Search of Anti-Nuclei with AMS-02

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AMS-02: The Alpha Magnetic Spectrometer

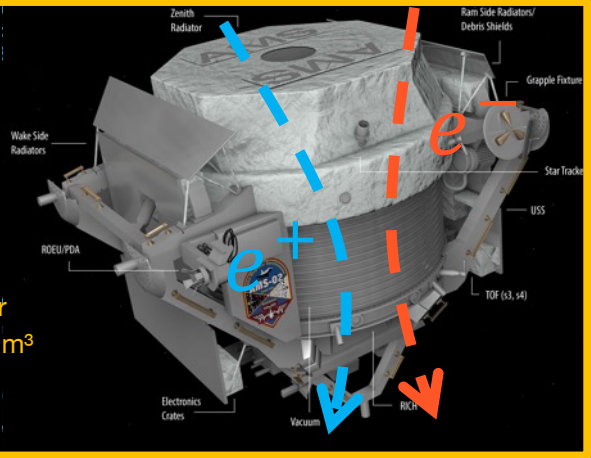
Installed in 2011 on the ISS. Takes data continuously since then.
AMS-02 collected more than **210 billion cosmic** rays up to now.

International Space Station (ISS)

Altitude	~ 400 km
Inclination	51°
Period	93 min
Construction	1998 - …
Dimensions	73 × 109 m²
Weight	420 t

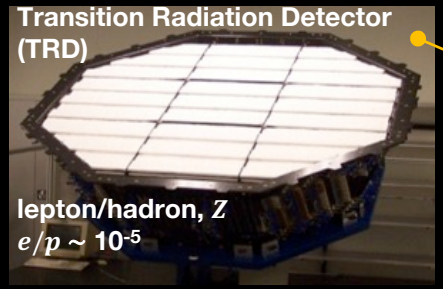
AMS-02

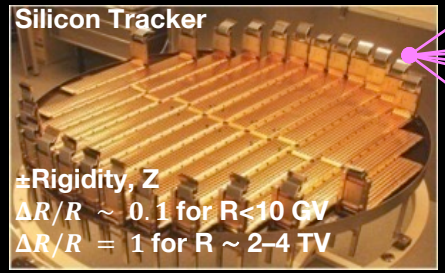
Launch	16/5/2011
	STS-134
	Endeavour
Dim.	3 × 4 × 5 m³
Weight	7.5 t
Power	2500 W

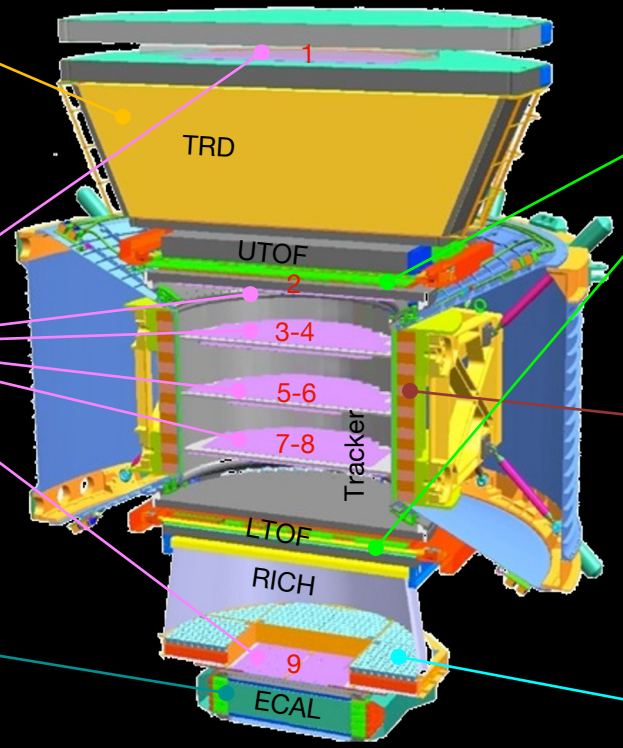


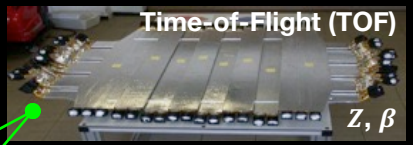
AMS-02: A TeV Multi-Purpose Spectrometer

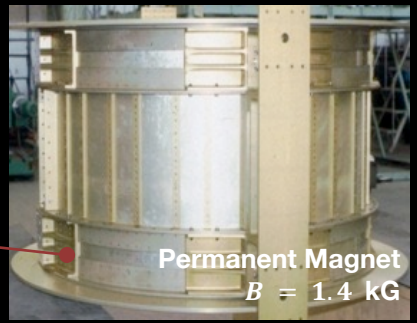
AMS-2 separates hadrons from leptons, matter from anti-matter,
chemical and isotopic composition from fraction of GeV to multi-TeV.

