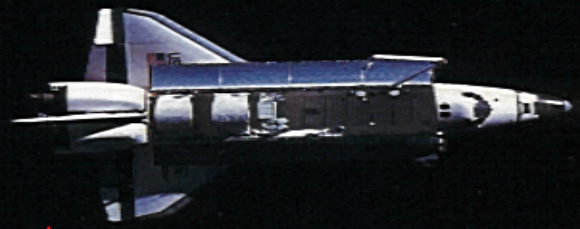
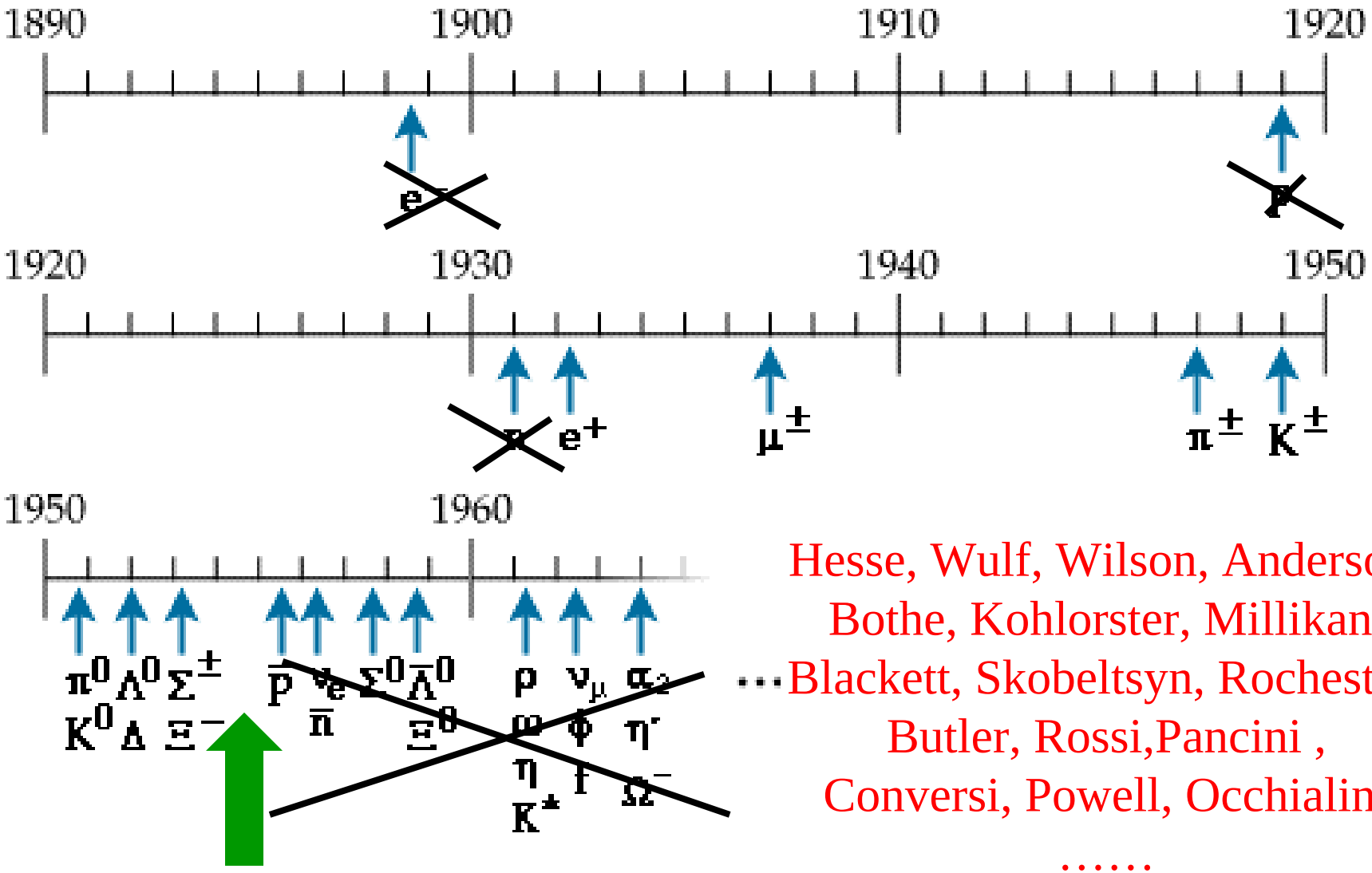
Physics results from AMS



Roberto Battiston
University and INFN of Perugia

XVI Rencontres de Physique de La Valleé d'Aoste
La Thuile, March 4th, 2002

PARTICLE PHYSICS BIRTH WAS DUE TO COSMIC RAYS



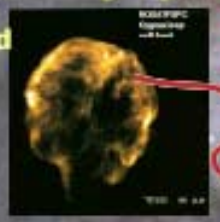
Hesse, Wulf, Wilson, Anderson, Bothe, Kohlorster, Millikan, …Blackett, Skobeltsyn, Rochester, Butler, Rossi,Pancini , Conversi, Powell, Occhialini ……

Advent of accelerators

High Energy Cosmic Rays in the Universe

Cygnus Loop

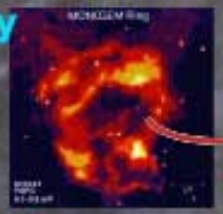
SNR 2 x 10^4 year-old
(2500 light-year).



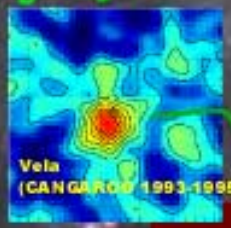
Monogem

SNR 8.6 x 10^4 year-old
(1000 light-year).

X-ray



γ-ray



X-ray

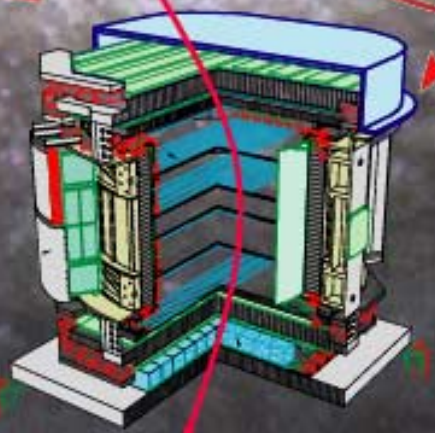
Vela

SNR ~10^4 year-old
(820 light-year).

X-ray

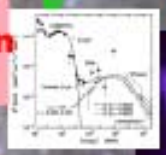
AMS

Anti
Matter Spectrometer



Proton
Electron
Ion

γ-ray

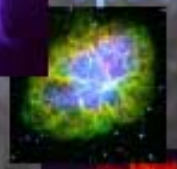


Crab Nebula

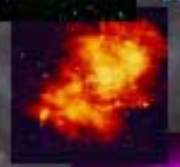
Supernova Remnant
exploded in 1054
(6500 light-year).

X-ray

Optical



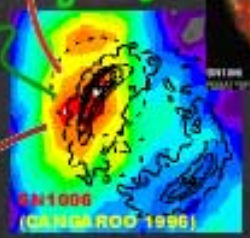
IR



Radio

X-ray

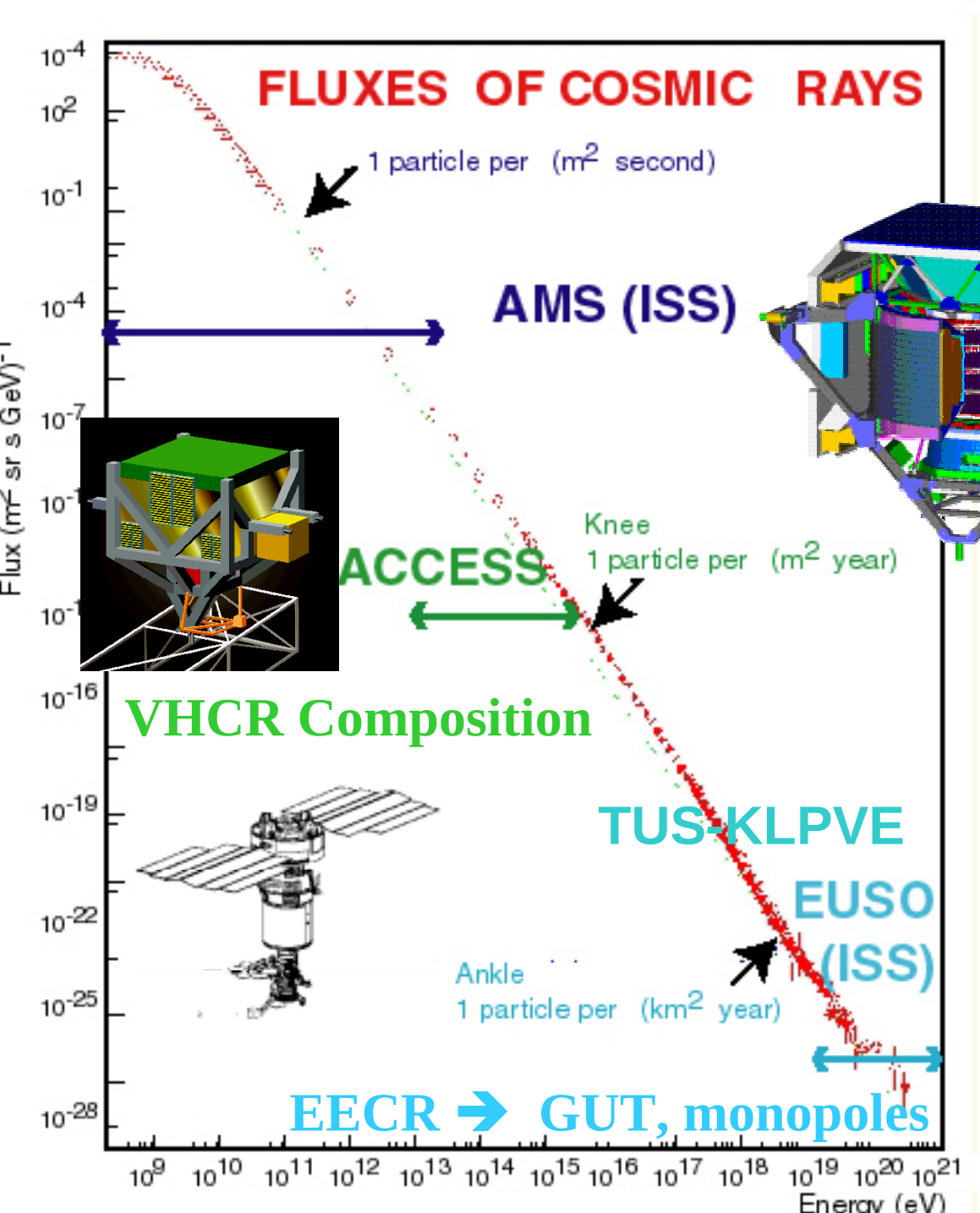
γ-ray

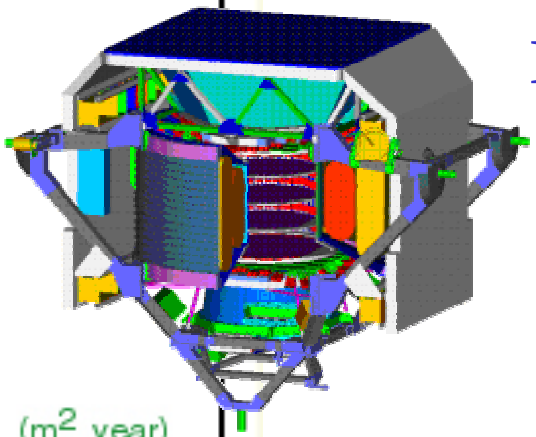


contour :
X-ray (ASCA)

SN1006

Supernova Remnant
exploded in 1006
(6500 light-year).

