DARK-MATTER
ANTI-MATTER
AMS-02

P.Zuccon
Trento University & TIFPA

Big Questions

What the universe is made of ?

How the Universe change with time ?

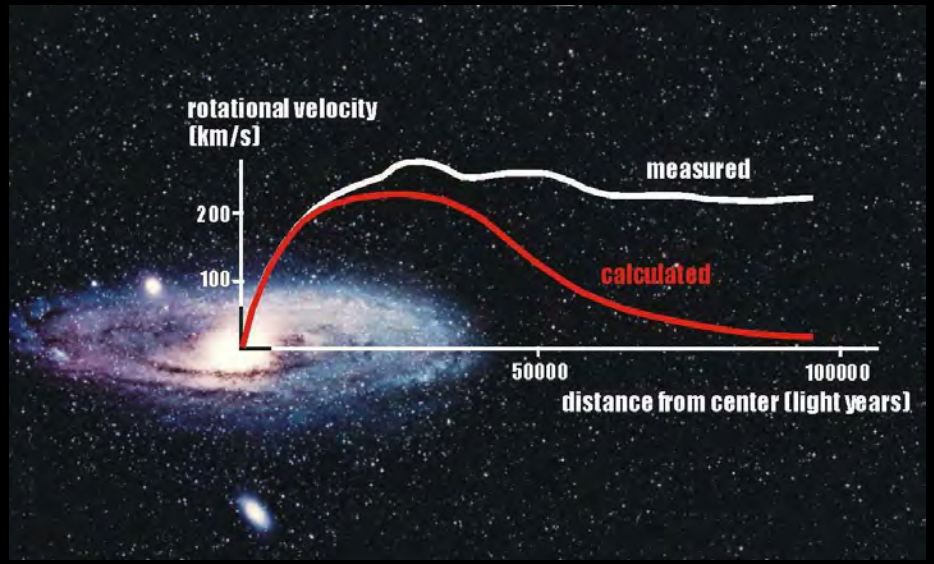
Why matter is organized in stars, galaxies, …?

How fundamental particle physics I related to the large scale?

Dark Matter history

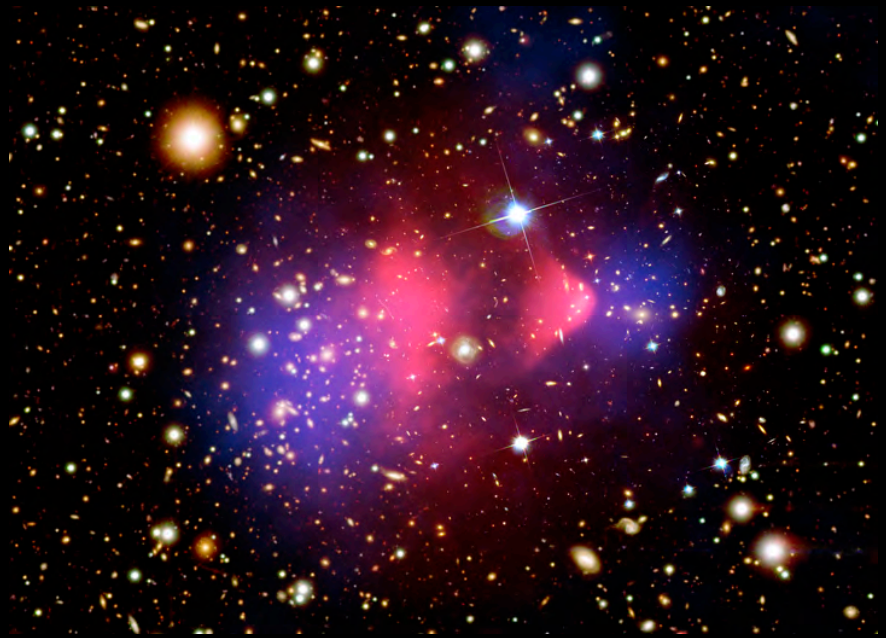
We know about the Dark Matter existence from his gravitational effects

Galaxy rotation curves

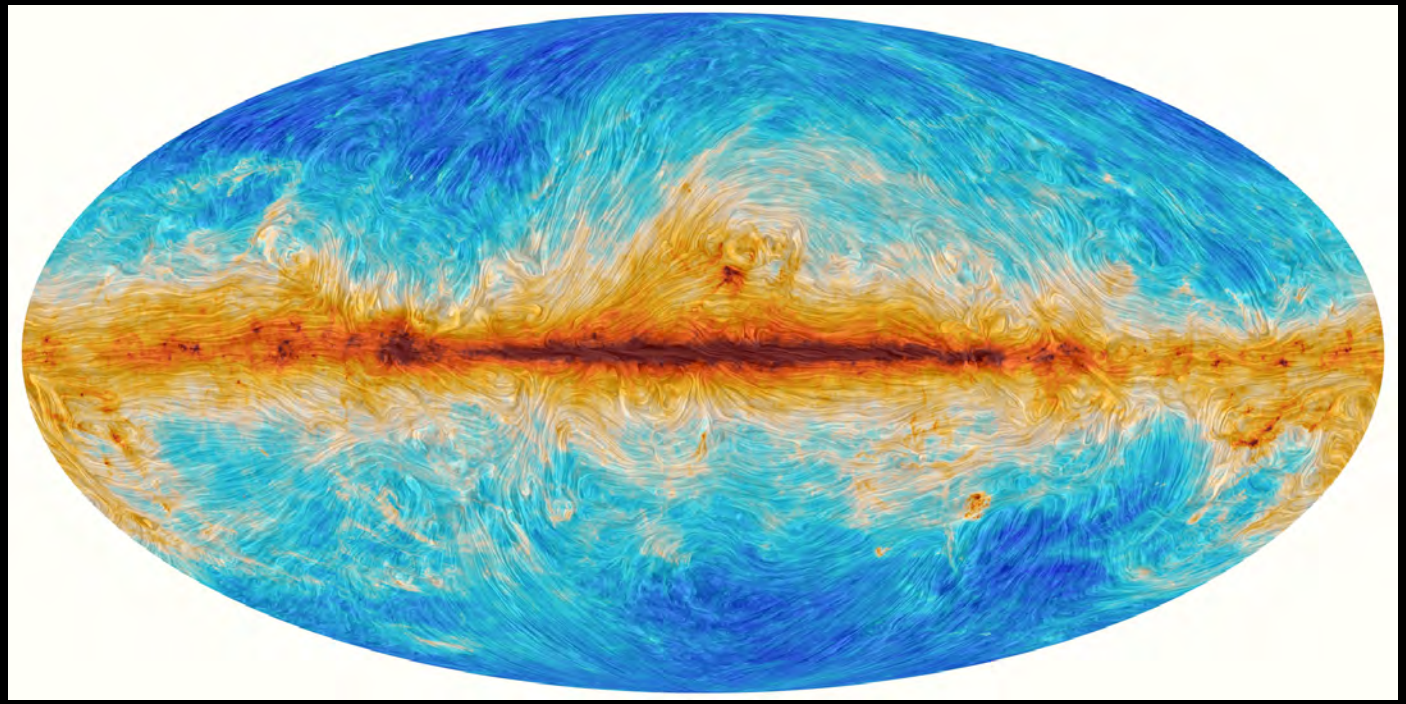


Relative motion of Galaxies

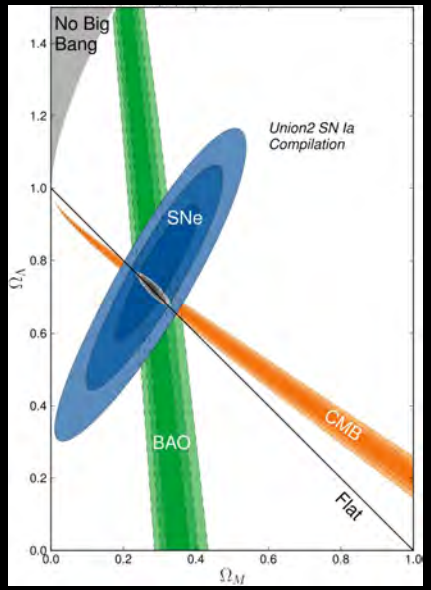
The Bullet cluster

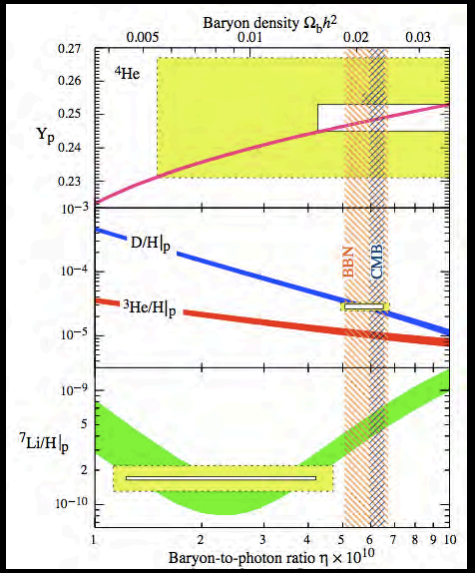


The PLANK CMB sky



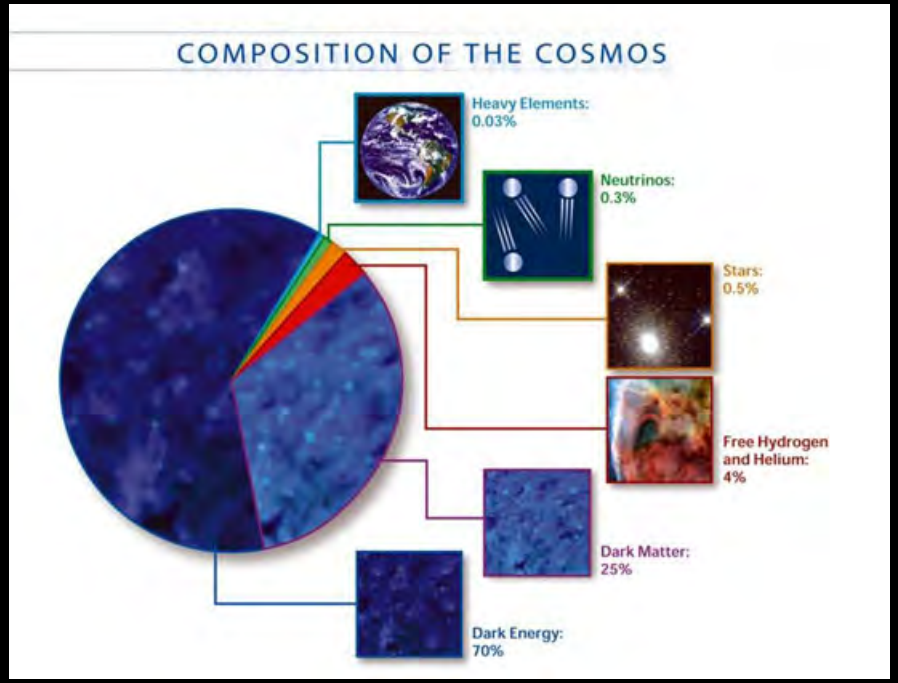
The Cosmic Equation





$$\Omega_T = \Omega_\Lambda + \Omega_{DM} + \Omega_{LM}$$

$$\Omega_{NB} + \Omega_B$$



What Dark Energy is ?

What Dark Matter is made of ?

