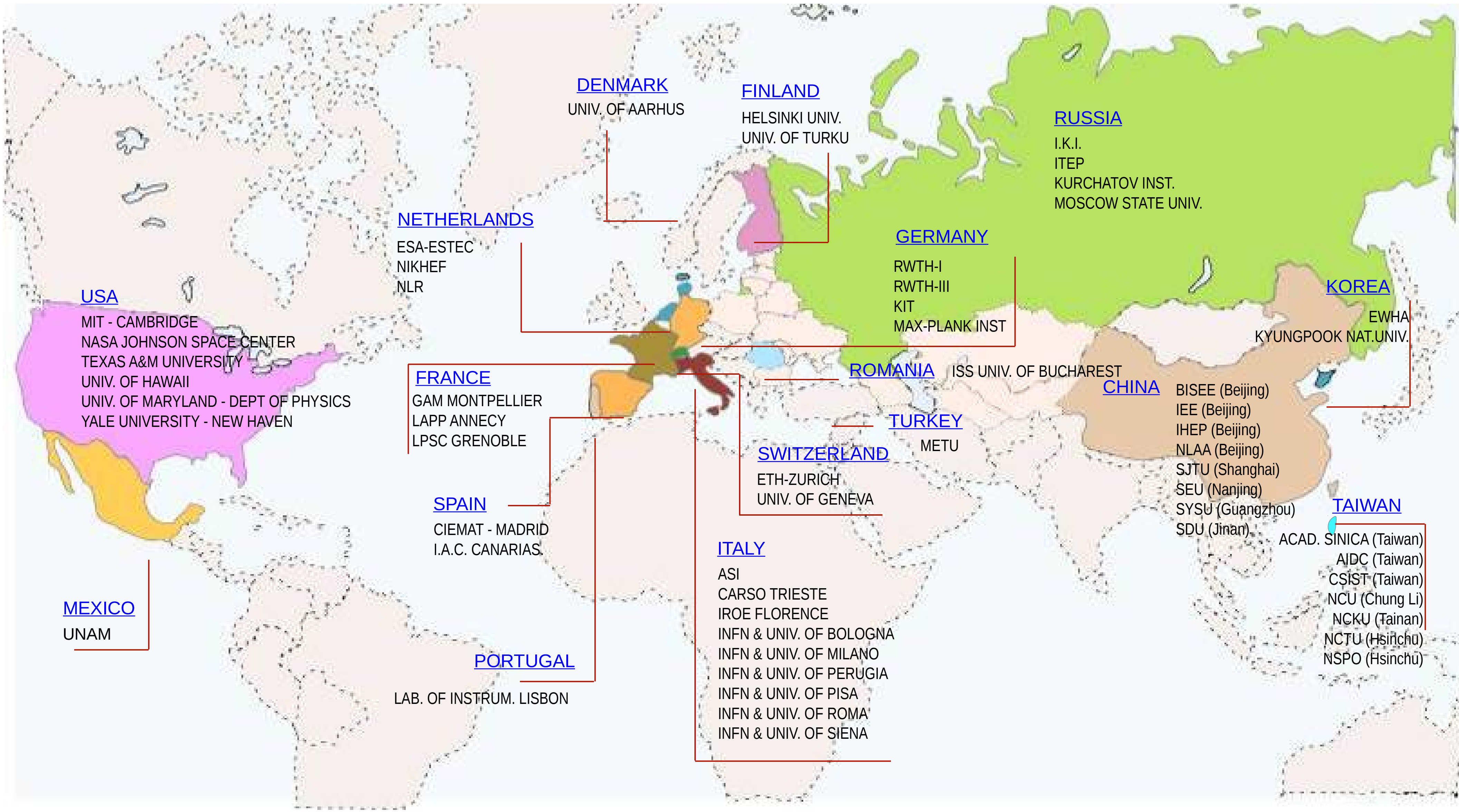
Measurement of Cosmic Rays with the AMS-02 detector on the ISS

Melanie Heil, KIT
On behalf of the AMS Collaboration

@EPS HEP 2013 Stockholm

Karlsruhe Institute of Technology

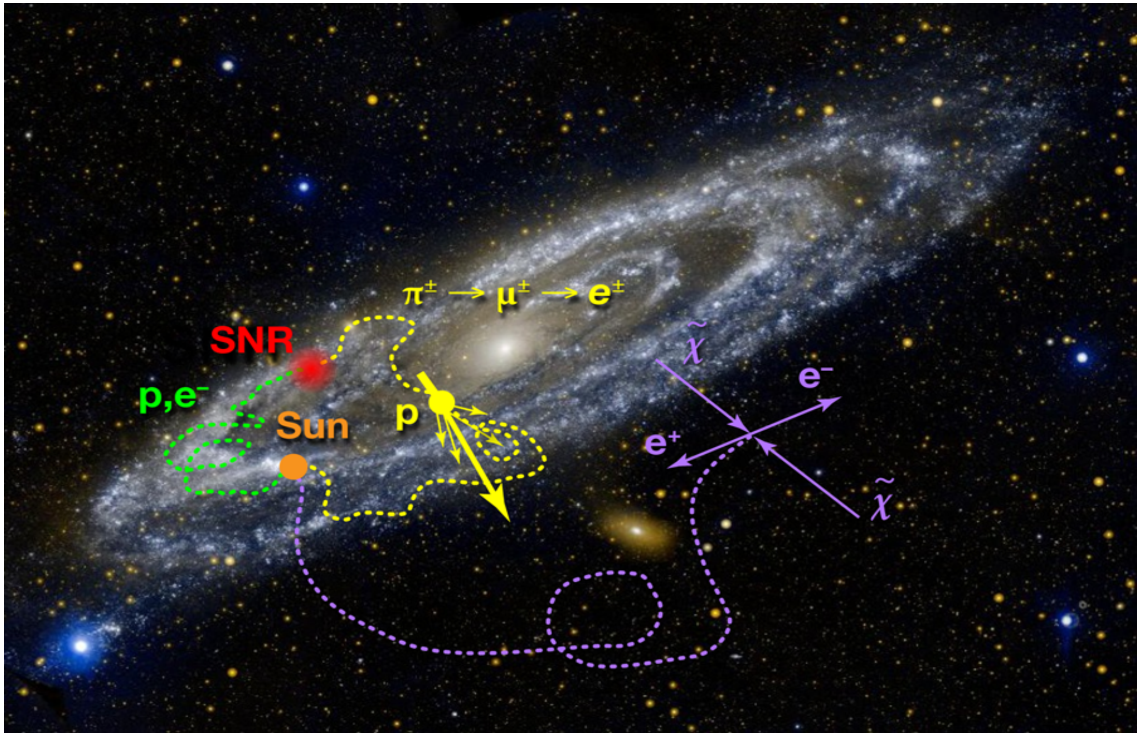
AMS: international collaboration of
> 15 countries, 56 institutes, 500 physicists



Physics of AMS

- **Measure cosmic rays with unprecedented precision up to TeV energies**
  → **help improve knowledge of cosmic ray transport (e.g. from B/C ratio)**

- **Search for the origin of Dark Matter:**



Collision of Cosmic Rays produce e+ …
Annihilation of Dark Matter will produce additional e+
These characteristics of additional e+ can be measured very accurately by AMS

- **Antimatter**

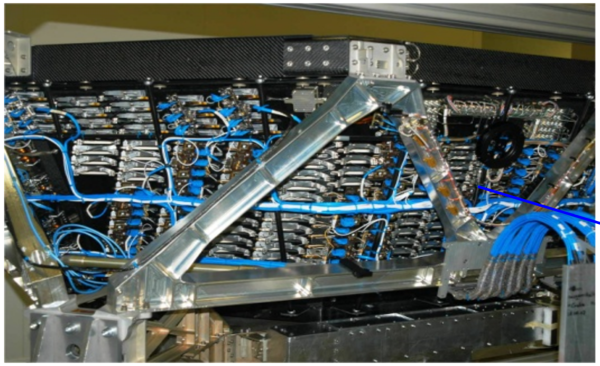
- **Strangelets and new physics**

The AMS-02 detector

AMS: A TeV precision, multipurpose spectrometer

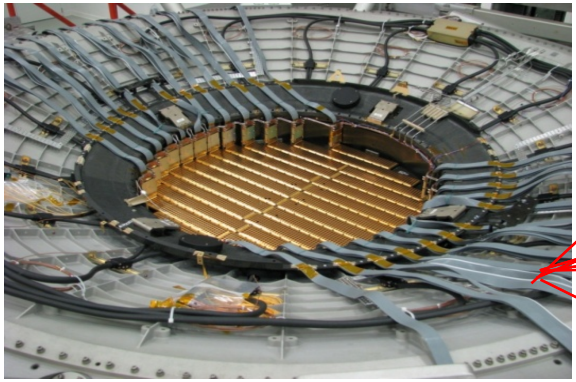
Particles and nuclei are defined by their charge (**Z**) and energy (**E ~ P**)

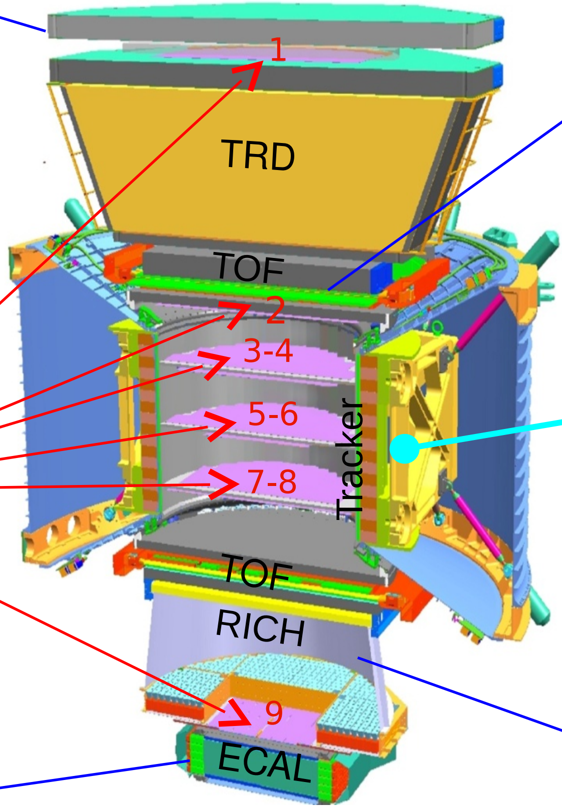
TRD
Identify e^+, e^-



TOF
Z, β

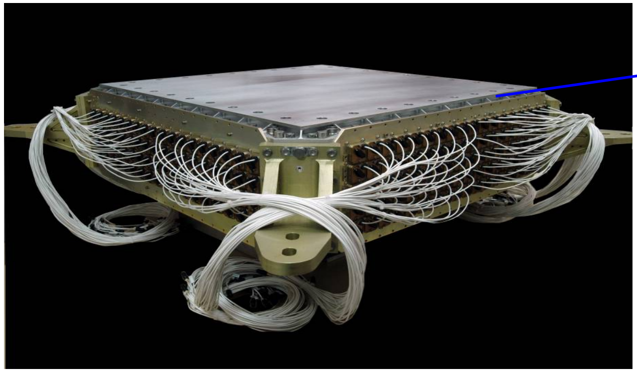
Silicon Tracker
Z, P



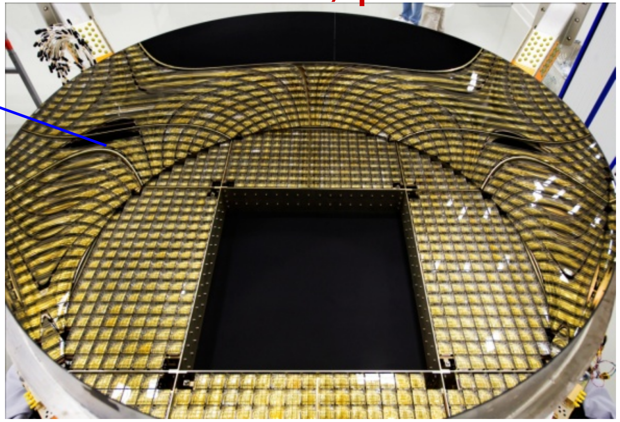


Magnet
±Z

ECAL
E of e^+, e^-, γ



RICH
Z, β



Z is measured independently by Tracker, RICH, TOF, TRD and ECAL

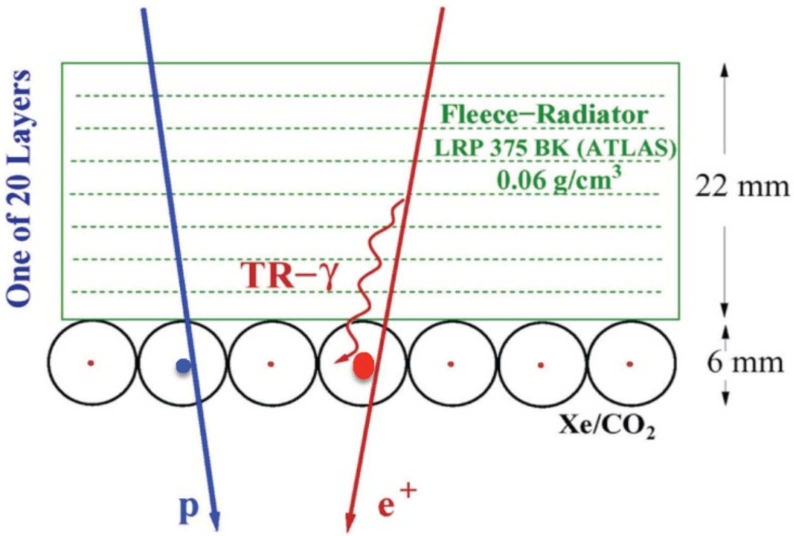
E (P,β) is measured independently by Tracker, ECAL, TOF and RICH

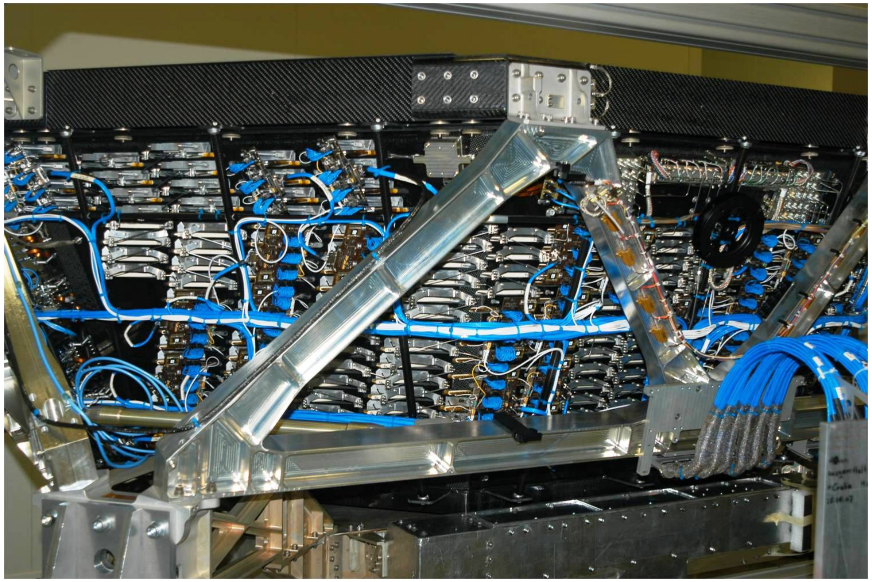
Transition Radiation Detector (TRD)

