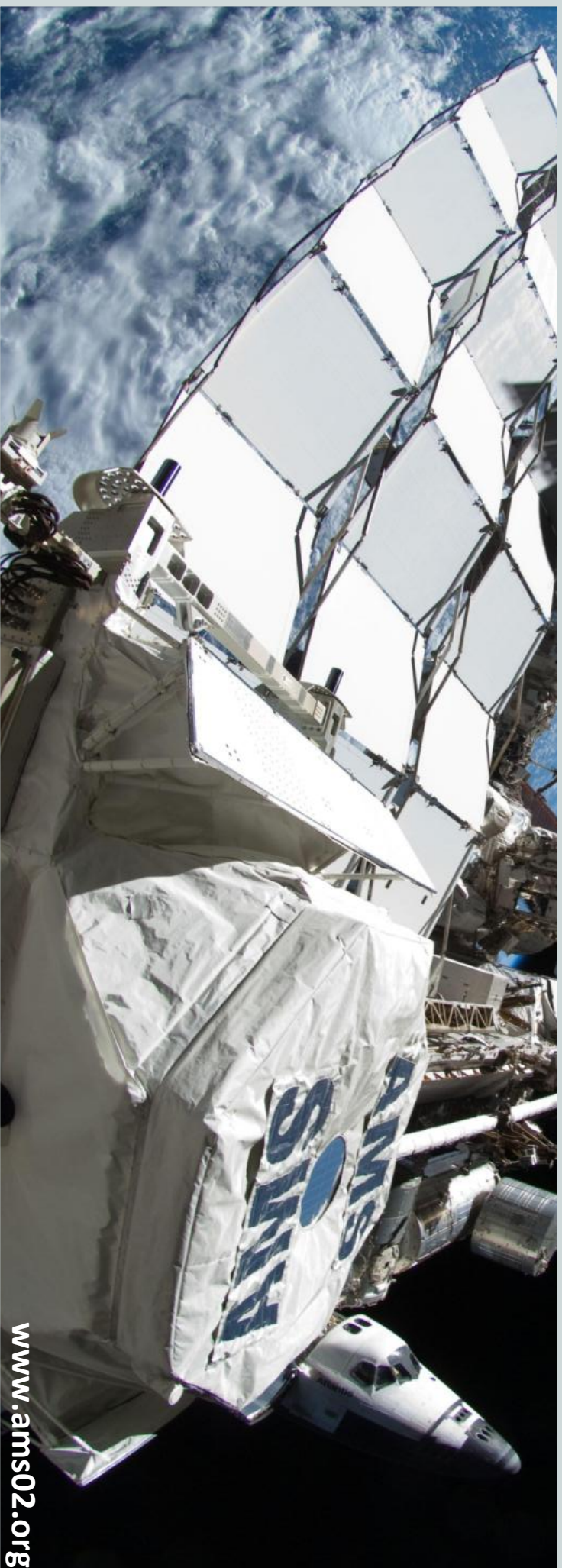


Cosmic ray detection in space

Valerio Vagelli

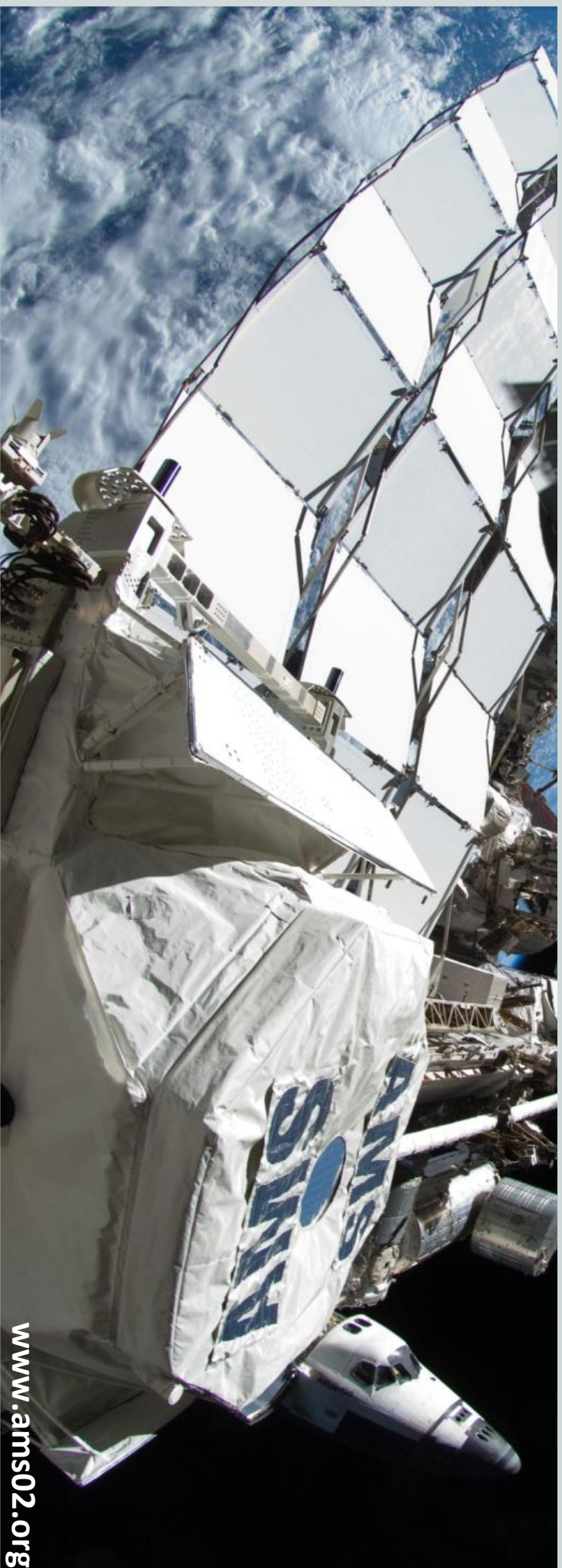
**I.N.F.N. Perugia, Università degli Studi di Perugia
Corso di Rivelatori di Particelle A.A. 2015/2016**



i) Introduction to Cosmic Rays ii) Space Borne Experiments iii) The AMS-02 detector

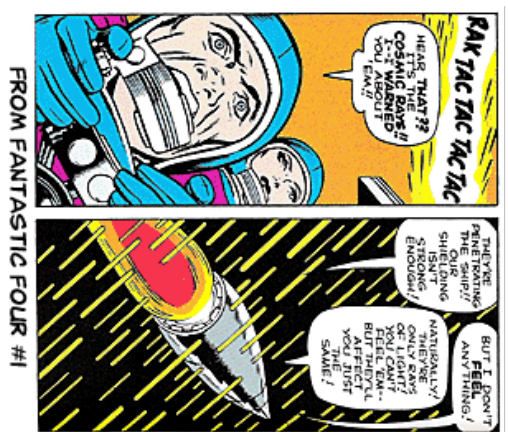
Valerio Vagelli

**I.N.F.N. Perugia, Università degli Studi di Perugia
Corso di Rivelatori di Particelle A.A. 2015/2016**



Cosmic Rays

Known by americans in 50s and used to grant superpowers to superheroes



During 70s, cosmic rays were used by Japan as one of the weapons to defend our planet from Vegans

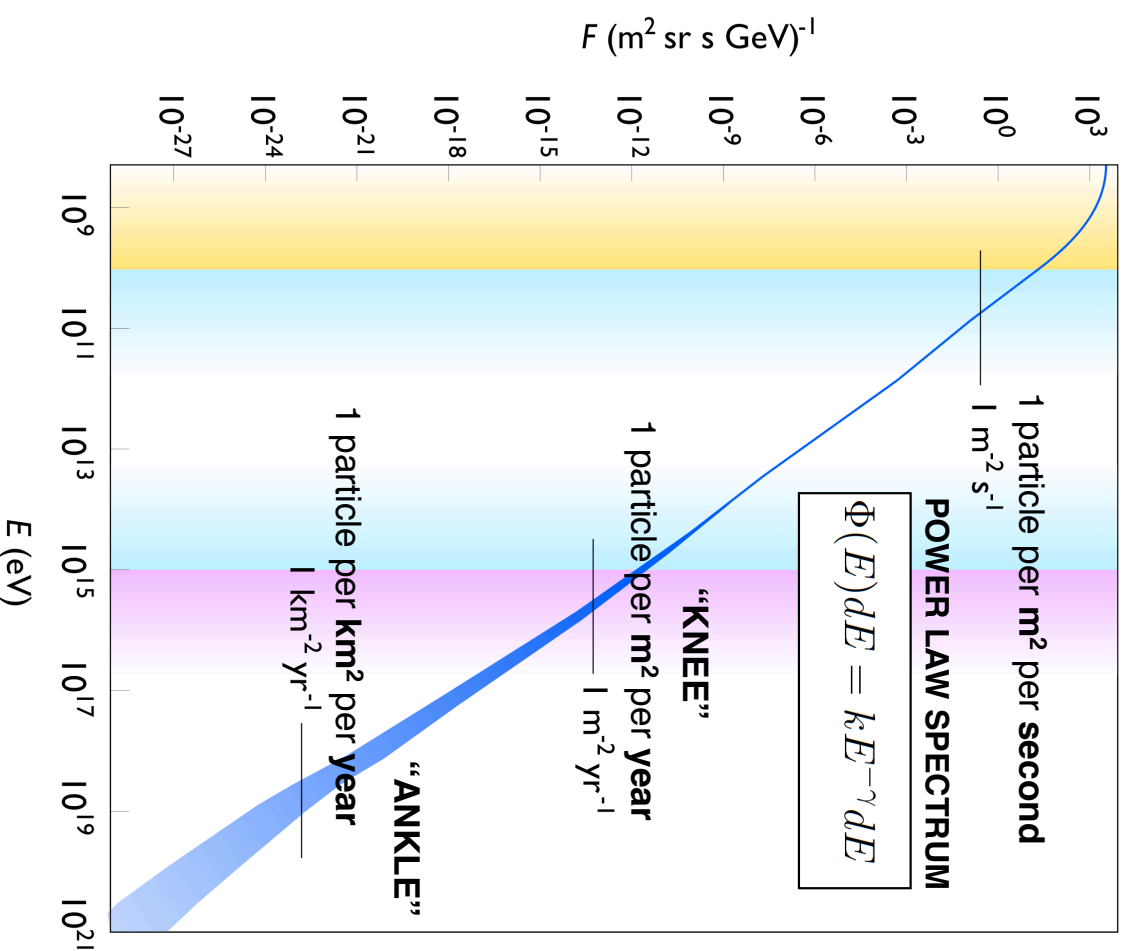


Cosmic rays are charged and neutral particles that reach Earth planet from outer space

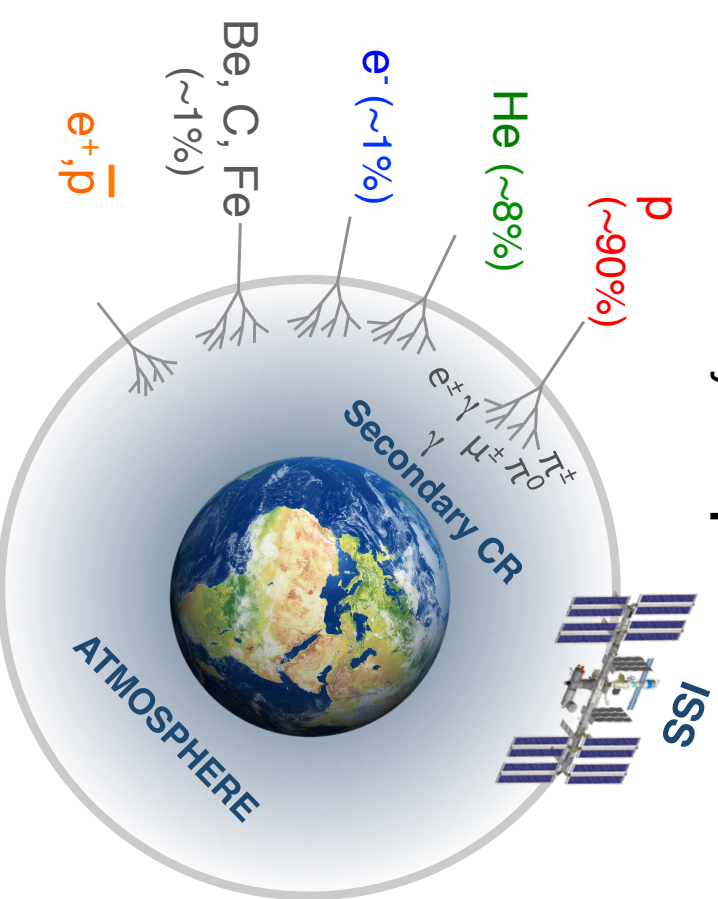


Cosmic Rays

Cosmic ray flux at Earth

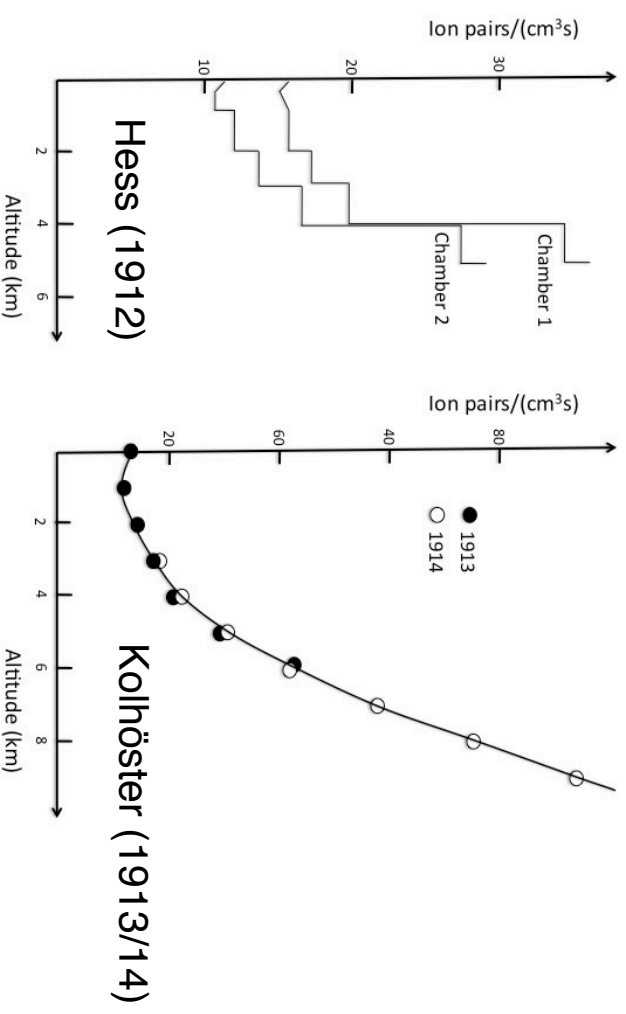


- Cosmic ray Flux: Intensity of CR in space per **unit of area, solid angle, time and energy**
- Energy range up to **10^{20} eV**
- Intensities spanning **30 orders of magnitude**
- Most of cosmic rays are protons and nuclei



Discovery of Cosmic Rays

- V. Hess balloon flight in 1912 → evidence of increase of ionization in atmosphere



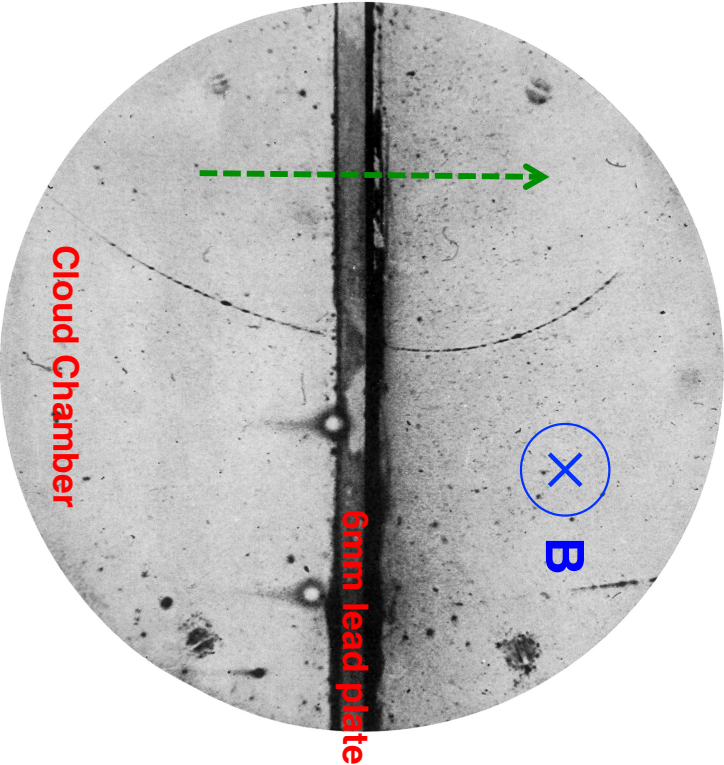
- 1931: Rossi → East-West effect: most of cosmic rays have positive charge
- 1934: Hess → Detection of extensive air showers
-
- 2013: NASA → Radiation Risk from Cosmic Rays may prevent a possible man mission to Mars

Cosmic Rays and Particle Physics

Particle	Year	Discoverer (Nobel Prize)	Method
e^-	1897	Thomson (1906)	Discharges in gases
p	1919	Rutherford	Natural radioactivity
n	1932	Chadwick (1935)	Natural radioactivity
e^+	1933	Anderson (1936)	Cosmic Rays
$\mu^\pm$	1937	Neddermeyer, Anderson	Cosmic Rays
$\pi^\pm$	1947	Powell (1950) , Occhialini	Cosmic Rays
$K^\pm$	1949	Powell (1950)	Cosmic Rays
π^0	1949	Bjorklund	Accelerator
K^0	1951	Armenteros	Cosmic Rays
Λ^0	1951	Armenteros	Cosmic Rays
Δ	1932	Anderson	Cosmic Rays
Ξ^-	1932	Armenteros	Cosmic Rays
$\Sigma^\pm$	1953	Bonetti	Cosmic Rays
p^-	1955	Chamberlain, Segre (1959)	Accelerators
anything else	1955 $\Rightarrow$ today	various groups	Accelerators
$m_\nu \neq 0$	2000	KAMIOKANDÉ	Cosmic rays

- Cosmic rays used as main source of high energy probes (beam-target interactions) until 50s
- After 2000, rediscovery of cosmic rays as probe for astrophysics and particle physics measurements

Discovery of positrons (Anderson)



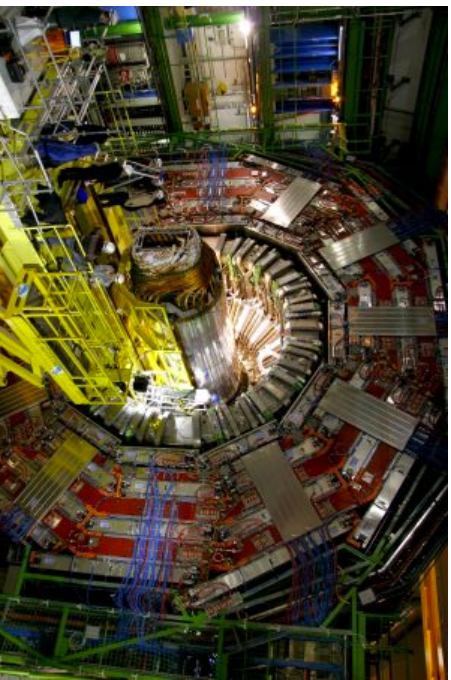
Cosmic Ray Physics

- **ASTROPHYSICS**

- Origin of cosmic rays
- Acceleration of charged particles up to PeV energies (“Pevatrons”)
- Peculiar sources (pulsars, quasars, black holes,)
- Star and solar system evolution
- Solar physics
-

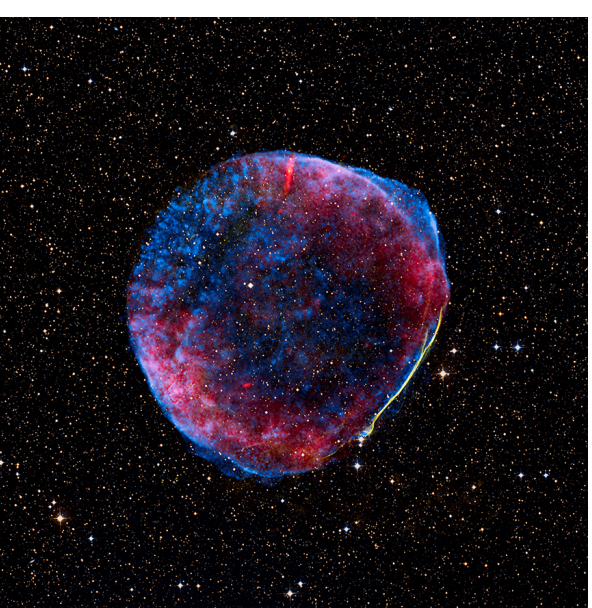
- **PARTICLE PHYSICS & COSMOLOGY**

- Hadronic interactions and X-sections (above LHC energies)
- Matter/Antimatter asymmetry
- Dark Matter searches
-



COSMIC RAYS

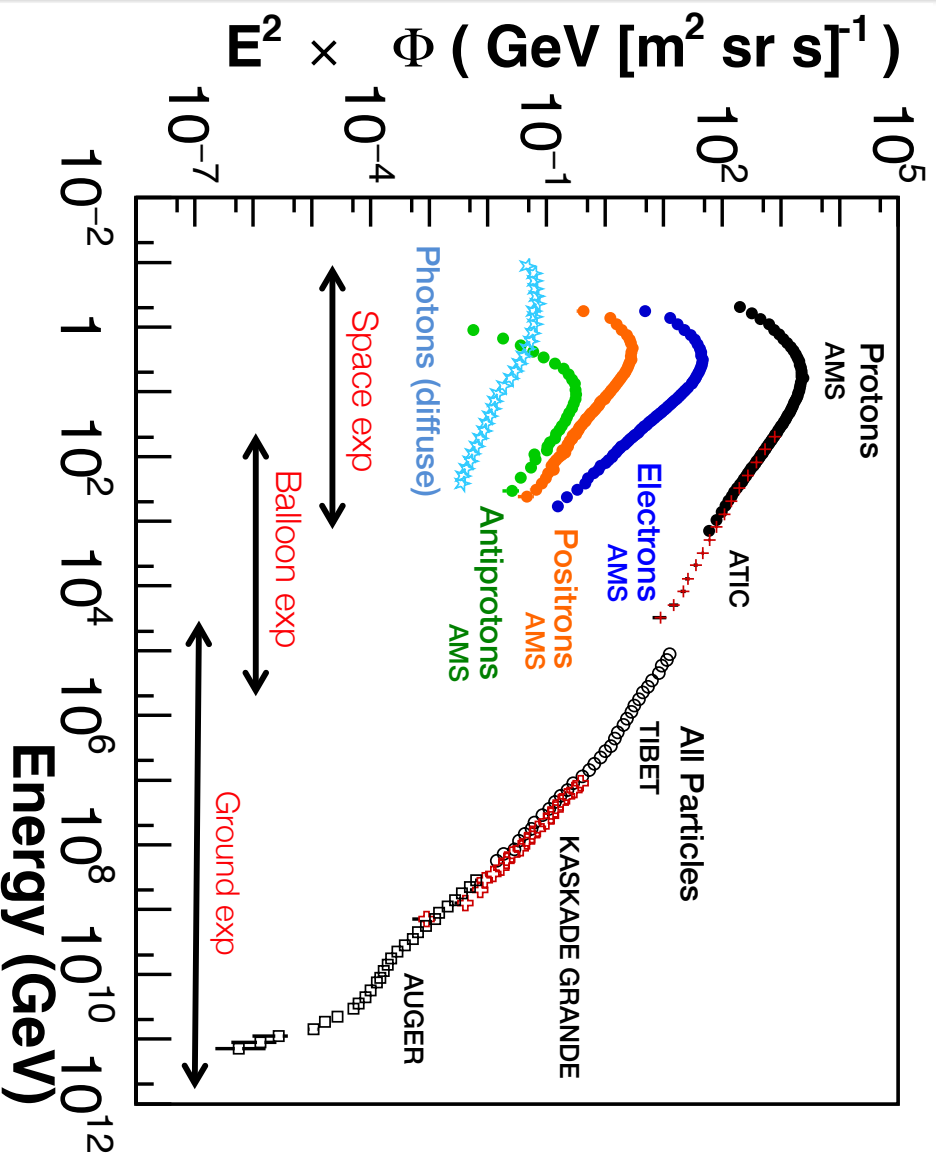
Intimate connection
between very small
and very high
distances



CMS experiment @ LHC

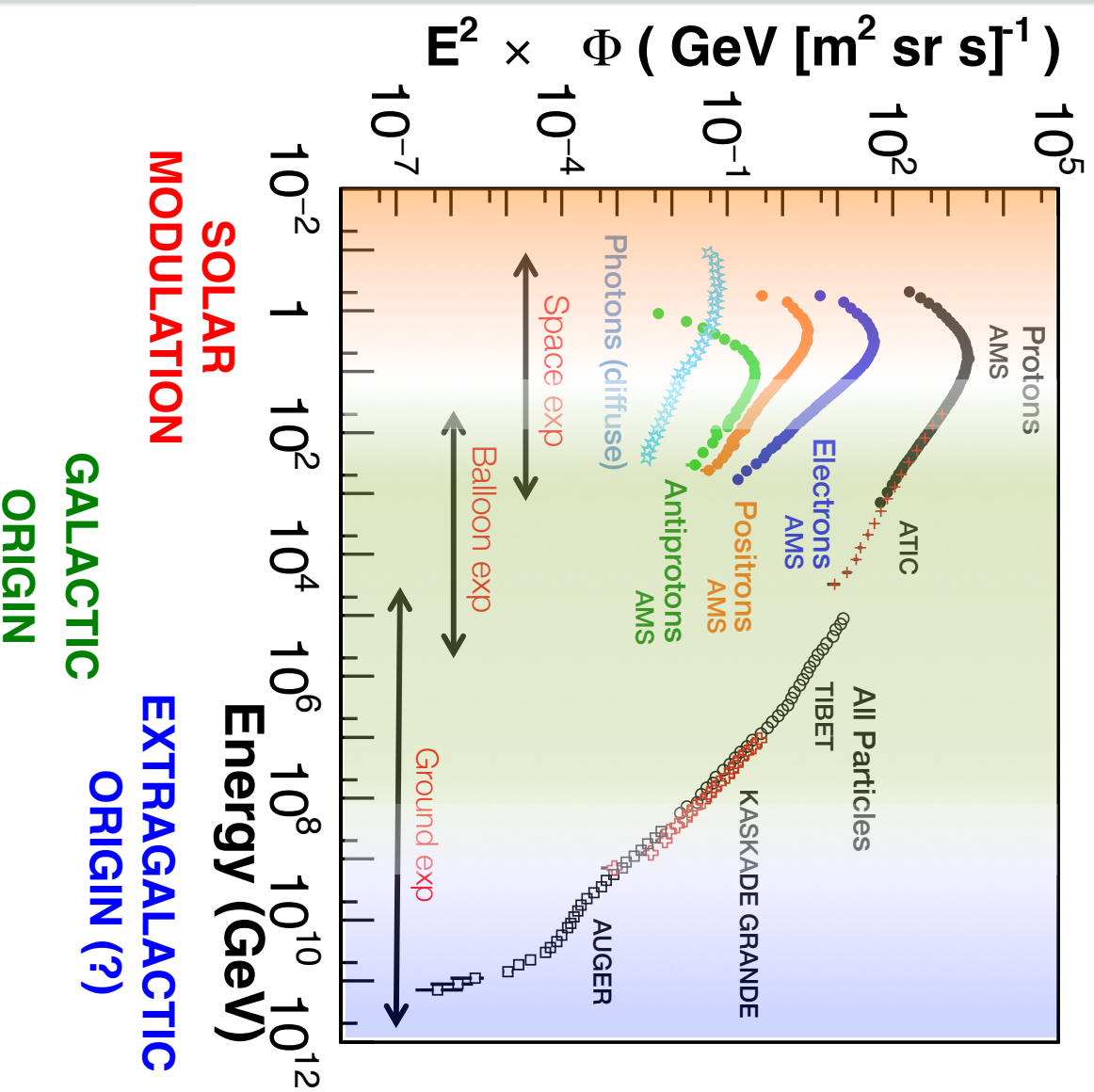
Supernova SN 1006

Cosmic Rays and Particle Physics



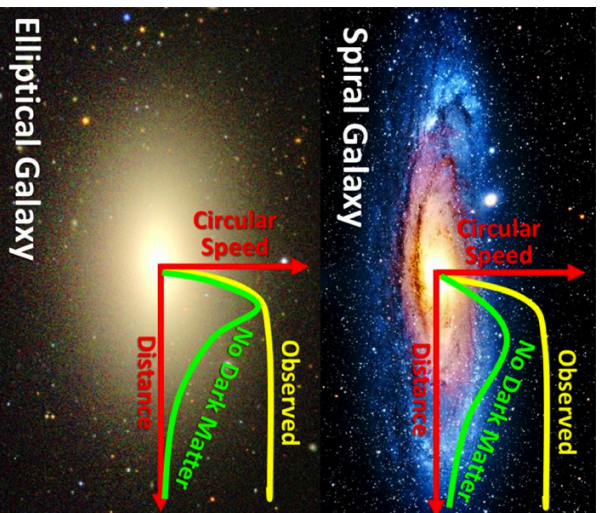
- Origin of very high energy CRs still not clear
- Many discussions about the origin of the “knee” and of the “ankle”
- Chemical composition above 1 TeV unknown
- Clear evidence of PeVatrons in the Universe

Cosmic Rays and Particle Physics



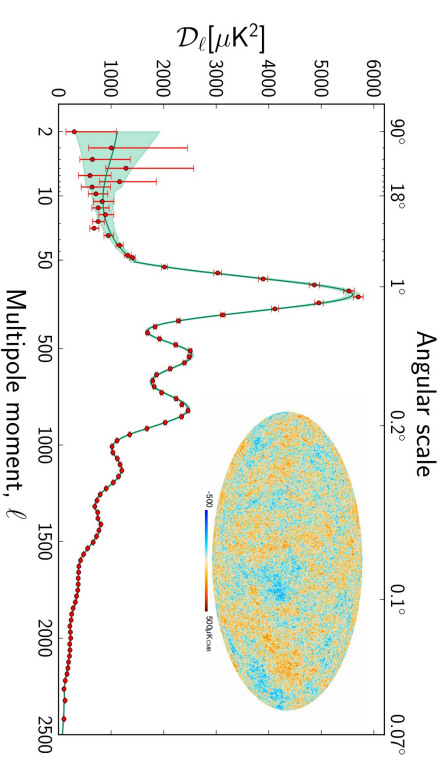
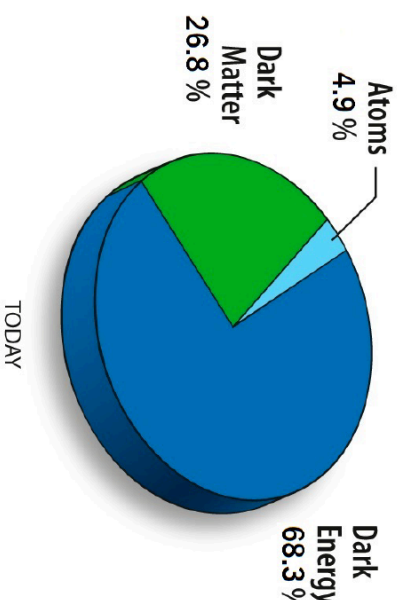
- Origin of very high energy CRs still not clear
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- Chemical composition above 1 TeV unknown
- Clear evidence of PeVatrons in the Universe

Physics topic example: Dark Matter

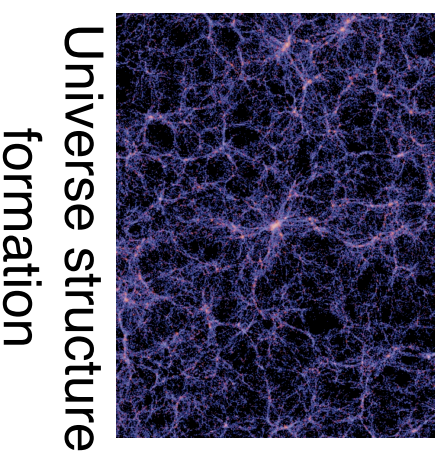


Galaxy rotation curves
(more grav. matter than what is
observed electromagnetically)

The “bullet” cluster
(matter that interacts only
gravitationally)

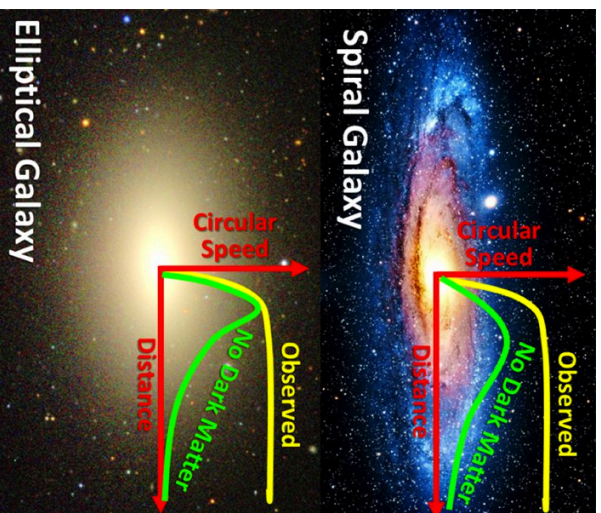


**Anisotropies of the residual
microwave background**
(requires Dark Matter and Dark Energy
to represent observations)



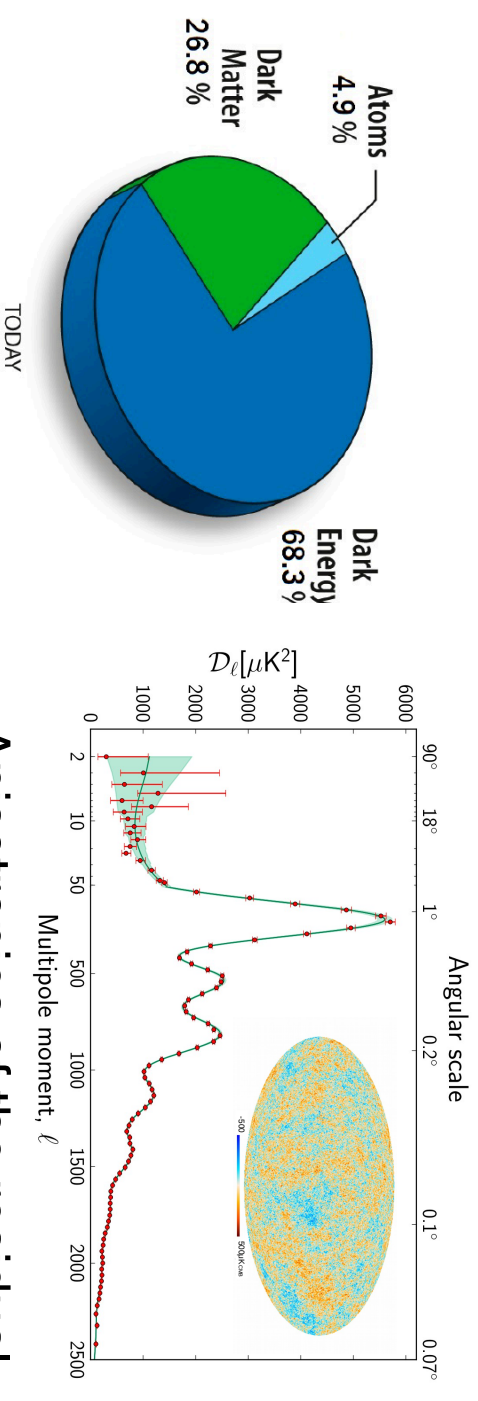
**Universe structure
formation**
(requires Dark Matter and Dark
Energy to represent observations)

Physics topic example: Dark Matter



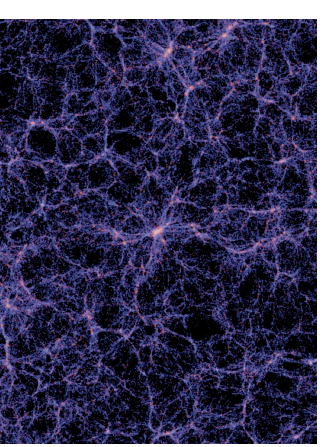
Galaxy rotation curves
(more grav. matter than what is
observed electromagnetically)

The “bullet” cluster
(matter that interacts only
gravitationally)



Dark Matter Exists!

Anisotropies of the residual
microwave background
(requires Dark Matter and Dark Energy
to represent observations)



Universe structure
formation
(requires Dark Matter and Dark
Energy to represent observations)

The quest for Dark Matter

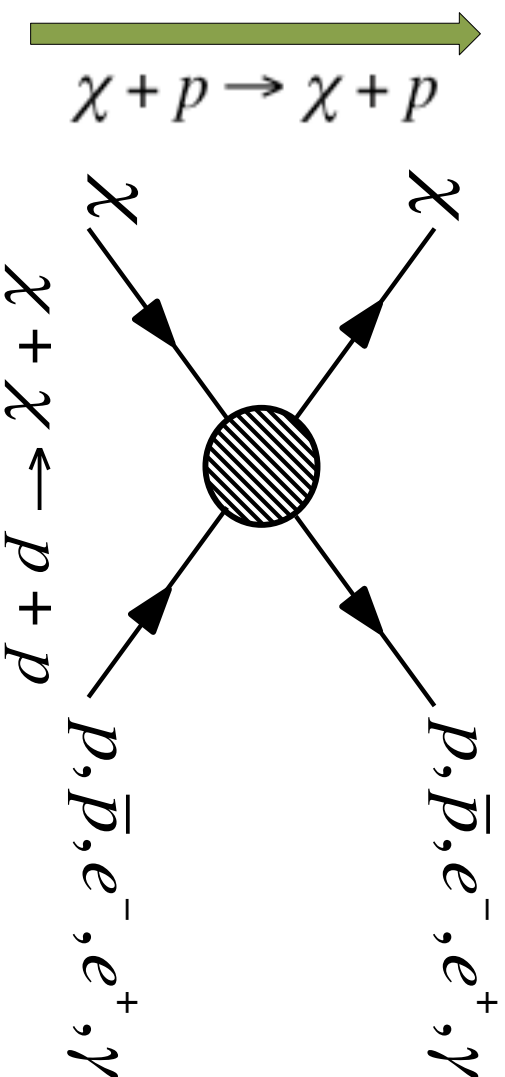
Cosmic Ray Experiments

(Pamela, AMS-02, DAMPE, Gaps,...)

Annihilation



$$\chi + \chi \rightarrow p, \bar{p}, e^-, e^+, \gamma$$



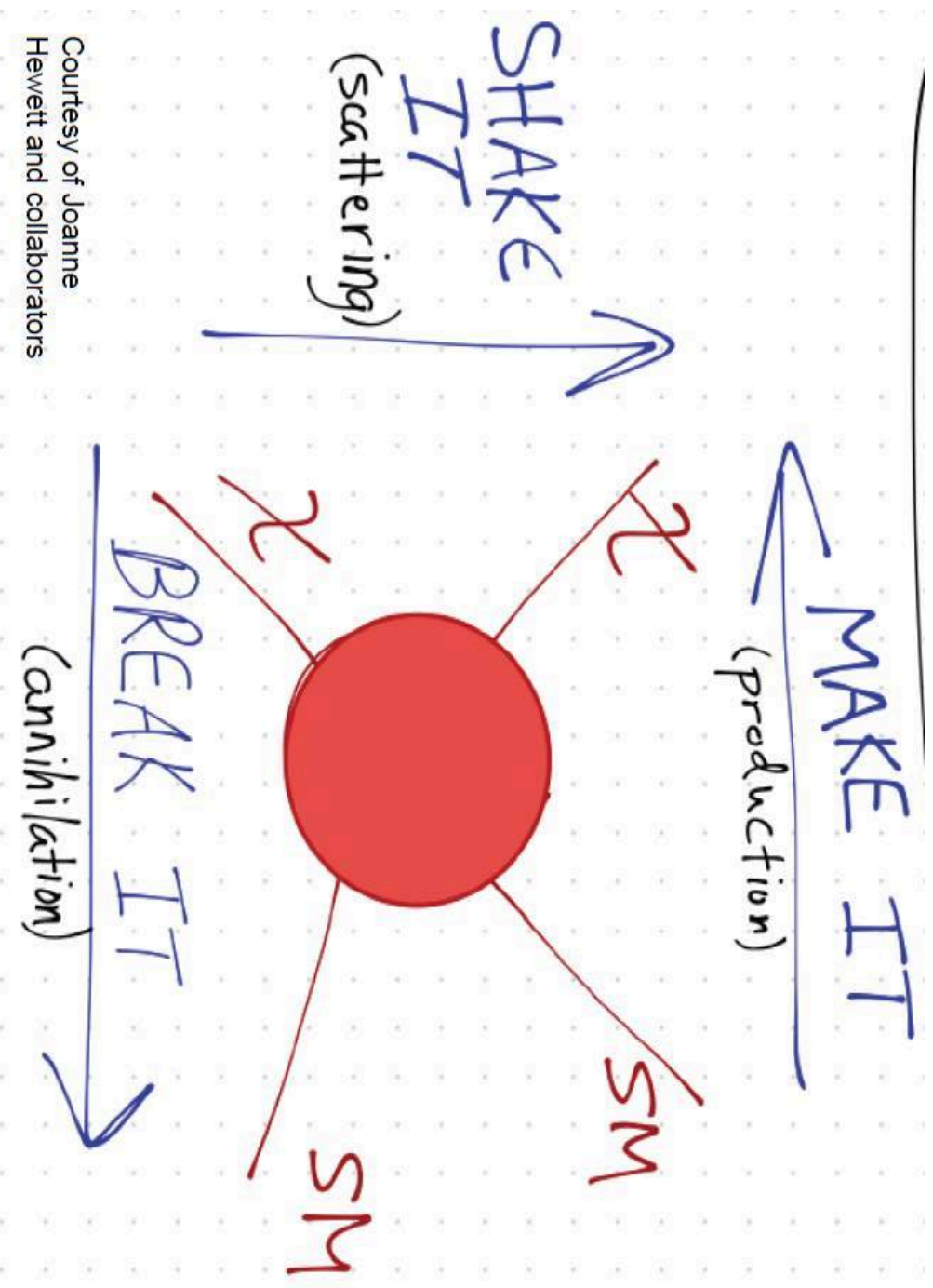
Underground
nuclear recoil
experiments
(DAMA, CRESST,
Edelweiss, LUX, ...)
Scattering