Is Anti-Matter really gone ?

the Cosmic Rays

A flux of charged particle from the galaxy that constantly irradiate the Earth

Their abundance versus the energy follows a power law : $F = E^{-k}$

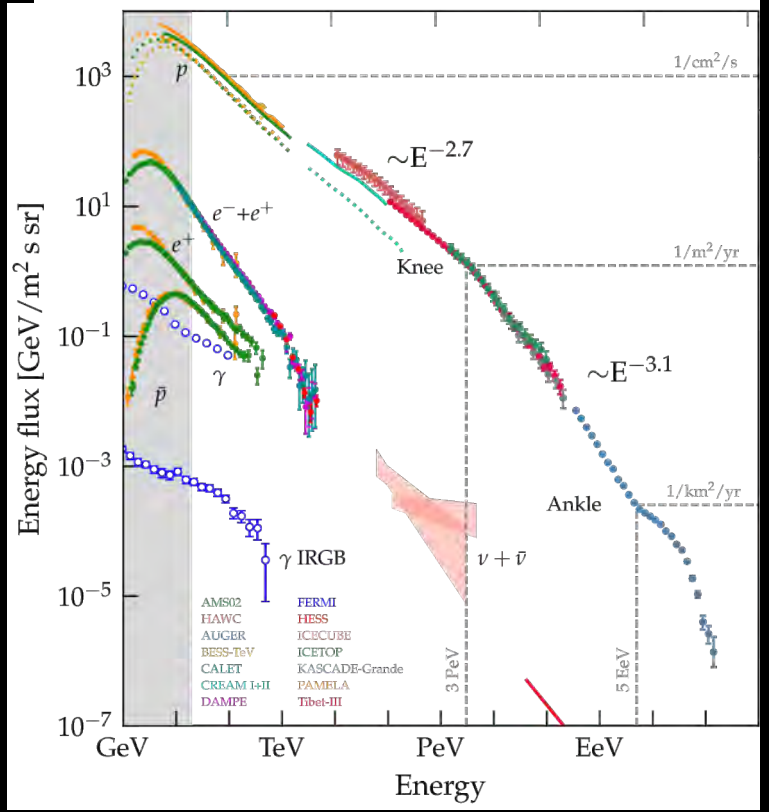
$\log F = -k \log E$

The energy spectrum cover 12 orders of magnitude for an intensity that spans over ~30 orders of magnitude

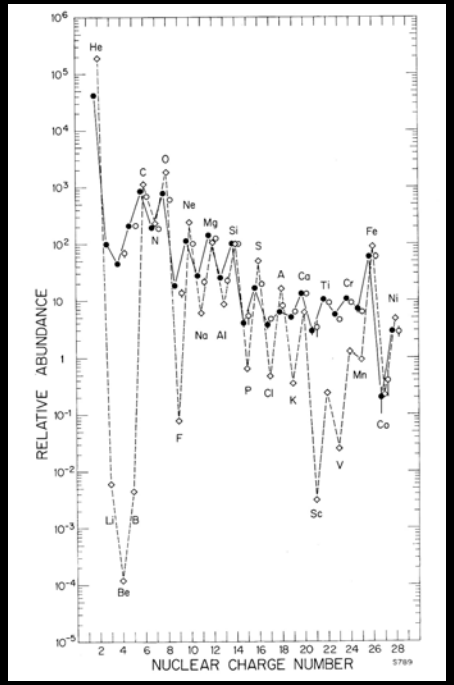
Composition:

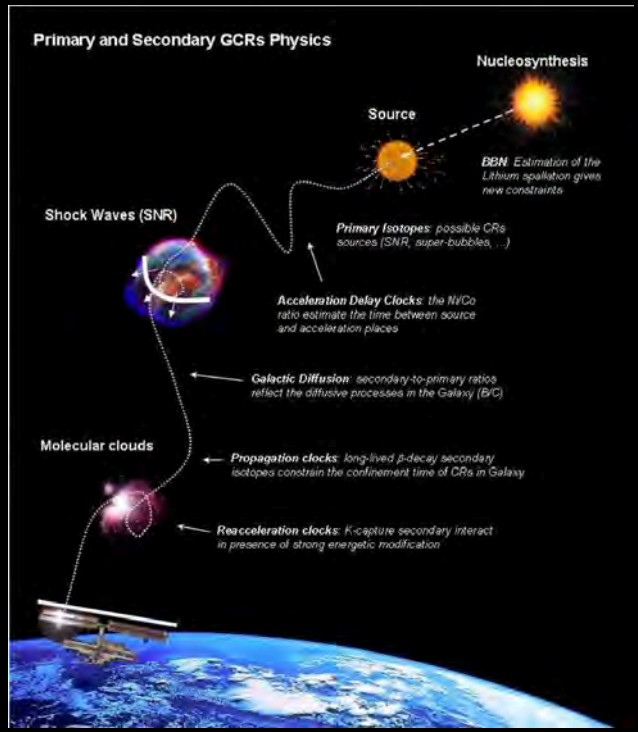
- 89% protons
- 9% He nuclei
- ~1% electrons
- ~1% Z>2 Nuclei
- <0.1 % positrons & anti-protons

C. Evoli, http://doi.org/10.5281/zenodo.2360277 (2018)



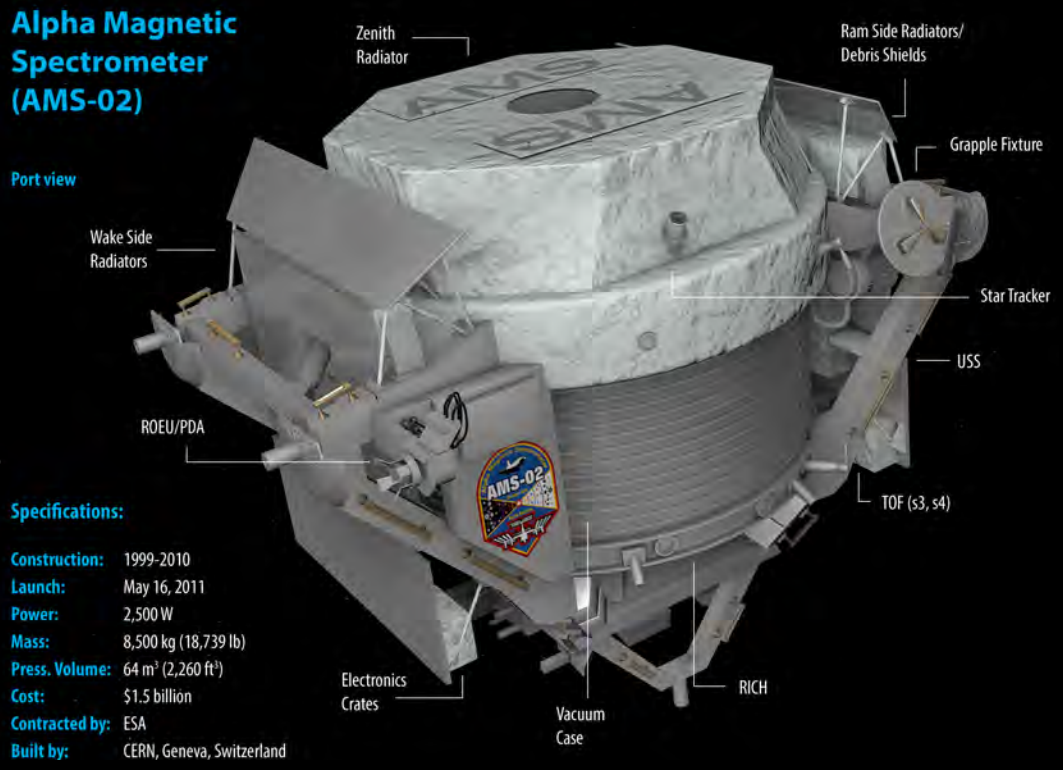
CR carry information about our galaxy





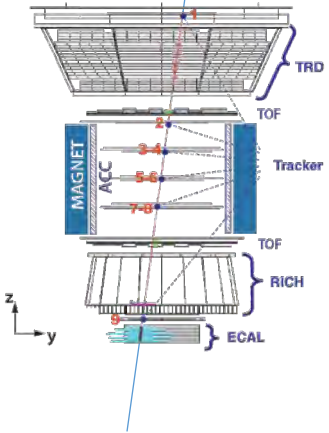
AMS-02: Alpha Magnetic Spectrometer

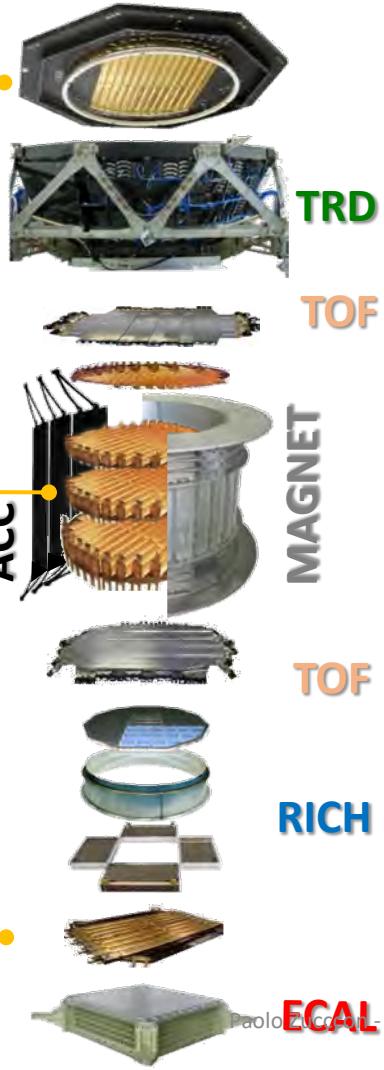
Launch	16/5/2011 (Endevour)
Construction	1999-2010
Dimensions	$3 \times 4 \times 5$ m³
Wheight	8.5 t
Power	2500 W

