AMS-02

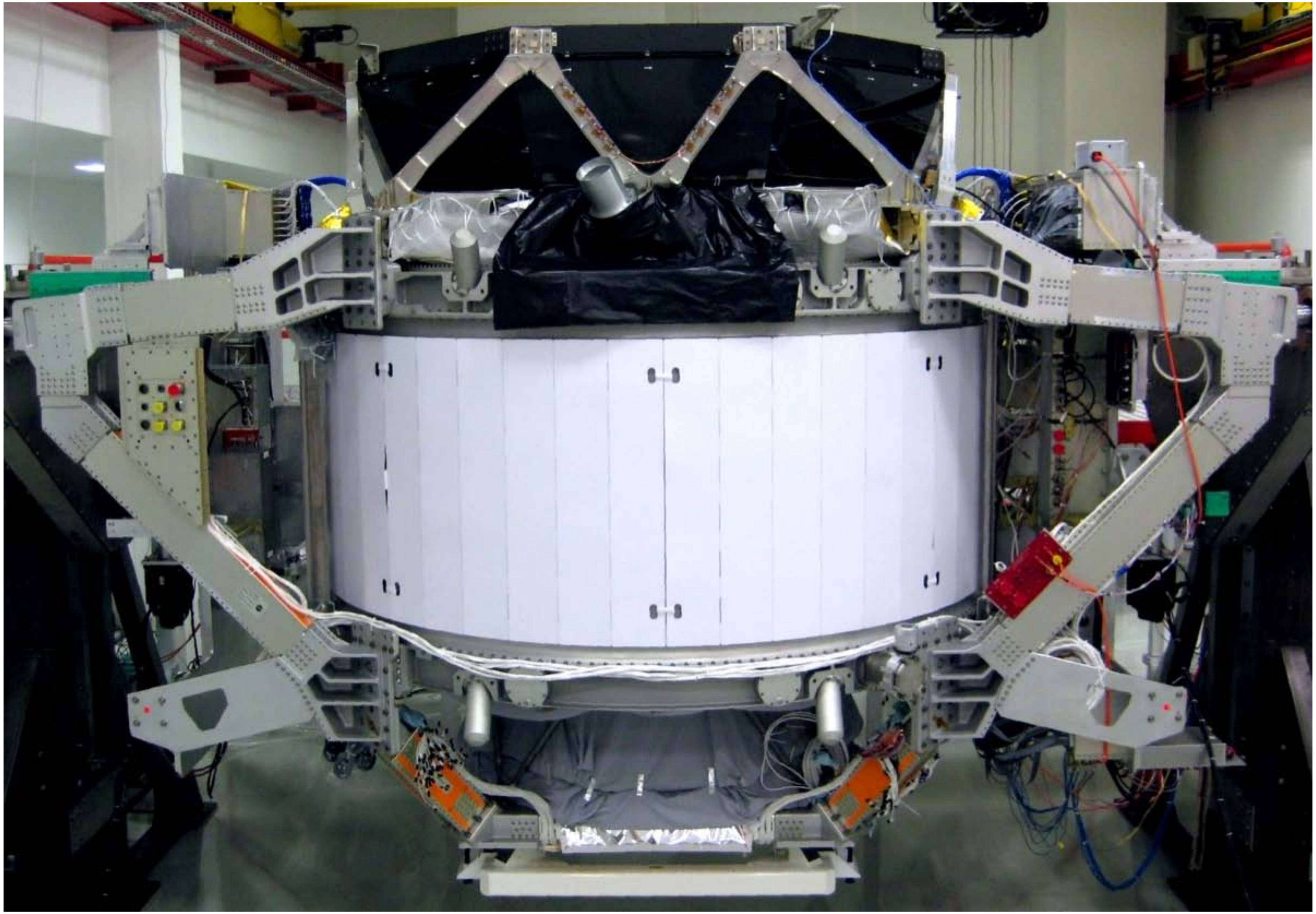
F.Cervelli, INFN-Pisa
Rome, May 26 2011

….the night before the exam

The Launch

The Launch

What was there?



AMS-02 IN FIGURES

Weight	8500 kg
Volume	64 cubic meters
Power	2500 watts
Data downlink	2 Mbps (average)
Magnetic field	0,125 Tesla
	Neodymium alloy ($Nd_2Fe_{14}B$),1200 kg
Construction	1999-2010
Cost	$1.5 billion (estimated)
Launch	16th May 2011, 2:47 pm
Data Taking	through the ISS lifetime, 2020 or longer

Almost There

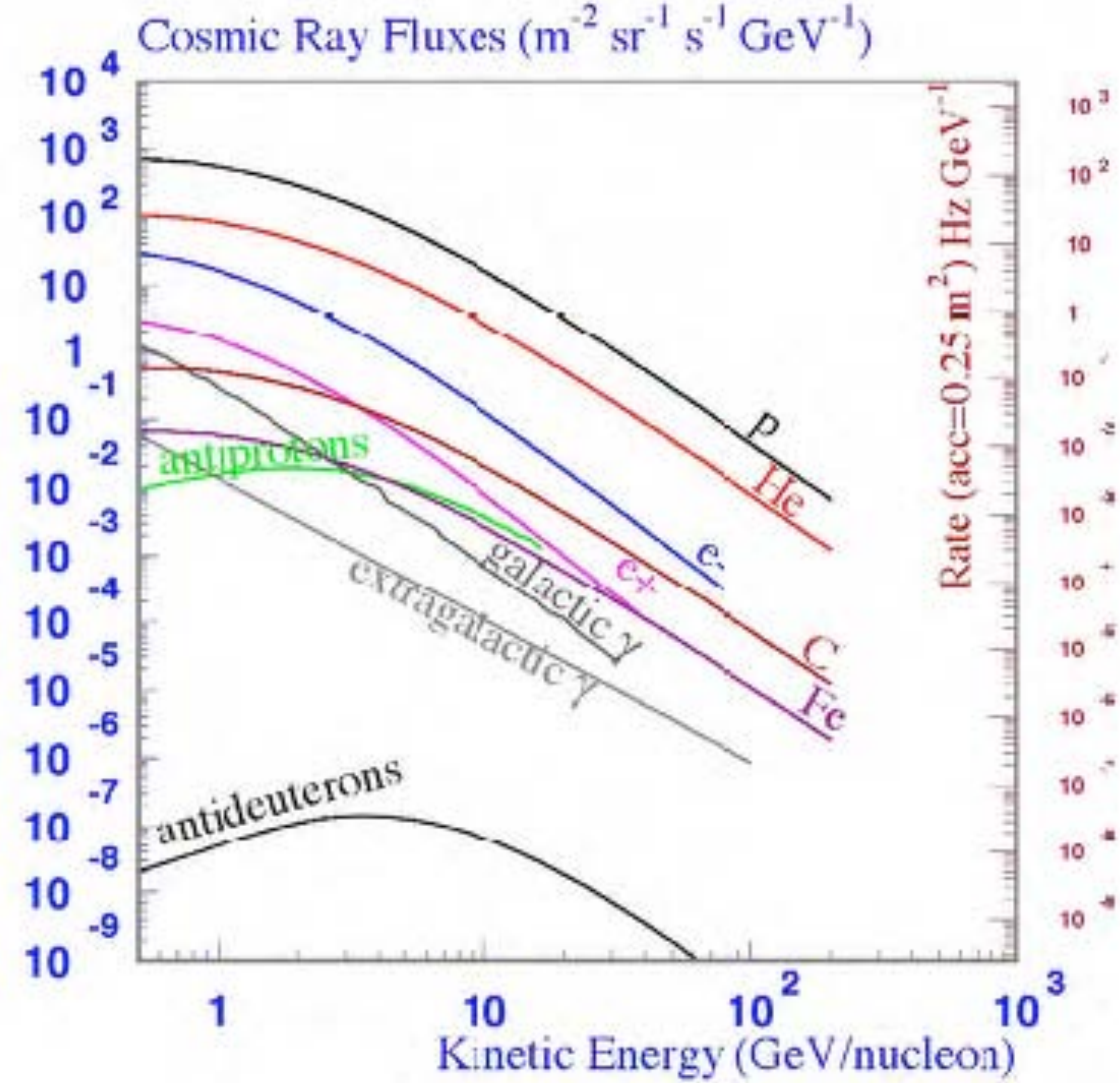
Ready for Installation

Installing AMS-02 on ISS

Installing…. just above Italy

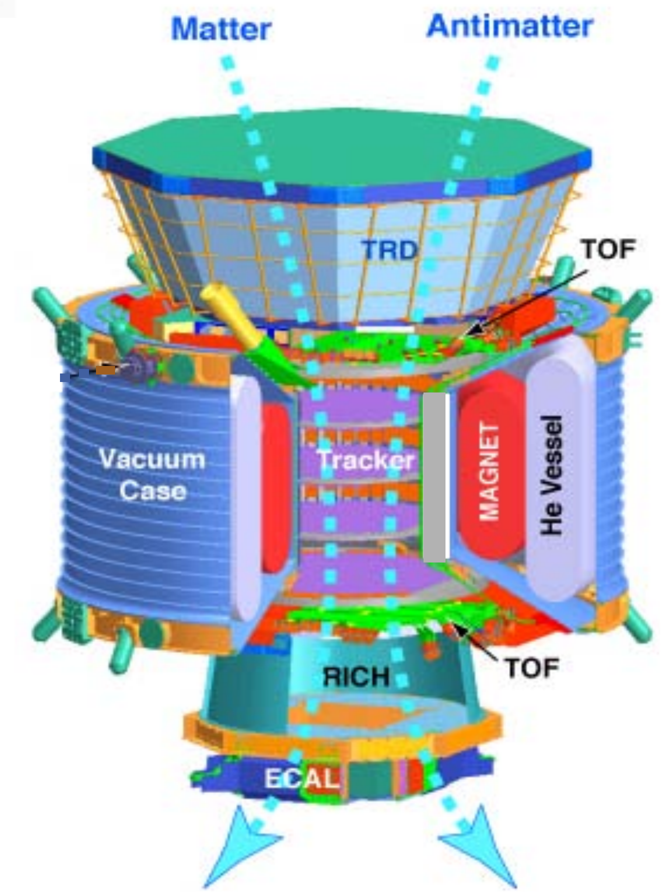
Installed on ISS

Fluxes

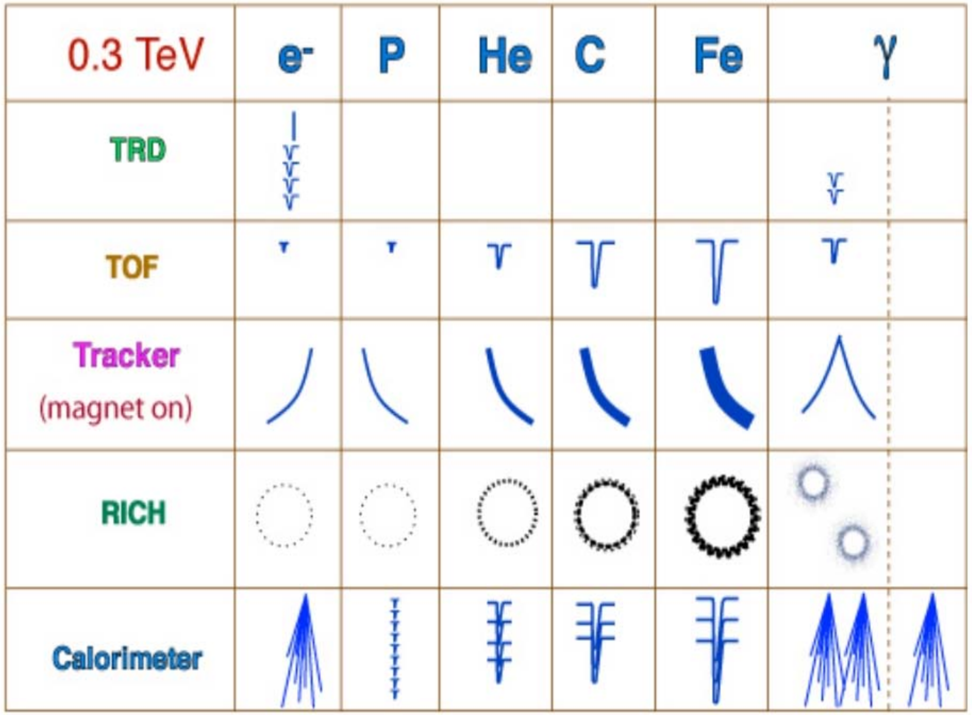


Cosmic Ray Fluxes (m^-2 sr^-1 s^-1 GeV^-1)
Rate (acc=0.25 m^2) Hz GeV^-1
p
He
e-
e+
C
Fe
antiprotons
galactic γ
extragalactic γ
antideuterons
Kinetic Energy (GeV/nucleon)

The AMS-02 Detector



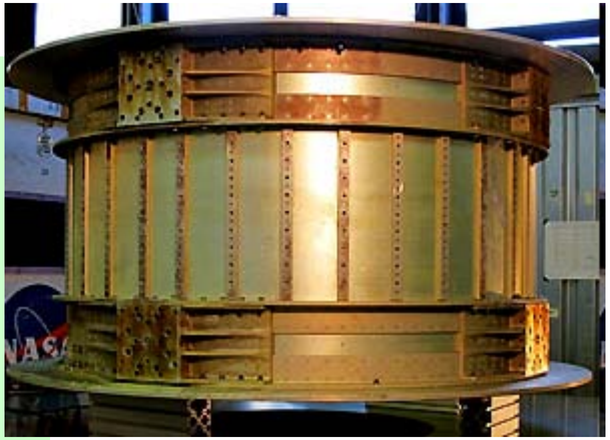
Dimensions: 7 tons and 3x3x3.5 m^3
Acceptance: 0.5m^{2}sr
Lifetime: min 3 years

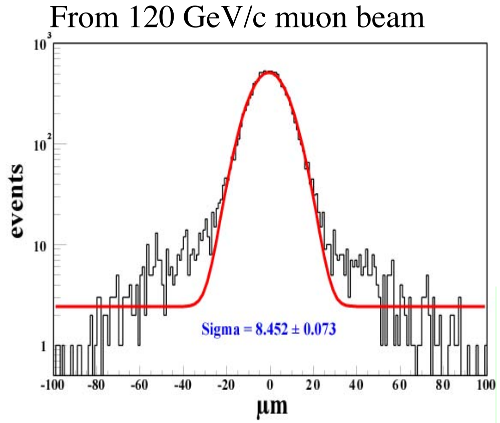


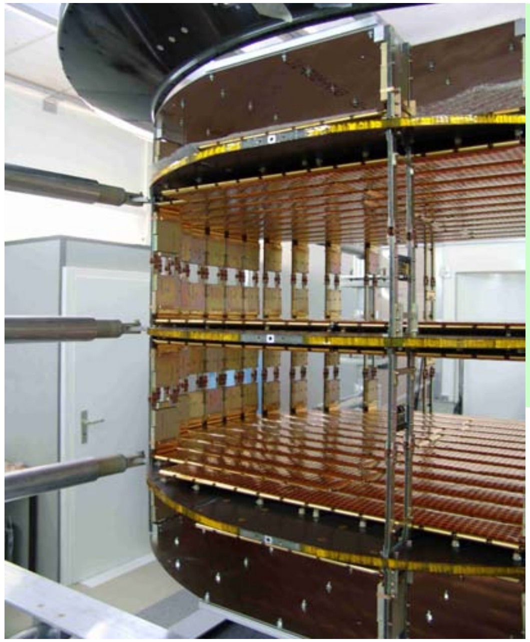
Redundant measurement in different subdetectors to gain precision

Flight Subdetector Hardware

Magnet: It consists by over 6000 Nd-Fe-B blocks and has dimensions of a cylinder of 1 m diameter and 1 m height. It develops a magnetic field of 0.15 T



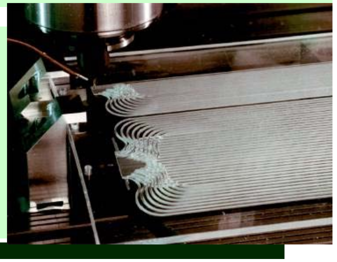




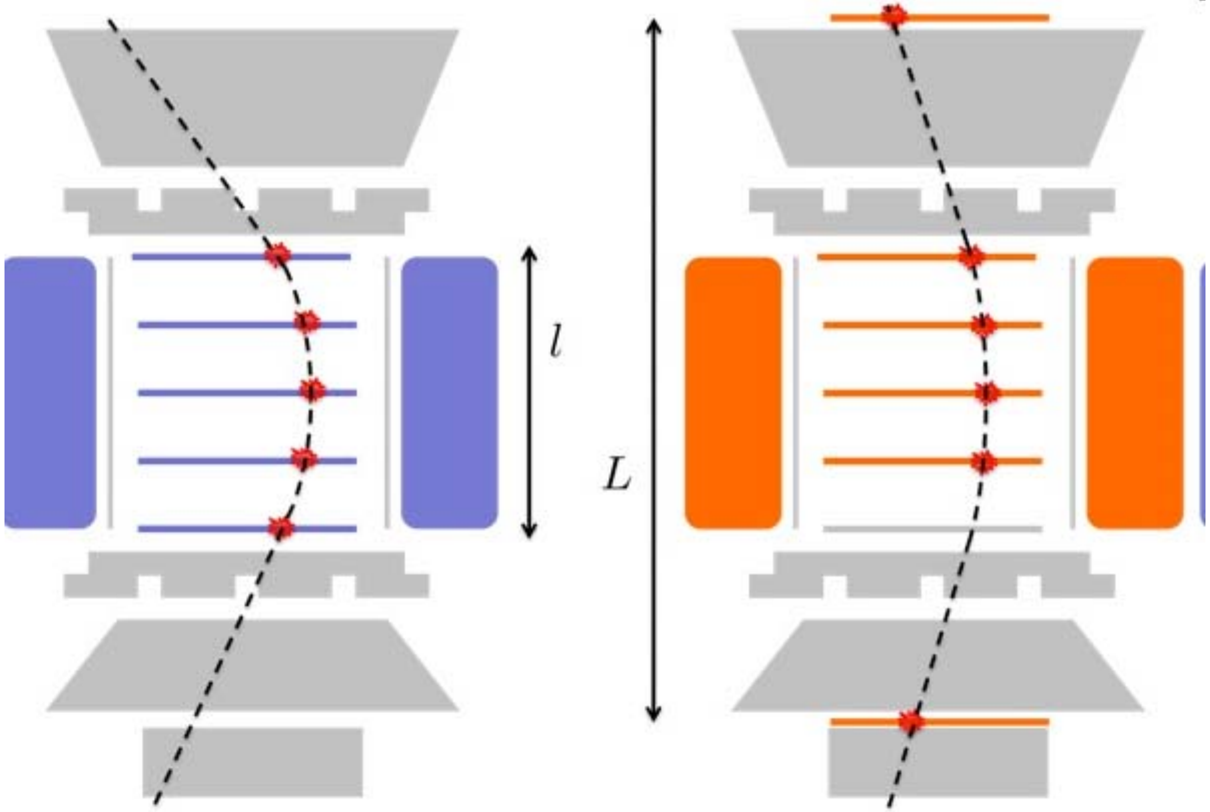
8 Plane **Silicon Tracker**:
200,000 channels on 6.6m^2 strips
Resolution σ=30μm and 10μm in bending direction

- Rigidity measurement up to few TeV
- Particle identification by dE/dx ~Z^2
- Measurement of gammas in conversion mode

Anticoincidence counters:
16 cylindrical shell paddels of plastic scintillator for veto



Permanent Mag vs. SC Mag



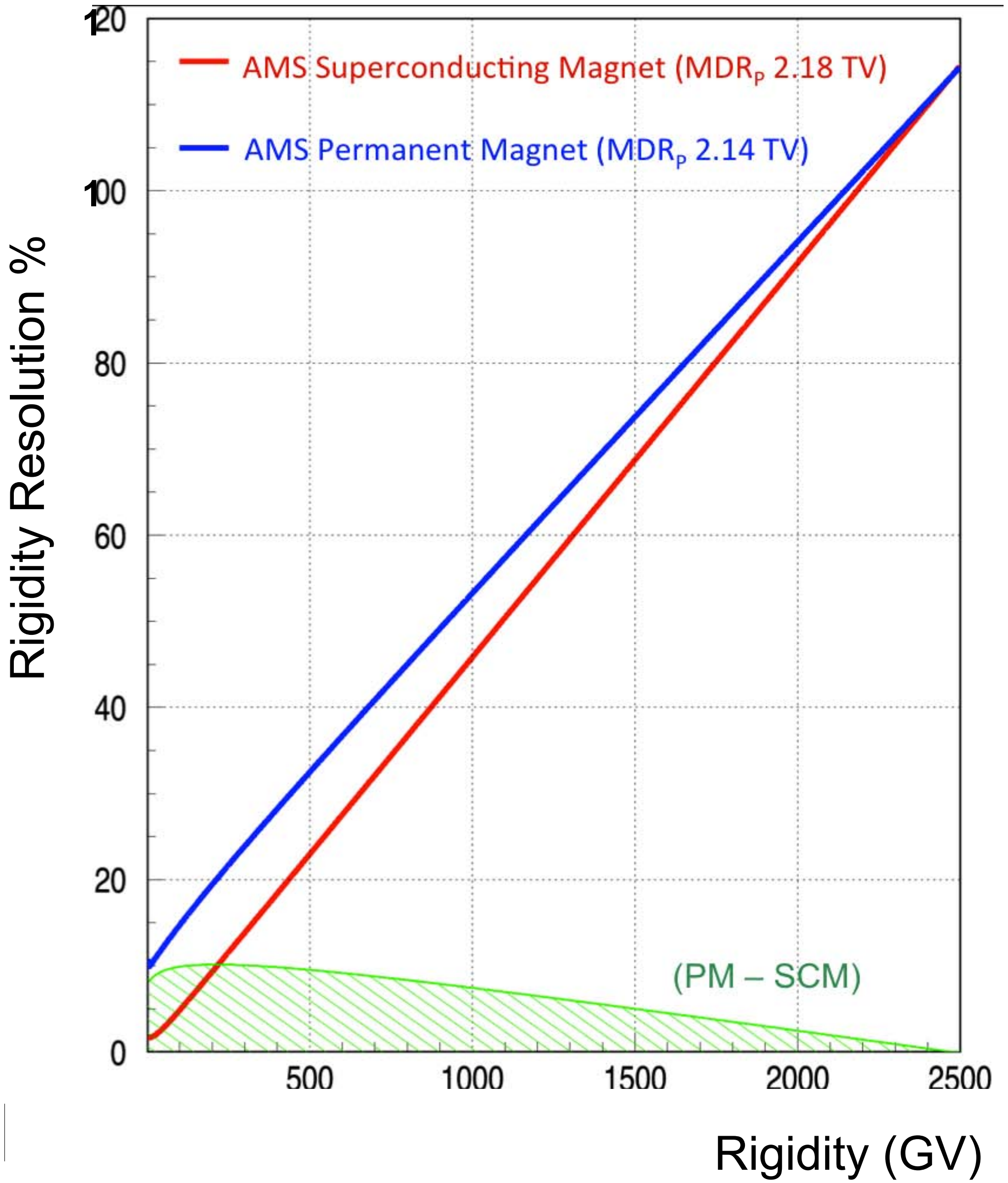
Superconducting Magnet Scenario

$$\frac{\Delta R}{R} \propto \frac{1}{B_{\mathrm{scm}} l^2}$$

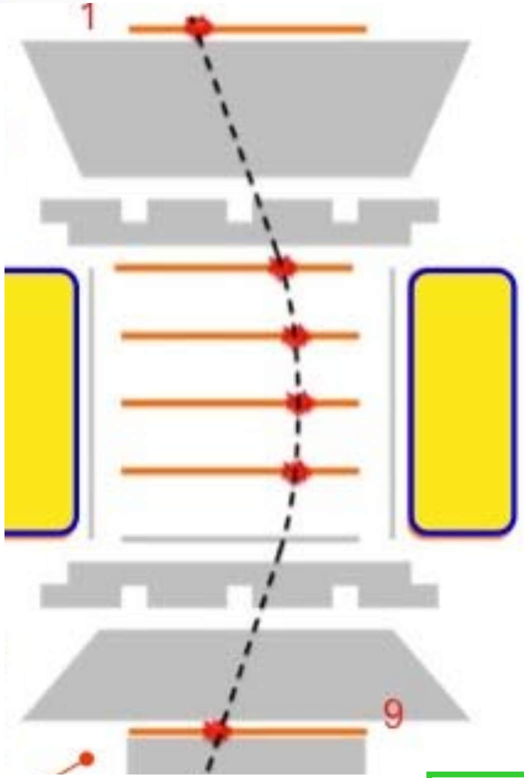
Permanent Magnet Scenario

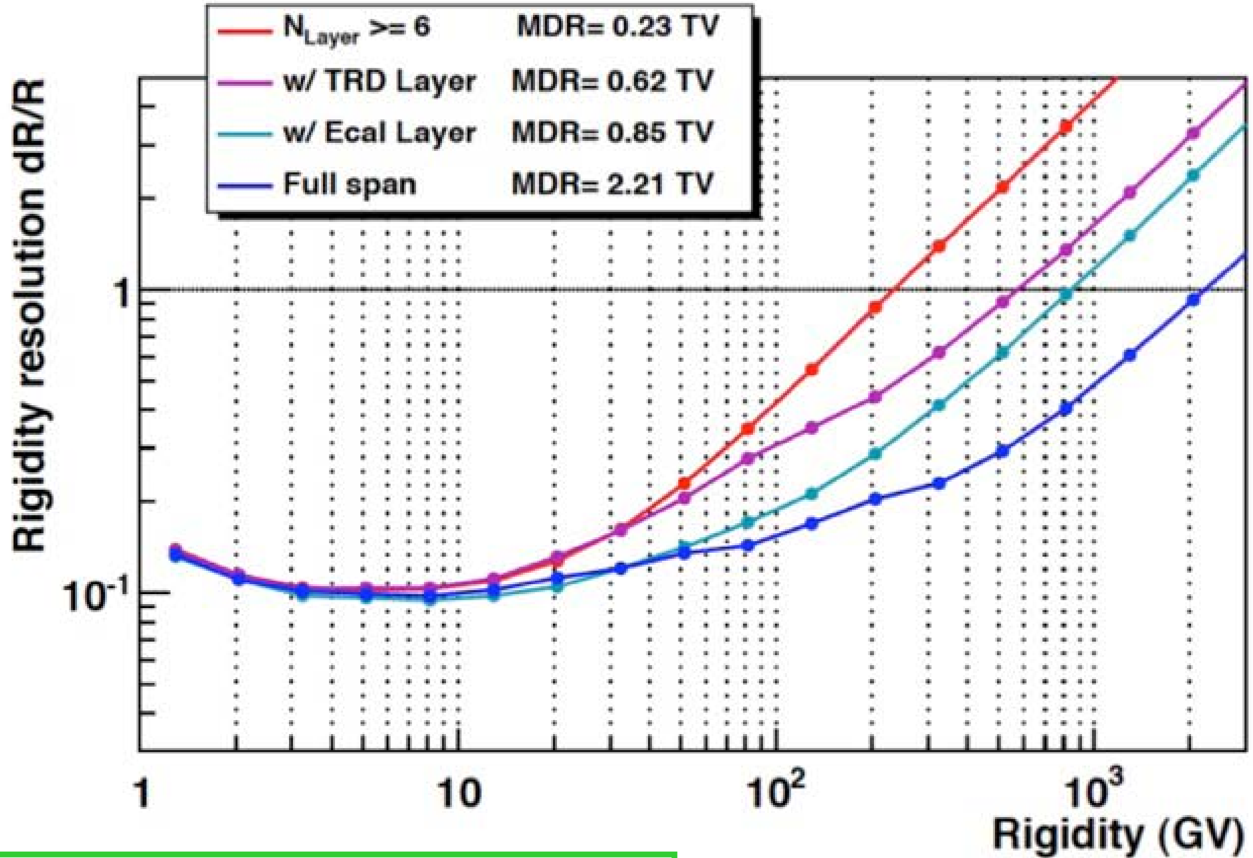
$$\frac{\Delta R}{R} \propto \frac{1}{B_{\mathrm{pm}} l L}$$

