MINISTERIO DE EDUCACIÓN Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

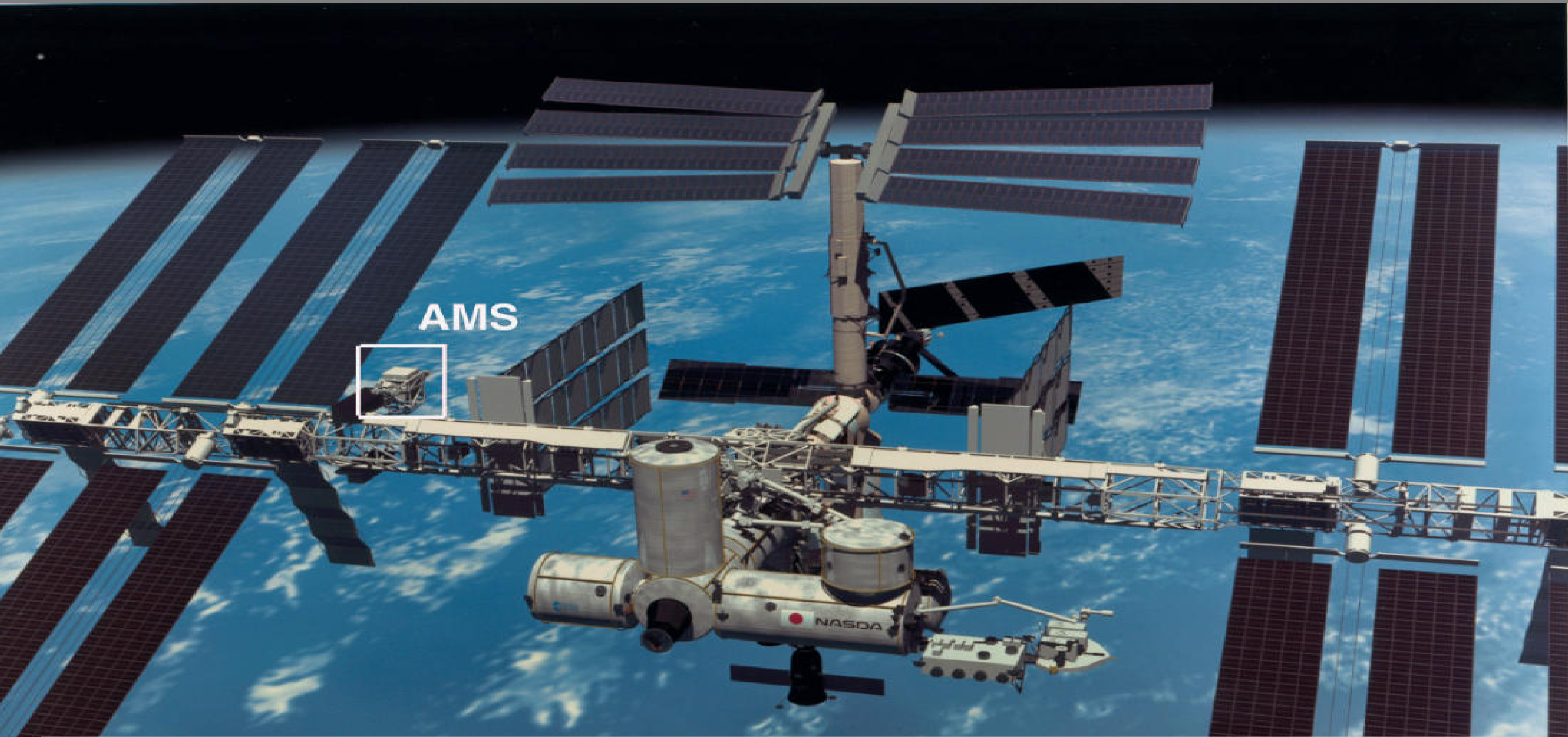
Search for Dark Matter with the AMS experiment

Carmen Palomares

CIEMAT (Madrid)

On behalf of the AMS Collaboration

The AMS experiment



AMS is a magnetic spectrometer to be installed on ISS (~ 450 km)

The aim of AMS is the direct detection of primary cosmic rays (E≤1 TeV/n)

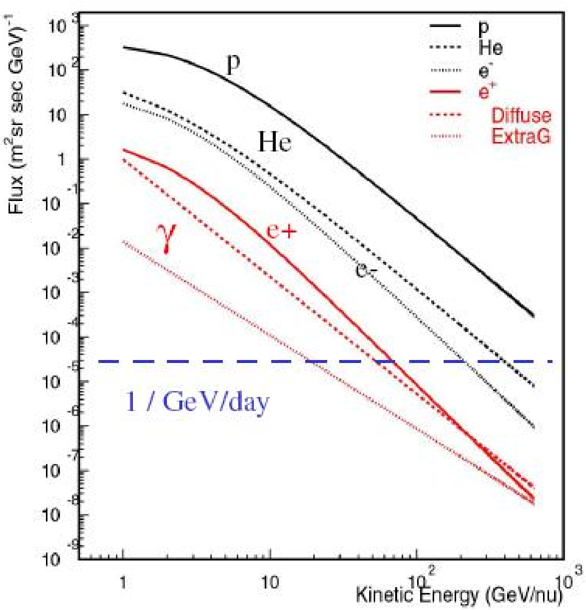
- **Large statistics (Large acceptance 0.45 m^2sr , long exposure > 3 years)**
- **Determination of energy with high resolution**
- **Very good particle identification**

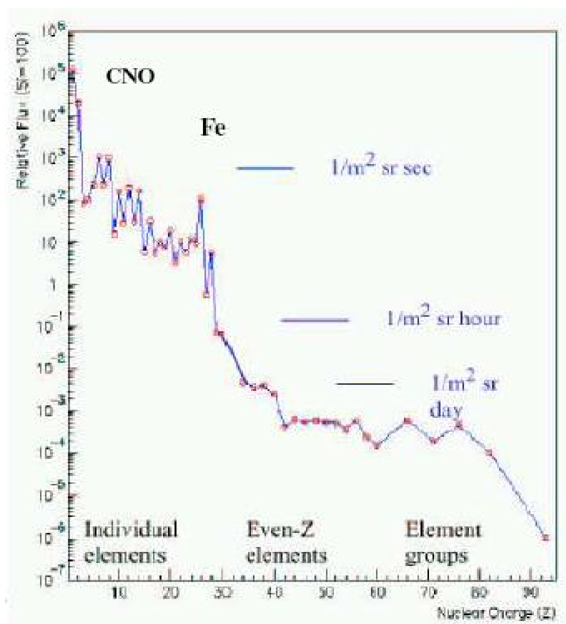
The AMS experiment: Specific objectives

➔ Direct detection and identification of primary cosmic rays

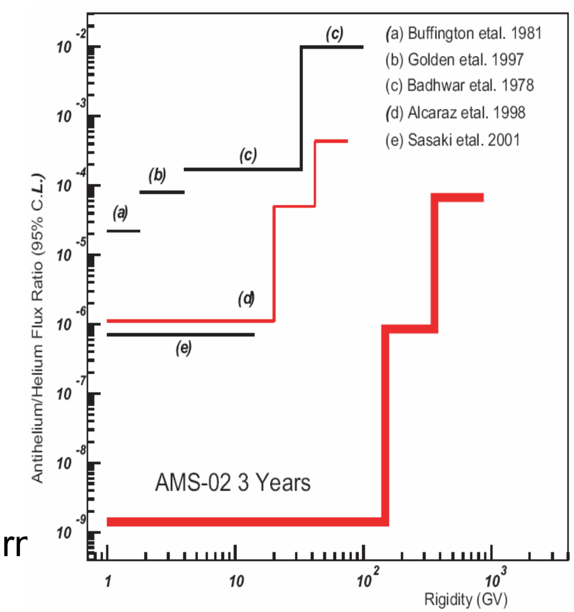
- Very <u>accurate</u> measurements of the spectrum of H & He (R≤ 1 TV)
- Chemical abundances (from H to Fe)
- Study of gamma rays in the GeV to TeV range
- The ratio of spallation products to the primary nuclei (B/C)
- Isotopic ratios of elements (E ≤ 10 GeV/n)