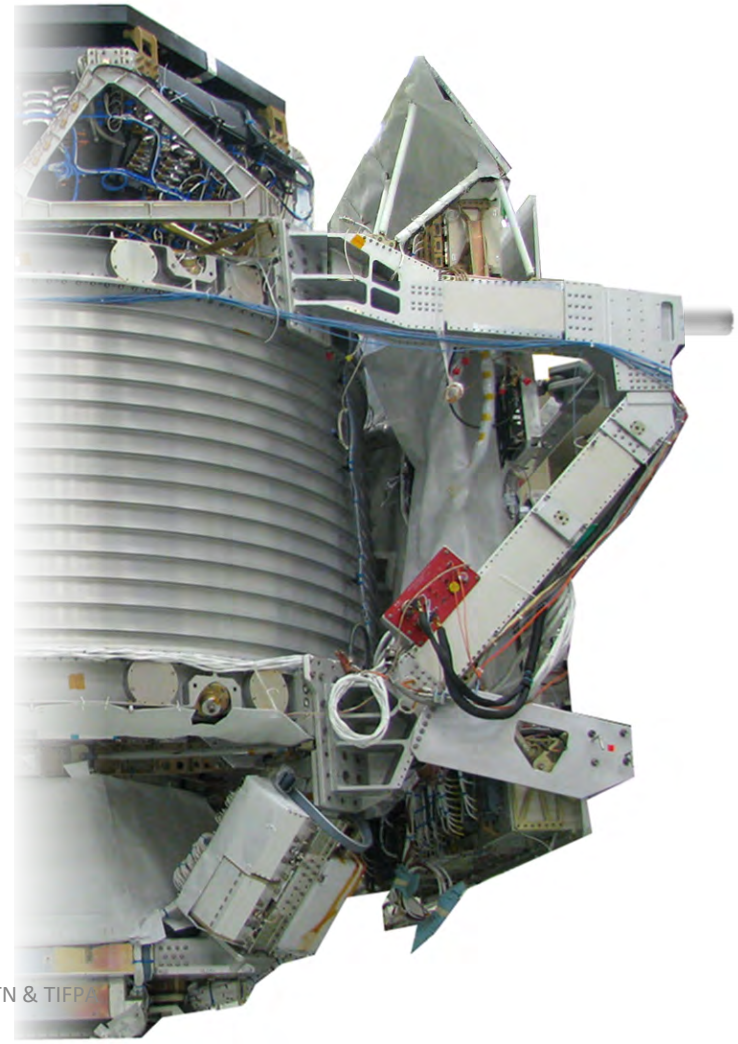


AMS-02 construction: EVA point of view

Tracker
planes

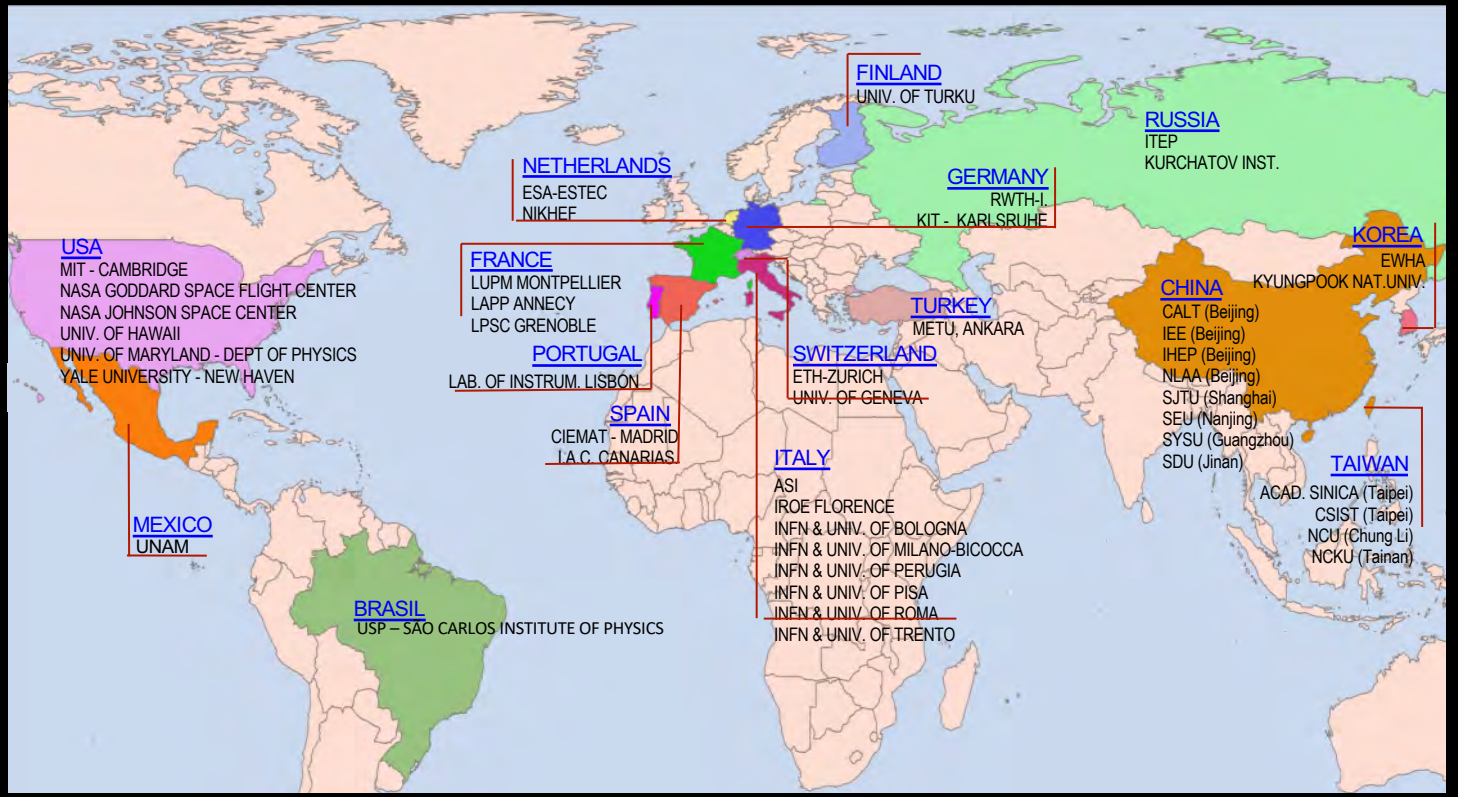






AMS International Collaboration

16 Countries, 60 Institutes and 600 Physicists



AMS-02 is controlled 24/7 from CERN, Geneva, Switzerland

AMS at CERN

Paolo Zucccon - UniTN & TIFPA

AMS-02 ITALIA

Università e INFN

Bologna
Milano “Bicocca”
Perugia
Pisa
Roma “La Sapienza”
Roma “Tor Vergata”
Trento

AMS-02 in Trento

Francesco Nozzoli

Paolo Zuccon

Roberto Battiston

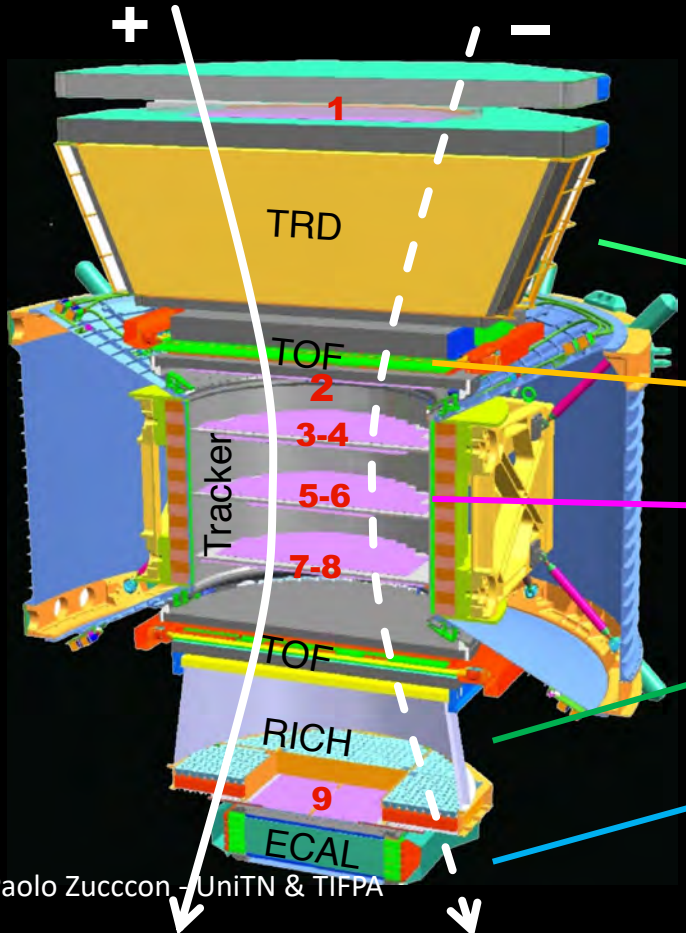
William J.Burger

Francesco Dimiccoli

Cinzia Cernetti

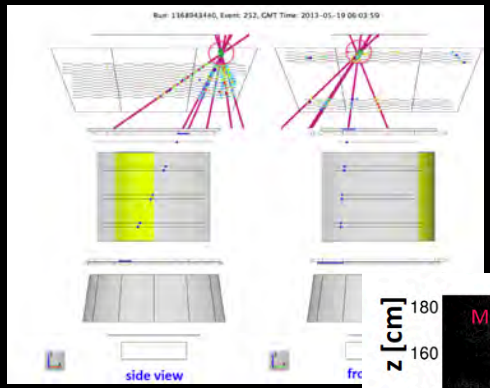
Ignazio Lazizzera

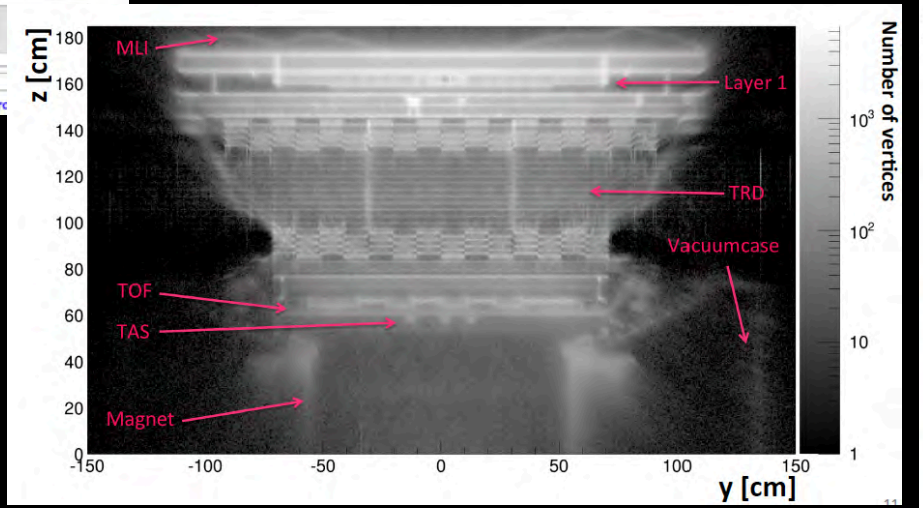
AMS identifies particles, from the different signals , released in the 5 sub-detectors.



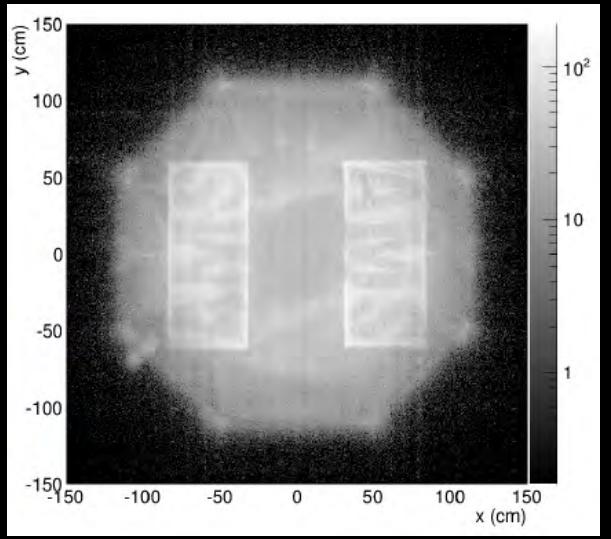
	Matter			Anti-matter		
	e^-	P	Fe	e^+	$\bar{P}$	$\overline{He}$
TRD						
TOF						
Tracker + Magnet						
RICH						
ECAL						

