Indirect Dark Matter Search with

Alpha Magnetic Spectrometer

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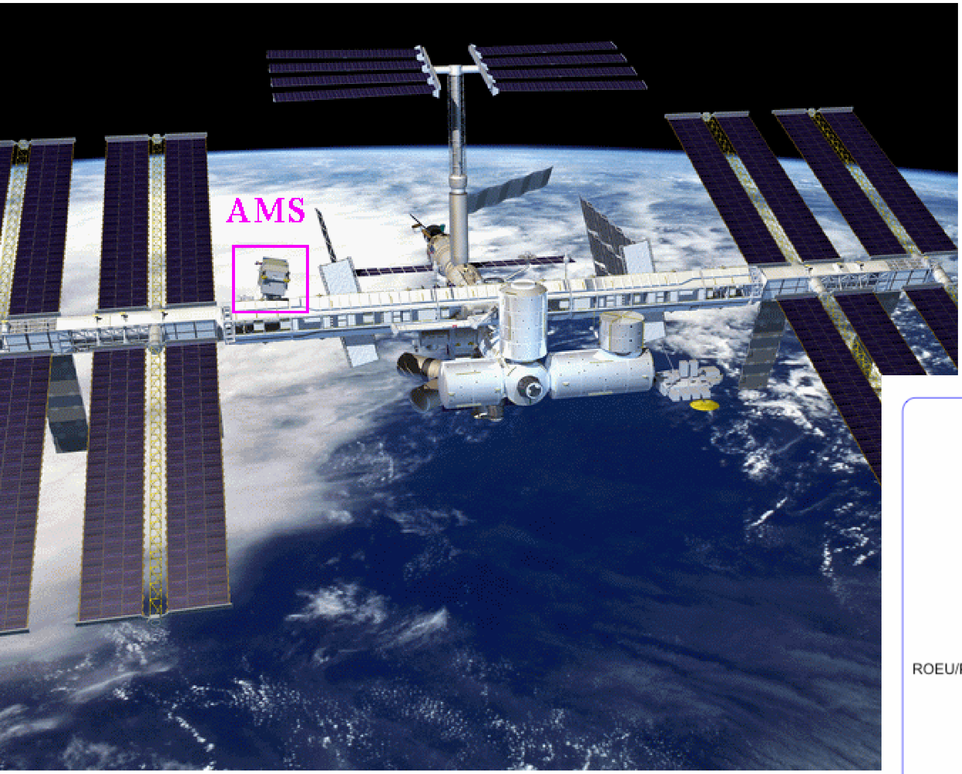
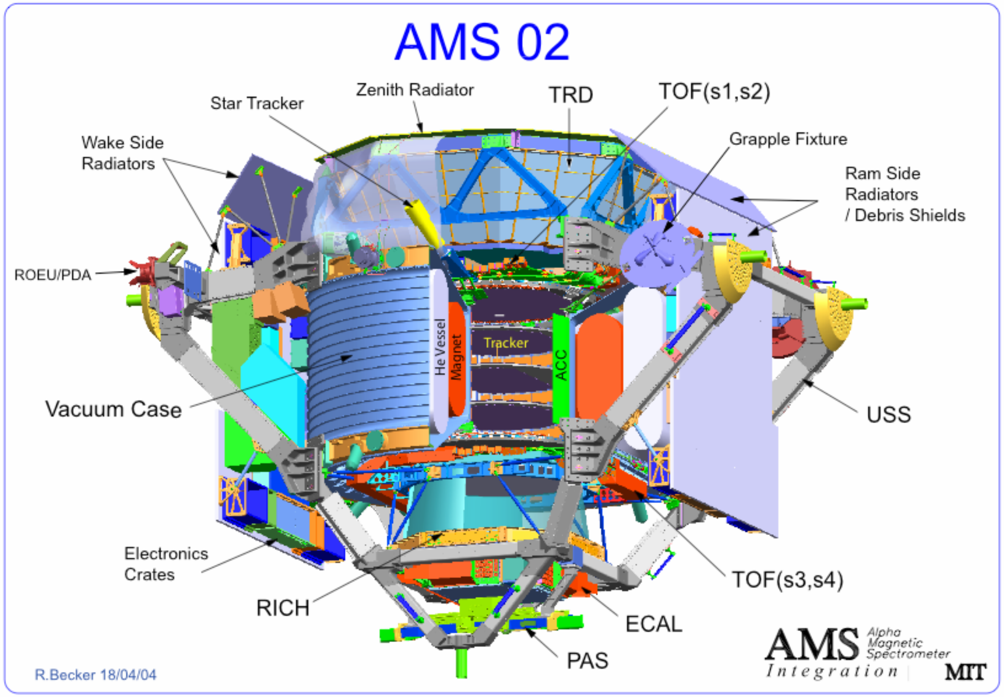
The AMS Experiment

AMS is a large acceptance superconducting magnetic spectrometer in space scheduled to be installed on ISS in 2007 for 3 to 5 years mission.





AMS 02: General characteristics:

Mechanical and geometrical characteristcs

- **Minimum amount of matter (X_0) before ECAL**
- **Acceptance 0.5 m^2.Sr -> anti-He search**
- **Velocity measurement $\Delta\beta/\beta = 0.1$ % to distinguish ^9Be, ^{10}Be, ^3He, ^4He isotopes.**
- **Rigidity R= pc/|Z|e (GV) proton resolution 20% at 0.5 TV and Helium resolution of 20% at 1 TV.**
- **Antihelium/Helium identification factor 10^{10}.**

Multiple and independent measurements to reach performances required :

- **|Z| measured from Tracker, RICH, TOF.**
- **Sign of charge Z measured from tracker (8 points).**
- **Velocity β measured from TOF, RICH.**
- **Hadron/electron separation from TRD, ECAL.**

Detector requirements :

- **Suppress proton background 10^{-6}**
- **Tracking up to 1 TV**

AMS 02: General Characteristics

Experiment in International Space Station
(--> Constraints for launch and space**):**

- **Environment** **(day/night: $\Delta T \sim 100^{o}C$)** **---> Thermal**
- **Launch: --->Vibration (6.8 G RMS) and G-Forces(17G)**
- **Limitation : Weight (14 809 lb) and Power (2000 W)**
- **Vacuum: $< 10^{-10}$ Torr ---> Cooling..**
- **Reliable for more than 3 years ---> Redundancy**
- **Radiation: Ionizing Flux ~1000 $cm^{-2}s^{-1}$**
- **Orbital Debris and Micrometeorites**
- **Must operate without services and human intervention**

AMS 02: Detector

Transition Radiation Detector : **$p^+/e^+ < 10^{-2}$ 10-300 GeV**
20 Layers Fleece +5248 6mm Straw Drift Tubes (Xe/CO_2)

Time Of Flight Upper 1,2 : **trigger, β**
scintillators, σ_t =~120ps

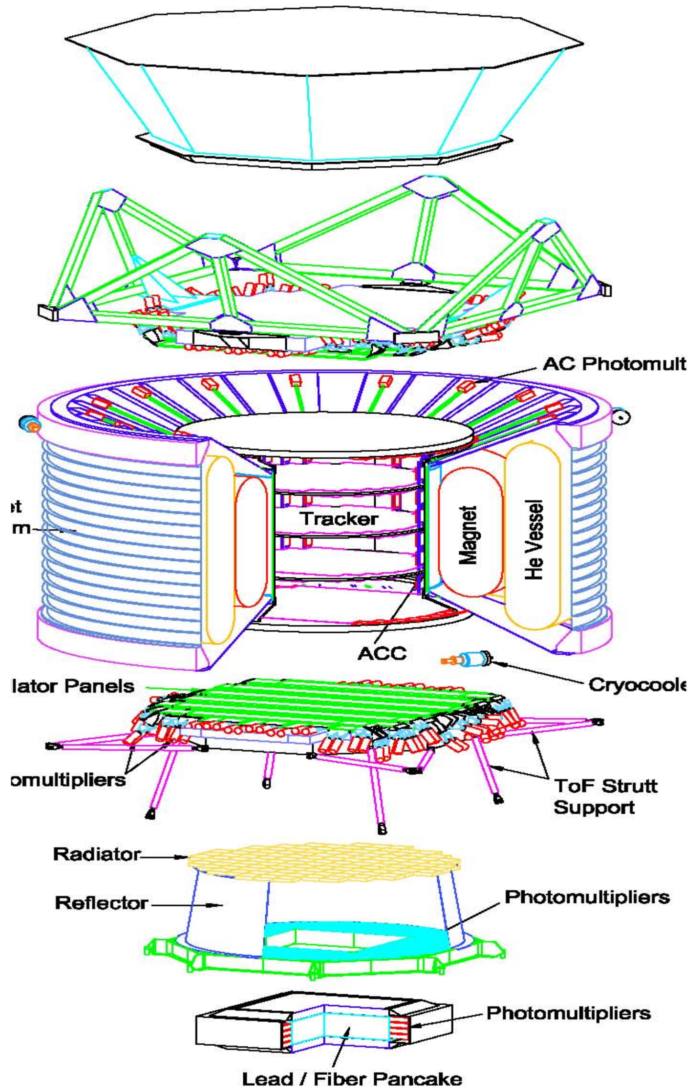
Superconducting Magnet : **Rigidity up to 1 TeV**
BL^2 = 0.85 Tm^2 V=0,6m^3 **charge separation, β**

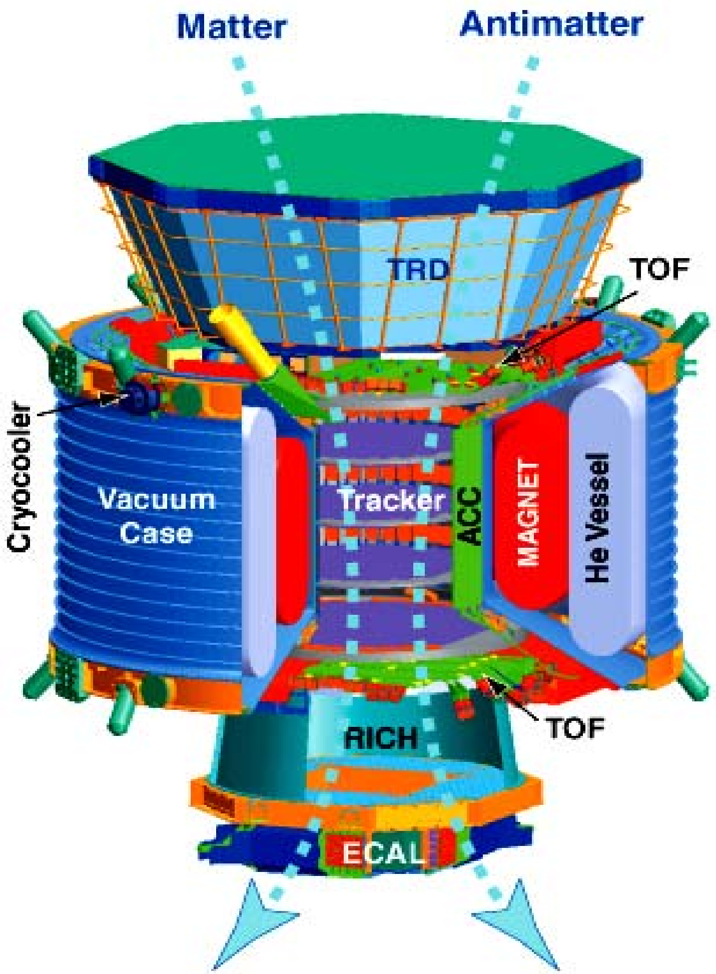
Tracker (8 layers) : **Charge separation**
3double +2single sided silicon strips, 6m^2

Time of Flight Lower 3,4 **$p^+/e^+ > 3\sigma$ <2 GeV**
scintillators,Dt =~120ps

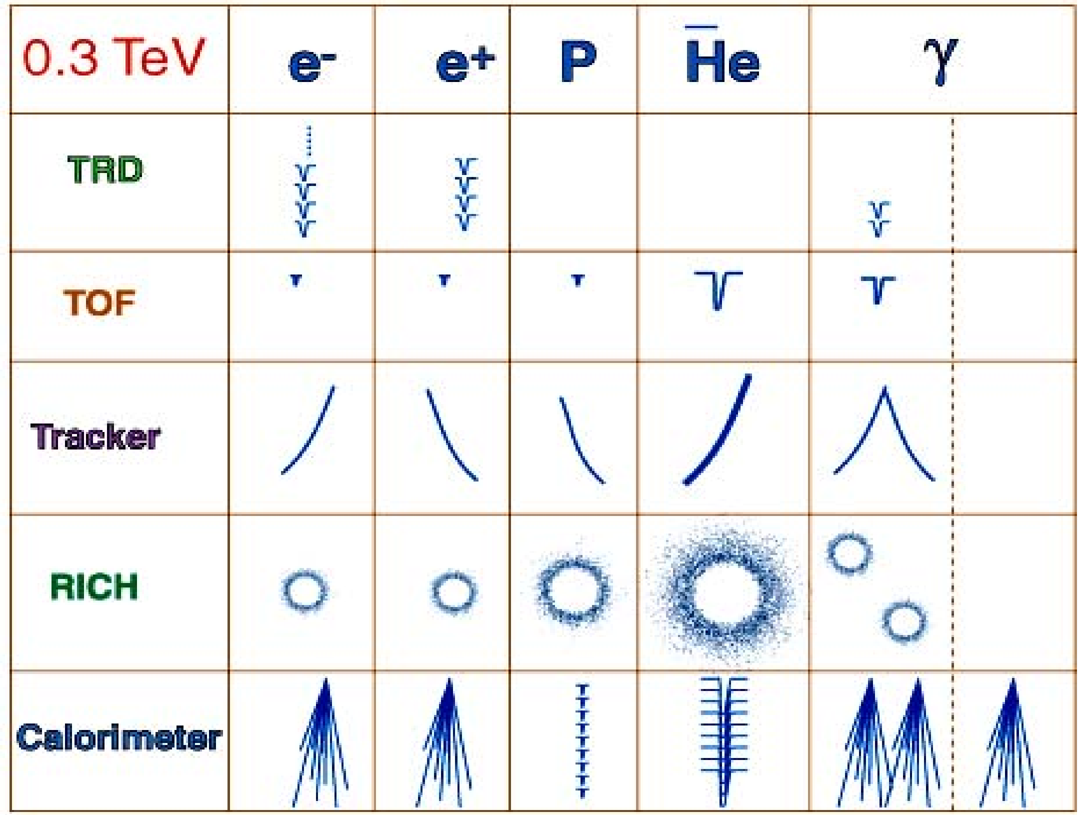
RICH : **β,Z^2 He^3,He^4,B,C A<27,Z<28**
Radiator (Aerogel,NAF) **3 σ 1 - 12 GeV**

