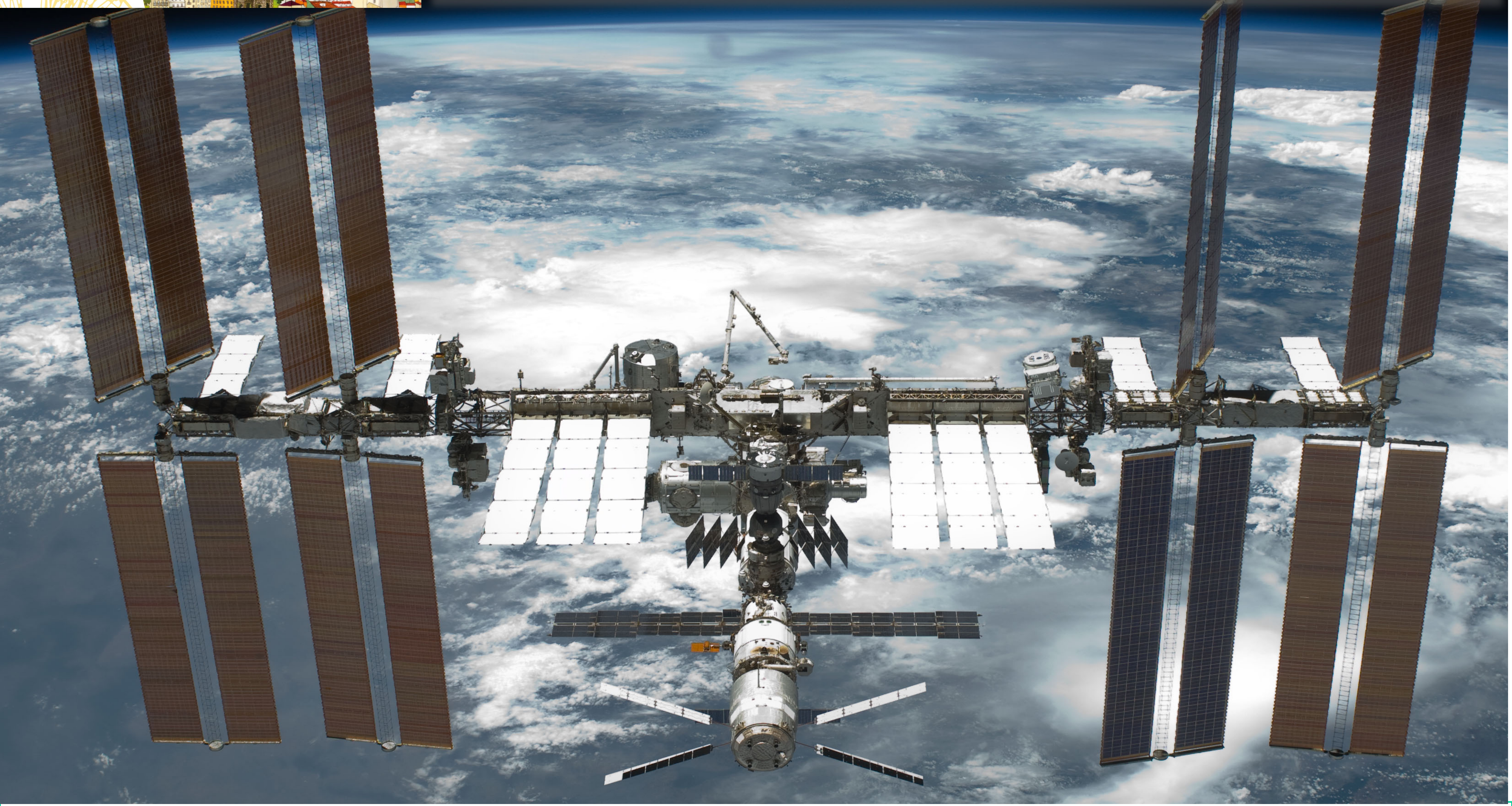
22nd edition
PANIC Lisbon Portugal
Particles and Nuclei International Conference

Opportunities of Si-microstrip LGAD for next-generation space detectors



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Outline

During this talk:

- why "timing" in an astro-particle detector tracker?

- why LGADs and why microstrip?

- what "side effects" can have LGADs?

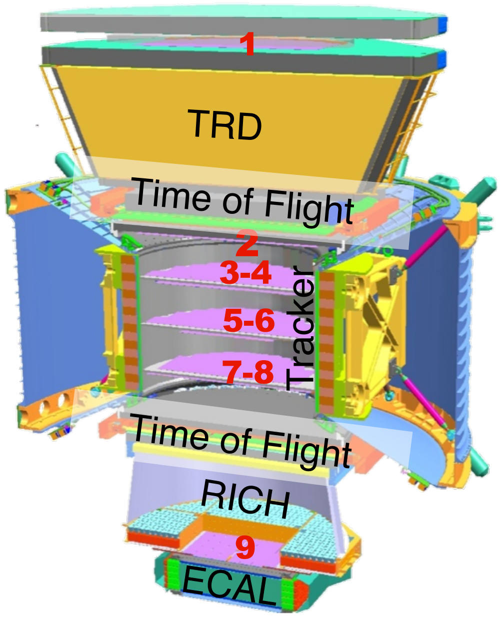
- how to prove the concept in space?

Timing in astro-particle detectors

(see M. Duranti, V. Vagelli *et al., Advantages and requirements in time resolving tracking for Astroparticle experiments in space*, Instruments 2021, 5(2), 20; https://doi.org/10.3390/instruments5020020)

Astro-particle detectors – state of the art

AMS-02 (in orbit since 16/05/2011):



- accurate spatial resolution (<10 μm) Si-μstrip for Rigidity measurement up to TVs;

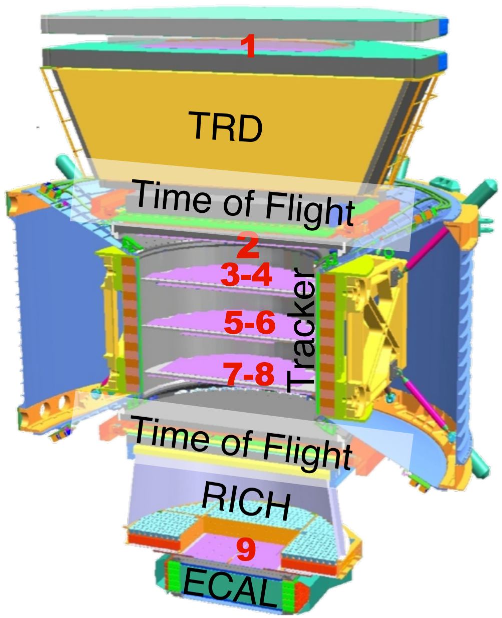
- Electromagnetic CALorimeter (17 X_0) for e^-,e^+,γ Energy measurement;

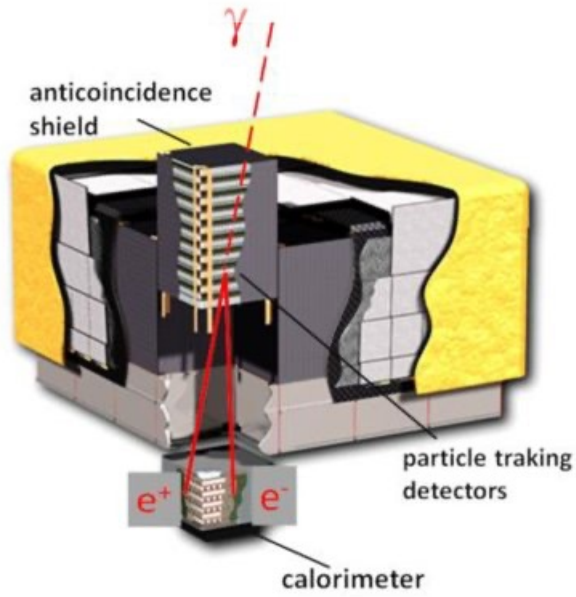
- Time of Flight (~ 120 ps time resolution) for trigger, arrival direction (upward/downward) and isotopic composition (up to few GeV, then Ring Imaging Cherenkov);

- Transition Radiation Detector and ECAL to distinguish hadrons (90% of Cosmic Rays, CR, are protons, 10% He) from electromagnetic particles (e^- are 1% of CR, e^+ 0.1%), e/p identification;

Astro-particle detectors – state of the art

AMS-02 (in orbit since 16/05/2011): Fermi-LAT (in orbit since 11/06/2008):





- moderate spatial resolution (~60 µm) Si-µstrip for pair-production measurement;
- electromagnetic calorimeter (10 X_0) for e^-,e^+,γ Energy measurement;
- plastic scintillator anticoincidence shield for charged CR veto;
- electromagnetic calorimeter to perform e/p identification;
- Tungsten plates in the tracker for photon conversion;

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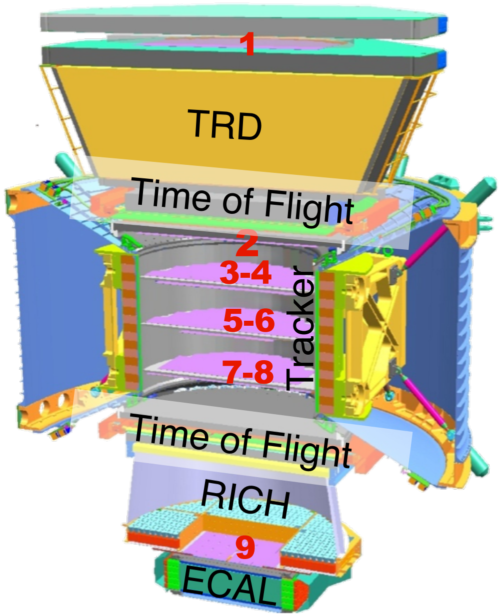
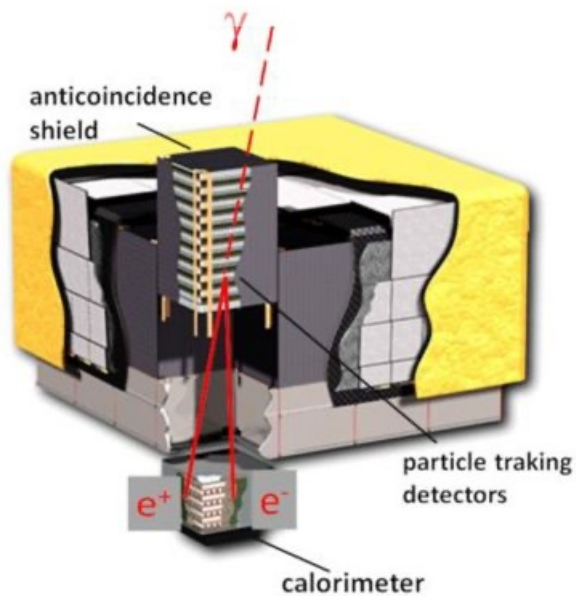
Astro-particle detectors – state of the art

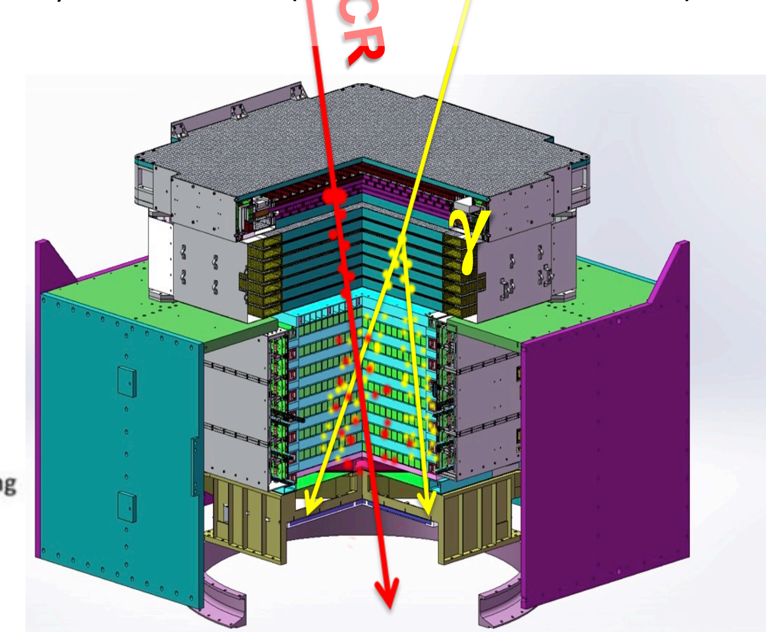
AMS-02 (in orbit since 16/05/2011):



Fermi-LAT (in orbit since 11/06/2008):

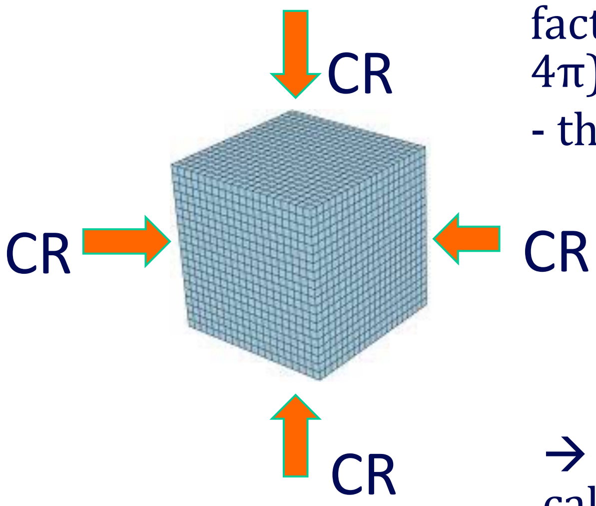


DAMPE (in orbit since 17/12/2015):



- moderate spatial resolution (~40 μm) Si-μstrip for pair-production measurement;
- electromagnetic calorimeter (31 X_0) for e^+, e^-, γ and hadron Energy measurement;
- Plastic Scintillator Detector, PSD, for charged CR veto;
- electromagnetic calorimeter to perform e/p identification;
- Tungsten plates in the tracker for photon conversion;

Astro-particle detectors – planned and dreamed

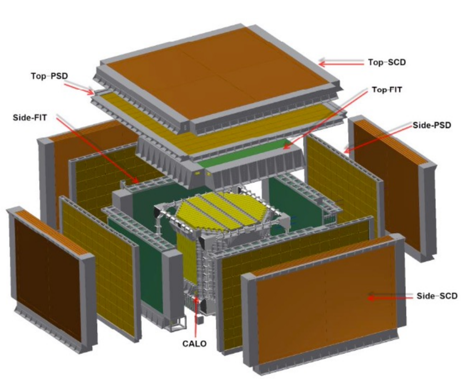


- exploit the CR "isotropy" to maximize the effective geometrical factor, by using all the surface of the detector (aiming to reach $\Omega = 4\pi$)

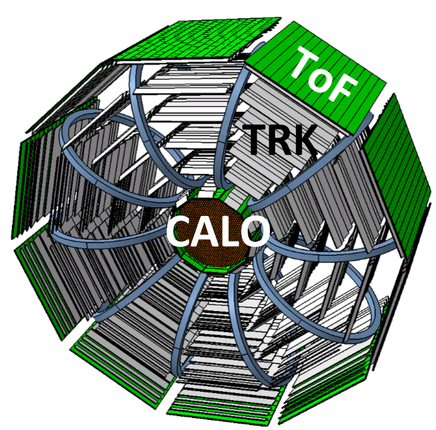
- the calorimeter should be highly isotropic and homogeneous:
  - the needed depth of the calorimeter must be guaranteed for all the sides (i.e. cube, sphere, …)
  - the segmentation of the calorimeter should be isotropic

→ this is in general doable just with an homogeneous calorimeter

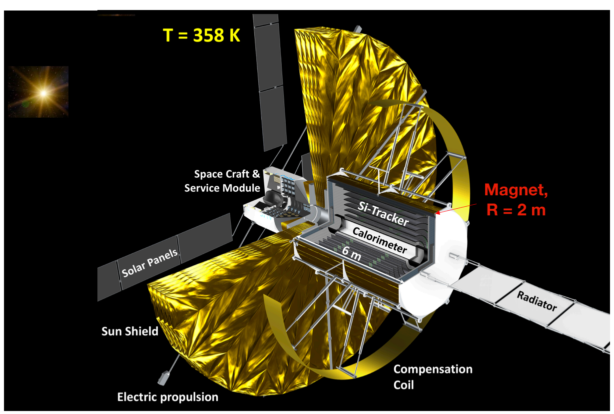
HERD on the CSS (2026):



ALADInO @L2 (2040?):



AMS-100 (2040?):



Timing in an astro-particle tracker

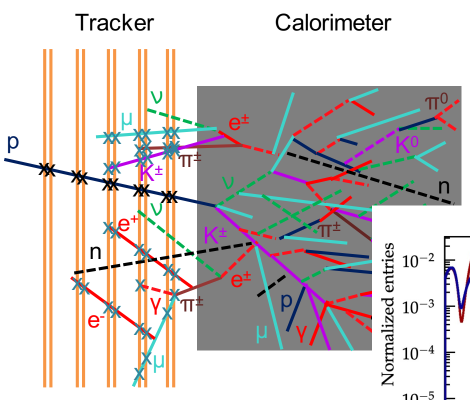
Including the timing into the Tracker of an astro-particle detector allows to:

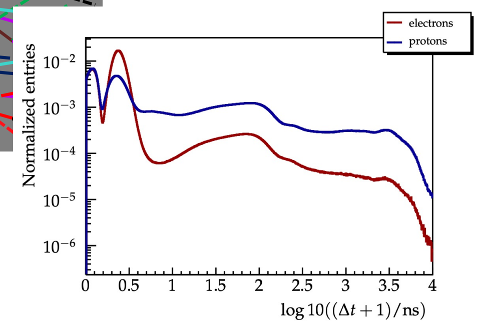
- substitute (or provide full redundancy to) any other **ToF detector** (i.e. planes of scintillators) in measuring $\beta \rightarrow$ arrival direction (downward vs upward), isotopic composition for nuclear species (combined with E or p measurement), …;

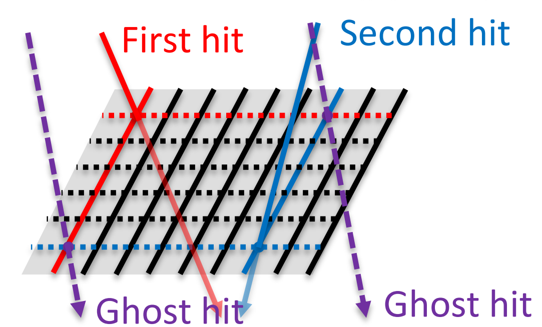
Timing in an astro-particle tracker

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 → arrival direction (downward vs upward), isotopic composition for nuclear species (combined with *E* or *p* measurement), …;
- help to mitigate/solve different limitations in current operating experiments such 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. *β<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…;

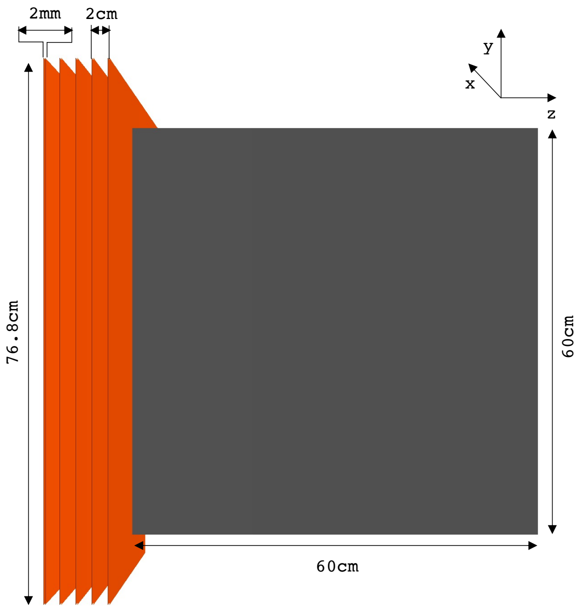




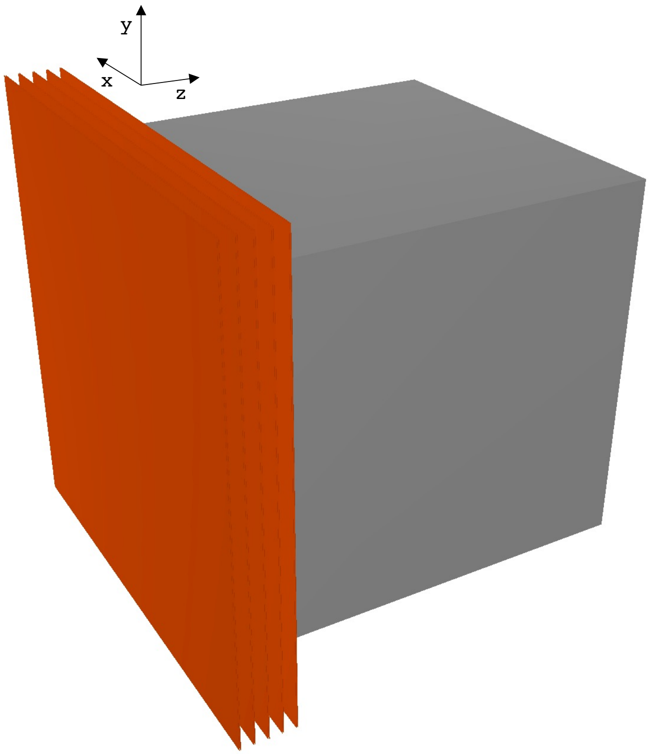


MC simulation

MC Simulation:
- based on Geant4 (via Generic Geant Simulation, GGS, *Mori, N Nuc. Instr. Meth. Section A, Volume 1002, 21 Jun 2021*)
- simple geometry "a la DAMPE": only tracker + calorimeter



Silicon Tracker BGO calorimeter



Informations saved:
- energy lost and deposited
- spatial coordinates
- timing
- ...

