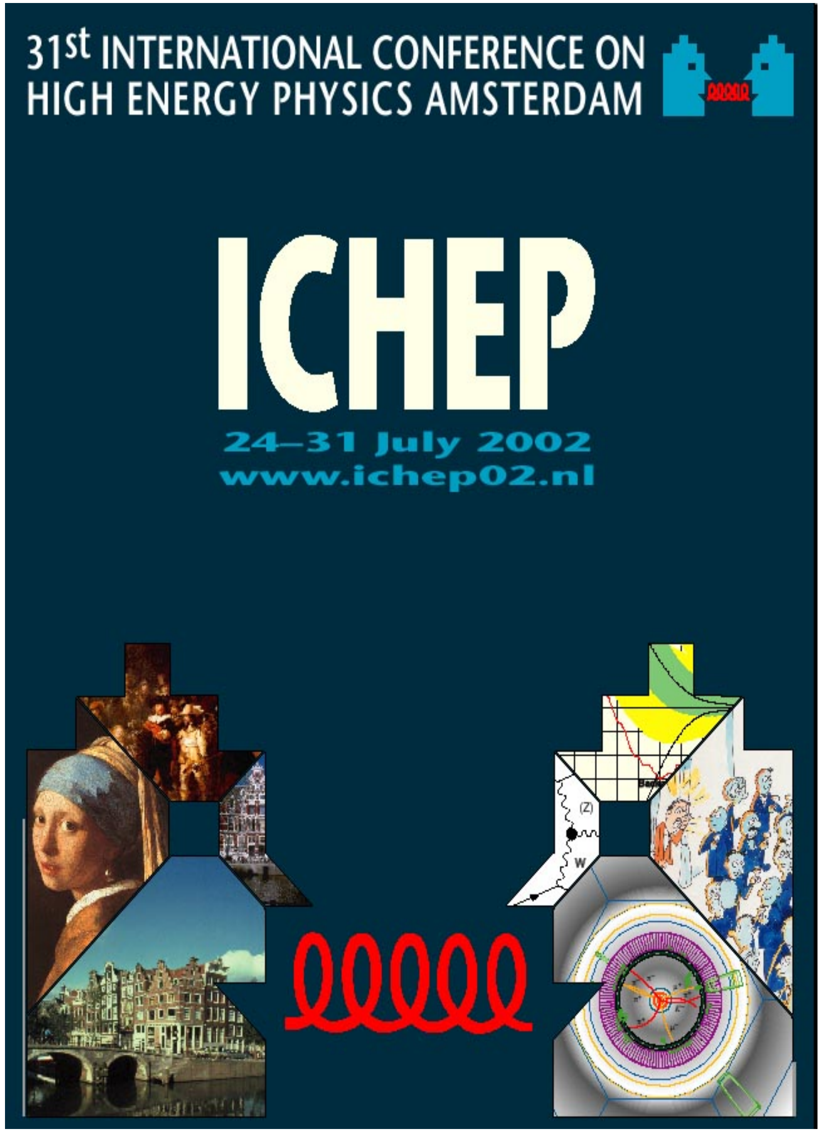
GAMMA–RAY DETECTION WITH THE ALPHA MAGNETIC SPECTROMETER



GIOVANNI LAMANNA

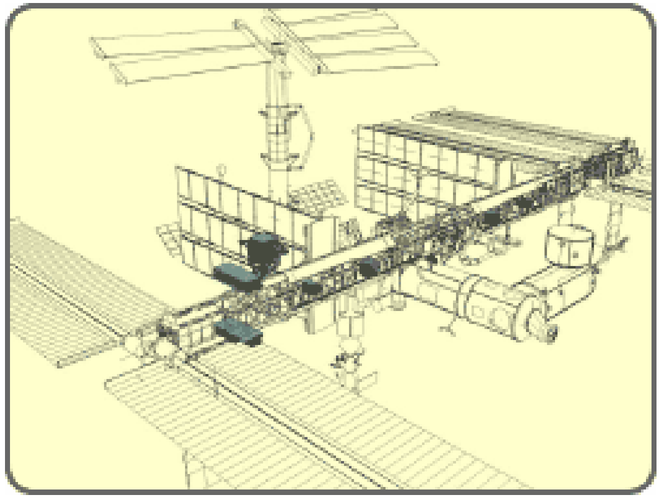
CERN

AMS collaboration

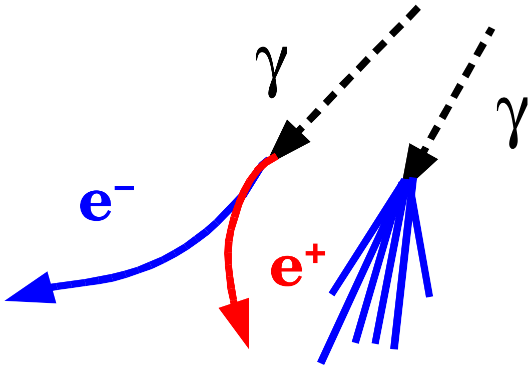
OUTLINE

- **Introduction:**

AMS02 on the *International Space Station*



- **Monte Carlo simulation study:**



Signal reconstruction through:
a) e^+e^- Conversion (Si–TRACKER–Mode).
b) Single Photon e.m. Shower (ECAL–Mode).

- **Results:** **AMS02–γ expected performance and sensitivity.**
Some scientific cases (Diffuse spectra, Undefined Sources, Pulsars, AGN and Blazars, ...)

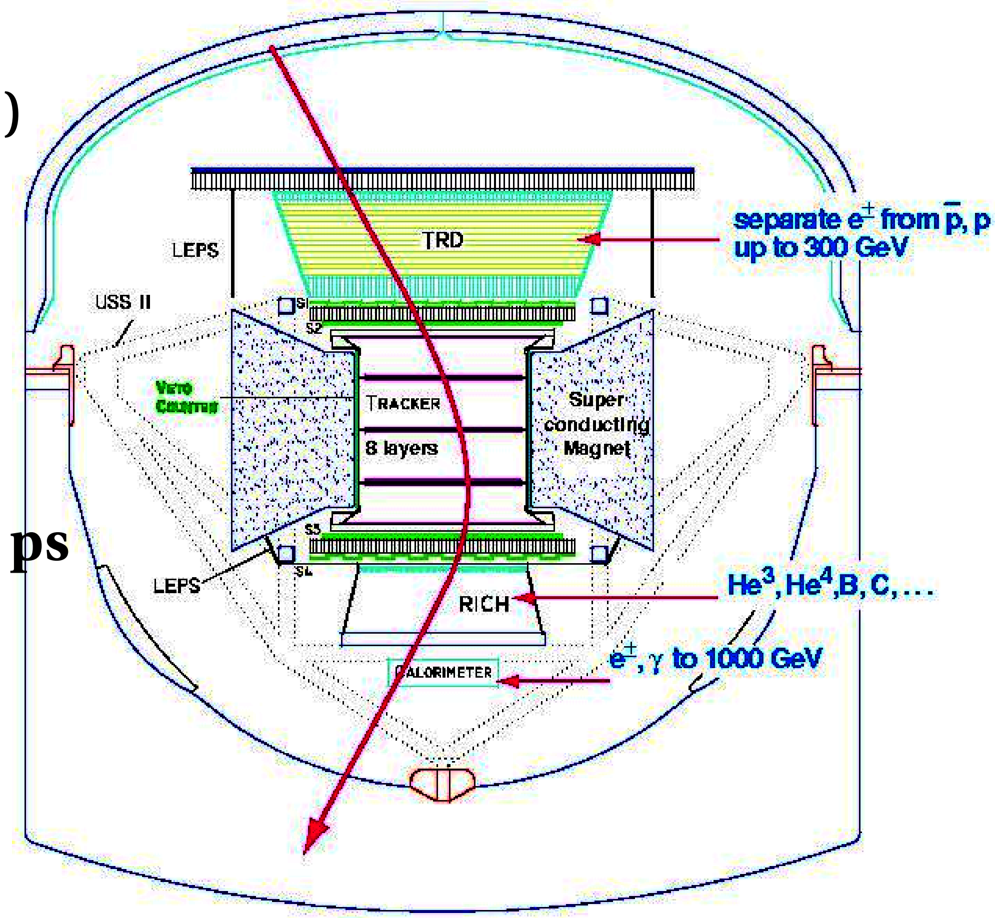
AMS-02 ON THE ISS

AMS is a Large Acceptance Magnetic Spectrometer for:

- **Antimatter Search ($\overline{He}$,$\overline{C}$) ($\overline{He}$/He < 10^{-9} – 10^{-10})**
- **Accurate measurements of Cosmic–ray composition and energy spectra**
- **Dark Matter Signatures (e^{+}, $\bar{p}$, $\overline{D}$, γ)**

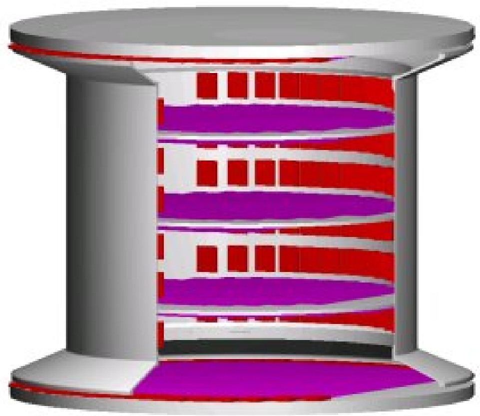
→ ***High–energy γ–ray sky exploration***

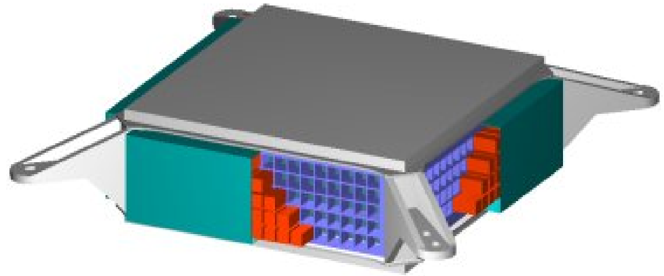
- Superconducting Magnet: **0.8 T**
- 4 layers of Scint. Counters (ToF)**:120 ps**
- 8 layers Si–Tracker**: MDR 2 – 3 TeV**
- Gaseous TRD**: h/e 10^2 – 10^3**
- Pb–Sci. ECAL**:h/e O(10^3)**
- Aerogel (1.05) RICH **: $\frac{d\beta}{\beta}$=0.07 – 1%**



AMS PHOTON DETECTION

AMS–02–γ is based on ... 2 main detectors





Si–TRACKER

8 planes of double–side Silicon sensors (8 m^2) providing: (x,y) hit–coordinates with (30μm,10μm) spatial resolution.

e^+e^- bended tracks from γ conversion are reconstructed.

