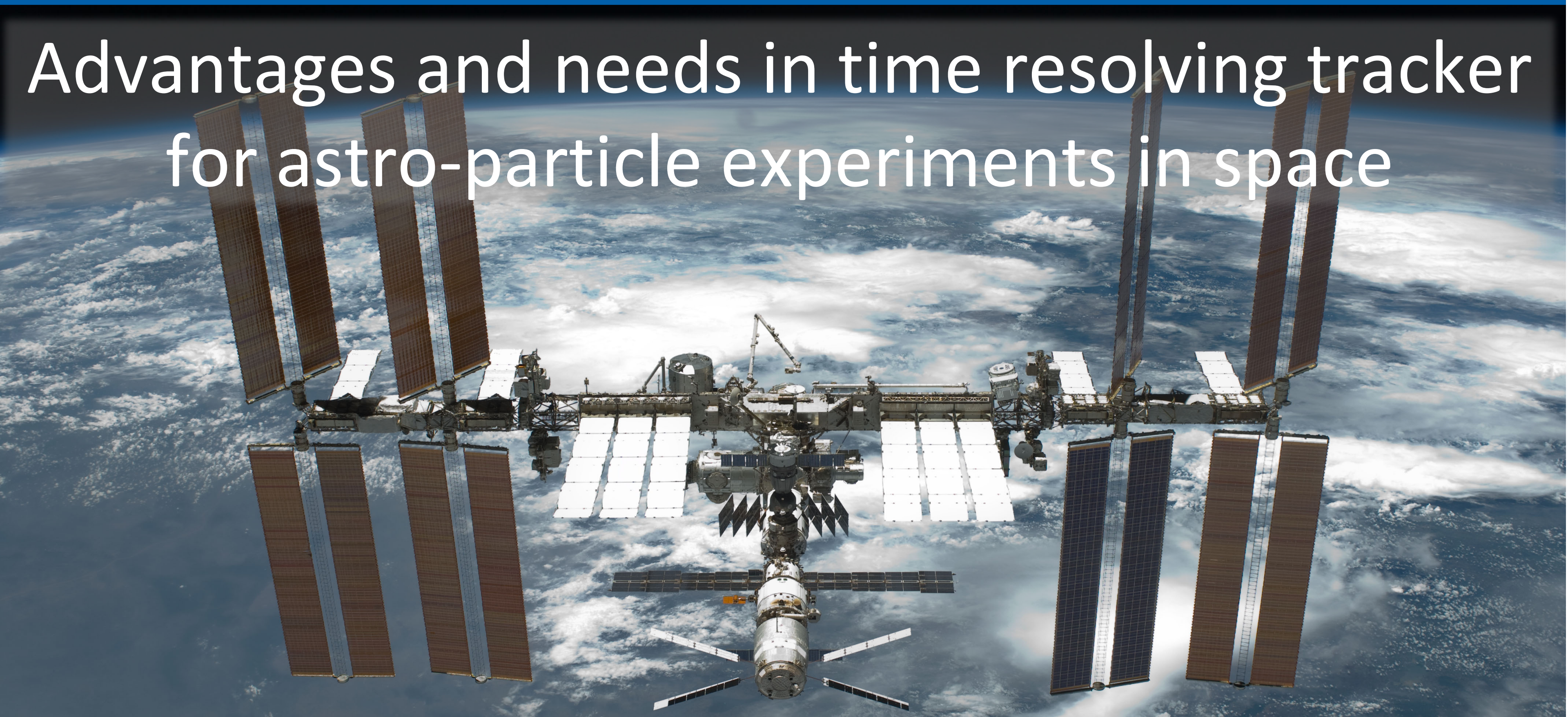
TREDI 2019

14th Trento Workshop on Advanced Silicon Radiator Detectors

Trento, from Monday 25 February to Wednesday 27 February 2019



Advantages and needs in time resolving tracker for astro-particle experiments in space

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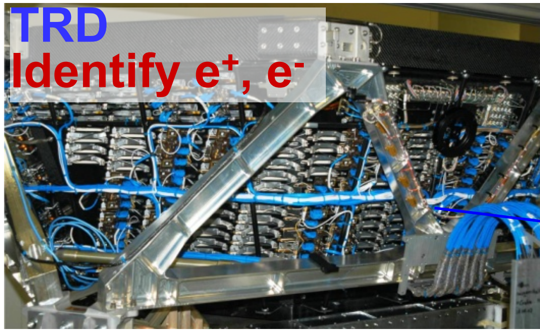
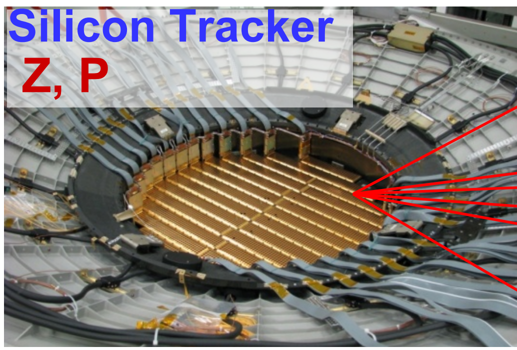
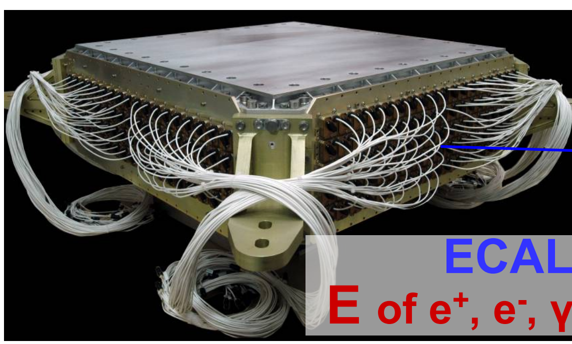
Outline

- Current and future Cosmic Rays Space experiments: their needs and their limitations
- What we can do with timing in the Tracker
- Geant4 simulation and ideas to optimize the layout

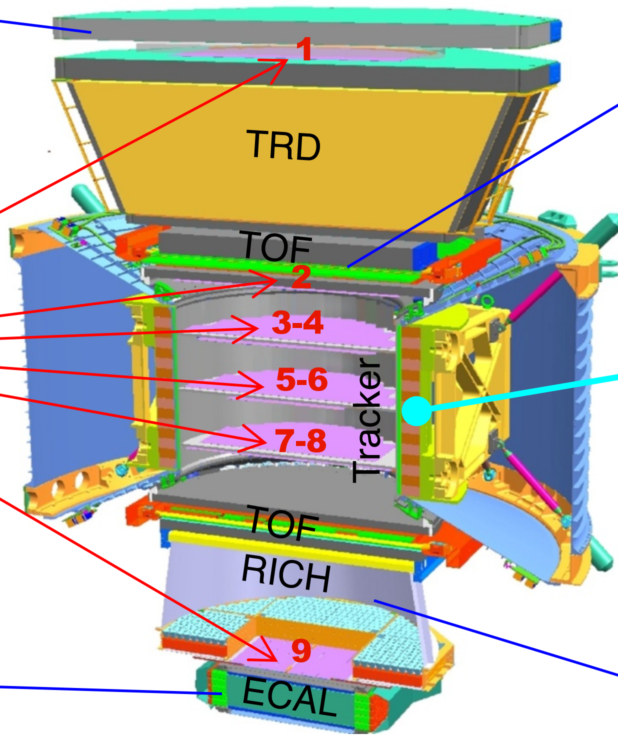
AMS-02: A precision, multipurpose, up to TeV spectrometer

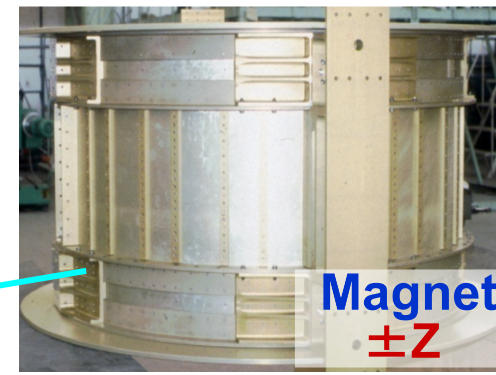


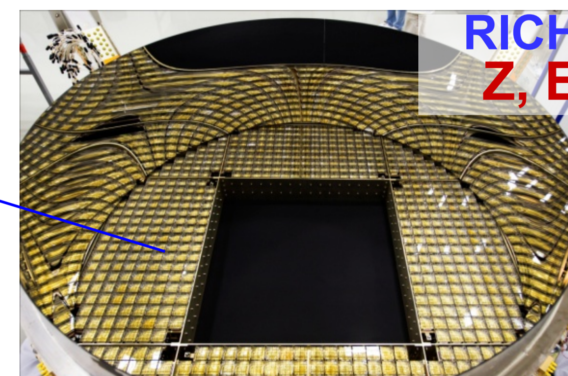




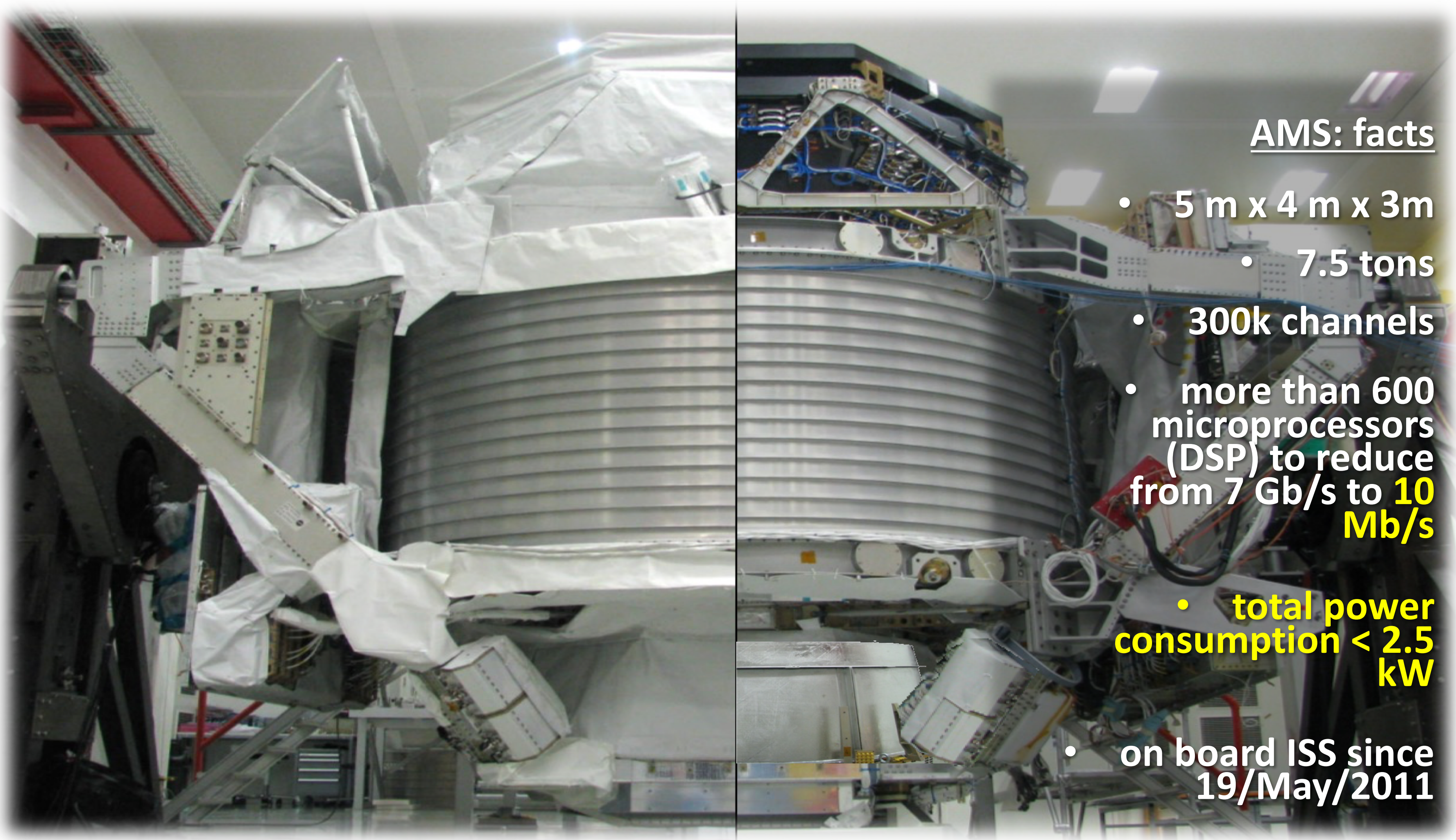
***Z, P* are measured independently by the Tracker, RICH, TOF and ECAL**







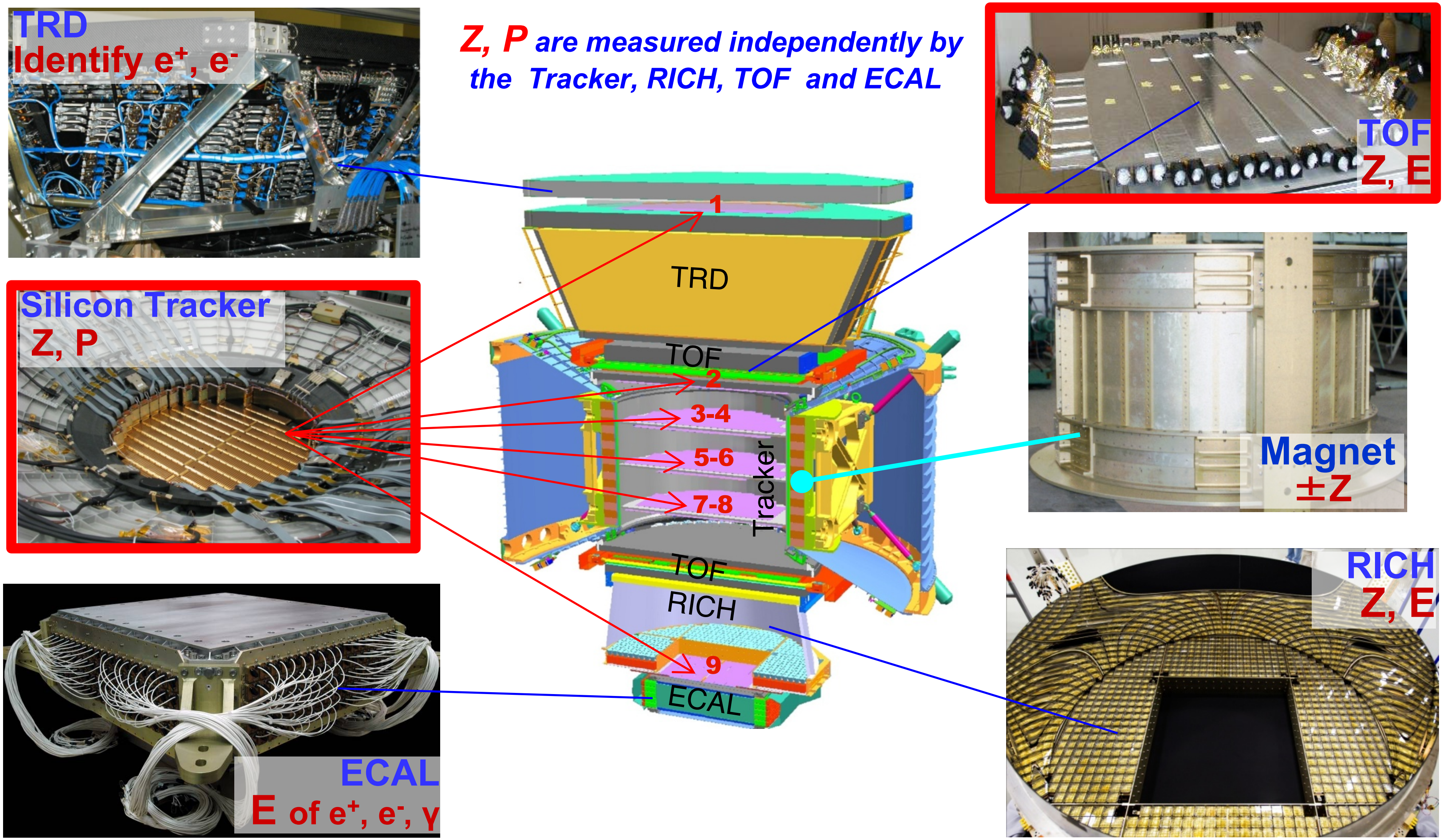
AMS-02: A precision, multipurpose, up to TeV spectrometer



