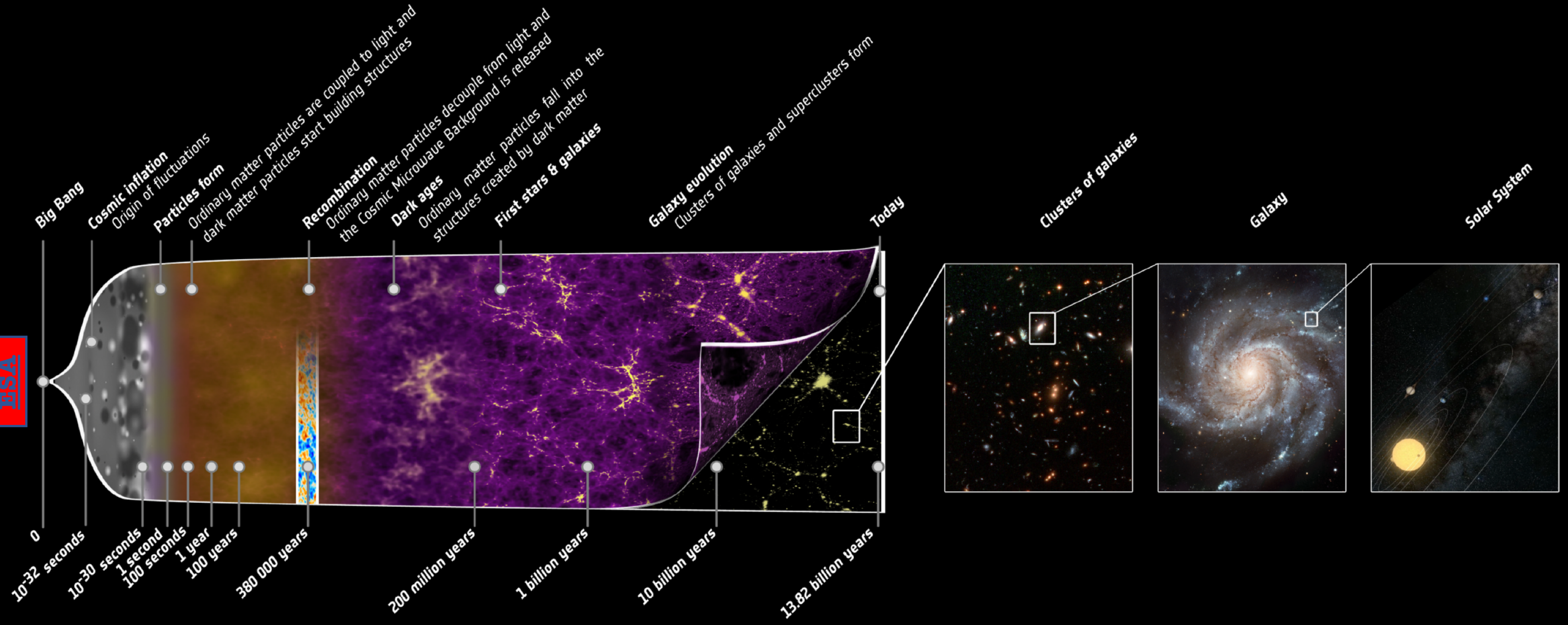
High Precision Particle Astrophysics as a New Window on the Universe

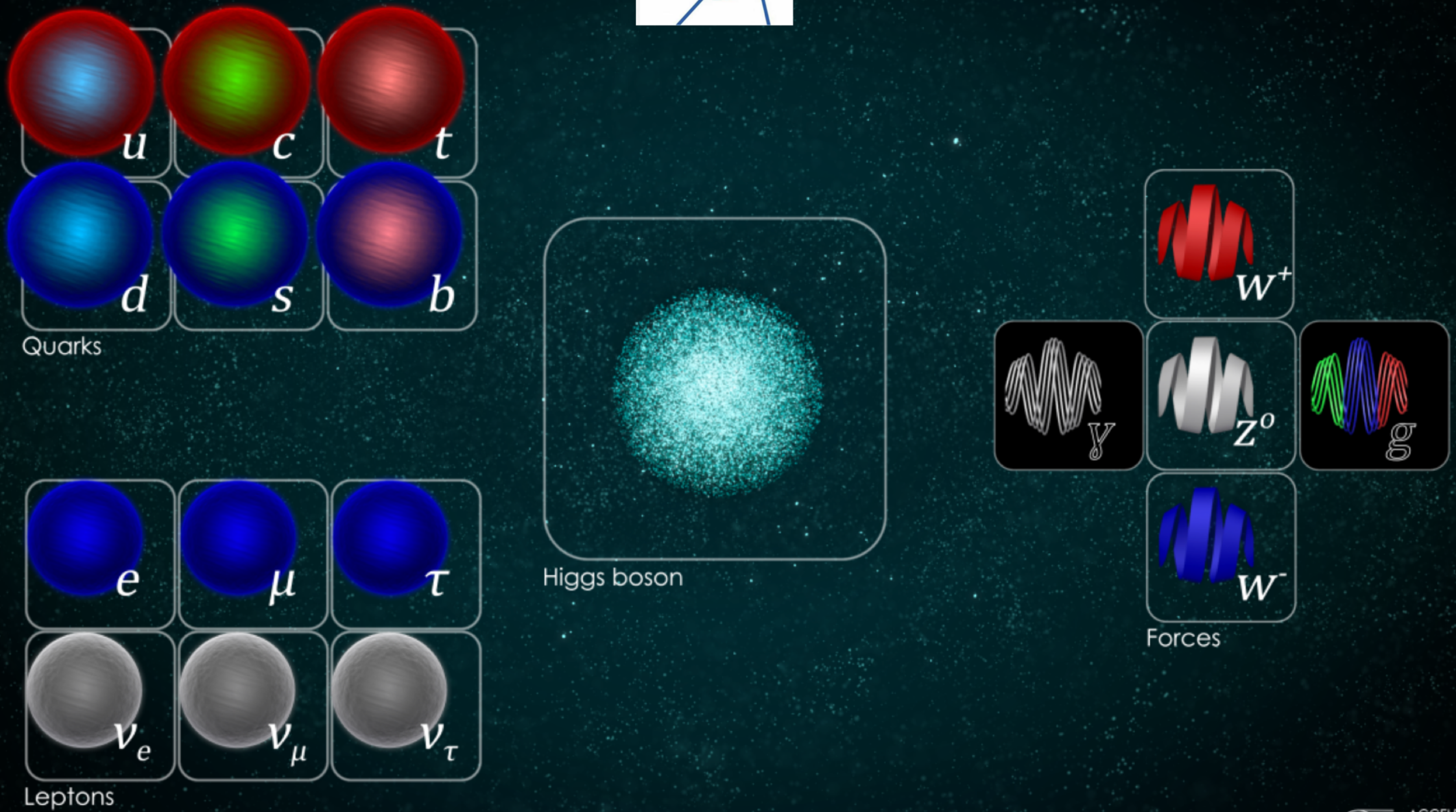
with an

Antimatter Large Acceptance Detector In Orbit (ALADInO)

Presenter: Roberto Battiston
University of Trento

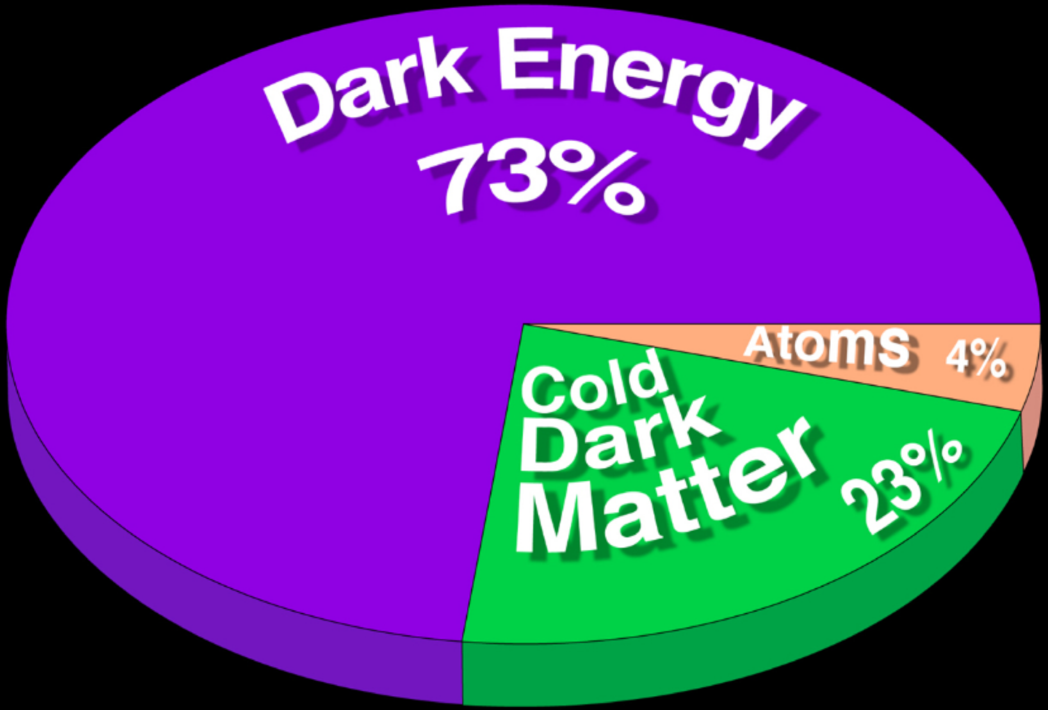
ESA Voyage 2050
Madrid 2019


Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
Clusters of galaxies
Galaxy
Solar System
0
10^{-32} seconds
10^{-30} seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years



