AMS-02 RICH detector in space: status and results

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Outline

- The AMS-02 Experiment
- The AMS-RICH detector
- Beta and Charge Measurements:
  - calibration
  - stability
  - performances
- Impact on physics & Conclusions

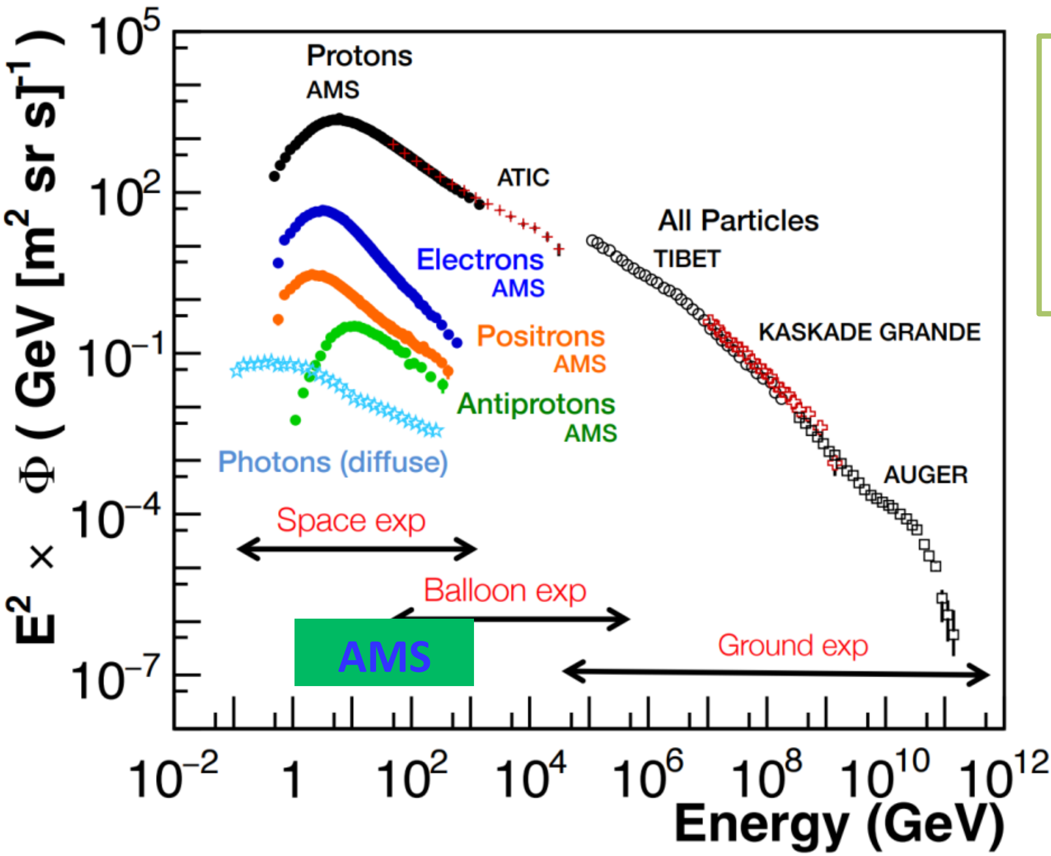
The AMS-02 Experiment

AMS-02 is successfully operating in space from its installation on ISS on May 2011

AMS has collected ~90 billion CRs so far.
It is expected to take data for all the ISS lifetime (2024).

The AMS-02 Experiment

AMS measures CRs with unprecedented statistics and precision, contributing to the **understanding of cosmic rays** origin, acceleration and propagation. Search signals of **Dark Matter** and **Anti-Matter**.

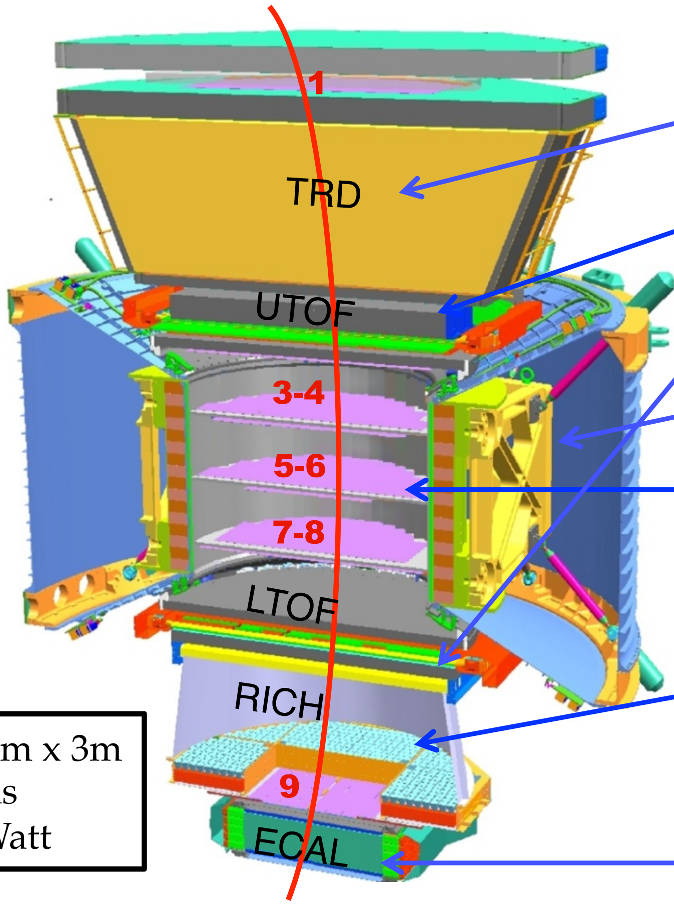


p ~90%
He ~8%
C,O,Fe… ~1%
e^- ~1%
e^+ $\bar{p}$ <<1%

- Energy of CRs range up to 10^{20} eV (AMS measures CRs from few GeV to TeV)
- Most of cosmic rays are proton and helium which are produced by astrophysical sources
- New physics can be hidden in cosmic ray signal (e.g. dark matter)

The AMS-02 Experiment

AMS-02 is a high energy particle physics magnetic spectrometer similar to those used for terrestrial HEP, with the feature that is operated at 400km orbit.



Transition Radiation Detector (TRD)

Time of Flight (ToF)

Permanent Magnet

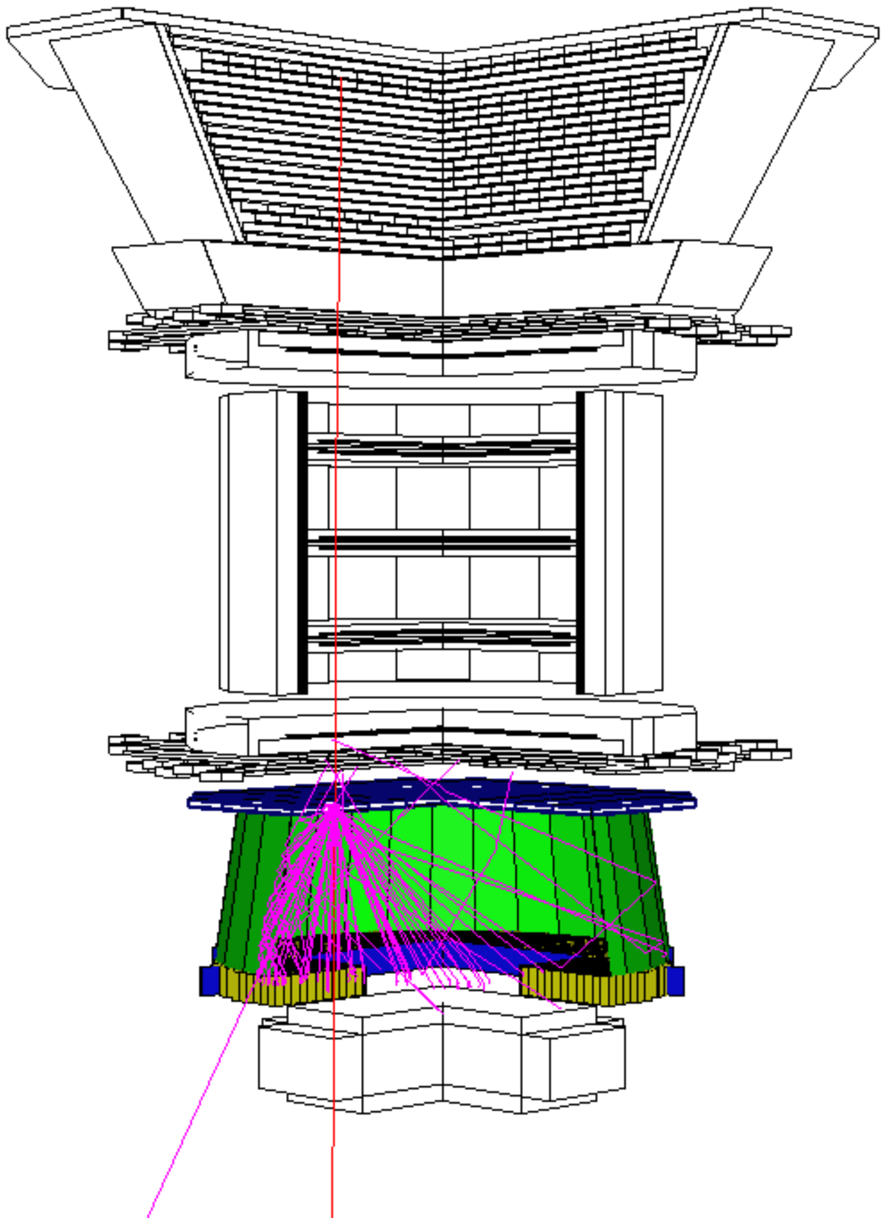
9 layers of Silicon Tracker (Tracker)

Ring imaging Cherenkov detector (RICH)

Electromagnetic Calorimeter (ECAL)

5m x 5m x 3m
7.5 tons
2.4 KWatt

The RICH detector



Physics motivations

The RICH provides AMS with:

- Precise measurement of charged particle velocity

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

- Particle charge identification till Z=26 (Iron)

