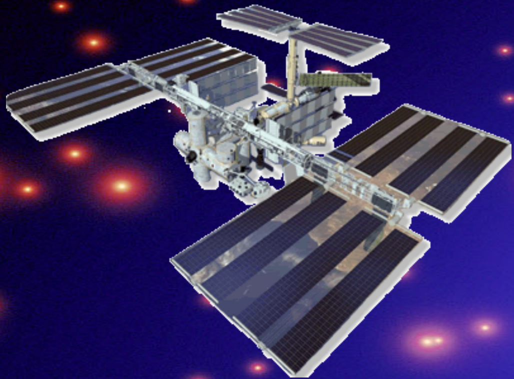
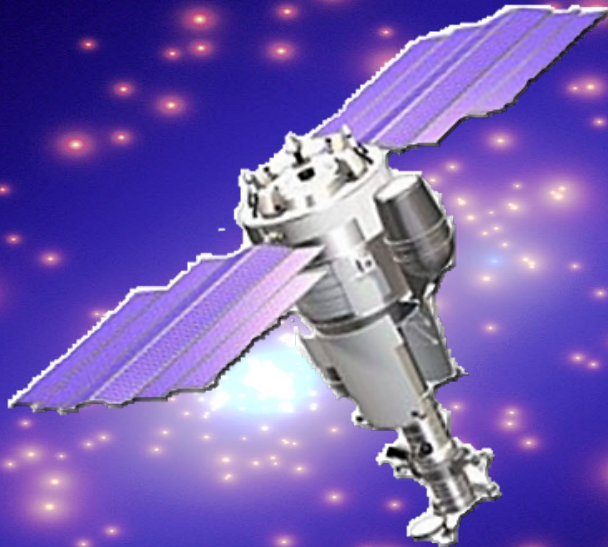
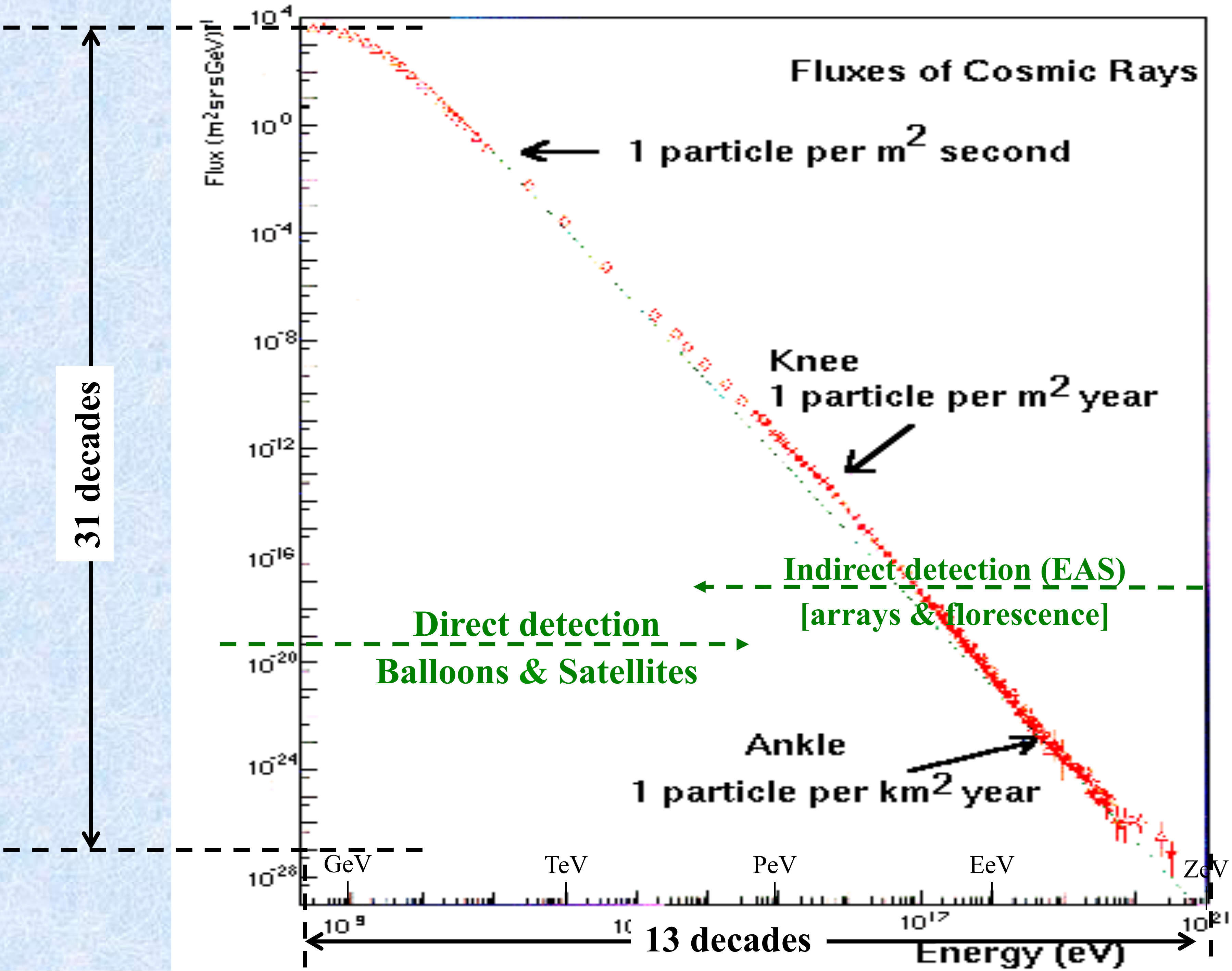
Cosmic Ray Direct Measurements



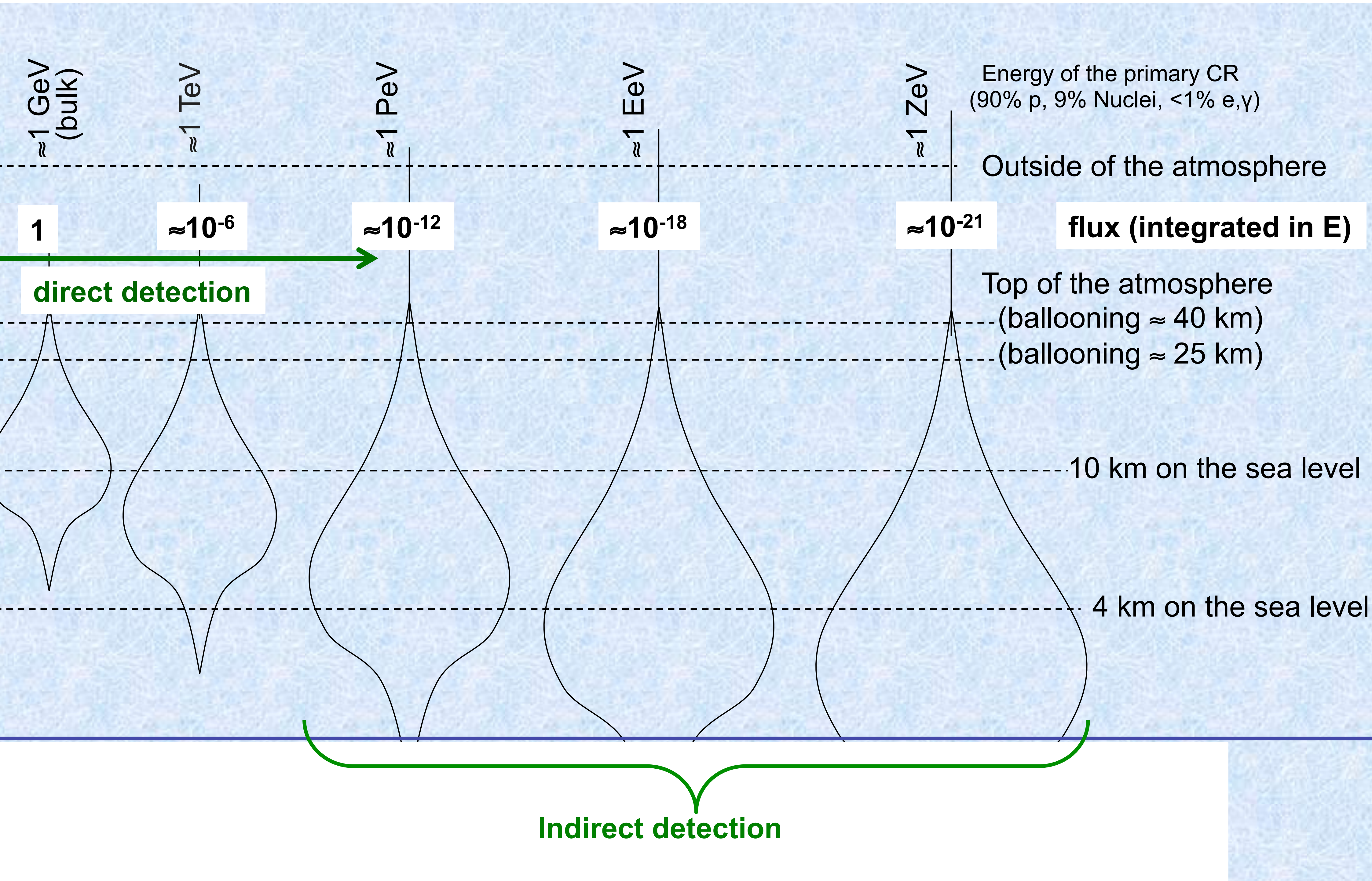


Piergiorgio Picozza
INFN and University of Rome Tor Vergata

Cosmic Ray Origin - beyond the standard models
San Vito di Cadore
September, 18-24, 2016



Fluxes of Cosmic Rays
Flux (m²srsGeV)⁻¹
Energy (eV)
1 particle per m² second
Knee
1 particle per m² year
Indirect detection (EAS)
[arrays & florescence]
Direct detection
Balloons & Satellites
Ankle
1 particle per km² year
31 decades
13 decades
GeV
TeV
PeV
EeV
ZeV

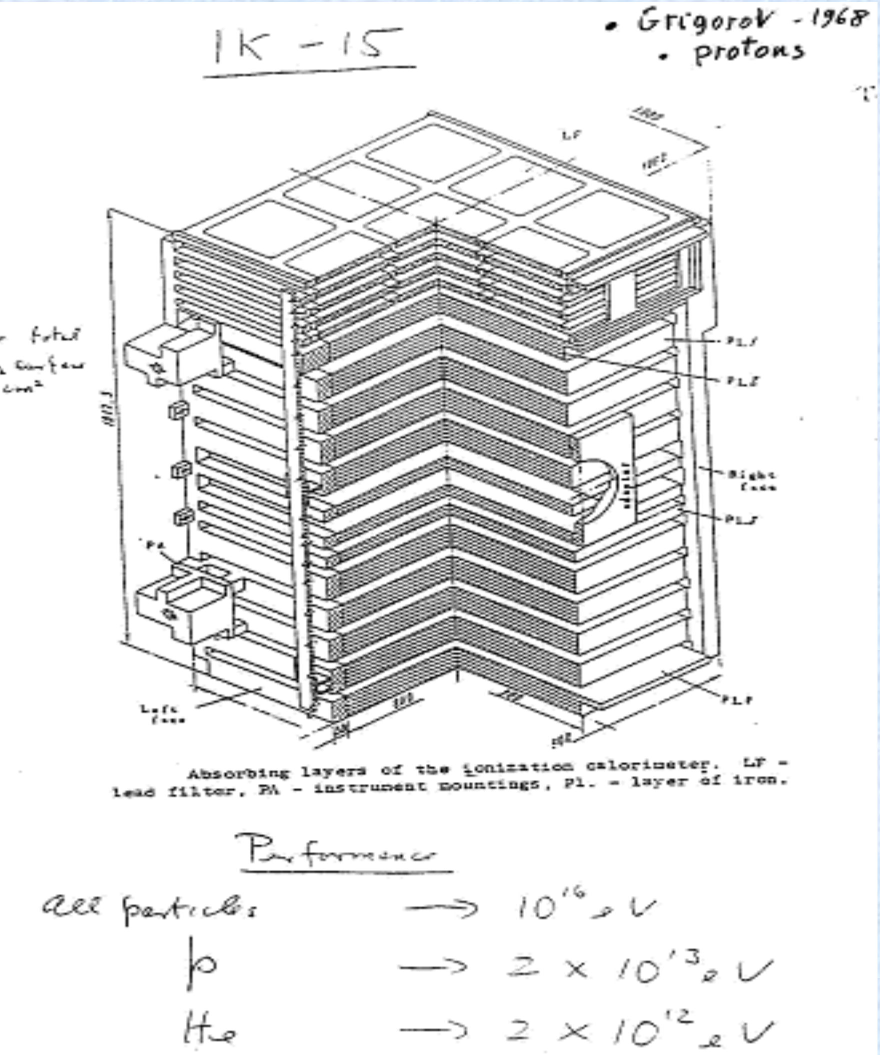

≈1 GeV (bulk)
≈1 TeV
≈1 PeV
≈1 EeV
≈1 ZeV
Energy of the primary CR
(90% p, 9% Nuclei, <1% e,γ)
Outside of the atmosphere
1
≈10-6
≈10-12
≈10-18
≈10-21
flux (integrated in E)
direct detection
Top of the atmosphere
(ballooning ≈ 40 km)
(ballooning ≈ 25 km)
10 km on the sea level
4 km on the sea level
Indirect detection

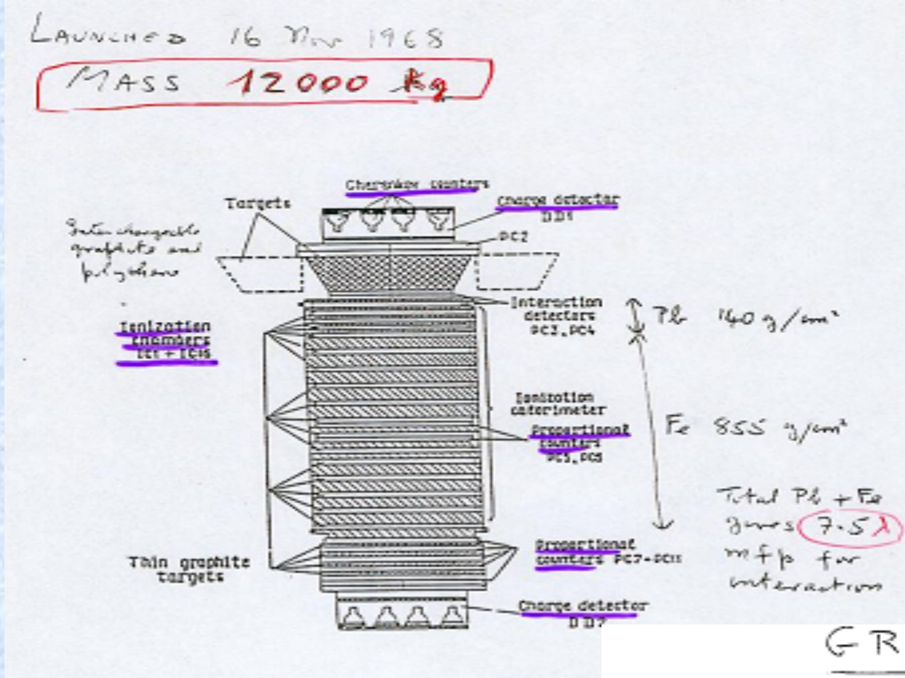
Direct detection experiments

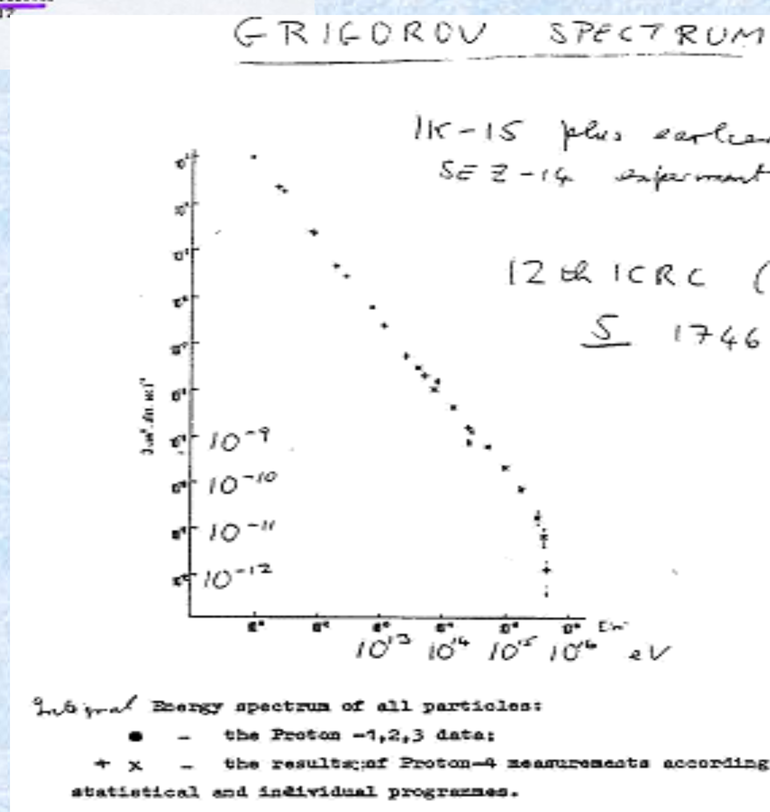
Grigorev expt's (satellite, 1968)	Discovery of the knee in p spectrum
HEAO-3 (satellite, 1979)	Elemental spectra up to 0.1 TeV/nucl
'Chicago egg' (Space-lab, 1985)	Elemental spectra up to 1 TeV/nucl
JACEE (>15 flights, Long Dur. Ball.)	} Elem. spectra →10**15 eV/nucleus
RUNJOB (>10 flights, ~Long Dur. B.)	
ATIC (1 Long. Dur. Ball. + *Ultra LDB*)	
CREAM (Ultra Long Duration Ballooning)	

RED: balloon borne experiments
VIOLET: satellite borne experiments

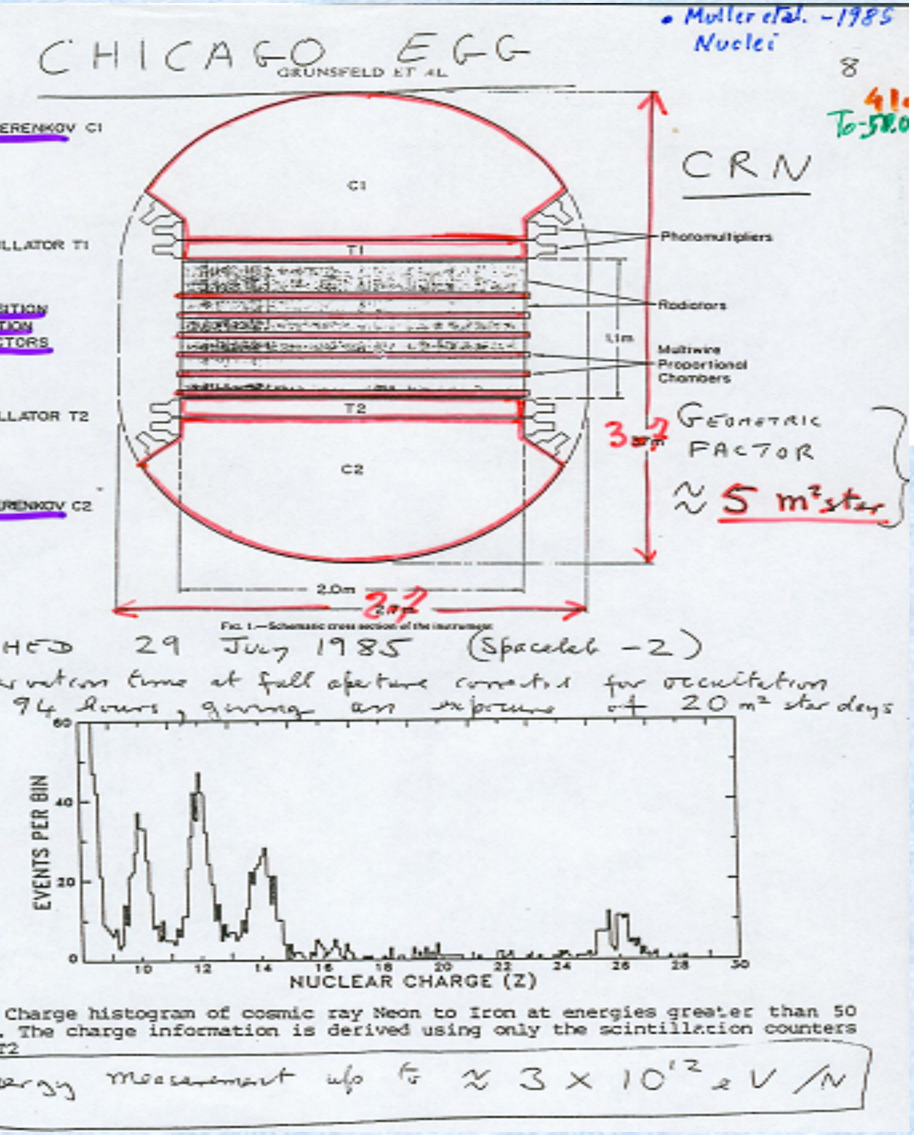
Grigorov, 1968

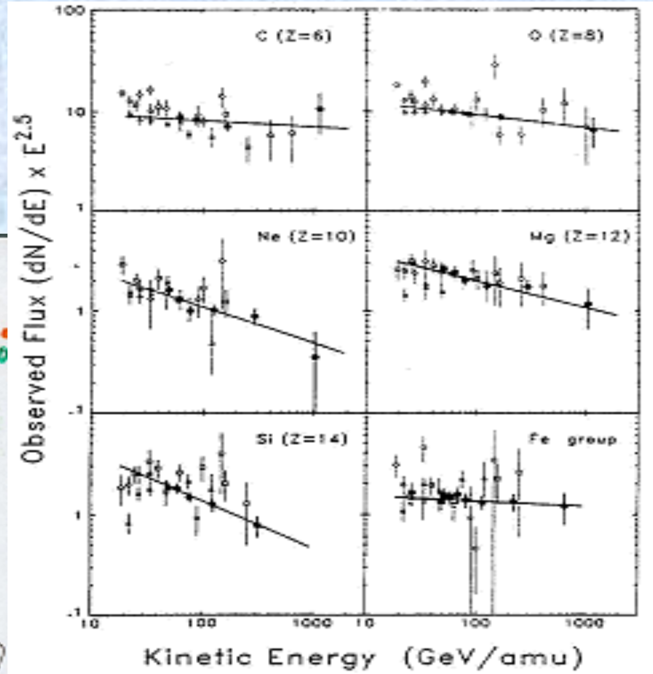


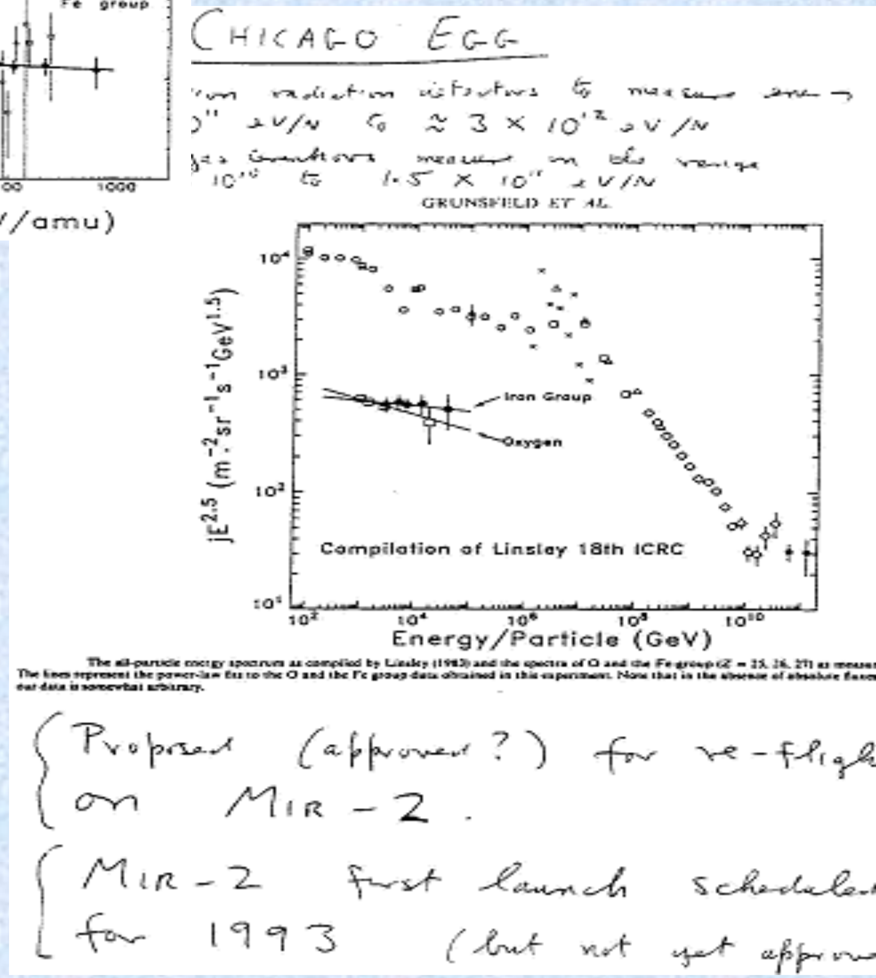




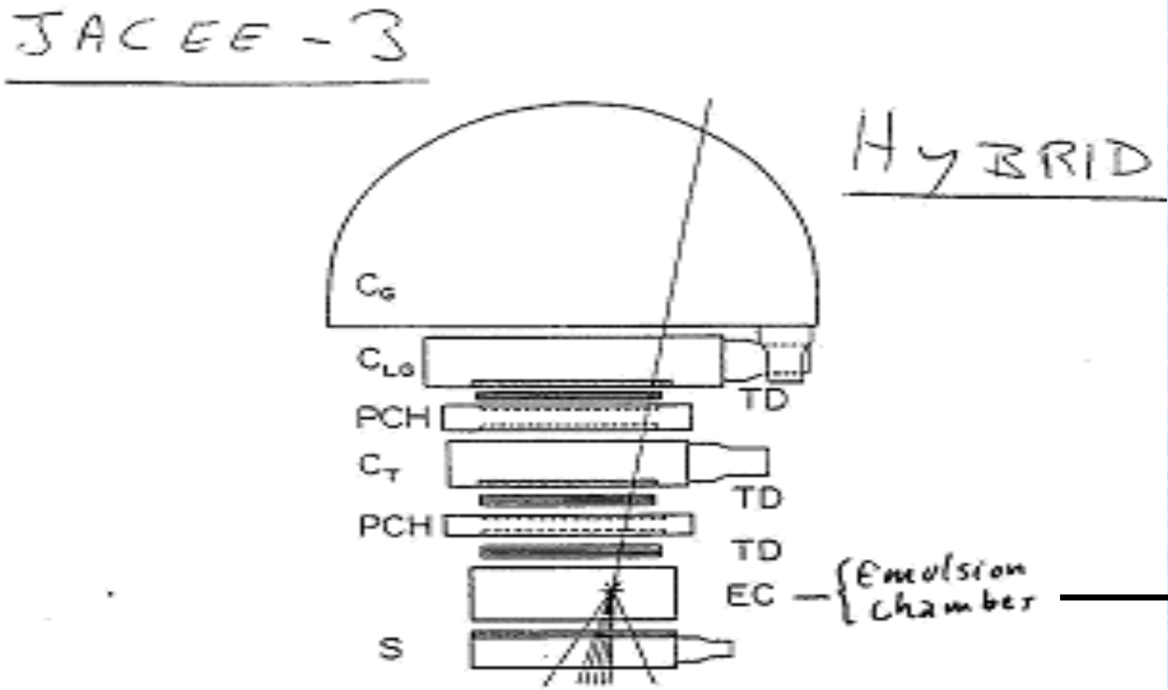
N (Chicago egg), 1985







JACEE



Schematic diagram of the hybrid counter-emulsion chamber instrument used for JACEE-3. Legend: C_G = 1-atmosphere freon-12 gas Cherenkov counter; C_{LG} = lead glass Cherenkov counter; PCH = proportional counter hodoscope; C_T = Teflon Cherenkov counter; EC = emulsion chamber; TD = passive tracking detectors; S = plastic scintillator. A hypothetical track through the counters, with an interaction in the emulsion chamber, is illustrated.

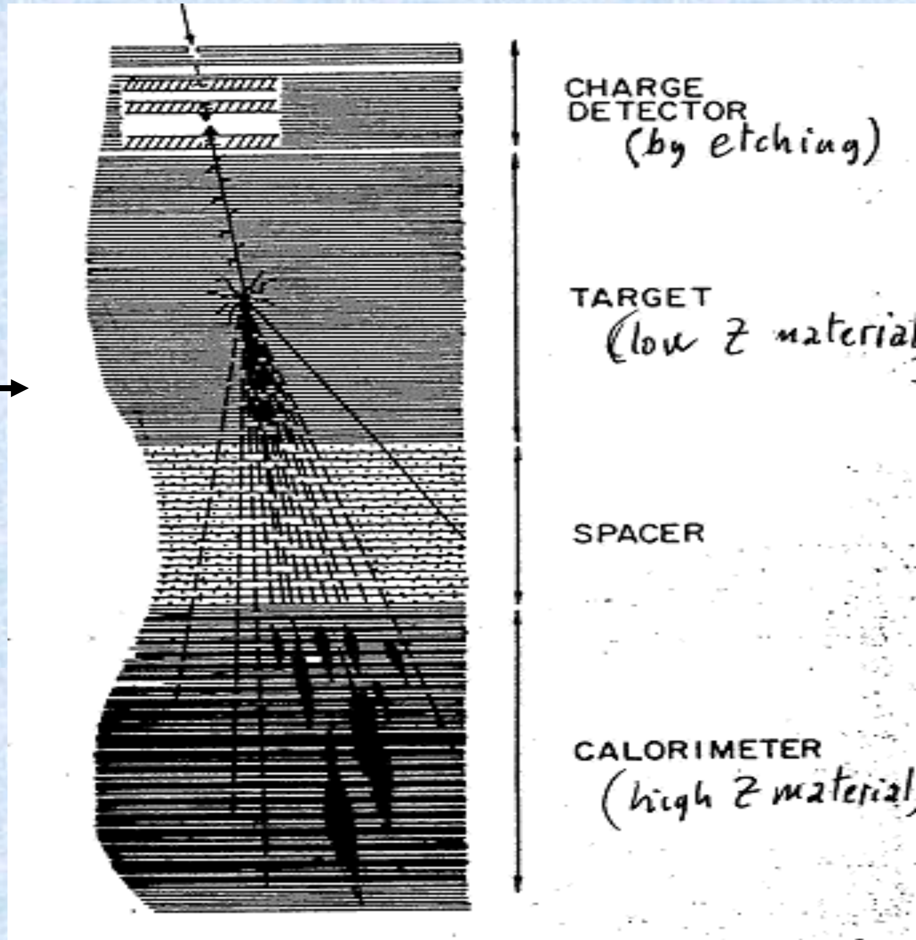


Fig. 1. Schematic diagram of the JACEE emulsion chambers. The JACEE-0 and JACEE-2 chambers did not have the spacer section.

1
matic view
amber

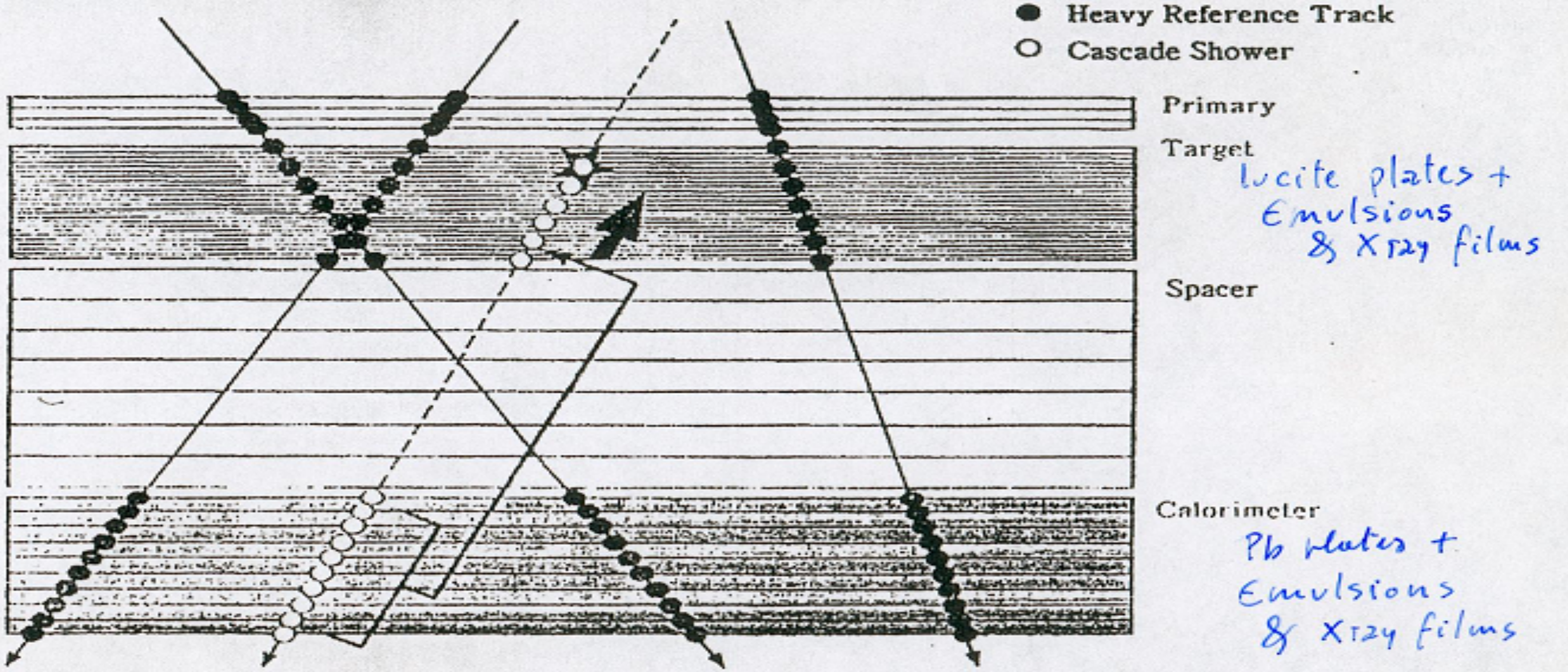
NJOB
periments

s begun in '95

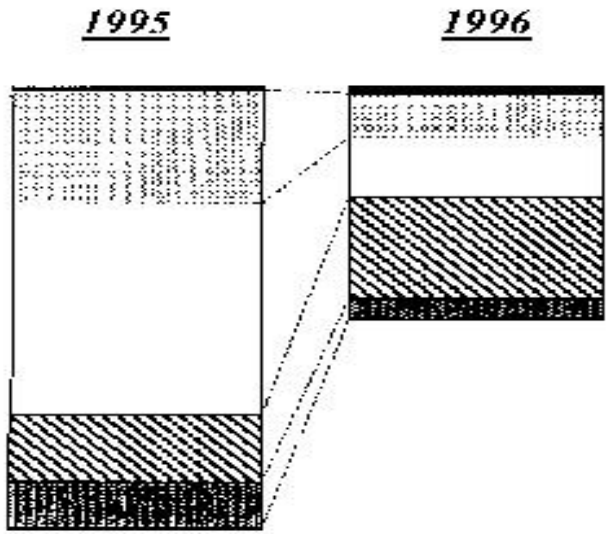
Kamchatka
rali mountains

6 days)

s = 230 kg

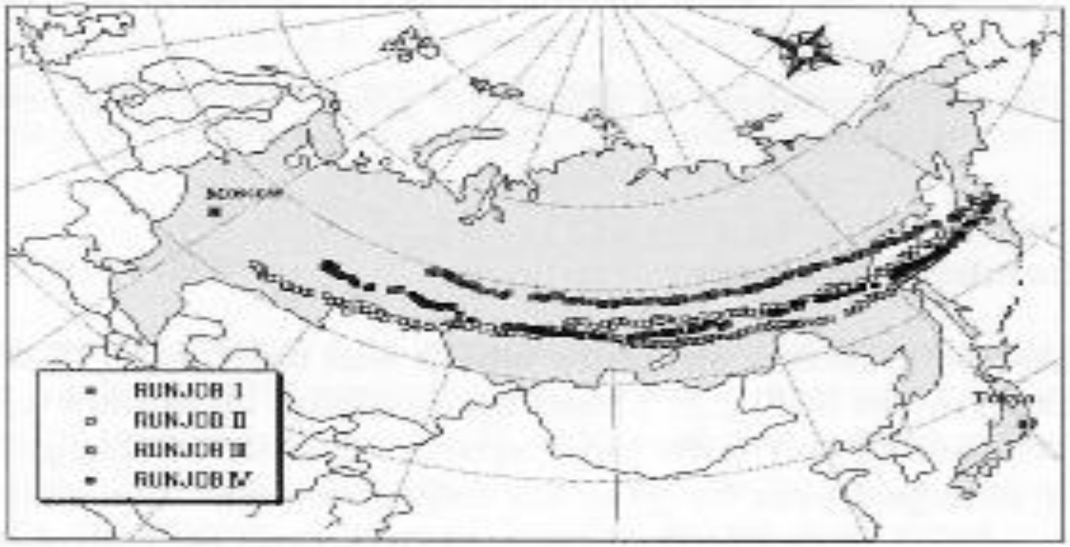


RUNJOB



: MODULE	THICKNESS for '95	for
: primary	4.6mm	8.9
: target	99.8mm	37.8
: spacer	187.4mm	53.2
: upper calorimeter	57.7mm	91.0
: lower calorimeter	43.4mm	19.8

RUNJOB



ig. 1. Trajectories of four balloon flights perforr
996

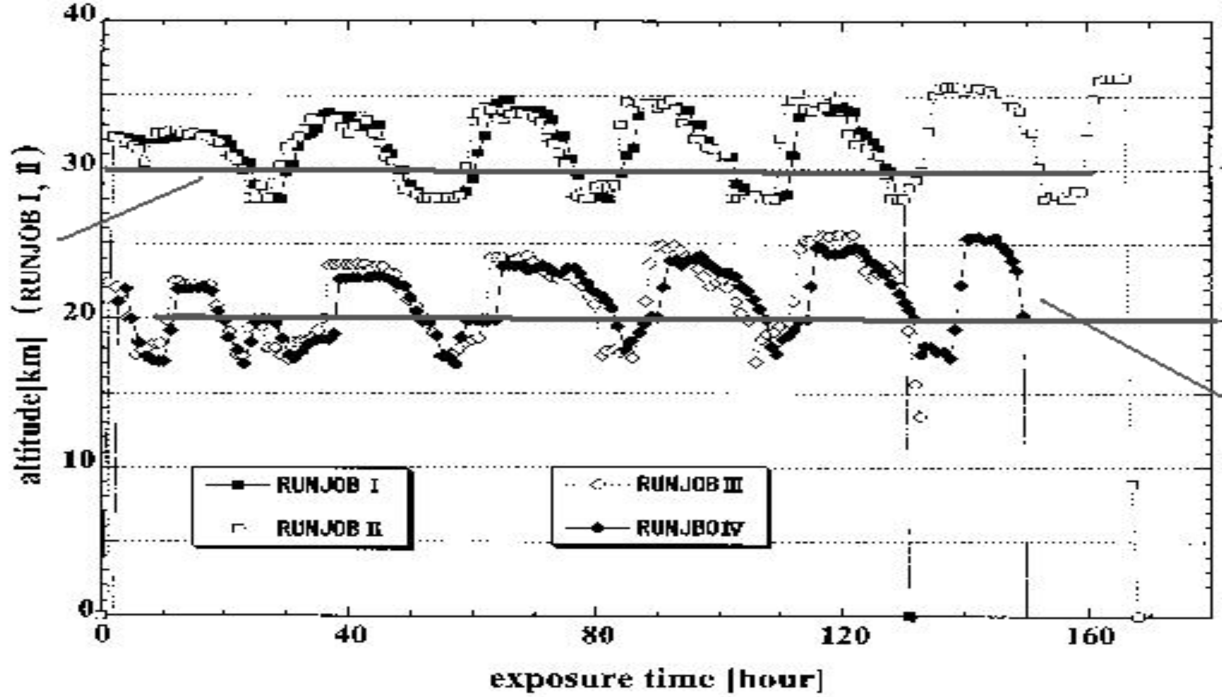


Fig. 2. altitude profiles of four balloons, RUNJOB I,II in 1995 and RUNJOB III,IV in 1996

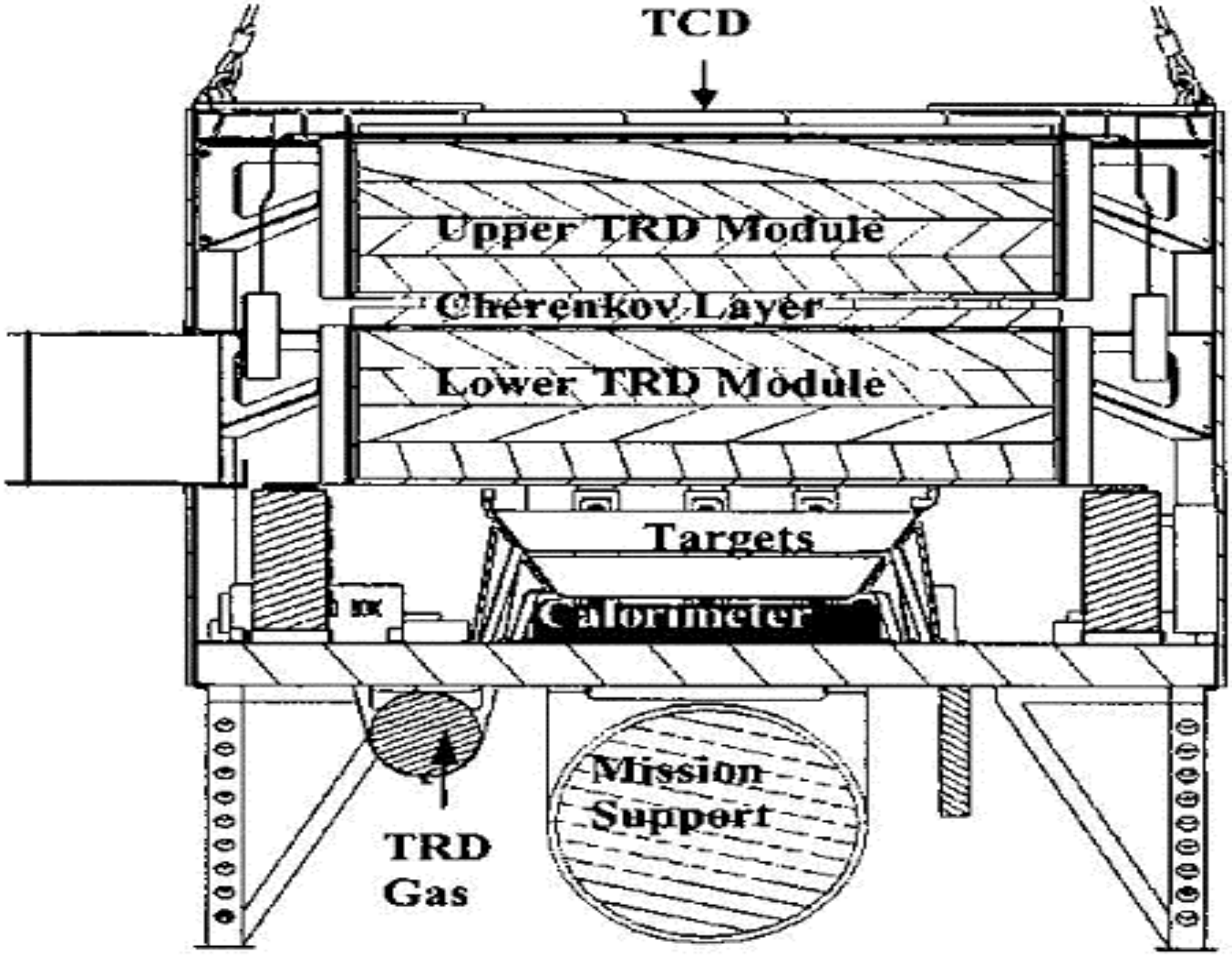
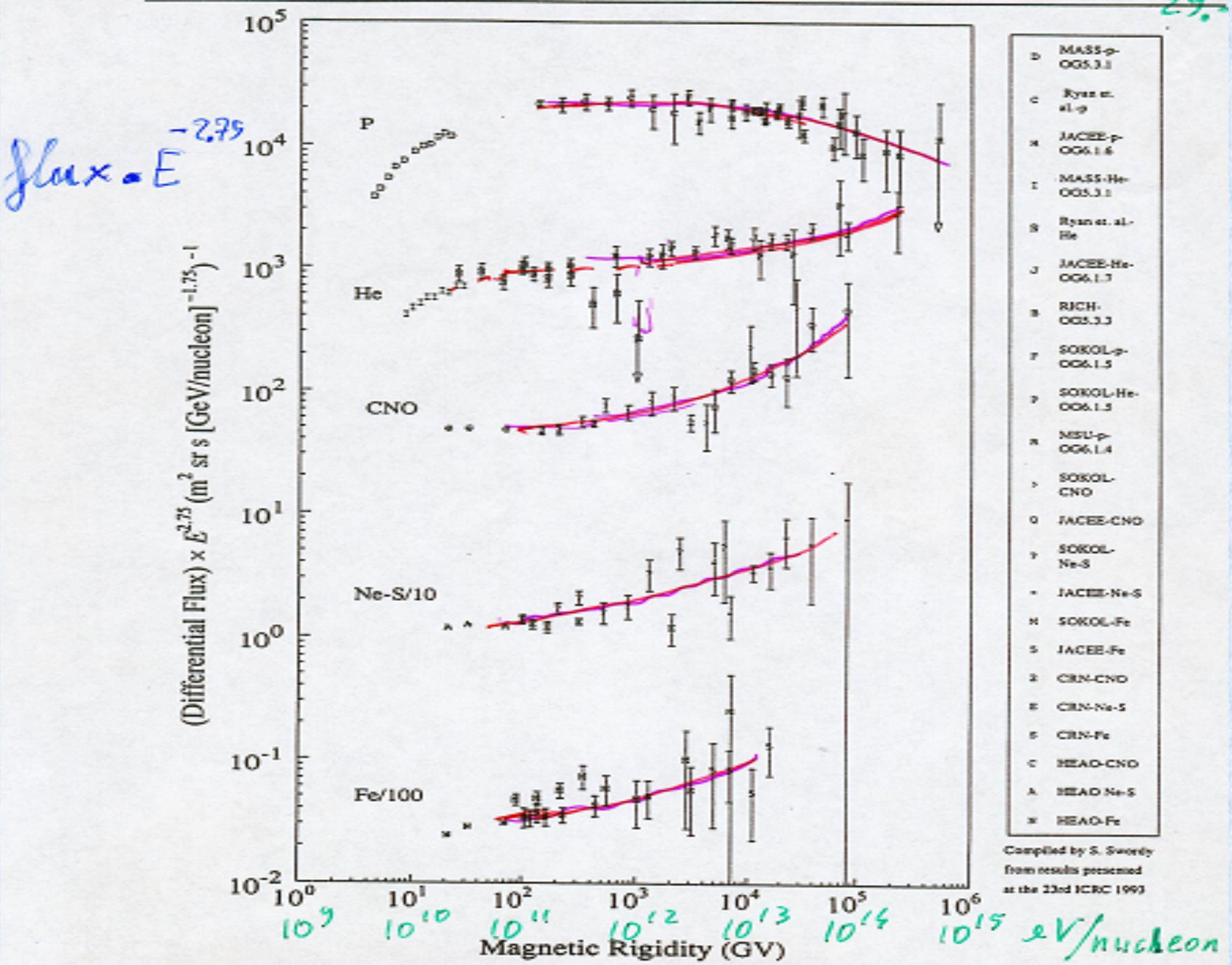


Fig. 1. Schematic cross-section of the CREAM payload.