➔ Antimatter search with a sensitivity 10^3 better than current limits





Carr



The AMS experiment: Detector

Transition Radiation Detector (TRD)
p/e separation $10^2 - 10^3$ up to 300 GeV

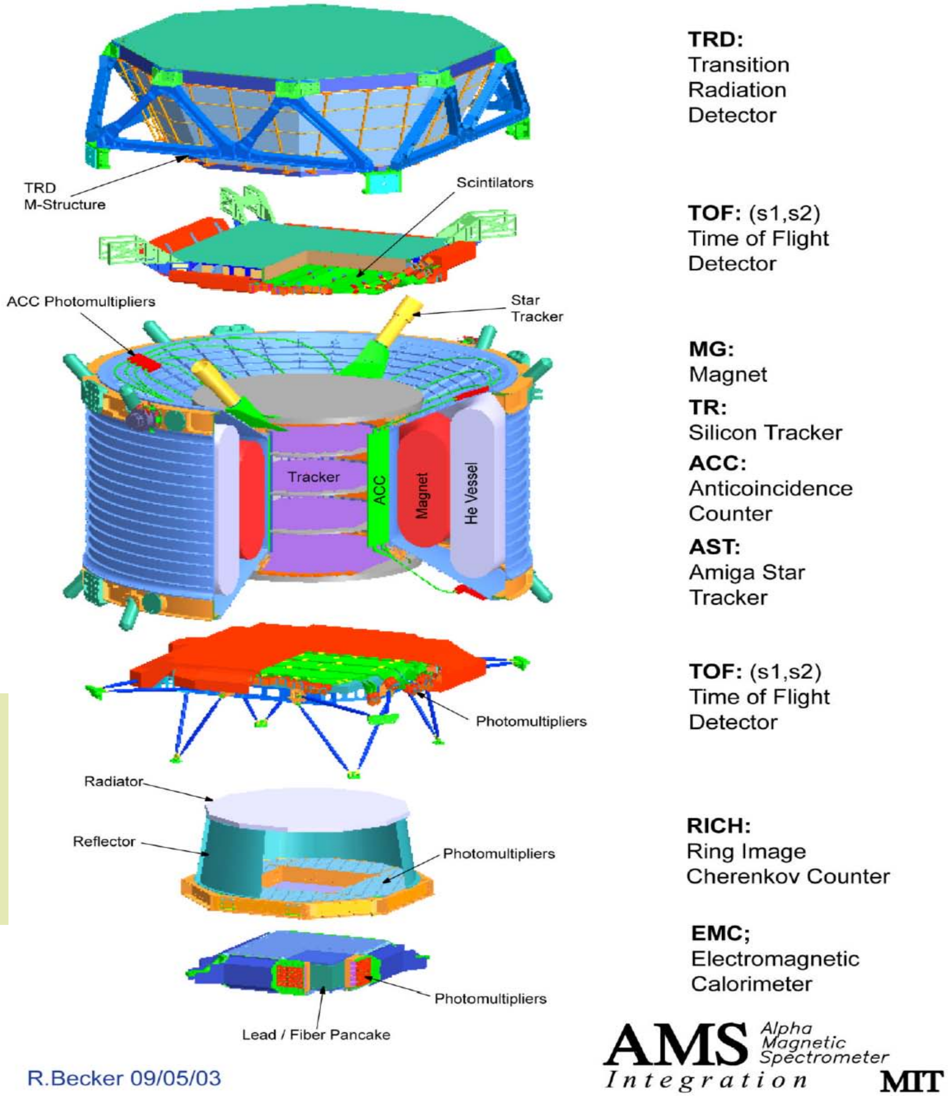
Time of Flight (TOF)
Trigger, Z identification
$\sigma(\beta)/\beta = 3.5\%$ ($\beta=1$), $\Delta t \sim 120$ ps

Superconducting magnet
$BL^2 = 0.85$ Tm^2

Silicon Tracker
$\sigma(R)/R = 1.5\%$ for 10 GV E≤ 1 TV
Z and sign(Z), Z~26

Ring Image Cerenkov Counter (RICH)
$\sigma(\beta)/\beta \sim 0.1\%$ for protons
Isotope separation $\sigma(m)/m = 2\%$
Z identification

Electromagnetic Calorimeter (ECAL)
$e^{\pm},\gamma$ detection $\sigma(E)/E < 3\%$ for 100 GeV
p/e rejection factor 10^4 for E<1TeV



AMS Detector Status

The sub-detectors have been tested:

- Test-beams at CERN using prototypes of the final detectors
- Qualification tests of the flight elements

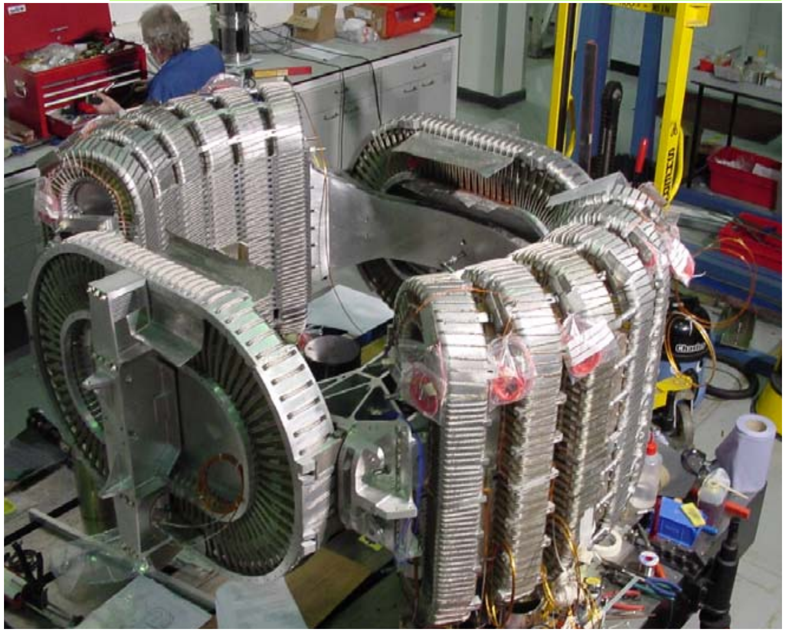
Most of the sub-detectors already constructed

Tracker and RICH are being assembled and qualified

Integration and functional tests of the whole detector at CERN (2007)

The detector will be completely ready to fly in 2008

Magnet: coils already done



ToF

Dark matter: neutralinos

CMB data (WMAP) confirms that most of the matter is non-baryonic

$$\boxed{\Omega_M h^2 = 0.135 \pm 0.008 \quad \Omega_b h^2 = 0.0224 \pm 0.0009}$$

Most of non-baryonic dark matter candidates require physics beyond the SM of particle physics

Large structure formation theories suggest a non-relativistic, weak interacting massive particle (WIMP)

Supersymmetry (one of the best motivated scenarios beyond the SM) predicts the existence of a weak interacting neutral particle with a mass of the order or below the TeV scale ➔ Neutralino

MSSM (R-parity)➔ Lightest supersymmetric particle (LSP) is stable
At present, Mass(LSP)>40 GeV from LEP experiments

Indirect detection of DM: neutralino annihilation

$XX \longrightarrow PP$ where P is fermion or boson

Signatures with small physical backgrounds

Gamma rays:

- Mono-energetic gamma-ray lines from $XX \rightarrow \gamma\gamma$, $XX \rightarrow \gamma Z$
- Continuum emission from the decay of other primary annihilation products

Positrons:

- From the decay of gauge bosons Ex: $XX \rightarrow WW \rightarrow e^+ \nu_e W^-$
- From heavy quark/lepton decay Ex: $XX \rightarrow bb \rightarrow e^+ \ldots$

Antiprotons and antideuterons:

- Production in neutralino annihilation by hadronization of quarks and gluons

AMS will measure all these fluxes simultaneously

DM Propagation to Earth vicinity

Flux in Earth vicinity

Charged Particles

$$\phi_{\bar{p}\bar{d}e^+} = \langle \rho^2 \rangle \frac{\langle \sigma_{anni} v \rangle}{m_\chi^2} N_{\bar{p}\bar{d}e^+} G(r_0, r)$$

Gamma

$$\phi_\gamma = \frac{\langle \sigma_{anni} v \rangle}{m_\chi^2} N_\gamma \int_{los} ds \rho^2(r)$$