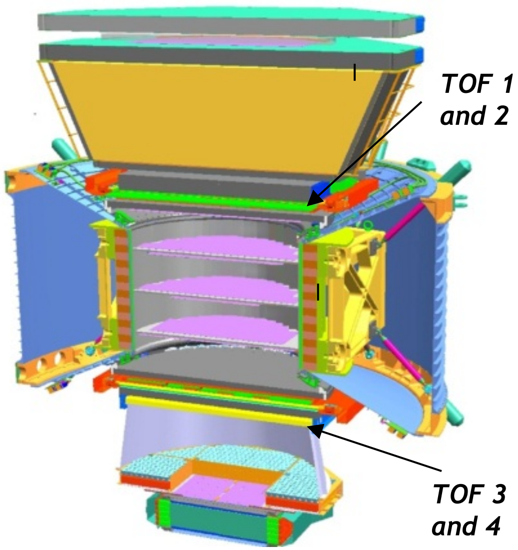
AMS: facts

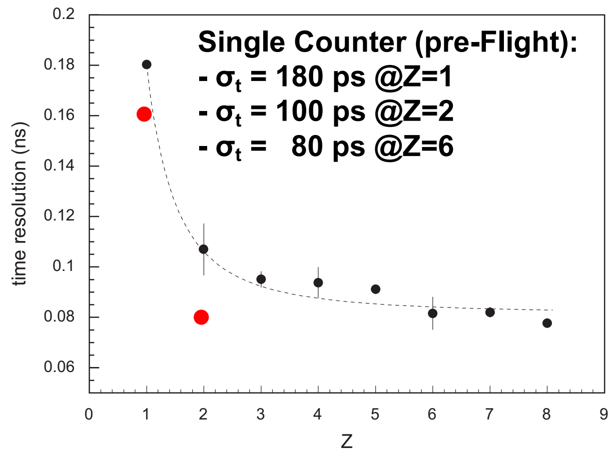
- 5 m x 4 m x 3m
- 7.5 tons
- 300k channels
- more than 600 microprocessors (DSP) to reduce from 7 Gb/s to 10 Mb/s
- total power consumption < 2.5 kW
- on board ISS since 19/May/2011

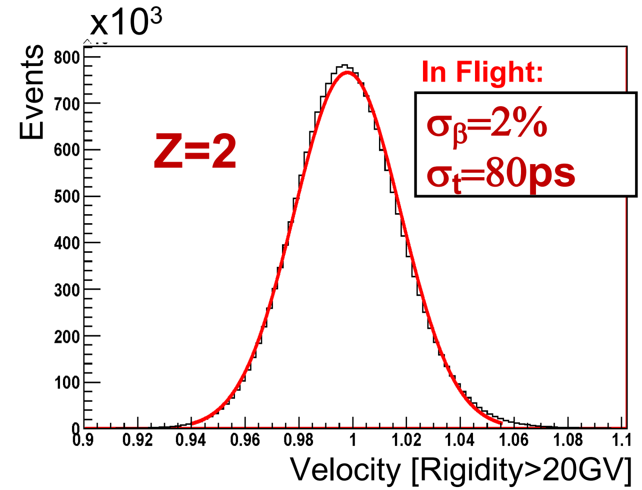
AMS-02: A precision, multipurpose, up to TeV spectrometer



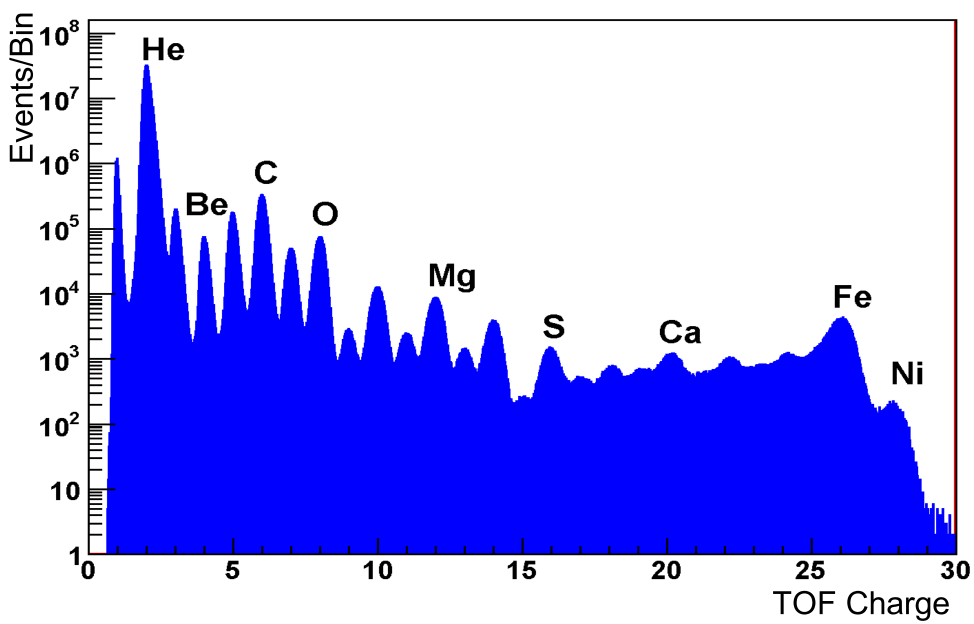
AMS-02: Time of Flight

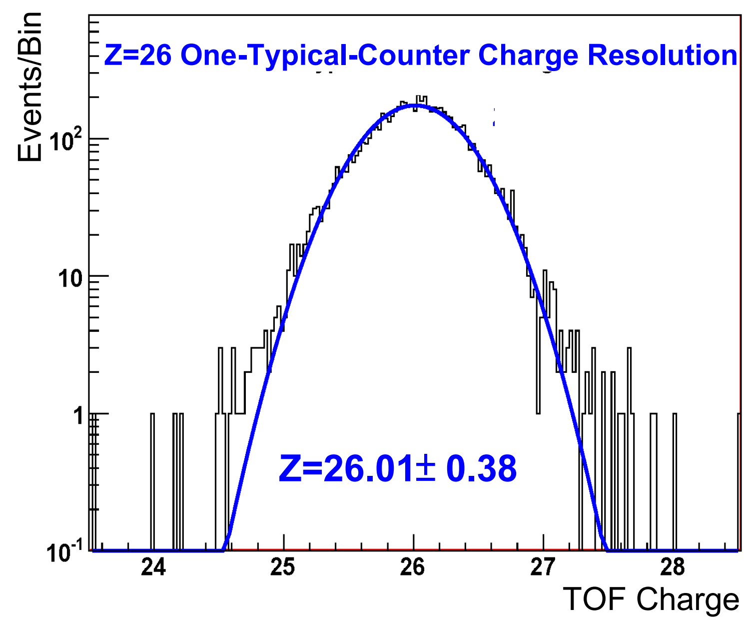






Measures Velocity and Charge of particles





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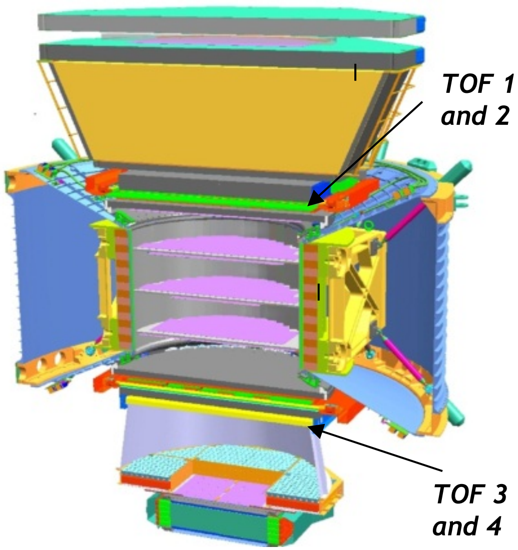

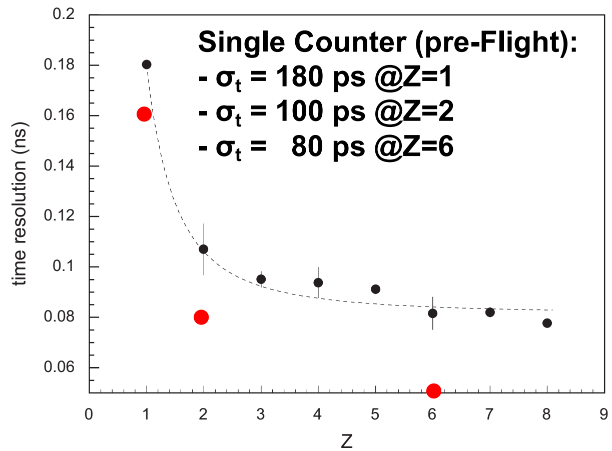

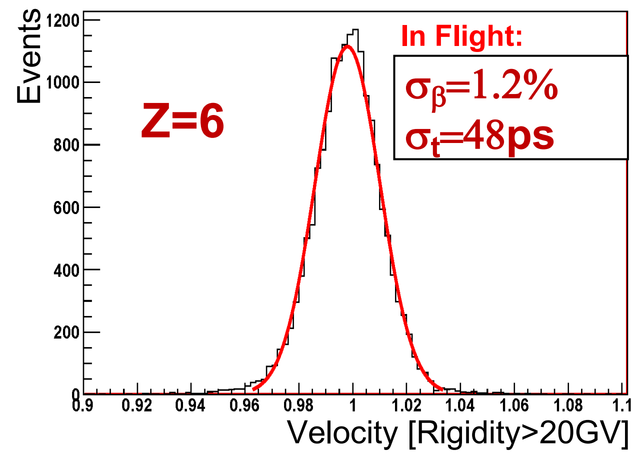

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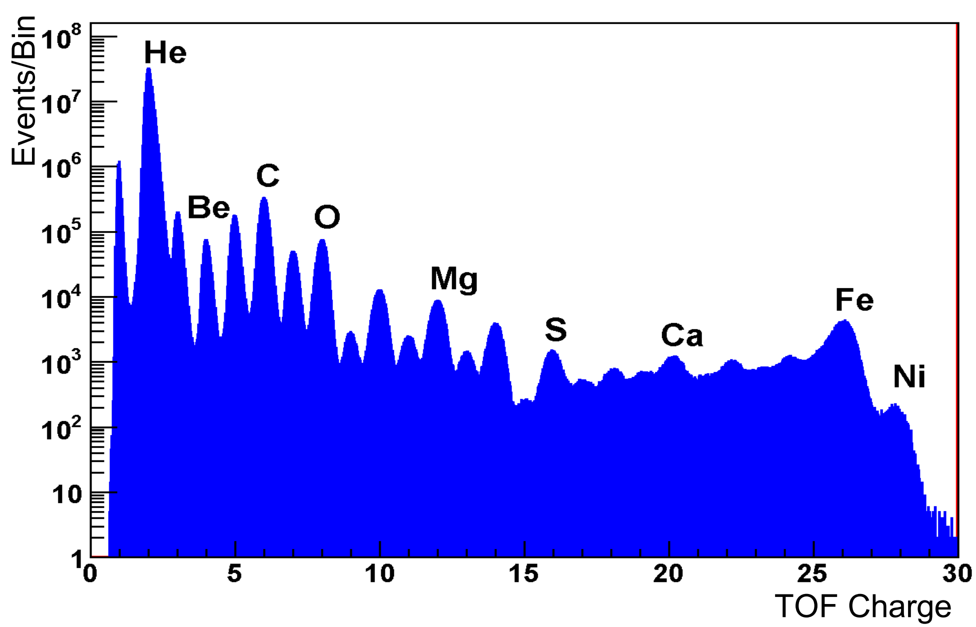

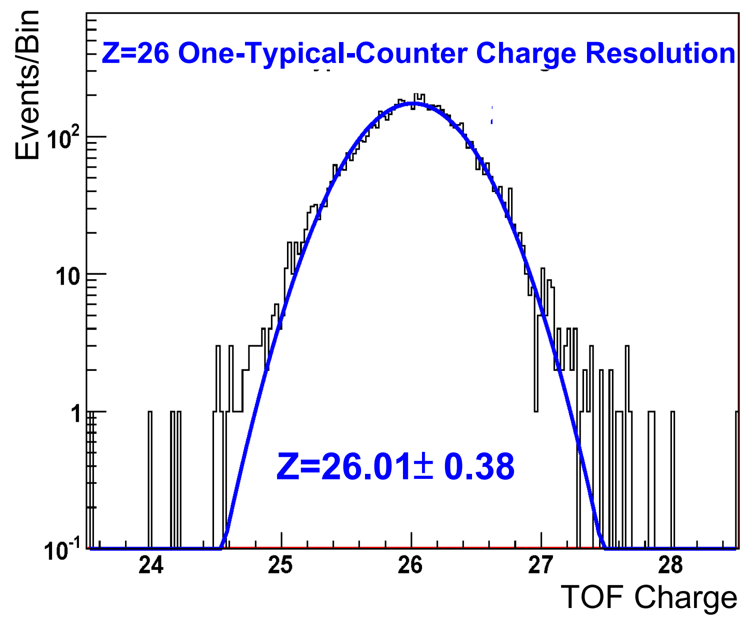

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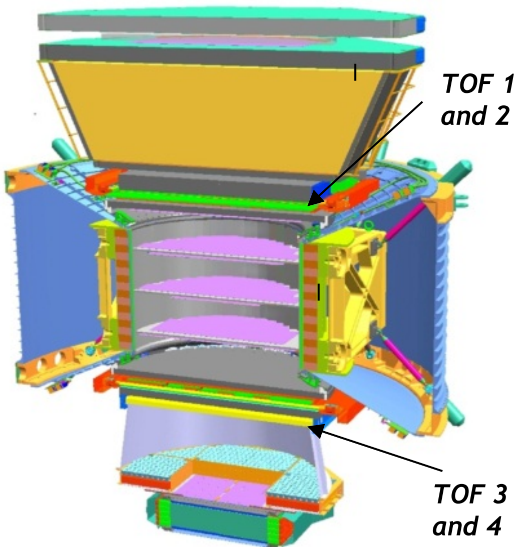
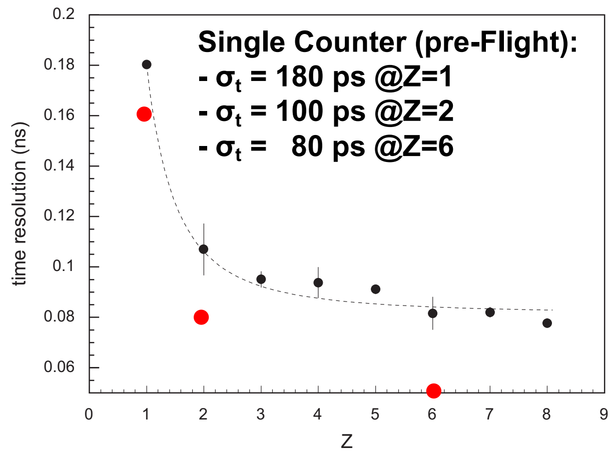
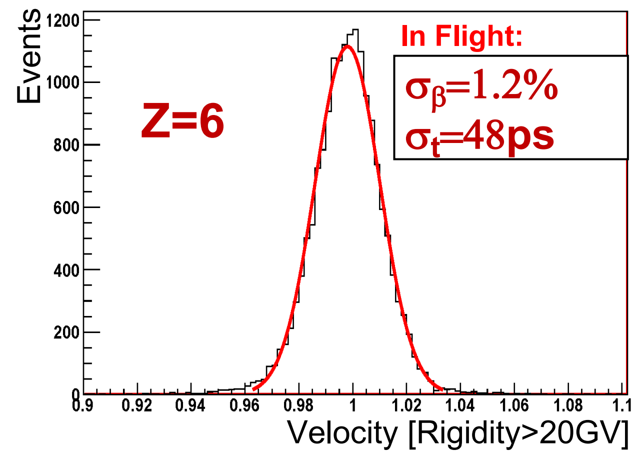


