The AMS Experiment: A Magnetic Spectrometer in Space

Jorge Casaus

CIEMAT

XXX International Winter Meeting on Fundamental Physics

Jaca, January 28th – February 1st 2002

Outline

- AMS Experiment
- AMS-01 Spectrometer
- AMS-01 Results
- AMS-02 Spectrometer
- AMS-02 Expected Performances
- Conclusions

AMS Experiment

- **AMS is a particle physics experiment in space**
- **The AMS experiment is mostly built in Europe**
- **The use of the Space Shuttle and the Space Station is based on a NASA – US DOE MOU (1995)**
- **The AMS collaboration has the responsibility for assessing the experiment's quality and merit and for the construction of AMS**
- **NASA is not involved in the construction of AMS**

ALPHA MAGNETIC SPCTROMETER (AMS)
ON THE SHUTTLE AND THE INTERNATIONAL SPACE STATION

PAYLOAD: DOE-INFN-ASI-IN2P3-CNES-DARA-ASI-Ac.Sinica-ETHZ-FNS-CIEMAT-TEKES

MISSION MANAGEMENT and SAFETY: NASA

M.Aguilar-Benitez,*x* J.Alcaraz,*x* D.Alvisi,*j* B.Alpat,*ab* G.Ambrosi,*r* H.Anderhub,α*f* L.Ao,*g* A.Arefiev,*aa* P.Azzarello,*r* E.Babucci,*ab* L.Baldini,φ,*l* M.Basile,*j* D.Barancourt,*s* F.Barao,ϖ,*u* G.Barbier,*s* G.Barreira,*v* R.Battiston,*ab* R.Becker,*l* U.Becker,*l* L.Bellagamba,*j* P.Bene,*r* J.Berdugo,*x* P.Berges,*l* B.Bertucci,*ab* A.Biland,α*f* S.Bizzaglia,*ab* S.Blasko,*ab* G.Boella,*y* M.Bourquin,*r* G.Bruni,*j* M.Buenerd,*s* J.D.Burger,*l* W.J.Burger,*ab* X.D.Cai,*l* R.Cavalletti,*j* C.Camps,*b* P.Cannarsa,α*f* M.Capell,*l* D.Casadei,*j* J.Casaus,*x* G.Castellini,*p* Y.H.Chang,*m* H.S.Chen,*i* Z.G.Chen,*g* N.A.Chernoplekov,*z* A.Chiarini,*j* T.H.Chiueh,*m* Y.L.Chuang,*ac* F.Cindolo,*j* V.Commichau,*b* A.Contin,*j* A.Cotta–Ramusino,*j* P.Crespo,*v* M.Cristinziani,*r* J.P. da Cunha,*n* T.S.Dai,*l* J.D.Deus,*u* L.K.Ding,*i* N.Dinu,*k* L.Djambazov,α*f* I.D'Antone,*j* Z.R.Dong,*h* P.Emonet,*r* F.J.Eppling,*l* T.Eronen,*ae* G.Esposito,*ab* P.Extermann,*r* J.Favier,*c* C.C.Feng,*w* E. Fiandrini,*ab* F.Finelli,*j* P.H.Fisher,*l* R.Flaminio,*c* G.Fluegge,*b* N.Fouque,*c* Yu.Galaktionov,*a*α,*l* M.Gervasi,*y* P.Giusti,*j* W.Q.Gu,*h* T.G.Guzik,*e* K.Hangarter,*b* A.Hasan,α*f* V.Hermel,*c* H.Hofer,α*f* M.A.Huang,*ac* W.Hungerford,α*f* M.Ionica,*k* R.Ionica,*k* J.Isbert,*e* M.Jongmanns,α*f* W.Karpinski,*a* G.Kenney,α*f* J.Kenny,*ab* W.Kim,*ad* A.Klimentov,λ,*aa* J.Krieger,α,1 R.Kossakowski,*c* V.Koutsenko,λ,*aa* G.Laborie,*s* T.Laitinen,*ae* G.Lamanna,*ab* G.Laurenti,*j* A.Lebedev,*l* S.C.Lee,*ac* G.Levi,*j* P.Levtchenko,*a*β,2 T.P.Li,*i* C.L.Liu,*w* H.T.Liu,*i* M.Lolli,*j* I.Lopes,*n* G.Lu,*g* Y.S.Lu,*i* K.Luebelsmeyer,*a*D.Luckey,*l* W.Lustermann,α*f* G.Maehlum,*a*β,3 C.Mana,*x* A.Margotti,*j* F.Massera,*j* F.Mayet,*s* R.R.McNeil,*e* B.Meillon,*s* M.Menichelli,*ab* F.Mezzanotte,*j* R.Mezzenga,*ab* A.Mihul,*k* G.Molinari,*j* A.Mourao,*u* A.Mujunen,*t* F.Palmonari,*j* G.Pancaldi,*j* A.Papi,*ab* I.H.Park,*ad* M.Pauluzzi,*ab* F.Pauss,α*f* E.Perrin,*r* A.Pesci,*j* A.Pevsner,*d* R.Pilastrini,*j* M.Pimenta,ϖ,*u* V.Plyaskin,*aa* V.Pojidaev,*aa* H.Postema,λ,4 E.Prati,*j* N.Produit,*r* P.G.Rancoita,*y* D.Rapin,*r* F.Raupach,*a* S.Recupero,*j* D.Ren,α*f* Z.Ren,*ac* M.Ribordy,*r* J.P.Richeux,*r* E.Riihonen,*ae* J.Ritakari,*t* U.Roeser,α*f* C.Roissin,*s* R.Sagdeev,*o* D.Santos,*s* G.Sartorelli,*j* A.Schultz von Dratzig,*a* G.Schwering,*a* V.Shoutko,*l* E.Shoumilov,*aa* R.Siedling,*a* D.Son,*ad* T.Song,*h* M.Steuer,*l* G.S.Sun,*h* H.Suter,α*f* X.W.Tang,*i* Samuel C.C.Ting,*l* S.M.Ting,*l* F.Tenbusch,*a* G.Torromeo,*j* J.Torsti,*ae* J.Trumper,*q* J.Ulbricht,α*f* S.Urpo,*t* I.Usoskin,*y* E.Valtonen,*ae* J.Vandenhirtz,*a* E.Velikhov,*z* B.Verlaat,α*f*,5 I.Vetlitsky,*aa* F.Vezzu,*s* J.P.Vialle,*c* G.Viertel,α*f* D.Vite,*r* H.Von Gunten,α*f* S.Waldmeier Wicki,α*f* W.Wallraff,*a* B.C.Wang,*w* J.Z.Wang,*g* Y.H.Wang,*ac* J.P.Wefel,*e* E.A.Werner,α,1 C.Williams,*j* S.X.Wu,λ,*m* P.C.Xia,*h* J.L.Yan,*g* L.G.Yan,*h* C.G.Yang,*i* M.Yang,*i* P.Yeh,*ac* H.Y.Zhang,*f* D.X.Zhao,*h* G.Y.Zhu,*i* W.Z.Zhu,*g* H.L.Zhuang,*i* A.Zichichi,*j*

J.Casaus, February 1st 2002, Jaca

a I. Physikalisches Institut, RWTH, D-52056 Aachen, Germany
b III. Physikalisches Institut, RWTH, D-52056 Aachen, Germany
c Laboratoire d'Annecy-le-Vieux de Physique des Particules, LAPP, F-74941 Annecy-le-Vieux CEDEX, France
e Louisiana State University, Baton Rouge, LA 70803, USA
d Johns Hopkins University, Baltimore, MD 21218, USA
f Center of Space Science and Application, Chinese Academy of Sciences, 100080 Beijing, China
g Chinese Academy of Launching Vehicle Technology, CALT, 100076 Beijing, China
h Institute of Electrical Engineering, IEE, Chinese Academy of Sciences, 100080 Beijing, China
i Institute of High Energy Physics, IHEP, Chinese Academy of Sciences, 100039 Beijing, China
j University of Bologna and INFN-Sezione di Bologna, I-40126 Bologna, Italy
k Institute of Microtechnology, Politechnica University of Bucharest and University of Bucharest, R-76900 Bucharest, Romania
l Massachusetts Institute of Technology, Cambridge, MA 02139, USA
m National Central University, Chung-Li, Taiwan 32054
n Laboratorio de Instrumentacao e Fisica Experimental de Particulas, LIP, P-3000 Coimbra, Portugal
o University of Maryland, College Park, MD 20742, USA
p INFN Sezione di Firenze, I-50125 Florence, Italy
q Max–Plank Institut fur Extraterrestrische Physik, D-85740 Garching, Germany
r University of Geneva, CH-1211 Geneva 4, Switzerland
s Institut des Sciences Nucleaires, F-38026 Grenoble, France
t Helsinki University of Technology, FIN-02540 Kylmala, Finland
u Instituto Superior Tecnico, IST, P-1096 Lisboa, Portugal
v Laboratorio de Instrumentacao e Fisica Experimental de Particulas, LIP, P-1000 Lisboa, Portugal
w Chung–Shan Institute of Science and Technology, Lung-Tan, Tao Yuan 325, Taiwan 11529
x Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, CIEMAT, E-28040 Madrid, Spain
y INFN-Sezione di Milano, I-20133 Milan, Italy
y INFN-Sezione di Pisa, I-50100 Pisa, Italy
z Kurchatov Institute, Moscow, 123182 Russia
aa Institute of Theoretical and Experimental Physics, ITEP, Moscow, 117259 Russia
ab INFN-Sezione di Perugia and Universita´ degli Studi di Perugia, I-06100 Perugia, Italy
ac Academia Sinica, Taipei, Taiwan
ad Kyungpook National University, 702-701 Taegu, Korea
ae University of Turku, FIN-20014 Turku, Finland
αf Eidgenossische Technische Hochschule, ETH Zurich, CH-8093 Zurich, Switzerland

Europe
US
ASIA

AMS Physics Goals

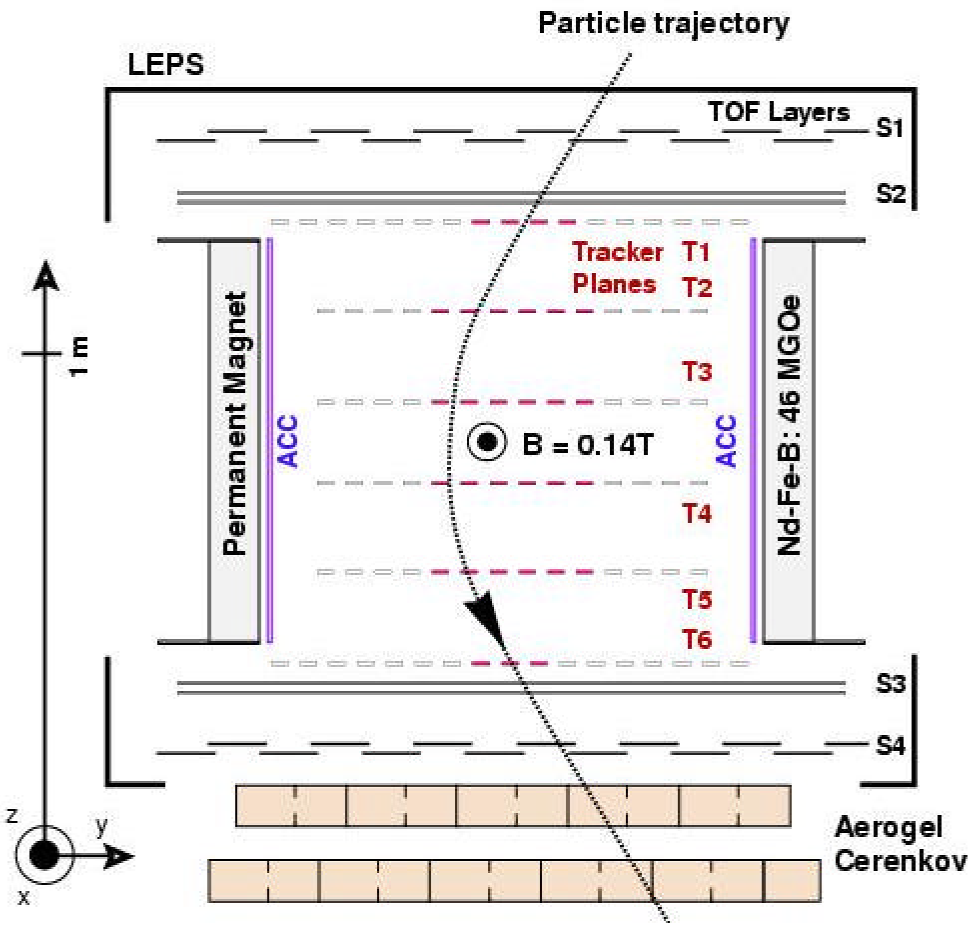
- Antimatter search ($\overline{He}$,$\overline{C}$) with a sensitivity 10^3 to 10^4 better than current limits.
- Dark Matter search
  - High statistics precision measurements of $e^{\pm}$, $\overline{p}$ and γ spectra
- Astrophysics studies
  - High statistics precision measurements of light isotope spectra

AMS Experimental Program

- Precursor flight aboard the Space Shuttle
  - ? Instrumental
  - ? Background Studies

- Long duration (3-year) mission at the International Space Station (ISS)

