Anti-Nuclei in Primary Cosmic Rays with the AMS on the ISS

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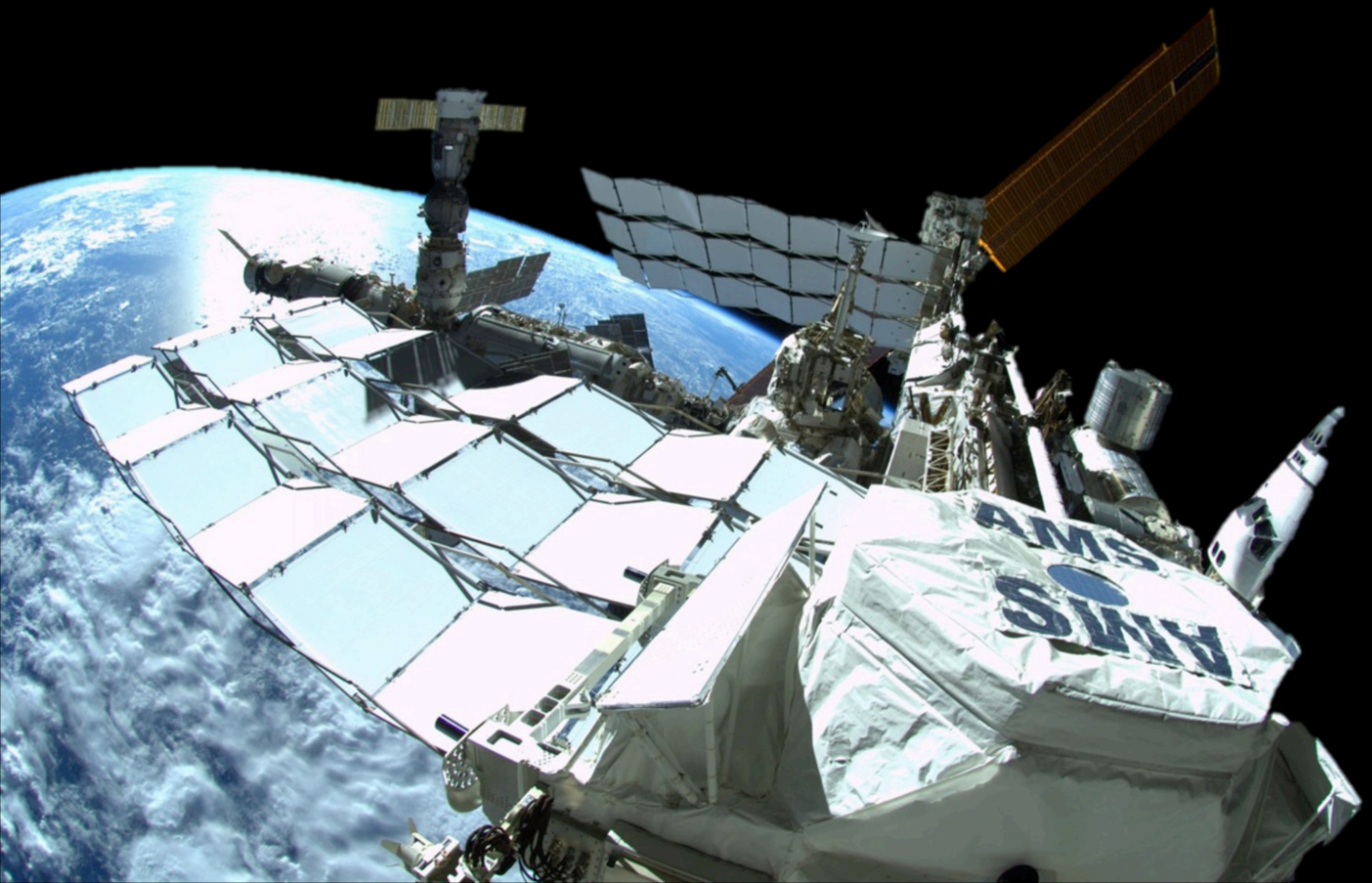
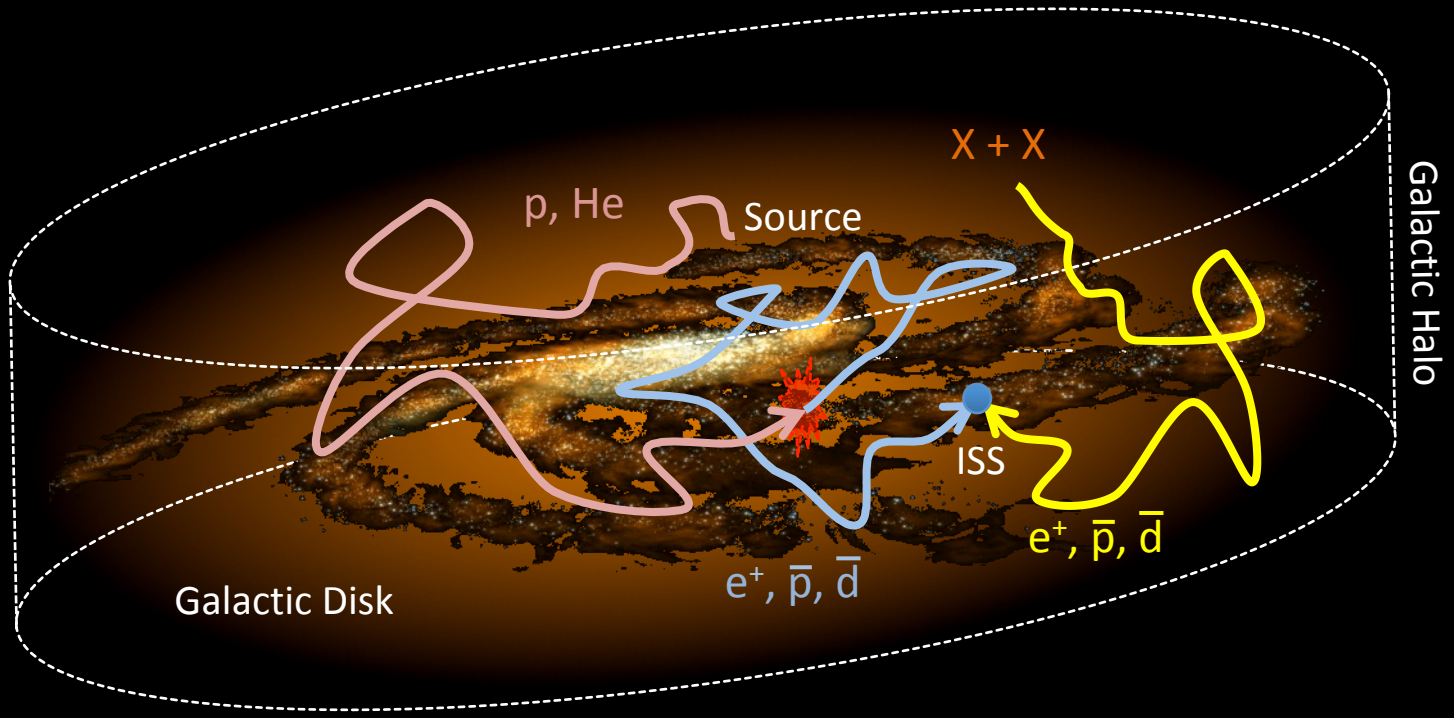


d-bar 2019,
27/03/2018,
UCLA, California, USA

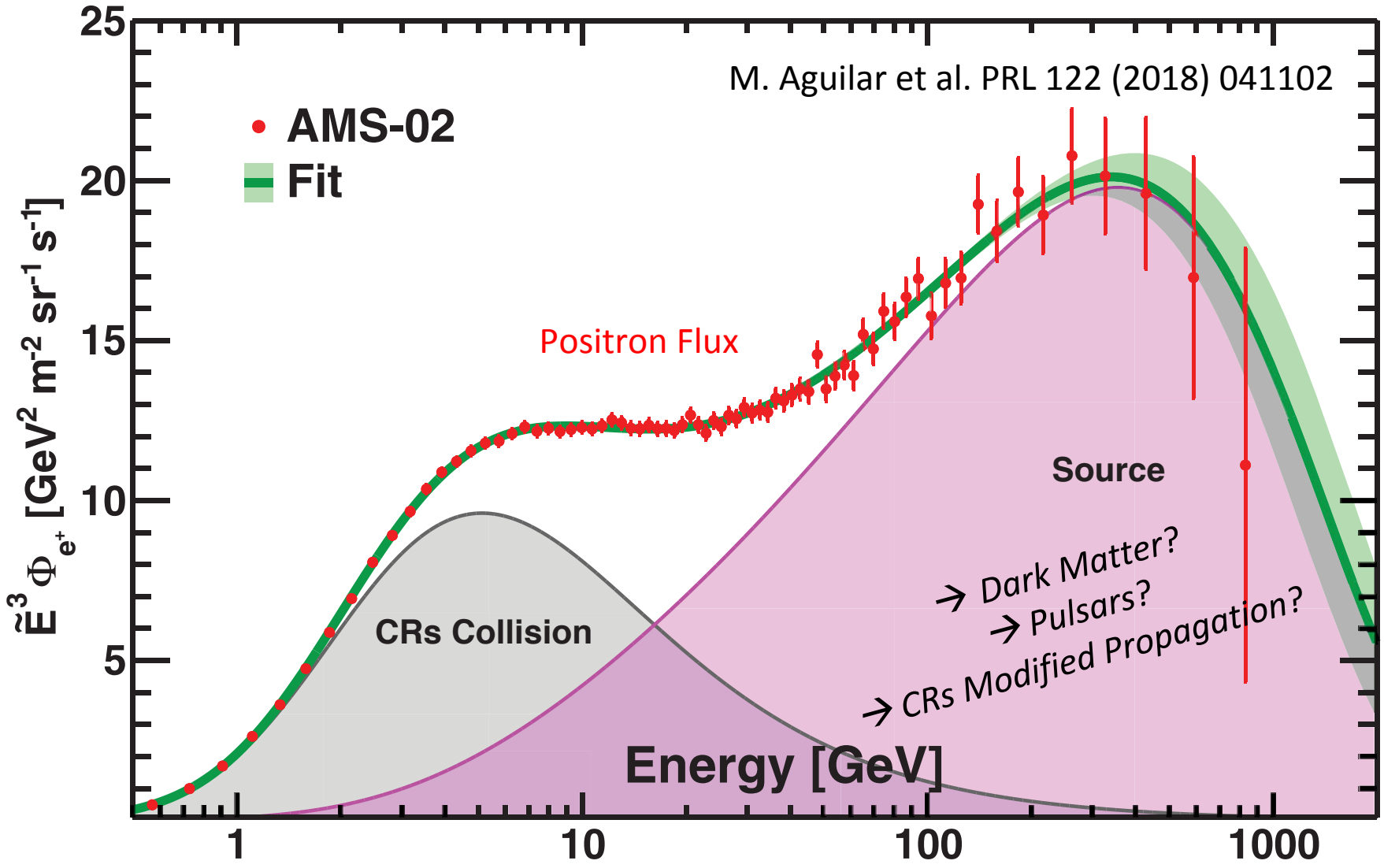
Indirect Search of Dark Matter

Collisions of dark matter particles (ex. neutralinos) may produce a signal of e^+, $\bar{p}$, $\bar{d}$, … that can be detected above the background from the collisions of primary CRs on interstellar medium



