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Rare Components in Cosmic Rays with AMS-02

TAUP Sendai Sep.07

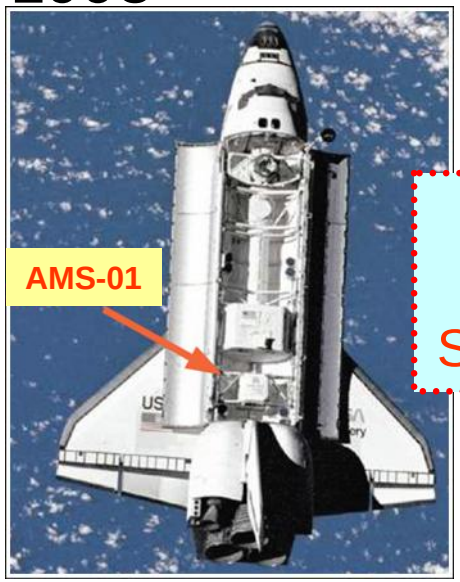
Andreas Sabellek

IEKP - Universität Karlsruhe (TH)

for the AMS Collaboration

The AMS Project: History and Future

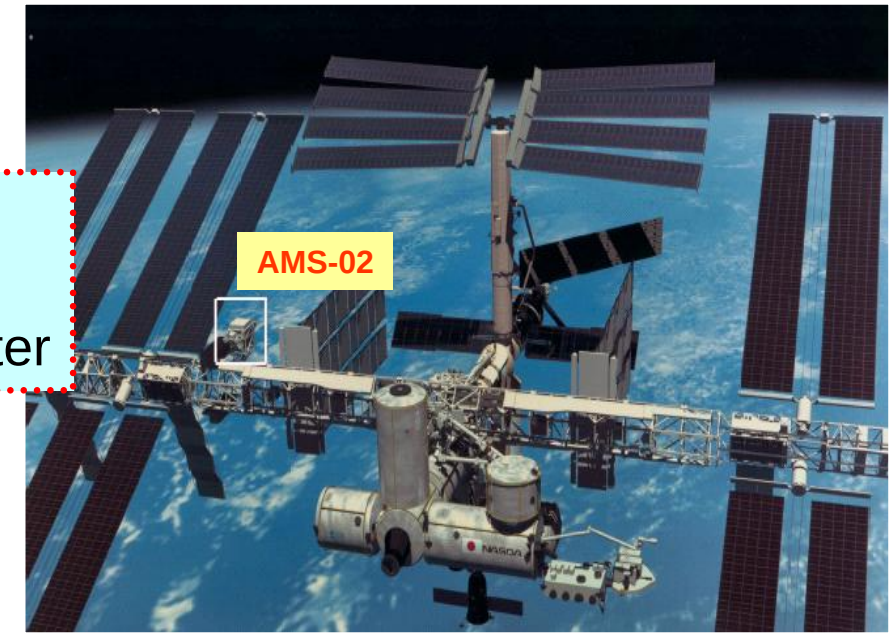
1998



10 days Precursor Flight on board the Space Shuttle Discovery

Alpha Magnetic Spectrometer

2008 again ready for launch



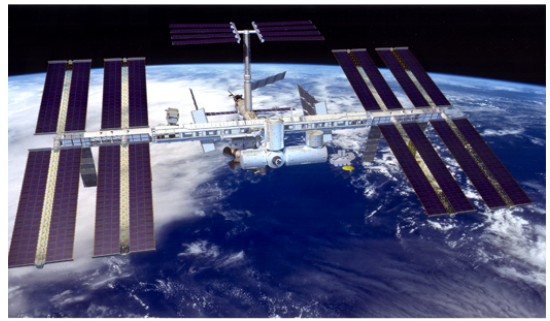
3 years on the International Space Station ISS with 1000-times higher statistics measurement

Spectra of primary and secondary p,e and He

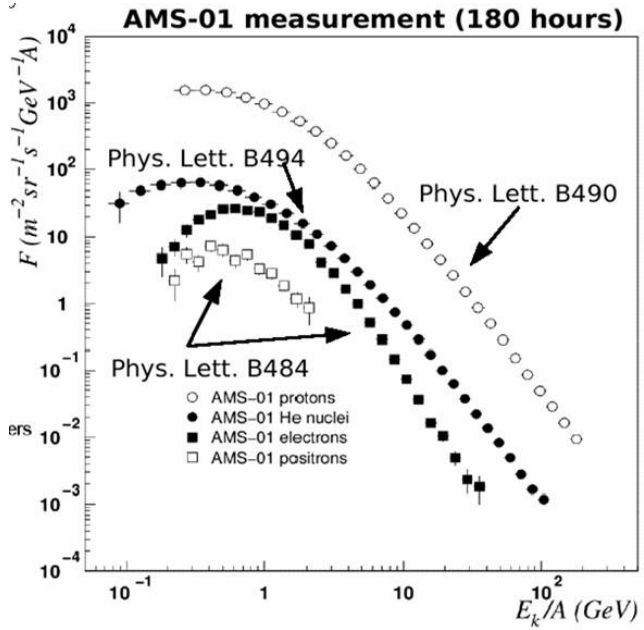
M. Aguilar et al., Physics Reports, vol. 366/6 (Aug.2002), pp.331-404

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

Outline

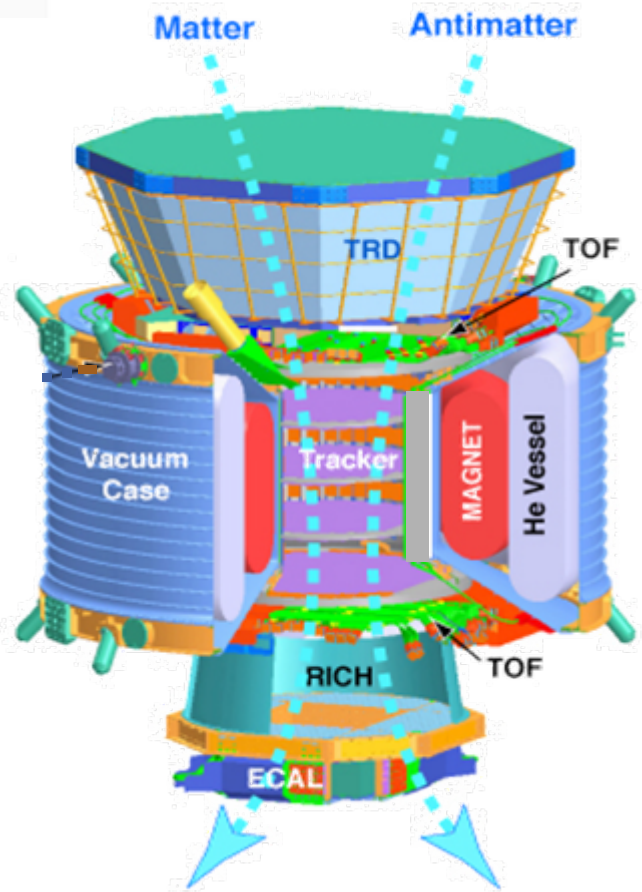


- AMS-02 Experiment on board the ISS
- Science with AMS-02 and Achievement Potential
  - "Standard Cosmology": Cosmic Ray Spectra and Composition
  - Gamma ray astrophysics
  - Indirect Dark Matter Search
  - Direct Search for Antimatter (a heavy Anti-nuceus)
  - Search or Exotic Matter: Strangelets, …
- 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 paticle identification

The AMS-02 Detector



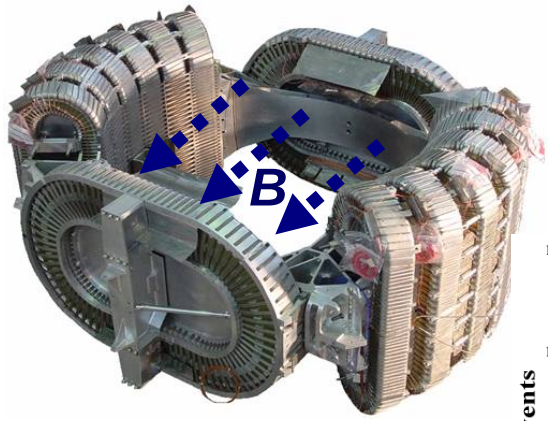
Dimensions: 7 tons and 3x3x3.5 m^3
Acceptance: 0.5m^2sr
Lifetime (cryomagnet): min 3 years