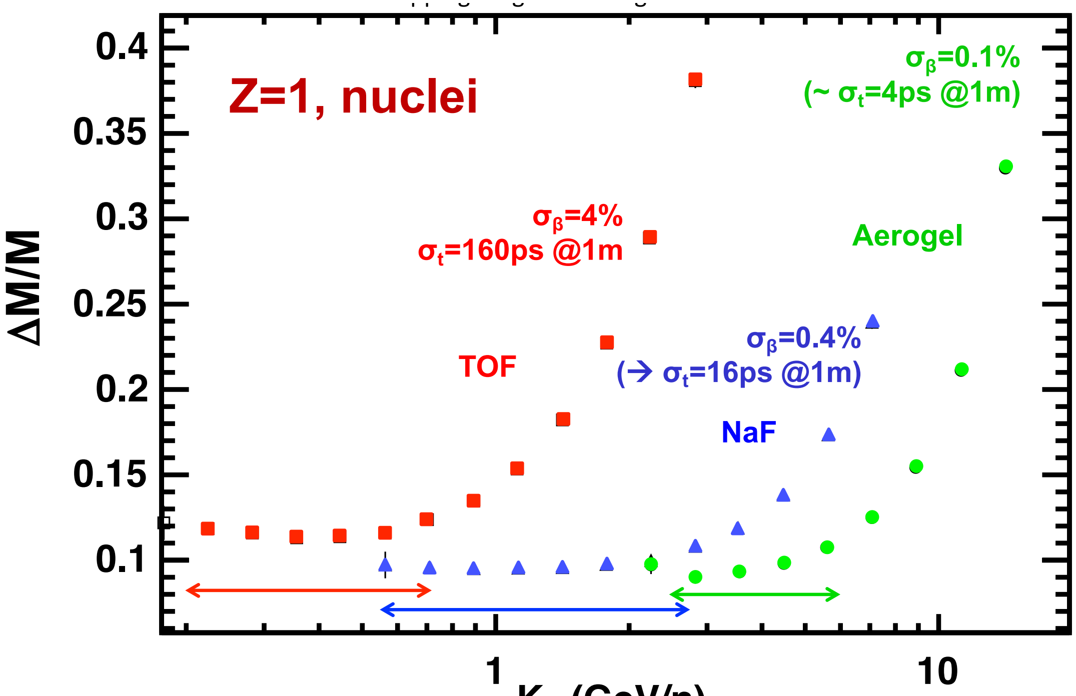




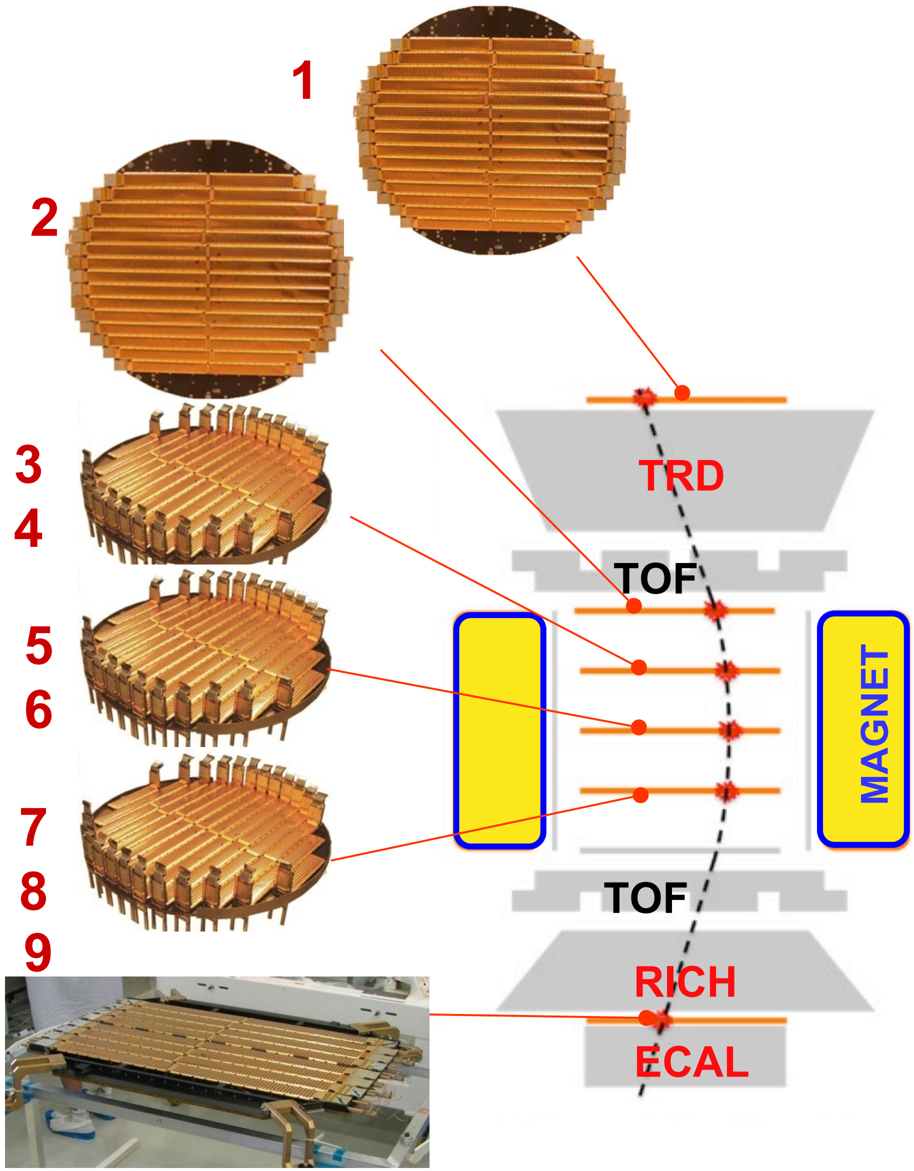
$$\frac{\delta M}{M} = \left(\frac{\delta p}{p}\right) \oplus \gamma^2 \left(\frac{\delta \beta}{\beta}\right)$$

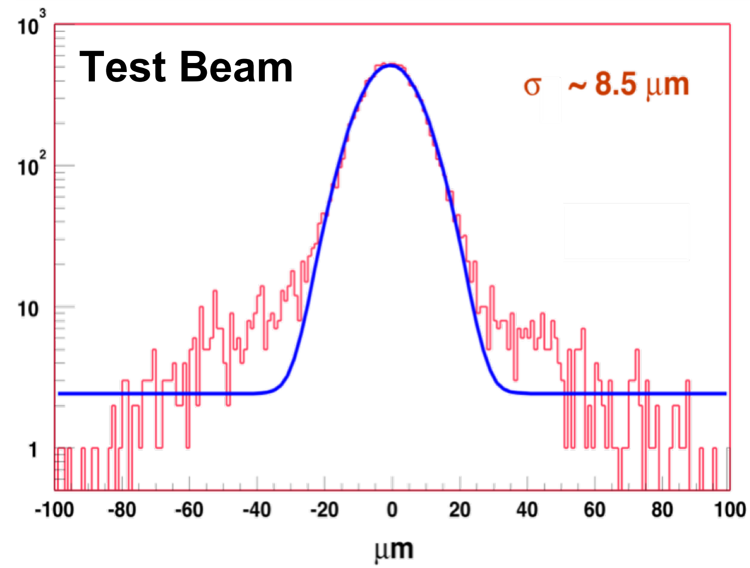
Velocity resolution is crucial for isotopical measurements:

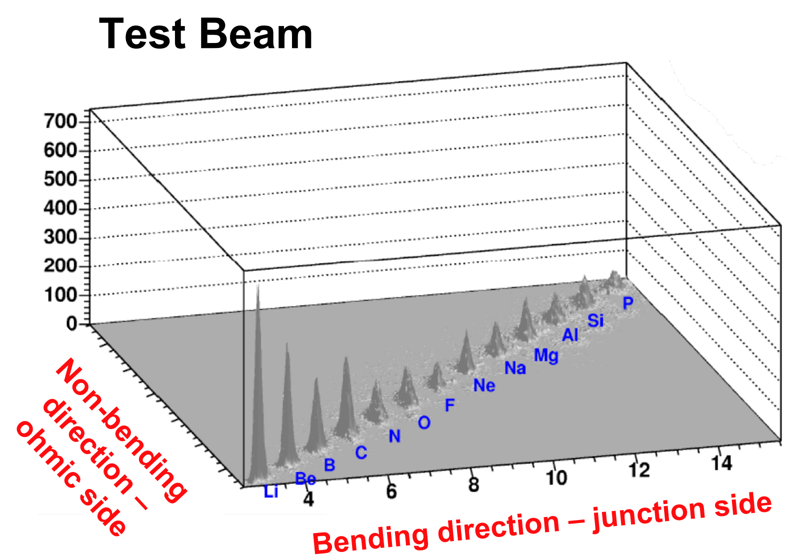
- d and anti-d
- $^3He/^4He$
- $^6Li/^7Li$
- …



AMS-02: Silicon Tracker

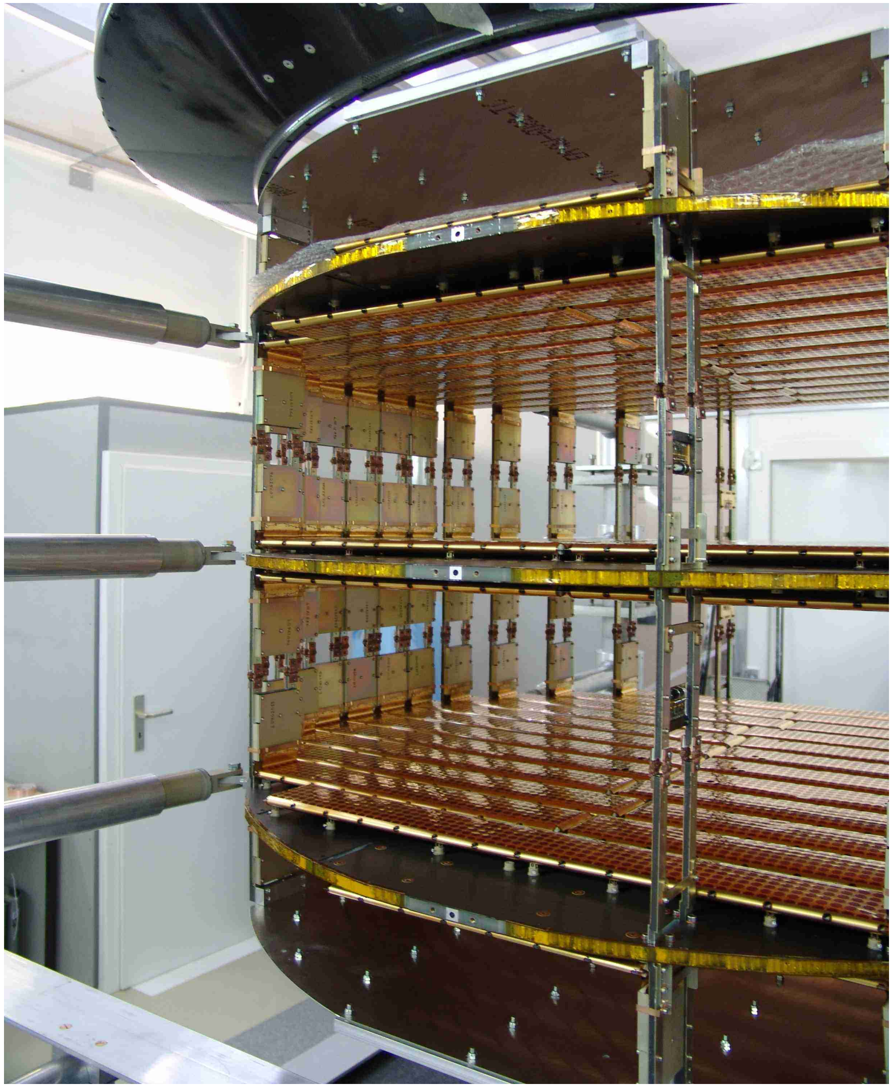




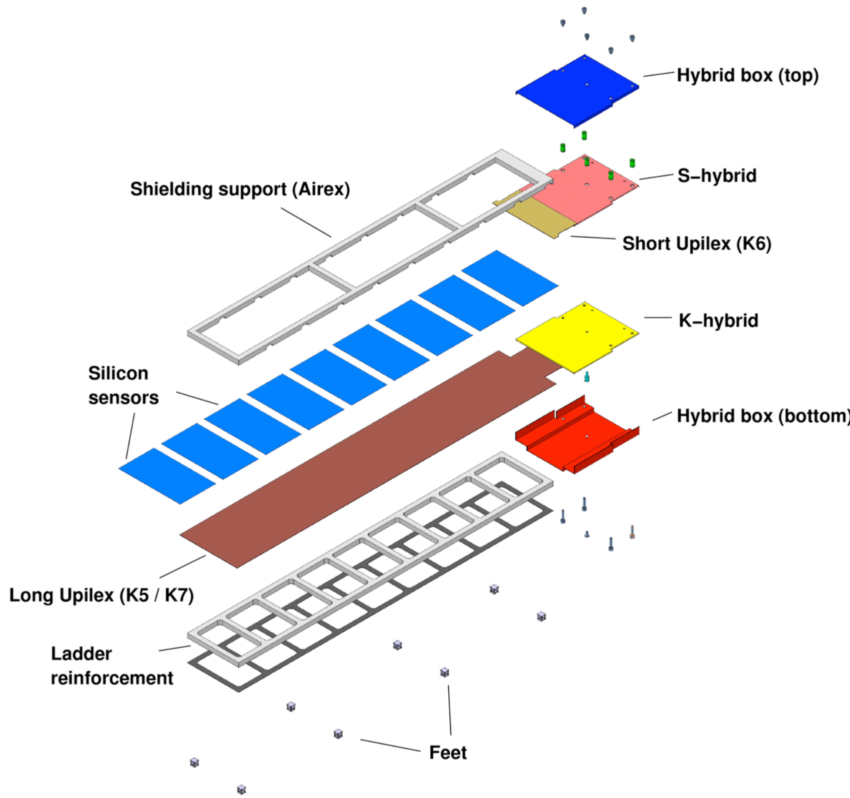


AMS-02: Silicon Tracker

- 9 layers of double sided silicon detectors arranged in 192 ladders
- ~6 m^2
- total of 200k channels for ~ 200 watt
- 10 μm (30 μm) spatial resolution in bending (non bending) plane
- momentum resolution ~10% @10 GeV
- high dynamic range front end for charge measurement
- wide temperature range (-20/+40 survival, -10/+30 oper.)
- 6 honeycomb carbon fiber plane
- detector material ~ 0.04 X_0

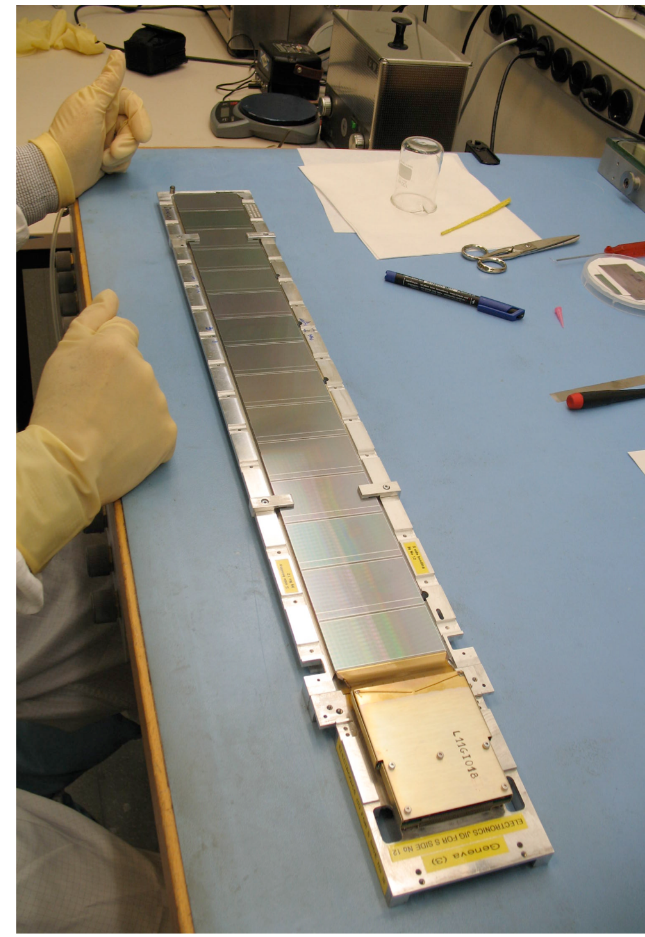


AMS-02: Silicon "ladder"



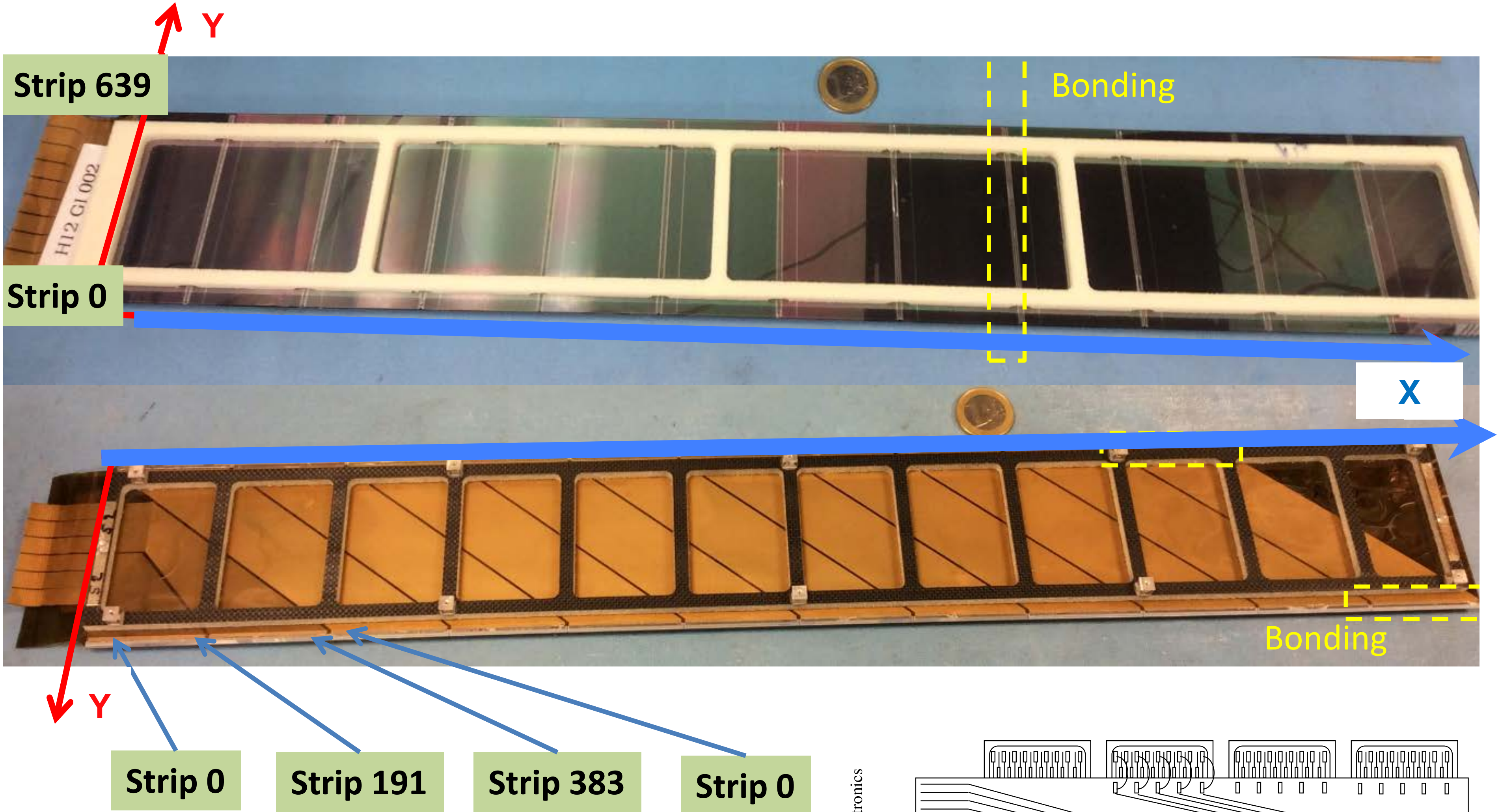
192 flight units

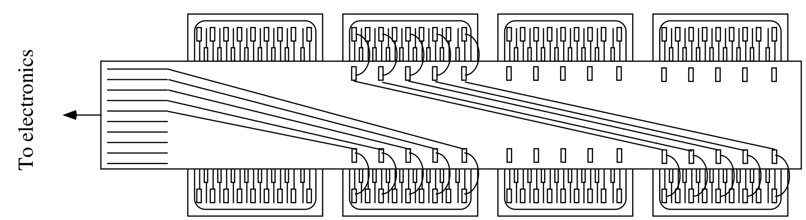
7 – 15 wafers (28 – 60 cm) each



- 1024 high dynamic range, AC coupled readout channels:
  - 640 on junction (S) side
  - 384 on ohmic (K) side
- Implant/readout pitch:
  - 27.5/110 μm ("S"/junction/bending side)
  - 104/208 μm ("K"/ohmic/non-bending side)

AMS-02: Silicon "ladder"





"multiplicity" (or "ambiguity"): the 1500-3000 K-side channels needed for each ladder are "merged" into 384.