Indirect Search of Dark Matter: Positrons

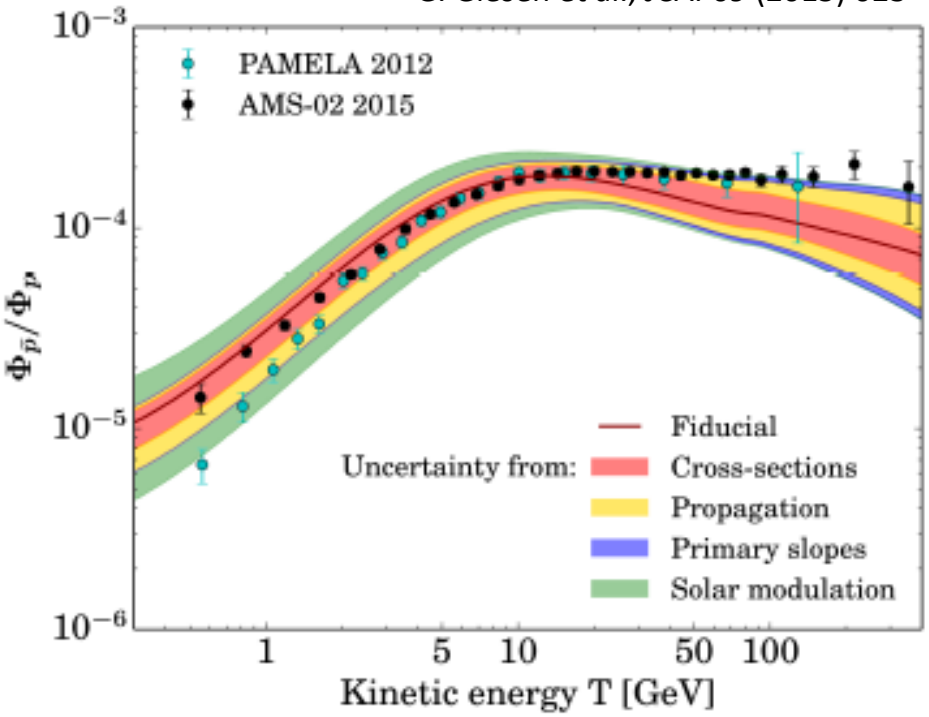
Collisions of dark matter particles (ex. neutralinos) may produce a signal of e^+, $\bar{p}$, $\bar{d}$, … that can be detected above the background from the collisions of primary CRs on interstellar medium



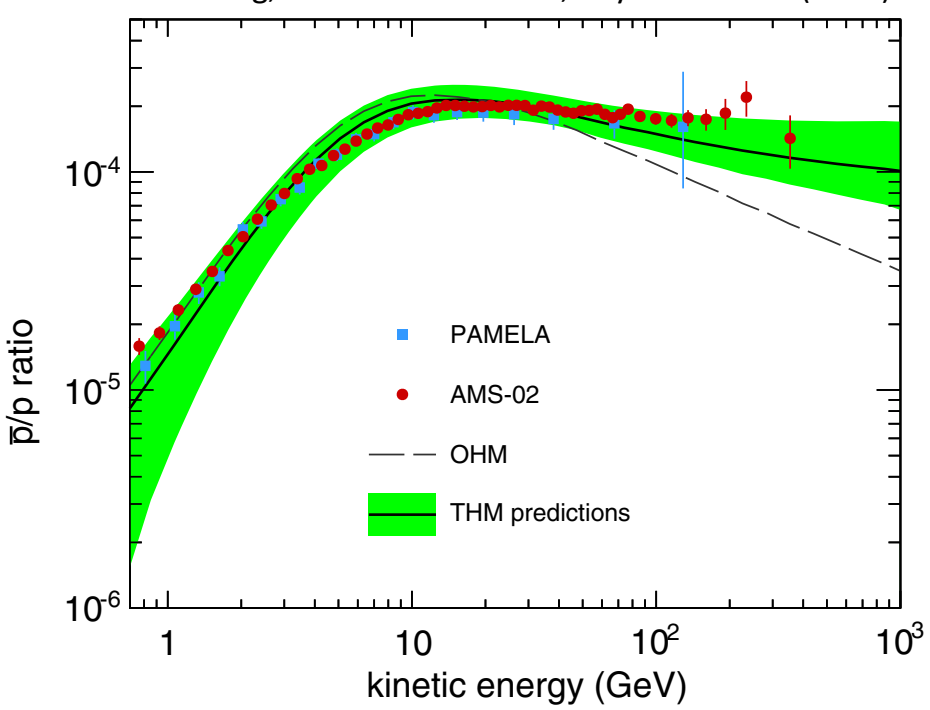
Indirect Search of Dark Matter: Anti-Protons

→ See P. Zuccon presentation.

G. Giesen et al., JCAP09 (2015) 023



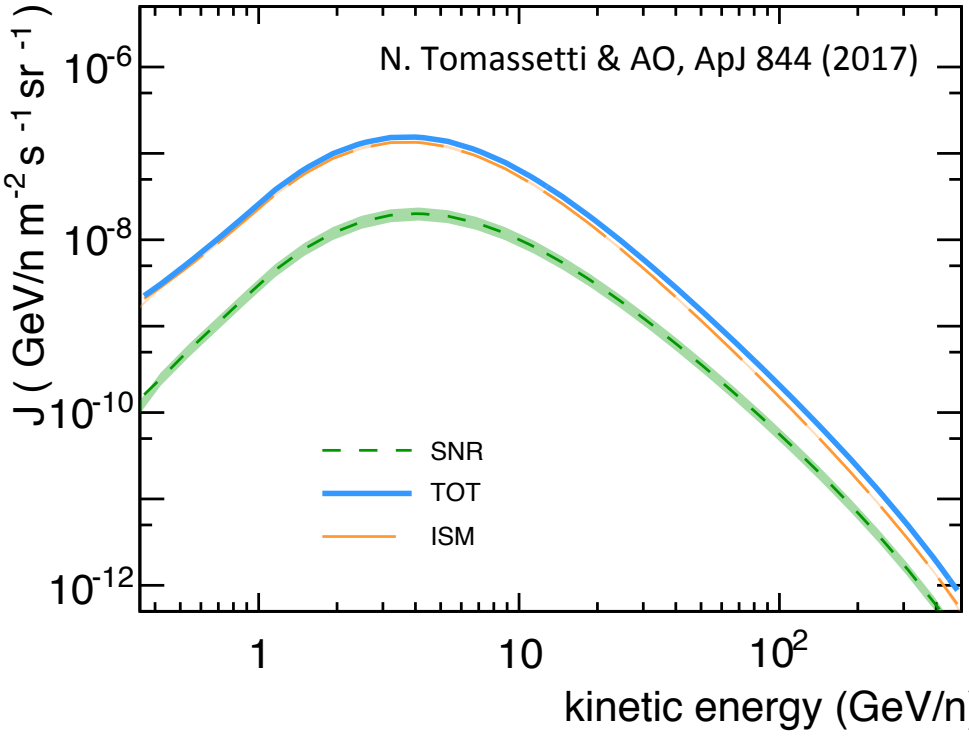
J. Feng, N. Tomassetti & AO, Phys. Rev. D 94 (2016)

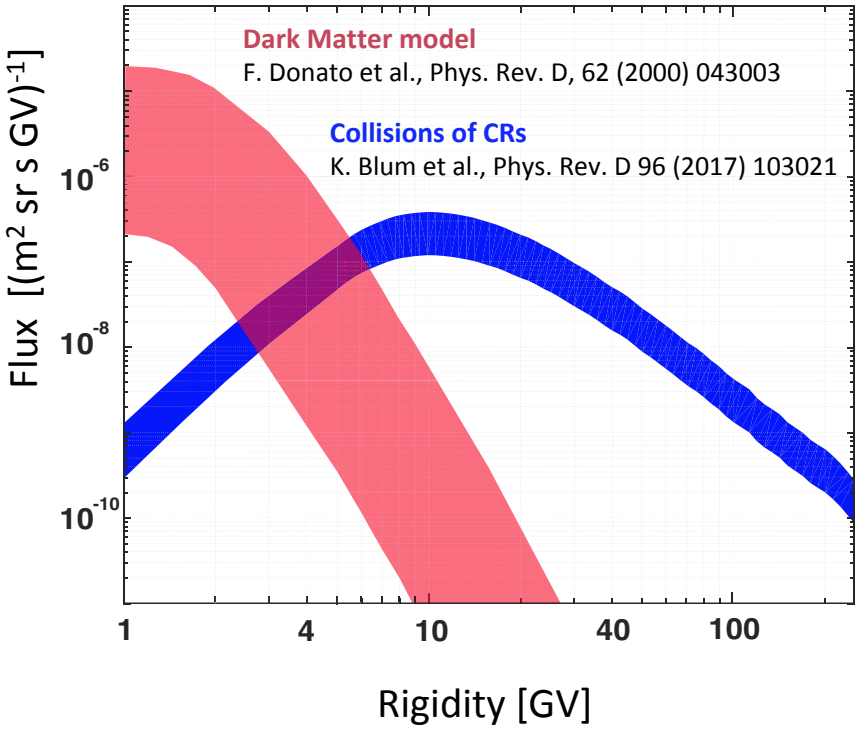


- Large uncertainity from p cross section knowledge:
    1. new measurements available (LHCb) and others are foreseen.
    2. better modeling of p production (M Winkler, JCAP07 (2017) 048, …)
- Uncertainity on propagation can be reduced using AMS-02 data (but again we miss some cross section relevant for cosmic rays nuclei)

Indirect Search of Dark Matter: Anti-Deuterons

Anti-deuteron have never been observed in cosmic rays.
In 7 years of data taking we collected over 120 billion events,
of which more than 10 billions proton, and 100 million deuterons.