AMS-01 Spectrometer

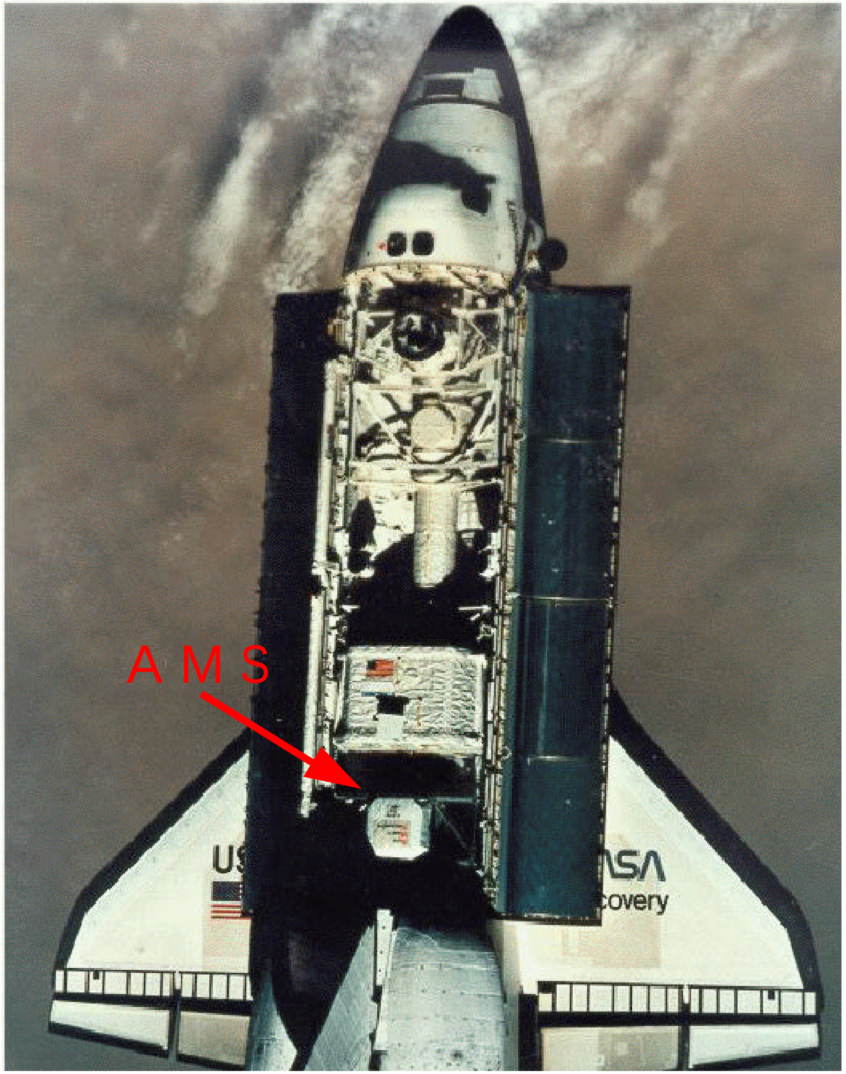


- Permanent Magnet
- Silicon Tracker
- Scintillator System
- Threshold Cerenkov

WEIGHT	3 T
POWER	1 KW

Acceptance: 0.3 m^2sr

STS-91 Flight



JUNE 2-12, 1998

Orbital Parameters

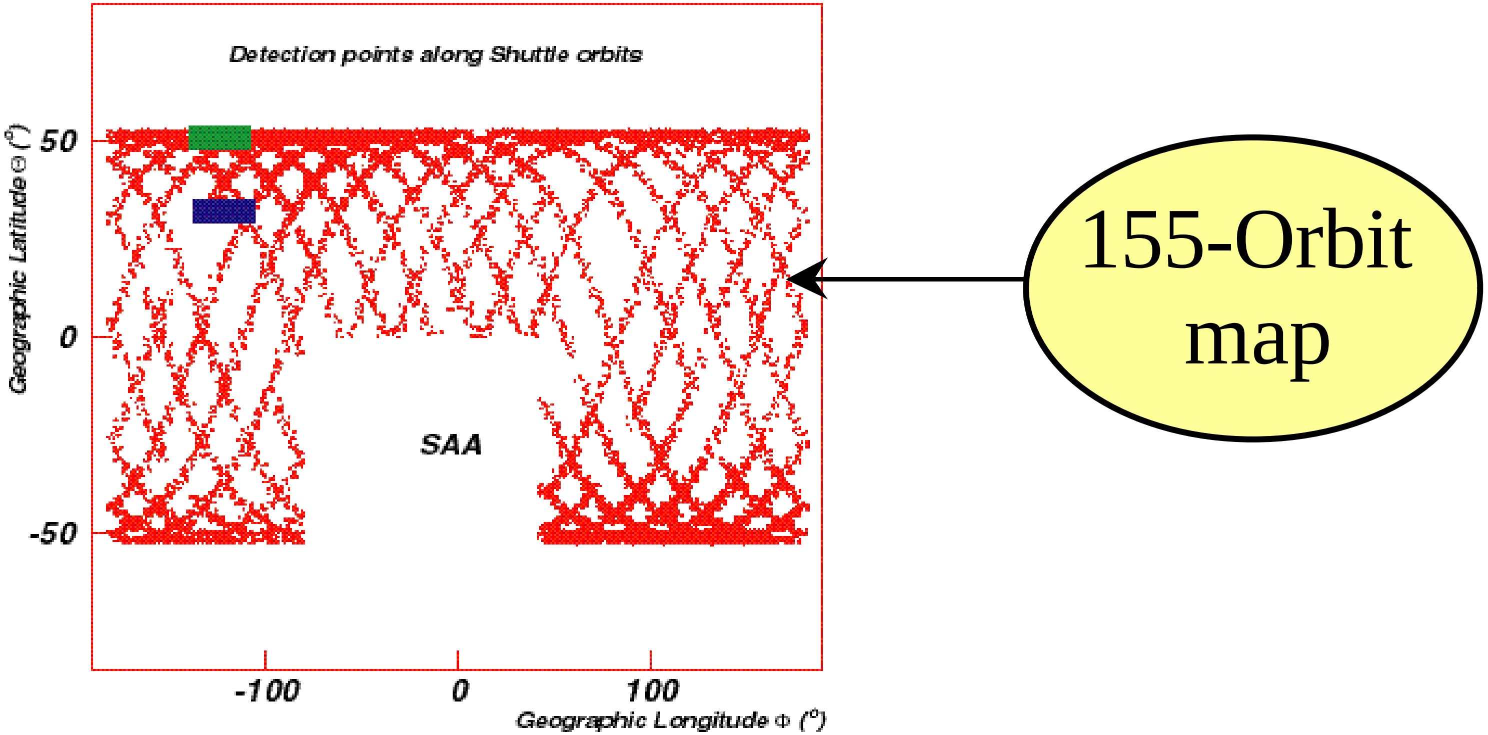
Inclination	51.7º
Altitude	320-390 km
Period	91 min

AMS

Trigger rate 100 – 700 Hz

100 Million events on tape

AMS-01 Geographic Coverage



	Cutoffs(GV)	Latitudes	Longitudes
AMS		+/- 51.7	all (SAA excluded)
BESS98	<0.5		(Lynn Lake - Canada)
CAPRICE94		+56.5 N	101-117 W (Lynn Lake - Canada)
MASS91	4.3	+34 N	104 W (Forth Sumner)
IMAX92	0.37-0.63	+56.5 N	101-118 W (Lynn Lake - Canada)
LEAP87	0.6-1.1	n.a.	n.a. (Prince Albert - Canada)

AMS-01 Post-flight Activities

Calibration & Alignment

- ✓ **He & C beams @ GSI (Darmstadt)**

  1.0-5.6 GV   600 angles

  45 Million Events

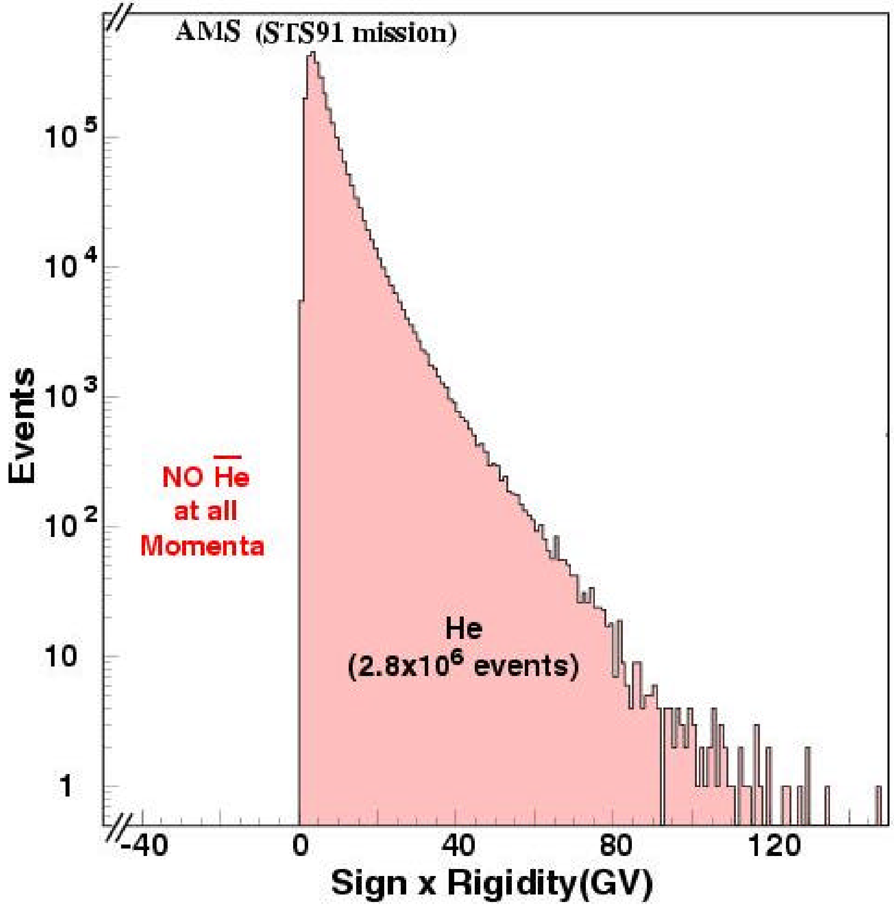
- ✓ **Proton & Pion beam @ CERN**

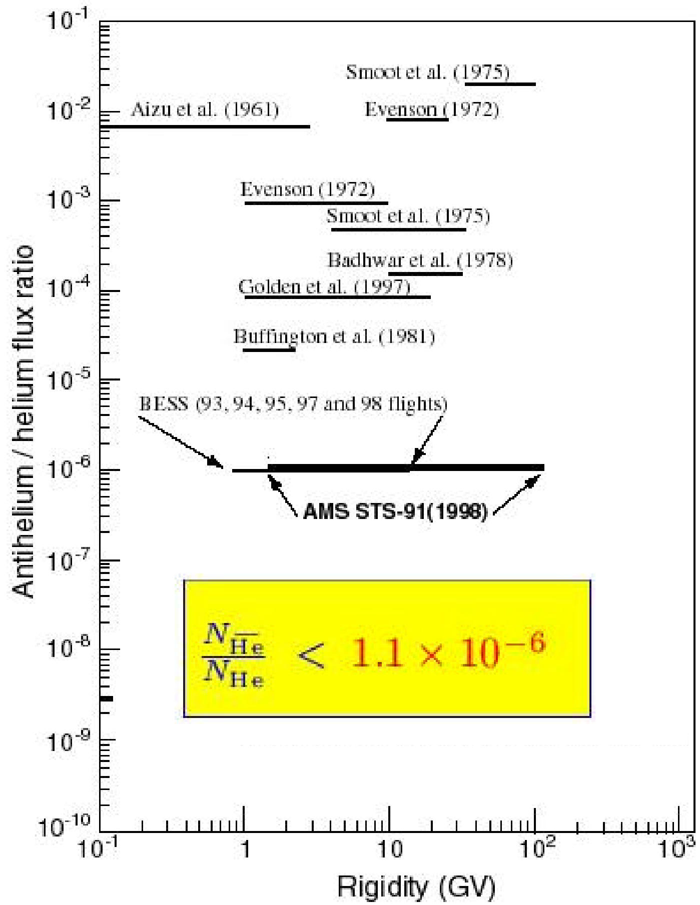
  2–14 GeV   1200 angles

  100 Million Events

AMS-01 Antimatter Search

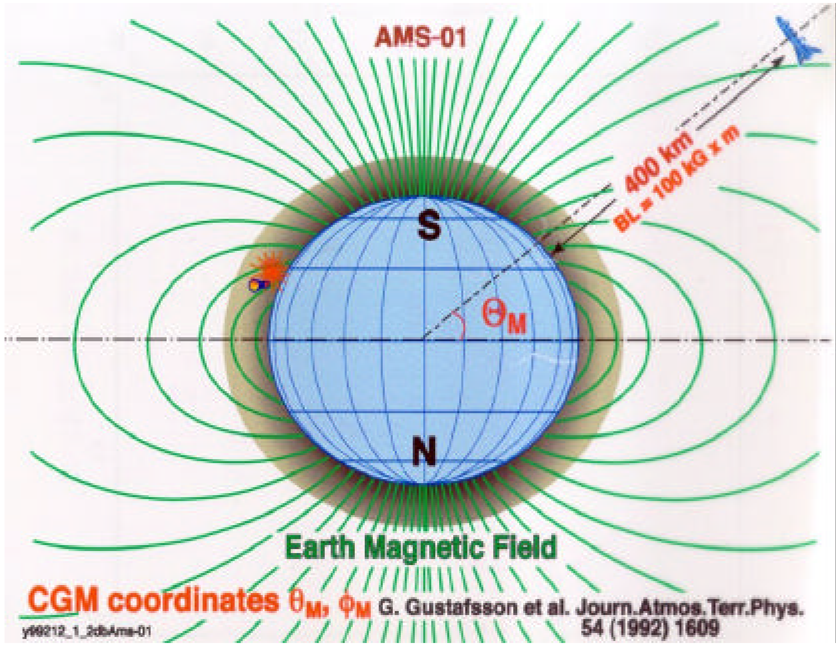
No $\overline{\text{He}}$ found in the range 1 – 140 GV

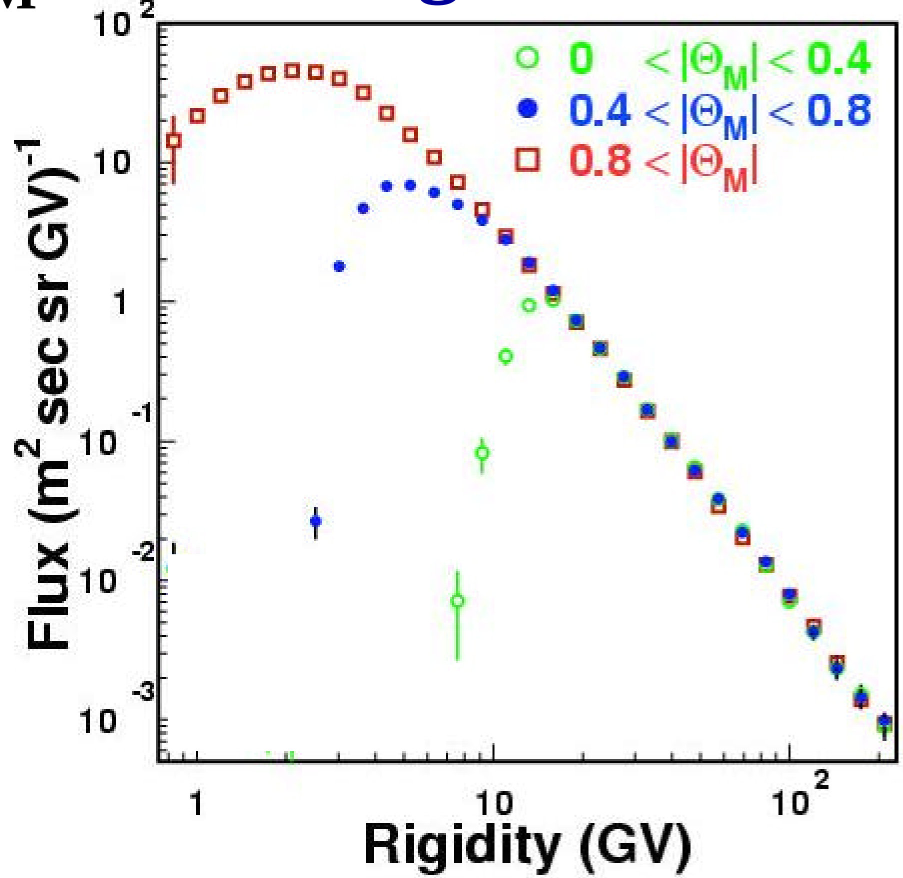




AMS-01 Cosmic Ray Spectra

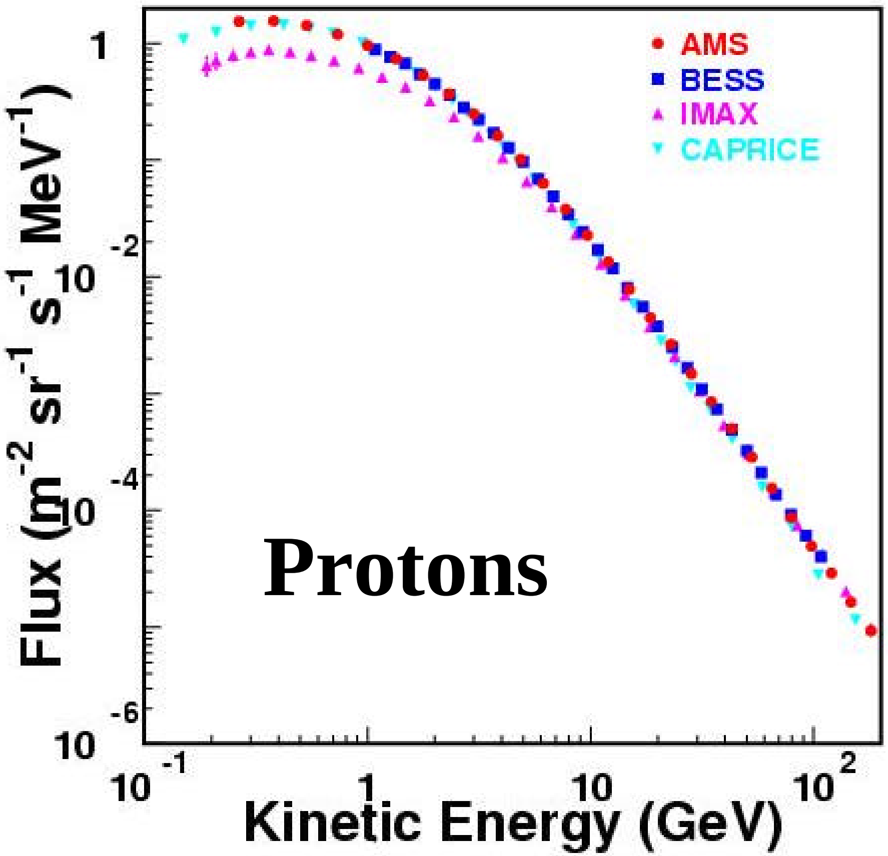
Earth's Magnetic Field shielding depends on the geomagnetic latitude T_M Þ Geomagnetic Cutoff