ρ: Density of DM

Local density 0.3 GeV/cm^3

Distribution: Clumps $<\rho^2>=\text{Boost} <\rho>^2$, Halo shape

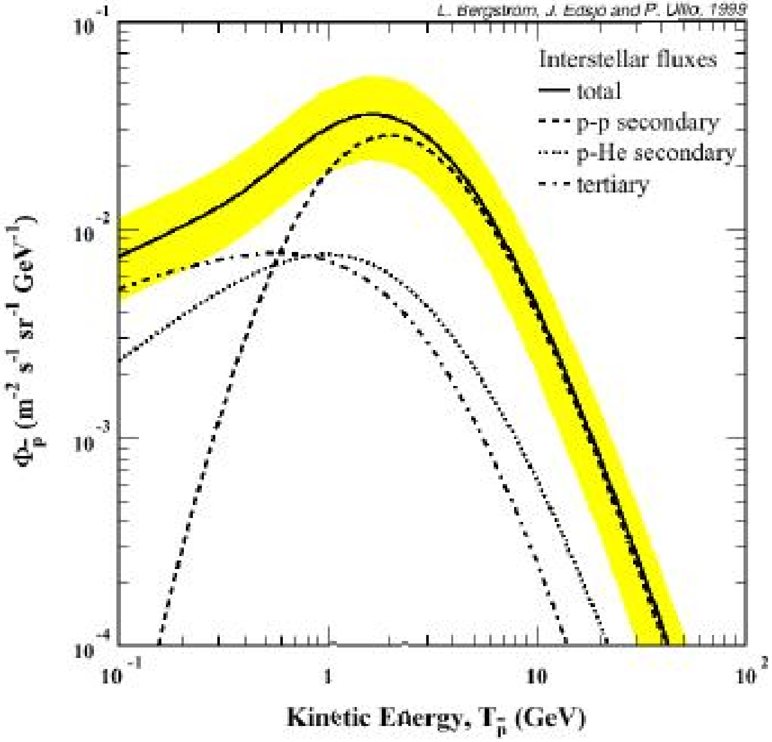
Ni: Number of particles of type i produced per annihilation

$<\sigma_{anni} v>$: Annihilation cross-section

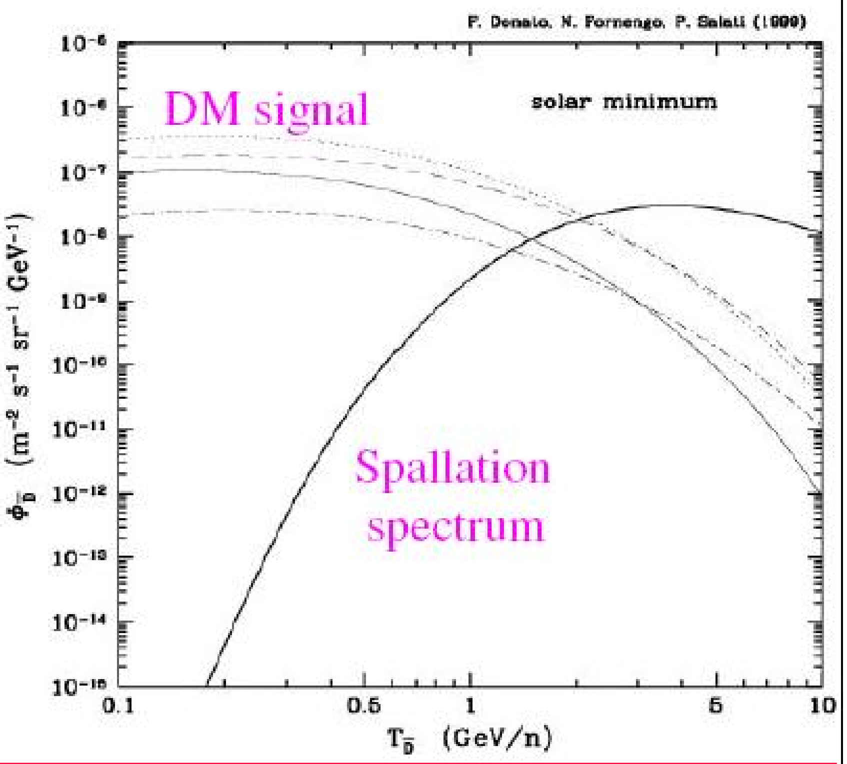
$G(r_0,r)$: Propagation term -> diffusion, reacceleration, solar modulation, etc…

Indirect detection: backgrounds

Antiprotons and positrons are secondary cosmic rays from interaction of nuclei with the ISM



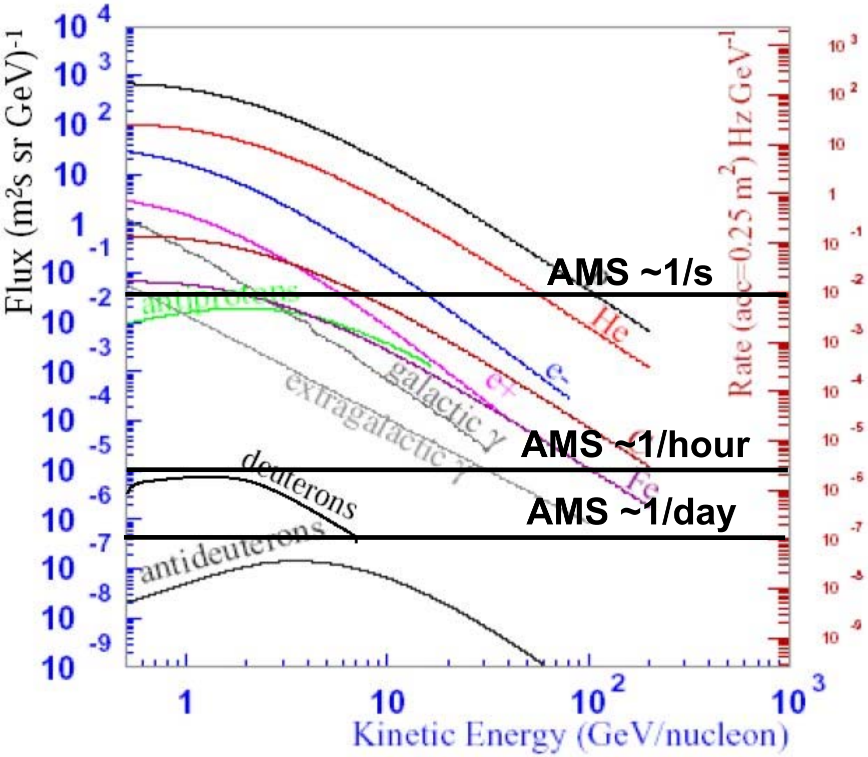
Antideuteron almost background free at low energies



Gamma: - Isotropic extragalactic γ-ray background radiation
- Galactic diffuse radiation

