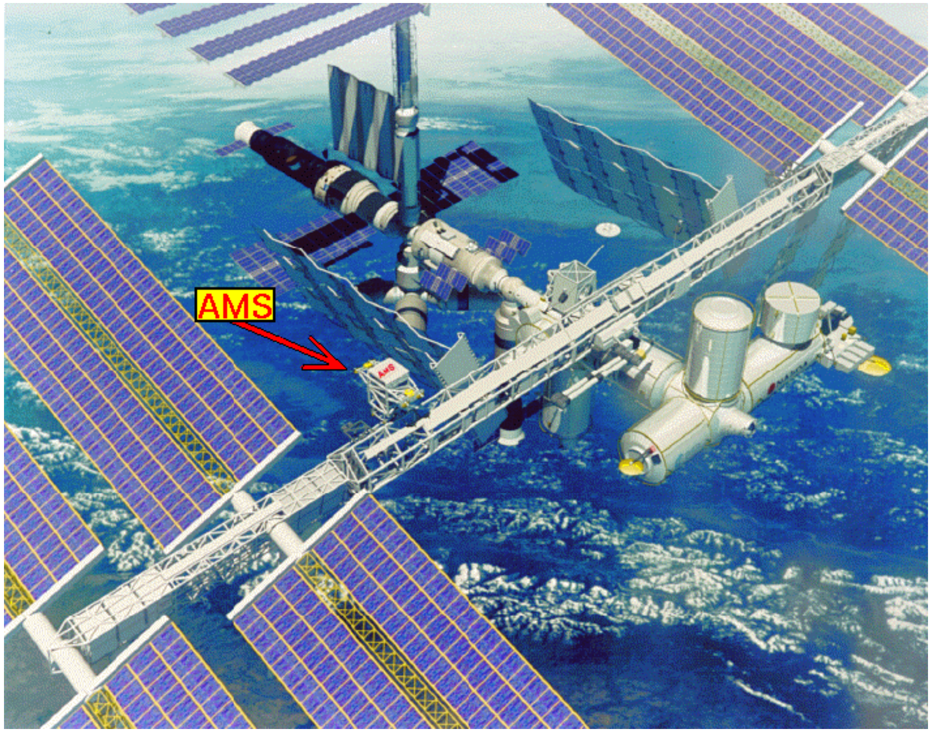
Indirect Search for Dark Matter with AMS experiment

Epiphany Conference
5-8 January 2006

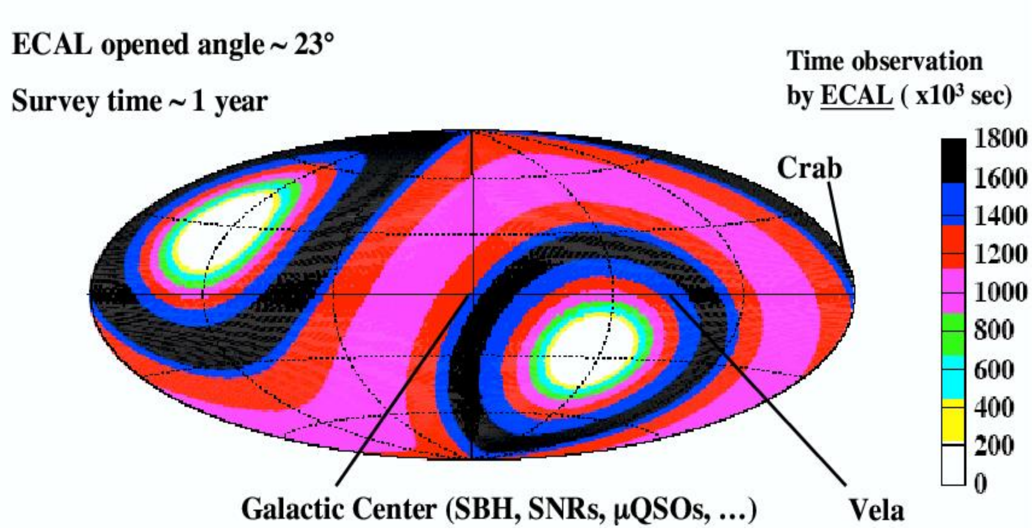
Mariusz Sapinski
INFN Roma and INP Krakow
on behalf of the AMS Collaboration

The AMS Experiment



AMS-02: Large acceptance cosmic-ray spectrometer to be located on the ISS for a period of at least three years (2008-...)

- Detector acceptance: 0.5 m^2 sr
- Rigidity measurements from 1 GV to 2-3 TV
- Charge determination up to Z=26

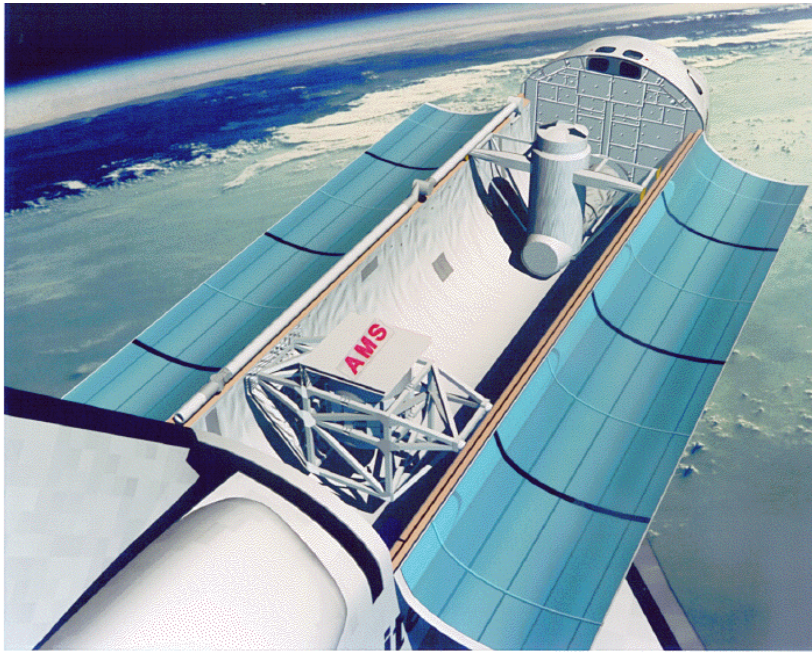


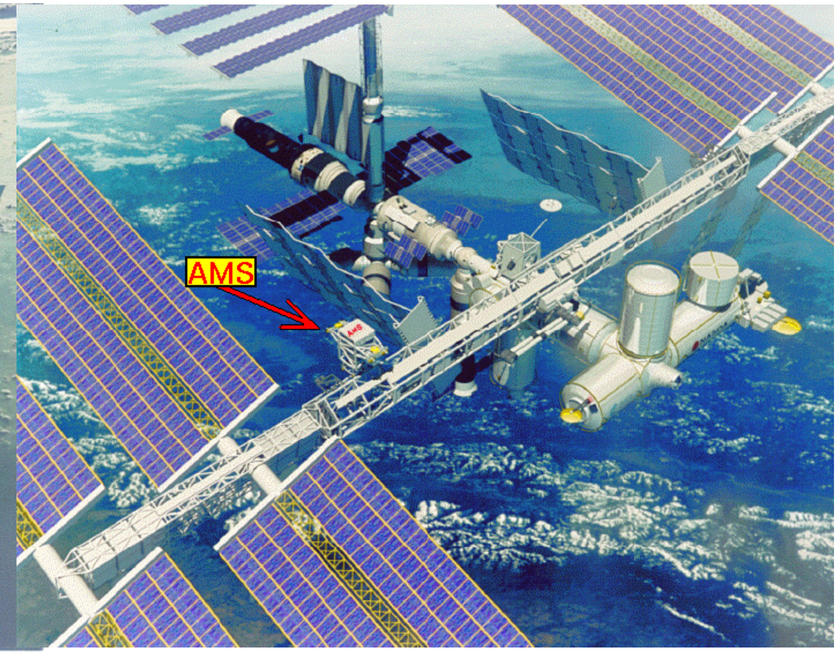
The orbit:

- ISS Altitude: ~ 400 km
- ~16 revolutions/day
- Orbit inclination: 51.57°
- Precession: ~ -5°/day

The AMS Experiment

AMS-01





AMS-02

Specific objectives

- a) Spectrum and composition of charged cosmic rays and study of gamma rays in the GeV to TeV range
- b) Search for antimatter/matter ratio with $1:10^9$ sensitivity and search for new physics effects: dark matter, ...

Precursor flight (AMS-01) of 10 days on the Discovery shuttle in June 1998. Results discussed in Phys. Rept. vol. 366/6 (2002) 331.

The AMS-02 subdetectors

Transition Radiation Detector (TRD):

Foam + Straw Drift Tubes (Xe/CO_2)

e/p separation, rejection power > 100 up to 300 GeV

Time of Flight (TOF):

scintillators, Δt =~160ps

Main trigger, charge separation, β with few % precision

Superconducting Magnet :

$BL^2 = 0.85\ Tm^2$

Tracker (8 layers) :

double sided silicon microstrip detector

<2% resolution below 10 GV, rigidity up to 2-3 TV, charge separation

RICH :

Radiator (Aerogel, NaF)

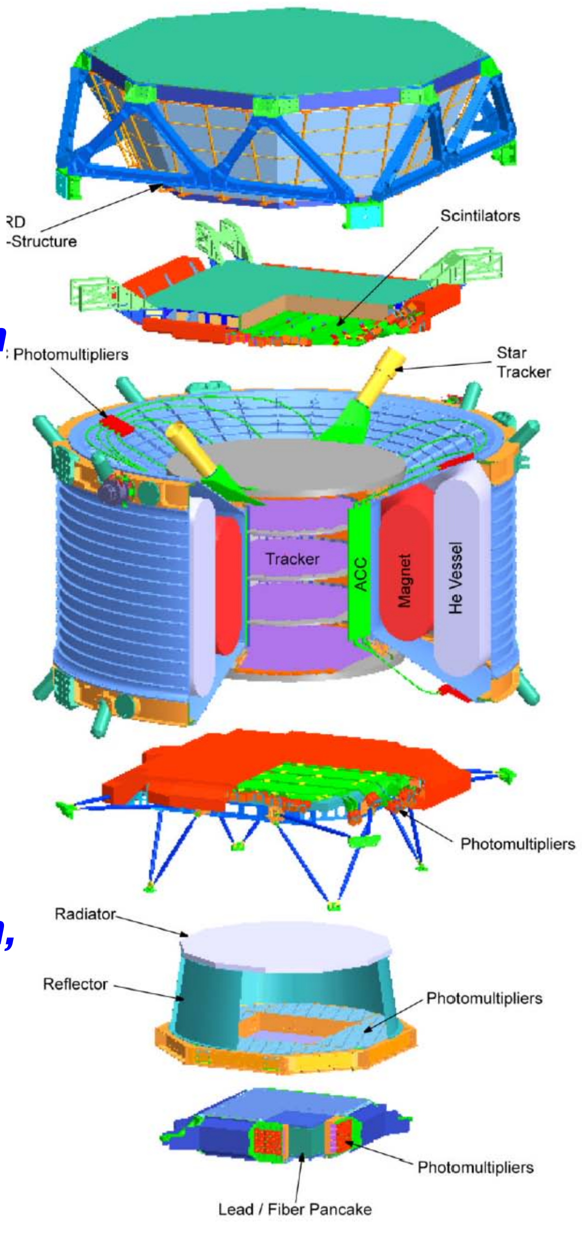
β measurement with 0.1% precision, charge separation, isotope separation (2% precision on mass below 10 GeV/n)

Electromagnetic Calorimeter (ECAL):