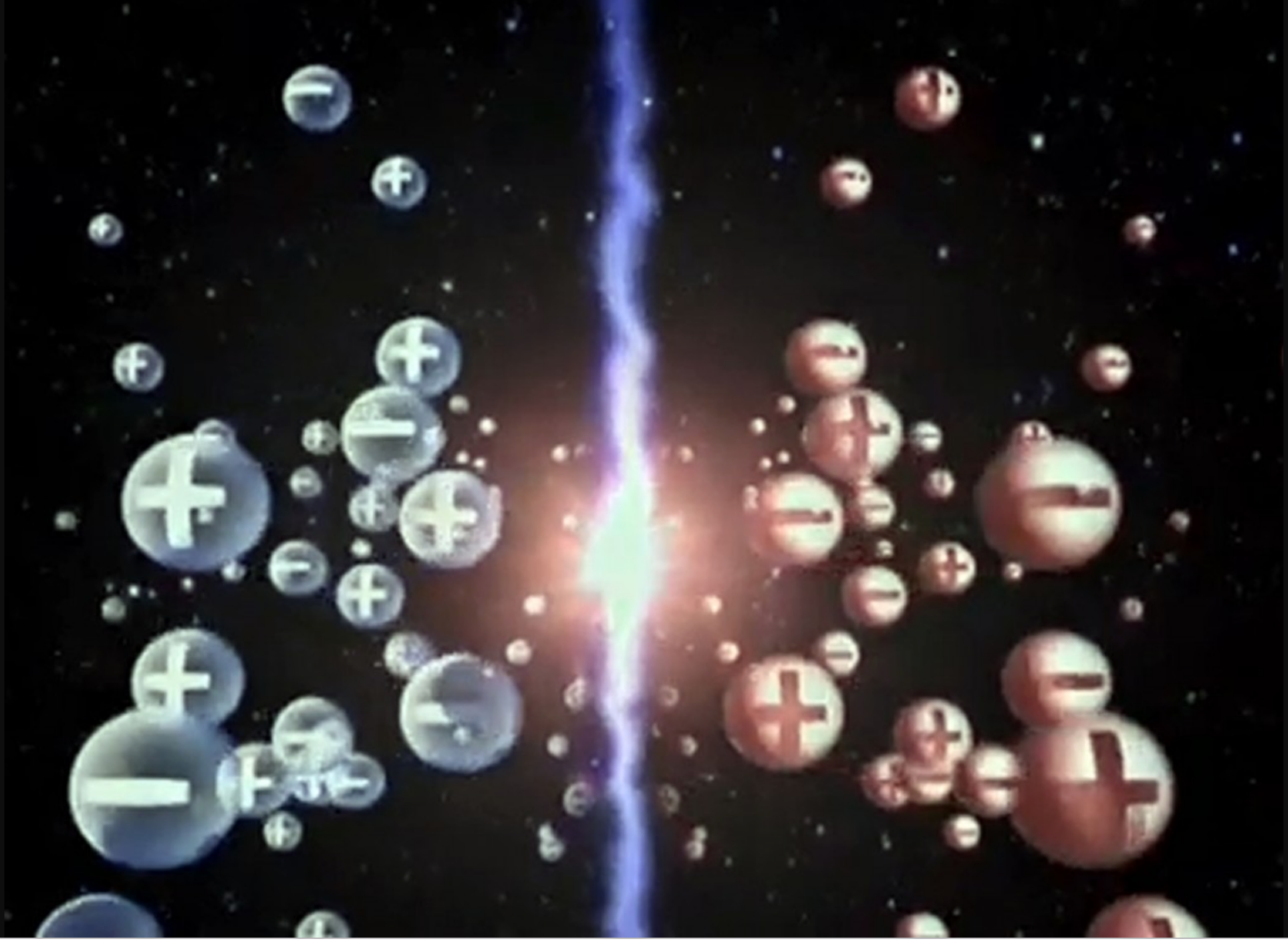
ACCELERATING SCIENCE

Planck



Dark matter in the universe

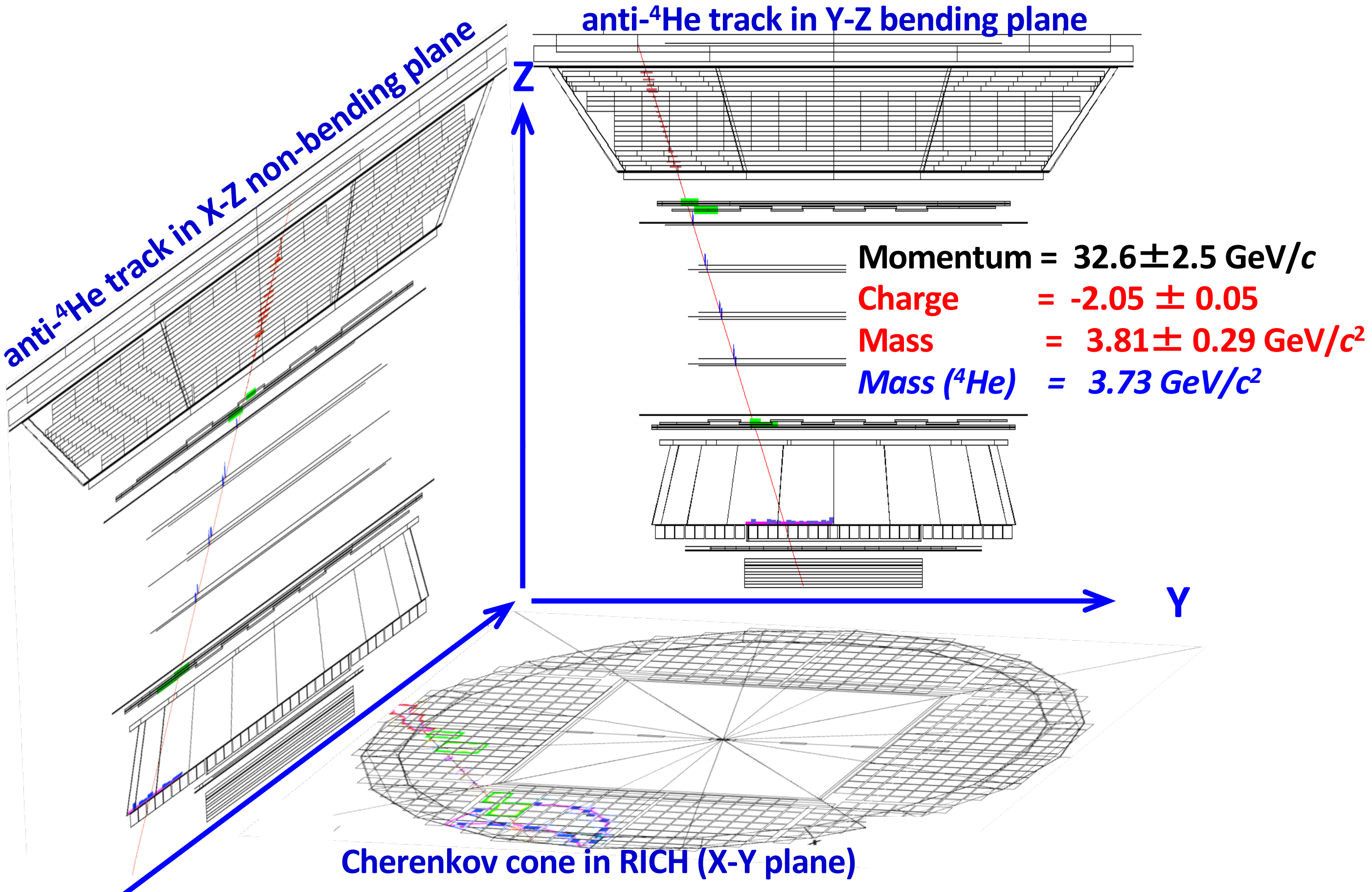
A jar with
a very few
edible candies



Antimatter in the universe

The lost can

An anti-^{4}He candidate (AMS preliminary)