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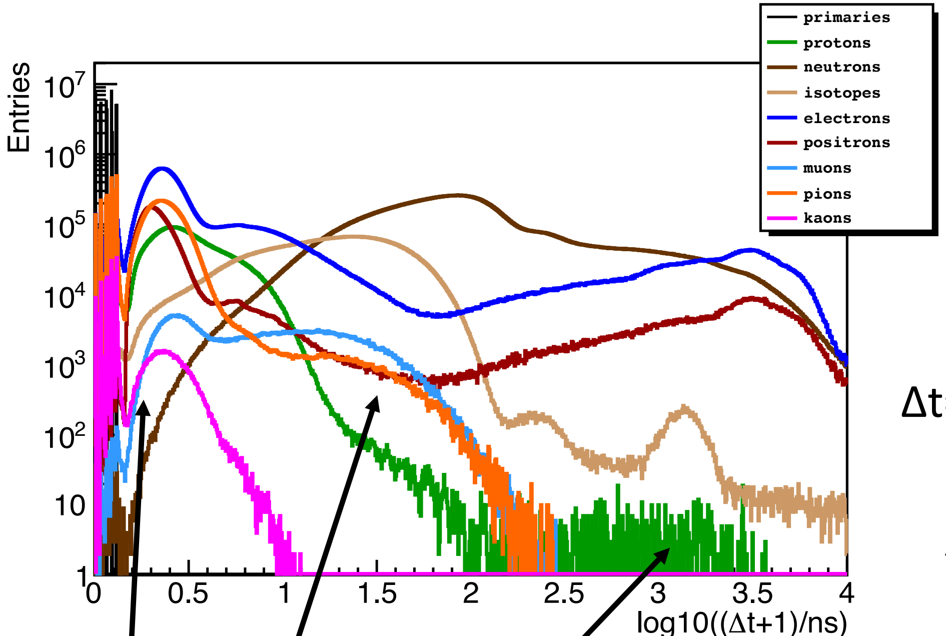
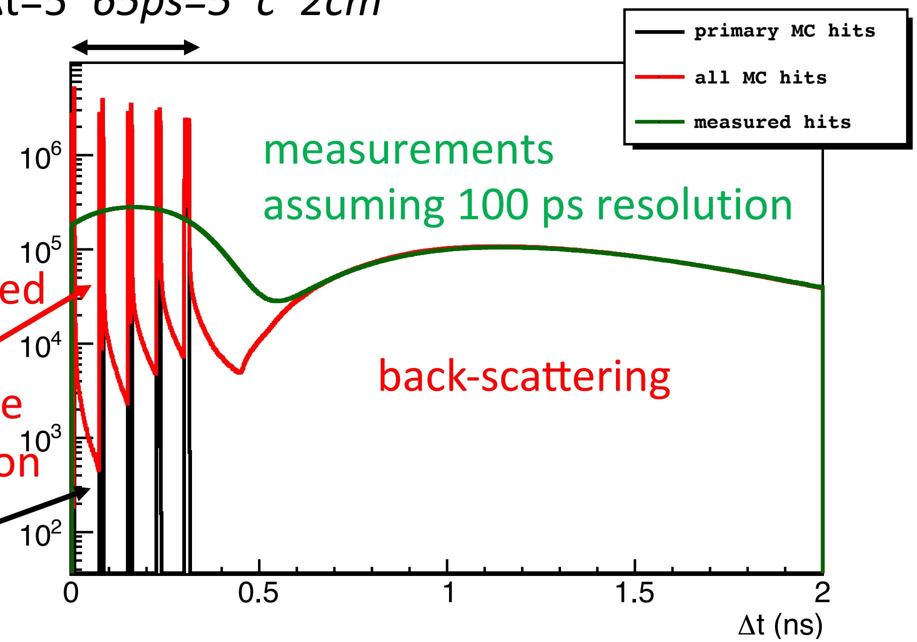
Back-scattering



1 TeV 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)

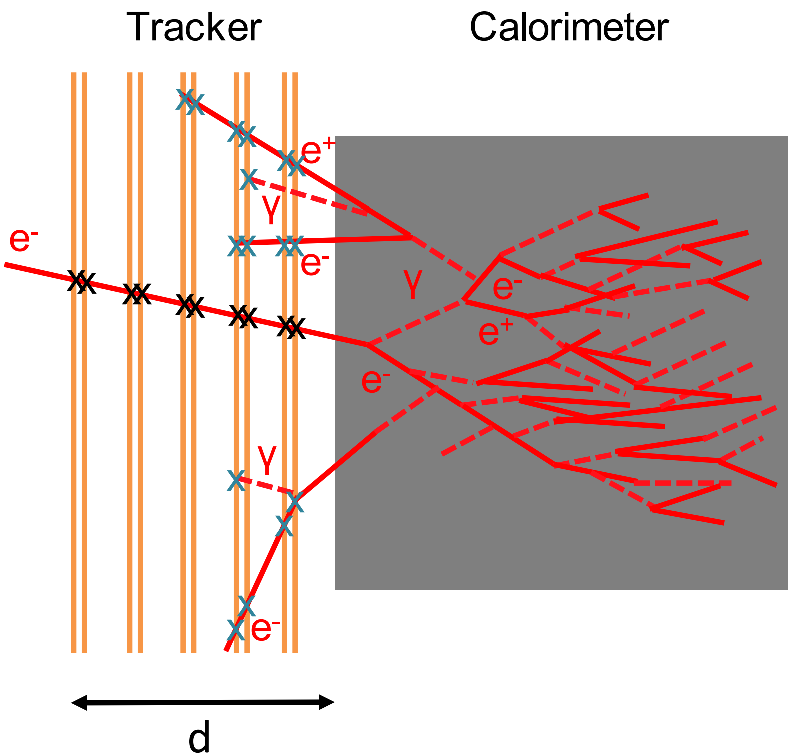
Hits from back-scattering

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

tracker layers

O(100ps) timing resolution enables to separate back-scattering from primary hits in the tracker → improved efficiency in track reconstruction

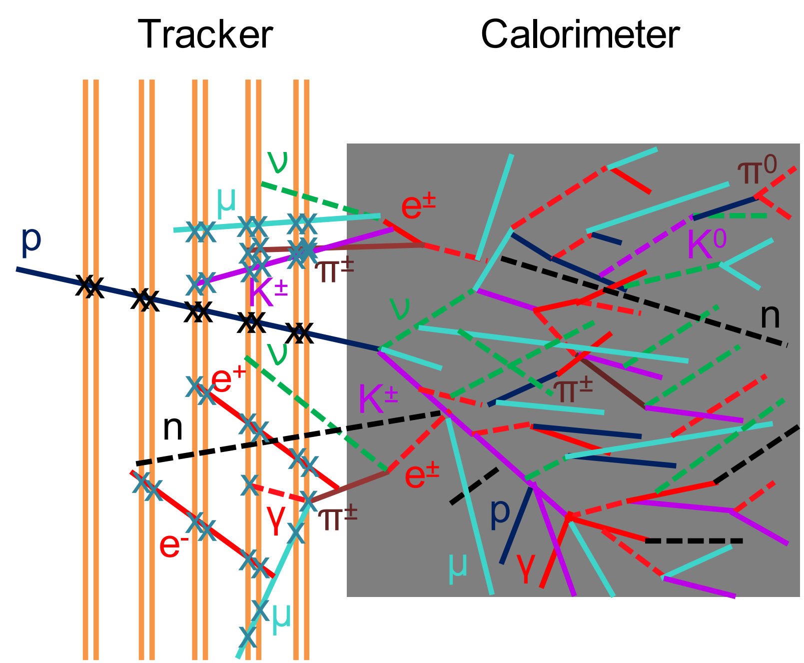
e/p identification



the electromagnetic shower is composed only by "ultra-relativistic" particles
→ the time arrival in the tracker is (at most):

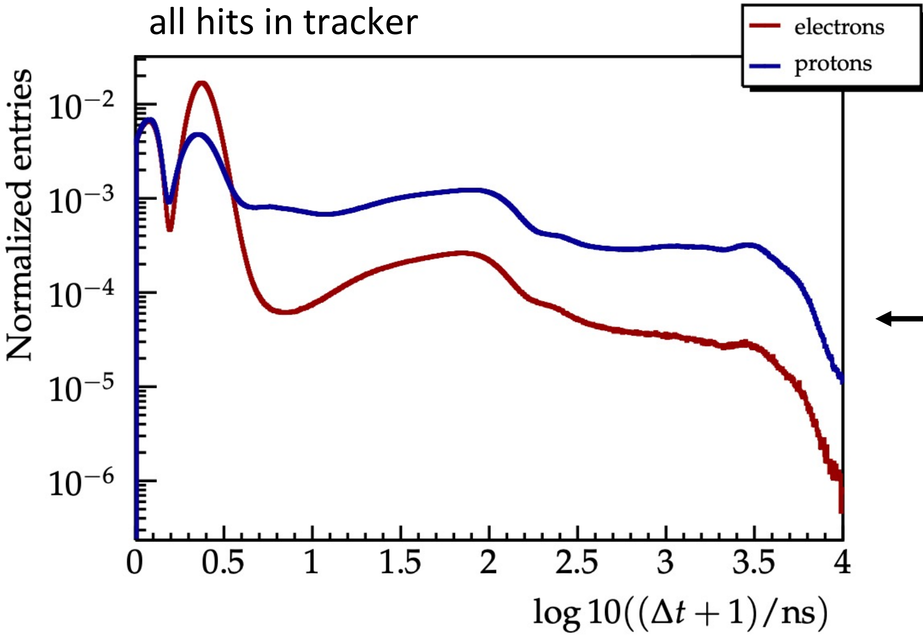
~ 2d / c

the hadronic shower could be composed by "slow" particles
→ the time arrival in the tracker could be delayed



e/p identification

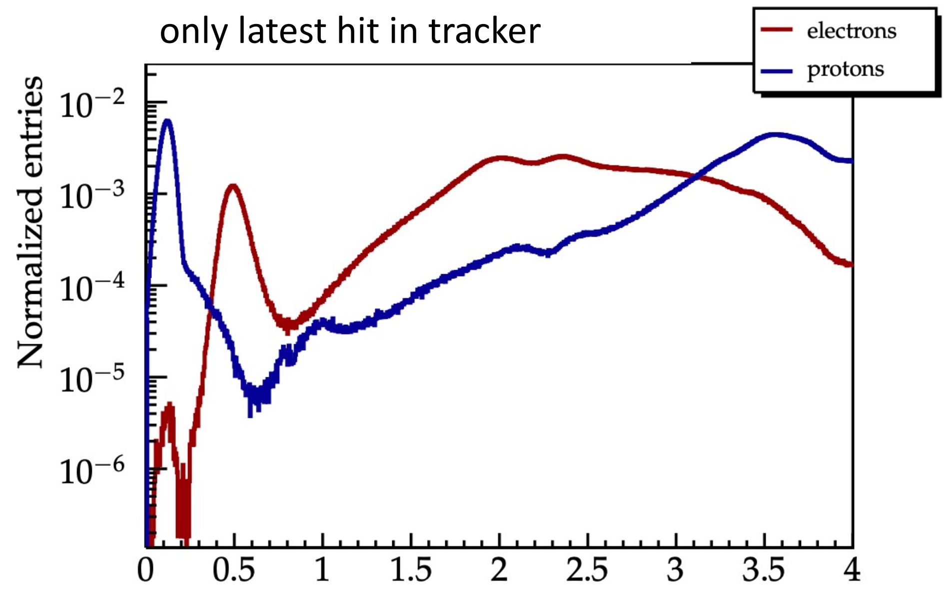
all hits in tracker



5M primaries generated:
- 700 GeV electrons
- 1 TeV protons (depositing ~ 700 GeV in the ECAL)

looking at all the hits in tracker offers an "high statistic" tool to, for example, train a Multi-Variate algorithm

only latest hit in tracker



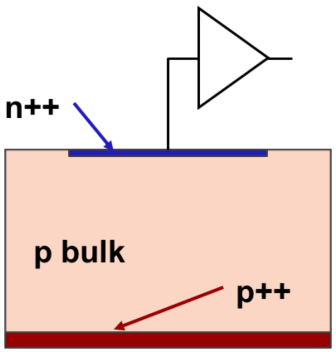
even the naive idea to look only at the "slower" hit in tracker shows two populations crearly distinct

the two populations (electrons and protons) are clearly distinct –> the e/p identification capability seems confirmed and seems also improving with energy

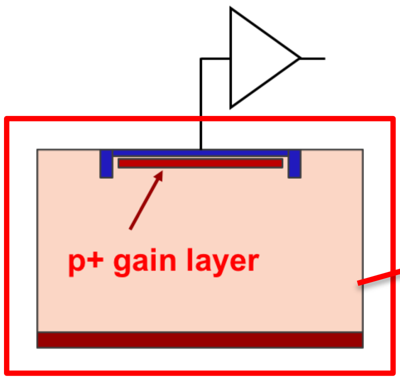
LGAD's and Si-microstrips

LGAD detectors

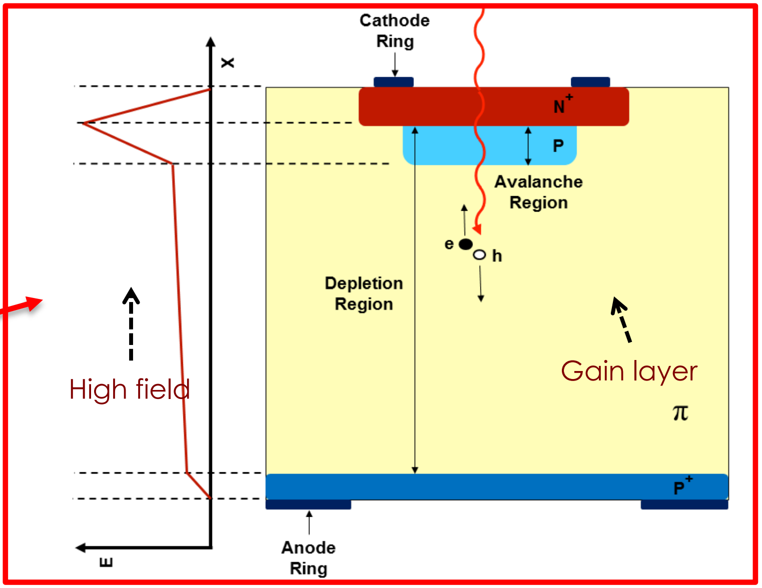
"invented" for underground...

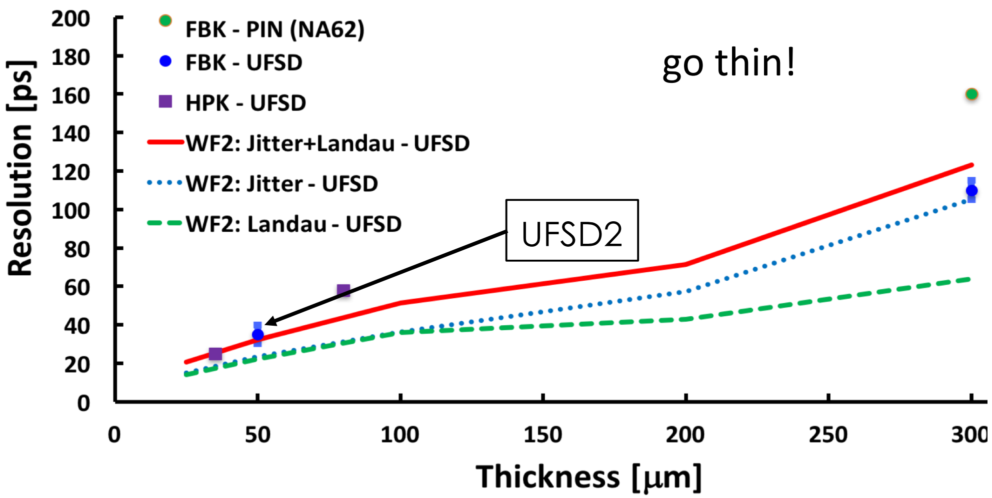


Traditional silicon diode



Low Gain Avalanche Diode





300 µm "traditional"(PIN) silicon detector without gain

... but we want to bring in space!

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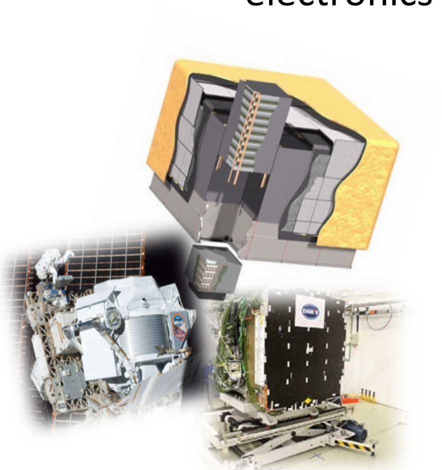
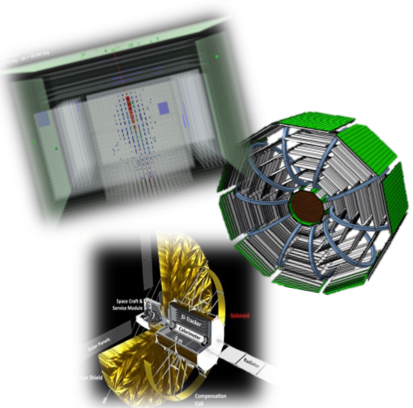
Silicon Microstrip detectors in space

Most of space detectors for charged cosmic ray and γ-ray measurements require **solid state tracking systems based on Si-µstrip sensors.**
Si-µstrip detectors are the only solution to instrument **large area detectors** with larger number of electronics channels coping with the **limitations on power consumption in space**





Operating Missions

	Mission Start	Si-sensor area	Strip-length	Readout channels	Readout pitch	Spatial resolution
Fermi-LAT	2008	$\sim 74\,m^2$	38 cm	$\sim 880 \cdot 10^3$	$228\,\mu m$	$\sim 66\,\mu m$
AMS-02	2011	$\sim 7\,m^2$	29–62 cm	$\sim 200 \cdot 10^3$	$110\,\mu m$	$\sim 7\,\mu m$
DAMPE	2015	$\sim 7\,m^2$	38 cm	$\sim 70 \cdot 10^3$	$242\,\mu m$	$\sim 40\,\mu m$

Future Missions

	Planned operations	Si-sensor area	Strip-length	Readout channels	Readout pitch	Spatial resolution
HERD	2030	$\sim 35\,m^2$	48–67 cm	$\sim 350 \cdot 10^3$	$\sim 242\,\mu m$	$\sim 40\,\mu m$
ALADInO	2050	$\sim$ 80-100 m^2	19–67 cm	$\sim 2.5 \cdot 10^6$	$\sim 100\,\mu m$	$\sim 5\,\mu m$
AMS-100	2050	$\sim$ 180-200 m^2	$\sim$ 100 cm	$\sim 8 \cdot 10^6$	$\sim 100\,\mu m$	$\sim 5\,\mu m$

[1] HERD Collaboration. *HERD Proposal, 2018* https://indico.ihep.ac.cn/event/8164/material/1/0.pdf

[2] Battiston, R.; Bertucci, B.; *et al. High precision particle astrophysics as a new window on the universe with an Antimatter Large Acceptance Detector In Orbit (ALADInO)*. Experimental Astronomy 2021. https://doi.org/10.1007/s10686-021-09708-w

[3] Schael, S.; *et al. AMS-100: The next generation magnetic spectrometer in space – An international science platform for physics and astrophysics at Lagrange point 2*. NIM-A 2019, 944, 162561. https://doi.org/10.1016/j.nima.2019.162561

"side effects" of thickness without Signal loss

From Fermi-LAT to PANGU

PANGU: A High Resolution Gamma-ray Space Telescope

Xin Wu[a], Meng Su[b], Alessandro Bravar[a], Jin Chang[c], Yizhong Fan[c], Martin Pohl[a] and Roland Walter[d]

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[c] *Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China;*
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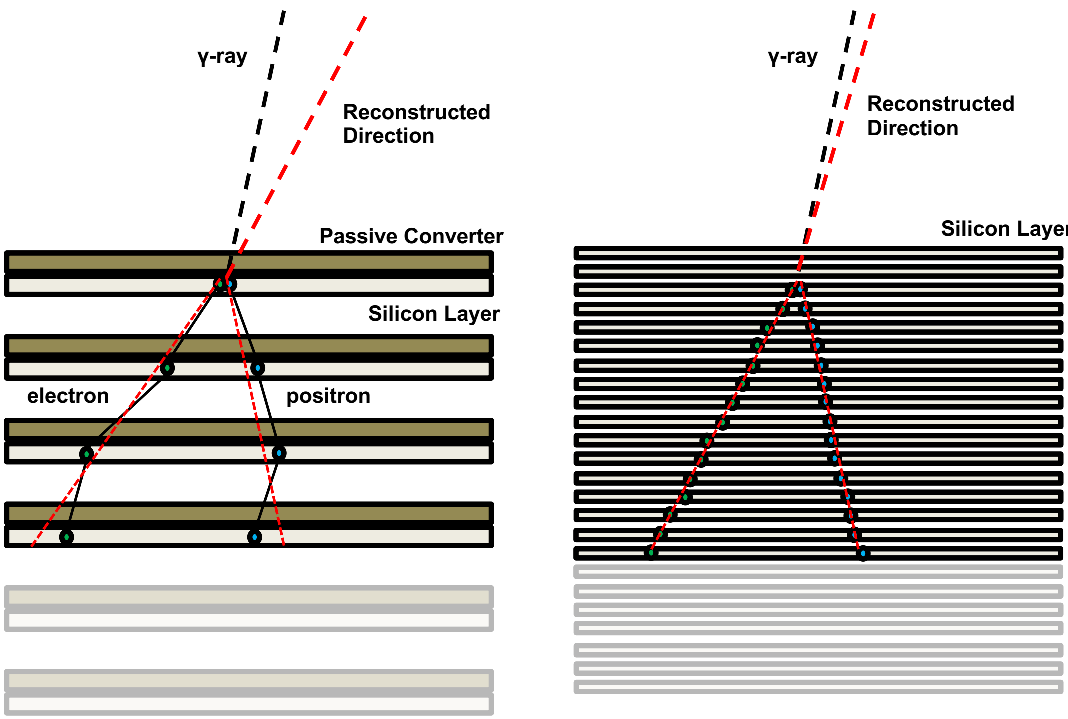

- remove the passive material (tungsten) and use thinner sensors
  → reduce MS
- increase the number of layers (up to 40-50) to keep a reasonable conversion probability

Potential breakthrough improvement in PSF for converting sub-GeV \gamma-rays

Space LGAD for Astroparticle - SLA

M. Duranti[1], V. Vagelli[2,1], M. Barbanera[3], E. Cavazzuti[2], F. Cossio[4], V. Formato[5], A. Oliva[6], L. Pacini[7]

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Agenzia Spaziale Italiana

Space LGAD for Astroparticle - SLA

The two developments could have something in common: LGAD sensors!