Summary of direct measurements of the major groups of elements at high energy



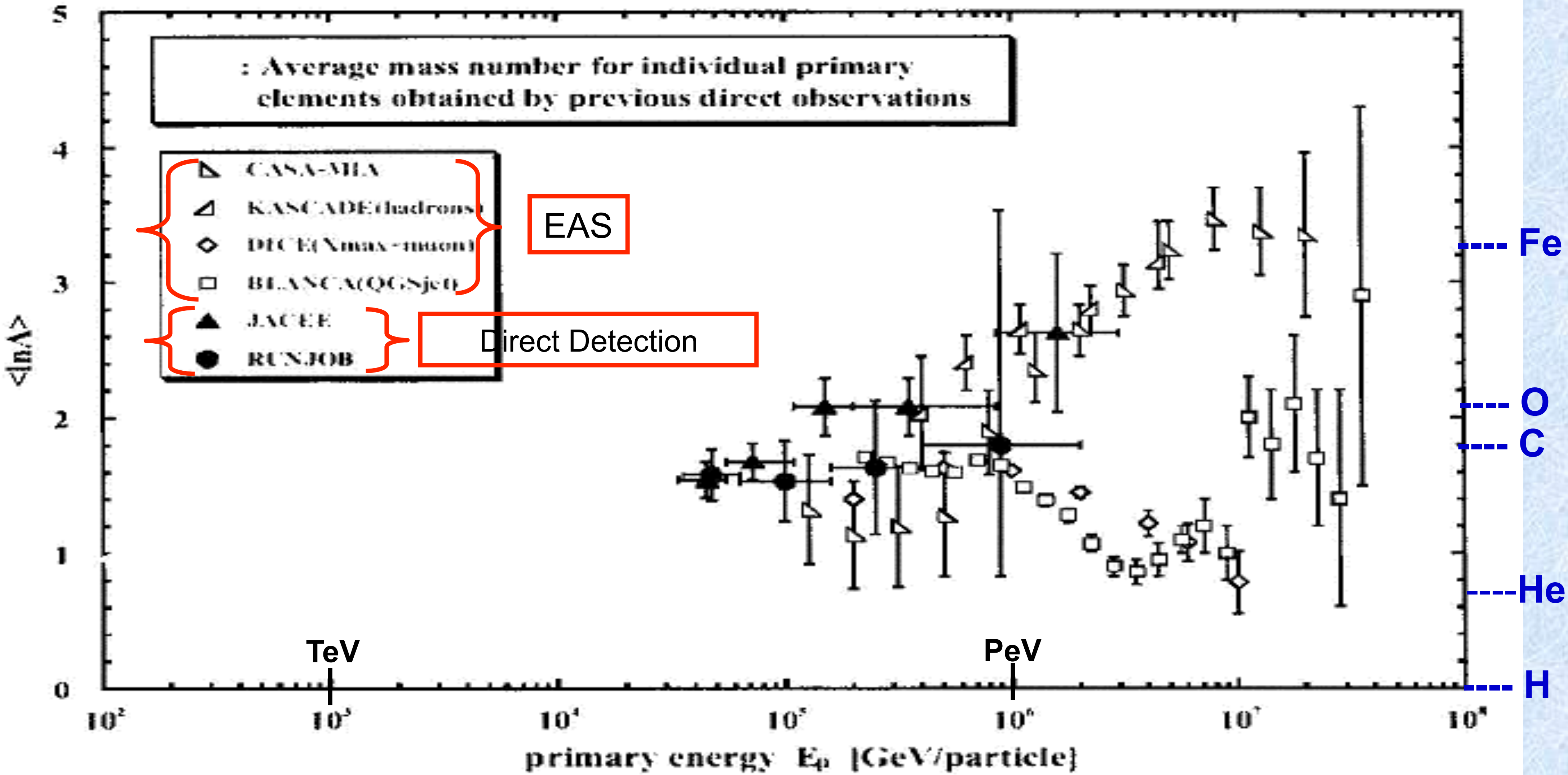
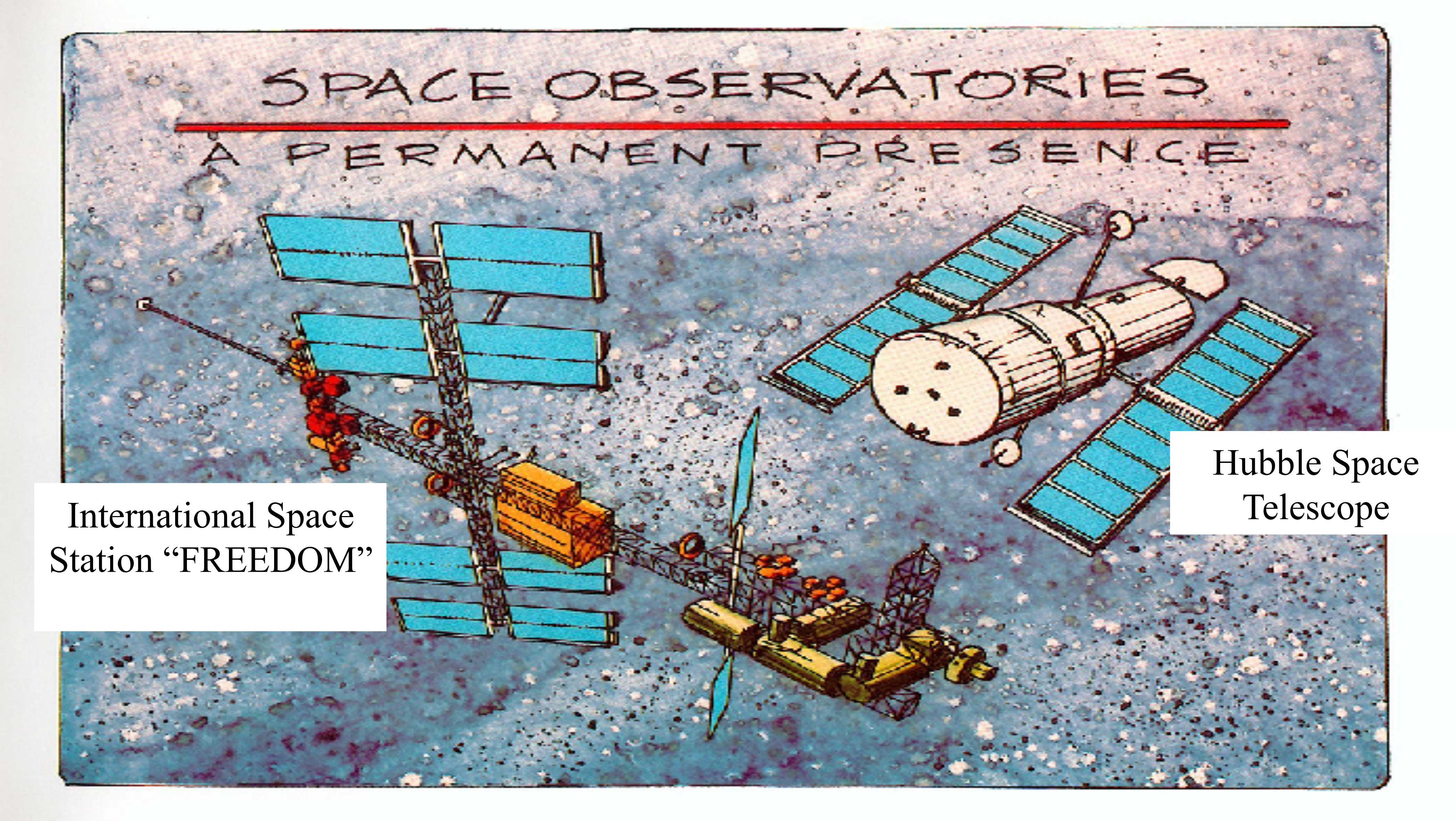
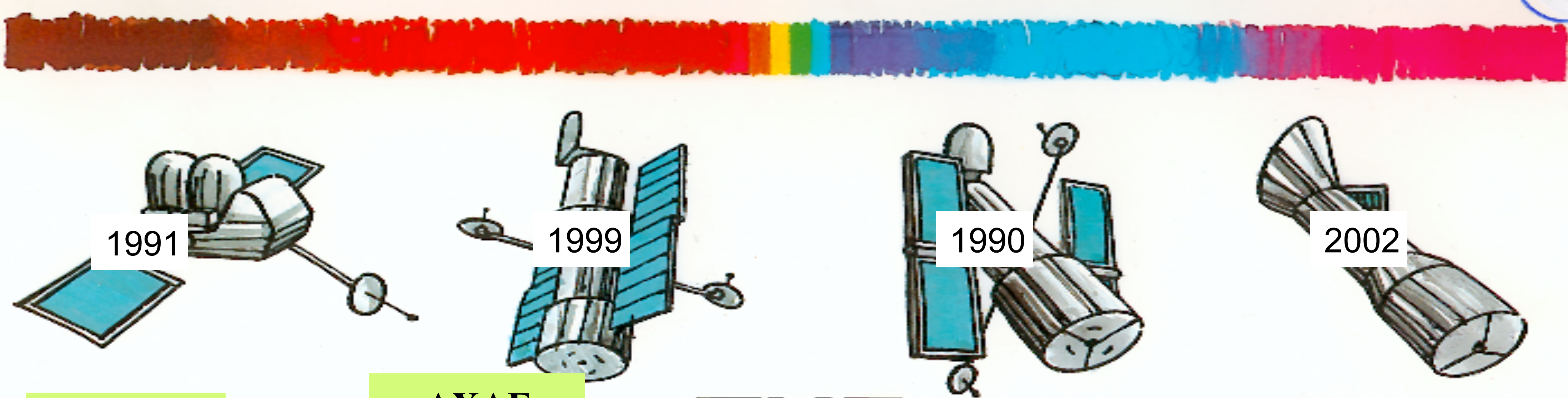


Fig. 3. Energy dependence of average mass number of primary cosmic-ray particles.

In coincidence with the preparation of the SHUTTLE fleet:





CGRO

AXAF (CXO +XMM)

HST

SIRTF

THE GREAT OBSERVATORIES

FOR SPACE ASTROPHYSICS

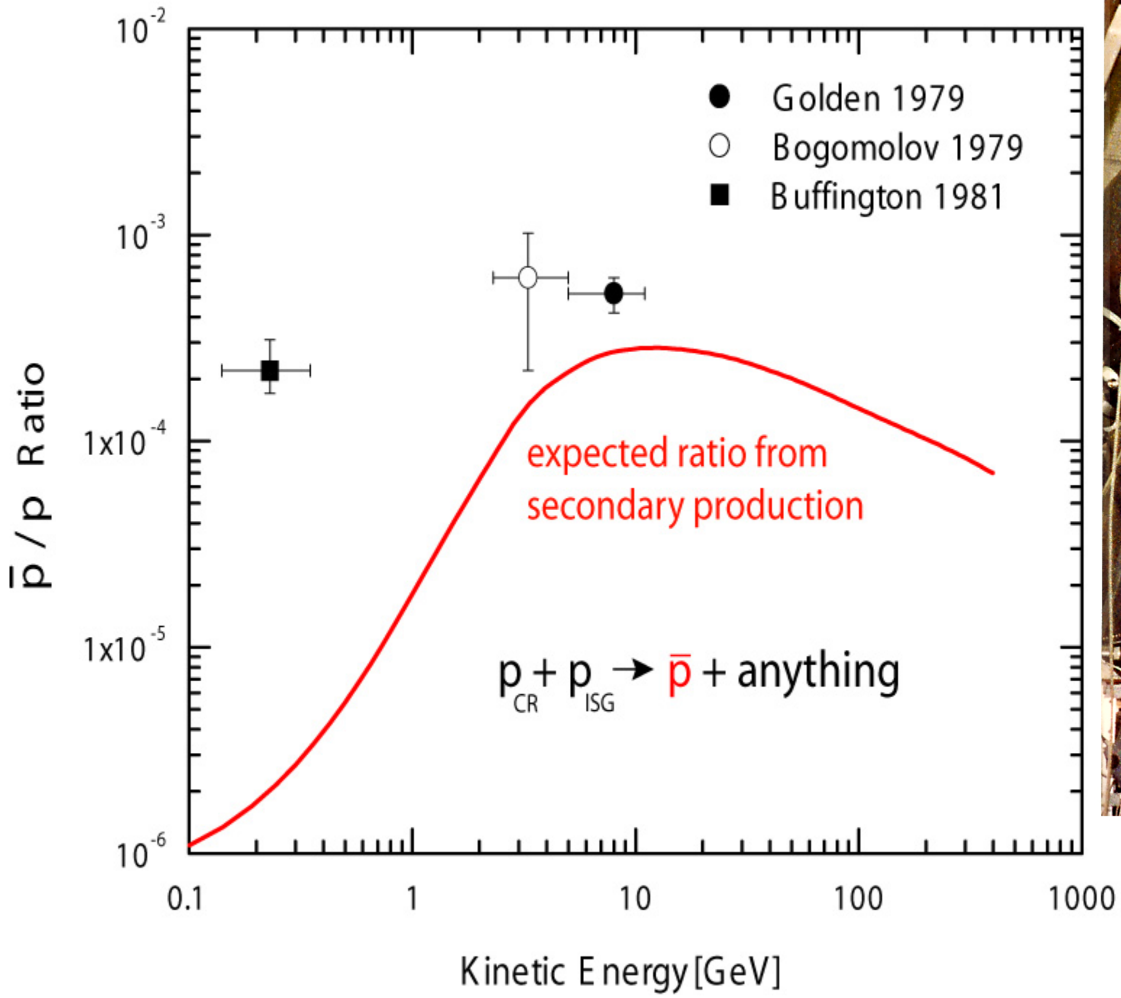
1999
Advanced Composition Explorer (ACE)

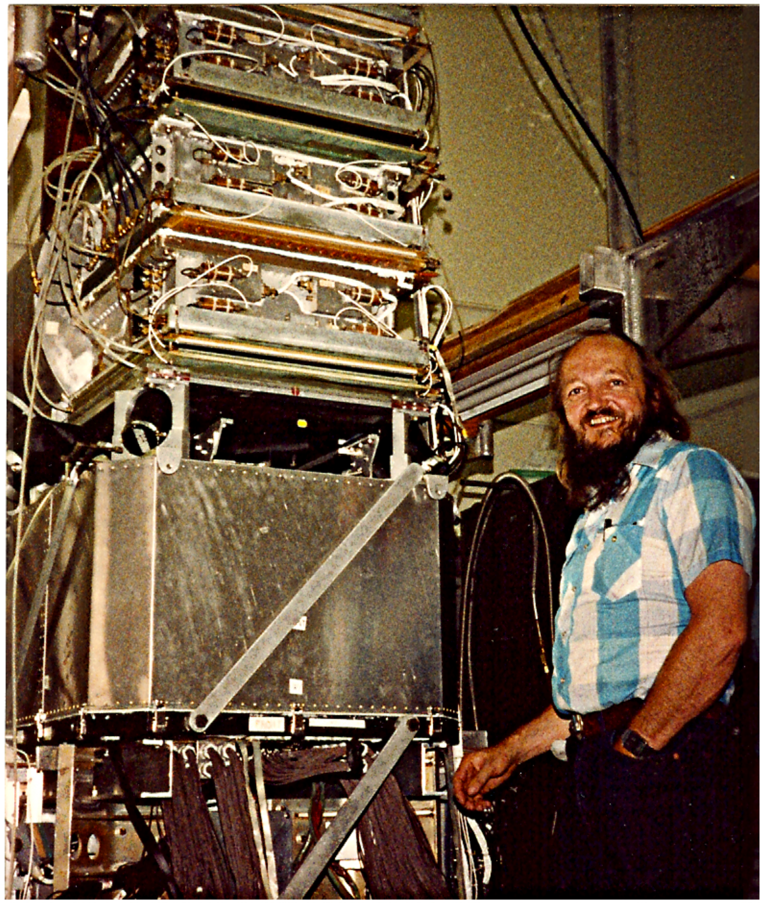
Heavy Nuclei Collecto NC)
and
Particle-Antipar conducting Magn MAG)
ities
on d of the Freedom SS

CANCELLED

+
Very Long Base Interferometer (VLBI)

The first historical measurements on galactic antiprotons



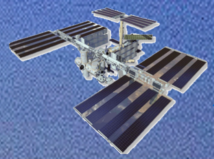


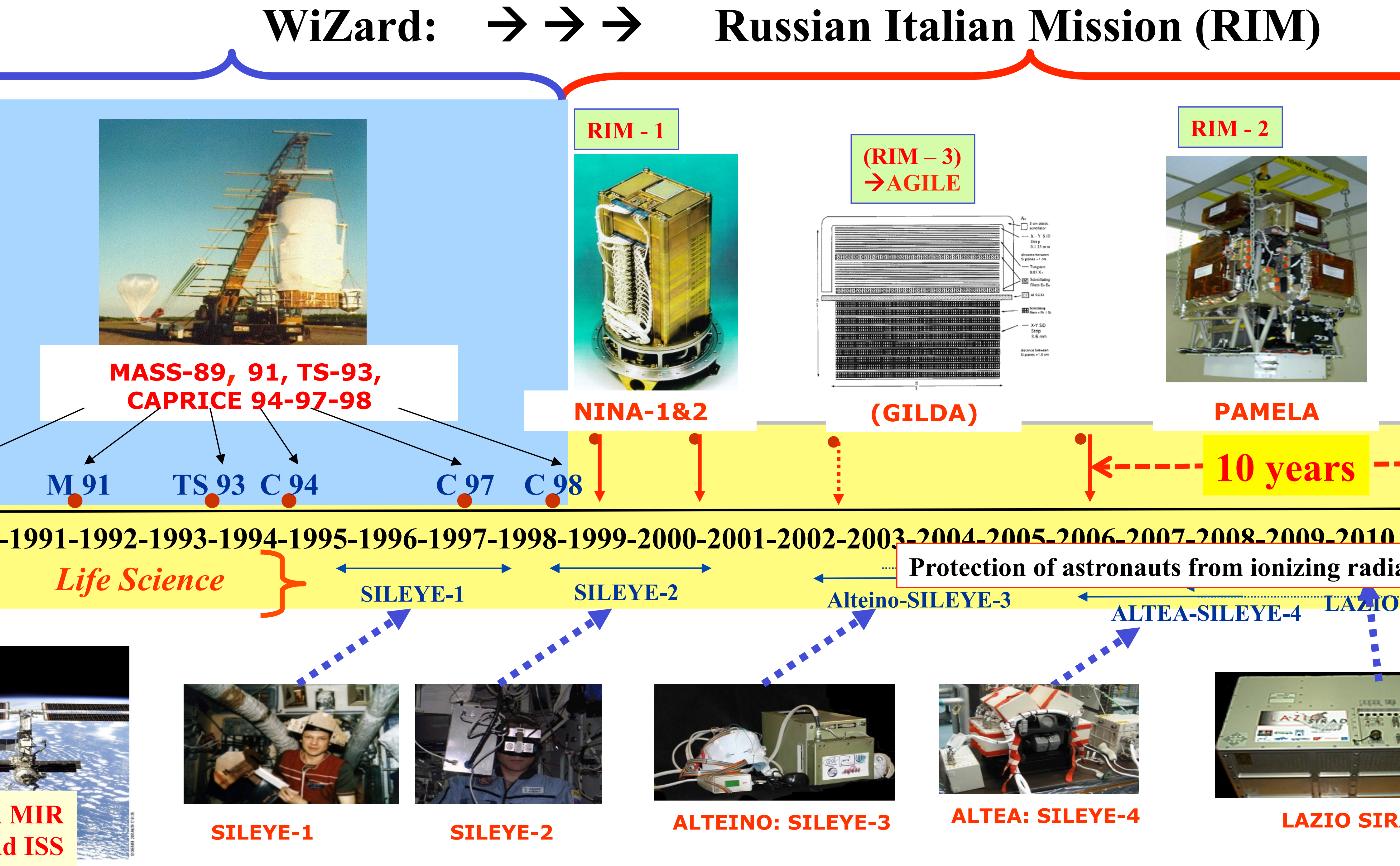
Robert L. Golden

Antimatter Search

Wizard Collaboration

- ✓ MASS - 1,2 (89,91)
- ✓ TrampSI (93)
- ✓ CAPRICE (94, 97, 98)
- ✓ BESS (93, 95, 97, 98, 2000)
- ✓ BESS Polar I (2004)
- ✓ Heat (94, 95, 2000)
- ✓ IMAX (96)
- ✓ AMS-01 (1998)




WiZard: → → → Russian Italian Mission (RIM)
MASS-89, 91, TS-93, CAPRICE 94-97-98
M 91
TS 93
C 94
C 97
C 98
RIM - 1
NINA-1&2
(RIM – 3) →AGILE
(GILDA)
RIM - 2
PAMELA
10 years
-1991-1992-1993-1994-1995-1996-1997-1998-1999-2000-2001-2002-2003-2004-2005-2006-2007-2008-2009-2010
Life Science
SILEYE-1
SILEYE-2
Alteino-SILEYE-3
Protection of astronauts from ionizing radia
ALTEA-SILEYE-4
LAZIO
MIR
d ISS
SILEYE-1
SILEYE-2
ALTEINO: SILEYE-3
ALTEA: SILEYE-4
LAZIO SIR

PAMELA conceived as a CR 'Observatory'

(in the limited mass volume and power imposed by satellite)

x Optimized MDR vs GF *(focus on antiparticles)*

x Quasi polar orbit +
low instrumental threshold
(both side read microstrip Si sensors)
} *Down to SEP events energy*

x Intensity and uniformity in the magnet gap *(clean pattern)*

High acquisition rate (>100Hz) *(fluxes in rad belts and SAA)*

x High granularity imaging calorimeter *(e/p, energy 'extention')*

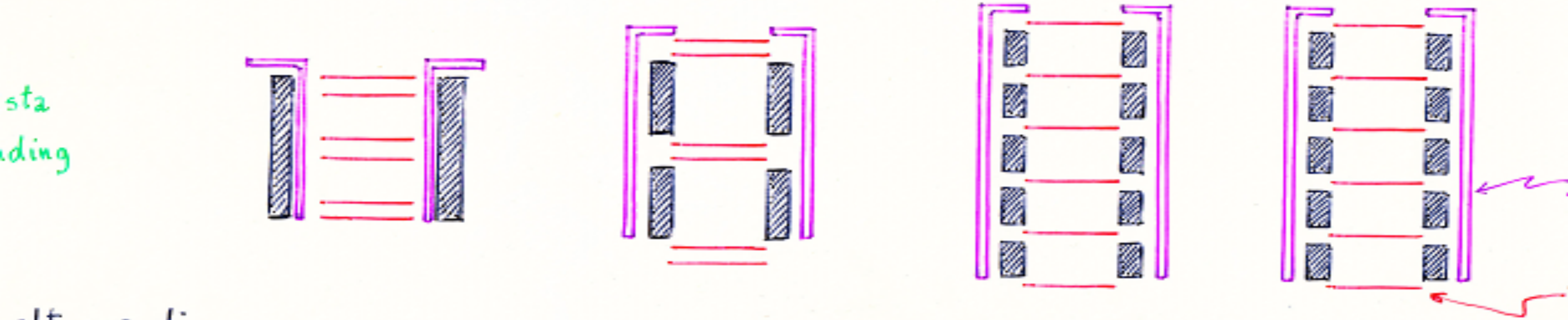
Shower tail catcher +
neutron hodoscope
} (e/p separation)

Multi (≈0.2ns) ToF *(low E meas., isotopes)*

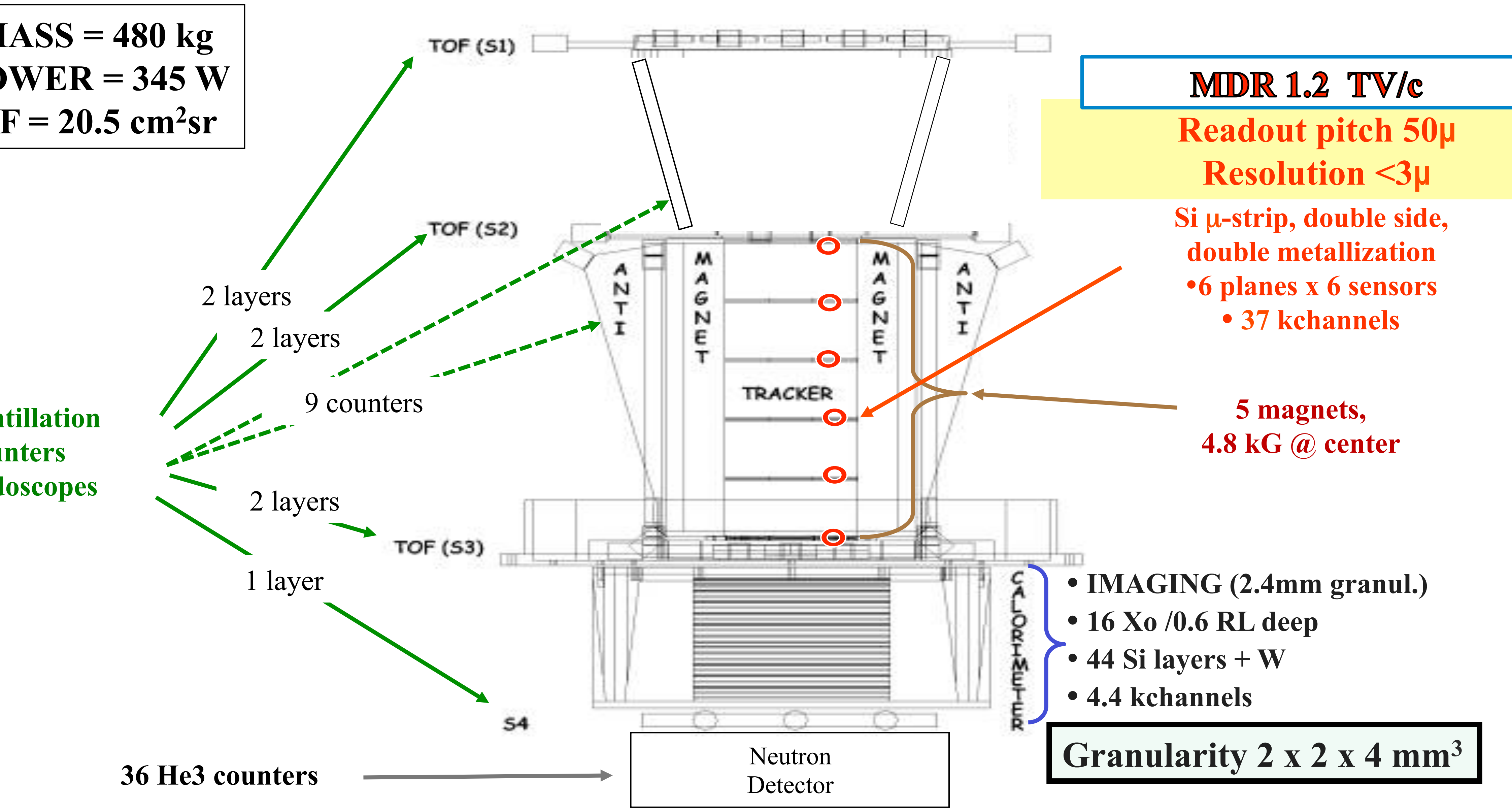
Full coverage anticounter system *(clean events)*

and …. long duration mission *(Solar min + toward Max ascent)*

	1994	1995	1996	1997
ete { Massa (Kg)	150	150	130	110
Gap (cm×cm)	20×18	16×14	16×14	16×12
lunghezza (cm)	30	35	45	45
campo (Kgauss)	2.5	3.5	3.5	4
F ($cm^2 sr$)	75	35	25	21
DR (GV/c)	200	300	440	740



altezza di tutto PAMELA (cm)	80	100	130	115

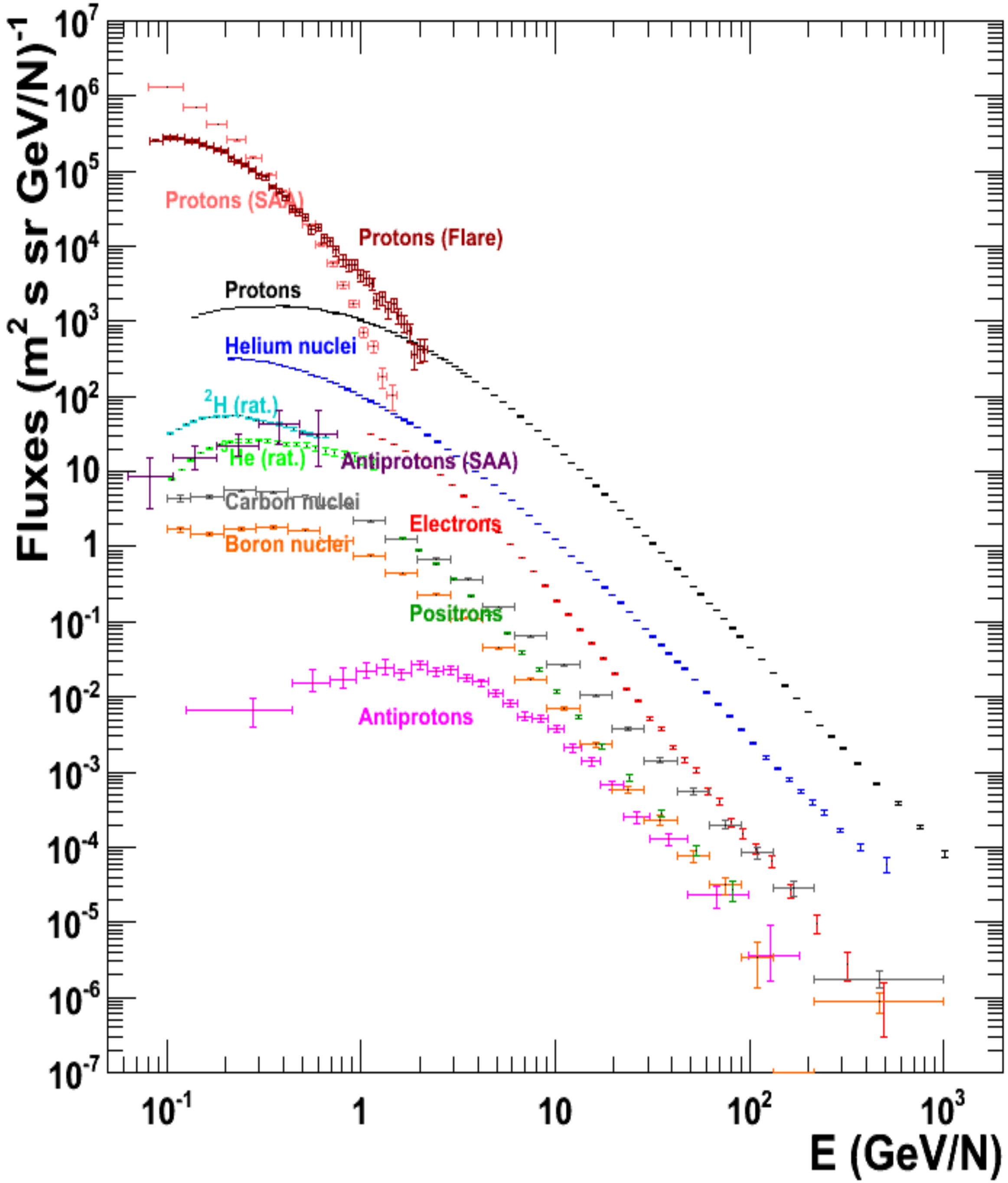


IASS = 480 kg
OWER = 345 W
F = 20.5 cm²sr
TOF (S1)
TOF (S2)
TOF (S3)
S4
ANTI
MAGNET
MAGNET
ANTI
TRACKER
2 layers
2 layers
9 counters
2 layers
1 layer
ntillation
unters
doscopes
MDR 1.2 TV/c
Readout pitch 50μ
Resolution <3μ
Si μ-strip, double side,
double metallization
•6 planes x 6 sensors
• 37 kchannels
5 magnets,
4.8 kG @ center
CALORIMETER
• IMAGING (2.4mm granul.)
• 16 Xo /0.6 RL deep
• 44 Si layers + W
• 4.4 kchannels
Granularity 2 x 2 x 4 mm³
36 He3 counters
Neutron
Detector

Items of CR physics possible to reach with PAMELA instrument:

item	'flag' results
ntiparticle spectra	***Positron fraction increases wit***
ntinuclei	***antiHe/He limit on wide E ran***
p, He, ions E spectra	***p & He '2' indexes, Ep→ 10xM***
ght isotopes E spectra	***B/C ra***
EP Energy tail study	***Dec 2006 event, E tails of SE***
arth magnetosph. (rad belts, SAA)	***antip trapped in S***
eliosphere	***'modulation' , HMF***

Summary of
PAMELA results



ysics Reports 544/4 (2014), 323

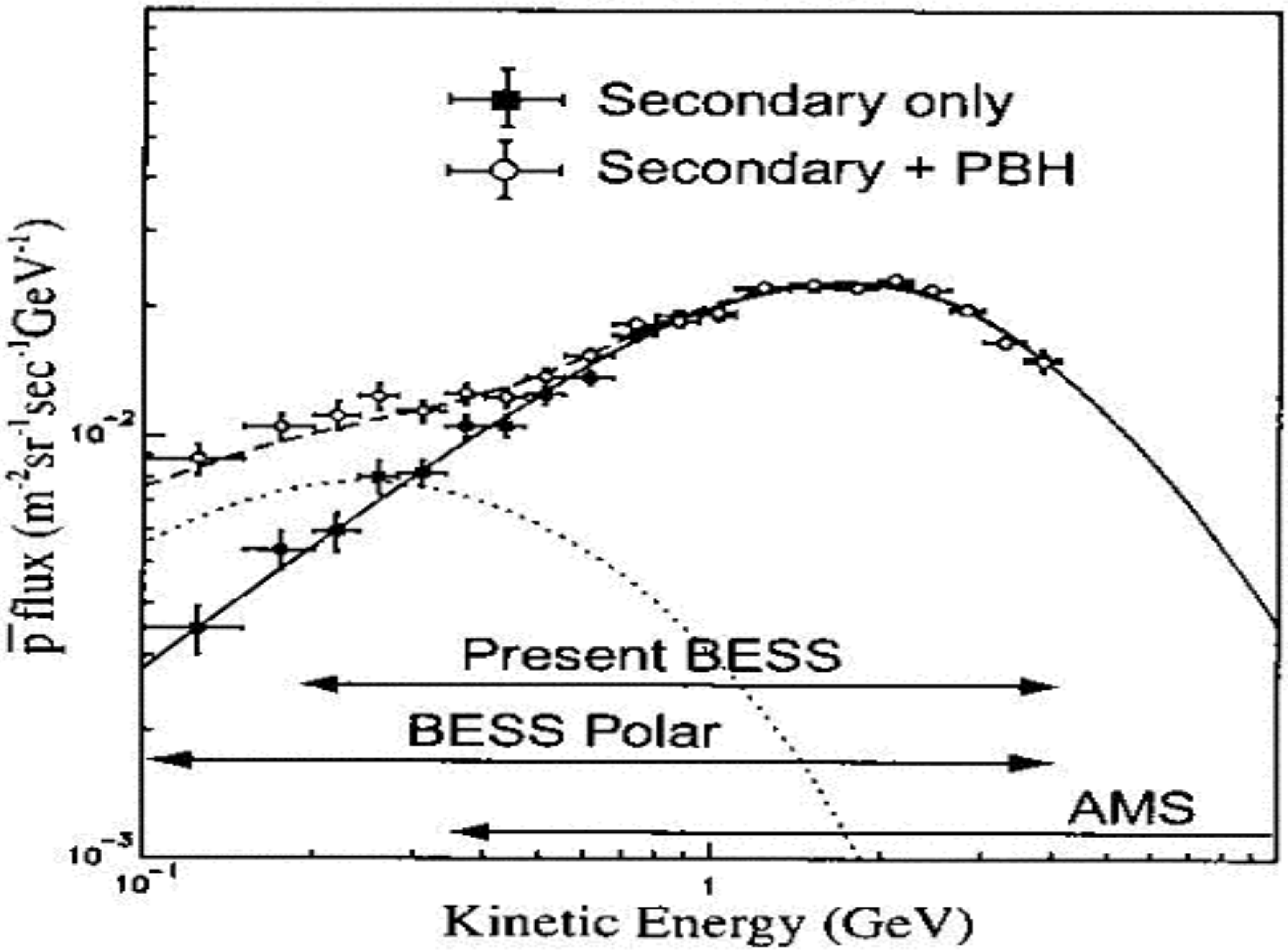
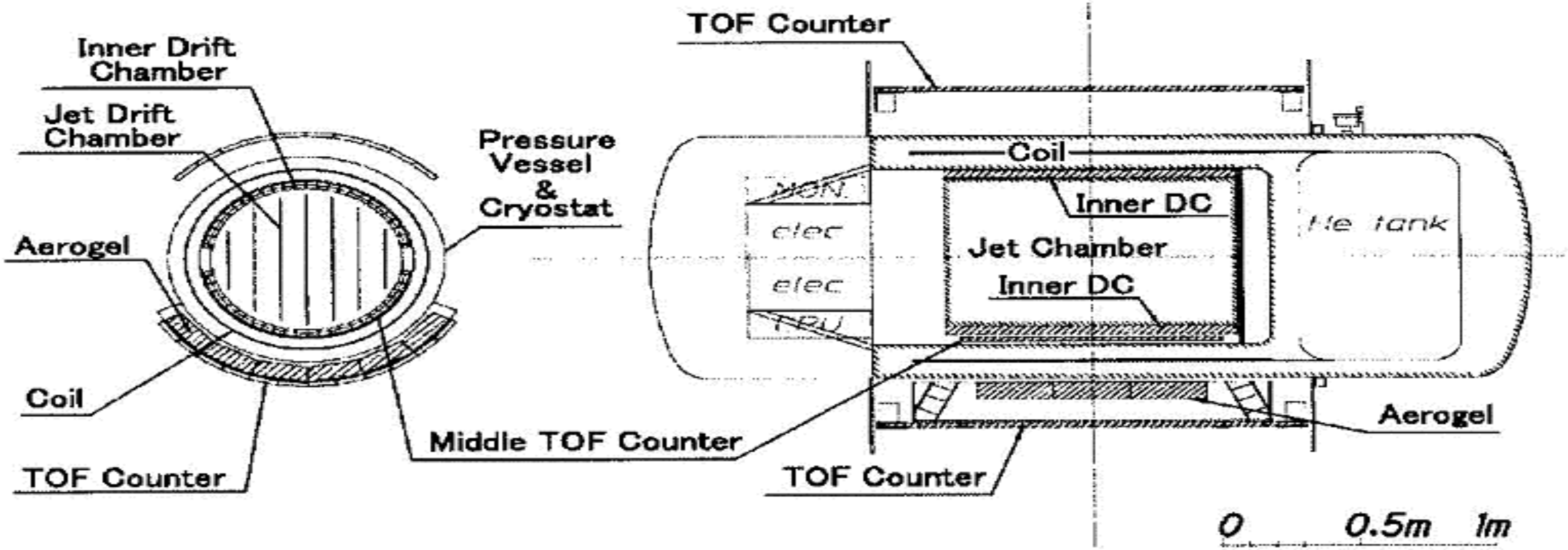


Fig. 3. Antiproton spectra in a simulation expected in a 20 days flight in Antarctica with and without primary origin of PBH.



. 4. Cross sections of the BESS-Polar spectrometer. The central tracker is placed inside the solenoid coil and others are plac
side the cryostat in vacuum.