ECAL

3D high–granularity (Pb–SCINT) sampling ECAL.
1Mm diameter fibers along x & y.
Overall 16X0 for (63x63x16 cm^2).

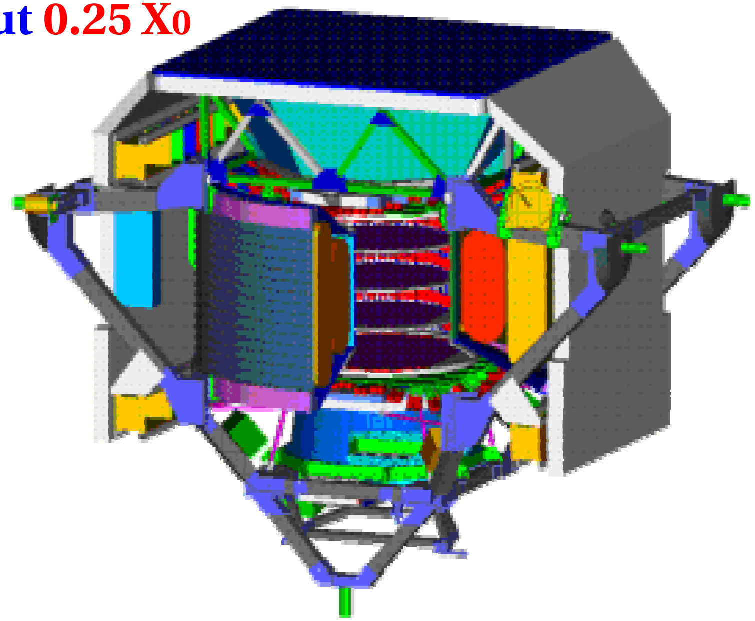
It provides e/h discrimination and electromagnetic shower from γ.

....we'll monitor the sky for 3 Years !!!

MONTE CARLO STUDY

ECAL .OR. TRACKER .... two complementary detections

1) The new layout (with respect to AMS–01) (TRD+Thermal&Mechanical structures) will provide about 0.25 X_0 for e^+e^- conversion upstream the first ToF level



TRACKER–mode Event Signature:

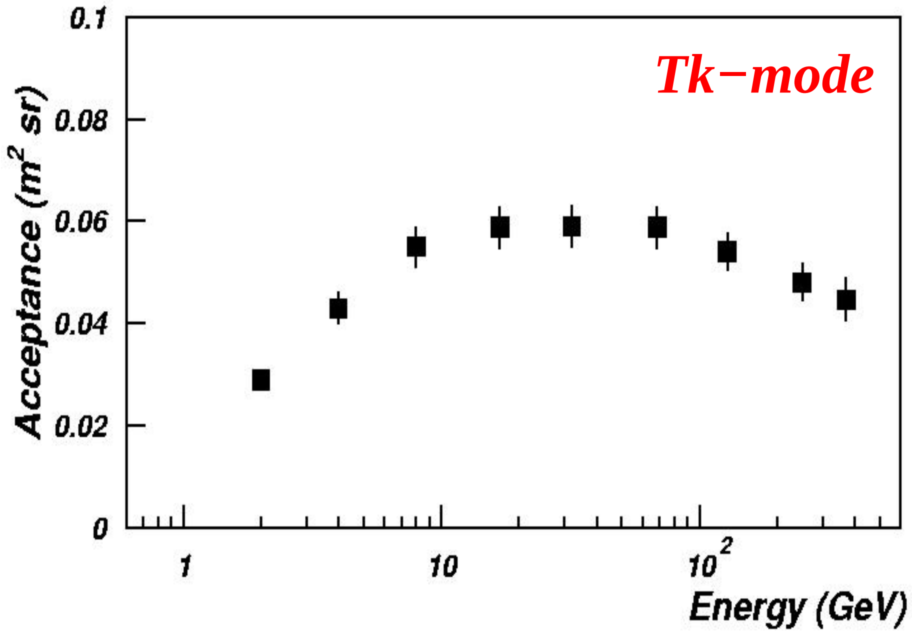
- –Quality–track reconstruction of e^+e^- coming from a common vertex
- –Track direction through the TRD
- –Two opposite charge tracks
- –Low invariant Mass

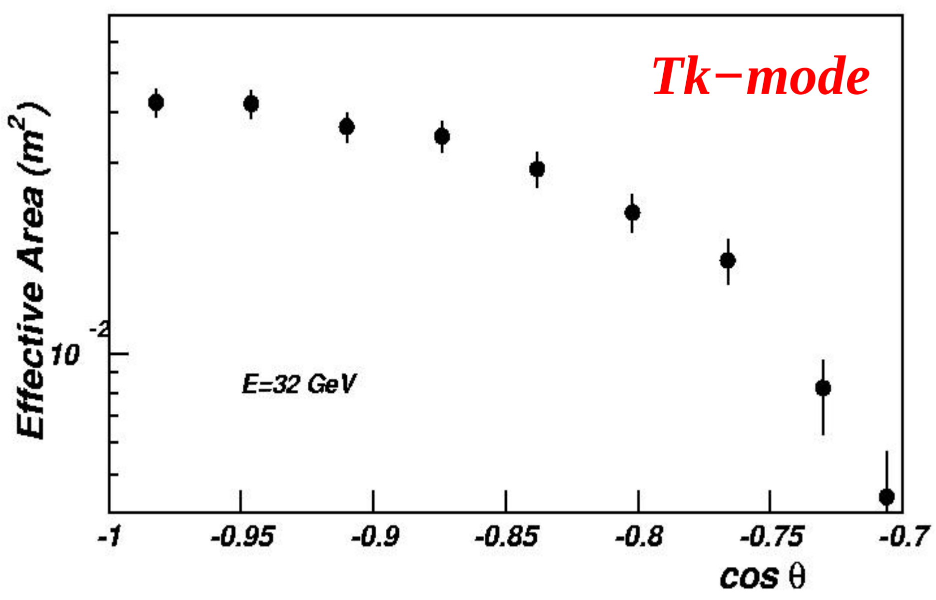
2) Even without a NEUTRAL TRIGGER (with respect to typical photon telescopes) ECAL will trigger stand alone events out LVL1 DAQ:

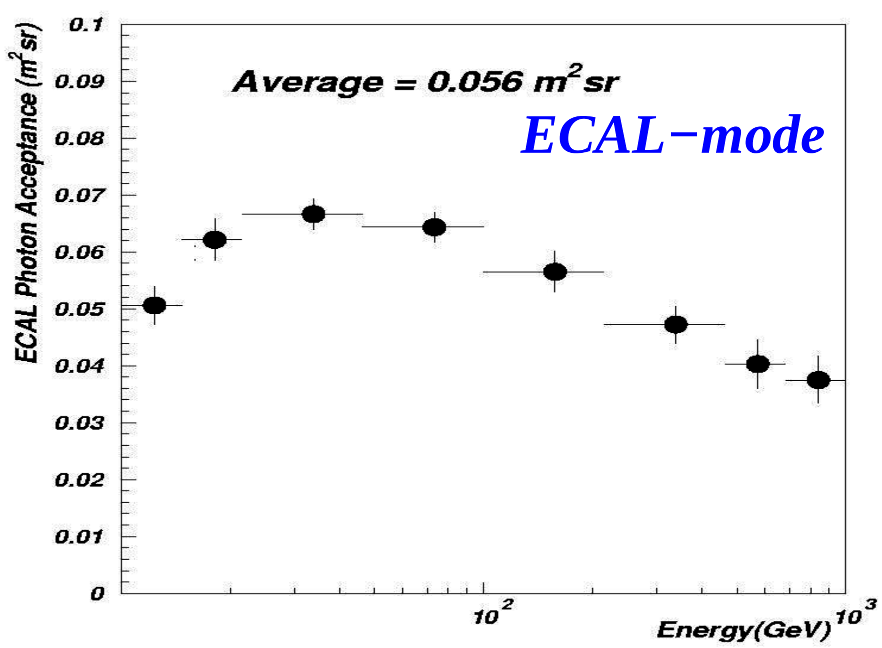
ECAL–mode Event Signature:

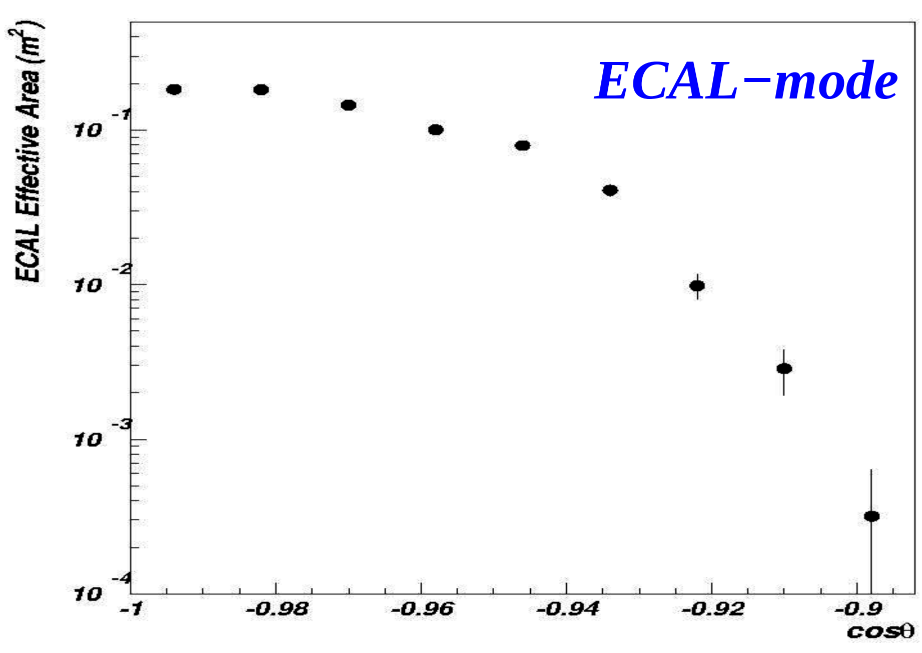
- –Electromagnetic shower in ECAL
- –(Almost) Nothing in other detectors

