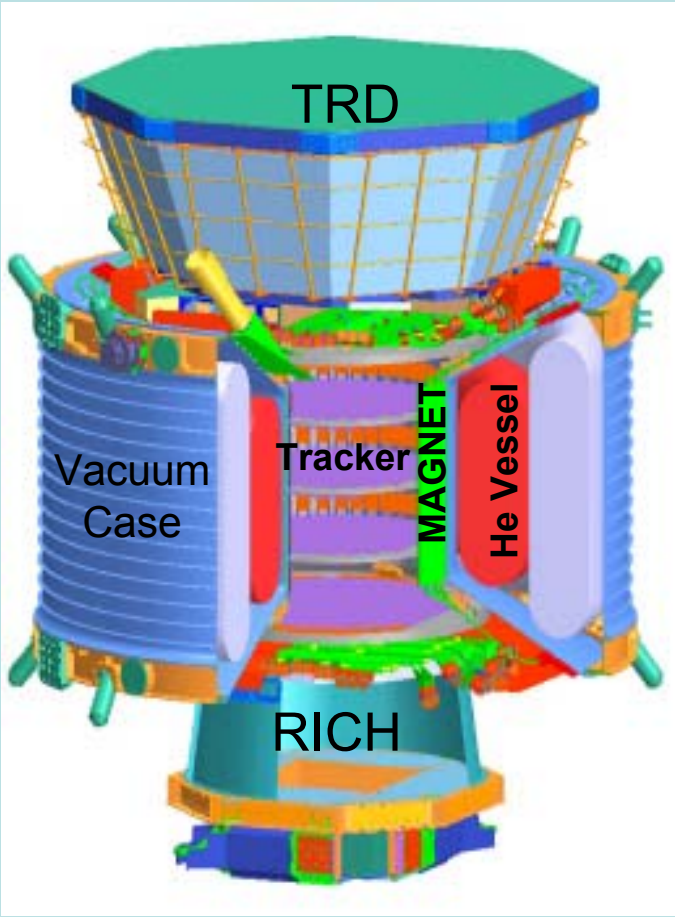
Preliminary!

- PAMELA is the first space experiment which is measuring the Antiprotons and Positrons to the high energies (> 150GeV) with an unprecedented statistical precision
- PAMELA is setting a new lower limit for finding Antihelium
- PAMELA is looking for Dark Matter candidates
- PAMELA is providing measurements on elemental spectra and low mass isotopes with an unprecedented statistical precision and is helping to improve the understanding of particle propagation in the interstellar medium
- PAMELA is able to measure the high energy tail of solar particles.


SRD, TRD, TOF
Support structure
SRD
TOF
(s1,s2)
Upper Crate
Column
(wake Side)
TRD
Upper Crate
Column (Ram Side)
CAB
Tracker
Magnet
He Vessel
USS
Cryocooler
power supply
Magnet
Vacuum
Case
ACC
Lower Crate
Column
(wake Side)
RICH
TOF
(s3,s4)
Lower Crate
Column (Ram Side)
EMC/RICH
Electronics boxes
EMC