Production

LHC + future colliders

The quest for Dark Matter

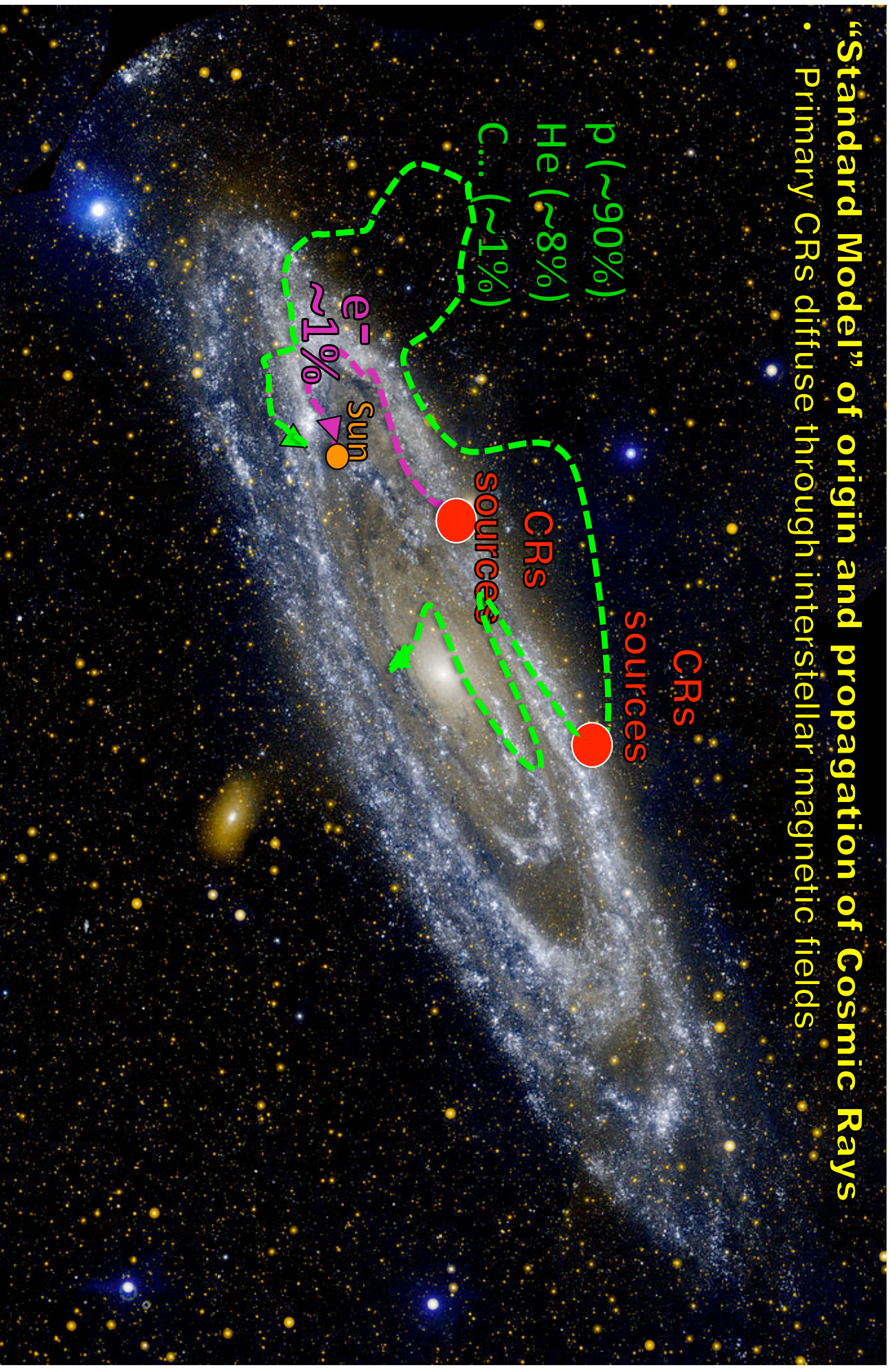


Courtesy of Joanne Hewett and collaborators

The “Standard Model” of Cosmic Rays

“Standard Model” of origin and propagation of Cosmic Rays

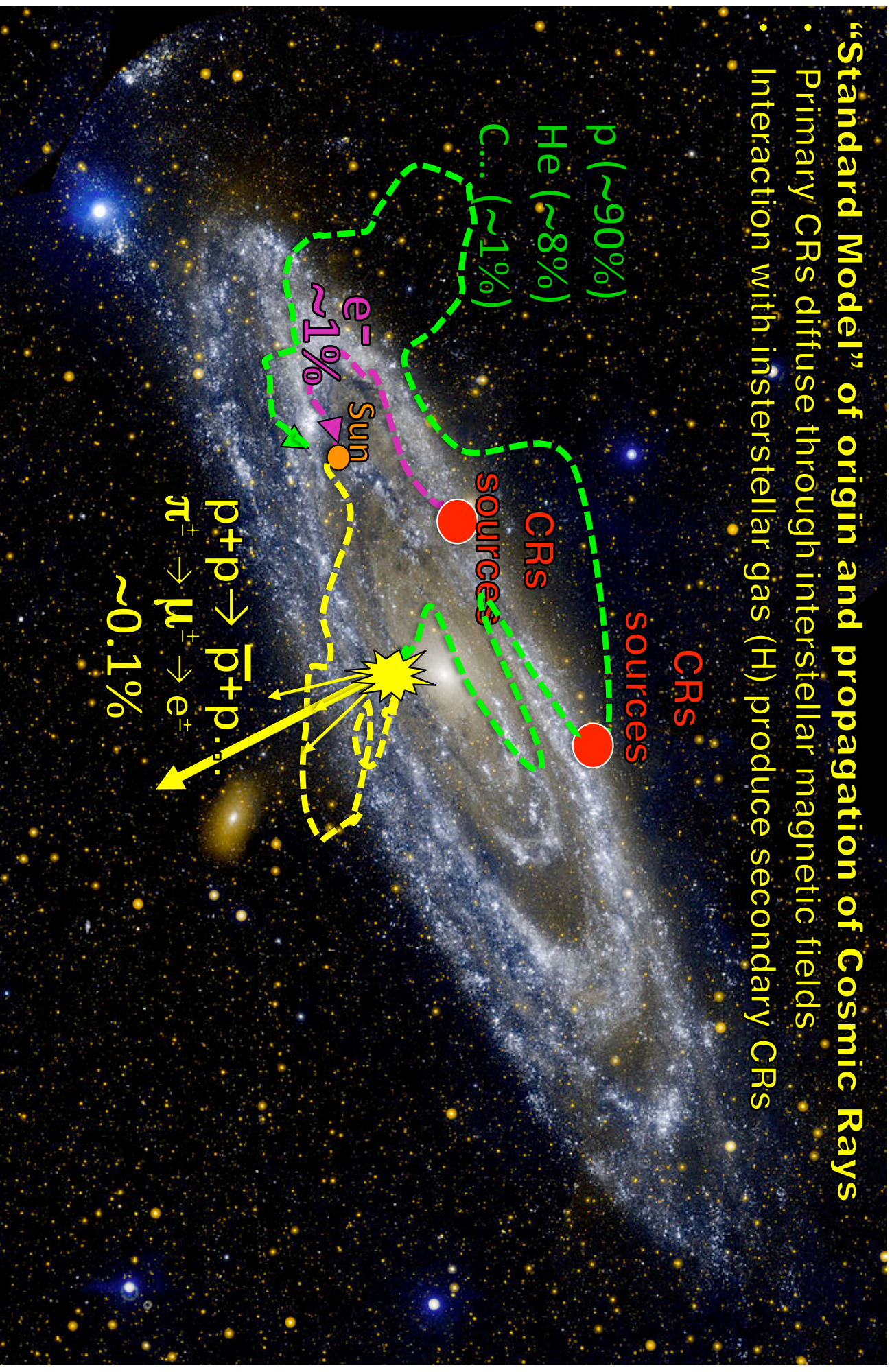
- Primary CRs diffuse through interstellar magnetic fields



The “Standard Model” of Cosmic Rays

“Standard Model” of origin and propagation of Cosmic Rays

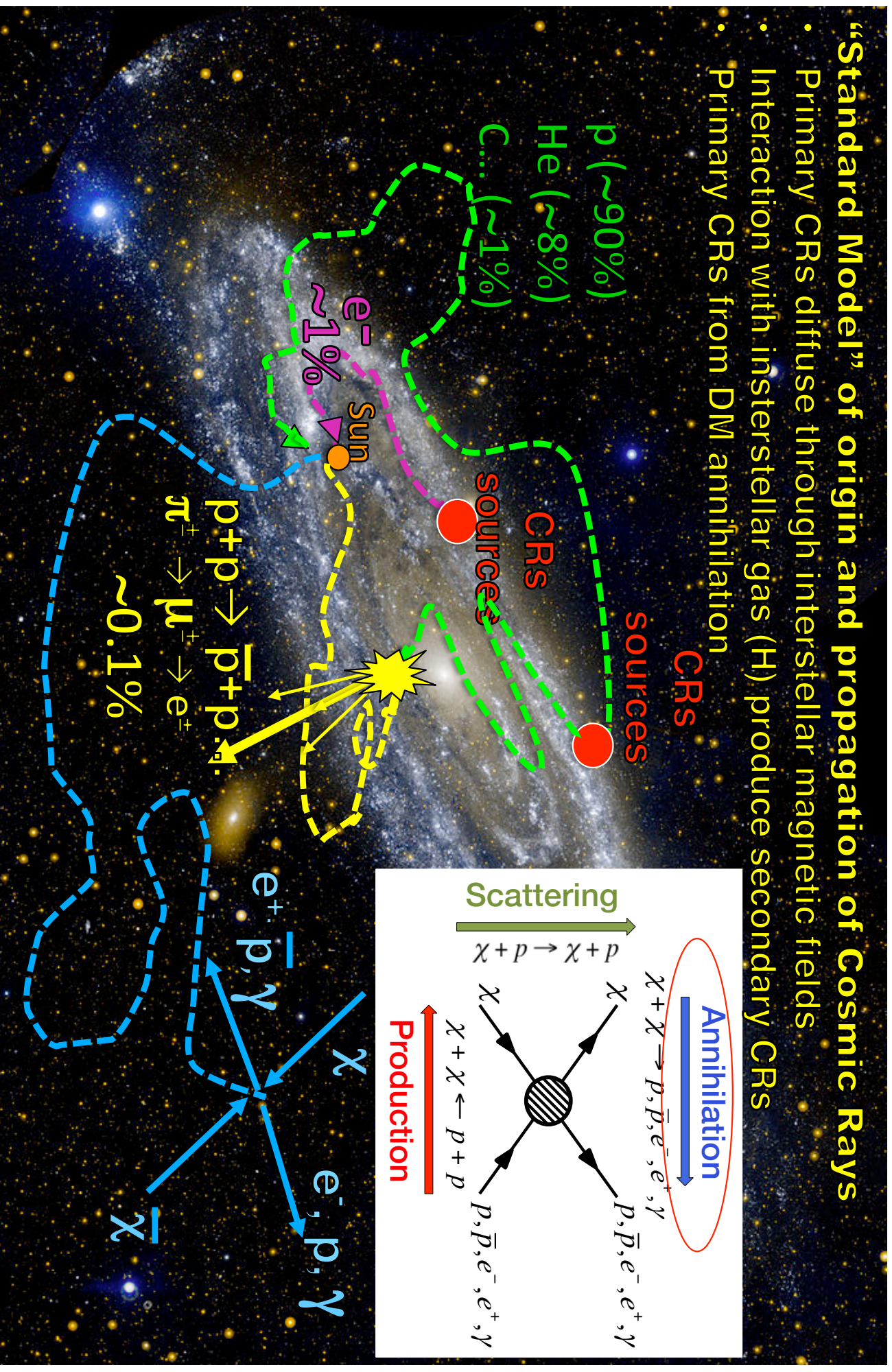
- Primary CRs diffuse through interstellar magnetic fields
- Interaction with interstellar gas (H) produce secondary CRs



The “Standard Model” of Cosmic Rays

“Standard Model” of origin and propagation of Cosmic Rays

- Primary CRs diffuse through interstellar magnetic fields
- Interaction with interstellar gas (H) produce secondary CRs
- Primary CRs from DM annihilation



The quest for Dark Matter

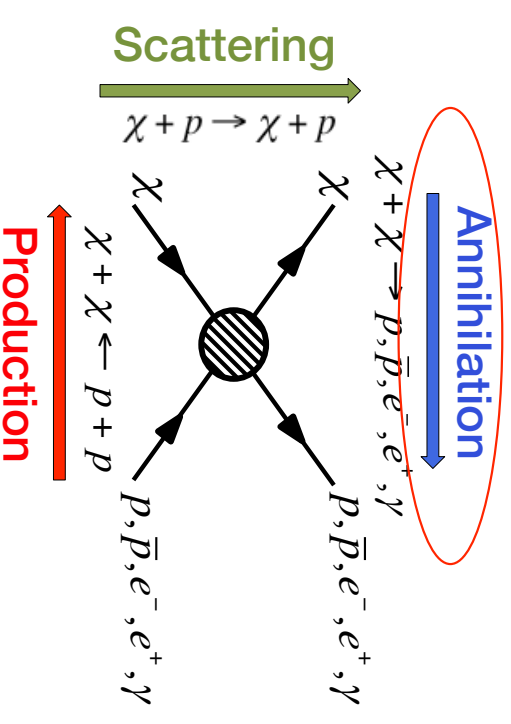
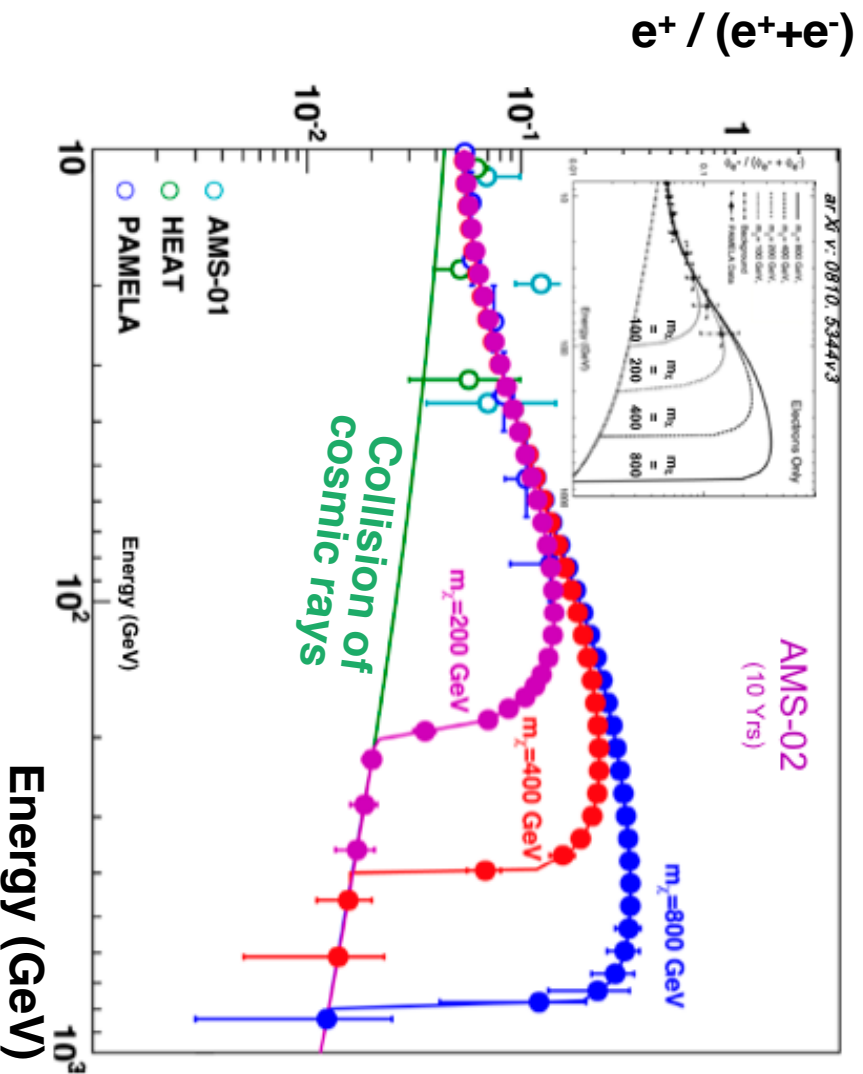
The most sensitive channels to indirect DM searches are the the rare components in cosmic rays, for which the

signal / noise

DM origin / astrophysical origin

is more convenient

Positron fraction



Increase in the positron fraction possible hint of DM annihilation

The quest for Dark Matter

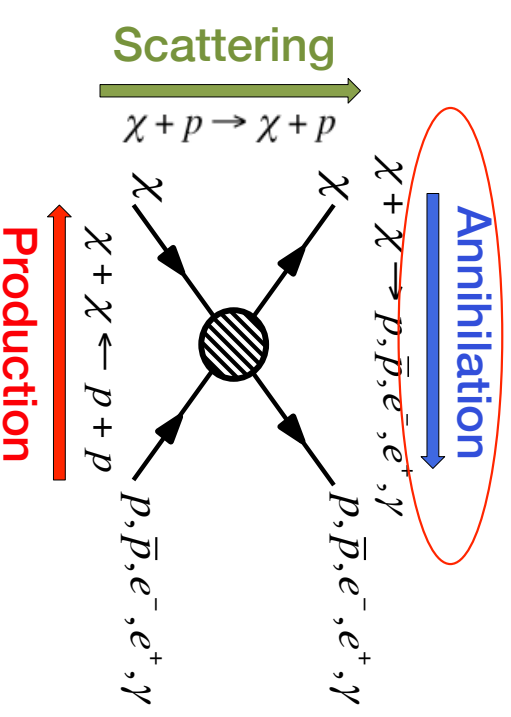
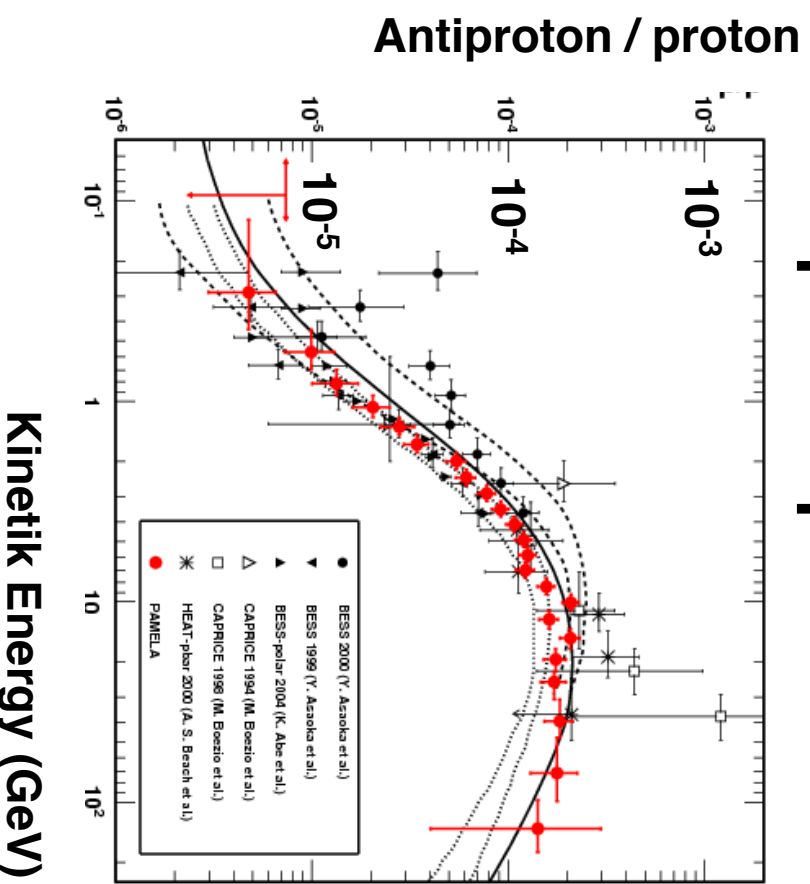
The most sensitive channels to indirect DM searches are the rare components in cosmic rays, for which the

signal / noise

DM origin / astrophysical origin

is more convenient

Antiproton/proton ratio



No antimatter overabundance
observed in the antiproton channel

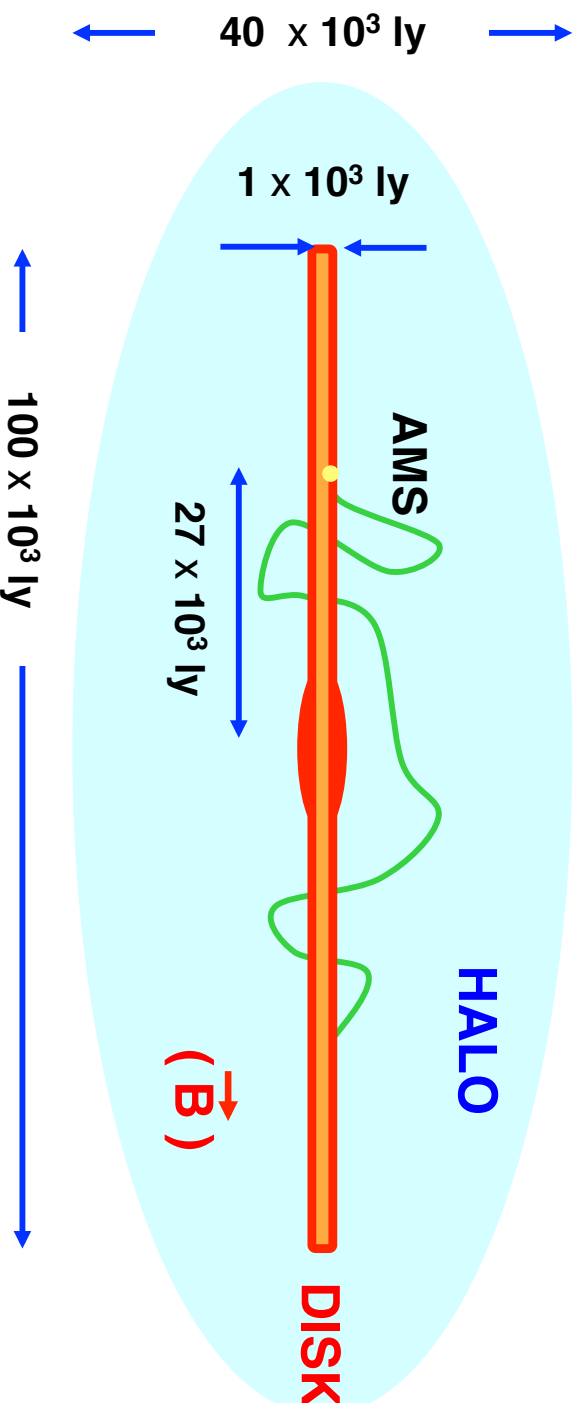
Strong constraints set on the DM
mass/interactions

The quest for Dark Matter

In the search for antimatter overabundances, the main issue is

KNOW YOUR BACKGROUND (expected secondary production)

- primary fluxes
- cross sections
- solar modulation (at low energies)



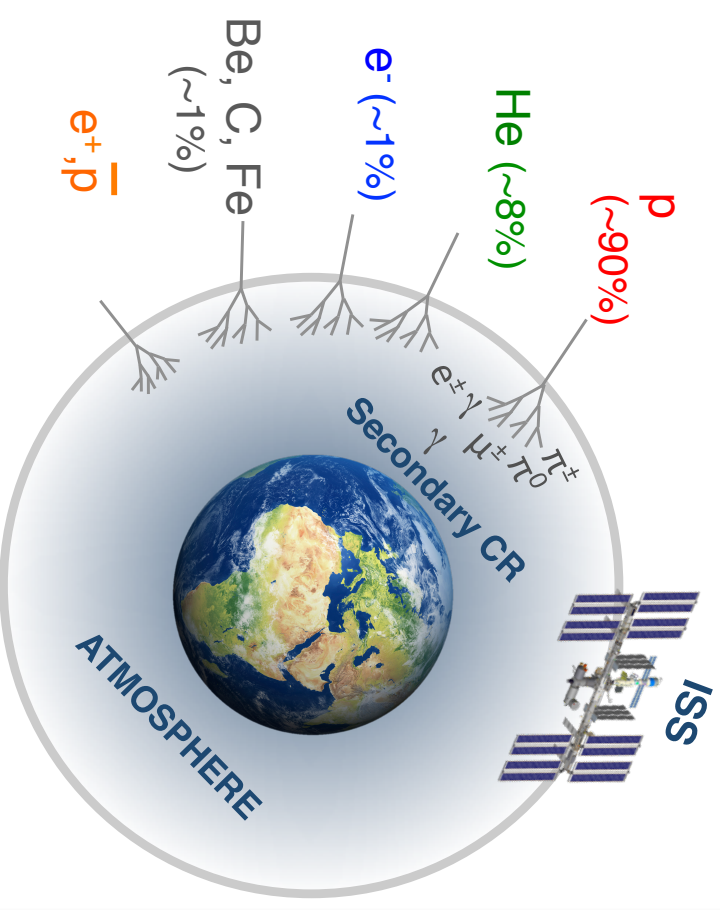
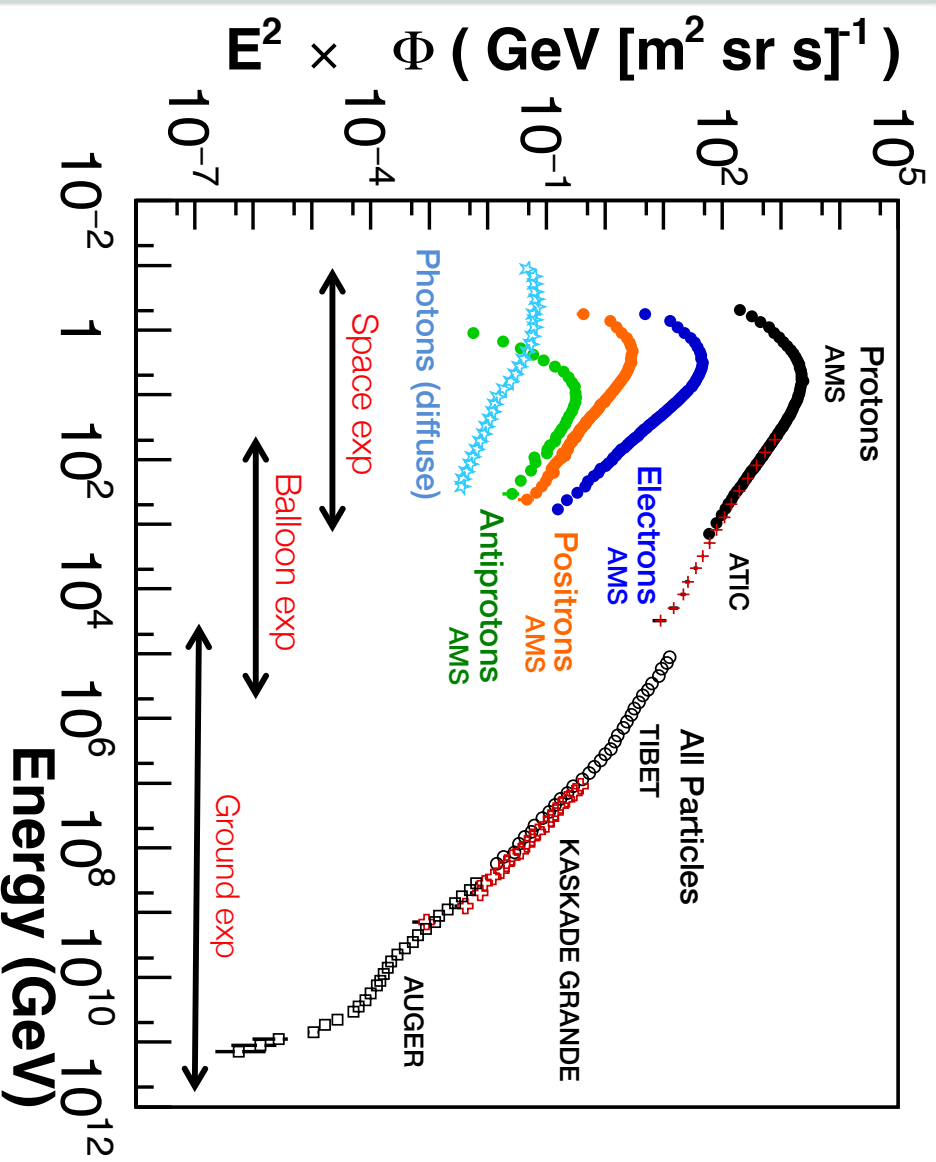
Diffusion
Convection
Reacceleration

Interactions with the
Interstellar Medium
(ISM):

- Fragmentation
- Secondaries
- Energy loss

Efforts to measure the flux of protons, Helium, Lithium, Carbon, Boron,

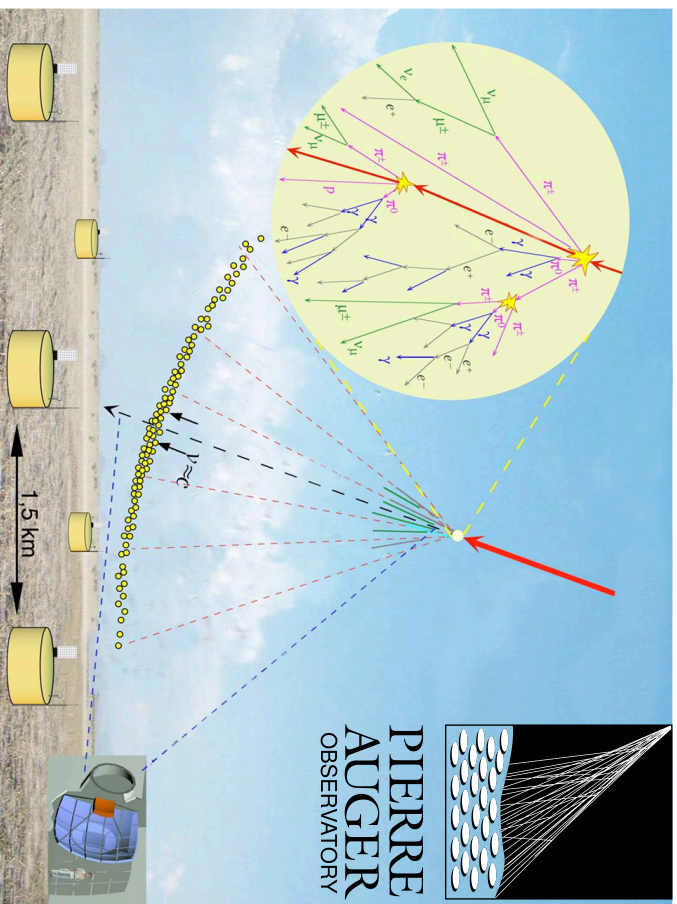
Experimental detection



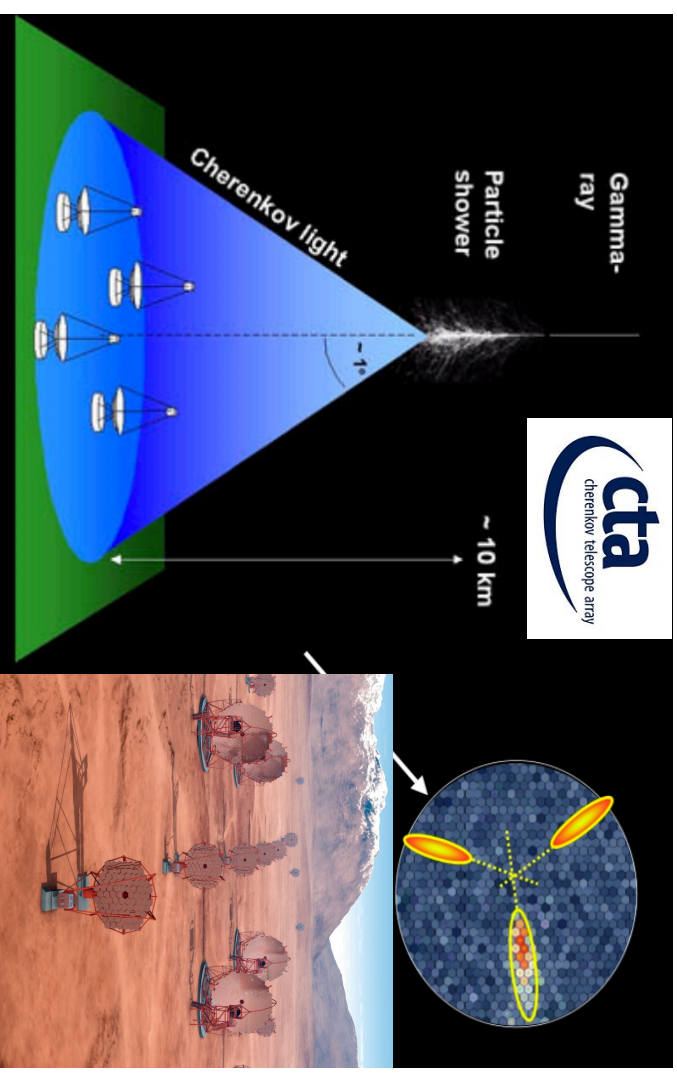
- Primary cosmic rays interact with atmosphere. Only secondary CRs from interactions reach the ground.
- Flux steeply falling as function of energy. Need large collection areas

Ground based experiments

Charged CRs



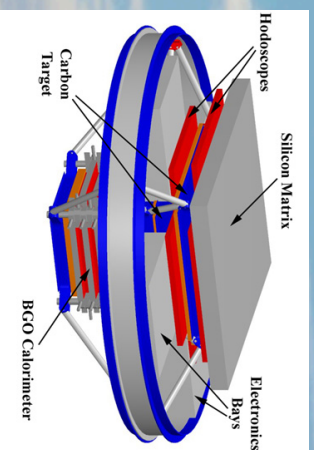
Gamma Rays



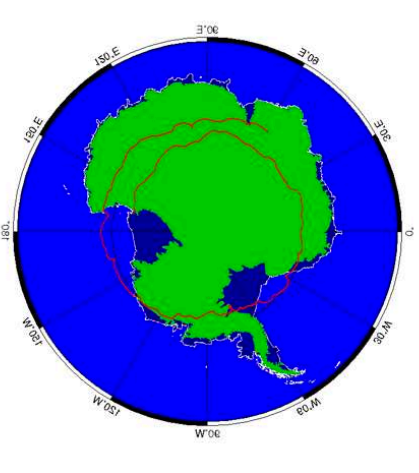
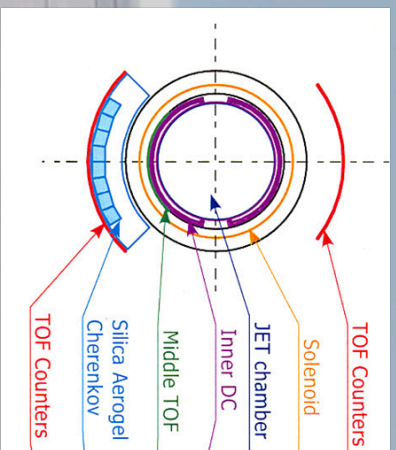
- ✓ Large collection areas → probe CR energies TeV –EeV ranges
- ✗ Indirect measurements
 - Primary CR identified via the analysis of shower shapes and composition at ground (highly rely on MonteCarlo simulations)
 - Main systematics are the parametrization of X-sections at very high energies

Balloon experiments

BESS

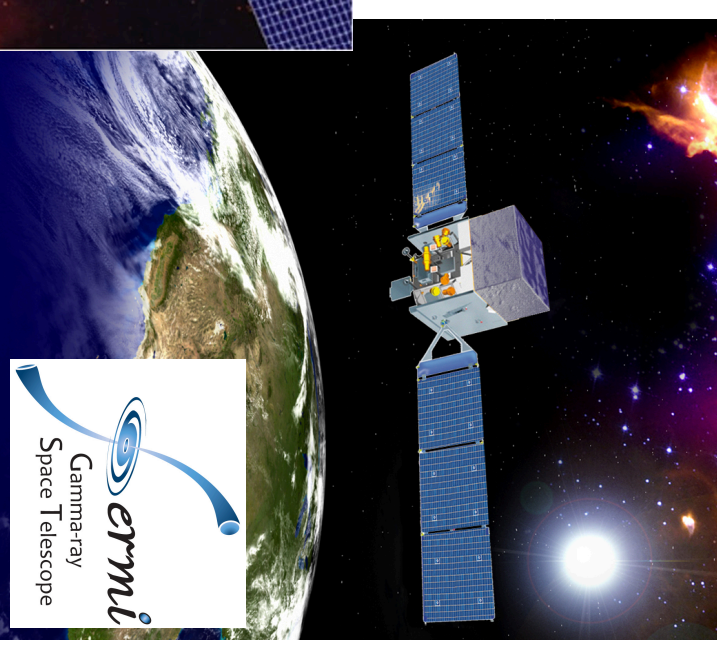
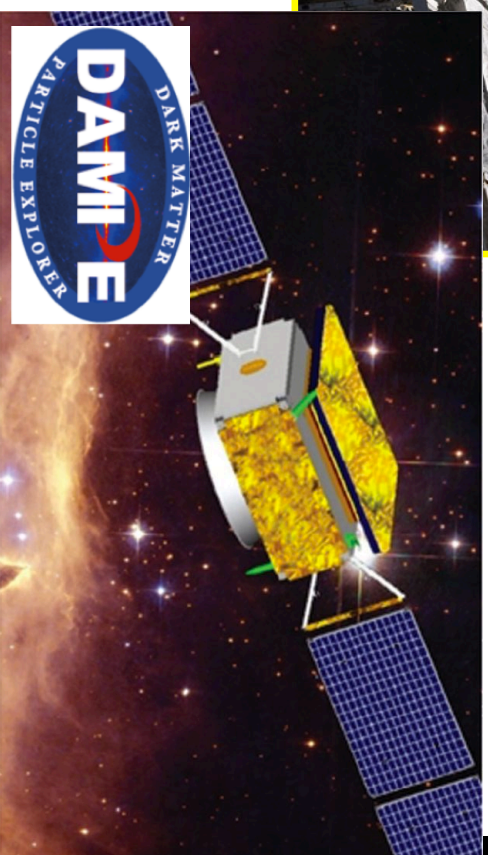


ATIC



- ✓ Larger acceptances than space borne experiments
- ✓ Direct measurements
- ✗ Orbit limited at North poles for maximum 1 month
- ✗ Residual atmosphere above the payload

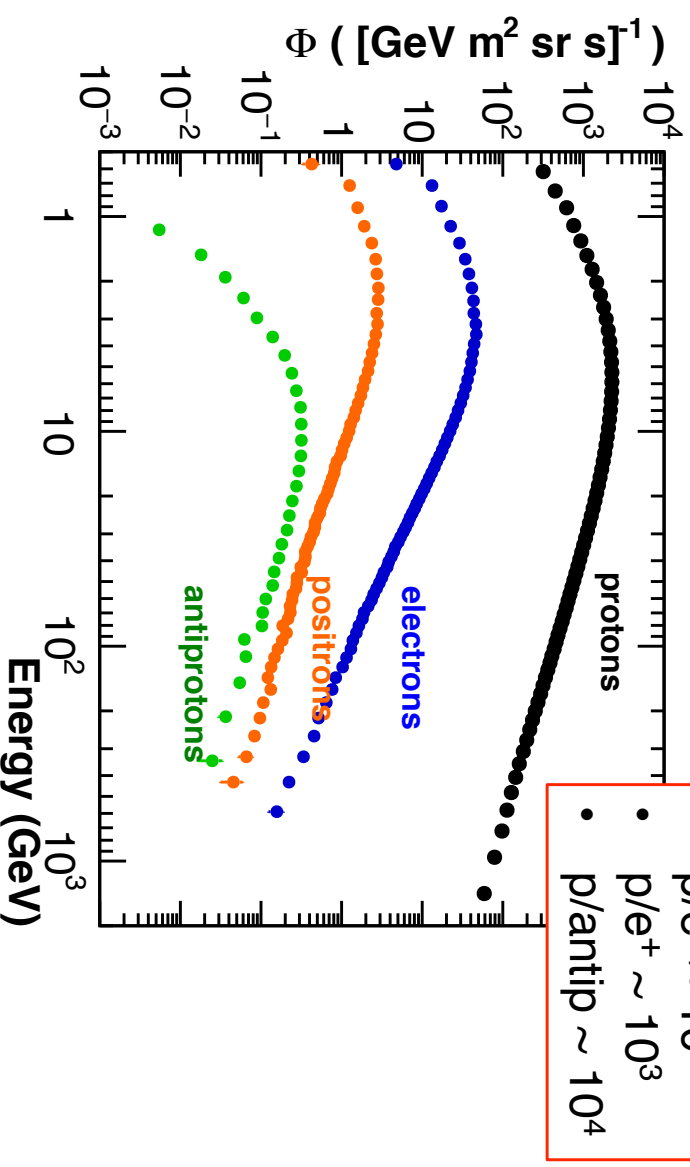
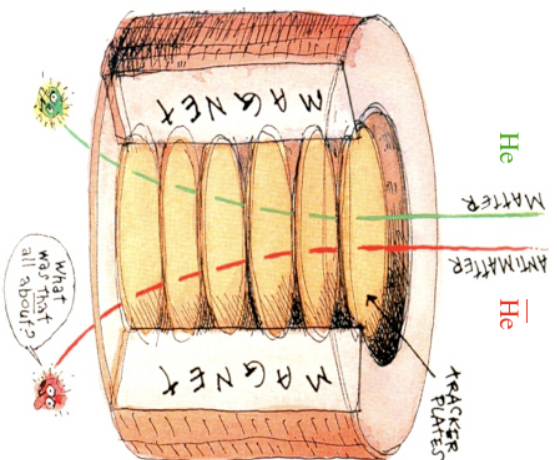
Space Borne experiments



- ✓ Direct measurements outside atmosphere
- ✓ Continuous duty cycles, typically many years of lifetime
- ✓ Field of view covering the whole sky
- ✗ Smaller acceptances
- ✗ Operation in space and communications not trivial
- ✗ “Use once and destroy”

Particle Identification (in space)

- Direct identification of the cosmic rays via measurement of their
 - **Velocity** (Time of Flight systems, Cherenkov Radiation detectors)
 - **Charge** (dE/dX detectors, Cherenkov Radiation detectors)
 - **Energy or Rigidity** (Calorimeters, Spectrometers)
 - **Sign of the charge** (Spectrometers)
 - **Peculiar Interactions** (TR detectors, Calorimeters, Neutron detectors, ...)
 - **Incoming Direction** (Tracking detectors)

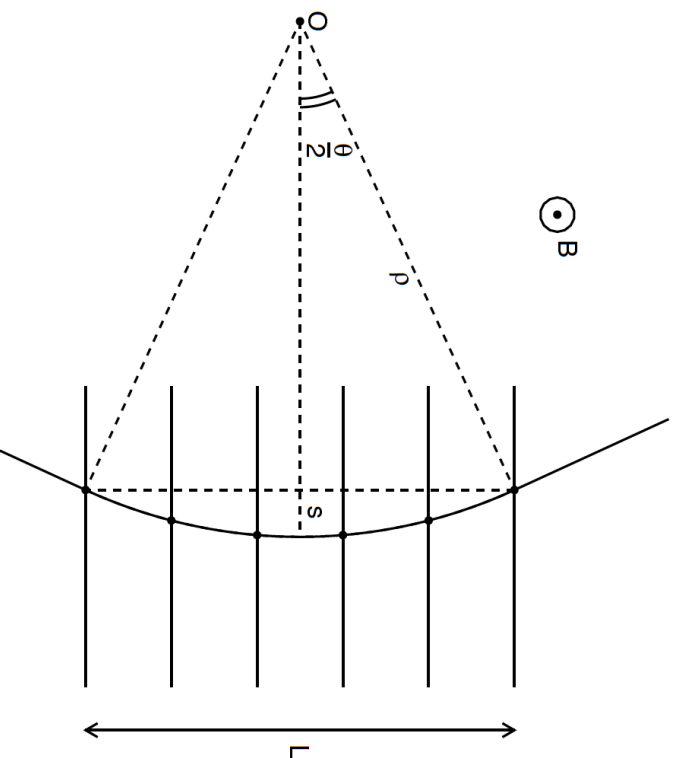


Particle identification is fundamental for antimatter measurements

Space born detectors

Magnetic Spectrometers

Simple 2D sagitta model



- Charged particle bent in magnetic field
- The sagitta is measured by sampling the particle trajectory through different planes
- The particle rigidity is inferred via

$$R = \frac{cBL^2}{2s} = \frac{37.5 \text{ B [T]} L^2 [\text{m}^2]}{s [\text{mm}]} \text{ GV}$$

- Rigidity resolution scale linearly as

$$\frac{\sigma_R}{R} = \frac{\sigma_s}{s} \propto R$$

- Maximum Detectable Rigidity MDR

$$\frac{\sigma_R}{R} = 1 \Rightarrow R(\text{MDR}) \propto \frac{L^2 B}{\sigma_s}$$

- $L \sim$ Spectrometer dimensions, limited by the space constraints
- B , limited by magnet size and technology (superconducting magnet in space?)
- $\sigma_s \sim$ position resolution $\rightarrow$ experimental effort to achieve resolutions below $10\mu\text{m}$

Space born detectors

- Distortion of the flux measurement above $\sim \text{MDR}$
- The flux can be corrected if the smearing/migration matrix is known (typically from MonteCarlo simulations)

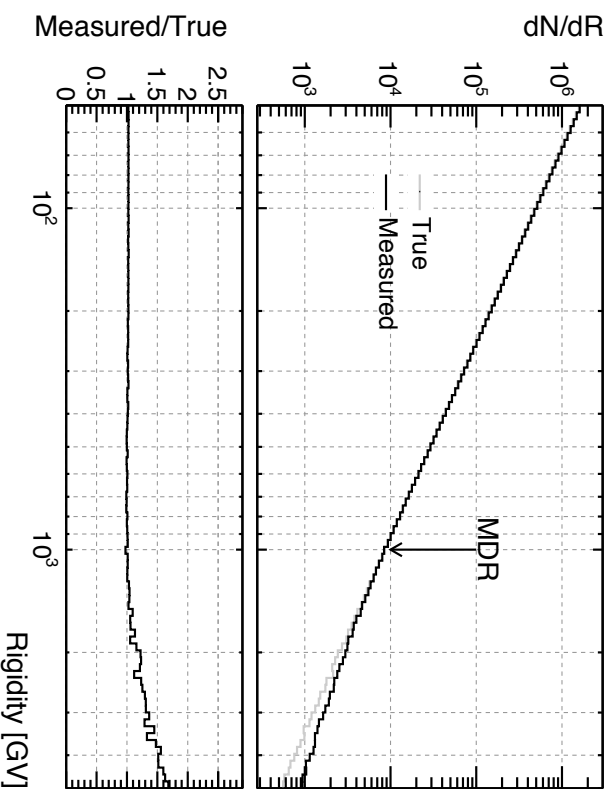


FIG. 62: Effect of a finite rigidity resolution on a toy Monte Carlo power-law spectrum with index 2.75, mimicking the primary cosmic-ray proton spectrum, for a maximum detectable rigidity of 1 TV. (For completeness, the smearing used for this illustration is gaussian in $1/R$. Though the relative fluctuation in R and $1/R$ are the same, the result would have been somewhat different if the smear was done in the rigidity space—we stress, however, that the point of the exercise was not to develop a realistic model of the rigidity dispersion.)

