Indirect searches of dark matter

Light charged particles

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Università degli Studi di Perugia

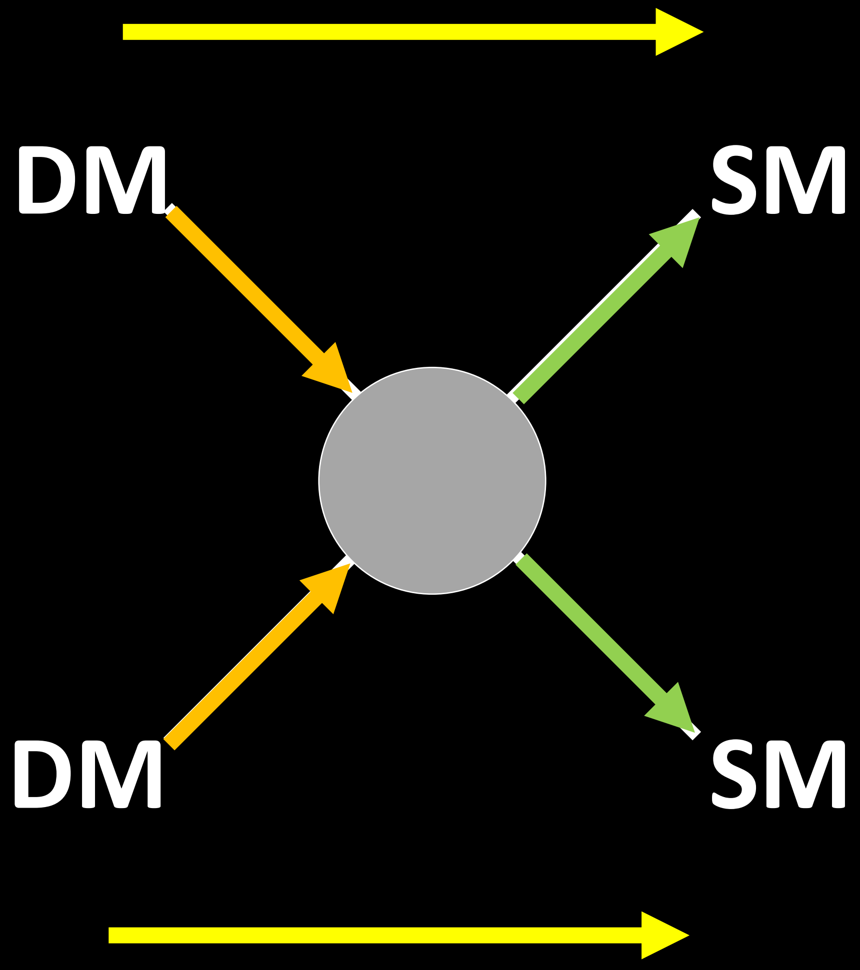
iDMEu kick-off meeting
10-11 May 2021 @ CERN/Zoom

A.D. 1308
unipg
DIPARTIMENTO
DI FISICA E GEOLOGIA

Università degli Studi di Perugia
C.R.I.S.P. ASI-UniPG 2019-2-HH.0

Indirect detection of DM

Goal: remotely sensing some effects which yield information on the particle nature of DM
Messengers: products of DM annihilation or decay in remote astrophysical sites



Annihilation in space

DM+DM --> (…) --> SM + SM

- ✓ Known particles
- ✓ Detectable
- ✓ Otherwise rare

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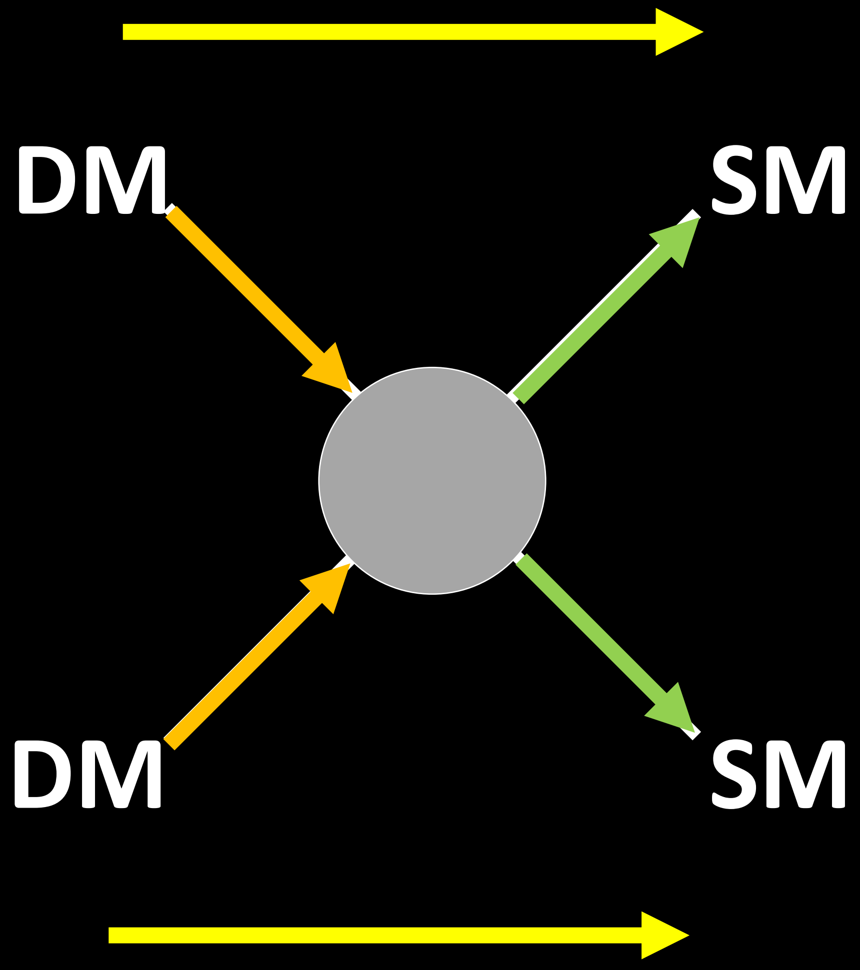

Annihilation in space

DM+DM --> (...) --> SM + SM

✓ ✓ ✓

e+ e- pbar, antinuclei

Indirect detection of DM

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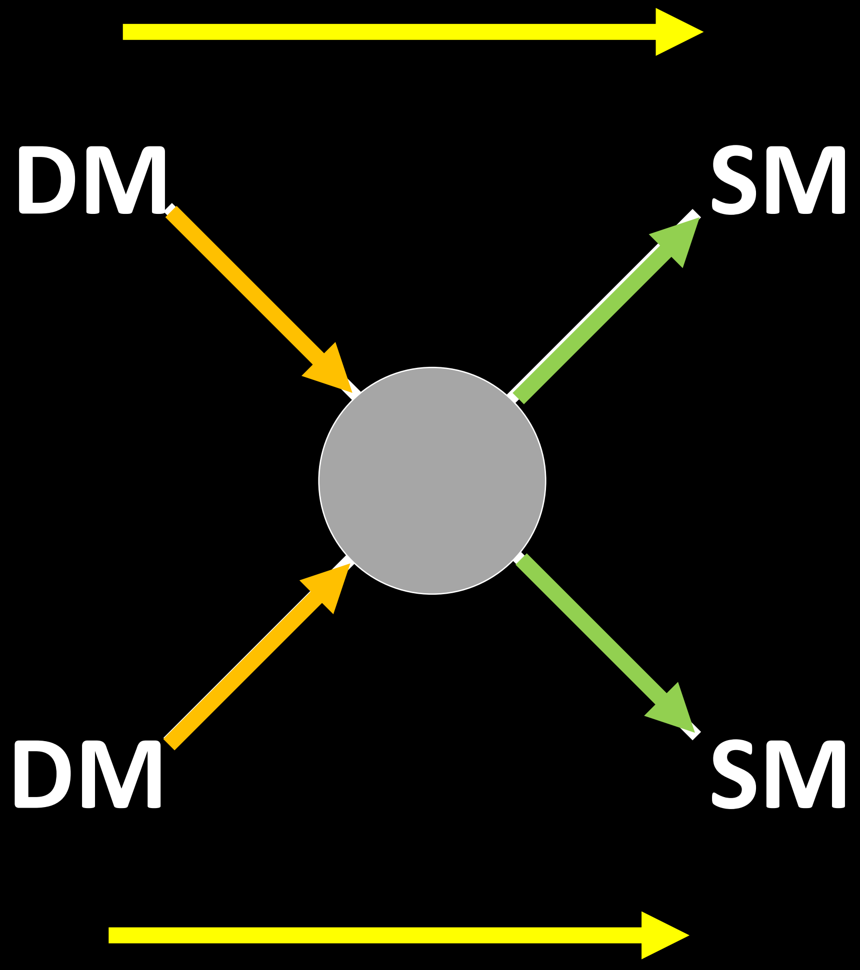
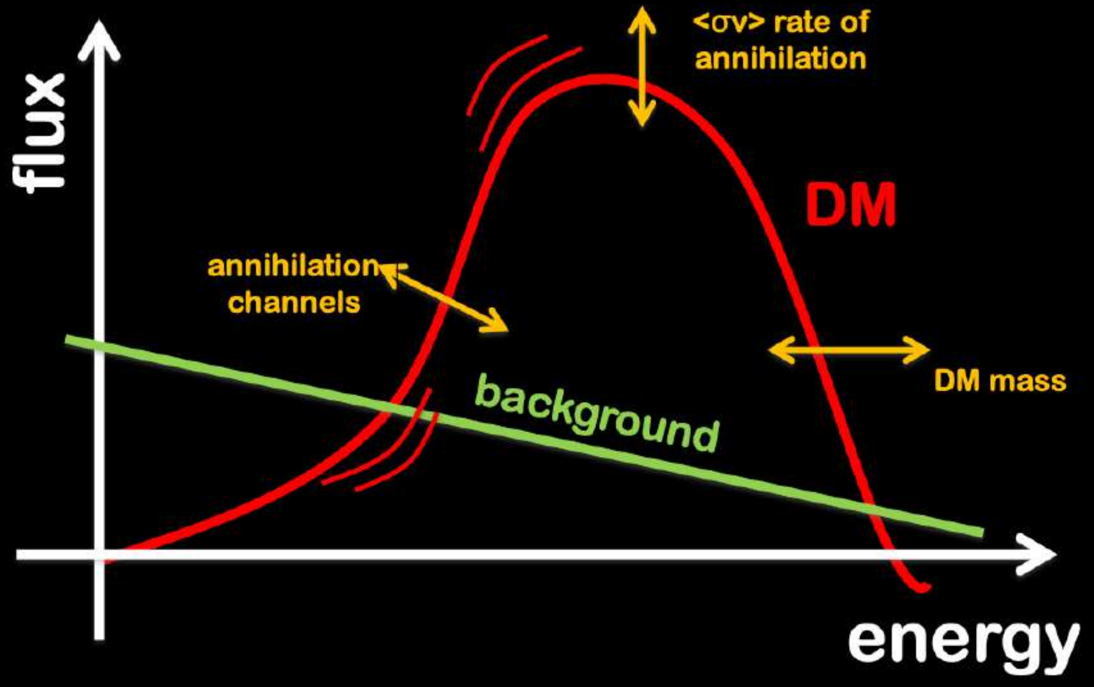
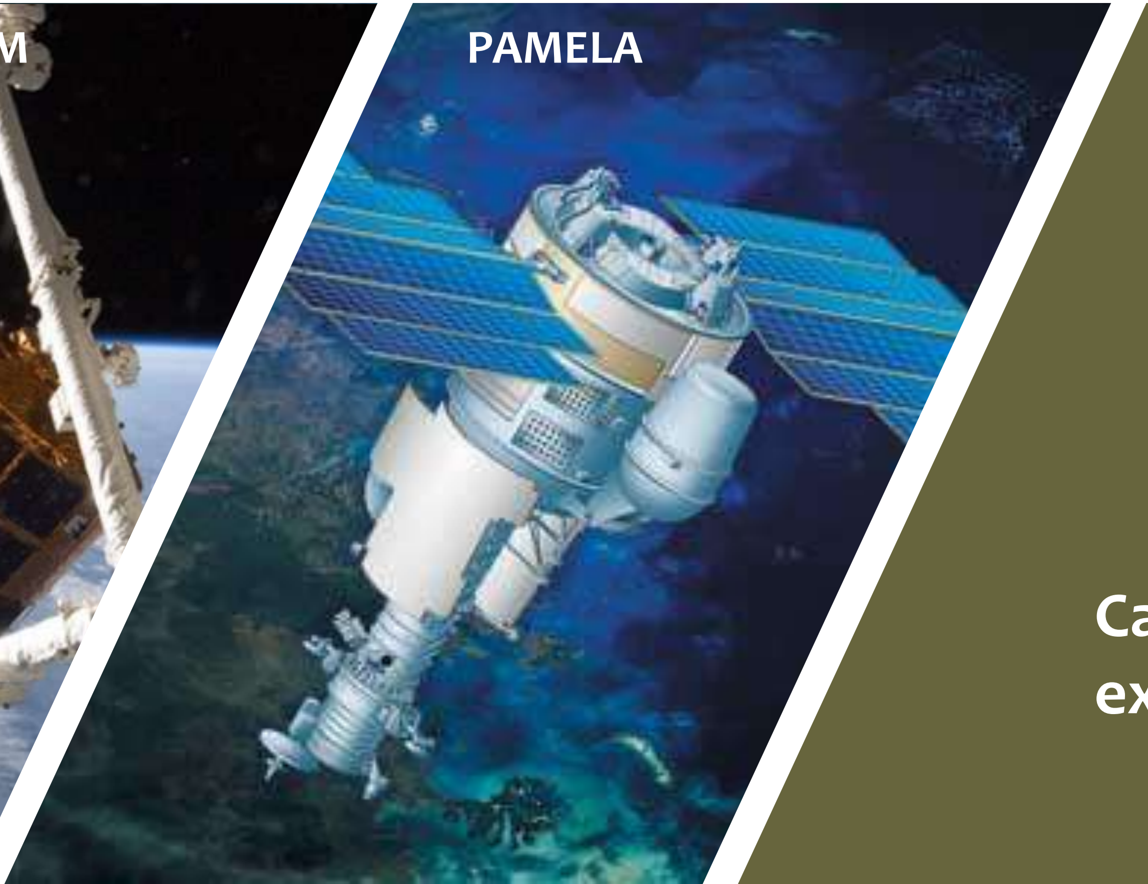


Annihilation in space

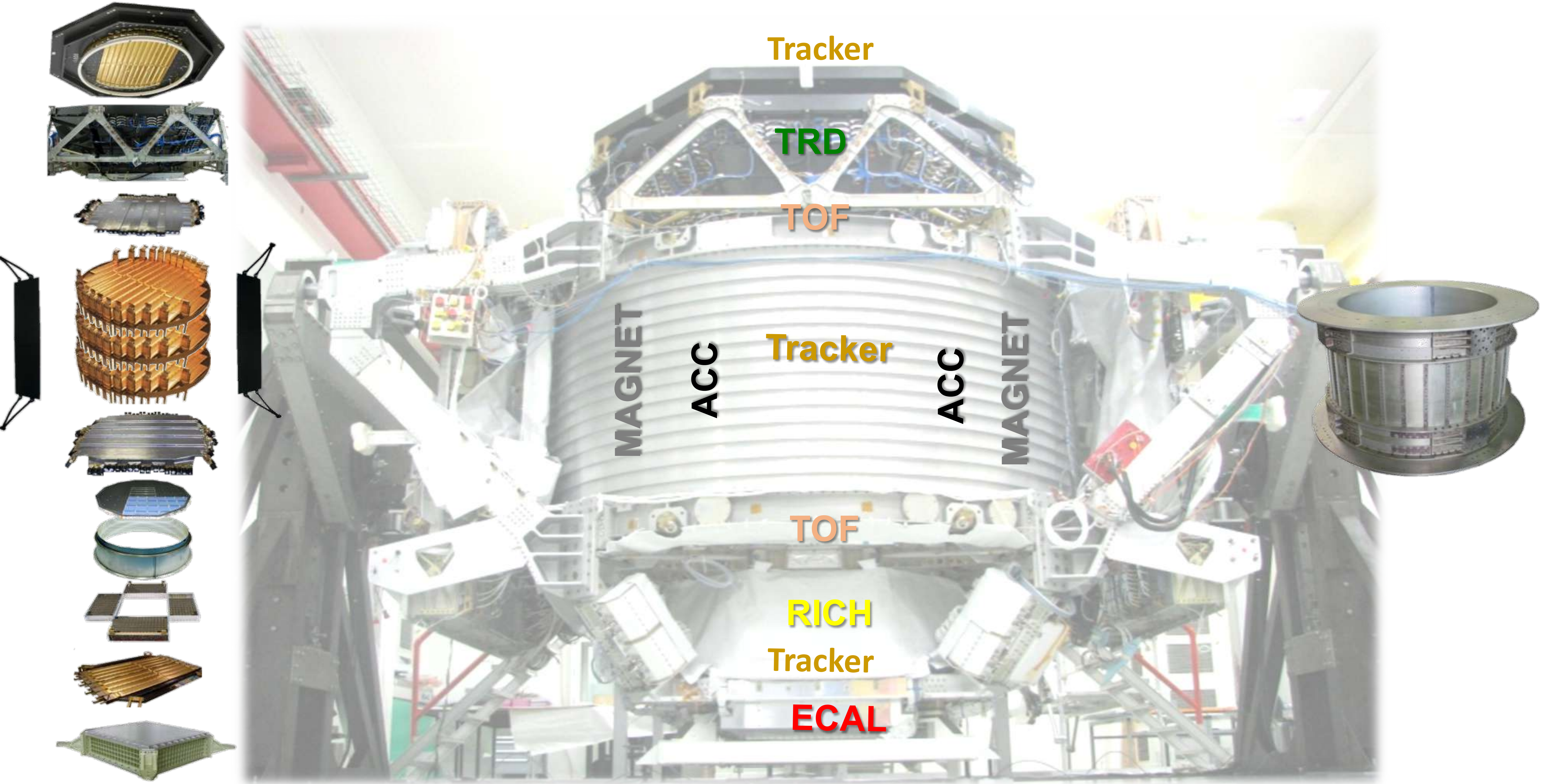
DM+DM --> (…) --> SM + SM





a golden age of new cosmic ray measurements

Magnetic Spectrometers	AMS-02 PAMELA
Calorimetric experiments	FERMI/LAT CALET DAMPE ISS-CREAM



