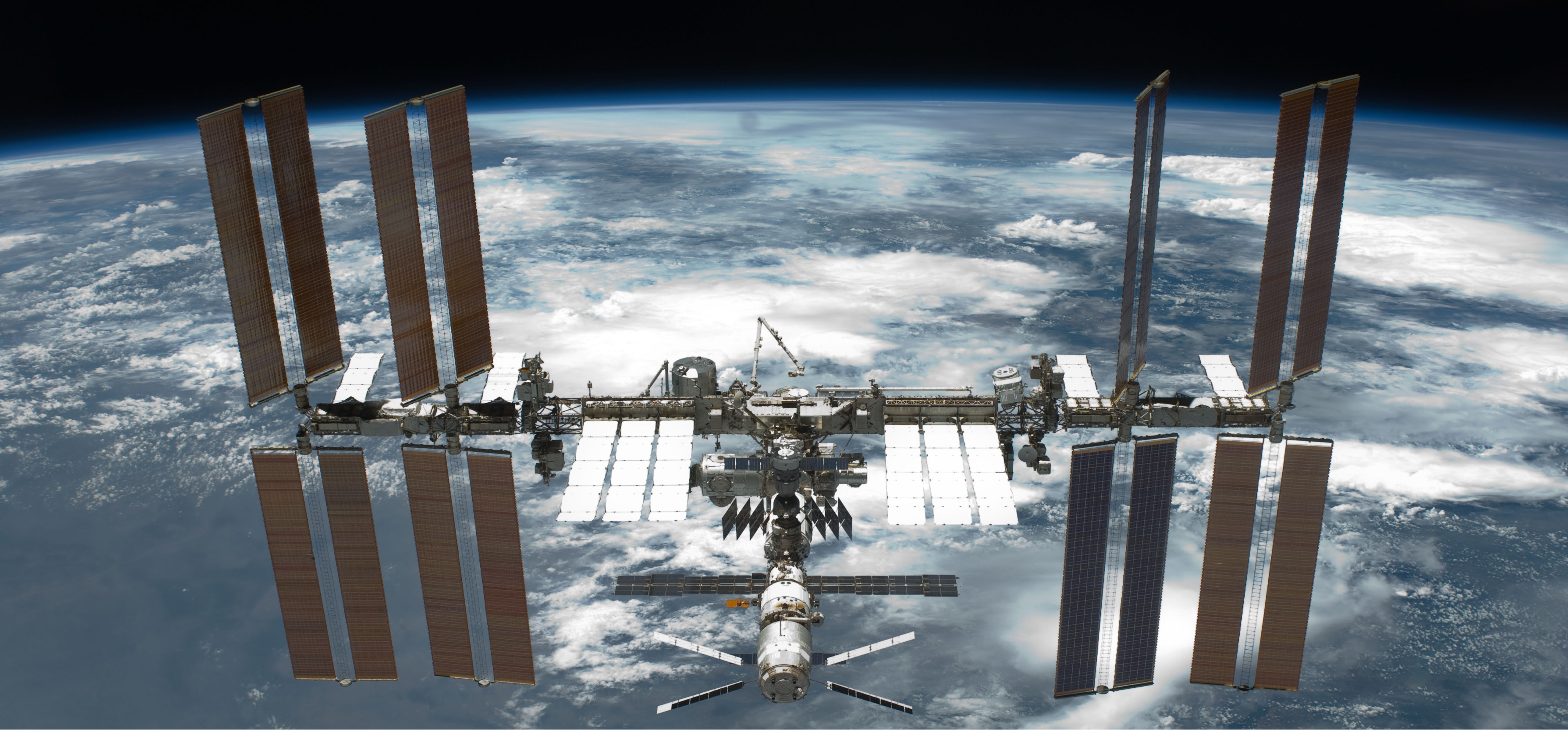
2nd EMMI Workshop: Anti-matter, hyper-matter and exotica production at the LHC

The AMS-02 detector on the ISS



Matteo Duranti on behalf of the AMS collaboration

Istituto Nazionale Fisica Nucleare, INFN Perugia

Outline

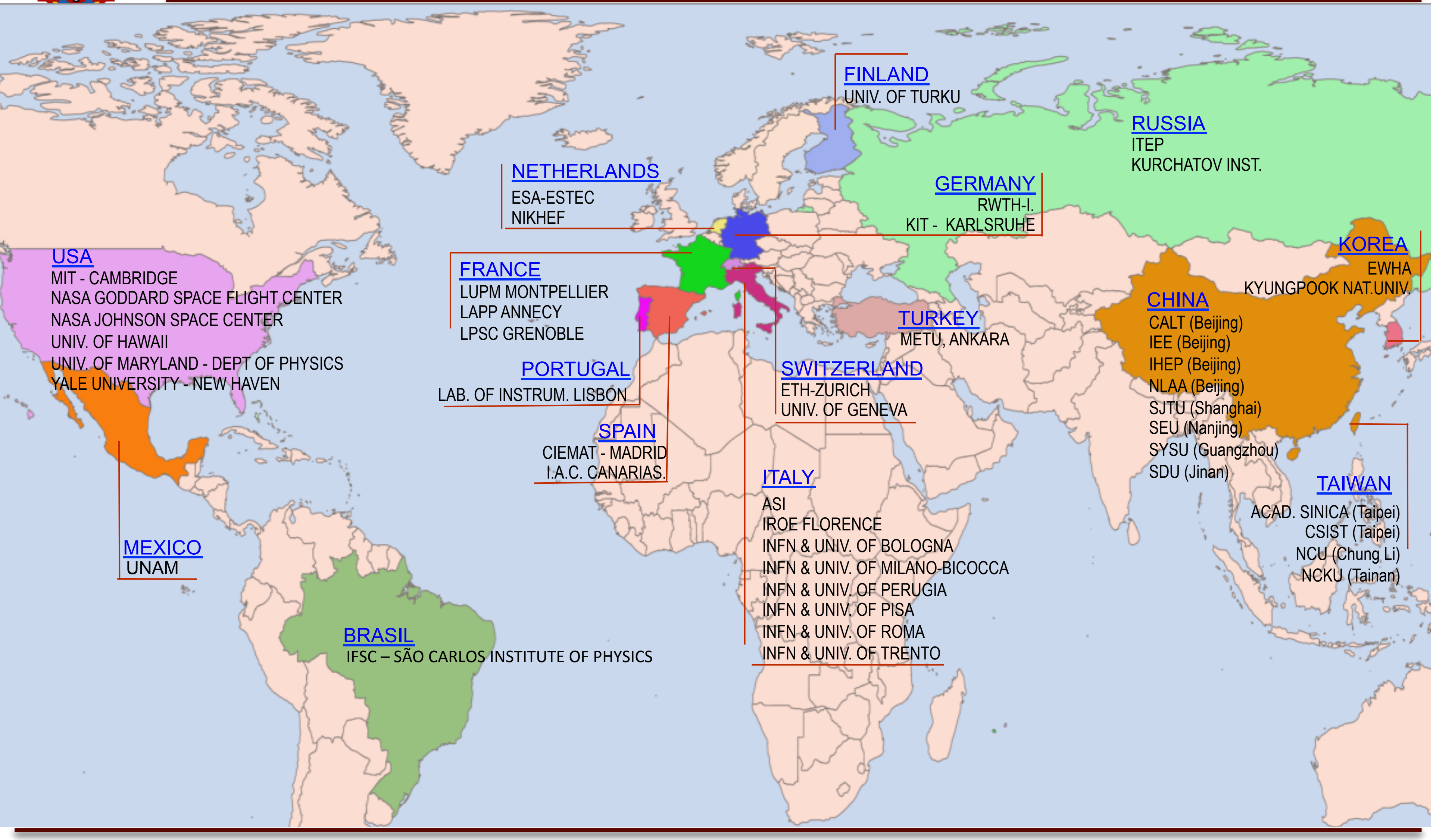
Not more than:

- The AMS detector and its science

- The scientific results of AMS

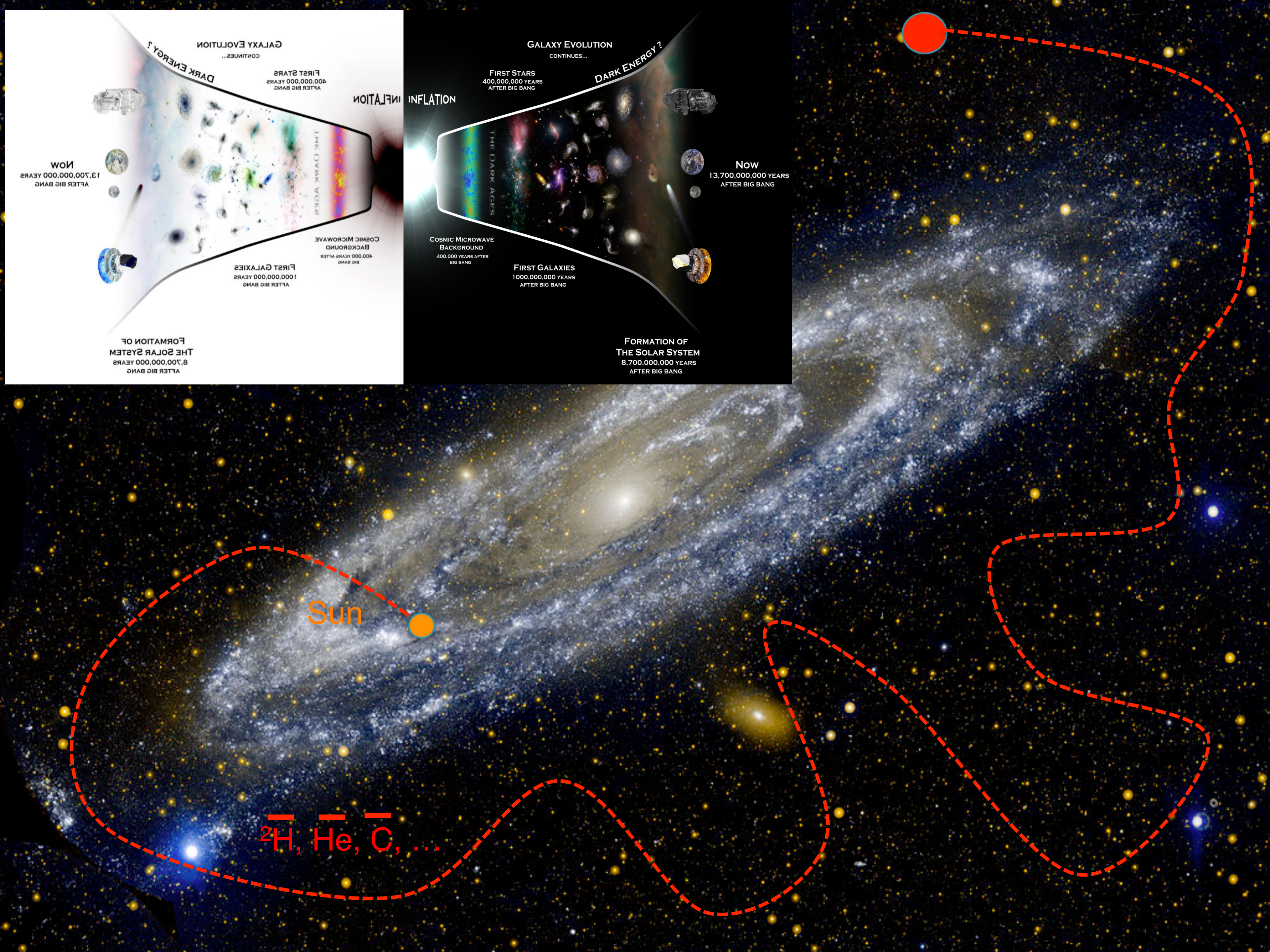
… but I'll try to focus on "details" relevant for the workshop

AMS Collaboration: since 1995



Objectives

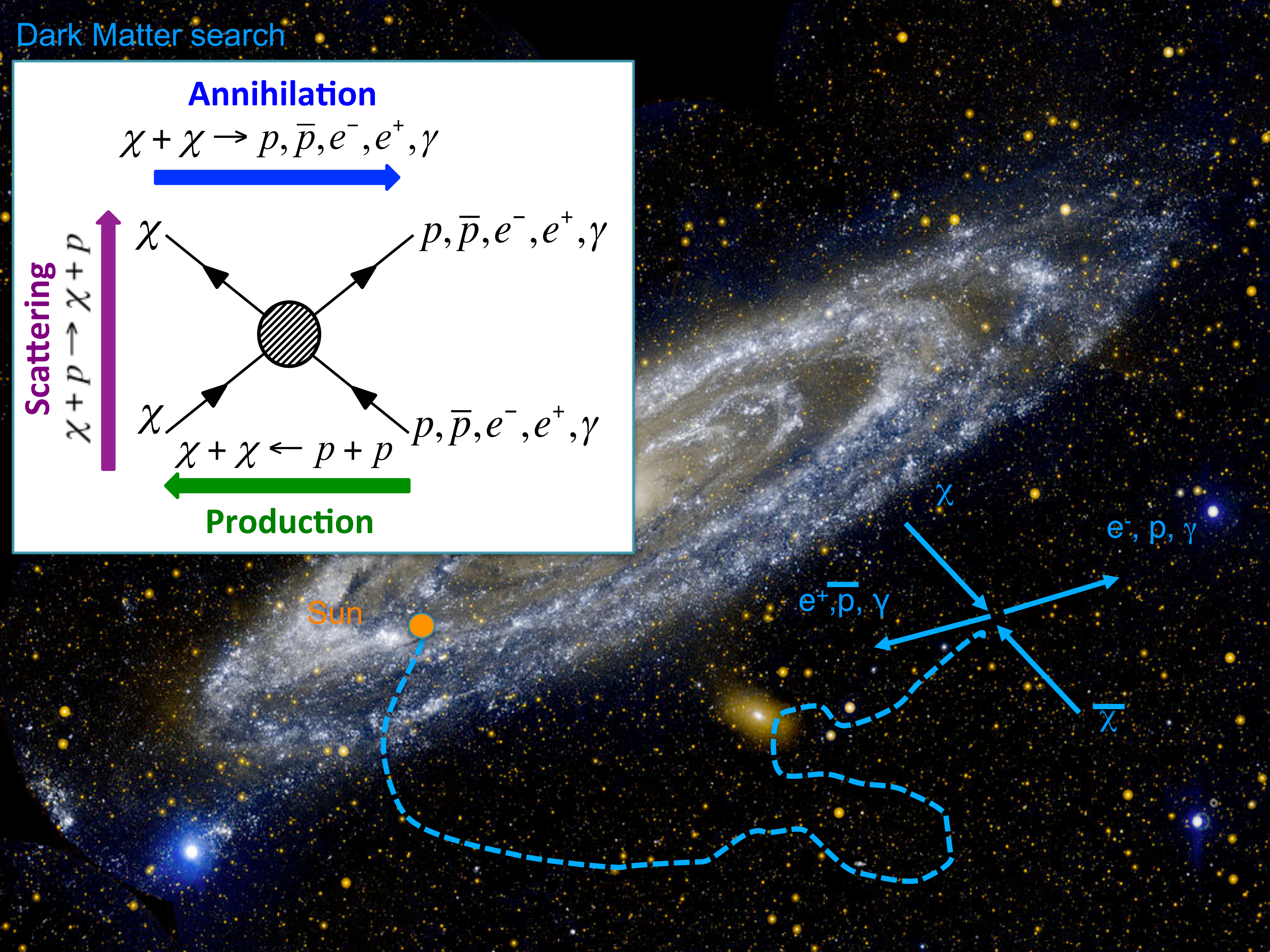
- Fundamental physics and antimatter:
  - primordial origin (signal: anti-nuclei)

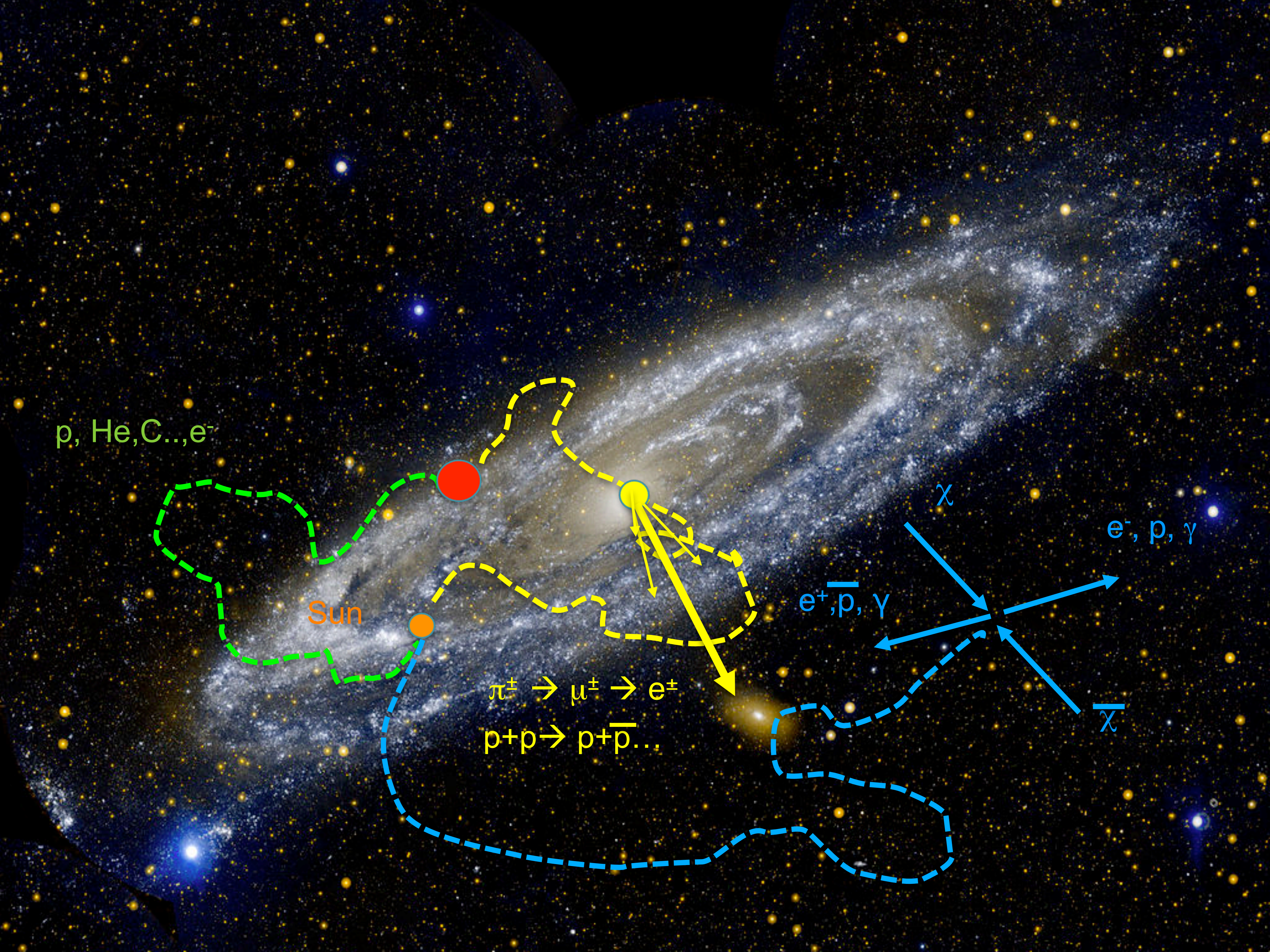


Galaxy Evolution
continues...
Dark Energy ?
First Stars
400,000,000 years
after Big Bang
Inflation
The Dark Ages
Now
13,700,000,000 years
after Big Bang
Cosmic Microwave
Background
400,000 years after
Big Bang
First Galaxies
1000,000,000 years
after Big Bang
Formation of
The Solar System
8,700,000,000 years
after Big Bang
Sun
$^2\bar{H}$, $\overline{He}$, $\bar{C}$, ...

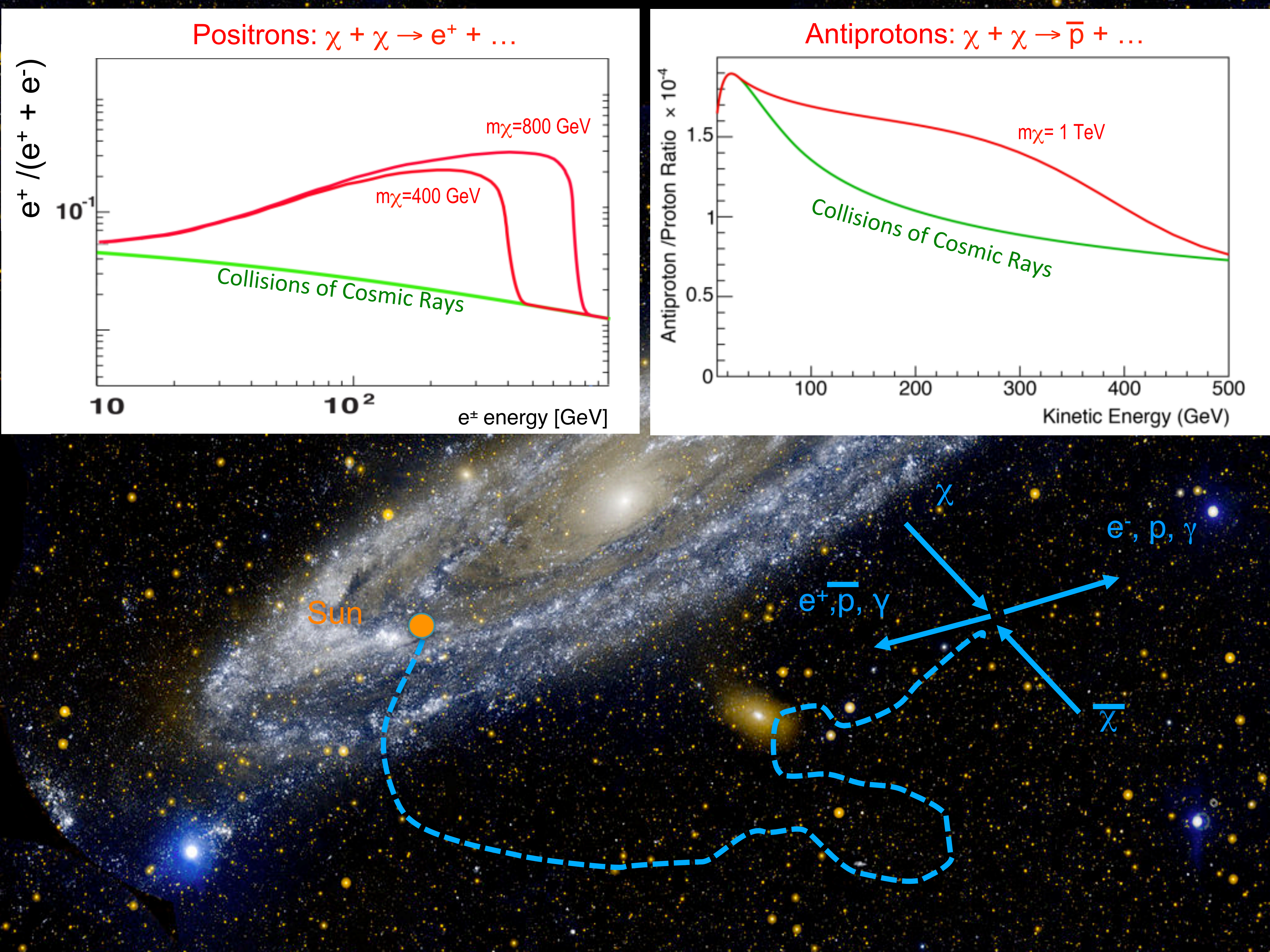
Objectives

- Fundamental physics and antimatter:
  - primordial origin (signal: anti-nuclei)
  - “exotic” sources (signal: positrons, anti-p, anti-D, γ)


Dark Matter search
Annihilation
$\chi + \chi \rightarrow p, \bar{p}, e^-, e^+, \gamma$
Scattering
$\chi + p \rightarrow \chi + p$
χ
χ
$p, \bar{p}, e^-, e^+, \gamma$
$p, \bar{p}, e^-, e^+, \gamma$
$\chi + \chi \leftarrow p + p$
Production
Sun
χ
e^-, p, γ
e^+, $\bar{p}$, γ
$\bar{\chi}$



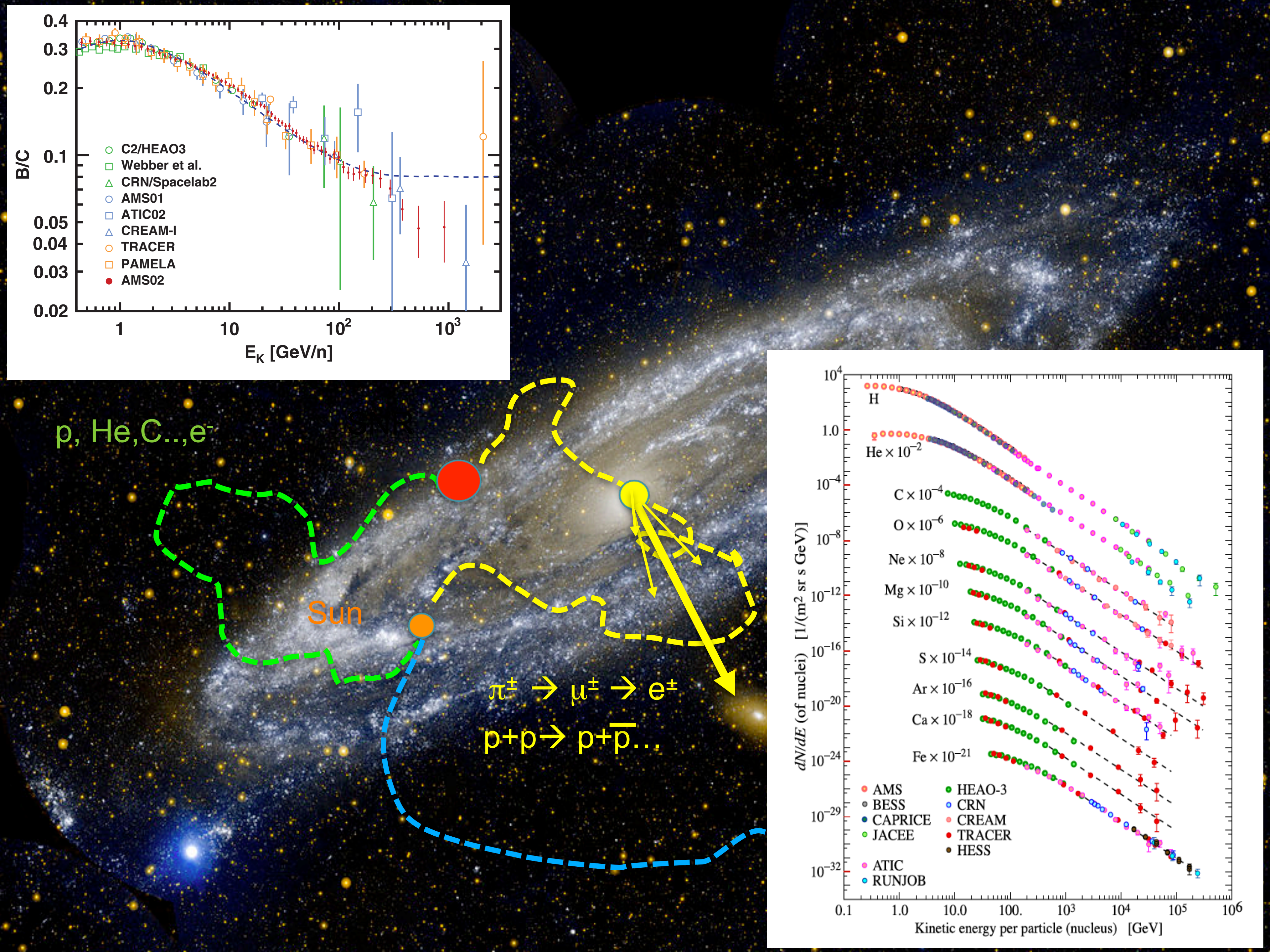
p, He,C..,e⁻
Sun
π± → μ± → e±
p+p→ p+p̄…
χ
e⁻, p, γ
e⁺,p̄, γ
χ̄



Positrons: χ + χ → e⁺ + …
e⁺ /(e⁺ + e⁻)
10⁻¹
mχ=800 GeV
mχ=400 GeV
Collisions of Cosmic Rays
10
10²
e± energy [GeV]
Antiprotons: χ + χ → p̄ + …
Antiproton /Proton Ratio × 10⁻⁴
1.5
1
0.5
0
mχ= 1 TeV
Collisions of Cosmic Rays
100
200
300
400
500
Kinetic Energy (GeV)
Sun
χ
e⁻, p, γ
e⁺,p̄, γ
χ̄

Objectives

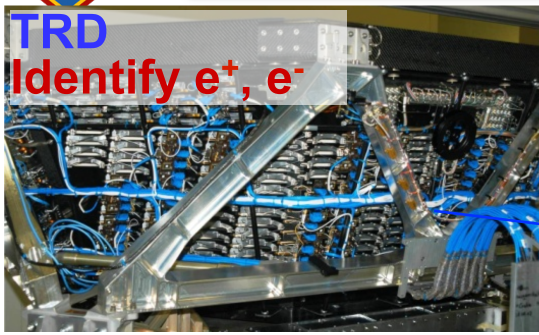
- Fundamental physics and antimatter:
  - primordial origin (signal: anti-nuclei)
  - “exotic” sources (signal: positrons, anti-p, anti-D, γ)
- Origin and composition of CRs
  - sources and acceleration: primaries (p, He, C, ...)
  - propagation in the ISM: secondaries (B/C, ...)

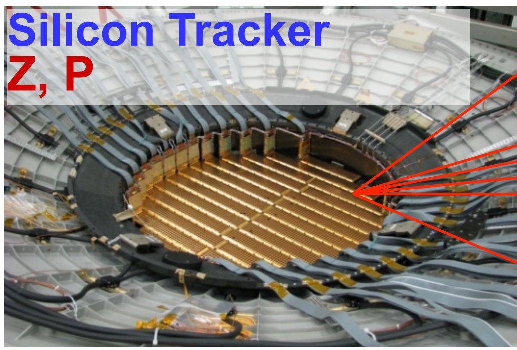

B/C
0.4
0.3
0.2
0.1
0.05
0.04
0.03
0.02
1
10
10^2
10^3
E_K [GeV/n]
C2/HEAO3
Webber et al.
CRN/Spacelab2
AMS01
ATIC02
CREAM-I
TRACER
PAMELA
AMS02
p, He,C..,e-
Sun
π± → μ± → e±
p+p→ p+p̄…
H
He × 10^-2
C × 10^-4
O × 10^-6
Ne × 10^-8
Mg × 10^-10
Si × 10^-12
S × 10^-14
Ar × 10^-16
Ca × 10^-18
Fe × 10^-21
dN/dE (of nuclei) [1/(m^2 sr s GeV)]
Kinetic energy per particle (nucleus) [GeV]
AMS
BESS
CAPRICE
JACEE
ATIC
RUNJOB
HEAO-3
CRN
CREAM
TRACER
HESS

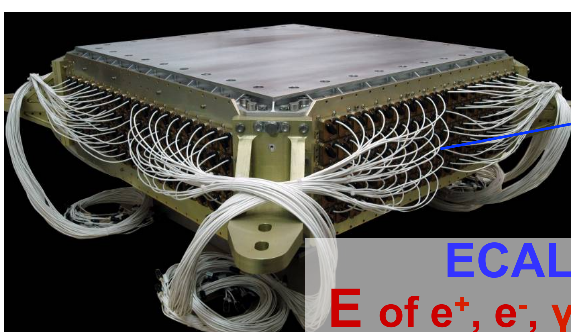
Objectives

- Fundamental physics and antimatter:
  - primordial origin (signal: anti-nuclei)
  - “exotic” sources (signal: positrons, anti-p, anti-D, γ)
- Origin and composition of CRs
  - sources and acceleration: primaries (p, He, C, ...)
  - propagation in the ISM: secondaries (B/C, ...)
- Study of the solar and geo-magnetical physics
  - effect of the solar modulation
  - geomagnetic cutoff

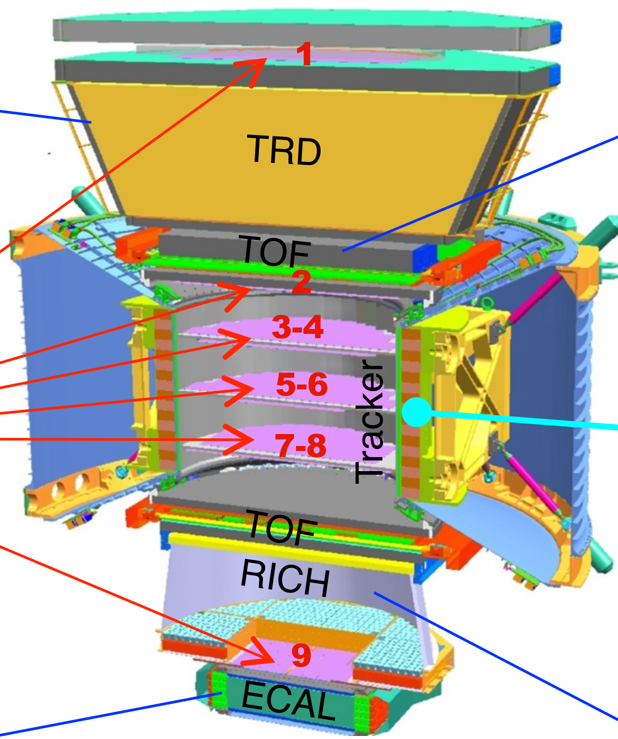
Alpha Magnetic Spectrometer – AMS-02

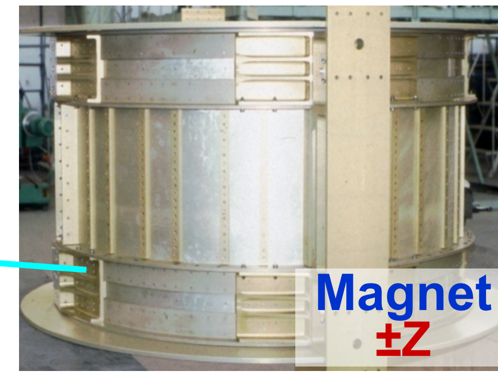


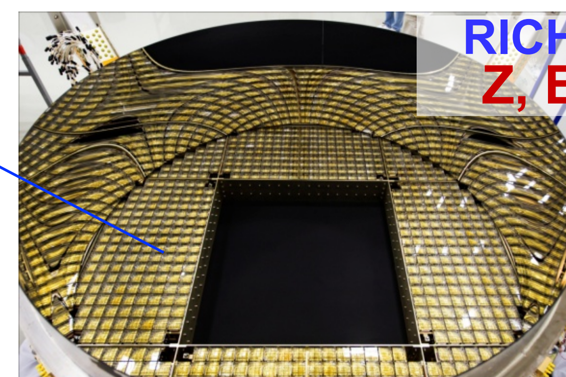




Z, P are measured independently by Tracker, RICH, TOF and ECAL

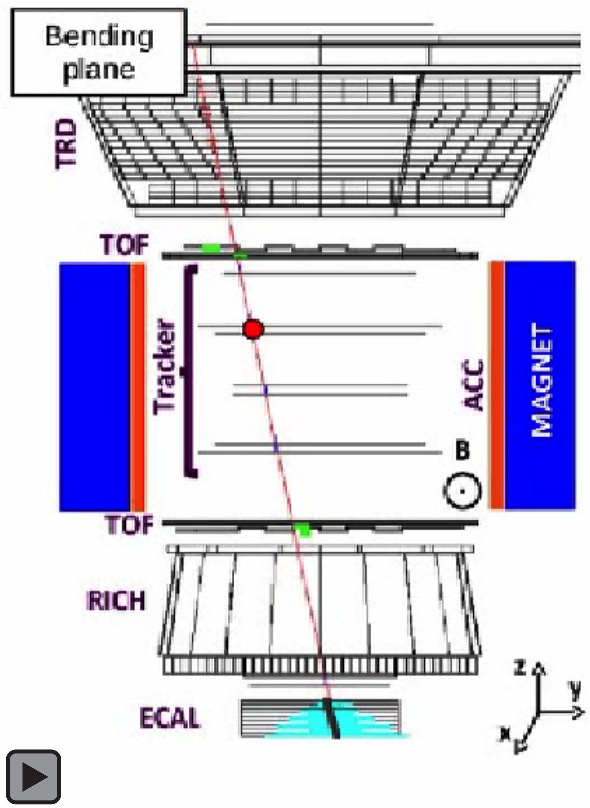


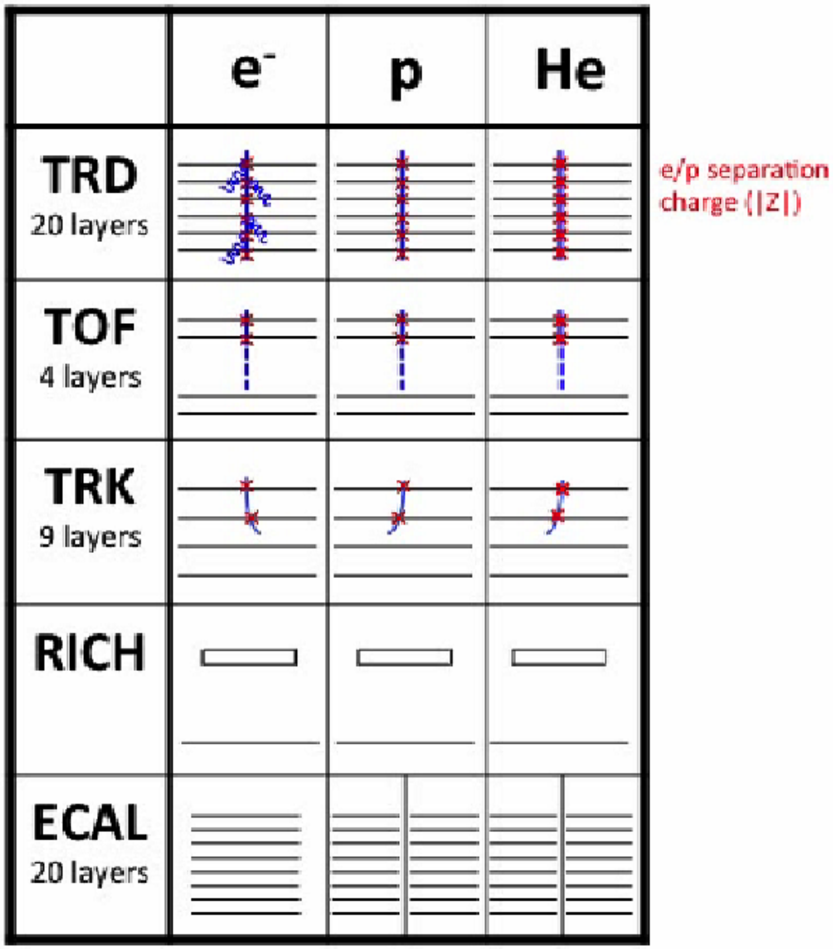




- *weight: 7 tons*
- *power consumption: 2.5 kW*
- *readout channels: 300k*
- *transmission bandwidth: ~10 Mbps*

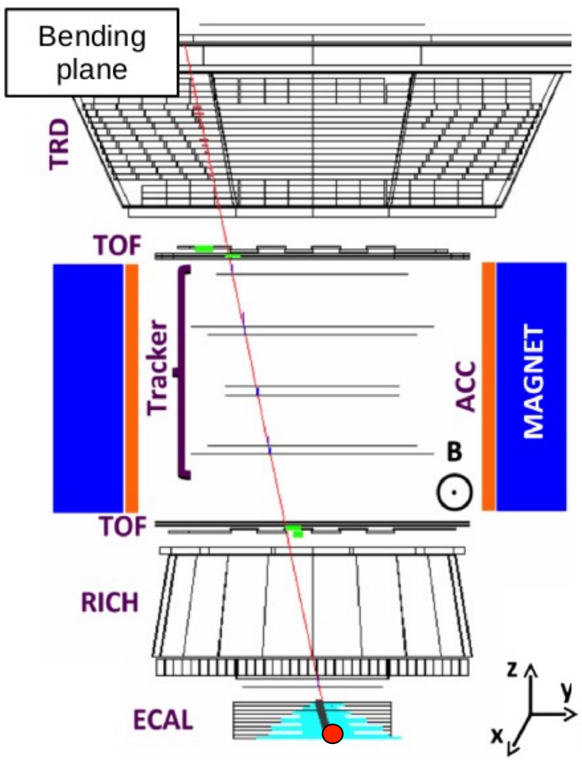
Single particle identification

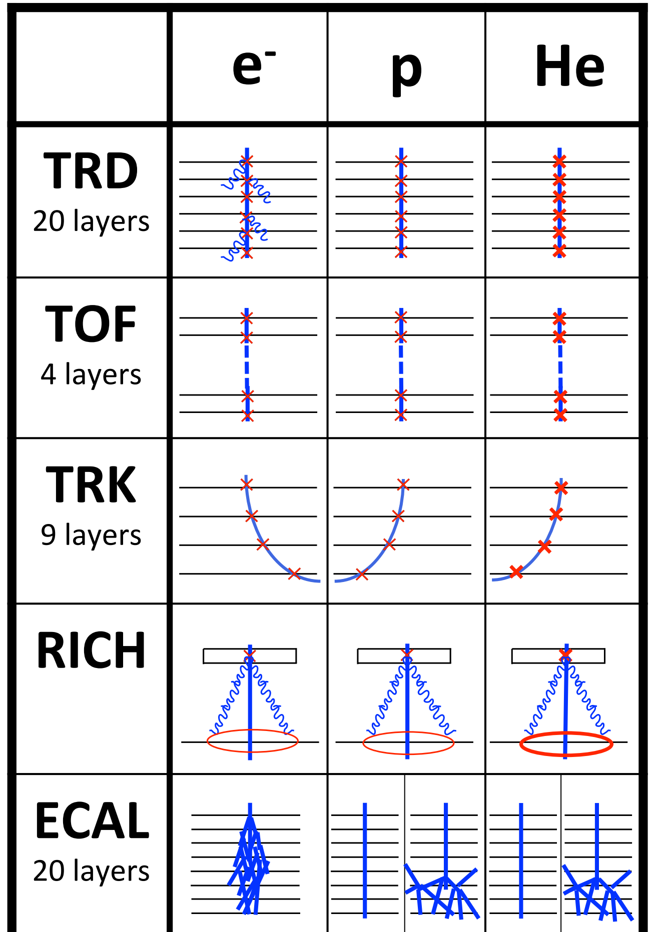




Single particle identification

Full coverage of anti-matter and CR physics





e/p separation
charge (|Z|)

trigger
velocity (β)
charge (|Z|)

momentum (p)
sign (±Q)
charge (|Z|)

velocity (β)
charge (|Z|)

e± energy
e/h separation
γ trigger

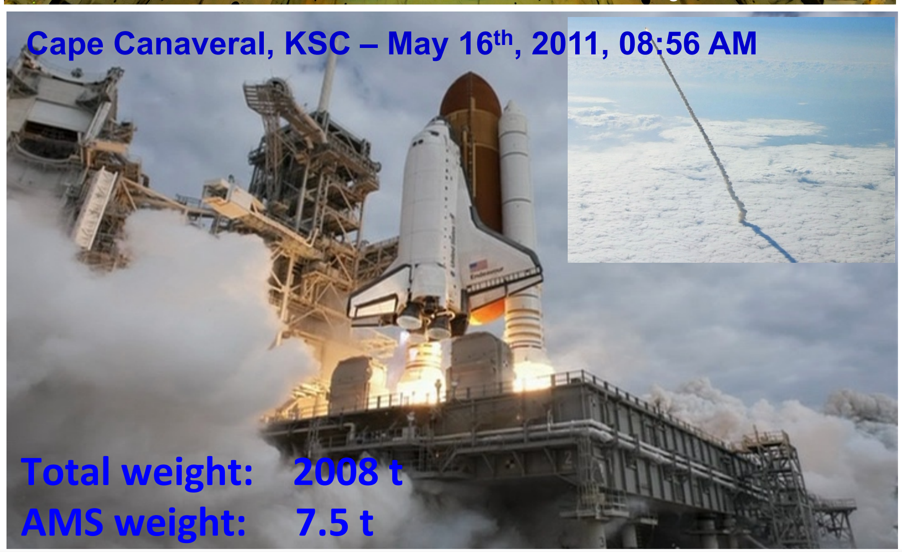
AMS launch and data taking start: May 2011

AMS in the Shuttle Endeavour (STS134) canister

© Michele Famiglietti / AMS Collaboration

Houston, JSC – May 16th, 2011@ 07:56 AM

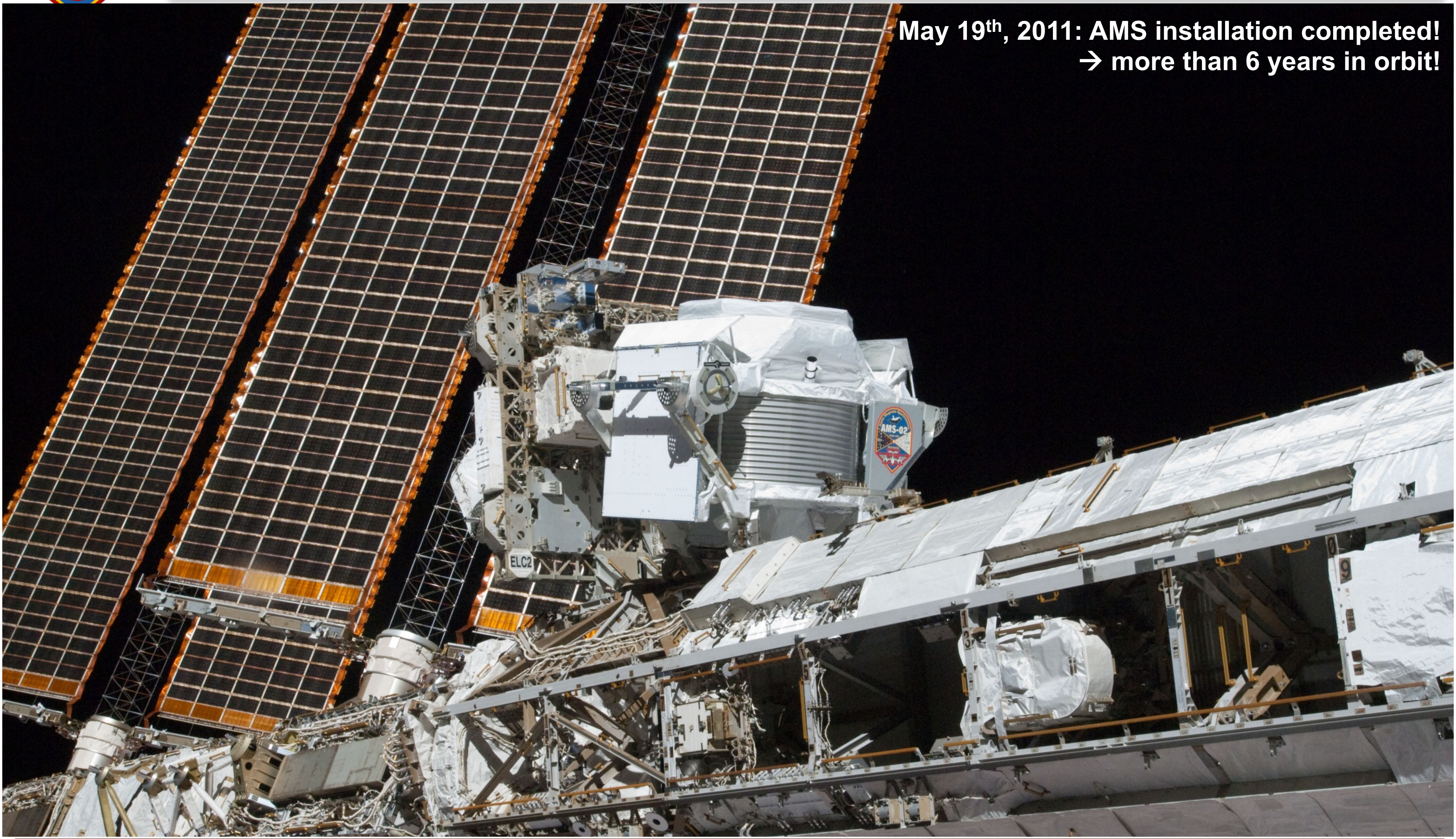
Cape Canaveral, KSC – May 16th, 2011, 08:56 AM