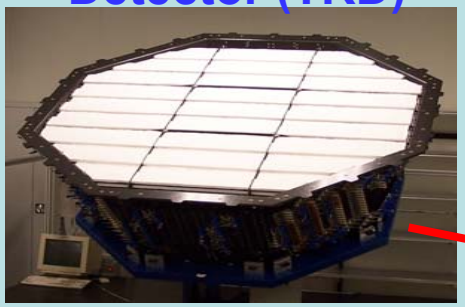
AMS-02 on ISS
In Orbit 2009



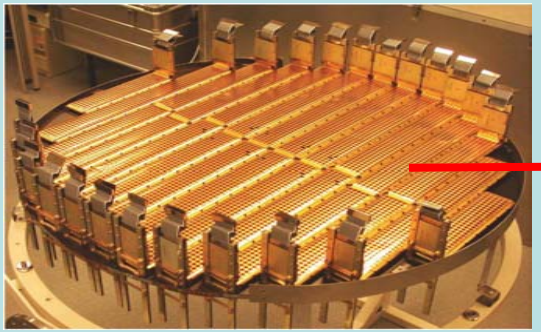


The Completed AMS Detector on ISS

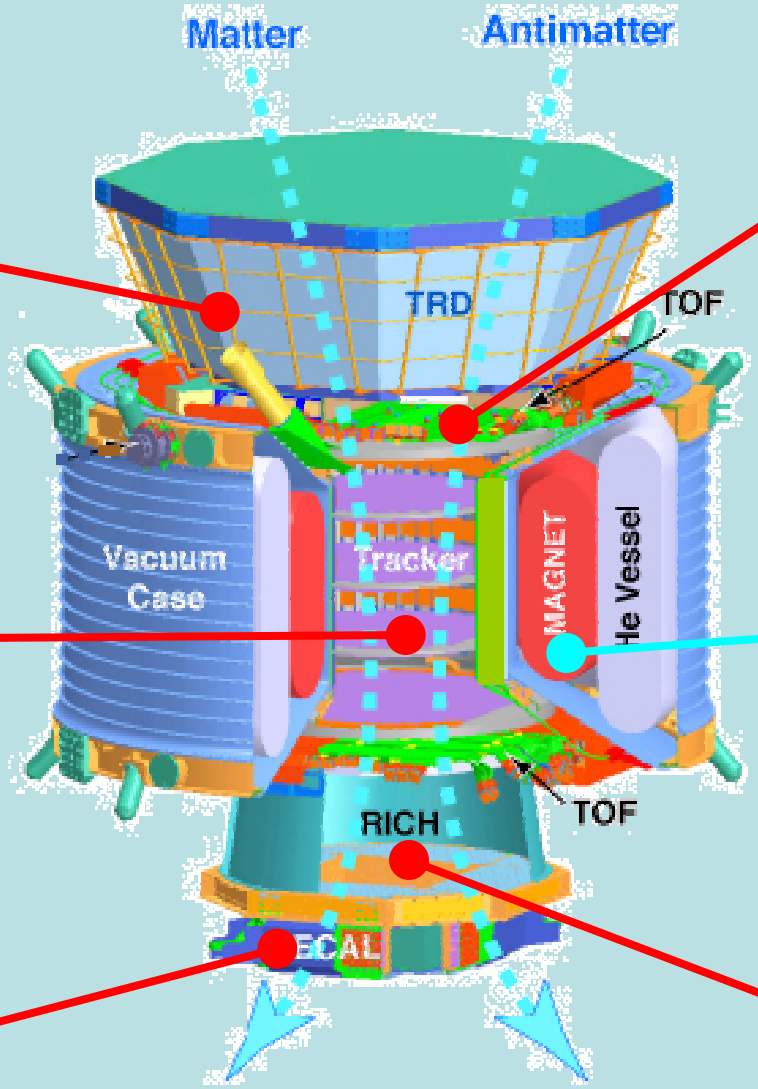
Transition Radiation Detector (TRD)



Silicon Tracker



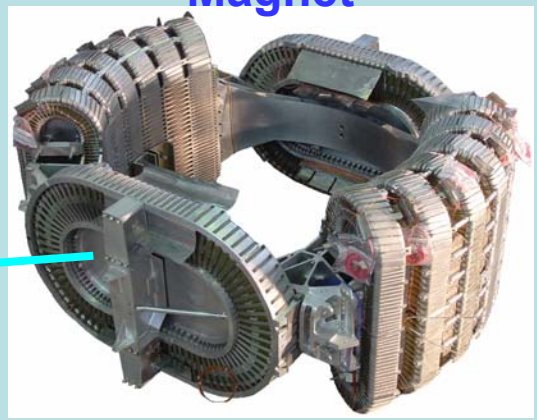
Electromagnetic Calorimeter (ECAL)



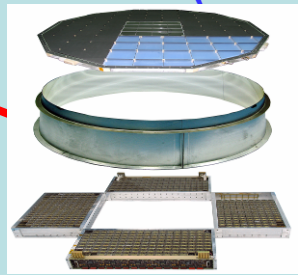
Size: 3m x 3m x 3m
Weight: 7 tons

Time of Flight Detector (TOF)