Tracker
TRD
TOF
MAGNET
ACC
Tracker
ACC
MAGNET
TOF
RICH
Tracker
ECAL

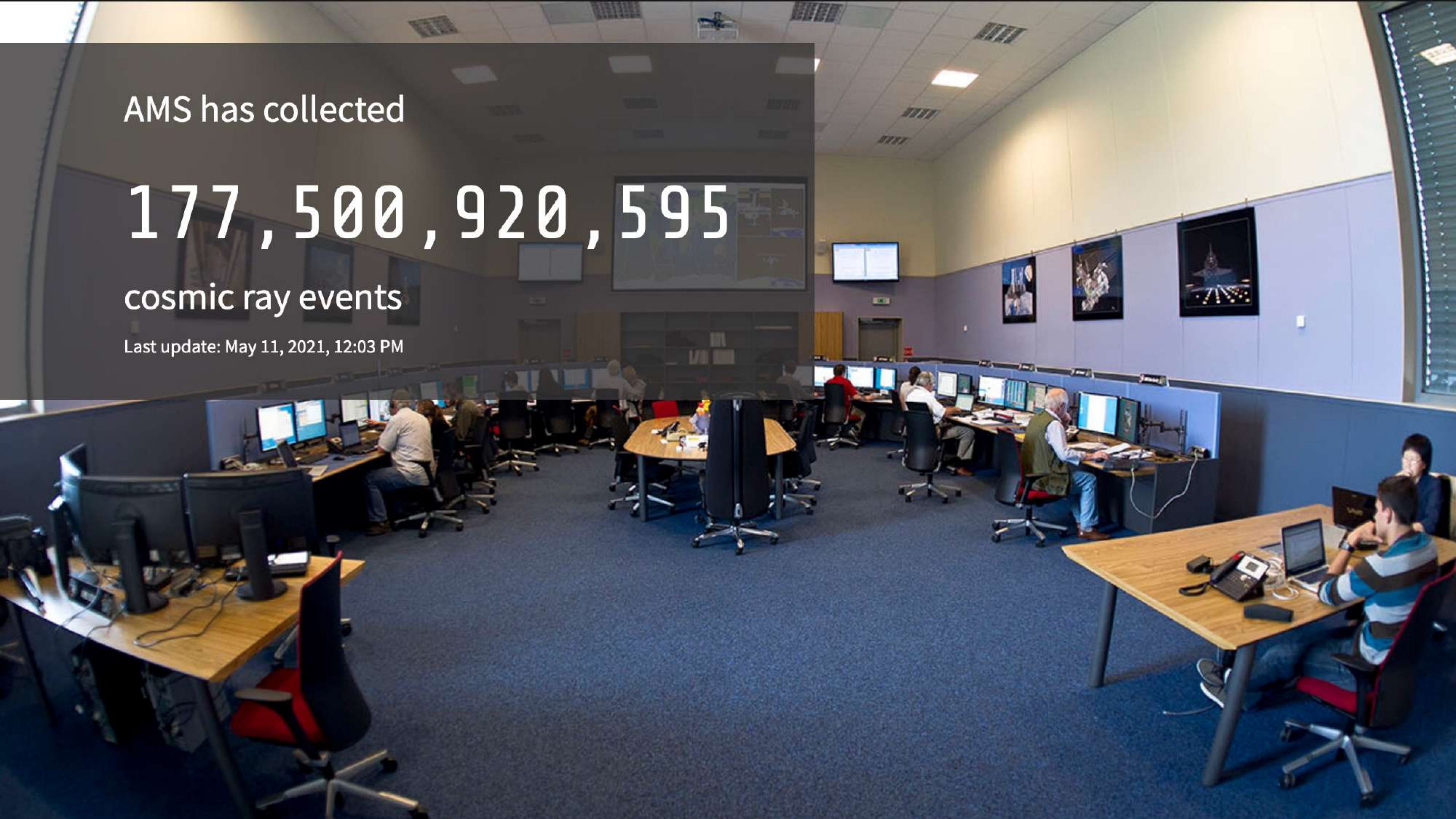
19 MAY 2011 THE AMS-02 LAUNCH

TEN YEARS

#SpacewalkforAMS

15 November 2019: the intervention

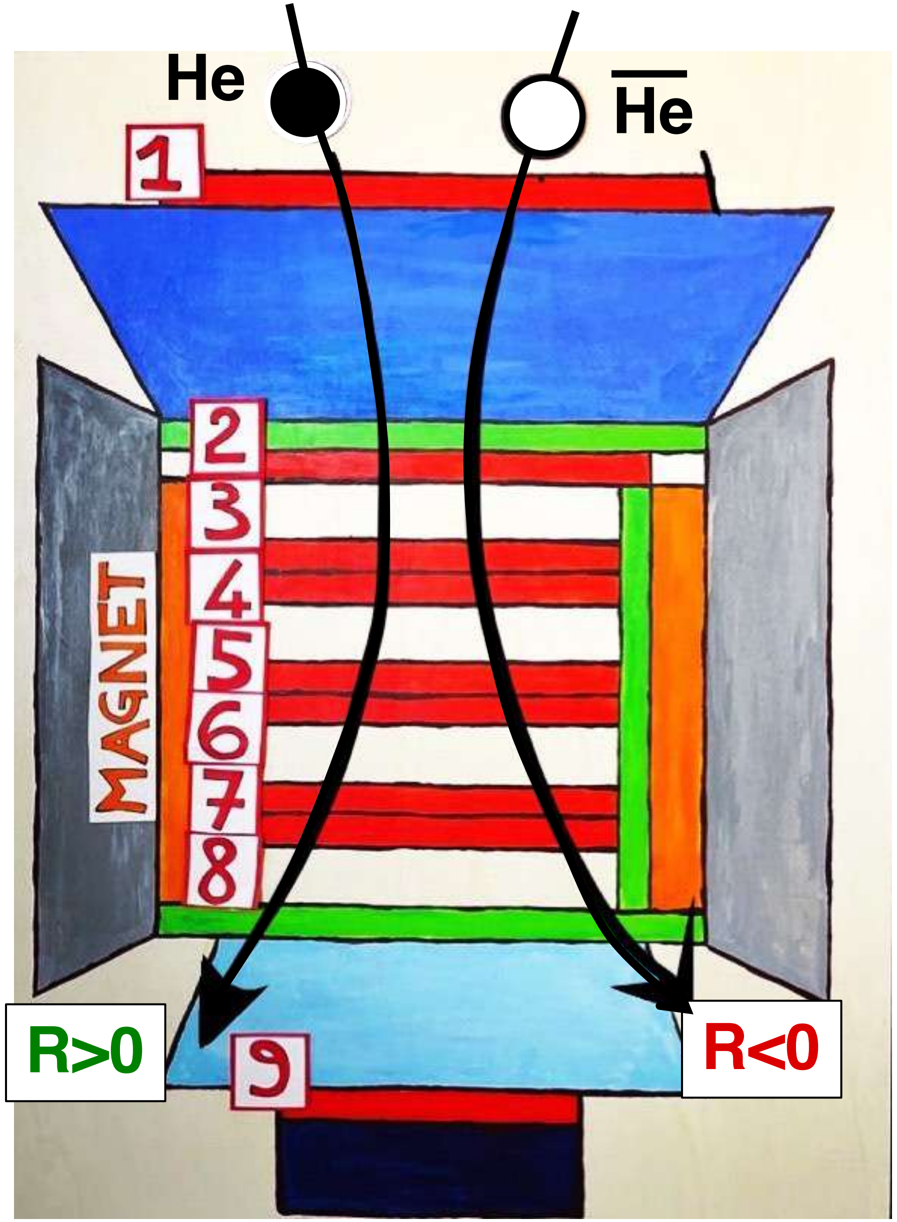
#SpaceWalkForAms


AMS has collected
177,500,920,595
cosmic ray events
Last update: May 11, 2021, 12:03 PM

Ten years of AMS-02 on the ISS

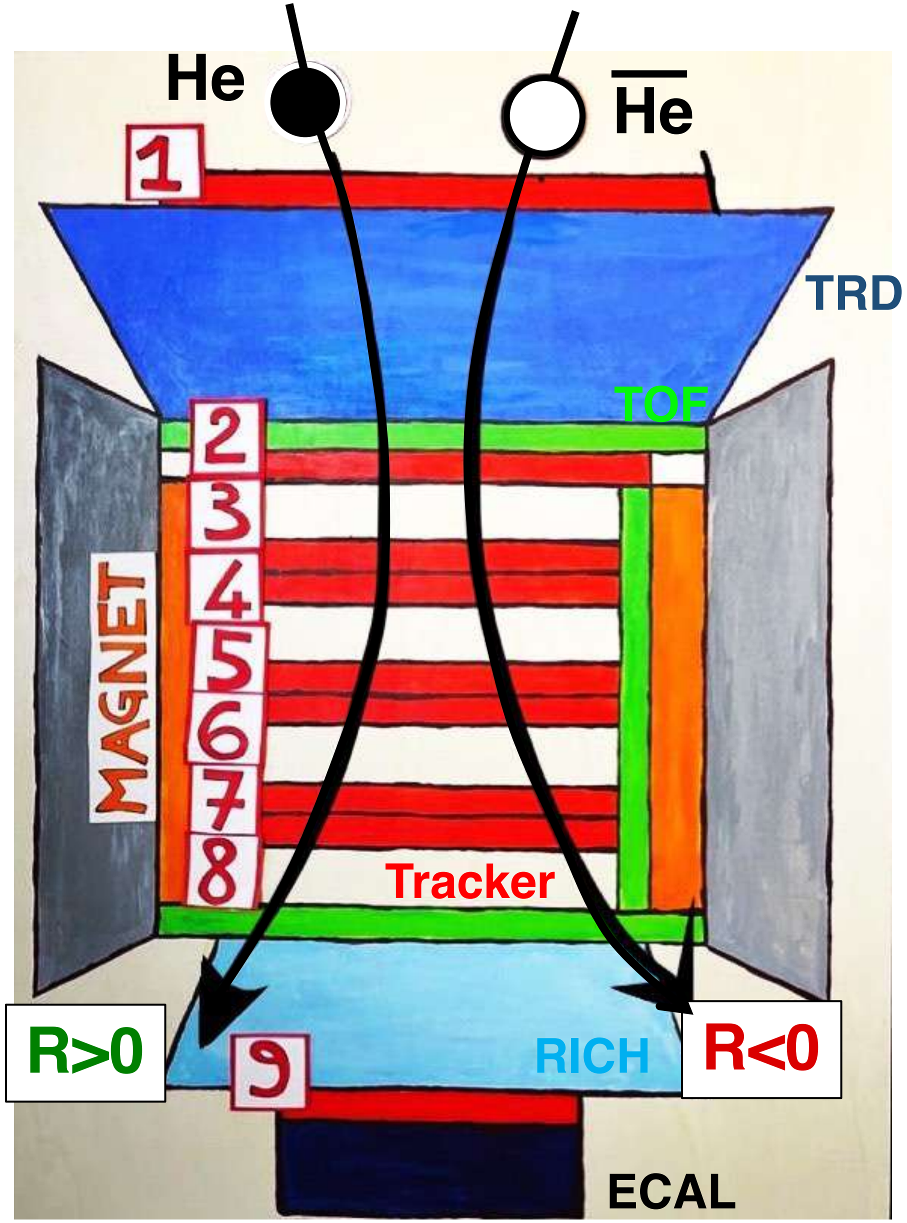
https://agenda.infn.it/event/26613

DETECTING ANTIMATTER WITH A MAGNET



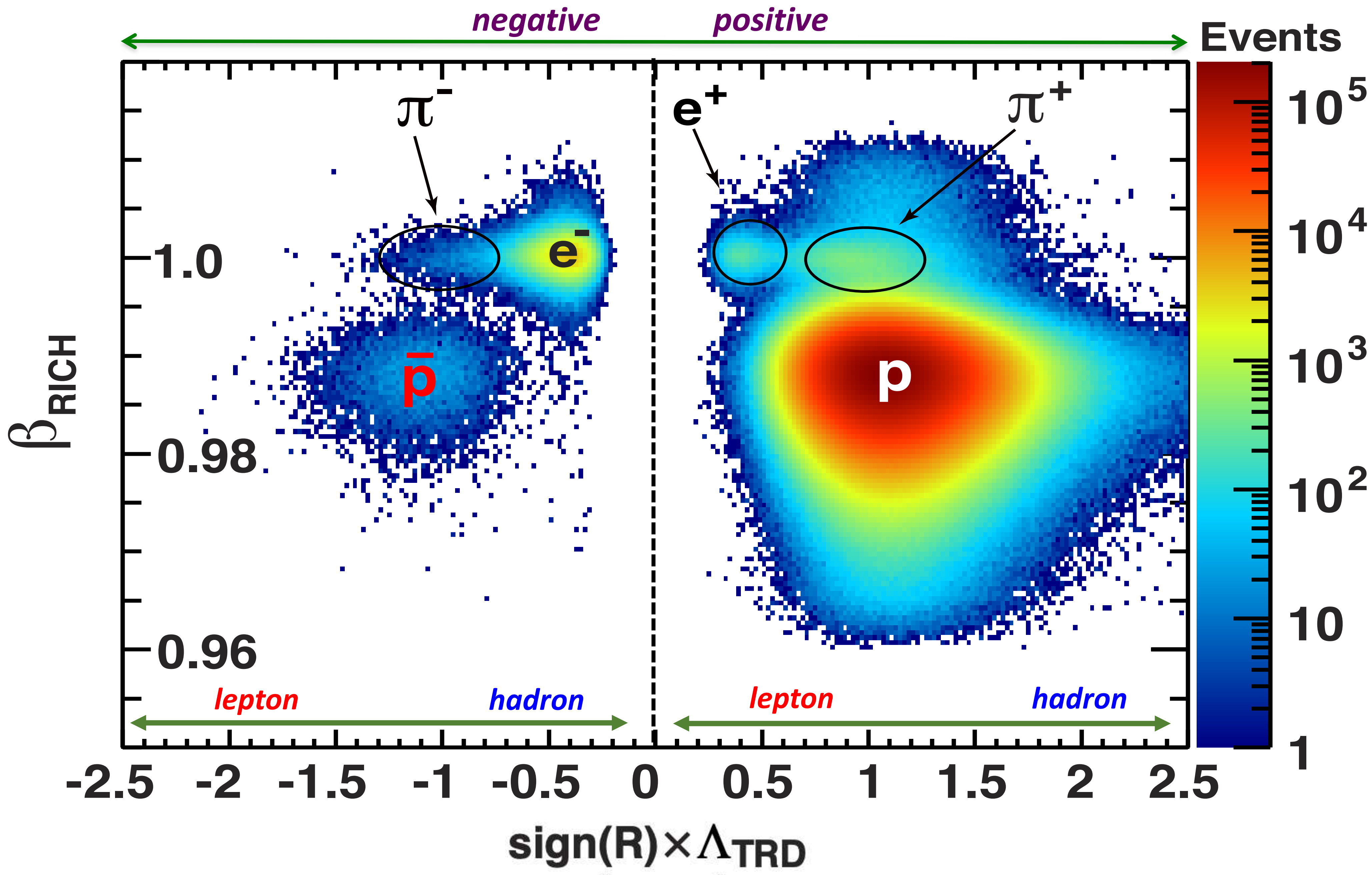
x Charge sign (**Tracker**)