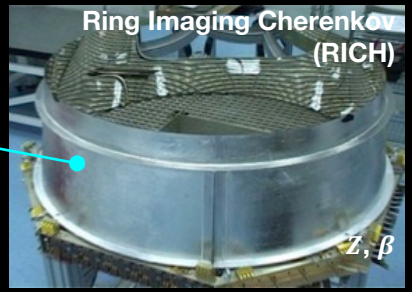






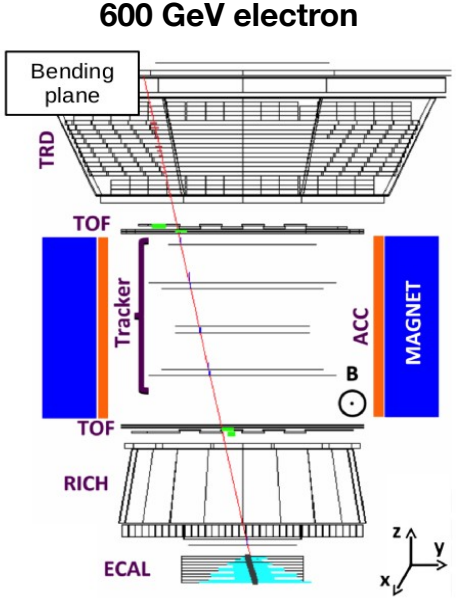






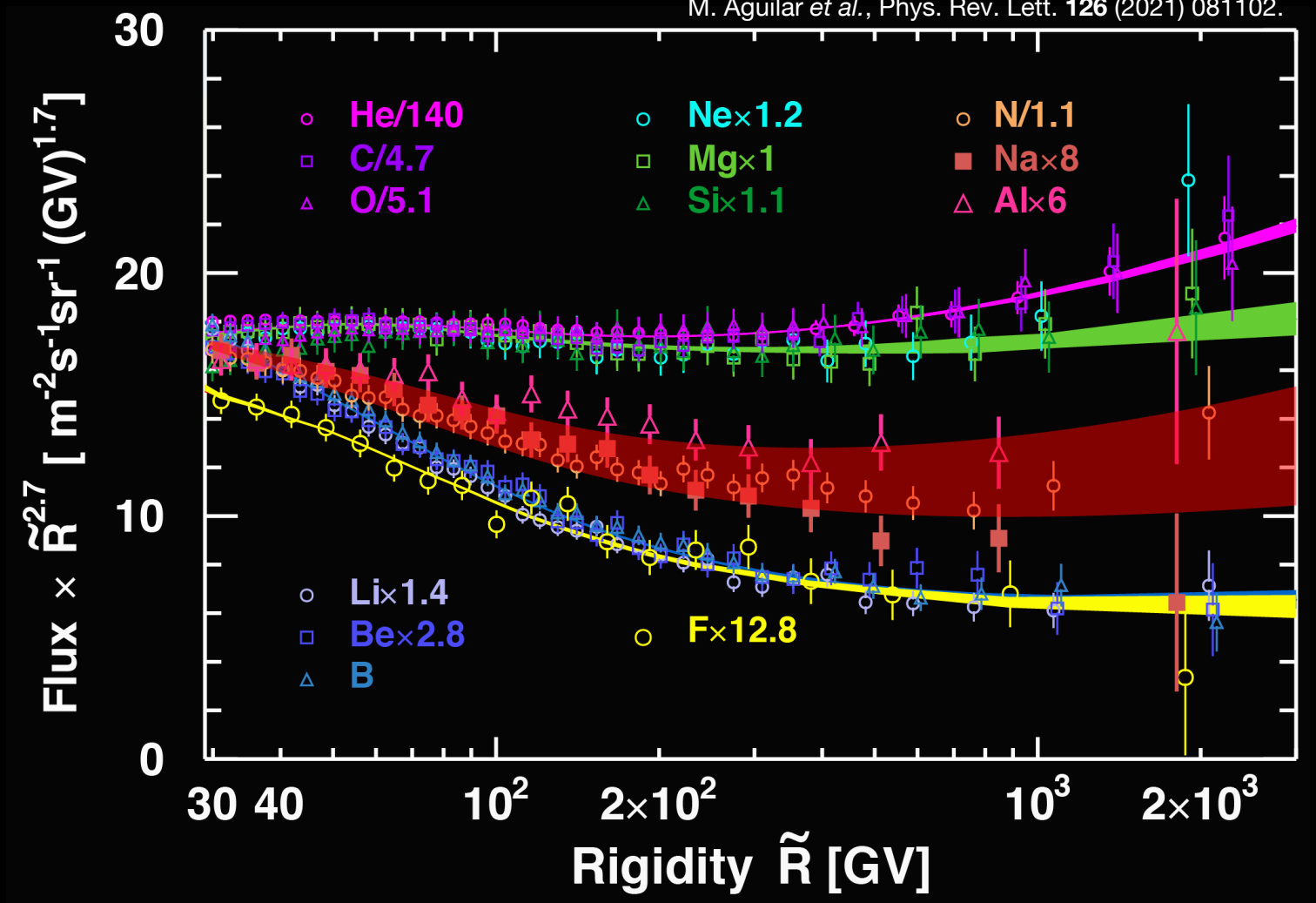
Multiple measurements of Charge (Z),
Energy (β, p, E) and Charge Sign (±).

AMS-02: A TeV Multi-Purpose Spectrometer



	e^+	e^-	p	$\bar{p}$	He	$\overline{He}$	
TRD 20 layers							e/p separation charge, z
TOF 4 layers							trigger velocity, β charge, z
TRK 9 layers							rigidity, p/Z sign, $\pm$ charge, z
RICH							velocity (β) charge, z
ECAL 18 layers							$e^{\pm}$,γ energy e/p separation EM-trigger

AMS-02 Measurement of CRs



PRL **128** (2022) 231102
PRL **127** (2021) 271102
PRL **127** (2021) 021102
PRL **126** (2021) 08102
Phys Rep. **894** (2021) 1
PRL **126** (2021) 041104
PRL **124** (2020) 211102
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PRL **121** (2018) 051103
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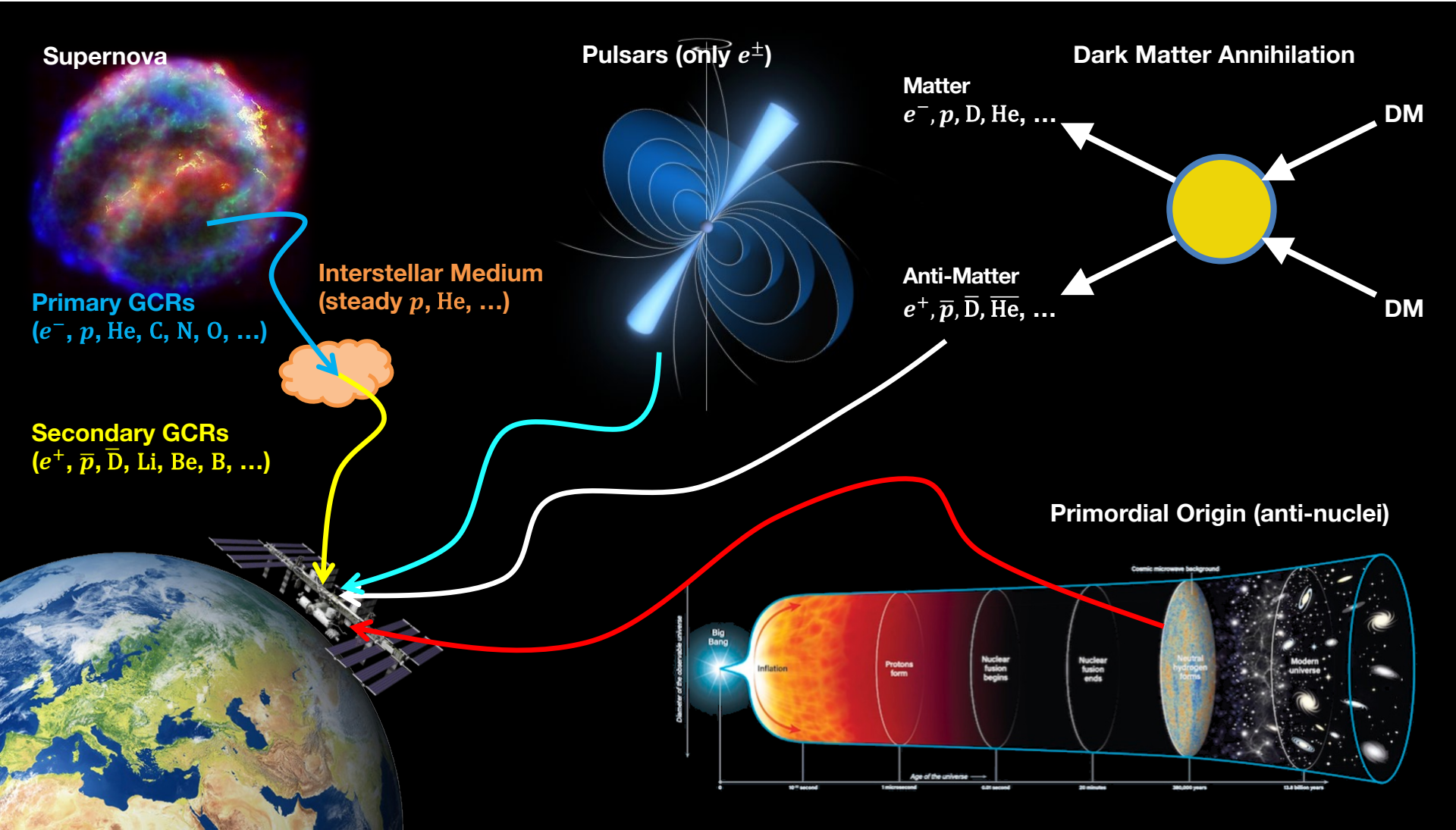
PRL **120** (2018) 021101
PRL **119** (2017) 251101
PRL **117** (2016) 231102
PRL **115** (2015) 211101
PRL **114** (2015) 171103
PRL **113** (2014) 221102
PRL **113** (2014) 121101
PRL **110** (2013) 141102