Electromagnetic Calorimeter :**$e^{\pm}$,γ to 1 TeV, $p^+/e^+ < 10^{-4}$**
Lead+scint. Fibers, 324 R7600 PMT's (4 pixels)



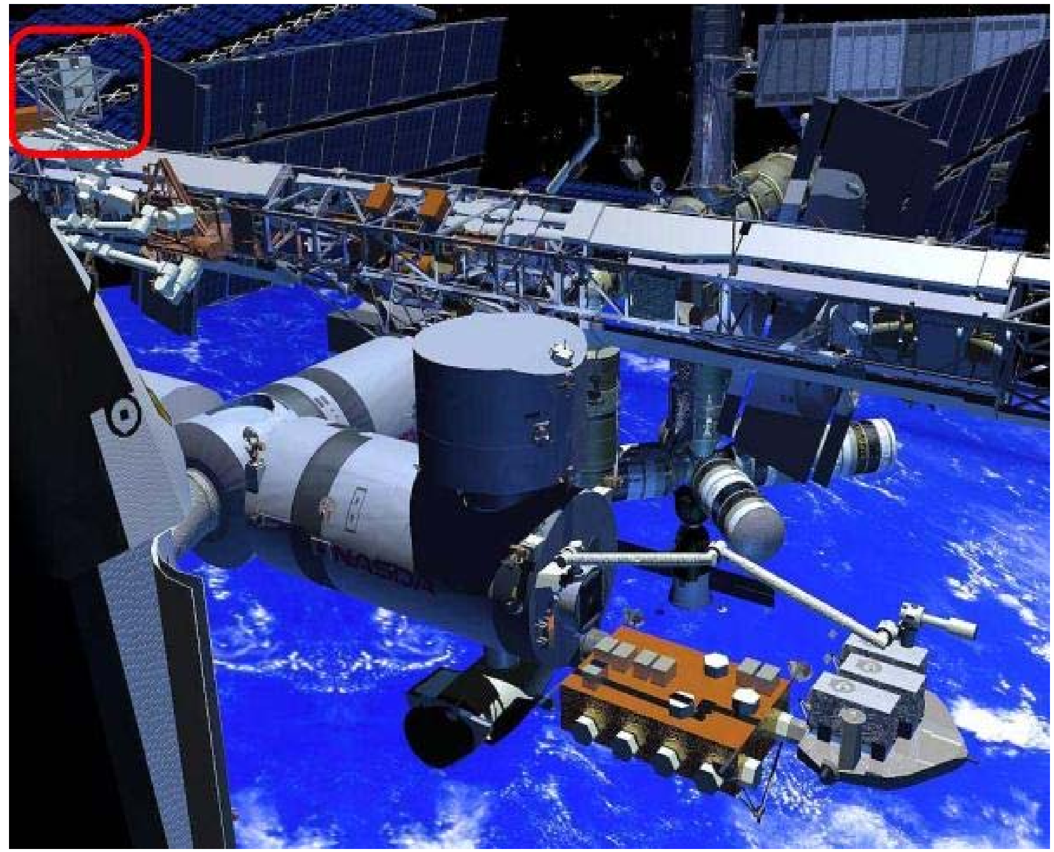


300,000 channels of electronics Δt = 100 ps, Δx = 10μ



AMS Physics program

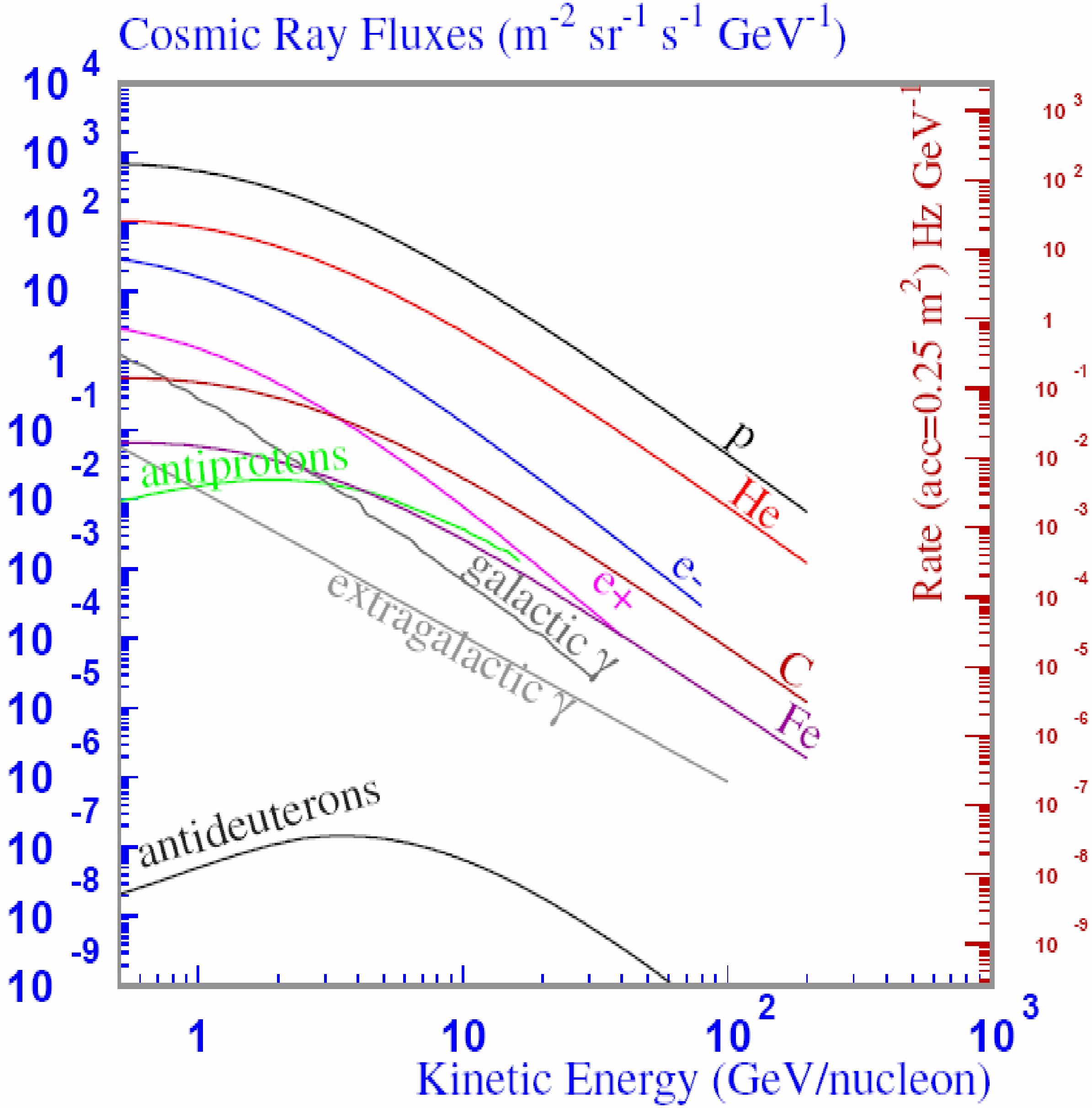
- **Precision measurement on charged particles and nuclei:**
  $e^{\pm}$, γ, $p^{\pm}$, ^{3,4}He, B, C, ^{9,10}Be, elements $Z<25$. GeV – TeV range
- **High Energy Cosmic Gamma ray astrophysics (GRB, SN,..)**
- **Direct search for cosmic antimatter (antihelium - sensitivity 10^{-9})**
- **Indirect search for non barionic Dark Matter**
- **Exotics (strangelets, mquasars,..)**
- **Total statistic expected > 10^{10} events.**



Indirect DARK MATTER searches:

Positrons, Anti-protons, Anti-deuterons, Gamma rays

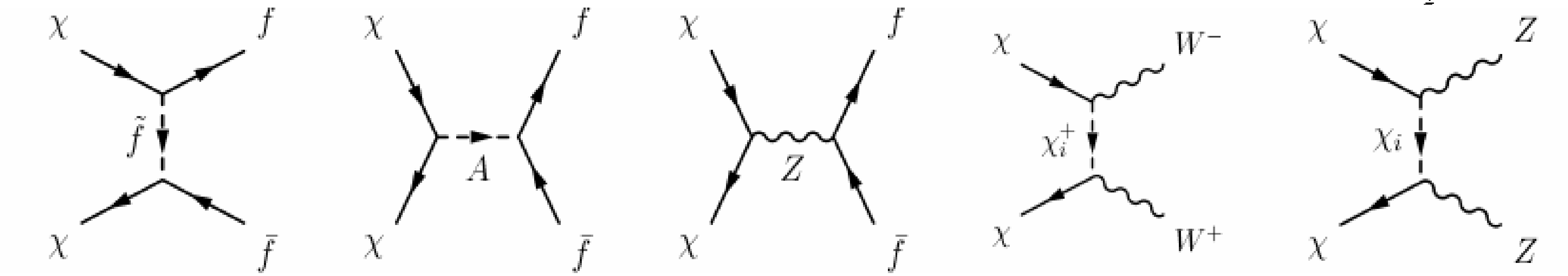
Capabilities of Cosmic Ray measurement at AMS



Indirect Dark Matter Search

- Universe Matter budget ~ 95 % is Dark & non baryonic
- SUSY provides an excellent WIMP candidate – neutralino : χ

$$\chi = \begin{pmatrix} \tilde{B} \\ \tilde{W}^3 \\ \tilde{H}_1^0 \\ \tilde{H}_2^0 \end{pmatrix}$$



$\chi\,\chi \rightarrow$ bb, WW, … $\rightarrow$ e^+, e^-, p, $\bar{p}$, $\bar{D}$, γ

$\chi\,\chi \rightarrow Z\gamma, \gamma\gamma$

- Completeness of AMS-02: (all the four possible complementary channels)
  - $\bar{p}$: Excess at High Energy (> ~ 5GeV)
  - D : Excess at E < 1 GeV
  - e^+ : Structure in Spectra above few GeV
  - γ : Energy Spectra differ from "power laws",
    or γ line detection $\chi^0_1\chi^0_1 \rightarrow \gamma\gamma,\ Z\gamma$ **(1st loop)**

Measurements possible because background very well known

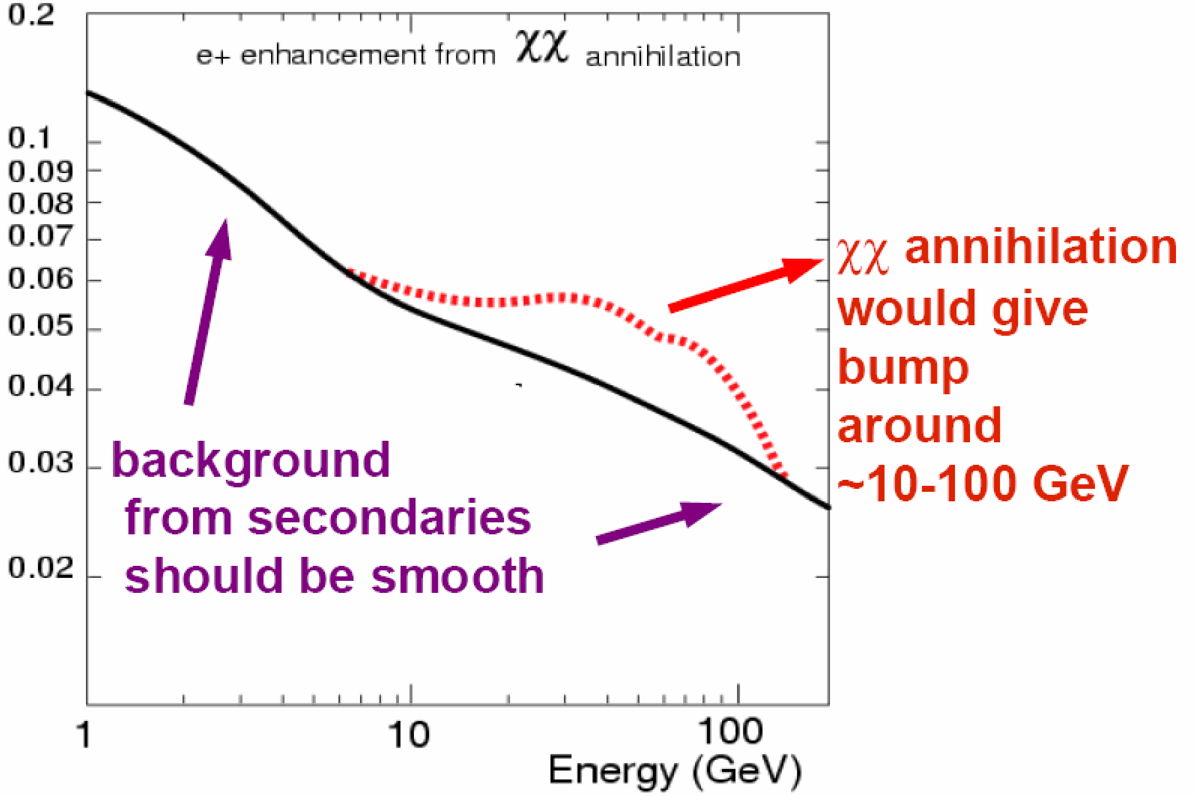
(1) Dark Matter Search: Positrons

Positrons from χ annihilation:

$$\chi\chi \rightarrow W^+ W^- \rightarrow e^+ \nu_e e^- \bar{\nu}_e$$
$$\chi\chi \rightarrow e^+ e^-$$
$$\chi\chi \rightarrow \tau^+ \tau^- \rightarrow e^+ \nu_e \bar{\nu}_\tau e^- \bar{\nu}_e \nu_\tau$$