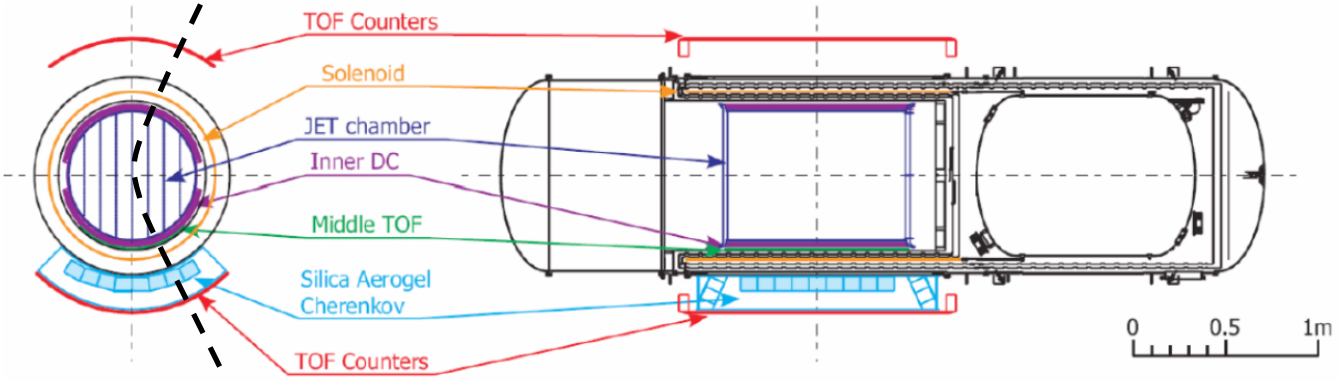


+ Very low background at low energy for indirect search of Dark Matter.
– Very low flux, high rejection to other species needed: $\bar{d}/\bar{p} < 10^{-4}$, $\bar{d}/p < 10^{-9}$, $\bar{d}/e^- < 10^{-6}$

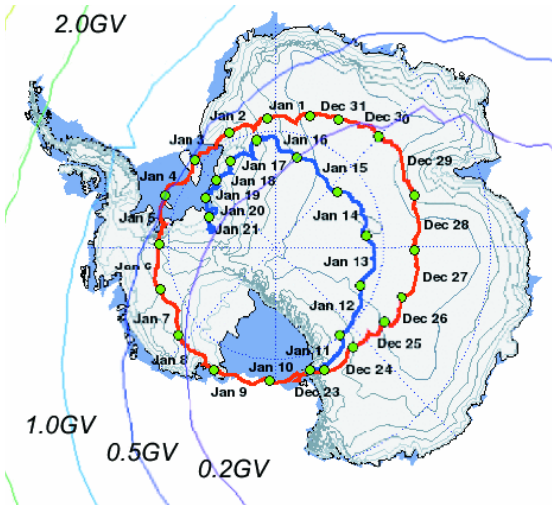
Anti-Deuteron Flux Limit: BESS Polar-II

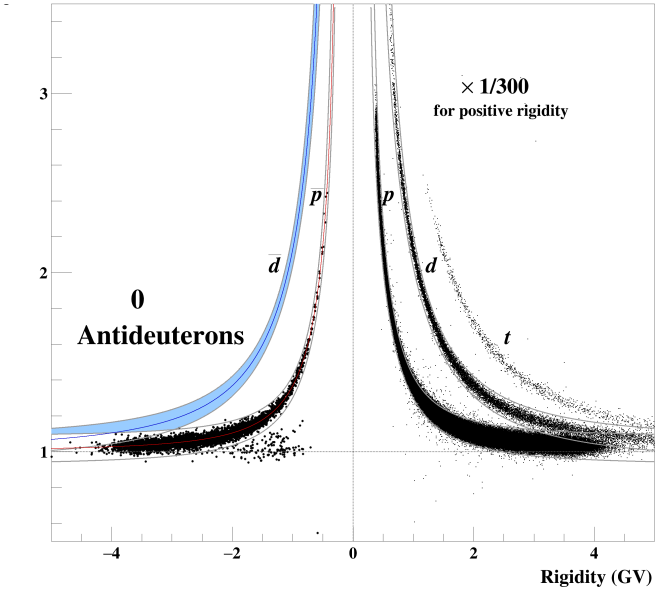
SC Magnet B = 0.8T
TOF Δβ/β = 2%
JET ΔR/R(R=1GV) = 0.4%
MDR = 270 GV

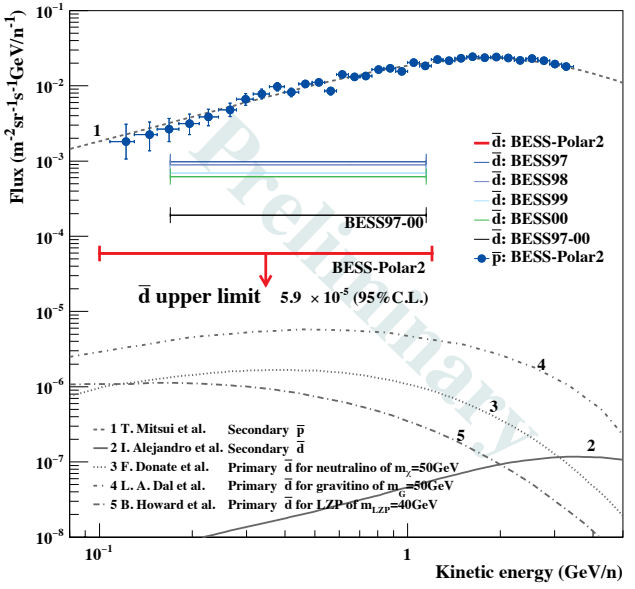
Acceptance = 0.3 m^2 sr
Exposure = 24.5 days
Geomagnetic cutoff below 0.5 GV



→ See K. Sakai presentation



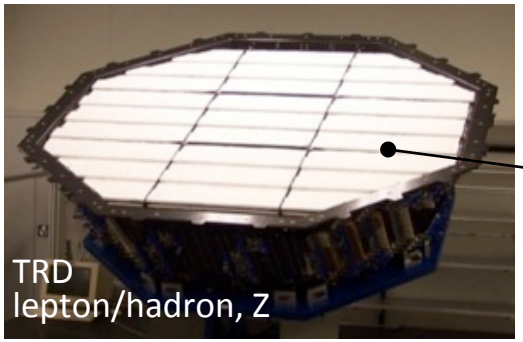


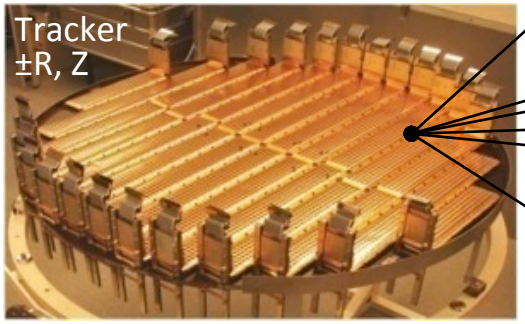


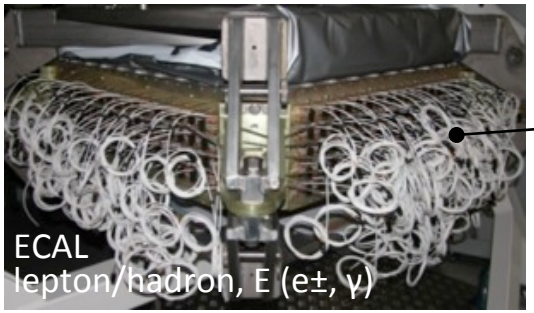
Has given the best upper limit on anti-deuteron flux: $J(\bar{d})<5.9\times10^{-5}$ $m^{-2}s^{-1}sr^{-1}(GeV/n)^{-1}$ (95% CL)

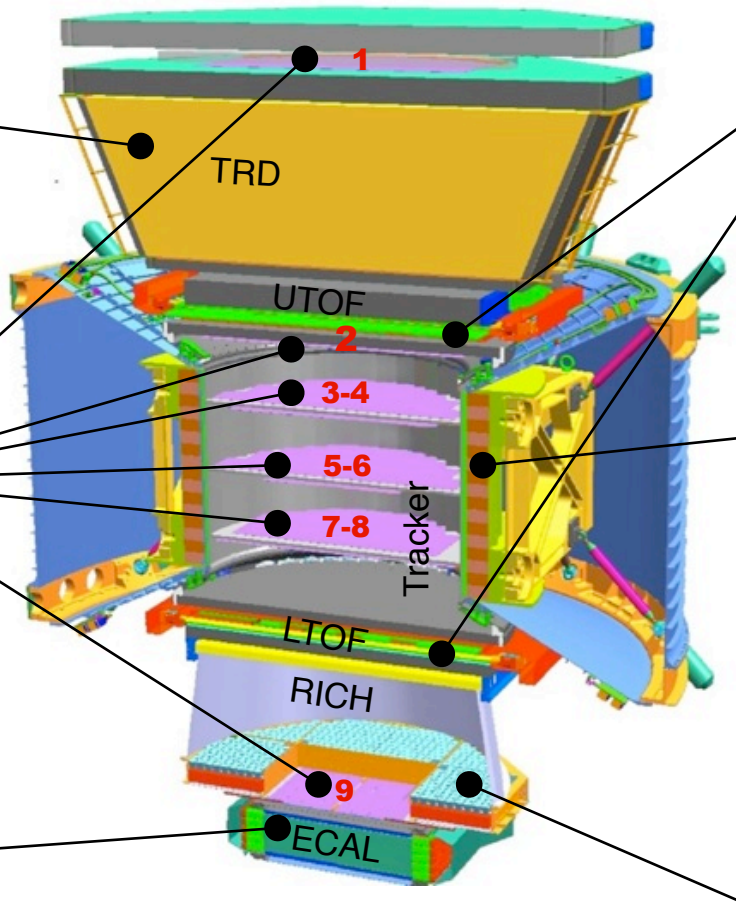
AMS-02: A TeV Multi-purpose Spectrometer