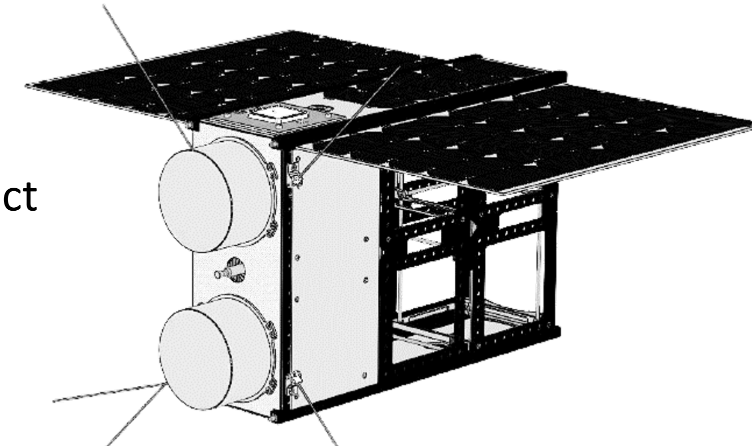
→ timing and 4D tracking

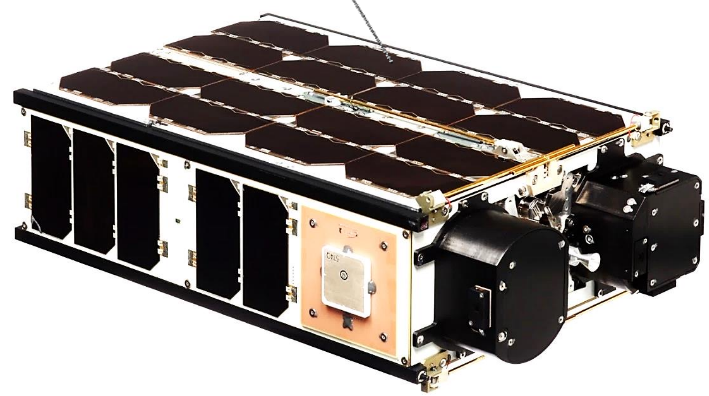
→ hits with very high S/N even with very thin detectors

- the idea has been proposed in an Italian Space Agency (ASI) "topical board"

- the idea has been included in a PRIN ("SLA"): the project include a demonstrator in a 3U or 6U CubeSat

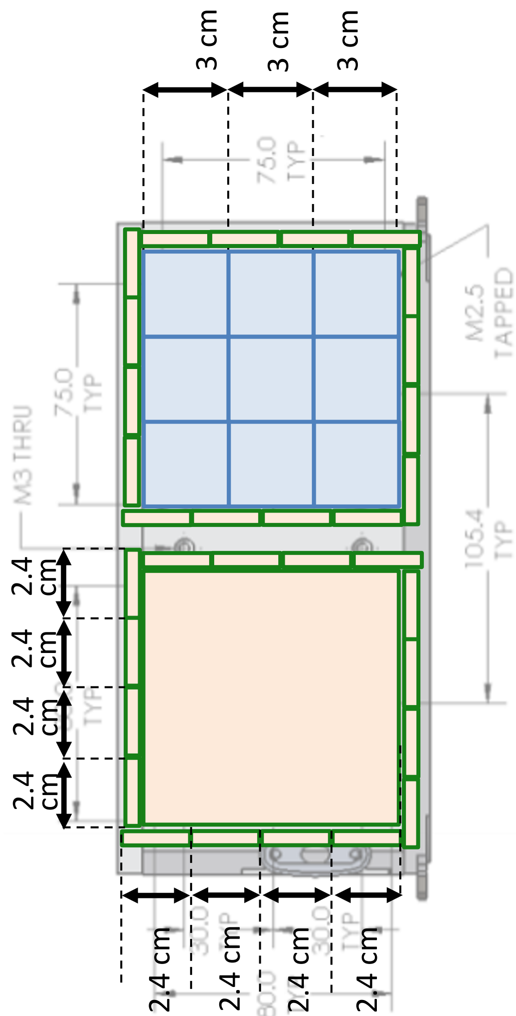
- the detector (launch included!) is doable with a ~ 1M€ budget envelope





*images from public websites(D-orbit, NanoAvionics, ISIS, …)

SLA layout


3 cm
3 cm
3 cm
75.0 TYP
M3 THRU
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M2.5 TAPPED
105.4 TYP
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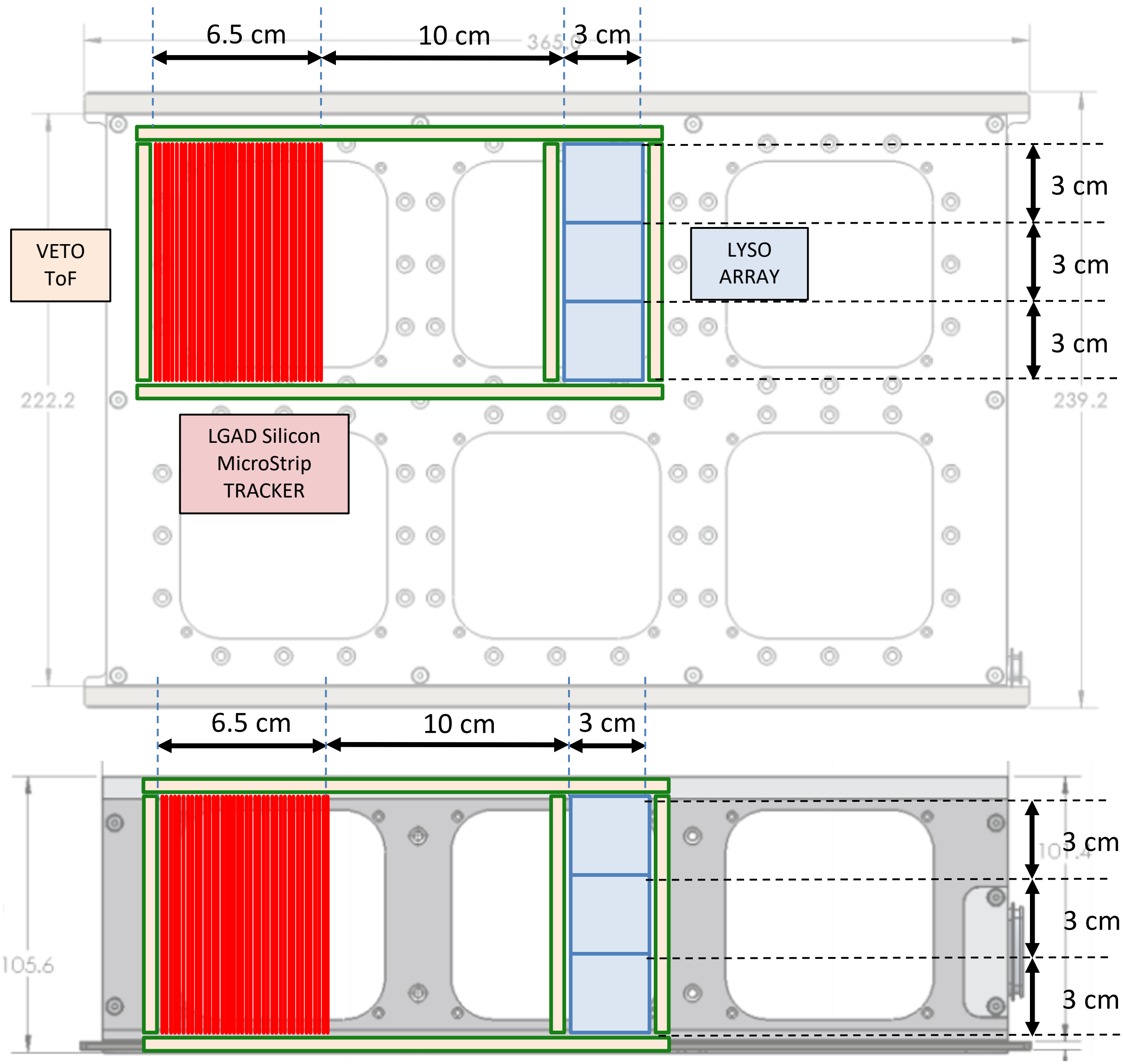

6.5 cm
10 cm
3 cm
365.0
VETO
ToF
LYSO
ARRAY
LGAD Silicon
MicroStrip
TRACKER
3 cm
3 cm
3 cm
222.2
239.2
6.5 cm
10 cm
3 cm
3 cm
3 cm
3 cm
105.6

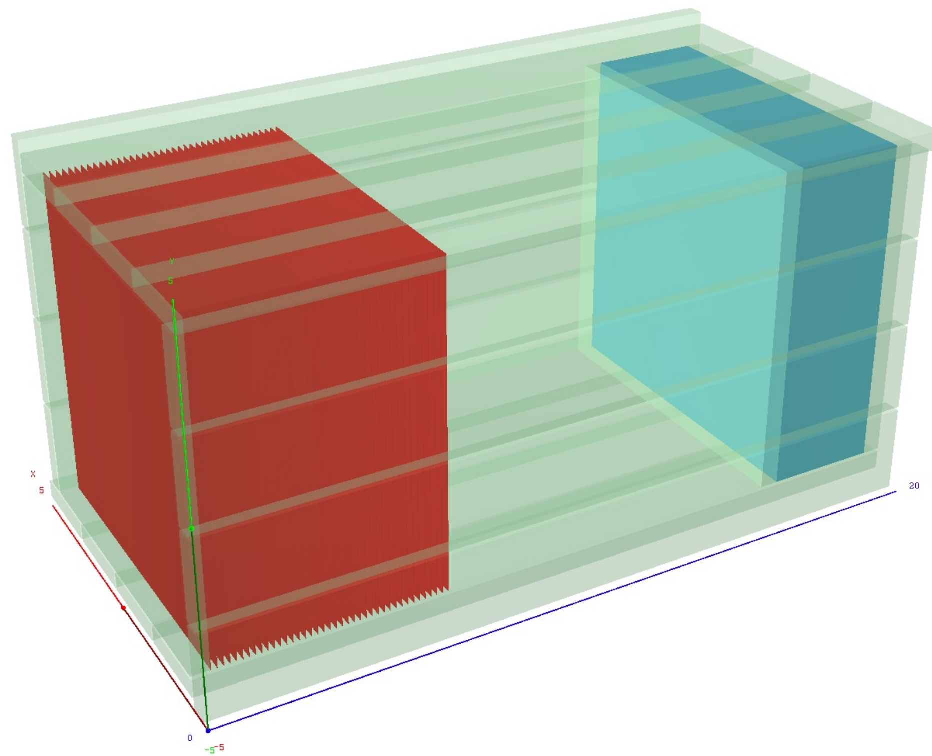
Space LGAD for Astroparticle - SLA

A conceptual design of the demonstrator compatible with the constraints in weight, volume and power budget of a CubeSat platform.
hosted in 2 units of a 3U CubeSat, with one additional units dedicated to the FEE and DAQ of the demonstrator.

LGAD SiMS Tracker
40 layers of 150 μm thick SiMS LGAD sensors
readout pitch: 150 μm --> expected $\Delta x \sim 15\mu m$
Target timing resolution ~ 100 ps

Veto / Time of Flight system
0.5 cm thick Sci-paddles
SiPM readout using commercial FEE.
$\Delta t \sim 30$ ps

Electromagnetic Calorimeter
3x3x3 cm^3 array of LYSO crystals
SiPM readout using commercial FEE
Feasibility to add another stack of LYSO array under study



*Geant4 geometry by G. Aristei

Weigth < 3 kg   Power < 20 W

Simulation of the detector performances is ongoing
FEE power mitigation techniques under investigation

Space LGAD for Astroparticle - SLA

GOAL 1. (Technological)
Demonstrate the feasibility of constructing and operating thin LGAD SiMS sensors in harsh space environment

GOAL 2. (Scientific)
Show that LGAD performances are adequate for next generation astroparticle experiments in space

Measurement of converting photons with E > 20 MeV in the LGAD SiMS tracker with reconstruction of the e^+/e^- pair angle in the tracker
with improved vertex reconstruction by identification of backsplash hits

Observation of photons with E > 20 MeV from the Crab Nebula
Verification of detector PSF and confirmation of conversion technique
Observation of photons from Crab in the 20 MeV – 50 MeV range
Comparison with previous experiments (CGRO/EGRET) above 50 MeV

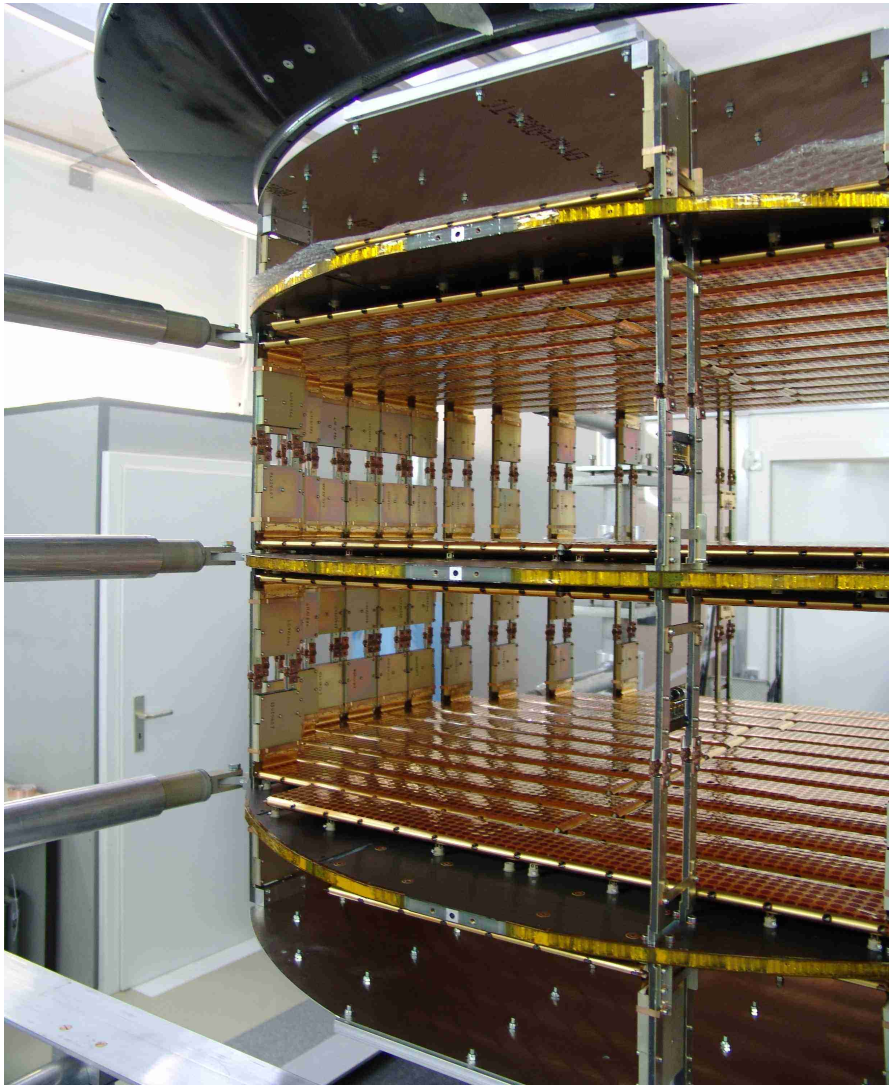
Study of charged CRs using the 5D tracking (position, energy deposit and timing) enabled by the LGAD SiMS tracker
Data-driven characterization of Tof capabilities for LGAD SiMS detectors
Data-driven characterization of e/p separation capabilities for LGAD SiMS detectors
Monitor the time variation of charged CRs and SEP events

Stay tuned...

Backup

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



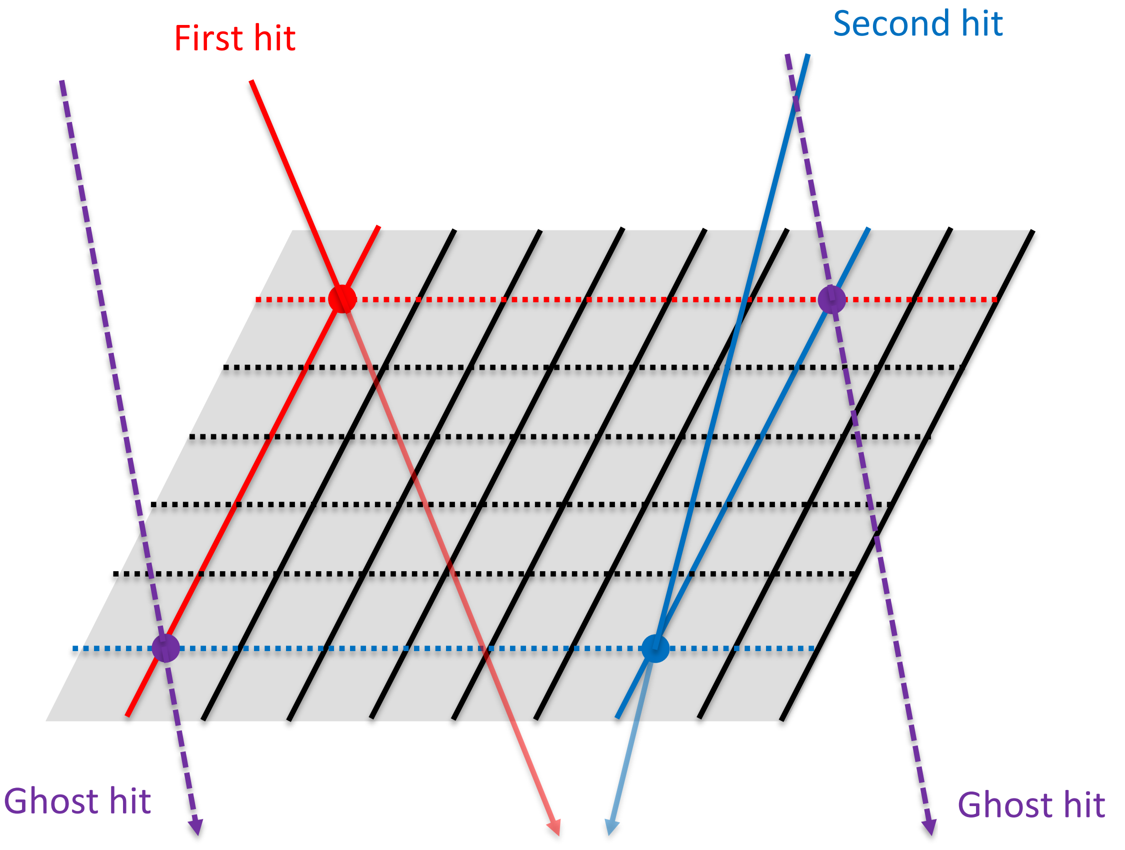
BOTE:

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

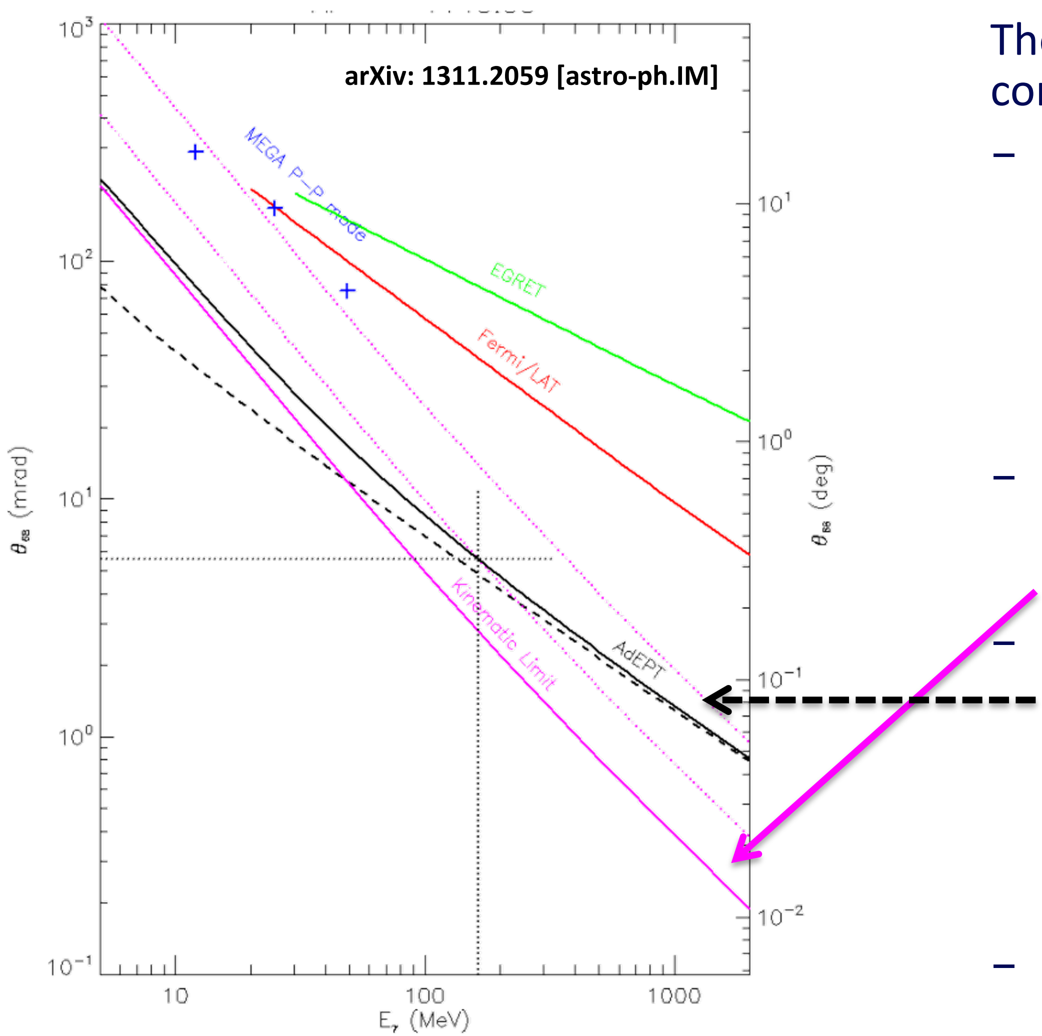
→ $strip = 2*120k \sim 10^5$

→ $pixel = 120k*120k \sim 10^{10}$

"Ghost"