RESULTS: ACCEPTANCE



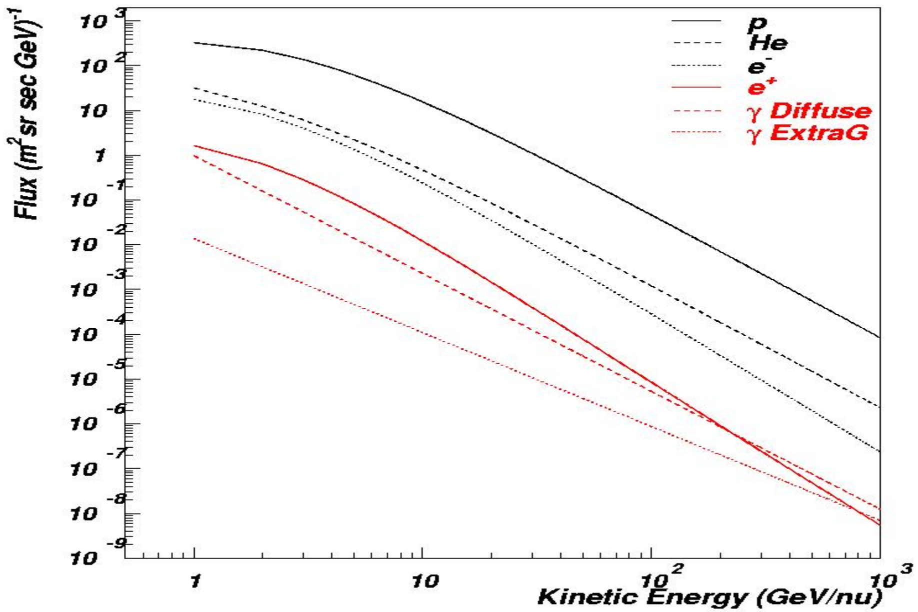






CR BACKGROUND

To obtain a background–to–signal ratio of a few percents, an O(10^4) to O(10^6) rejection is needed.

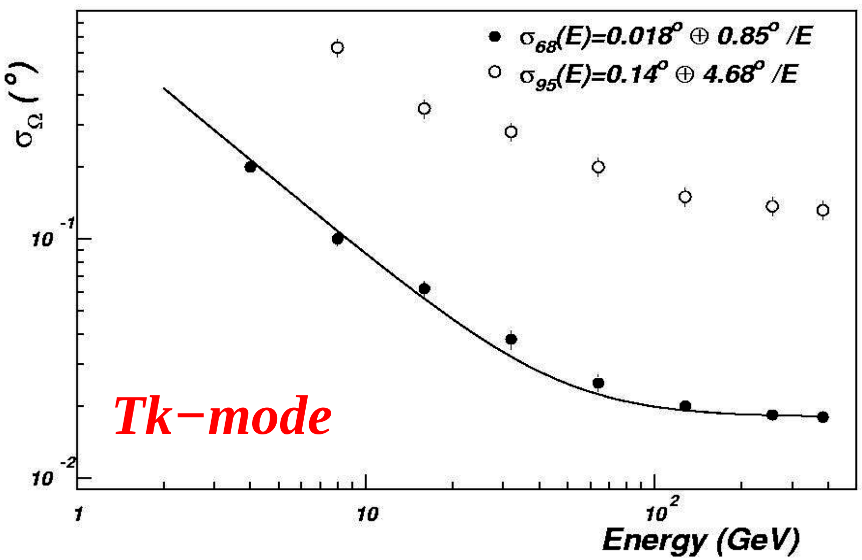


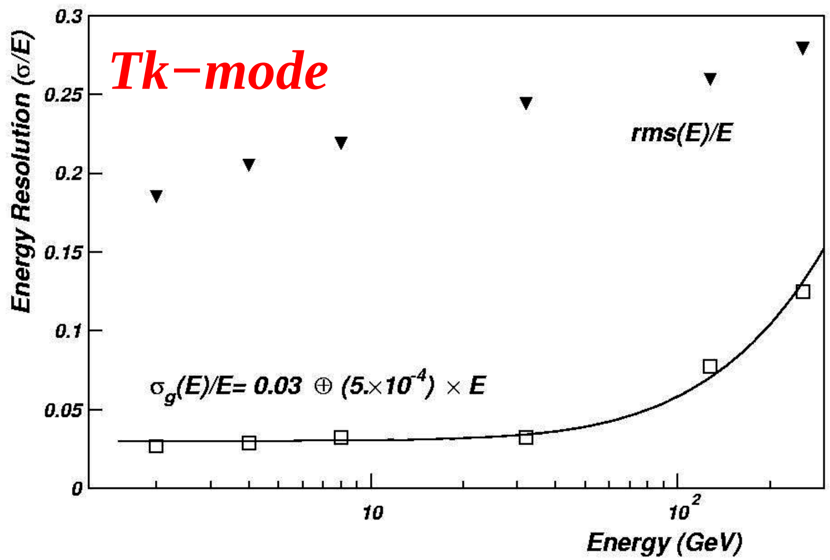
Rejection factors:
e^{+-} > 0.5 x 10^6
p (2.5+−0.1) x 10^6
He > 1.7 x 10^6

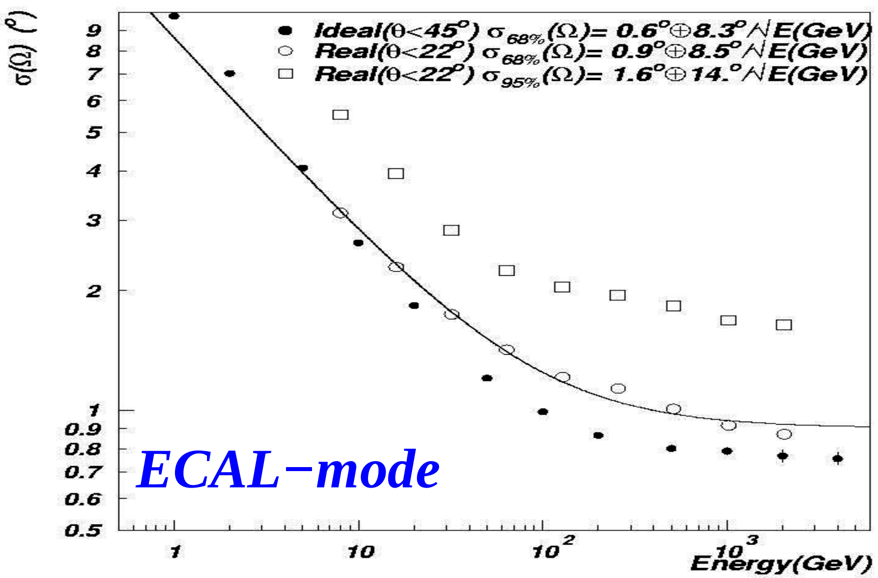
ECAL–mode background events due to charged particles passing undetected in the gaps or by the sides.

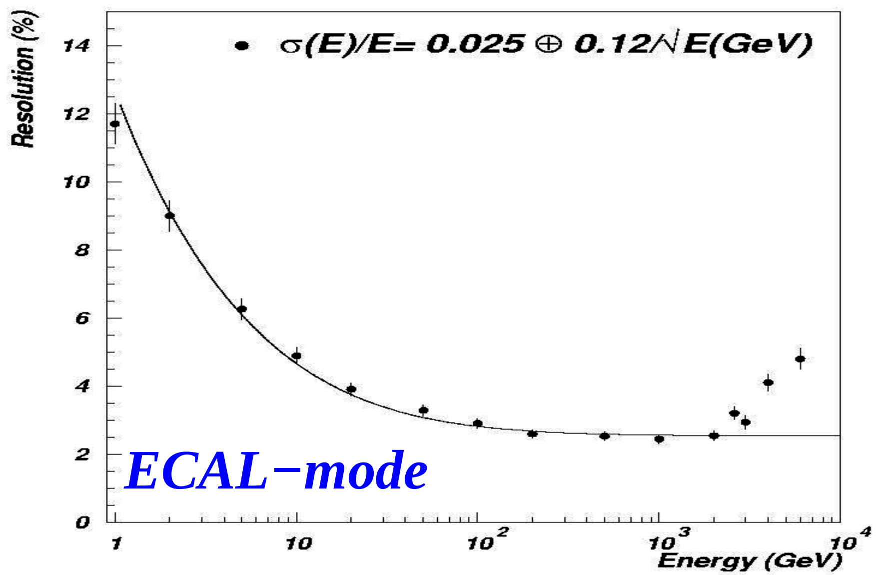
Tracker–mode background events :*p* and *e^-*,interacted with the AMS material and producing secondaries: mainly δ–rays. They mimick double–tracks *e^+e^-* pair events from γ conversion.