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

Particle ID -> Isotopes Composition of CRs

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

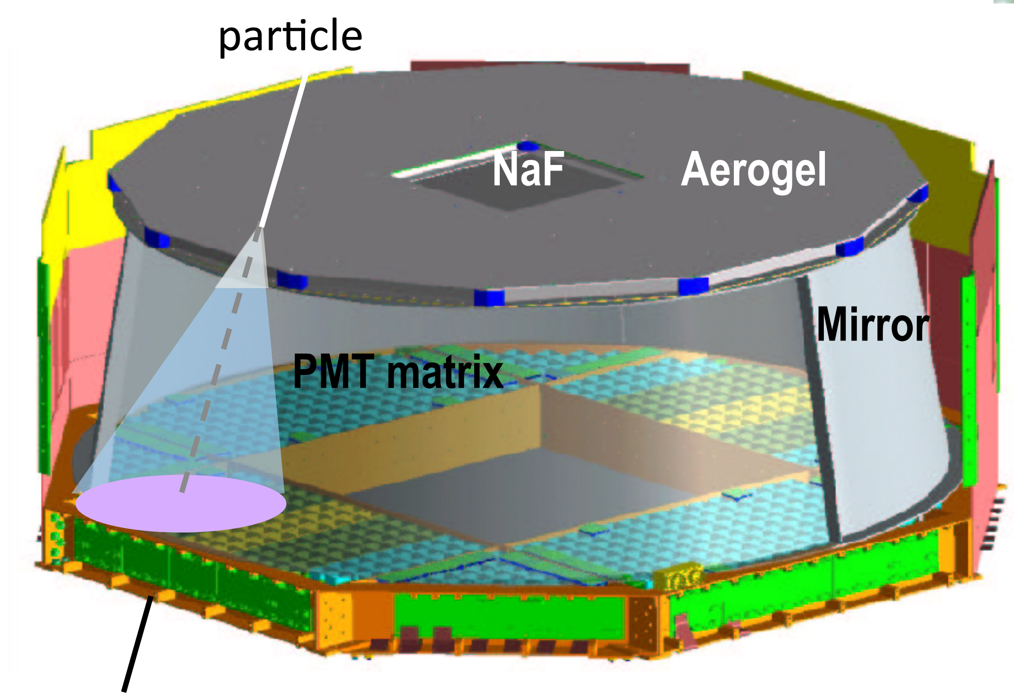
Rigidity(p/Z):TRACKER

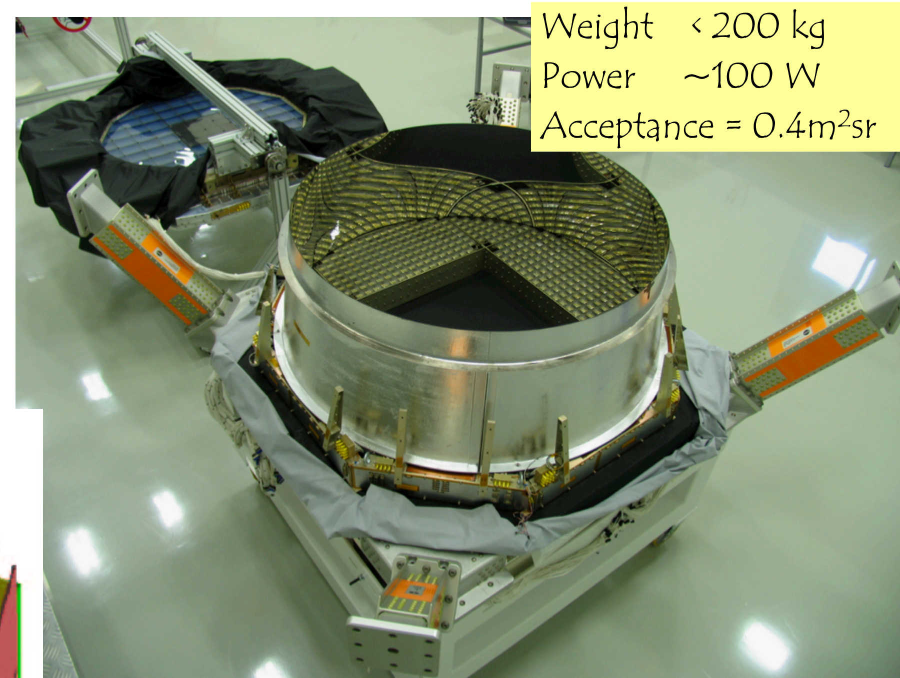
Velocity: TOF (2% for Z=2) + RICH (0.1% for Z=2)

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

Detector layout

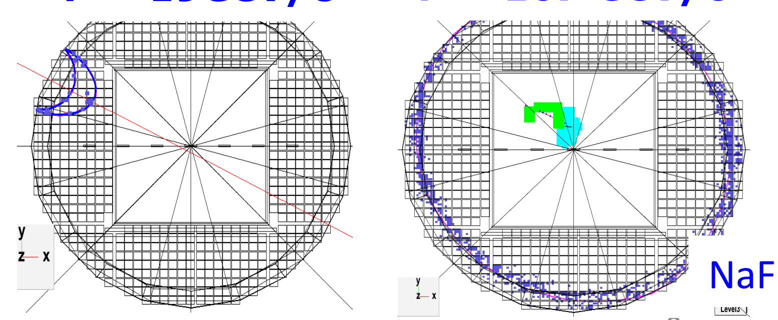
- Proximity Focusing detector
- Dual Radiator configuration
- Conical mirror to increase acceptance
- Detection matrix with central hole (ECAL)





Z = 2 (^{3}He)
P = 19GeV/c

Z = 26 (Fe)
P = 167 GeV/c

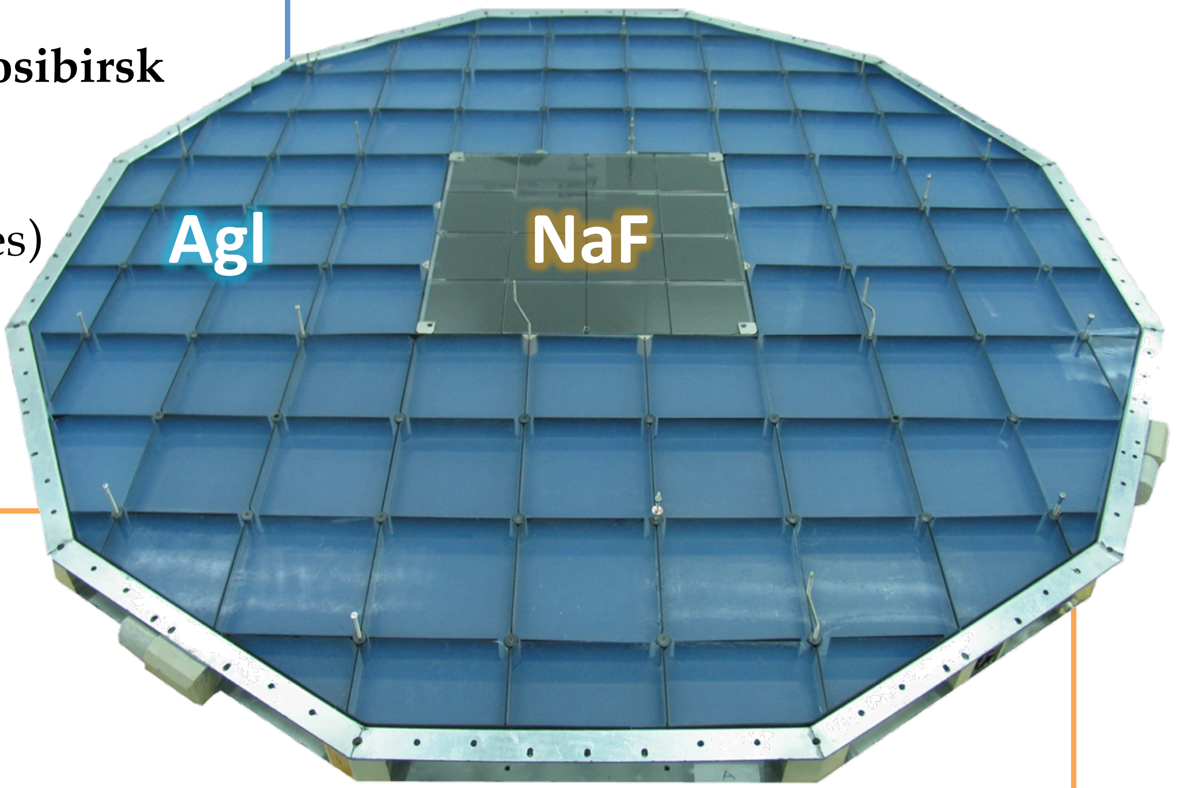


RICH Radiator

In space preferably no consumable !

Silica aerogel

- **Catalysis Institute of Novosibirsk**
- 80 tiles
- n=1.05
- $\Delta n \leq 0.005$ (for different tiles)
- hydrophilic
- 11.3 cm x 11.3 cm x 2.5cm
- ring ≈31cm for $\beta=1$
- $E_{kin}>2.1$ GeV/n



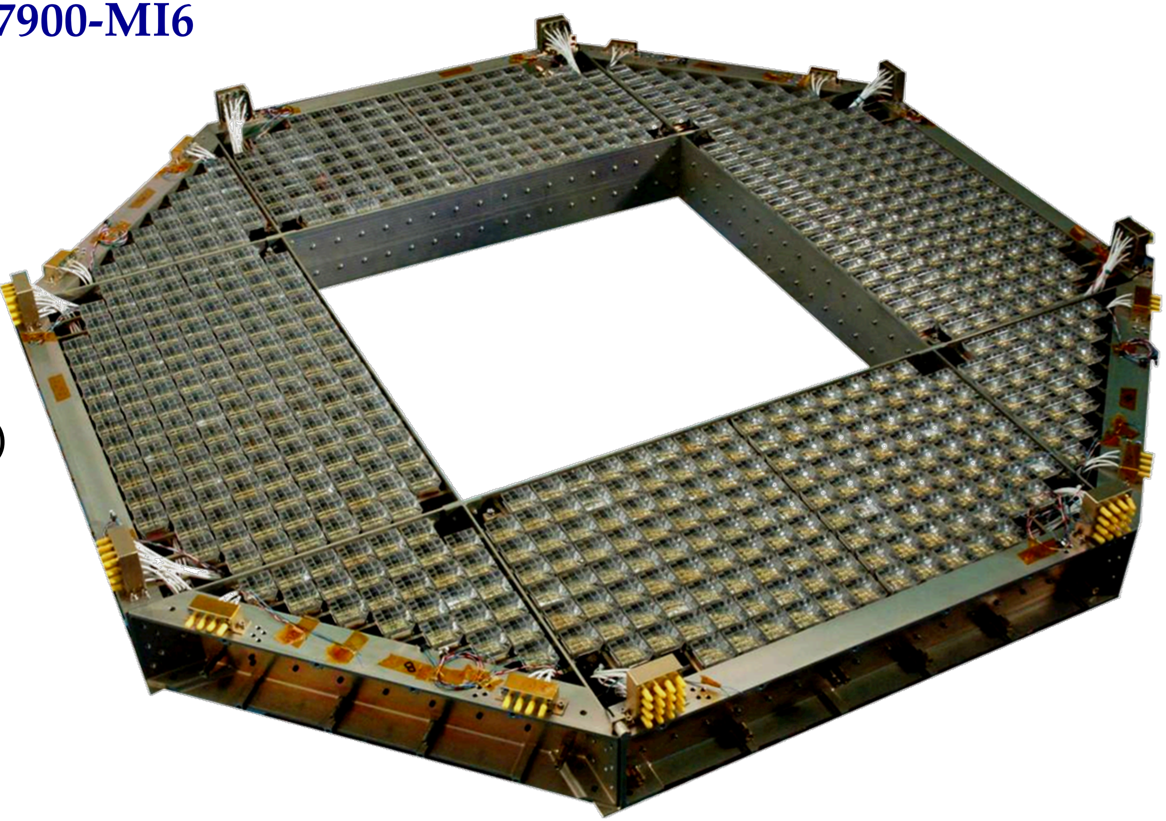
NaF crystals

- 16 tiles
- n=1.33
- 8.5 x 8.5 x 0.5 cm
- ring ≈85cm for $\beta=1$
- Larger Cherenkov 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 for PID

