AMS-02 RICH detector status and physics results

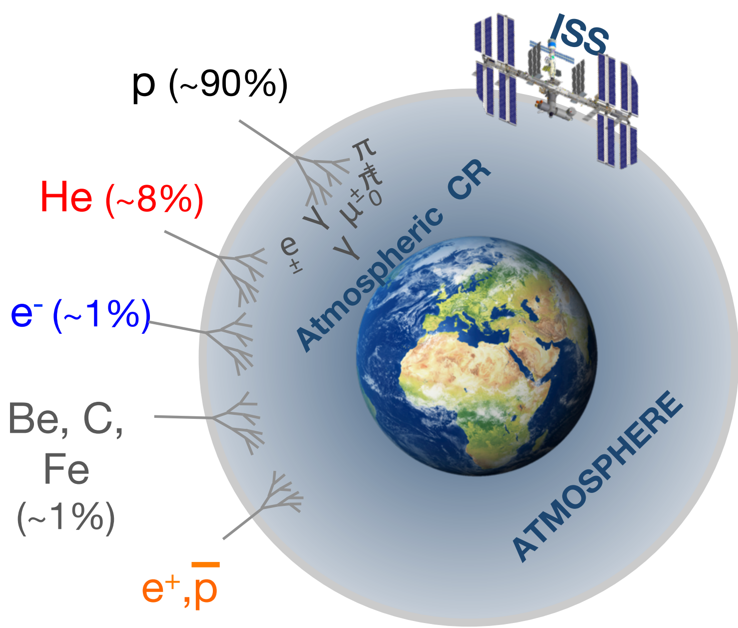
F. Giovacchini
for the AMS-RICH Collaboration

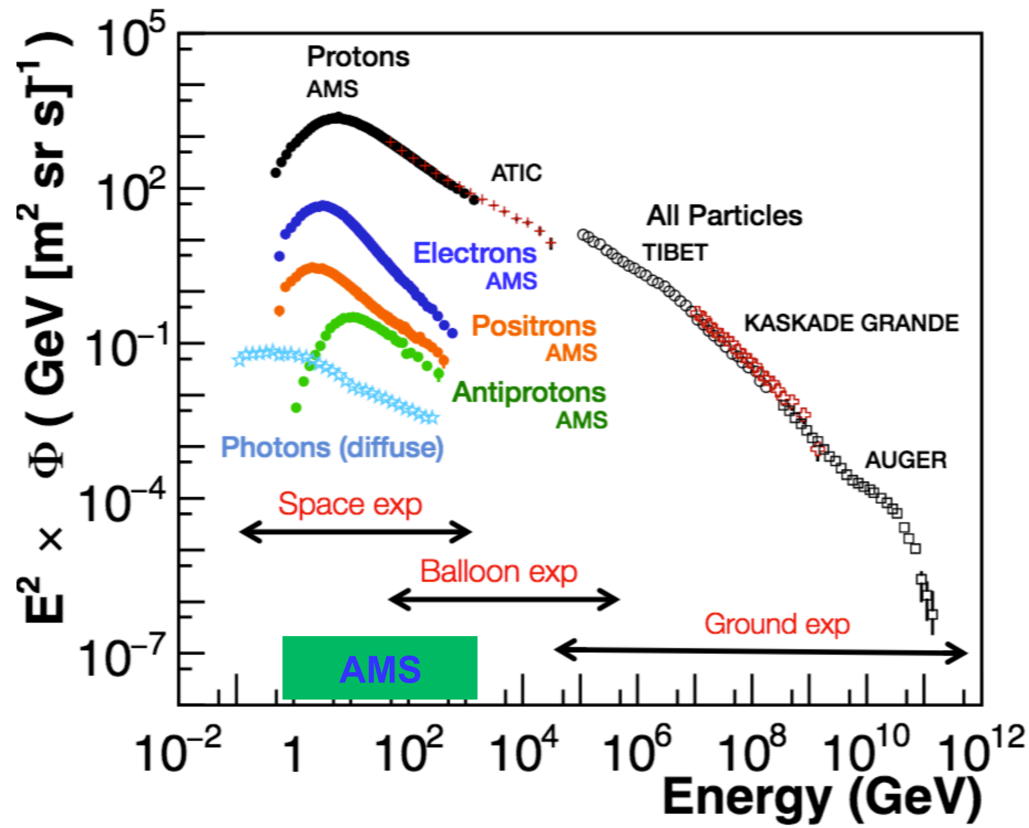
Outline

- Cosmic Rays with AMS
- RICH detector and its performances in space
- Main contributions to AMS physics topics
- Conclusions

Cosmic Rays

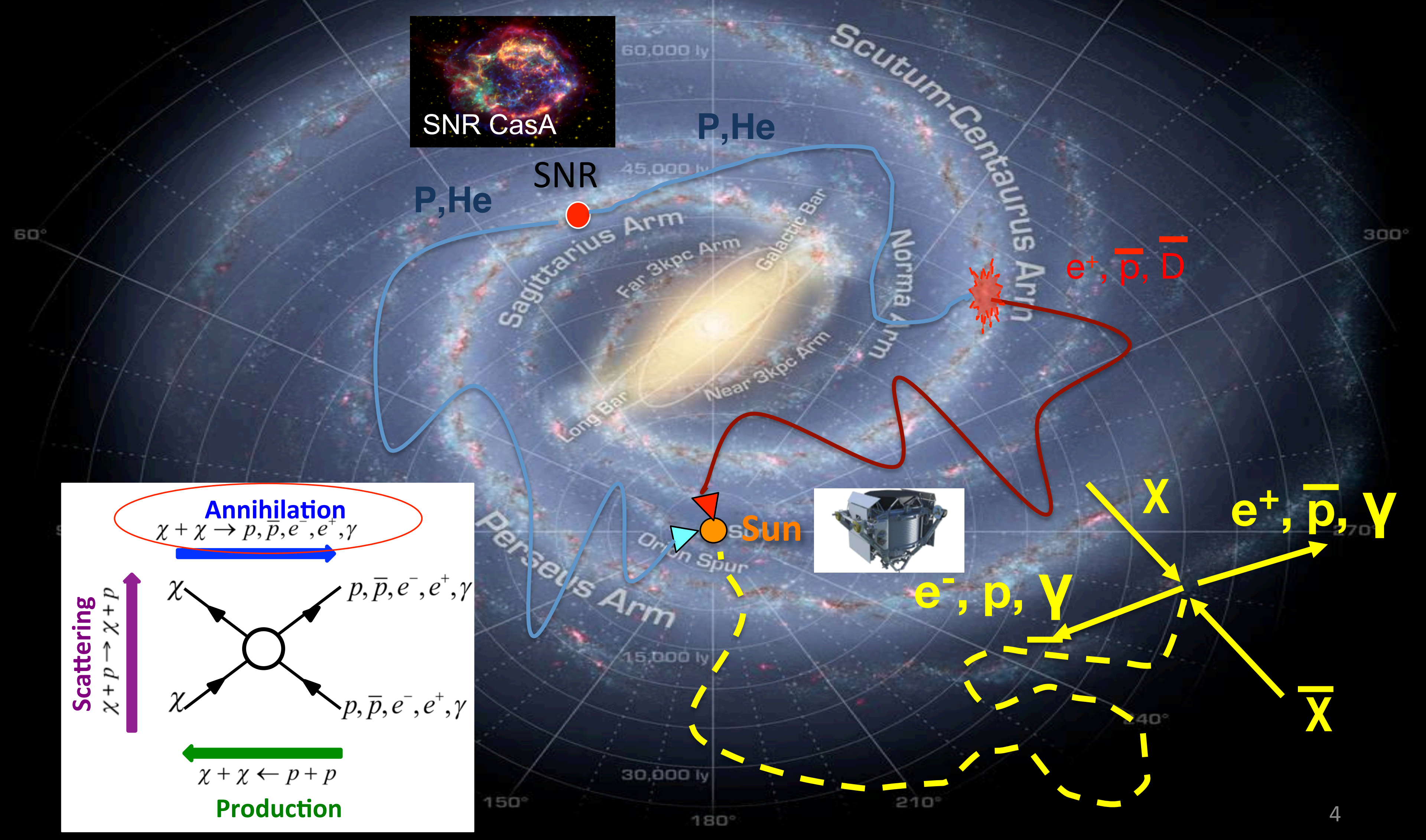
Cosmic rays are a sample of solar, galactic and extragalactic matter which includes all known nuclei and their isotopes, as well as electrons, positrons and antiprotons





AMS Physics goals: precision measurement of Galactic Cosmic rays, Dark matter and AntiMatter search

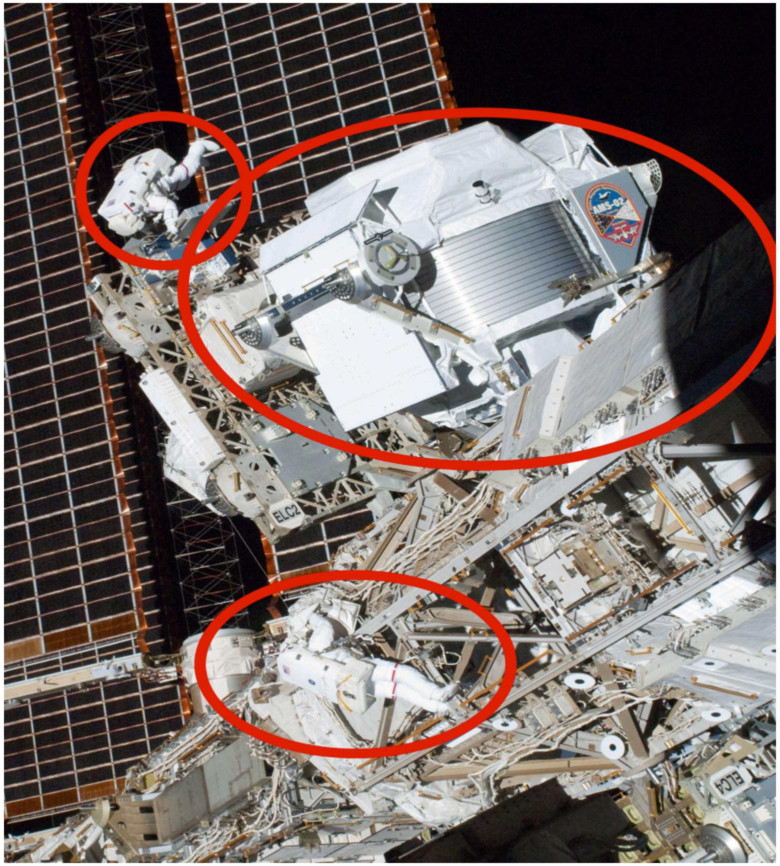
CRs propagation in the galaxy (diffusion, energy loss, reacceleration, convection…)
Collision of Cosmic Rays with Interstellar Matter produces e^+, $\overline{p}$, $\overline{D}$
New Physics may be hidden: Dark Matter annihilation also produces an excess of light antimatter: e^+, $\overline{p}$, $\overline{D}$.



AMS-02 on ISS

AMS is operating continuously on ISS since its launch in May 2011 and it has collected >120 billion charge particles so far.

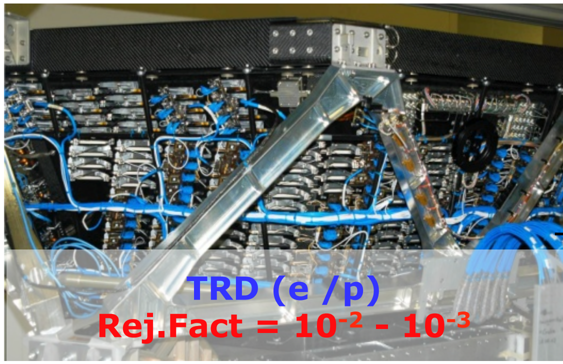
AMS measures CRs with unprecedented statistics and precision, contributing to the understanding of their origin, acceleration and propagation, Search signals of dark matter and anti-matter

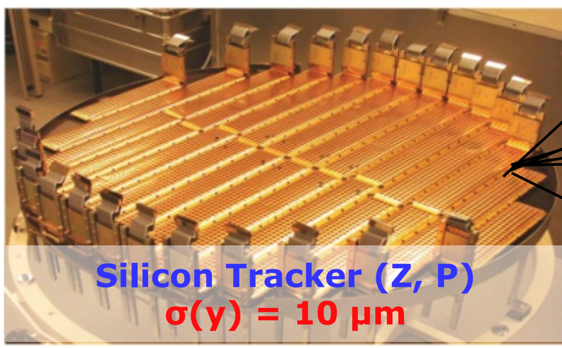


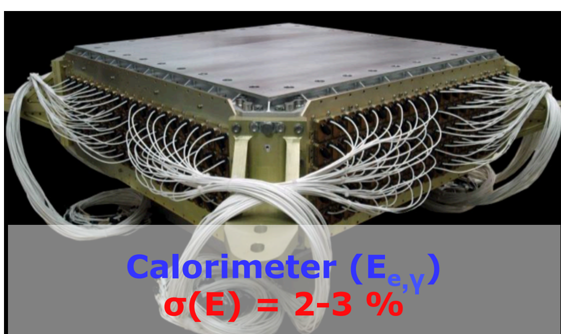
- 5 x 4 x 3 m
- Acceptance 0.5 m^2sr
- Weight 7500 kg
- Power consumption 2500 W
- 300k readout channels, > 600 microprocessors
- Data downlink reduction rate from 7 Gb/s to 10 Mb/s
- Mission duration: Until the end of ISS lifetime (currently 2024)

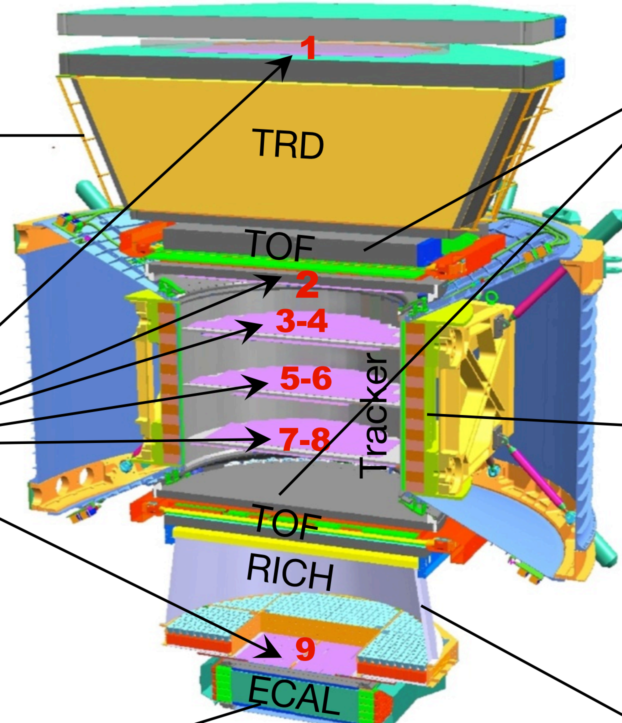
AMS: A TeV precision, multi-purpose spectrometer