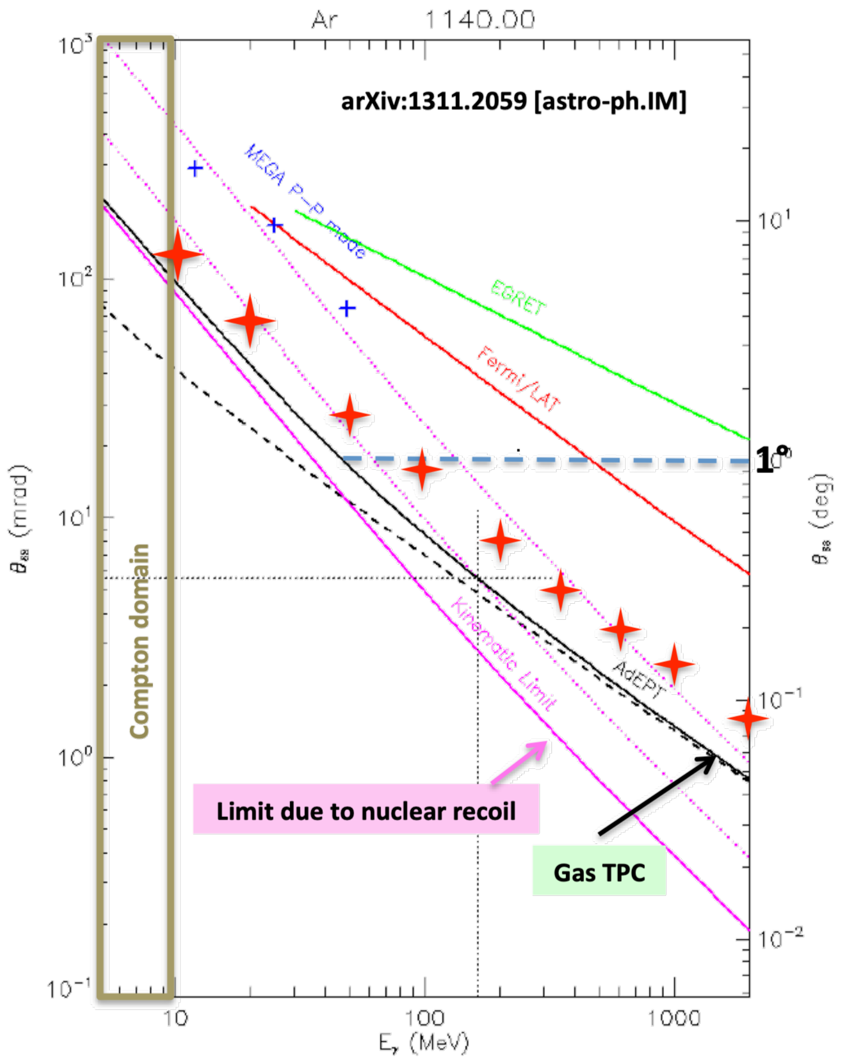
Pair-conversion telescope angular resolution

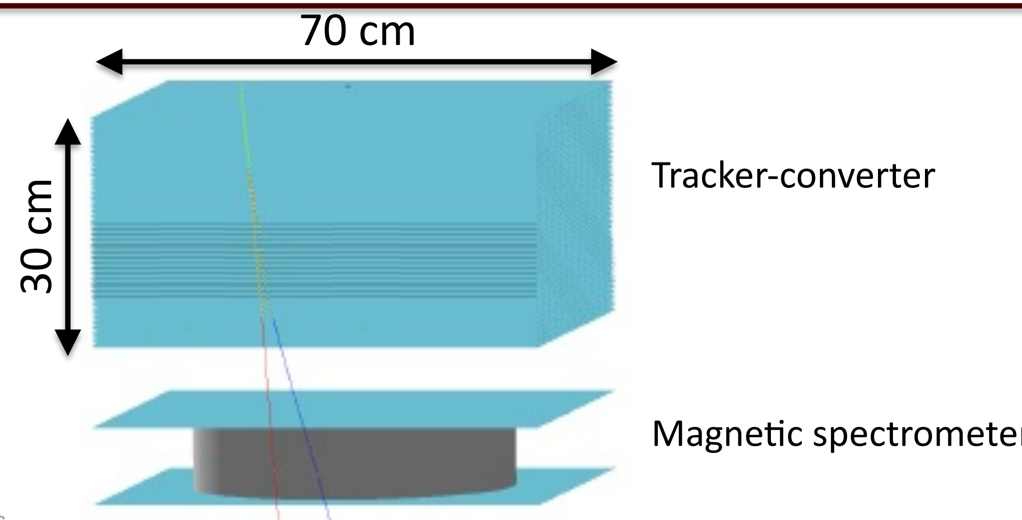


The angular resolution of a pair-conversion telescope:

- relies on the reconstruction of the photon incident angle by the full kinematic measurement of the electron-positron pair
  - → energy/rigidity measurement
  - → direction (i.e. tracking)
- is limited by the uncertainty on the nucleus (or electron) recoil energy (i.e. "kinematic limit")
- is limited by the Multiple Scattering changing the electron and positron direction
  - → the MS is dominating after few mX_0 (10 mX_0 for 900 MeV photons)
- decreases as the energy increases

PANGU telescope angular resolution



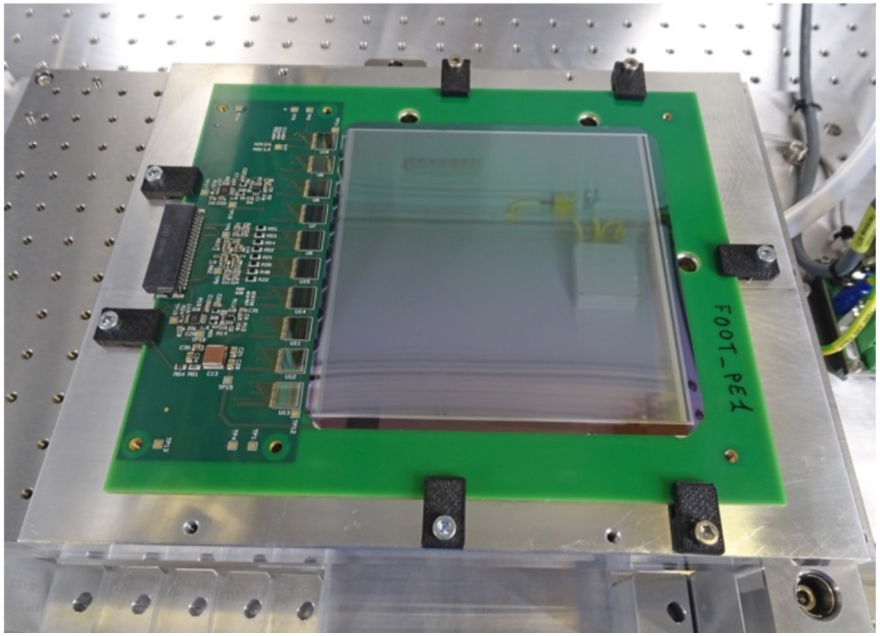


Geant4 "fast" Monte Carlo (MC) simulation:

- 150 µm Si detector;
- 242 µm pitch
  → 70 µm resolution simulated
  (very conservative:
  35 µm resolution @ 242 µm
  10 µm resolution @ 110 µm
  easily achievable)

→ results very preliminary and to be confirmed with a dedicated and reliable MC

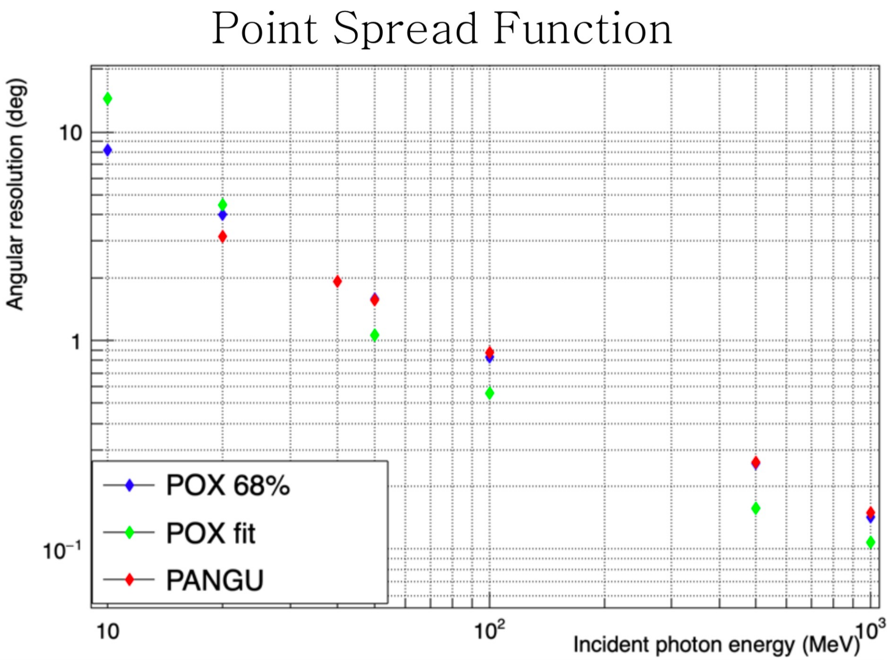
Results (so far)



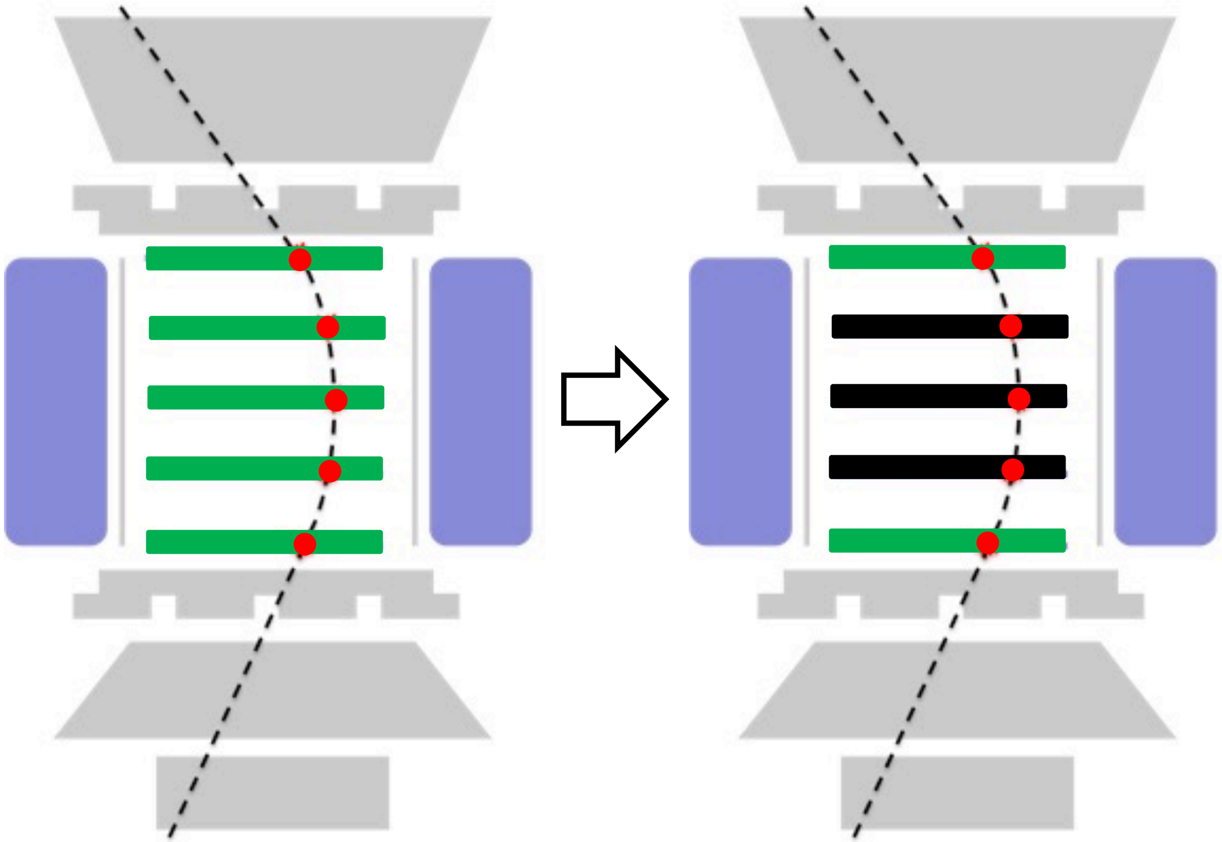
- we designed and start to produce (in sinergy with the FOOT project) the new sensors 9.5 x 9.5 cm² (150 µm thickness)

- the sensors work very well but the signal is halved wrt 300 µm thick "standard" sensors

- we implemented the Geant4 simulation
- we implemented the track and "vertex" finding algorithms
- we confirmed the preliminary performances predicted by the PANGU collaboration
- we implemented the track fitting in the magnetic field



How to stay into the power limitations?



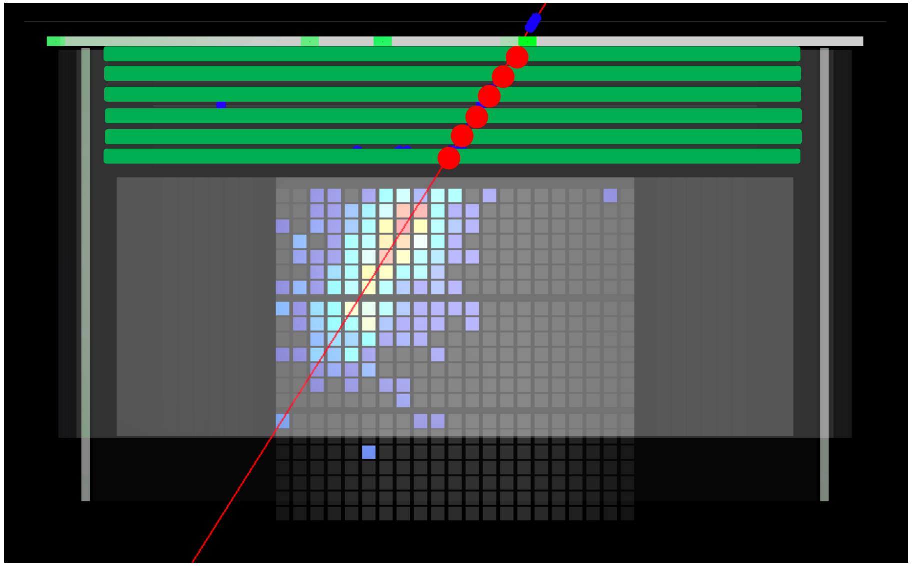
- basic capabilities kept
- isotopic separation / β resolution degraded
- timing redundancy and efficiency reduced

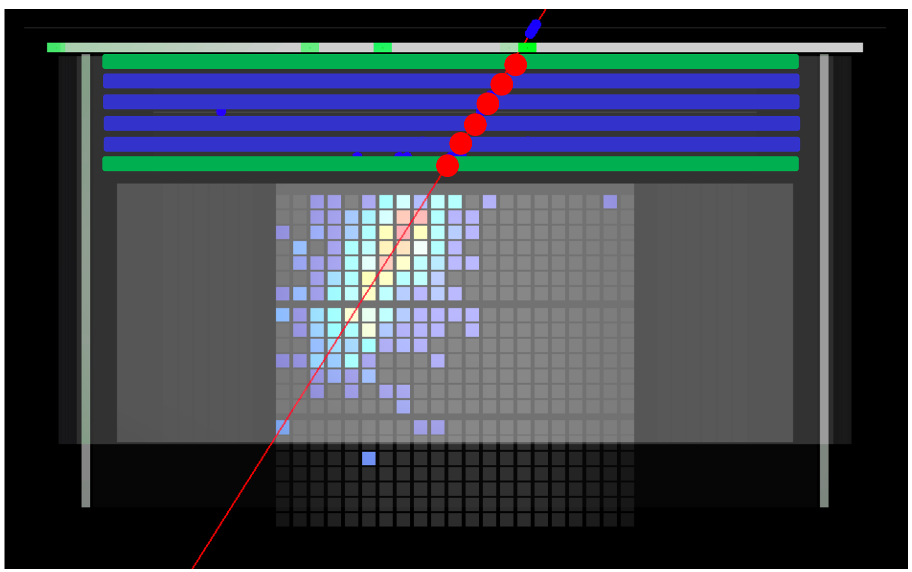
- "timing" layer
- "normal" layer

How to stay into the power limitations?

- "timing" layer

- "normal" layer





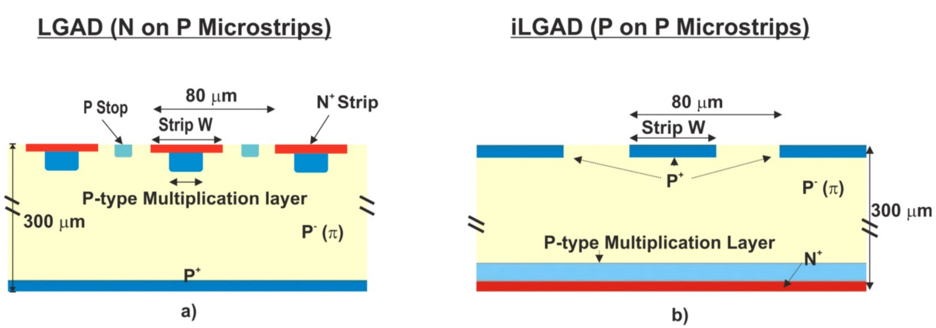
- basic capabilities kept
- isotopic separation / β resolution degraded
- timing redundancy and efficiency reduced

How and how to cope with power limitations?

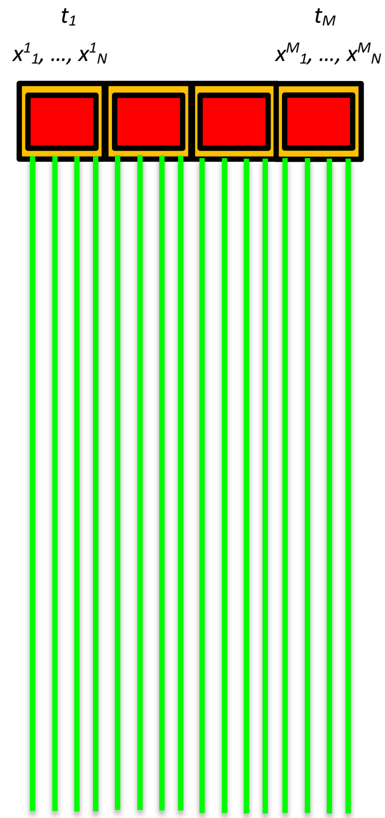
→ Si LDAG microstrip

→ "group" N *position* channels into one *timing* channel, or create large timing channels

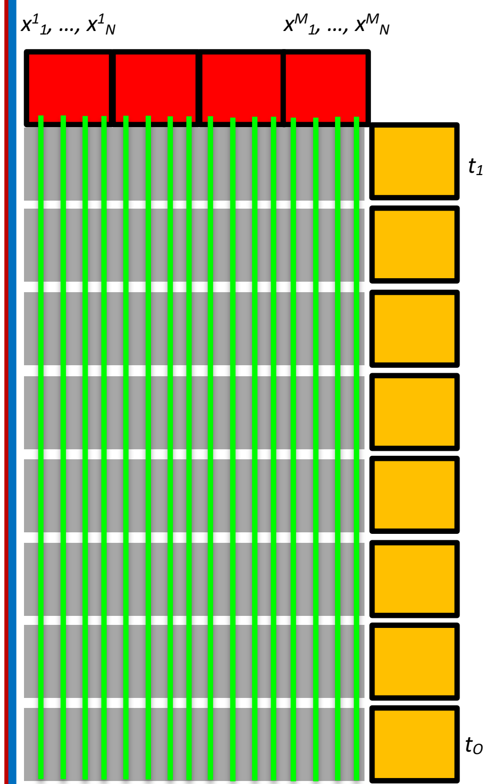
cfr.
M. Duranti, V. Vagelli *et al., Advantages and requirements in time resolving tracking for Astroparticle experiments in space*, accepted for publications in Instruments



taken from
E. Currás, et al. *Inverse Low Gain Avalanche Detectors (iLGADs) for precise tracking and timing applications*, NIM-A Volume 958, 2020, 162545,
https://doi.org/10.1016/j.nima.2019.162545



- standard LGAD with a dedicated Front-End ASIC
- iLGAD with separate Front-End ASICs for position and timing (on the back)



- positon and timing strip orthogonal
- iLGAD (or AC-LGAD?) fro the timing

ASTRA-LGAD

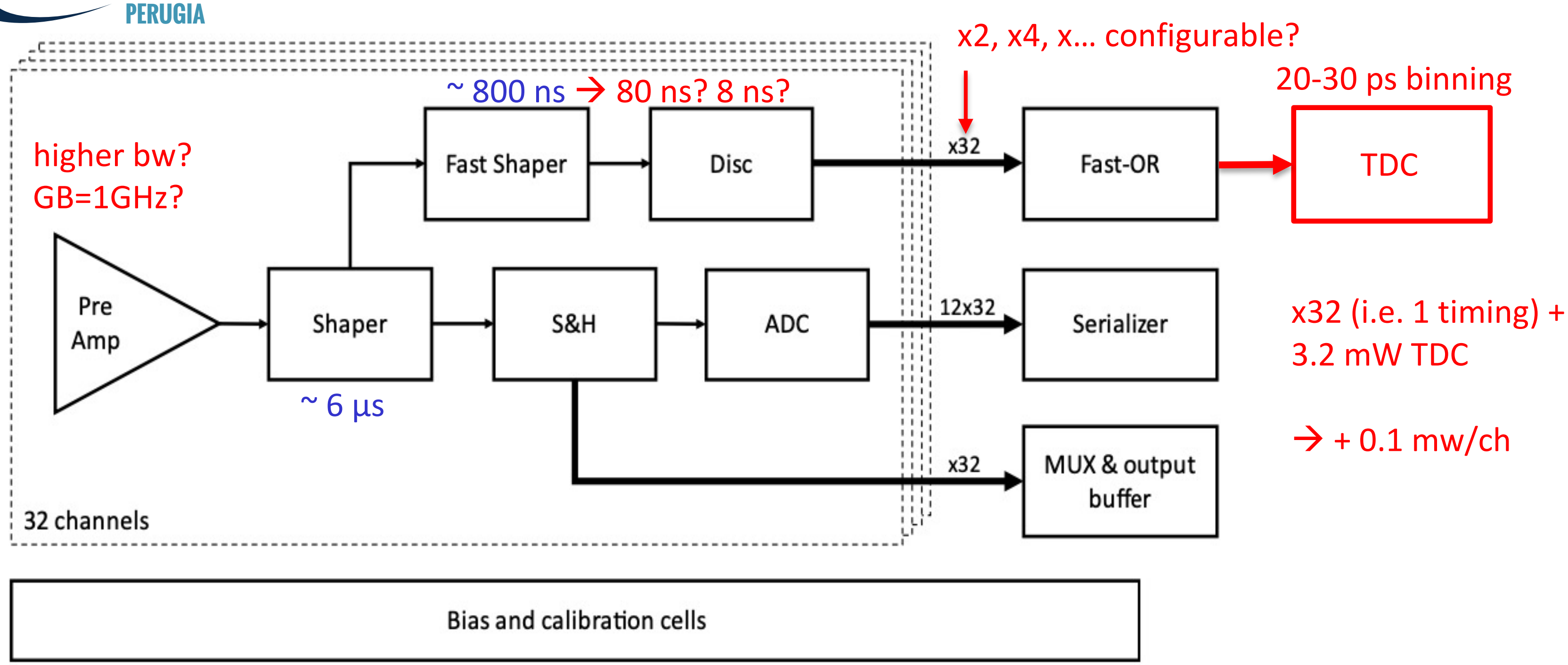


Figure 3 ASTRA 32-channel architecture

- LGAD timing "resolution" ~ 50-100 ps
- LGAD capacitance could be larger
- LGAD signal would be ~ 10 larger

5.1 Power consumption

Table 9 reports the power consumption of each block composing the ASIC.