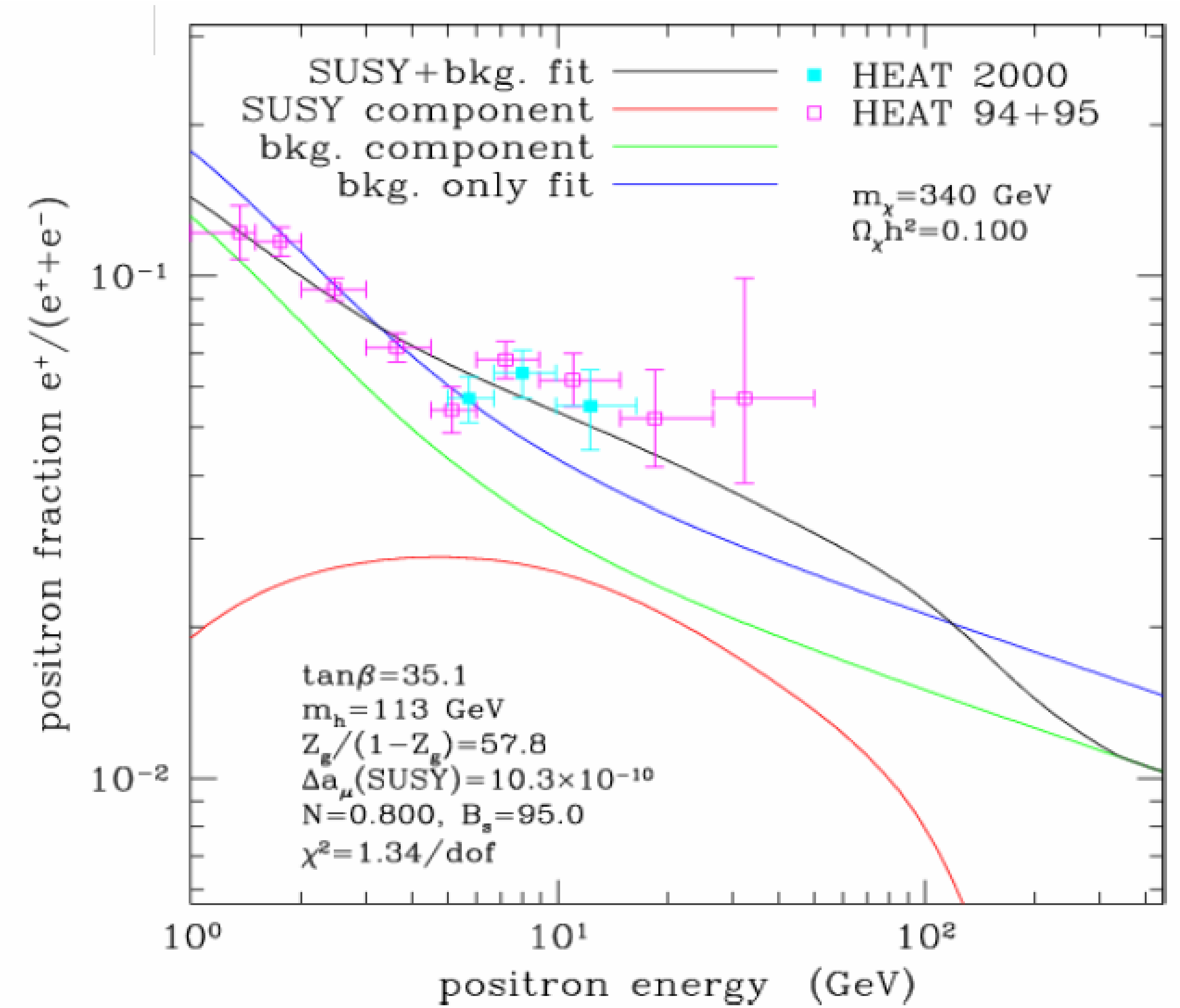
etc.

In this case it is more difficult to model propagation, energy losses, solar modulation, etc. To reduce uncertainties, positron fractions are often considered as a signature.



A hint from a balloon experiment, HEAT.

→ **Interpretation in terms of SUSY DM**



What do you need to see an anomalous positron signal?

Around 10 GeV,

get 1 e^- for 100 p,

get few e^+ for 100 e^-

→Need **excellent e^+/p separation**

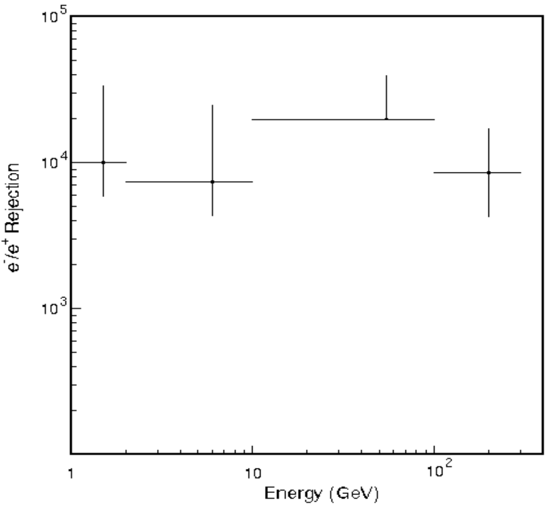
→ **Misidentification rate must be < 1 in 10^5**

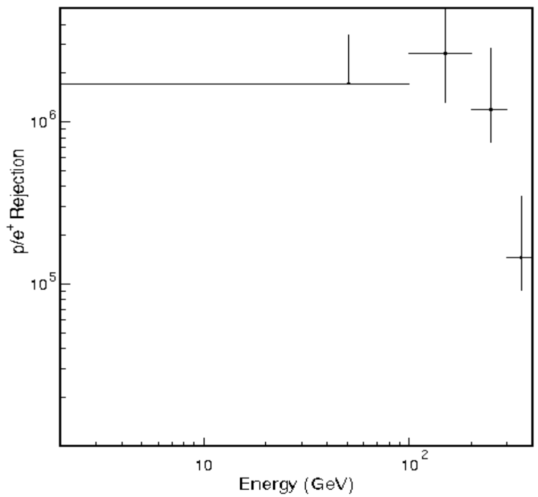
To achieve this goal:

Transition Radiation Detector (TRD): proton rejection ~ 10^3

Electromagnetic Calorimeter (ECAL): proton rejection ~ 10^3

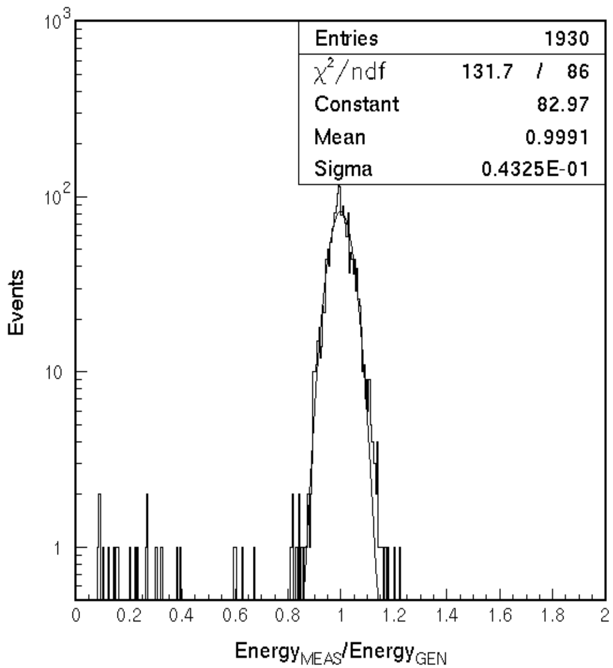
Positrons in AMS 02

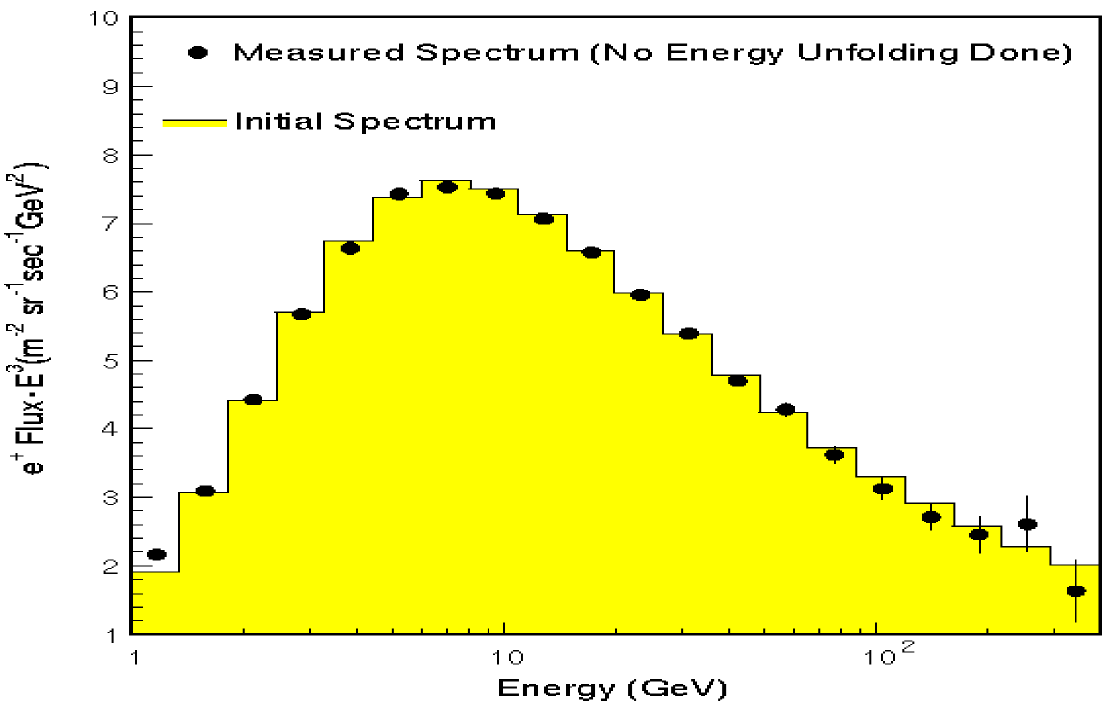




e^+ AMS02-spectrum after 3 years of data taking:

- p/e^+ and e^-/e^+ background rejection: 10^4-10^6
- Excellent energy resolution.
- ~30% stat error at 300 GeV.
- ~1% stat error at 50 GeV.