Indirect detection of DM by AMS

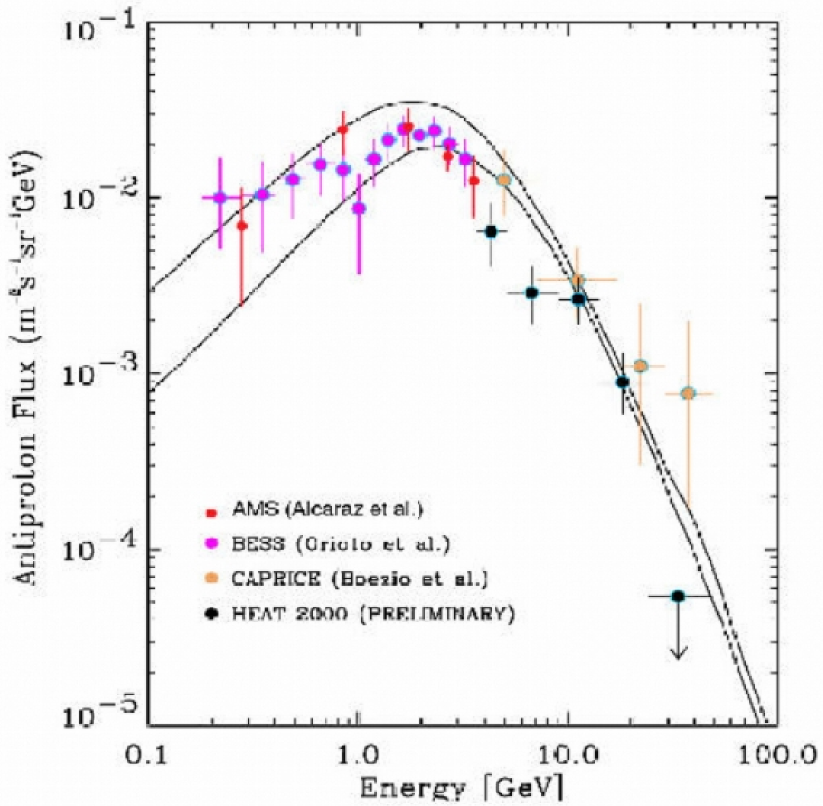
Cosmic Ray flux



Particle	Energy range (GeV)
Antiproton	0.5-400
Positron	0.1-400
Gamma	1-1000

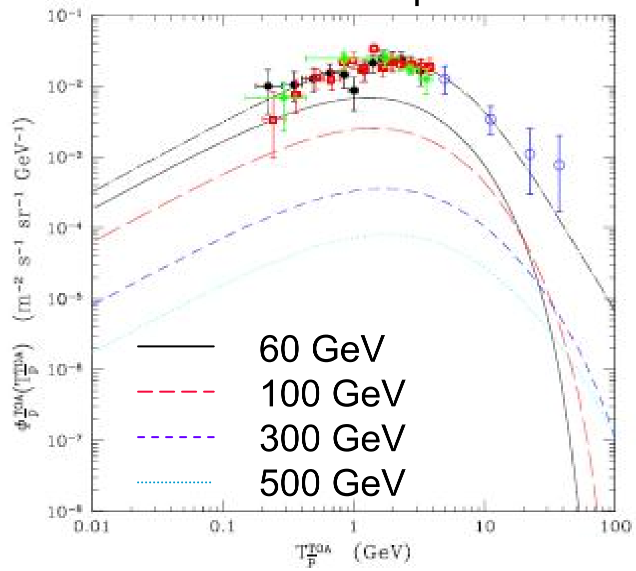
Indirect detection of DM by AMS: antiproton signature

Data well explained by secondary contribution alone

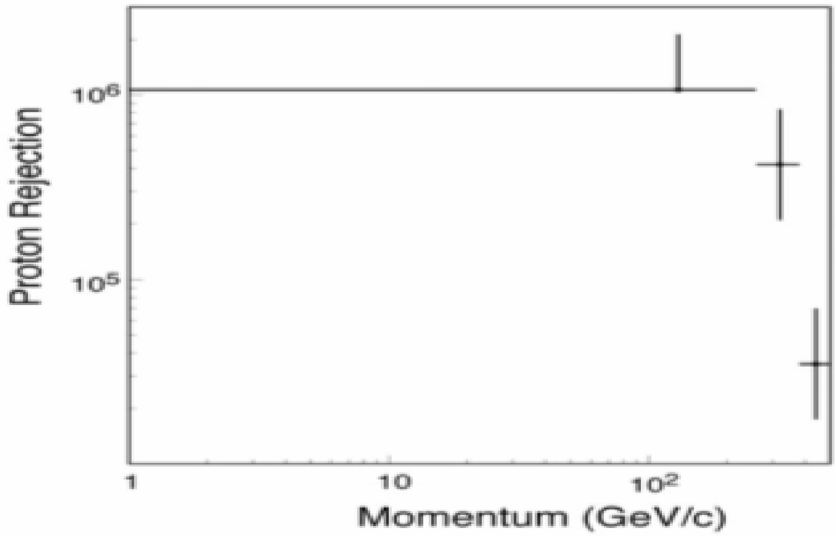


The detailed calculation of secondary and DM spectra depends on the propagation model, that will be constrained by the B/C data (very precise measurement by AMS-02)
Clumpy DM to cause significant distortions to the high energy secondary spectrum

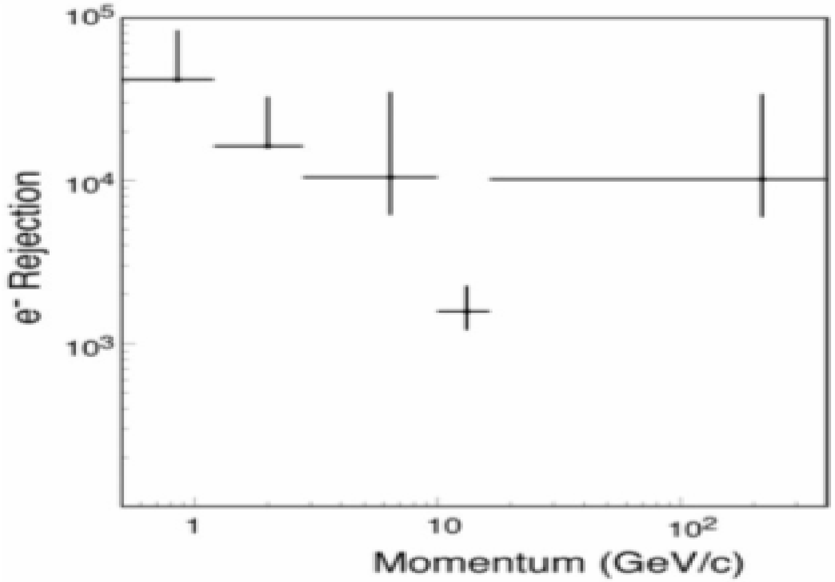
Donato et al. astro-ph/0306207



Antiproton selection



<u>Proton rejection</u>: control of charge confusion, interactions with the detector and misreconstructed tracks

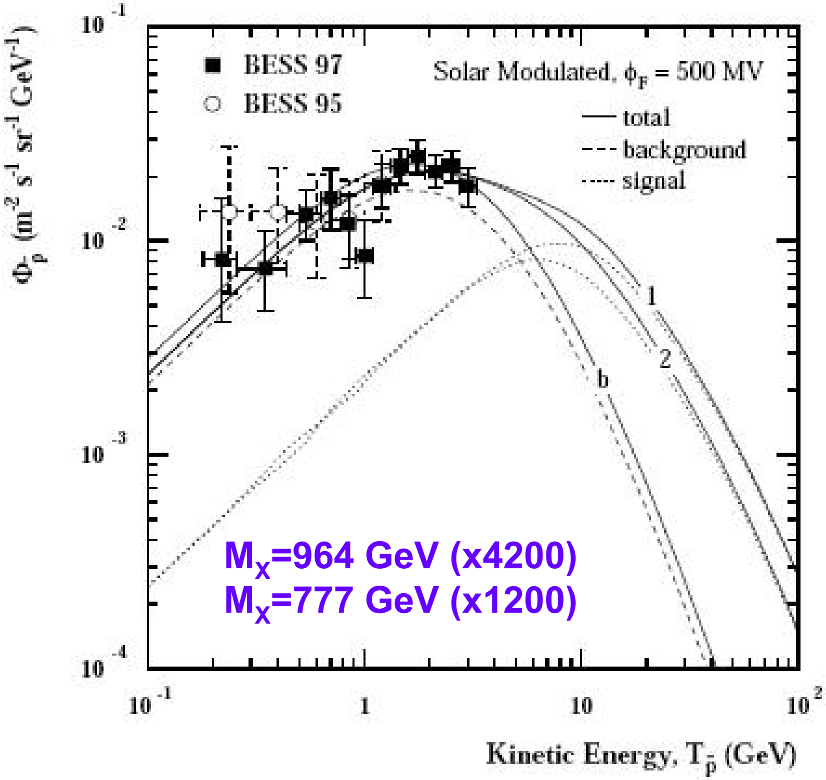


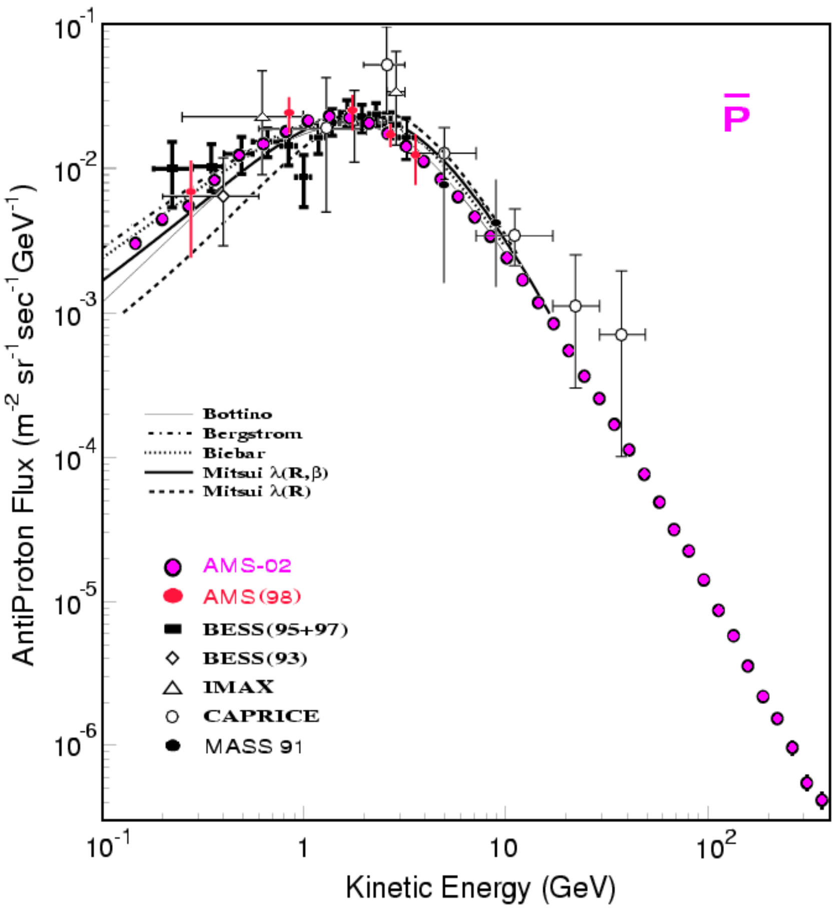
<u>Electron rejection</u>:
TOF+RICH β measurement at low energies
TRD+ECAL rejection capabilities at high energies

