# IFD2022
# Workshop on Future Detectors
# SFIDE FUTURE: underground


Aldo Ianni

INFN-LNGS


17/10/2022

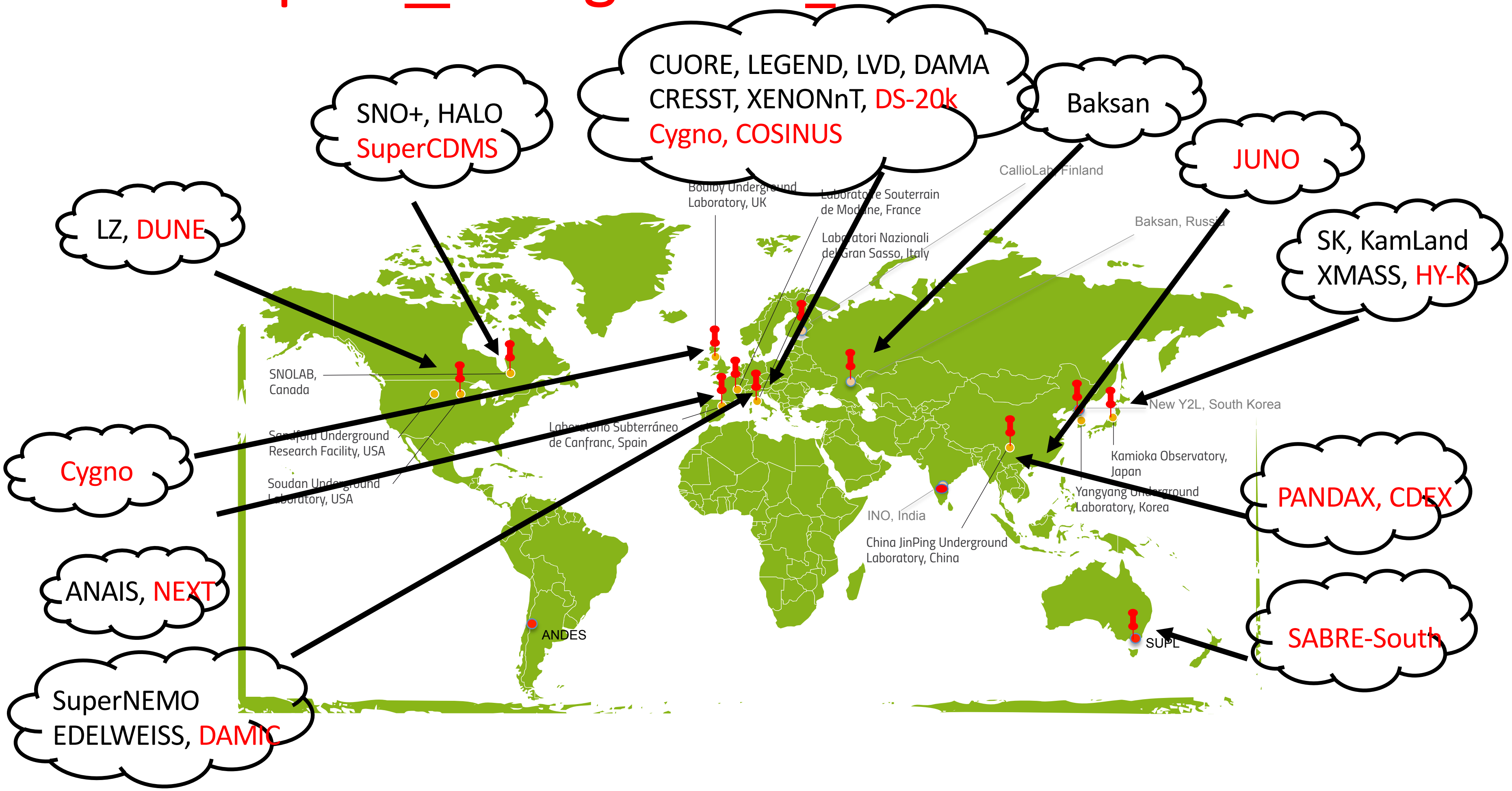
# Physics case and detectors in ULs

- Direct detection of Dark Matter
  - WIMP-like > 10 GeV/$c^2$
  - WIMP-like < 10 GeV/$c^2$
  - Model-independent
- Neutrinoless double beta decay
- Neutrino physics
  - Mass ordering
  - Oscillation parameters
- Detectors
  - Massive organic liquid scintillators
  - Massive TPC with LXe, LAr, Gxe
  - Bolometers
  - Crystals arrays

# DM Direct detection not in ULs

- Solar axions:
  - low background (~ $10^{-7}$ cts/keV/cm$^2$/s ) high sensitivity X-rays detectors (M. Camerlingo)
  - large-size super-conducting magnets
- QCD axions and ALPs
  - cryogenic technology
  - large-size super-conducting magnets
  - low power microwave cavities ($10^{-21}$ W)

# Map of Underground Labs: SN detectors



# Innovations required [1]

- **Advancement in radio-purity assay**
  - need measurement to the O(1) $10^{-12}$ g/g level of $^{238}U$, $^{232}Th$, and $10^{-10}$ g/g level of $^{40}K$
  - Improvement in detectors radiopurity
    - exploit Cu electro-forming technology
    - exploit PSD
- **Advancement in Rn-free environments**
  - $< 100$ mBq/$m^3$
  - crucial for Dark Matter detectors assembly
- **Advancement in Additive Manufacturing**
  - low background, light and high radio-purity components
  - testing atomization of e-formed Cu and other high radio-purity materials
  - testing mechanical properties at room and cryogenic temperature
- **Gd-loaded water Cherenkov detectors** (A. Mancuso)
  - high physics case potentiality
  - active neutron veto
  - selection of high radio-purity Gd salt
  - loading and unloading

# Innovations required [2]

- **Advancement in SiPM-based photodetectors**
  - low background (~mBq/unit) electronics (M. da Rocha Rolo)
  - cryogenic applications (A. Falcone) and refrigerated (NEXT, JUNO ND)
  - large (10 $m^2$) SiPM arrays (L. Consiglio, F. di Capua)
  - packaging in controlled environment (L. Consiglio)
- **Large LXe and LAr detectors** (M. Selvi, F. di Capua)
  - procurement
  - underground argon
  - photodetection (talk on DARWIN) and partnership with industry
  - for LAr efforts by vendors to achieve PDE to avoid without wavelength shifter
  - TPB coating by vacuum evaporation and other deposition techniques
    - Issue with large surfaces, aging and low temperature use (shrinking) with TPB coating
    - Alternative to TPB such as PEN (poly methyl metacrylate)
  - Ar-Xe mixture to increase LY

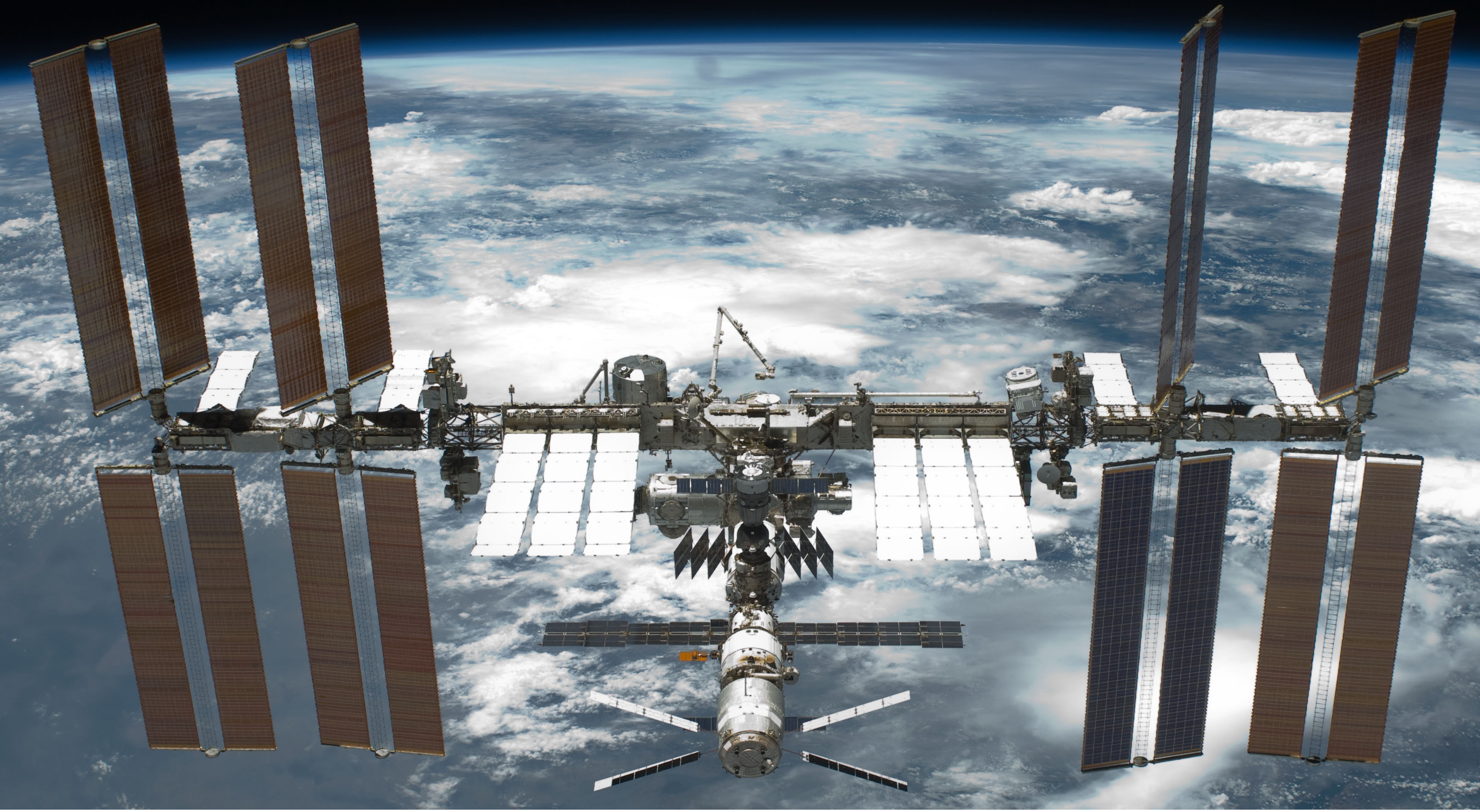
# Innovations required [3]

- **Cryogenic detectors at mk scale**
  - understanding of the events created by the accumulation and release of microscopic stress
  - reduction of vibrational noise coming from pulse tubes and the optimisation of the response in low background facilities
- **Crystal growth facilities**
  - DM and DBD physics case
  - Underground growth
  - partnership with industry
- **Model-independet DM signature**
  - High radio-purity crystals with industrial partnership
  - Gas TPC with O(keV) threshold high ER rejection power (F. di Giambattista)

# Challenges for facilities Underground

- Massive TPC with cryogenic nobel gas
  - Common to several projects
- Gas TPC at atmospheric and high pressure
  - Specific projects
- Large instrumented aread with photosensors in the VUV
  - Common to several projects
- Integrated low background cryogenic electronics
  - Common to several projects
- Radiopurity and signal transmission
  - Common to several projects
- Large light collection coverage (with PMTs or SiPMs)
  - Common to several projects
- Depleted argon and high purity xenon
  - Specific projects (growing interest)
- mK scale detectors technology and background reduction
  - Common to several projects (interest for quantum computing)

# Sfide future: Spazio
# IFD 2022 – Workshop on future detectors



**Matteo Duranti**

Istituto Nazionale Fisica Nucleare – Sez. di Perugia

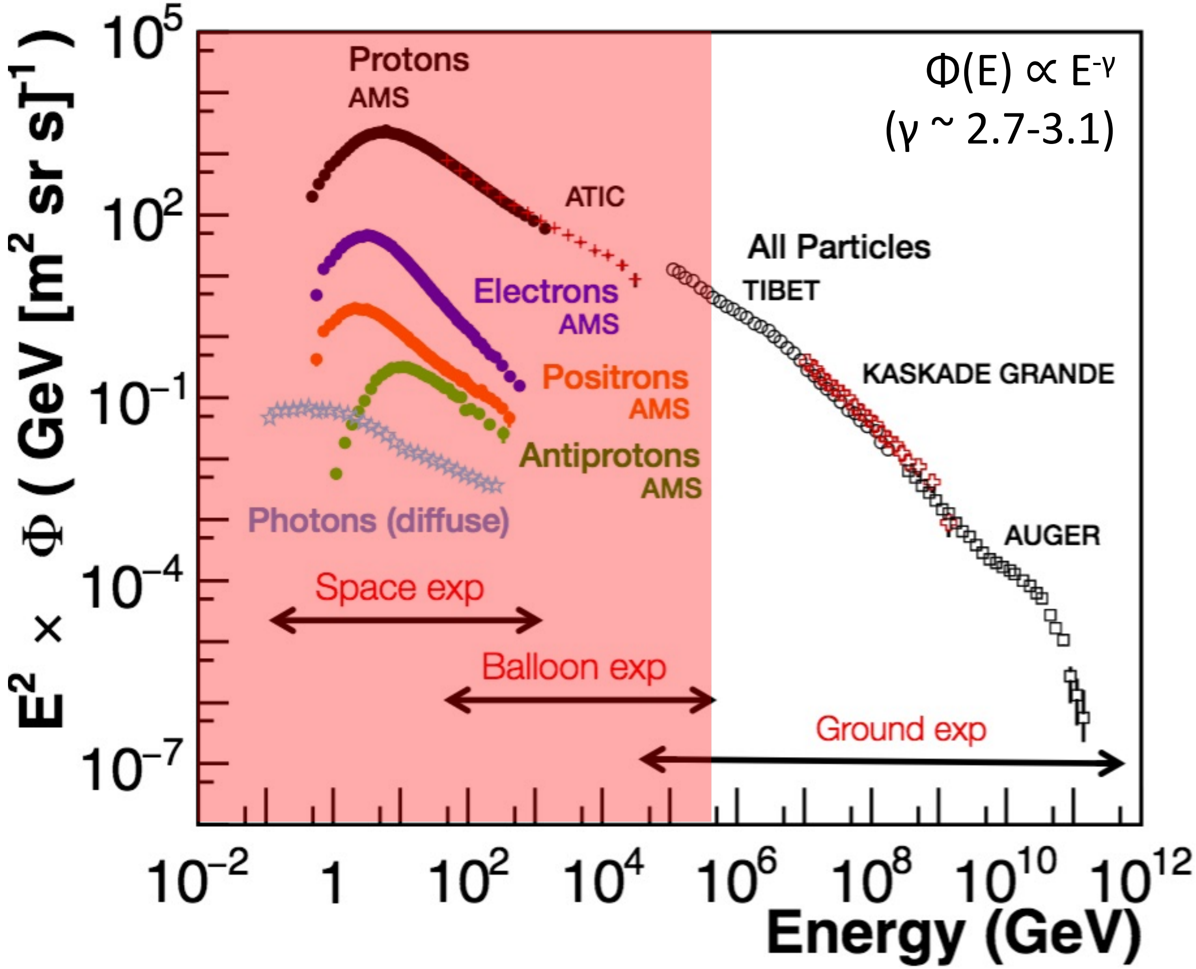
INFN PERUGIA

# Cosmic Rays

measuring in Space (or balloon) permits to measure at single particle level
→ precise composition and spectra measurement

BUT

cosmic ray spectra are tipically power laws:
1 order of magnitude in energy → 2 orders of magnitude in flux (i.e. in statistics)

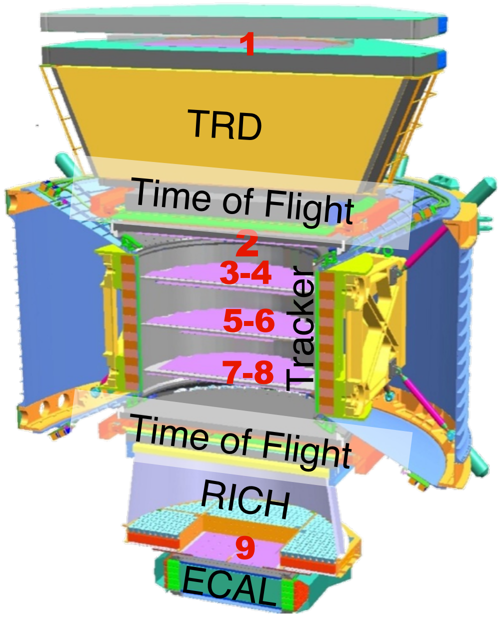



Physics Case:

- extend statistics at high energy (PeV) for all species
- antimatter
- high statistics photons with % E resolution
- …

# Astro-particle detectors – state of the art

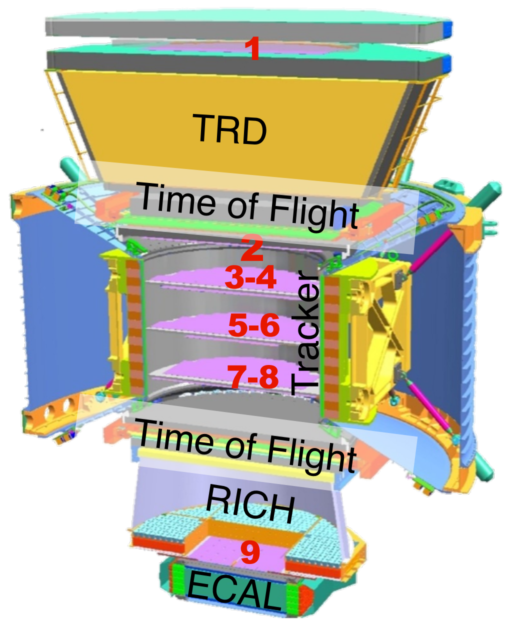
AMS-02 (in orbit since 16/05/2011):