Stage	Current [μA]	Power/ch [μW]
Preamplifier	250	300
Inverting stage*	20	24
Shaper	55	66
Fast Shaper	27	32
Discriminator	15	18
S&H	90	108
ADC	30	36
----------------------------	----------------------------	----------------------------
Single-to-Diff. Amp.	210	8
Output Buffers (2)	980**	37
Counter + Serializer	3	0.12
SLVS RX (3)	80x3	9
SLVS TX (2)***	2500x2	190

Table 9 Power consumption of each ASIC block

- how much power for the needed bw?
- additional power?
- how much power for the needed T_p?

- additional power?

Weeroc Petiroc 2A

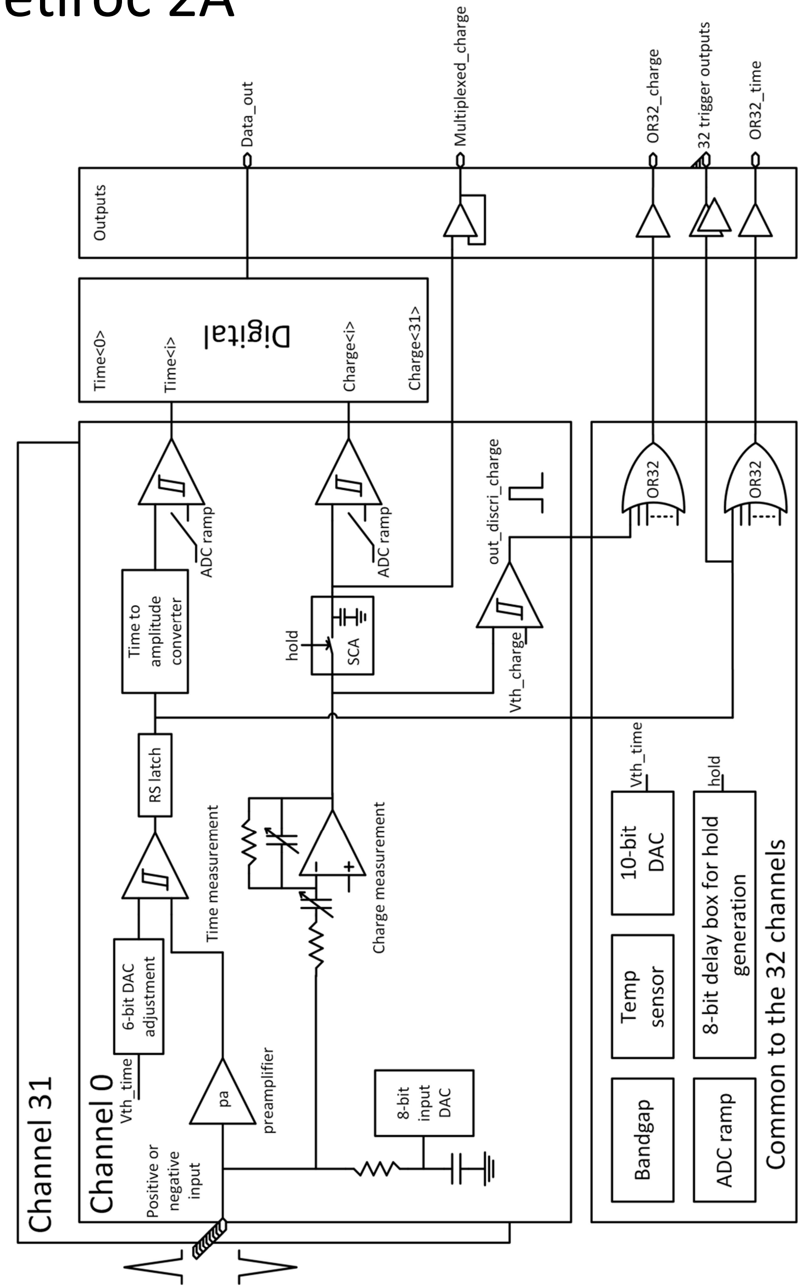
weeroc

Petiroc 2A

SiPM read-out for time-of-flight PET

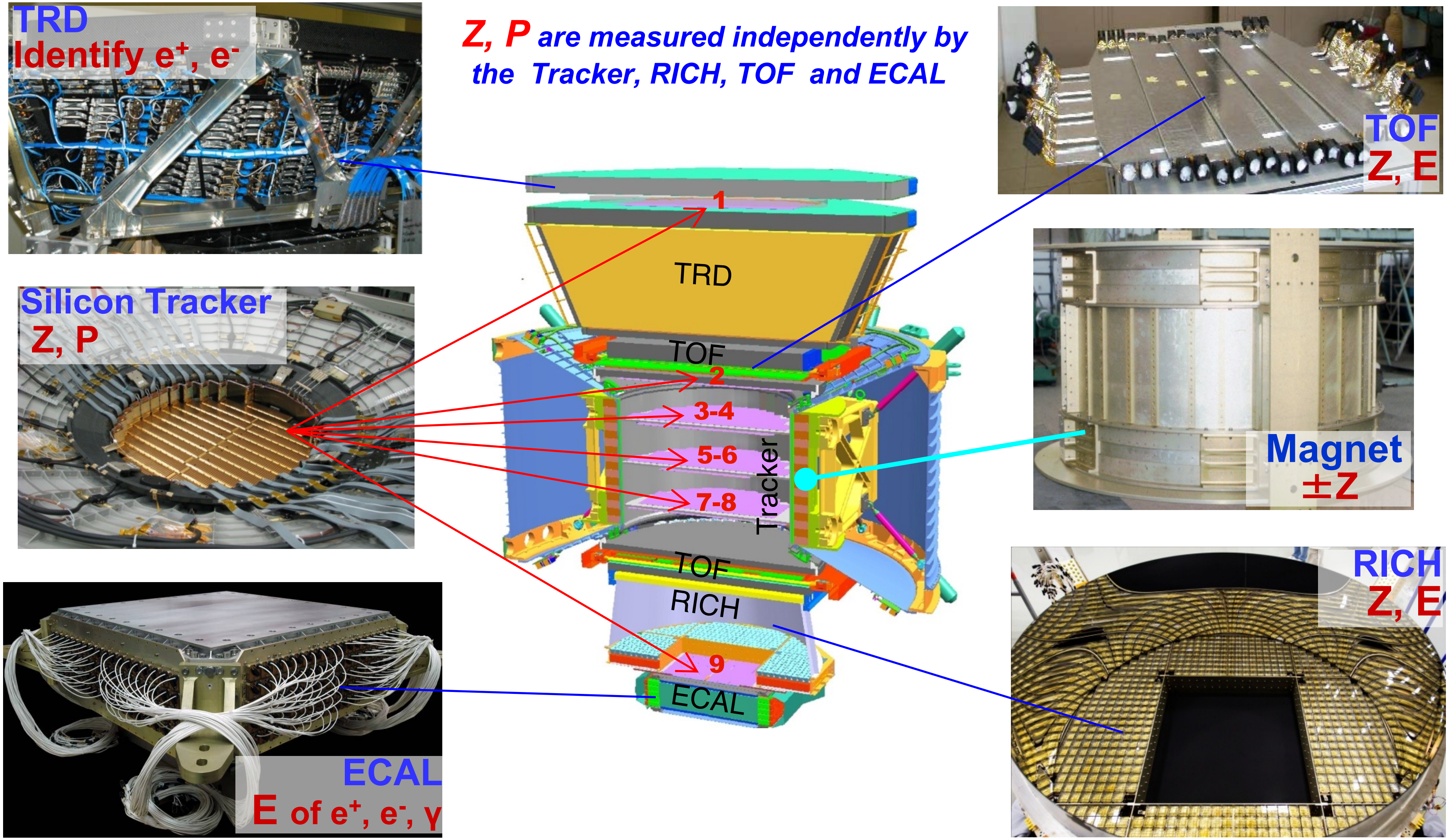
Parameter	Value
Detector Read-Out	SiPM
Number of Channels	32
Signal Polarity	positive or negative
Sensitivity	Voltage input amplifier, 200 Ohm matching
Timing Resolution	~ 18 ps RMS on trigger output (4 photoelectrons injected)
Dynamic Range	160 fC up to 400pC
Packaging & Dimension	LQFP 208 (28x28x1.4 mm) TFBGA 353 (12x12x1.2mm)
Power Consumption	6 mW/channel
Inputs	32 analogue inputs for SiPM connection, no external component required Inputs DC are adjustable to correct SIPM breakdown voltage non uniformity.
Outputs	32-channel trigger outputs ASIC level general trigger (OR of all channel) ASIC level second level general trigger (OR of all channel for energy cut) Charge measurement (10 bits Time measurement (10 bits TDC interpolating 40MHz coarse time) One multiplexed analogue charge output One multiplexed digital trigger output
Internal Programmable Features	Common trigger threshold adjustment and 6bit-DAC/channel for individual adjustment Shaping time & gain of the charge shaper 32 8bit-input DAC for SiPM HV adjustment over 1V span

Table 1 – ASIC main parameters

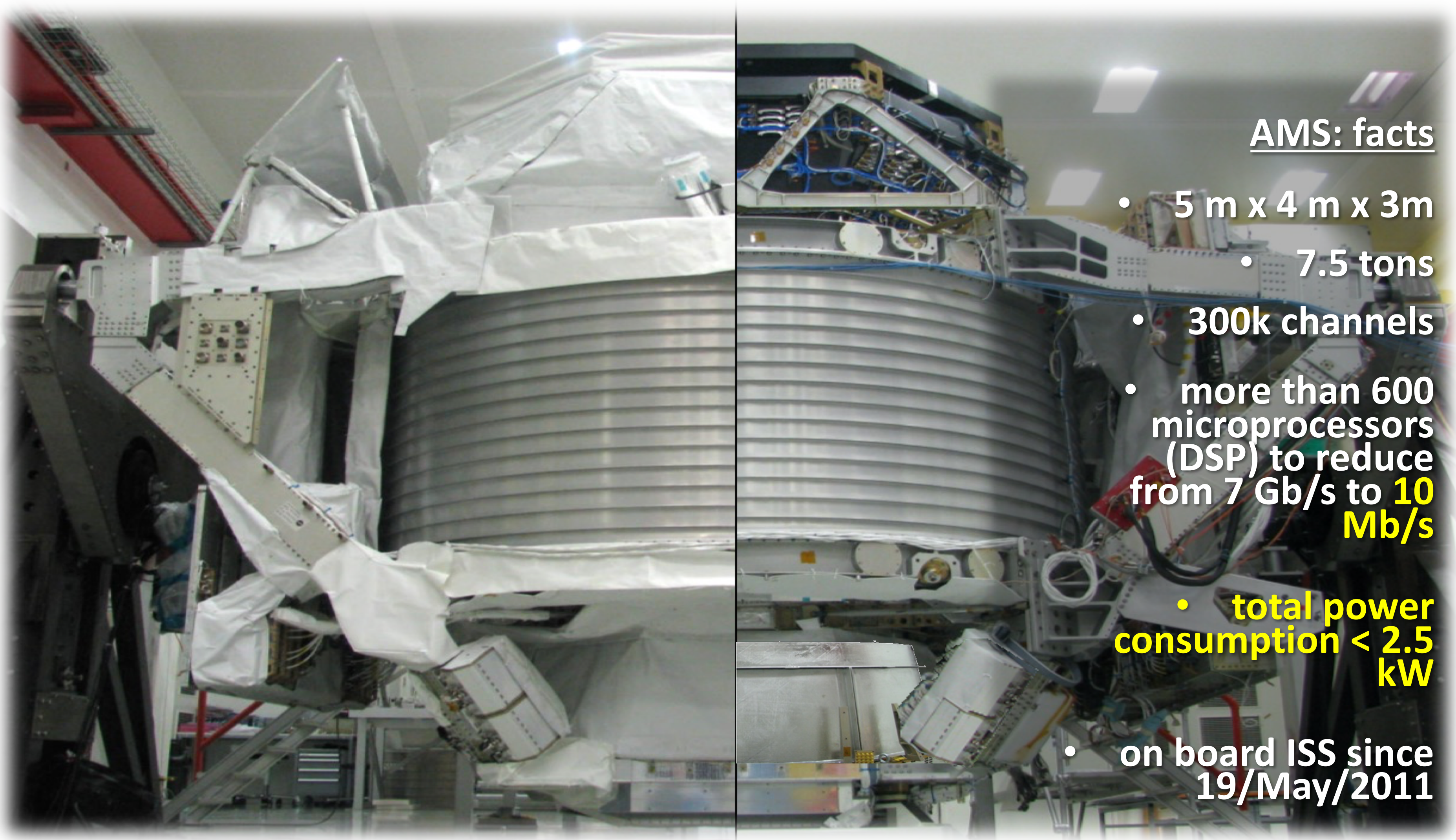


AMS-02: A precision, multipurpose, up to TeV spectrometer

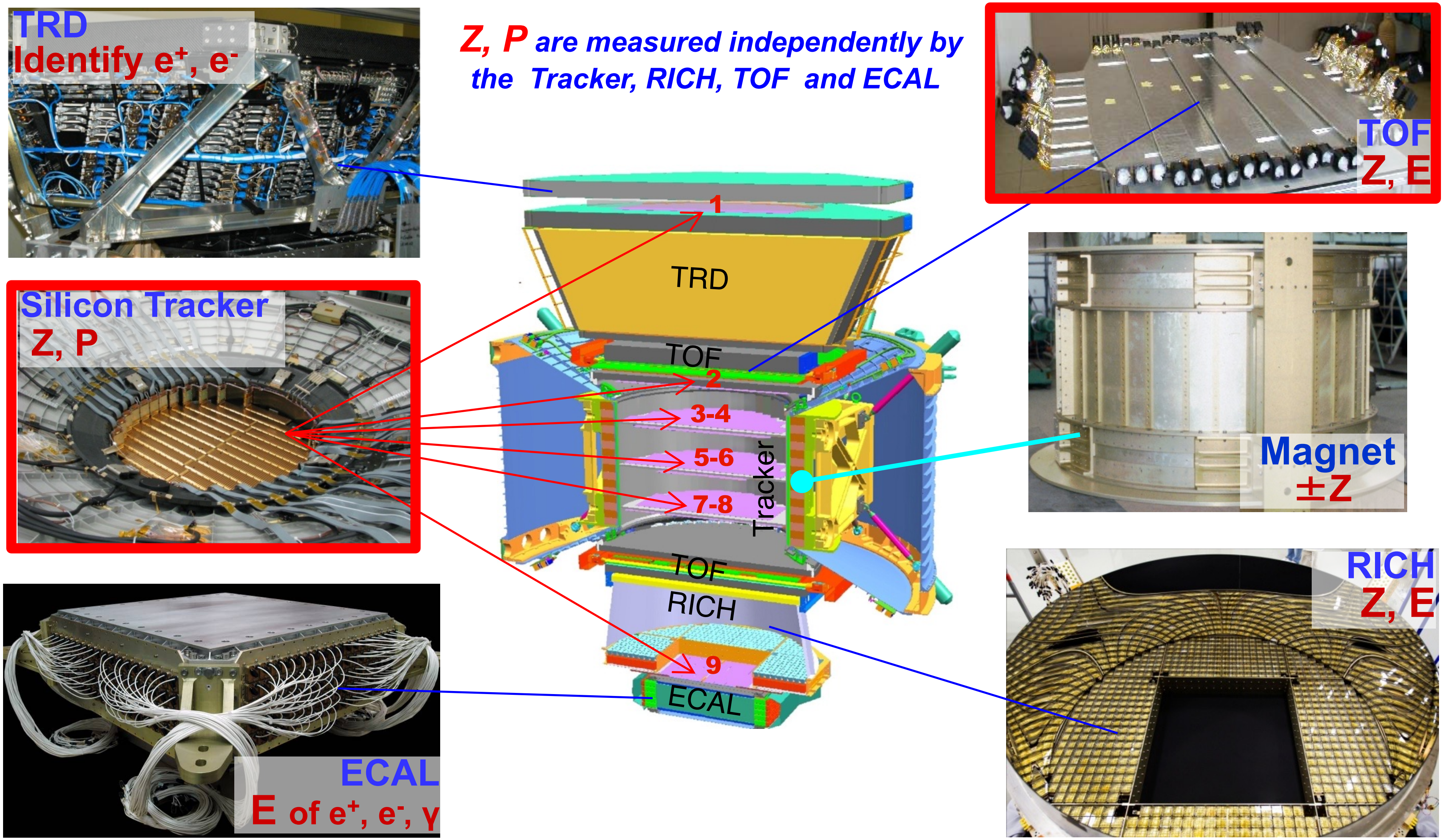
***Z, P** are measured independently by the Tracker, RICH, TOF and ECAL*



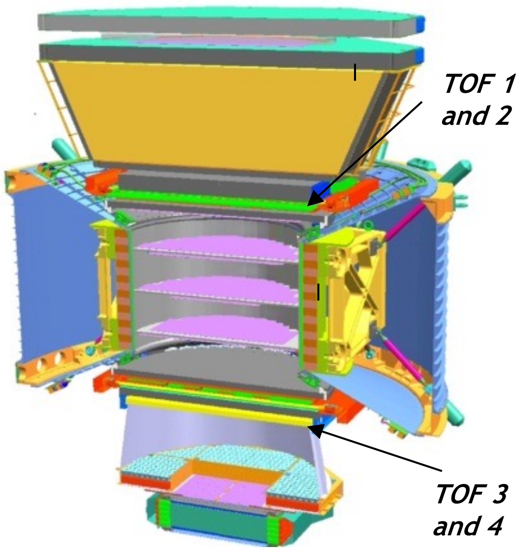
AMS-02: A precision, multipurpose, up to TeV spectrometer

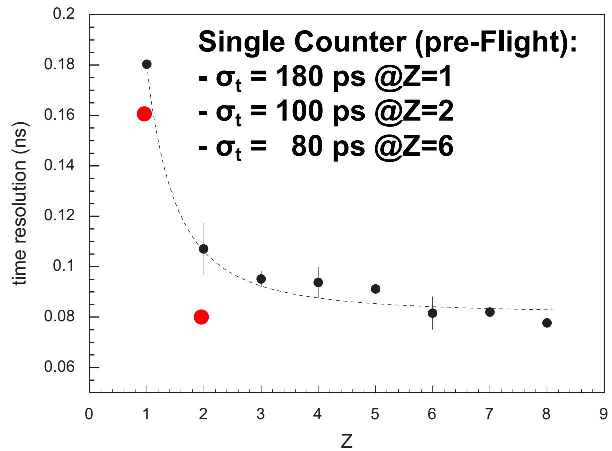


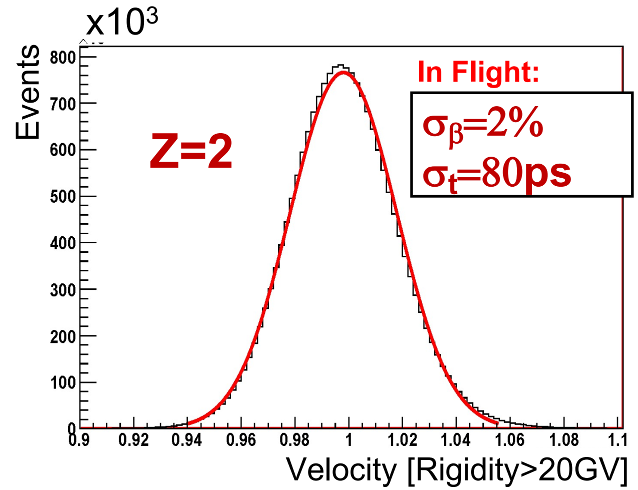
AMS-02: A precision, multipurpose, up to TeV spectrometer