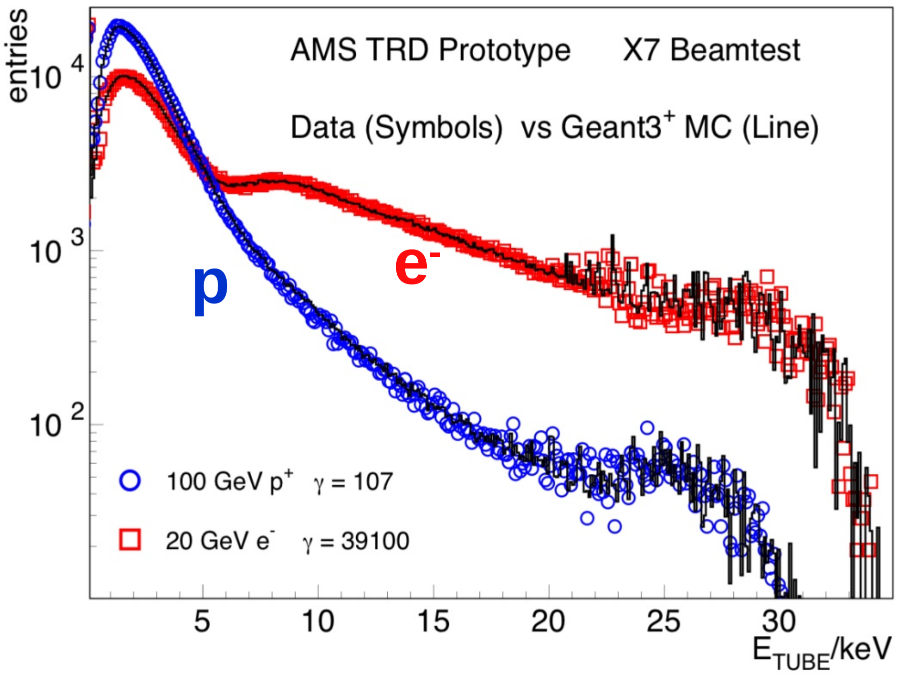
Identifies Positrons, Electrons by transition radiation and Nuclei by dE/dX

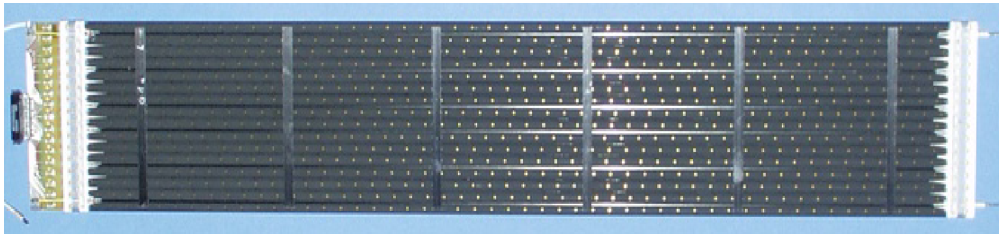
20 Layers each consisting of:

- **22 mm fibre fleece**
- **Ø 6 mm straw tubes filled with Xe/CO_2**



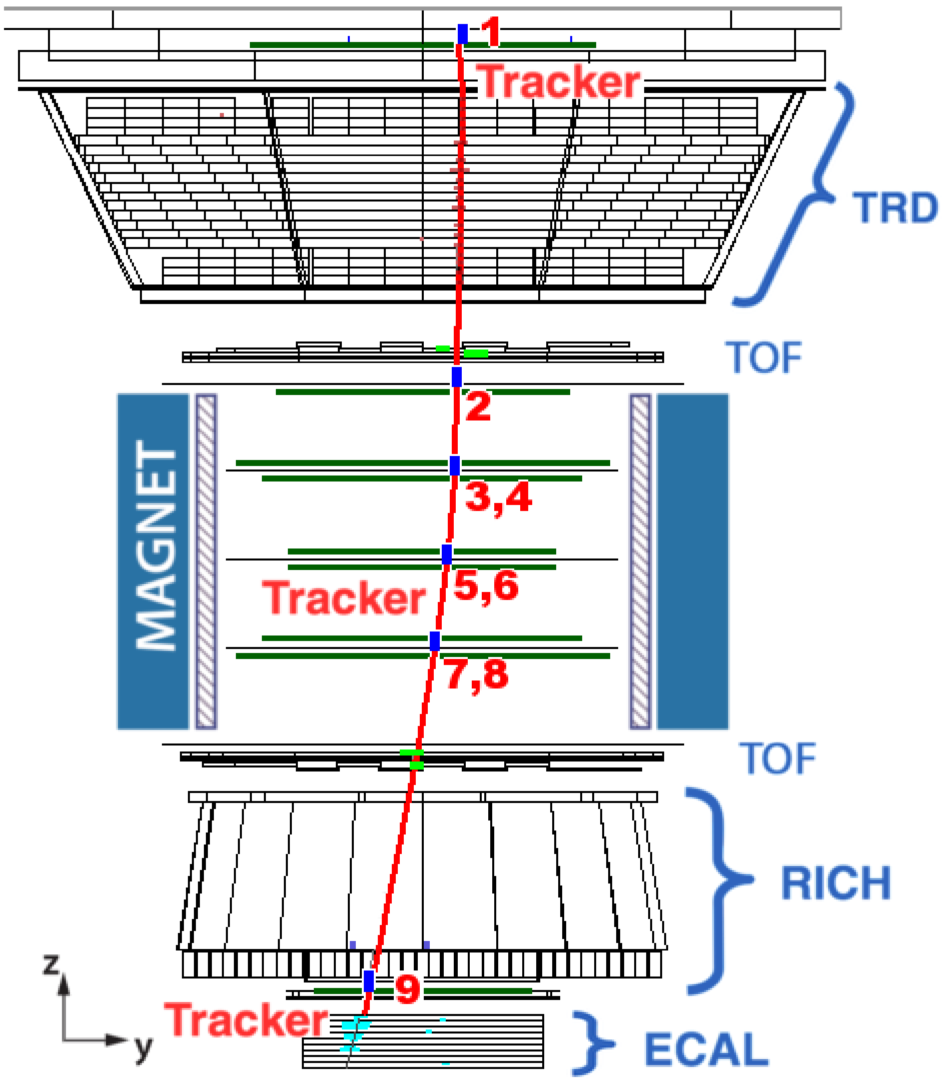






The Tracker

There are 9 planes with 200,000 channels aligned to 3 microns

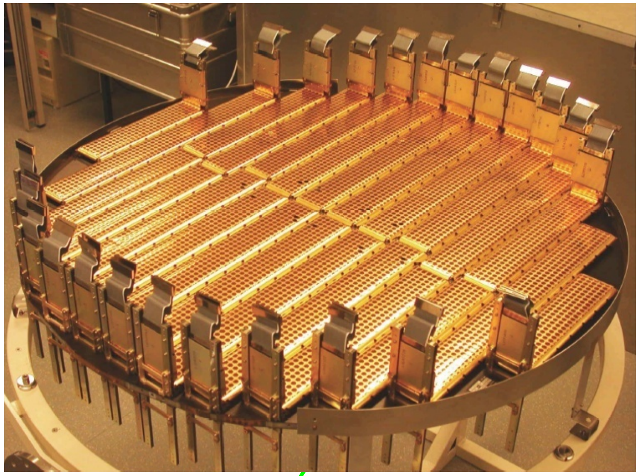


$Bx = \sim 0.14\ \mathrm{T}$

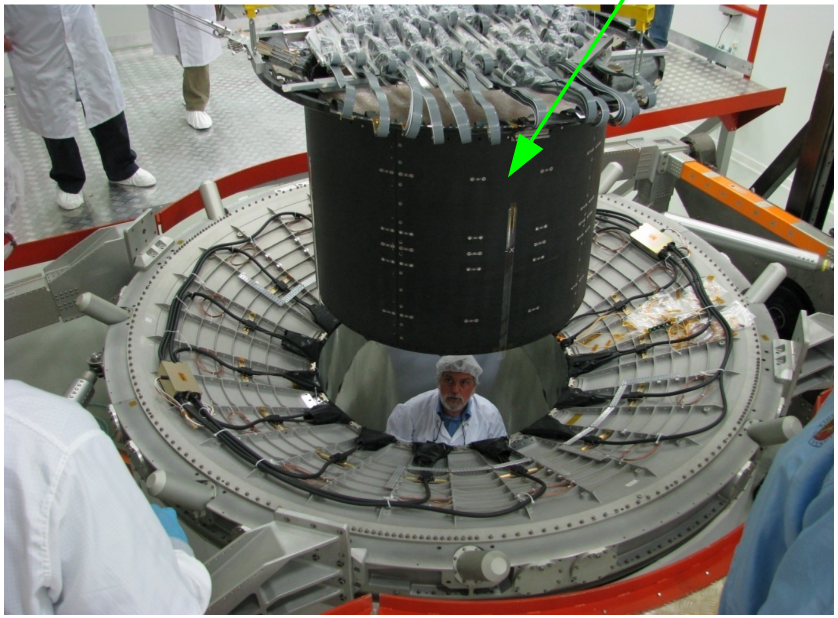
$L = \sim 3\mathrm{m}$

$\sigma y = \sim 10\mu\mathrm{m}$

MDR : ~2TV
(Maximum Detectable Rigidity)

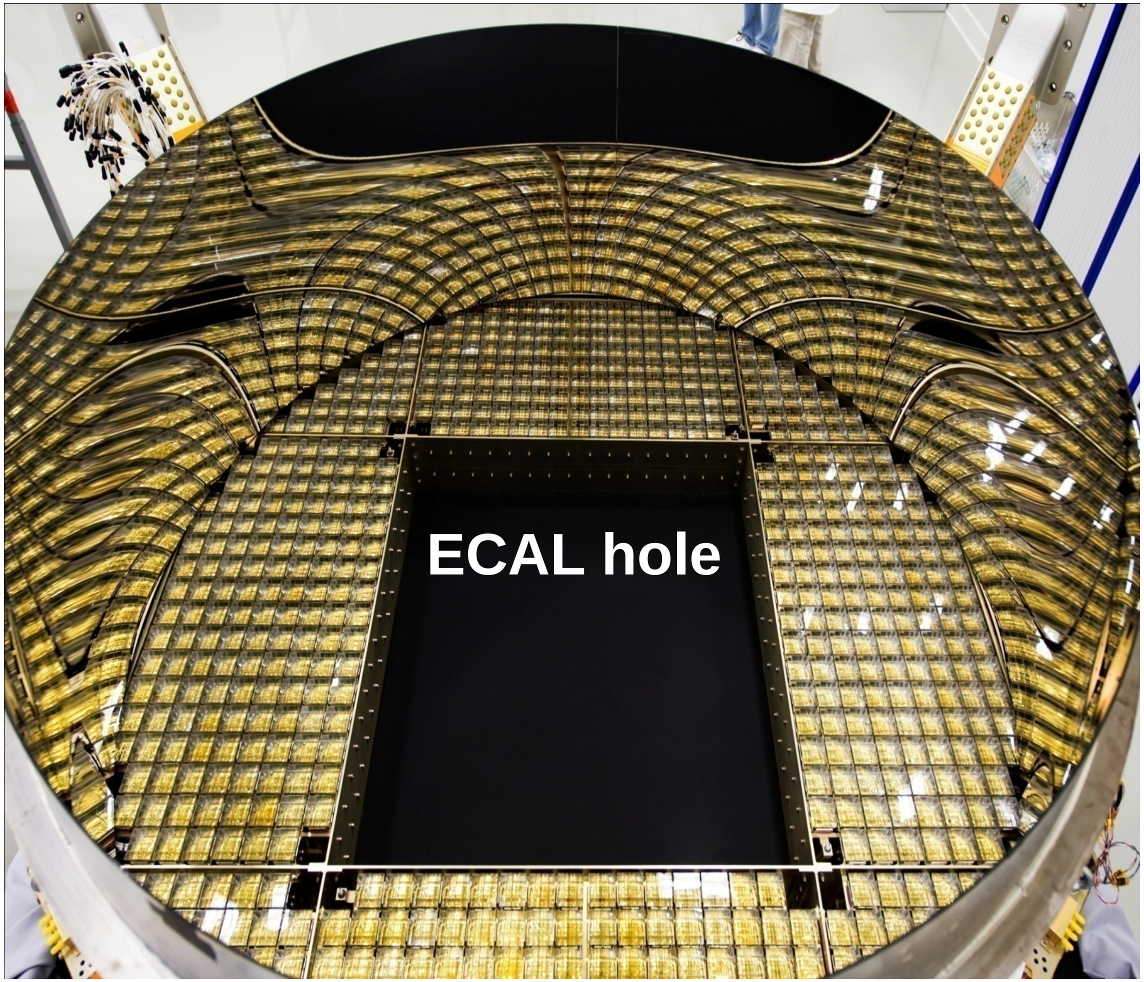


x 3



Ring Imaging Cherenkov (RICH)

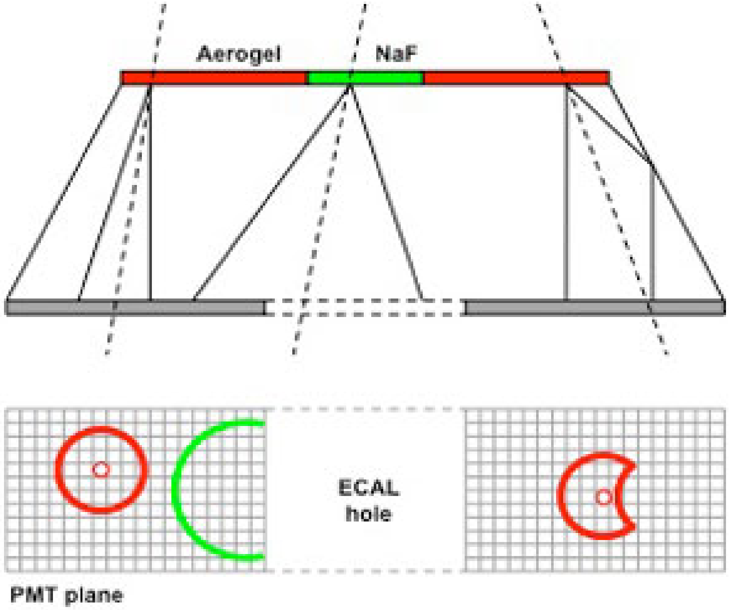
10,880 photosensors to identify nuclei and their energy



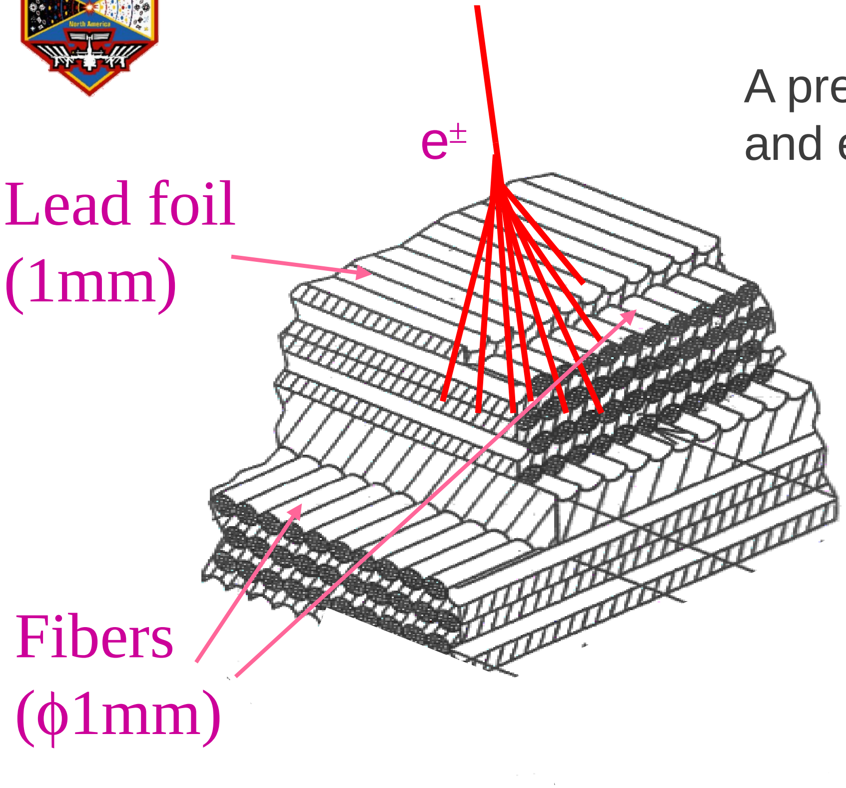
2 different radiators:

NaF: n = 1.34

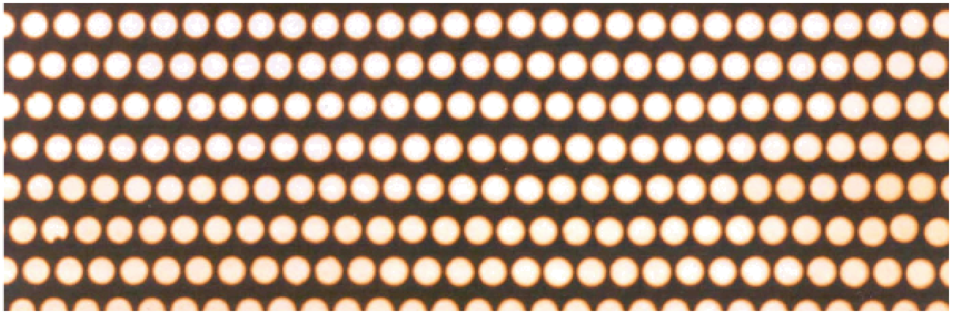
Aerogel: n ~ 1.04



Electromagnetic Calorimeter (ECAL)

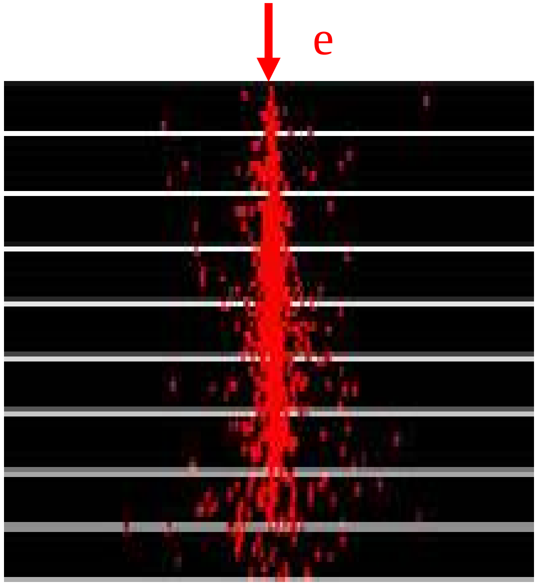


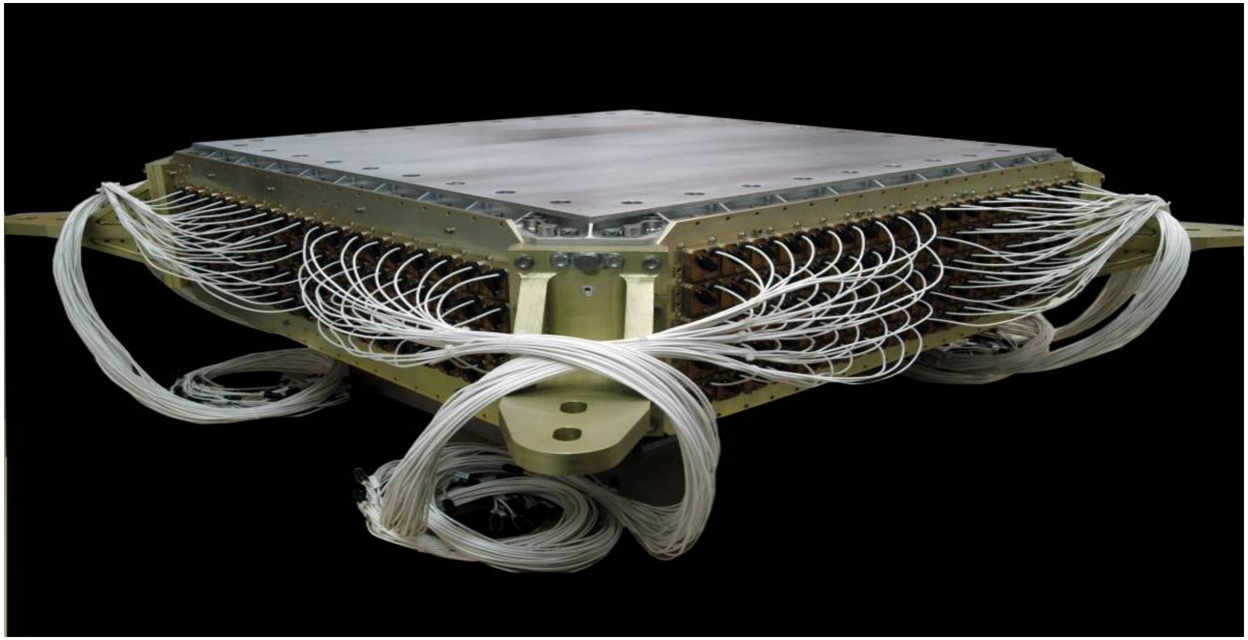
A precision, 3-D measurement (8 x, 10 y) of the directions and energies of gamma rays and electrons up to 1 TeV



600 kg of lead

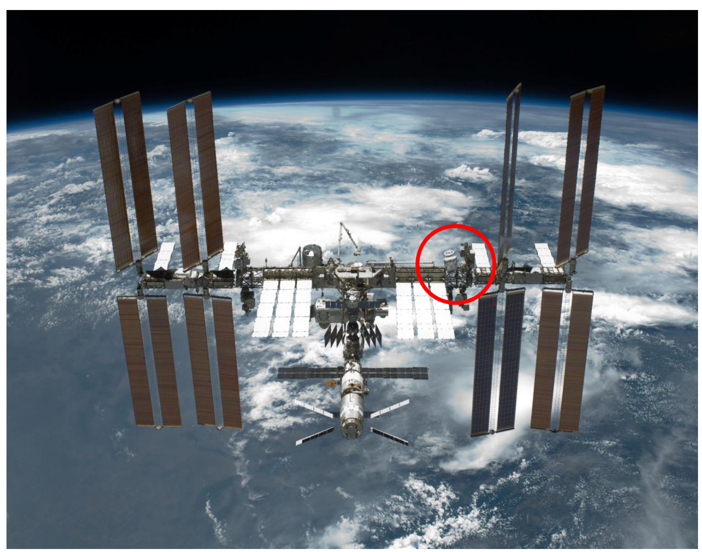
Total 17 X_0





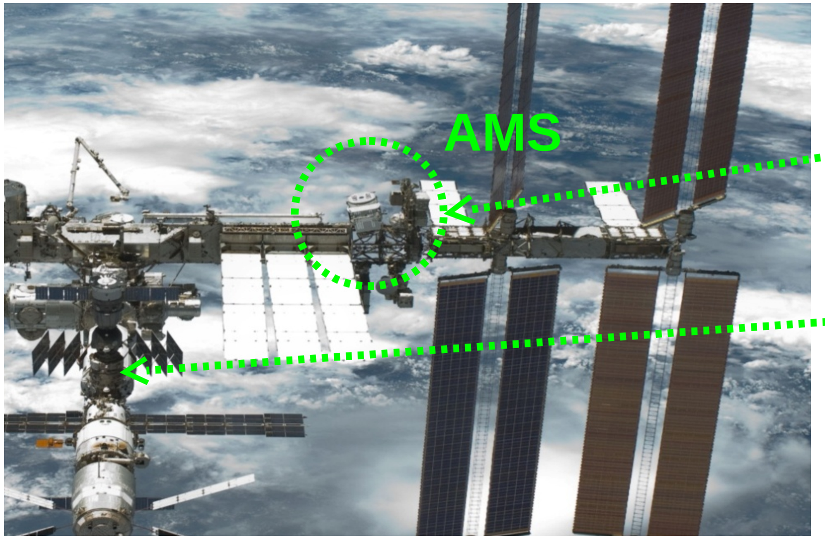

16th May 2011

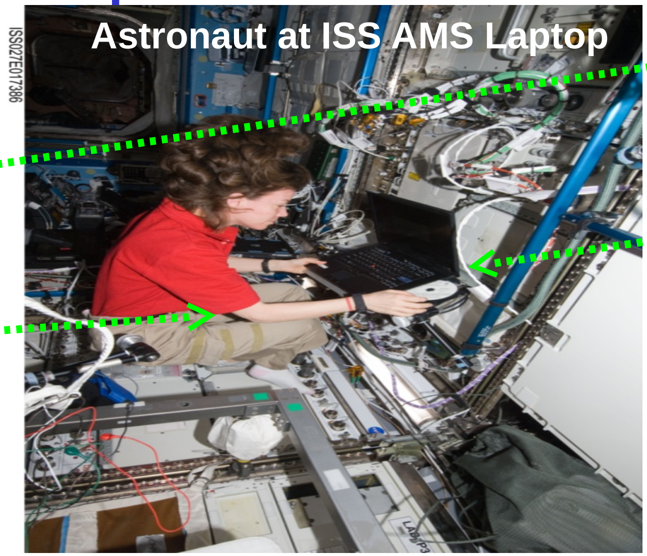

19th May 2011

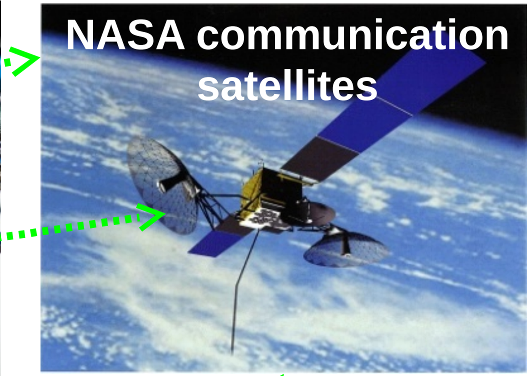


Operation on the ISS

AMS Operations







Flight Operations

Ku-Band
High Rate (down):
Events <10Mbit/s>

Ground Operations

S-Band
Low Rate (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s

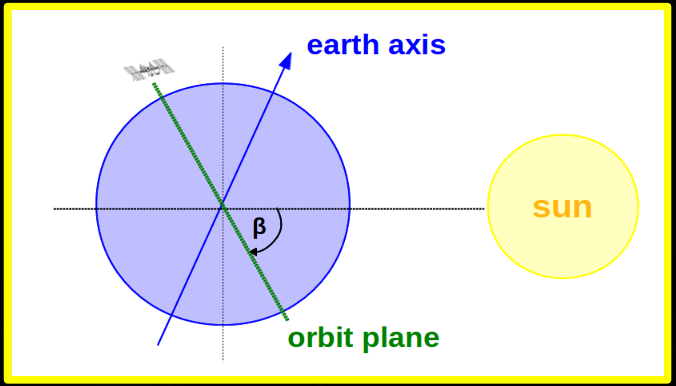
AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

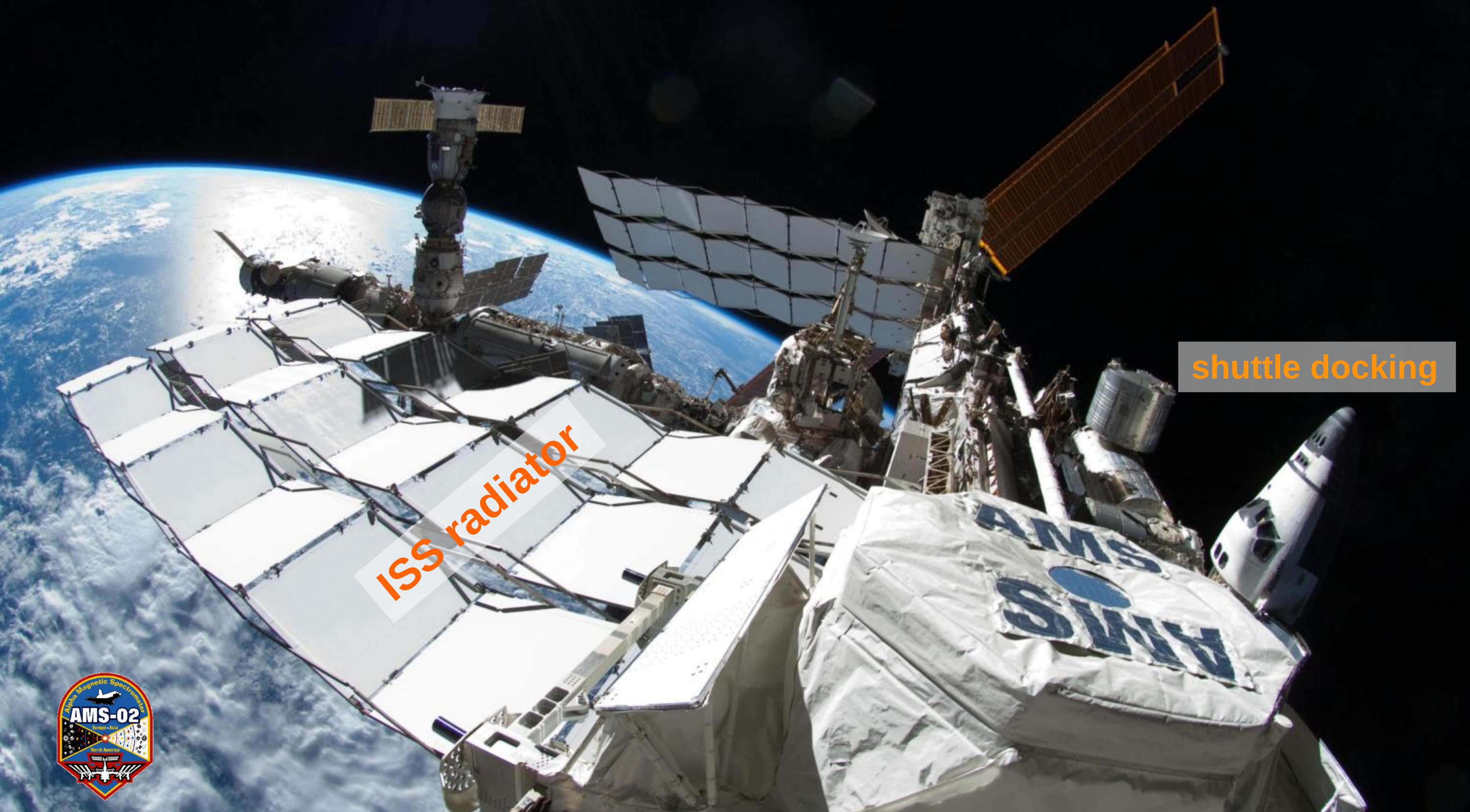
AMS Computers at Marshall Space Flight Center

White Sands Ground Terminal, New Mexico

Thermal variables:

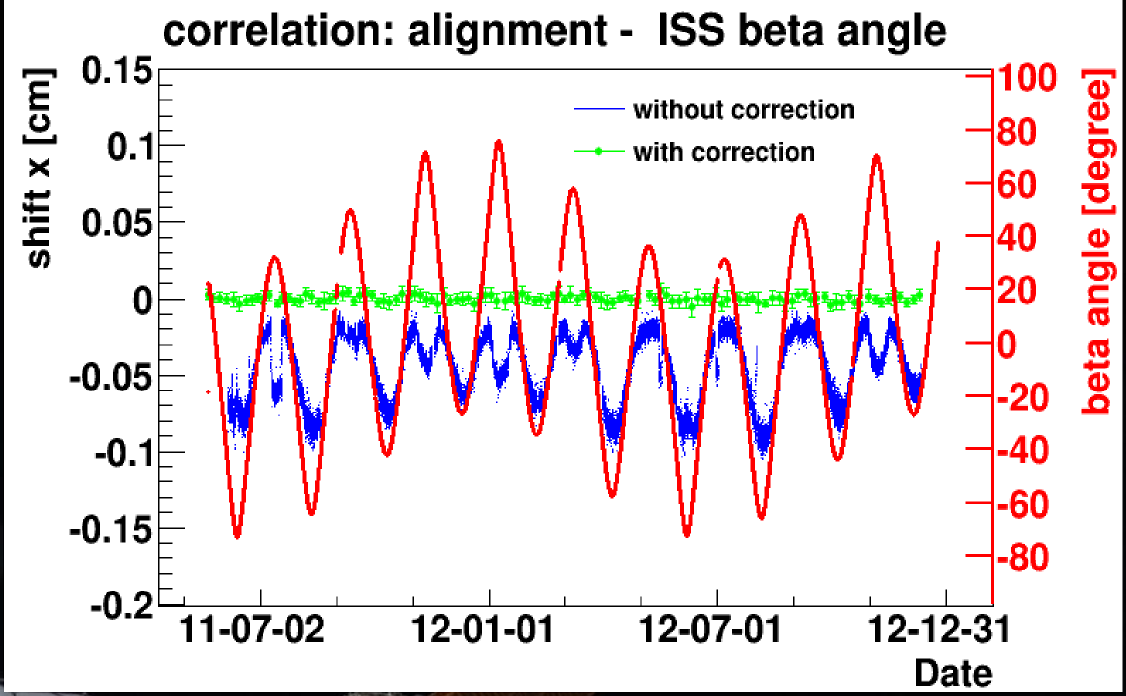
- ISS beta angle
- ISS Radiator positions
- ISS attitude changes
  (primarily for visiting vehicles)

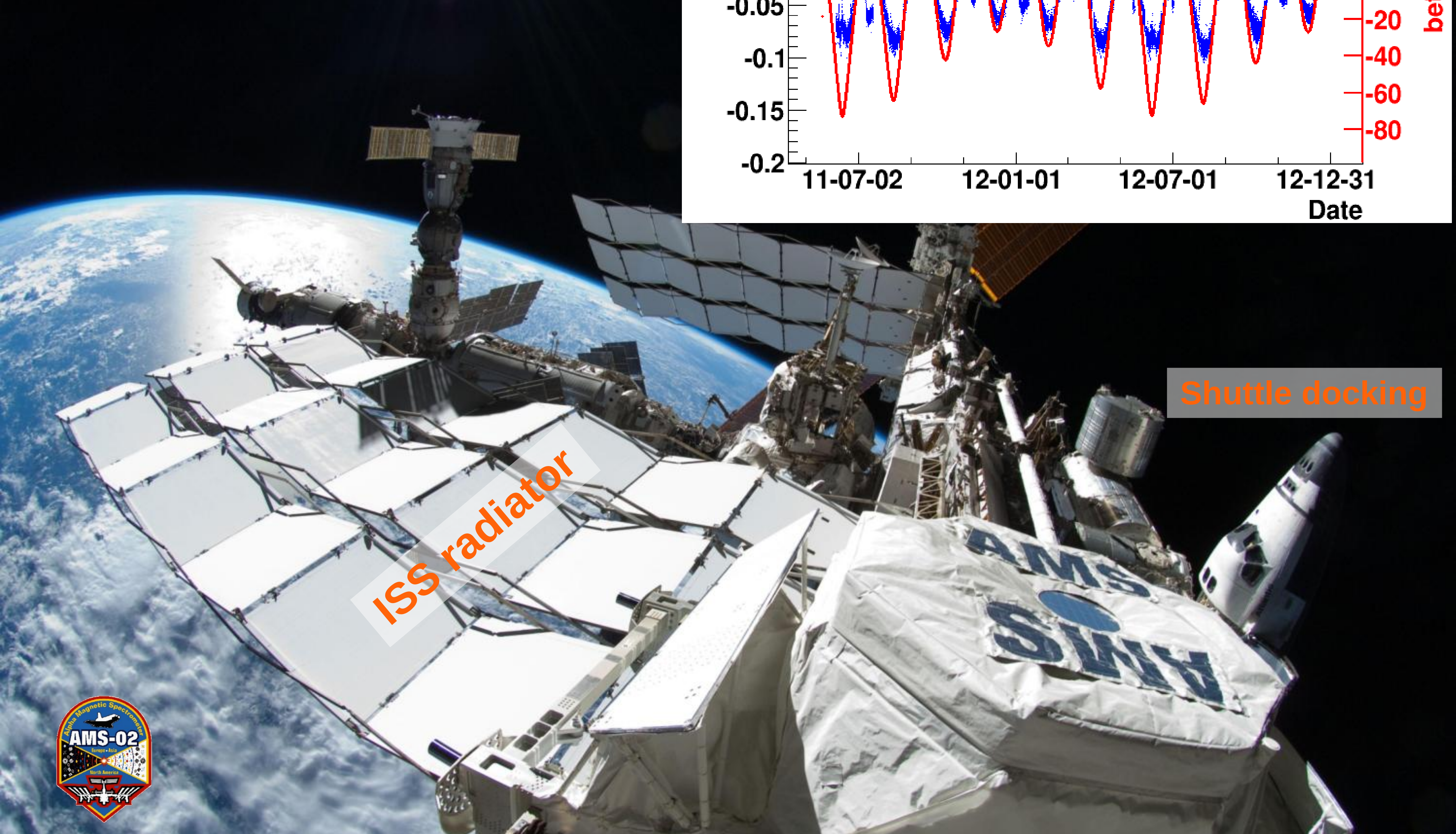




Thermal variables:

- ISS beta angle
- ISS Radiator positions
- ISS attitude changes
  (primarily for visiting vehicles)





Measurement

PRL 110, 141102 (2013)

(with 18 month of data → only 8% of total expected data!)

Flux and Ratio Determination

Number of counts

$$\Phi(\overline{K_{\mathrm{n}}}) = \frac{N(K_{\mathrm{n}}, K_{\mathrm{n}} + \Delta K_{\mathrm{n}})}{A\,\epsilon\,\Delta T\,\Delta K_{\mathrm{n}}}$$

Acceptance (m^2 sr) — *Efficiency* — *Exposure Time* — *Bin Width*

- K_n is the **kinetic energy per nucleon**, it is measured by TOF and RICH (beta) and by Tracker (rigidity)
- or K_n is the **energy** of electrons/positrons measured by ECAL

Flux and Ratio Determination

Number of counts

$$\Phi(\overline{K_{\mathrm{n}}}) = \frac{N(K_{\mathrm{n}}, K_{\mathrm{n}} + \Delta K_{\mathrm{n}})}{A\,\epsilon\,\Delta T\,\Delta K_{\mathrm{n}}}$$

cancel for ratio!

Acceptance (m^2 sr)

Efficiency

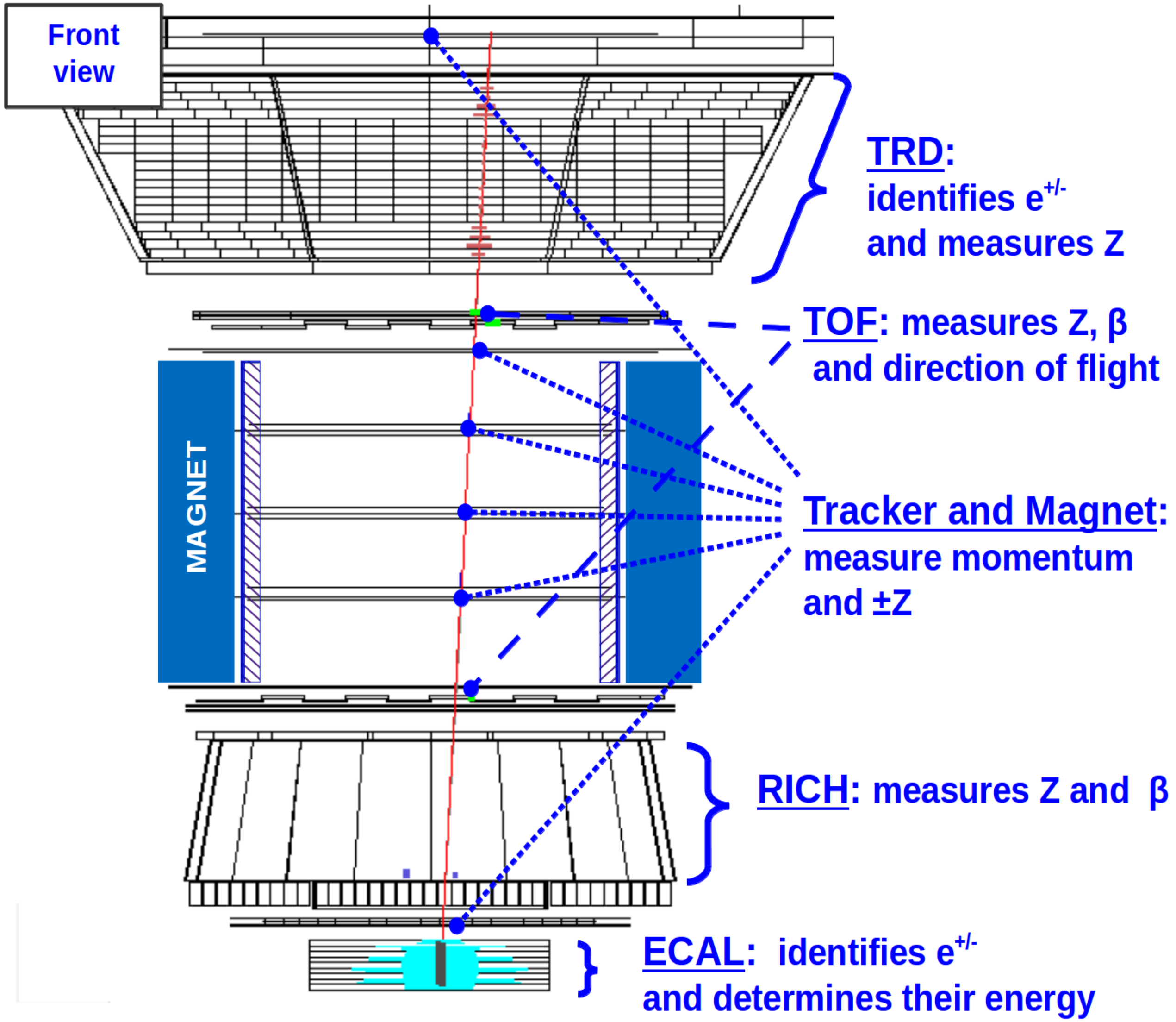
Exposure Time

Bin Width

- K_n is the **kinetic energy per nucleon**, it is measured by TOF and RICH (beta) and by Tracker (rigidity)
- or K_n is the **energy** of electrons/positrons measured by ECAL

Particle identification

Need to reconstruct magnitude and sign of charge and determine kin. Energy:

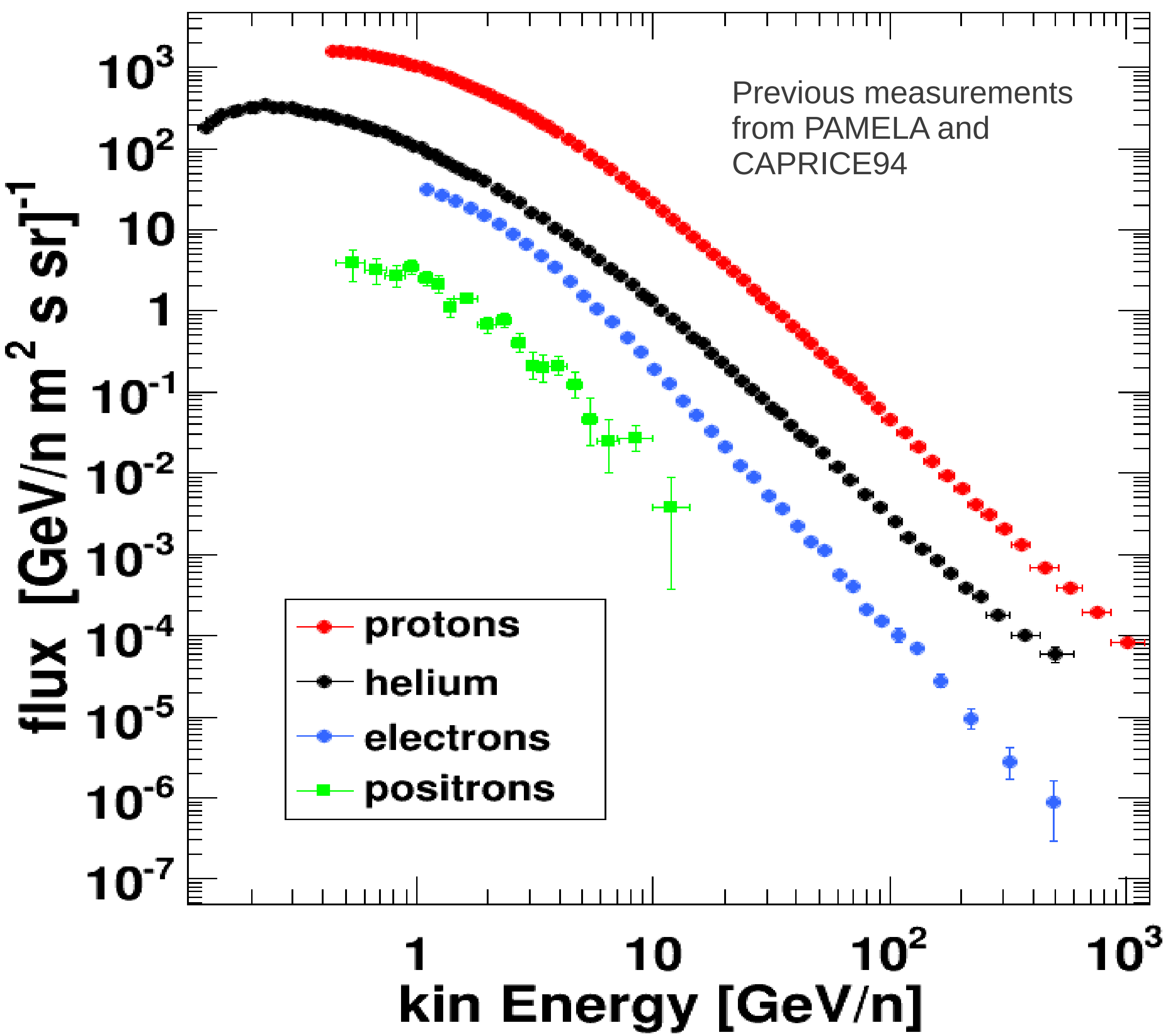


- Z measured redundantly through the detector (TRD, TOF, Tracker, RICH) → particle conversion can be traced

- 3 positron - proton discriminators :

  1) TRD estimator
  2) energy/rigidity ratio
  3) EcalBDT

particle identificiation: main background for positrons



main backgrounds:

- wrong identified protons

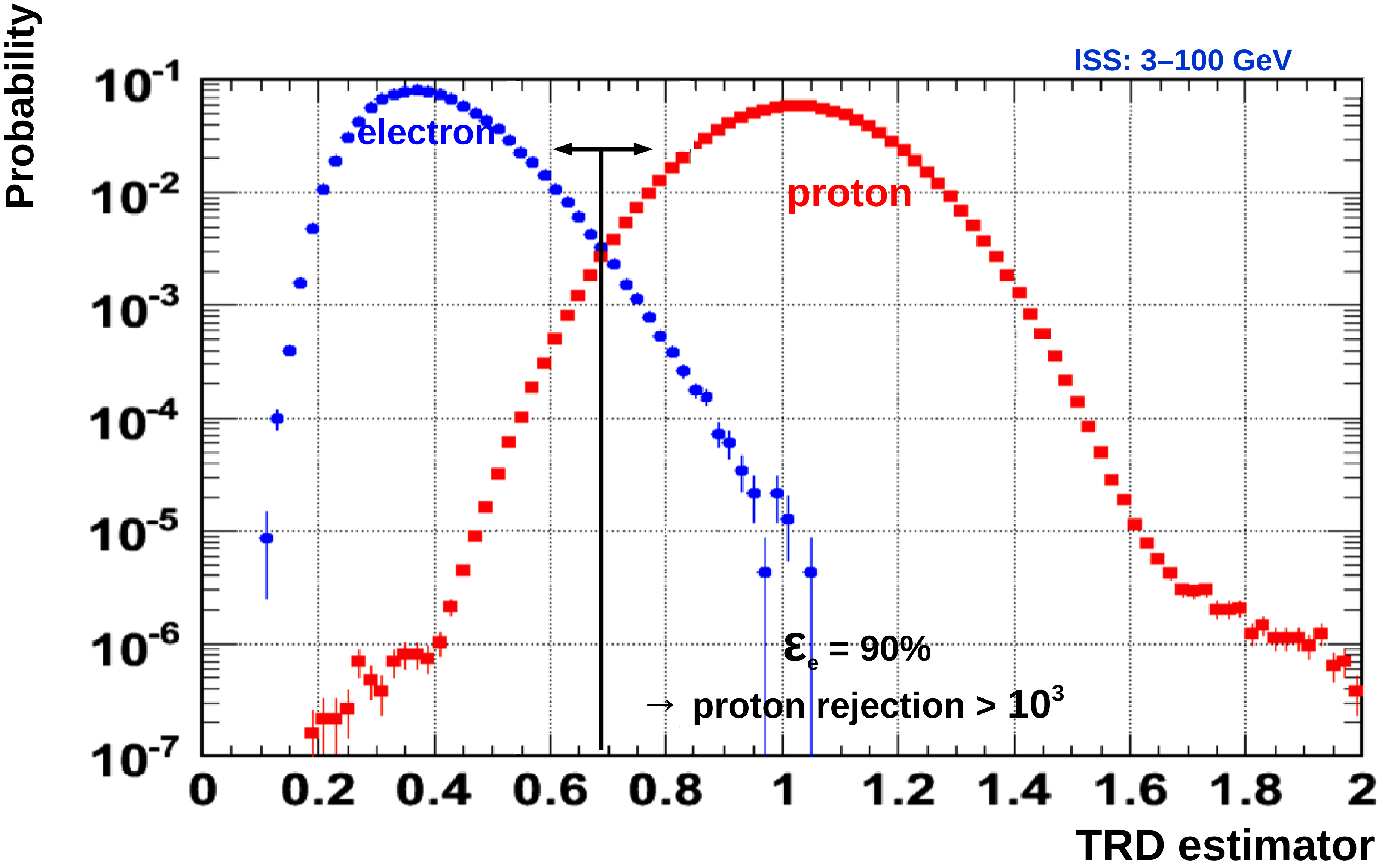
  → TRD & ECAL

- charge confused electrons

  → Tracker & ECAL

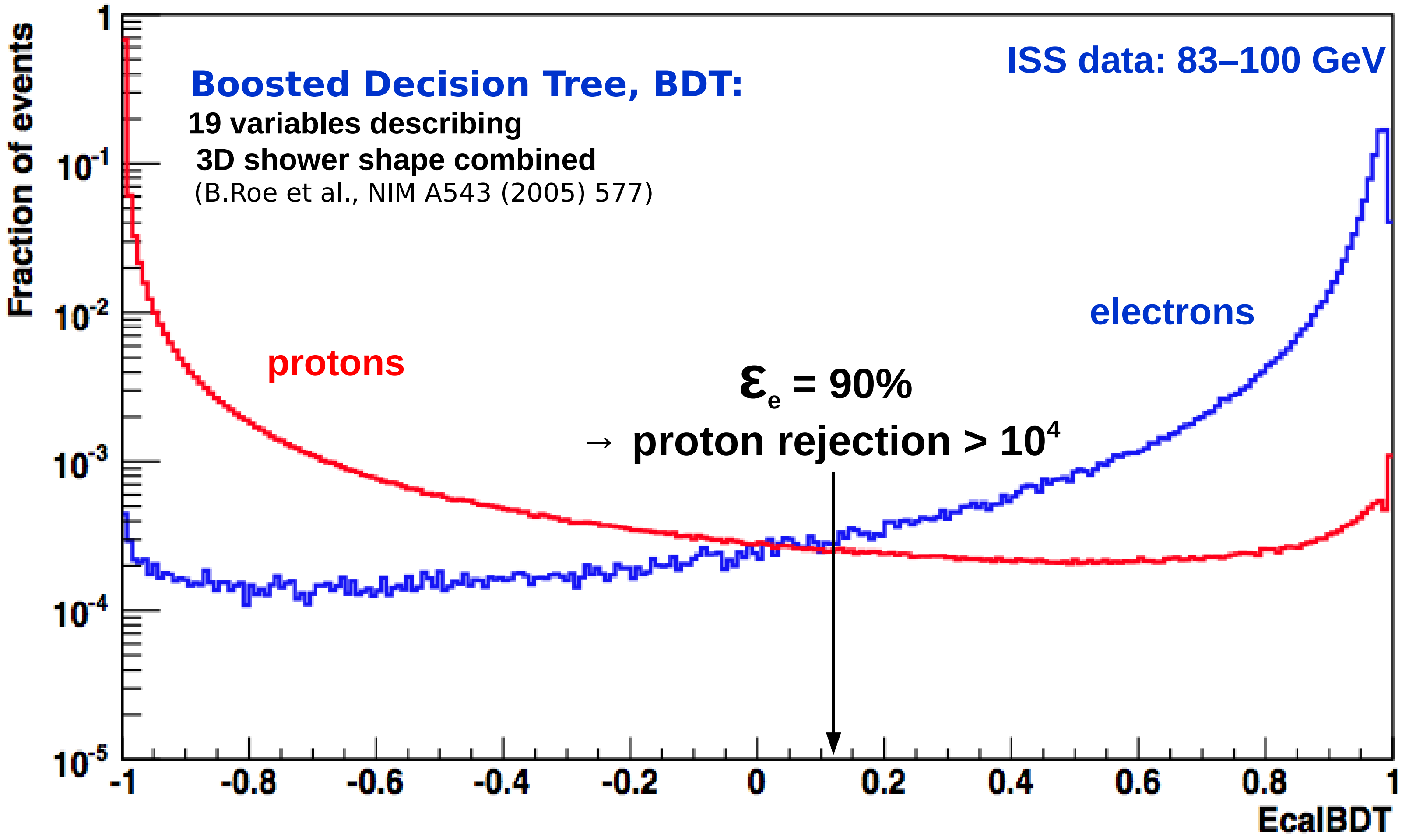
particle identification with TRD

TRD estimator = $-\ln(P_e/(P_e+P_p))$



particle identificiation with ECAL

Ecal discriminator : Boosted Decision Tree

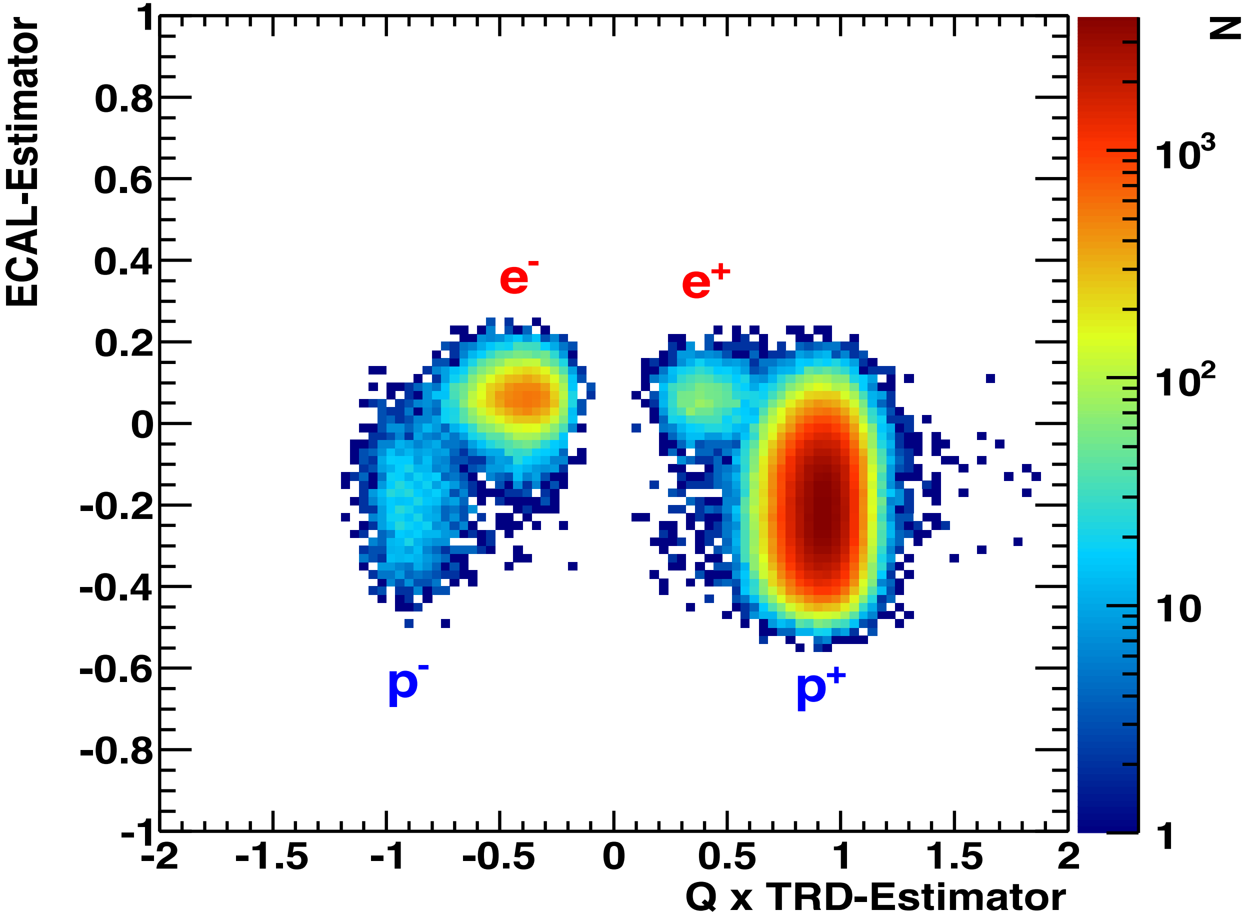


Positron fraction measurement: particle identification

- **TRD estimator**
- **EcalBDT**
- **E/R**

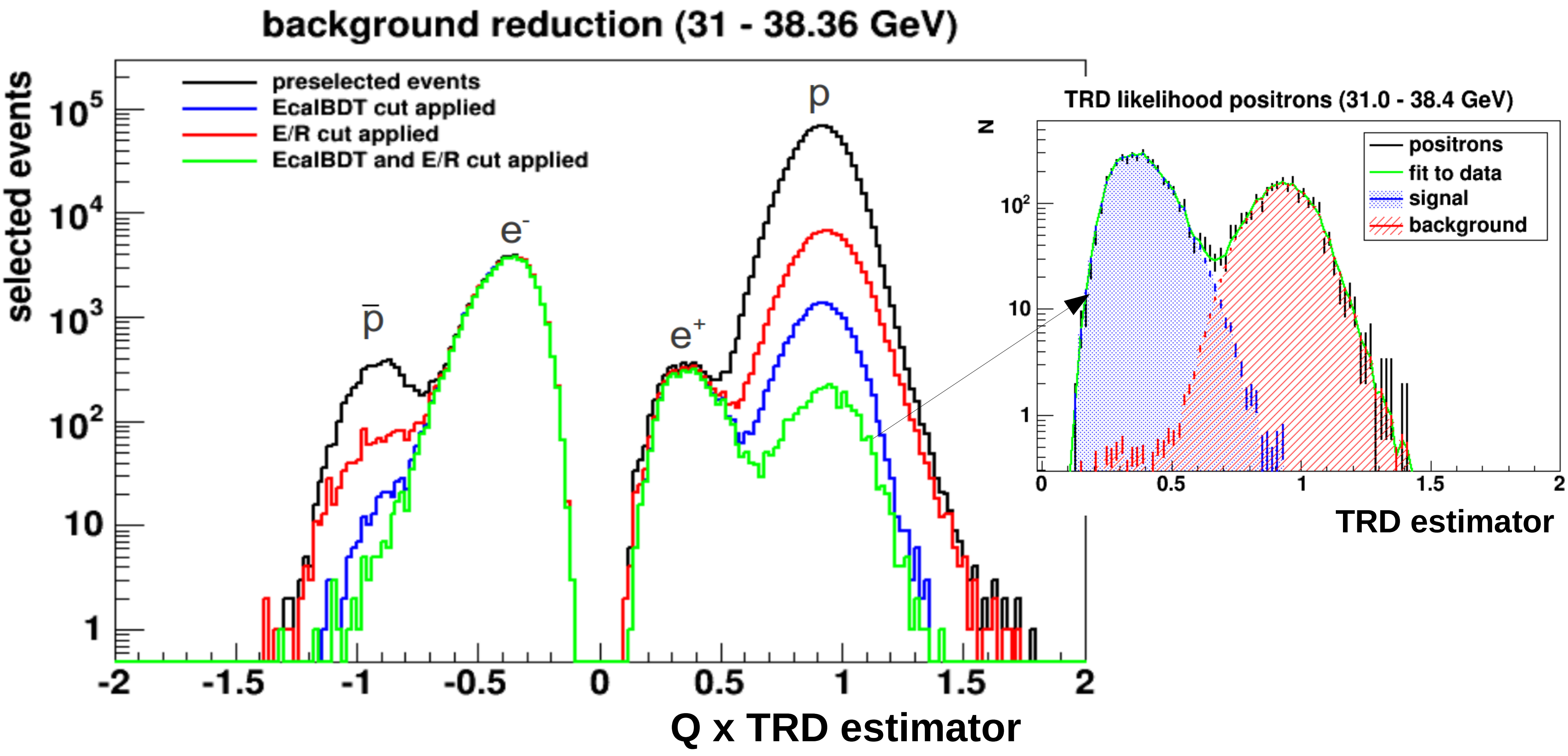
→ all combinations have been tested

- consecutive cuts,
- cuts on 2 variables + template fit,
- cut on one variable + 2D template fit