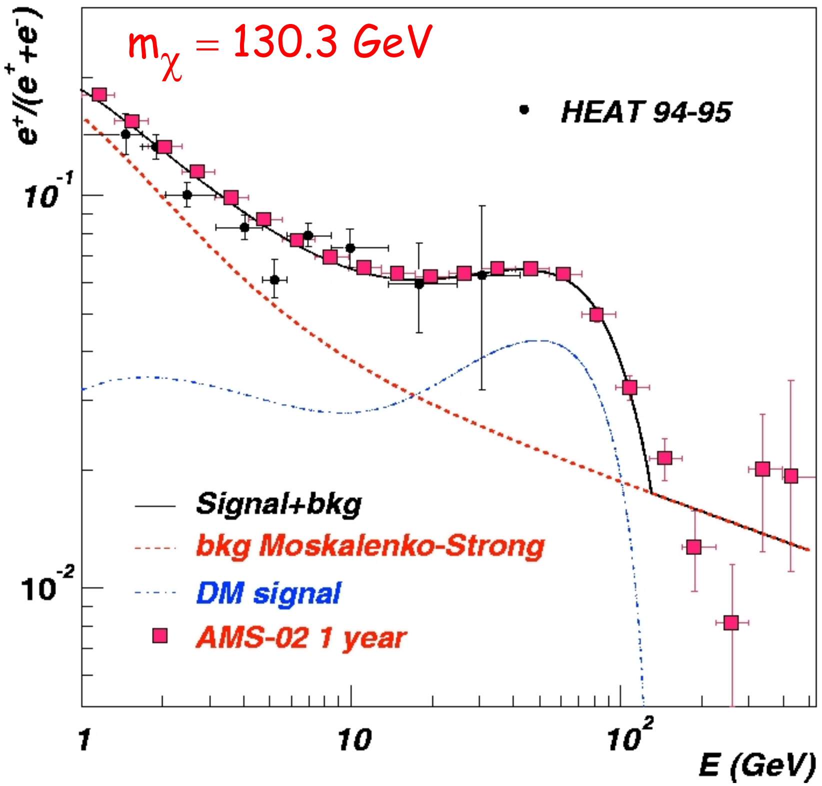
Dark Matter Search: Positrons

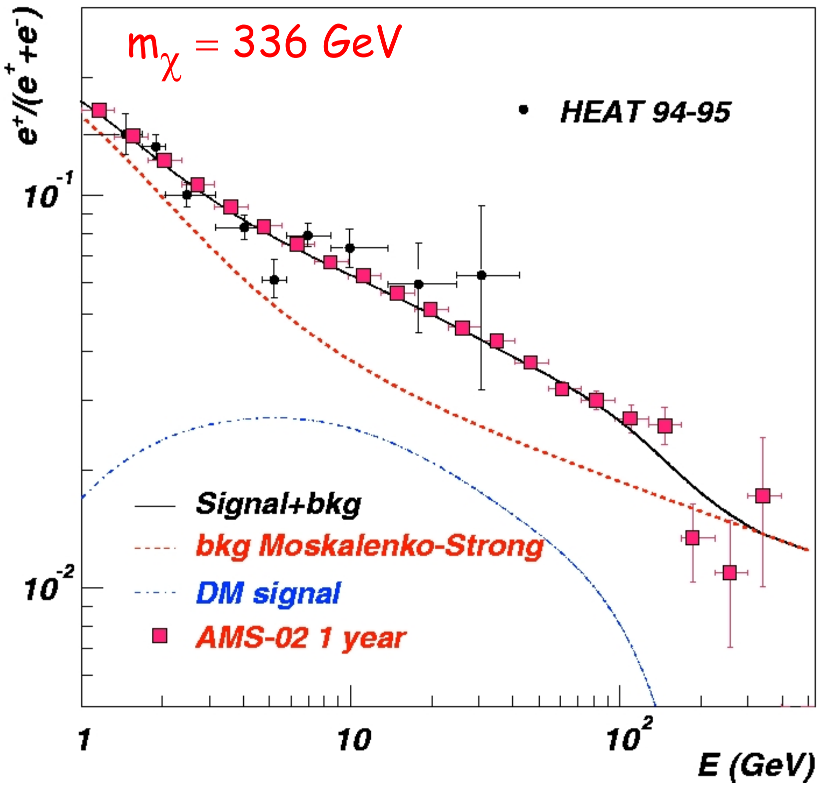
Heat Data : a bump in energy around 10 GeV, no standard astrophysical interpretation of e^+/e^- energy distribution

→ Precise data extended to higher energies will be provided by AMS

MSSM simulation for AMS-02 need high "boost factors"

Based on the work of E.A. Balts et al. 99



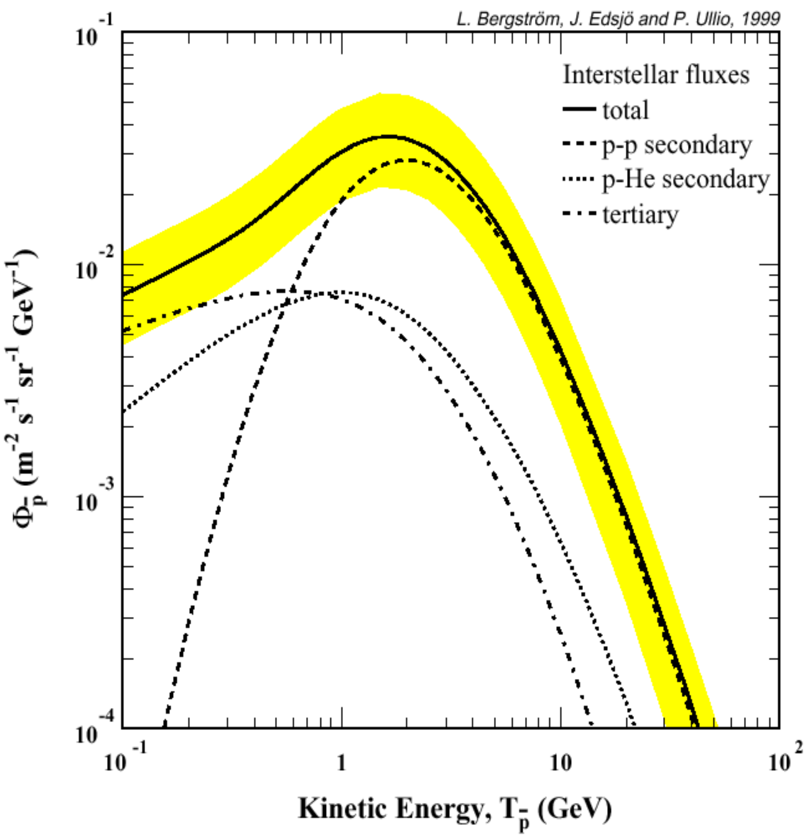


(2) Dark Matter Search: Antiprotons

Motivation and Signature:

- No "standard" primary $\bar{p}$ cosmic rays.
- Secondary $\bar{p}$'s are mainly from p p → $\bar{p}$ X.

Kinematics → $\bar{p}$ flux suppressed at low energies



The primary p flux from χ annihilations in the galactic halo is not expected to be suppressed at low energies:

an excess of $\bar{p}$'s at low energy as an evidence for dark matter

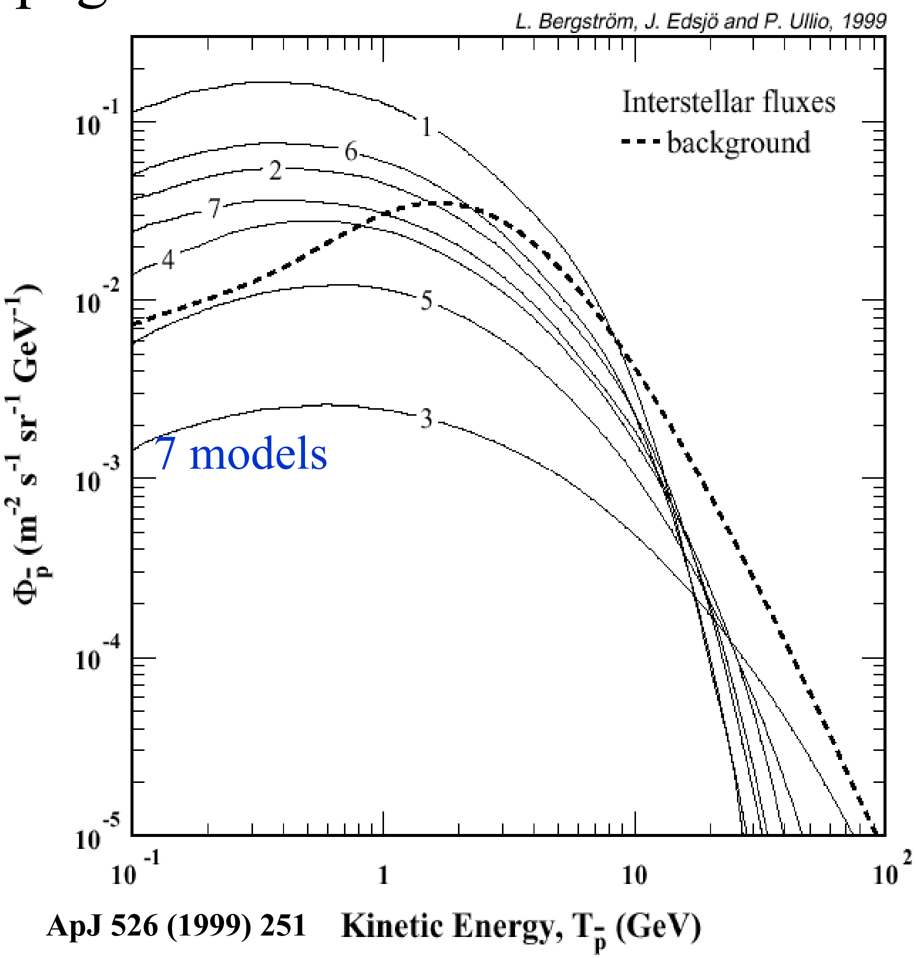
Silk & Srendnicki, Phys. Rev. Lett. 53 (1984) 624

Dark Matter Search: Antiprotons

Source function is defined as

$$Q_{\bar{p}}^{\chi}(T,\vec{x}) = (\sigma_A v)\left(\frac{\rho_\chi(\vec{x})}{M_\chi}\right)^2 \sum_f B_f \frac{dN_f}{dT}$$

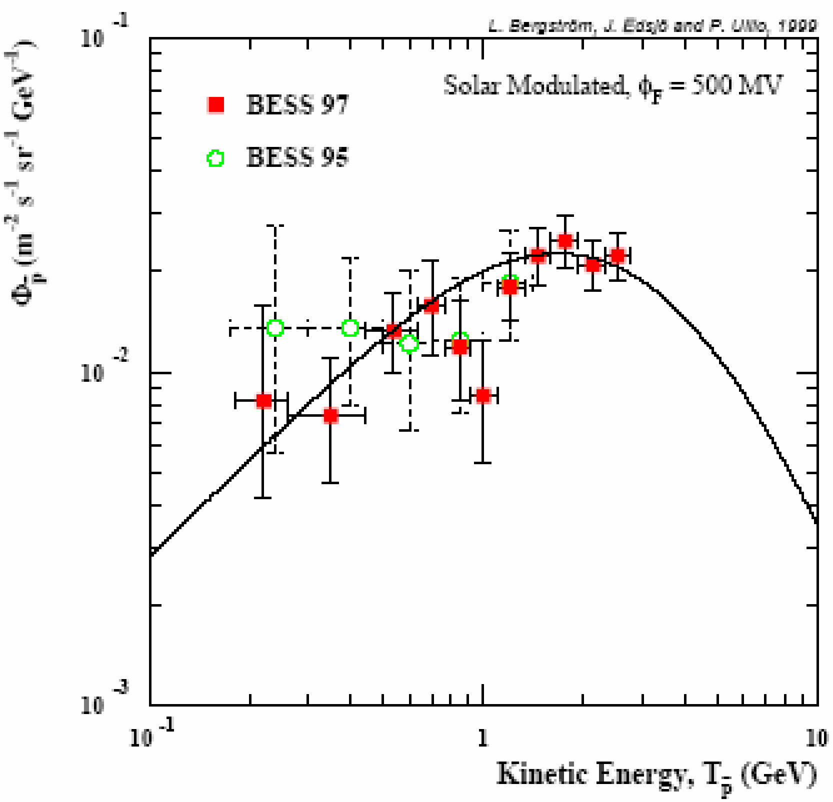
Fix the WIMP distribution and p propagation model and compute the exotic flux component:



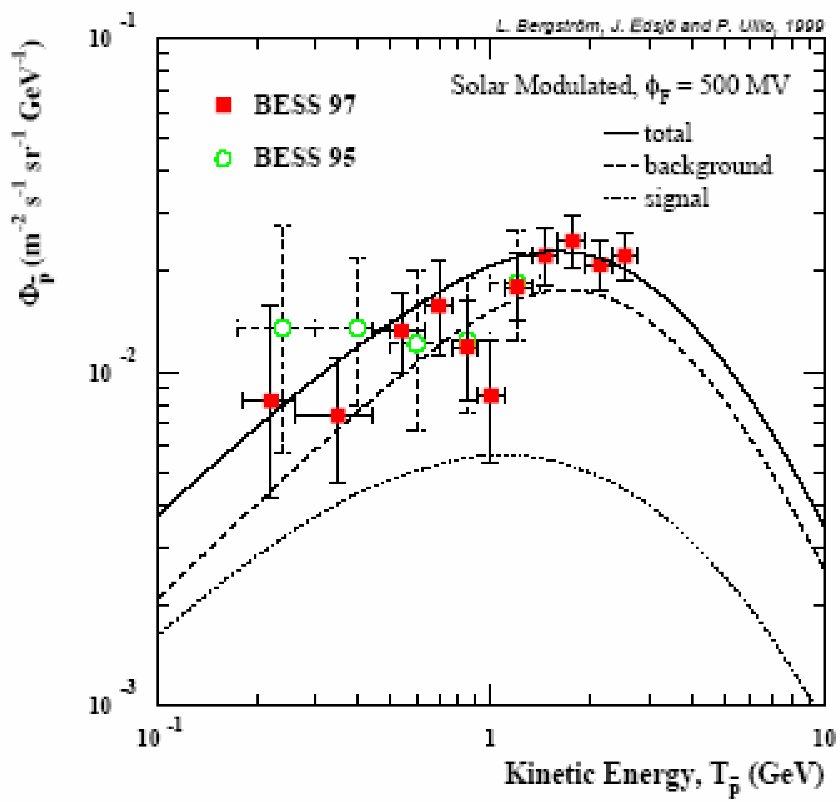
ApJ 526 (1999) 251

In order to disentangle the WIMP induced signal at low kinetic energies a great confidence in the background prediction is needed.