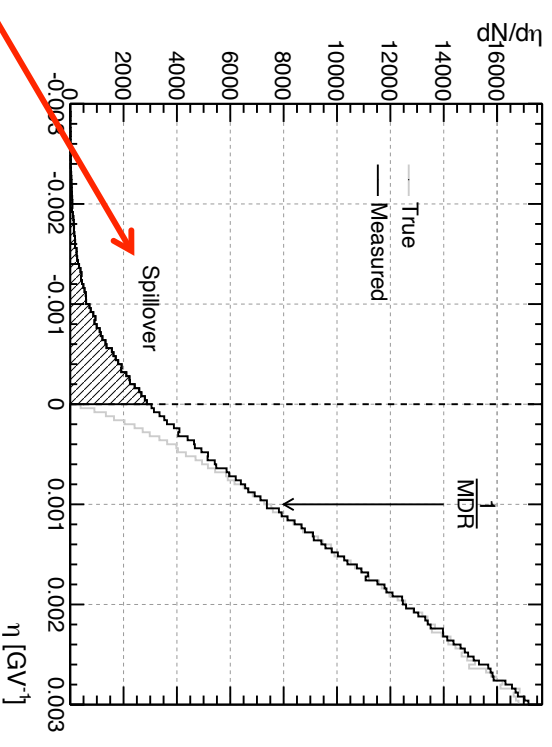


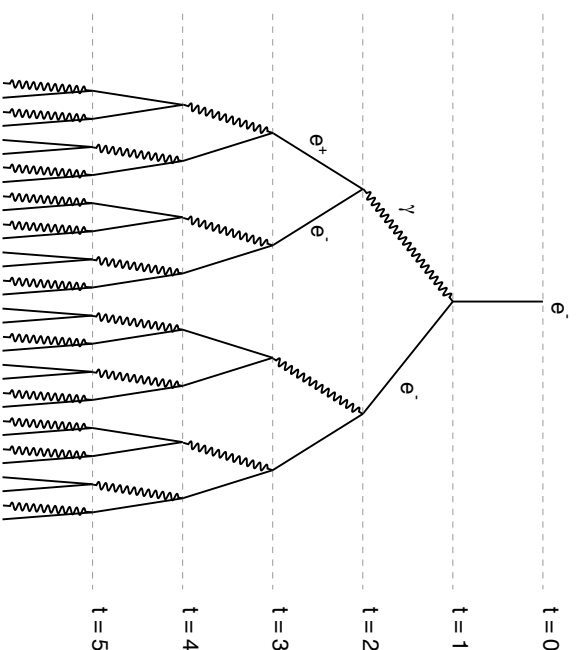
FIG. 63: Illustration of the spillover effect. Here the same (true and measured) spectra in figure 62 are shown in the η space. We remind again that for this toy simulation the smearing is gaussian in η , assuming a MDR of 1 TV.

- Charge flip probability increases as the energy increases
- **SPILLOVER or CHARGE CONFUSION**

Space born detectors

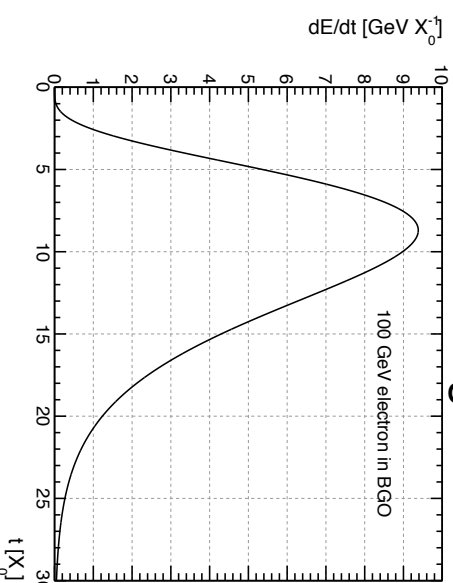
Calorimeters

Simple electromagnetic shower profile



- Calorimeters measures the energy releases of the particle

- Homogeneous / Sampling
- Electromagnetic / Hadronic



$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

Statistical fluctuations
Inhomogenities, calibration, energy leaks,...

- The energy resolution improves

as the energy increases

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

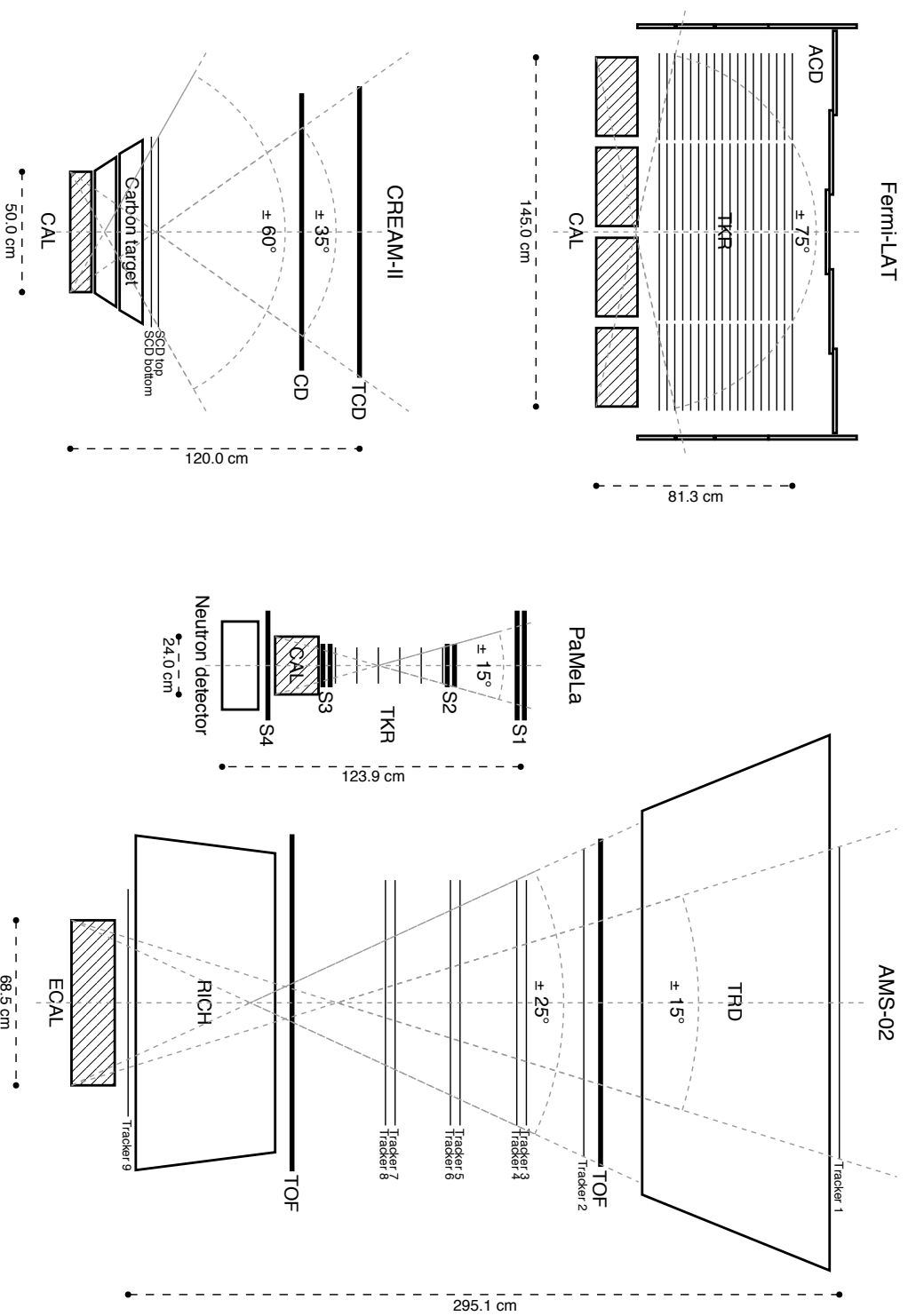
Electronics

- BUT: energy resolution is not everything. Typically the dominant systematic is the knowledge of the energy scale!!

- Resolution → Symmetric smearing of measured energy
- Energy scale → Systematic shift of measured energy

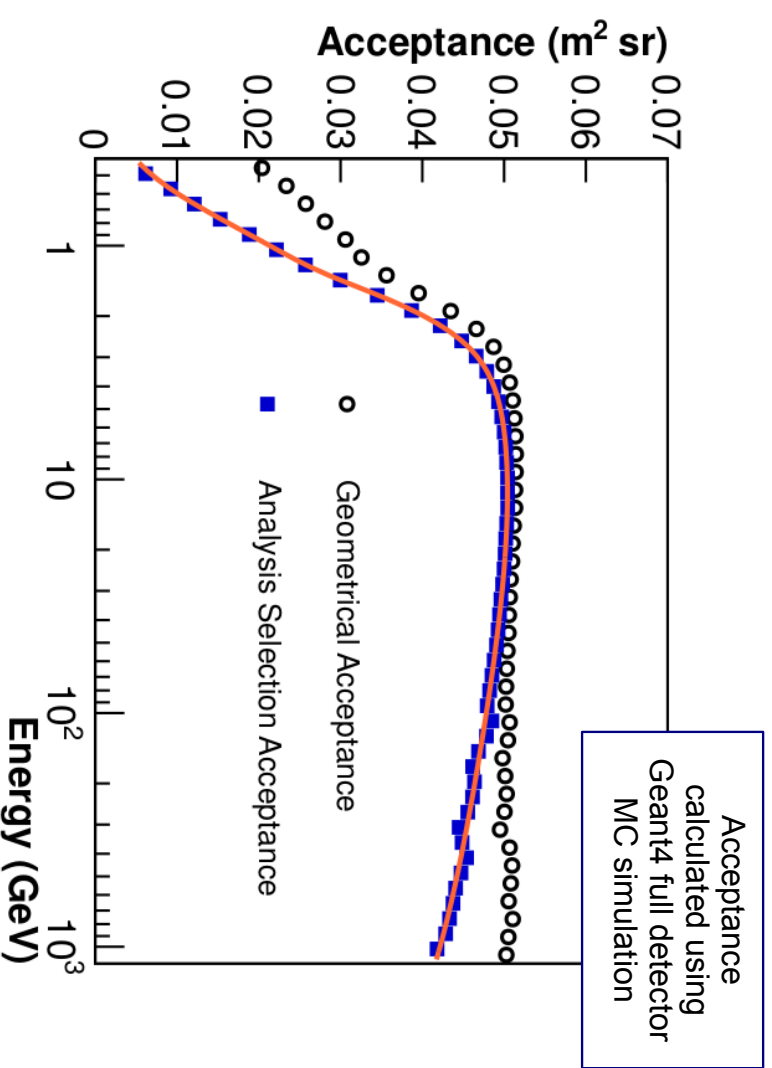
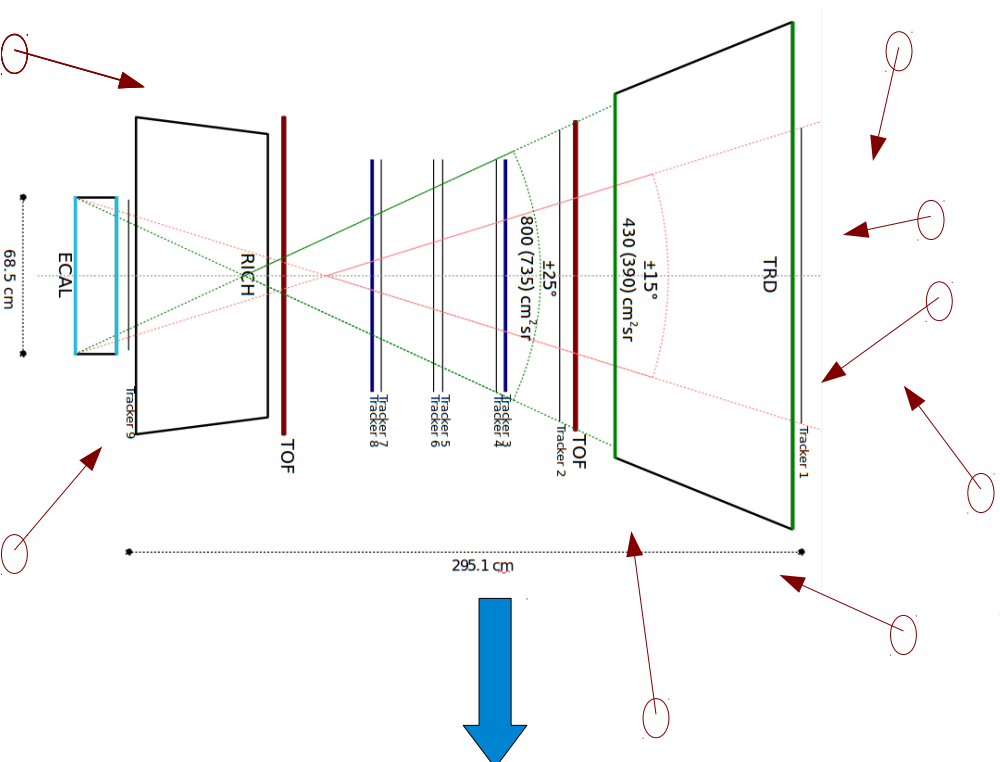
Space born detectors

ACCEPTANCE: measurement of the collection capabilities of the detector



Space born detectors

ACCEPTANCE: measurement of the collection capabilities of the detector
Typically measured with MonteCarlo simulations including the detector geometry, materials and interactions with the detector



Typical quantities

- Cosmic ray physics is (almost) all about **FLUXES**
 - **DIFFERENTIAL FLUX**: number of CRs per unit of time and energy (*) crossing the unit vector area towards a given direction in the sky
 - Measured in [$\text{GeV}^{-1} \text{m}^{-2} \text{s}^{-1}$]
 - Used for point source studies (like gamma rays)
 - **FLUX or INTENSITY**: number of CRs per unit of time, energy (*) and solid angle crossing the unit vector area
 - Measured in [$\text{GeV}^{-1} \text{m}^{-2} \text{s}^{-1} \text{sr}^{-1}$]
 - Used for isotropic measurements (charged cosmic rays)
- (*) Fluxes can be expressed as function of different improper definition of “energy”
- Kinetik energy (calorimeters)
 - Kinetik energy per nucleon (calorimeters)
 - Rigidity (spectrometers)

The Flux Measurement

Precision knowledge of the detector acceptance, response and resolution, and of the data acquisition in space.

$$\Phi(E) = \frac{N}{\Delta E \Delta T Acc \epsilon_{sel} \epsilon_{trig}}$$

FLUX

Number of cosmic rays collected

Energy/Rigidity (GeV)
size of the bin

Exposure Time (s)
also called "Livetime"

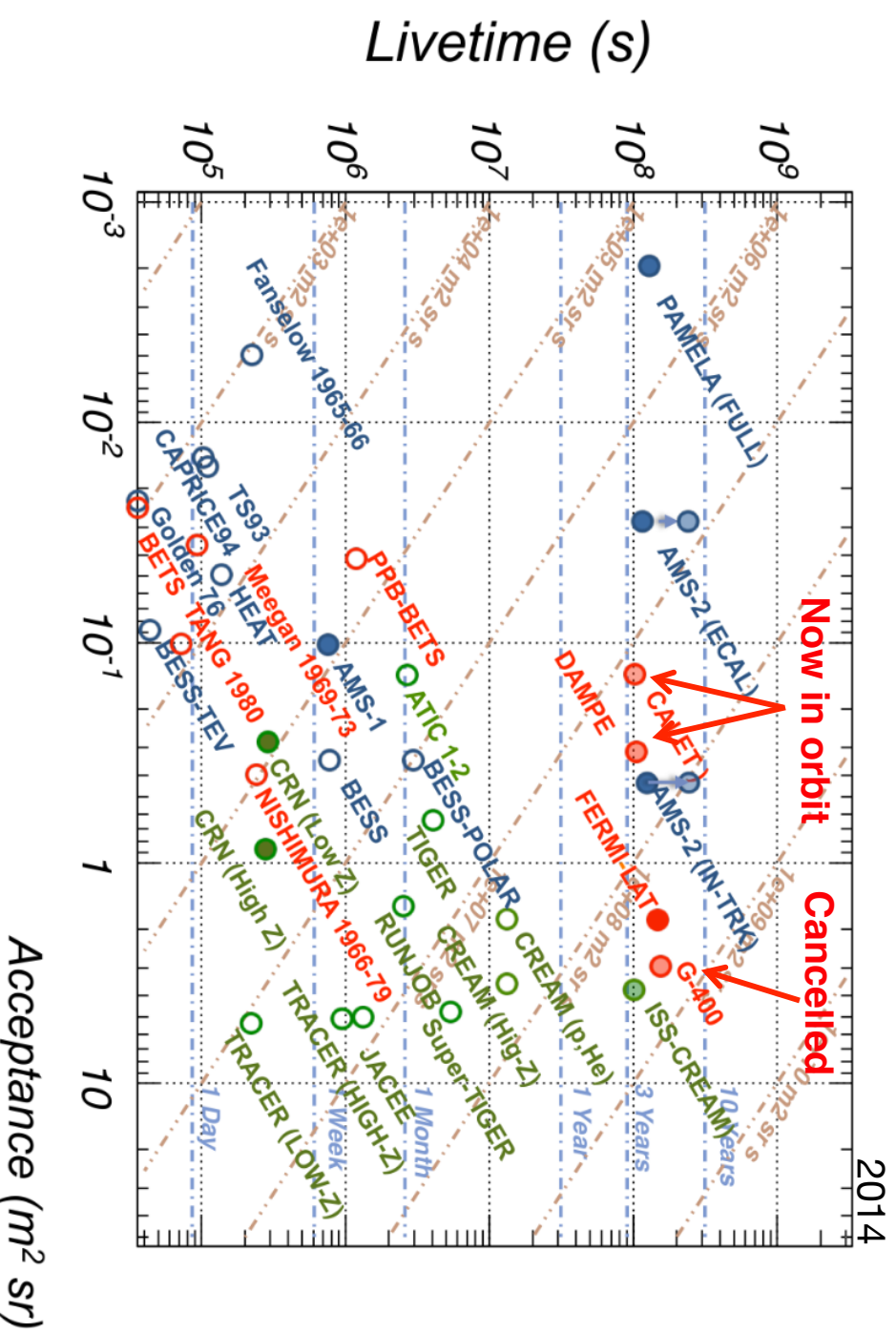
Acceptance (m² sr)
usually calculated using MC sims

Particle selection efficiency
based on the statistical techniques employed to extract N

Trigger Efficiency

Each factor uncertainty contributes equally to the final measurement.
Systematic uncertainty studies for each factor are fundamental

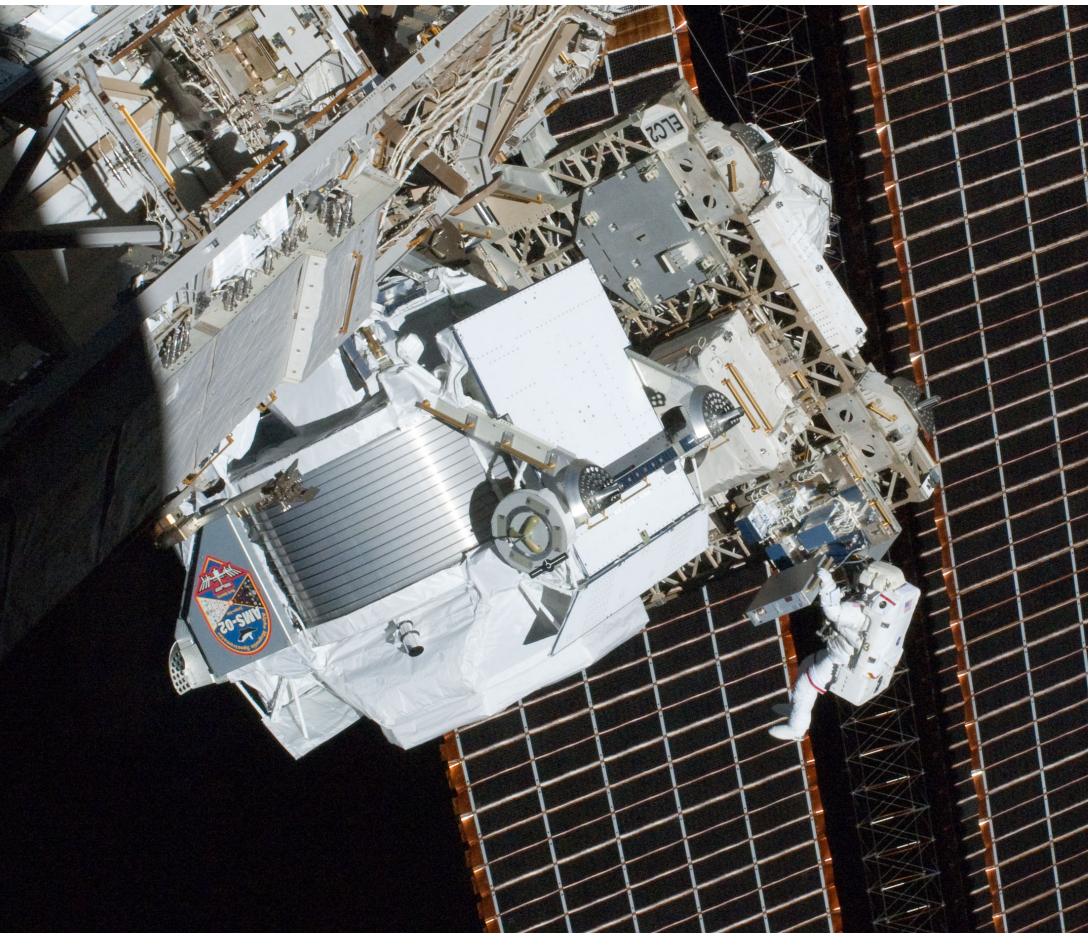
Future experiments



- No B field, different techniques with main focus on Z
- No B field, different techniques with main focus on e, γ
- Magnetic spectrometers
- Balloon
- Space
- Space (planned)

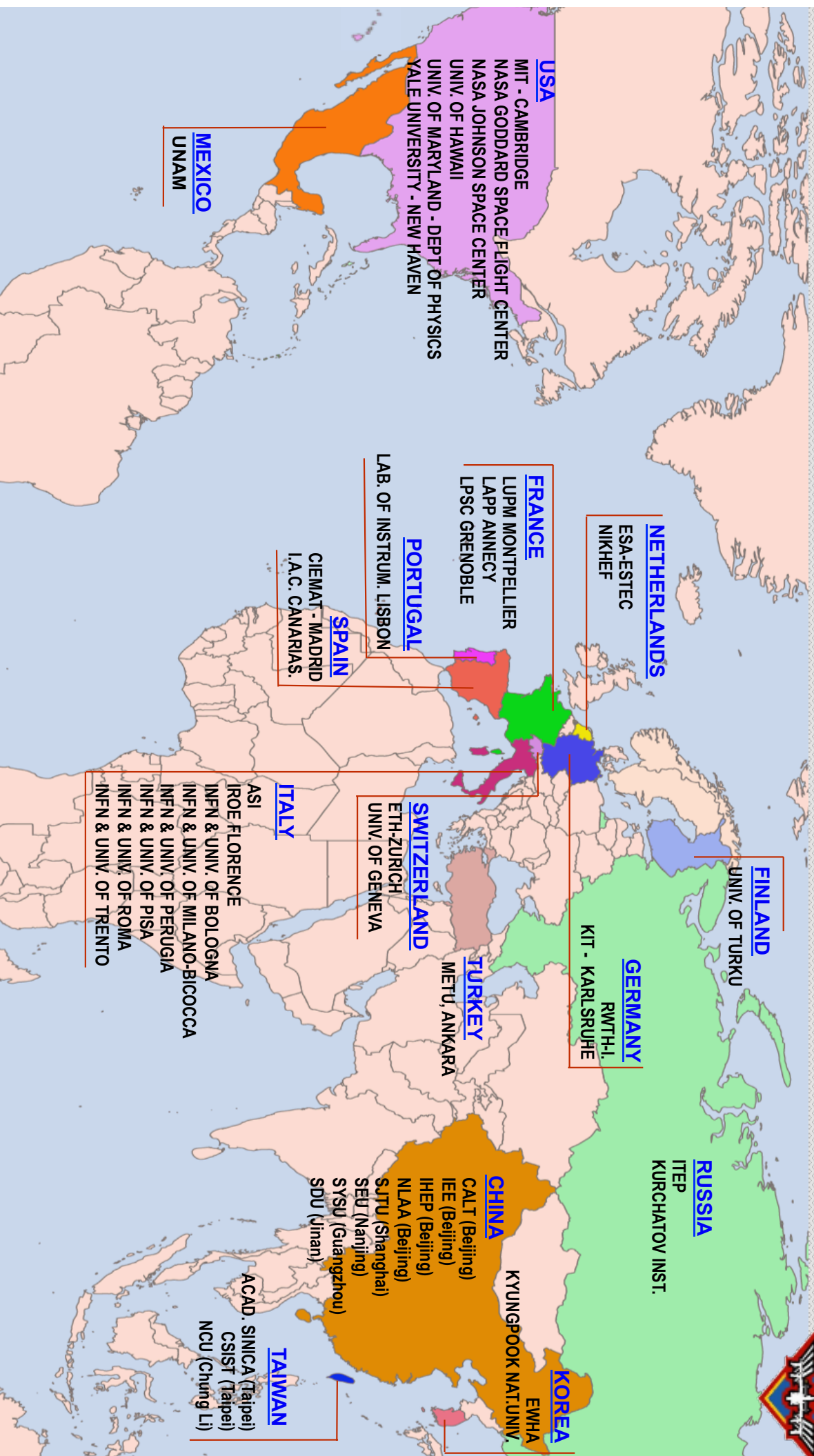
AMS-02 will be the unique magnetic spectrometer in space
able to distinguish matter from antimatter for the next 10 years.

The AMS-02 detector



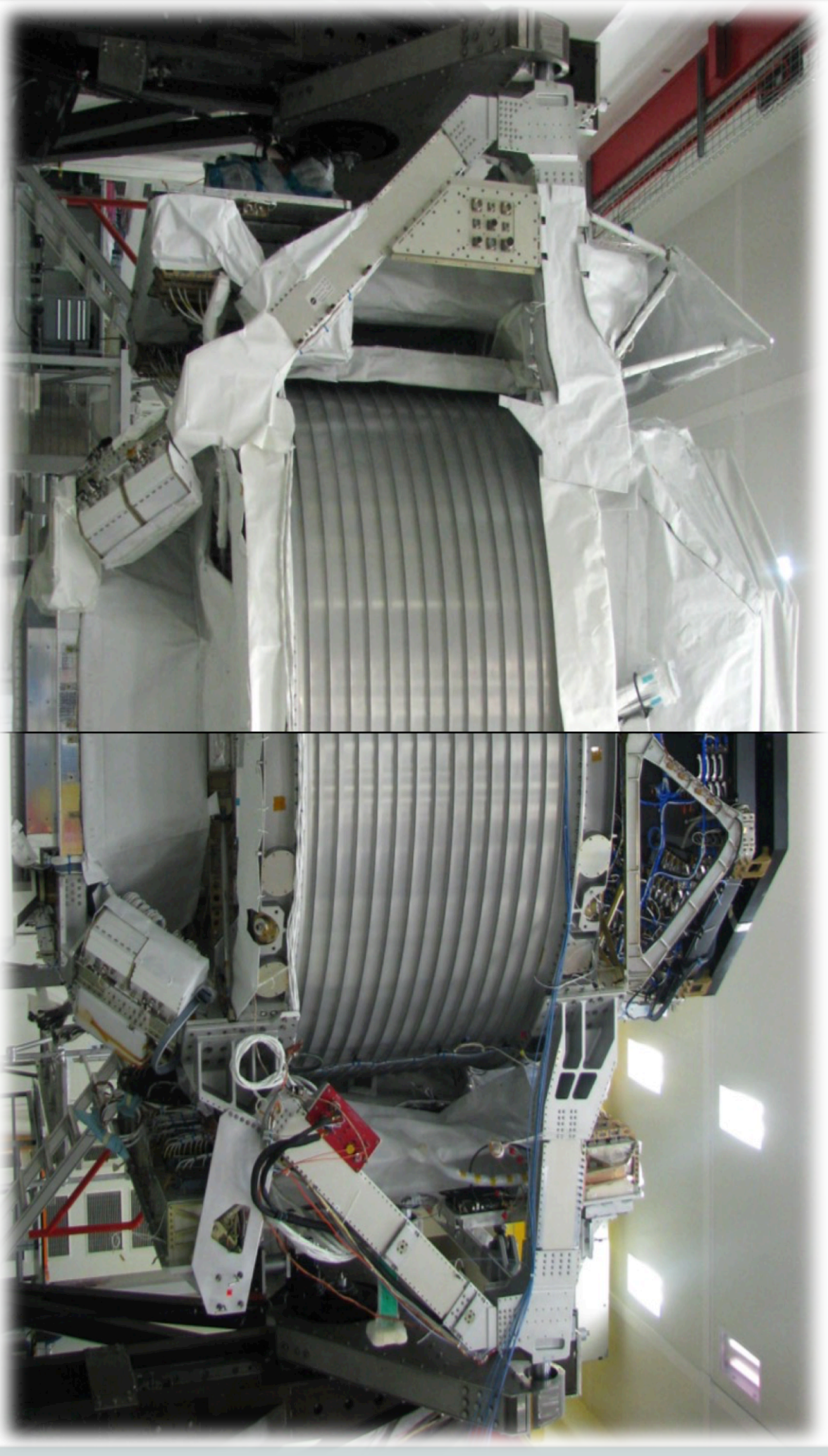
- **Size** 5 x 4 x 4 m, 7500 kg
 - **Power** 2500 W
- **Data Readout** 300,000 channels
 - **<Data Downlink>** ~ 12 Mbps
 - **Magnetic Field** 0.14 T
- **Mission duration** until the end of the ISS operations (currently 2024)

AMS : A large international collaboration

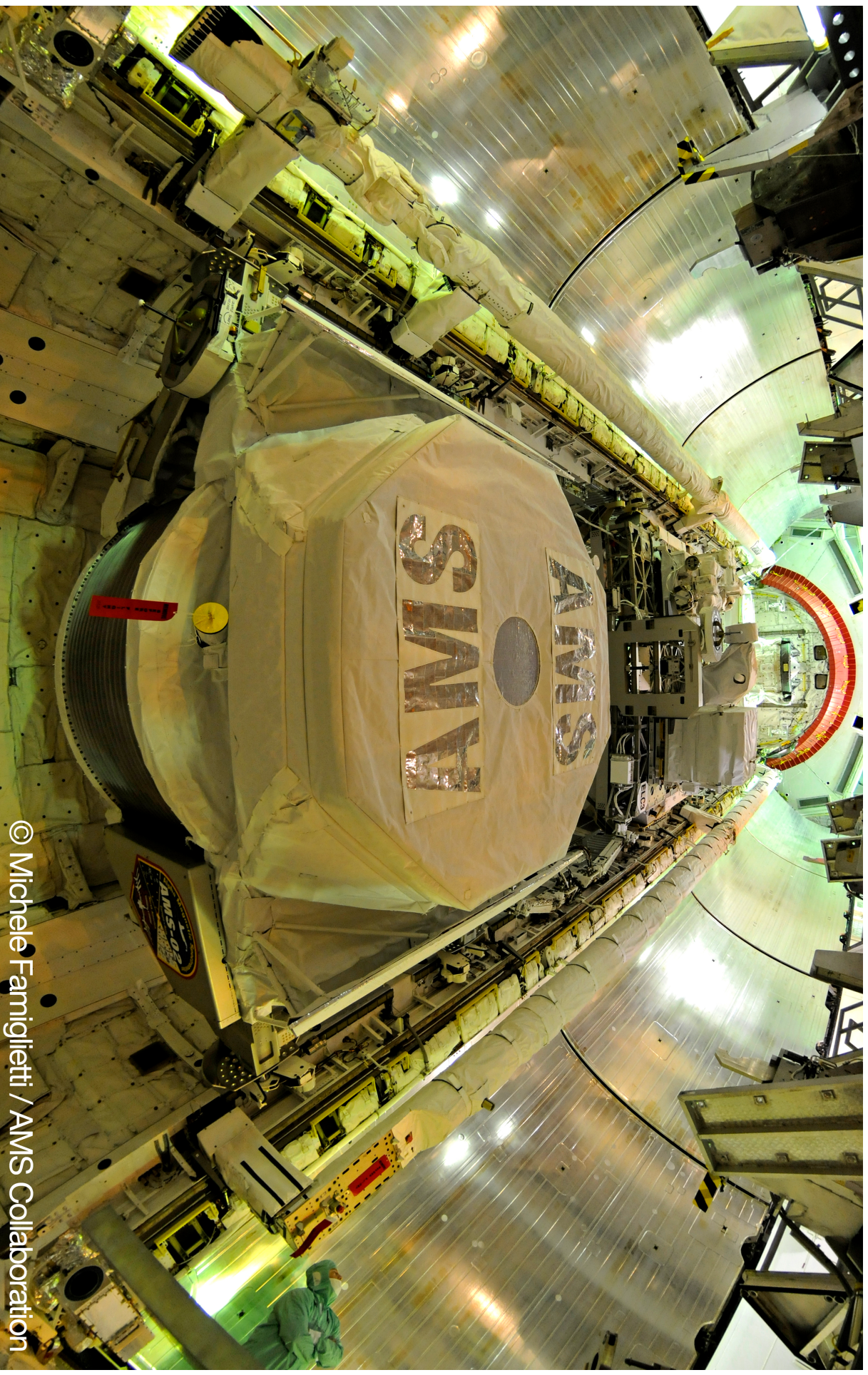


≈ 600 physicist & engineers from 57 institutes in ASIA, USA, EUROPE
working together in the past 20 years...

The AMS-02 detector



The AMS-02 detector

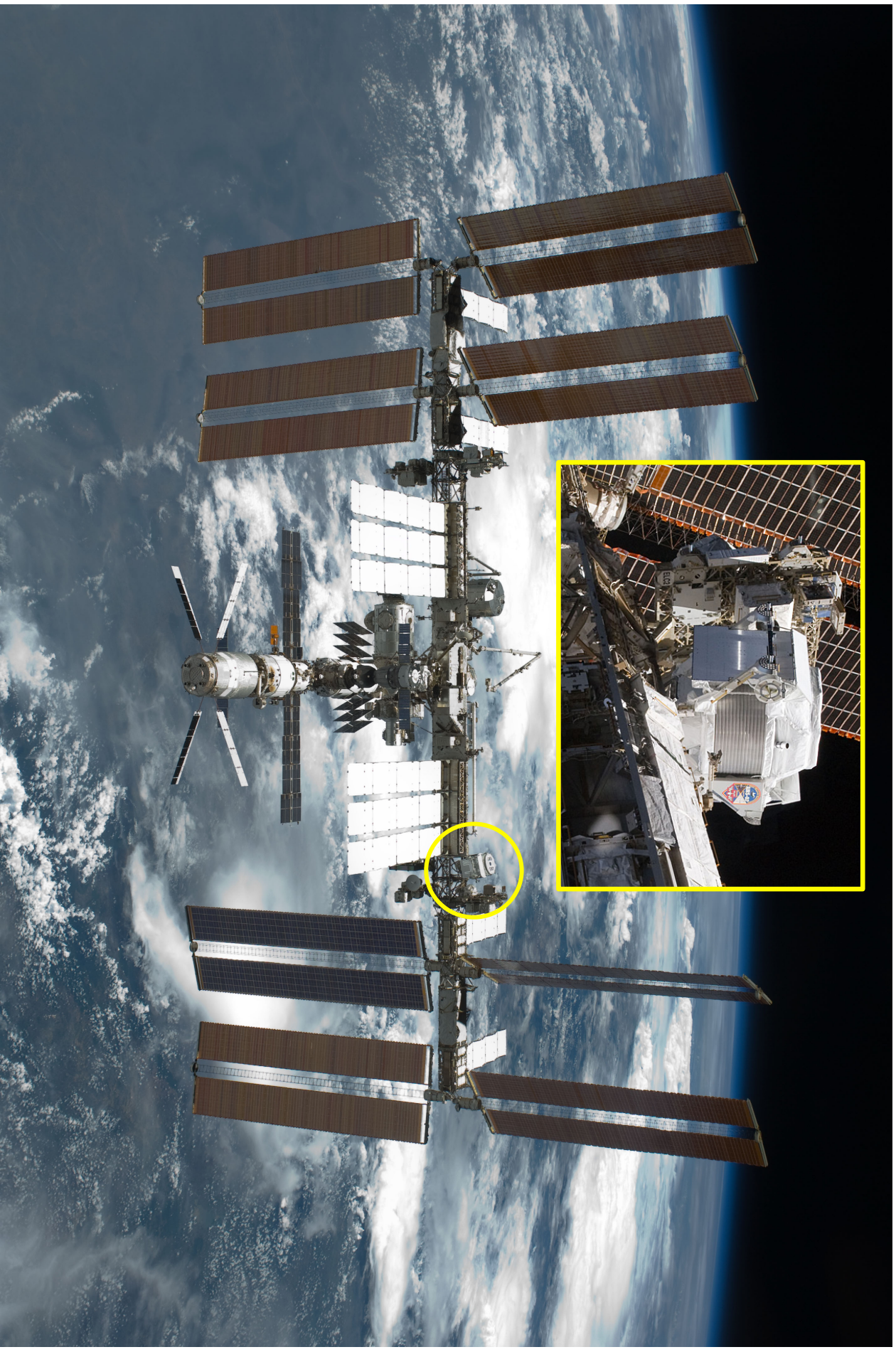


© Michele Famiglietti / AMS Collaboration

The AMS-02 detector



AMS-02 on the ISS



AMS-02 Physics

FUNDAMENTAL PHYSICS

- Indirect search for Dark Matter (e^+ , anti- p ,....)
- Search for primordial antimatter (anti-He)

COSMIC RAY COMPOSITION AND ENERGETICS

- Precise measurement of the energy spectra of H, He, Li, B, C
- to provide information on CR interactions and propagation in the galactic environment

TO ACHIEVE THIS.....

Particle identification and Energy measurement up to TeV

- Matter/antimatter separation using magnetic field
- e/p separation using independent subdetectors

Maximize the data sample

- Detector size (acceptance)
- Exposure time: ISS in space

AMS: TeV precision spectrometer

TRD

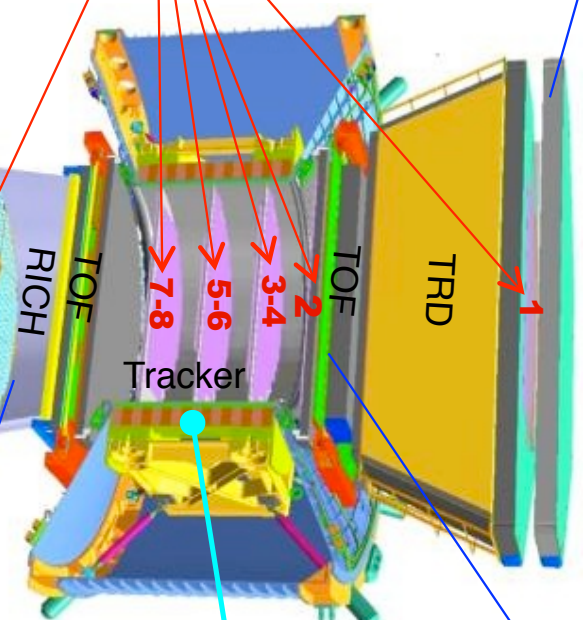
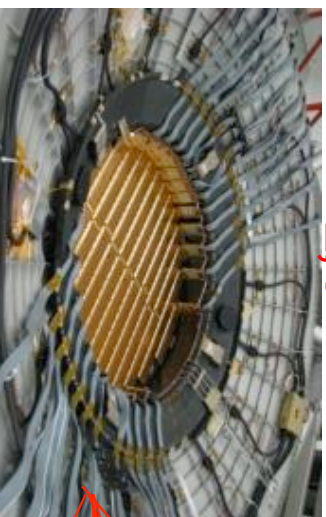
Identifies e^+ , e^-



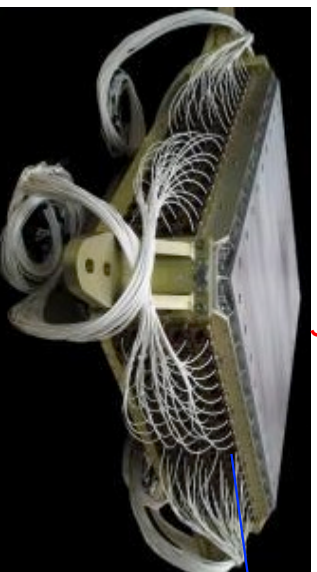
Particles and nuclei are defined

by their charge (Z)
and energy ($E \sim P$)

Silicon Tracker
 Z, P



ECAL
 E of e^+ , e^-



are measured independently by the

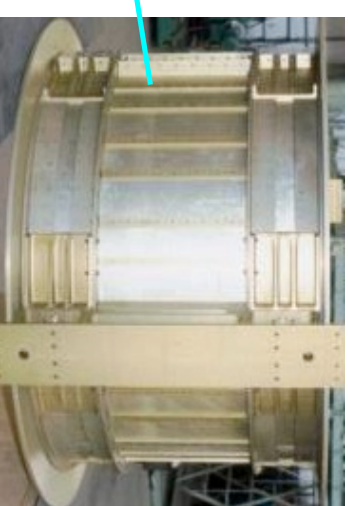
Tracker, RICH, TOF and ECAL

Z and $P \sim E$

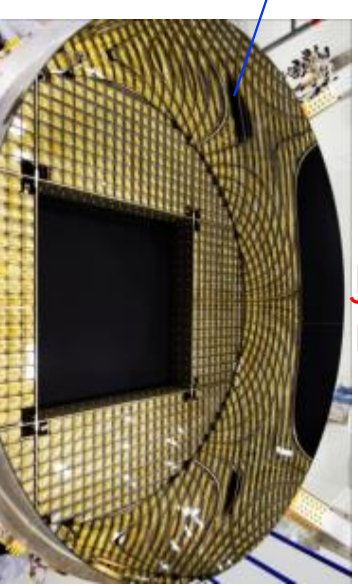
TOF
 Z, E



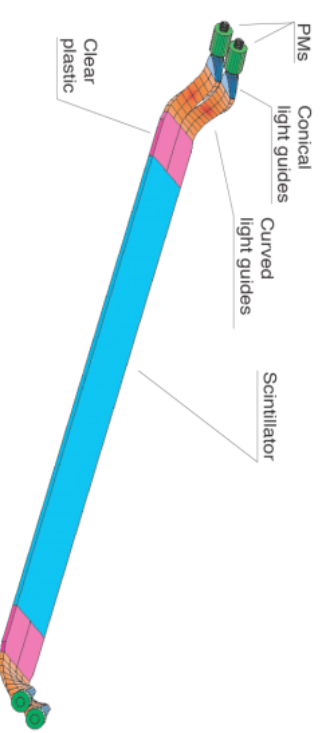
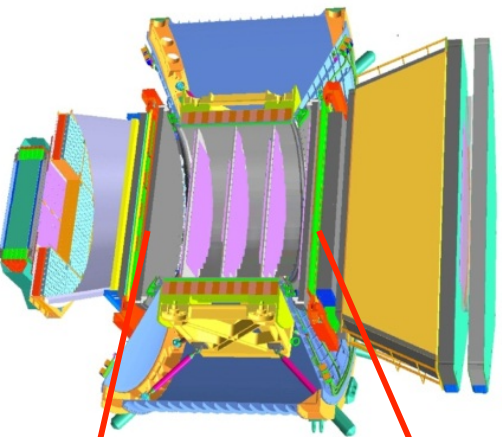
Magnet
 $\pm Z$



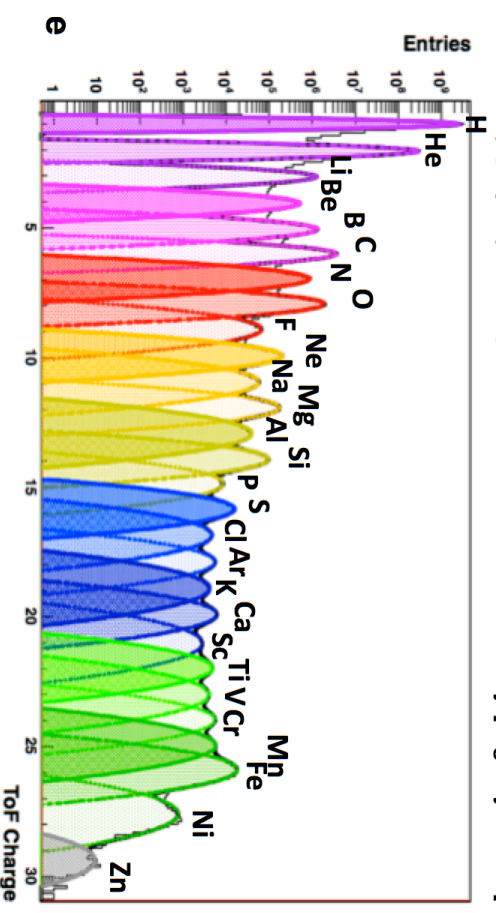
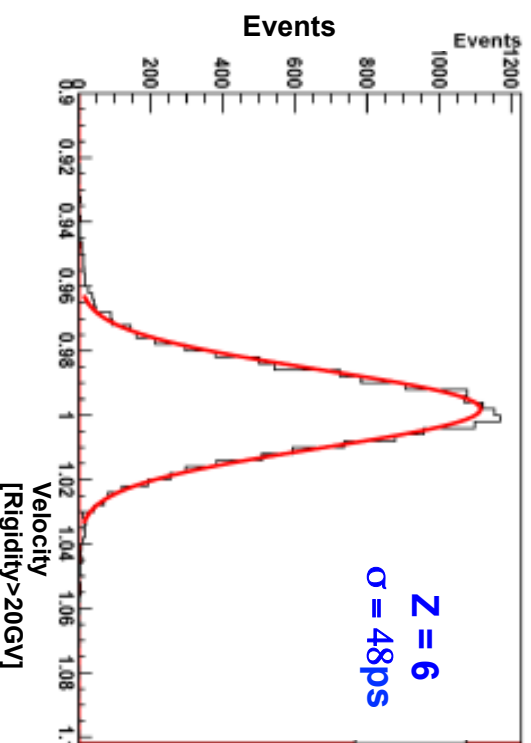
RICH
 Z, E