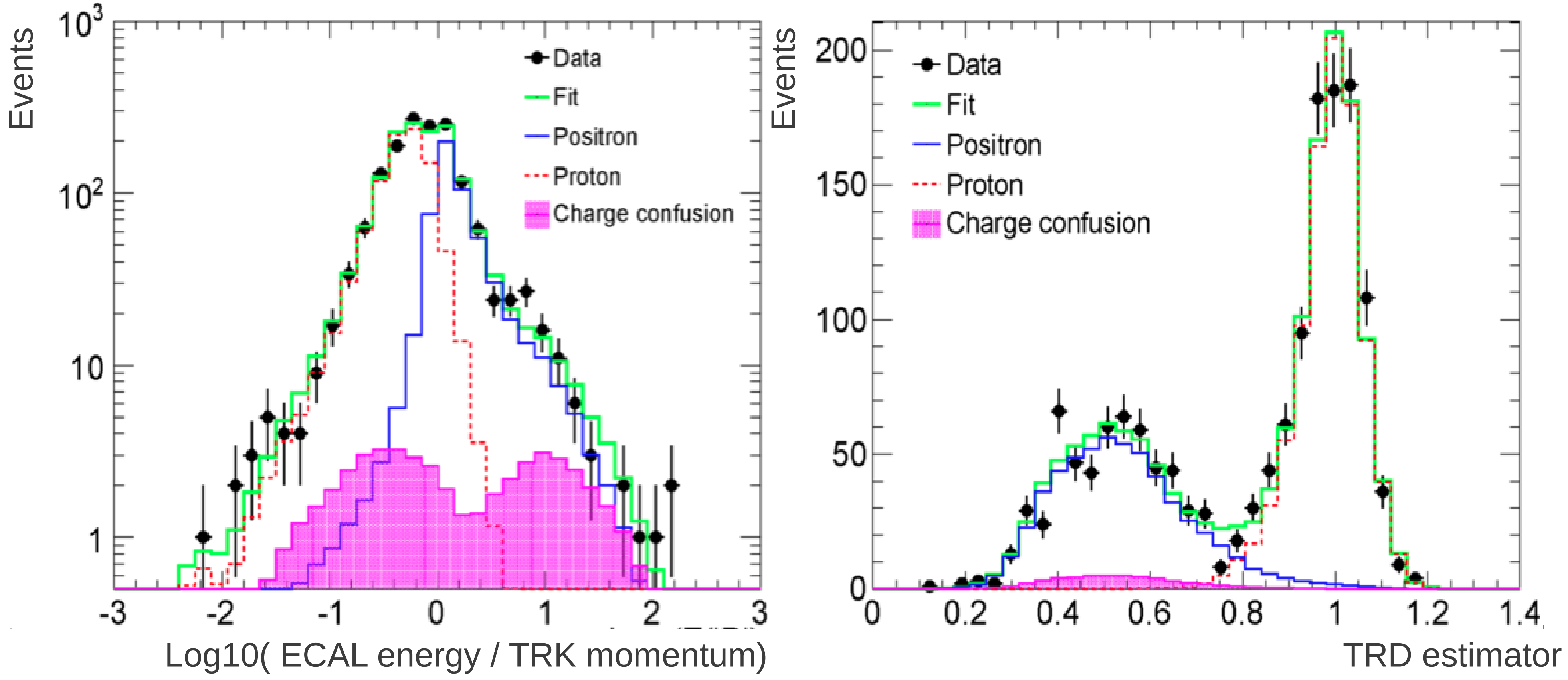
Positron fraction measurement: particle identification

- Example: cuts on EcalBDT and E/R + fit in TRD estimator



Positron fraction measurement: official analysis

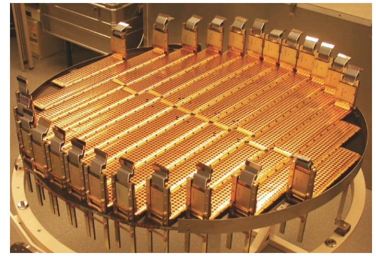
Official analysis: cut on EcalBDT + 2D- Fit in [TRD estimator – E/R] plane



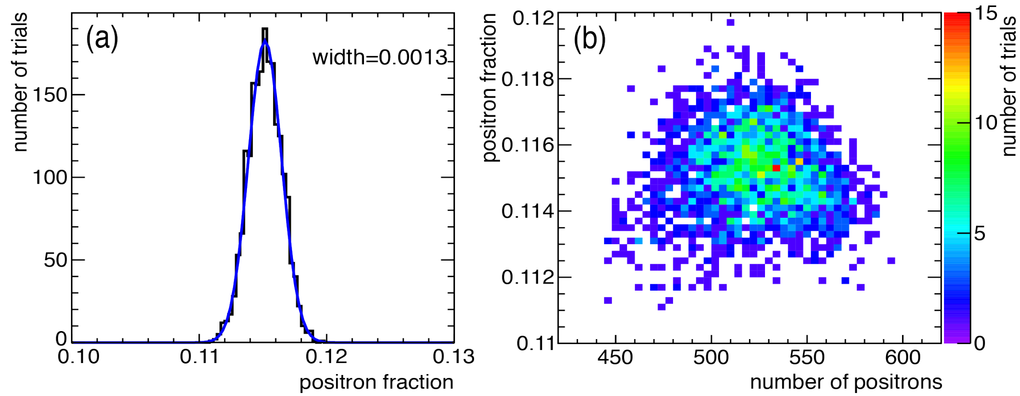
- charge confusion can be determined simultaneously
- results of the fit: in the signal region only 1 % of protons

Positron fraction measurement: systematic errors

- Acceptance asymmetry:
  (minute Tracker asymmetries)



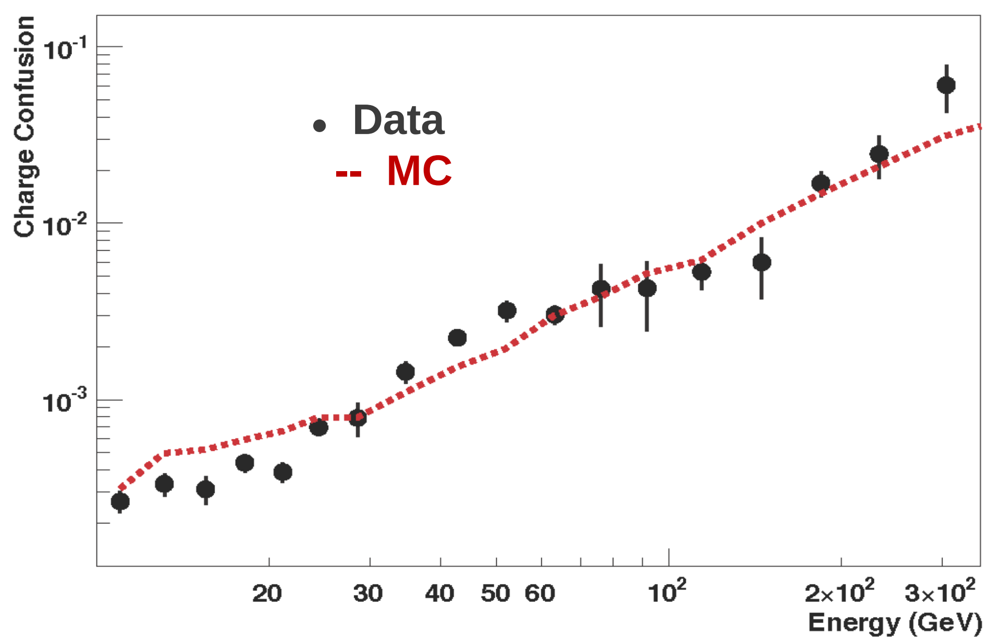
- Selection dependence:
  (choice of working point)



- Bin-to-bin migration
  (folding of measured spectra
  with ECAL energy resolution)

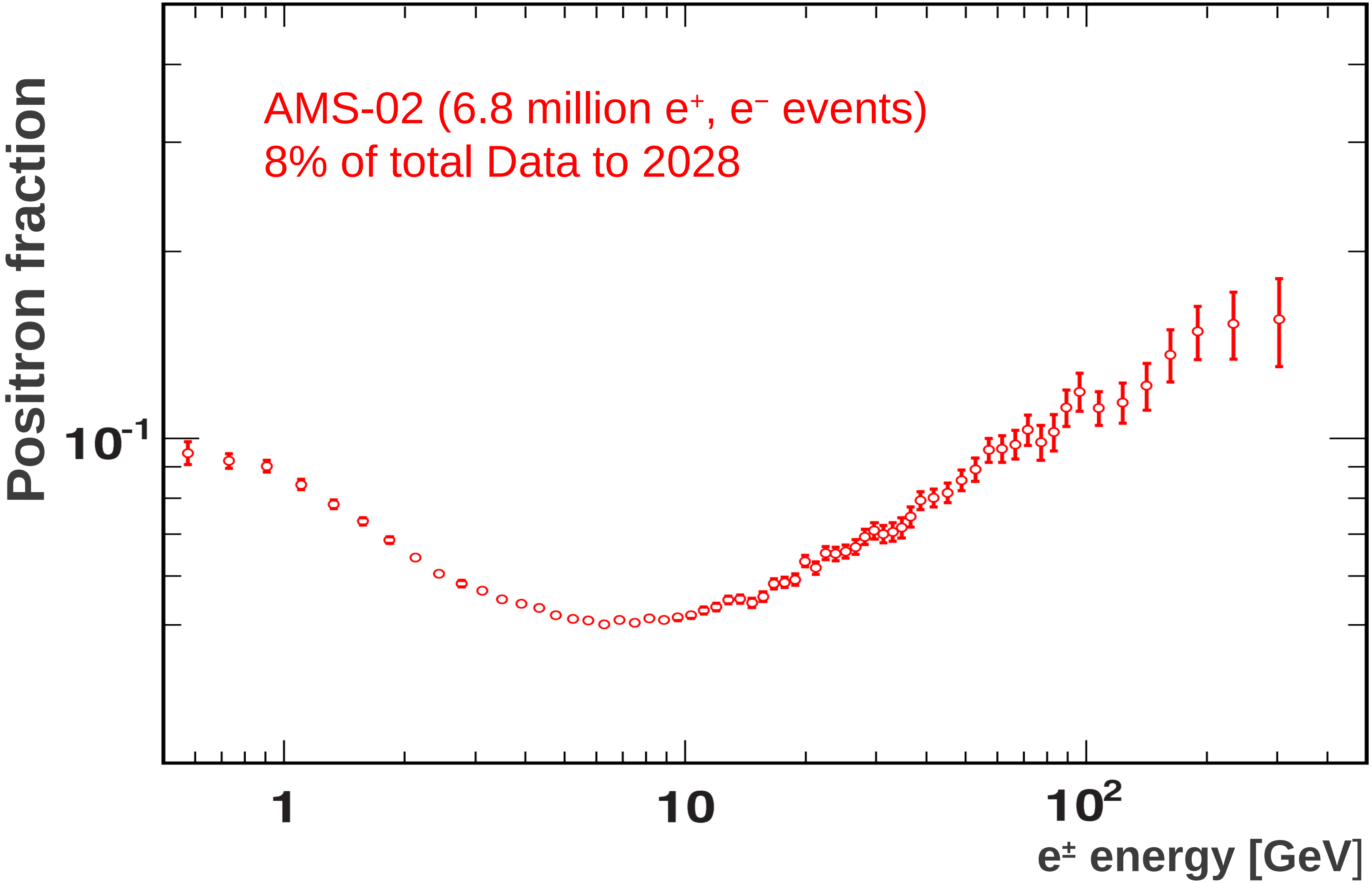
- Reference spectra
  (definition of reference spectra
  from finite statistics)

- Charge confusion:
  (large angle scattering and
  secondary tracks)



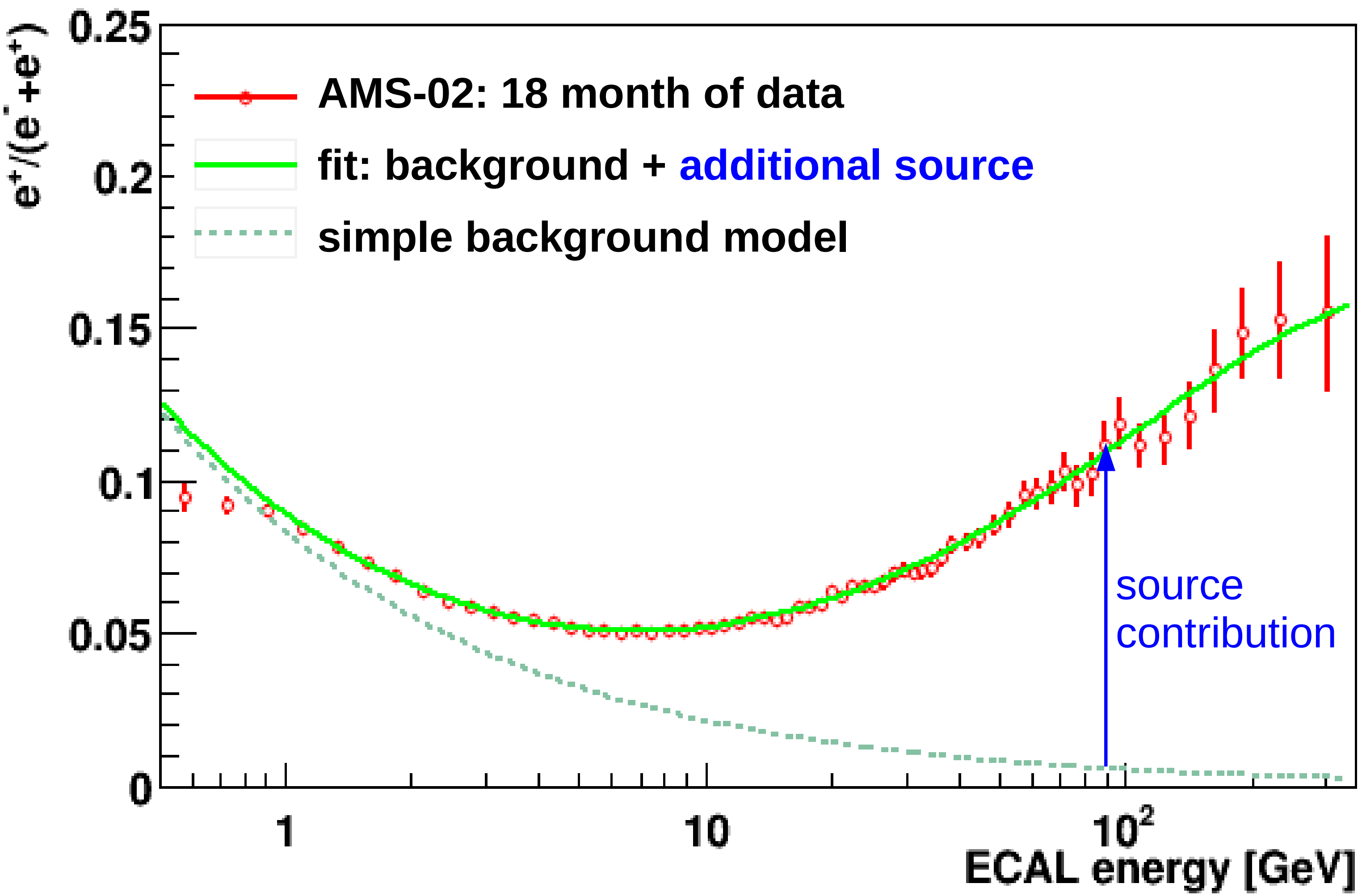
Positron fraction measurement: result

- data shows decrease up to ~ 7 GeV
- above 7 GeV the positron fraction increases steadily
- No significant spectral features observed