Rigidity


AMS Superconducting Magnet (MDR$_p$ 2.18 TV)
AMS Permanent Magnet (MDR$_p$ 2.14 TV)
(PM – SCM)
Rigidity Resolution %
Rigidity (GV)
0
20
40
60
80
100
120
500
1000
1500
2000
2500

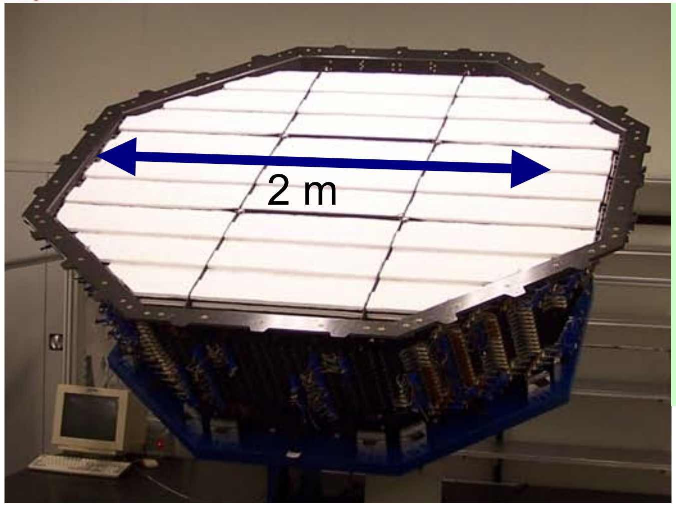
Geometrical Acceptance and MDR



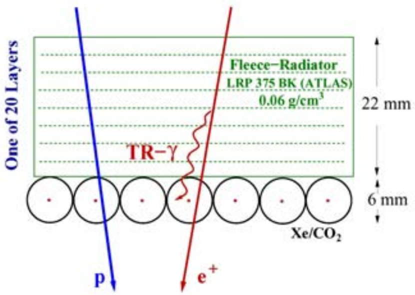


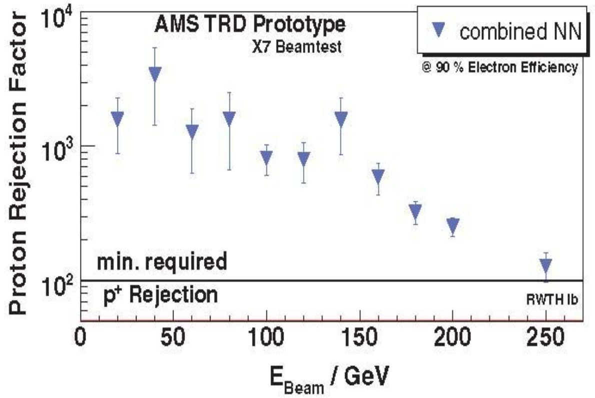
N_{Layer}>=6	0.41 sr·m^2
w TRD Layer	0.06 sr·m^2
w ECAL Layer	0.03 sr·m^2
Full Span	0.01 sr·m^2
Full Span + ECAL SL9	0.006 sr·m^2

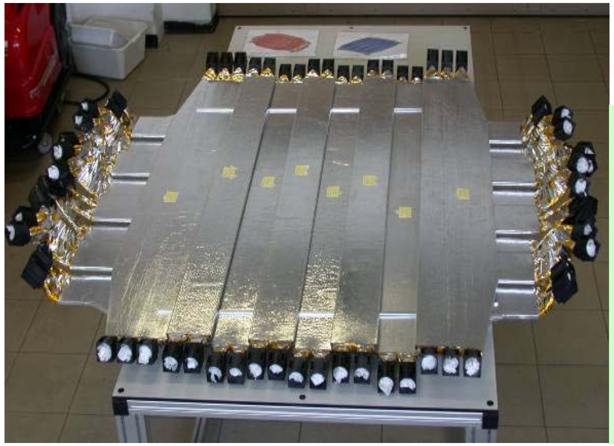
Flight Subdetector Hardware



Transition Radiation Detector:
20 layers, 5248 strawtubes
with Xe/CO_2 Gas @ 1bar
Fleece radiator for electron/proton separation
• e/h rejection > 100
• dE/dx measurement



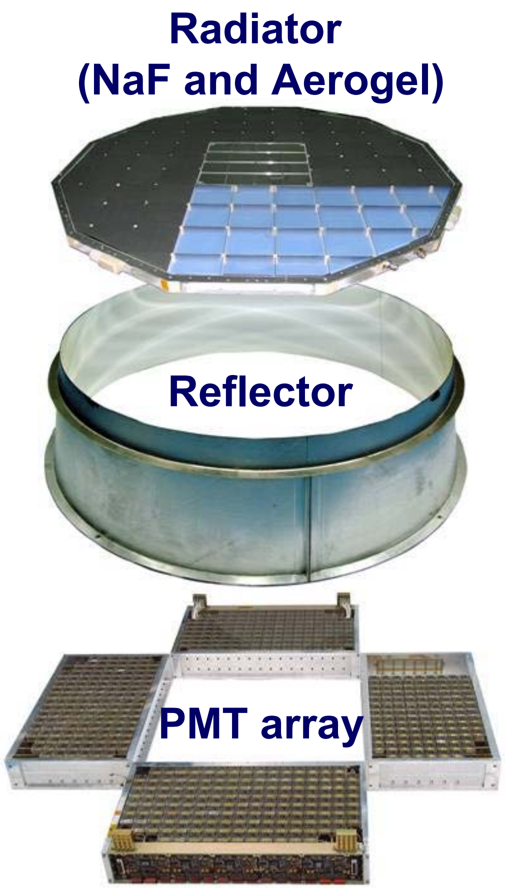




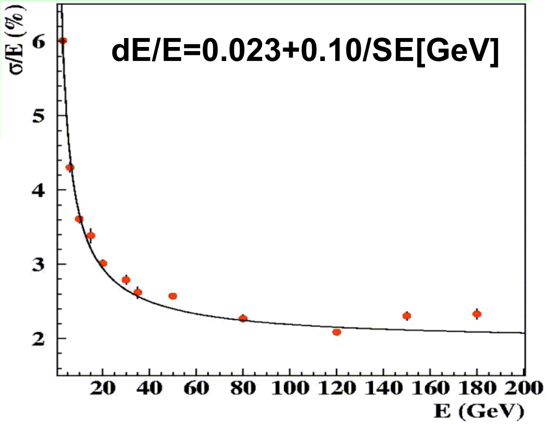
Time of Flight:
2x2 scintillator planes as primary trigger
Resolution t<130ps
• Velocity measurement $d\beta/\beta$~3%
• dE/dx measurement

Flight Subdetector Hardware

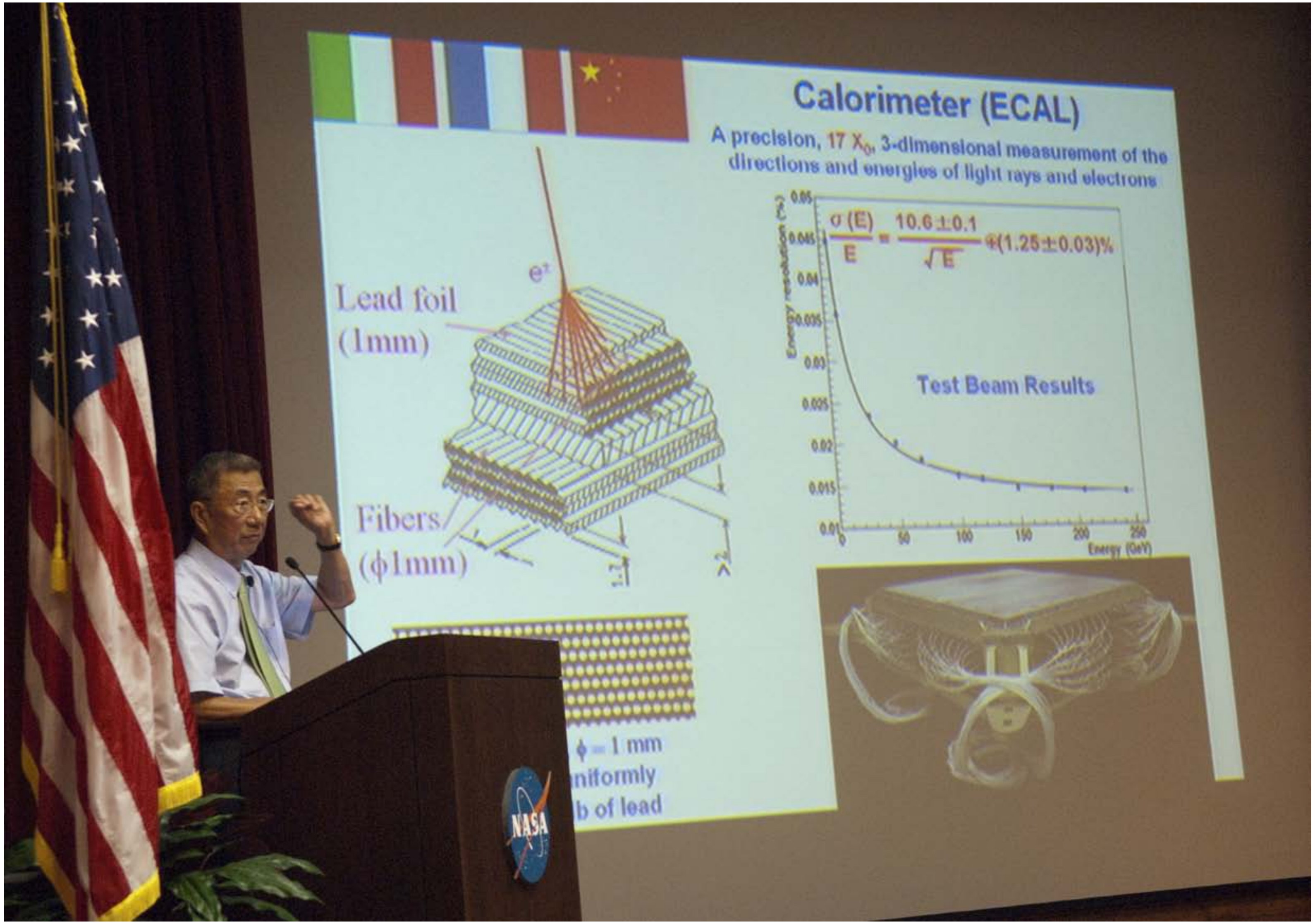
Ring Image Cherenkov Detector:
NaF (n=1.336) and Aerogel (n=1.035) radiator
PMT's array of spatial pixel size 8.5x8.5 mm
- β measurement up to 20GeV/n
- Charge measurement up to Z=26 ($N\gamma \sim Z^2$)



Electromagnetic Calorimeter:
18 planes (640kg) of Pb with scintillator fiber inserts; thickness $16X_0$ /$.5\lambda_h$
e/p separation ~1000 to 1Tev

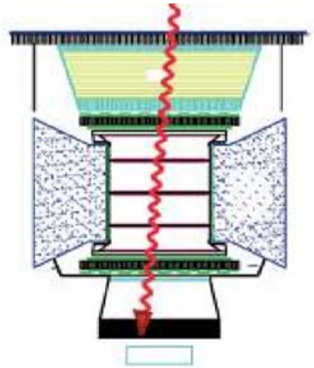


Space qualified electronics running with 650 micropocessors to read out 300000 channels, **GPS, Startracker Camera** and **heat control systems**.


Calorimeter (ECAL)
A precision, 17 X_0, 3-dimensional measurement of the directions and energies of light rays and electrons
$\frac{\sigma(E)}{E} = \frac{10.6 \pm 0.1}{\sqrt{E}} \oplus (1.25 \pm 0.03)\%$
Energy resolution (%)
Test Beam Results
Energy (GeV)
Lead foil (1mm)
$e^{\pm}$
Fibers (φ1mm)
φ = 1 mm
NASA

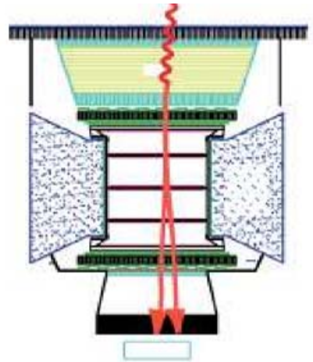
Photon Detection with AMS-02

Single photon mode



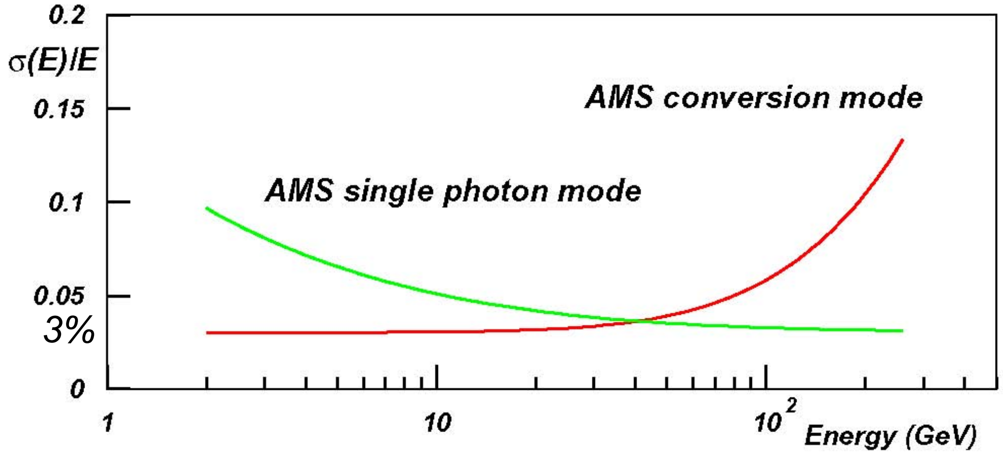
$\gamma \rightarrow$ EM Shower

Conversion mode

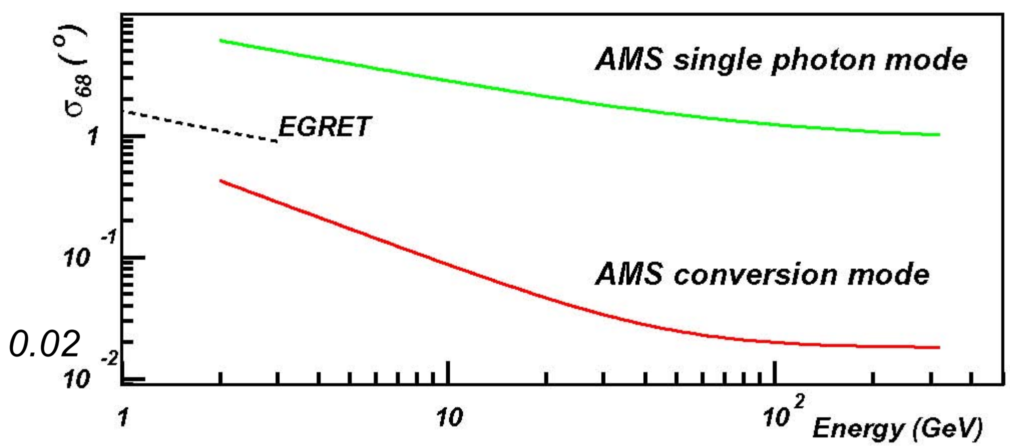


$\gamma \rightarrow e^+/e^-$-pair

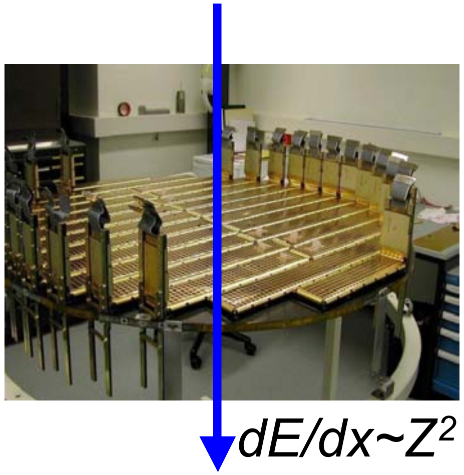
Energy resolution (100GeV) ~3%



Angular resolution (100GeV) ~0.02°

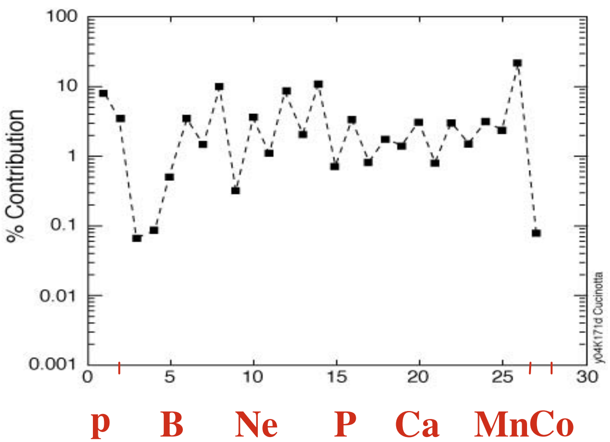


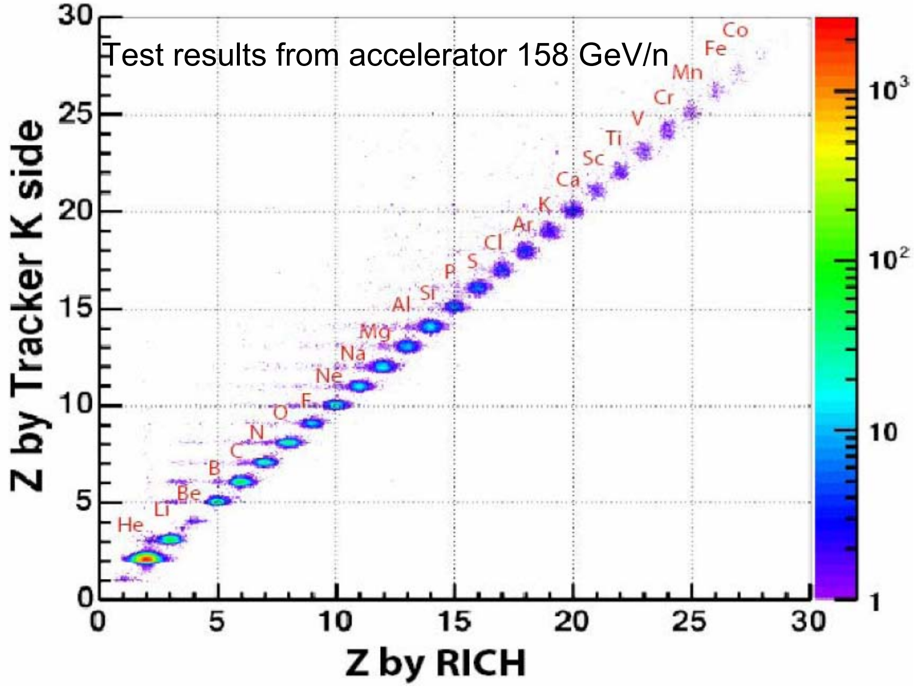
Chemical Composition Measurement



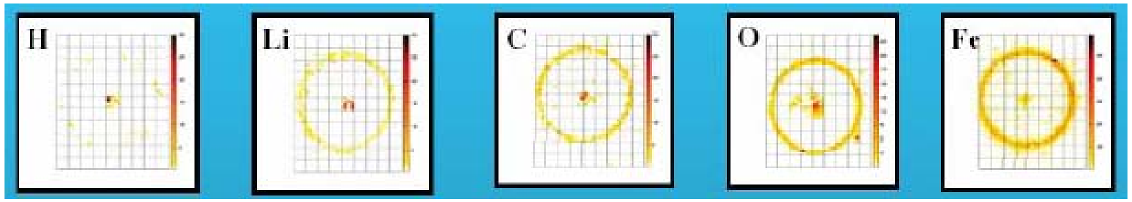
$dE/dx \sim Z^2$

Abundance of cosmic nuclei





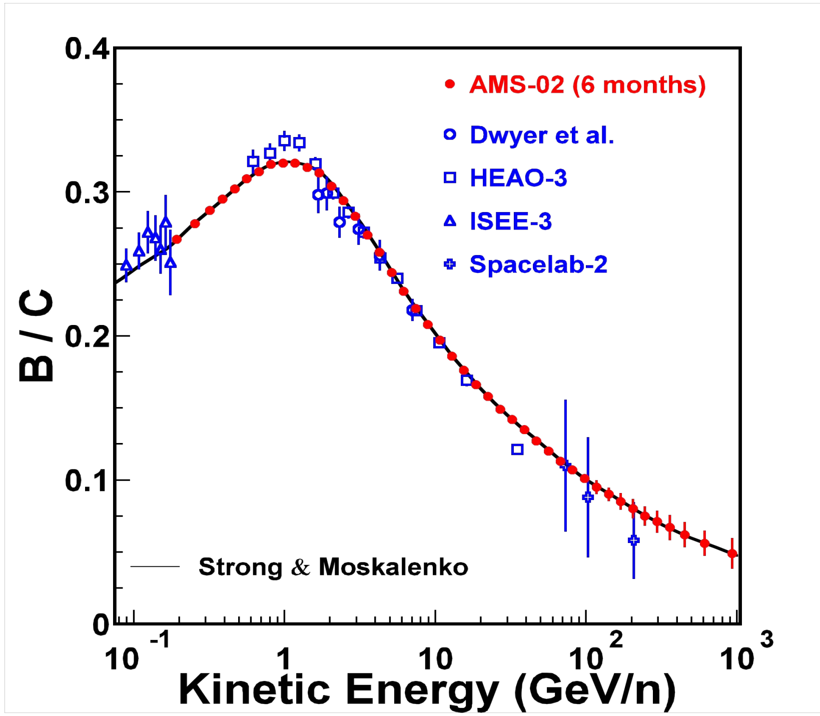
$N\gamma \sim Z^2$

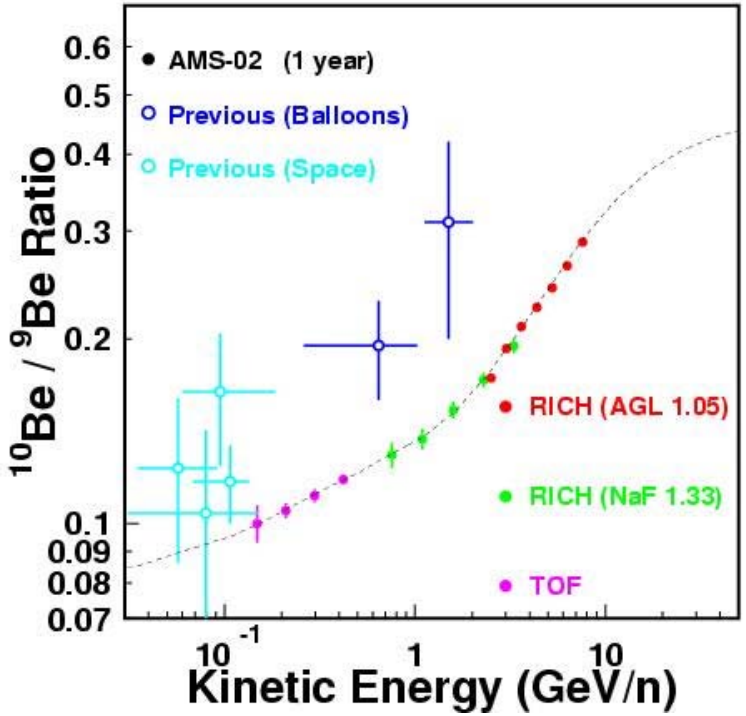


Cosmic spectra with 1% accuracy from Helium to Cobalt

Precision Study of Cosmic Rays – Radioactive Isotopes

- **AMS-02 will collect 10^5 ^{10}Be isotopes in 3 years**





- … and collect 10^5 C and 10^4 B to measure the ratio of Carbon to its spallation secondary Boron