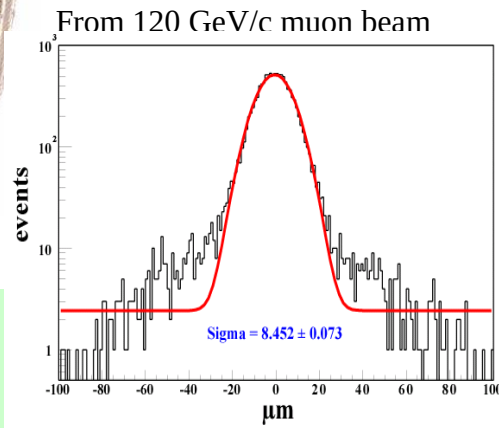
0.3 TeV	e^-	P	He	C	Fe	γ
TRD						
TOF						
Tracker (magnet on)						
RICH						
Calorimeter						

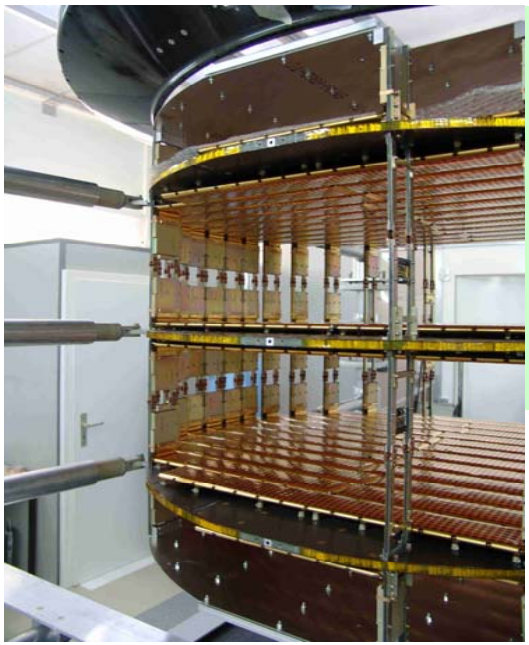
Redundant measurement in different subdetectors to gain precision

Flight Subdetector Hardware

Superconducting Magnet:
Field 0.86 Tesla; 5.2 MJ stored
NbTi/Copper conductor I~460A;
Cooled to 1.8K by 2500l
Superfluid Helium

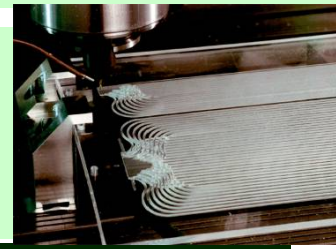




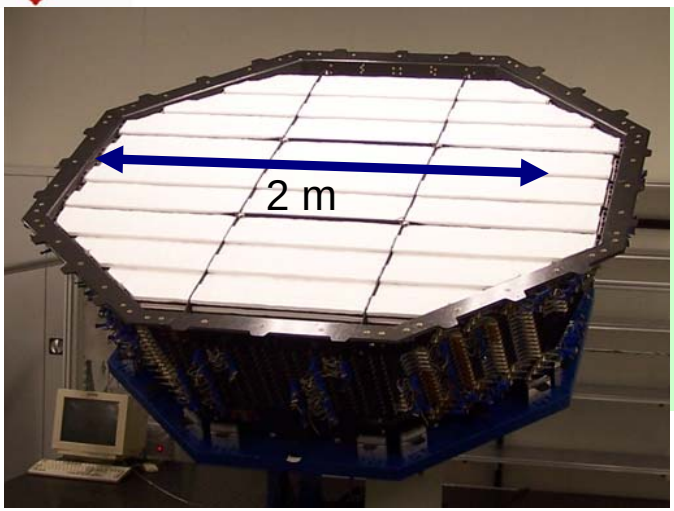


8 Plane **Silicon Tracker**:
200,000 channels on 6.6m^2 strips
Resolution σ=30μm and 10μm in bending direction
- Rigidity measurement up to few TeV
- Particle identification by dE/dx ~Z^2
- Measurement of gammes in conversion mode

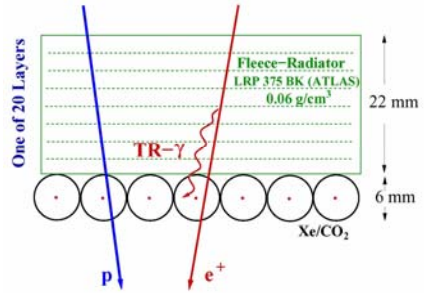
Anticoincidence counters:
16 cylindrical shell paddels of plastic scintillator for veto

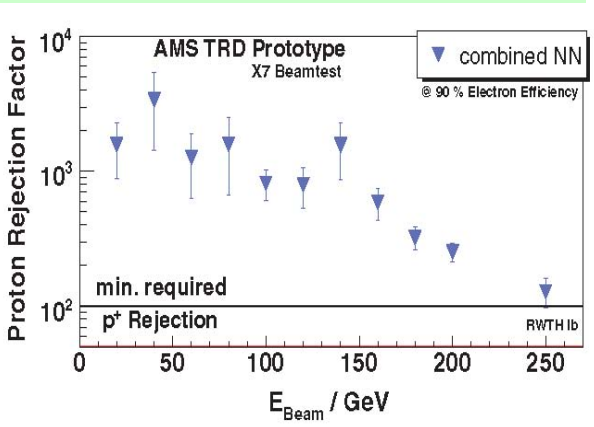


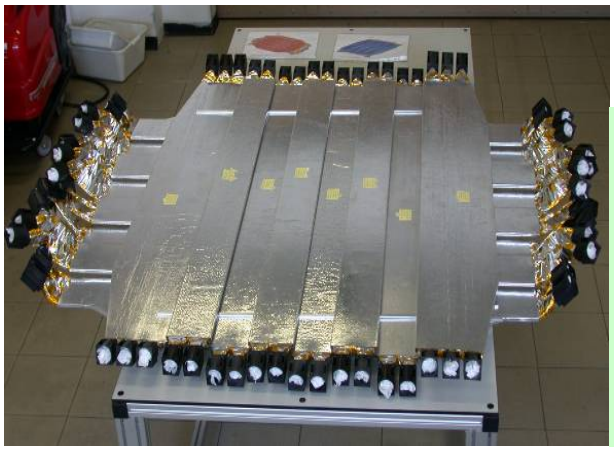
Flight Subdetector Hardware



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



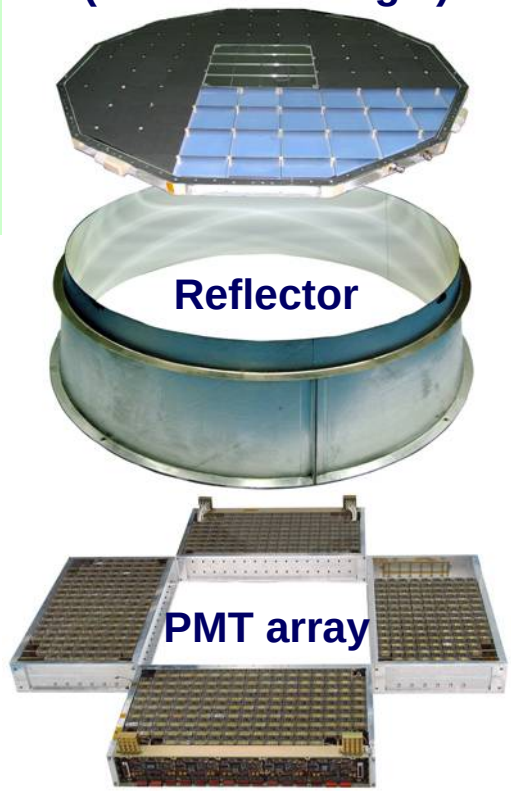




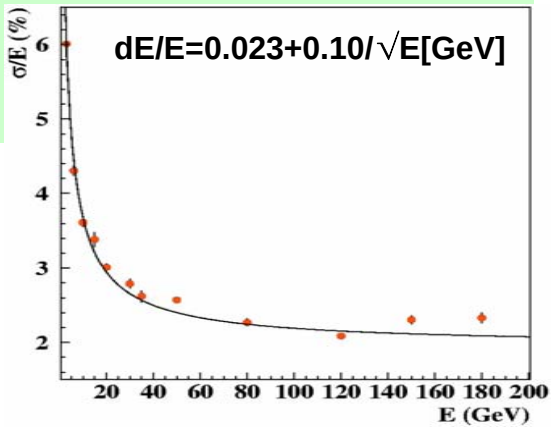
Time of Flight:
2x2 scintillator planes as primary trigger
Resolution t<130ps
- Velocity measurement $d\beta/\beta$~3%
- dE/dx measurement