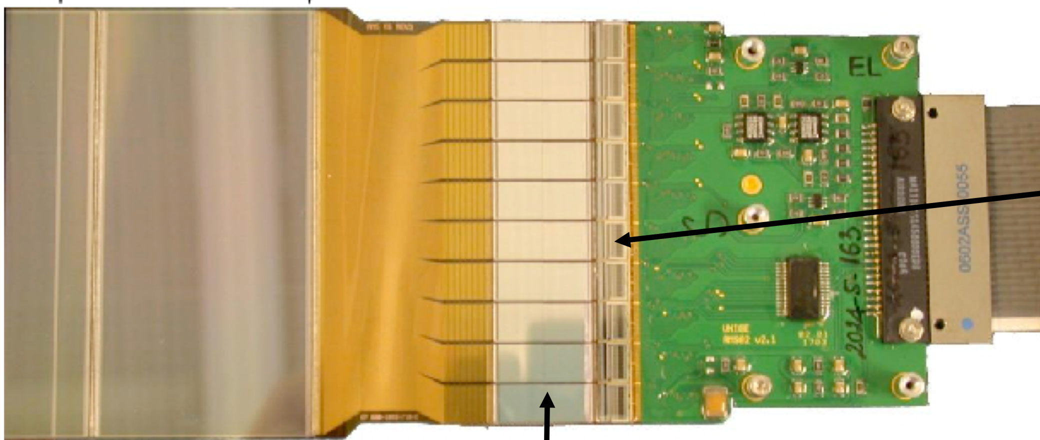
INFN PERUGIA

AMS-02: Ladder hybrids

2nd bonding pad row

K6 Upilex

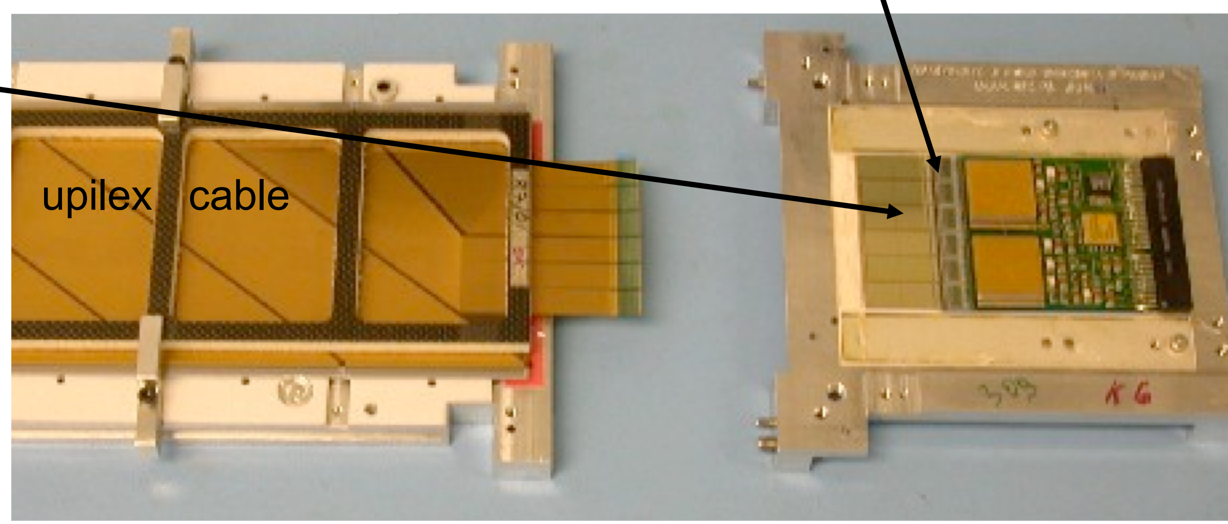
S–hybrid



1st sensor edge

6-10 *VA_hdr64a* (IDEAS, NO)
640 channels, 0.7 mW power each
CR-RC shaper and S&H
4 μs shaping time
100 MIP dynamic range

700 pF coupling capacitances

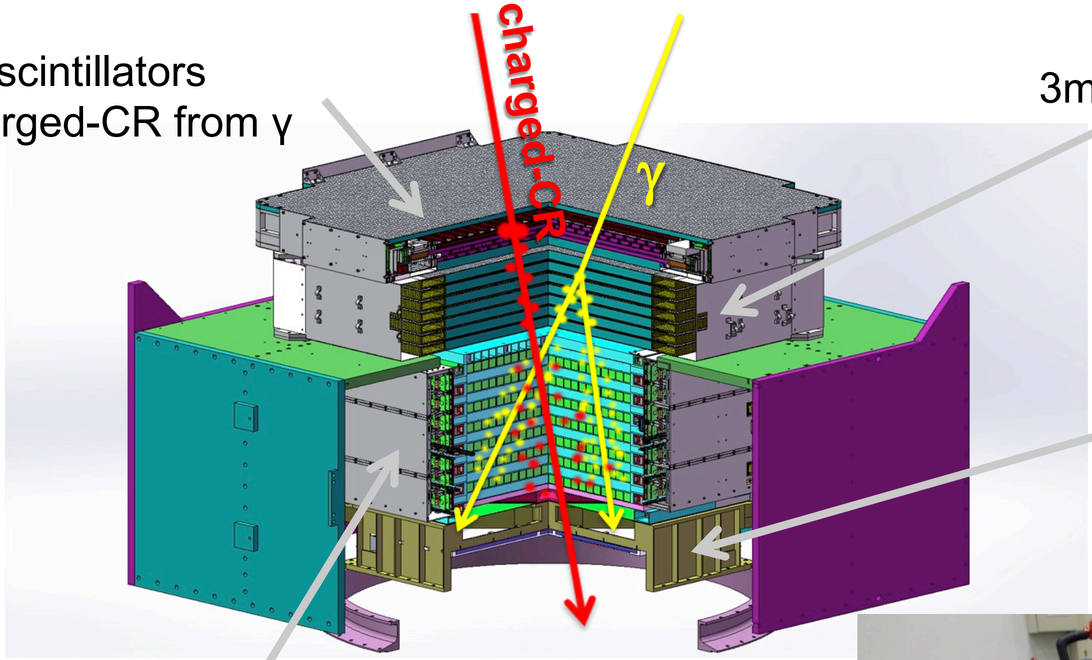


double sided, DC coupled
300 μm thickness
7 - 15 sensors in a ladder produced at:
- Colybris, CH
- IRST, IT

DAMPE: DArk Matter Particle Explorer

PSD: scintillators
Z, charged-CR from γ

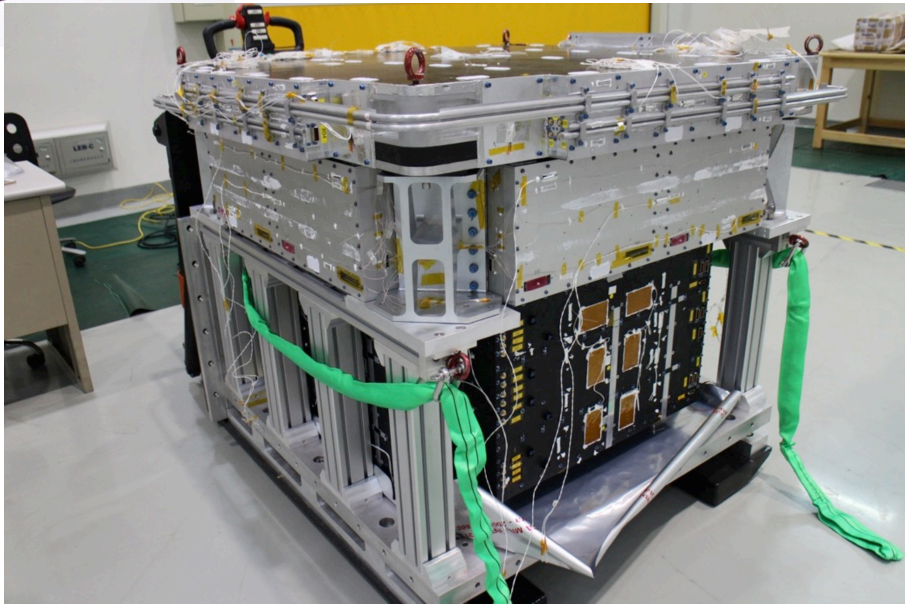
STK: 6 tracking planes +
3mm tungsten γ converter, Z,
tracking for charged-CR



NUD: neutron detector to
identify hadrons (from
electron and γ)

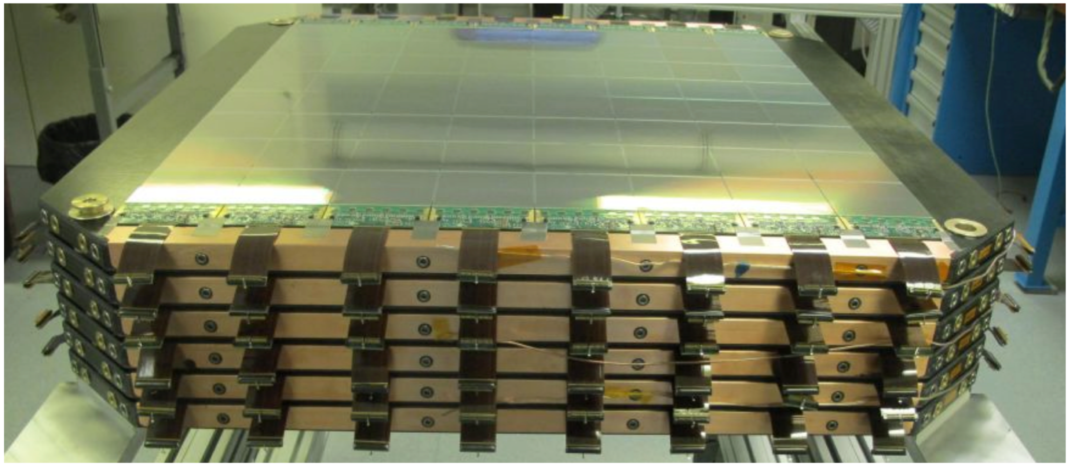
BGO: 308 calorimetric BGO
bars (~31 radiation lengths)
Trigger, E measurement

In orbit on a
Chinese Satellite
since 17/Dec/2015

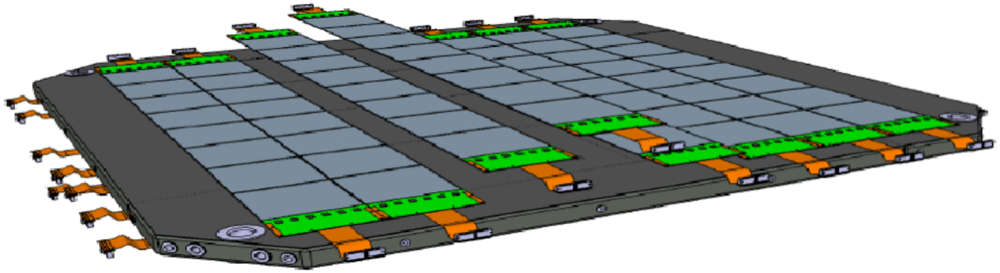


DAMPE: Silicon-Tungsten Tracker-Converter

Tracker:
- $7\ m^2$
- 12 layers for single sided microstrip detectors (6 for X and 6 for Y)
- 3 * 1mm W foils
- 70k channels
- 25 W for FE + 35 W for read-out

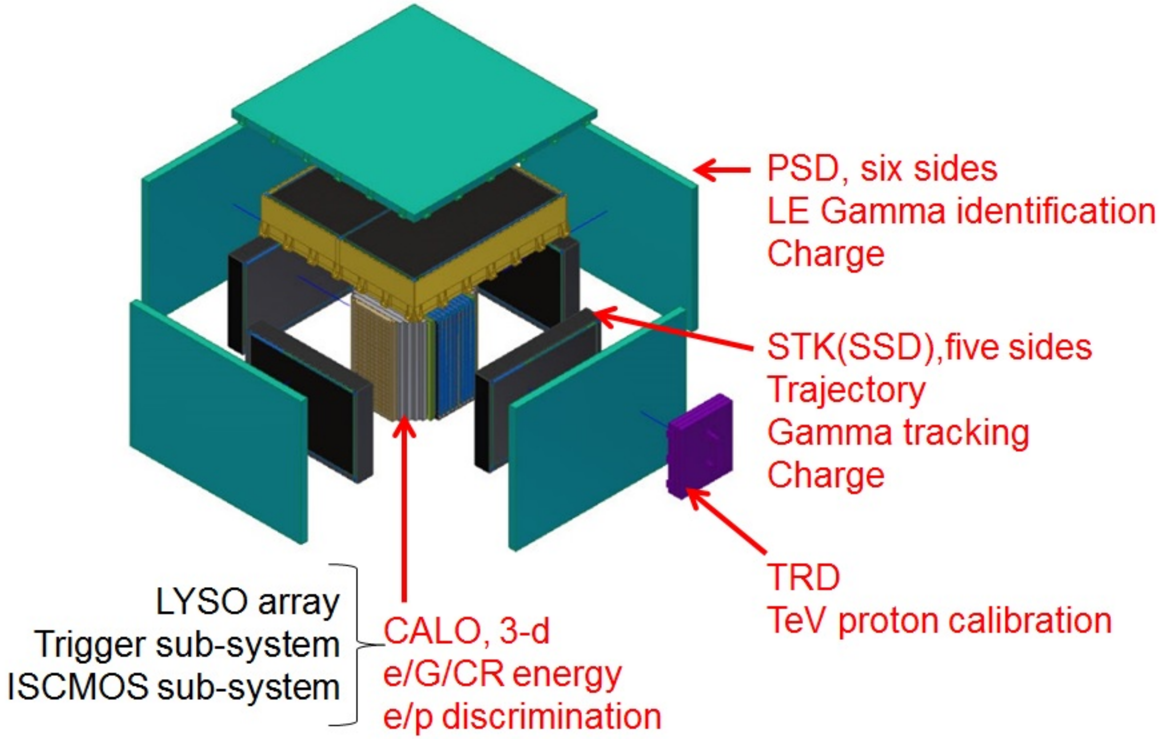


Layer:
- 4 "quarters"
- 4 ladders per quarter



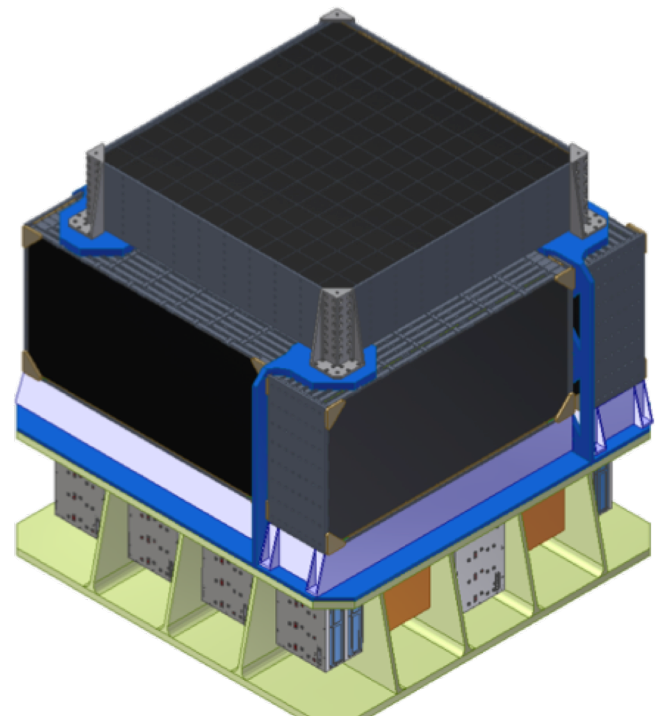
Ladder:
- single sided
- 320 μm
- 121/242 μm implant/read-out pitch → 35 μm resolution
- $9.5*38\ cm^2$ ($4*9.5*9.5\ cm^2$)
- pitch 240 μm
- resolution 40 μm
- 6 * *va140* FE chip, 0.3 mW each