DM search in AMS: antiproton signature

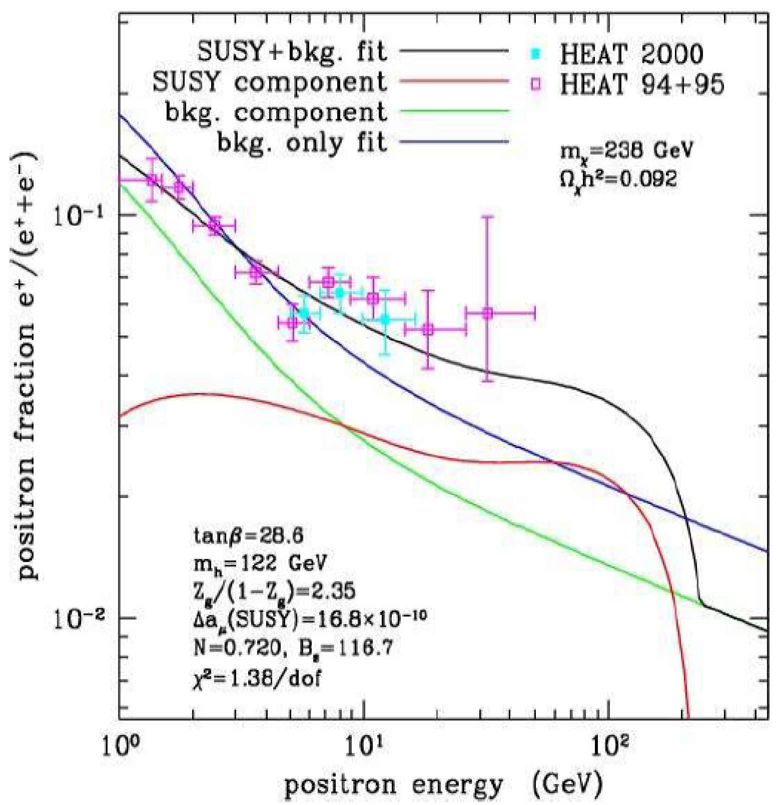
Very precise measurement of the antiproton spectrum at high momentum by AMS-02

Several SUSY configurations could be excluded at these energies for most favorable configurations





Indirect detection of DM by AMS: positron signature



E.A. Baltz et al., Phys.Rev.D65:063511,2002

The HEAT experiment (94+95,2000) observed a flux of cosmic e^+ in excess of the predicted rate

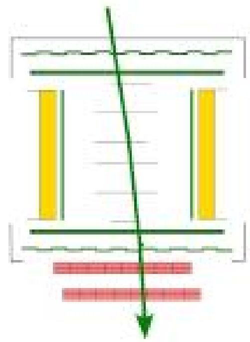
Positrons travel shorter distances than antiprotons. Therefore, the flux in Earth vicinity depends on local DM distribution

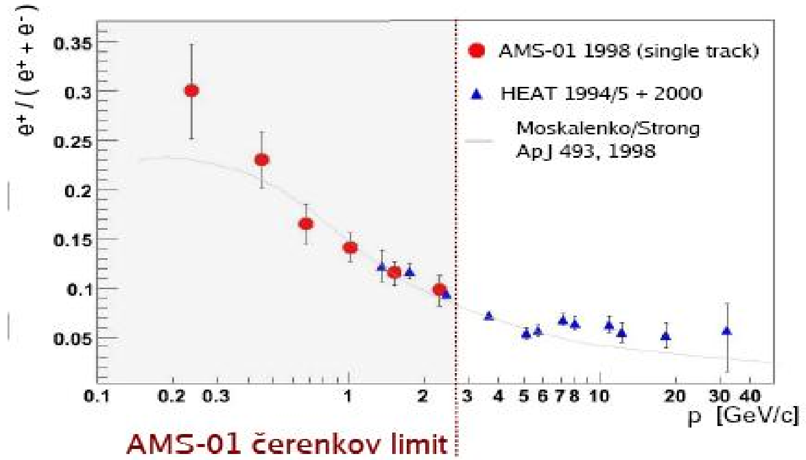
Clumpiness of DM enhances the annihilation rate of WIMP,s increasing the discovery potential

Non-negligible uncertainties on background due to propagation effects.

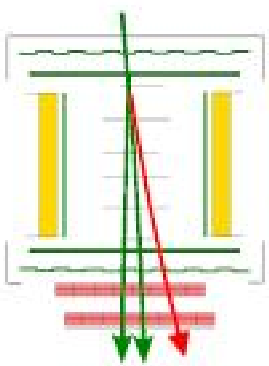
Indirect detection of DM by AMS-01: positron signature

- **Positron fraction spectrum measured by AMS-01 '98 using single tracks.**
- **e^+/p separation up to 3 GeV (Cerenkov counter)**

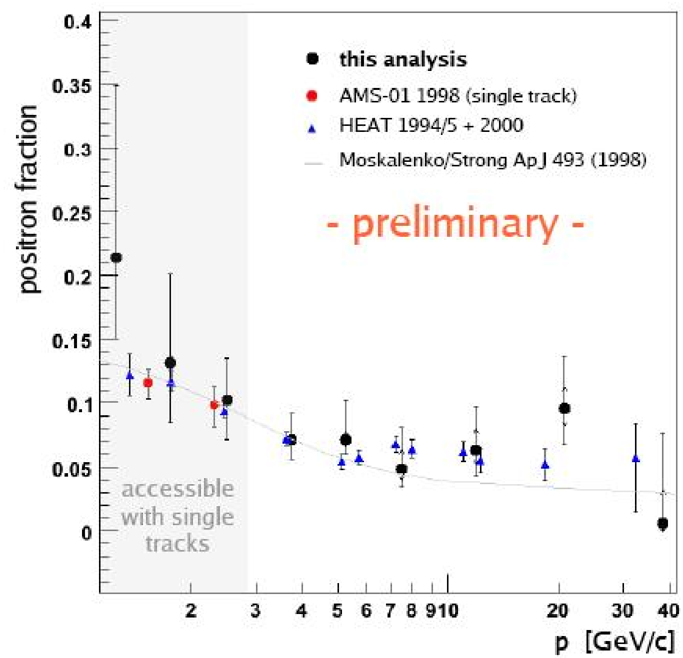




- **New analysis 2006 extends sensitivity to 40 GeV**
- **Positron identification using bremsstrahlung events**
  3 track signature: primary e^+,e^- radiate brem γ and γ converts to e^+e^-