"Editor's Suggestion" or Featured in Physics
Physics Viewpoint

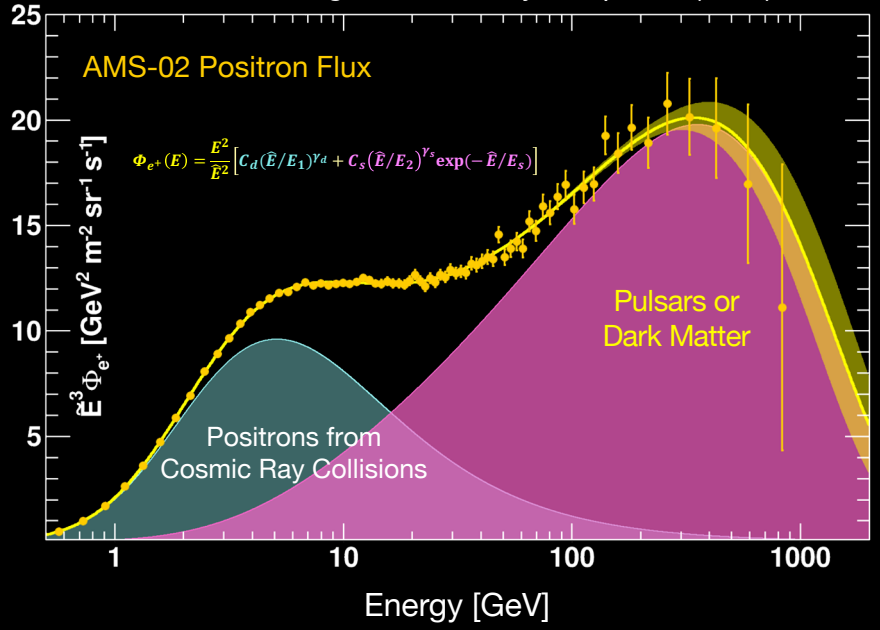
CRs Anti-Matter as a Probe for New Physics



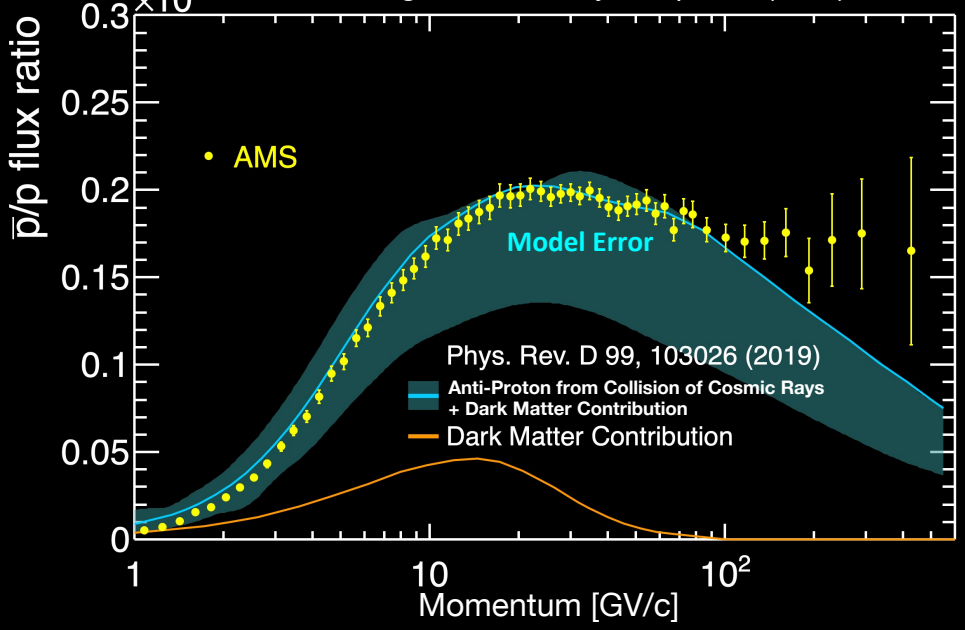
AMS-02 Positron and Anti-Proton Flux

AMS data shows new features of **positron** and **anti-proton** spectra.

M. Aguilar *et al.*, Phys. Rep. **894** (2021) 1-116.



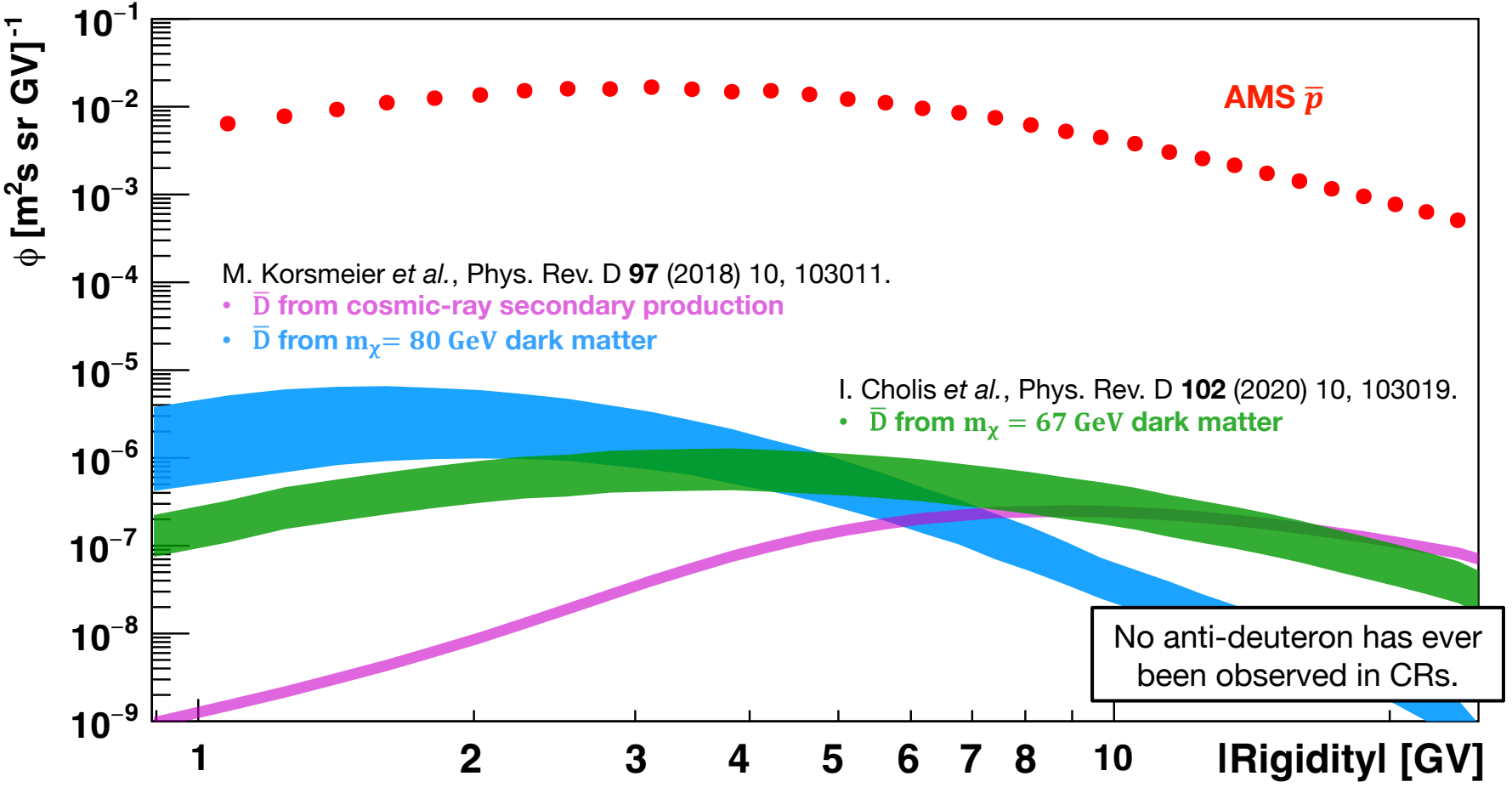
M. Aguilar *et al.*, Phys. Rep. **894** (2021) 1-116.