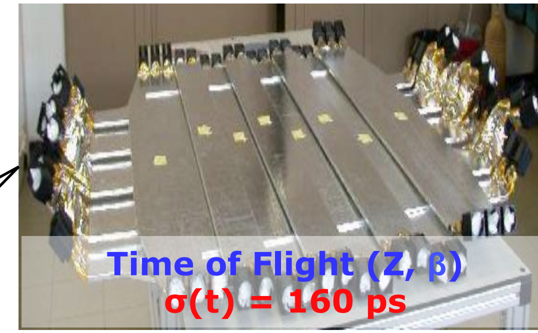
Separates hadrons from leptons, matter from antimatter and able to do CRs chemical and isotopic composition in GeV to TeV range

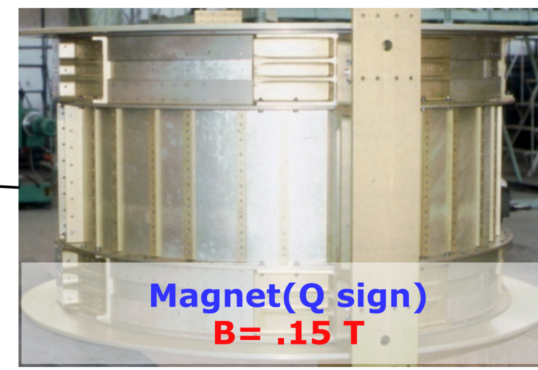


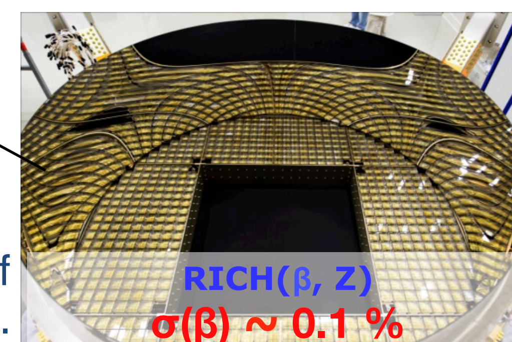






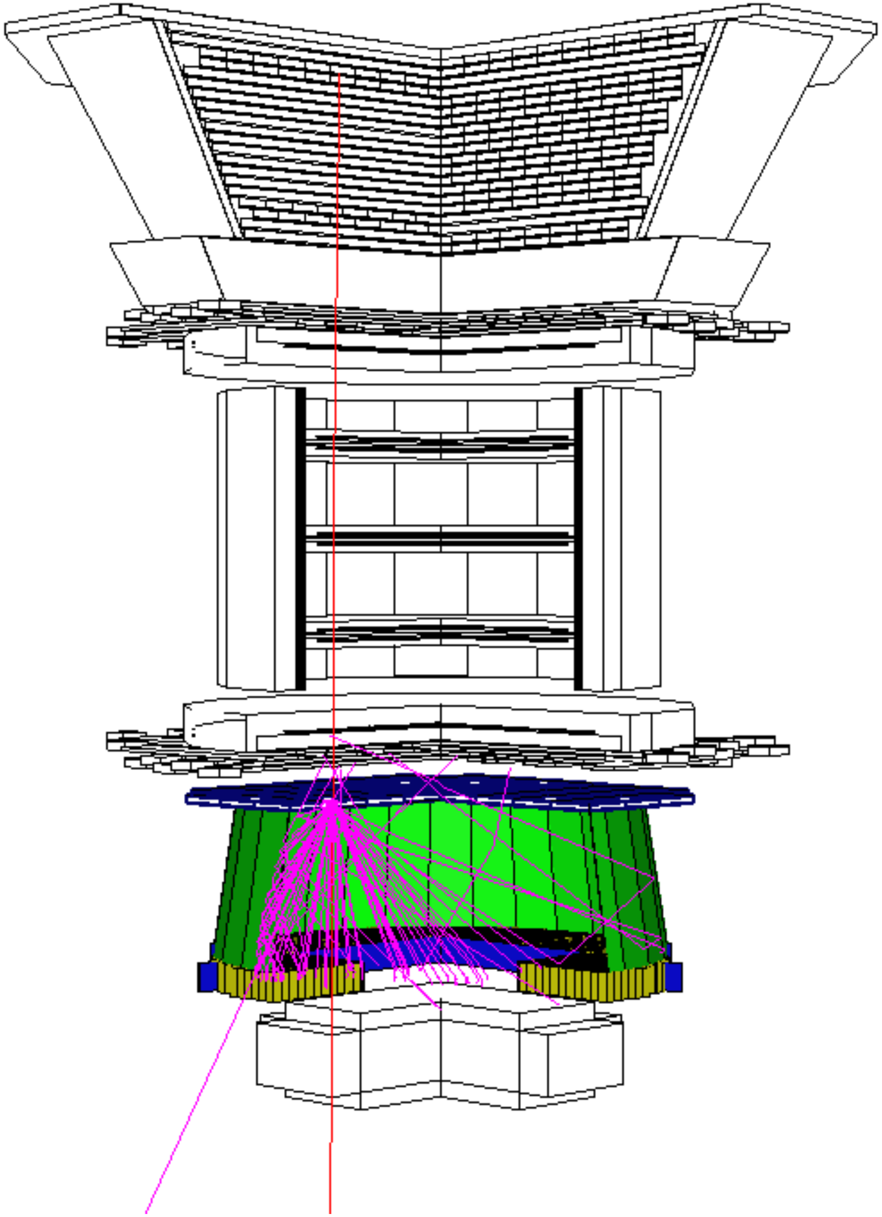






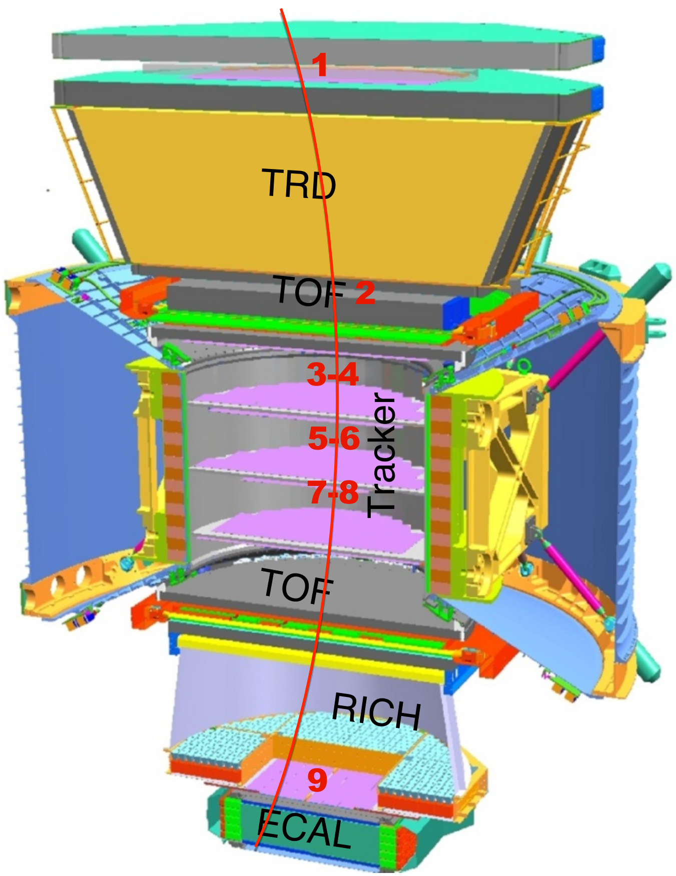
Multiple and independent measurement of Charge (Z), Energy (β,p,E) and Q sign (±).

The AMS-02 RICH detector



Physics motivations: mass reconstruction

PID: antiprotons, deuteron, antideuterons, isotopes …



$$m = ZR / \beta\gamma$$

$$\sigma(m)/m = \sigma(R)/R \oplus \gamma^2 \sigma(\beta)/\beta$$

Rigidity(p/Z): TRACKER

Velocity: TOF(2% for Z=2)+RICH(0.08% for Z=2)

Charge: TRACKER(9)+TRD+TOF(4)+RICH

The RICH provides AMS of:

- Precise measurement of charged particle velocity

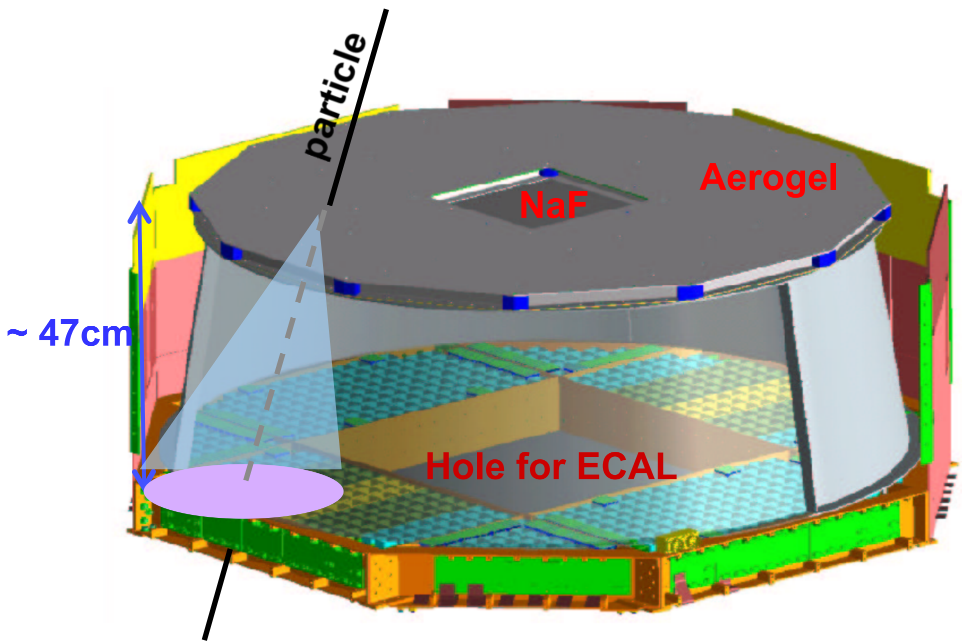
$$\cos(\theta_c)=1/n\beta$$

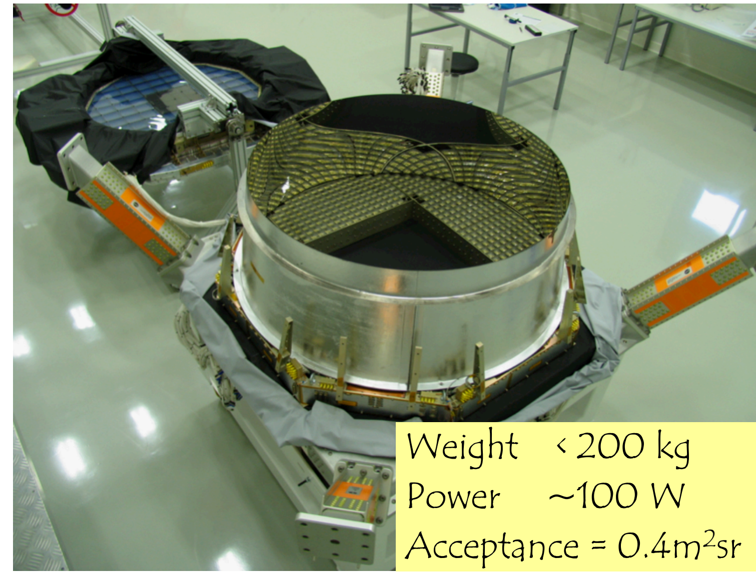
- Particle charge identification till Z=26 (Iron)

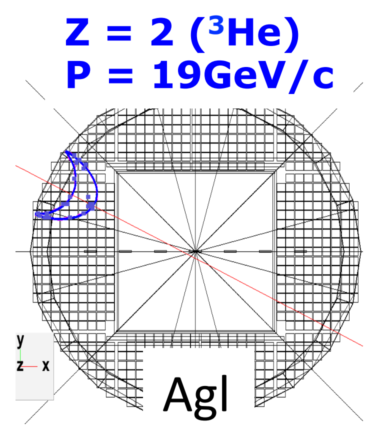
$$N_{p.e.} \sim Z^2 \sin^2(\theta_c) \qquad Z = N_{hit}/N_{exp(Z=1,\ \beta=1)}$$

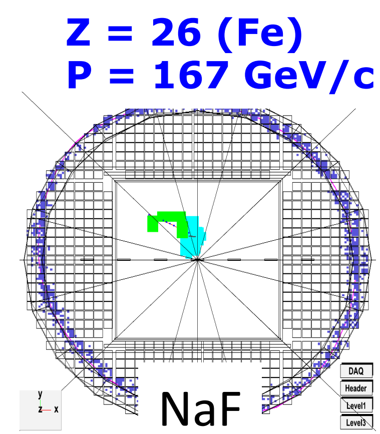
Detector Layout

- Proximity Focusing detector
- Dual Radiator configuration
- Conical mirror to increase acceptance
- Detection matrix with central hole (ECAL)