RICH detection plane

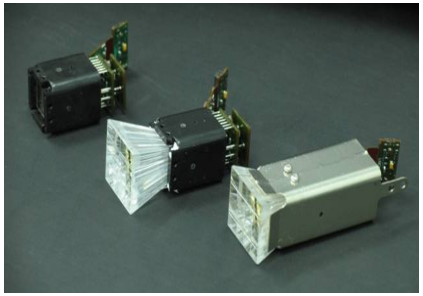
The RICH detection Plane is made of 680 multianode pmts (10880 pixels)

Hamamatsu R7900-MI6



- High single-photon detection efficiency
- Low sensitivity to external B field (metal channel dynodes)

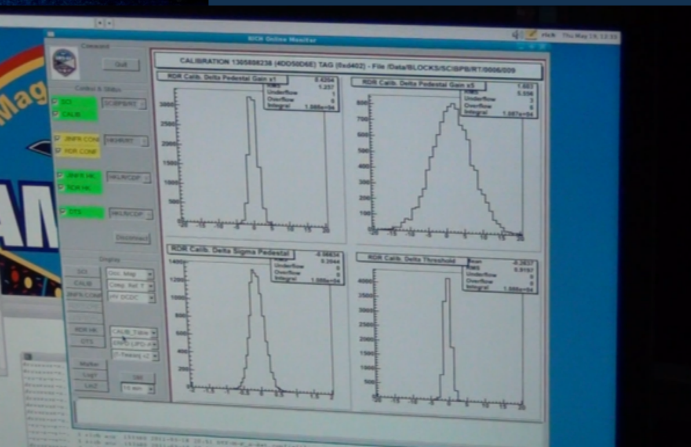
Light Guides & magnetic shielding

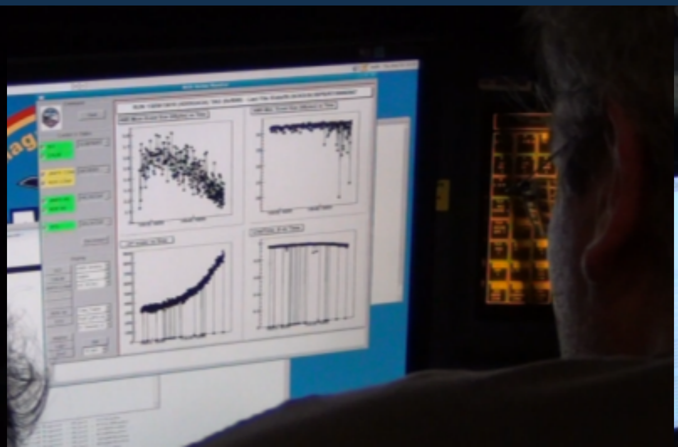


Final detection granularity: 8.5 x 8.5 mm^2

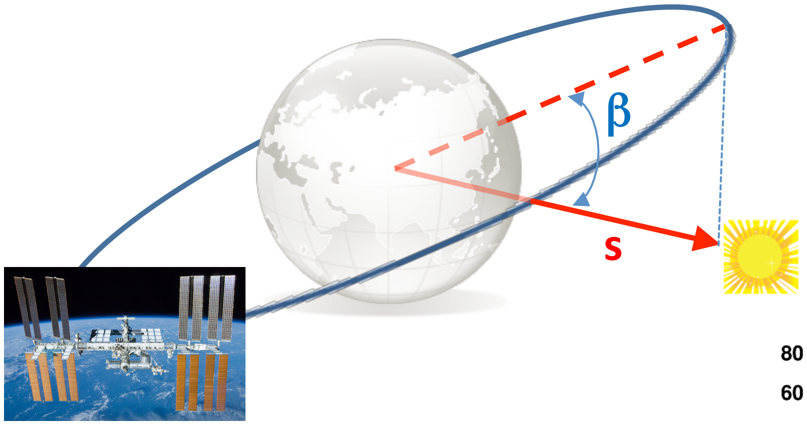
RICH
Monitoring & operations

- The detector in continosly running
- RICH critical parameters are constantly monitored 24/7 at CERN AMS Payload Control Center (POCC) to ensure detector integrity and optimal performances
- In ~6 years of data taking no major intervention required
- More than 95% of the channels are working properly

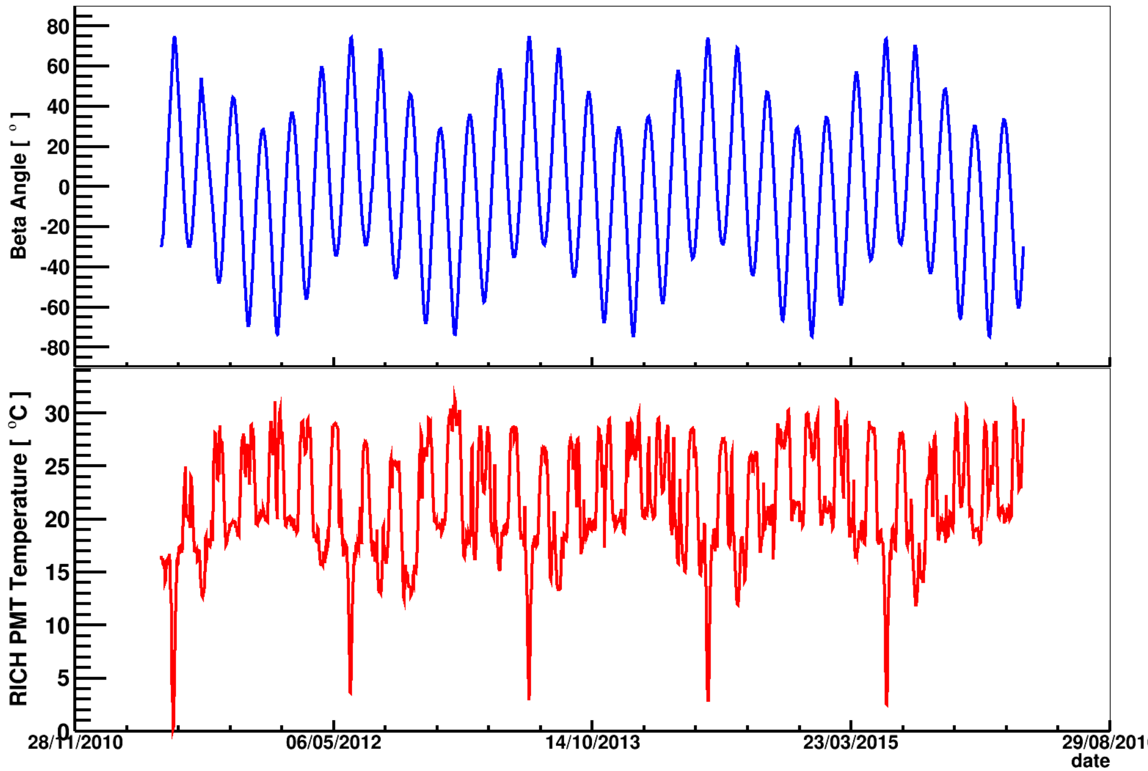




On orbit thermal environement



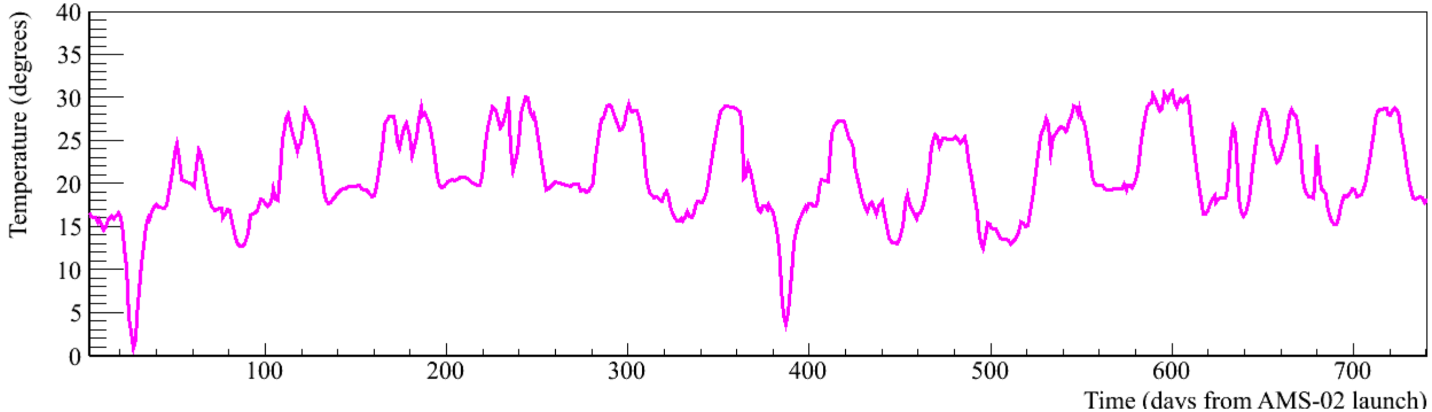
Beta angle (β) is the angle between the solar vector, **s**, and its projection onto the orbit plane. As β changes, the heating incident on the AMS surface changes and determines its temperature

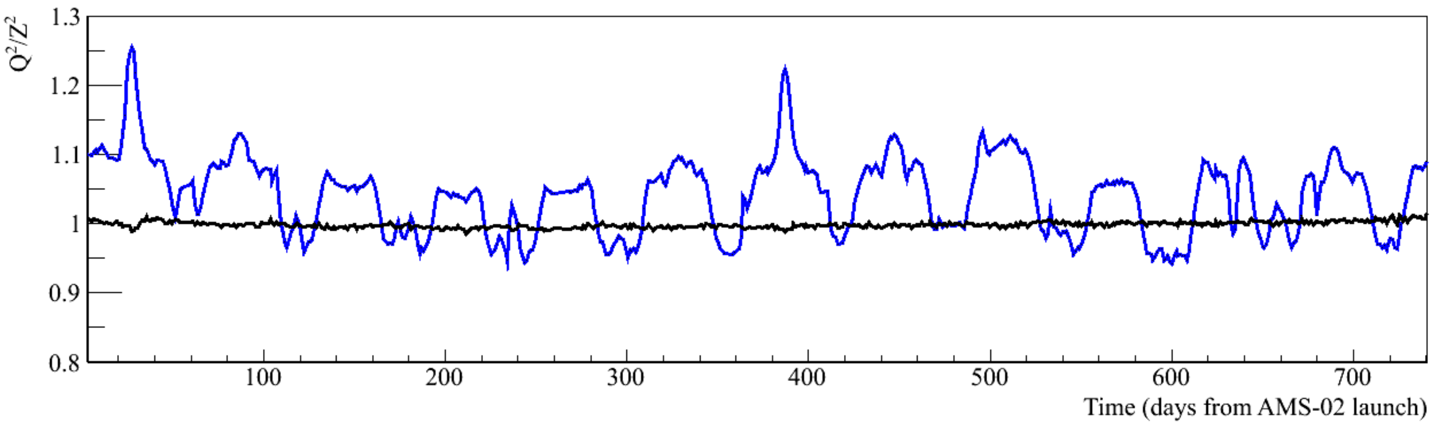


48(+48) Dallas sensor in the detection plane measure T. RICH components are qualified to operate within specific ranges of temperature (+50 C,-30 C)

Time-dependent corrections

Temperature is the most important time-dependent environmental factor affecting charge determination due to its effect on the phodetectors.