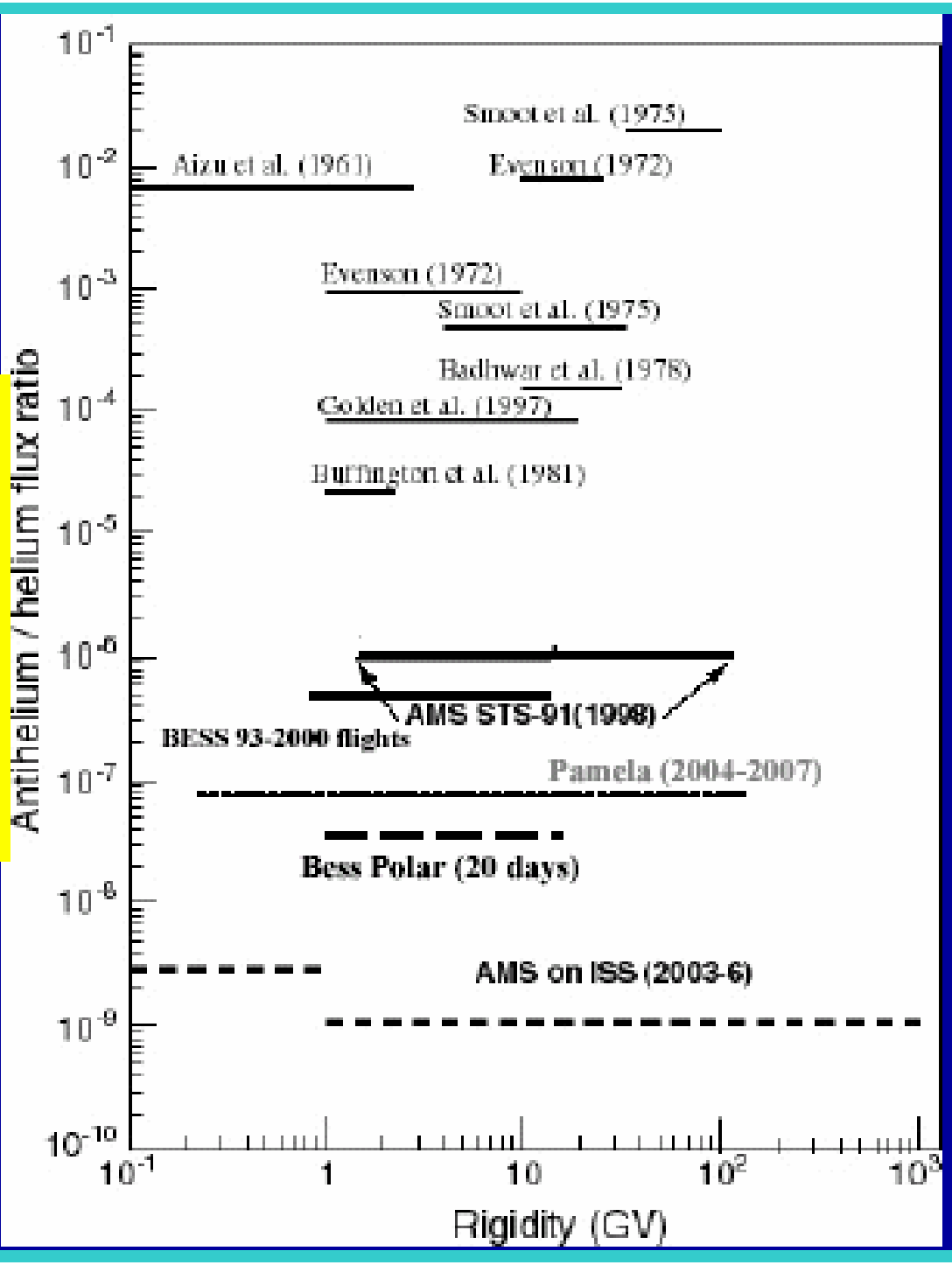
Magnet



Ring Image Cerenkov Counter (RICH)



