Silicon in Space

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PERUGIA

Silicon in Space

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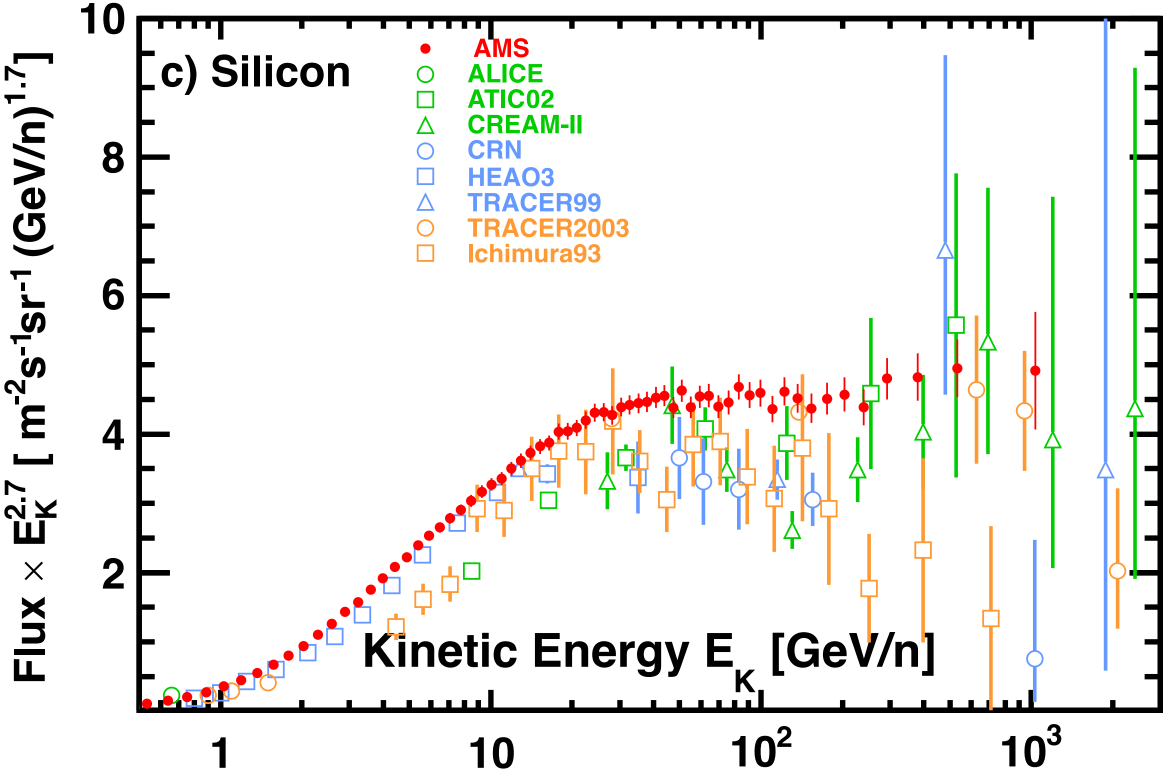