HERD: High Energy Radiation Detector



HERD on the Chinese Space Station (2024-2025):

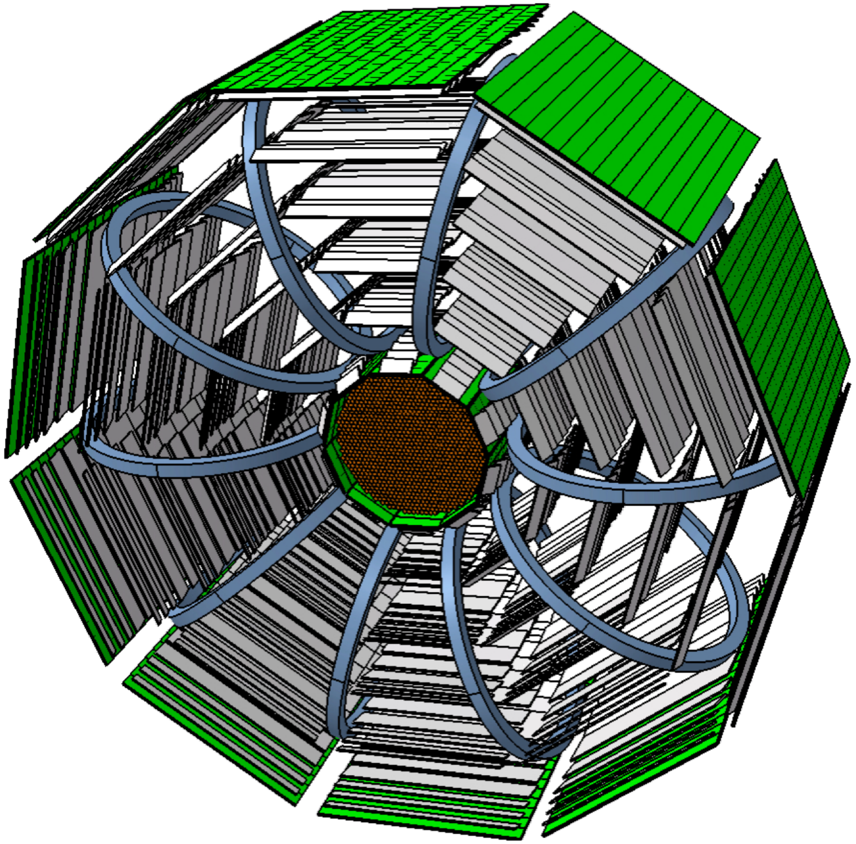
- LYSO calorimeter (55 radiation lengths, 3 interaction lengths)
- 5 sides PSD
- 5 sides Tracker
- small TRD for hadronic energy calibration



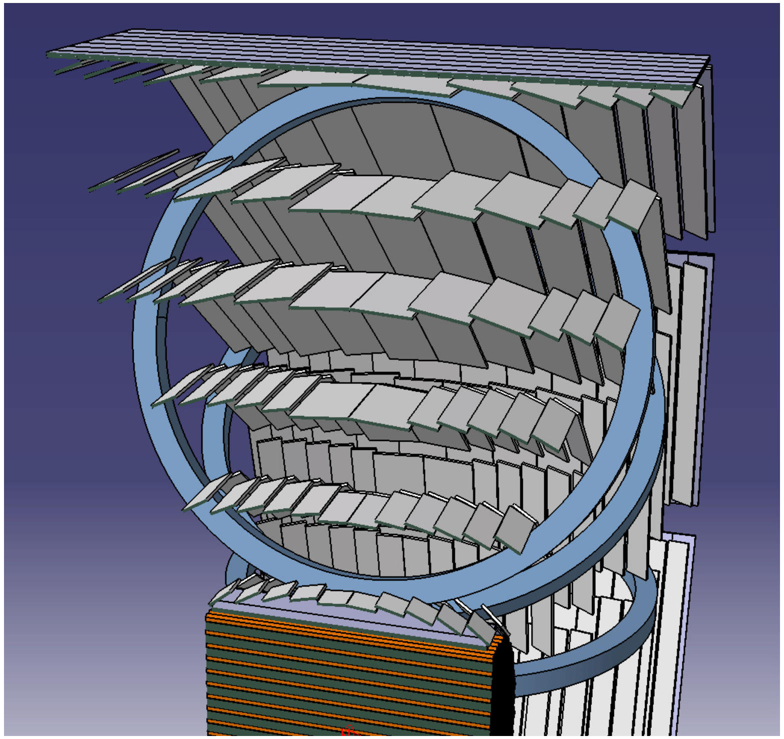
Tracker:

- 40 m^2
- 200-400k channels
- ~ 100 W for FE
- ~ 200 W for read-out

ALADInO: Antimatter Large Acceptance Detector In Orbit



HERD on L2:
- LYSO calorimeter (61 radiation lengths, 3.5 interaction lengths)
- 2π PSD (and ToF)
- 2π Tracker (Spectrometer)
- 3T (0.8T average) B-field by "hot" super-conducting magnet (MgB_2)



Tracker:
- 80 m^2
- 1.5M channels
- ~ 1 kW

Timing in an astro-particle tracker

Including the timing into the Tracker of an astro-particle detector permits to:

- substitute (or provide full redundancy to) any other **ToF detector** (i.e. planes of scintillators) in measuring β → isotopic composition for nuclear species (combined with *E* or *p* measurement);

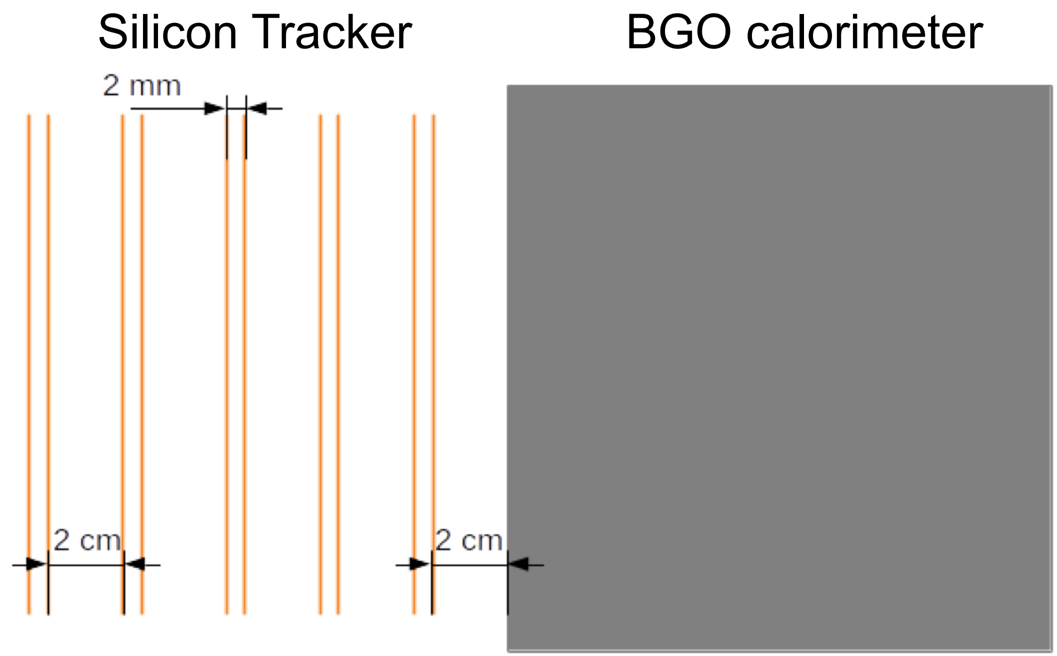
- solve different problematics as:

    - identification of the hits coming from **back-scattering** from the calorimeter. Example: identify photons without vetoing when large back-scattering (DAMPE: photons lost due to back-scattering 30%@100GeV, 50%@1TeV);

    - **e/p identification**. The presence of a low energy (i.e. $\beta<1$) back-scattered particles (i.e. hadrons) from a shower identifies the CR as hadron;

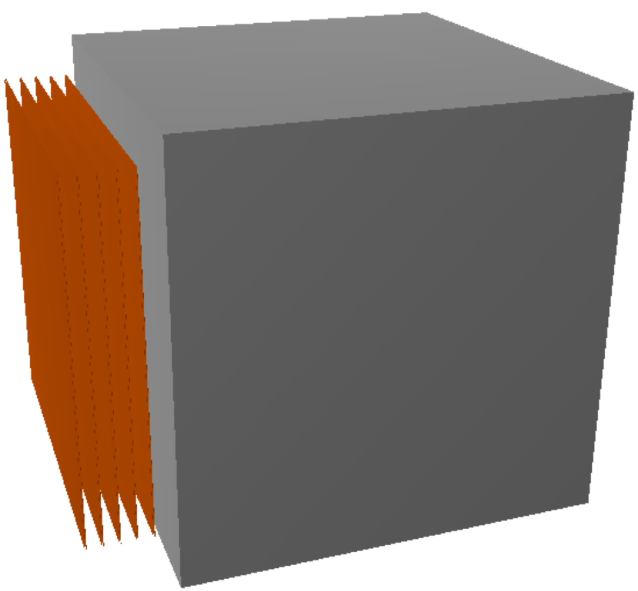
    - solve the **"ghost"** problem, typical of a microstrip silicon sensor, from back-scattering, pile-up particles, etc…;

MC Simulation



MC Simulation:

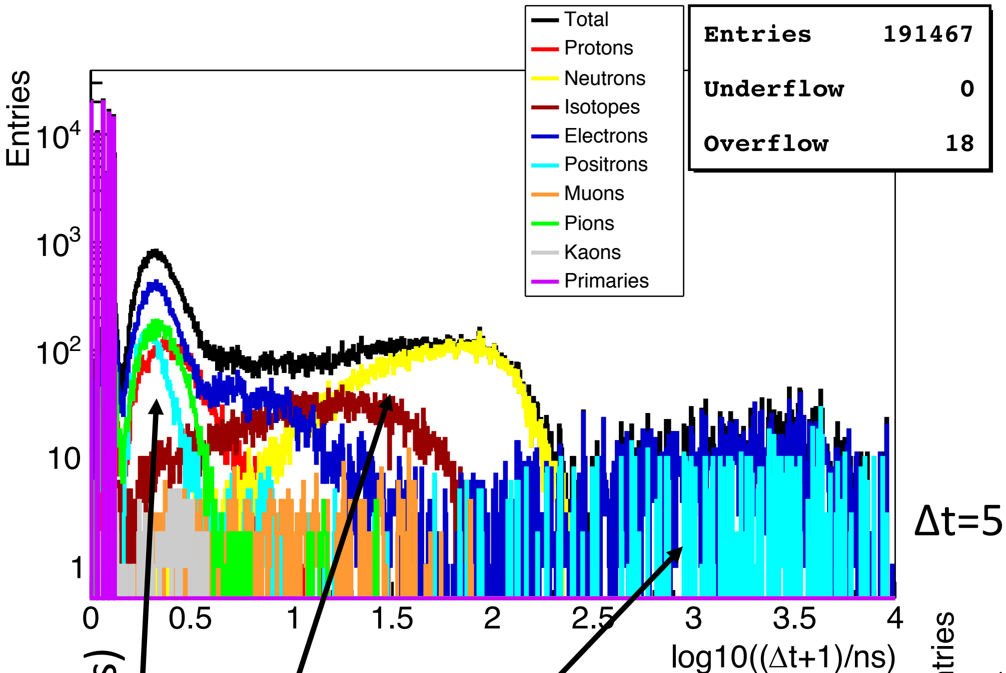
- based on Geant4 (via Generic Geant Simulation, GGS, by N.Mori https://baltig.infn.it/mori/GGSSoftware)
- simple geometry "a la DAMPE"
- only tracker + calorimeter



Informations saved:

- energy lost and deposited
- spatial coordinates
- timing

Back-scattering



100 GeV protons

Hits in the tracker (E_{dep} >10 keV vs Δt between the i^th hit and the 1^st hit (i.e. the CR passing in the first layer of the tracker)

Δt=5**65ps=5*c*2cm*

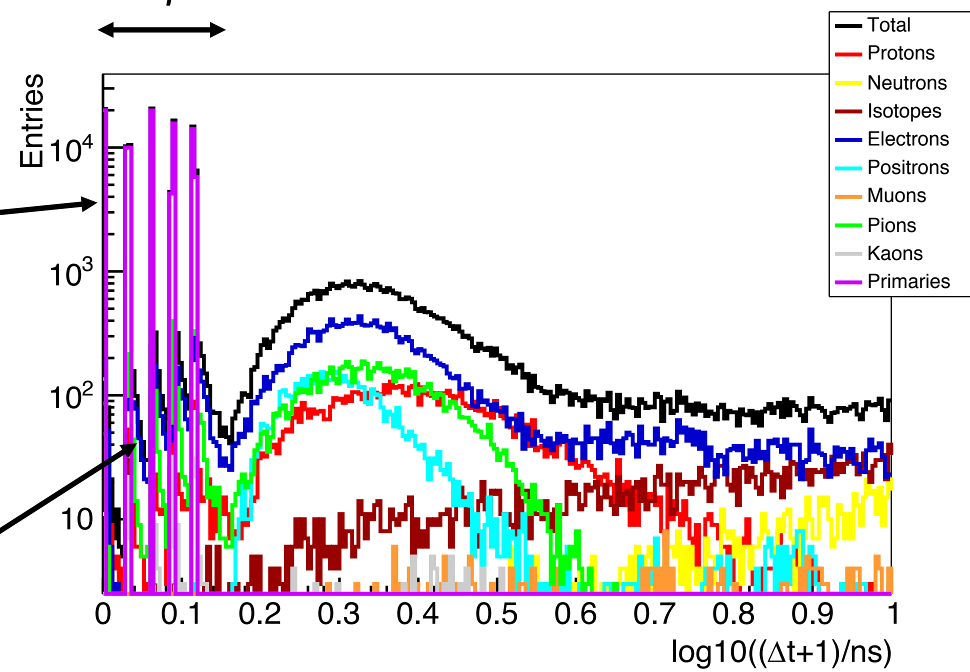
Δt=O(100ps)

Δt=O(10ns)

Δt=O(10μs)

Tracker layers

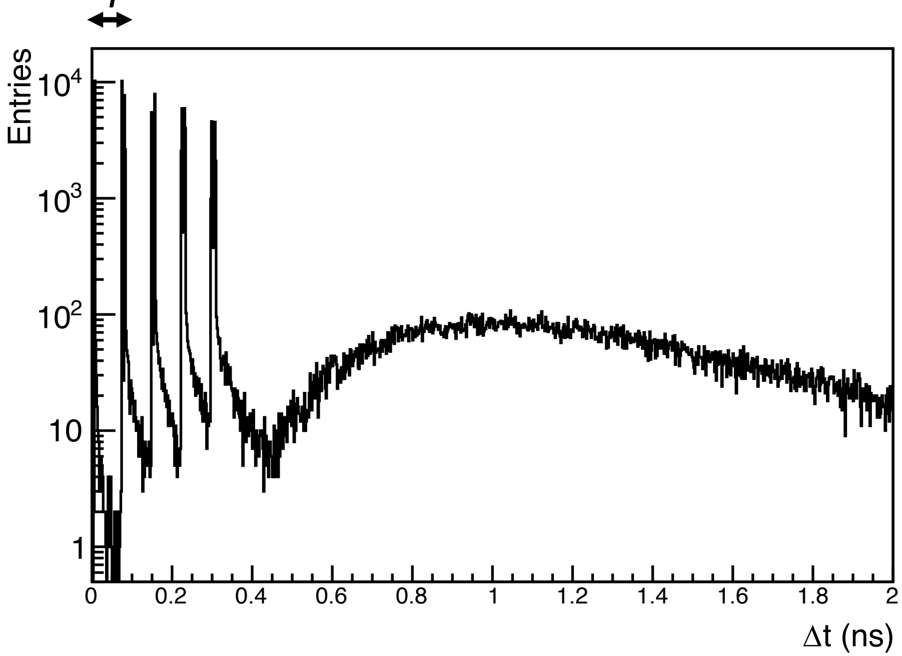
Hits from back-scattering



Particles produced from the interaction of the CR with the silicon detectors

Back-scattering

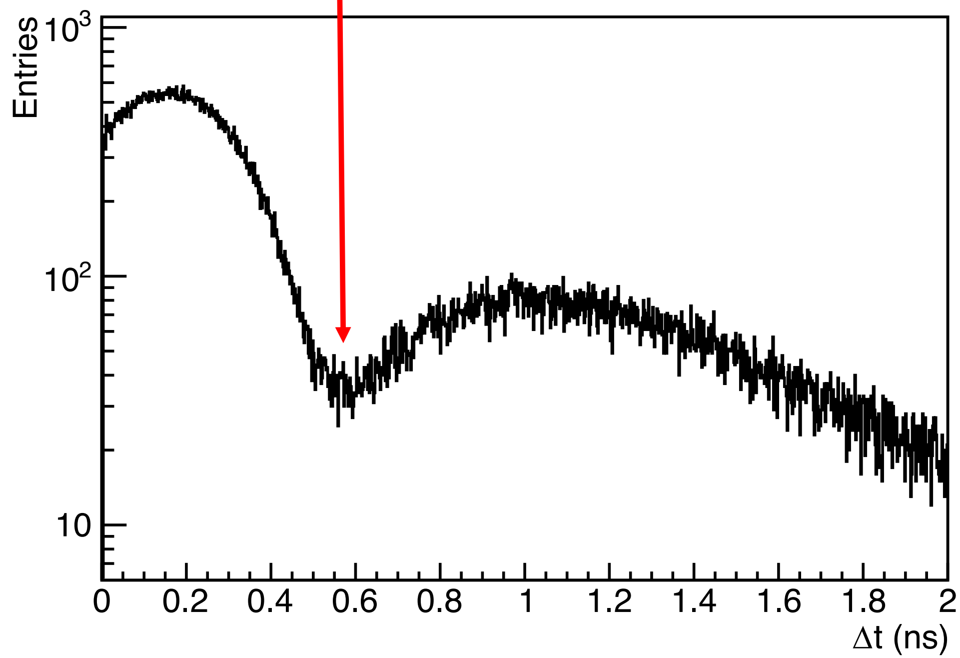
Δt=*65ps=c*2cm*



A simple cut (e.g. *550ps* from the first), removes:

- ~ 40% of the hits
- ~ 90% of the back-scattering hits

Simulating a timing resolution (gaussian with σ=100ps)



What we can do…

- new FE + current microstrip silicon detectors: develop a custom FE or borrow something developed for something similar, e.g.