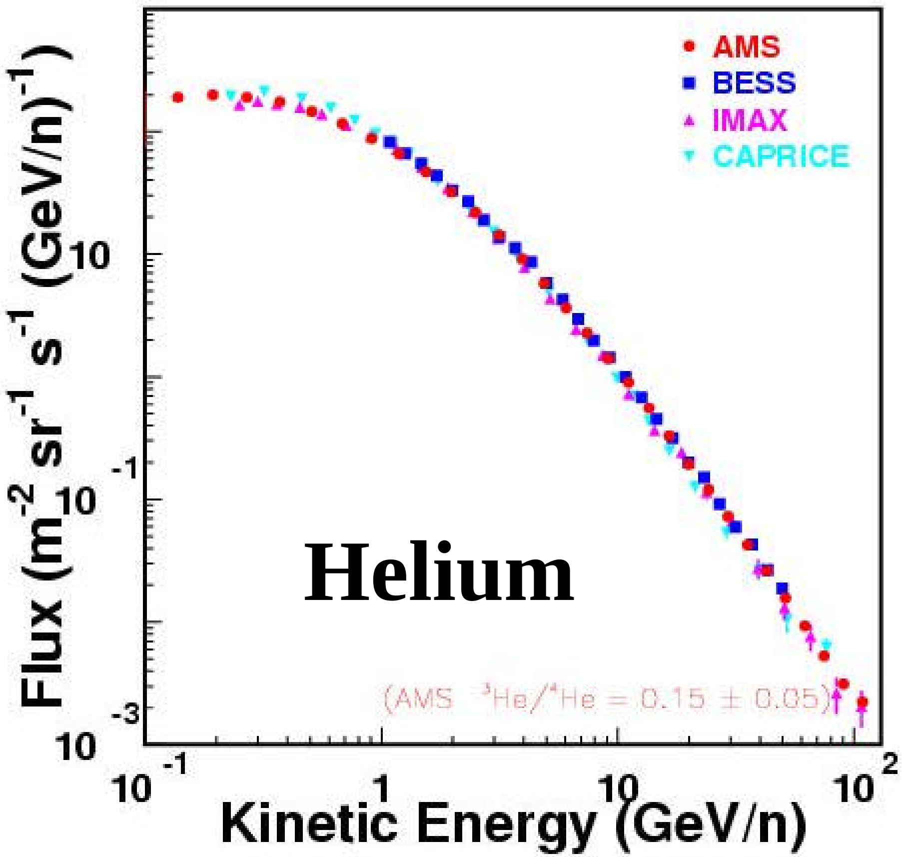




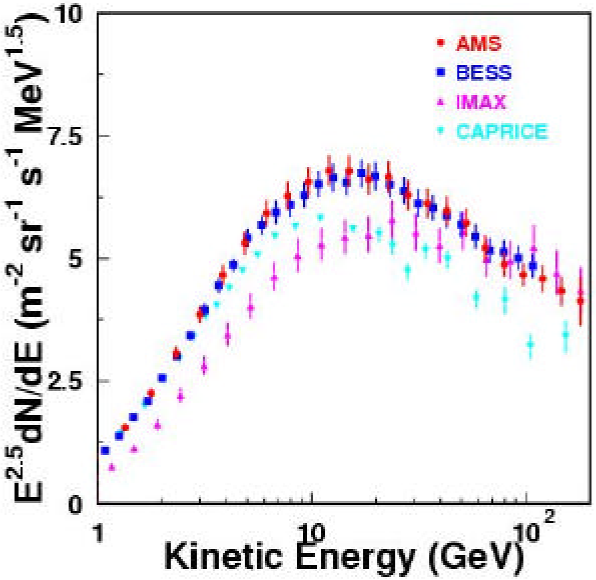
AMS-01 Protons & Helium

H ~ 10^7 events **He ~ 10^6 events**





AMS-01 Protons & Helium



$$\Phi_0\, R^{-\gamma_H} \quad (R > 10\,\mathrm{GV})$$

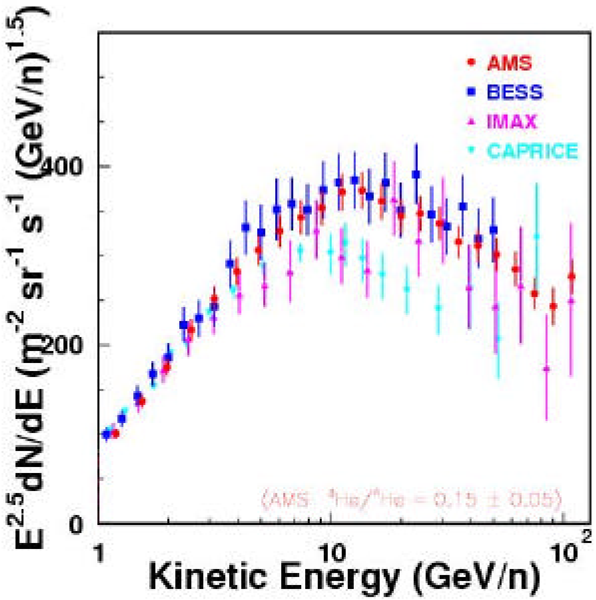
$$\gamma_H = 2.780 \pm 0.009\ (\mathrm{fit}) \pm 0.019\ (\mathrm{sys})$$

$$\Phi_0 = 17.10 \pm 0.15\ (\mathrm{fit}) \pm 1.30\ (\mathrm{sys}) \pm 1.50\ (\gamma_H)\ \frac{\mathrm{Hz\ GV}^{2.78}}{\mathrm{m}^2\ \mathrm{s\ sr\ MV}}$$

$$\Phi_0\, R^{-\gamma_{He}} \quad (R > 20\,\mathrm{GV})$$

$$\gamma_{He} = 2.740 \pm 0.010\ (\mathrm{fit}) \pm 0.016\ (\mathrm{sys})$$

$$\Phi_0 = 2.52 \pm 0.09\ (\mathrm{fit}) \pm 0.14\ (\mathrm{sys}) \pm 0.14\ (\gamma_{He})\ \frac{\mathrm{Hz\ GV}^{2.74}}{\mathrm{m}^2\ \mathrm{s\ sr\ MV}}$$

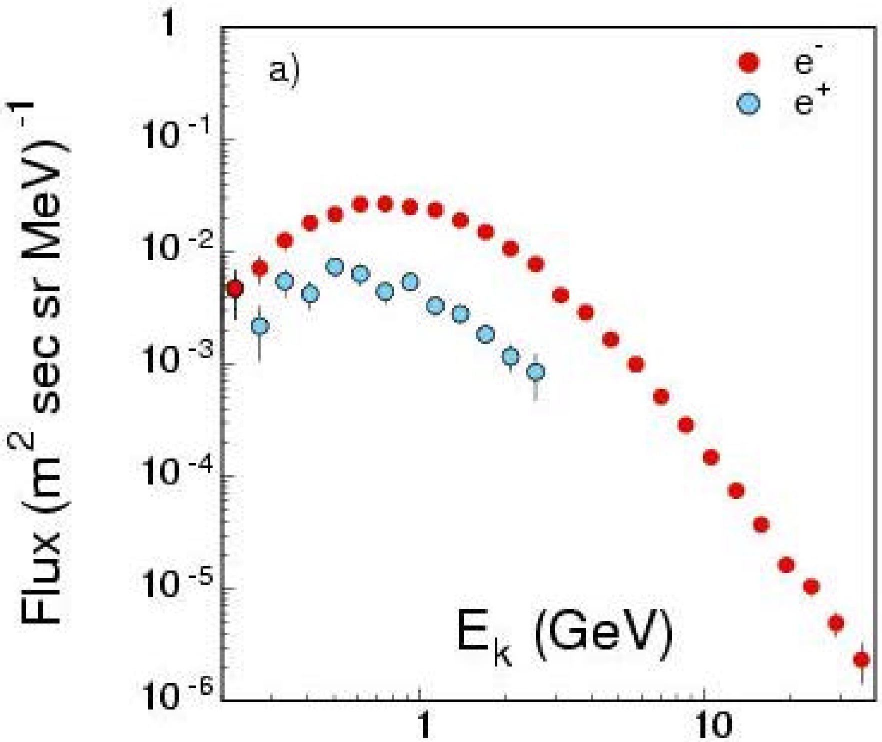


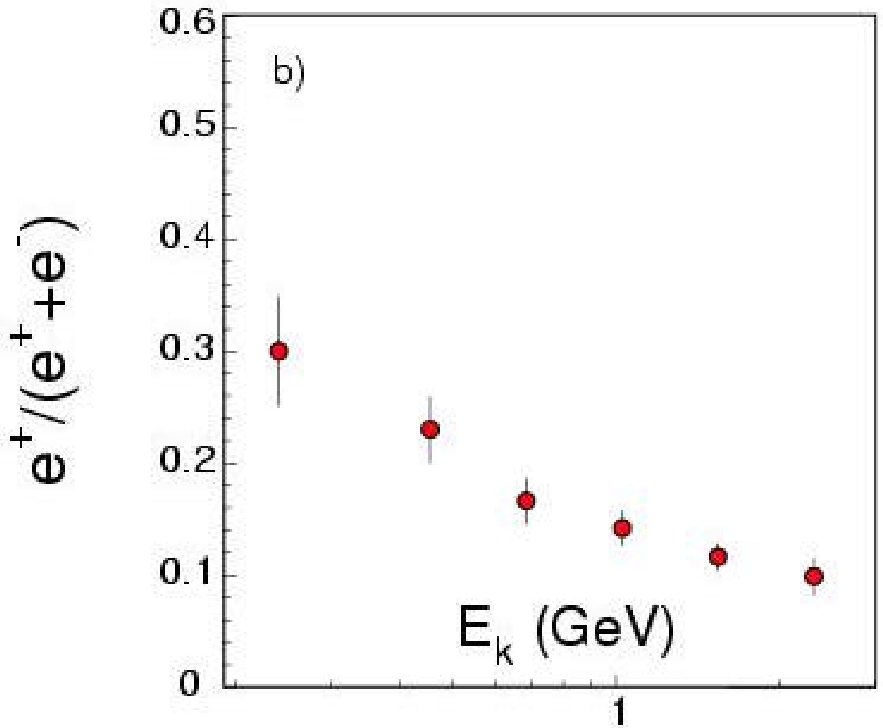
J.Casaus, February 1st 2002, Jaca

AMS-01 Electrons & Positrons

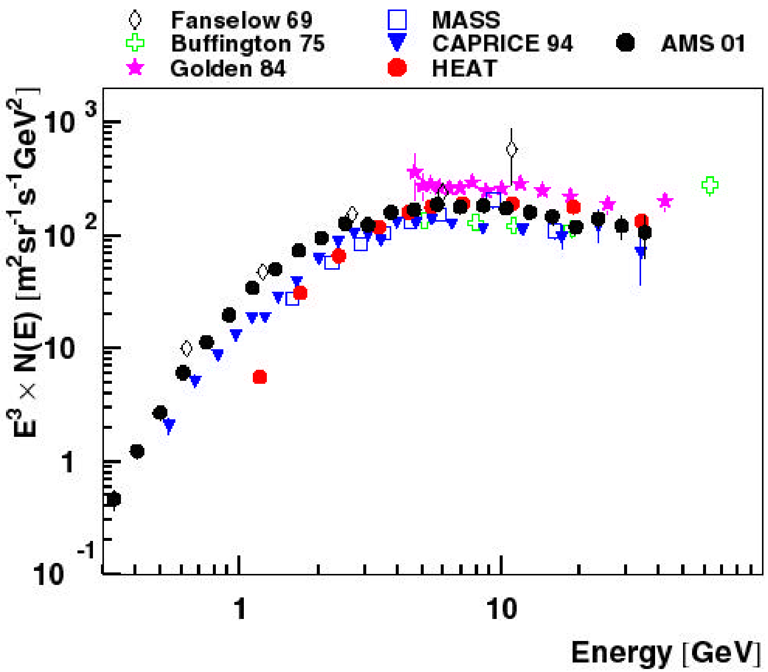
~ 10^5 events

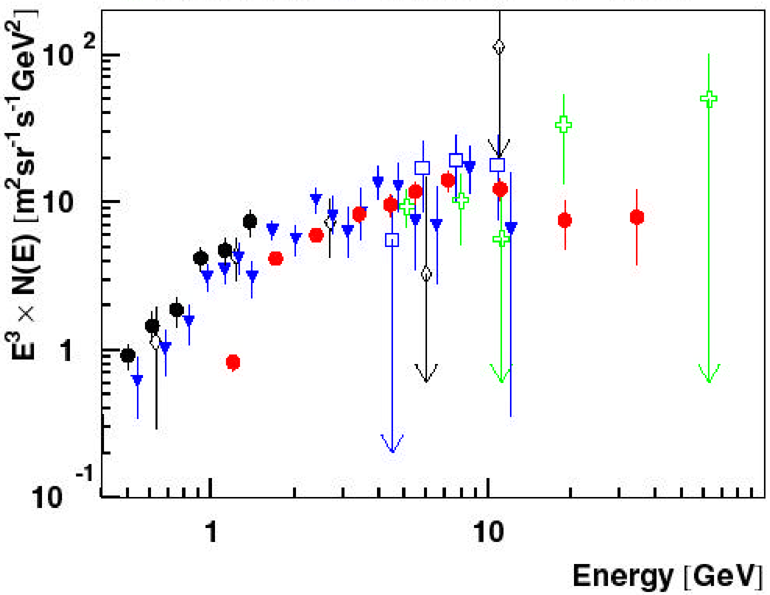
e^- : 0.2 – 40 GeV **e^+ : 0.2 – 3 GeV**

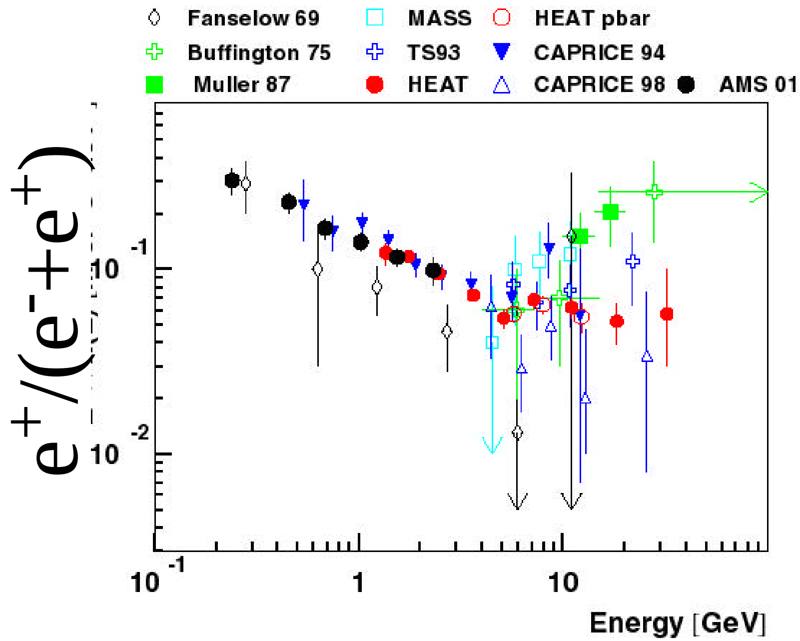




AMS-01 e^- & e^+


Fanselow 69
Buffington 75
Golden 84
MASS
CAPRICE 94
HEAT
AMS 01
E3 × N(E) [m2sr-1s-1GeV2]
Energy [GeV]


E3 × N(E) [m2sr-1s-1GeV2]
Energy [GeV]


