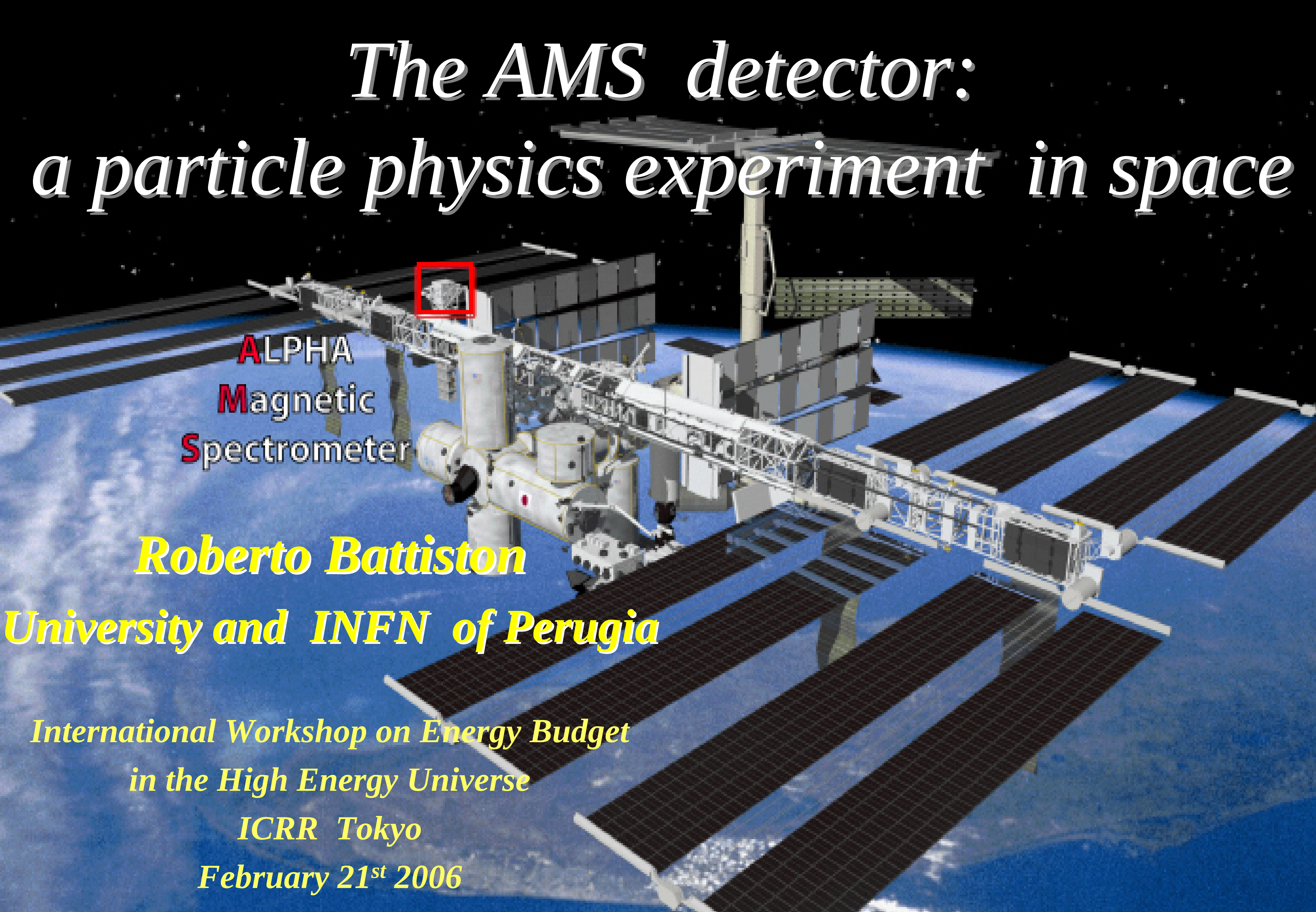
The AMS detector:
a particle physics experiment in space

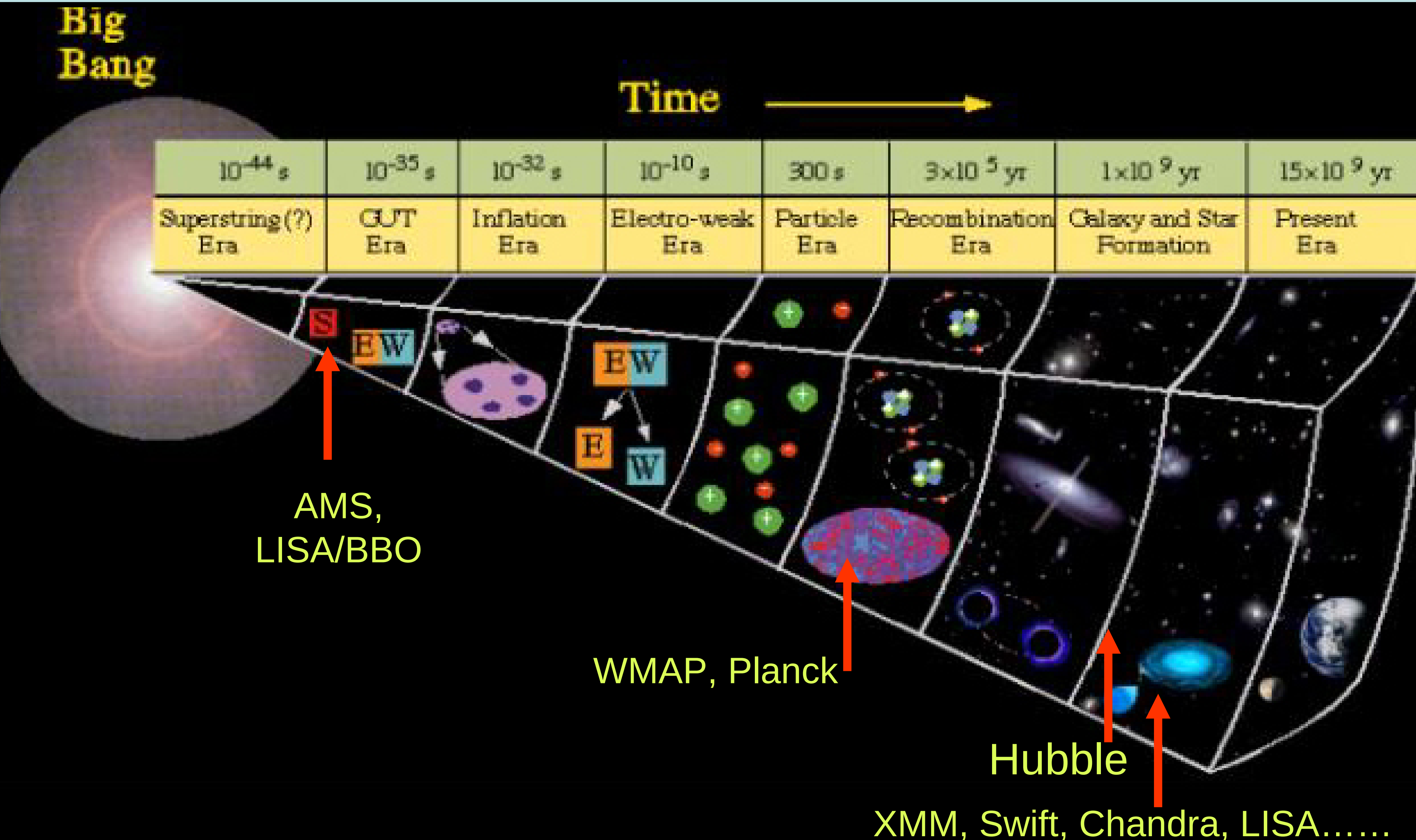


Roberto Battiston

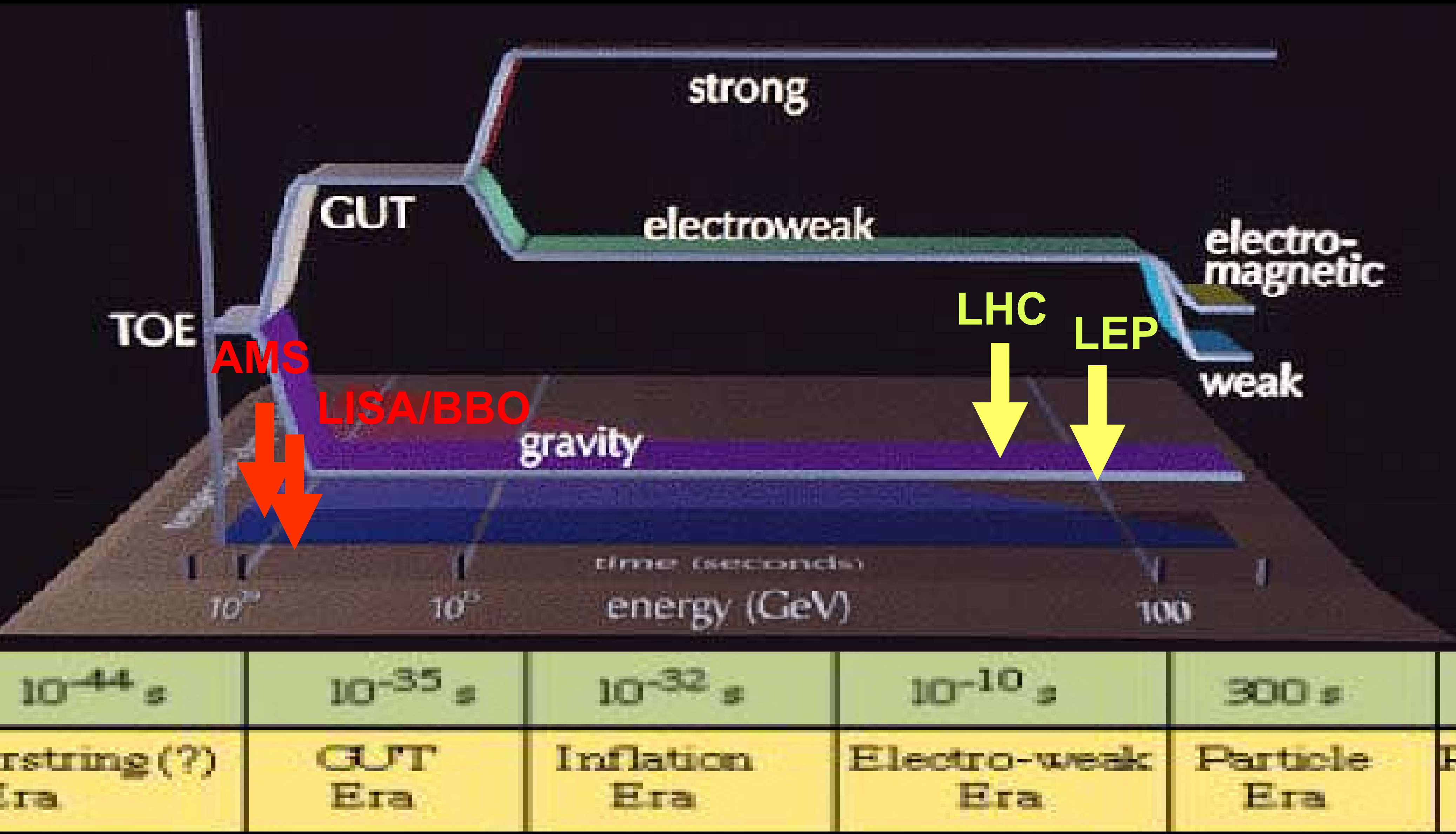
University and INFN of Perugia

International Workshop on Energy Budget
in the High Energy Universe
ICRR Tokyo
February 21st 2006

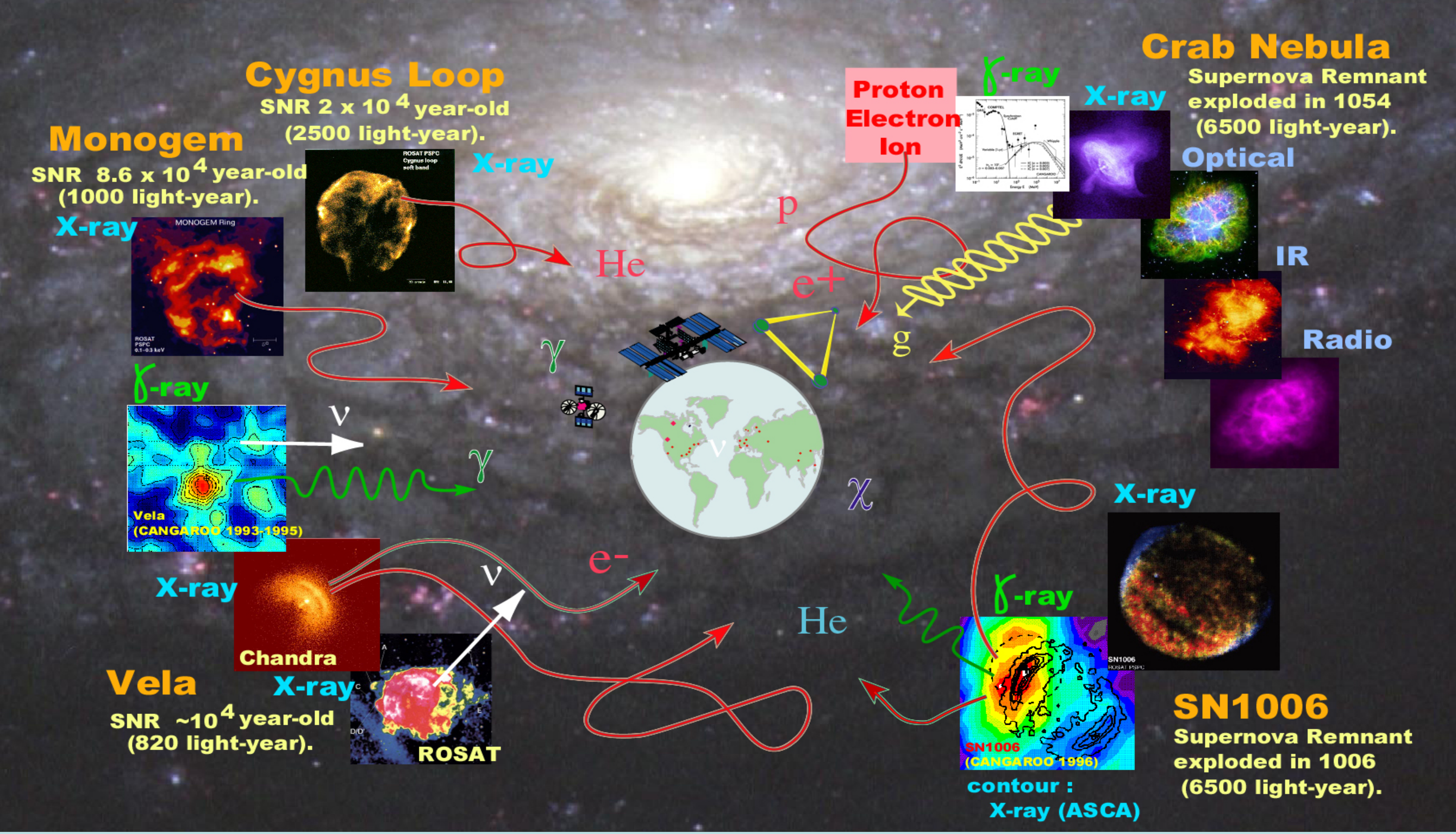
The universe is the ultimate laboratory to study fundamental physics…….



…….reaching energies which cannot be studied at accelerators………

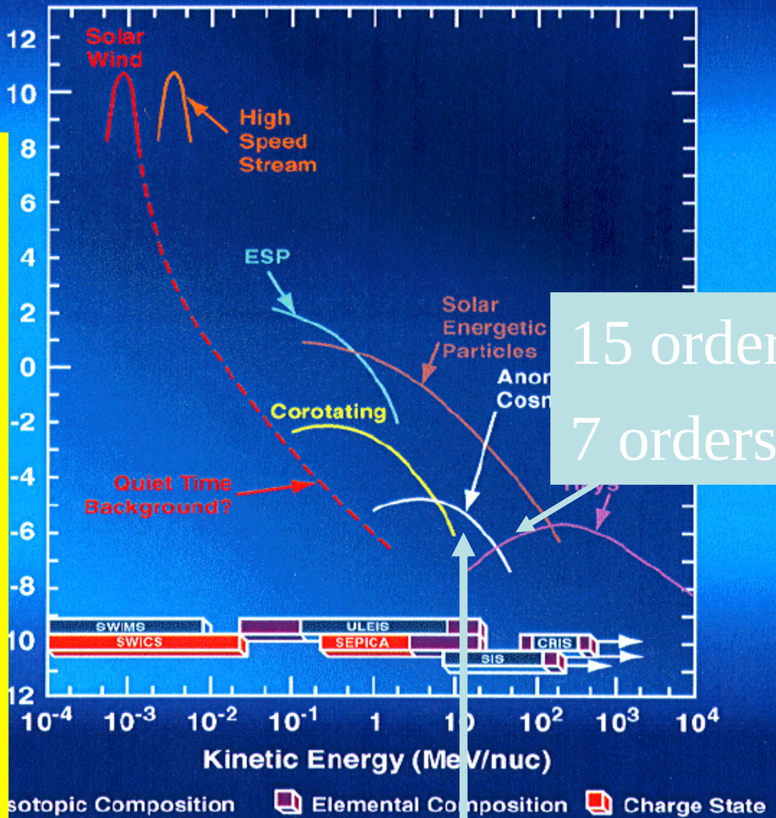


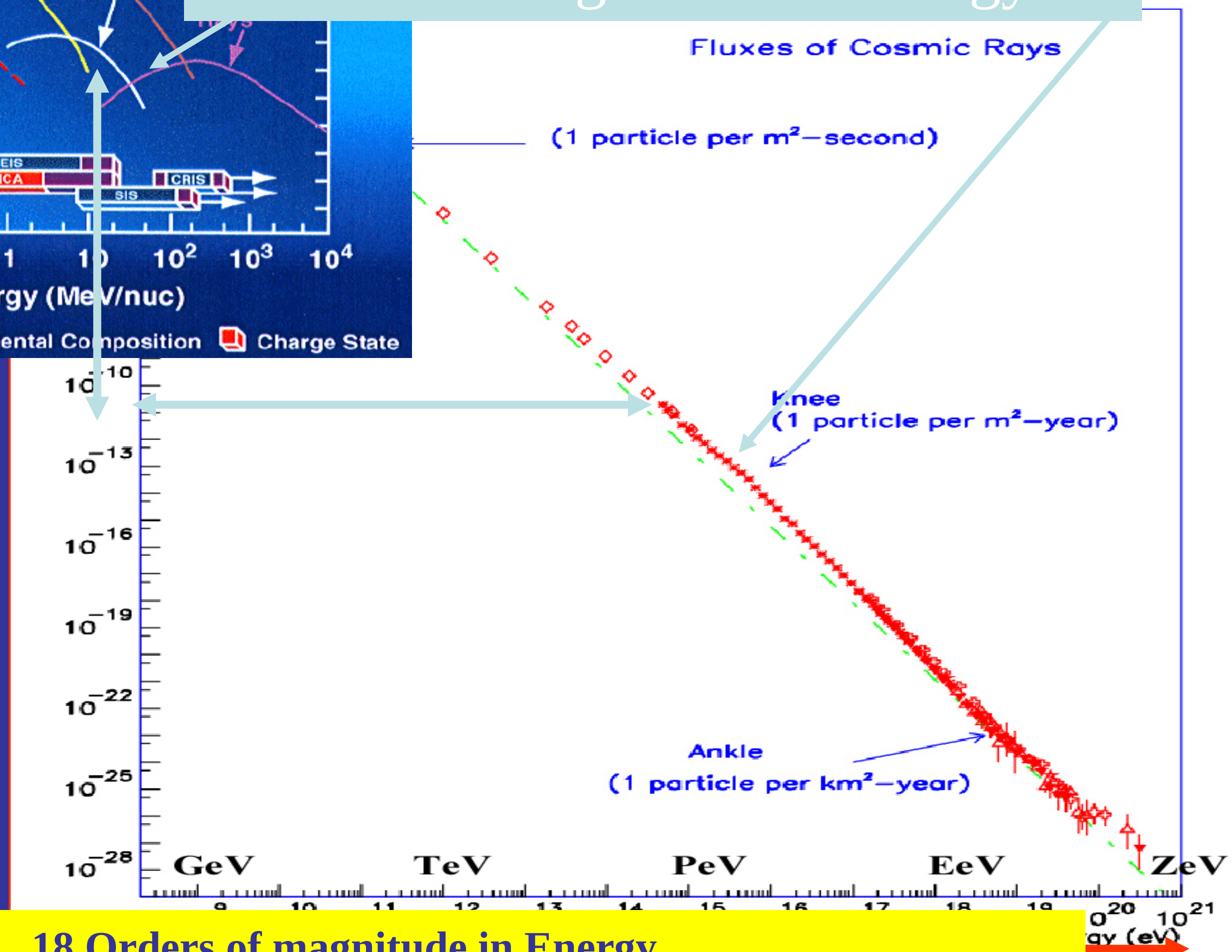
High Energy Cosmic Rays in the Universe



Messengers are photons, charged/neutral particles, gravitational waves…….