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

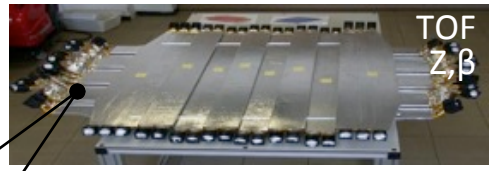


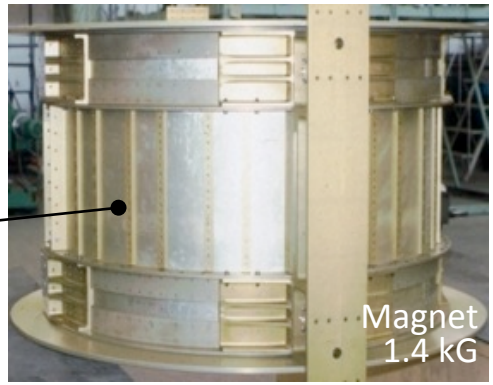


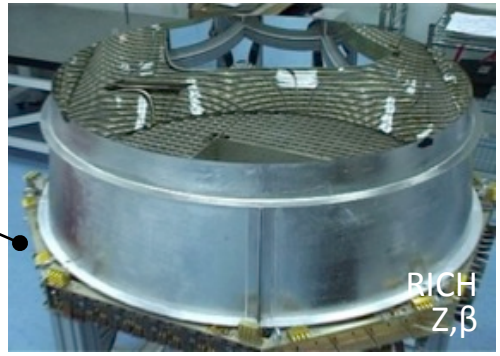




Multiple and Independent Measurement of Charge (Z), Energy (β, p, E) and Charge Sign (±).





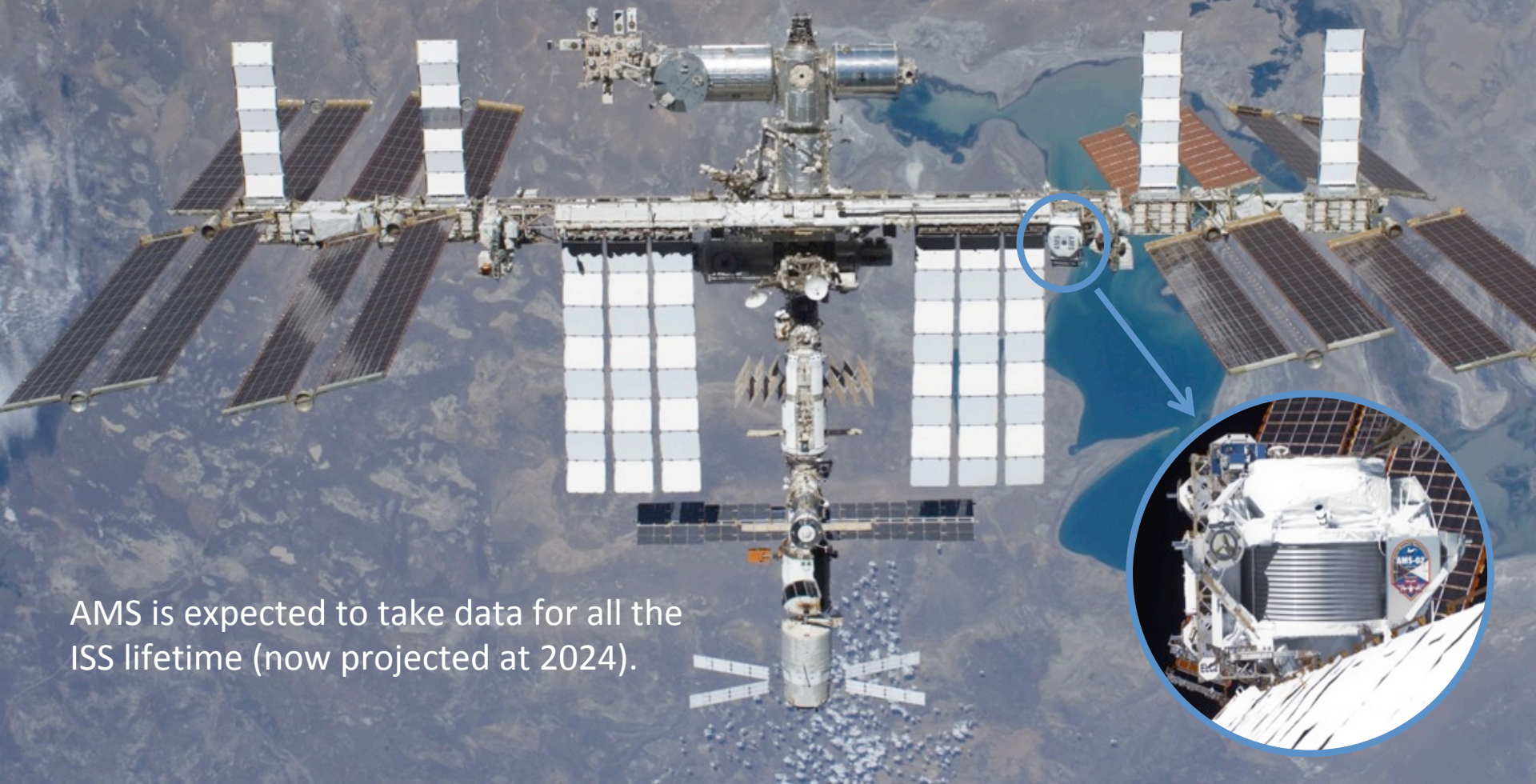


AMS-02 On Orbit

From May 19th 2011 active on ISS, operating continuously since then.

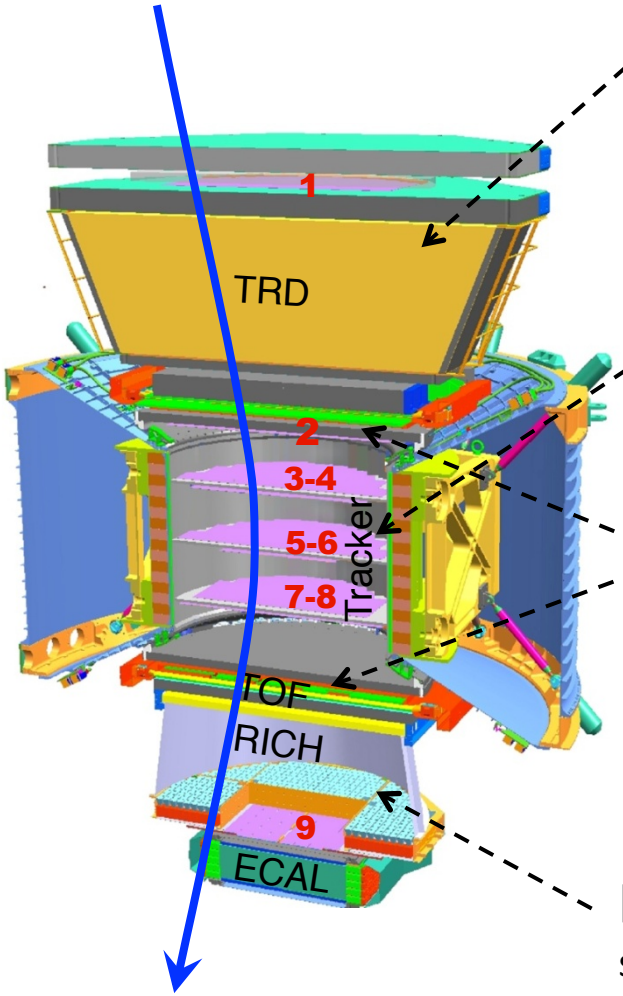
AMS has collected >130 billion cosmic rays in 8 years.

With such a statistics the most rare components of the cosmic rays are visible.



AMS is expected to take data for all the ISS lifetime (now projected at 2024).

Z=−1 Charge Identification



TRD

elimination of electron background

select **|Z|=1** particles (ΔZ/Z ≈ 0.1 c.u.)

Tracker

select **|Z|=1** particles ($\Delta Z/Z_{Inner}$ ≈ 0.05 c.u.)

particle sign (+/–), MDR = 1.8 TV

ToF

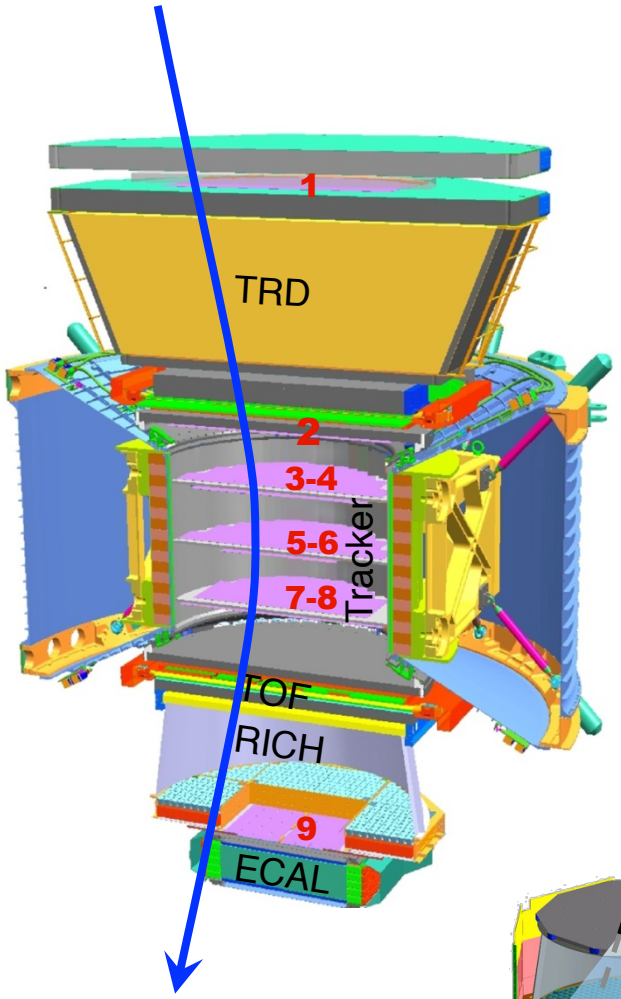
select **|Z|=1** particles ($\Delta Z/Z_{Plane}$ ≈ 0.06 c.u.)

separate **upgoing/downgoing**

RICH

select **|Z|=1** particles (ΔZ/Z ≈ 0.3 c.u.)