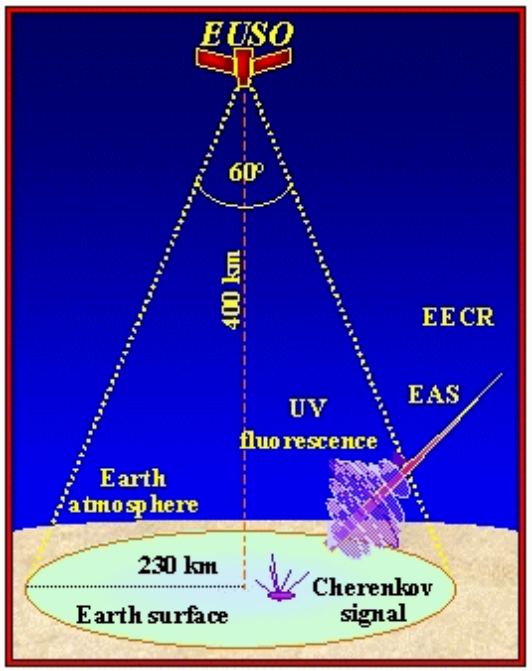




Absence of Antimatter → CP violation, GUT

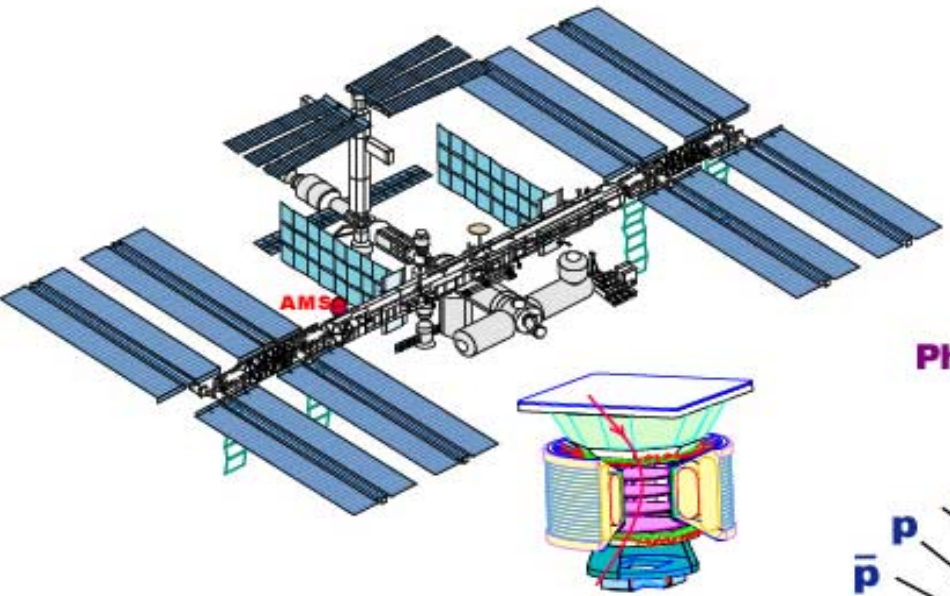
Dark Matter → SUSY, Axions

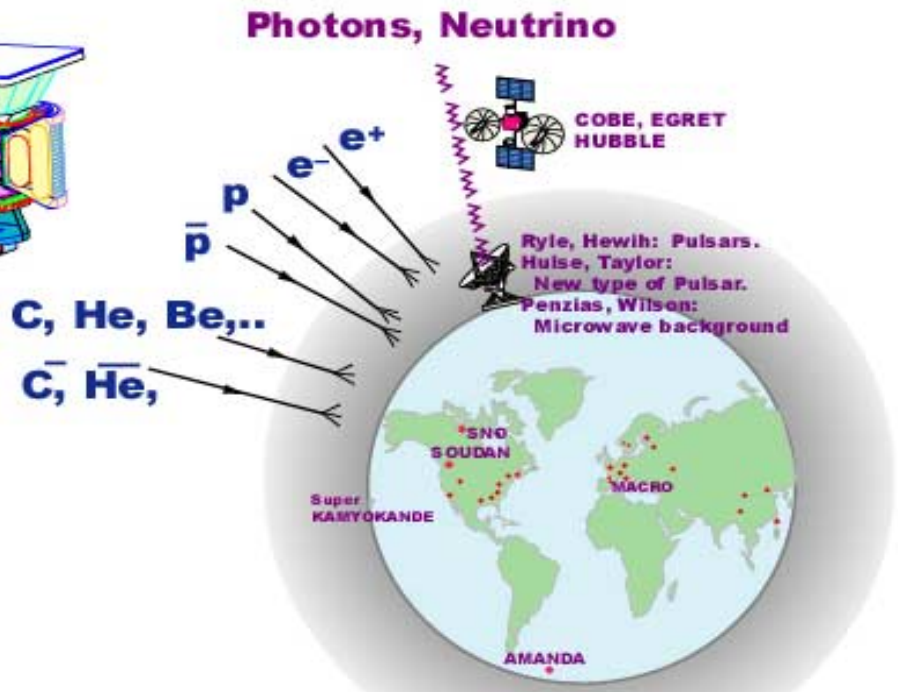
Atmospheric neutrinos → Neutrino mass

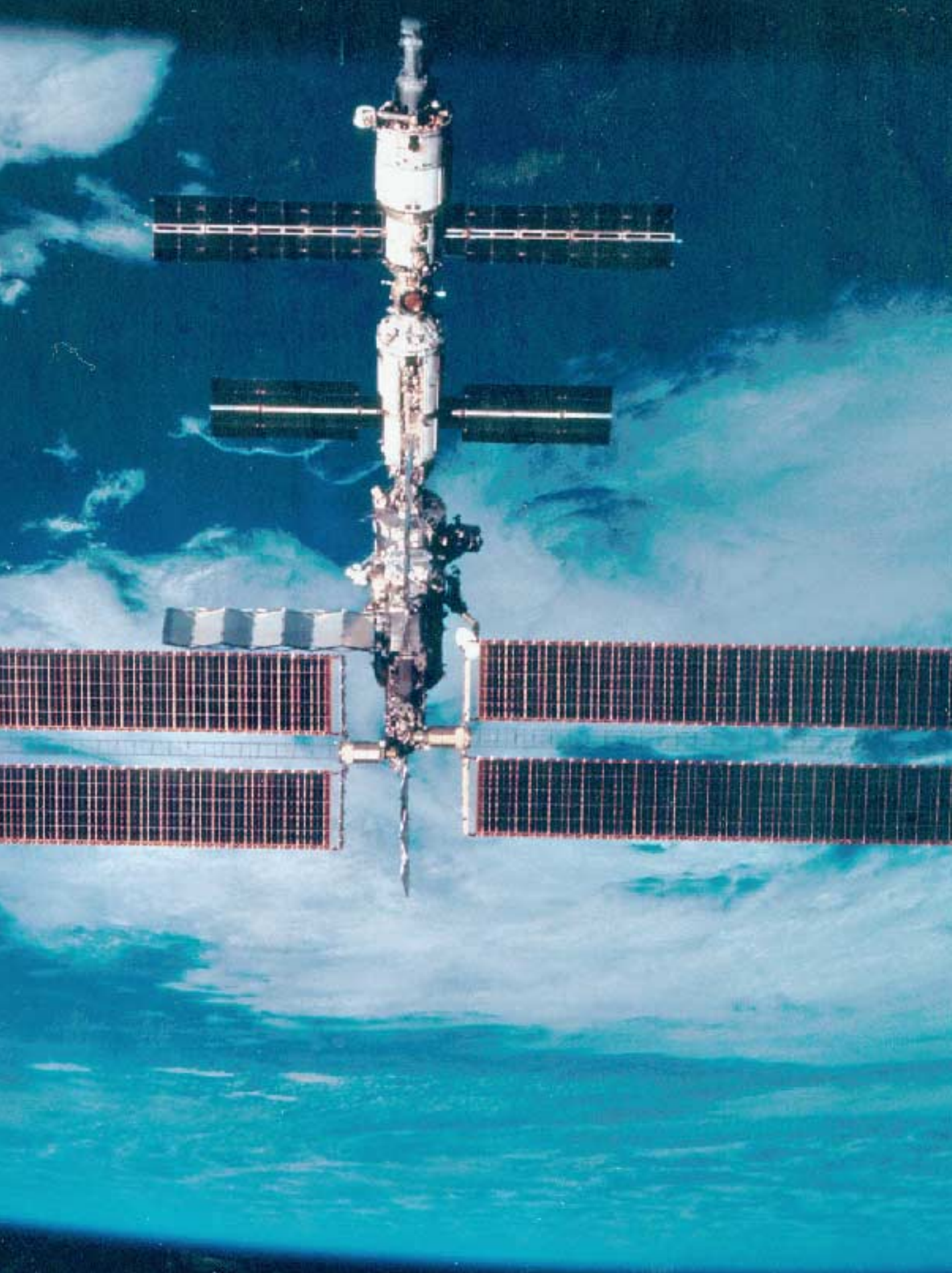


AMS is a particle physics experiment:

SUSY (Super Symmetry)
Grand Unified Theory
Baryon number violation
CP violation



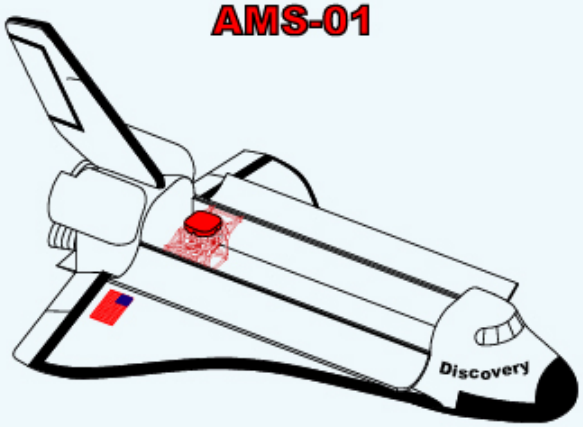




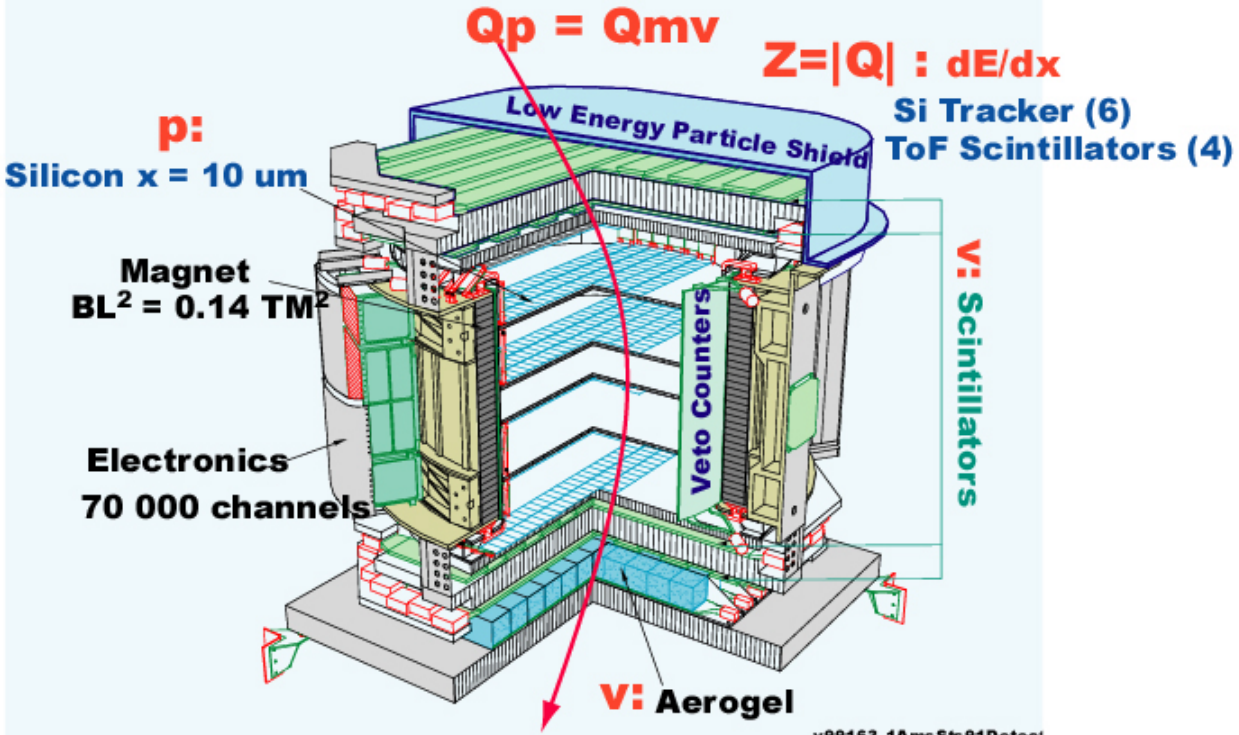
Alpha Magnetic Spectrometer

First flight, STS-91, 2 June 1998 (10 days)

AMS-01



Construction of AMS-01



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US
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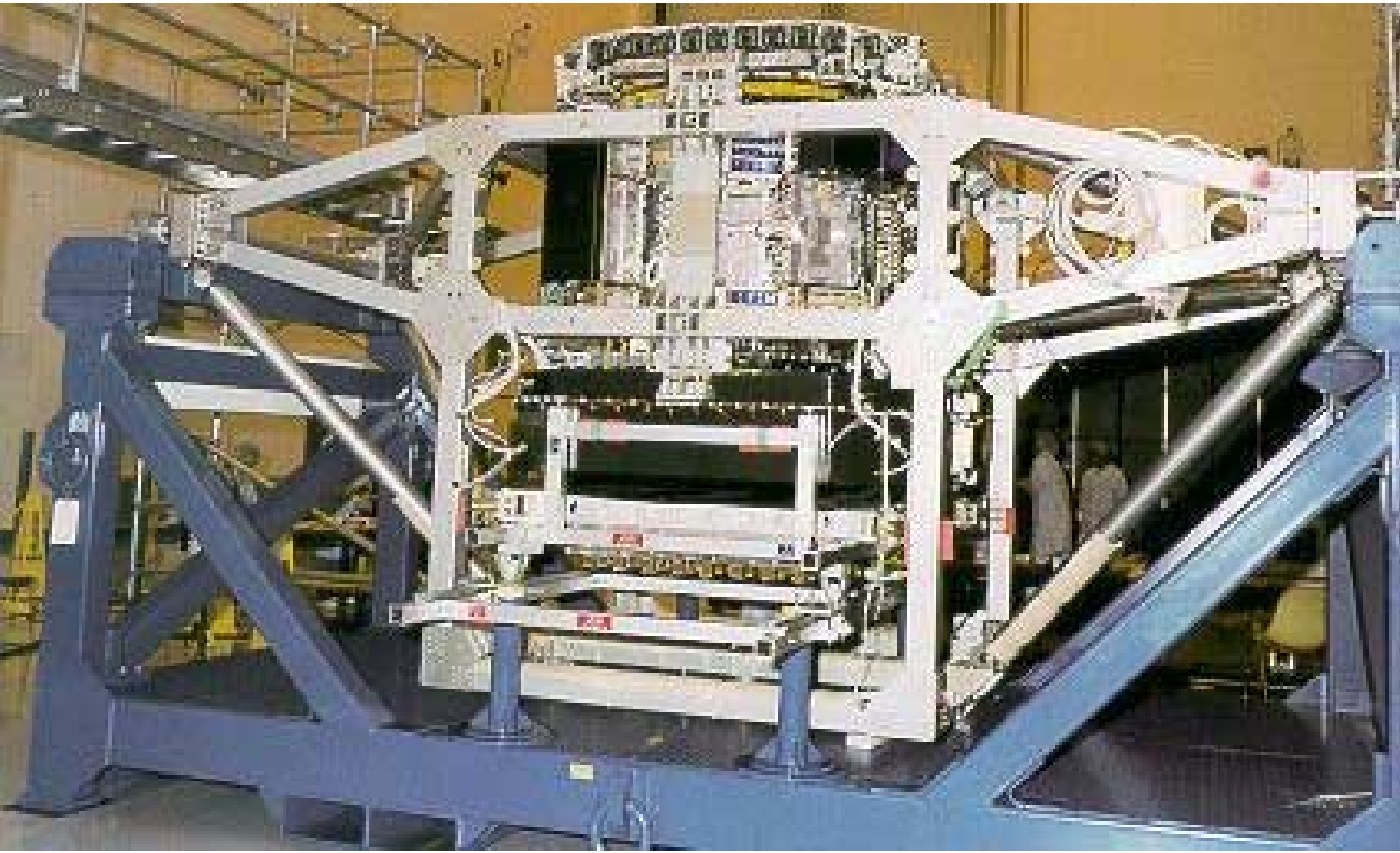
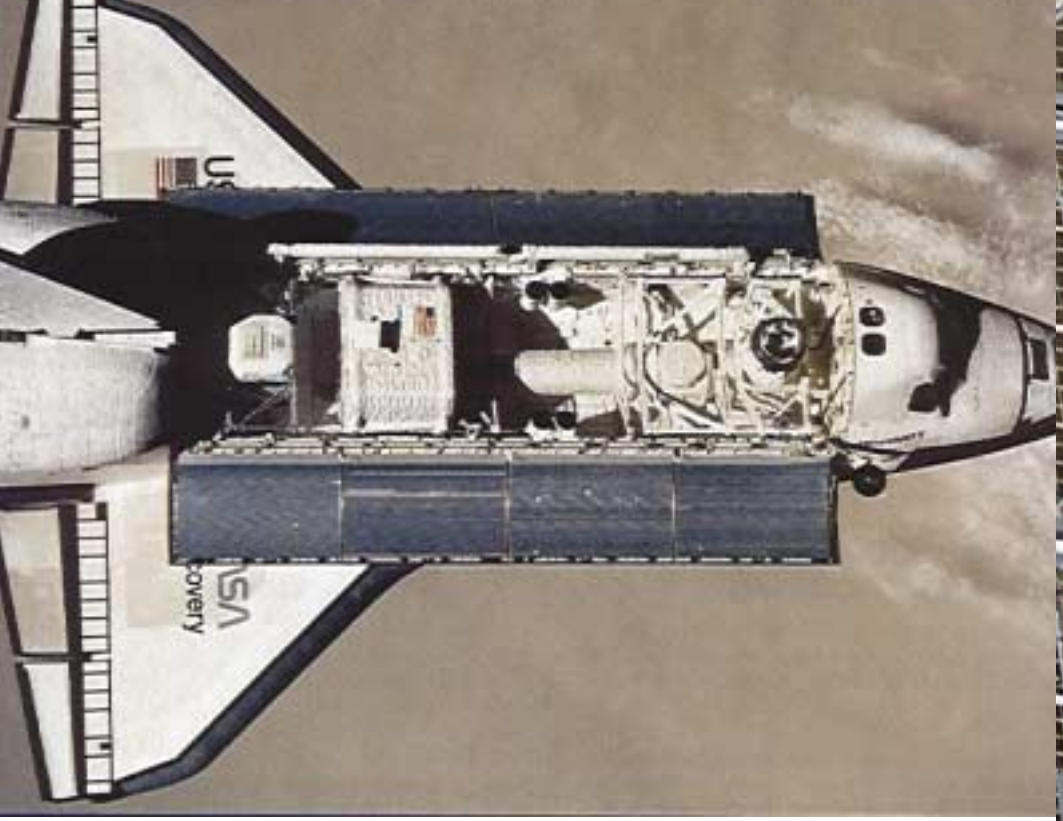
ac Academia Sinica, Taipei, Taiwan
ad Kyungpook National University, 702-701 Taegu, Korea
ae University of Turku, FIN-20014 Turku, Finland
α*f* Eidgenossische Technische Hochschule, ETH Zurich, CH-8093 Zurich, Switzerland