Background only



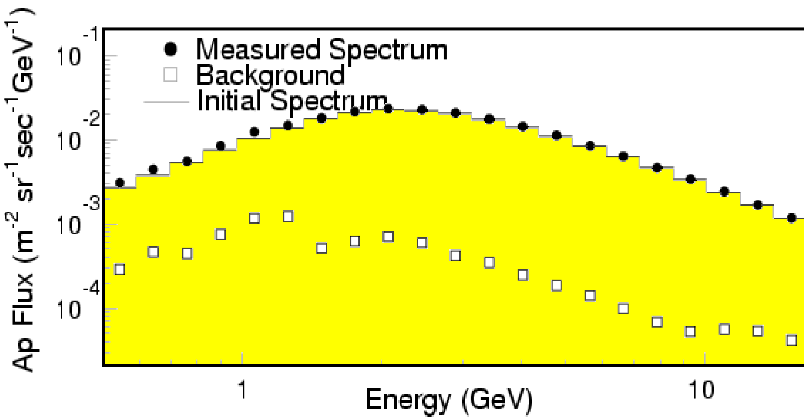
Background+signal

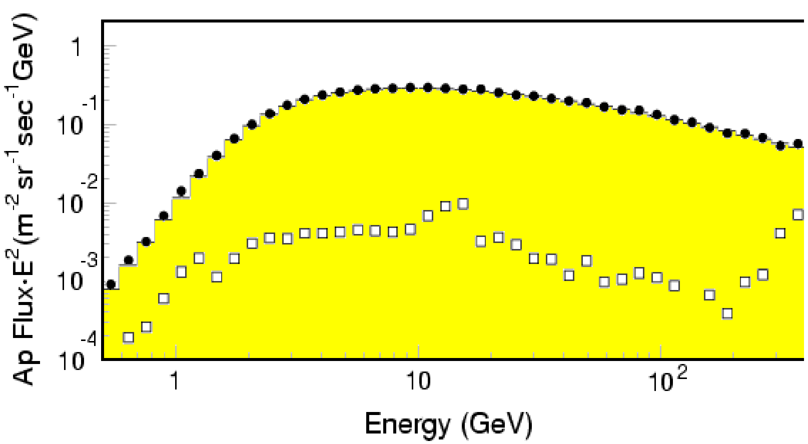


Dark Matter Search: Antiprotons

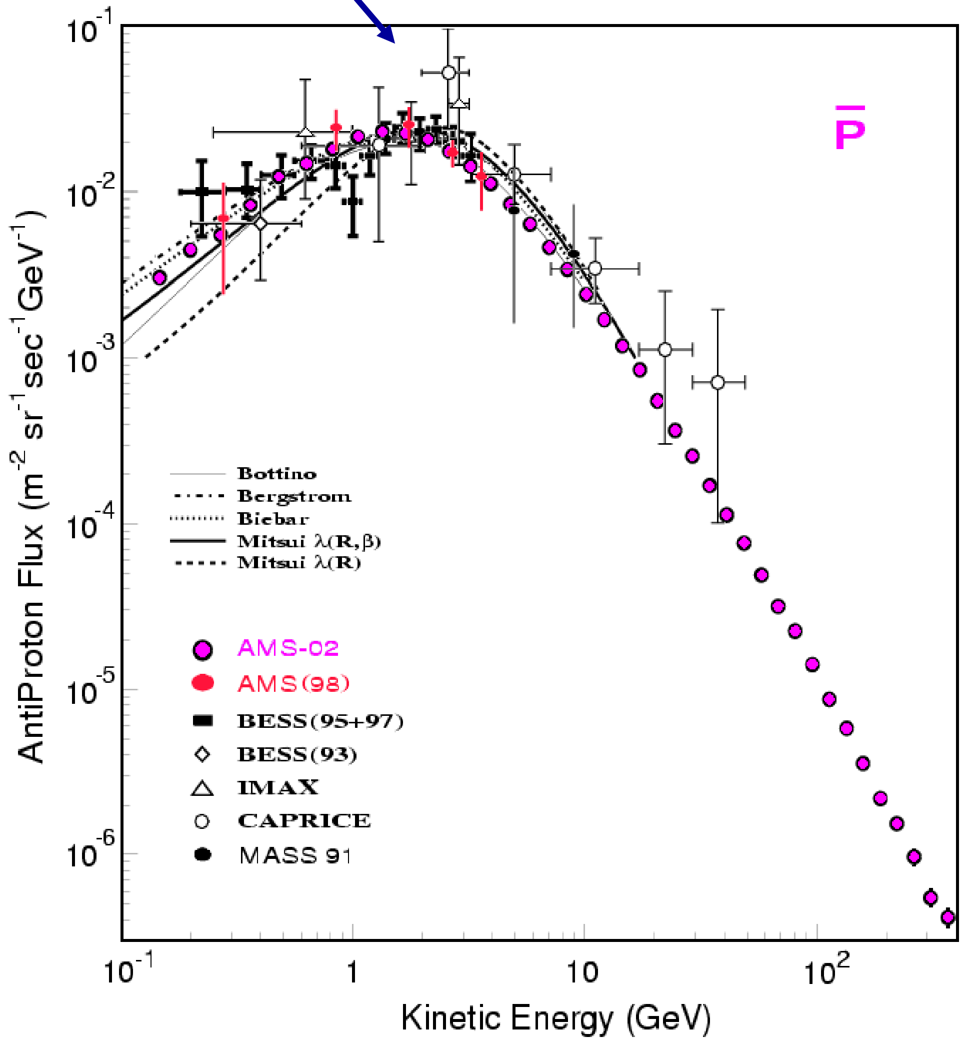
Background rejection:

$p/p^- > 10^6$ and $e^-/p^- \; 10^3$-10^4





AMS 3 years secondary spectrum



(3) Dark Matter Search: Anti-deuteron

Motivations and Signature:

-There is no “standard” primary $\bar{D}$ component.

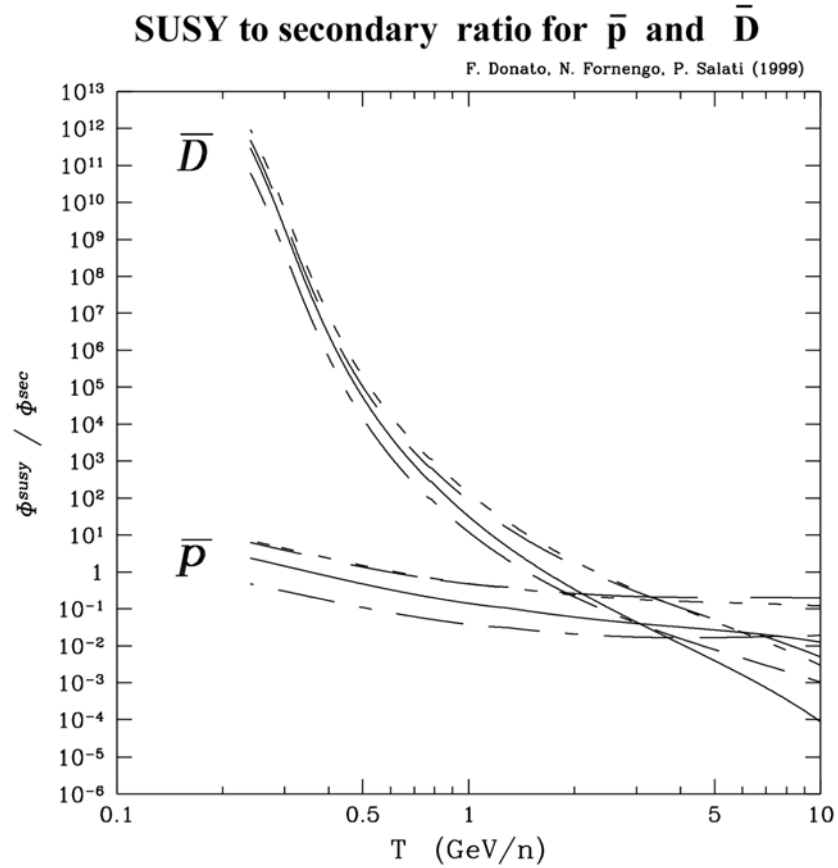
- Secondary $\bar{D}$s are kinematically suppressed at low kinetic energies.

- The exotic component from WIMP annihilation is instead peaked at low energies.

- AMS acceptance:

$\bar{D}$: 5.5 x 10^7 m^2 s sr GeV

$\bar{p}$: 2.2 x 10^7 m^2 s sr GeV

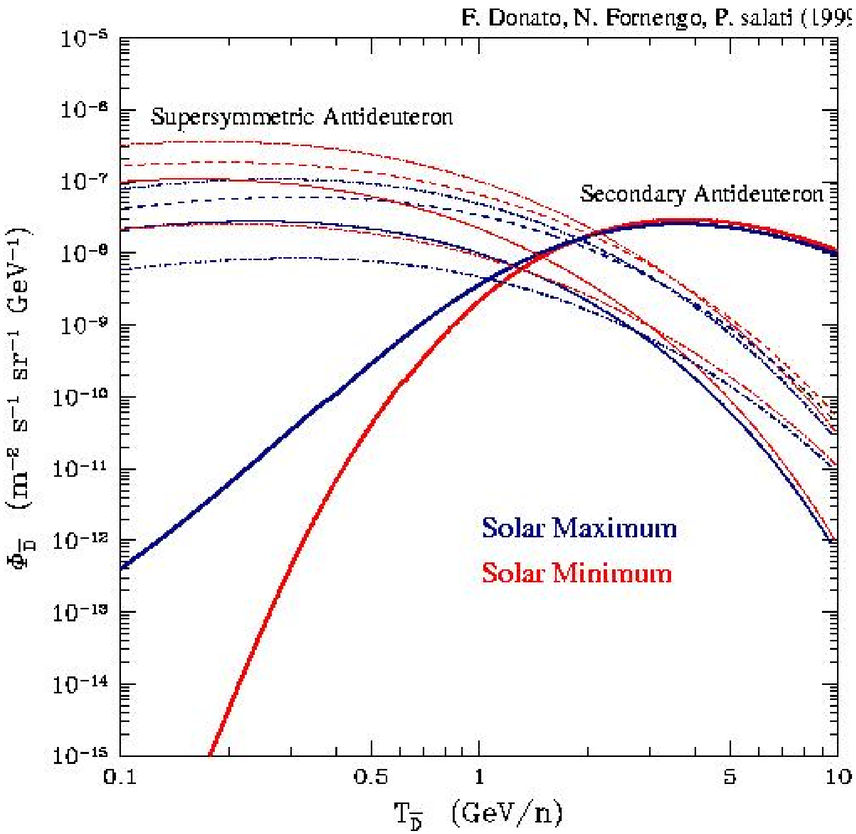


PRD62 043003

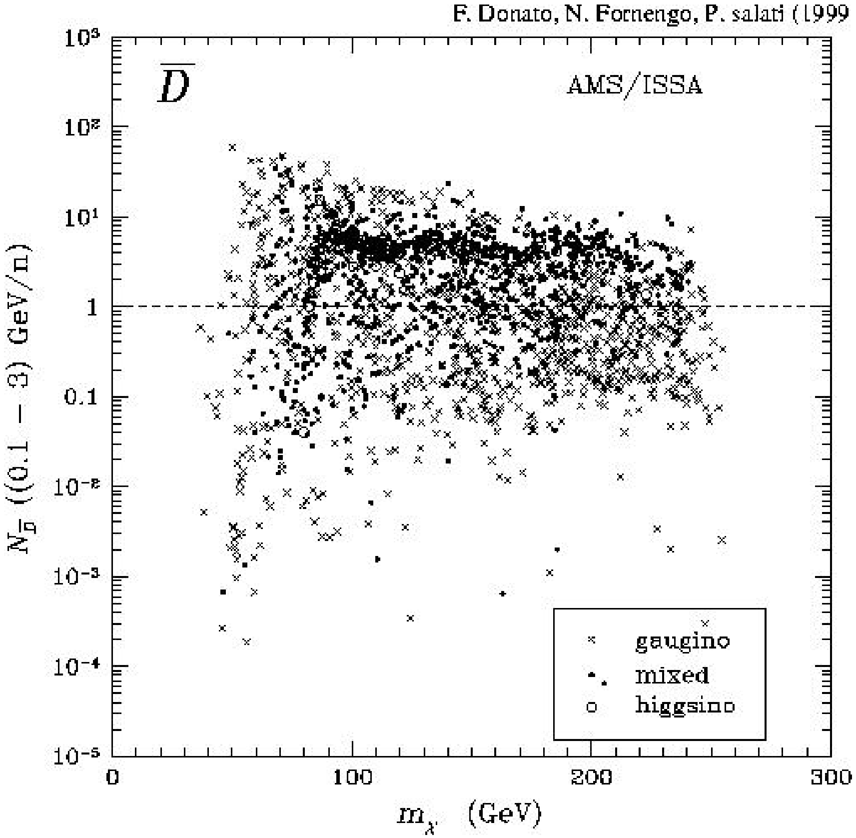
More promising than antiprotons

Dark Matter : $\overline{D}$

Estimated $\overline{D}$ flux :



Estimated $\overline{D}$ yield for AMS (3 years) :



→ Mass identification ($\overline{p}/\overline{D} \sim 10^5$!)

(4) Dark Matter Search: Gamma-rays

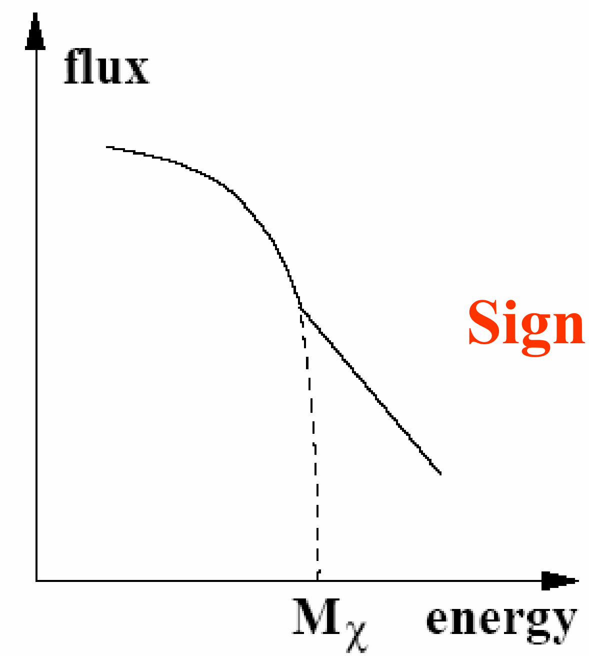
1) γ-rays with continuum energy spectrum

Produced in final state jets:

$$\chi\chi \to \ldots \to \pi^0 \to 2\gamma$$

~1/3 energy released in this channel.