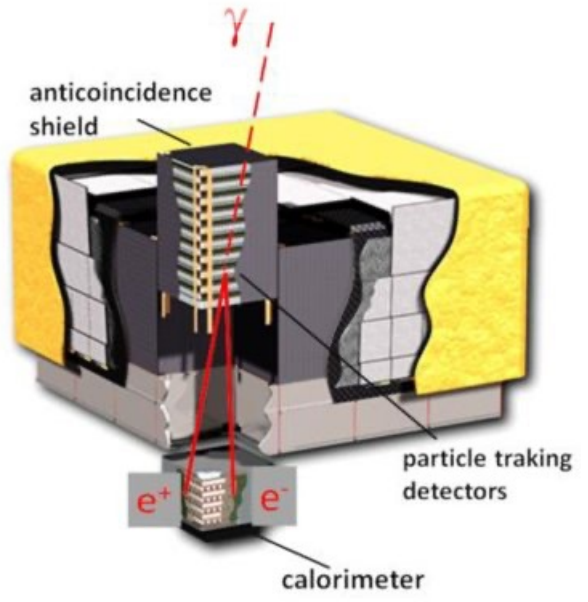

- accurate spatial resolution (<10 μm) Si-μstrip for Rigidity measurement up to TVs;
- Electromagnetic CALorimeter (17 $X_0$) for $e^+$, $e^-$, γ Energy measurement;
- Time of Flight ($\sigma_t \sim$ 120 ps, $\sigma_\beta \sim$ %) for trigger, arrival direction (upward/downward) and isotopic composition (up to few GeV, then Ring Imaging Cherenkov, $\sigma_\beta \sim$ 0.1 %);
- 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;
- ~ 2 kW

# Astro-particle detectors – state of the art

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



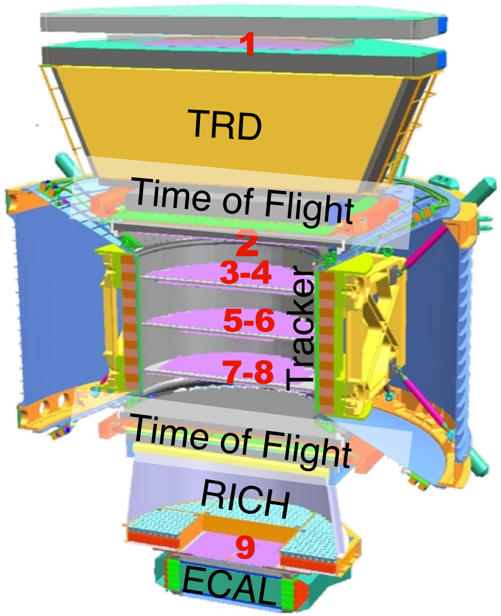

Fermi-LAT (in orbit since 11/06/2008):



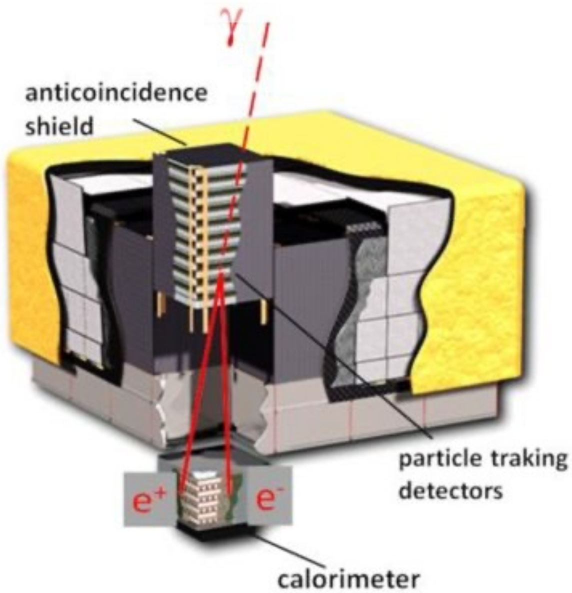

- moderate spatial resolution (~60 µm) Si-µstrip for pair-production measurement;
- electromagnetic calorimeter (10 $X_0$) for $e^+$, $e^-$, γ Energy measurement;
- plastic scintillator anticoincidence shield for charged CR veto;
- electromagnetic calorimeter to perform e/p identification;
- Tungsten plates in the tracker for photon conversion;
- ~ 1.5 kW

# Astro-particle detectors – state of the art

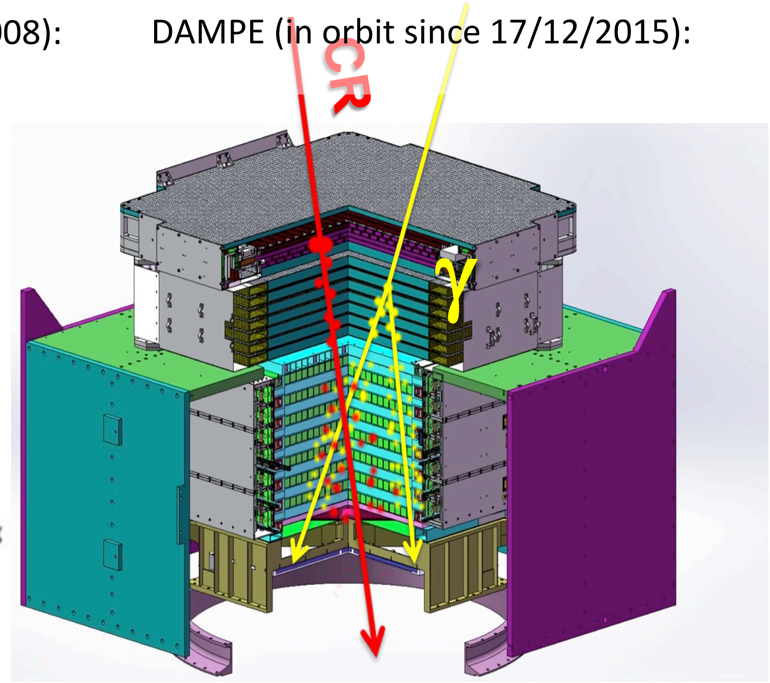
AMS-02 (in orbit since 16/05/2011):




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;
- ~ 0.5 kW

# Detectors/technologies used

- calorimetry
- tracking/spectrometry
- scintillators/anti-coincidence/Time-of-Flight
- Additional detectors?

# Detectors/technologies used/foreseen

- calorimetry
  - electromagnetic (sampling or homogeneous)
  - segmentation used for PID (e/p separation)

- tracking/spectrometry

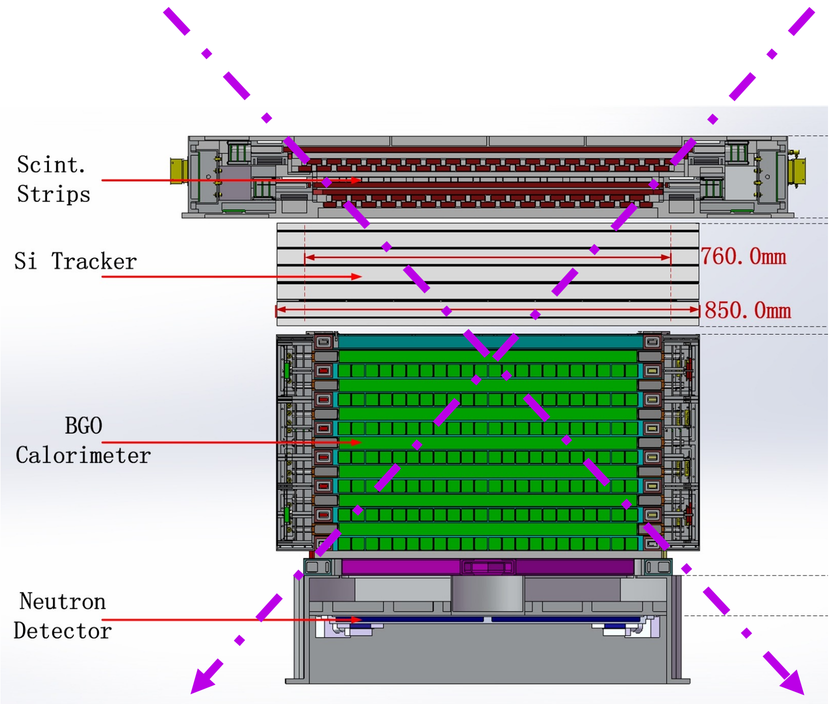
- scintillators/anti-coincidence/Time-of-Flight

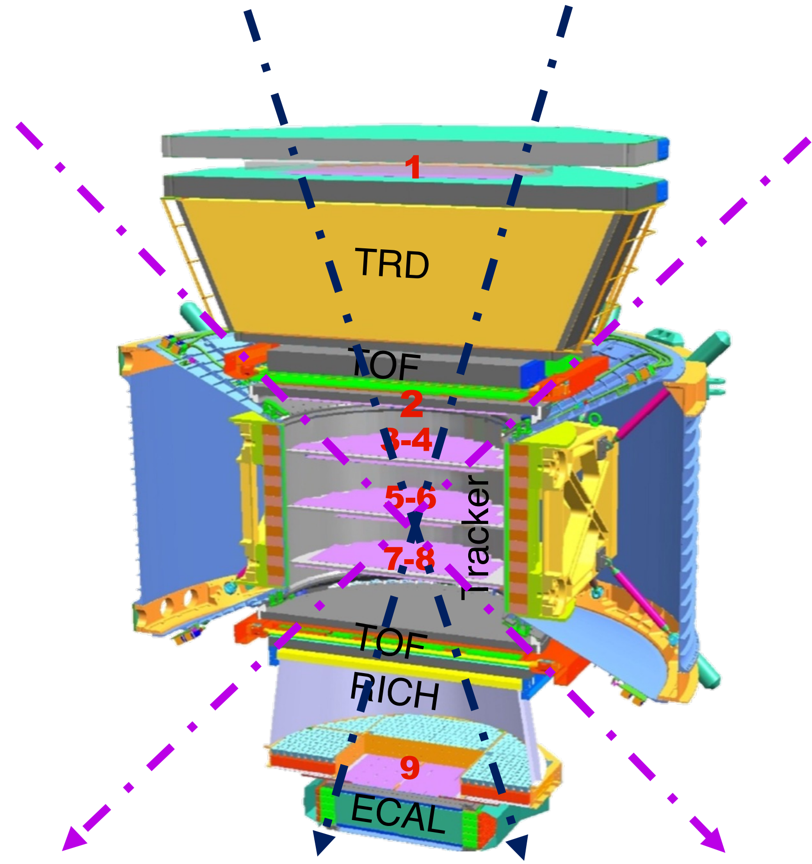
- Additional detectors?

# Current operating "telescopes"

DAMPE Field of View ~ 1 sr
→ Acc ~ 0.3 $m^2$ sr

AMS Inner ~ 0.5 $m^2$ sr
AMS Full Span ~ 0.05 $m^2$ sr

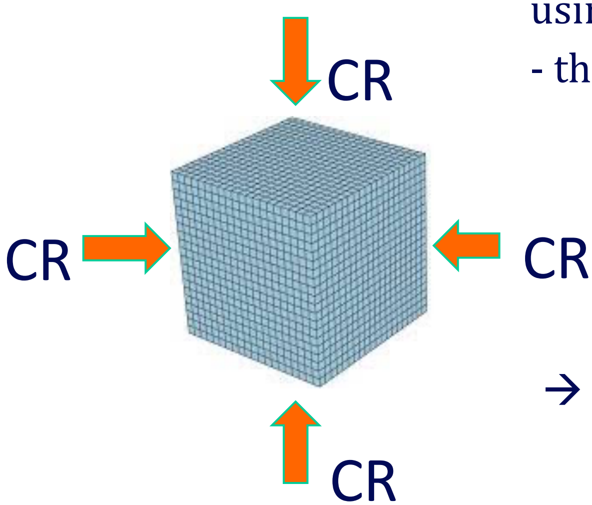



All the current and past detectors are designed as 'telescopes': they're sensitive only to particles impinging from "the top"

limited FoV → small acceptance

# Astro-particle detectors – planned and dreamed

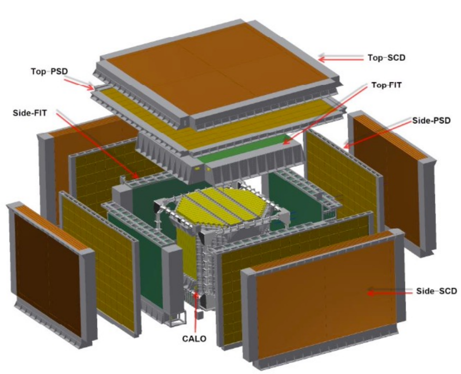



- exploit the CR "isotropy" to maximize the effective geometrical factor, by using all the surface of the detector (aiming to reach $\Omega = 4\pi$)
- the calorimeter should be highly isotropic and homogeneous:
  – the needed depth of the calorimeter must be guaranteed for all the sides (i.e. cube, sphere, …)
  – the segmentation of the calorimeter should be isotropic

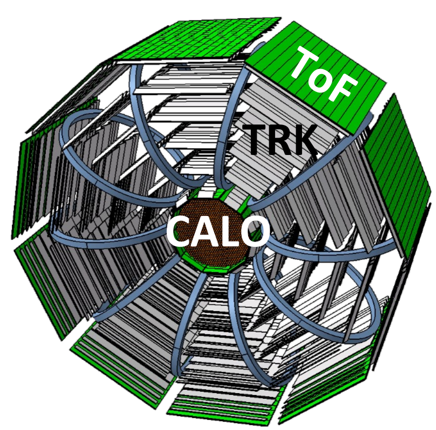
→ this is in general doable just with an homogeneous calorimeter

→ CaloCube

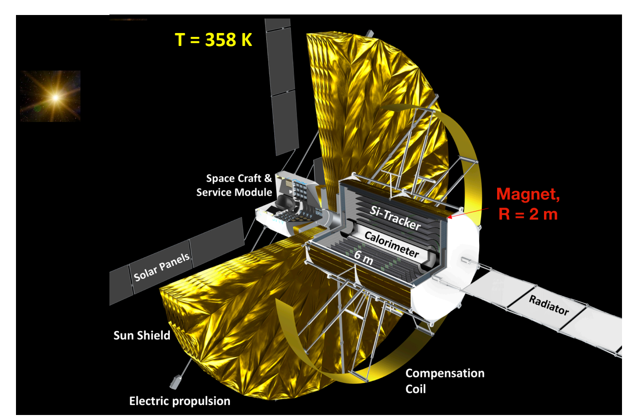
HERD on the CSS (2027):




ALADInO @L2 (2050?):

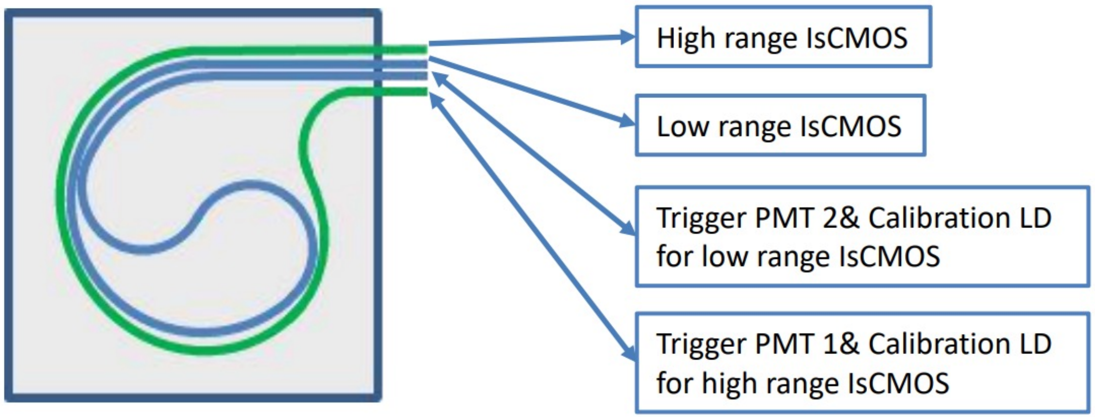


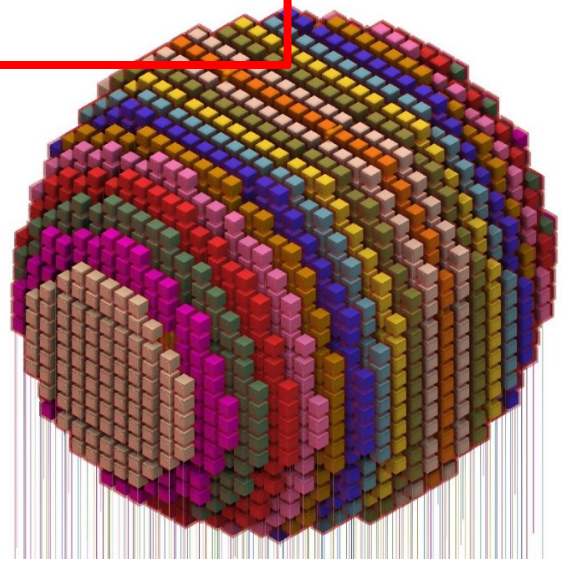

AMS-100 (2050?):

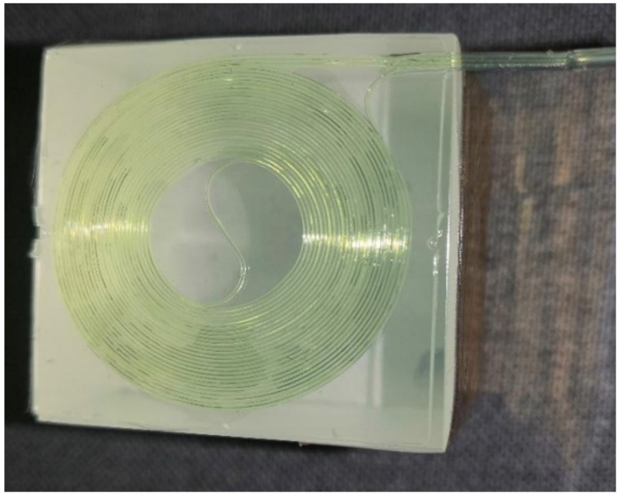


# HERD calorimeter

- dual read-out (IsCMOS/PD) + PMT for trigger (only selected channels)
- two ranges for WLSF and two different range PDs





open area for the PD glueing

# Detectors/technologies used/foreseen

- Calorimetry:
  - Electromagnetic (sampling or homogeneous)
  - Eegmentation used for PID (e/p separation)
  - CaloCube/4π (cubes/prisms read-out by PDs, SiPMs or CMOS pixels. Dynamic range!)
- Tracking/spectrometry
- Scintillators/anti-coincidence/Time-of-Flight
- Additional detectors?