BESS Spectrometer Progress

BESS-93,94	BESS-95	BESS-97,98	BESS-99,00	BESS01,02 BESS-TeV	⇒Future BESS-Polar
	Larger Vessel			Larger Vessel	No Vessel
σ_{TOF}=300 ps	σ_{TOF}=110 ps	σ_{TOF}=70 ps Aerogel C 97 n=1.03 $\bar{p}$ 0.2-3.5 GeV 98 n=1.02	Shower Counter $2X_0$ Lead e/μ sep.	New ODC's New JET/IDC's p/He up to 1 TeV	New Mag (ultra thin)
$\bar{p}$ 0.2-0.6 GeV	$\bar{p}$ 0.2-1.4 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.1-4.2 GeV

BESS improved in every 9 successful flights

Maximizing advantages in Balloon Experiments

BESS-Polar Program

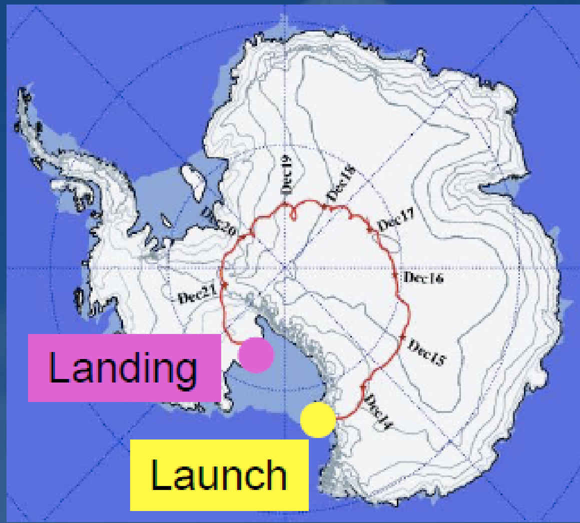
Status of the BESS-Polar I Flight

Observation Time: 8.5 days

Float Time: 8.5 days (12/13/2004-12/21/2004)

Events recorded: > 0.9×10^9

Data volume: ~ 2.1 terabytes
Data recovery: **completed** 2004
Payload recovery: **completed** 2004



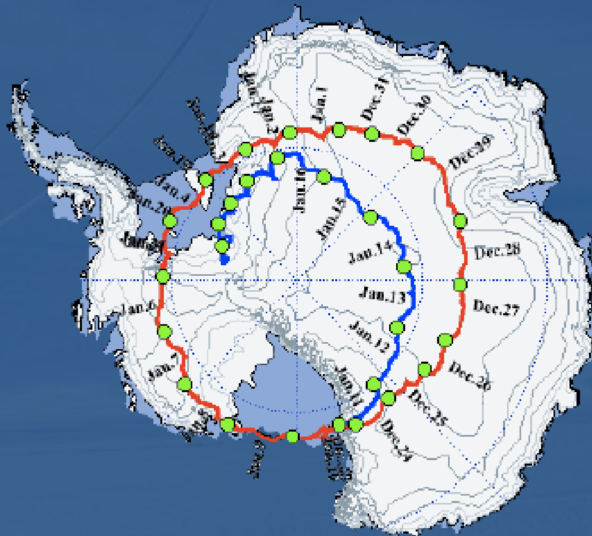
Status of the BESS-Polar II Flight

Observation Time: 24.5 days

Float Time: 29.5 days (12/23/2007-01/21/2008)

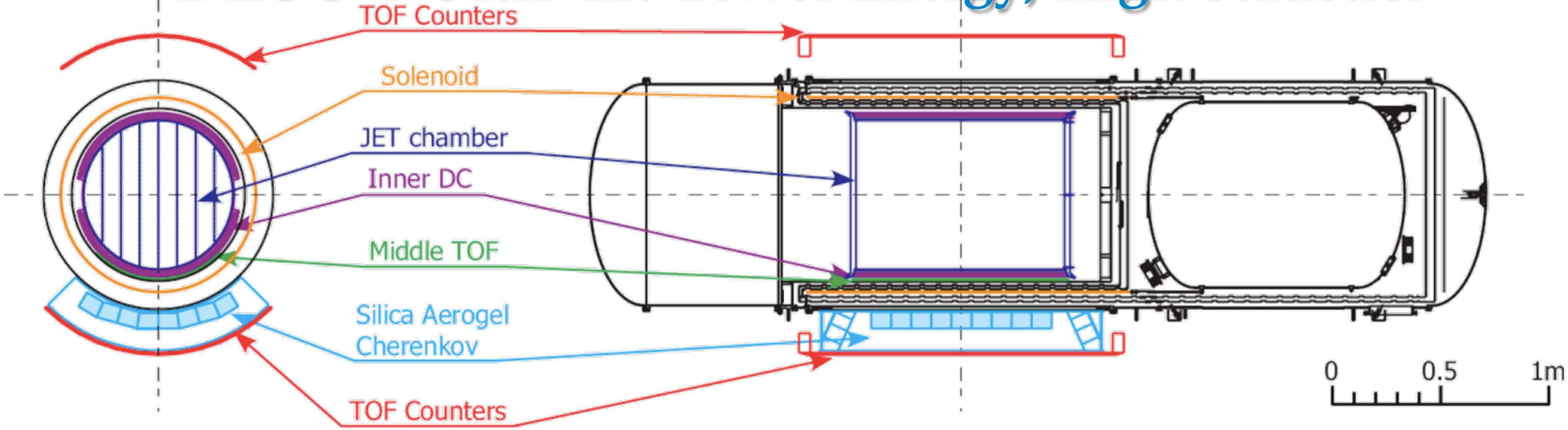
Events recorded: > 4.7×10^9

Data volume: ~ 13.5 terabytes
Data recovery: **completed** Feb 3, 2008
Payload recovery: **completed** Jan 16, 2010



Makoto Sasaki, Antideuteron 2014, UCLA

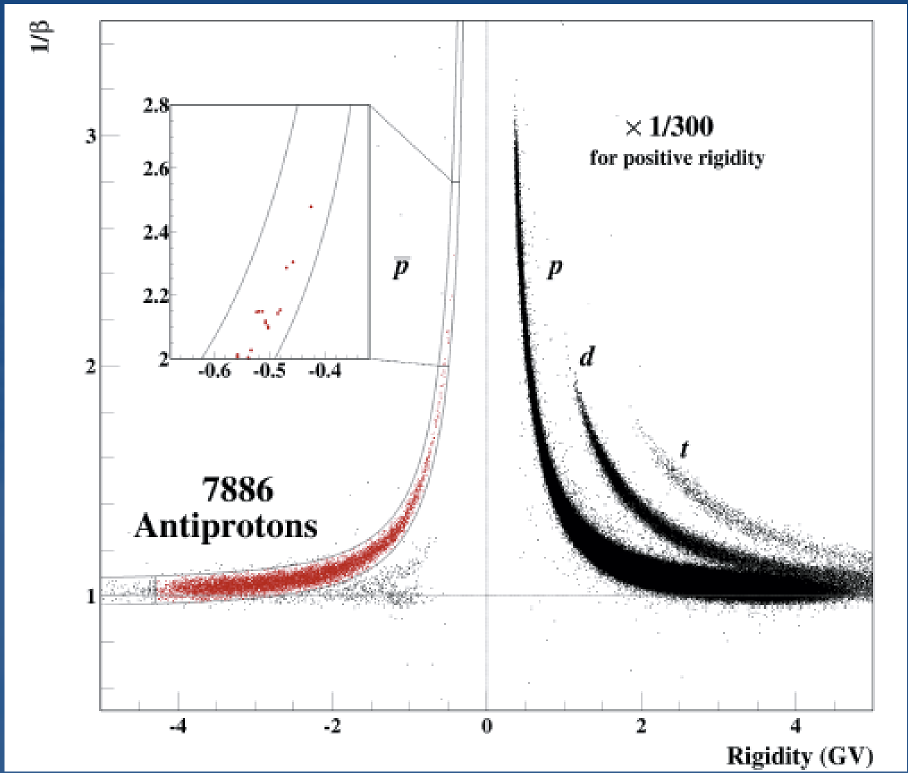
BESS-Polar II: Lower Energy, High Statistics



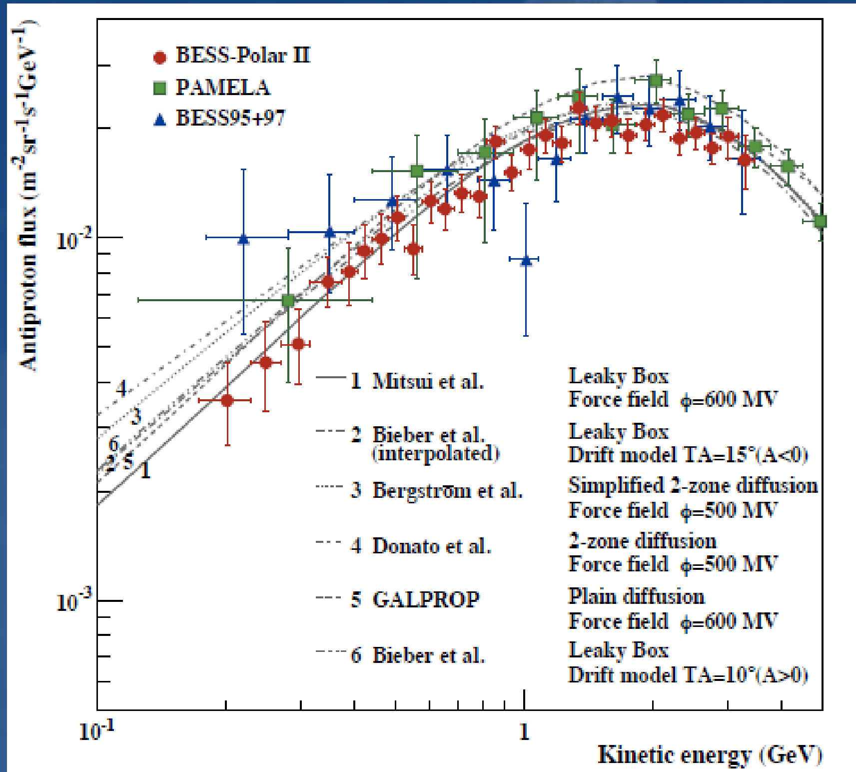
BESS

Antiproton Measurement

BESS-Polar II Z=1 Particle Id



Antiproton Spectrum



- MDR 240 GV, TOF 120 ps, ACC rejection 6100
- 7886 Antiprotons ~10-20 times previous Solar minimum dataset

- BESS-Polar II and PAMELA spectra agree in shape but differ ~14% in absolute flux
- Both agree in shape with secondary

Satellite Missions and LDF

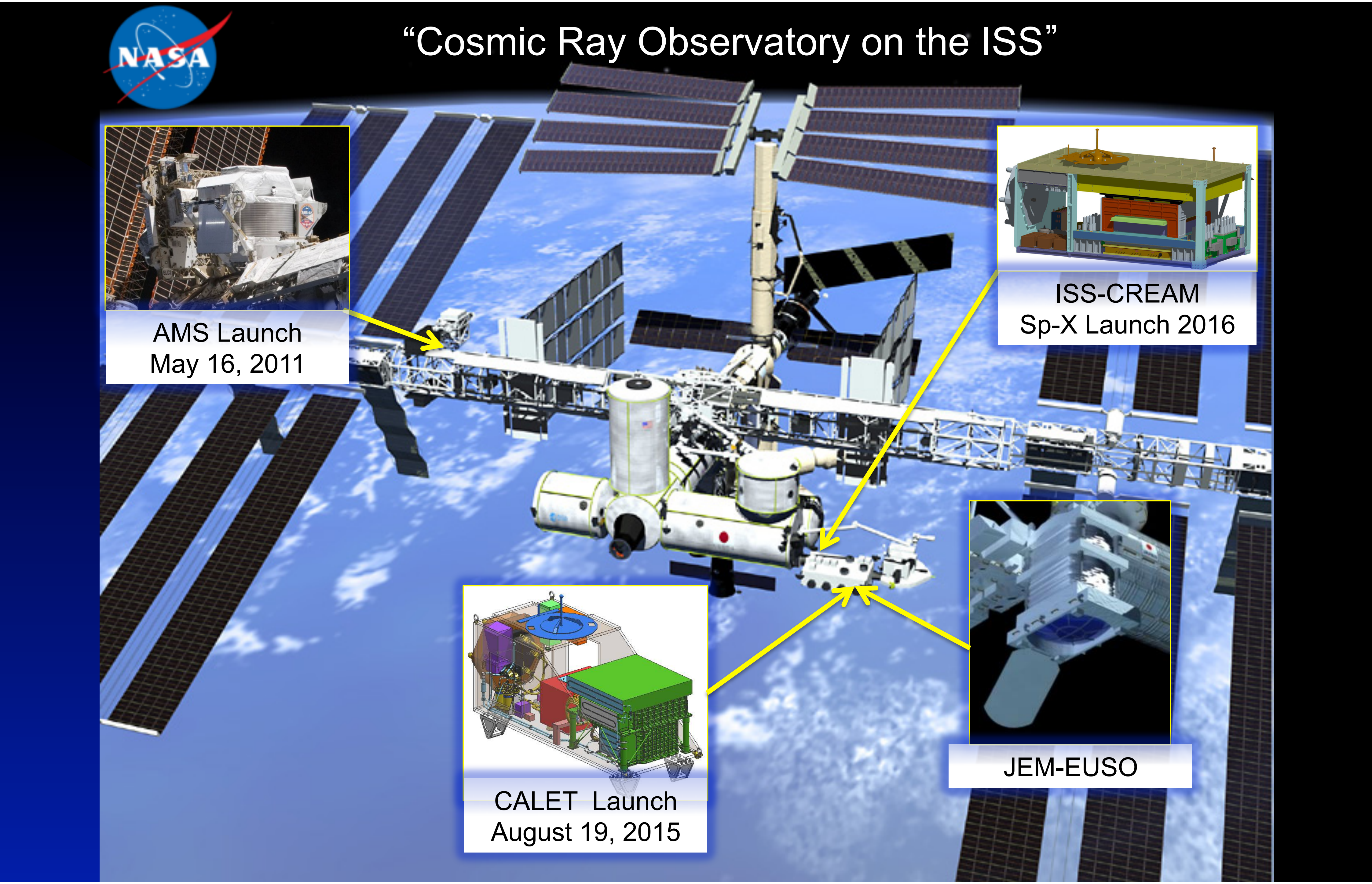
/GLAST
-2008

PAMELA
15-06-2006

BESS
Polar II 23-12-200

PE
2015

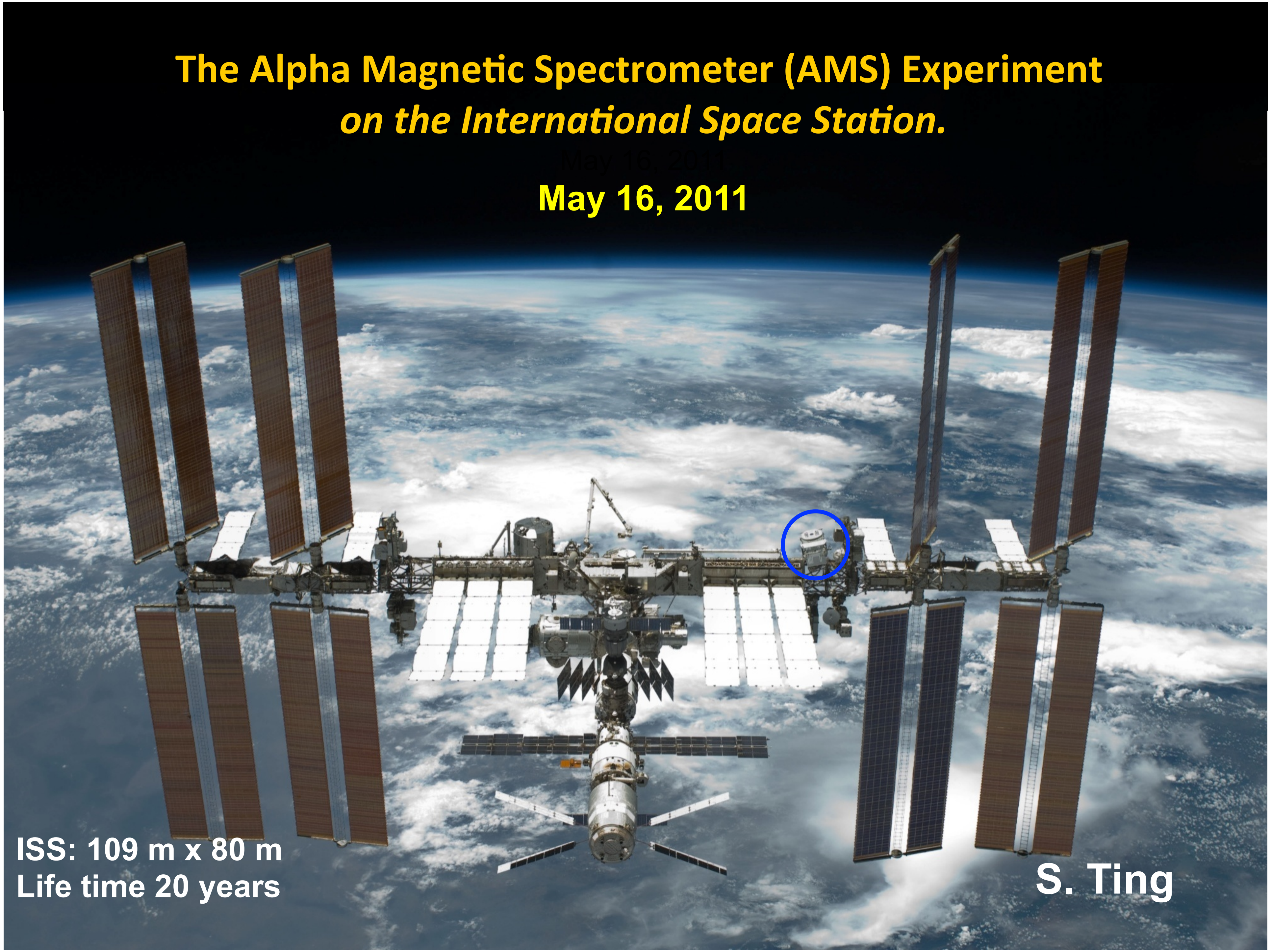
GAPS

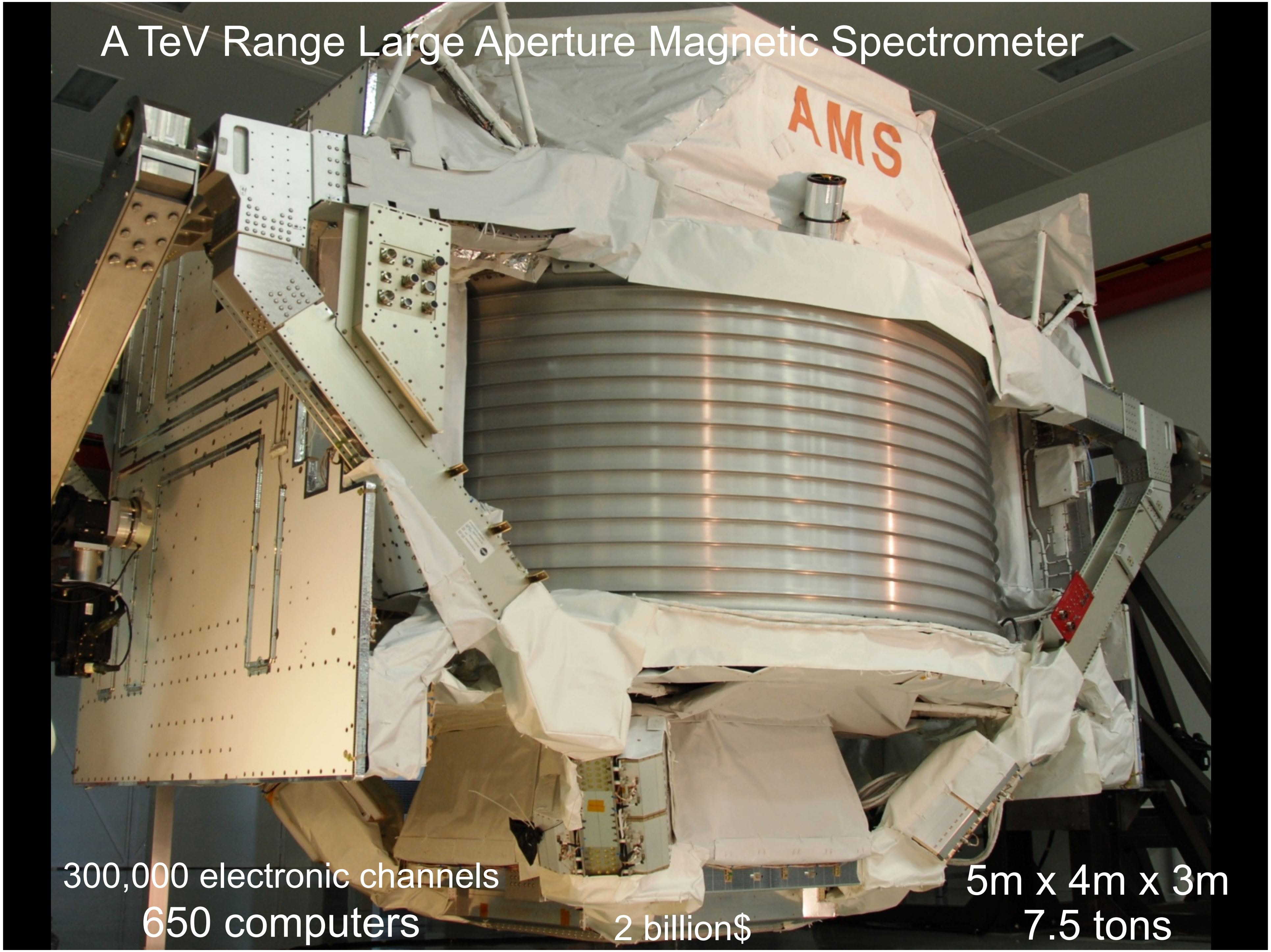

"Cosmic Ray Observatory on the ISS"
AMS Launch
May 16, 2011
ISS-CREAM
Sp-X Launch 2016
CALET Launch
August 19, 2015
JEM-EUSO

The Alpha Magnetic Spectrometer (AMS) Experiment
on the International Space Station.

May 16, 2011

May 16, 2011

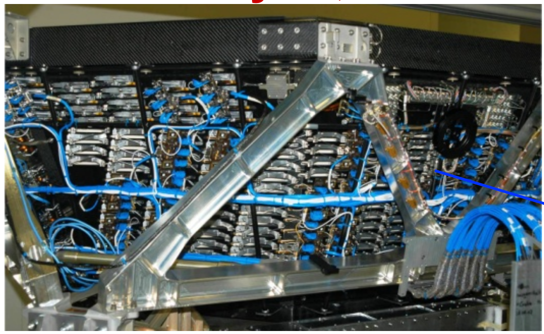



A TeV Range Large Aperture Magnetic Spectrometer
AMS
300,000 electronic channels
650 computers
2 billion$
5m x 4m x 3m
7.5 tons

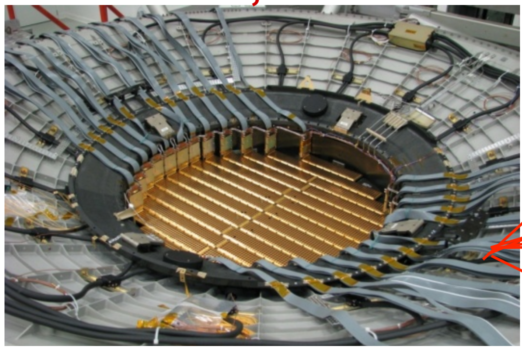
AMS: A TeV precision, multipurpose spectrometer

Particles and nuclei are defined by their charge (Z) and energy (E ~ P)

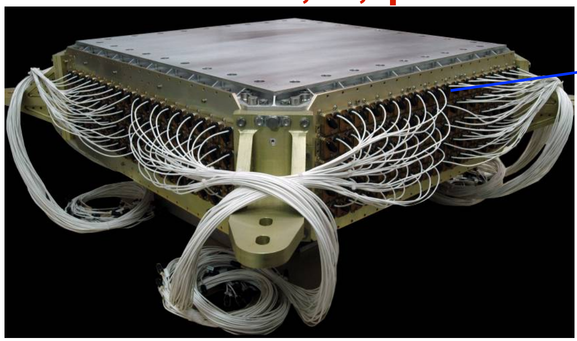
TRD
Identify e^+, e^-

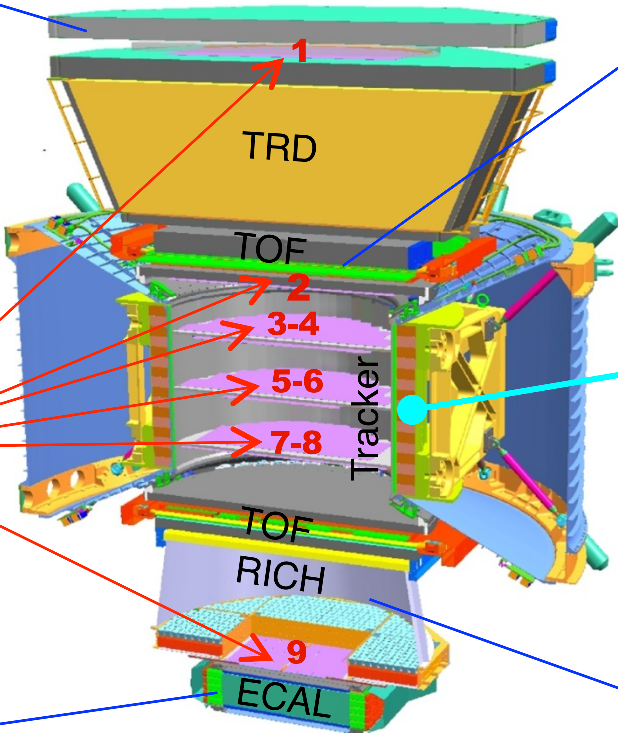


Silicon Tracker
Z, P



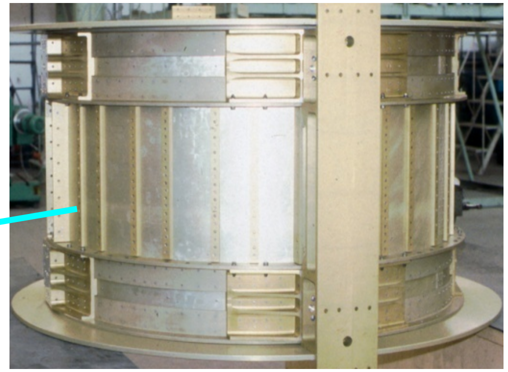
ECAL
E of e^+, e^-, γ



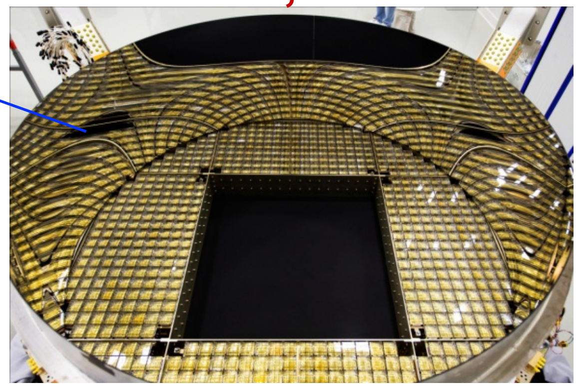


TOF
Z, E

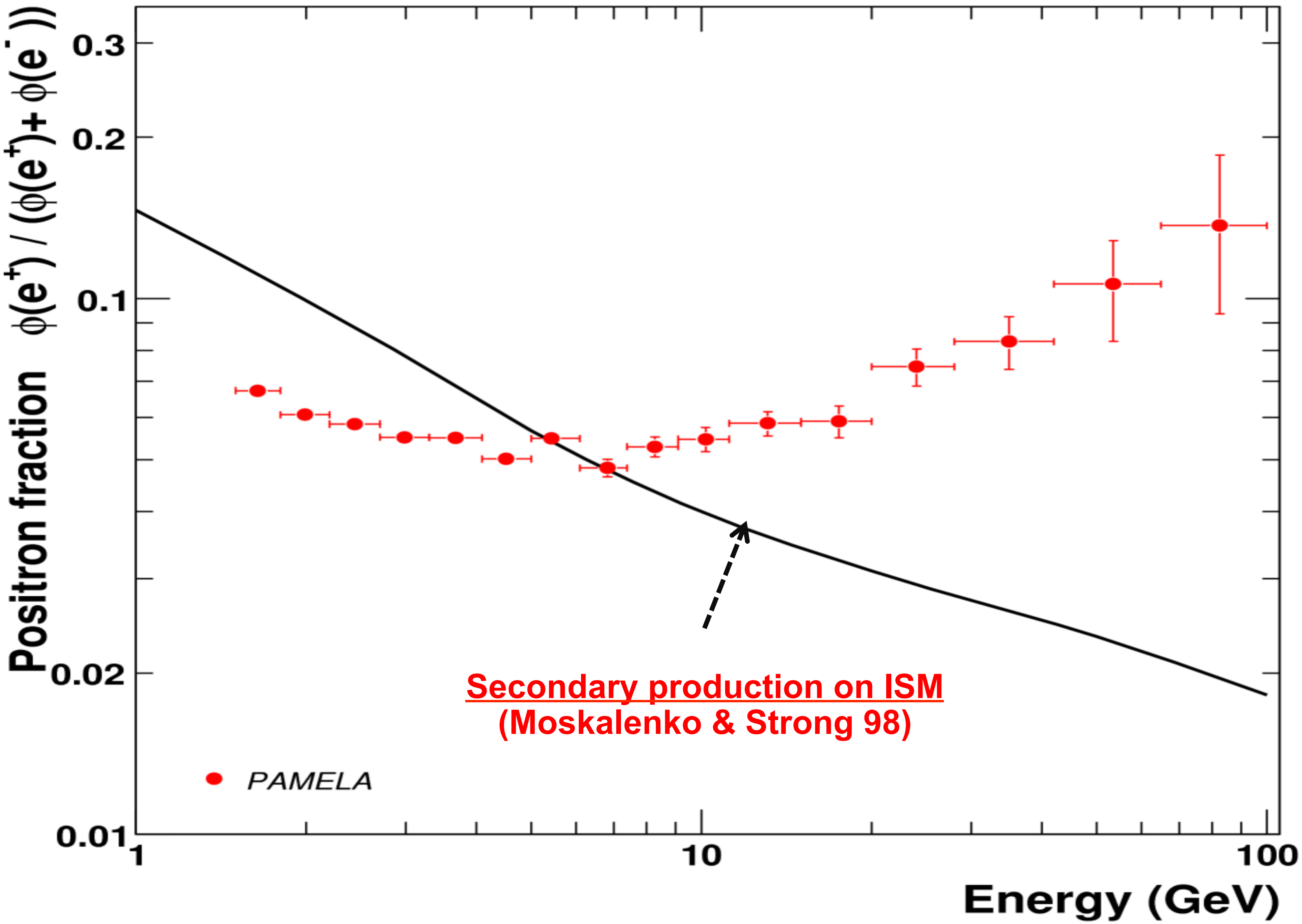
Magnet
±Z

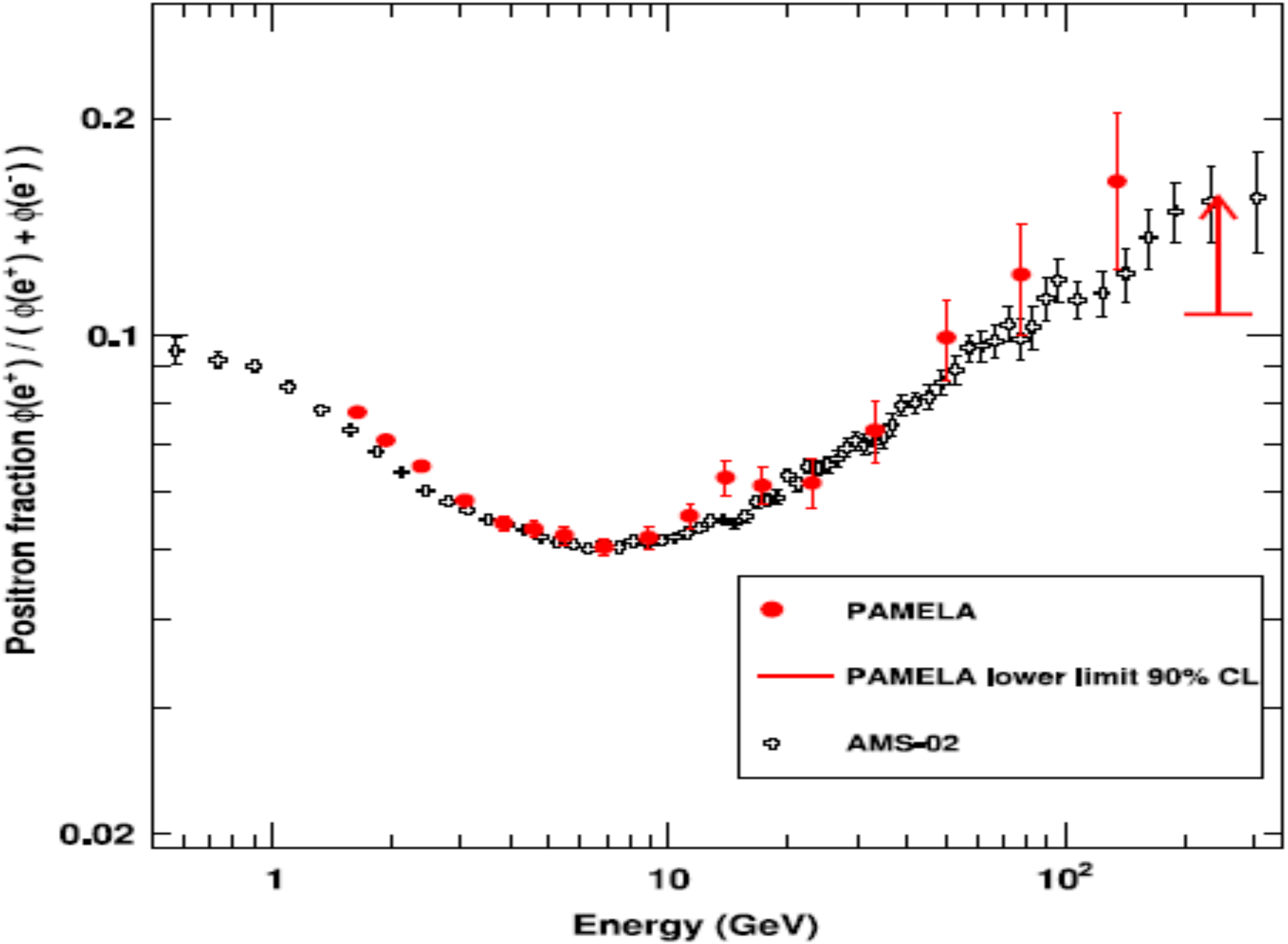


RICH
Z, E



Z, P are measured independently by the Tracker, RICH, TOF and ECAL

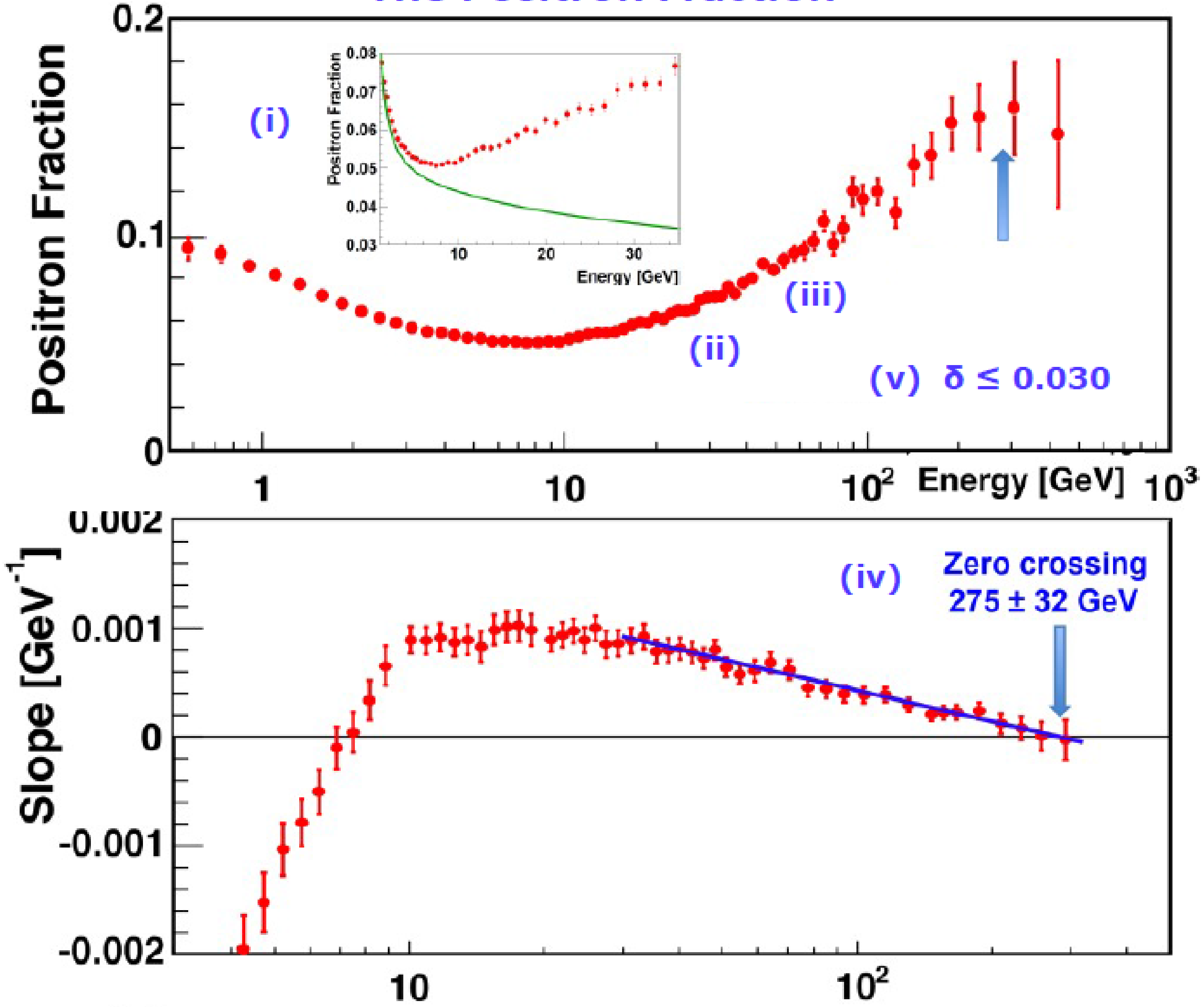

Positron fraction φ(e⁺) / (φ(e⁺)+ φ(e⁻))
0.3
0.2
0.1
0.02
0.01
1
10
100
Energy (GeV)
Secondary production on ISM
(Moskalenko & Strong 98)
PAMELA



Positron fraction $\phi(e^+) / (\phi(e^+) + \phi(e^-))$
0.2
0.1
0.02
1
10
10^2
Energy (GeV)
PAMELA
PAMELA lower limit 90% CL
AMS-02

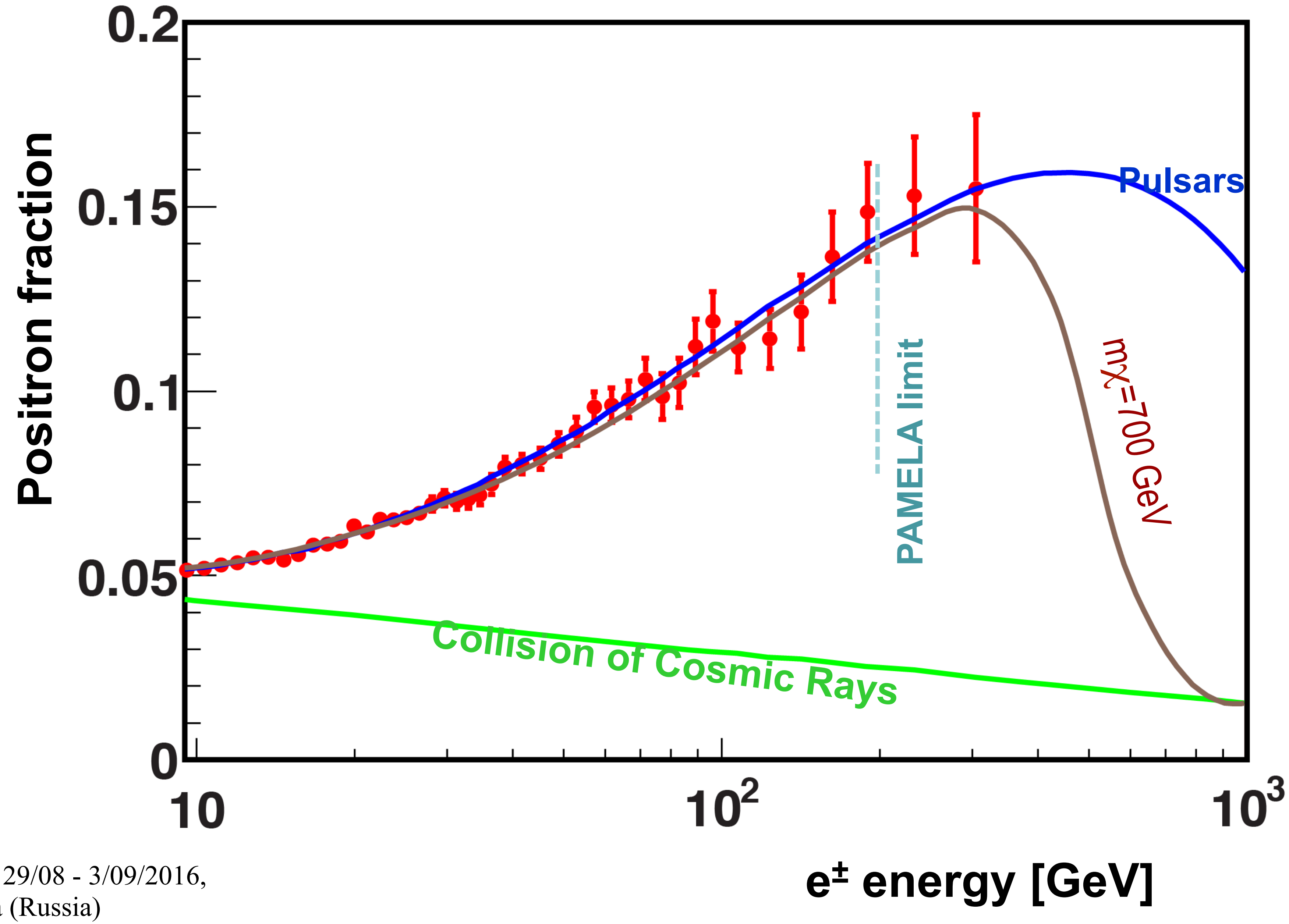
AMS-02

The Positron Fraction

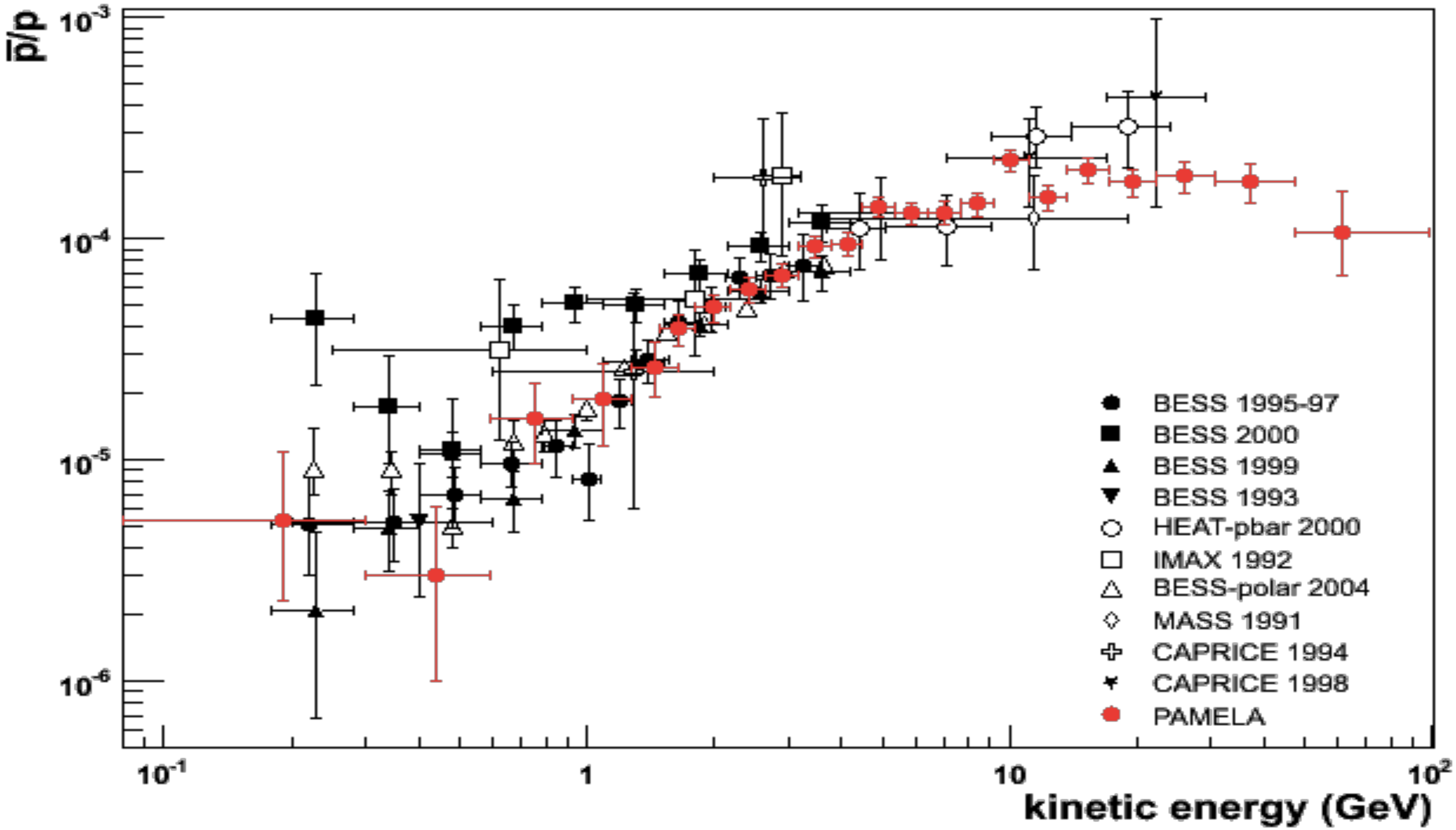


Phys. Rev. Lett. **113**, 121101, 2014

Dark Matter or Pulsar?