Fanselow 69
Buffington 75
Muller 87
MASS
TS93
HEAT
HEAT pbar
CAPRICE 94
CAPRICE 98
AMS 01
e+/(e-+e+)
Energy [GeV]

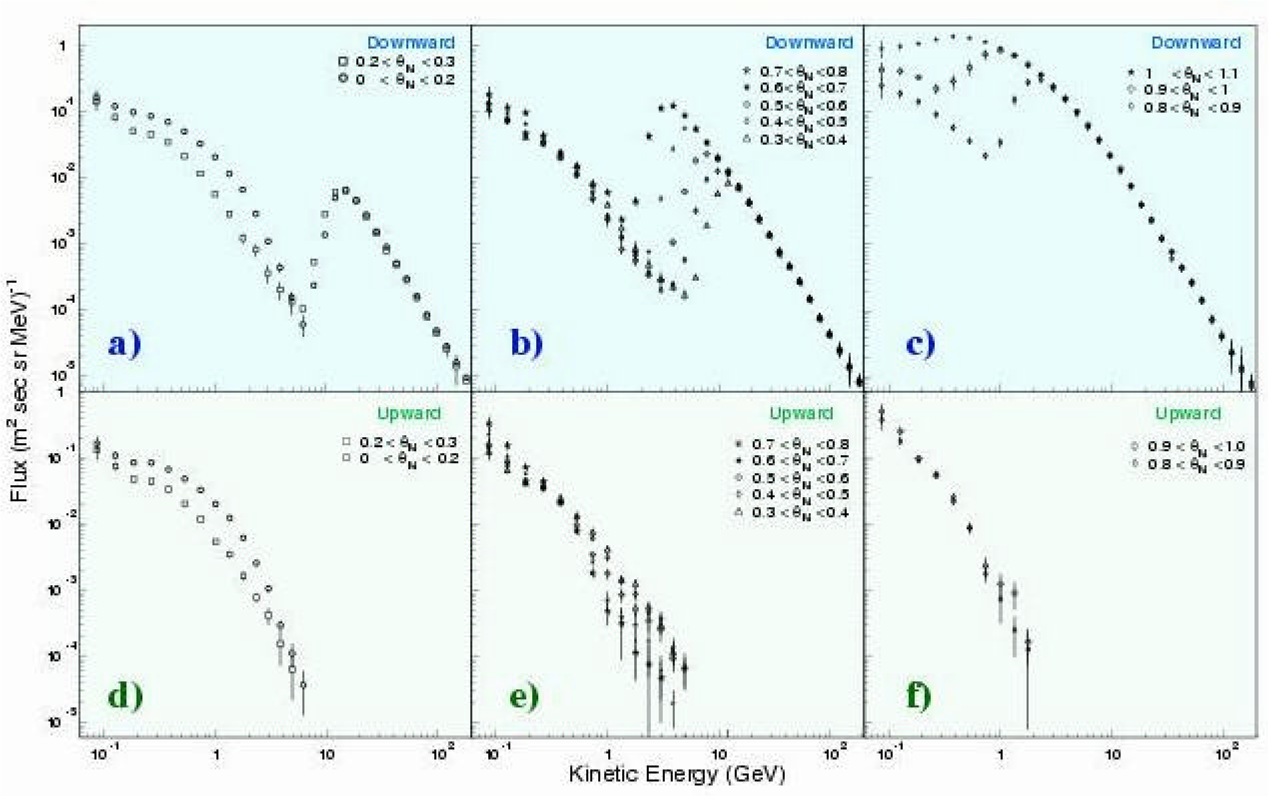
AMS-01 Under Cutoff Spectra (1/3)

A substantial flux detected below the geomagnetic cutoff

protons

Downward ⇒

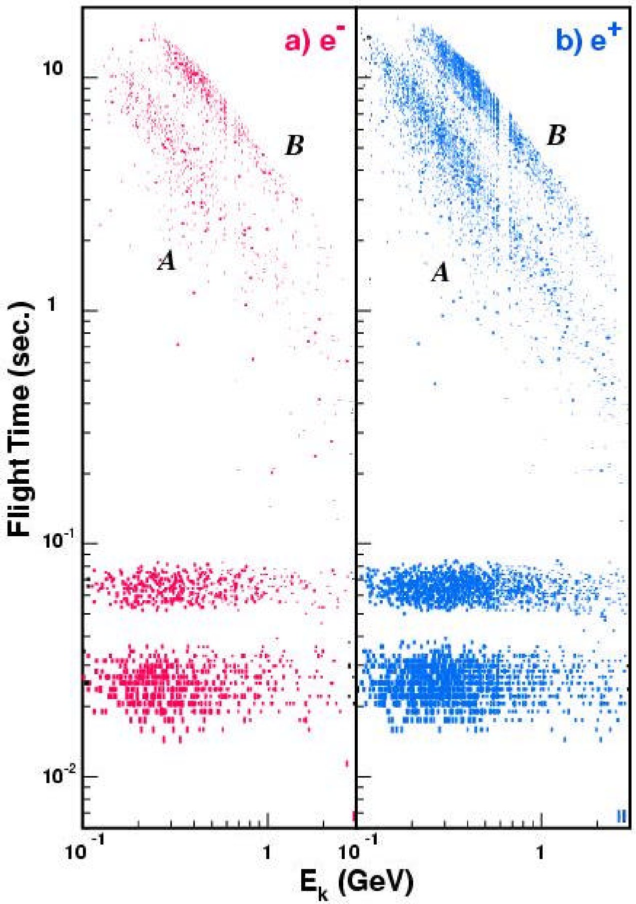
Upward ⇒



J.Casaus, February 1st 2002, Jaca

AMS-01 Under Cutoff Spectra (2/3)

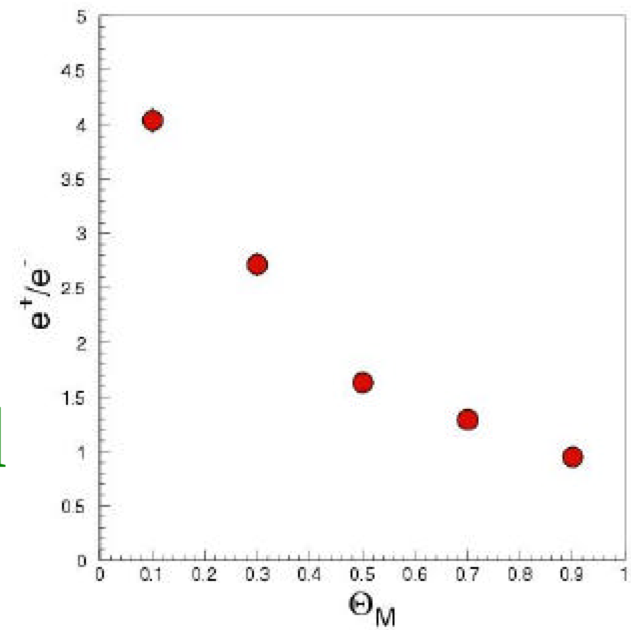
A substantial flux detected below the geomagnetic cutoff



⇐ Long-lived

⇐ Short-lived

e^- & e^+

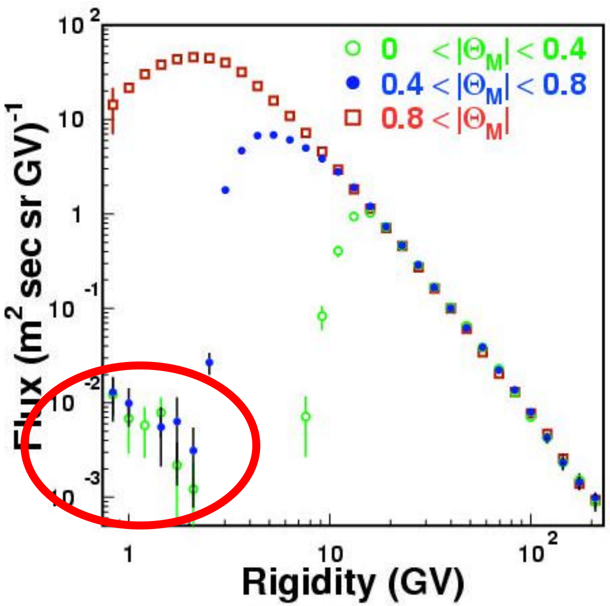


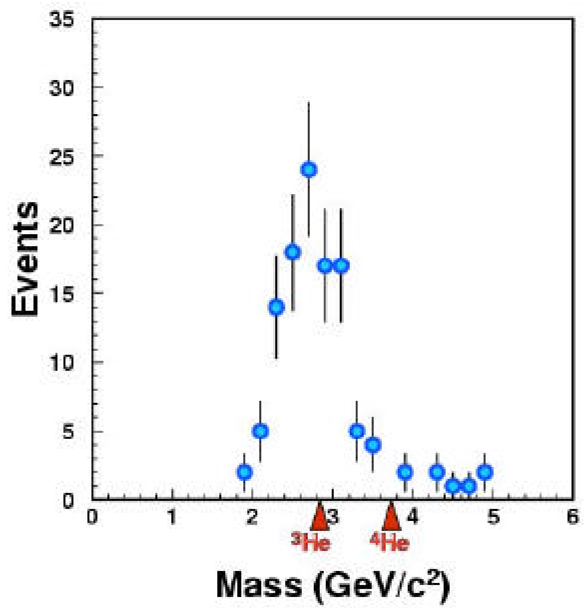
AMS-01 Under Cutoff Spectra (3/3)

A substantial flux detected below the geomagnetic cutoff

Helium

^{3}He dominance in the 2nd spectrum





J.Casaus, February 1st 2002, Jaca

AMS-01 Under Cutoff Spectra

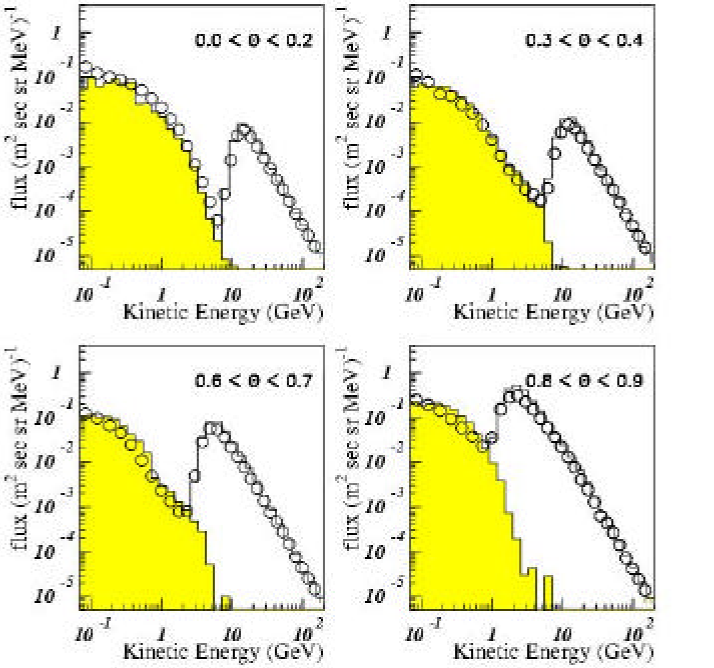
General Features:

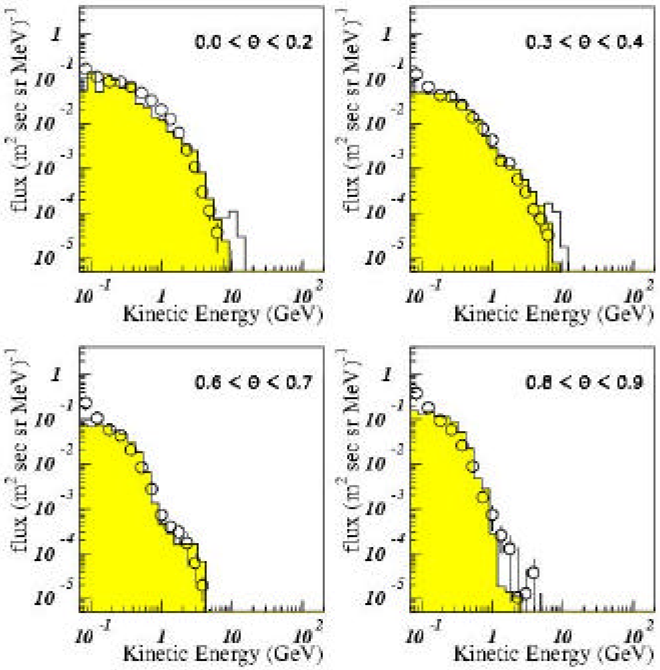
- Originated in the atmosphere
- Flux Upwards = Flux Downwards
- Short & Long-lived components
- Distinctive composition

Secondary fluxes in near Earth Orbit

- Primary Fluxes
- Interaction in the Earth’s atmosphere
- Tracing through the geomagnetic field

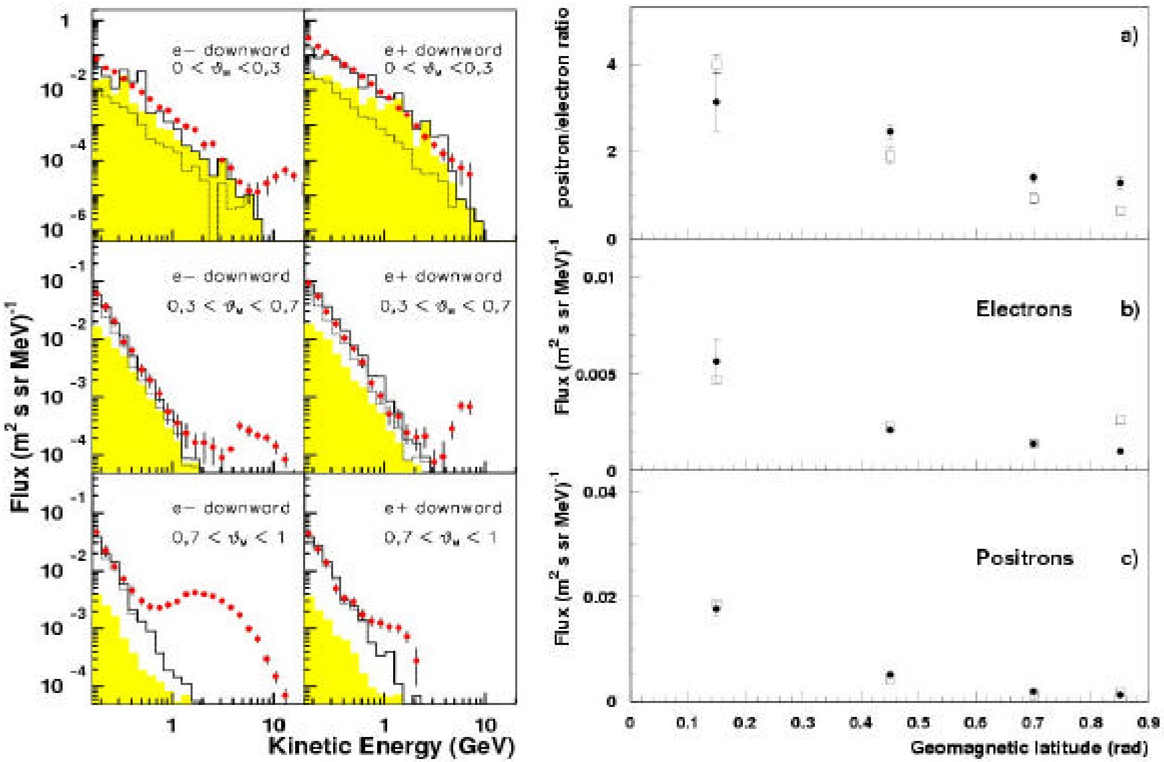
L. Derome et al., Phys. Lett. B489(2000)1