- Temperature affect both PMT gains and efficiencies.
- Precise determination of PMT Gains and Efficiencies T coeff. per each PMT channel.

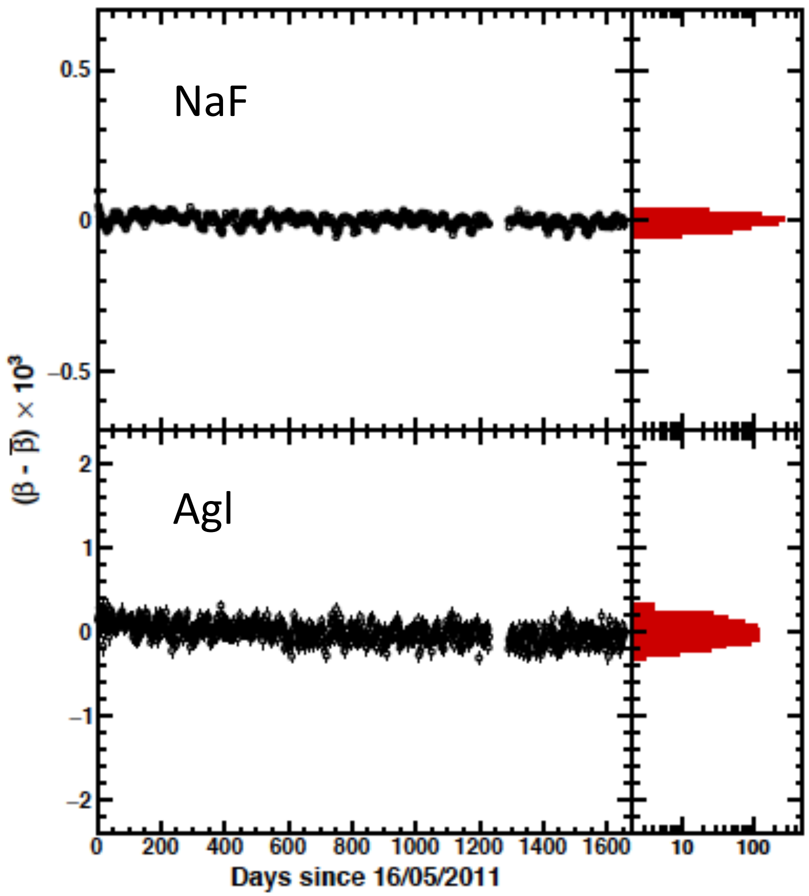
Gain T coefficient $C_g = (-0.81 \pm 0.12(\mathrm{RMS}))\% /^{\circ}\mathrm{C}$
Efficiency T coefficient $C_e = (-0.23 \pm 0.14(\mathrm{RMS}))\% /^{\circ}\mathrm{C}$

Response stability in time

Charge: after temperature corrections the detectors response is stable

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

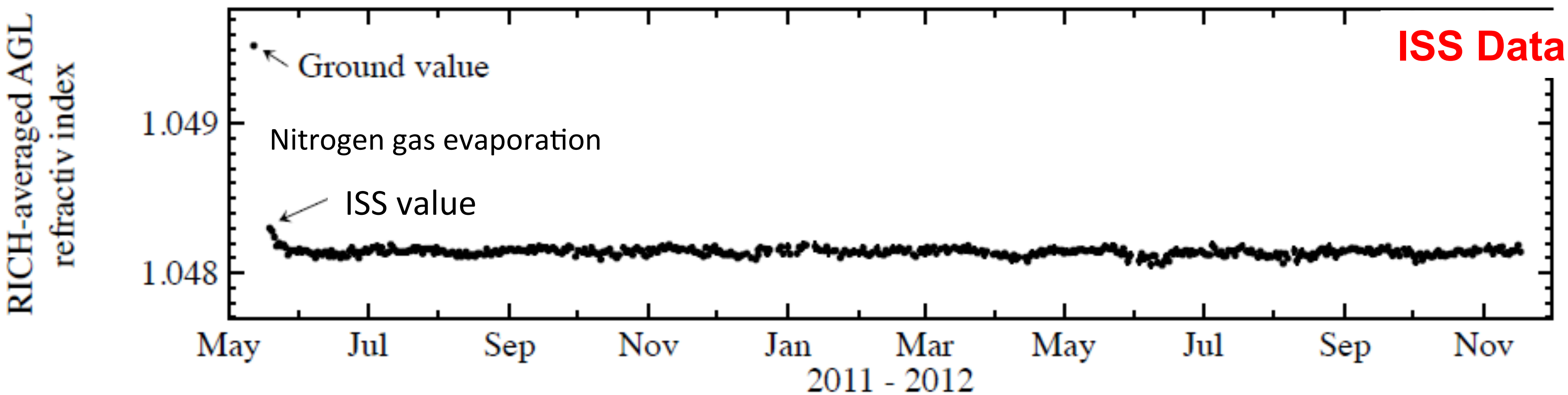
Beta:



Y axis range equivalent to +- 1σ

- Residual effect on beta are small enought to have no impact in the resolution

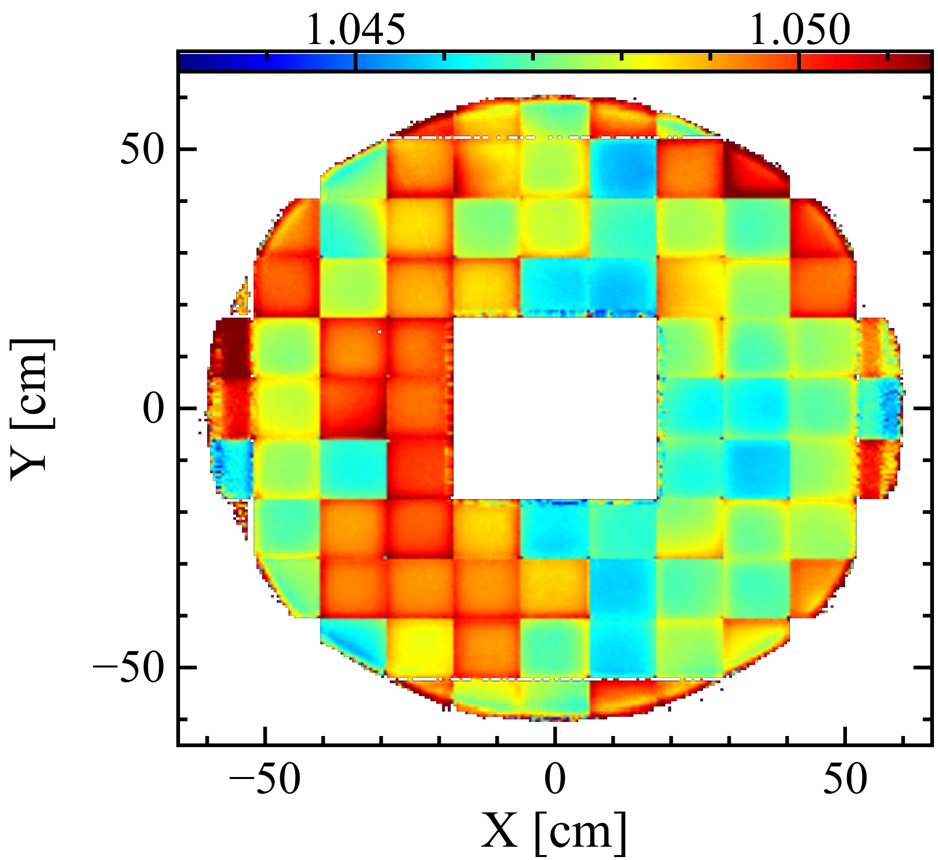
Agl Radiator Refractive Index



Agl refractive index depends on environment conditions (air humidity).
The mean refractive index drops from ground to vacuum of **~1.5 x 10^{-3}**.
Radiator container was filled with neutral gas (Nitrogen) to protect Agl from humidity, compensate pressure variation and to assure venting capabilities during launch.
A dynamical procedure monitors changes in the average tile refractive index.

AgI Radiator Refractive Index

From Lab measurements we expected variation within the tile of the order of 10^{-3}
Resolution requirements on β and charge measuremnts : $\Delta n/n \leq 10^{-4}$



Map using 1 year in-flight data proton sample (with R>10GV)

- Different AgI tiles have different density and therefore different mean n;
- Inside each tile there is n gradient associated to: density variations due to thermal processing of the material, geometrical variations on tile thickness and border effects;
- Thanks to high statistics the map ($0.5 \times 0.5\ cm^2$) : precision $\mathbf{\Delta n/n \approx 2 \times} 10^{-5}$

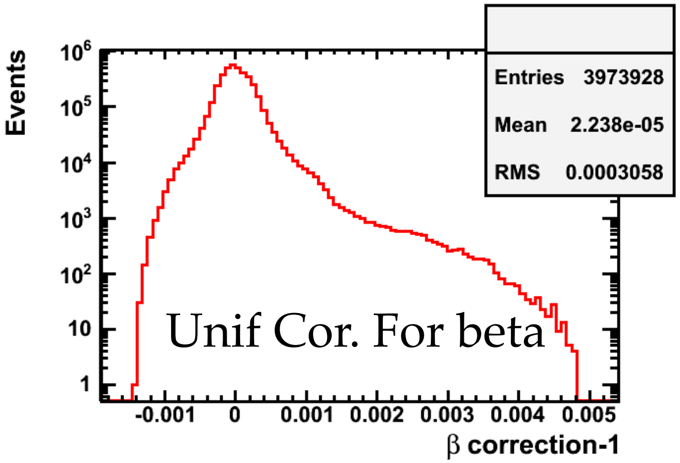
RICH Calibration

Detector Uniformity corrections

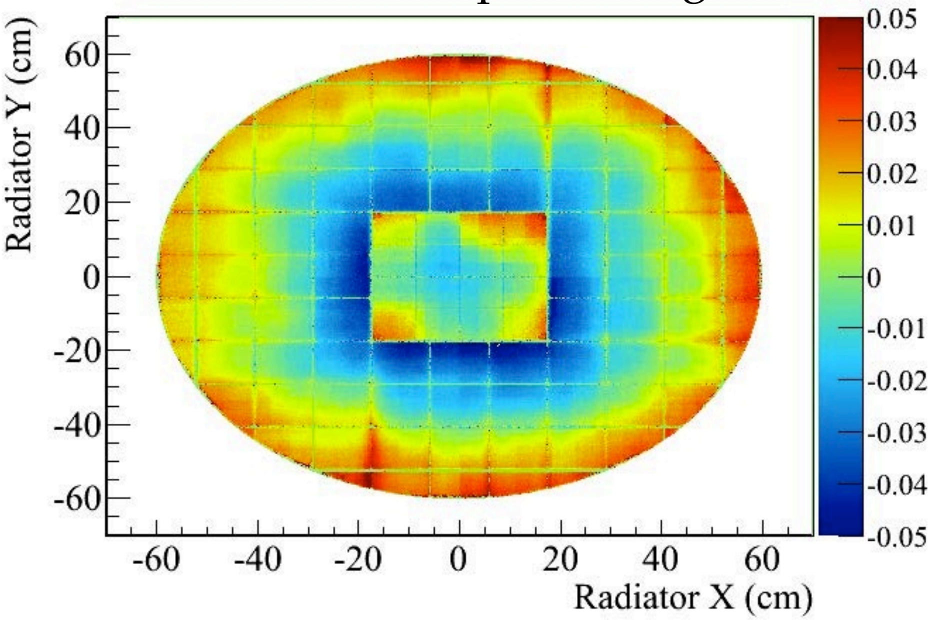
- Effective corrections to account for additional detector inhomogeneity: border effects, mechanical structure of the radiator container, mirror reflectivity, LG eff and cross talk etc
- Lab measurements at Earth not enough accurate; the required precision in their knowledge could be only achieved using high statistic cosmic data .