Time of Flight TOF



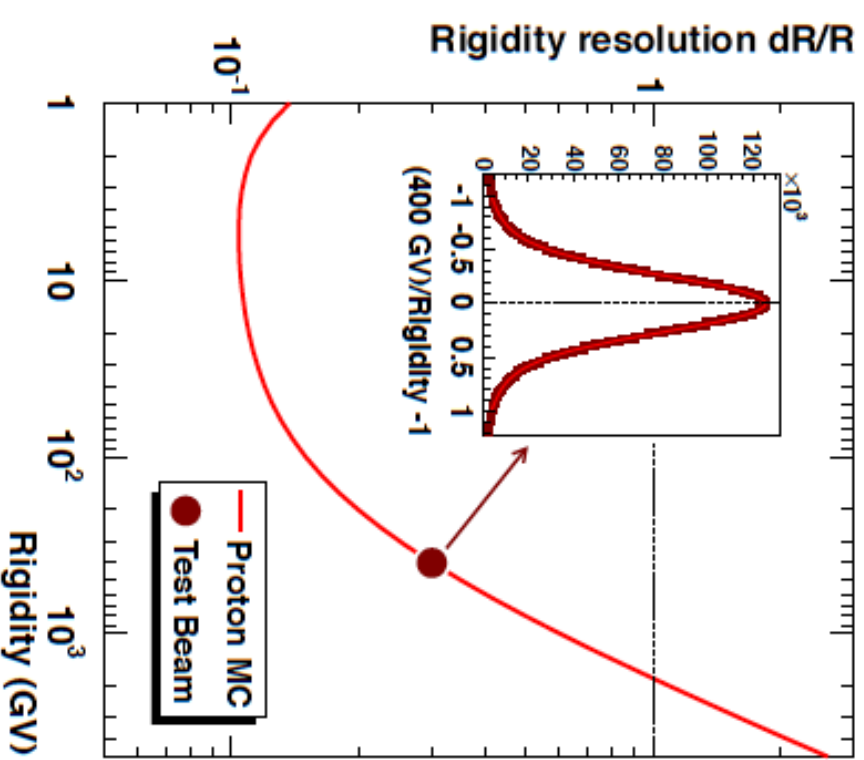
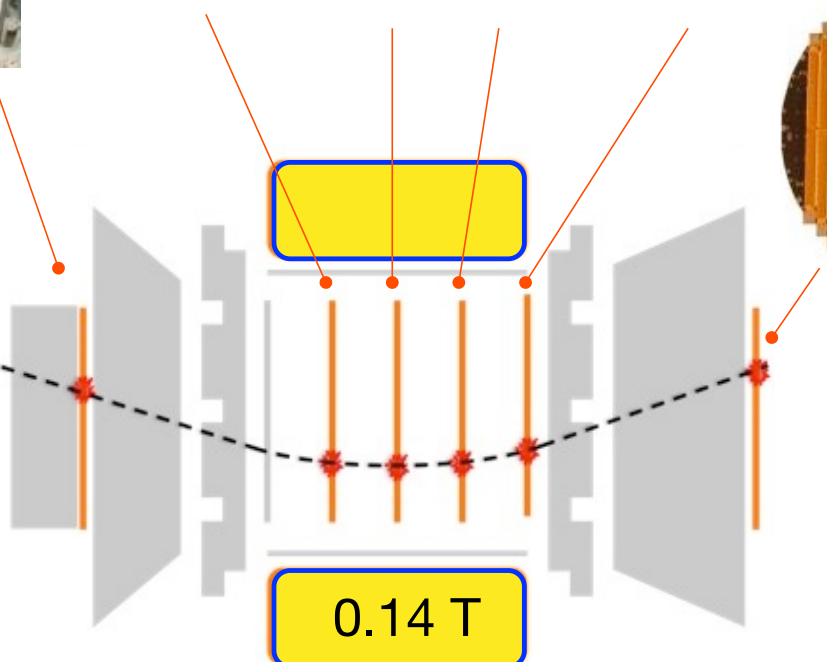
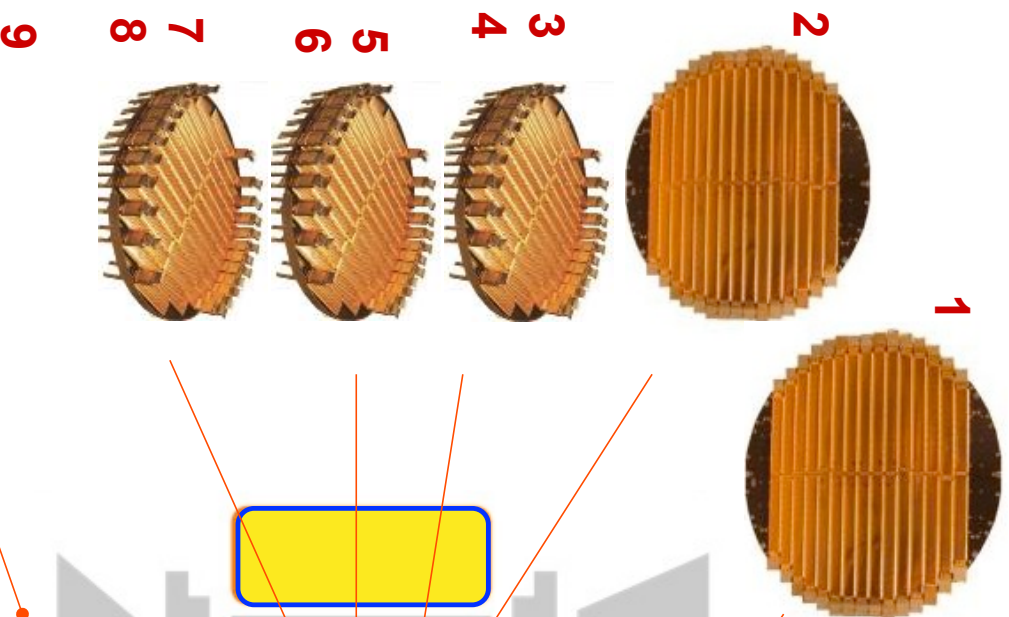
- Measurement of β
 → Up-going particles (fake anti-matter!) rejection up to 10^9
- The dE/dx can be used to measure the charge



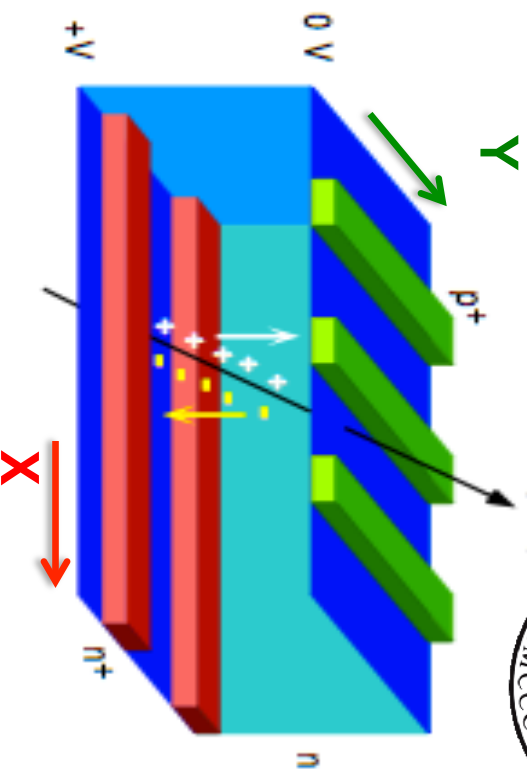
Magnetic Spectrometer



9 layers of **double sided silicon microstrip detectors**
192 ladders / 2598 sensors/ 200k readout channels

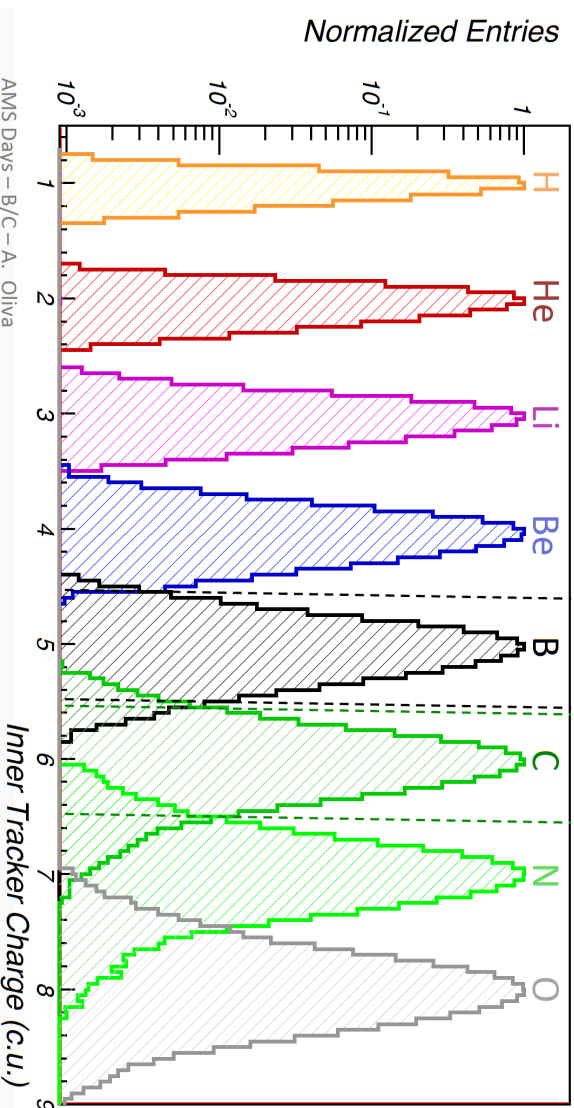
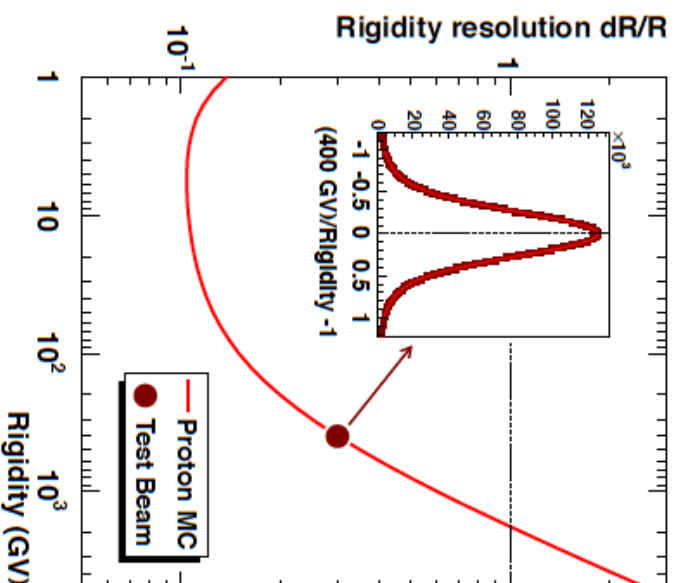


Magnetic Spectrometer



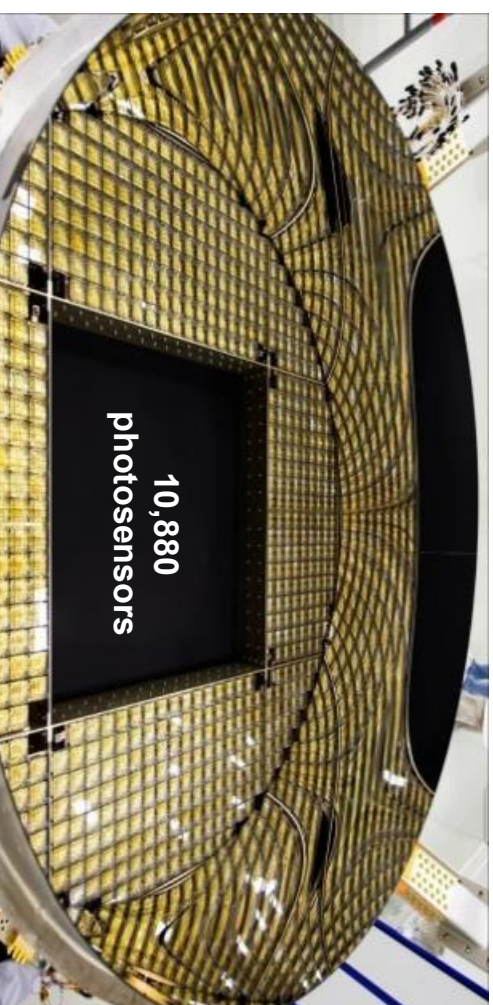
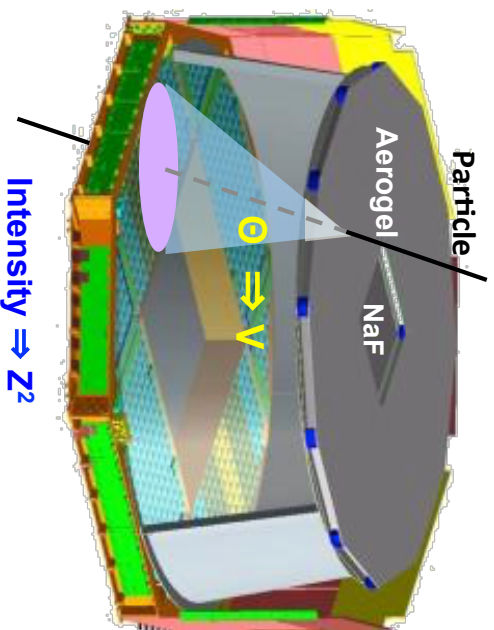
2 TV MDR for $Z=1$

14 dE/dX samples in Inner Tracker
4 dE/dX samples in external planes

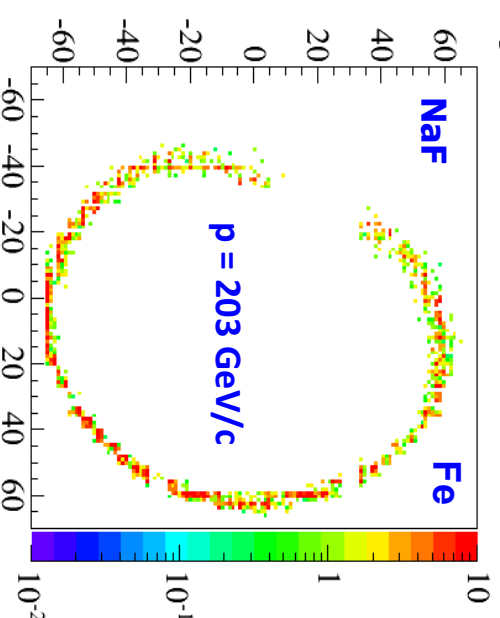
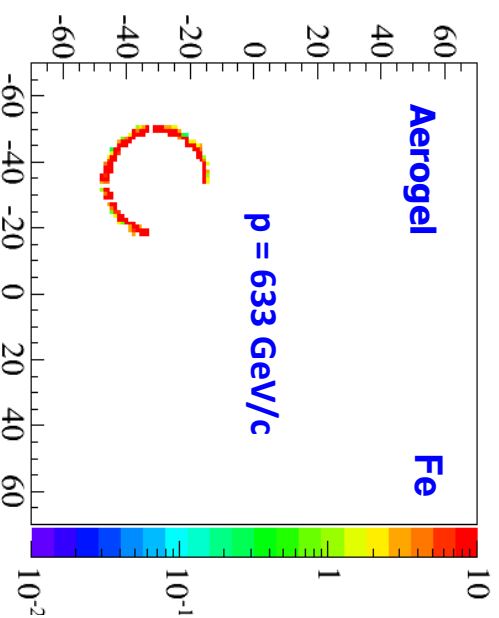


Ring Imaging Cherenkov RICH

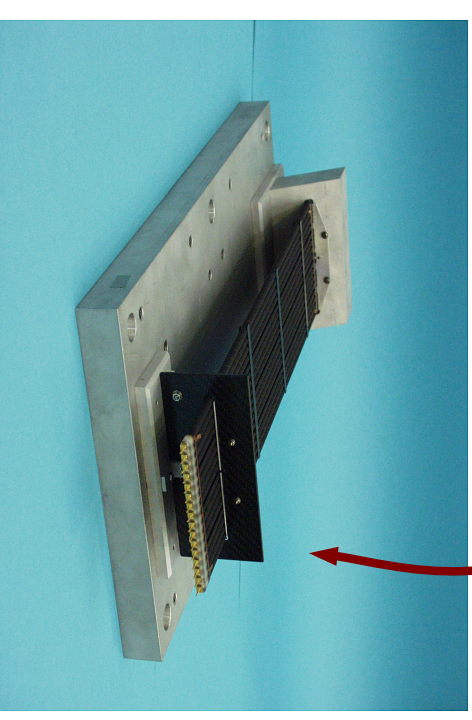
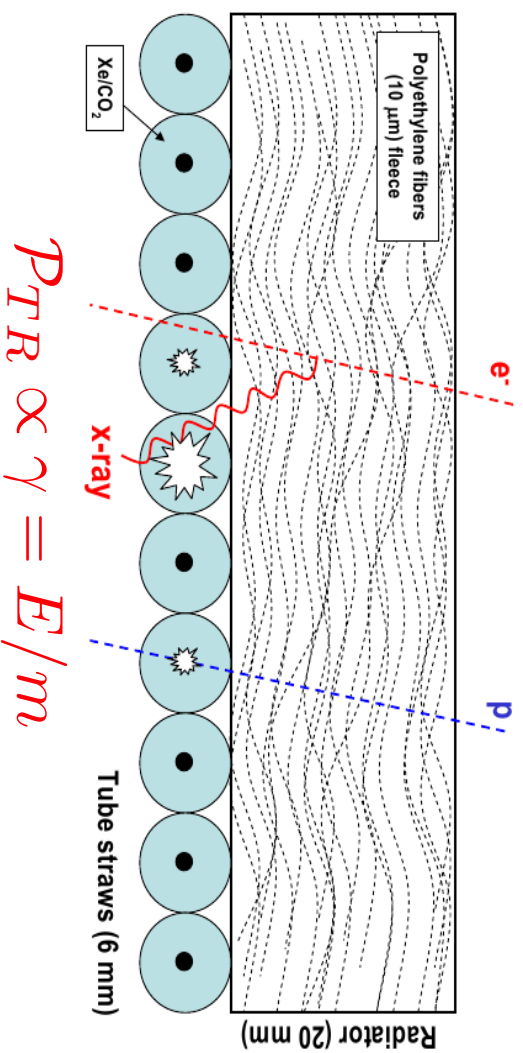
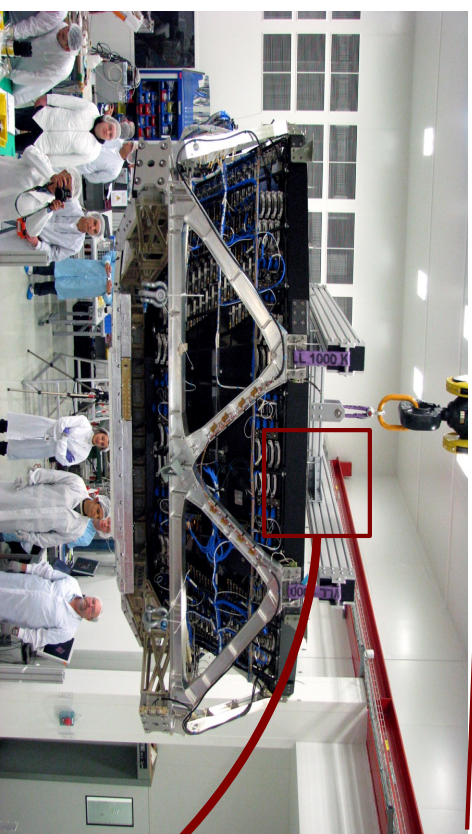
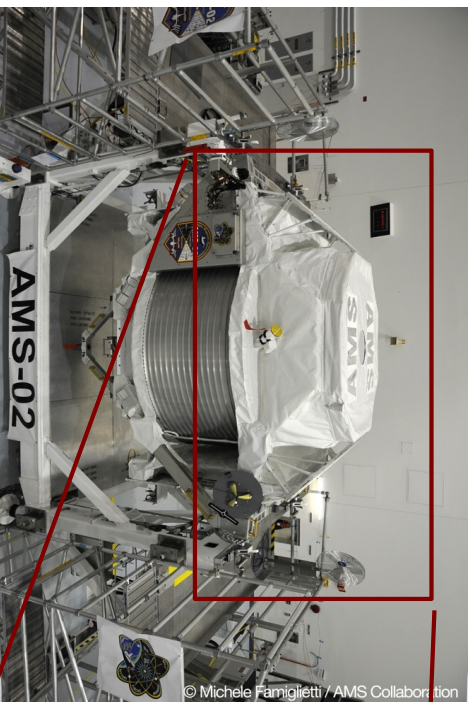
Measurement of Nuclear Charge (Z^2) and its Velocity to $1/1000$



- Ring aperture $\rightarrow \beta$
- Light intensity $\rightarrow Z^2$

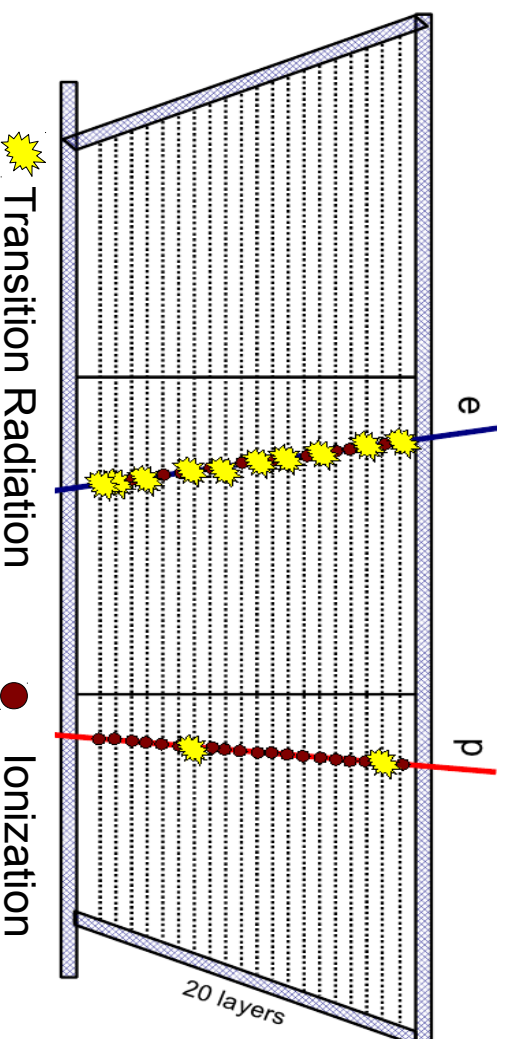


Transition Radiation Detector TRD



20 Layers of radiator (fleece) to induce X ray radiation
Straw tubes for $\sim\text{KeV}$ xray detection (Xe/CO₂ gas)

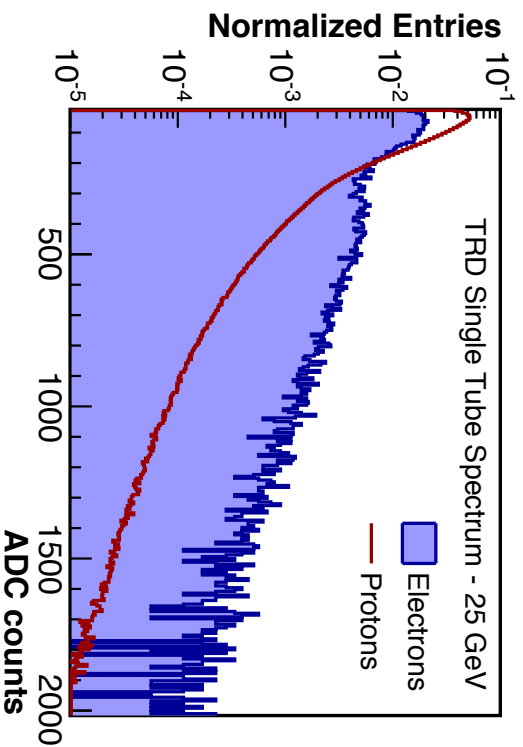
Transition Radiation Detector TRD



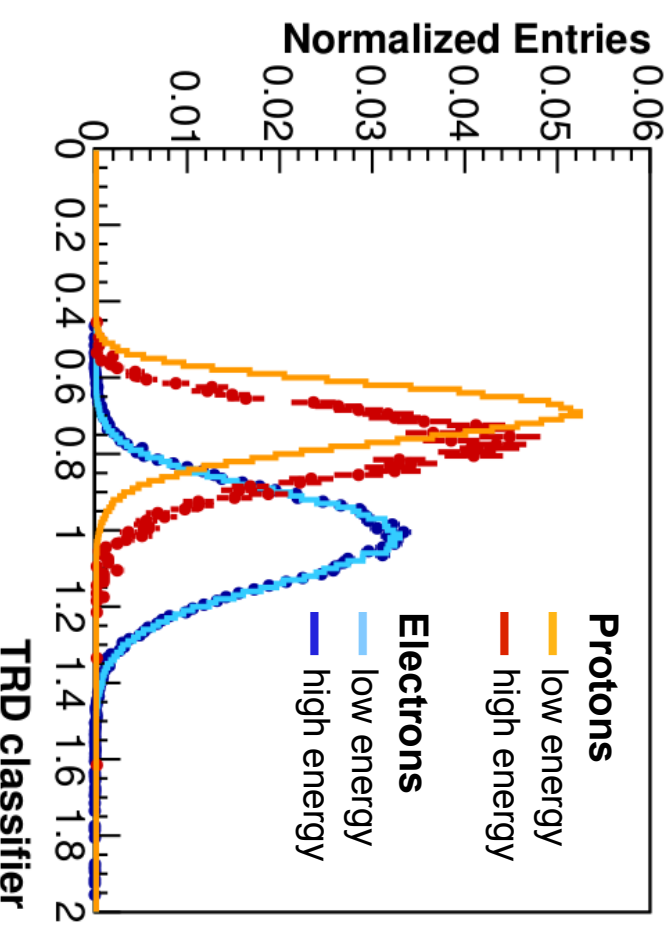
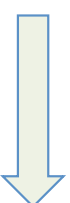
$$\mathcal{P}_{TR} \propto \gamma = E/m$$

For same Rigidity or Energy particles

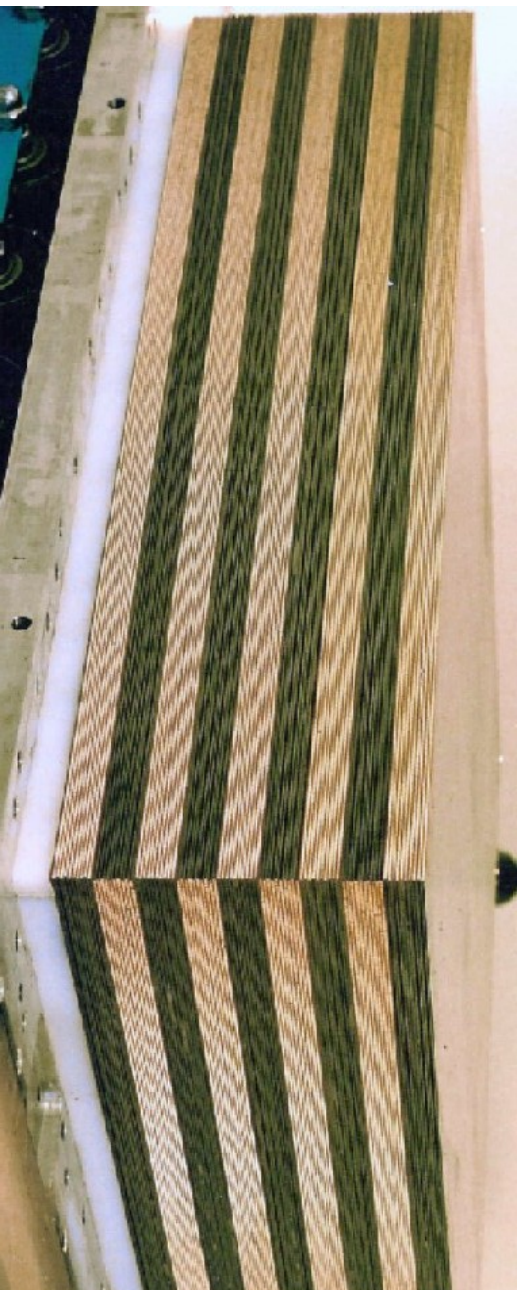
$$\mathcal{P}_{TR}(e^{\pm}) \gg \mathcal{P}_{TR}(p)$$



$$P_e = \sqrt[n]{\prod_i P_e^{(i)}(A)}$$



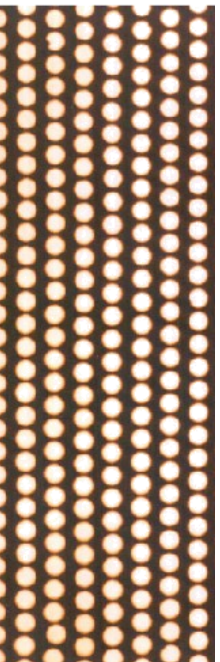
Electromagnetic Calorimeter ECAL



SAMPLING CALORIMETER

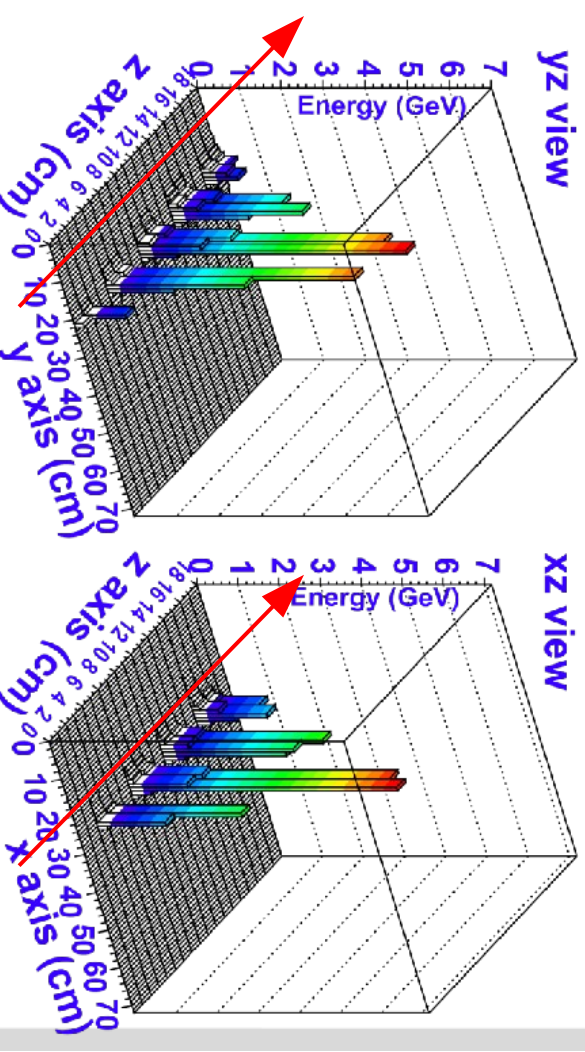
Lead + Scintillating fibers
66 x 66 x 17 cm³
1296 readout cells
17 X₀, 0.6 A_{nucl}

1 superlayer

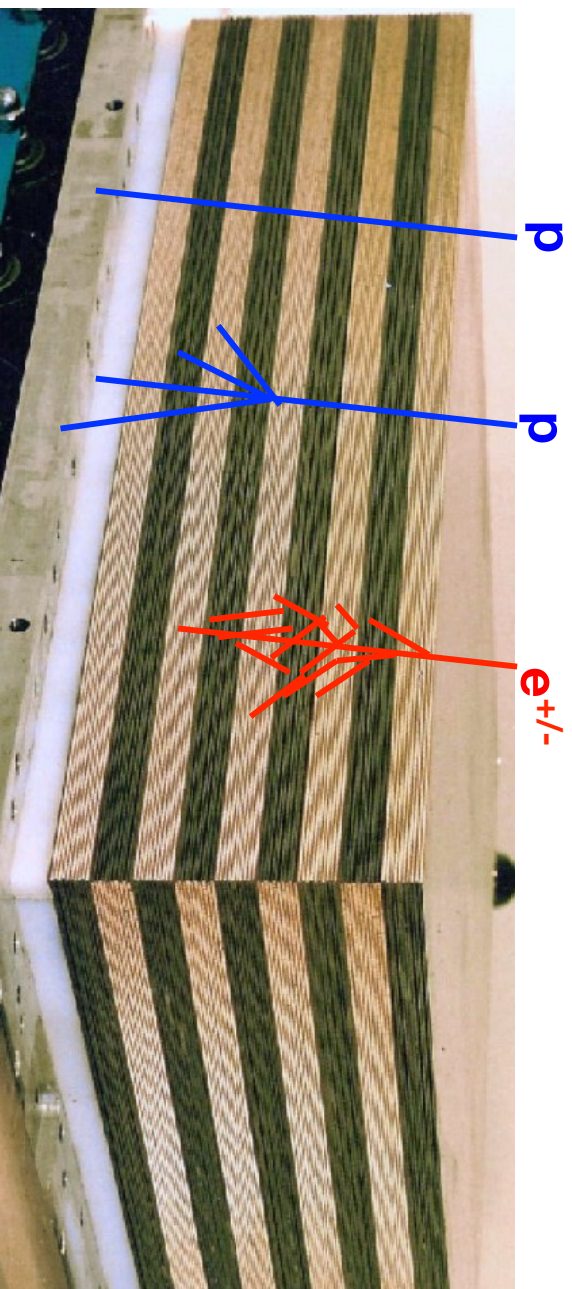


50,000 fibers, $\Phi=1\text{mm}$
Uniformly distributed in 600 kg of lead

Energy and **arrival direction**
measurement of electrons and photons up
to 1 TeV



Electromagnetic Calorimeter ECAL

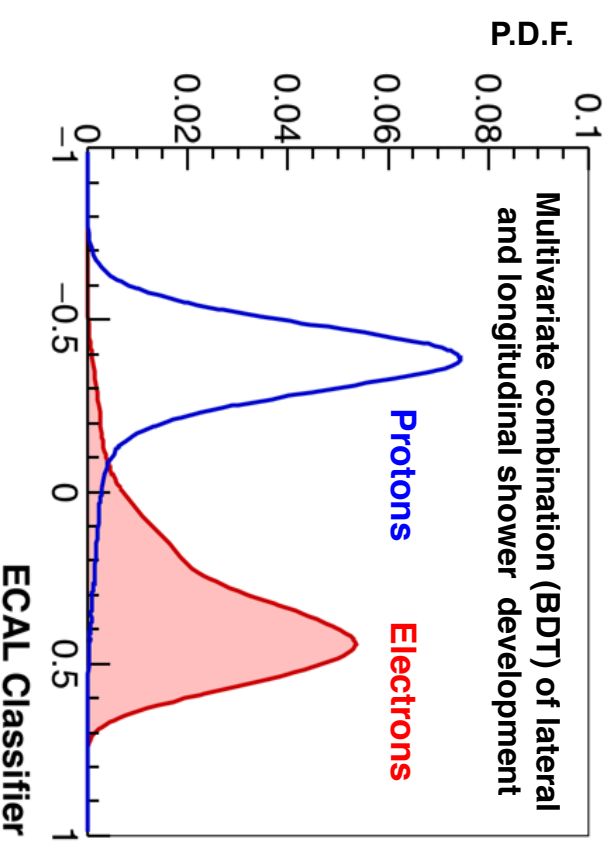
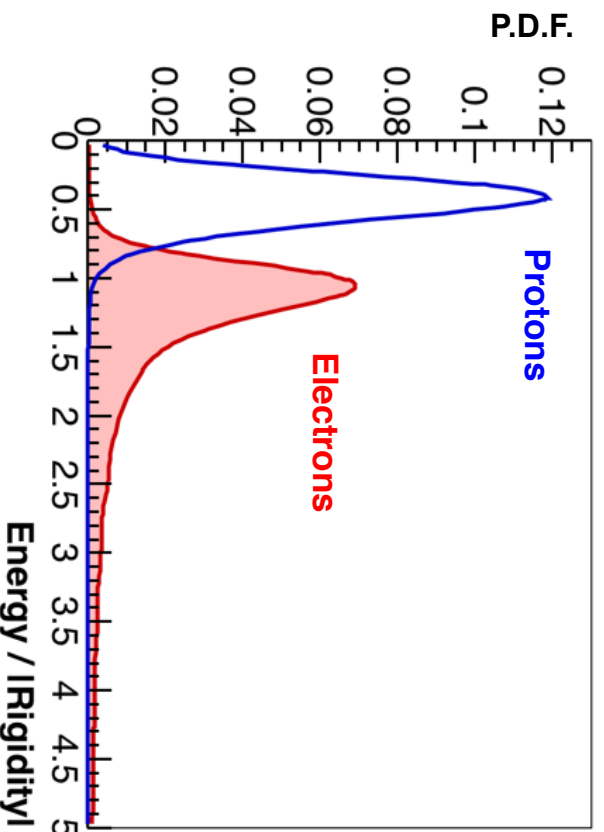


Electrons

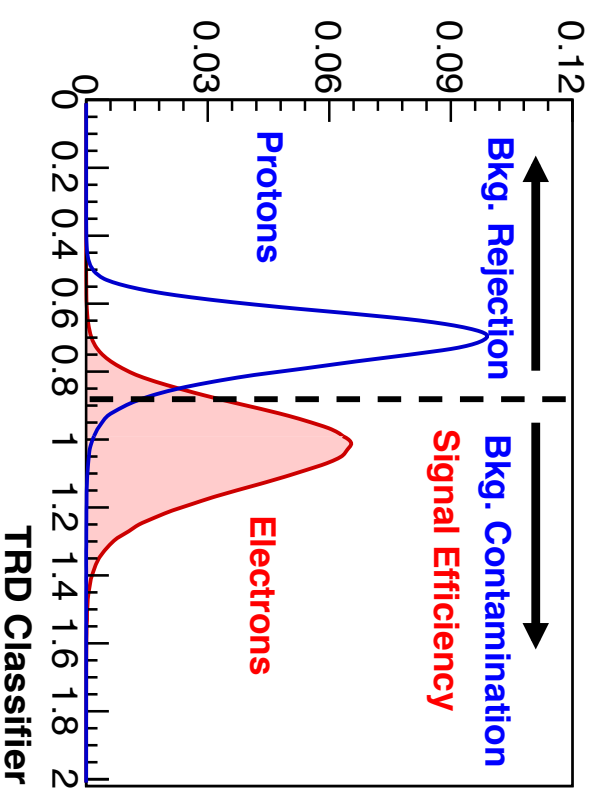
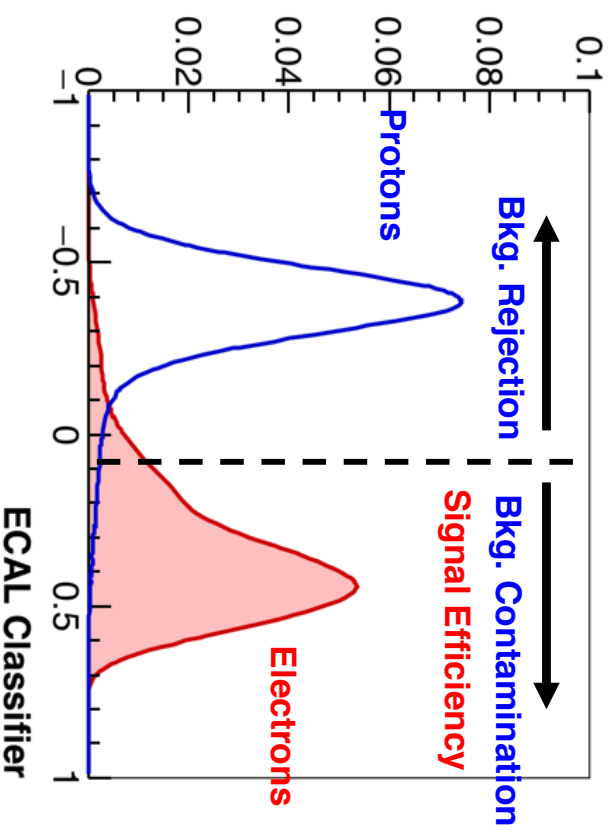
Electromagnetic Shower
Energy contained
EECAL $\sim$ PTRACKER

Protons

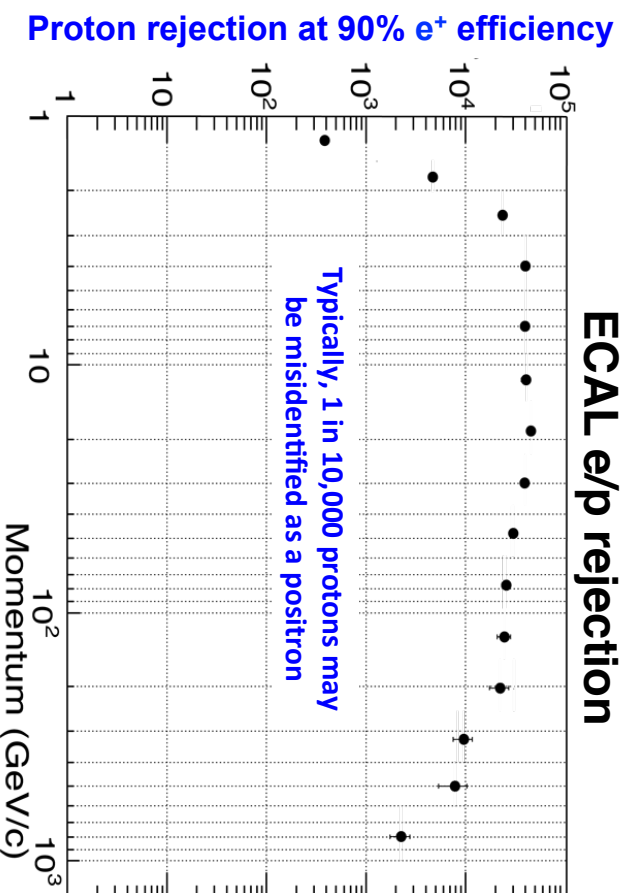
MIP or Hadronic Shower
Irregular shower
EECAL $\ll$ PTRACKER



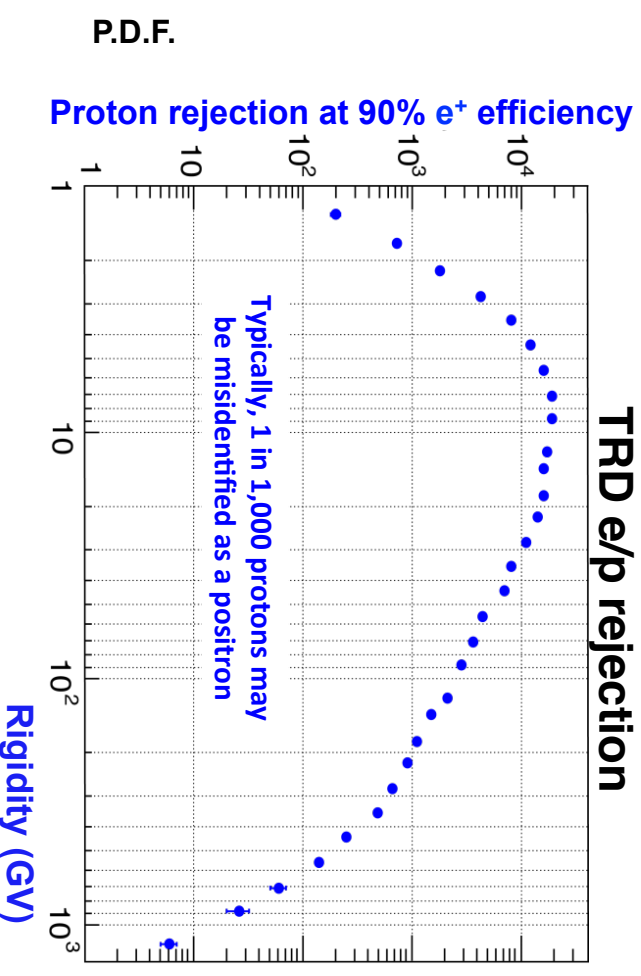
ECAL and TRD e/p separation



ECAL e/p rejection



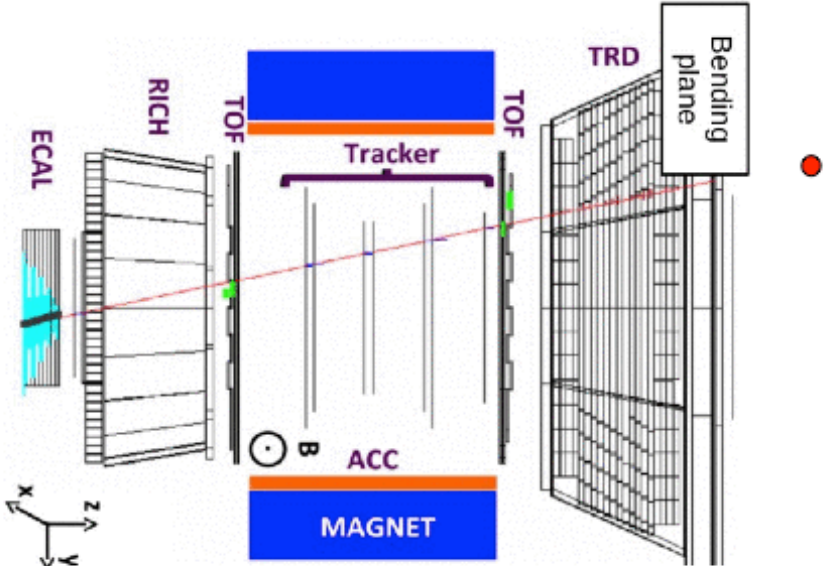
TRD e/p rejection



P.D.F.