AMS “tomography” using rare nuclear interaction events



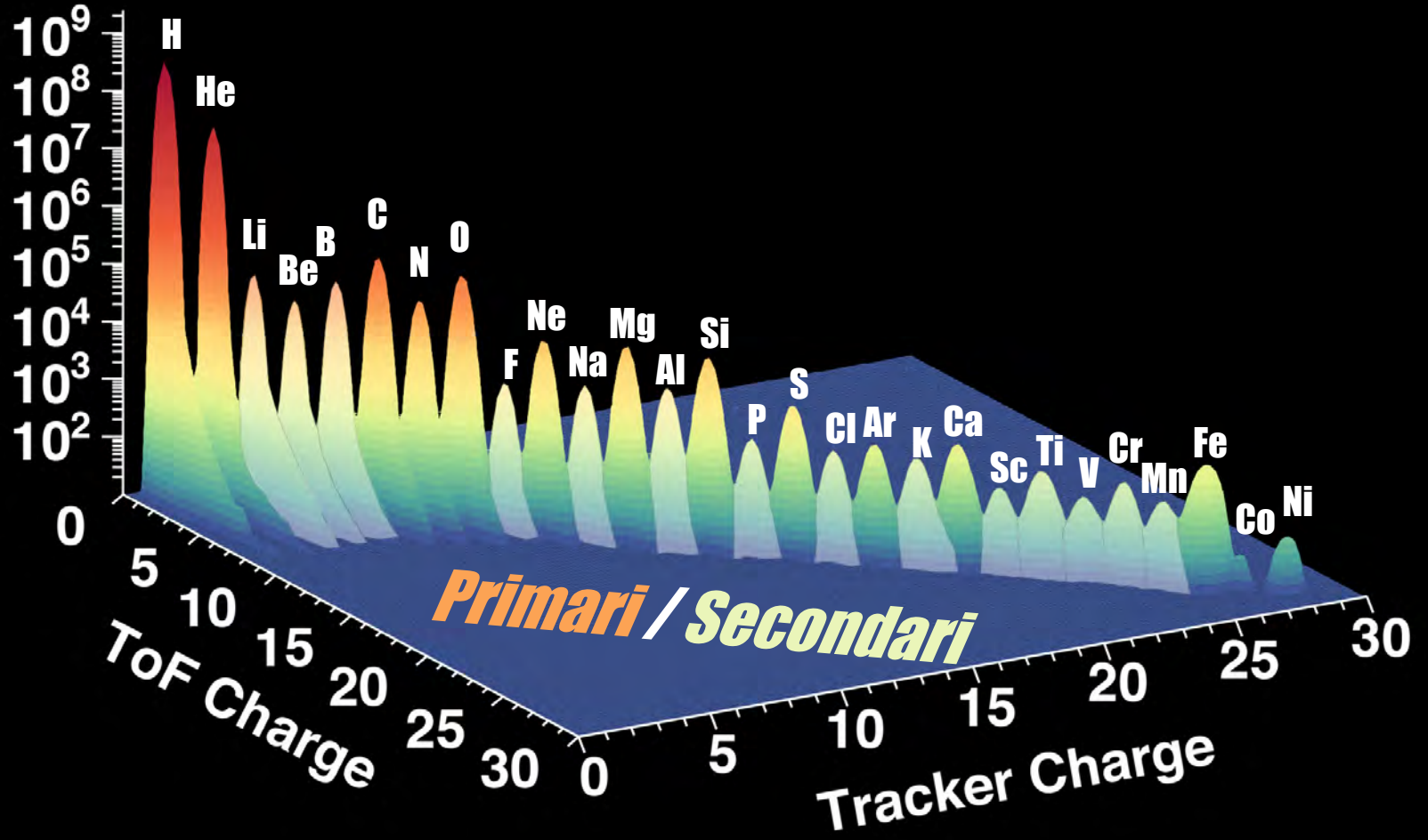


Z=178.5 cm

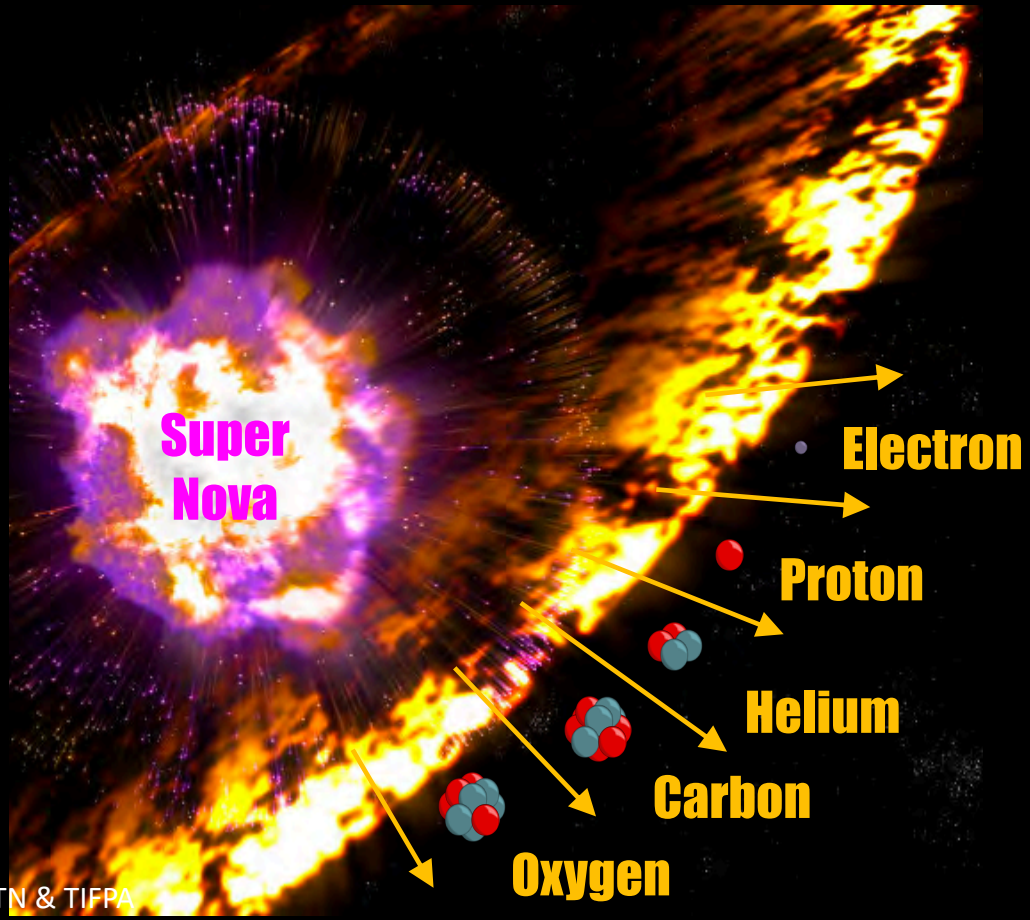


The gray scale is proportional the the number of found vertices

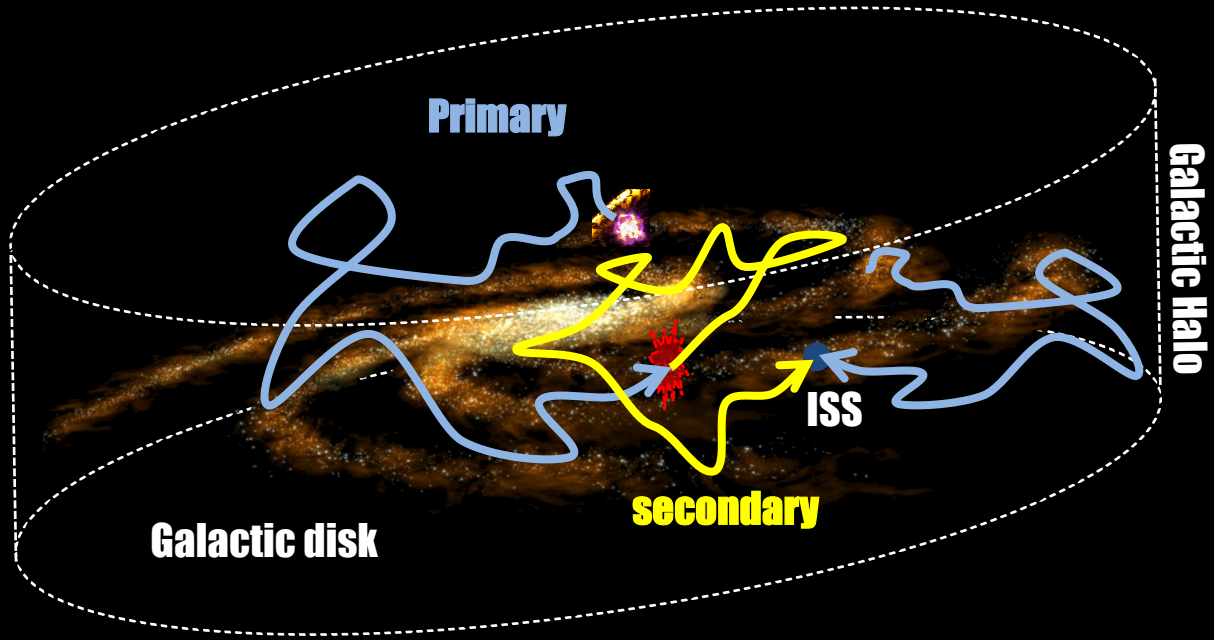
Periodic table of elements with AMS-02



Primary Cosmic Rays



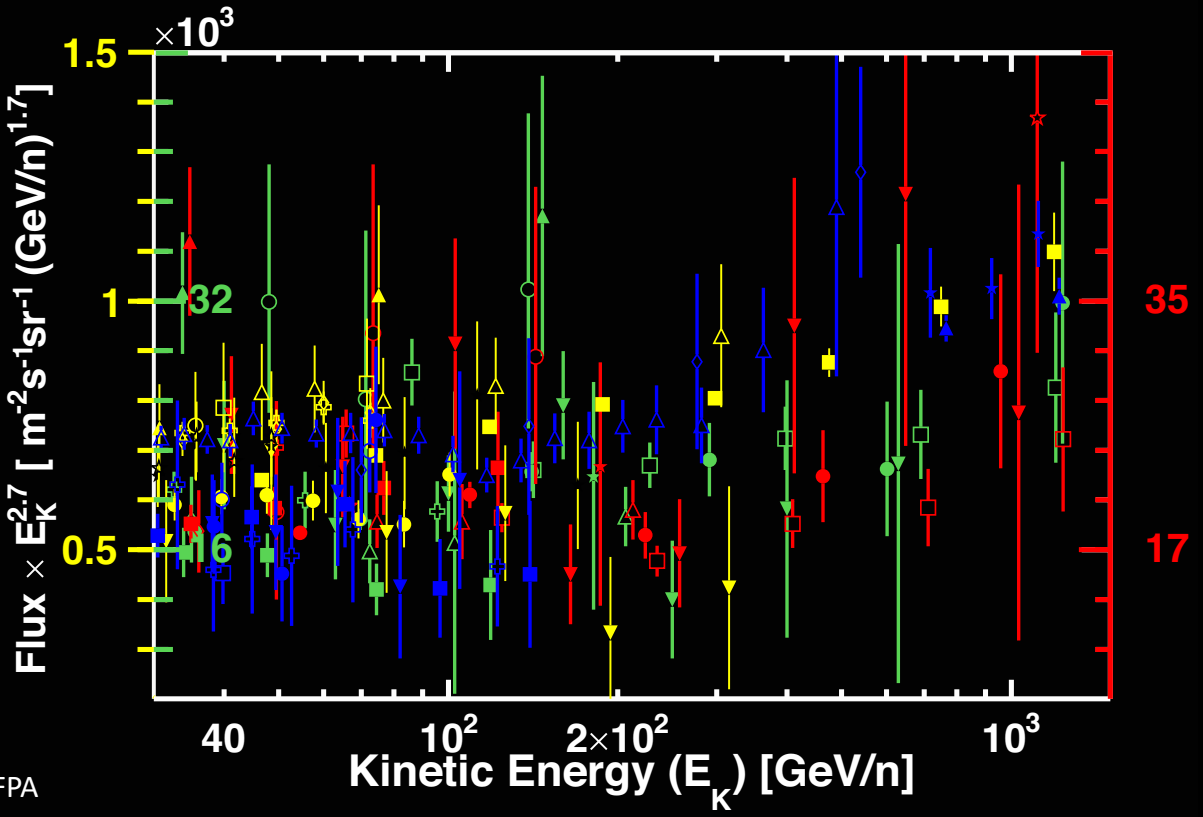
Secondary Cosmic Rays



Primary cosmic rays are produced from astrophysics sources,
Secondary cosmic rays are produced in collisions with the inter stellar medium.