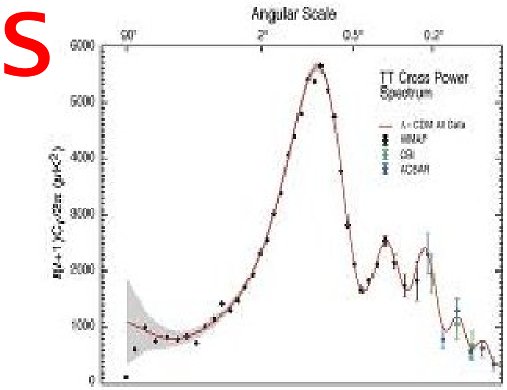
Lead+scint. Fibers

$e^{\pm}$,γ, detection, standalone trigger

<3% en. res. above 10 GeV, e/p separation >1000



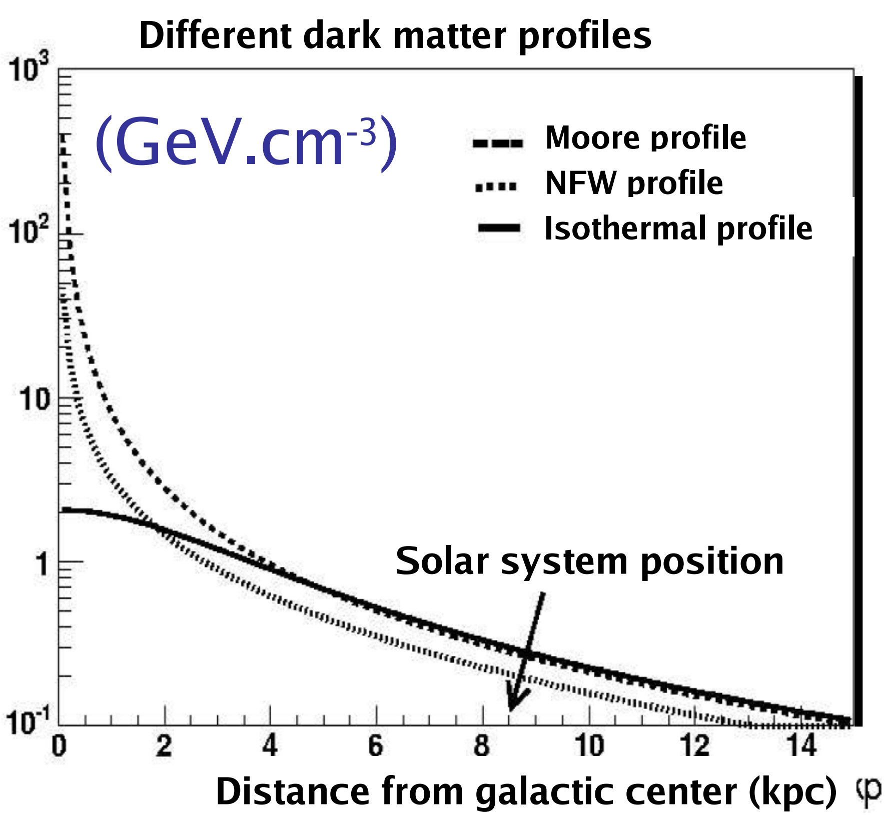
Dark matter properties



WMAP: $\Omega_M h^2 = 0.135 \pm 0.008; \; \Omega_b h^2 = 0.0224 \pm 0.0009$

83% - DM

Dark Matter: non-hadronic, weakly interacting, “cold”, massive particles, halo profile:

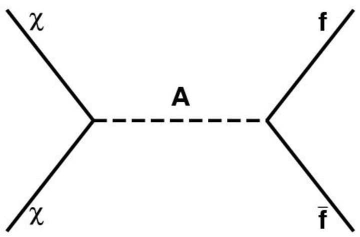


Possible local clumps – boost factors

Detection methods: direct (CDMS,DAMA) and indirect by measurements of anomalies in Cosmic Ray spectra.
balloon: BESS,CAPRICE
satellite: PAMELA, GLAST, AMS

Dark matter

- **Supersymmetry at the TeV scale is one of the best motivated scenarios beyond the Standard Model. In many SUSY implementations, it exists a stable, weakly interacting neutral particle with a mass of the order of TeV scale. This is an ideal 'cold dark matter' candidate.**



$\chi\chi$->A-> $\bar{b}$b dominant in many scenarios

$$\chi\chi \rightarrow W^{+}W^{-} \rightarrow e^{+} + \nu_{e} + W^{-}$$

$$\chi\chi \rightarrow b\bar{b} \rightarrow e^{+} + X$$

$$\chi\chi \rightarrow \gamma\gamma \quad (via\ loops)$$

$$\chi\chi \rightarrow hadrons \rightarrow \pi^{0} + X \rightarrow \gamma\gamma + X$$

$$\chi\chi \rightarrow hadrons \rightarrow \bar{p} + Y$$

$$\chi\chi \rightarrow hadrons \rightarrow \bar{D} + Y$$

- **Universal Extra dimensions: all SM fields propagate in e.d. => Kaluza-Klein partiy conservation in 4-dimensioal effective theory => stable LKP with m = 1/R > 300 GeV. The most promising LKP is the first level of KK modes of the hypercharge gauge boson $B^{(1)}$**

$B^{(1)} B^{(1)}$ -> ff -> e^+, $\bar{p}$, $\bar{d}$

eg. G.Bertone et al. Phys. Rev. D68 (2003) 044008

Propagation and rates

$$Flux_{part} \propto n_{part} \otimes \frac{\langle \sigma v \rangle}{m_\chi^2} \otimes \rho_\chi^2 \otimes \underline{Propagation\ term}$$

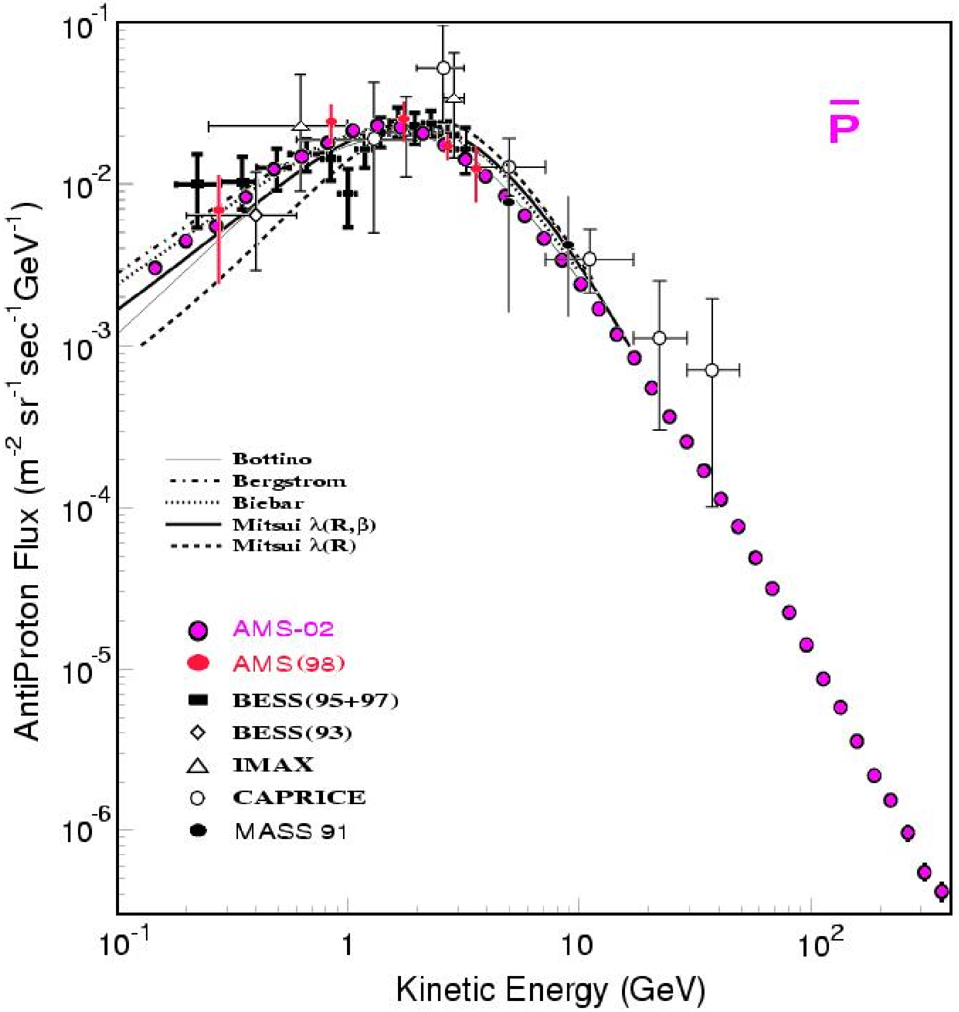
- **n_{part}: Number of particles of type 'part' produced per $\chi\chi$ annihilation.**

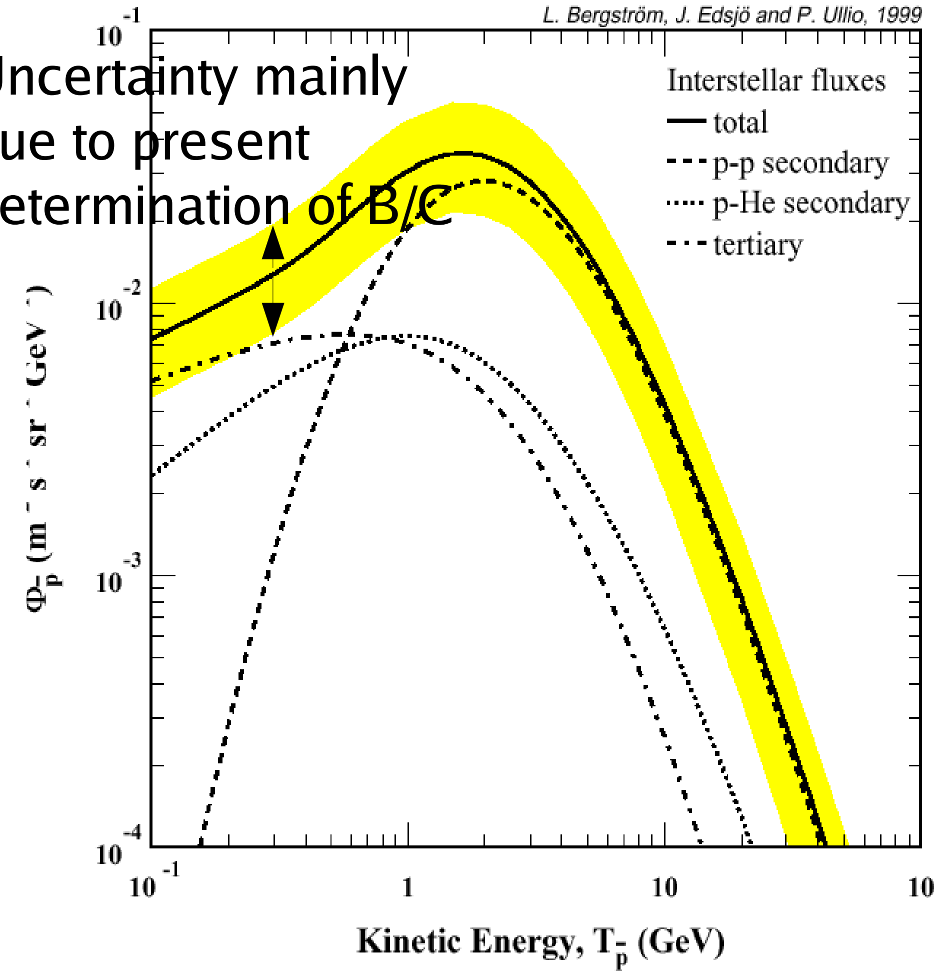
- **$<\sigma v>$: determined from cosmology at freeze-out time (typical expected value ~ 10^{-27} - 10^{-26} $cm^3\ s^{-1}$)**

- **ρ_χ: neutralino density. $<\rho_\chi{}^2> = B <\rho_\chi>^2$ (B: boost factor in case of clumpy dark matter). Typical $<\rho_\chi>$ value ~ 0.3 GeV/cm^3**

- **Propagation term: diffusion, convection, reacceleration, solar modulation,... (in case of gamma signal it is integral over line of sight)**

Antiprotons on orbit



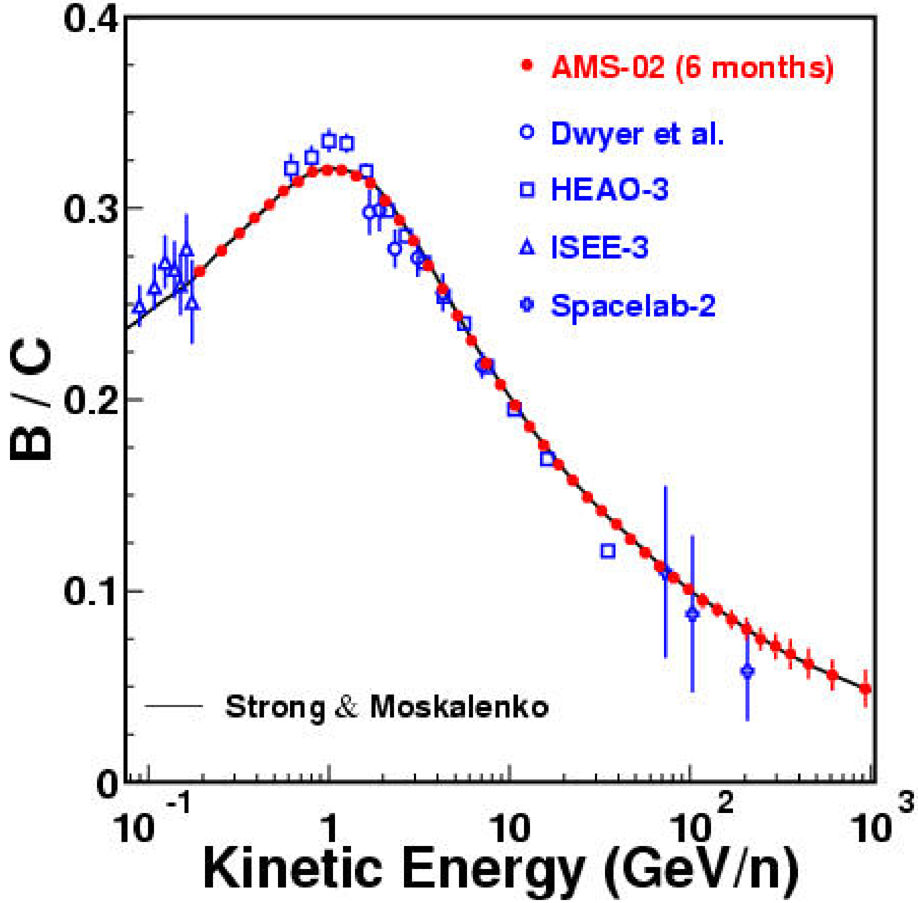


Antiprotons have been measured by many balloon and satellite experiments.