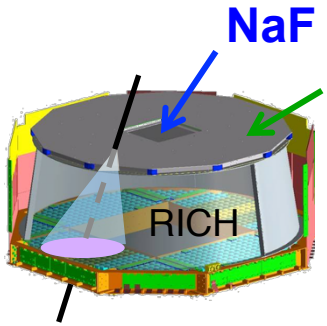
|Z|=1 Mass Measurement



$$M = p\frac{\sqrt{1-\beta^2}}{\beta}$$

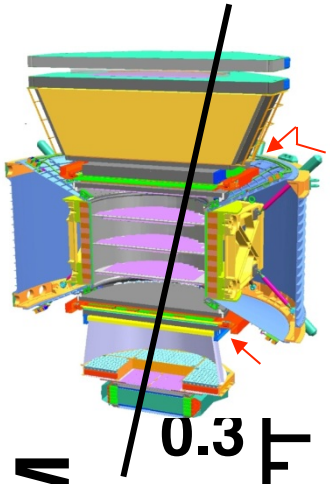
Tracker, momentum p,
Δp/p ≈ 10% up to 20 GV

ToF, velocity β
Δβ/β ≈ 4% × β



RICH, velocity β, in two radiators
NaF radiator: Δβ/β ≈ 0.4%, β>0.75 (ε=0.1)
Aerogel radiator: Δβ/β ≈ 0.1%, β>0.96 (ε=0.7)

|Z|=1 Mass Measurement

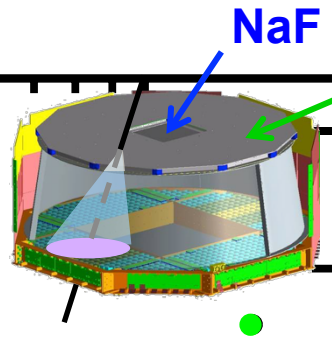


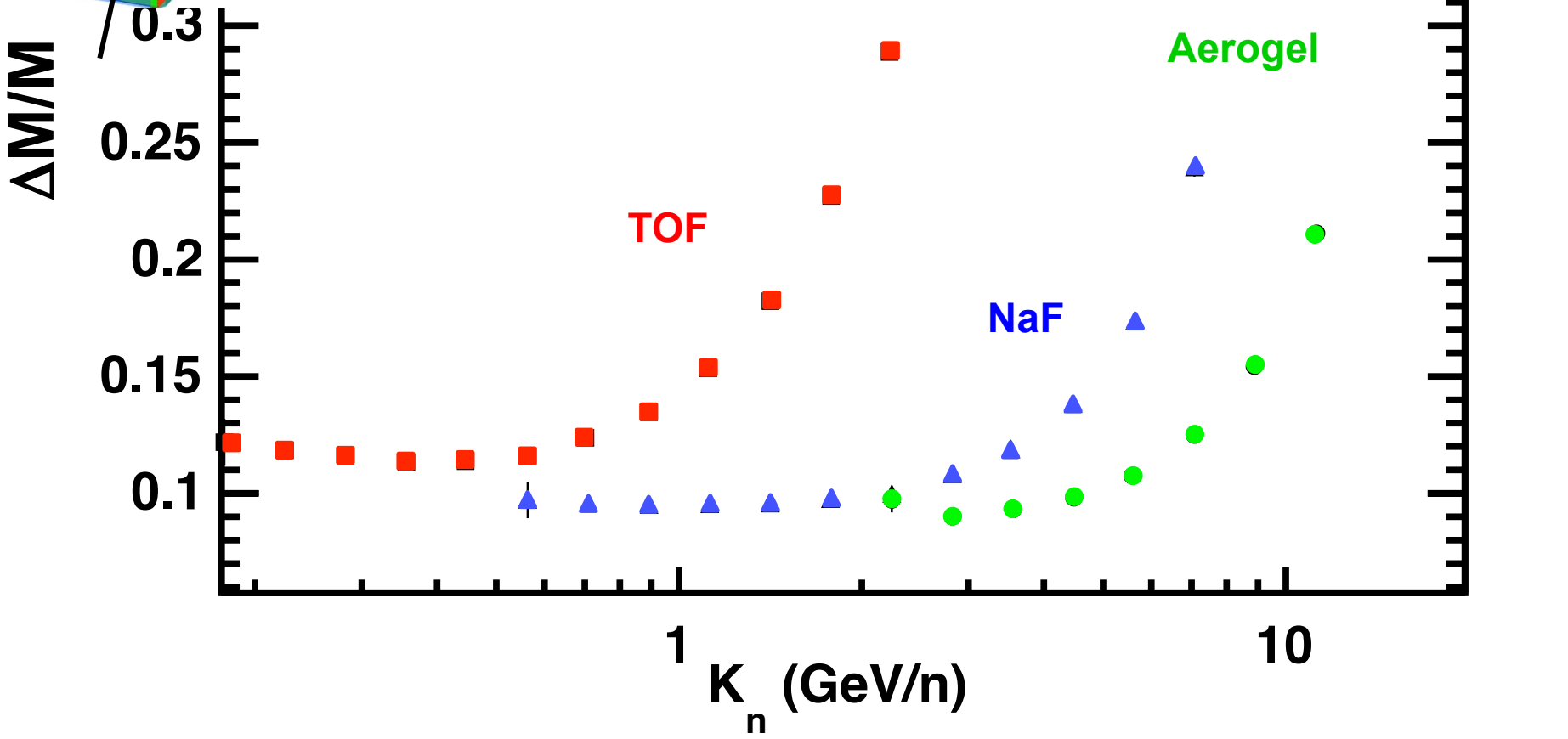
Upper TOF

DT

Lower TOF

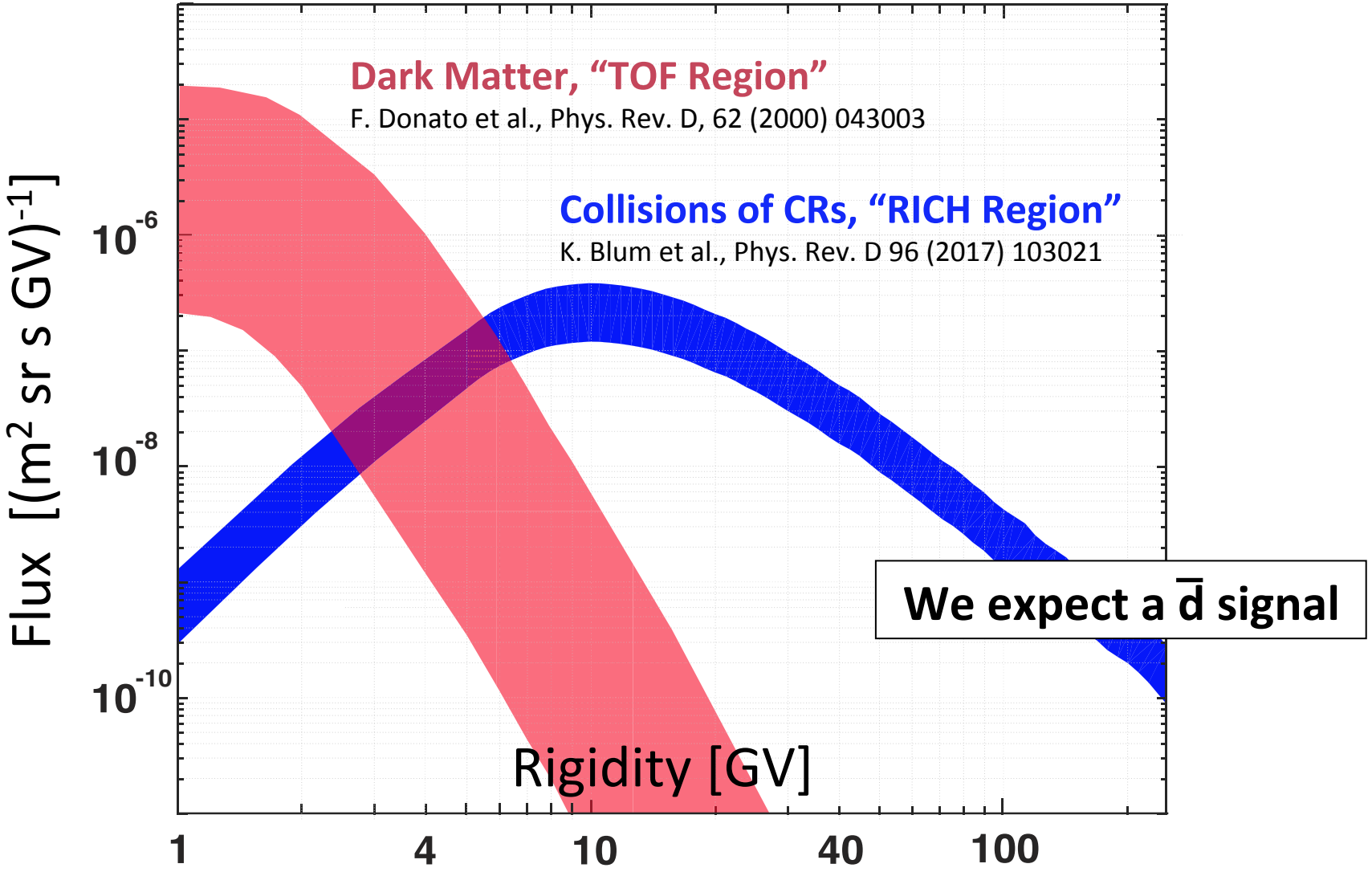
$$\frac{\Delta M}{M} = \left(\frac{\Delta p}{p}\right) \oplus \frac{1}{(1-\beta^2)}\left(\frac{\Delta \beta}{\beta}\right)$$