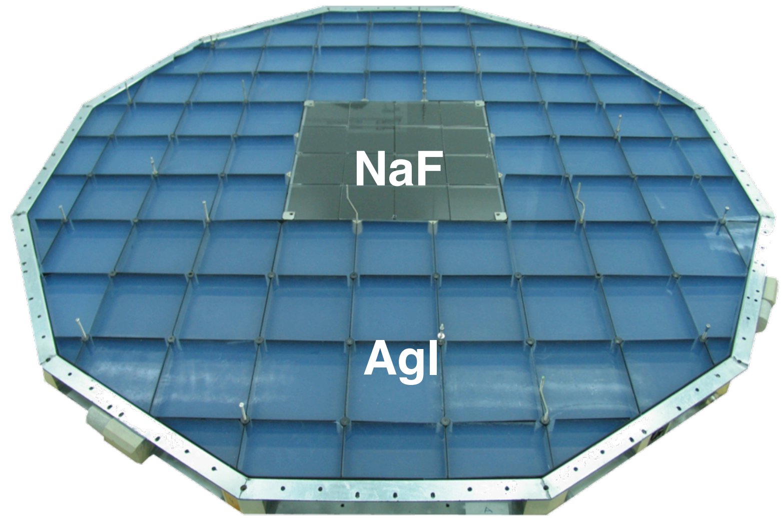


- On average one ring per event is reconstructed
- Tracker inner track provide the entry point and direction

RICH detector

Dual solid radiator configuration
Silica aerogel:

- ✧ 80 tiles
- ✧ n=1.05
- ✧ 11.3 cm x 11.3 cm x 2.5cm
- ✧ ring ≈31cm for β=1
- ✧ E_{kin}>2.1 GeV/n



NaF crystals:

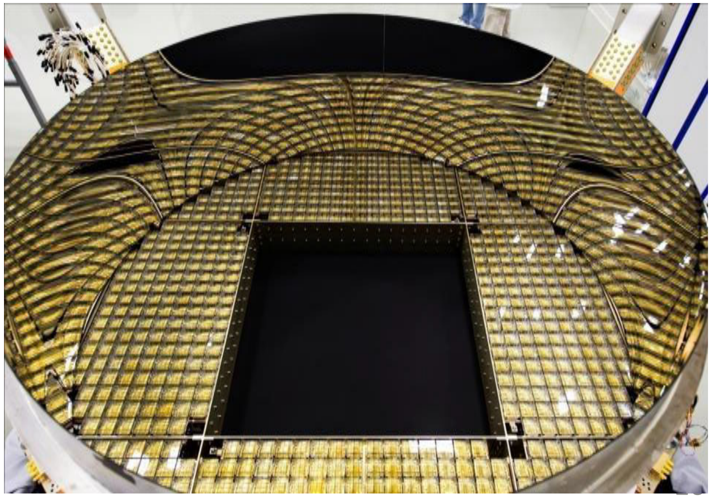
- ✧ 16 tiles
- ✧ n=1.33
- ✧ 8.5 x 8.5 x 0.5 cm
- ✧ ring ≈85cm for β=1, arger C angle to reduce photon loss in the central hole
- ✧ Extend RICH beta range to lower Energies (E_{kin} > 0.5 GeV/n) to match with TOF

Mirror

- ✧ 3 sectors of multilayer structure deposited on a carbon Fiber Substrate
- ✧ Reflectivity ≥ 85% (at λ= 420nm)

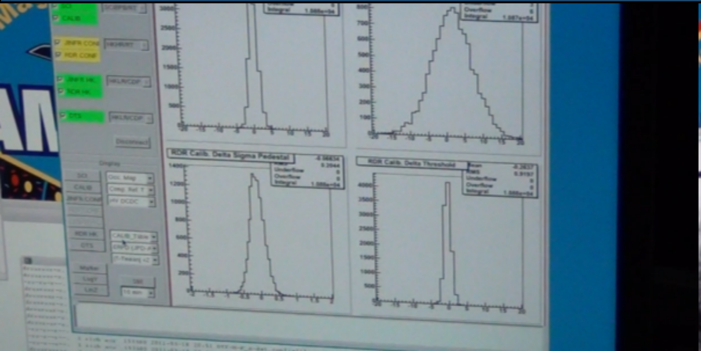
Detection plane

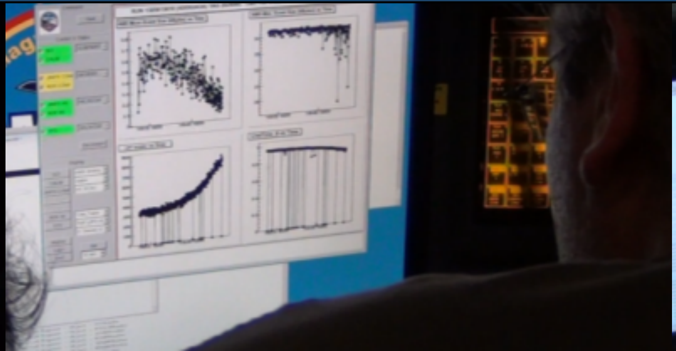
- ✧ 680 multianode pmts R7900-M16 (10880 pixels)
- ✧ Detection granularity: 8.5 x 8.5 mm^2
- ✧ High single-photon detection efficiency
- ✧ Low sensitivity to external B field

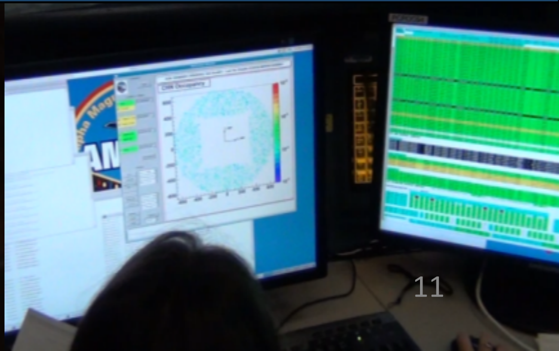


RICH Monitoring & operations

The AMS Payload Control Center (POCC) is located at CERN
RICH critical parameters are constantly monitored 24/7 to ensure detector integrity and optimal performances
The RICH detector is continously running and taking data
In >7 years of operations no major intervention required
More than 95% of the channels functioning properly

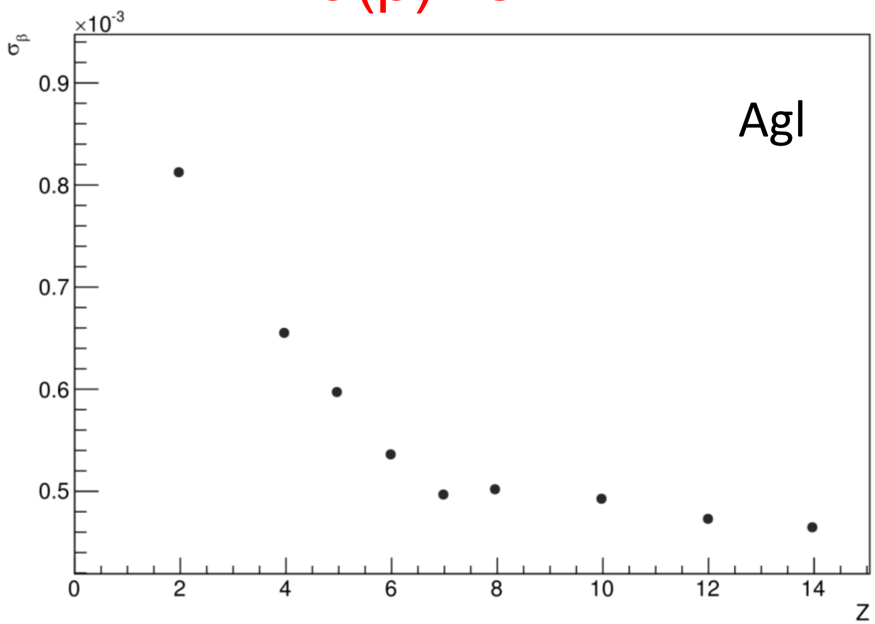




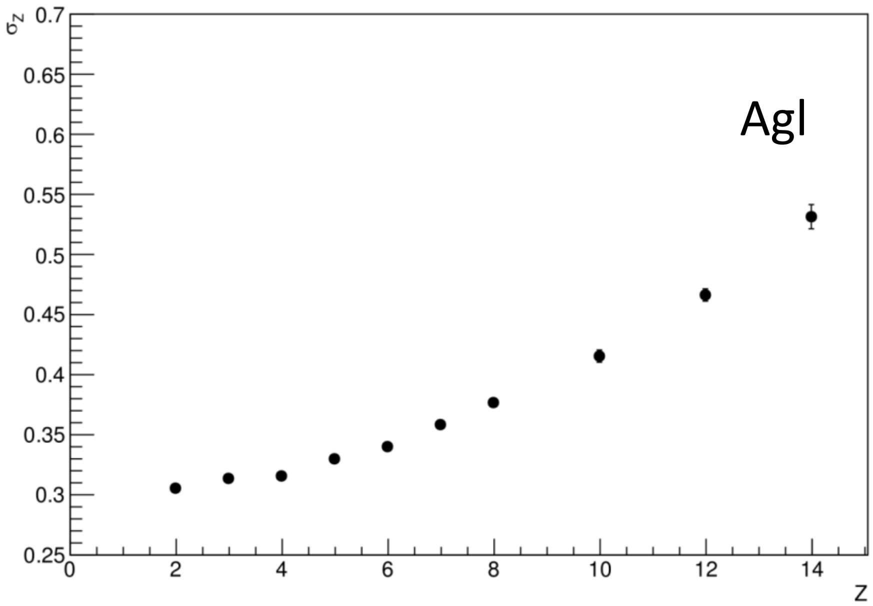


RICH Performances on ISS

σ(β) vs Z



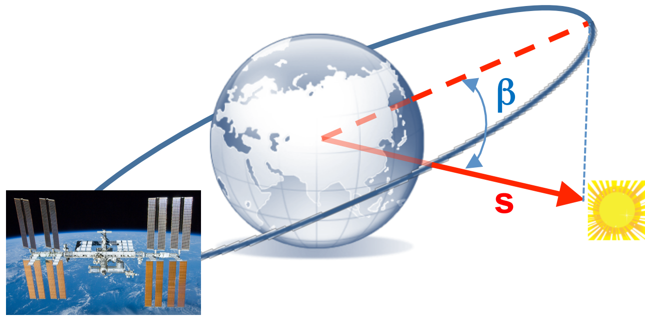
σ(Z) vs Z

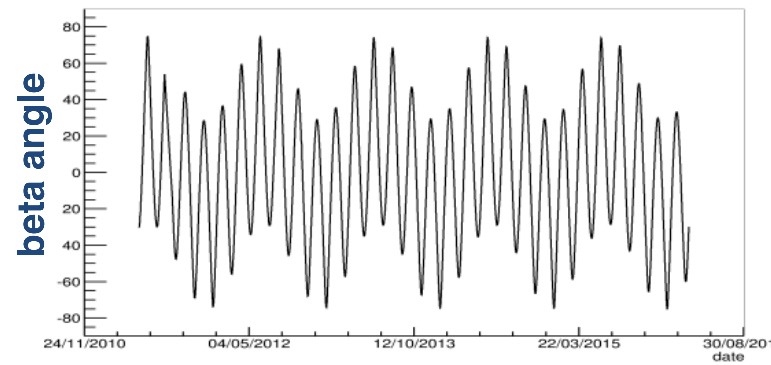


- Beta resolution (R>50GV) is about 0.8 per mil per Helium and better for higher Z
- Charge Resolution ~ 0.3 for Helium

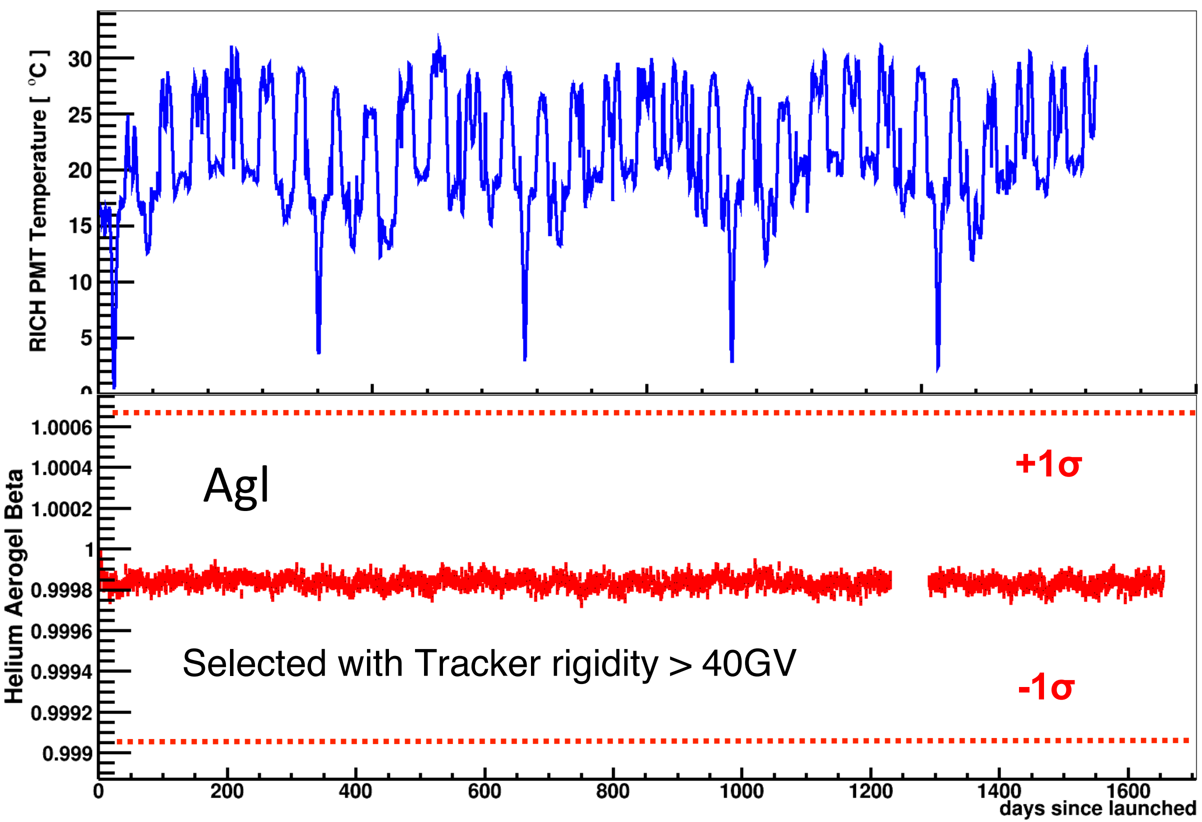
Response Stability in time

Thermal environment variation





As β changes, the heating incident on the AMS surface changes and determines its temperature.