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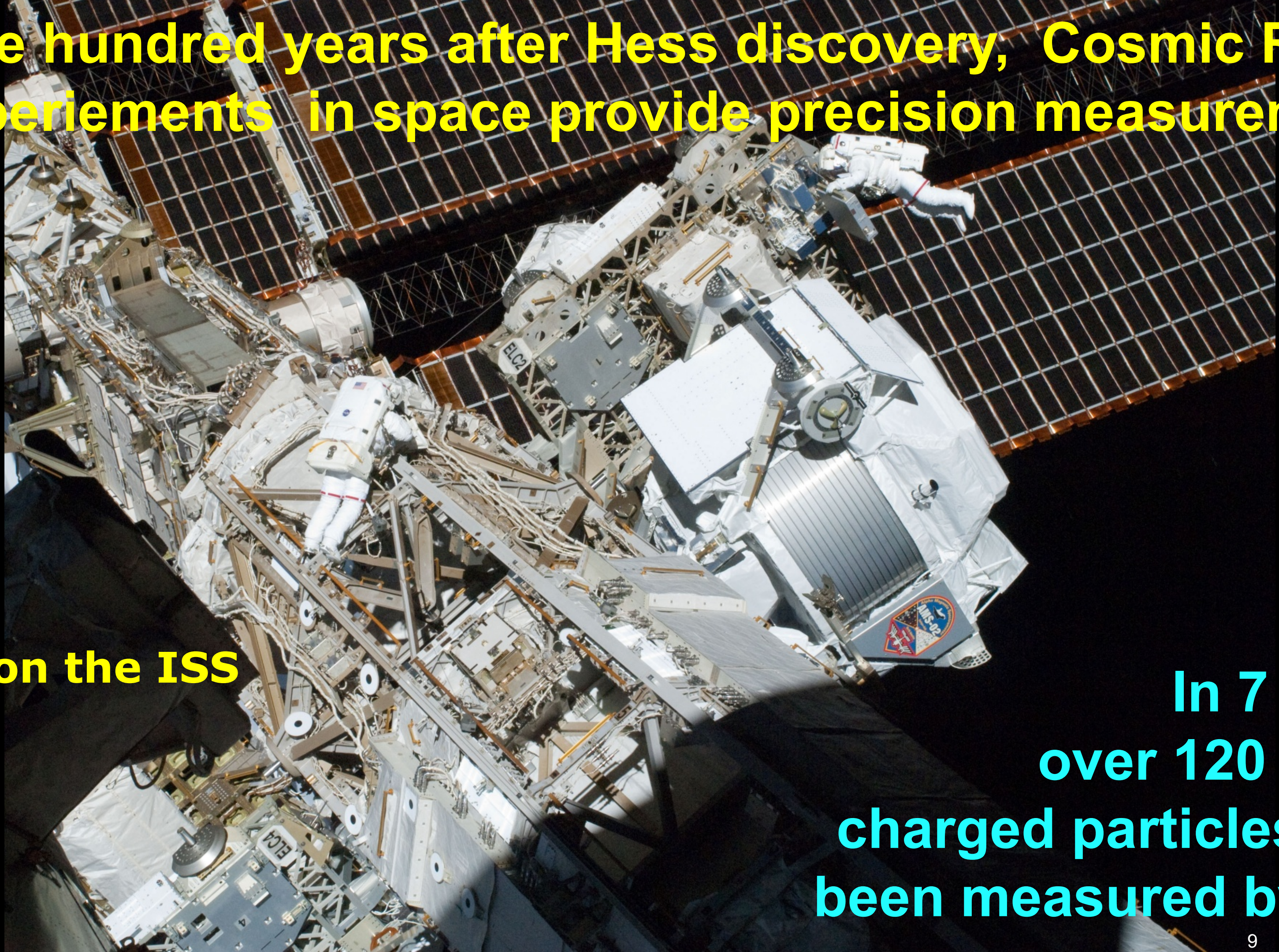
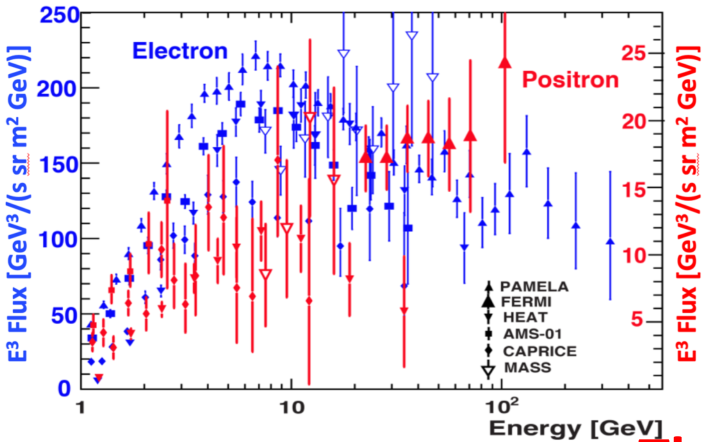
One hundred years after Hess discovery, Cosmic Rays experiements in space provide precision measurements



AMS-02 on the ISS

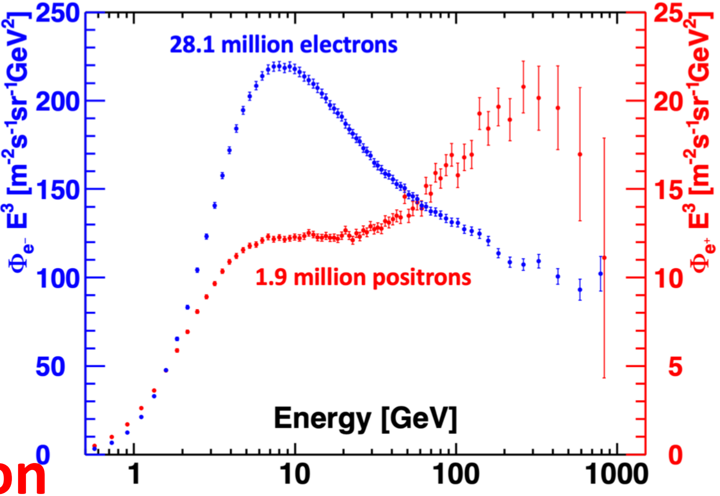
**In 7 years,
over 120 billion
charged particles have
been measured by AMS**

Data of the Electron and Positron spectra before AMS



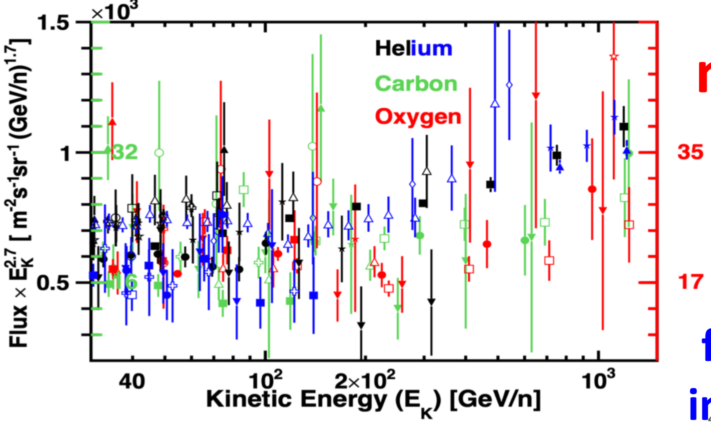
Alpha Magnetic Specrometer AMS

Latest AMS results on positron and electron fluxes

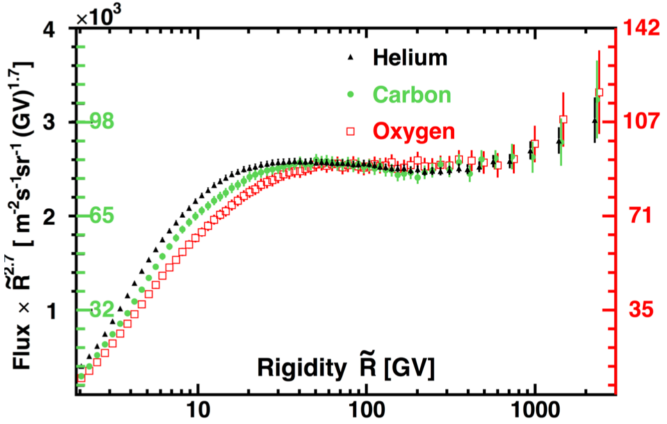


The Era of Precision Cosmic Ray measurements

Before AMS: results on Primary Cosmic Rays (Helium, Carbon, Oxygen) from balloon and satellite experiments



The AMS results on primary cosmic rays He, C, and O.



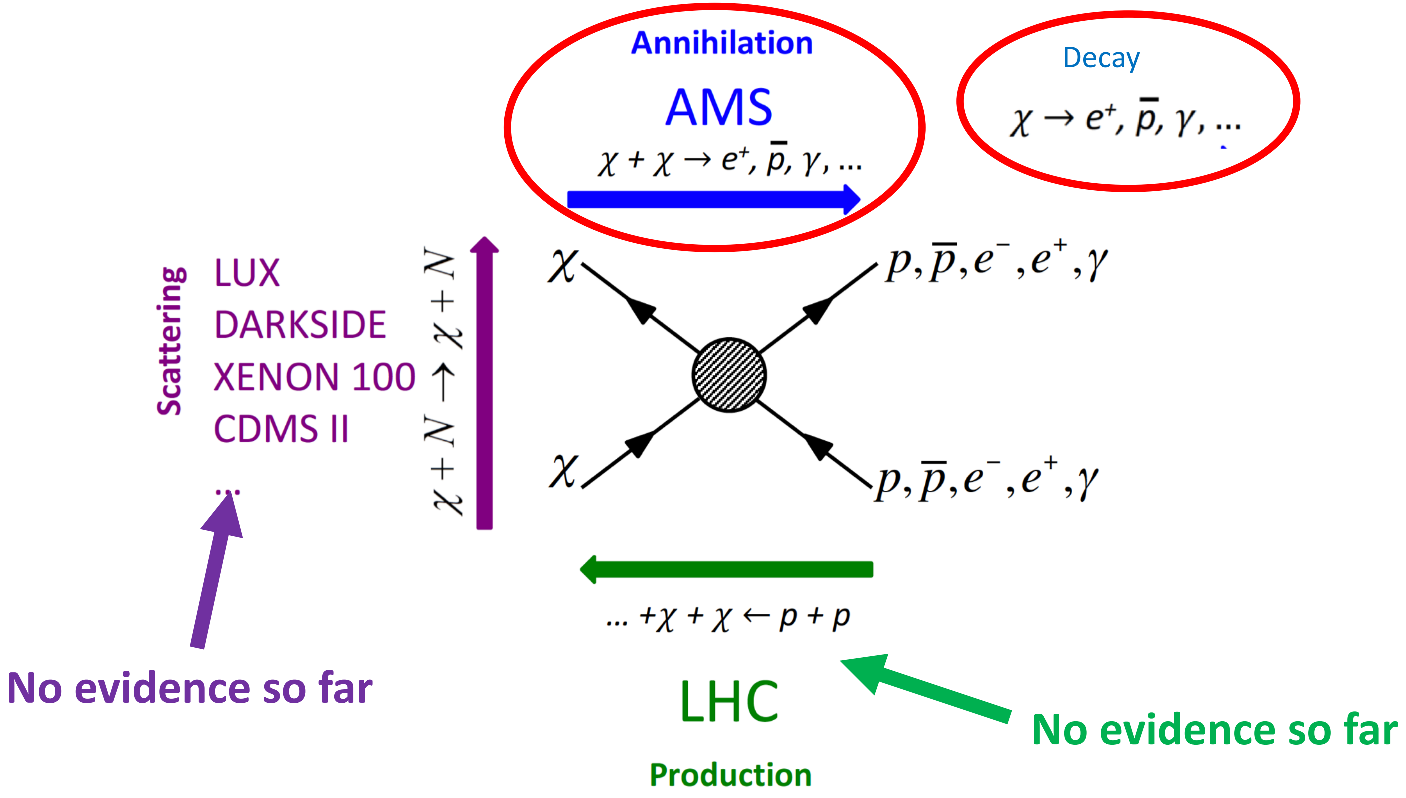
AMS results : first time % accuracy in Cosmic Ray physics