High stat He sample to compute Beta and charge correction as function of:

- Impact point in the radiator (X,Y)
- Particle direction (ϑ,ϕ)
- (Particle reconstructed velocity (β))

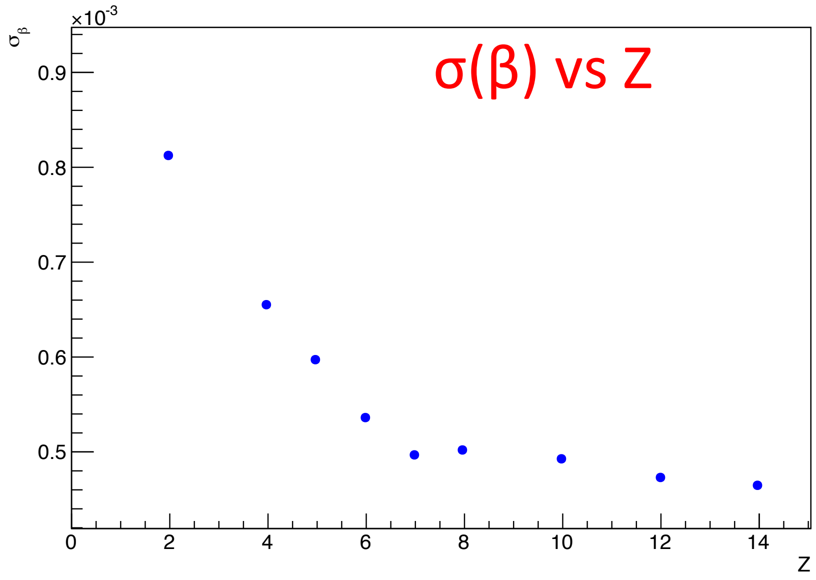


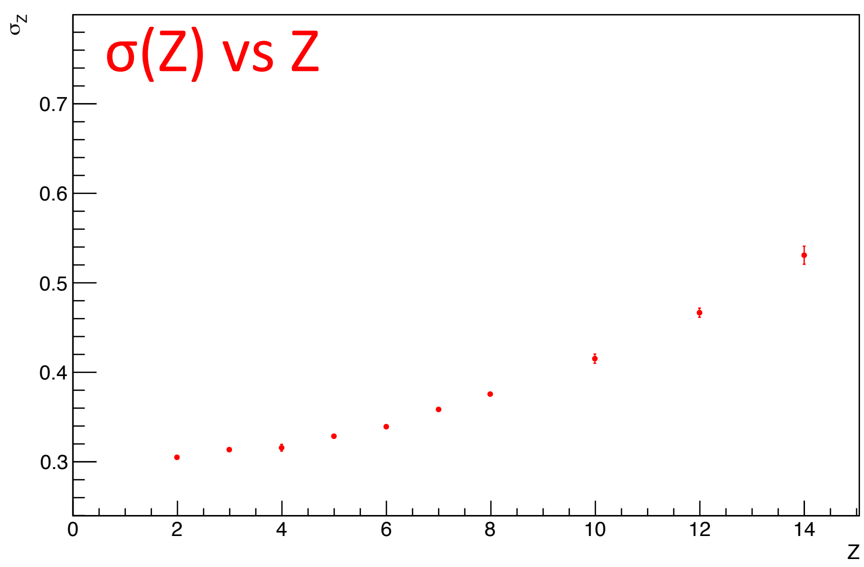
Unif Cor Map for charge



RICH Performances

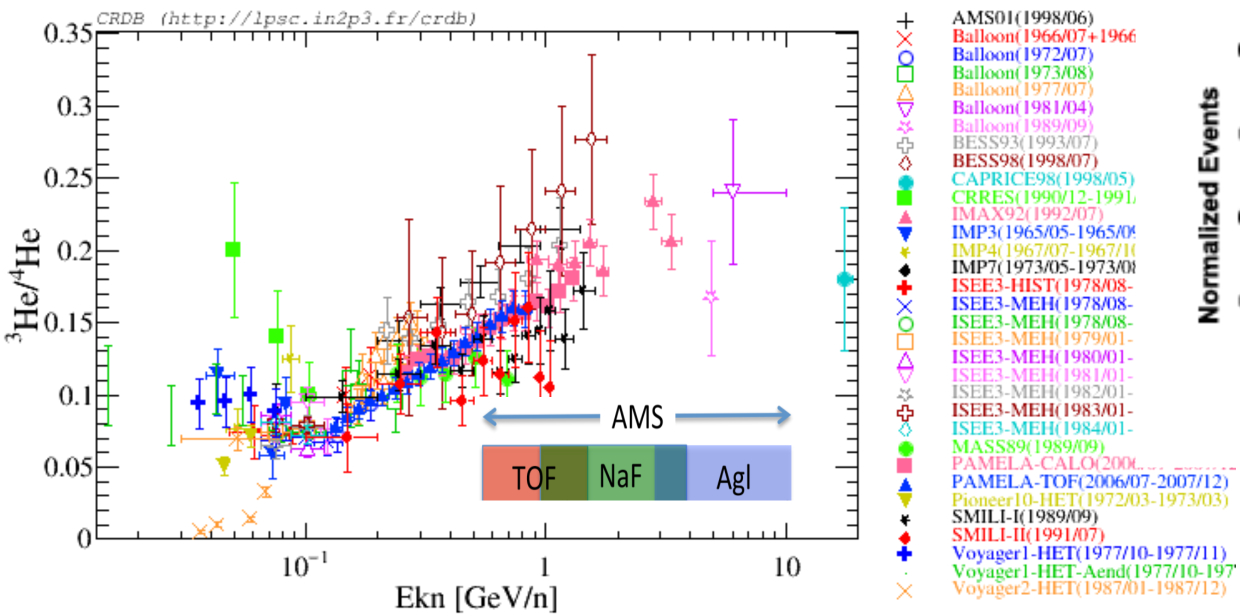
- Beta resolution ~ 0.8 per mil per Helium and better for higher Z
- Charge Resolution ~0.3 for Helium

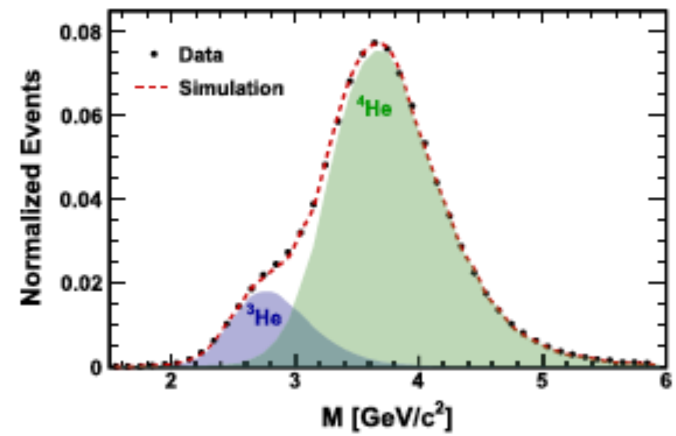




Physics impact

- Main Physics motivations: measurement of CRs Isotopic Composition up to 4 with unprecedented statistics (^{3}He/^{4}He, ^{6}Li/^{7}Li, ^{7}Be/Be).





- In $\bar{p}/p$ analysis RICH is used to reduce the e$^-$ bg for E<10GeV [PRL 117-091103 (2016)]
- In B/C analysis RICH is used to determine the B isotopes fraction [PRL 117,231102(2016)]

Conclusions

- AMS-02 experiment is sucessfully operating in space
- The RICH detector is working well
- Time dependent effects have been taken into account (mainly Temperature), residual effect are well within intrinsic resolution
- Agl refractive index accurate map
- Rich Performance are matching design expectation
- The stability in time of measurements evinces no effect of aging in Silica Agl so far
- Measurement of Isotopes composition of CRs from AMS-02 is in preparation