This data, along with the measurements that AMS made of the GCRs matter component, generated woks in many topics ranging from dark matter annihilation, to lepton production in pulsars, to secondary production in SNR, alternative galactic propagation model …

Anti-Deuterons in GCRs

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



AMS-02 Identification of |Z|=1 Particles

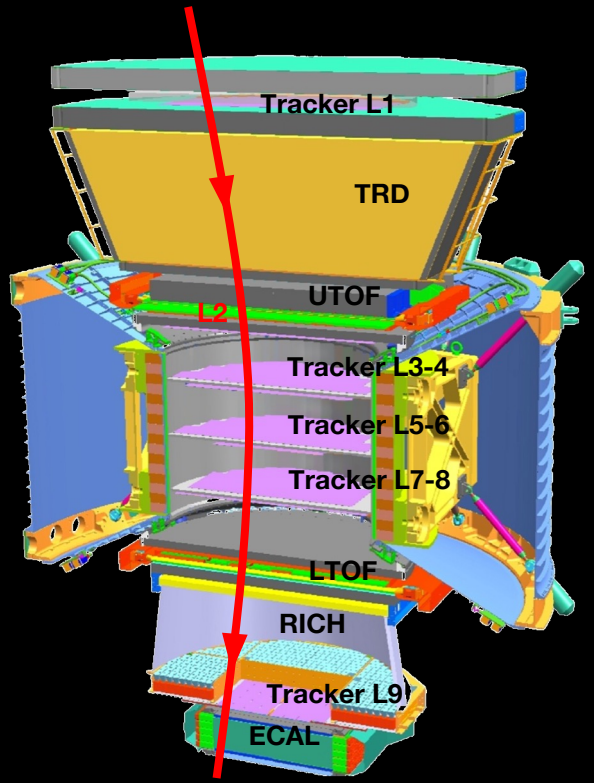
Charge and Sign

TRD, elimination of electron background,
select $|Z| = 1, \Delta Z/Z \approx 0.1$ c.u.

Tracker, particle sign (+/–),
select $|Z| = 1, \Delta Z/Z \approx 0.5$ c.u.

ToF, separate upgoing/downgoing
select $|Z| = 1, \Delta Z/Z \approx 0.6$ c.u.

RICH, select $|Z| = 1, \Delta Z/Z \approx 0.3$ c.u.

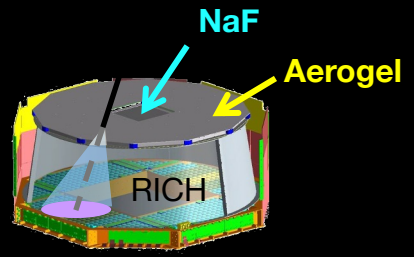


Mass Separation

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

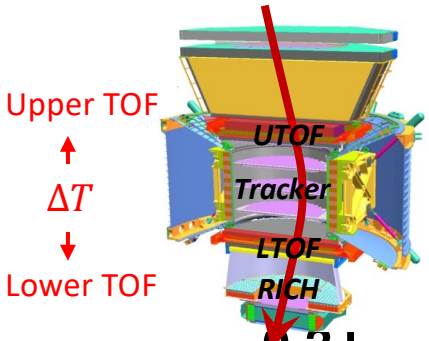
$$M = p\frac{\sqrt{1-\beta^2}}{\beta}$$

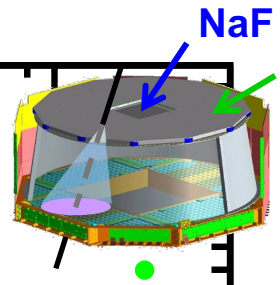
ToF, velocity $\beta, \Delta\beta/\beta^2 \approx 4\%$



RICH, velocity β, in two radiators:
NaF: $\Delta\beta/\beta \approx 0.4\%, \beta > 0.75$
Aerogel: $\Delta\beta/\beta \approx 0.1\%, \beta > 0.96$

AMS-02 Mass Measurement of |Z|=1 Particles

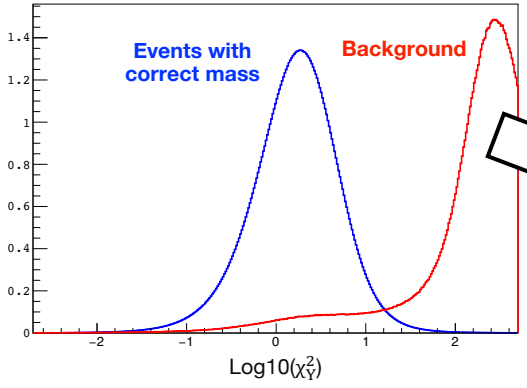


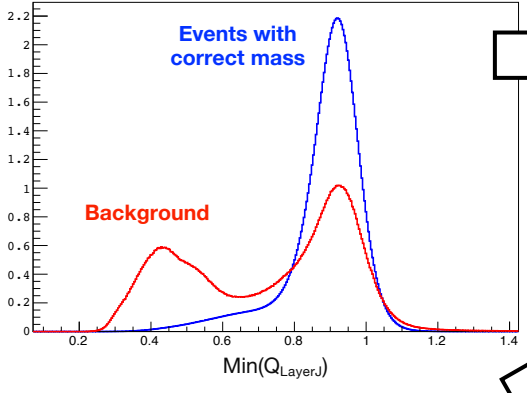


$$\frac{\Delta M}{M} = \left(\frac{\Delta p}{p}\right) \oplus \frac{1}{(1-\beta^2)}\left(\frac{\Delta \beta}{\beta}\right)$$

Anti-Deuteron Background Rejection

Use multivariate global estimators trained on data collected in space combining variables from TOF, Tracker, RICH, and TRD. These estimators can remove events with wrong momentum or velocity reconstruction.