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 $Z=26$ ($N\gamma \sim Z^2$)



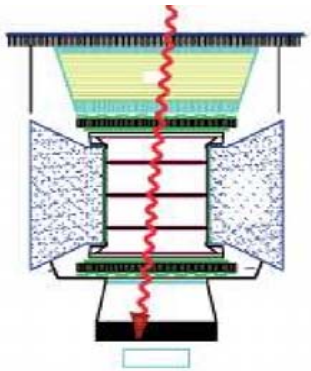
Electromagnetic Calorimeter:
18 planes (640kg) of Pb with scintillator fiber inserts; thickness $16X_0$ /.$5\lambda_h$
e/p separation ~1000 to 1Tev



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

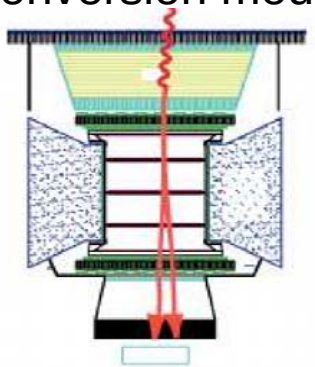
Photon Detection with AMS-02

Single photon mode



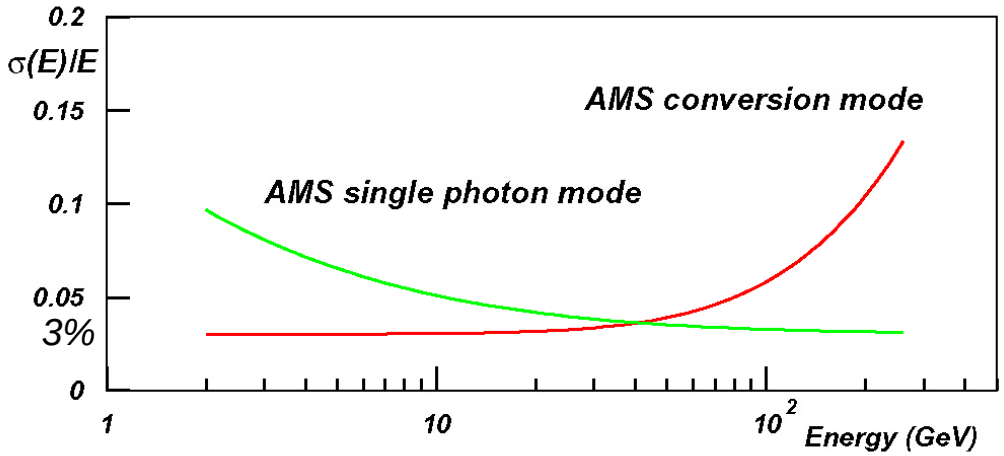
γ→EM Shower

Conversion mode

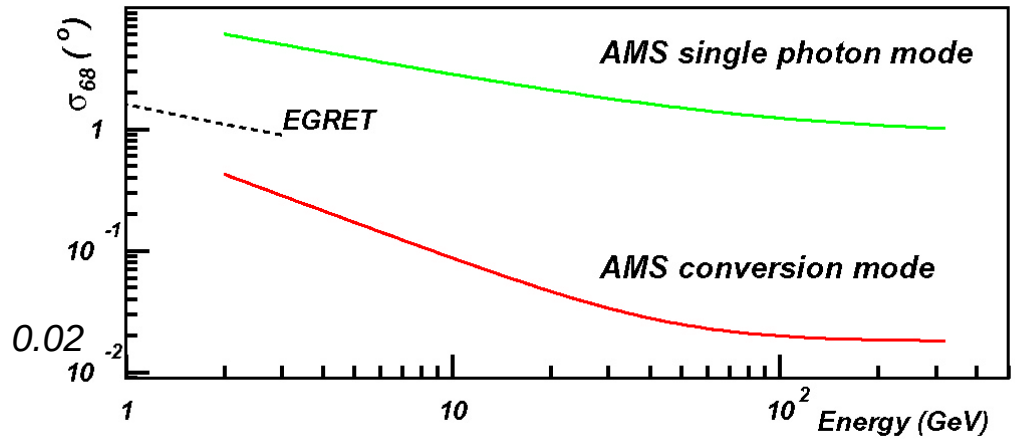


$\gamma \rightarrow e^+/e^-$-pair

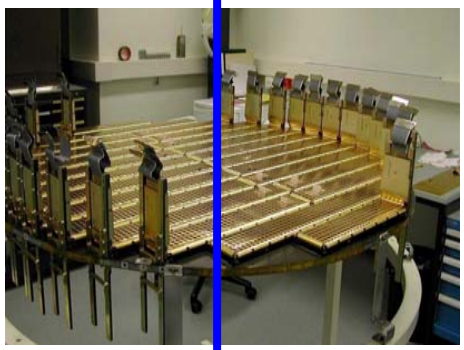
Energy resolution (100GeV) ~3%



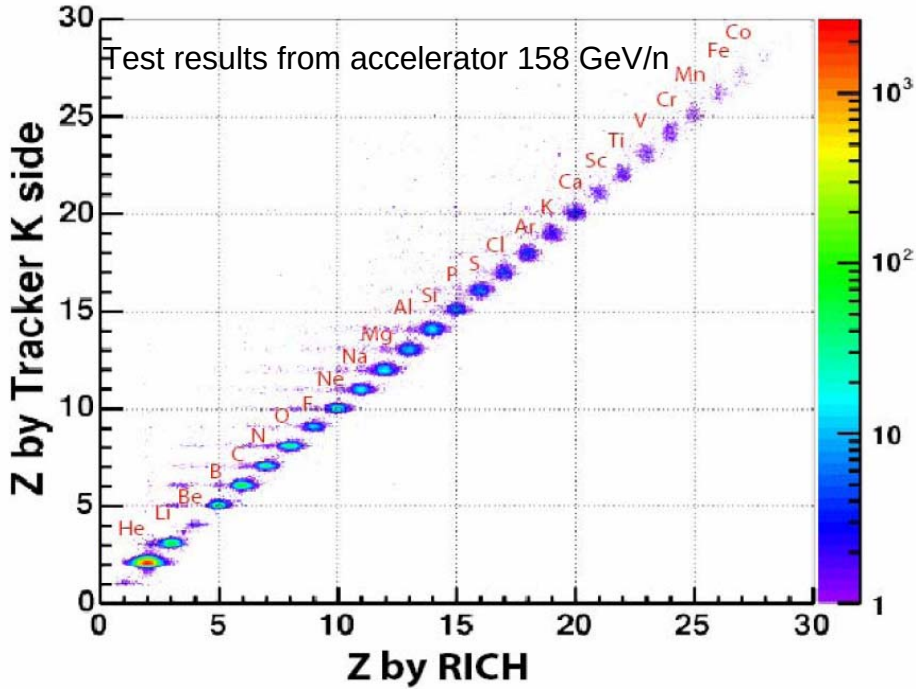
Angular resolution (100GeV) ~0.02°



Chemical Composition Measurement

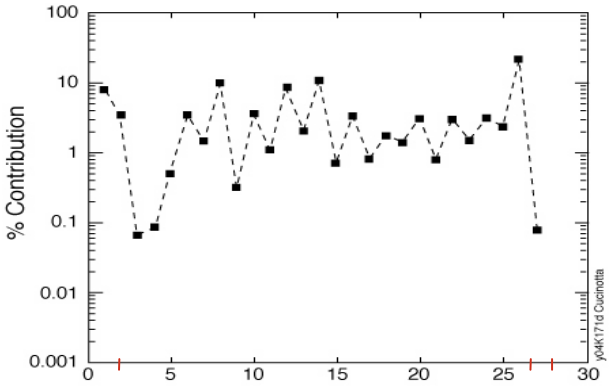


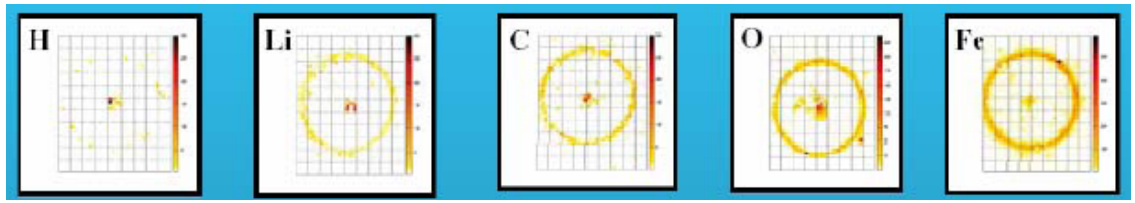