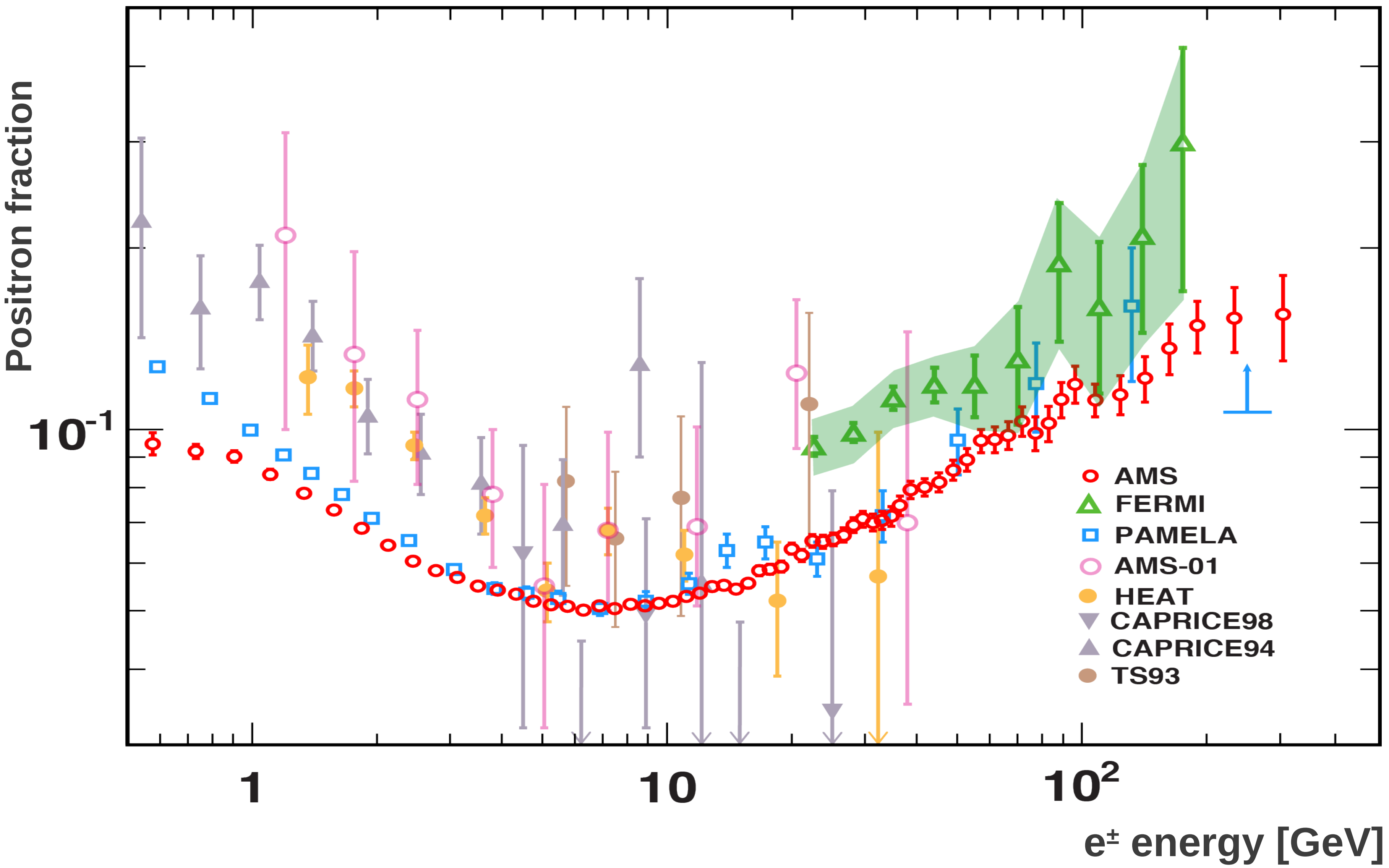


Positron fraction measurement: result

- data can approximately be described with a simple model of individual background power laws (regular cosmic ray fluxes) and a common power law with a cut-off energy for an additional source

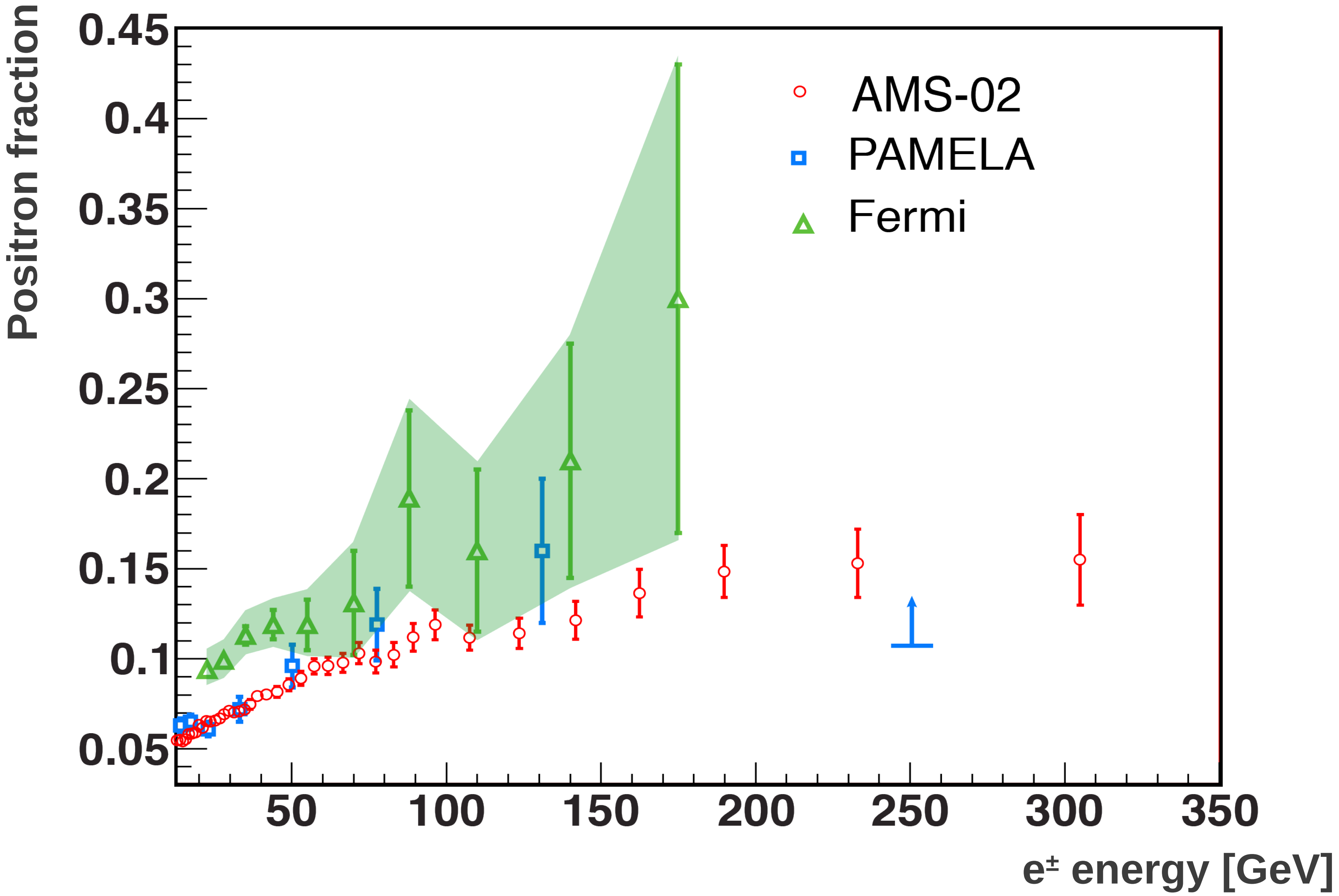


Positron fraction measurement: result



- AMS-02 extended the energy range by about factor 2 already!

Positron fraction measurement: result

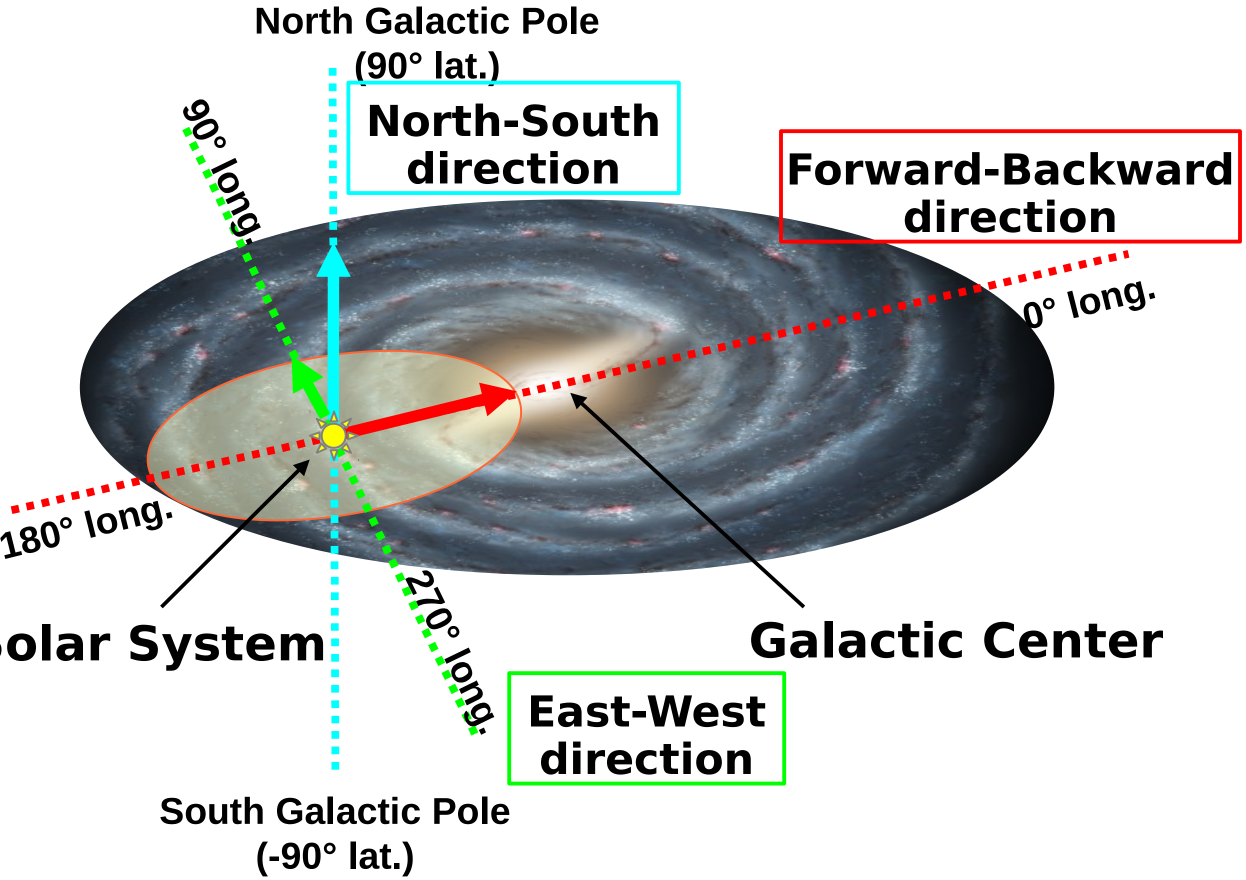


- Slope decreases by an order of magnitude form 20 GeV to 250 GeV!

positron anisotropy with AMS

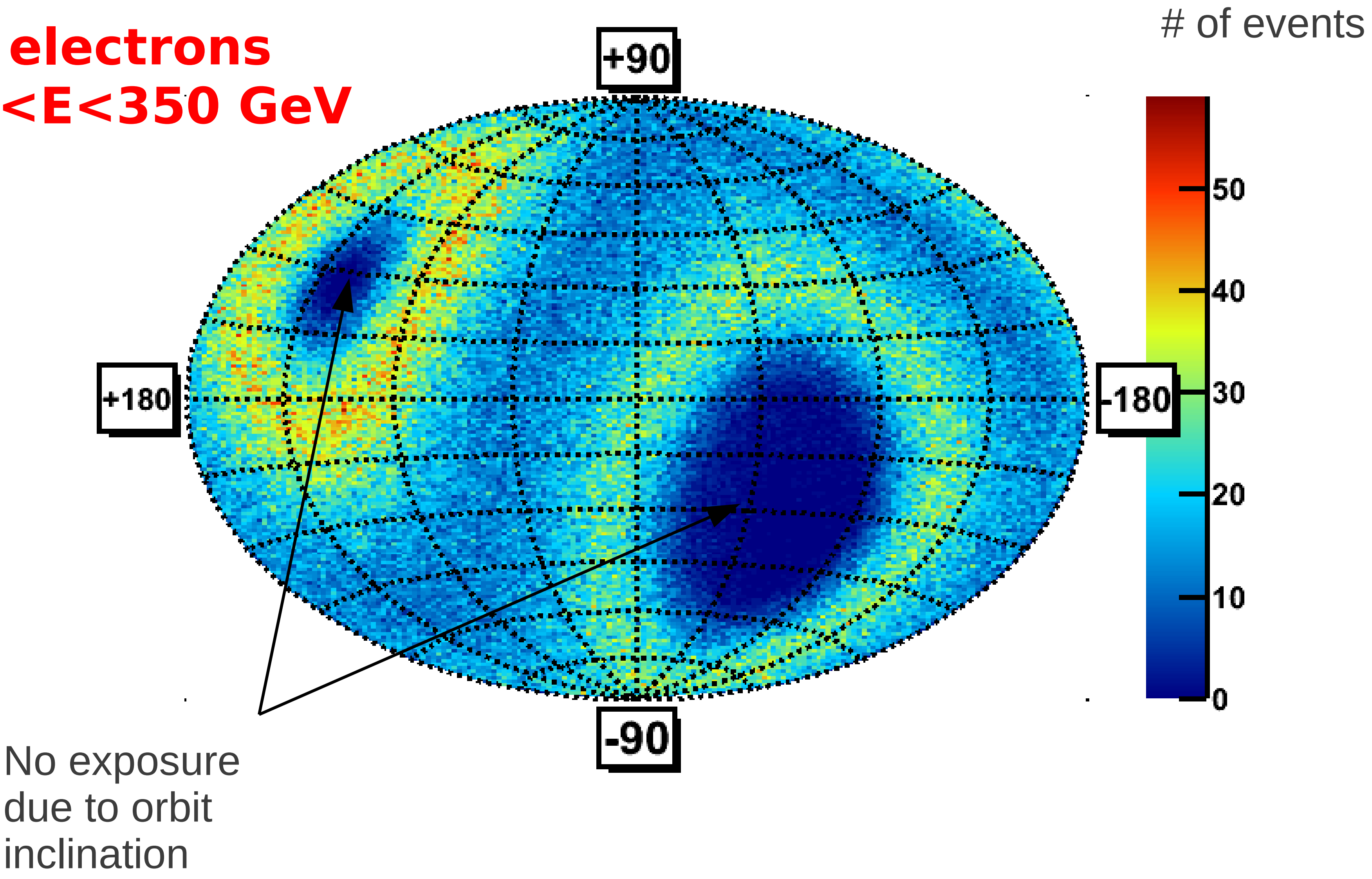
Selected events are grouped into 5 cumulative energy bins: 16-350, 25-350, 40-350, 65-350 and 100-350 GeV

Their arrival directions are used to build sky maps in galactic coordinates, (*b*,*l*), containing the number of observed positrons and electrons