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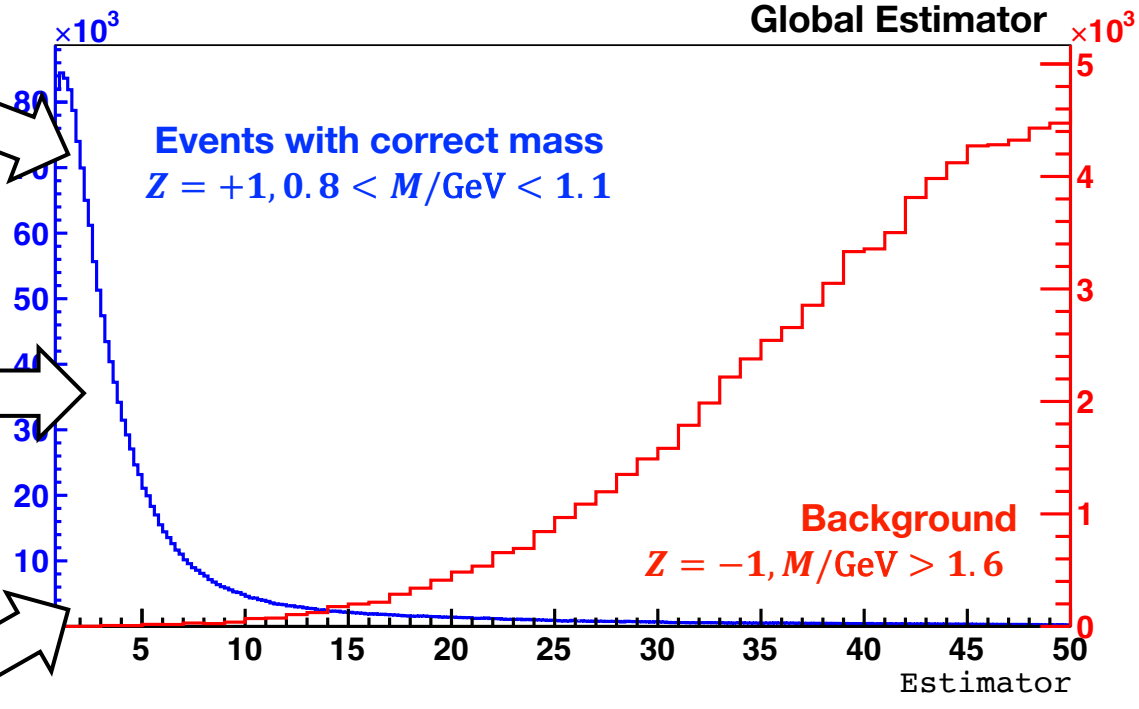
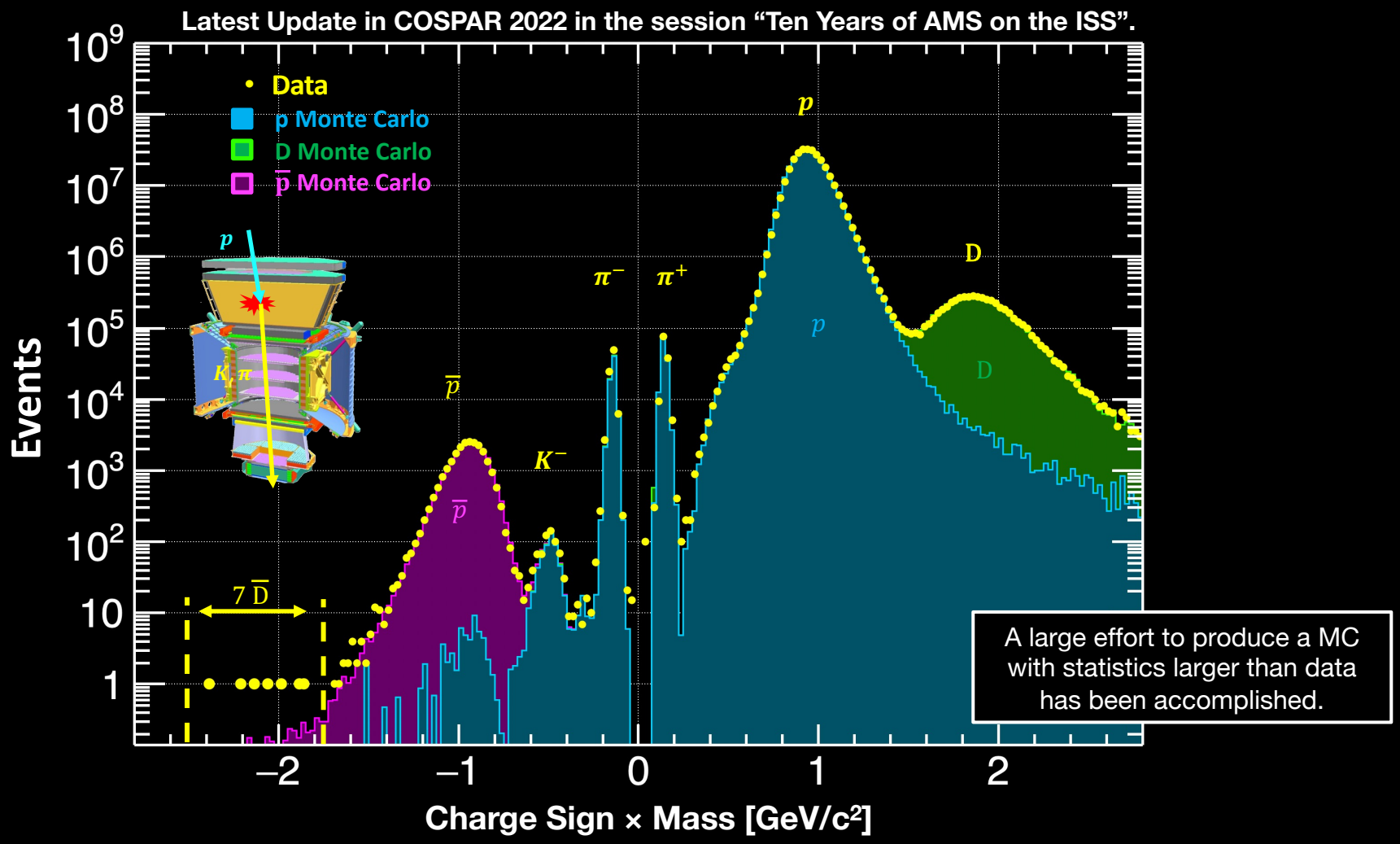
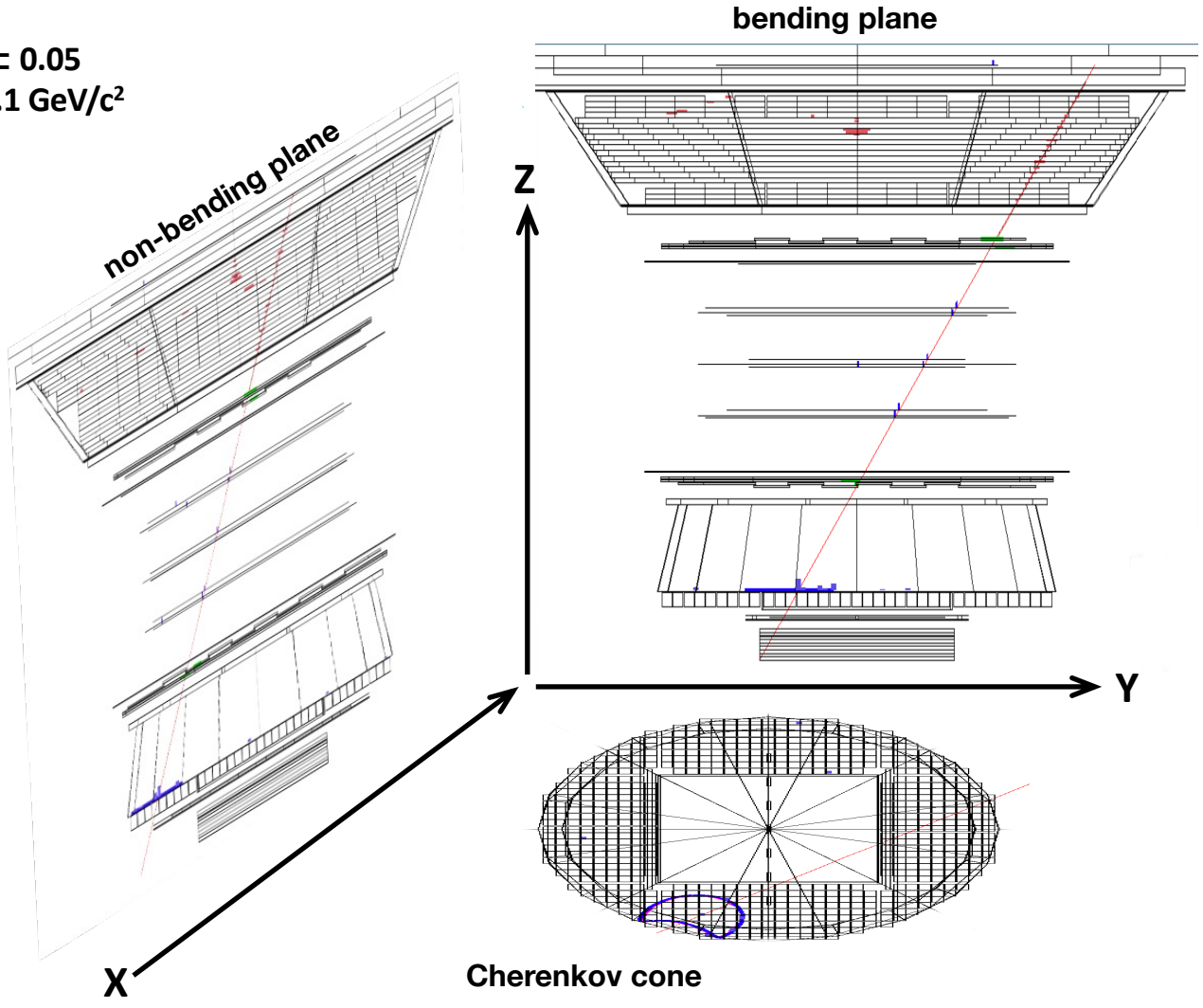