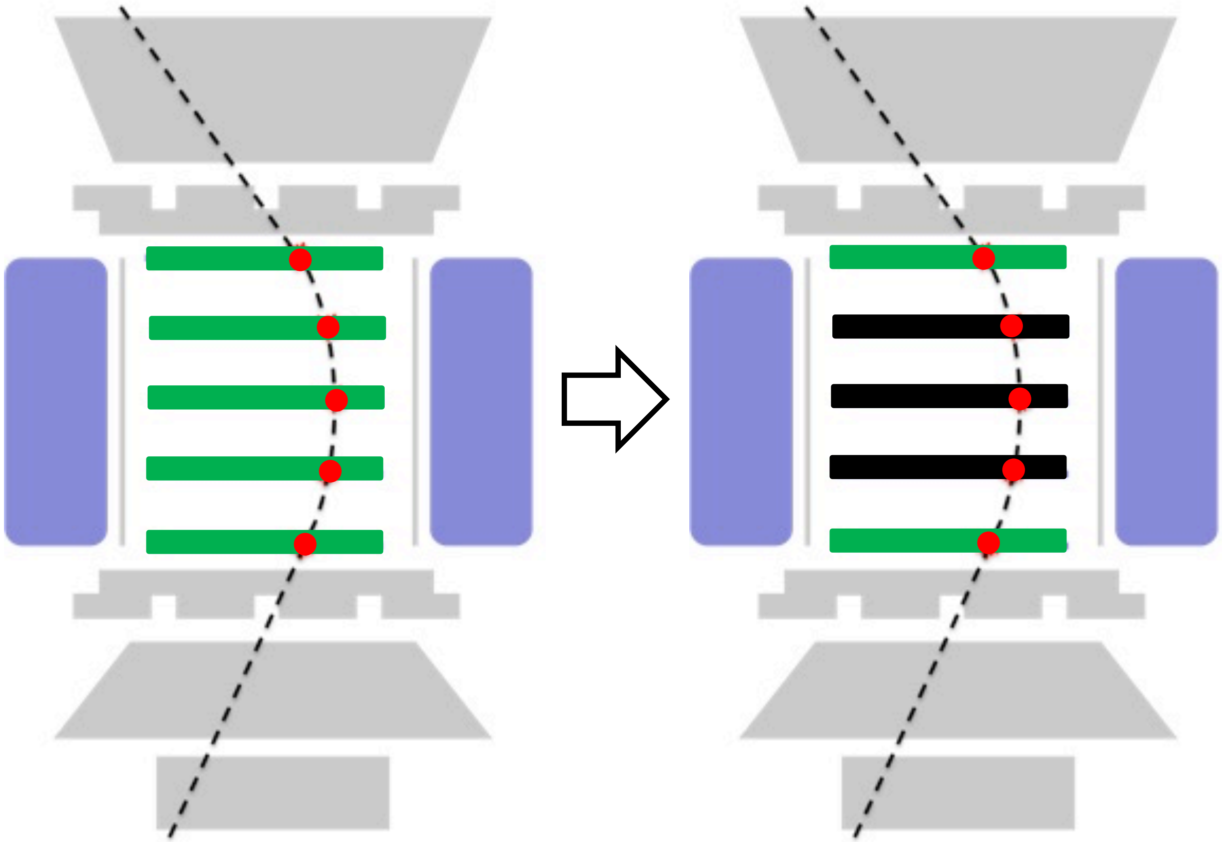
  INFN-TO chip:

  - up to *25ps* resolution → ~ *100ps* with our sensors (to try!)

  - *3mW* per channel (10 times our current FE)

- LGAD + custom FE (assuming INFN-TO chip):
  - *30ps* (?) (far beyond 160ps of AMS ToF)
  - *3mW* per channel (10 times our current FE)

How to stay into the power limitations?



- basic capabilities kept
- isotopic separation / β resolution degraded
- timing redundancy and efficiency reduced

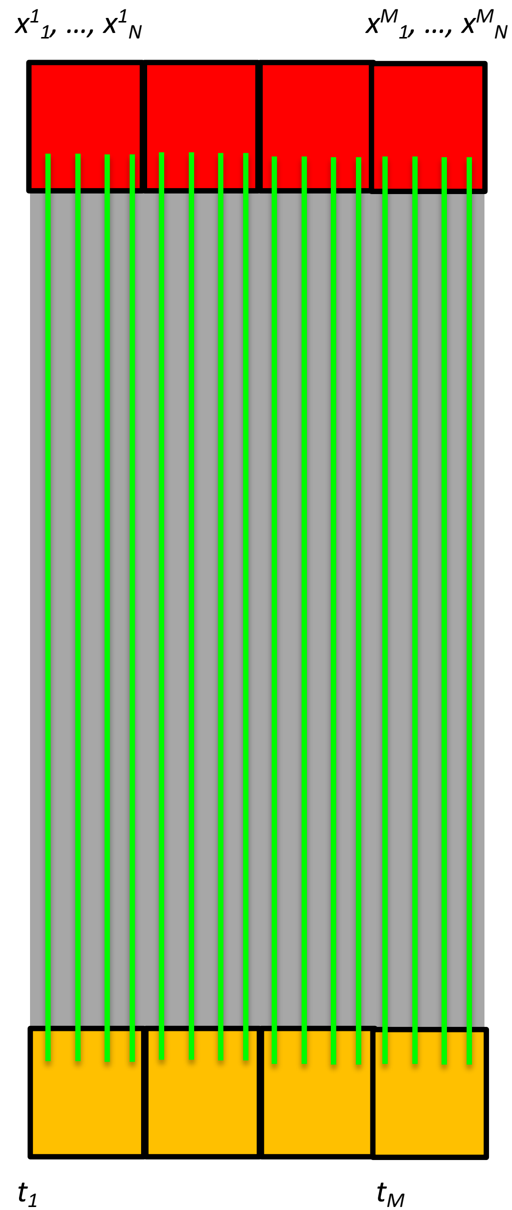
- "timing" layer
- "normal" layer

How to stay into the power limitations?

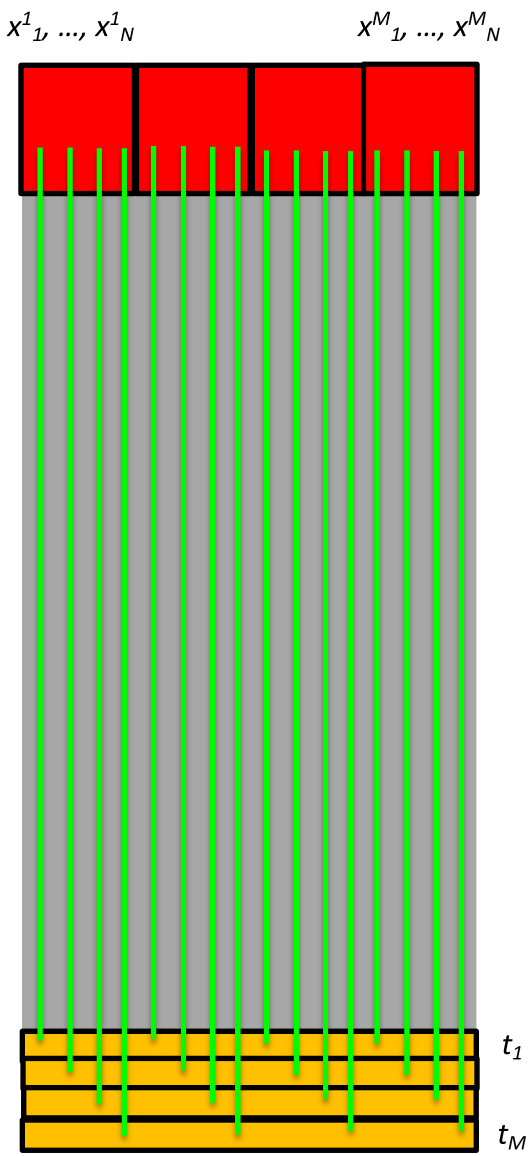
Adopt the "multiplicity" concept also for the timing coordinate:

- "group" different strips into a single time measurement

- optimize the "pattern" for the grouping (using the MC simulation



vs



Conclusions

- The advantages coming from timing layers into the Tracker of an astro-particle detector are clear

- We want to "couple" our sensors to a "modern" FE time-capable and measure the time resolution

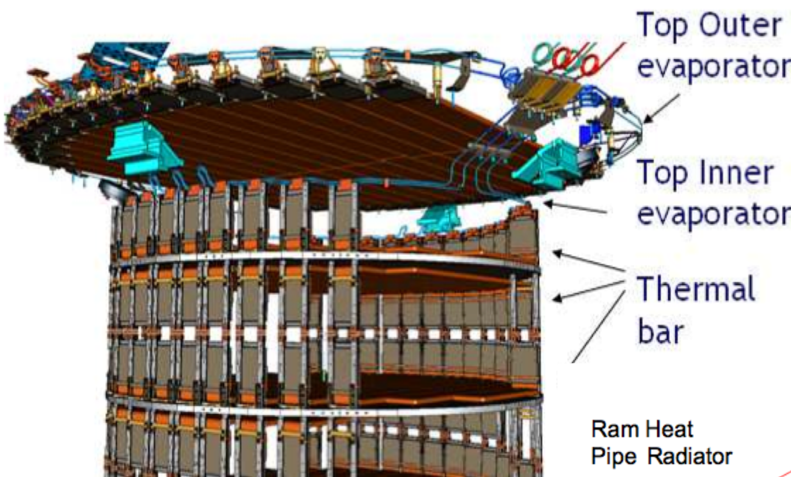
- A Geant4 simulation is being developed to:

  - evaluate the costs/benefits between the "lazy" (~ 100*ps*) and the LGAD (30*ps*) solutions

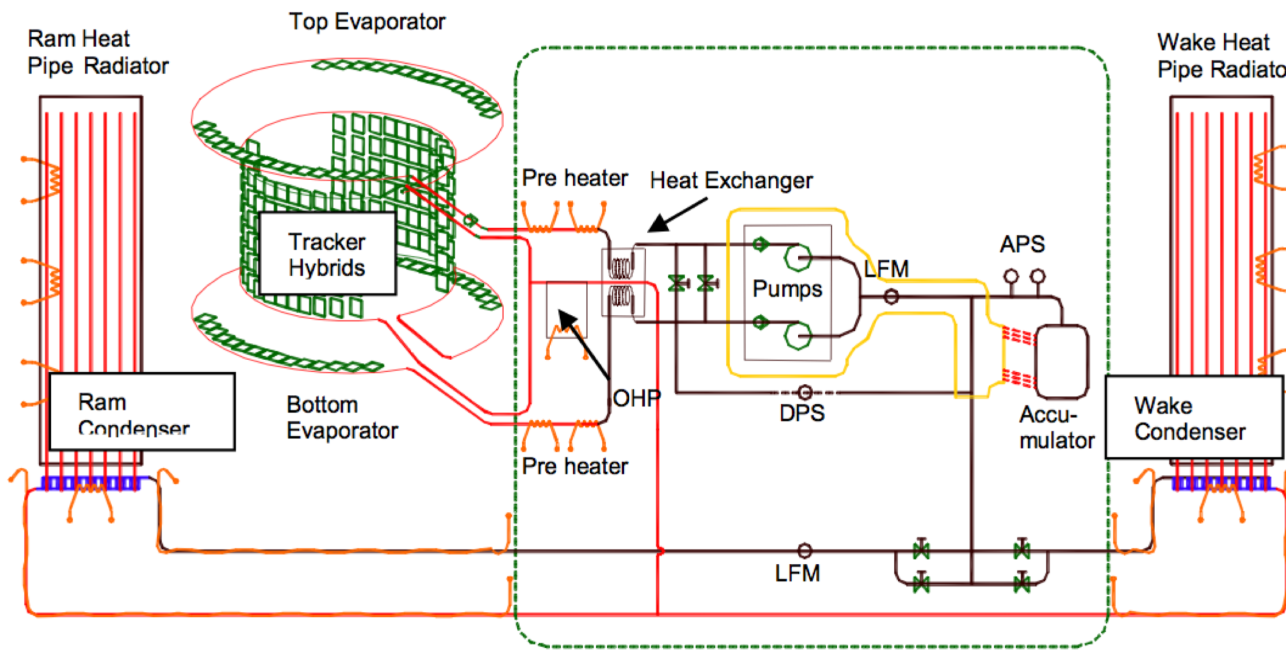
  - optimize the geometry to bring the power consumption inside the typical limitations of a space experiment

Backup

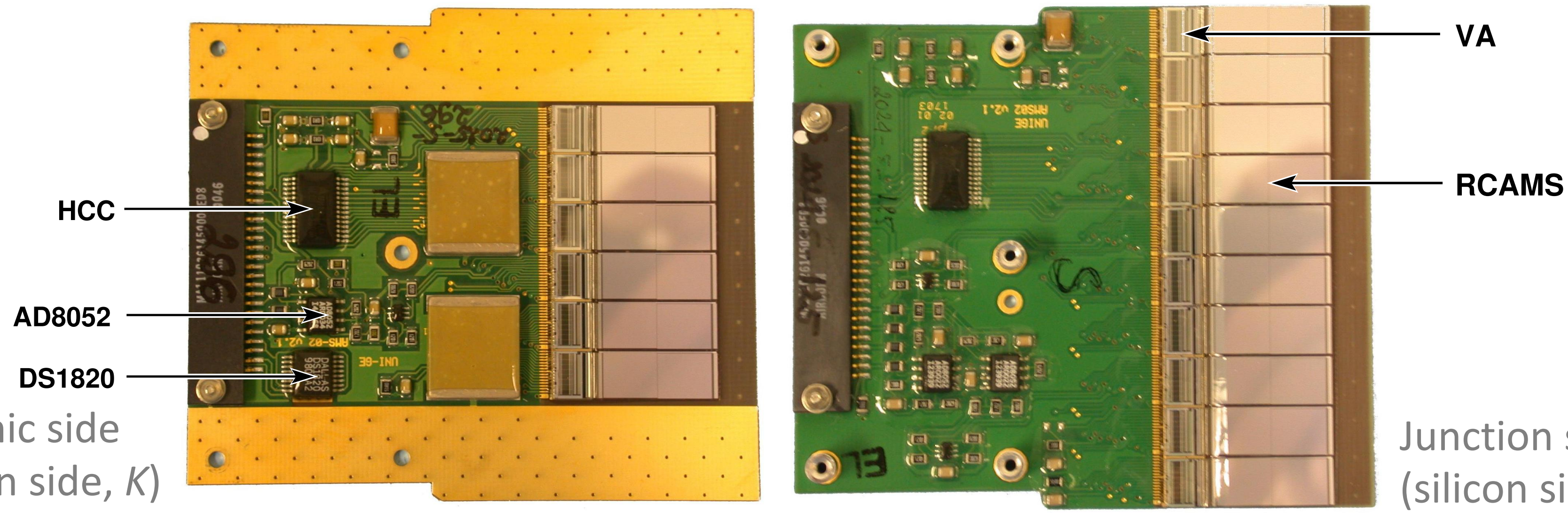
AMS-02: Cooling with 2-phases CO_2 pumped loop



Tracker Thermal Cooling System (TTCS)



AMS-02: Front End (“hybrids”)



Ohmic side (kapton side, *K*)

Junction side (silicon side, *S*)