AMS: TeV precision spectrometer

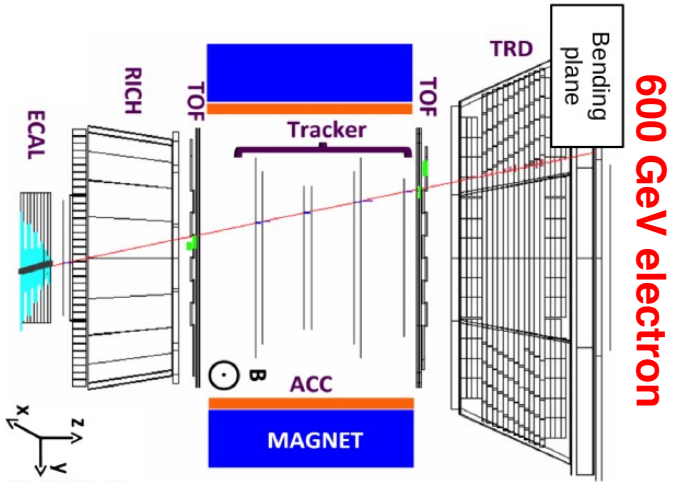
Full coverage of **anti-matter** and **CR physics**



	e ⁻	p	He
TRD 20 layers			
TOF 4 layers			
TRK 9 layers			
RICH			
ECAL 20 layers			

AMS: TeV precision spectrometer

Full coverage of **anti-matter** and **CR physics**



	e^+	e^-	p	$\bar{p}$	He	$\bar{\text{He}}$
TRD 20 layers						
TOF 4 layers						
TRK 9 layers						
RICH						
ECAL 18 layers						

e/p separation
charge ($|Z|$)

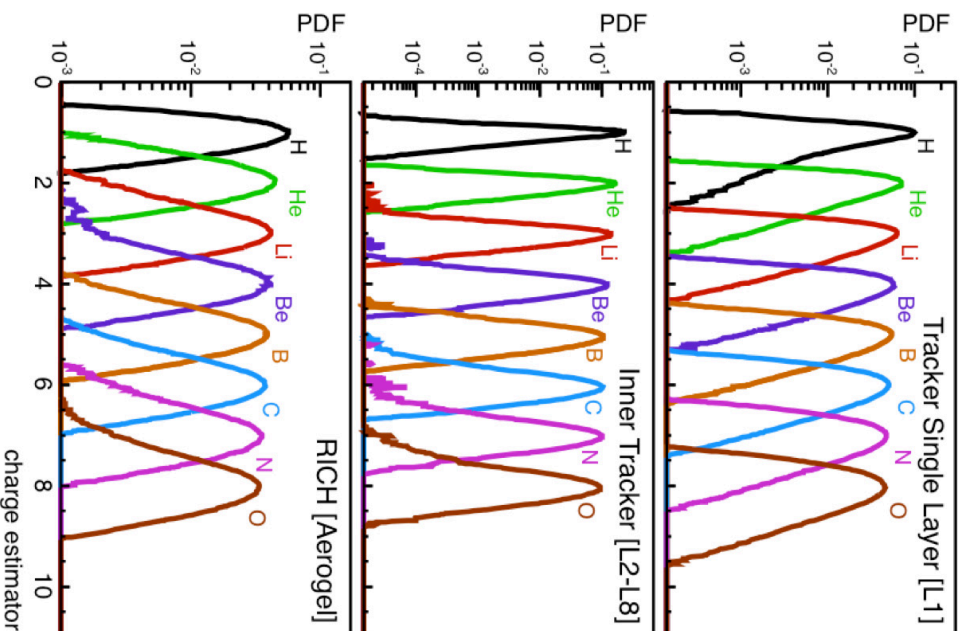
trigger
velocity (β)
charge ($|Z|$)

momentum (p)
sign ($\pm Q$)
charge ($|Z|$)

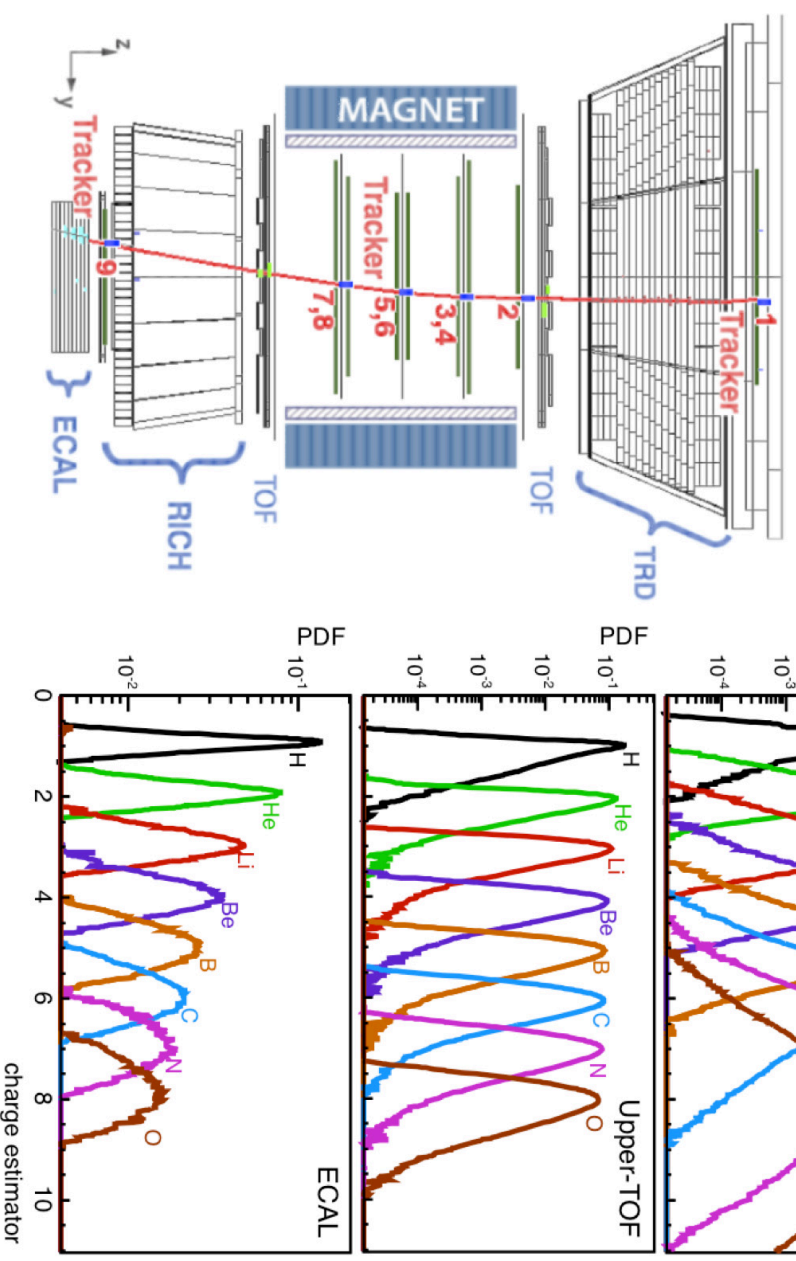
velocity (β)
charge ($|Z|$)

e^+ energy
e/h separation
 γ trigger

AMS-02 Charge Measurement



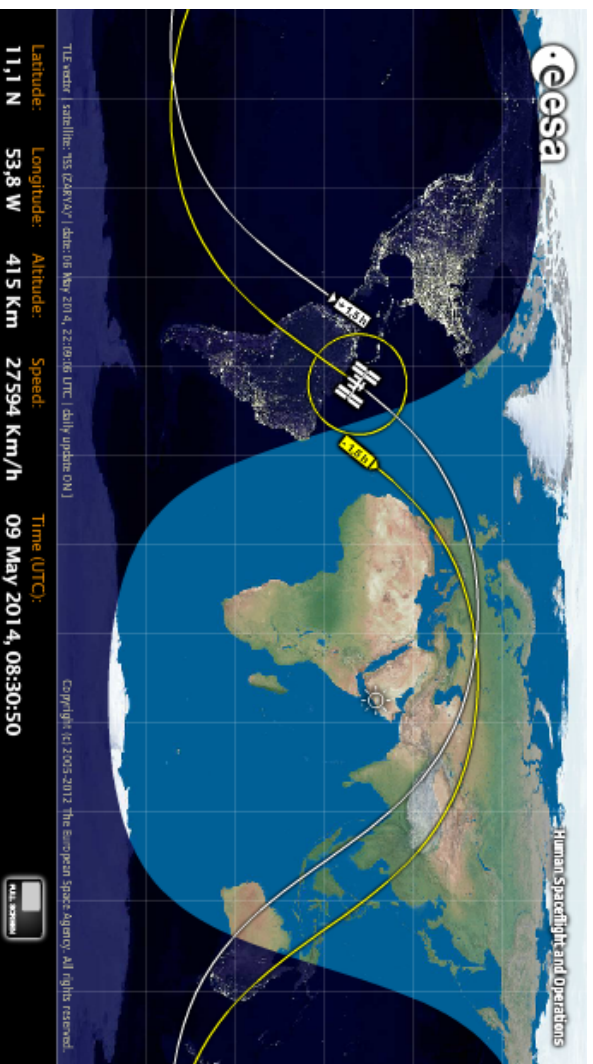
Charge Measurements of Light CR Nuclei



Redundant measurements of the nuclear charge at different depths of the detector.

Precise understanding of nuclear fragmentation in the materials.

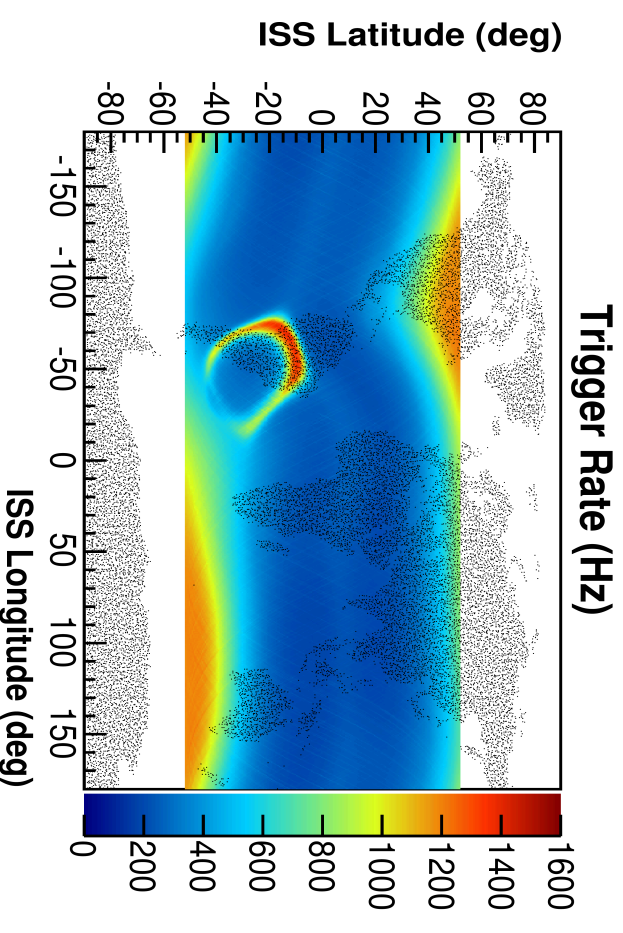
AMS orbit



DAQ operations depend on orbit position

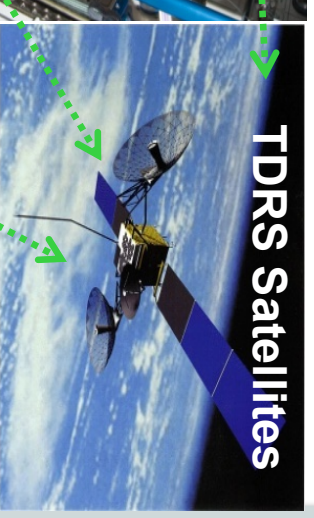
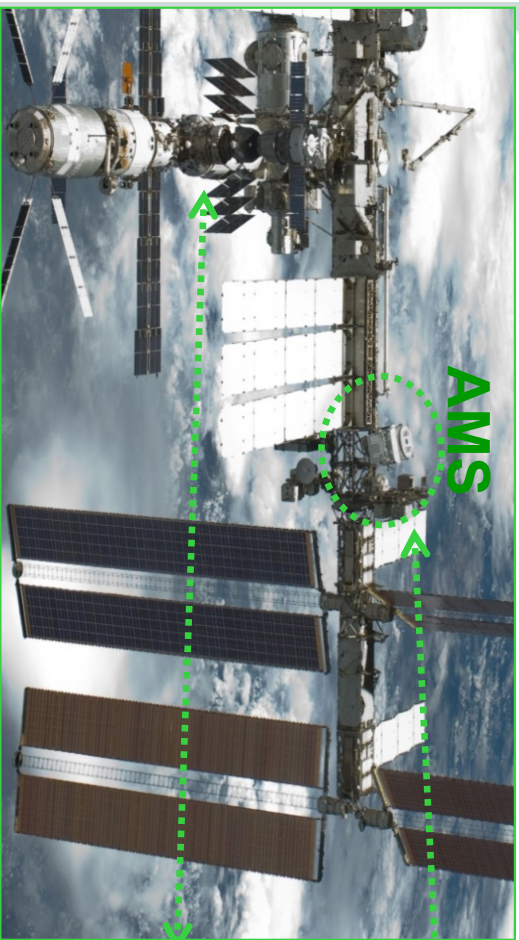
Increase of trigger rate in polar region (low magnetic field and trapped particles) and in the South Atlantic Anomaly

ISS orbit period ~ 90min
+/- 50 deg latitude covered



Detector operated continuously around the clock since May 2011 with no major interruptions

Data transfer



Flight Operations

Ku-Band
High Rate (down):
Events <10Mbit/s>
≈30 billion triggers
70 TB of raw data

Ground Operations

S-Band
Low Rate (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s



AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

AMS Computers at MSFC, AL

White Sands Ground Terminal, NM

AMS physics results

LEPTONS / ANTIMATTER

- Positrons fraction $e^+/(e^++e^-)$
- Electron and Positron fluxes (e^+ , e^-)
- Electron plus Positron flux (e^++e^-)
- Antiprotons/protons

Sensitive to
Dark Matter signal

HADRONS

- Proton and Helium (p , He)
- Lithium, Boron, Carbon (Li , B , C)

Probes to improve
the astrophysical background
knowledge

AMS-02 is providing precise data to search for new physics in the Cosmic Ray channels while improving the understanding of the astrophysical background with a coherent set of data

AMS physics results

LEPTONS / ANTIMATTER

- Positrons fraction $e^+/(e^++e^-)$
- Electron and Positron fluxes (e^+ , e^-)
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Sensitive to
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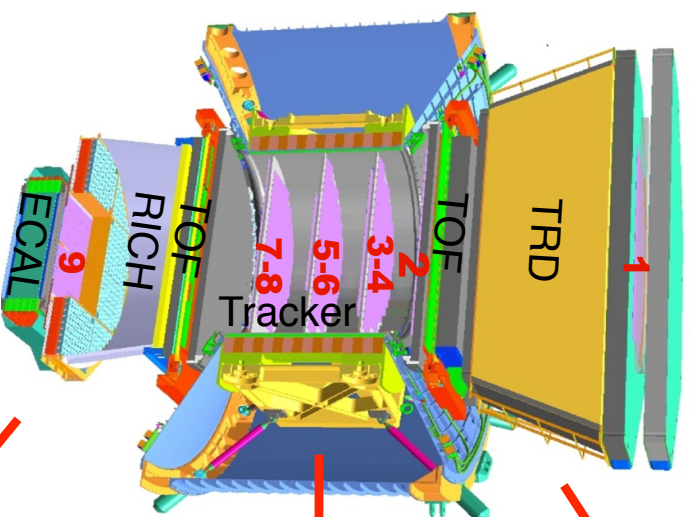
HADRONS

- Proton and Helium fluxes (p, He)
- Lithium, Boron, Carbon (Li, B, C)

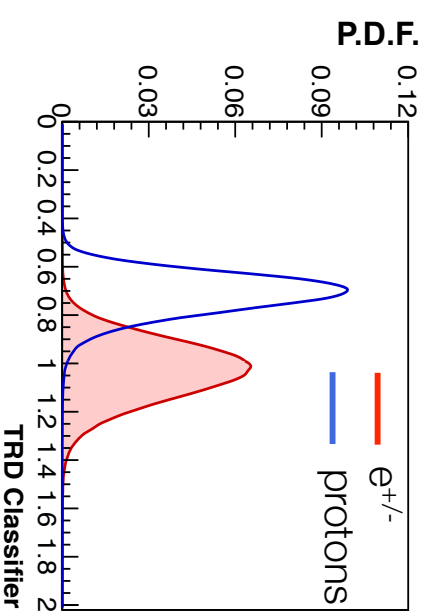
Probes to improve
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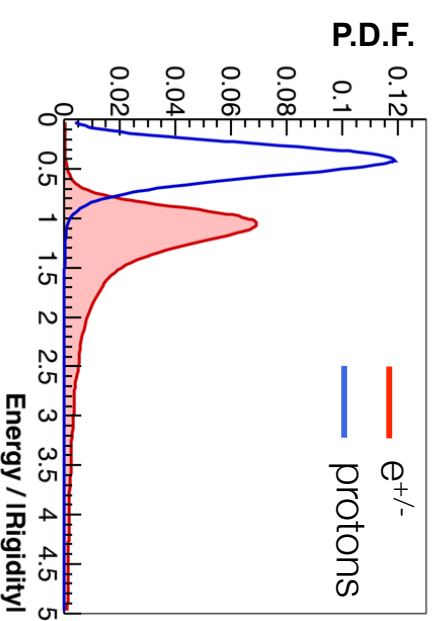
Identification of $e^{+/-}$



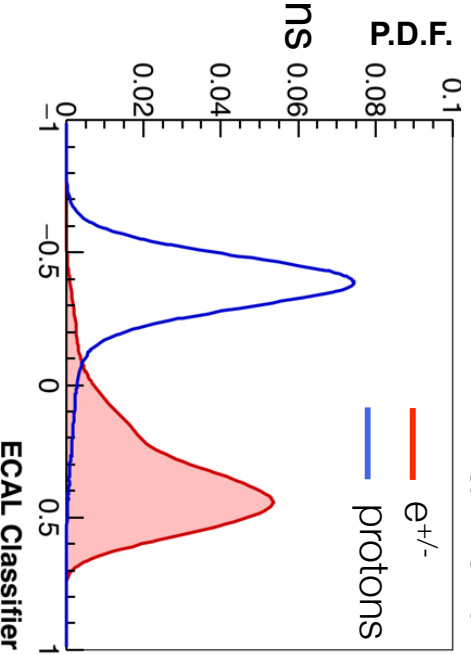
TRD
Transition Radiation
to identify $e^{+/-}$



TRACKER
Momentum P
 $e^{+/-}$: $P_{\text{TRK}} = E_{\text{ECAL}}$
Protons: $P_{\text{TRK}} \gg E_{\text{ECAL}}$

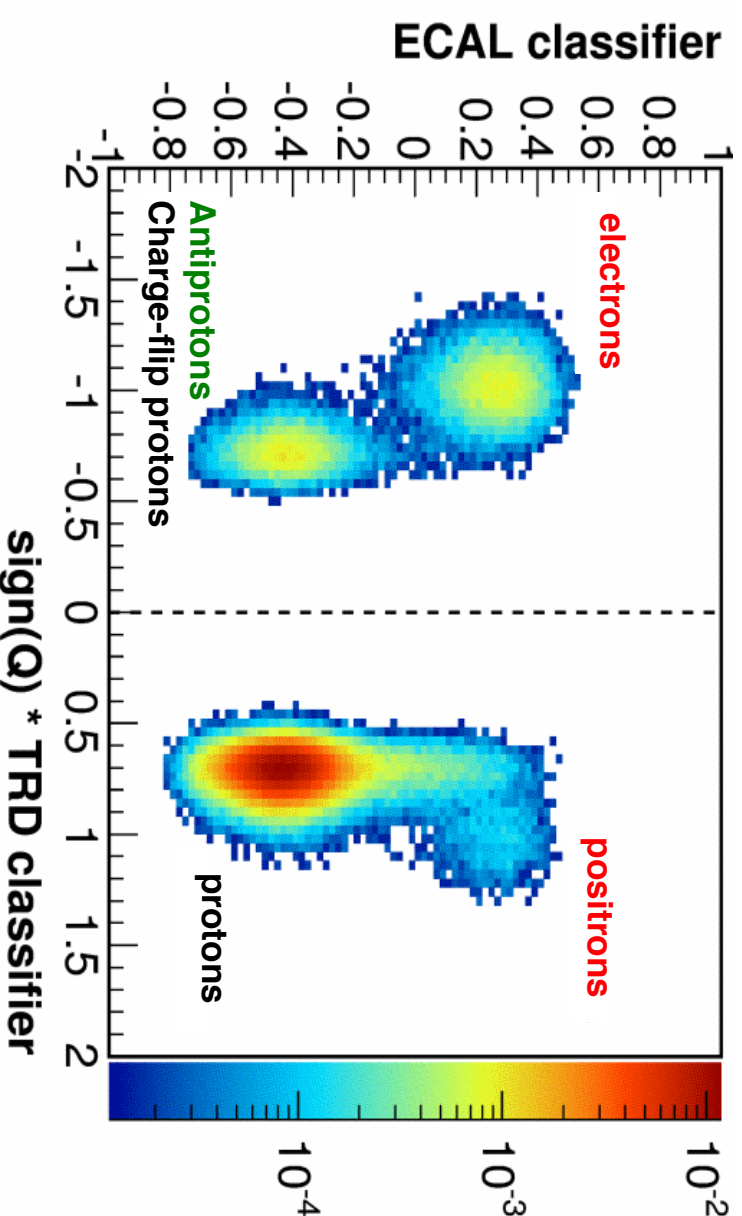


ECAL
Shower Topology
to separate $e^{+/-}$ from protons



Identification of $e^{\pm/}$

The whole ECAL and TRD subdetector information is gathered in the so called “classifier” 1-D variables, trained to reject protons.

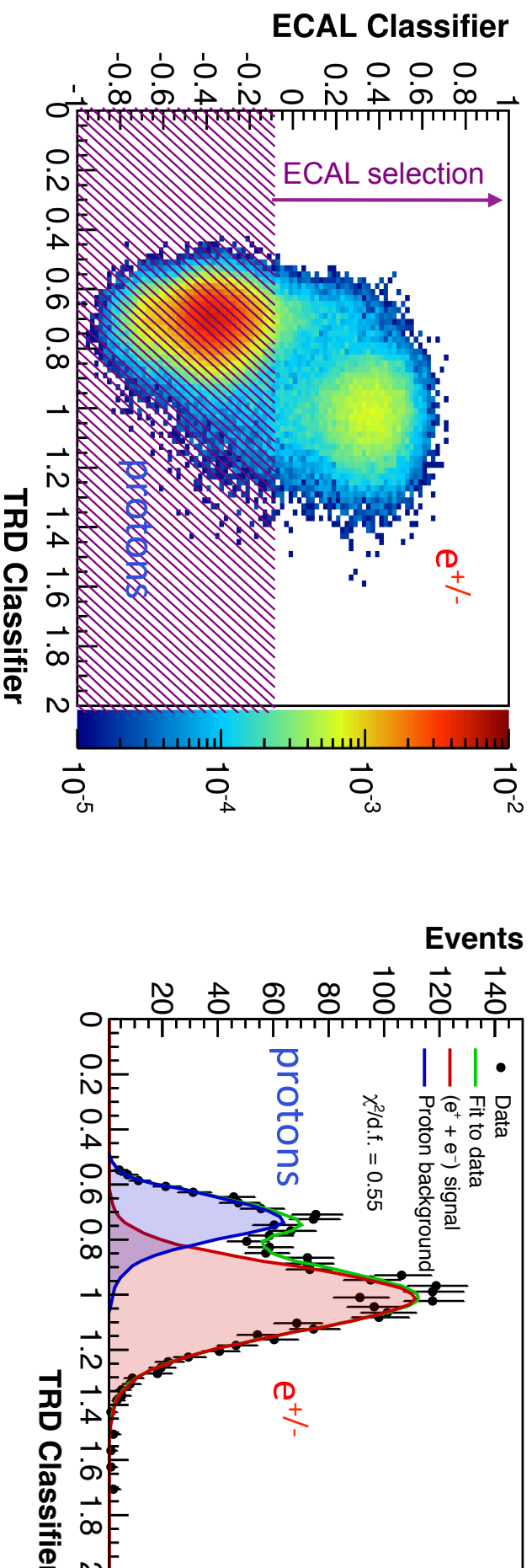


ECAL and TRD, separated by the magnet, efficiently and independently discriminate the signal ($e^{\pm/}$) from the background (protons)

Identification of (e^+e^-)

TRD Classifier template fit

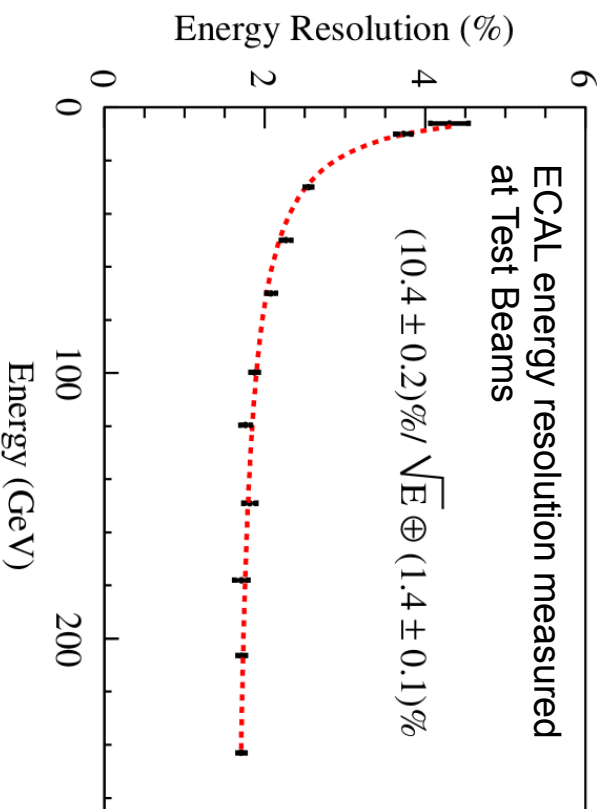
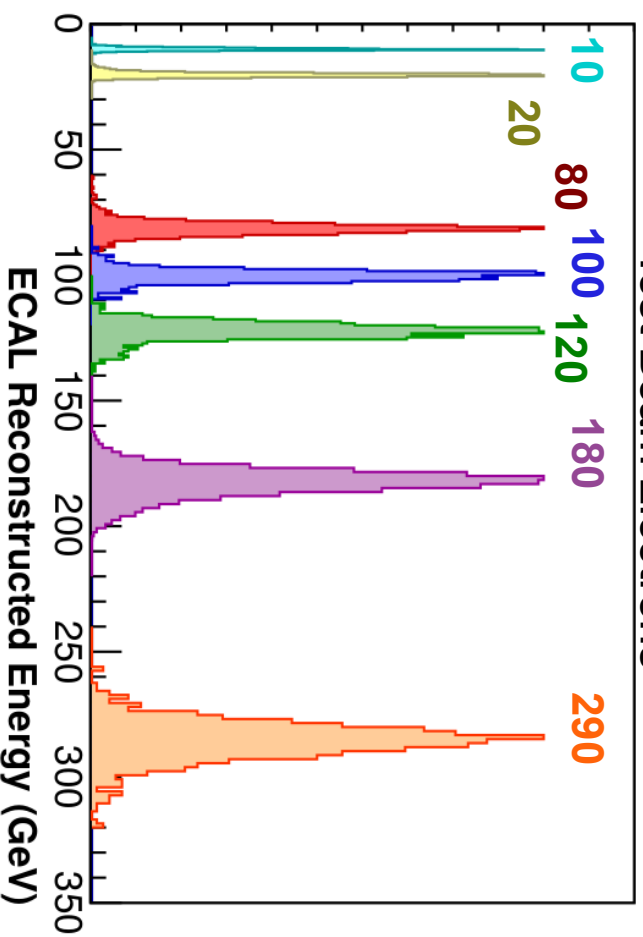
Reference spectra for the signal and the background are fitted to data as a function of the TRD classifier for different cuts on the ECAL BDT estimator



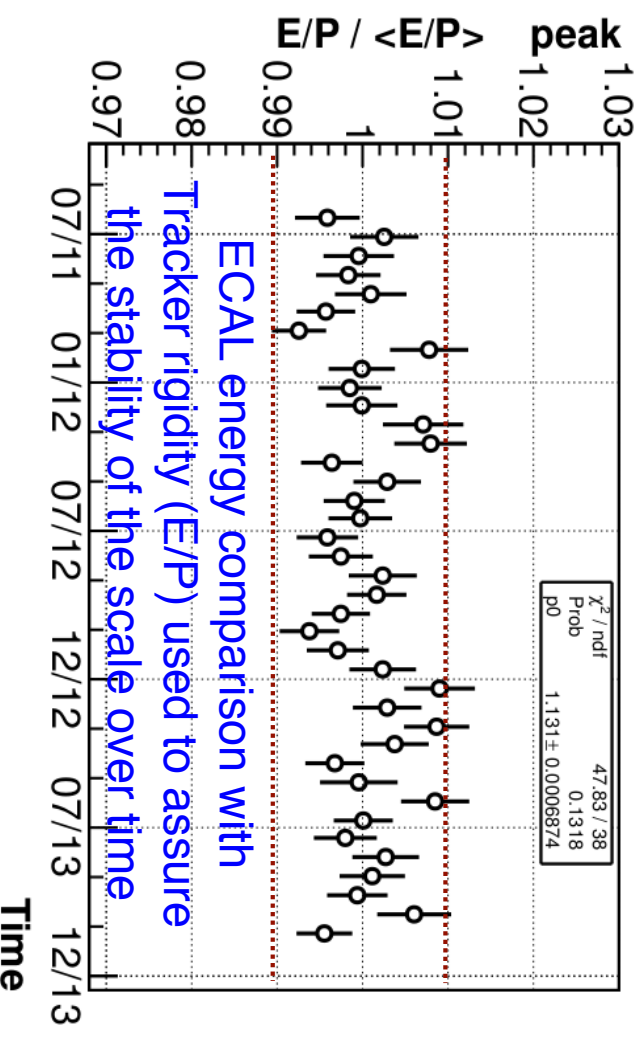
1. **ECAL** efficiently removes the majority of background protons
2. **TRD** independently evaluates the tiny remaining protons in the selected e^+e^- sample

Energy Measurement

Test Beam Electrons



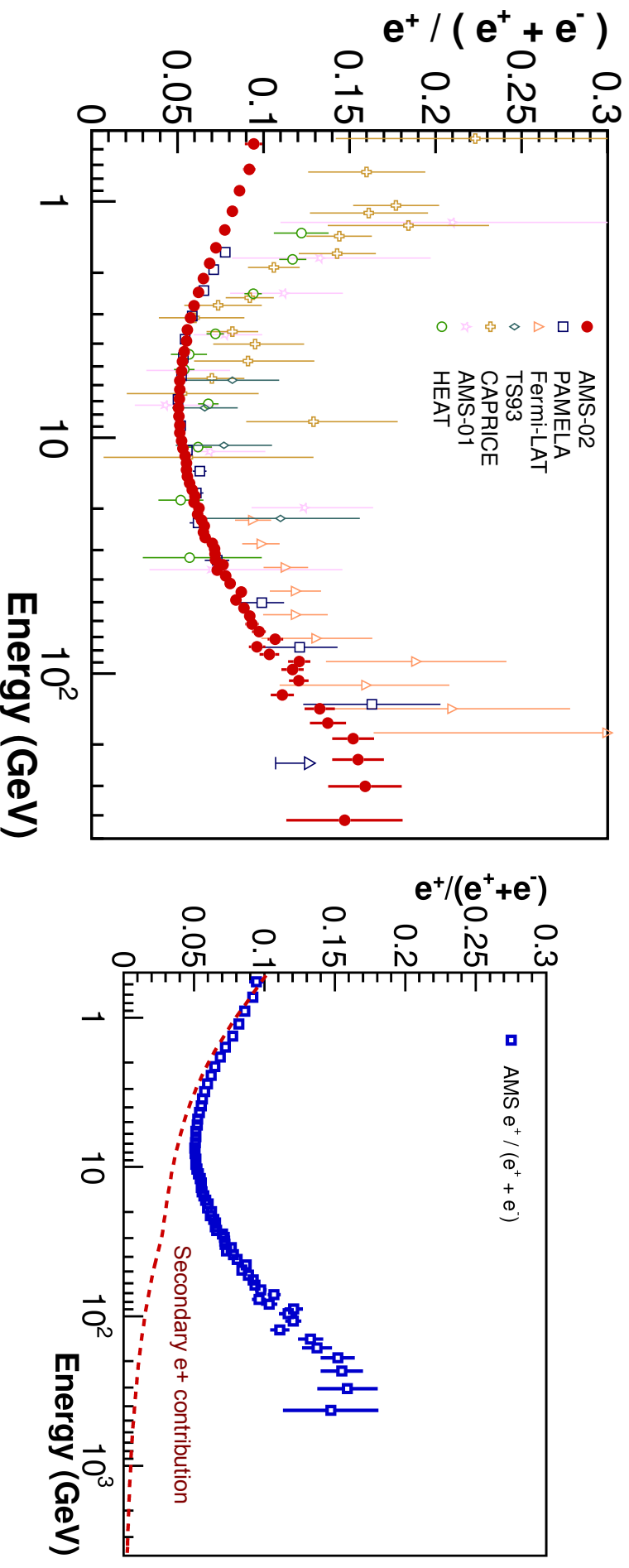
- ECAL energy resolution $\sim 2\%$
- ECAL energy absolute scale tested during test beams on ground
- We have no line in space (as in collider exp.) to calibrate the energy scale in orbit!
- MIP ionization used to cross-calibrate the energy scale in orbit



ECAL energy scale known at 2% level in [10.0 – 290.0] GeV

Positron Fraction

Rise in the fraction of positrons (antimatter) over electrons (matter) not expected by the current Standard Model of CR origin and propagation

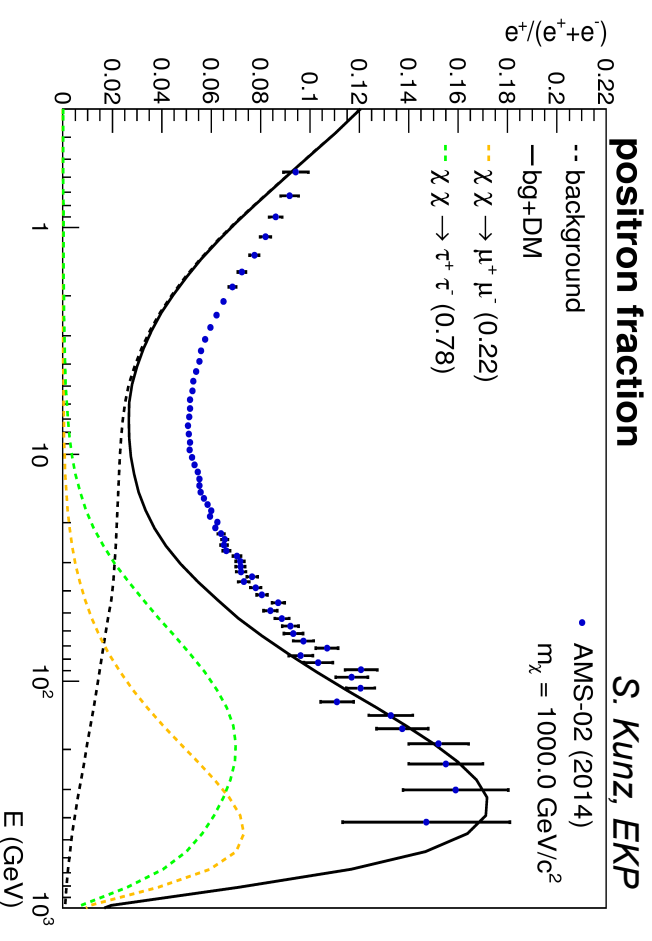
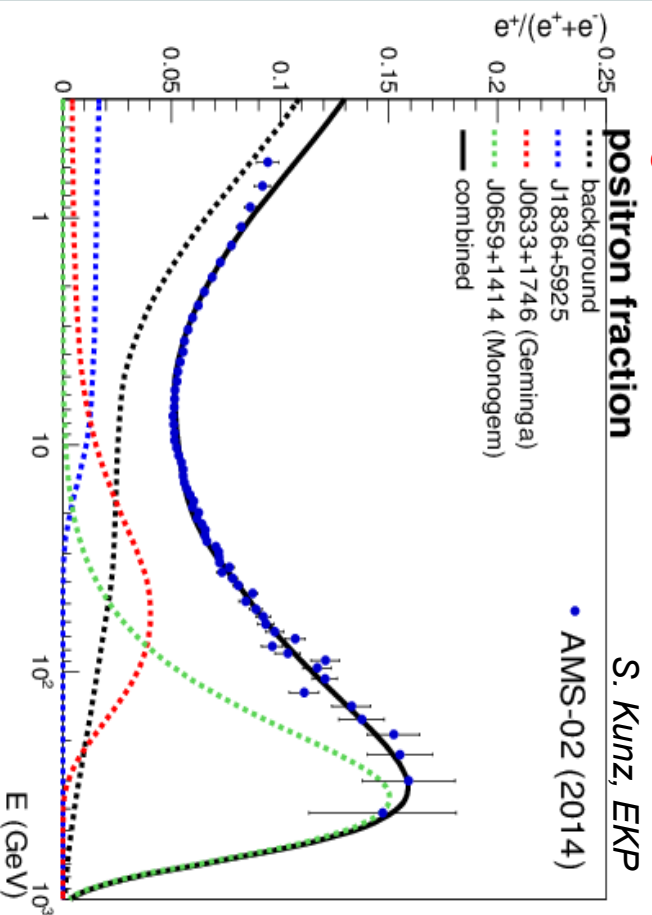
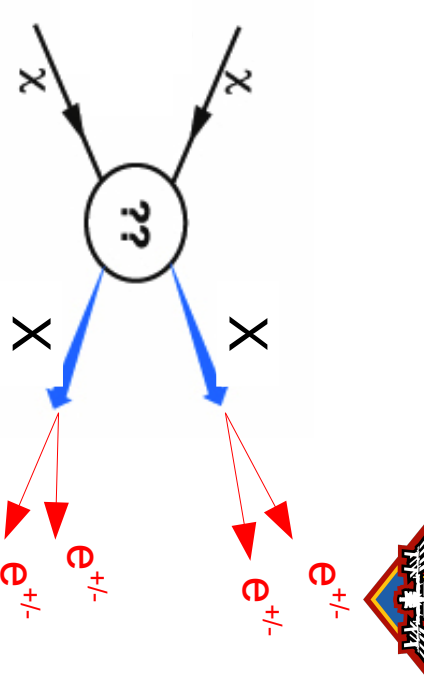
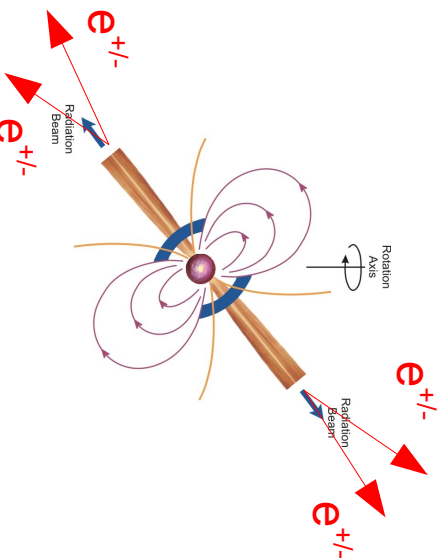


Unprecedented accuracy and energy range allowed a detailed study of the positron fraction behavior with energy

Positron Fraction

■ PULSARS

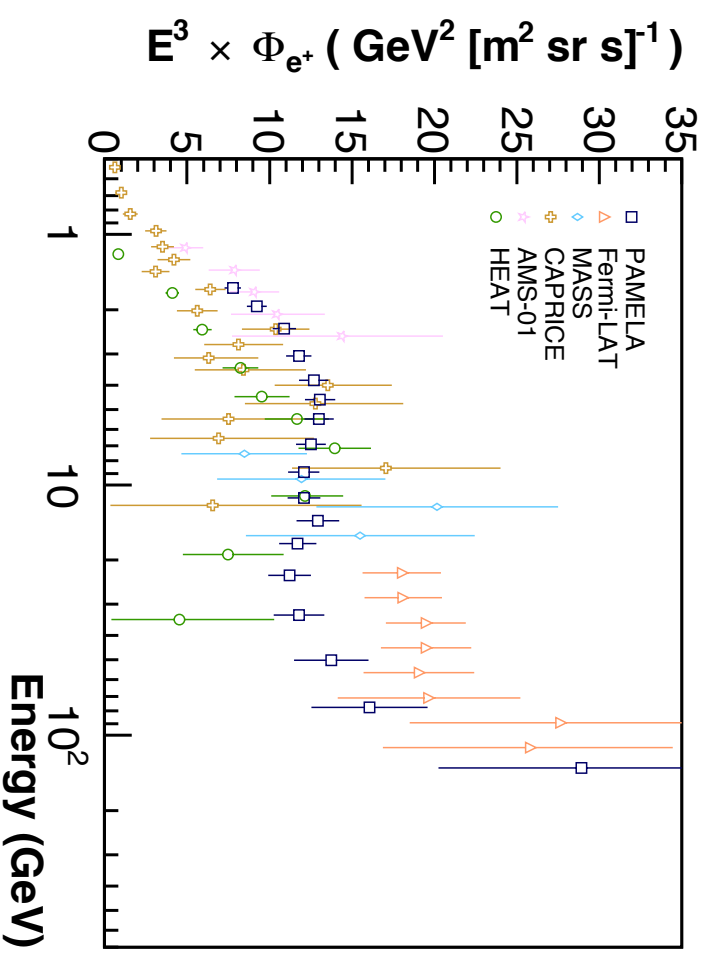
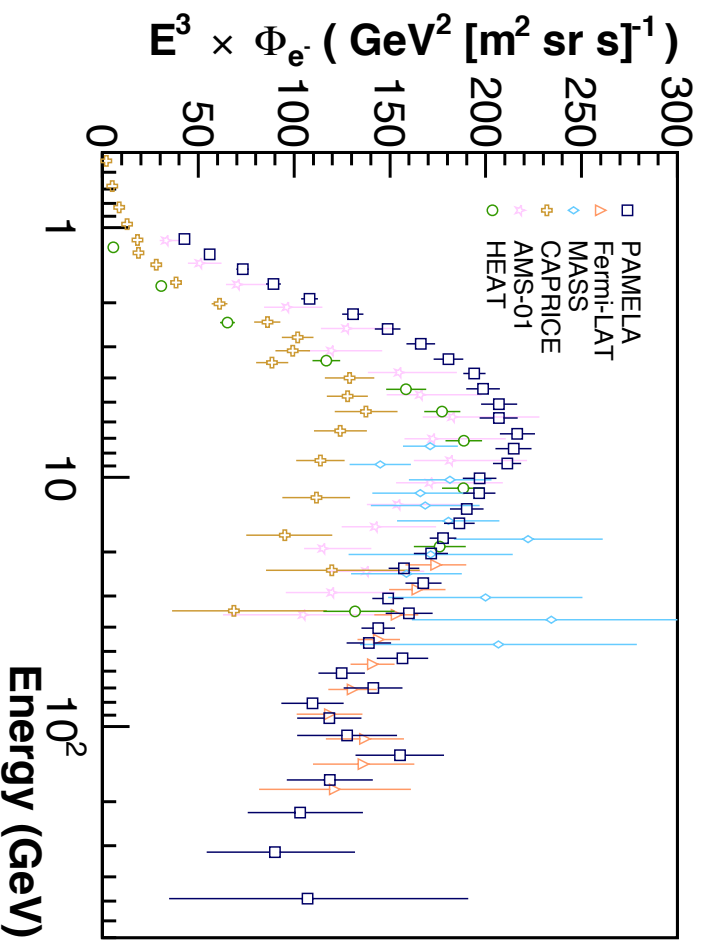
■ Dark Matter annihilation



■ Both mechanisms can be tuned to explain the data.