Cosmic Ray Origin & Direct Measurements





15 orders of magnitude in flux Intensity

7 orders of magnitude in Energy

50 Orders of magnitude in flux Intensity

Log Intensity / m^2 sr sec GeV

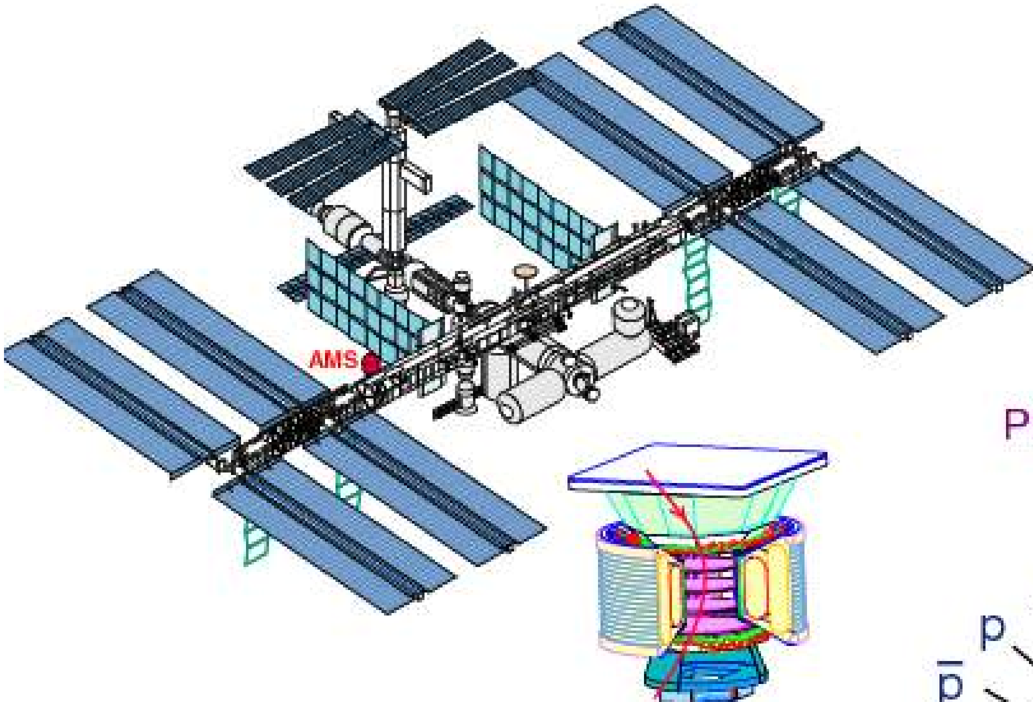
18 Orders of magnitude in Energy

The purpose of the AMS experiment is to perform accurate, high statistics, long duration measurements in space of

- energetic (0.1 GV - few TV) charged CR

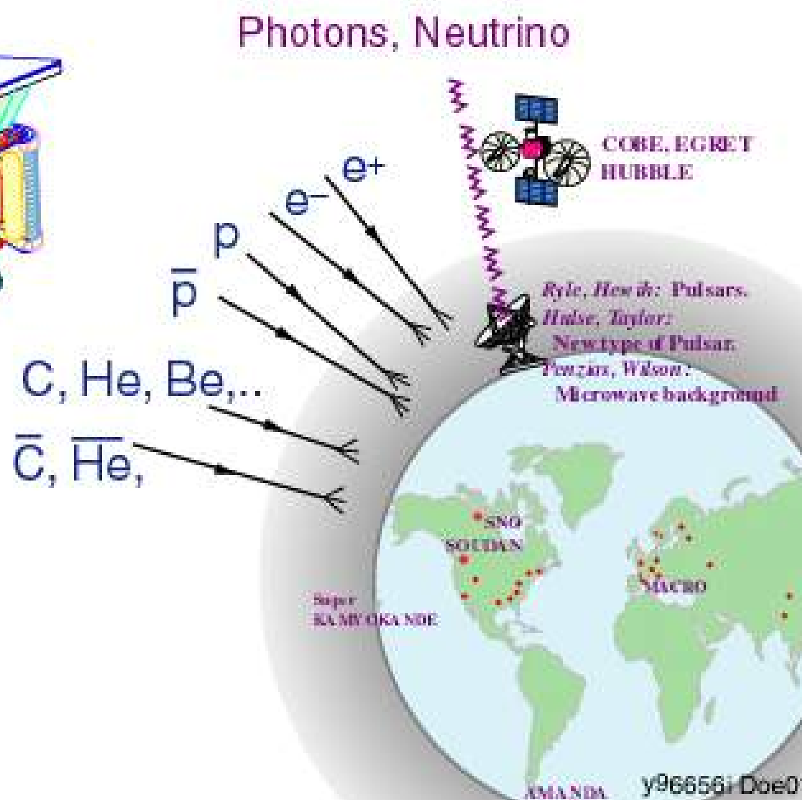
- energetic (>1 GeV) gamma rays.

AMS is a particle physics experiment:



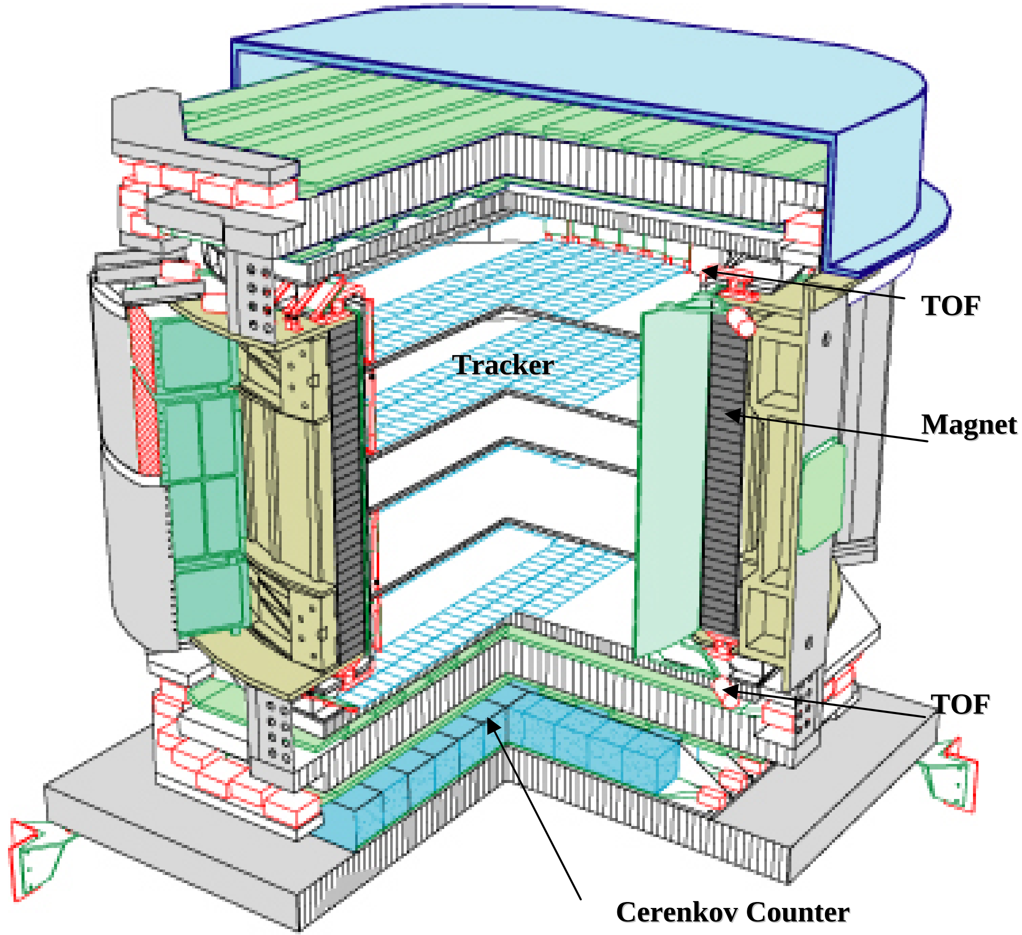
SUSY (Super Symmetry)
Grand Unified Theory
Baryon number violation
CP violation

Nobel Prizes,
(1) Pulsar,
(2) Microwave,
(3) Binary Pulsars,
(4) Solar neutrino
X Ray sources



Alpha Magnetic Spectrometer - AMS-01

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



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PHYSICS REPORTS

A Review Section of Physics Letters

THE ALPHA MAGNETIC SPECTROMETER (AMS) ON THE INTERNATIONAL SPACE STATION: PART I – RESULTS FROM THE TEST FLIGHT ON THE SPACE SHUTTLE

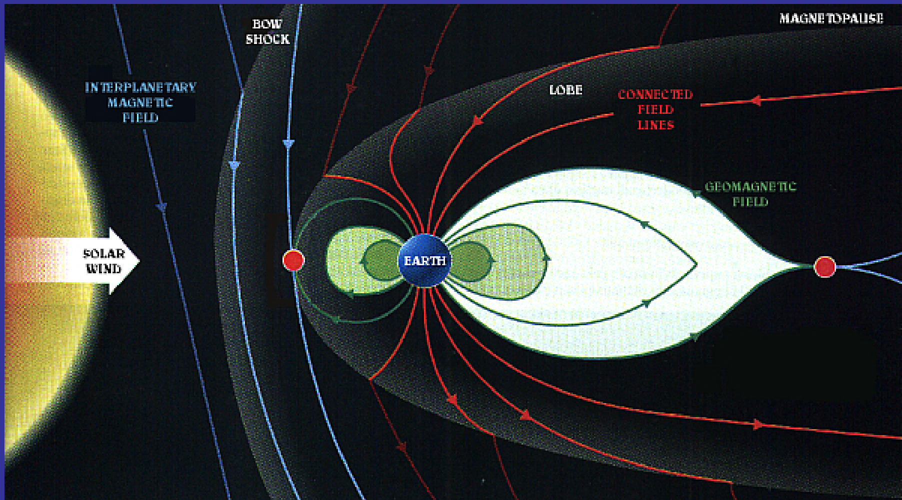
M. AGUILAR et al.
(AMS Collaboration)

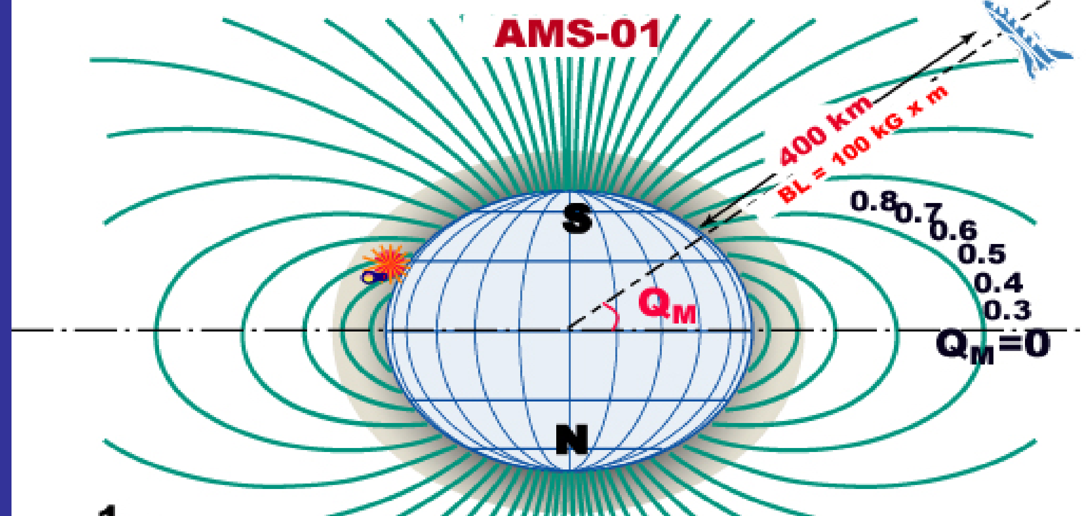
LAST ISSUE OF THIS VOLUME

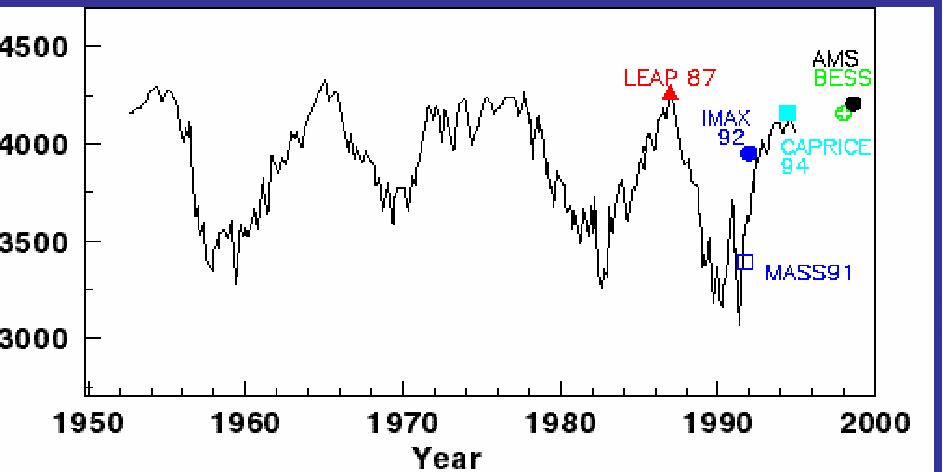
NORTH-HOLLAND
http://www.elsevier.com/locate/physrep

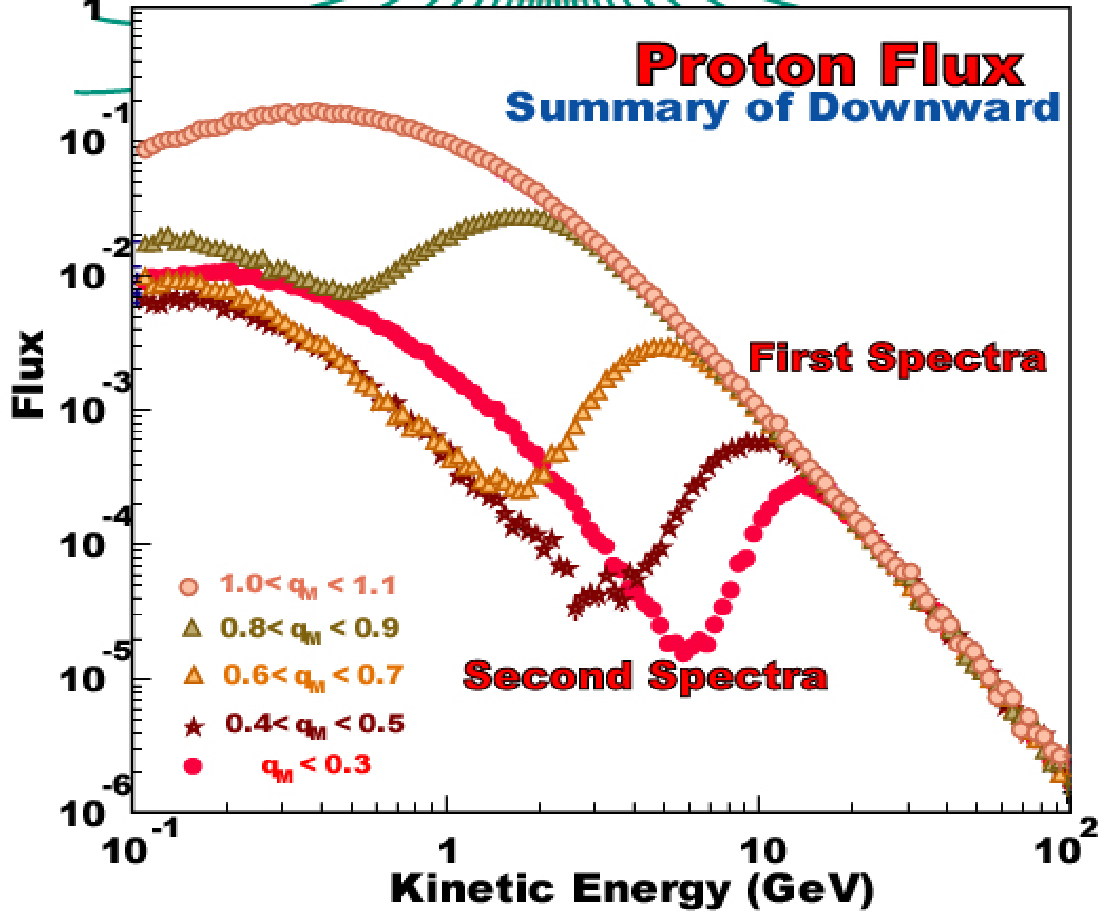
Ib02K064

Magnetosphere effects





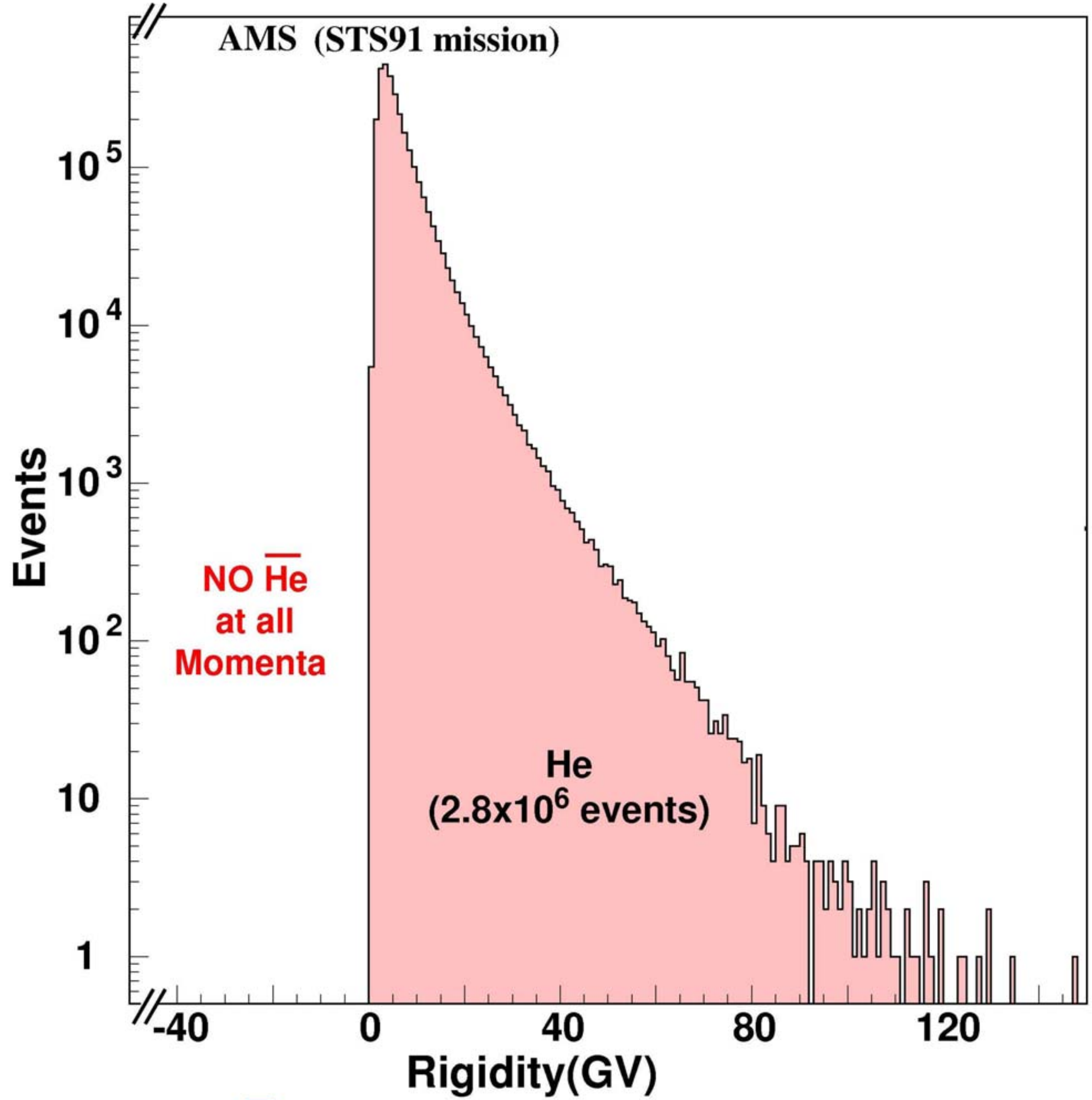




AMS has flown in space during a period of solar maximum

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)