Primaries before AMS-02

Helium
Carbon
Oxygen

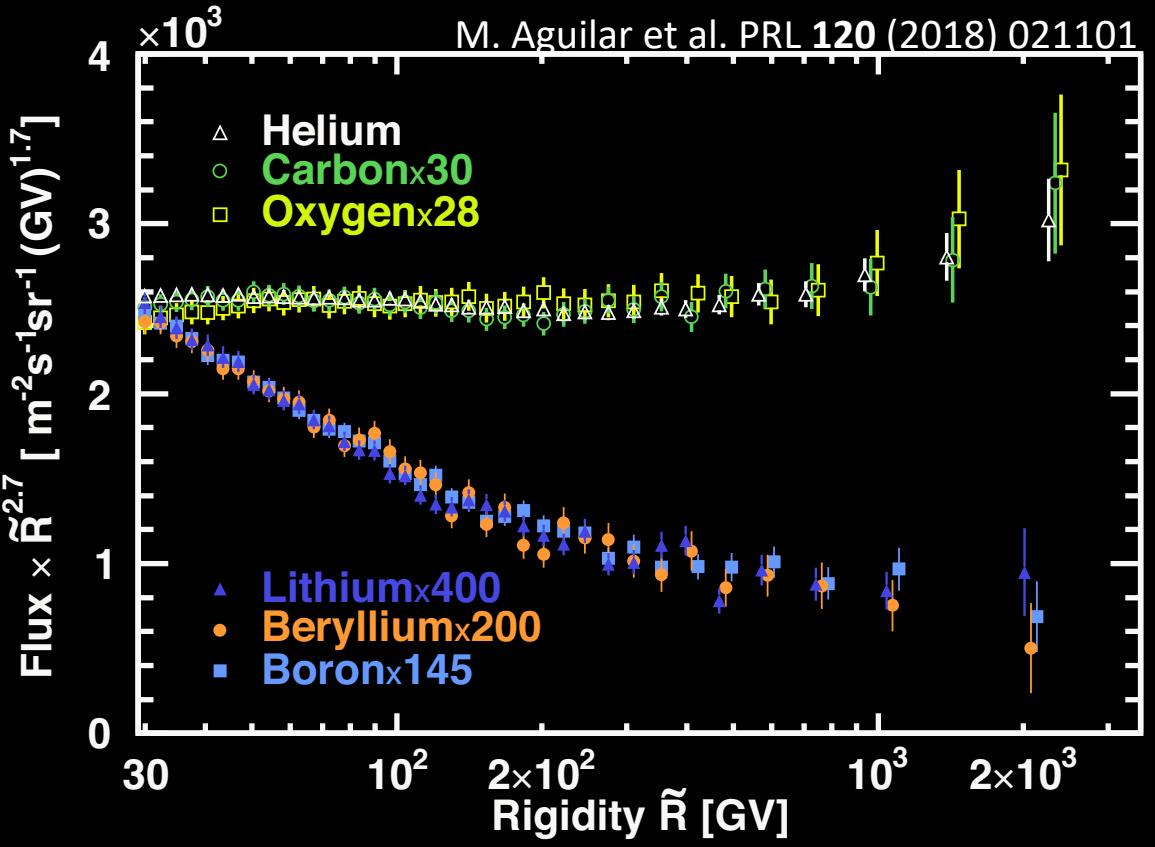


AMS01(1998/06)
ATIC02(2003/01)
Balloon(1970/09+1971/05)
Balloon(1970/11)
Balloon(1976/05)
Balloon(1979/06)
Balloon(1991/09)
BESS-Polarl(2004/12)
BESS-PolarII(2007/12-2008/01)
BESS-TeV(2002/08)
BESS98(1998/07)
CAPRICE94(1994/08)
CAPRICE98(1998/05)
CREAM-I(2004/12-2005/01)
IMAX92(1992/07)
LEAP(1987/08)
MASS91(1991/09)
PAMELA(2006/07-2008/12)
PAMELA-CALO(2006/06-2010/01)
RICH-II(1997/10)
SOKOL(1984/03-1986/01)
ATIC02(2003/01)
Balloon(1971/09+1972/10)
Balloon(1972/10)
Balloon(1976/10)
Balloon(1991/09)
CREAM-II(2005/12-2006/01)
CRN-Spacelab2(1985/07-1985/08)
HEAO3-C2(1979/10-1980/06)
PAMELA(2006/07-2008/03)
TRACER06(2006/07)
ATIC02(2003/01)
Balloon(1971/09+1972/10)
Balloon(1972/10)
Balloon(1976/10)
Balloon(1991/09)
CREAM-II(2005/12-2006/01)
CRN-Spacelab2(1985/07-1985/08)
HEAO3-C2(1979/10-1980/06)
TRACER03(2003/12)
TRACER06(2006/07)
TRACER99

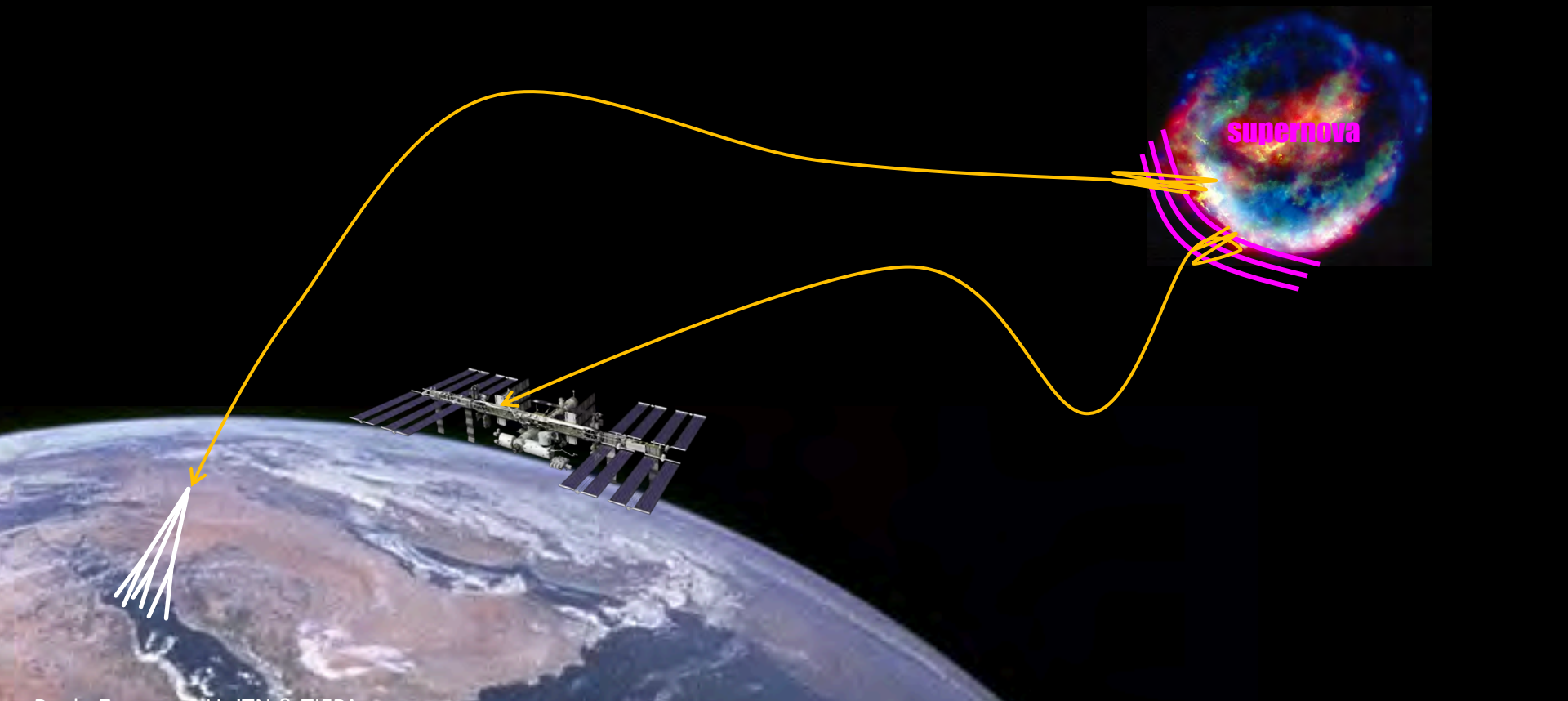
AMS-02 Primaries e Secondaries

Helium
Carbon (×30)
Oxygen (×28)

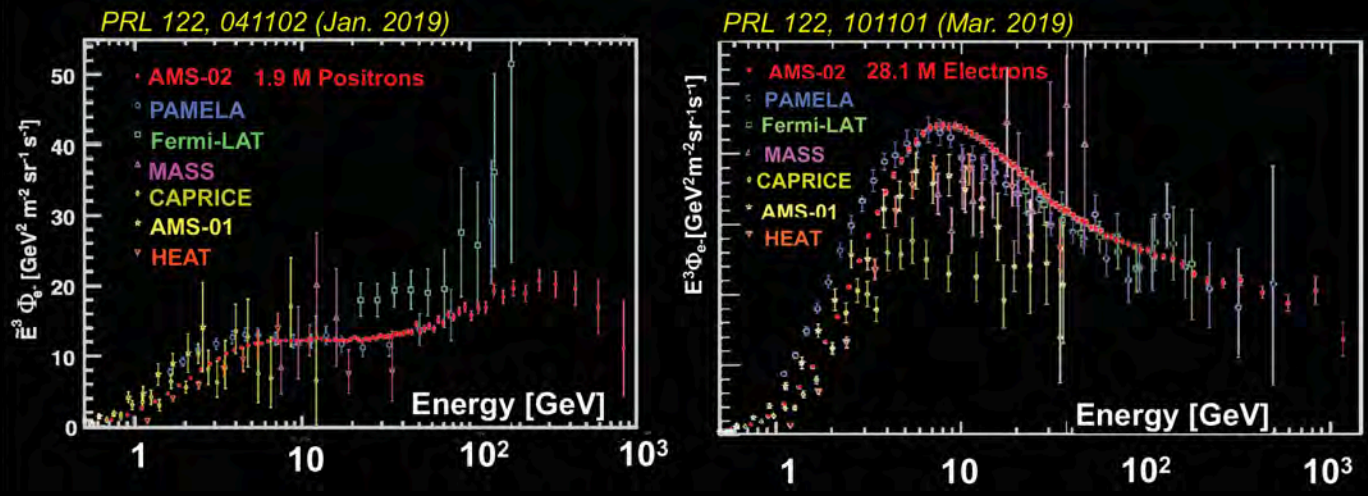
Lithium (×200)
Beryllium (×400)
Boron (×145)