DETECTING ANTIMATTER WITH A MAGNET

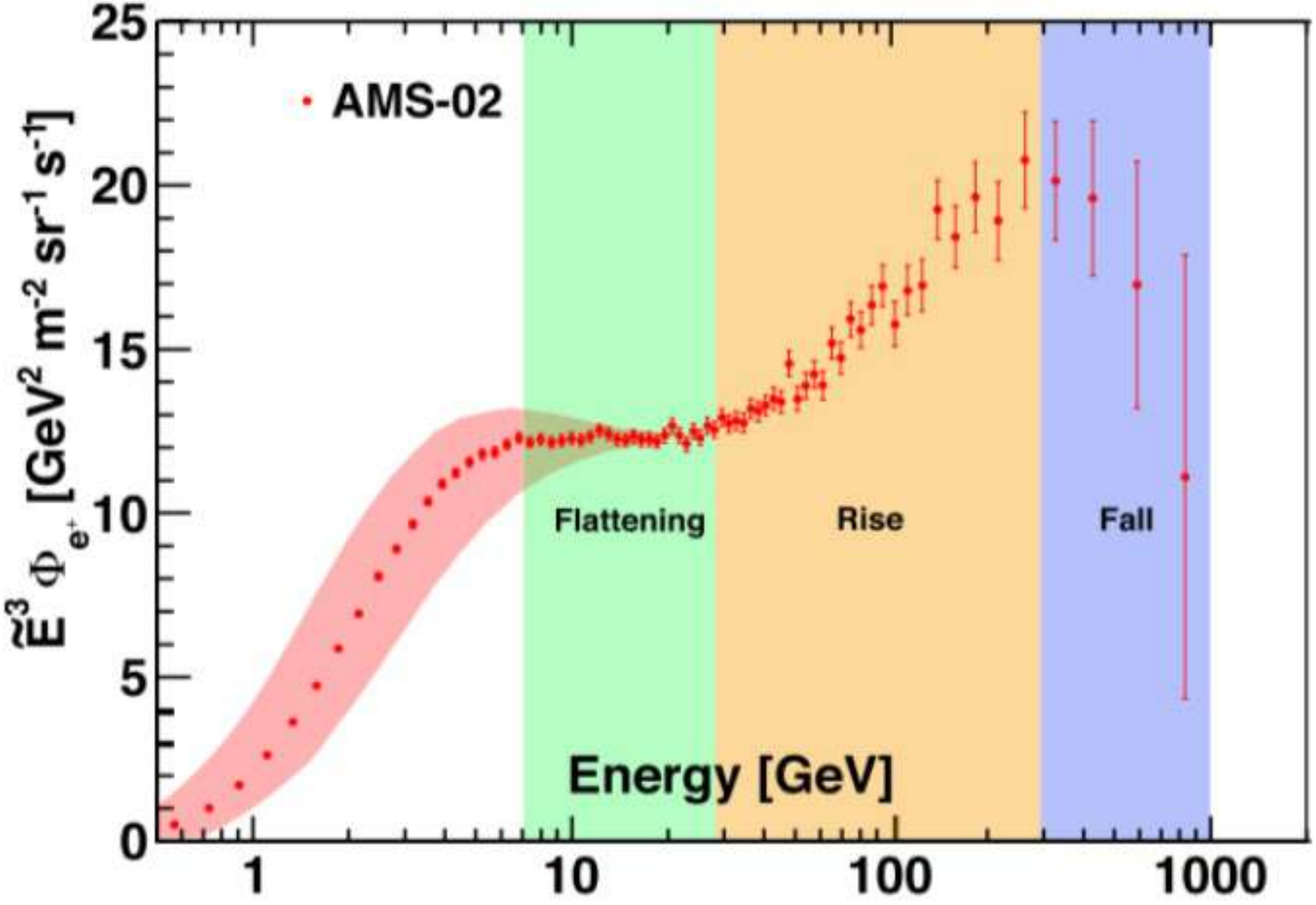


- x Charge sign (**Tracker**)
- + Rigidity |R| (**Tracker**)
- + Up/down direction (**TOF**)
- + Speed (**TOF**, **RICH**)
- + Hadroness (**ECAL**, **TRD**,**Tracker**)
- + Total energy E (**ECAL**)
- + Charge magnitude |Z| (All)

AMS Data w/ R= 6 GV:



Positron Flux x E^3



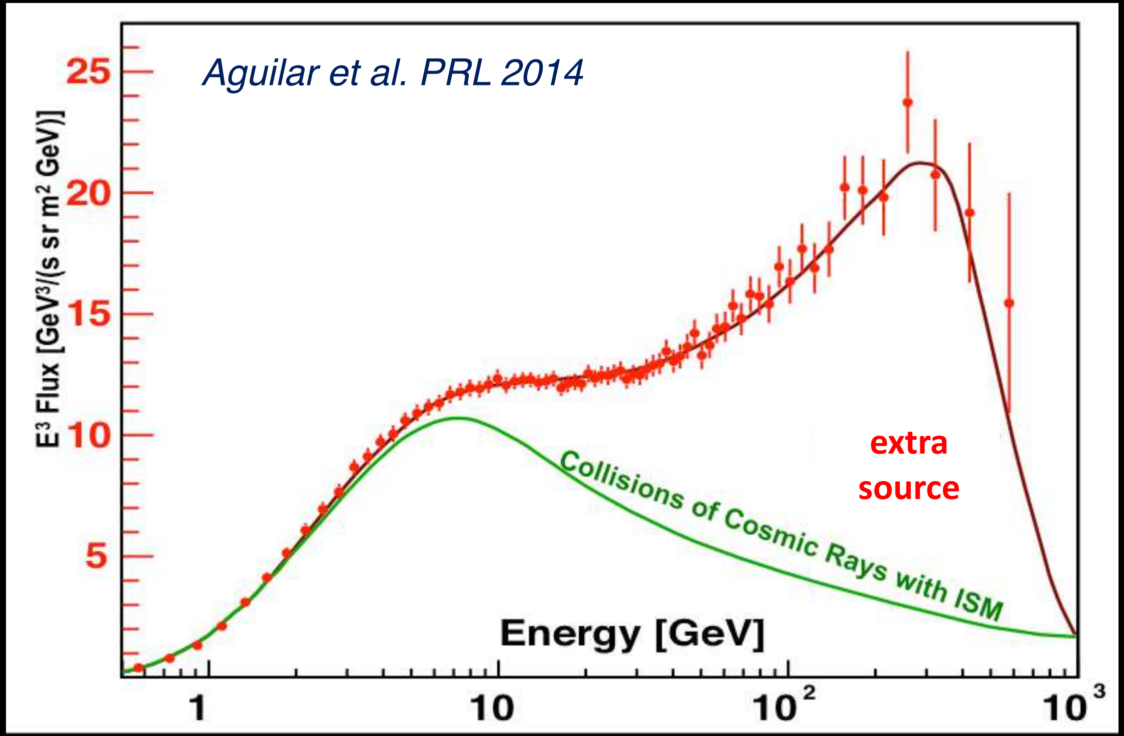
Aguilar et al. Phys. Rept. 894 (2021)

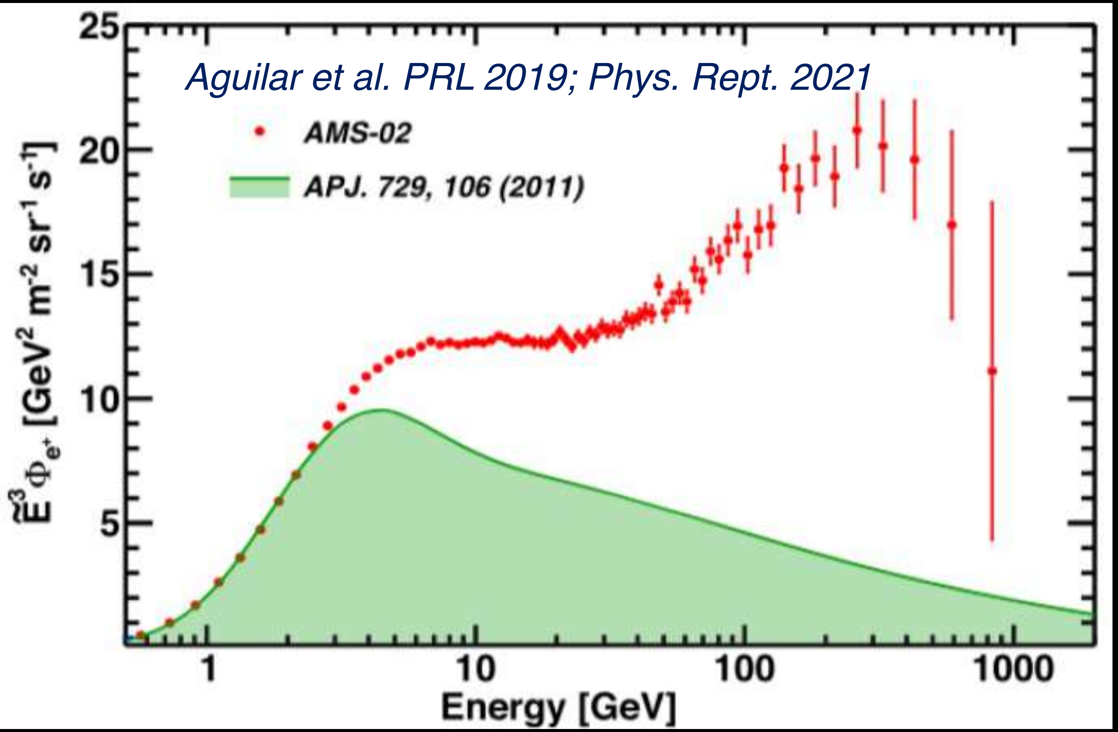
Aguilar et al. PRL 122 0411012 (2021)

Data: positron flux

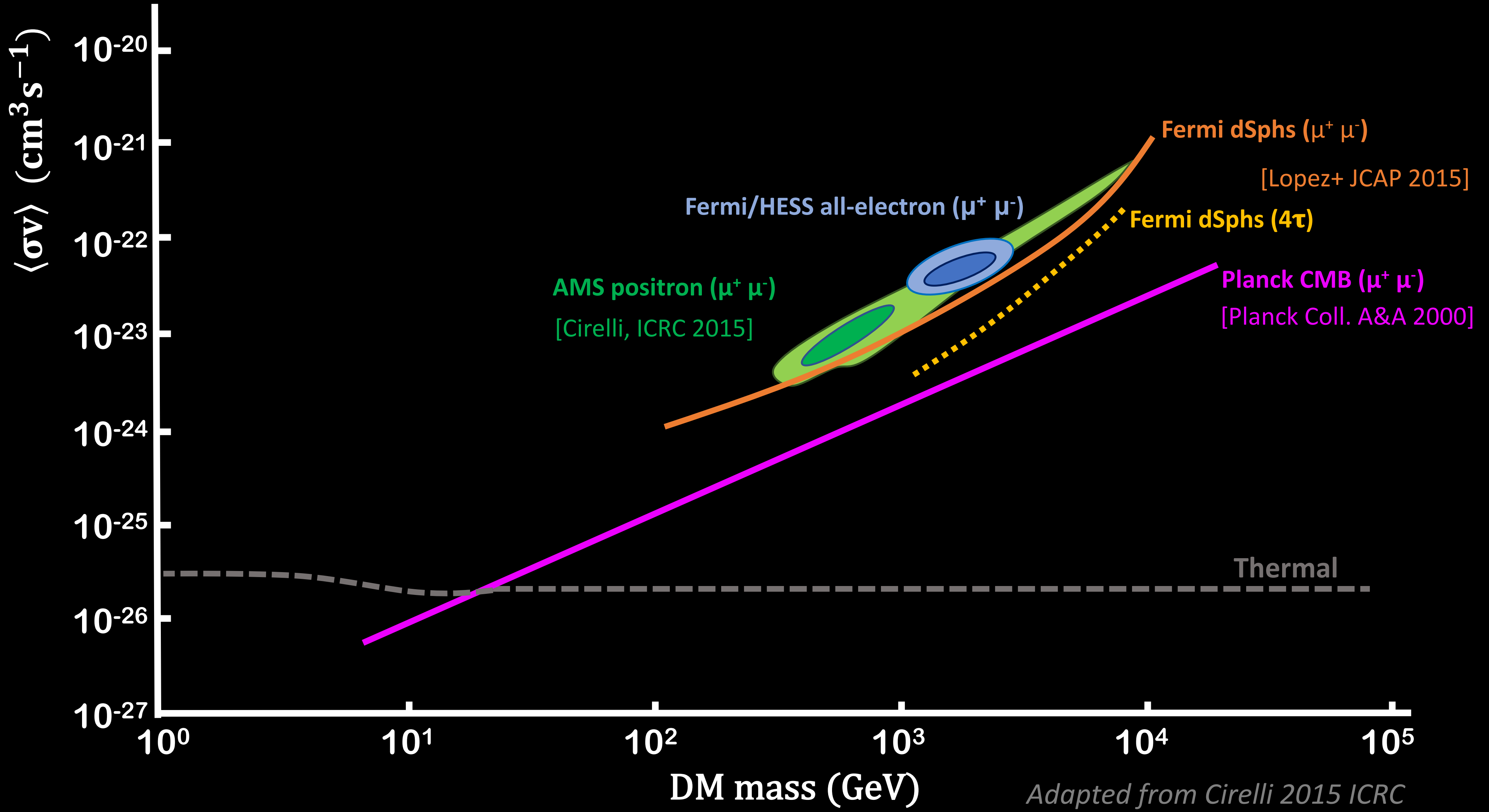
- ✓ Data up to 1 TeV. Unequivocal excess wrt secondary production models
- ✓ Viable DM interpretation: multi-TeVmass, leptophilic w/ large <σv> ~ 10^{23} cm^3/s

- ❖ Tension with other observations: dSphs, Halo, CMB
- ❖ Astrophysical sources of HE positrons: pulsars, if not SNRs