$dE/dx \sim Z^2$



$N\gamma \sim Z^2$

Abundance of cosmic nuclei

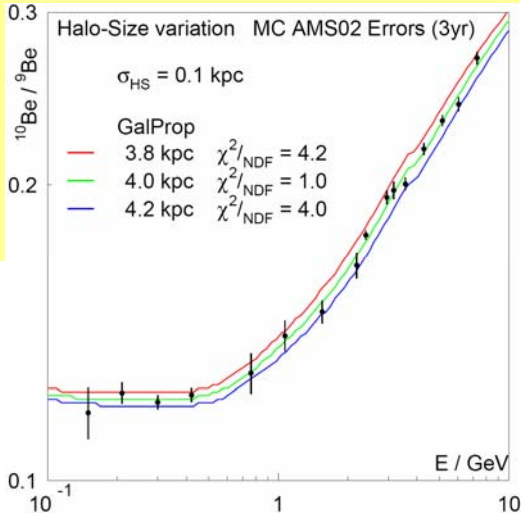


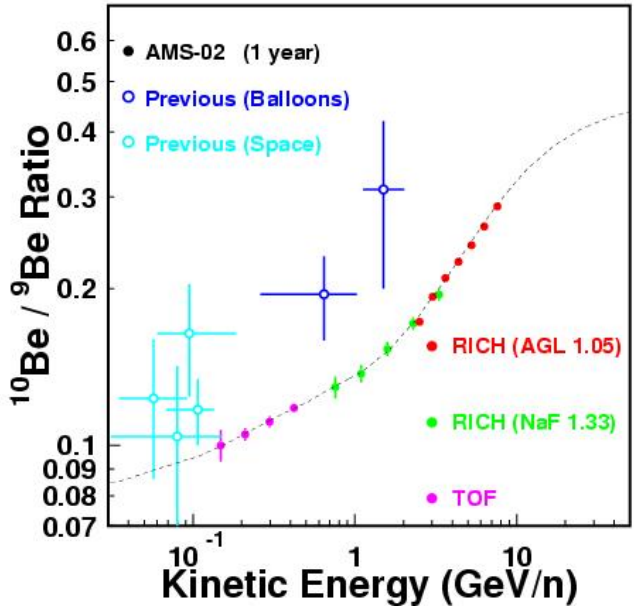


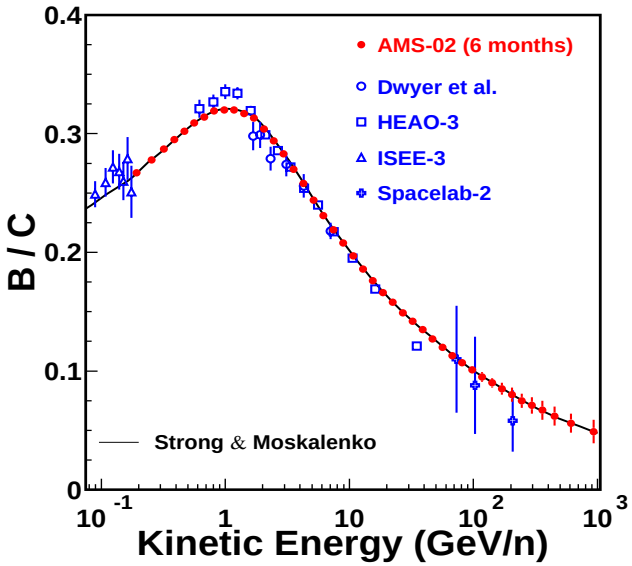
Cosmic spectra with 1% accuracy from Helium to Cobalt

Precision Study of Cosmic Rays – Radioactive Isotopes

- AMS-02 will collect 10^5 ^{10}Be isotopes in 3 years
- Half-life of ^{10}Be in the order of confinement time
- Information about
  - Confinement time
  - Galactic halo size



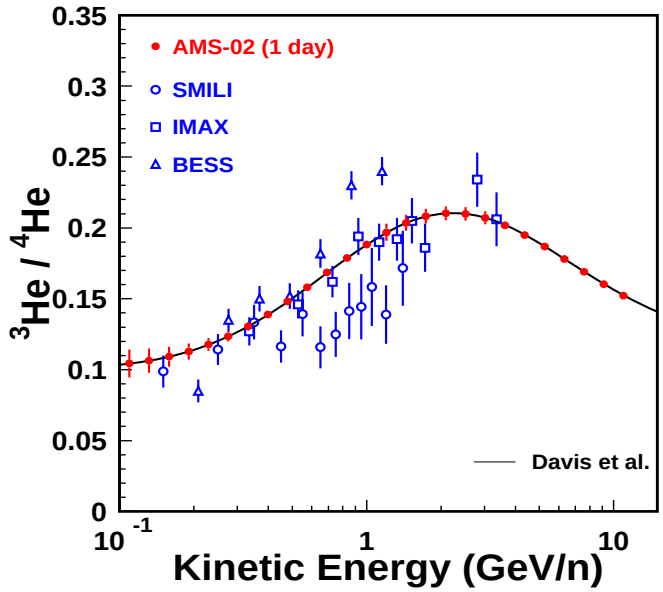


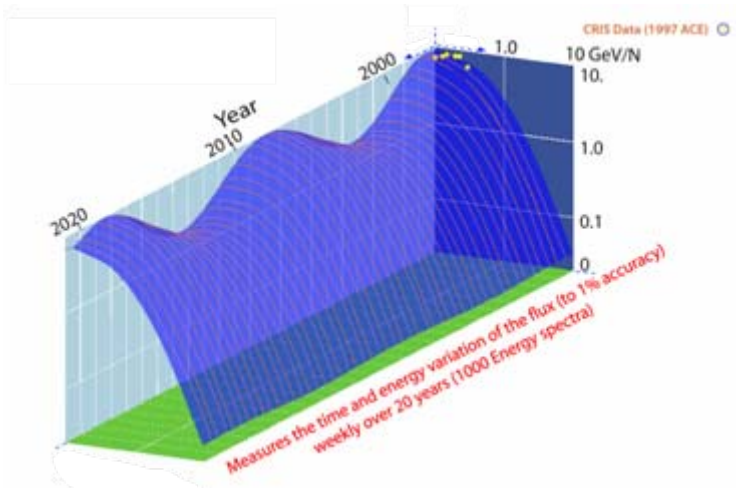


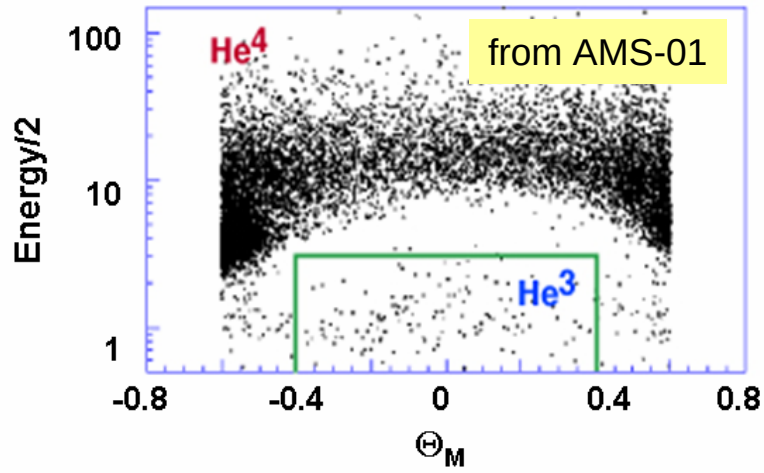
- … and collect 10^5 C and 10^4 B to measure the ratio of Carbon to its spallation secondary Boron up to 1TeV/n
- Information about
  - Amount of matter traversed
  - Diffusion (to understand propagation and to fix free parameters of models)