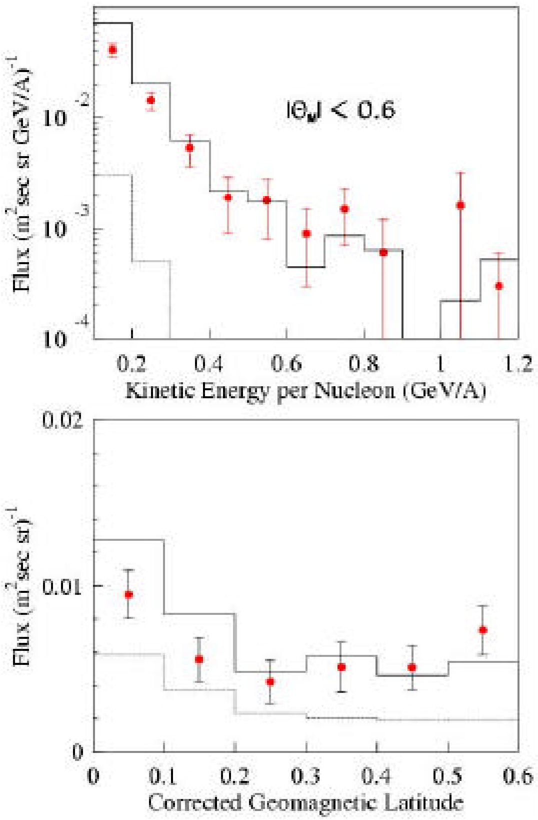


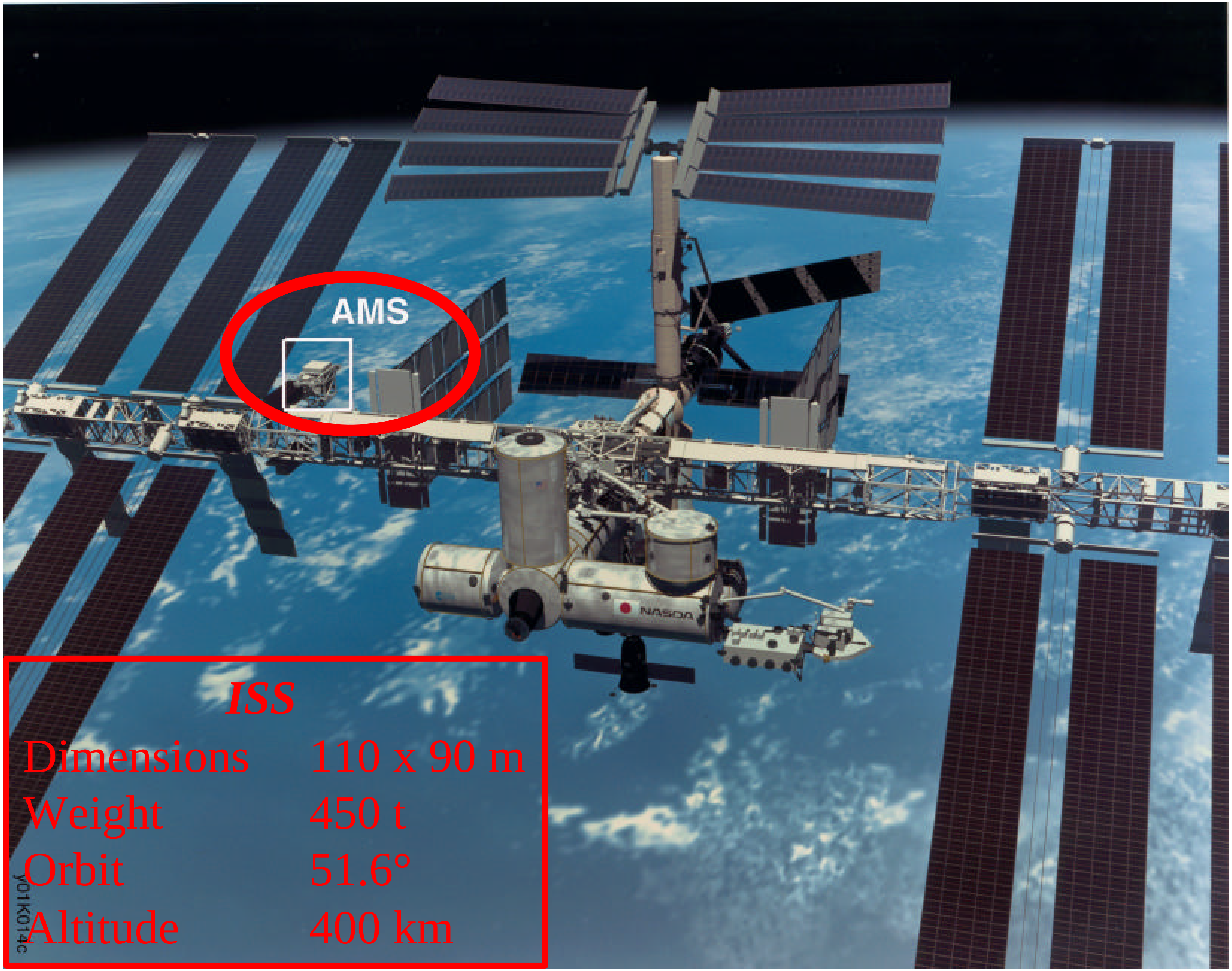
Secondary fluxes in near Earth Orbit

P. Zuccon et al., astro-ph/0111111

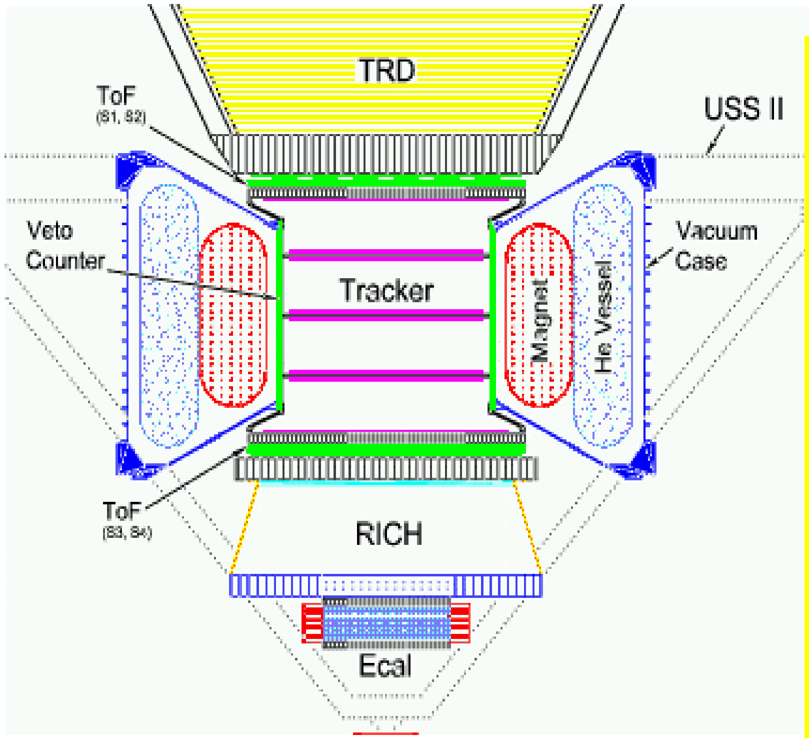


L. Derome et al., Phys. Lett. B521(2001)139




AMS
ISS
Dimensions 110 x 90 m
Weight 450 t
Orbit 51.6°
Altitude 400 km

AMS-02 Spectrometer



- Superconducting Magnet
- Silicon Tracker
- Scintillator System
- Transition Radiation Detector
- Ring Imaging Cerenkov
- Electromagnetic Calorimeter

WEIGHT 6 T

POWER 2 KW

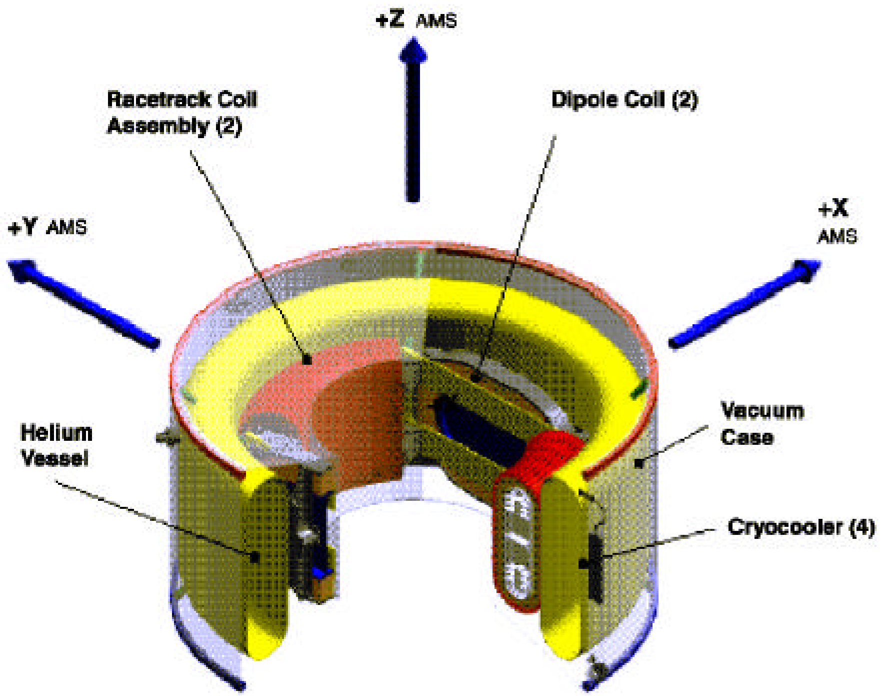
Acceptance: 0.45 $m^2 sr$

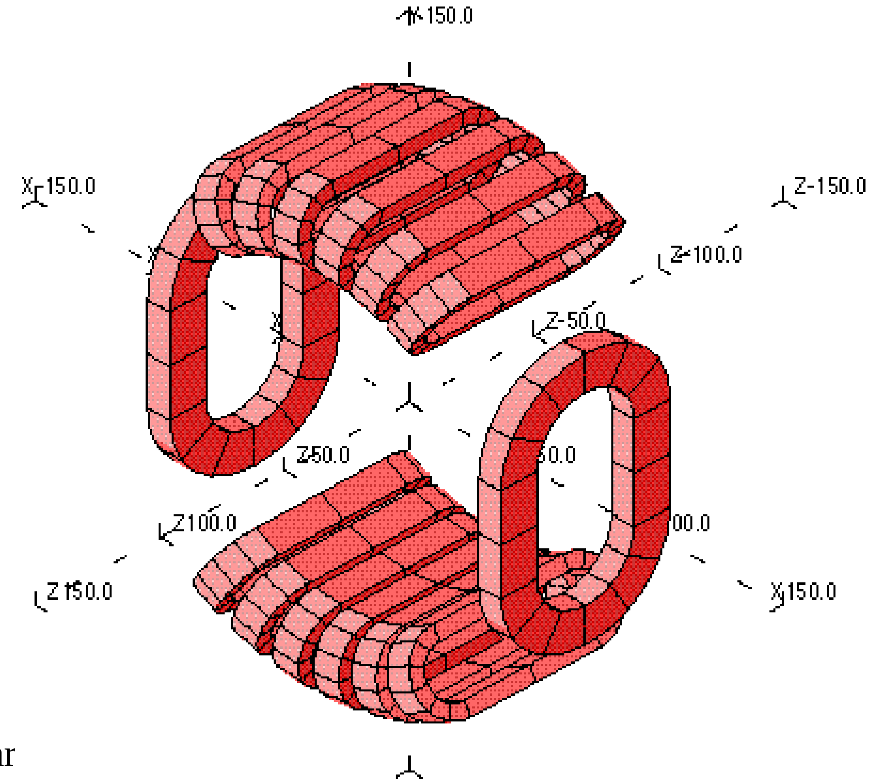
AMS-02 Superconducting Magnet

12 racetrack coils & 2 dipole coils

2500 liters of superfluid helium

$BL^2 = 0.86\ Tm^2$



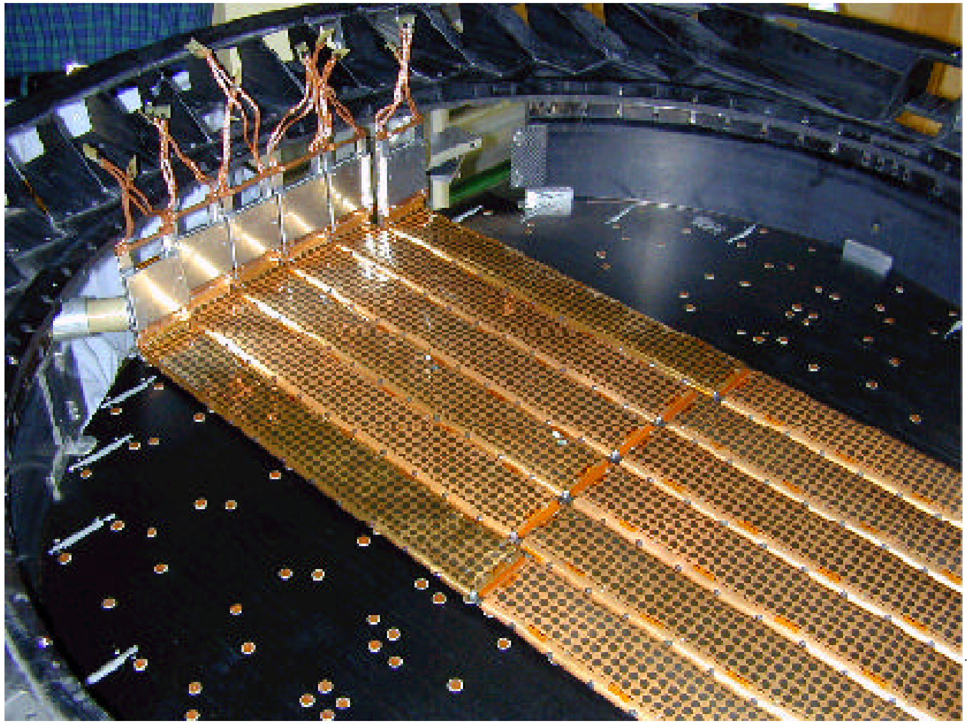


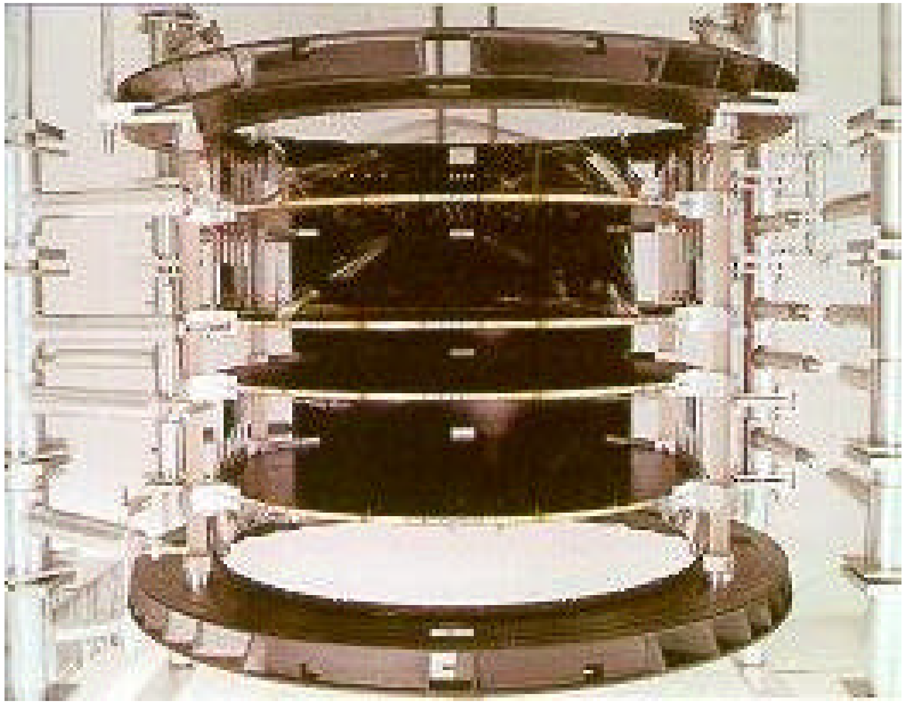
AMS-02 Silicon Tracker

8 layers of double sided silicon sensors

6.5m^2 192 Ladders (196k channels)

s (p)/p = 1.5% @ 10 GeV, MDR = 2.6 TeV (protons)