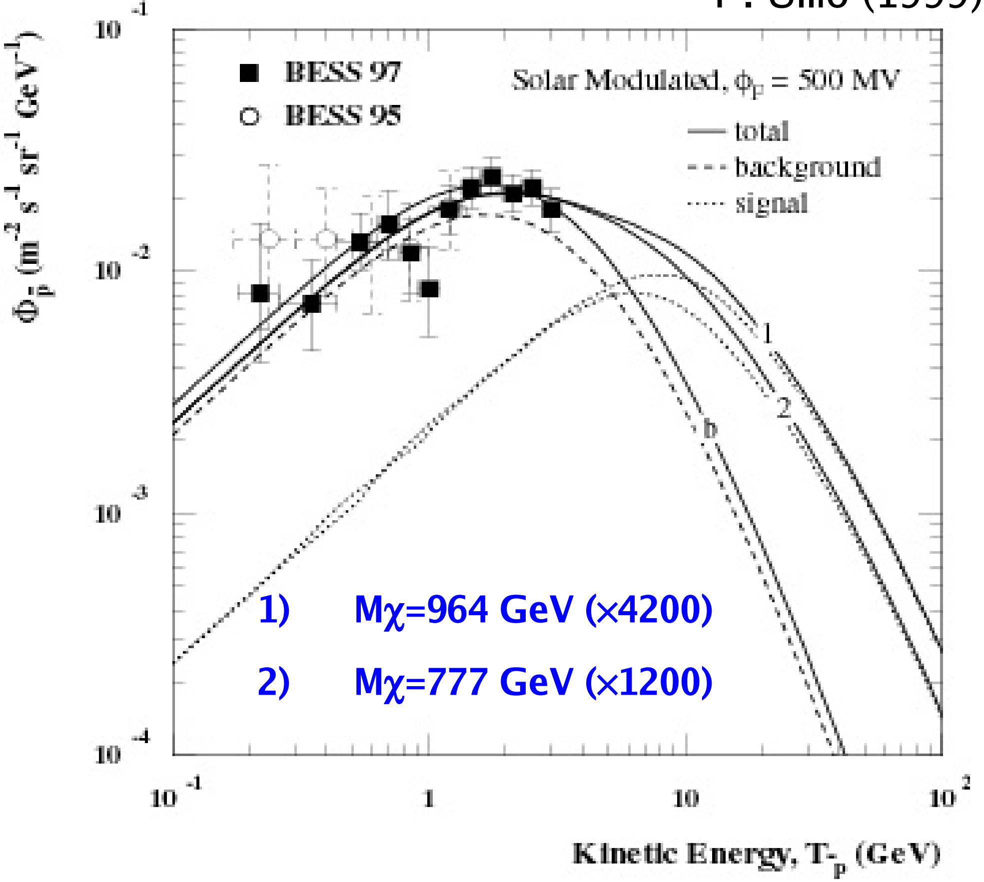
They are very sensitive to the physics details of cosmic ray propagation, particularly at low momentum. This is controlled by secondary/primary ratios, like B/C. AMS will measure the B/C ratio with high precision

AMS DM searches in the antiproton channel

Focus on dark matter signals at high momentum and control the propagation by B/C:



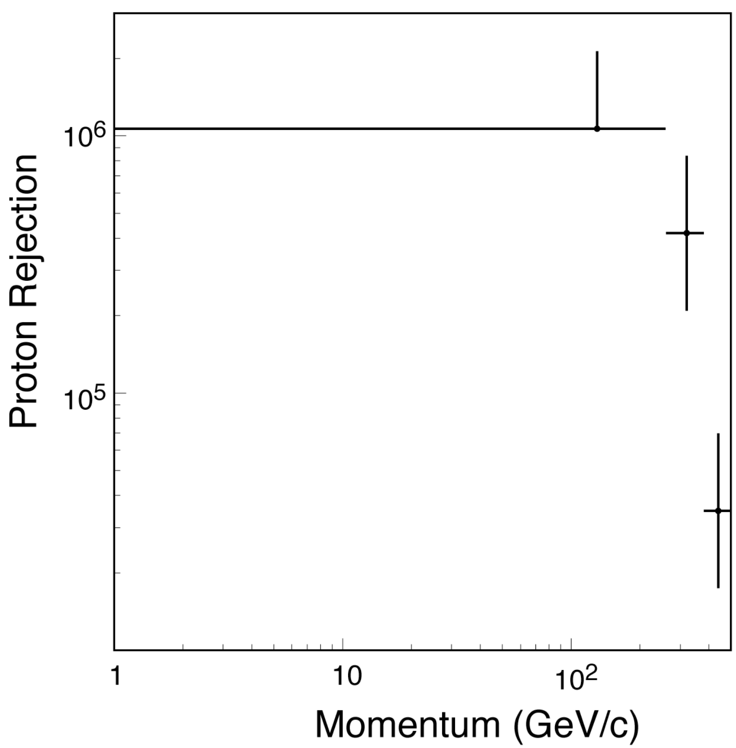
P. Ullio (1999)



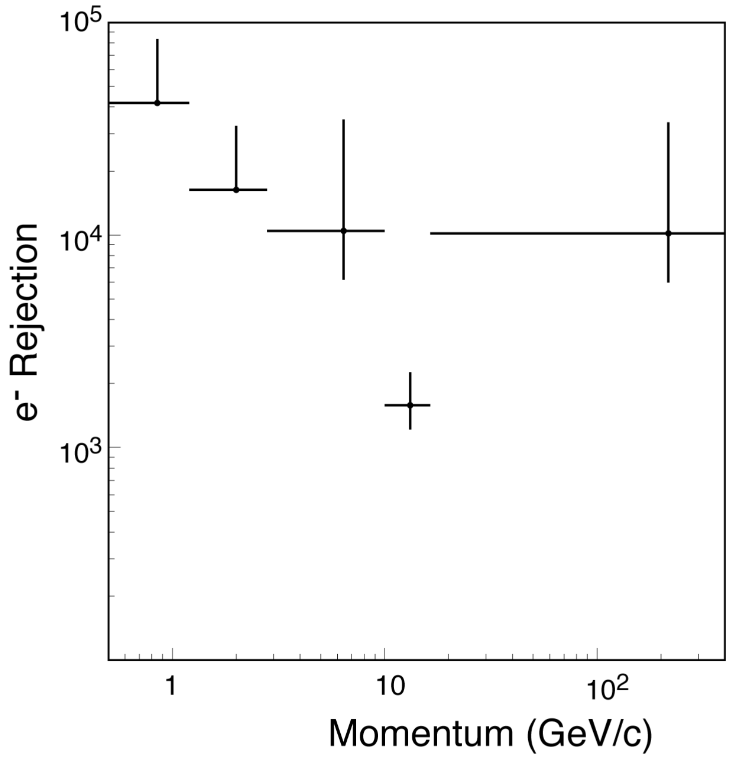
Ultra-precise measurement of the antiproton spectrum by AMS-02

Antiproton selection

- **Proton rejection: good control of charge confusion, interactions with the detector and misreconstructed tracks.**
- **Electron rejection: use TOF+RICH beta measurement at low energies, TRD and ECAL rejection capabilities at high energies.**



Rejection power ~10^6

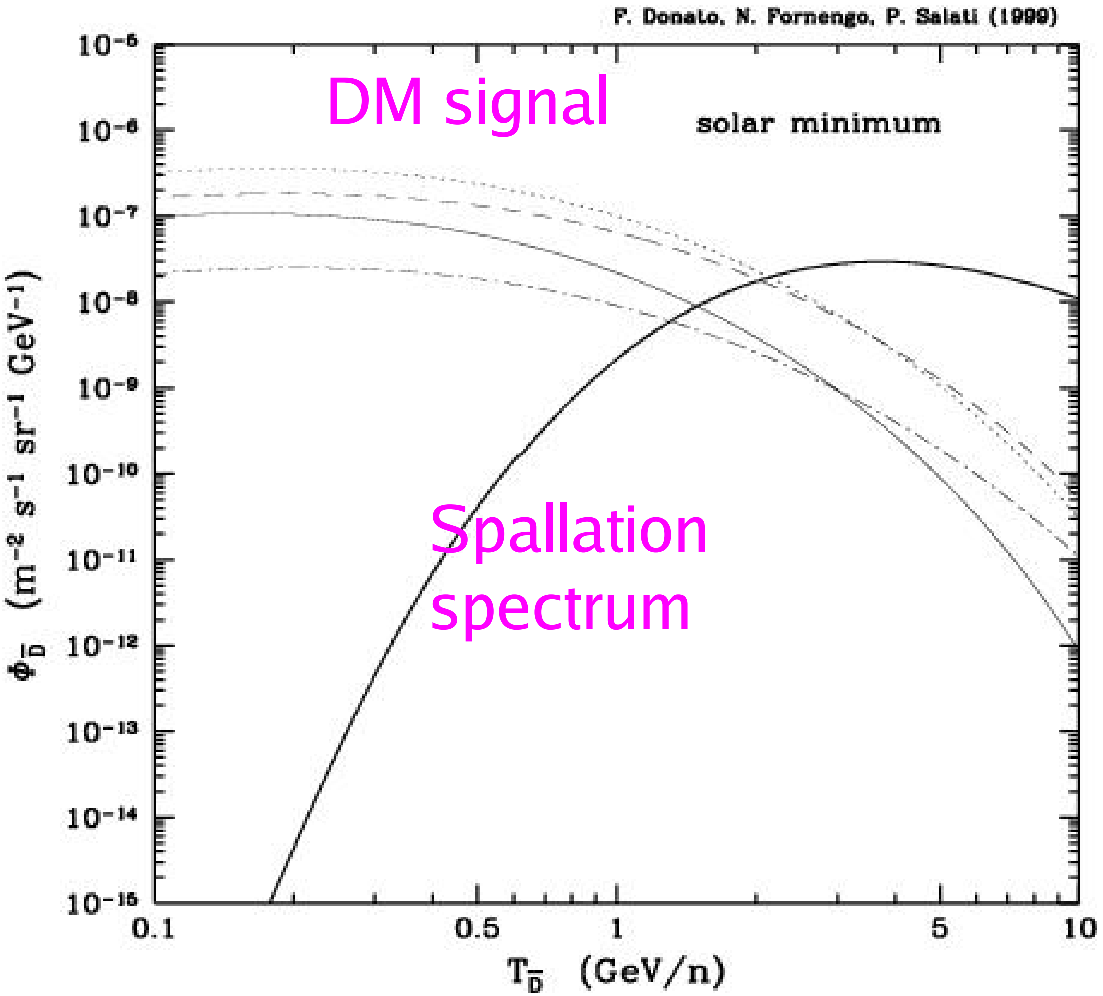


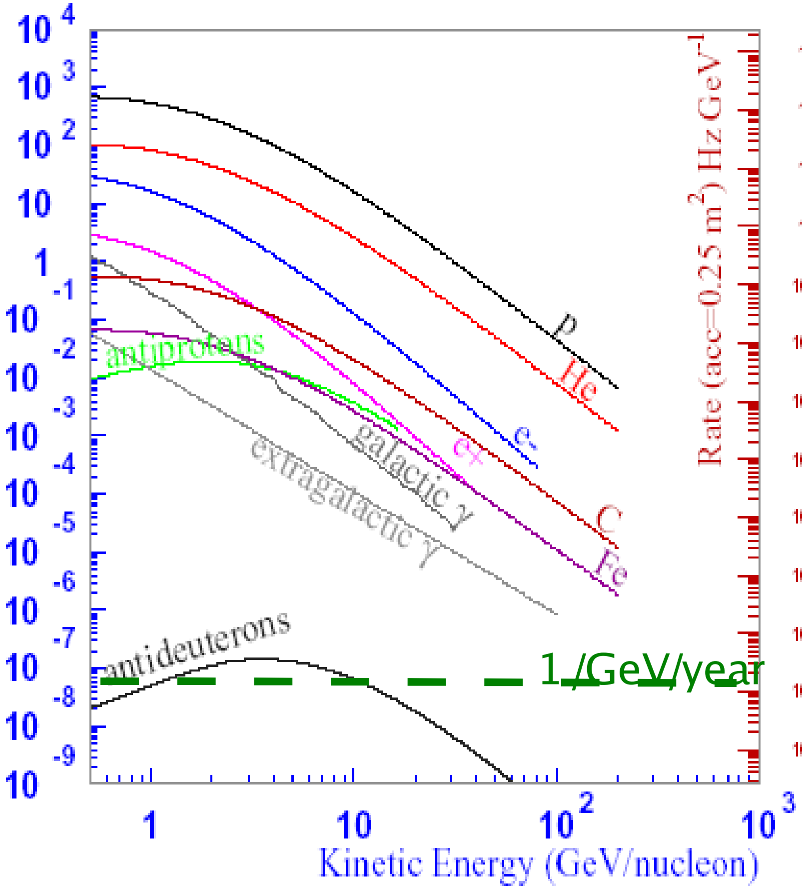
Rejection power >10^4

Acceptance:
0.16 m^2.sr
for [0.5-16] GeV
0.033 m^2.sr
for [16-300] GeV

Antideuterons on orbit

- **Antideuterons have never been measured in CR**
- **could be an alternative channel to look for dark matter signals.**
  Claim: almost background-free channel at low energies