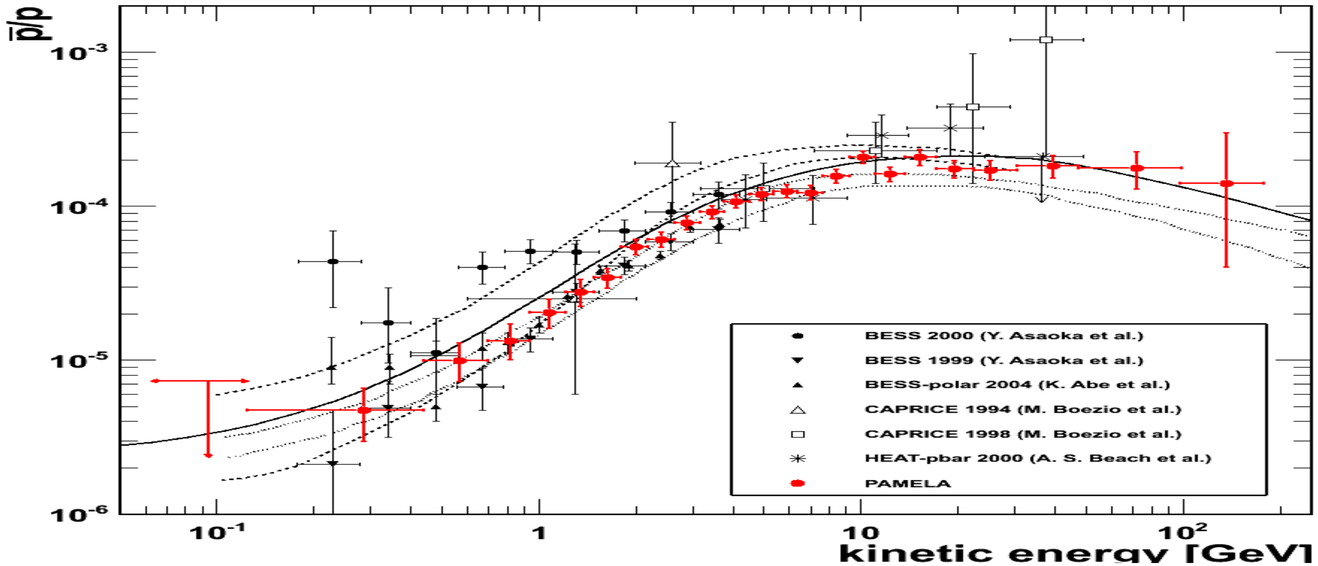


Antiproton-to-proton ratio

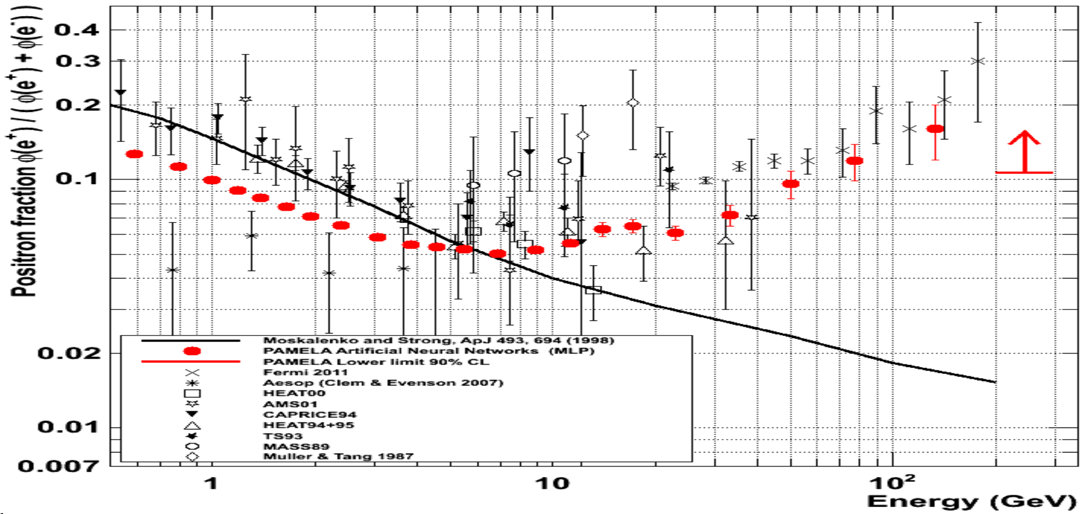


A Challenging Puzzle for Dark Matter Interpretation

antip/p



+/(e- + e+)



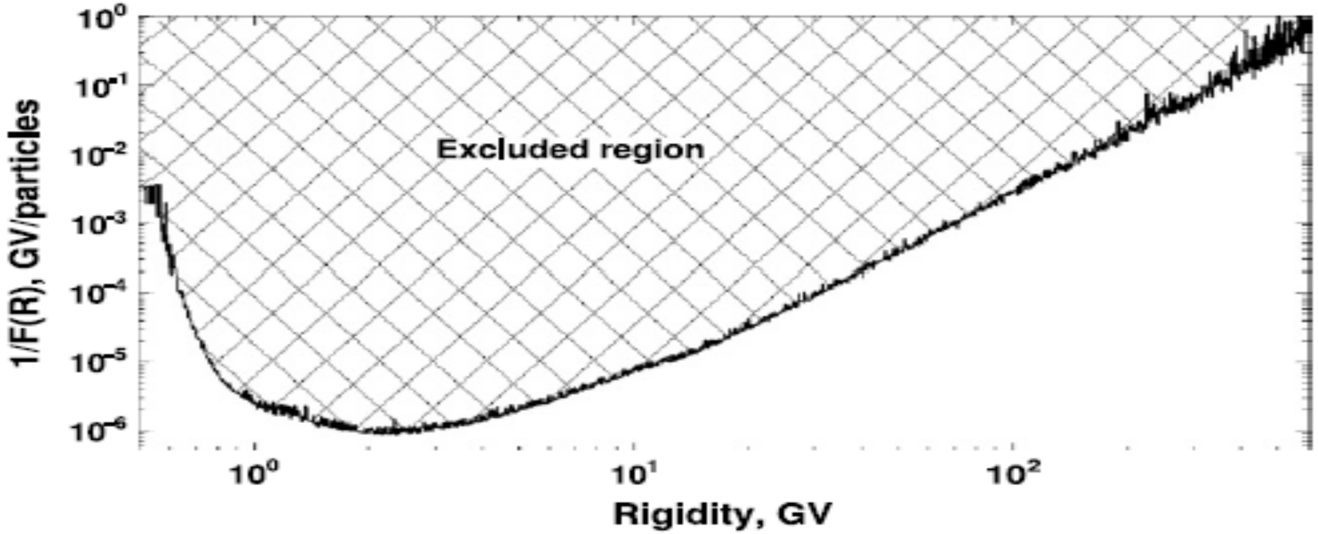
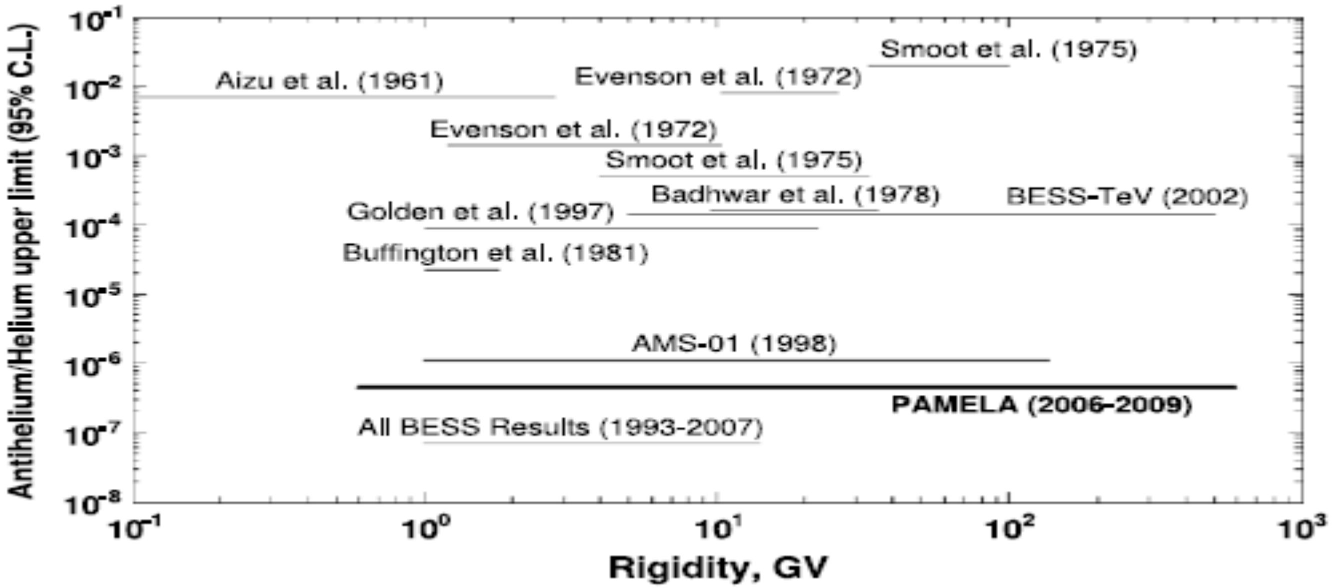
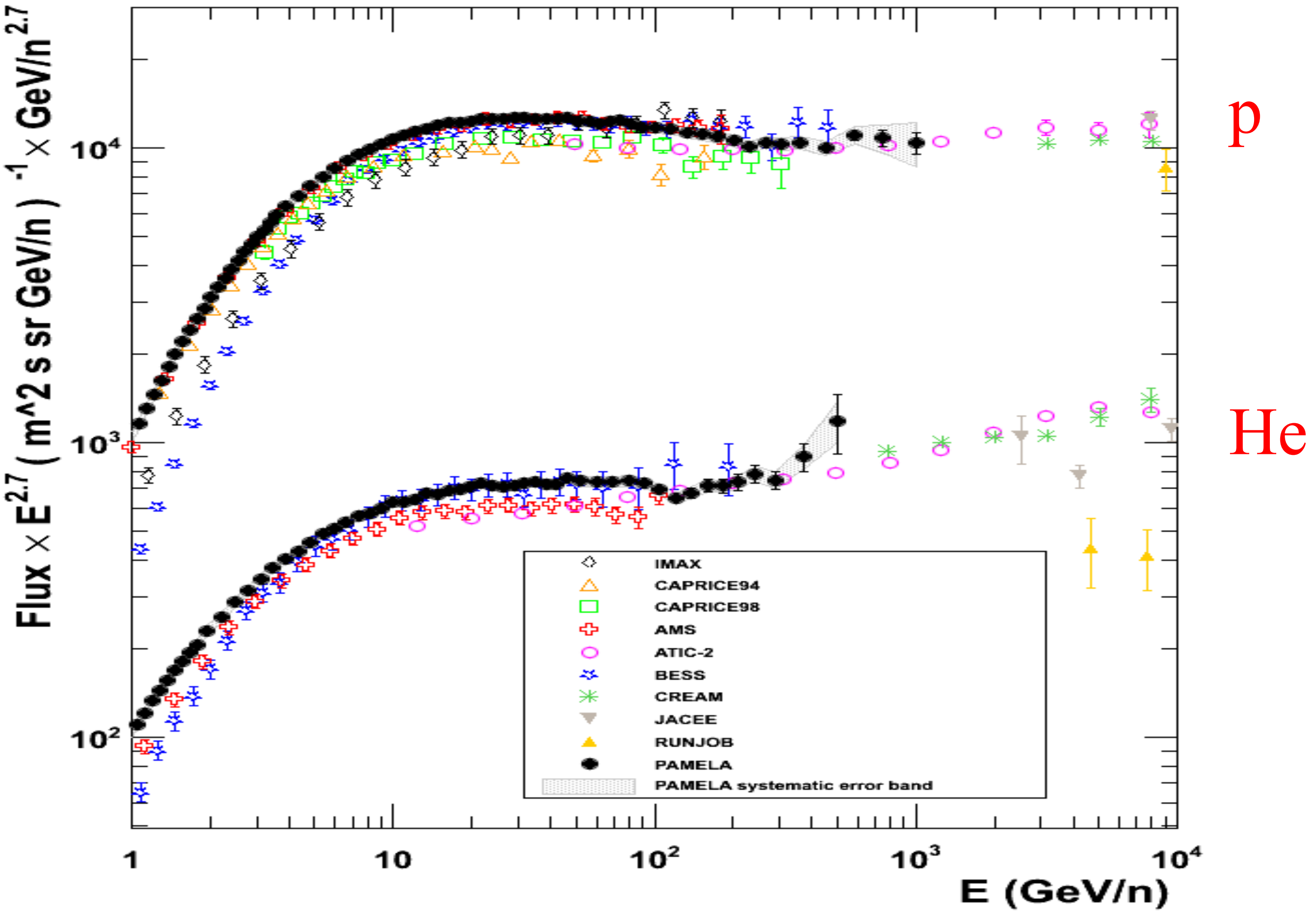


Fig. 22. PAMELA differential upper limit (see text).

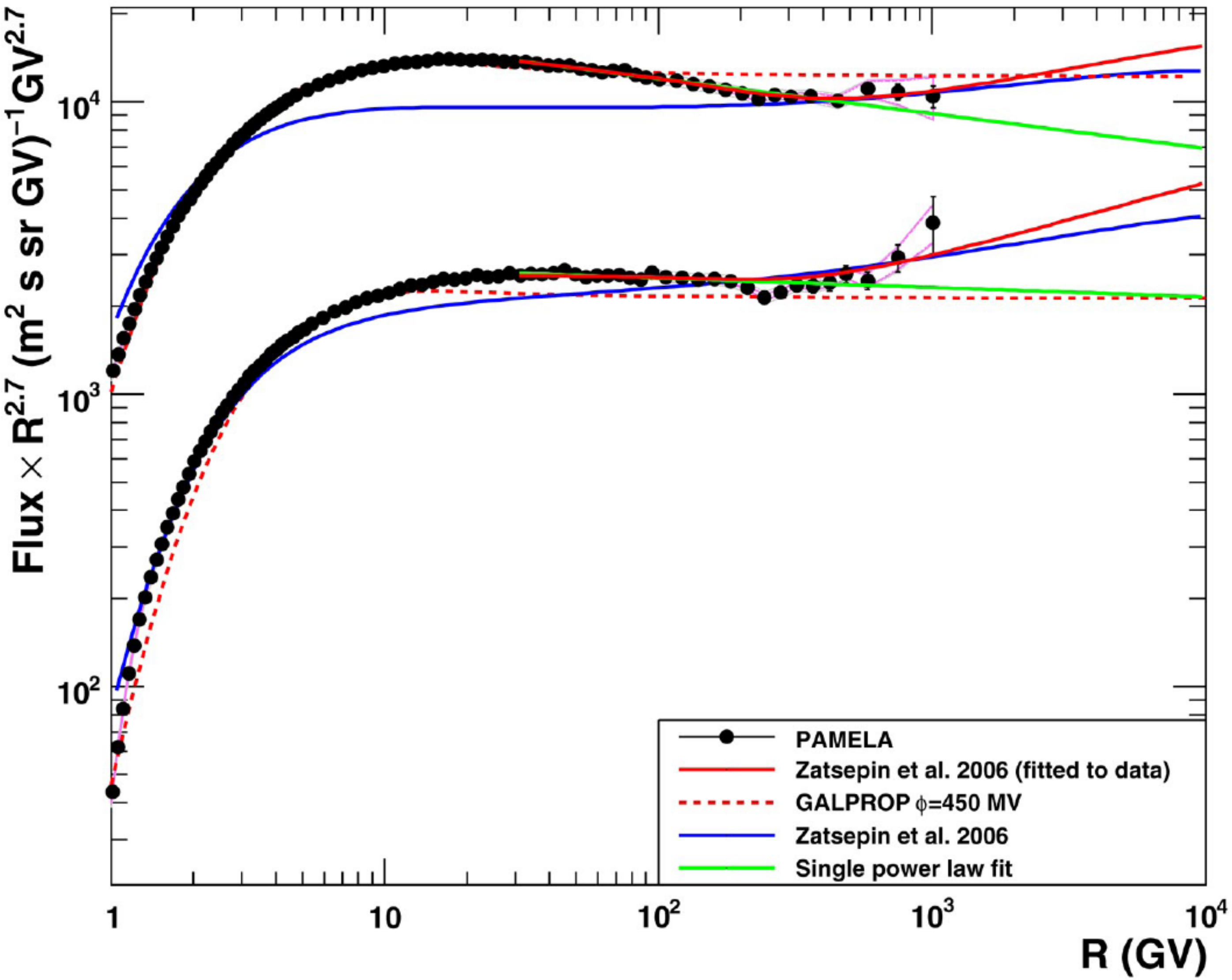


Proton and Helium fluxes

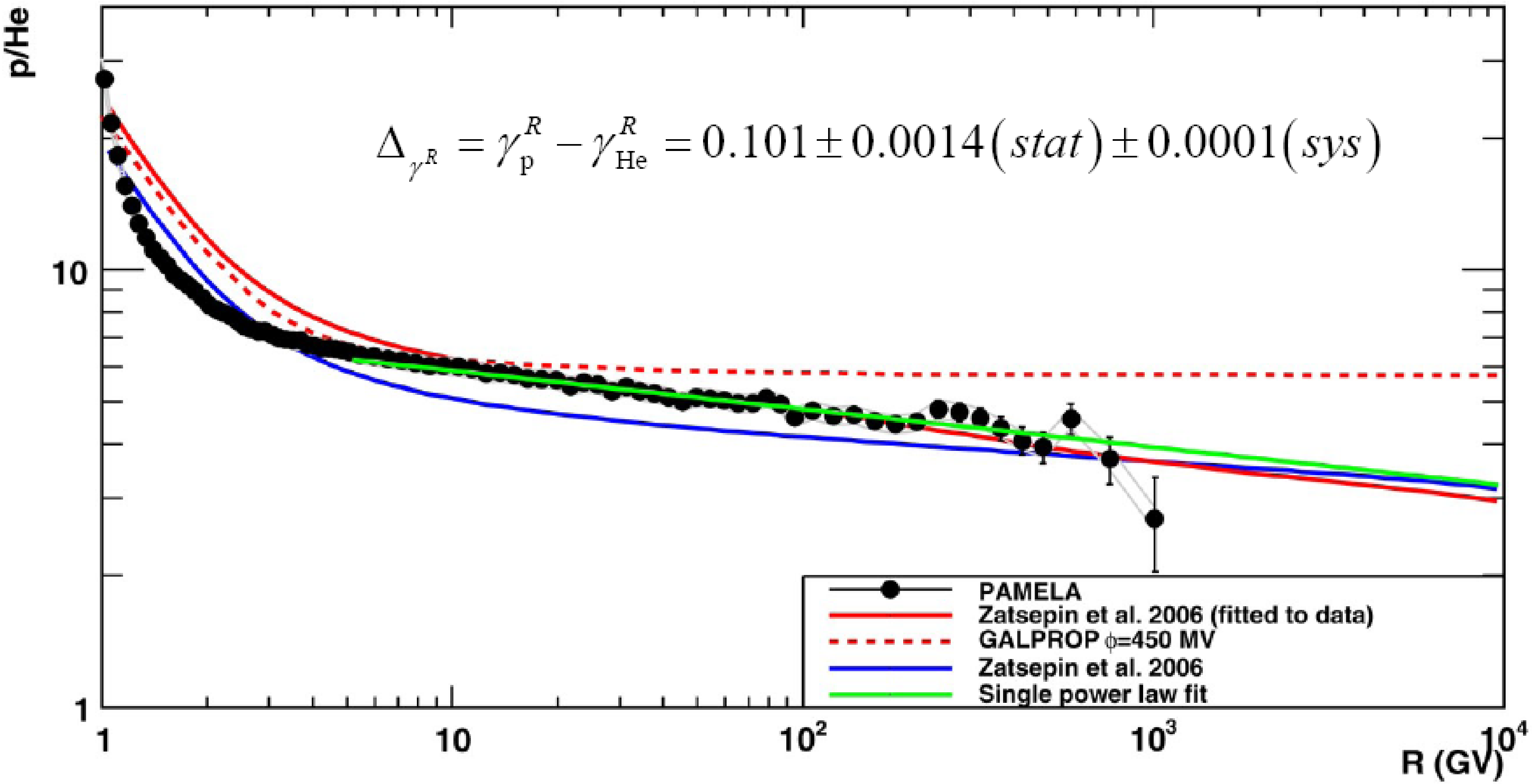


PAMELA Science 332,69 (2011)

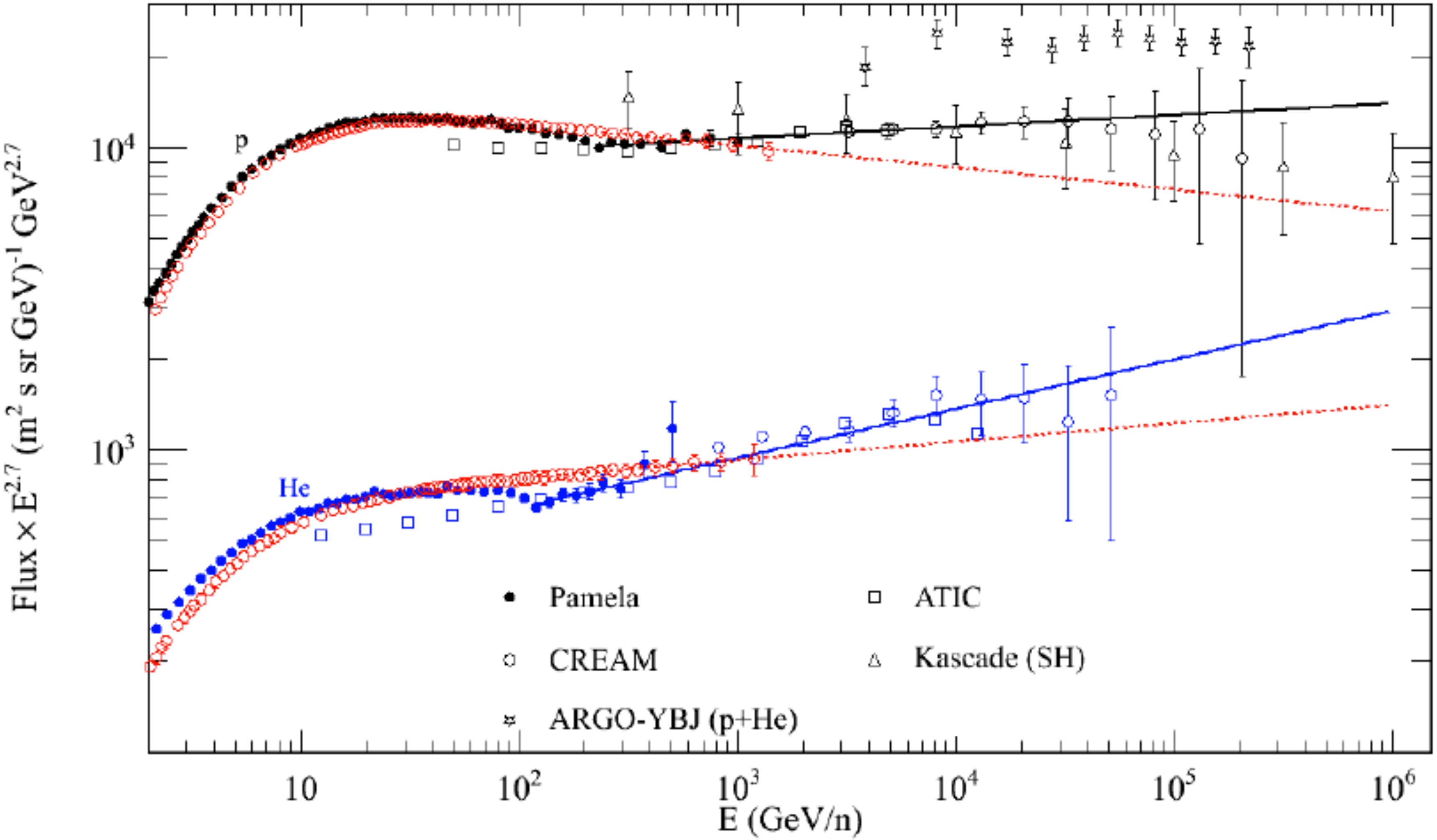
Proton and Helium fluxes



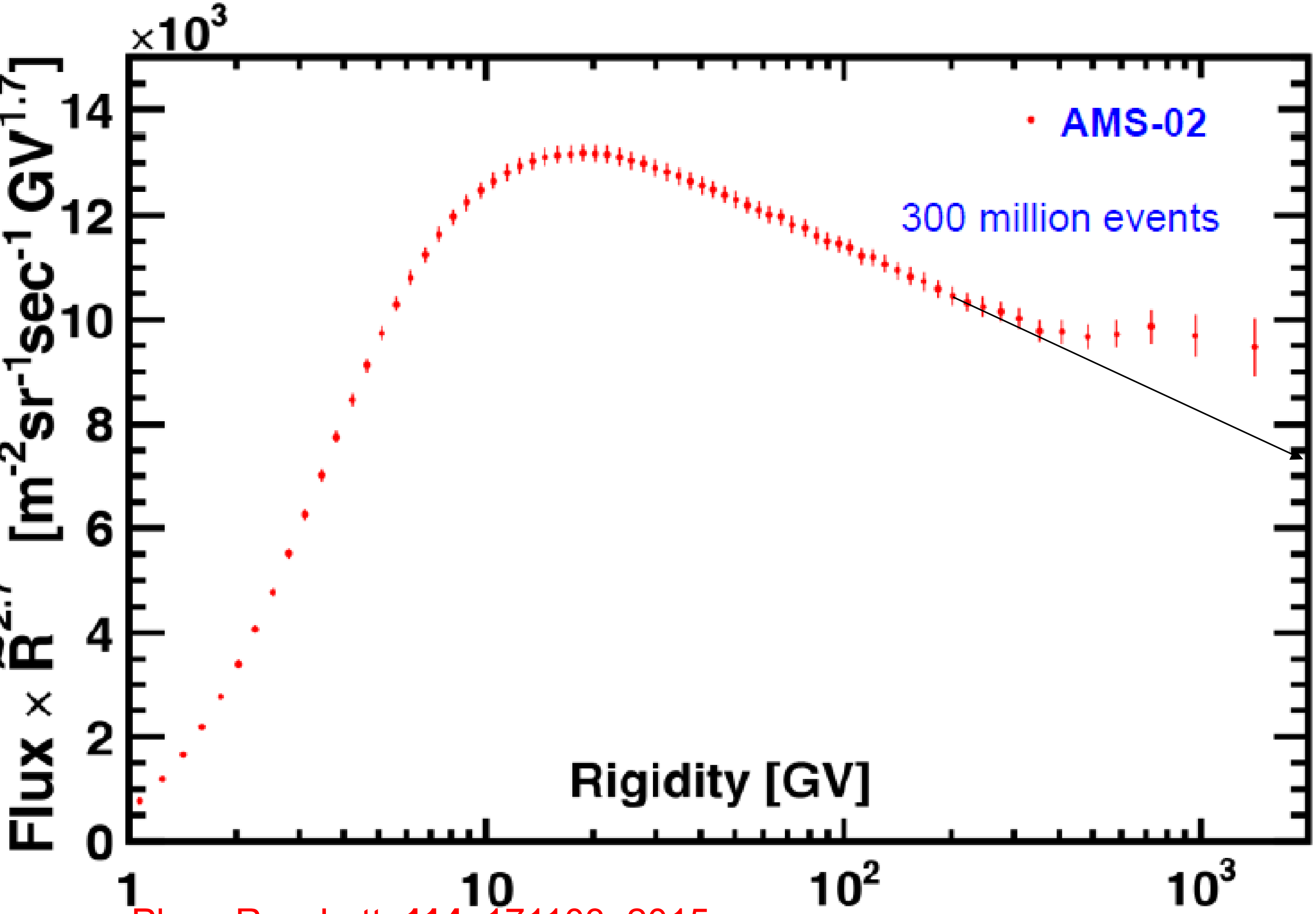
Proton to Helium ratio



Proton and Helium Nuclei Spectra

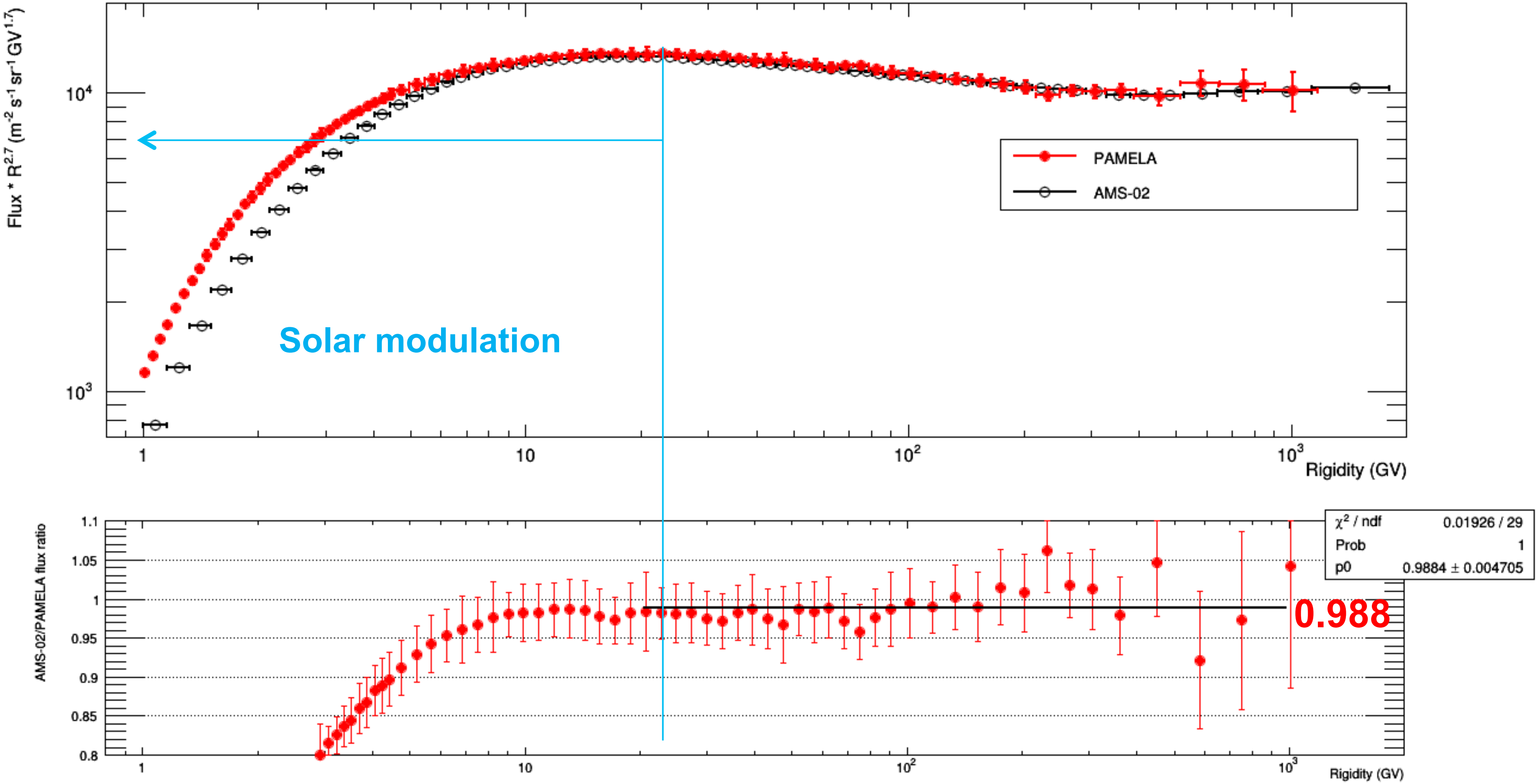


AMS proton flux

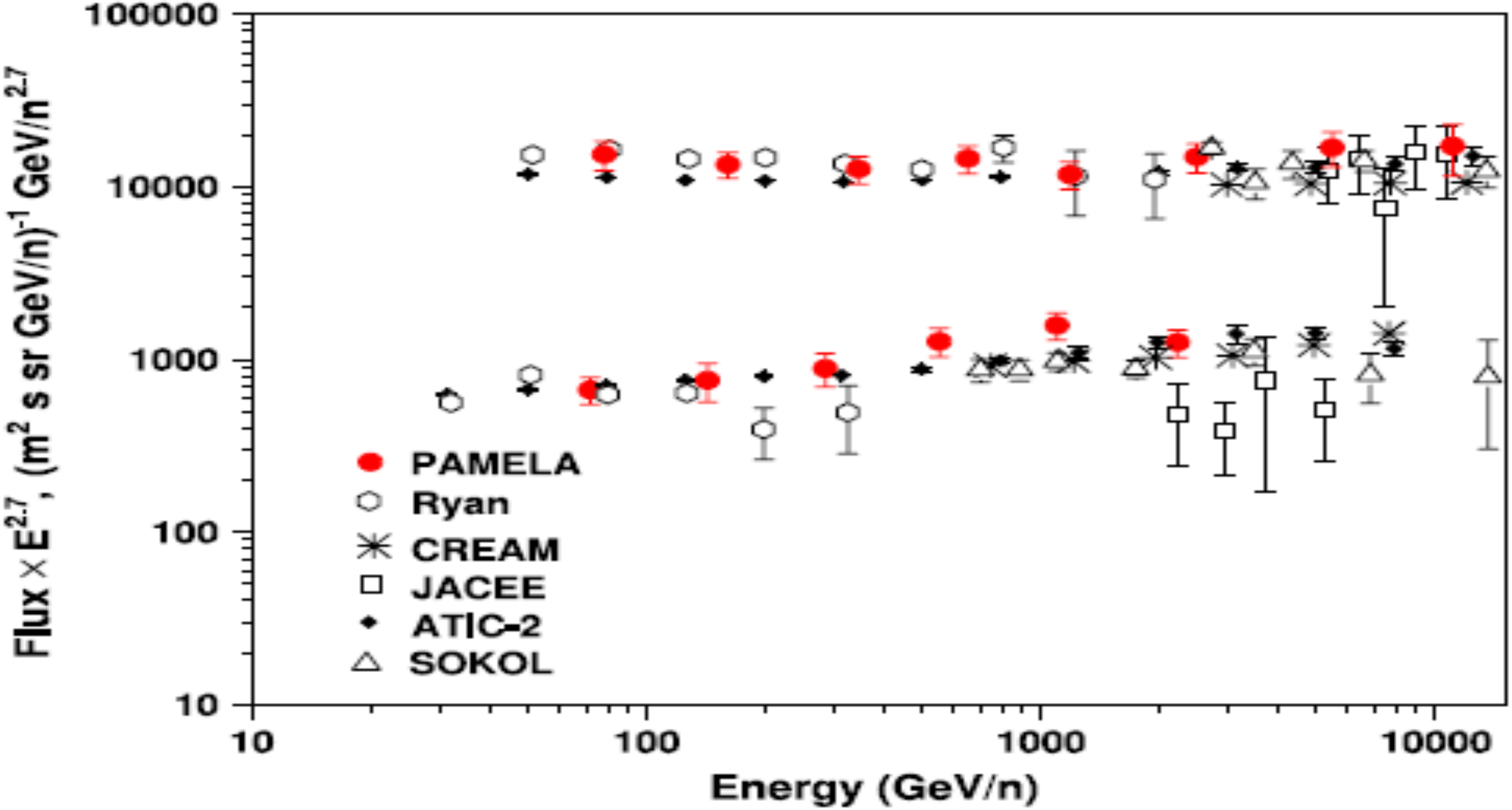


Phys. Rev. Lett. **114**, 171103, 2015

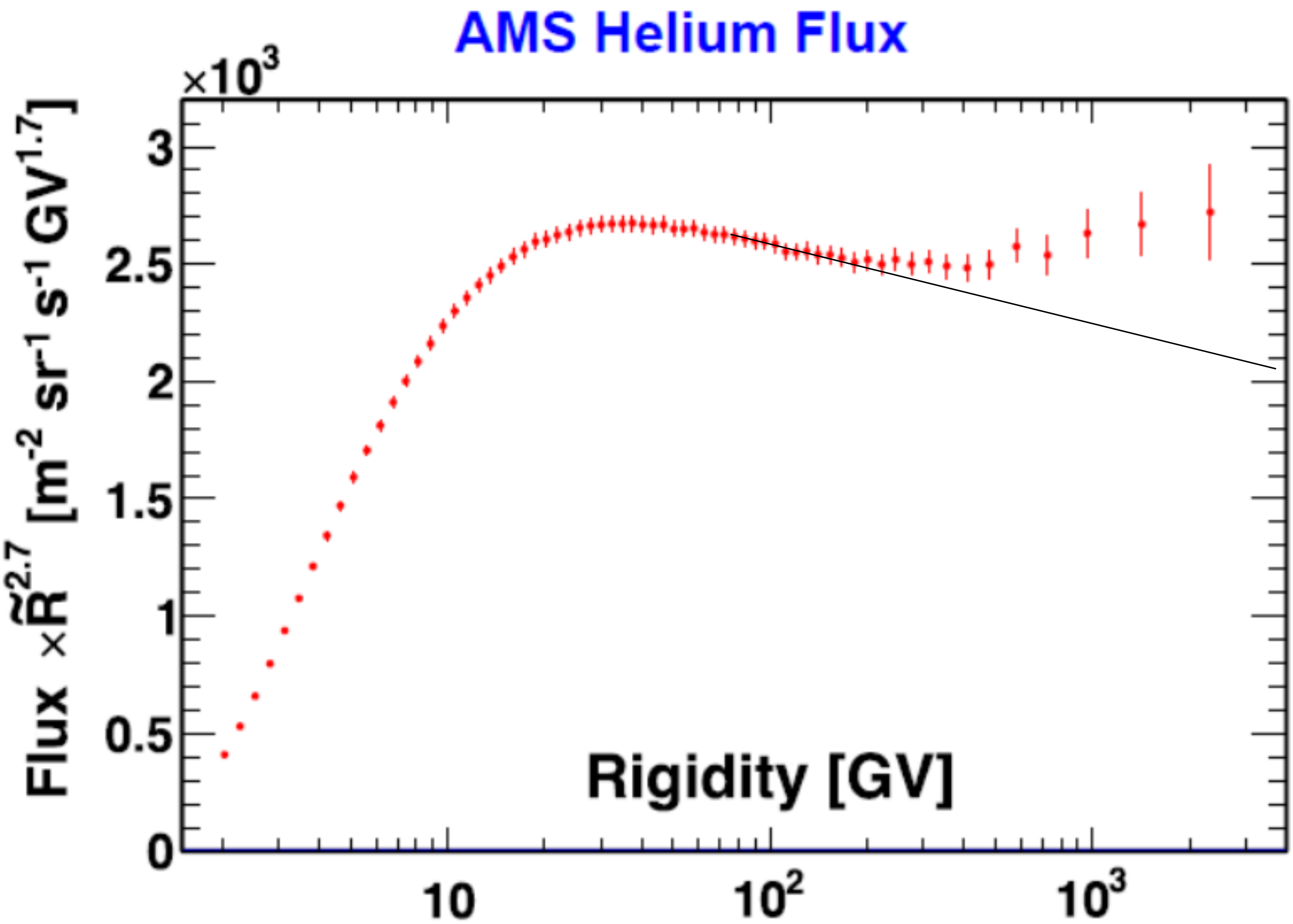
PAMELA vs AMS-02 proton spectrum



O. Adriani et al, Phys. Rep. (2014)

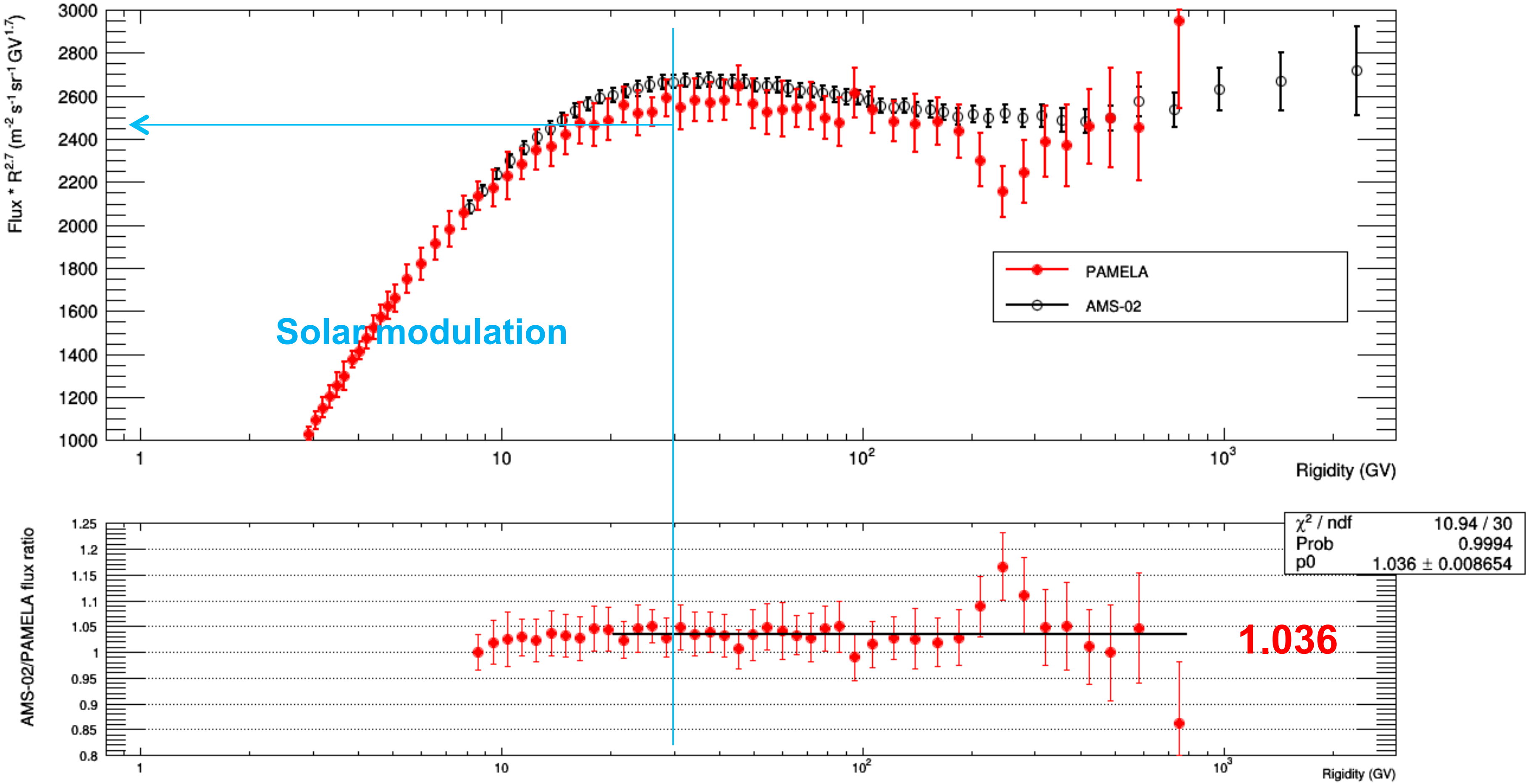


100000
10000
1000
100
10
10
100
1000
10000
Energy (GeV/n)
Flux × E^2.7, (m^2 s sr GeV/n)^-1 GeV/n^2.7
PAMELA
Ryan
CREAM
JACEE
ATIC-2
SOKOL

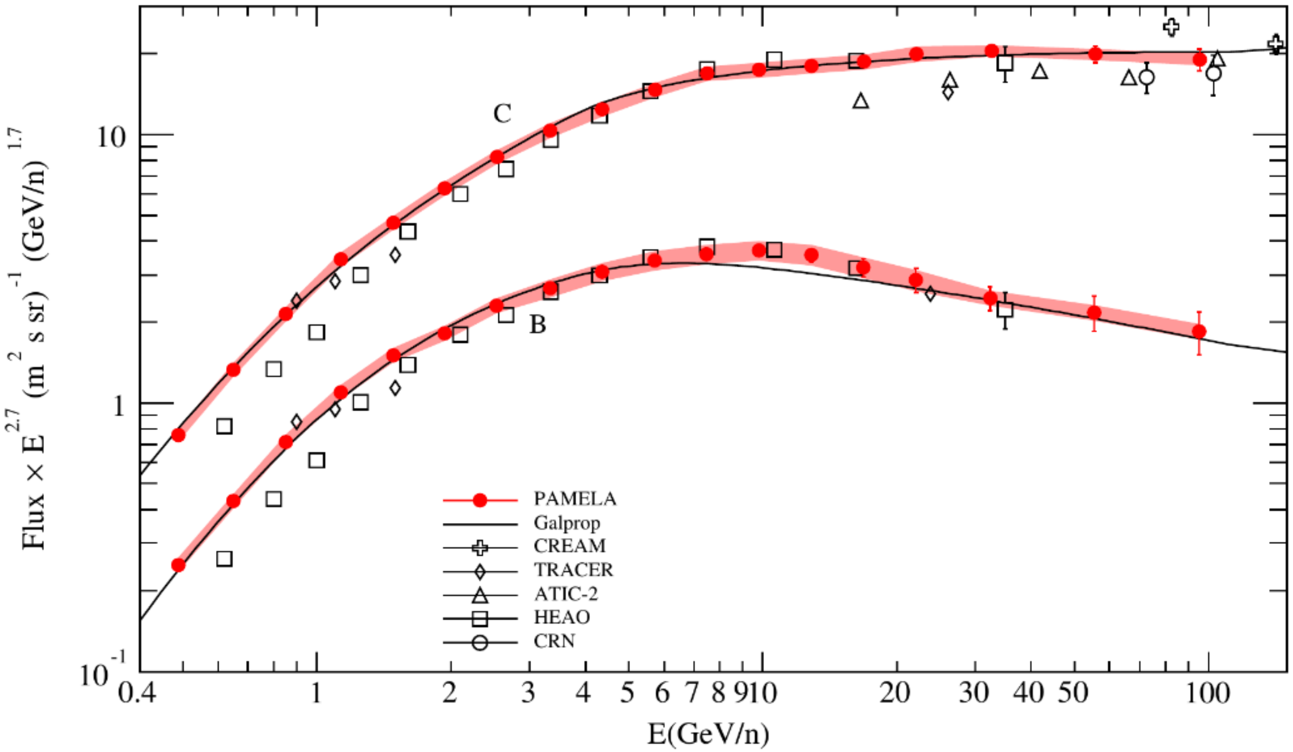


PRL 115, 211101 (2015)