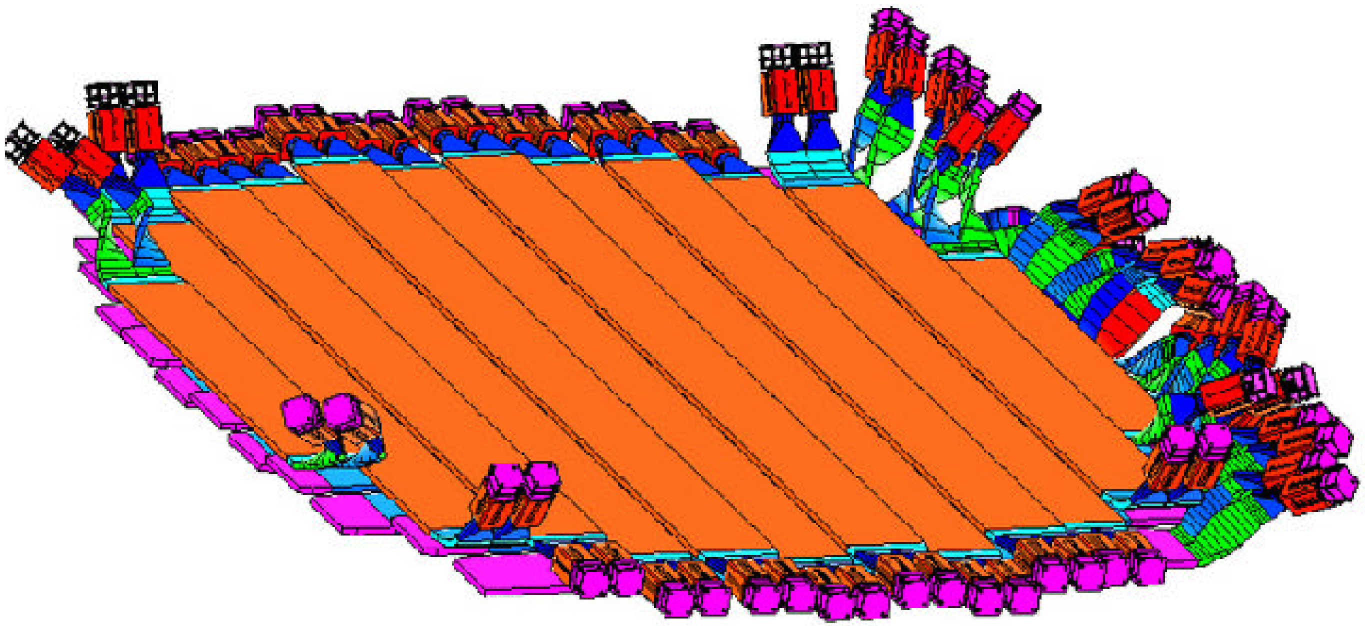


AMS-02 Time of Flight System

4 planes, 12 scintillator paddles

seen by 2 PMTs on each side

s (ß)/ß = 3.7% @ ß = 1 (protons)

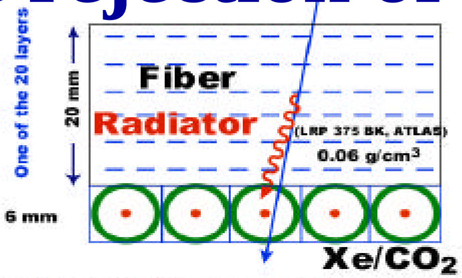


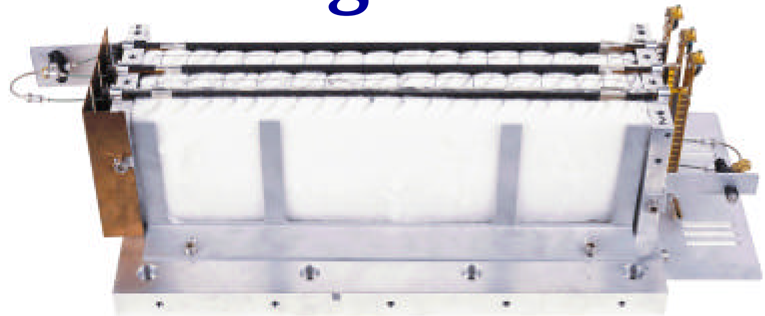
AMS-02 Transition Radiation Detector

20 layers of TRD

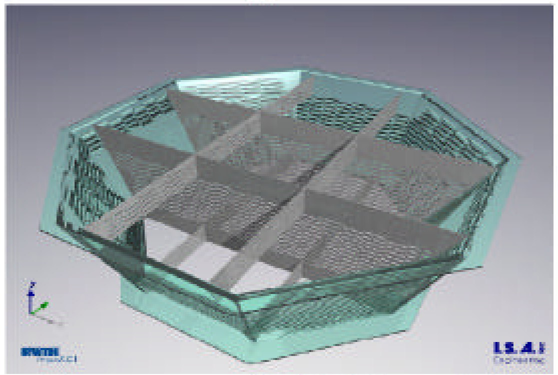
5248 straw tubes

h/e rejection of $10^2 – 10^3$ in the range 3 – 300 GeV

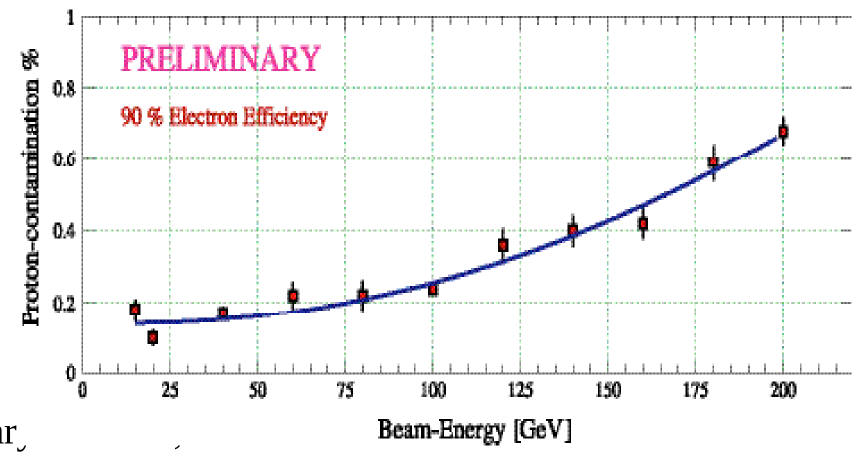




The TRD support structure



Top 4 layers (measure y coordinate), 12 layers (x), 4 layers (y)

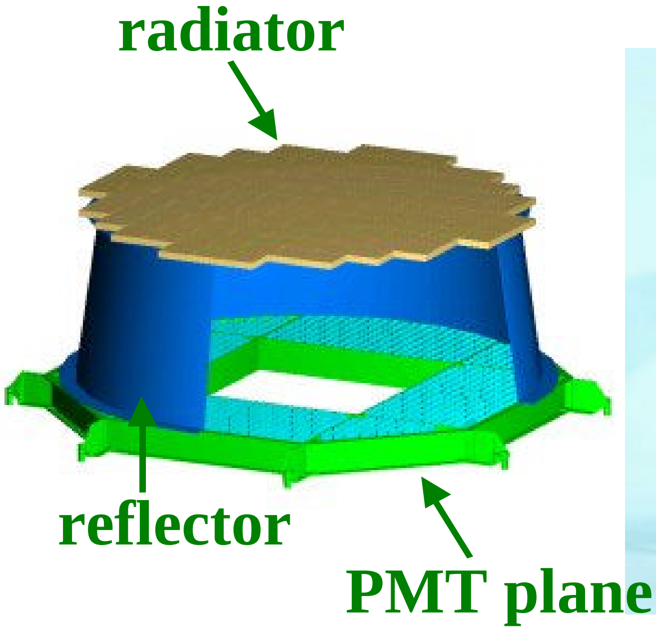


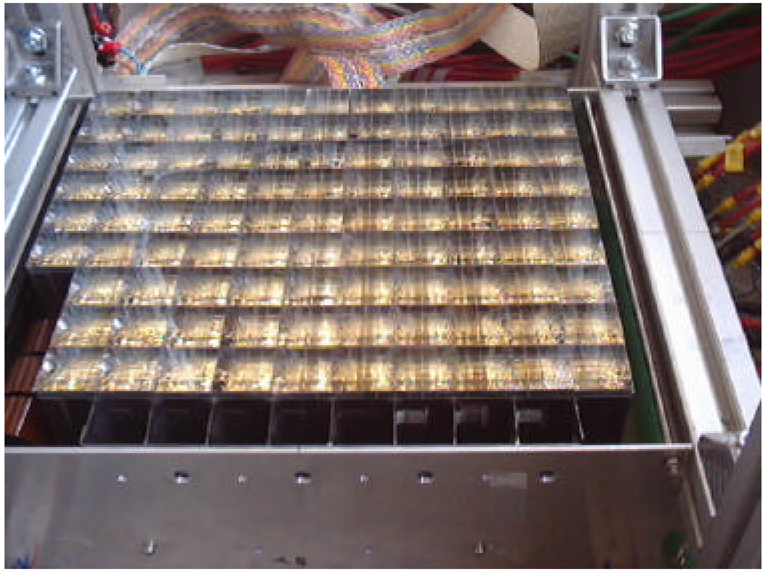
AMS-02 Ring Imaging Cerenkov Counter

3 cm silica aerogel (n=1.05) radiator

680 multianode (4x4) PMTs

s (ß)/ß = 0.1% @ ß = 1 (protons)



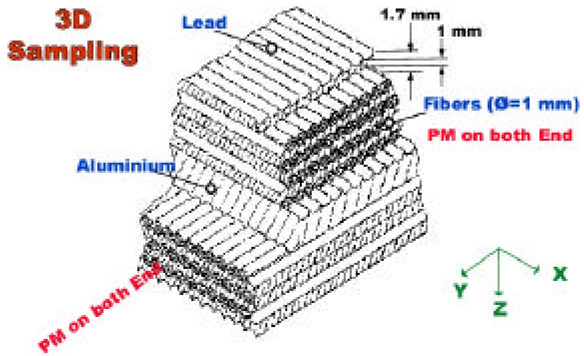


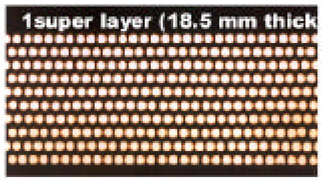
AMS-02 Electromagnetic Calorimeter

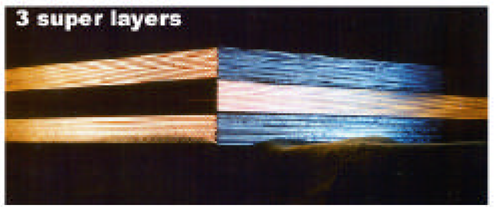
9 super layers of Sci-Fiber/Lead (15 Xo)