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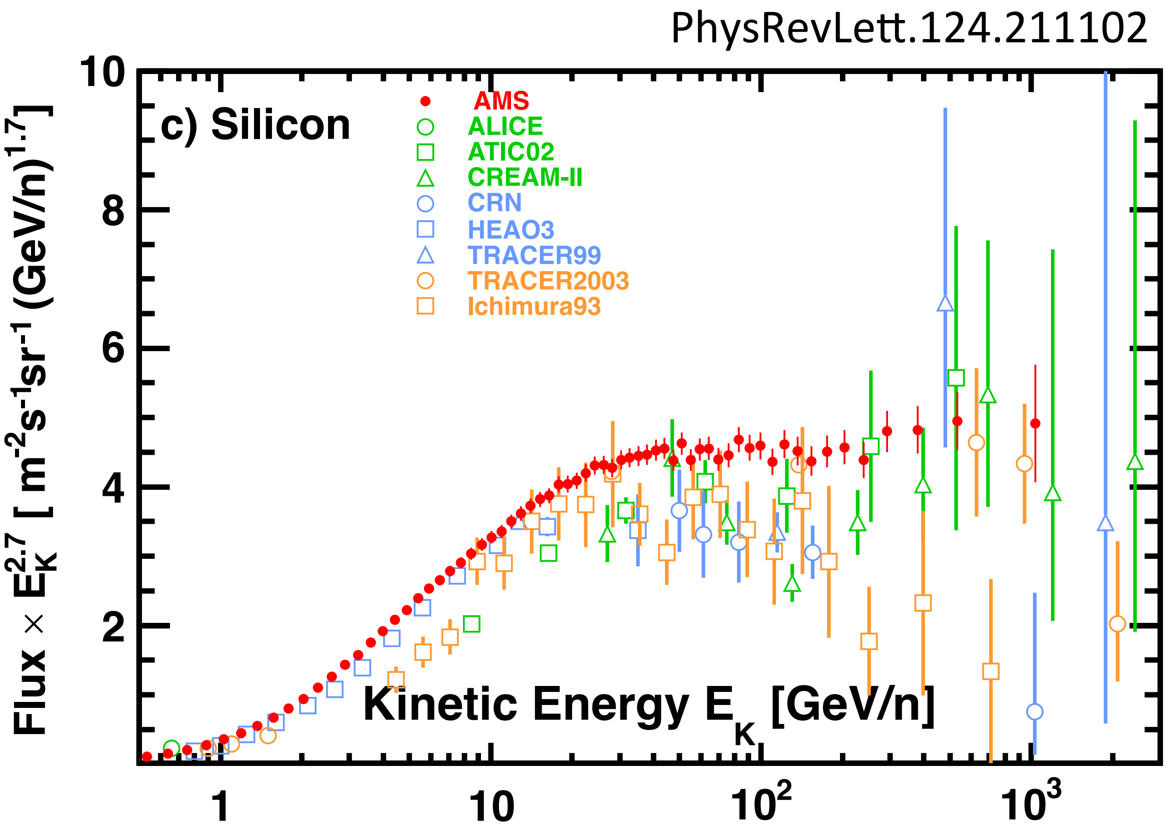

Jokes apart:

- we use our detectors (mainly the Si trackers) to measure the *Z* of the CR particles

- input charge could be 6^2 or 8^2 (C and O), 14^2 (Si) or even 26^2 (Fe) or above, times a MIP…