Assume $\overline{He}$ and He have the same spectrum up to 140 GV then $\overline{He}$ / He is < ~ 1.1 10^{-6}

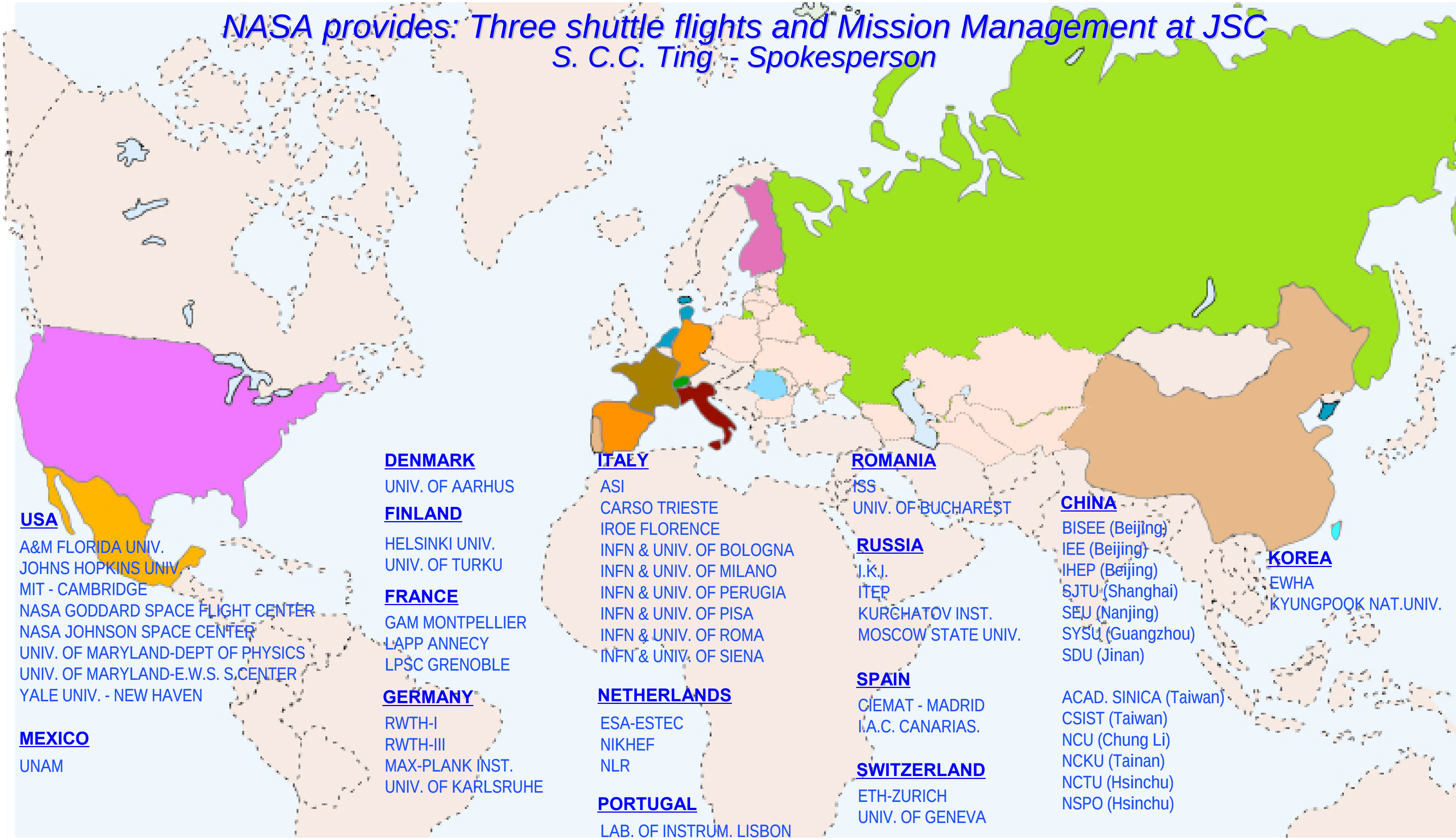
International Space Station

February 2006

Final configuration

AMS is an International Collaboration

NASA provides: Three shuttle flights and Mission Management at JSC
S. C.C. Ting - Spokesperson



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JOHNS HOPKINS UNIV.
MIT - CAMBRIDGE
NASA GODDARD SPACE FLIGHT CENTER
NASA JOHNSON SPACE CENTER
UNIV. OF MARYLAND-DEPT OF PHYSICS
UNIV. OF MARYLAND-E.W.S. S.CENTER
YALE UNIV. - NEW HAVEN

MEXICO
UNAM

DENMARK
UNIV. OF AARHUS

FINLAND
HELSINKI UNIV.
UNIV. OF TURKU

FRANCE
GAM MONTPELLIER
LAPP ANNECY
LPSC GRENOBLE

GERMANY
RWTH-I
RWTH-III
MAX-PLANK INST.
UNIV. OF KARLSRUHE

ITALY
ASI
CARSO TRIESTE
IROE FLORENCE
INFN & UNIV. OF BOLOGNA
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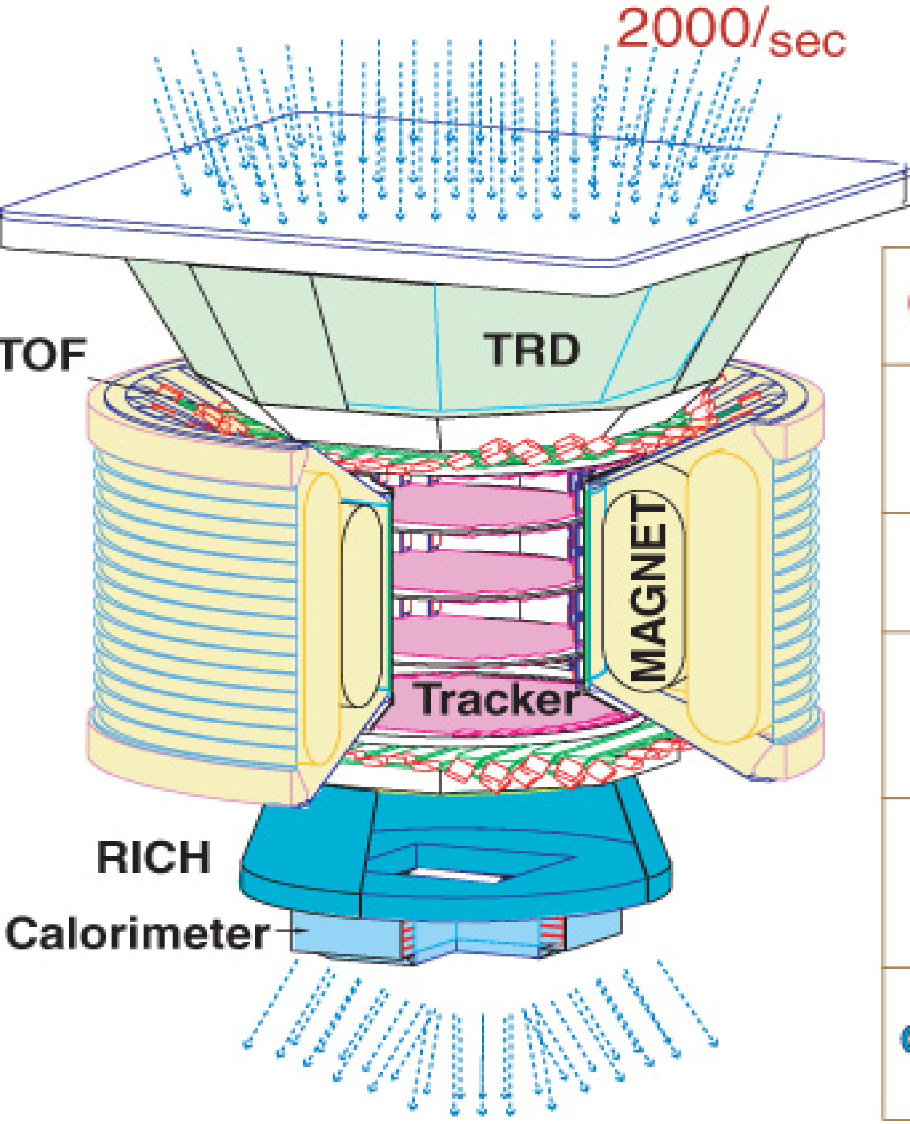
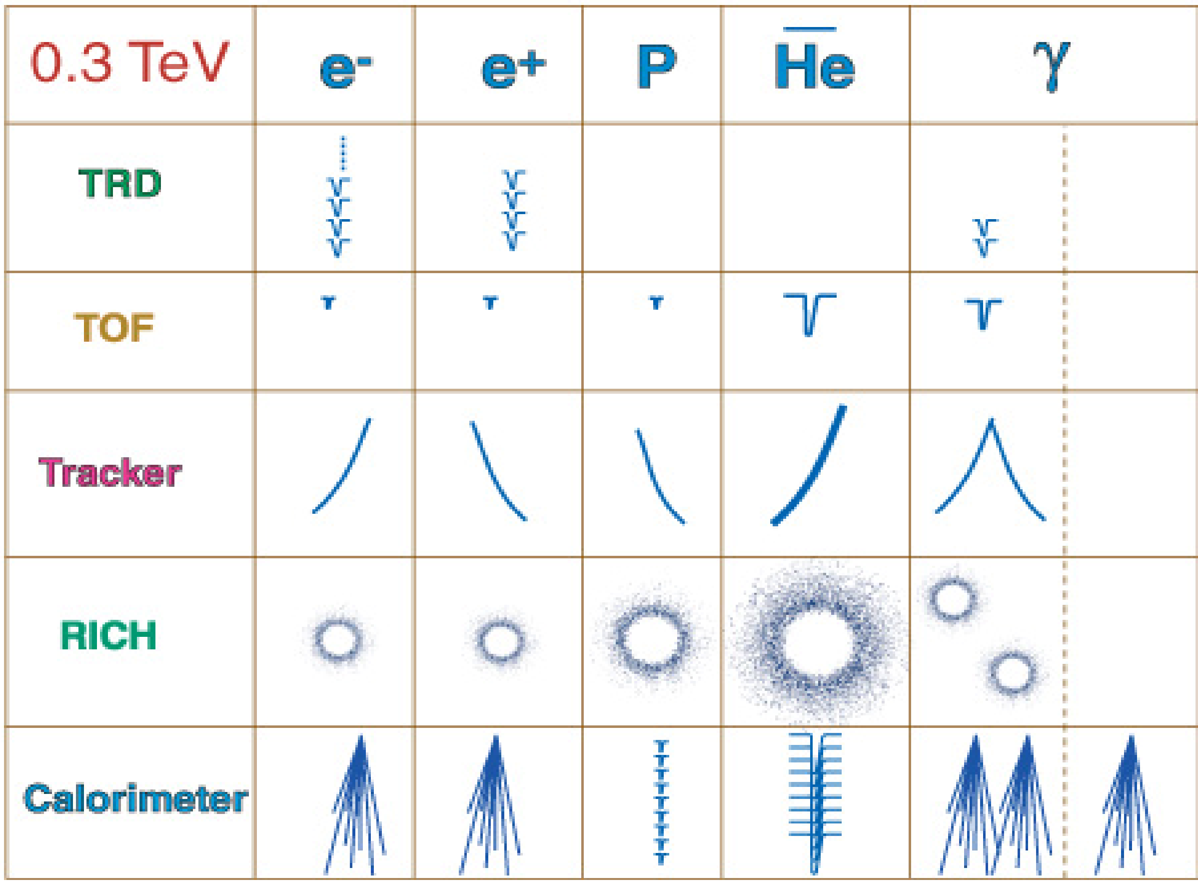
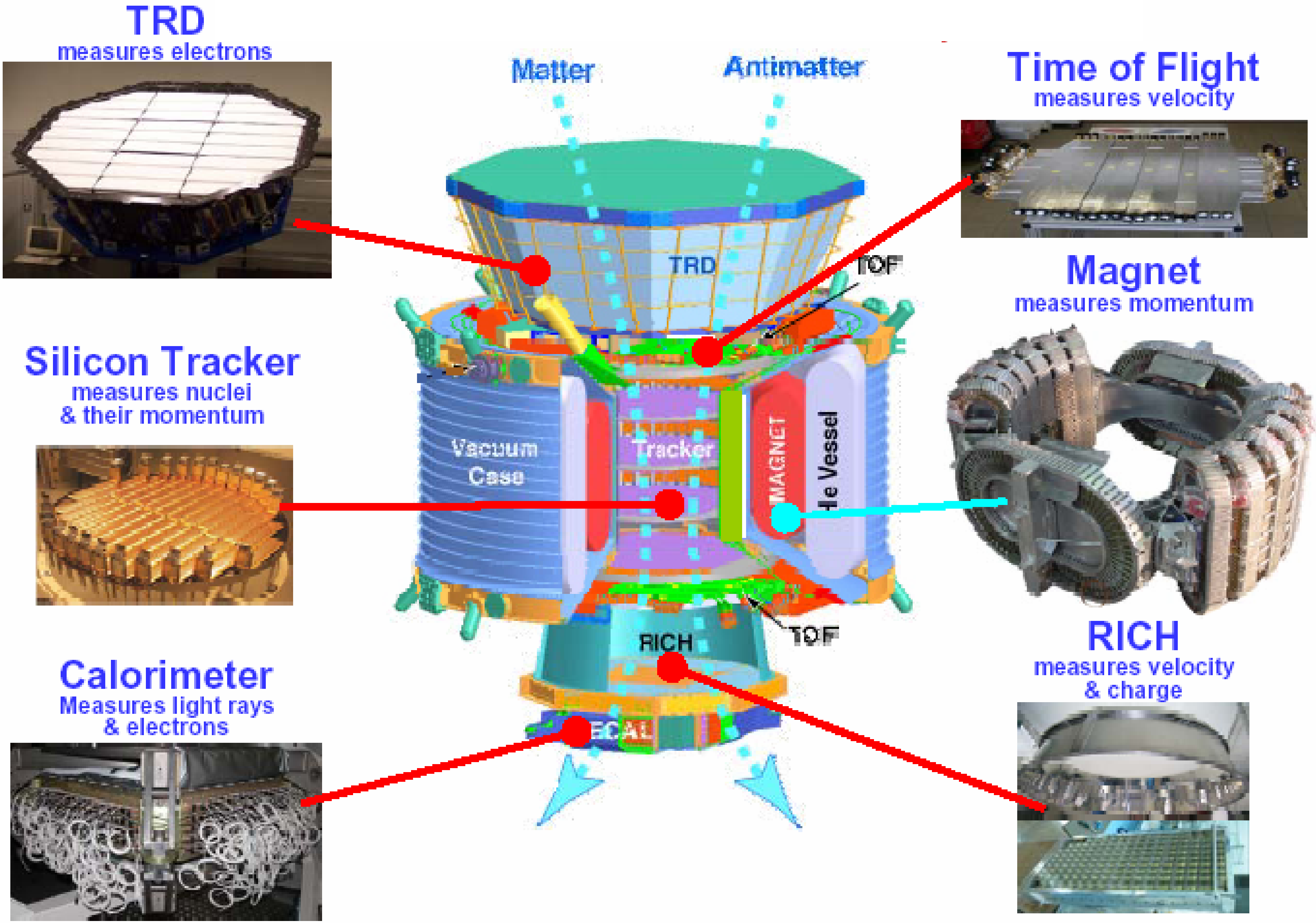
AMS: A TeV Magnetic Spectrometer in Space



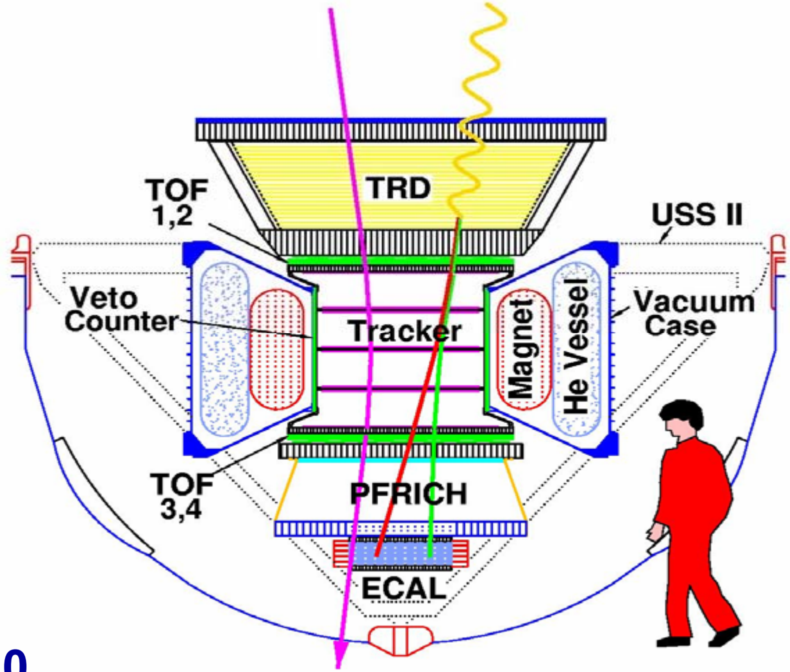
G.F. 5000 cm^2 sr
Exposure > 3 yrs



$dP/P^2 \sim 0.004 \rightarrow$ MDR = 2.5 TV, h/e = 10^{-6} (ECAL +TRD)


TRD
measures electrons
Matter
Antimatter
Time of Flight
measures velocity
TRD
TOF
Magnet
measures momentum
Silicon Tracker
measures nuclei
& their momentum
Vacuum
Case
Tracker
MAGNET
He Vessel
TOF
RICH
RICH
measures velocity
& charge
Calorimeter
Measures light rays
& electrons
ECAL

AMS-02 spectrometer



- **Acceptance for charged CR**: **0.5 m²sr**
- **Exposure: at least 3 years** (from 2008)
- **Charge:**

  Z determination up to Z = 26

  charge confusion < 10^{-7} @ Z=1 & < 10% @ Z>10
- **Rigidity (R=p/Z):**
  σ(R)/R = 1.5% @ 10 GV, Max Detectable Rigidity > 2-3 TV

- **Velocity** (β):
  TOF: $\sigma(\beta)/\beta$ = 3.5% (protons)
  RICH: $\sigma(\beta)/\beta$ = 0.1% (protons)

Expected data statistics for AMS on ISS

Above	> 1 GeV/c	>5 GeV/c	>10 GeV/c	>100 GeV	> 1 TeV
Protons			6.1×10^9	1.5×10^8	2.5×10^6
Electrons	1.4×10^8	7.3×10^7	6.8×10^6	7.2×10^4	5.4×10^2
Positrons	9×10^6	3.8×10^6	3×10^5	1.6×10^3	6
Antiprotons	1.5×10^6	1.1×10^6	1.4×10^4	3.2×10^3	5.8×10^2
Helium	6.4×10^8	4.3×10^8	2.1×10^8	7.3×10^6	1.7×10^5

AMS-02 goals and capabilities

Cosmic rays spectra and chemical composition up to 1 TeV

Search for Antimatter in Space

Search for Dark Matter

AMS will identify and measure the fluxes for:

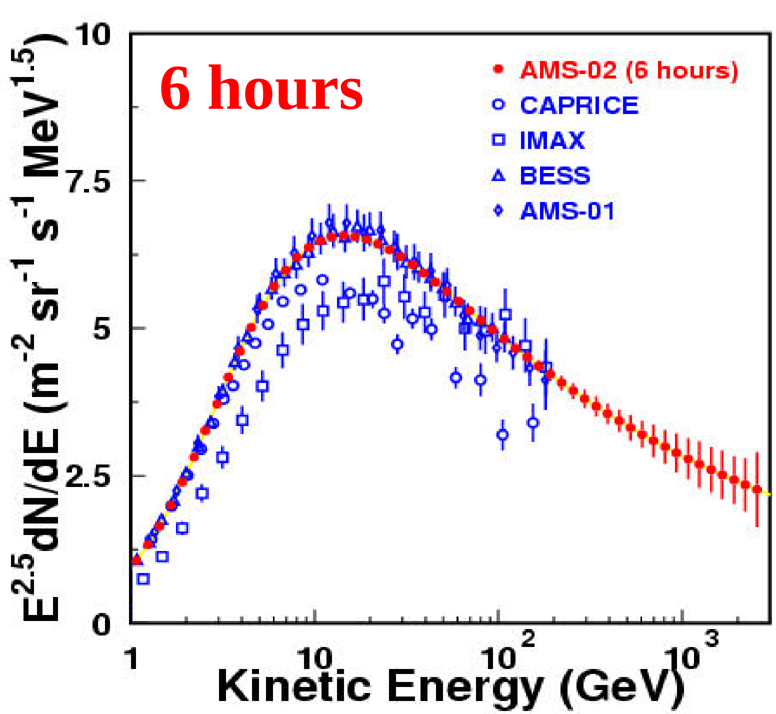
- **p for E < 1 TeV with unprecedented precision**
- **e+ for E < 300 GeV and e– for E < 1 TeV (unprecedented precision)**
- **Light Isotopes for E < 10 GeV/n**
- **Individual elements up to Z = 26 for E < 1 TeV/n**

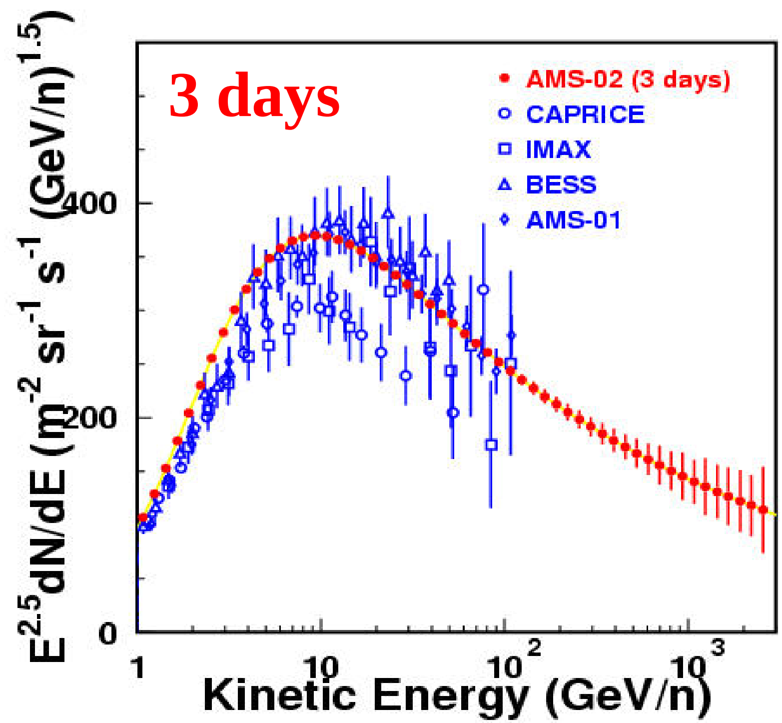
Absolute fluxes and spectrum shapes of protons and helium are important for calculation of atmospheric neutrino fluxes

Composition and spectra are important to constraint propagation, confinement, ISM density

Protons and helium

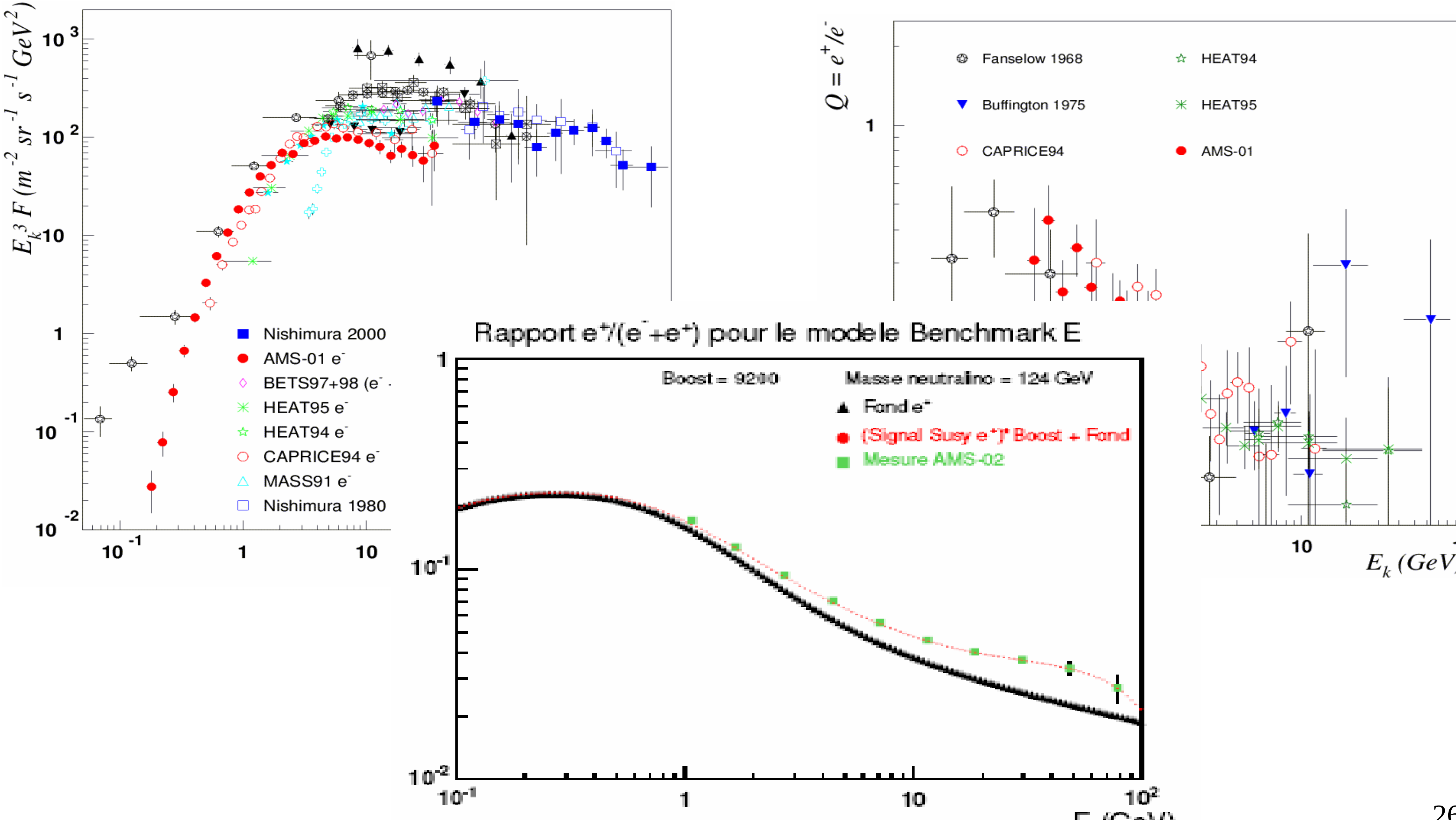
- **AMS will measure H & He fluxes for E < 1 TeV**
- **after 3 years will collect ≈10^8 H with E > 100 GeV**
- **and ≈10^7 He with E > 100 GeV/n**





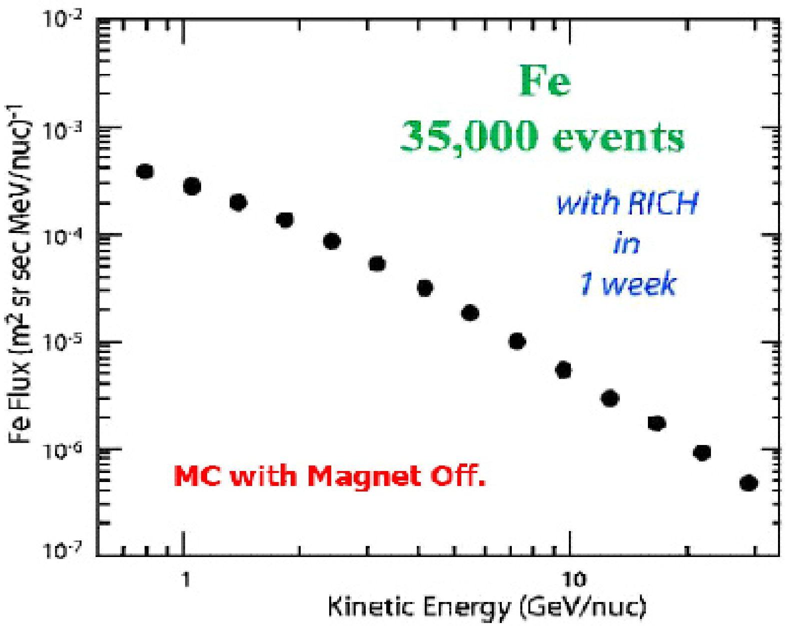
Electrons and positrons

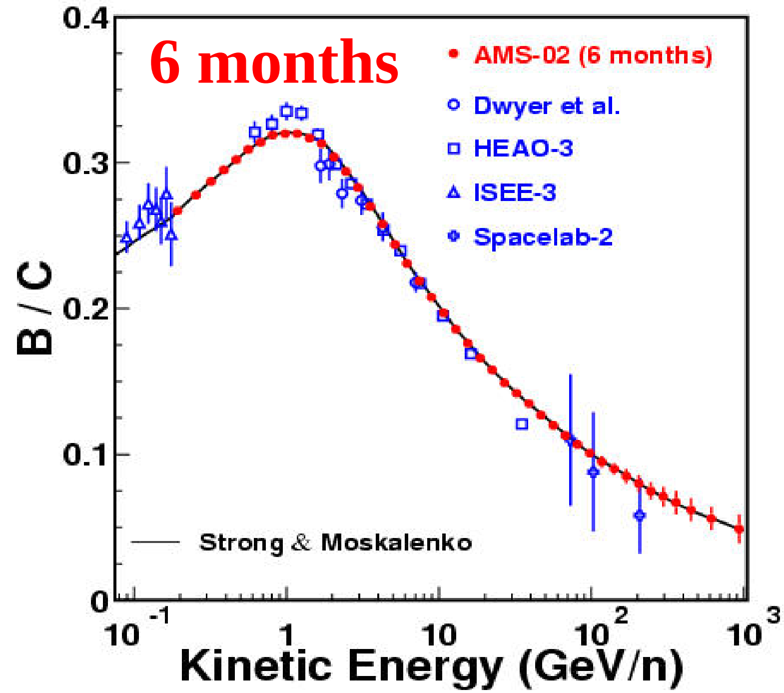
Energetic e+/e– cannot diffuse more than few kpc: they are sensitive probes of the Local Bubble and its neighbourhood.



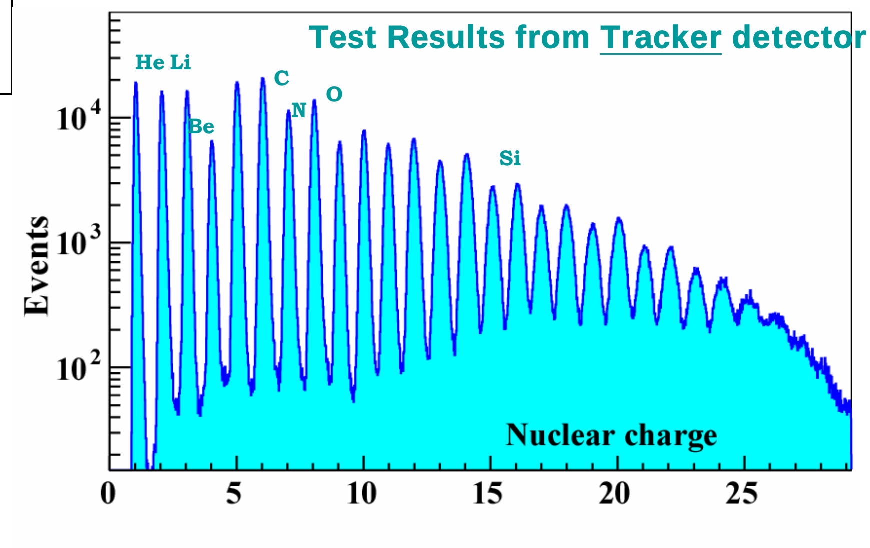
Heavier nuclei

- AMS will measure the flux of $Z \leq 26$ for $E < 1$ TeV/n
- The secondary to primary ratio B/C is used to fit the CR diffusion parameters
- After 3 years will collect $\approx 10^5$ Carbon with $E > 100$ GeV/n and $\approx 10^4$ Boron with $E > 100$ GeV/n





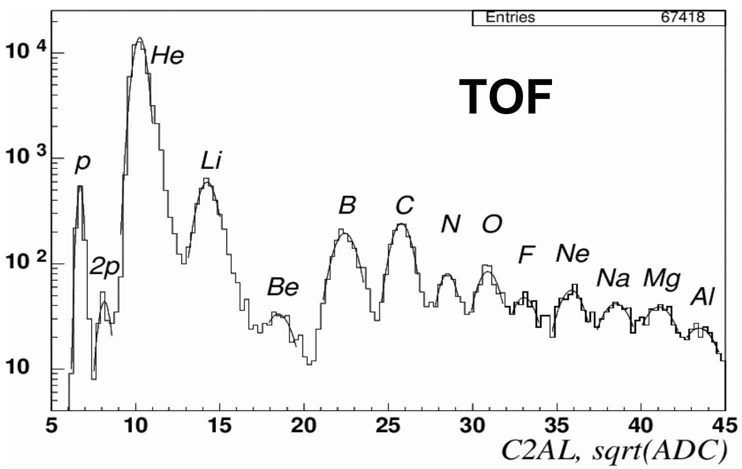
Nuclei separation

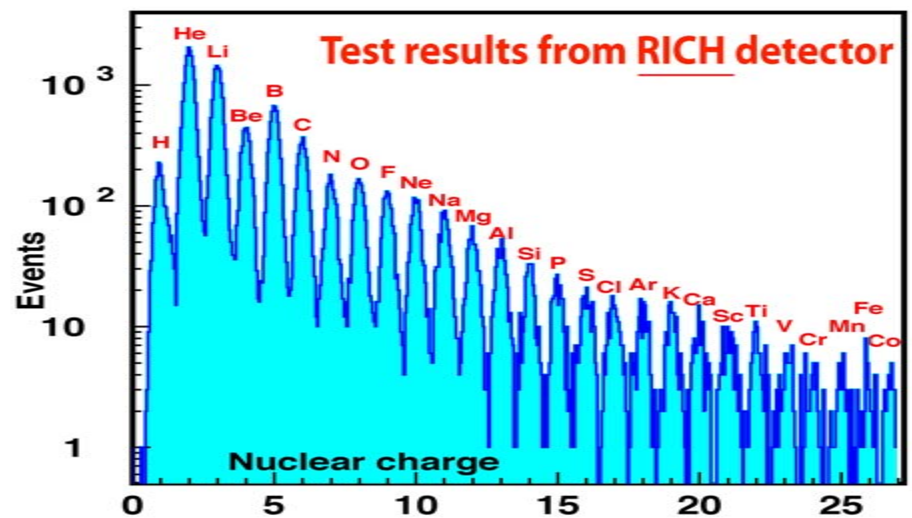


Charge measurement:

TOF, Tracker and RICH

Verified by heavy ion beam tests at CERN & GSI.

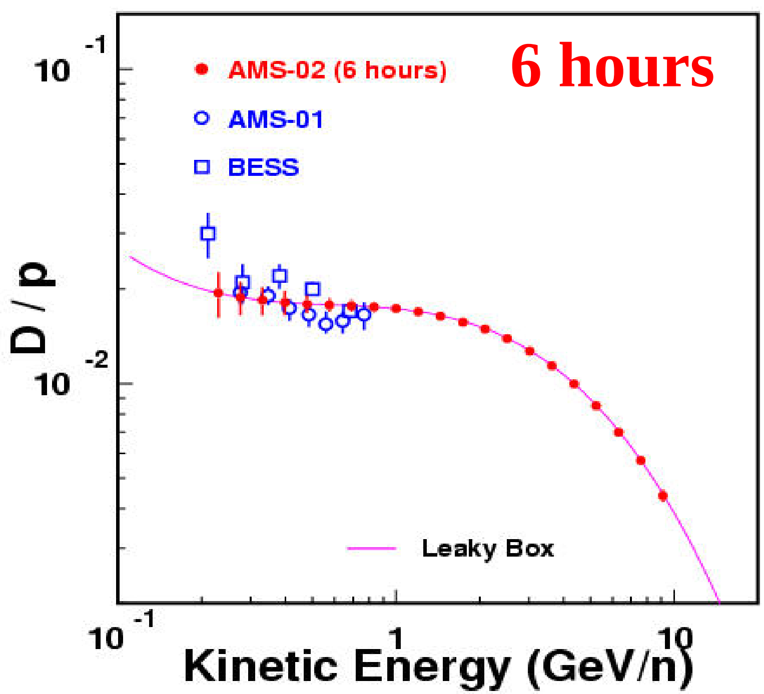


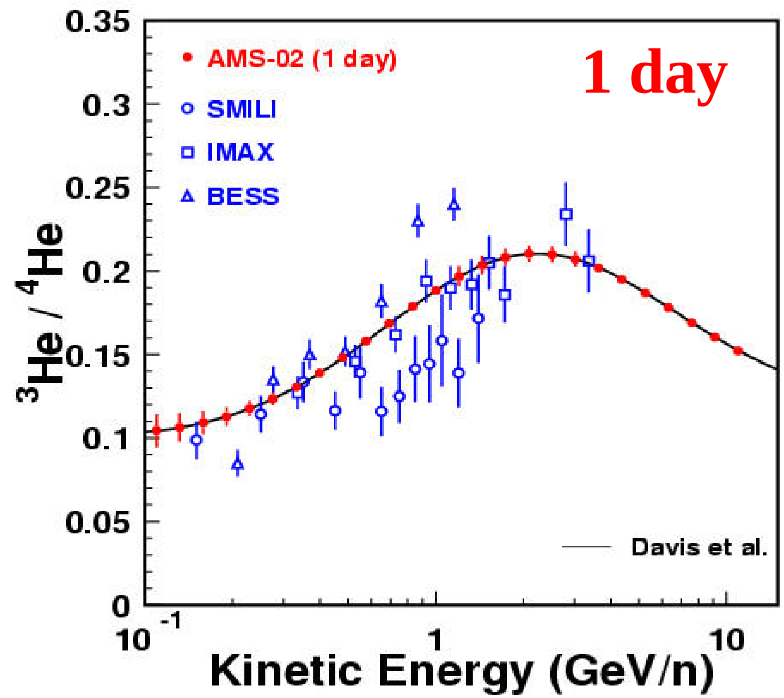


Light isotopes

Hydrogen and helium isotopes (deuterium and ^{3}He) are important tests of Big Bang nucleosynthesis which is their main source.