Current Experiments

Comparison of High-Energy Electron Missions

Mission	Upper Energy (TeV)	Collecting Power ($m^2 sr$)	Calorimeter Thickness (X_0)	Energy Resolution (%)
CALET	20	0.75	30.8	< 3 (over 100 GeV)
PAMELA	0.25 (spectrometer) 2 (calorimeter)	0.0022 0.04	16.3	5.5 (300 GeV) 12 (300 GeV) 16 (1TeV)
GLAST Fermi	0.7	2.1 (100 GeV) 0.7 (700 GeV)	8.3	6 (100 GeV) 16 (700 GeV)
AMS-02	0.66 (spectrometer) 1 (calorimeter)	0.5 0.06 (100 GeV) < 0.04 (1 TeV)	16.0	< 3 (over 100 GeV)

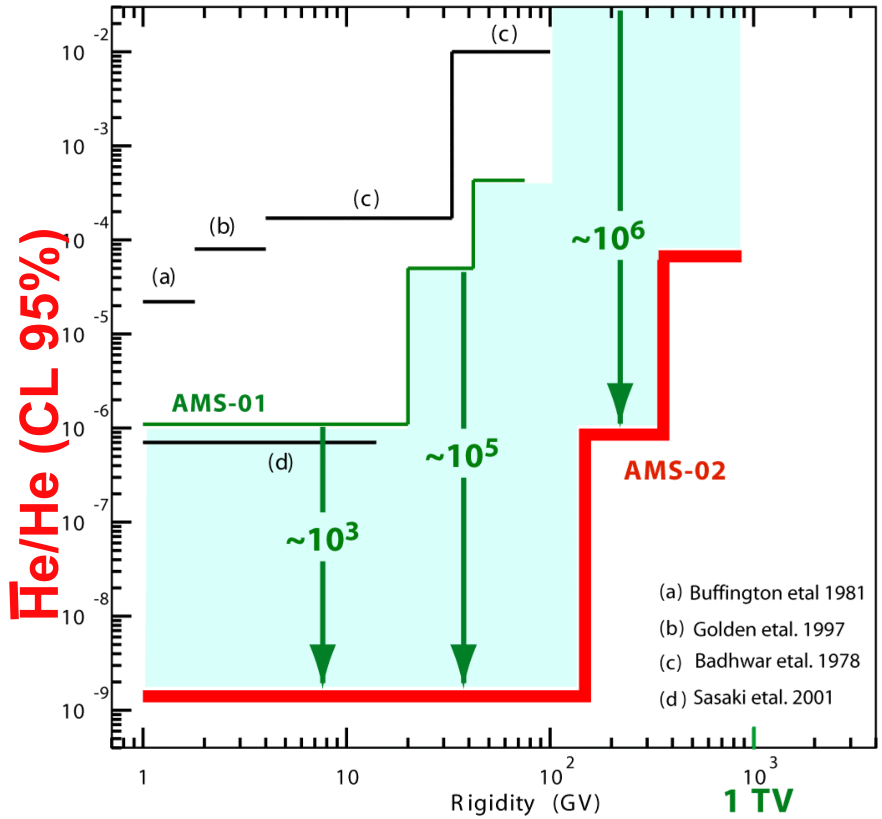
Current Experiments

	BESS-Polar	PAMELA	AMS-02
Acceptance ($m^2 sr$)	0.3	0.002	0.5
MDR (GV)	150	740	2500
Flight duration (days)	10+20	1000	1000
Flight Altitude (km)	36	690	350
Residual air (g/cm^2)	5	-	-
Weight (tons)	1.5	0.38	~7
Power consumption (W)	600	345	2000
Magnetic field (Tesla)	0.8-1	0.4	0.87
Flight latidude (deg.)	80	±70	±52
Energy region (GeV)	> 0.1	> 0.1	~ > 0.5
Flight vehicle	Balloon	Satellite	ISS
# of events for:			
protons (range in GeV/n)	$3\ 10^9$ (0.2-200)	$3\ 10^8$ (0.08-700)	$2\ 10^{10}$ (0.5-2500)
antiprotons	$3\ 10^4$ (0.2-4)	$3\ 10^4$ (0.08-190)	$3\ 10^6$ (0.08-700)
e^-	-	$6\ 10^6$ (0.05-2000)	$6\ 10^8$ (0.5-5000)
e^+	-	$3\ 10^5$ (0.05-270)	$3\ 10^7$ (1-400)
Anti-He/He	$3\ 10^{-8}$	$7\ 10^{-8}$	$1\ 10^{-9}$
Anti-D/D	10^{-5}	-	$3\ 10^{-7}$

Search for the existence of Antimatter in the Universe

The primordial antimatter content of the Universe is unknown.

- Up to today existance of antimatter domains in the universe is not excluded (predicted by Big Bang)
- No antimatter annihilation signal from within our cluster
- No antimatter particle found by AMS-02 means there is no Antimatter in the Universe
- A single anti-C: there are antimatter stars!

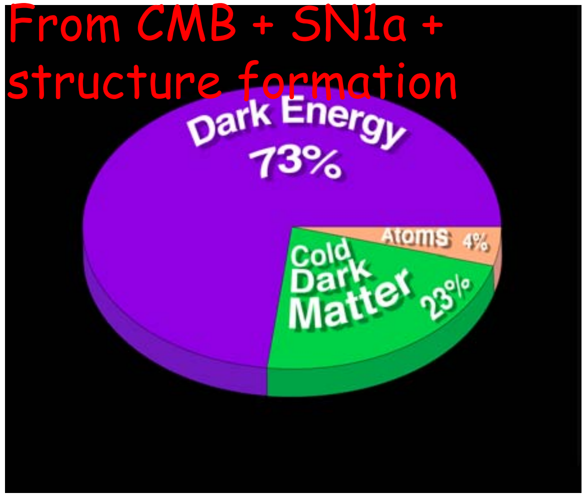


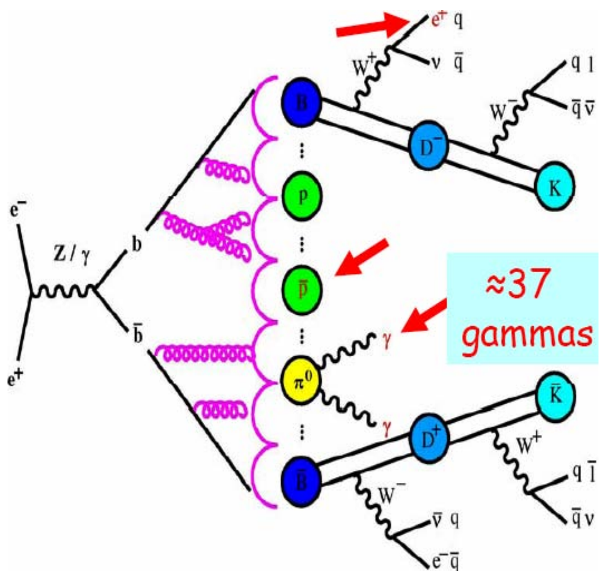
Probe the Unknown

- Dark Energy ~73%
- Matter ~27%
  - ~4.4% Barions (~0.5% Stars)
  - **23% Cold Dark Matter**

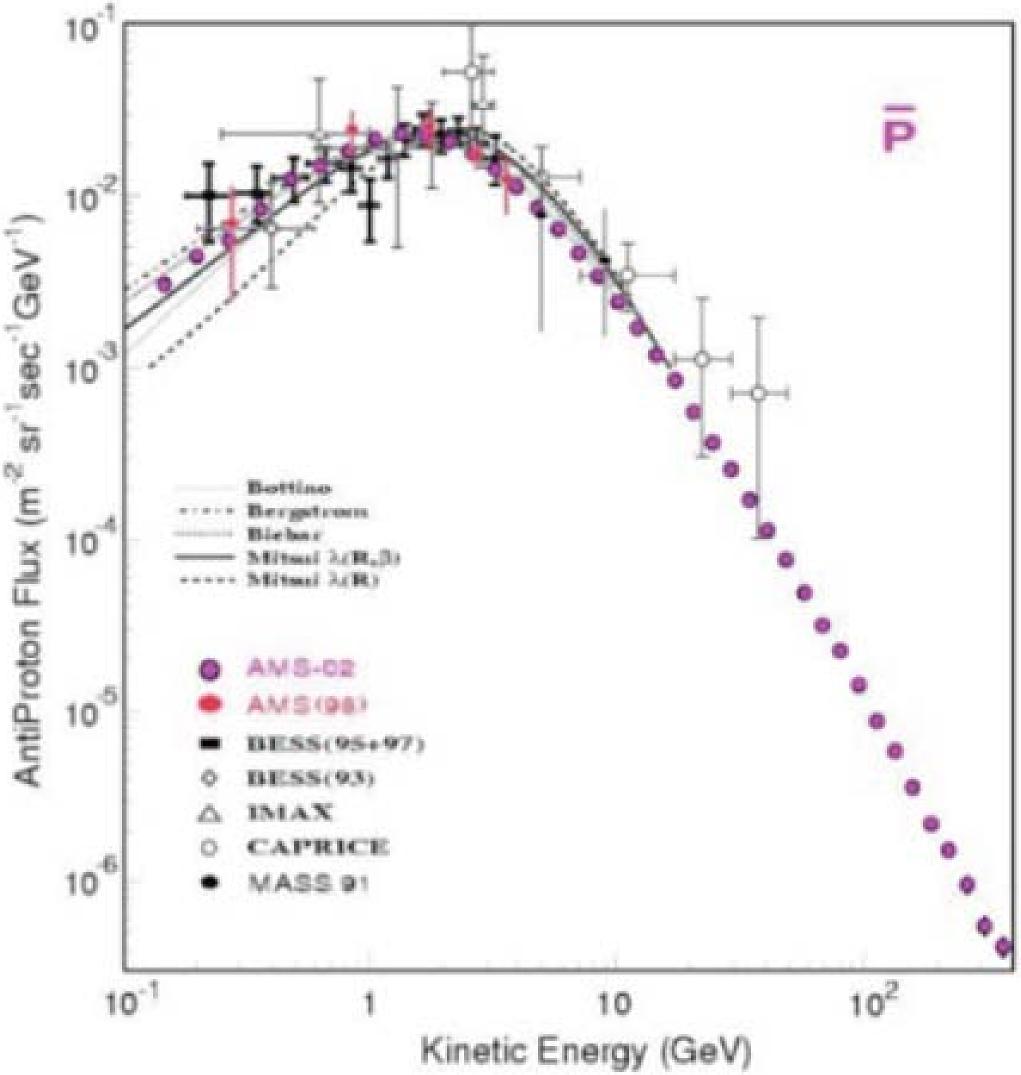
- Leading idea is some kind of not-yet-seen stable particle (WIMP candidate: Neutralino as lightest SUSY-particle in R-conserving model)

- Direct search on Earth ongoing (if the Earth not in a void, results expected)
- Indirect searches are based on $\chi + \chi \rightarrow b\bar{b}$ quark pair production in annihilation, its decay then is well known from accelerator experiments