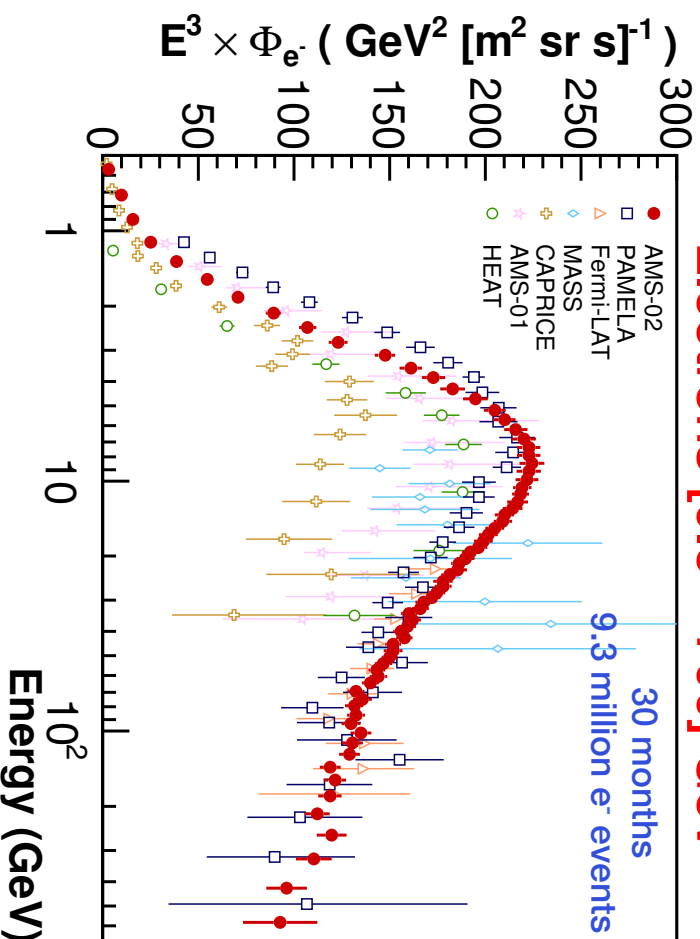
■ The measurement of the spectral shape alone cannot disentangle between the two sources.....

e^+ and e^- Fluxes

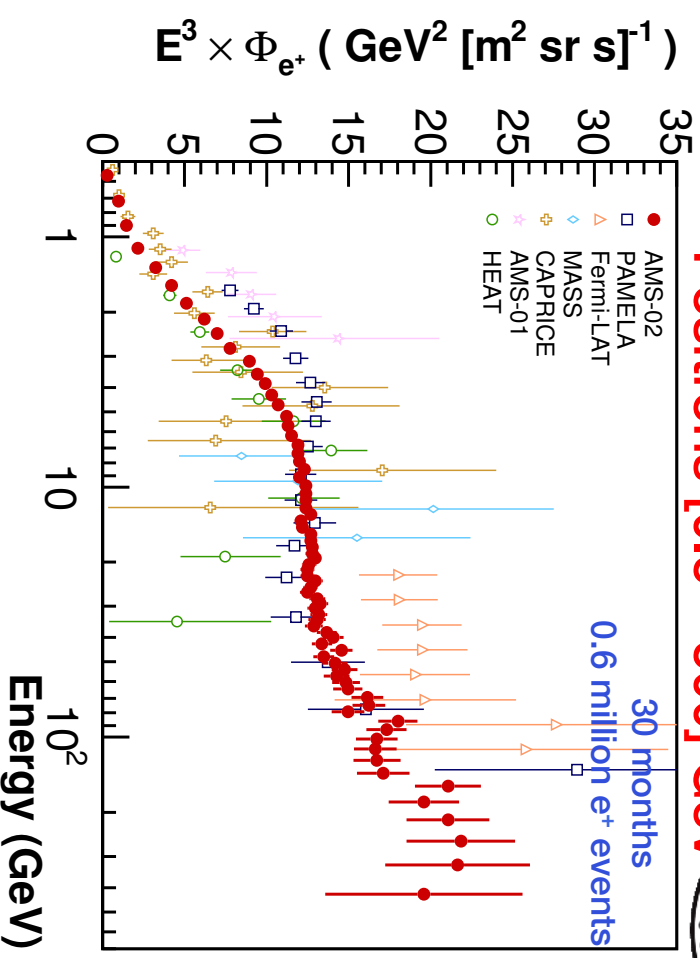


e^+ and e^- Fluxes

Electrons [0.5 – 700] GeV

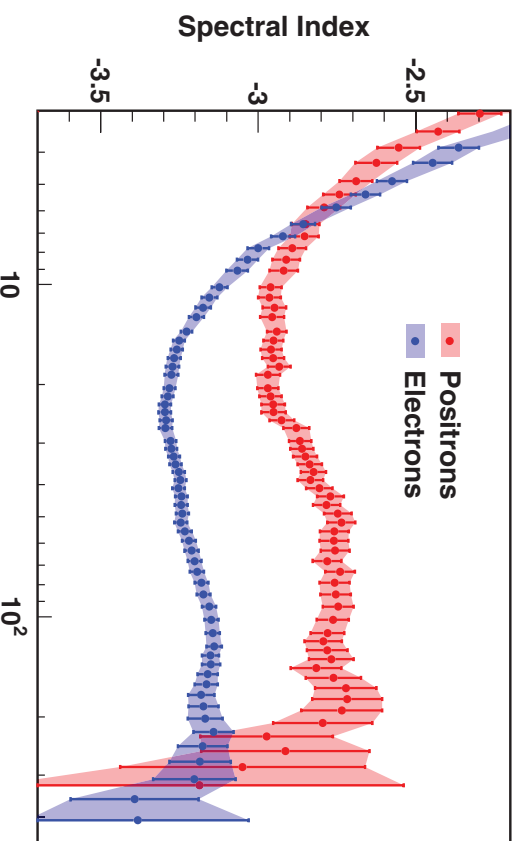


Positrons [0.5 – 500] GeV



e^+ and e^- flux are significantly different in their magnitude and energy dependence

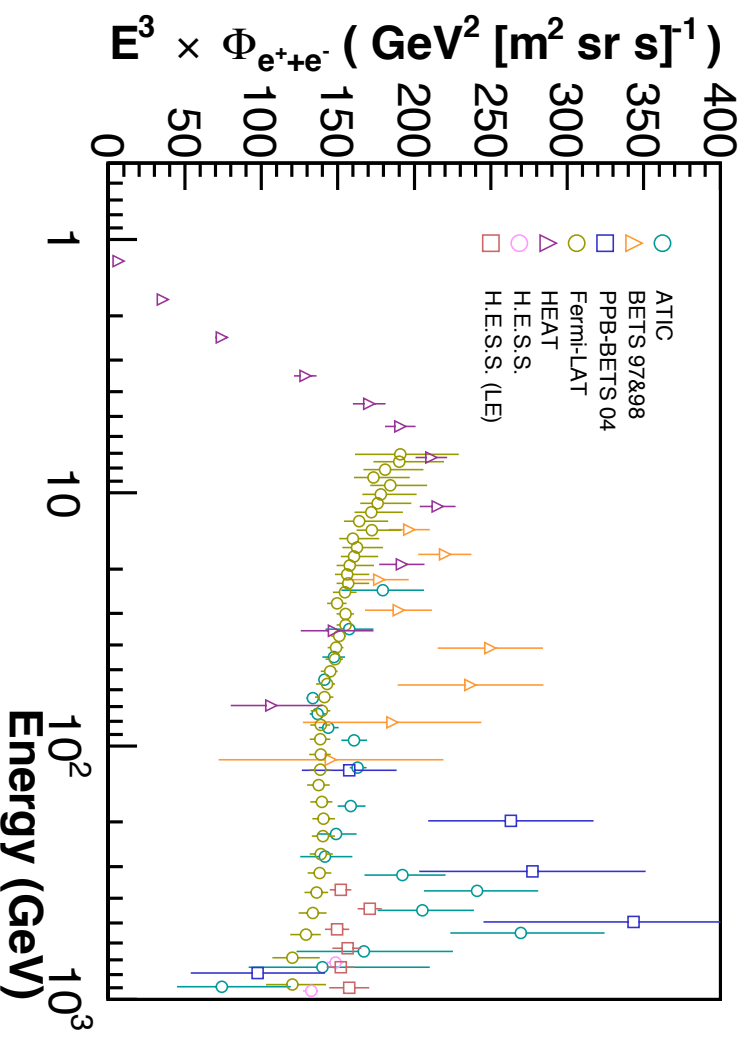
The positron fraction rise is due to an **excess of positrons**, not due to a unpredicted decrease of electrons.



$(e^+ + e^-)$ Flux

Independent measurement of the total e^+e^- flux without identification of the charge sign.

Higher energy reach and improved accuracy due to looser selection.

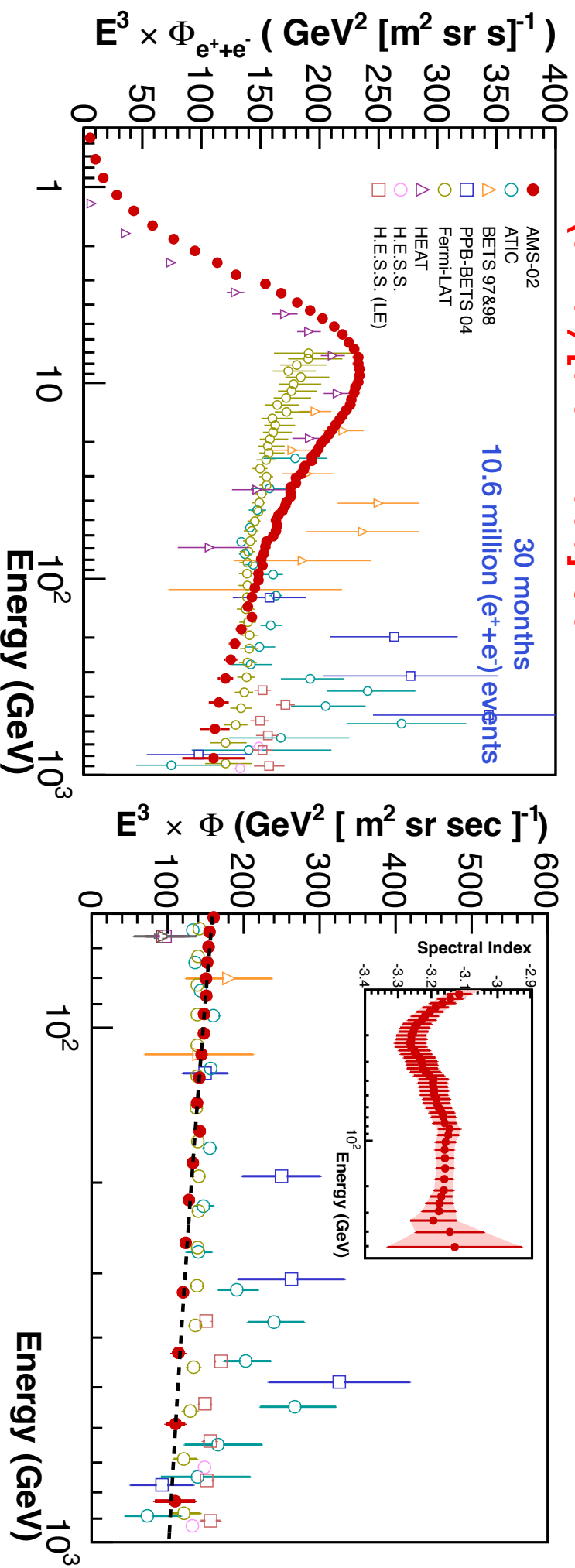


(e^+e^-) Flux

Independent measurement of the total e^+e^- flux without identification of the charge sign.

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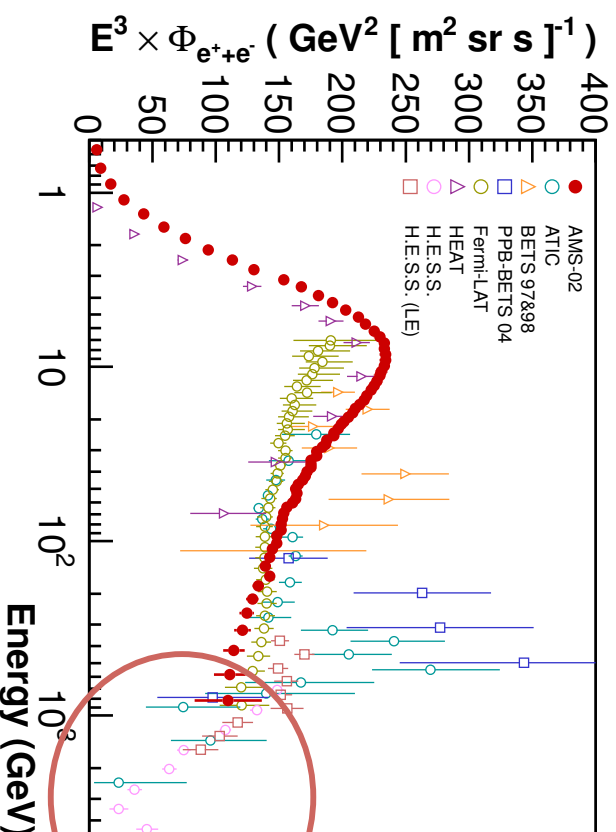
(e^+e^-) [0.5 – 1000] GeV



The (e^+e^-) flux is smooth, and can be described by a single power law starting from 30 GeV up to 1 TeV.

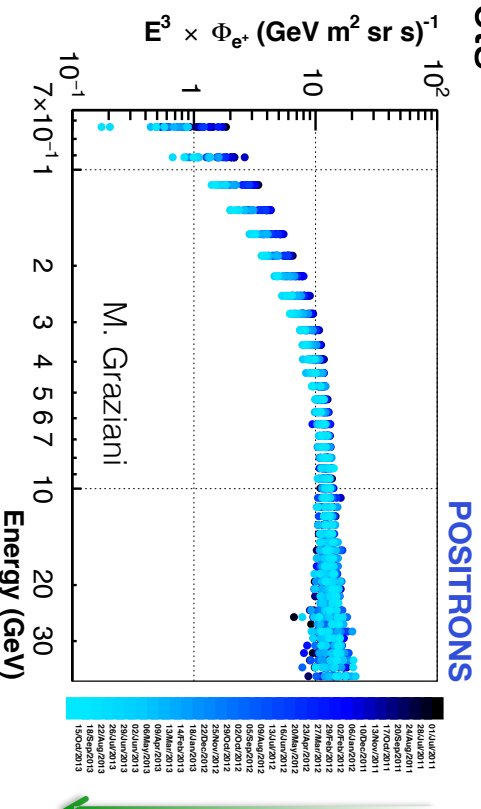
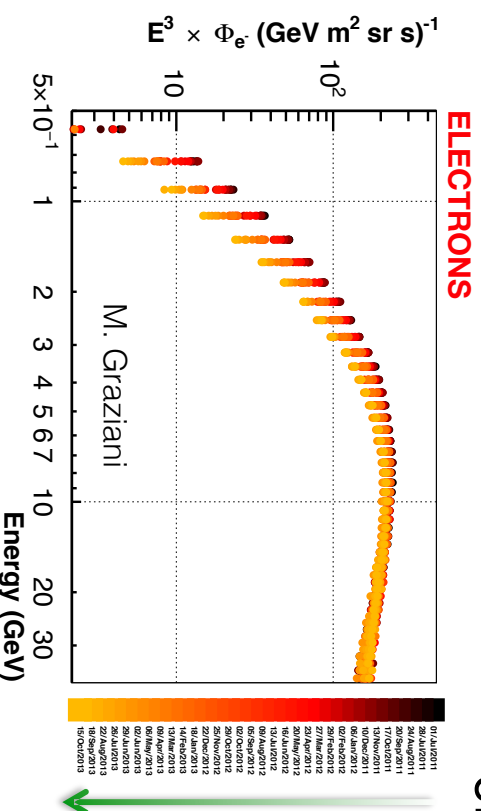
No evidence of fine structures has been observed in the (e^+e^-) spectrum.

What's next....



- Explore the TeV energy range
- Overlap with ground experiments
- Search for spectral features

Explore the GeV range to study for Solar time dependent modulation and transient effects



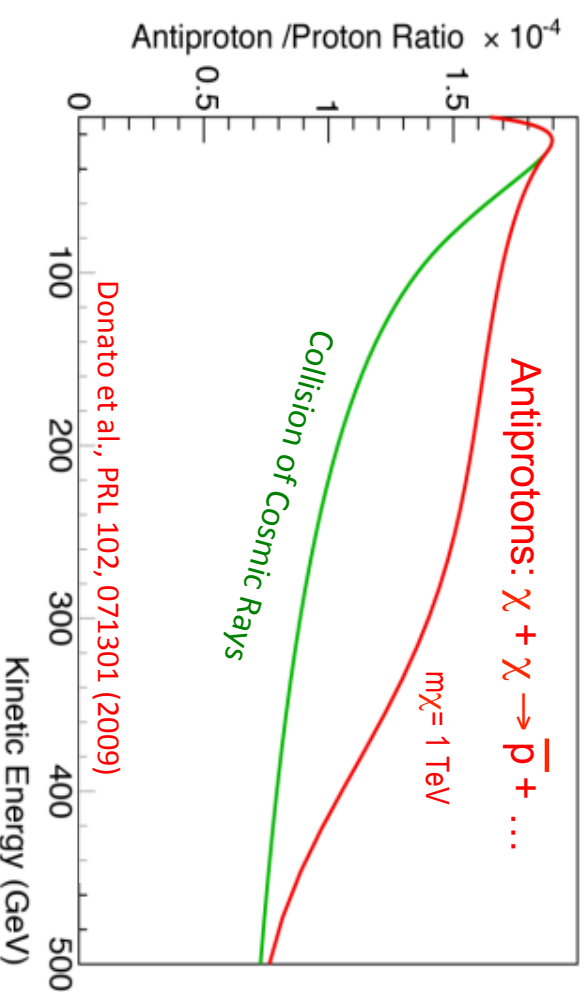
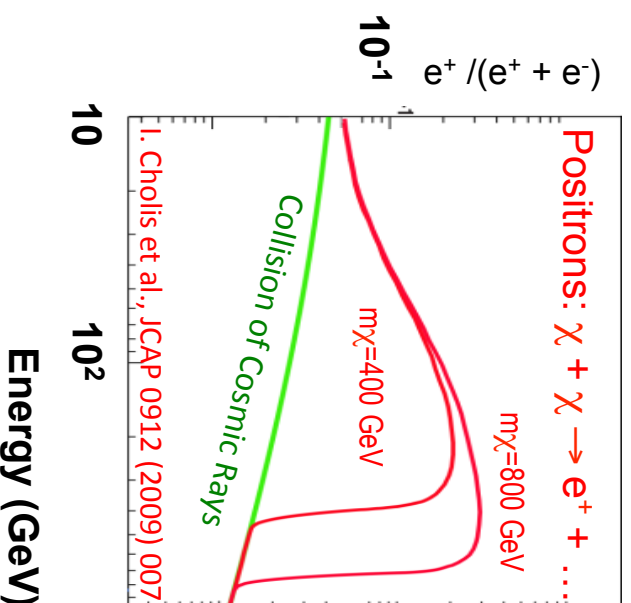
TIME

What is AMS observing?

Something “different” with respect to conventional models of e^+ production by collisions of CR hadrons with the interstellar medium (ISM)

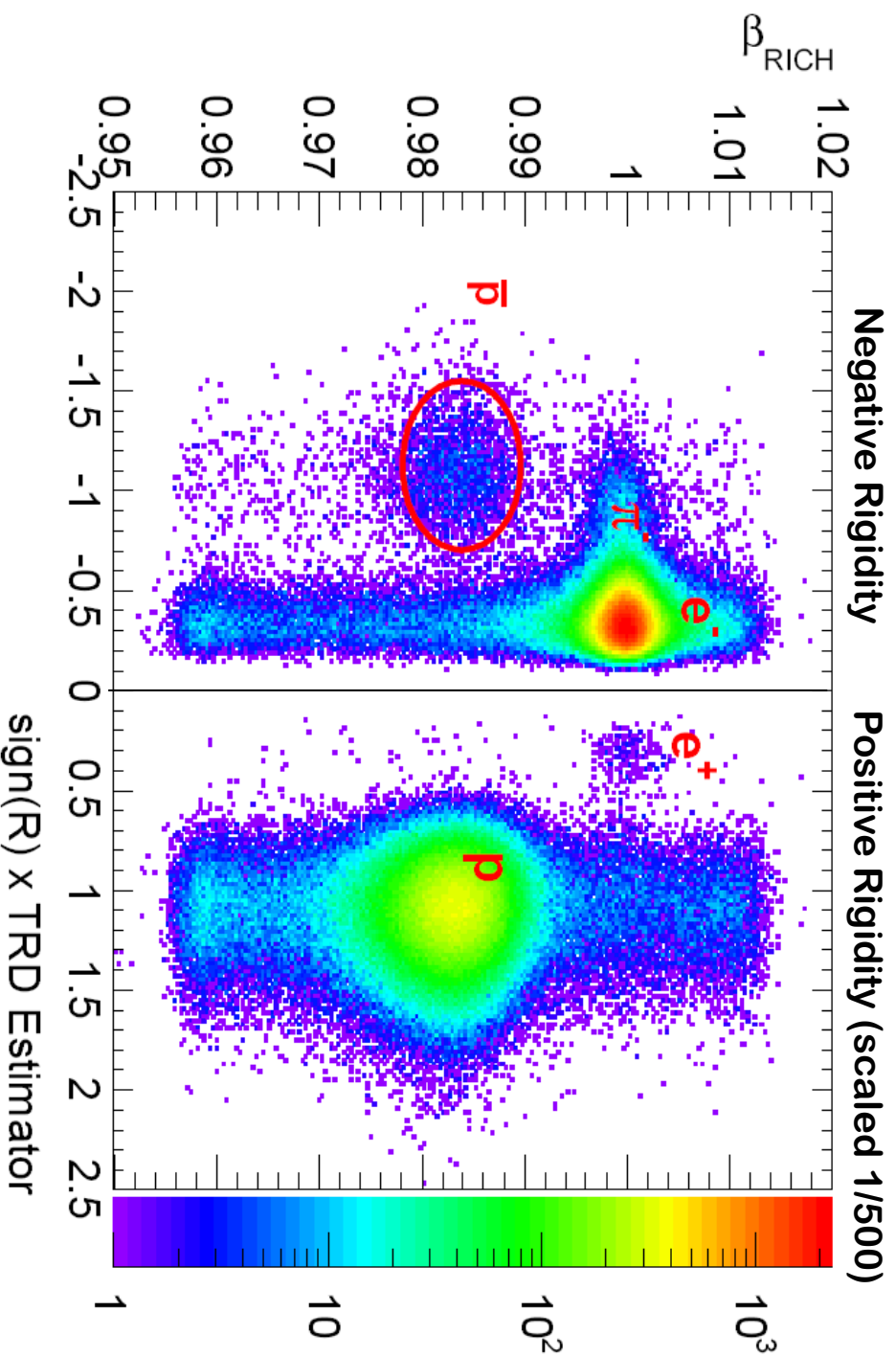
Astrophysical Sources?

- Local sources as pulsars ($e^{\pm}$ only source, anisotropy..)
 - Additional acceleration mechanisms (reacceleration of CR hadrons in old SNRs)
- ## Dark matter?
- Isotropic distribution arrival for $e^{\pm}$
 - Signatures in other channels (like antiprotons)



Antiprotons

The low energies

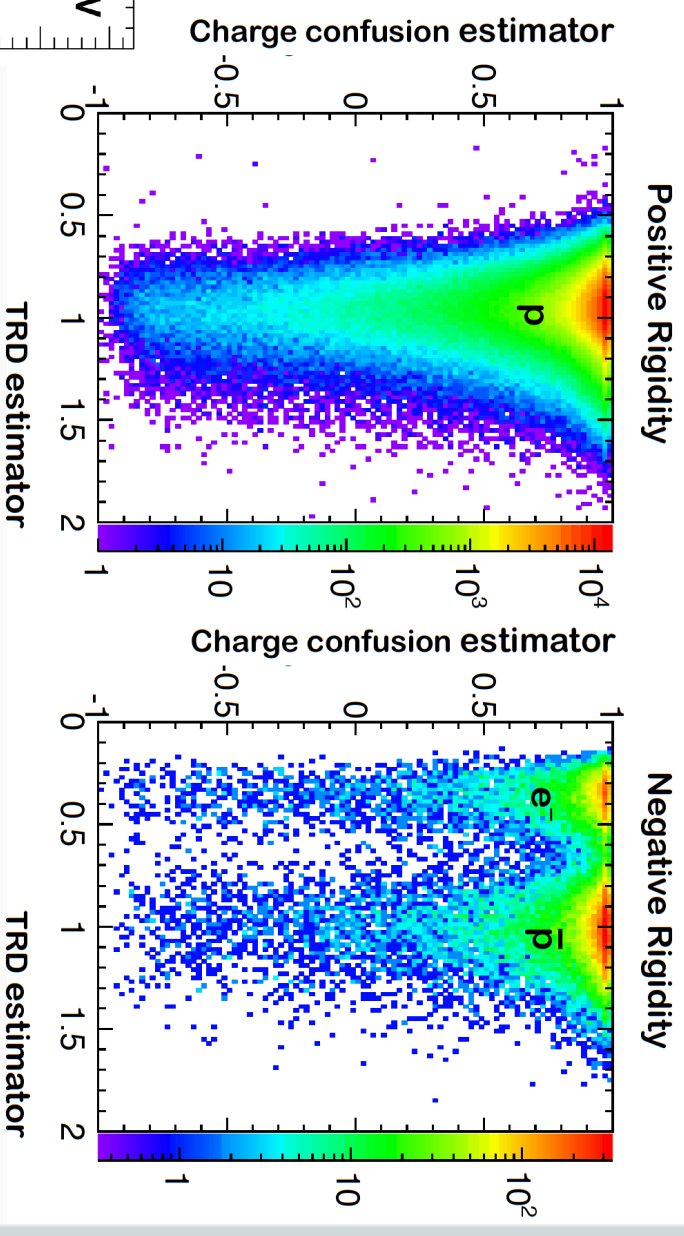
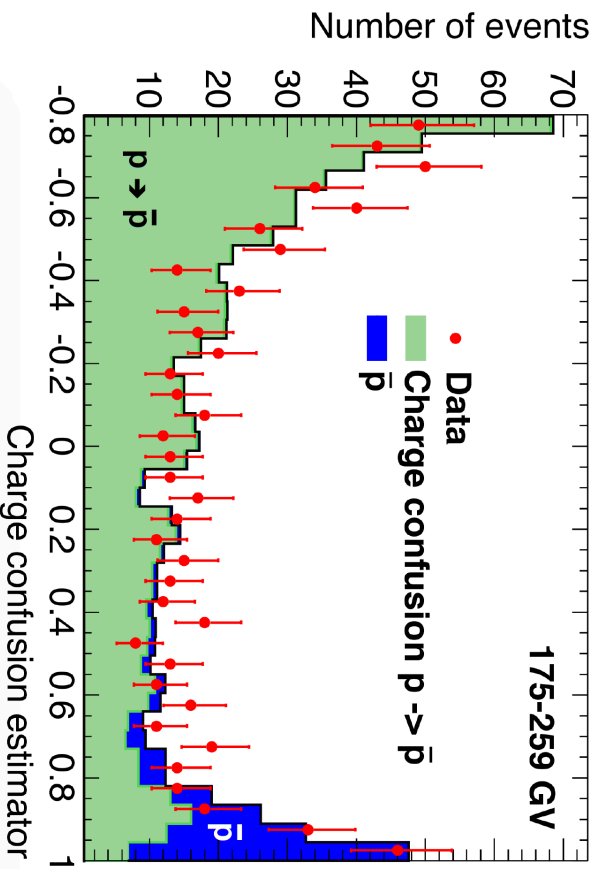


Below 10 GV, the RICH and TRD efficiently separate antiprotons from $e^{+/-}$ and local pions produced by interactions of CRs with the detector material

Antiprotons

Anti-p are 10^4 less abundant than p. Charge sign flip is the dominating systematic

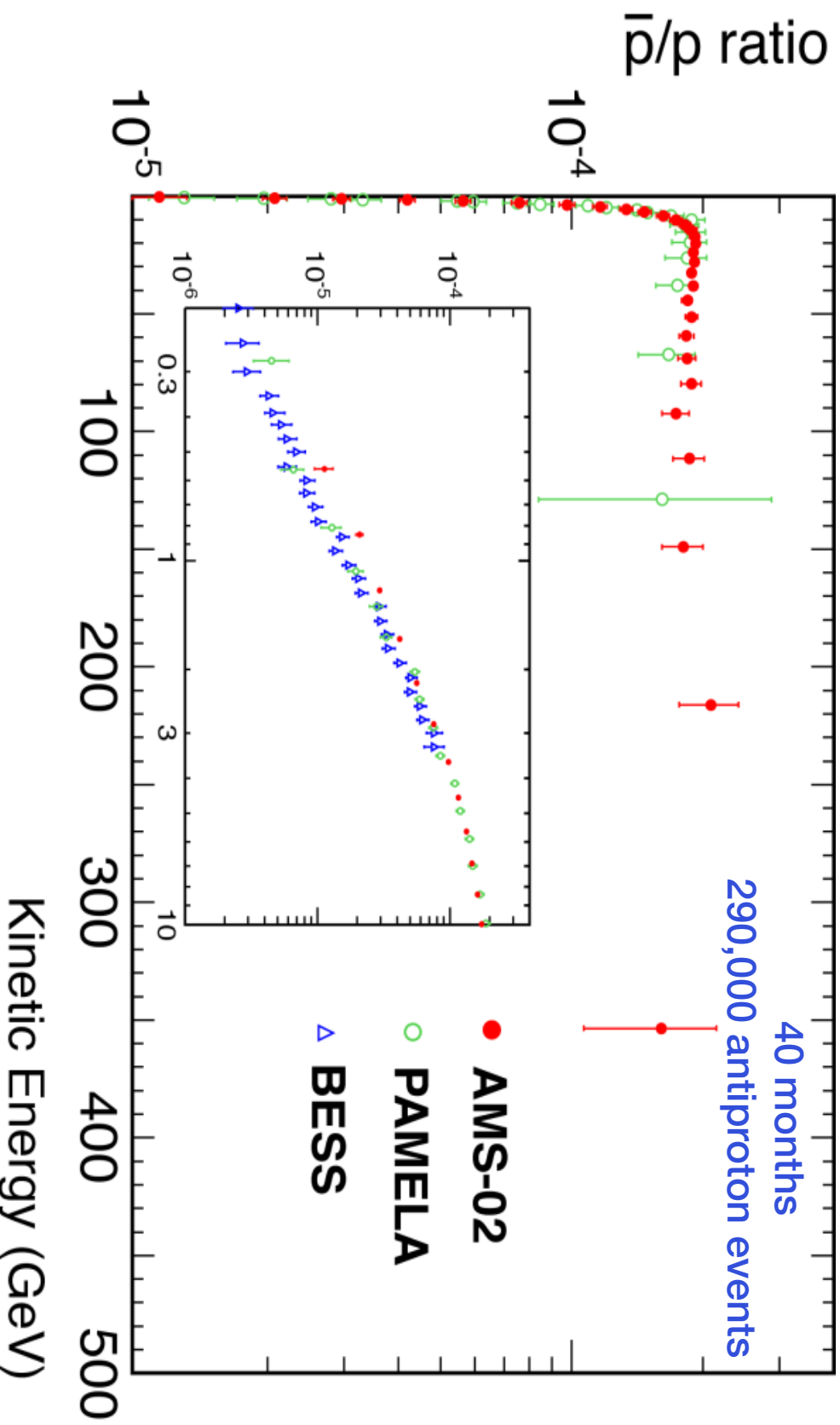
- **TRD discriminates e^- / anti-p**
- The negative “anti-p” sample is dominated by charge-flip protons



Reference spectra of charge-flip protons and genuine anti-p have been fit to data to estimate the background in the selected “negative-charge” sample

Antiprotons

$\bar{p}/p$ ratio [1 – 450] GeV

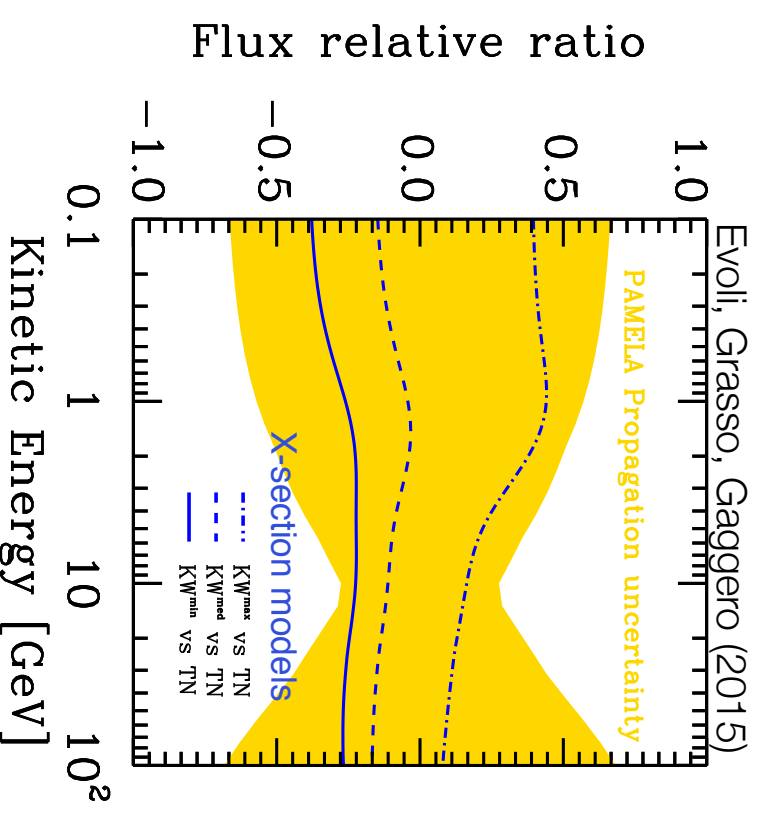
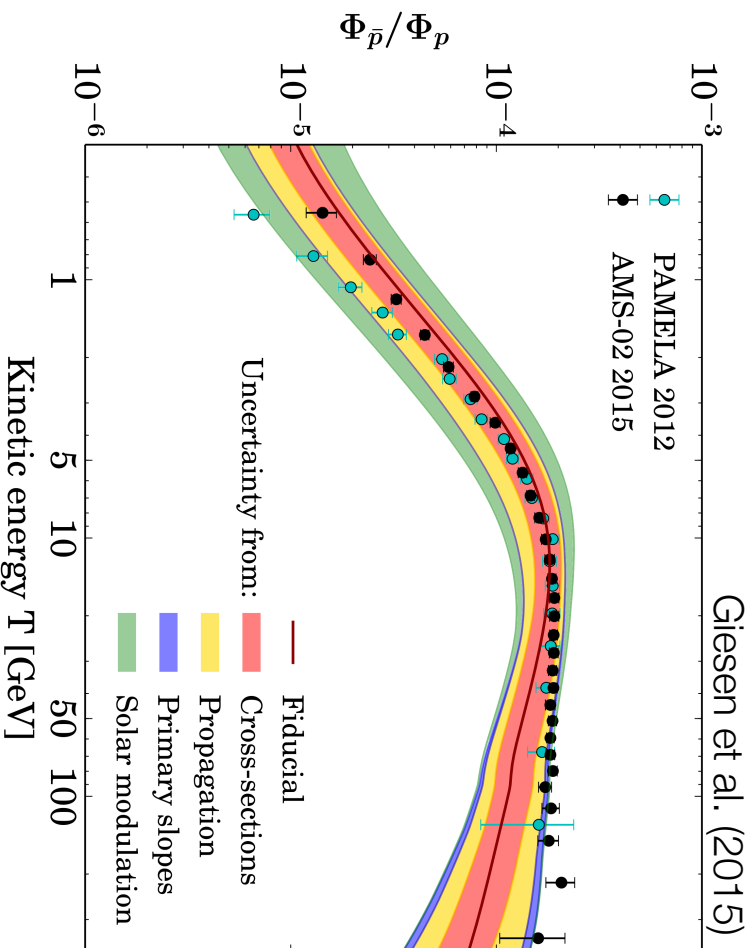


The AMS measurement extends with high precision into a new energy frontier.



Antiprotons

The accuracy of the AMS measurement challenges the current knowledge of cosmic background



Evoli, Grasso, Gaggero (2015)

Upcoming measurements (in particular, from AMS-02 [1], CALET [54], and ISS-CREAM [49]) are expected to significantly improve our knowledge of propagation parameters and then to reduce the associated uncertainties. In that situation, antiproton production cross sections will prevent us to provide predictions for the astrophysical backgrounds as accurate as the forecasted sensitivities.

AMS physics results

LEPTONS / ANTIMATTER

- Positrons fraction $e^+/(e^++e^-)$
- Electron and Positron fluxes (e^+ , e^-)
- Electron plus Positron flux (e^++e^-)
- Antiprotons/protons

Sensitive to
Dark Matter signal

HADRONS

- Proton and Helium fluxes (p, He)
- Lithium, Boron, Carbon (Li, B, C)

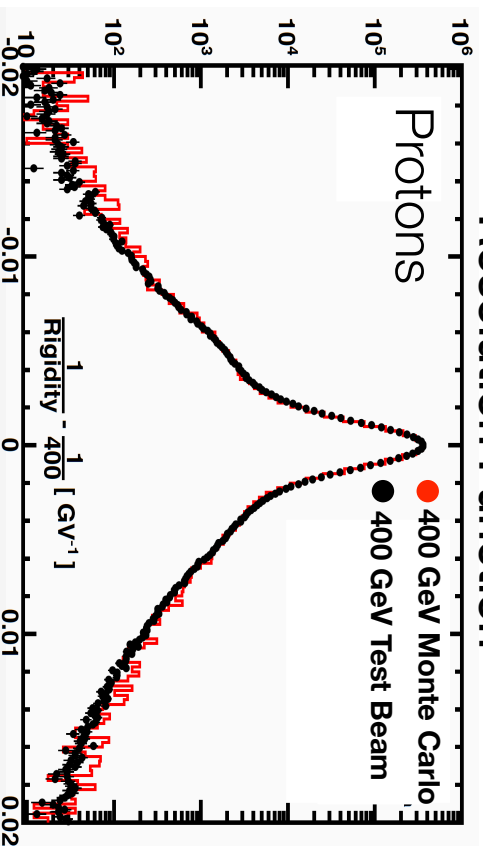
Probes to improve
the astrophysical background
knowledge

AMS-02 is providing precise data to **search for new physics** in the Cosmic Ray channels while **improving the understanding of the astrophysical background** with a coherent set of data

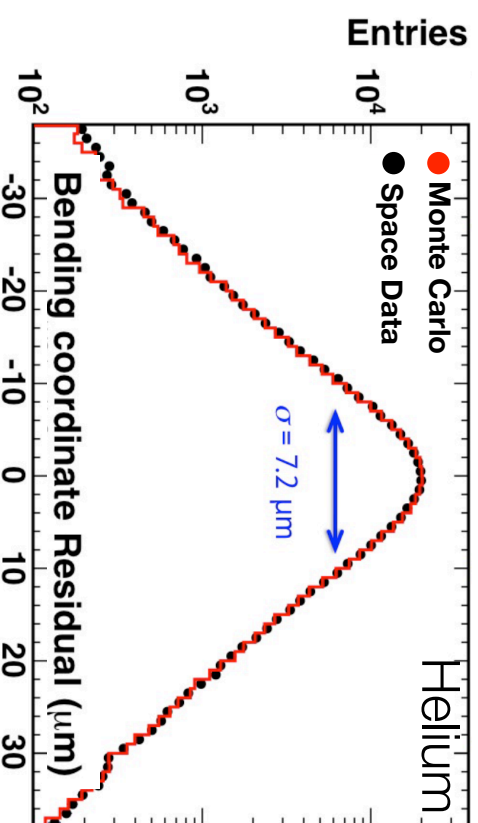
Proton and Helium Fluxes

The AMS-02 Tracker Rigidity resolution has been checked comparing Test Beam data and Monte Carlo Simulations to Space data.