Production chain, however, common to secondary γ-rays, with π^0 "bump" just shifted depending on χ mass.



Signature: break in γ-ray spectrum

2) Detection of Monochromatic γ-rays

$$\chi\,\chi \rightarrow \gamma\,X^0$$

The above process is forbidden at tree-level but allowed at 1-loop level.

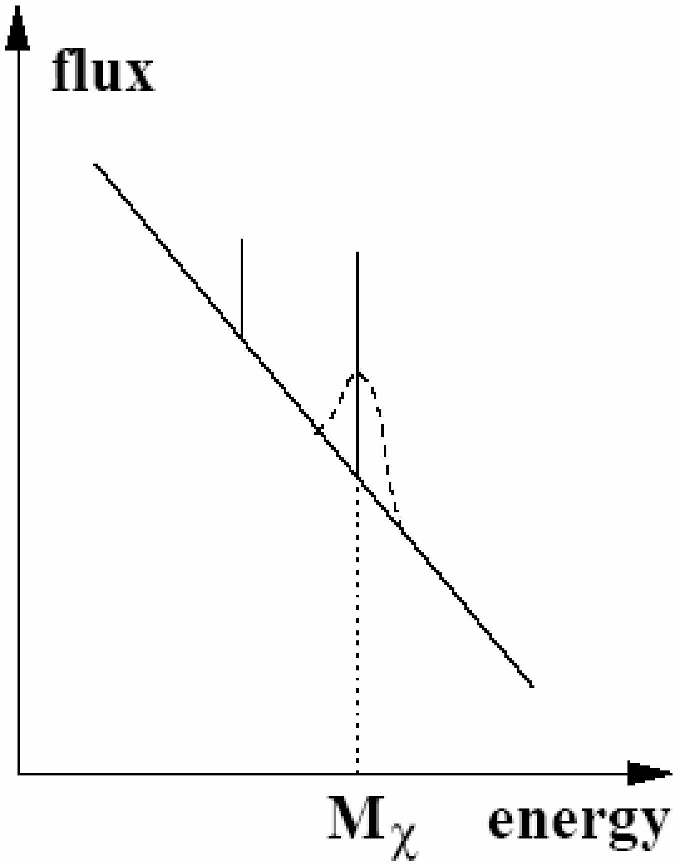
χs in the galactic halo are non-relativistic

$\Downarrow$

γ in the final state is nearly monochromatic

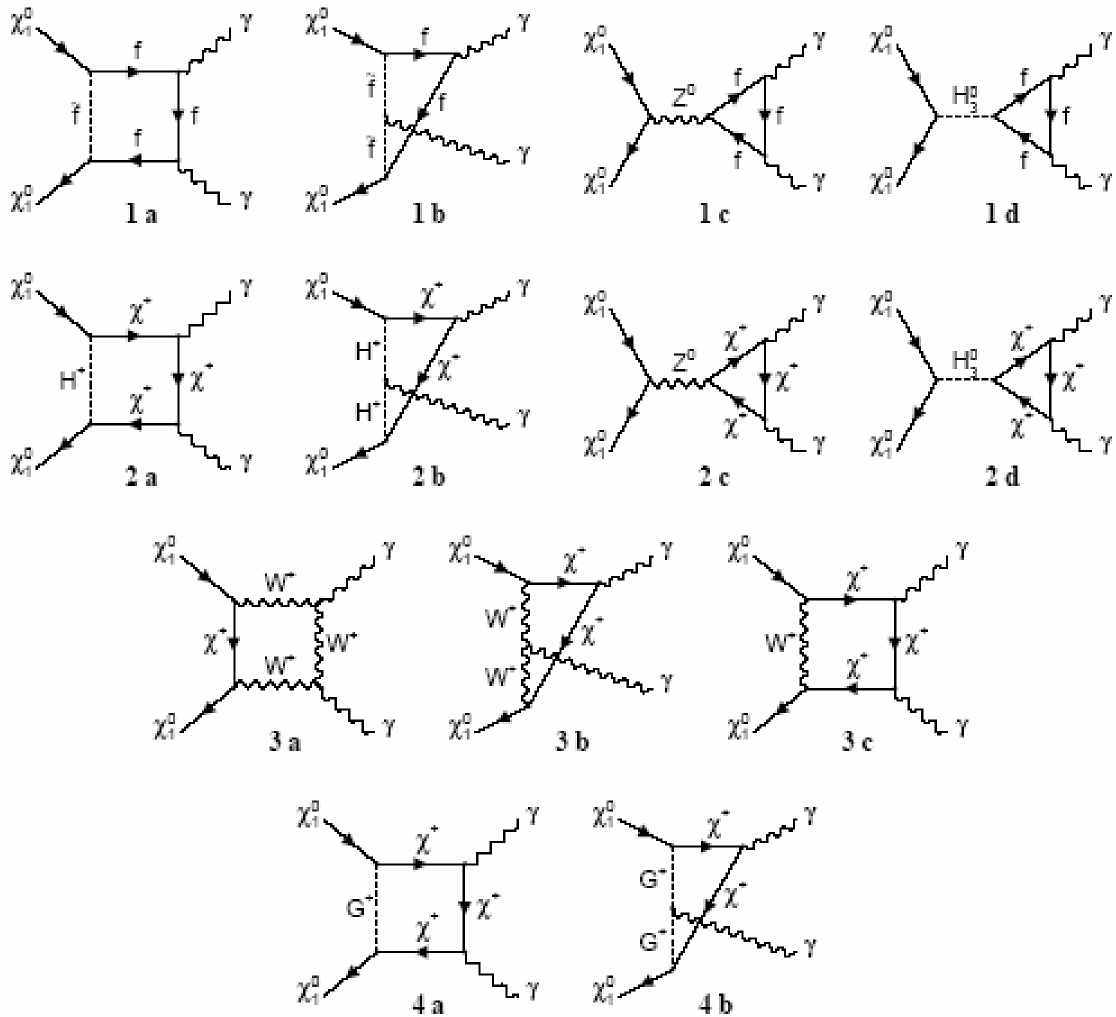
$\Downarrow$

No plausible astrophysical background



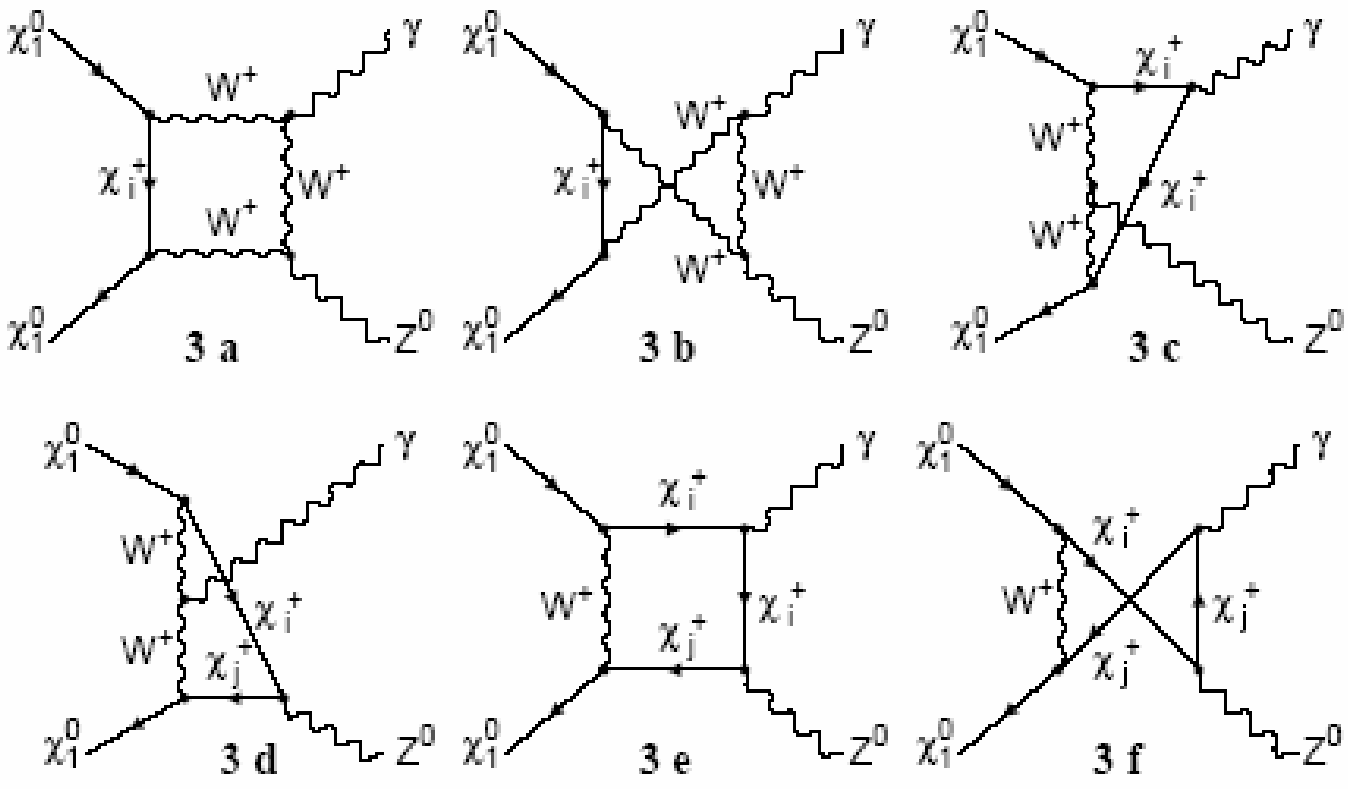
3) Dark Matter is the lightest neutralino χ in the MSSM

(1) $\chi\chi \rightarrow \gamma\gamma$ production



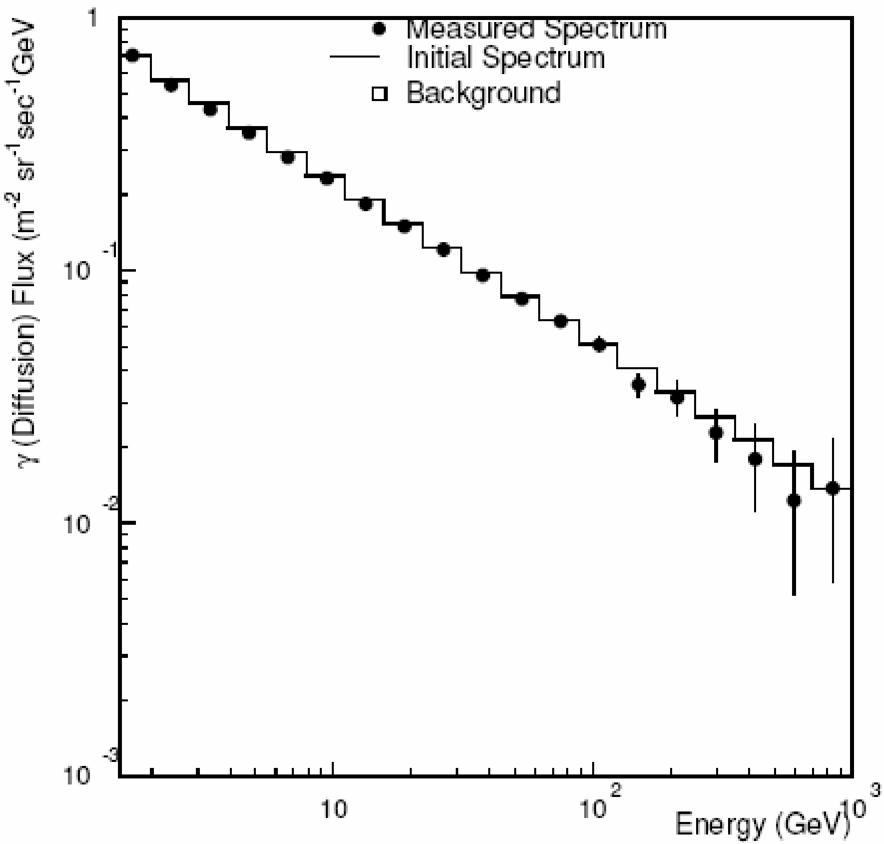
3) Dark Matter is the lightest neutralino χ in the MSSM