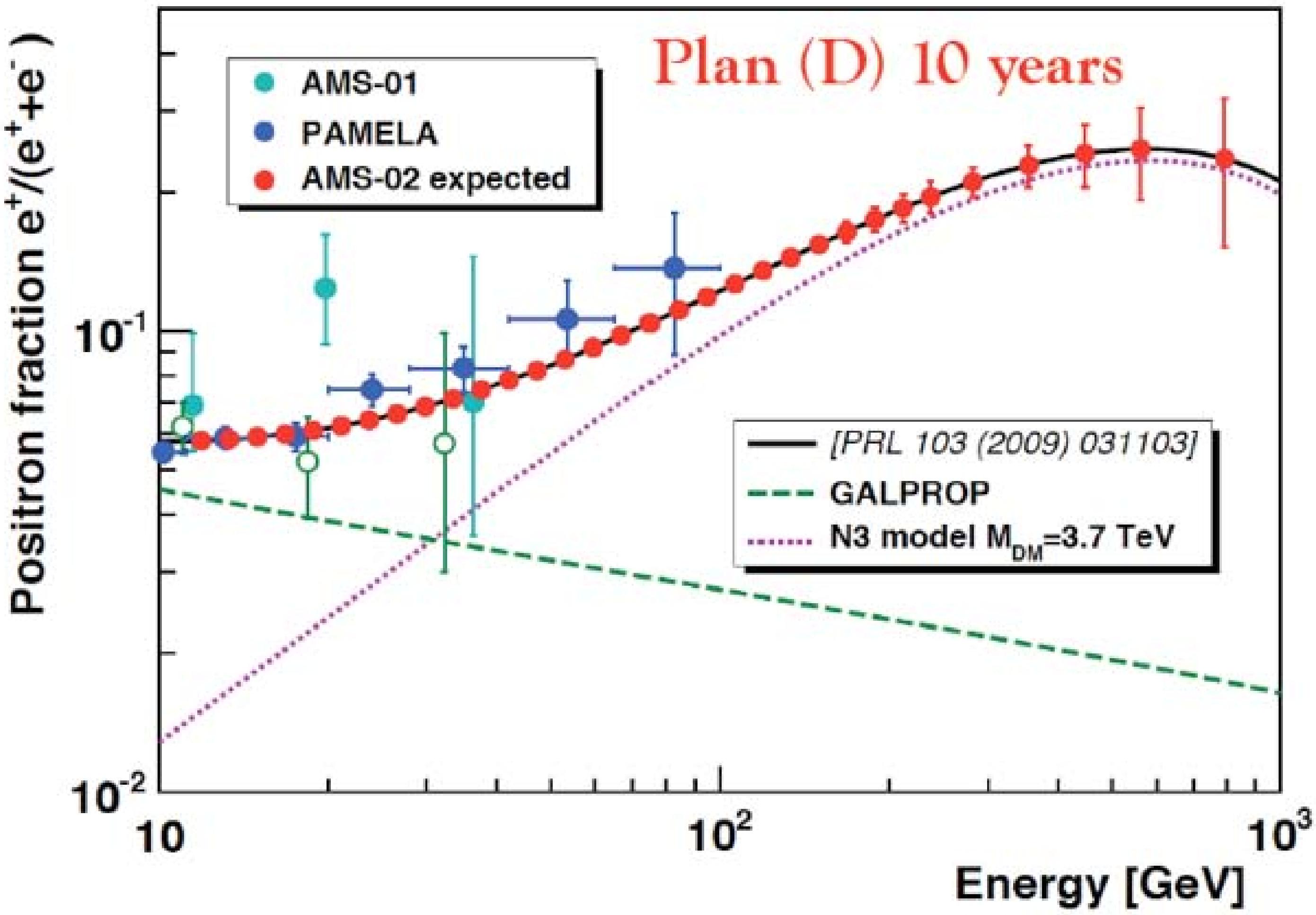




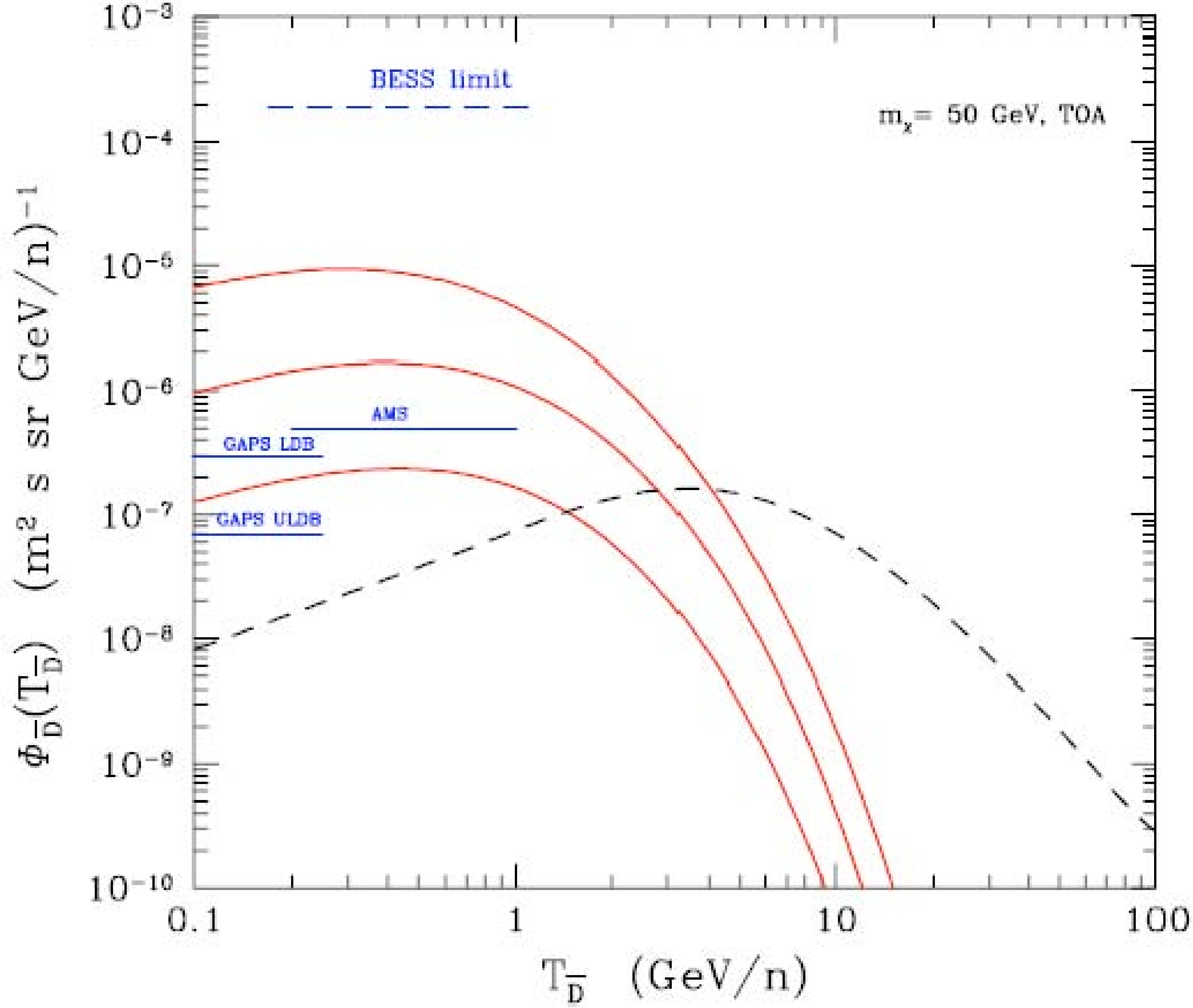
AntiProtons in 10 years



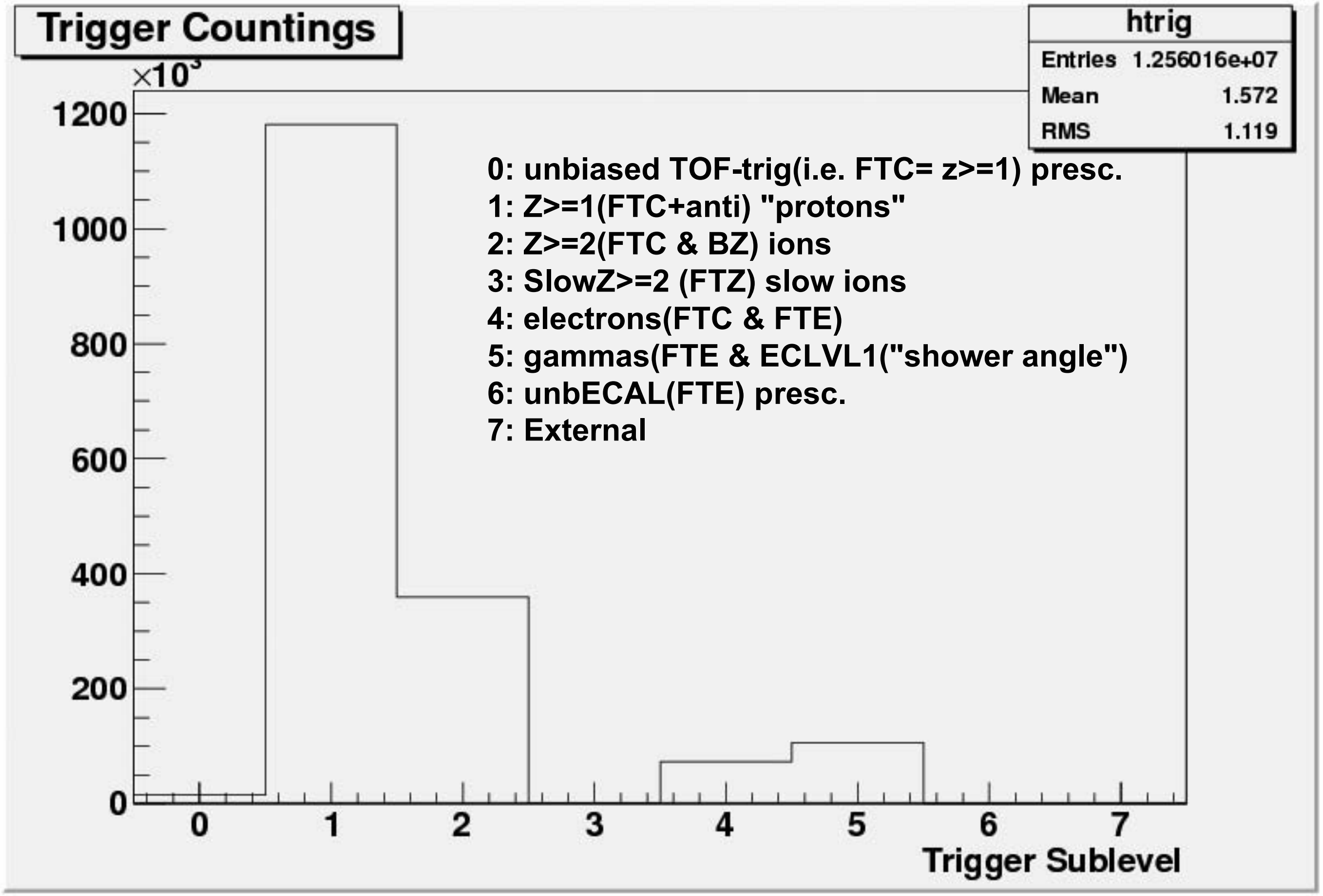
Positron Fraction



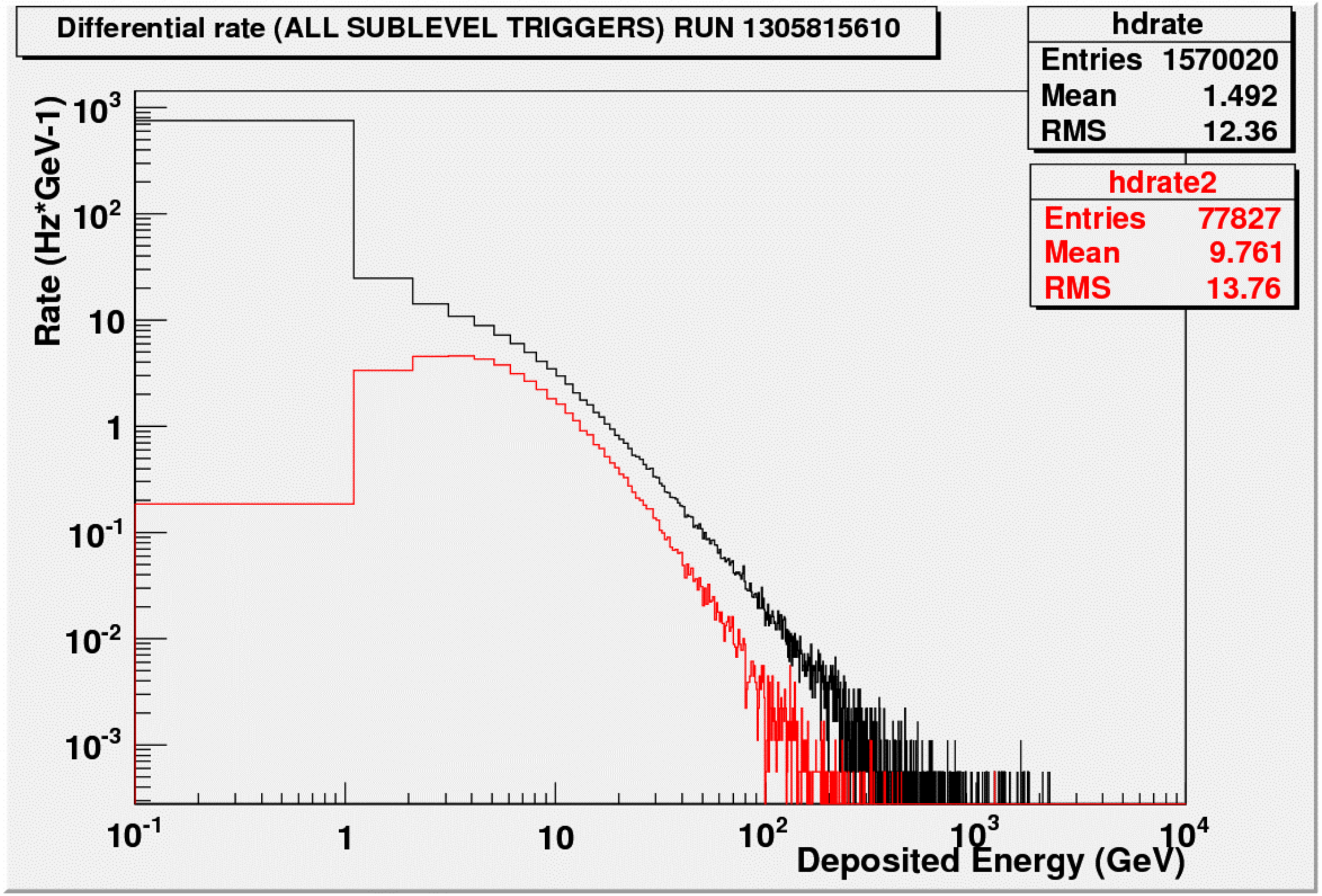
AntiDeuterium



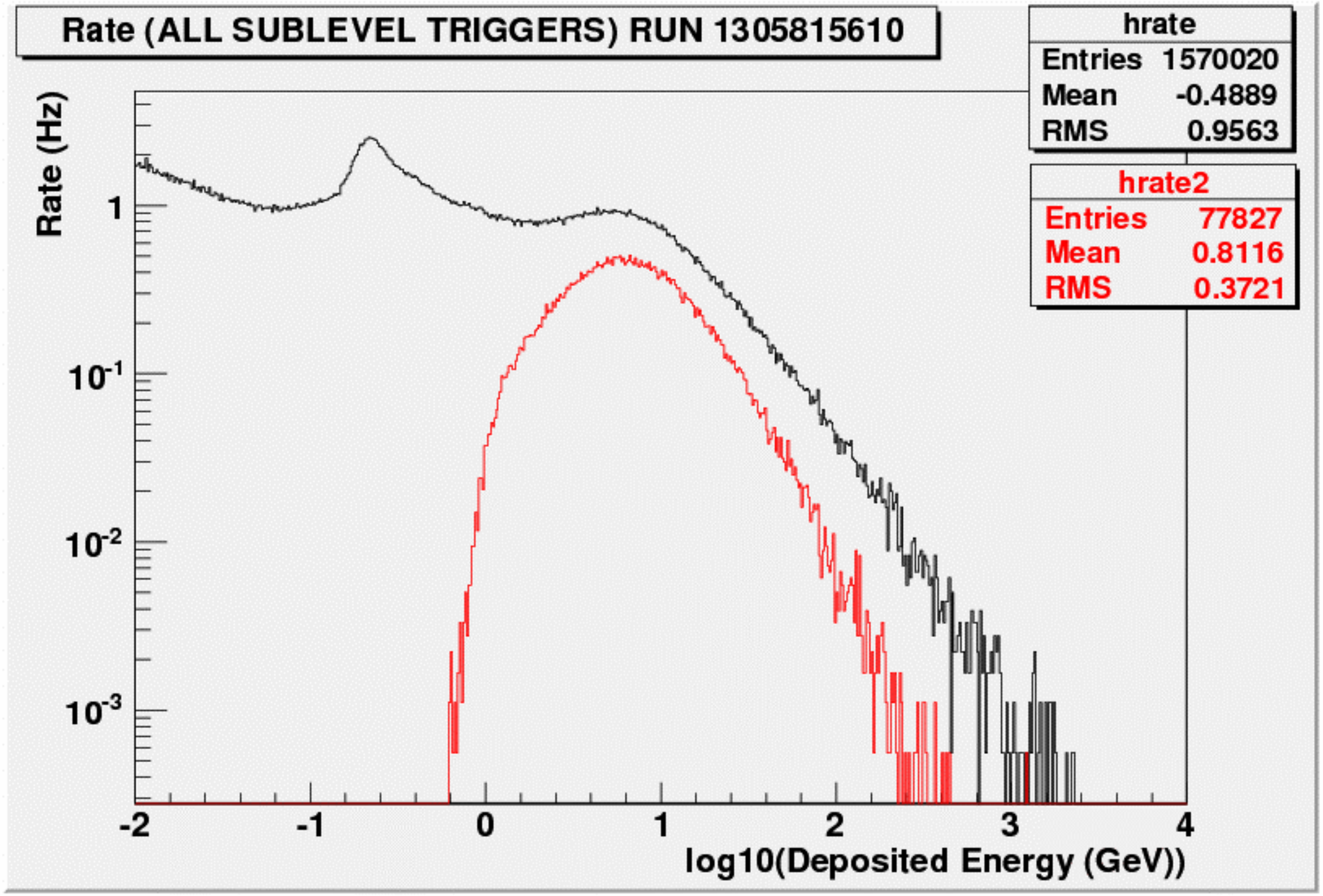
Active Triggers



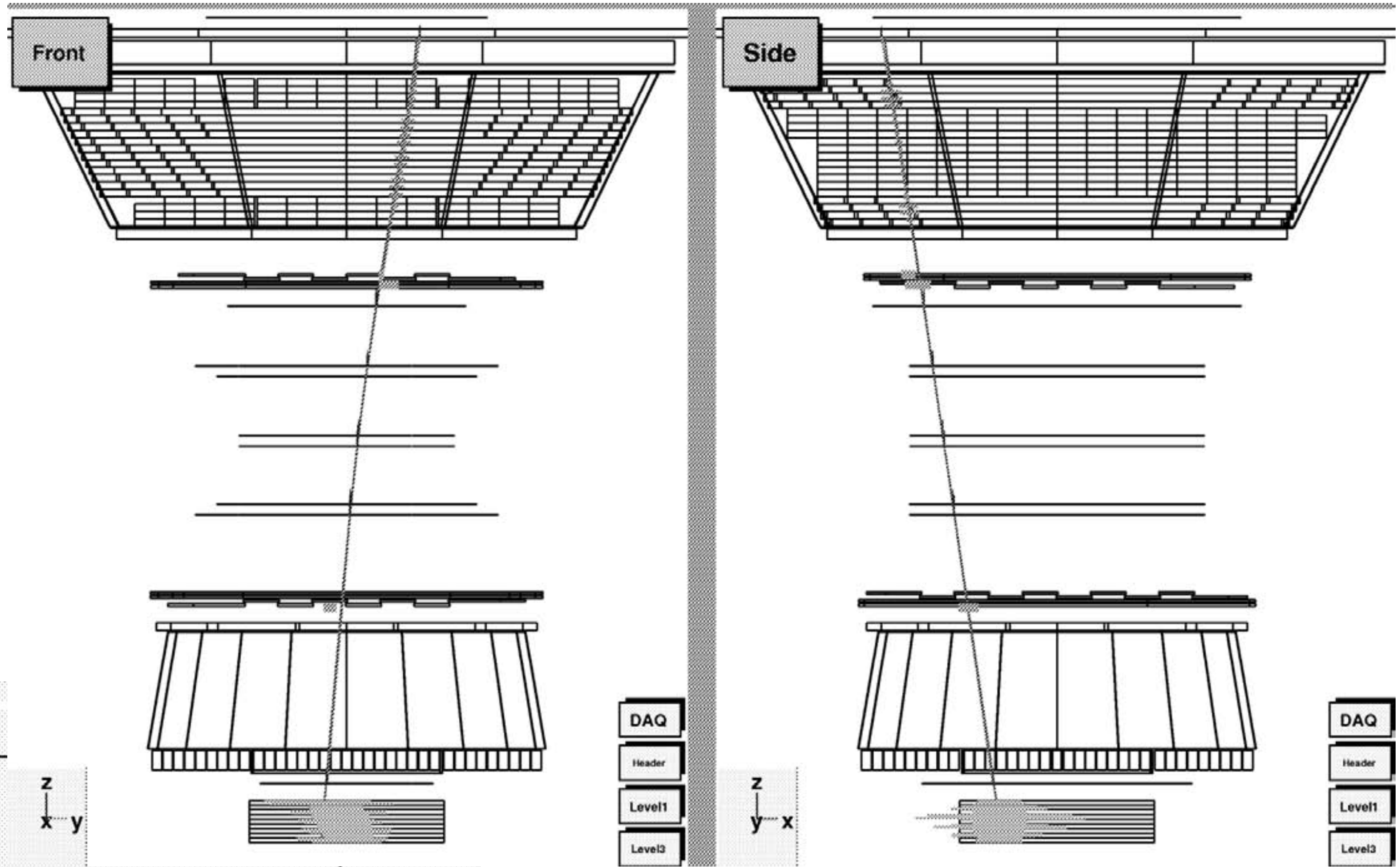
Trigger: Differential Rate

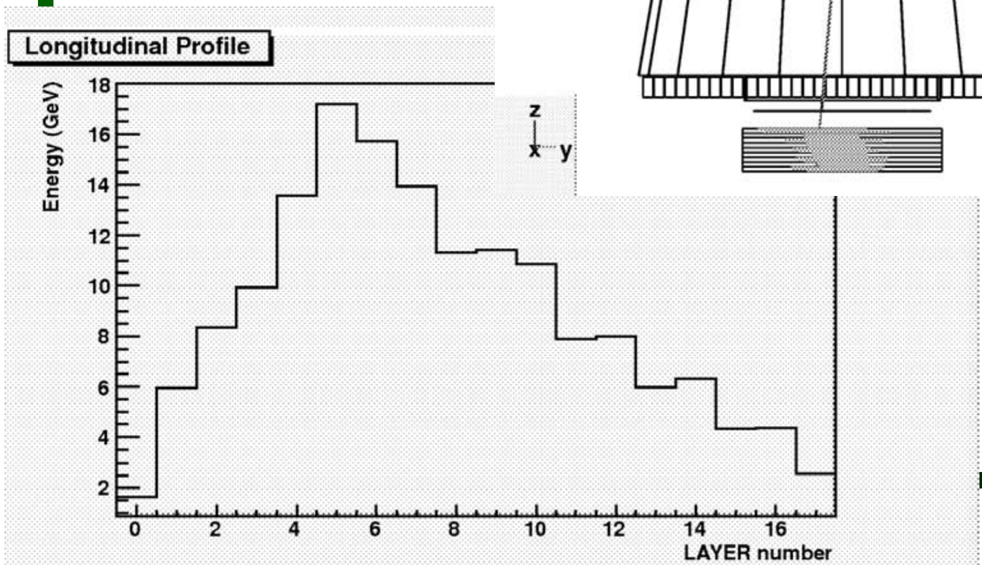


Trigger Rate

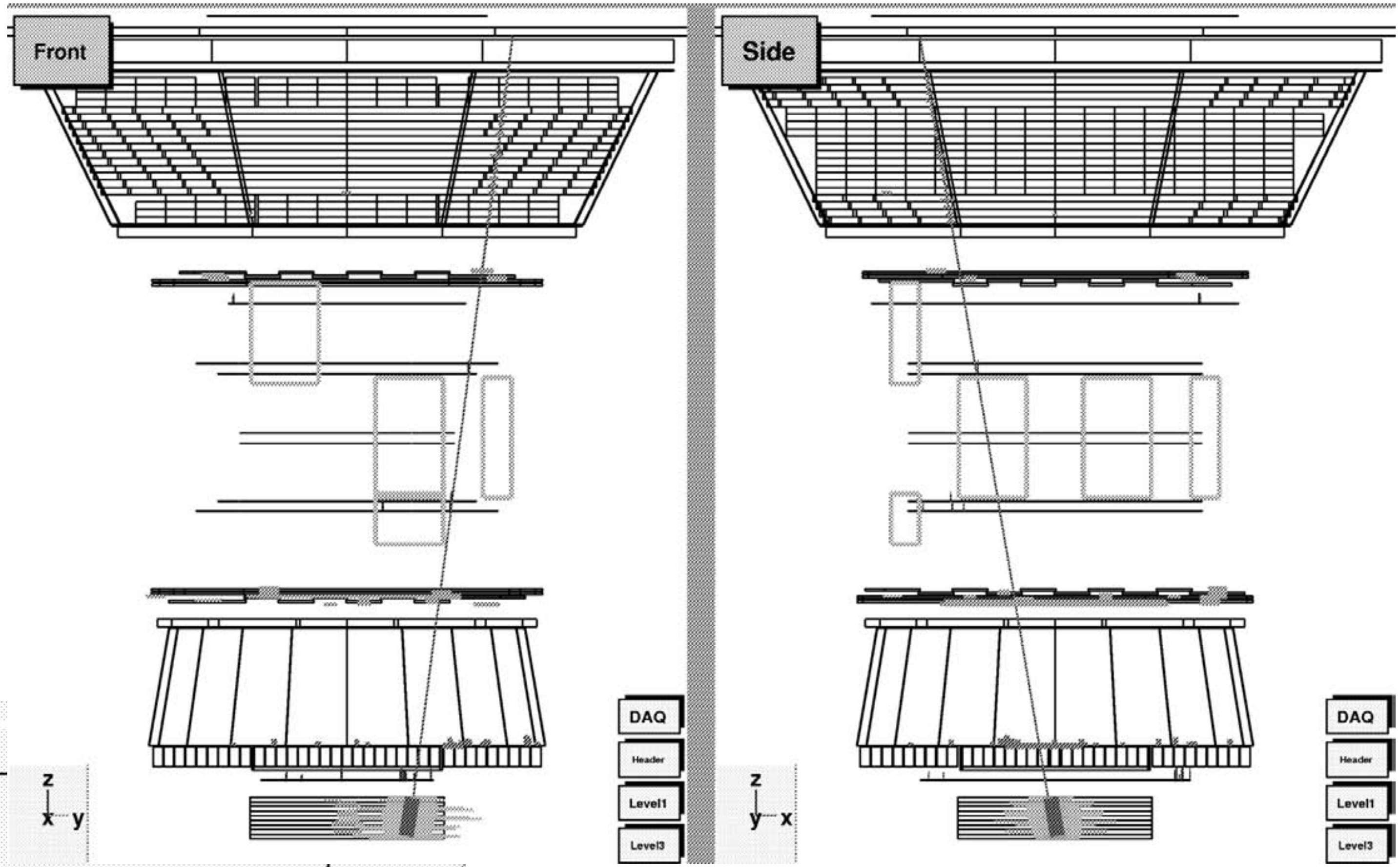


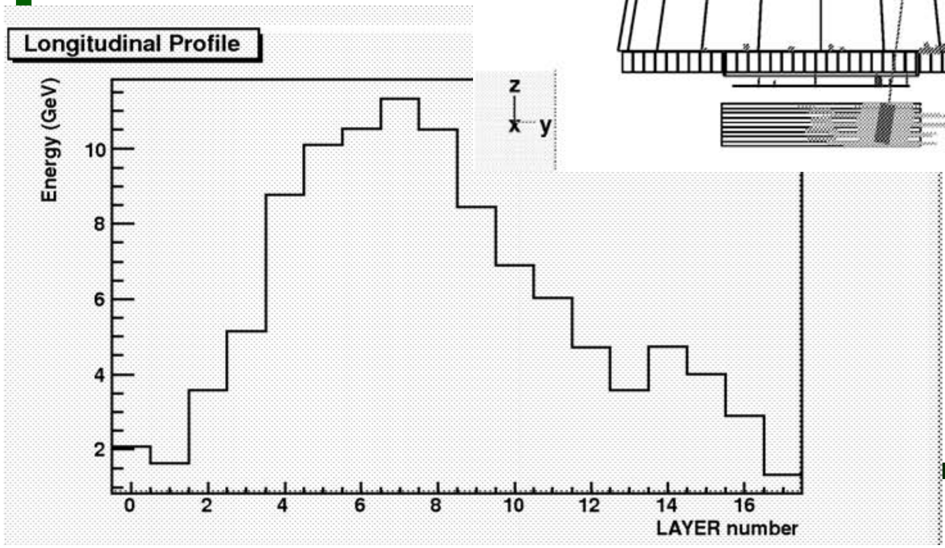
Electron: 158 GeV



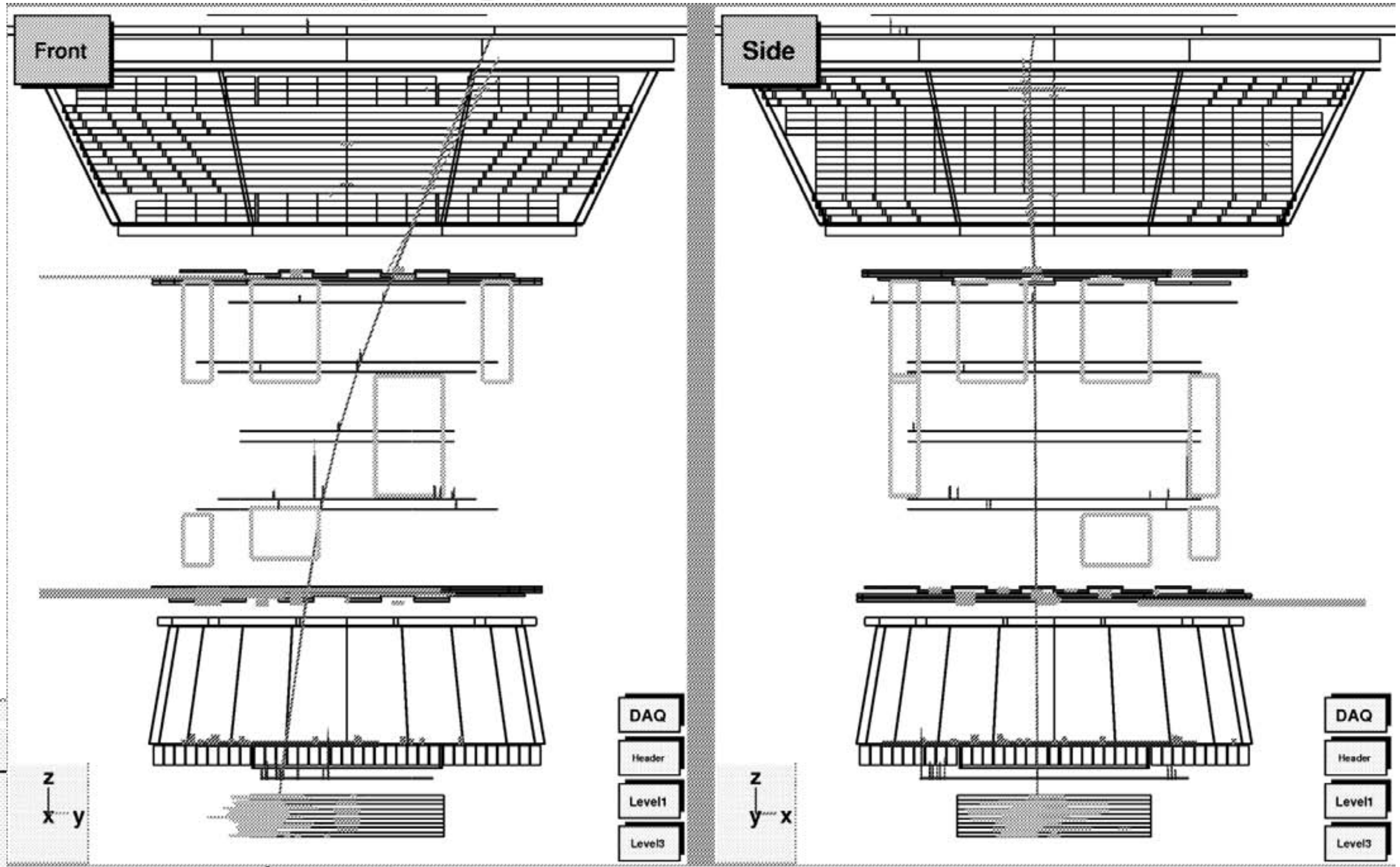


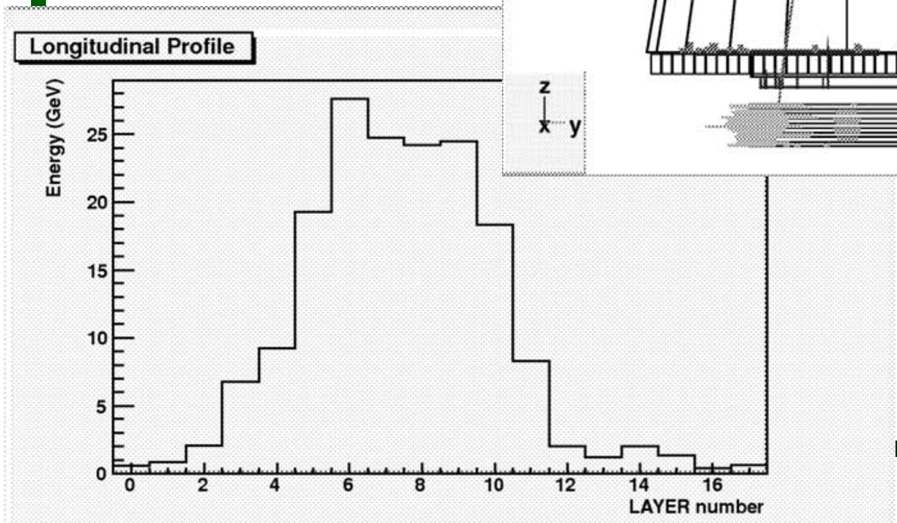
Electron: 112 GeV



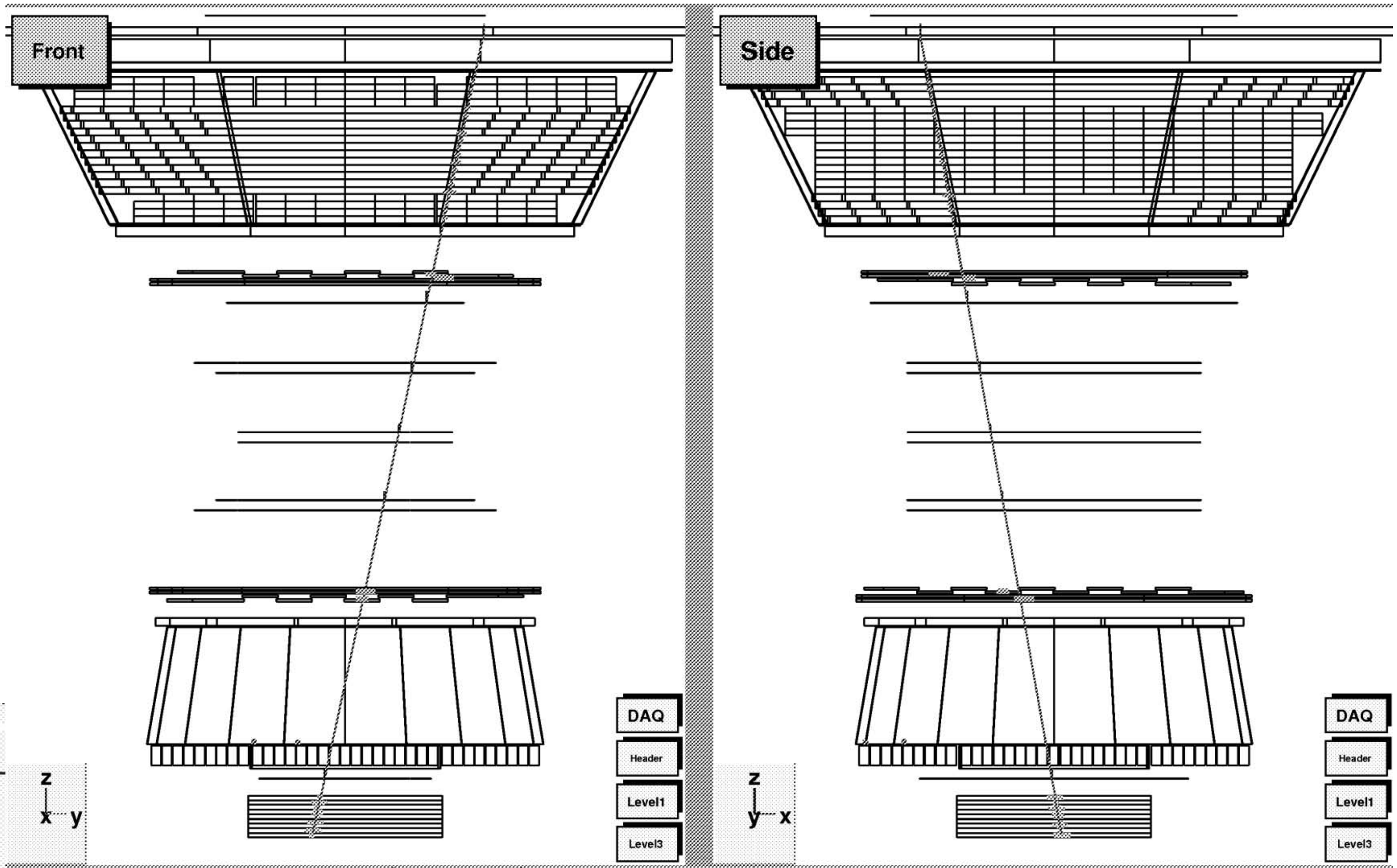


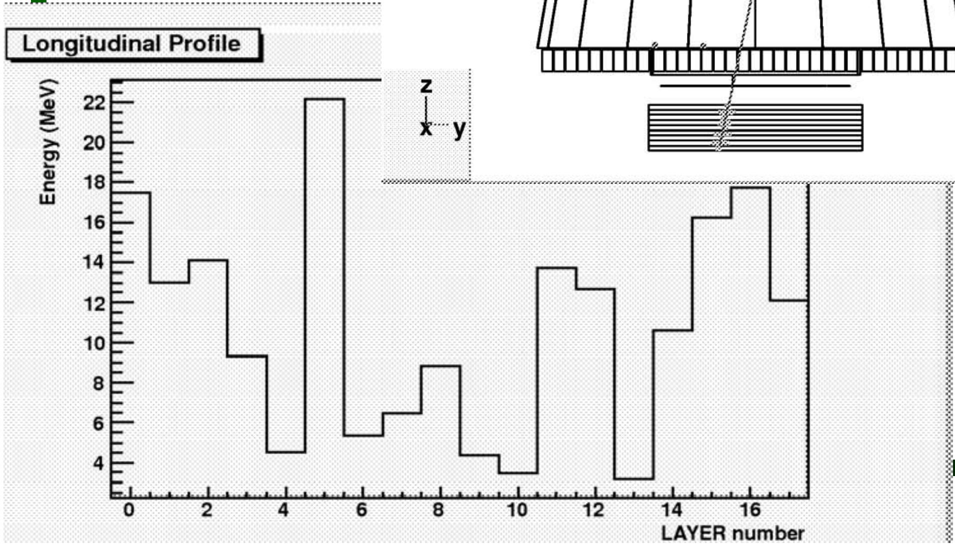
Electron with Lateral Leakage: 178 GeV



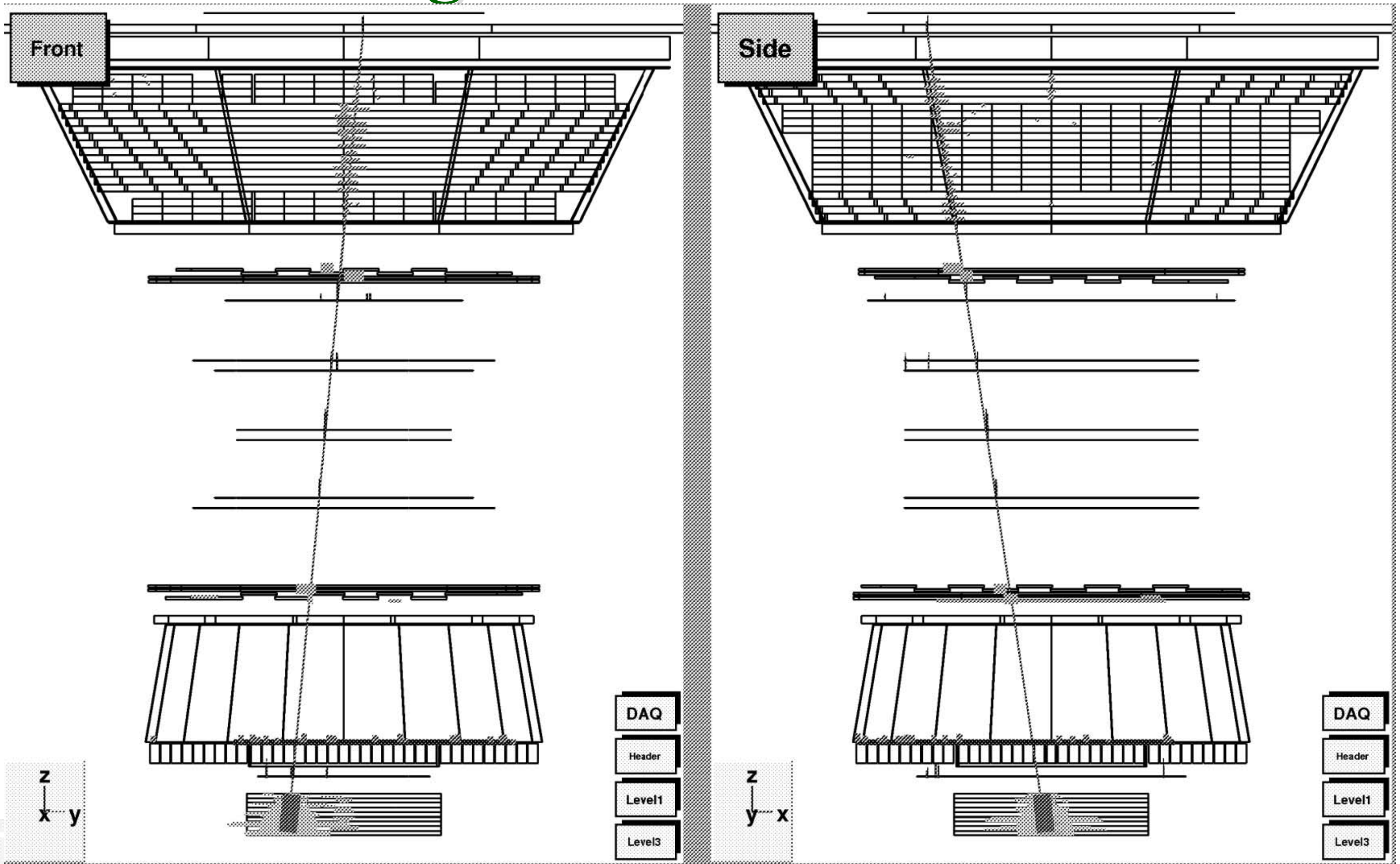


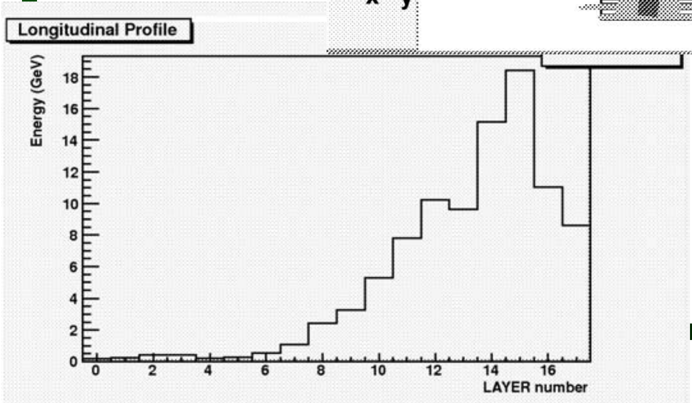
MIP


Front
Side
DAQ
Header
Level1
Level3
z
x
y