AMS deintegration at CERN: Permanent Magnet and Anti Counters

AMS deintegration at CERN: Silicon Tracker on assembly jig



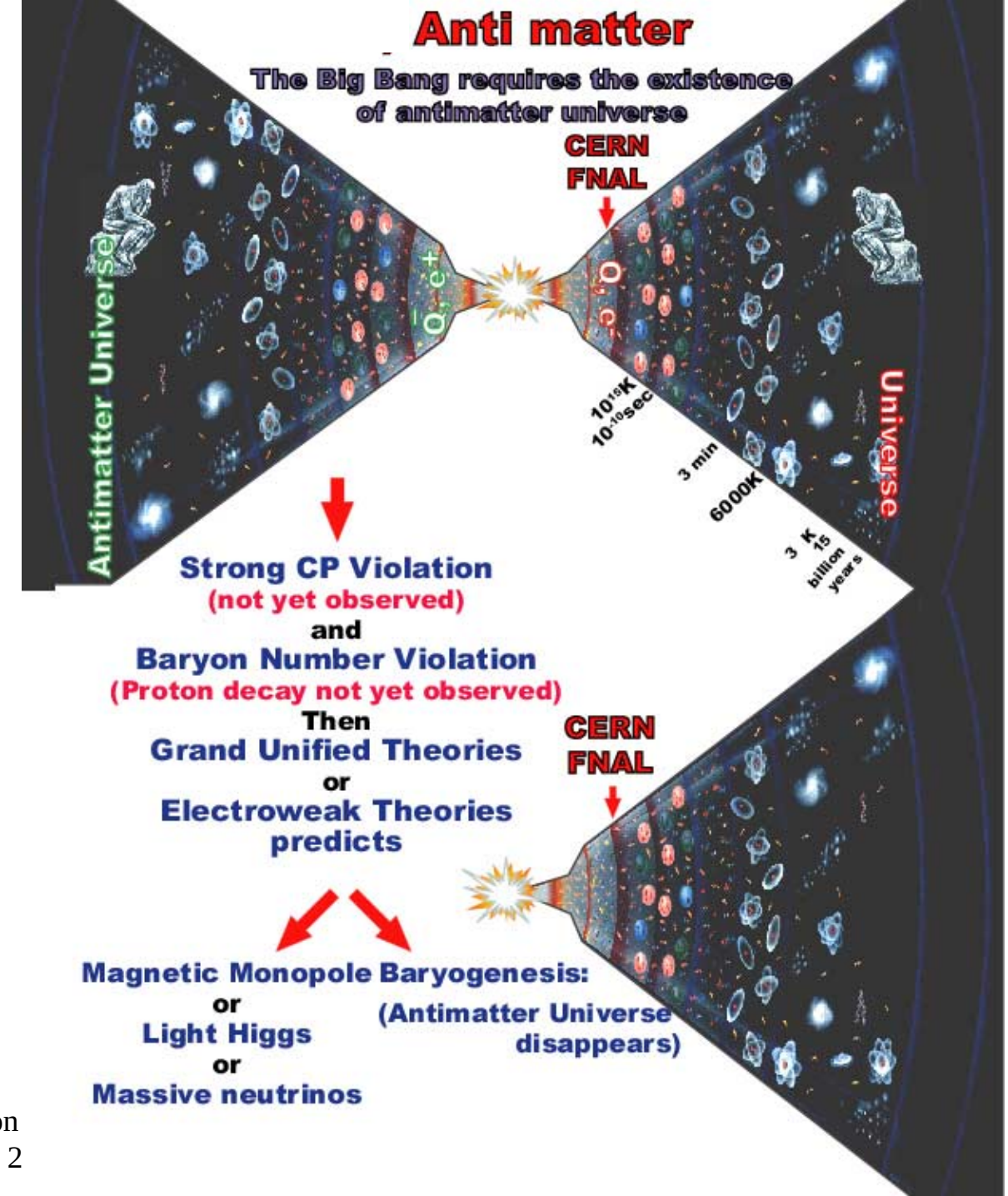
AMS at JSC before the installation on the Shuttle (1998)

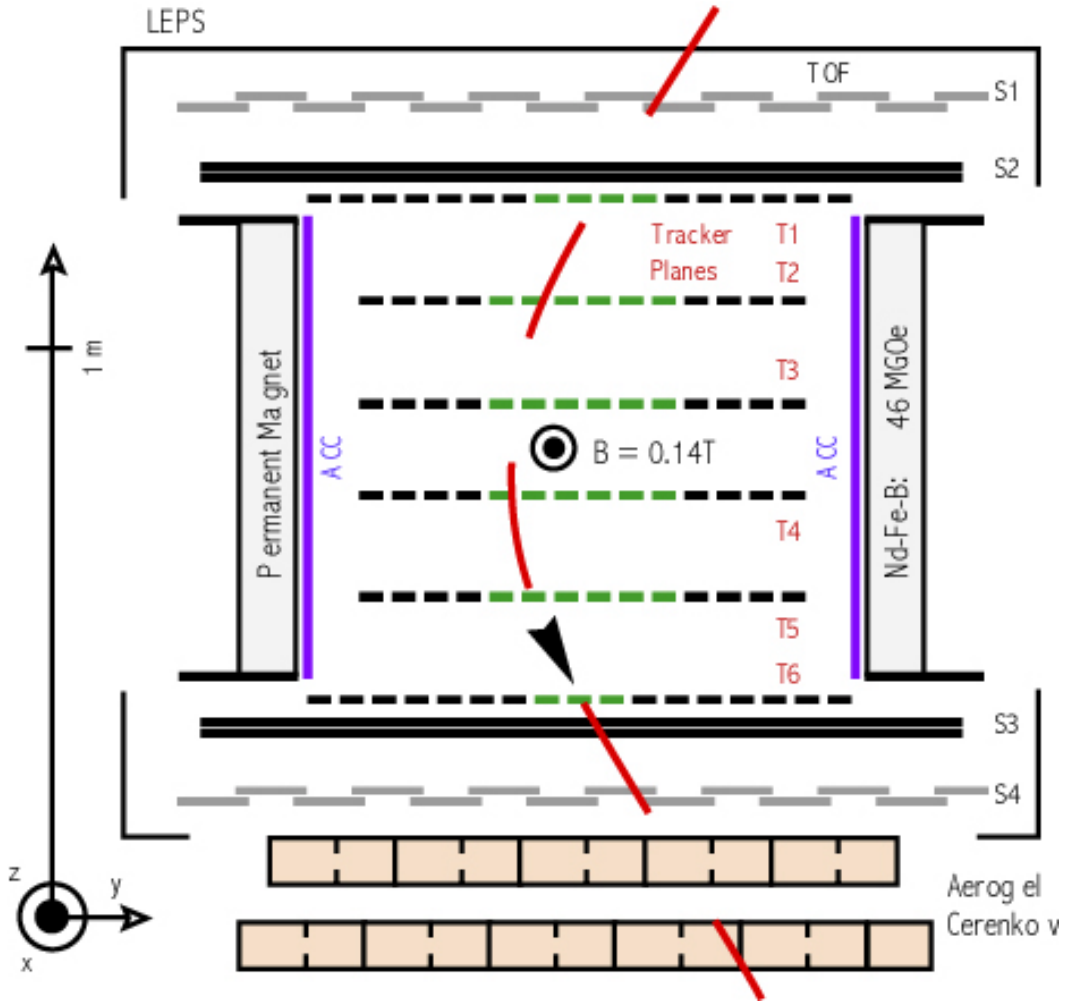


STS 91 Flight, June 1998

AMS PHYSICS RESULTS

STS 91 Flight, June 1998


Anti matter
The Big Bang requires the existence of antimatter universe
CERN
FNAL
Antimatter Universe
Universe
10^{15}K
10^{-10}sec
3 min
6000K
3 K
15 billion years
Strong CP Violation
(not yet observed)
and
Baryon Number Violation
(Proton decay not yet observed)
Then
Grand Unified Theories
or
Electroweak Theories
predicts
CERN
FNAL
Magnetic Monopole
or
Light Higgs
or
Massive neutrinos
Baryogenesis:
(Antimatter Universe disappears)



Measure

Rigidity (R, R1, R2)

Sign of Rigidity

Absolute value of Z

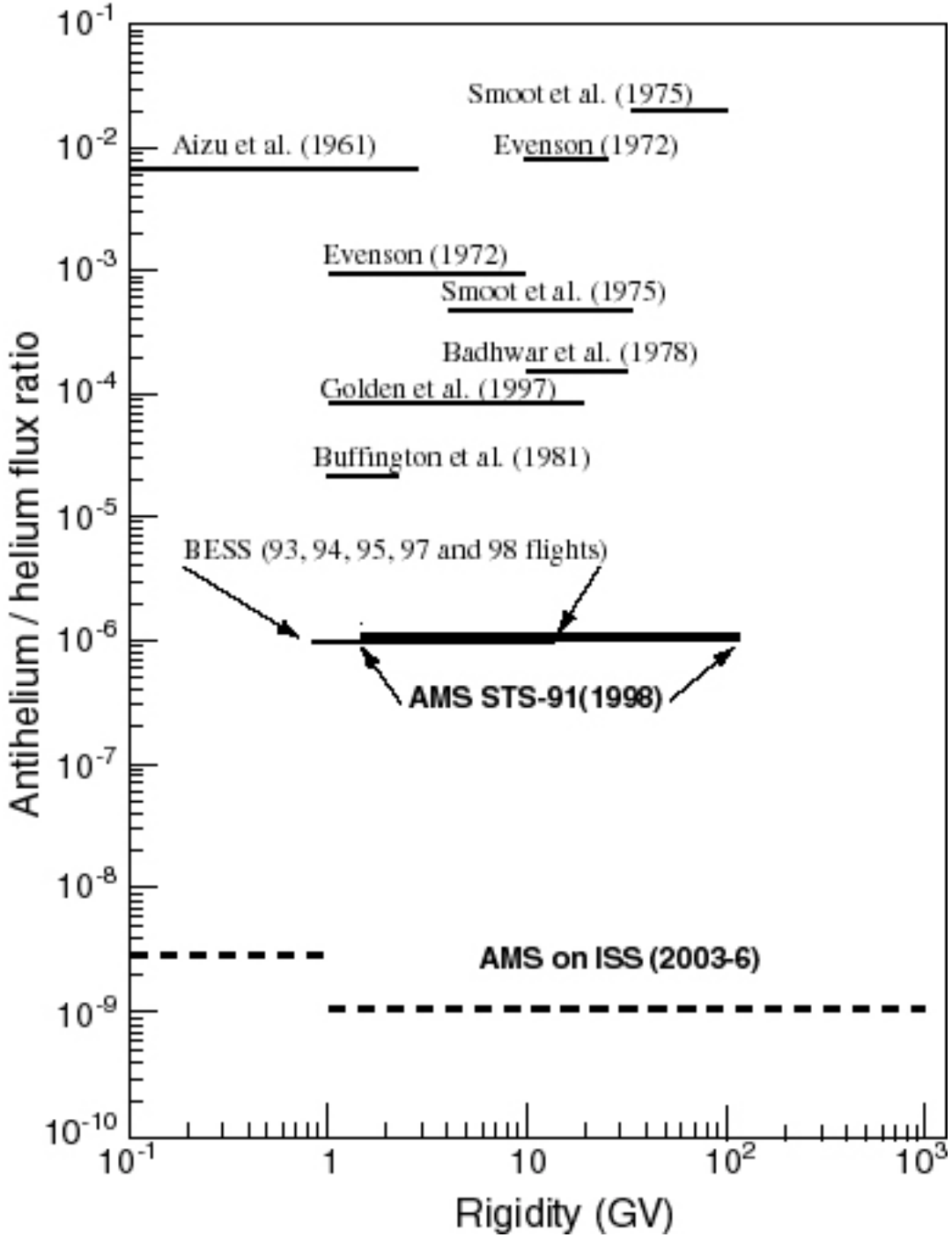
Velocity (β)