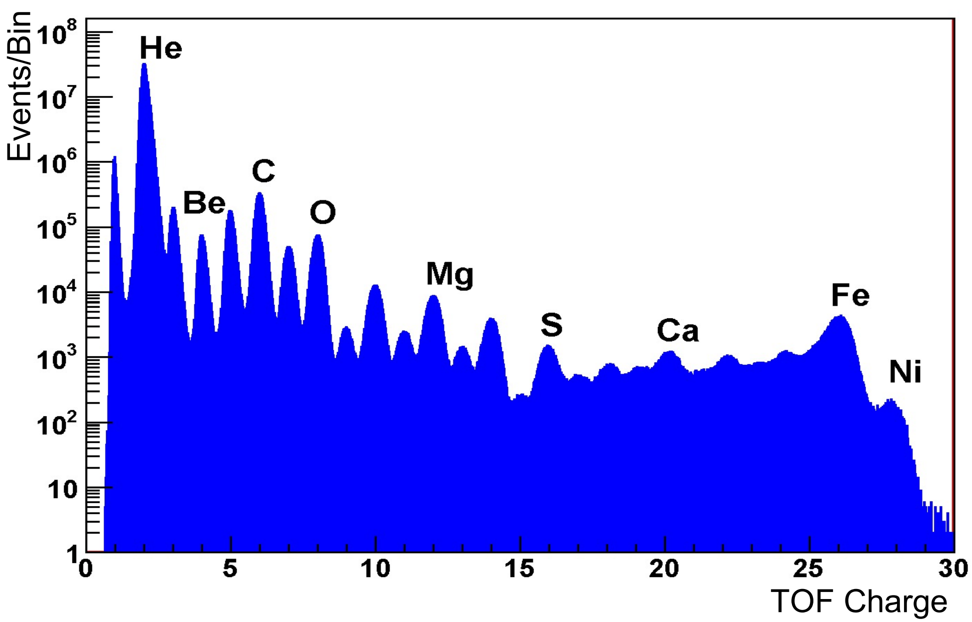
AMS-02: Time of Flight

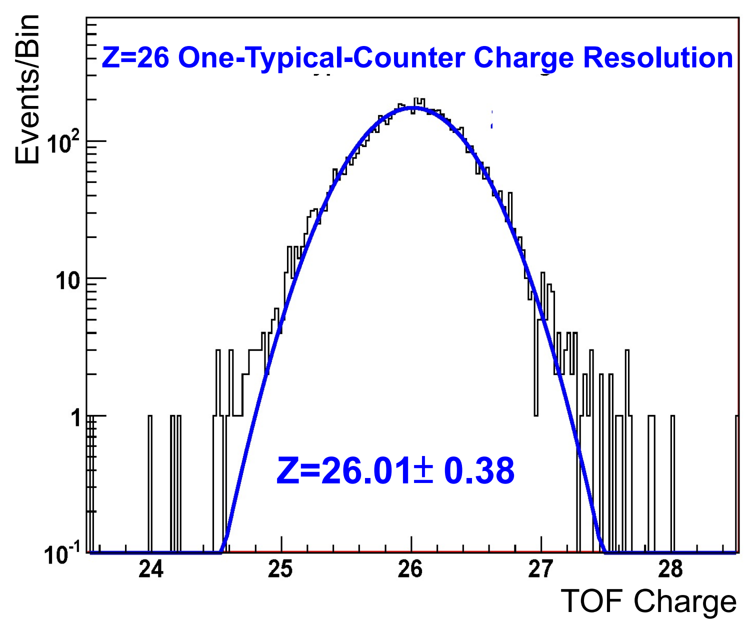




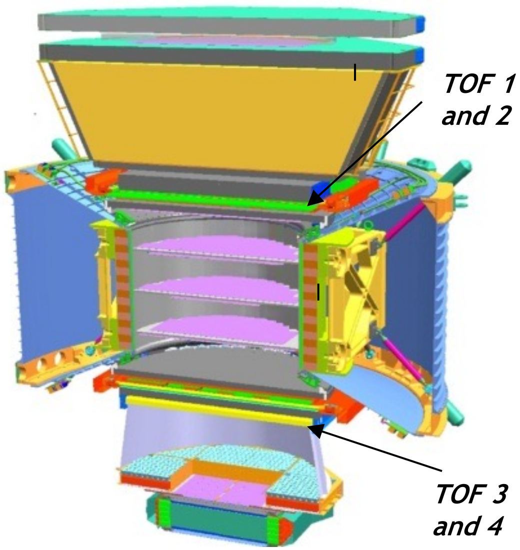


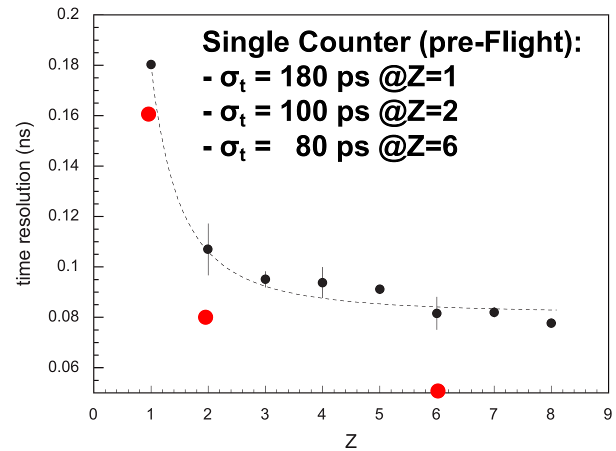
Measures Velocity and Charge of particles

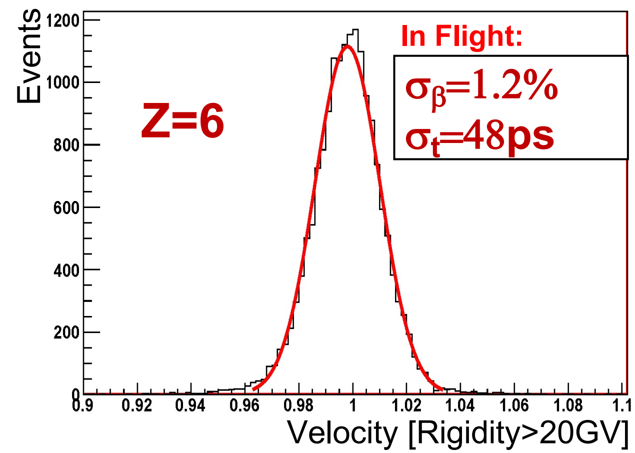




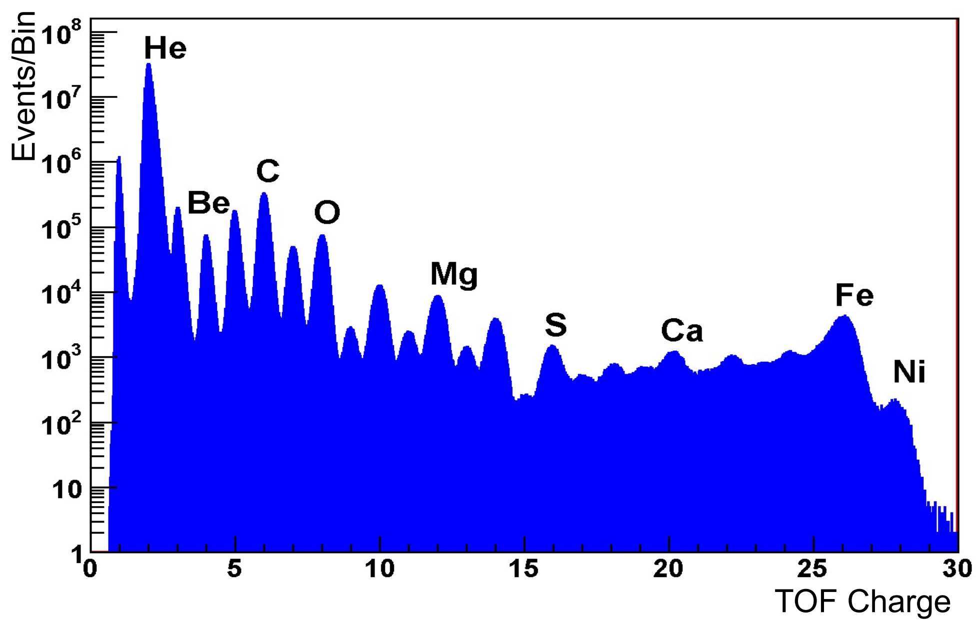
AMS-02: Time of Flight

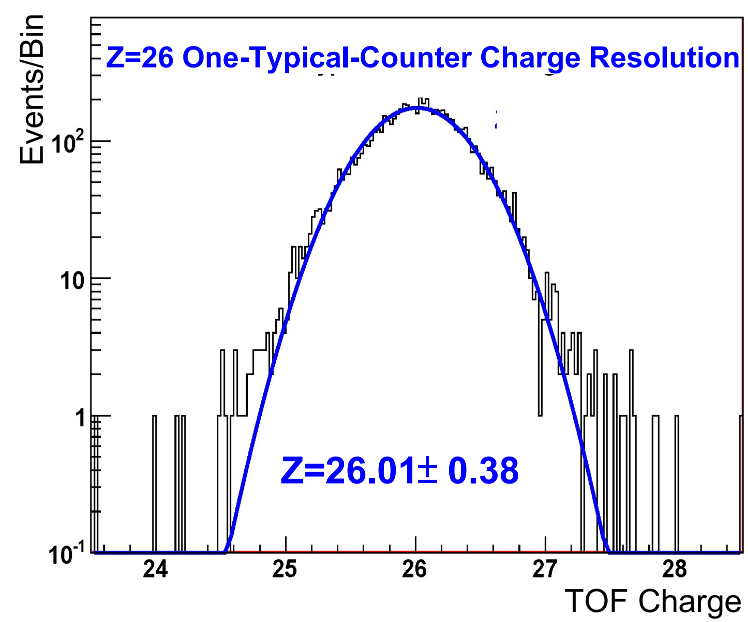




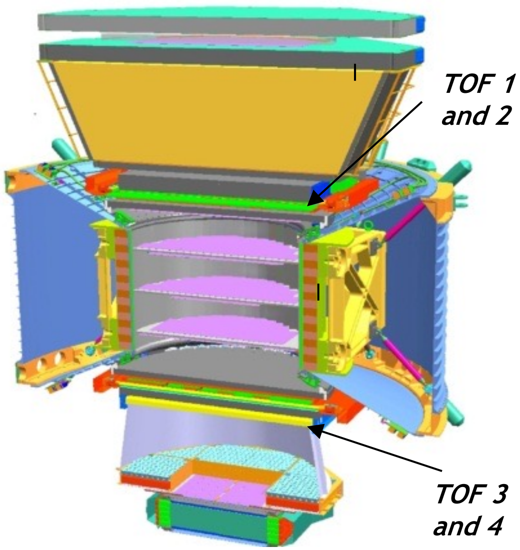


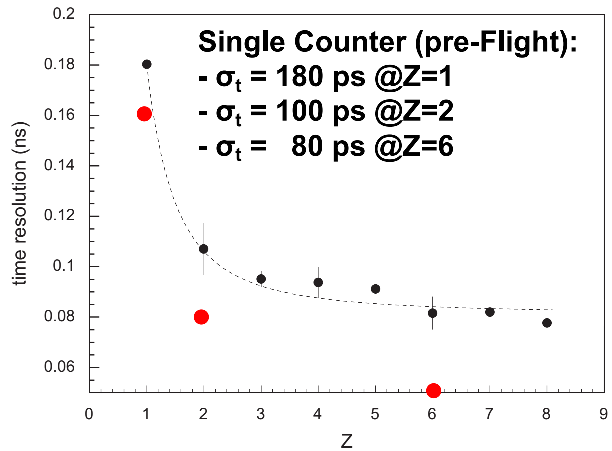
Measures Velocity and Charge of particles

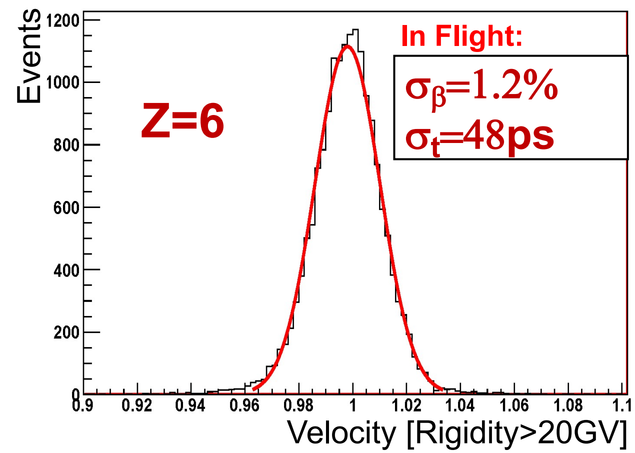




AMS-02: Time of Flight



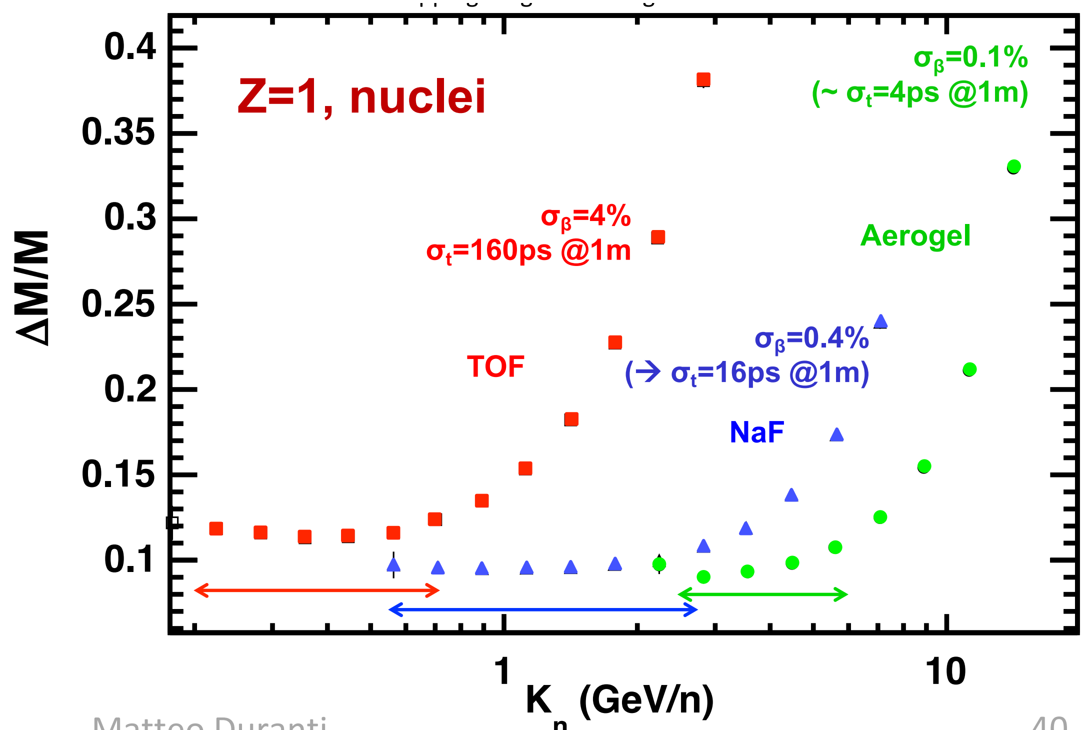




$$\frac{\delta M}{M} = \left(\frac{\delta p}{p}\right) \oplus \gamma^2 \left(\frac{\delta \beta}{\beta}\right)$$

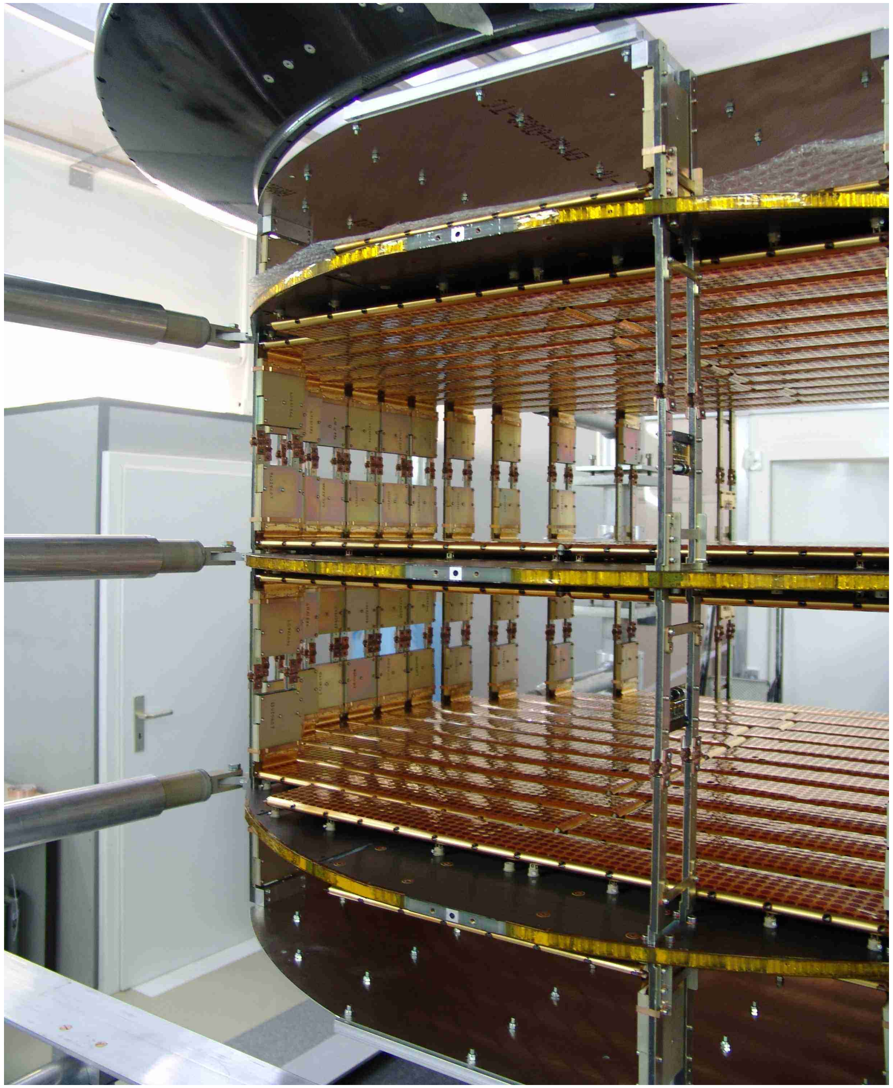
Velocity resolution is crucial for isotopical measurements:

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

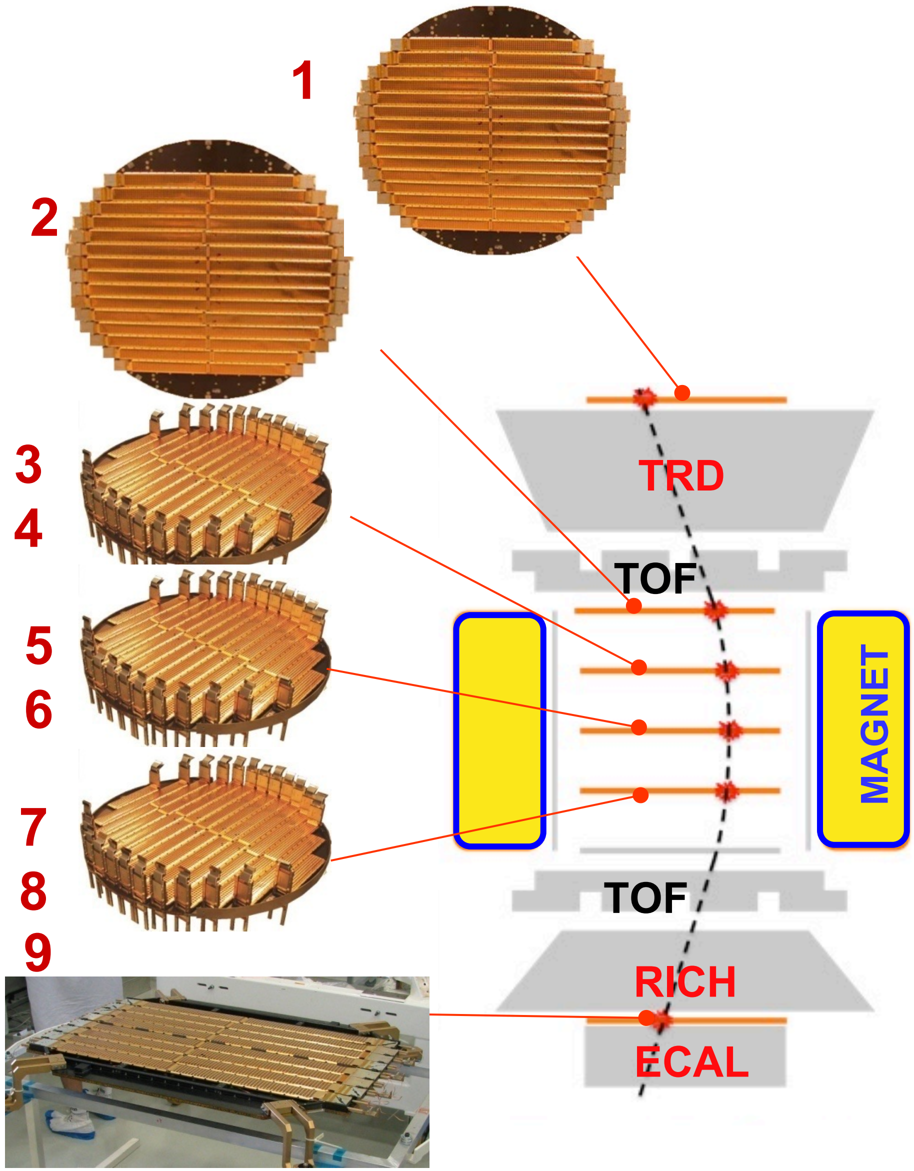


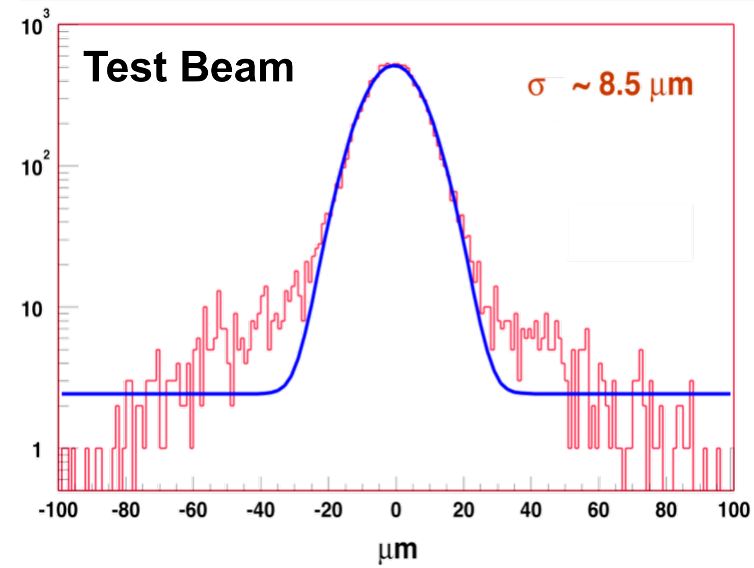
AMS-02: Silicon Tracker

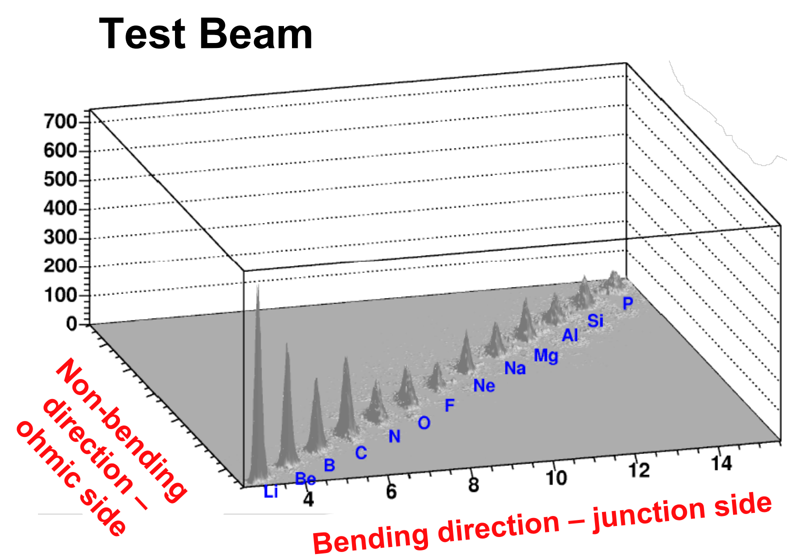
- 9 layers of double sided silicon detectors arranged in 192 ladders
- ~6 m^2
- total of 200k channels for ~ 200 watt
- 10 μm (30 μm) spatial resolution in bending (non bending) plane
- momentum resolution ~10% @10 GeV
- high dynamic range front end for charge measurement
- wide temperature range (-20/+40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



AMS-02: Silicon Tracker

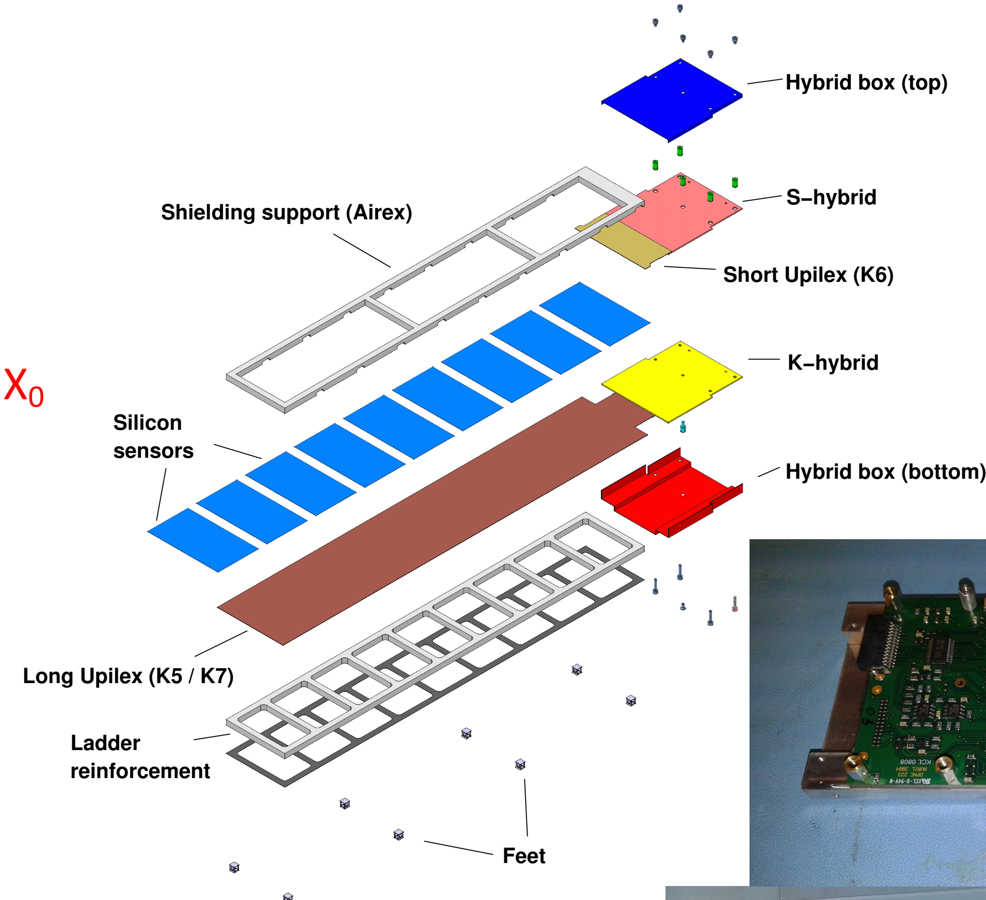


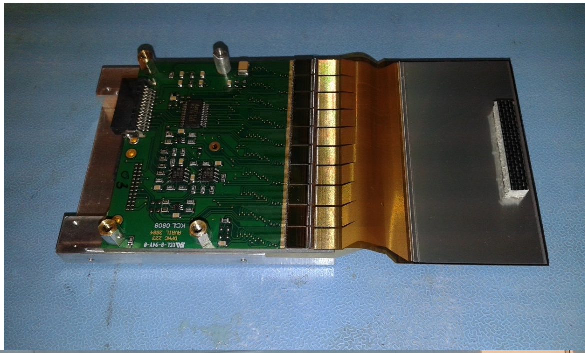




AMS-02 microstrip silicon sensors

- 7(+2) AMS-02 spare microstrip silicon sensors
- resolution: 10µm/30µm
- size: 7x[4-48] cm^2
- thickness: 300µm → one sensor accounts for 0.3% X_0 (i.e. 3 mX_0 or 3mRL)



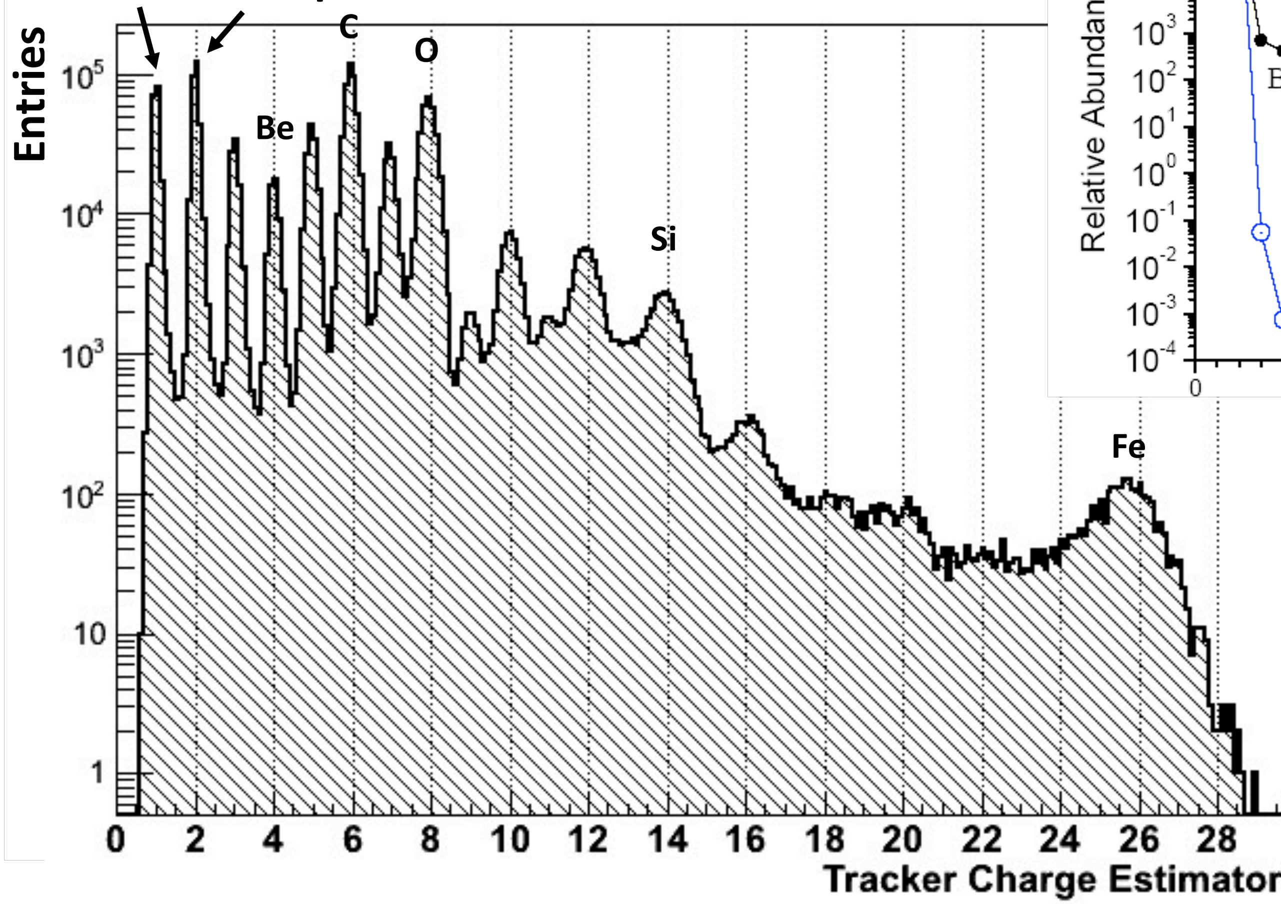


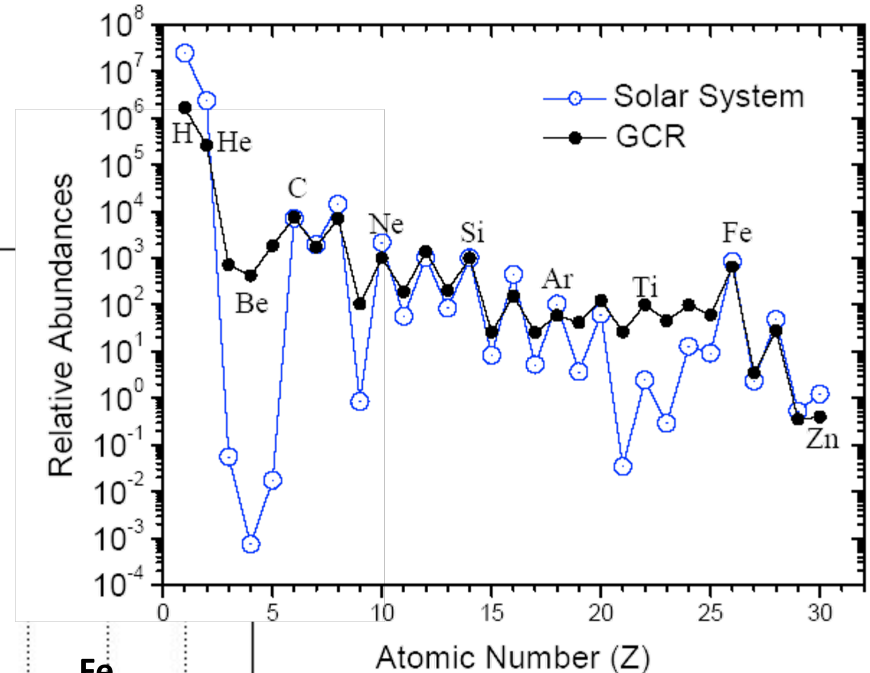
One of the “in kind” contribution given for the project is constituted by several spare part and modules built for the AMS-02 Silicon Tracker

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

Abundances not corrected for detector efficiencies

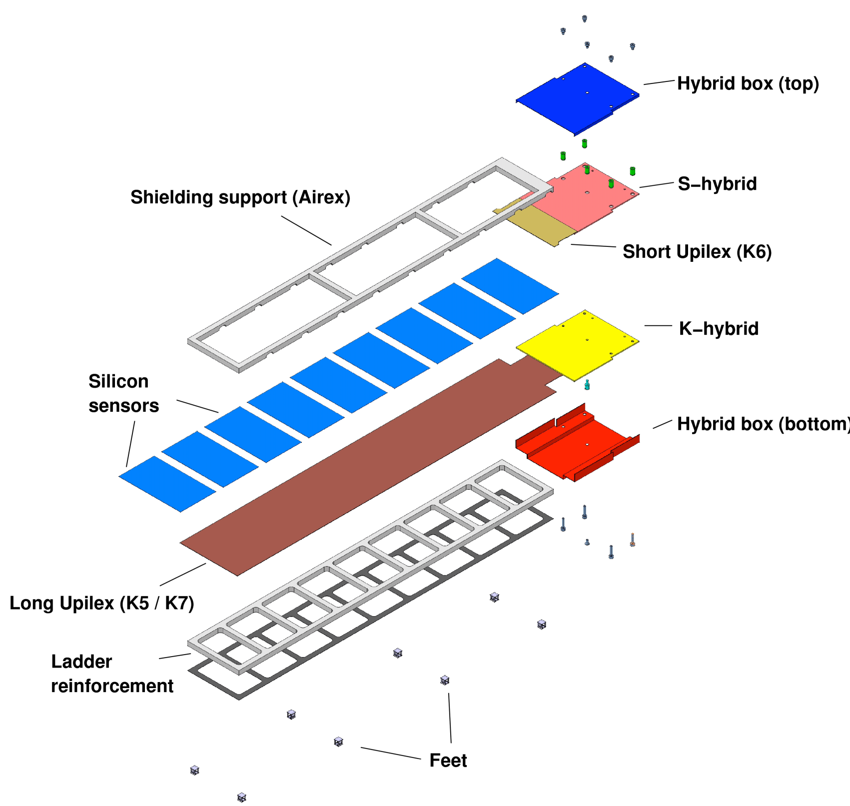
H and He prescaled





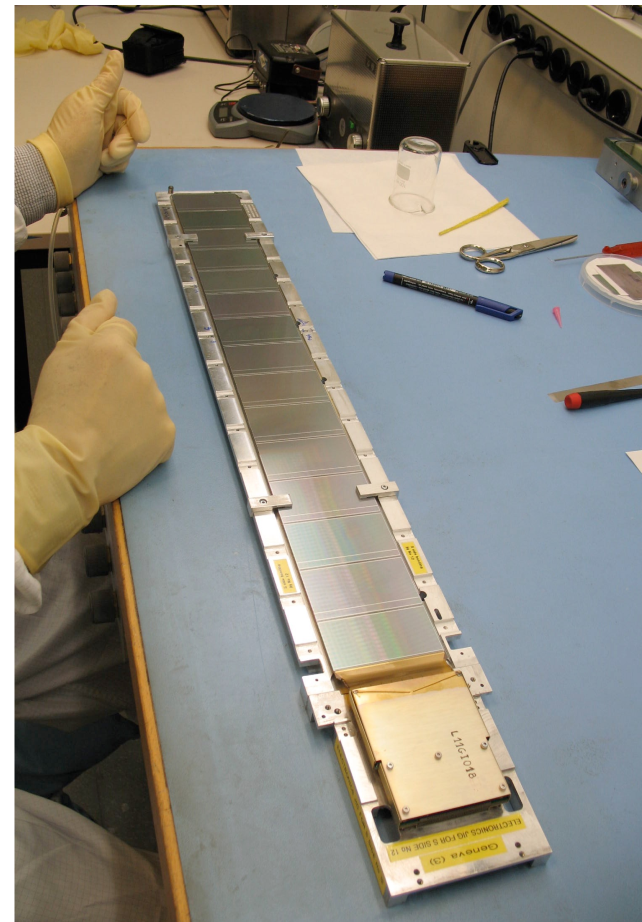
After few months of data on space the galactic cosmic rays (GCR) nuclear abundances are easily observed with an unprecedented statistics

AMS-02: Silicon "ladder"



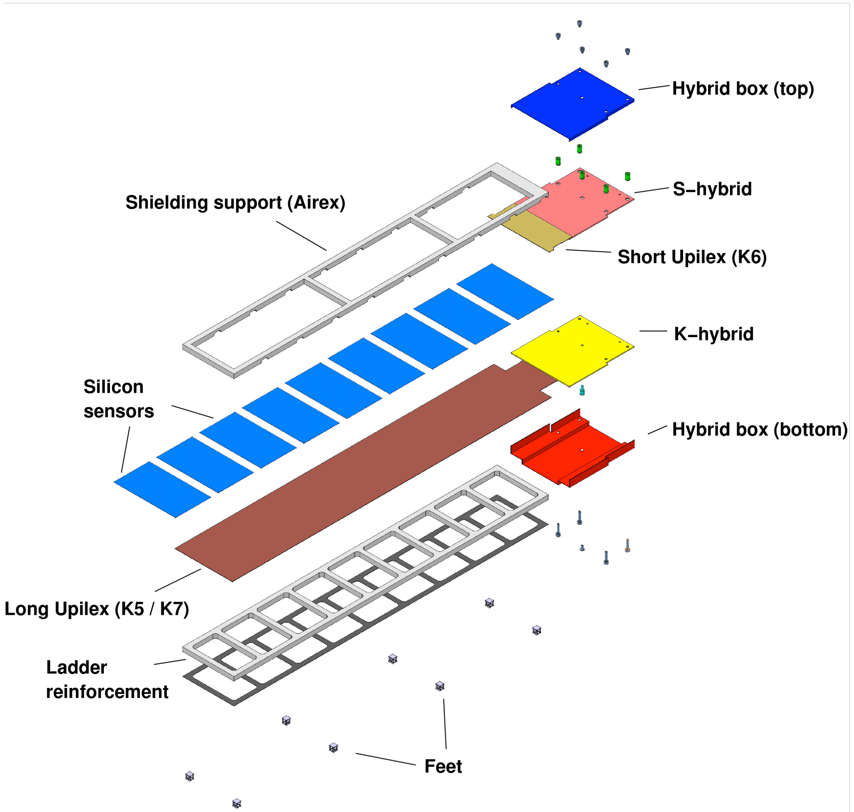
192 flight units

7 – 15 wafers (28 – 60 cm) each

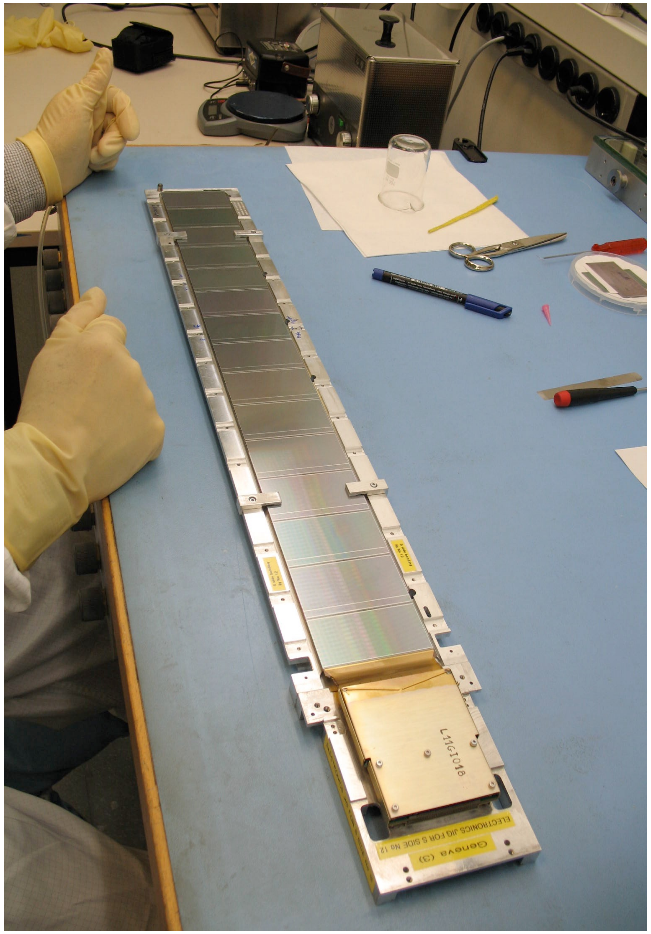


- 1024 high dynamic range, AC coupled readout channels:
  - 640 on junction (S) side
  - 384 on ohmic (K) side
- Implant/readout pitch:
  - 27.5/110 μm ("S"/junction/bending side)
  - 104/208 μm ("K"/ohmic/non-bending side)