Charge: after temperature corrections the detectors response is stable

- The residual Photon Yield variation $< 2 \times 10^{-3}$ (95% CL) well within requirements (1%)

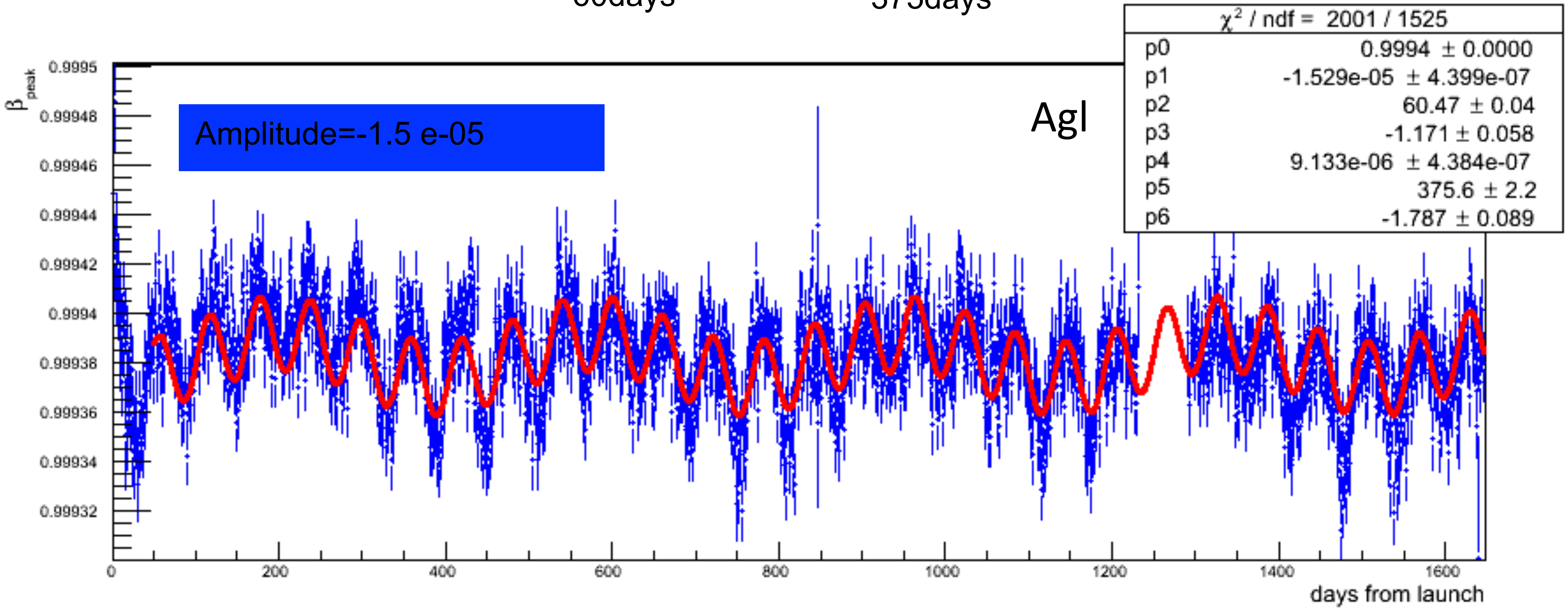
Beta: residual effects on beta are small enought to have no impact to the resolution

Response Stability in time

Beta peak position evolution in time for AgI events (Helium sample with R>40GV).

$$\text{Beta} = \text{Beta\_Mean} + A \sin(2\pi x/T_1+\theta_1) + B \sin(2\pi x/T_2+\theta_2)$$

~60days ~375days

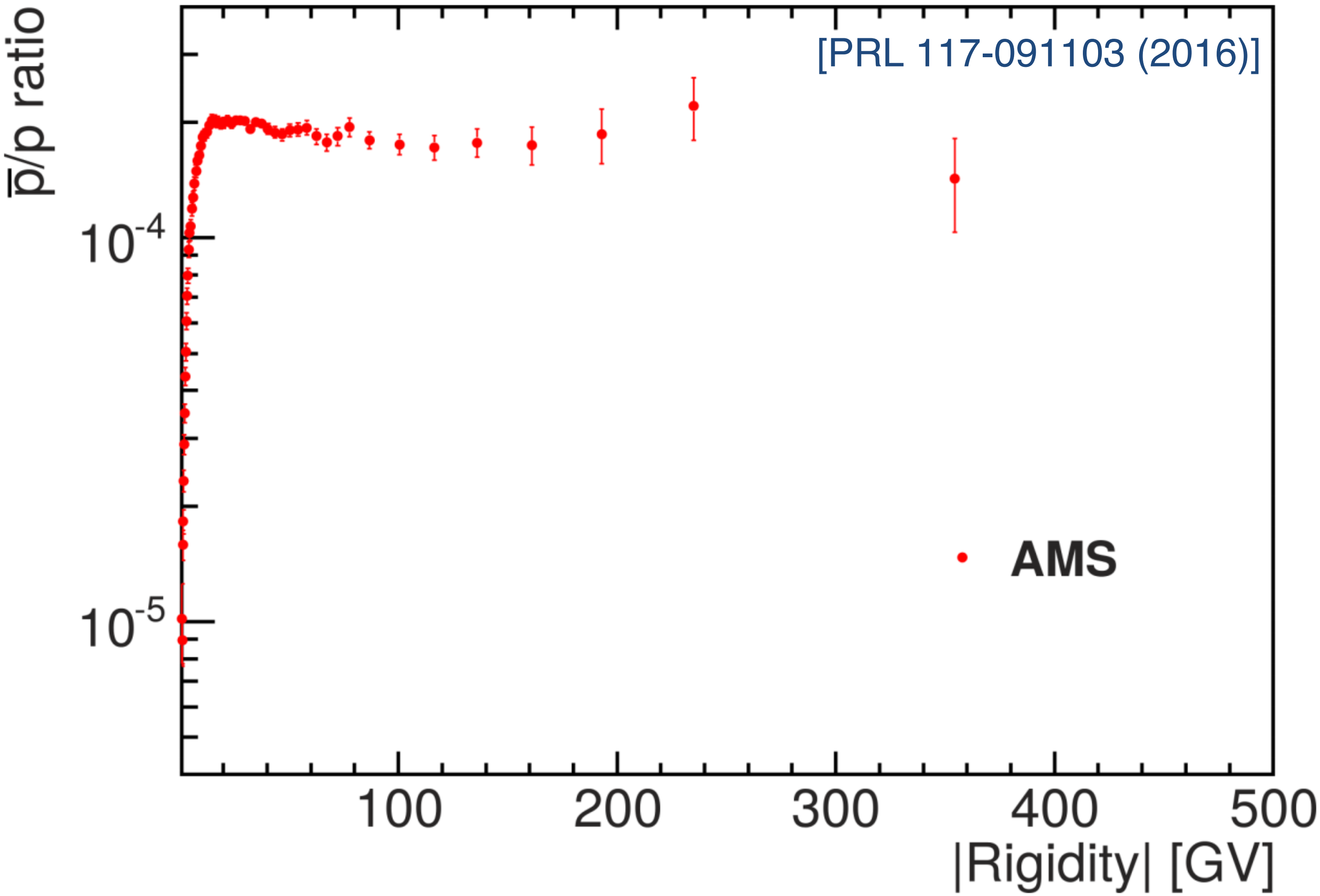


Small oscillations following the beta angle are visible.
Amplitude ~ 10^{-5} still well within the intrinsic resolution (8x10-4).

Physics Results: Antiprotons

AMS looked for new physics in the antiprotons signal (PRL 117-091103, 2016).
The RICH beta measurement is used at intermediate rigidities (2.97-18GV) to reduce e^- and π^- contamination.

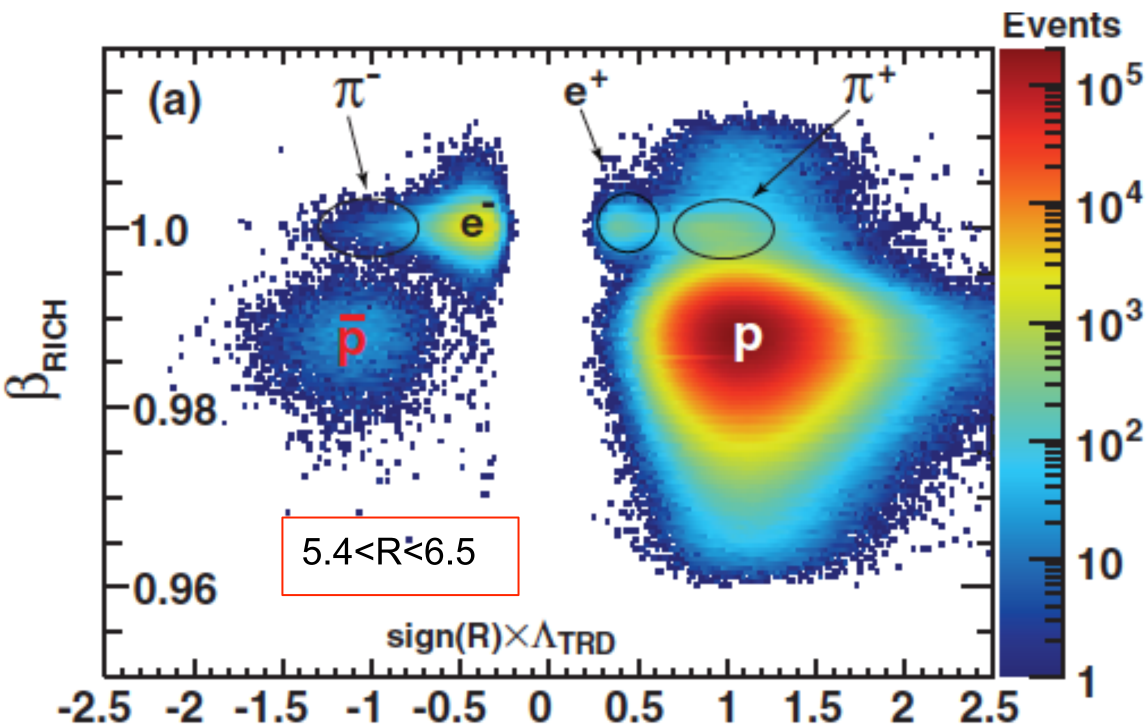
4 years data sample:
0.35 million $\bar{p}$ events
and 2.4 billion p events



Physics Results: Antiprotons

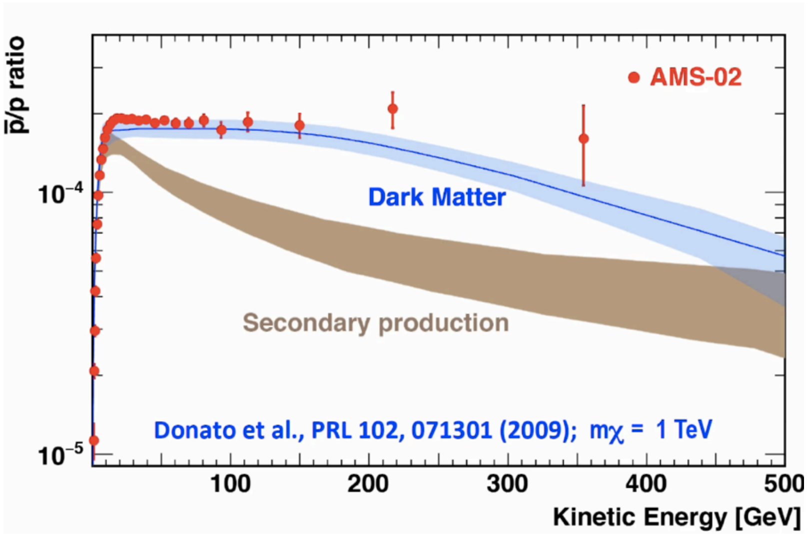
In the antiprotons analysis, the RICH beta measurement is used at intermediate rigidities (2.97-18GV) to reduce e^- and π^-.

- Signal identification using RICH and TRD estimator.



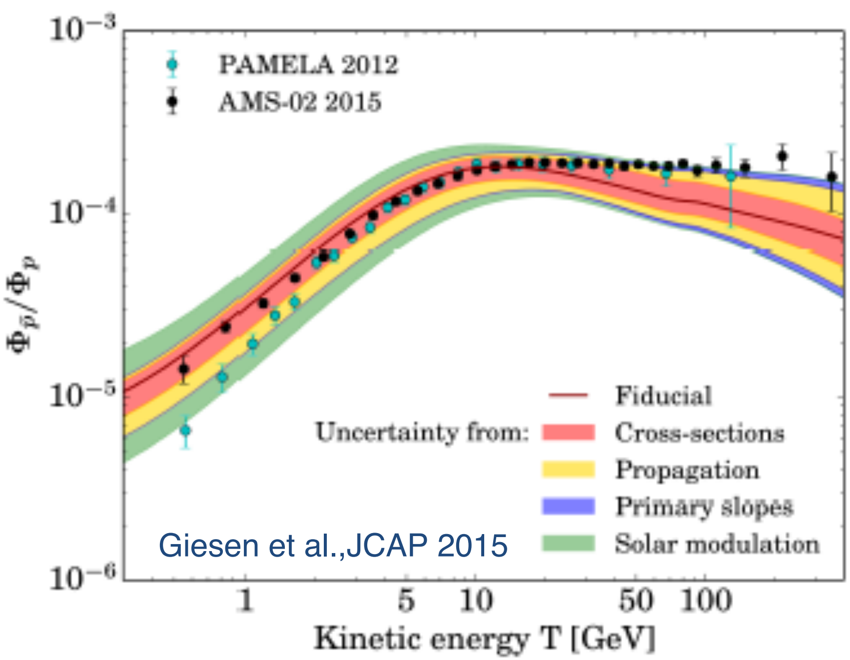
- RICH used at VETO below threshold.