PAMELA vs AMS-02 helium spectrum

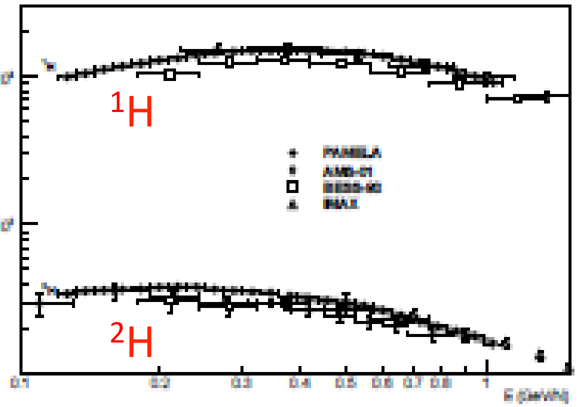


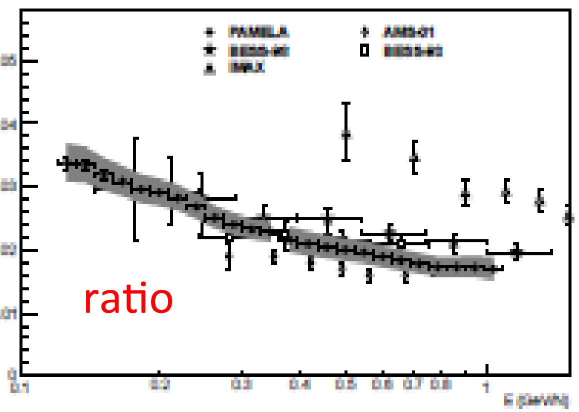
Boron and Carbon fluxes

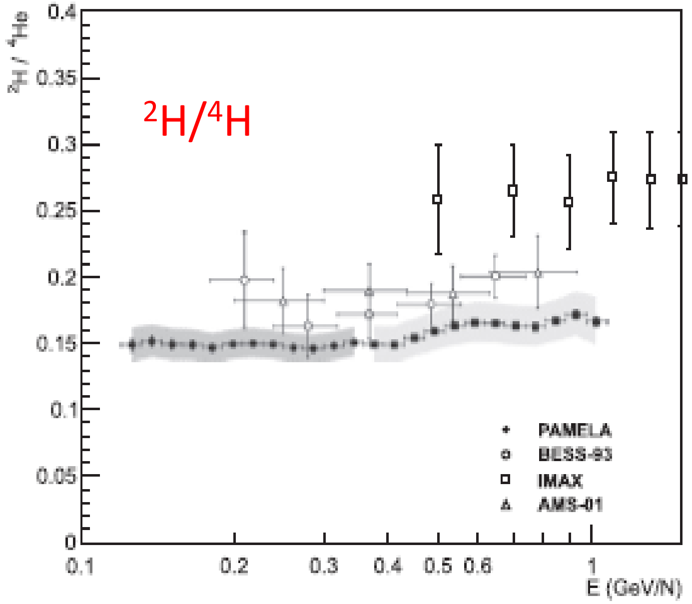


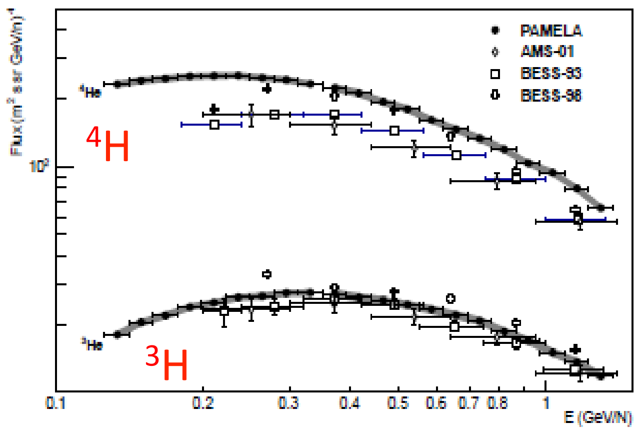
PAMELA Coll., ApJ 791 (2014), 93

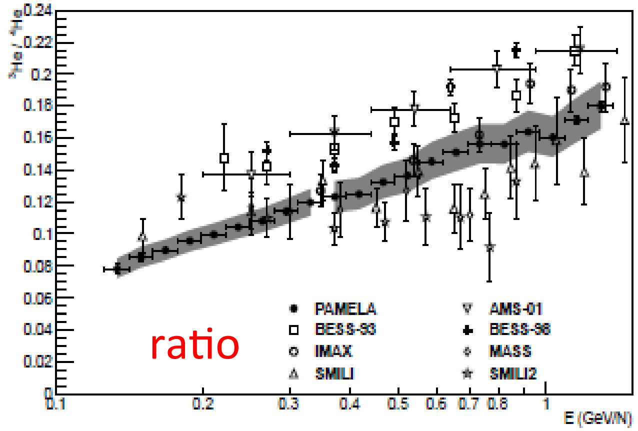
Hydrogen and Helium Isotopes





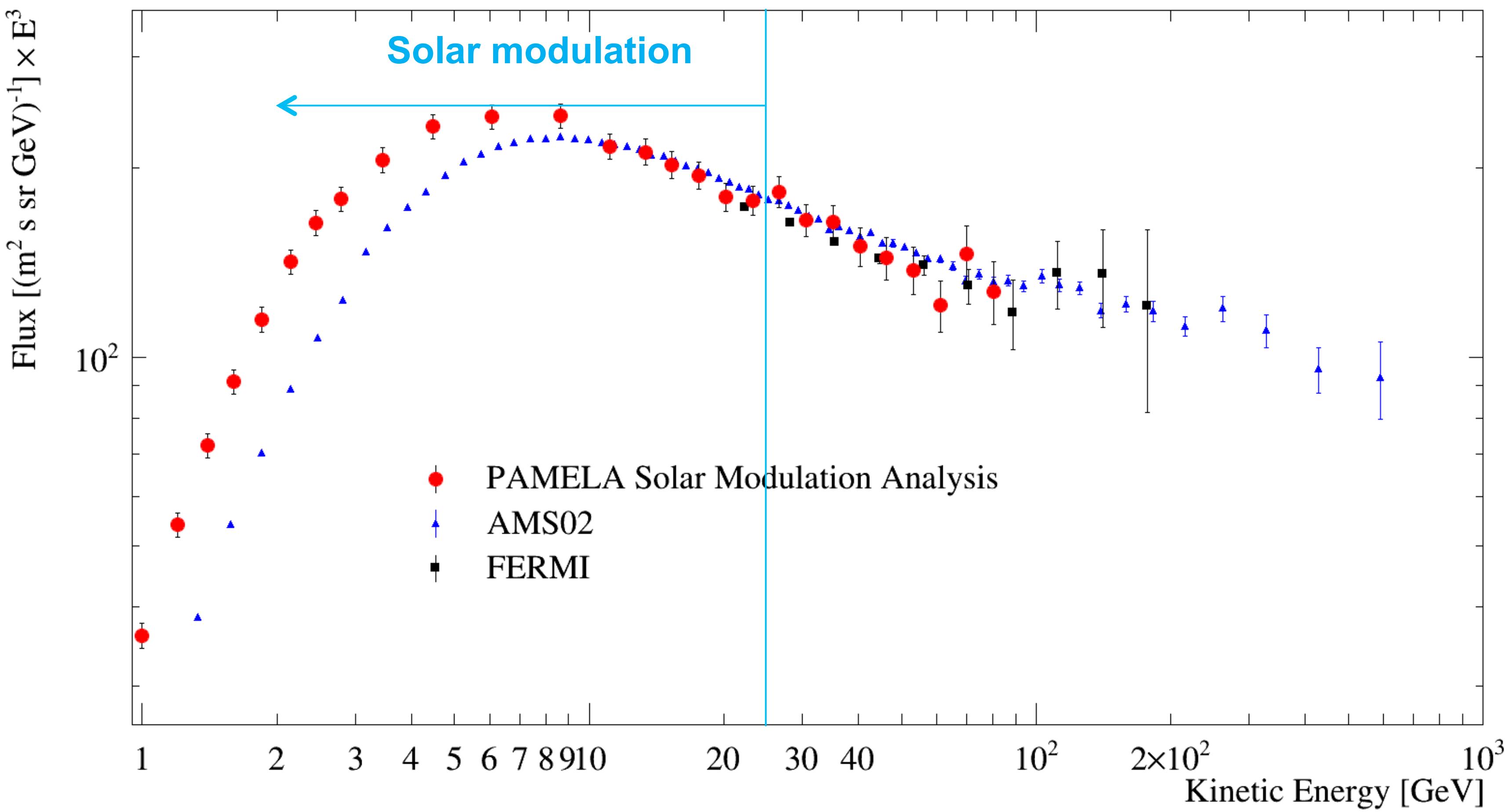


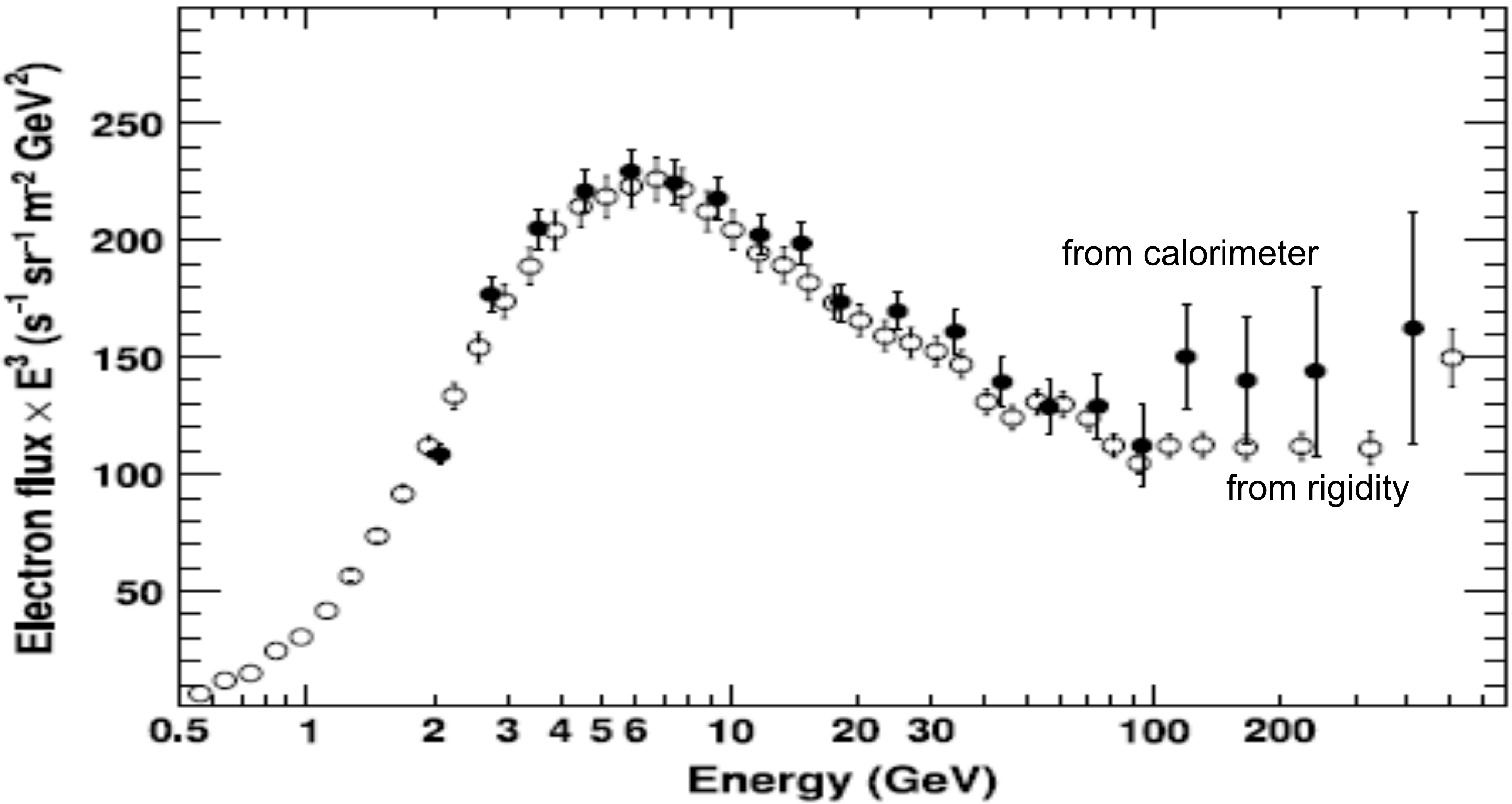




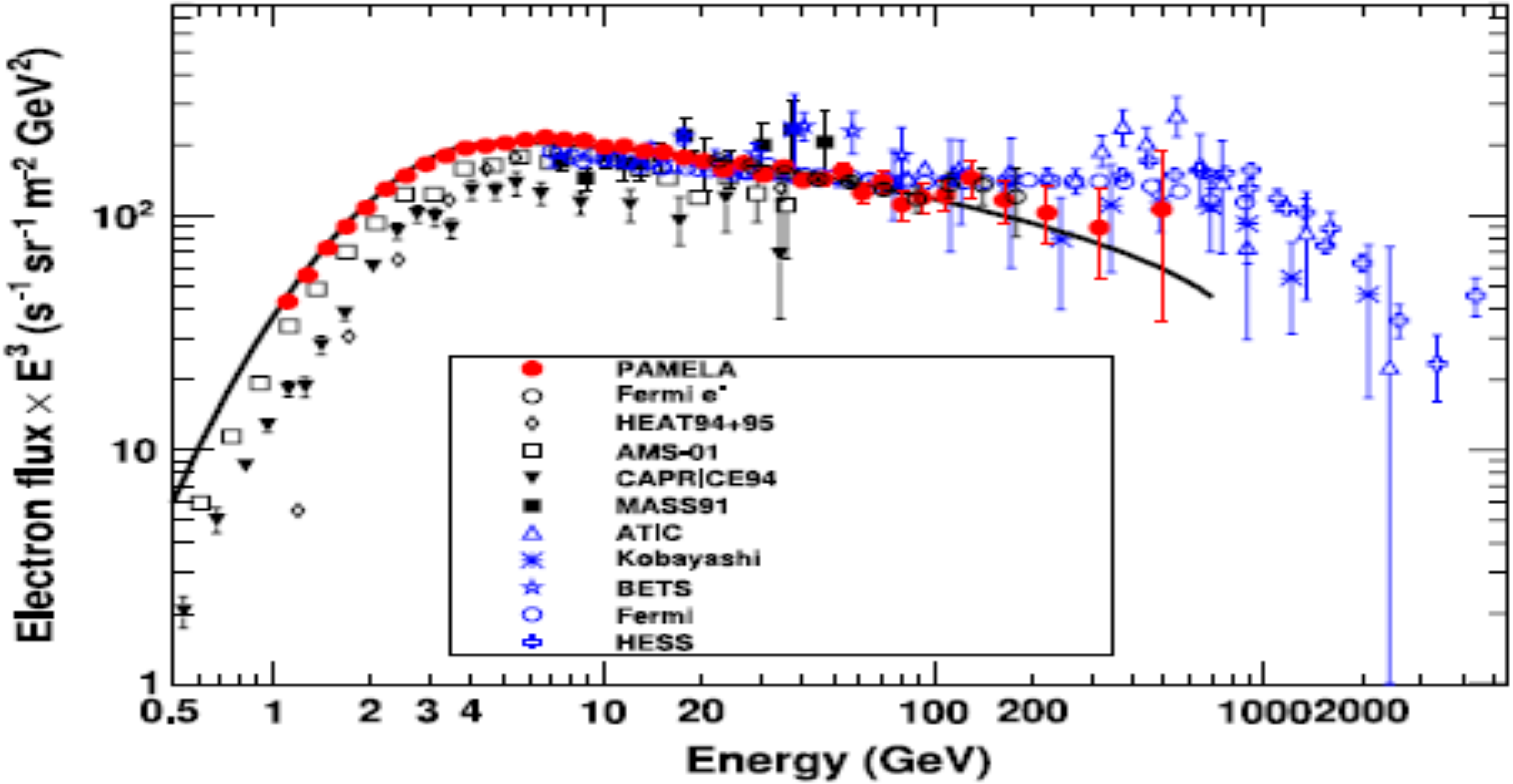
Pamela coll. APJ 818,1,68 (2016)

PAMELA&AMS (and Fermi) Electron (e^-) Spectrum

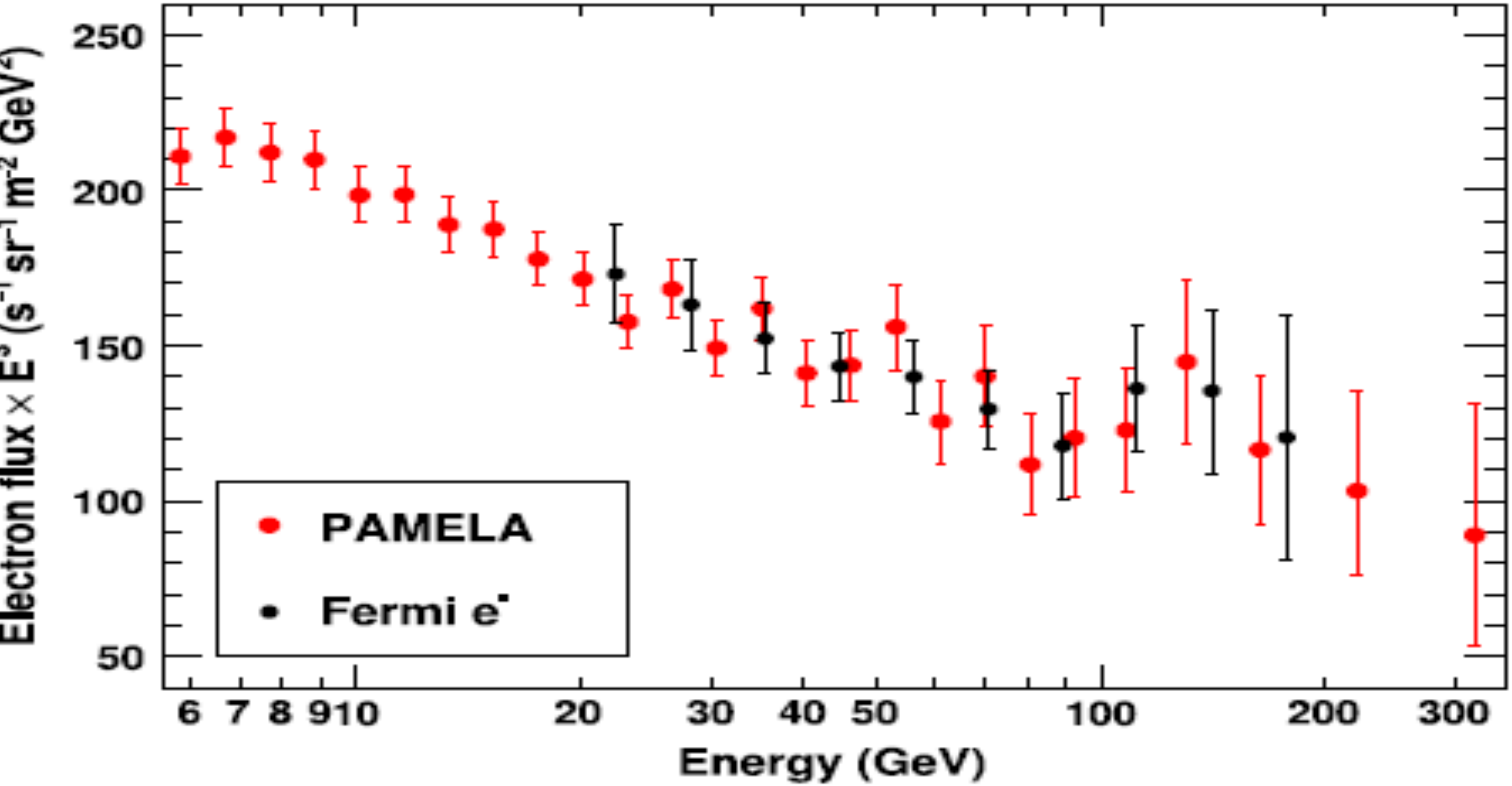




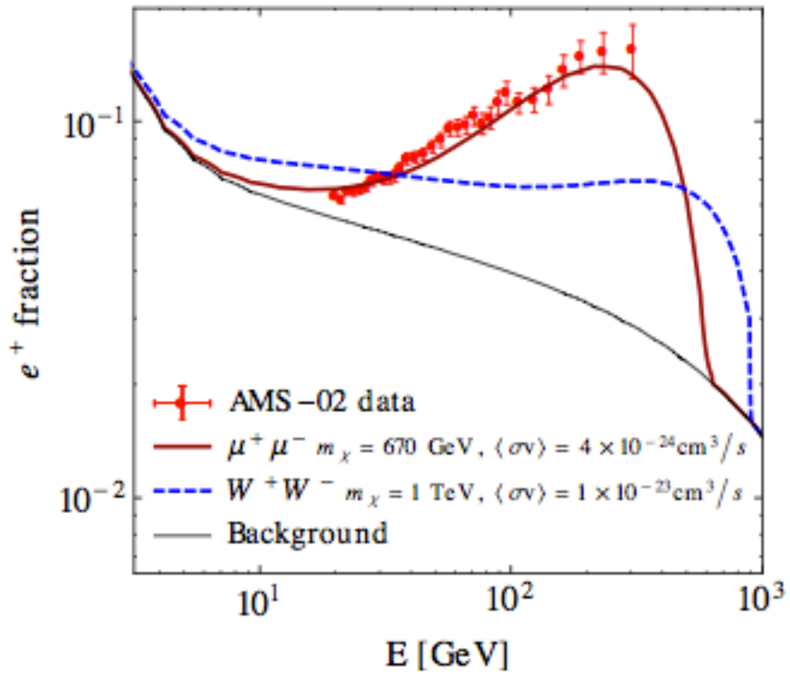
Electron flux × E^3 (s^-1 sr^-1 m^-2 GeV^2)
250
200
150
100
50
0.5
1
2
3
4
5
6
10
20
30
100
200
Energy (GeV)
from calorimeter
from rigidity



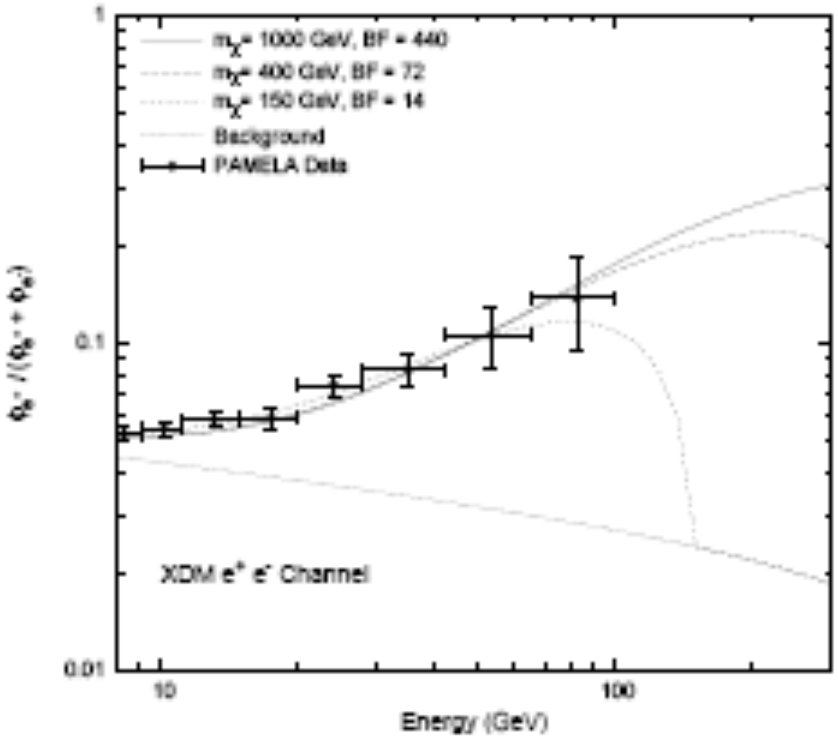
Electron flux × E^3 (s^{-1} sr^{-1} m^{-2} GeV^2)
1
10
10^2
0.5
1
2
3
4
10
20
100
200
10002000
Energy (GeV)
PAMELA
Fermi e$^-$
HEAT94+95
AMS-01
CAPRICE94
MASS91
ATIC
Kobayashi
BETS
Fermi
HESS


Electron flux × E³ (s⁻¹ sr⁻¹ m⁻² GeV²)
250
200
150
100
50
6 7 8 910 20 30 40 50 100 200 300
Energy (GeV)
PAMELA
Fermi e⁻

Dark Matter Explanation

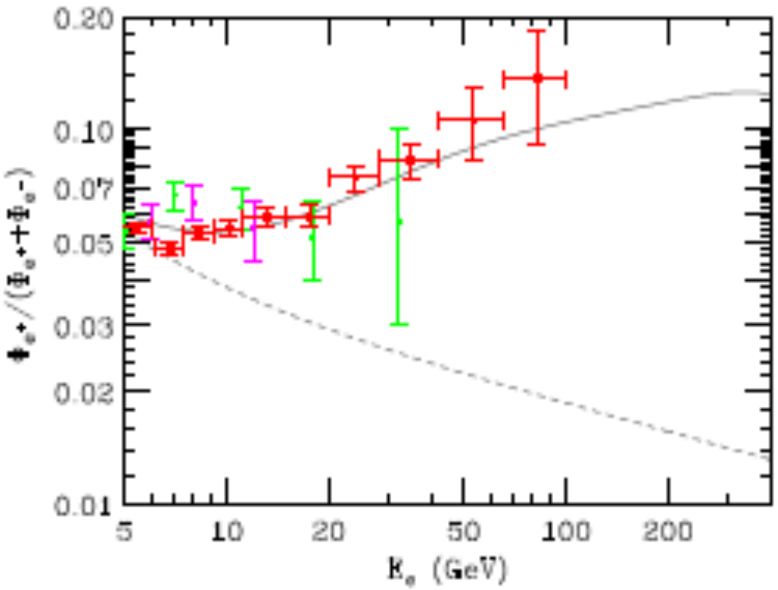


J. Kopp, Phys. Rev. D 88 (2013) 076013; arXiv:1304.1184

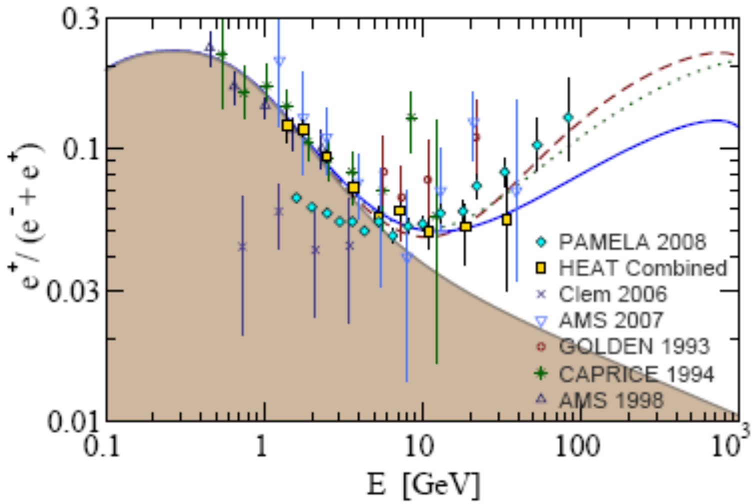


I. Cholis et al., Phys. Rev. D 80 (2009) 123518; arXiv:0811.3641v1

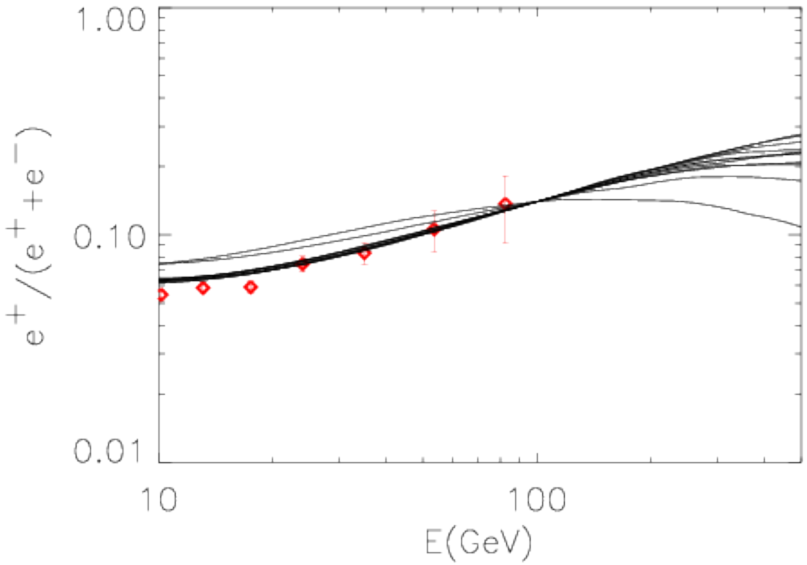
Pulsar Explanation



D. Hooper, P. Blasi, and P. Serpico, JCAP 0901:025,2009; arXiv:0810.1527
Contribution from diffuse mature &nearby young pulsars.

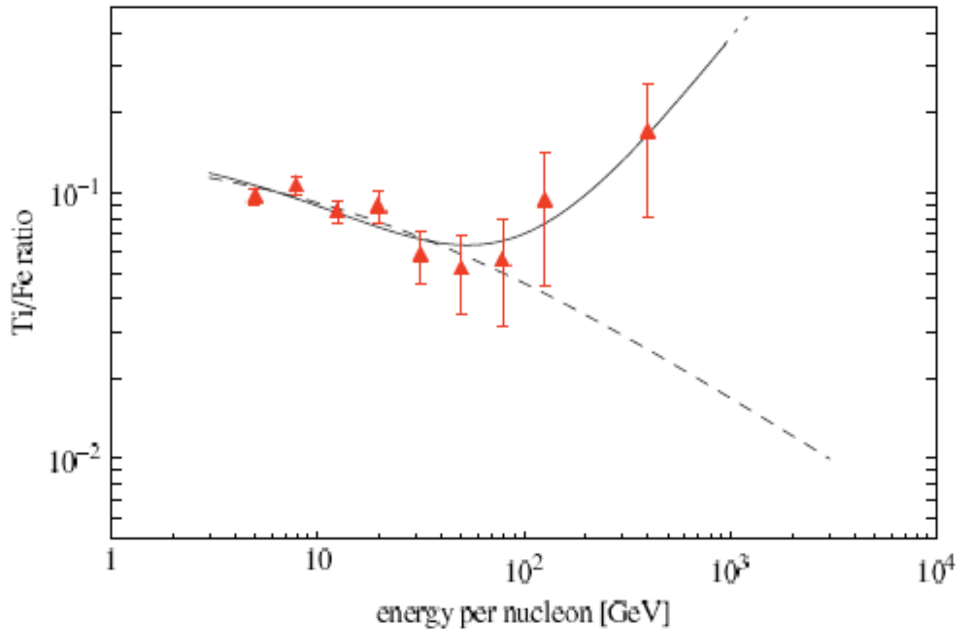


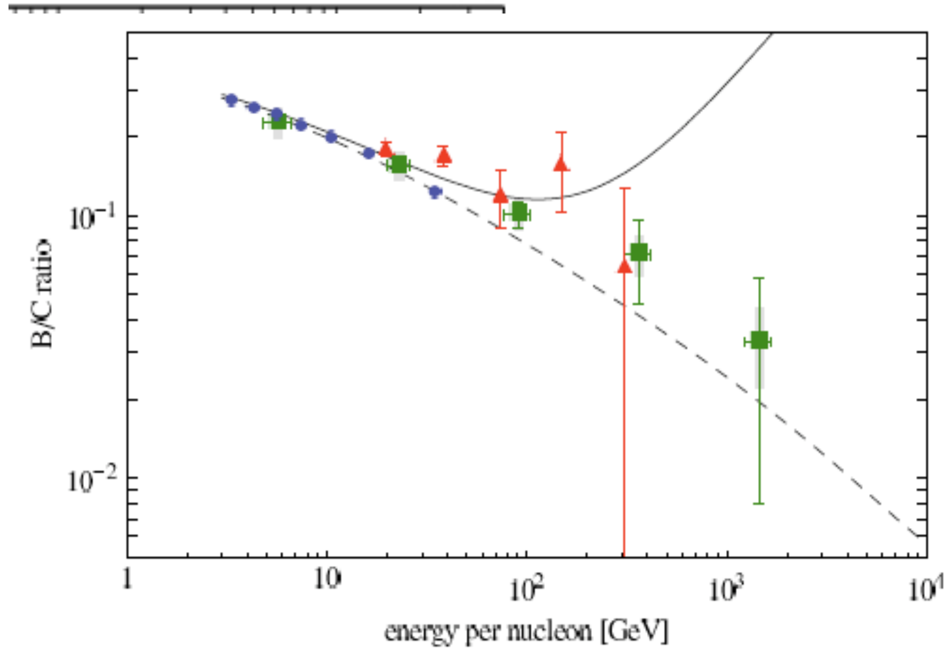
H. Yuksel et al., PRL 103 (2009) 051101; arXiv:0810.2784v2
Contributions of e^- & e^+ from Geminga assuming different distance, age and energetic of the pulsar

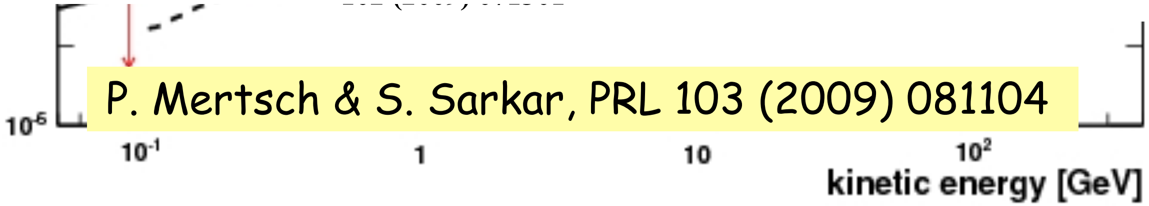


P. Blasi & E. Amato, arXiv:1007.4745
Contribution from pulsars varying the injection index and location of the sources.

SNR Explanation





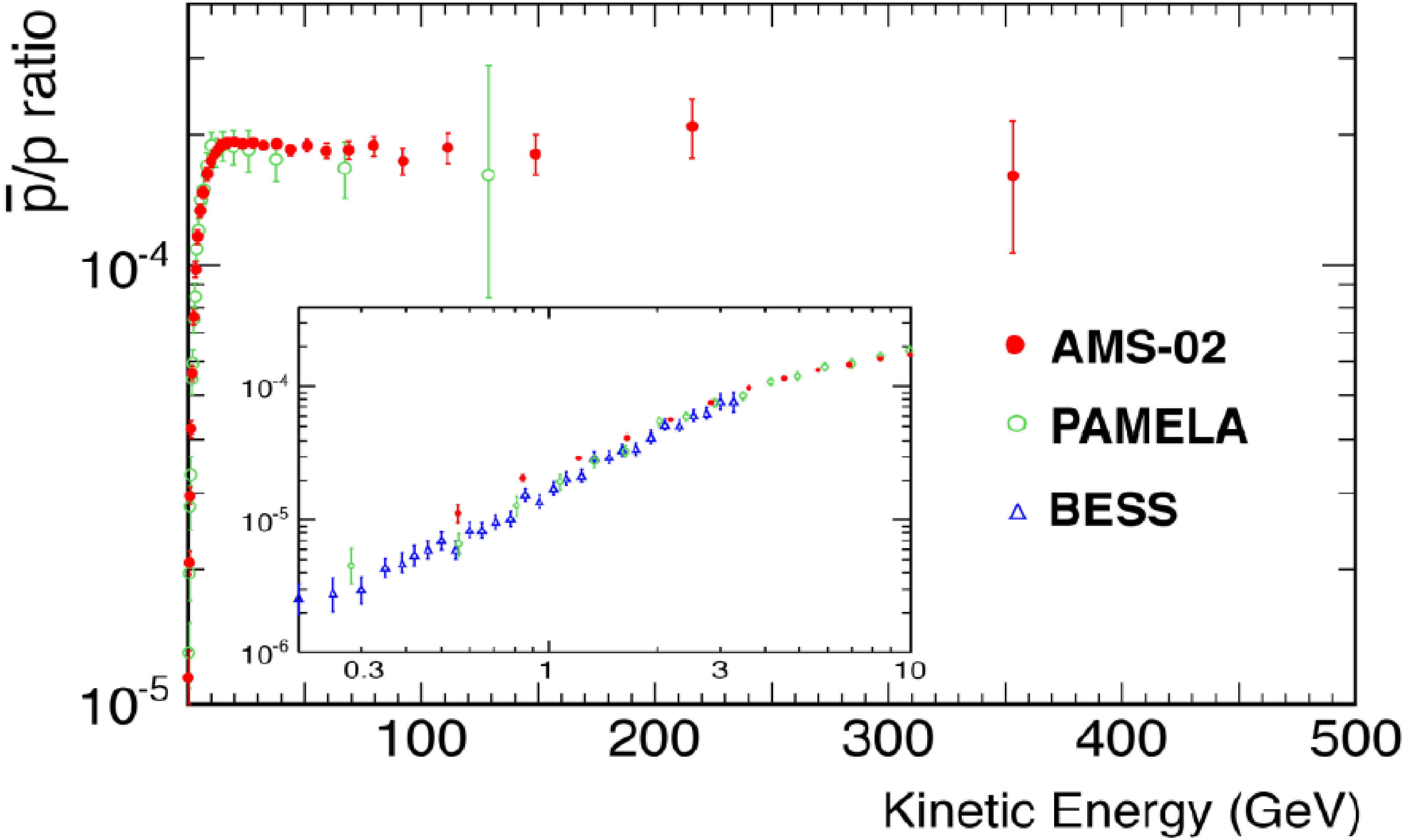


P. Mertsch & S. Sarkar, PRL 103 (2009) 081104

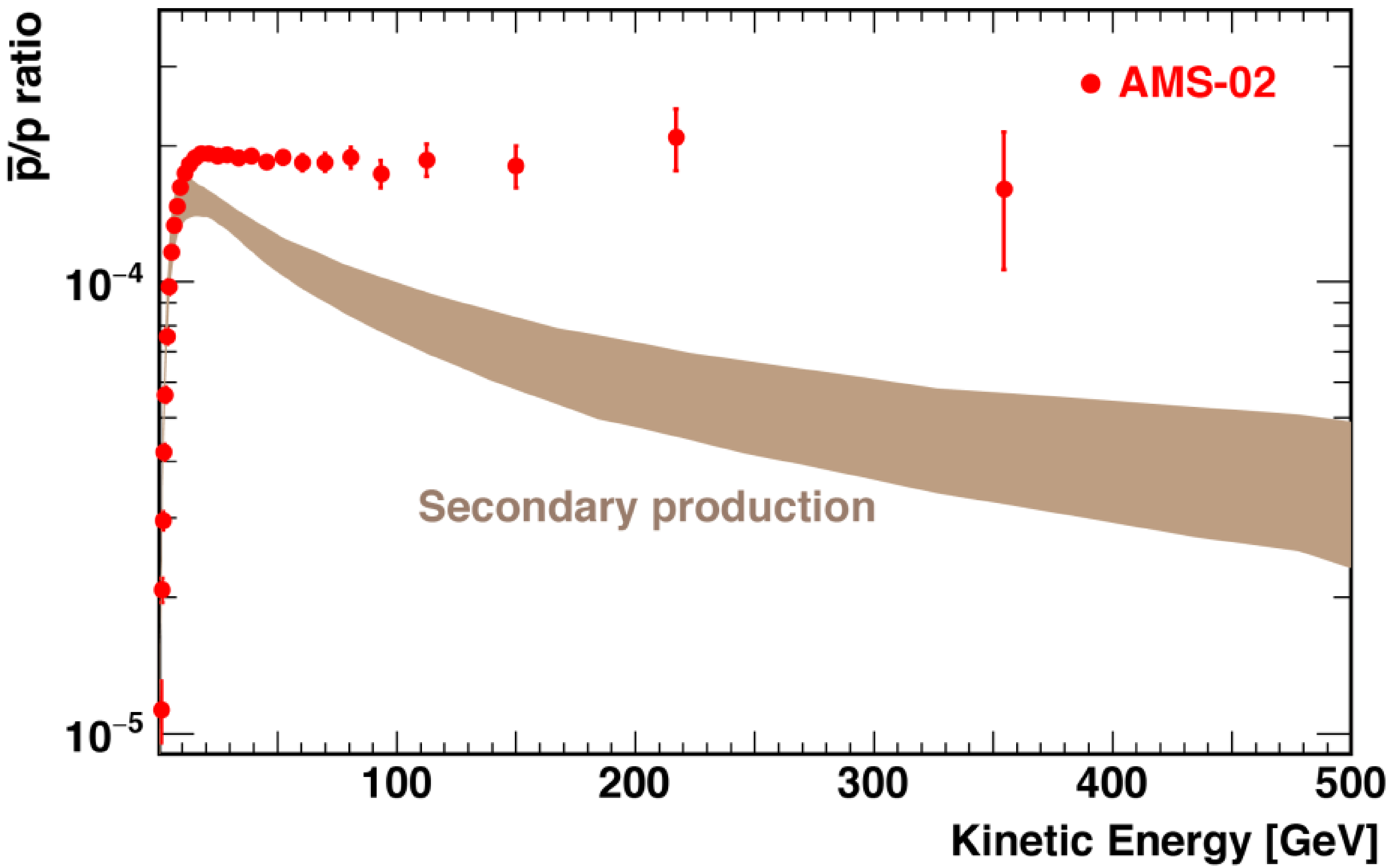
P.Blasi, PRL 103 (2009) 051104 (see also Y. Fujita et al., PRD 80 (2009) 063003, M. Ahlers et al. PRD 80 (2009) 123017) Positrons (and electrons) produced as secondaries in the sources (e.g. SNR) where CRs are accelerated.

But also other secondaries are produced: significant increase expected in the p/p and secondary nuclei ratios.