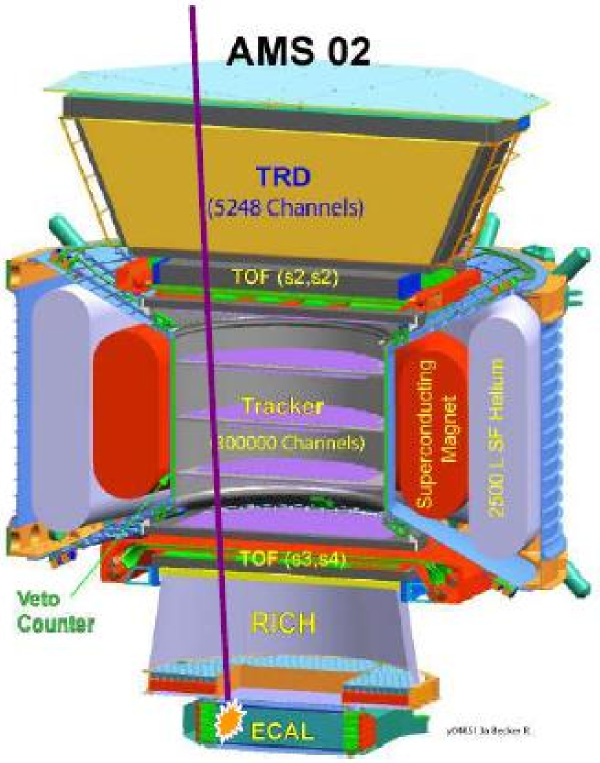


Result compatible with HEAT data

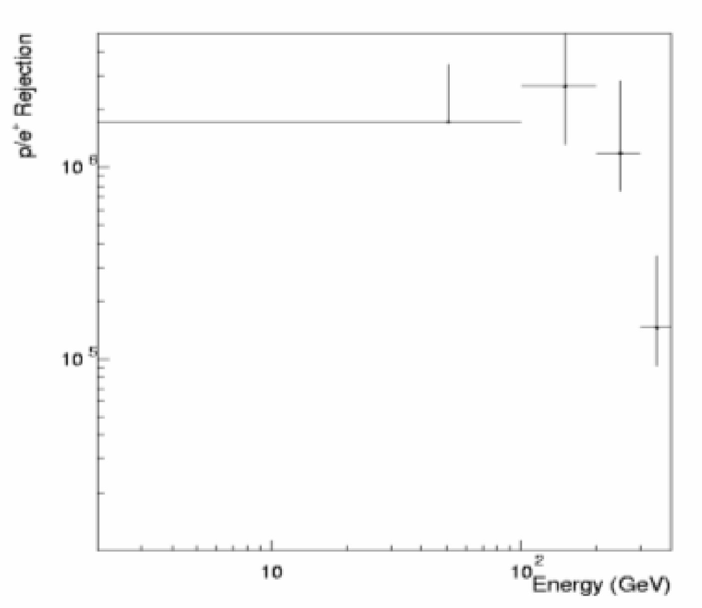


Positron selection in AMS-02

e^+ / p separation



ECAL: electromagnetic shape up to 1 TeV
TRD: large X ray activity up to 300 GeV
Overall proton rejection of ~ 10^5



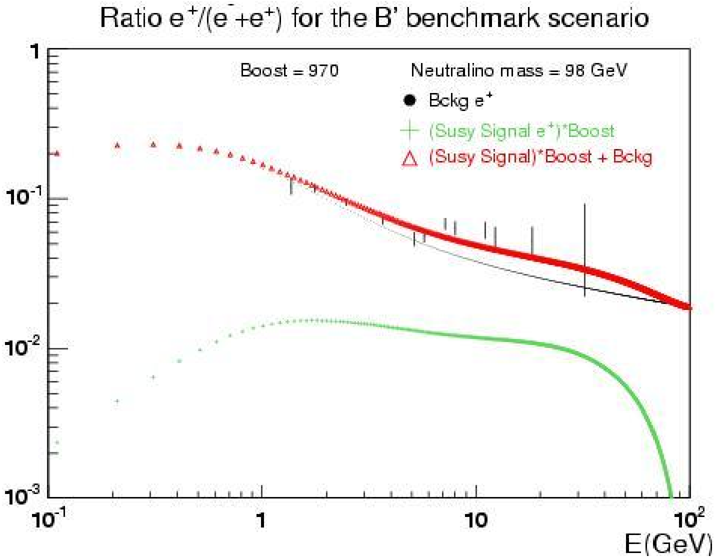
DM search in AMS: positron signature

The flux of positrons depends on:

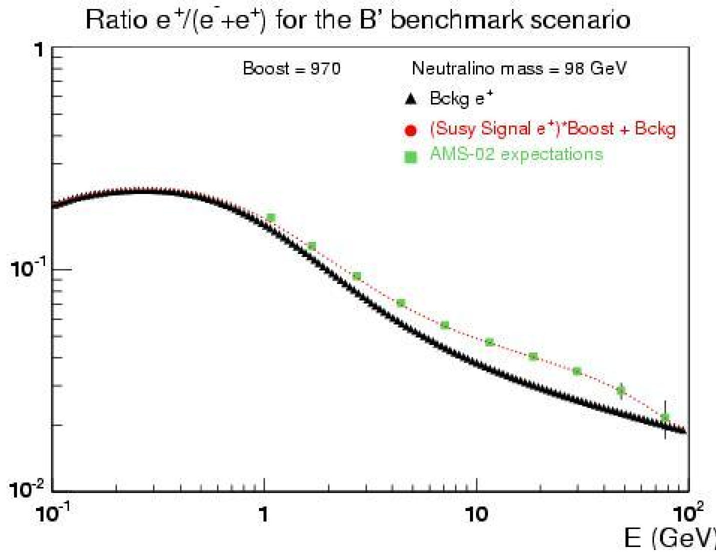
1. **SUSY scenario (set of parameters)**
2. **Boost factor**
   Enhancement of flux due to the clumpiness of DM in the galactic halo
   Tuned in order to match the HEAT excess