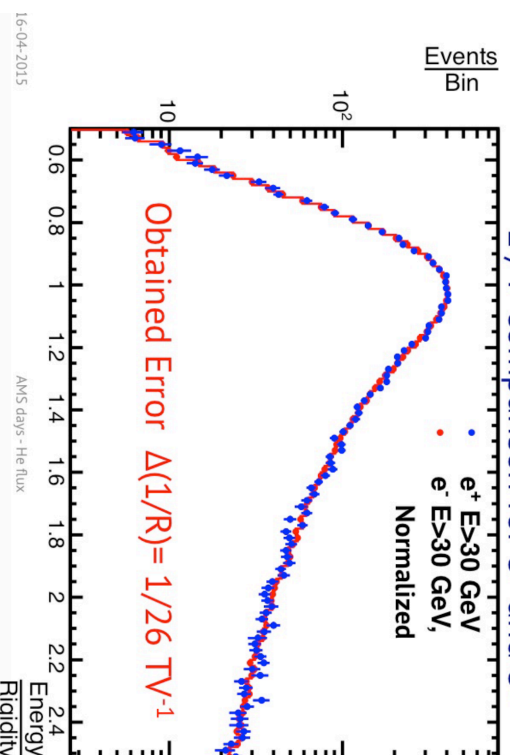
Resolution Function



Coordinate resolution

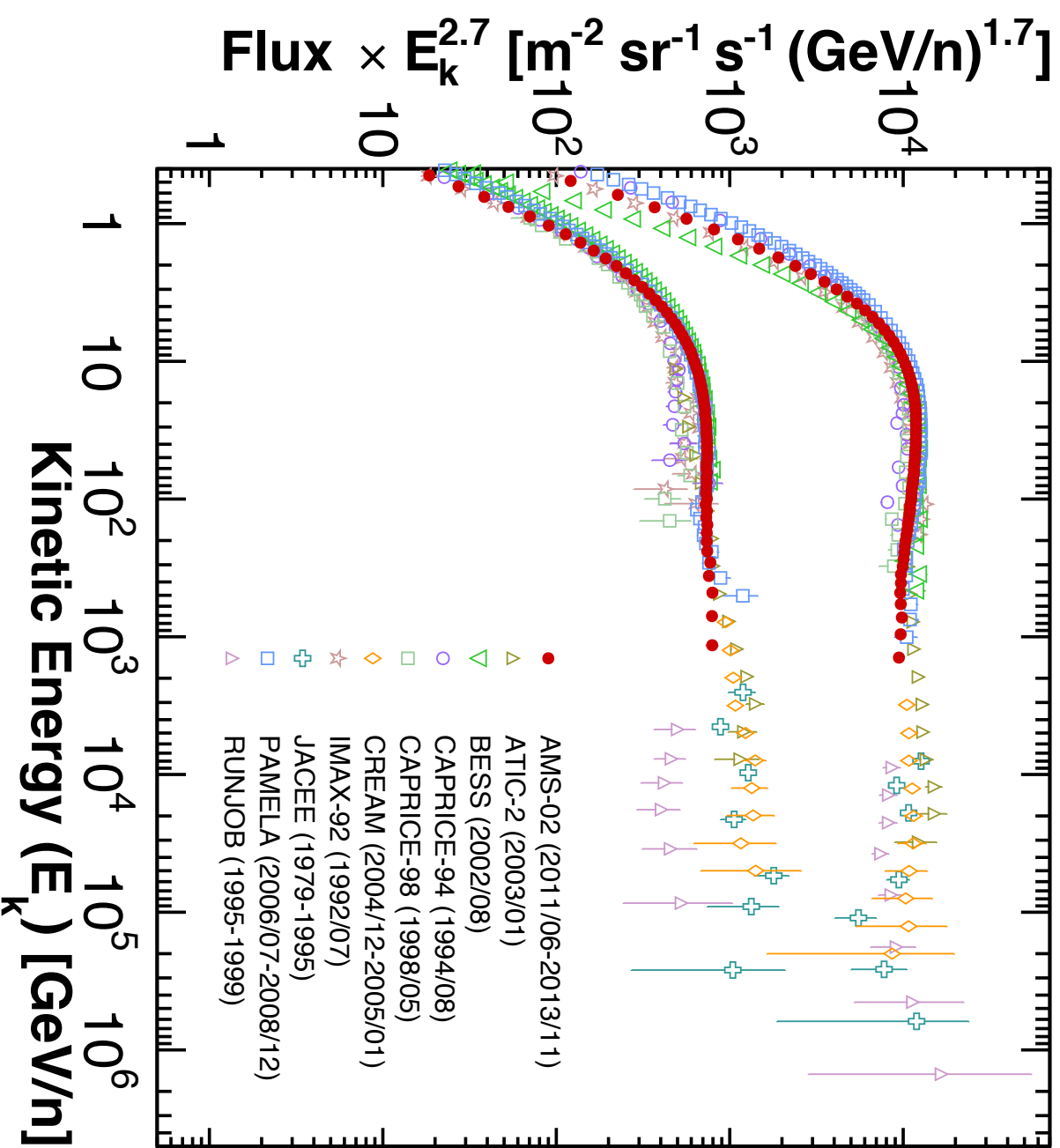


E / P comparison for e⁺ and e⁻



The **redundant measurement** of the e[±]-energy with the ECAL is used to further control the Tracker rigidity scale

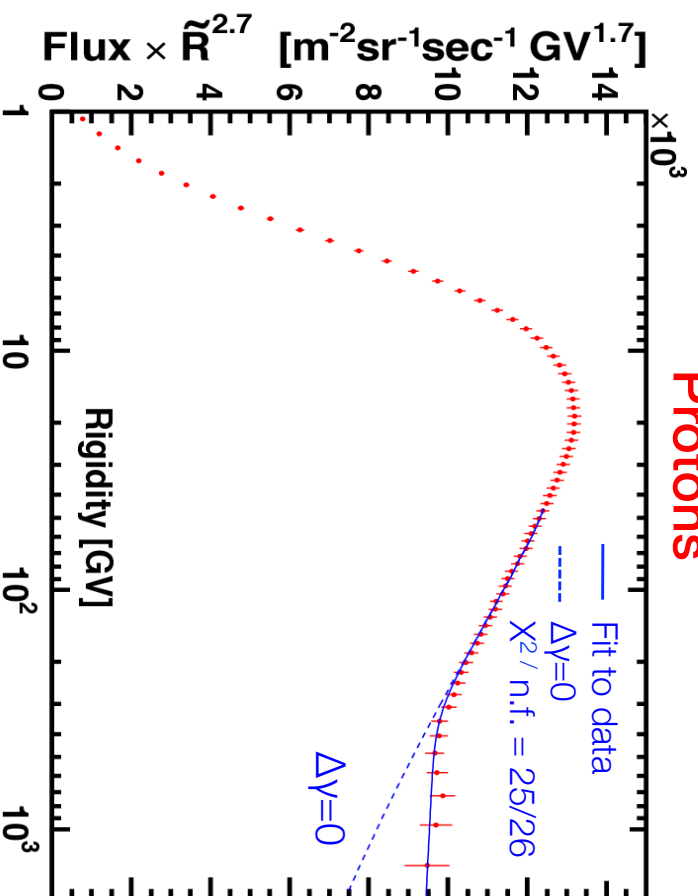
Proton and Helium Fluxes



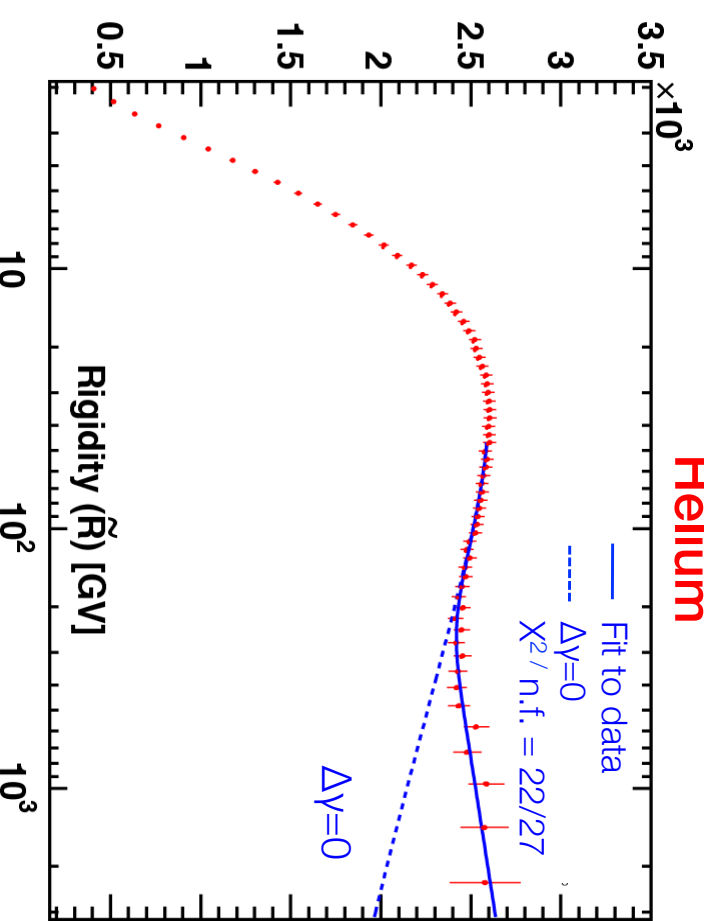
Proton and Helium Fluxes

$$\Phi = C \left(\frac{R}{45 \text{ GV}} \right)^\gamma \left[1 + \left(\frac{R}{R_0} \right)^{\Delta\gamma/s} \right]^s$$

Protons



Helium

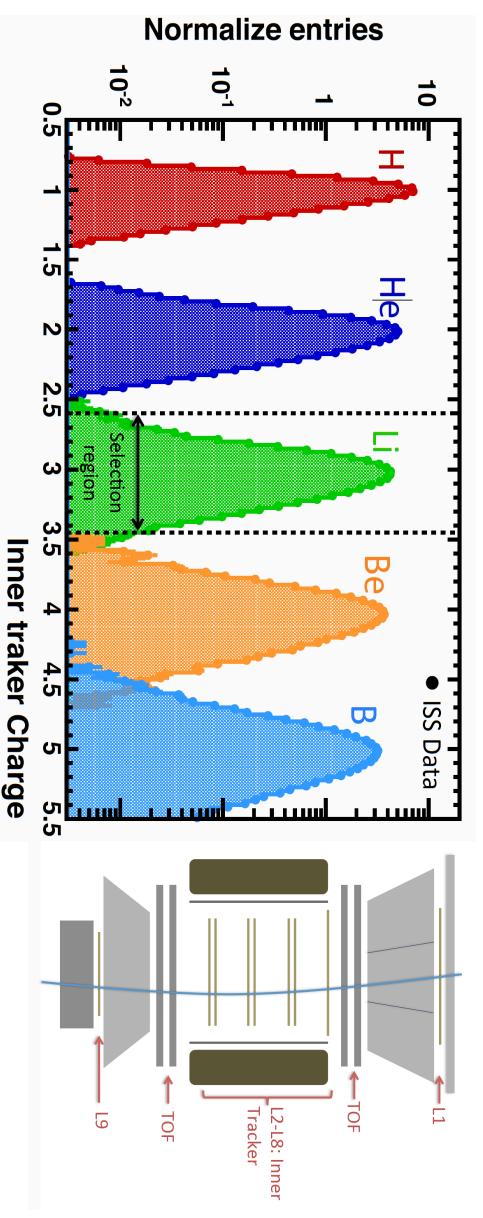


The H and He spectra harden with increasing rigidity

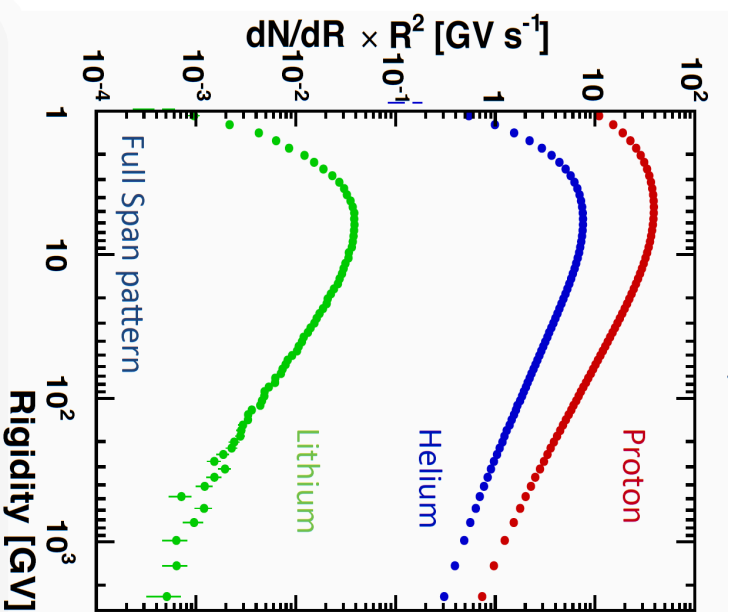
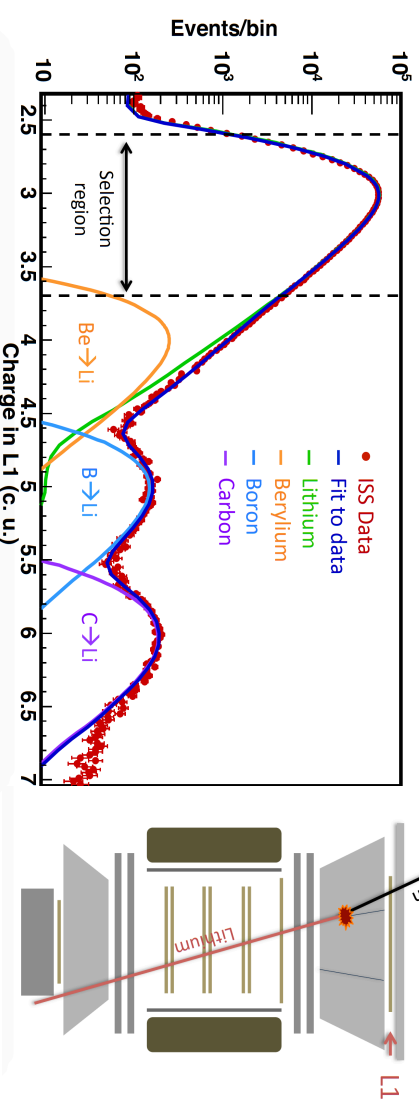
Both fluxes cannot be described by single power laws. A break in the power law at $R \sim 300$ GV is required to describe the data.

Lithium

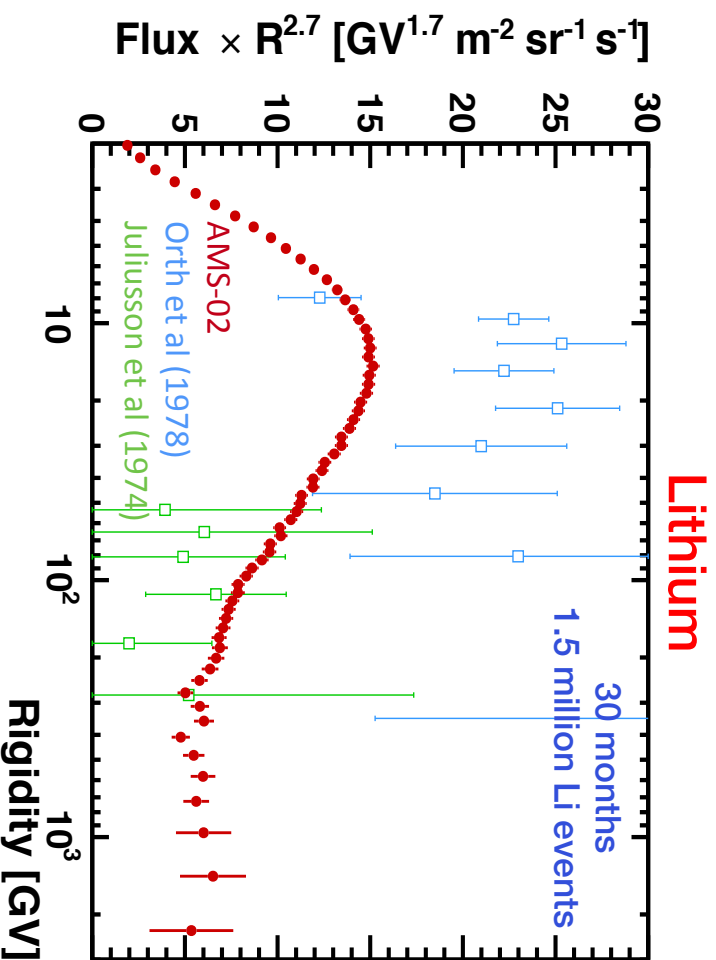
Inner Tracker IZI selection



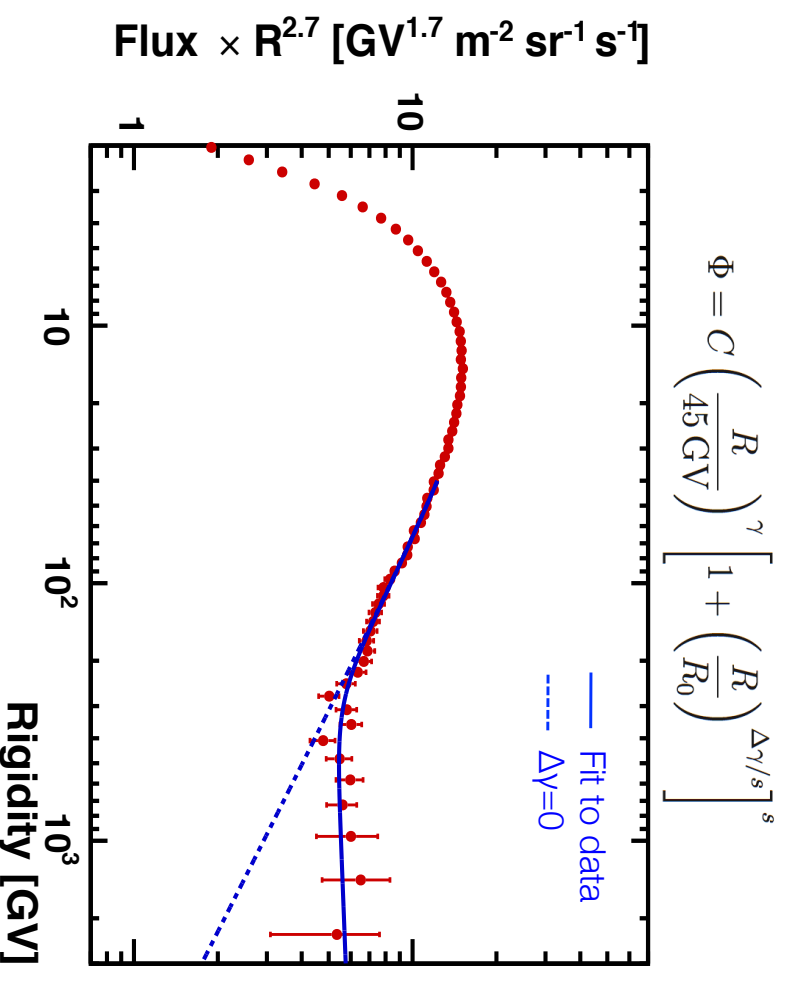
Tracker L1 fragmentation estimation



Lithium Flux



The large size of the collected statistics and the charge identification capabilities of AMS allow to measure the Li flux with unprecedented precision.

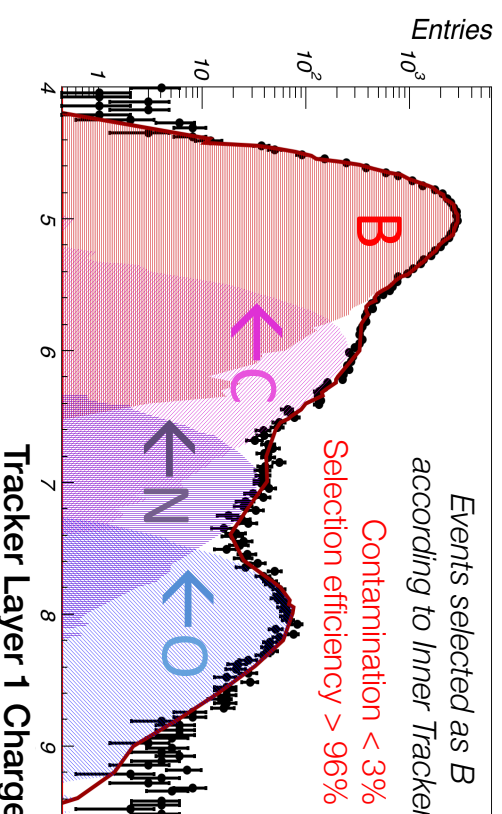
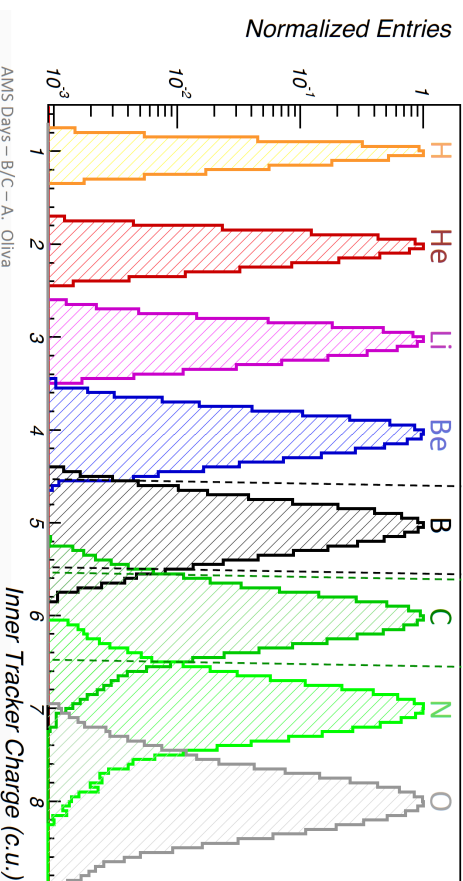
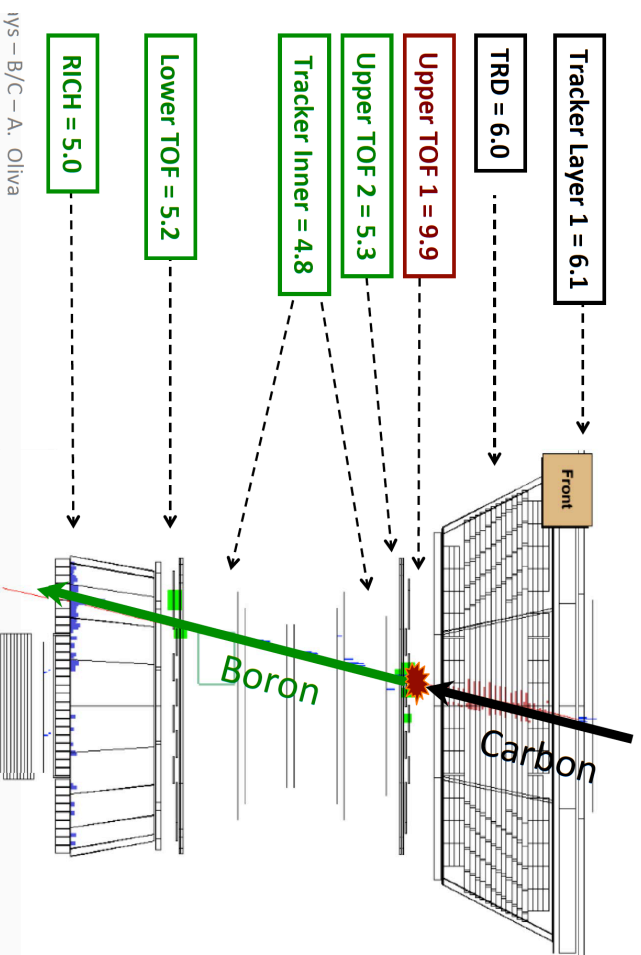


Boron/Carbon

- B is produced by spallation of CNO with the ISM. C is a primary species
- Sensitive to propagation mechanisms and and its galactic environment
- Experimentally convenient to measure, B and C have similar interaction with matter

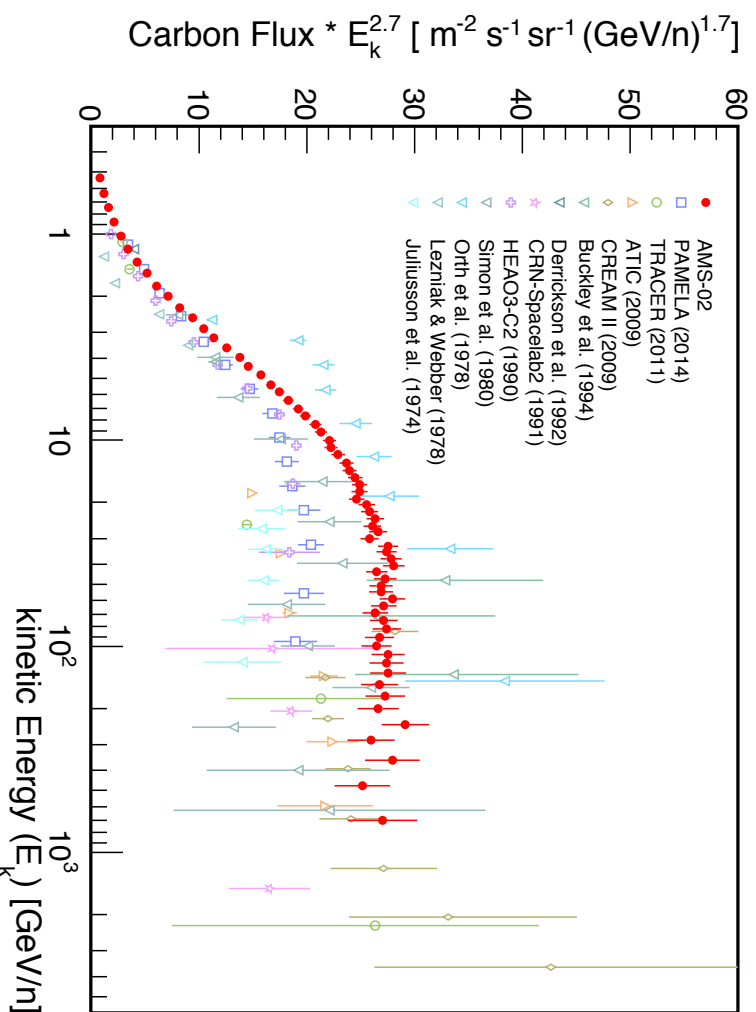
B and C identification

1. Inner Tracker Charge selection
2. Tracker Layer 1 Charge used to estimate CNO $\rightarrow$ B fragmentation

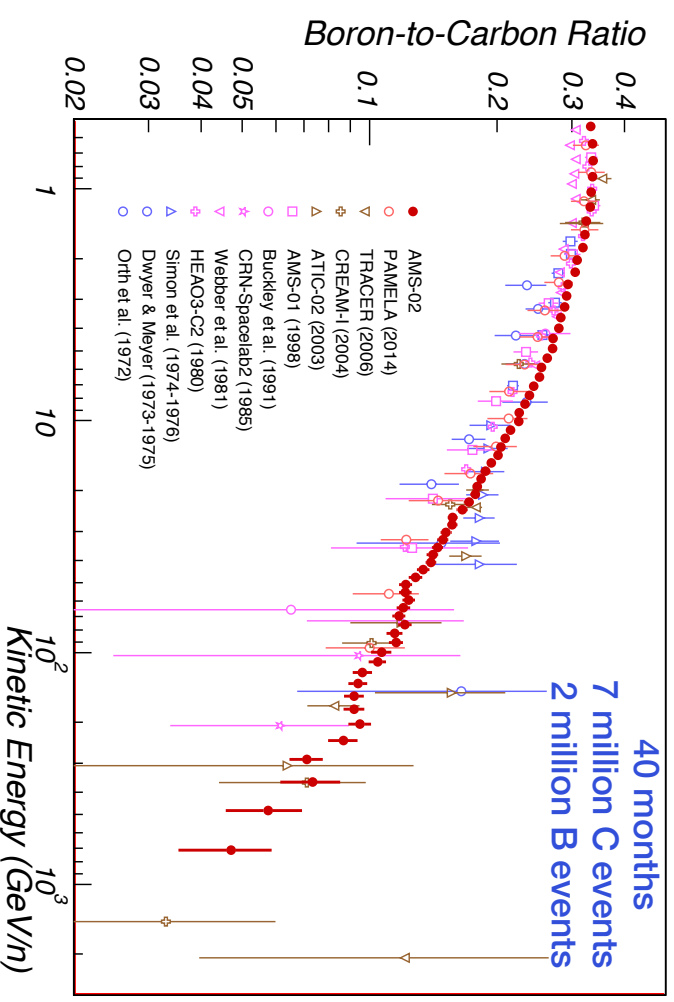


Carbon and Boron

Carbon



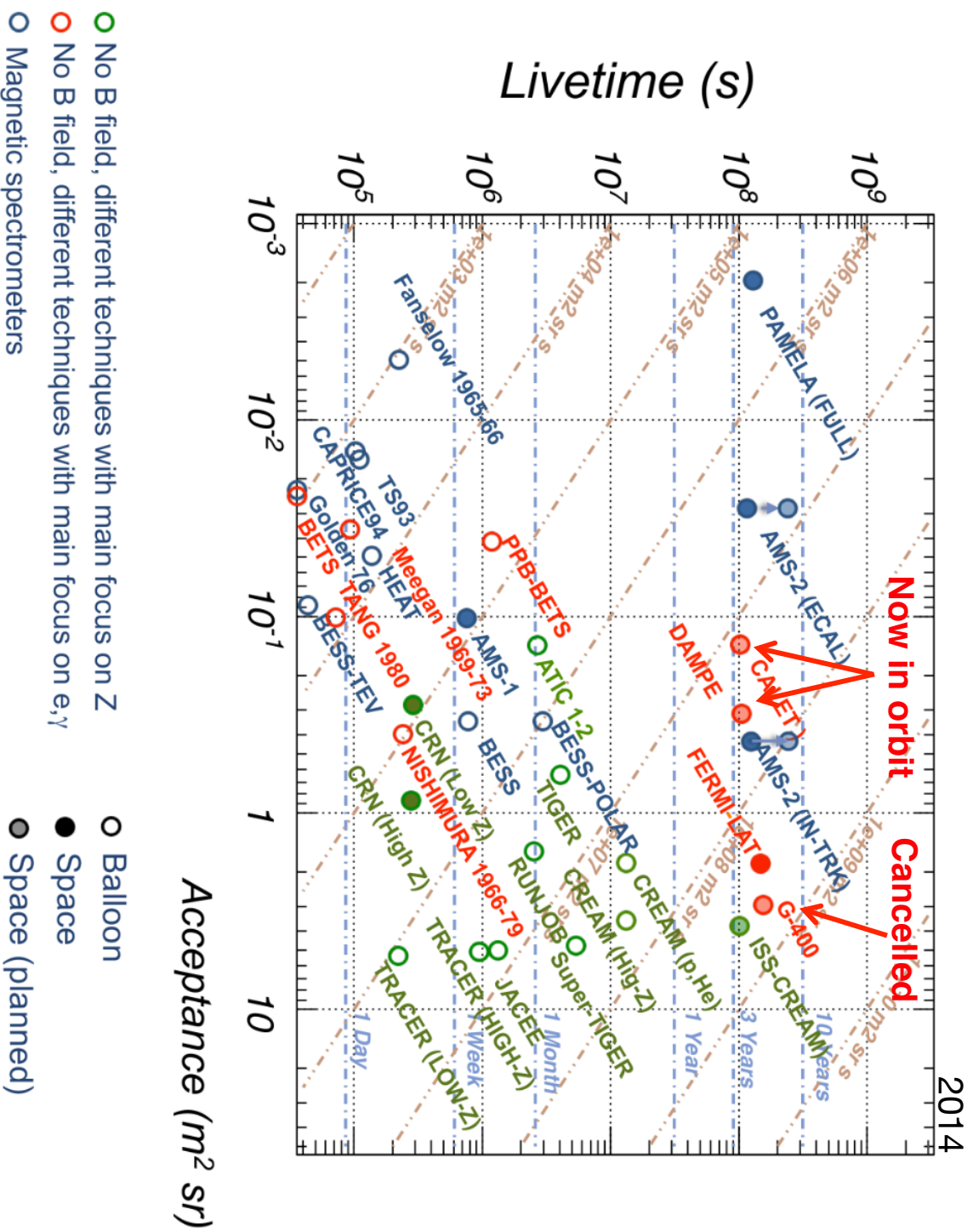
Boron/Carbon



No structures or features are observed in the C flux nor in the B/C ratio.

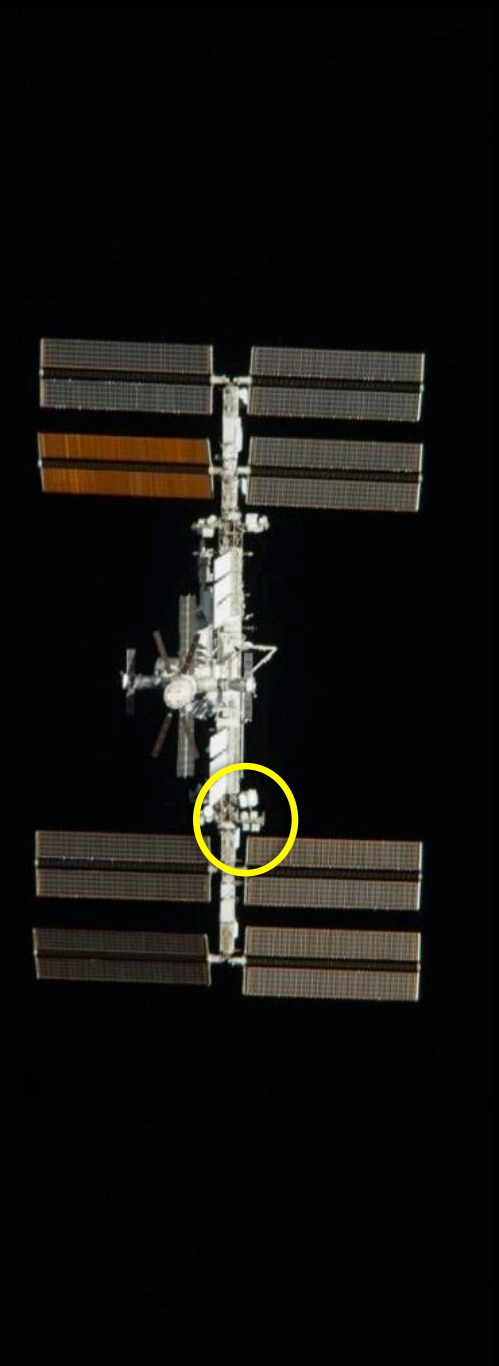
Additional statistics will provide more quantitative information on the behavior at high energies

Future experiments



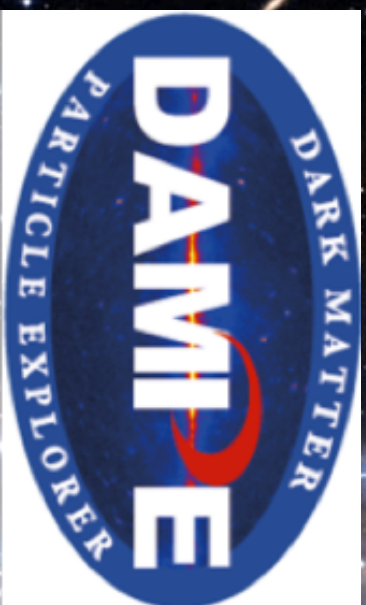
AMS-02 will be the unique magnetic spectrometer in space able to distinguish matter from antimatter for the next 10 years.

Conclusions

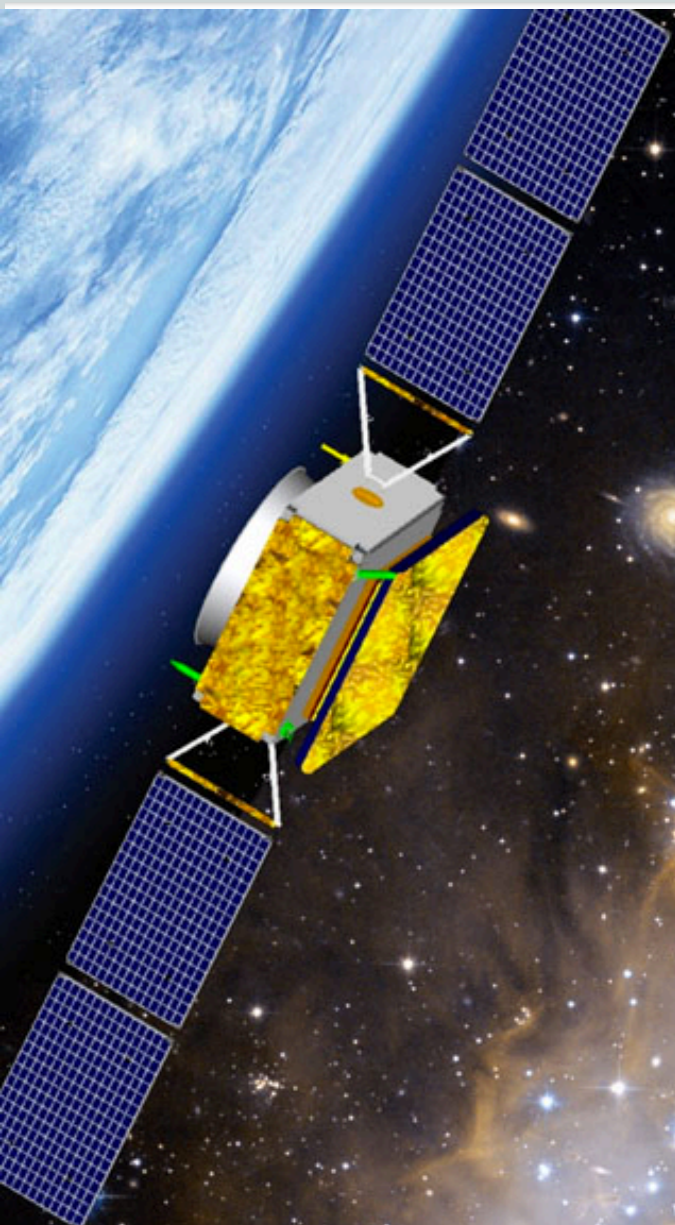


AMS will match the lifetime of the Space Station

- Continue the search for Dark Matter
- Improve the CR origin and propagation models
- Quest for the existence of primordial Antimatter
 - Search for new phenomena, ...
- Time dependent effects of low energy CR



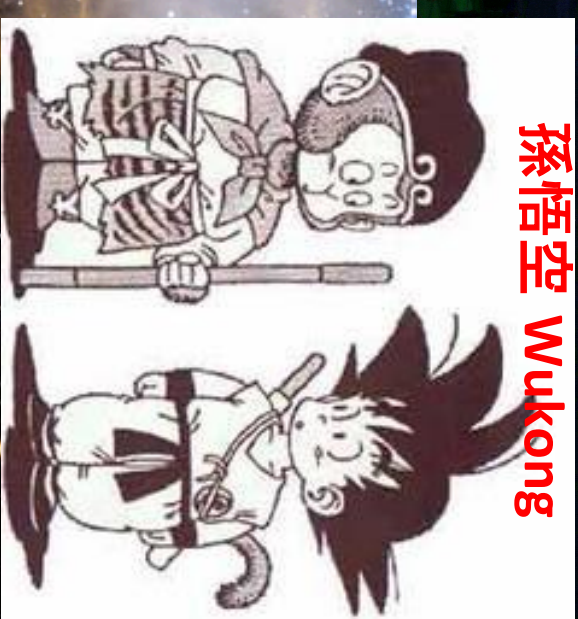
NOW IN SPACE



Dec. 17th (8:12), 2015



孫悟空 Wukong



DAMPE Science

Satellite for high energy cosmic ray direct detection

- Indirect search for Dark Matter with $e^{+/-}$ and gamma-rays
- Precise measurement of the cosmic ray spectrum and composition
 - High energy gamma-ray astronomy
 - Detection of 5 GeV - 10 TeV e/γ
 - Measurement of 100 GeV – 100 TeV cosmic rays
 - Excellent energy resolution and tracking precision

Follow-up mission to AMS-02 and Fermi-LAT

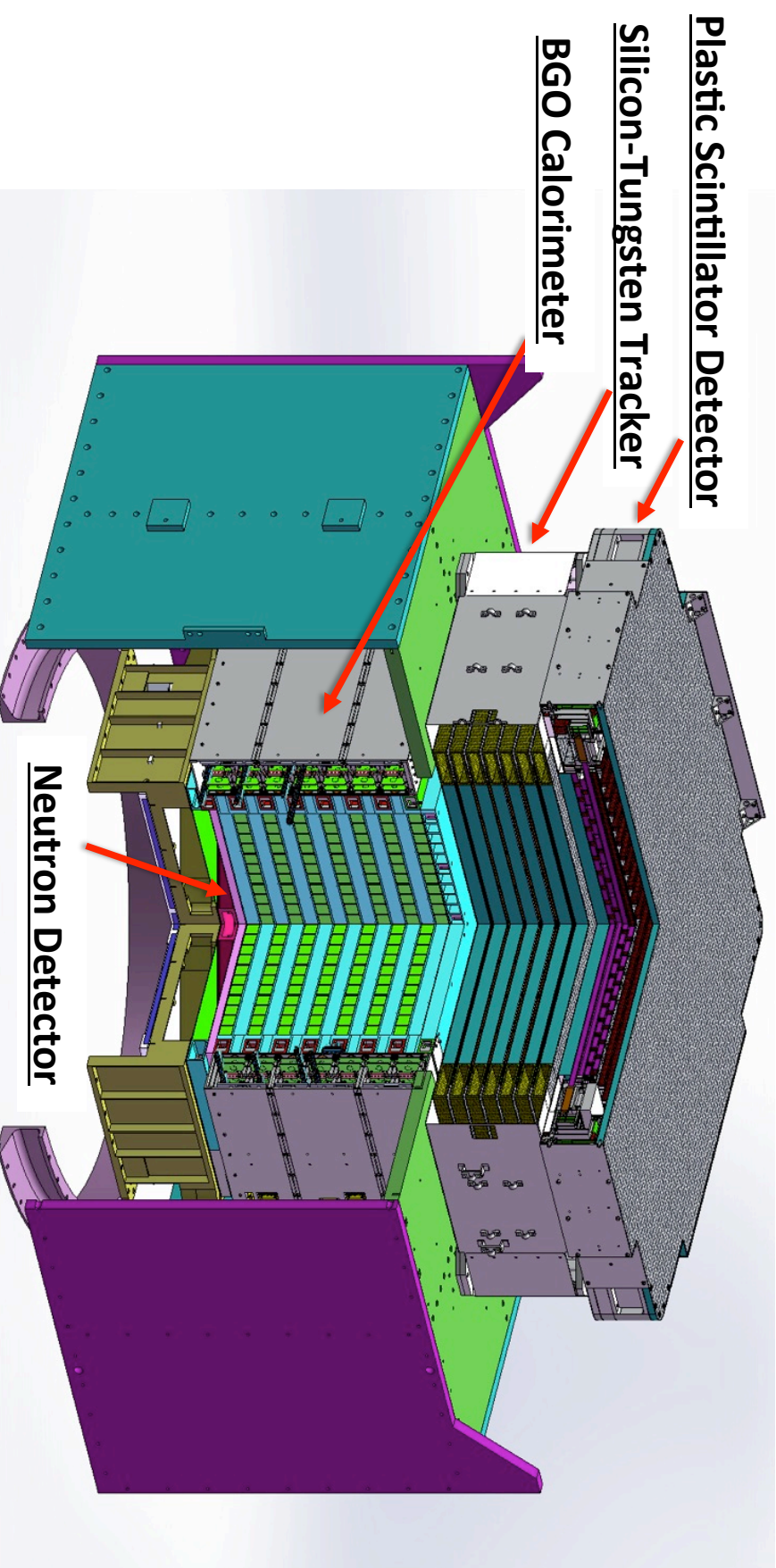
- Extend the energy range above the TeV region with improved energy resolution
 - Overlap with Fermi for some time



University and INFN of Perugia
University and INFN of Lecce
University and INFN of Bari

The Dark Matter Particle Explorer

The DAMPE Detector

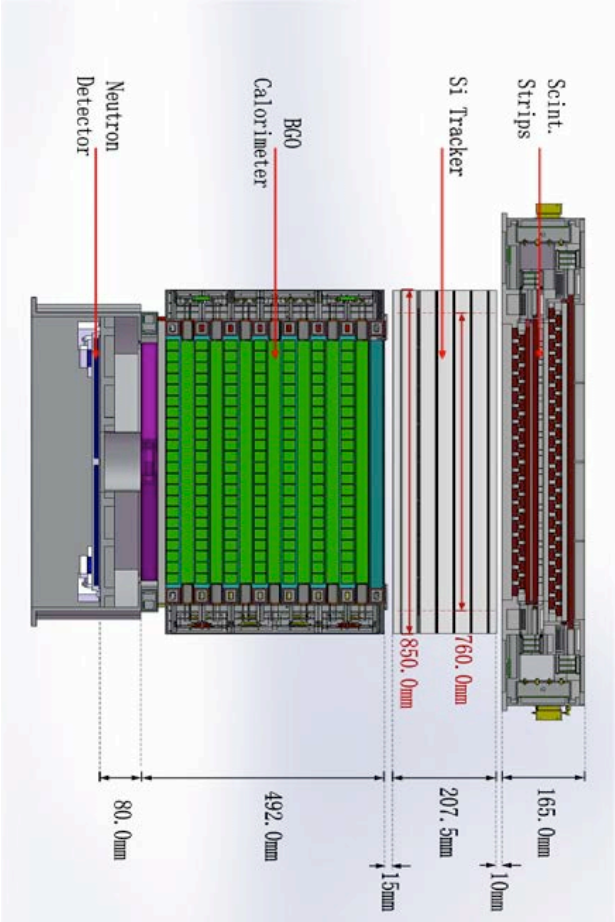


W converter + thick calorimeter (total 33 X0)
+ precise tracking + charge measurement ➡
high energy γ -ray, electron and CR telescope

The Dark Matter Particle Explorer

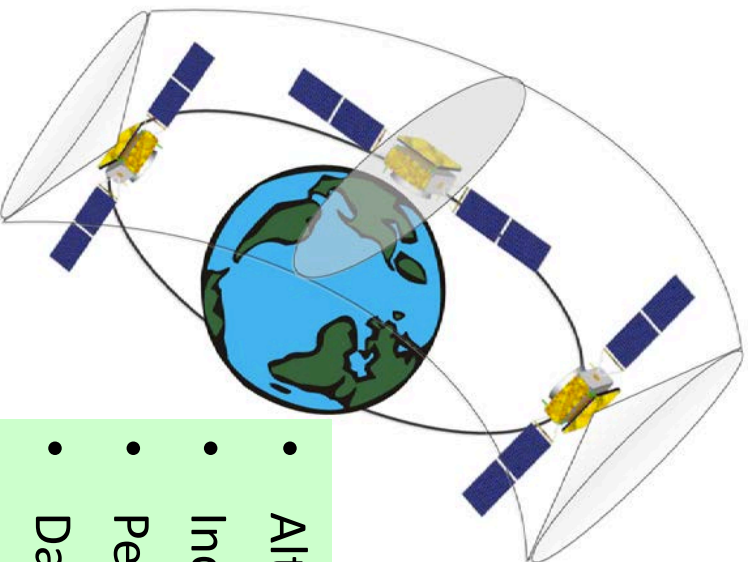
	DAMPE	AMS-02	Fermi LAT
e/ γ Energy res.@100 GeV (%)	1.5	3	10
e/ γ Angular res.@100 GeV (°)	0.1	0.3	0.1
e/p discrimination	10^5	$10^5 - 10^6$	10^3
Calorimeter thickness (X_0)	31	17	8.6
Geometrical accep. (m^2sr)	0.29	0.09	1

- Geometrical acceptance with BGO alone: $0.36\ m^2sr$
 - BGO+STK+PSD: $0.29\ m^2sr$
 - First 10 layers of BGO ($22\ X_0$) +STK+PSD: $0.36\ m^2sr$



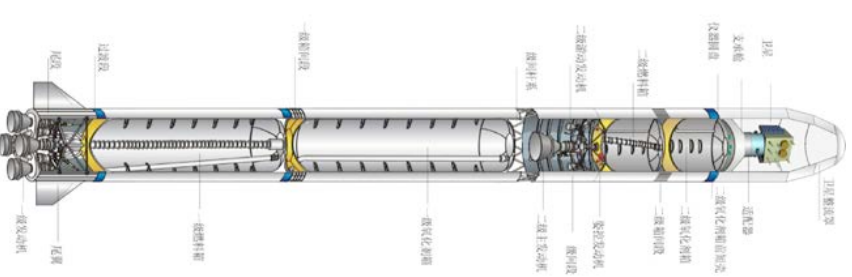
The Dark Matter Particle Explorer

- One of the 5 satellite missions of the Strategic Priority Research Program in Space Science of CAS
 - Approved for construction (phase C/D) in Dec. 2011
 - Scheduled launch date **December 17, 2015** from Jiuquan Satellite Launch Center in the Gobi desert

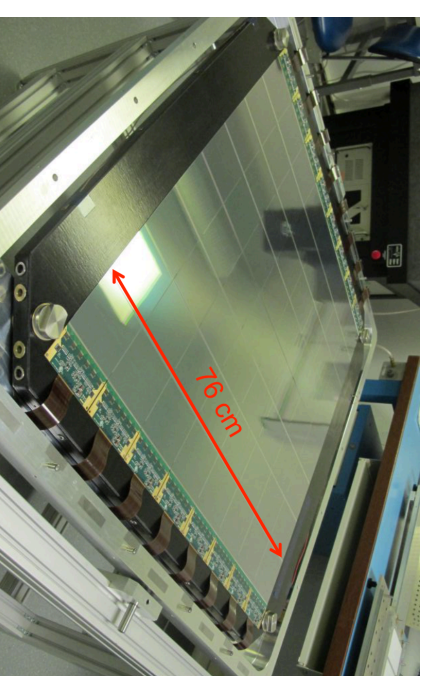
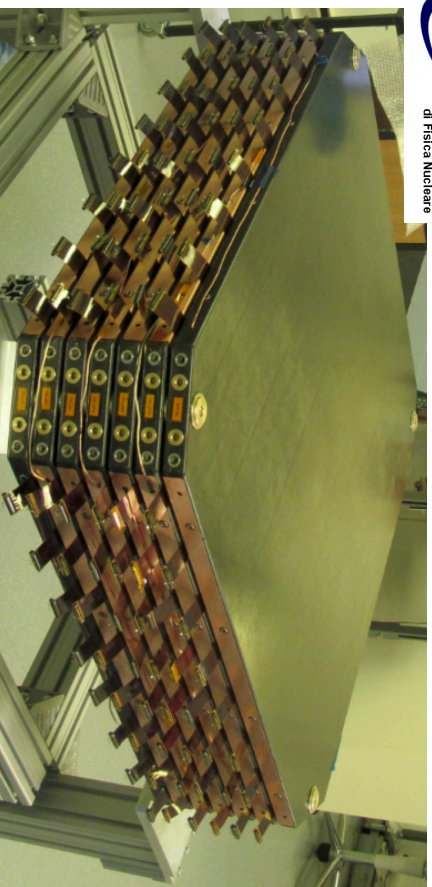


- Satellite < 1900 kg, payload ~1340kg
- Power consumption 640W (400 W)
- Lifetime > 3 years
- Launched by CZ-2D rockets

- Altitude 500 km
- Inclination 87.4065°
- Period 90 minutes
- Dawn/dusk (6:30 AM) sun-synchronous orbit

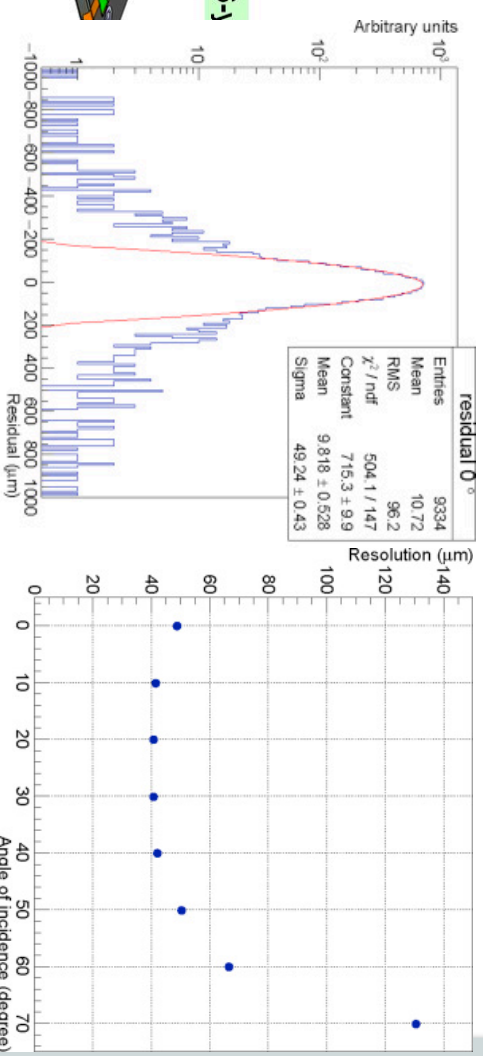
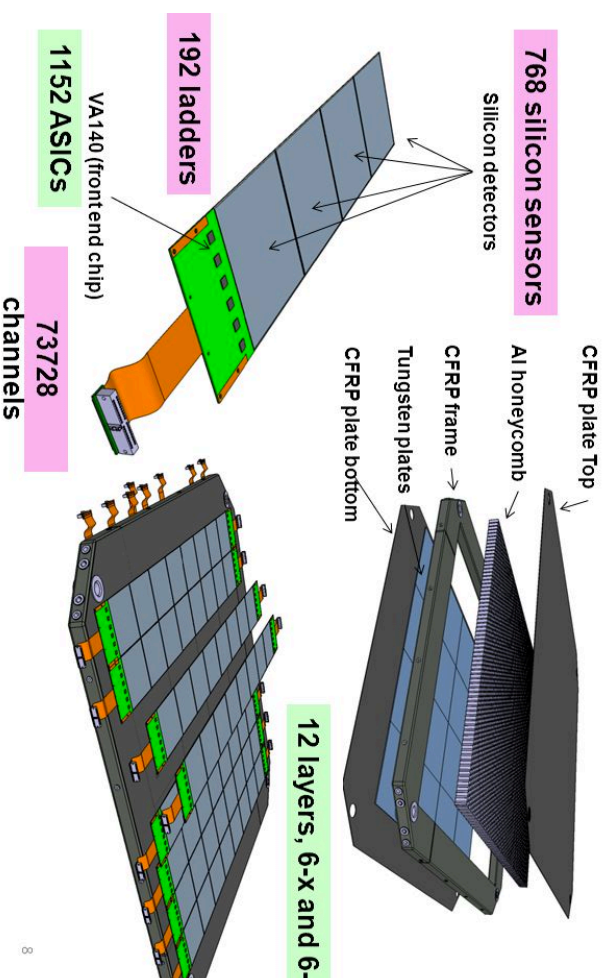


Silicon Tracker STK



6 planes of Si micro-strip detector
interleaved with W converter layers.