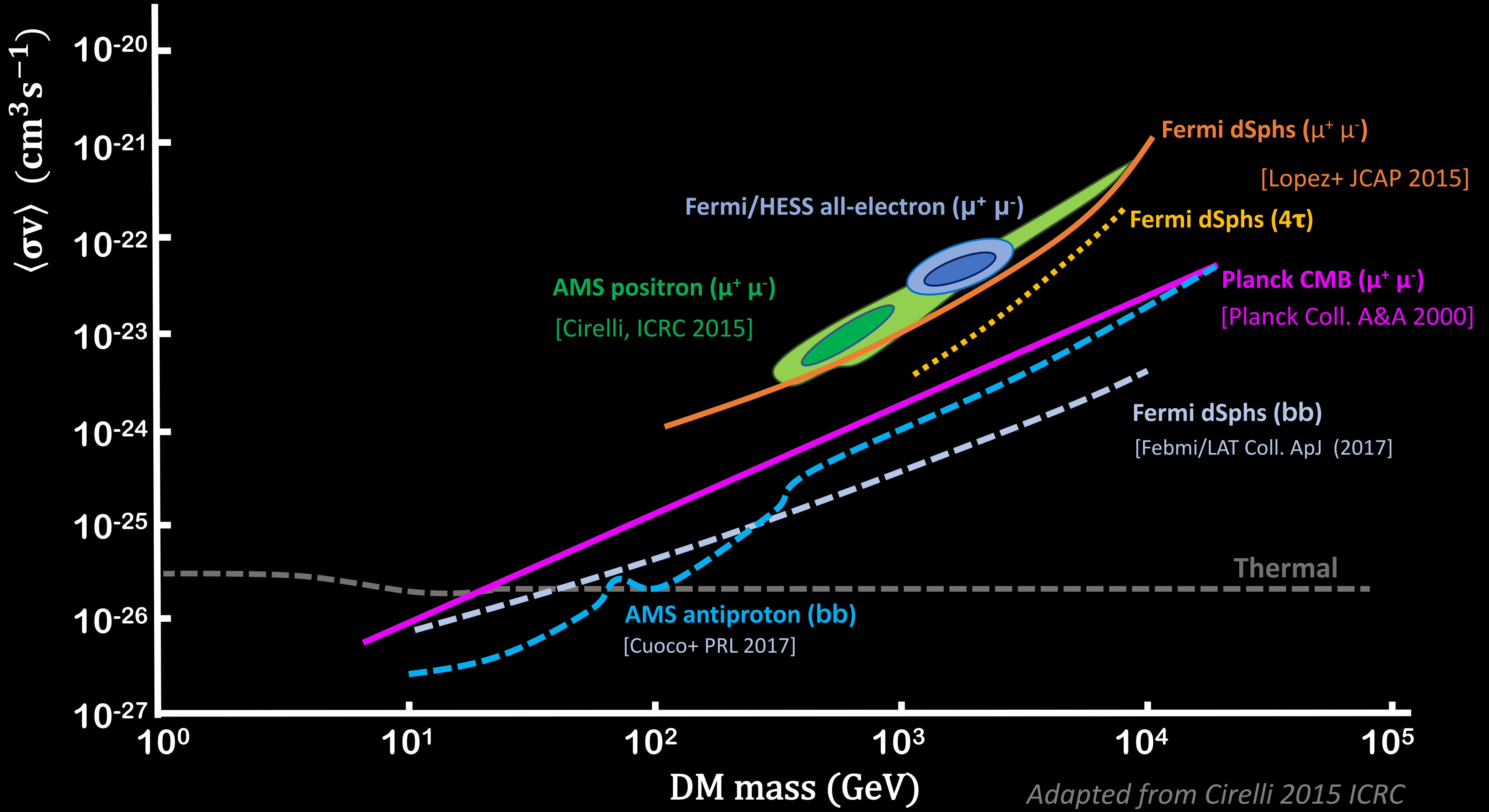


Comparing bounds



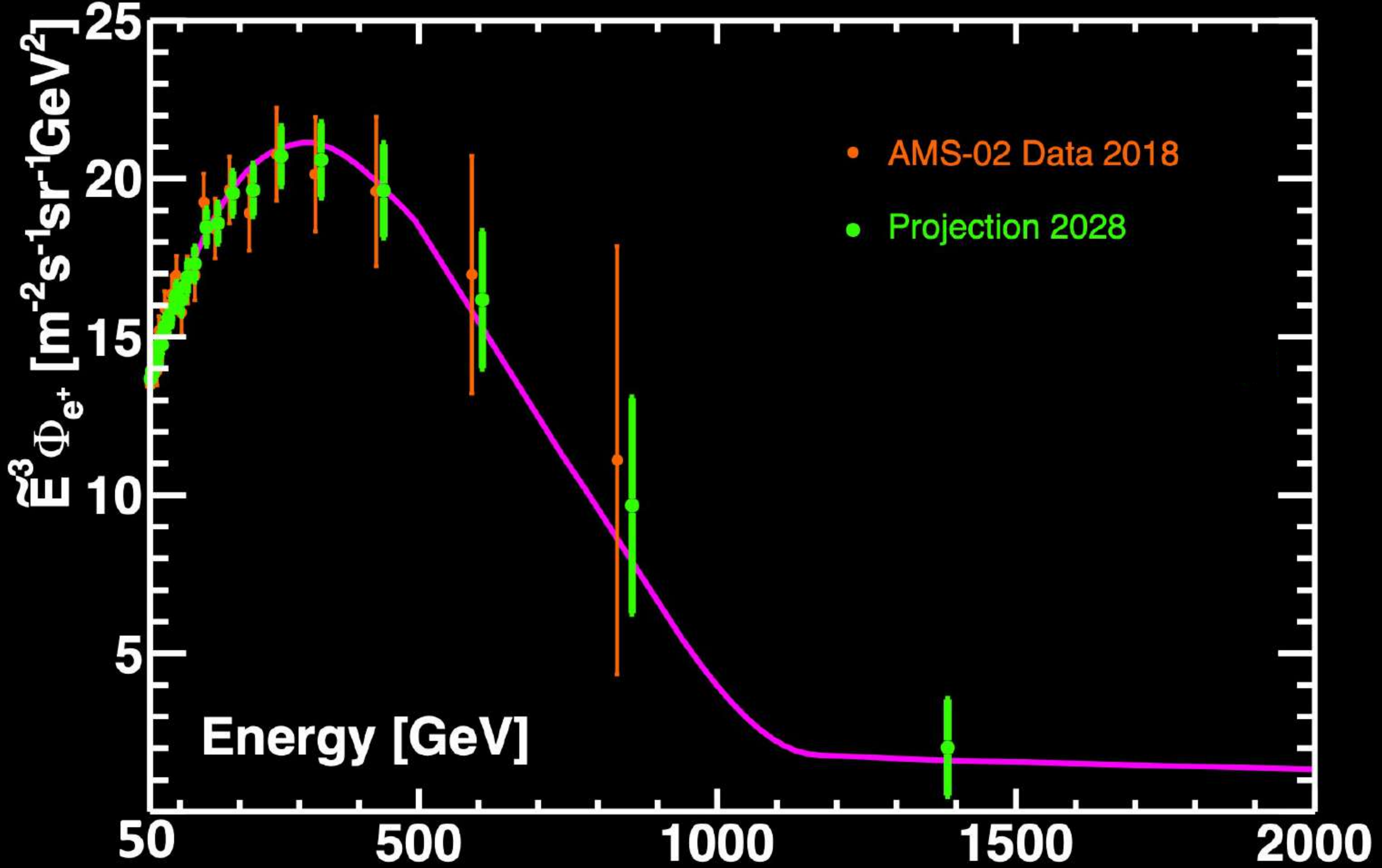
Adapted from Cirelli 2015 ICRC

Comparing bounds

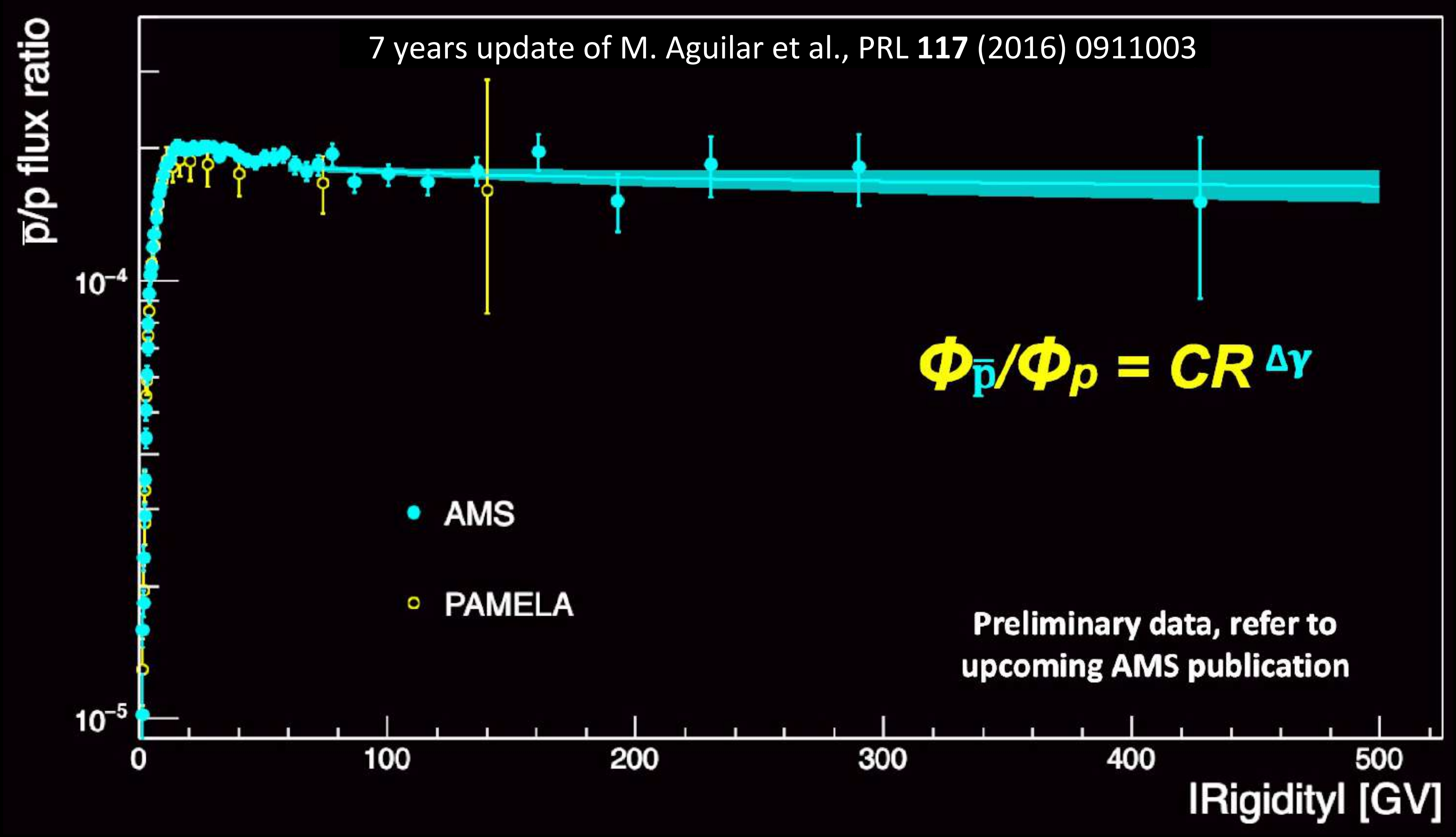


Adapted from Cirelli 2015 ICRC

AMS-02 projection to 2028



AMS-02 antiprotons

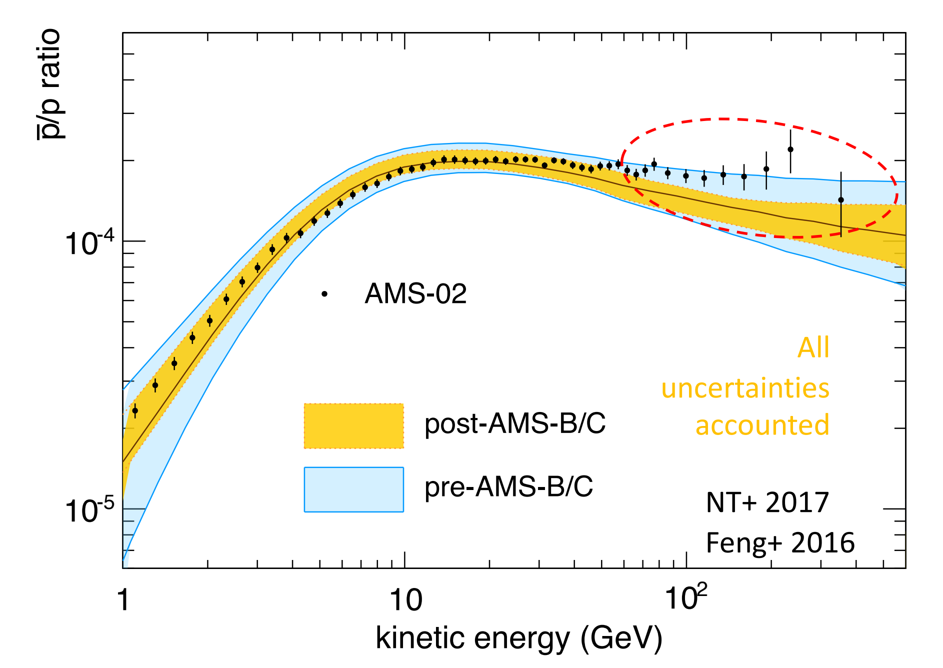


Hard antiproton spectrum, as hard as proton spectrum

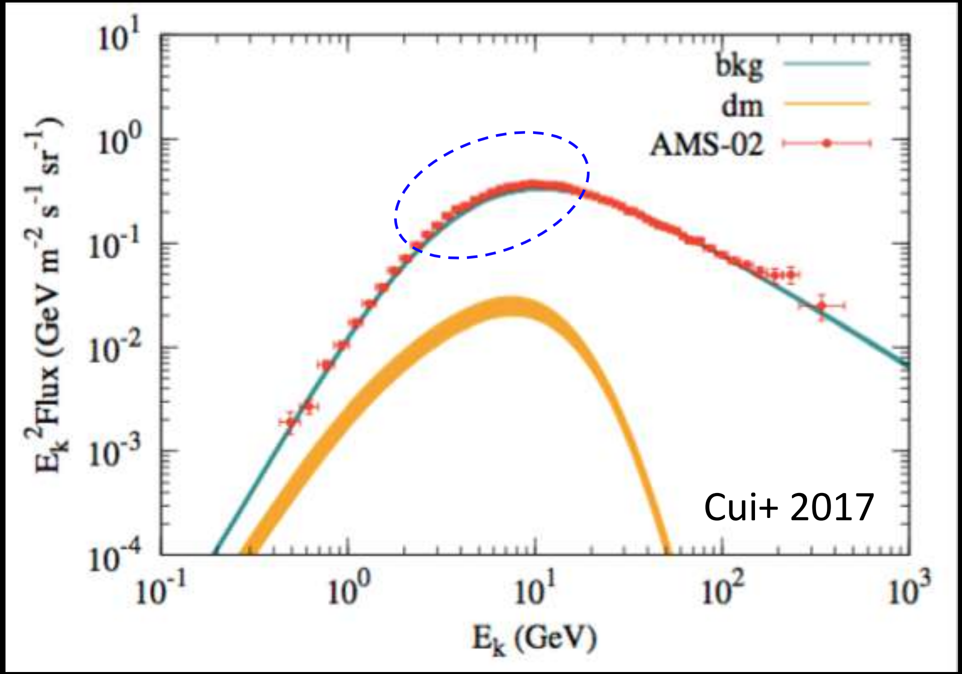
Antiproton anomalies

1) The antiproton specturm is too hard w.r.t. B/C-driven predictions, even in new models that account for the spectral hardening in primary and secondary CR nuclei
2) Standard propagation models underpredict antiprotons at the 10 GeV scale. Evidence for an antiproton excess?

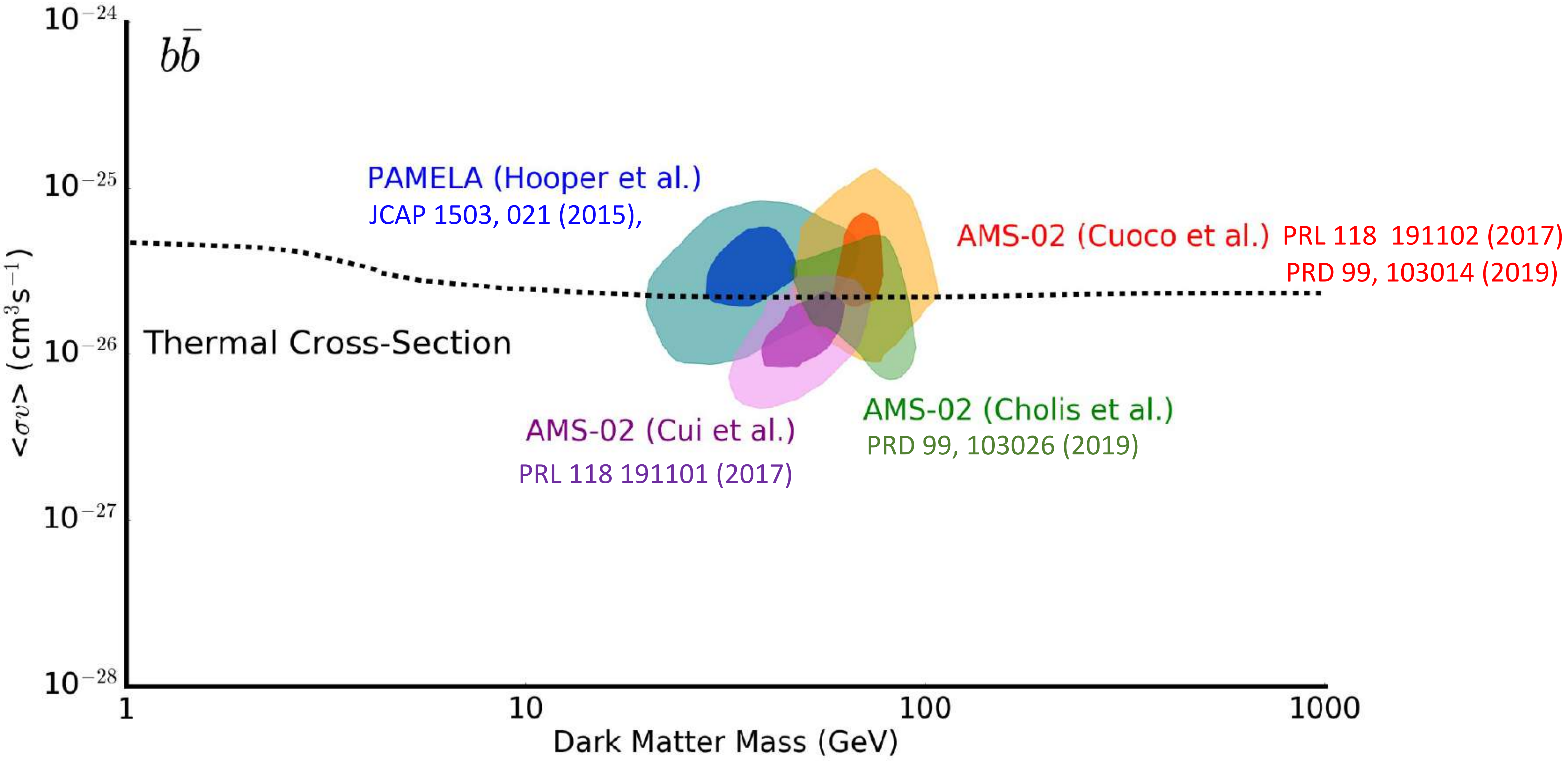
pbar/p prediction [THM+MCMC]



pbar/p prediction [Galprop Std + DM]



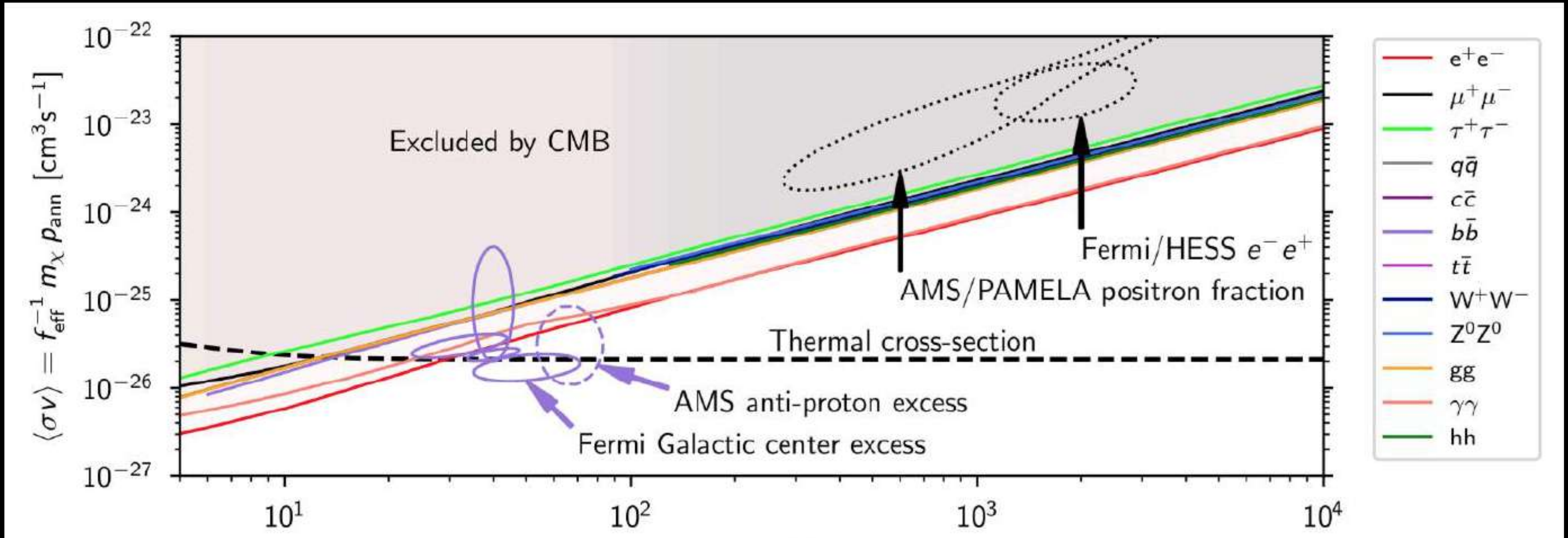
Dark Matter fits



From Tim Linden

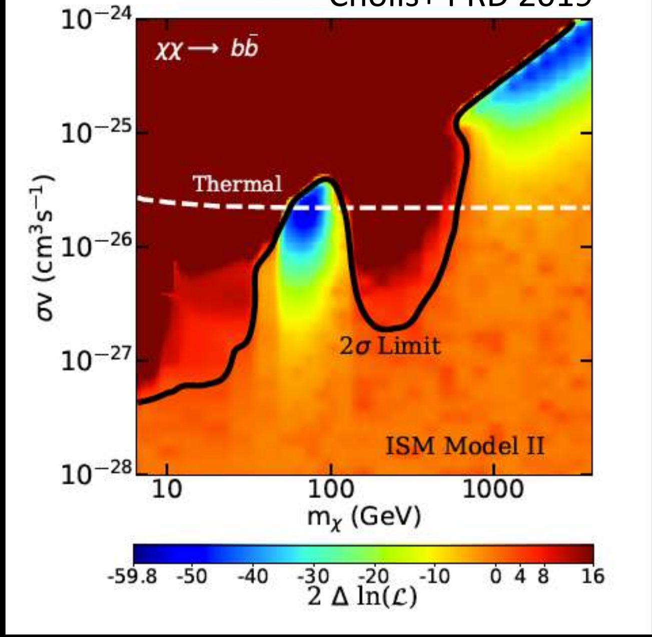
Dark Matter fits

- ✓ WIMP mass at ~50-80 GeV scale mass. Annihilation rate of <σv> ~ $3x10^{26}$ cm^3/s !
- ✓ Compatible with bounds derived from dwarf spheroidal galaxies (Fermi/LAT ApJ 2016)
- ✓ Compatible with PLANCK exclusion limits from observations of the CMB (Planck A&A 641, A6 (2020)
- ✓ In agreement with DM interpretations of the Galactic center gamma-ray excess (Calore+ PRD 2015)