Apply cuts

Test antiHe hypothesis

Compute limit

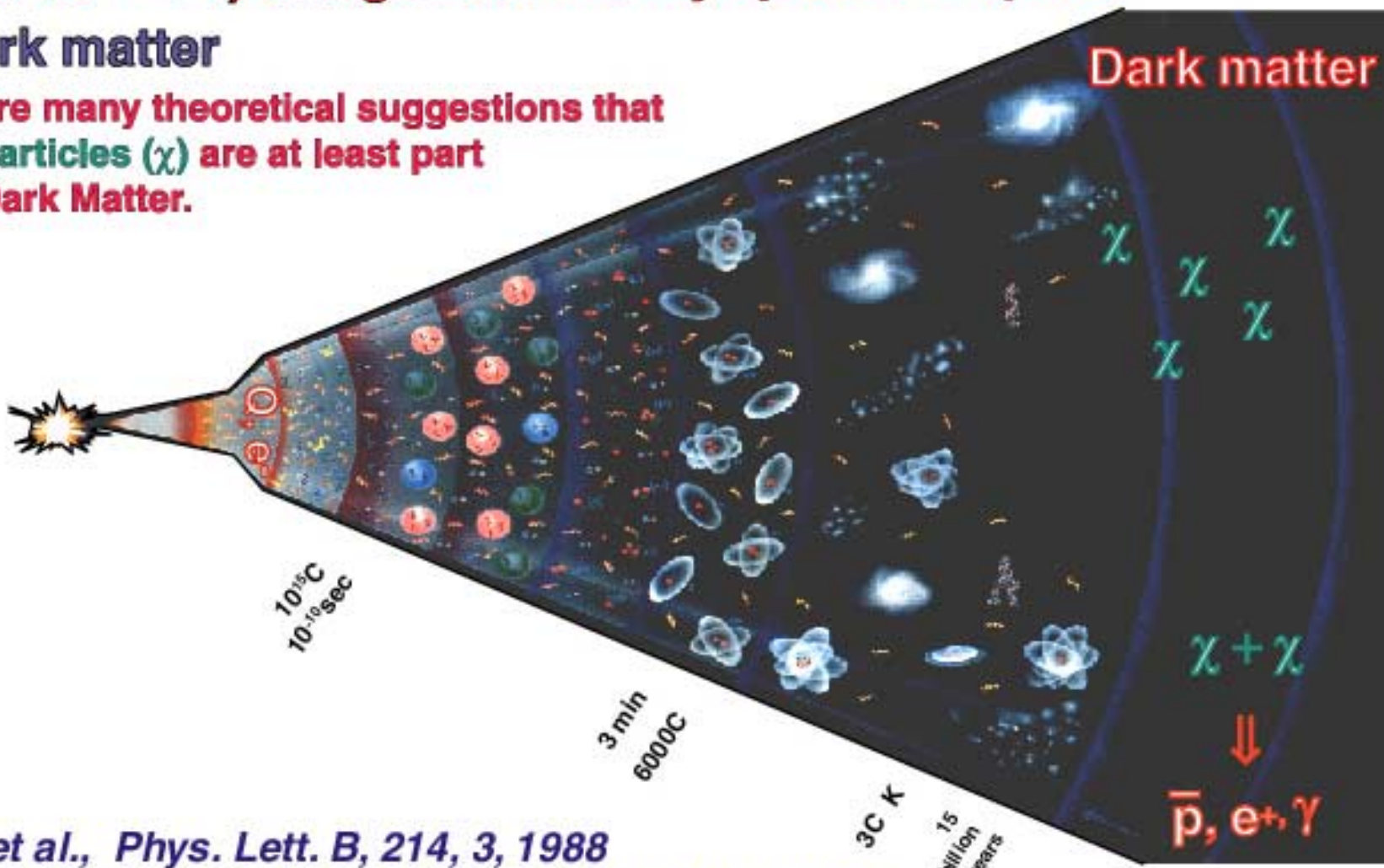
Model dependent limit



The purpose of the AMS experiment is to perform accurate, high statistics, long duration measurements of energetic (0.1 GV to ~ TV) charged cosmic ray spectra in space.

1) Dark matter

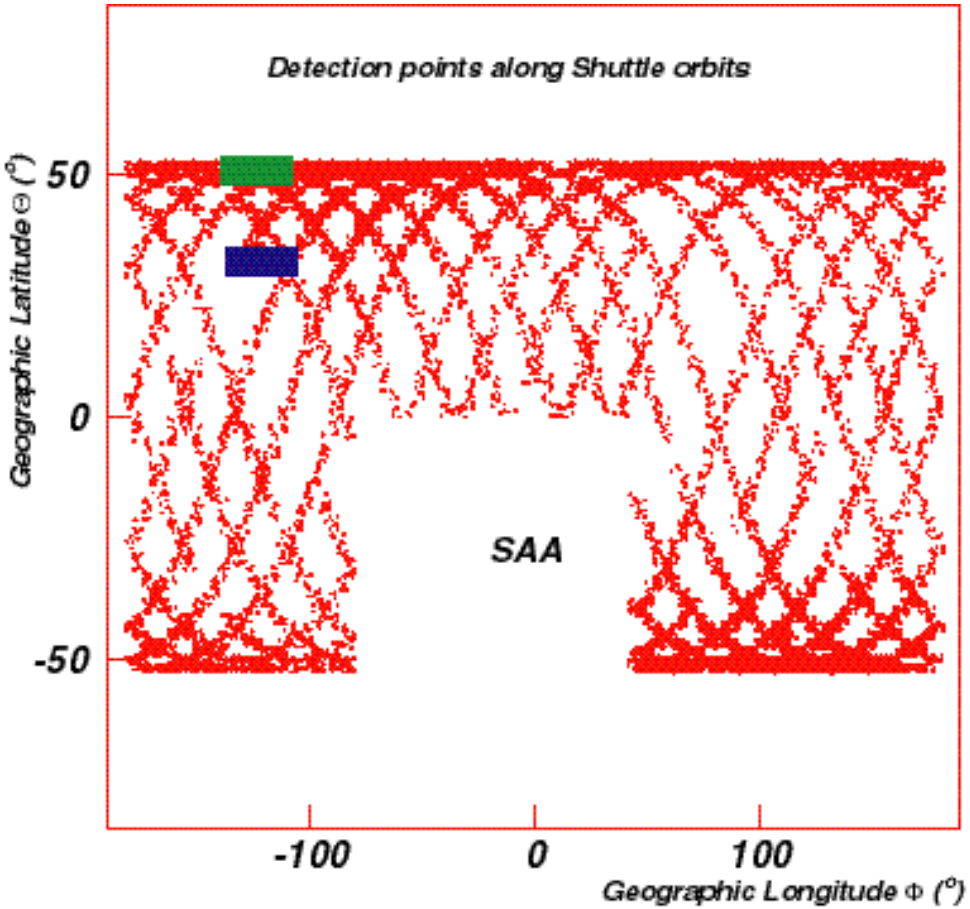
There are many theoretical suggestions that SUSY particles (χ) are at least part of the Dark Matter.



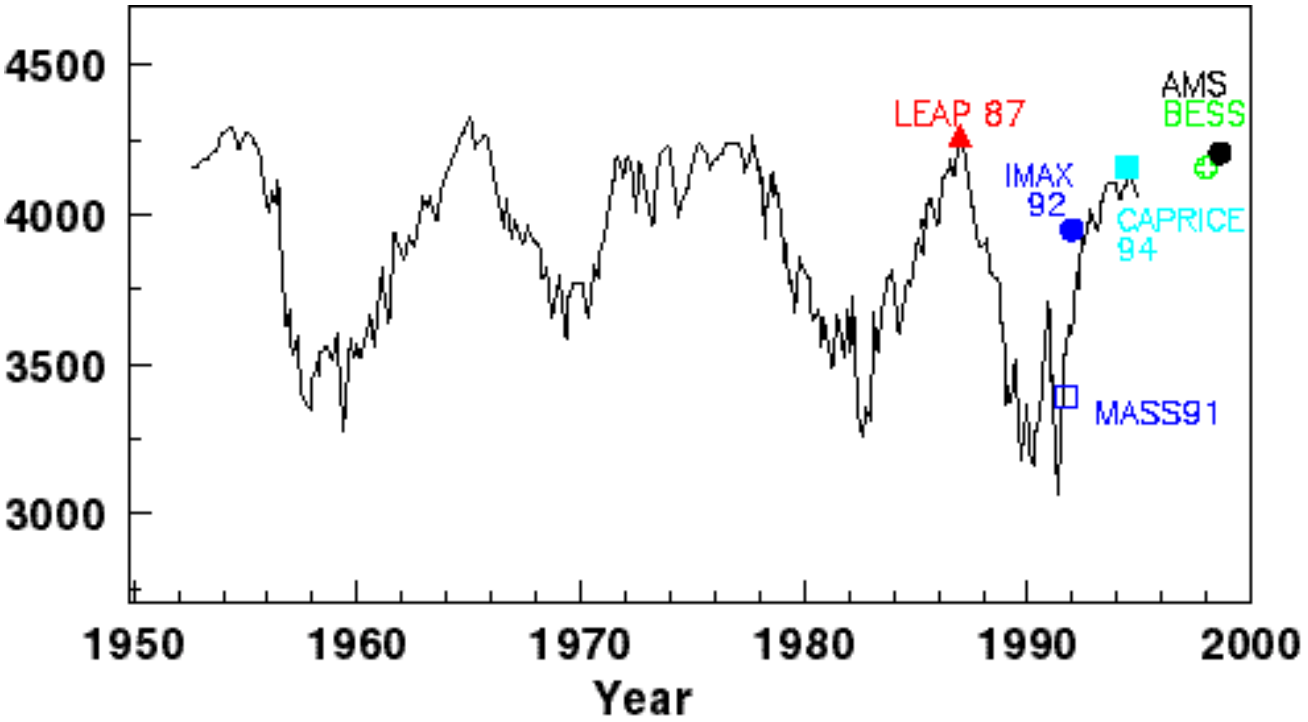
J. Ellis et al., Phys. Lett. B, 214, 3, 1988
and M. Turner and F. Wilczek, Phys. Rev. D, 42, 4, 1990.

E.A. Baltz, J. Edsjo, P.R.D59, 23511, 1999

RESULTS
on
Primary Cosmic Ray Spectra and Composition



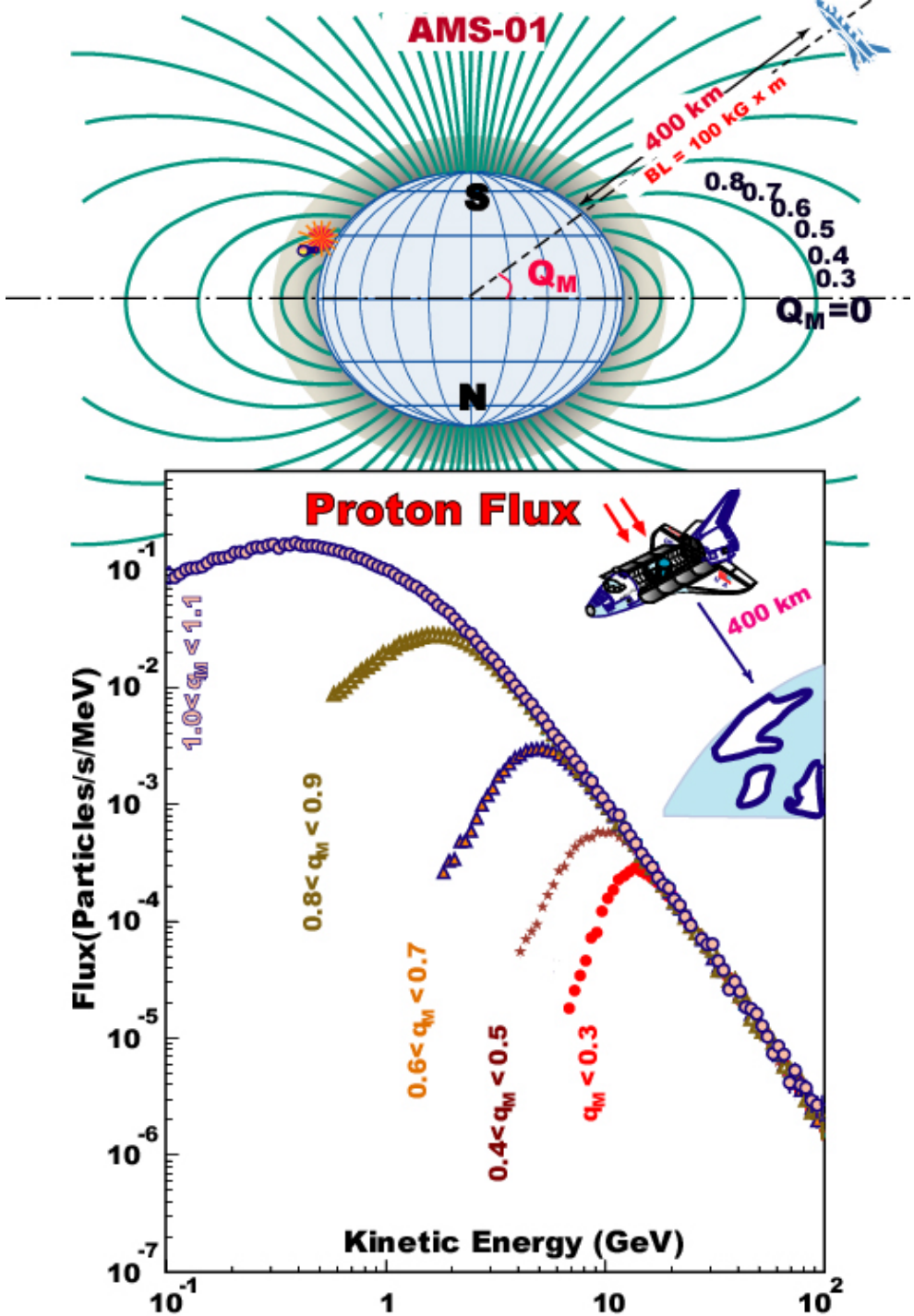
	Cutoffs(GV)	Latitudes	Longitudes
AMS		+/- 51.7	all (SAA excluded)
BESS98	<0.5		(Lynn Lake - Canada)
CAPRICE94		+56.5 N	101-117 W (Lynn Lake - Canada)
MASS91	4.3	+34 N	104 W (Forth Sumner)
IMAX92	0.37-0.63	+56.5 N	101-118 W (Lynn Lake - Canada)
LEAP87	0.6-1.1	n.a.	n.a. (Prince Albert - Canada)



AMS has flown in space during a period of solar maximum

At low energy (below cutoff, up to R ~ 15 GeV) latitude dependence and solar modulation influence the spectra

At high energy (above R~ 20 GeV) the measurement of the primary flux should give the same result in experiments performed at similar solar activities (LEAP, IMAX, CAPRICE, BESS, AMS)


AMS-01
400 km
BL = 100 kG x m
0.8
0.7
0.6
0.5
0.4
0.3
S
N
Q_M
Q_M=0
Proton Flux
400 km
Flux(Particles/s/MeV)
Kinetic Energy (GeV)
1.0< q_M <1.1
0.8< q_M <0.9
0.6< q_M <0.7
0.4< q_M <0.5
q_M <0.3