AMS-02 will identify D and ^{3}He up to 10 GeV/n



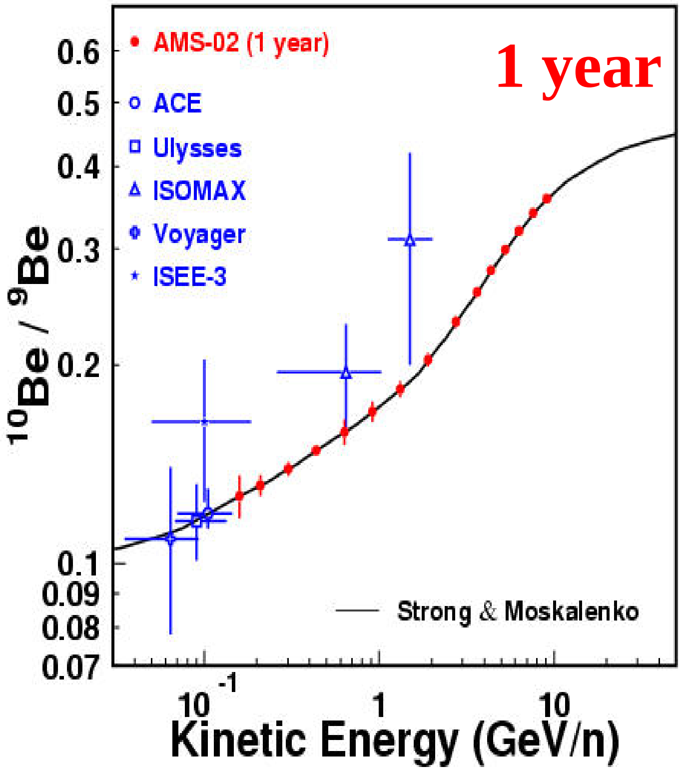


After 3 years AMS-02 will collect about 10^8 D and ^{3}He

$^{10}Be/^{9}Be$ – radioactive clock

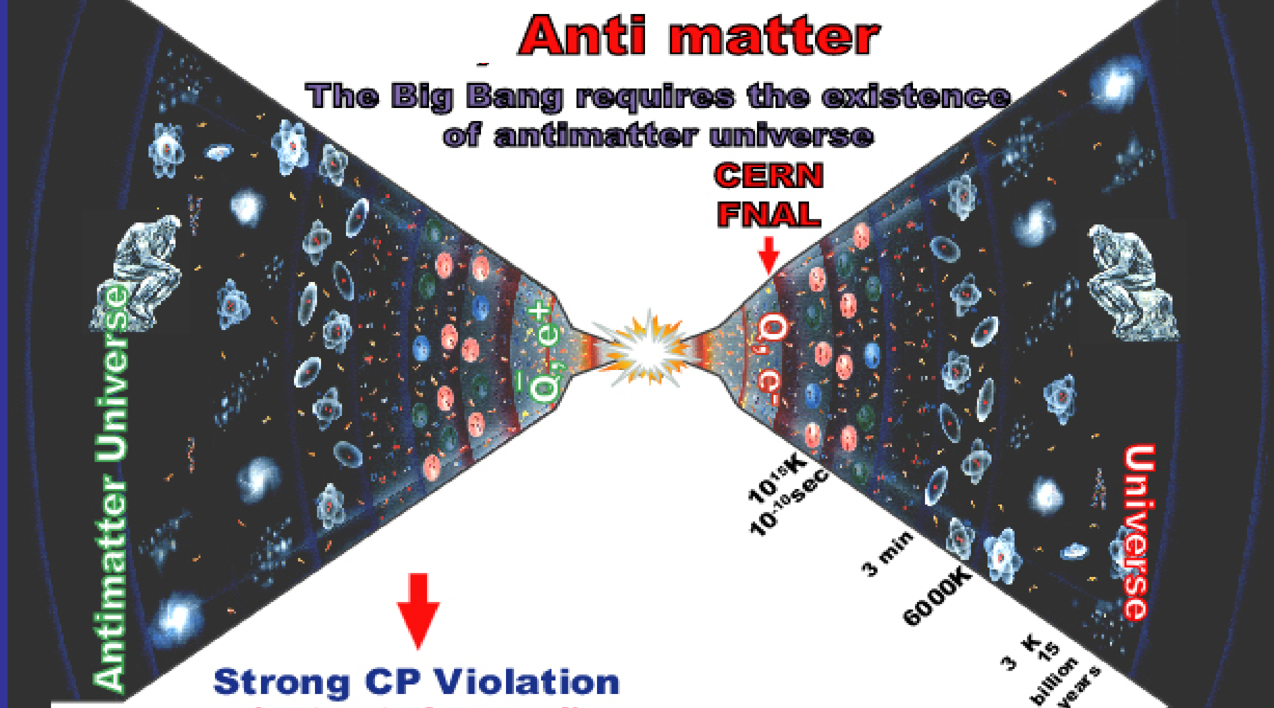
- ^{10}Be ($t_{1/2}$ = 1.51 Myr) is the lightest β -radioactive secondary isotope having a half-life comparable with the CR confinement time in the Galaxy.
- In diffusion models, the ratio $^{10}Be/^{9}Be$ is sensitive to the size of the halo and to the properties of the local interstellar medium

AMS will separate ^{10}Be from ^{9}Be for
0.15 GeV/n < E < 10 GeV/n
after 3 years will collect $\approx 10^5$ ^{10}Be

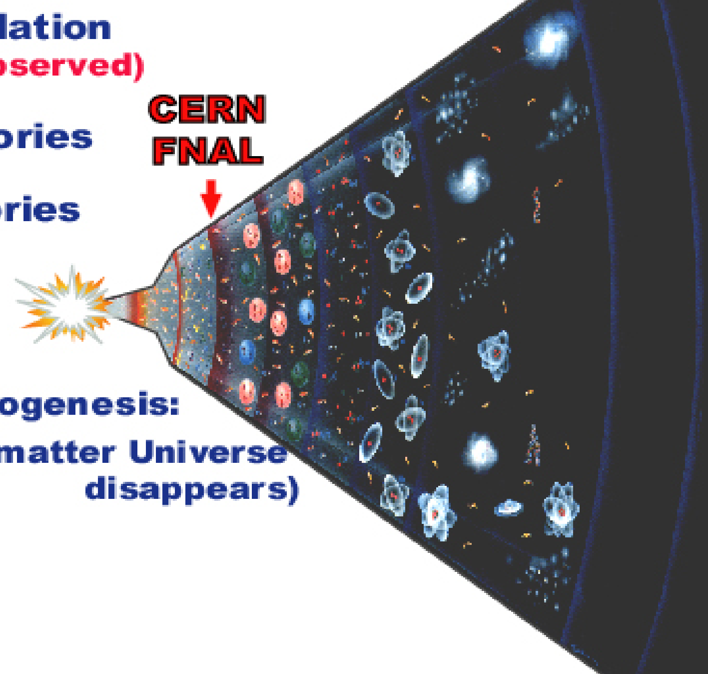


Anti matter

The Big Bang requires the existence of antimatter universe



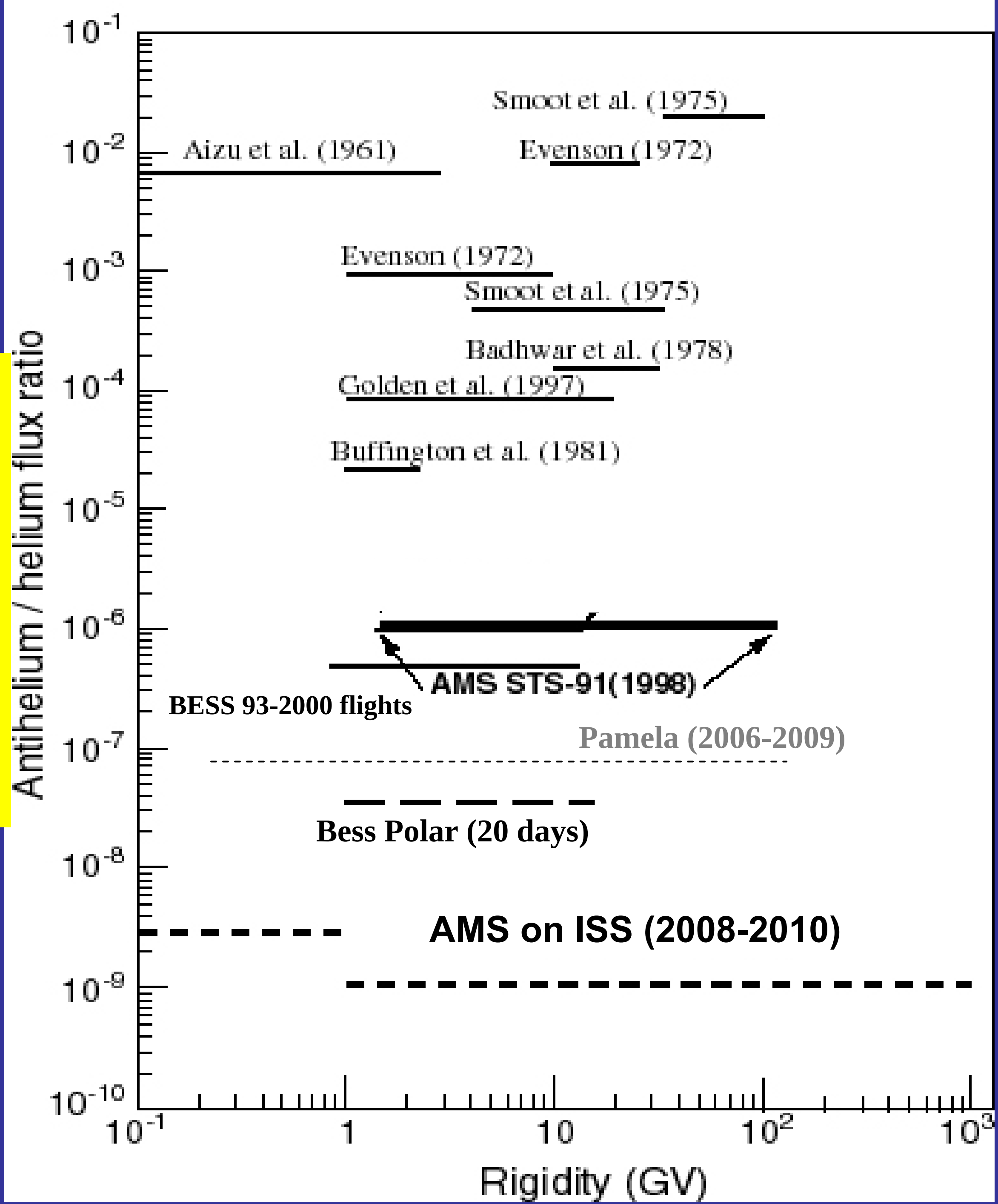
Strong CP Violation
(not yet observed)
and
Baryon Number Violation
(Proton decay not yet observed)
Then
Grand Unified Theories
or
Electroweak Theories
predicts



Magnetic Monopole
or
Light Higgs
or
Massive neutrinos

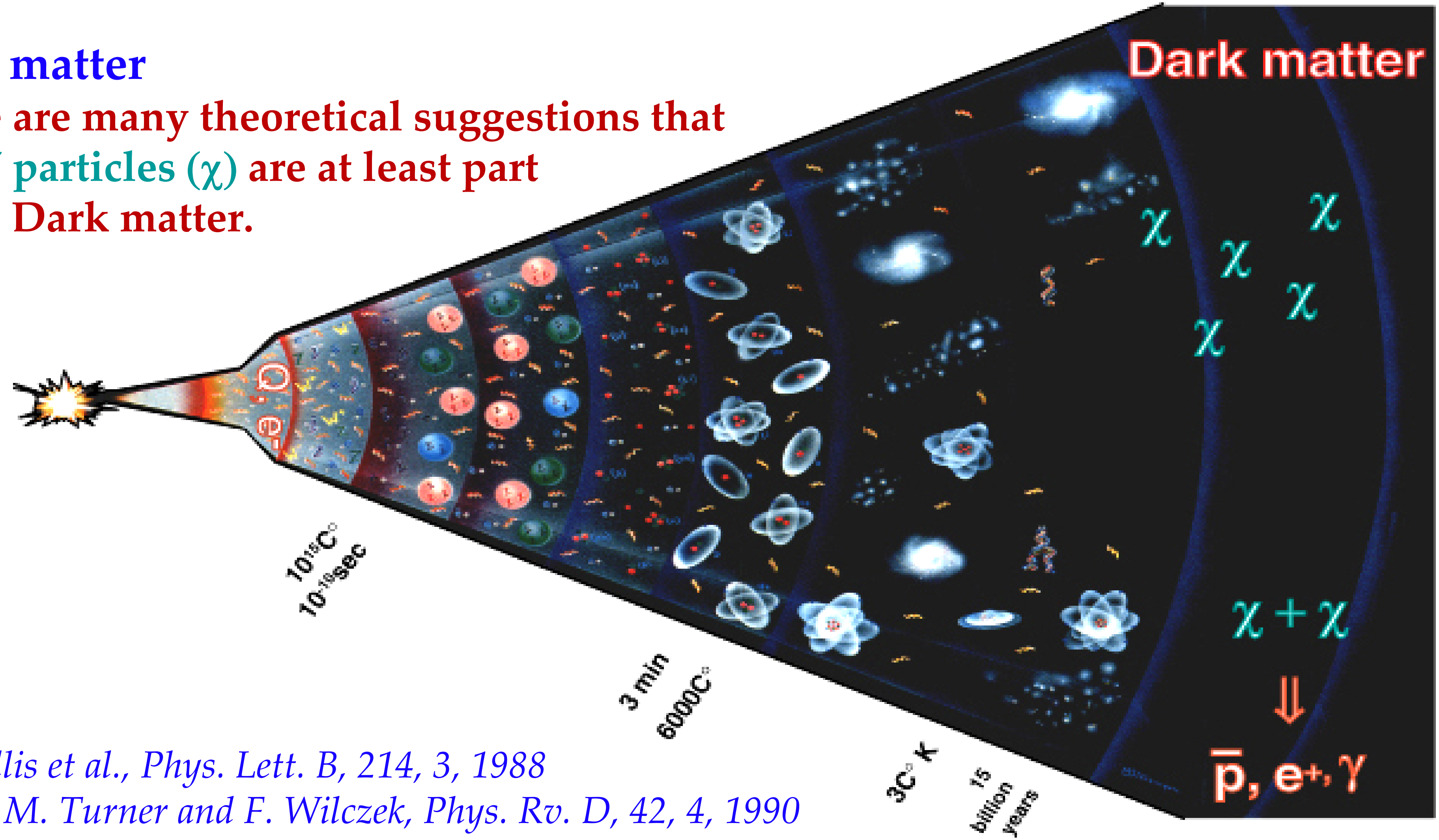
Baryogenesis:
(Antimatter Universe disappears)

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



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. Rv. D, 42, 4, 1990
E.A. Baltz, J. Edsjo, P.R. D59, 23511, 1999

Non baryonic Dark Matter

➢Indirect search with annihilation of DM candidates into standard model particles

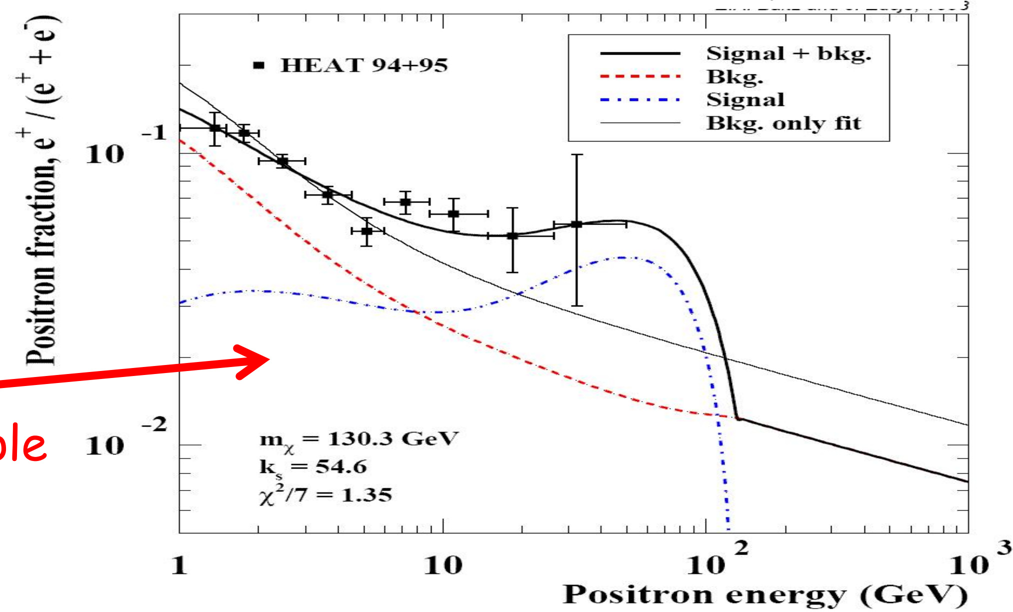
♦ neutralino χ^0 from mSugra (SuSy)

$\chi^o \chi^o \rightarrow$ qq, W^+W^-, HZ^o, $\gamma\gamma$, $\nu\nu$,…..

↘ $\bar{p}$, p, $\mathbf{e^+}$, e^-, γ

e^+ example

Baltz and Edsjo (1998)



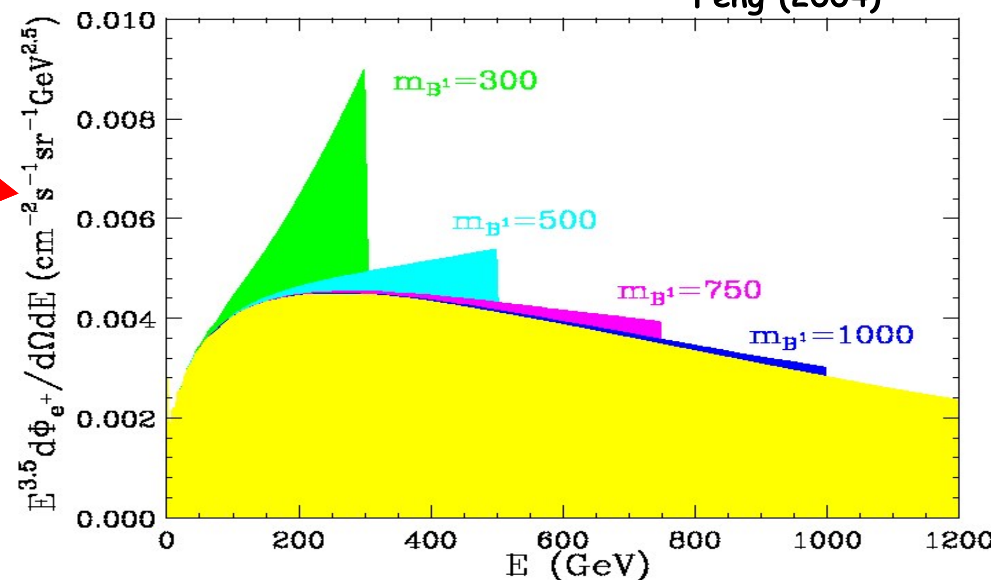
♦ stable particles from Kaluza-Klein (KK photon in UED: B^1)

$B^1 B^1 \rightarrow$ ff, HH

↘ $\bar{p}$, p, $\mathbf{e^+}$, e^-

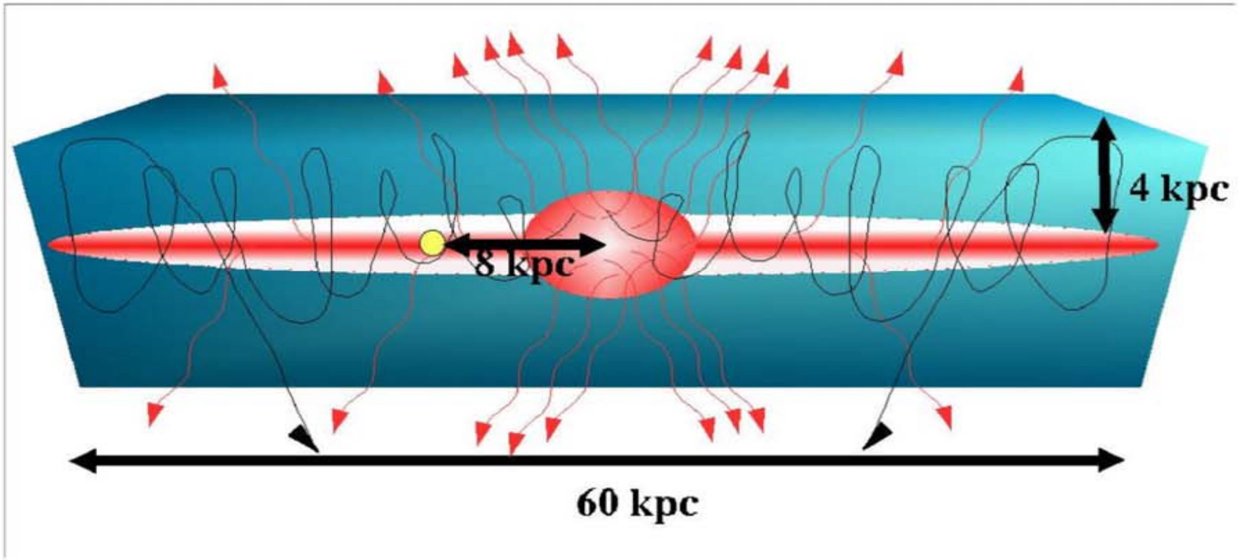
e^+ example

Feng (2004)



➢AMS-02 can measure simultaneously indirect DM signal : $\mathbf{e^+}$, $\mathbf{\bar{p}}$, $\mathbf{\bar{D}}$ and γ.

Model of our Galaxy



Primary particles by supernovae explosions, pulsars, ...

Secondary particles nuclear interactions.