Search for antimatter at the 10^{-9} level of sensitivity with AMS-02 on the ISS



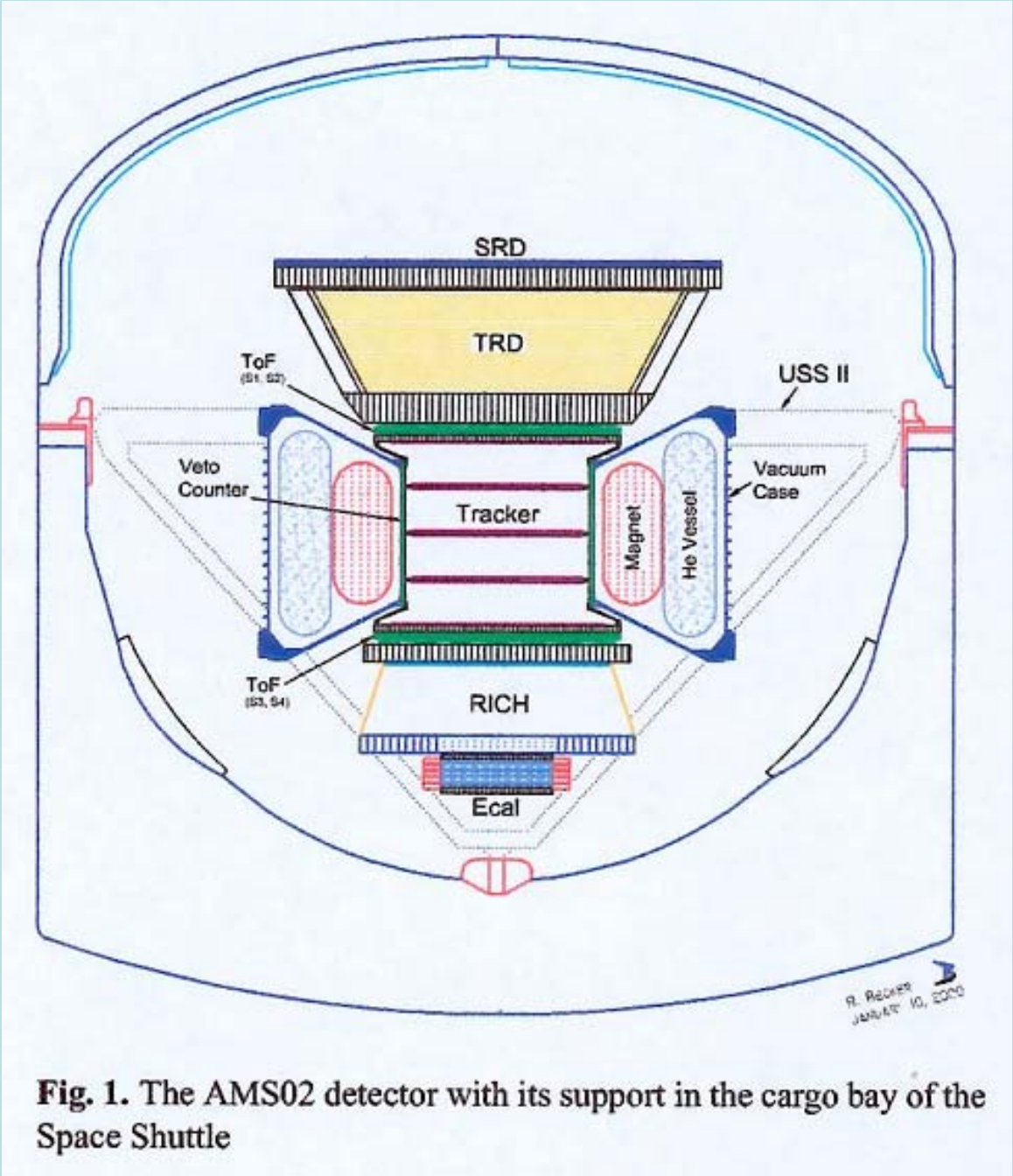
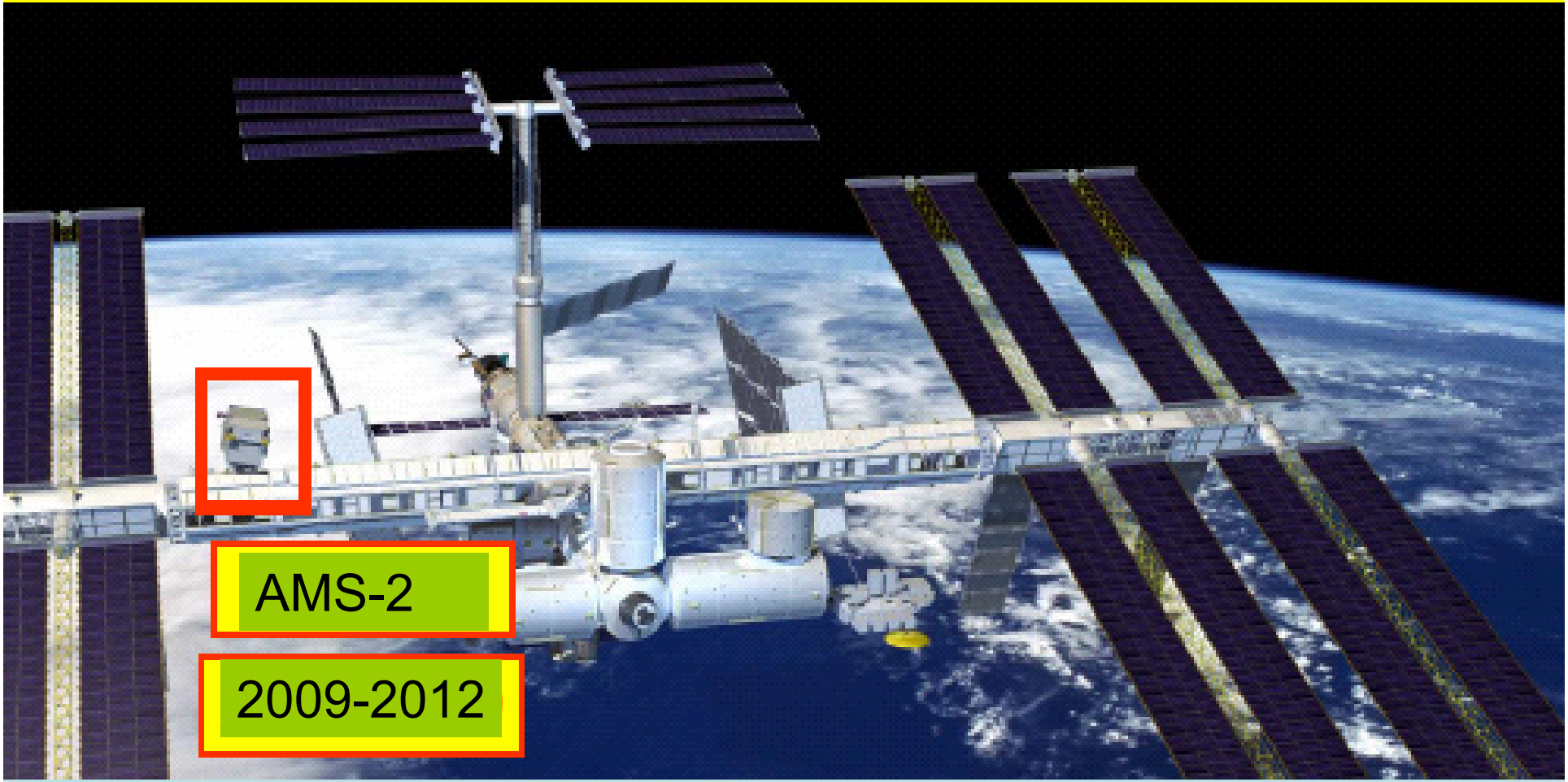