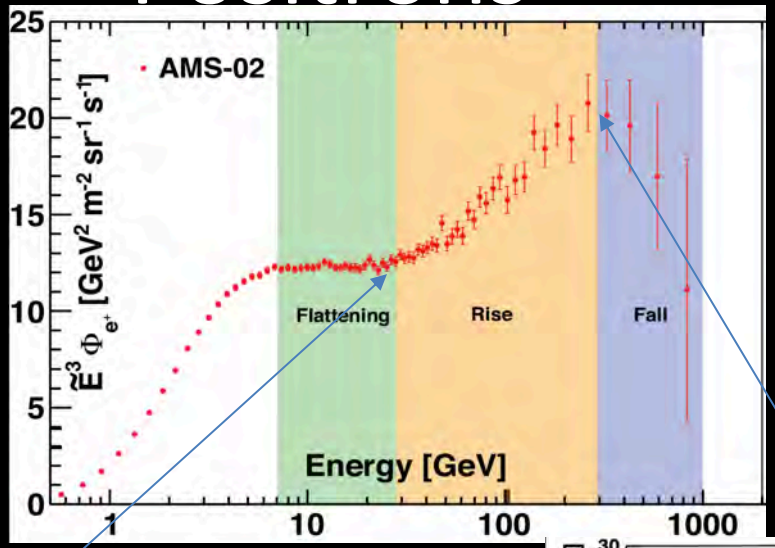
Matter and Anti-Matter in Cosmic Rays

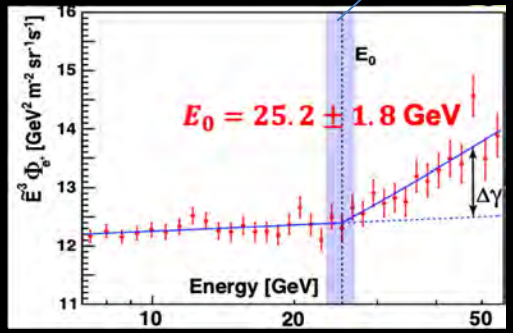


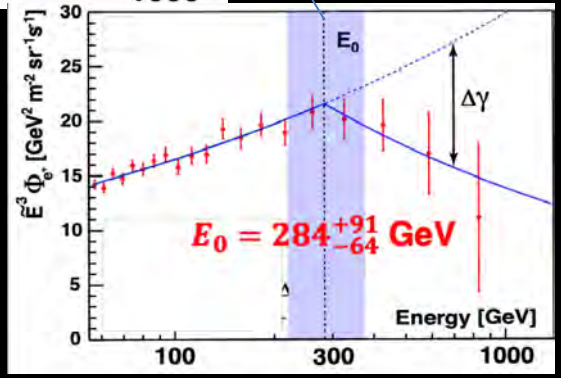
Positron and Electron fluxes



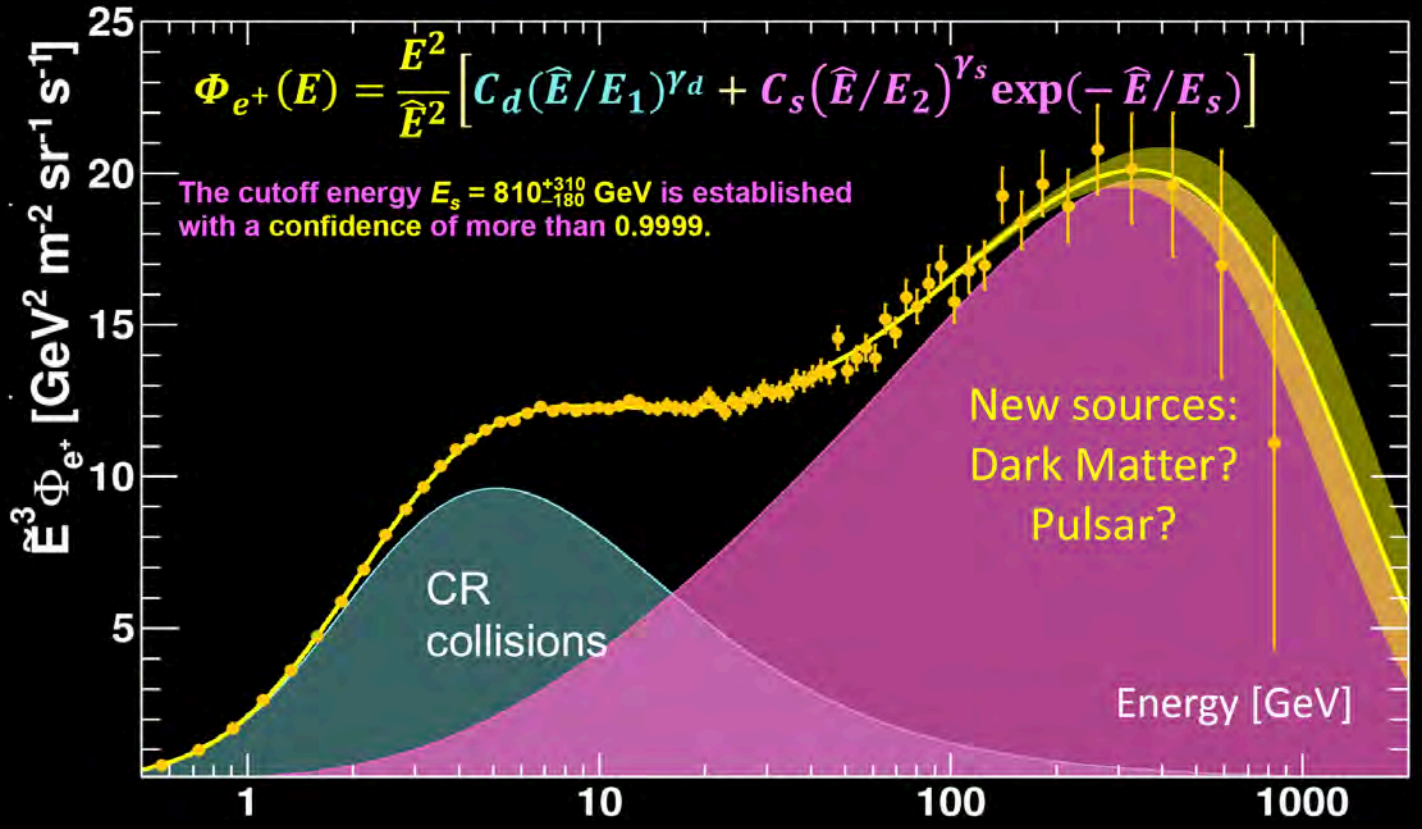
Positrons


AMS-02
Flattening
Rise
Fall
Energy [GeV]
$\tilde{E}^3 \Phi_{e^+}$ [GeV^2 m^{-2} sr^{-1} s^{-1}]


$E_0 = 25.2 \pm 1.8$ GeV
E_0
$\Delta\gamma$
Energy [GeV]

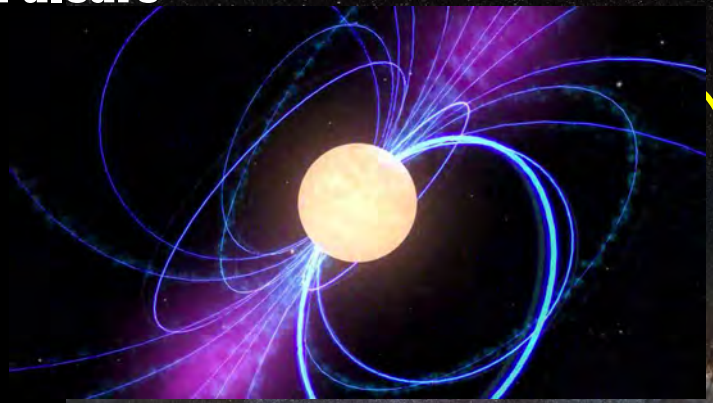

$E_0 = 284^{+91}_{-64}$ GeV
E_0
$\Delta\gamma$
Energy [GeV]

Positron Flux: two components



The origin of positron excess ?