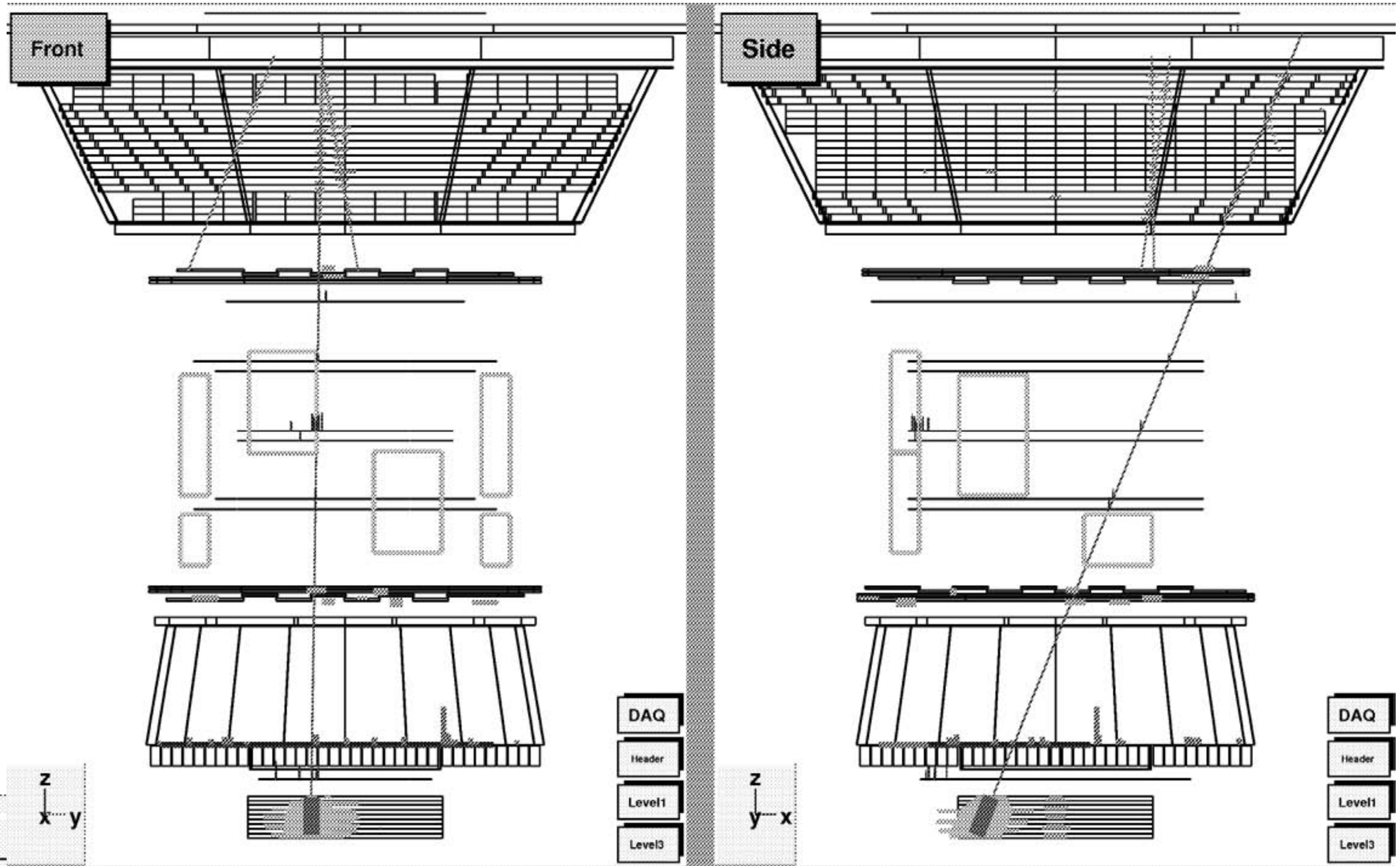

Longitudinal Profile
Energy (MeV)
LAYER number
0
2
4
6
8
10
12
14
16
22
20
18

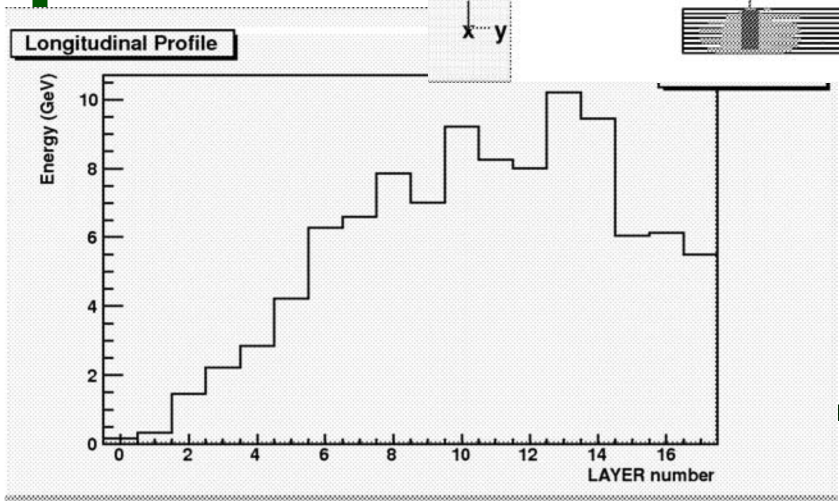
Interacting Proton>95 GeV



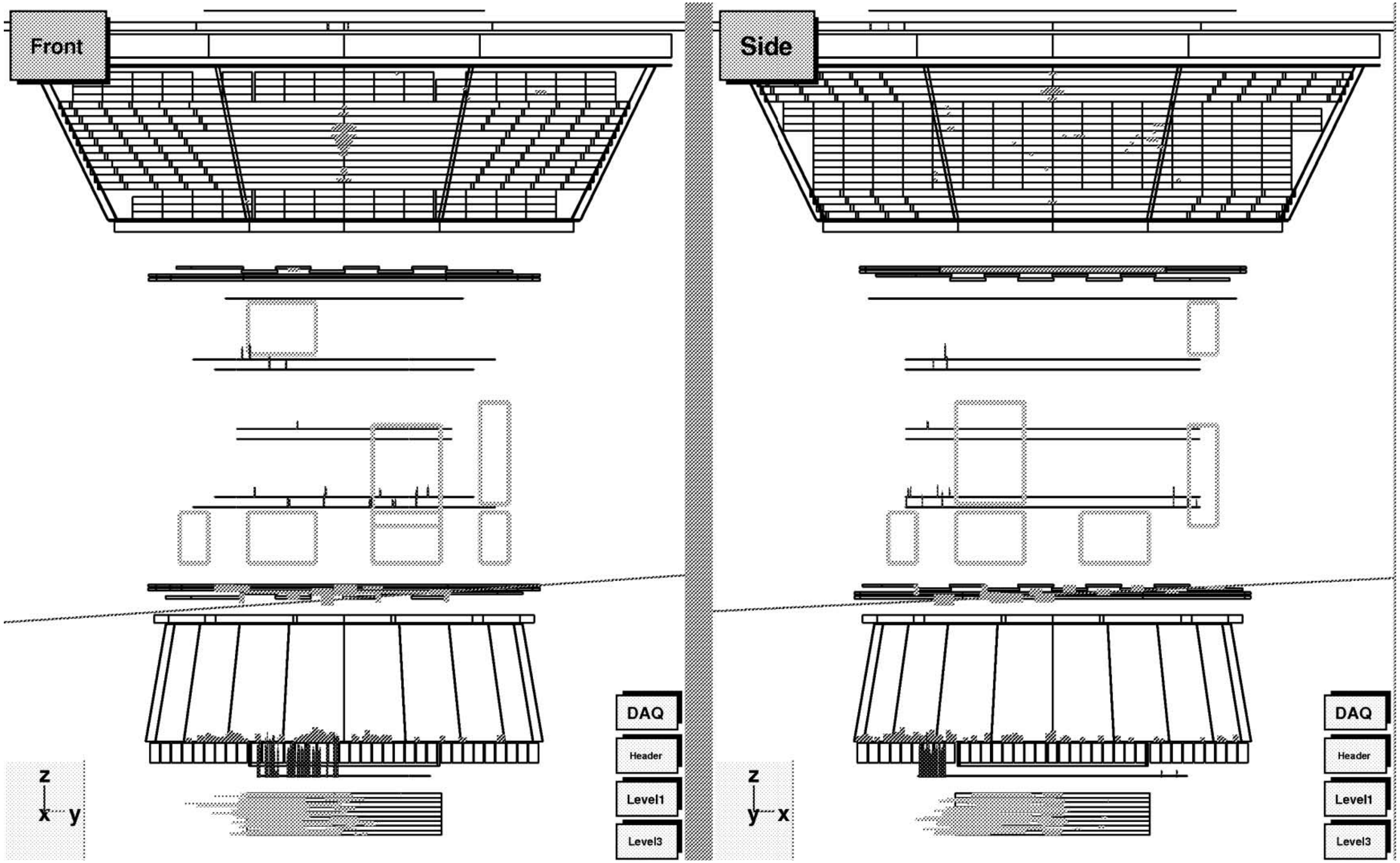


Interacting Proton > 120 GeV





The Long Way to Final Results



Summary

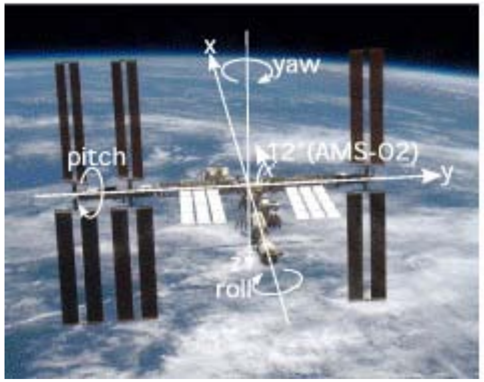
- AMS-02 perfectly complements current big experiments in exploring new physics and is a general purpose instrument

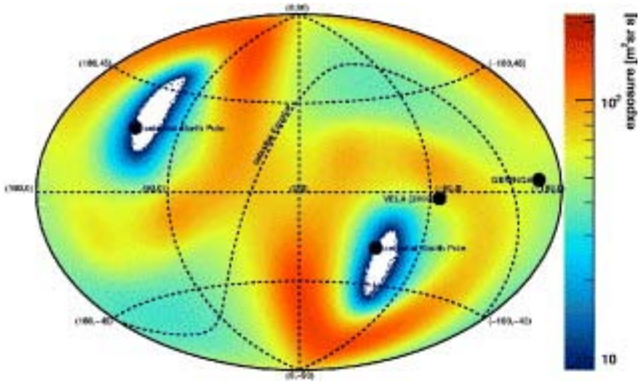
- It will take high statistics and long duration cosmic ray data on board ISS

- It will provide simultaneous measurements to
  – tune parameters of current cosmic models
  – allow combined dark matter search on matter/antimatter ratios and gamma ray spectra

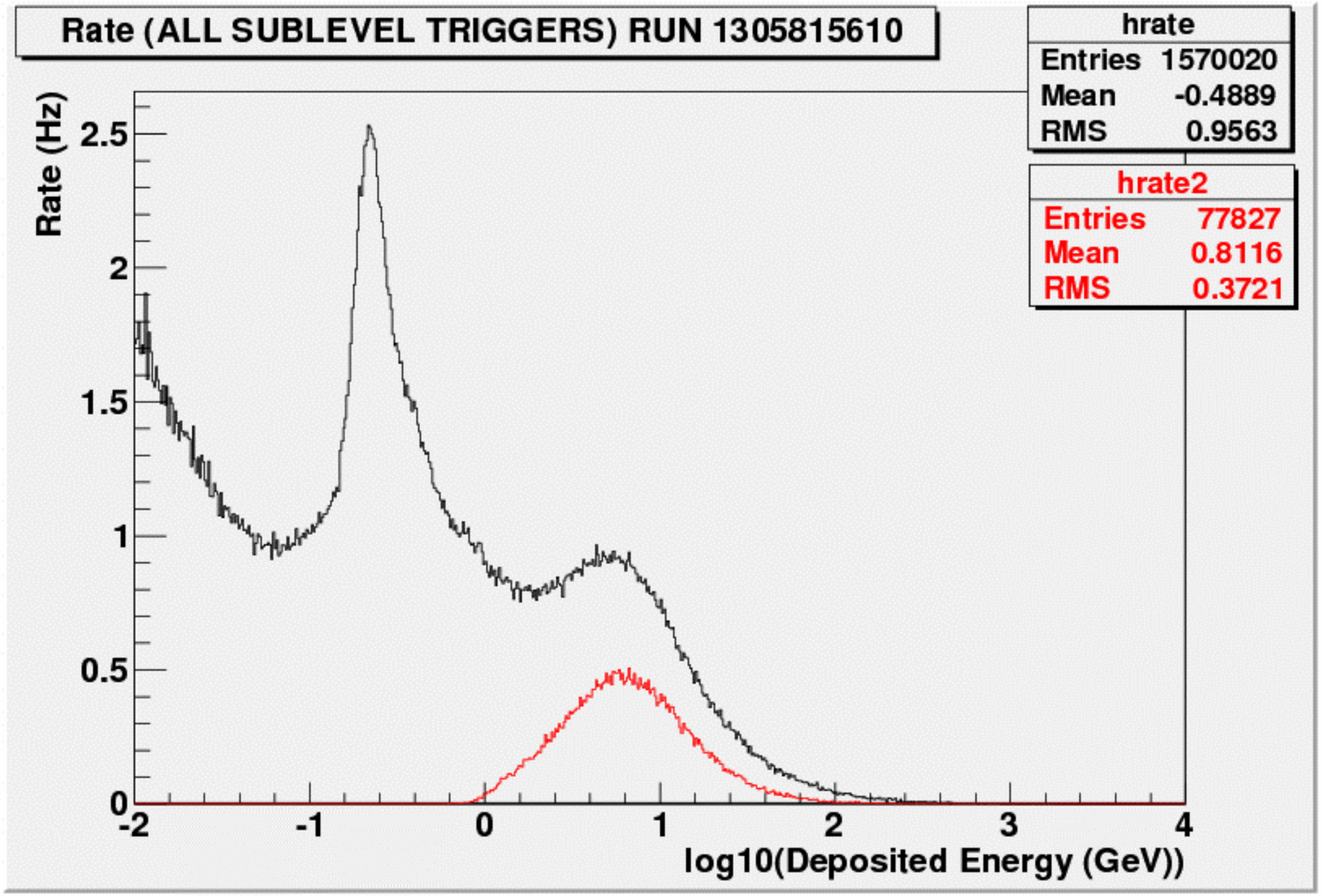
- AMS-02 will strongly extend limits on direct searches for heavy Antimatter as well as exotics in the Universe