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)

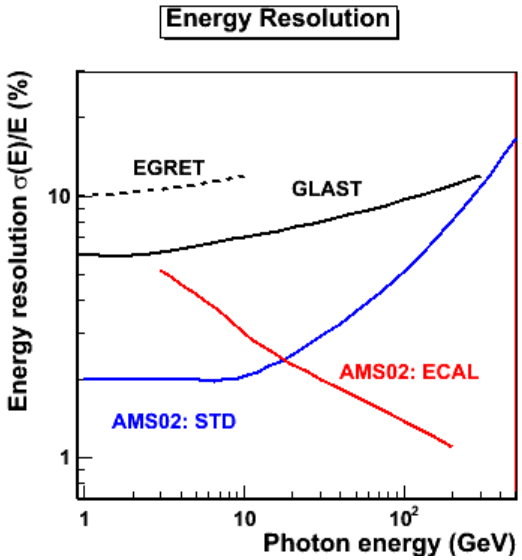


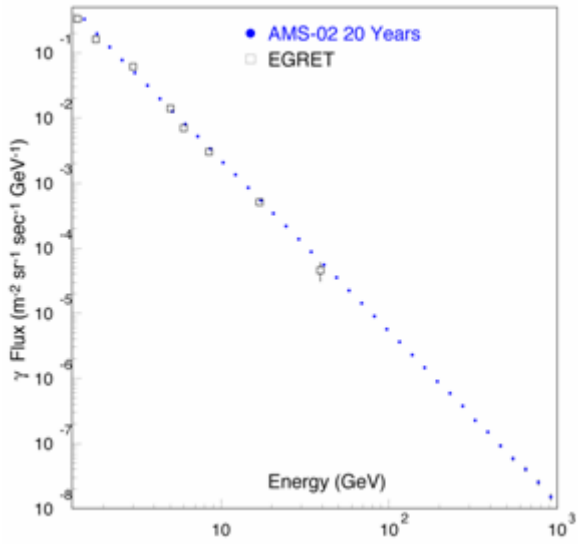


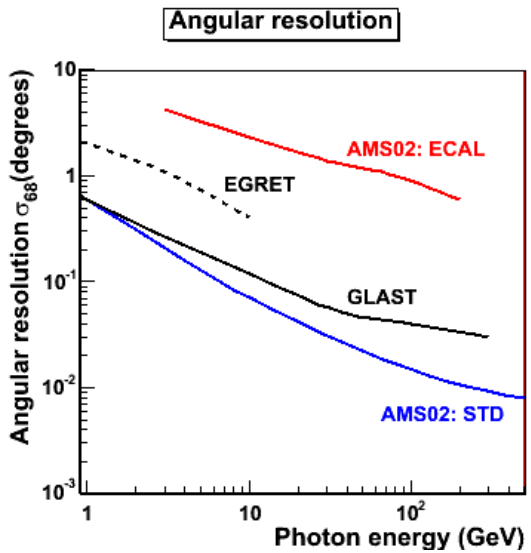


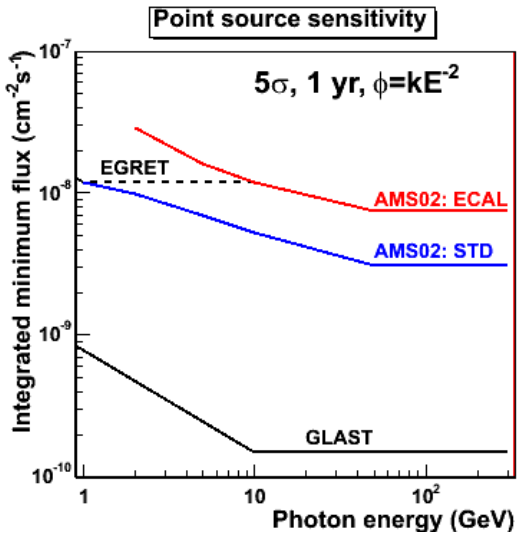
Diffuse Gamma Rays and Sky Survey

- 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









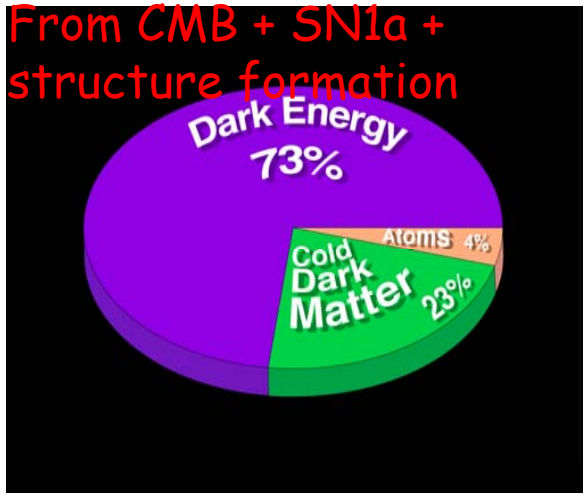
Probe the Unknown

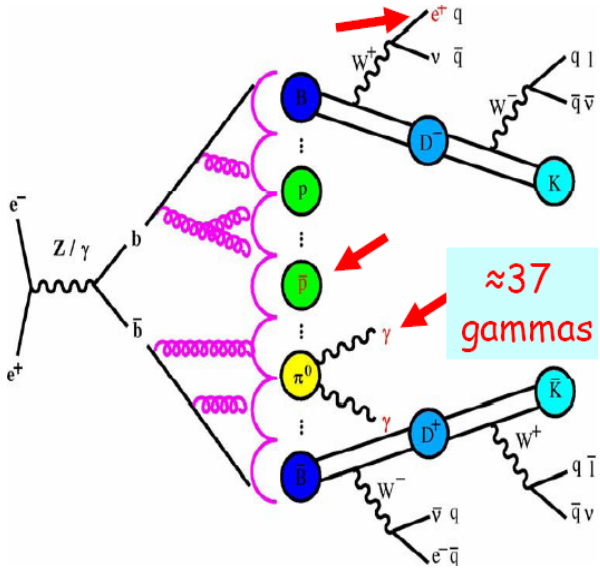
- Dark Energy ~73%
- Matter ~27%
  - ~4.4% Barions (~0.5% Stars)
  - **23% Cold Dark Matter**

- 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

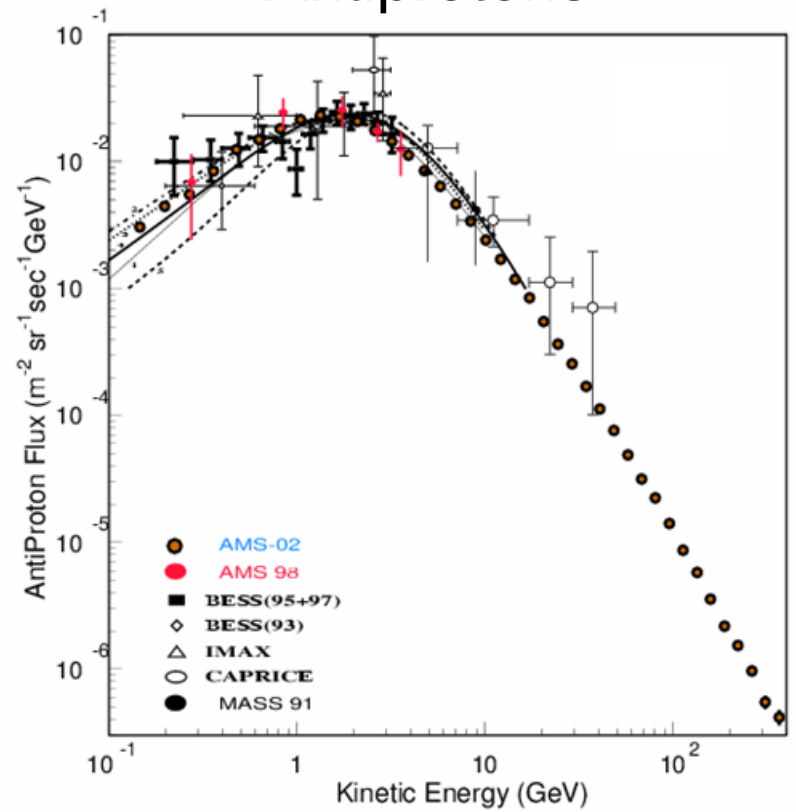
  $\chi + \chi \rightarrow$ $b\bar{b}$ quark pair production in annihilation, its decay then is well known from accelerator experiments