High Precision Particle Astrophysics using antimatter particles

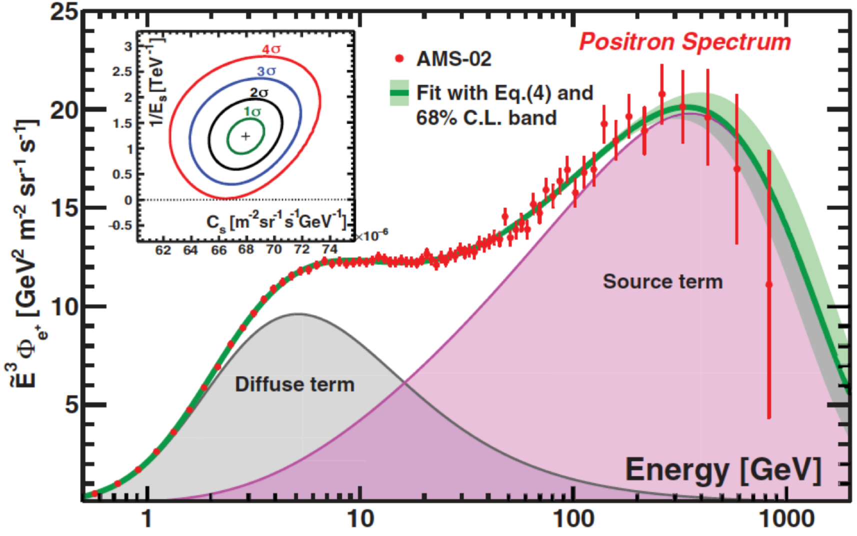
Antimatter particles in Cosmic Rays (CR) represent a small fraction of the total flux, about $5\ 10^{-3}$ for e+, 10^{-5} for p-bar, 10^{-7} for d-bar, less than 10^{-9} for anti-^{3}He or heavier antinuclei: these tiny fluxes, however, carry a great amount of information, since the origin of antiparticles is intimately related to fundamental processes.

First example of physics topics for High Precision Particle Astrophysics «Search for the origin of dark matter»

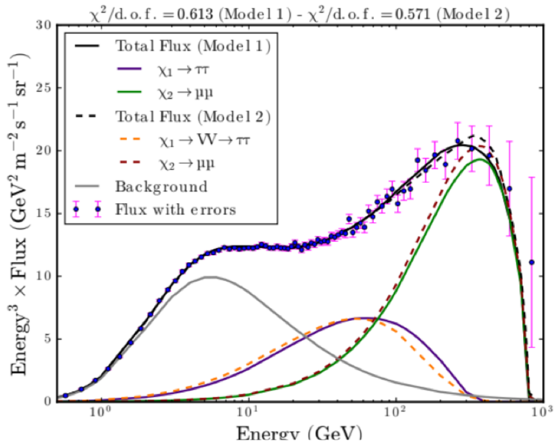
Three independent methods to search for Dark Matter

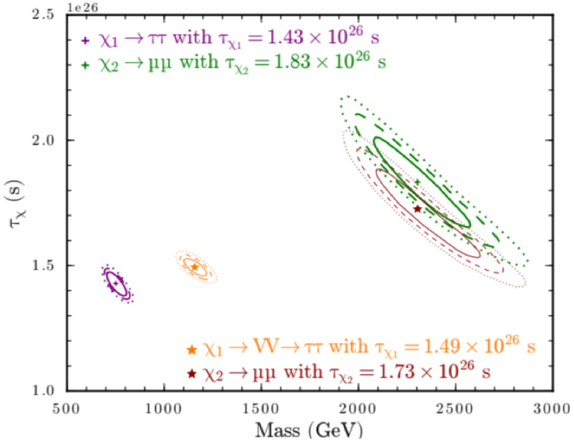


AMS-02 has observed a clear positron excess due to a source term



AMS Collaboration, Phys. Rev. Lett. 122, 041102 (2019)

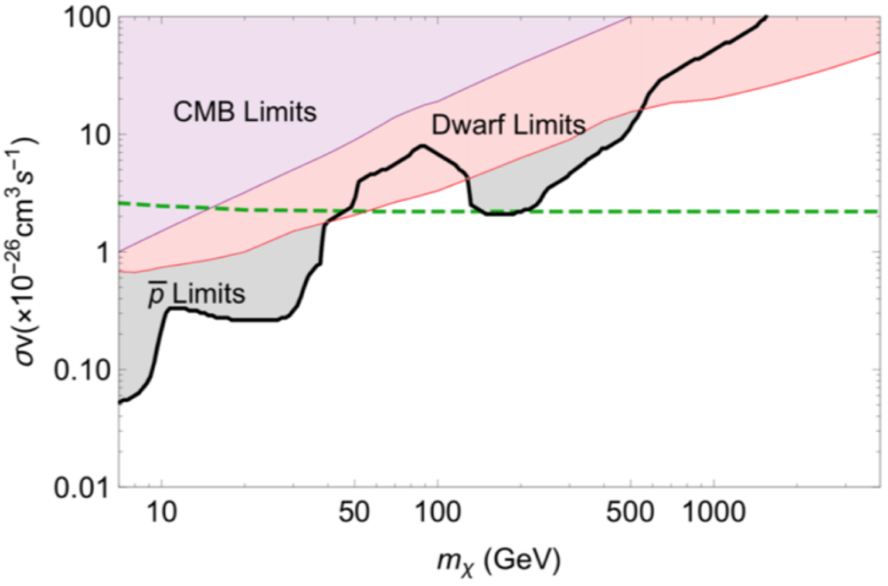


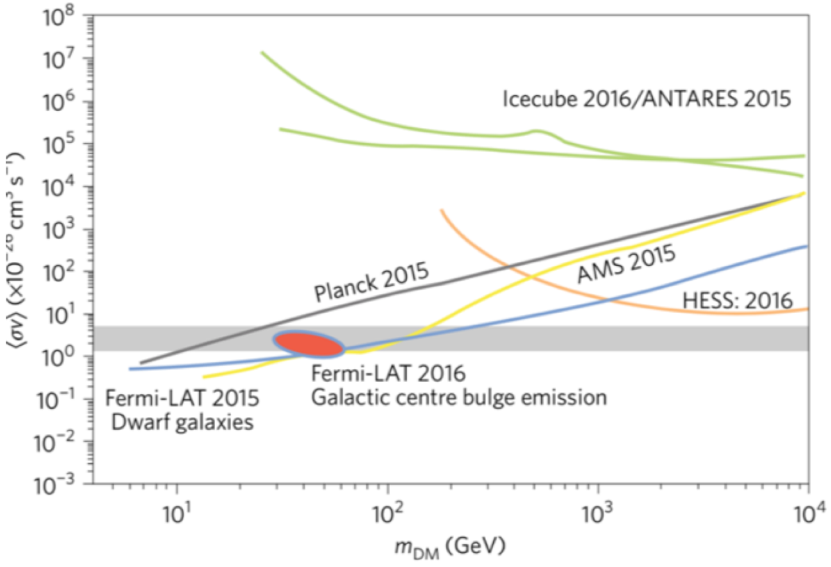


A two component DM decay would fit the AMS e+ excess

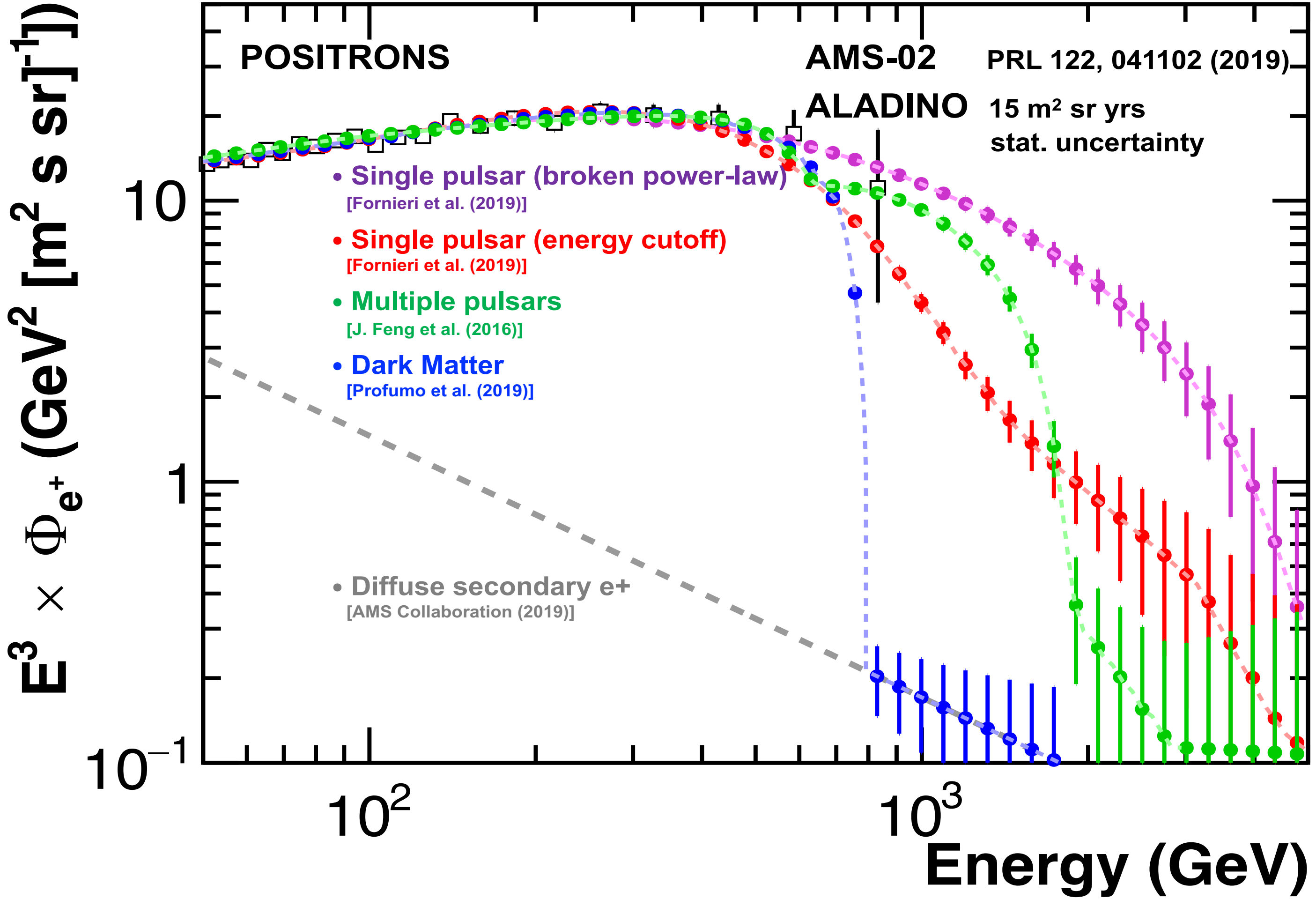
Profumo et al. arXiv:1903.07638v1 [hep-ph] 18 Mar 2019