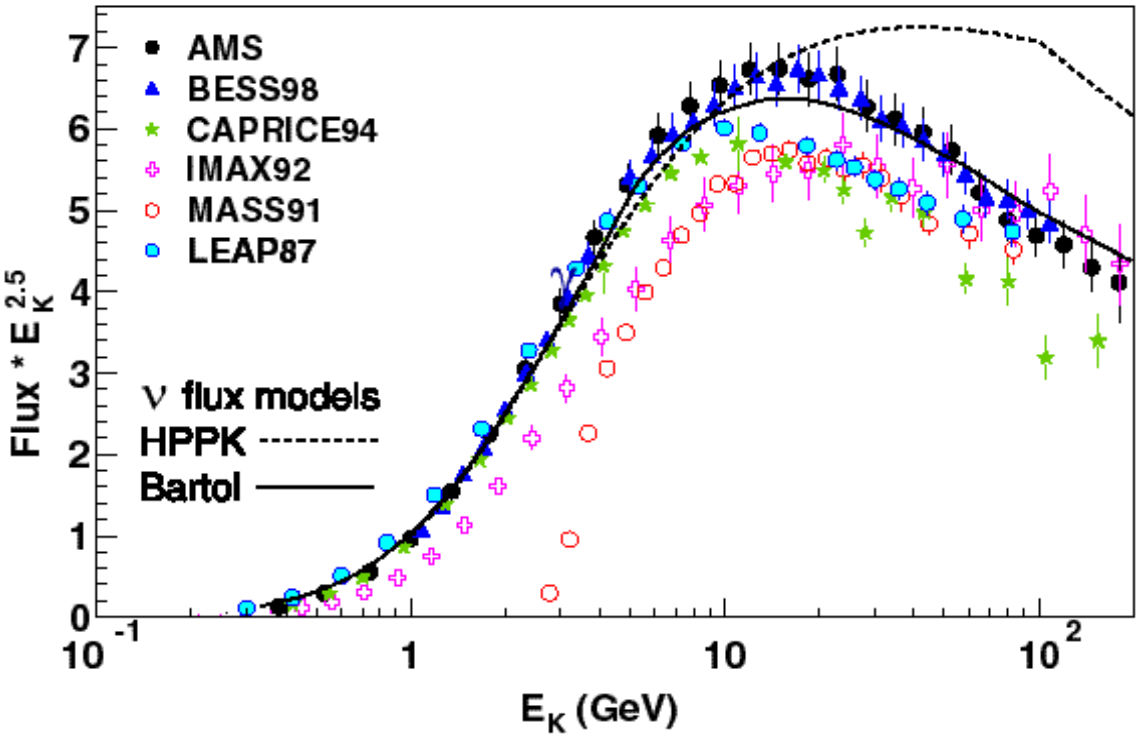
AMS STS91 Mission - June 1998 Science Results

Proton Spectra(1)

AMS Data Fit to Φ_o/R^{γ} for 10GV < R < 200GV :

$\gamma = 2.78 \pm 0.009(\text{fit}) \pm 0.019(\text{sys})$

$\Phi_o = 17.1 \pm 0.15\,(\text{fit}) \pm 1.3\,(\text{sys}) \pm 1.5(\gamma)\ \text{GV}^{2.78}/(\text{m}^2\,\text{s}\,\text{sr}\,\text{MeV})$



AMS STS91 Mission
June 1998
Science Results

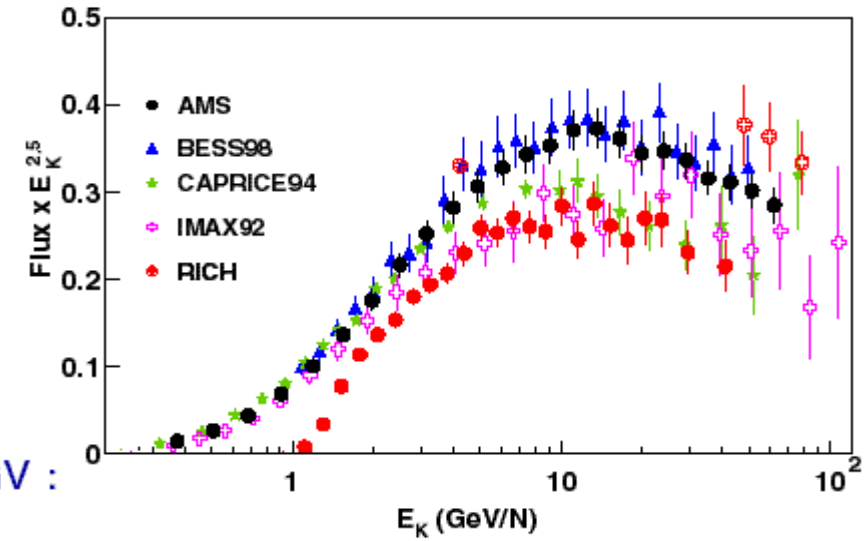
Helium spectra

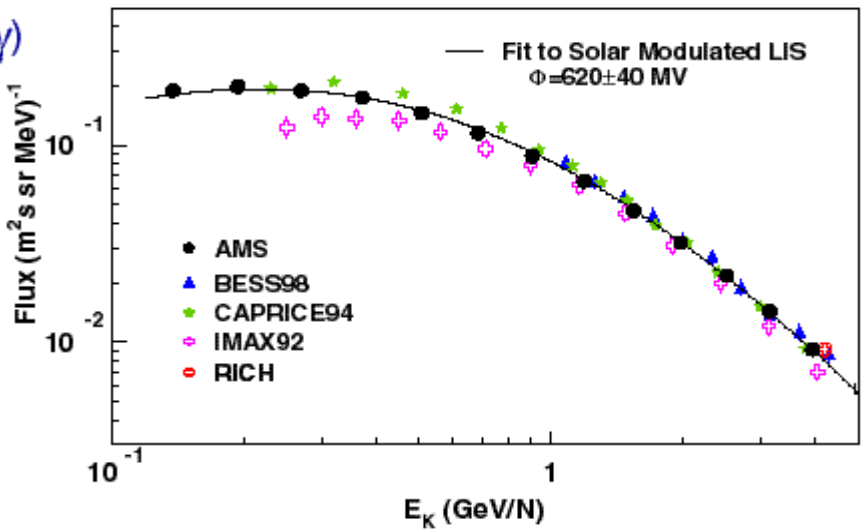
AMS Data Fit to Φ_o/R for R:[20, 200] GV :

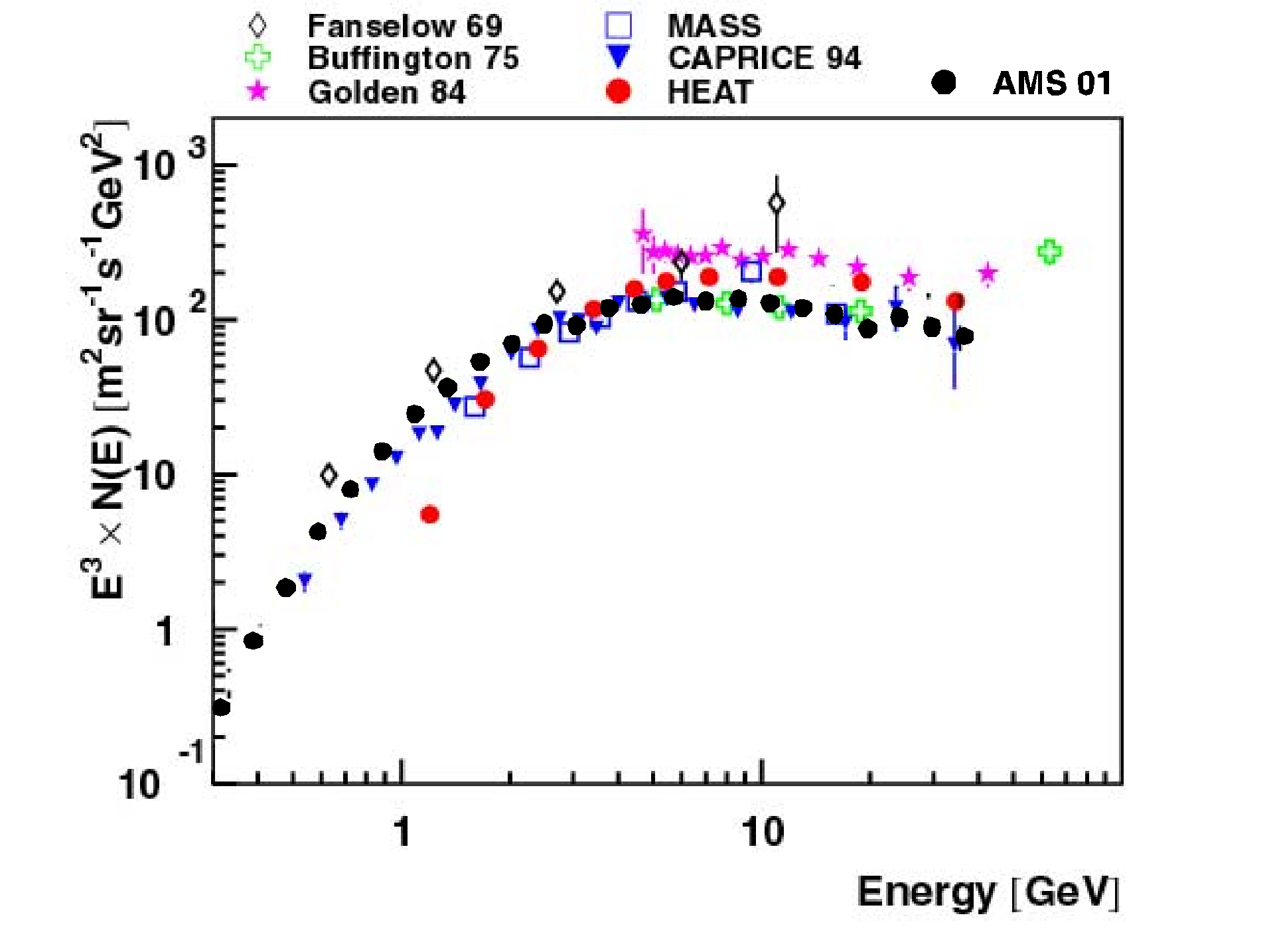
$\gamma = 2.740 \pm 0.010\,(\text{fit}) \pm 0.016\,(\text{sys})$

$\Phi_o = 2.52 \pm 0.09\,(\text{fit}) \pm 0.13\,(\text{sys}) \pm 0.14\,(\gamma)$

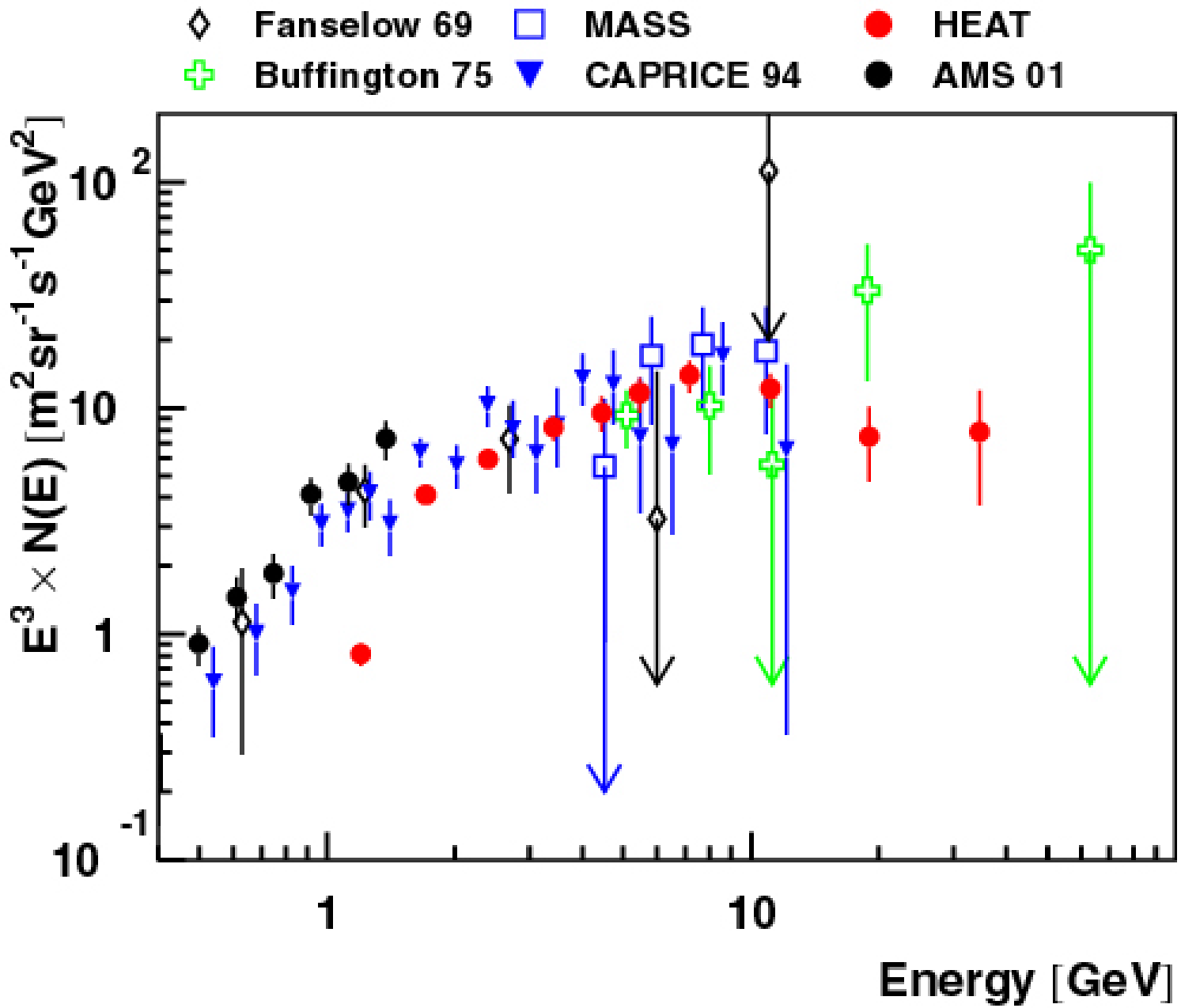
$\frac{GV^{2.74}}{m^2\,s\,sr\,MeV}$





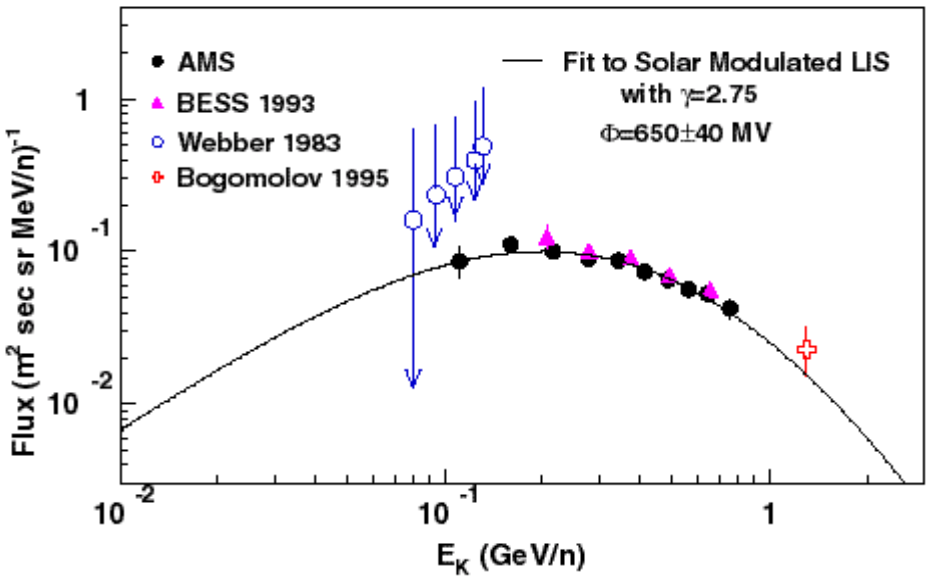

Fanselow 69
Buffington 75
Golden 84
MASS
CAPRICE 94
HEAT
AMS 01
$E^3 \times N(E)$ [$m^2 sr^{-1} s^{-1} GeV^2$]
10^3
10^2
10
1
10^{-1}
1
10
Energy [GeV]