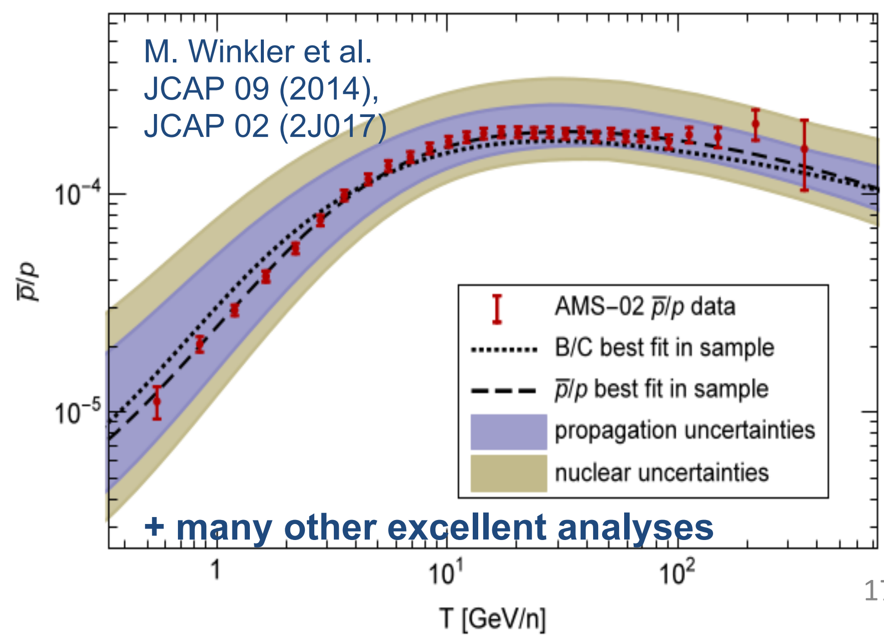
Antiproton to proton ratio



Secondary production estimated with pre-AMS data.

Tuned with AMS B/C, p and new cross sections data

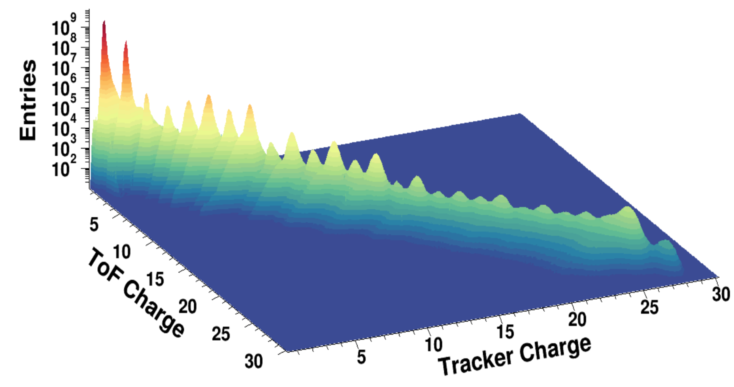


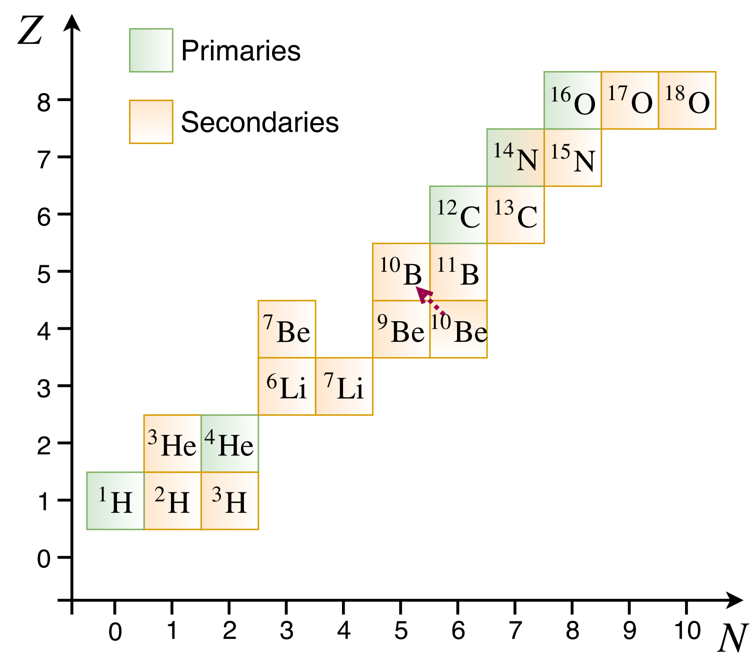


Physics : Light Isotopes in Cosmic rays

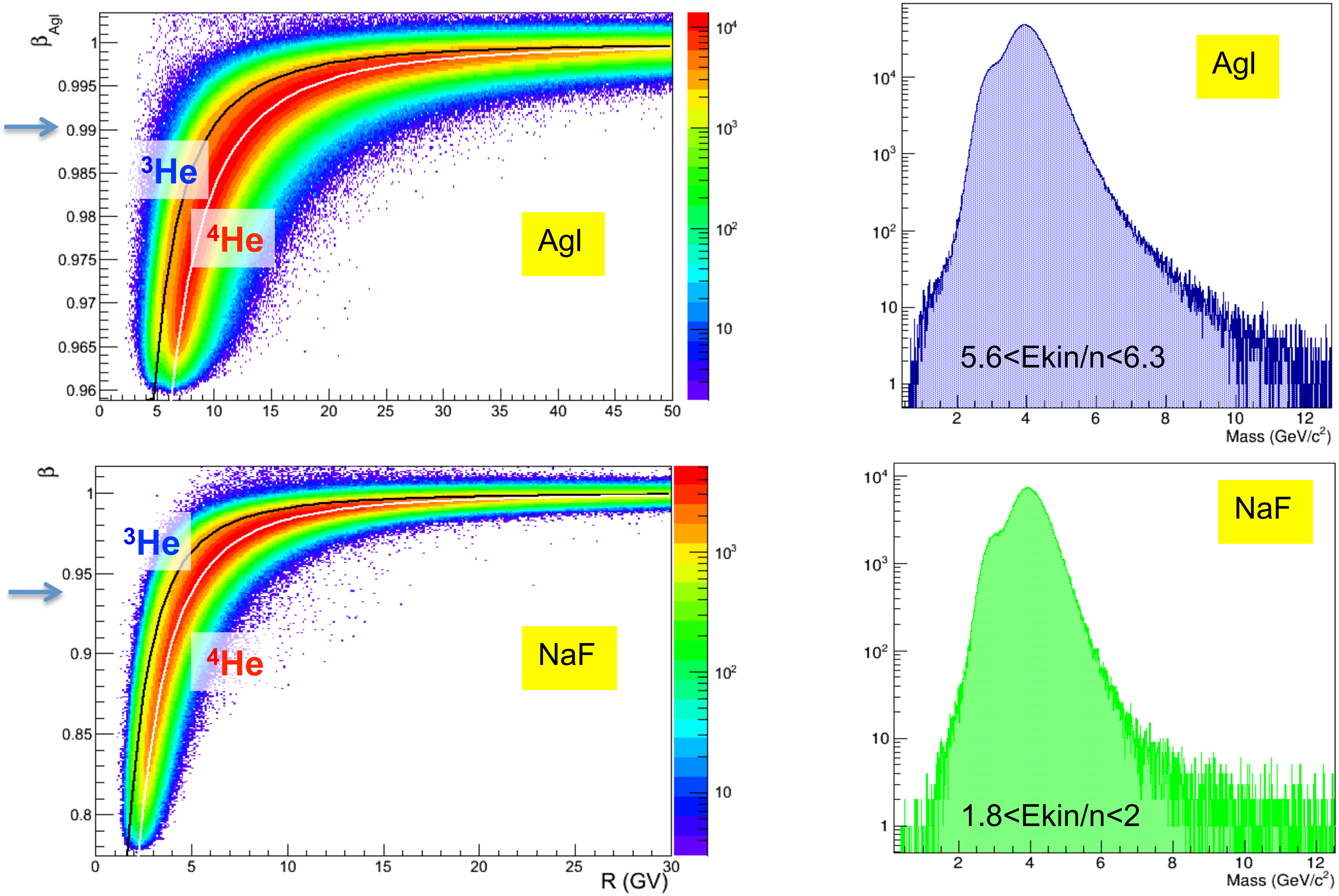
Motivations:

- AMS is providing new and precise data in CRs (i.e. antiprotons)
- Their interpretation require accurate modelling of CRs propagation processes in the galaxy to estimate the secondary production, which is the background for the search of new physics.
- Secondary-to-primary ratios as Li/O, Be/O, B/O provide information to constrain the transport parameter;
- The study of isotopic ratios ($^3He/^4He$, $^6Li/^7Li$, $^7Be/Be$) but with different A/Z probe different propagation distances and test the universality of the models.





Physics Results : He isotopes



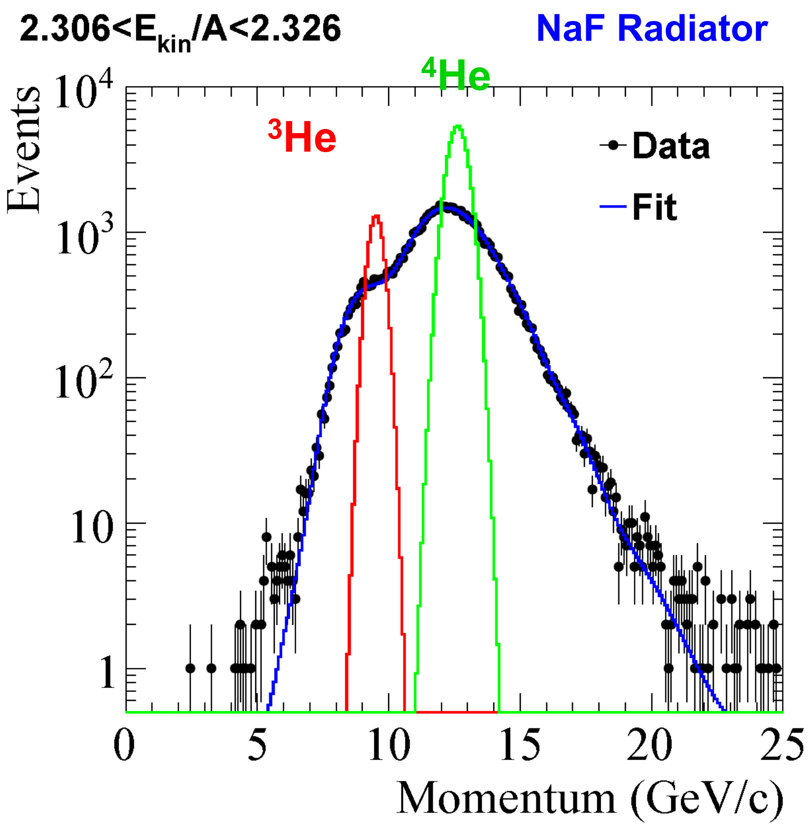
Physics Results : He isotopes

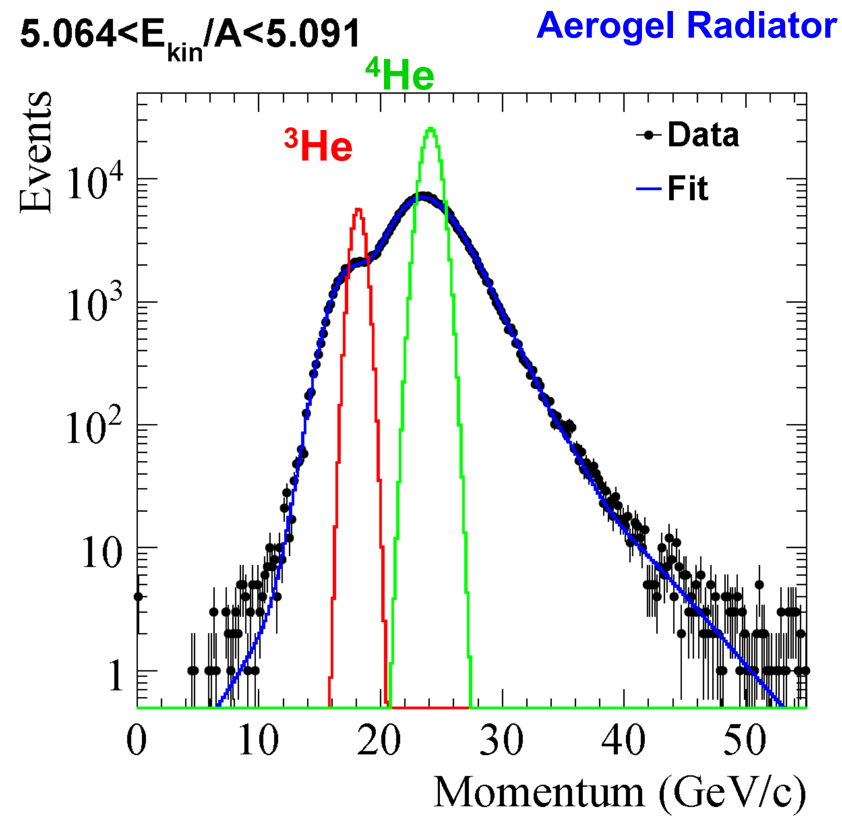
Different independent statistical approaches have been developed:

Data Template (GeoMagnetic CutOff)