324 multianode (2x2) PMTs

s (E)/E = 3% @ 100 GeV   h/e rejection of 10^4

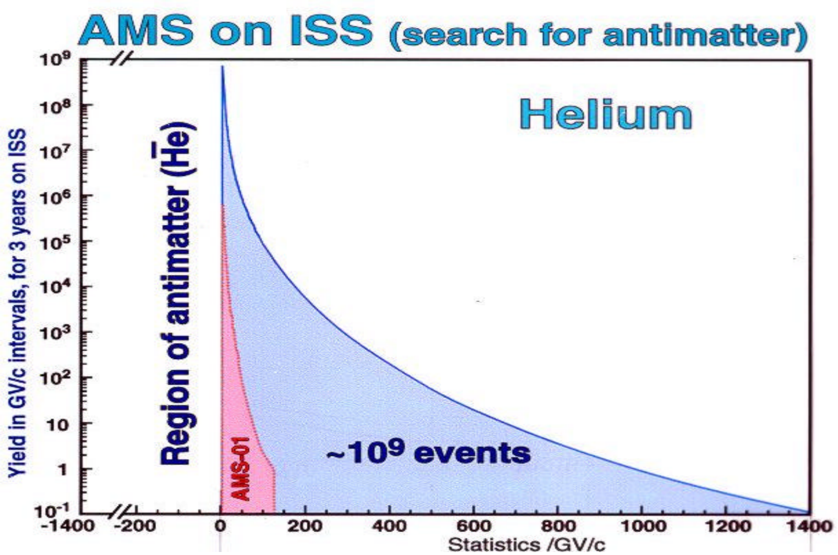


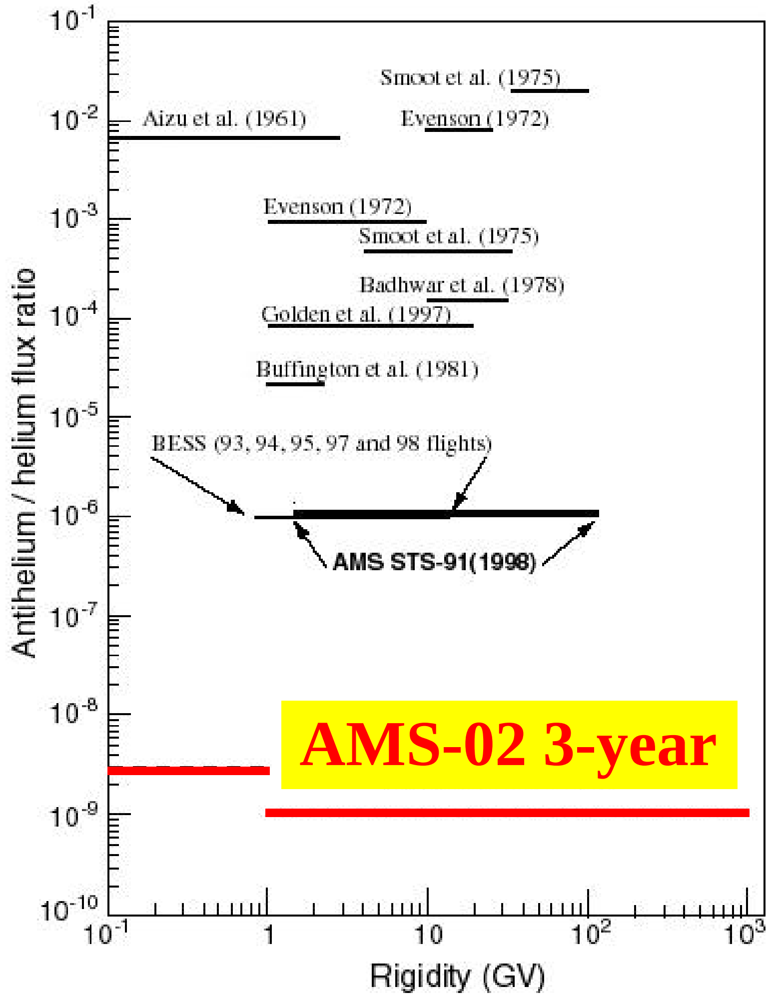




AMS-02 Antimatter Sensitivity

In 3 years AMS will collect 10^9 He with E≲1 TeV

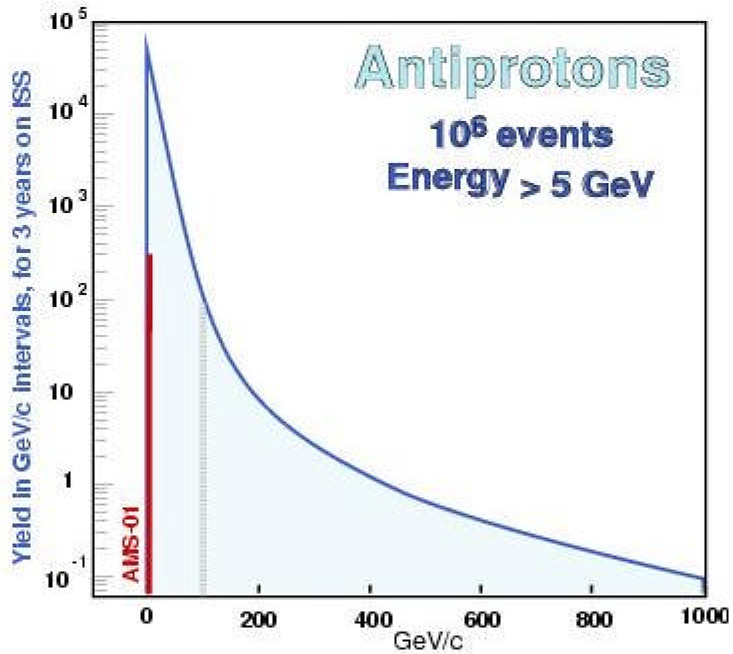




AMS-02 Antiprotons

AMS will measure the $\bar{p}$ flux up to few 100 GeV

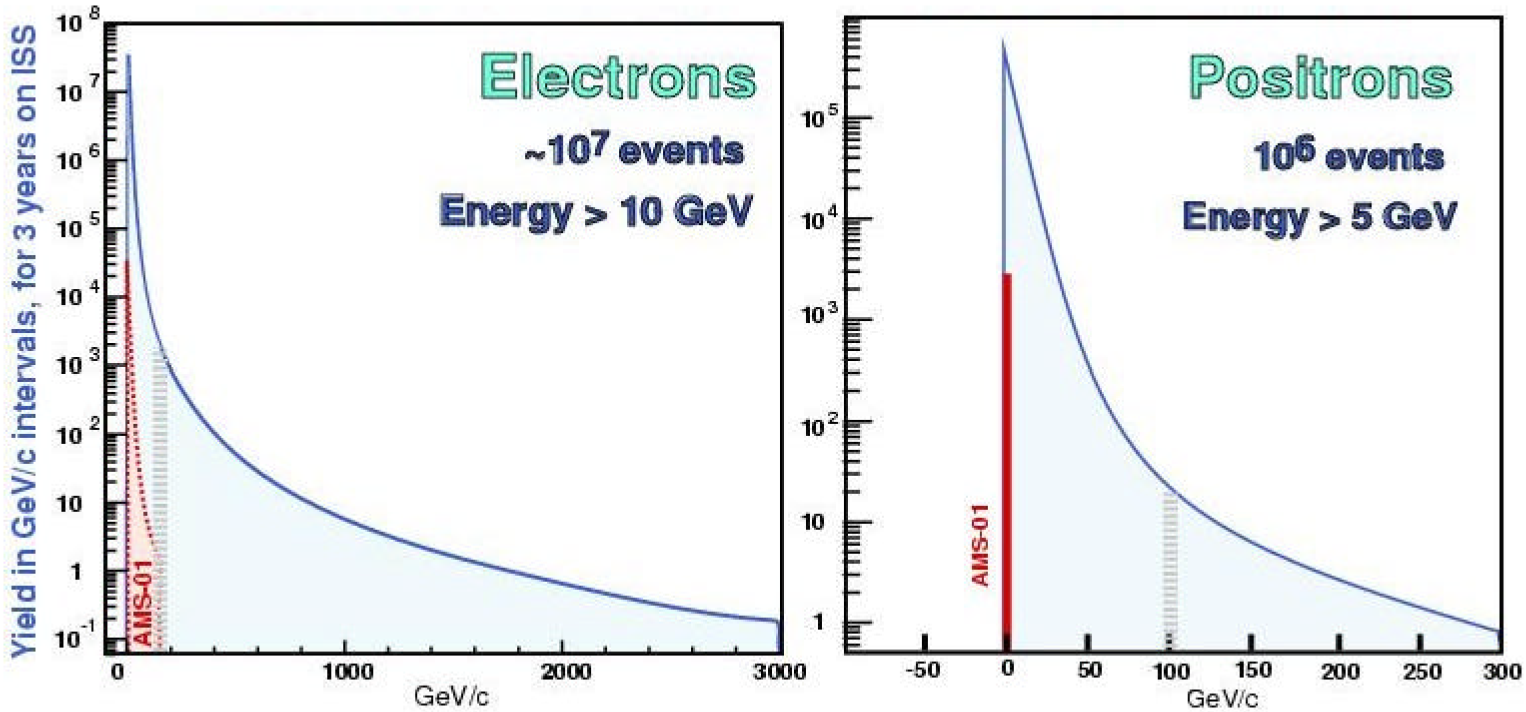
After 3 years will collect »10^6 $\bar{p}$



AMS-02 Electrons & Positrons

AMS will measure the e^- flux up to O(TeV)

and the e^+ flux up to » 300 GeV

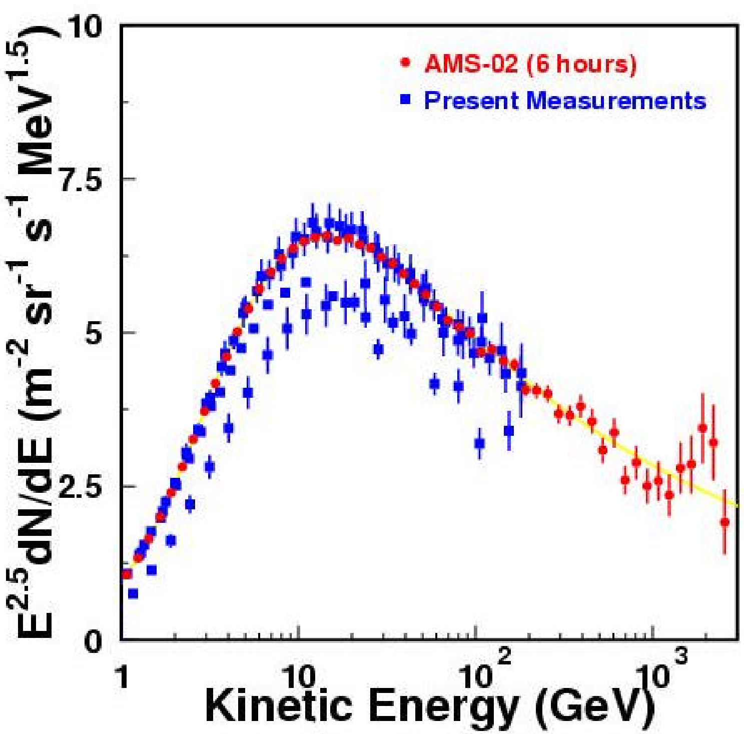


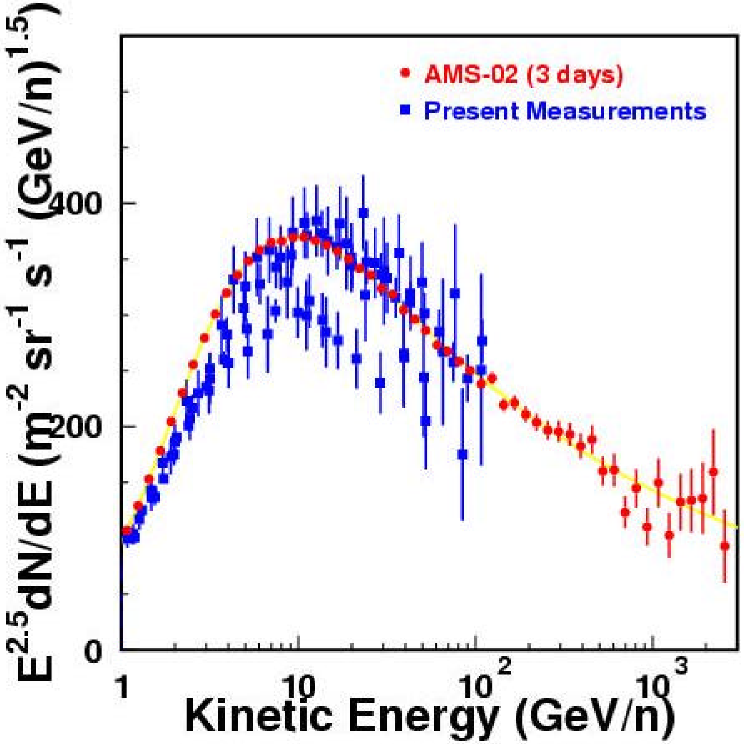
AMS-02 Protons & Helium

AMS will measure H & He fluxes for E≲1 TeV

after 3 years will collect »10^8 H with E > 100 GeV

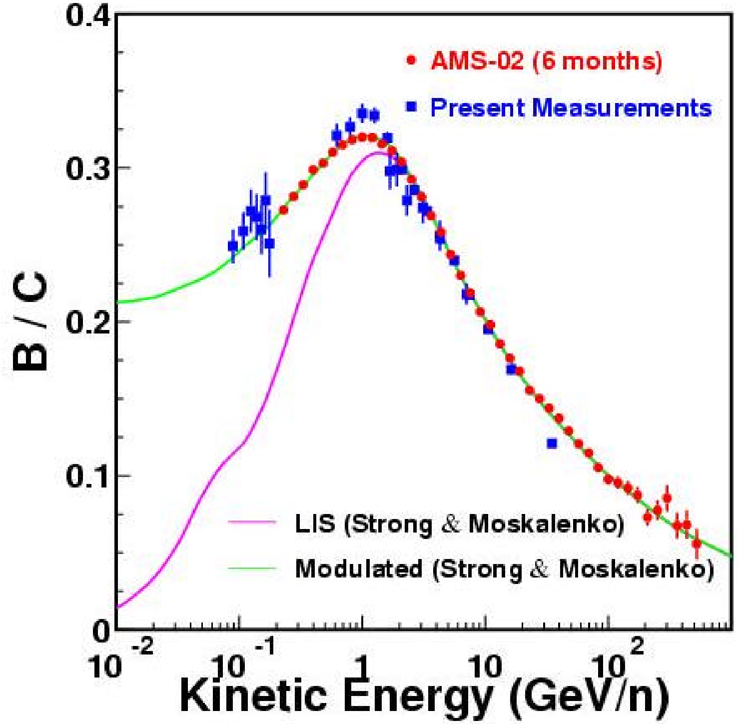
and »10^7 He with E > 100 GeV/n





AMS-02 Light Elements

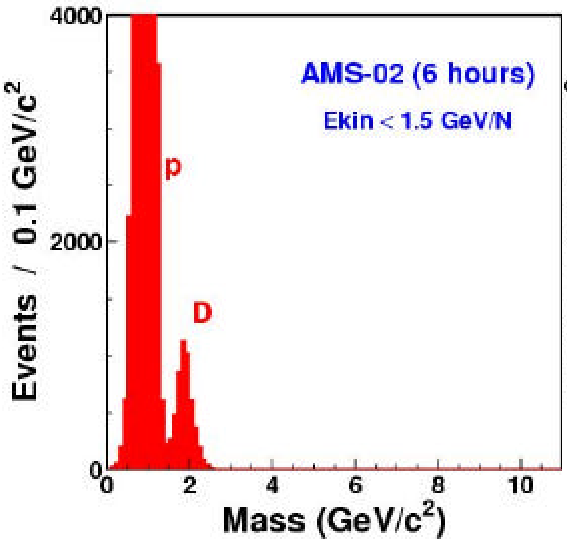
AMS will measure the spectrum for E ≲ 1 TeV/n
after 3 years will collect »10^5 C with E > 100 GeV/n
and »10^4 B with E > 100 GeV/n

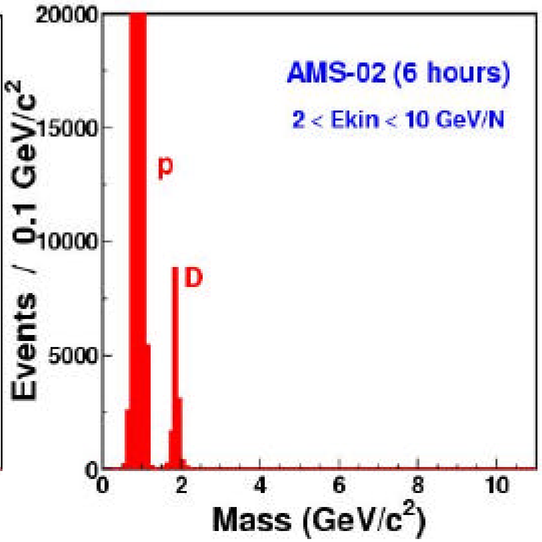


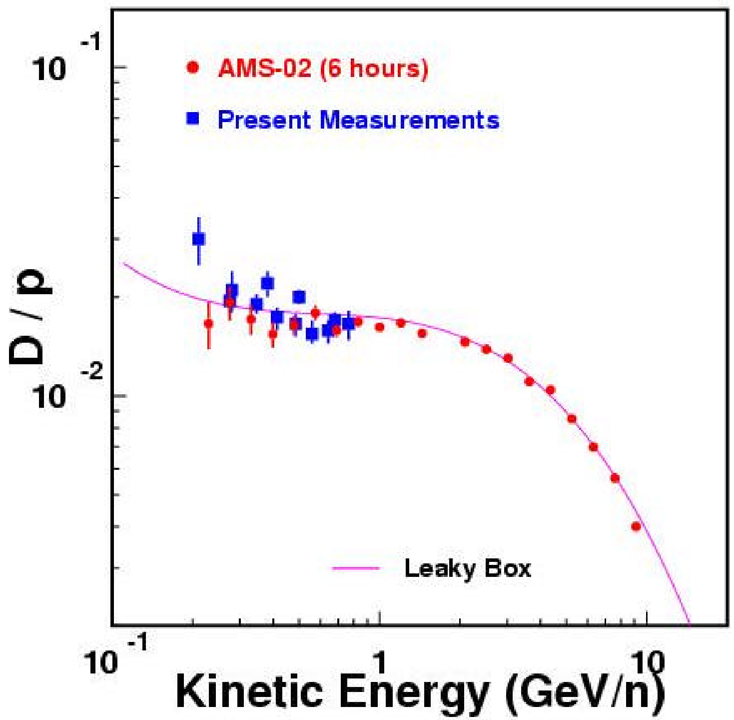
AMS-02 Light Isotopes (1/3)

AMS will identify D up to 10 GeV/n

after 3 years will collect »10^8 D



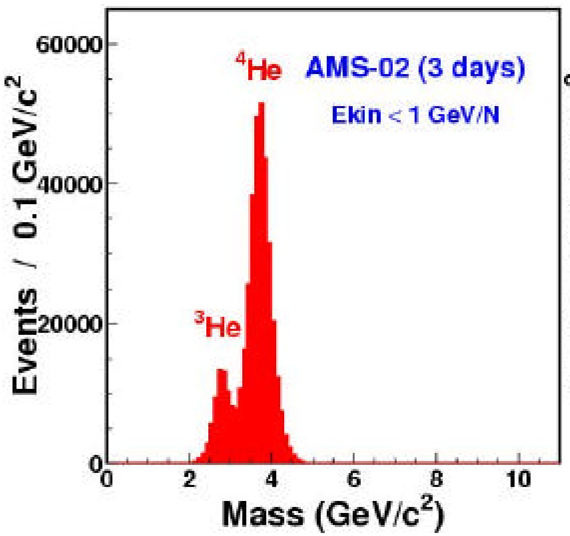


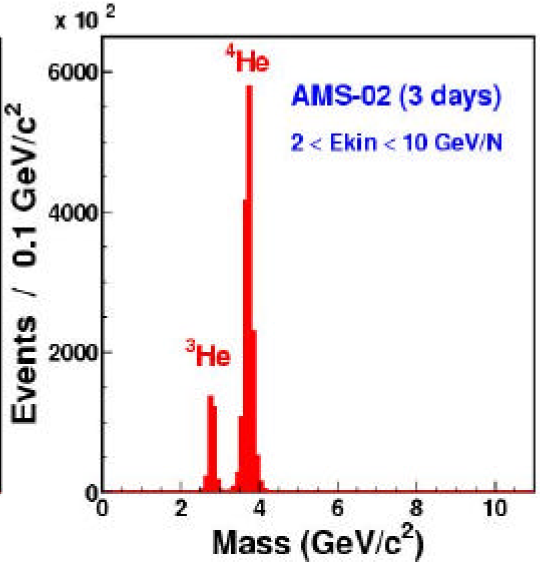


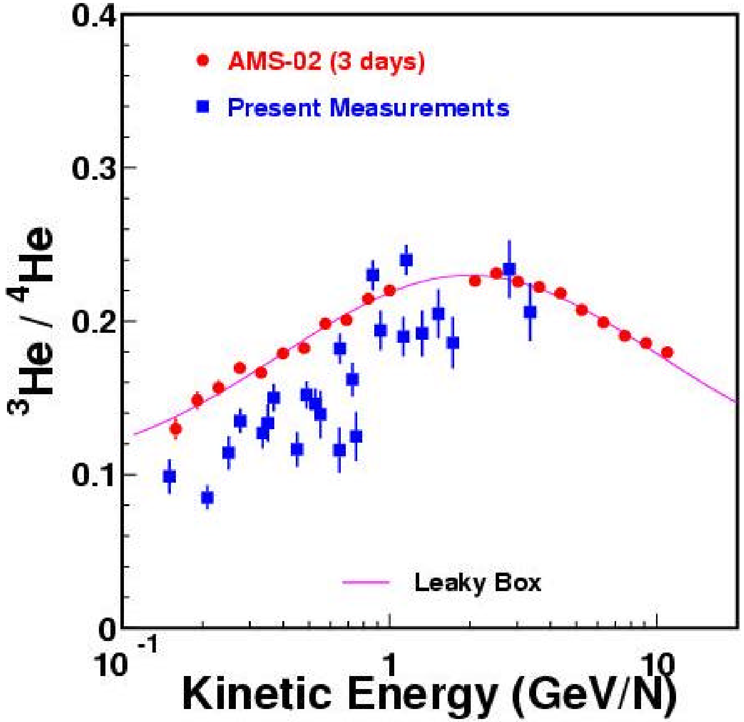
AMS-02 Light Isotopes (2/3)