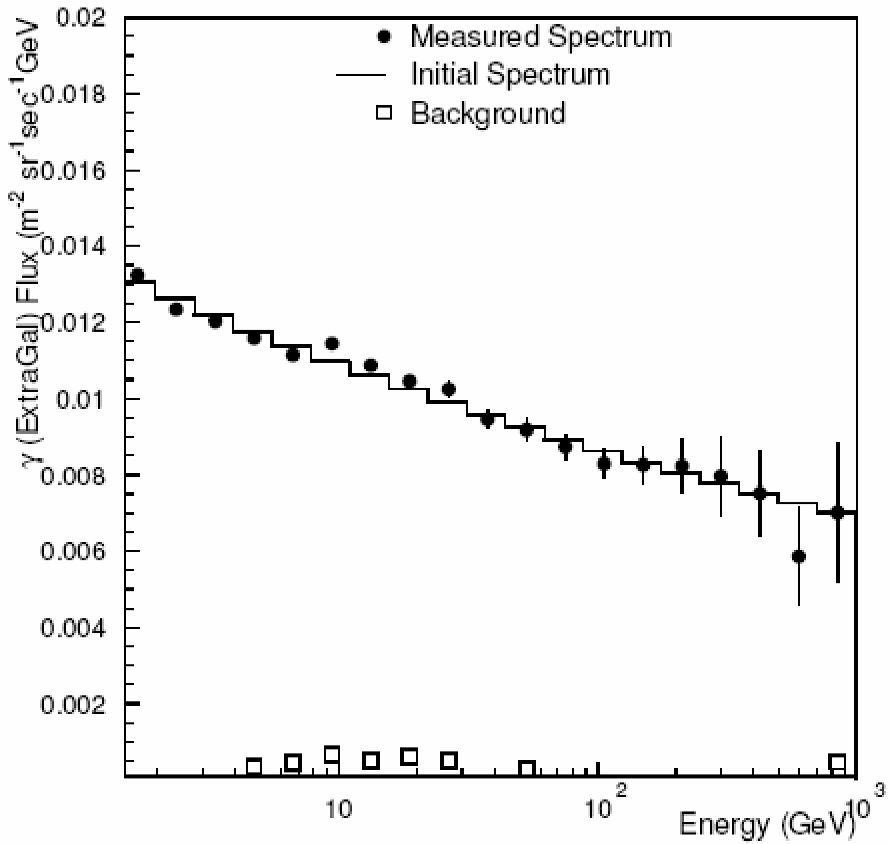
(2) $\chi\chi \rightarrow \gamma Z^0$ production



Gamma Rays in AMS02

Measurements of γ rays up to 1000 GeV

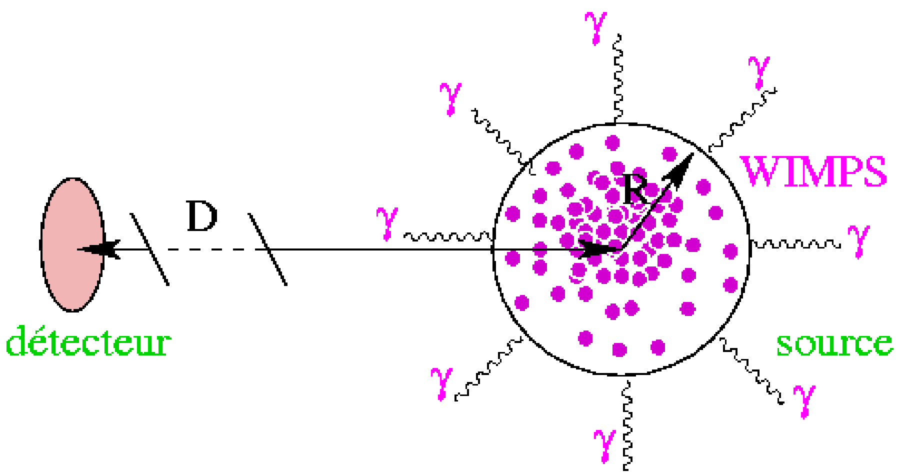




for example 90 γ's of Extragalactic origin with energies above 100 GeV per year γ

Dark Matter - γ ray

Detection rate (source) :

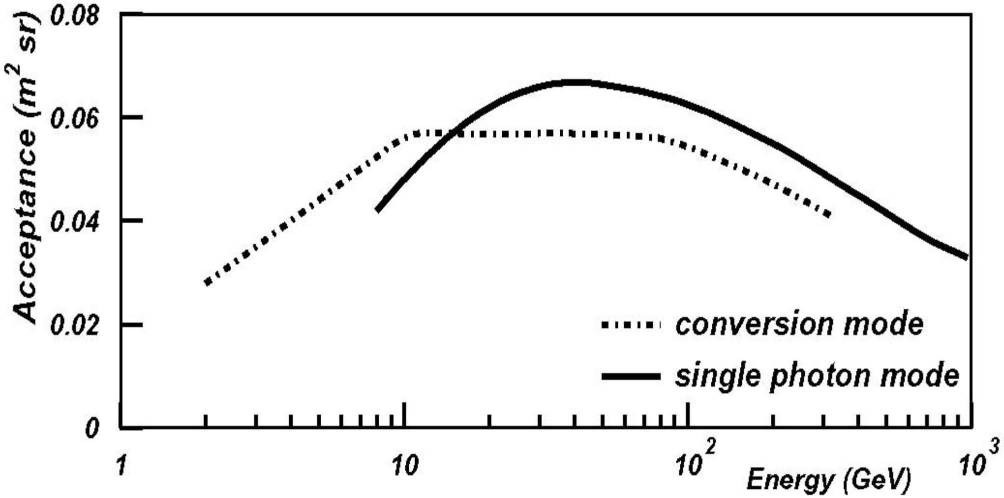


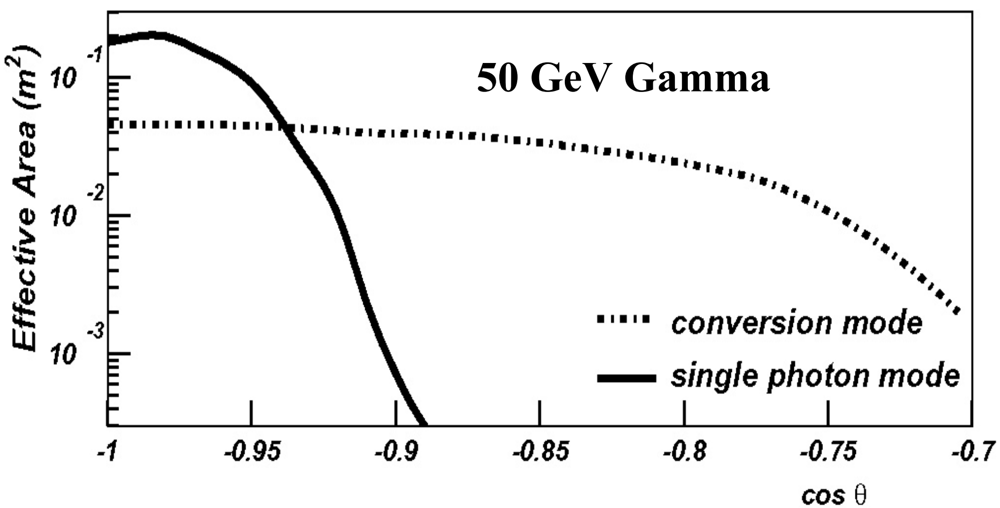
$$\Phi\,\gamma \sim \underbrace{\frac{N\gamma\,\langle\sigma v\rangle}{m^2_{\chi}}}_{\text{SUSY}}\ \underbrace{\int\int_{los} \rho^2\,(r)\,dl(\theta)\,d\Omega}_{\text{Astrophysics}}$$

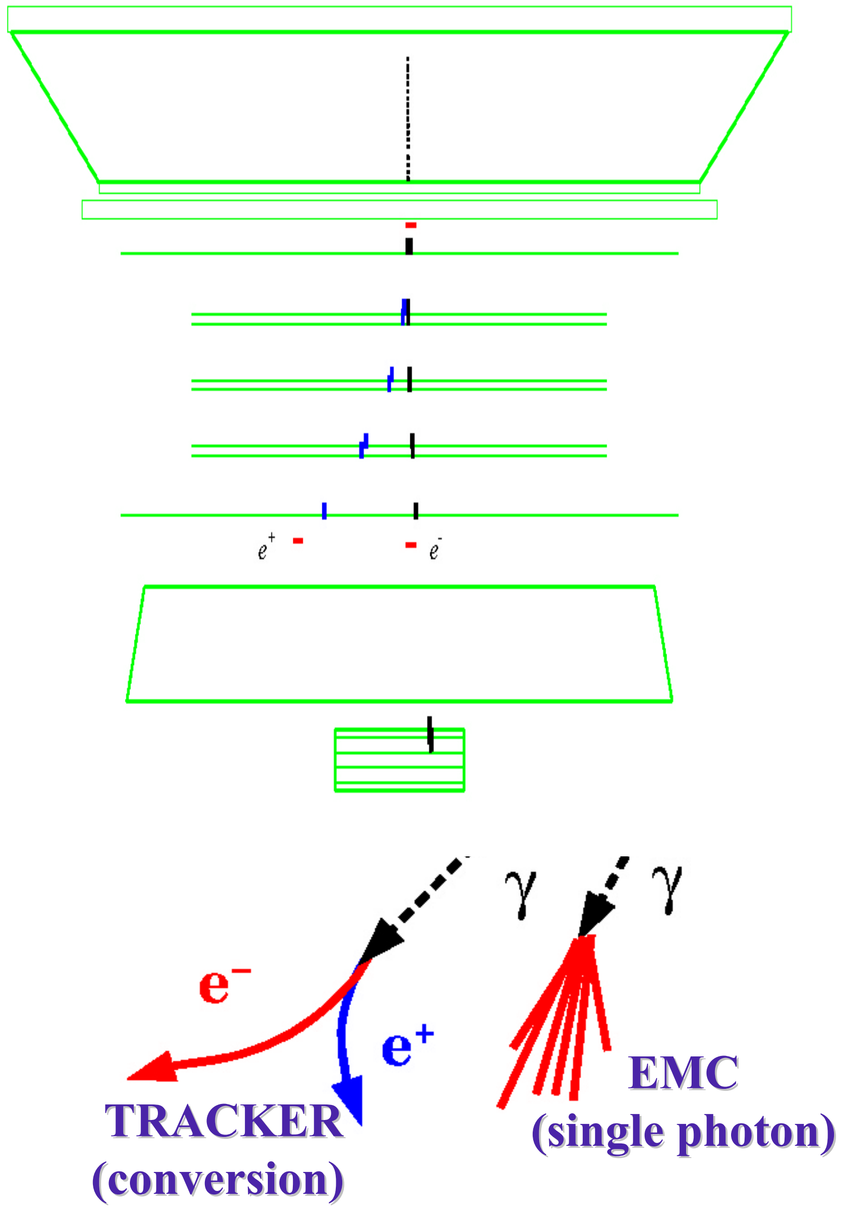
- diffuse D M : galactic as ν , e+ , p-, D-, Direct Detection
  extragalactic
- source D M :
  - Galactic Centre (G. C.) of Milky Way
  - Nearby Spiral Galaxies : e. g. M31, M87, or clouds: LMC, SMC
  - Dwarf Spheroidals : e. g. DRACO
  - Globular Clusters : ϖ - centauris, Palomar13