Total weight: 2008 t

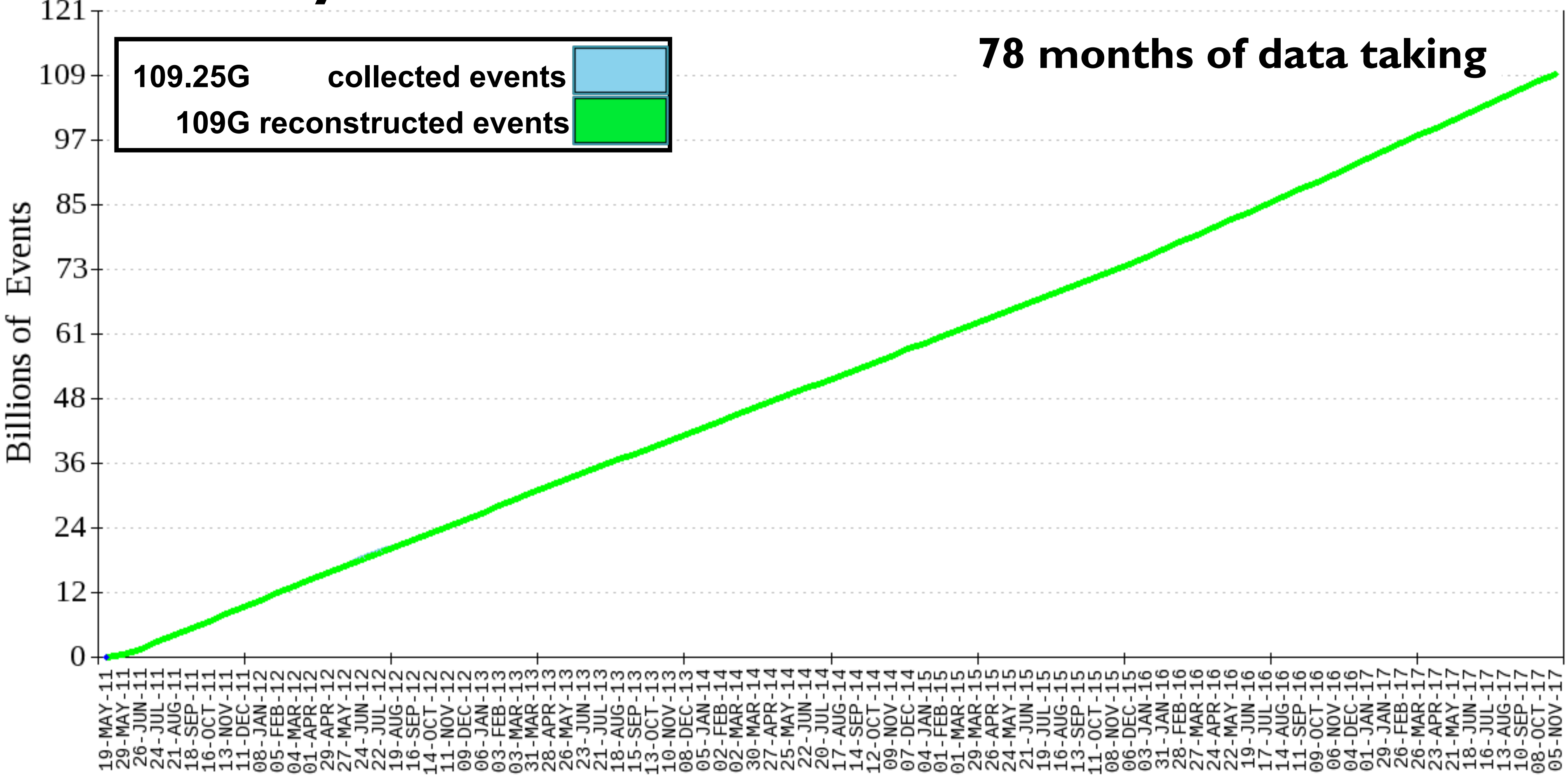
AMS weight: 7.5 t

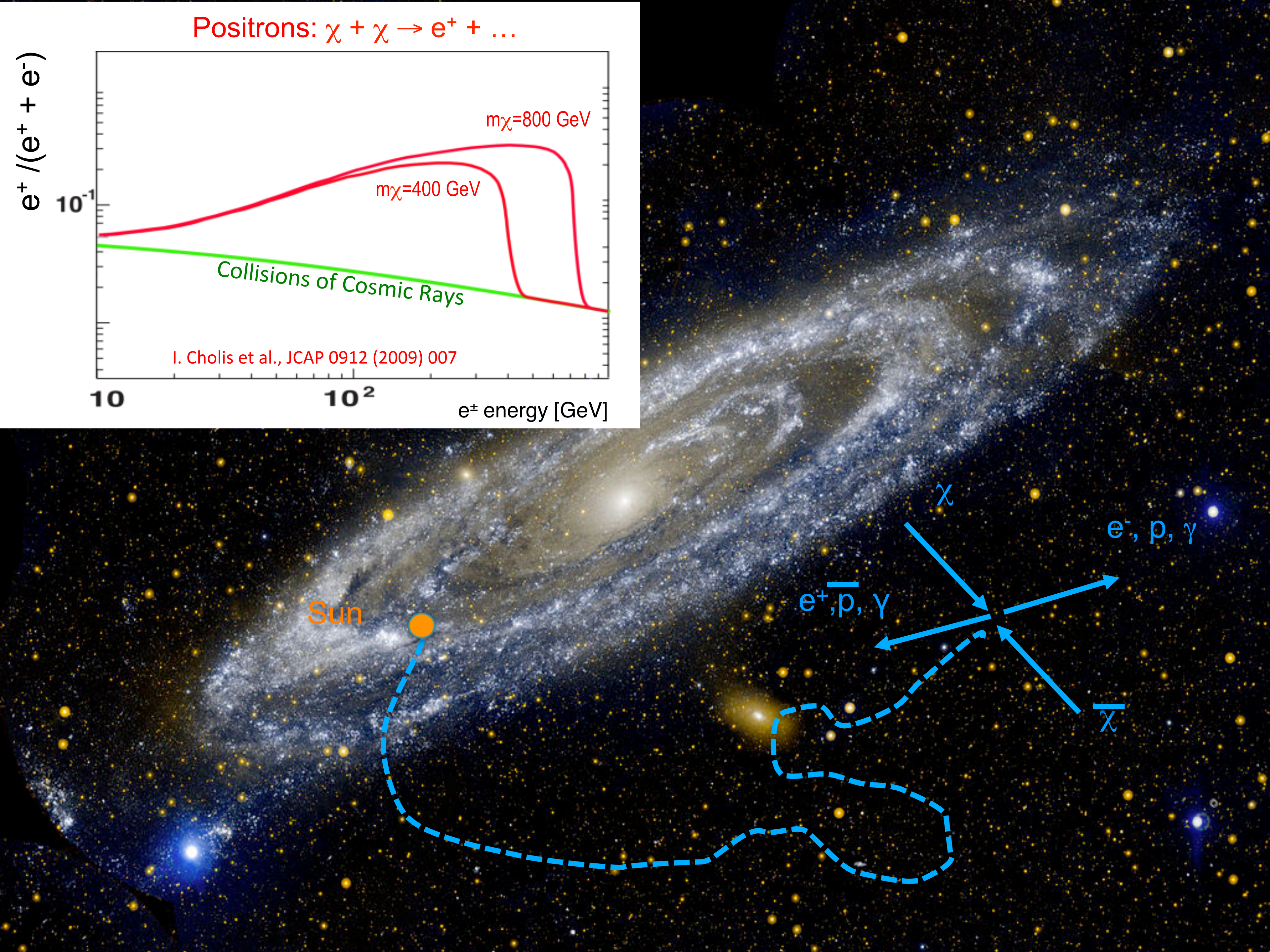
AMS launch and data taking start: May 2011



The collected statistics

Today AMS collected ~ 110 billion of events

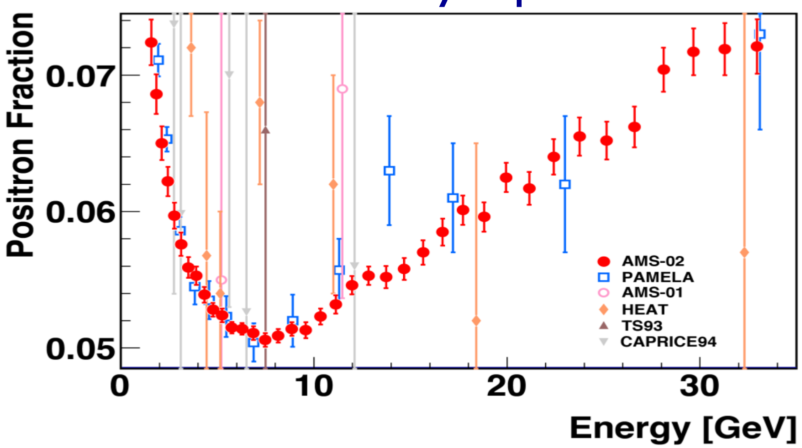


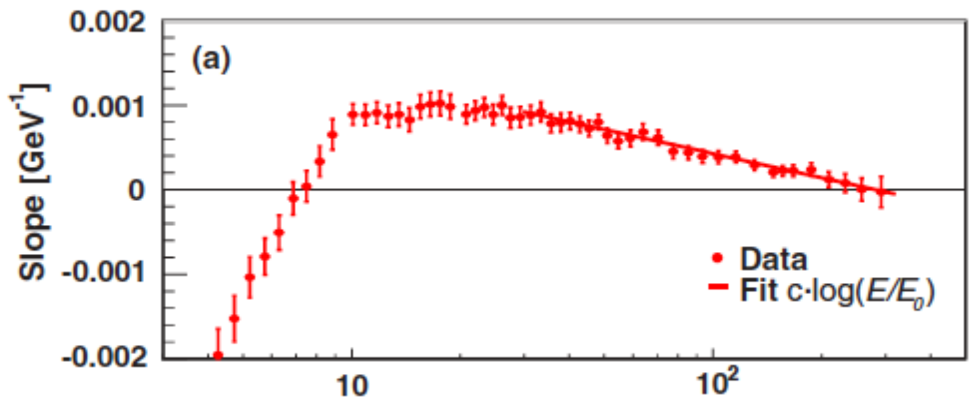


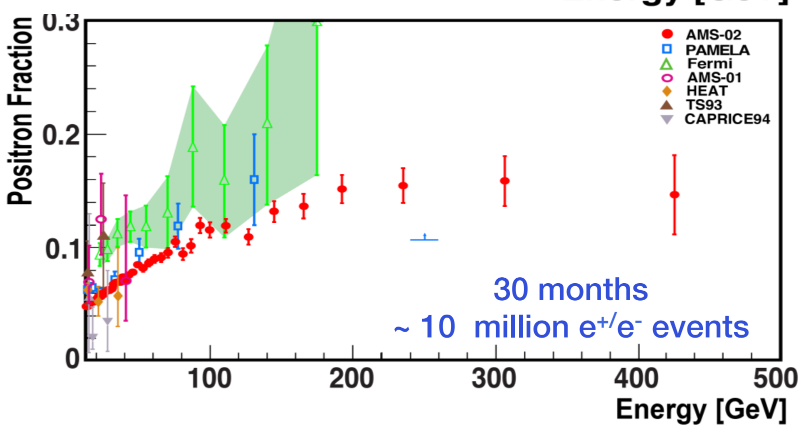
Positrons: χ + χ → e⁺ + …
e⁺ /(e⁺ + e⁻)
10⁻¹
mχ=800 GeV
mχ=400 GeV
Collisions of Cosmic Rays
I. Cholis et al., JCAP 0912 (2009) 007
10
10²
e± energy [GeV]
Sun
χ
e⁻, p, γ
e⁺, p̄, γ
χ̄

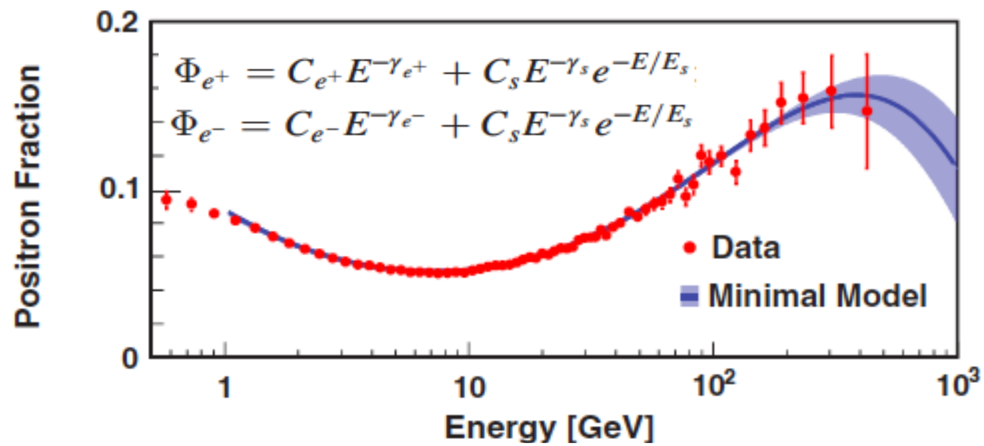
Positron fraction (PRL 110, 141102 - 2013 & 113, 121101 - 2014)

- ✓ No evidence of structures
- ✓ Steady increase up to ~ 275 GeV
- ✓ Well described by a power law + cut-off term, common for e^+/e^-

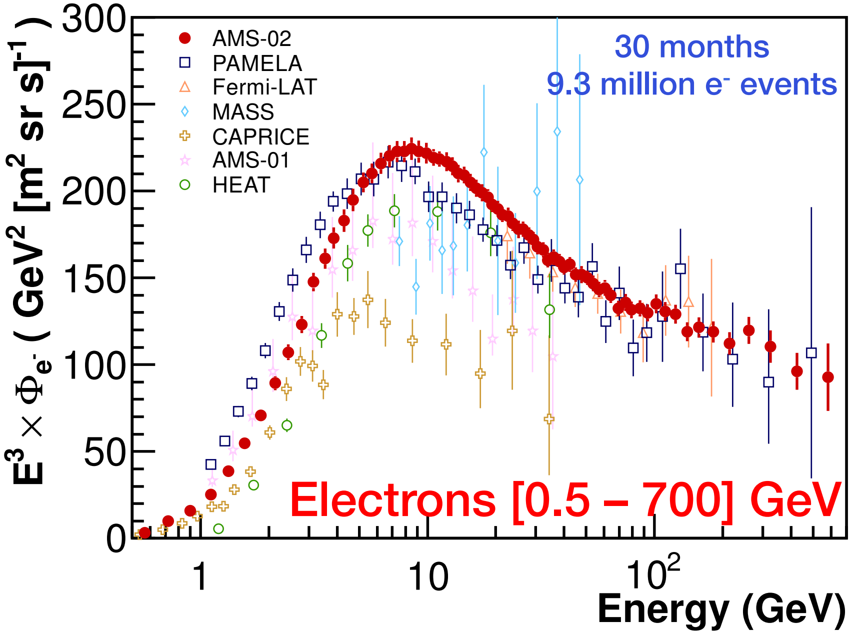


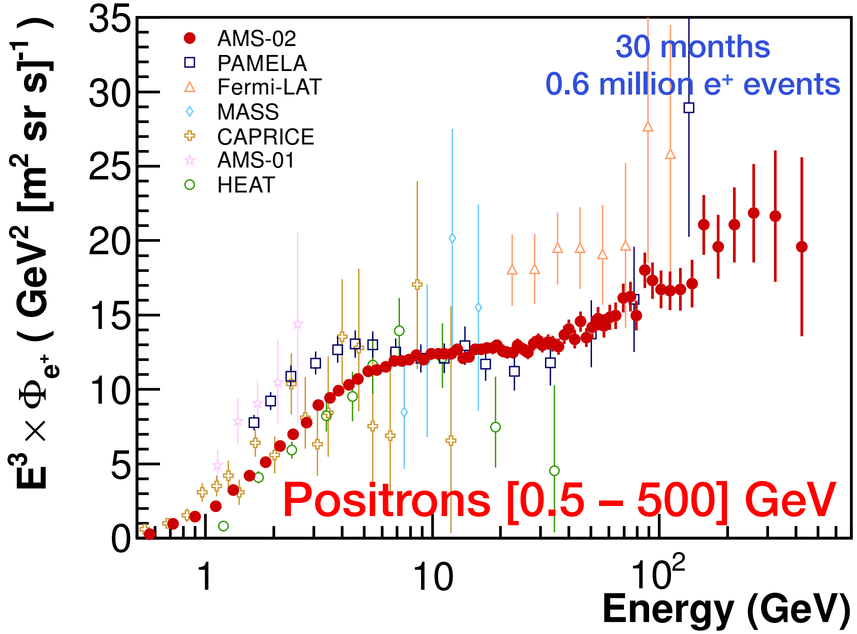


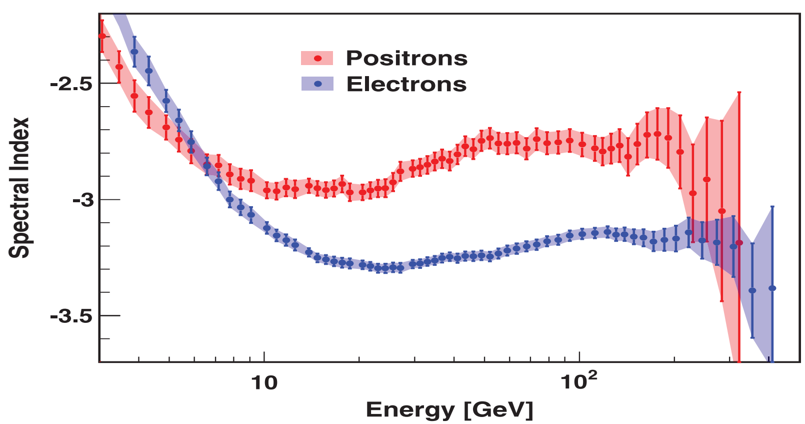




Positron and electron fluxes (PRL 113, 121102 - 2014)







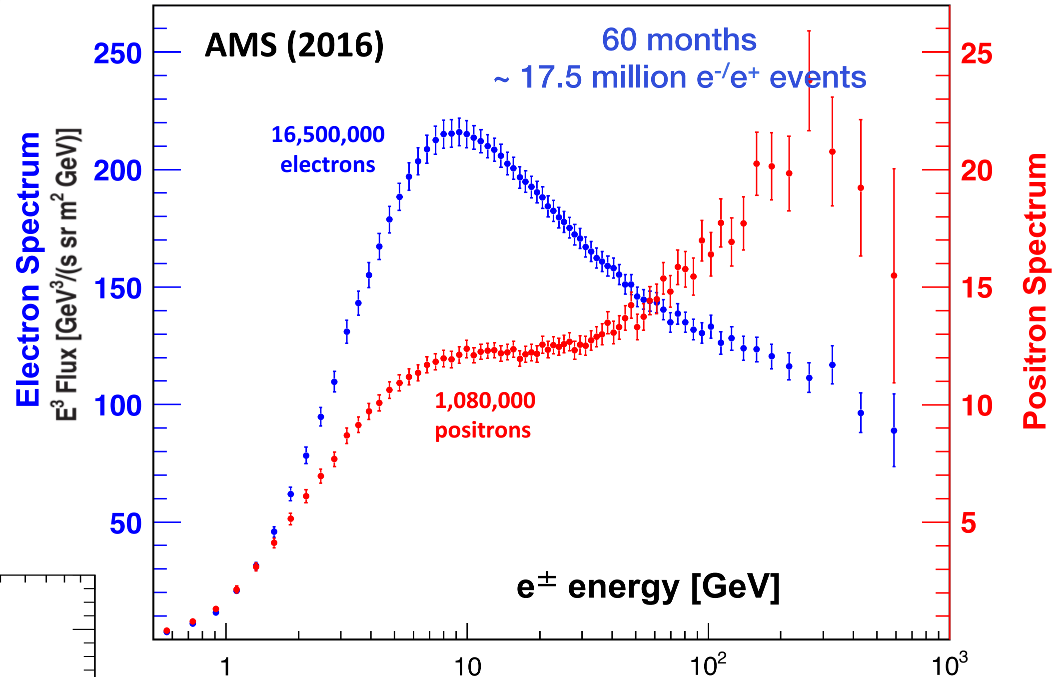
The two fluxes of e^+ and e^- are significantly different in absolute value and energy dependence

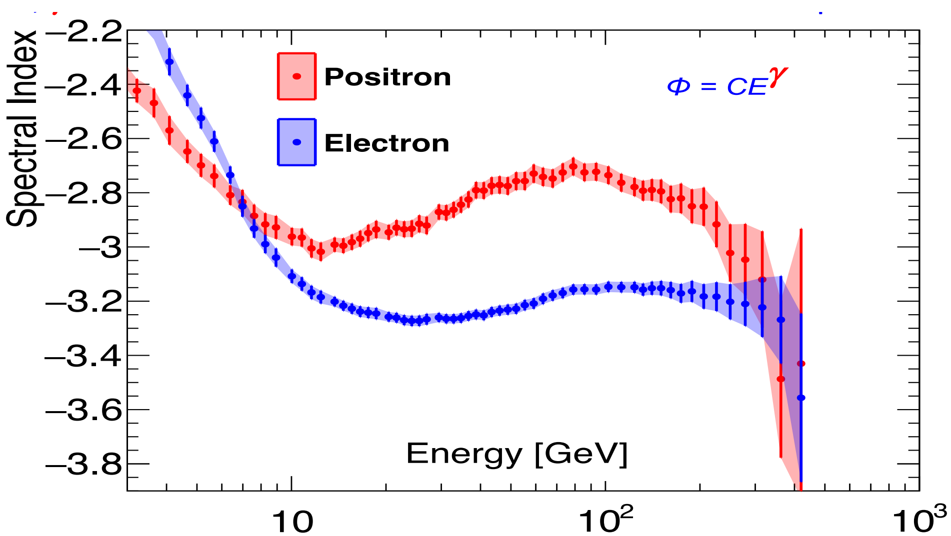
The positron “raise” is due to an **excess of positrons**, not to a lack of electrons

Positron and electron fluxes (status report)

We're updating the results, including the last data collected (more than the double w.r.t. the publication) and trying to reach higher energies

Electrons and Positrons [0.5 – 700] GeV





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Preliminary data - Please refer to the forthcoming AMS publication in PRL

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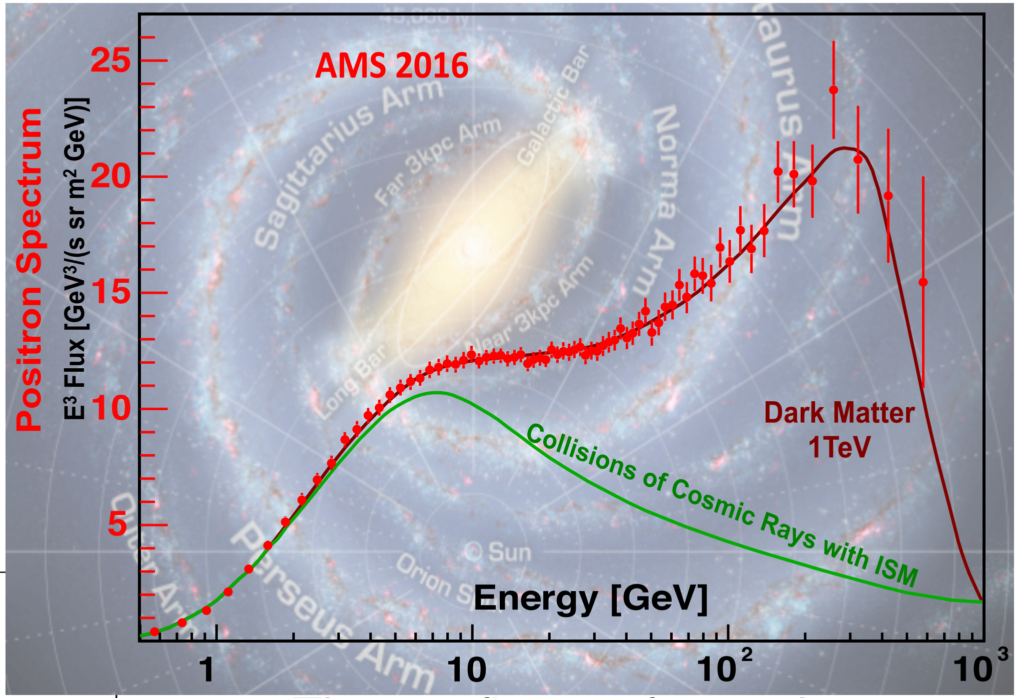
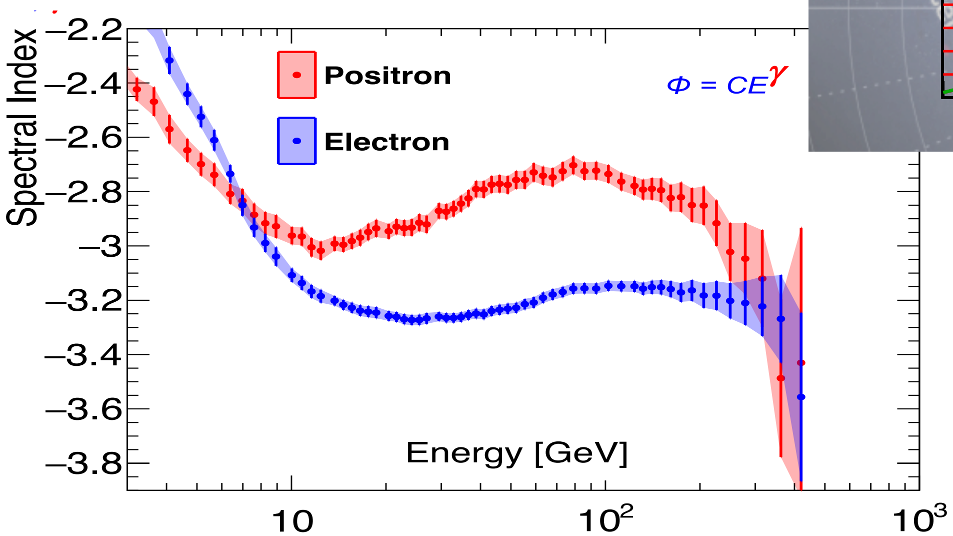




The two fluxes of e^+ and e^- are significantly different in absolute value and energy dependence

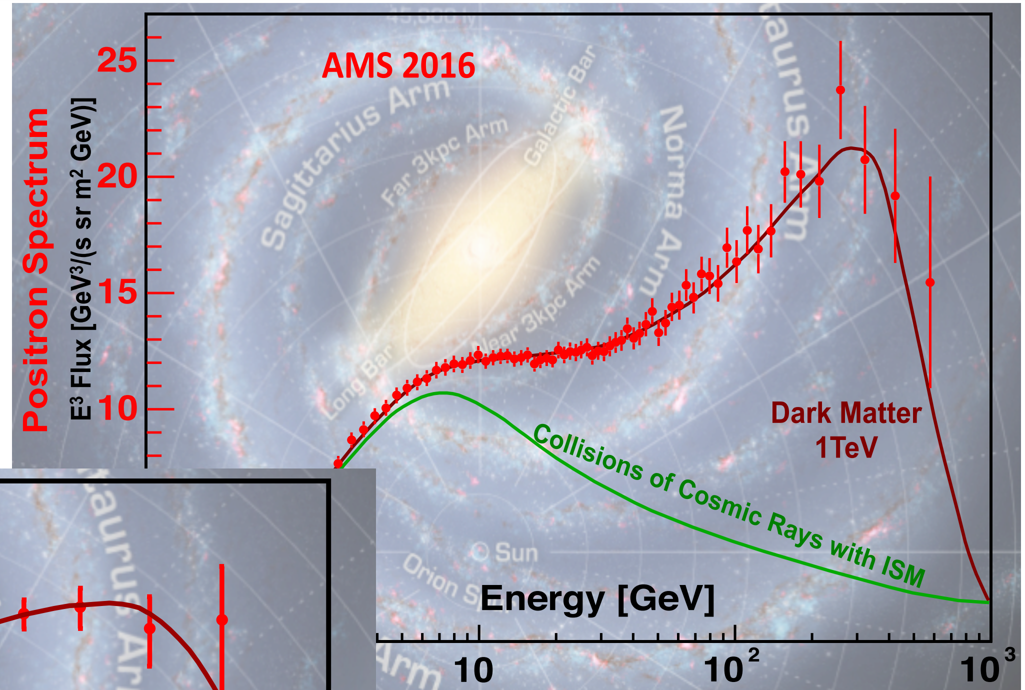
The positron "raise" is due to an **excess of positrons**, not to a lack of electrons

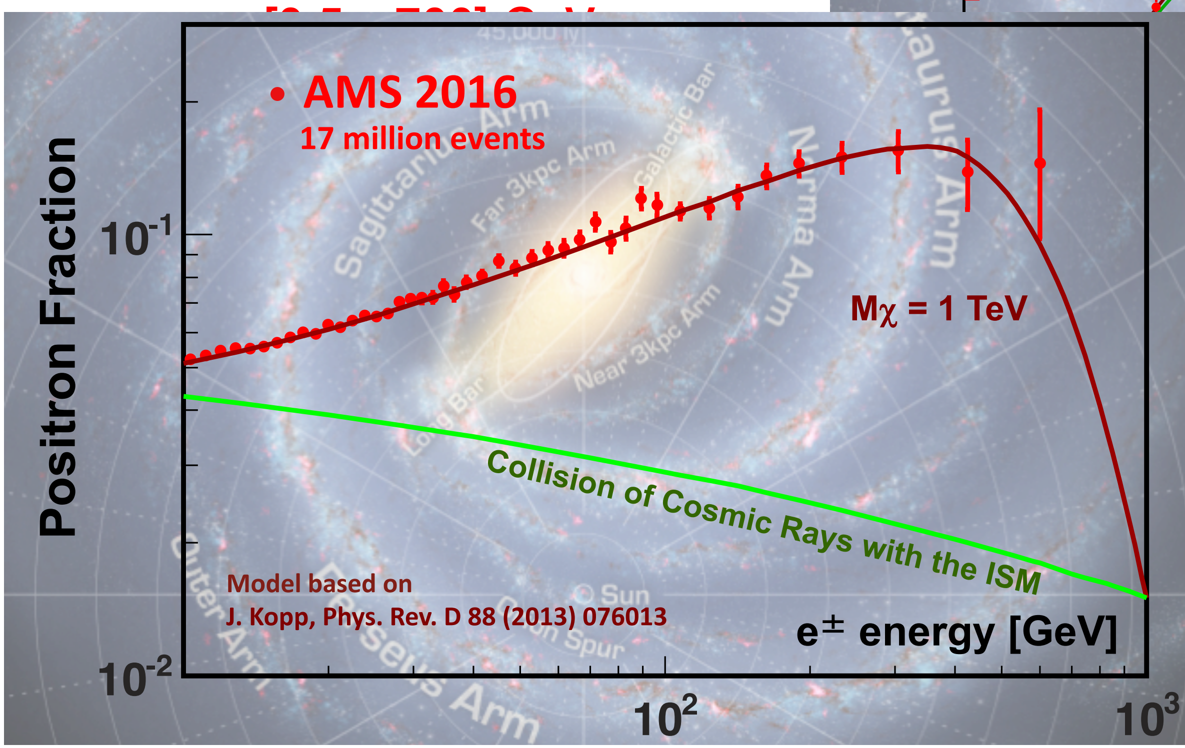
Preliminary data - Please refer to the forthcoming AMS publication in PRL

Positron and electron fluxes, positron fraction (status report)

We're updating the results, including the last data collected (more than the double w.r.t. the publication) and trying to reach higher energies

Electrons and Positrons



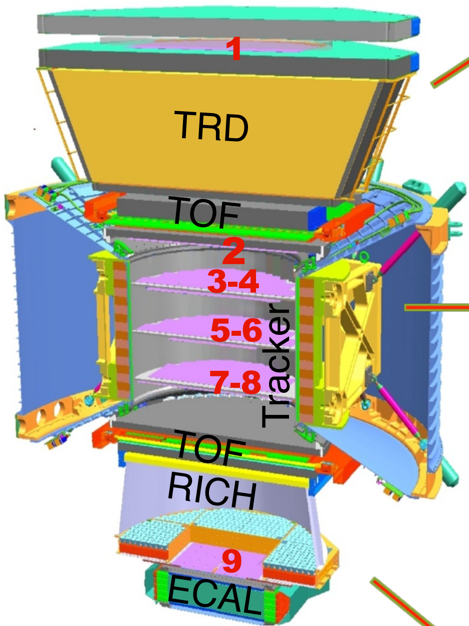


e two fluxes of e^+ and e^- are
antly different in absolute value
and energy dependence

itron "raise" is due to an **excess**
trons, not to a lack of electrons

Preliminary data - Please refer to the forthcoming AMS publication in PRL

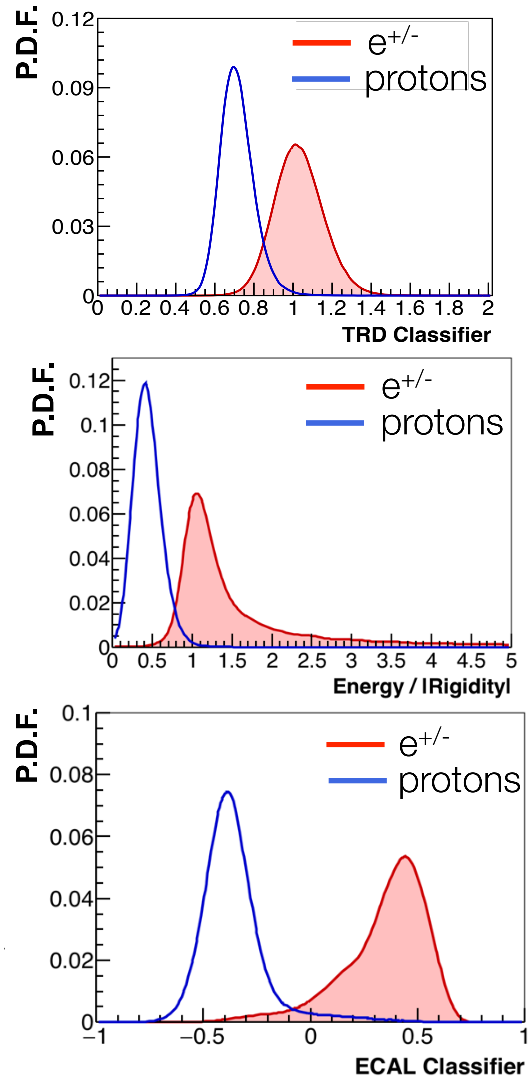
Identification of $e^{+/-}$



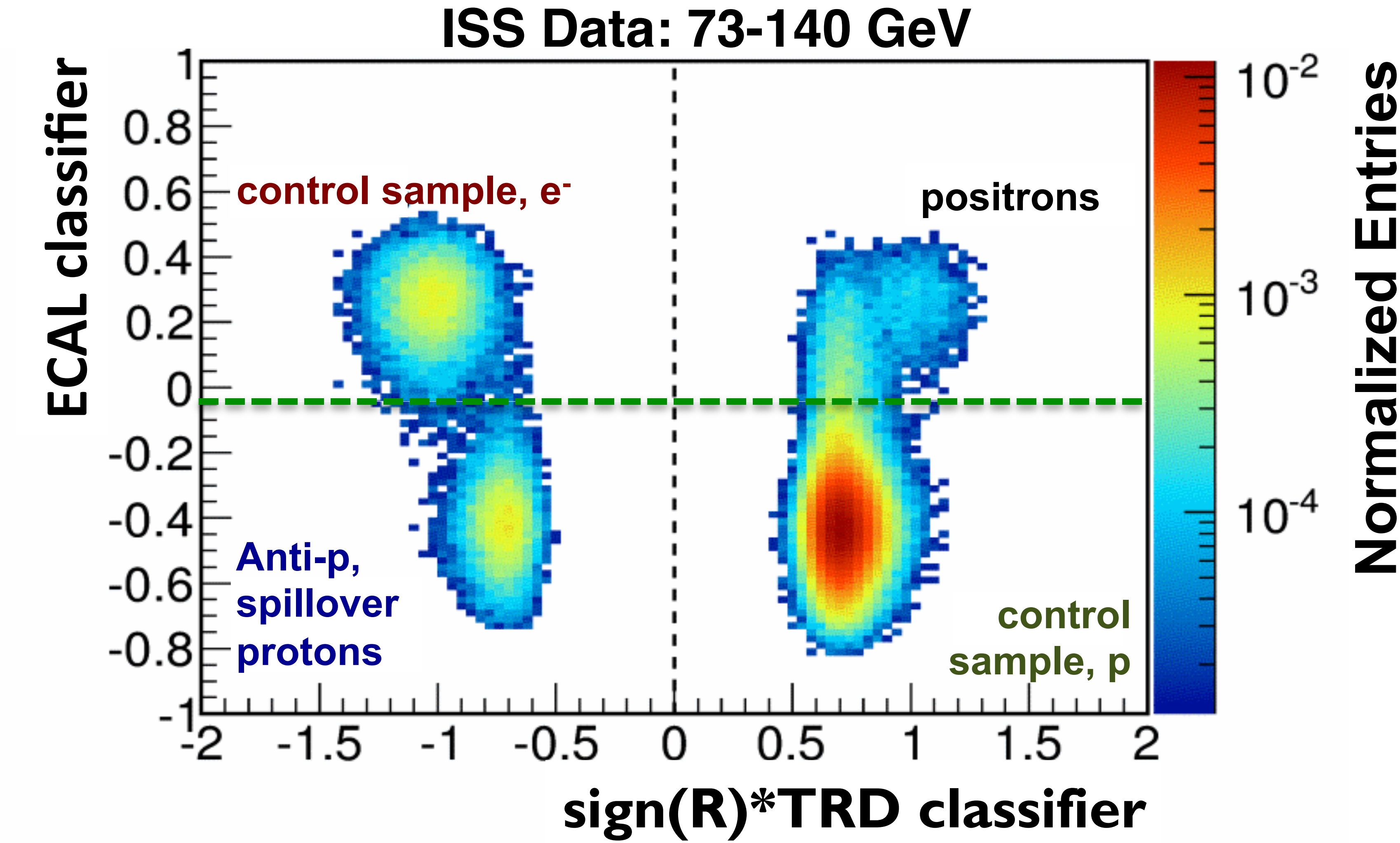
TRD
Transition Radiation
to identify $e^{+/-}$

TRACKER
Momentum P
$e^{+/-}$: $P_{TRK} = E_{ECAL}$
Protons: $P_{TRK} >> E_{ECAL}$

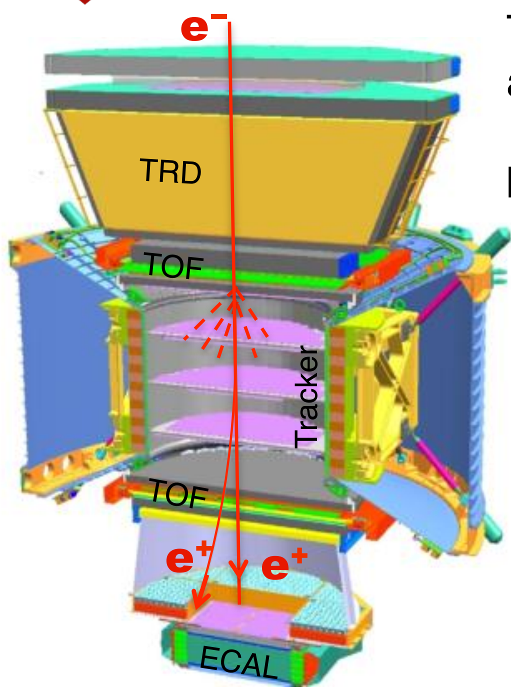
ECAL
Shower Topology
to separate $e^{+/-}$ from proton



Redundancy and complementarity



Charge Confusion



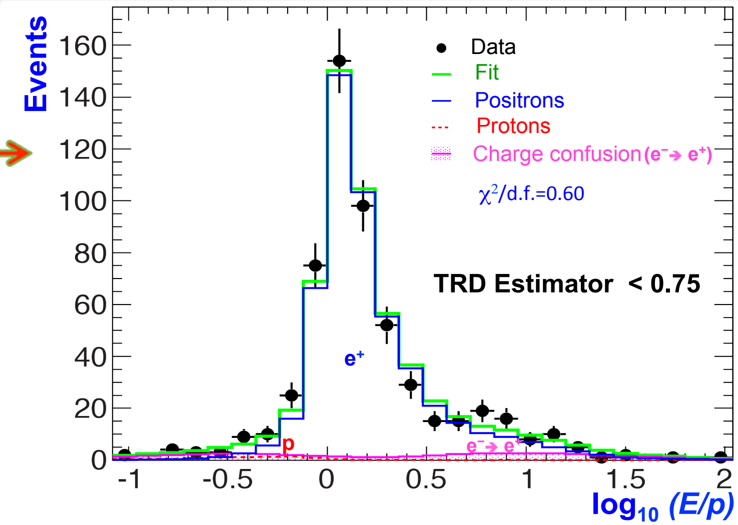
Two sources:

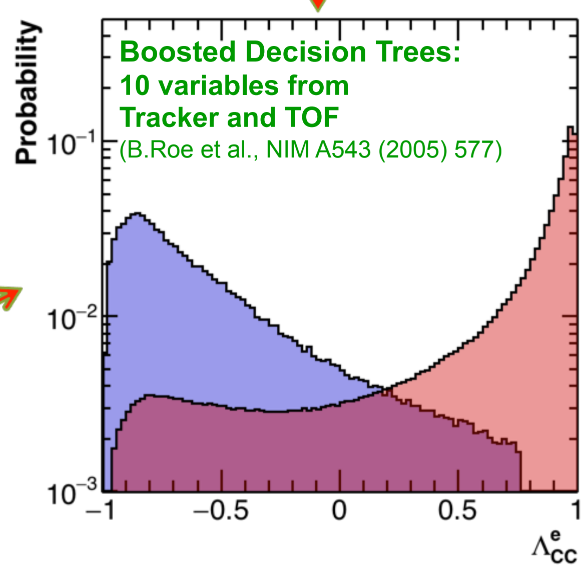
a) finite spectrometer resolution (only at high energies)

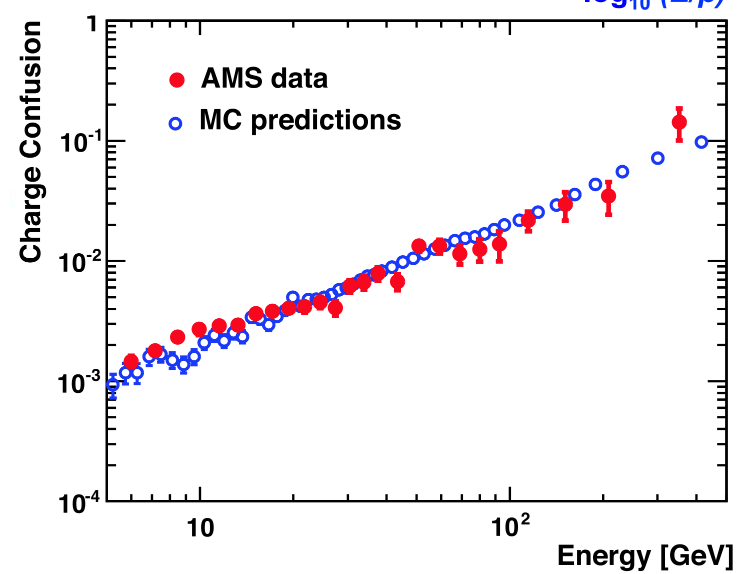
b) interactions

1) large angle scattering

2) production of secondary tracks along the path of the primary track

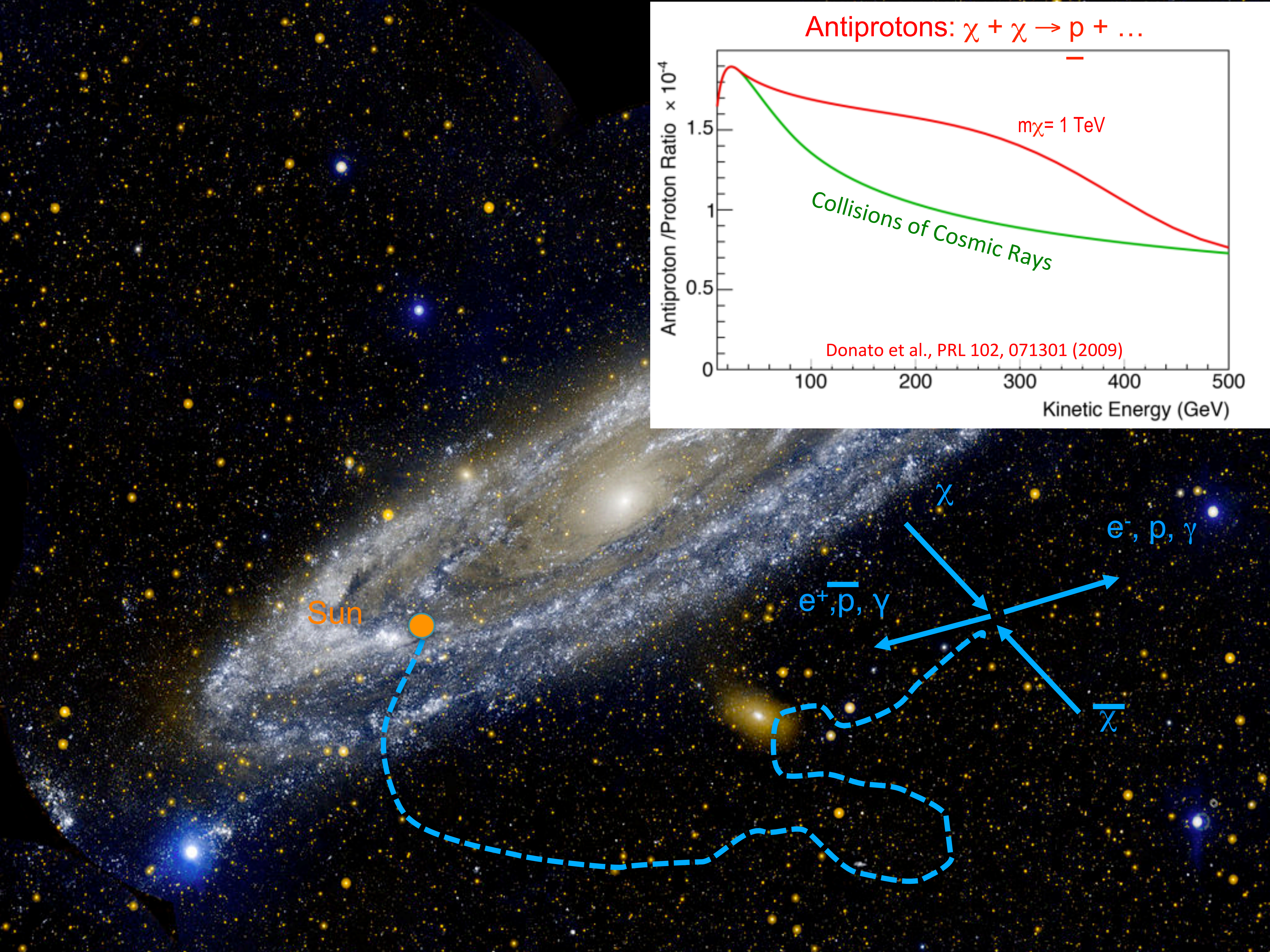






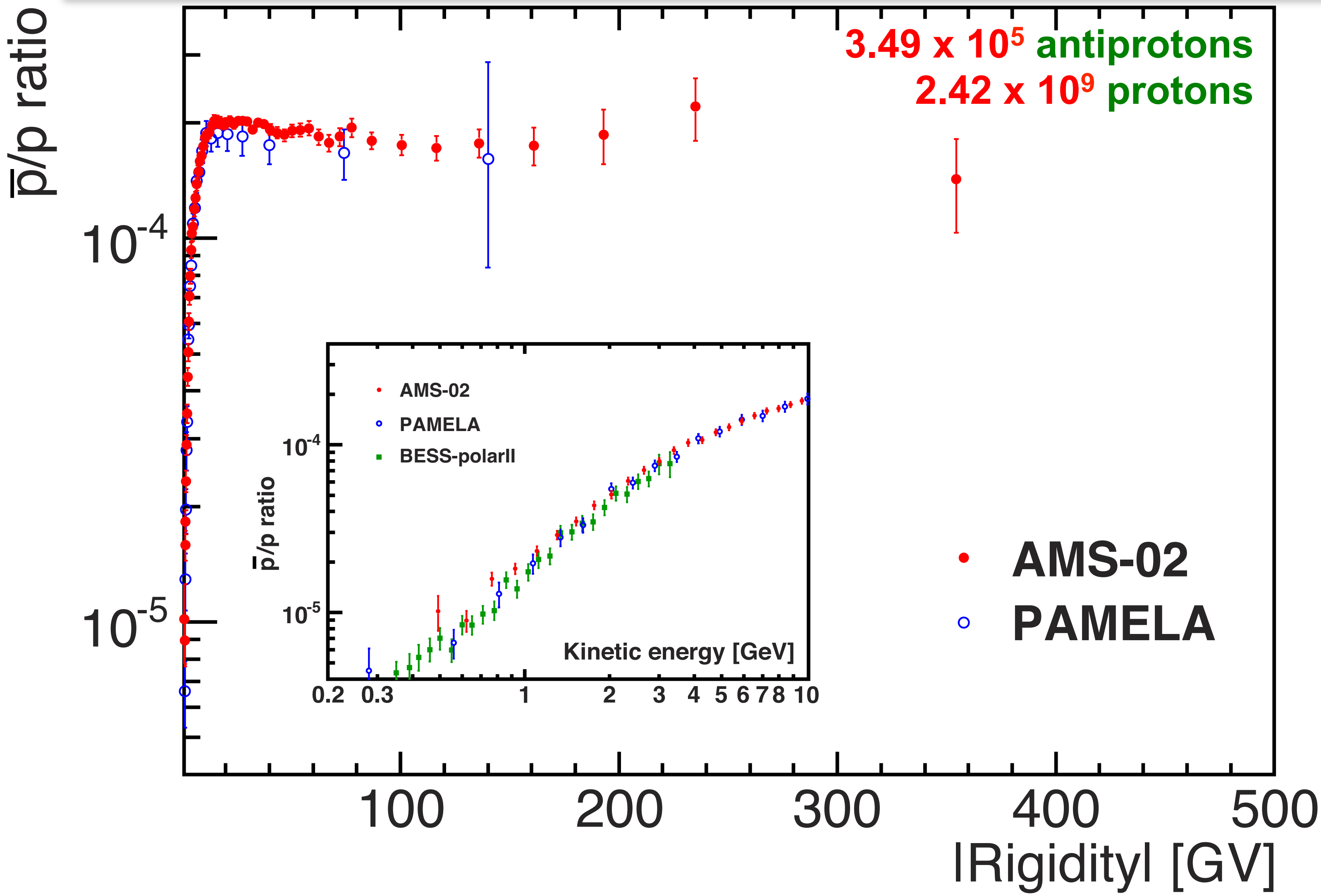
Looking to:

- the energy deposits before the tracker;
- **“activity” below the tracker**

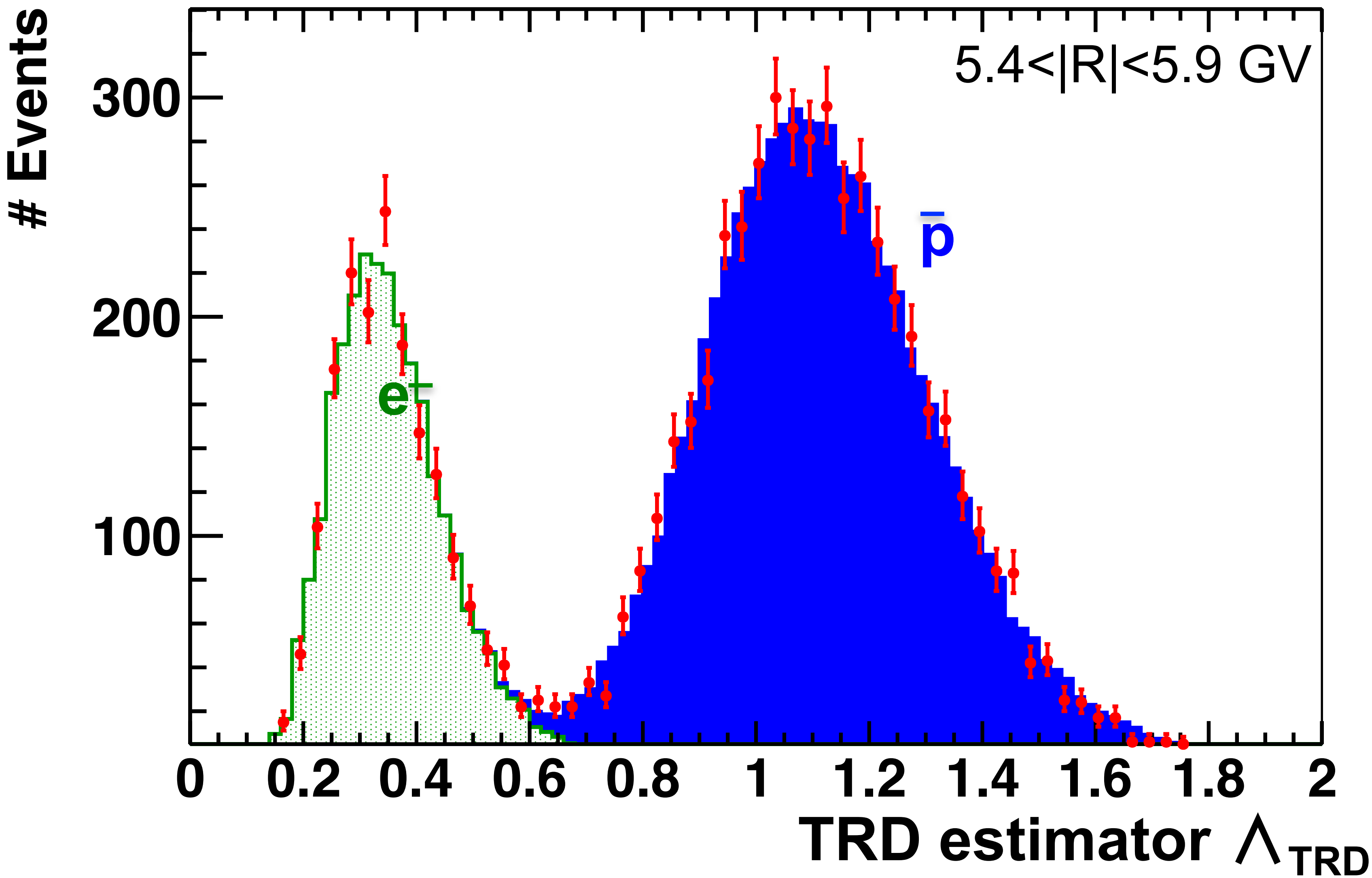


Antiprotons: χ + χ → p̄ + …
Antiproton /Proton Ratio × 10^-4
Kinetic Energy (GeV)
mχ= 1 TeV
Collisions of Cosmic Rays
Donato et al., PRL 102, 071301 (2009)
Sun
χ
e-, p, γ
e+,p̄, γ
χ̄

Anti-proton/proton ratio (PRL 117, 091103 - 2016)

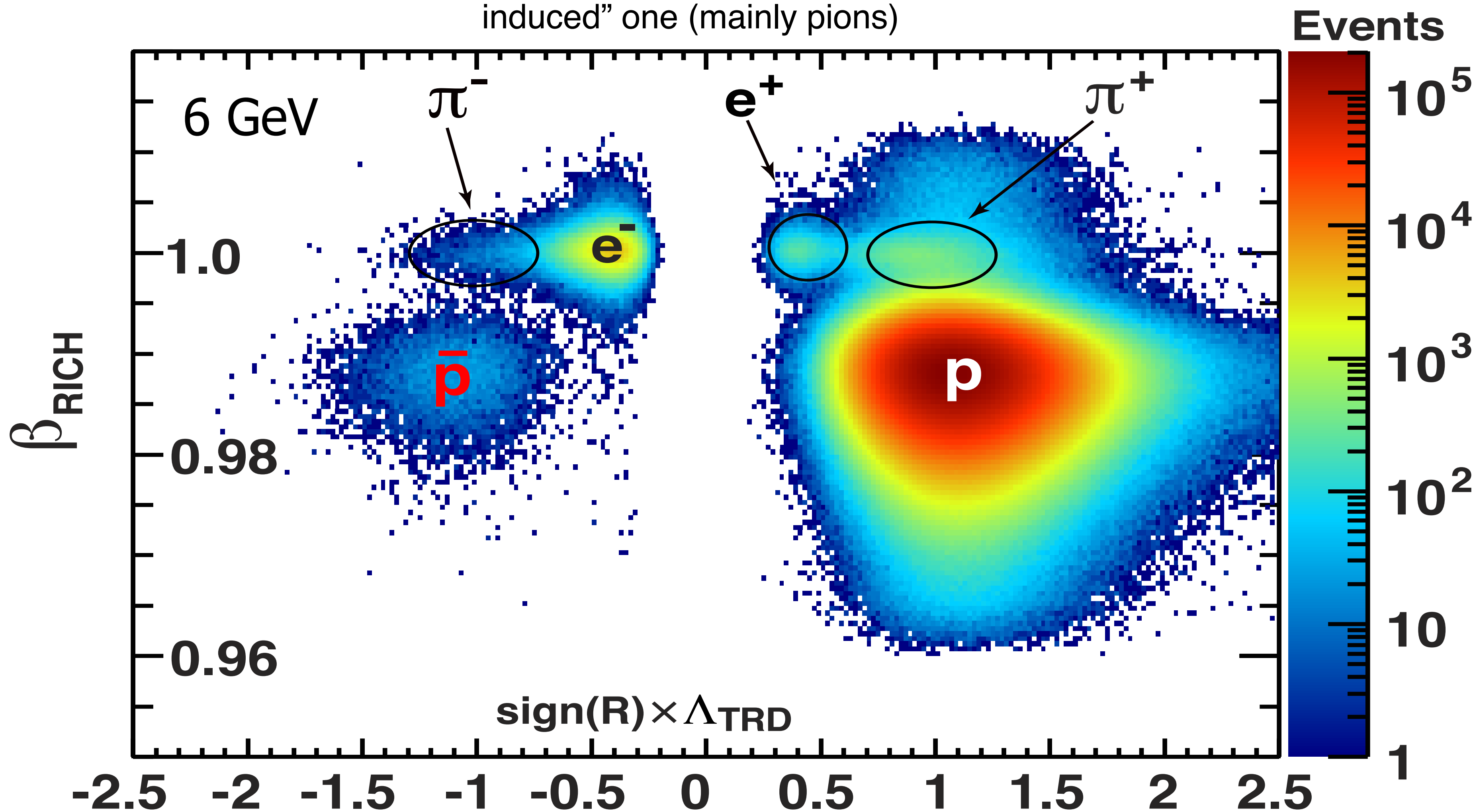


Antiproton identification at intermediate energies (10<R<100)



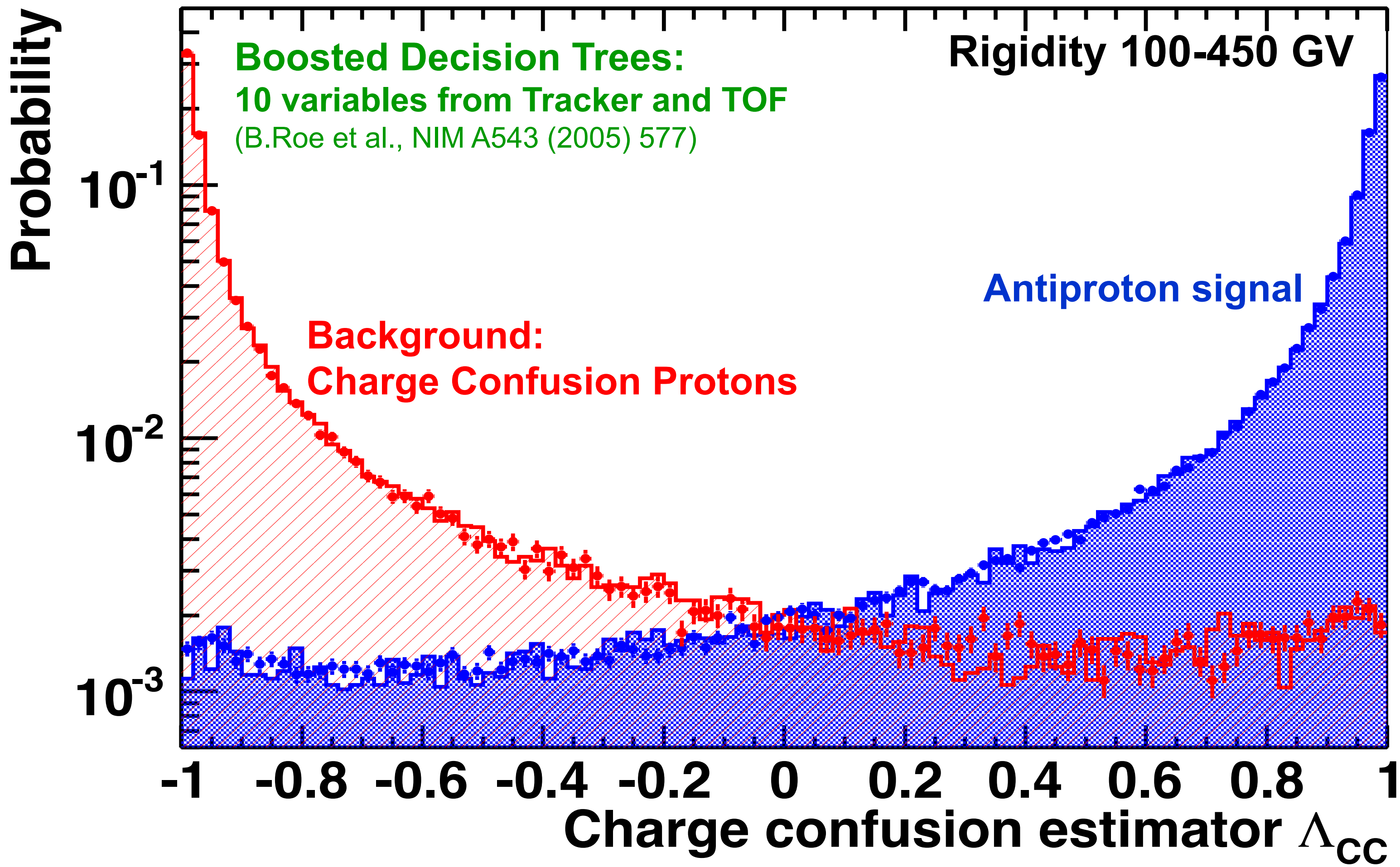
Antiproton identification at low energies (R<10)

We need to reject the "external" background as well as the "detector induced" one (mainly pions)



Antiproton identification at high energies (R>100)

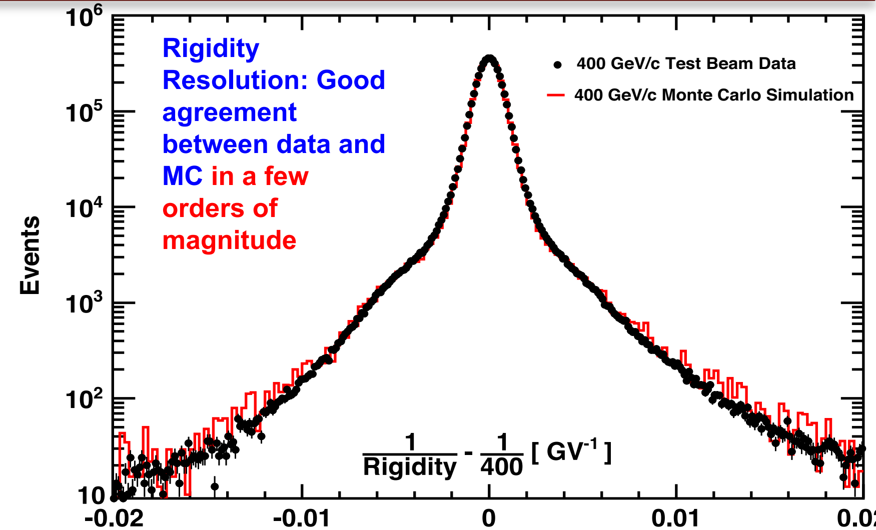
Also for antiprotons, looking at the energy deposits above the tracker and the "activity" below it, it's possible to identify the charge confused protons

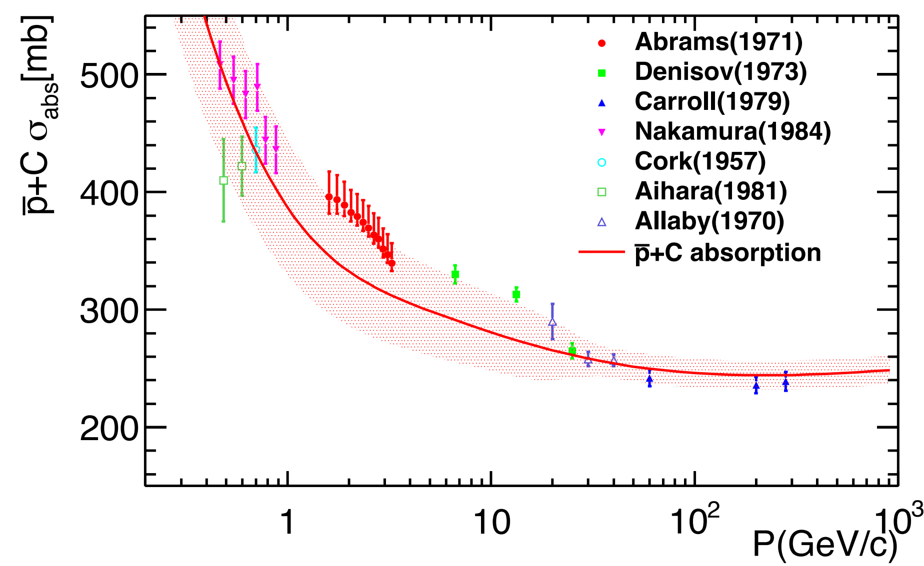


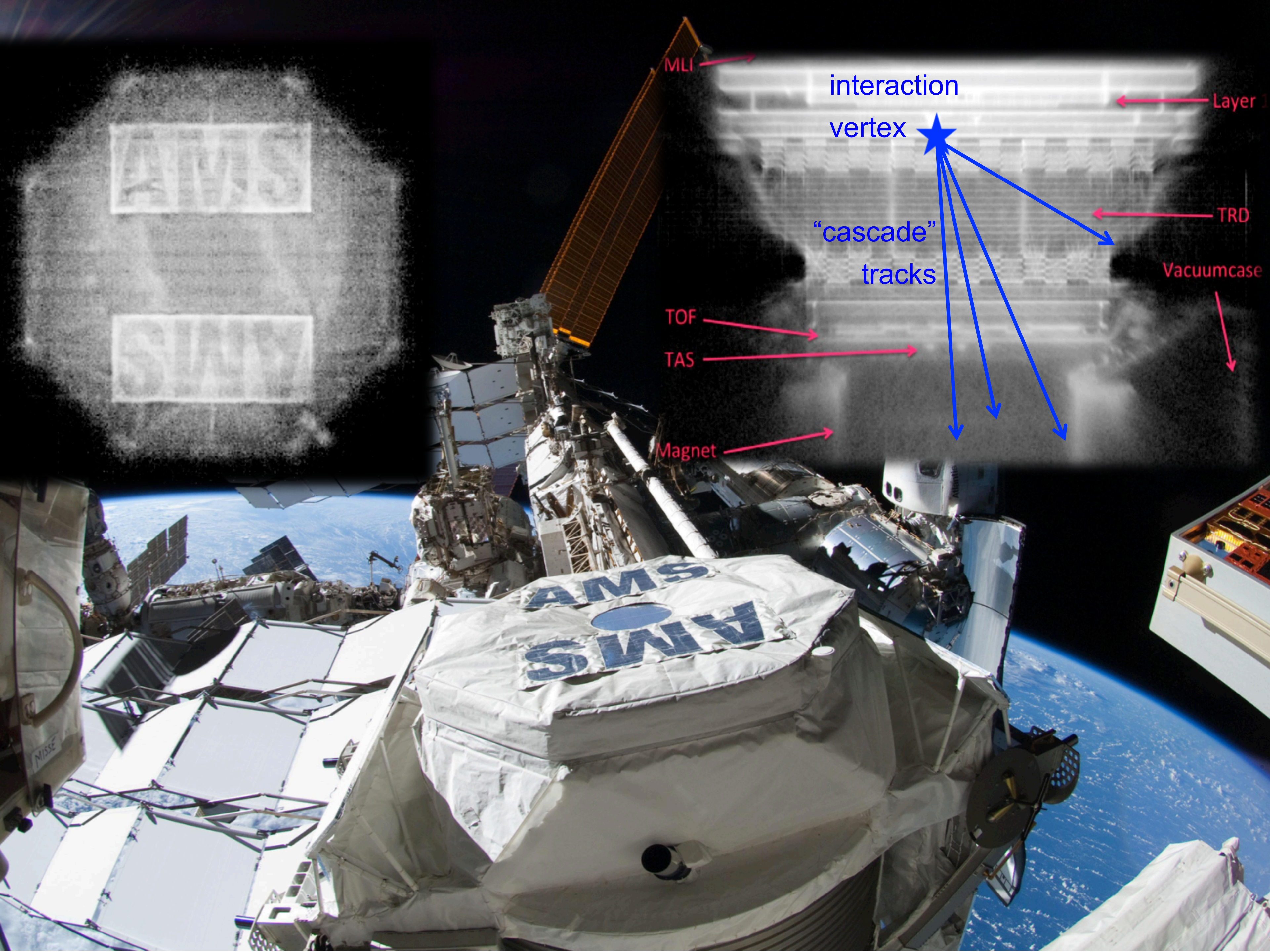
Antiproton systematics

- **Antiproton counting σ_N:**
  - Event selection
  - Knowledge of charge confusion
- **Acceptance, σ_A:**
  - **Cross sections**
  - Migration matrix
  - Small correction in normalization
- **Rigidity scale, σ_R:**
  - Affect positive and negative rigidity in opposite direction

From ~100GV, systematic errors are much smaller than statistic ones





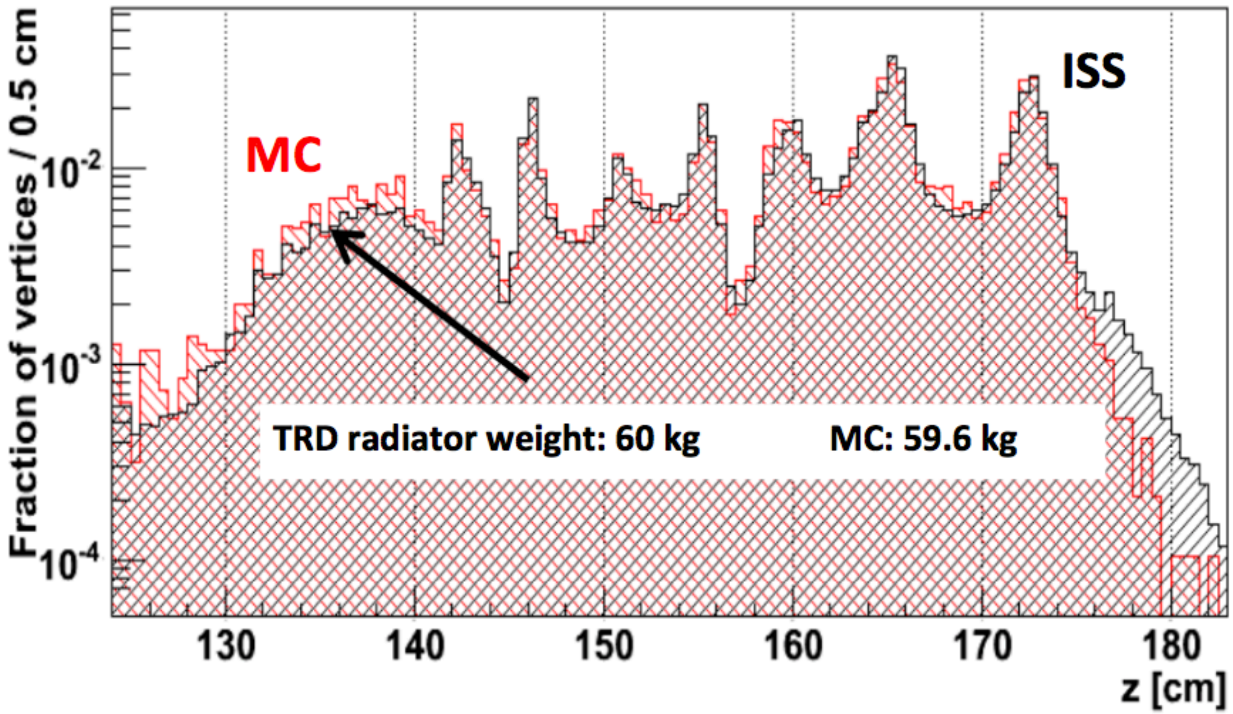

AMS
AMS
MLI
interaction
vertex
Layer
TRD
"cascade"
tracks
Vacuumcase
TOF
TAS
Magnet
AMS
AMS
MISSE

Interactions inside the detector

Effective Acceptance: $A_{eff}=A_{geom}\cdot \varepsilon_{sel}\cdot \varepsilon_{id}\cdot (1+\delta)$

- Estimated from MC
- Correction obtained based on efficiency measured from Data
- Systematic uncertainties: 2% ~ 3%

Example: Material distribution

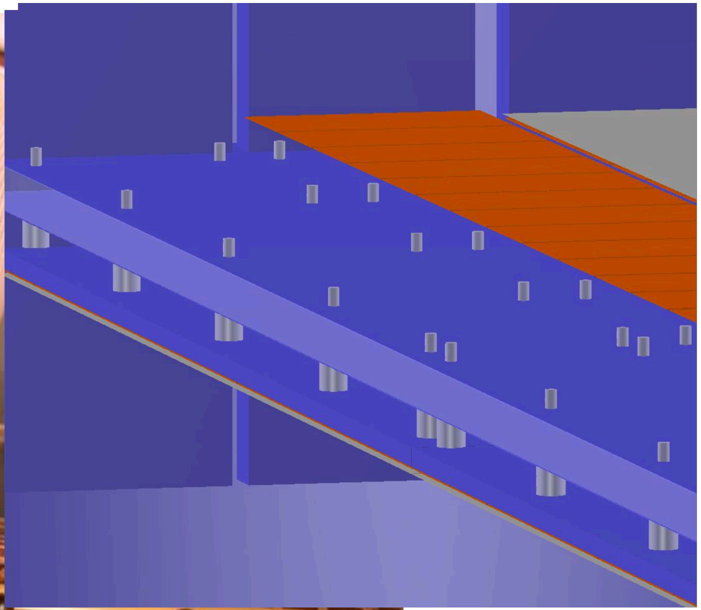


“details”…

Feet glued to silicon ladders

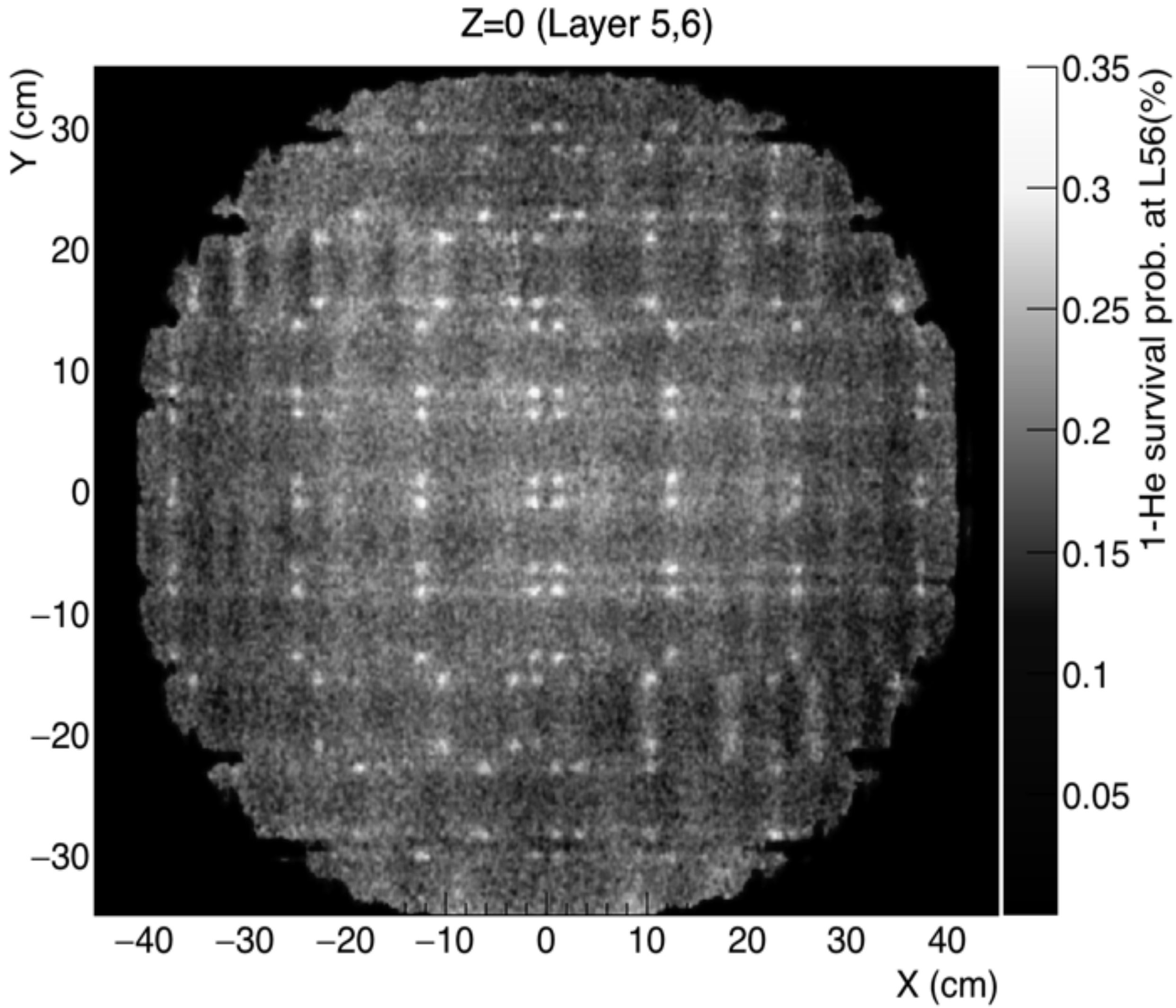
Example of ladder fixation

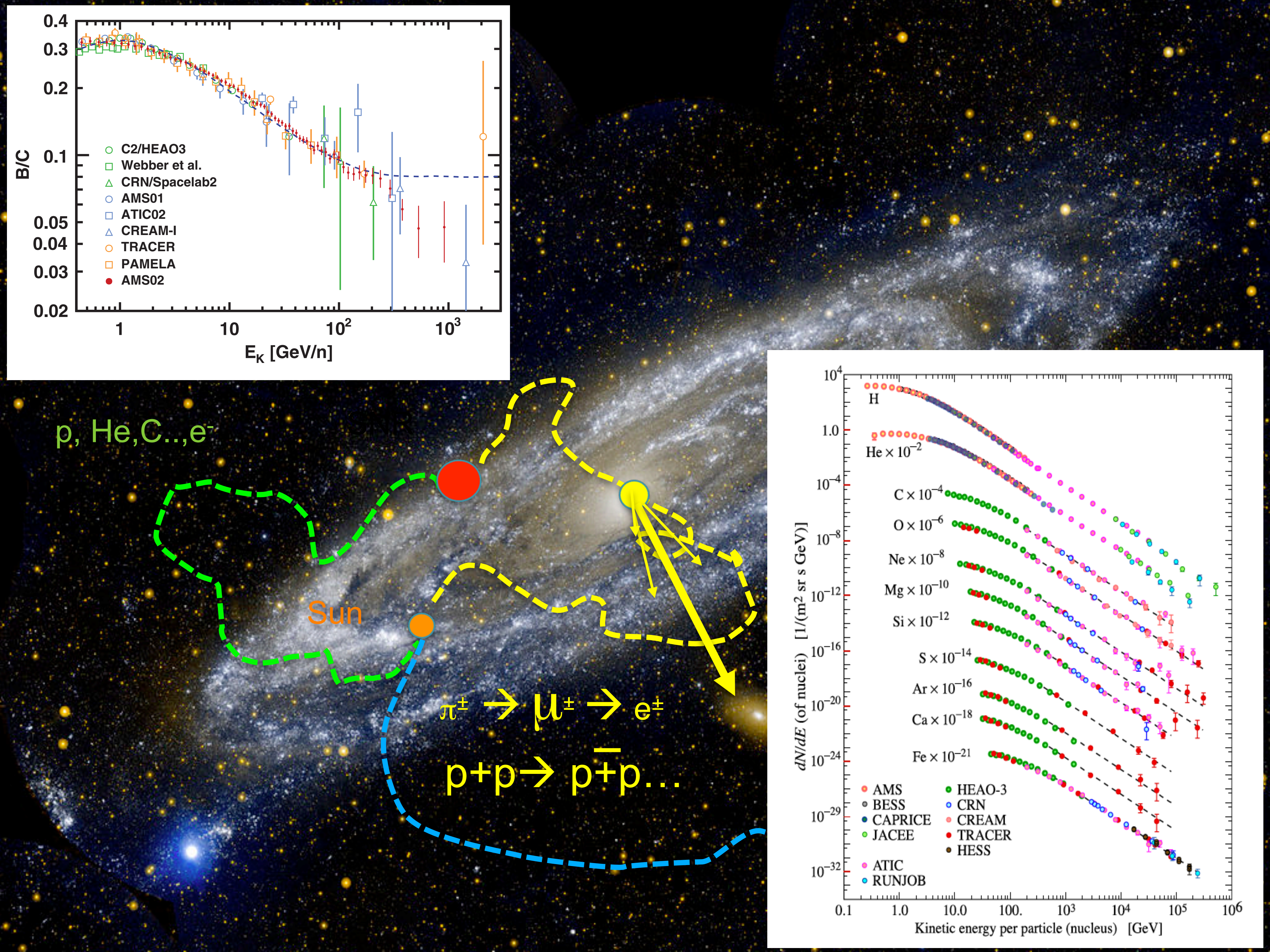
MC implementation



“X-ray” map of He interaction

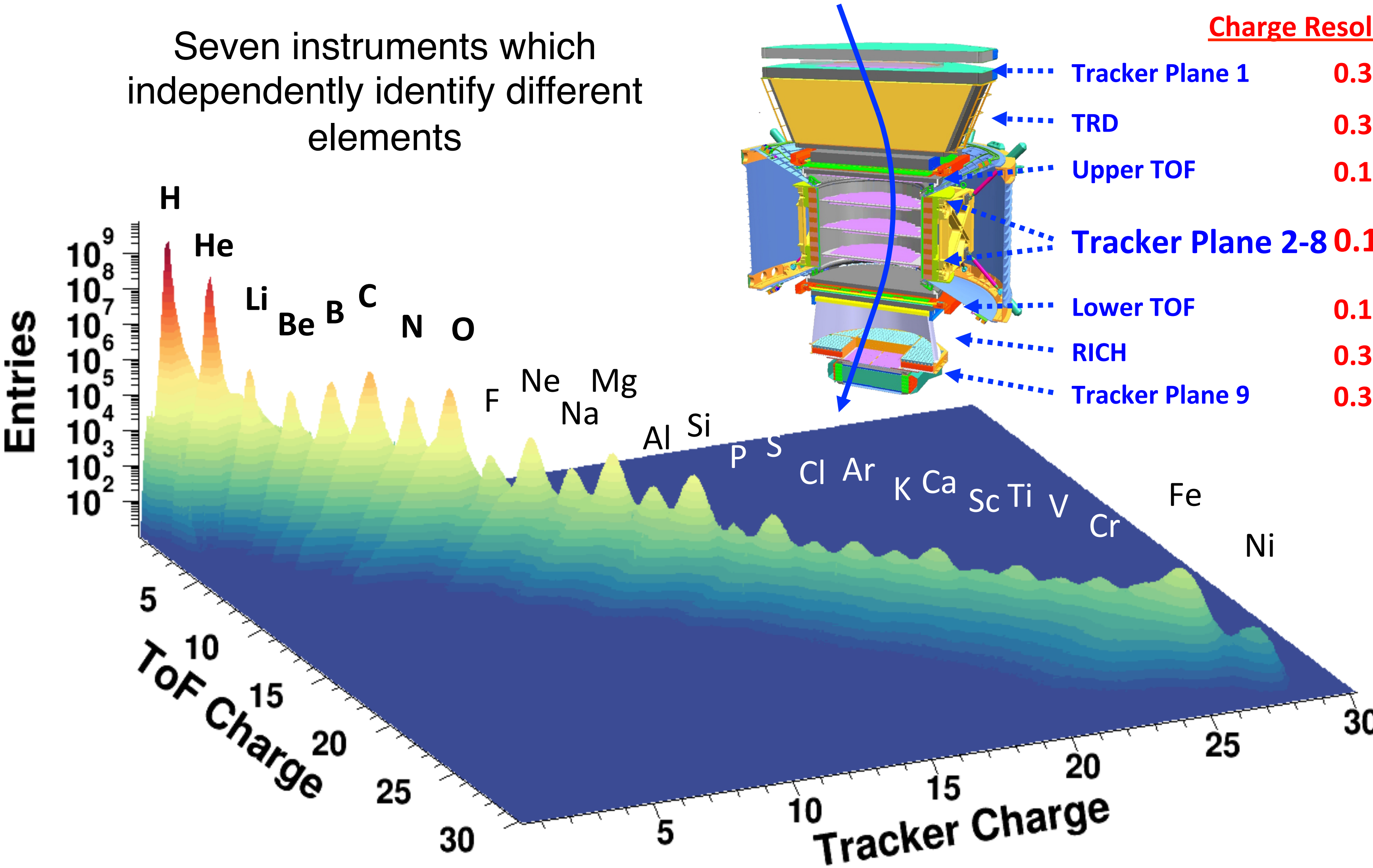
Not only looking for vertices but also looking for “missing particles: looking at the “flux”, as a function of the position *(X,Y)* in the detector one can search for “hot spots”. The position (X,Y) is obtained by the particle track and depends on *Z*: looking at different *Z* is like “focusing” the “x-ray” on a different plane.



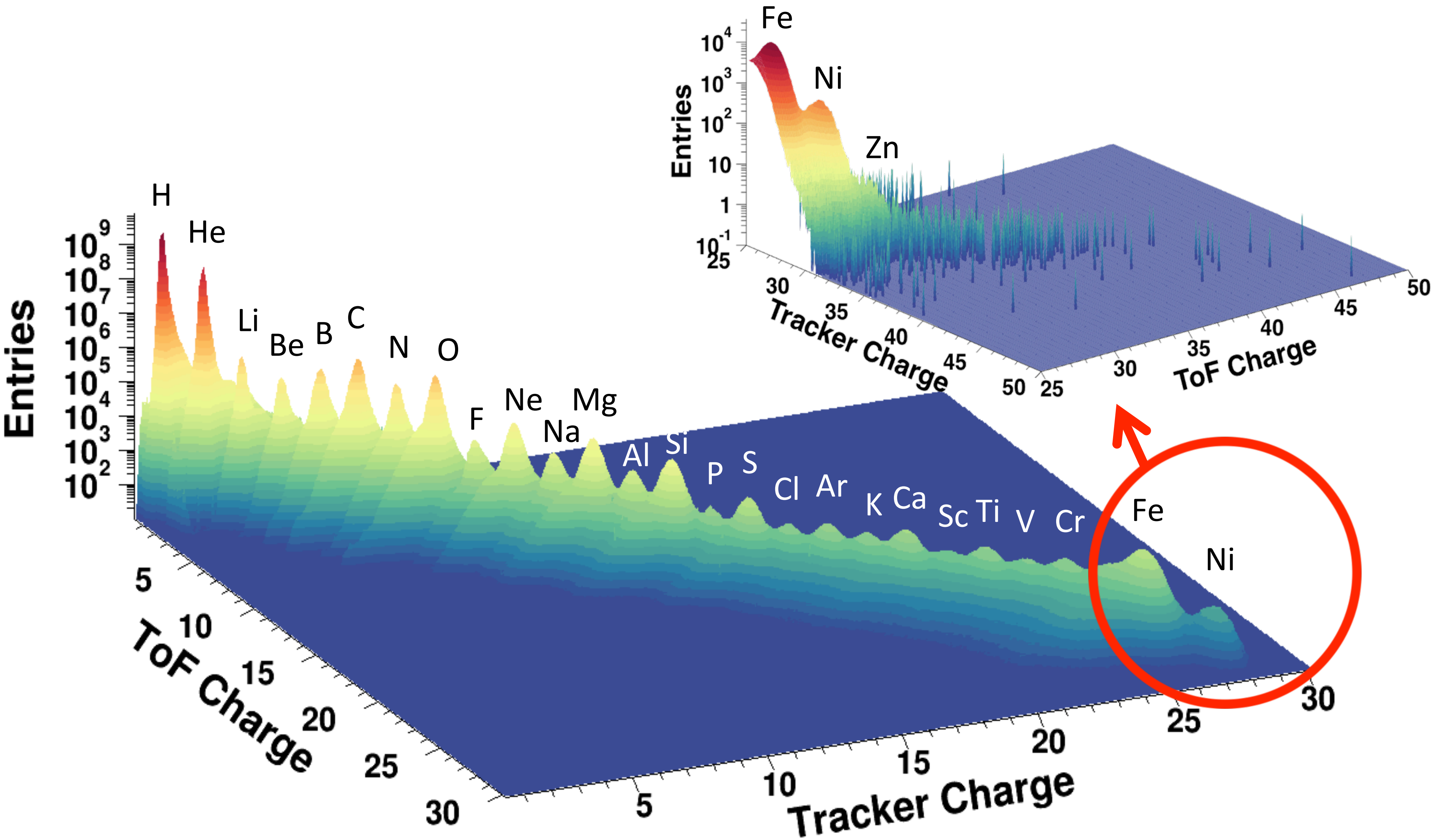

B/C
E_K [GeV/n]
C2/HEAO3
Webber et al.
CRN/Spacelab2
AMS01
ATIC02
CREAM-I
TRACER
PAMELA
AMS02
p, He,C..,e-
Sun
π± → μ± → e±
p+p→ p p̄ p…
dN/dE (of nuclei) [1/(m2 sr s GeV)]
Kinetic energy per particle (nucleus) [GeV]
H
He × 10−2
C × 10−4
O × 10−6
Ne × 10−8
Mg × 10−10
Si × 10−12
S × 10−14
Ar × 10−16
Ca × 10−18
Fe × 10−21
AMS
BESS
CAPRICE
JACEE
HEAO-3
CRN
CREAM
TRACER
HESS
ATIC
RUNJOB

Nuclear identification

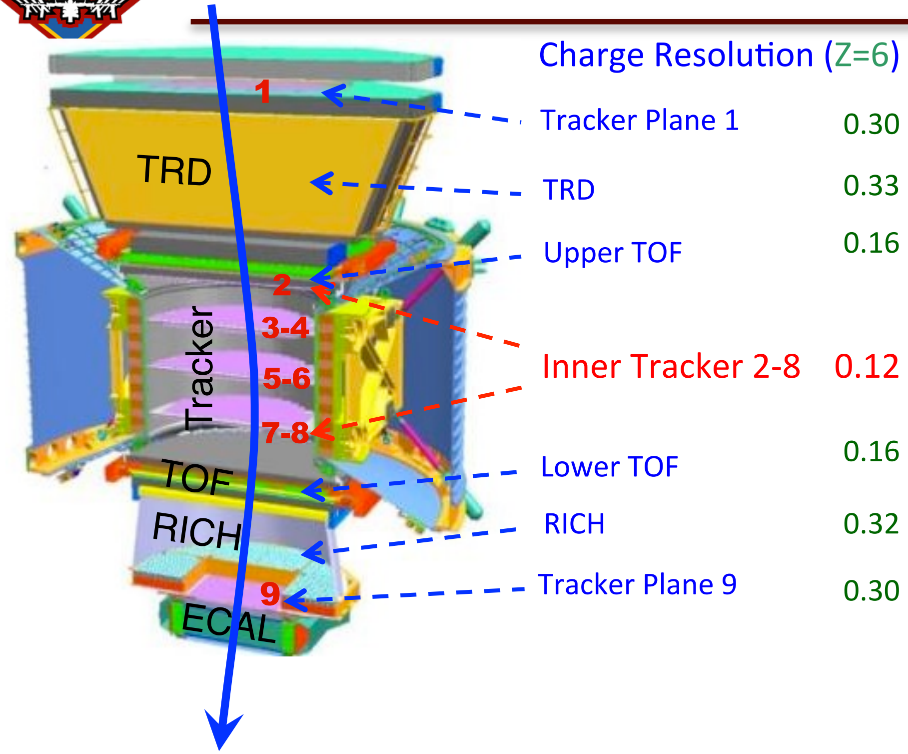
Seven instruments which independently identify different elements

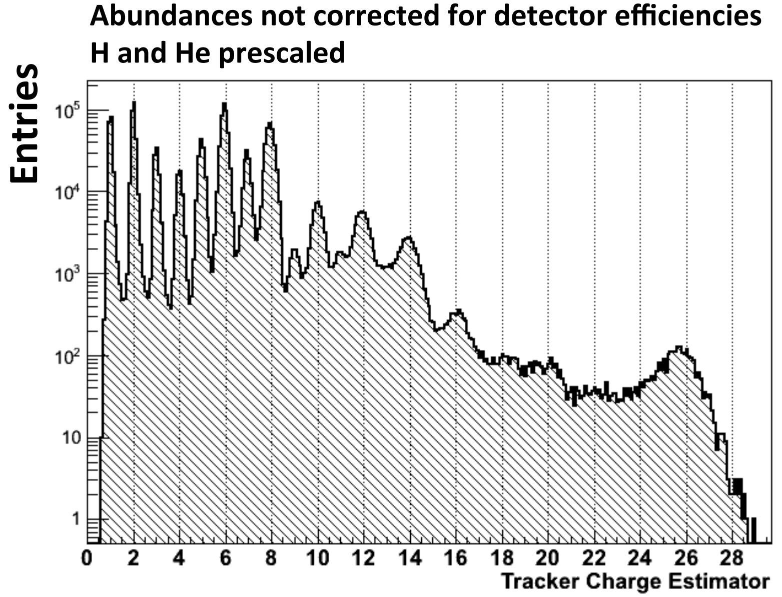


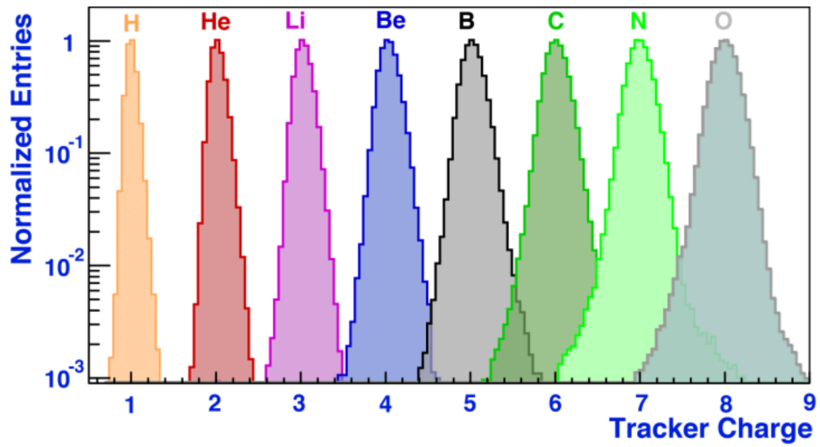
… even beyond Iron!