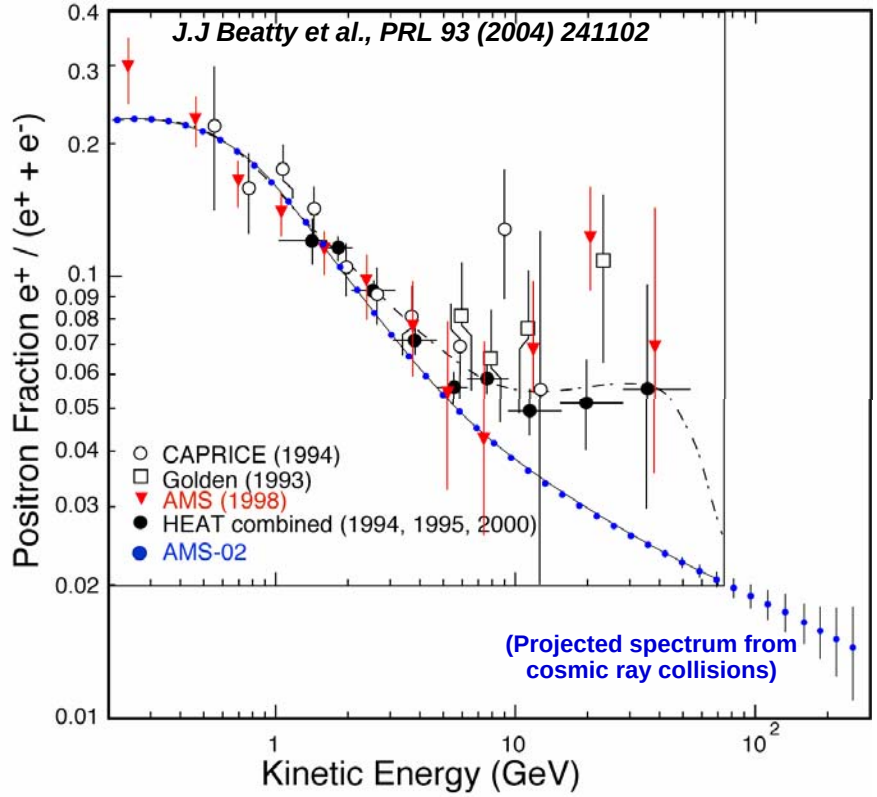


Search for Cold Dark Matter Annihilation

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.

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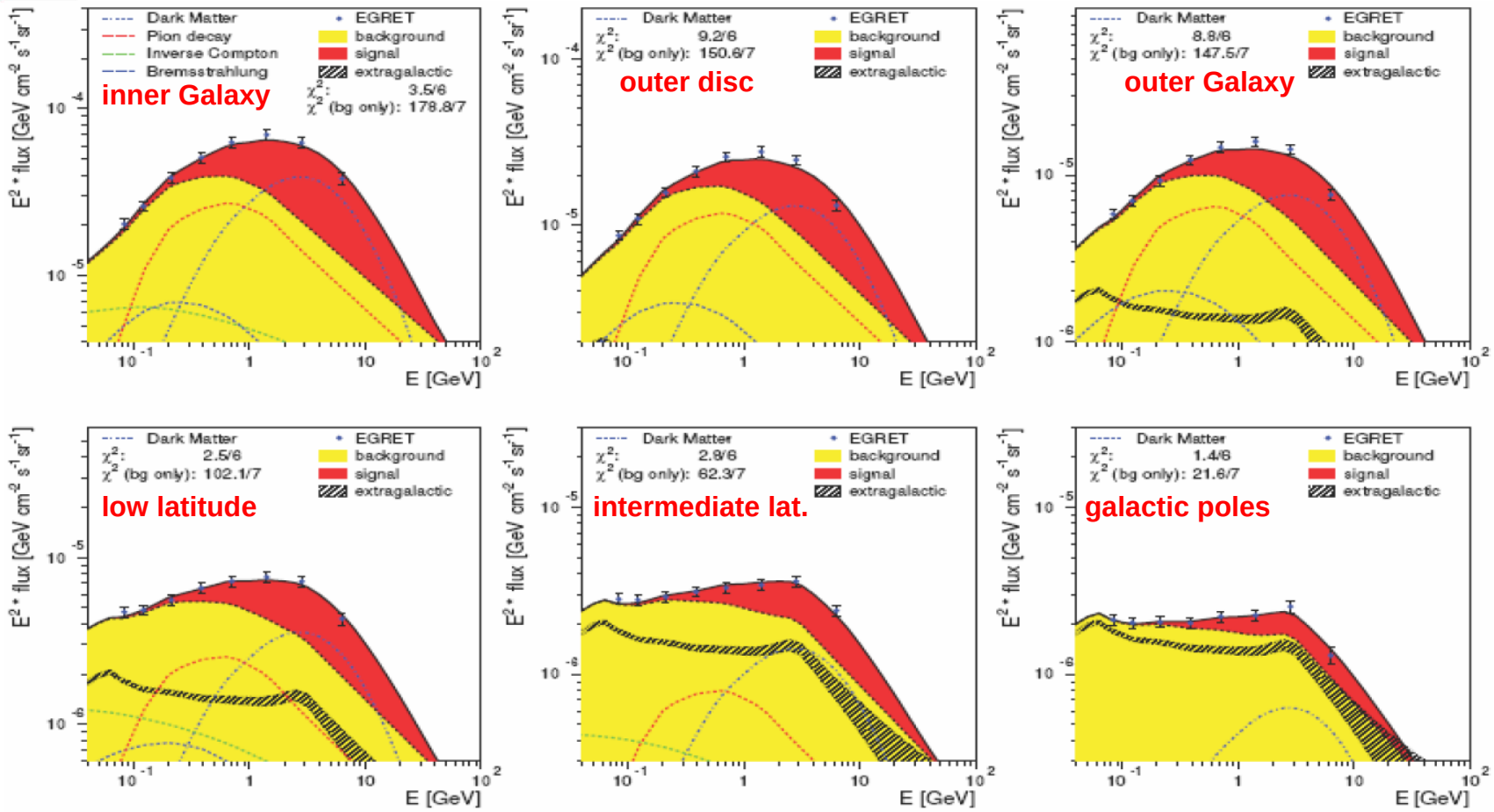

3 components gamma spectrum: galactic background + extragalactic bg + DM annihilation fitted simultaneously with same WIMP mass in all directions.

Dark Matter Ring Interpretation

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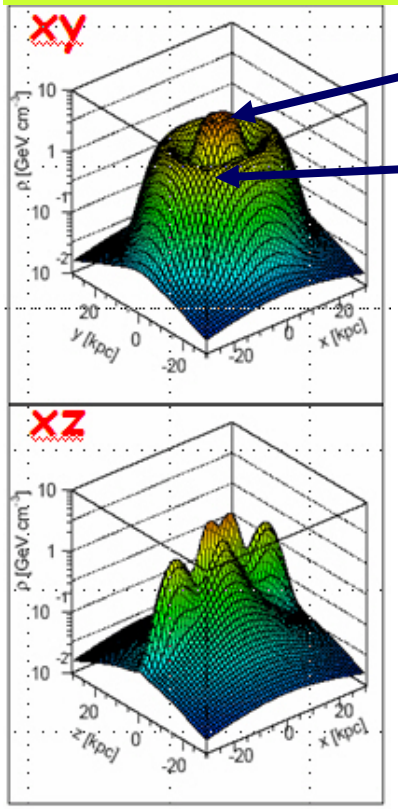
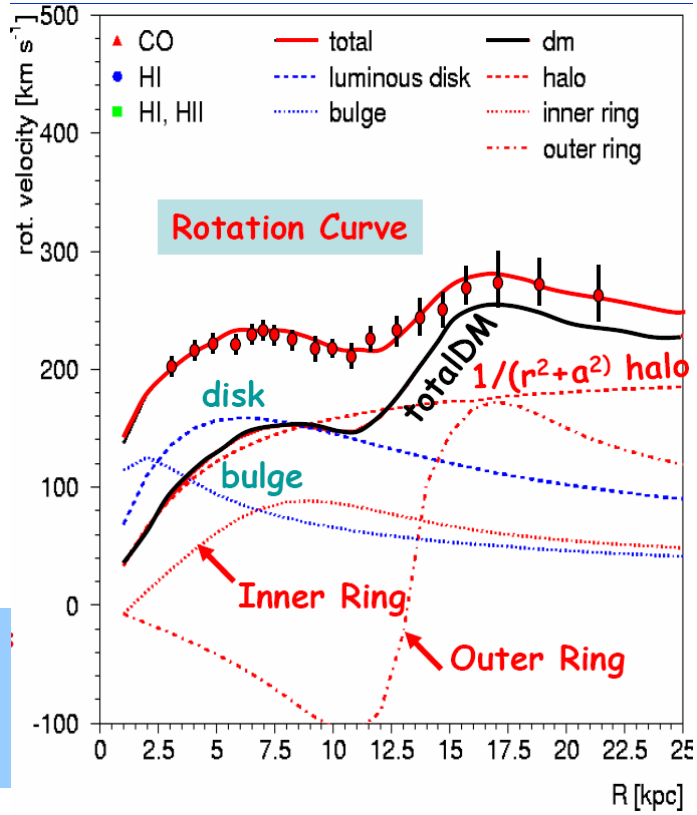
Fit in 180 directions implies substructure in the galactic distribution. Observed rotation curve of our galaxy then can be very well explained with obtained dark matter profile.