AMS-02 Current Status on Anti-Deuteron Search



An AMS-02 Anti-Deuteron Candidate

Charge = -1.02 ± 0.05
Mass = 1.9±0.1 GeV/c^2

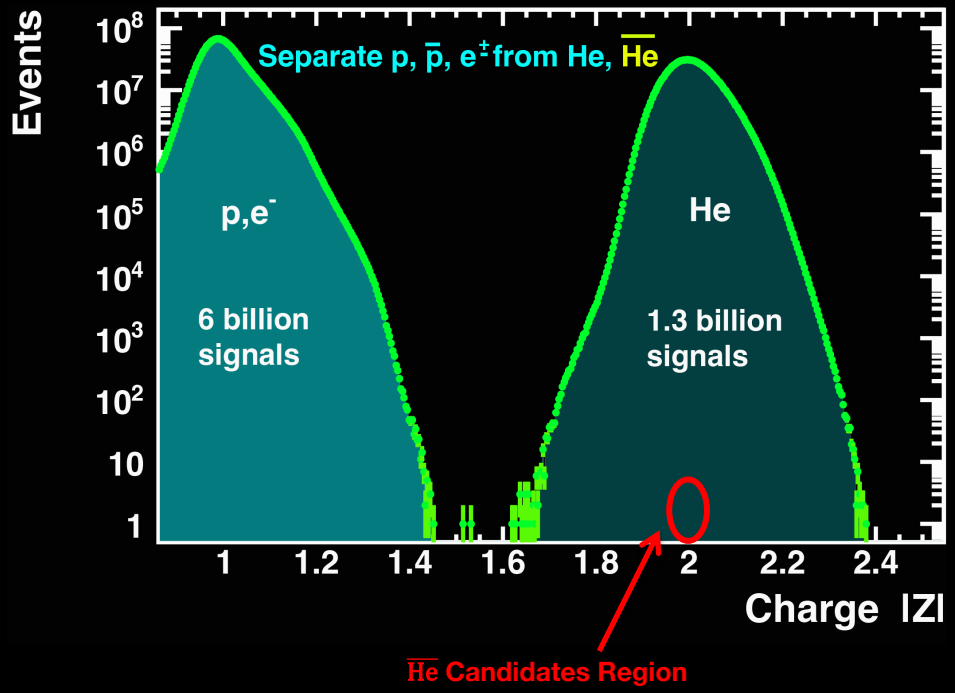


AMS-02 Identification of |Z|=2 Particles

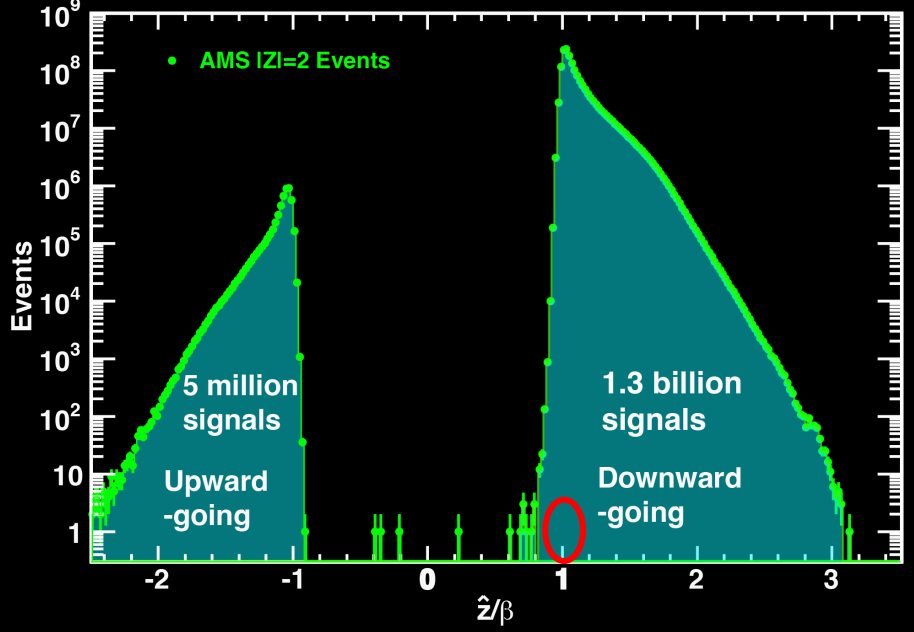
|Z|=2 is a relatively easier channel than |Z|=1:

- Better spatial resolution, better velocity resolution.
- No leptons
- Backgrounds of $|Z| = 1$ are suppressed.
- Anti-helium candidates can be identified without using mass reconstruction.