Understanding the AMS positron peak origin in term of DM:



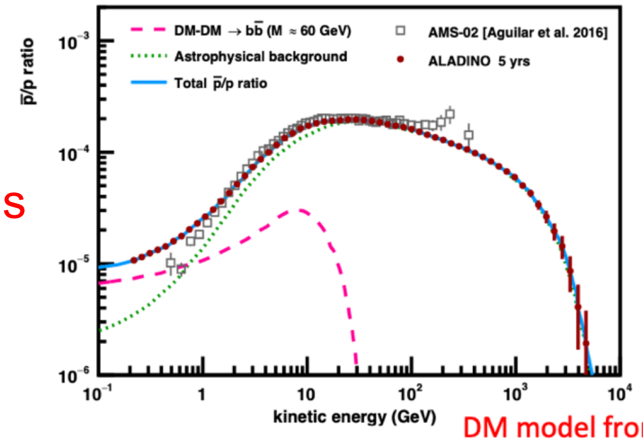


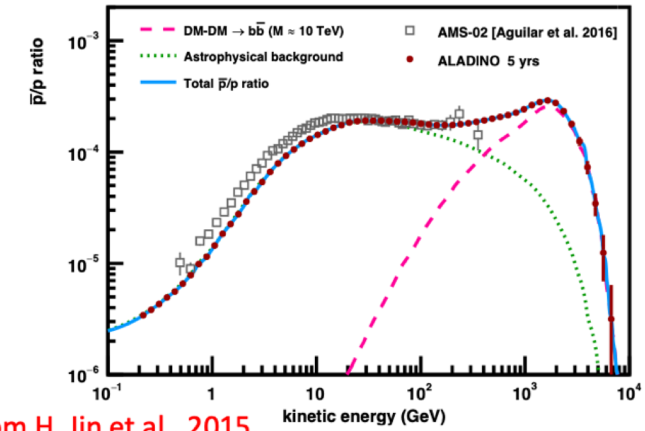
ALADInO would clearly identify the origin of the AMS positron excess



ALADInO: example of additional antiprotons anti-deuterium and anti-helium potential DM signatures

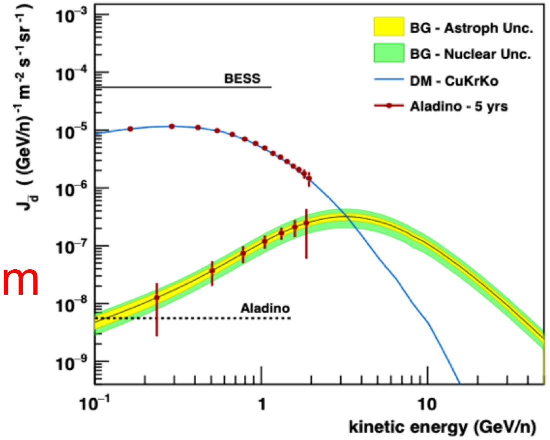
antiprotons

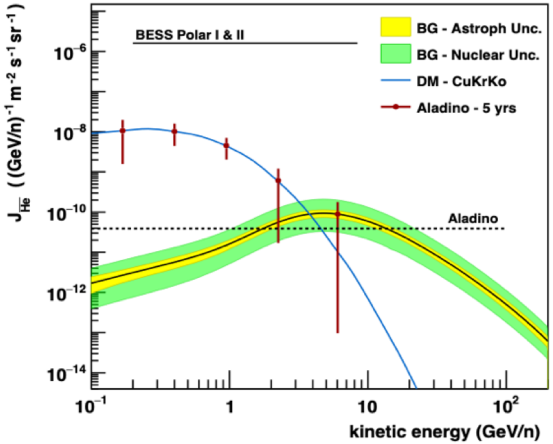




DM model from H. Jin et al., 2015, Phys. Rev. D 92, no. 5, 055027

anti-deuterium





anti-helium

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

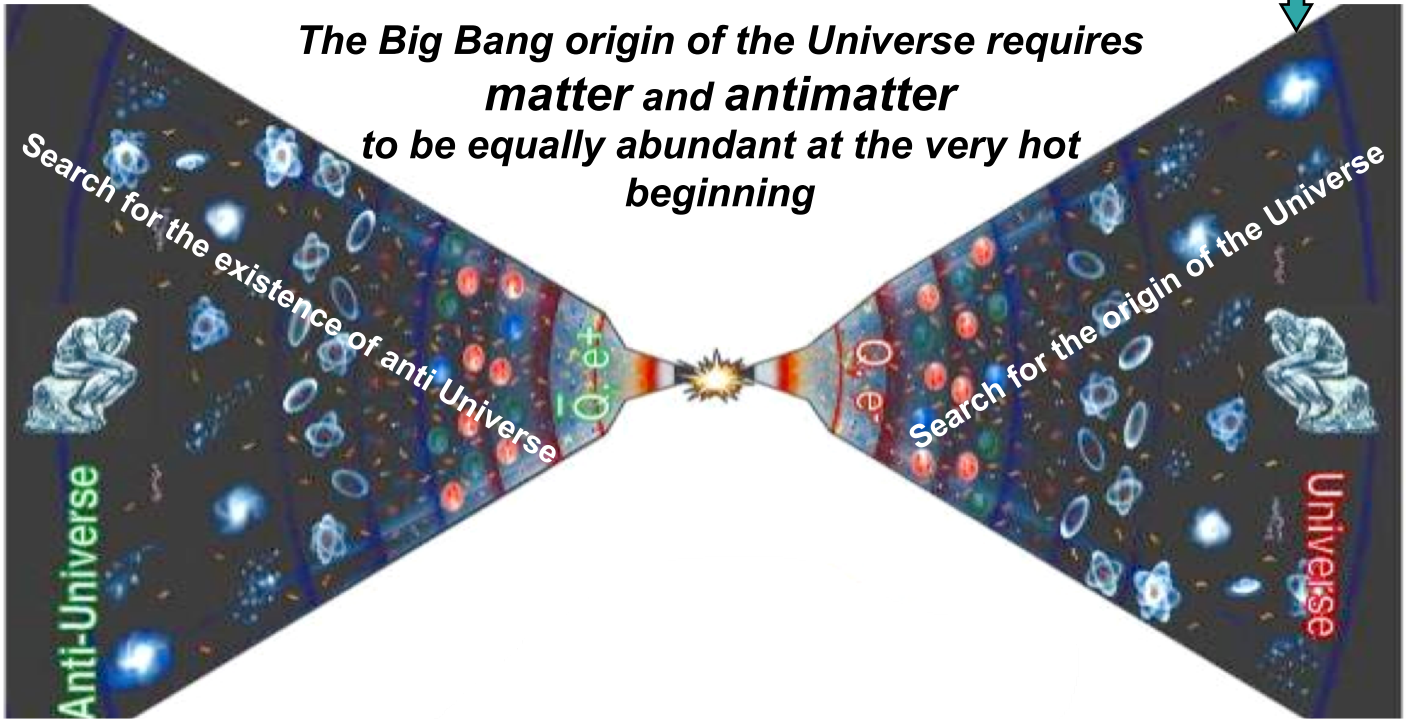
High DM masses >O(1) TeV/c^2 are also compatible with limits from LHC & direct searches

Precision measurements of the detailed features of the energy spectra and arrival directions of CR positrons and electrons at the TeV scale are needed to clarify whether DM annihilations or new astrophysics phenomena are the surce of the anomalies observed on the positron flux.

Second example of physics topics for High Precision Particle Astrophysics: «Disappearance of nuclear antimatter»

Cosmic Rays in Space

The Big Bang origin of the Universe requires ***matter*** *and* ***antimatter*** *to be equally abundant at the very hot beginning*



AMS

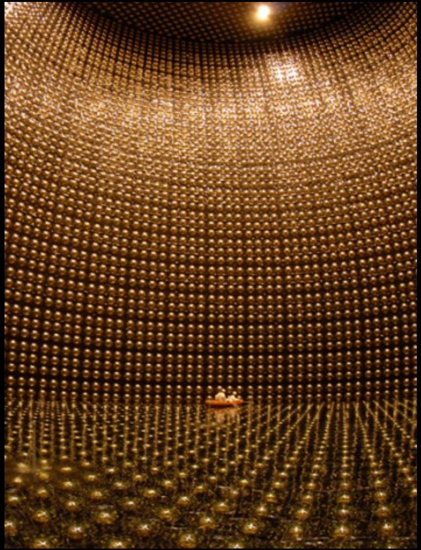
Observation and detailed study of nuclear antimatter would be a game changer in our understanding of the physics of early Universe and of the fundamental properties of particle and fields.