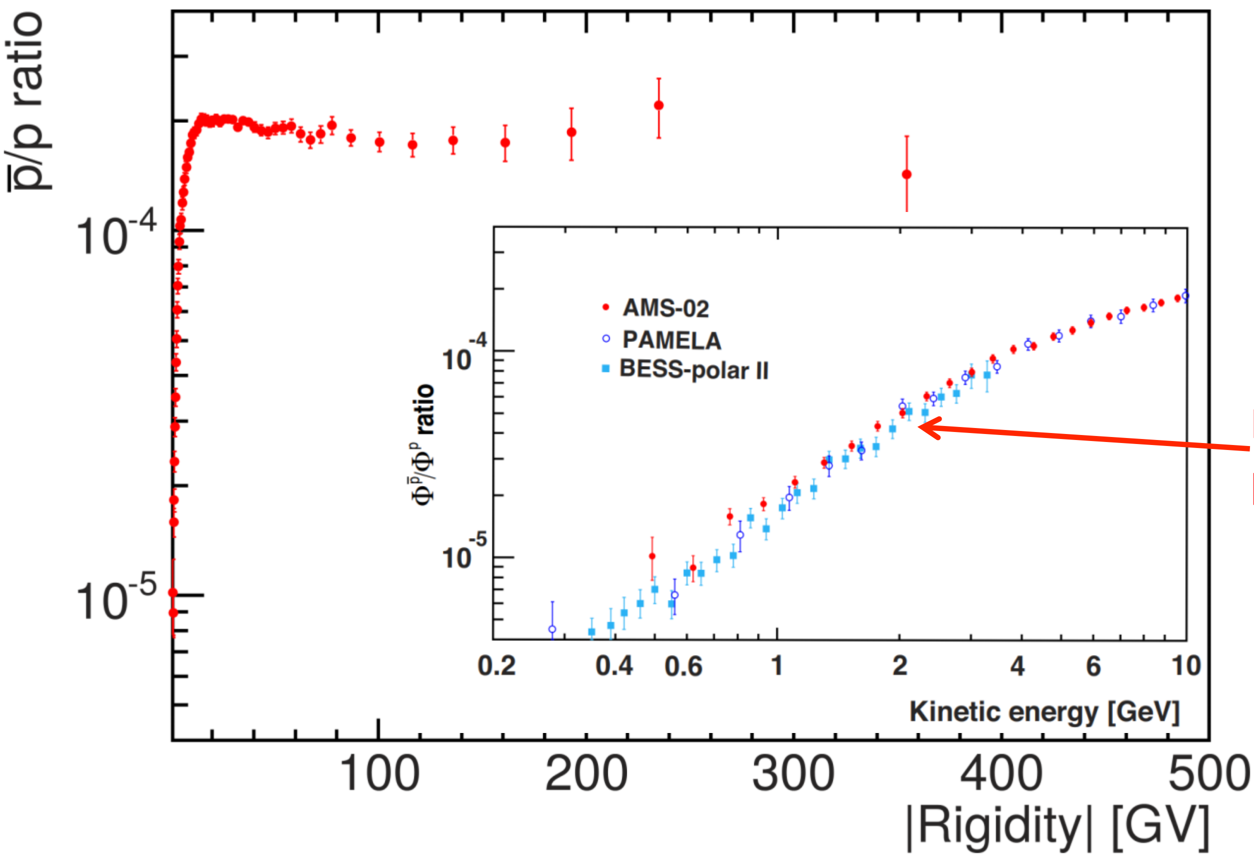
Backup

AMS Latest Publication: $\bar{p}/p$ Flux Ratio

PRL **117**, 091103 (2016) PHYSICAL REVIEW LETTERS week ending 26 AUGUST 2016

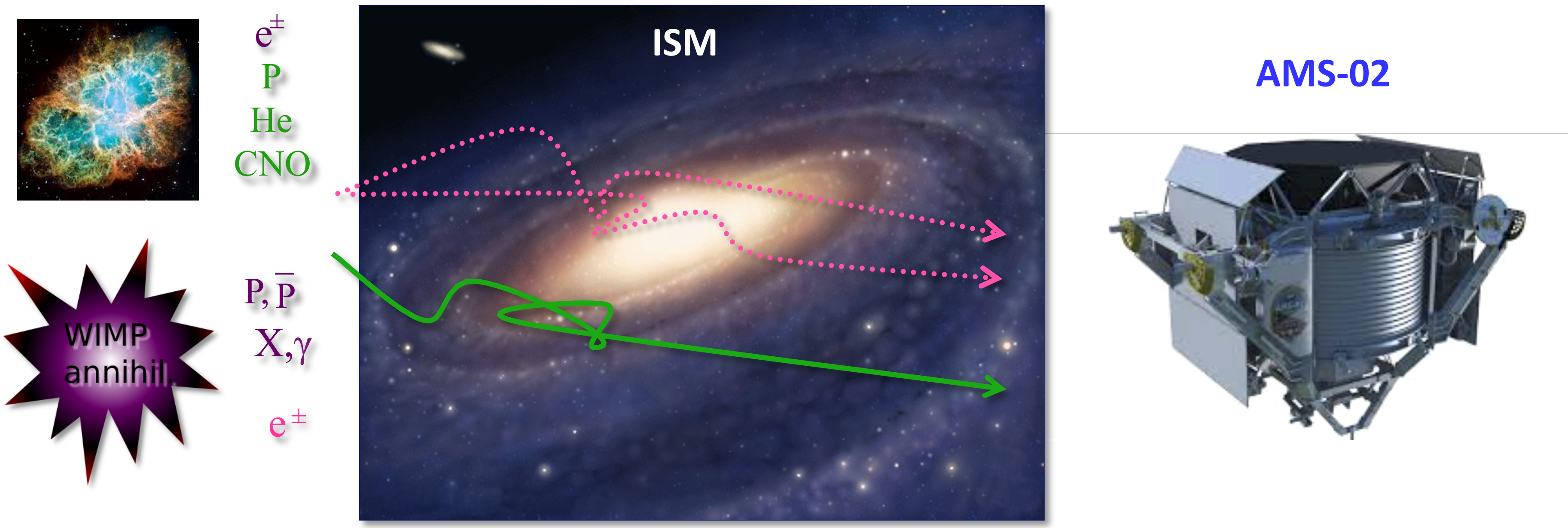
Antiproton Flux, Antiproton-to-Proton Flux Ratio, and Properties of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station

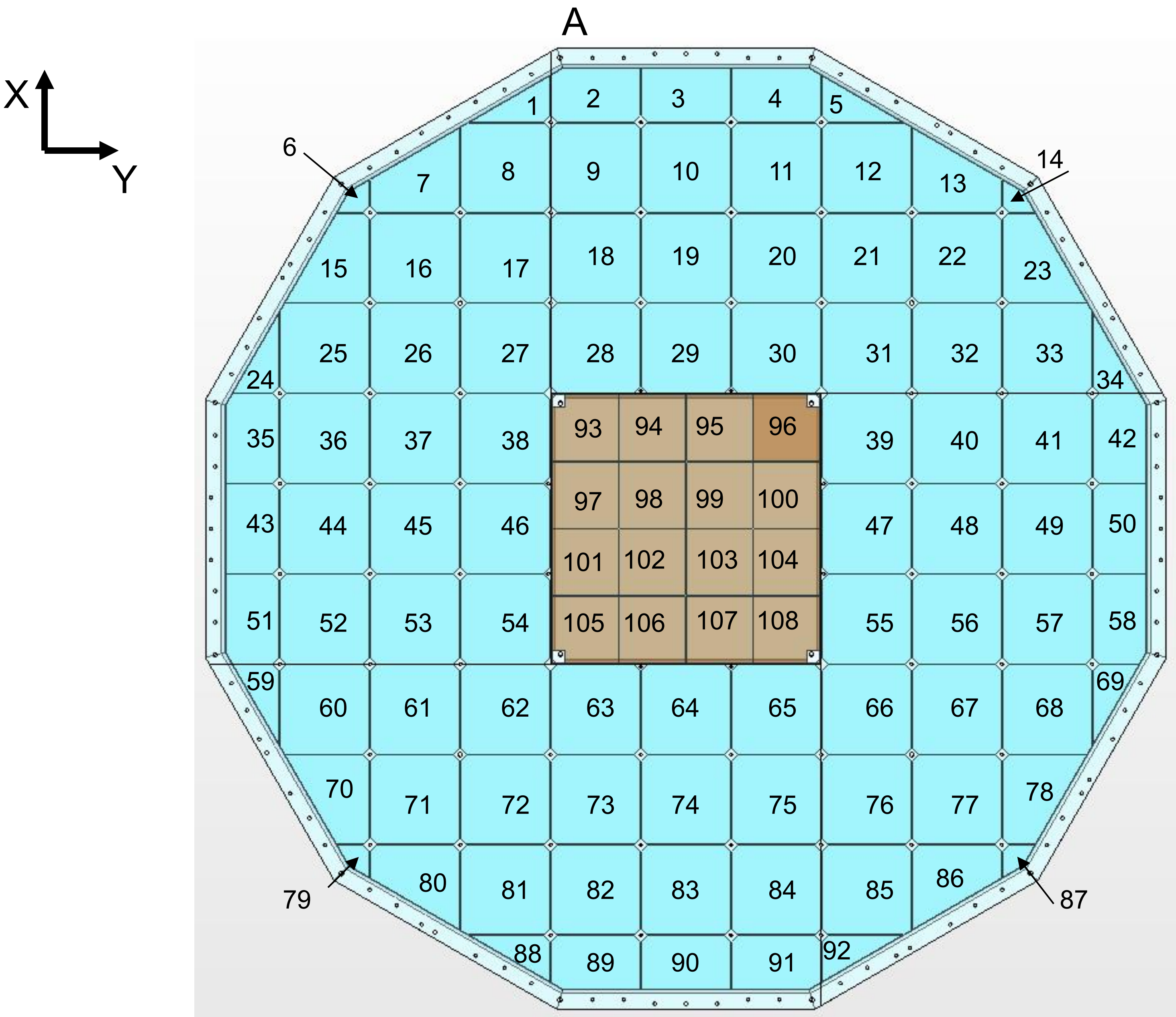
0.35 million $\bar{p}$ events and 2.4 billion p events



RICH is used to reject electron background below 10 GeV

The AMS-02 Experiment





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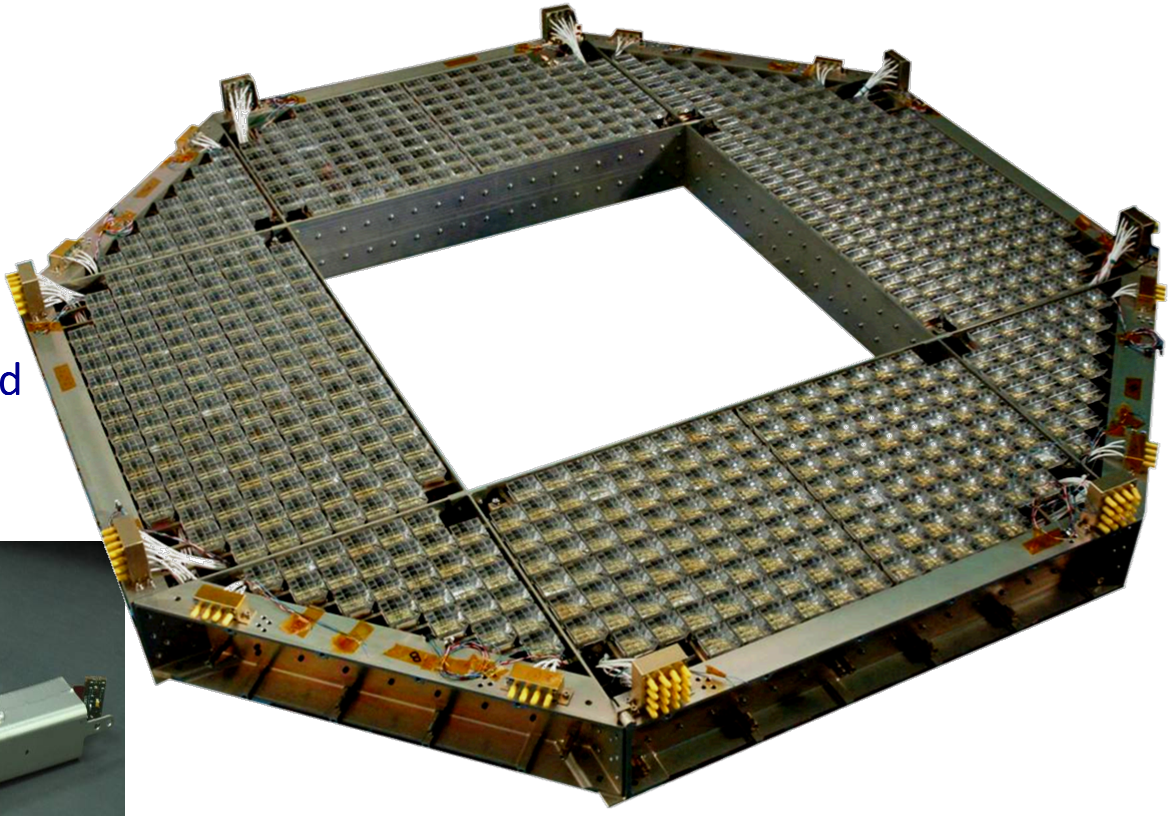
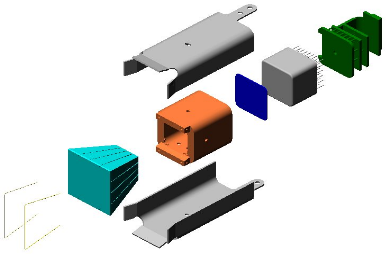
RICH Detection Plane