Event Selection

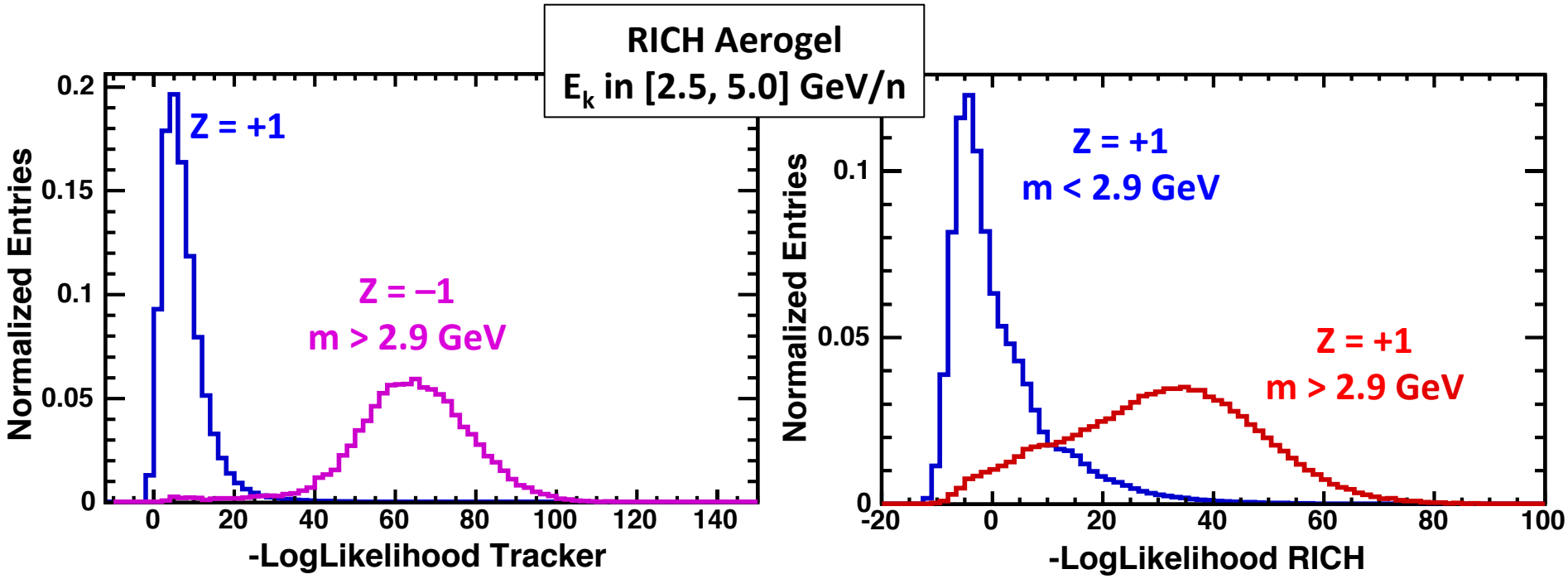
In 7 years of data taking we collected over 120 billion events,
of which more than 10 billions proton, and 100 million deuterons.



Background

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.

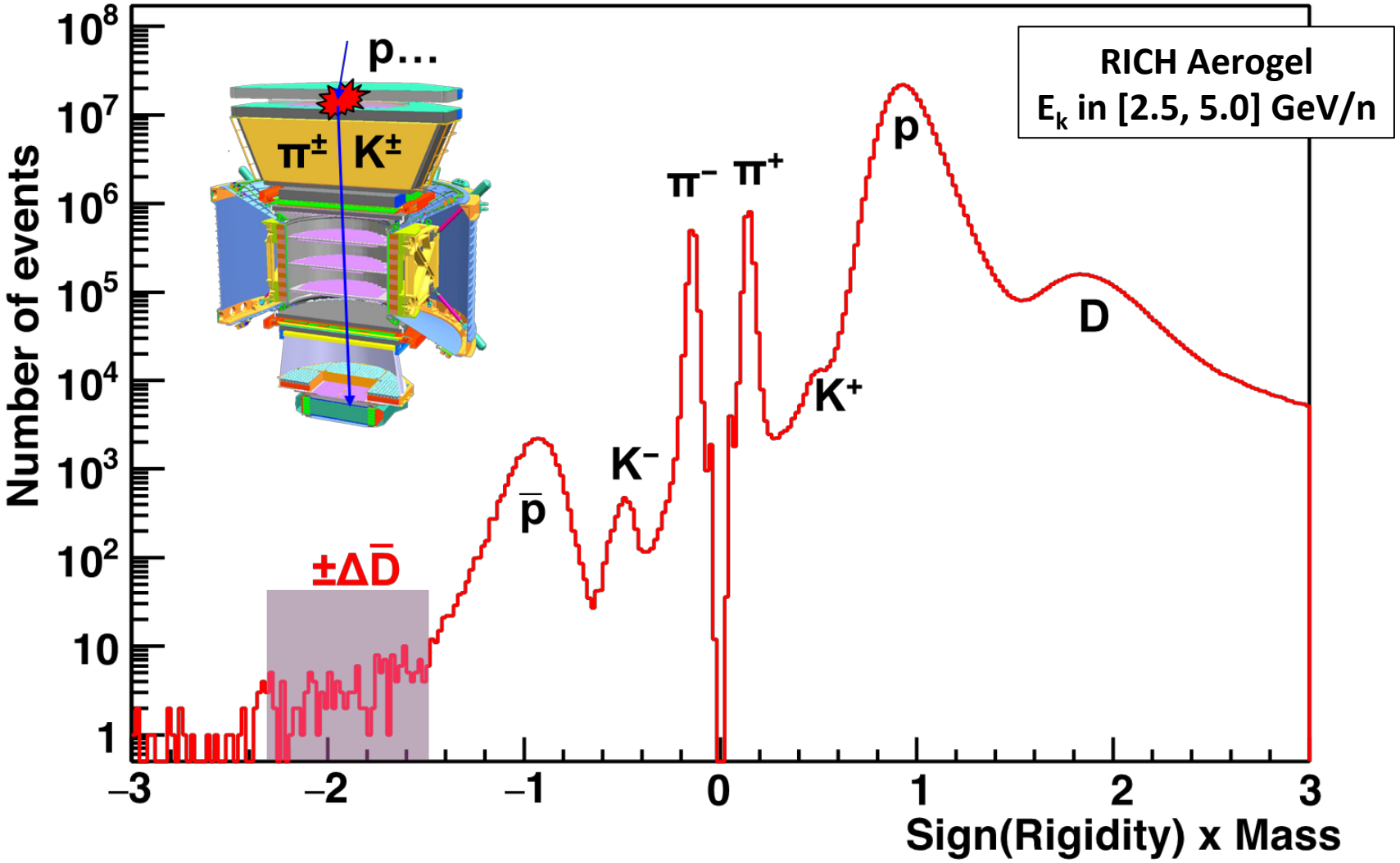


Tracker variables mostly control the removal of events with **wrong sign**

Variables of RICH mostly control removal of events with **wrong mass**

Anti-Deuteron Search Status

Data Sample (May 2011 – May 2017): TRD – Inner Tracker Acceptance
41×10^9 events selected with TOF ($\beta > 0.5$) and Tracker $|R| > 0.8$



AMS-02 Anti-Deuteron Simulation

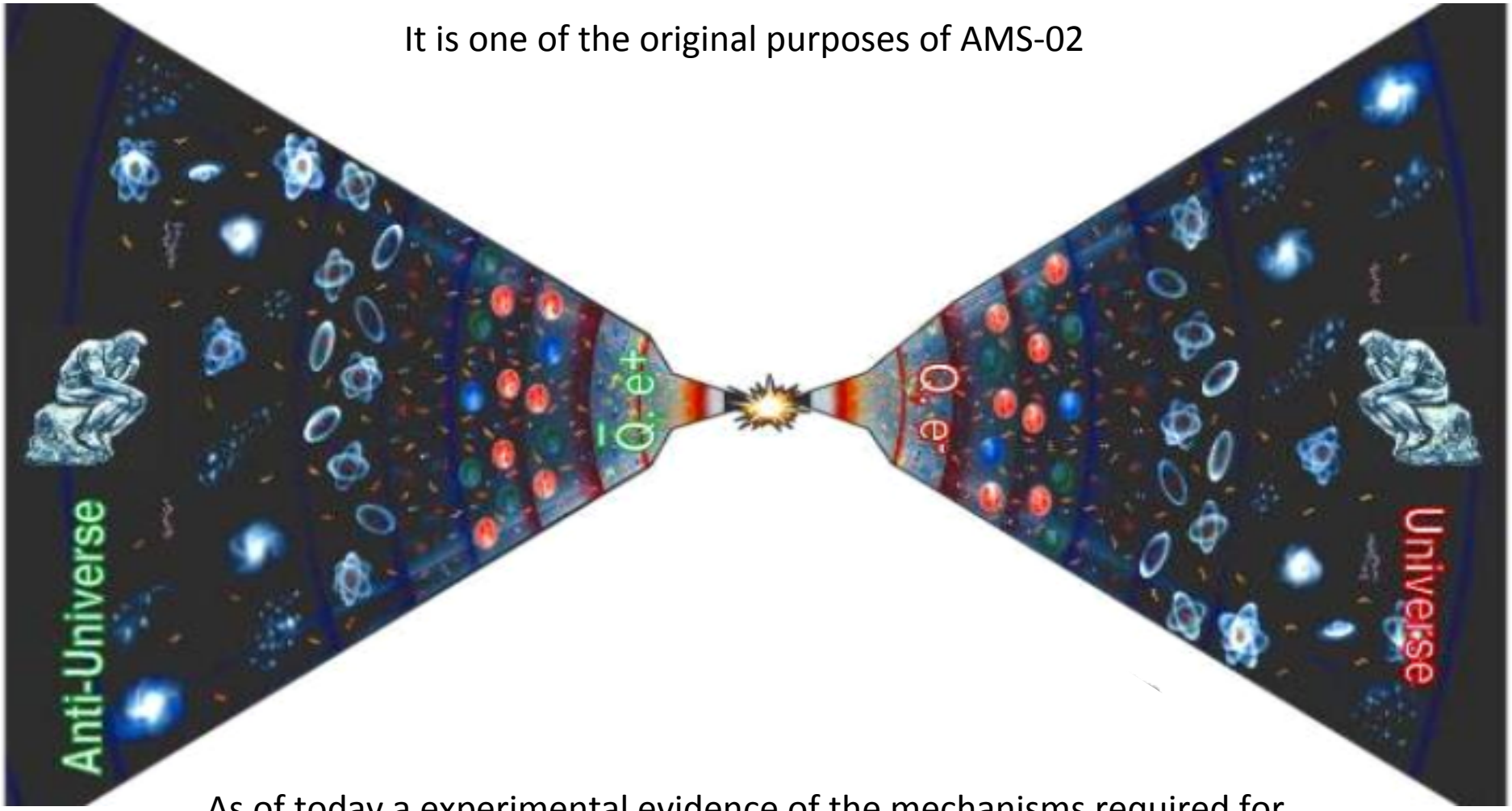
AMS Monte Carlo program simulates electromagnetic and hadronic interactions of particles in the material of AMS and generates detector responses.