Silicon (μstrip) in Space

State of the art and perspectives for Si microstrip tracking systems in space

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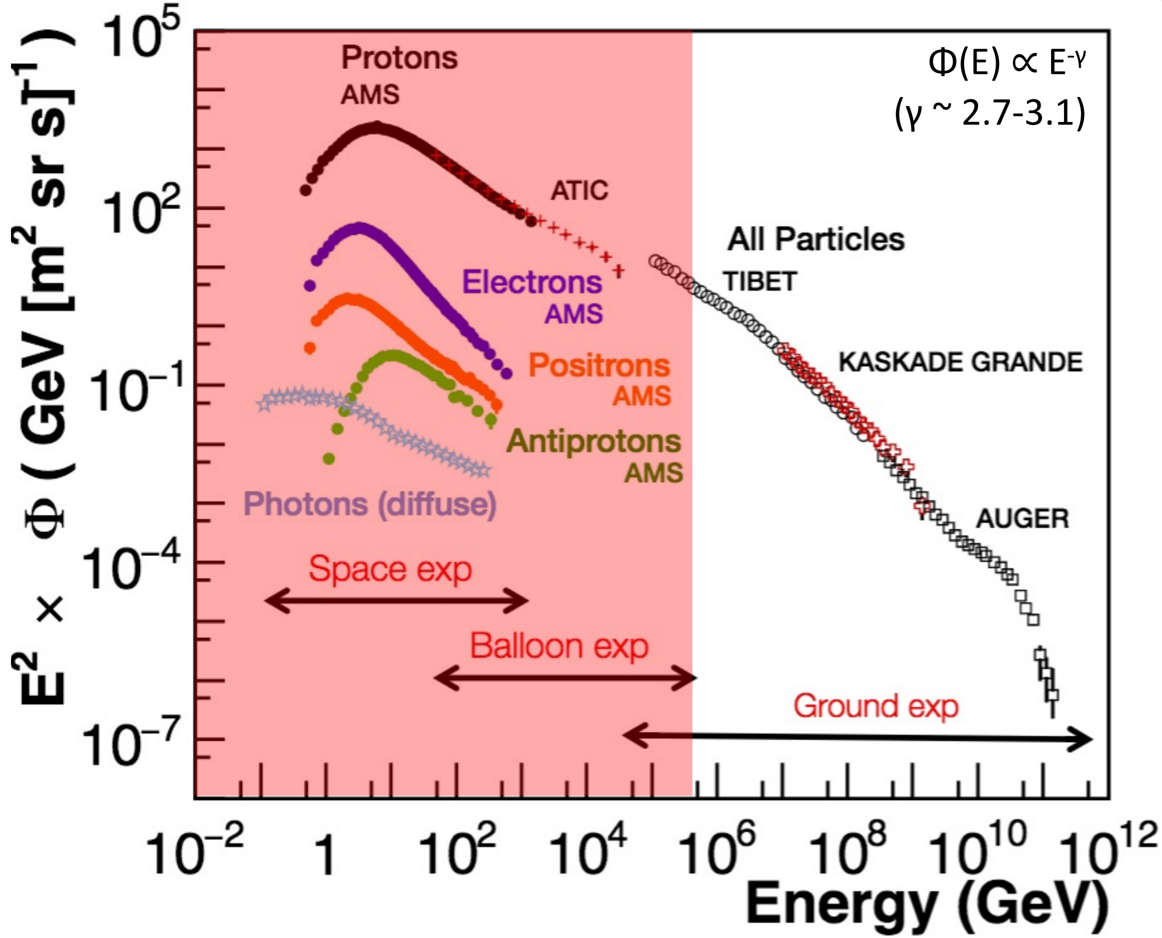
Outline

- Scientific case and state of the art
- (far, intermediate and near) future
- pros and cons of μstrips
- LGADs?

Cosmic Rays



measuring in Space (or balloon) allows single particle measurements
→ 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)

The experimental challenge

No atmosphere:

- Stratospheric ballon
- Satellite / Space station

Limits on size / weight / time / power consumption

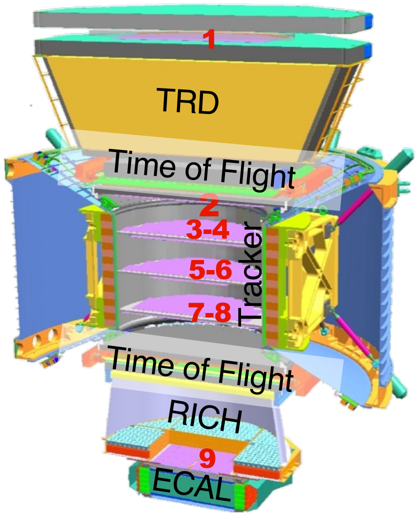
Detector design focused on specific measurements