→ Enhancement factors from cuspy halos, clumpiness or/and SBH

γ-ray detection in AMS-02

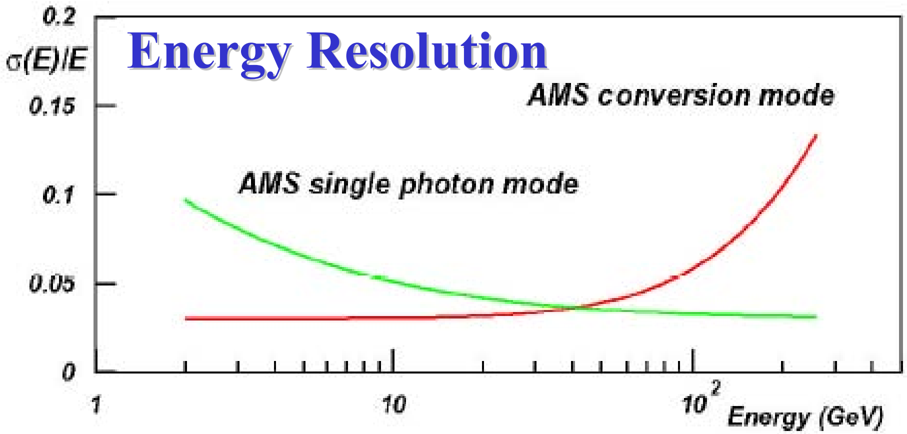


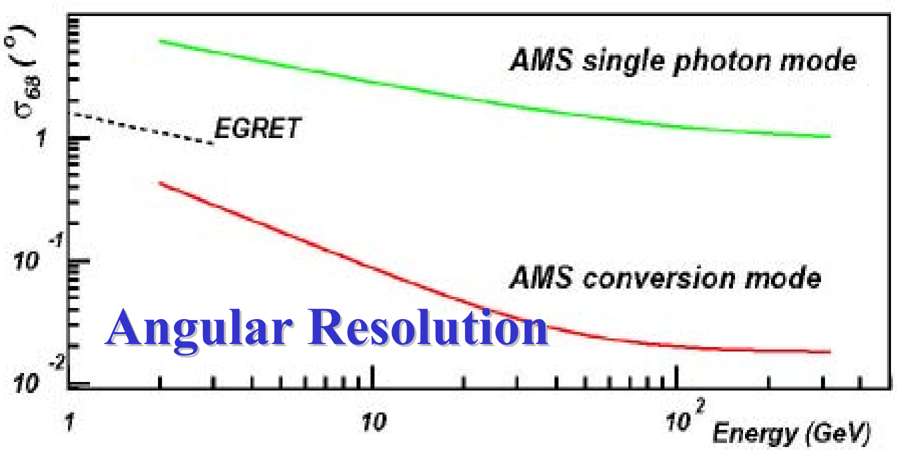


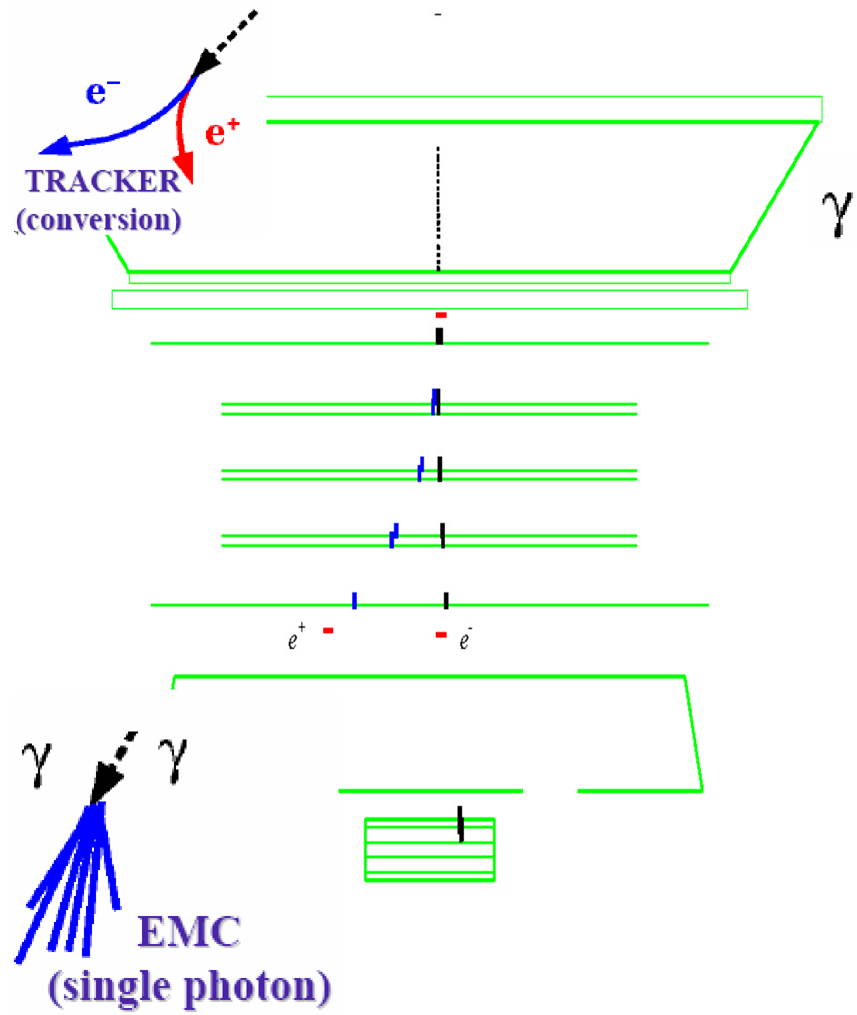


AMS-02 γ

Two complementary detection modes :





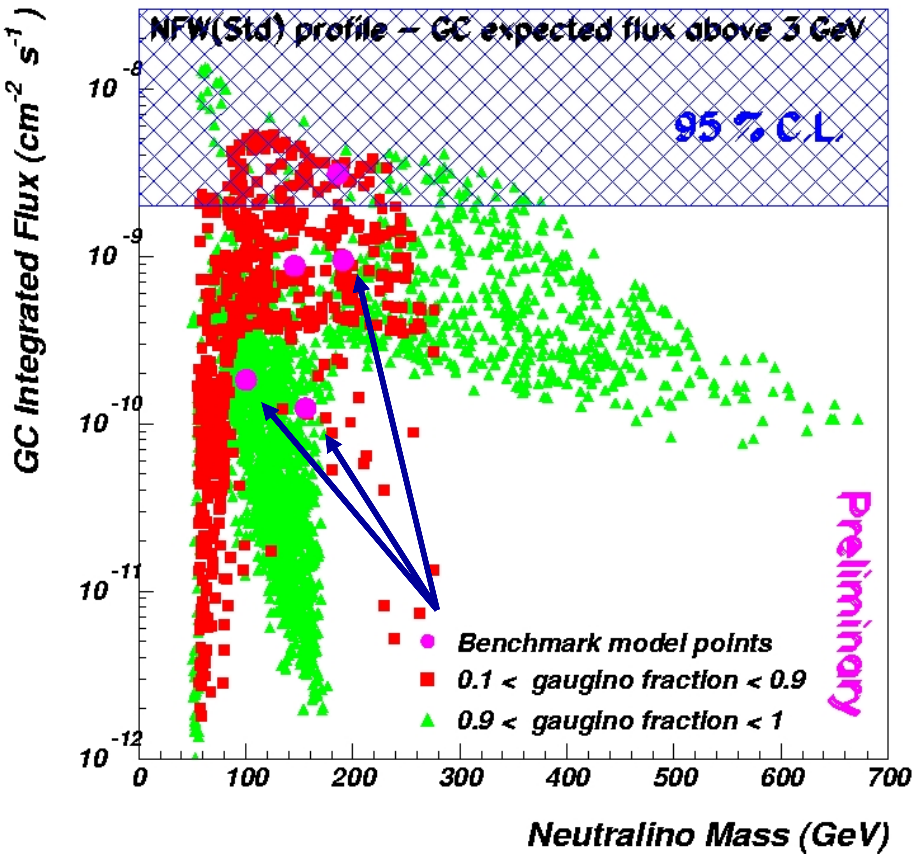


Dark Matter Search: Gamma-ray

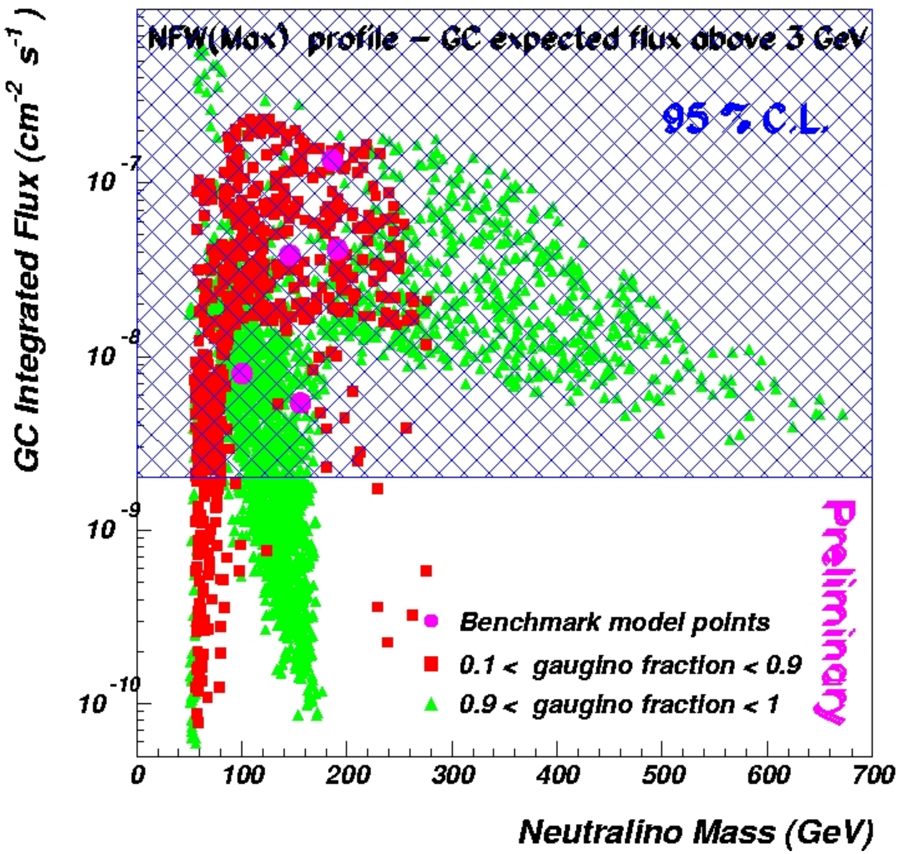
"wild scan"

mSUGRA results: Integrated flux from GC as a function of m_χ in the Focus Point scenario (large m_0 values), for two NFW halo profile parametrizations.

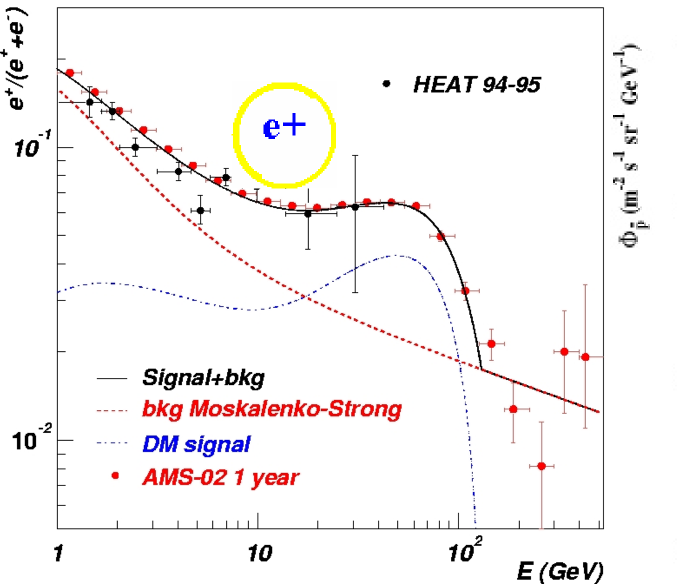
$\boldsymbol{R_0} = 8.0\ kpc$, $\boldsymbol{r_0} = 0.3\ GeV/cm^3$, $\boldsymbol{a} = 20\ kpc$



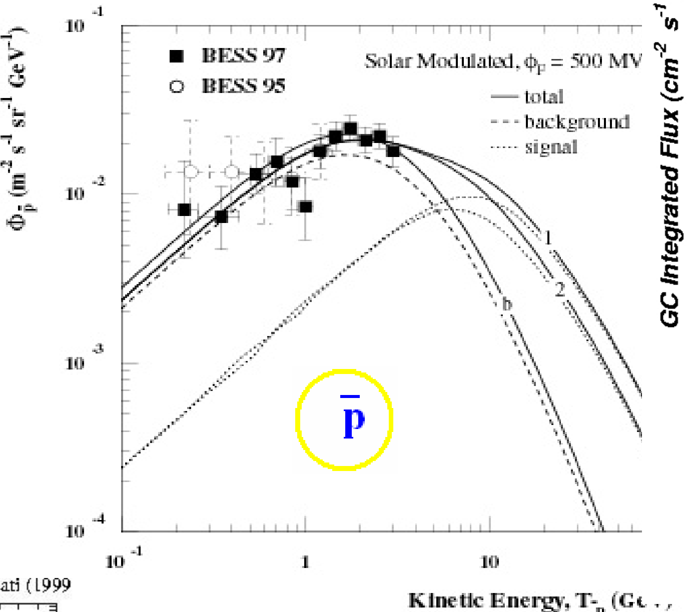
$\boldsymbol{R_0} = 8.5\ kpc$, $\boldsymbol{r_0} = 0.4\ GeV/cm^3$, $\boldsymbol{a} = 4\ kpc$

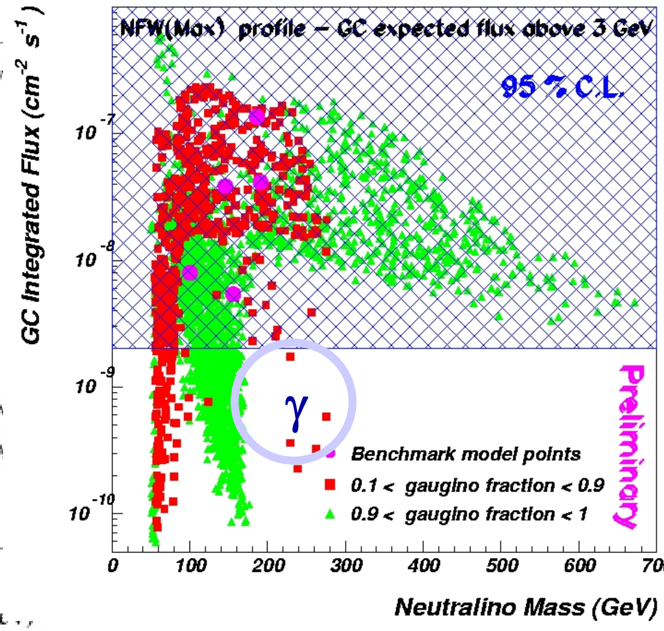


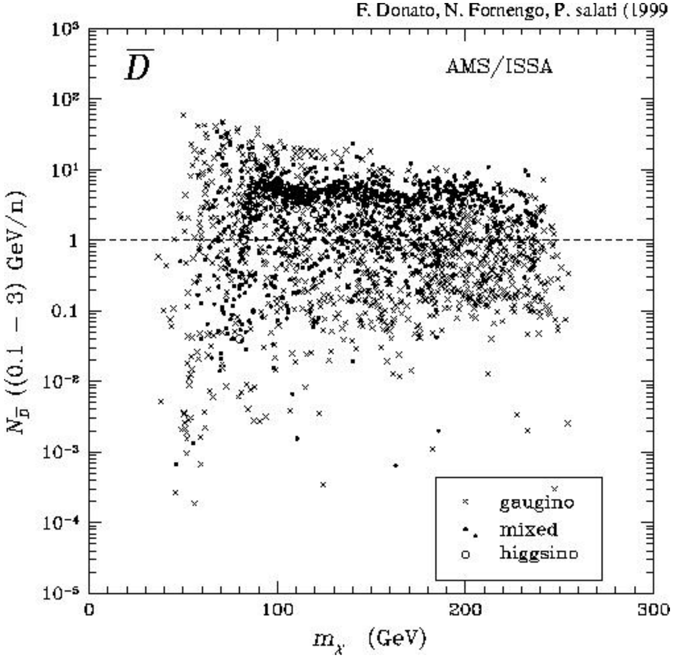
Summary



F. Donato, N. Fornengo, P. salati (1999







AMS offers:

Precise measurements of all particle spectra

Measurements of Nuclei fluxes for propagation model

Wide range of SUSY annihilation products.

Potential gain in sensitivity by combining them

Could provide benchmark data to validate models