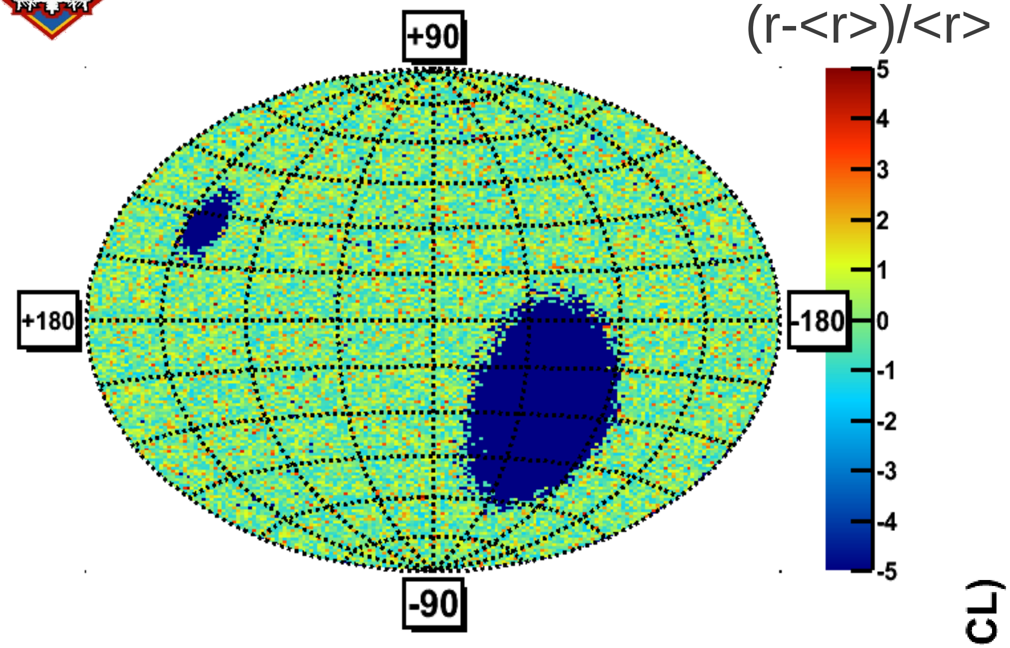


positron anisotropy with AMS

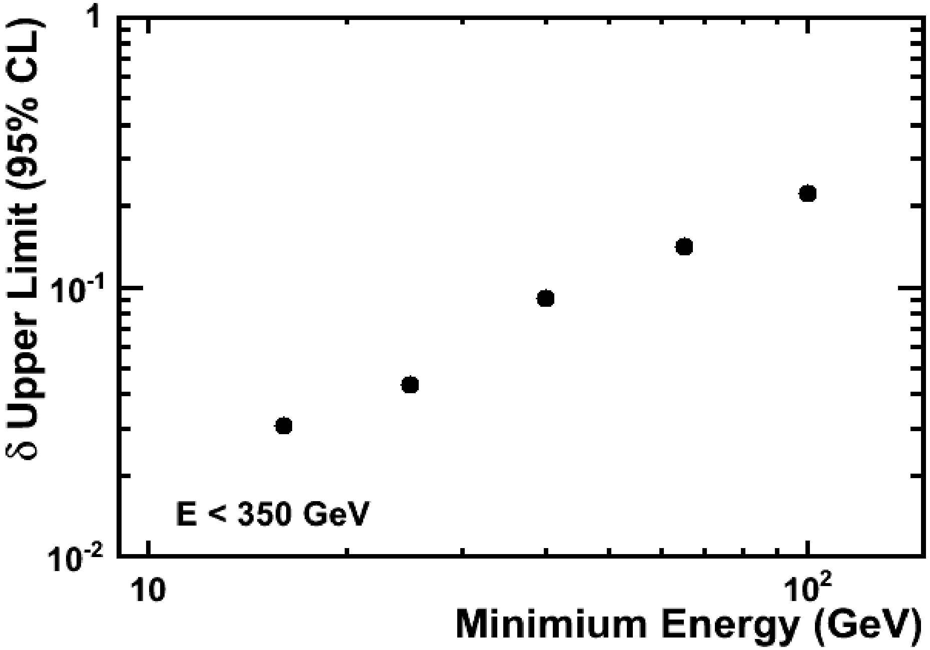
electrons
16<E<350 GeV



positron anisotropy with AMS



The relative fluctuations of the positron ratio, e^+/e^-, across the observed sky map show no evident pattern



The coefficients of the multipole expansion are found consistent with the expectations from isotropy → upper limits are obtained:

$\delta < 0.030$

for 16<E<350GeV

Conclusions

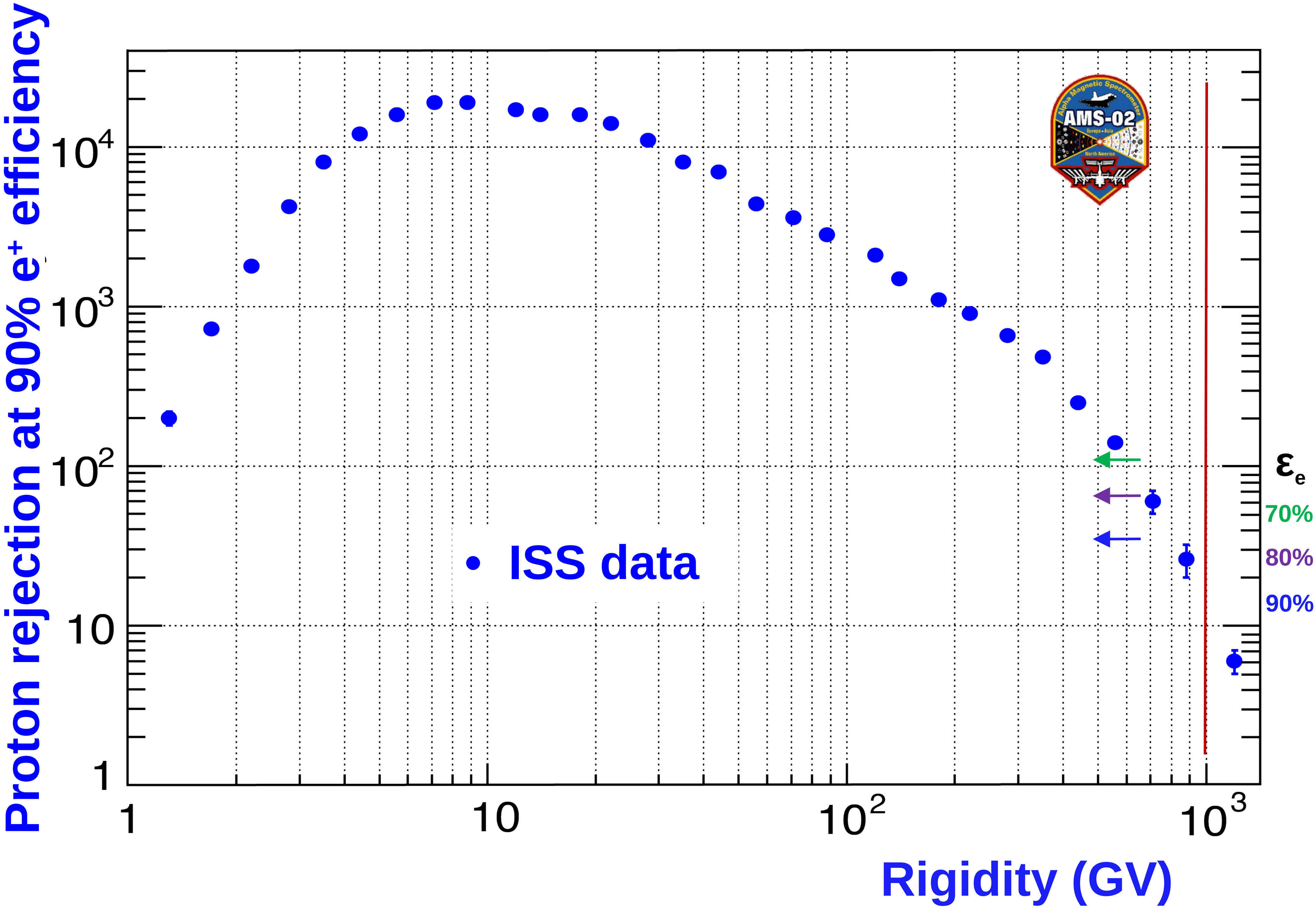
- AMS-02 has been taken cosmic ray data for over 2 years now
- Operation in space needs extensive monitoring and leads to multiple time-dependent calibrations
- First measurement presented on 3rd of April 2013:
  - positron fraction from 0.5-350 GeV
  - positron anisotropy: upper limit $\delta < 0.030$ @ 95% CL
- Preliminary measurements presented at ICRC on 8th of July (see www.ams02.org):
  - All electron (e^{-}+e^{+}) flux from 0.5-700 GeV
  - Separate electron and positron flux (1-500 GeV and 1-300 GeV)
  - Proton flux from 1 GV – 1.8 GV
  - Helium flux from 2 GV – 3.2 TV
  - B/C ratio from 0.5 – 670 GeV/n

Will be published in ~ 2 month!!

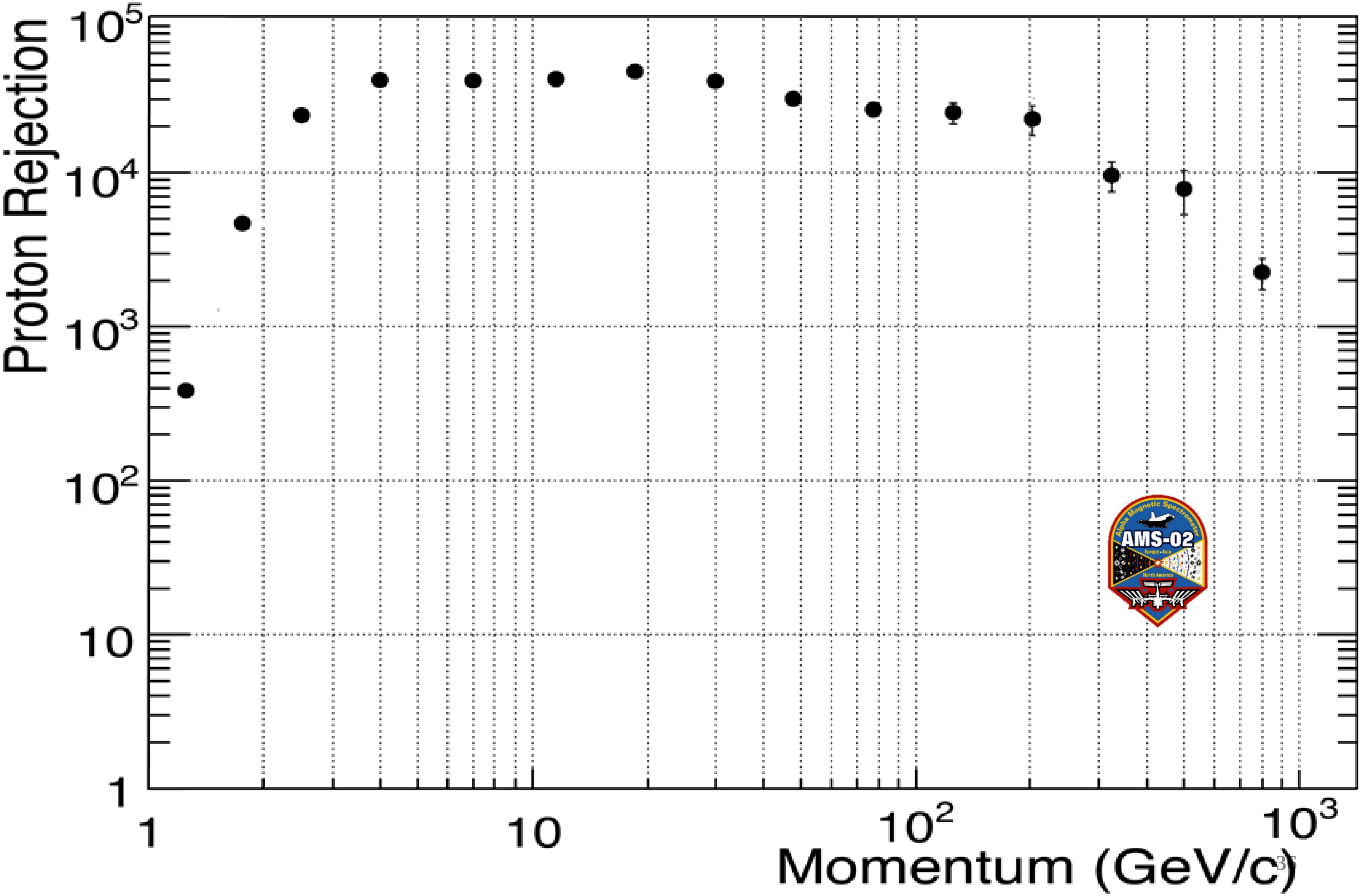
- Analyses will be refined/extended and further analyses will follow with more data
  → only 10 % of total expected data recorded yet!

Back-up

TRD performance on ISS



Data from ISS: Proton rejection using the ECAL



AMS Result: Measurement of the positron fraction

Positron events, positron fraction in each energy bin				Systematic Errors					
Energy [GeV]	N_{e+}	Fraction	statistical error	acceptance asymmetry	event selection	bin-to-bin migration	reference spectra	charge confusion	total systematic uncertainty
Energy[GeV]	N_{e+}	Fraction	$\sigma_{stat.}$	$\sigma_{acc.}$	$\sigma_{sel.}$	$\sigma_{mig.}$	$\sigma_{ref.}$	$\sigma_{c.c.}$	$\sigma_{syst.}$
1.00-1.21	9335	0.0842	0.0008	0.0005	0.0009	0.0008	0.0001	0.0005	0.0014
1.97-2.28	23893	0.0642	0.0004	0.0002	0.0005	0.0002	0.0001	0.0002	0.0006
3.30-3.70	20707	0.0550	0.0004	0.0001	0.0003	0.0000	0.0001	0.0002	0.0004
6.56-7.16	13153	0.0510	0.0004	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
09.95-10.73	7161	0.0519	0.0006	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
19.37-20.54	2322	0.0634	0.0013	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
30.45-32.10	1094	0.0701	0.0022	0.0001	0.0002	0.0000	0.0001	0.0003	0.0004
40.00-43.39	976	0.0802	0.0026	0.0002	0.0005	0.0000	0.0001	0.0004	0.0007
50.87-54.98	605	0.0891	0.0038	0.0002	0.0006	0.0000	0.0001	0.0004	0.0008
64.03-69.00	392	0.0978	0.0050	0.0002	0.0010	0.0000	0.0002	0.0007	0.0013
74.30-80.00	276	0.0985	0.0062	0.0002	0.0010	0.0000	0.0002	0.0010	0.0014
86.00-92.50	240	0.1120	0.0075	0.0002	0.0010	0.0000	0.0003	0.0011	0.0015
100.0-115.1	304	0.1118	0.0066	0.0002	0.0015	0.0000	0.0003	0.0015	0.0022
115.1-132.1	223	0.1142	0.0080	0.0002	0.0019	0.0000	0.0004	0.0019	0.0027
132.1-151.5	156	0.1215	0.0100	0.0002	0.0021	0.0000	0.0005	0.0024	0.0032
151.5-173.5	144	0.1364	0.0121	0.0002	0.0026	0.0000	0.0006	0.0045	0.0052
173.5-206.0	134	0.1485	0.0133	0.0002	0.0031	0.0000	0.0009	0.0050	0.0060
206.0-260.0	101	0.1530	0.0160	0.0003	0.0031	0.0000	0.0013	0.0095	0.0101
260.0-350.0	72	0.1550	0.0200	0.0003	0.0056	0.0000	0.0018	0.0140	0.0152

The coefficients of the angular power spectrum of the fluctuations, C_l are defined as:

$$C_\ell = \frac{1}{2\ell+1}\sum_{m=-\ell}^{\ell} a_{\ell m}^2$$

the dipole anisotropy parameter:

$$\delta = 3\sqrt{\frac{C_1}{4\pi}}$$