M.Sapinski, Epiphany 2006

Antideuterons on orbit

PHYSICAL REVIEW D 71, 083013 (2005)

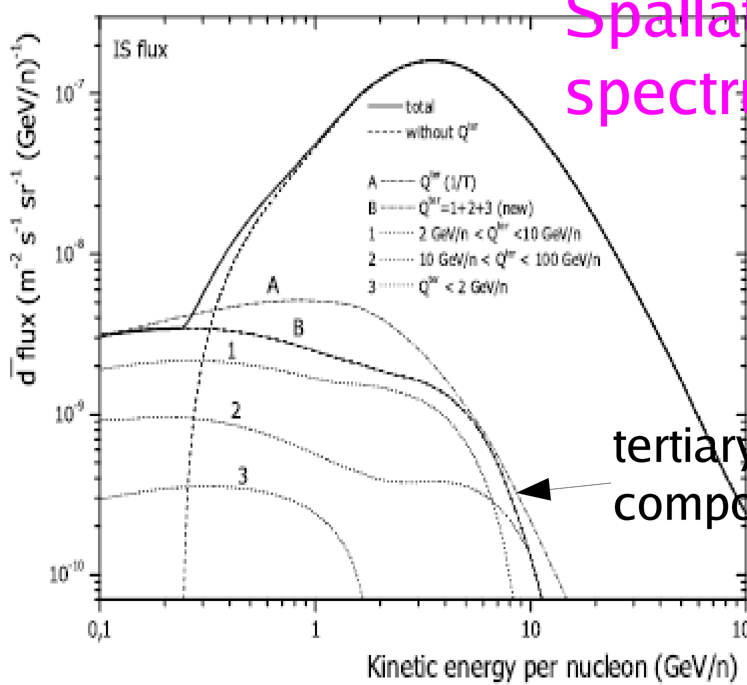
Flux of light antimatter nuclei near Earth, induced by cosmic rays in the Galaxy and in the atmosphere

R. Duperray,[1] B. Baret,[1] D. Maurin,[2] G. Boudoul,[1,*] A. Barrau,[1] L. Derome,[1] K. Protasov,[1] and M. Buénerd[1,†]
[1]*Laboratoire de Physique Subatomique et de Cosmologie, CNRS/IN2P3, 53 avenue des Martyrs, 38026 Grenoble-cedex, France*
[2]*Service d'Astrophysique, SAp CEA-Saclay, F-91191 Gif-sur-Yvette CEDEX, France*
(Received 18 November 2004; published 26 April 2005)

The fluxes of light antinuclei $A \leq 4$ induced near Earth by cosmic ray interactions with the interstellar matter in the Galaxy and with the Earth's atmosphere are calculated in a phenomenological framework. The hadronic production cross section for antinucleons is based on a recent parametrization of a wide set of accelerator data. The production of light nuclei is calculated using coalescence models. For the standard coalescence model, the coalescence radius is fitted to the available experimental data. The nonannihilating inelastic scattering process for the antideuterons is discussed and taken into account for the first time via a more realistic procedure than used so far for antipro

DOI: 10.1103/PhysRevD.71.083013

Spallation spectrum



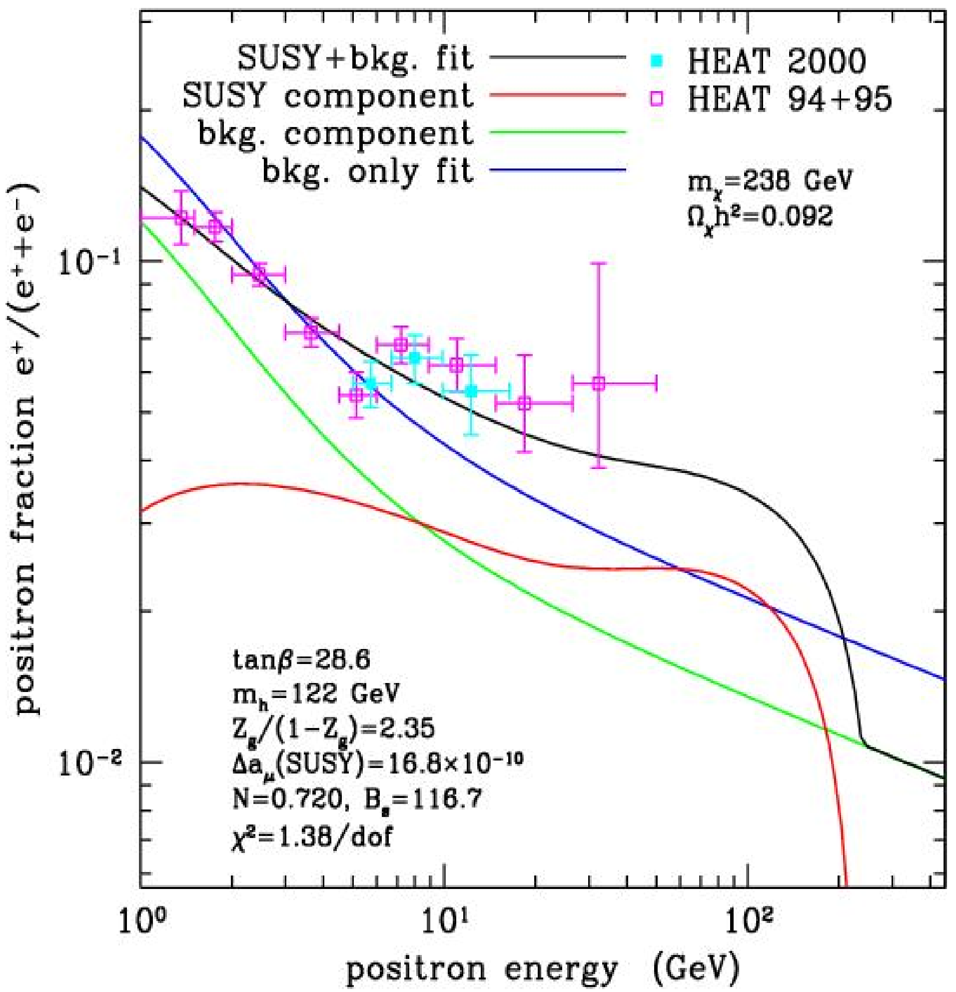
tertiary component

Estimate of AMS potential under study: focused on low momenta, antiproton flux is the main background – need 10^5 discrimination - mass resolution is crucial!

TOA flux prediction is even less optimistic

Positron signals of dark matter

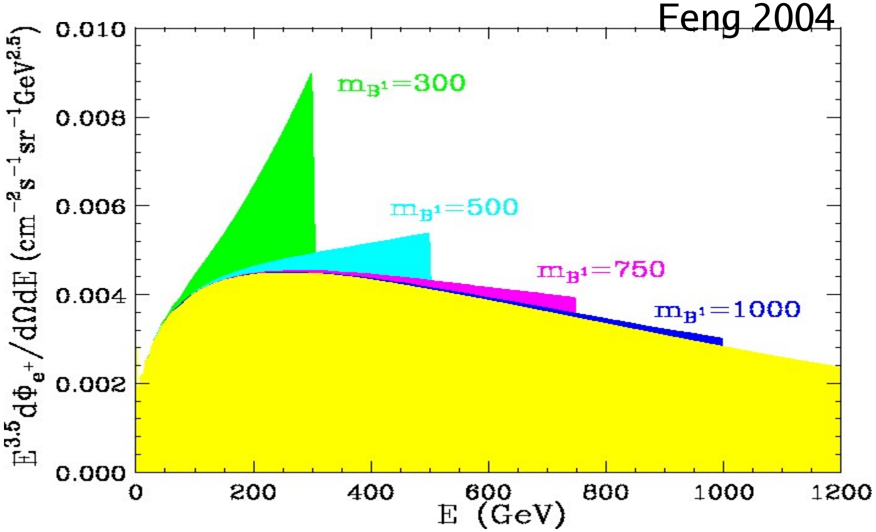
- **Positrons travel shorter distances (a few kpc), so the discovery potential is just dependent on the dark matter density at the local level.**



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

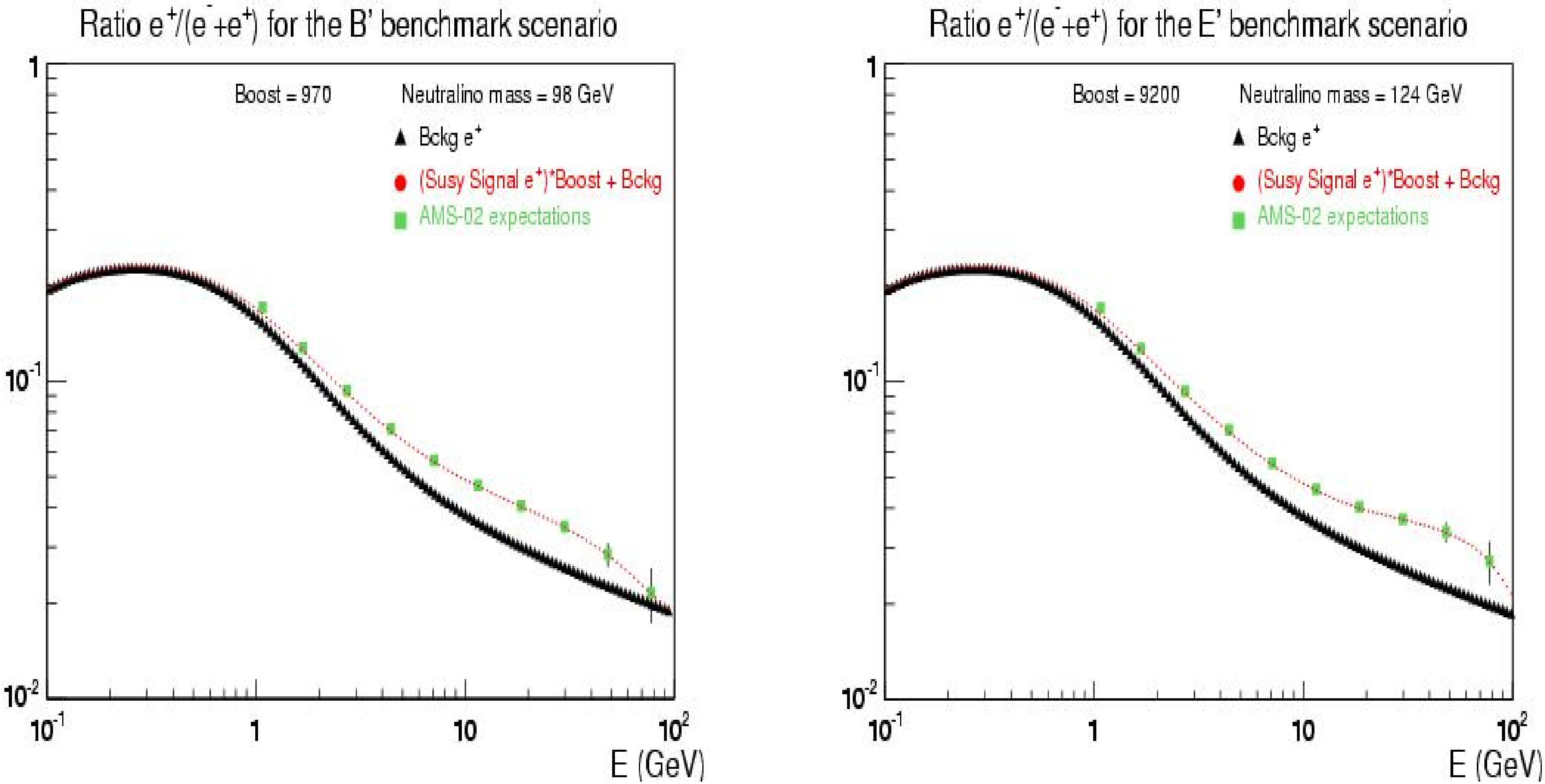
- **Very sensitive to boost factors (clumpiness).**
- **Non-negligible uncertainties on cosmic-ray propagation effects: $e^+/(e^++e^-)$ fraction used (less sensitive to solar modulation)**
- **Hint of a dark matter component in HEAT data?**