Pulsars



Seconday Production

supernova

primaries

Inter Stellar medium

positrons

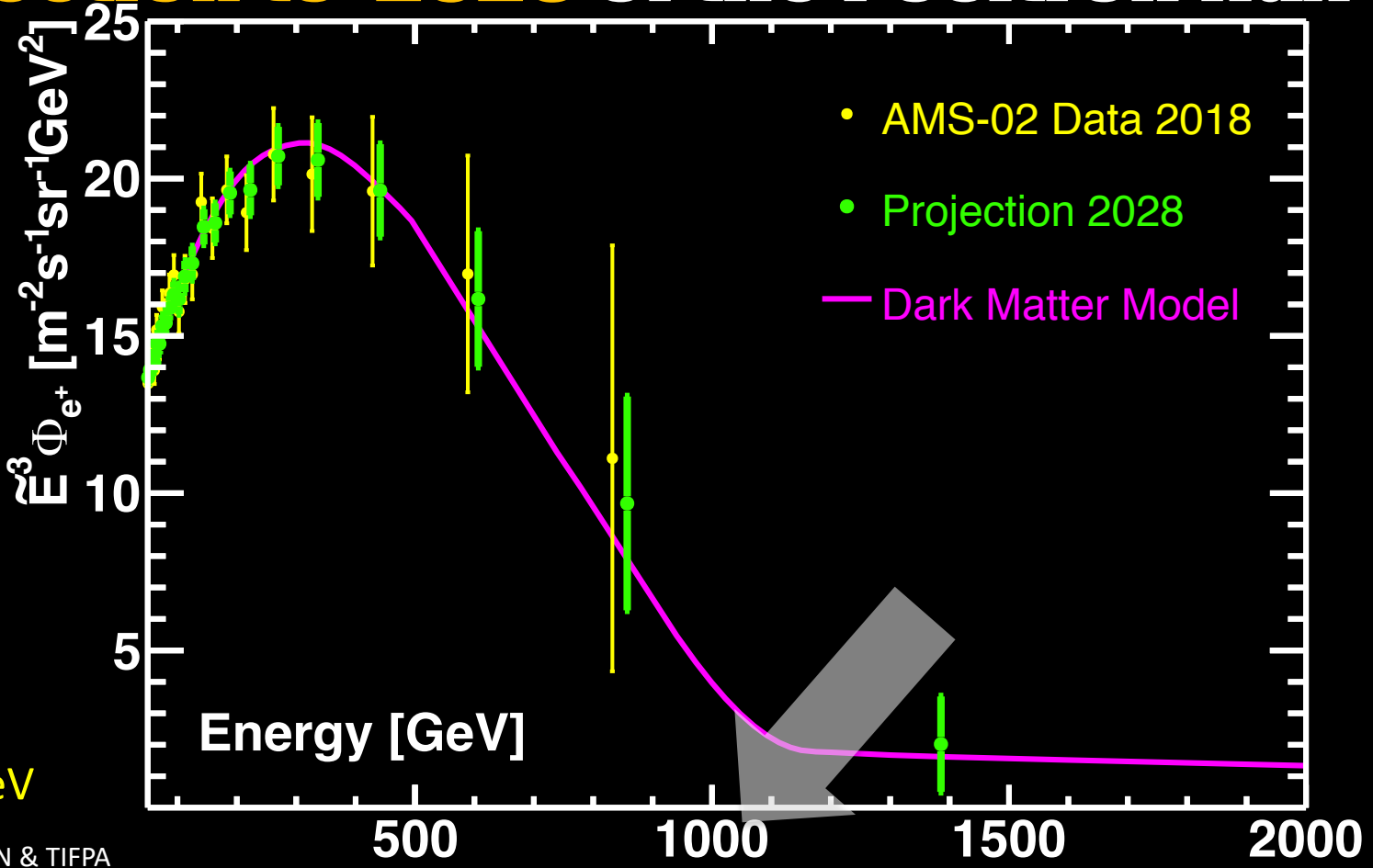
Dark Matter

electrons

positrons

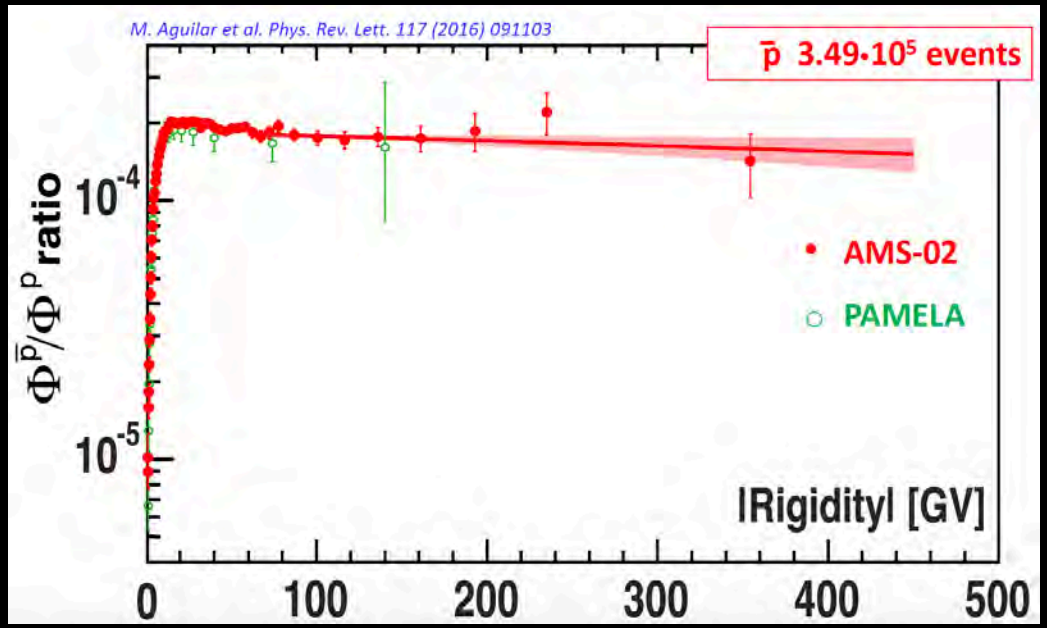
Dark matter

Projection to 2028 of the Positron flux

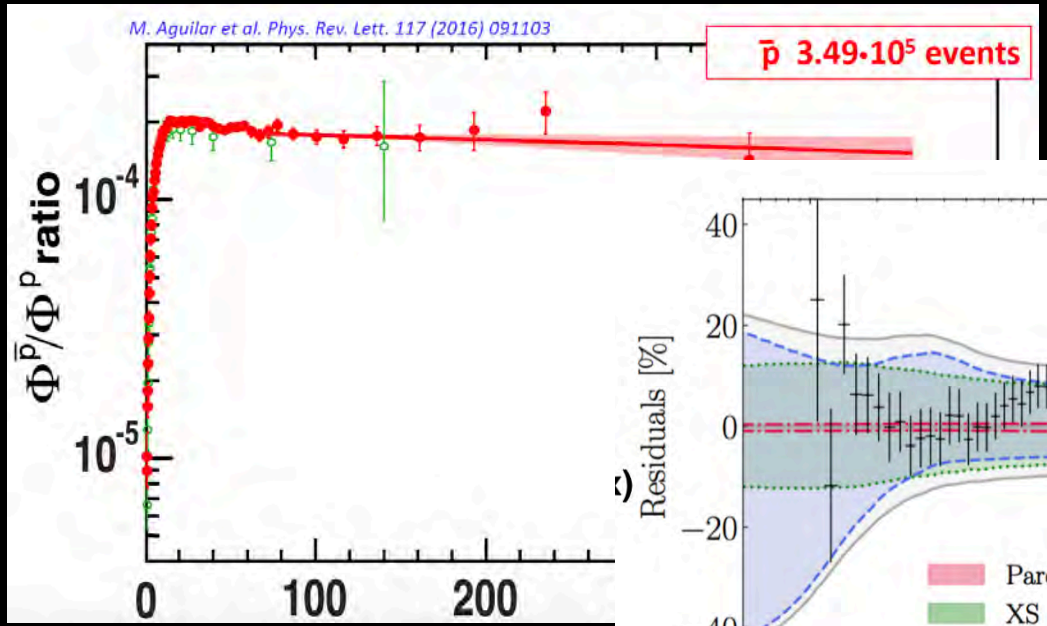


Max ~ 284 GeV

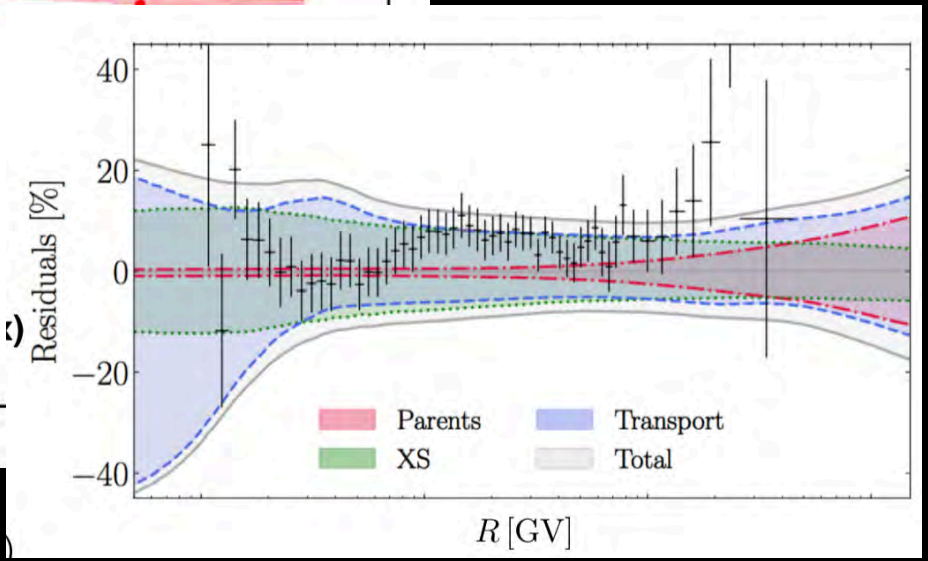
AMS anti-proton to proton ratio



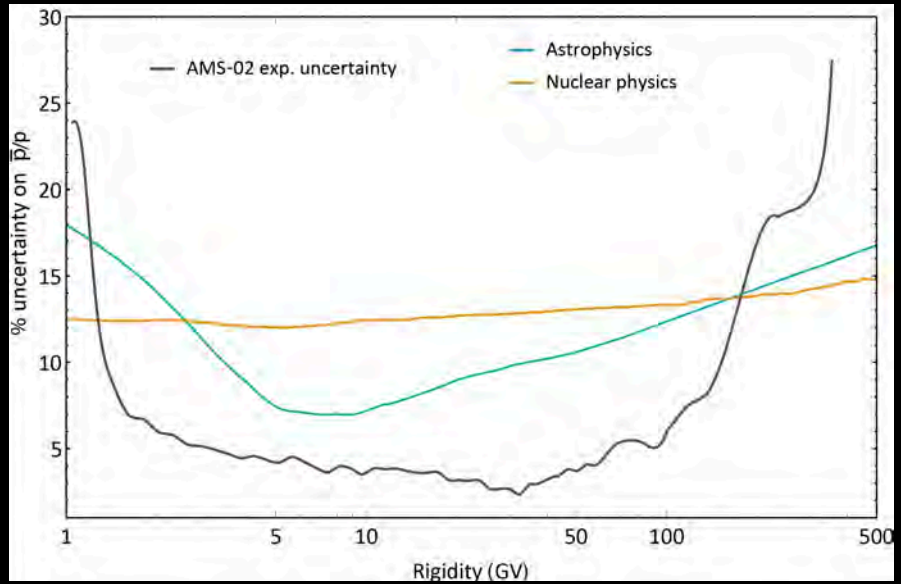
AMS anti-proton to proton ratio



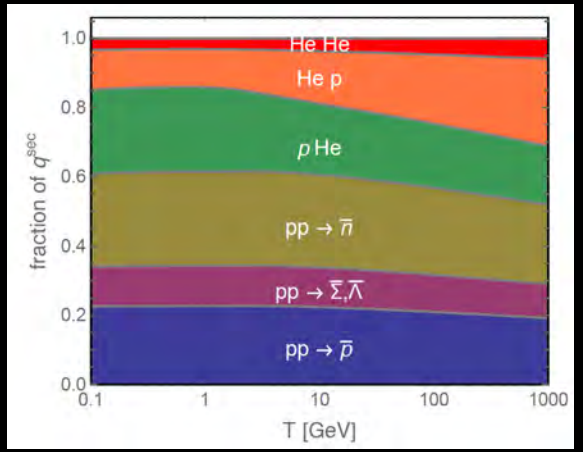
M. Boudaud –ICRC 2019



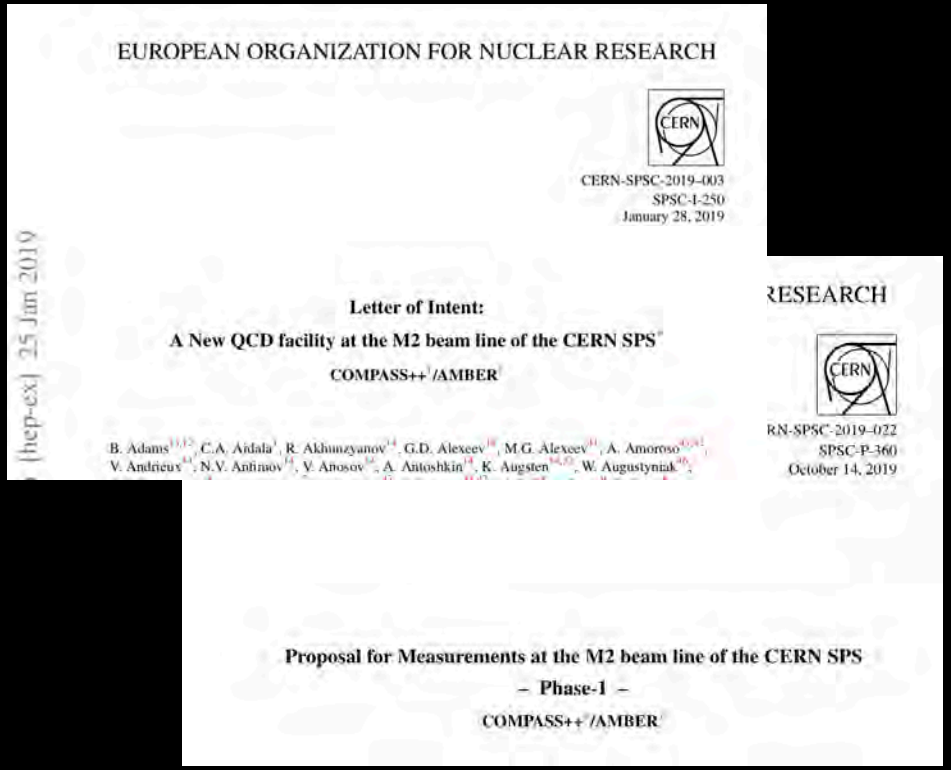
Prediction Uncertainties



Nicolò Masi, INFN-Bo



AMBER @ CERN



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2019-003
SPSC-I-250
January 28, 2019