Fig. 1. The AMS02 detector with its support in the cargo bay of the Space Shuttle


USA
y04K604

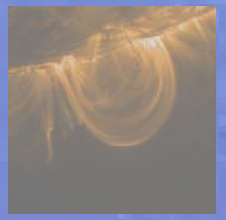
AMS-02 on the International Space Station



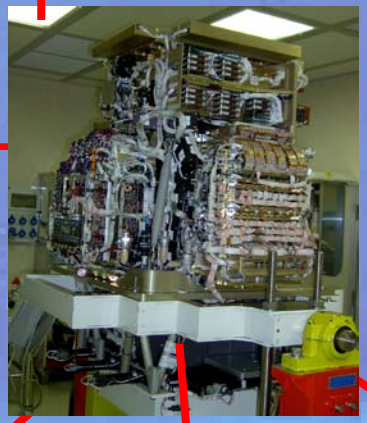
Pamela and AMS-02
Space Observatories at 1AU

Matter : Antimatter
PBH Dark Matter
Galactic cosmic rays

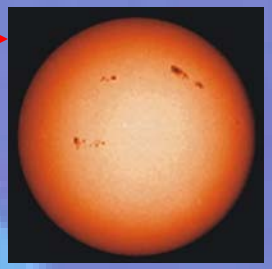
Solar Energetic particles



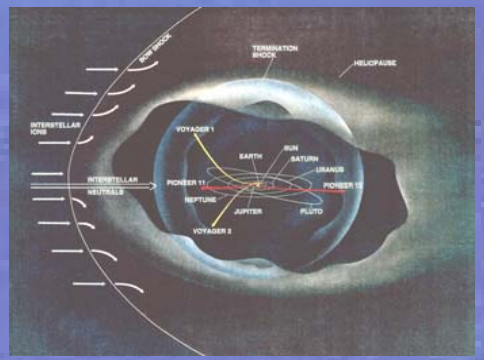
Jovian electrons



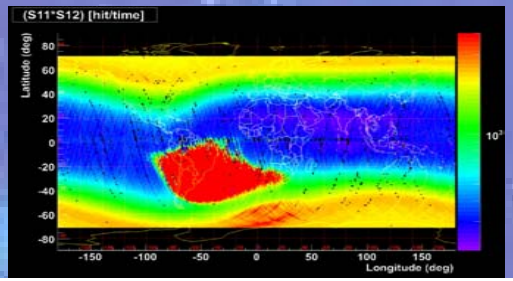
Solar Modulation



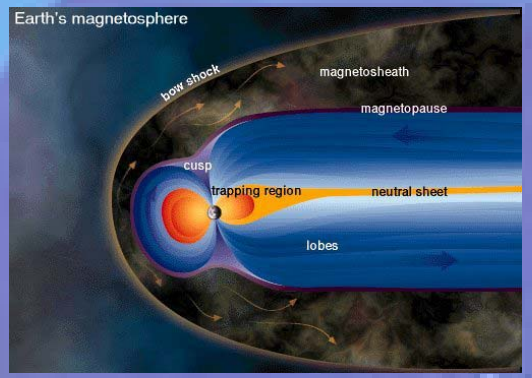
Anomalous Nuclei
Nearby e⁻ Sources



R. B., SAA, Albedo,
secondary particle



Magnetospheric physics



What for the next future?

and what for the far future?

High Z – nothing in program

Worthwhile to be considered as one of the first generation experiments on the Moon

Rare elements and isotopes:

low energies (≤1 GeV/nucleon): ACE continues

higher energies: no new proposals, rely on by-products from PAMELA, BESS, AMS

Small but complex device possible on the ISS or on the Moon

Antiparticles and antinuclei: PAMELA other >2 years

(+dark matter) BESS Polar continues

AMS several years

?(To be considered on the Moon if terrestrial bending could be used)?

CR@Knee: TRACER, CREAM, ATIC balloon.

NUCLEON and CALET in orbit

Possible on ISS (→ 10 PeV on Moon if a 'condominium' base will exist)

UHECR: TUS (precursor), LORD (test of the method), projects JEM-EUSO, S-EUSO

S-EUSO could open HE-neutrino astronomy

A Neutrino Observatory could be considered around Moon if LORD will be successful

Thank you for your attention

Grazie per l’attenzione