Experimental work on Antimatter in the Universe

Search for Baryogenesis

New symmetry breaking

Proton has finite lifetime



LHC-b,

Super Kamiokande

$\tau_p > 6.6 * 10^{33}$ years

No explanation found for the absence of antimatter (no reason why antimatter should not exist)

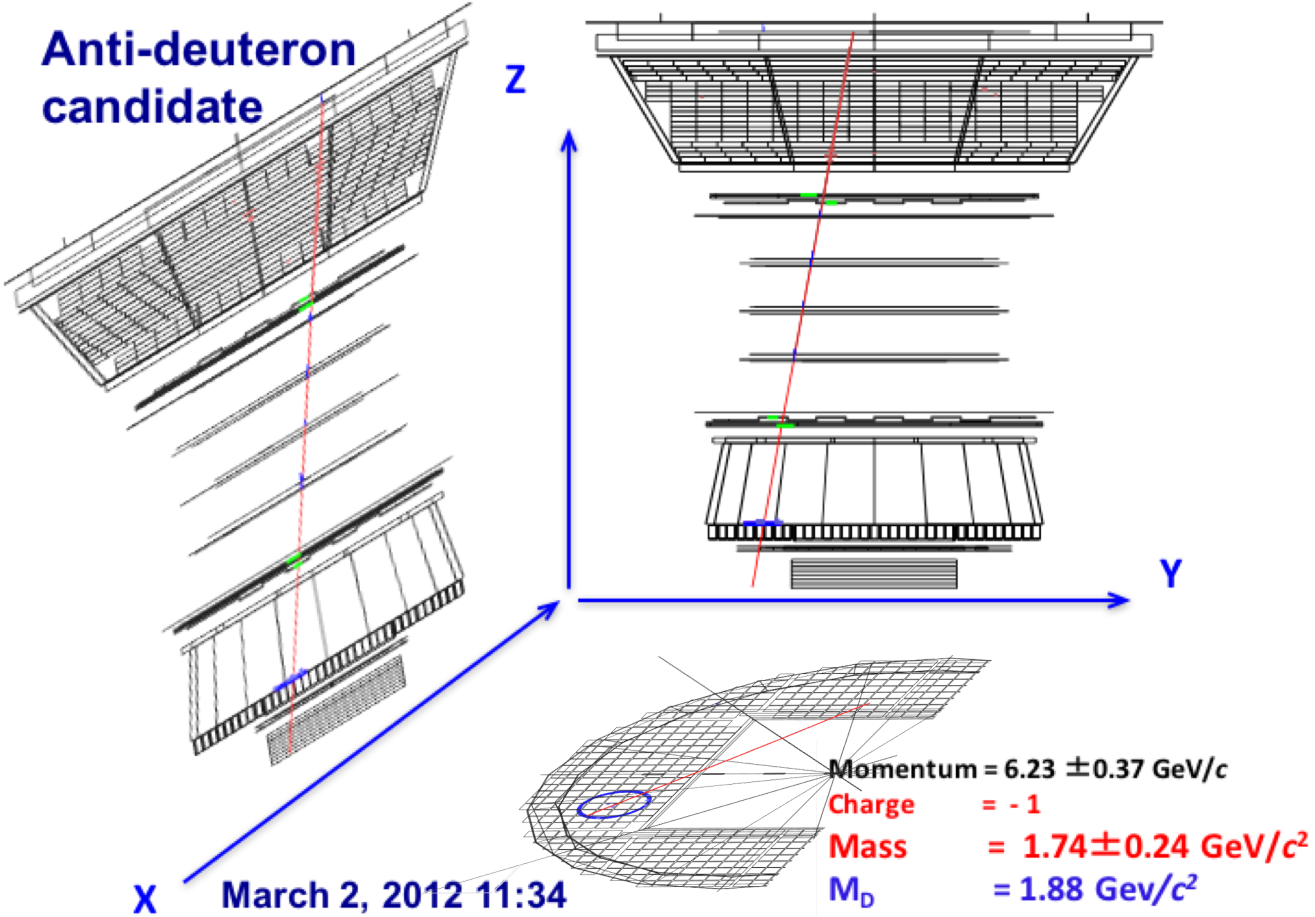
Direct search

AMS

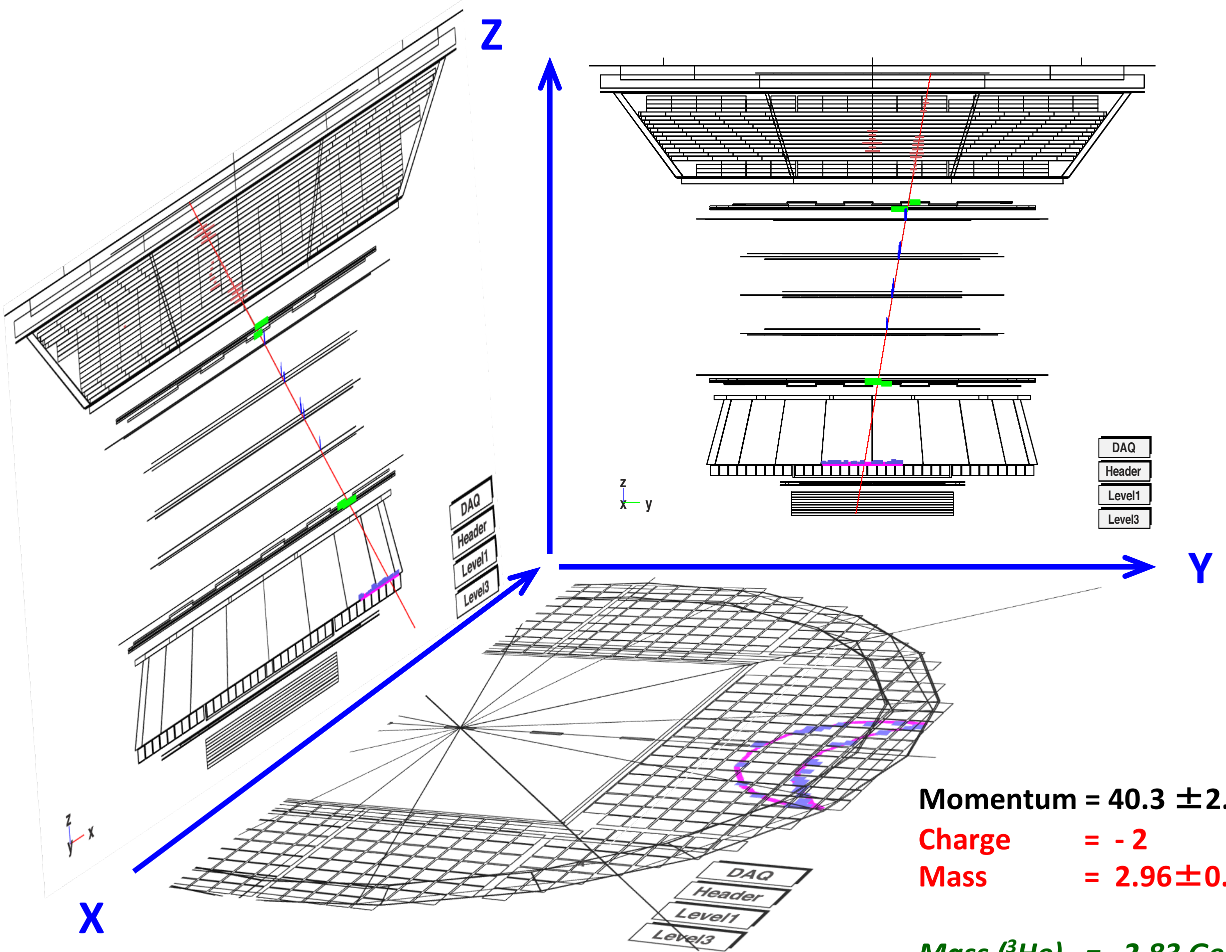
Increase in sensitivity: x $10^3 – 10^6$

Increase in energy to ~TeV

An anti-deuteron candidate (AMS preliminary)



An anti-^{3}He candidate (AMS preliminary)