AMS will identify ^{3}He up to 10 GeV/n

after 3 years will collect »10^{8} ^{3}He





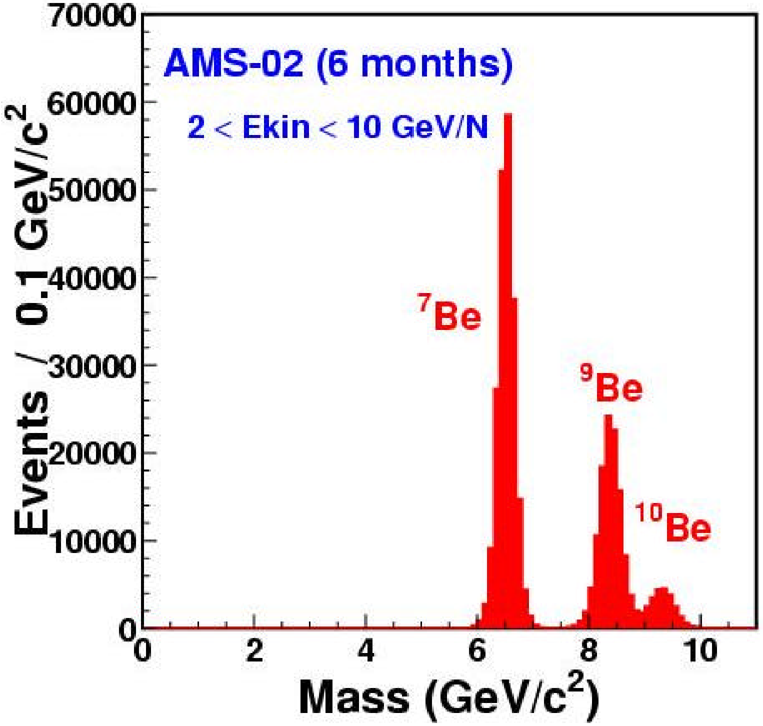


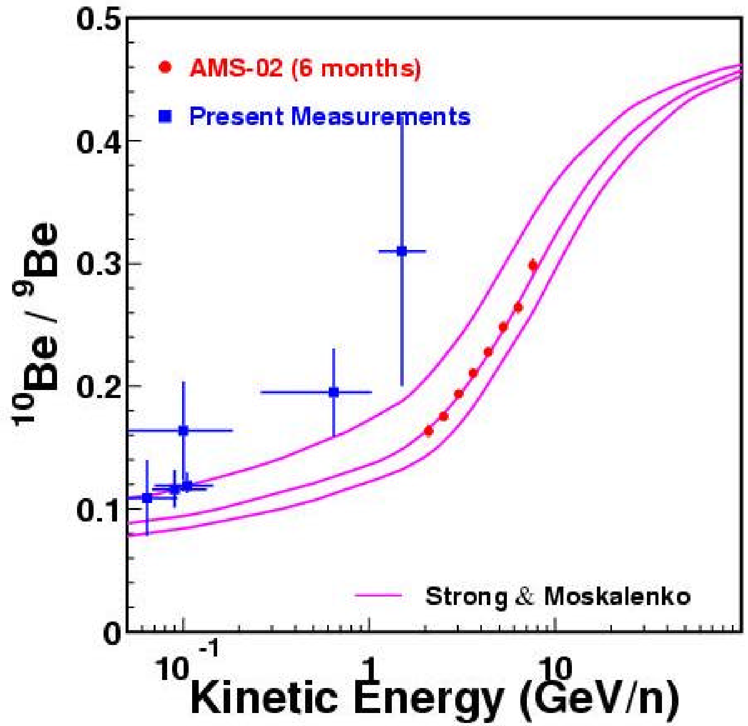
AMS-02 Light Isotopes (3/3)

AMS will separate ^{10}Be from ^{9}Be for

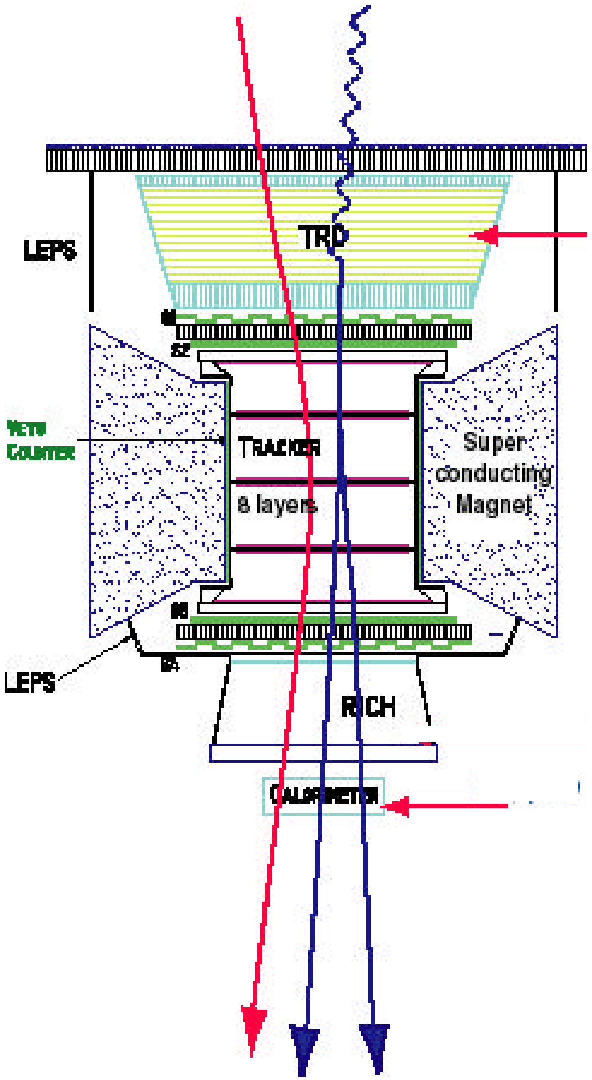
2 GeV/n < E < 10 GeV/n

after 3 years will collect »10^5 ^{10}Be





AMS-02 ?-ray Capabilities



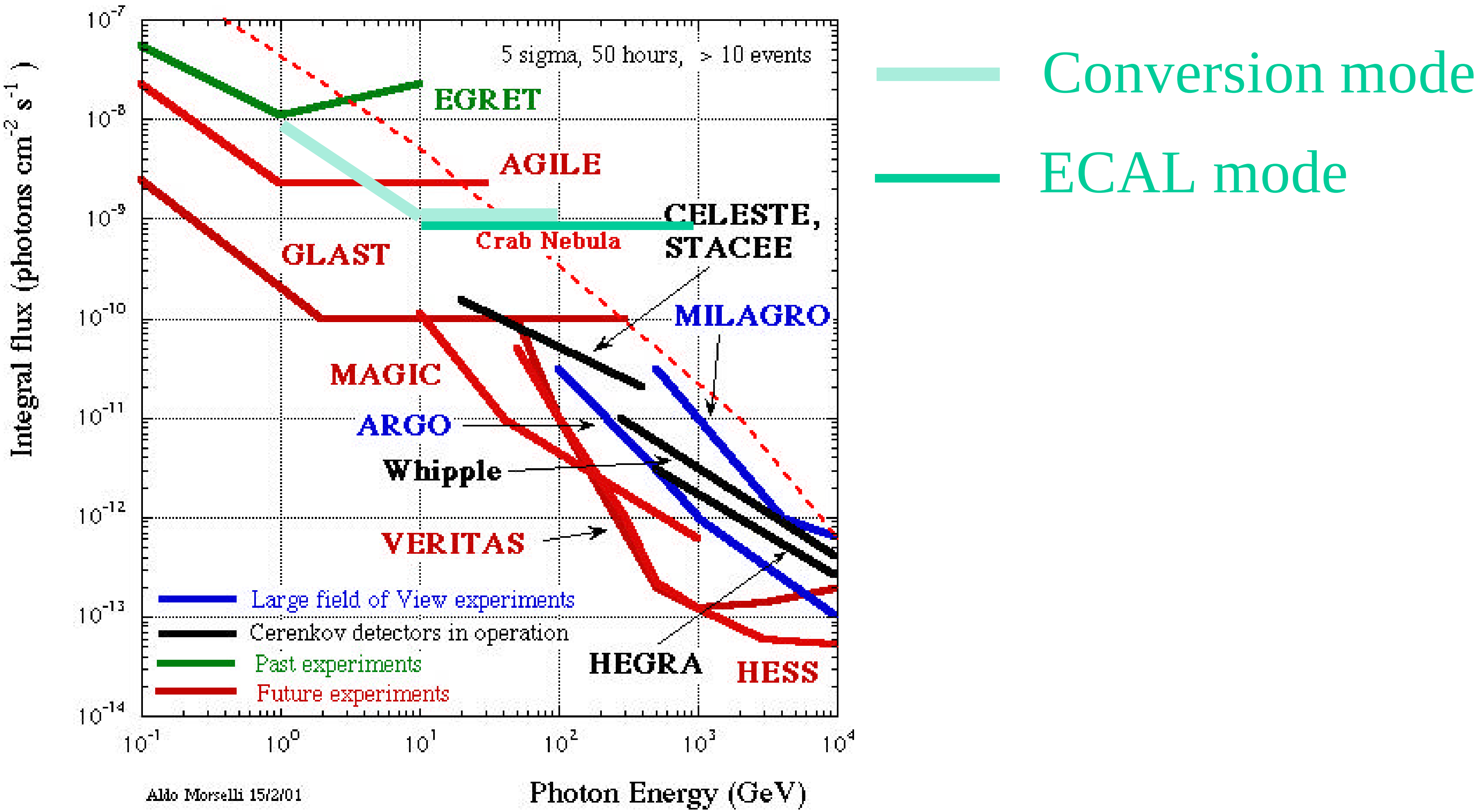
Conversion mode

Energy range	1 – 100 GeV
Acceptance	0.06 m^2sr
E resolution	2% @ 10 GeV
? resolution	0.03º @ 10 GeV

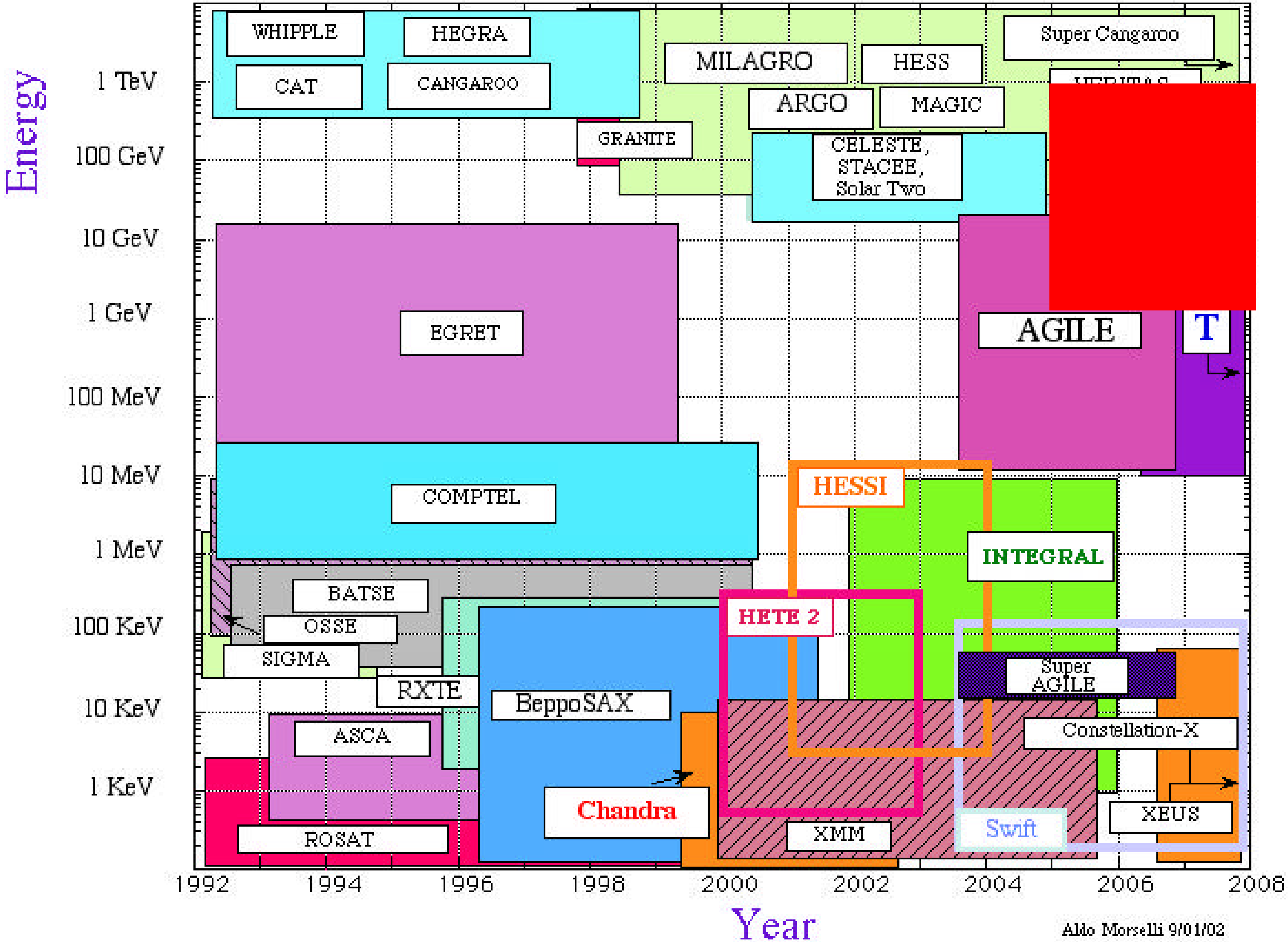
ECAL mode

Energy range	10 – 1000 GeV
Acceptance	0.06 m^2sr
E resolution	3% @ 100 GeV
? resolution	0.5º @ 100 GeV

AMS/? Point Source Sensitivity



AMS/? Sky Survey



Conclusions

- AMS had a successful operation in space during a 10-day flight in 1998
- Precise results have been obtained on primary and under cutoff spectra as well as a new limit on the existence of nuclear antimatter
- AMS is approved by NASA to operate on the ISS for 3 years
- AMS will be ready to fly in 2005
- AMS large acceptance and long exposure time will allow an unprecedented sensitive study of CR from the ISS