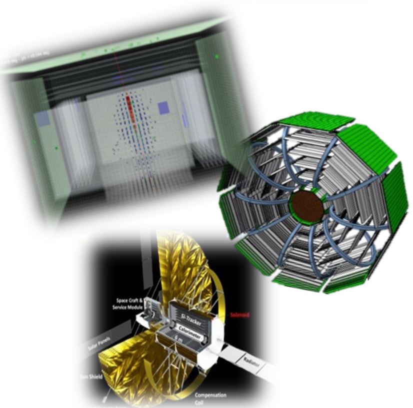
# Silicon Microstrip detectors in space

(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)

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

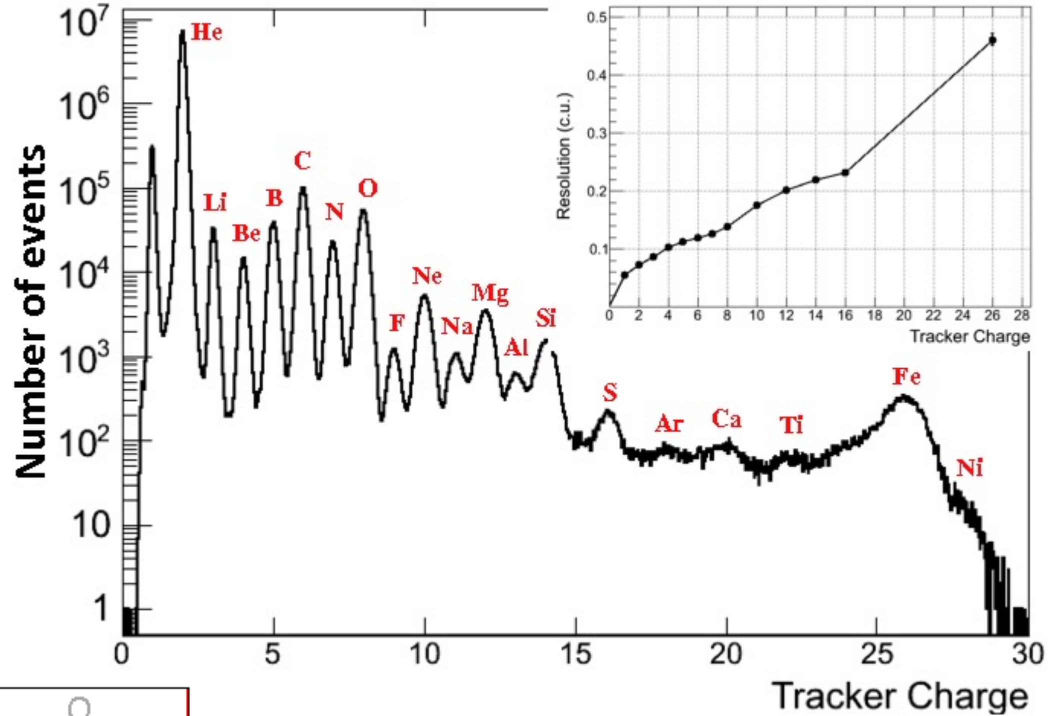
# High dynamic range energy deposit / charge measurement

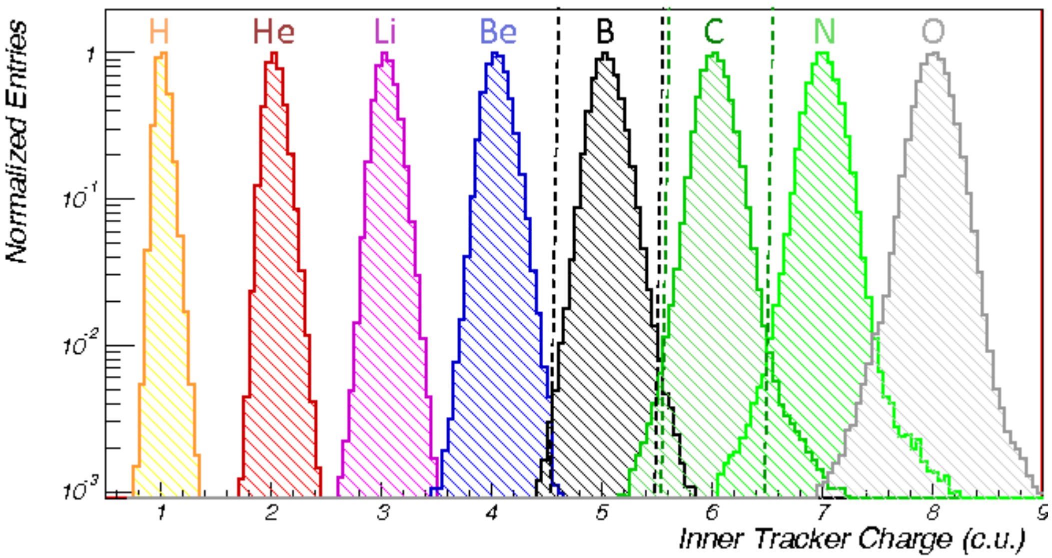
Often silicon detectors are used as (main) charge detectors:

→ analog readout

→ full depletion

→ high dynamic range required




If we go with MAPS (after solving the problem of # of channels and power):

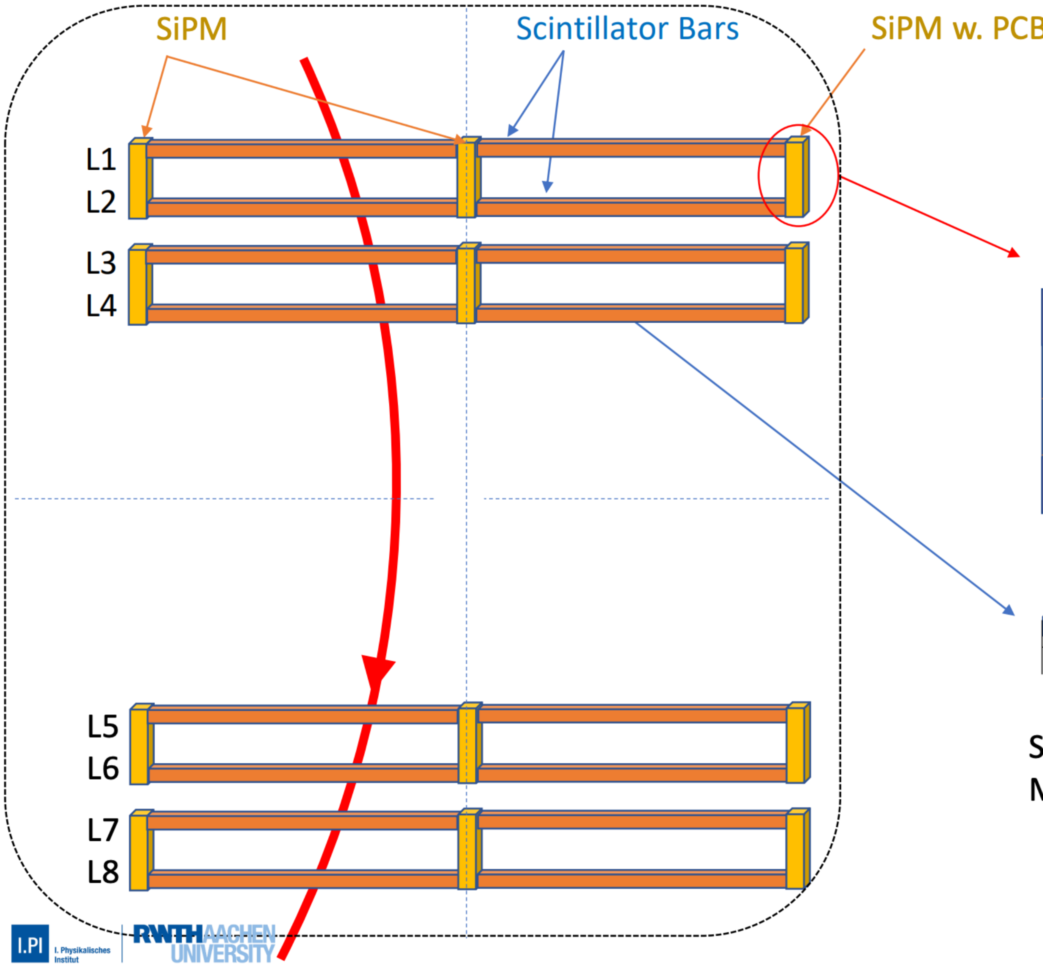
FD-MAPS?

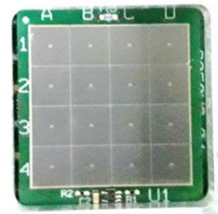
# Detectors/technologies used/foreseen

- Calorimetry
  - Electromagnetic (sampling or homogeneous)
  - Segmentation used for PID (e/p separation)
  - CaloCube/4π (cubes/prisms read-out by PDs, SiPMs or CMOS pixels. Dynamic range!)
- Tracking/spectrometry
  - < 20 W/m$^2$. Si-μstrip or FD-MAPS?
  - Timing (<100 ps)?
  - High Temperature Superconducting Magnets
- Scintillators/anti-coincidence/Time-of-Flight

- Additional detectors?

## AMS-100: Time of Flight System



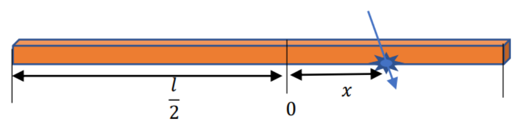



SiPM
**(Hamamatsu S14161-6050HS-04)**

Single Array Size = 6mm × 6mm
Total Nr. Arrays = 4 × 4
Array Connection : Hybrid
VBR = 38V
Peak Sensitivity (450nm, PDE=50%)
Capacitance $C_{SiPM}$ = 2000 pF

| |
|---|
| ON |
| OFF |
| OFF |
| ON |

→ 4 Array signals are summed up and fed into one channel




**(Eljen 228)**

Single Scintillator Size (D×W×L) = 6mm × 25mm × 90 mm
Matching-Factor = 1.0 (fased D×W sides to SiPM)

TOF Time Resolution$(\sigma_t)_{req.}$ $= 20\ (ps)$



$$\sigma_t = (39.3\ \pm 0.1(stst.) \pm 0.7(syst.))\ ps$$

T. Kirn @ VCI2022 https://indico.cern.ch/event/1044975/contributions/4663642/

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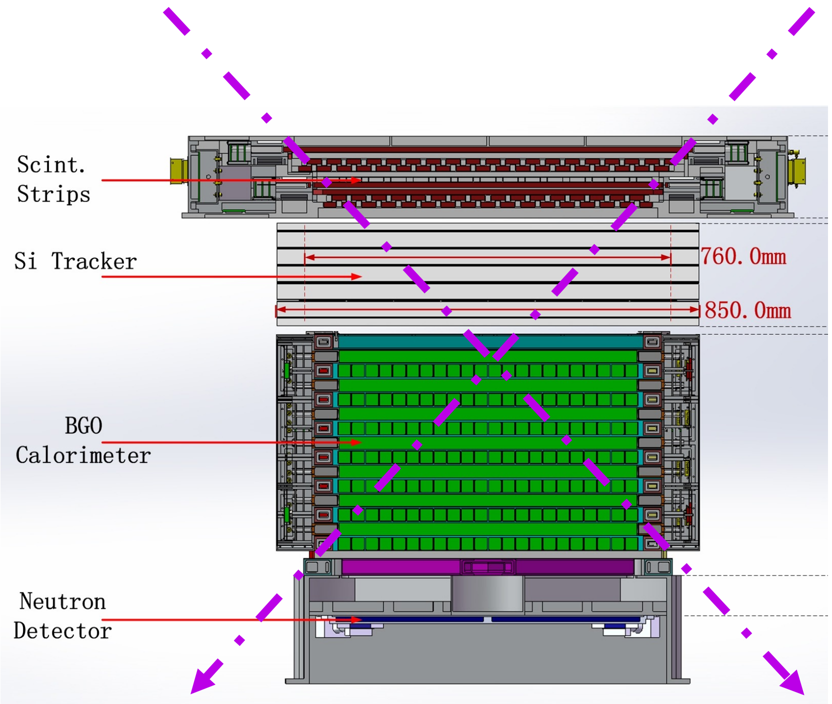
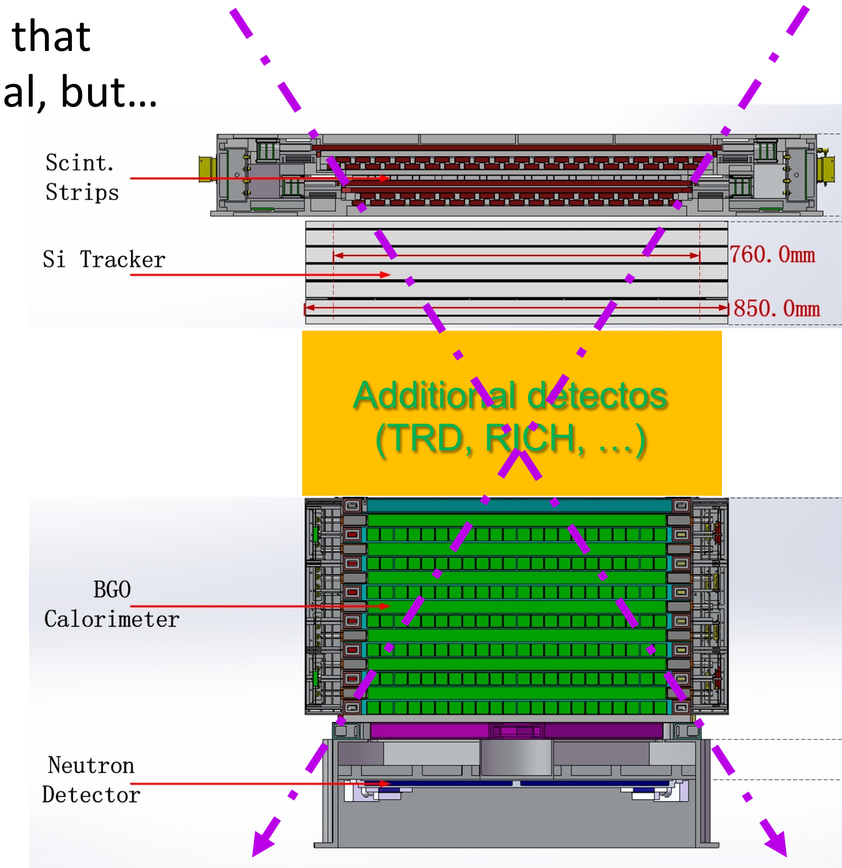
- Tracking/spectrometry
  - < 20 W/m$^2$. Si-µstrip or FD-MAPS?
  - Timing (<100 ps)?
  - High Temperature Superconducting Magnets
- Ccintillators/anti-coincidence/Time-of-Flight
  - Thin (~ 5 mm)
  - Timing (~ 20 ps)
  - High dynamic range for Z measurement
- Additional detectors?