Results: Resolutions





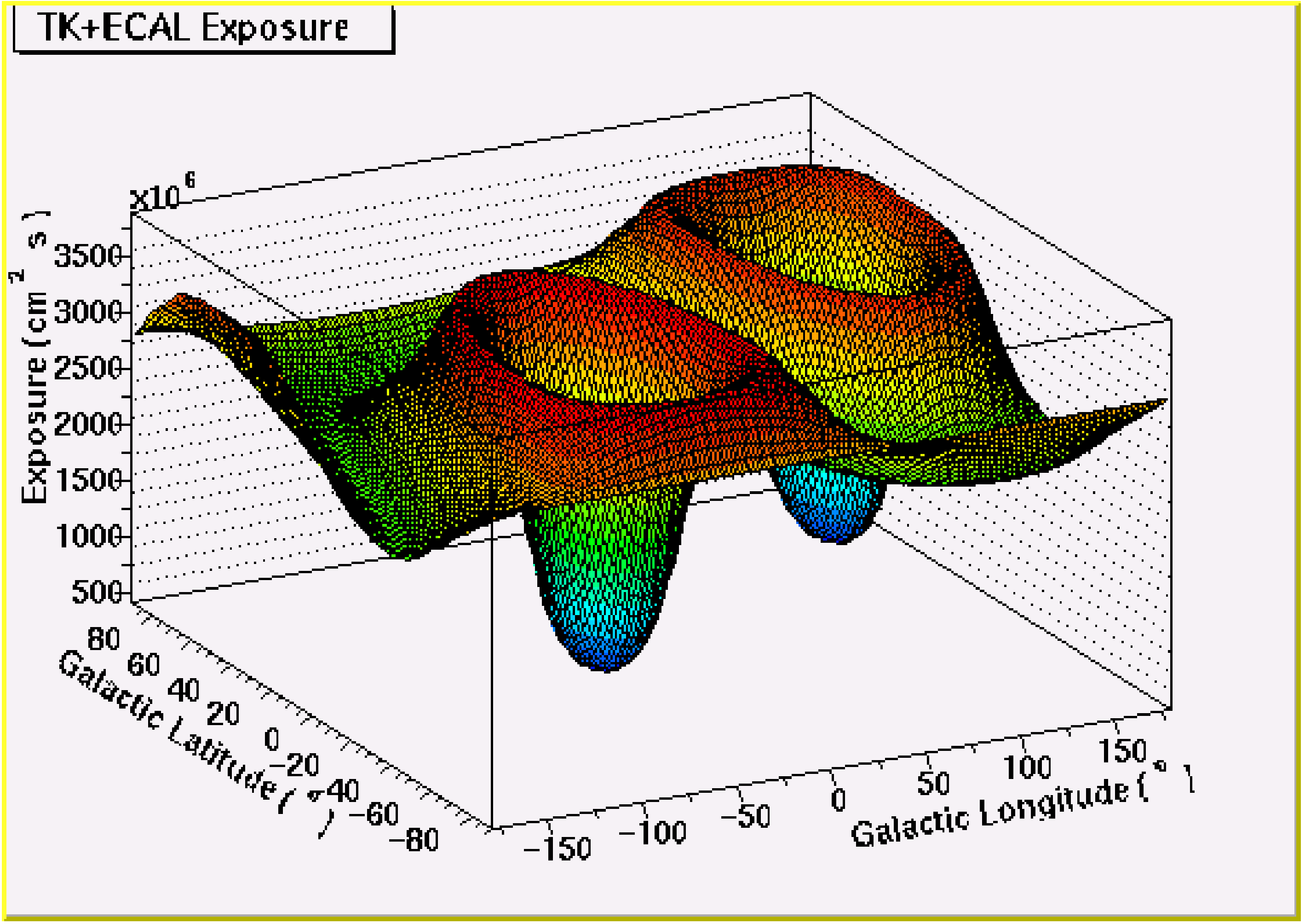




AMS Sky Sensitivity

1 Year Exposure : Tk + ECAL

From ~ 0.4 to ~ 4. 10^9 cm^2 s



POINT SOURCE SENSITIVITY

Point Source Sensitivity: **Minimum source flux required to achieve a specified level of detection significance S**

$$S(>E_t) \simeq \frac{N(>E_t)}{\sqrt{B(>E_t)}} \simeq \frac{\int_{E_t}^{\infty} \frac{dN}{dE} A(E)\, t\, dE}{\sqrt{\int_{E_t}^{\infty} \frac{dB}{dE} A(E)\, \Omega(E)\, t\, dE}}$$

Numerator → **Total number of detected γ from the source > Et**

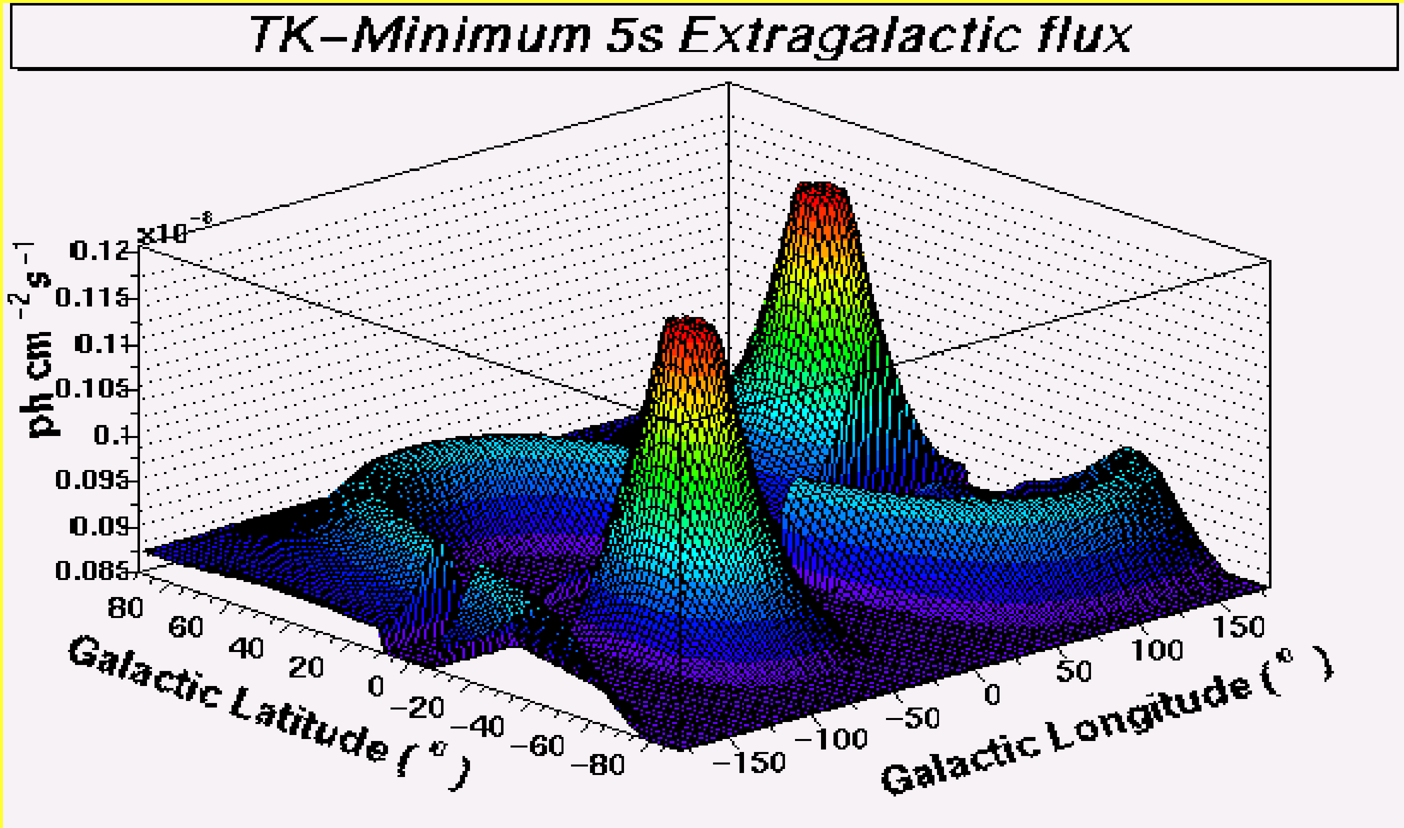
Denominator → **Number of bg. γ falling within the source area > Et**

N and B are function of :

1) **Effective Area A(E)** *vs* $\Delta\theta$
2) **Angular Resolution in solid angle** $\Omega(E)=\pi\sigma_{68}^2(E)$
3) **Viewing Time t** (by simulating 1 year ISS orbit and AMS FOV without SAA)
4) **Differential Source Spectra** $dN/dE=n_0\left(\frac{E}{1\,GeV}\right)^{-\gamma}$ $(cm^2\ s\ GeV)^{-1}$
5) **Differential Bg. Spectra dB/dE** (Galactic and Extragalactic from EGRET)

AMS Sky Sensitivity

Let's assume AMS point source sensitivity as the minimum value n_0 which gives a 5σ signal integrated over 1 year of operation *(in l x b = 2° x 2° bins)*



–TRACKER–: The limited A_{eff} is partially balanced by the angular resolution:
Minimum (Average) n_0 (E>1 GeV)=
(|*b*|>*10°*) 8.5 (9.7) x 10^{-10} cm^{-2} s^{-1}
(|*b*|<*10°*) 5.0 (13.) x 10^{-9} cm^{-2} s^{-1}