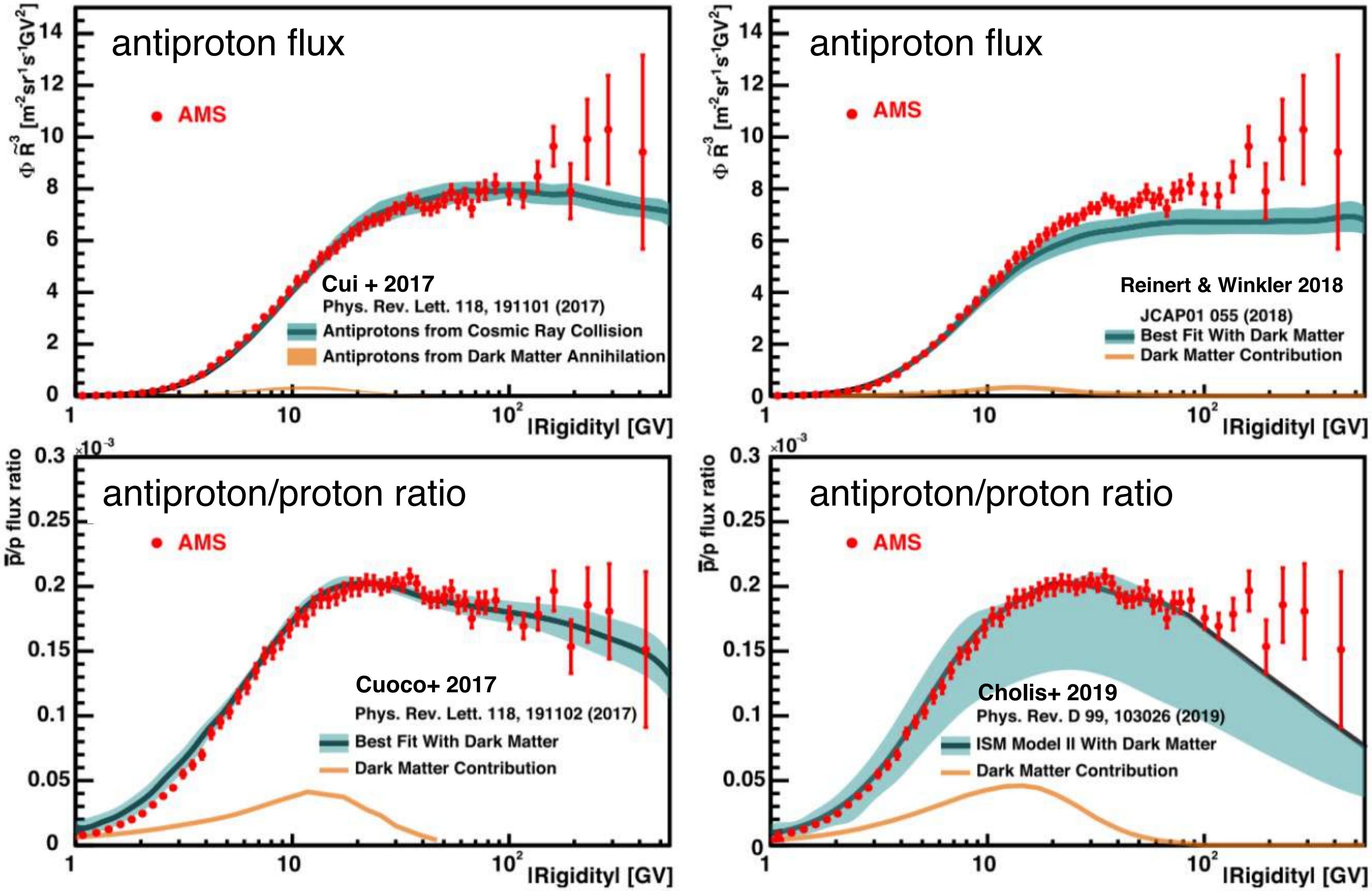
PLANCK A&A 641, A6 (2020)

Cholis+ PRD 2019



AMS-02 antiprotons

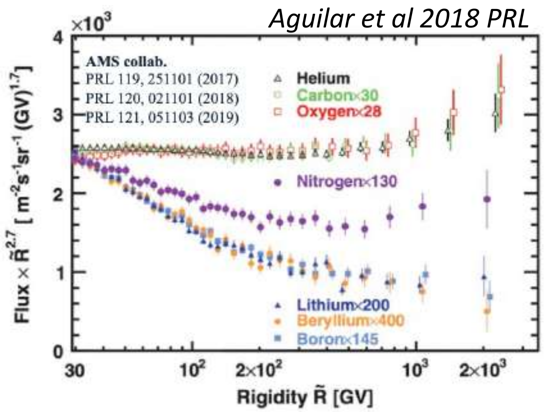
Aguilar et al. Phys. Rept. 894 (2021)

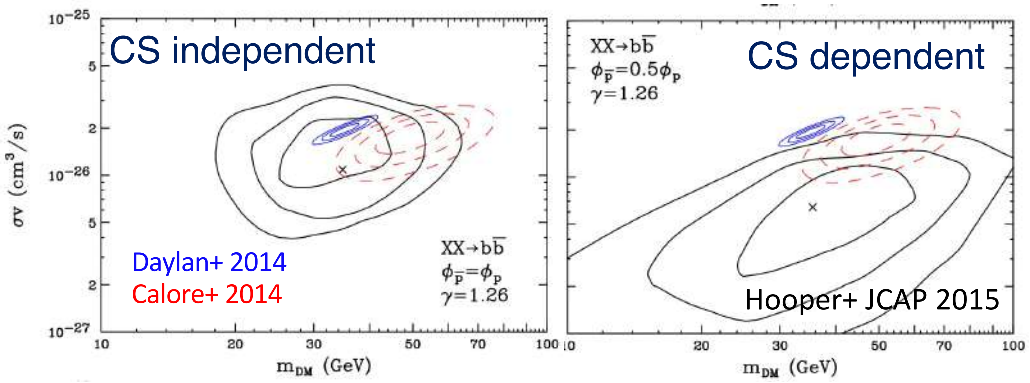


Interstellar propagation

CR propagation models rely on several (questioning) simplifying assumptions.
Unclear role of astrophysical processes e.g. reacceleration & convection
Spectral anomalies in CR nuclei fluxes to be properly accounted

Aguilar et al 2018 PRL



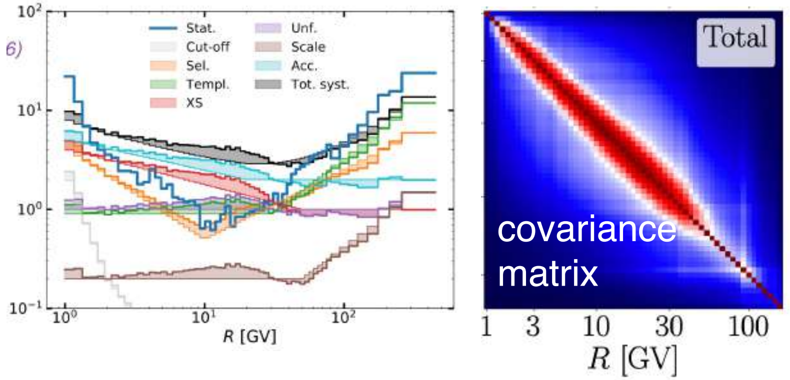


Charge-sign dependent CR modulation

Force-field model is inadequate for precise data at GeV
Charge-sign dependence and B-polarity should be accounted

Hooper+ JCAP 2015, Cholis+ PRD 99, 103026 (2019)

Uncertainties in experimental CR data



Boudaud et al. PRR 2, 023022 (2020)
Cuoco et al PRD 99, 103014 *(2019)*

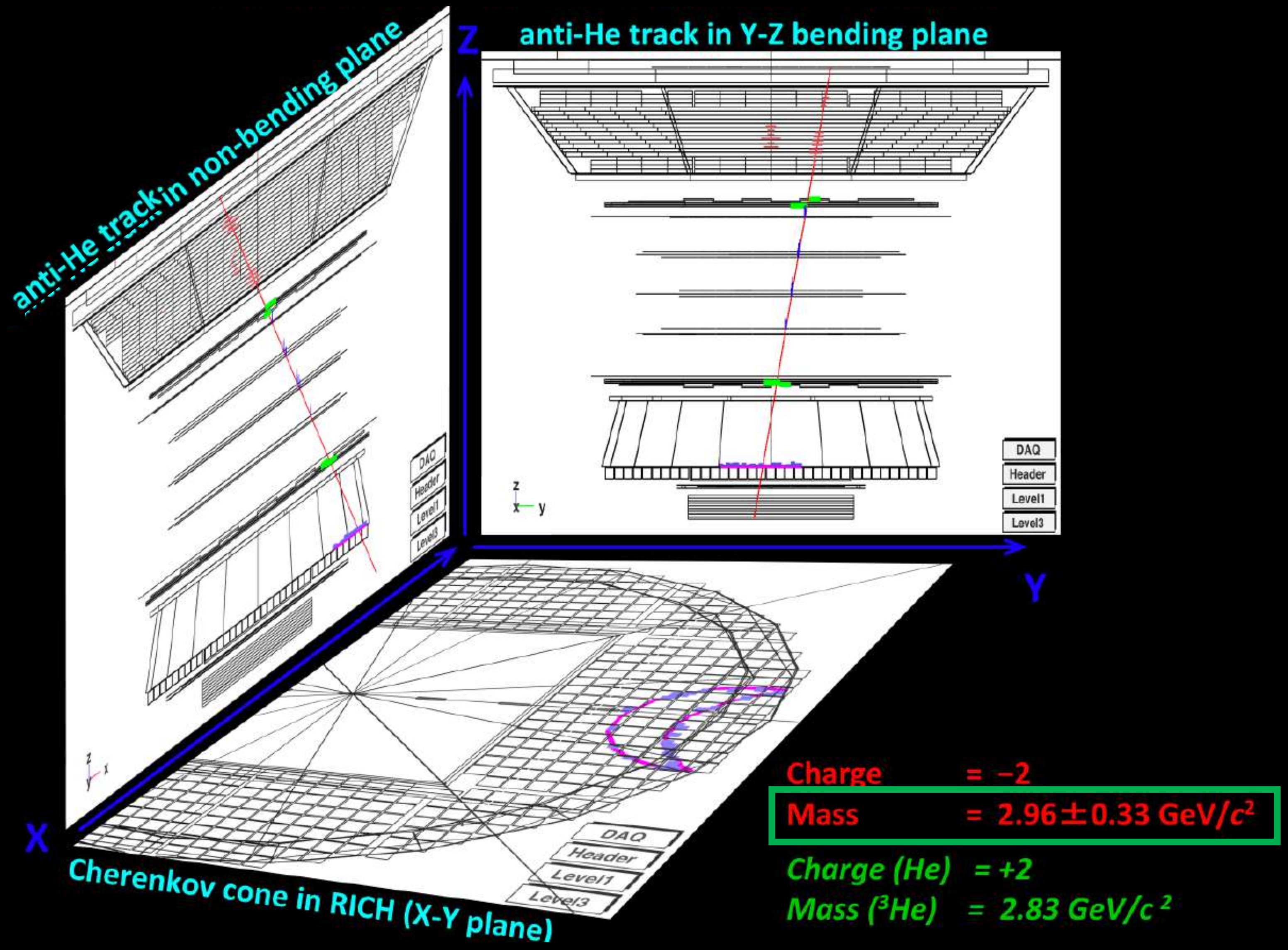
Error bars include many sources of uncertainties of different nature.
AMS data are dominated by systematic errors w/ high R-correlations.

Examination of error breakdown may lead to better constraints

Fragmentation cross-sections & uncertainties

Antiproton production/destruction for many CR+ISM combinations.
Exploit recent data from NA49, NA61, BRAHMS, LHCb, ALICE

Antinuclei: search in progress



Future facilities in space

- ALADInO in L2
- AMS-100 in L2
- HERD on the CSS
- PAN in deep space

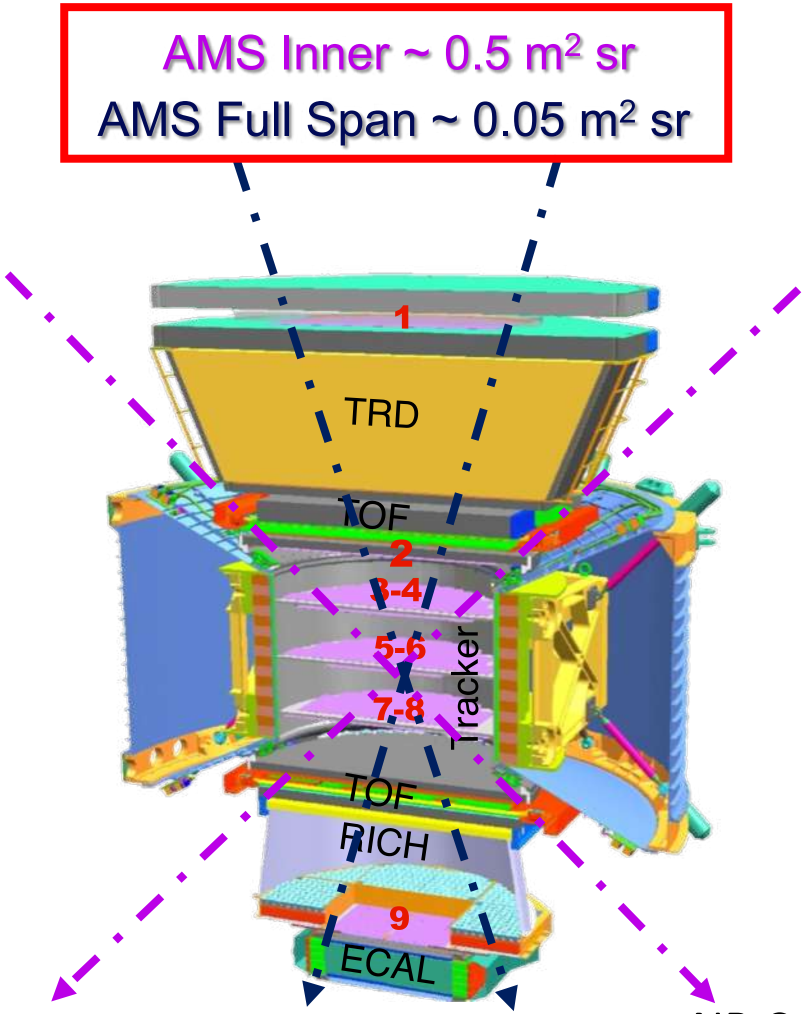
Giant magnetic spectrometers (for multi-TeV antimatter) — ALADInO, AMS-100

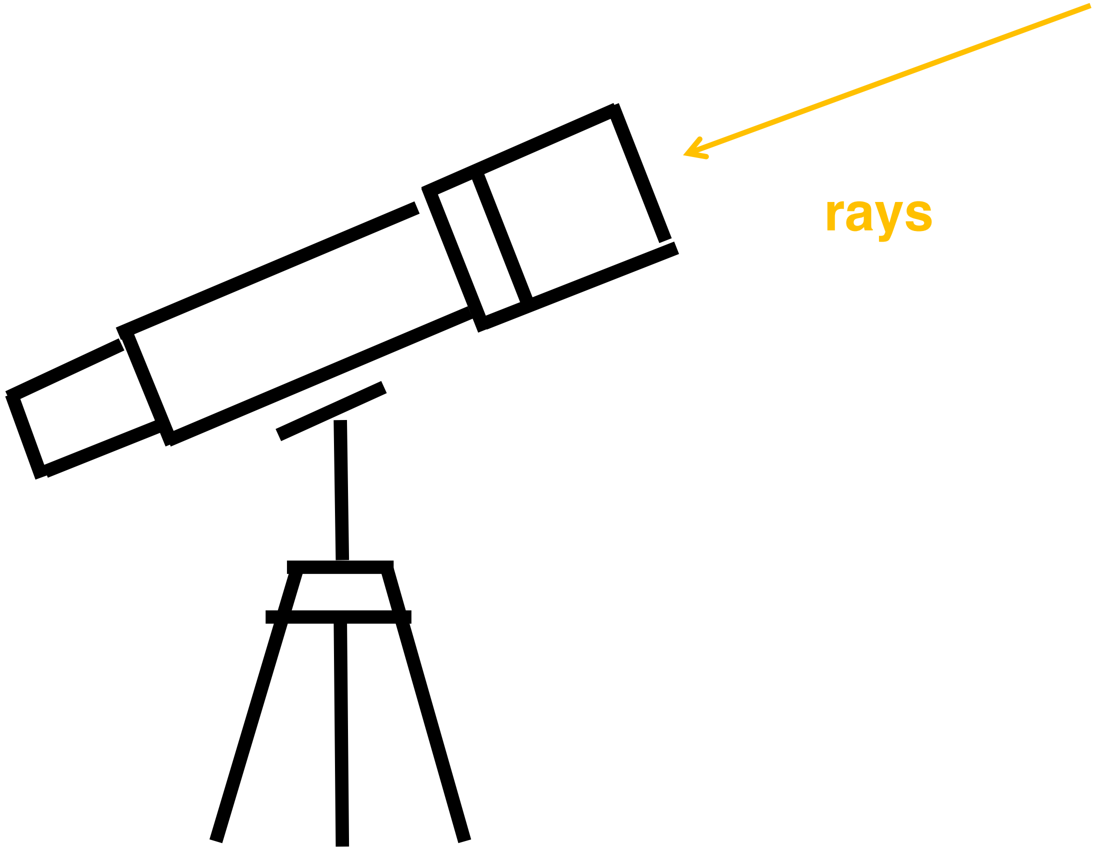
Calorimetric detector — HERD

Mini spectrometer (sub-GeV) — PAN

The 4π paradigm

Current and past detectors are designed as 'telescopes': sensitive only to particles from above.
For ground-based detectors, balloons or low-Earth-orbit space experiments, it's ok!