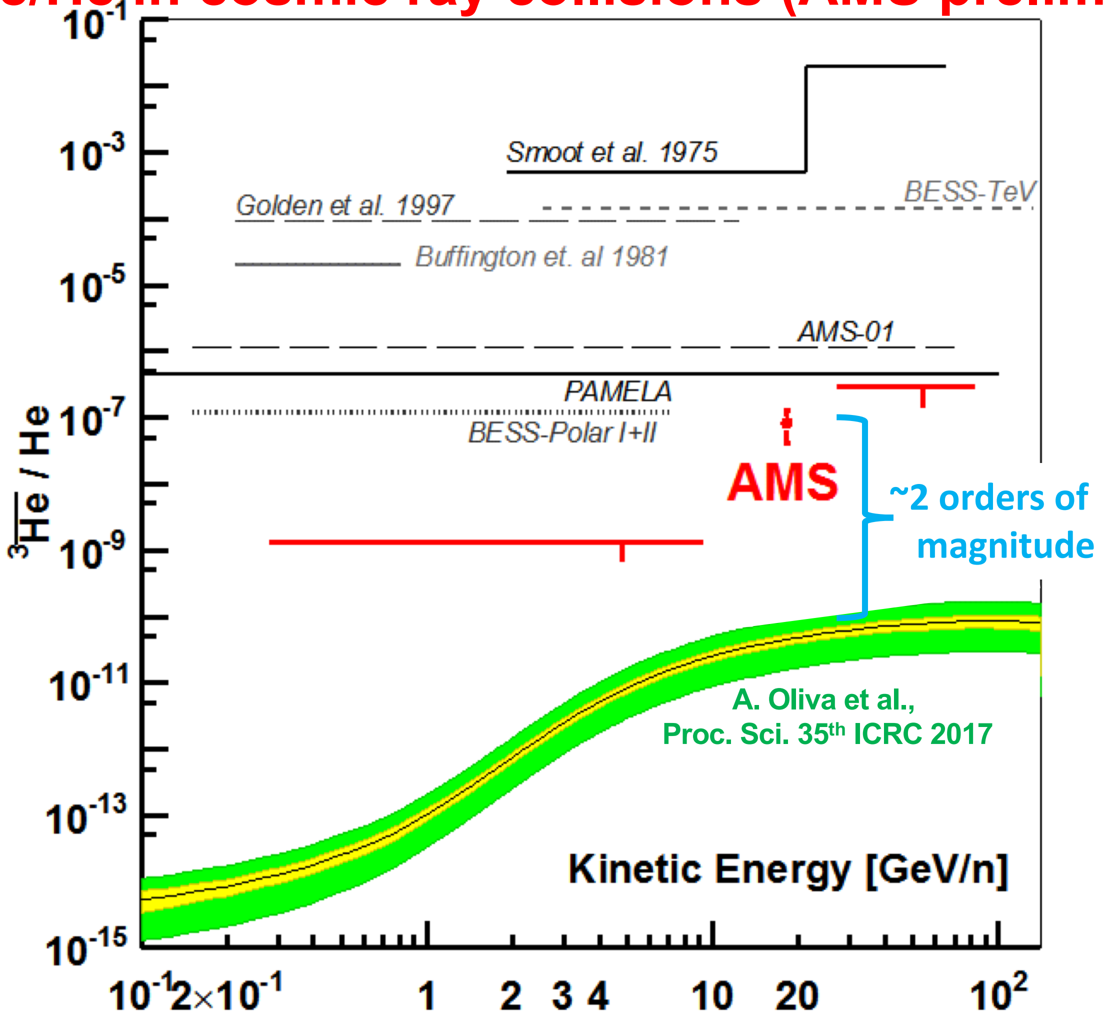
Momentum = 40.3 ±2.9 GeV/*c*

Charge = - 2

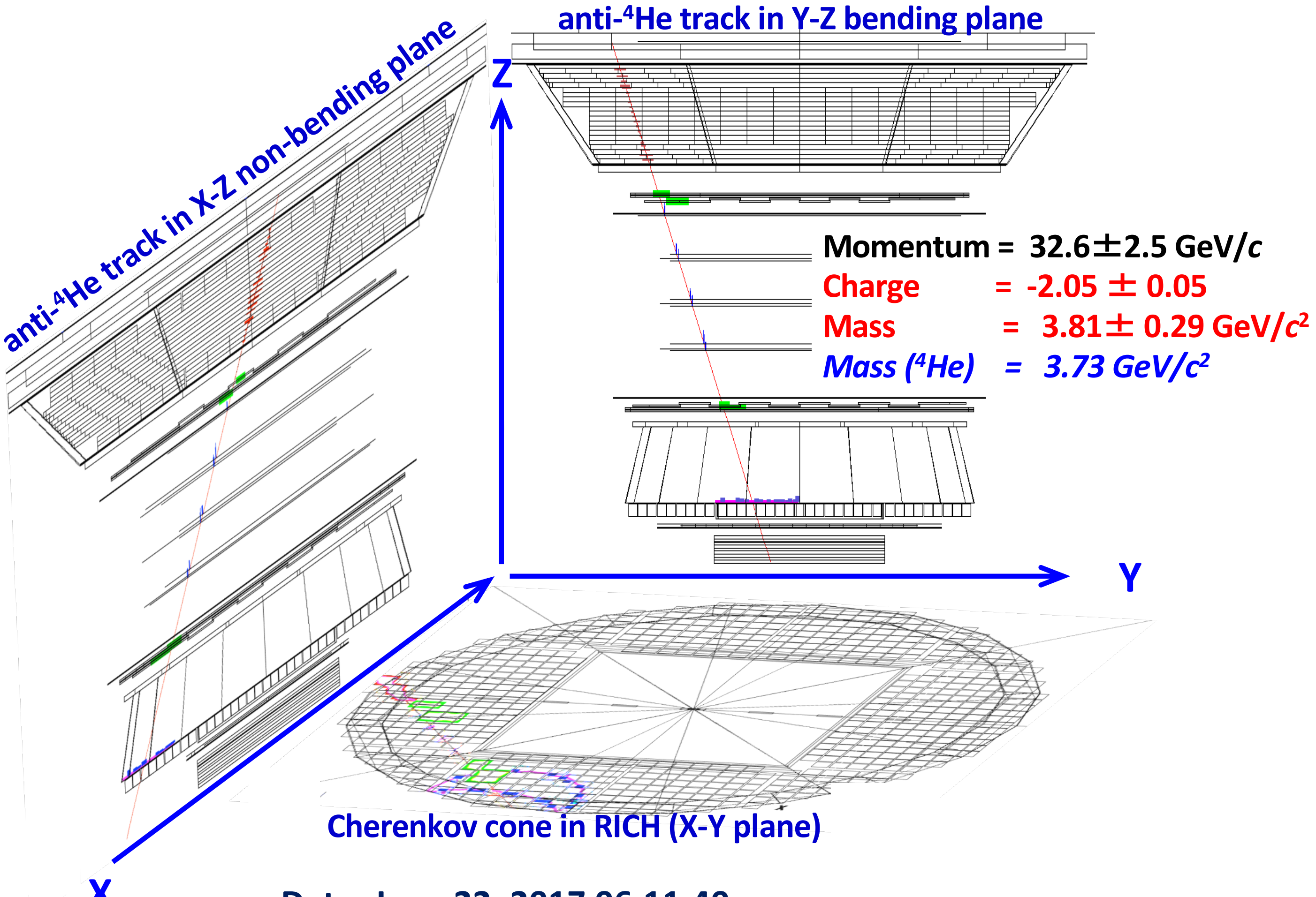
Mass = 2.96±0.33 GeV/*c*^{2}

Mass (^{3}He) = 2.83 GeV/c ^{2}

$^3\overline{He}/He$ in cosmic ray collisions (AMS preliminary)



An anti-^{4}He candidate (AMS preliminary)



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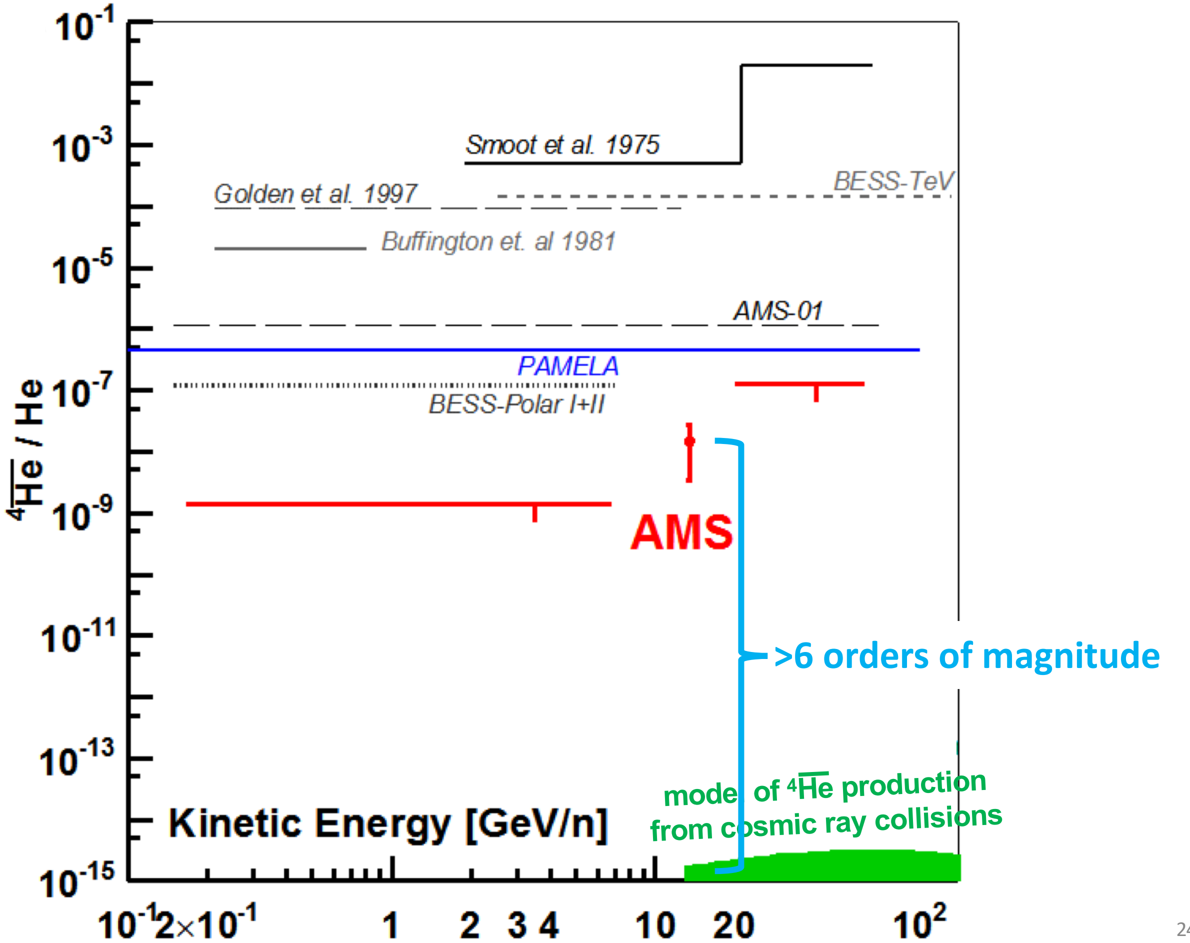
The AMS $^4\overline{\text{He}}$/He ratio is six orders of magnitude greater than predictions based on cosmic ray collisions (AMS preliminary)



Breakthrough physics

AMS / 7 years / ISS

120 Billions of events collected

about 1 anti-He event/year

Statistical sample too small to allow for accurate MC simulation ($1/10^{10}$) particles