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

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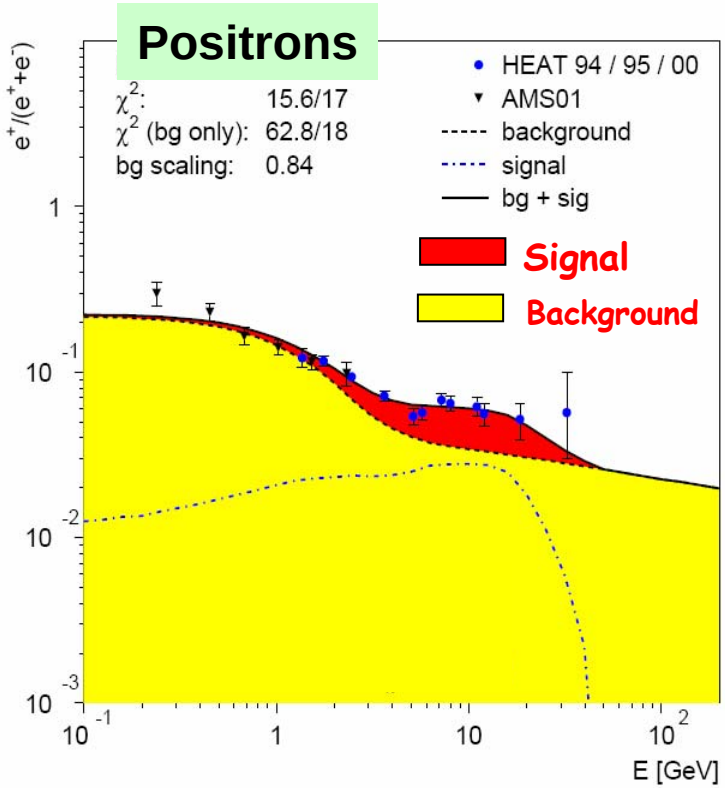
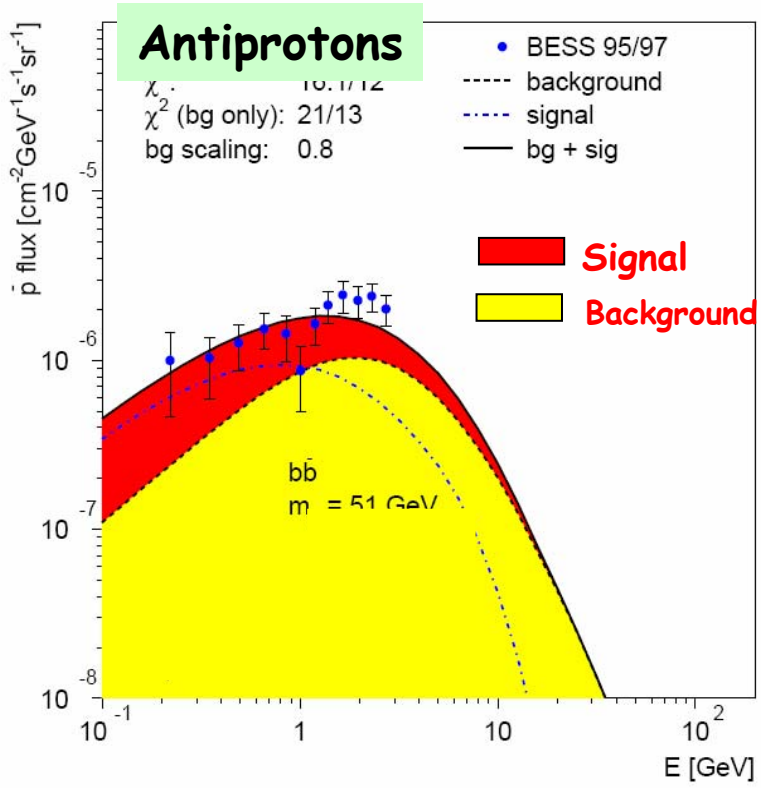
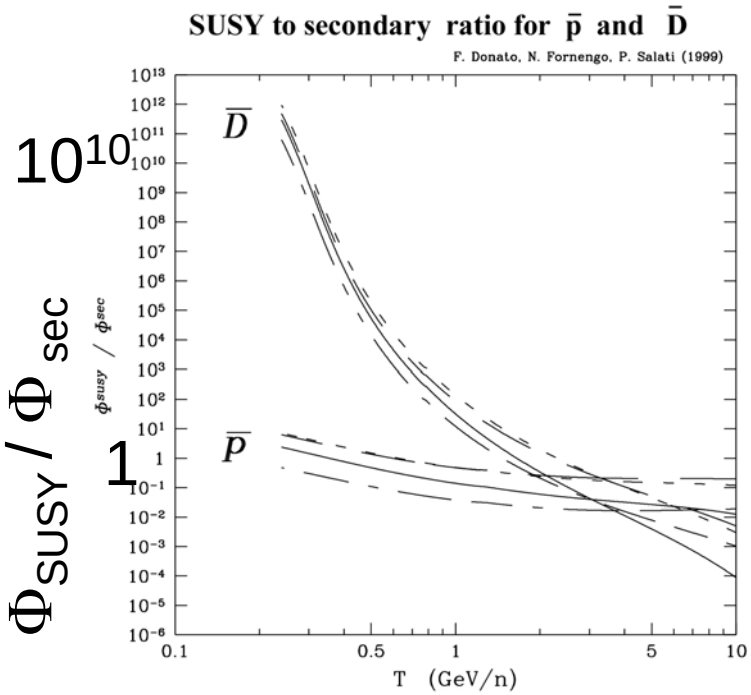


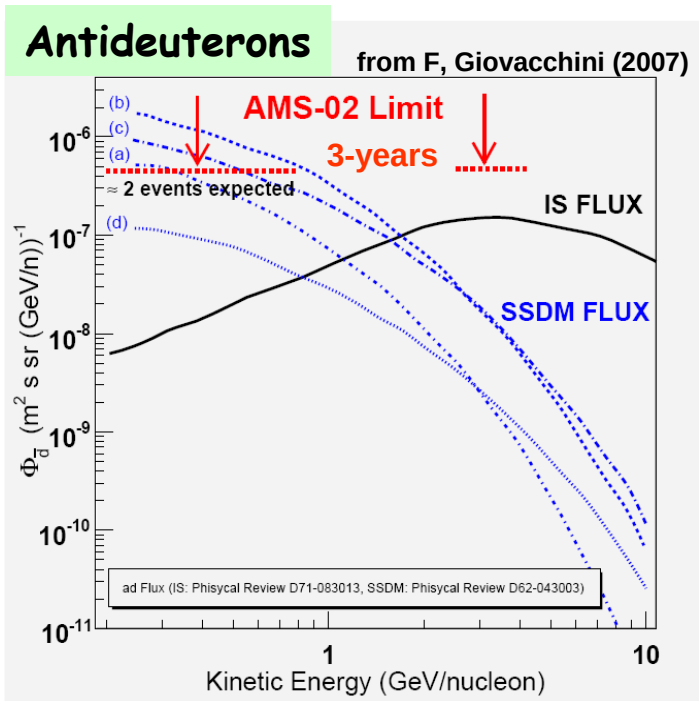


Fluxes of Positrons and Antiprotons dependent on propagation models, but Dark Matter Annihilation with same Halo and WIMP parameters from Gamma Rays could (as input) be used to tune cosmic models, e.g. introduce unisotropic diffusion.