# Adding detectors…

The past and current experience clearly showed that having redundancy in terms of detectors is crucial, but…




There are a net effect:

- reducing the Field of View (i.e. the Acceptance → the statistics)
- increasing the dimension envelope, in contrast with the limited launcher's ogive

→ TRD, RICH, etc… very compact and possibly low material budget

# Detectors/technologies used/foreseen

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- Ccintillators/anti-coincidence/Time-of-Flight
  - Thin (~ 5 mm)
  - Timing (~ 20 ps)
  - High dynamic range for Z measurement
- Additional detectors?
  - Wanted/needed
  - Must be very compact and possibly low material budget

# Sfide future: acceleratori

**IFD 2022**

**Workshop on Future Detectors**

**SFIDE FUTURE**

**Acceleratori**

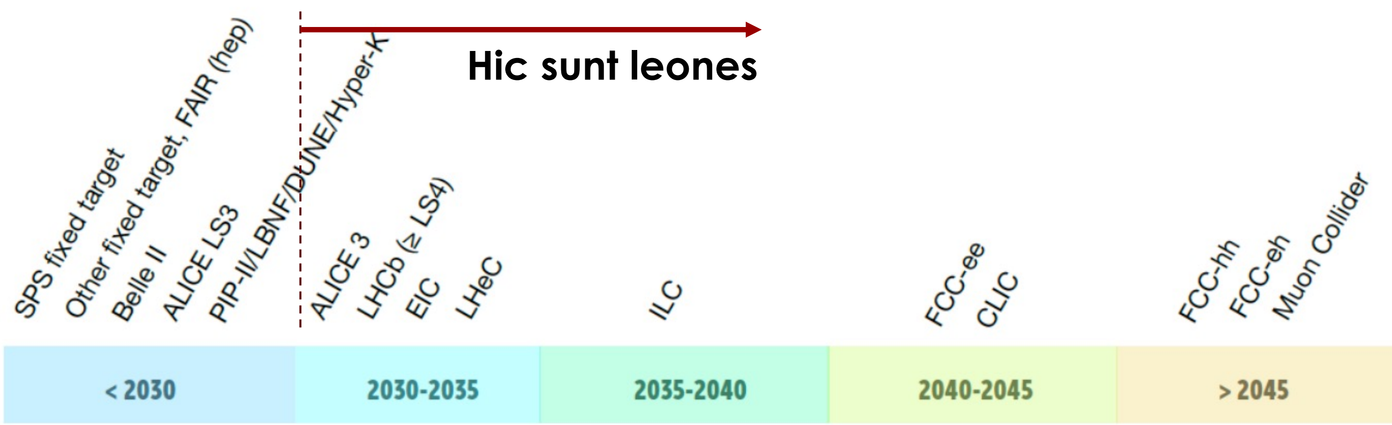
N. Cartiglia
INFN-Torino
17/10/2022

# The R&D problem

**Most of detector R&D money are now funnelled via the construction of HL-LHC (and EIC)**

Once this streams dries out, the funding for R&D will be much lower

How do we finance the detector R&D adequately in the next 20 years?



# The ECFA plan

**"The European Committee for Future Accelerators (ECFA) was mandated by the CERN Council to develop a detector R&D roadmap"**

"In order to address long-term R&D efforts in a coherent way, **the proposal is to set up new detector R&D collaborations (DRDs) anchored at CERN. "**

"At the end of April 2022, a presentation to funding agency representatives followed by a discussion session was held (https://indico.cern.ch/event/1133070/timetable/).

The purpose was to establish whether funding agencies would be able to support the proposed structure.

**In general, the plan of setting up a long-term structured R&D programme involving detector R&D collaborations was supported. In addition, the plan was discussed within Restricted ECFA, shared with the national contact physicists for detector R&D "**

**==> INFN was present, and it did not raise objections**

# More information on DRDs

"There will be a limited number of DRDs, probably 5-7"

==> Il CERN ha esplicitamente limitato il loro numero

**Punto chiave del piano presentato:**

**"As with existing collaborations** (tipo ALICE, CMS, ATLAS..), resources are expected to be awarded to and held at the participating institutes, which would determine the appropriate organisational structure and take ultimate responsibility for meeting the commitments to identified deliverables "

**MOU ed organi di controllo:**

**"The funding agencies would be involved through a dedicated Resources Review Board** (RRB). This board should initially endorse the **sharing of responsibilities among the participating institutes and funding agencies, as laid down in memoranda of understanding (MoUs)** to be prepared by the DRD collaborations. "

**Timeline:**

"DRD collaborations need to **come into existence in 2023**, and requests for **new resources** would typically anticipate a **ramp-up of requirements through 2024/25** before a reasonably steady state is reached in 2026."

# Traduzione del piano ECFA: esempio pratico

**Nel piano ECFA, i DRDs sono organizzati come esperimenti:**

- hanno una lista di CORE costs
- Hanno delle spese di gestione M&O-A,B
- Hanno un MoU
- Sono finanziati dalle funding agency

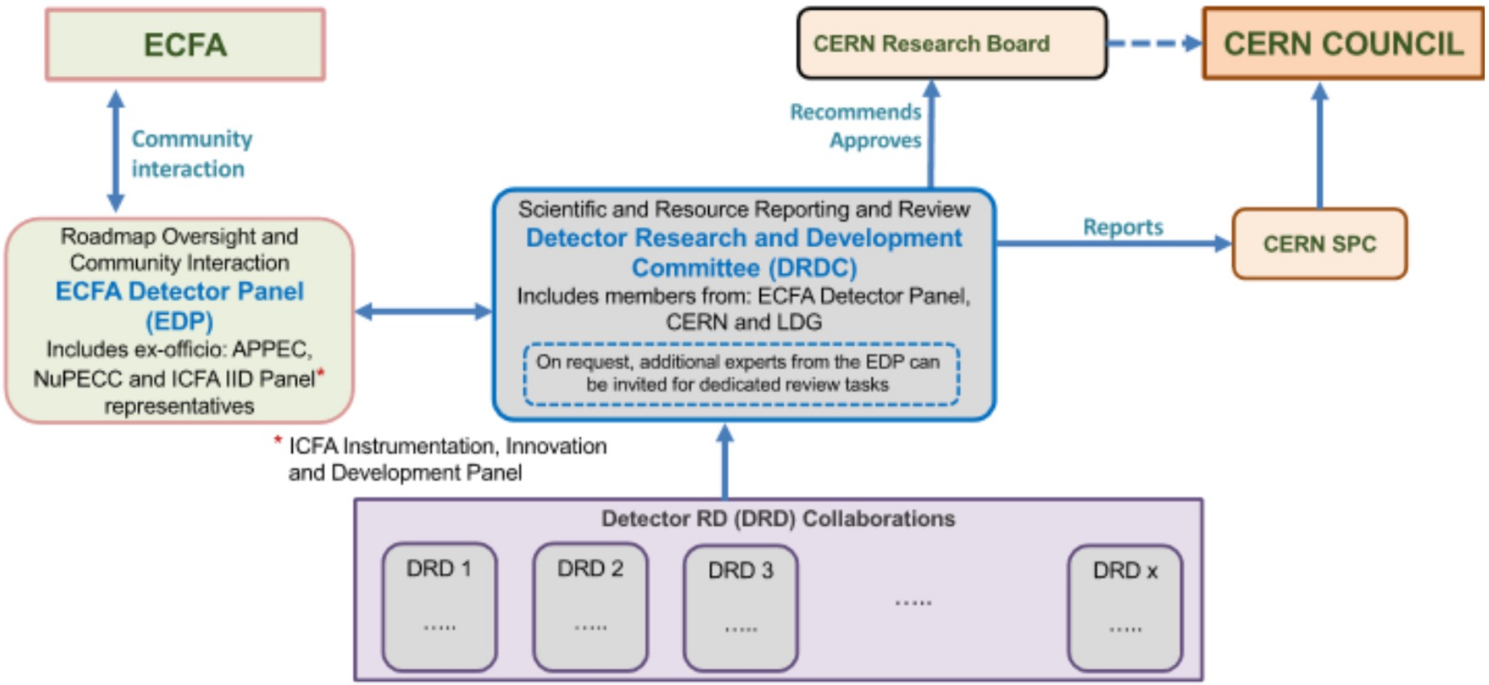
**Esempio di finanziamento ad un esperimento:**

- CMS decide che ha bisogno di un **nuovo tracker**
- Si sceglie la tecnologia, si valuta il costo, si fa un TDR, un EDR, oversight di P2UG, RRB…
- Le nazioni prendono in carico vari aspetti del tracciatore
- L'INFN paga (su fondi di Gruppo I) la sua parte

**Equivalenza con un DRD**

- Il DRD3 (stato solido) decide che le **interconnessioni tra strati di silicio sono fondamentali**
- Si sceglie la tecnologia, si valuta il costo, si fa un TDR, un EDR..
- Le nazioni prendono in carico vari aspetti del processo
- L'INFN paga (su fondi di Gruppo XXX) la sua parte

# The DRDs organizational workflow



# Lista dei possibili DRDs

**Nell'ECFA report ci sono 9 capitoli, i DRDs ricalcheranno questa divisione (non interamente)**

1. Gaseous detectors
2. Liquid detectors
3. Solid-state detectors
4. PID and photon detectors
5. Calorimetry
6. Quantum
7. Electronics
8. Integration
9. Training

# Conseguenze di questo modello di R&D all'interno dell'INFN

**il futuro, di nuovo ignoto, scorre verso di noi…. (Sara O'Connor, Terminator II )**

Al momento, **l'INFN non ha ancora preso una posizione ufficiale** sul metodo di finanziamento proposto dai DRDs.

Il management di ECFA è però soddisfatto del fatto che **nessuna funding agency abbia avanzato dubbi nelle varie presentazioni.**

La transizione deve essere rapida, firma MoUs nel 2023, e nel 2024 ci si aspetta i primi finanziamenti

# Challenges for facilities at accelerators

**Need to find a model to finance detector R&D behyond the upgrade for HL-LHC.**

**This model needs to:**

- Be "non-experiment" specific, it should be linked to an R&D, not to a given experiment/facility(CLIC, FCC-ee, muColl…)
- Be able to tackle and solve very complex and costly projects
- Be based on the collaboration with other countries
- Have long temporal horizon (10-20 years)

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# Future challenges

## Space:

Calorimetry

- electromagnetic
- segmentation used for PID
- CaloCube/4π (Dynamic range!)

Tracking/spectrometry

- < 20 W/m$^2$. µstrip or FD-MAPS
- Timing (<100 ps)
- HTS Magnets

Scintillators/ACC/ToF

- Thin (~ 5 mm)
- Timing (~ 20 ps)
- High dynamic range

Additional detectors?

- wanted/needed
- must be very compact

## Underground:

Massive TPC with cryogenic nobel gas

Common to several projects

Gas TPC at atmospheric and high pressure

Specific projects

Large instrumented aread with photosensors in the VUV

Common to several projects

Integrated low background cryogenic electronics

Common to several projects

Radiopurity and signal transmission

Common to several projects

Large light collection coverage (with PMTs or SiPMs)

Common to several projects

Depleted argon and high purity xenon

Specific projects (growing interest)

mK scale detectors technology and background reduction

Common to several projects (interest for quantum computing)

## Accelerators:

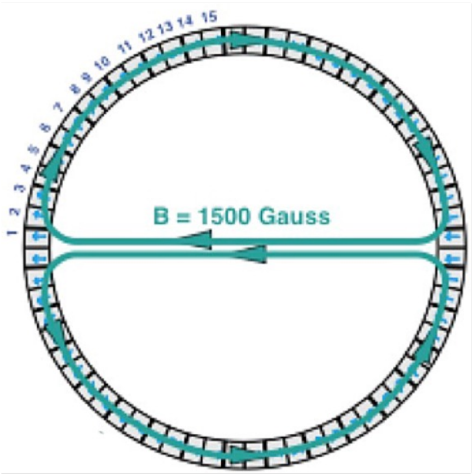
Need to find a model to finance detector R&D behyond the upgrade for HL-LHC.

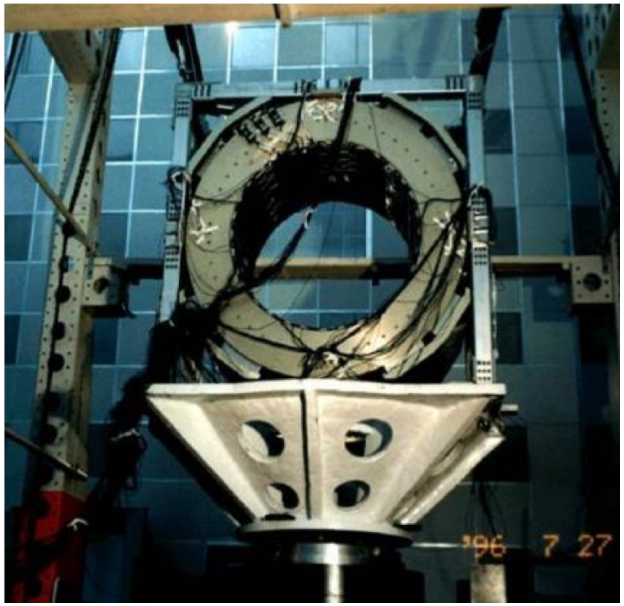
This model needs to:

- Be "non-experiment" specific, it should be linked to an R&D, not to a given experiment/facility(CLIC, FCC-ee, muColl…)
- Be able to tackle and solve very complex and costly projects
- Be based on the collaboration with other countries
- Have long temporal horizon (10-20 years)

# Backup

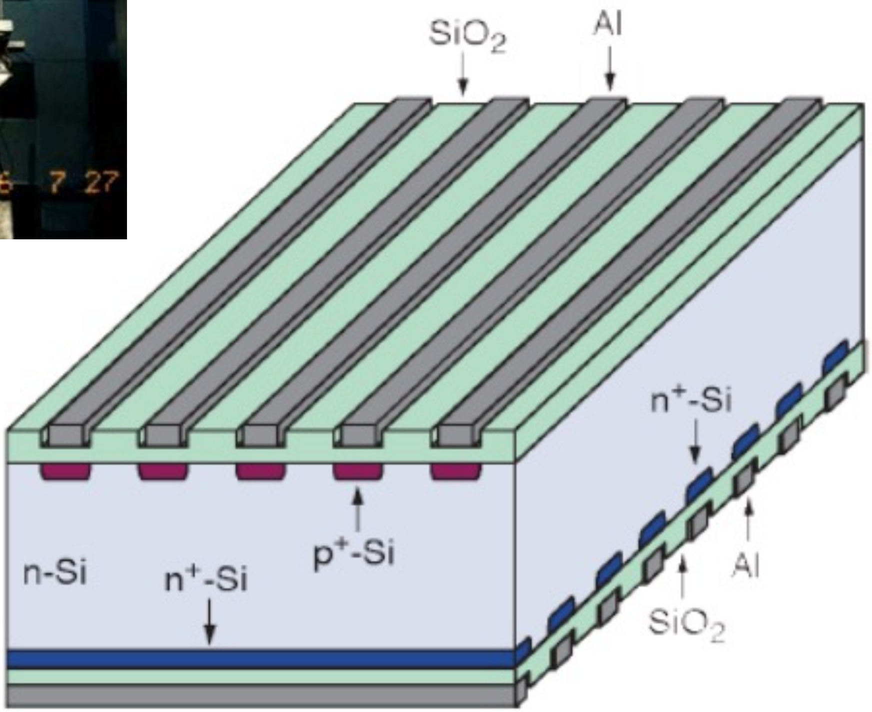
# Spectrometer power consumption mitigation (AMS)




Placing the magnetic field in smart configurations (e.g. the Halbach array configuration in AMS) allows to have:

- bending direction
- non-bending (*) direction




This allow to push the spatial resolution (and so the power consumption) only in one direction.