Diffusion parameters determined from sec./prim. ratios, e.g. B/C ratio

Halo size determined from radioactive isotopes, e.g $^{10}Be/^{9}Be$ ratio
($\tau(^{10}Be) = 1.6 \cdot 10^6$ yr)

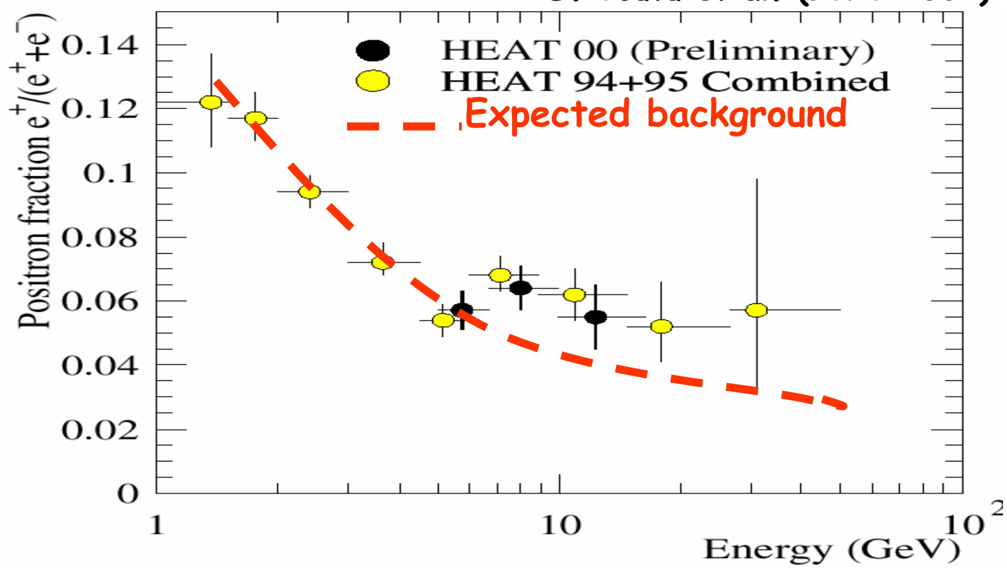
Best diffusion parameters for nuclear spectra yield:

too few hard gammas, too few antiprotons and too few hard positrons!

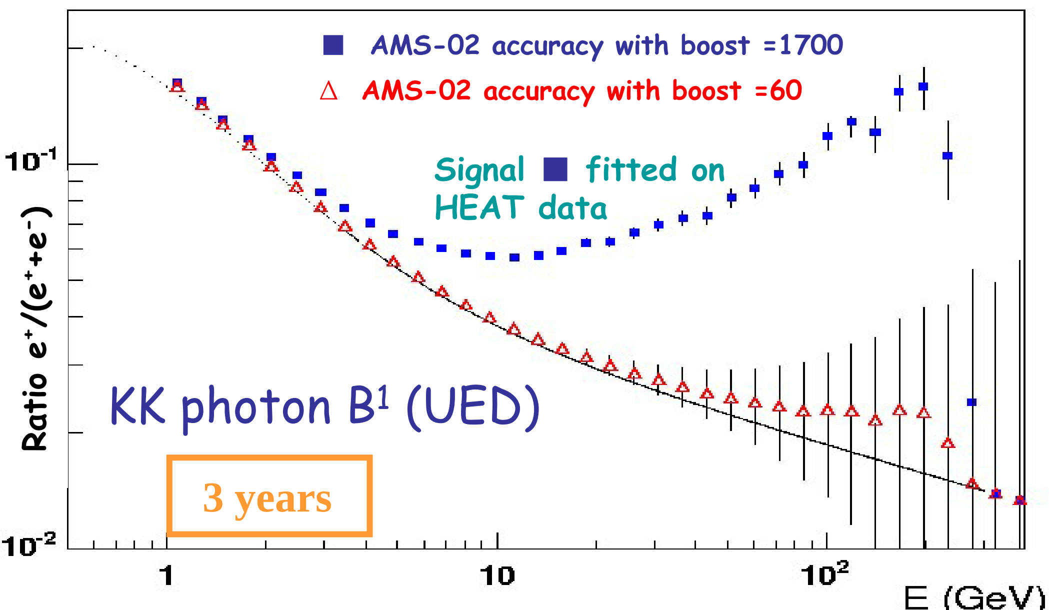
Positron search

- Possible excess seen at 8 GeV by HEAT in cosmic positron fraction.
- DM interpretation.
- AMS-02 accuracy with e^+ from
  - KK photon B^1 (UED) annihilation,
  - χ^0 (mSugra) annihilation.

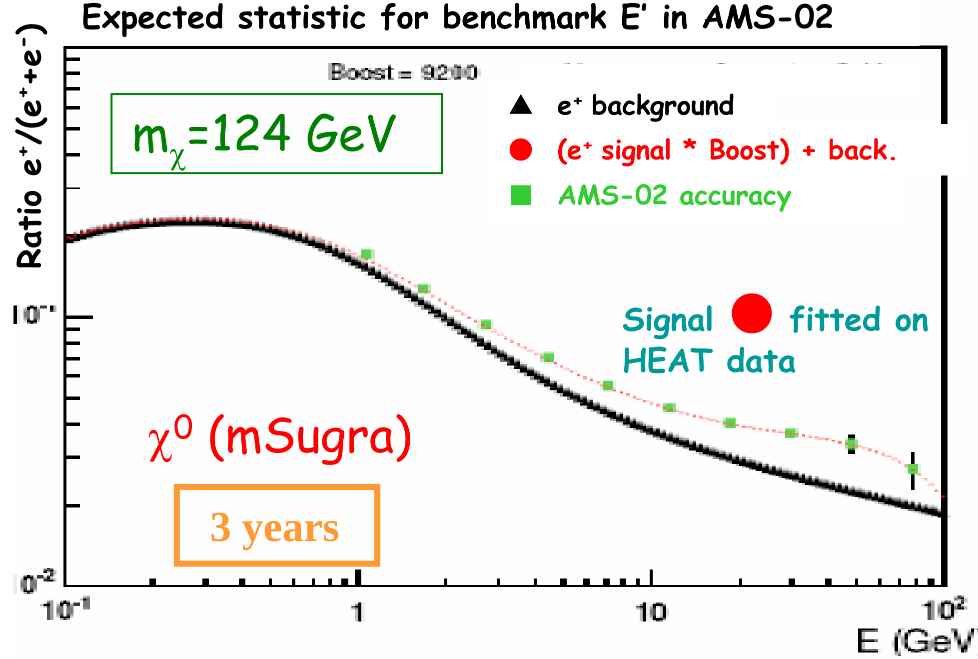
S. Coutu et al. (ICRC 2001)



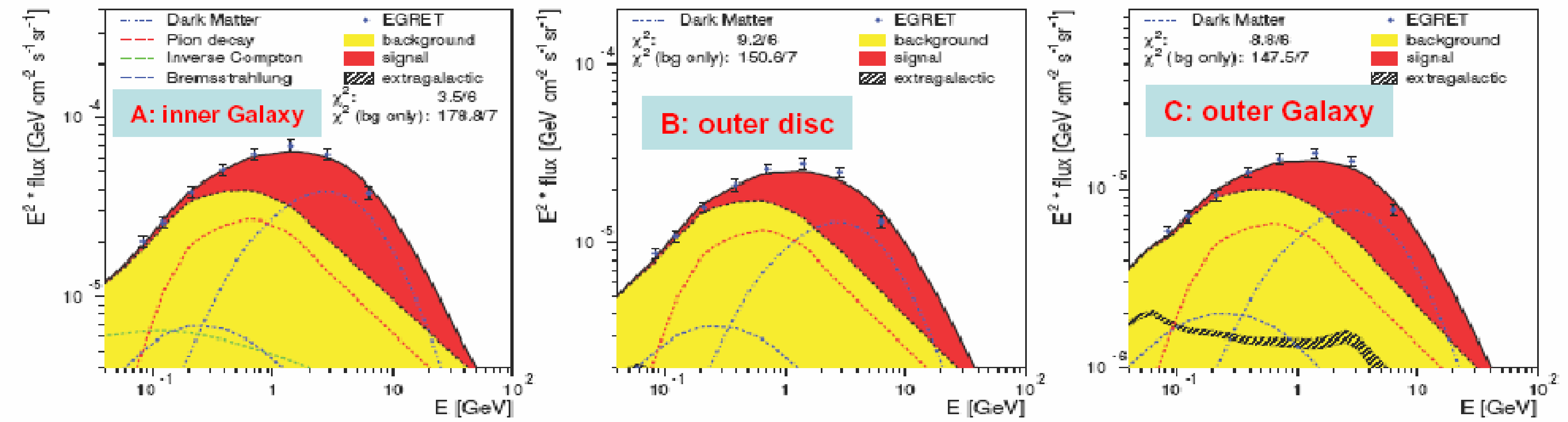
Expected statistic for LKP of 300 GeV in AMS-02



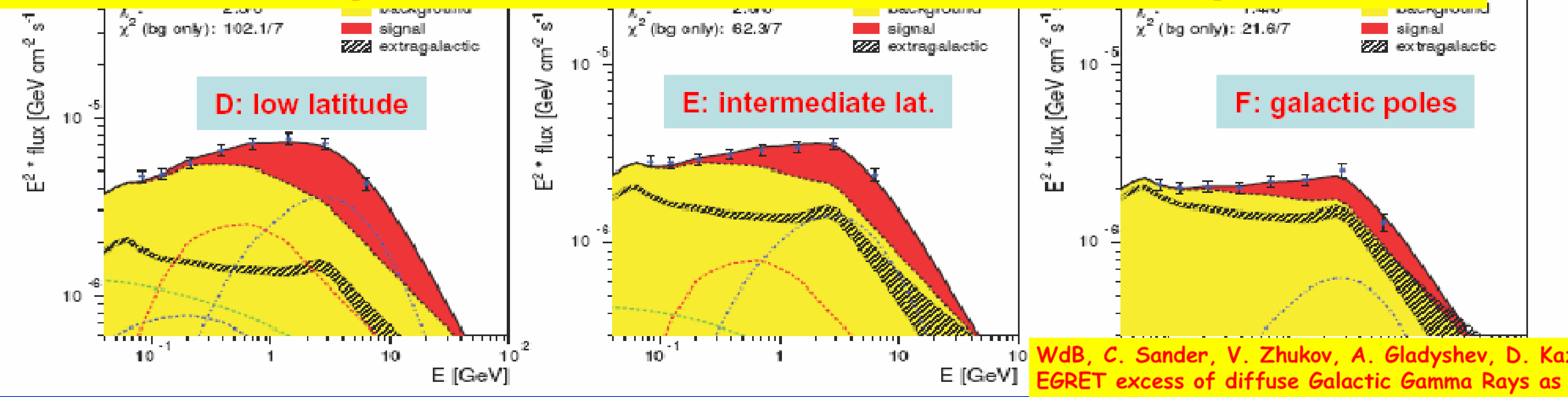
Expected statistic for benchmark E' in AMS-02



Analysis of EGRET Data in 6 sky directions



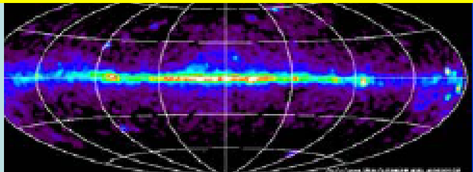
Total χ^2 for all regions :28/36 $\Rightarrow$ Prob.= 0.8 Excess above background > 10σ.



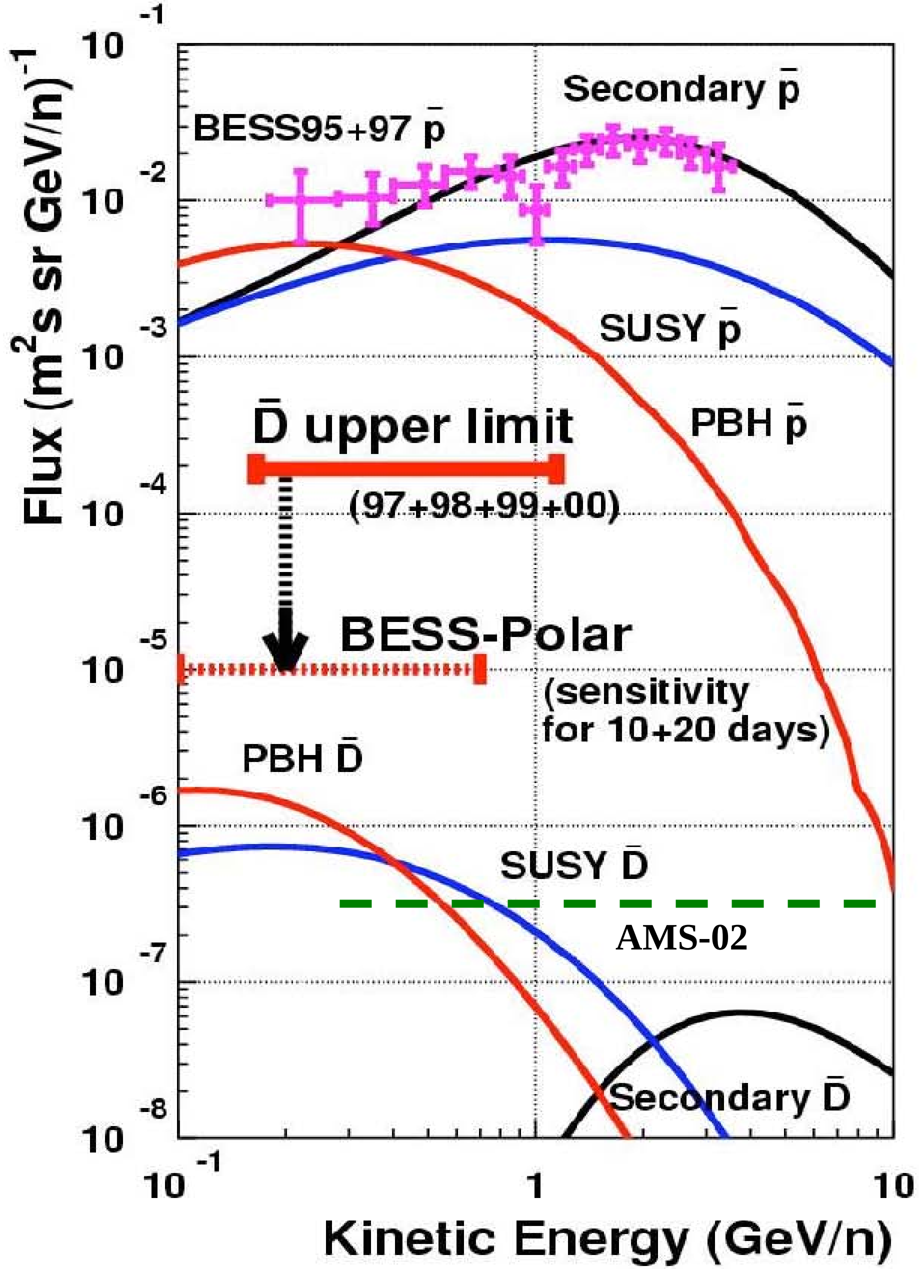
WdB, C. Sander, V. Zhukov, A. Gladyshev, D. Kazakov, EGRET excess of diffuse Galactic Gamma Rays as Tracer of DM, astro-ph/0508617, A&A, 444 (2005) 51

A: inner Galaxy (l=±30^0, |b|<5^0)
B: Galactic plane avoiding A
C: Outer Galaxy

D: low latitude (10-20^0)
E: intermediate lat. (20-60^0)
F: Galactic poles (60-90^0)



AMS sensitivity to anti D



AMS-02 acceptances

- Antiproton acceptance

  0.16 m².sr for [0.5-16] GeV
  0.033 m².sr for [16-300] GeV

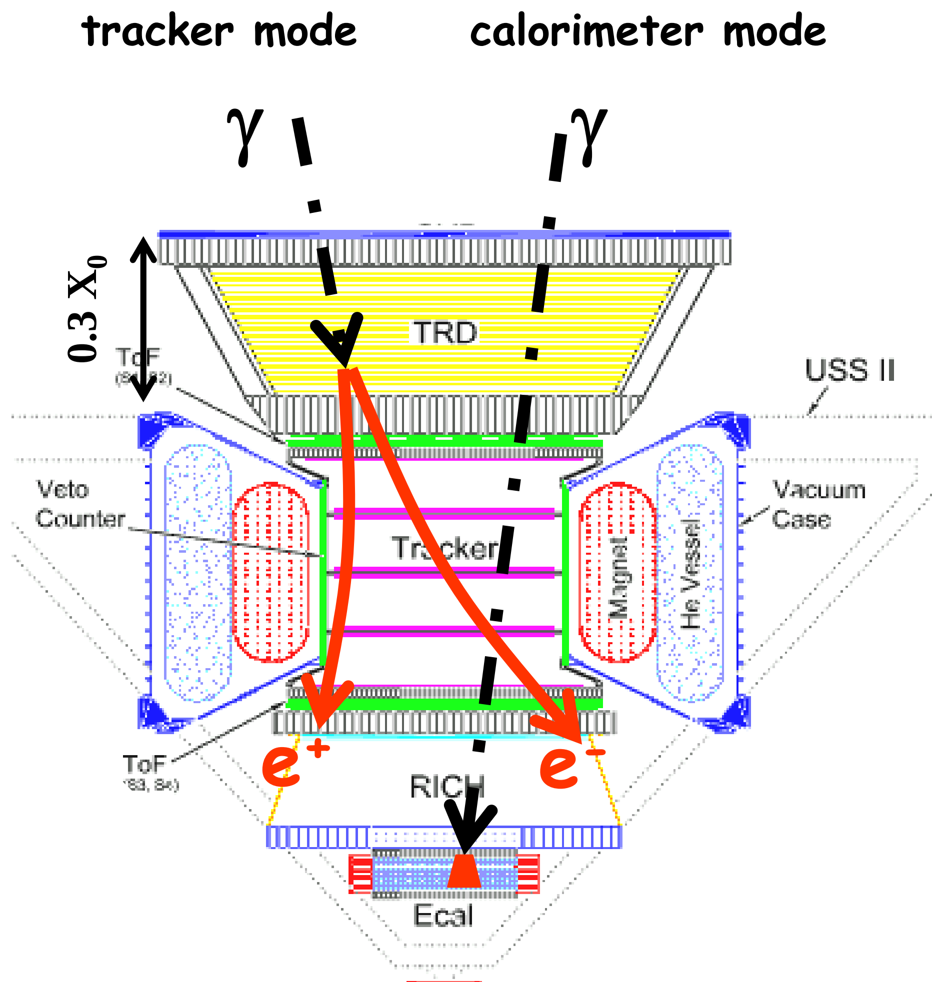
- Positron acceptance

  0.042 m².sr for E_{e+}>4 GeV

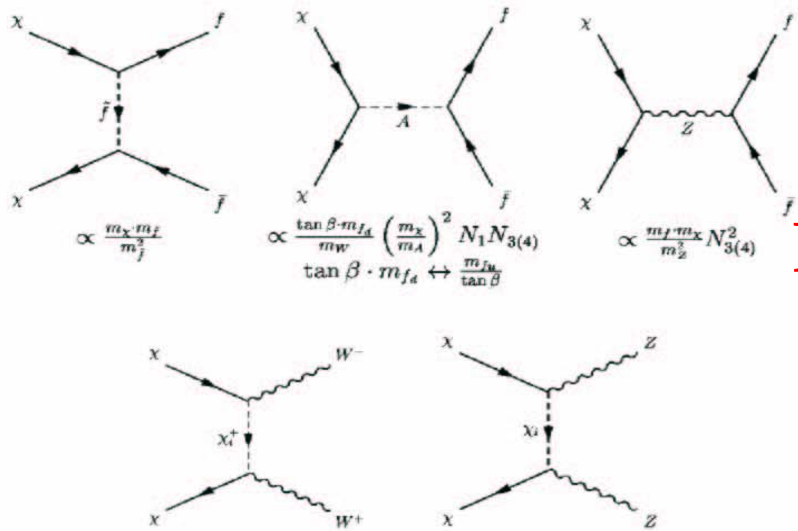
- Gamma acceptance

  - tracker mode:
    $\gamma \to e^+e^-$ in the upper sub-detector
    0.05 m².sr for [5-300] GeV