Silicon tracker







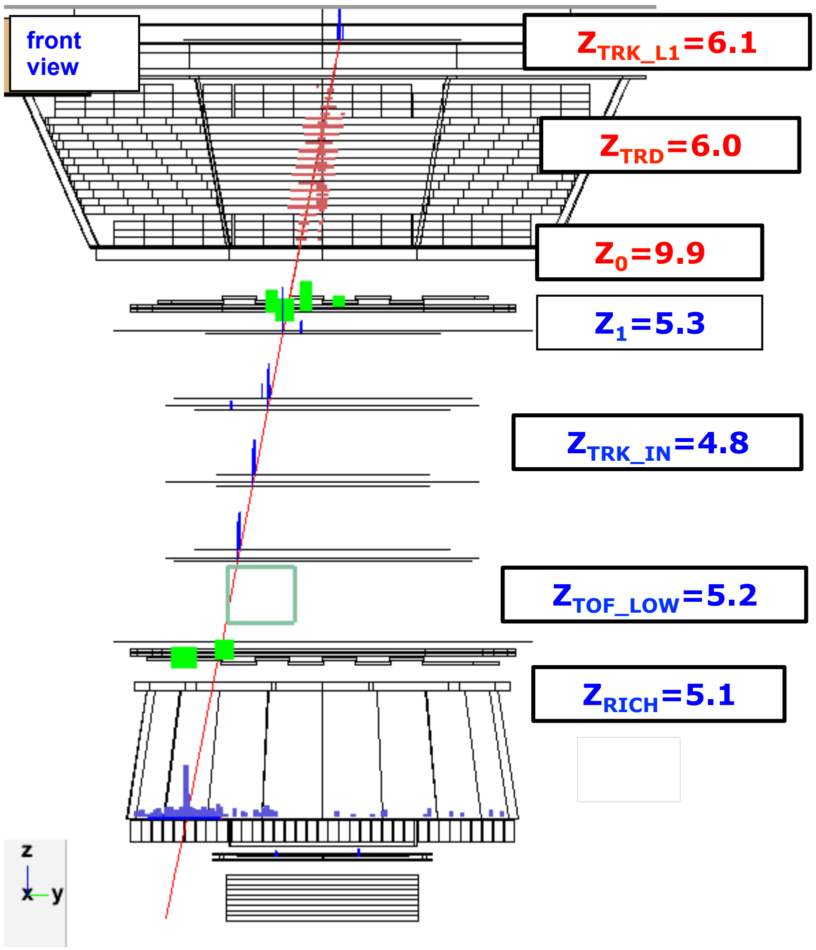
Thanks the High Dynamic Range of the Front End electronics, the Silicon Tracker has a very accurate charge resolution

→ ~ 0.3 c.u. for a single layer

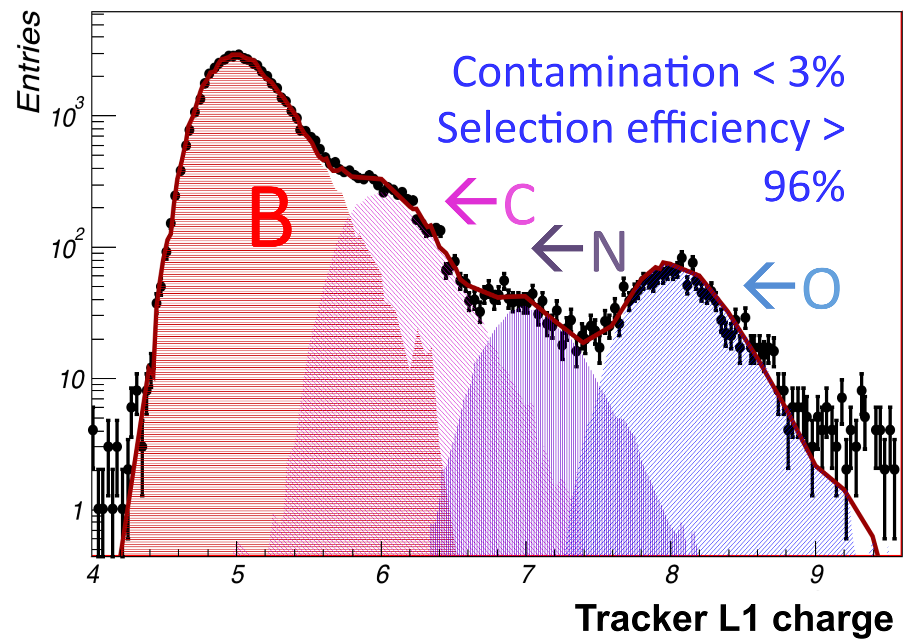
→ ~ 0.1 c.u. combining 7 layers

Control of fragmentation inside the detector

Carbon Fragmentation to Boron R = 10.6 GV



For all the nuclear species, AMS-02 can measure, directly from data, the fraction of the 'flux' coming from the fragmentation of heavier species

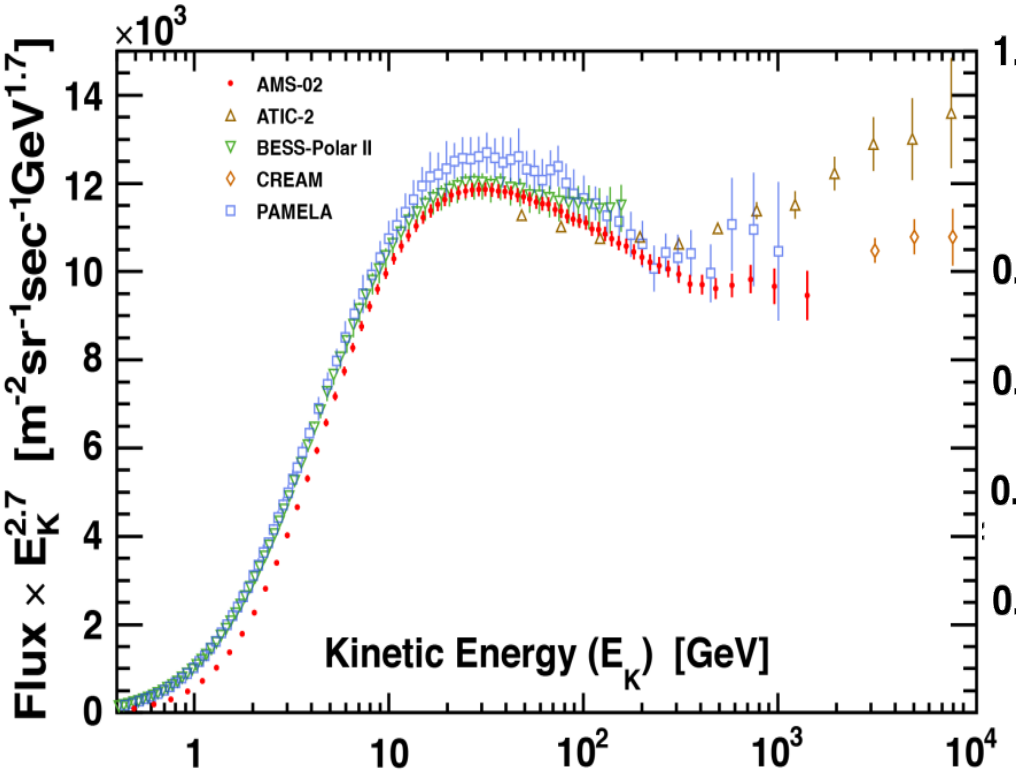


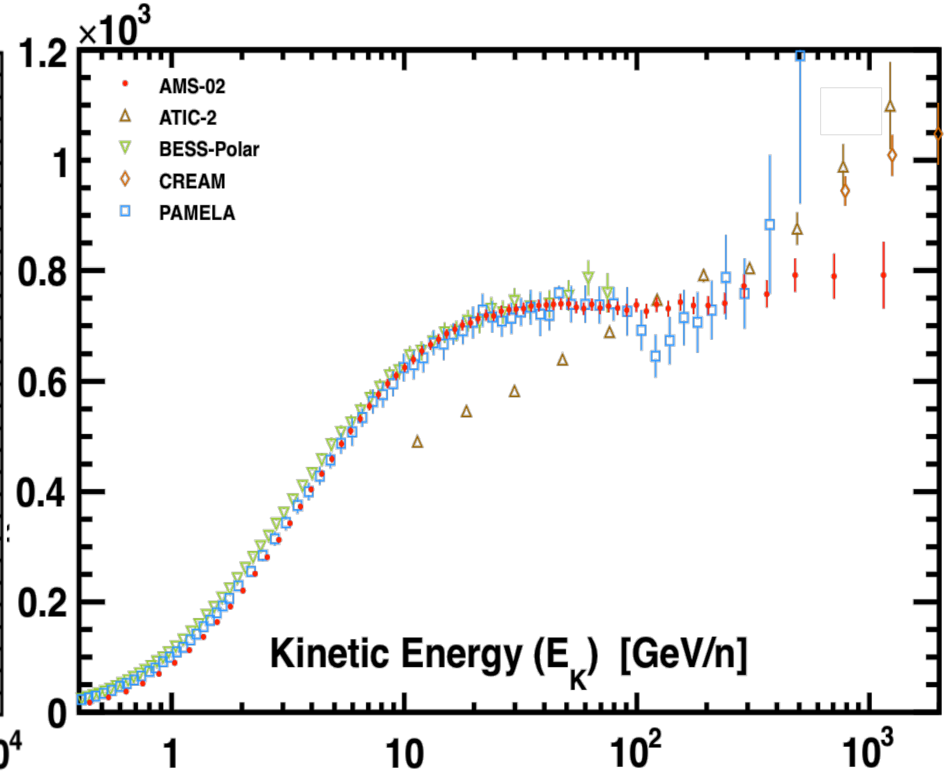
Proton and Helium fluxes (PRL 114, 171103 & 115, 211101 – 2015)

Both proton and helium fluxes show an hardening

H flux measurement:
300 million events

He flux measurement:
50 million events

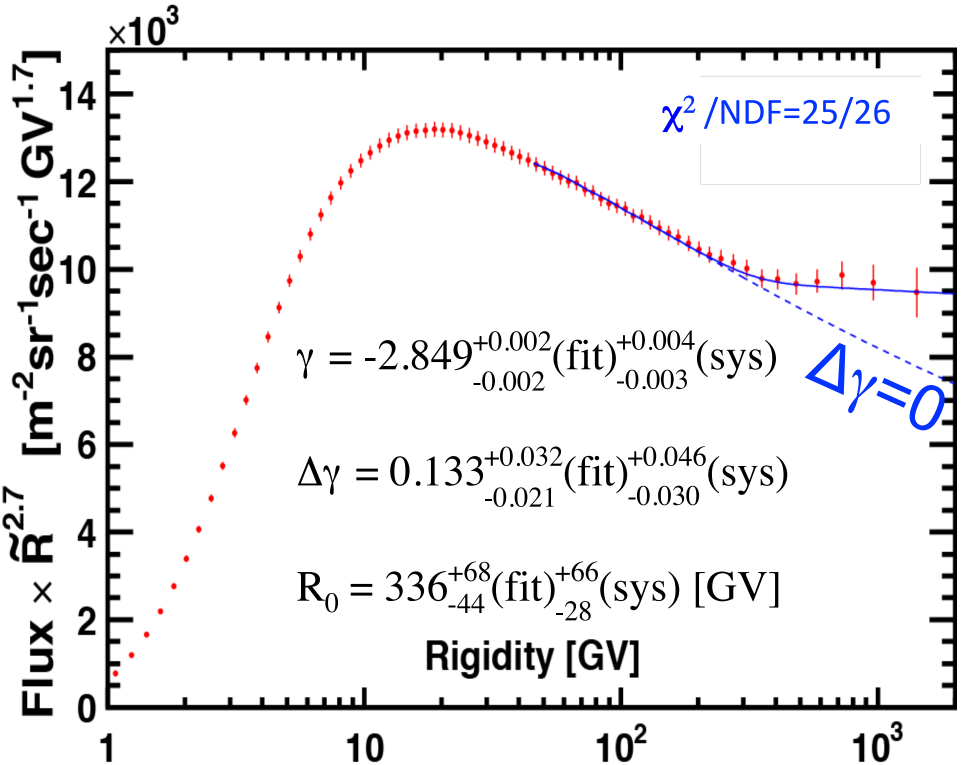


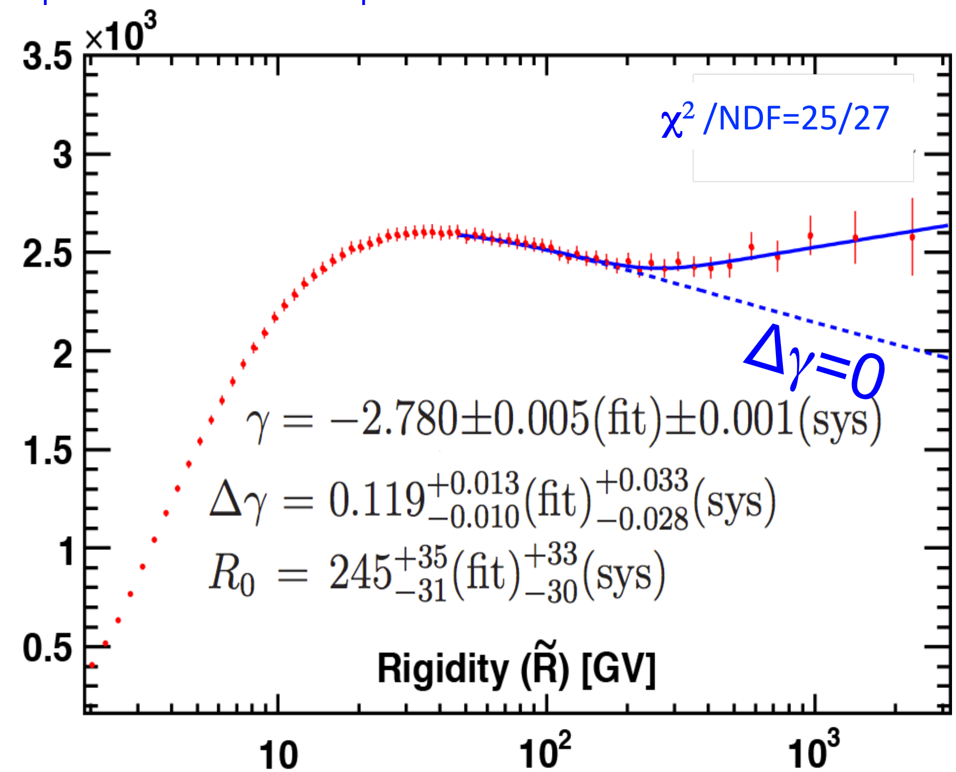


Proton and Helium fluxes (PRL 114, 171103 & 115, 211101 – 2015)

Two power-laws $R^{\gamma}, R^{\gamma+1}$ with a transition rigidity R_0 and a *smoothness* parameters: this well describe the experimental data:

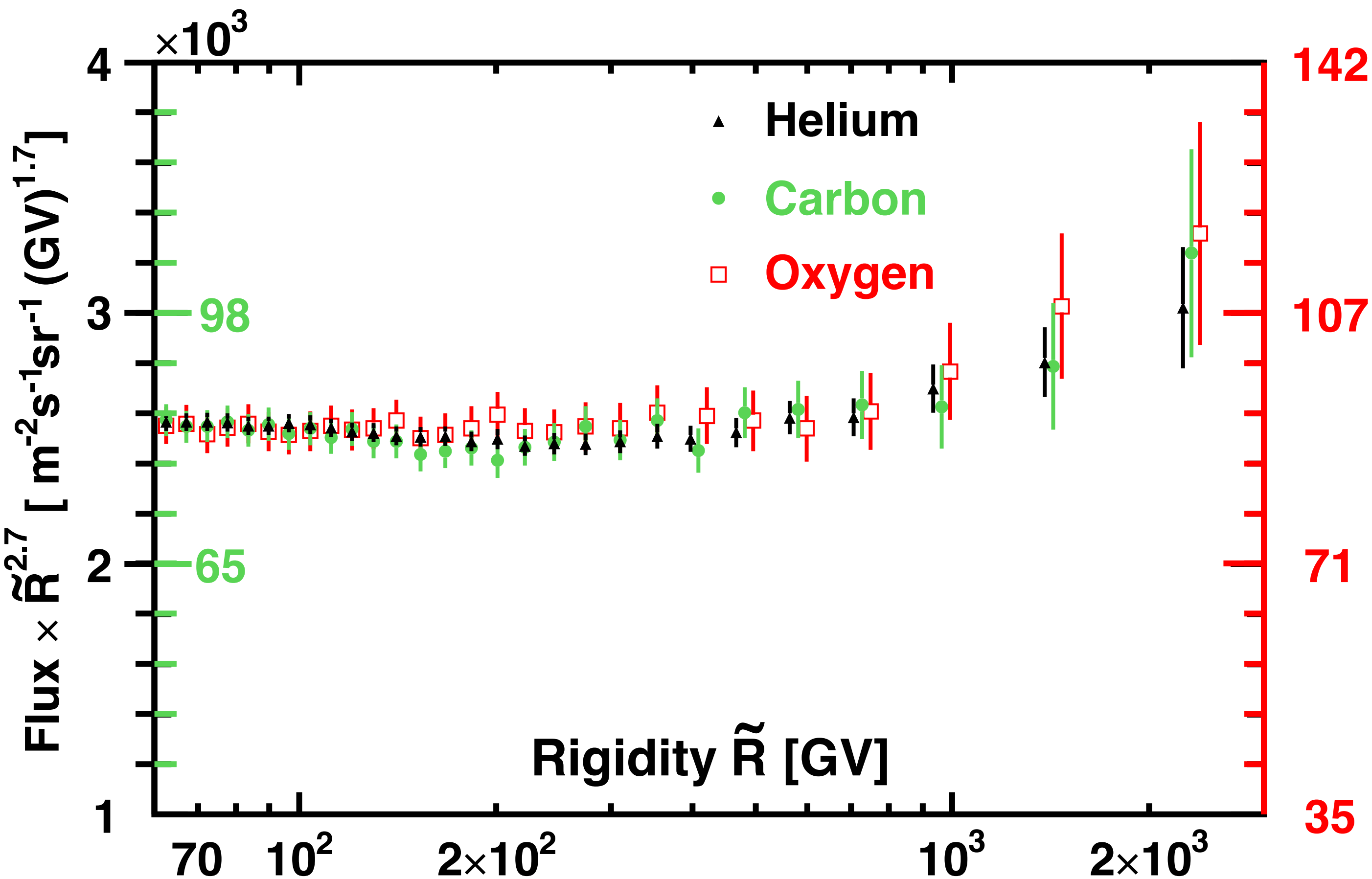
$$\Phi = C\left(\frac{R}{45GV}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$$





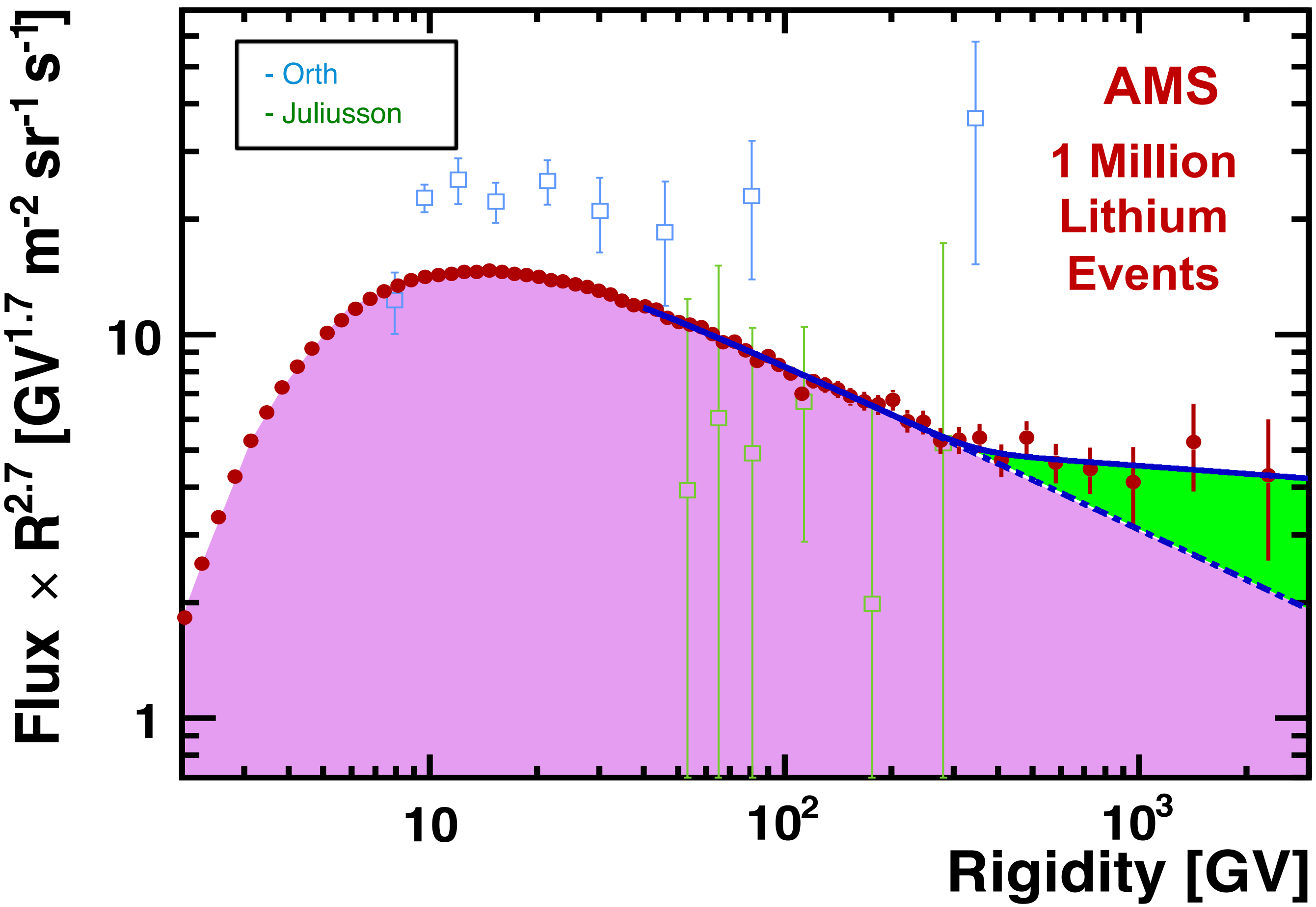
Primaries… (accepted on PRL)

Also for Carbon and Oxygen the single-power law behavior is excluded by AMS-02 data: a change of spectral index is observed at ≈ the same rigidity.



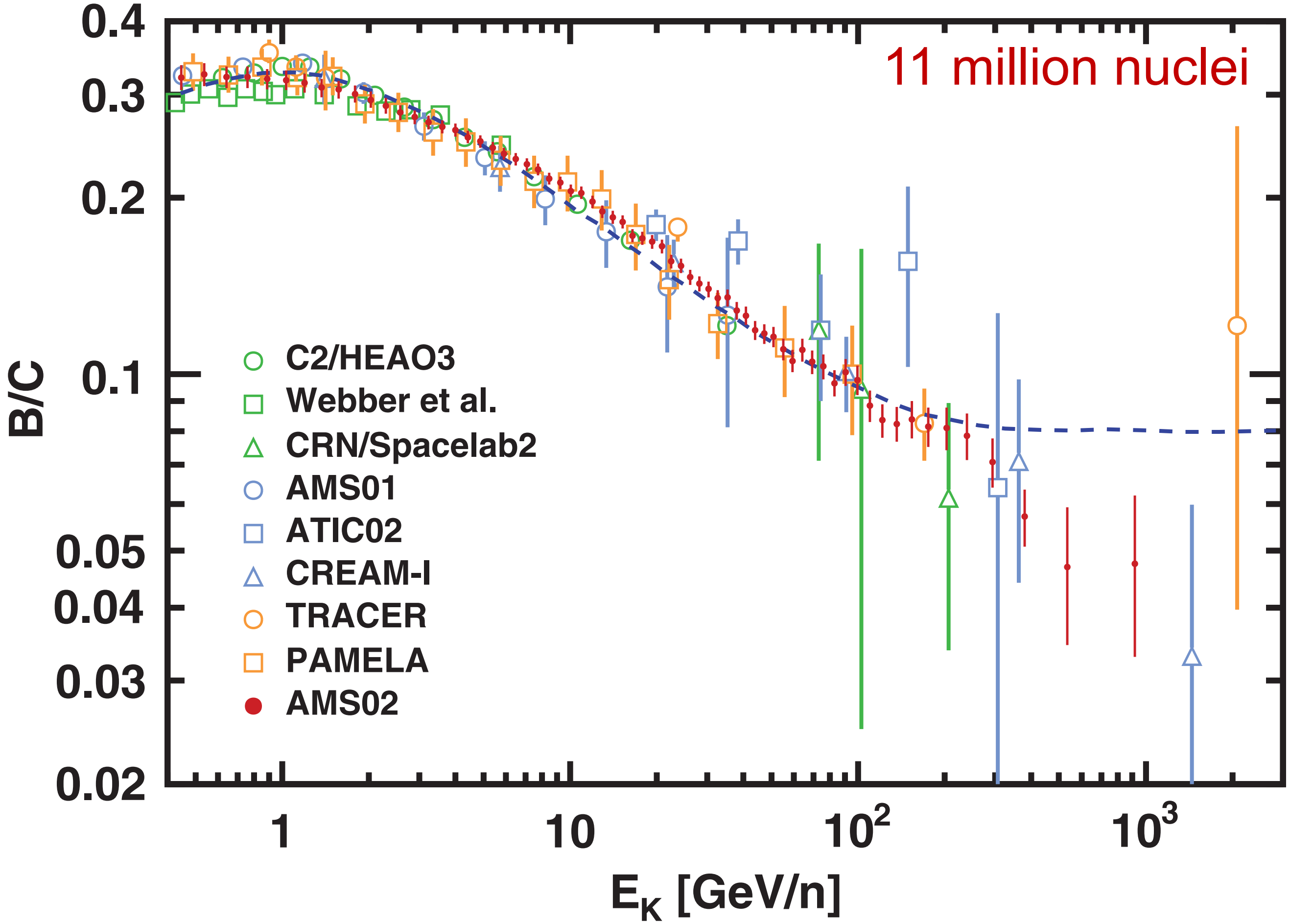
…and secondaries… (submitted to PRL)

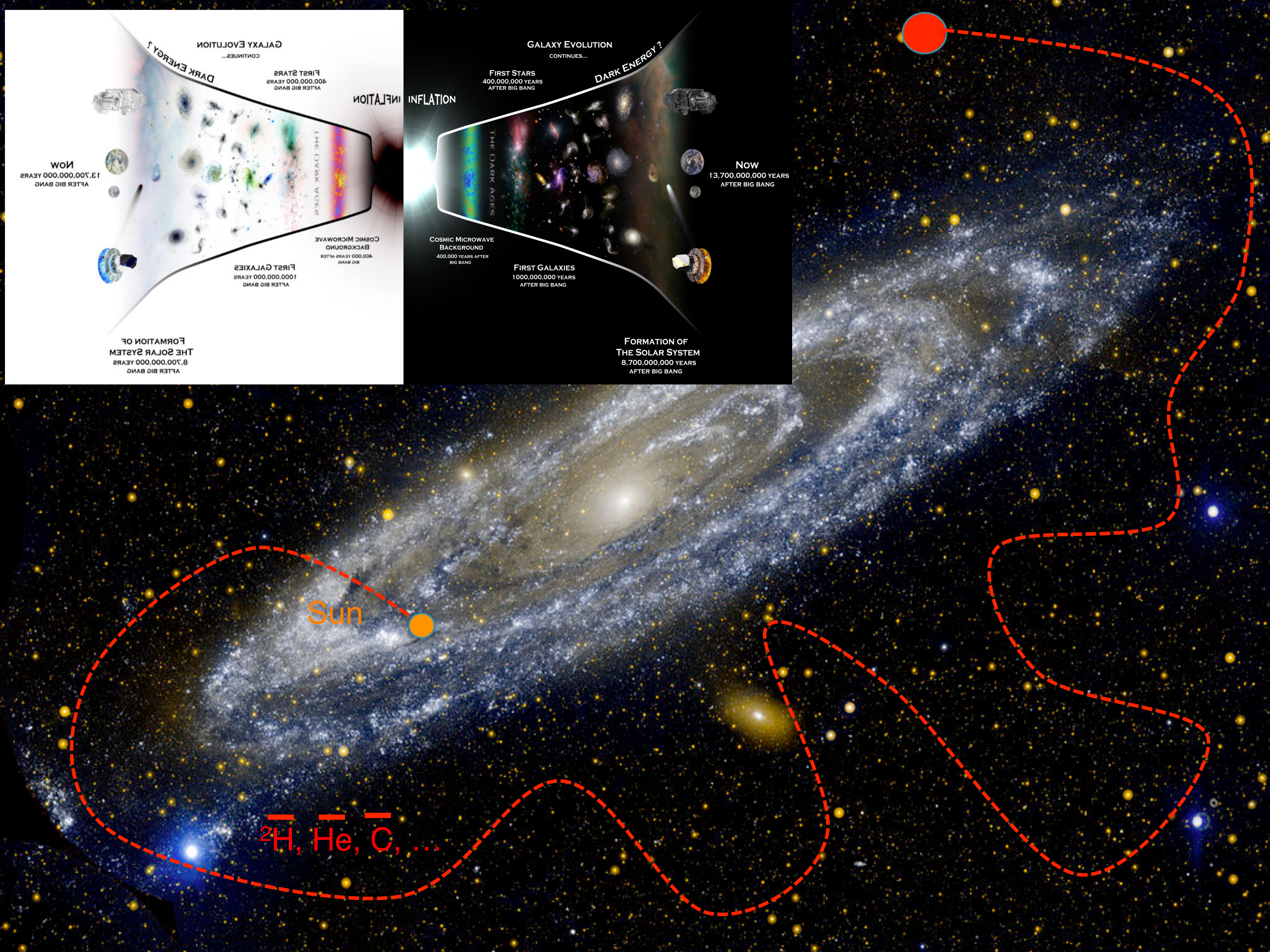
Lithium (secondary) exhibits a double power law behavior as for the primaries



Secondary CRs: Boron to Carbon flux ratio (PRL 117, 231101 – 2016)

The flux ratio between primaries (C) and secondaries (B) provides information on propagation and the ISM

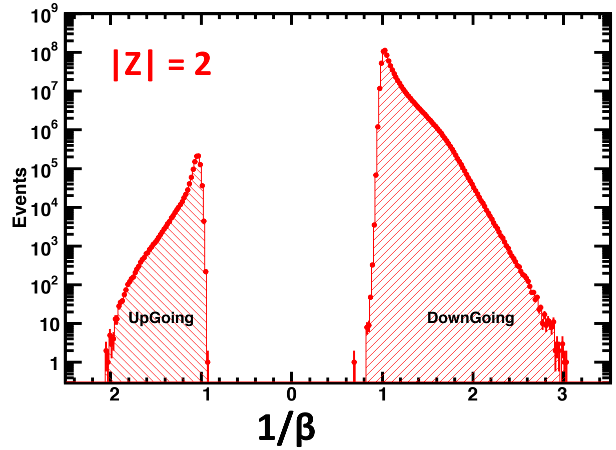




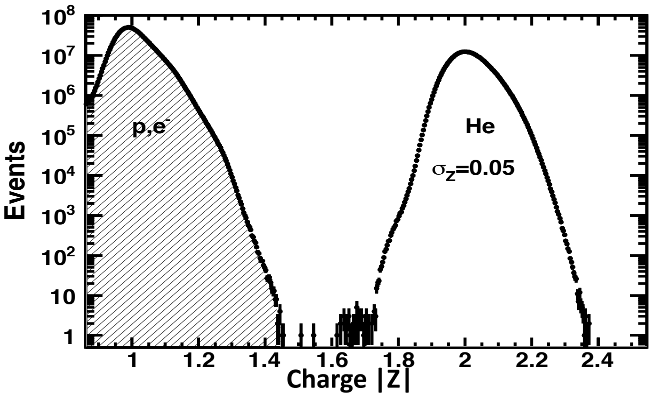
INFLATION
Galaxy Evolution
continues...
First Stars
400,000,000 years
after big bang
Dark Energy ?
The Dark Ages
Now
13,700,000,000 years
after big bang
Cosmic Microwave
Background
400,000 years after
big bang
First Galaxies
1000,000,000 years
after big bang
Formation of
The Solar System
8,700,000,000 years
after big bang
Sun
$\overline{^{2}H}$, $\overline{He}$, $\overline{C}$, ...

Identification of anti-helium

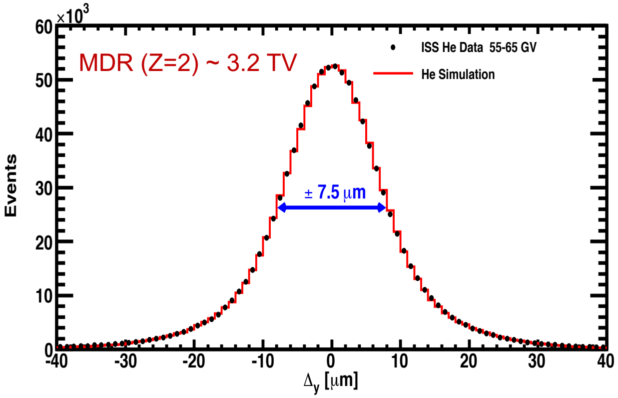
1. Determine direction with TOF.



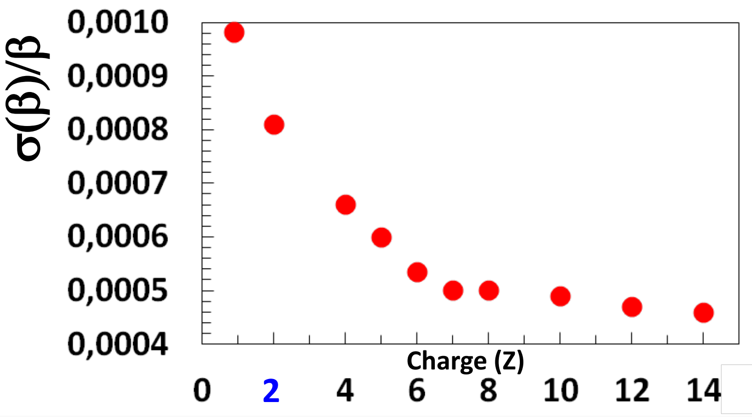
2. To measure |Z|, use the TOF+Tracker+RICH to separate p,e$^{\pm}$ from He



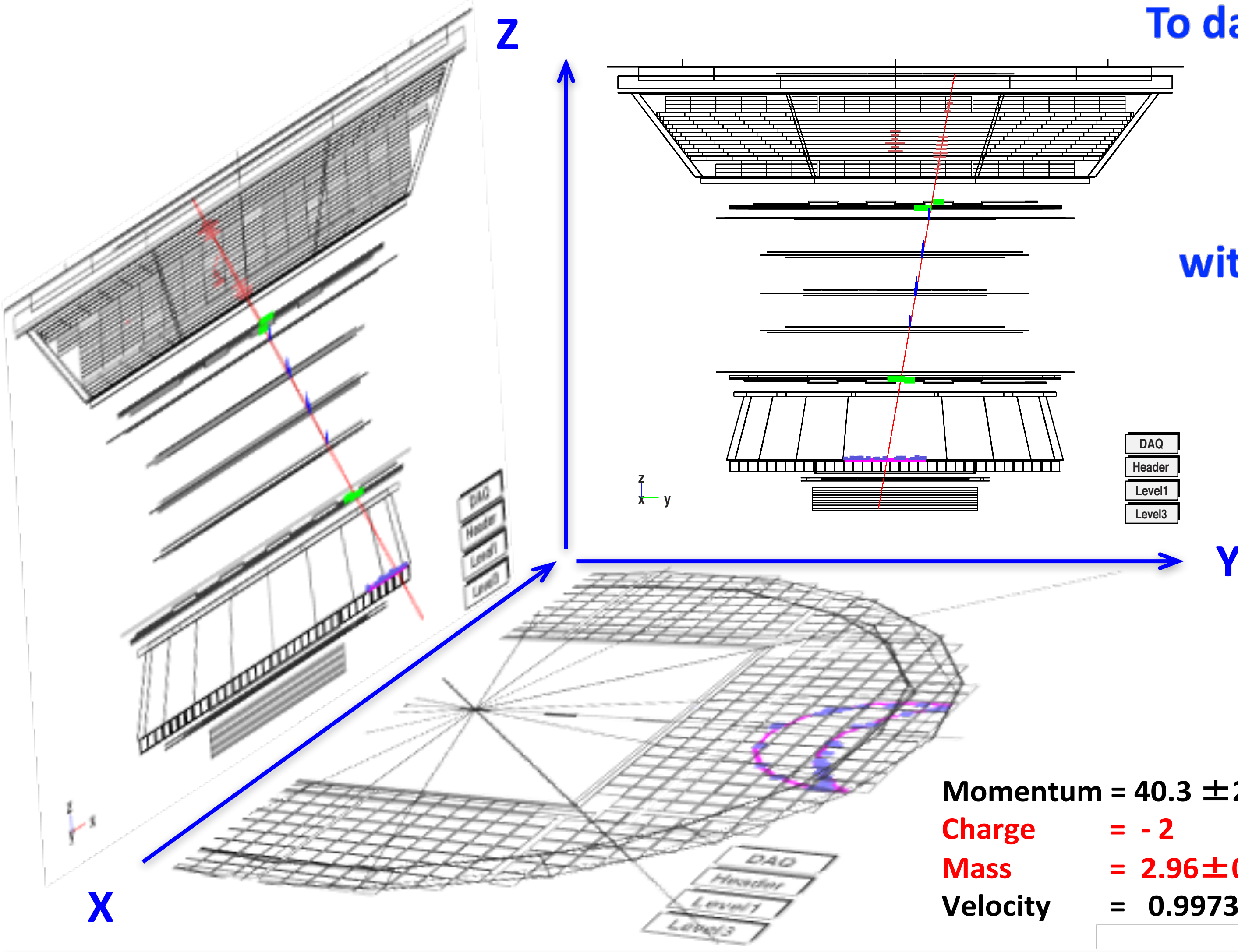
3. To measure momentum and sign of the charge, use Tracker



4. To determine mass, use the RICH to measure the velocity.



An anti-helium candidate



To date we have observed a few events with Z = -2 and with mass around ^{3}He.

Momentum = 40.3 ±2.9 GeV/*c*
Charge = - 2
Mass = 2.96±0.33 GeV/c^2
Velocity = 0.9973±0.0005 *c*

CPU effort…

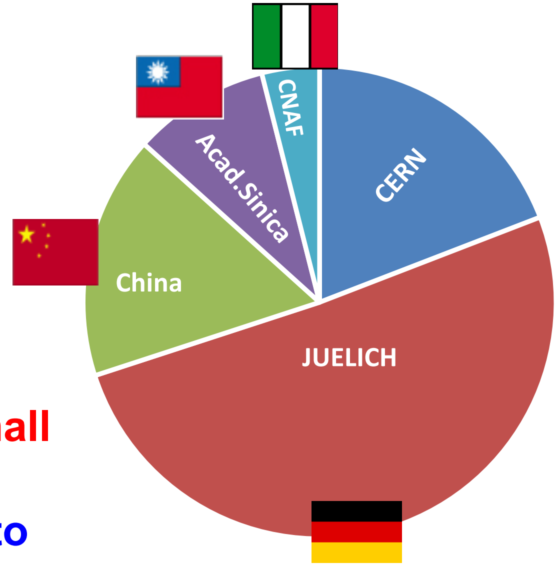
At a signal to background ratio of one in one billion, detailed understanding of the instrument is required.

Detector verification is difficult.

1. The magnetic field cannot be changed.

2. The rate is ~1 per year.

3. Simulation studies:



Helium simulation to date:
2.2 million CPU-Days =
35 billion simulated helium events:
Monte Carlo study shows the background is small

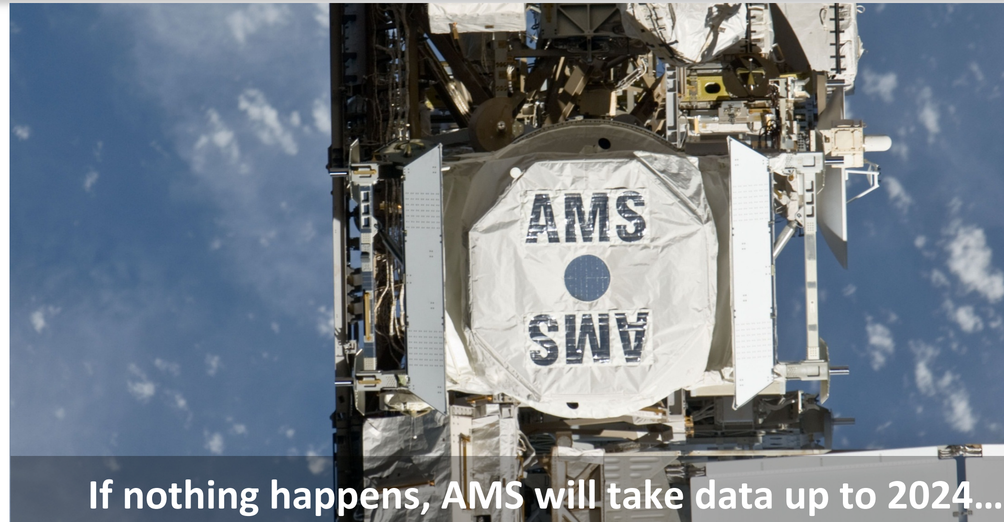
How to ensure that the simulation is accurate to one in one billion?

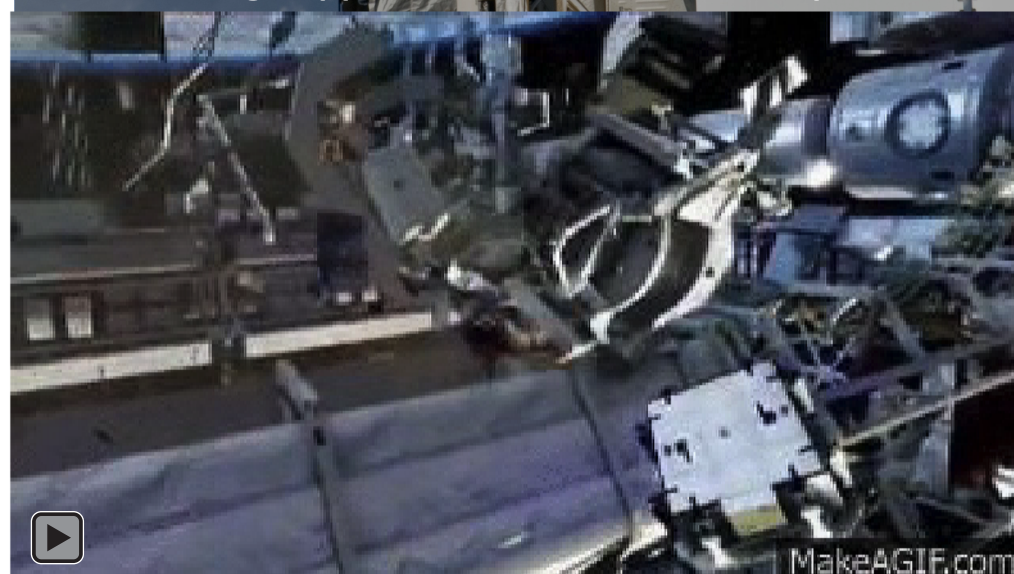
The few events have mass 2.8 GeV and charge -2 like $^{3}\overline{He}$.
Their existence has fundamental implication in physics.

…stay tuned but it will take a while…

Conclusions

- **AMS is the Cosmic Rays observatory and it will stay also in next decade**
- **The collaboration is providing the absolute and relative abundances of the various species**
- **The accuracy of the experimental measurements is currently better than the uncertainty in the phenomenological models and is allowing very detailed studies**

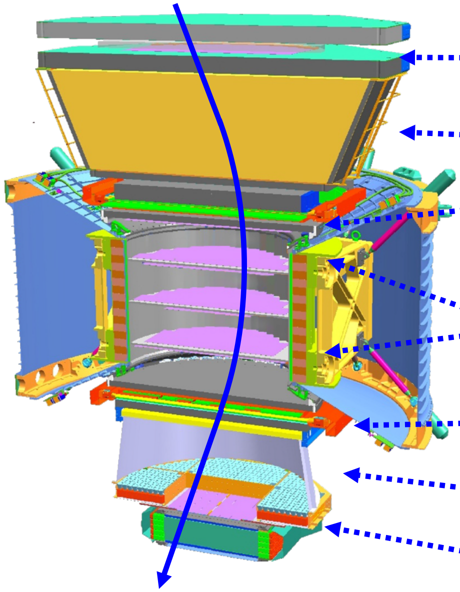




Backup

AntiHe analysis

In five years, 3.7 billion helium events have been collected by AMS when both the Upper and Lower TOF measure |Z| = 2 with an accuracy of 0.08



Of these, 100 million passed through the full lever arm (L1 to L9) and are used in the analysis of the helium spectrum.

In our helium publication we used the first 2.5 years of data (50 million events).

In searching for antihelium we use a larger acceptance (L2 to L8) with 700 million helium events to date.

To date we have observed

a few events

with Z = -2 and

with mass around ^{3}He.

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,†]

Predicted $\overline{He}$/He ratio

produced by ordinary cosmic rays :

$^{3}\overline{He}$/He[16-60]GeV/c = 6 X 10^{-12}

$^{4}\overline{He}$/He[16-60]GeV/c < 5 X 10^{-17}

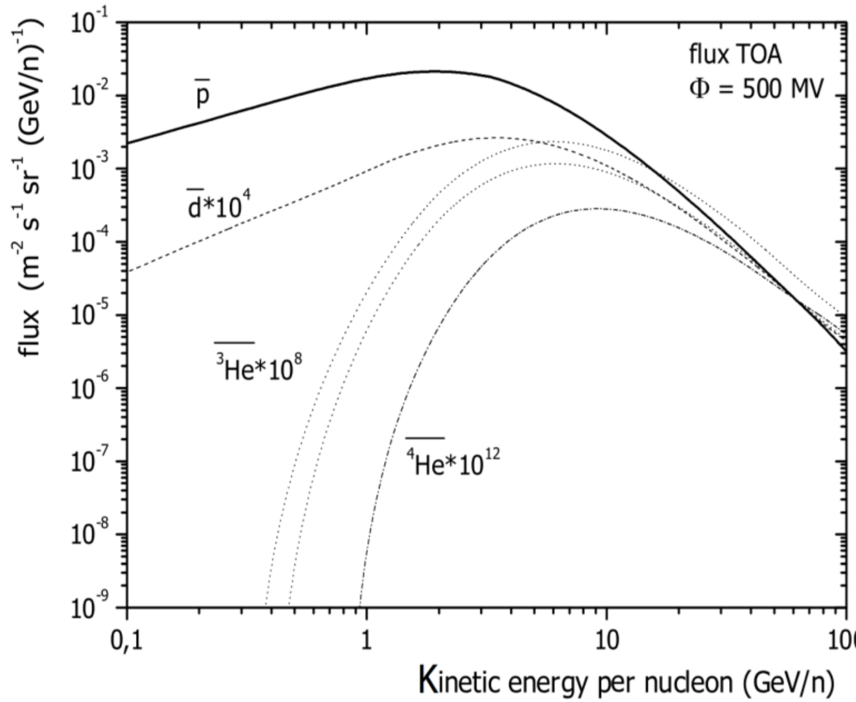
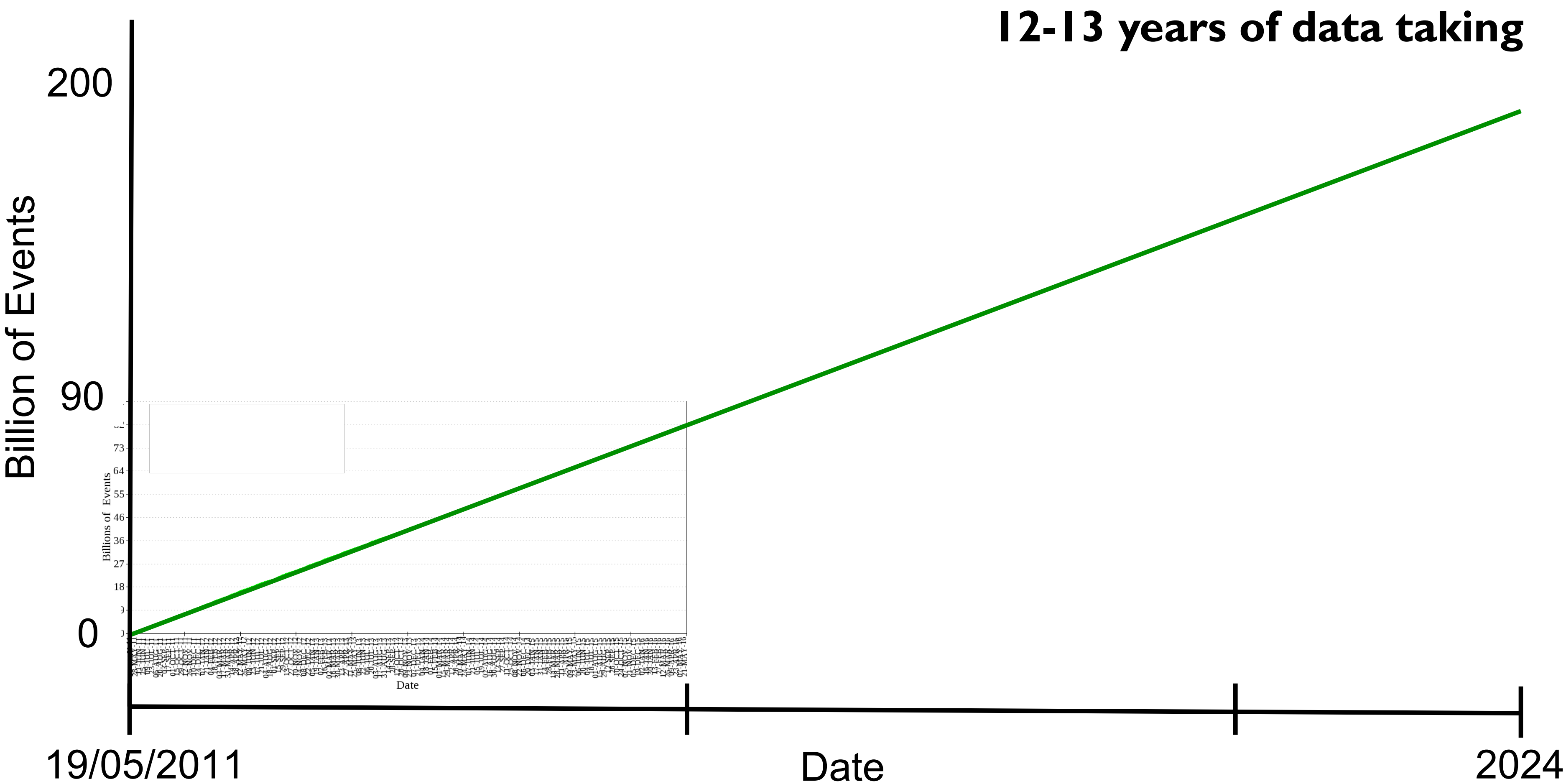


FIG. 15. Galactic flux for $\bar{p}$ (solid line), $\bar{d}$ (dashed), $^{3}\bar{He}$ (dash-dotted), and $^{4}\bar{He}$ (dotted) antimatter particles. The lower (respectively upper) dashed line correponds to the case where the ^{3}H production is not taken (respectively taken) into account (see text for details).