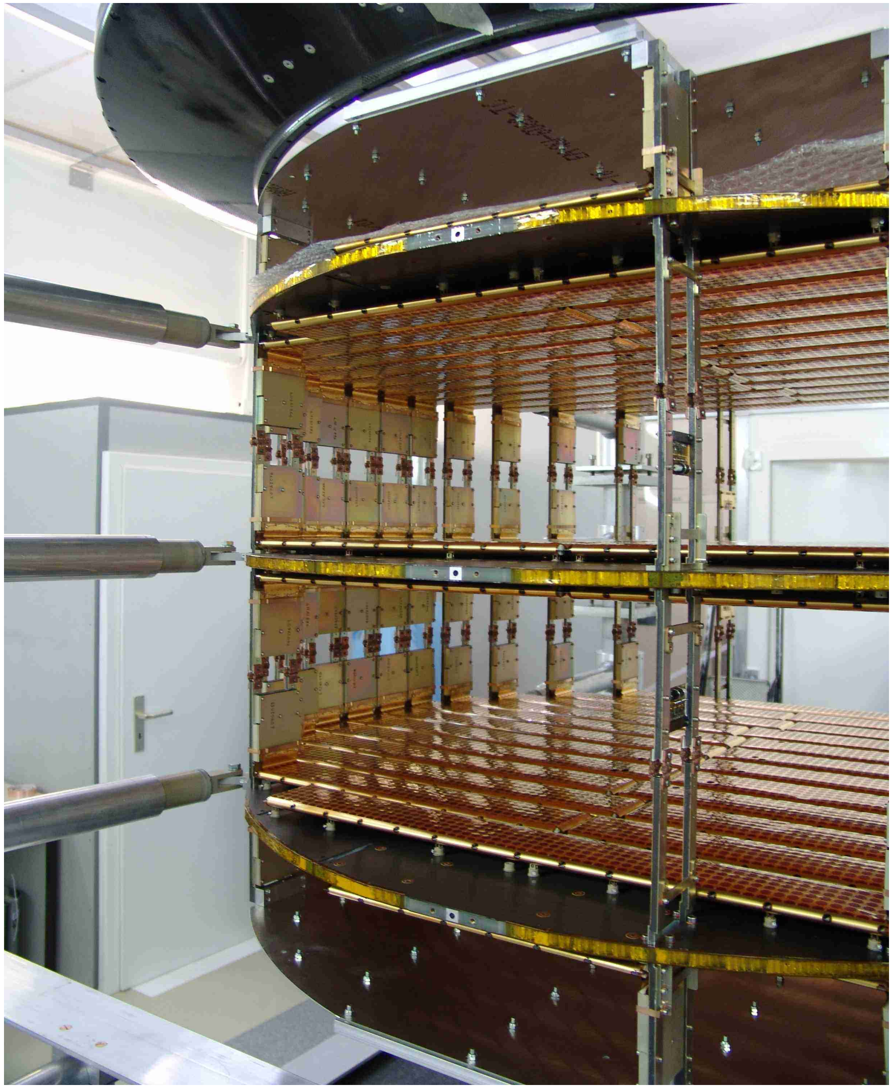
For example in AMS, for He nuclei:

- bending direction, ~ 7μm;
- non-bending, , ~ 30μm;

* actually the particle is bent also in this direction. It's only true that its momentum in this direction is not modified…

# 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:

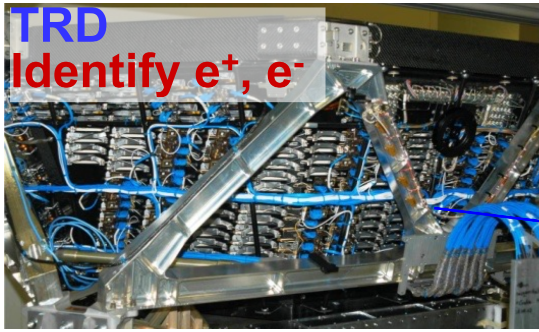
- x-side, *s=sqrt(6)*
- maximum length of ladders: *l=0.5 m*
- #ladders per y-side (or layers) = *s/l*
- pitch: $p = 100\ \mu m = 10^{-4}\ m$
- $\#channels_{strip} = s*(s/l)/p = 120k$

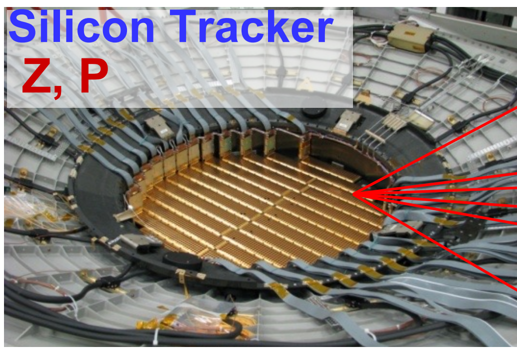
→ $strip = 2*120k \sim 10^5$

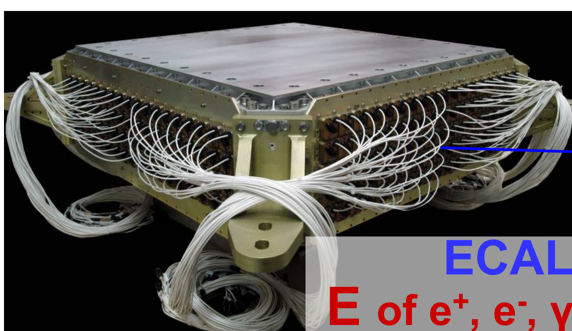
→ $pixel = 120k*120k \sim 10^{10}$

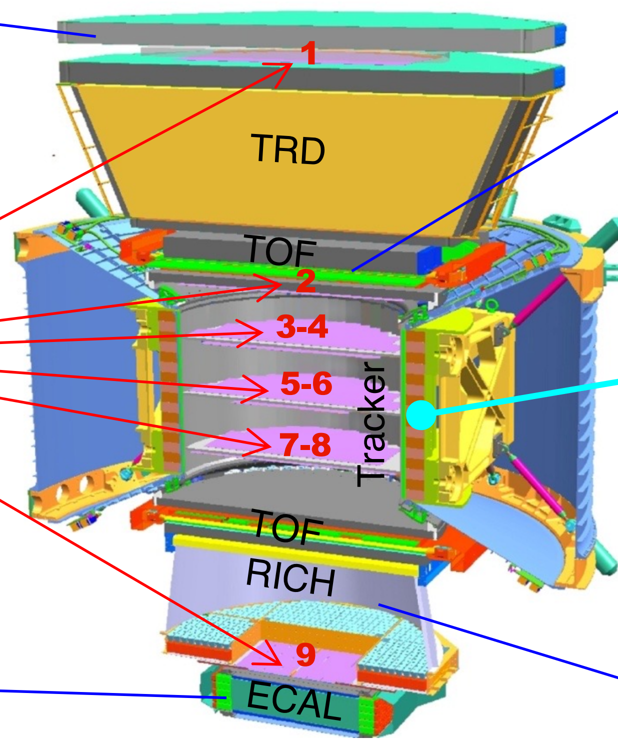
# AMS-02: A precision, multipurpose, up to TeV spectrometer

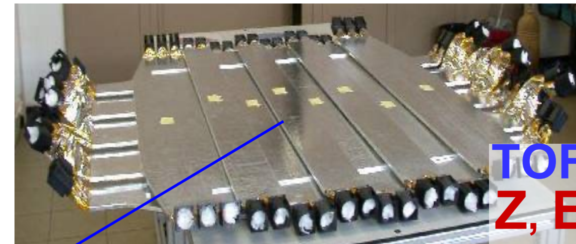
***Z, P* are measured independently by the Tracker, RICH, TOF and ECAL**

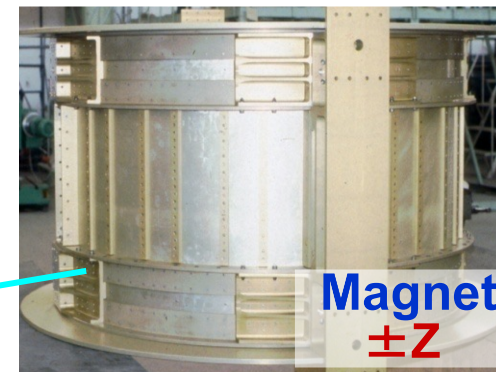


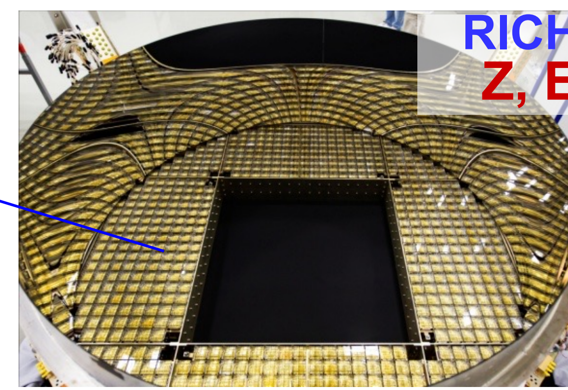



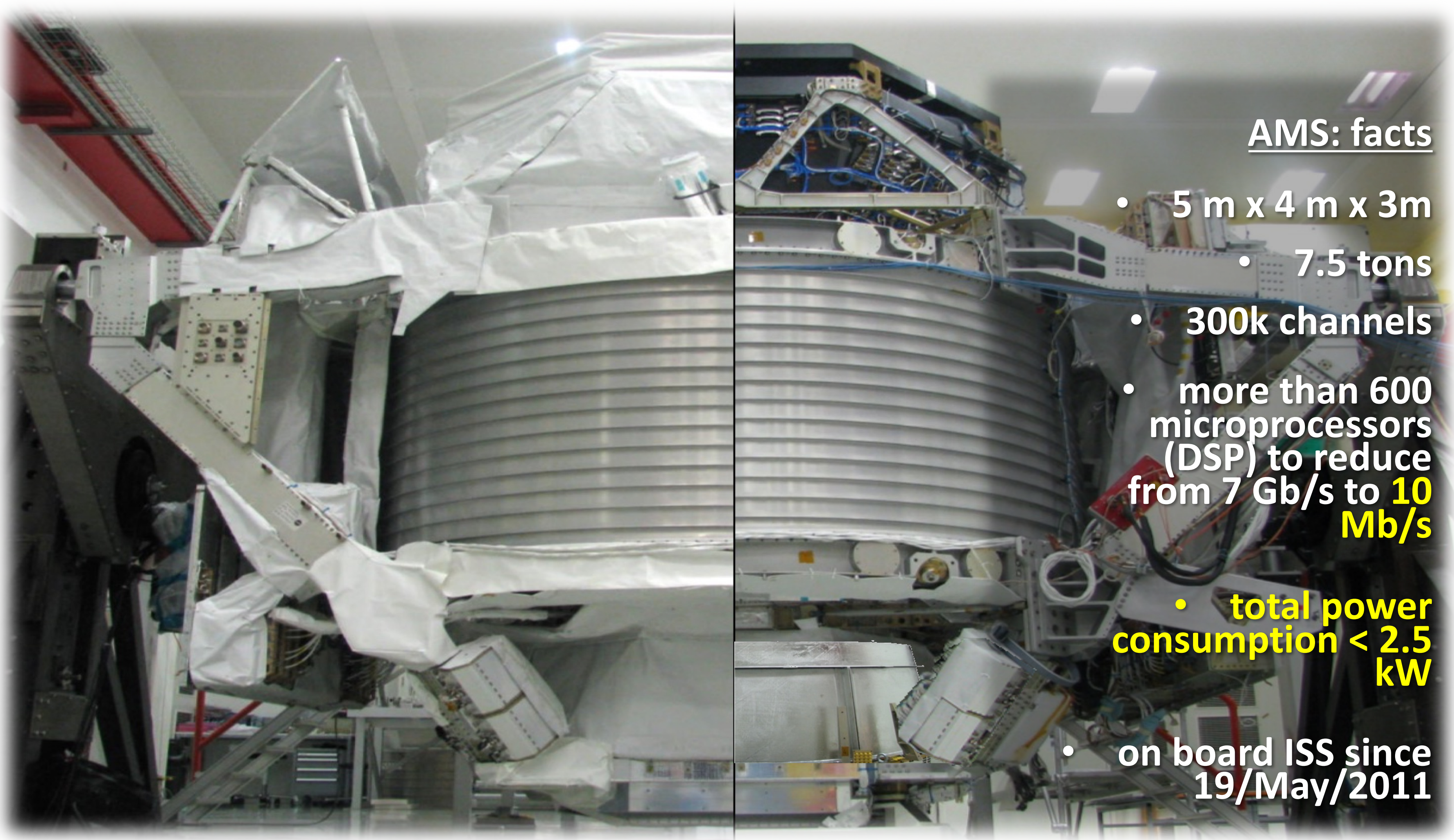



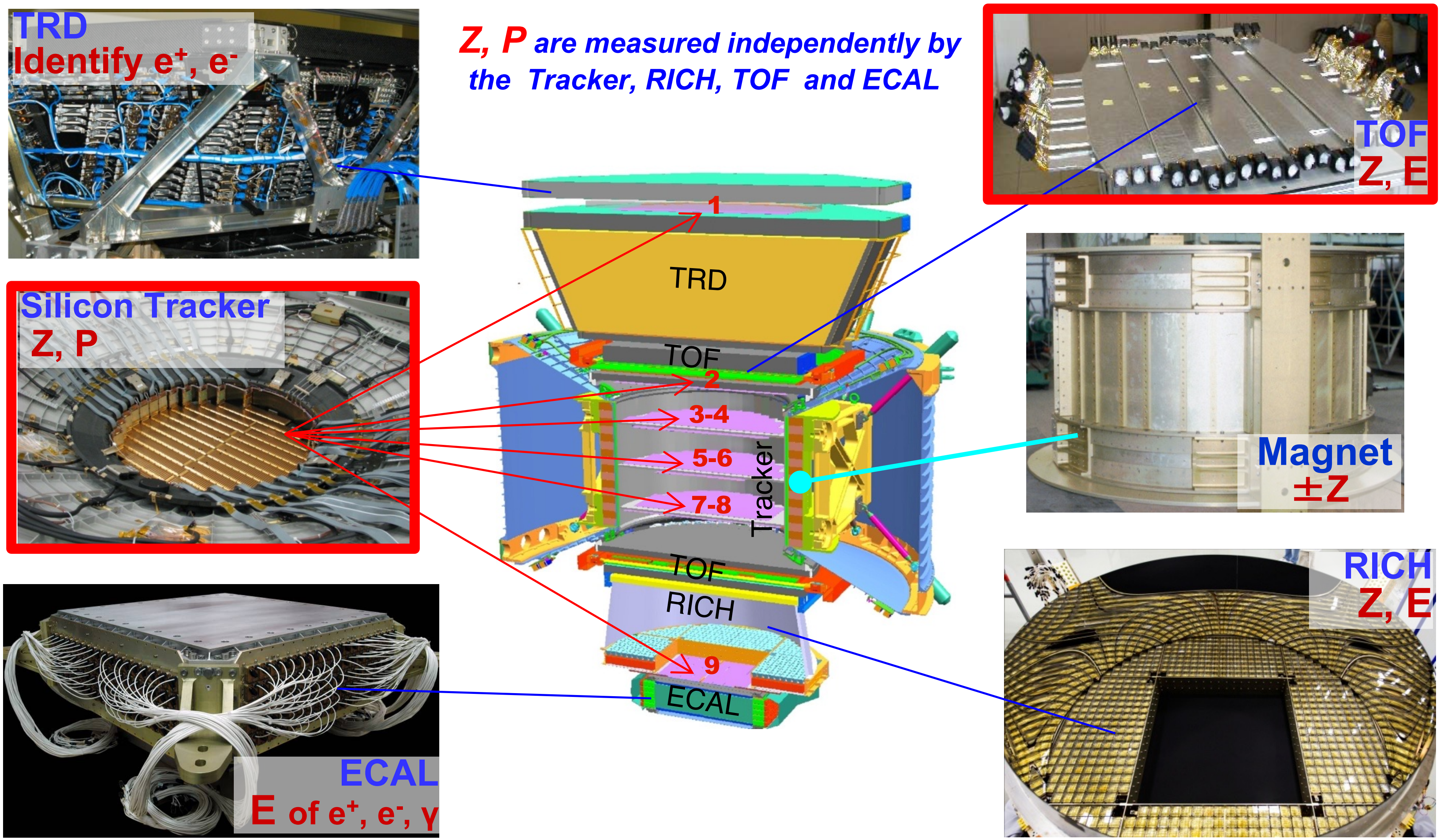
# AMS-02: A precision, multipurpose, up to TeV spectrometer



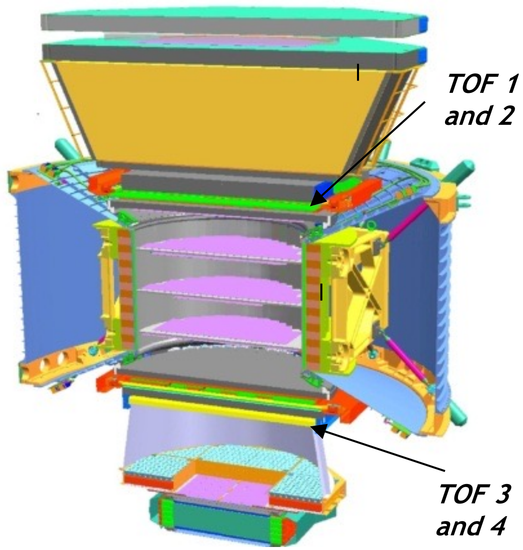
**AMS: facts**

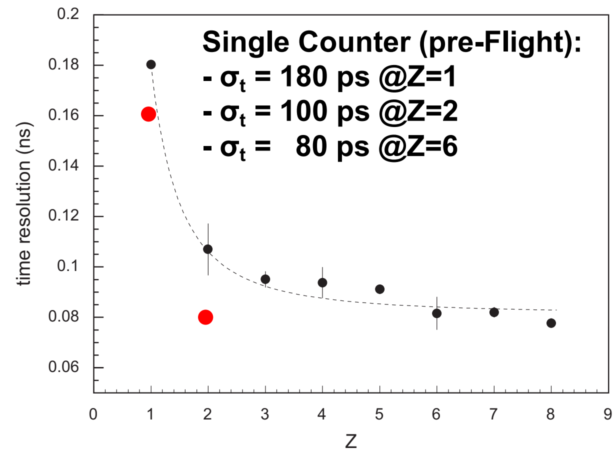
- 5 m x 4 m x 3m
- 7.5 tons
- 300k channels
- more than 600 microprocessors (DSP) to reduce from 7 Gb/s to 10 Mb/s
- total power consumption < 2.5 kW
- on board ISS since 19/May/2011

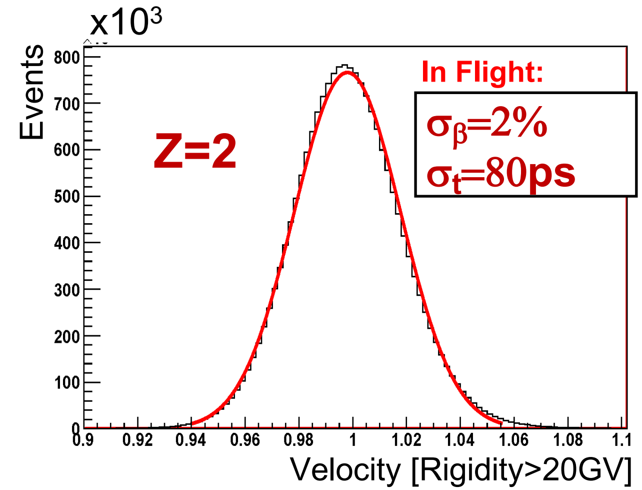
# AMS-02: A precision, multipurpose, up to TeV spectrometer