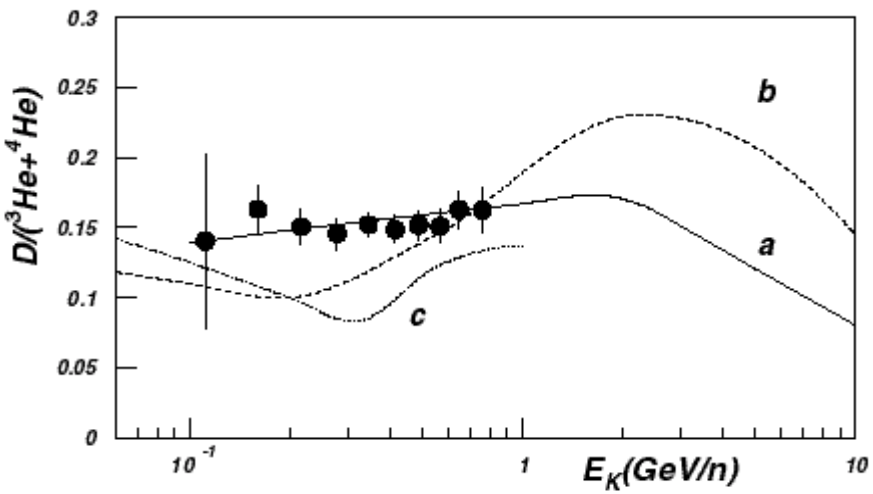
Positrons spectrum



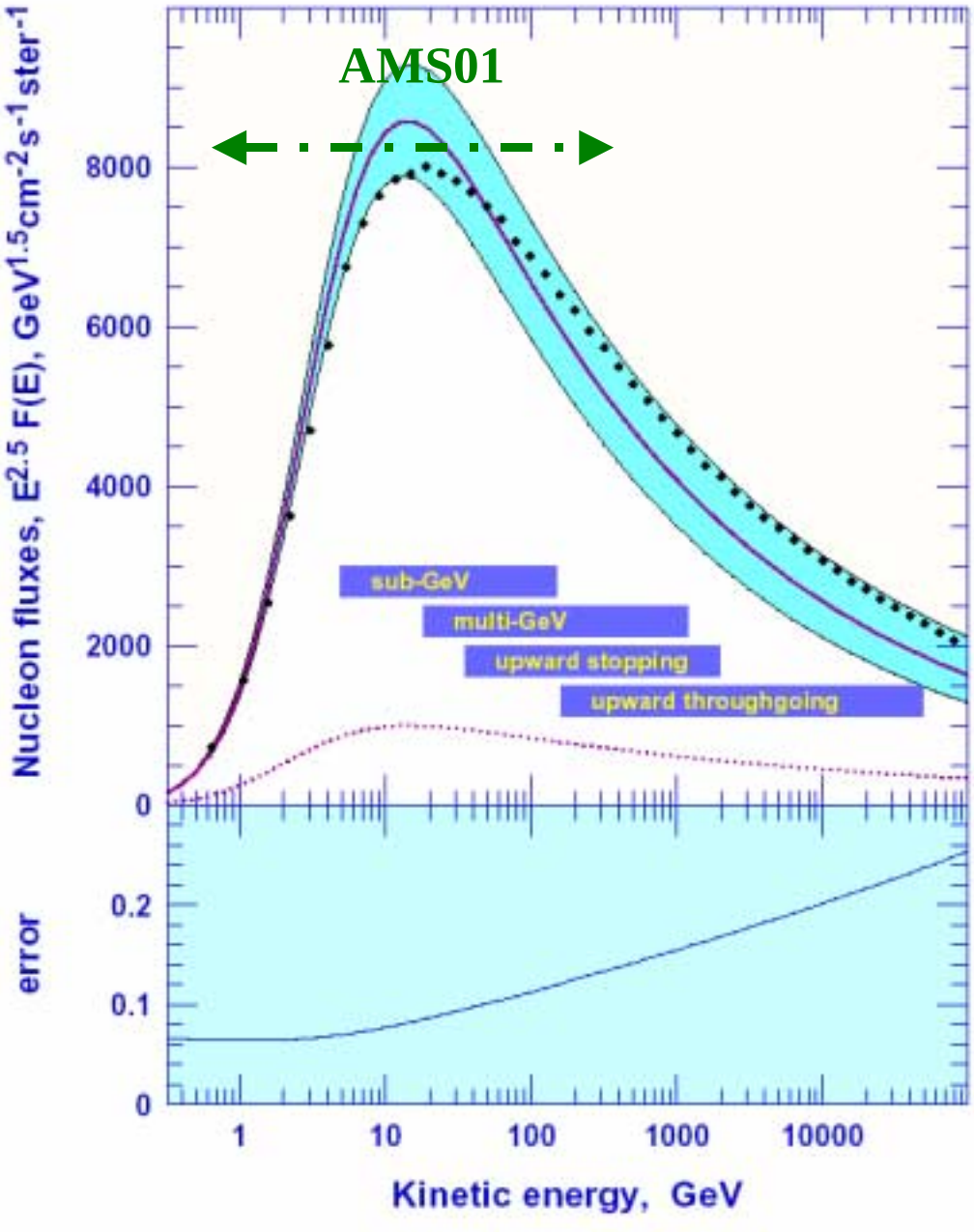
AMS STS91 Mission
June 1998
Science Results

Deuteron spectra





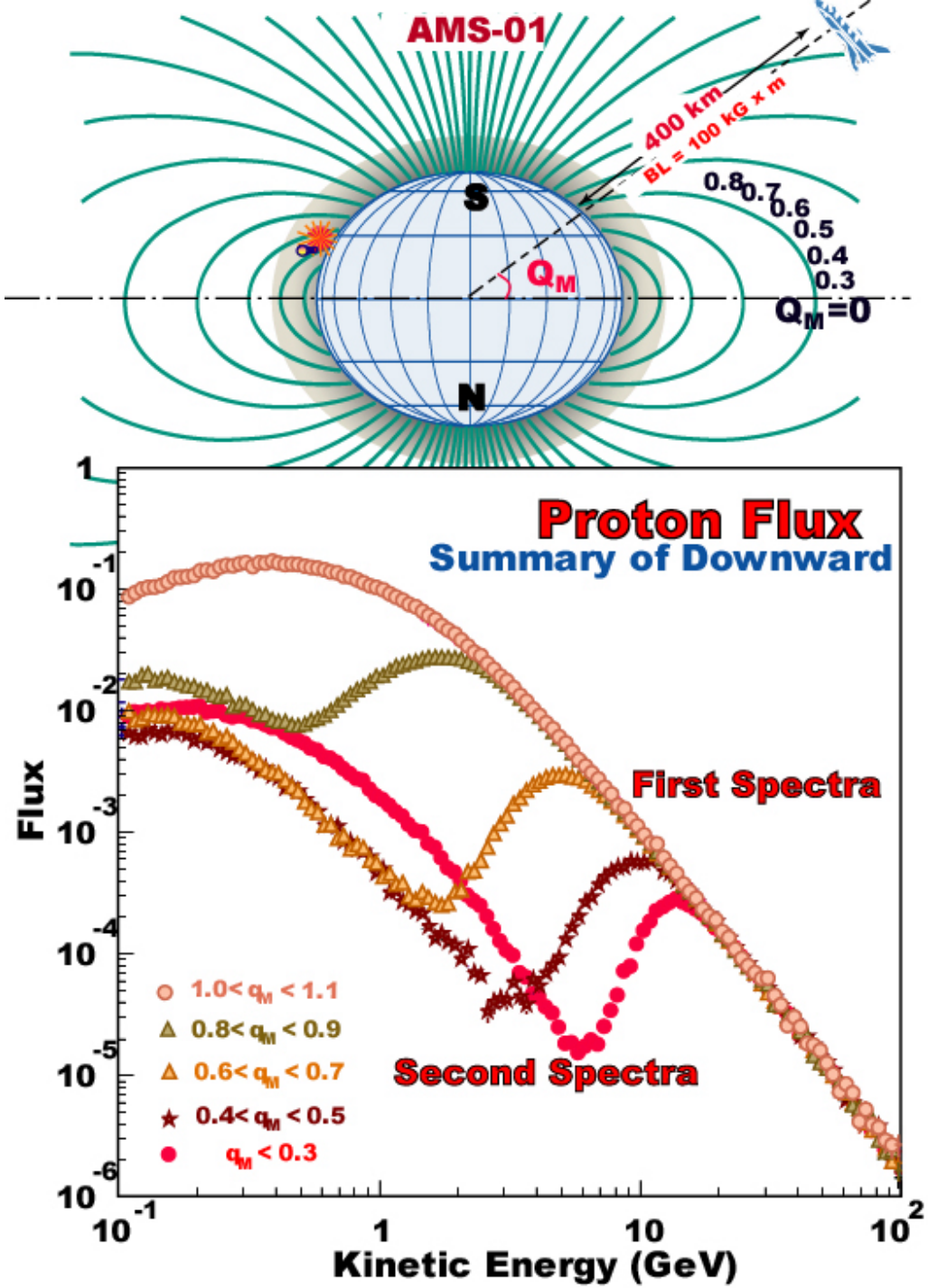
a) Stephens, Adv.Space Res 9(1998) 145.
b) R.A.Mewaldt, Conf.Procs. of Cosmic Abund. of Matter 180 (1989) 124.
c) E.S.Seo et al., APJ 432(1994) 656.

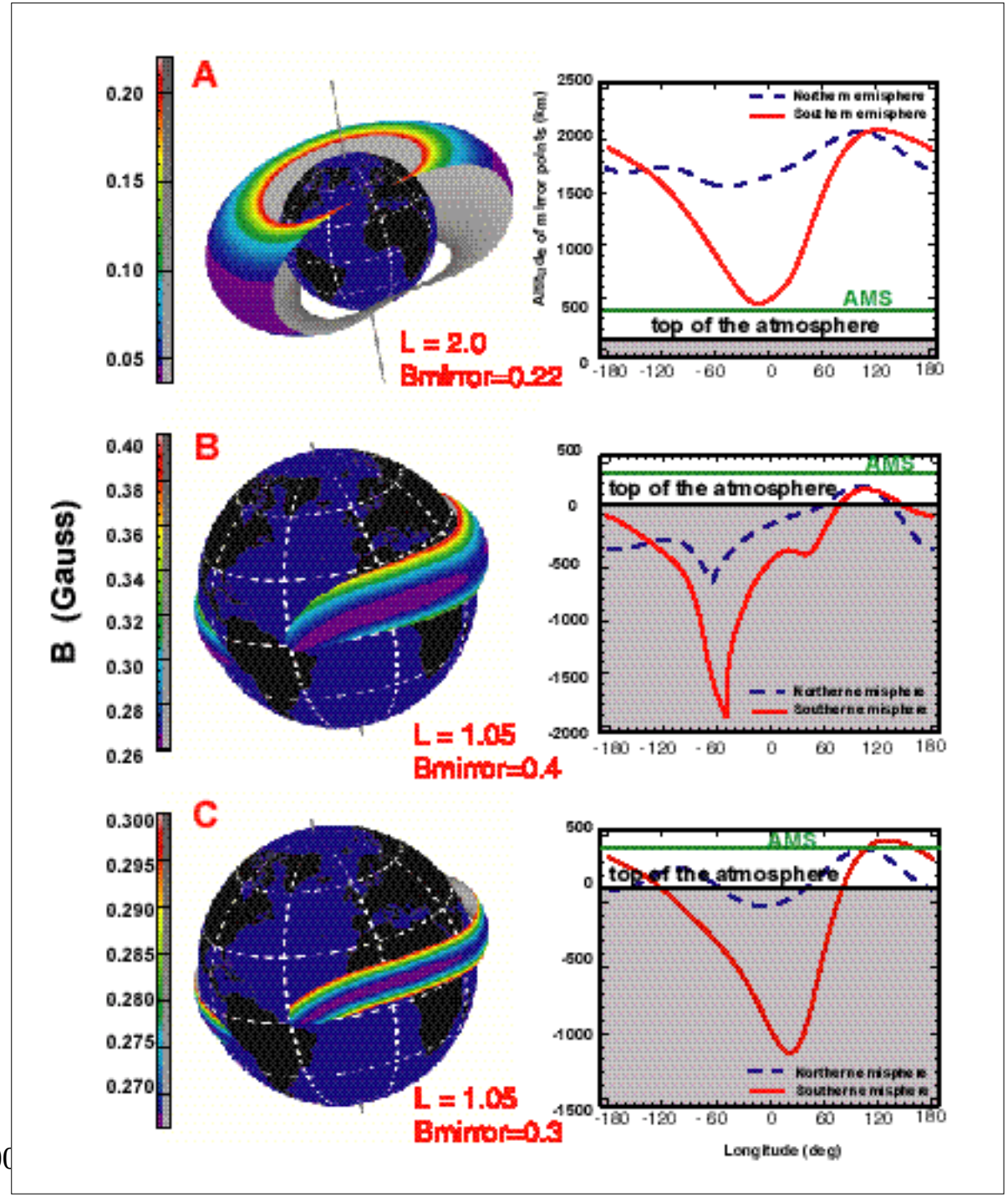


Atmospheric neutrinos relevant for N oscillation searches are produced by CR with energy exceeding 10 TeV interacting with the atmosphere

Accurate knowledge of the CR primary Flux and composition over the entire Earth is possible only with space born detectors

AMS01 data are now the reference for atmospheric neutrinos calculations


AMS-01
400 km
BL = 100 kG x m
0.8
0.7
0.6
0.5
0.4
0.3
S
N
Q_M
Q_M=0
Proton Flux
Summary of Downward
First Spectra
Second Spectra
1.0< q_M < 1.1
0.8< q_M < 0.9
0.6< q_M < 0.7
0.4< q_M < 0.5
q_M < 0.3
Flux
Kinetic Energy (GeV)


A
B
C
B (Gauss)
0.20
0.15
0.10
0.05
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.300
0.295
0.290
0.285
0.280
0.275
0.270
L = 2.0
Bmirror=0.22
L = 1.05
Bmirror=0.4
L = 1.05
Bmirror=0.3
Northern emisphere
Southern emisphere
AMS
top of the atmosphere
Altitude of mirror points (km)
Longitude (deg)

AMS belts vs Van Allen belts

- Van Allen belts:
  - Low energy from ~ 1 MeV to ~ 100 MeV
  - Contains e-, p
  - High L-shells ⇔ high altitude
  - Life time O(years) => trapped