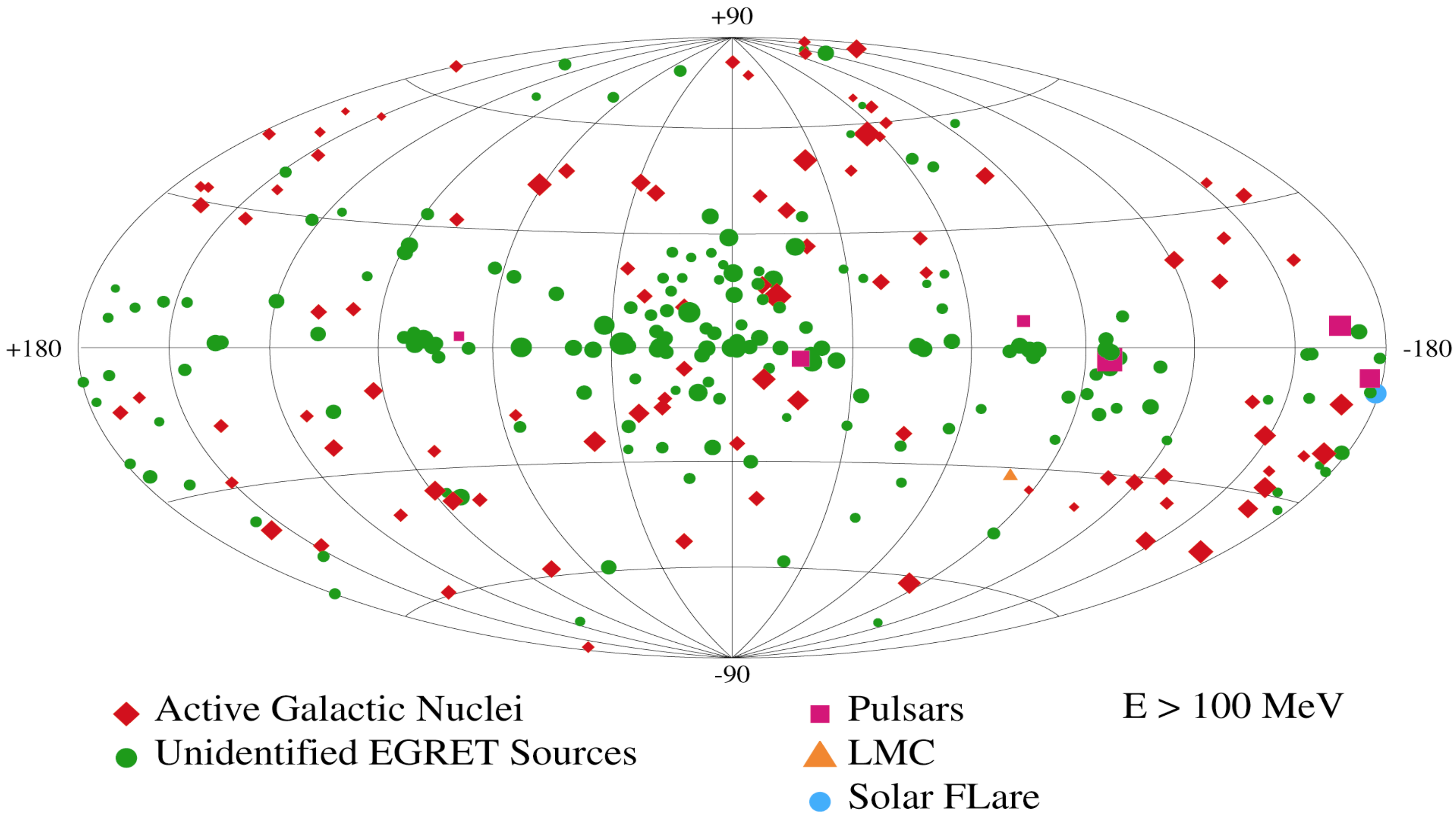
–ECAL–: The angular resolution limits the point source sensitivity:
Minimum (Average) n_0 (E>10 GeV)=
(|*b*|>*10°*) 1.4 (2.5) x 10^{-9} cm^{-2} s^{-1}
(|*b*|<*10°*) 5.0 (10.3) x 10^{-9} cm^{-2} s^{-1}

THE SCIENTIFIC CASE

More than 60% of the 271 Third EGRET Catalog high–energy gamma–ray sources are UNIDENTIFIED.

With AMS we could:

Reduce source location error boxes to less than few arcminutes



UNIDENTIFIED SOURCES WITH AMS

SOURCE LOCALIZATION: Comparable with GLAST

(Source localization < 5’ and higher sensitivity)

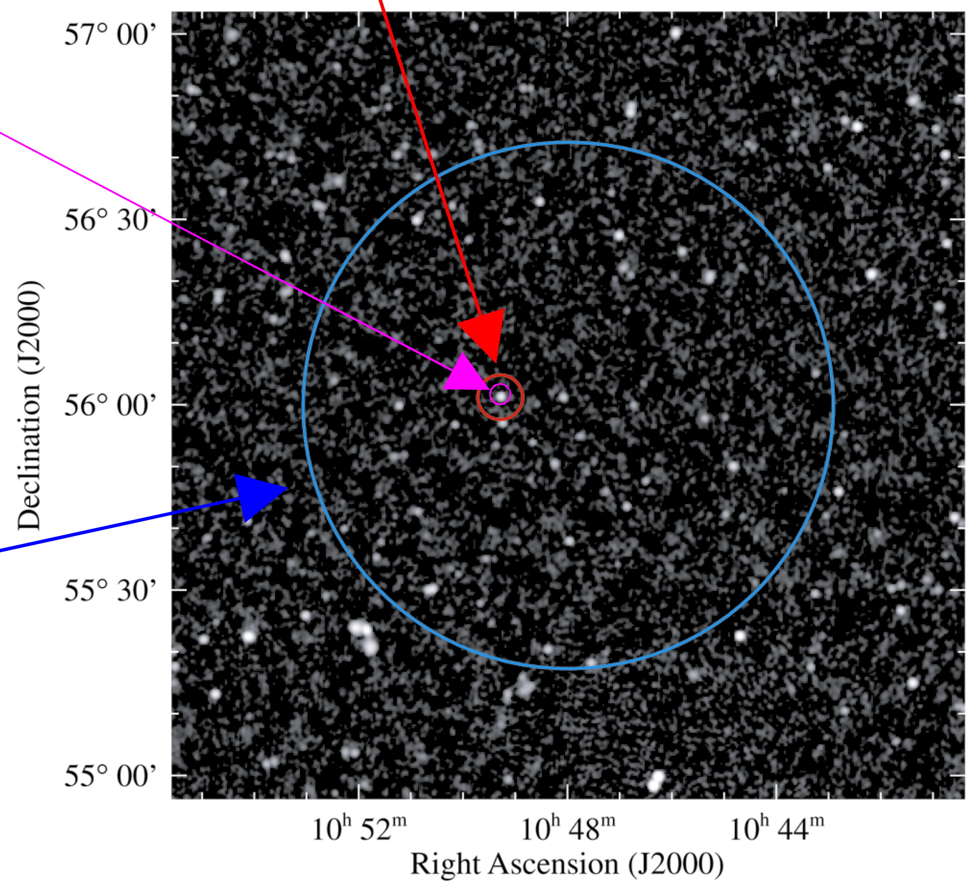
AMS–TK & STAR–MAPPER

Source localization :

–in 1 Year
–with S–M: 0.5’
–for Sources of strength
$\sim 10^{-8}$ ph cm^{-2} s^{-1} (E>1GeV)

AMS–TK: < 5’

– **Improving** at higher energy < 2’–3’



EGRET

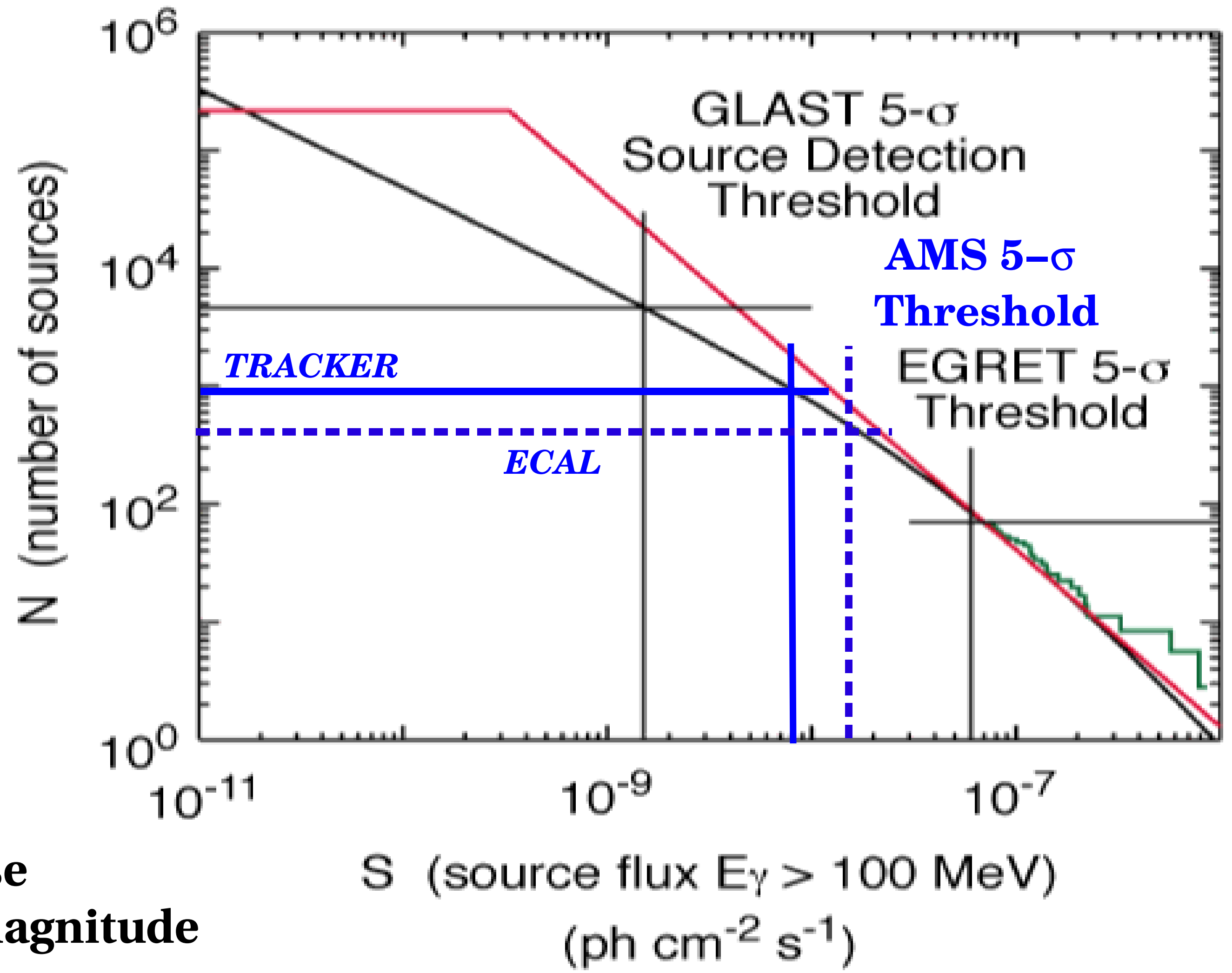
– Source localization: < 30’ for source of strength 10^{-8} ph cm^{-2} s^{-1}
– Limited sensitivity above 1 GeV

Unidentified Sources with AMS

Number of sources of the detected integral γ–ray flux above 0.1GeV in one year.