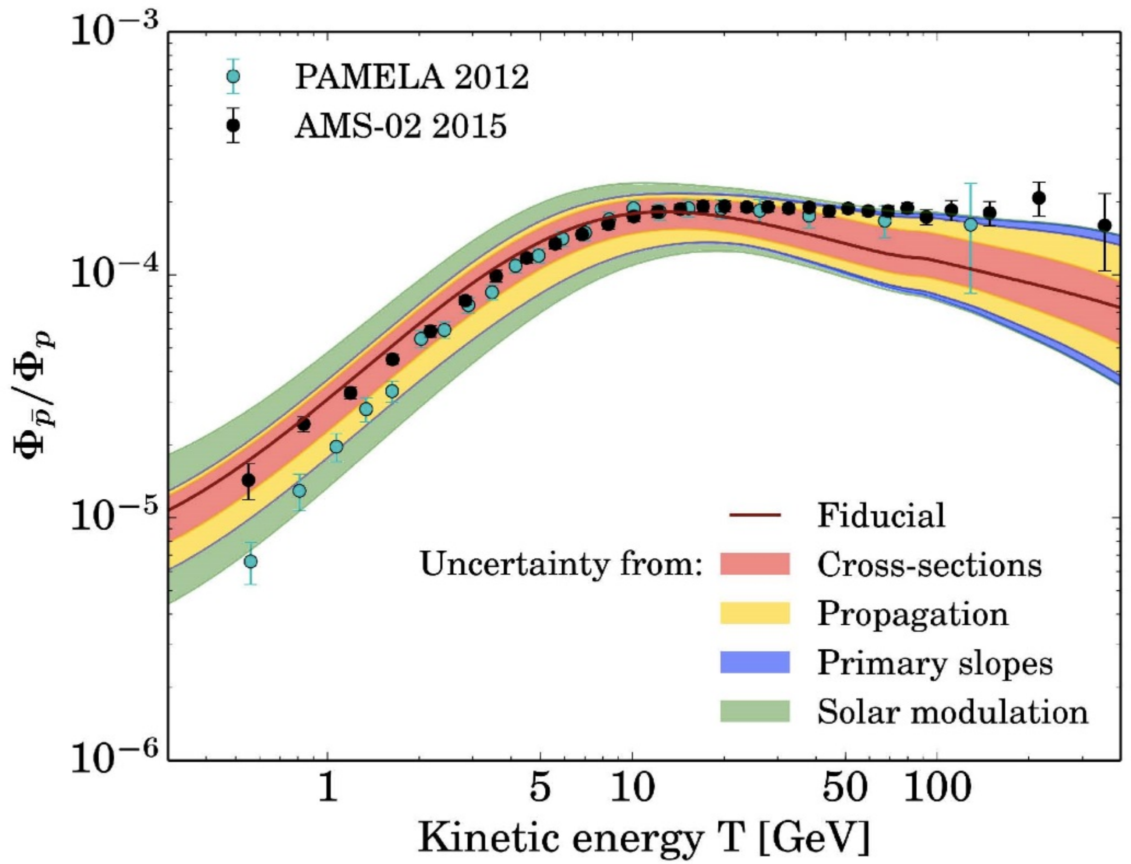
AMS $\bar{p}/p$ results



Antiproton to proton fraction

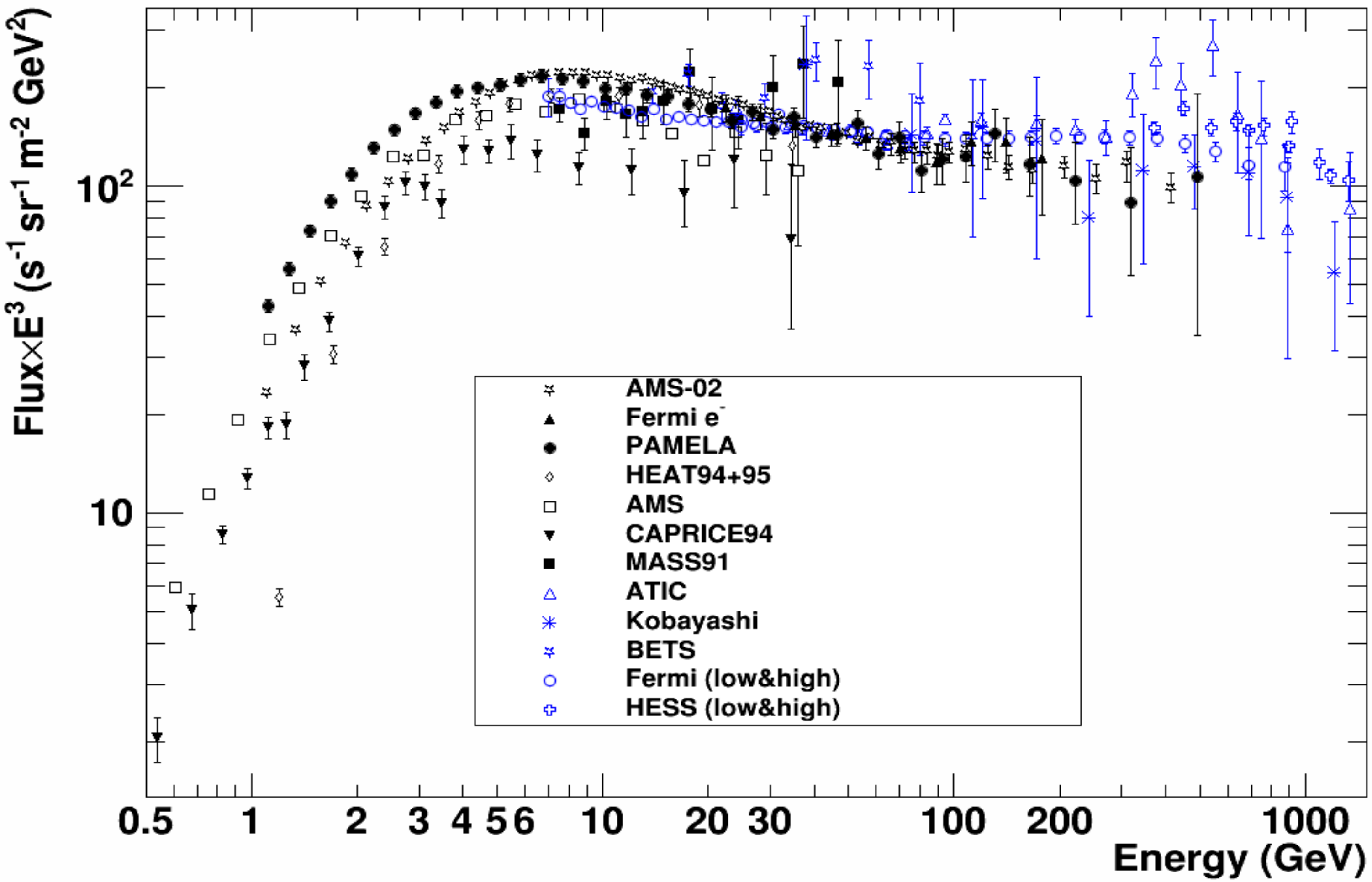


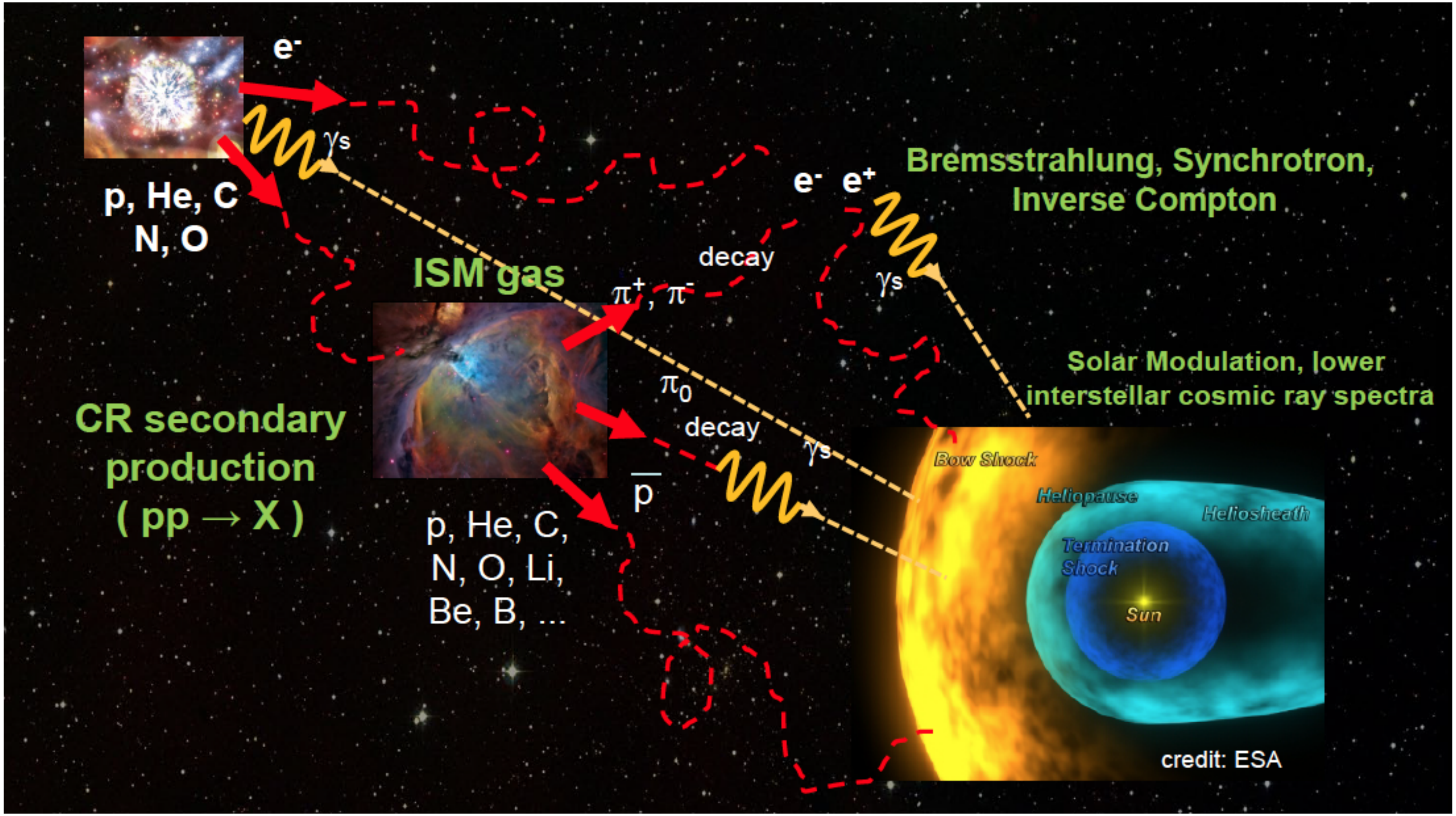
Cosmic-Ray Antiprotons and DM limits



G. Giesen et al., JCAP 1509 (2015) 023,
arXiv: 1504:04276

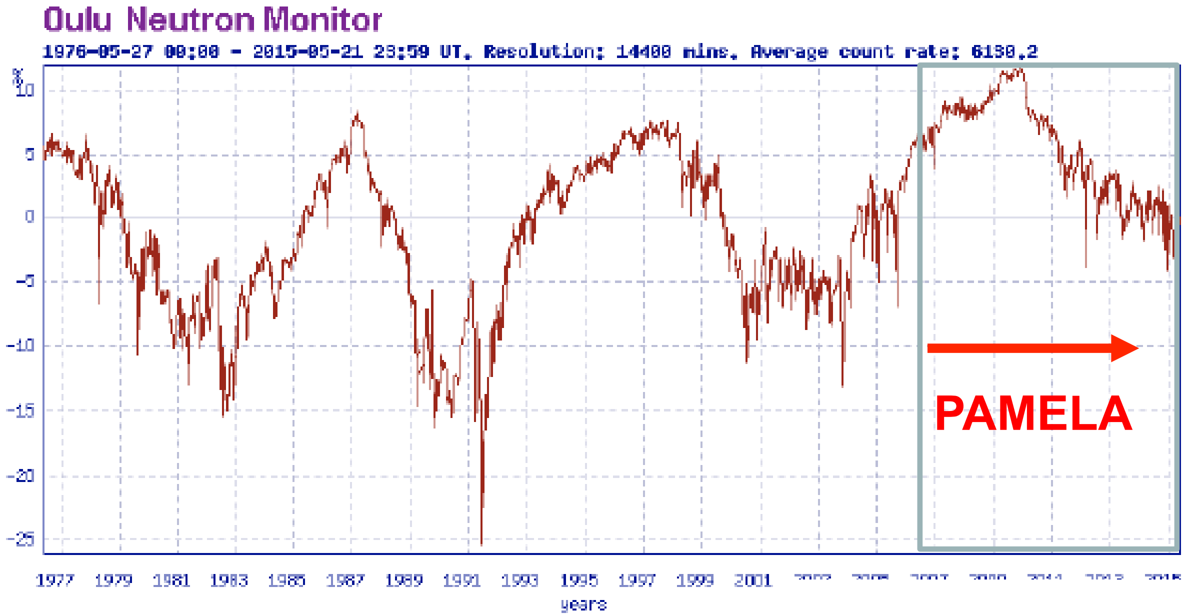
Electron Spectrum





Cosmic rays in the heliosphere

Heliospheric conditions during PAMELA observations

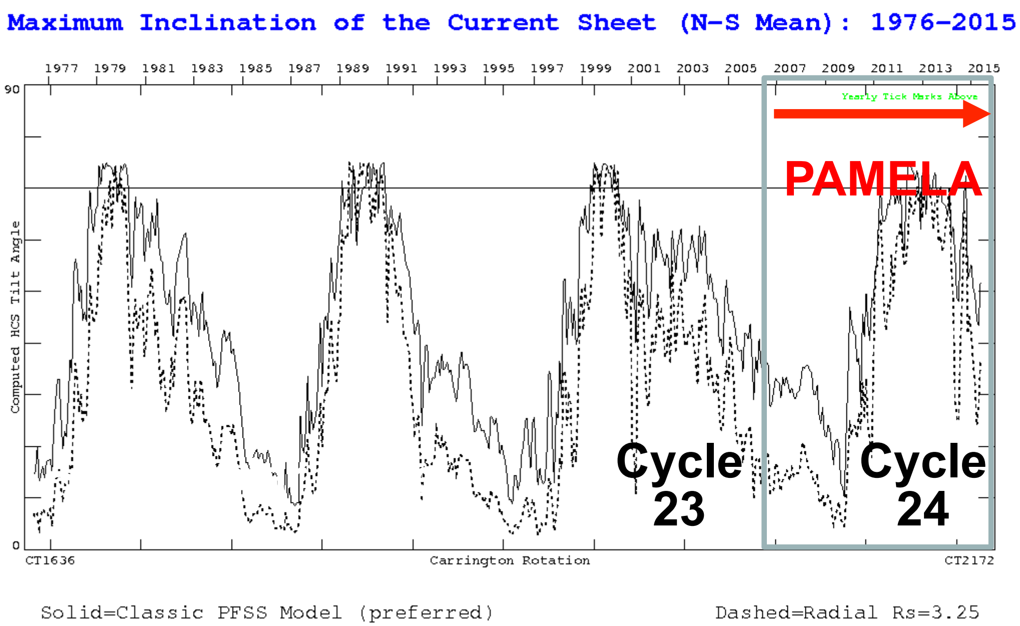


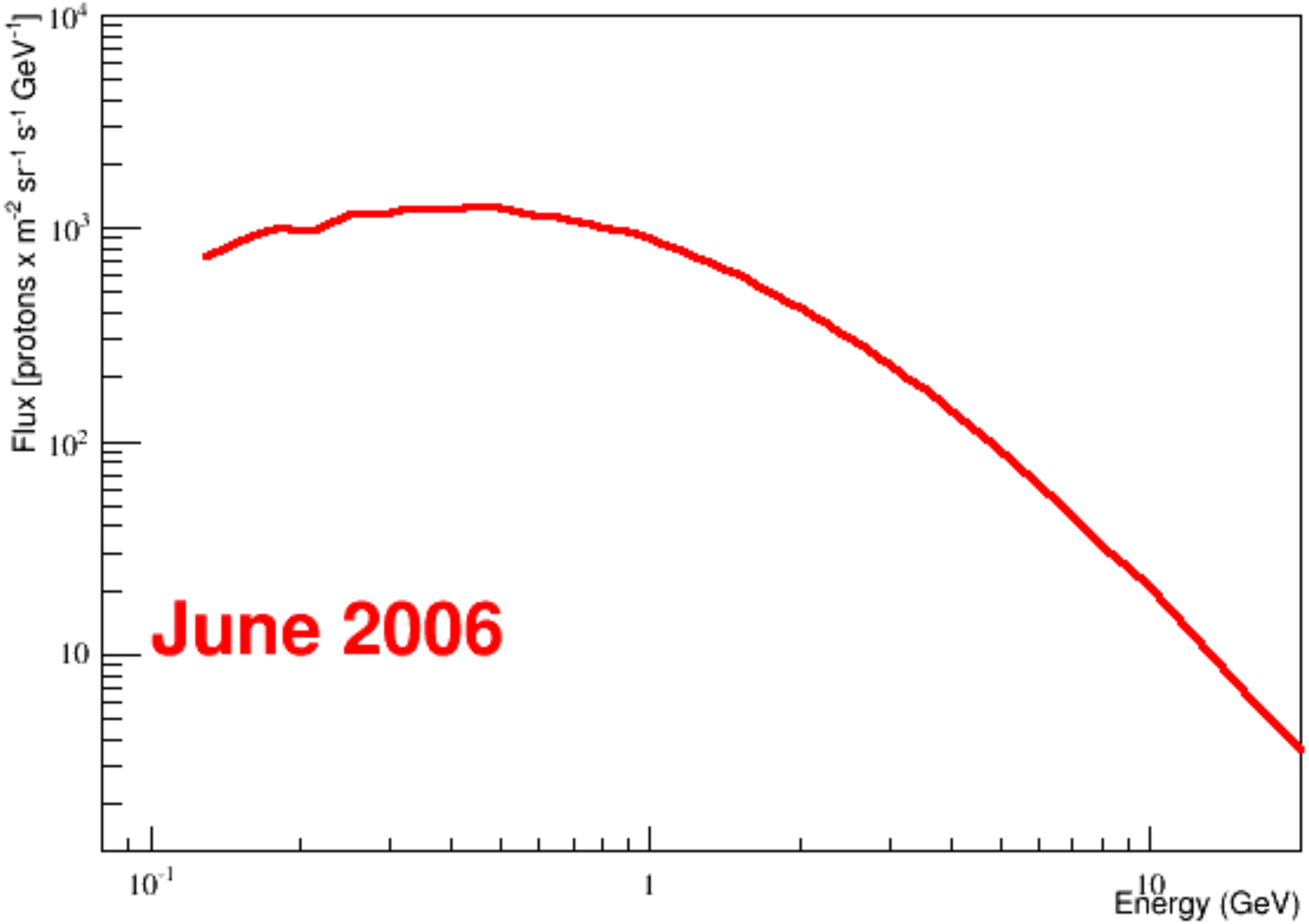
Neutron Monitor counts

Data from http://cosmicrays.oulu.fi/

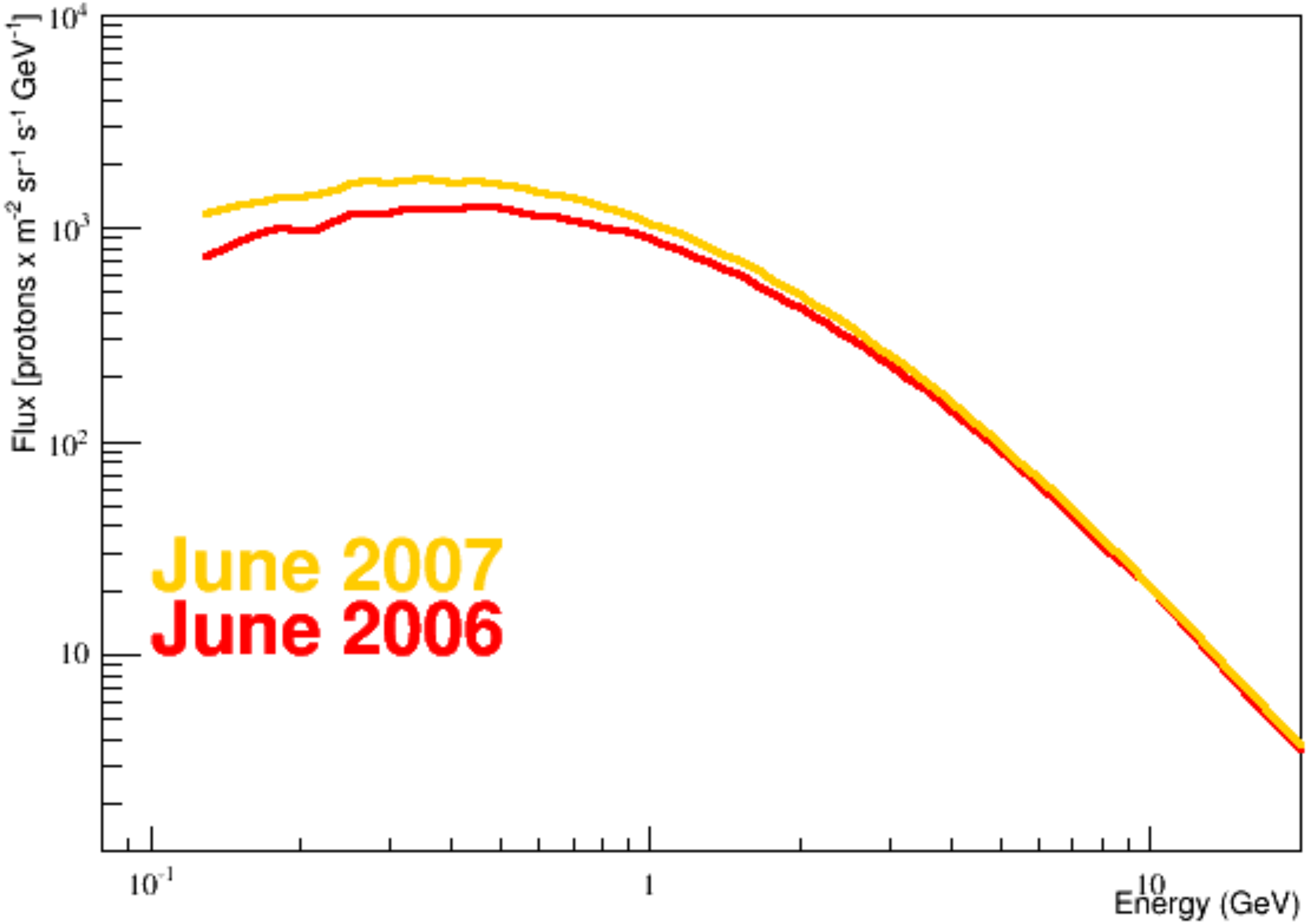
Computed HCS tilt angle

Data from http://wso.stanford.edu/

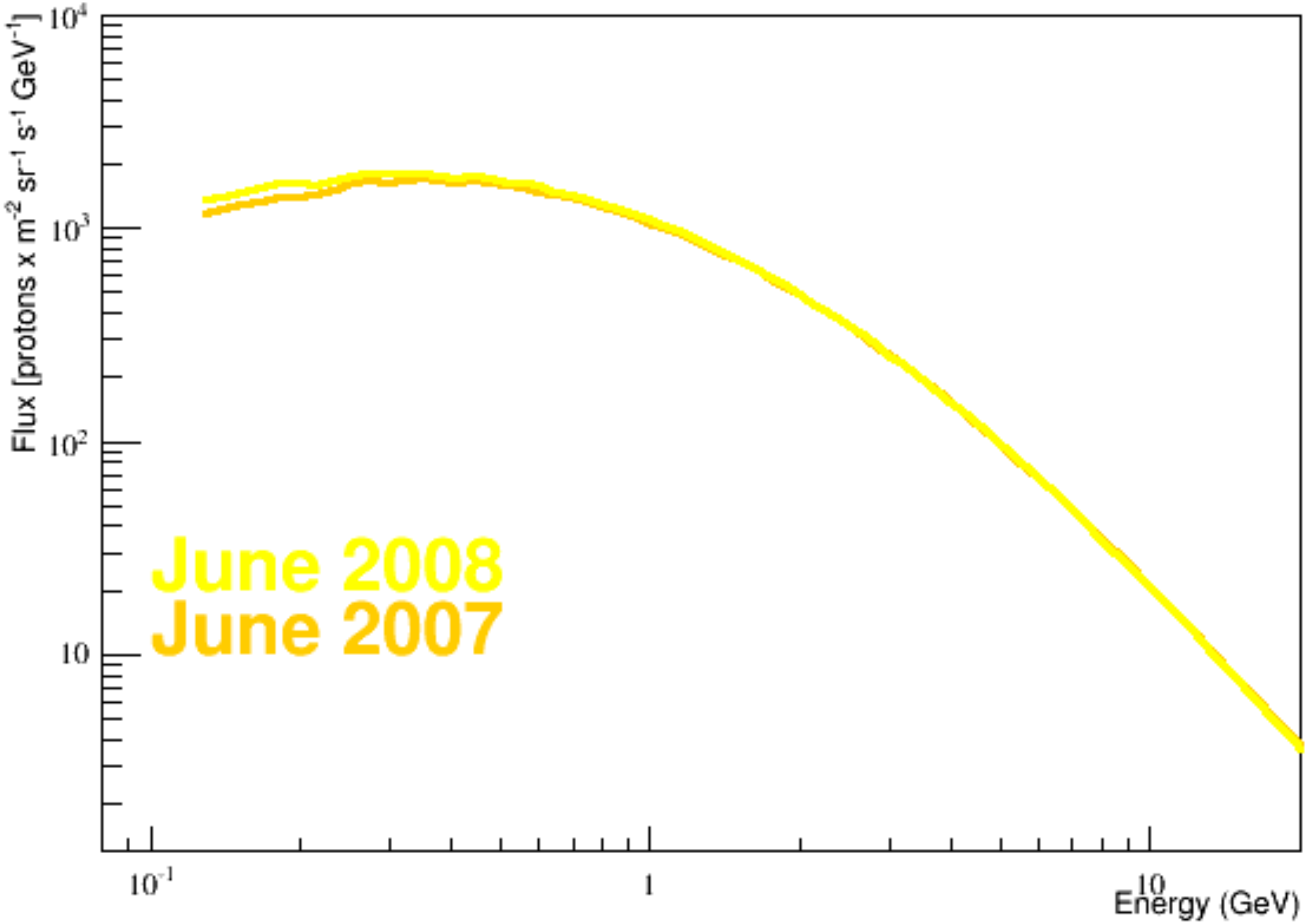




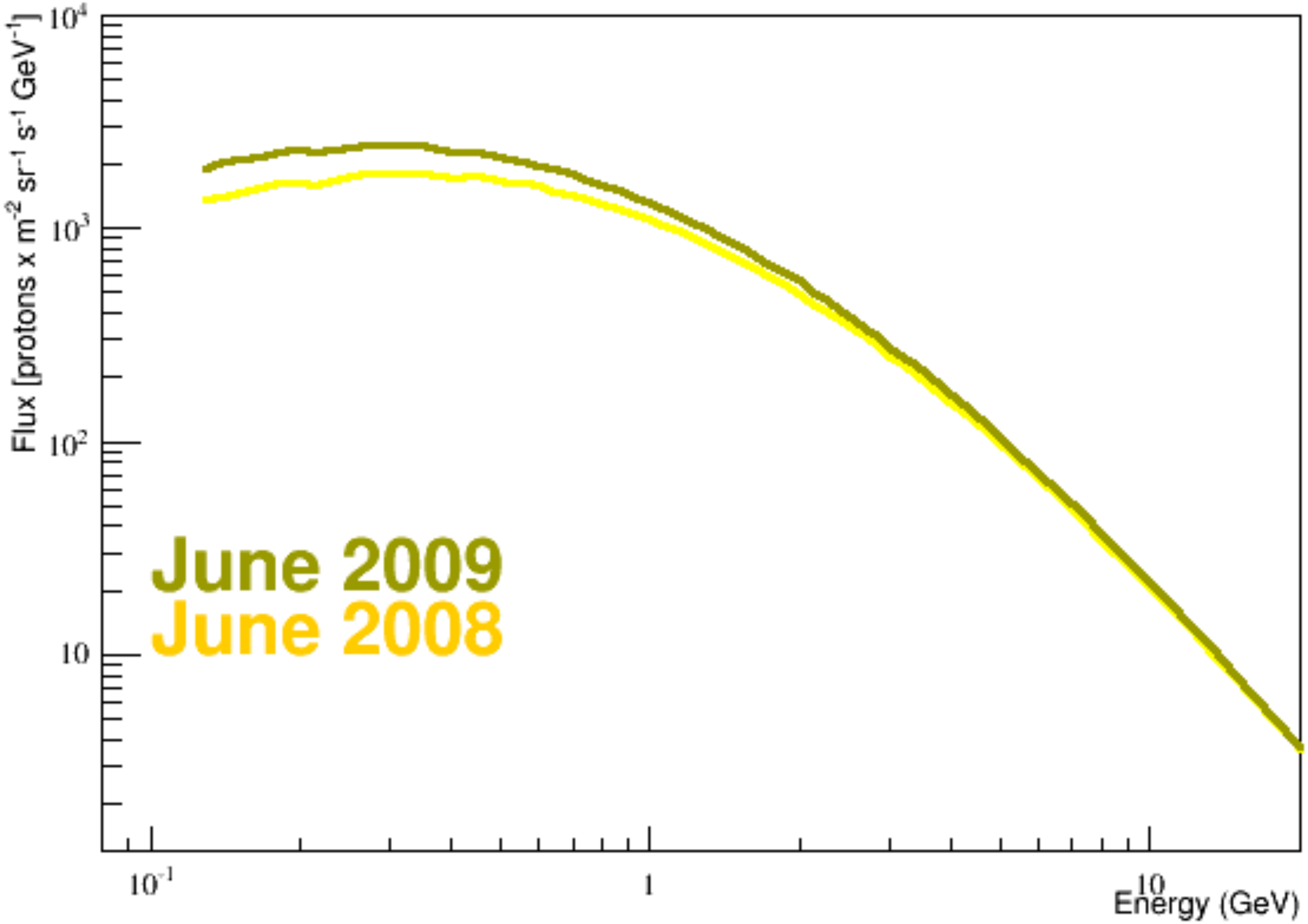
Flux [protons x m^{-2} sr^{-1} s^{-1} GeV^{-1}]
10^4
10^3
10^2
10
10^{-1}
1
10
Energy (GeV)
June 2006

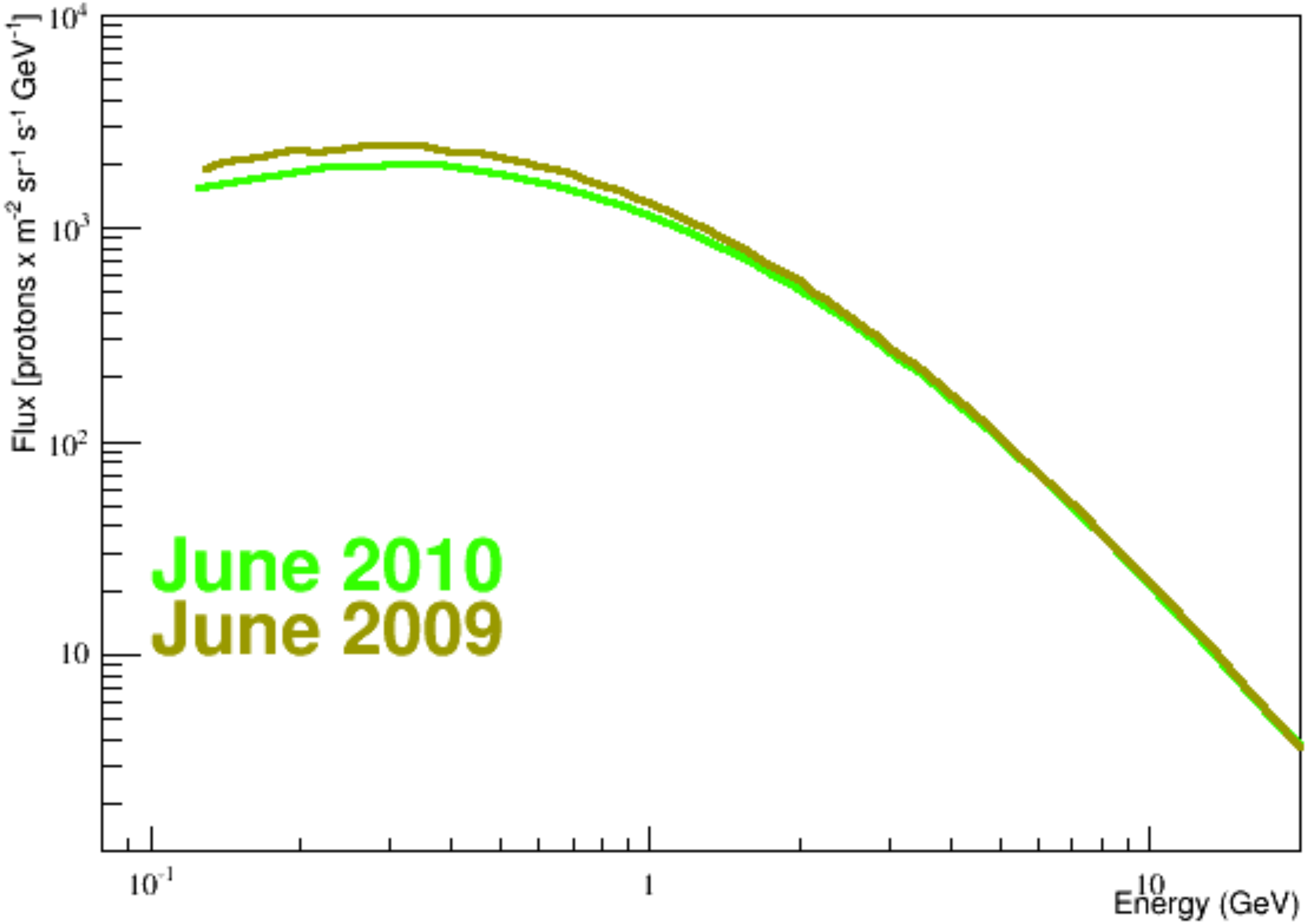


Flux [protons x m^{-2} sr^{-1} s^{-1} GeV^{-1}]
10^4
10^3
10^2
10
10^{-1}
1
10
Energy (GeV)
June 2007
June 2006

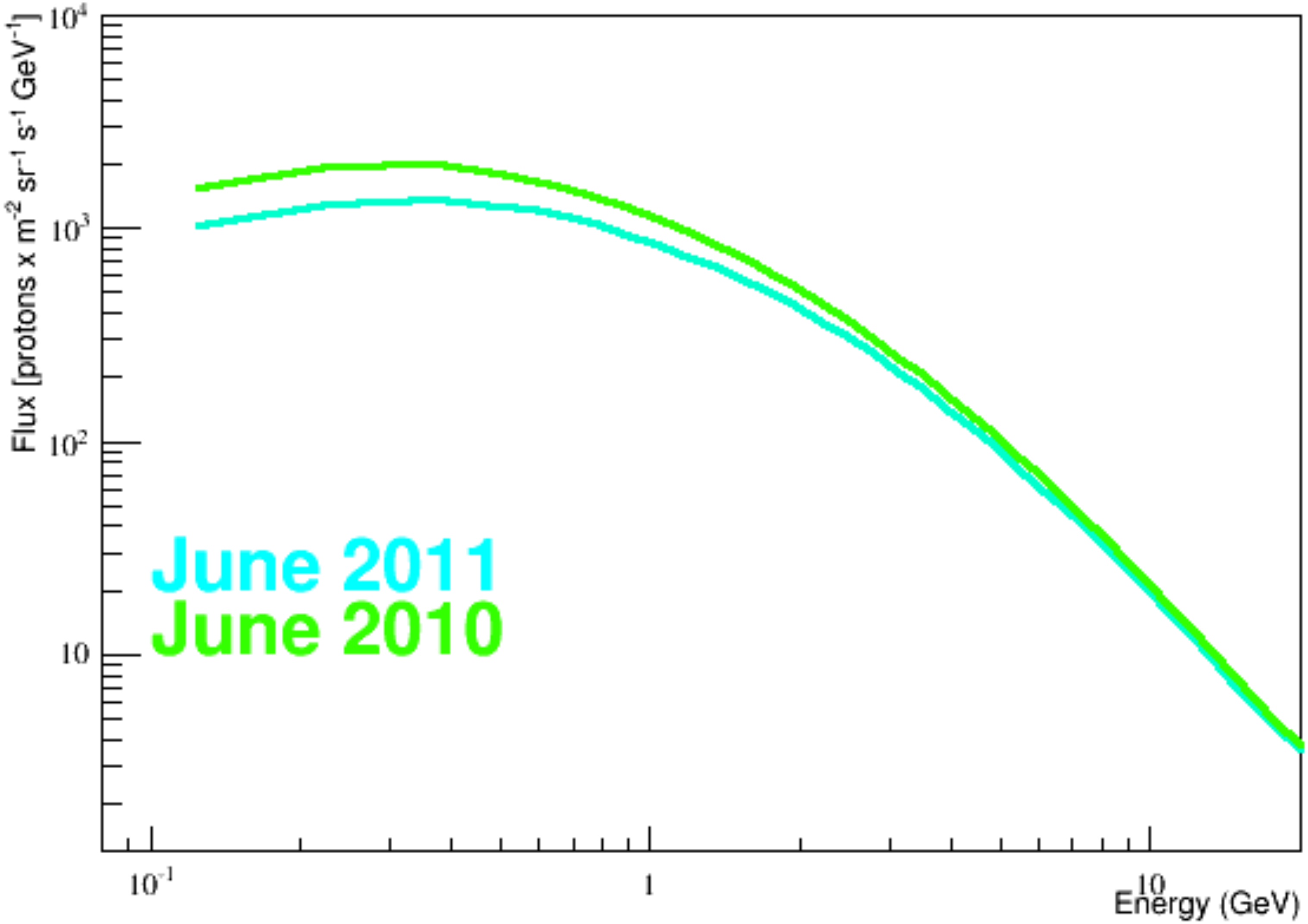


Flux [protons x m^{-2} sr^{-1} s^{-1} GeV^{-1}]
10^4
10^3
10^2
10
June 2008
June 2007
10^{-1}
1
10
Energy (GeV)

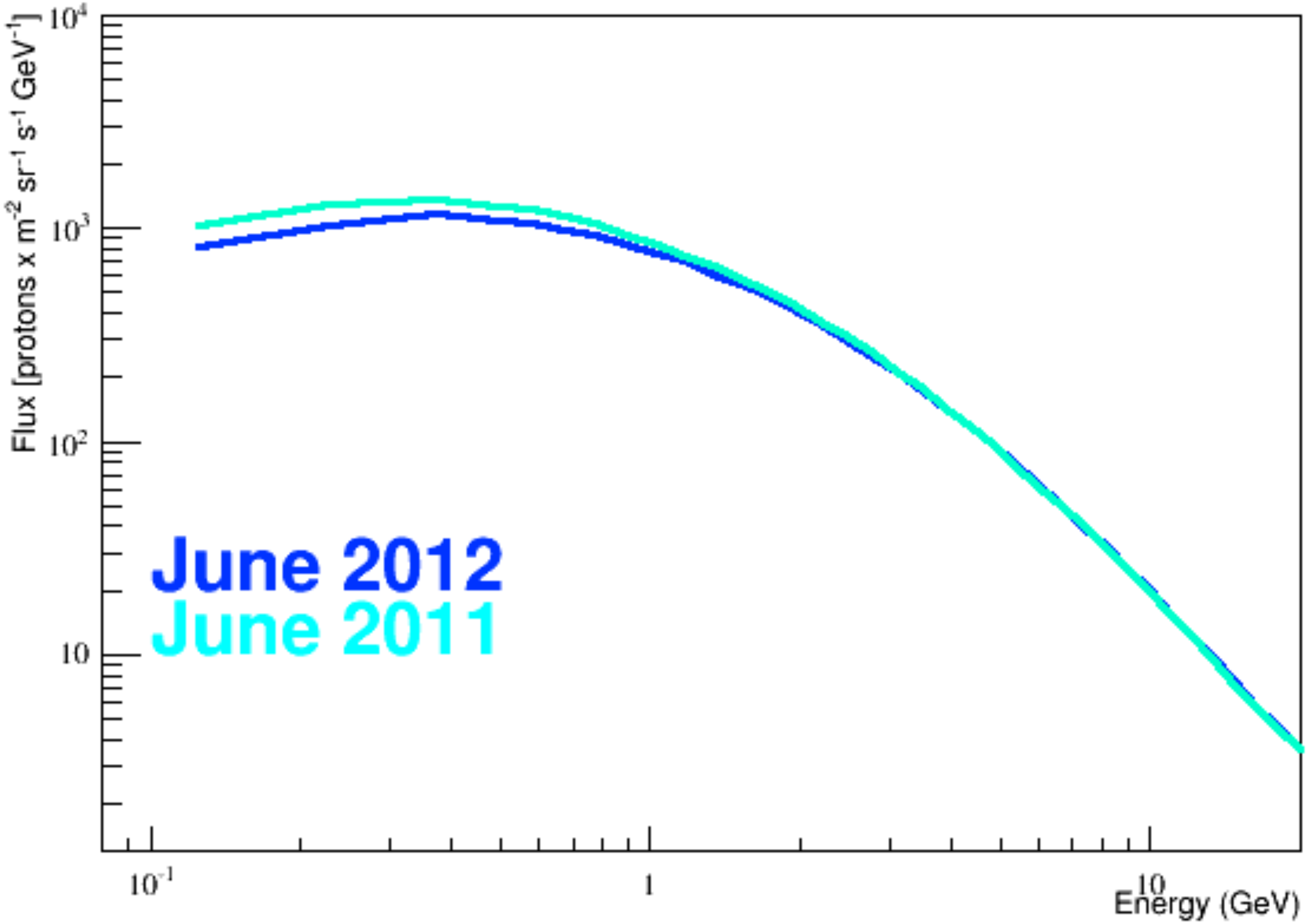

Flux [protons x m^{-2} sr^{-1} s^{-1} GeV^{-1}]
10^4
10^3
10^2
10
June 2009
June 2008
10^{-1}
1
10
Energy (GeV)



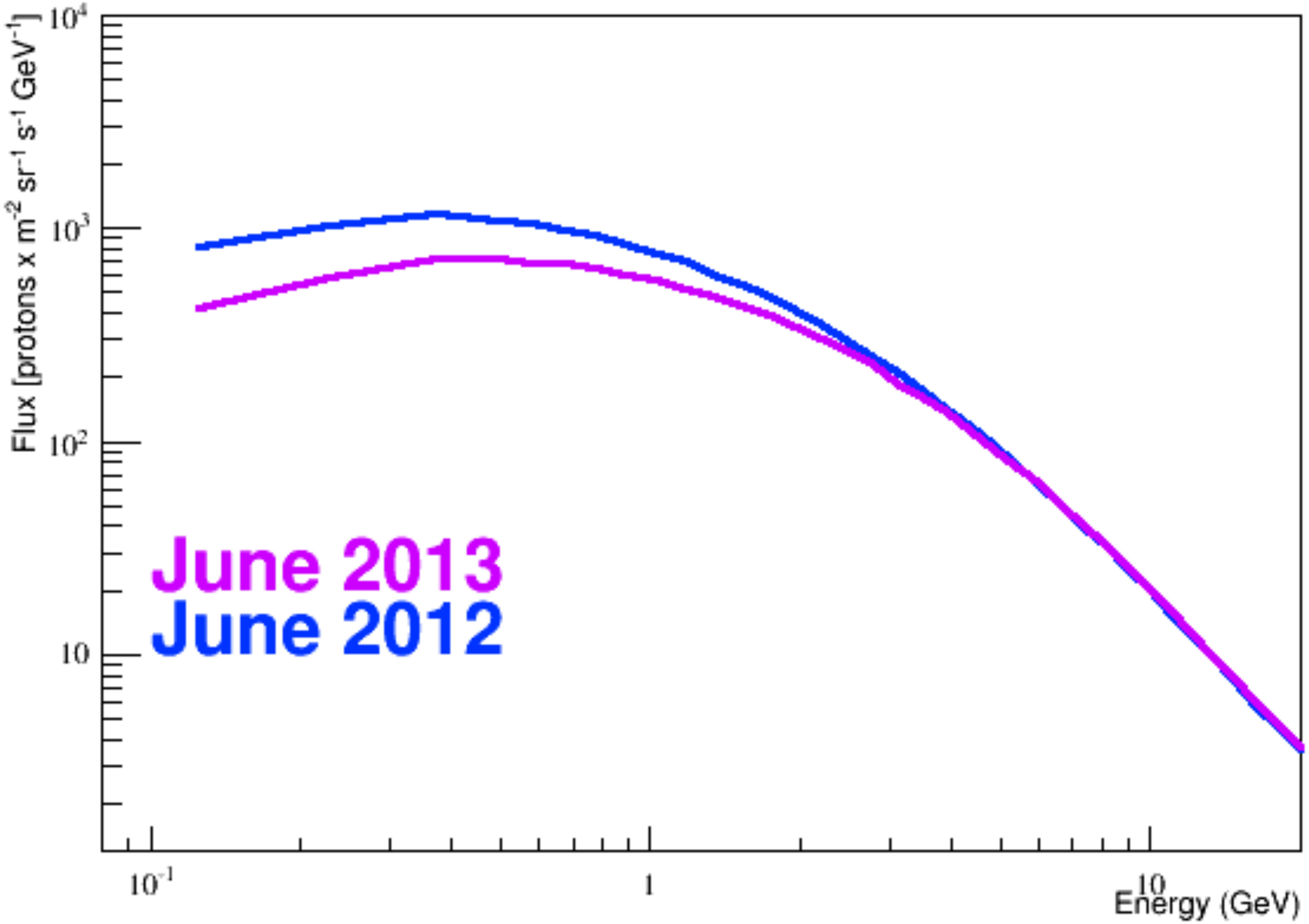
Flux [protons x m^-2 sr^-1 s^-1 GeV^-1]
10^4
10^3
10^2
10
June 2010
June 2009
10^-1
1
10
Energy (GeV)



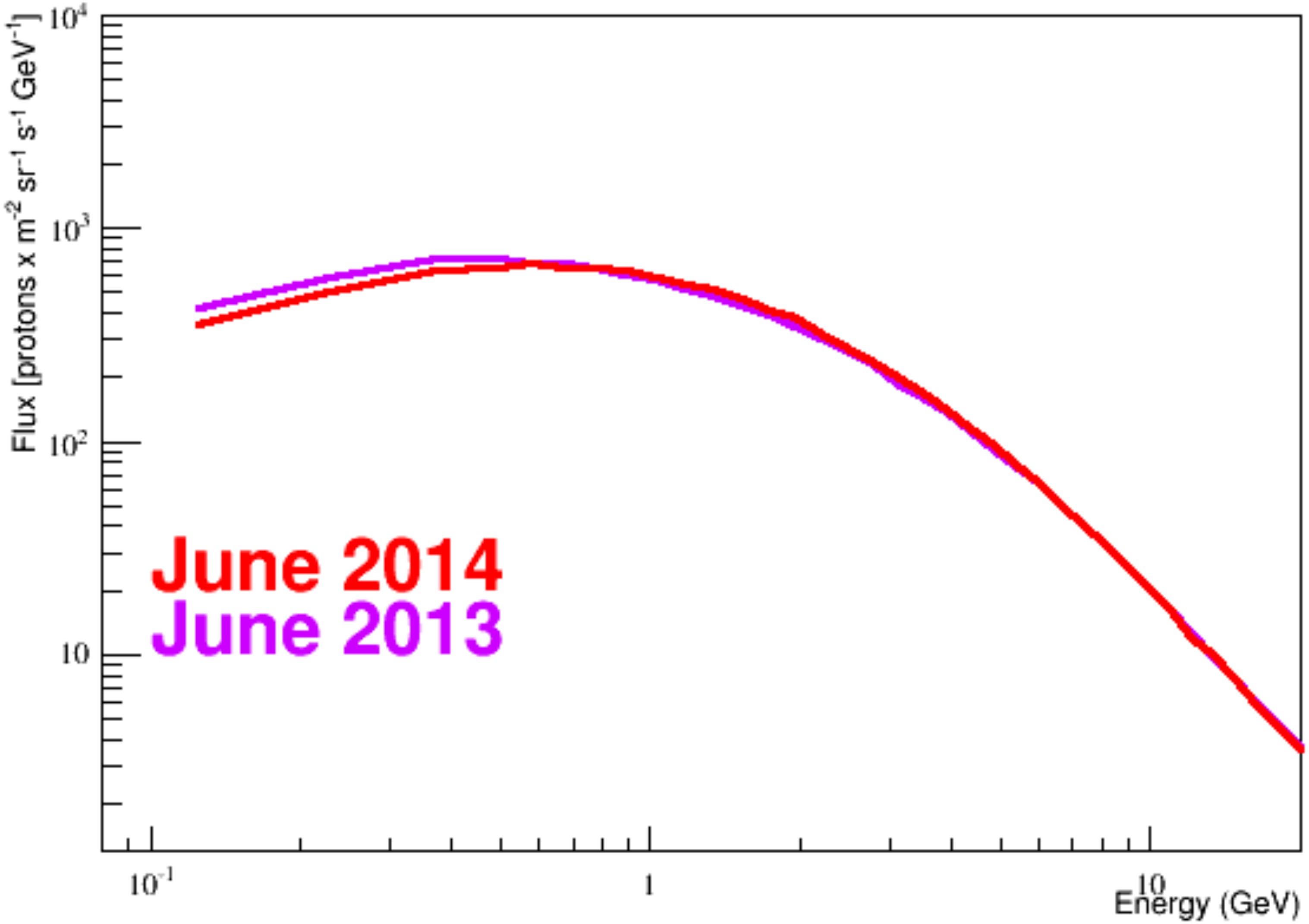
Flux [protons x m^{-2} sr^{-1} s^{-1} GeV^{-1}]
10^4
10^3
10^2
10
10^{-1}
1
10
Energy (GeV)
June 2011
June 2010



Flux [protons x m^{-2} sr^{-1} s^{-1} GeV^{-1}]
10^4
10^3
10^2
10
10^{-1}
1
10
Energy (GeV)
June 2012
June 2011



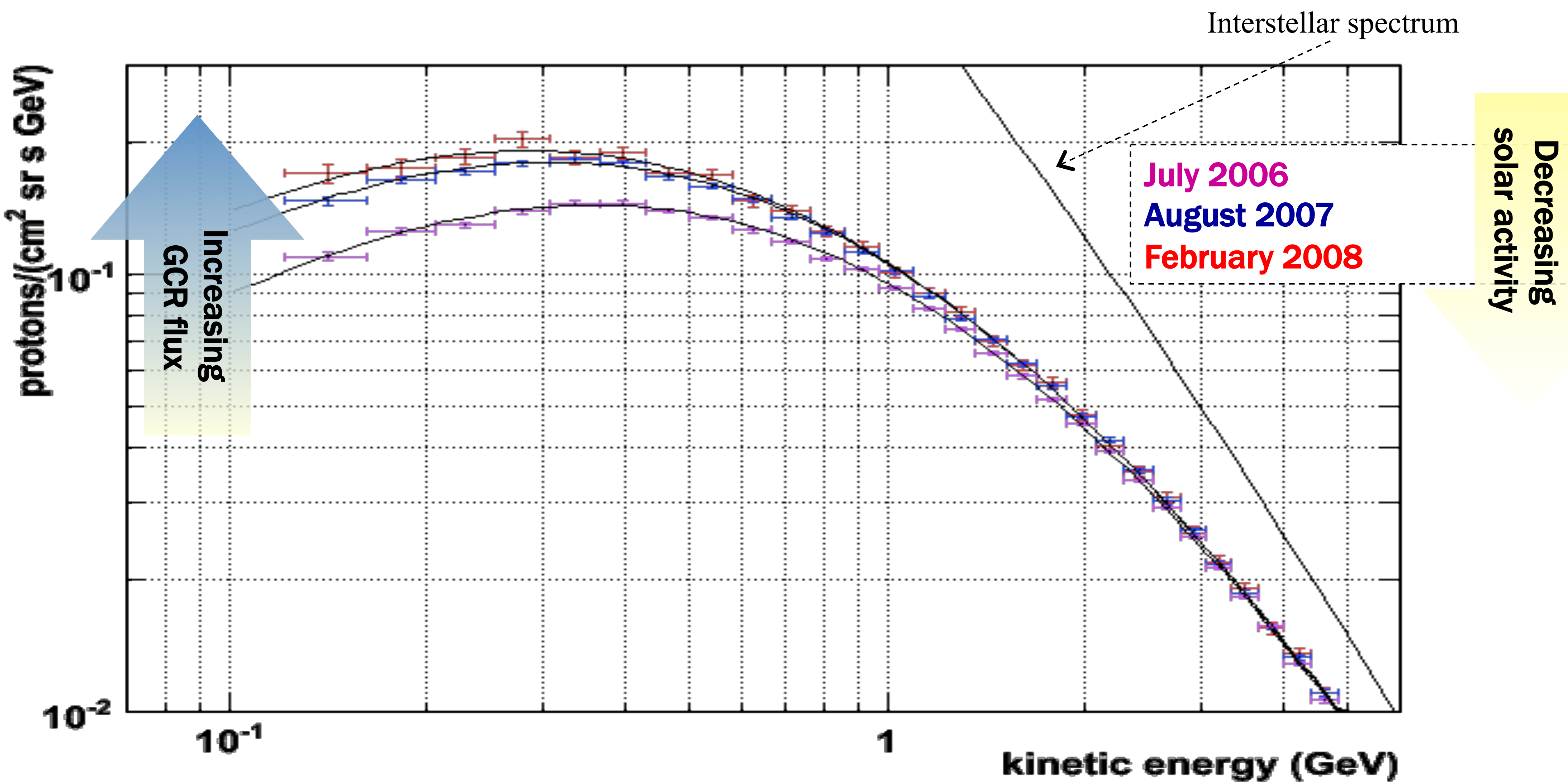
Flux [protons x m^{-2} sr^{-1} s^{-1} GeV^{-1}]
10^4
10^3
10^2
10
June 2013
June 2012
10^{-1}
1
10
Energy (GeV)