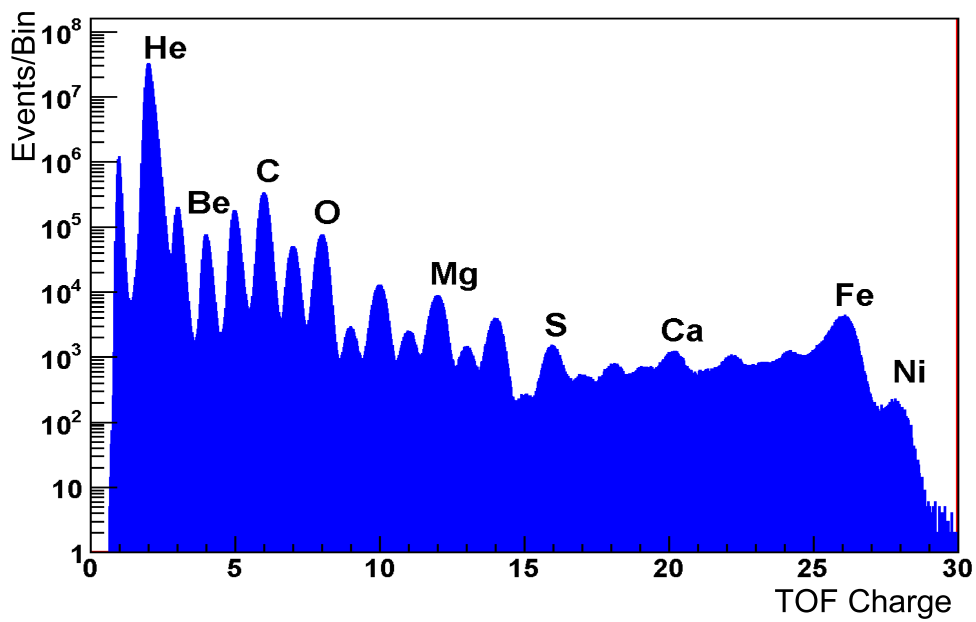
# AMS-02: Time of Flight

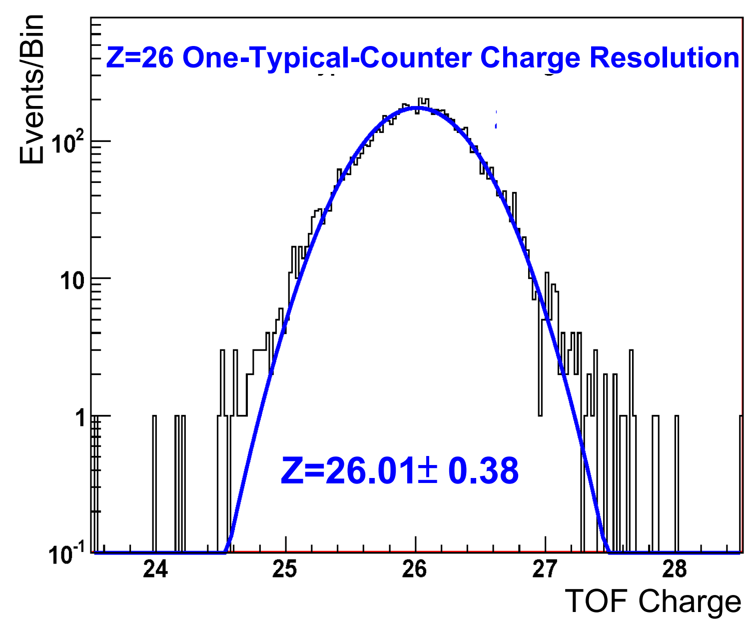



**Measures Velocity and Charge of particles**



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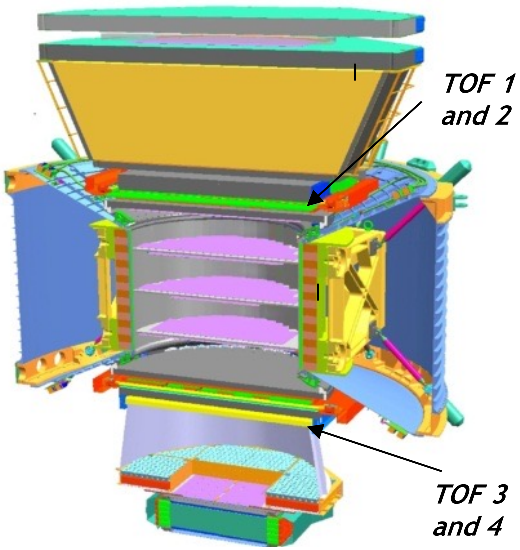


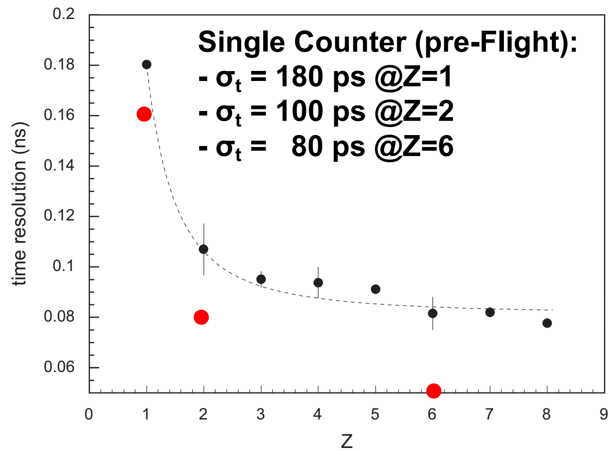


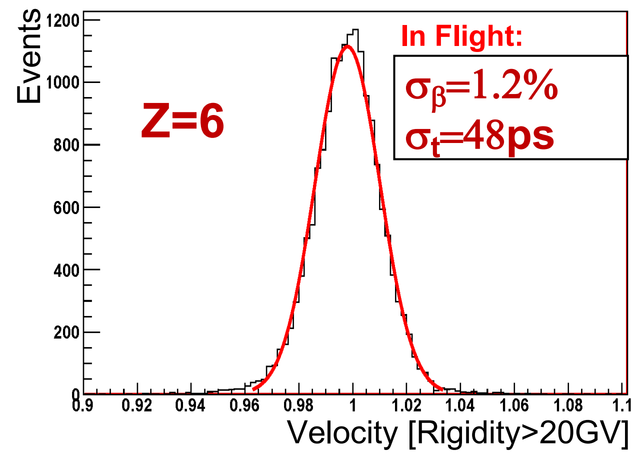


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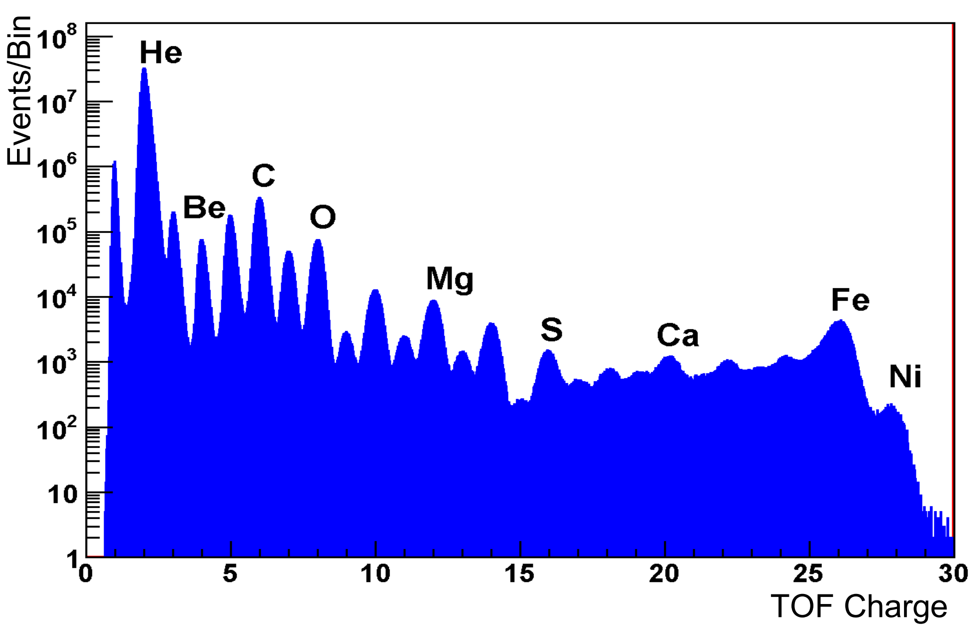


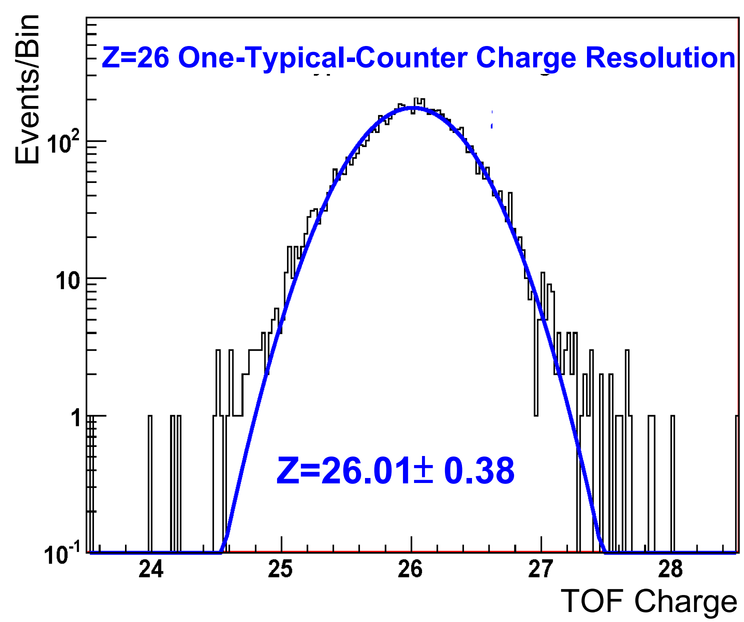

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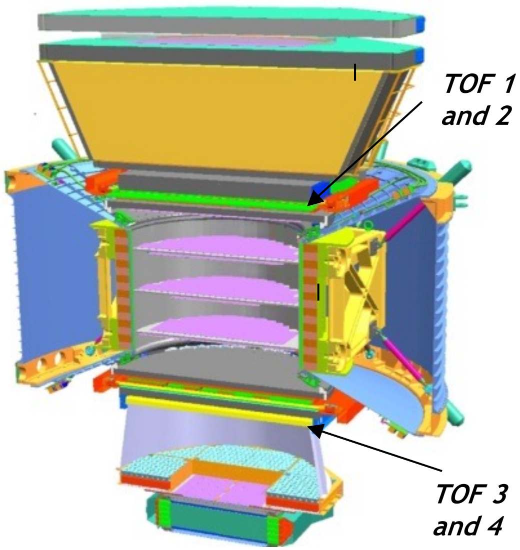
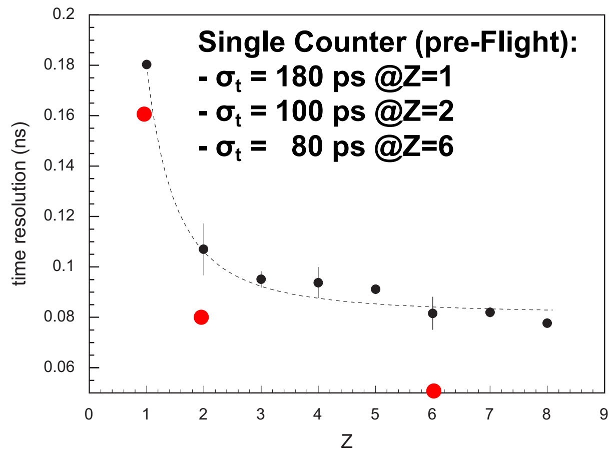
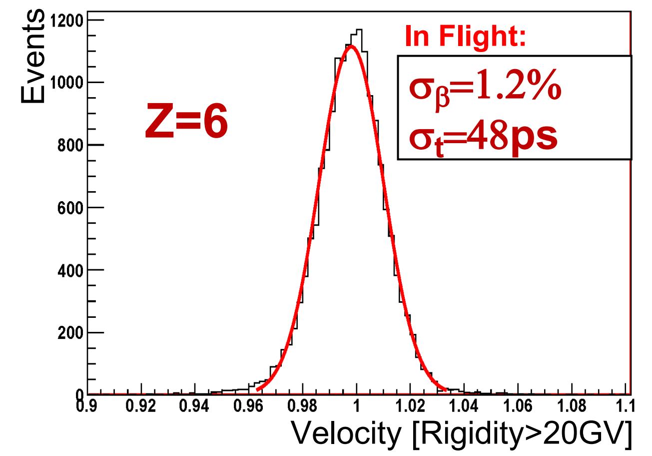


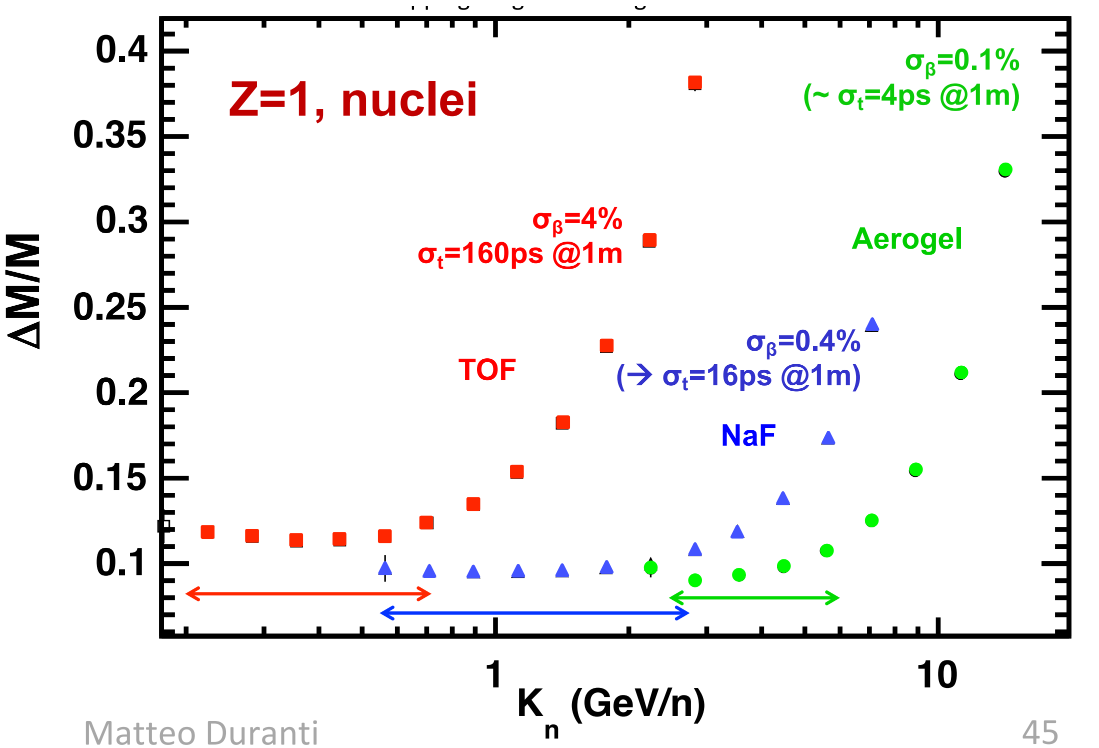




$$\frac{\delta M}{M} = \left(\frac{\delta p}{p}\right) \oplus \gamma^2 \left(\frac{\delta \beta}{\beta}\right)$$

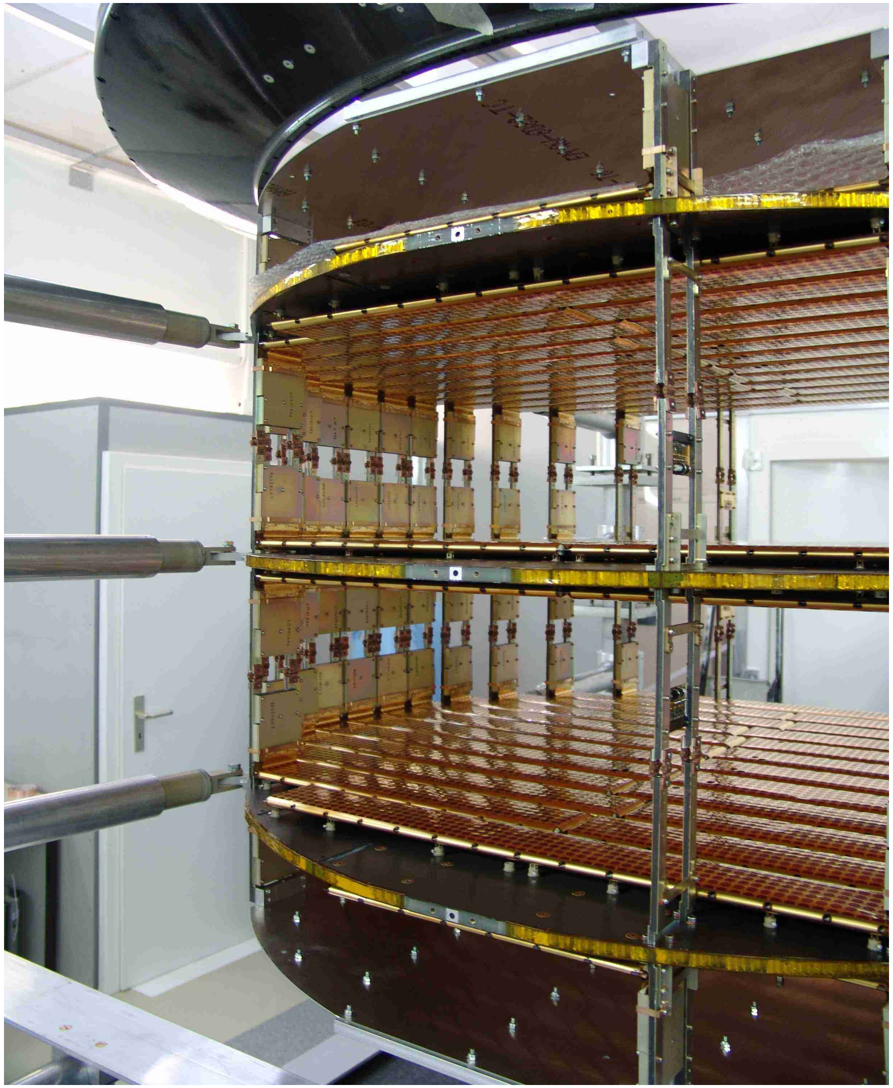
Velocity resolution is crucial for isotopical measurements:

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



# AMS-02: Silicon Tracker

- 9 layers of double sided silicon detectors arranged in 192 ladders
- ~6 $m^2$
- total of 200k channels for ~ 200 watt
- 10 $\mu$m (30 $\mu$m) 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 $X_0$



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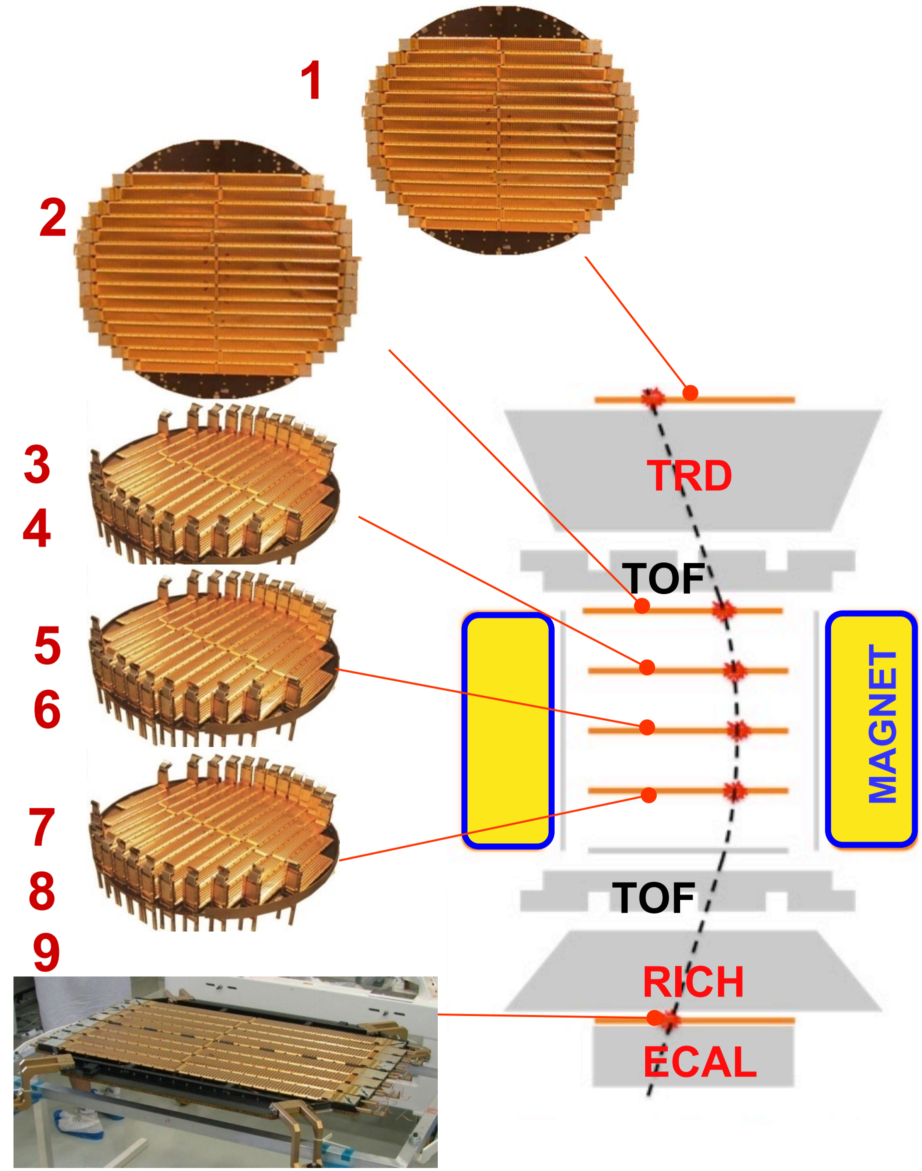
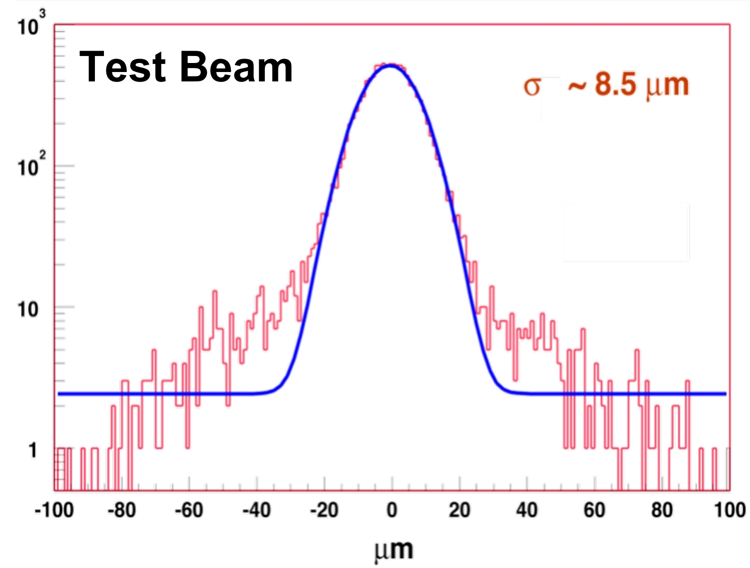
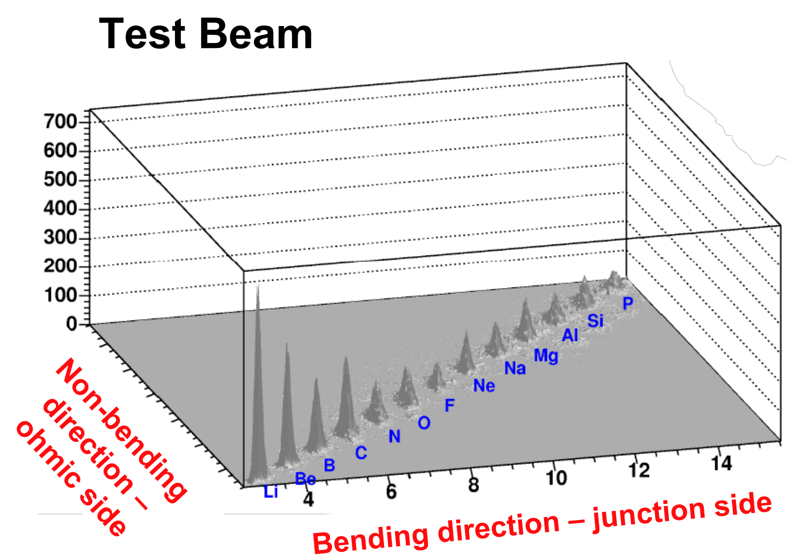
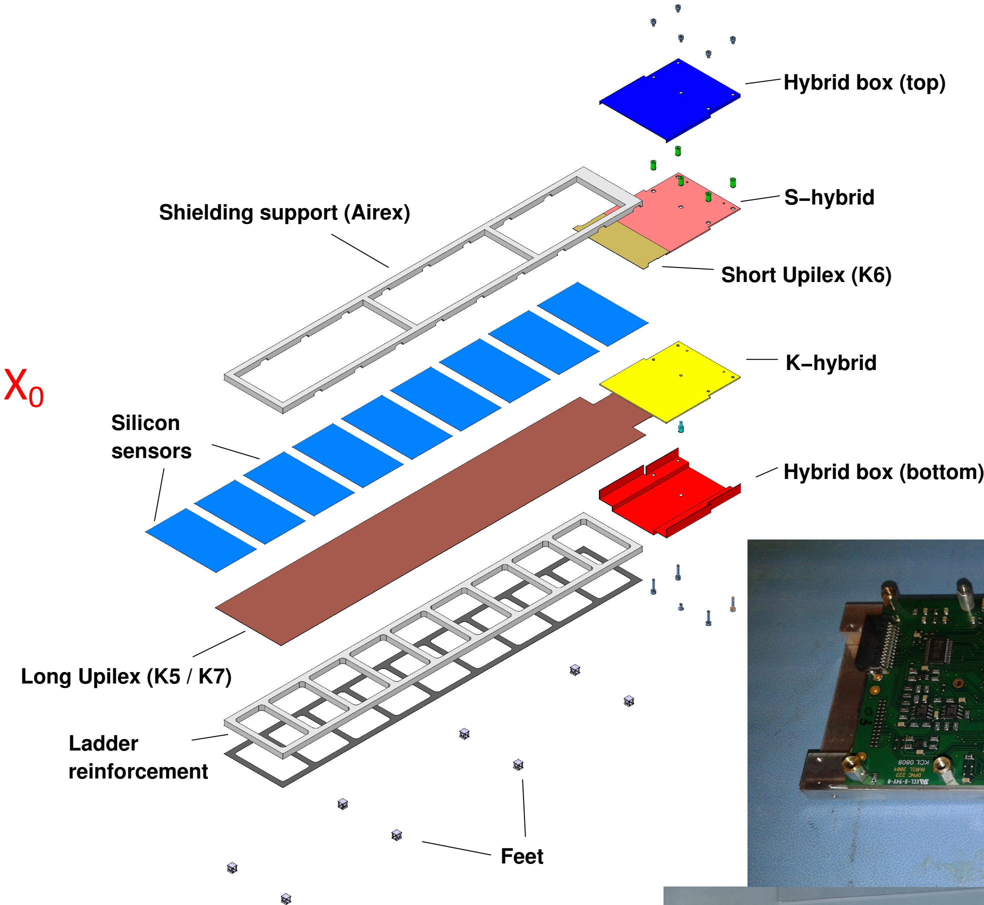


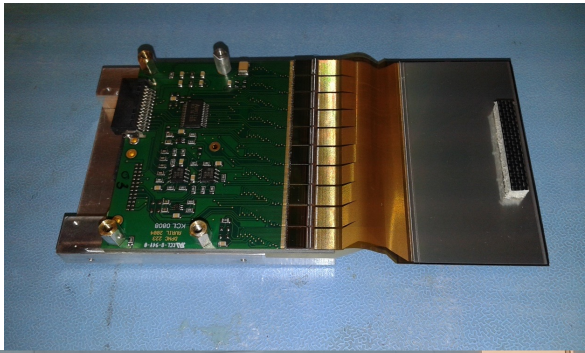



# AMS-02 microstrip silicon sensors

- 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 m$X_0$ or 3mRL)



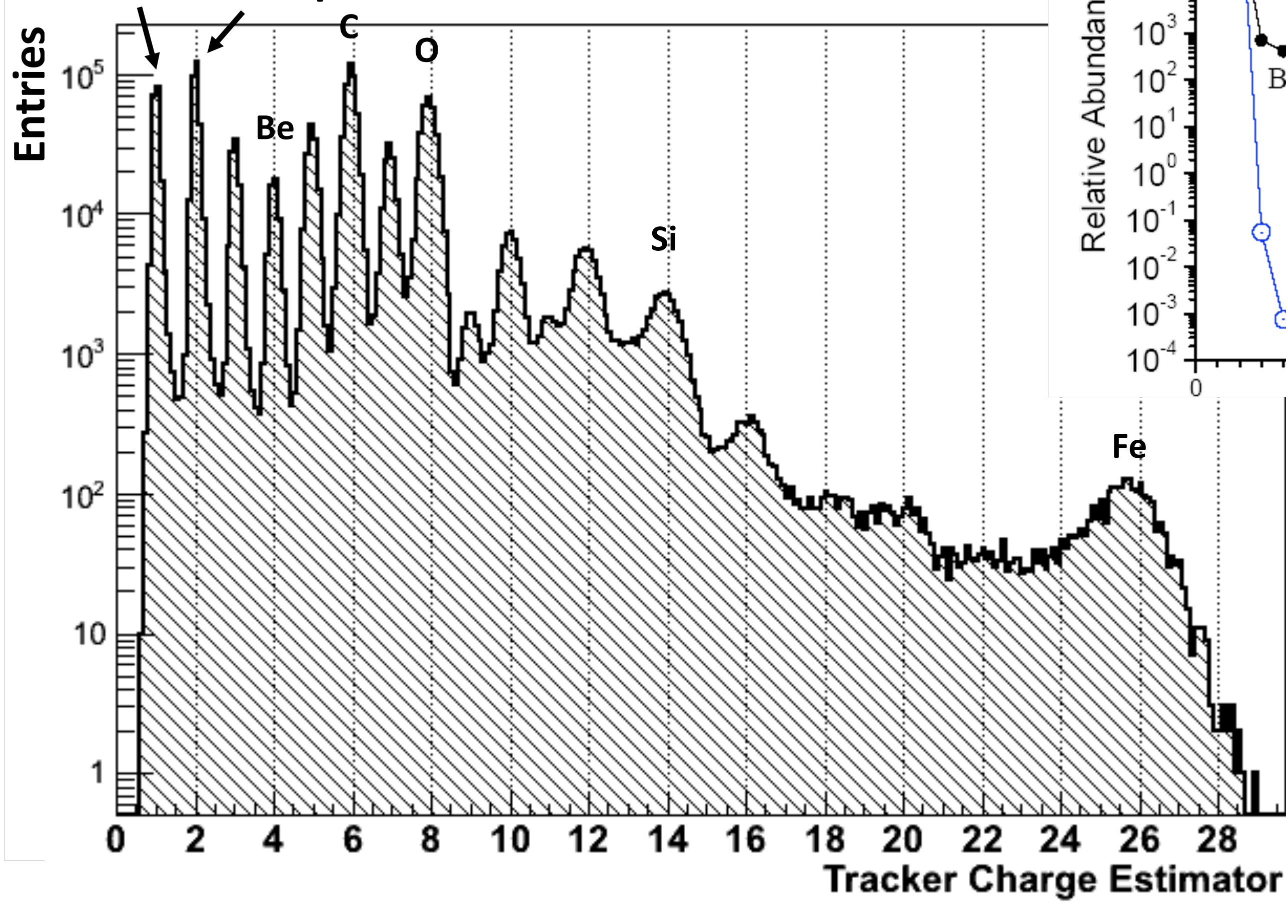



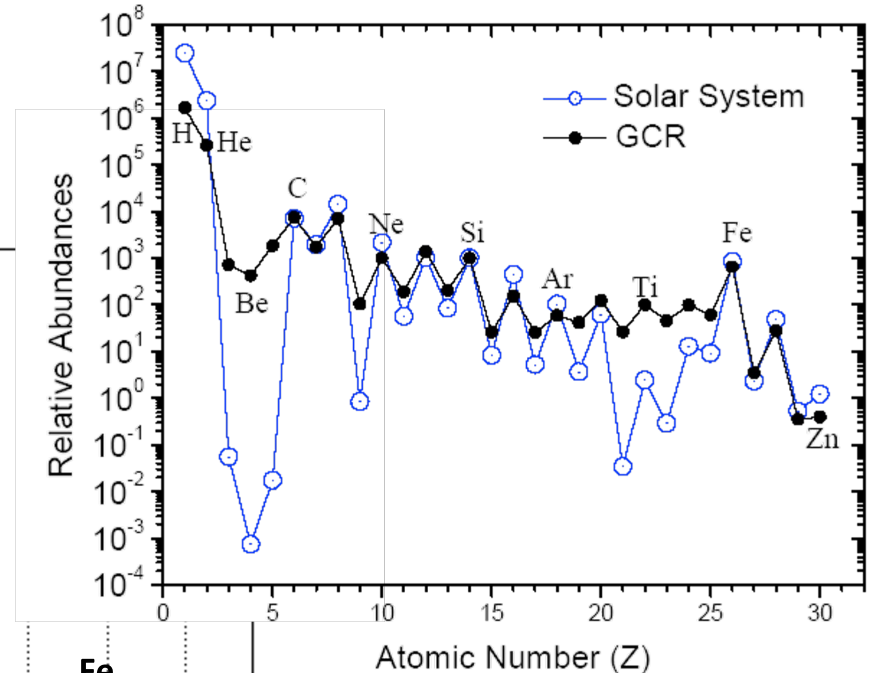
One of the “in kind” contribution given for the project is constituted by several spare part and modules built for the AMS-02 Silicon Tracker