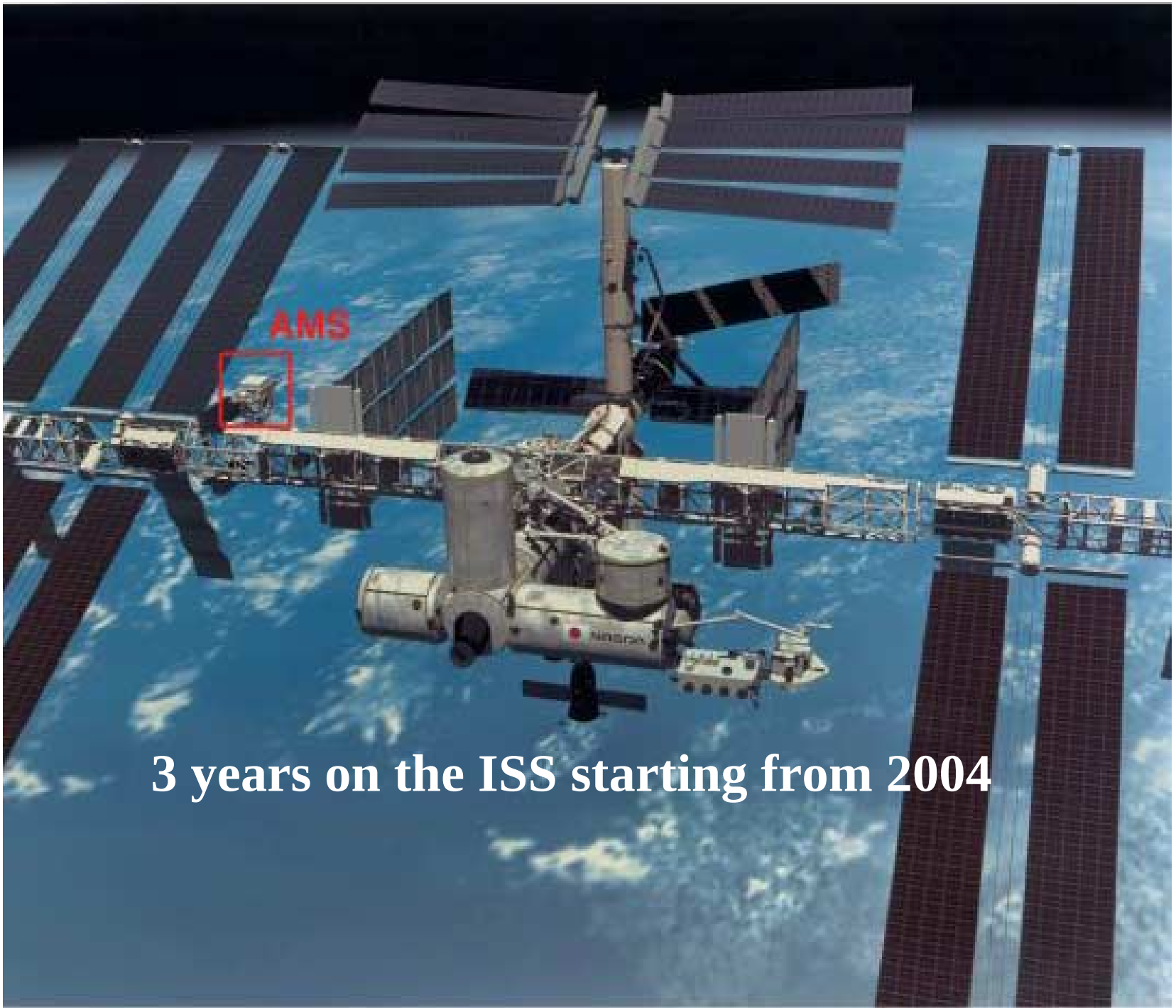
  ⇒Decays of neutrons produced in interactions of primary with the atmosphere (CRAND)

  ⇒ Solar wind induced magnetic storms

AMS belts vs Van Allen belts

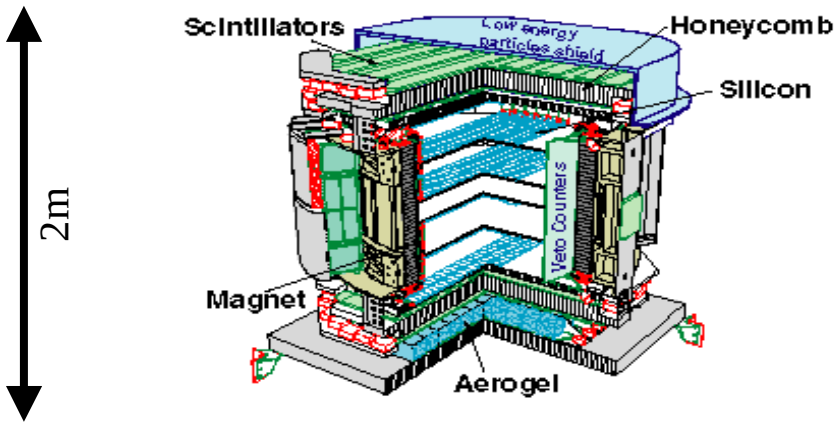
- AMS belts:
  - High energy from ~ 1 GeV to ~ 10 GeV
  - Contains e+, e-, p, ^{3}He
  - e+ over e- dominance
  - Low L- shell ⇔ low altitude
  - Life time O(seconds) => quasi trapped

=> Secondary production from CR interaction with atmosphere

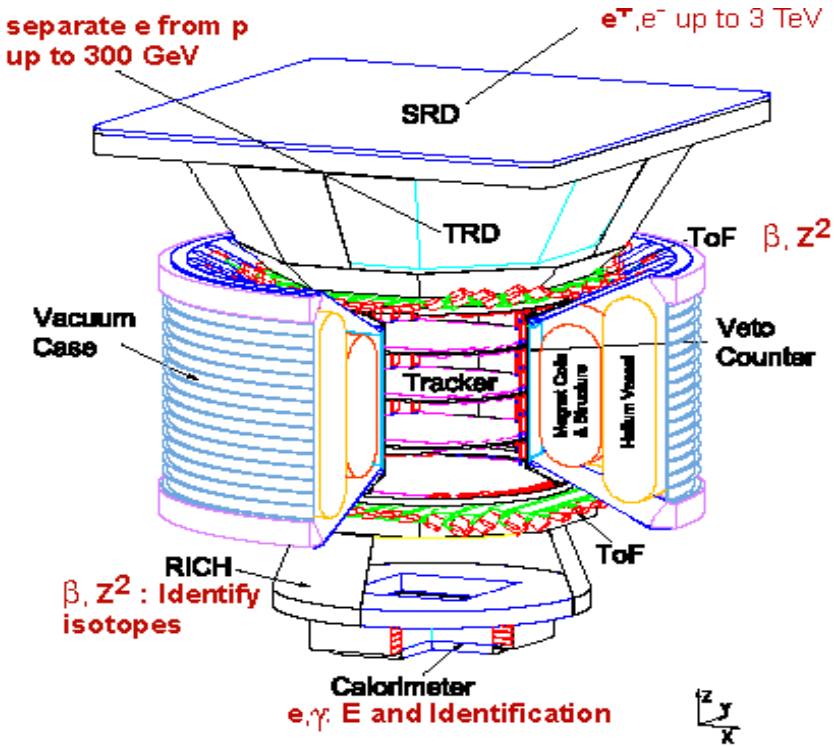


3 years on the ISS starting from 2004

AMS01 vs AMS02



AMS01



AMS02

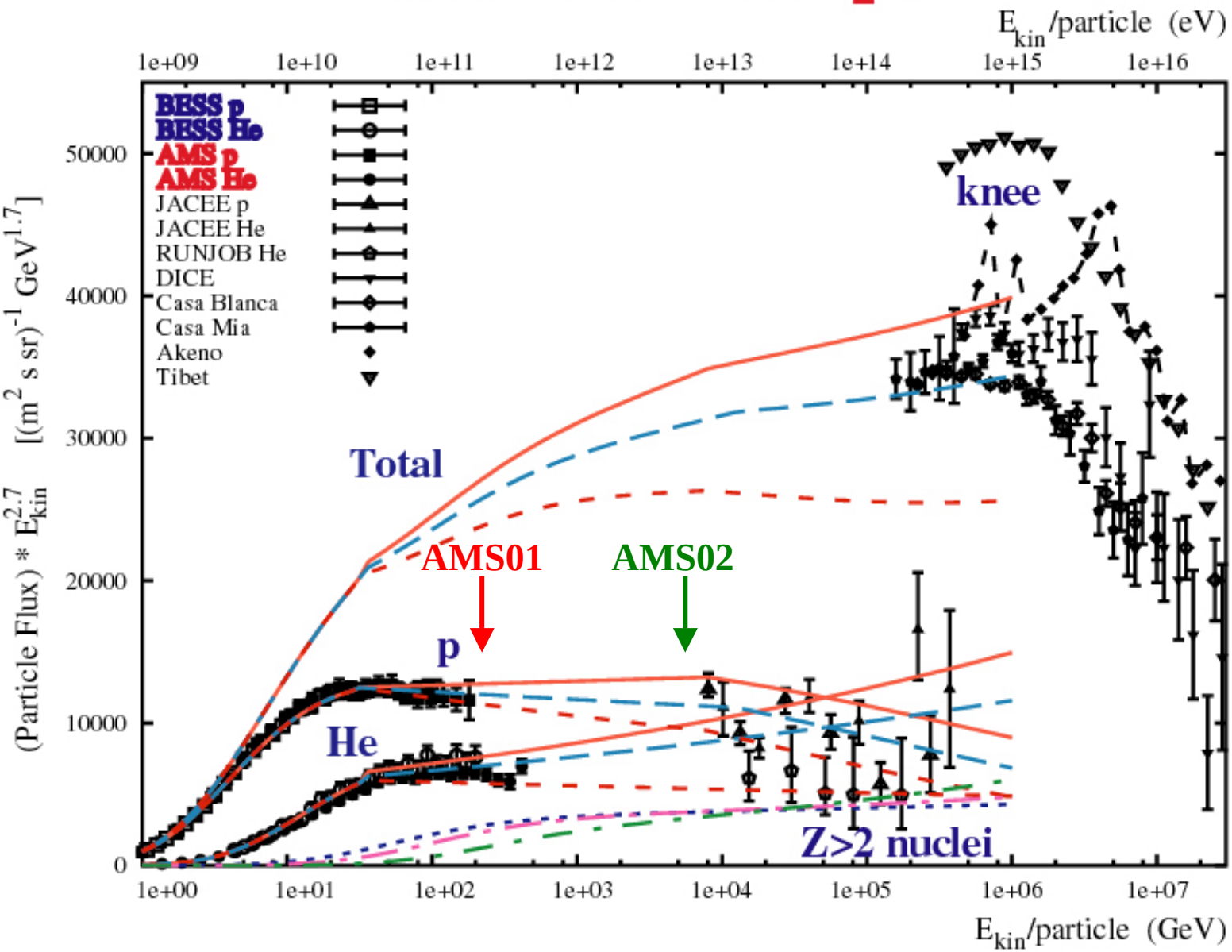
Improved detector (larger acceptance, 5 times stronger magnetic field)

Largely improved particle id (TRD, RICH, EM Calorimeter)

Energy Range of AMS on ISS 2004 →

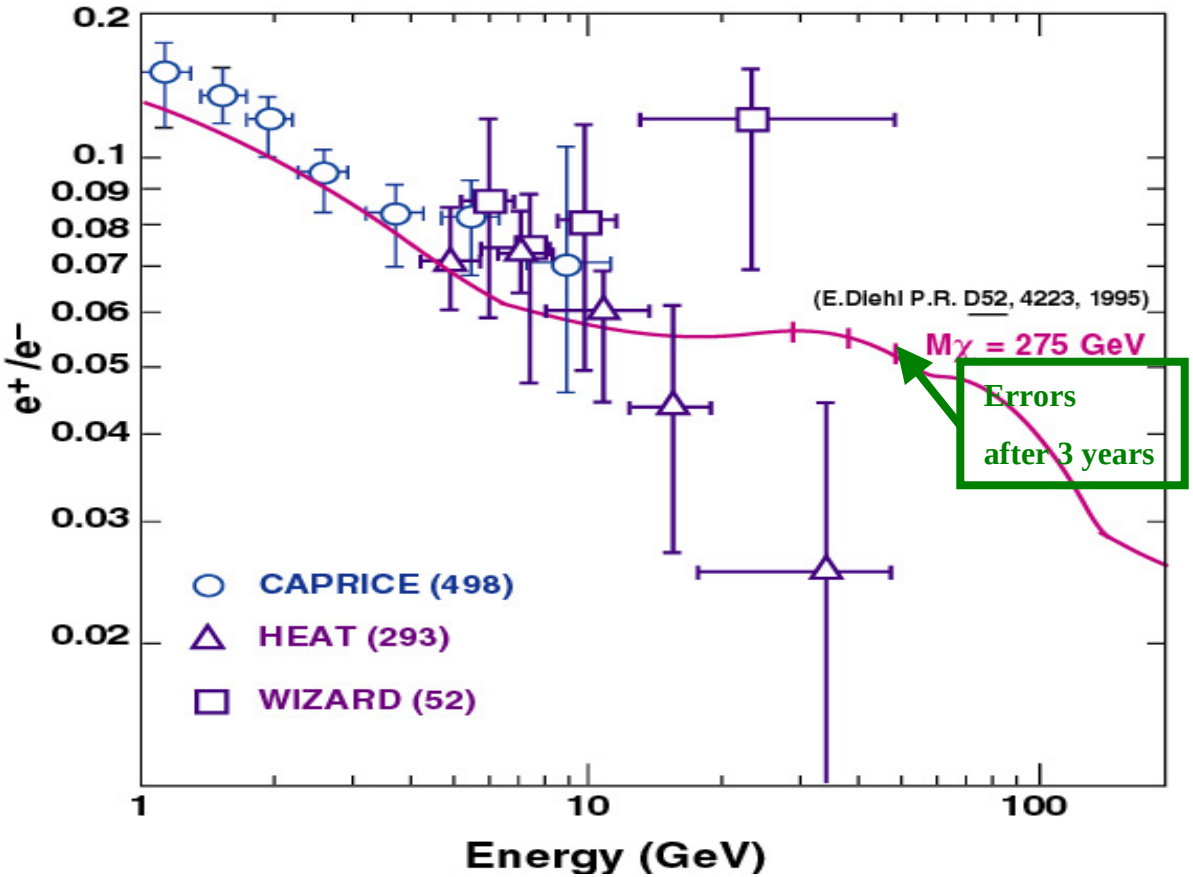
p^+	up to several TeV
p^-	up to 200 GeV
e^-	up to O(TeV)
e^+	up to 200 GeV
He,….C	up to several TeV
anti – He…C	up to O(TeV)
γ	up to 300 GeV
Light Isotopes	up to 20 GeV