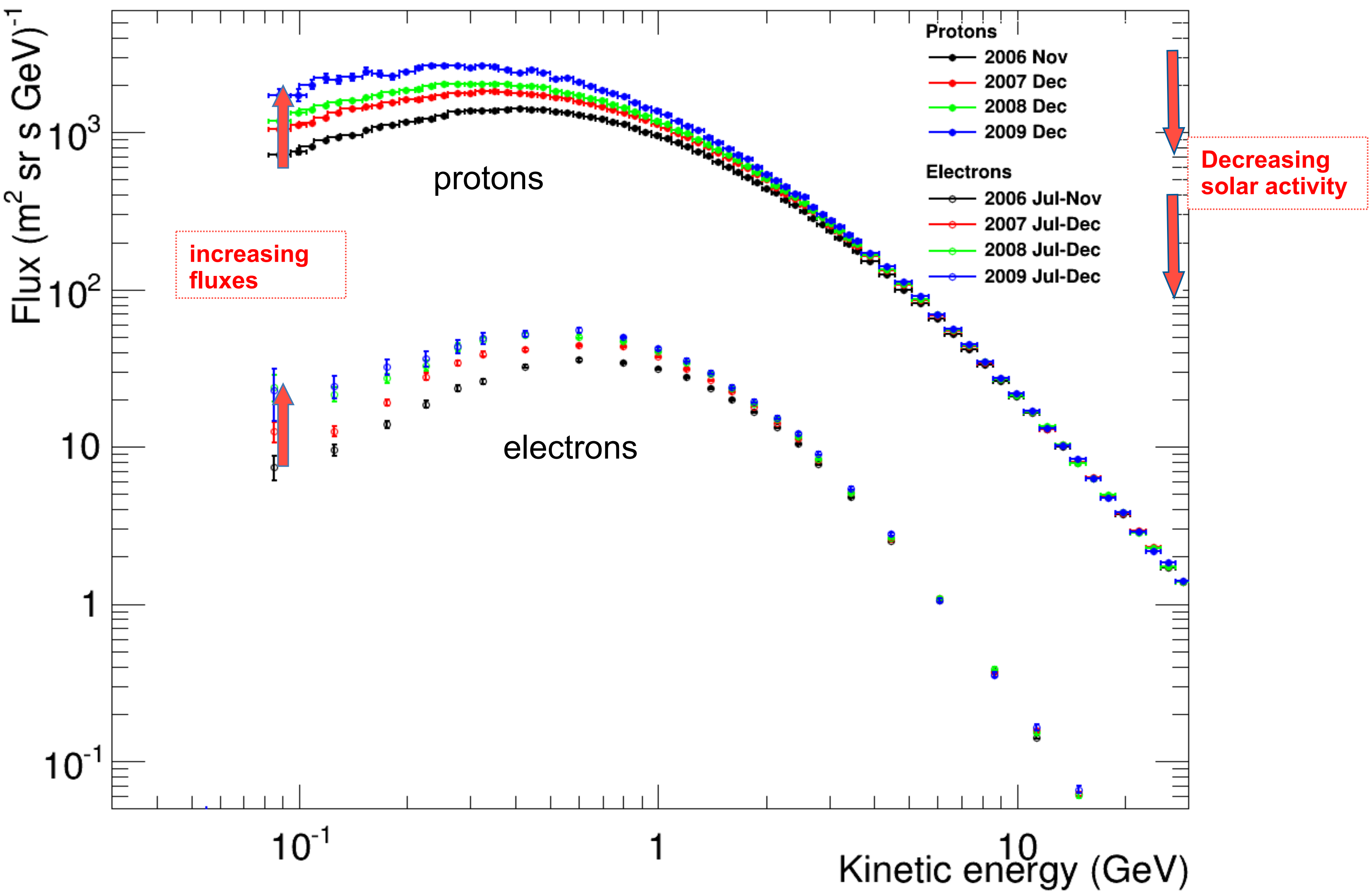
Flux [protons x m^{-2} sr^{-1} s^{-1} GeV^{-1}]
10^4
10^3
10^2
10
10^{-1}
1
10
Energy (GeV)
June 2014
June 2013

Solar modulation

(statistical errors only)

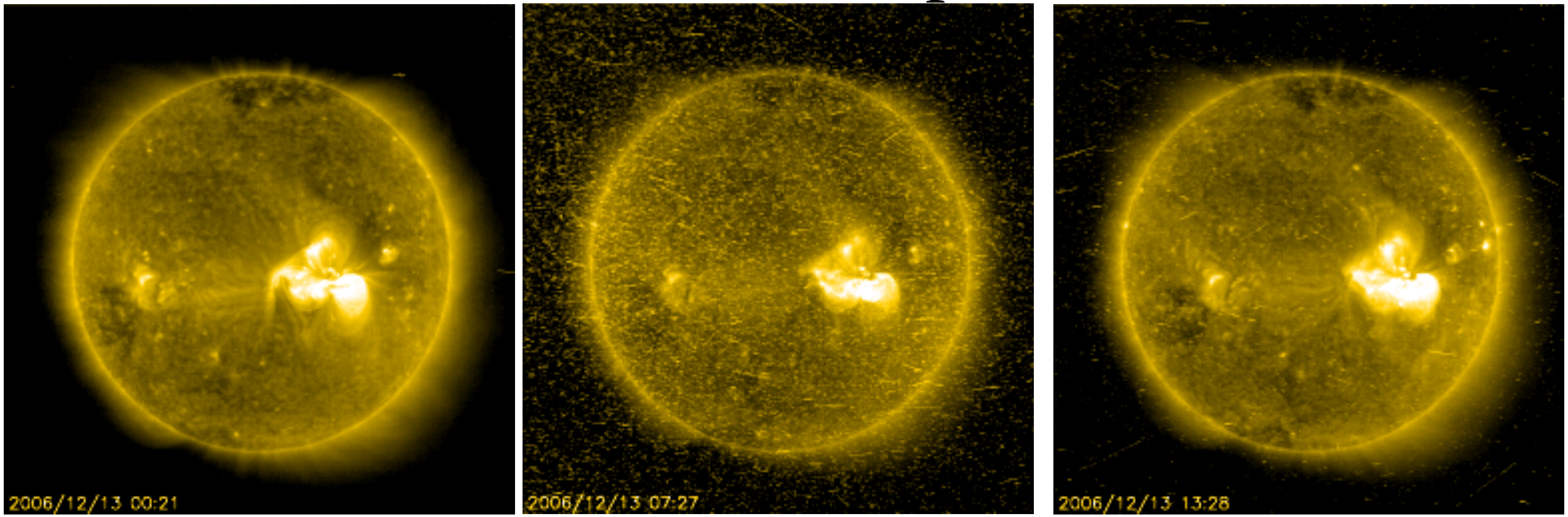


Solar modulation in the heliosphere

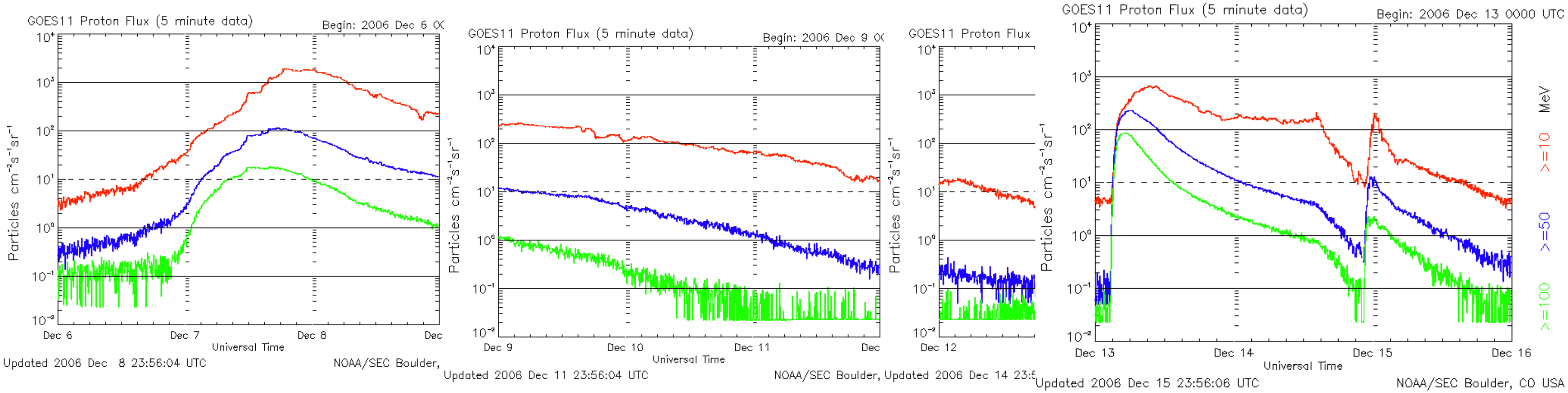


O. Adriani et al., ApJ 765 (2013), 91;
M. S. Potgieter et al., Sol. Phys. (2014), 289

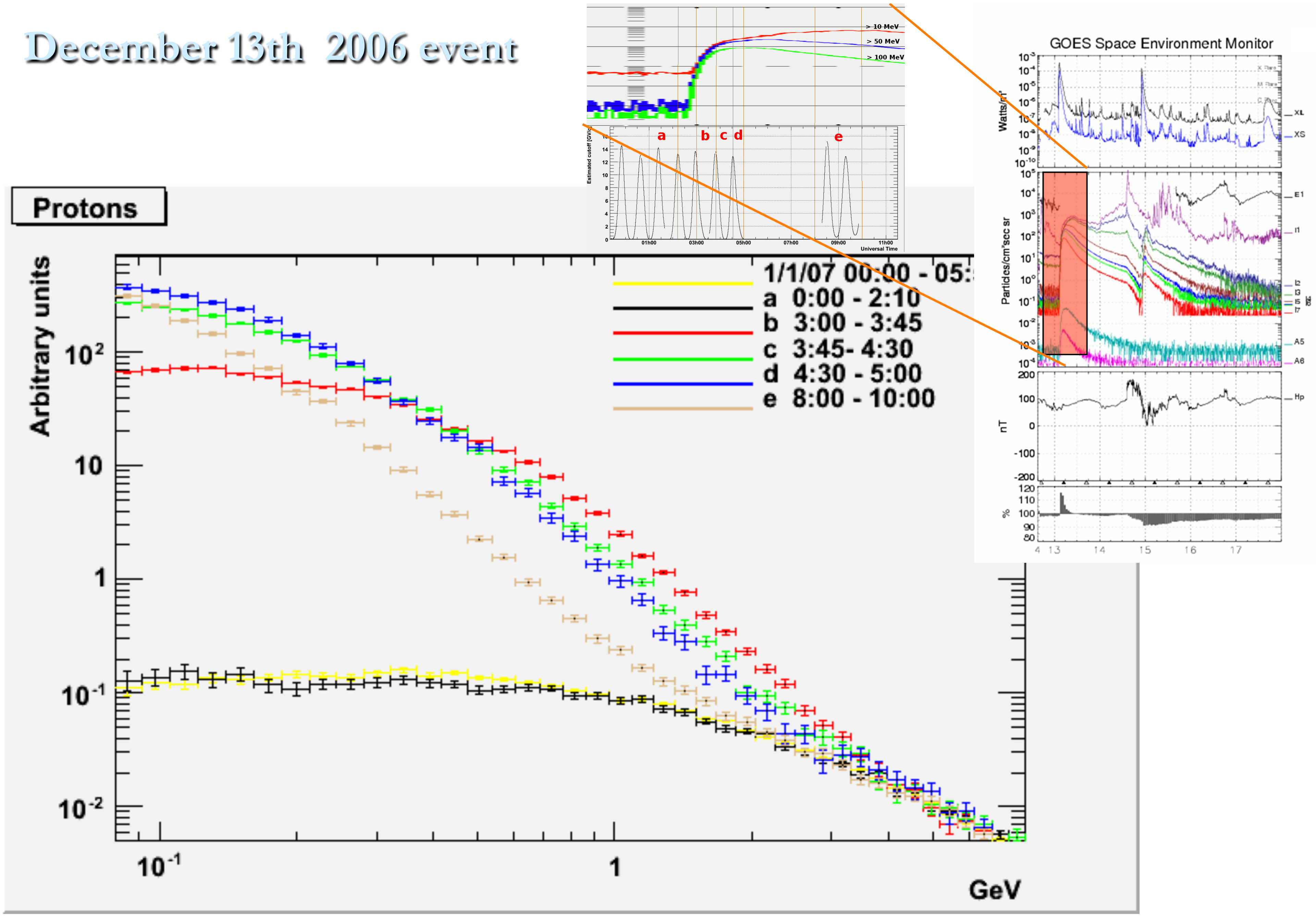
December 2006 Solar particle events



X3.4 solar flare.



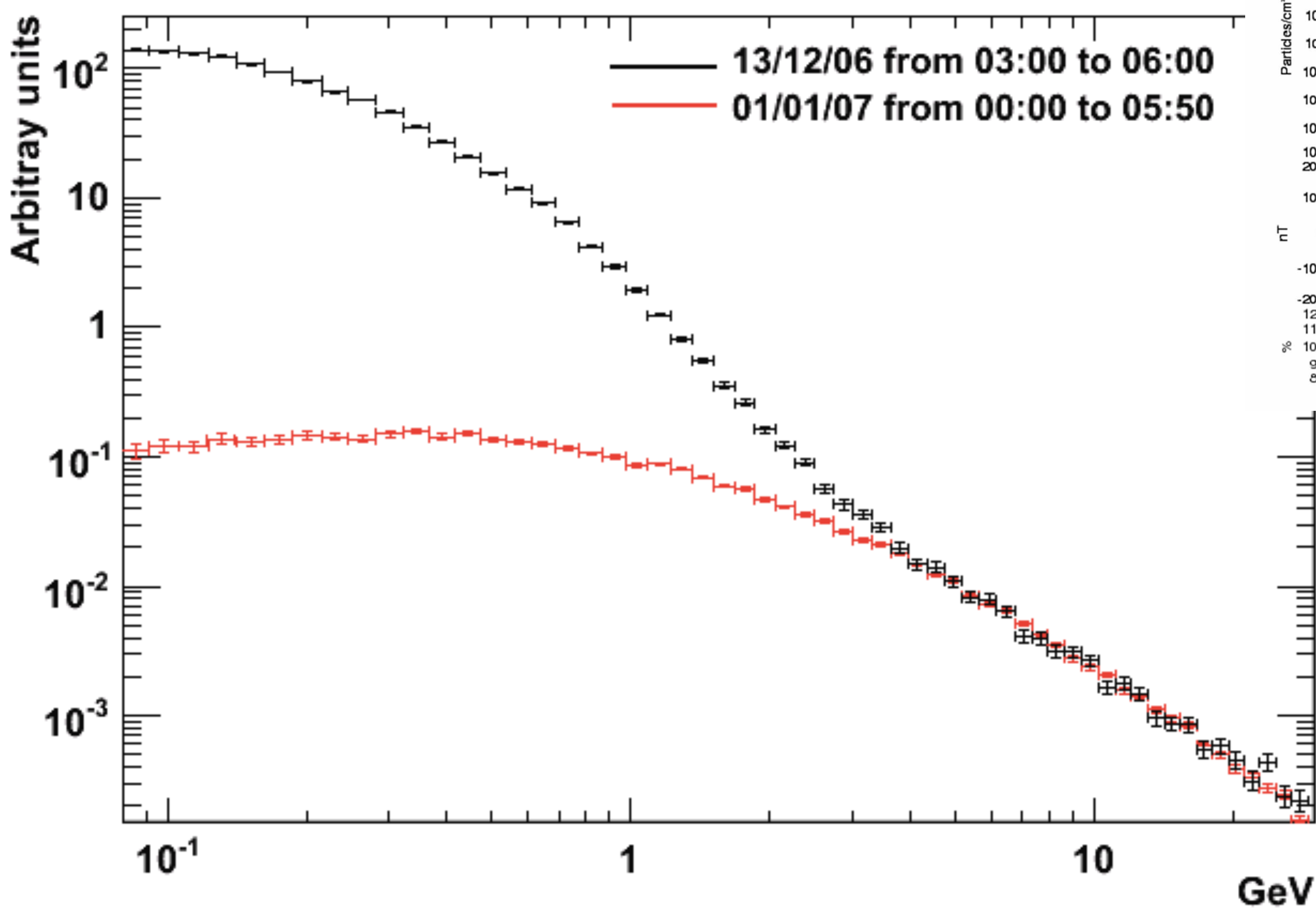
December 13th 2006 event

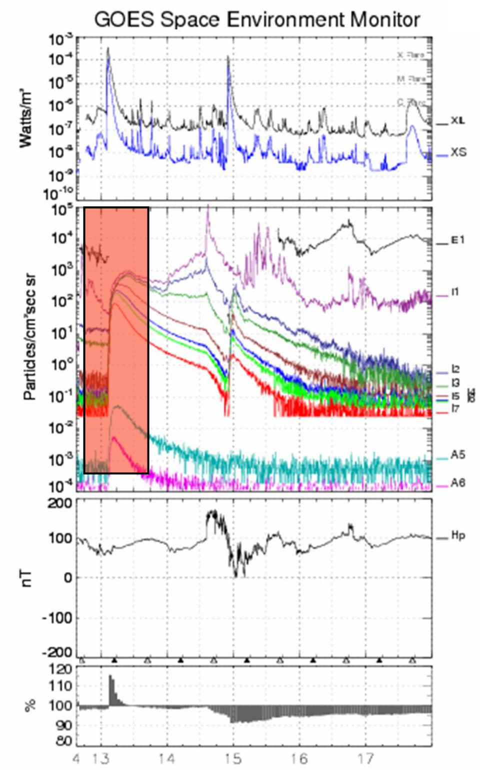


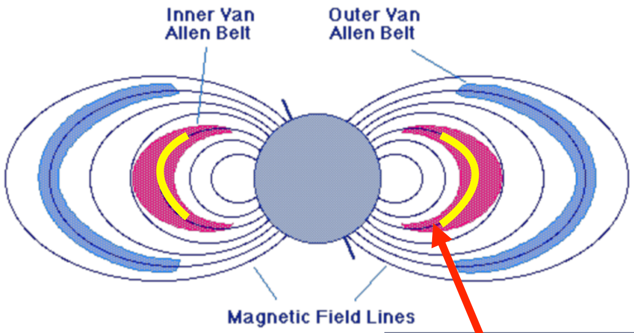
Preliminary!

December 13th 2006 He differential spectrum

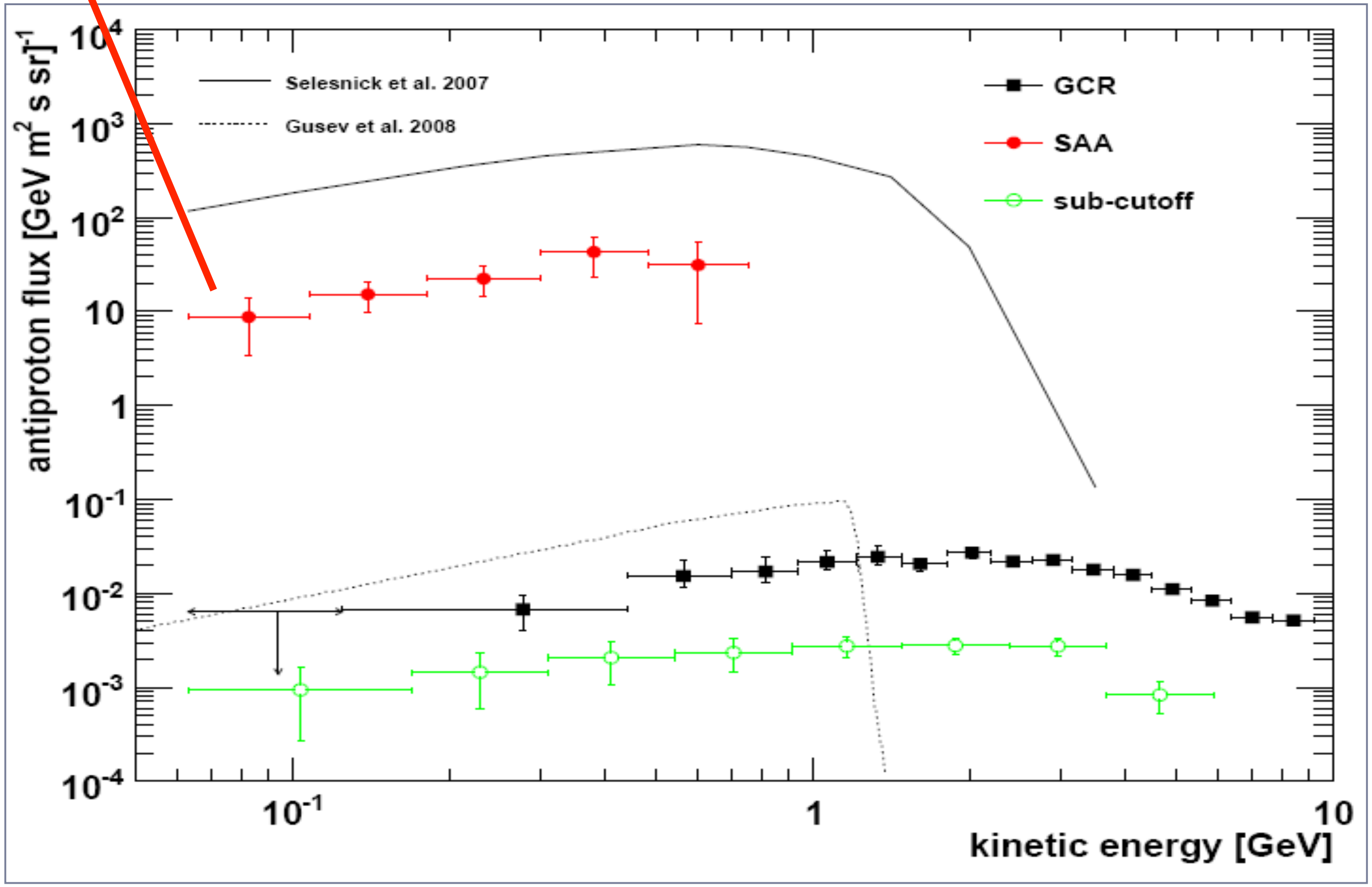
[redacted]







Anti-proton radiation belt



O. Adriani et al., ApJL 737 (2011), L29

Solar Physics

Solar CR propagation

Solar Energetic Particle events (SEPs)

ton detection threshold **80 MeV**

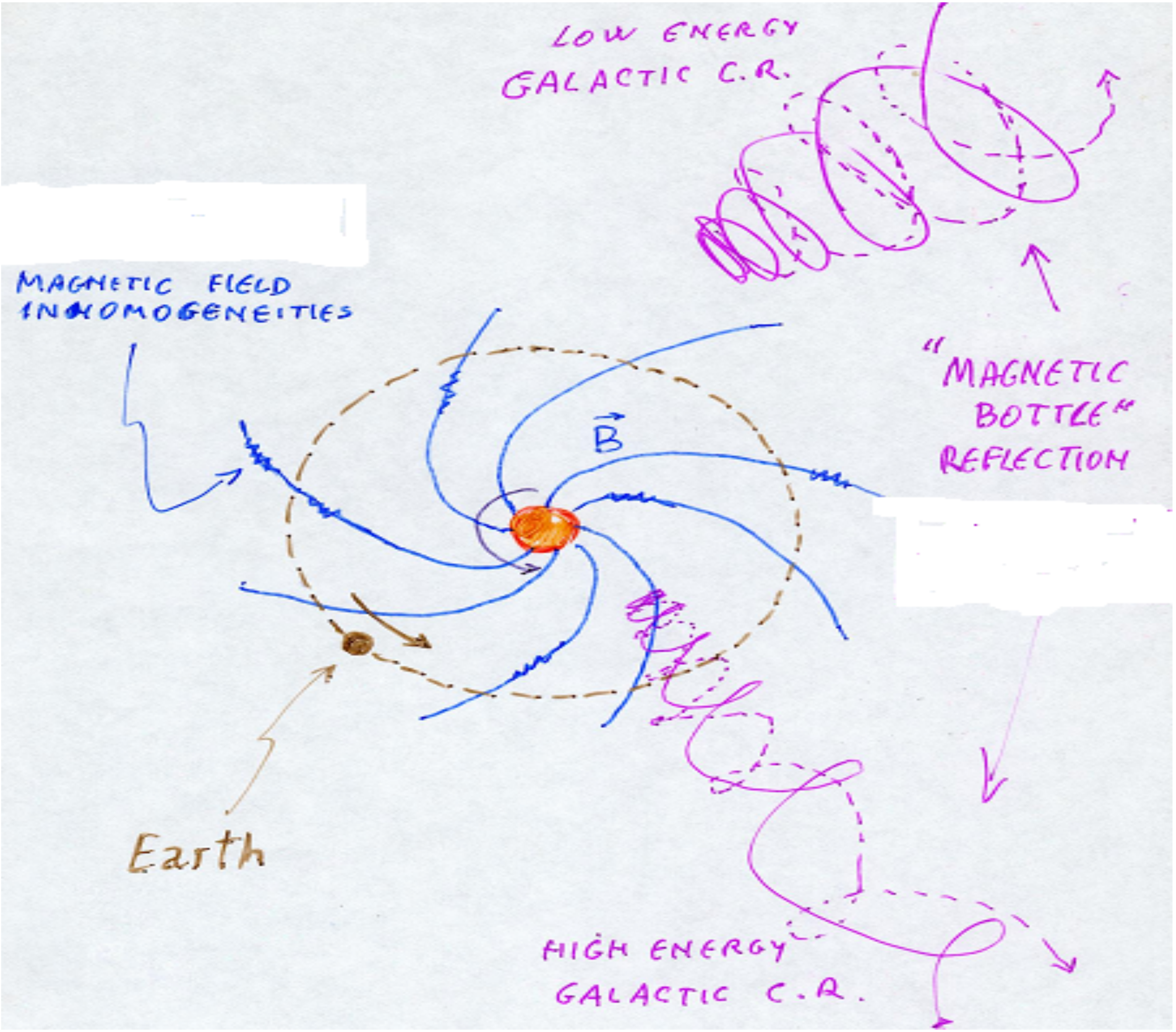
-Solar modulation effects
-High energy component of Solar Proton Events (from 80 Mev to 10 GeV)

tron detection threshold **50 MeV**

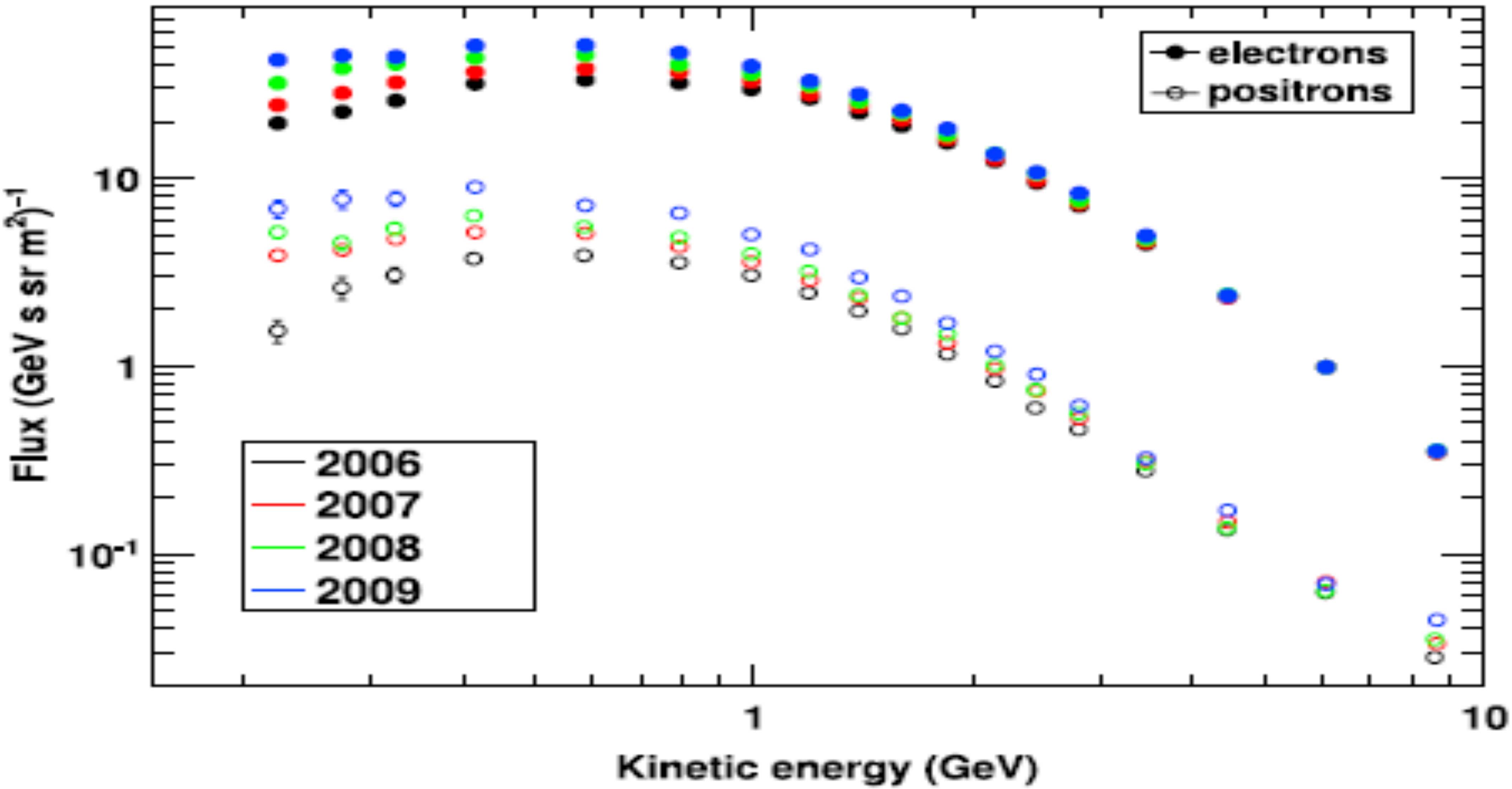
-High energy component of e- and e+ in Solar Events (from 50 MeV)

+ Nuclear composition of Gradual and Impulsive Events

+ He isotopic composition



LOW ENERGY
GALACTIC C.R.
MAGNETIC FIELD
INHOMOGENEITIES
"MAGNETIC
BOTTLE"
REFLECTION
$\vec{B}$
Earth
HIGH ENERGY
GALACTIC C.R.



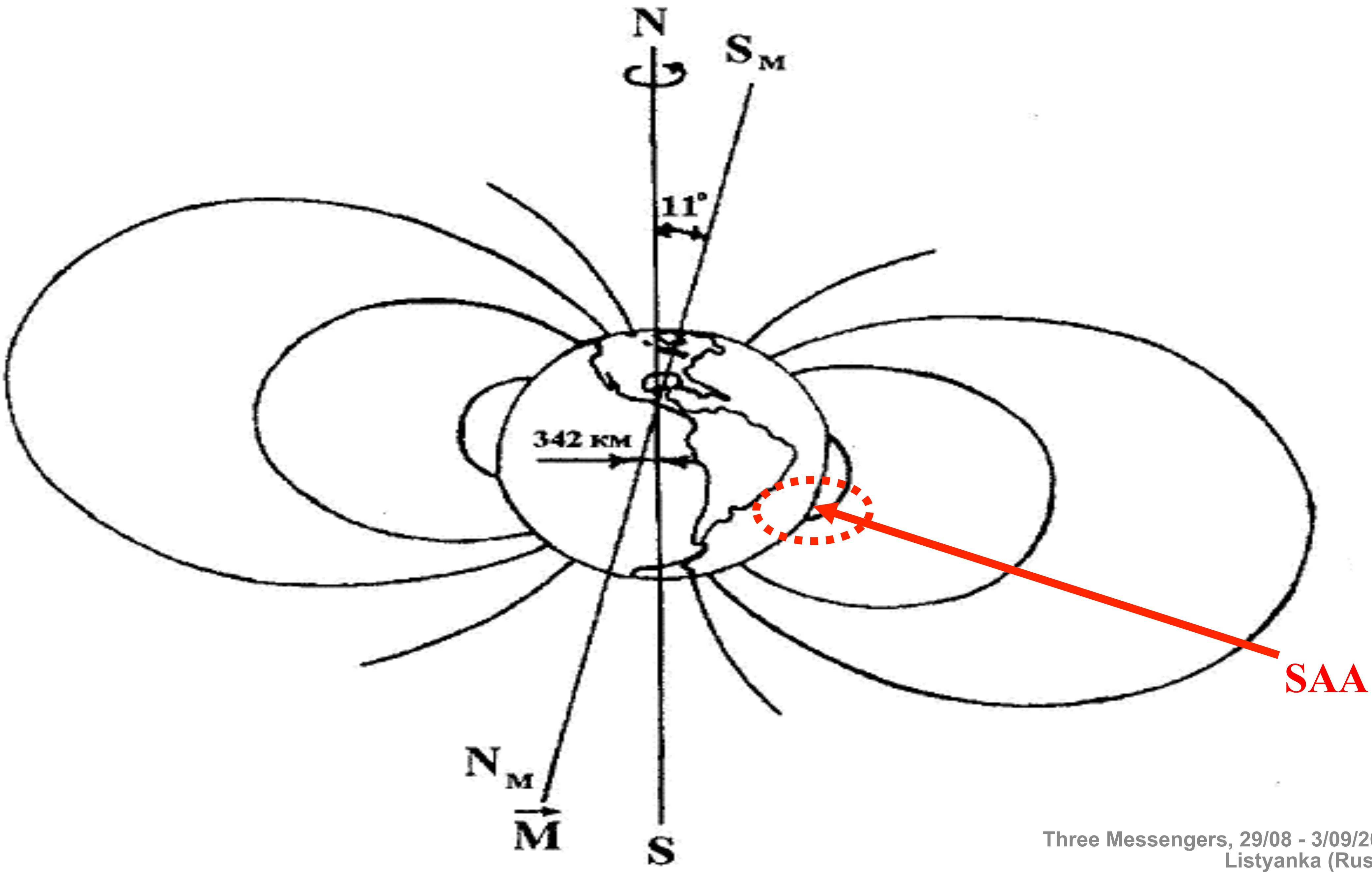
Flux (GeV s sr m^2)$^{-1}$
10
1
10^{-1}
1
10
Kinetic energy (GeV)
electrons
positrons
2006
2007
2008
2009

Terrestrial physics

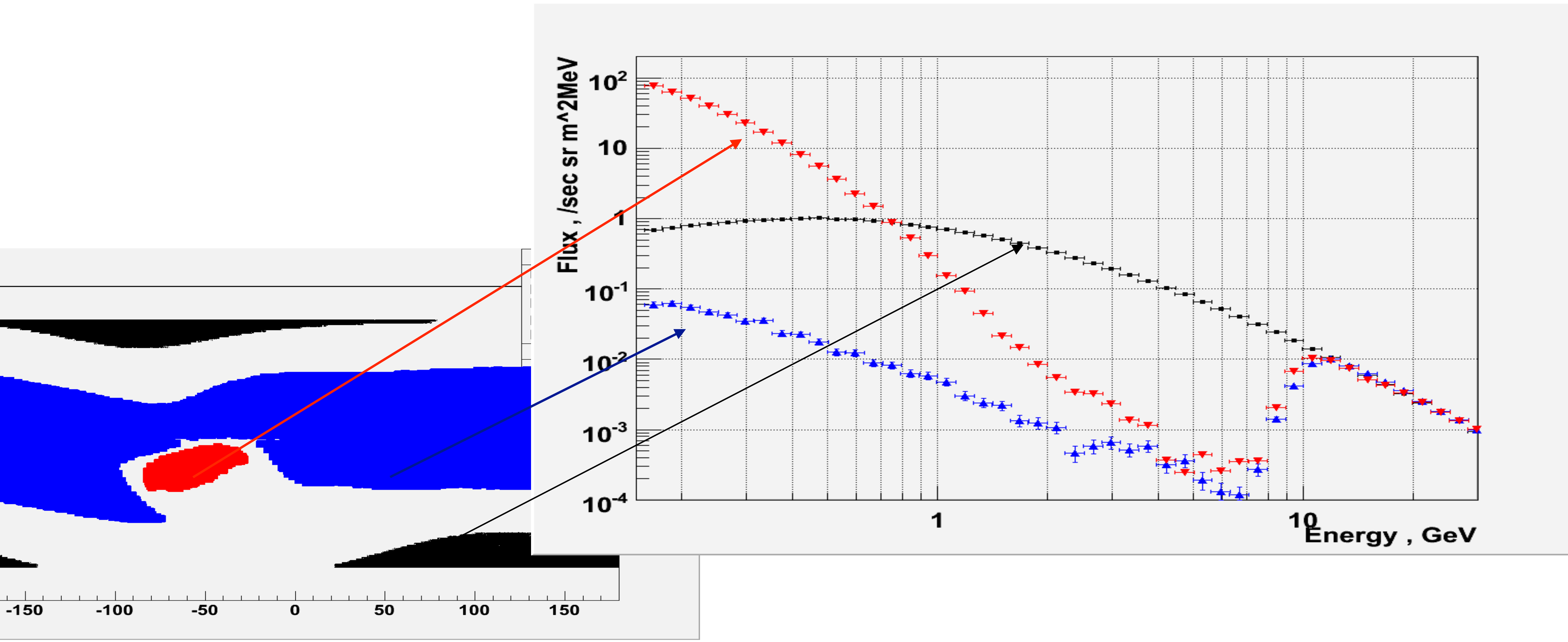
Magnetosphere

Radiation belts & SAA

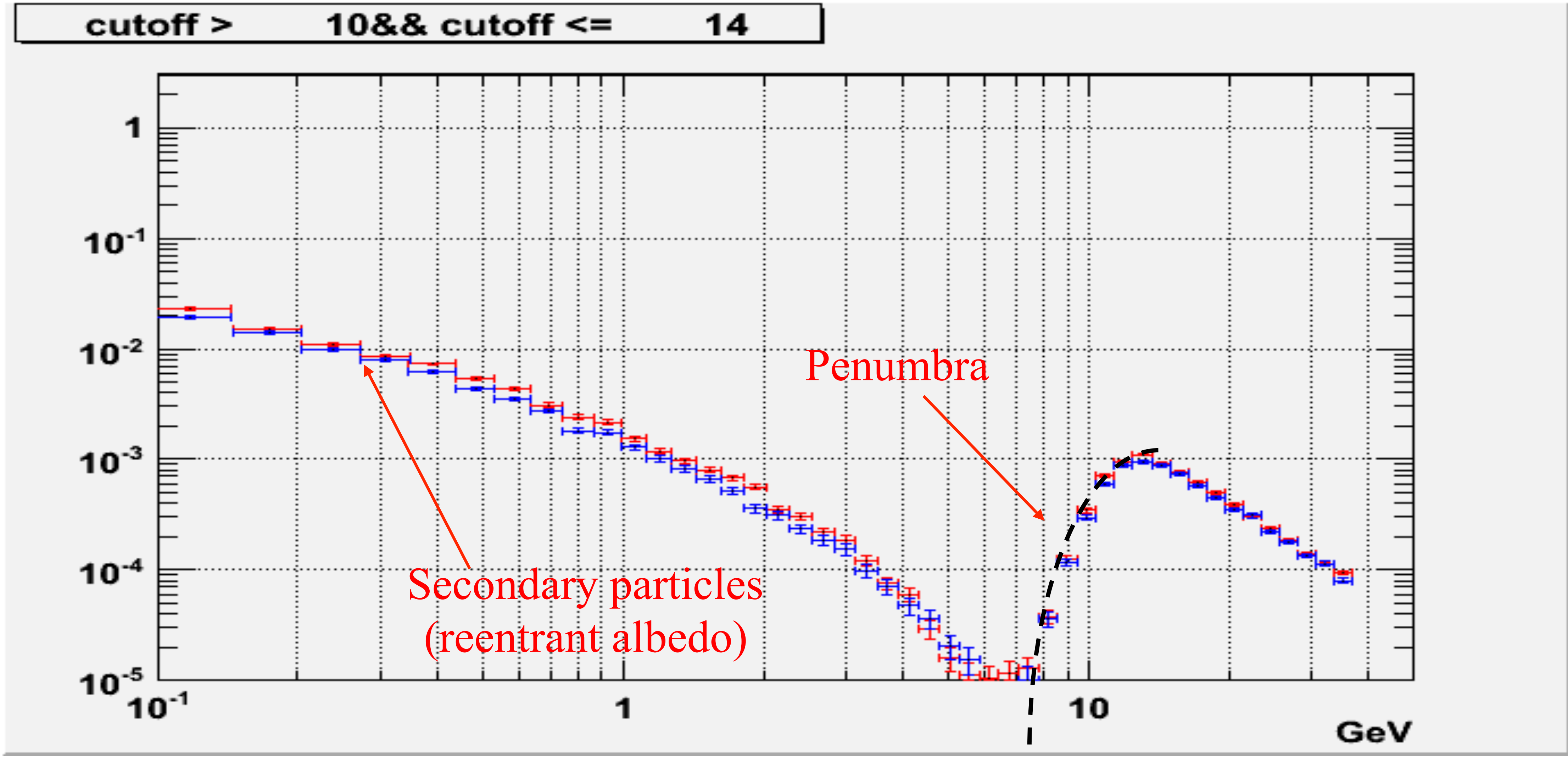
Interactions of CRs with the atmosphere


N
S_M
11°
342 км
SAA
N_M
M
S

Proton spectrum in SAA, polar and equatorial regions



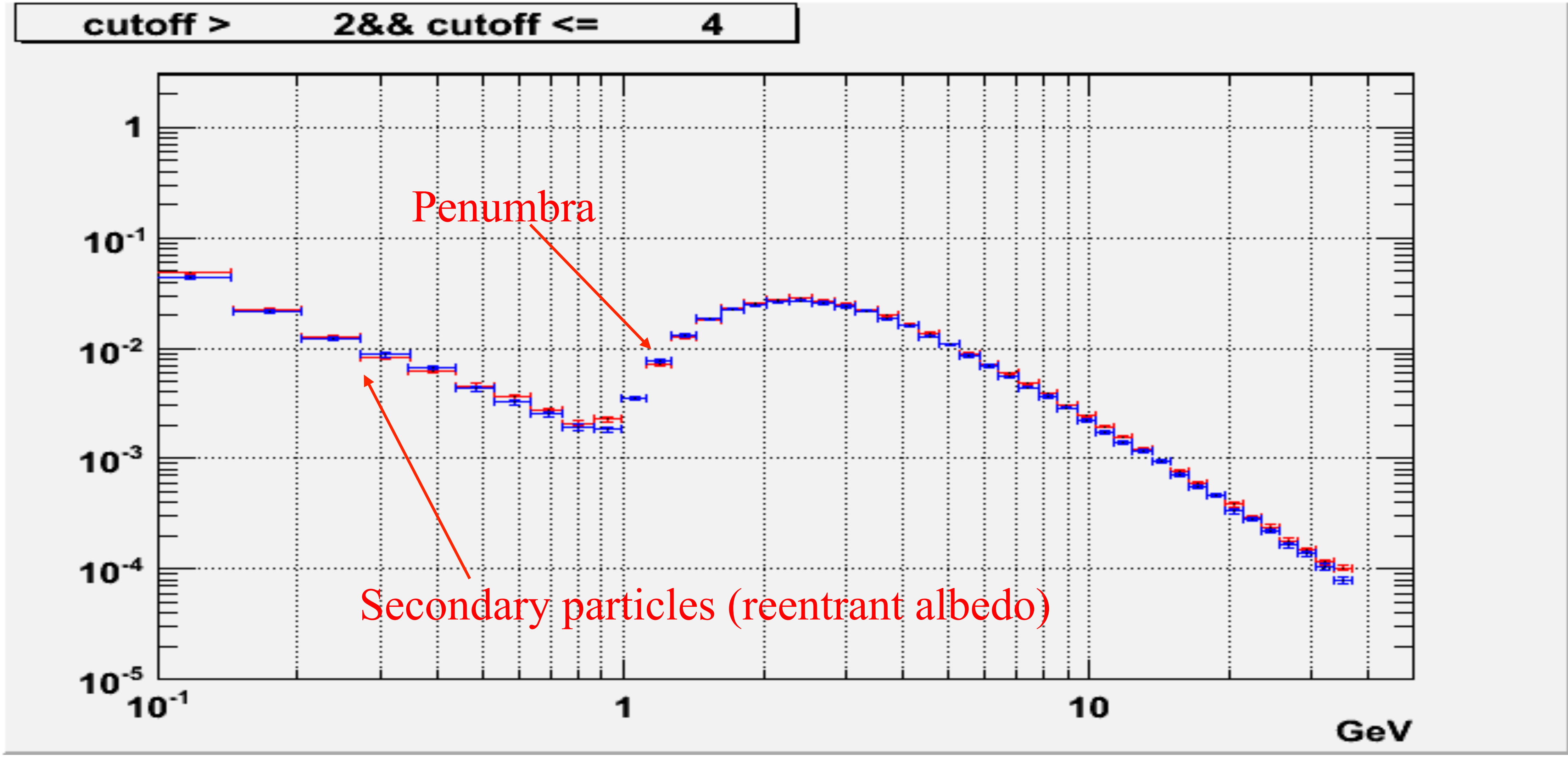
Primary and secondary spectra: magnetic Equator