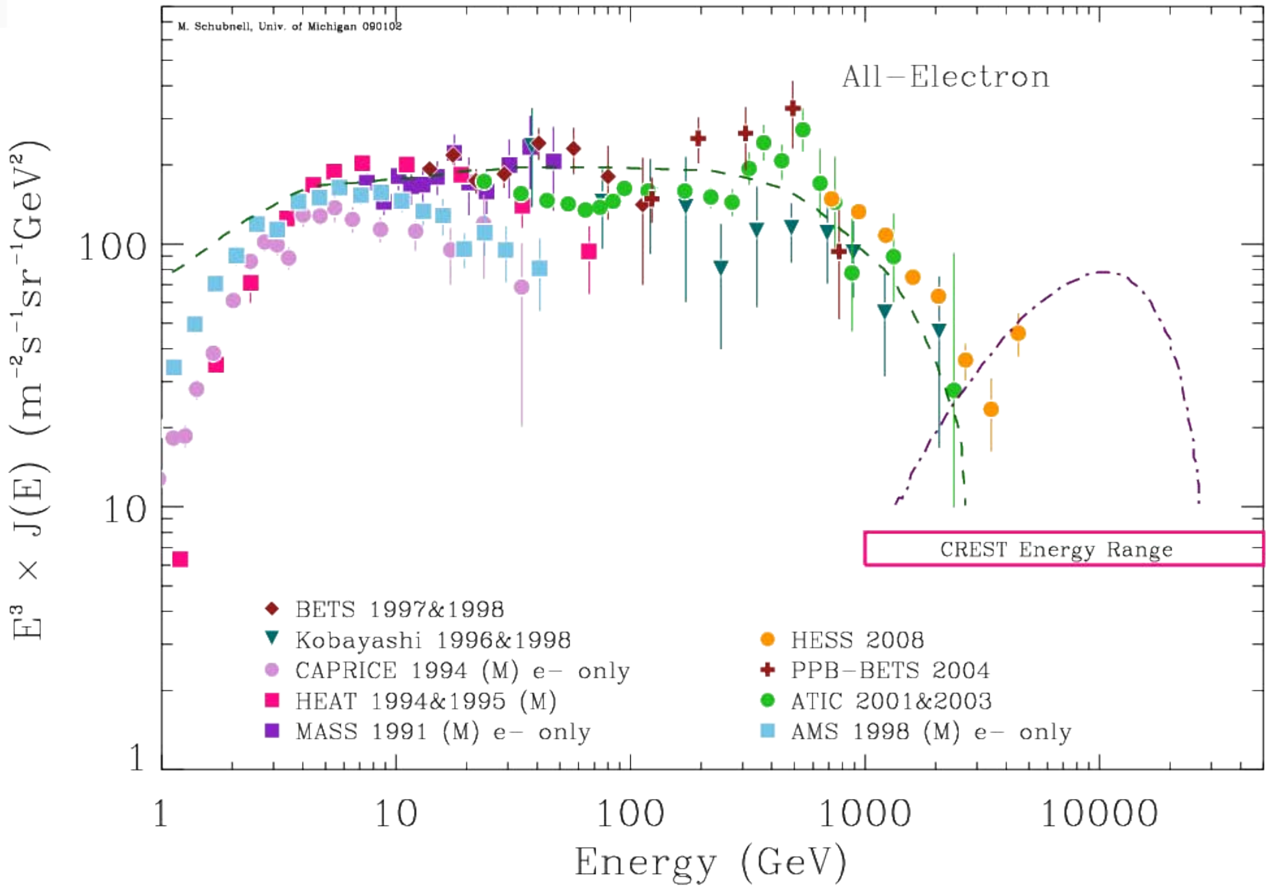
Backups

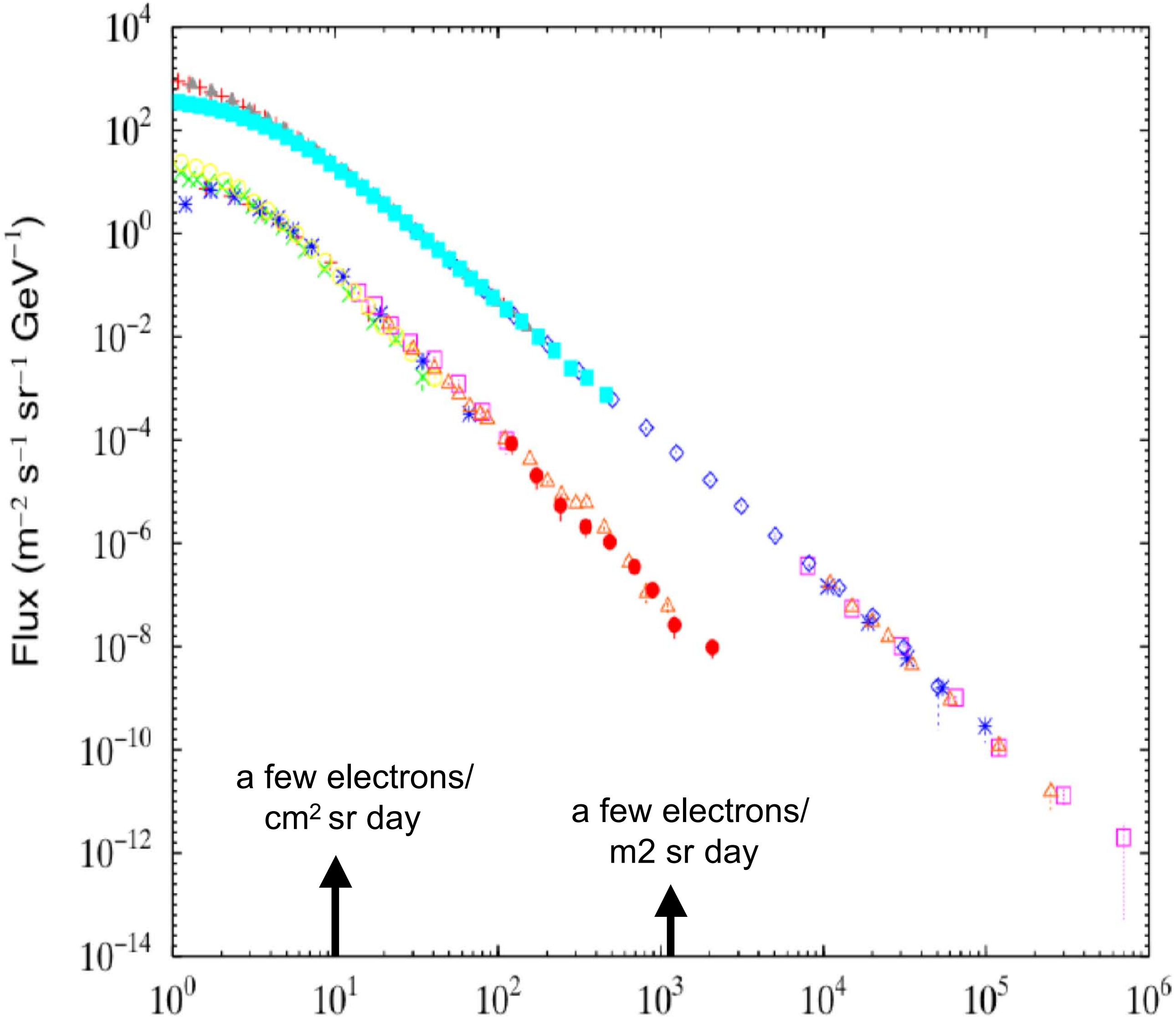

x
yaw
pitch
12°(AMS-02)
y
z
roll


exposure [m²sr s]
10²
10

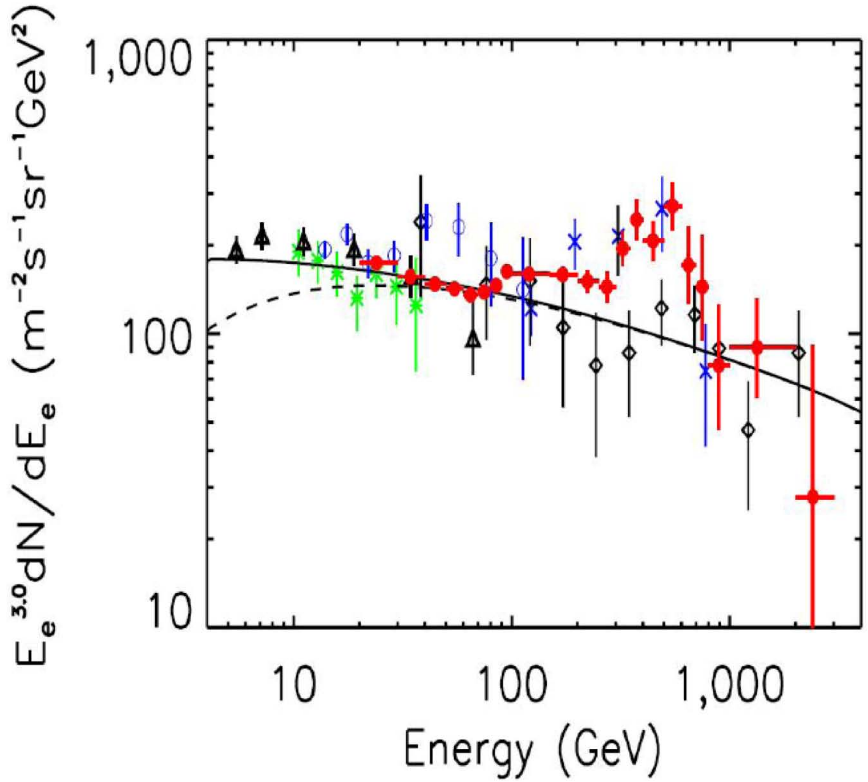
Trigger Rate




M. Schubnell, Univ. of Michigan 090102
All−Electron
$E^3 \times J(E)$ $(m^{-2}s^{-1}sr^{-1}GeV^2)$
Energy (GeV)
CREST Energy Range
BETS 1997&1998
Kobayashi 1996&1998
CAPRICE 1994 (M) e− only
HEAT 1994&1995 (M)
MASS 1991 (M) e− only
HESS 2008
PPB−BETS 2004
ATIC 2001&2003
AMS 1998 (M) e− only

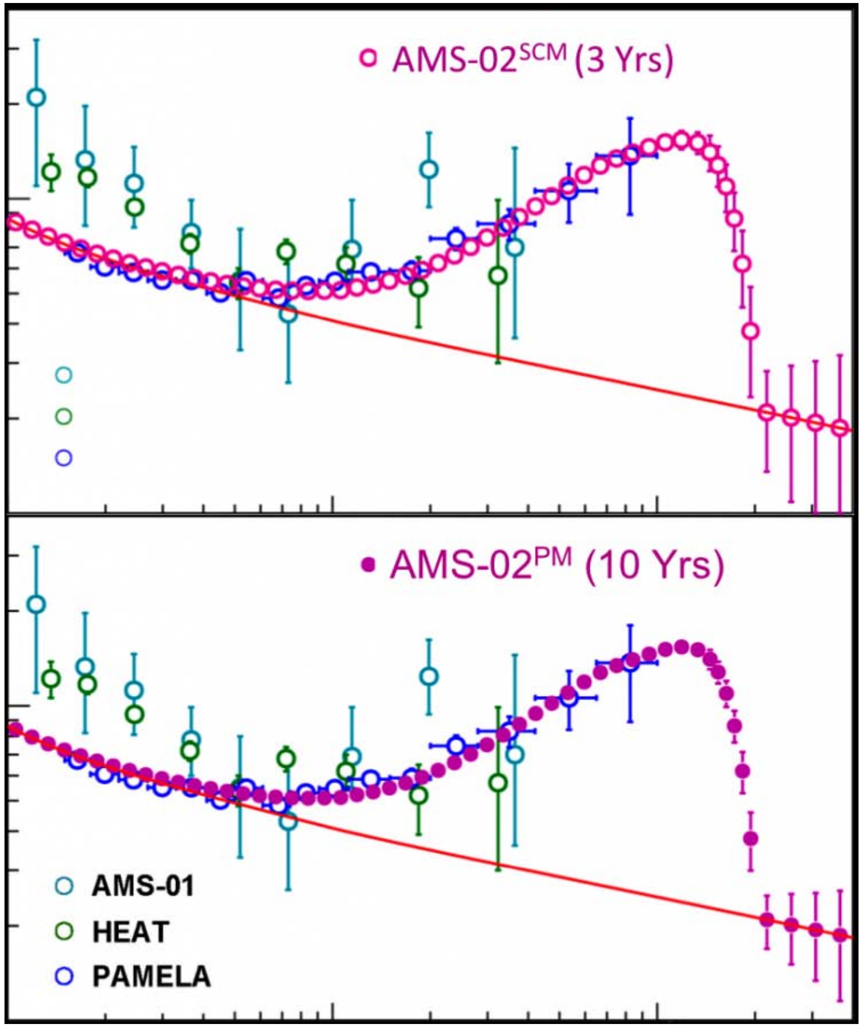


Flux (m^{-2} s^{-1} sr^{-1} GeV^{-1})
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
a few electrons/
cm^{2} sr day
a few electrons/
m2 sr day

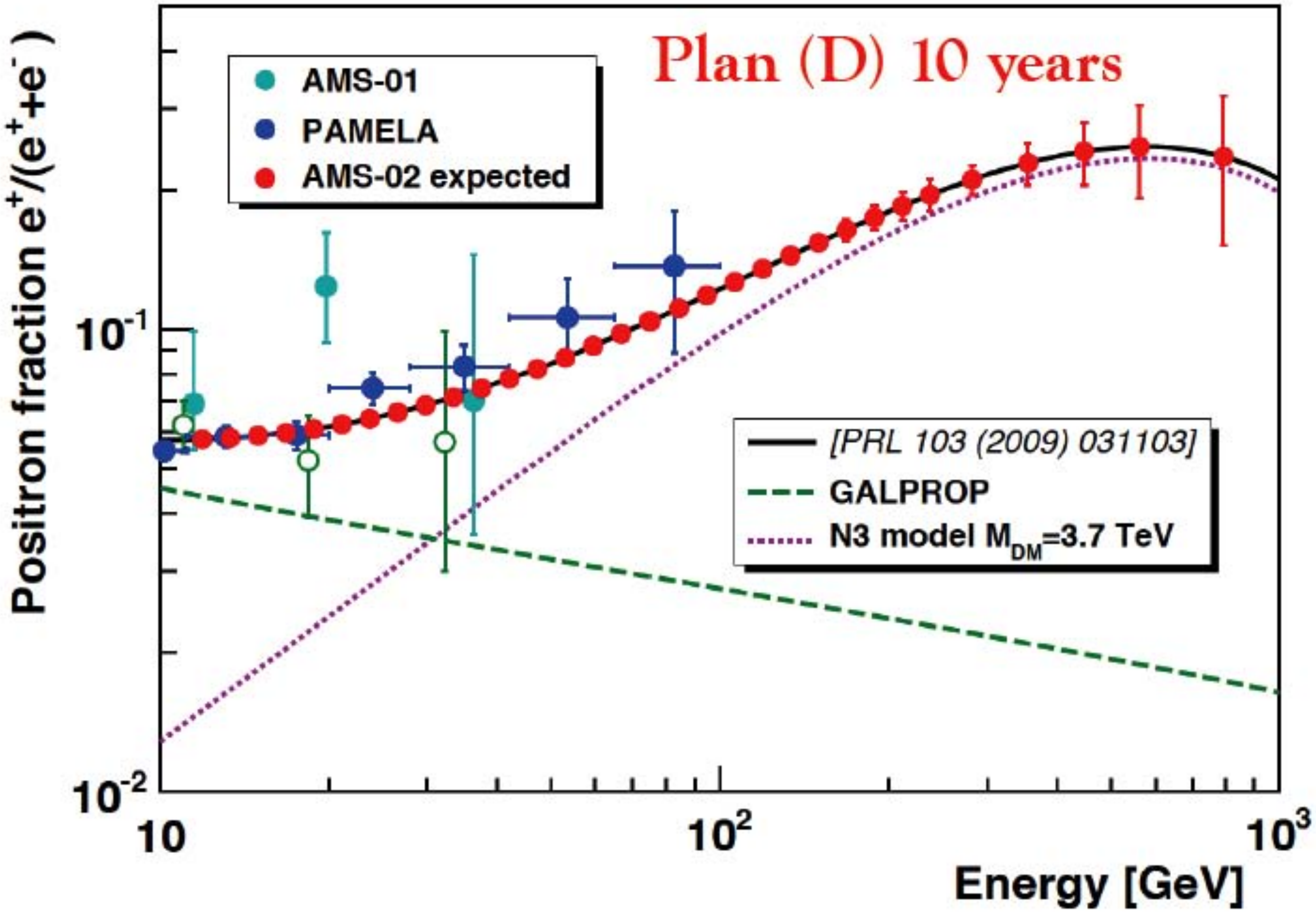


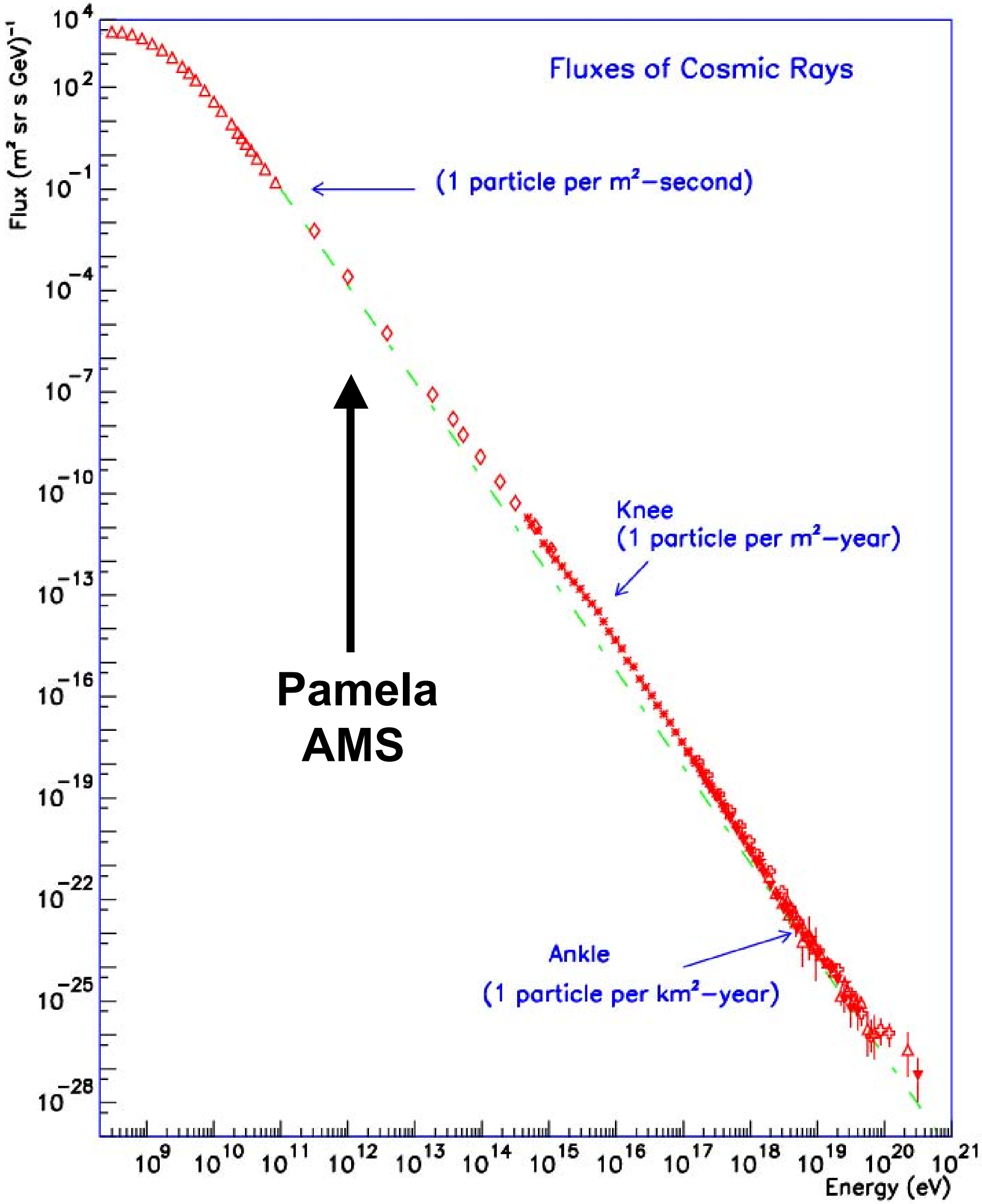
1,000
100
10
10
100
1,000
Energy (GeV)
$E_e^{3.0} dN/dE_e$ ($m^{-2}s^{-1}sr^{-1}GeV^2$)

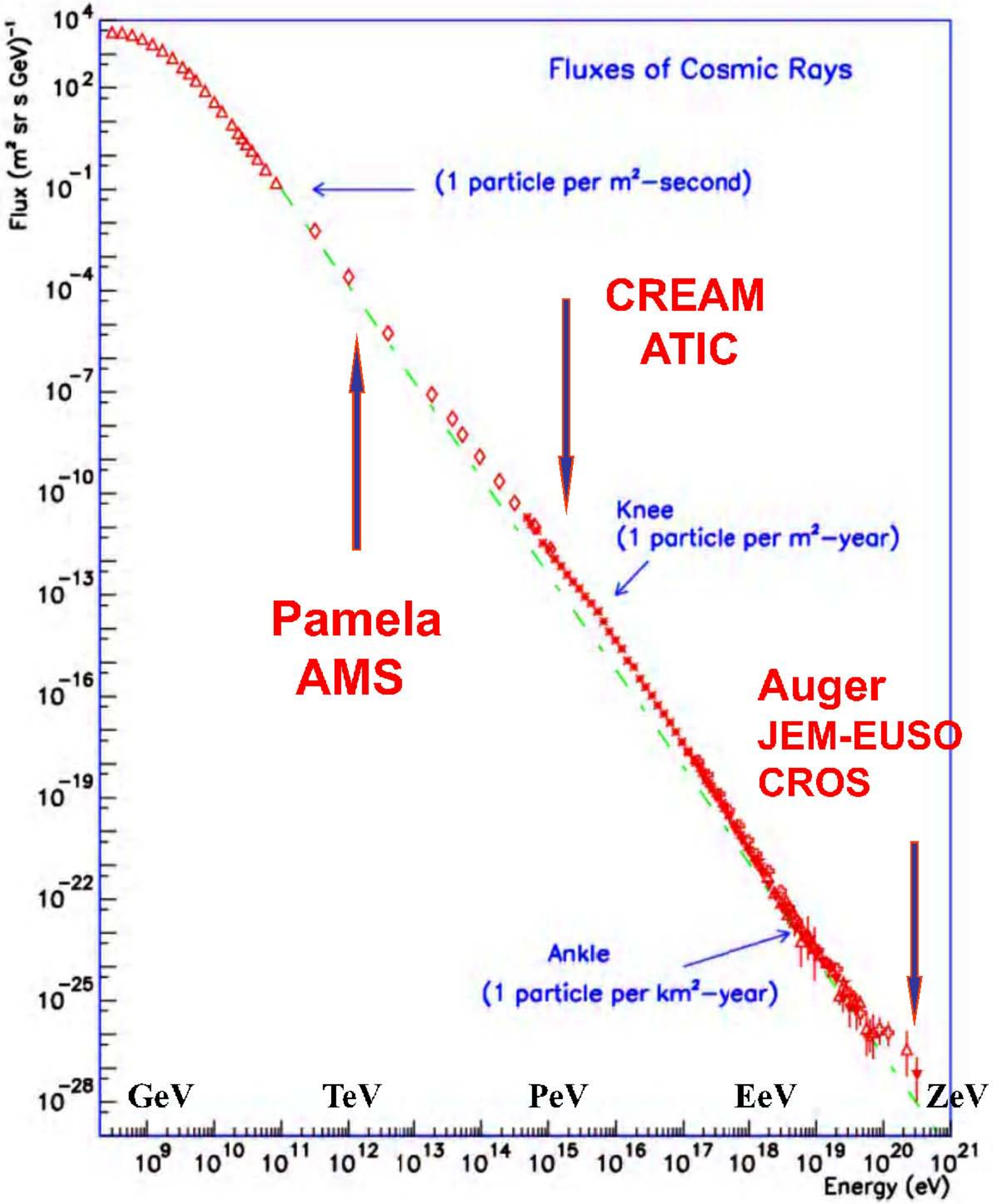
Neutralino candidate for m=200GeV

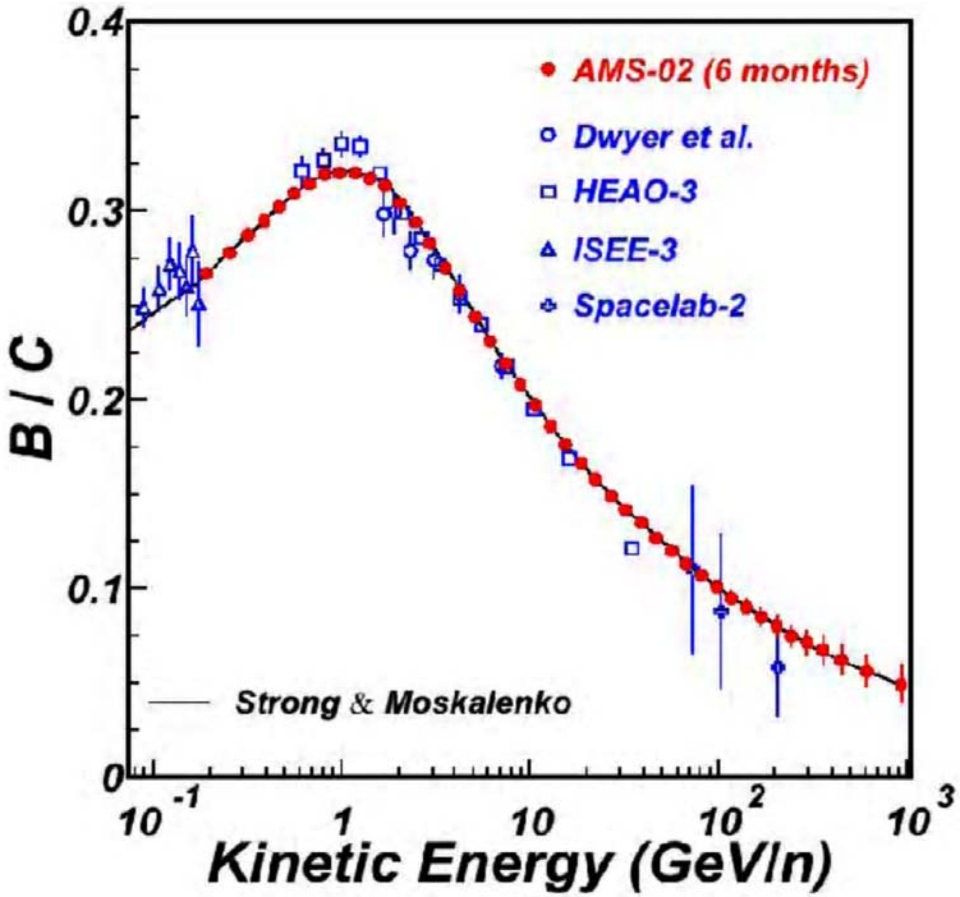


Estimation of e+ fraction

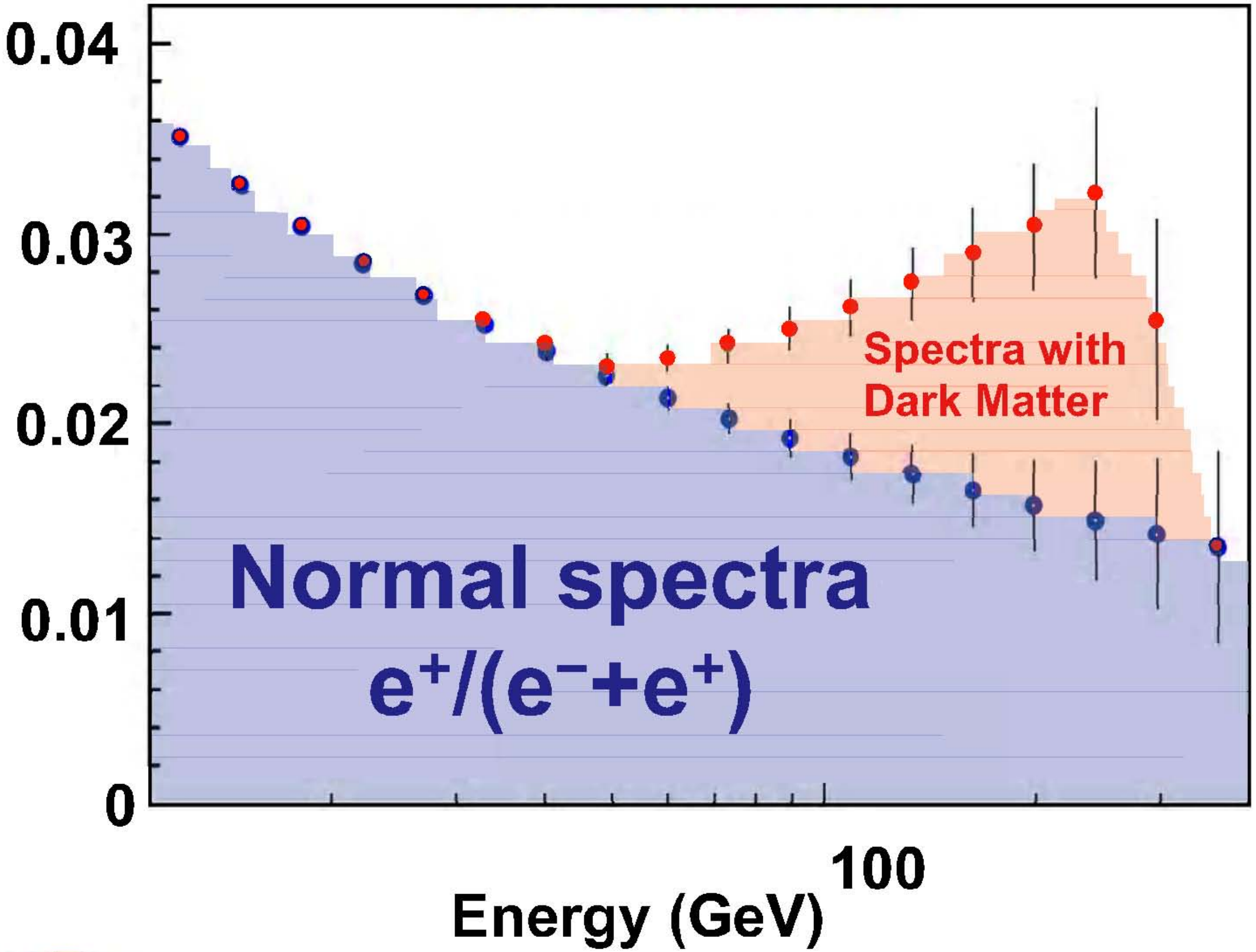



Fluxes of Cosmic Rays
Flux (m² sr s GeV)⁻¹
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
Pamela
AMS
Energy (eV)