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS*

COMPASS++[1]/AMBER[2]

B. Adams[11,12], C.A. Aidala[1], R. Akhunzyanov[14], G.D. Alexeev[10], M.G. Alexeev[11], A. Amoroso[9,8], V. Andrieux[41], N.V. Anfimov[14], V. Anosov[14], A. Antoshkin[14], K. Augsten[14,42], W. Augustyniak[36],

RESEARCH

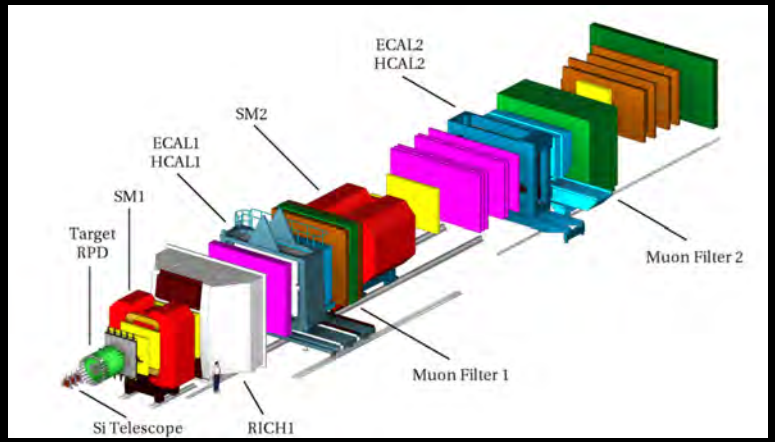
RN-SPSC-2019-022
SPSC-P-360
October 14, 2019

Proposal for Measurements at the M2 beam line of the CERN SPS

– Phase-1 –

COMPASS++[1]/AMBER[2]

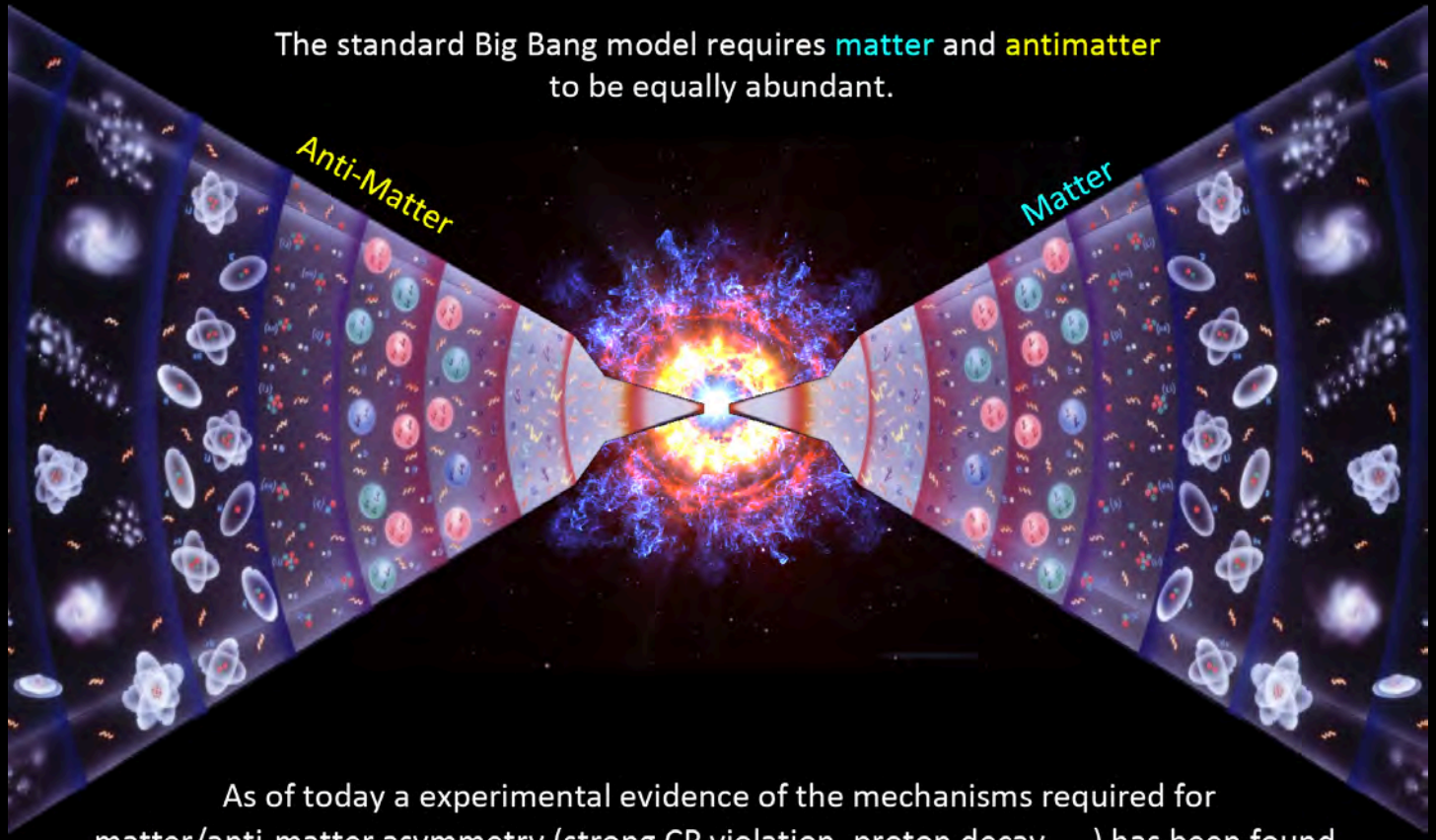
COMPASS spectrometer



2022-2023 @ CERN SPS

Heavy Anti-Matter Search

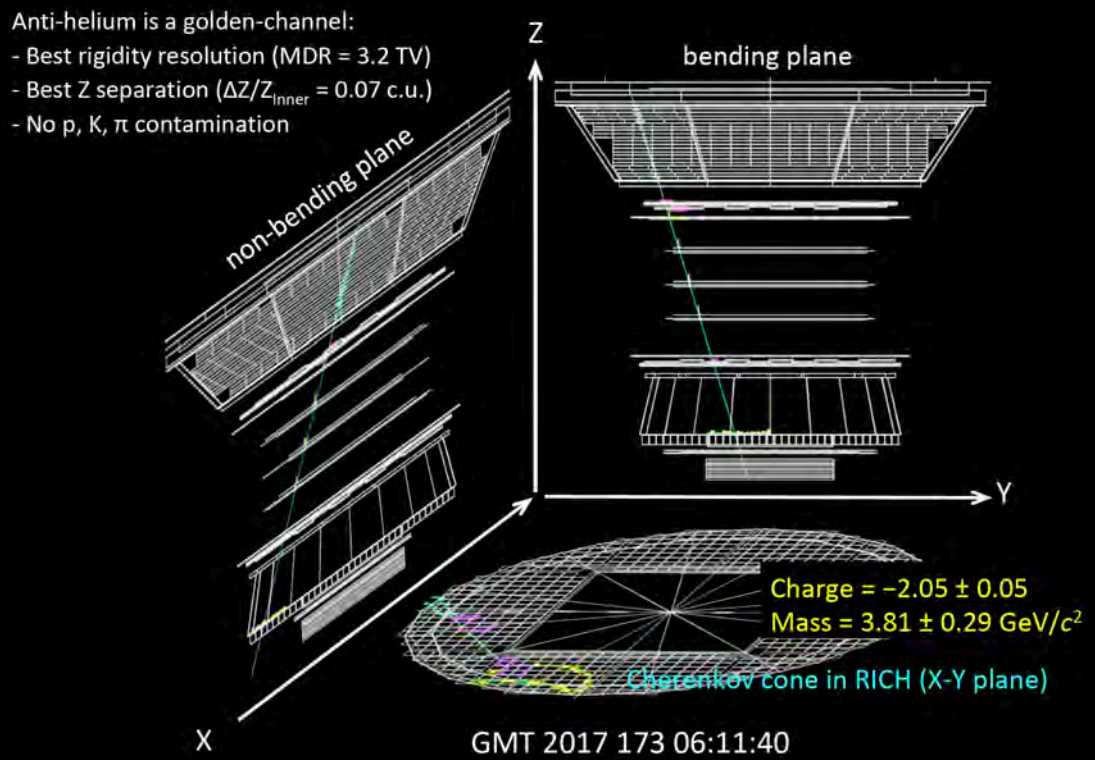
The standard Big Bang model requires matter and antimatter to be equally abundant.



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.

Anti-Helium a candidate event

Anti-helium is a *golden-channel*



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 in AMS of antihelium candidates is less than 1 in 100 million helium.

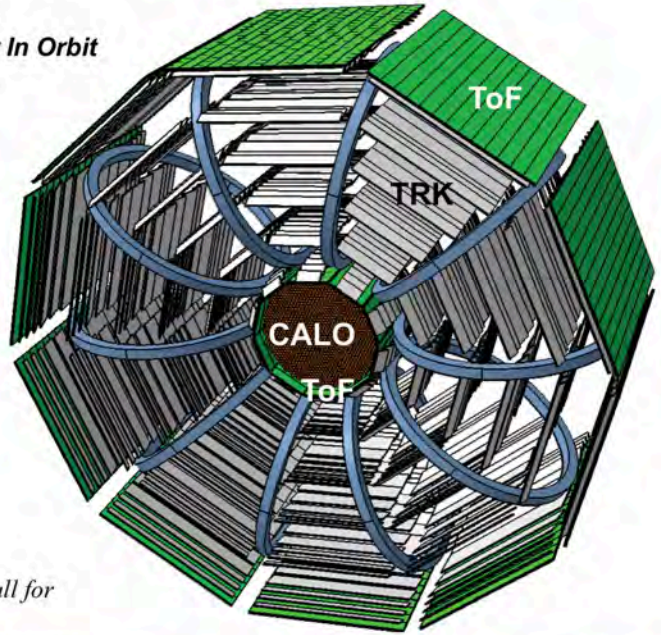
At this extremely low rate, more data (through the lifetime of the ISS)
is required to further check the origin of these events.

What's next ?

High Precision Particle Astrophysics as a New Window on the Universe

with an Antimatter Large Acceptance Detector In Orbit

(ALADInO)



A White Paper submitted in response to ESA's Call for the VOYAGE 2050 long-term plan

https://www.cosmos.esa.int/web/voyage-2050/white-papers

https://www.cosmos.esa.int/documents/1866264/3219248/BattistonR_ALADINO_PROPOSAL_20190805_v1.pdf

Summary

- The recent observations point consistently to an Universe filled of dark-matter
- A lot of questions are open and the natural laboratory of the space is a place to search for answers.
- We live in a exciting age where the large knowledge we built, disclose to us an uncharted new landscape.
- Cosmic rays are one of the open window to the Universe and they have the potential to reveal new physics
- Current and future experiments measuring cosmic rays may help in writing the map of this new territory.

https://AMS02.space

AMS-02 represents a big success and shows, the scientific and technologic excellence achieved by INFN, ASI and the Italian Universities.

INFN
Istituto Nazionale di Fisica Nucleare

ASI
Agenzia Spaziale Italiana

Please visit