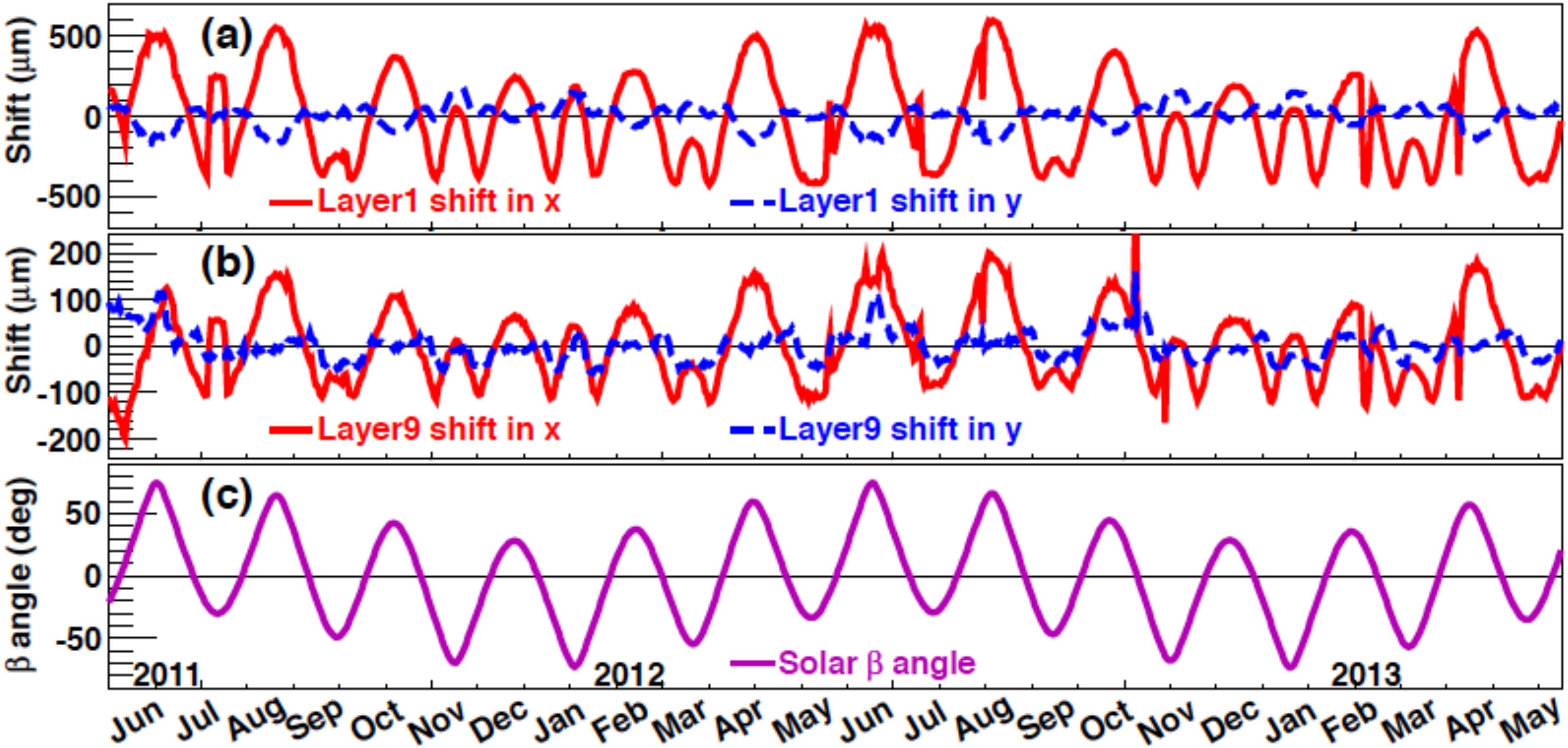
Detectors and statistics

The statistics

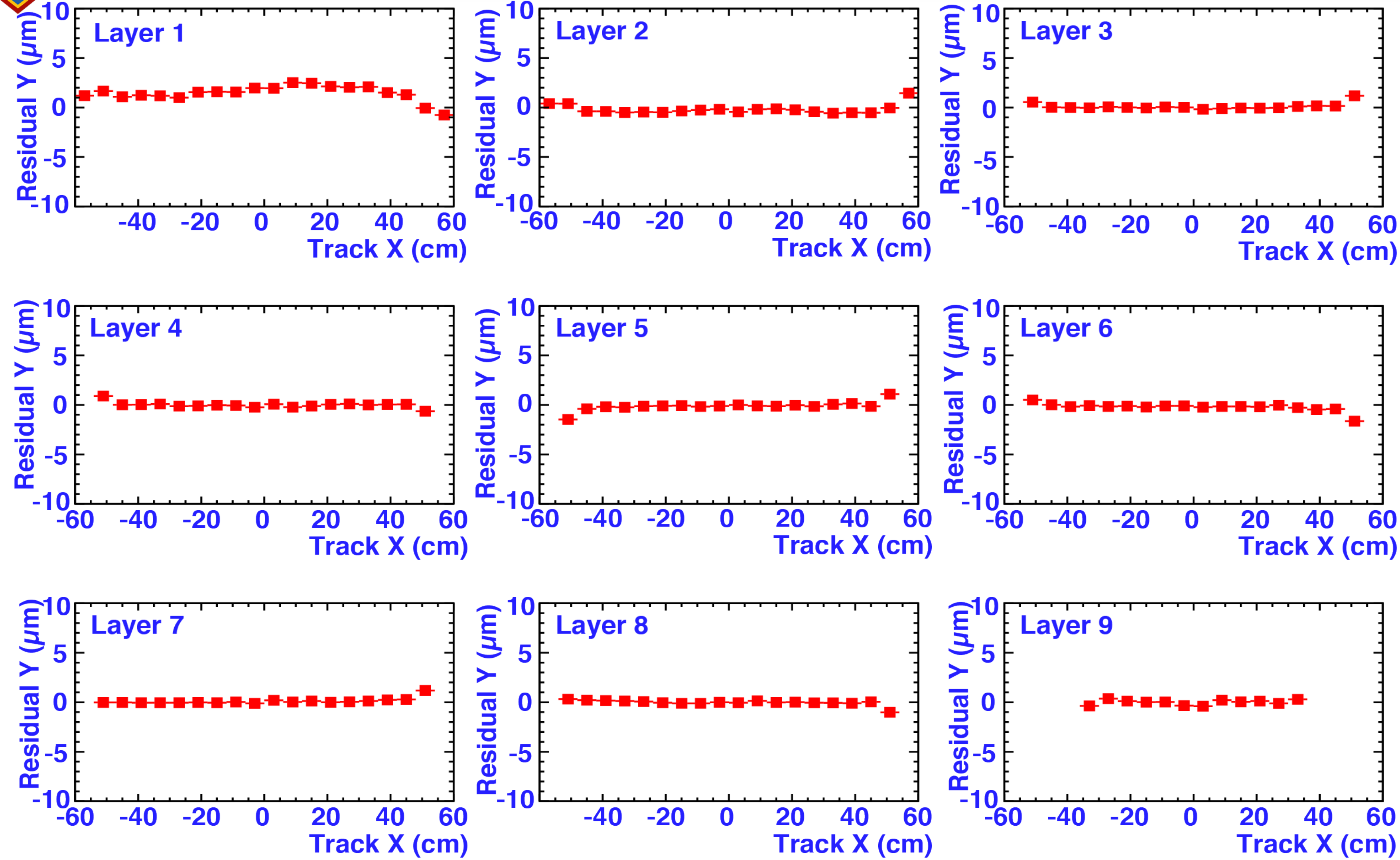
@2024 AMS will collect ~ 200 billion of events



Tracker stability

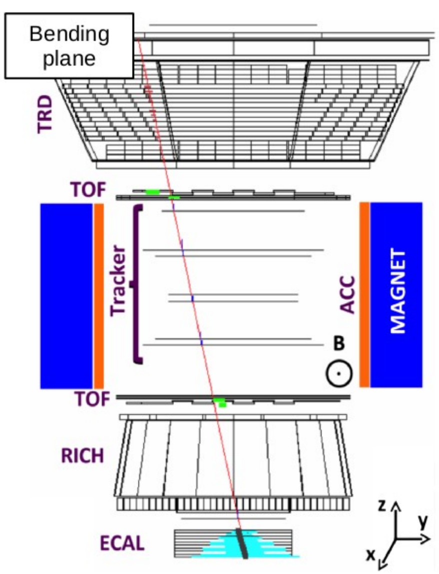


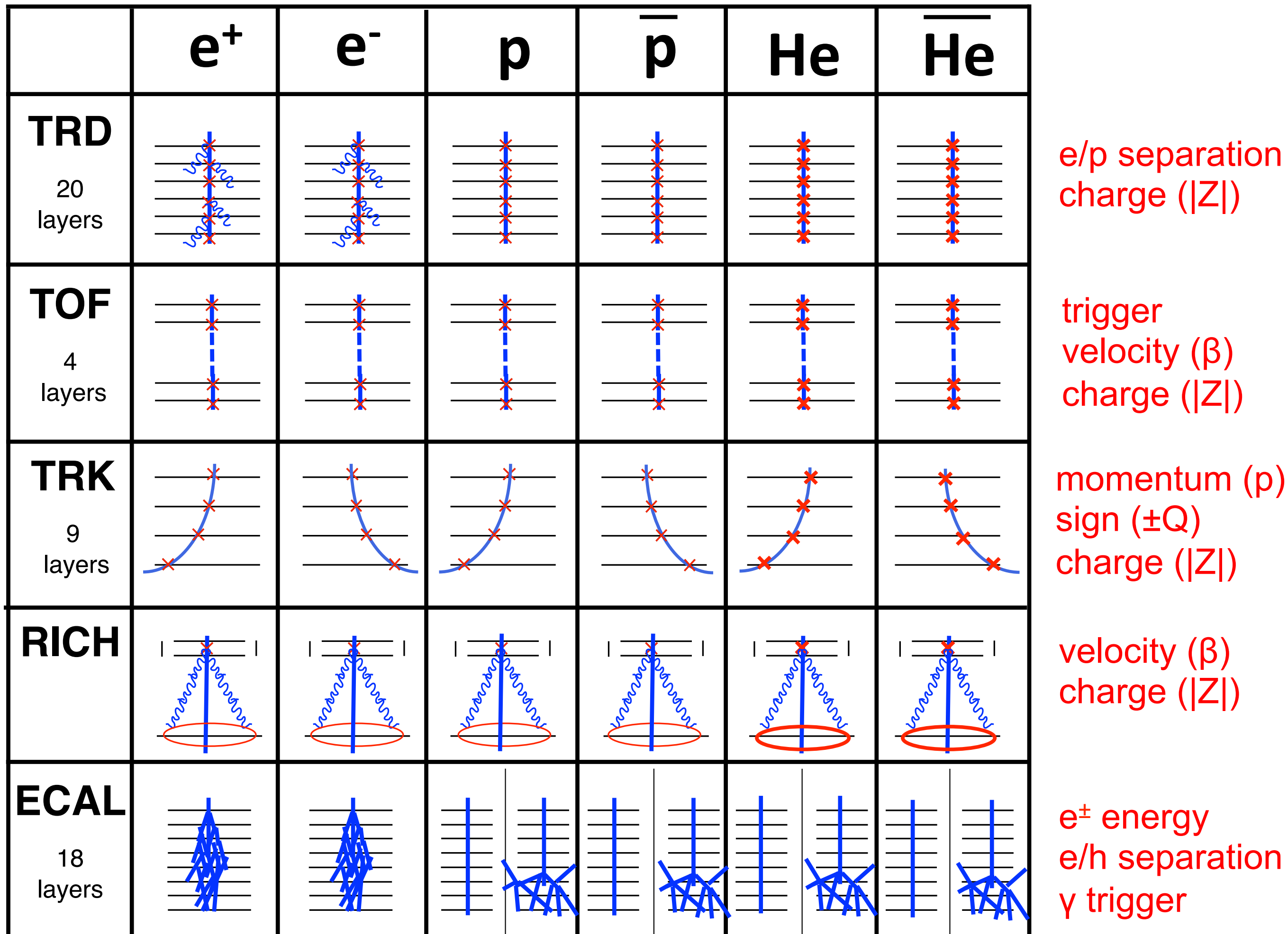
Tracker alignment



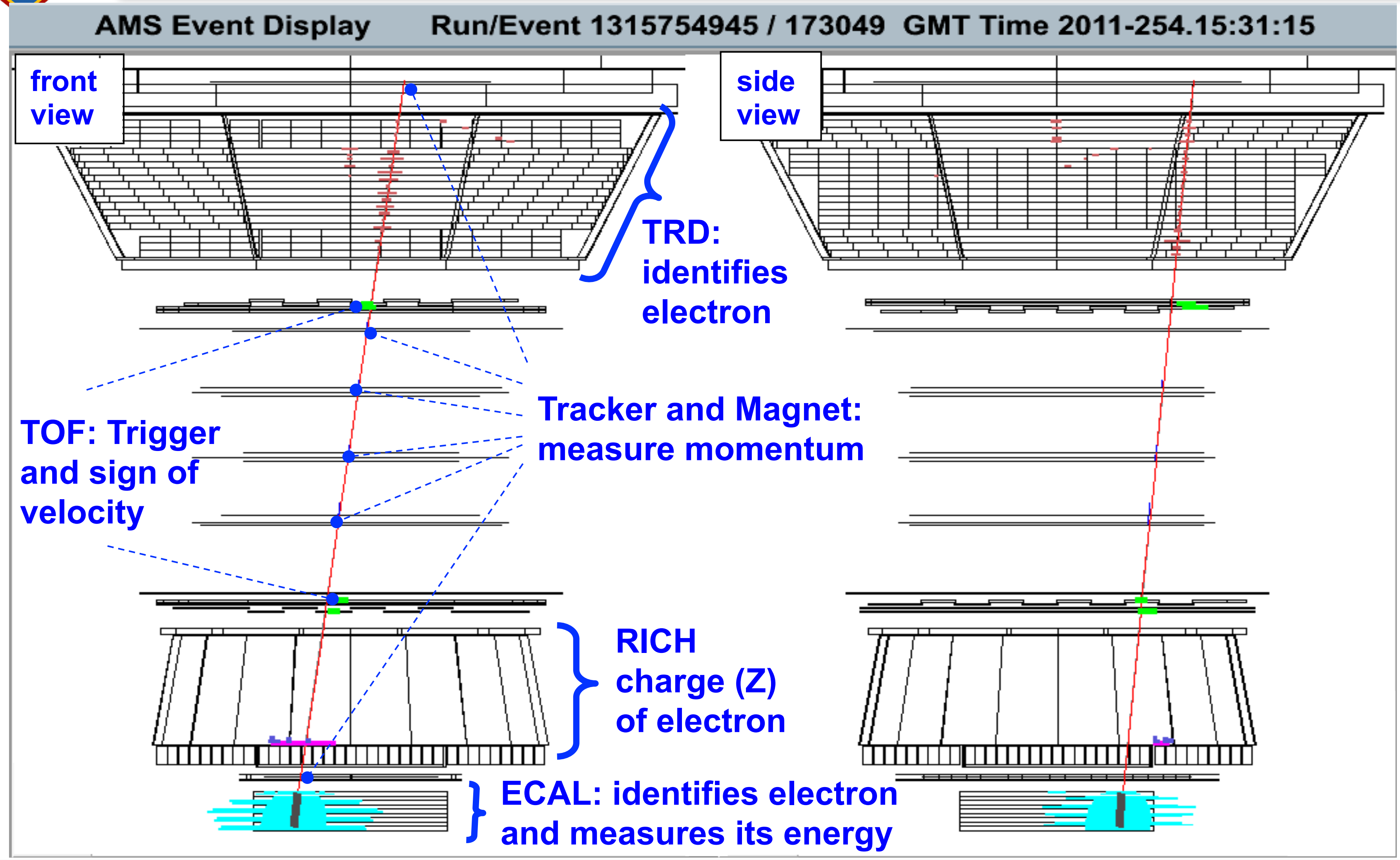
Single particle ID

Full coverage of anti-matter and RC physics



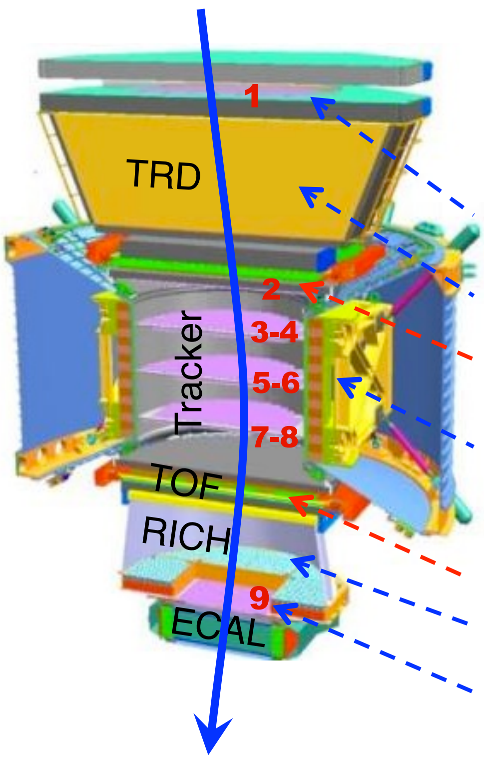


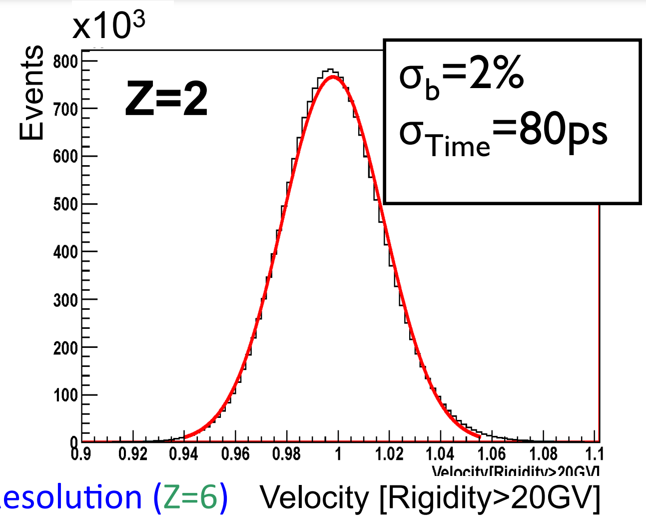
AMS data on ISS - 1.03 TeV electron

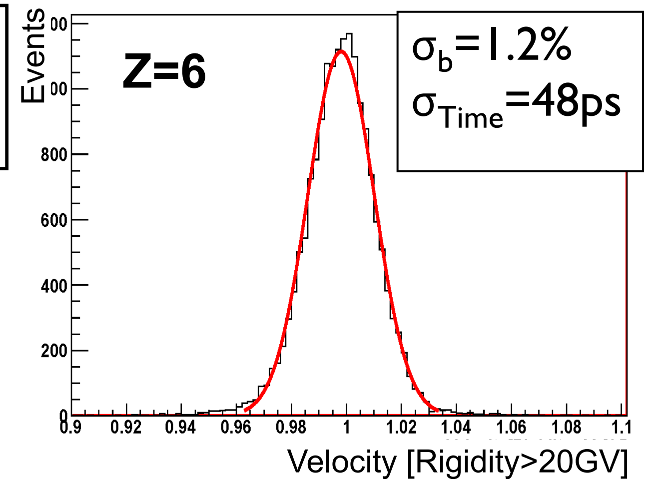


Time of Flight (TOF)

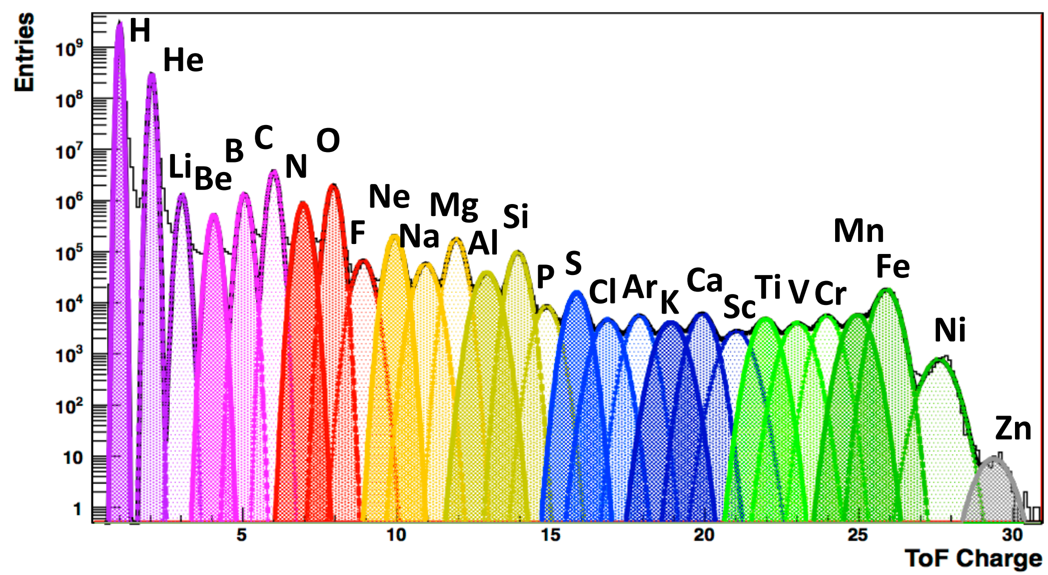
Up-going particles (fake anti-matter!) rejection up to 10^9



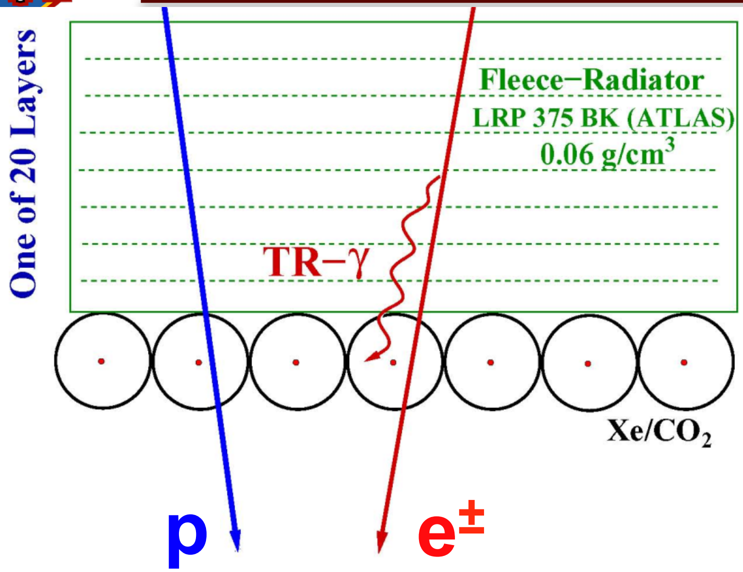


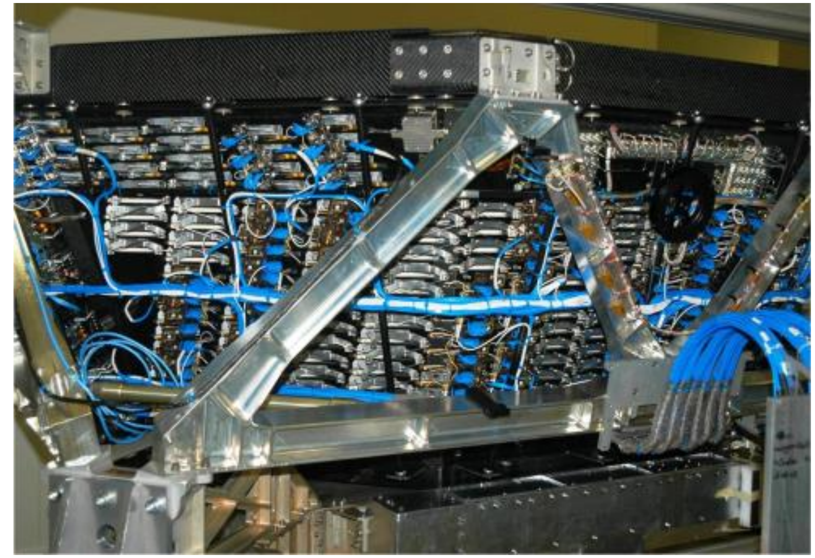


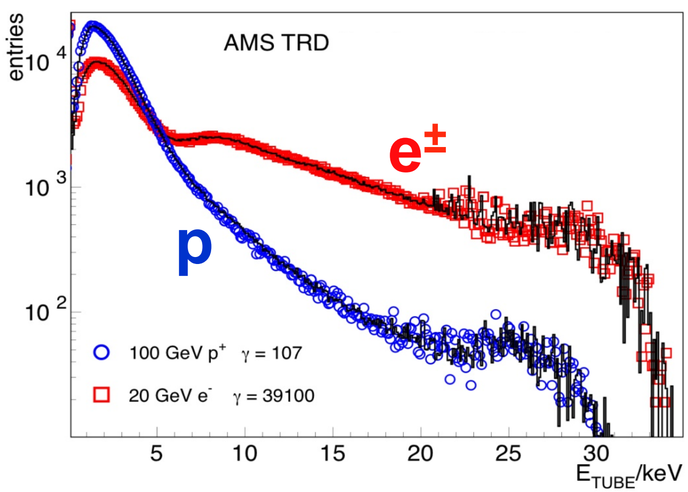
Charge Resolution (Z=6)	
Tracker Plane 1	0.30
TRD	0.33
Upper TOF	0.16
Inner Tracker 2-8	0.12
Lower TOF	0.16
RICH	0.32
Tracker Plane 9	0.30



Transition Radiation Detector (TRD)



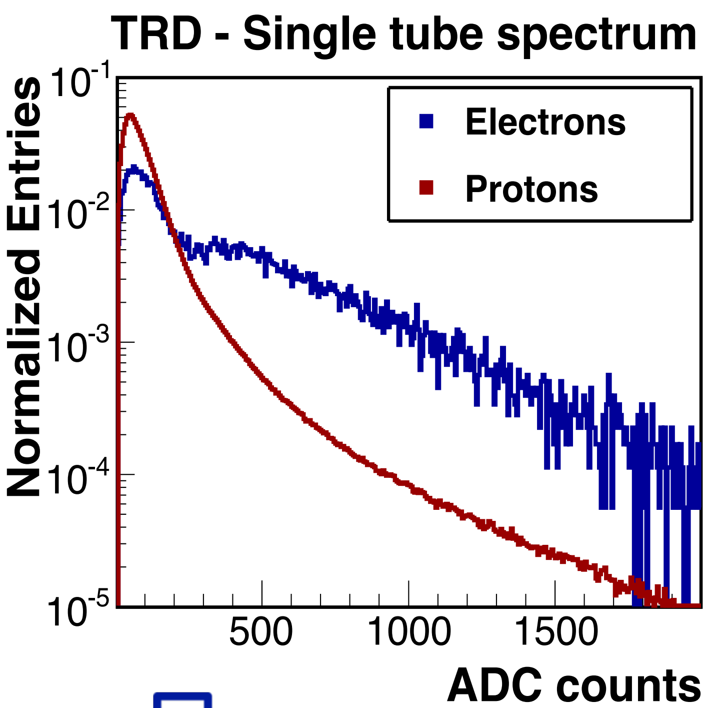




$$P_e = \sqrt[n]{\prod_{i}^{n} P_e^{(i)}(A)}$$

$$P_p = \sqrt[n]{\prod_{i}^{n} P_p^{(i)}(A)}$$

TRD e/p signals

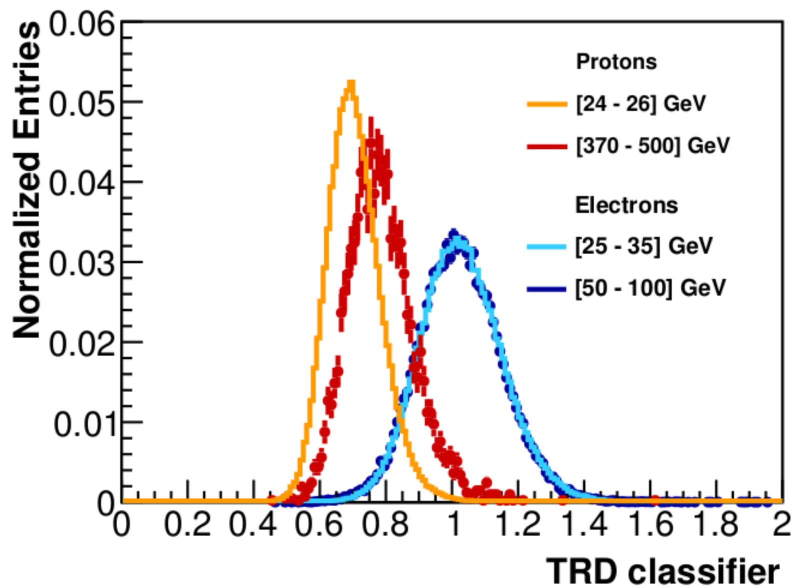


icles the energy deposit in TRD is expected to be lependent from energy.

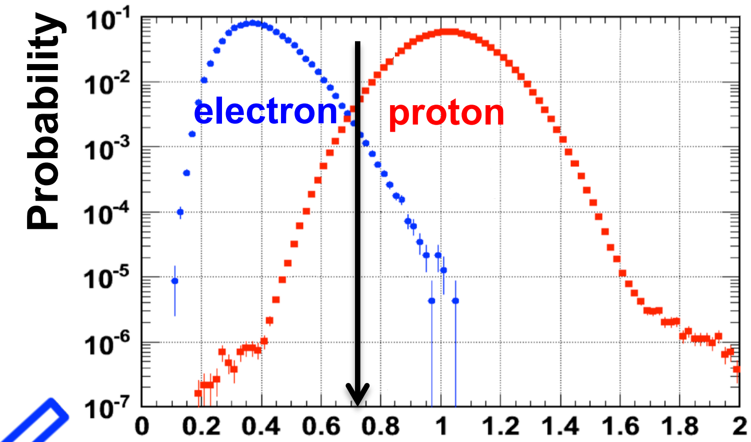
GeV was possible to build an **universal** template racted directly from data

TRD-LLe = $\text{Log}_{10}(P_e)$

$$P_e = \sqrt[n]{\prod_{i}^{n} P_e^{(i)}(A)}$$



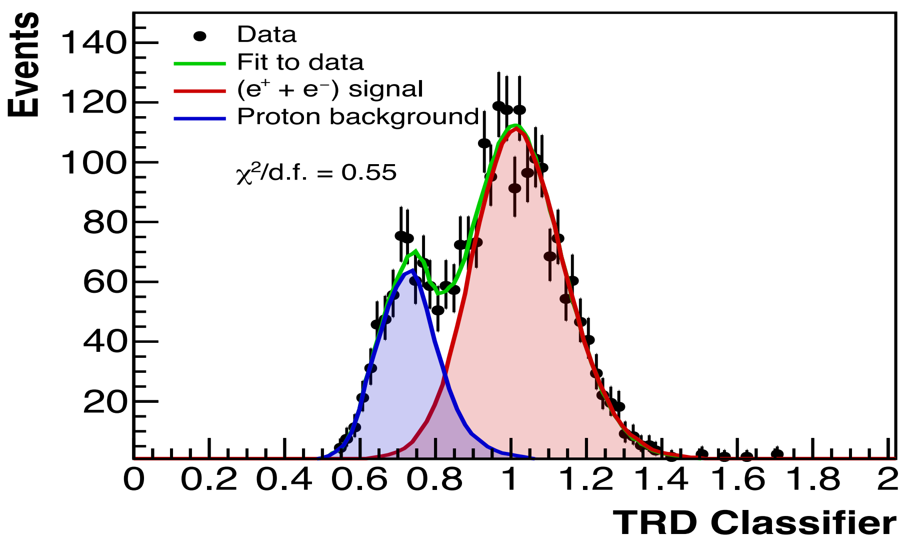
TRD e/p separation

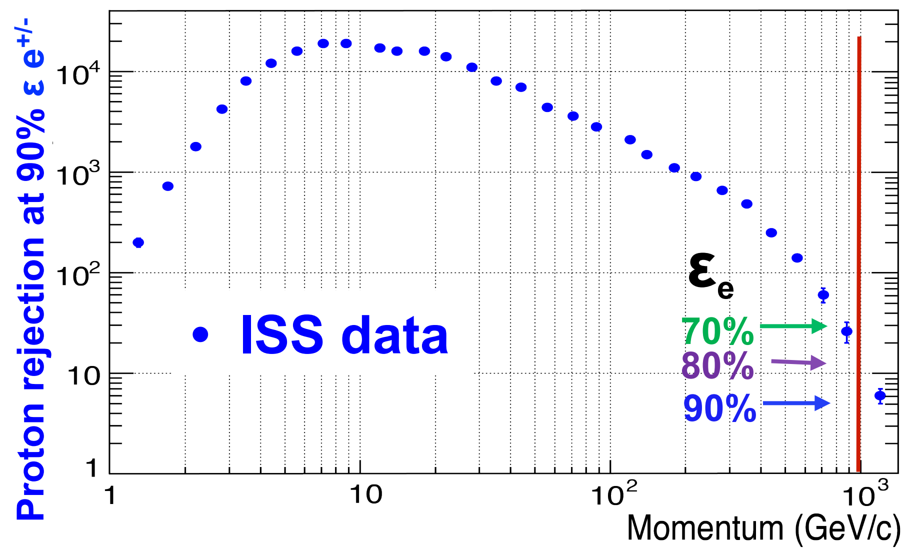


FIT

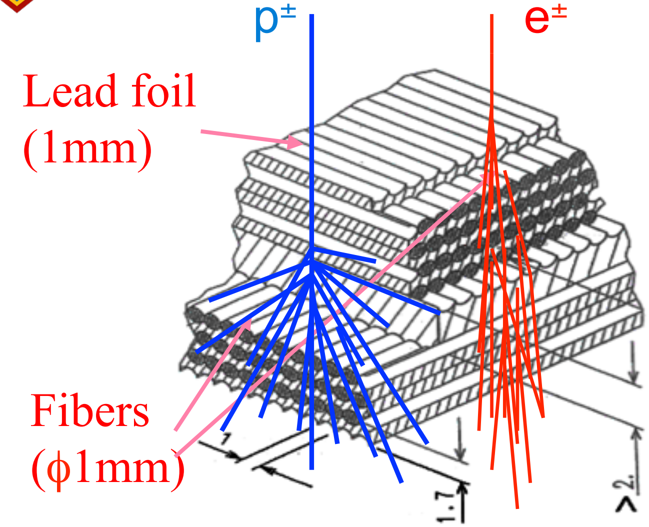
CUT

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

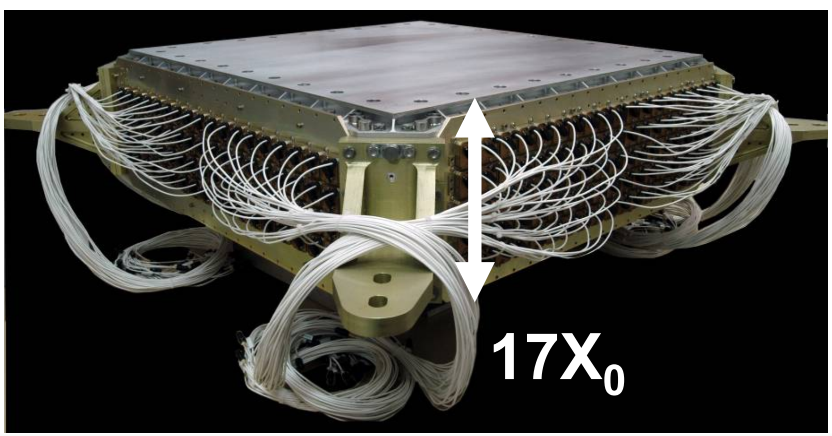




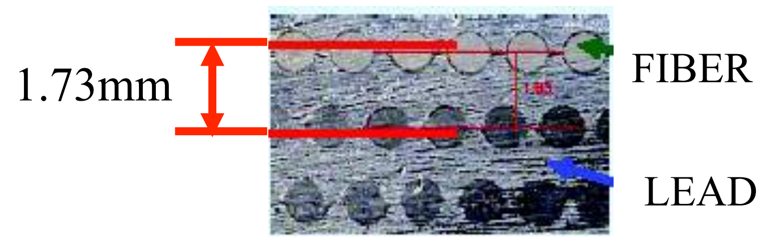
Electromagnetic Calorimeter (ECAL)

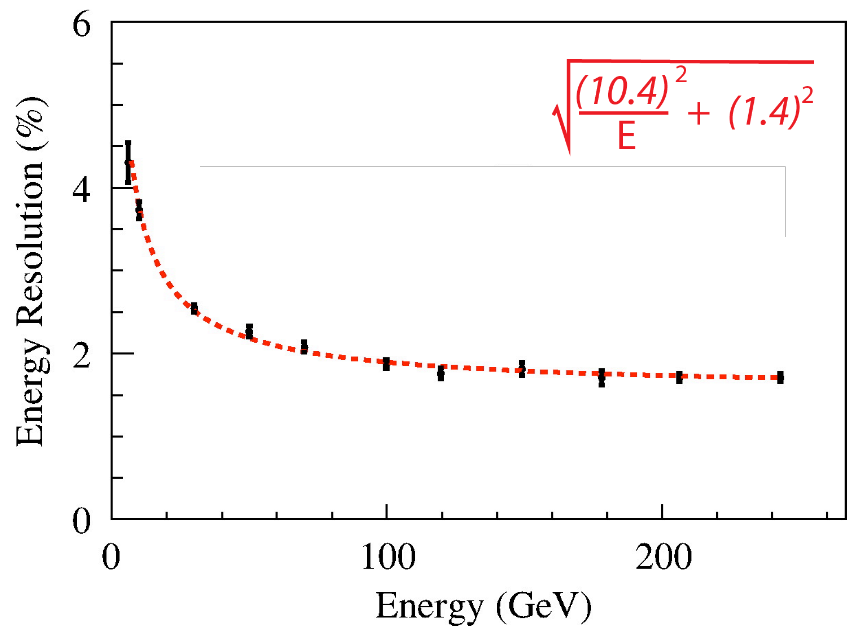


50,000 fibers, ϕ = 1 mm
distributed uniformly Inside 600 kg of lead

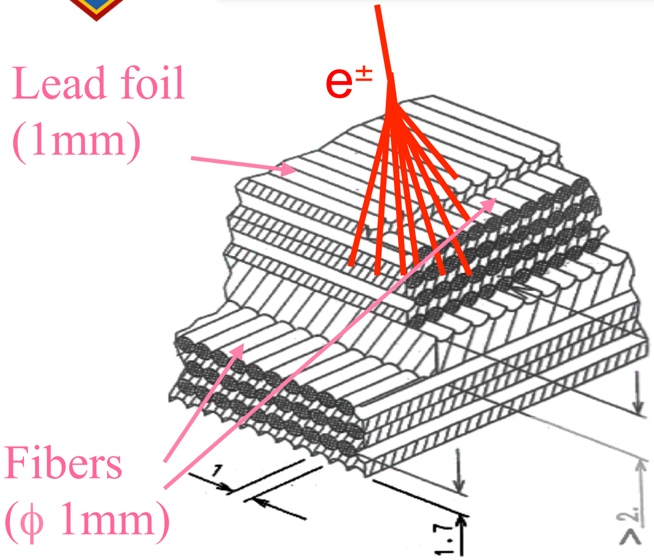


A precision, 3-D measurement of the directions and energies of gammas and electrons up to 1 TeV





ECAL segmentation

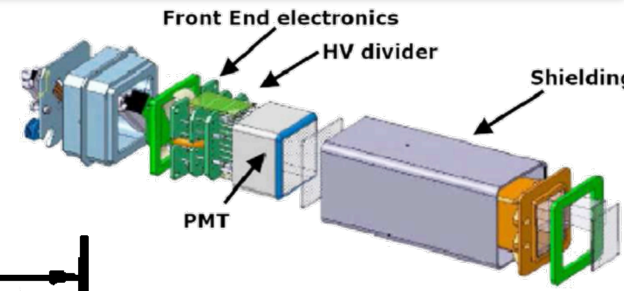


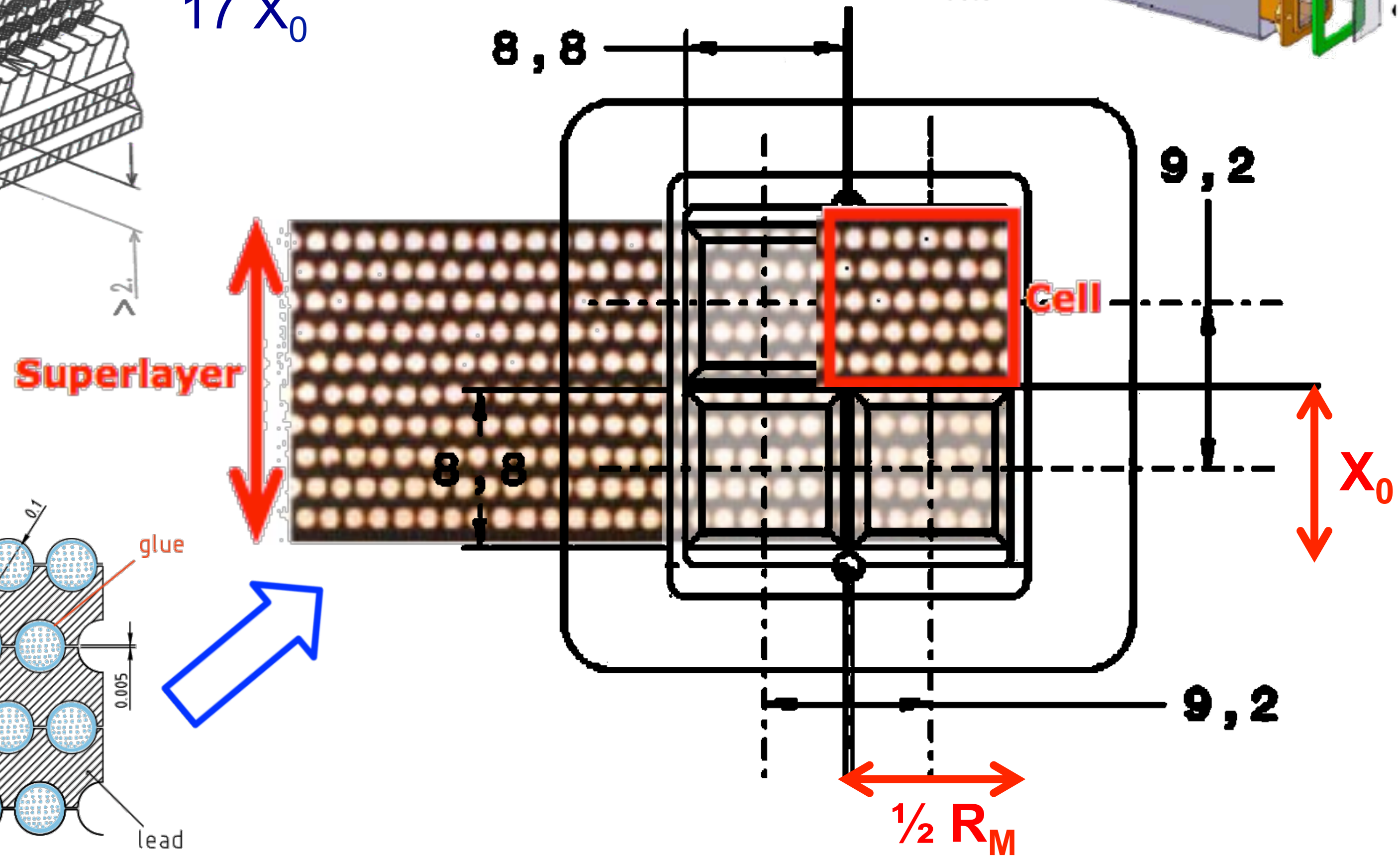
AMS ECAL:

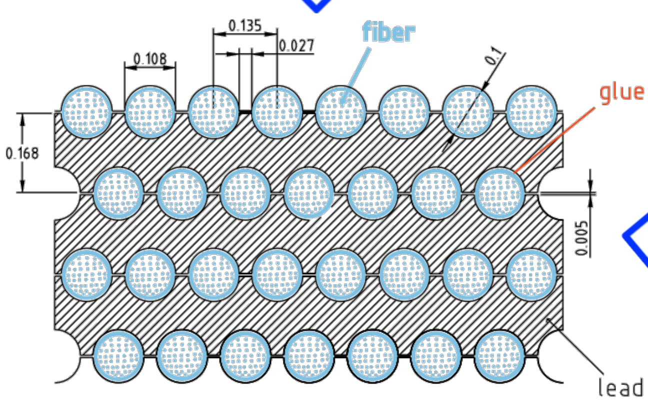
18 layers

9 super-layers

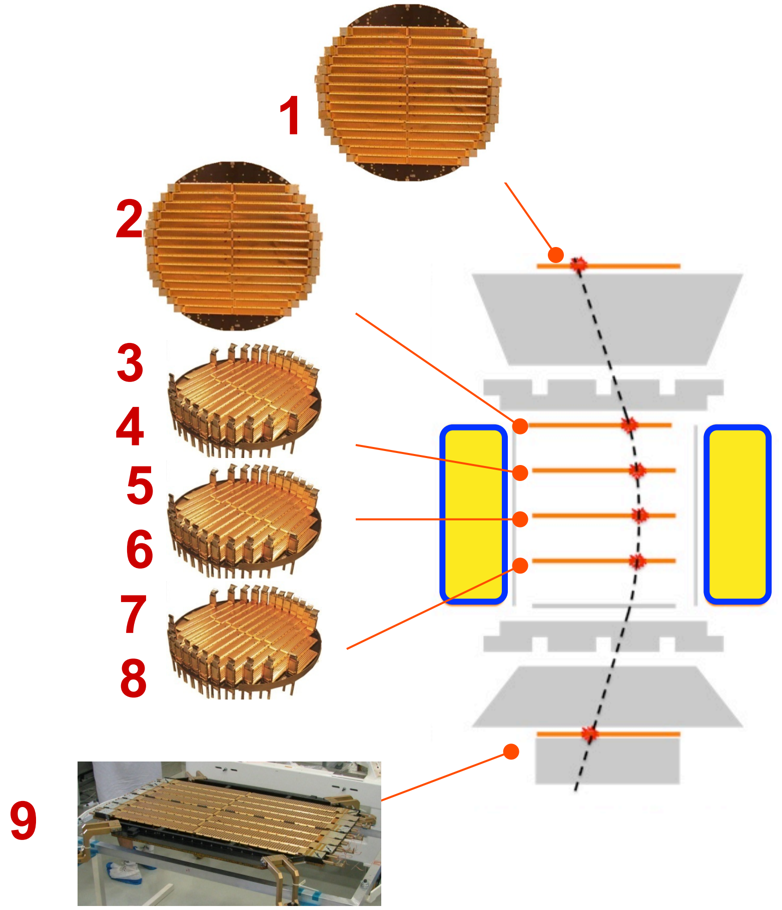
17 X_0







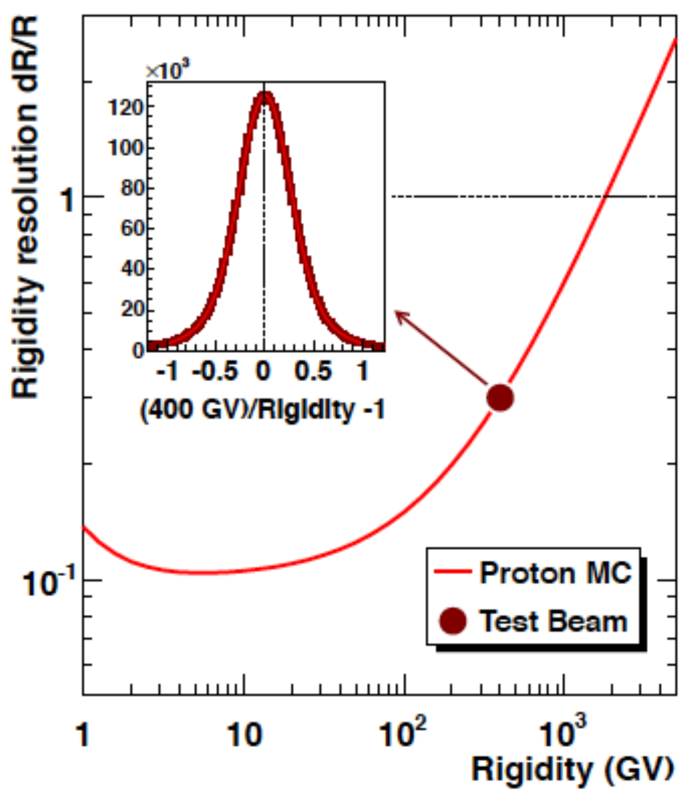
Silicon Tracker



Coordinate resolution 10 μm

→ 20–UV Lasers to monitor inner tracker alignment

→ Cosmic rays to monitor outer tracker alignment

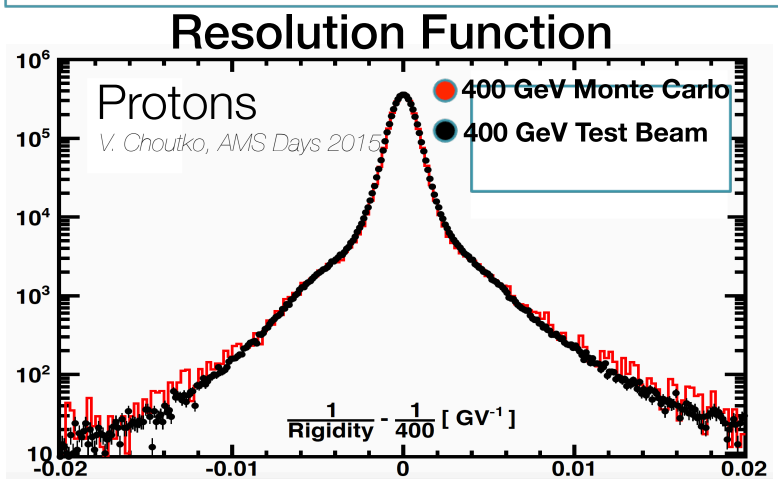


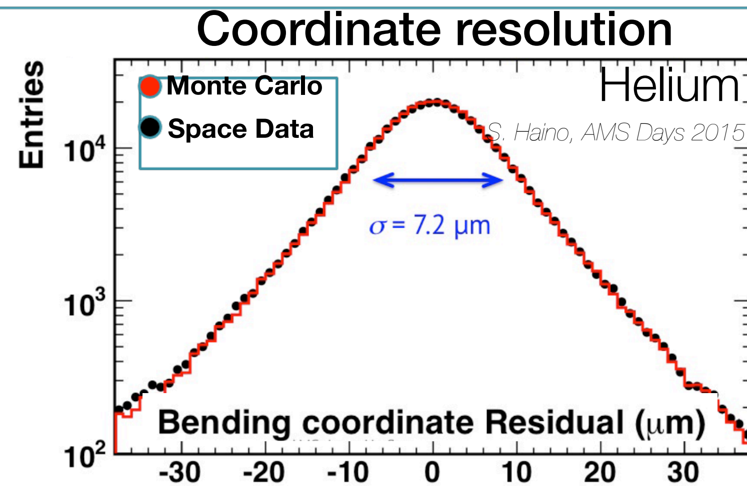
9 layers of double sided silicon microstrip detectors

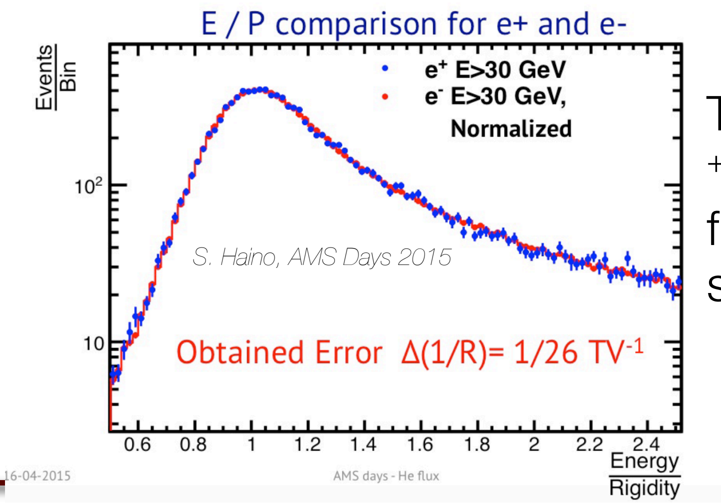
192 ladders / 2598 sensors/ 200k readout channels

AMS-02 Tracker Performances

The AMS-02 Tracker Rigidity resolution has been checked comparing **Test Beam** data and **Monte Carlo Simulations** to **Space data**.