NB Calorimeters are always at the bottom, i.e. at the end of the particle travel

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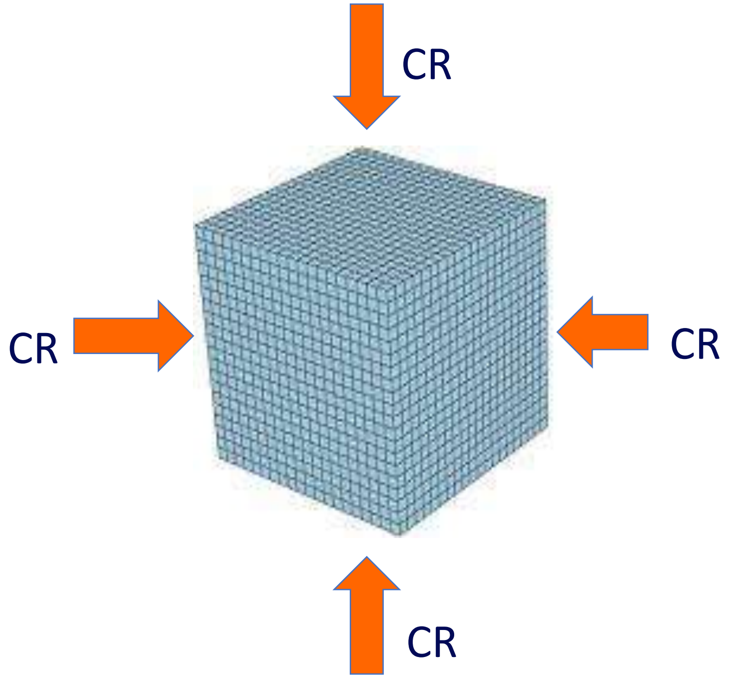


$\Omega = 4\pi$ is the target FoV of future projects.
To exploit the CR "isotropy» and maximize the geometrical factor by using all the detector surface

How a 4π calorimeter should be

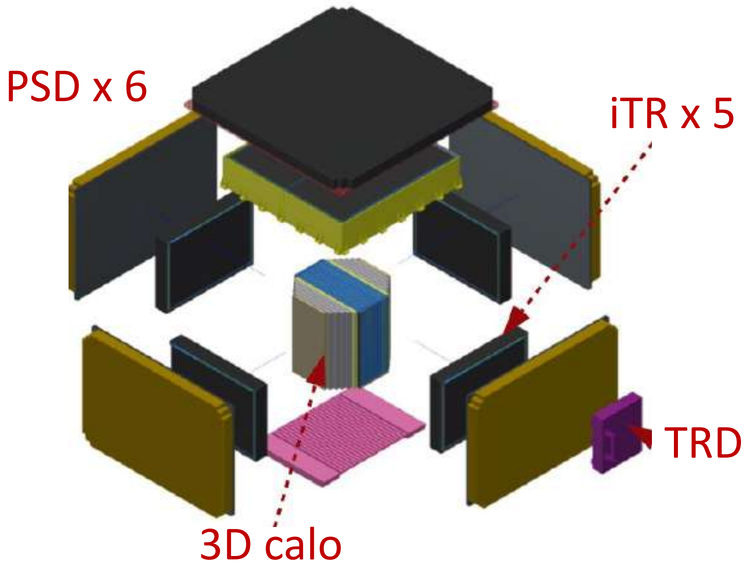
- **Highly isotropic and homogeneous**
- **3D Segmented along x, y, z**
- **Same depth in all sides (sphere, cube…)**
- **Special care to readout electronics**
- **Placed in the center of the detector, not at the bottom.**

E.g. **CaloCube: a novel calorimeter for high-energy CRs in space** [Cattaneo et al. JINST 12 C060004 (2017)]
CaloCube is a INFN R&D project inspiring the next generation of large cosmic rays detectors in space

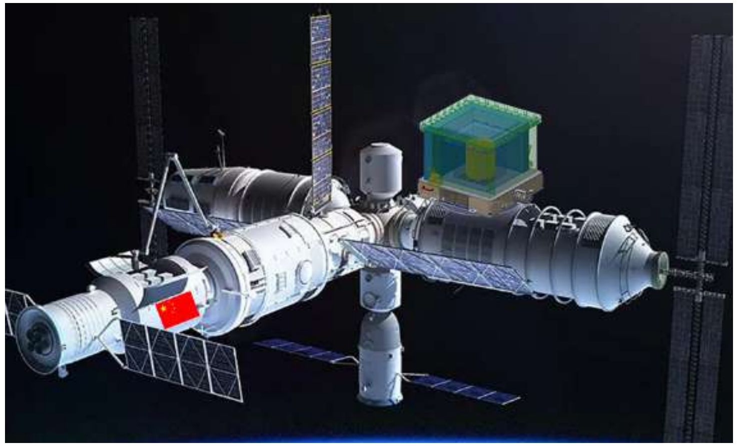
The HERD experiment in the Chinese Space Station

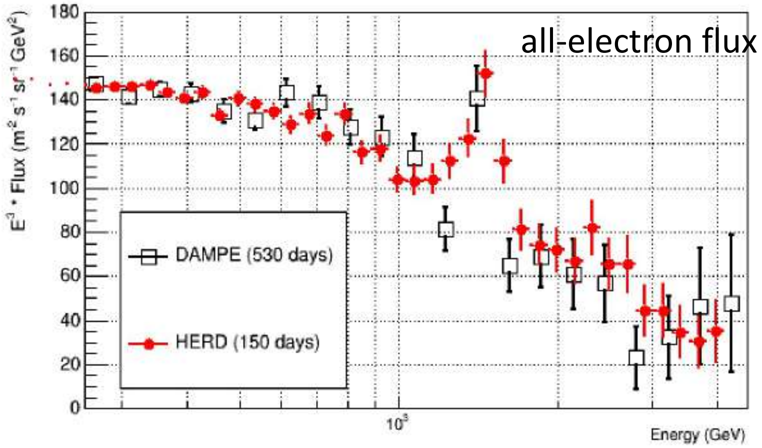
The HERD consortium: 130+ scientists from China + Italy, Switzerland, Spain:

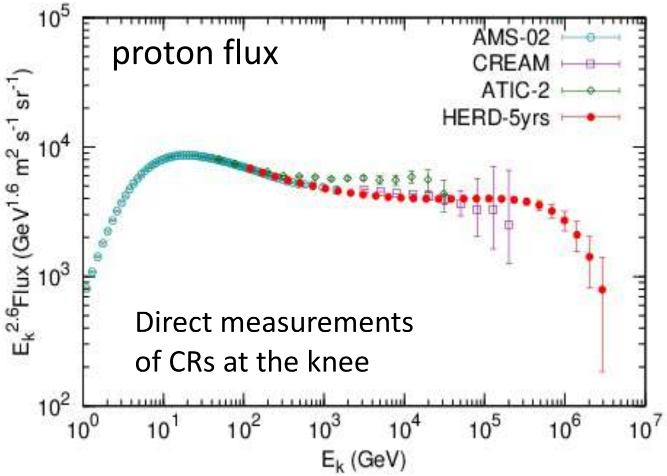
Operation planned around 2025 with ~10 yrs lifetime (Exp ~ 20 m^2 sr yrs)



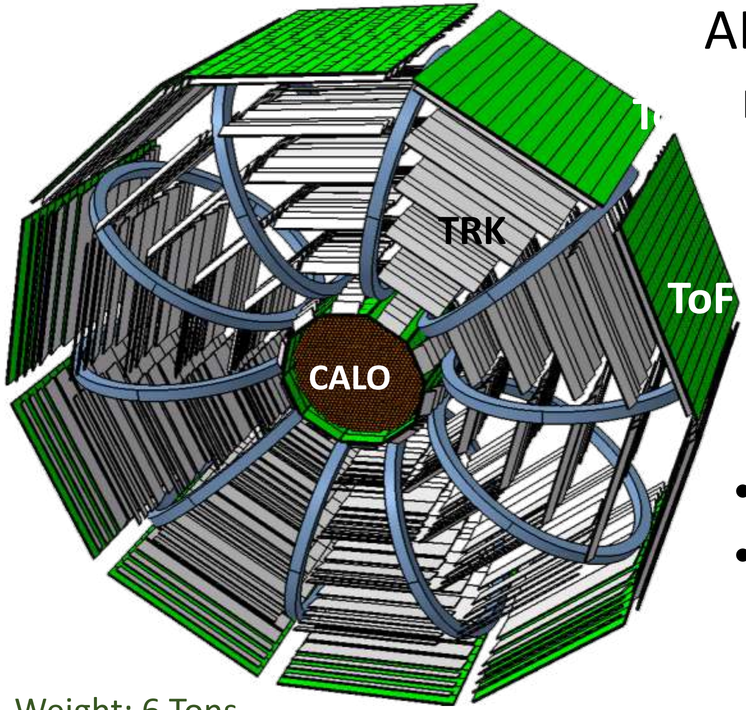
Energy range (e/γ)	10 GeV-100 TeV(e); 0.5 GeV-100 TeV (γ)
Energy range (CR)	30 GeV – 3 PeV
Angular resolution	0.1 deg. @ 10 GeV
Charge measurement resolution	0.15 – 0.2 c.u
Energy resolution (e)	1-2% @ 200 GeV
Energy resolution (p)	20-30% @100 GeV – PeV
e/p separation	~10^{-6}
G.F. (e)	>3 m^2sr @ 200 GeV







ALADInO: A Large Antimatter Detector In space



ALADINO is a concept for a spectrometer to operate in L2 for measurement to extend the legacy of PAMELA and AMS-02

Presented at ESA call VOYAGE 2050

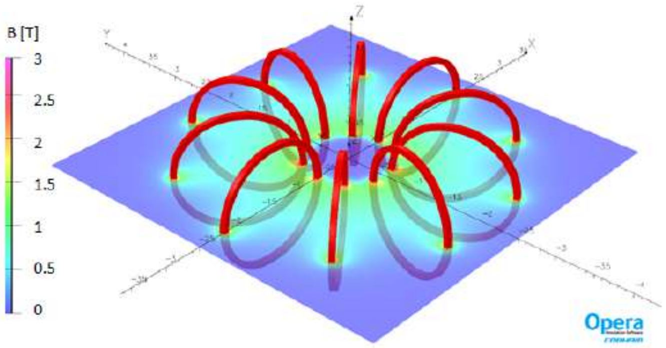
High Precision Particle Astrophysics as a New Window on the Universe ***with an Antimatter Large Acceptance Detector In Orbit (ALADInO)***

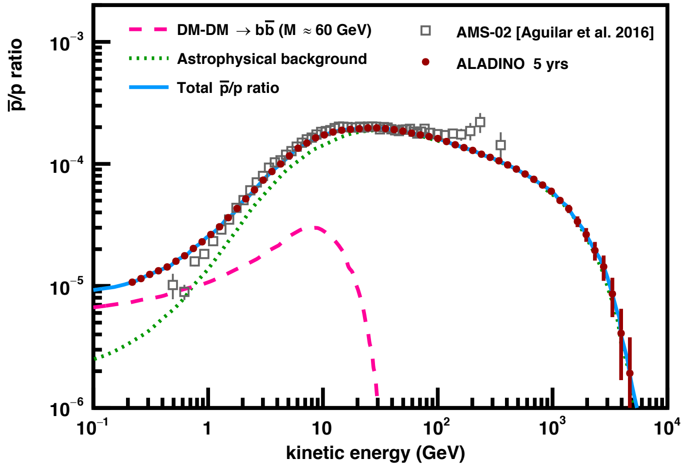
Core team members from IT, FR, DE, SE, CZ, CH

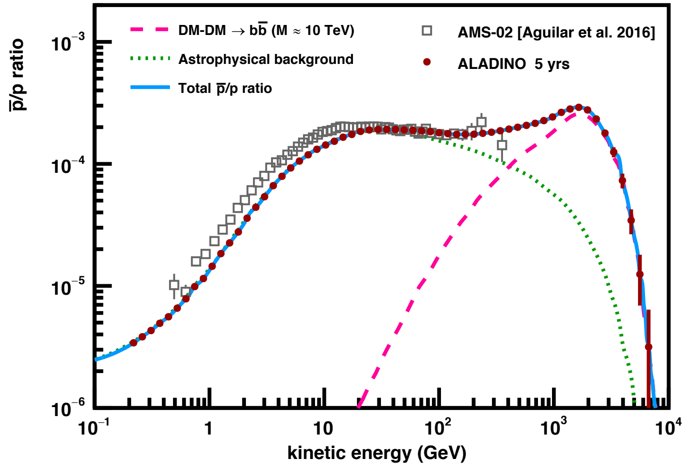
- Isotropic 3D calorimeter à la HERD surrounded by a toroidal tracker
- Tracking system placed within high-T superconducting coils (B= 0.8 T)

Total acceptance	10 m^2sr	Calo resolution	2% (e) – 30% (N)
MDR	20 TV	TOF resolution	100 ps

Weight: 6 Tons
Power: 4 kW
channels: 2.5 M





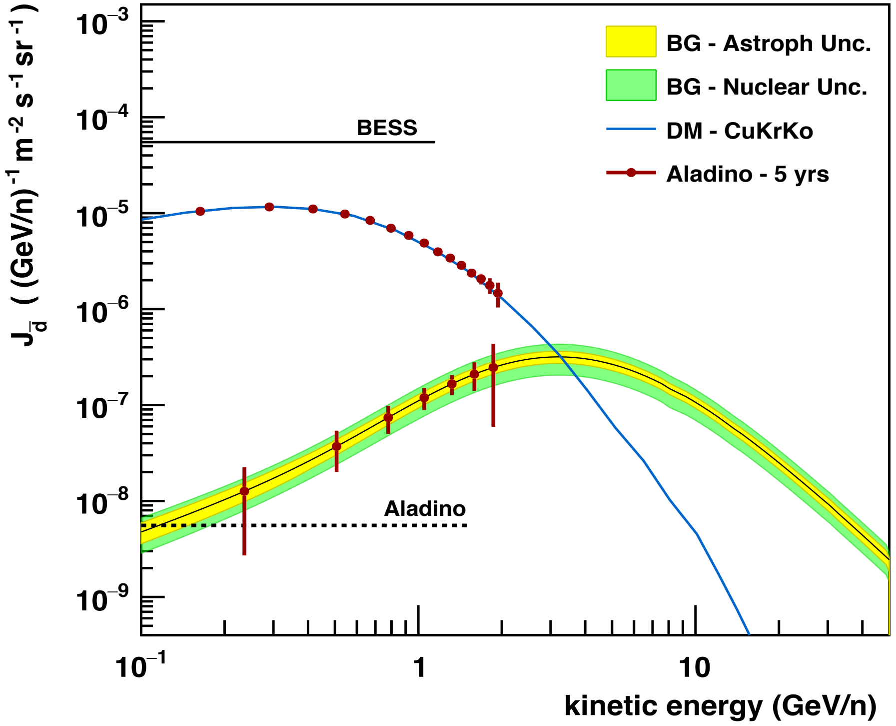


DM model from H. Jin et al., 2015, Phys. Rev. D 92, no. 5, 055027

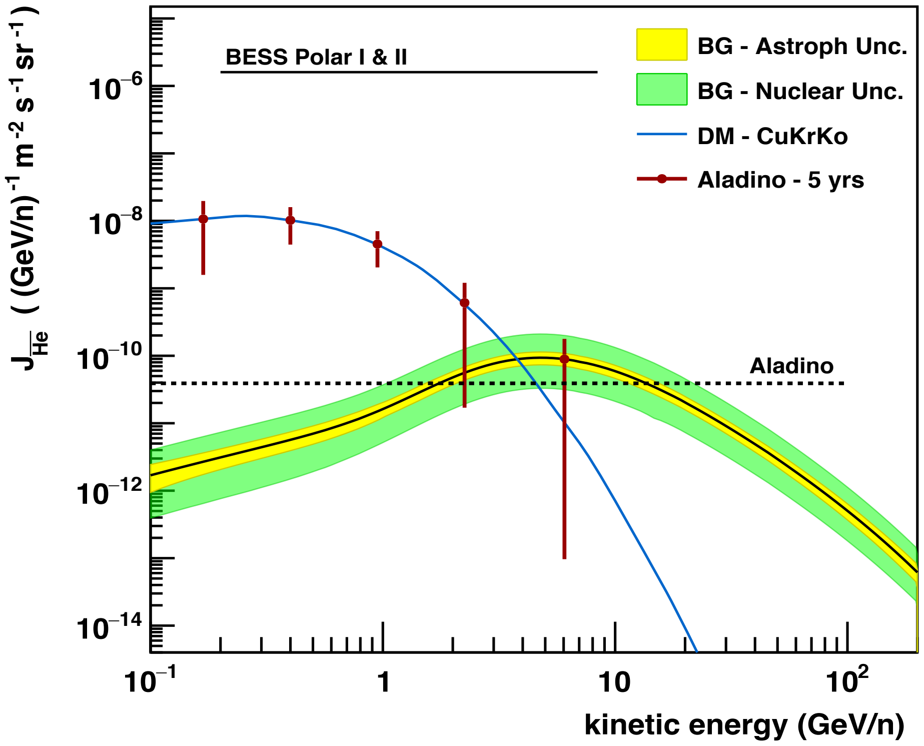
ALADInO: A Large Antimatter Detector In space