768 sensors with 121 μm pitch / 242 μm readout

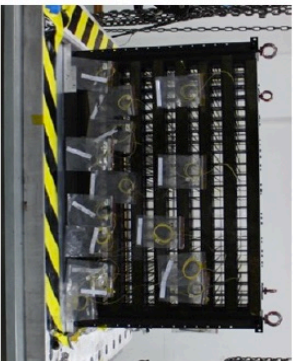
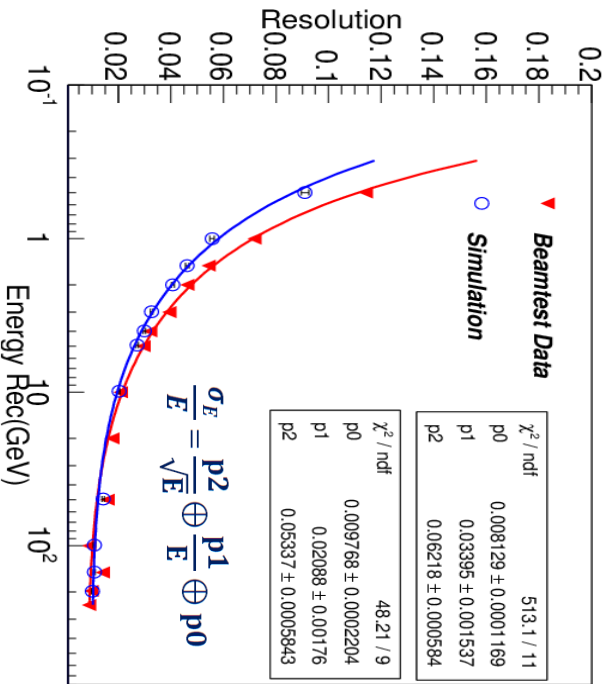


Tracker tested at CERN test beams.
Calibration/alignment using flight data ongoing

BGO Calorimeter



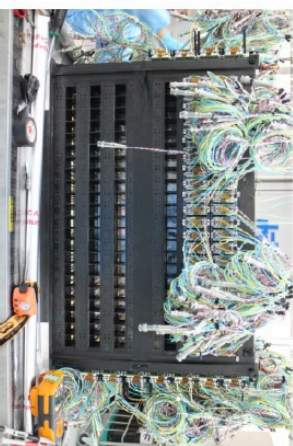
14 layers of BGO bars
22 bars/layers, 308 total
 $X_0=32$, $\lambda=1.6$ for high e/p separation



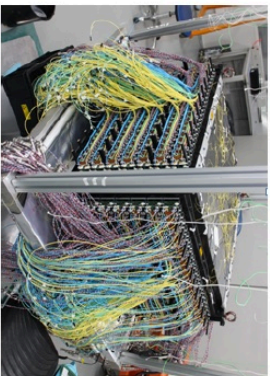
Carbon Fiber Structure



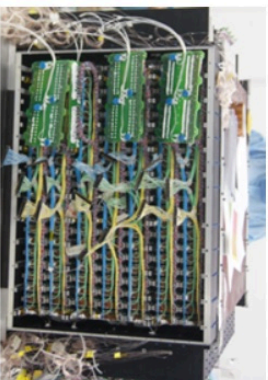
BGO crystal installation



PMT installation



Cabling

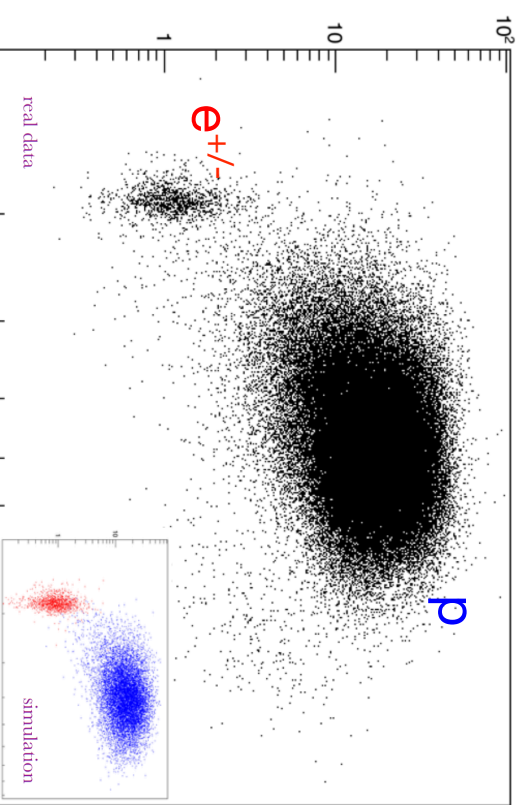


Cable connector



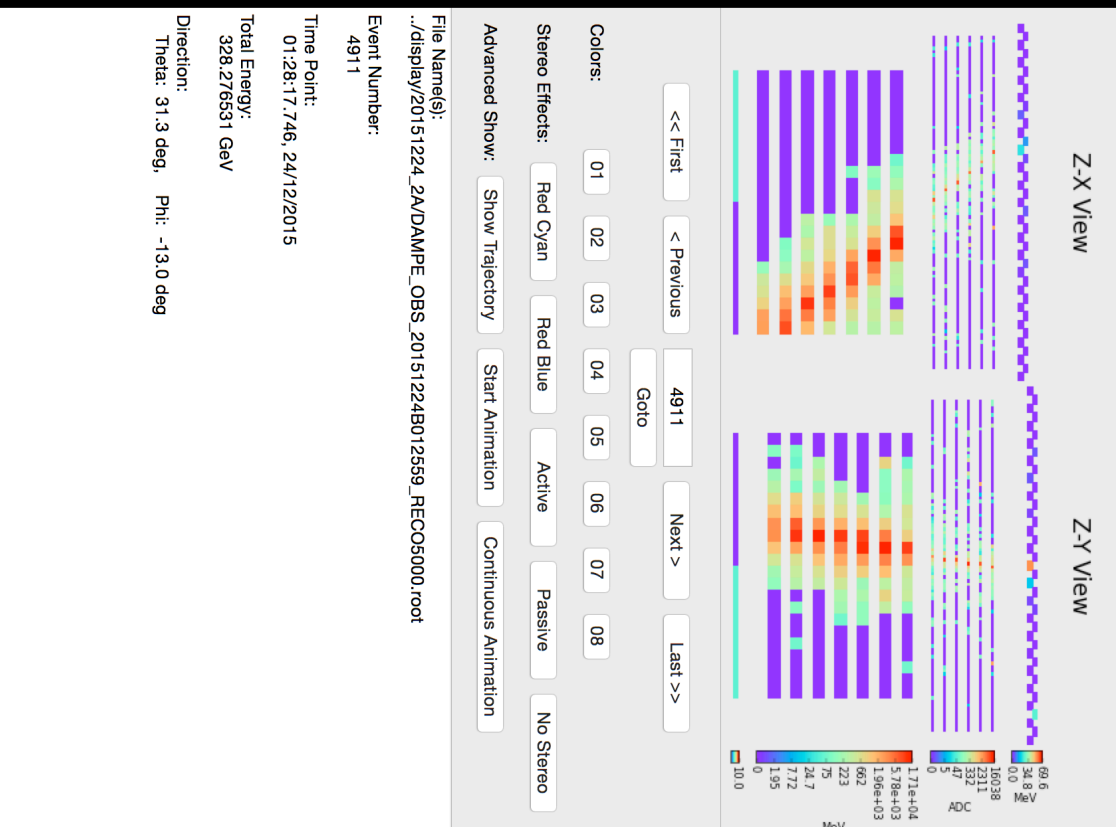
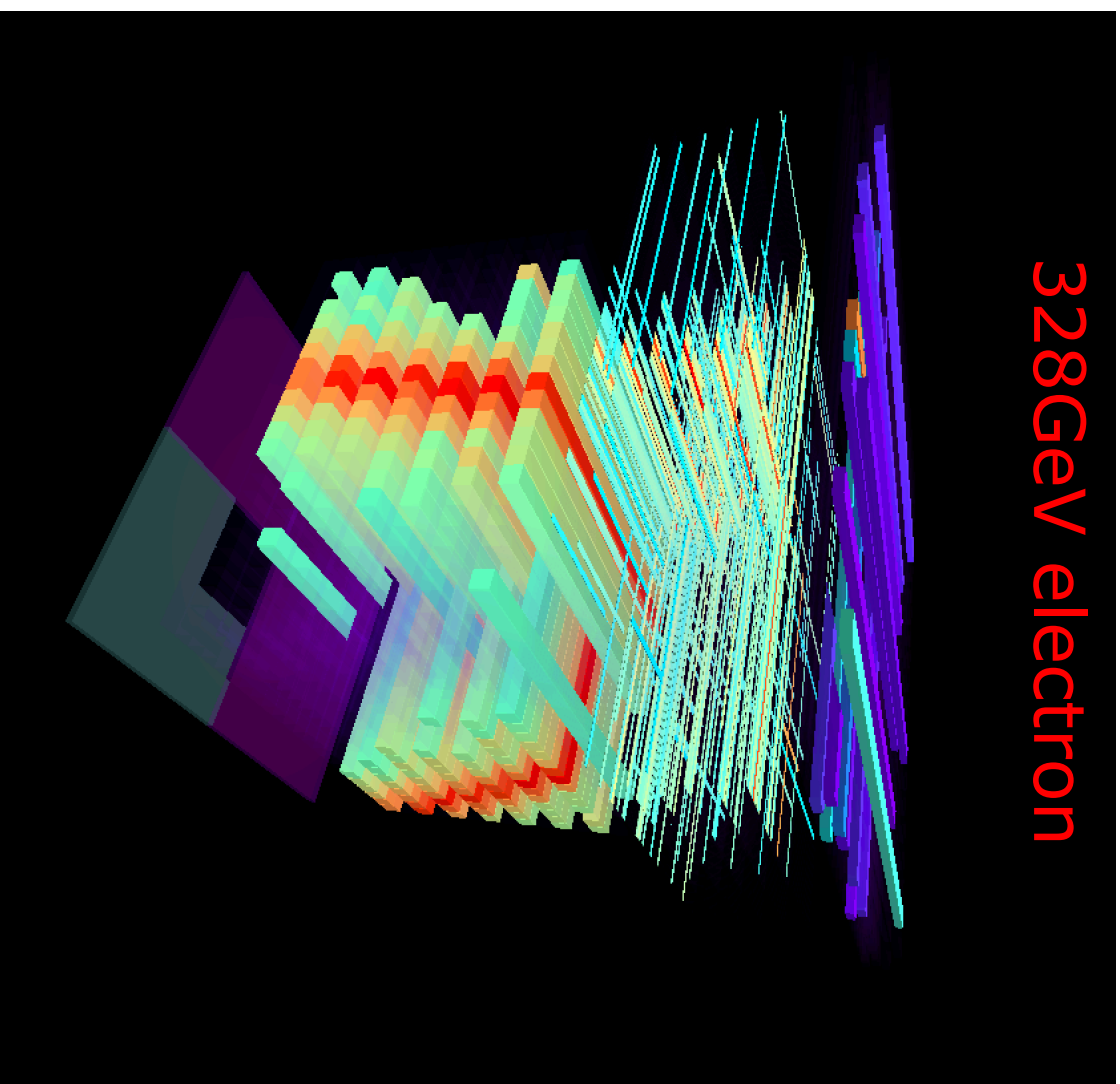
BGO Calorimeter

Longitudinal shower development

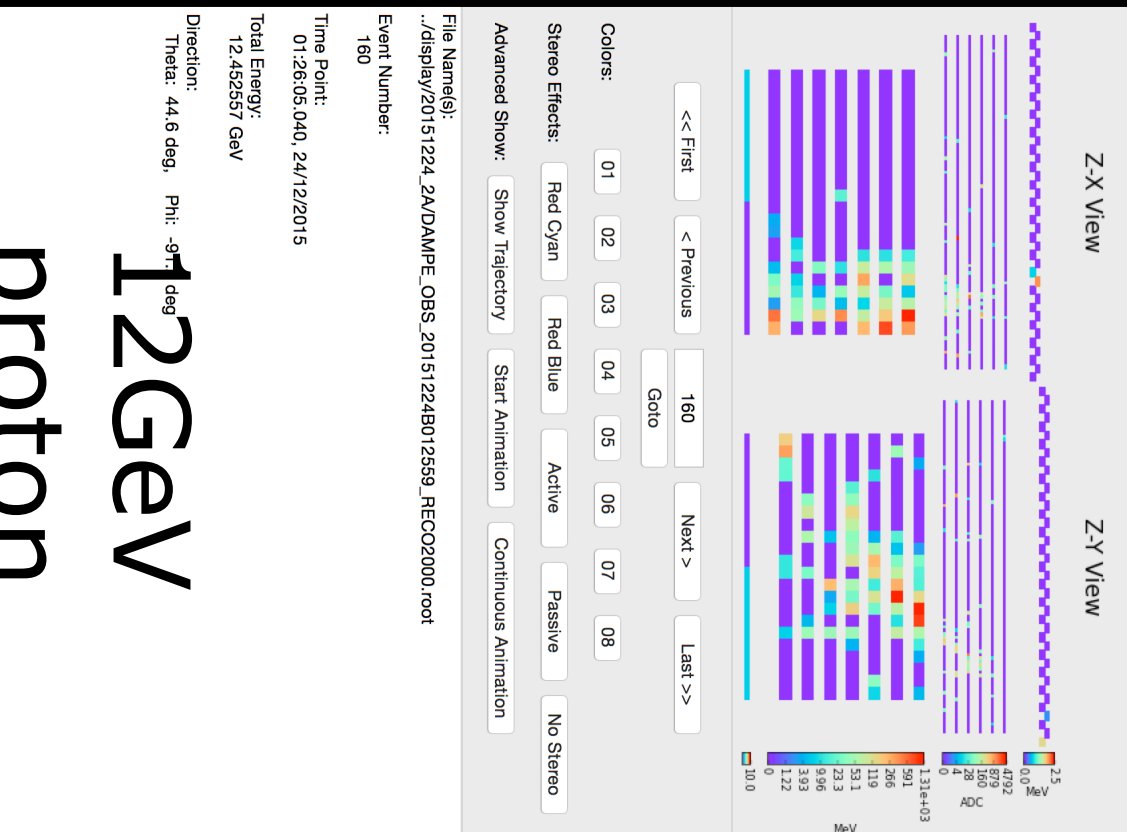
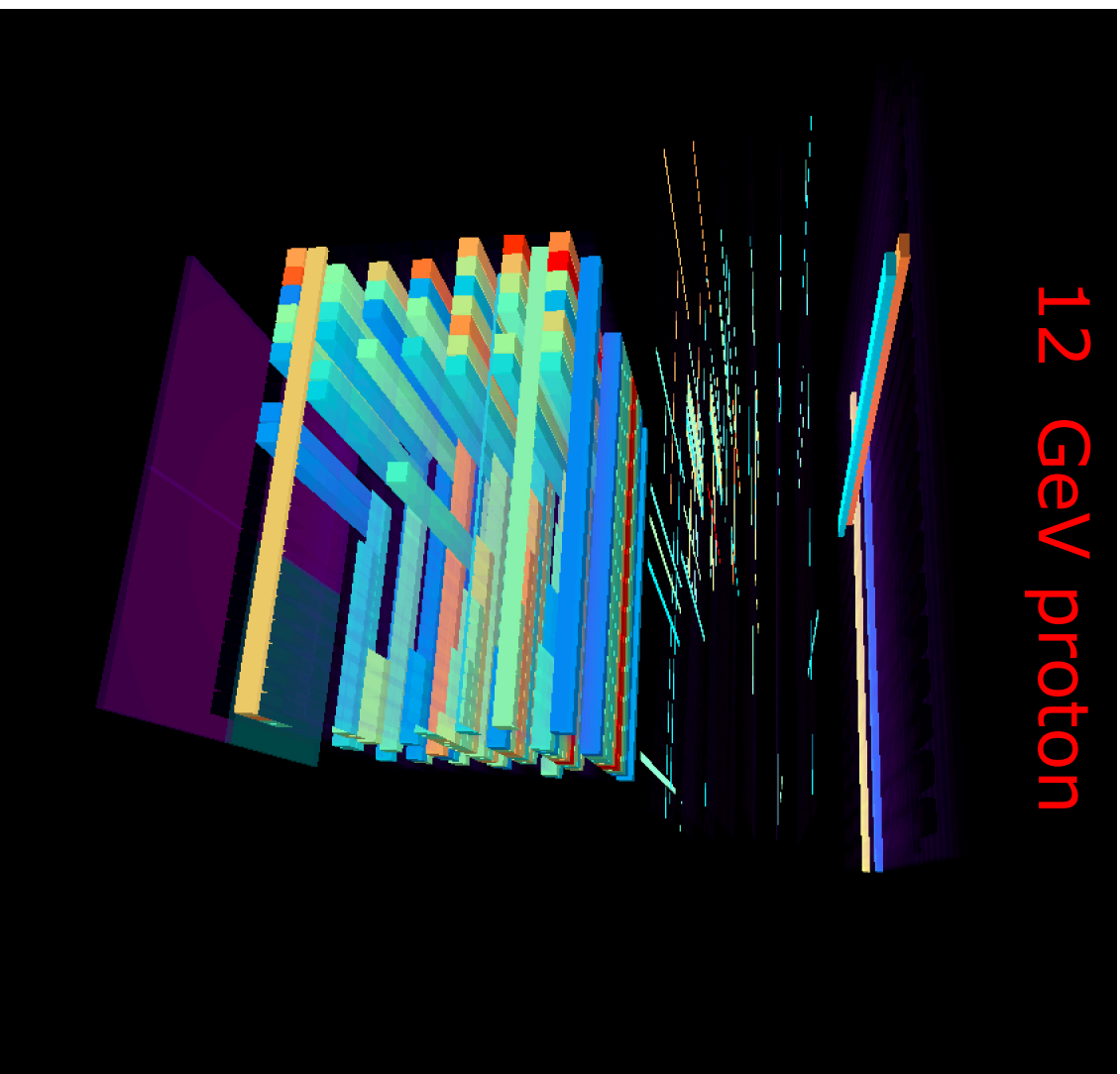


Lateral shower development

First Space events

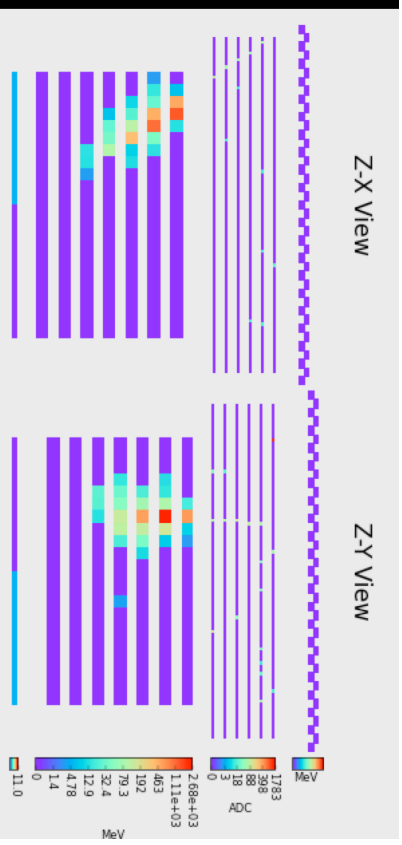
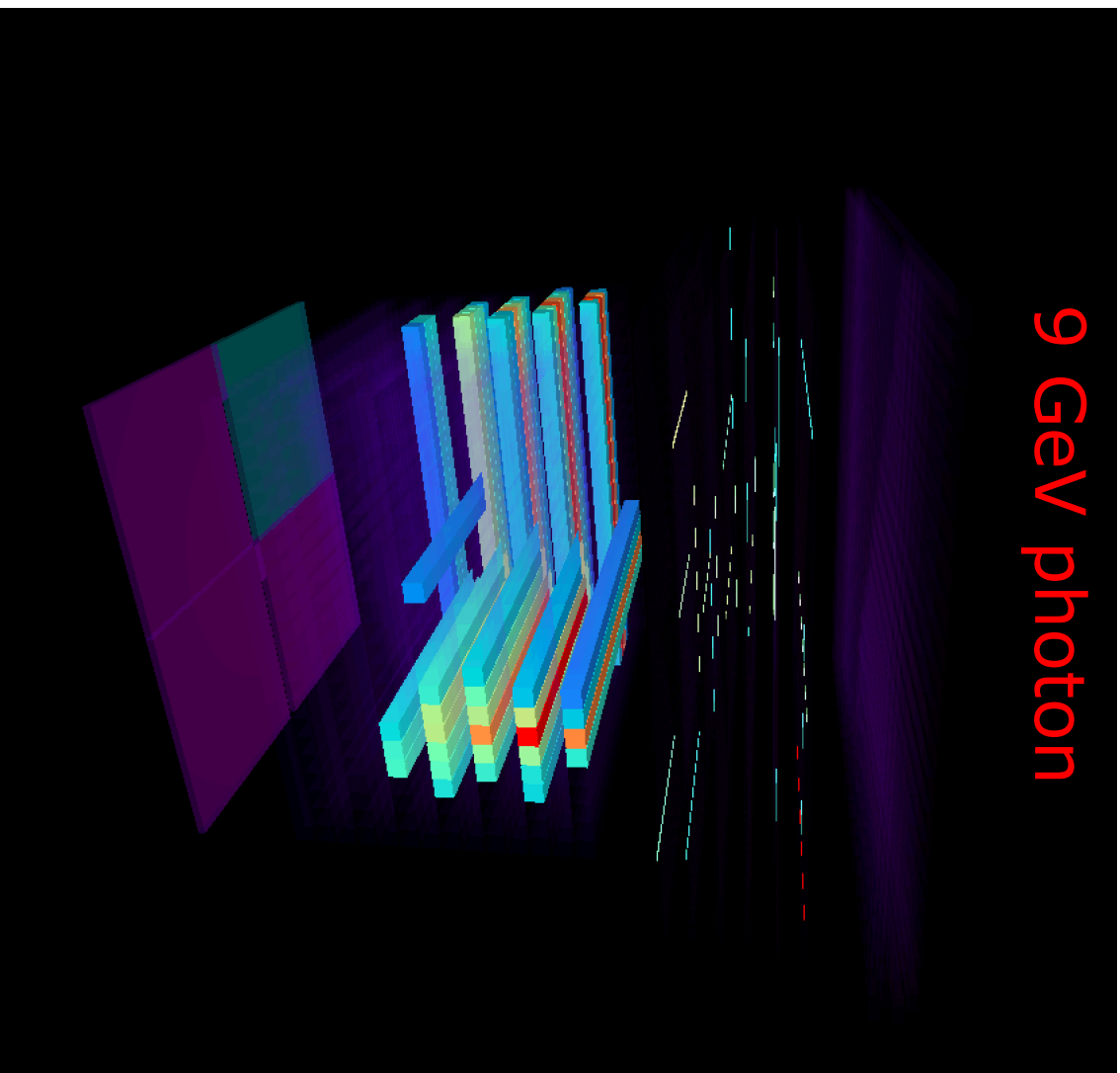


First Space events



12 GeV
proton

First Space events



<< First < Previous 157 Next > Last >>
Goto

Colors: 01 02 03 04 05 06 07 08

Stereo Effects: Red Cyan Red Blue Active Passive No Stereo

Advanced Show: Show Trajectory Start Animation Continuous Animation

File Name(s):
../display/20151224_2A/DAMPE_OBS_20151224B012559_REC02000.root

Event Number:
157

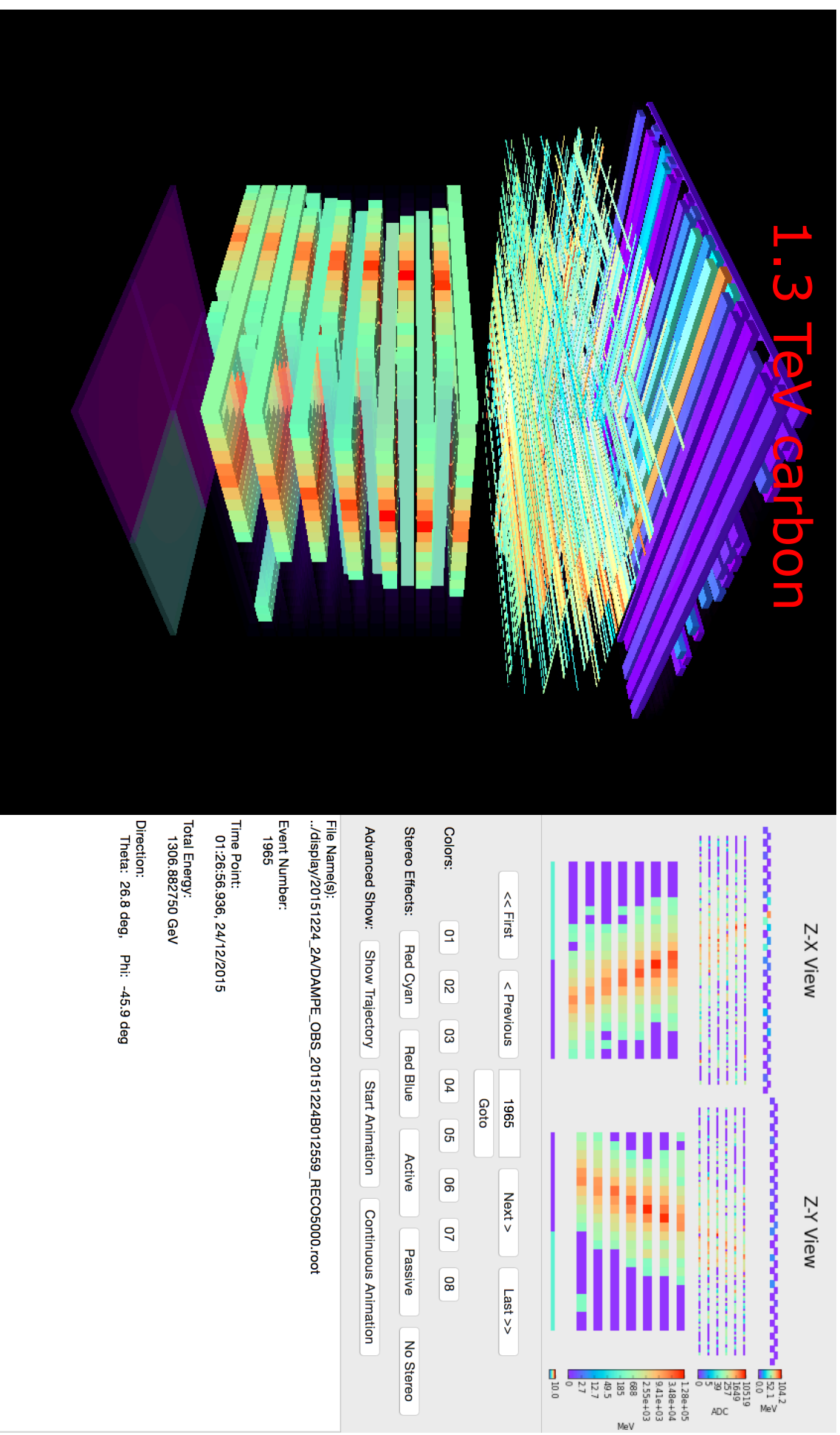
Time Point:
01:26:04.915, 24/12/2015

Total Energy:
9.213810 GeV

Direction:
Theta: 29.0 deg, Phi: -4.3 deg

9GeV gamma-ray

First Space events

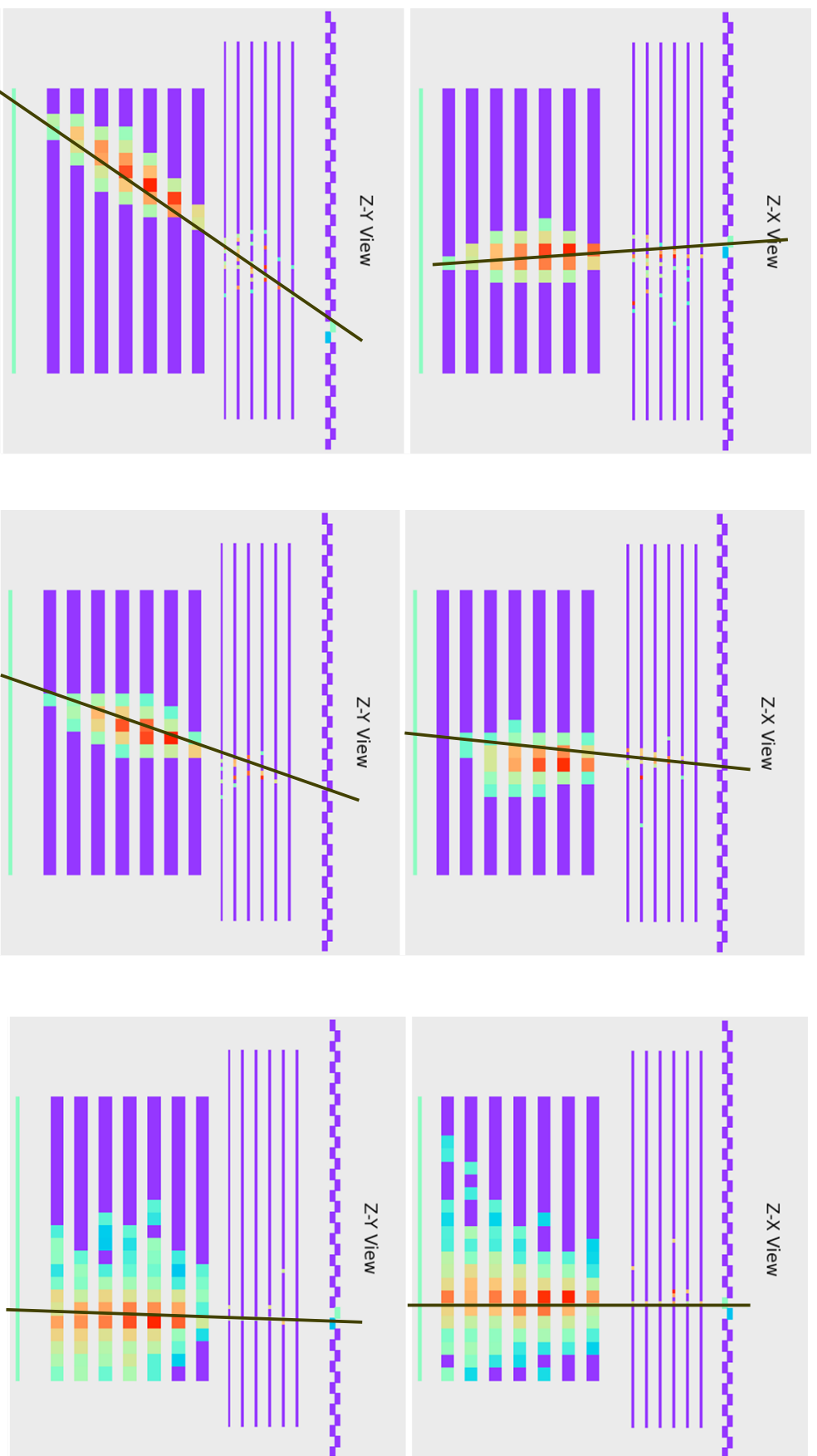


First Space events

electron

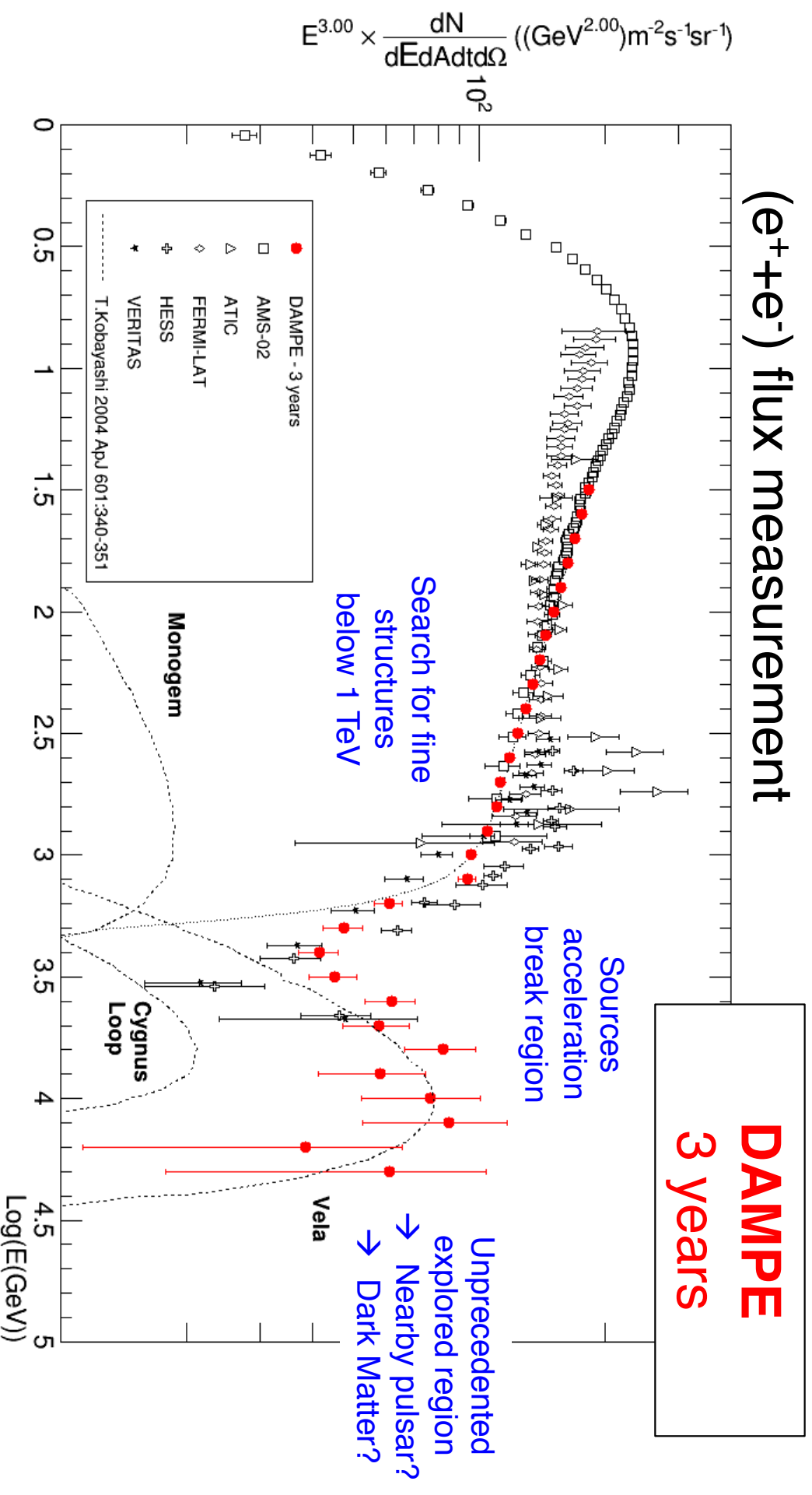
gamma-ray

Proton



Science Prospects

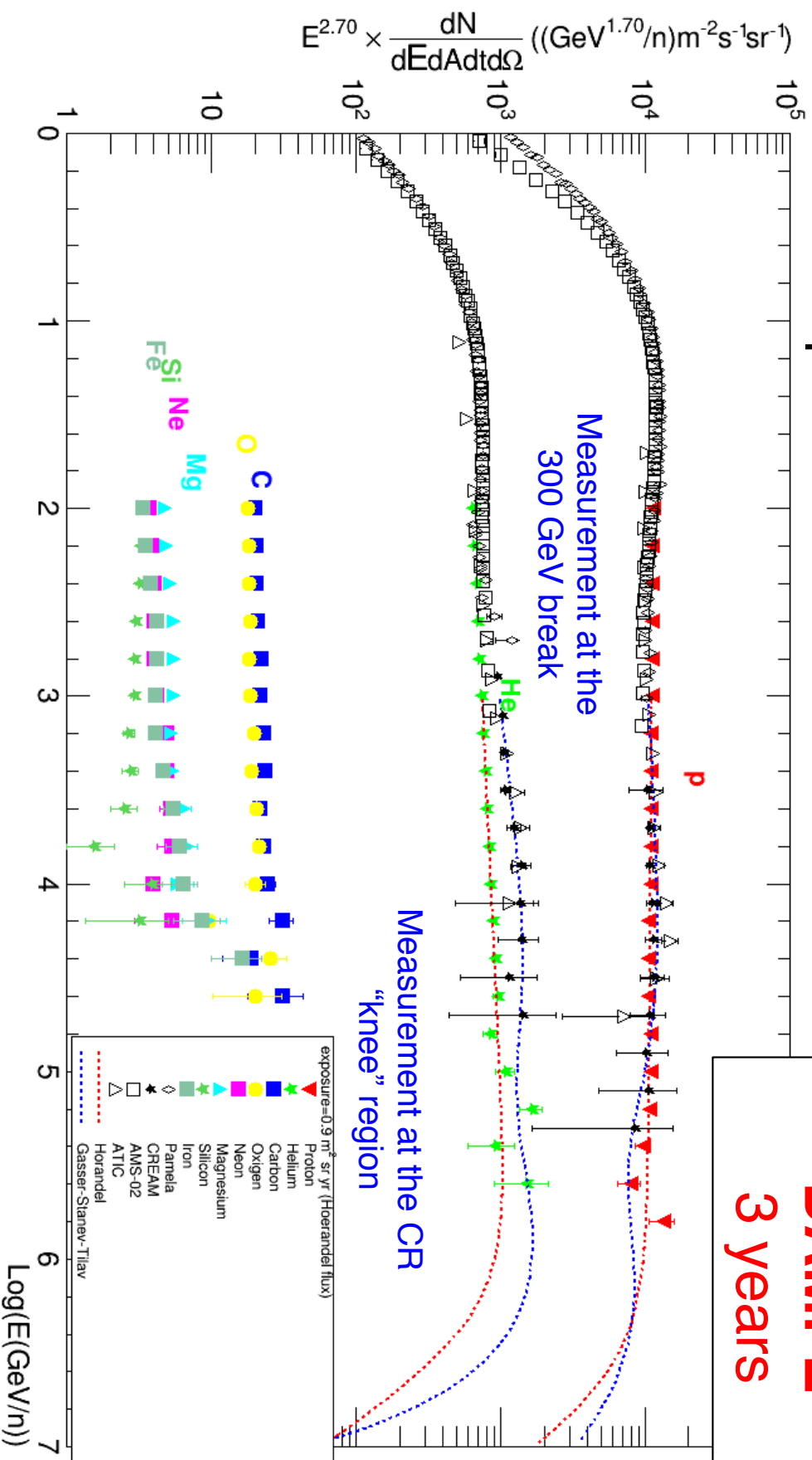
(e⁺+e⁻) flux measurement



Science Prospects

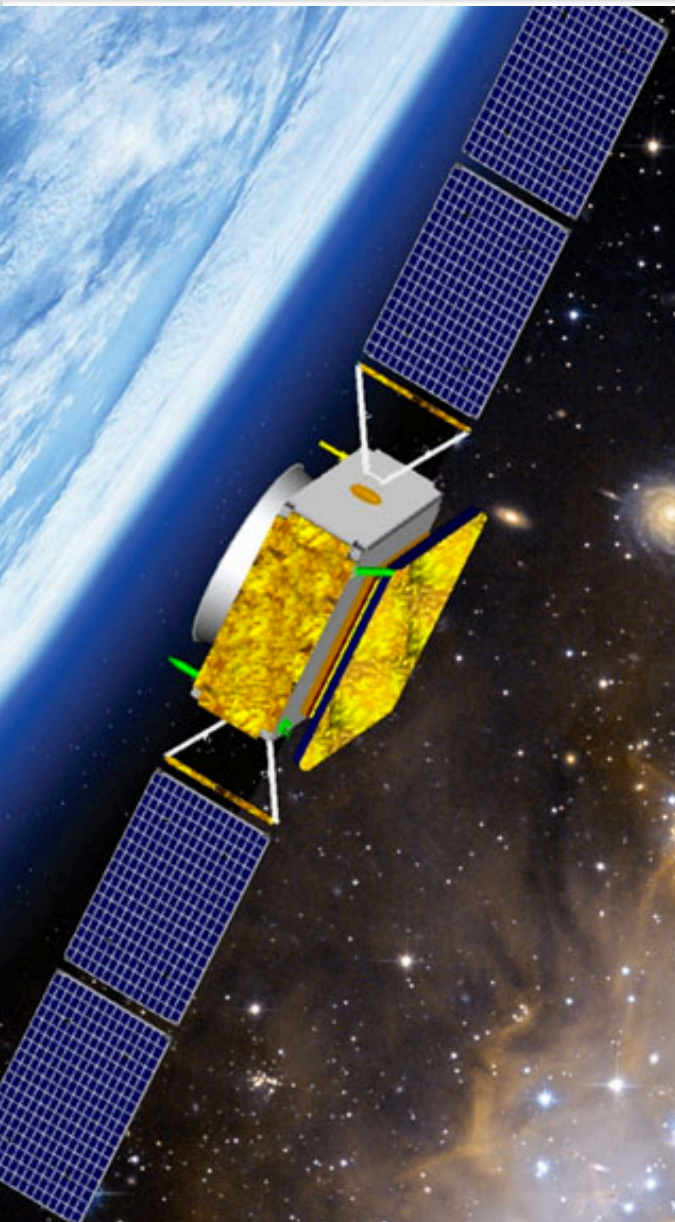
p and He fluxes

DAMPE
3 years



DAMPE is working properly, as expected, and collecting data
Currently many efforts to calibrate the detector
(tracker alignment, calorimeter e/p, charge calibration,
MonteCarlo tuning...)

Physics results will come soon. Stay tuned!





BRAINLESS TALES