MC Templated

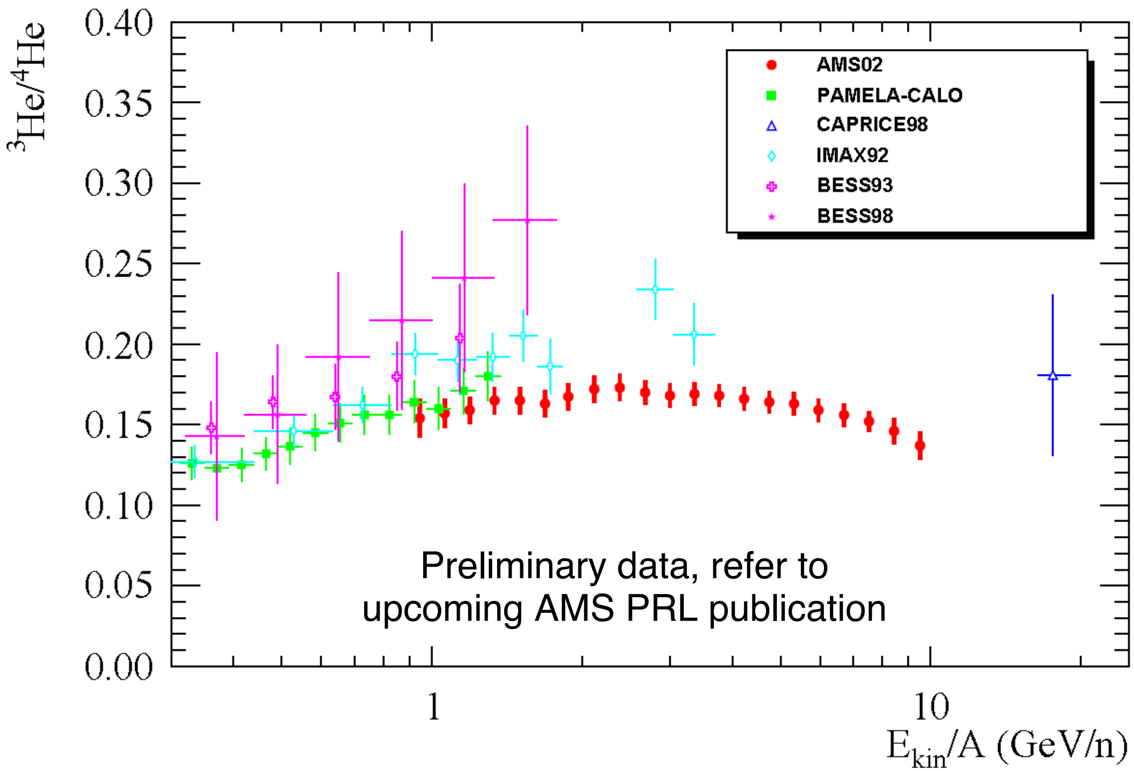
Unfolding/Folding Method



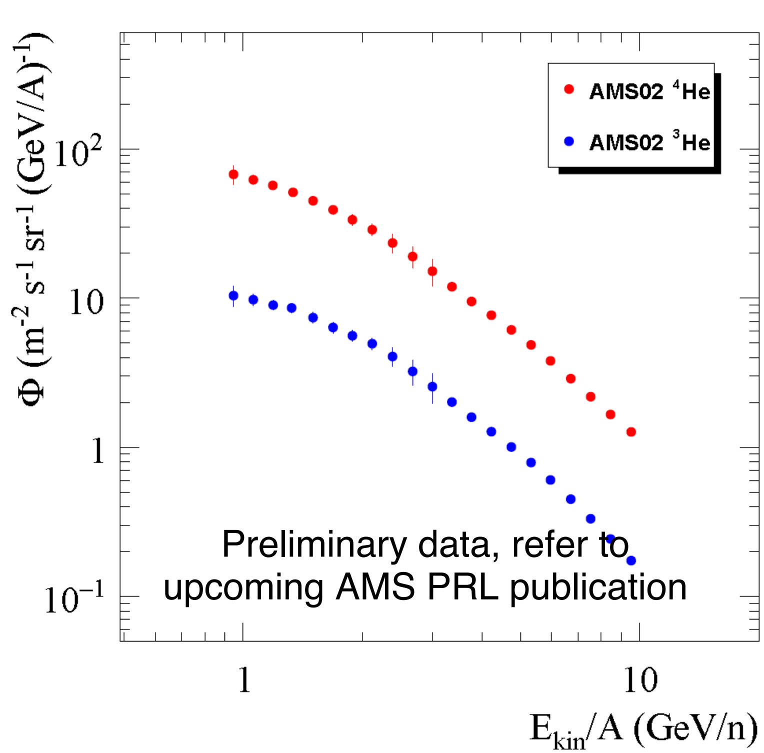


Physics Results : $^3He/^4He$ and ^3He and ^4He fluxes

AMS measures $^3He/^4He$ composition with unprecedented statistic.
The measurement extends in the energy range from 1 to 10 GeV/n with errors of 4% (both stat. and sys.).



Individual fluxes are measured from relative abundances, effective acceptances and exposure time.

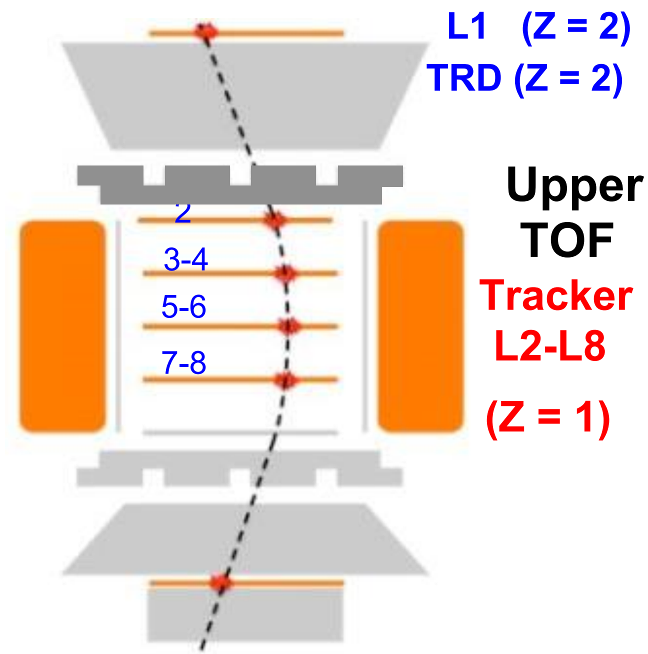


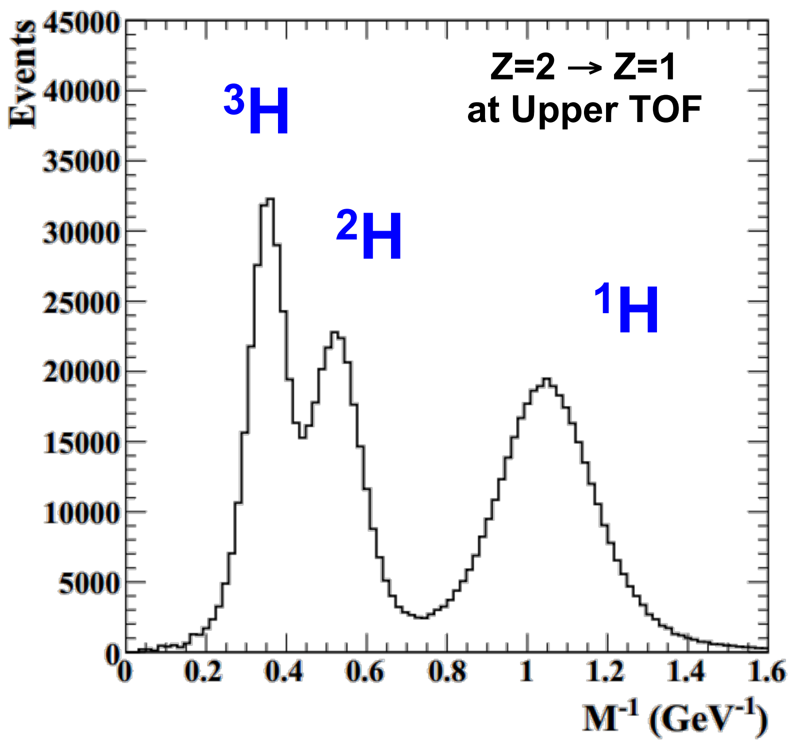
Physics Results : He isotopes ToI corrections

The error is dominated by systematics and the most relevant one is the uncertanty on the fragmentation cross section $^4He \rightarrow {}^3He$ inside the detector needed to extract the TOI measurement.

In AMS we can estimate it from $^4He \rightarrow {}^3H$ direct measurement, where, changing the charge, we can profit of AMS redundant charge tagging capabilities all along the particle trajectory in the detector.

Under the well motivated assumption that $^4He \rightarrow {}^3He$ and $^4He \rightarrow {}^3H$ have similar probabilities at high energy.





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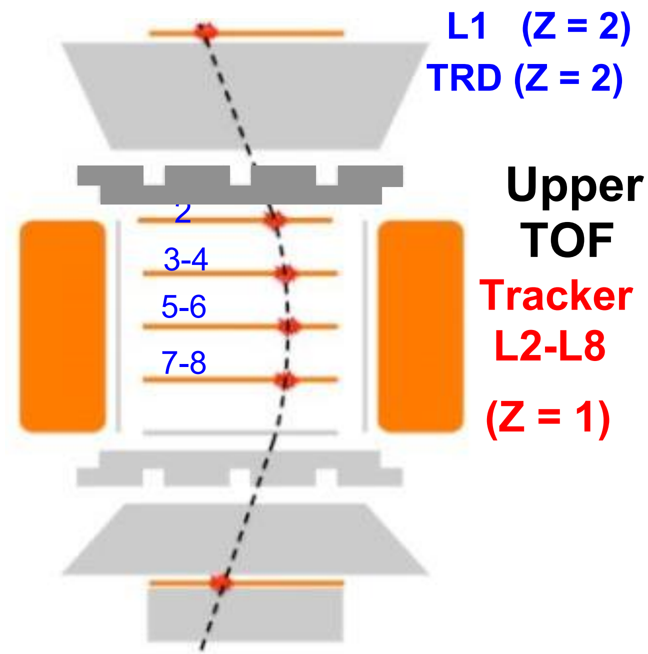
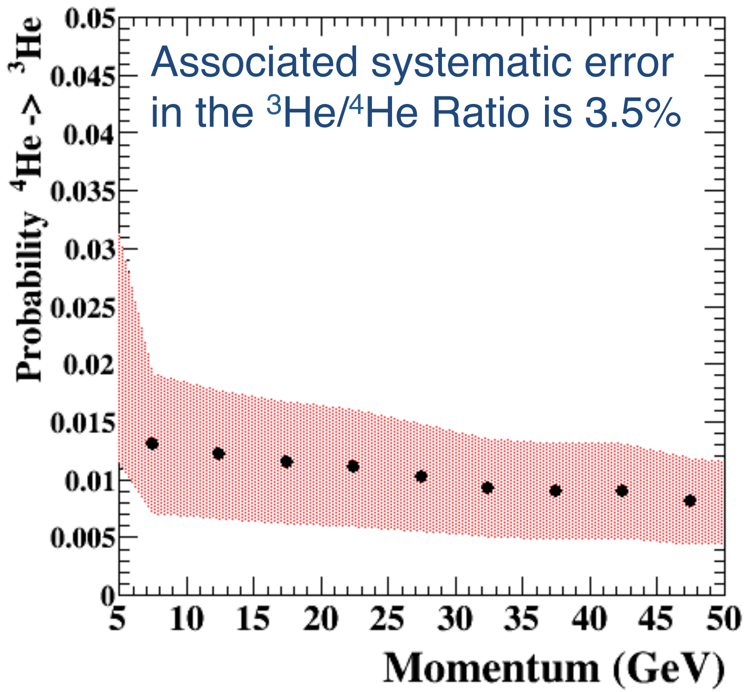
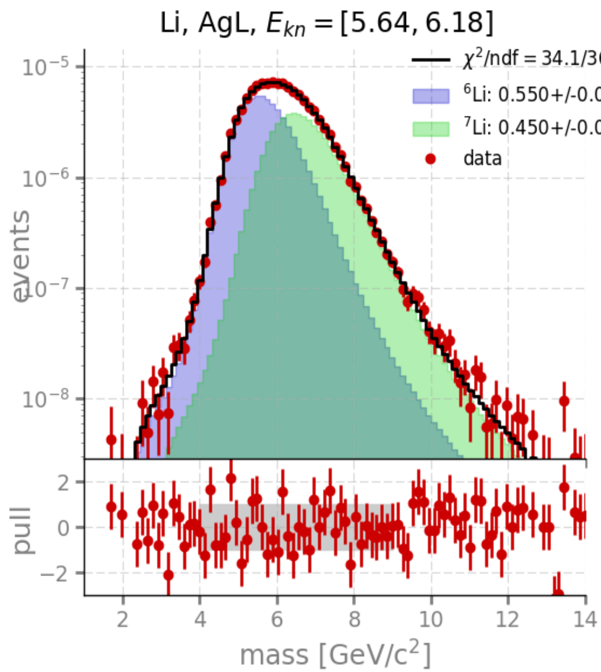
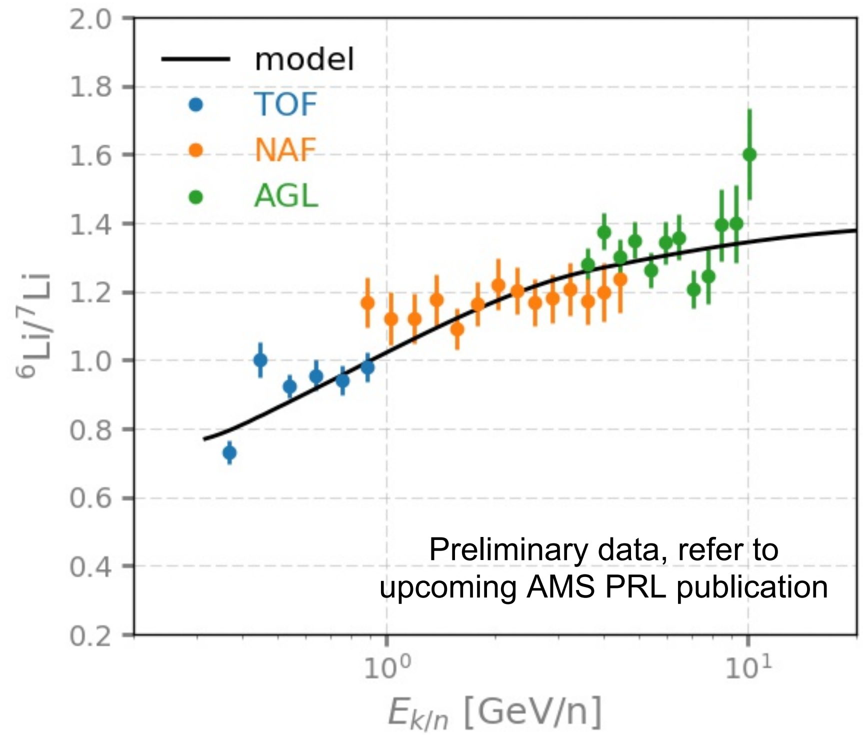
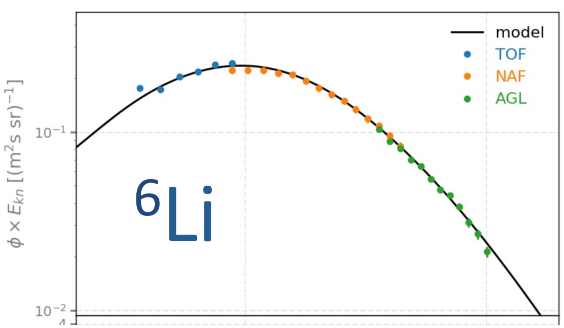




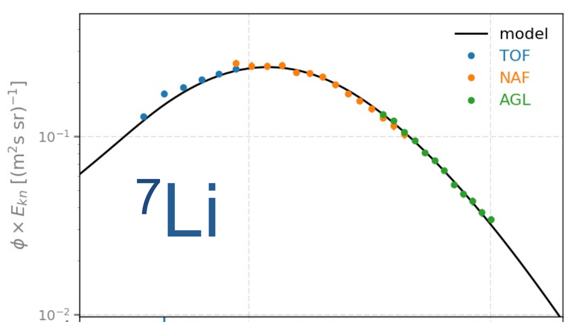
Physics Results : ^{6}Litium and ^{7}Litium isotopes







Preliminary data, refer to upcoming AMS PRL publication



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Next are Berillium isotopes
More diffucult as as $\Delta m/m$ becomes smaller.