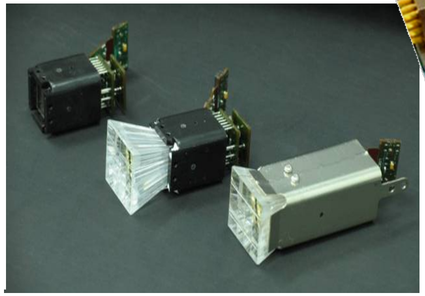
The RICH detection Plane is made of 680 multianode pmts (10880 pixels)



PMT Hamamatsu R7900-MI6:

- ✧ High single-photon detection efficiency
- ✧ High response uniformity
- ✧ Low sensitivity to expernal B field (metal channel dynodes)
- ✧ Gain ≈ 10^6 @ 800V

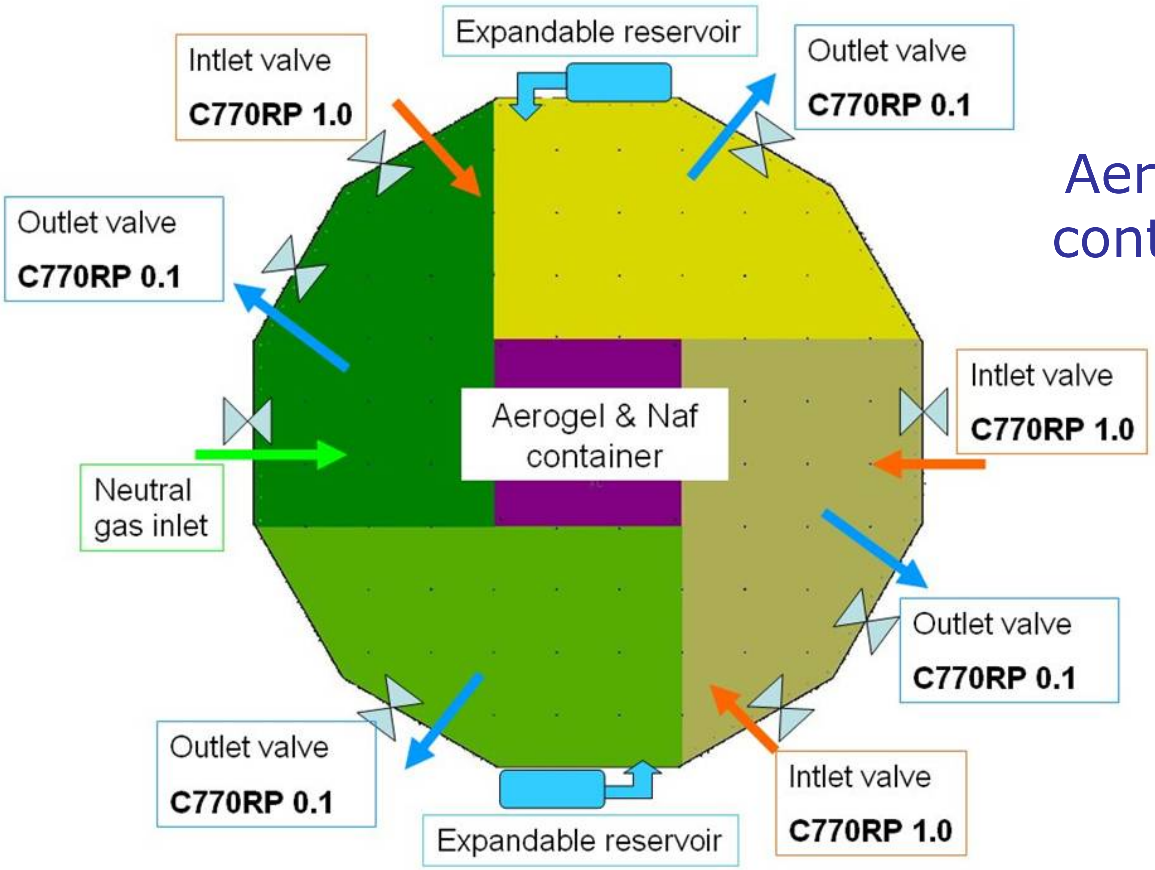




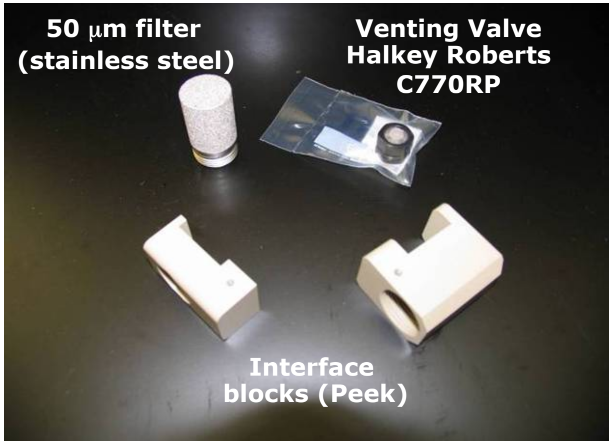
Light Guides acrylic plastic free of UV absorbing additives
Shielding to magnetic field in Alu plates (0.8-1.3 mm)

Detection granularity: 8.5 x 8.5 mm^2

Radiator: Venting



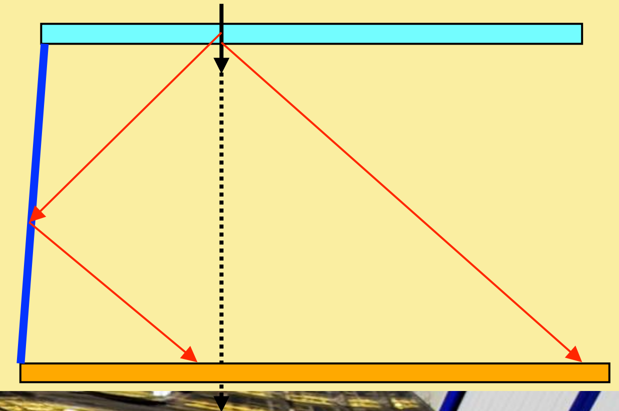
Aerogel and NaF require a controlled dry environment



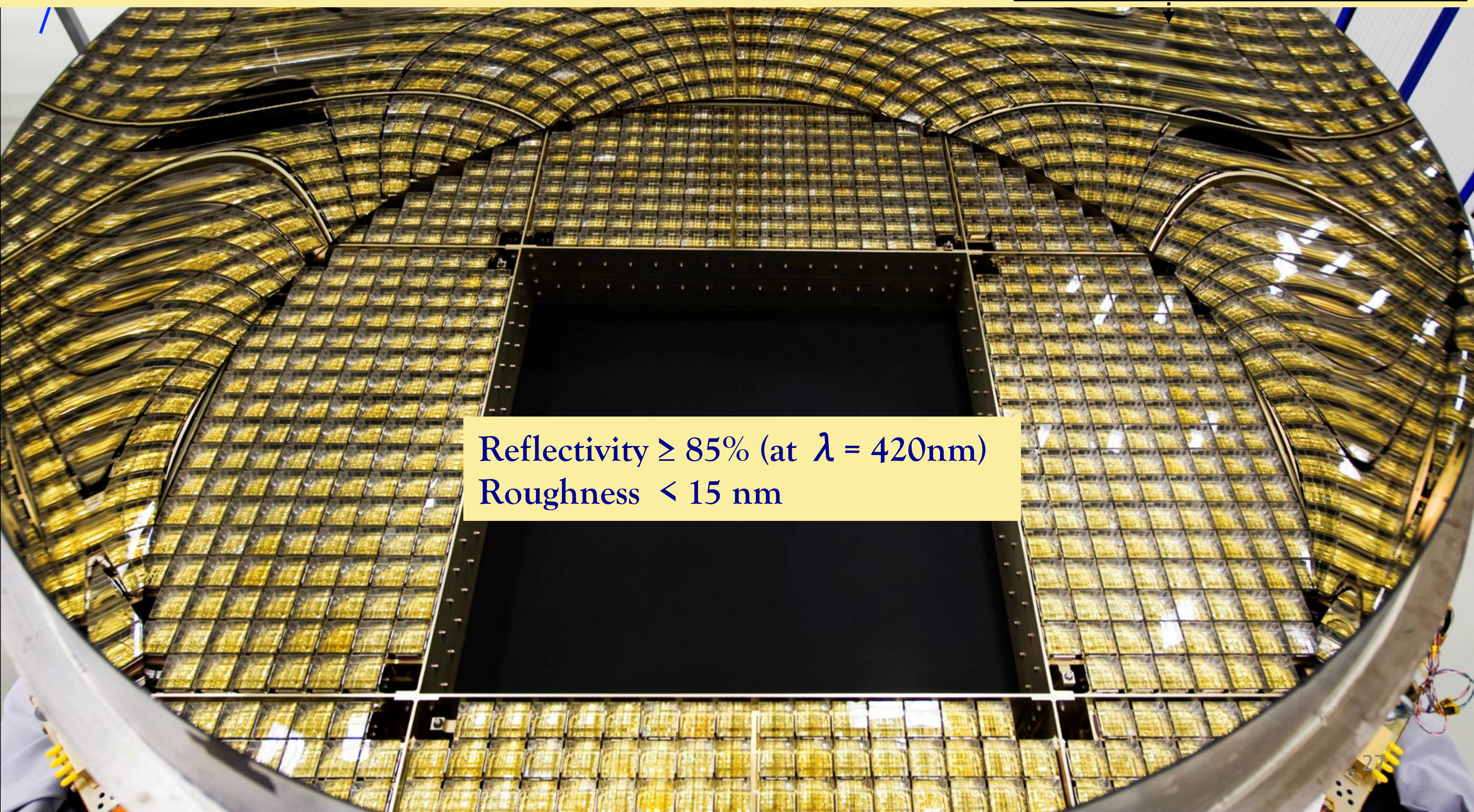
Container filled with neutral gas (Nitrogen) whenever not in dry atmosphere

- compensates atmospheric pressure variations
- Launch/landing venting capability