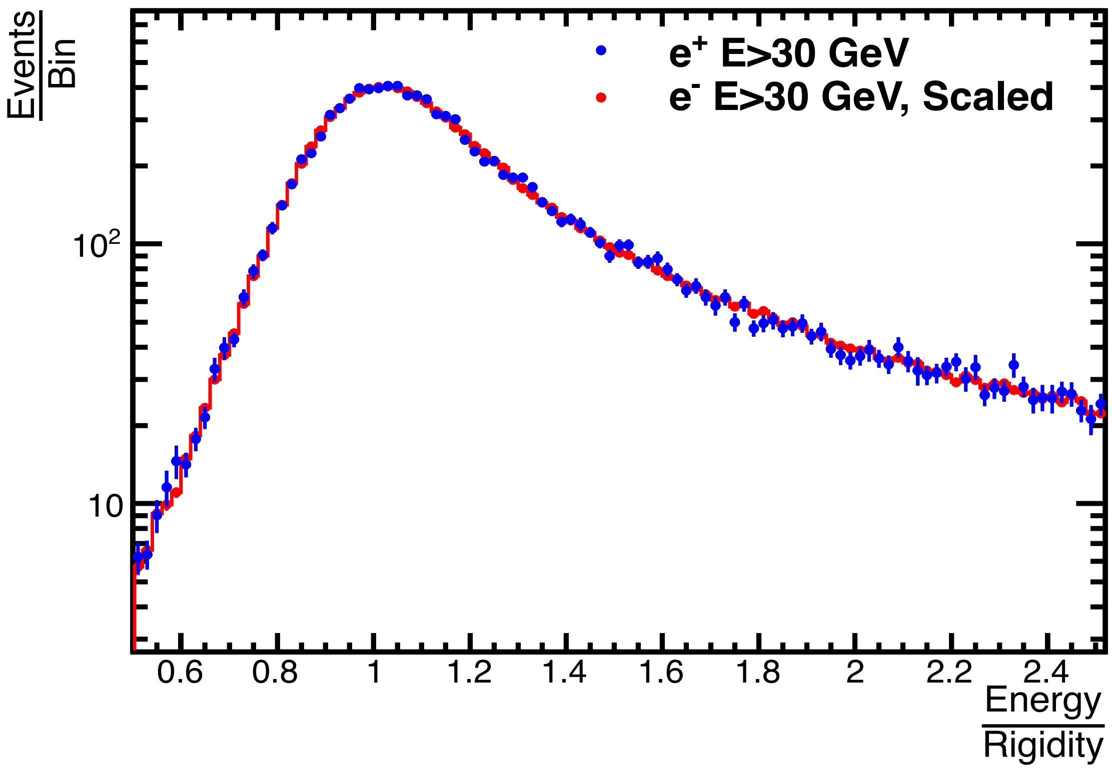




The redundant measurement of the $e^{+/-}$ energy with the ECAL is used to further control the Tracker rigidity scale

Rigidity scale

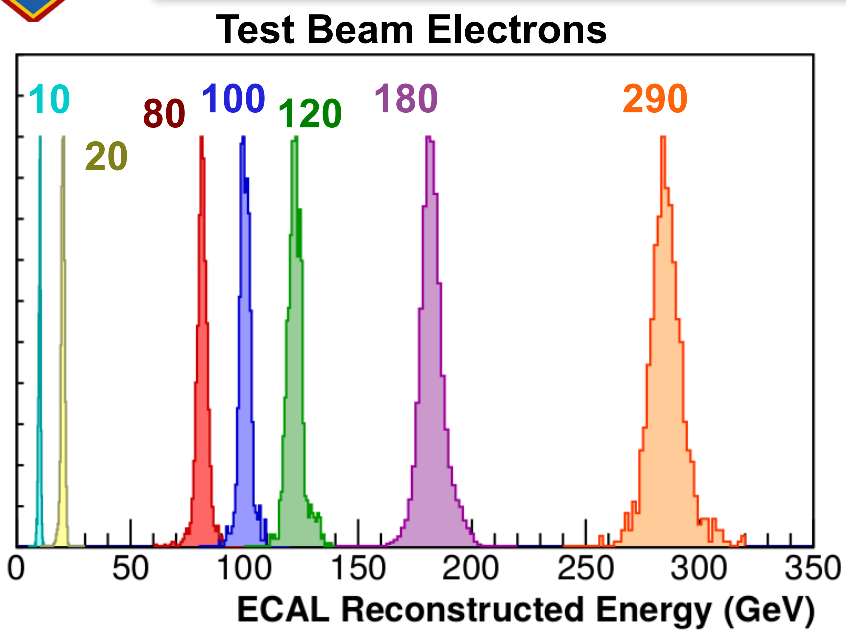
Residual tracker misalignment, i.e. how the measured average inverse rigidity of straight tracks differs from zero. This was measured by comparing the *Energy*[E, Measured by ECAL]/*Rigidity*[R, Measured by Tracker] ratio for electron and positron events and was found to be less than 1/(26TV), limited mostly by the high energy positron statistics



$$\frac{1}{\Delta} = \frac{\overline{(E/R)}_{e^+} - \overline{(E/R)}_{e^-}}{\overline{E}_{e^+} + \overline{E}_{e^-}}$$

$1/\Delta \sim 0$ $\sigma(1/\Delta)=1/26\ \mathrm{TV}^{-1}$

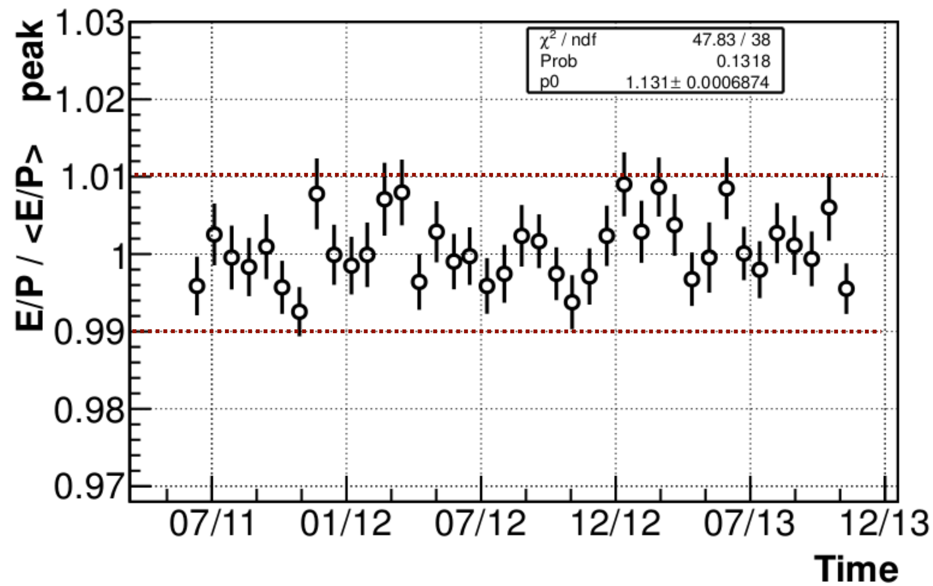
Energy measurement



- **ECAL energy resolution ~2%**
- **ECAL energy absolute scale** tested during test beams on ground

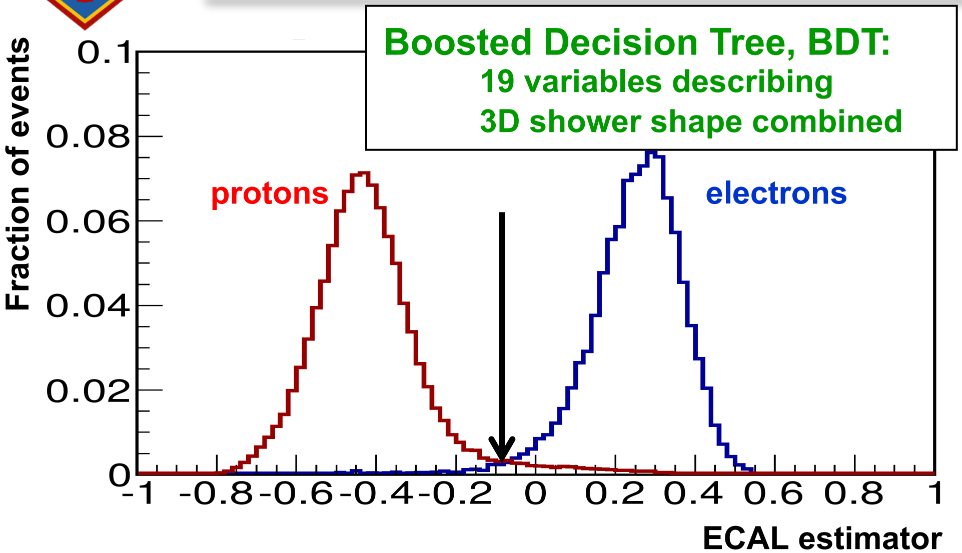
ECAL energy comparison with Tracker rigidity used to assure the stability of the scale over time

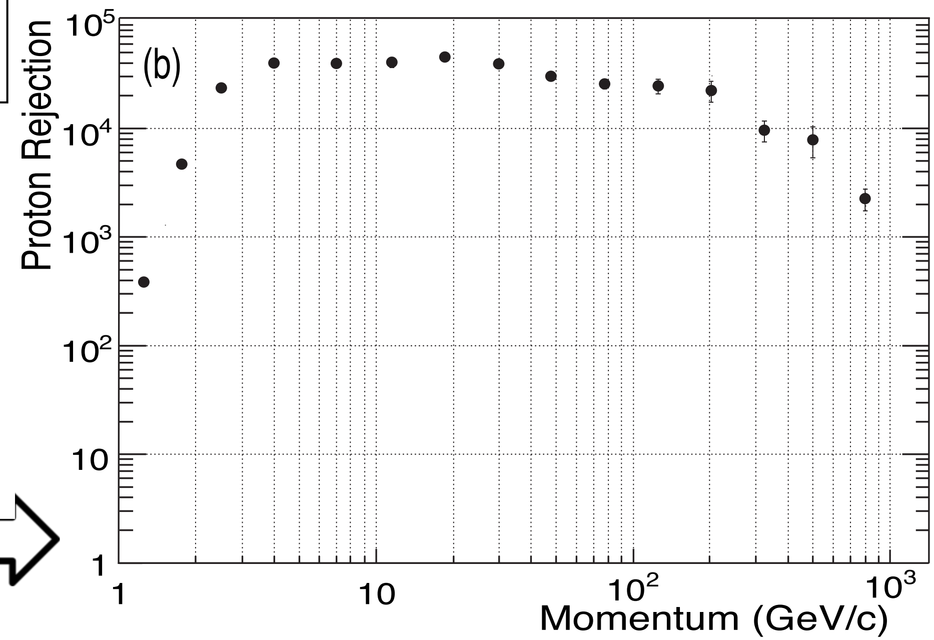
MIP ionization used to cross-calibrate the energy scale in flight

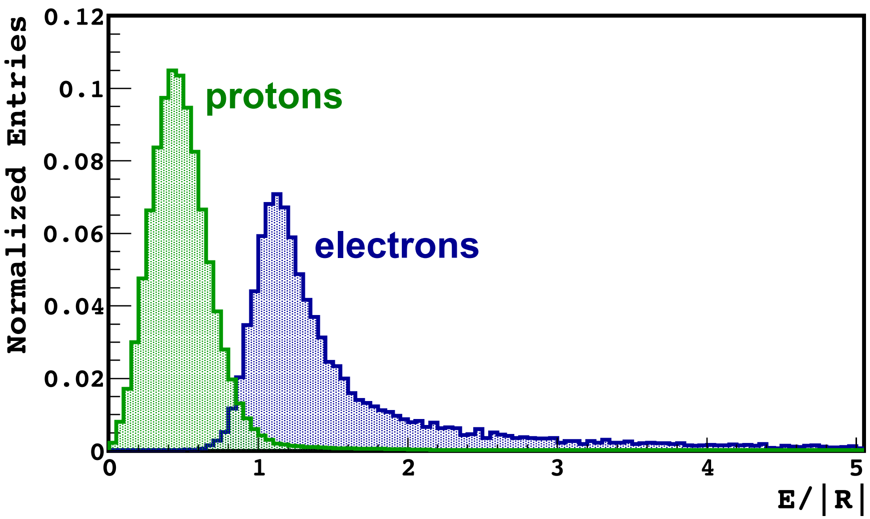


ECAL energy scale known at 2% level in [10.0 – 290.0] GeV

ECAL e/p rejection





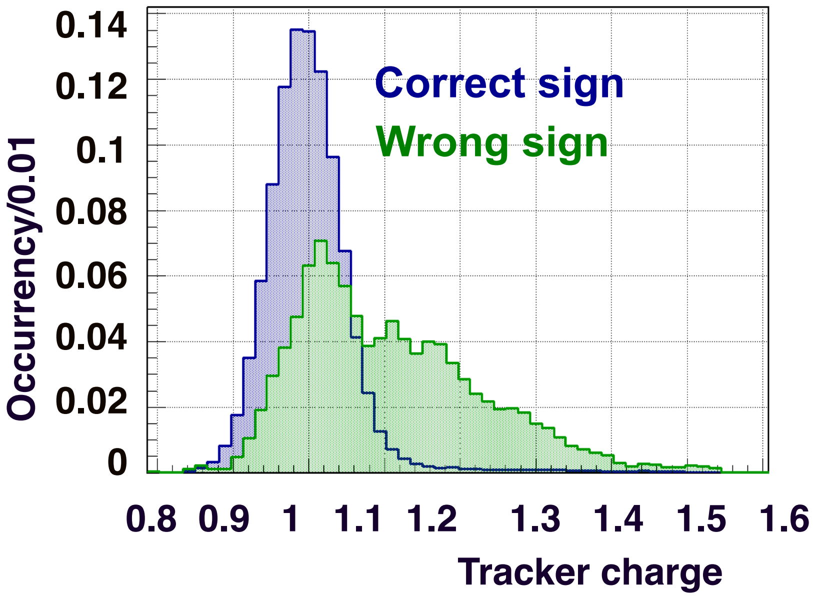


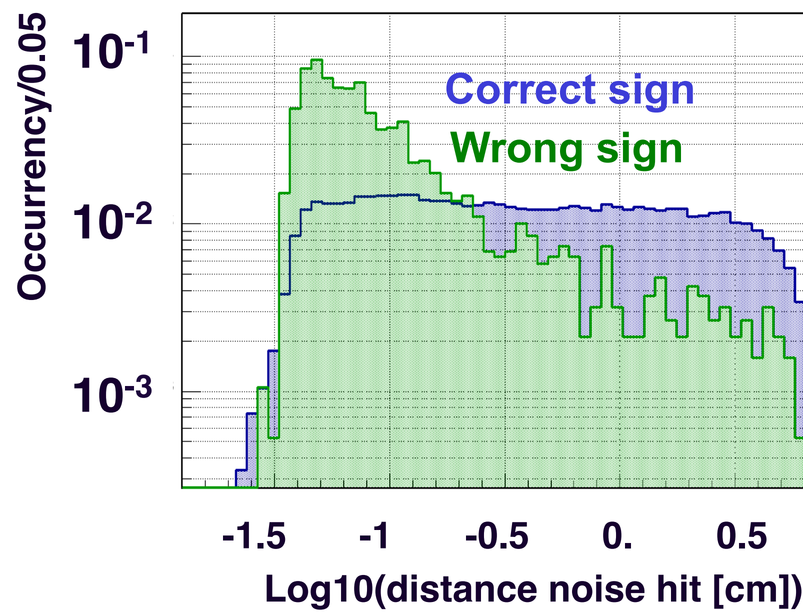
The Calorimeter thanks to its shower shape imaging capabilities can discriminate very sensibly eletromagnetic from hadronic showers

Combining the ECAL energy information with the Tracker Rigidity (E/R) the e/p rejection can be furtherly increased

Charge confusion from interactions

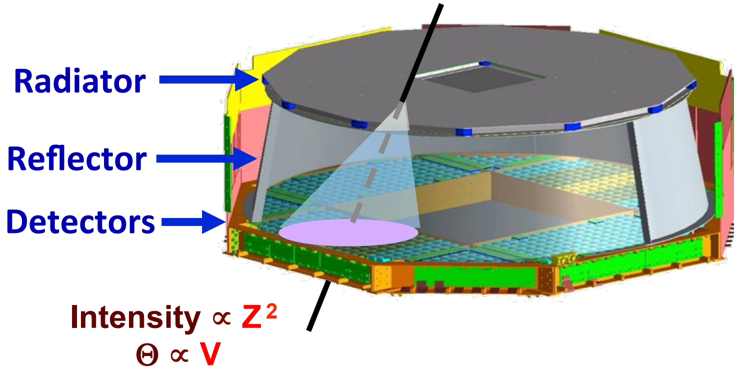
Different reconstructed quantities are sensitive to interactions and can be used to separate Correct and Wrong Charge Sign assignment

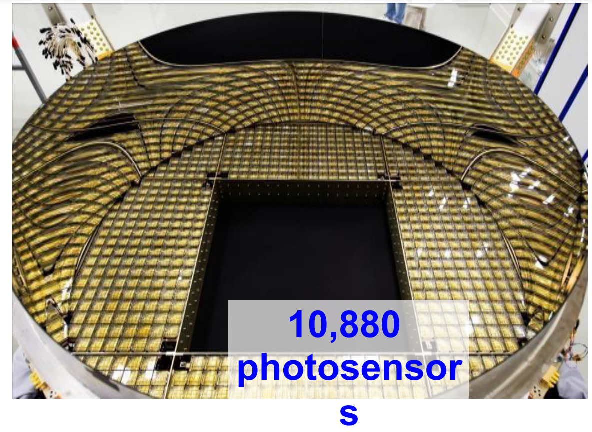


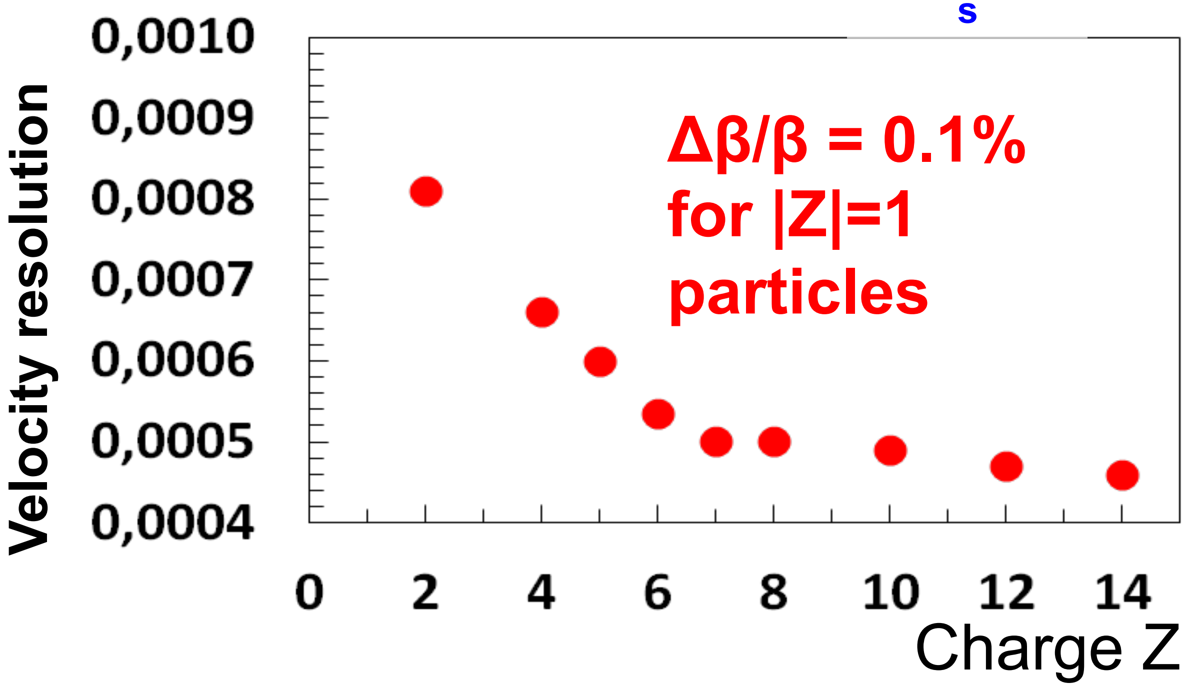


Use a statistical estimator to build a tracker charge sign discriminating variable

Ring Imagin Cherenkov







Leptons

Electron+positron flux

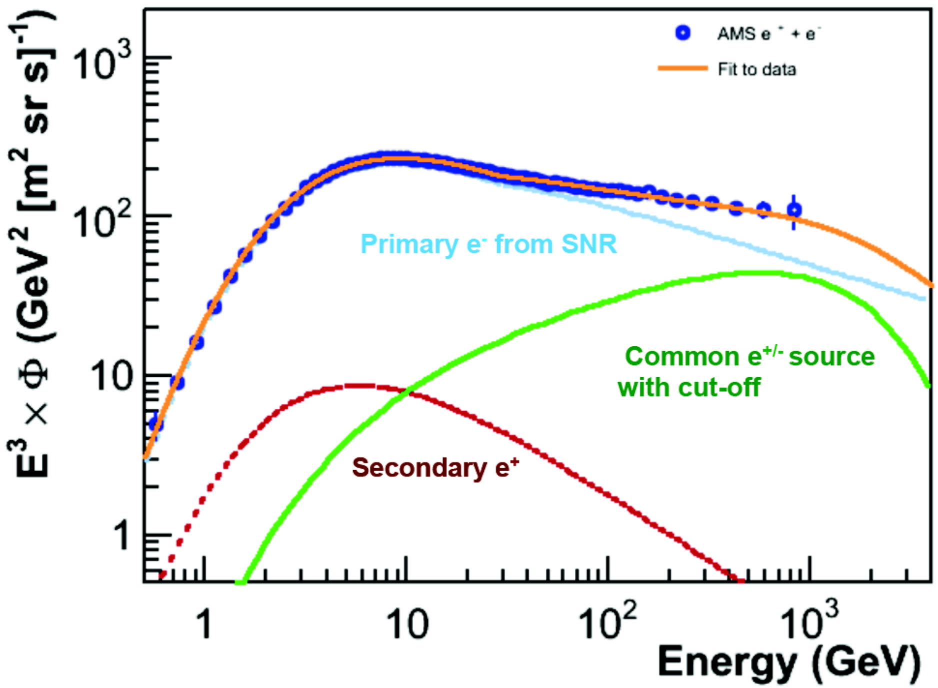
secondary positrons
from ISM interactions

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

common source
with a cutoff energy:

primary
electrons
from SNR

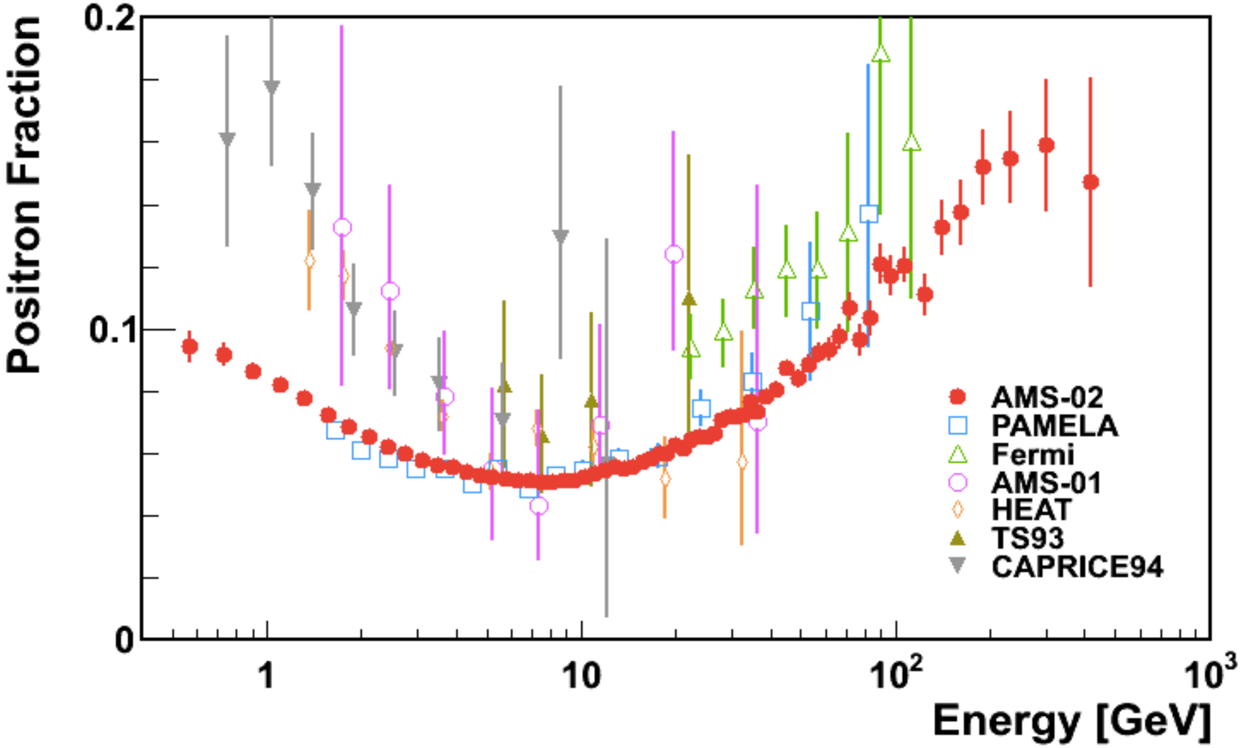


Last result on positron fraction: AMS

PRL **113,** 121101 (2014) PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2014

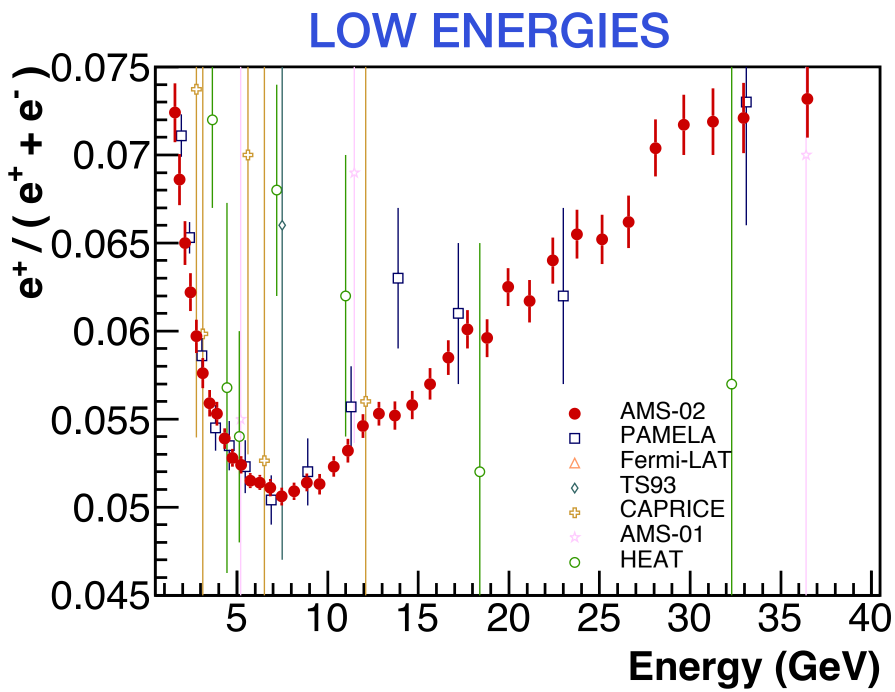
High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

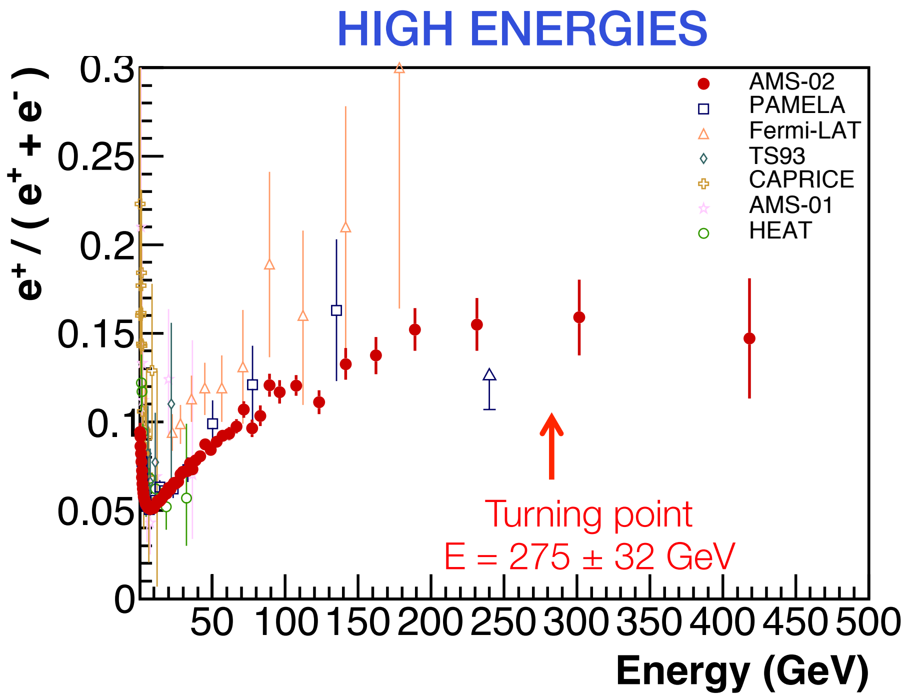
10.9 million e+ and e- events



Positron Fraction

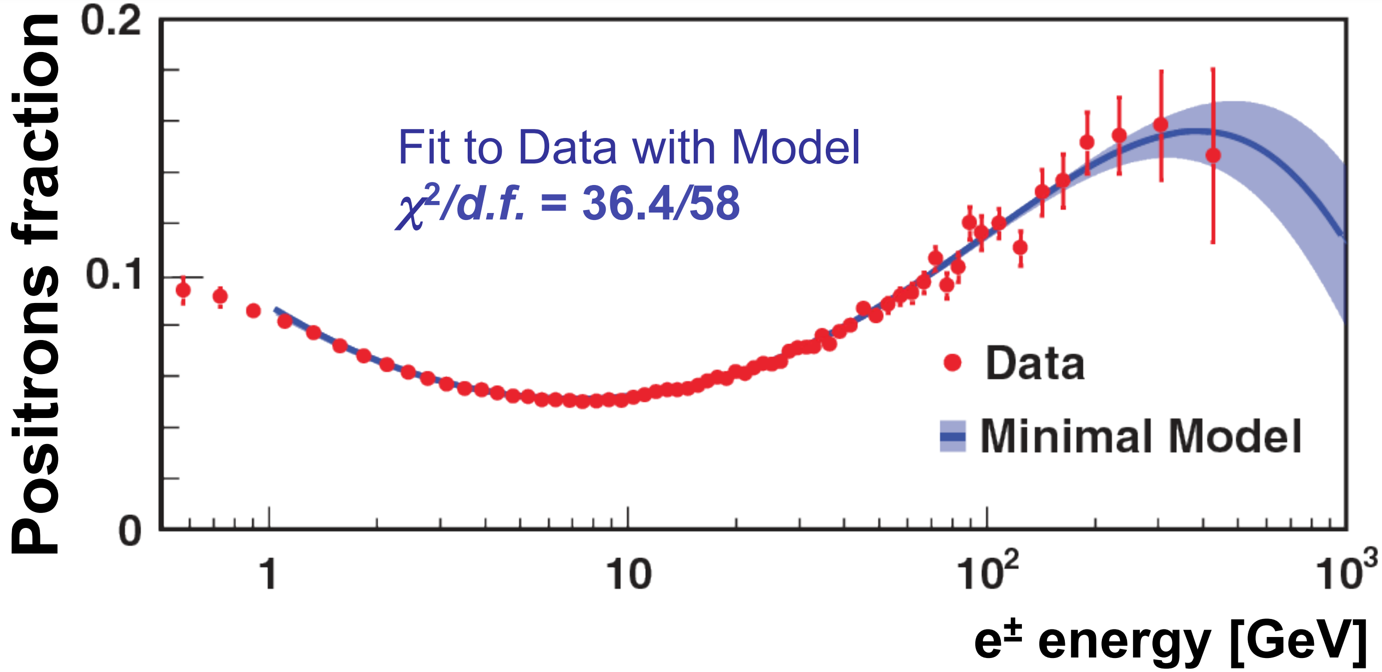
Rise in the fraction of positrons (antimatter) over electrons (matter) not expected by the current Standard Model of CR origin and propagation





- Precision measurement of the fraction minimum
- No sharp structures observed in the spectrum
- The slope decreases with increasing energy

Empirical "minimal" model



Describe electron and positron fluxes as a sum of a **"diffuse" component** and a **common source** with a cutoff energy:

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

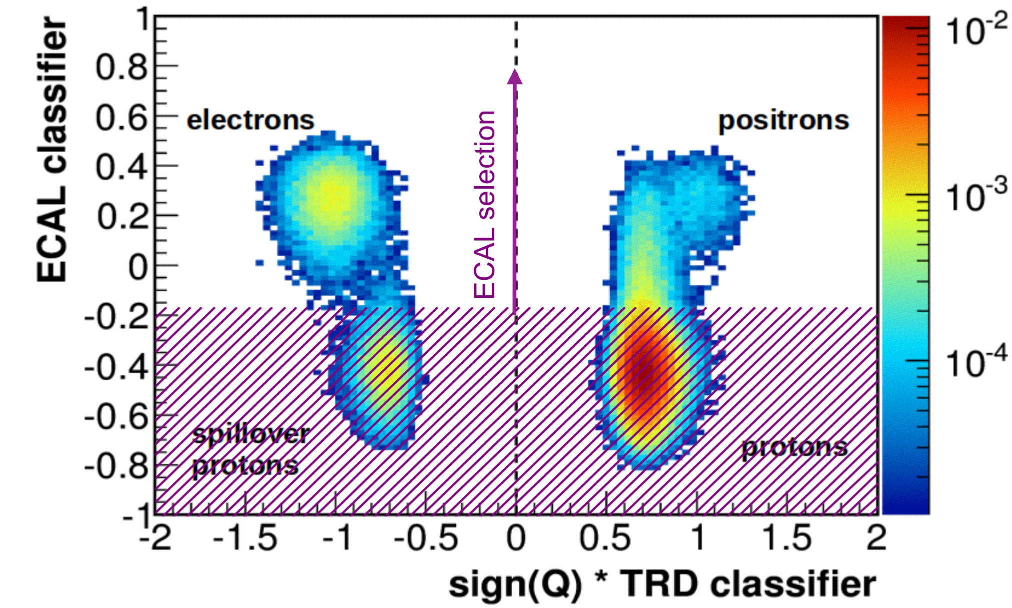
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

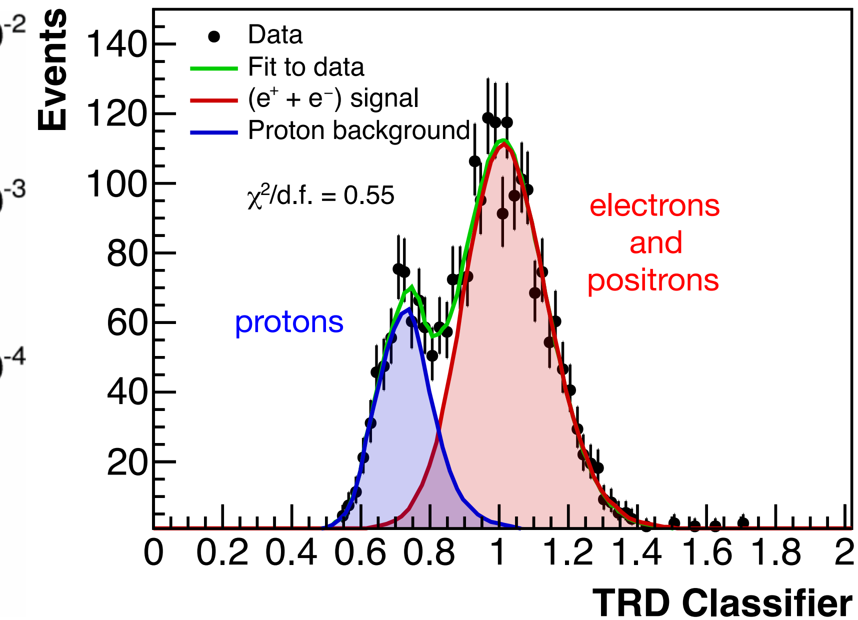
$\gamma_{e-} - \gamma_{e+} = -0.56 \pm 0.03$
$\gamma_{e-} - \gamma_S = 0.72 \pm 0.04$
$C_{e+}/C_{e-} = 0.091 \pm 0.001$
$C_S/C_{e-} = 0.0061 \pm 0.0009$
$1/E_s = 1.84 \pm 0.58$ TeV^{-1}

Template fit to measure N_e and N_p

Data driven background subtraction

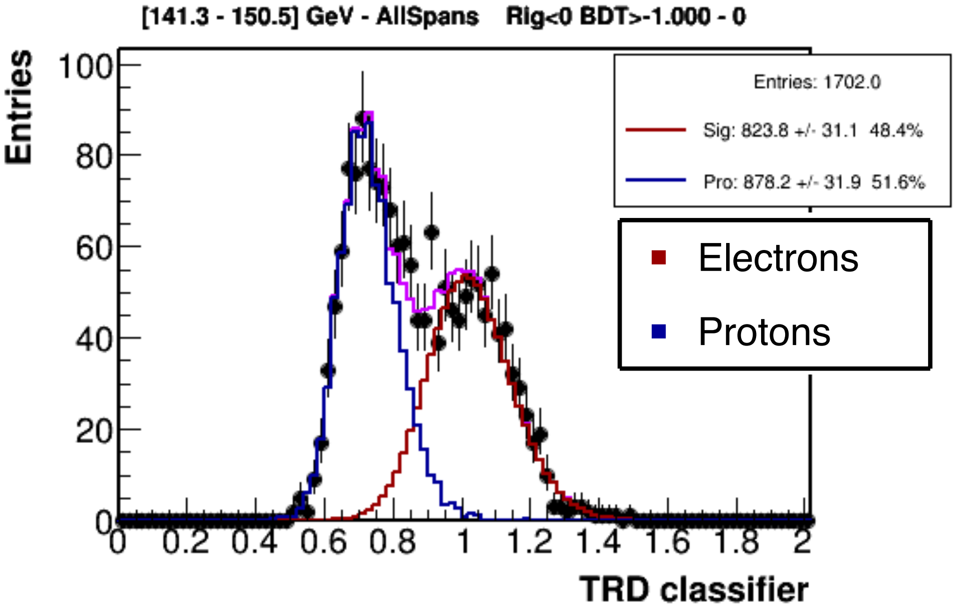
Reference spectra for the signal and the background are fitted to data as a function of the TRD classifier for different cuts on the ECAL BDT estimator

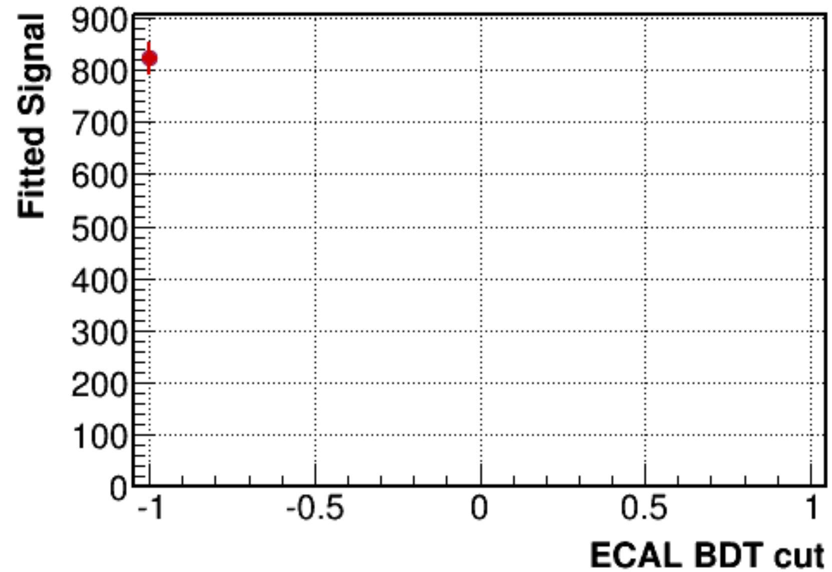




Measurement is performed for the cut on the ECAL classifier that minimizes the overall statistical + systematic uncertainty

BDT efficiency evaluation

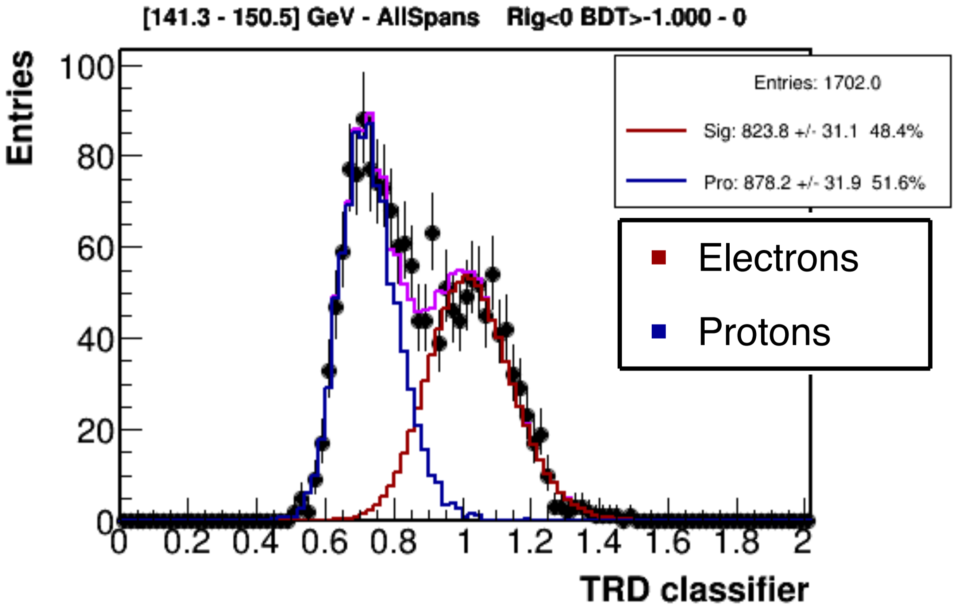


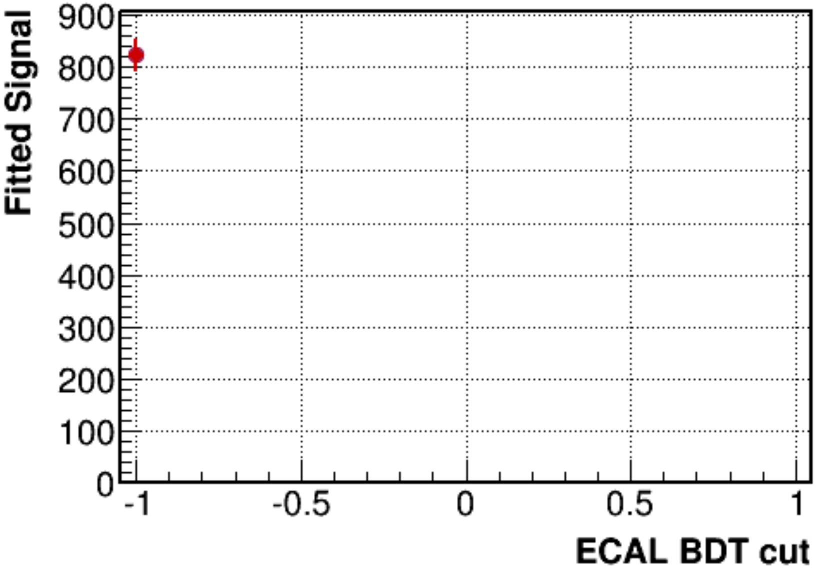


The BDT efficiency evaluation is done on the negative sample (R<0), selected with the Tracker