Mass Resolution for Z=1

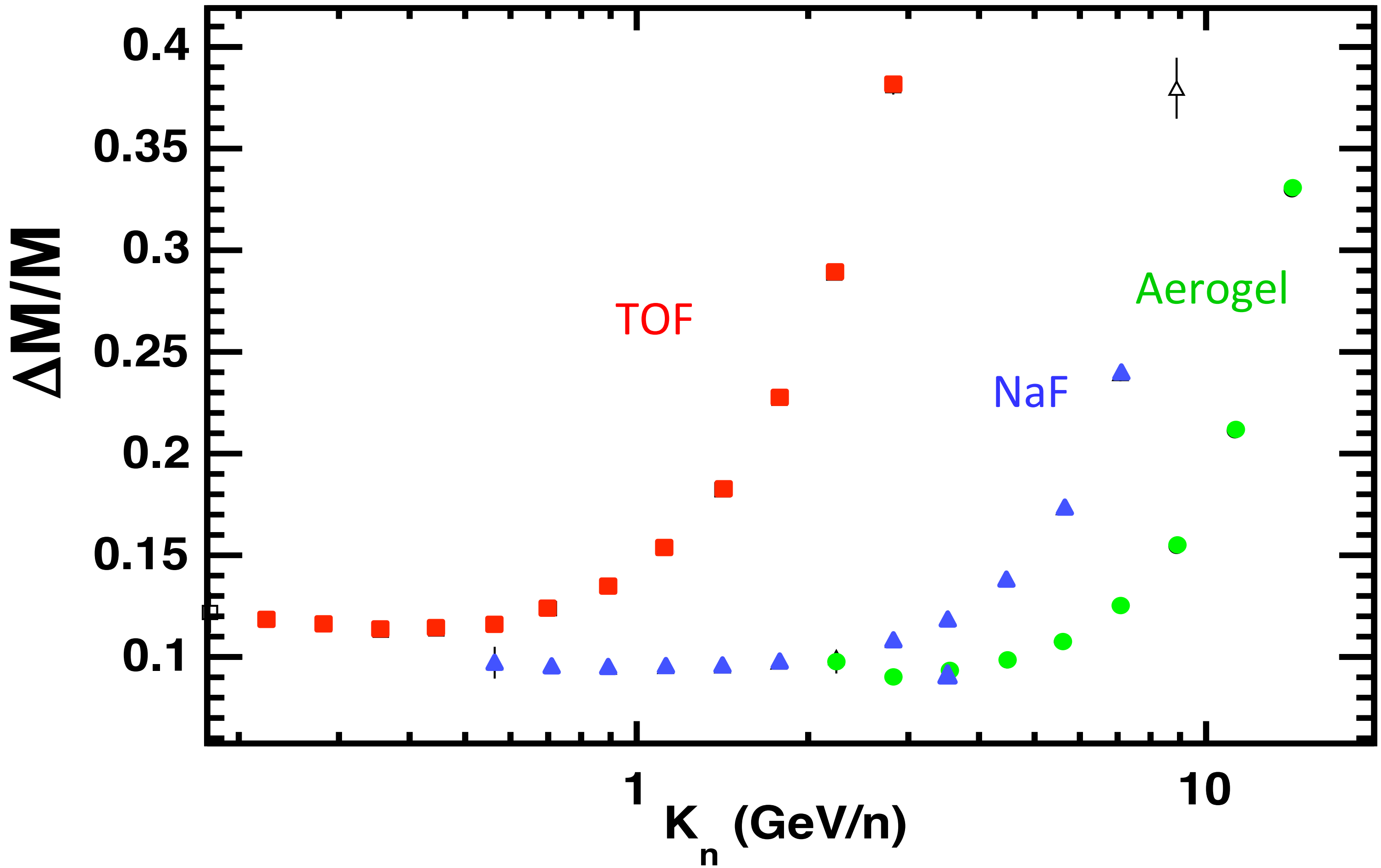
$$\frac{\Delta M}{M} = \left(\frac{\Delta p}{p}\right) \oplus \frac{1}{(1-\beta^2)}\left(\frac{\Delta \beta}{\beta}\right)$$

Tracker, $\Delta p/p \approx 10\%$ up to 20 GV

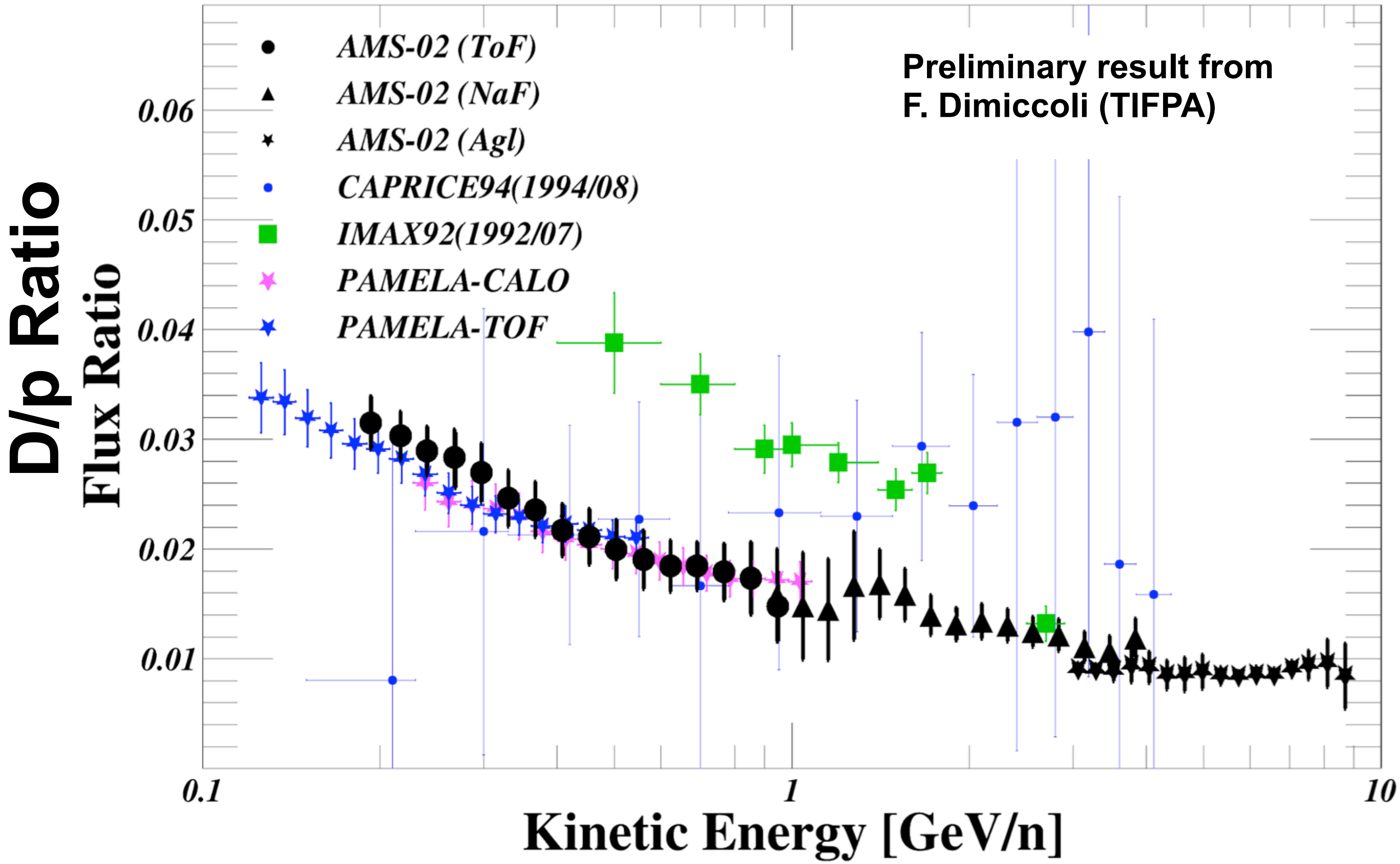
ToF, $\Delta\beta/\beta^2 \approx 4\%$

NaF: $\Delta\beta/\beta \approx 0.4\%$, $\beta>0.75$

Aerogel: $\Delta\beta/\beta \approx 0.1\%$, $\beta>0.96$

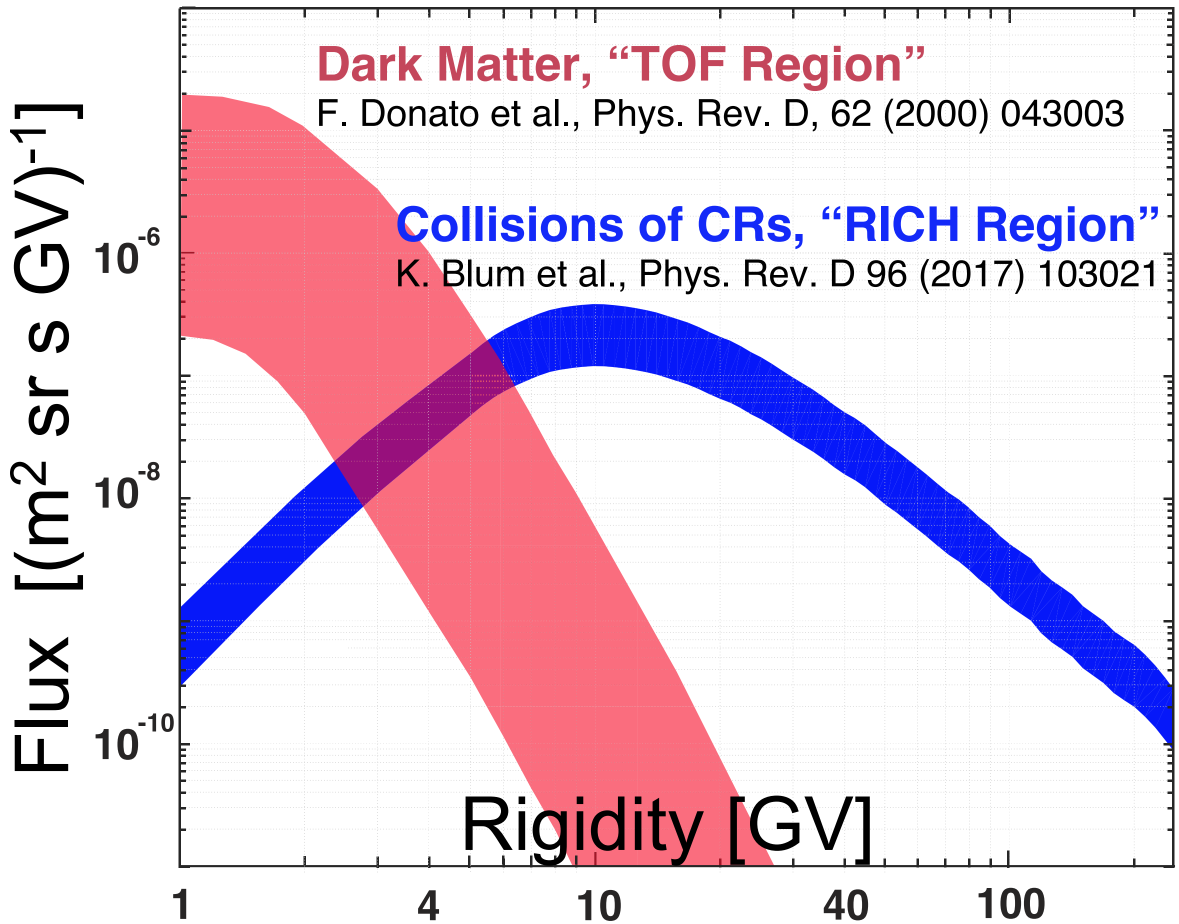


Physics : Deuteron to proton ratio



Physics : AntiDeuteron Search

Antideuterons have been proposed as an almost background free channel for dark matter indirect detection at low energy.
Very low flux: high rejection to other species needed ($\bar{D}/\bar{p} < 10^{-4}$, $\bar{D}/p < 10^{-9}$, $\bar{D}/e^{-} < 10^{-6}$)

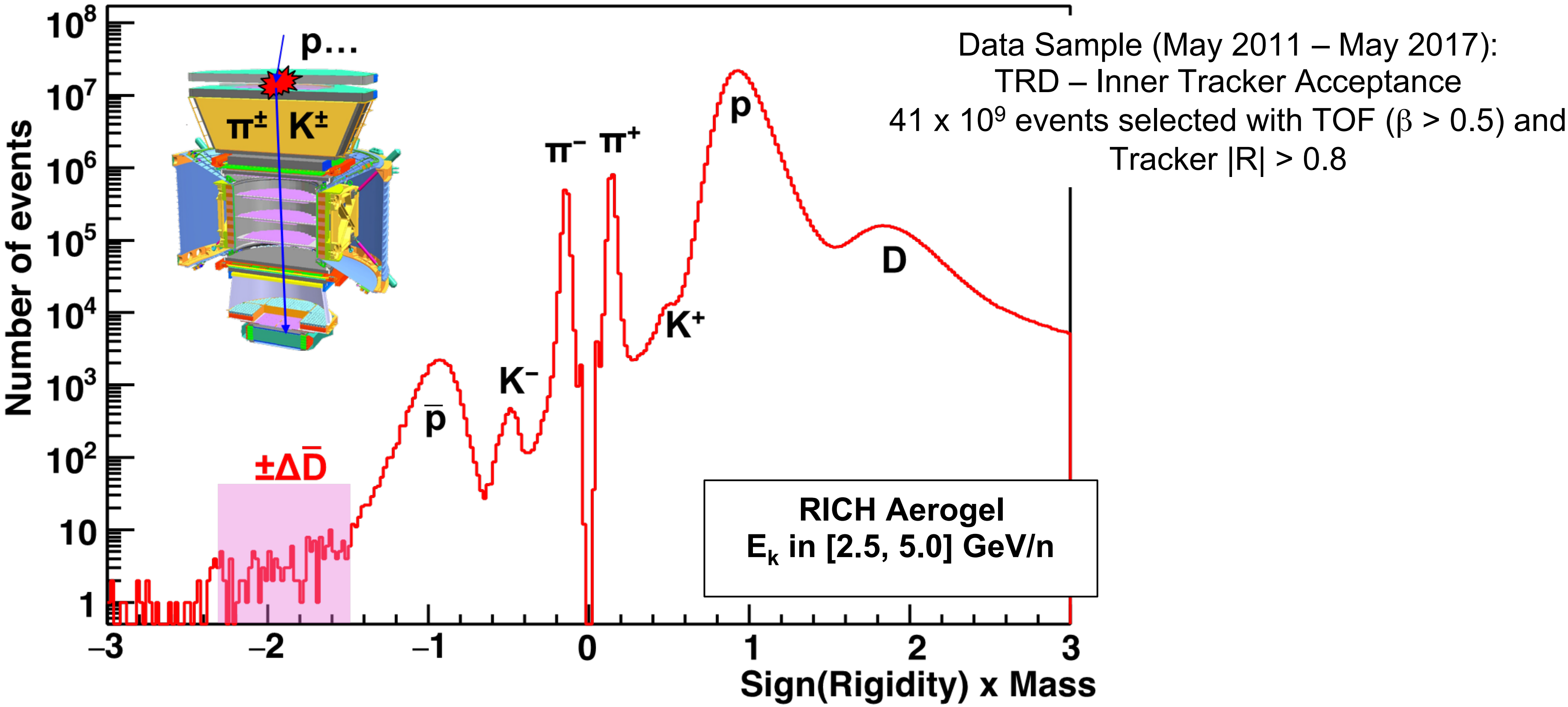


$\bar{D}$ have never been observed in CRs.