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.!!).



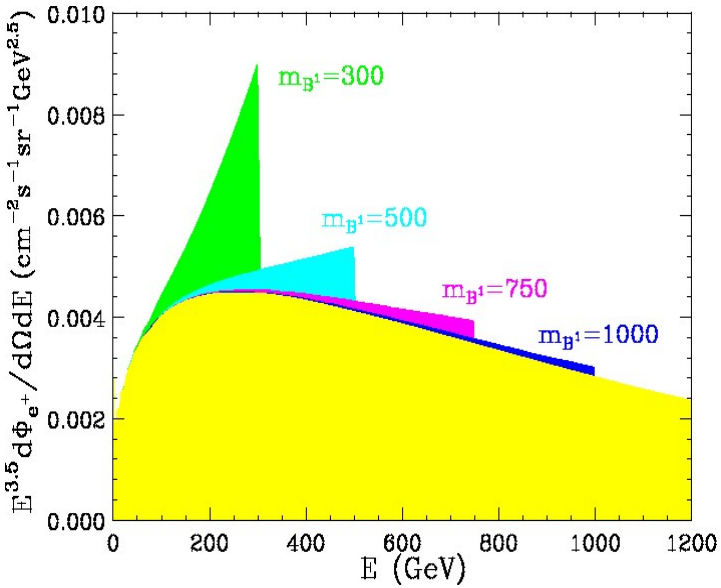


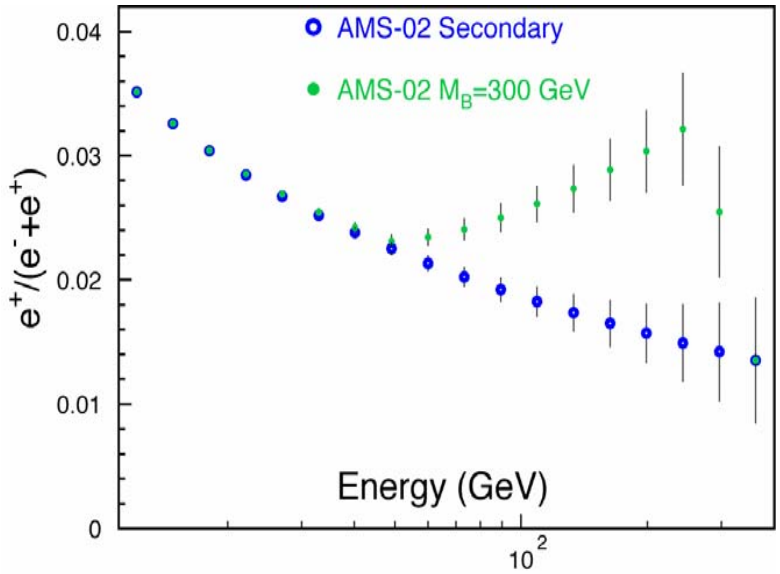
A large acceptance spectrometer like AMS-02 is required to measure the extremely low fluxes.

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





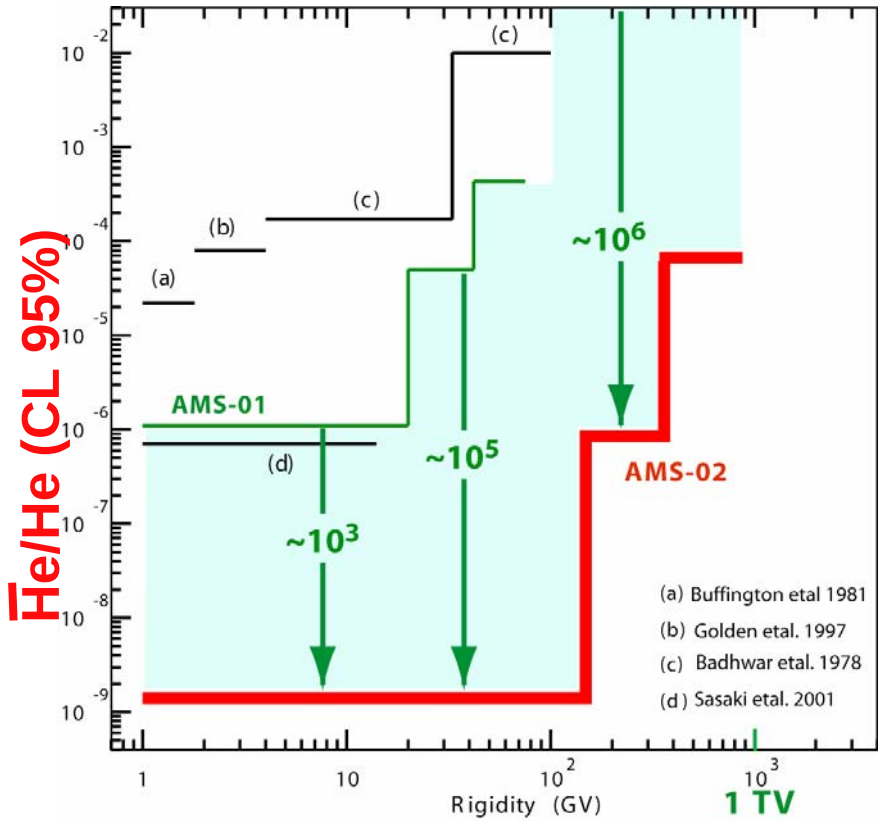
Excess from possible Boson mass of 300 GeV can be seen by AMS-02

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

Search for the existence of Antimatter in the Universe

The primordial antimatter content of the Universe is unknown.

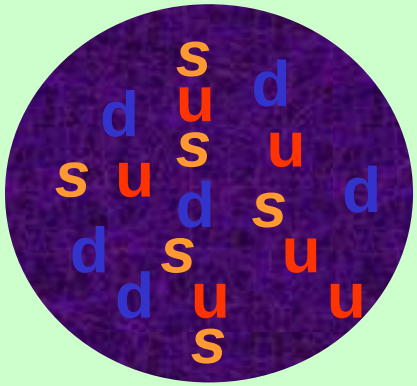
- Up to today existance of antimatter domains in the universe is not excluded (predicted by Big Bang)
- No antimatter annihilation signal from within our cluster
- No antimatter particle found by AMS-02 means there is no Antimatter in the Universe
- A single anti-C: there are antimatter stars!



Example for Exotic Matter in the Universe: Strangelets

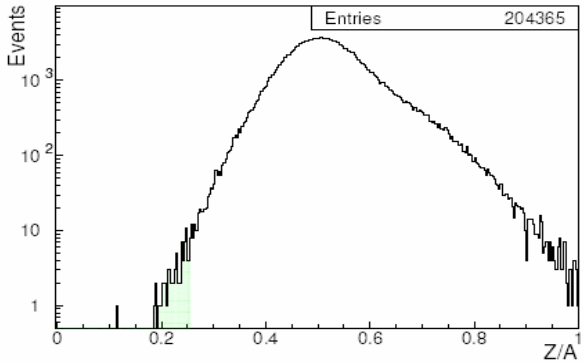
Signature of a Strangelet event simply is anomalous Z/A

STRANGELET
Nucleus



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

$Z/A < 0.12$



Latitude	Longitude	Angle(Dir, 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

CERN Cleanroom

Jul.07

ISS constuction continued ‘06

today

Kennedy-Space-Center

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 and is ready for launch early 2009
- 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

Thank you!


Alpha Magnetic Spectrometer
AMS-02
Europe • Asia
North America

Backups

Current Experiments

	BESS-Polar	PAMELA	AMS-02
Acceptance (m^2sr)	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 vehicule	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}	-	$3\ 10^{-7}$

R. Battiston, Direct Measurements and Origin of CR, ICRC,2003