CR Hadronic Component



G. Battistoni unpublished

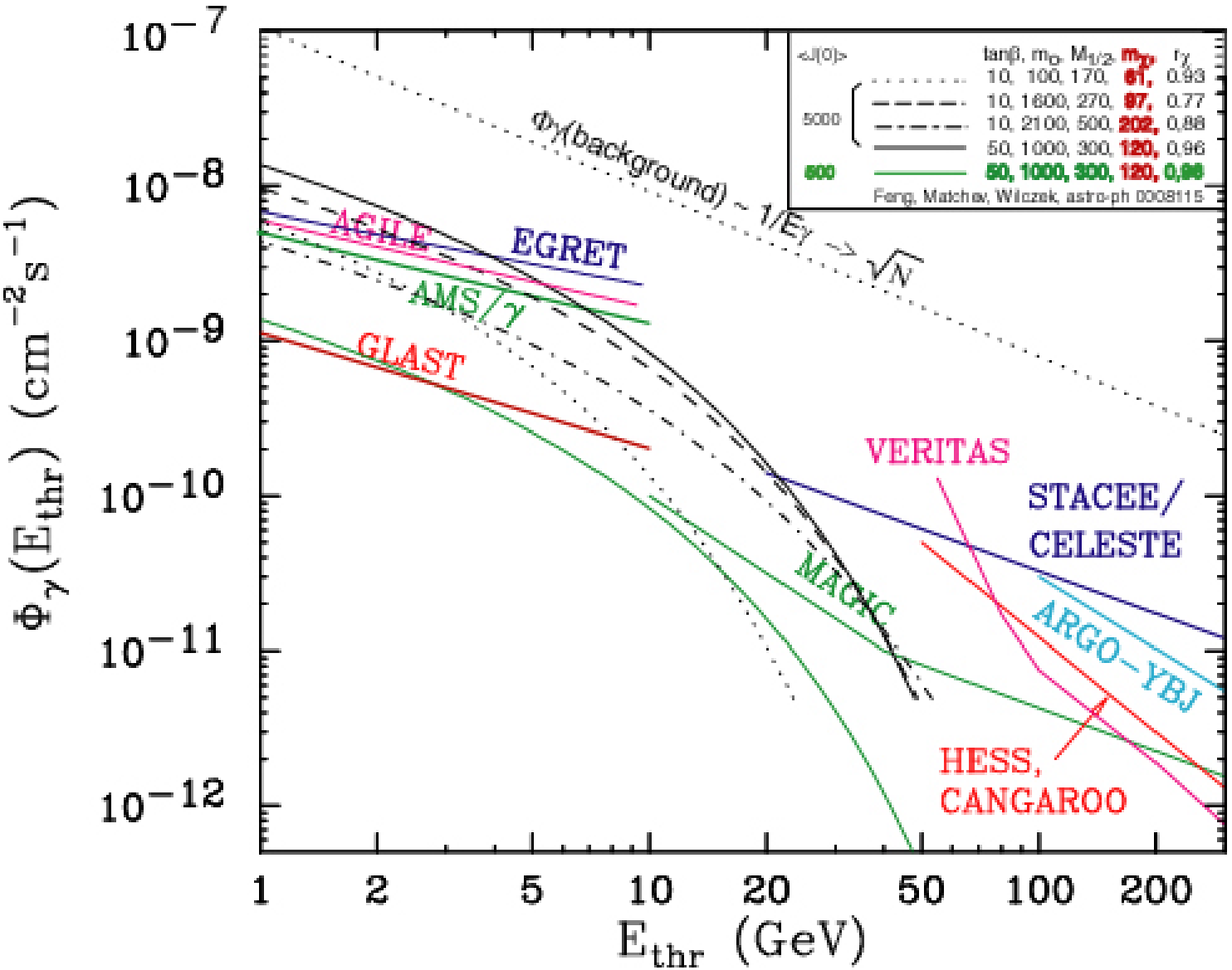
Positron to Electron ratio



- Region around 7 GeV will be well measured.
- ~30% stat error at 300 GeV.
- ~1% stat error at 50 GeV.
- Sensitivity to exotic flux greater than $10^{-7}\ E^{-2}\ (cm^2\ .s.sr.GeV)^{-1}$.

High enery gamma rays

SUSY D.M. γ fluxes above E_{thr} vs Point Source Sensitivity



Complementarity of γ, $\bar{p}$, e^+

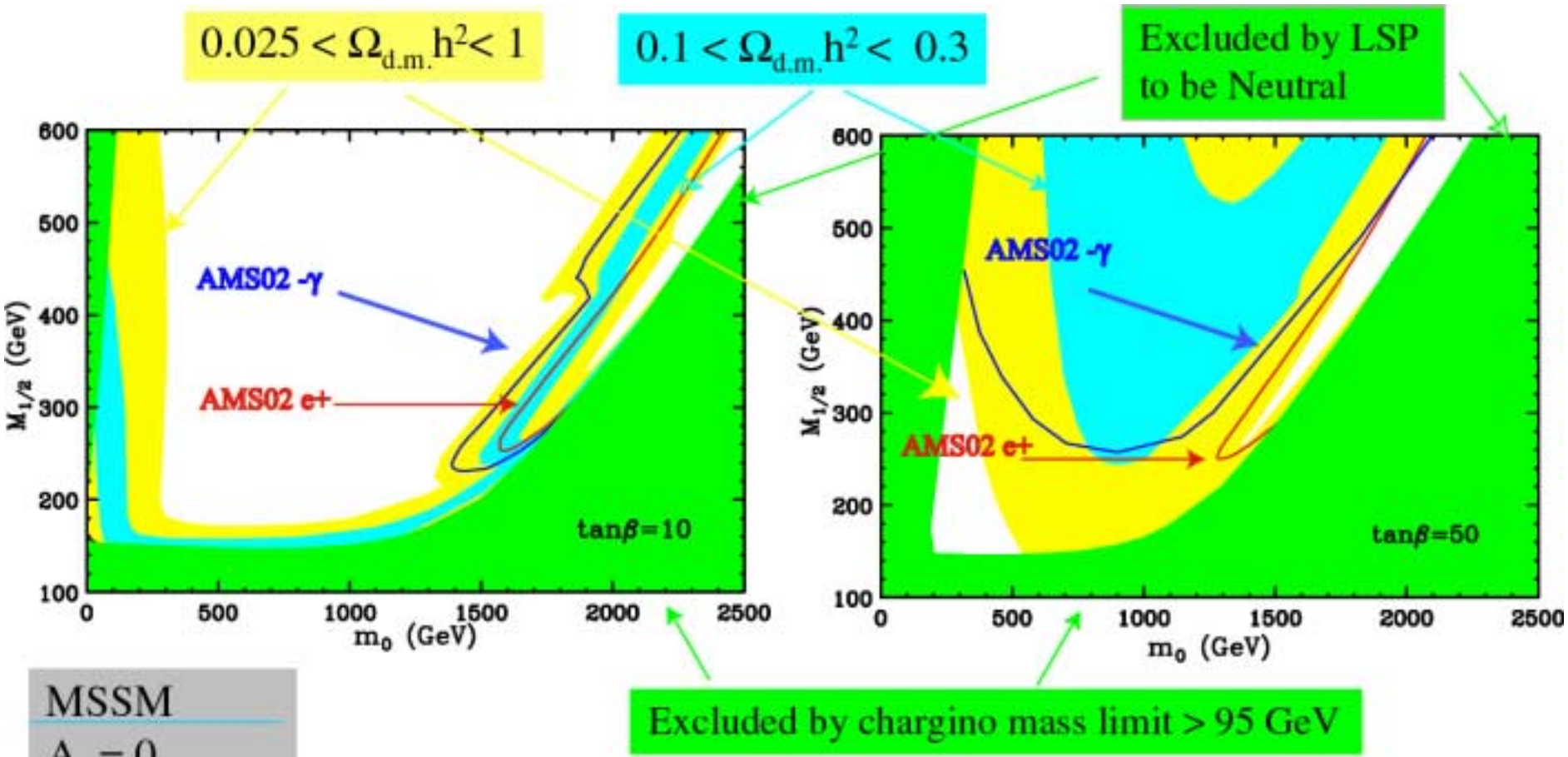
AMS will have the unique possibility to measure in space, with the same detector

γ, $\bar{p}$, e^+ spectra

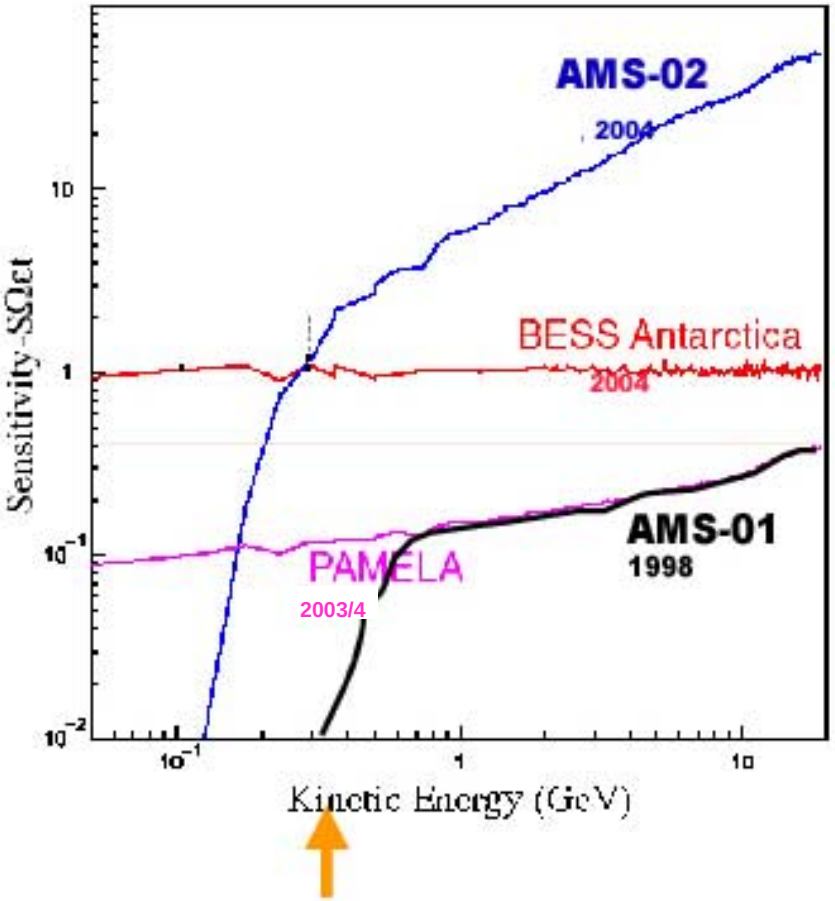
it will be the <u>only experiment</u> in space able to make an extensive test of the neutralino based dark matter scenario.

<u>No other detectors, planned or operating will be able to do this measurement</u>

Example of AMS sensitivity to SUSY Dark Matter



Comparison of future Cosmic Rays Experiments



	AMS-01	AMS-02	BESS	PAMELA
Aperture (c m²•sr)	2300	5000	3000	21
Duration (days)	10	1000	20	1000
Altitude (km)	320~390	320~390	36	690
Latitude (deg)	< 51.7 SpaceStation	< 51.7 SpaceStation	> 70 Ballooning	70 Saltellite
Launching (year)	1998	2004	2004	2003/4
Area*time	1 :	217 :	2.6 :	1.1

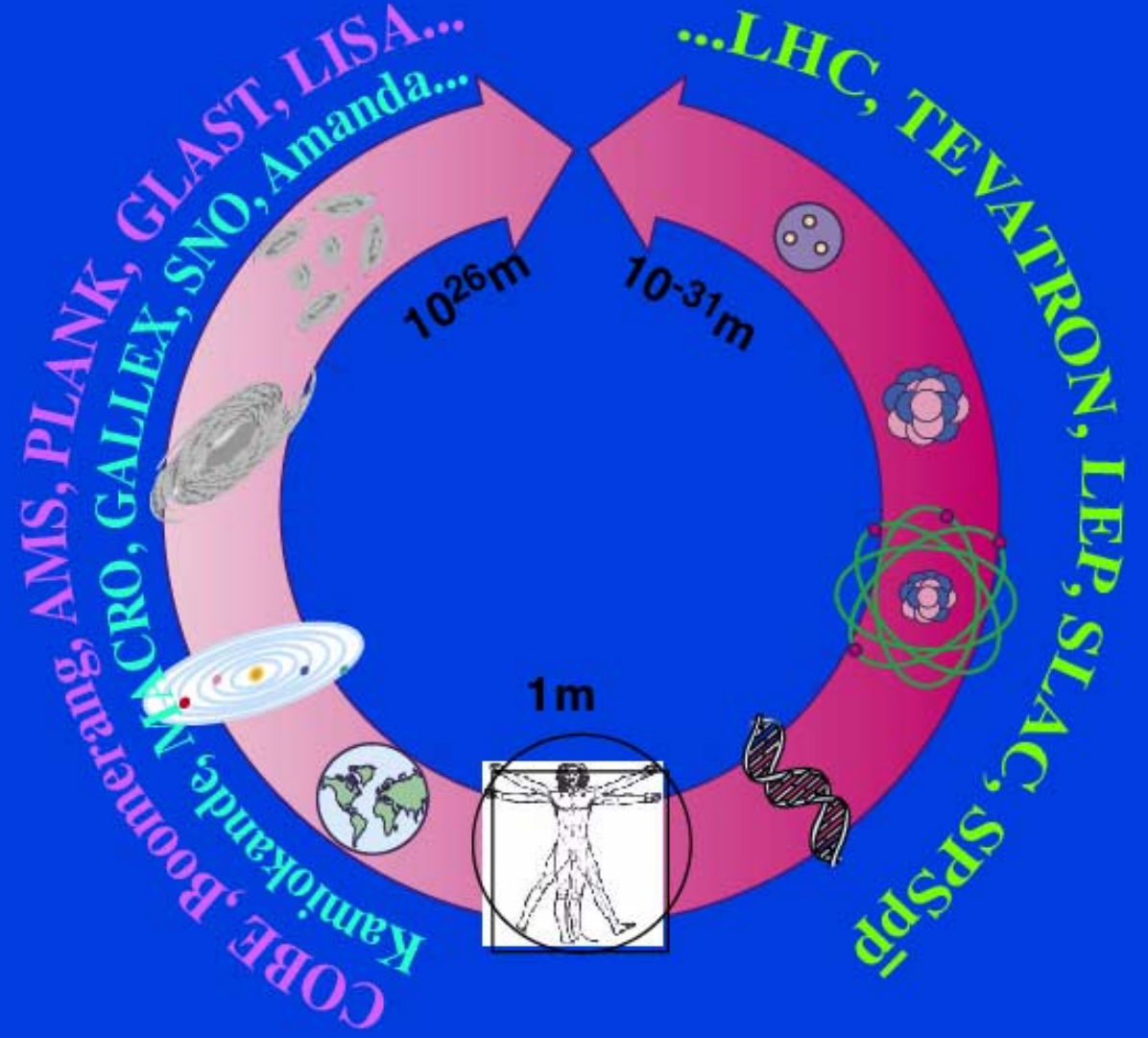
AMS-02 most sensitive > 0.3 GeV ----> TeV

BESS most sensitive < 0.3 GeV ----> low E

Conclusions

- AMS has operated successfully in space during 10 days in 1998 collecting 100 Million CR events
- Precise results have been obtained on primary and second spectra around the Earth 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 starting in 2004
- The large aperture as well as the long exposure time will allow an unprecedented accuracy on the search for antimatter and dark matter from the ISS

Astro Particle Physics



Antiproton signal from AMS-01 1998 Flight
Preliminary data