→ the S/N in the sample is naturally enhanced and the evaluation is possible up to highest energies

BDT efficiency evaluation





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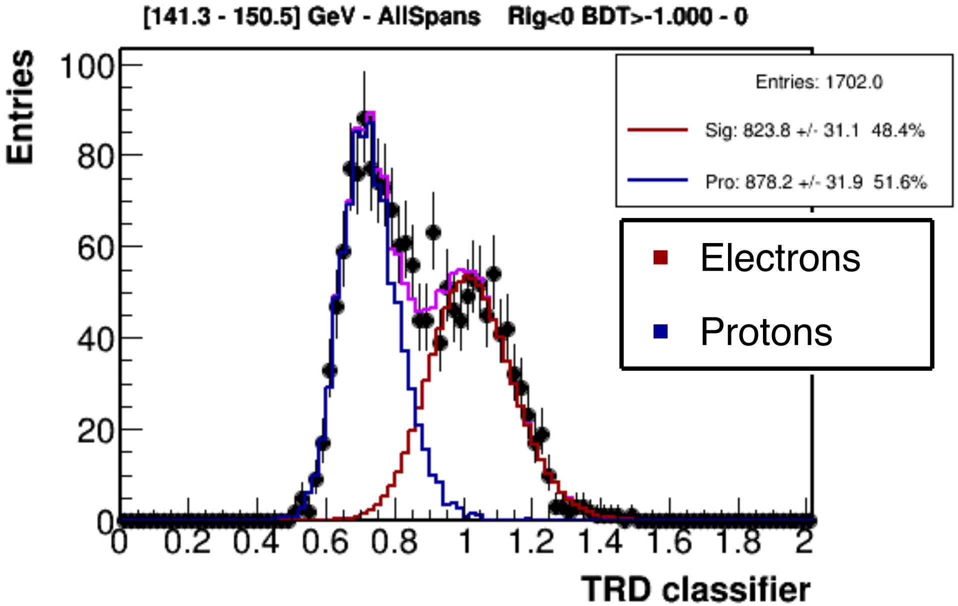
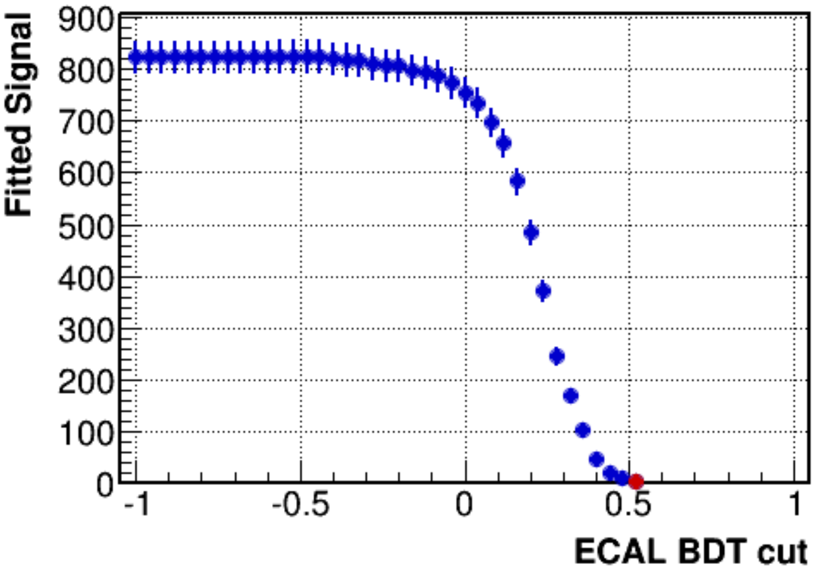
BDT efficiency evaluation





The BDT efficiency evaluation is done on the negative sample (R<0), selected with the Tracker

→ the S/N in the sample is naturally enhanced and the evaluation is possible up to highest energies

The $(e^{+}+e^{-})$ flux measurement

$$\Phi(\mathrm{E}, \mathrm{E}+\Delta\mathrm{E}) = \frac{N_{obs}(\mathrm{E}, \mathrm{E}+\Delta\mathrm{E})}{\Delta E\,\Delta T_{\mathrm{exp}}\,A_{\mathrm{eff}}\,\epsilon_{\mathrm{trig}}}$$

Φ = Absolute differential flux ($m^{-2}\,sr^{-1}\,GeV^{-1}$)
N_{obs} = Number of observed events
ΔT_{exp} = Exposure time (s)
A_{eff} = Effective acceptance ($m^2 sr$)
E_{trig} = Trigger efficiency

Detector Acceptance

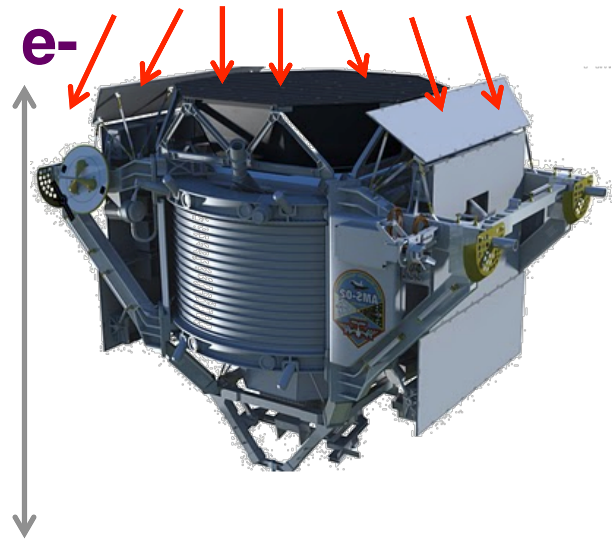
- Calculated with MC (Geant 4)

$$A_{geom}(E) = A_{gen} \times \frac{N_{sel}(E)}{N_{gen}(E)}$$

-

A_{gen} = acceptance of the generation surface

N_{sel} = events passing through TRD,TOF,TRK,ECAL



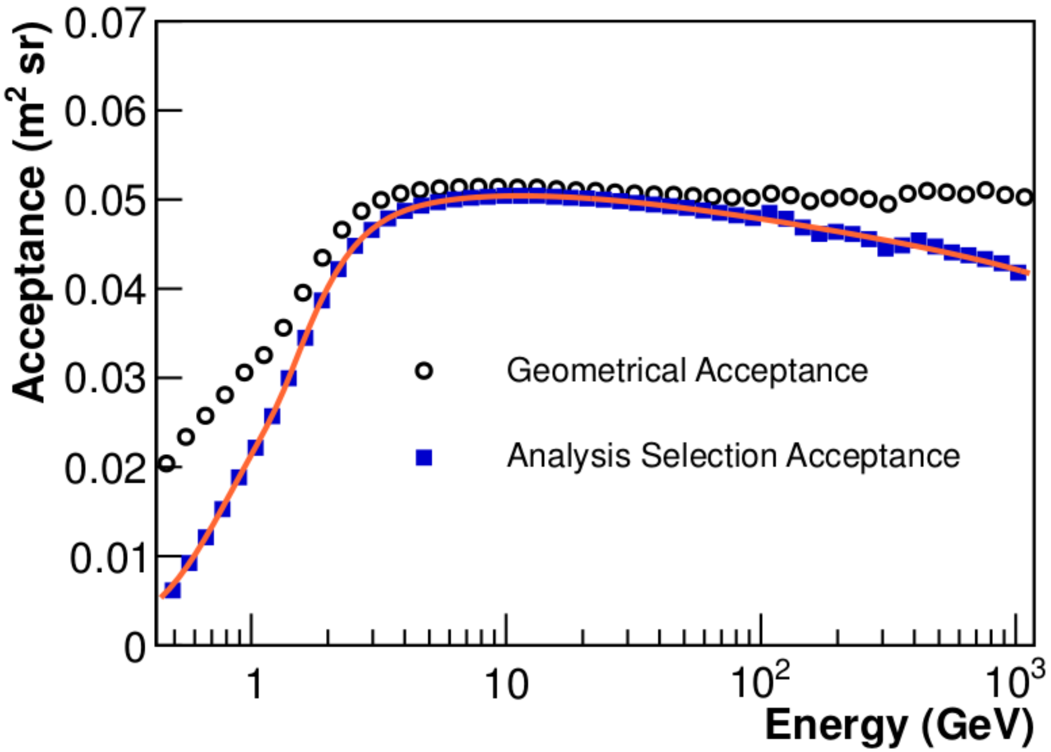
$$A_{eff}(E) = A_{geom} \times \epsilon_{sel} \times (1 + \delta)$$

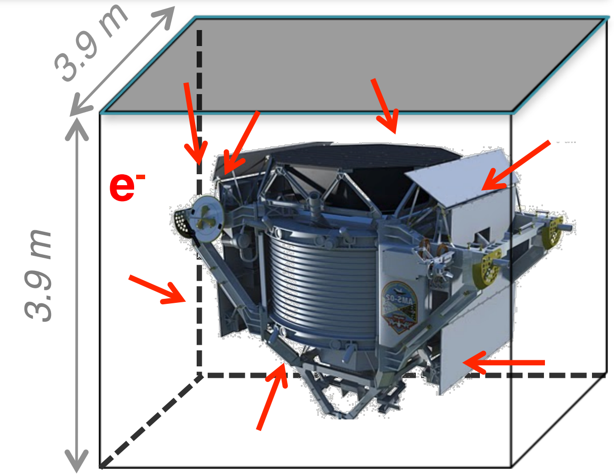
ε_{sel} = selection efficiency

δ = data driven correction

Acceptance

The final acceptance (i.e. after the selection cuts) is evaluated using MC (but the BDT cut)



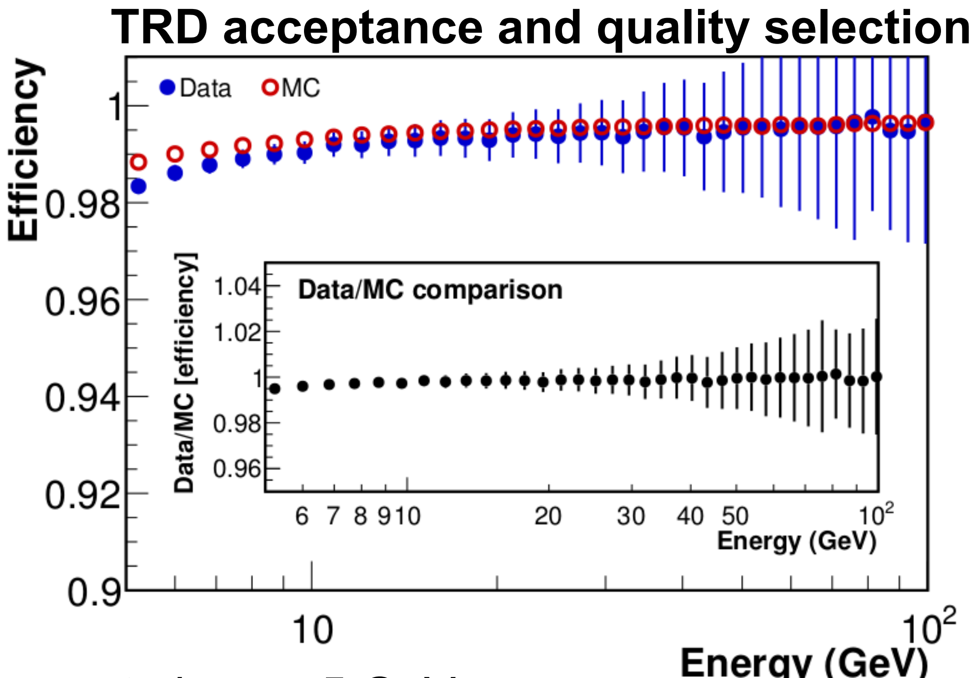


The effect of each cut has been checked on ISS data and, if needed, the value of acceptance "corrected" (O(%))

- Geometrical acceptance plateau at 500 cm^2sr defined by calorimeter volume
- **Very efficient particle selection** does not suppress the acceptance, even at high energies

Acceptance systematics

For **every selection cut** and for **trigger**, acceptance systematics is assessed by comparing the effect of selection on data and MC

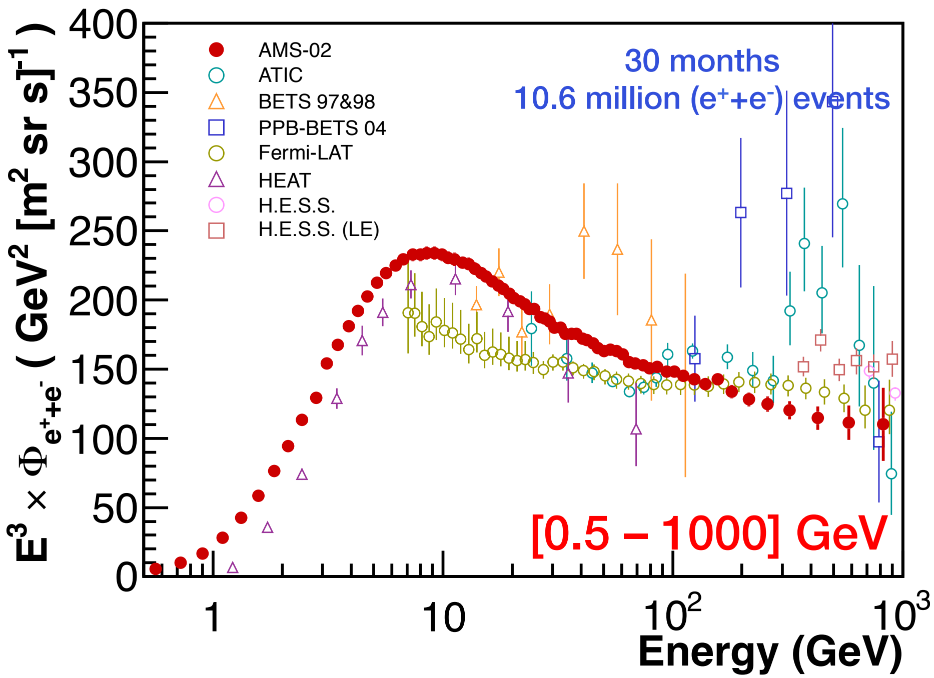


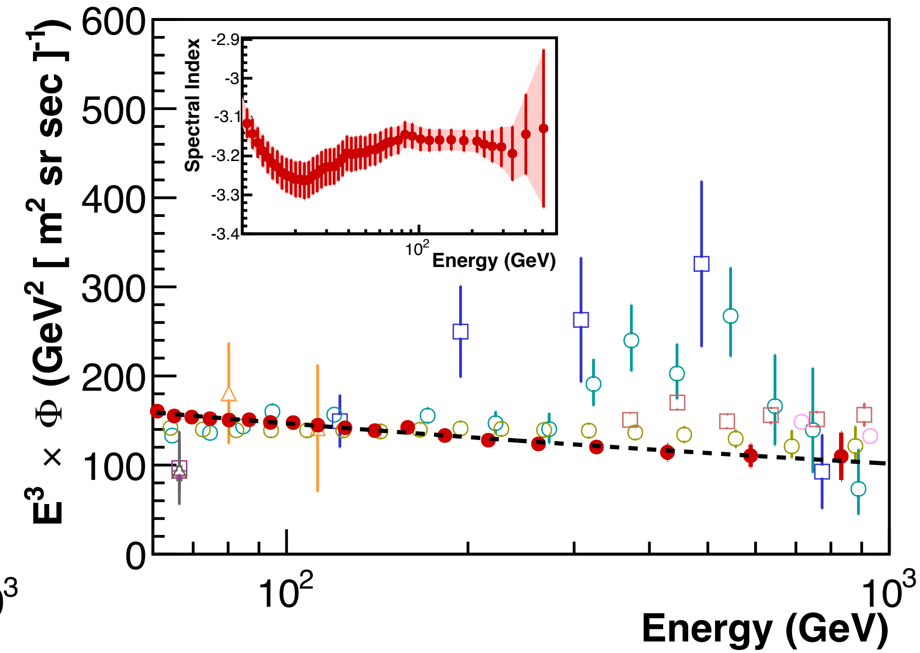
- Very good agreement above ~5 GeV
- Any deviation contributes to the final systematic

A global systematic from acceptance evaluation of few % from all the analysis cuts contributes to the measurement uncertainty

“All electrons” flux (PRL 113, 221102 - 2014)

Independent measure of the total $e^+ + e^-$ without identification of the charge sign. Less systematic uncertainties, higher energy reach, directly comparable with purely calorimetric measurements.



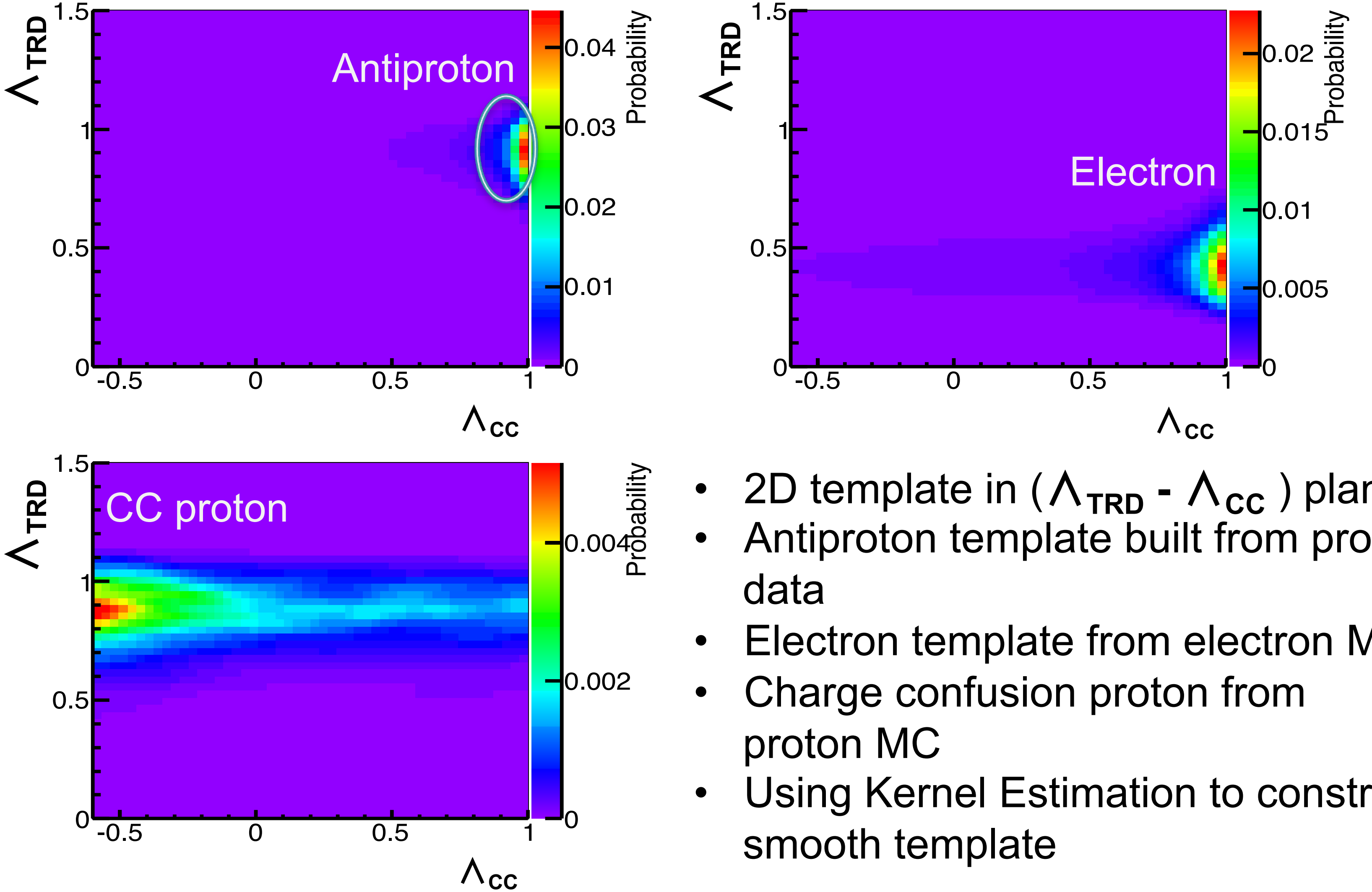


The $(e^+ + e^-)$ flux can be described by a single power-law, starting from ~30 GeV, and up to 1 TeV.

No evidence of fine structures

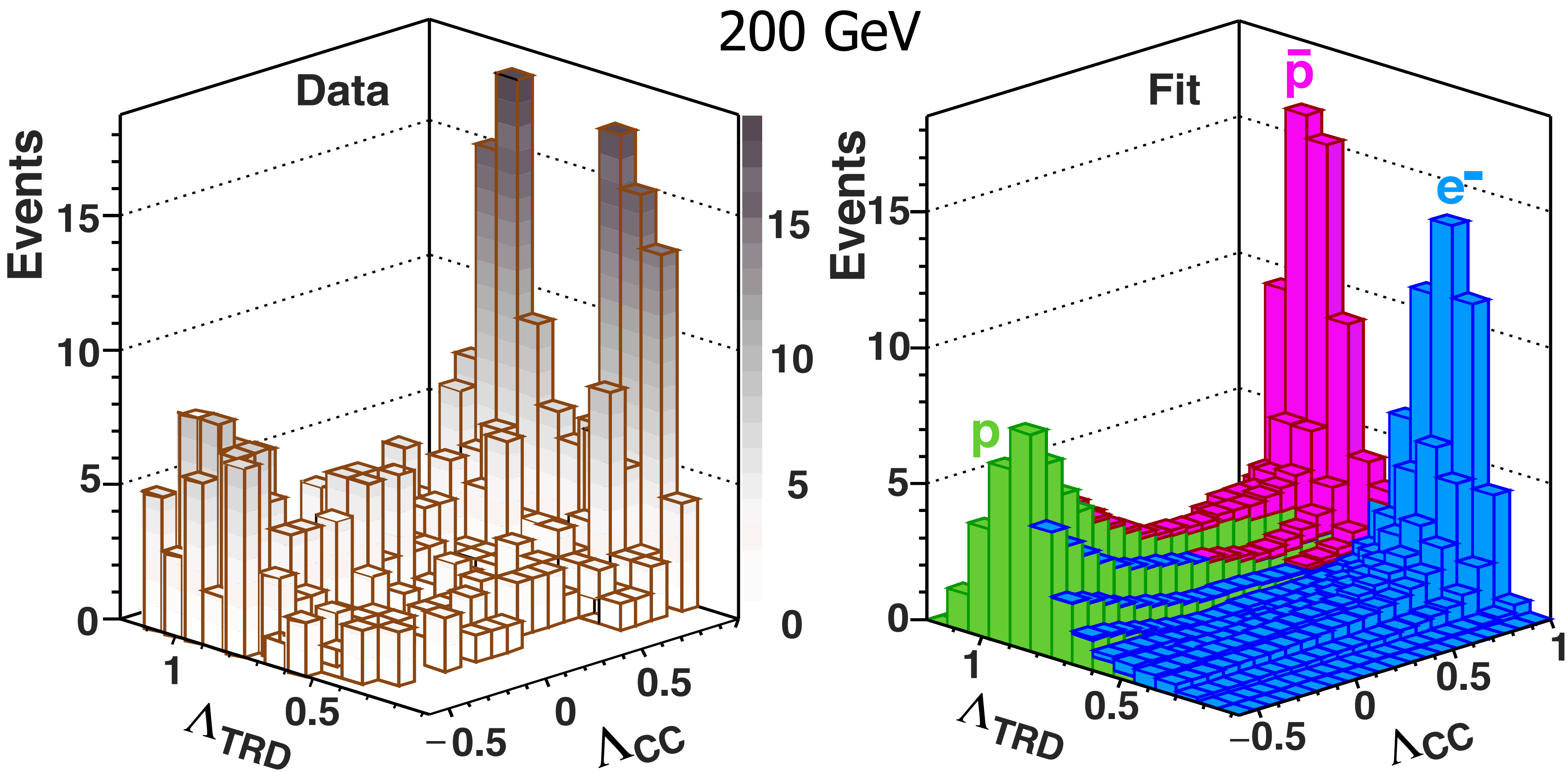
Antiprotons

Antiproton identification at high rigidity



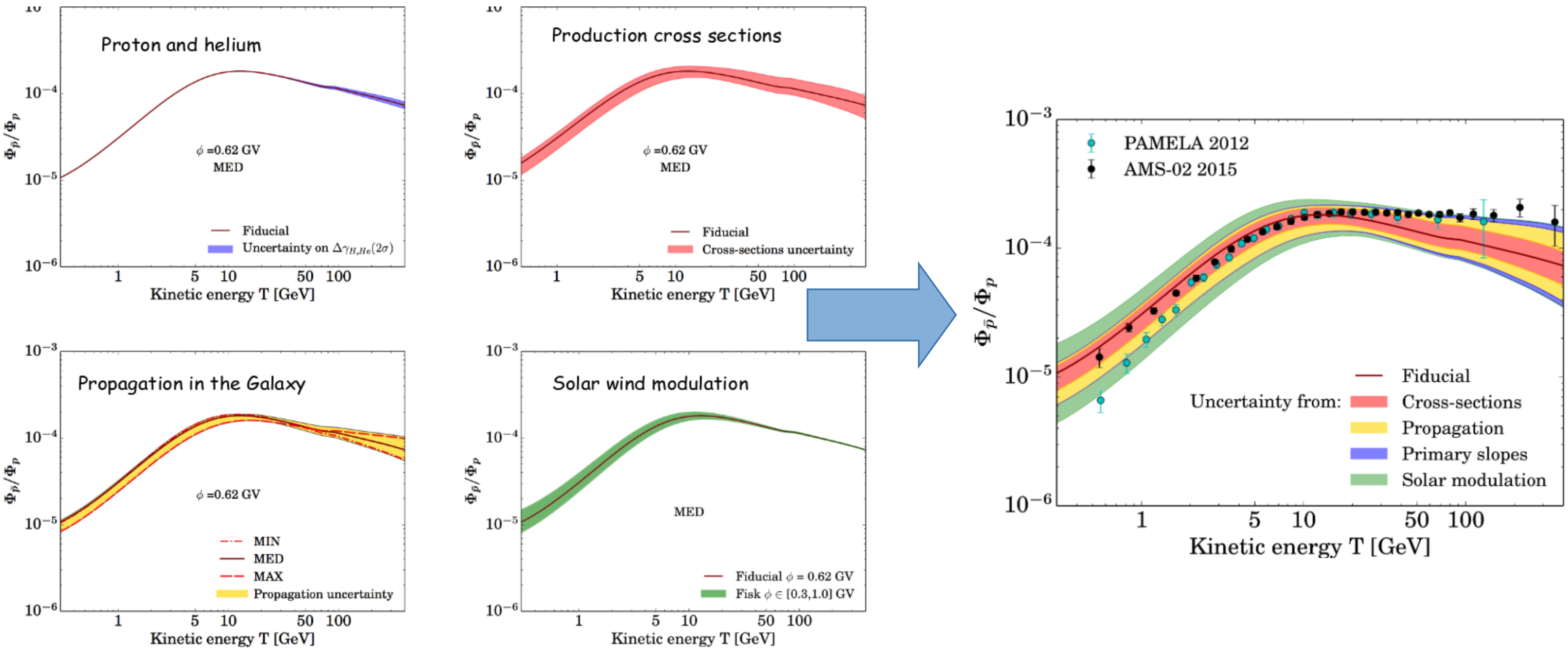
- 2D template in (Λ_{TRD} - Λ_{CC}) plane
- Antiproton template built from proton data
- Electron template from electron MC
- Charge confusion proton from proton MC
- Using Kernel Estimation to construct smooth template

Antiproton identification at high rigidity



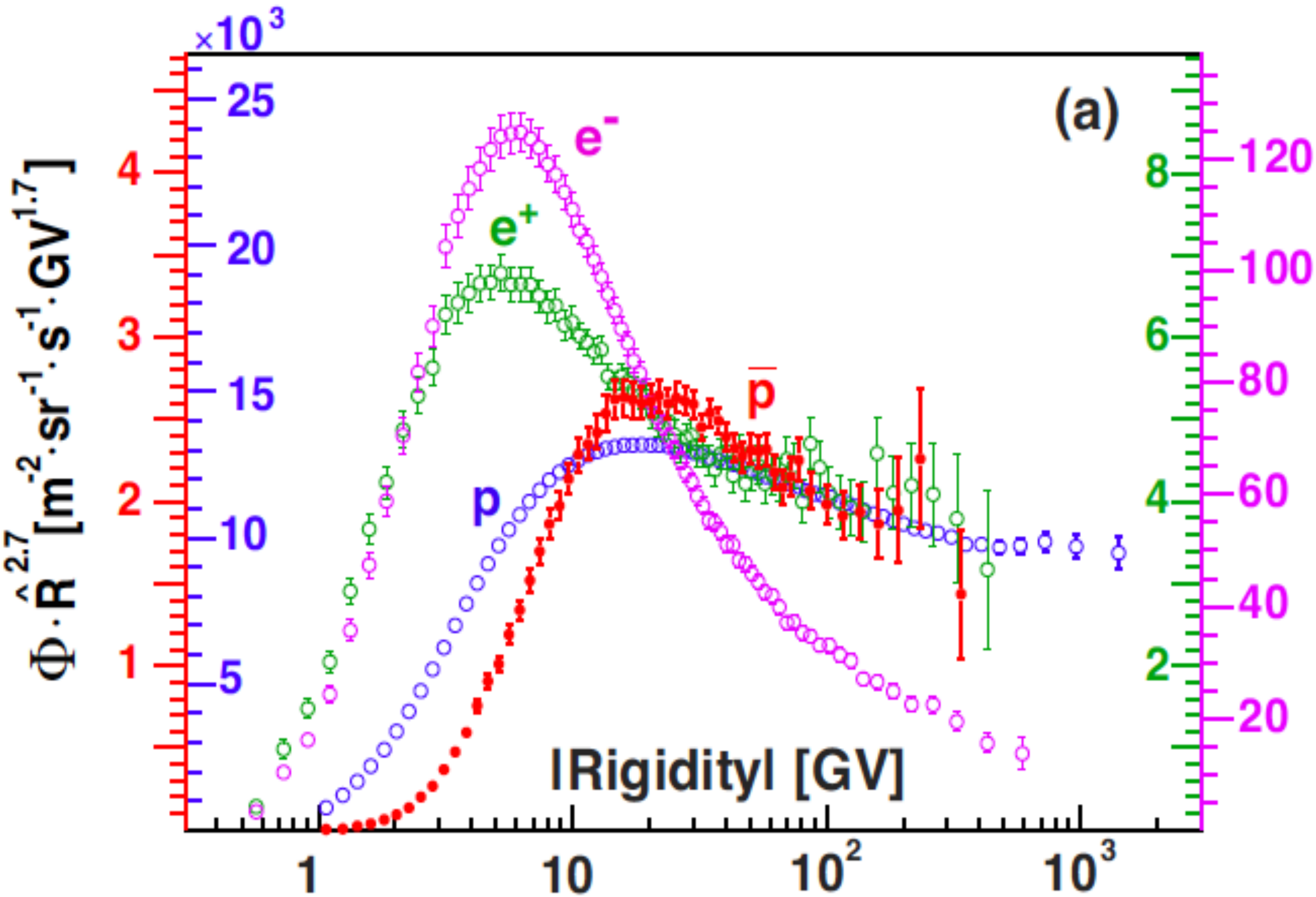
Example of model uncertainties

Example: Giesen et al. arXiv:1504.04276 tuning only AMS02-P and preliminary AMS02-He (no tuning on other preliminary AMS02 nuclei data)

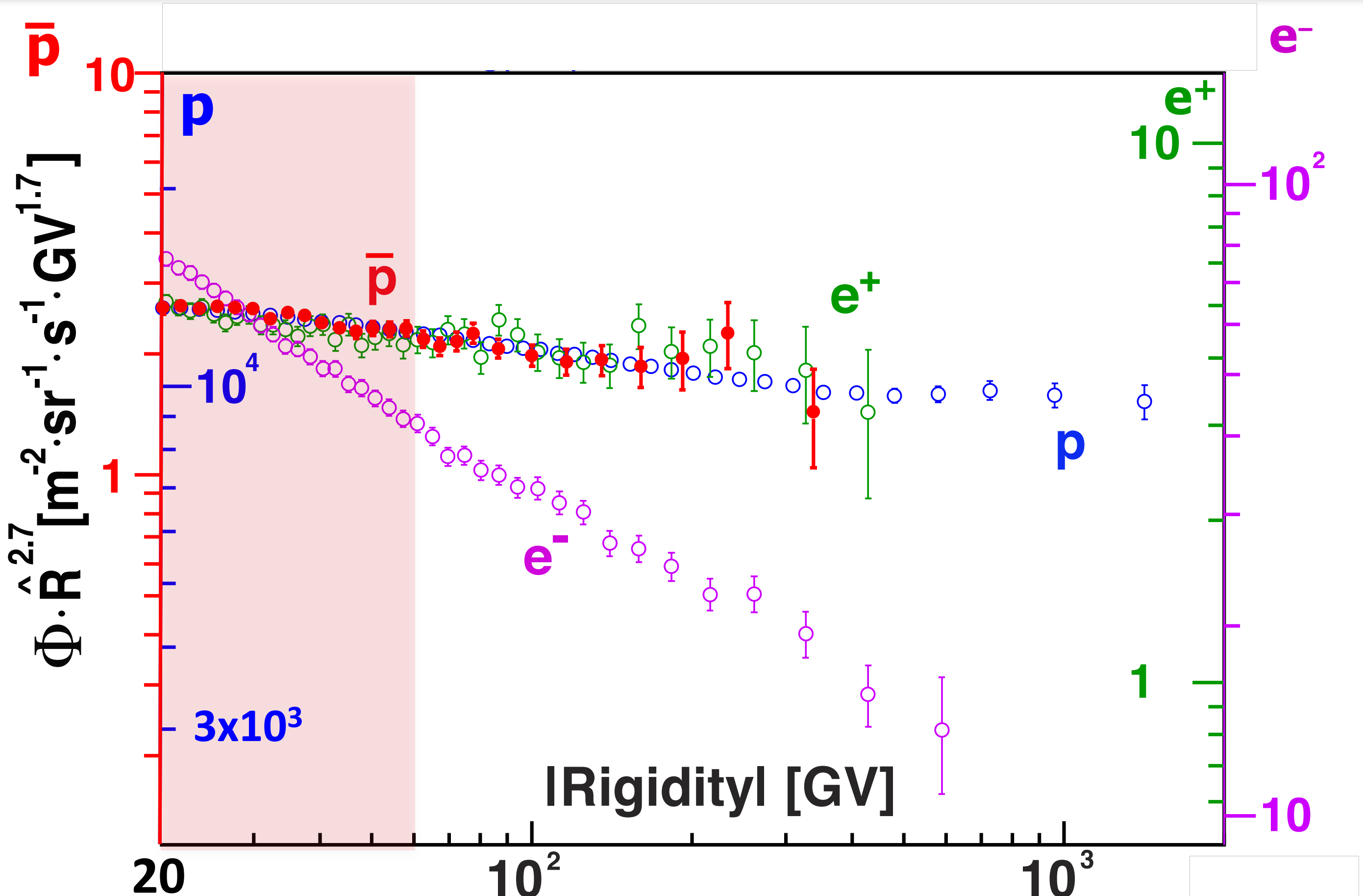


uncertainties from secondary anti-p production cross sections and propagation models are much larger than AMS02 errors in the anti-p ratio measurement

Elementary particle fluxes measured by AMS

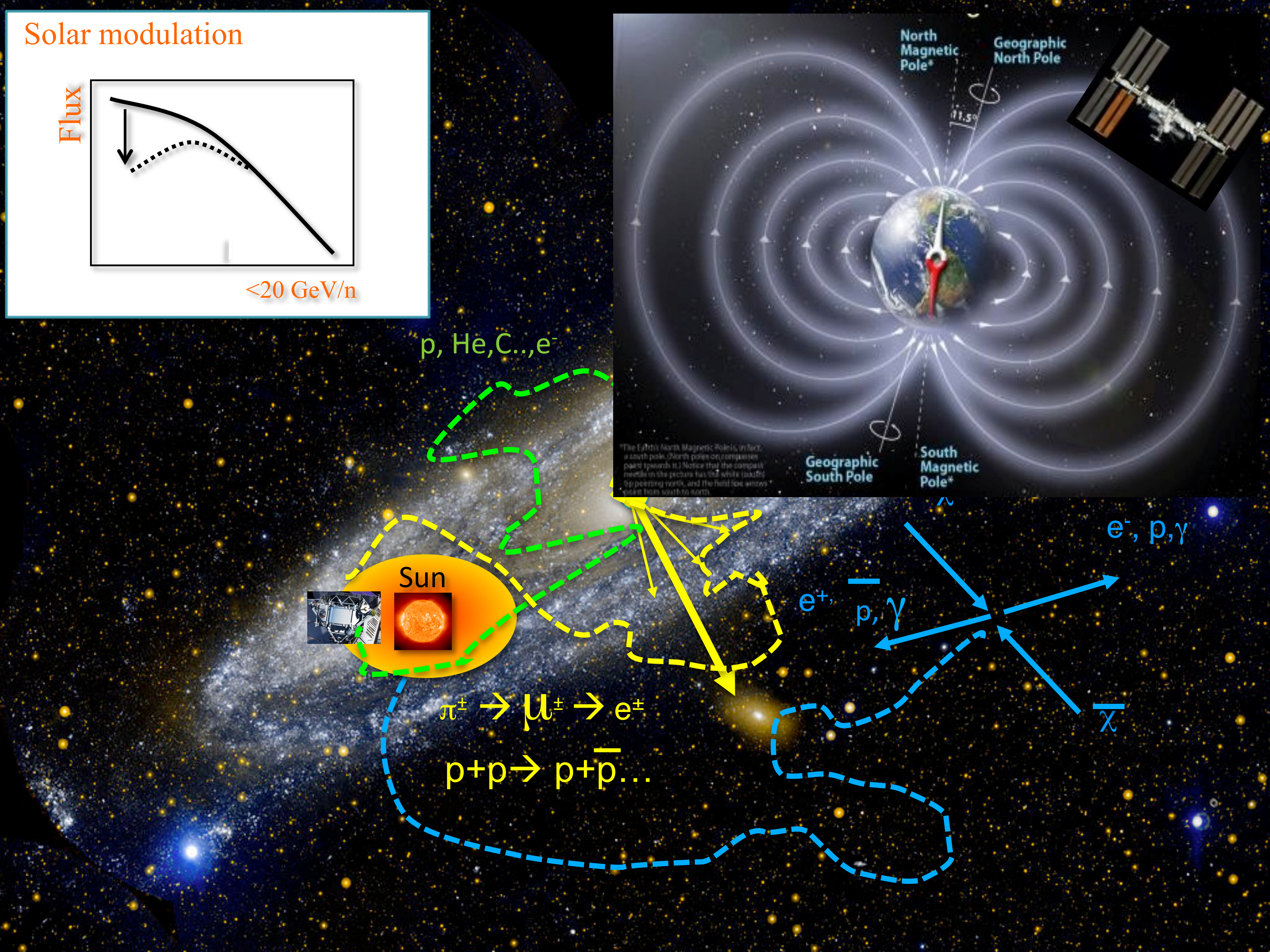


Anti-proton/proton ratio (PRL 117, 091103 - 2016)

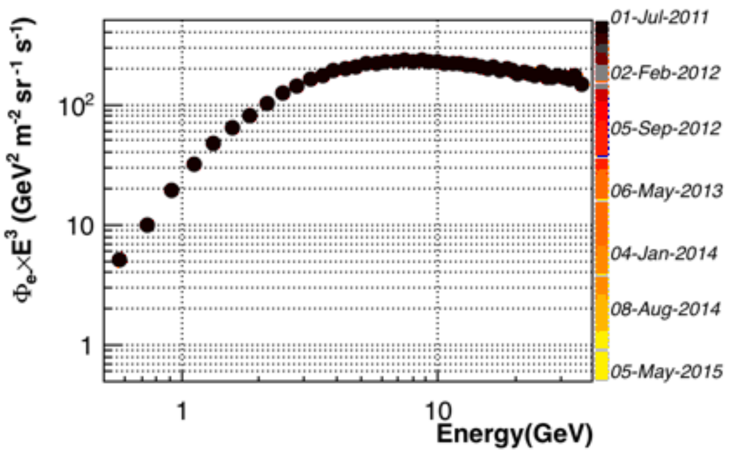


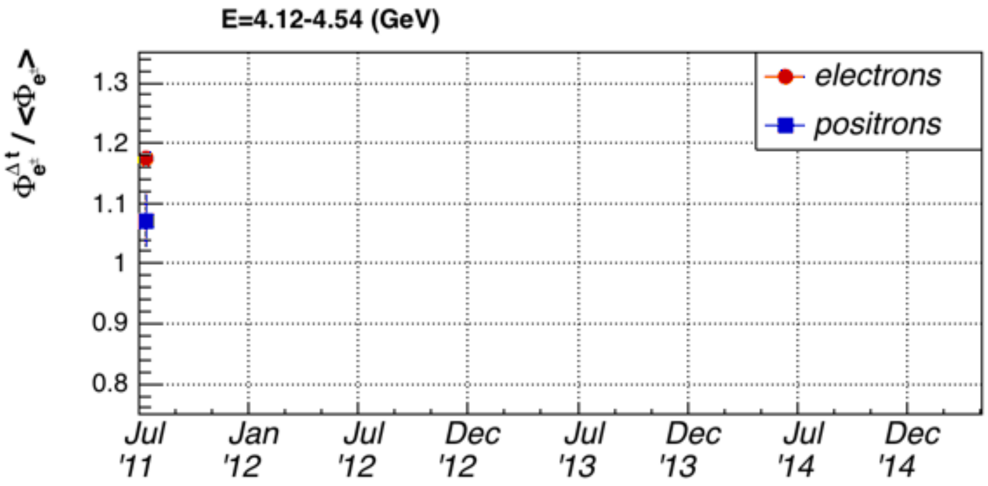
The study of the flux variation with energy seems to indicate that protons, antiprotons and positrons, but not electrons, have the same spectral index. By chance or something more profound?