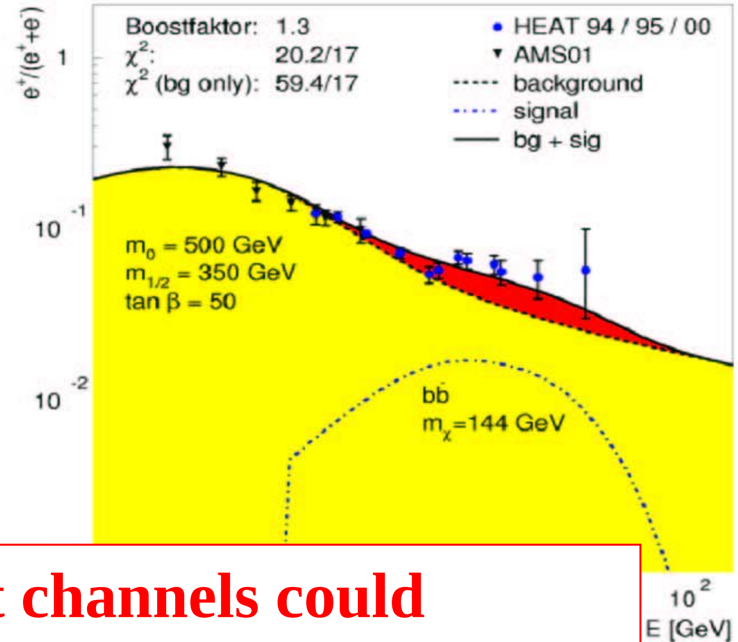
  - calorimeter mode:
    no γ conversion until ECAL
    0.08 m².sr for [10-300] GeV



~350 γ from galactic center during 1 year

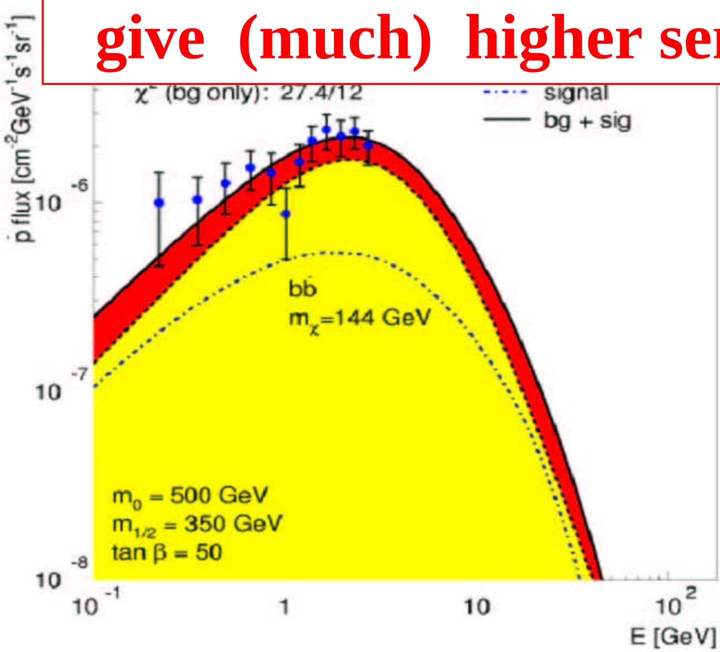


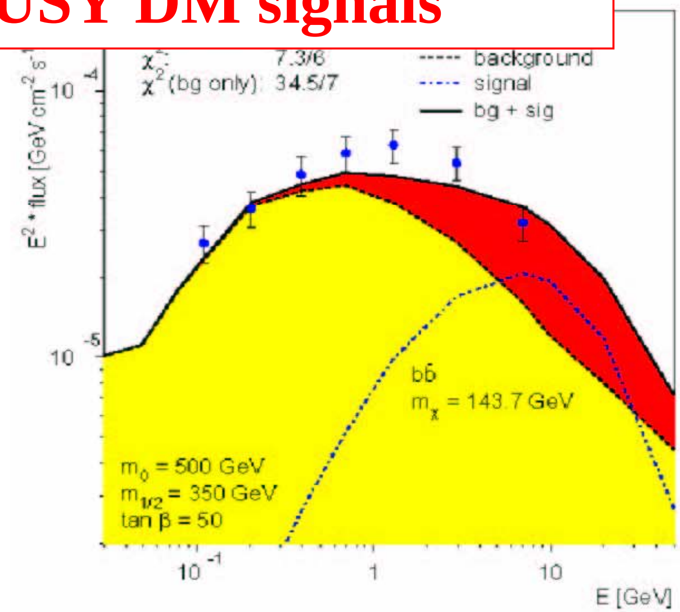
Unique Feature of AMS

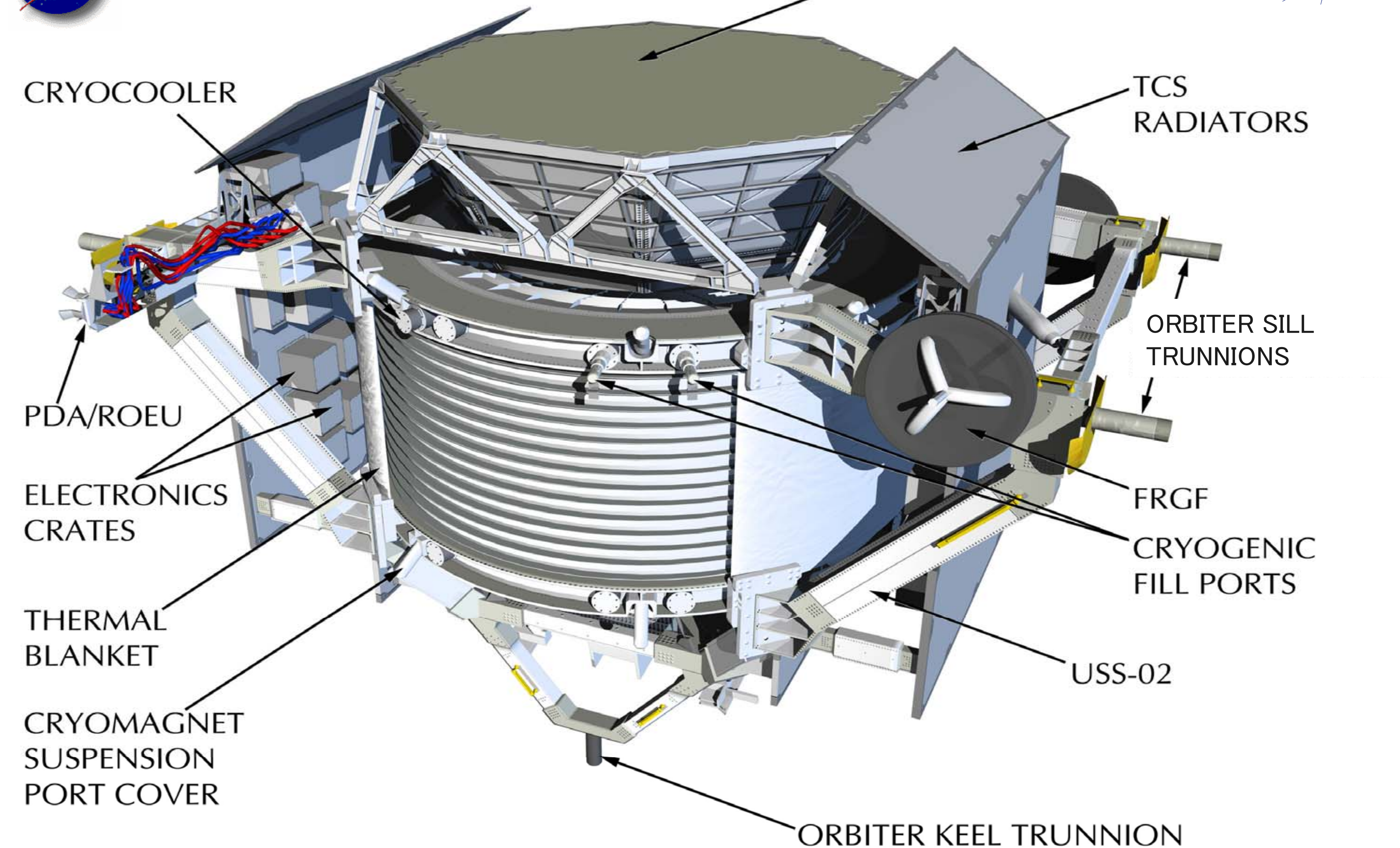


Combining searches in different channels could give (much) higher sensitiviy to SUSY DM signals

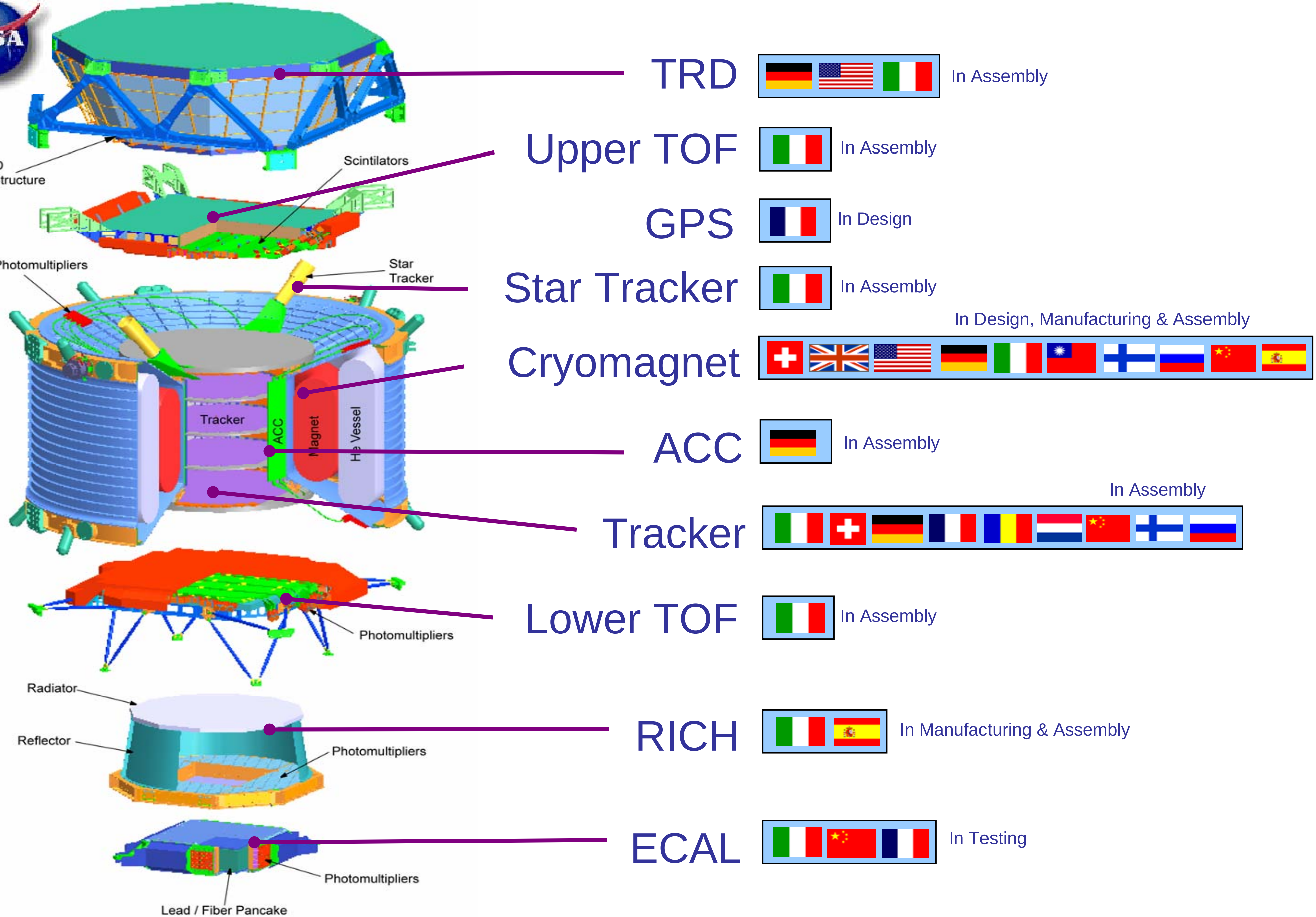
Wim de Boer et al., EPS867







TRD
CRYOCOOLER
TCS RADIATORS
ORBITER SILL TRUNNIONS
PDA/ROEU
ELECTRONICS CRATES
FRGF
CRYOGENIC FILL PORTS
THERMAL BLANKET
USS-02
CRYOMAGNET SUSPENSION PORT COVER
ORBITER KEEL TRUNNION



NASA
TRD
In Assembly
TRD M-Structure
Upper TOF
In Assembly
Scintilators
GPS
In Design
ACC Photomultipliers
Star Tracker
Star Tracker
In Assembly
In Design, Manufacturing & Assembly
Cryomagnet
Tracker
ACC
Magnet
He Vessel
ACC
In Assembly
In Assembly
Tracker
Lower TOF
In Assembly
Photomultipliers
Radiator
Reflector
Photomultipliers
RICH
In Manufacturing & Assembly
ECAL
In Testing
Photomultipliers
Lead / Fiber Pancake

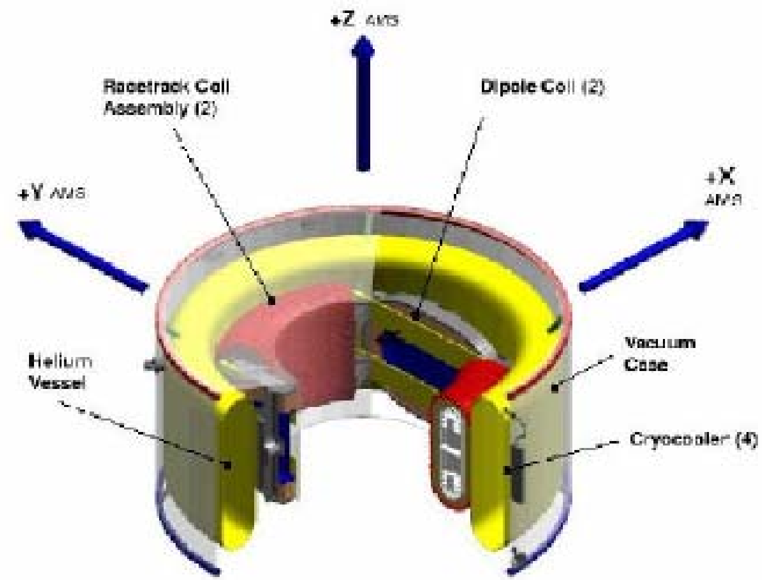
AMS-02: Superconducting Magnet

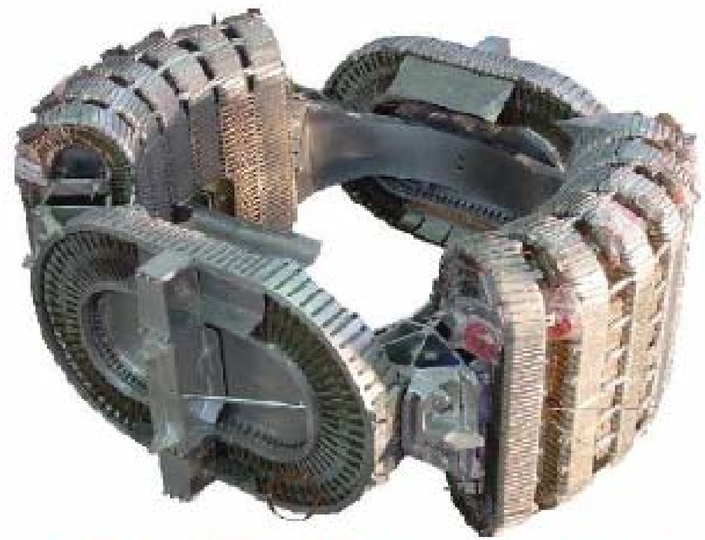
- 14 superconducting coils
- Geometrical configuration to ensure a null magnetic dipole moment
- Indirect cooling system based on superfluid helium
- Helium vessel: 2500 liters
- Dimensions: inner diameter 1.1m, weight: 2360 Kg
- an intense magnetic field: ~ 0.9 T
- a large bending power: ~ 0.8 T.m^2

▷ All coils are produced, tested individually at 1.8 K and assembled

▷ Vacuum vessel is completed

▷ Magnet delivered to CERN where the integration will start in 2006



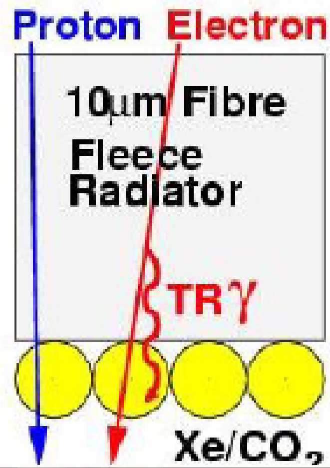


R.H. MacMahon he-24

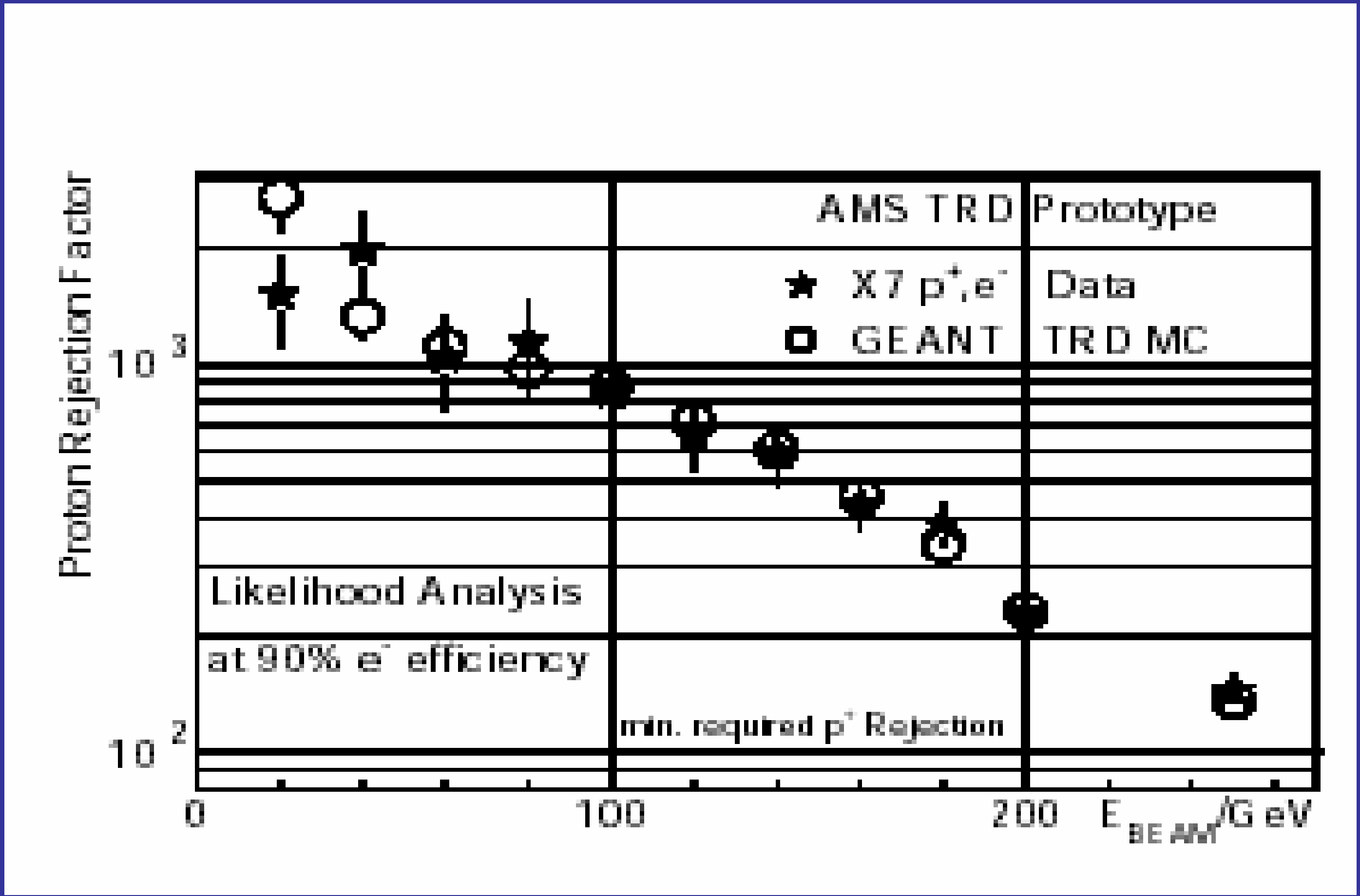
AMS-02: Transition Radiation Detector

- Modules (328) made of fleece radiator and straw tubes
  - $E_\gamma \sim \gamma$(eV)
  - Emission probability small (10^{-2}) $N_\gamma \sim \alpha N_{transitions}$
  - TRD photons detected in proportional straw tubes Xe/CO_2
- 20 layers assembled in an octogonal shape structure
- Separation of e^-/e^+ from $\bar{p}/p$ up to 300 GeV

▷ All modules produced
▷ 14 layers with 220 modules inserted in supporting structure
▷ Detector finished in Spring 2006