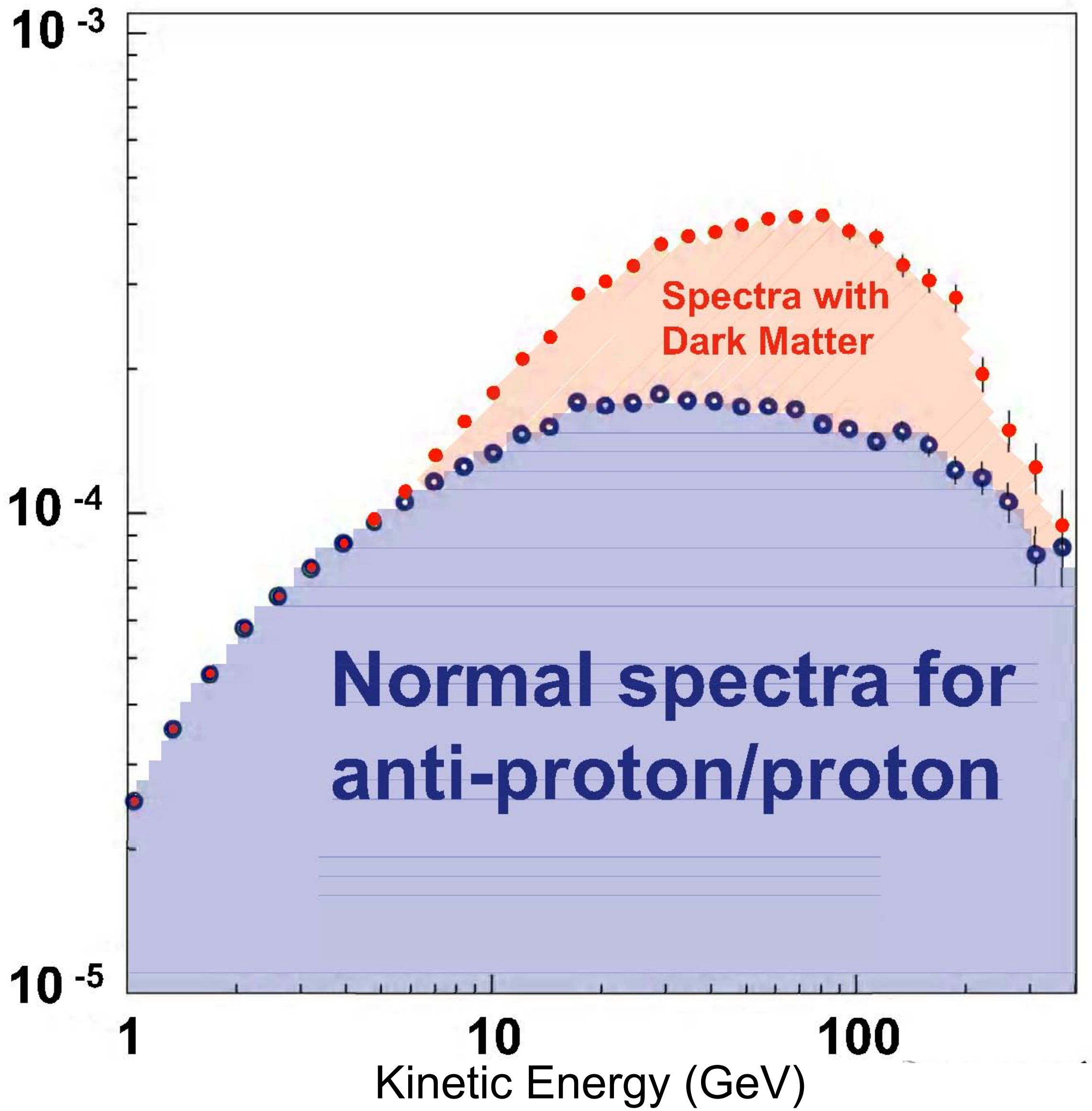

Fluxes of Cosmic Rays
Flux (m² sr s GeV)⁻¹
(1 particle per m²–second)
CREAM
ATIC
Knee
(1 particle per m²–year)
Pamela
AMS
Auger
JEM-EUSO
CROS
Ankle
(1 particle per km²–year)
GeV
TeV
PeV
EeV
ZeV
Energy (eV)



AMS-02 (6 months)
Dwyer et al.
HEAO-3
ISEE-3
Spacelab-2
Strong & Moskalenko
B / C
Kinetic Energy (GeV/n)



Dark Matter is a Kaluza-Klein Boson
- assumes extra dimensions - with a typical
mass of MB = 300GeV



Dark Matter is a supersymmetric particle
with MX = 840 GeV.
This is barely accessible to LHC


Alpha Magnetic Spectrometer
AMS-02

Alpha Magnetic Spectrometer
AMS-02

AMS-02

LA RICERCA SCIENTIFICA

AMS cerca l'altra materia

1. Antimateria

AMS cerca quella primordiale.

Se trovasse un solo nucleo di **anti-elio** vorrebbe dire che esistono grandi quantità di antimateria nucleare nascosta da qualche parte nell'Universo.

Materia e antimateria

2. Materia oscura

AMS potrebbe osservare eccessi di alcune particelle rare e questo potrebbe essere causato dalla presenza della **misteriosa materia oscura**, per esempio potrebbe essere dovuta a particella chiamata **neutralino.**

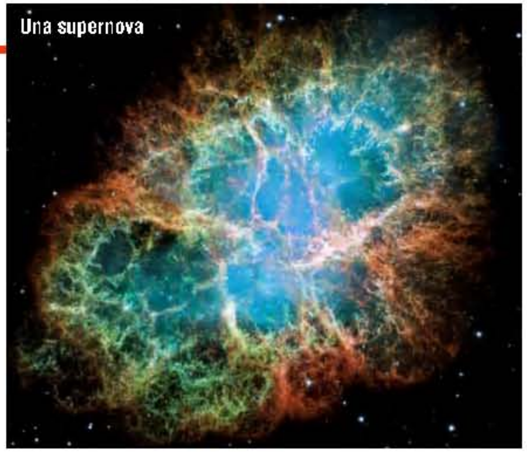
Materia oscura

3. Materia strana

Sulla Terra, tutti gli atomi sono fatti da due tipi di quark (up e down).

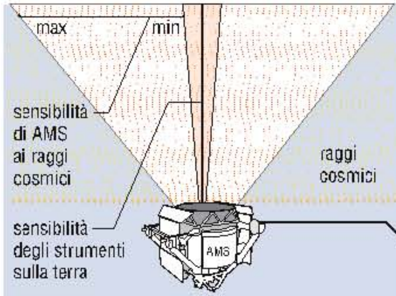
Ma potrebbe esistere nello spazio della materia fatta anche con altri tipi di quark.

È la **"materia strana"**, composta da particelle chiamate "strangelets' che sarebbero rivelabili da AMS.



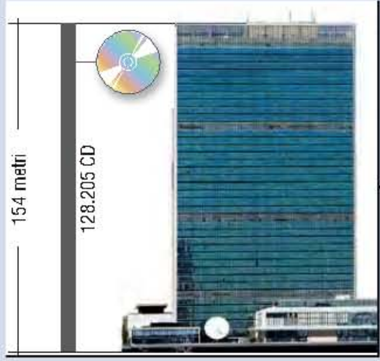
Una supernova

AMS è l'Hubble dei raggi cosmici



1. AMS cercherà nuovi tipi di materia catturando un'enorme quantità di raggi cosmici.

2. AMS è in grado - come è stato per il telescopio spaziale Hubble - di aumentare di un grande fattore, compreso **tra 100 e 1000,** la sensibilità alle componenti rare dei raggi cosmici.



È la quantità di dati che potrebbe stare in una colonna di CD sovrapposti alta quanto il Palazzo di vetro dell'ONU

3. L'esperimento in dieci anni raccoglierà l'equivalente di **100 Terabyte di dati.**

4. A bordo di AMS i dati di **300.000 canali di elettronica,** pari a tutti i canali della Stazione Spaziale, sono compressi di un fattore 1000, prima di inviarli sulla Terra, utilizzando una banda di comunicazione di **6 Mbit al secondo.**

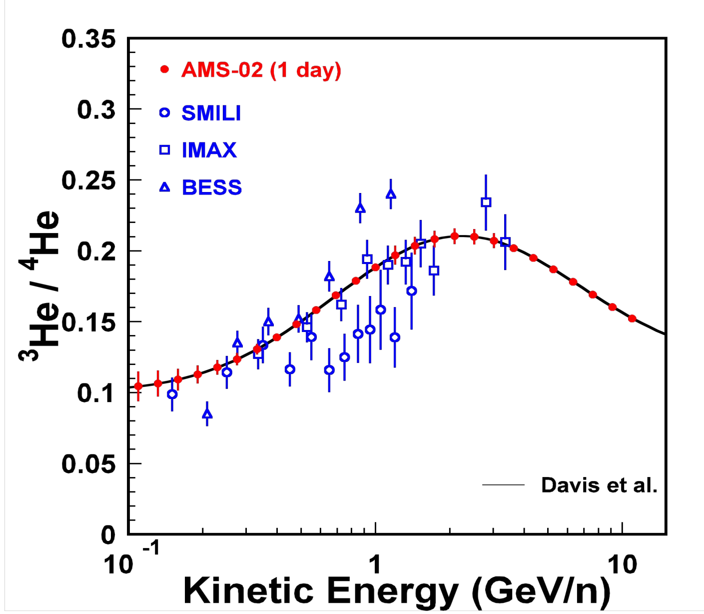
Le domande alla base della ricerca

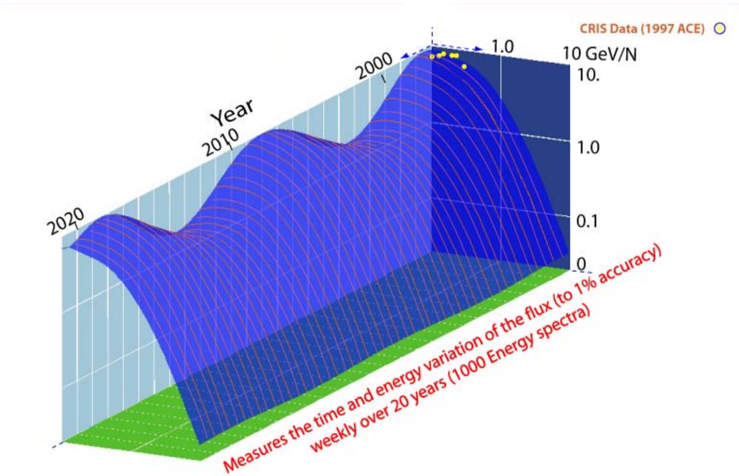
- Perché materia e antimateria, simmetricamente presenti all'inizio dell'Universo, hanno seguito due destini diversi?
- Come mai solo l antimateria è praticamente sparita?
- Esistono davvero le particelle di materia oscura di cui vediamo gli effetti nelle galassie ma che non riusciamo ad osservare direttamente?
- La ricetta a base di quark per la materia esistente sulla Terra può non essere la stessa nel resto del cosmo?

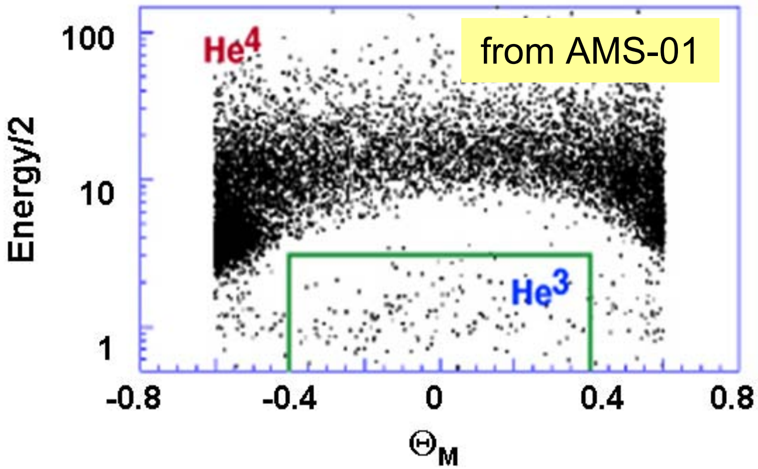

FW
AFT
NASA

Isotope Identification

- AMS-02 can destinguish ^{4}He and ^{3}He
- There is room for discoveries in different channels
  - Unexpected result from AMS-01: He Isotopes are completely separated
- AMS-02 is also a long duration cosmic radiation monitor (e.g. solar modulation)

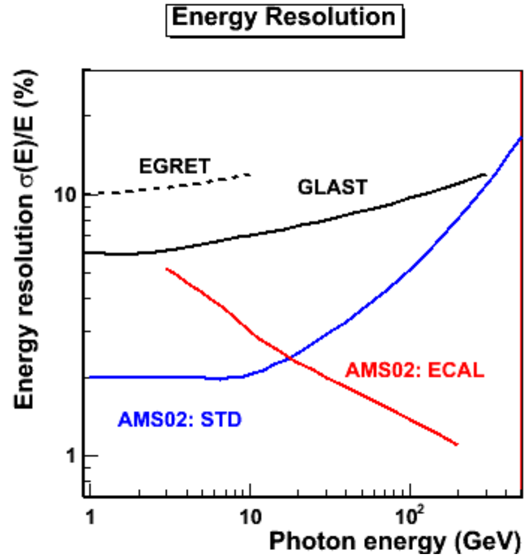


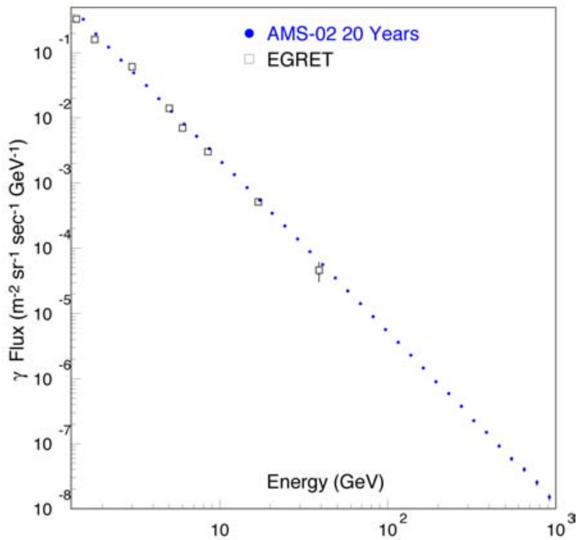


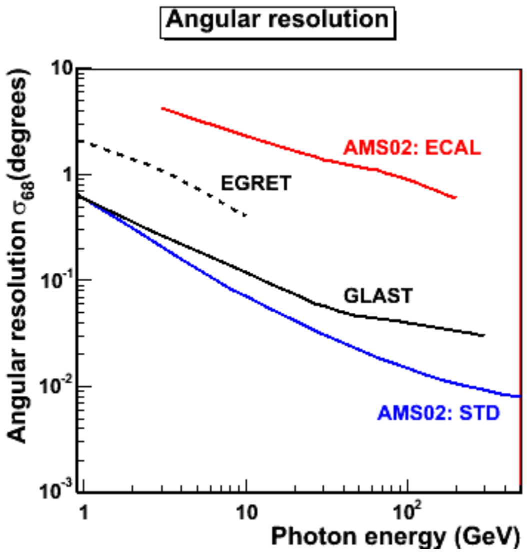


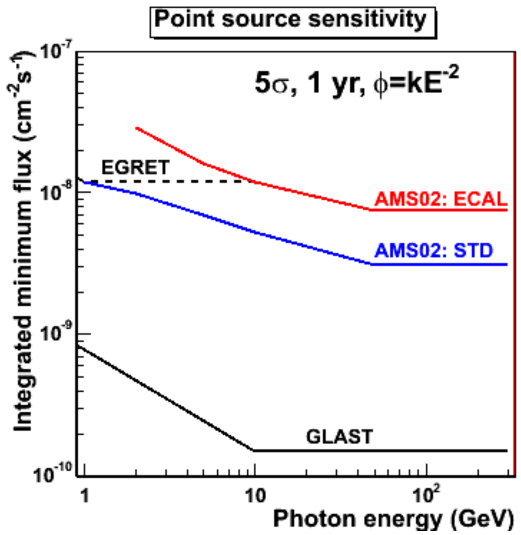
Diffuse Gamma Rays and Sky Survey

- Two complementary modes for Gamma detection
- Main source: cosmic ray interaction with gas (Pion decay, Bremsstrahlung, Inverse Compton)
- Information about
  - Interstellar matter
  - Accelerating processes and origin of cosmic rays in 'standard' astrophysics









Alpha Magnetic Spectrometer
AMS-02

Alpha Magnetic Spectrometer

AMS-02

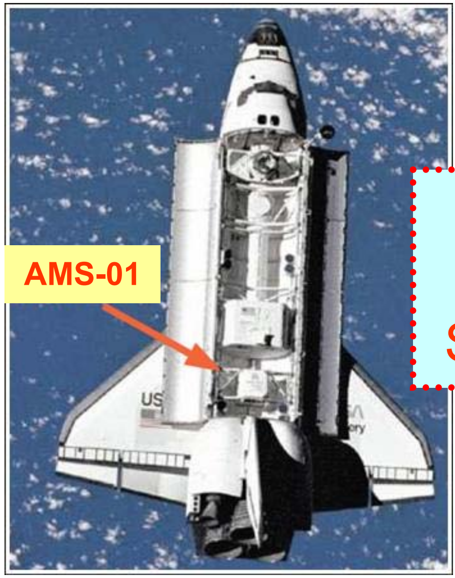
Europe • Asia

North America

Alpha Magnetic Spectrometer
AMS-02
Europe • Asia
North America

The AMS Project: History and Future

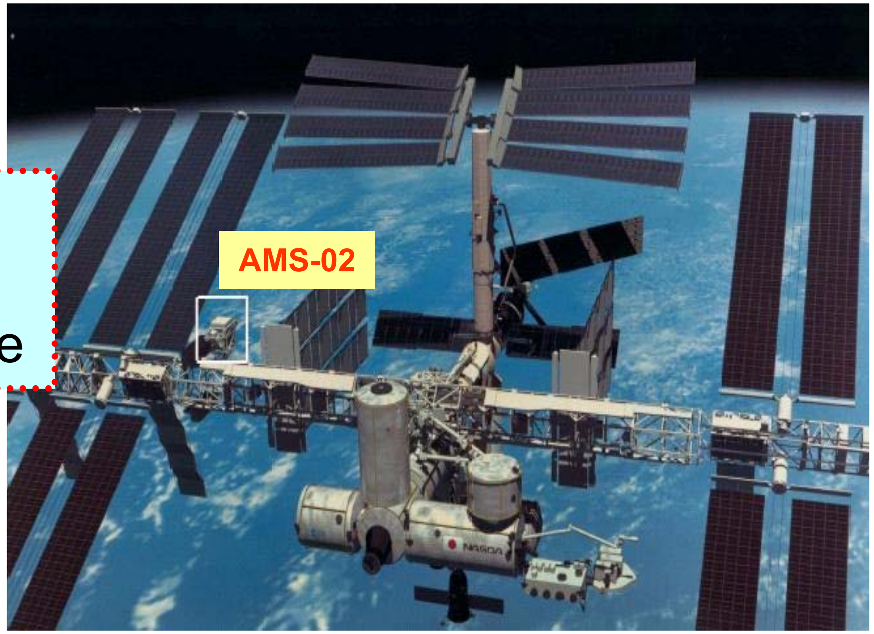
1998



10 days Precursor Flight on board the Space Shuttle Discovery

Alpha Magnetic Spectrometer

2010 again ready for launch

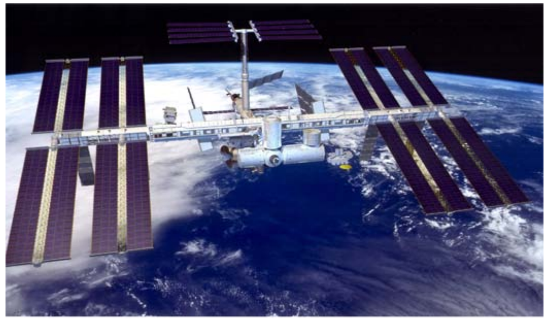


10 years on the International Space Station ISS with 1000-times higher statistics

Spectra of primary and secondary p,e and He

Permanent magnet and new subdetectors for better particle identification:
Precise antimatter and heavy nuclei fluxes measurement

Outline

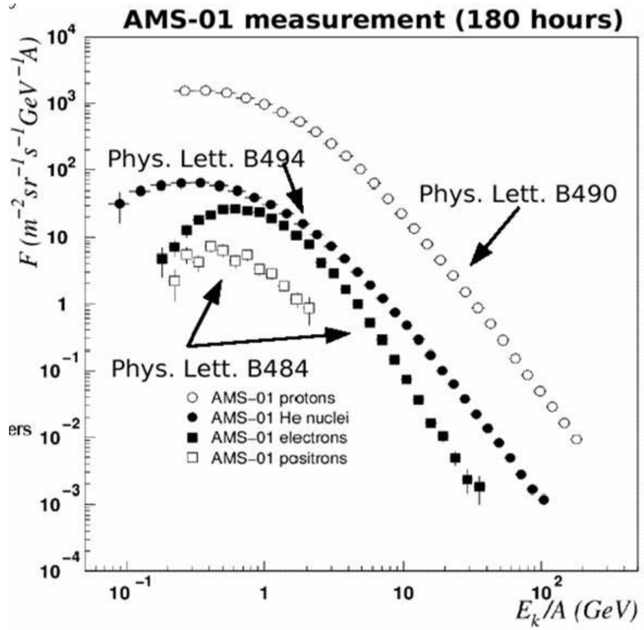


- AMS-02 Experiment
  on board the ISS

- Science with AMS-02 and Achievement Potential

  – "Standard Cosmology": Cosmic Ray Spectra and Composition
  – Gamma ray astrophysics
  – Indirect Dark Matter Search
  – Direct Search for Antimatter (a heavy Anti-nuceus)
  – Search or Exotic Matter: Strangelets, …

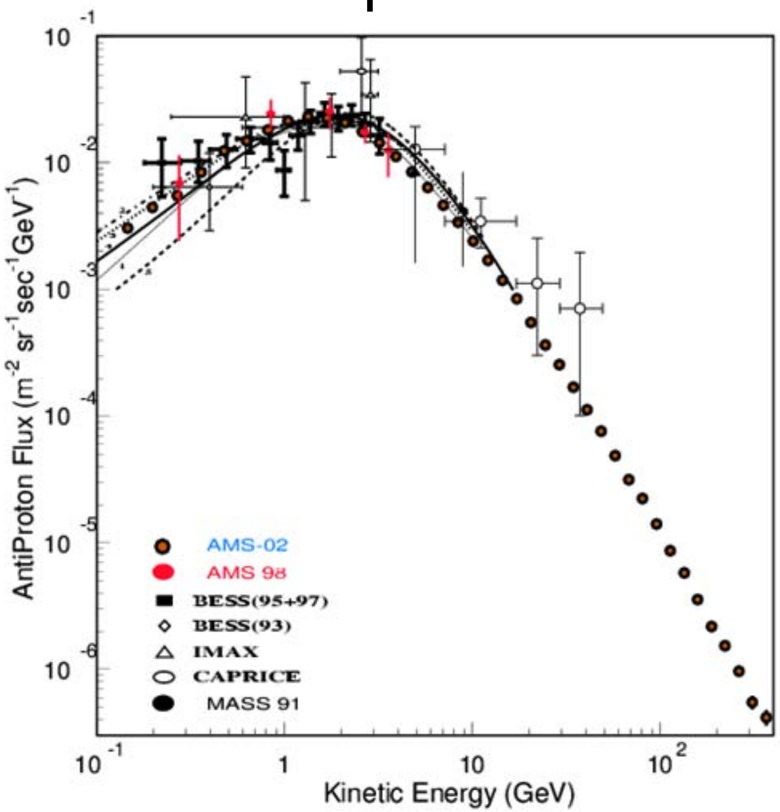
- Flight Status and Summary



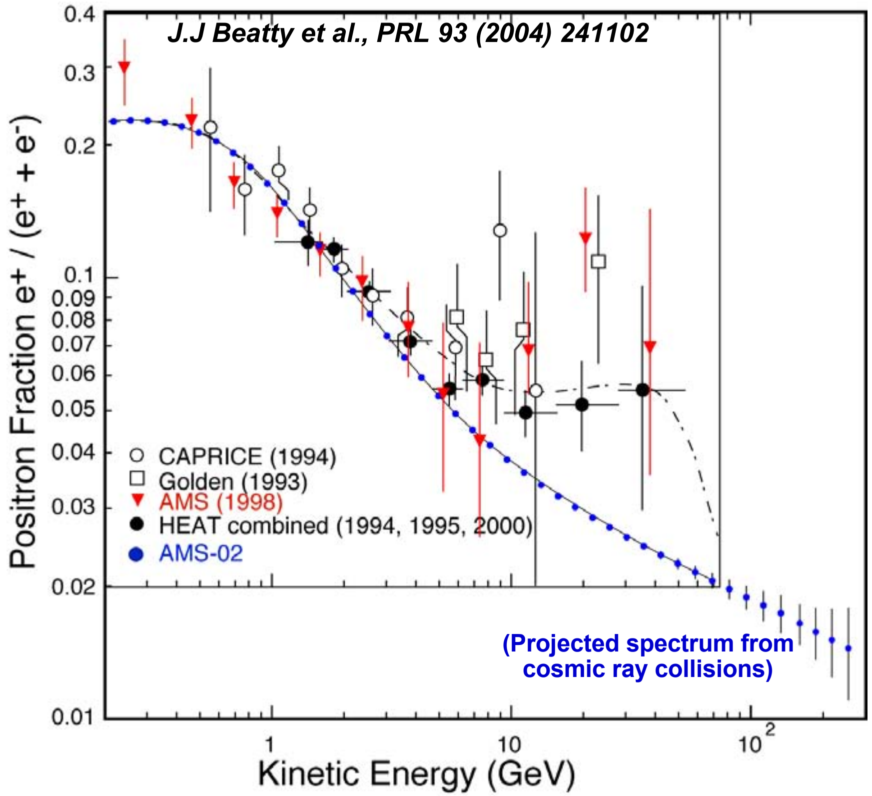
AMS-02 will record about 2 * 10^{10} physics events from comic rays in 3 years and identify its rare components with excellent particle identification