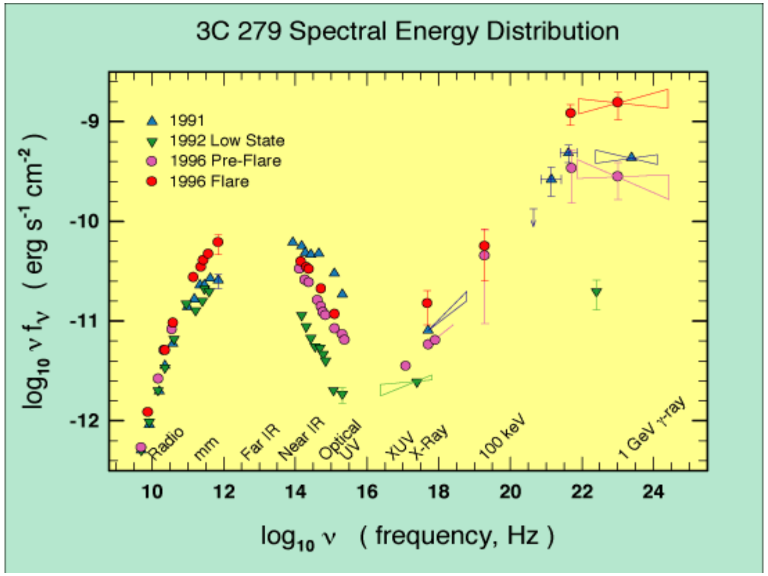
The AMS minimal (*b>10º*) point source integral flux sensitivity for the ECAL and TRACKER options.

The >1 GeV flux sensitivity has been scaled for the equivalent 0.1 GeV by having assumed a nominal E^{-2} differential source energy spectrum.



In one year AMS will increase of more than one order of magnitude the statistics of high–energy γ–ray Sources.

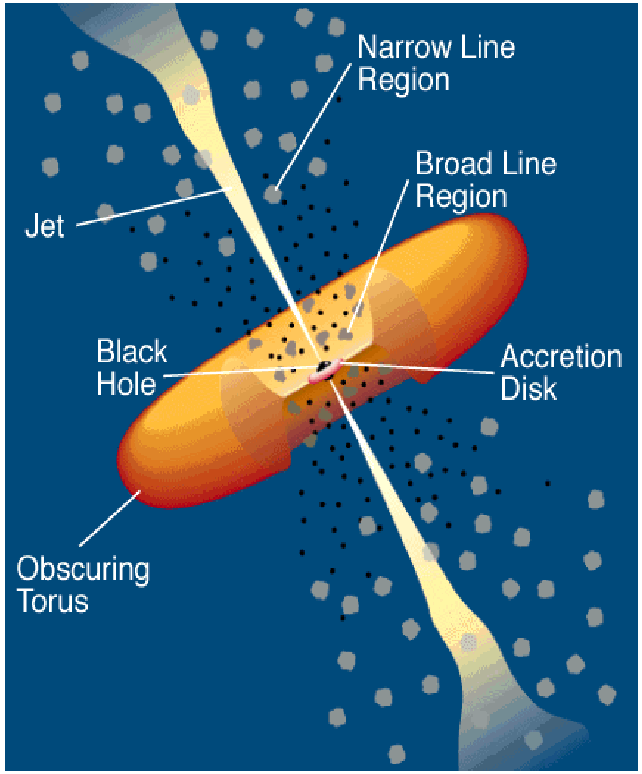
BLAZARS AND AGN



EGRET blazars' spectra apparently fall off over the experimental cutoff (~20 GeV). They are not detected by ground–based instruments (>200 GeV).

We need space observations at higher energy and in overlapping with ground–based ones.

Within the unified model the blazar signature is function of relativistic beaming effect of plasma jets towards the Earth….

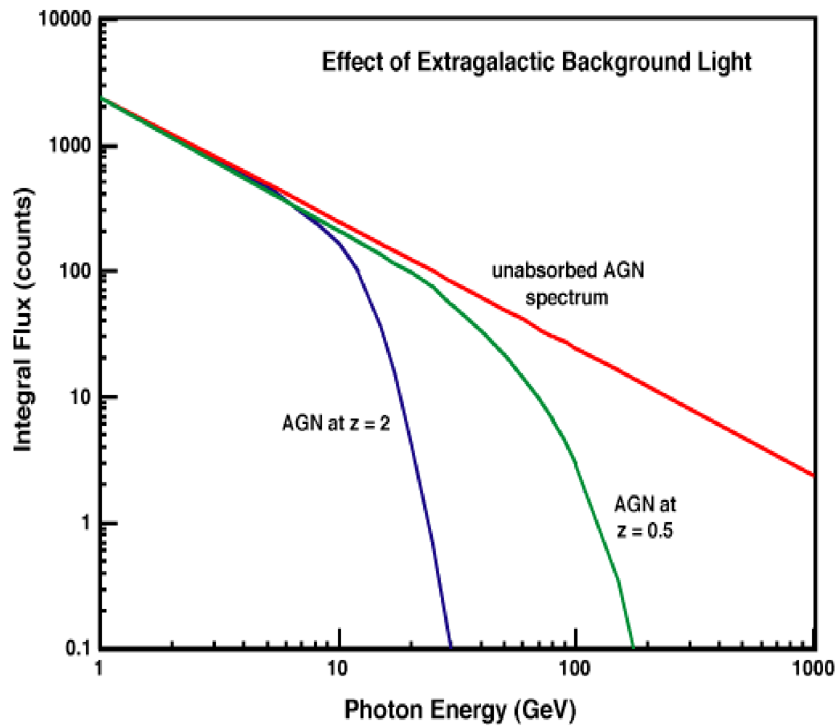


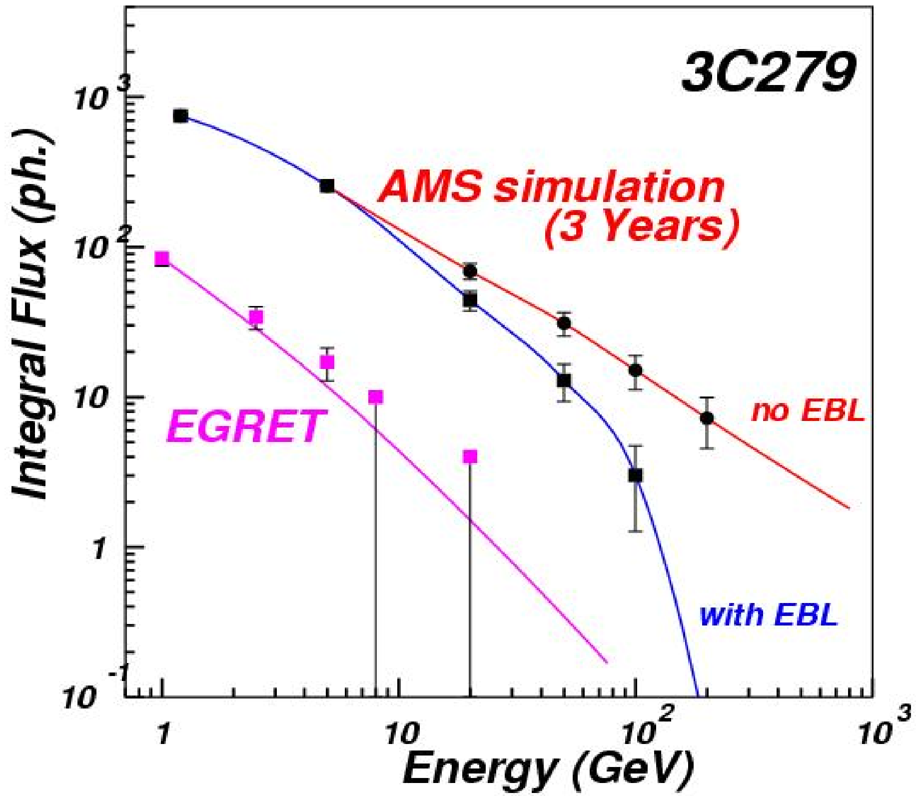
Blazars and AGN with AMS

Is their cutoff due to intrinsic processes within jets ?

...Or is it due to extinction of gamma rays off the diffuse soft photons (IR–optical) background ?