Pontential for antinuclei detection

antideuteron flux

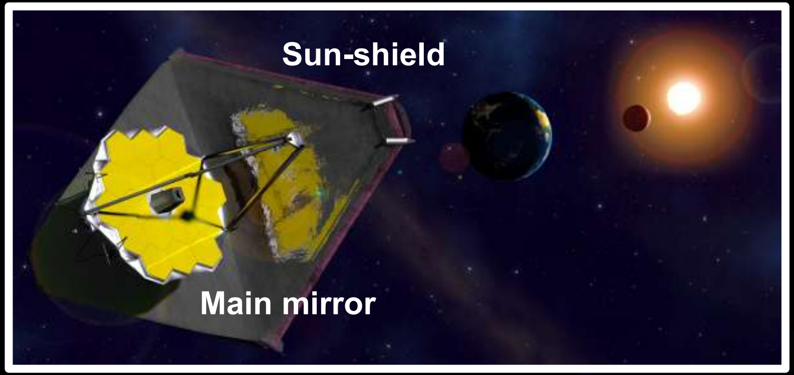


antihelium flux

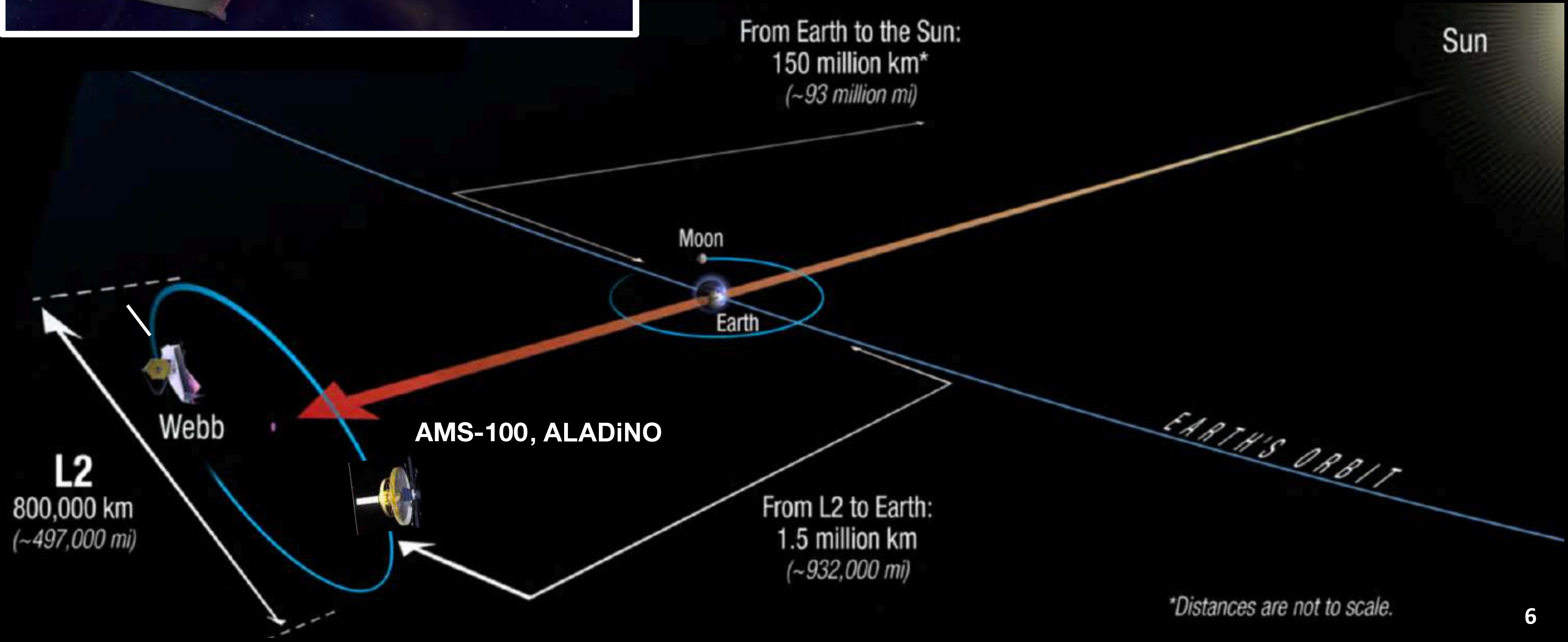


DM model from A. Cuoco et al. 2017, Phys. Rev. Lett. 118, 191102, M. Korsmeier et al., 2018, Phys. Rev. D 97 n.10, 103011
BKG model from N. Tomassetti and A. Oliva, 2017, ApJ Lett. 844

Orbiting @ the second Lagrange point or L2

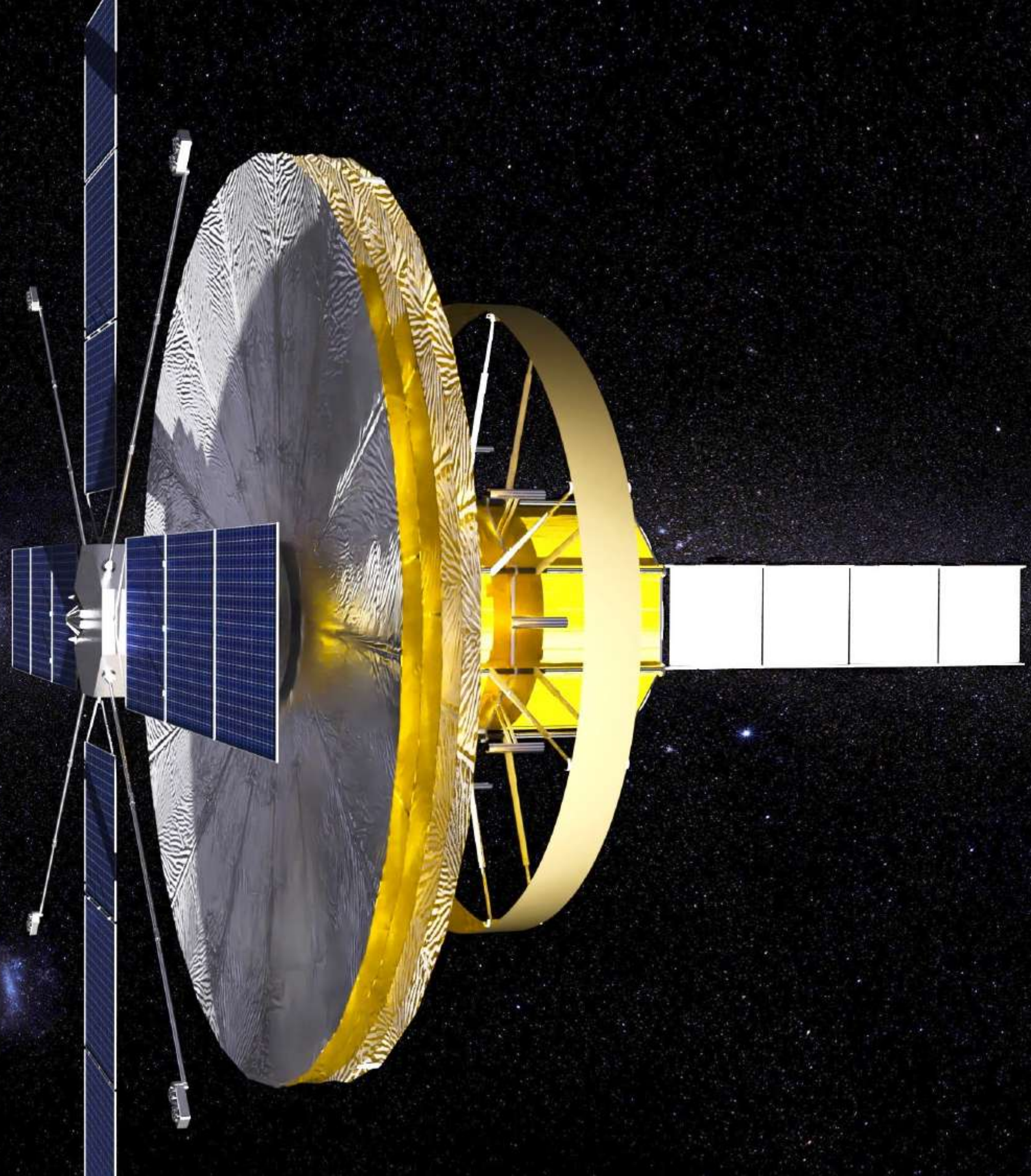


The best place where to operate a cryogenic superconducting magnet is the Lagrange Point 2, like the Webb space telescope



AMS-100

The Next Generation Magnetic Spectrometer



Presented at ESA call VOYAGE 2050

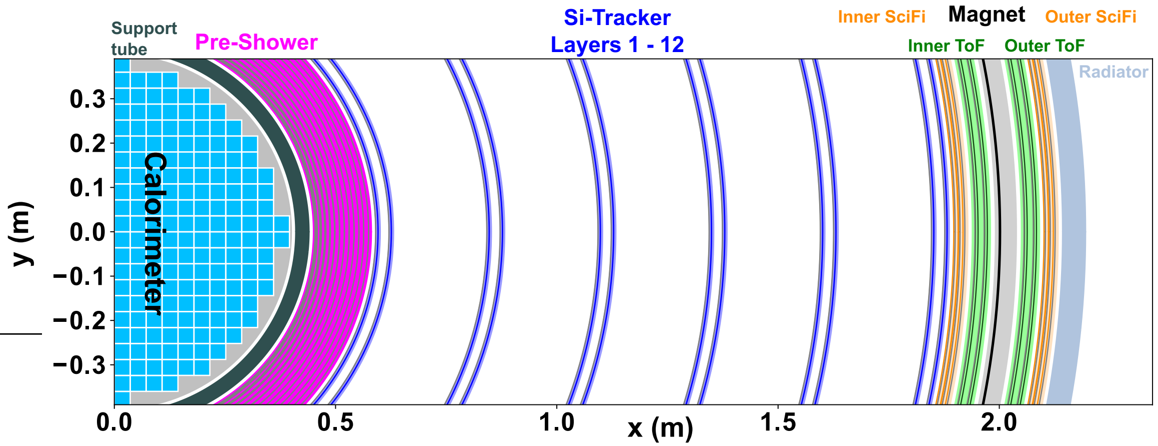
The Next Generation Magnetic Spectrometer in Space – An International Science Platform for Physics and Astrophysics at Lagrange Point 2

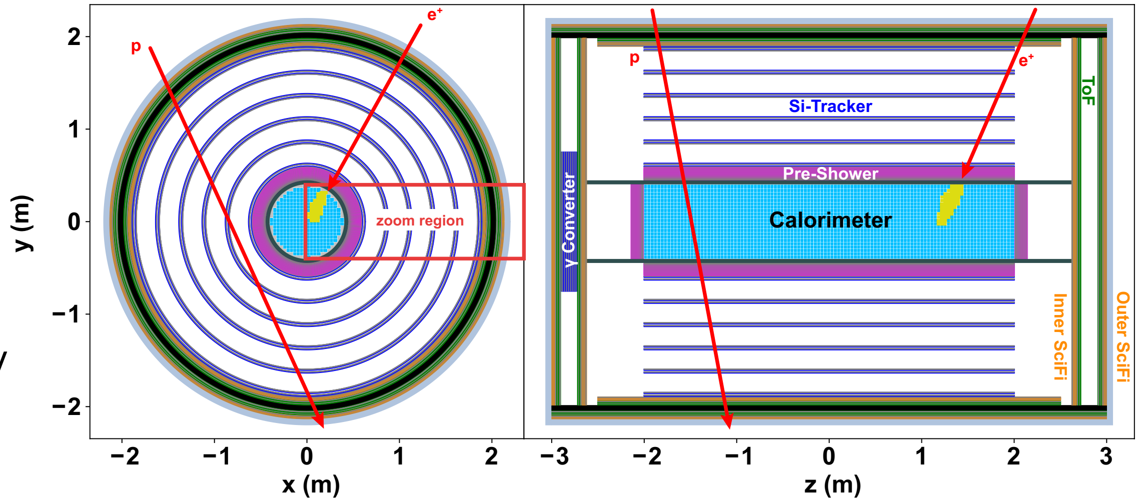
White paper: Shael et al. NIM A 944 162561 (2019)

AMS-100 detector

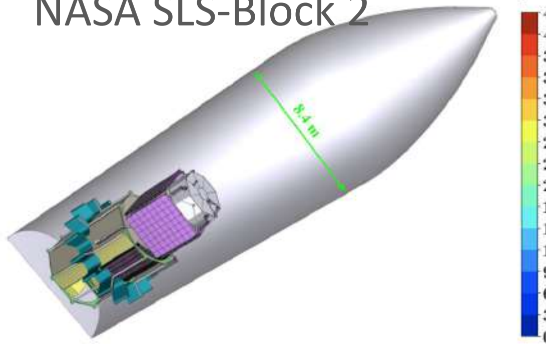
- Cylindrical shape multipurpose HEP detector for γ/CRs
- Physics program from CR/ γ astrophysics to new physics

Acceptance	$100\,\mathrm{m}^2\,\mathrm{sr}$	
MDR	100 TV	for $\lvert Z \rvert = 1$
Material budget	$0.12\,X_0$	
of main solenoid	$0.012\,\lambda_I$	
Calorimeter depth	$70\,X_0,\ 4\,\lambda_I$	
Energy reach	10^{16} eV	for nucleons
	10 TeV	for e^+, $\bar{p}$
	8 GeV/n	for $\bar{D}$
Angular resolution	$4''$	for photons at 1 TeV
	$0''.4$	for photons at 10 TeV
Spatial resolution (SciFi)	40 µm	
Spatial resoultion (Si-Tracker)	5 µm	
Time resolution of single ToF bar	20 ps	
Incoming particle rate	2 MHz	
High-level trigger rate	few kHz	
Downlink data rate	~28 Mbps	
Instrument weight	43 t	
Number of readout channels	8 million	
Power consumption	15 kW	
Mission flight time	10 years	