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

**Abundances not corrected for detector efficiencies**

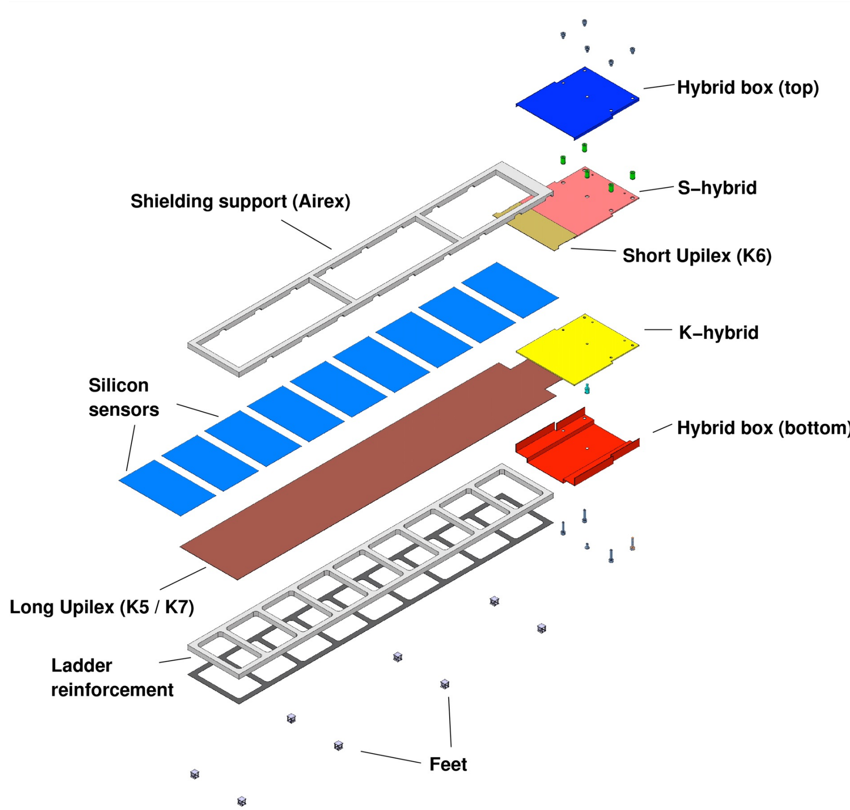
**H and He prescaled**



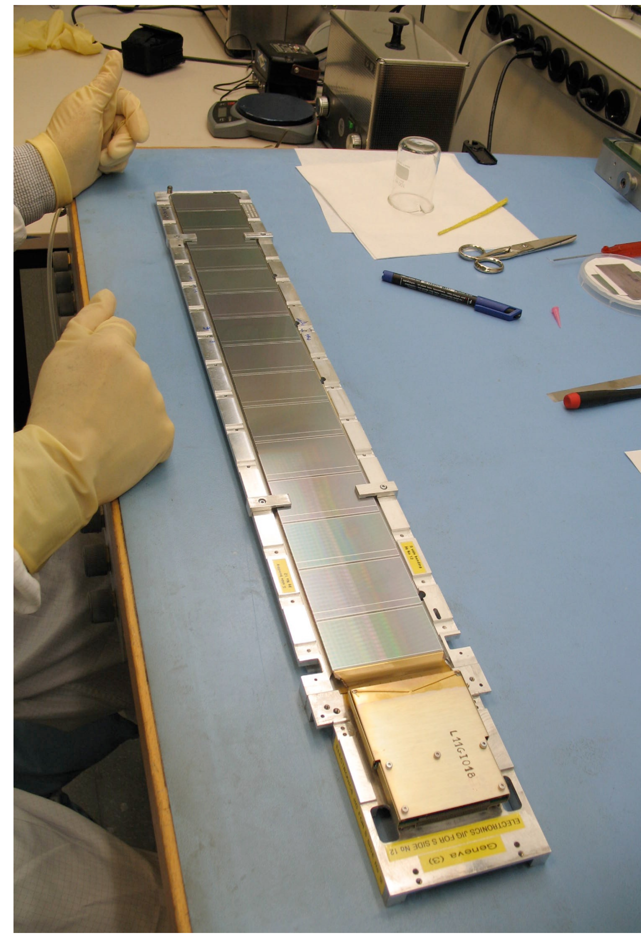

After few months of data on space the galactic cosmic rays (GCR) nuclear abundances are easily observed with an unprecedented statistics

# AMS-02: Silicon "ladder"



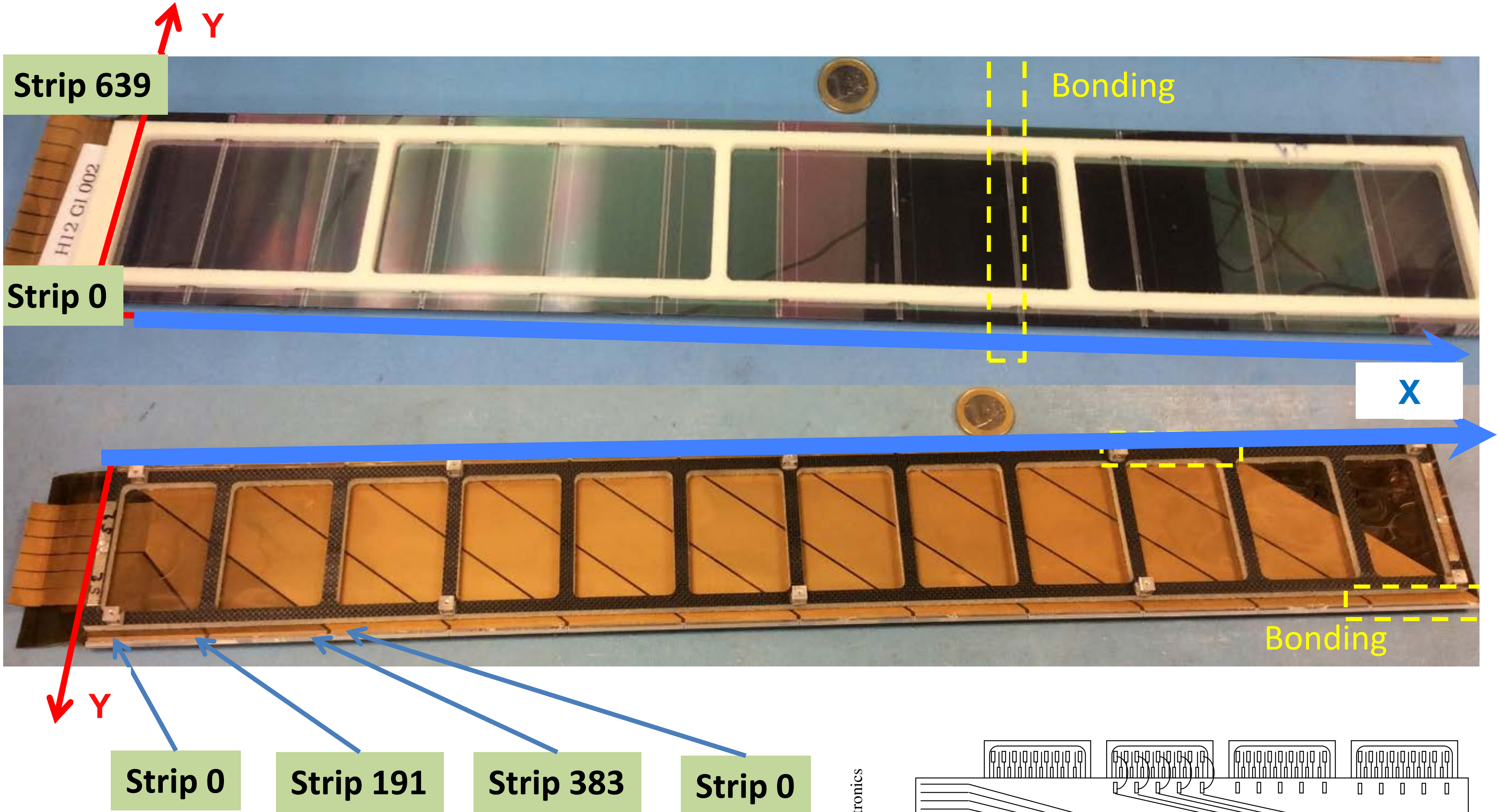

192 flight units

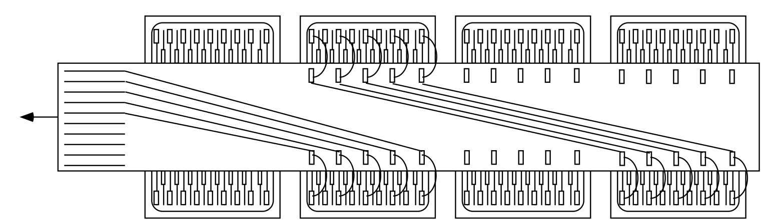
7 – 15 wafers (28 – 60 cm) each



- 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"



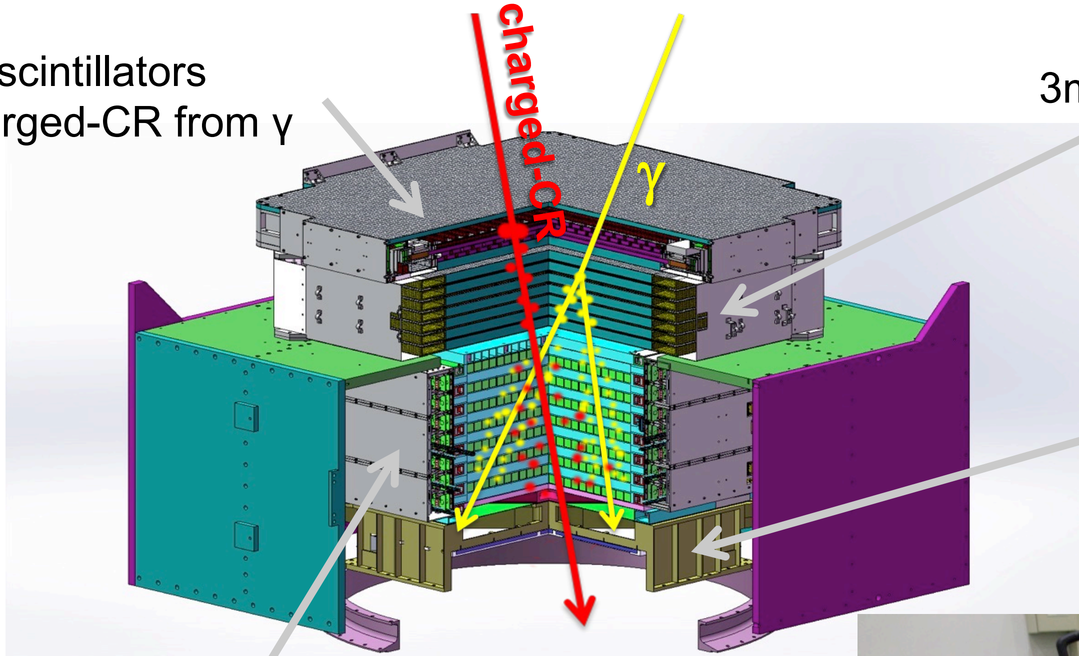




"multiplicity" (or "ambiguity"): the 1500-3000 K-side channels needed for each ladder are "merged" into 384.

# DAMPE: DArk Matter Particle Explorer

**PSD:** scintillators
Z, charged-CR from γ

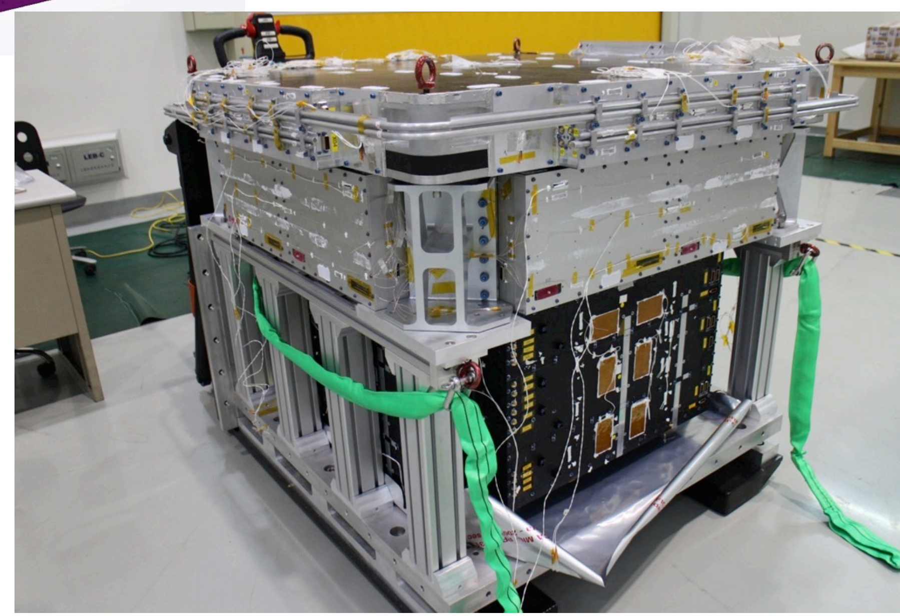
**STK:** 6 tracking planes +
3mm tungsten γ converter, Z,
tracking for charged-CR



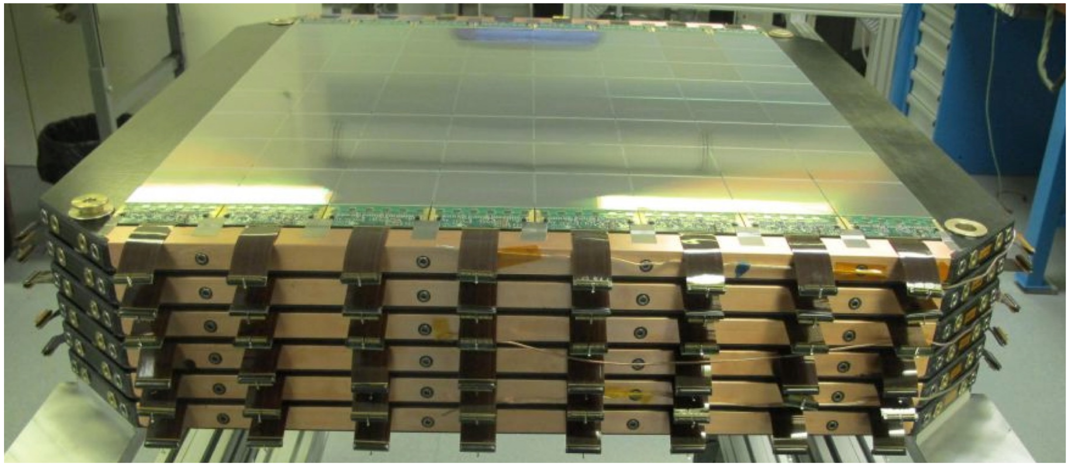

**NUD:** neutron detector to
identify hadrons (from
electron and γ)

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

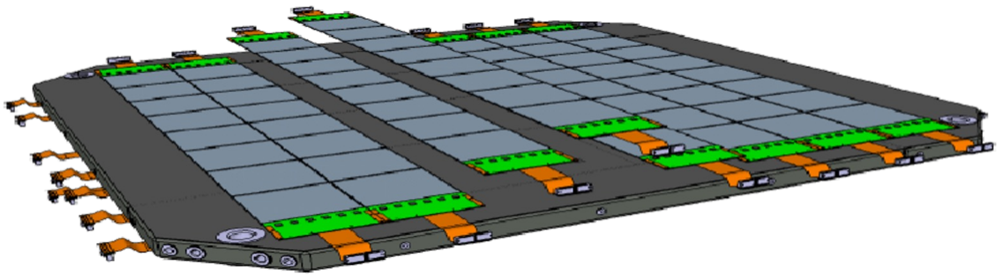
In orbit on a
Chinese Satellite
since 17/Dec/2015



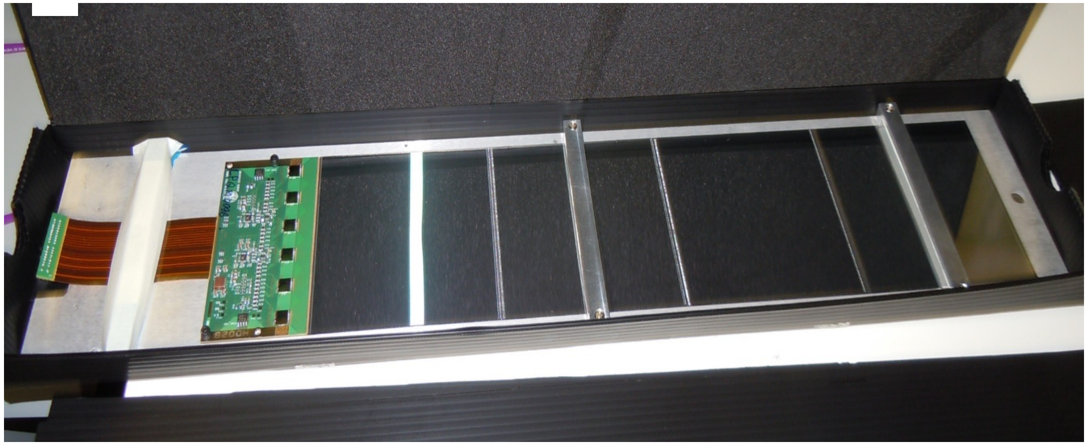
# DAMPE: Silicon-Tungsten Tracker-Converter



Tracker:
- 7 m²
- 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 cm² (4*9.5*9.5 cm²)
- pitch 240 μm
- resolution 40 μm
- 6 * *va140* FE chip, 0.3 mW each