Search for Cold Dark Matter Annihilation

Antiprotons



Antielectrons



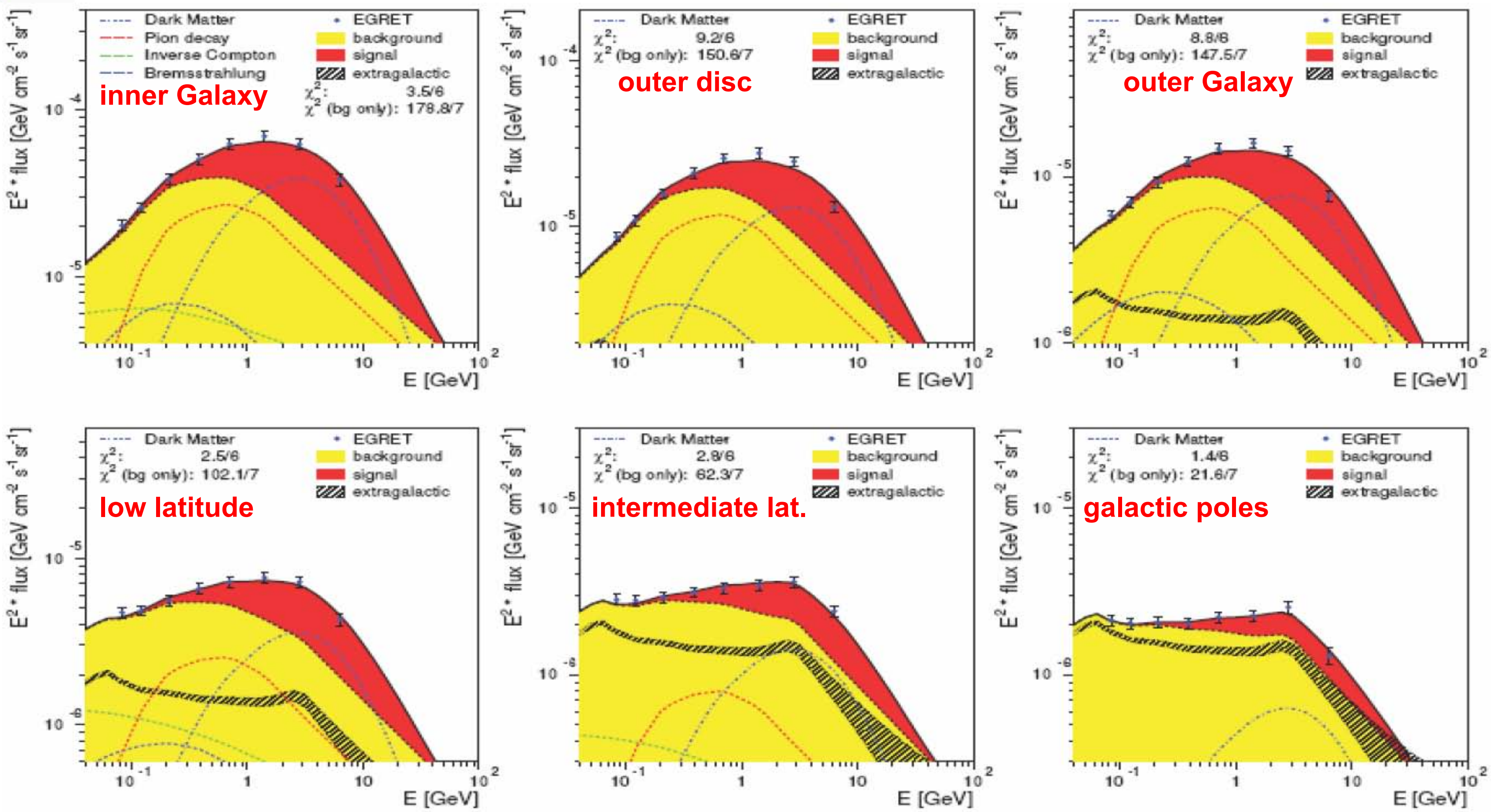
AMS-02 will at the same time measure p^- and e^+ spectra, which may contain an antimatter excess from annihilating dark matter particles

Dark Matter Fit in different Sky Directions

EGRET Data

W. de Boer et al.

Univ. of Karlsruhe

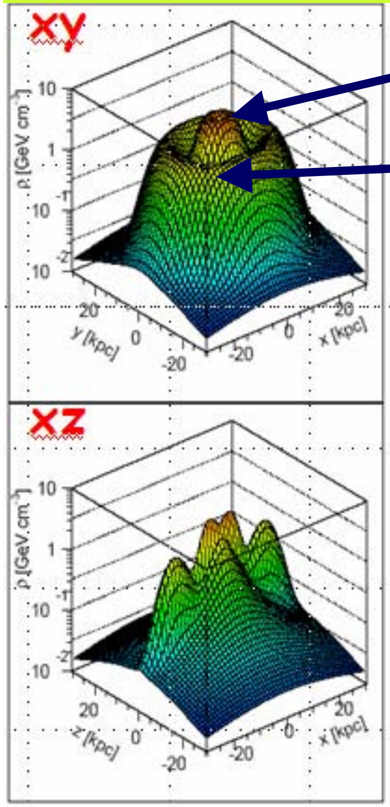


3 components gamma spectrum: galactic background + extragalactic bg + DM annihilation fitted simultaneously with same WIMP mass in all directions.

Dark Matter Ring Interpretation

Univ. of Karlsruhe

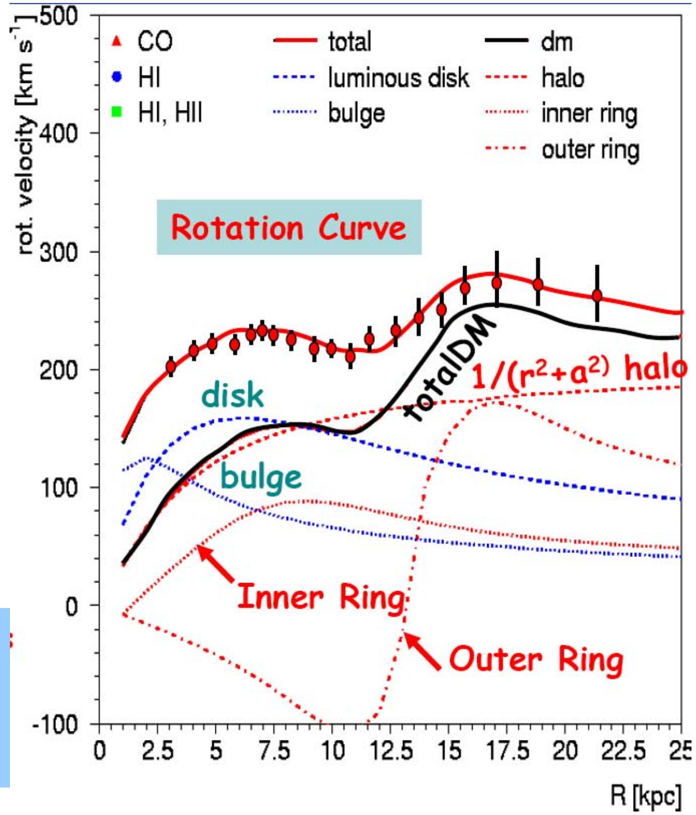
Fit in 180 directions implies substructure in the galactic distribution. Observed rotation curve of our galaxy then can be very well explained with obtained dark matter profile.



Inner ring (coincidences with H_2 ring)

Outer ring (coincidences with orbit of dwarf galaxy, which looses mass by tidal forces)

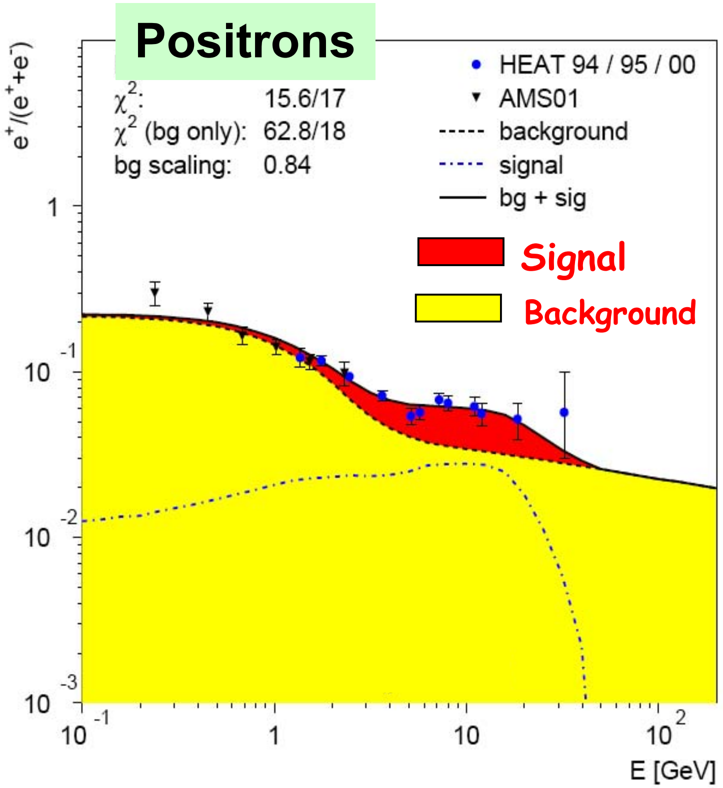
W. de Boer, C. Sander, V. Zhukov, A. Gladyshev, D. Kazakov, EGRET excess of diffuse Galactic Gamma Rays as Tracer of DM, astro-ph/0508617, A&A, 444 (2005) 51

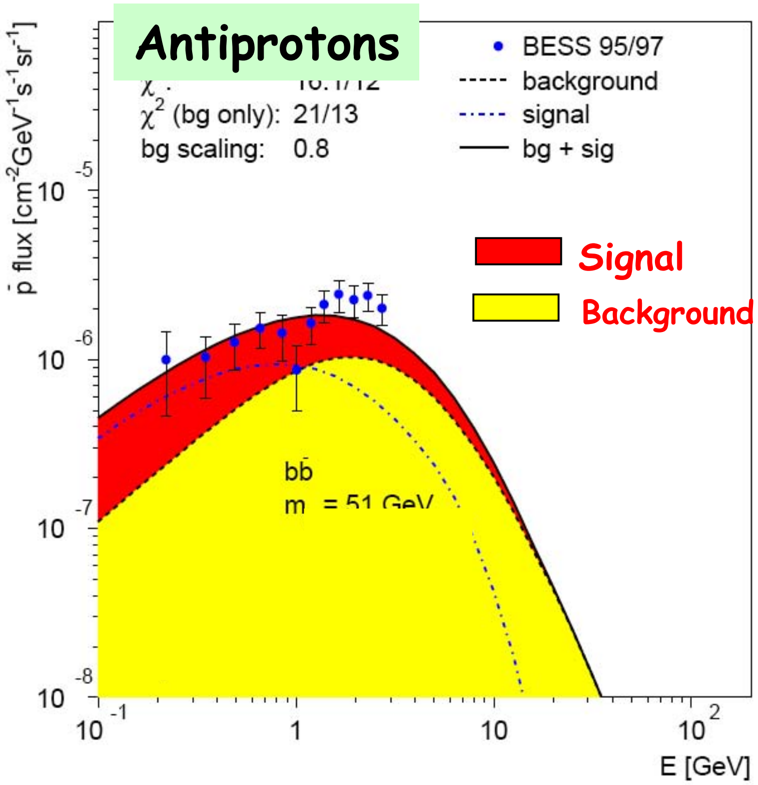


→Promising hint for annihilation of 60 GeV WIMP from Gamma rays: Verification of EGRET data necessary!
→Theory could allow to predict mass spectrum of SUSY from annihilation, which could be checked with accelerators.

Combined Analysis – Charged Particles

Univ. of Karlsruhe

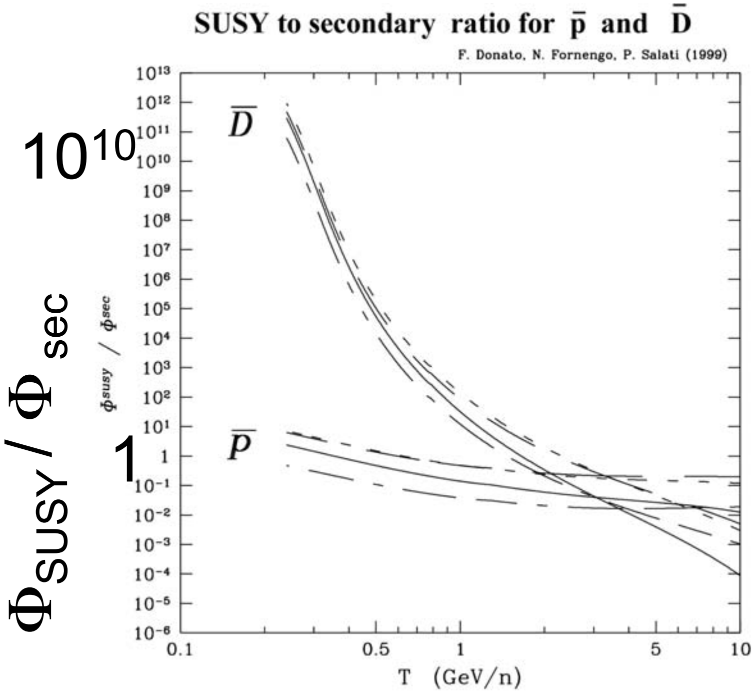


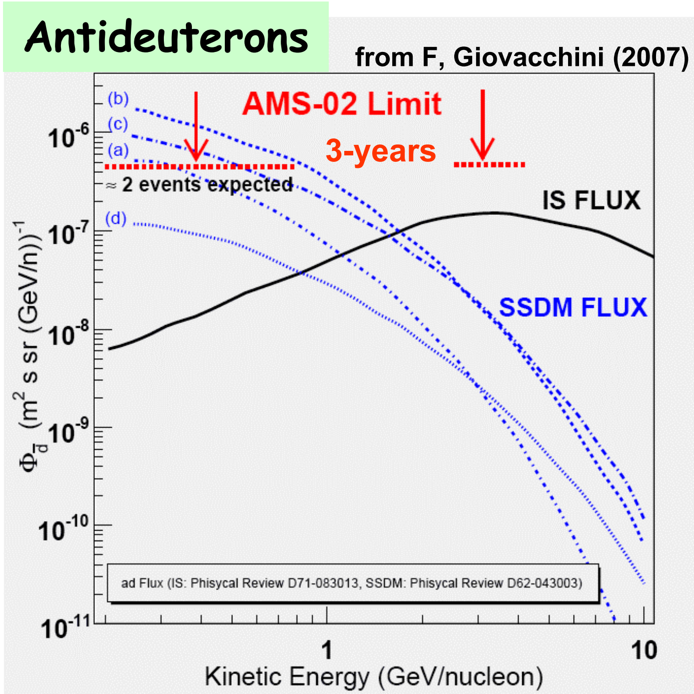


Fluxes of Positrons and Antiprotons dependent on propagation models, but Dark Matter Annihilation with same Halo and WIMP parameters from Gamma Rays could (as input) be used to tune cosmic models, e.g. introduce unisotropic diffusion.

Search for Neutralino DM with Anti-Deuterons

Antideuterons in standard astrophysics are produced with high energies, whereas antideuterons from Neutralino annihilation can be found below 1 GeV. This is more promising than antiprotons since easier extraction of SUSY signal (orders of magn.!!).

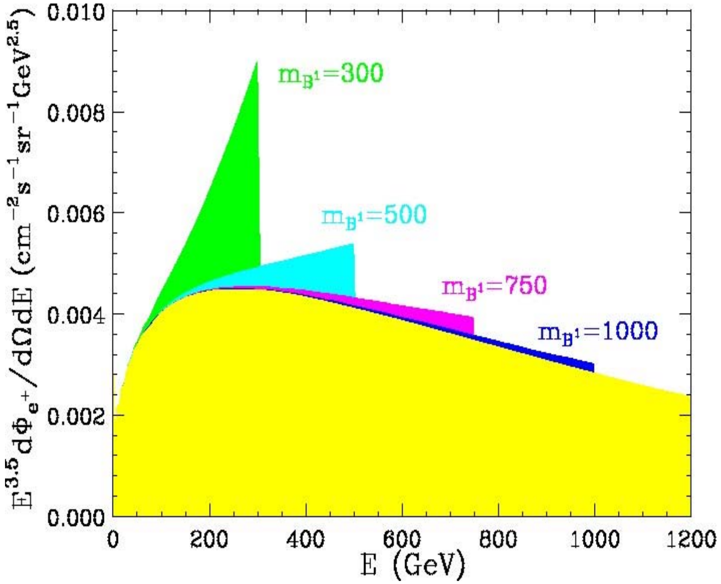


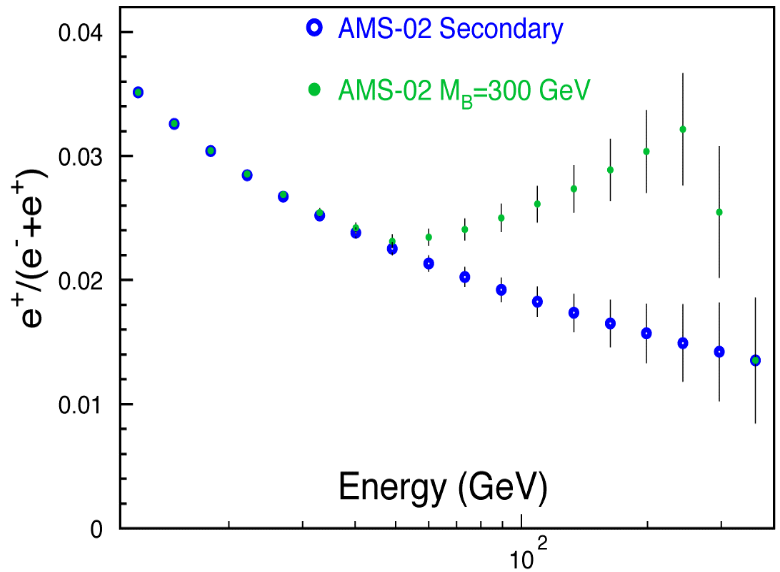


A large acceptance spectrometer like AMS-02 is required to measure the extremely low fluxes.

Kaluza-Klein Bosons as Dark Matter Candidates

Low Scale Quantum Gravity (extra-dimensional) predicts Bosons with mass, allowing direct annihilation into $e^{+/}e^{-}$ pairs (dominant channel ~20%).
→ steep spectra from BB collisions are different from neutralino annihilation





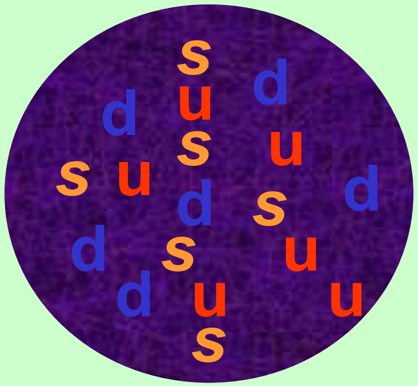
Excess from possible Boson mass of 300 GeV can be seen by AMS-02

H.C.Cheng, J.L.Feng and K.T.Matchev, Phys.Rev.Lett V89, N21 (2002) 211301-1;
J.Feng,Nucl.Phys.Proc.Suppl.134 (2004) 95

Example for Exotic Matter in the Universe: Strangelets

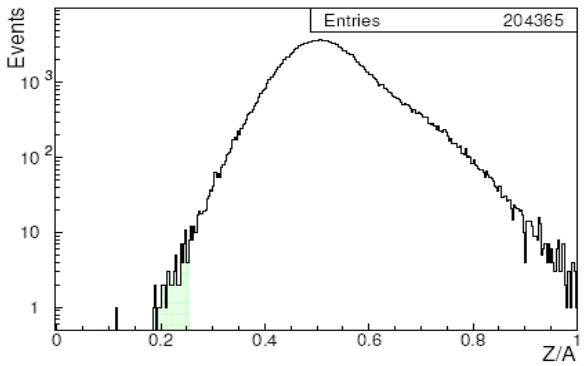
Signature of a Strangelet event simply is anomalous Z/A

STRANGELET
Nucleus



$Z \sim 0.3A^{2/3}$

$Z/A < 0.12$



Latitude	Longitude	Angle($\vec{Dir}$, $\vec{Zenith}$)	Rigidity (GV)	β_{TOF}	β_{dE}	Z/A	Cutoff (GV)
-44.38°	23.70°	77.5°	4.31±0.38	0.462±0.005	0.44±0.04	0.114	1.95±0.1

One anomalous event was reported by AMS-01 (background probability $<10^{-3}$), compatible with a Strangelet.

Stable strange quark matter was first proposed by E. Witten, Phys. Rev. D,272-285 (1984)

Could there be another new type of matter?

AMS-02 Flight Status

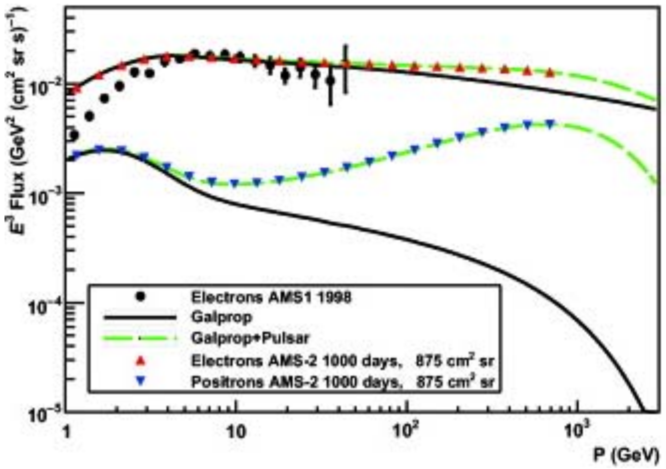
- Final Detector Intergation at CERN,Geneva cleanroom in progress
- … and completed for detector test at ESTEC,NL space simulating chamber in Summer 2008
- AMS-02 is strongly supported by NASA and on schedule for delivery to KSC, Florida in December 2008

Alpha Magnetic Spectrometer

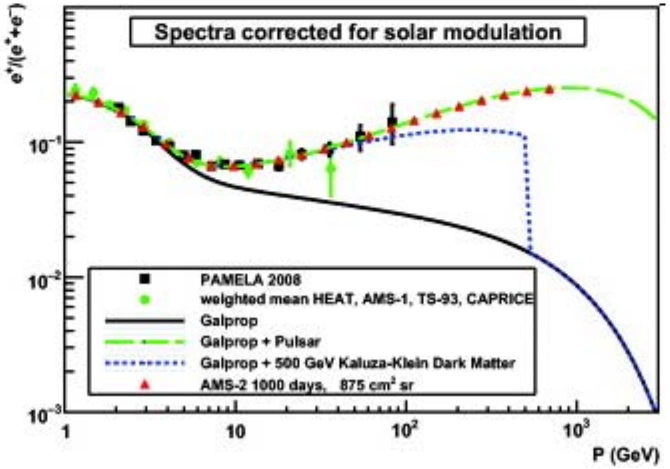
AMS-02

Europe • Asia

North America



E^3 Flux (GeV^2 (cm^2 sr s)$^{-1}$)
Electrons AMS1 1998
Galprop
Galprop+Pulsar
Electrons AMS-2 1000 days, 875 cm^2 sr
Positrons AMS-2 1000 days, 875 cm^2 sr
P (GeV)



Spectra corrected for solar modulation
$e^+/(e^++e^-)$
PAMELA 2008
weighted mean HEAT, AMS-1, TS-93, CAPRICE
Galprop
Galprop + Pulsar
Galprop + 500 GeV Kaluza-Klein Dark Matter
AMS-2 1000 days, 875 cm^2 sr
P (GeV)