Feng 2004



SUSY DM searches in the positron channel

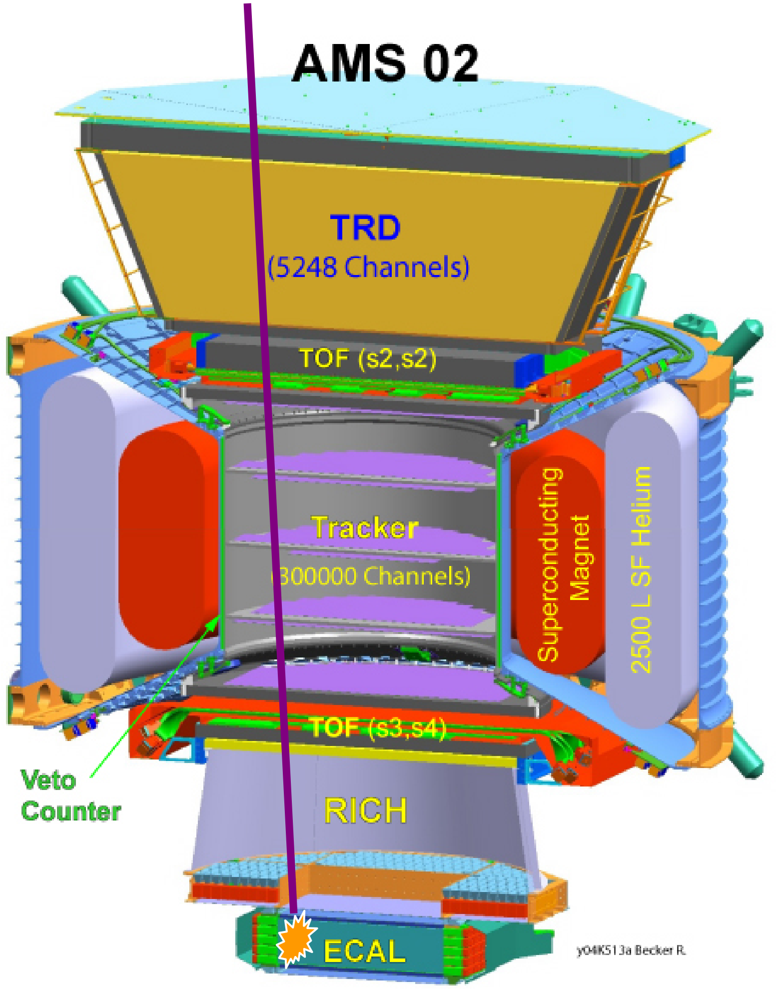
Boost factors tuned in order to match the HEAT excess

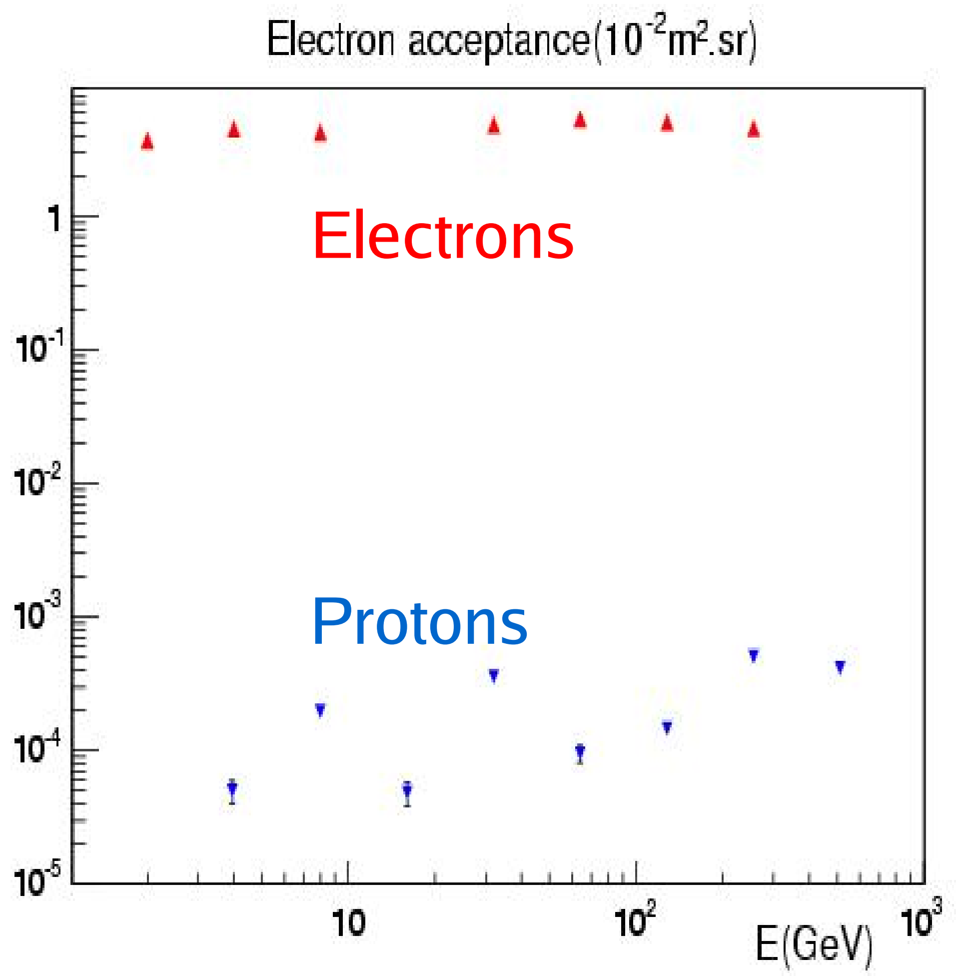


B' ('bulk') and E' ('focus point', $\chi\chi$->WW dominated) benchmark scenarios (convention from Ellis, Olive et. al., 2003)

Distinctive feature: sudden drop at high energies

Positron detection in AMS



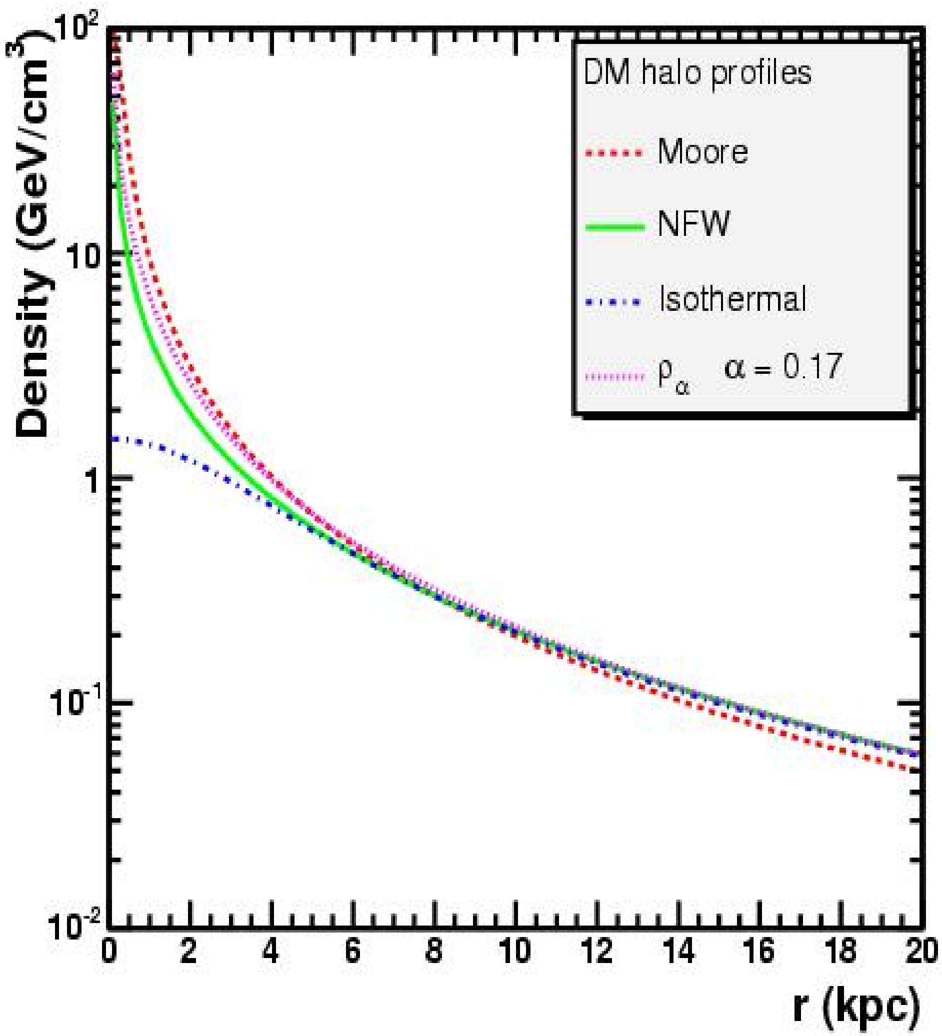


Positrons: precise measurement in the electromagnetic calorimeter.

Main criteria to reject protons (main background): 'electromagnetic shape' in ECAL, large X ray activity in TRD

Gamma signals of dark matter

- **Gammas travel long distances, point to the source, detection highly dependent on the dark matter halo profile of the galaxy**



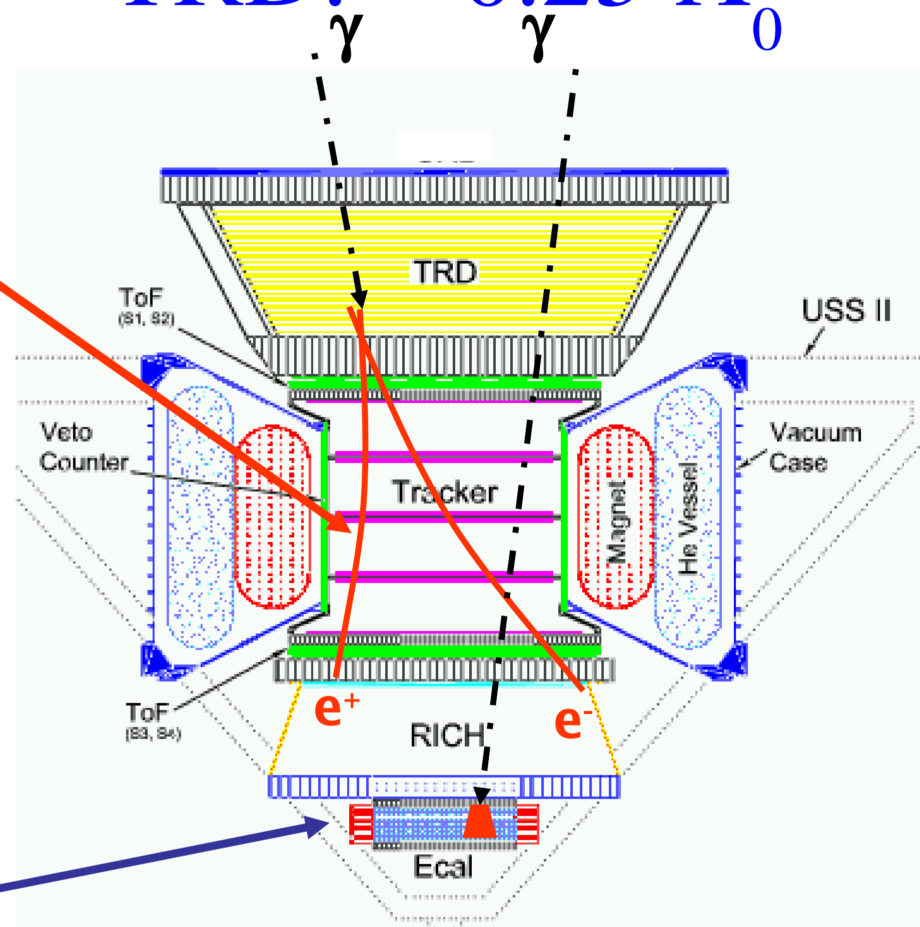
- **Possibility to treat the center of the galaxy as a very intense point-like source of gammas from dark matter annihilations.**
- **How cuspy is the halo profile at r=0? Controversial issue.**
- **Possibilities of enhancement at the galaxy center: super-massive black hole (SMBH), adiabatic compression,...**