Antimatter / Isotopes ⇒ Magnetic spectrometers

Nuclei / e^{+}+e^{-} / Gammas ⇒ Calorimeters

Astro-particle detectors – state of the art

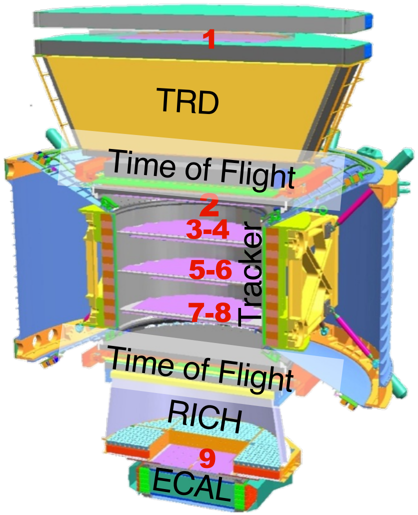
AMS-02 (in orbit since 16/05/2011):



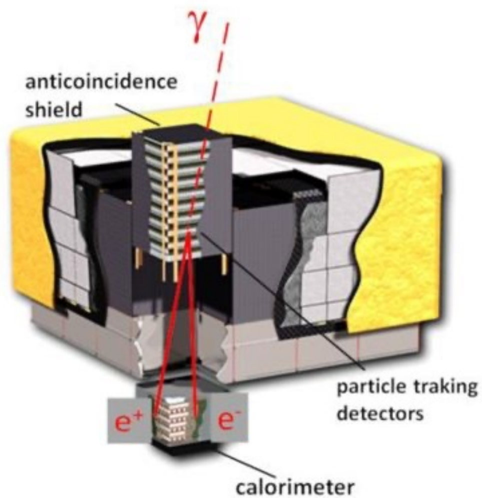
- accurate spatial resolution (<10 μm) Si-μstrip for Rigidity measurement up to TVs;
- charge measurement capability (0.1 c.u.) for at least a couple of detectors (Tracker, Time of Flight);
- Electromagnetic CALorimeter (17 X_0) for e^+, e^-, γ Energy measurement;
- Time of Flight (σ_t ~ 120 ps, σ_β ~ %) for trigger, arrival direction (upward/downward) and isotopic composition (up to few GeV, then Ring Imaging Cherenkov, σ_β ~ 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):



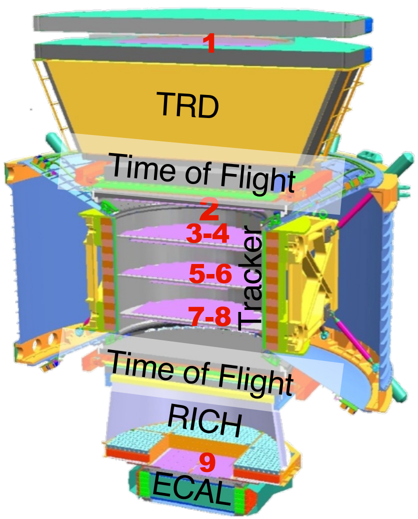
Fermi-LAT (in orbit since 11/06/2008):



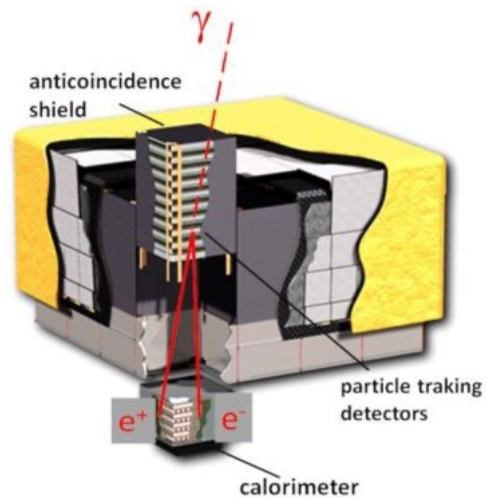
- moderate spatial resolution (~60 μm) Si-μstrip for pair-production measurement;
- electromagnetic calorimeter (10 X_0) for e^+, e^-, γ Energy measurement;
- plastic scintillator anticoincidence shield for charged CR veto;
- electromagnetic calorimeter to perform e/p identification;
- Tungsten plates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