AMS-02: Silicon "ladder"



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

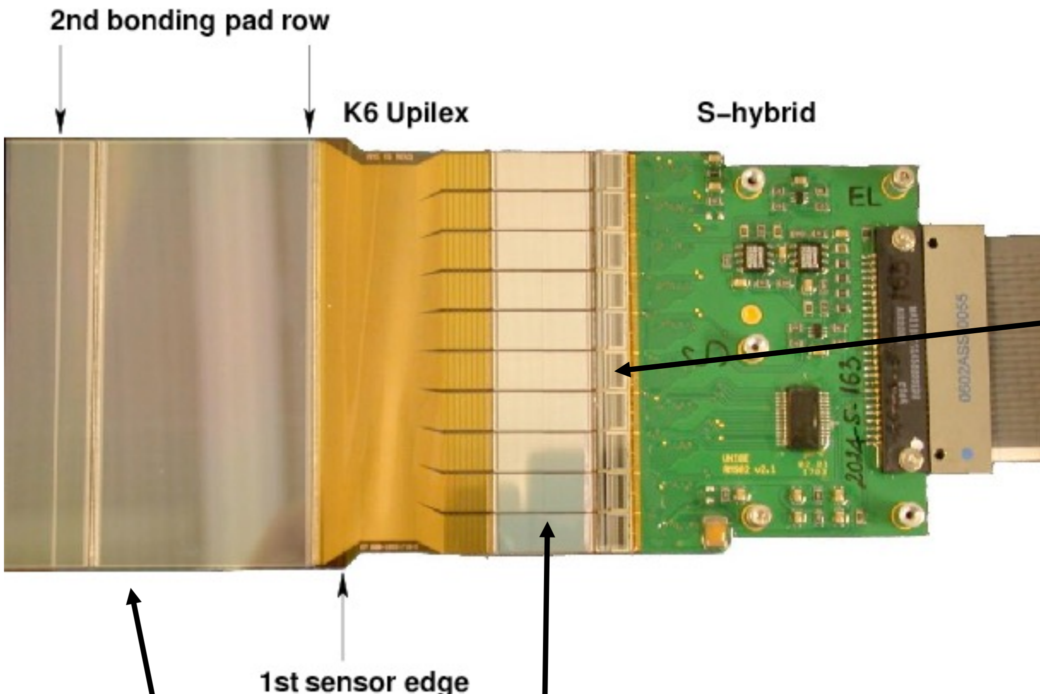


- C_b = 7pF
- C_{strip} = 1.2pF/cm

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

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

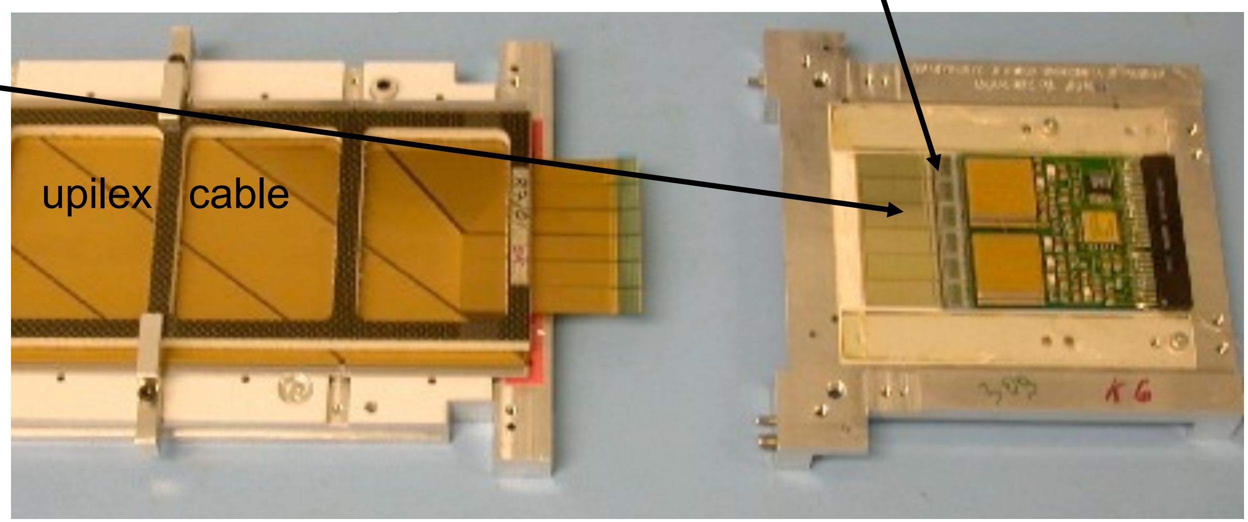
AMS-02: Ladder hybrids



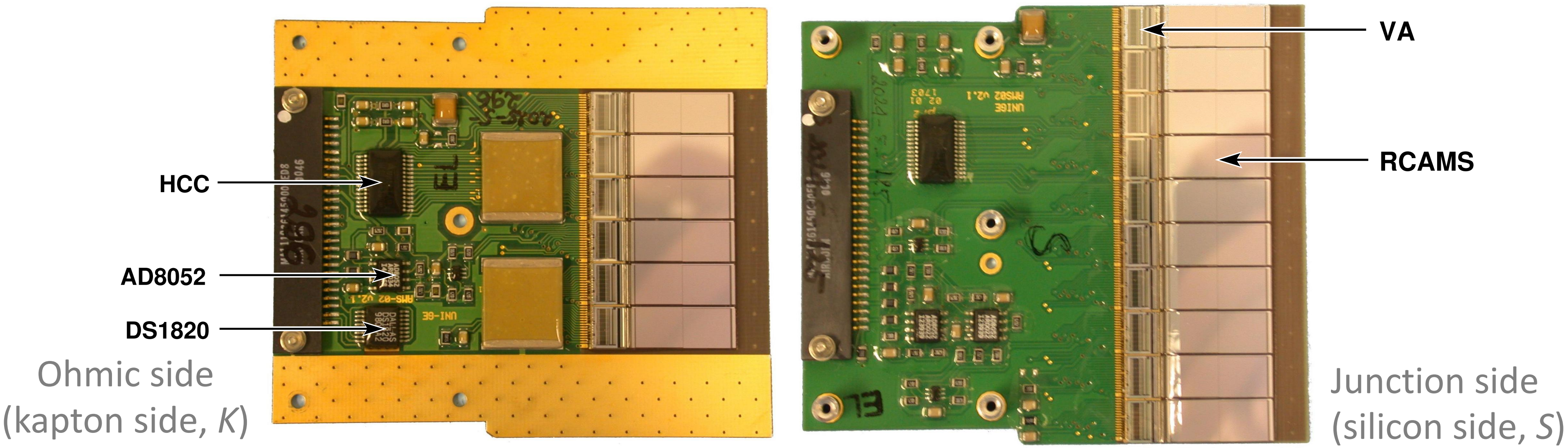
6-10 *VA_hdr64a* (IDEAS, NO)
640 channels, 0.7 mW power each
CR-RC shaper and S&H
4 μs shaping time
100 MIP dynamic range

700 pF coupling capacitances

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



AMS-02: Front End (“hybrids”)

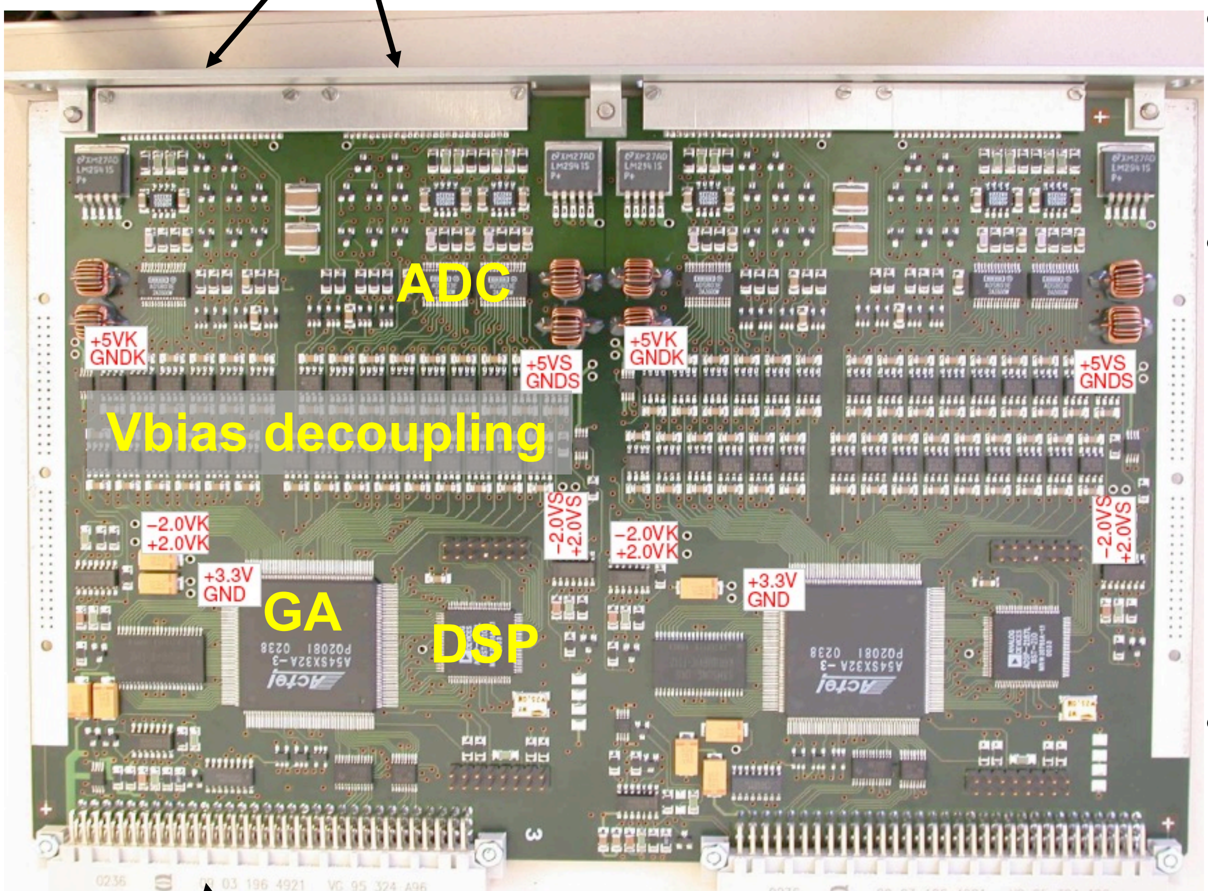


AMS-02 Front End circuit:

- 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: Data Reduction Board (TDR2)

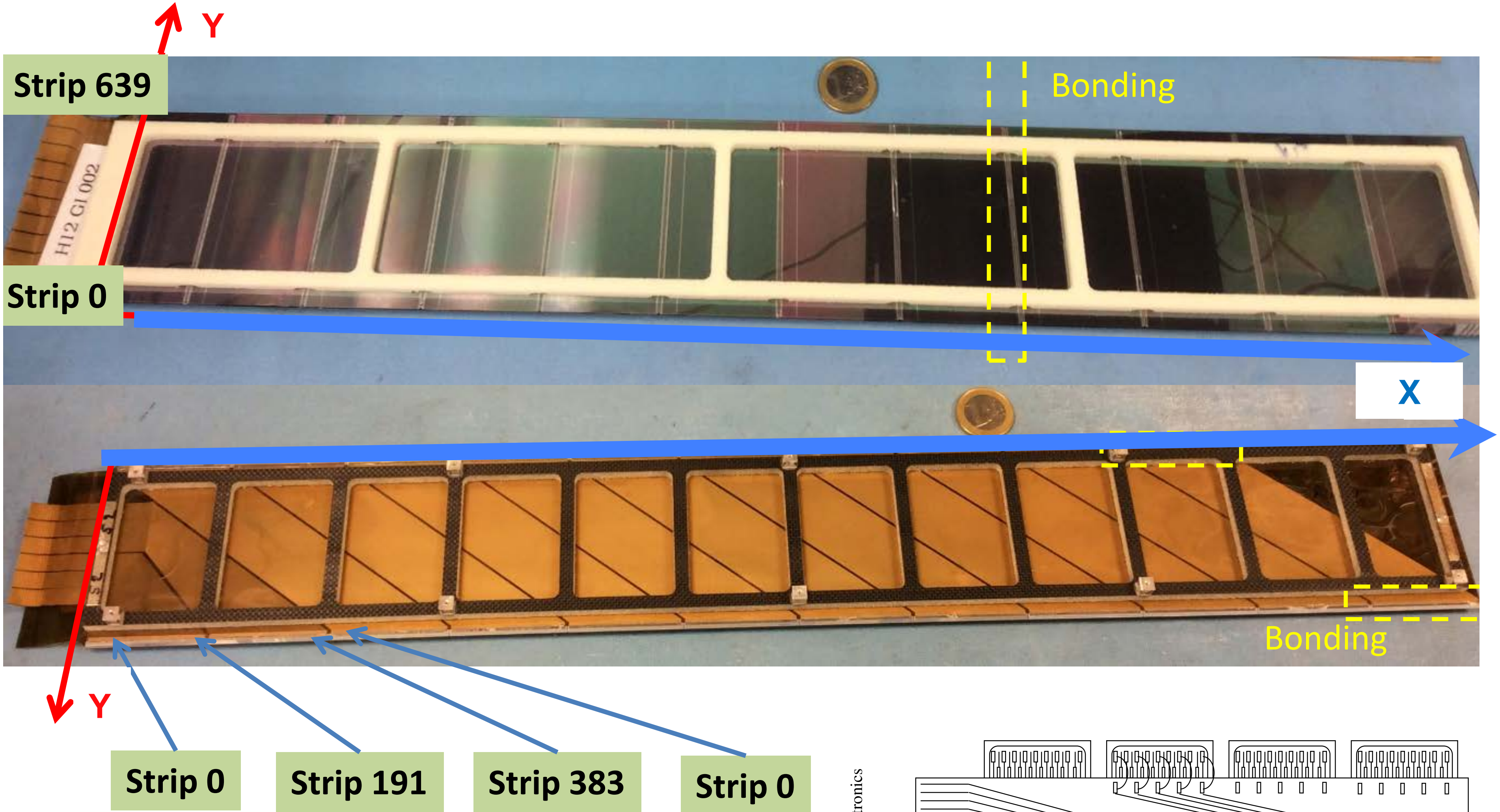
analog signal in from a ladder

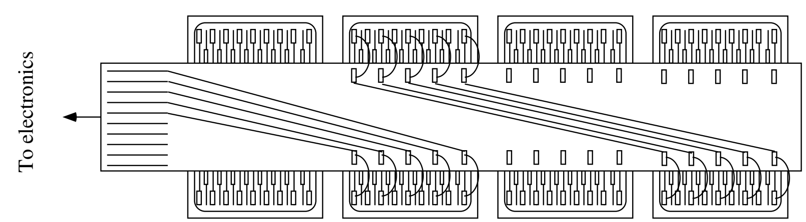


compressed digital out to crate backplane

- 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 "ladder"



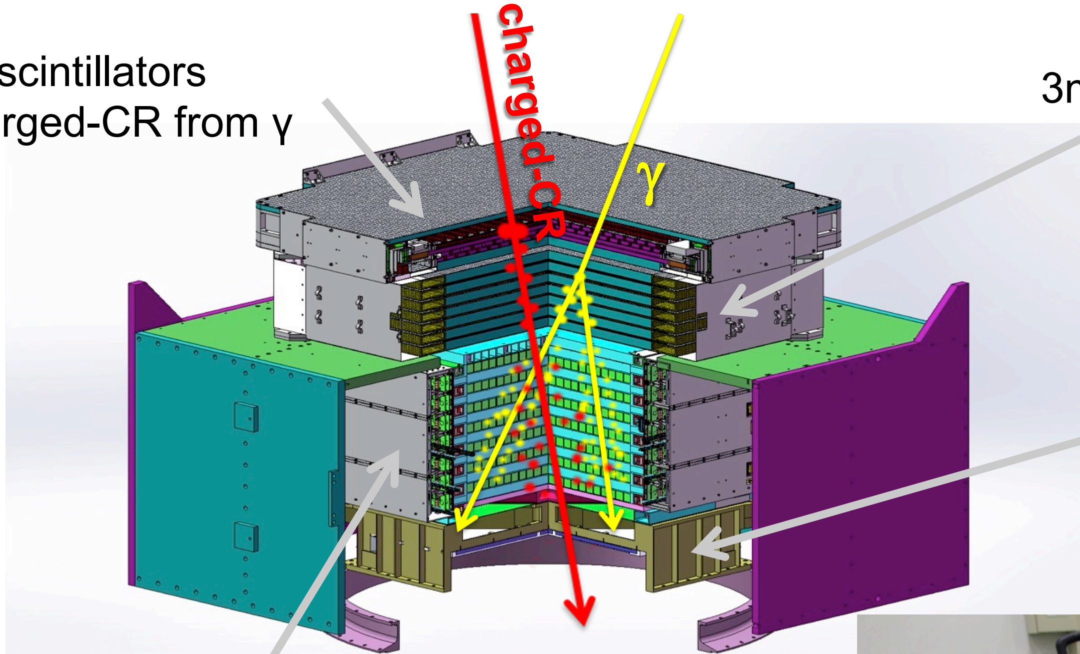


"multiplicity" (or "ambiguity"): the 1500-3000 K-side channels needed for each ladder are "merged" into 384.

DAMPE: DArk Matter Particle Explorer

PSD: scintillators
Z, charged-CR from γ

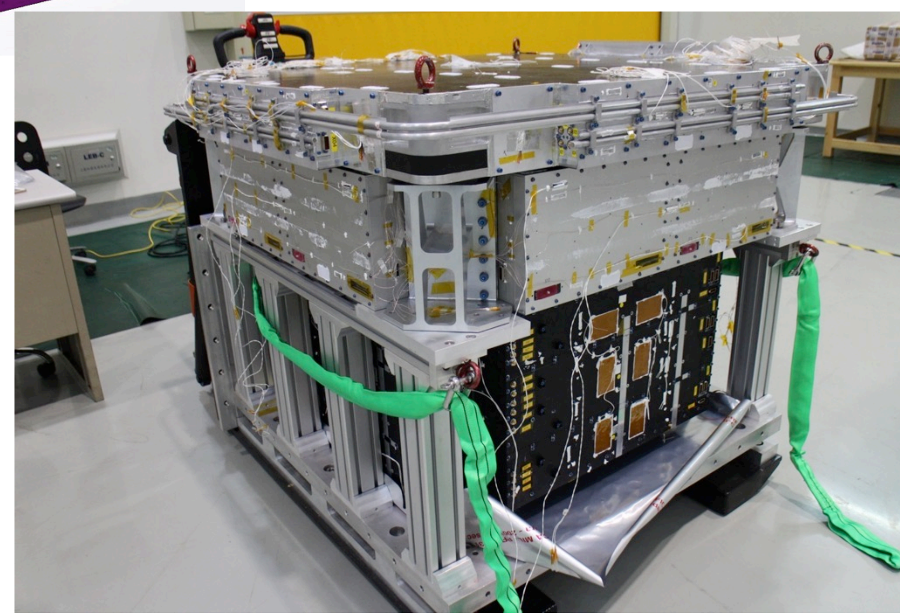
STK: 6 tracking planes +
3mm tungsten γ converter, Z,
tracking for charged-CR



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

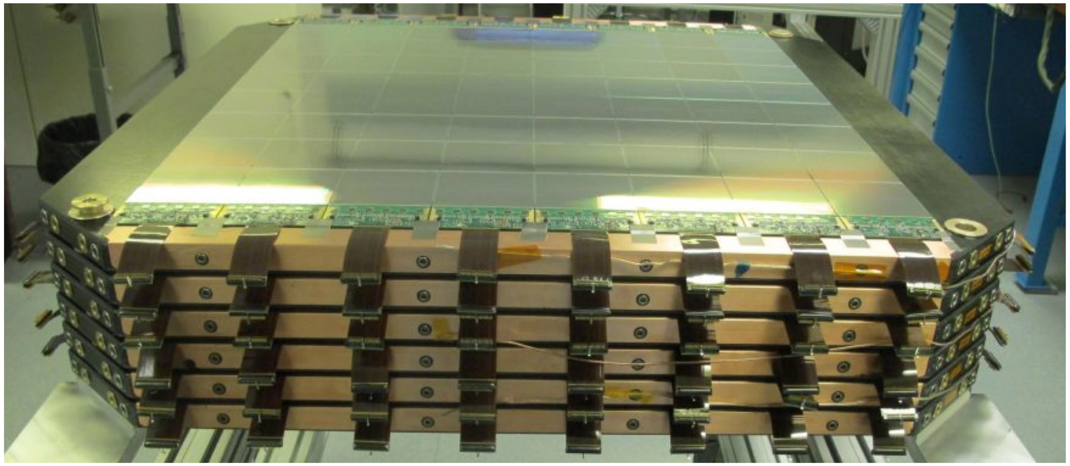
BGO: 308 calorimetric BGO
bars (~31 radiation lengths)
Trigger, E measurement

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

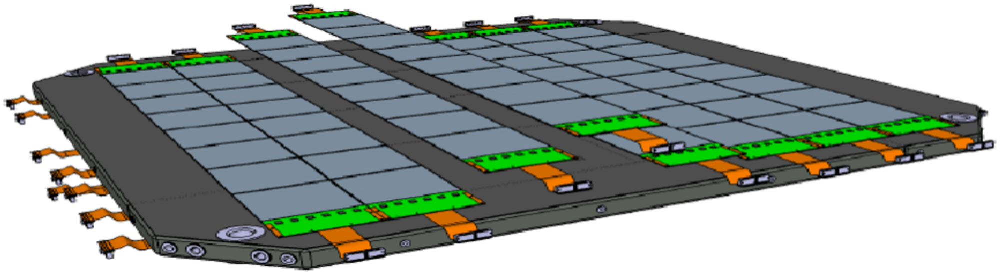


DAMPE: Silicon-Tungsten Tracker-Converter

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