Gamma detection in AMS

- **Two complementary modes:**

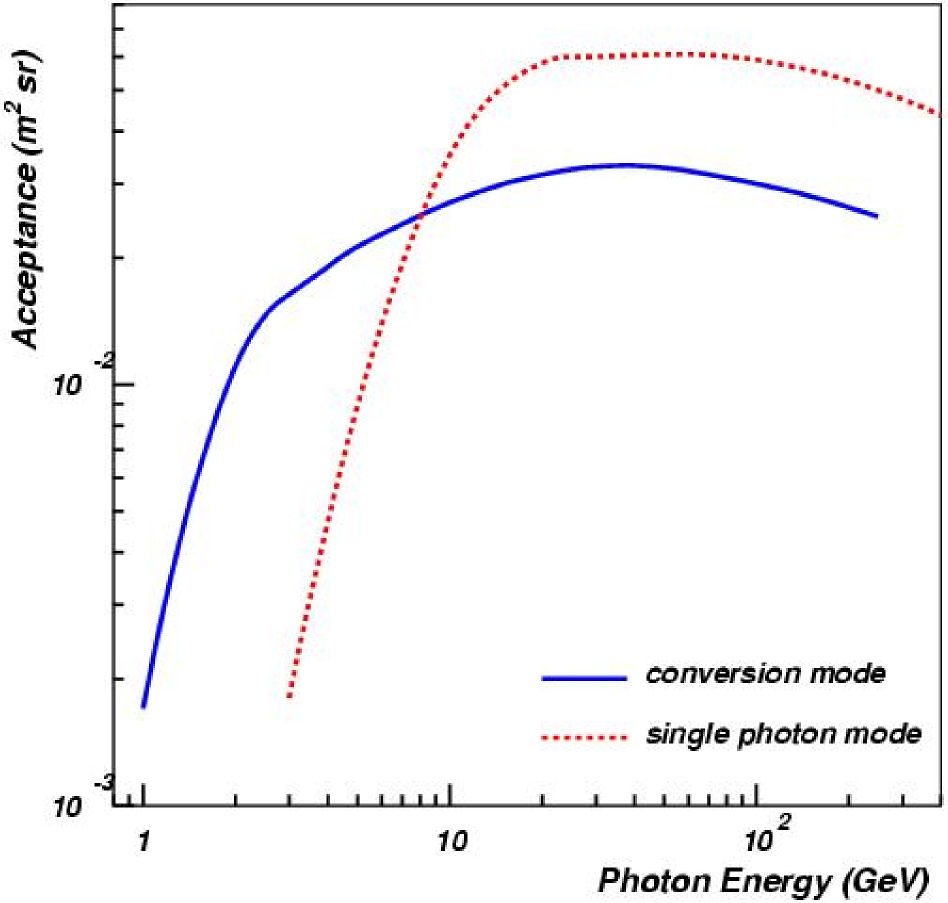
Tracker: photon conversion in upstream layers of the detector. Criteria: very small invariant mass, no TRD activity in the top layers, no particle activity in the rest of the detector

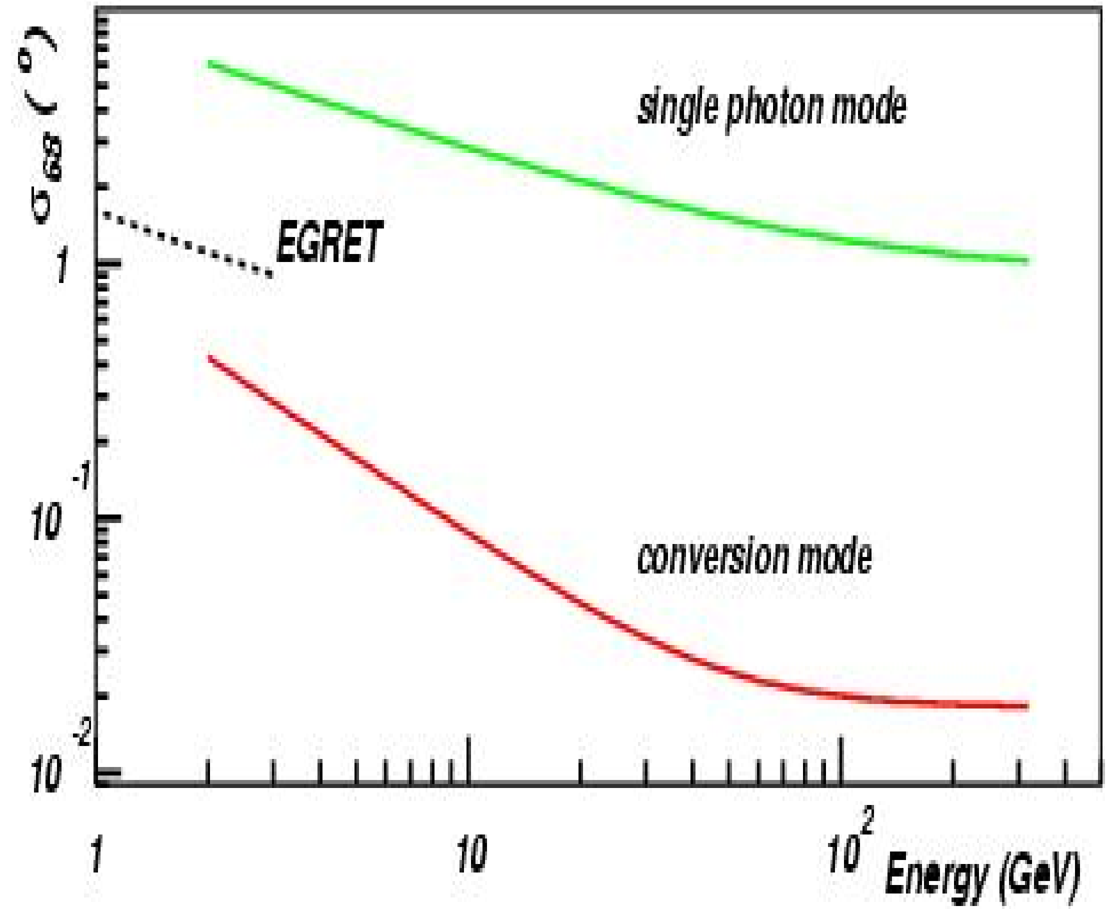
TRD: ~ 0.25 X_0



ECAL: detection in the electromagnetic calorimeter. Criteria: 'electromagnetic shape', no activity in the rest of the detector

Gamma acceptance/resolution in AMS



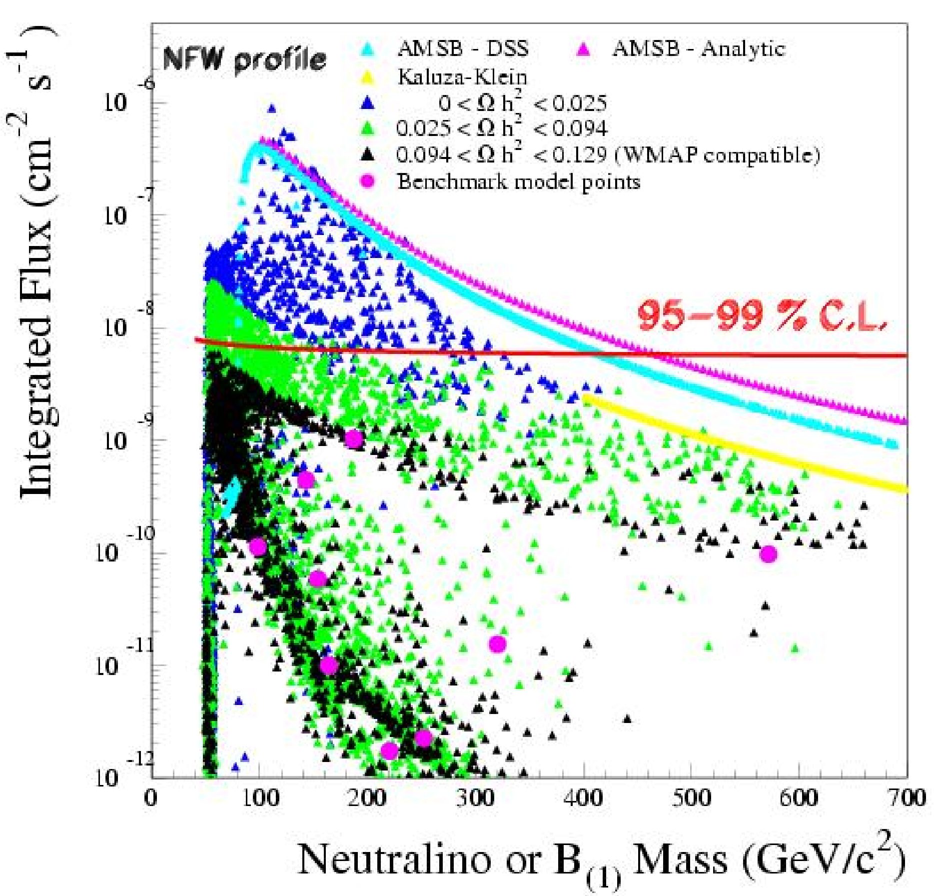


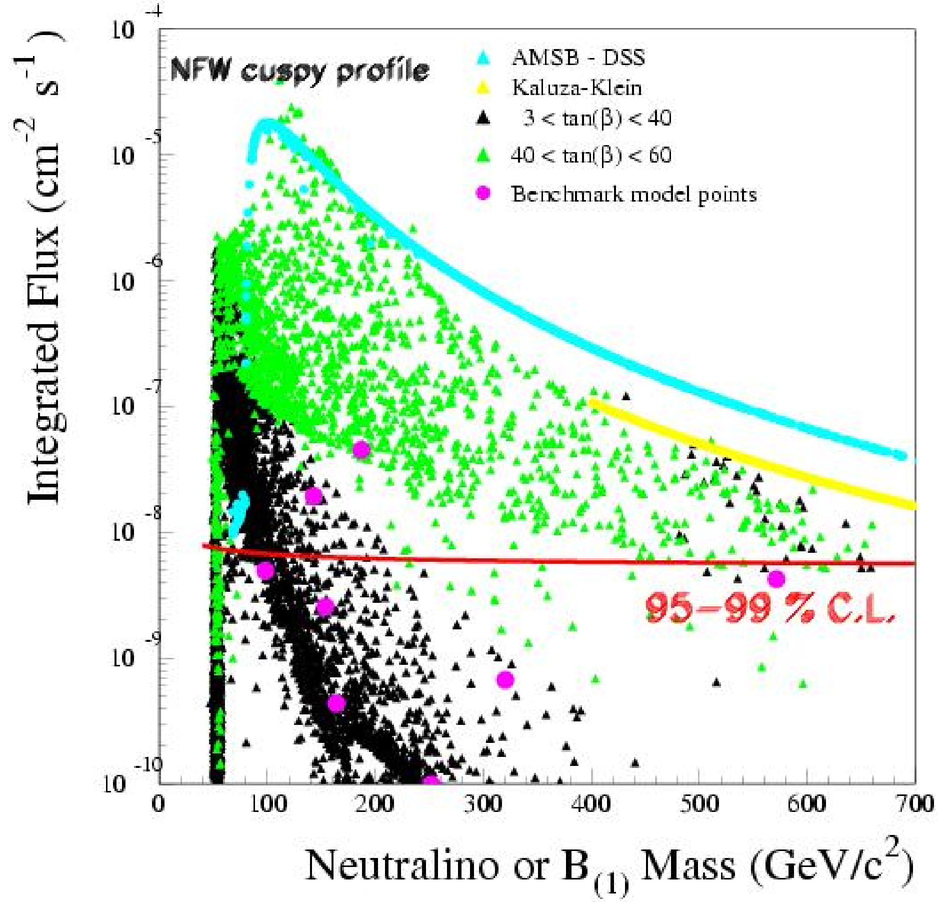
- **Lower energy threshold for the 'conversion' (tracker) mode.**
- **Larger acceptance in 'single photon' (ECAL) mode at high energies.**

- **Excellent angular resolution for the 'conversion' (tracker) mode (~0.02° at high energy)**

SUSY DM searches in the γ channel

Assume a cuspy profile at the center of the galaxy and treat it as a point-like source. No extra boost factors considered:





astro-ph/0508349

Large exclusion potential for AMSB models and cuspy halos

Other more distinctive effects under study:

directional dependence, monoenergetic peaks

M.Sapinski, Epiphany 2006

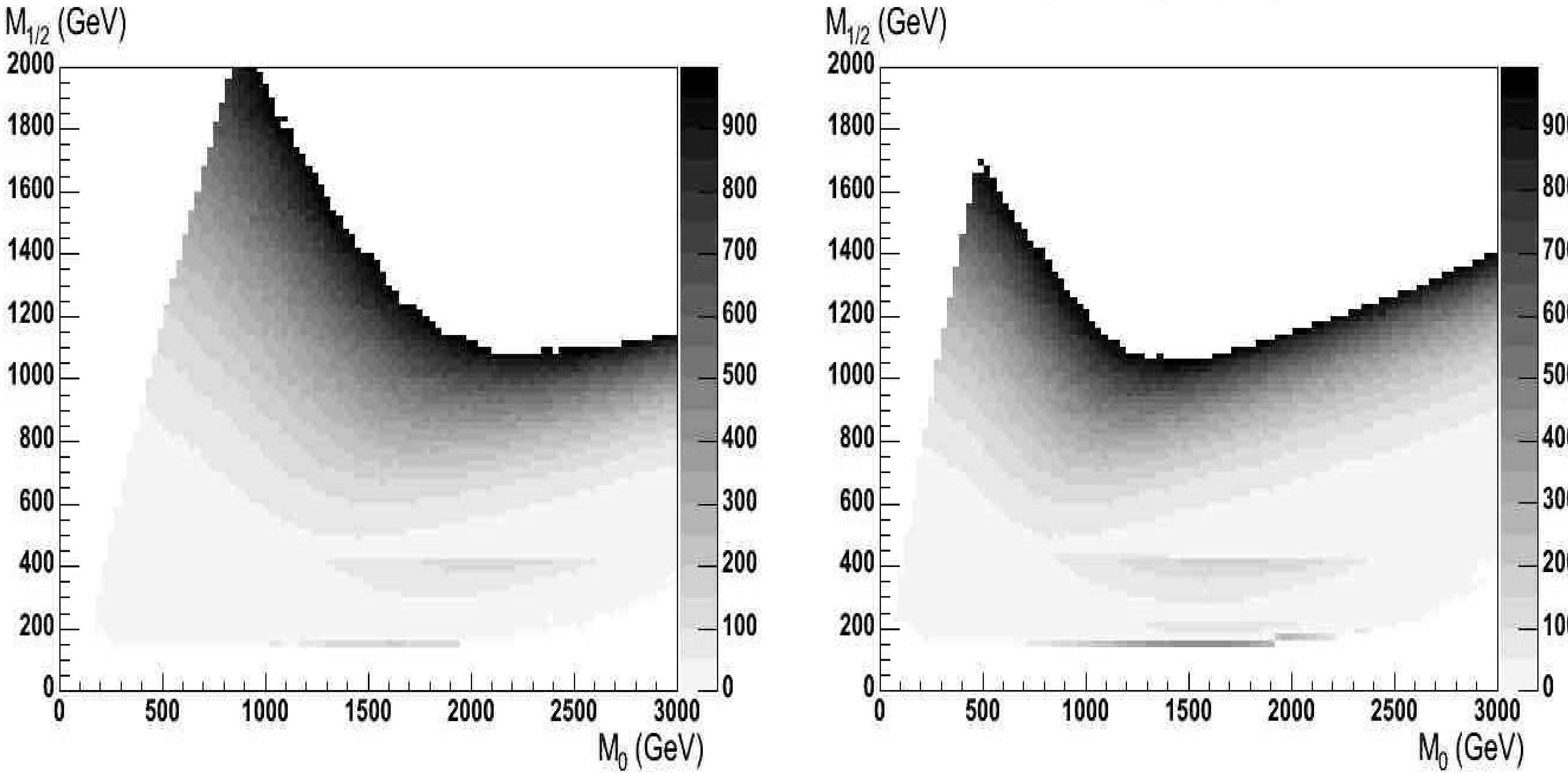
Summary

- **The AMS experiment, during its 3 year mission, will be able to measure simultaneously and with high precision the rates and spectra of antiprotons, antideuterons, positrons and gammas in the GeV-TeV range.**
- **AMS will measure the high energy tail of the antiproton spectrum to an unprecedented accuracy.**
- **AMS will be able to confirm or disprove with high accuracy the excess in HEAT positron data in the few GeV region.**
- **A gamma dark DM signal from the galactic center will be visible in AMS in the case of a cuspy halo profile or extra enhancements (SMBH, adiabatic compression). Other -maybe more distinctive- DM features are under study.**
- **These are some of the most promising channels for indirect detection of SUSY dark matter. A simultaneous study of these channels, together with other quantities (B/C ratio, ...) is a necessary step to disentangle purely astrophysical effects from true dark matter signals.**

Extra slides

Boost factors and general MSSM scans

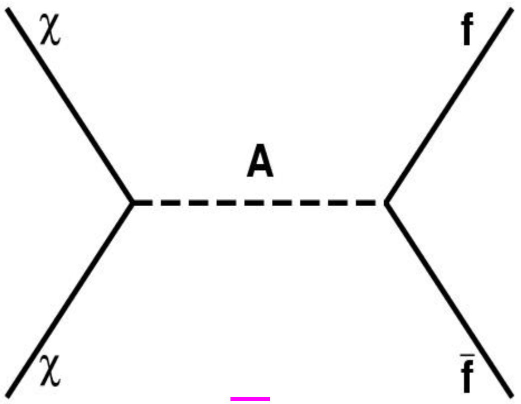
Minimal boost factors for discovery in a scan of the mSugra parameter space



$M_1=M_2=M_3=M_{½}$; tan β=40 **$M_1=M_2=M_{½}$; M_3= 0.8 $M_{½}$; tan β=20**

Boost factors may change substantially with slightly different assumptions at the GUT scale

Indirect detection: neutralino annihilation



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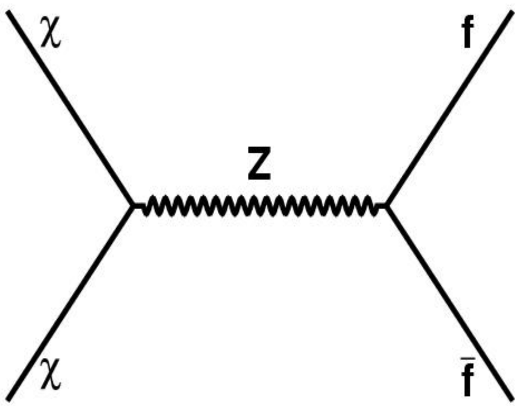

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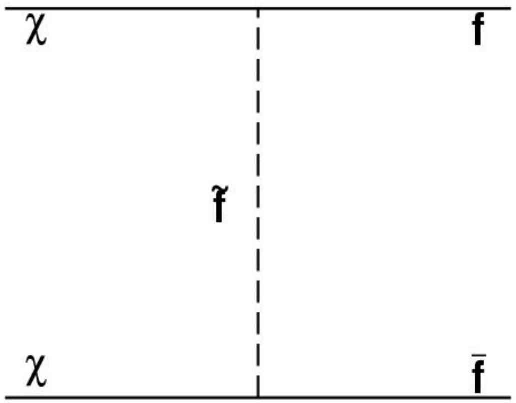

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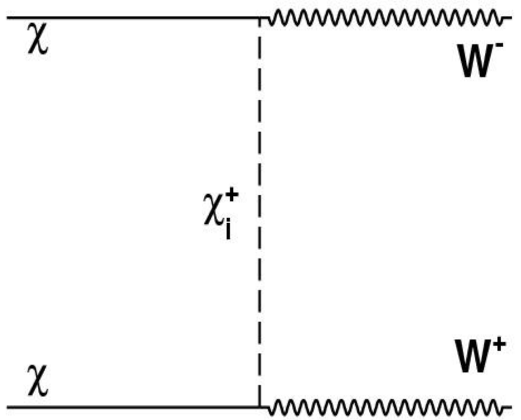
$\chi\chi$->A-> $\bar{b}$b dominant in many scenarios



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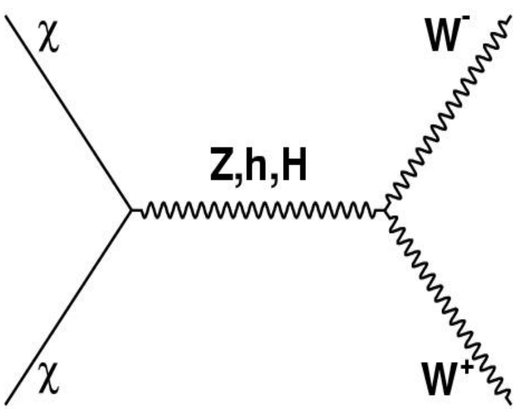

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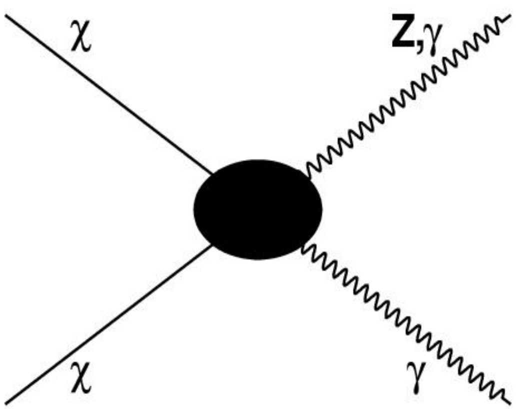
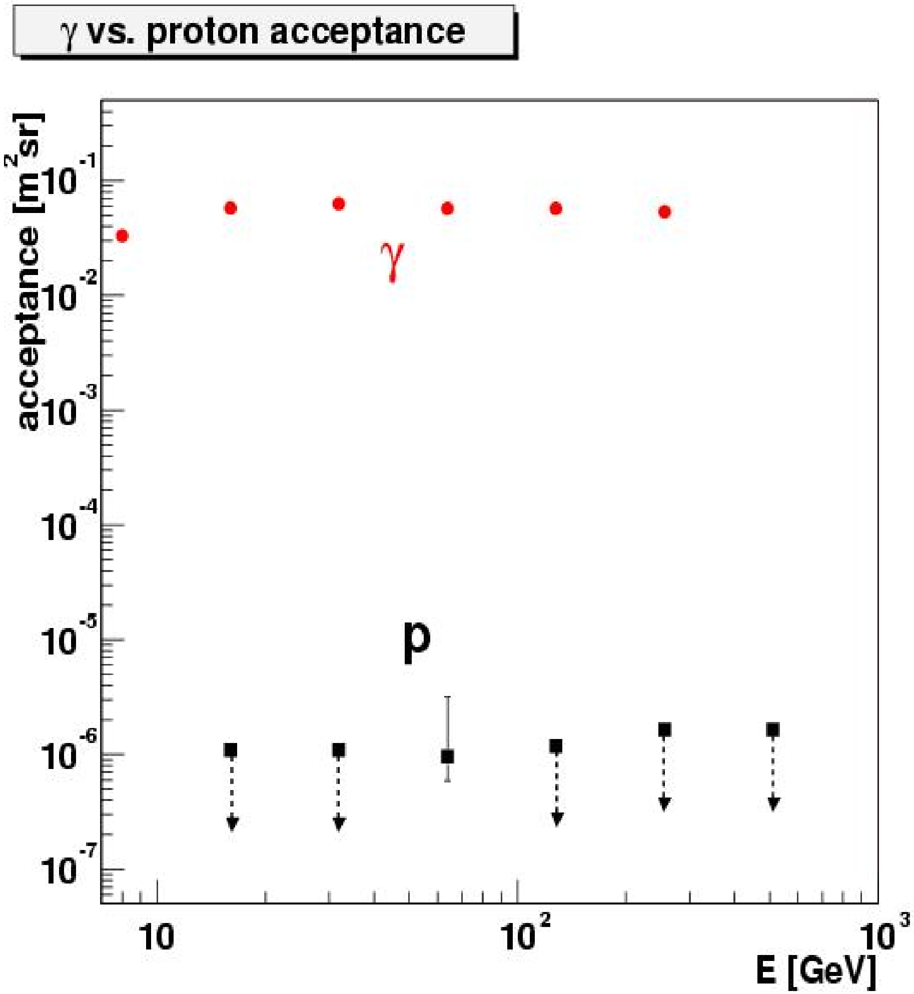