B′ ("bulk") benchmark scenario: m_0=60, $m_{1/2}$=250, tanβ=10, $m_χ$=98 GeV

Fit HEAT data

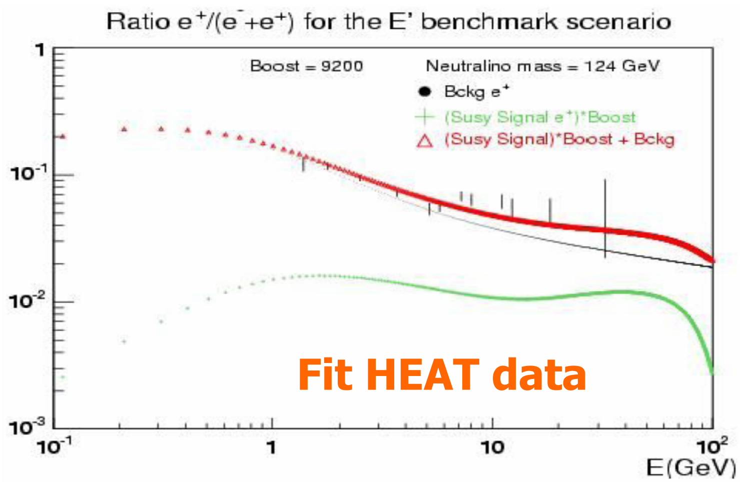


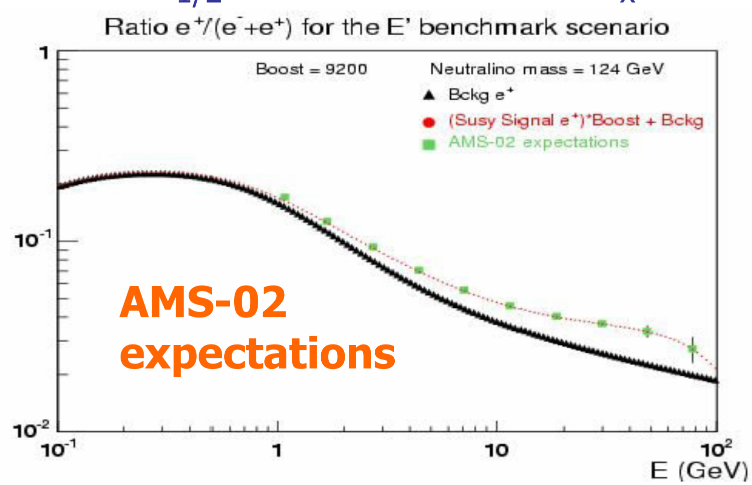
AMS-02 expectations



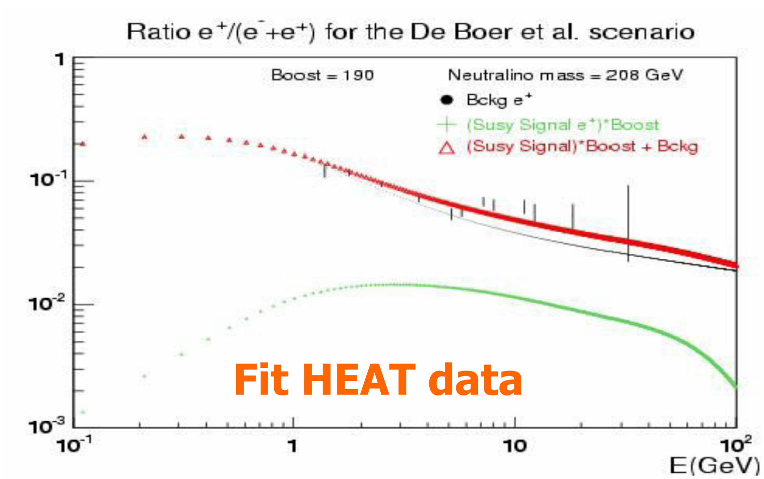
DM search in AMS: positron signature

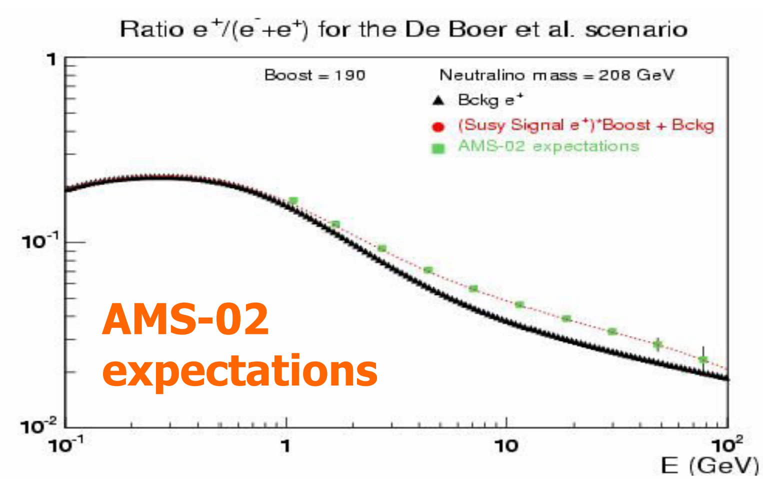
E' ("focus point") benchmark scenario: m_0=1530, $m_{1/2}$=300, tanβ=10, m_χ=124 GeV



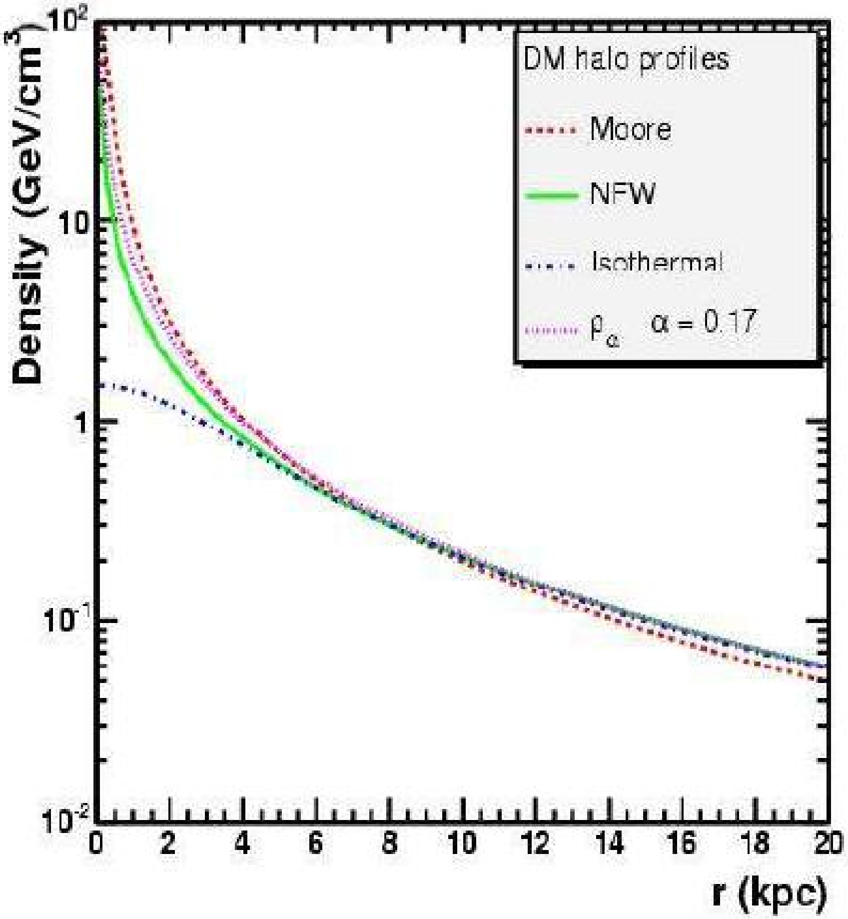


W. de Boer scenario: m_0=500, $m_{1/2}$=500, tanβ=50, m_χ=208 GeV
Simultaneous fit to antiproton spectrum + HEAT + EGRET





Gamma signal of Dark Matter



Discovery potential of DM through indirect detection of γ-ray depends on:

Dark Matter structure and density profile near the Galactic Center

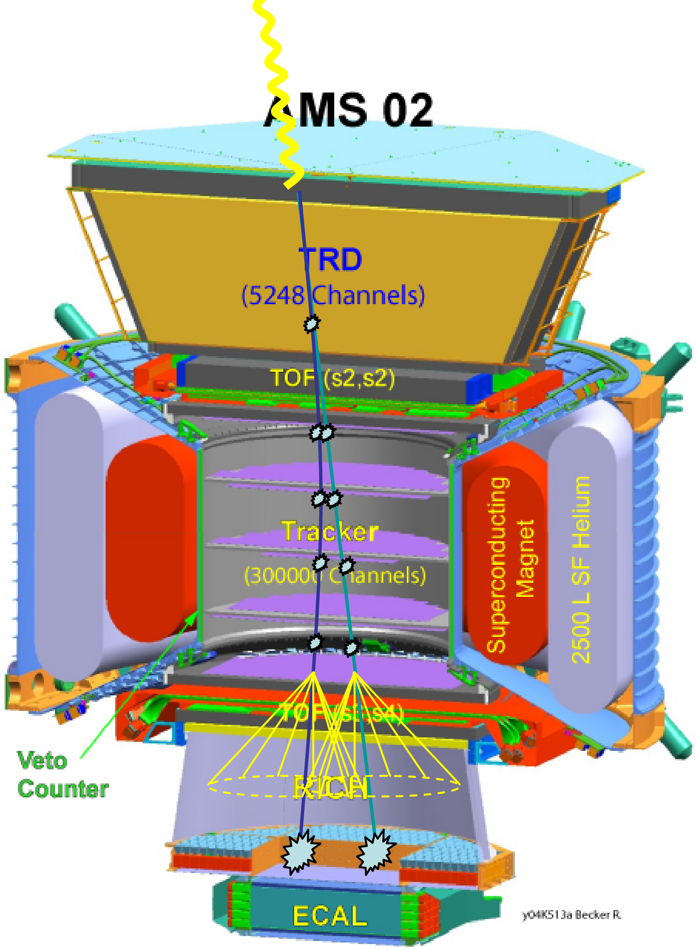
Different dark matter candidates

$$\phi_\gamma = \frac{\langle \sigma_{anni} v \rangle}{m_\chi^2} N_\gamma \int_{los} ds \rho^2(r)$$

Photon detection in AMS

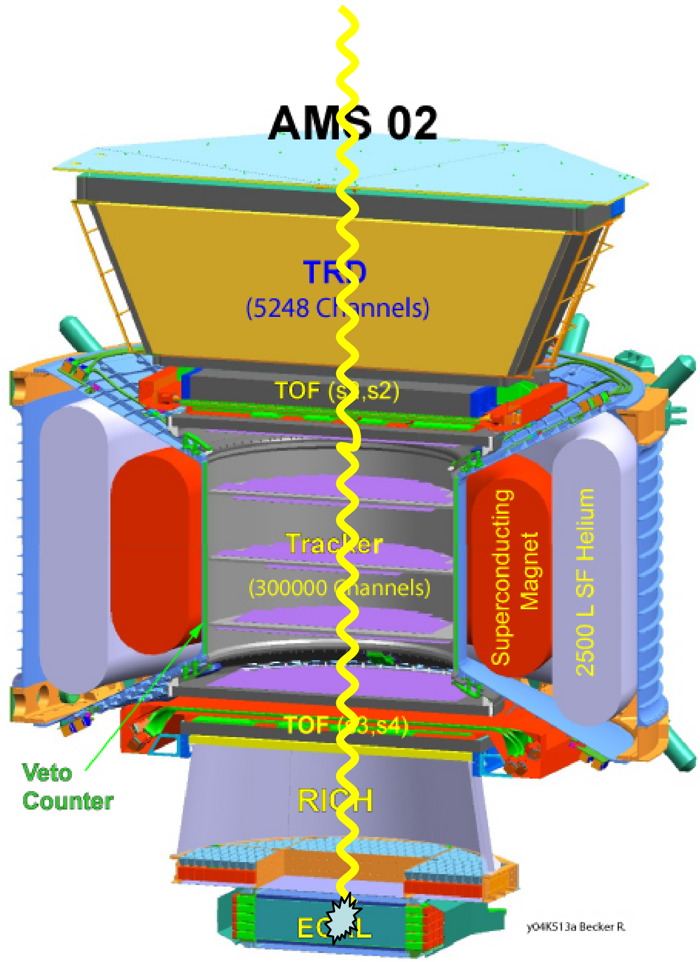
Conversion mode

Detection in the tracker of the e^+e^- pairs from photon conversion in upstream layers