We expect a $\bar{D}$ signal

Physics : AntiDeuteron Search

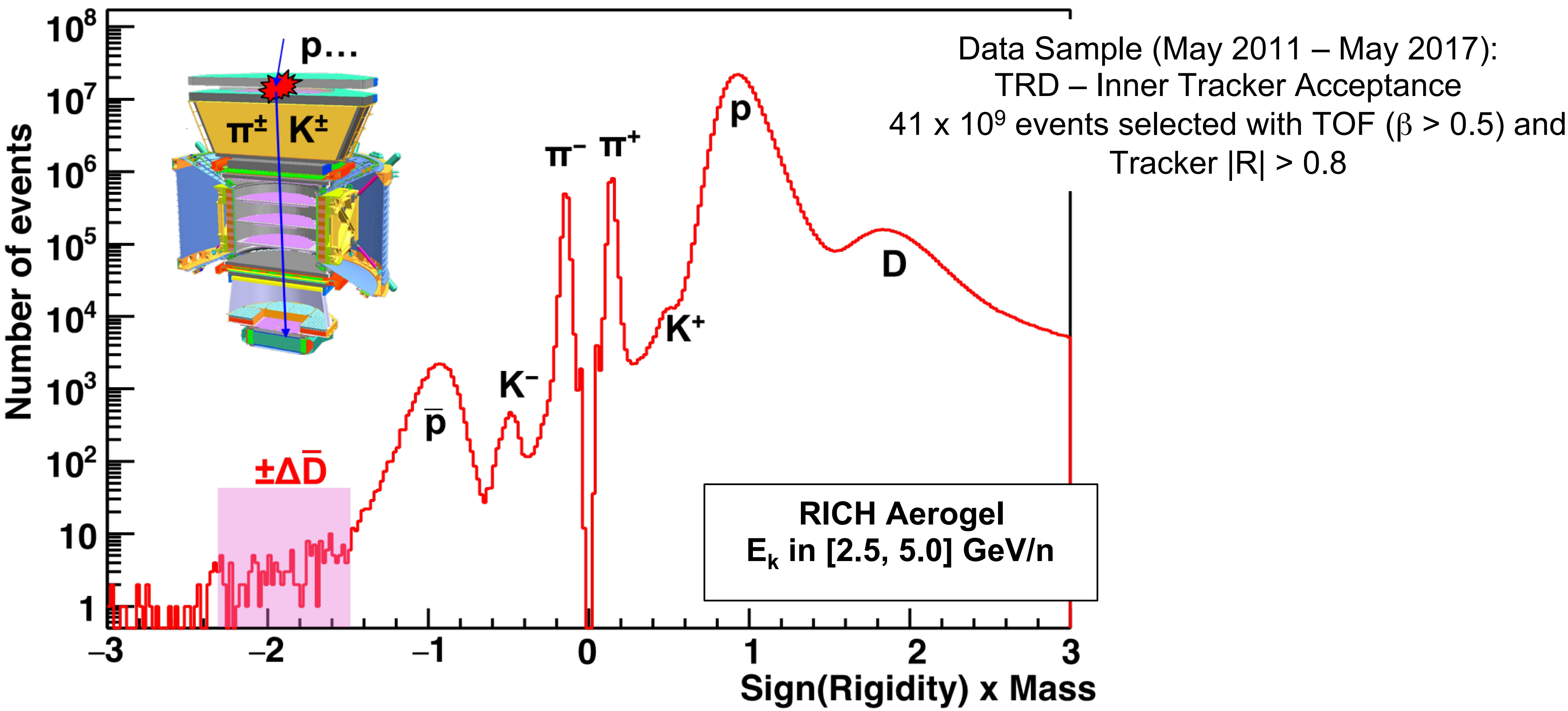
This analysis just started



Two sources of background are events reconstructed with **wrong sign** (ex. events with a large scattering angle in inner tracker), and events reconstructed with **wrong mass** (ex. production of photons from secondaries in the RICH radiator).Likelihoods based on response of detector to well reconstructed protons are able to clean up from most of this bad reconstructed events.

Physics : AntiDeuteron Search

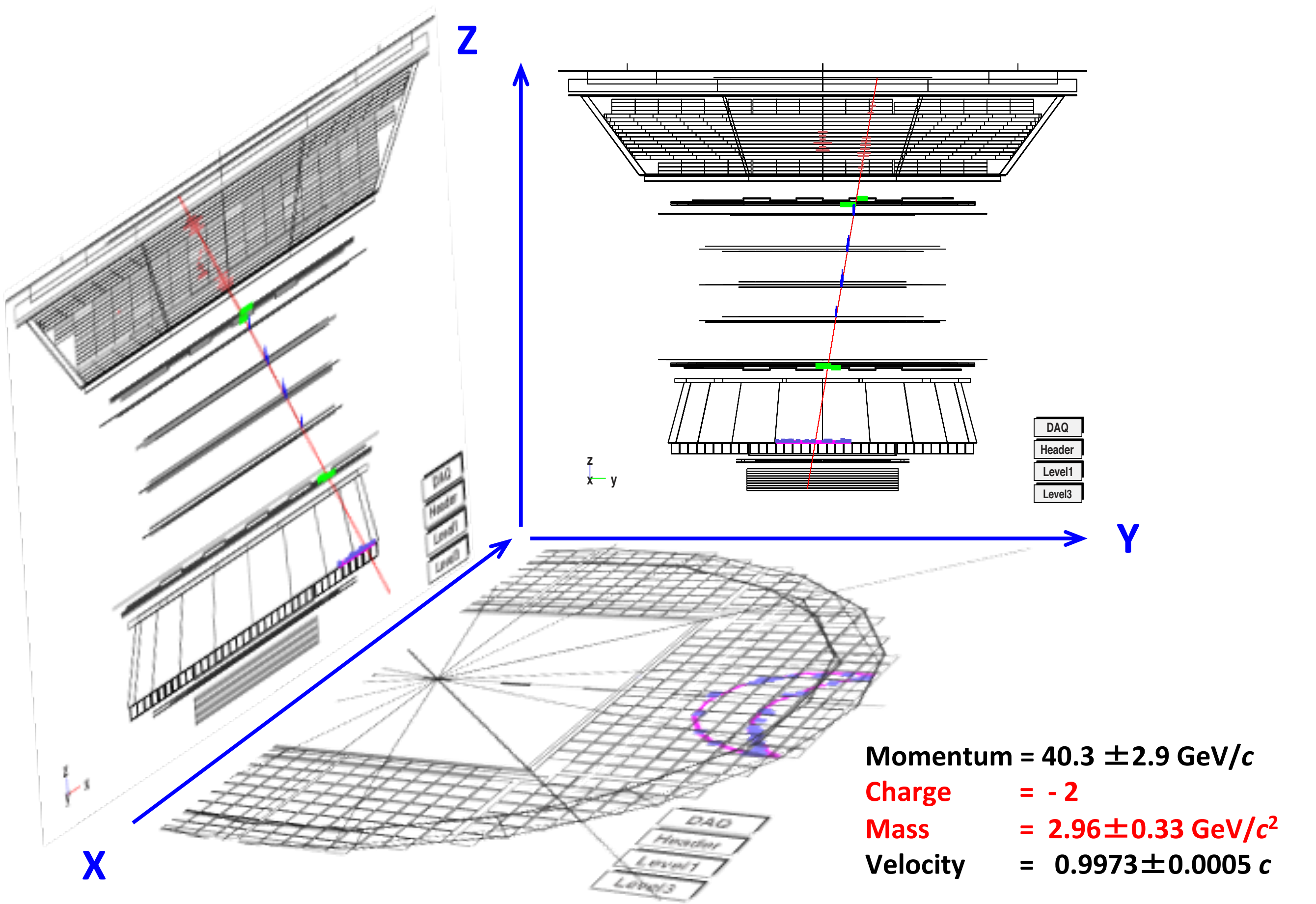
This analysis just started



At a signal to background ratio of one in one billion, a detailed understanding of the instrument is required. Eventually this will provide the best rejection and will allow the determination of the amount of remaining background.

Anti Matter Search

We have observed a few events with Z = -2



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

Conclusions

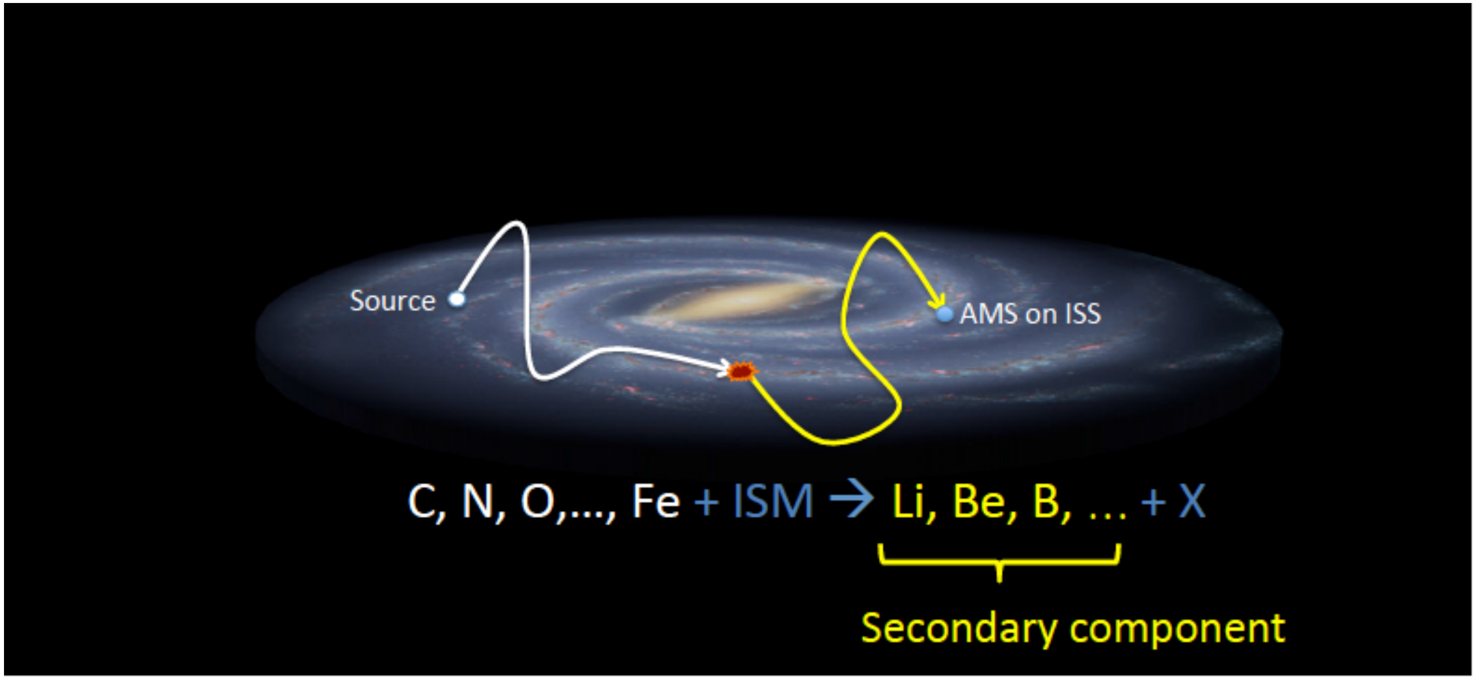
- AMS-02 experiment is succesfully operating in space providing precision meausurement of CRs;
- The RICH detector is running continously showing stable response and performances which are matching design expectations. No signs of deterioration observed so far;
- Rich detector contributed to AMS published results like antiprotons flux;
- It provides a unique clue to measure isotopes components in space, which are important for secondary production estimation ($^{3}He/^{4}He$,$^{6}Li/^{7}Li$,D/p…);
- With the unprecedented statistics and accuracy of the data, AMS has an unique capability to detect antimatter in cosmic rays and the RICH is a key detector in this search


AMS-02
ELC2
THANK YOU !

BACKUP

Nuclei Fluxes: secondary/primary

- The interaction of CR with the ISM produce by fragmentation the secondary component



- Li,Be,B are 100% secondary. C,O are dominated by primary component
- Li,Be, B are sensitive to CR propagation parameters (diffusion, convenction, reacceleration) and provide information on propagation models.
- Secondary/primary used to constrain propagation models.
- Lack of accurate and large energy range measurements before
- Models tuned on B/C Only so far