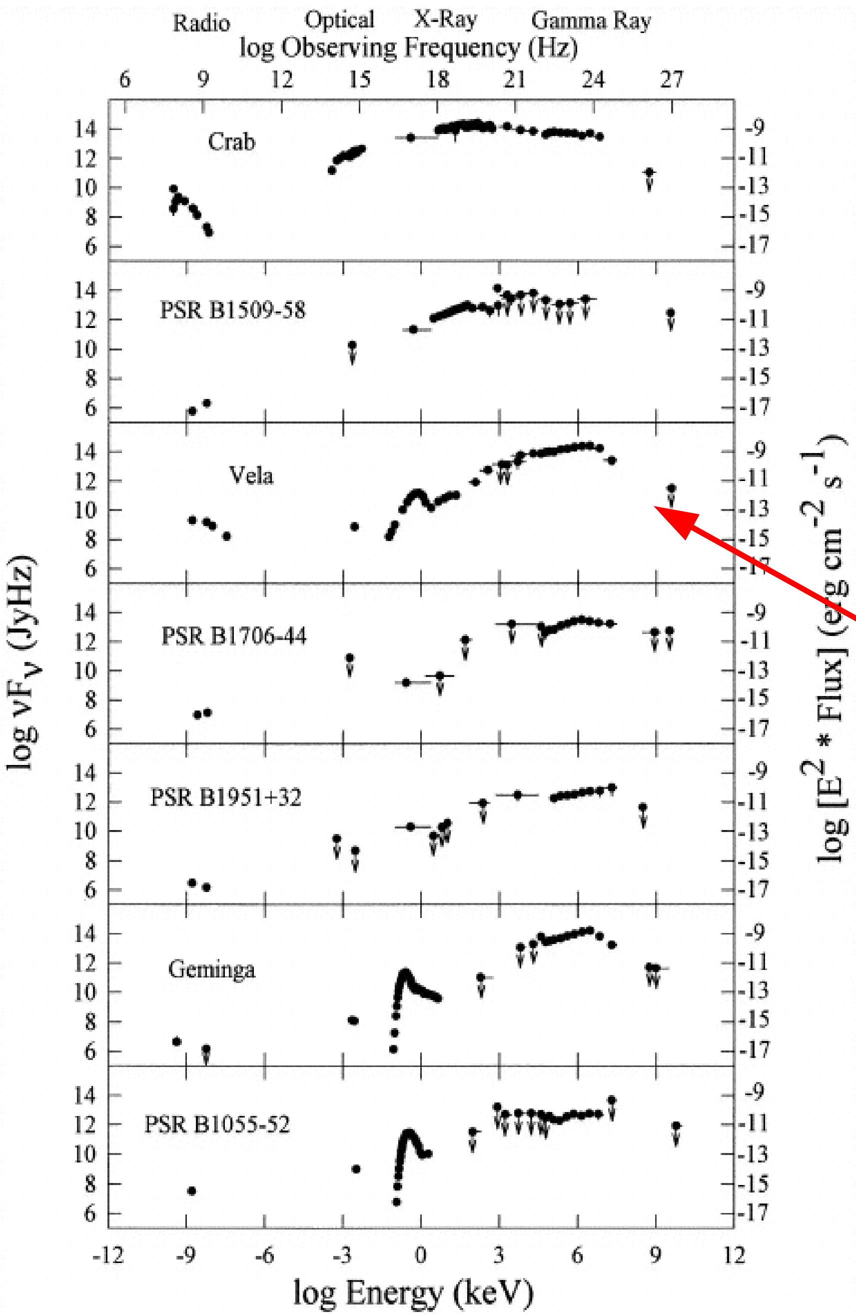
$\gamma\gamma \rightarrow e^+e^-$





The 3 years AMS observation of 3C279 will allow to accumulate significant statistics to disentangle the expected EBL cutoff at high energy.

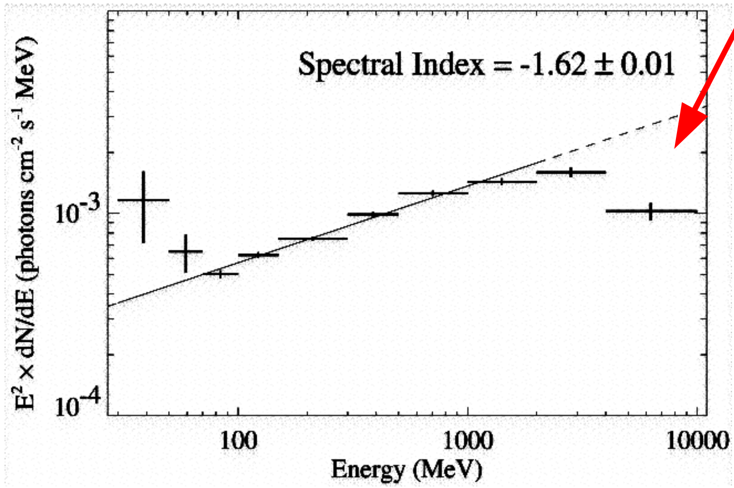
PULSARS



They provide some of the highest energy particle accelerators in the Universe.

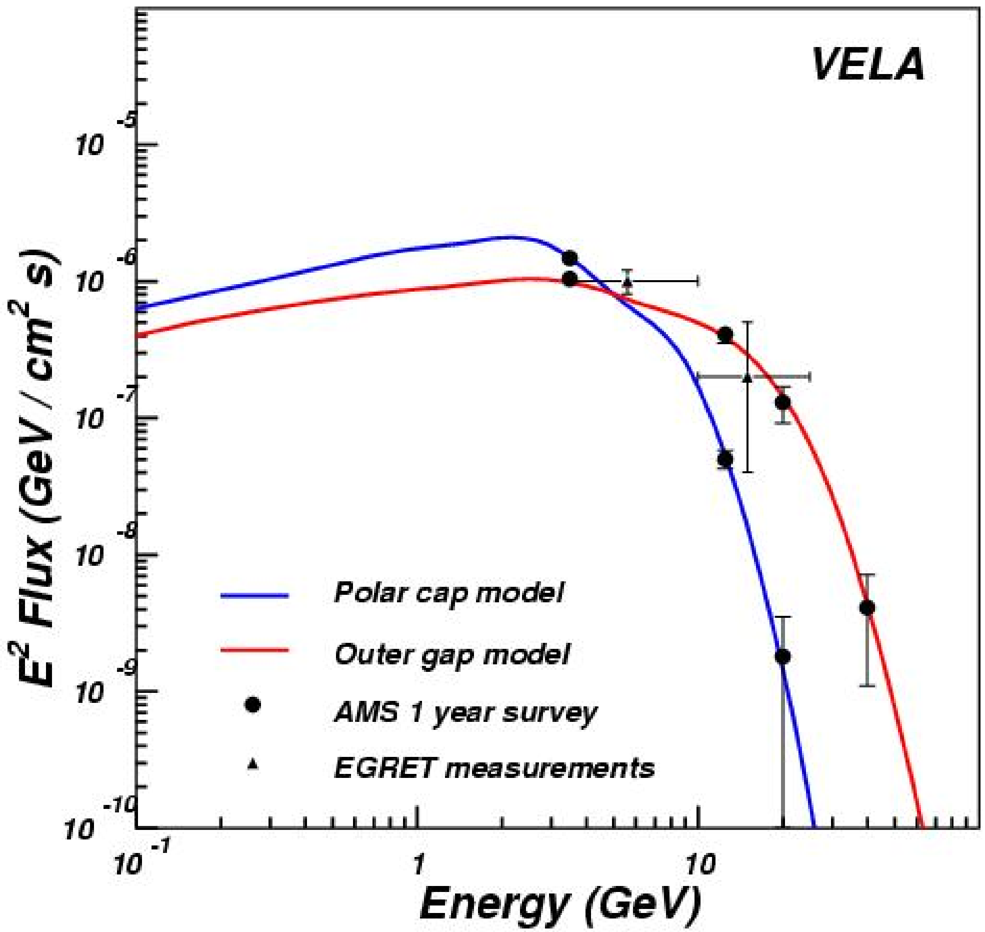
How do they work and how is their energy converted to photons ?

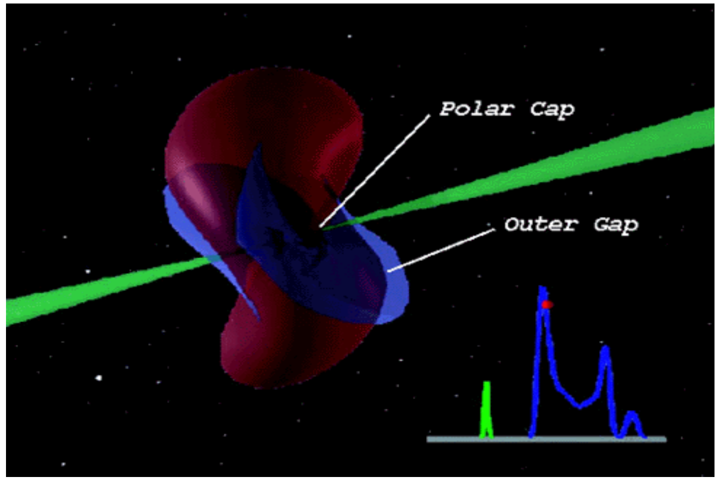
The spectral index would change above few GeV. High sensitivity is needed to investigate such a cut–off.



Pulsars with AMS

...In some case (e.g. VELA) the number of photons detected will not be critically affected by assuming a spectral index >2 (E>10 GeV) .

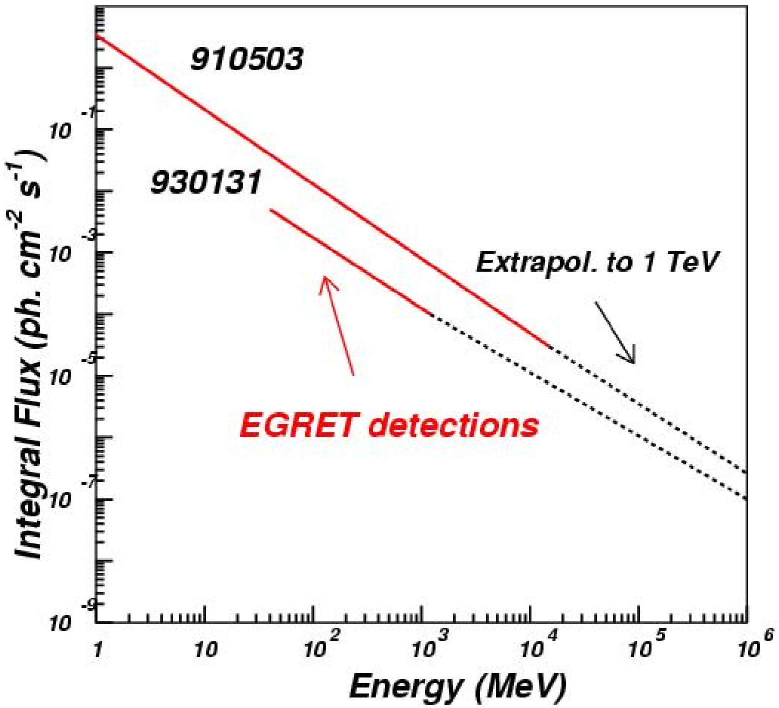




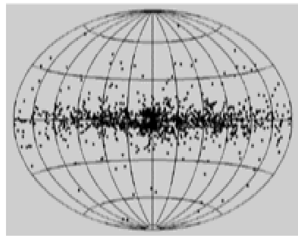
Depending on the model:
Polar cap or Outer gap, different high energy fluxes are expected.

In both cases AMS in 1 year will detect enough statistics to distinguish between the two models.