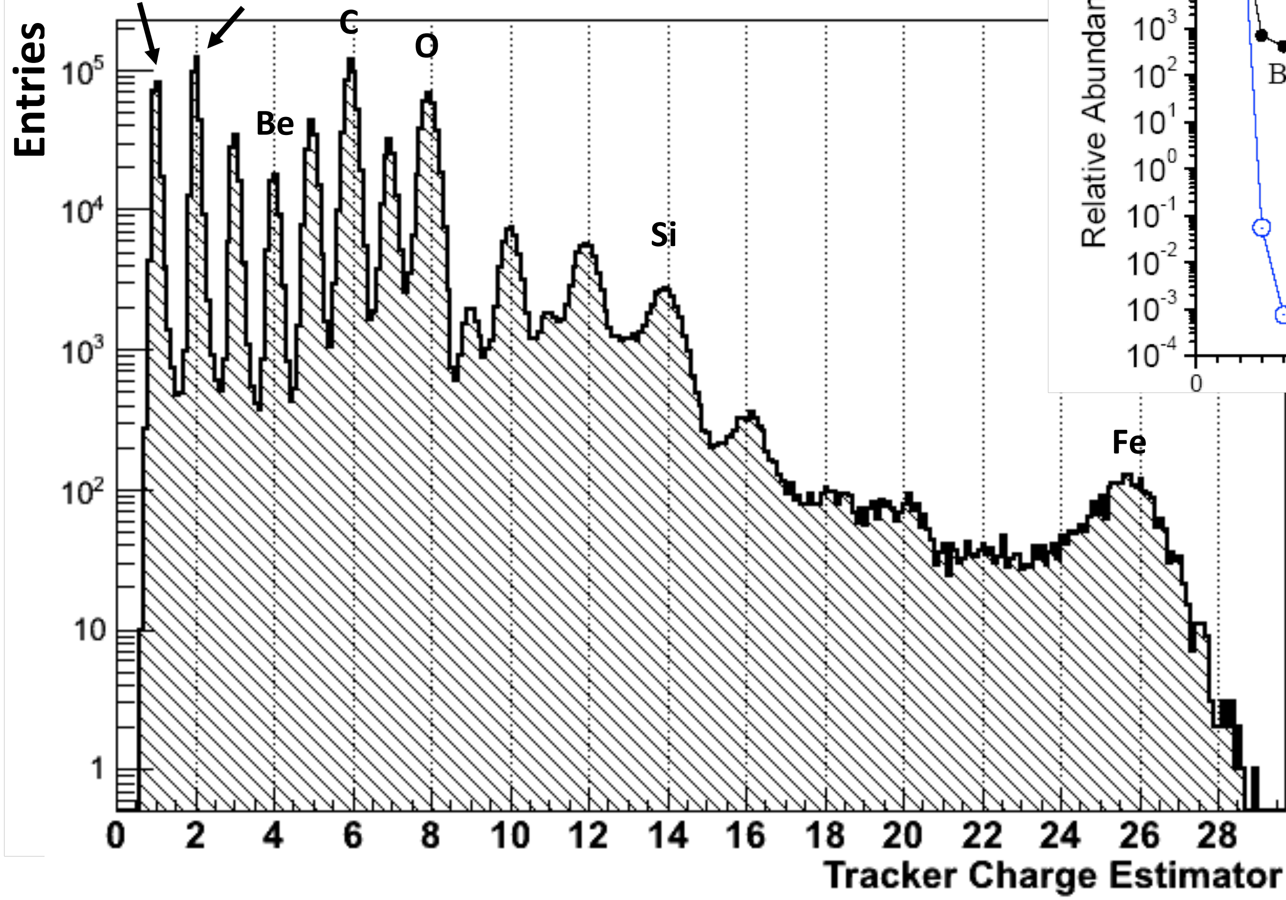
AMS-02 Front End circuit:

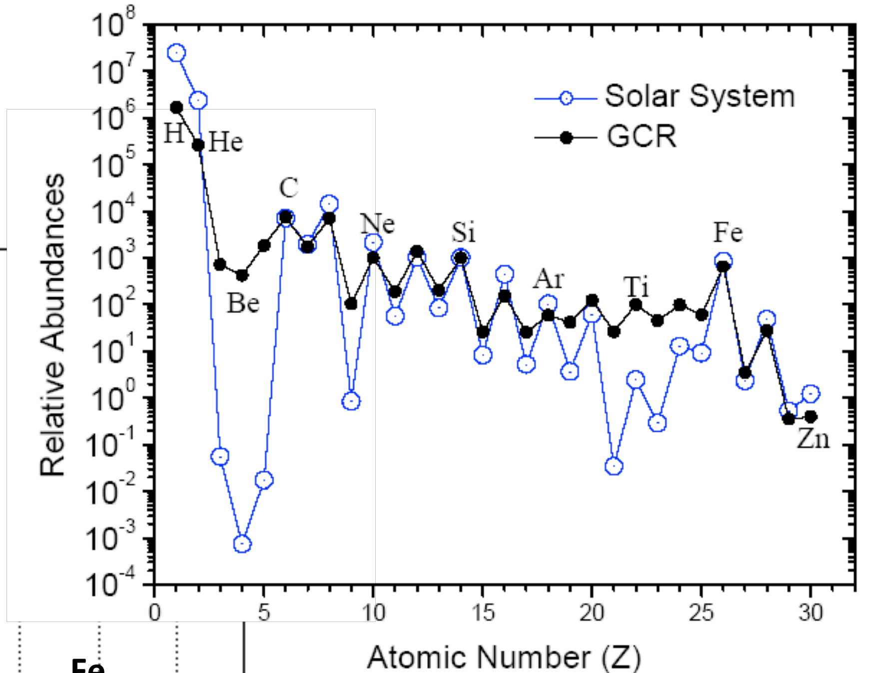
- preamplifier-shaper ASICs, *VA (this is the expensive part of the hybrid). Each VA reads 64 micro-strips*;
- VA digital control sequence circuit, *HCC;*
- doupling capacitor pad, *RCAMS* (can be easily removed if silicon already in DC);
- operational amplifier to send a differential signal to the ADC board (*TDR*), *AD8052*;
- a temperature sensor, *DS1820*;
- two versions: ”grounded” for the junction side and “floating” the ohmic, biased, side. Up to 10 VA’s per side;

AMS-02: Charge collection (few months of data)

Abundances not corrected for detector efficiencies

H and He prescaled

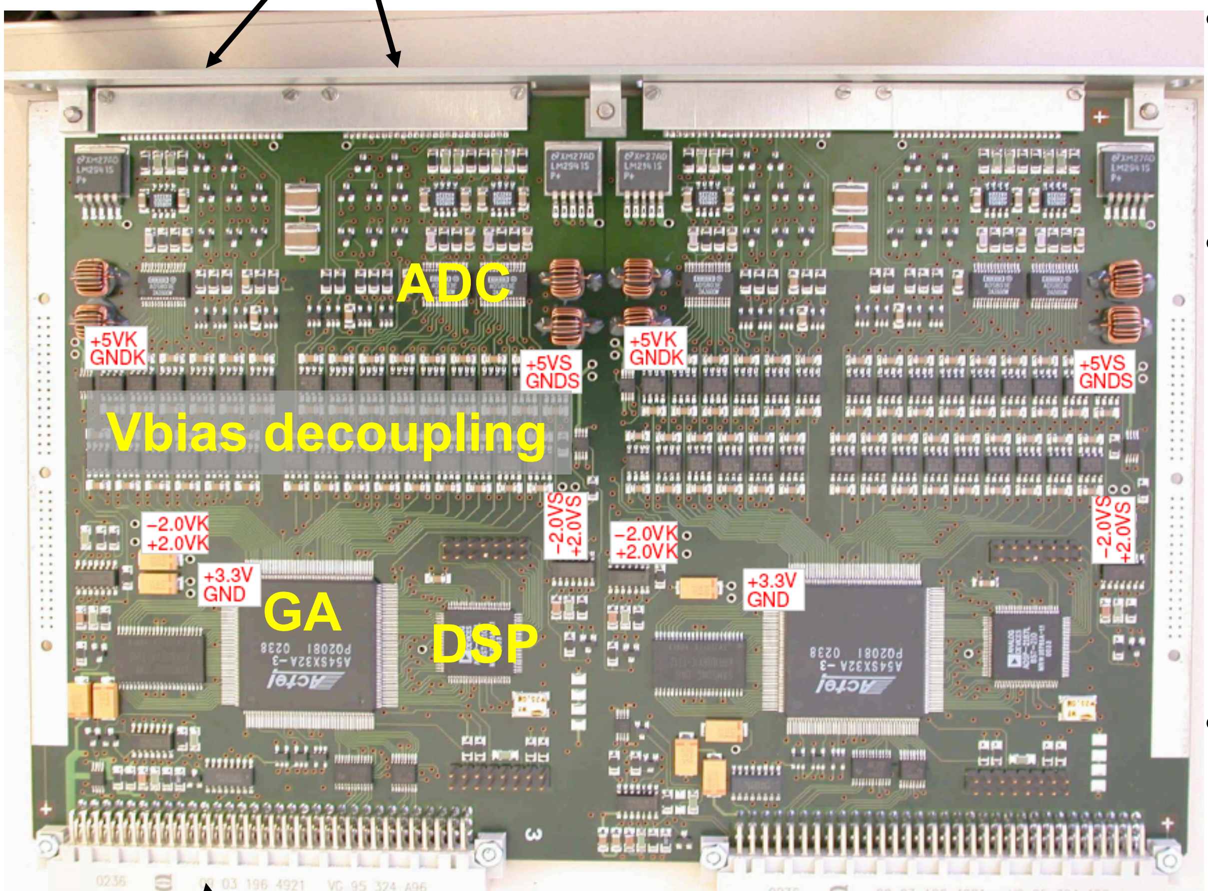




After few months of data on space the galactic cosmic rays (GCR) nuclear abundances are easily observed with an unprecedented statistics

AMS-02: Data Reduction Board (TDR2)

analog signal in from a ladder

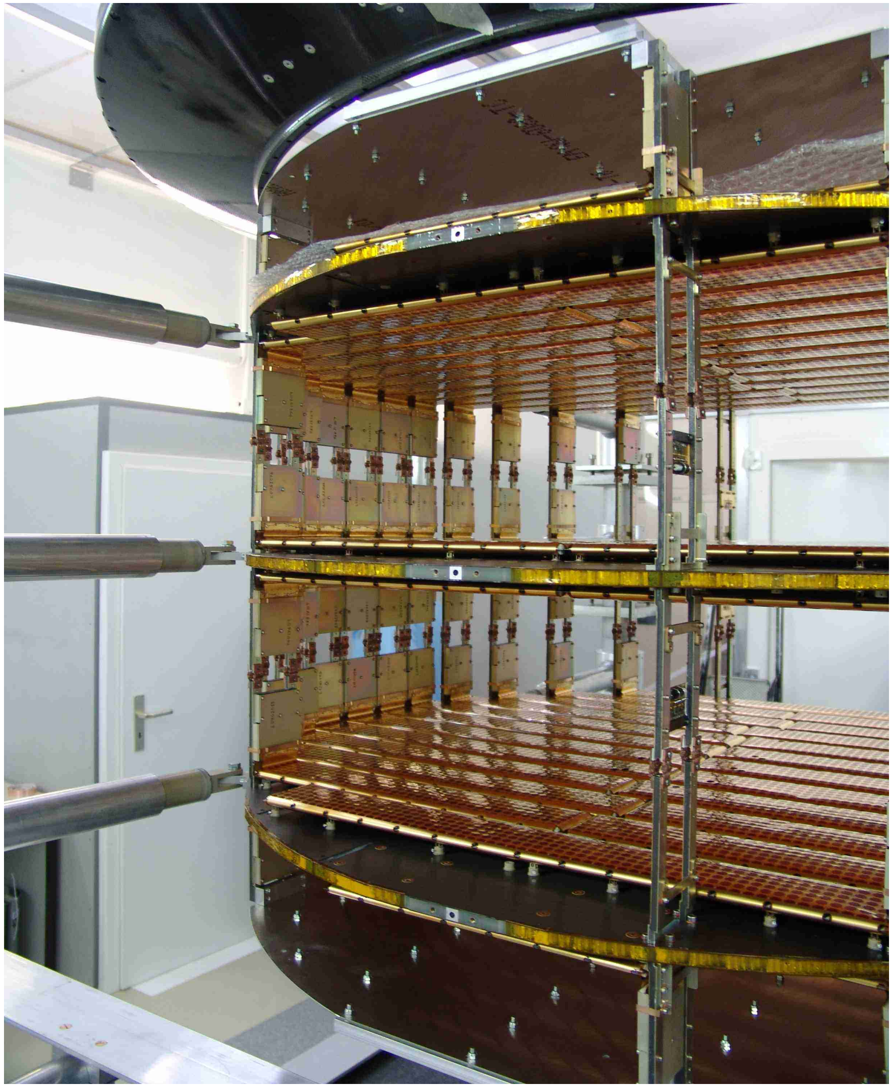


compressed digital out to crate backplane

- Collect analog data and digitize it (90 μs irreducible dead time)
- Perform online data compression
  - Remove Pedestals
  - Calculate and Remove Common Noise
  - Search Clusters
- Up to 5 KHz trigger rate in compressed mode

AMS-02: Silicon Tracker – Back of the envelope

- ~6 m^2
- total of 200k channels for ~ 200 watt
- 100 μm pitch → 10 μm (30 μm) spatial resolution in bending (non bending) plane



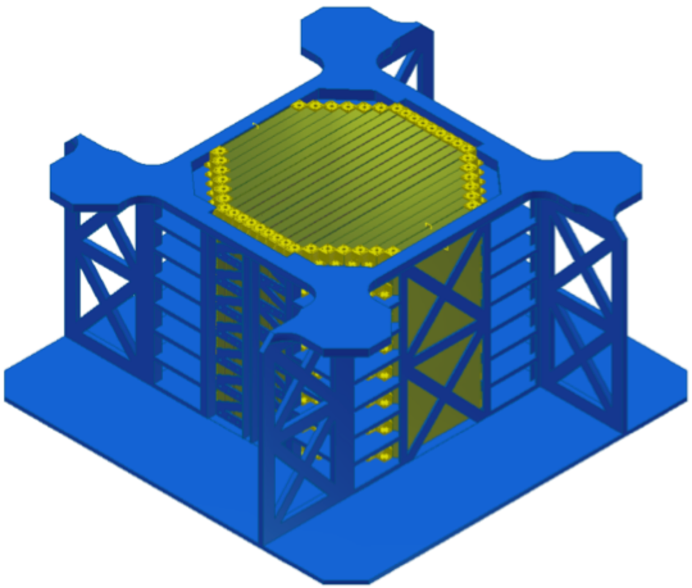
BOTE:

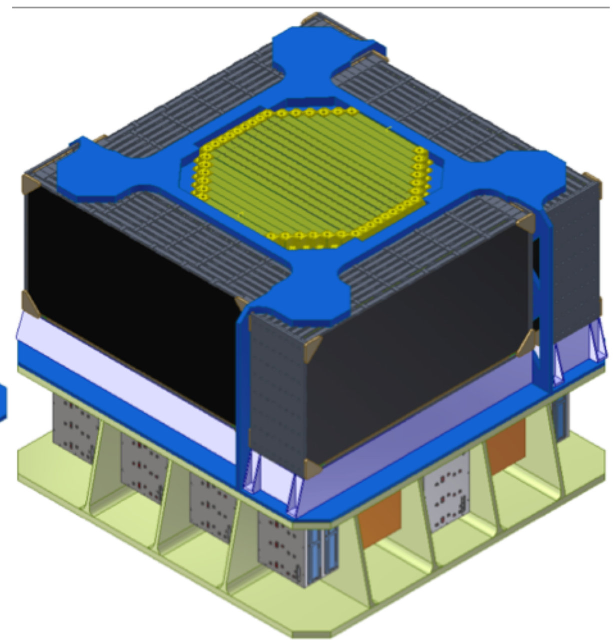
- x-side, *s=sqrt(6)*
- maximum length of ladders: *l=0.5 m*
- #ladders per y-side (or layers) = *s/l*
- pitch: $p = 100\ \mu m = 10^{-4}\ m$
- $\#channels_{strip} = s*(s/l)/p = 120k$