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.

In 7 years, more than 10 billion proton and 100 million deuteron cosmic ray were collected by AMS. **An equivalent of 100 billion of proton, deuteron and antiproton events in the rigidity range 0.5-100 GV need to be simulated.**

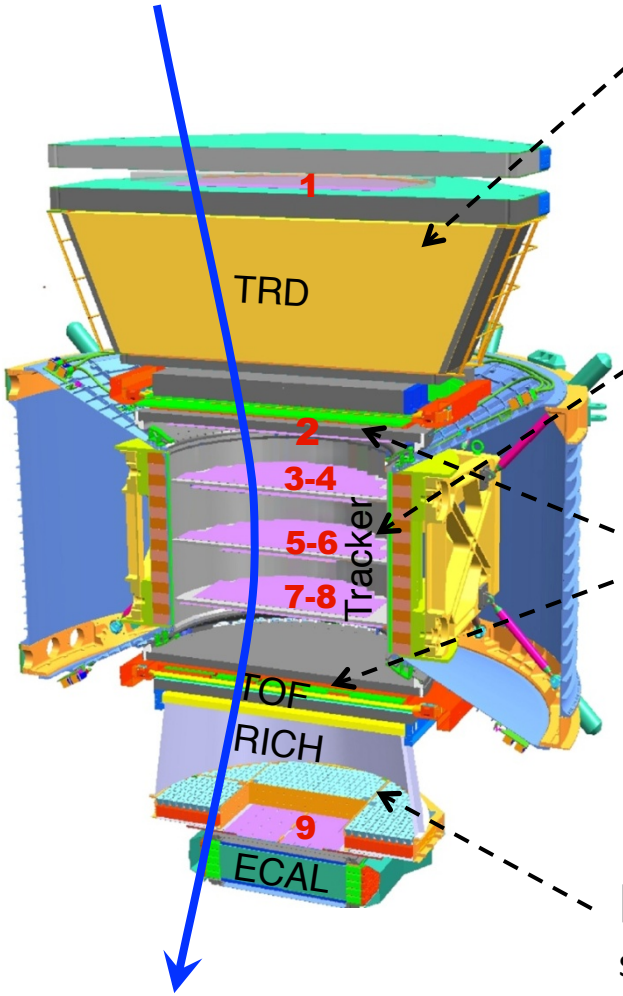
More on Heavy Anti-Matter Search

It is one of the original purposes of AMS-02



As of today a experimental evidence of the mechanisms required for matter/anti-matter asymmetry (strong CP violation, proton decay, …) has been found. Neither has a single anti-nucleus been seen in cosmic rays.

Z=−2 Charge Identification



TRD

select **|Z|=2** particles ($\Delta Z/Z \approx 0.2$ c.u.)

Tracker

select **|Z|=2** particles ($\Delta Z/Z_{Inner} \approx 0.07$ c.u.)

particle sign (+/–), MDR = 3.2 TV

ToF

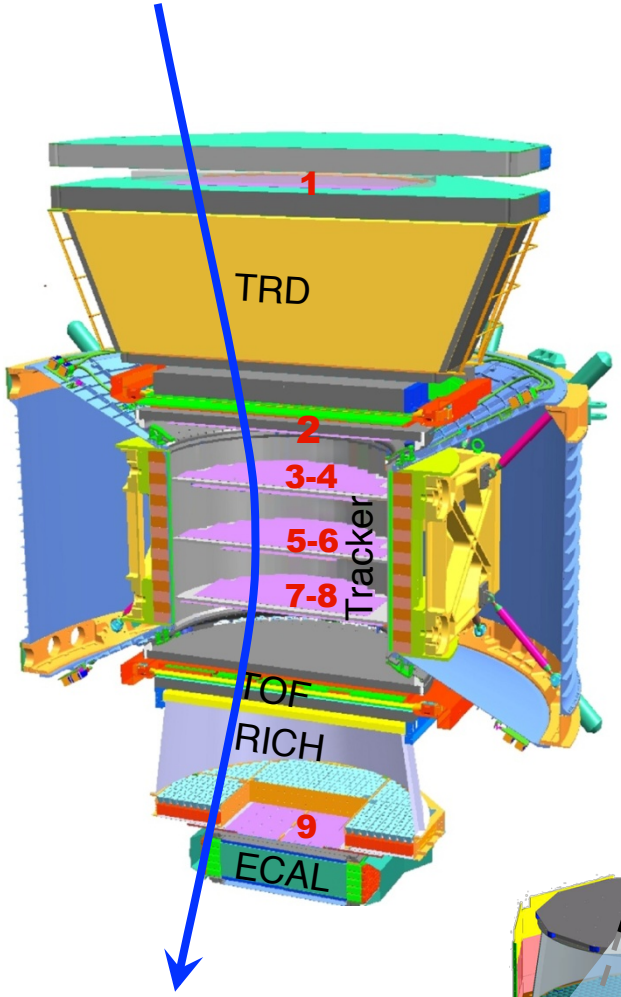
select **|Z|=2** particles ($\Delta Z/Z_{Plane} \approx 0.08$ c.u.)

separate **upgoing/downgoing**

RICH

select **|Z|=2** particles ($\Delta Z/Z \approx 0.3$ c.u.)

|Z|=2 Mass Identification



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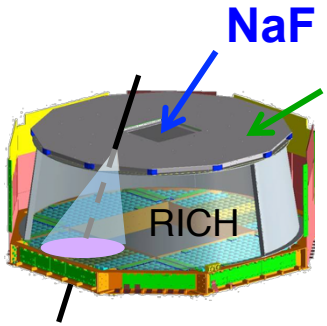
Tracker, momentum p,
Δp/p ≈ 10% up to 20 GV

ToF, velocity β
Δβ/β ≈ 2% × β



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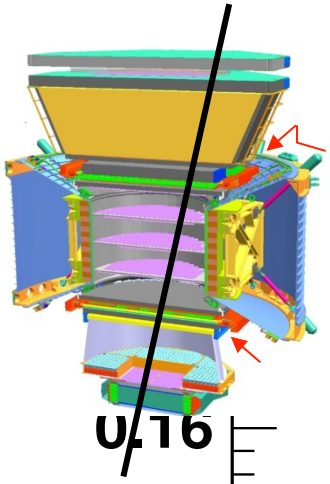
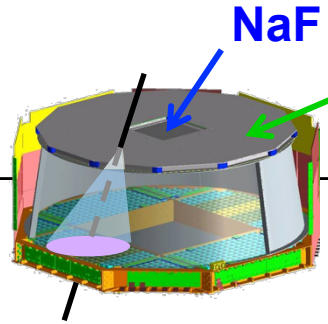
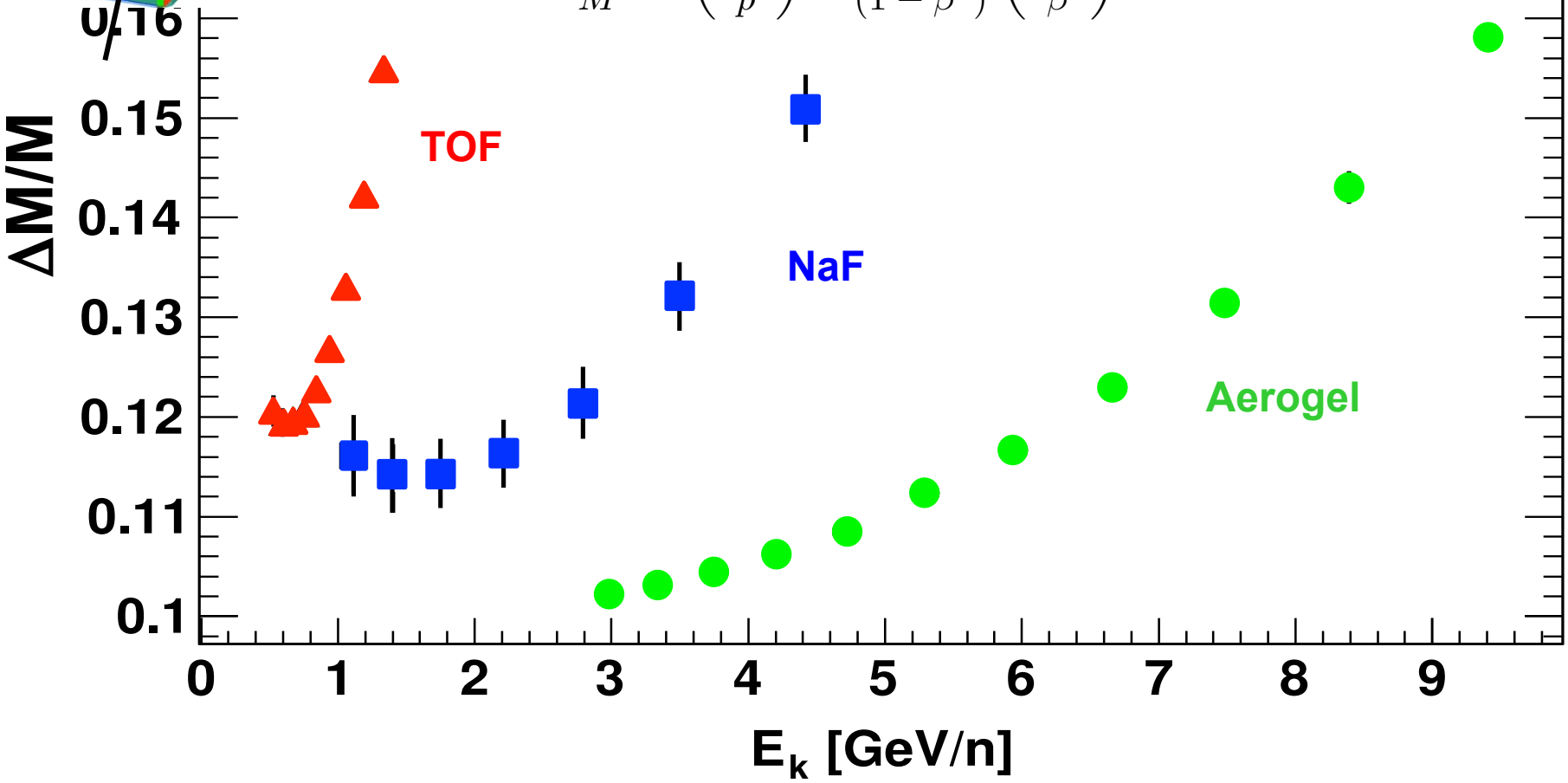
Aerogel radiator: Δβ/β ≈ 0.07%, β>0.96 (ε=0.7)