ALADInO will observe 100 times more event/year than AMS

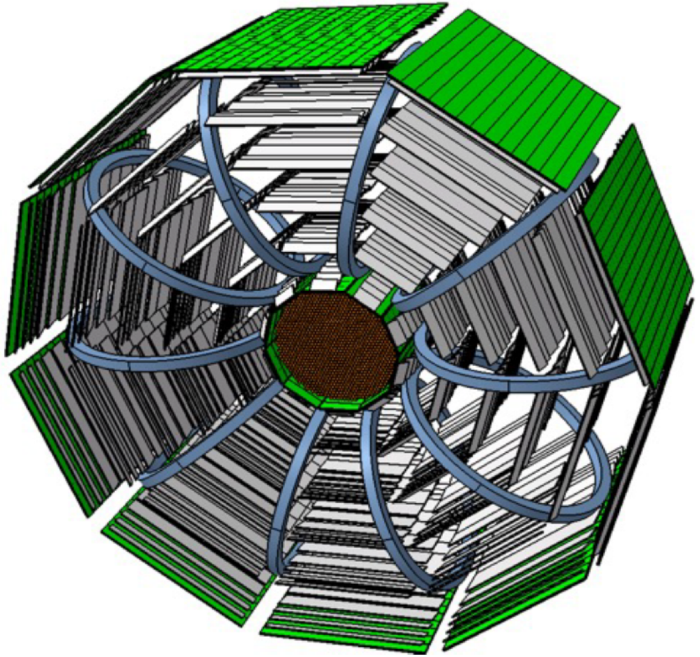
Allowing for

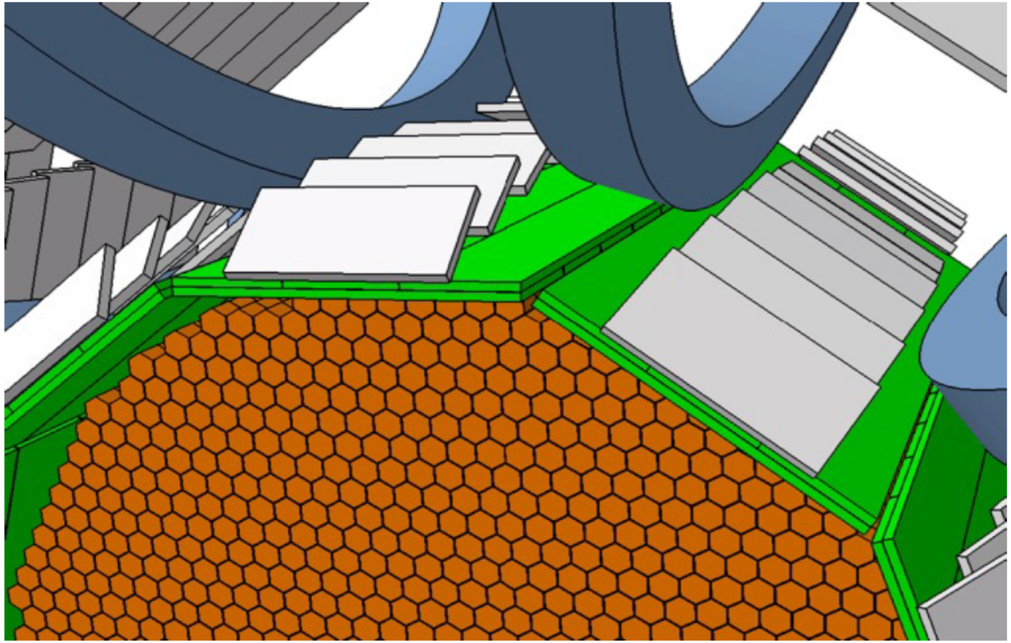
1- unambiguous determination of the antimatter signal

2- measurement of mass and energy spectrum

3- search of higher Z antimatter

An Antimatter Large Acceptance Detector In Orbit
ALADInO



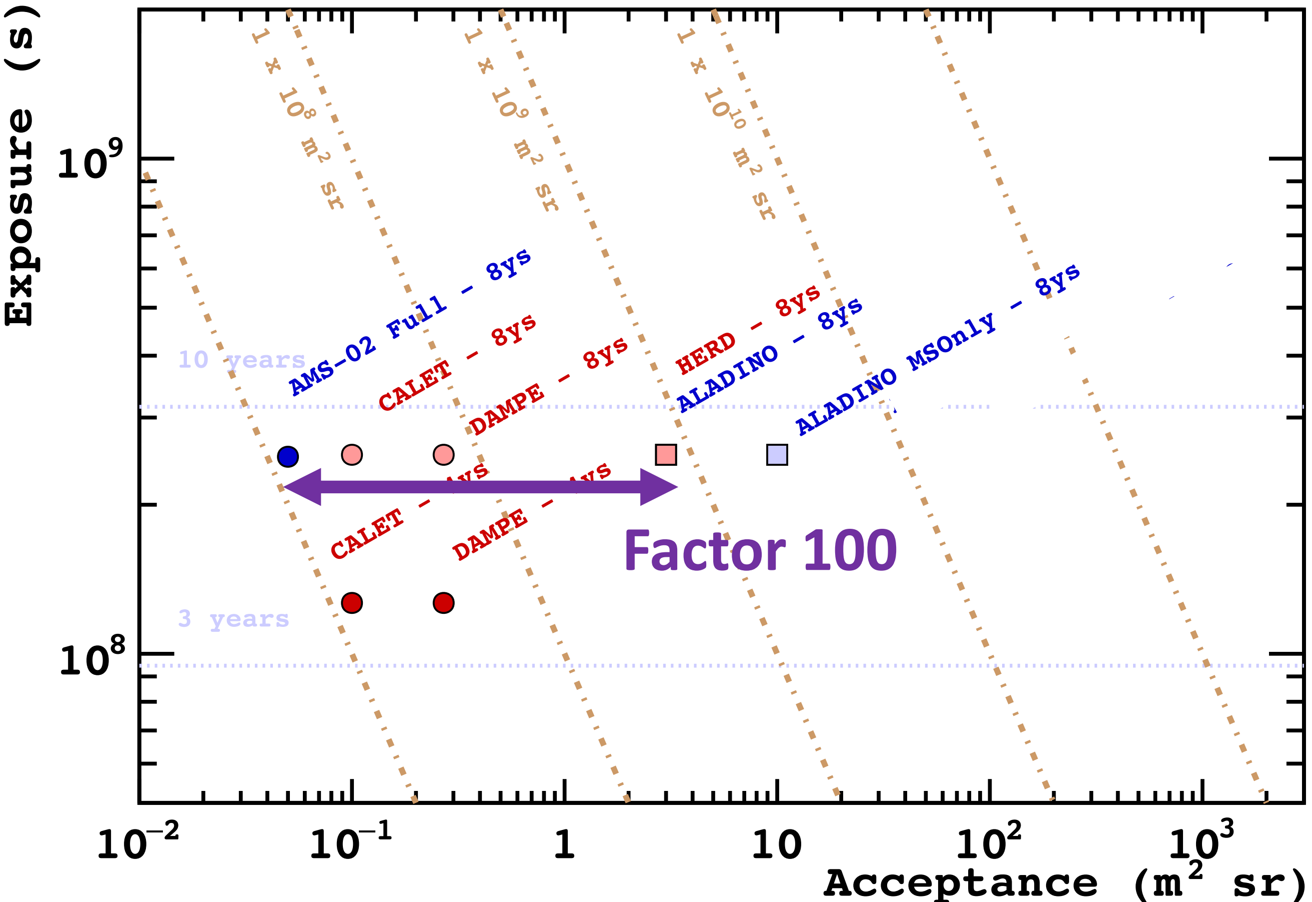


ALADiNO
Performances (10x - 100x current/future)

Calorimeter acceptance	~ 9 m^2 sr
Spectrometer acceptance	>10 m^2 sr (~ 3 m^2 sr w/i CALO)
Spectrometer Maximum Detectable Rigidity (MDR)	> 20 TV
Calorimeter depth	61 X_0, 3.5 λ_I
Calorimeter energy resolution	25% ÷ 35% (for nuclei) 2% (for electrons and positrons)
Calorimeter e/p rejection power	> 10^5
Time of Flight measurement resolution	~100 ps
High energy γ-ray acceptance (Calorimeter)	~ 9 m^2 sr
Low energy γ-ray acceptance (Tracker)	~ 0.5 m^2 sr
γ-ray Point Spread Function	< 0.5 deg

Table 1: *Key performance parameters of the ALADINO apparatus*

ALADiNO: the ultimate space detector for High Precision Astroparticle Physics



ALADiNO technology path:

- **Tracker**: *silicon strip detectors*, **already space qualified (AMS, Pamela, Fermi, Agile, Dampe…)**
- **Tracker**: *pixel strip detectors*, **advanced development for LHC upgrade ongoing (CERN-Atlas, Alice), space qualification ongoing (ASI - CSES2)**
- **Calorimeter**: *cube crystals* **R&D completed for HERD, space qualification ongoing (INFN)**
- **Superconducting Magnet**: *YBCO magnets* **under advanced development at CERN for LHC upgrade and future accelerators. Long standing collaboration between ASI, INFN and CERN.** ***Space qualification needed.***
- **Low power cryogenics**: *very efficient Pulsed Heat Pipes* **developed through the H2020 SR2S program (CEA Saclay).** ***Space qualification needed***
- **Electronics**: **extensive experience and space qualification of** *CERN experiments (micro) electronics up to O(10^6) channels* **: AMS, Pamela, Fermi, Agile, Dampe…**
- **Thermal shield**: *passive thermal shield* **to be derived from e.g. Planck, Gaia**

Lagrangian Point L2

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

Conceptual design of a high temperature superconducting magnet for a particle physics experiment in space

Magnus Dam[1], Roberto Battiston[2,3], William Jerome Burger[3], Rita Carpentiero[4], Enrico Chesta[1], Roberto Iuppa[2,3], Gijs de Rijk[1] and Lucio Rossi[1,5]

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[4] ASI, Italian Space Agency, IT-00133 Rome RM, Italy
[5] On leave from: Department of Physics, University of Milan, IT-20133 Milano MI, Italy

ALADiNO pathfinder strategy:

- **PATHFINDER:**
  - Reduced magnetic field (10 times less) same collecting area
  - Physics goal : nuclear antimatter up to 100 GV, first class science
  - Physics goal : precision GeV energy CR physics
  - 2 Tons weight

~ 2030

- **FULL VERSION:**
  - Full magnetic field
  - 6.5 Tons weight
  - Lagrangian 2 point
  - Physics goal :
    - nuclear antimatter up to 1000 GV
    - Dark matter at the multi TeV/c^2
    - Composition of CR in the multi 10 TV, approaching the knee

~ 2040

Core Team members

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AMS-01

AMS-02

Pamela

FERMI

Dampe

Arina

Agile

CSES-01

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