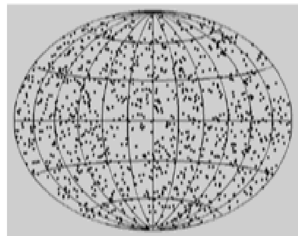
GRB WITH AMS



Distribution of Gamma-Ray Bursts on the Sky



Expected



Observed

GRB lasting 100s would be seen by AMS by detecting hundreds of photons (E>1GeV)

The two higher energy GRB out of 5 seen by EGRET (Hunley et al. 1995)

1991 May 3rd   Emax=10 GeV , Δt=84 s,
extrapolating: **AMS ~70 ph** $\geq 5\sigma$, in 100s , E>1 GeV

1993 January 31st   Emax=1.2 GeV , Δt=100 s,
extrapolating: **AMS ~10 ph** $\geq 5\sigma$, in 100s , E>1 GeV

[....]

CONCLUSIONS

The results of MC simulation study of the AMS02 as a γ–ray detector are presented: broad energy range, few percents energy resolution, remarkable (0.018°–1°) angular resolution, high level CR–background rejection.

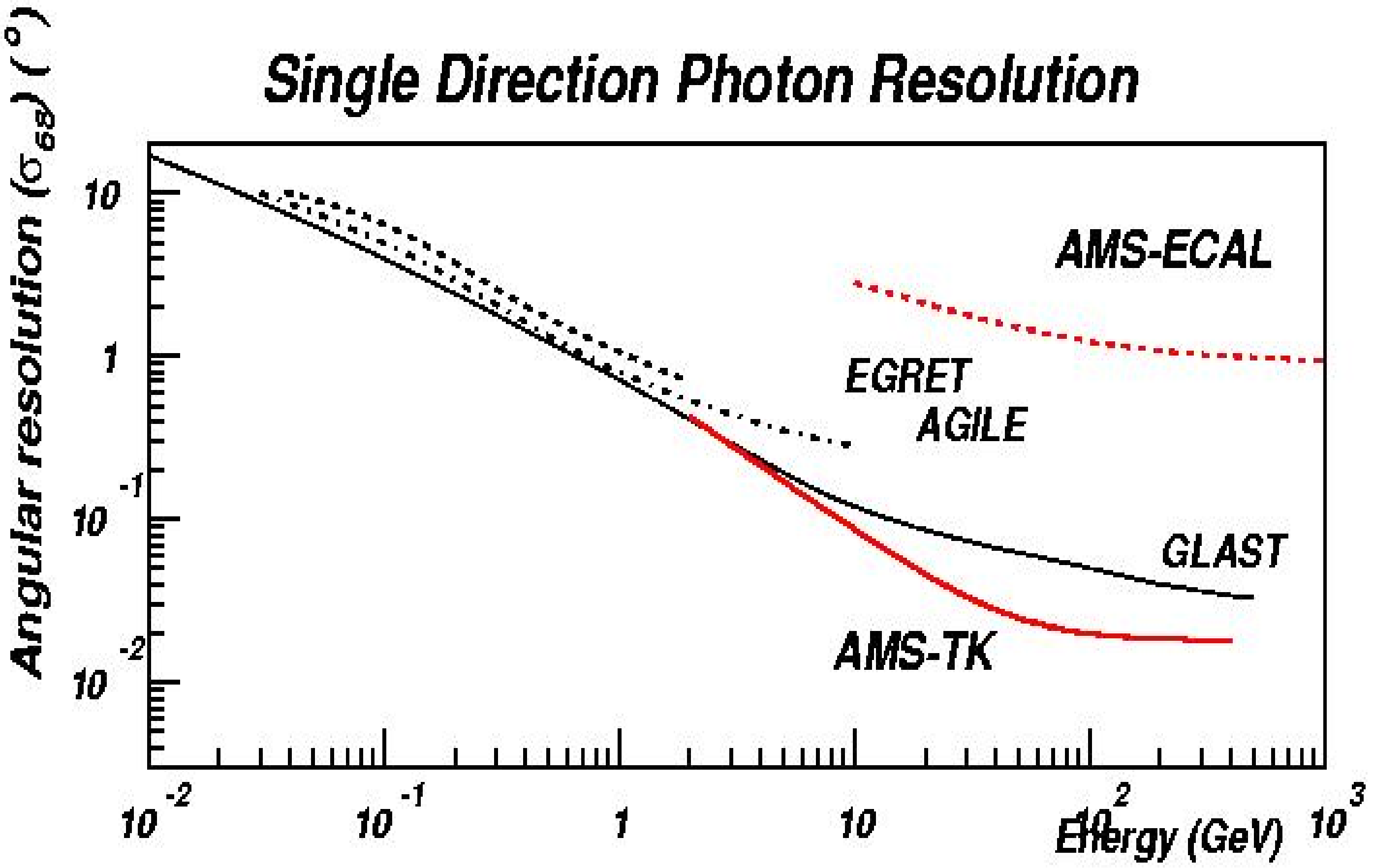
Sensitivity study for ISS orbit simulation case, has demonstrated the high precision of point source localization and the high sensitivity at high energy γ–ray sources physics.

A few examples of physics objectives are presented, pointing out the challenging results which AMS02 will achieve on board the ISS.

AMS02 will perform a vast line of research and "atrophysical" observations in Space on board the International Space Station .

Backup

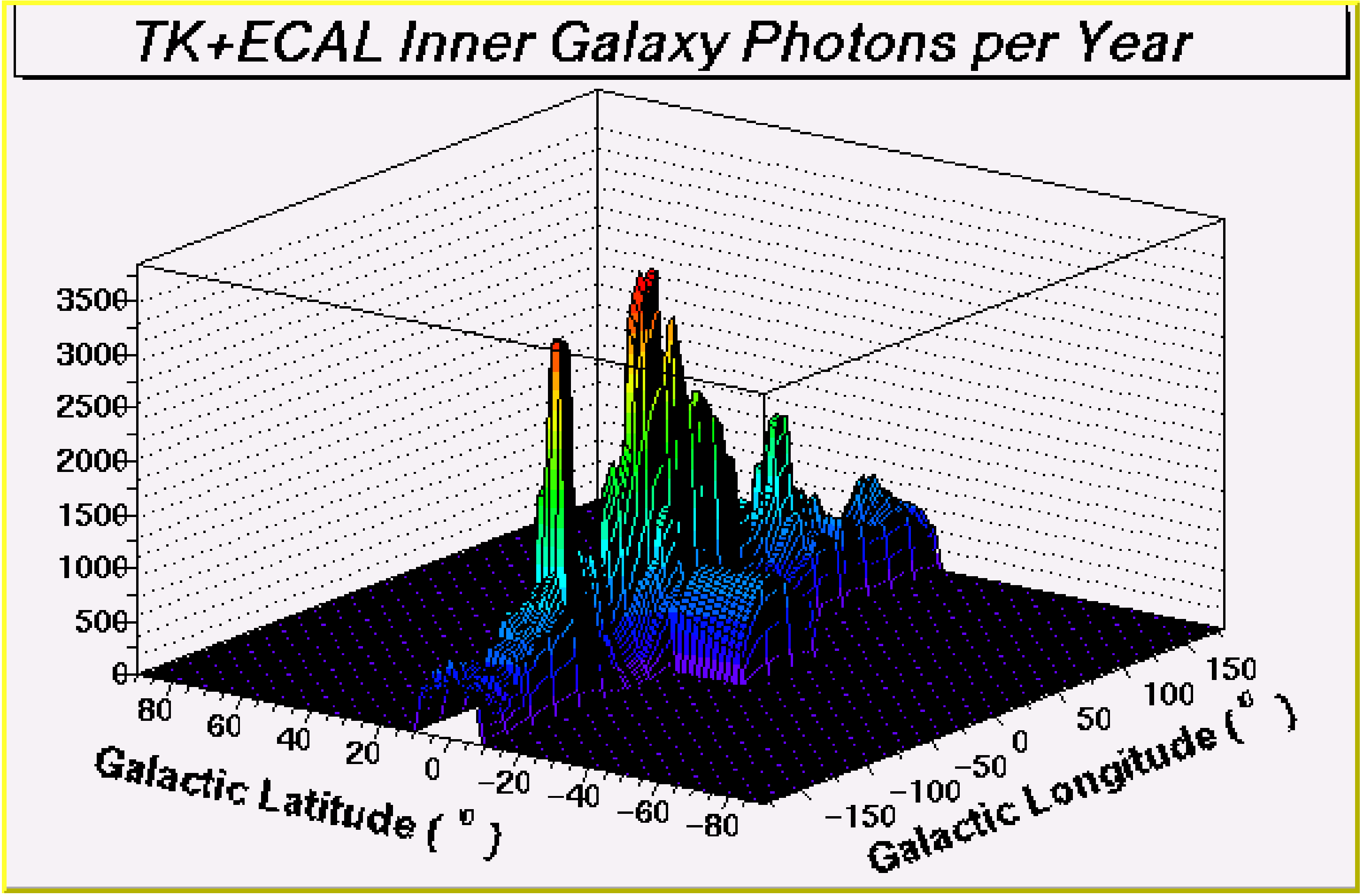
MC-Study: Results



The AMS–TK (e^+e^-) angular resolution is one of the most interesting and promising figure of merits.

AMS γ-DIFFUSE SPECTRA

In one year *(simulated)* ISS orbit, AMS will detect *(in l x b =2º x 2º bins)* up to a maximum of 4. 10^3 *ph* from the Inner Galaxy spectrum. *(>1 GeV)* …… while a maximum of 30 *ph* from Extragalactic Diffuse spectrum *(> 1 GeV)*



COMPARISON

Quantity	EGRET	GLAST	AMS
Energy range	20MeV–30GeV	20MeV–300GeV	~10GeV–1TeV ECAL 1GeV–300GeV TK
Peak effective area *....duty time..*	$1500\ cm^2$ *50%*	$10000\ cm^2$ *?*	~ $2200\ cm^2$ (~ 1750ECAL, ~450TK)
Energy resolution	10%	<10%	<3% ECAL 3% (<5% at 100GeV) TK
Single photon angular resolution	2^o–3^o ?? (>1 GeV)	< 0.15^o (>10 GeV)	< 2.8^o (> 10 GeV) ECAL < 0.8^o (1 GeV) TK < 0.08^o (10 GeV) TK <0.02^o (100 GeV) TK
Source location determination	5'–30'	< 5'	3'–6' (>1GeV) < 2' (>10 GeV)
Field of view	0.5 sr	3 sr	~1 sr ECAL ~2 sr TK