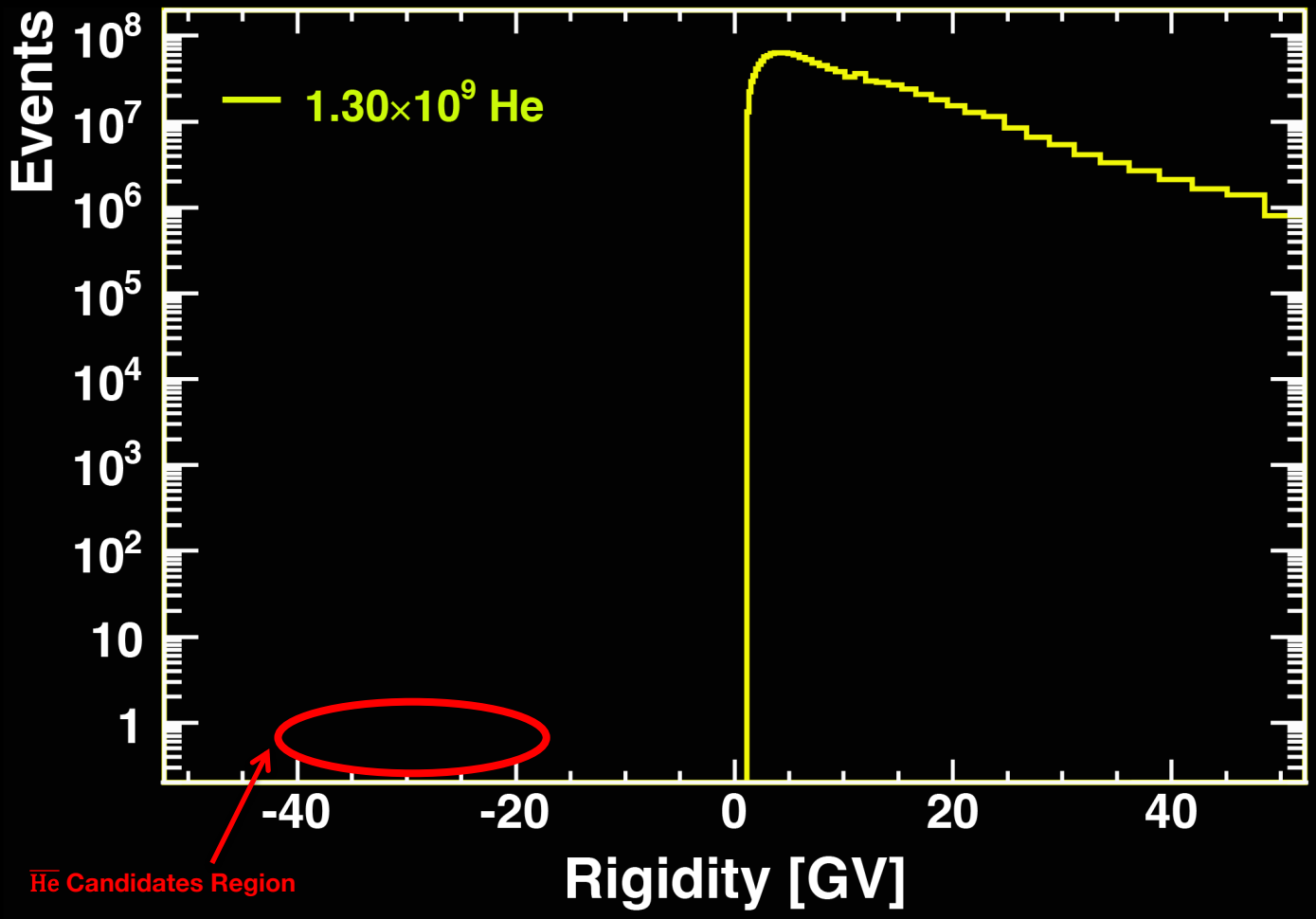
Charge Identification



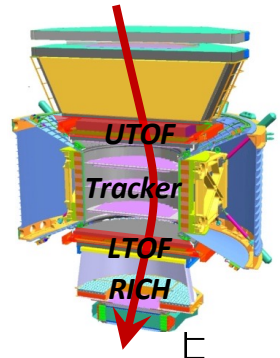
Downgoing/Upgoing Separation



AMS-02 Anti-Helium Identification



AMS-02 Mass Measurement of |Z|=2 Particles



X. Xia *et al.*, Nucl. Instr. Meth. A **868** (2017) 139-141.

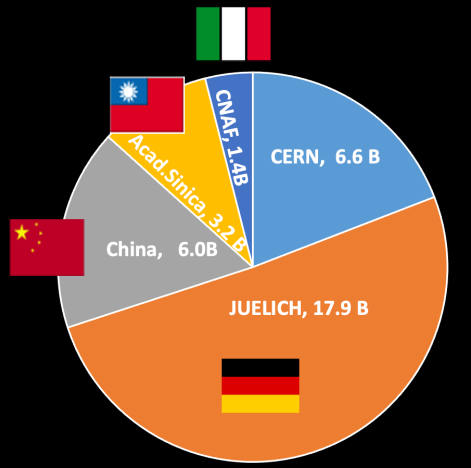
$$M = \frac{RZ}{\gamma\beta} \rightarrow \frac{\Delta M}{M} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\gamma^2 \frac{\Delta\beta}{\beta}\right)^2}$$

AMS-02 Anti-Helium Events

Latest Update in COSPAR 2022 in the session "Ten Years of AMS on the ISS".

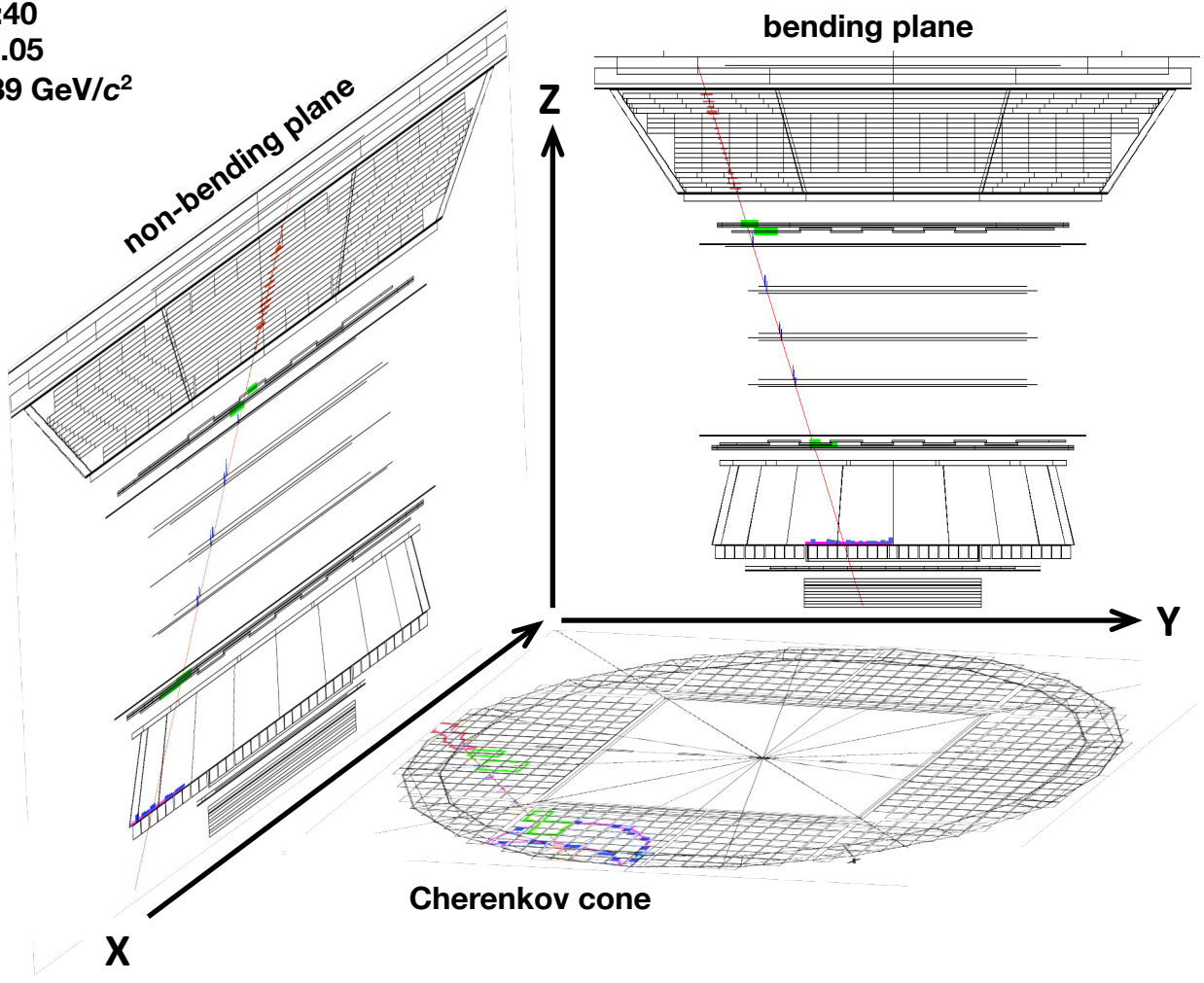
- To date, we have observed few events in the mass region from 0 to 10 GeV/c^2 with $Z = -2$ with $R < 50$ GV.
- All events masses are in the ^{3}He or ^{4}He mass region.
- The event rate is 1 anti-helium in ~100 million helium.

- A helium MC of 35 billion events (50 million CPU hours) has been produced.
- We did not find background to anti-helium events.
- However, at this level of rejection, the Monte Carlo simulations are difficult to validate.