Single photon mode

Detection in the ECAL



Photon detection in AMS

Selection Criteria

Conversion mode:

1. Very small invariant mass
2. No TRD activity in the top layers
3. No particle activity in the rest of the detector

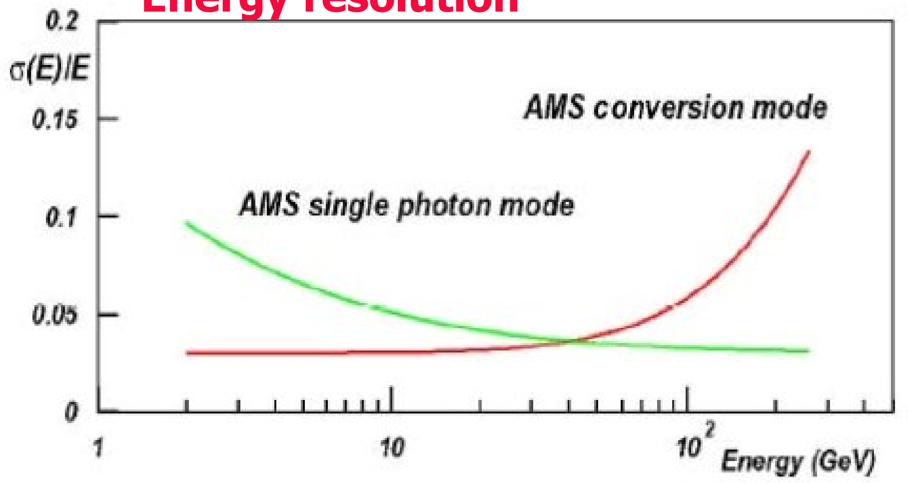
p and e- rejection factor ~ 5x10^4

Single Photon mode:

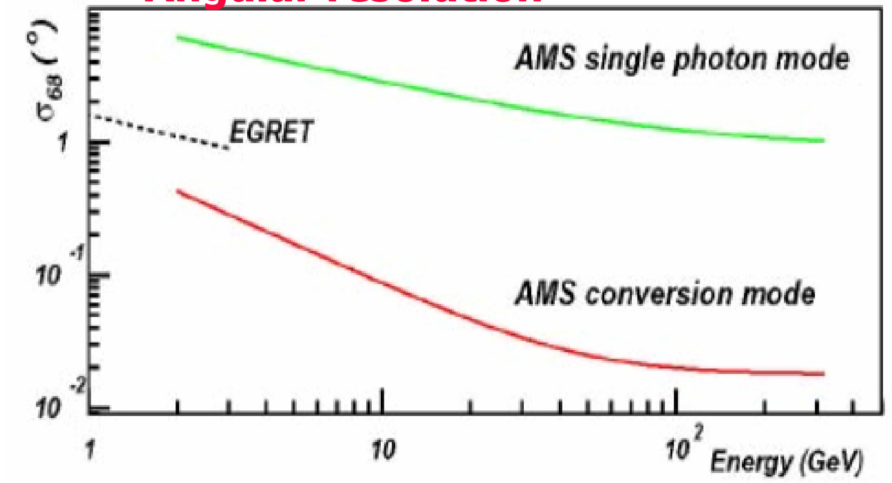
1. Electromagnetic shower in the ECAL
2. Reconstructed trajectory inside sensitive volume
3. No activity in the rest of the detector

p and e- rejection factor > 10^5

Energy resolution



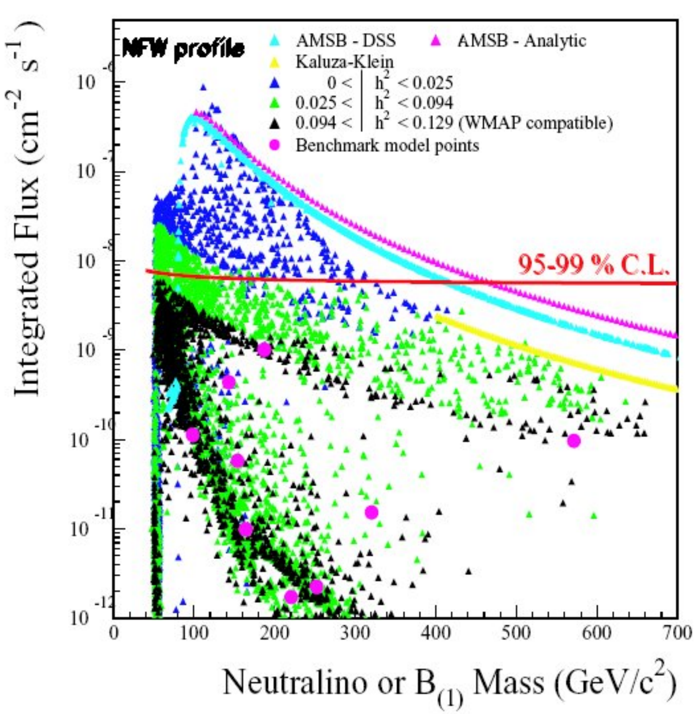
Angular resolution

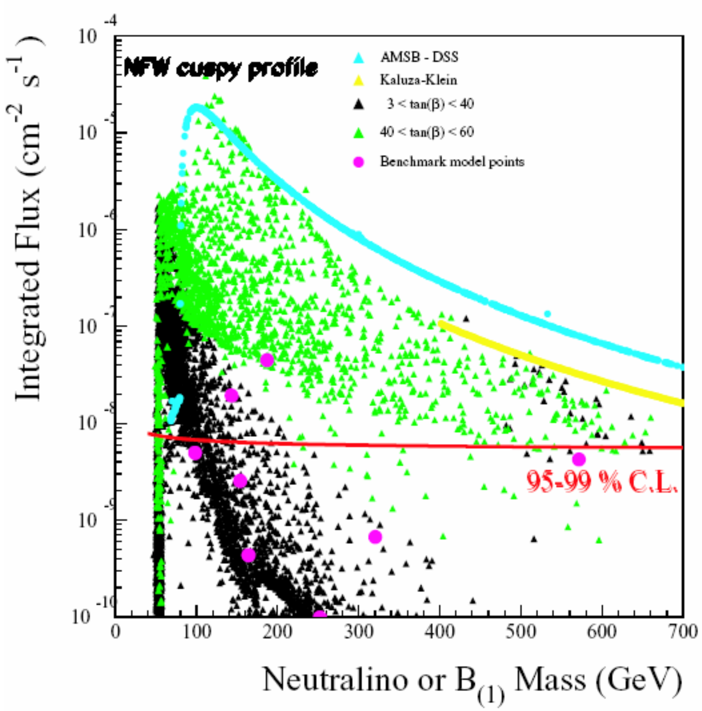


AMS sensitivity for different scenarios

DM candidates: **Different SUSY benchmark models + scan of many SUSY configurations**

Galactic halo profile: **The discovery potential increases for cuspy profiles**





Carmen Palomares AMS-CIEMAT

Summary

- AMS is a multipurpose detector in space that will search for signatures of neutralino annihilation in the galactic halo.
- AMS will make use of high statistic (3 years mission and large acceptance) and very precise particle identification.
- The AMS measurements of B/C and $^{10}Be/^{9}Be$ ratios will impose severe constraints to Galaxy models and diffusion parameters for background estimation
- AMS will measure the high energy tail (50-400 GeV) of the antiproton spectrum to an unprecedented accuracy.
- AMS will be able to confirm or disprove the slight excess in HEAT/AMS-01 positron data for E>10 GeV
- A gamma dark matter signal from the galactic center will be visible in AMS in cuspy profile scenarios or in case of other enhancements.