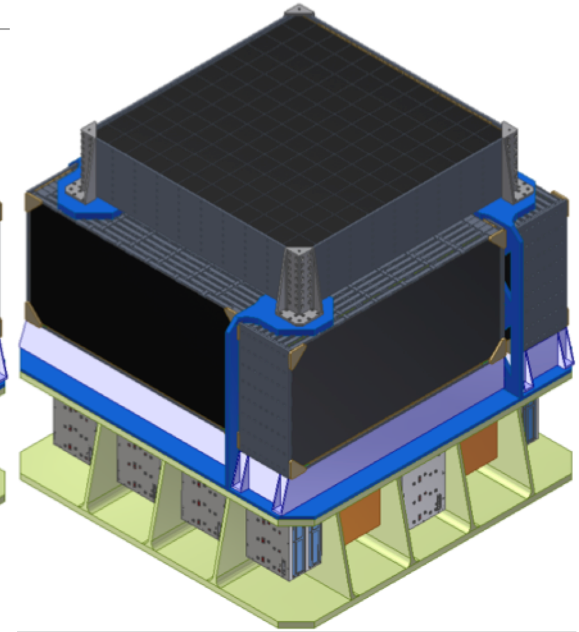
→ $strip = 2*120k \sim 10^5$

→ $pixel = 120k*120k \sim 10^{10}$

HERD: layout

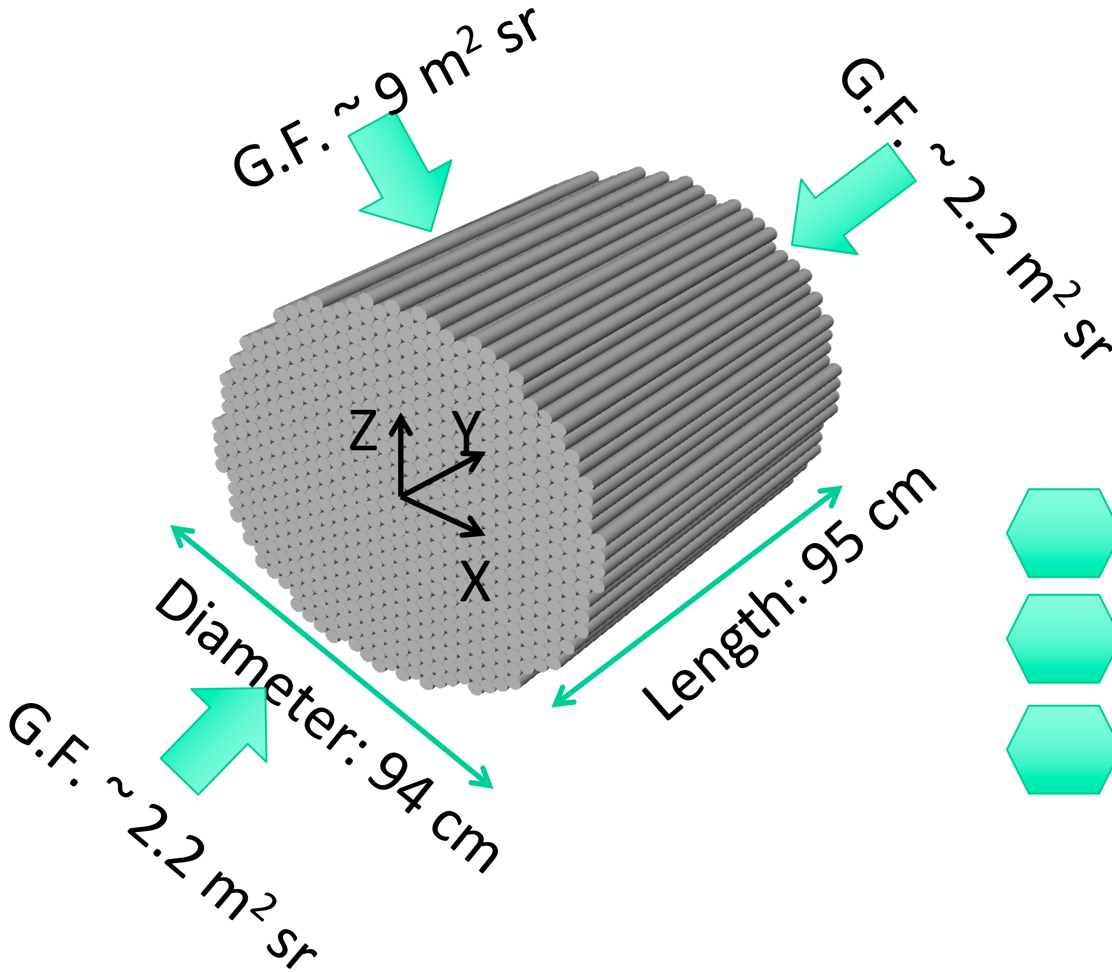


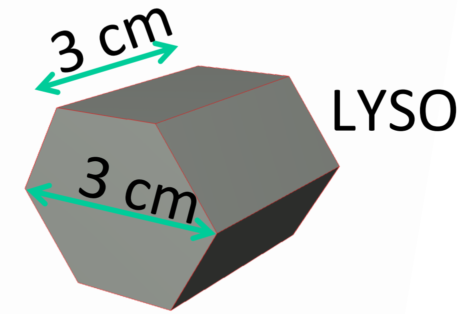




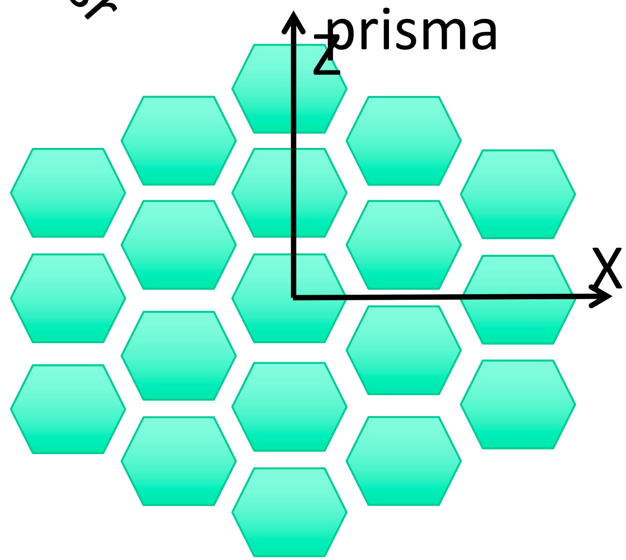
ALADINO: Calorimeter

Weight~(2000+300) kg
N. crystals: ~20.000



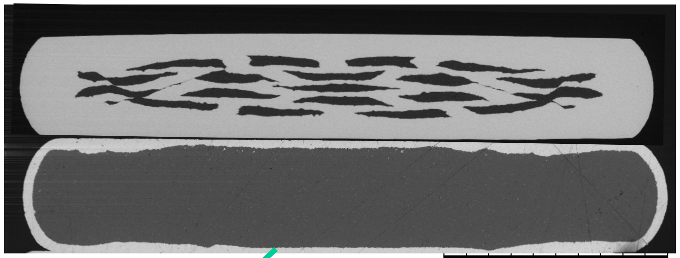


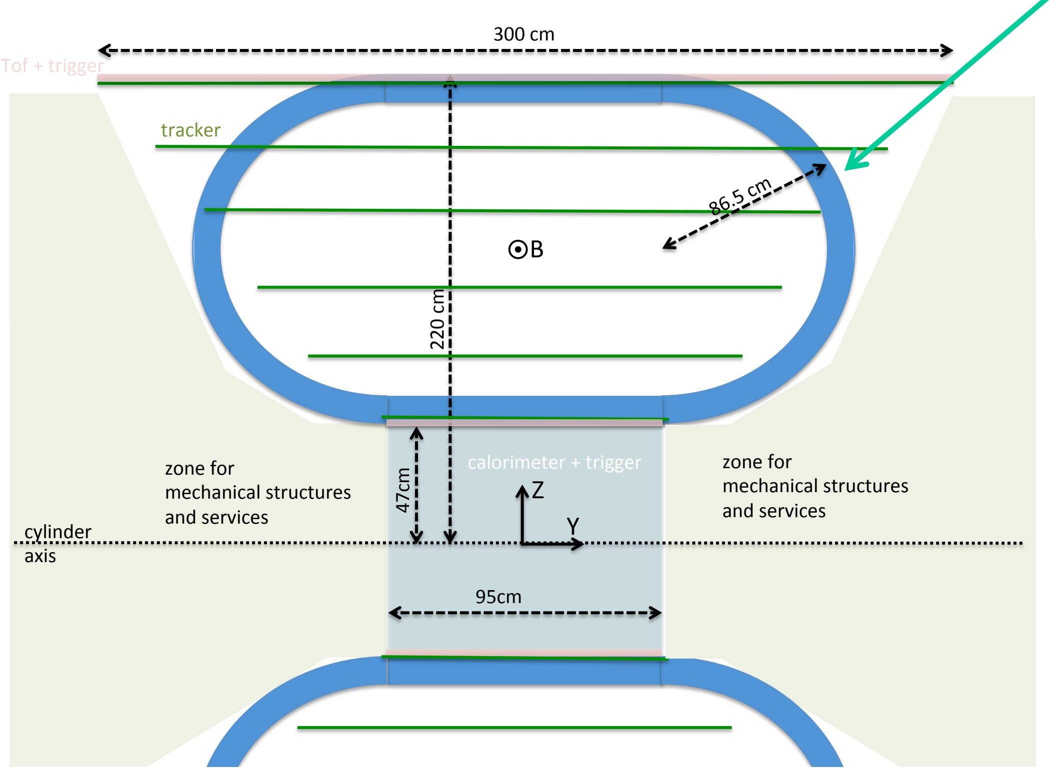
Basic crystal: hexagonal base prisma

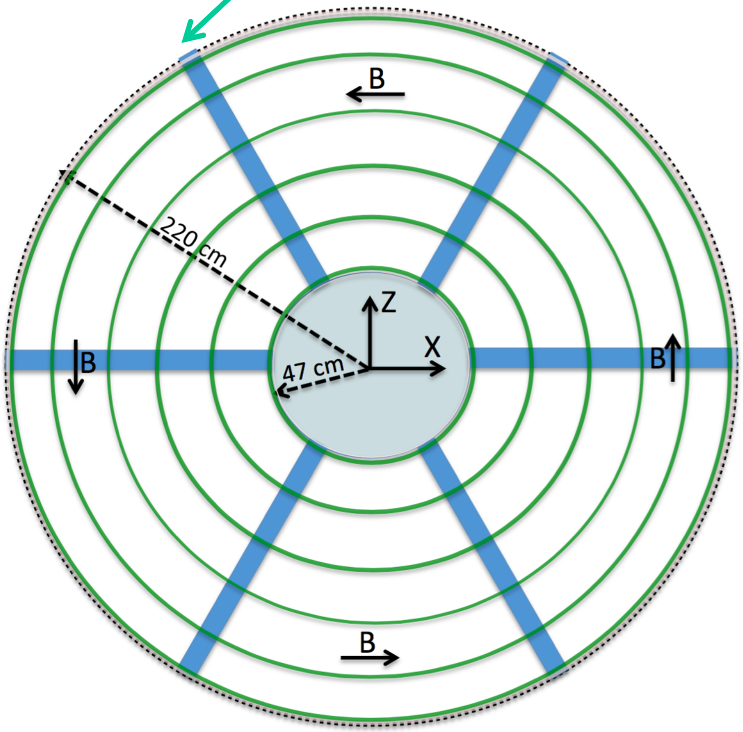


ALADINO: Magnet

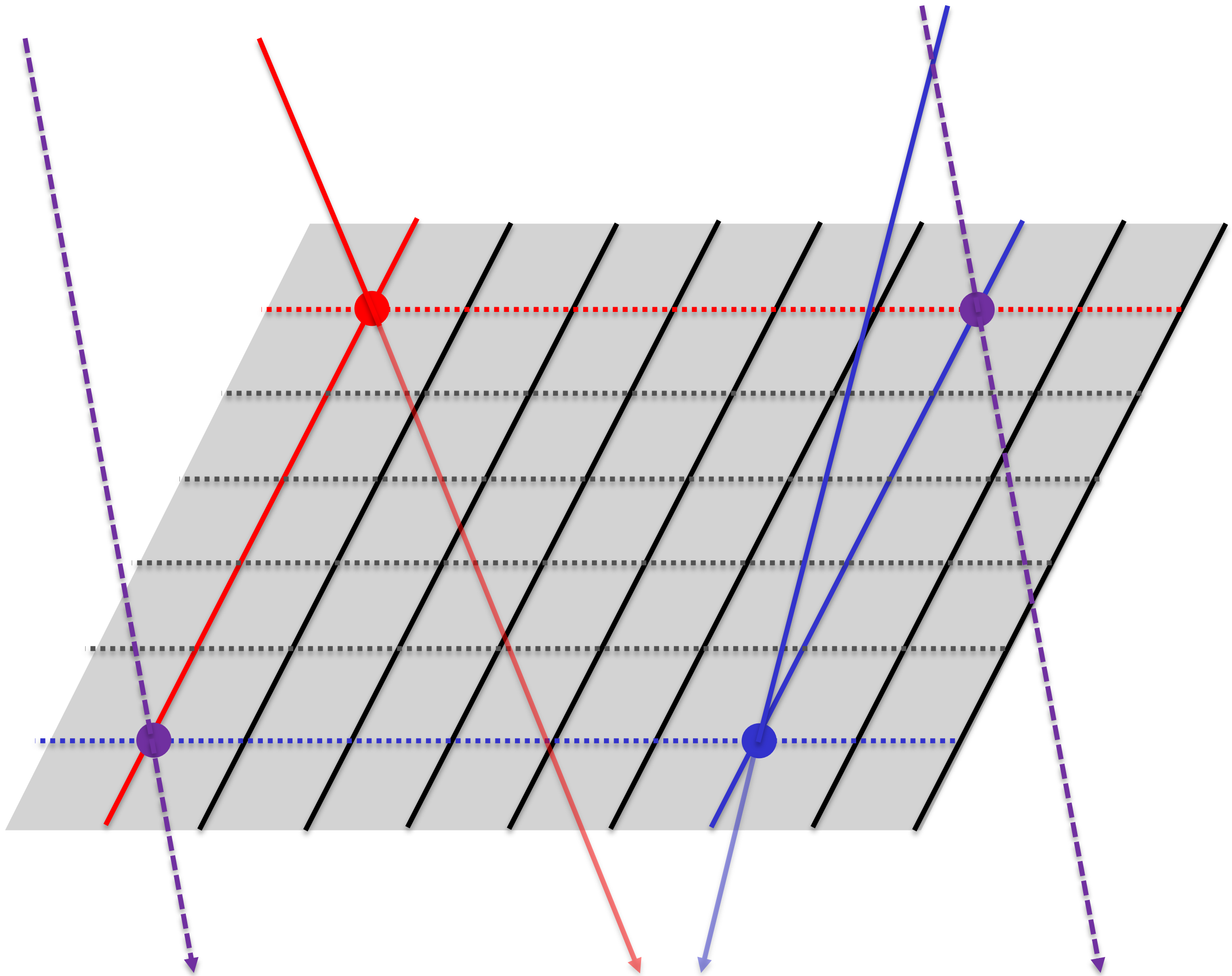
Benefit from the R&D of high temperature superconducting magnets (MgB_2) for space applications (T ≈ 10÷20 °K)



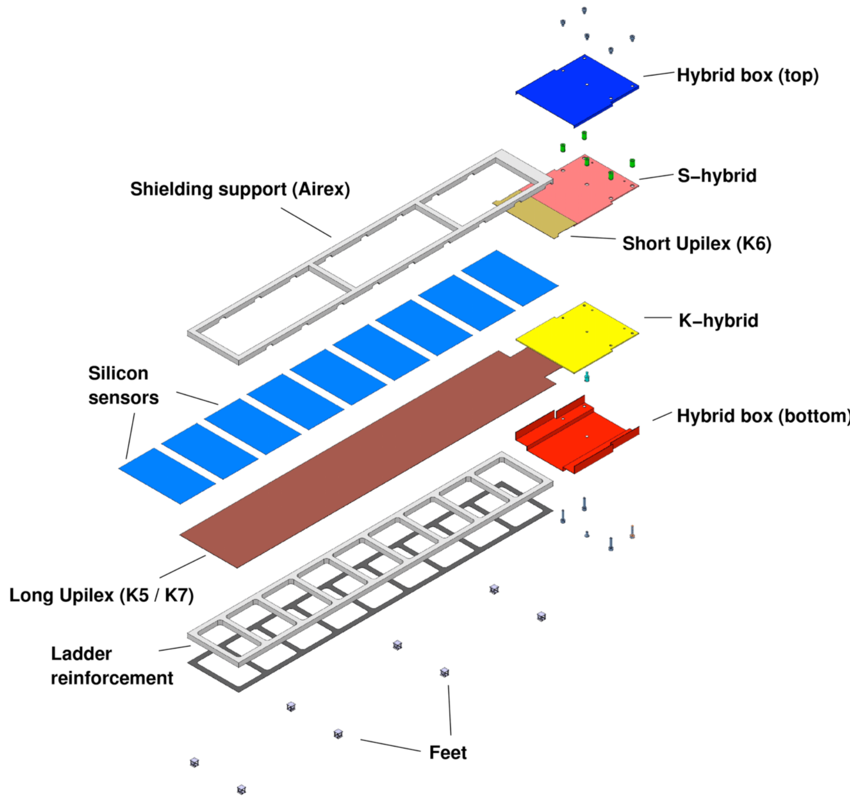




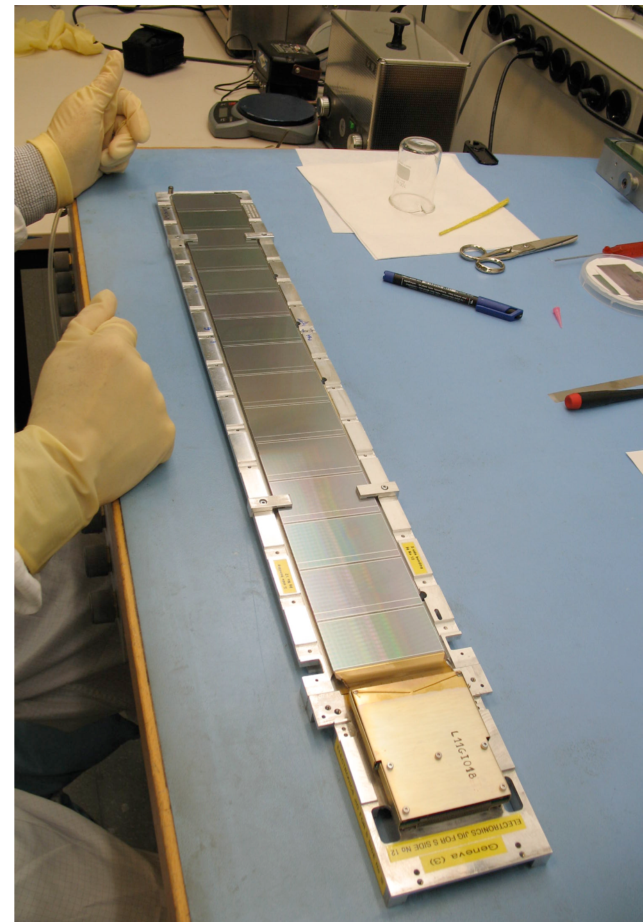
Ghost hits/tracks



AMS-02: Silicon "ladder"



192 flight units
7 – 15 wafers (28 – 60 cm) each



- C_b = 7pF
- C_{strip} = 1.2pF/cm

  → $C_b + C_{strip} \sim C_{strip}$
- $C_{coupling}$ = 700pF

  → $1/C_{strip} + 1/C_{coupling} \sim 1/C_{strip}$