RED: JULY 2006

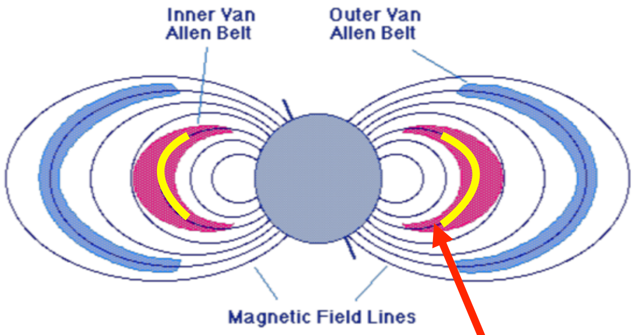
BLUE: AUGUST 2007

Primary and secondary spectra: Intermediate latitudes



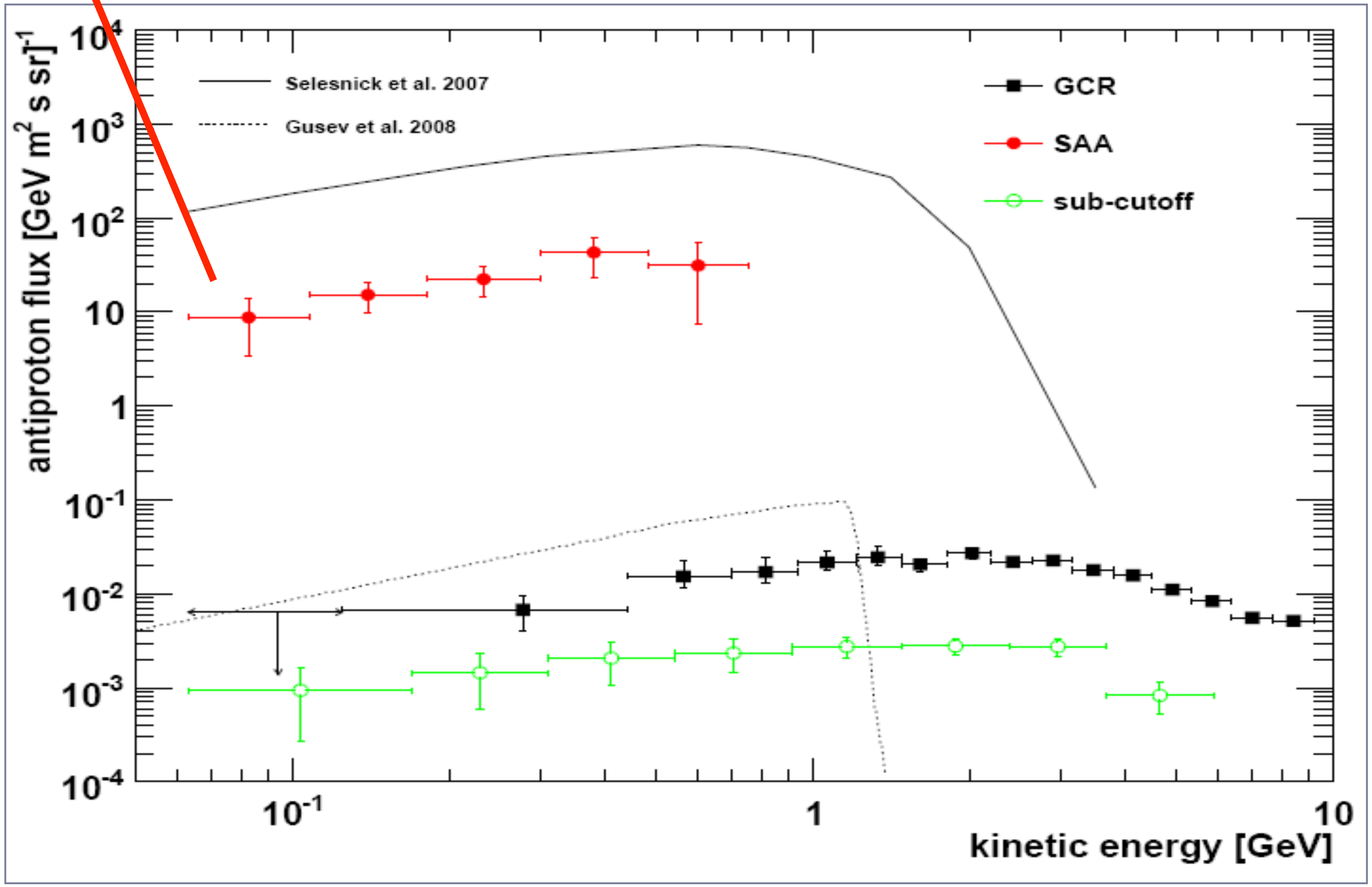
RED: JULY 2006

BLUE: AUGUST 2007

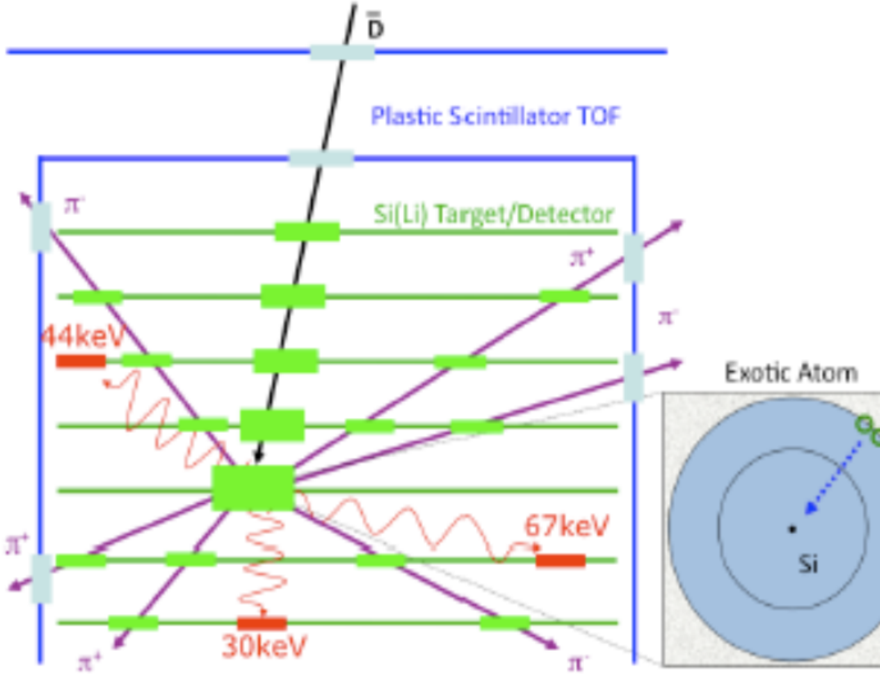


Anti-proton radiation belt

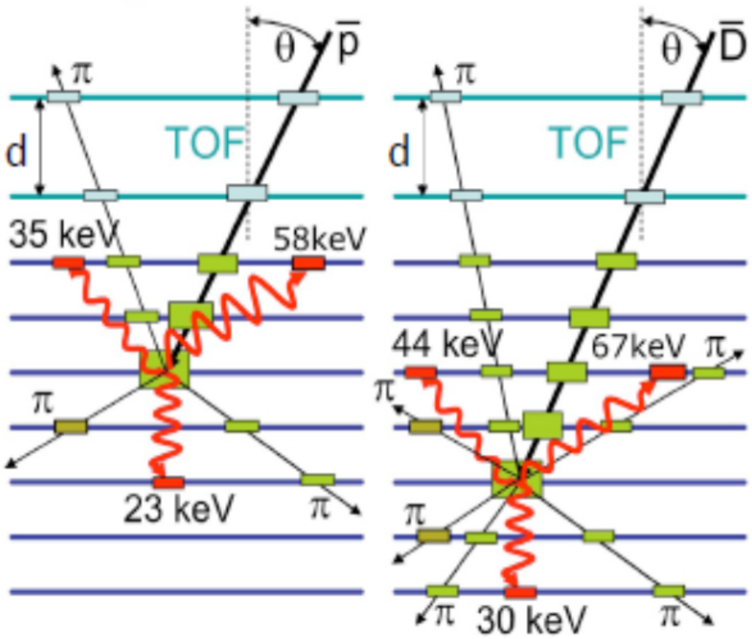
driani et al., ApJL 737 (2011), L29



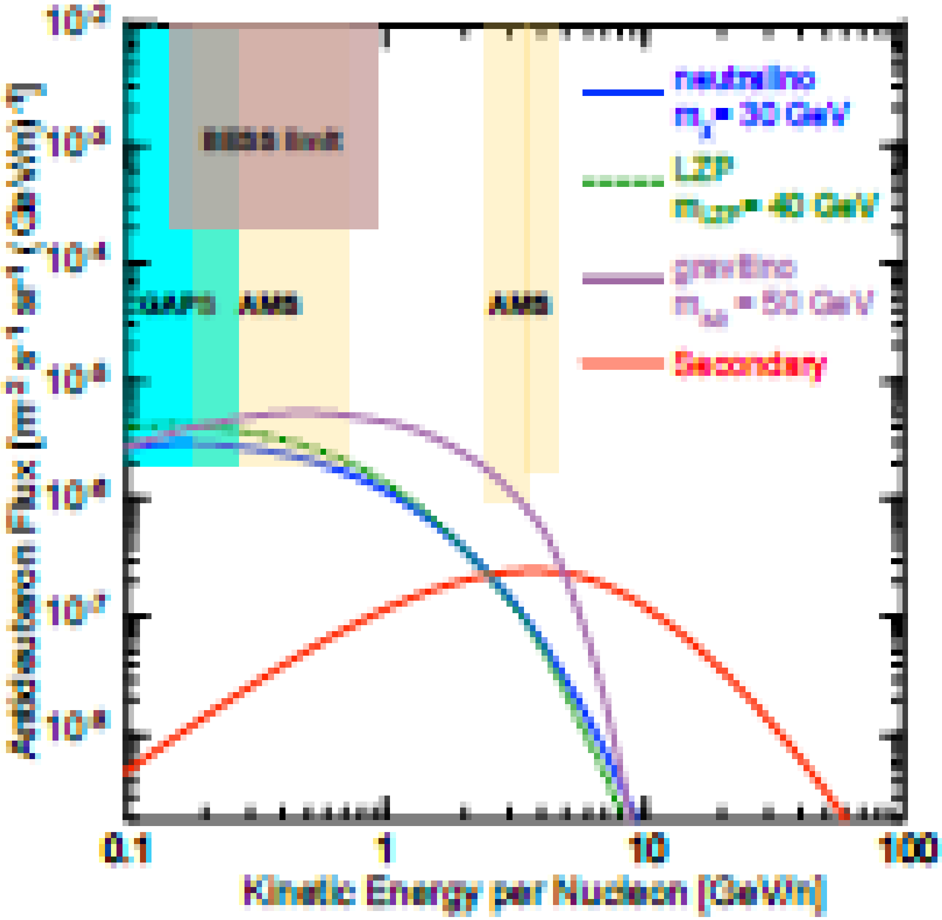
General Antiparticle Spectrometer GAPS



GAPS

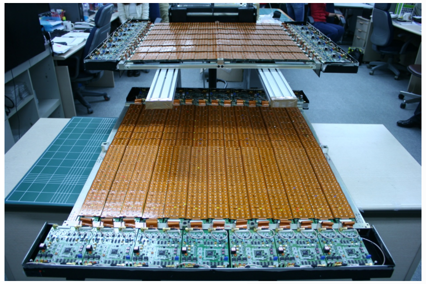


θ
p̄
π
d
TOF
35 keV
58keV
π
23 keV
π
θ
D̄
π
d
TOF
44 keV
67keV
π
π
π
π
30 keV
π



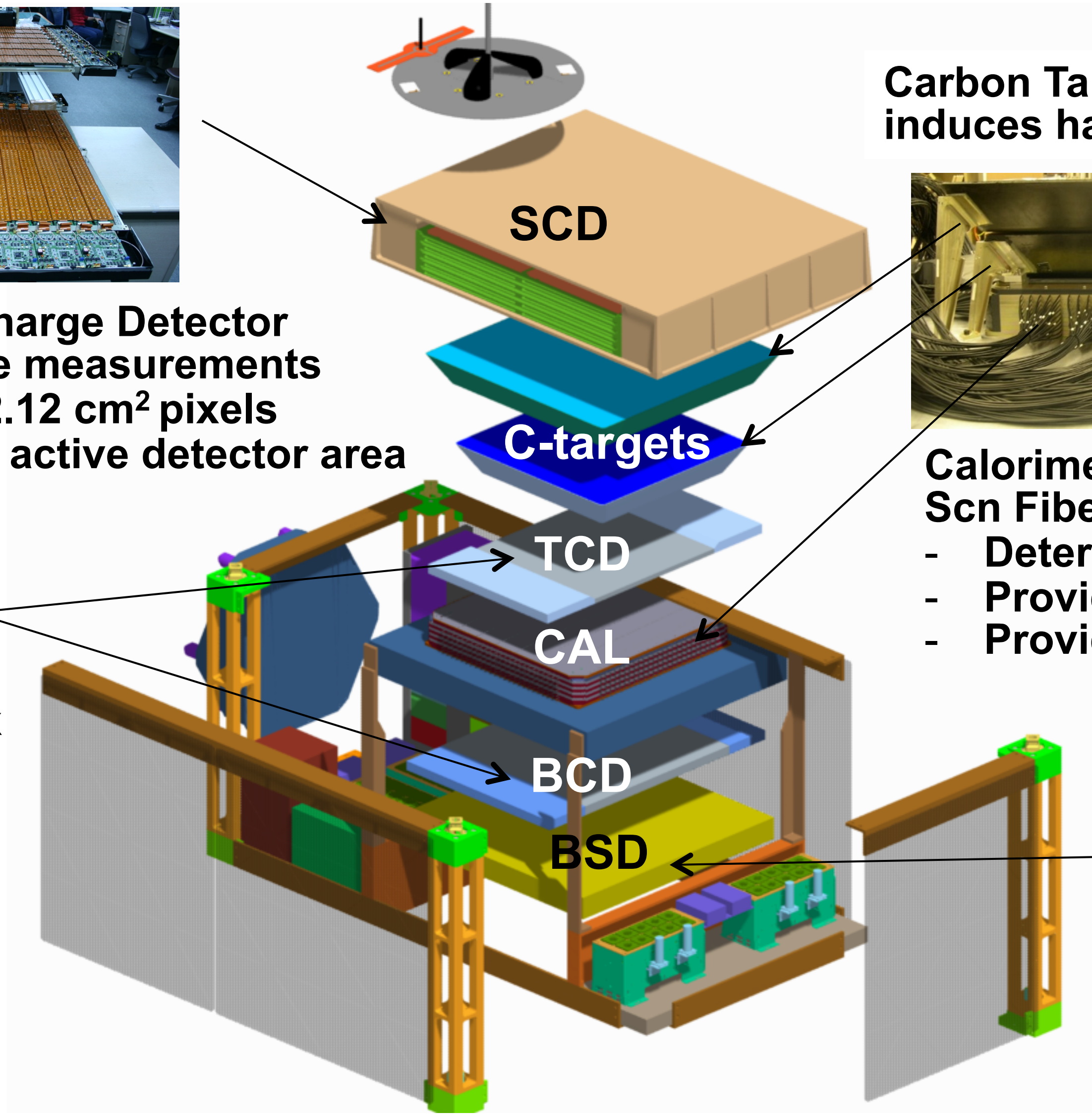
Antideuteron Flux [m⁻² s⁻¹ sr⁻¹ (GeV/n)⁻¹]
Kinetic Energy per Nucleon [GeV/n]
0.1
1
10
100
BESS limit
GAPS
AMS
AMS
neutralino
LZP
gravitino
Secondary

ISS-CREAM Instrument



4 layer Silicon Charge Detector
- Precise charge measurements
- 380-μm thick 2.12 cm^2 pixels
- 79 cm x 79 cm active detector area

Top & Bottom Counting Detectors
- Each with 20 x 20 photodiodes and a plastic scitillator for e/p separation
- Independent Trigger



Carbon Targets (0.5 λ_{int}) induces hadronic interactions

Calorimeter (20 layers W + Scn Fibers)
- Determine Energy
- Provide tracking
- Provide Trigger

Boronated Scintillator Detector
- Additional e/p separation
- Neutron signals

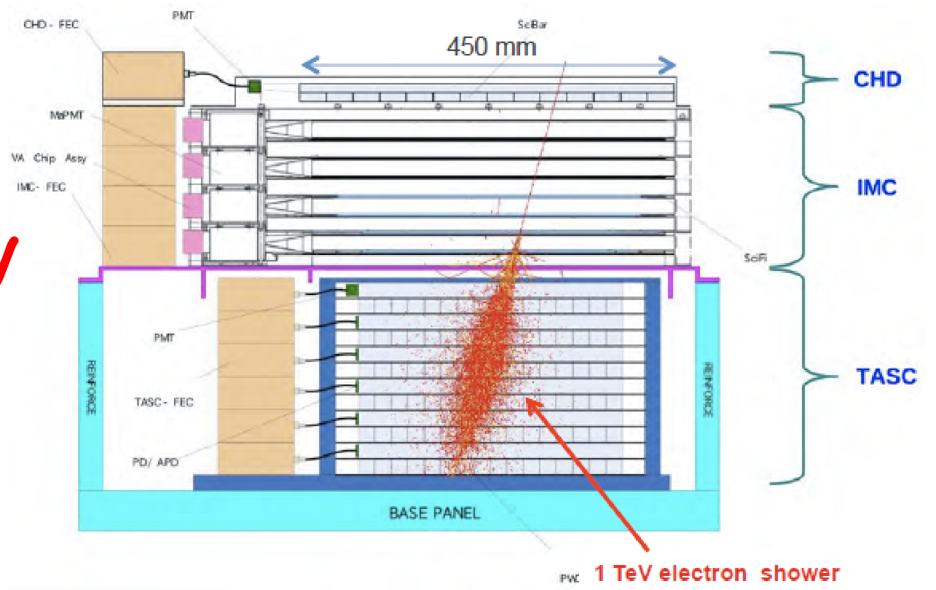
Launch 2017

CALET

CALorimetric Electron Telescope

Main Telescope: CAL (Calorimeter)

eV – 10TeV

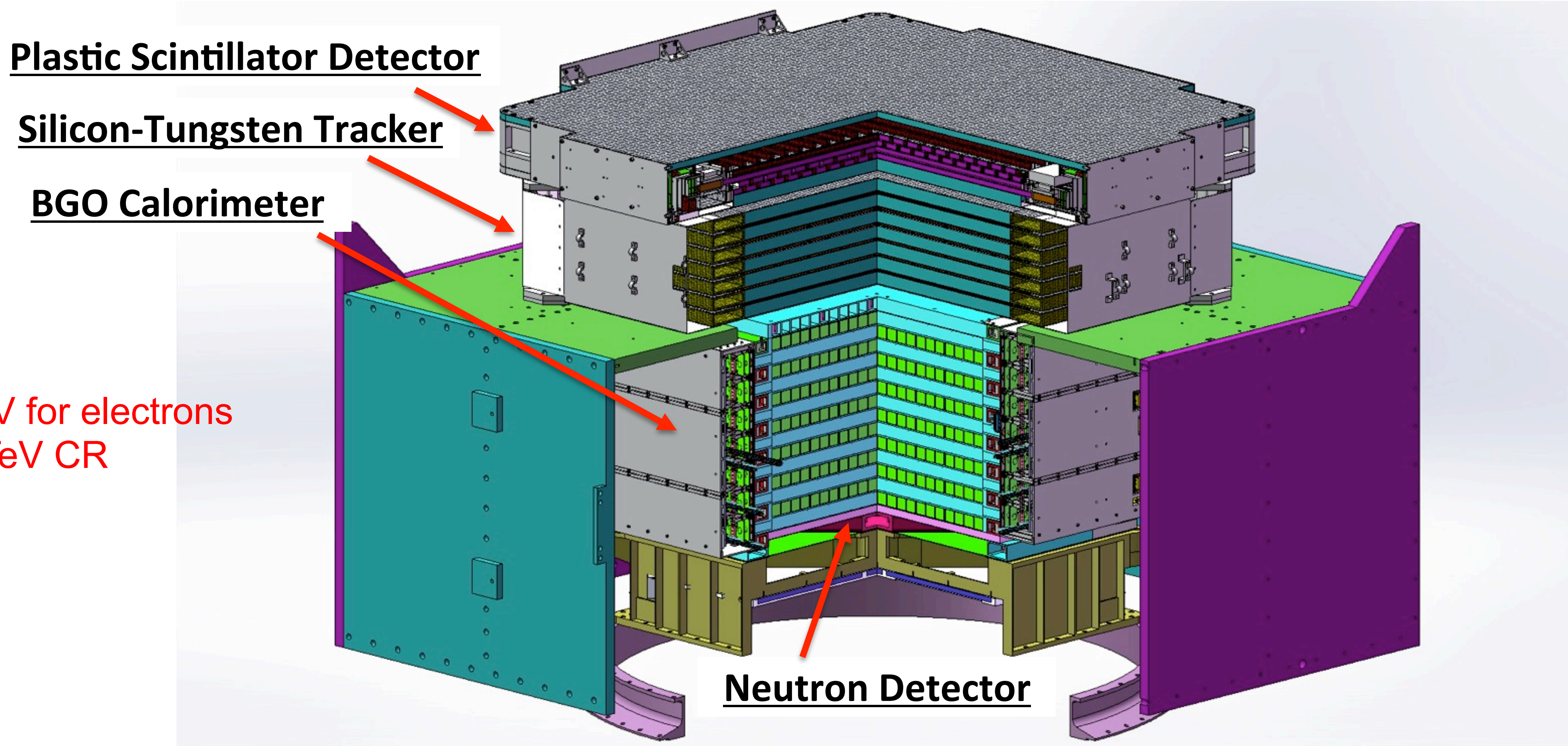


Expected Performance
(from Simulations and/or Beam Tests)

- SΩ :
  1200 cm^2sr for electrons, light nuclei
  1000 cm^2sr for gamma-rays
  4000 cm^2sr for ultra-heavy nuclei*
  * for E > 600 MeV/nucleon
- ΔE/E :
  ~2% (>10 GeV) for e's, γ's
  ~30 % for protons
- e/p separation: 10^{5}
- Charge resolution: 0.15-0.3 e
- Angular resolution: ~0.1° e's, γ's

	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z=1-46)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	Plastic Scintillator : 14 × 1 layer (x,y) Unit Size: 32mm x 10mm x 450mm	SciFi : 448 x 8 layers (x,y) = 7168 Unit size: $1mm^2$ x 448 mm **Total thickness of Tungsten: 3 X_0**	PWO log: 16 x 6 layers (x,y)= 192 Unit size: 19mm x 20mm x 326mm **Total Thickness of PWO: 27 X_0**
Readout	PMT+CSA	64 -anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)

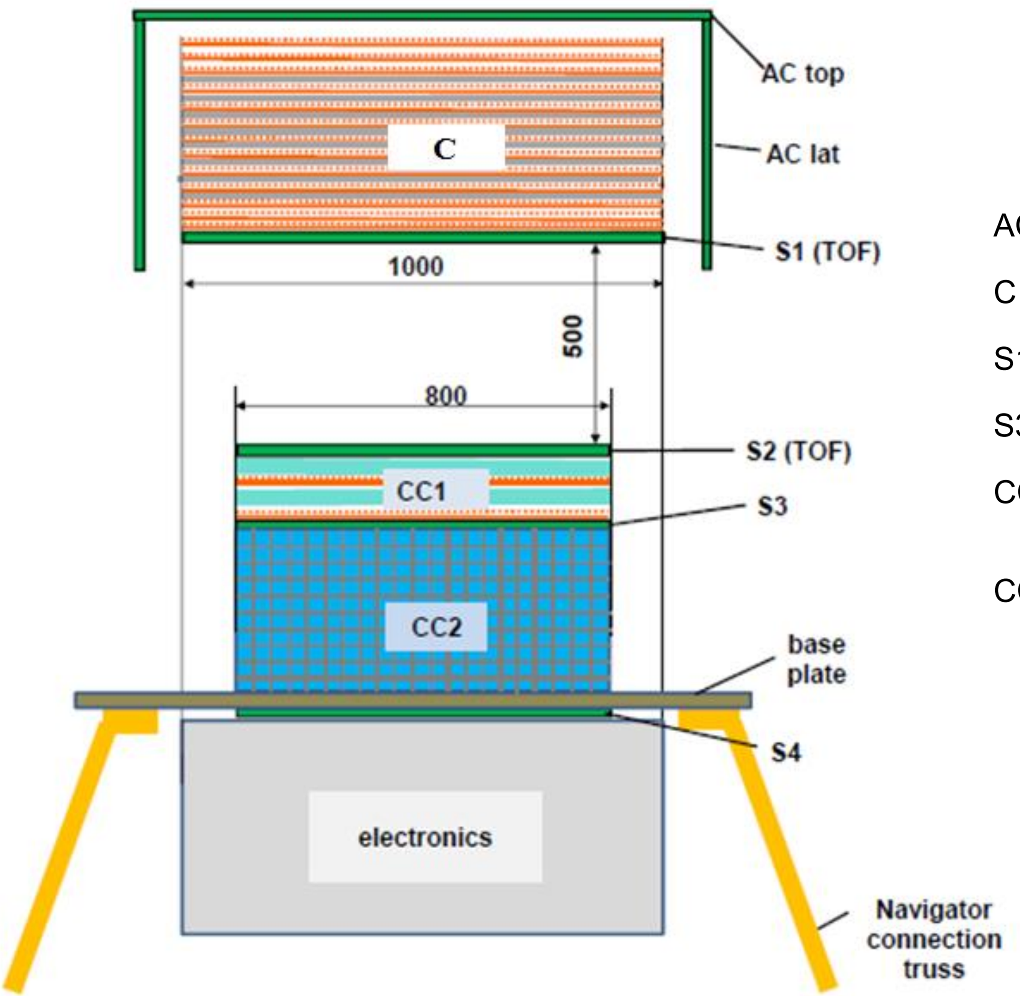
DAMPE -Dark Matter Particle Explorer



– 10 TeV for electrons
ev - !00TeV CR

W converter + thick calorimeter (total 33 X_0) + precise tracking + charge measurement ➨ high energy γ-ray, electron and CR telescope

GAMMA-400



AC – anticoincidence detectors

C – Conveter-Tracker

S1, S2 – ToF detectors

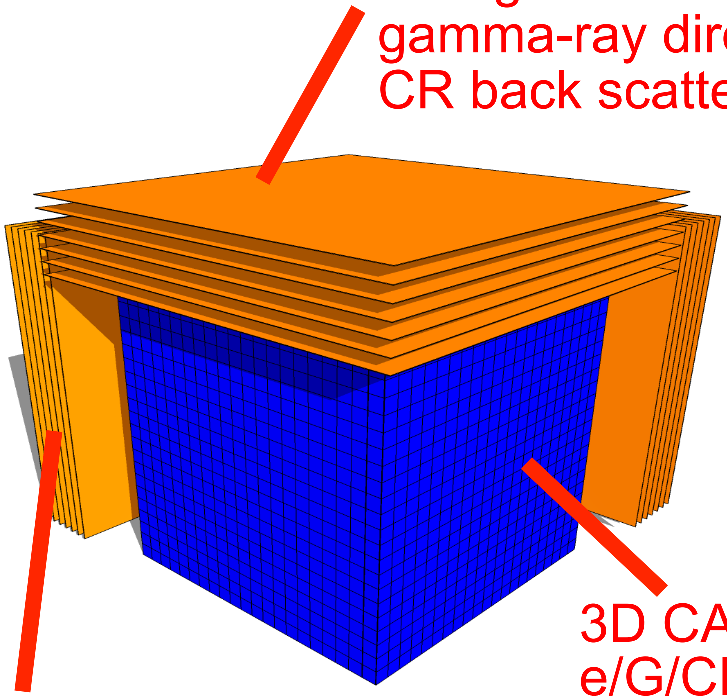
S3, S4 calorimeter scintillator detectors

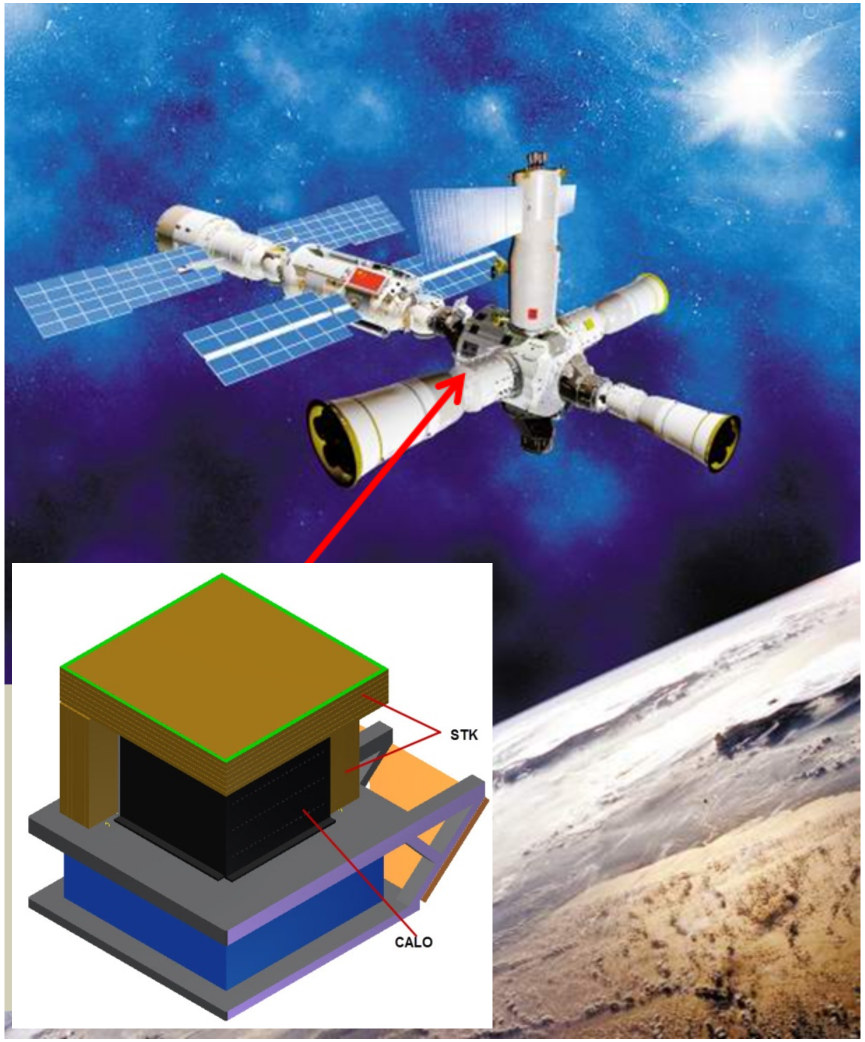
CC1 – imaging calorimeter (2 X_0)
2 layers: CsI(Ti) 1 X_0 + Si(x,y) (pitch 0.1 mm)

CC2 - electromagnetic calorimeter
CsI(Tl) 20 X_0 3.6x3.6x3.6 cm^3 – 22x22x10 = 4840

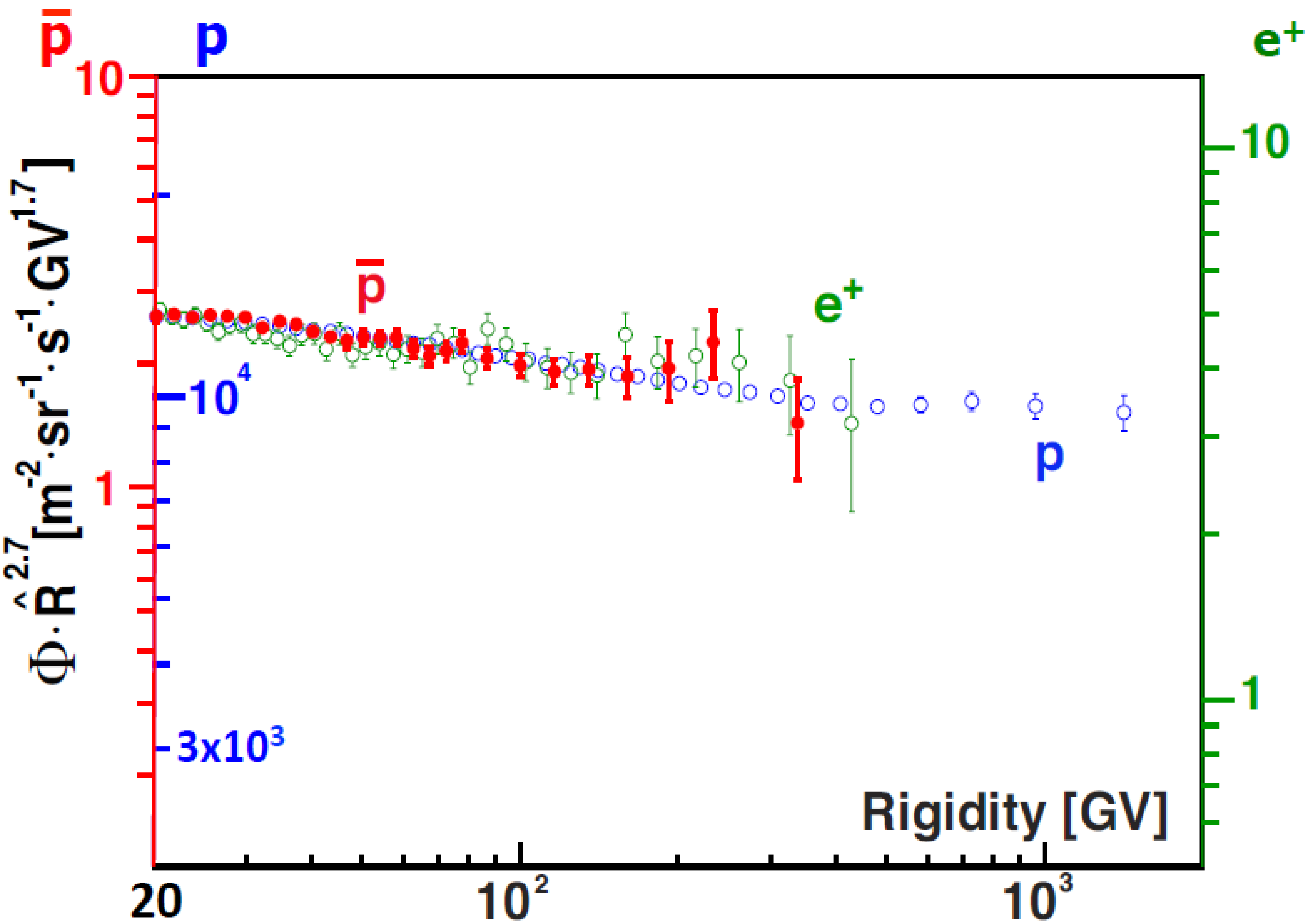
HERD Design：3D Calo & 5-Side Sensitive

About a factor 10 increase in statistics respect to existing experiments with a weight 2.3 T ~1/3 AMS

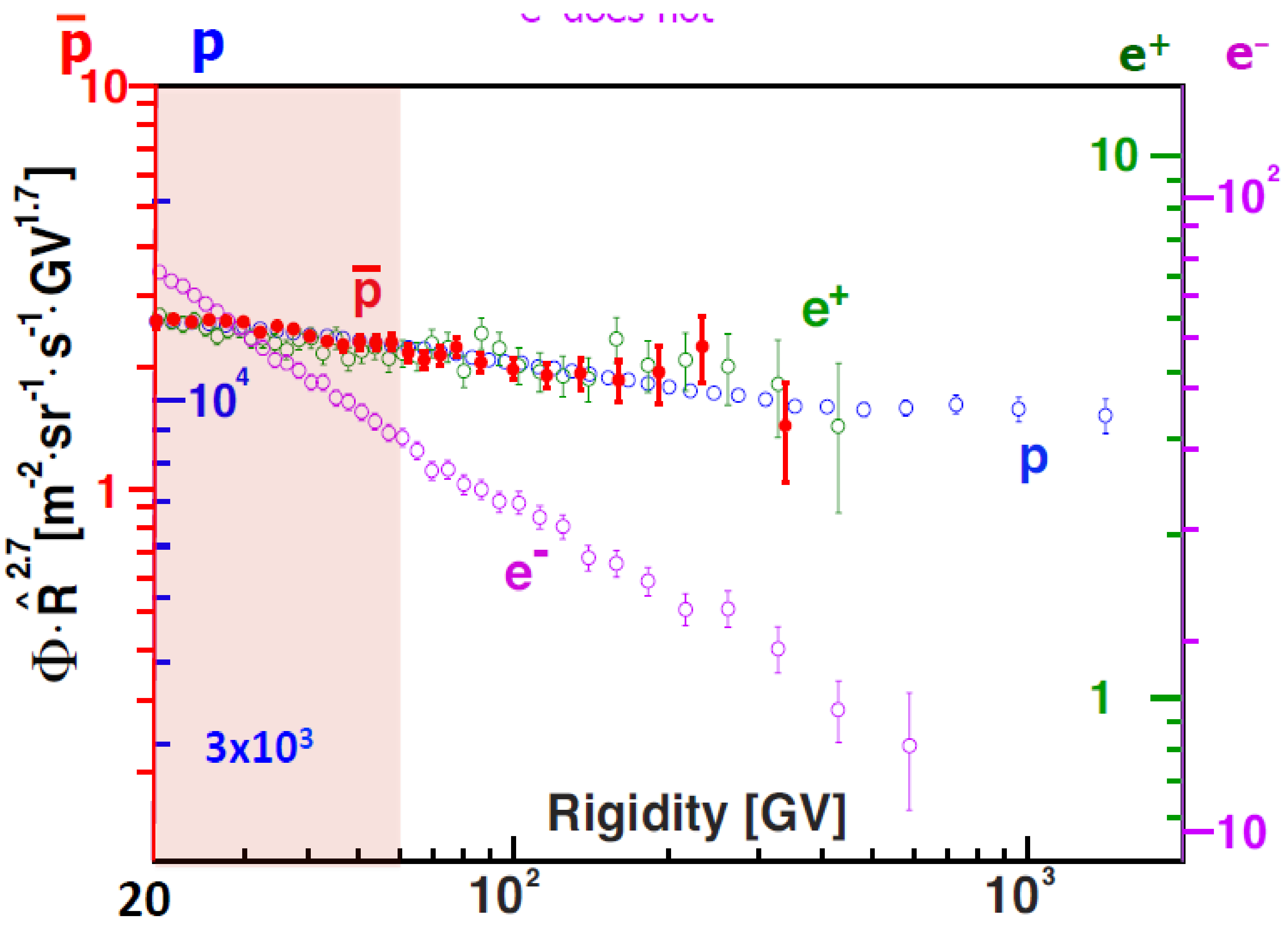




Spectrum of Elementary Particles e^+, $\bar{p}$, p
have identical energy dependence above 60 GeV



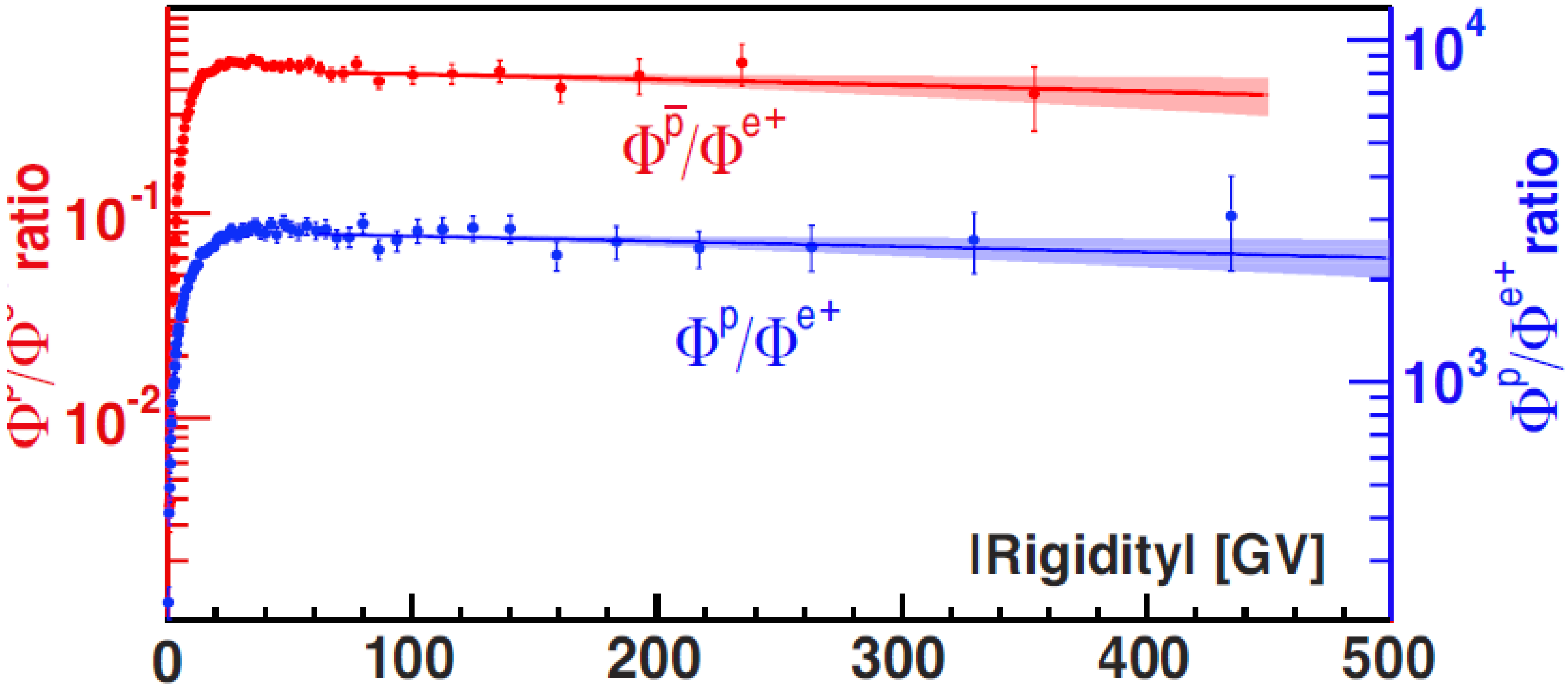
Dependence of Elementary Particles from Energy



A. Kounine

IDM 2016

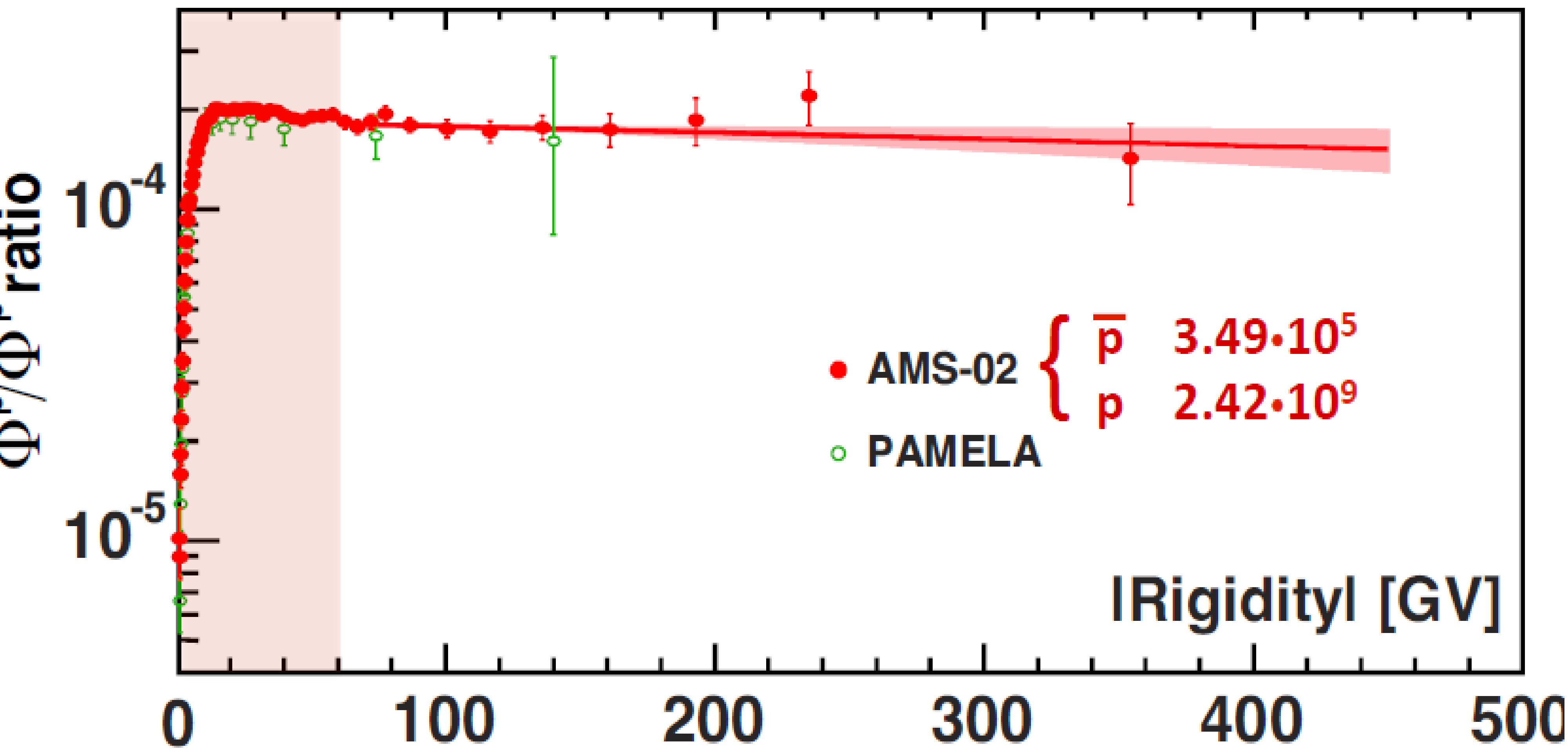
Flux Ratios $\bar{p}/e^+$ and p/e^+ are also energy independent in the interval 60–450 GV



Unexpected Result

Flux Ratio of Elementary Particles $\bar{p}/p$

is energy independent above 60 GeV



Flux Ratios $\bar{p}/e^-$ and p/e^- are not energy independent in the interval 60–450 GV