TRD Performances



20 layer prototype tested with e^-, μ^-, π^+, p^+

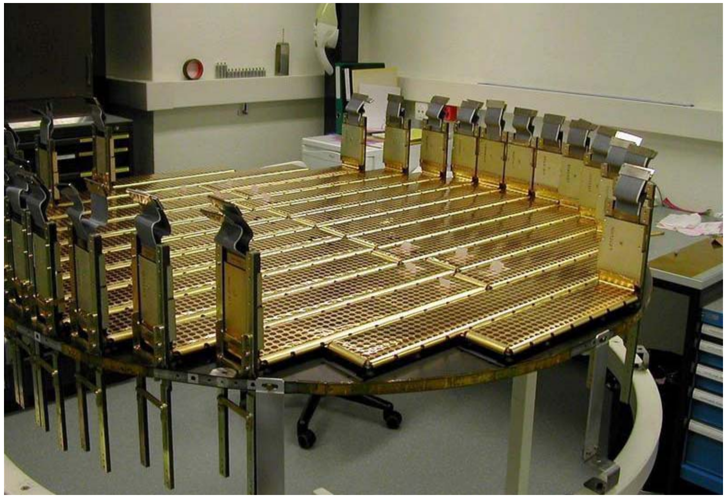
Proton rejection $>10^2$

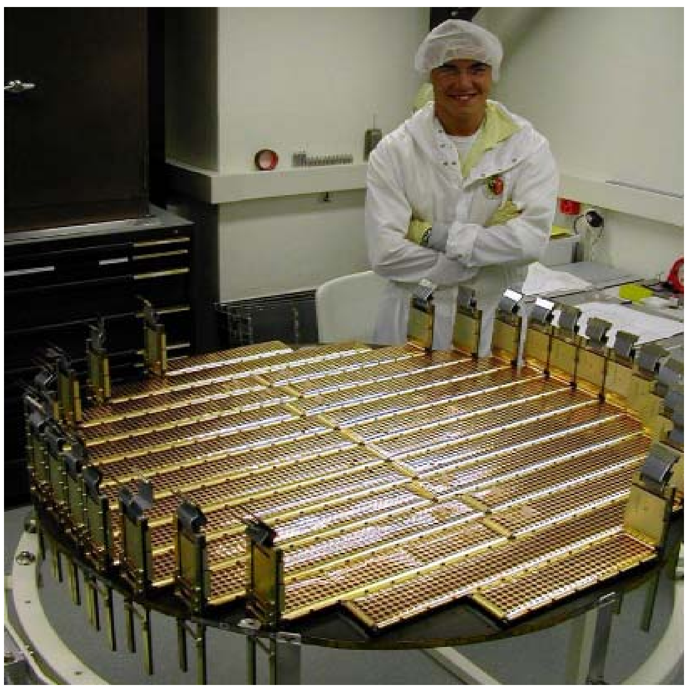
reached up to 250GeV with 90% electron efficiency

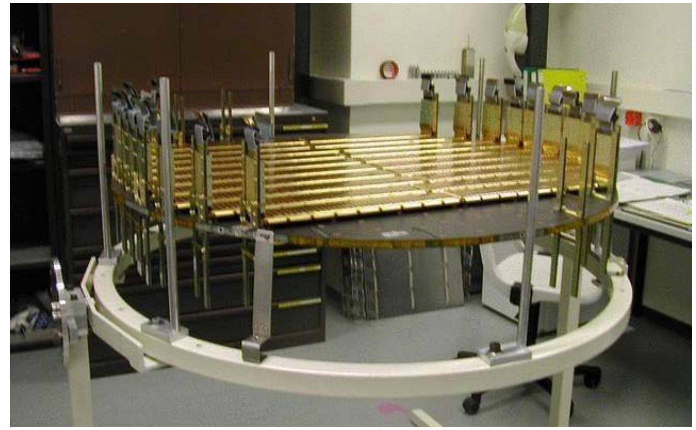
Silicon Tracker

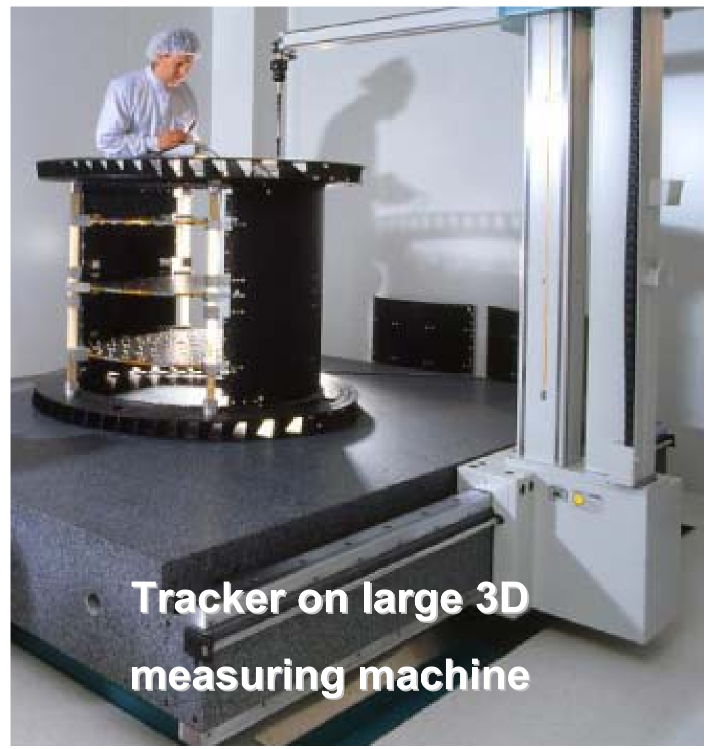
All 8 planes, 300,000 channels have been produced

Coordinator: R.Battiston

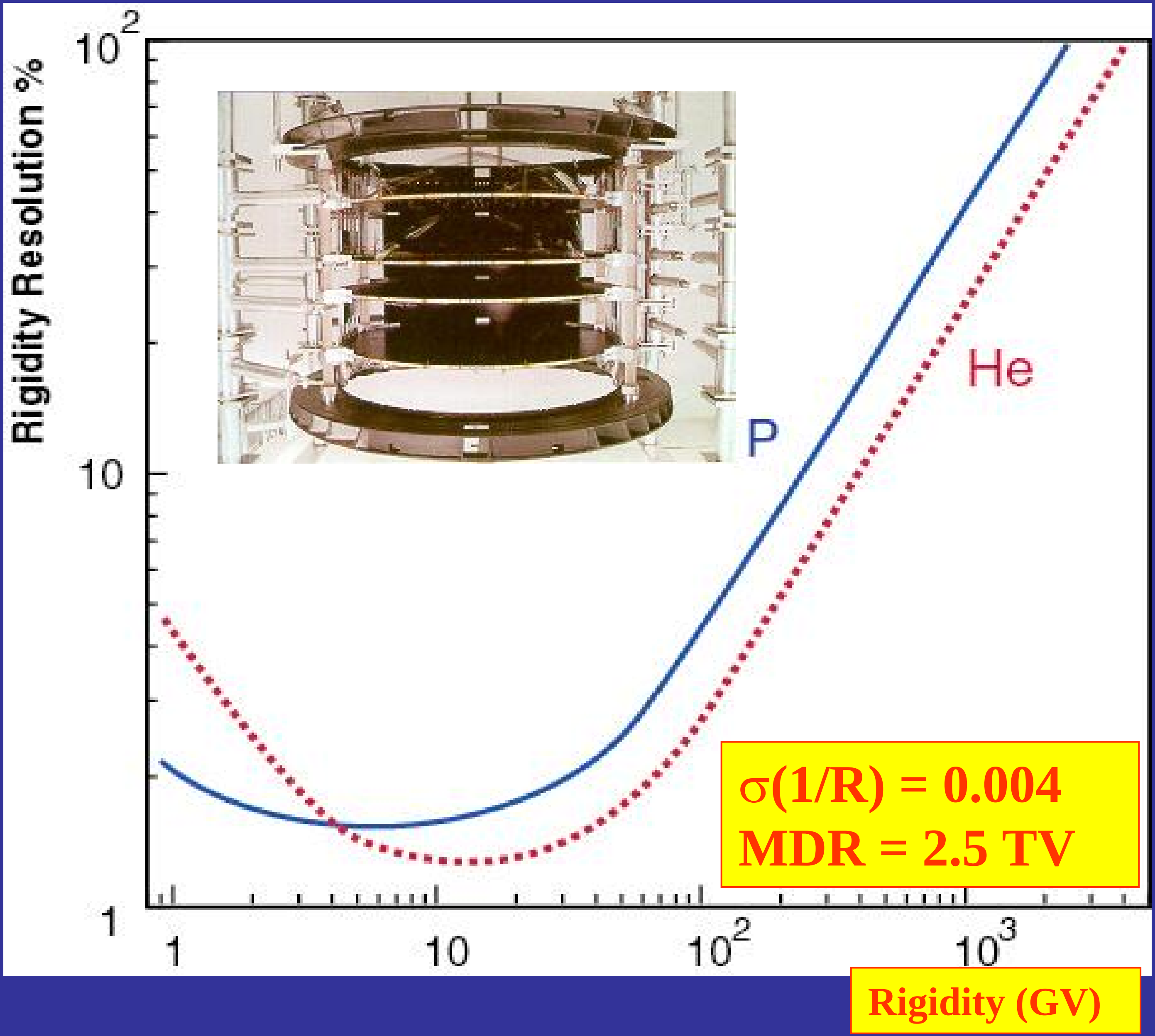






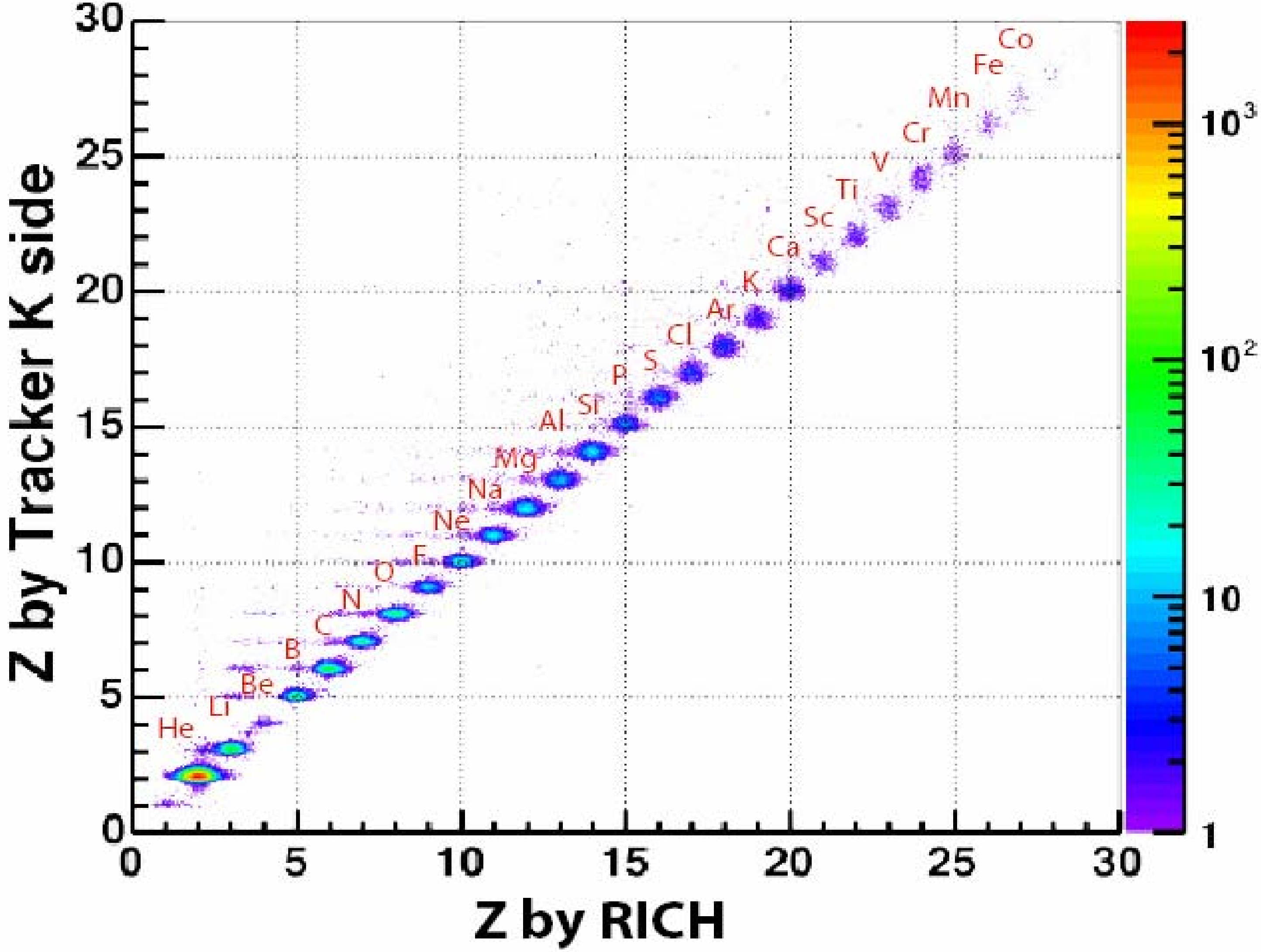


AMS-02 Silicon Spectrometer Rigidity Resolution/



Accurate measurement of cosmic radiation for all atomic nuclei

Test results from accelerator using both RICH and Tracker 158 GeV/N

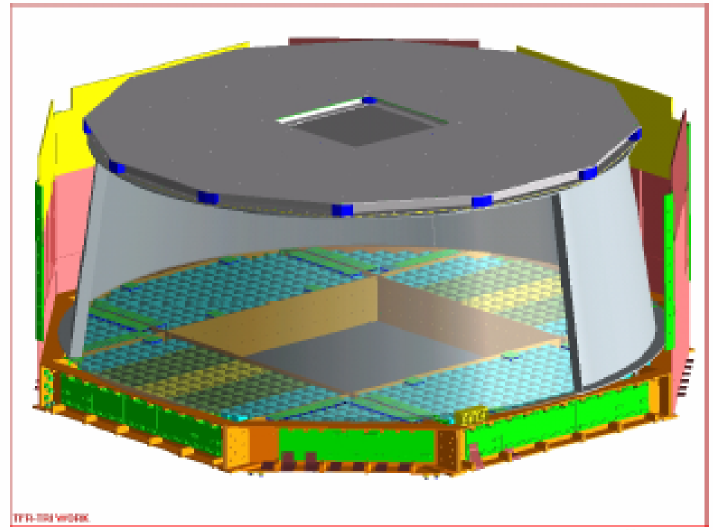


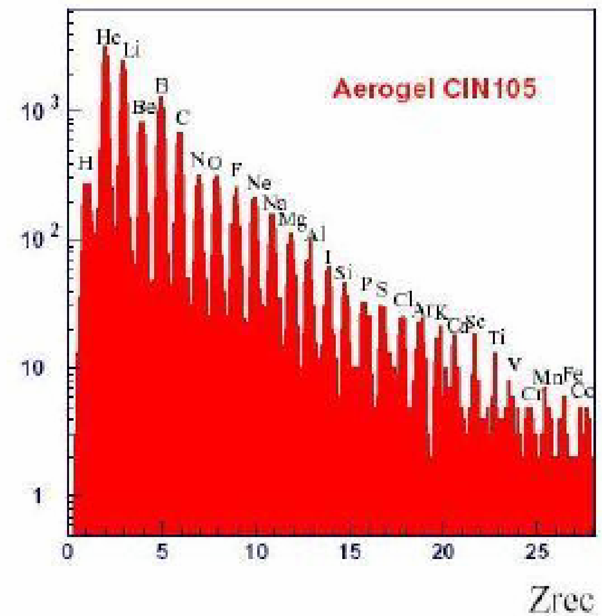
y04K335c TKvsR.ai

AMS-02: Ring Imaging Cherenkov Detector

- Proximity focusing Ring Imaging Detector
- 2 different radiators:
  Aerogel, n=1.05, 2.7 cm thickness
  Sodium fluoride, n=1.336, 0.5 cm thickness
- Conical reflector
- Photomultiplier matrix (680)
- velocity measurement from emission angle
  $\Delta\beta/\beta \sim 0.1\%$ for single charge particles
- Number of photo-electrons measures Z
  ΔZ $\simeq$0.2-0.25 up to Fe
- directional sensitivity

▷ RICH is currently being assembled
▷ will be integrated in AMS in June 2006

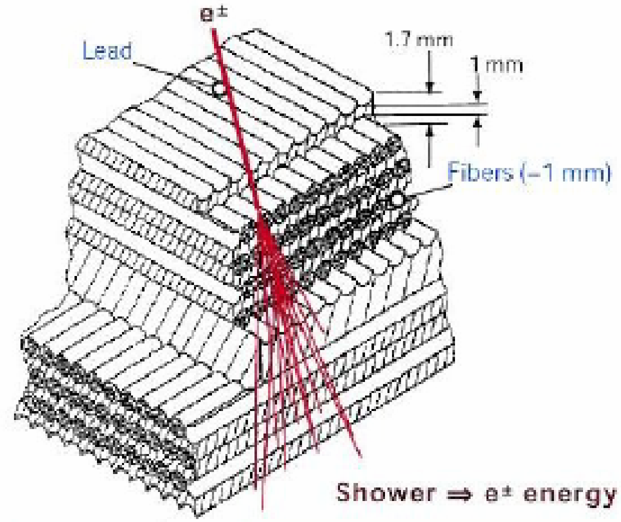


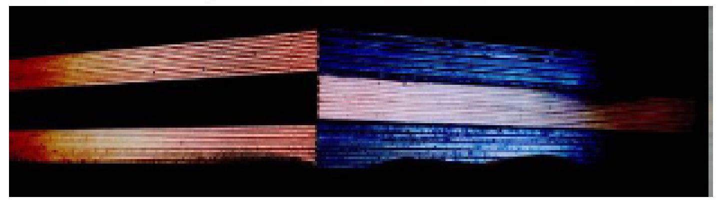


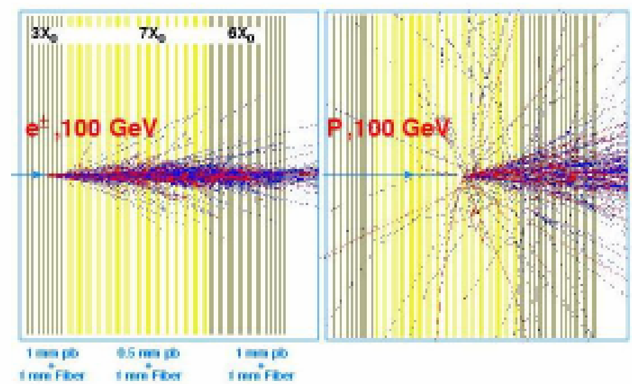
F. Barao og-15

AMS-02: Electromagnetic Calorimeter

- Lead scintillating fiber sandwich (640 kg), 3D sampling by crossed layer
- $\sim 17X_o$ radiation lenghts
- 9 superlayers piled up disposed along Y and X alternately
- Energy resolution (GeV) $\Delta E/E \simeq 10.1\%/\sqrt{E} \oplus 2.6\%$
- Distinction between hadrons and e/γ by shower shape
- Protons supressed by 10^{-4} up to 500 GeV. Together with TRD, rejection of hadrons/electrons $\geq 10^6$
- Independent γ detector, angular resolution $\sim 2^\circ$, γ independently triggered







J. Pochon he-24

▷ All superlayers installed in mechanical structure

▷ Final calibration in e^- test beam in 2006

Conclusions

- Cosmic Rays carry important informations about the non thermal universe
- AMS-02 has been designed to measure with ppb accuracy primary CR composition up the TeV region
- These accurate measurements will allow to undertand propagation and confinement mechanisms in our Galaxy
- The study of the rare components would allow to search for new phenomena (Dark Matter, strangelets) or to better constrain fundamental issues like the existence of primordial antimatter

Addressing fundamental questions aiming for a breakthrough

Accelerator	Original purpose	Discovery
AGS Brookhaven (1960)	π N interactions	2 kinds of neutrinos, Breakdown of time reversal symmetry, 4-th Quark
FNAL Batavia (1970)	neutrino physics	5-th Quark, 6-th Quark
SLAC Spear (1970)	ep, QED	Partons, 4-th Quark, 3rd electron
PETRA Hamburg (1980)	6-th Quark	Gluons
Super Kamiokande (2000)	Proton Decay	Neutrino Oscillation
Hubble Space Telescope	Galactic Survey	Curvature of the universe
AMS on ISS	Dark Matter Antimatter	?