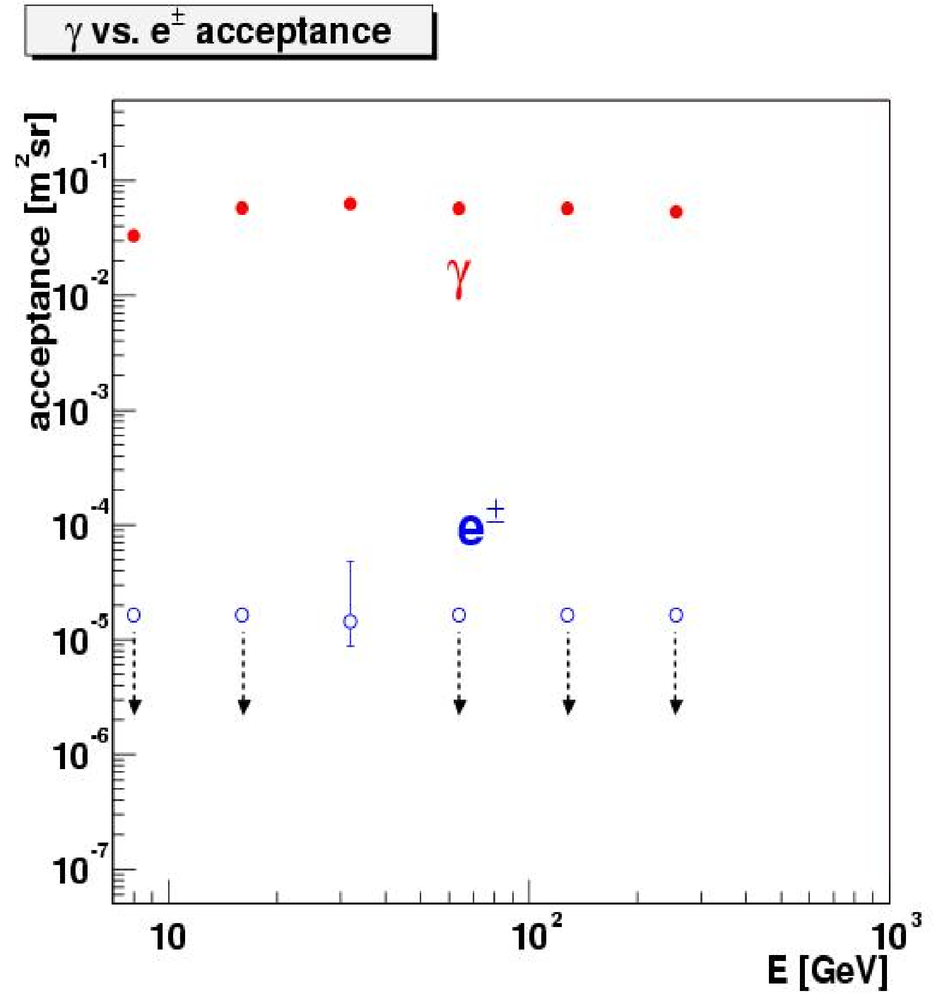
, …

W-> e ν decay is interesting

Low rate, but monoenergetic signals

Background rejection in ECAL mode





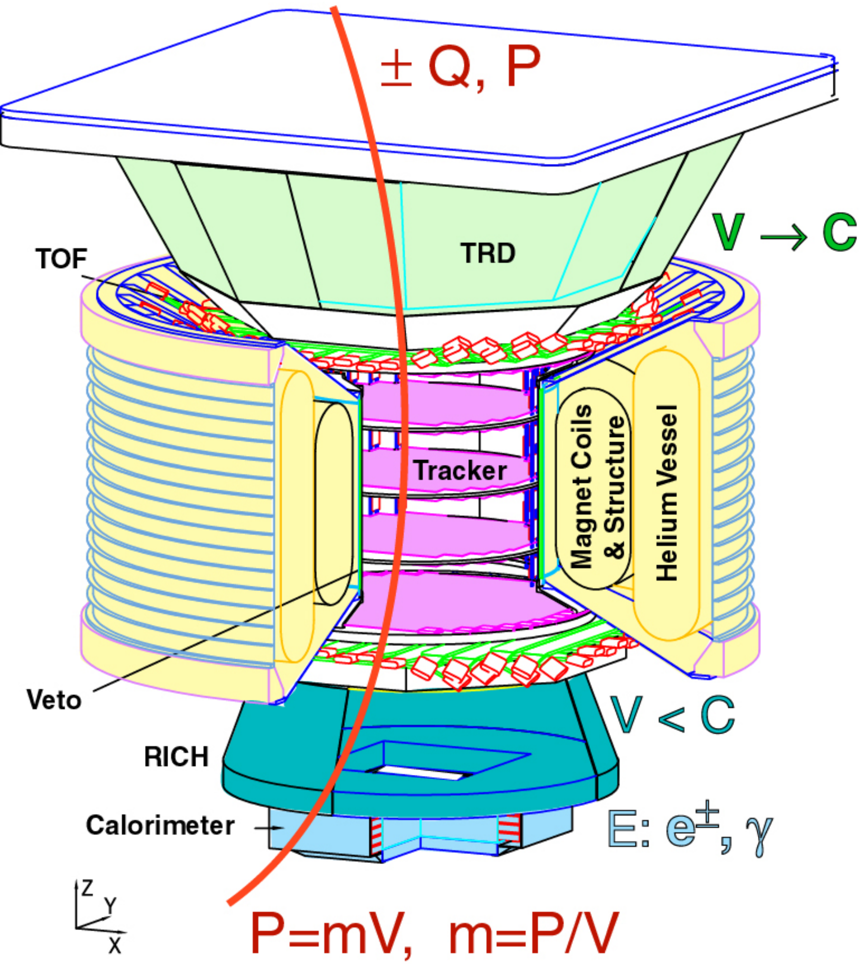
Rejection power ~10^5

Rejection power ~10^4

Similar order of magnitude results for the 'conversion' mode

Identification criteria in AMS-02

AMS-02

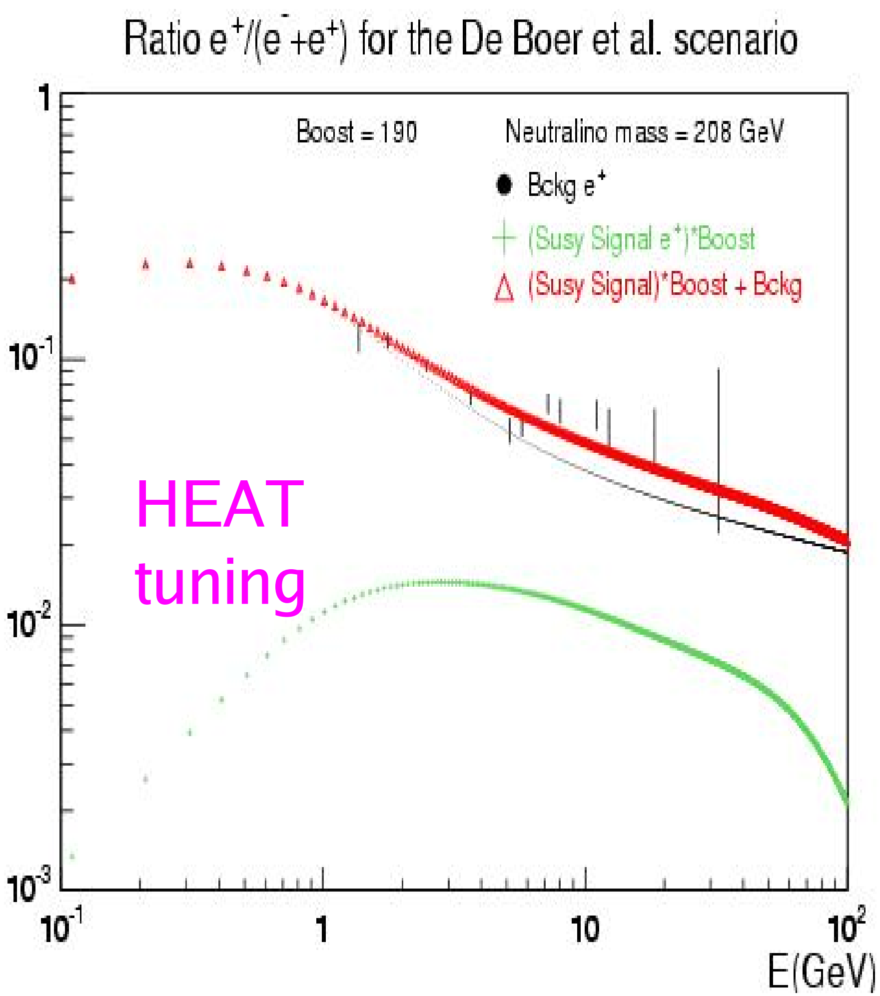


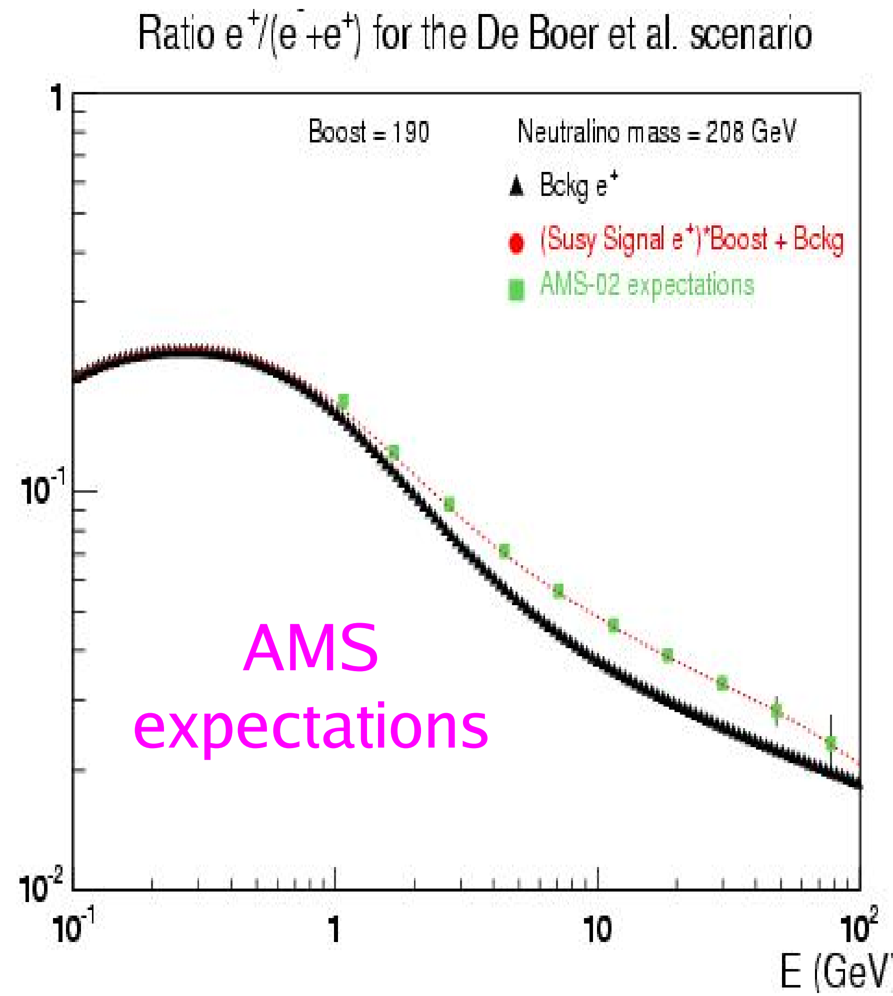
300 GeV	e^-	e^+	P	$\overline{He}$	γ	γ
TRD						
TOF						
Tracker						
RICH						
Calorimeter						

Charged particles: $Q, P, V \rightarrow Q, m \Rightarrow$ *identification*

SUSY DM searches in the positron channel

Boost factors tuned in order to match the HEAT excess. De Boer et al. scenario (simultaneous fit to $\bar{p}$ spectrum+HEAT+EGRET excesses, 2003), with a $\chi\chi \rightarrow \bar{b}b$ dominant decay (tan β = 50)





Model description: Astrophysics

The way to parameterize the mass density profile can be generically given by the following equation:

$$\rho_\chi(r) \;=\; \rho_0 \left(\frac{R_0}{r}\right)^\gamma \left\{\frac{R_0^\alpha + a^\alpha}{r^\alpha + a^\alpha}\right\}^\epsilon \quad , \qquad (1)$$

which counts for a simple spherical Galactic halo.

The parameters that enter the halo modelling are:

- R_0 - distance from Earth to GC,
- ρ_0 - halo density at the R_0,
- a - core radius - for $r < a$ halo density is equal to $\rho(a)$ to avoid singularity in case of the isothermal parametrization.

For the conventional NFW-*standard* model the generic parameter values are: $R_0 = 8.0\ kpc$, $\rho_0 = 0.3\ GeV/cm^3$, $a = 20\ kpc$. As shown in [18], the (ρ_0, a) parameters can be chosen to get the high value of the photon flux: $R_0 = 8.5\ kpc$, $\rho_0 = 0.4\ GeV/cm^3$, $a = 4\ kpc$ (NFW-*cuspy*). These two configurations were considered. The values for Moore profile have been chosen in the following way: $R_0 = 8.0\ kpc$, $\rho_0 = 0.3\ GeV/cm^3$, $a = 28\ kpc$.

$$\Phi_\gamma \;=\; \frac{1}{4\pi}\,\frac{\langle\sigma v\rangle\, n_\gamma}{2\, m_{wimp}^2} \int_{\rm los} \rho_{wimp}^2(r)\, ds \quad . \qquad (2)$$

Model description: Extra Dimensions

Universal Extra Dimension: all SM fields propagate in e.d. =>
=> Kaluza-Klein parity conservation in four-dimensional effective theory: LKP stable

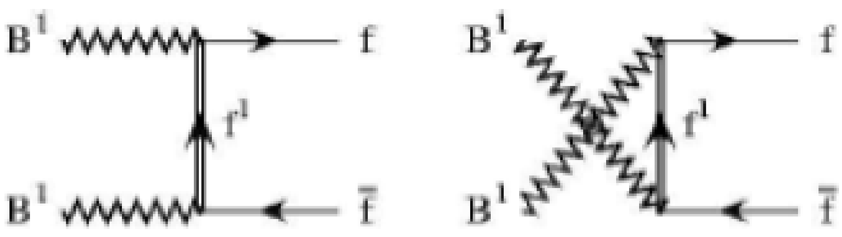
$$m_{LKP} \approx \frac{1}{R} > 300 \text{ GeV} \qquad 400\ GeV \leq m_{LKP} \leq 1200\ GeV$$

The most promising LKP, non-baryonic and neutral is the first level of KK modes of the hypercharge gauge boson B $^{(1)}$

It can decays into two fermions: $B^{(1)}B^{(1)} \to f\bar{f}$

G. Bertone et al. Phys.Rev. D68 (2003) 044008
G.Servant and T.Tait, Nucl.Phys. B650 (2003) 391-419

Channel	Branching ratio
quark pairs	35%
charged lepton pairs	59%
neutrino pairs	4%
Higgs bosons	2%



$$\Phi_\gamma(\Delta\Omega, E_\gamma > E_{th}) = 3.4\,10^{-12}\,N_\gamma \left(\frac{1\,TeV}{m}\right)^4 J(\Delta\Omega)\times\Delta\Omega \quad cm^{-2}s^{-1}$$