|Z|=2 Mass Measurement



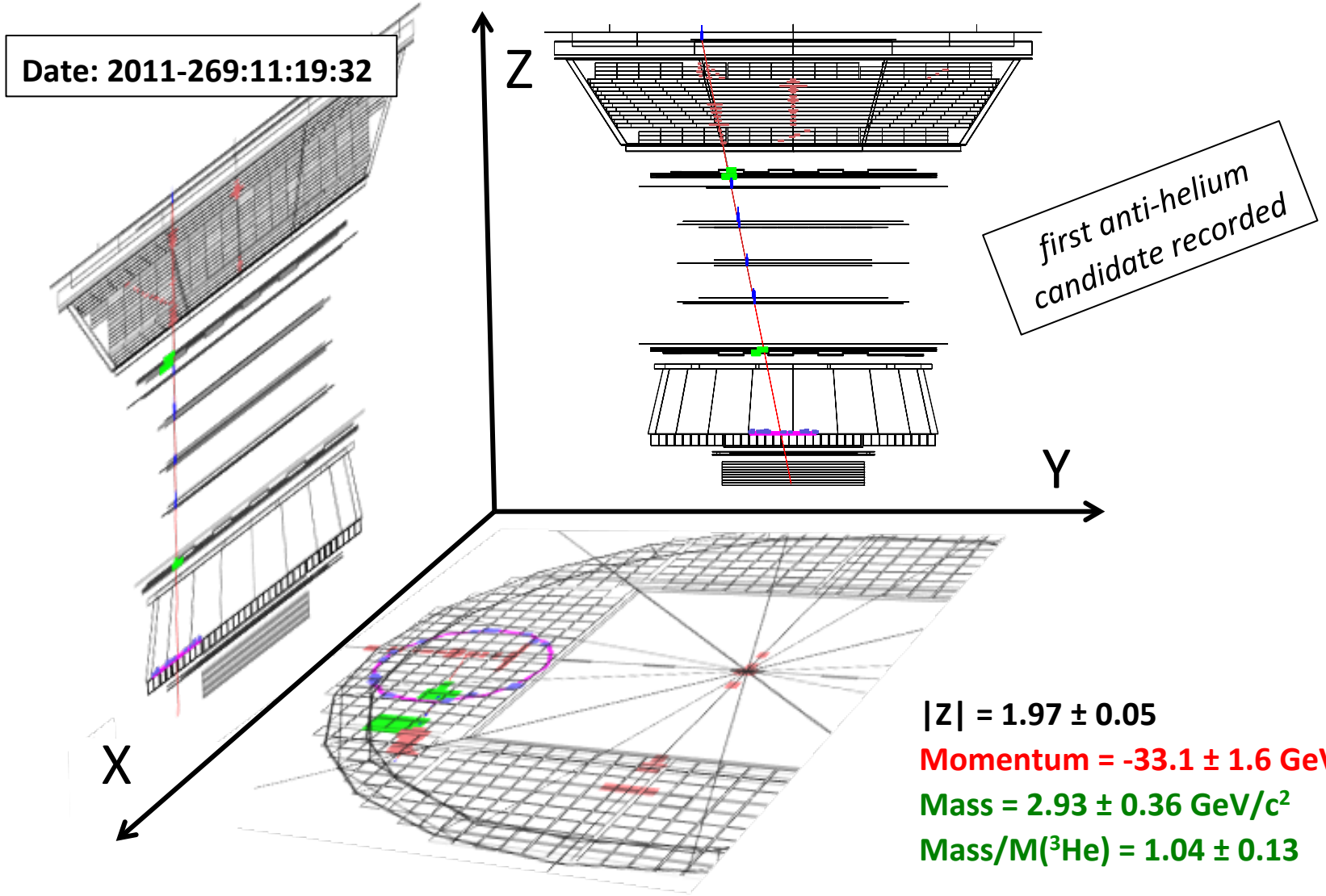


$$\frac{\Delta M}{M} = \left(\frac{\Delta p}{p}\right) \oplus \frac{1}{(1-\beta^2)}\left(\frac{\Delta \beta}{\beta}\right)$$



Anti-Helium Search Status

Anti-helium is a “golden”-channel, there is no $\bar{p}$,K,π contamination, |Z| is well separated, and rigidity resolution is better than |Z|=1 particles (MDR = 3.2 TV).



|Z| = 1.97 ± 0.05

Momentum = -33.1 ± 1.6 GeV/c

Mass = 2.93 ± 0.36 GeV/c^2

Mass/M(^{3}He) = 1.04 ± 0.13

Anti-Helium Search Status

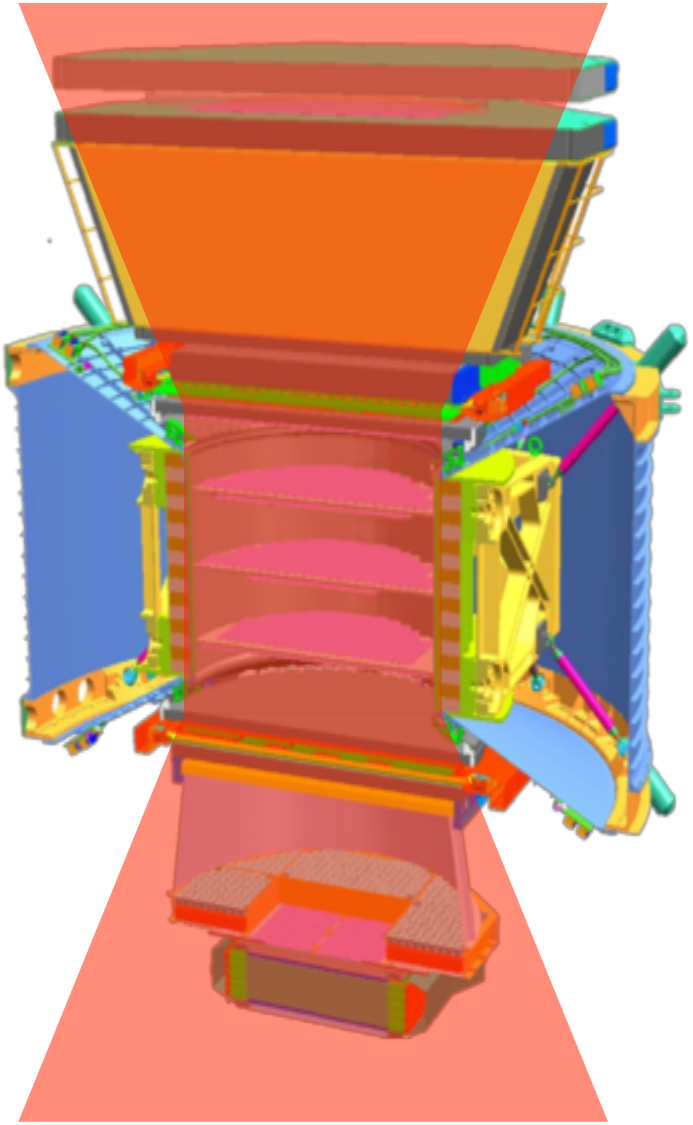
Currently, AMS observed 8 anti-helium candidates (mass region from 0-10 GeV/c^2) with rigidity <50 GV with respect to a sample of 700 million helium events selected.

The rate of anti-helium is about 1 in 100 million helium.

Six candidates are in the mass region of 3He and two in the mass region of ^{4}He.

More events are necessary to augment the significance and ensure that there are no backgrounds.

Anti-Nuclei Search Status



Study of Anti-Carbon and Anti-Oxygen can be carried out up to 100 GV (as the He) in a wide acceptance.

By 2024 we will have more than 100 million Carbon and Oxygen to study anti-nuclei.

AMS has been operating in the Space Station since May 2011 performing precision measurements of cosmic rays and searching for dark matter.

With the unprecedented statistics and accuracy of the data, AMS has an unique capability to detect antimatter in cosmic rays.