An AMS-02 Anti-Helium Candidate

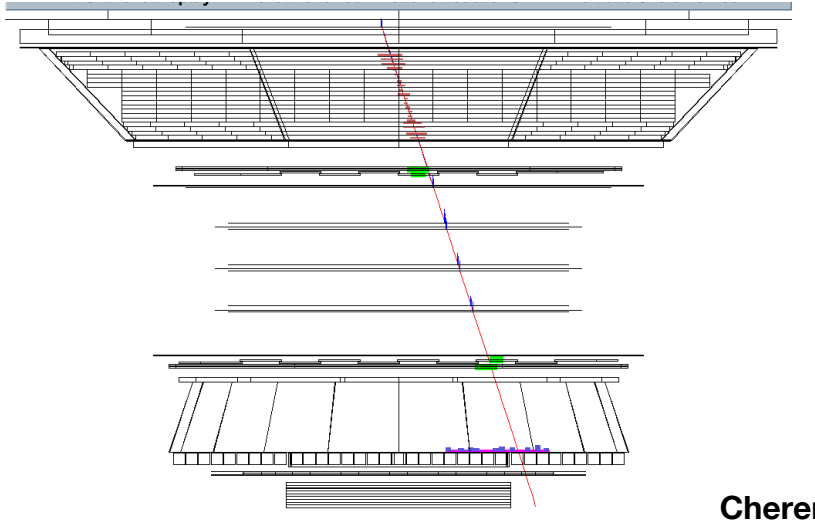
June 20, 2017, 06:11:40
Charge = -2.05 ± 0.05
Mass = 3.81± 0.39 GeV/c^2



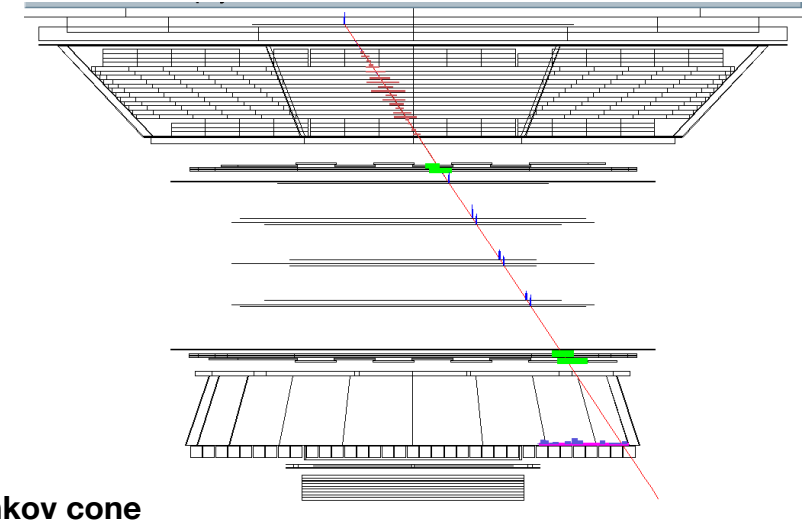
Latest AMS-02 Anti-Helium Candidate

Latest anti-helium event in 10 years: December 10, 2020, 07:04:30
Charge = −2.05 ± 0.05
Mass = 4.1 ± 0.9 GeV/c^2

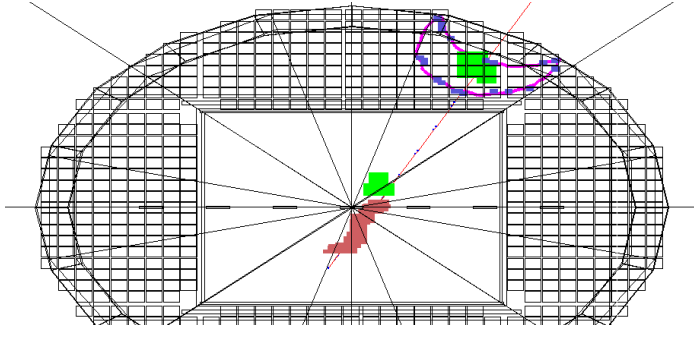
non-bending plane



bending plane

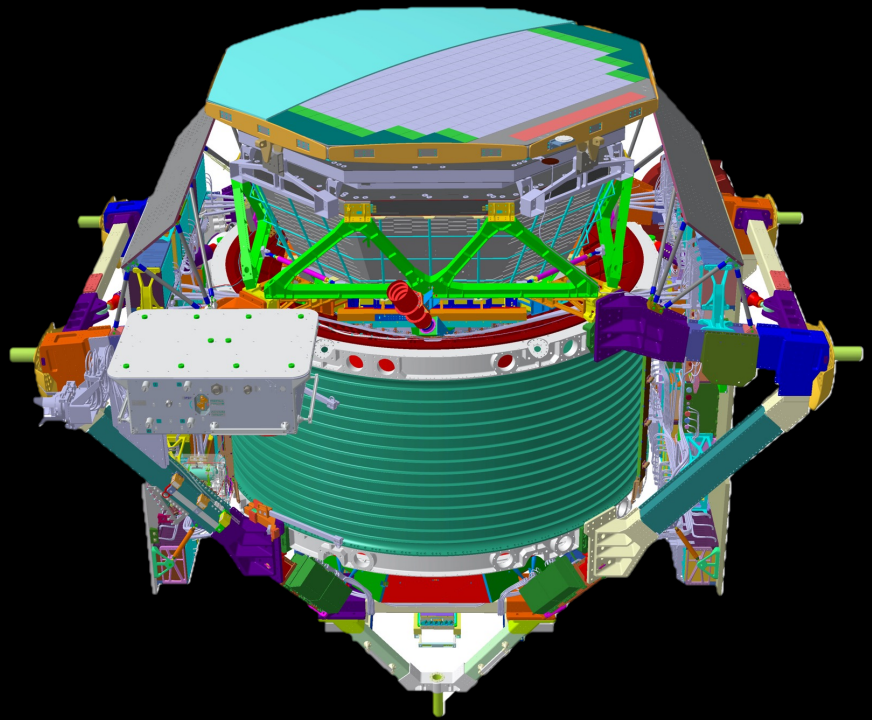


Cherenkov cone

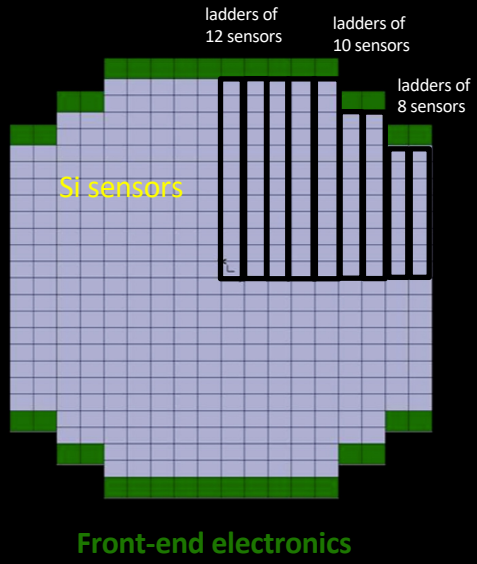


AMS-02 Upgrade

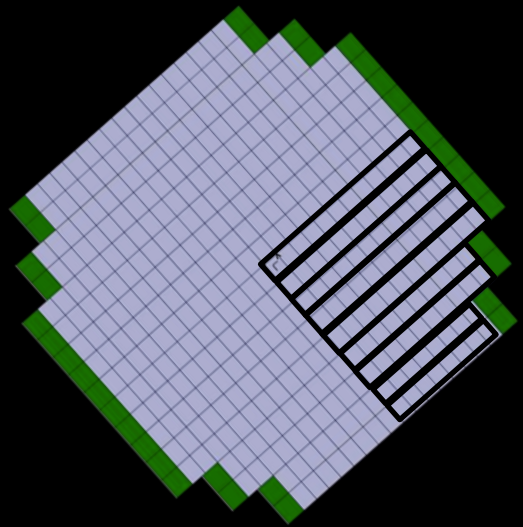
Installation of an additional plane with two silicon micro-strip detector with 7 μm spatial resolution.
This new detector has an active area of about 7 m^2.



L0-Y



L0-U



This new layers allows for an increment on acceptance of a factor 3. It is a significant operation that will allow AMS to increase sizably the collected statistics of anti-nuclei candidates in few years of acquisition.

Conclusions

- AMS has been operating in the Space Station since May 2011 performing precision measurements of cosmic rays and revealing new details about origin and propagation of all CRs species.
- With its unprecedented statistics and accuracy, AMS has a unique capability to detect antimatter in cosmic rays and study their properties.
- AMS is the only operating spectrometer in space and will continue to collect and analyze data for the lifetime of the Space Station.