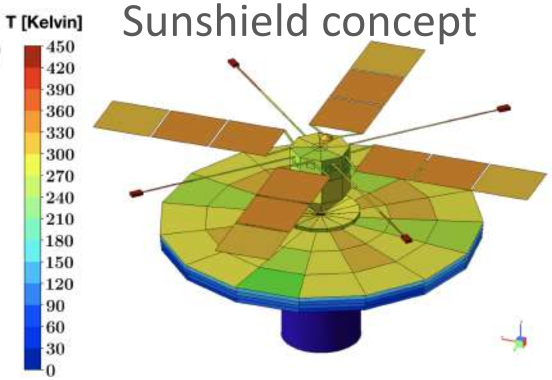




NASA SLS-Block 2



Sunshield concept



Possible launch date NET 2039

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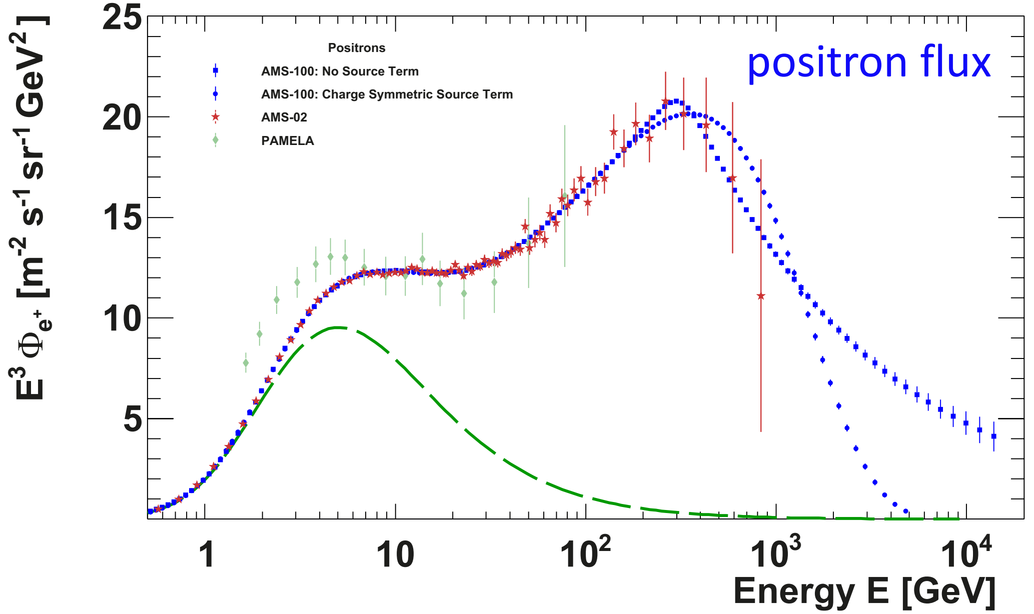
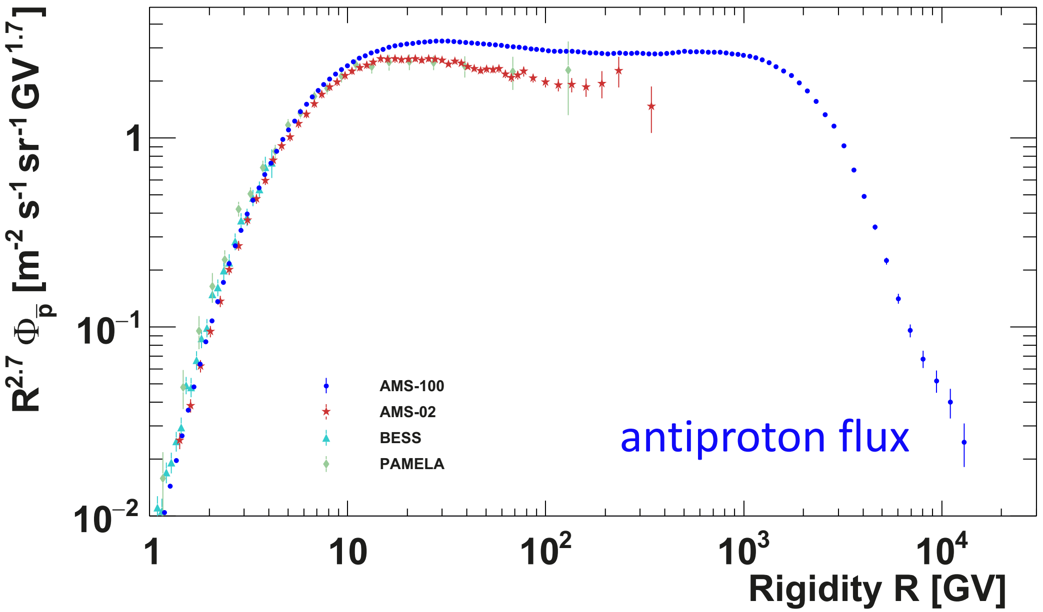
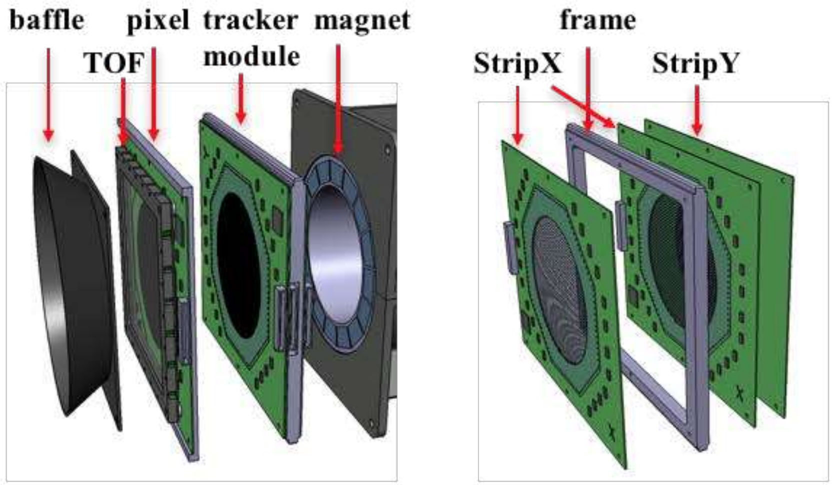
Mission flight time	10 years	





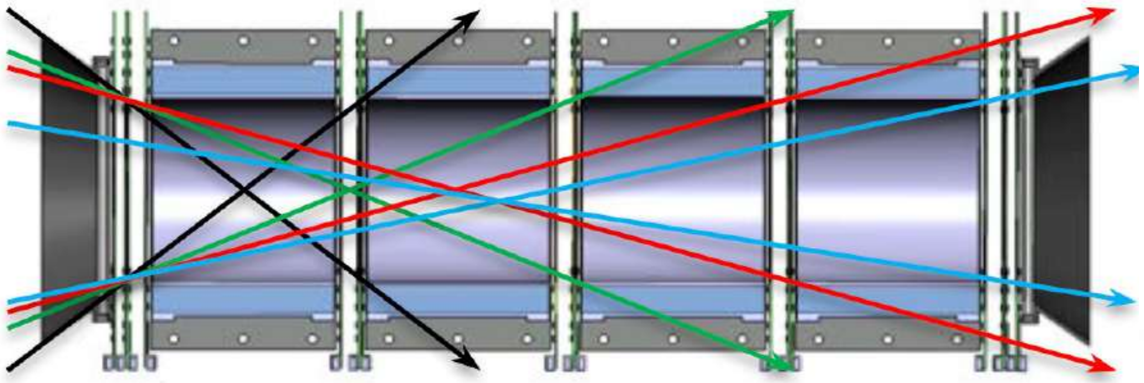
Compact and modular: PAN - Penetrating particle ANalyzer



PAN is a concept for a spectrometer to be operated as ancillary module of exploration missions or detector array in the solar system. As an onboard equipment.

Precise measurement of CR energy, charge, sign of the charge and time dependences in the [50 MeV – 20 GeV] range using a spectrometric approach in **long duration planetary and exploration missions**

"Mini-PAN" demonstrator funded by EU H2020 FET_OPEN

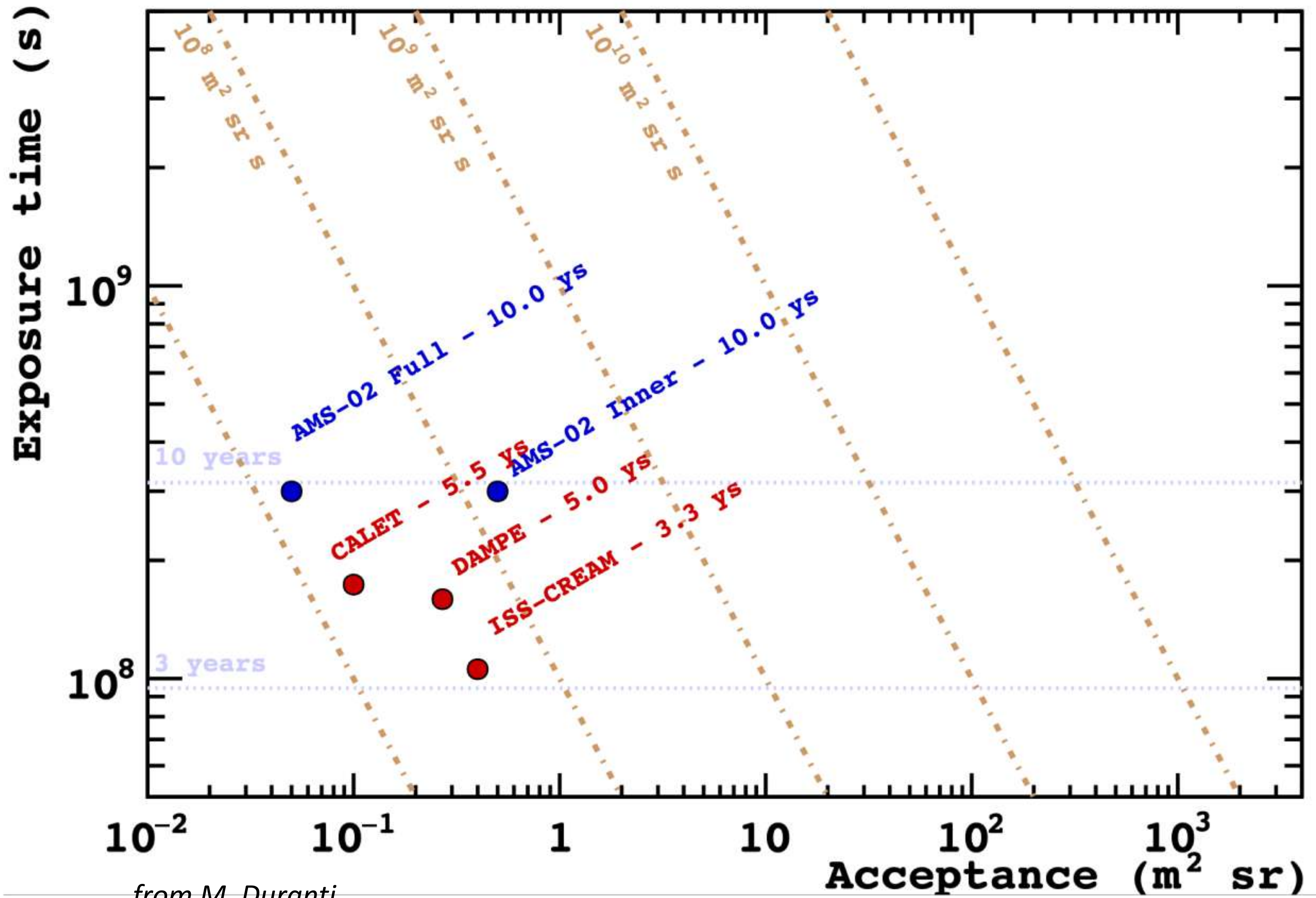


SECTORS	4	3	2	1 (*)
GF (cm^2 sr) 1 side	3	5	10	32
ΔE/E (H, 2 GeV)	5%	6%	8%	20%
Opening angle	25°	33°	47°	80°

(*) Bending angle method

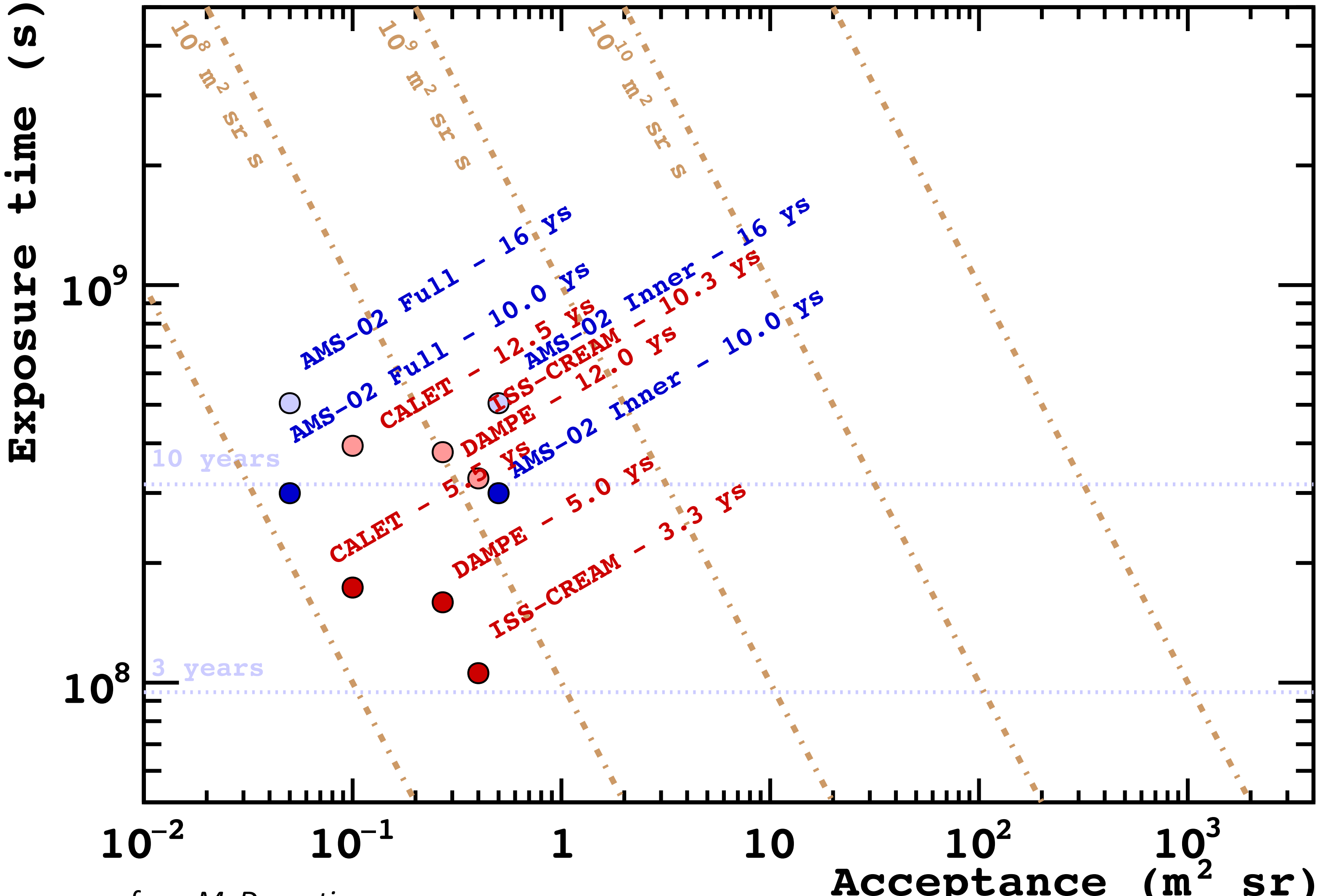
PAN white paper: X. Wu et al. Adv Space Res. 63 (2019)

Current operating experiments



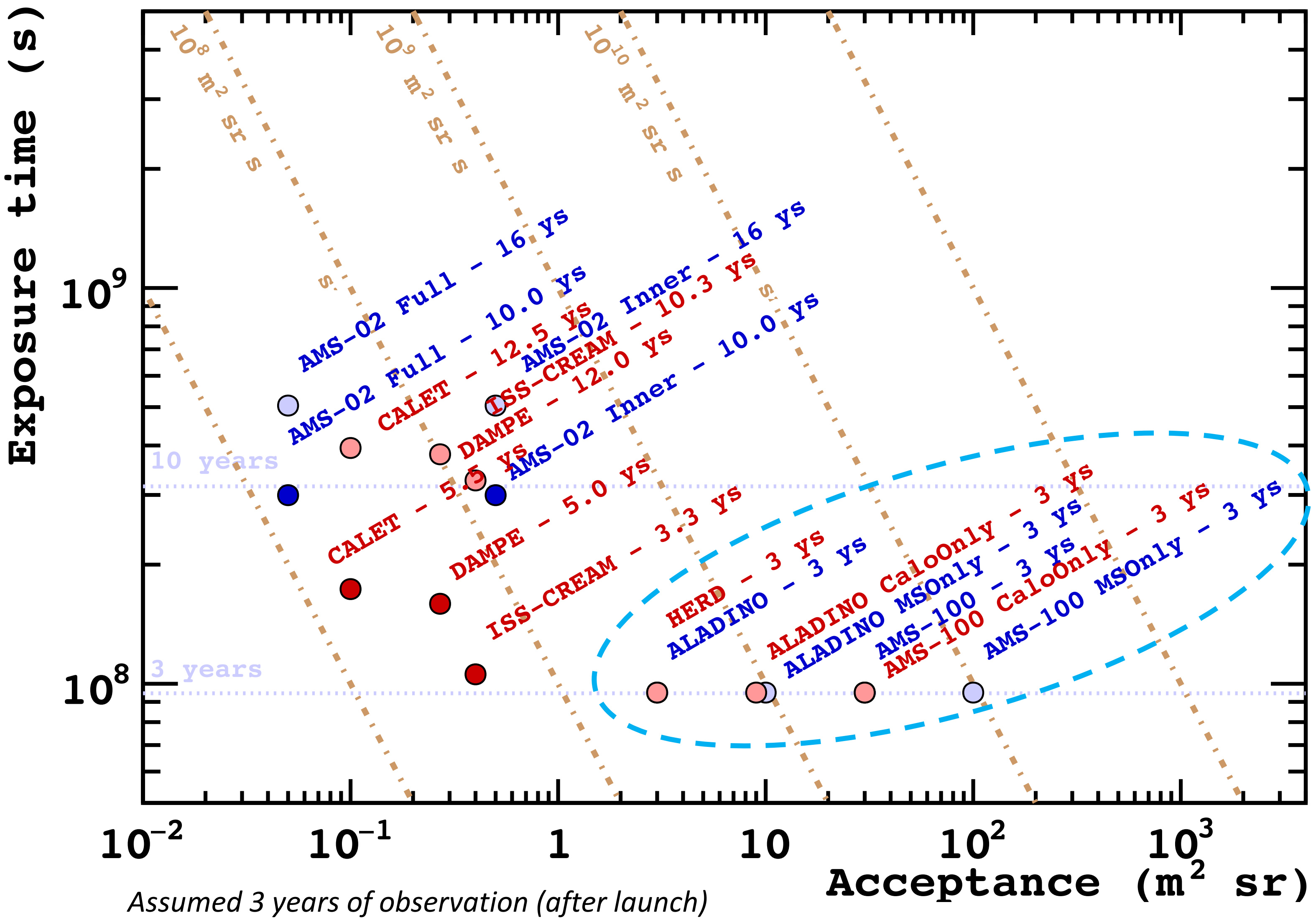
from M. Duranti

Current operating experiments @2028



from M. Duranti

Future facilities w/ 3 yrs data



Assumed 3 years of observation (after launch)