RICH Reflector



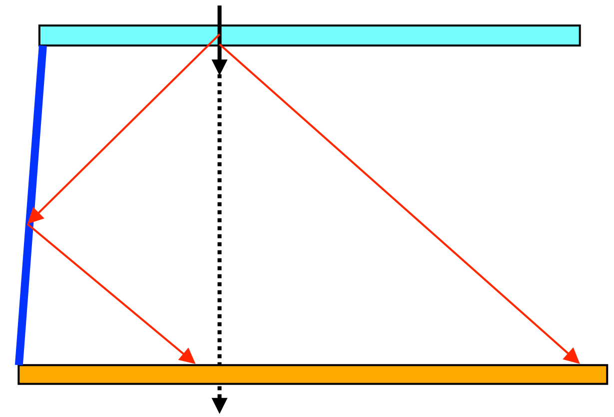
About 30 % of the Č photons point ouside of the detection array
The mirror is made of 3 sectors
Multilayer structure deposited on a carbon Fiber Substrate

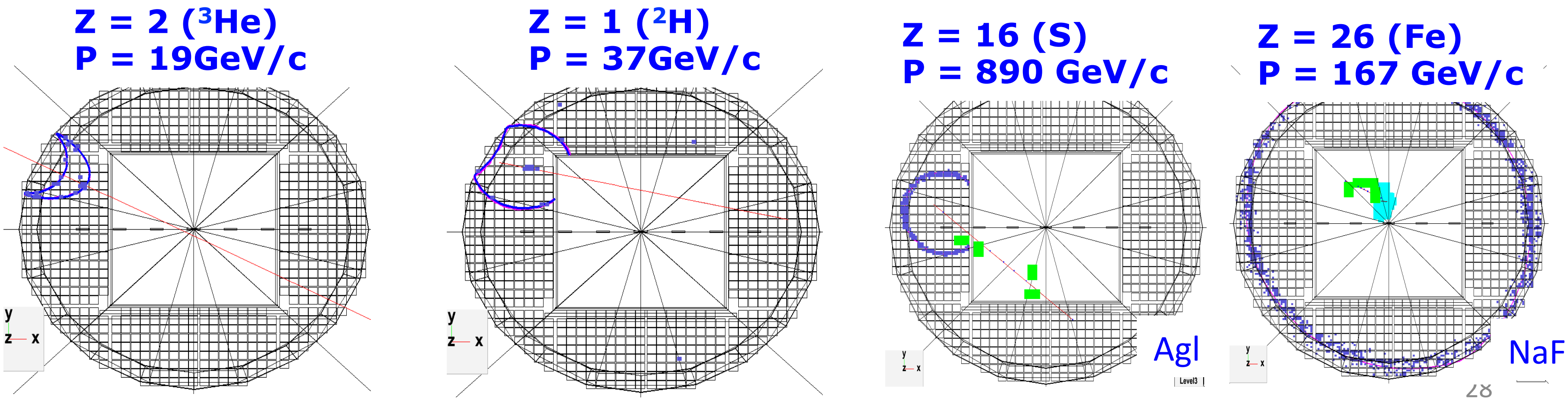


Reflectivity ≥ 85% (at λ = 420nm)
Roughness < 15 nm

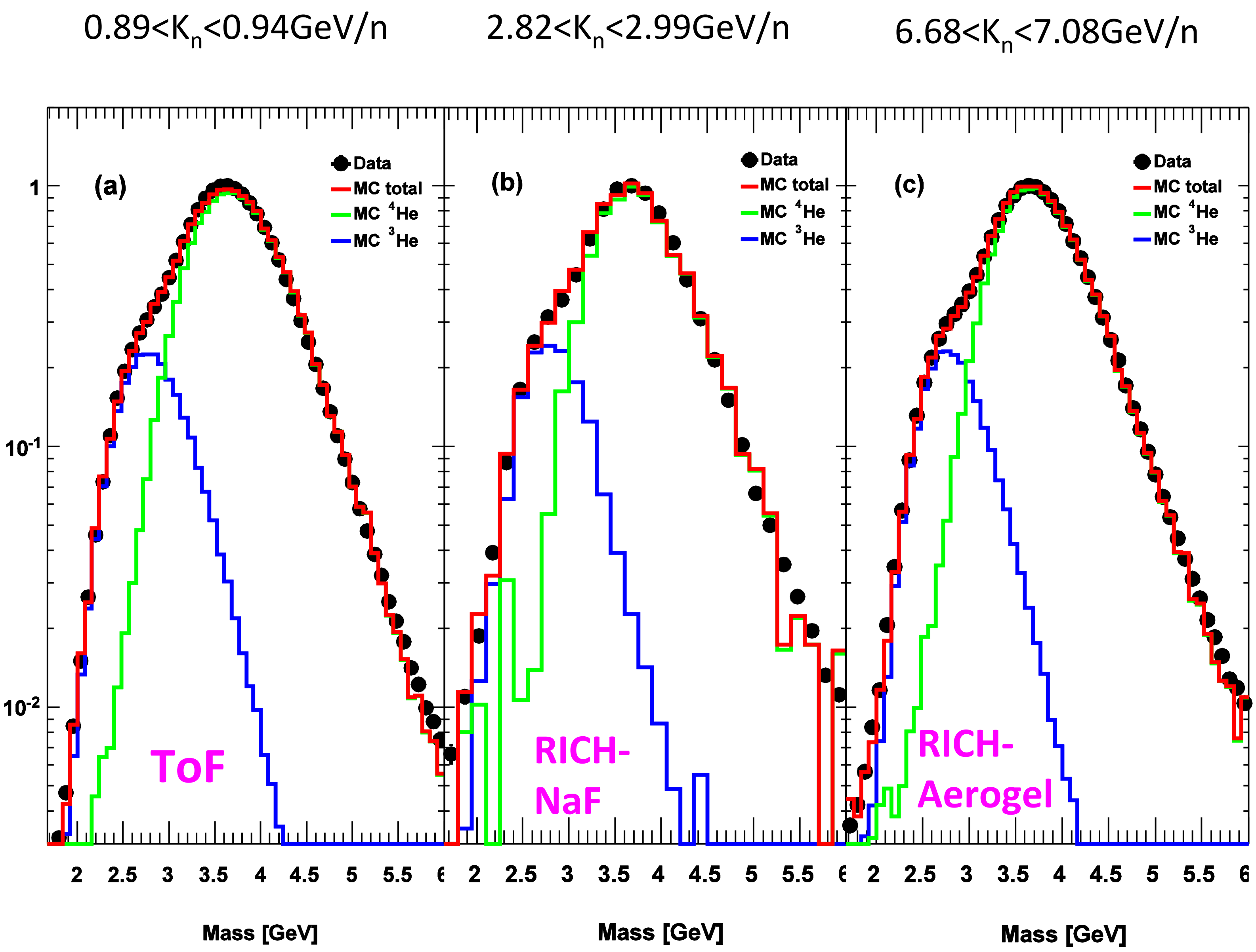
Reconstruction

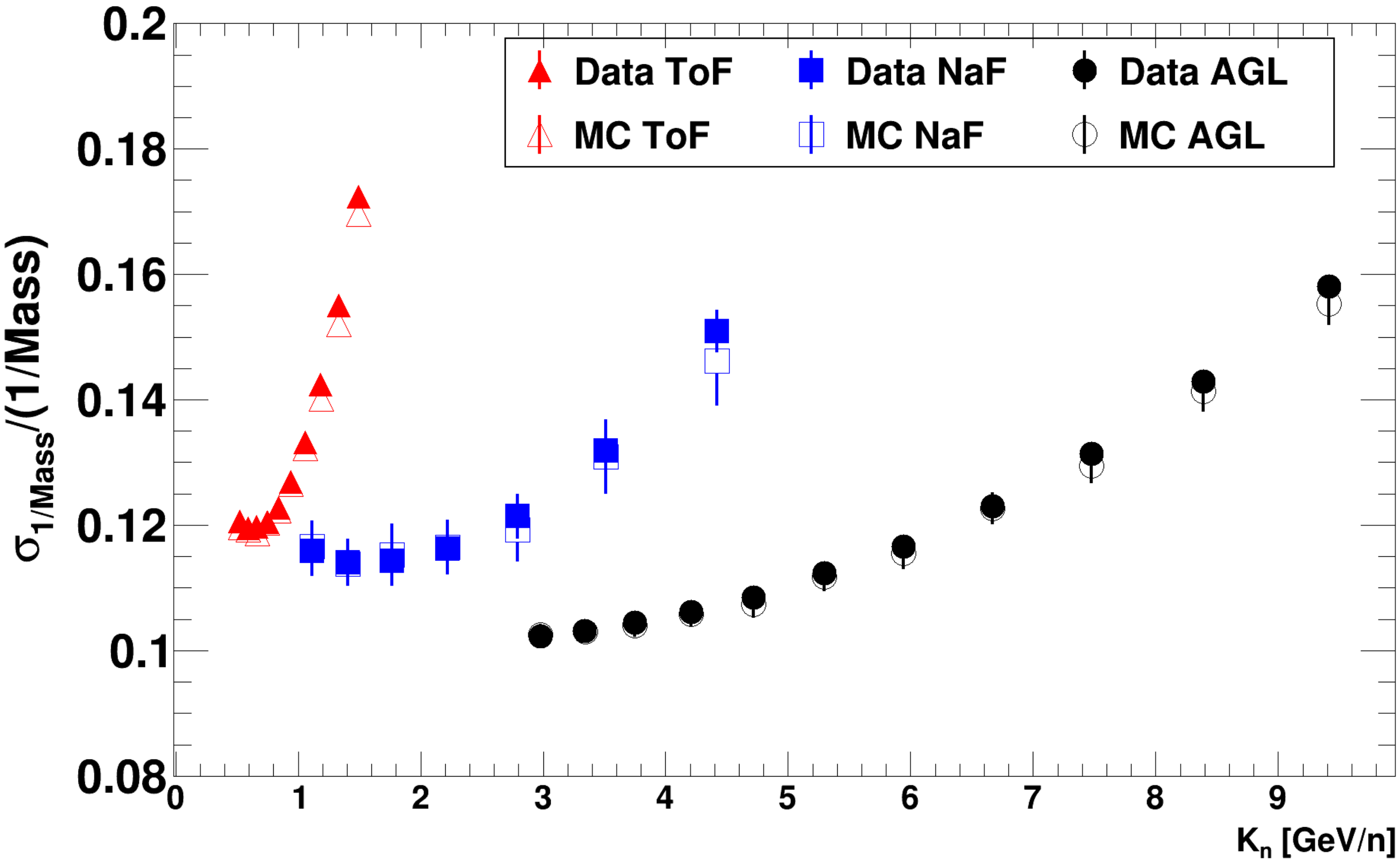
- ✧ On average one ring per event reconstructed
- ✧ Tracker inner track provide the entry point and direction





Fit Data with MC Template





Data ToF
Data NaF
Data AGL
MC ToF
MC NaF
MC AGL
$\sigma_{1/Mass}/(1/Mass)$
K_n [GeV/n]
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0 1 2 3 4 5 6 7 8 9

Geomagnetic Cutoff