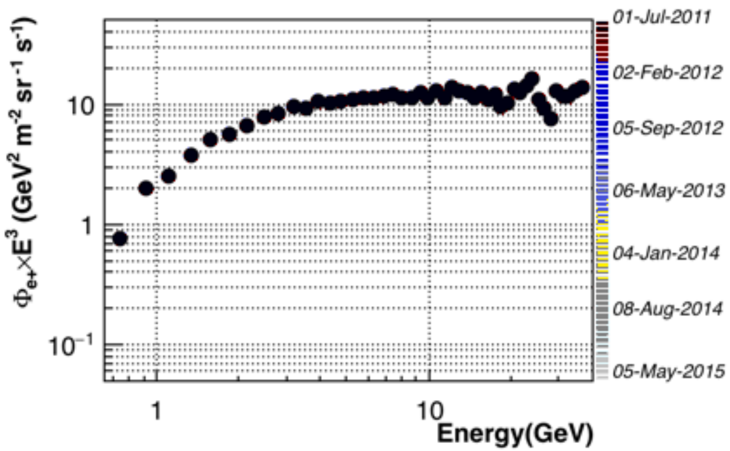
Time variabilities

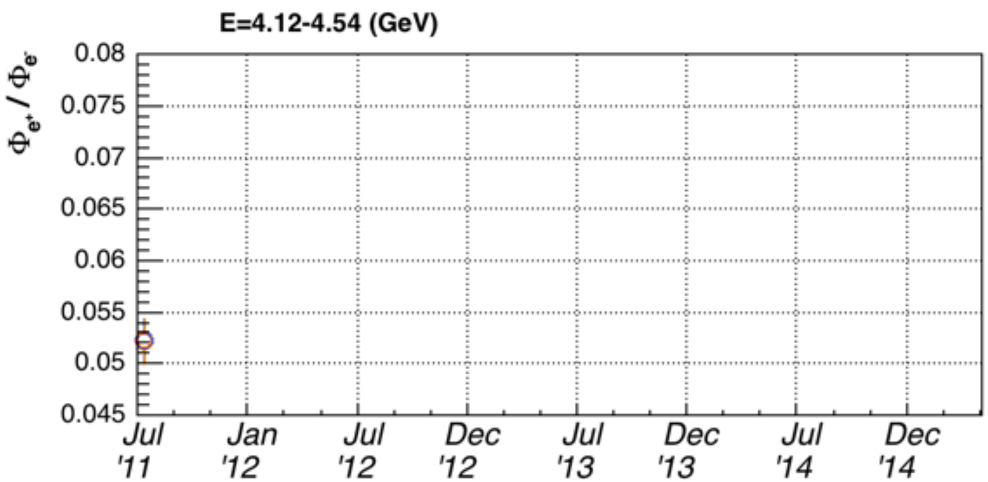

Solar modulation
Flux
<20 GeV/n
North Magnetic Pole*
Geographic North Pole
11.5°
Geographic South Pole
South Magnetic Pole*
p, He,C..,e⁻
Sun
π± → μ± → e±
p+p→ p+p̄…
e+, p̄, γ
e⁻, p,γ
χ
χ̄

Fluxes as function of time, e^+/e^-

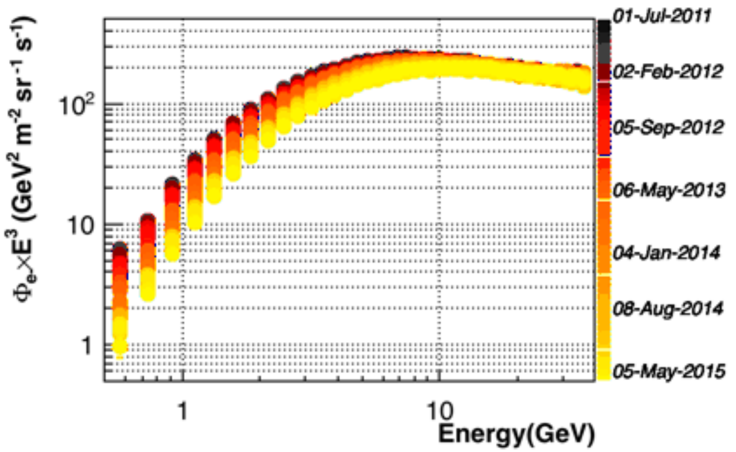


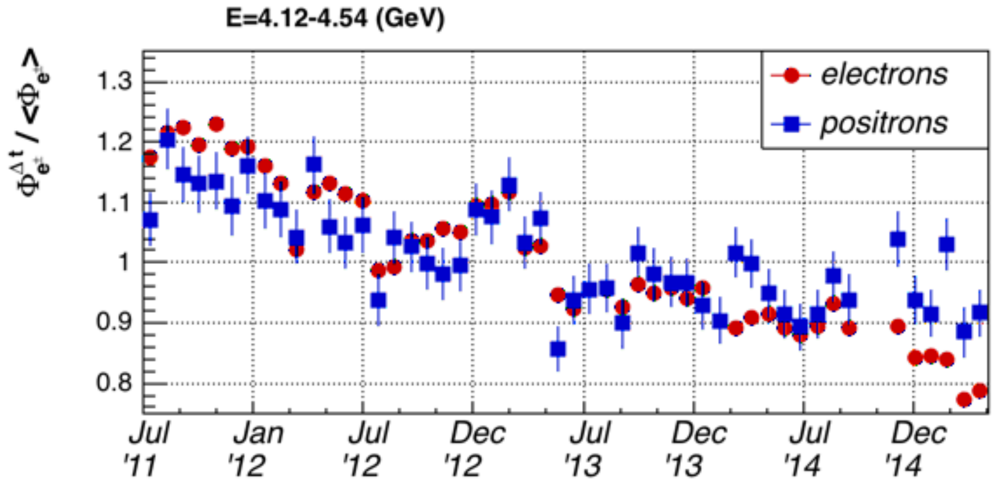


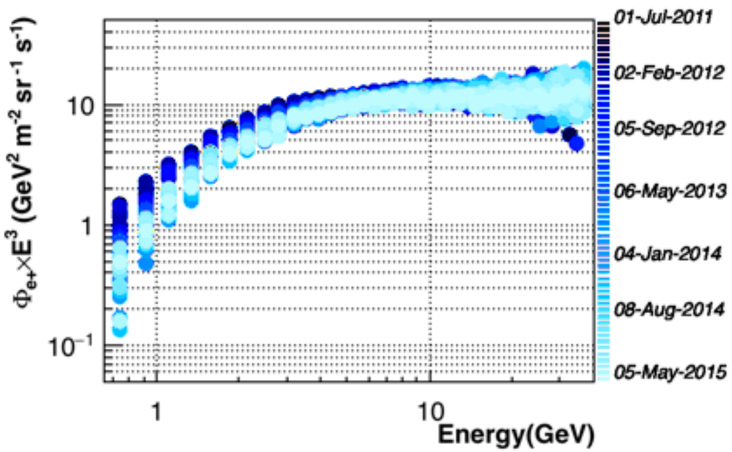


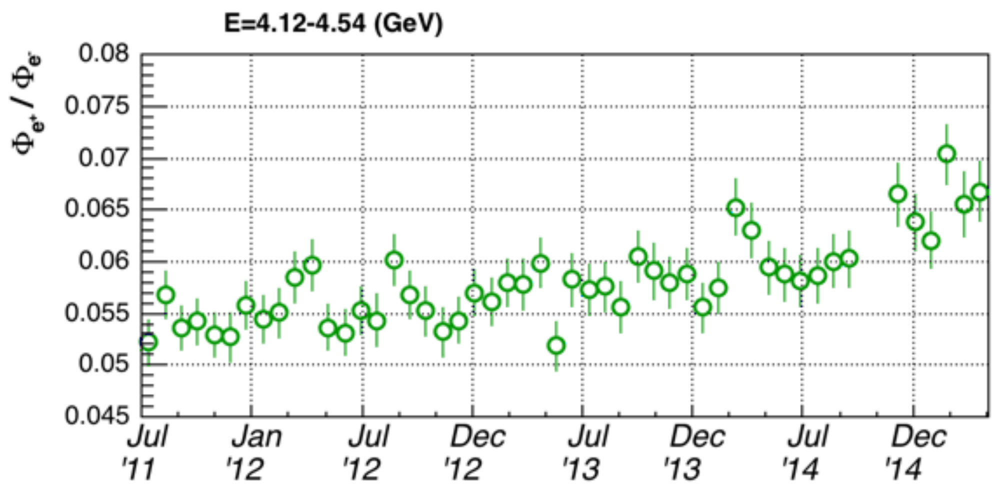


Fluxes as function of time, e^+/e^-







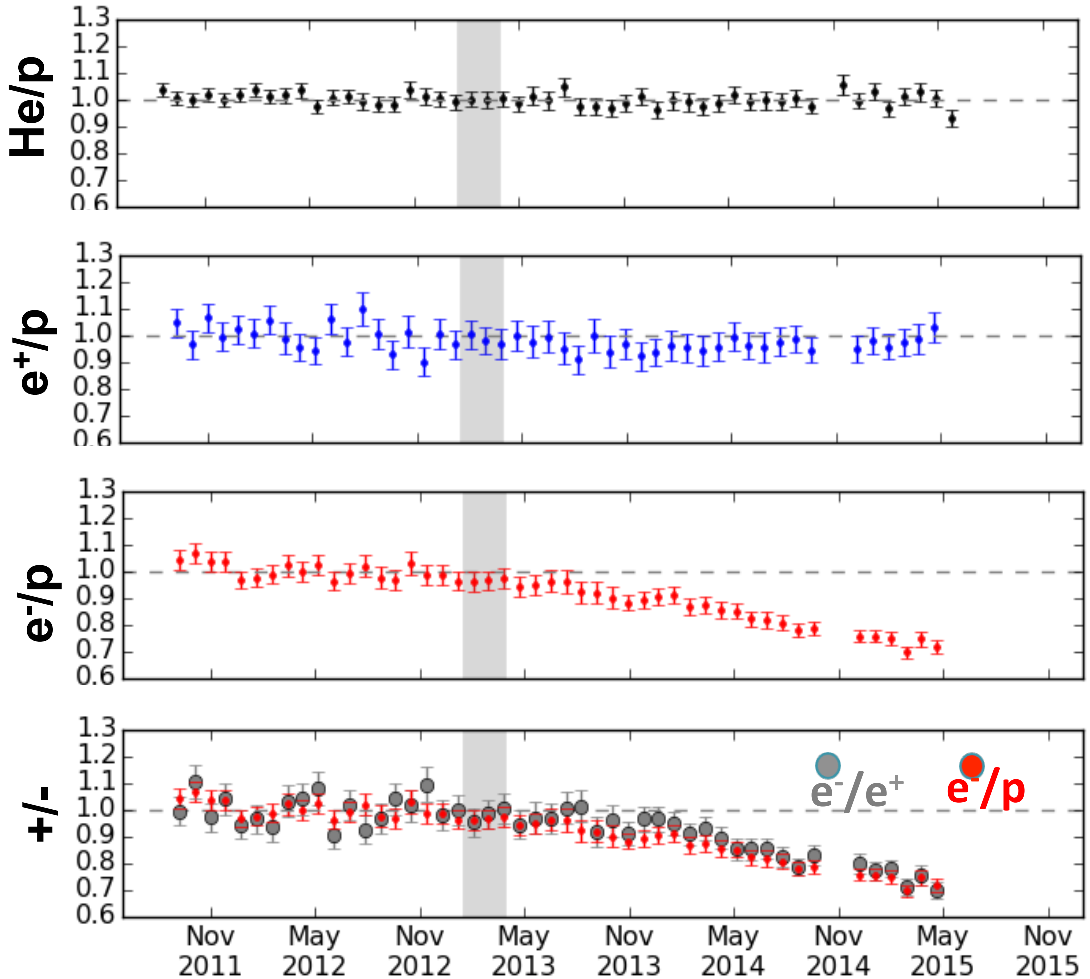


Fluxes as function of time, charge sign effects

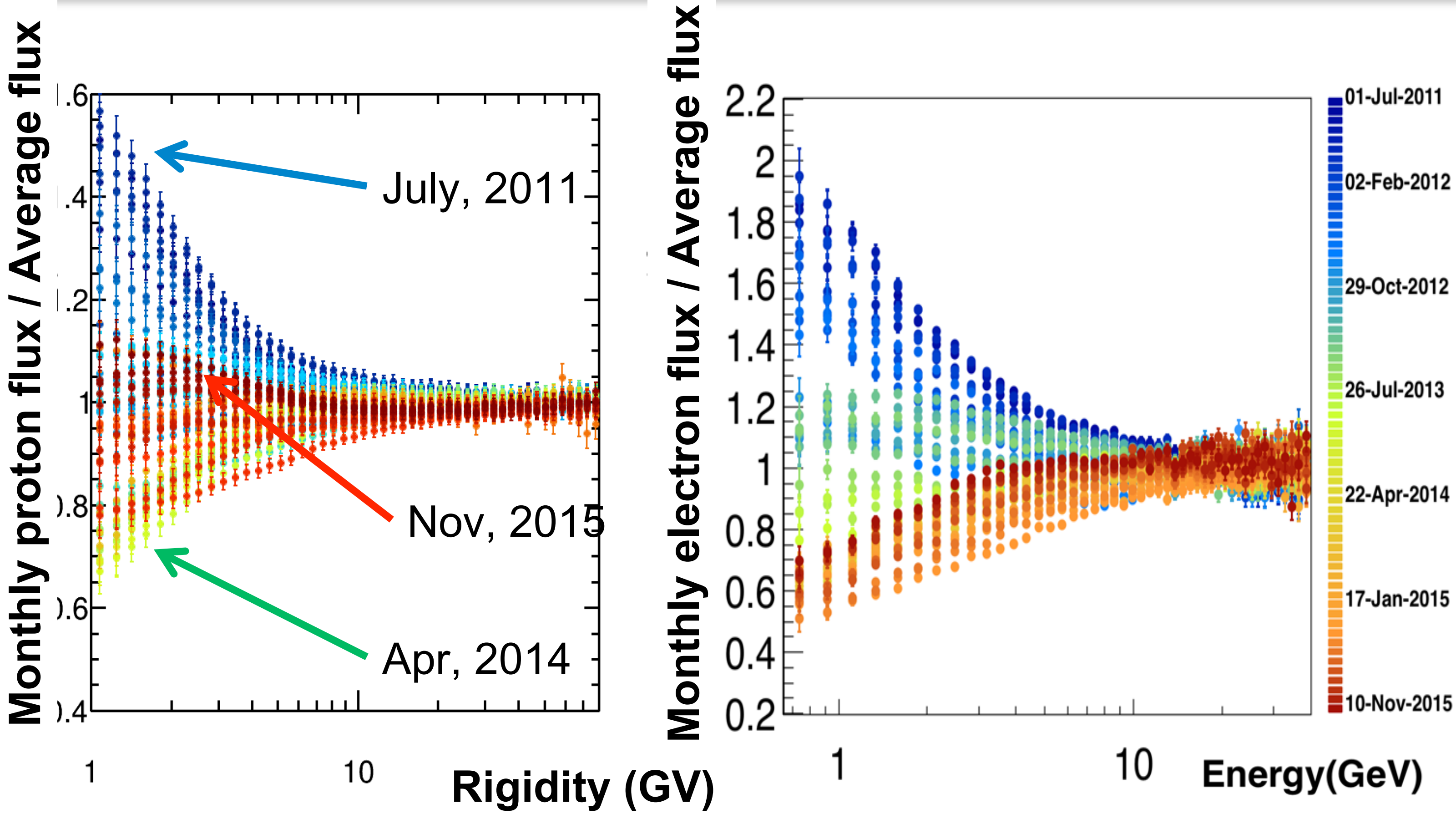
2 GeV

Different species, same sign of charge

Different species, different sign of the charge



Solar effects & flux time dependence



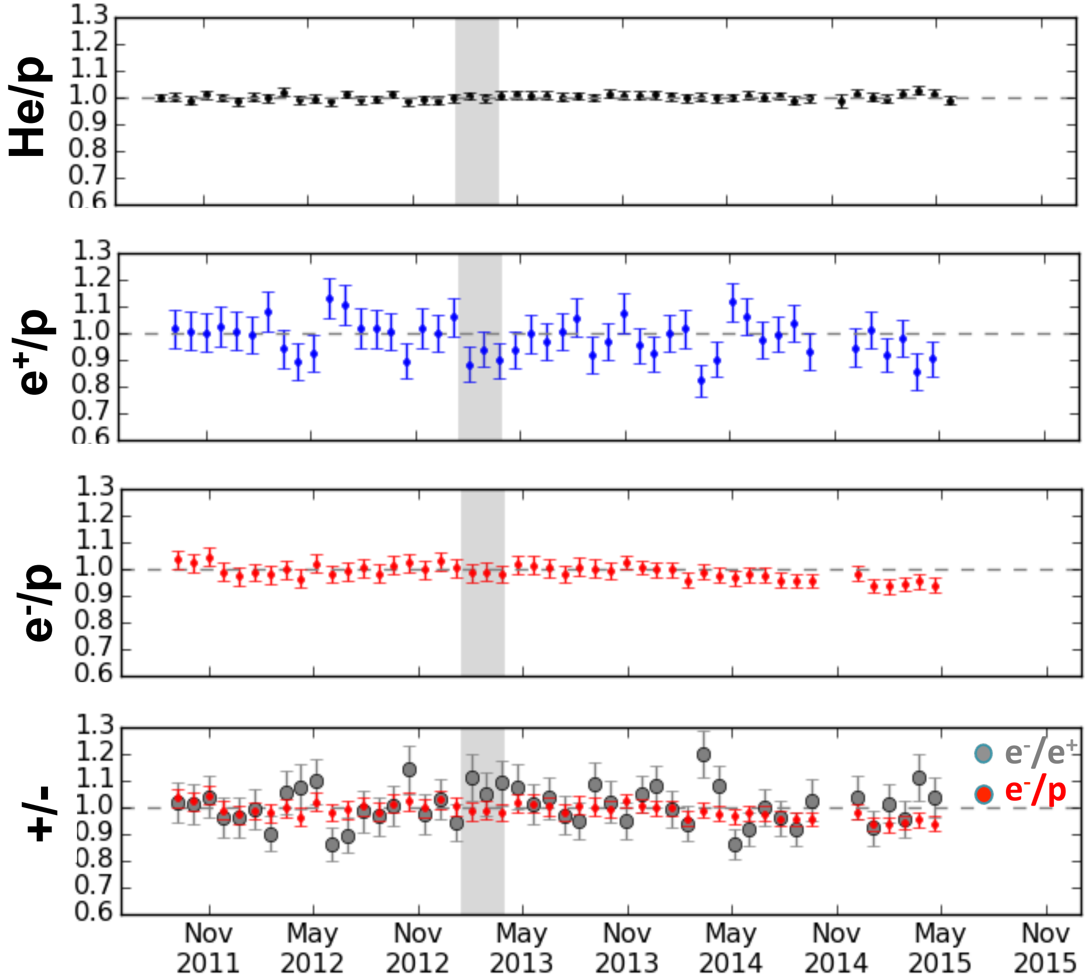
Time variation of proton and electron fluxes from mid-2011 to end 2015. Reported is the monthly flux with respect to average flux over ≈4 years.

Solar effects & flux time dependence

10 GeV

Different species
Same charge sign

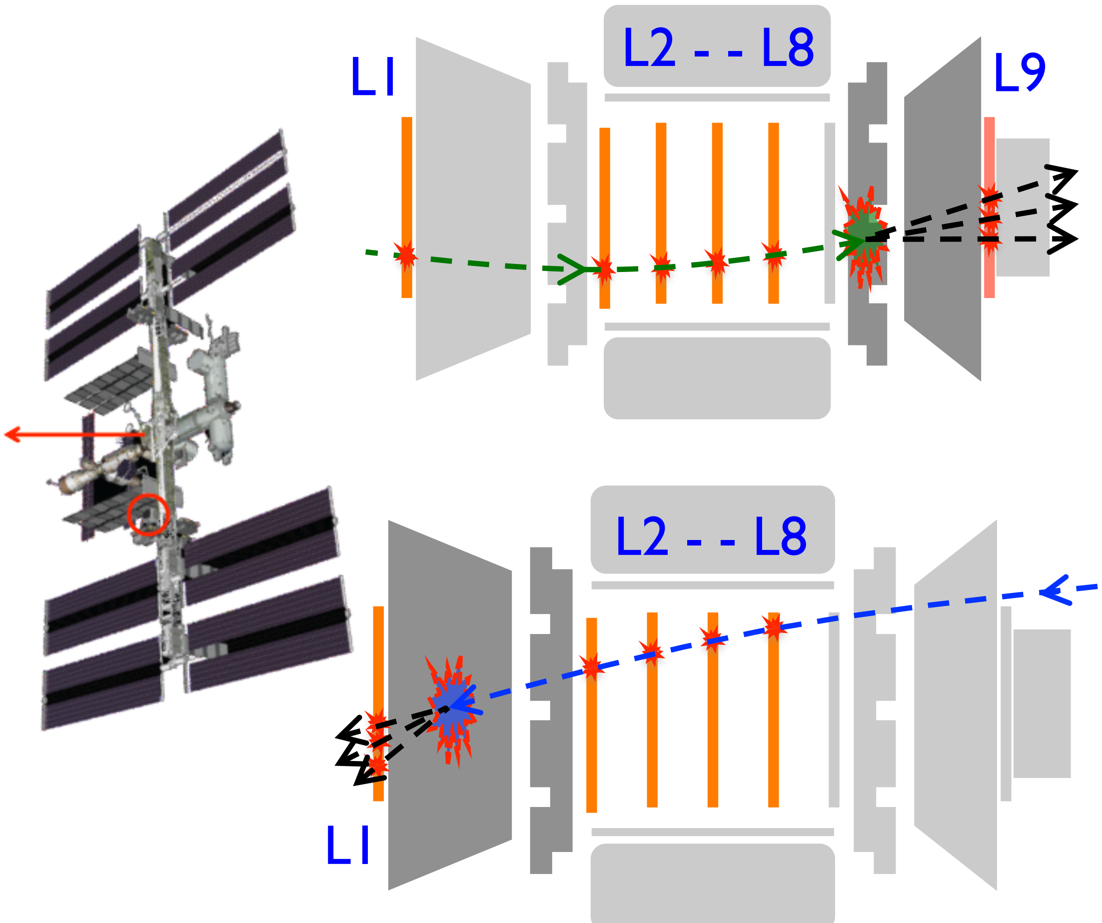
Different species
opposite charge sign



Protons, helium and nuclei

Full control of the effects from detector material

Measurement of nuclear cross sections / accurate check of the materials when AMS is flying in horizontal attitude



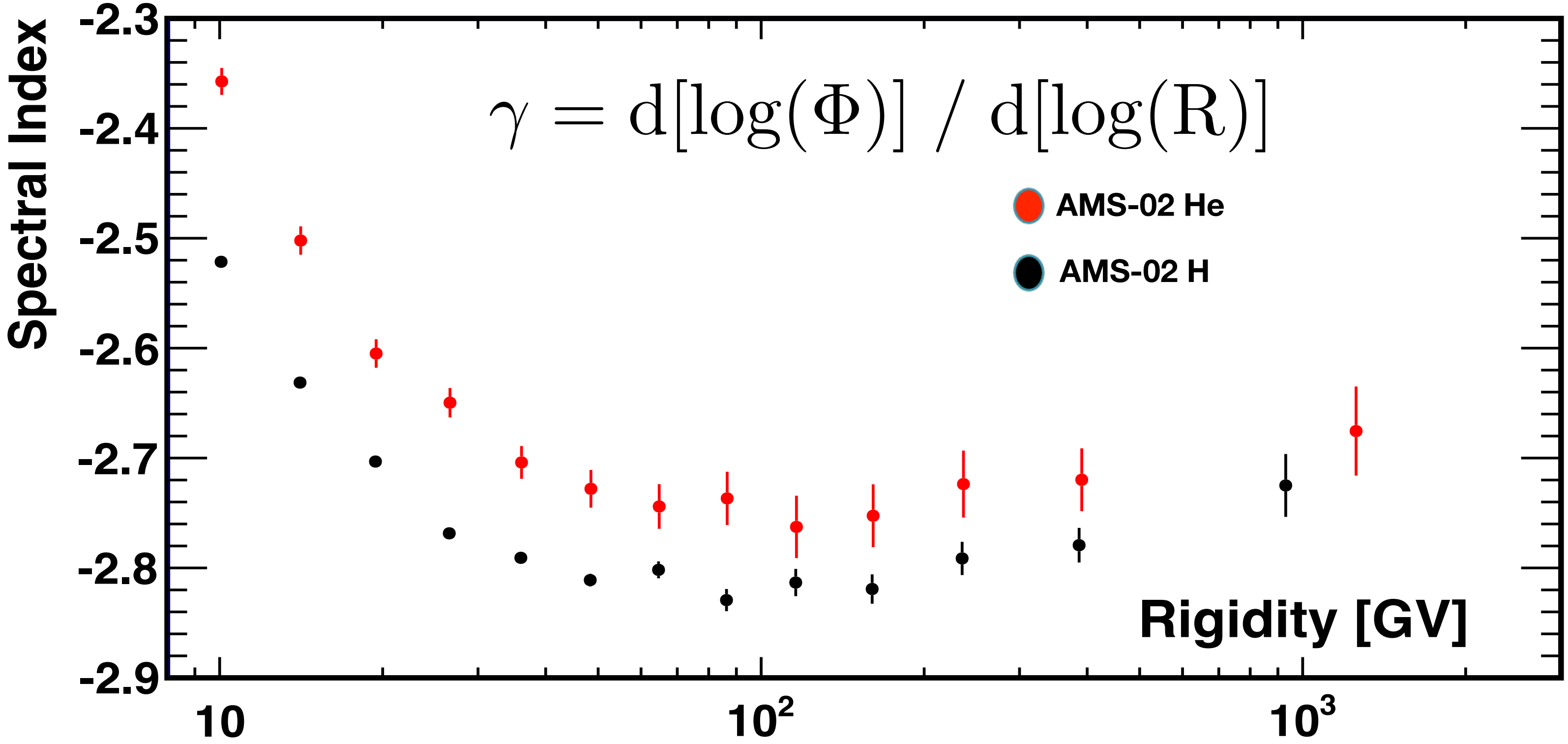
First, we use the seven inner tracker layers, L2-L8, to define beams of nuclei: He, Li, Be, B, …

Second, we use left-to-right particles to measure the nuclear interactions in the lower part of the detector.

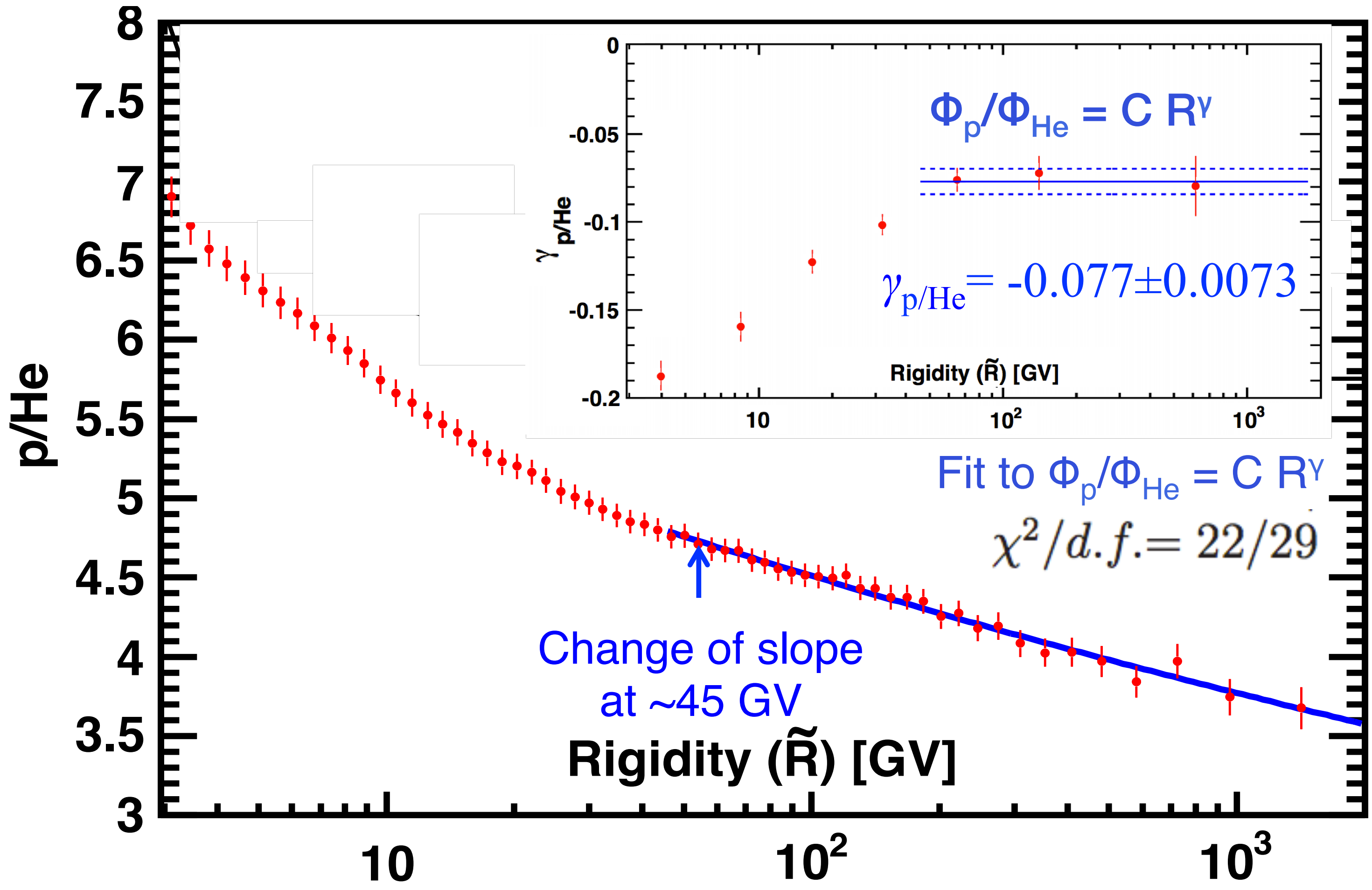
Third, we use right-to-left particles to measure the nuclear interactions in the upper part of detector.

Proton and Helium Fluxes

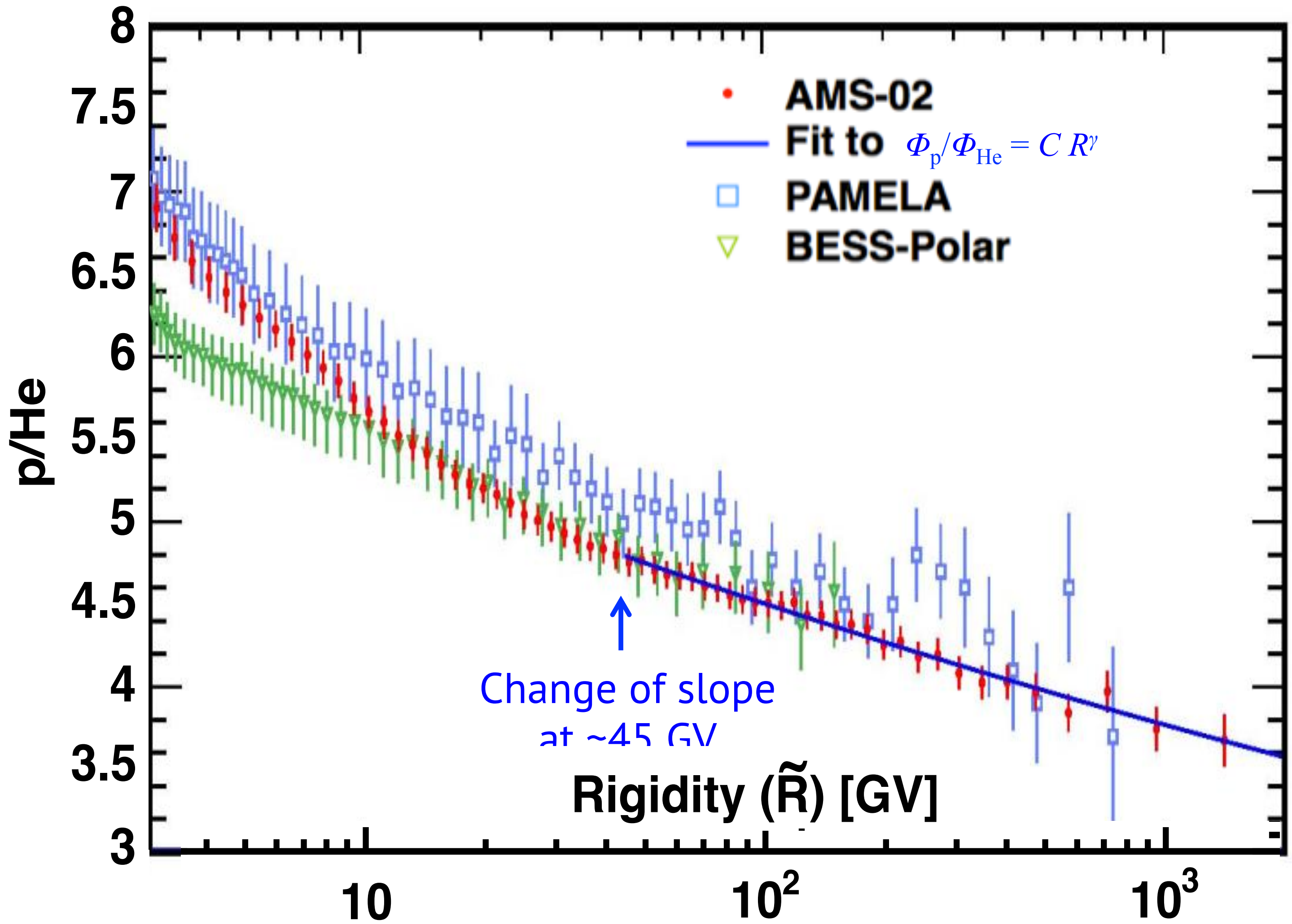
Model independent spectral index analysis



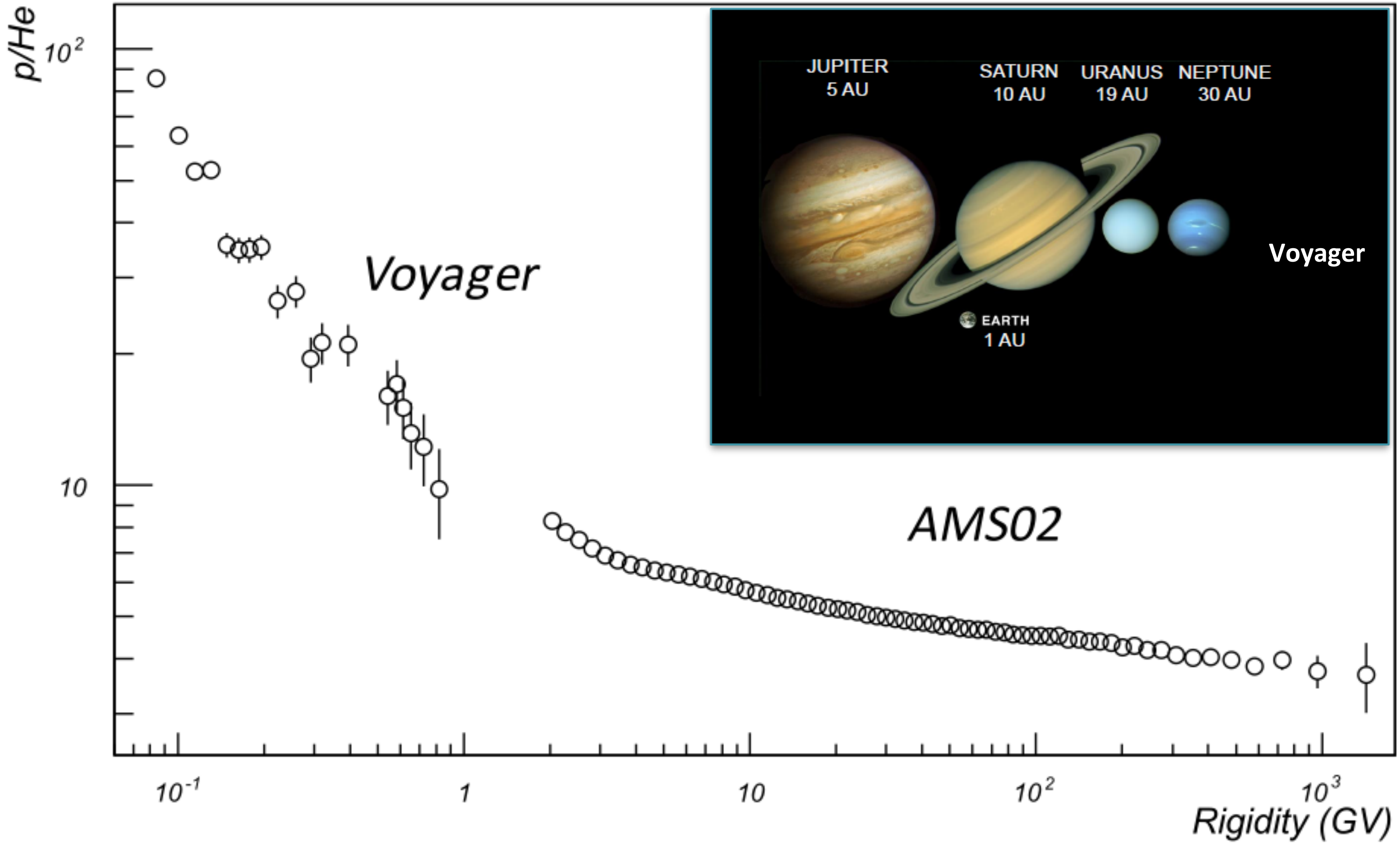
Proton and Helium Fluxes



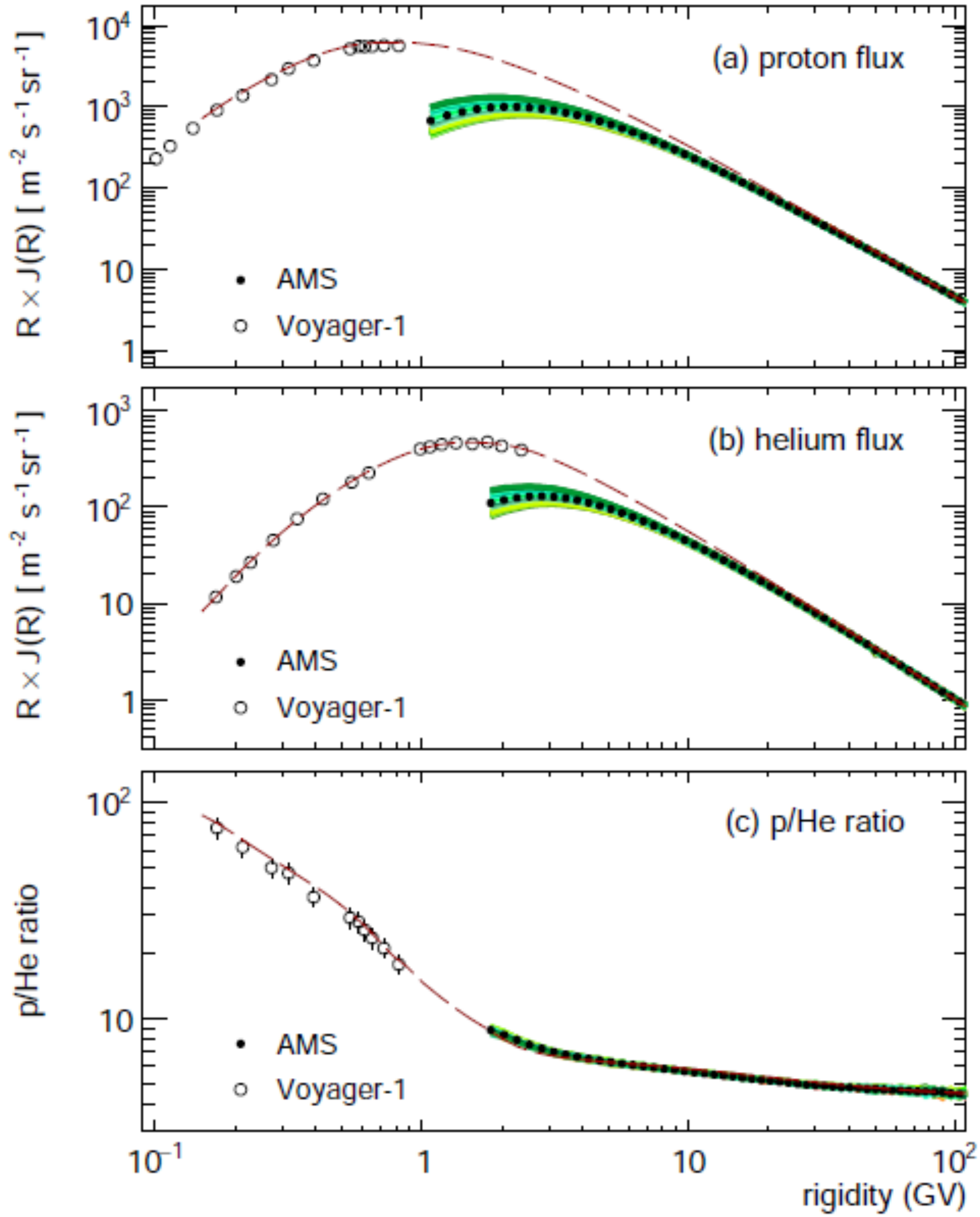
AMS p/He flux ratio



AMS p/He flux ratio vs time

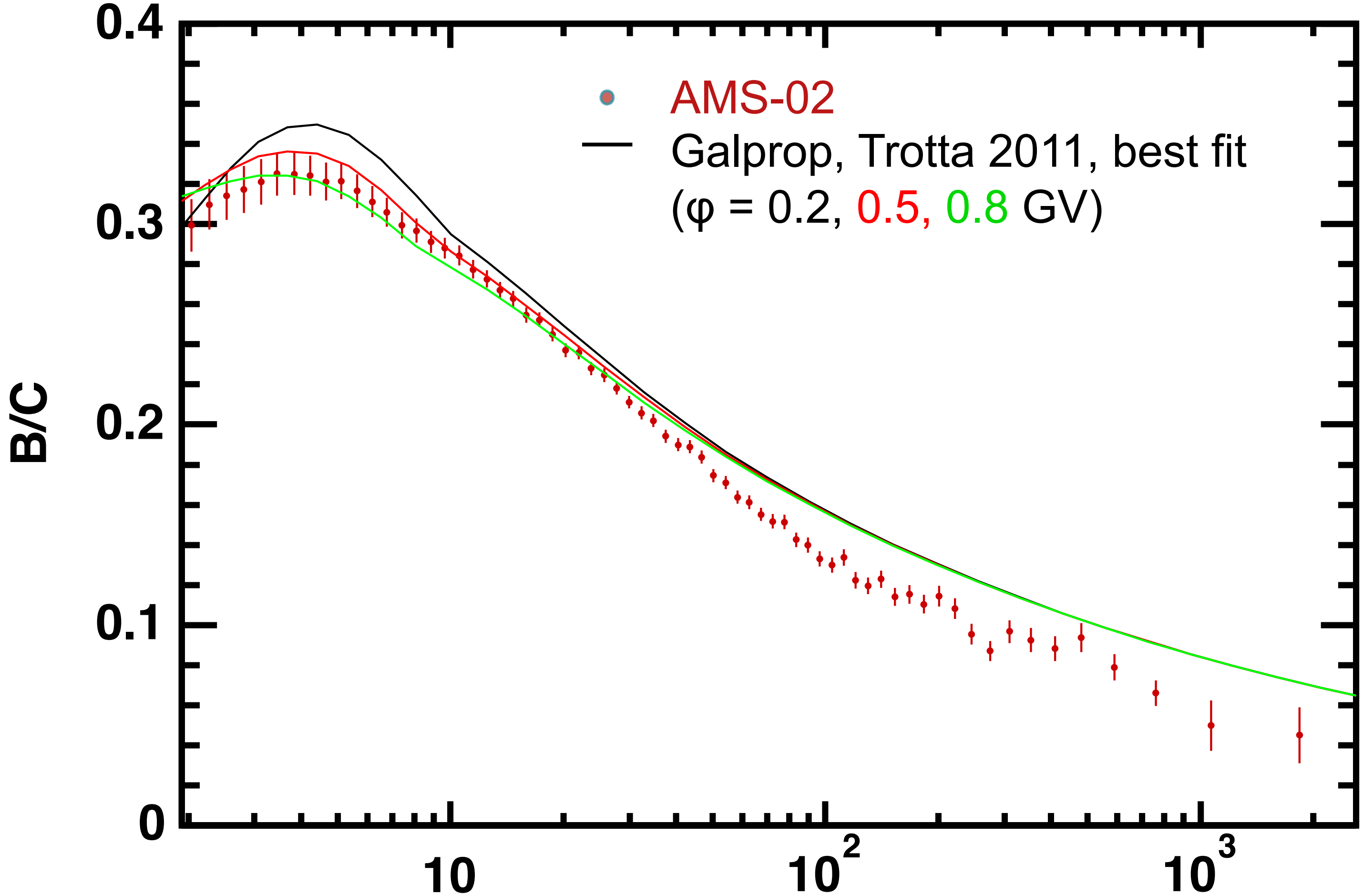


The p/He ratio is independent of solar activity

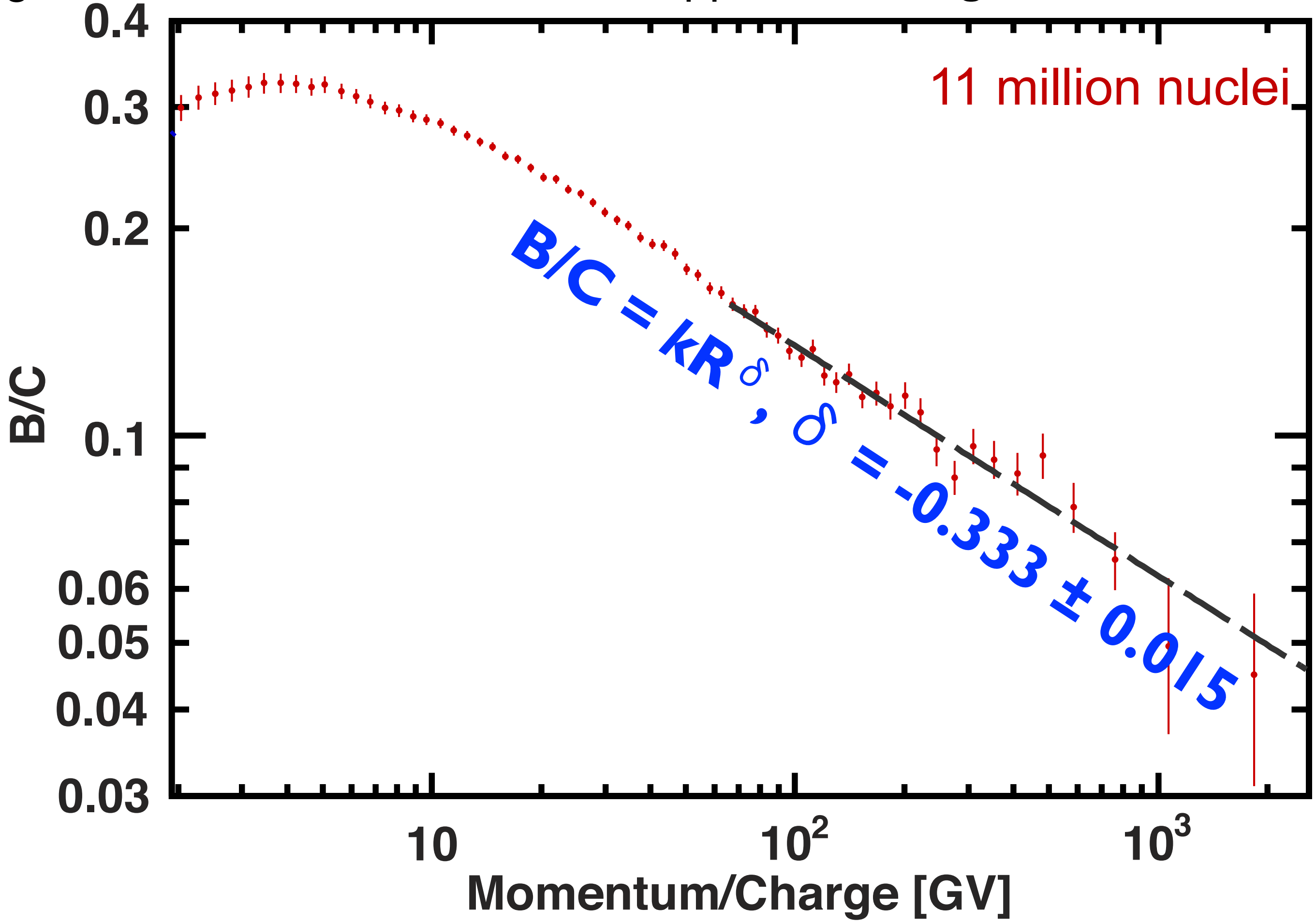

(a) proton flux
(b) helium flux
(c) p/He ratio
AMS
Voyager-1
R × J(R) [m^-2 s^-1 sr^-1]
p/He ratio
rigidity (GV)

Secondary CRs: Boron to Carbon flux ratio

AMS-02 precision challenges current theoretical models



The flux ratio between primaries (C) and secondaries (B) provides information on propagation and the ISM: AMS data supports Kolmogorov turbulence model



AMS B/C results

The B/C ratio does not show any significant structures in contrast to many cosmic ray models that require such structures at high rigidities.

Remarkably, above 65 GV, the B/C ratio is well described by a single power law
B/C = *k* R^δ with **δ = -0.333 ± 0.015.**

$B/C = k R^{\delta}$ with $\delta = -0.333 \pm 0.015$.

This is in agreement with
the Kolmogorov turbulence model
of magnetized plasma of
δ = -1/3 asymptotically.

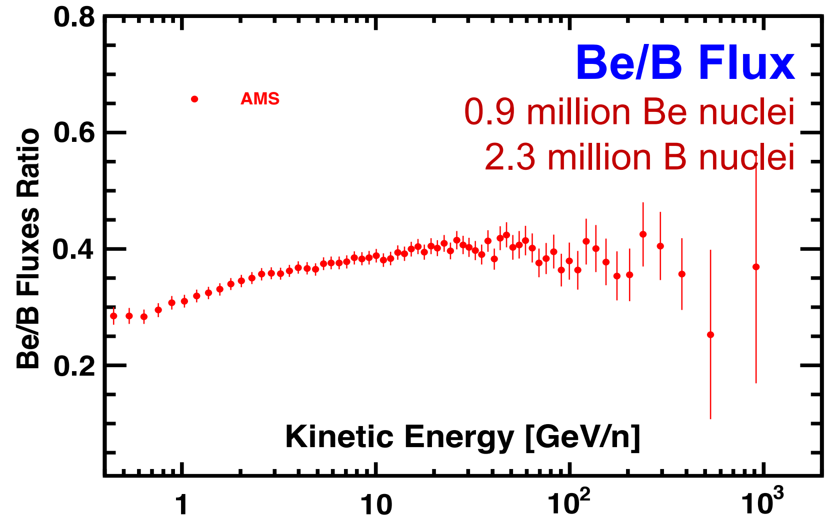
(Kraichnan: δ=-1/2)

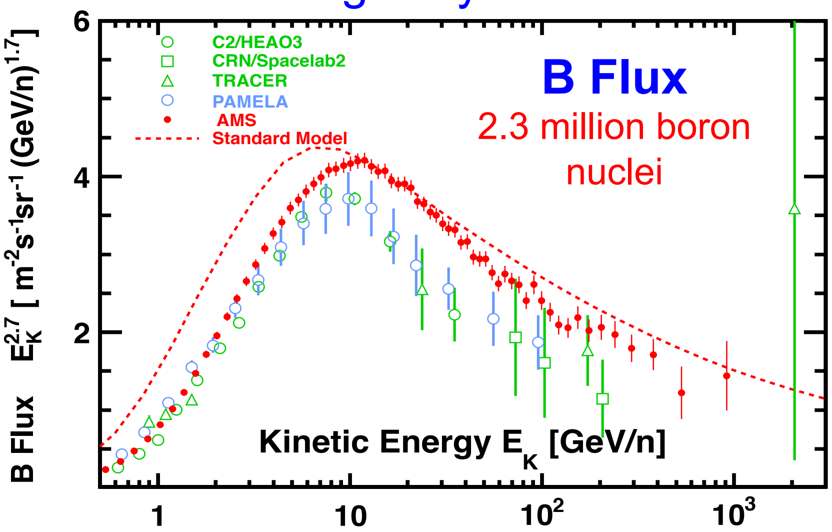
Still on secondaries…

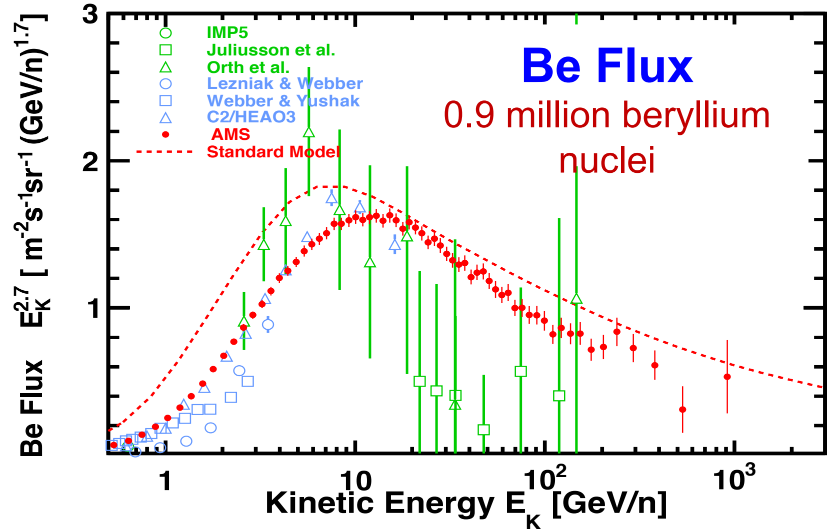
^{10}Be is a natural *clock* to measure the residence time of CR in the galaxy: $^{10}Be \rightarrow {}^{10}B + e^{-} + \nu_e$ with half-life of 1.5 x 10^6 years

Relativistic time dilation at high energies delays the ^{10}Be decay and makes the the Be/B ratio to increase.

A fit to the Be/B ratio can be used to extract residence time in the galaxy







Primaries with higher charge…

AMS-02 measures Carbon, Nitrogen, Oxygen fluxes in an extended energy range and unprecedented prevision.

Ongoing analyses based on ~ 6 years data (2011-2017):

- Standard model: GALPROP

with best fit parameters *Trotta et al, 2011*