Astro-particle detectors – state of the art

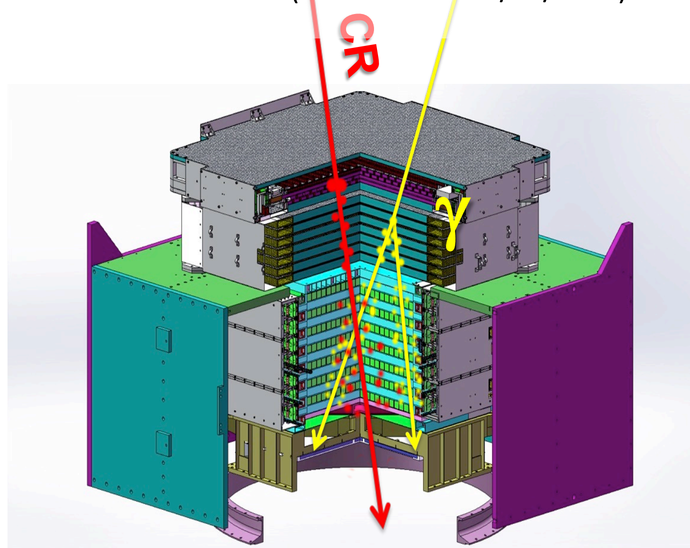
AMS-02 (in orbit since 16/05/2011):



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

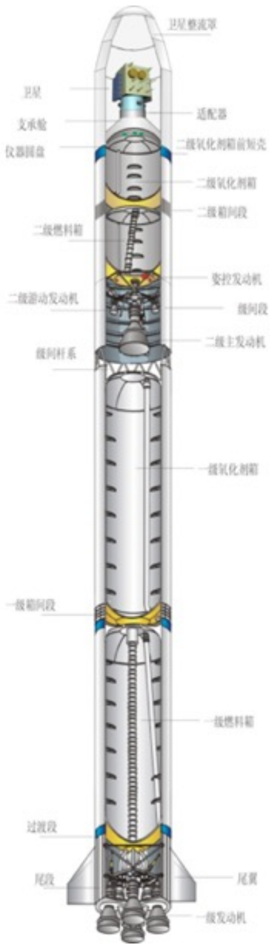


DAMPE (in orbit since 17/12/2015):



- moderate spatial resolution (~40 μm) Si-μstrip for pair-production measurement;
- charge measurement capability (0.1 c.u.) for at least a couple of detectors (Tracker, Plastic Scintillator Detector);
- 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

HEP detectors in Space

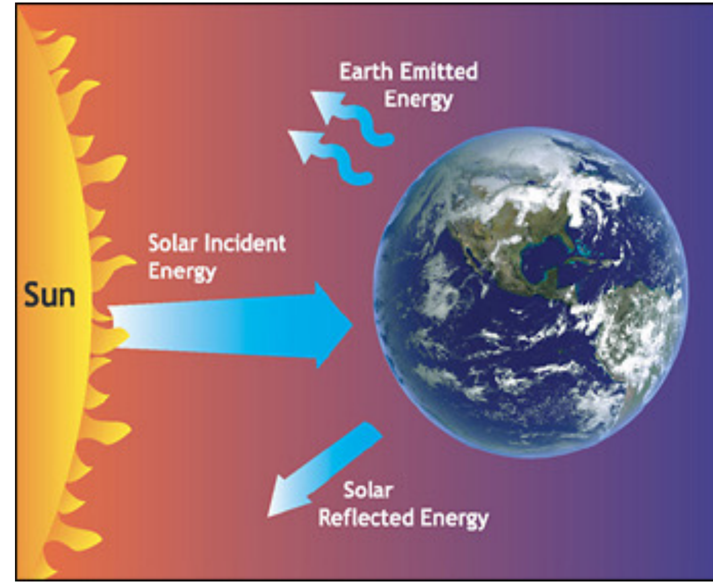


Mechanical stress at launch:

- Static acceleration
- Random vibration
- Sinusoidal vibration
- Pyroshock

Life in space:

- **Thermal stresses due to Sun-light (seasonal / day-night effects)**
- **Vacuum**
- ~~**Radiation**~~



Careful Design, Model validation and Qualification are needed to ensure *highest possible reliability*

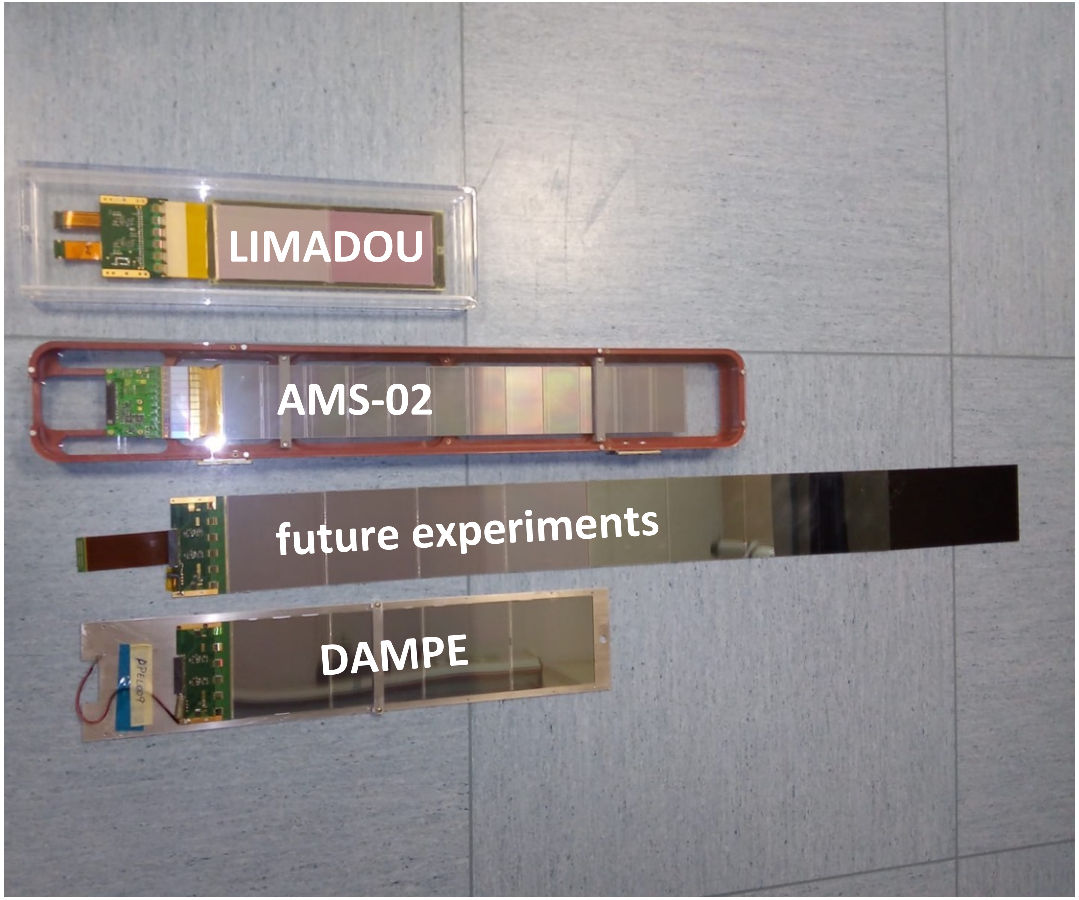
Perugia / µstrip in Space

State of the art

- strongly biased from/towards activities conducted in Perugia
- focused on µstrip sensors. Why µstrip? Example AMS-02 tracker:
  - ~6 m^2
  - total of 200k channels for ~ 200 watt
  - 100 µm pitch → 10 µm (30 µm) spatial resolution in bending (non bending) plane

Back of the Envelope:

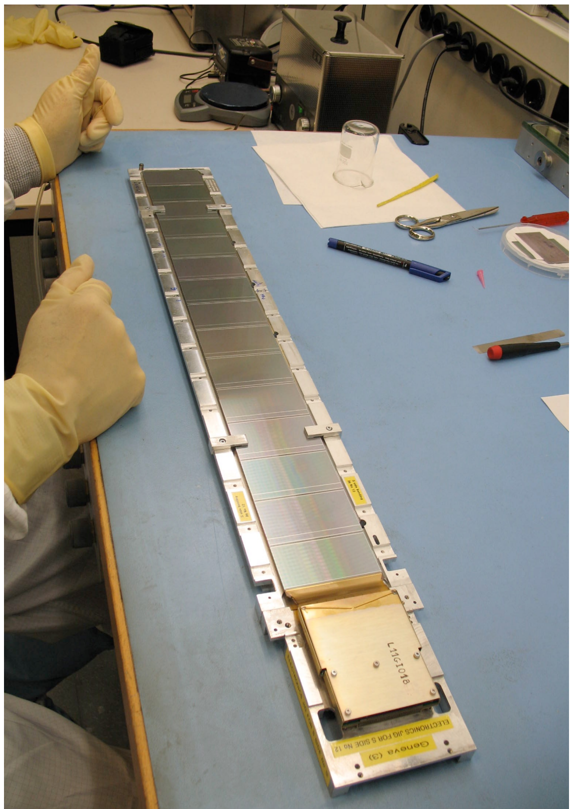
- *x*-side =sqrt(6m^2) ~ 2.5m^2
- maximum length of ladders: l=0.5 m
- #ladders per *y*-side (or layers) = s/l
- pitch, p = 100 µm = 10^{-4} m
- $\#channels_{strip}$ = (s/l) * s/p = 120k
- → strip = 2*120k ~ 10^5
- → pixel = 120k*120k ~ 10^{10}



AMS-02: Silicon "ladder"

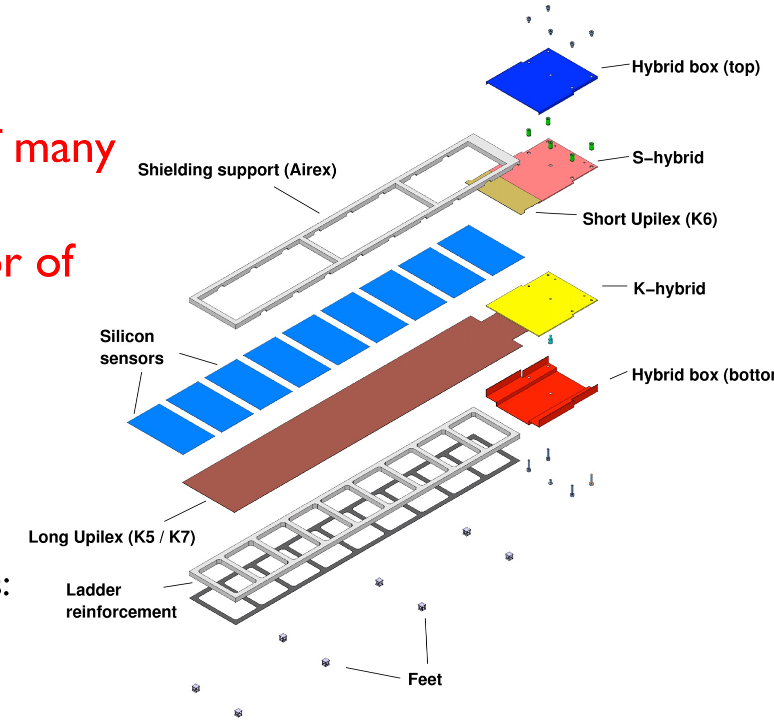
192 flight units

5 – 15 wafers (28 – 60 cm) each



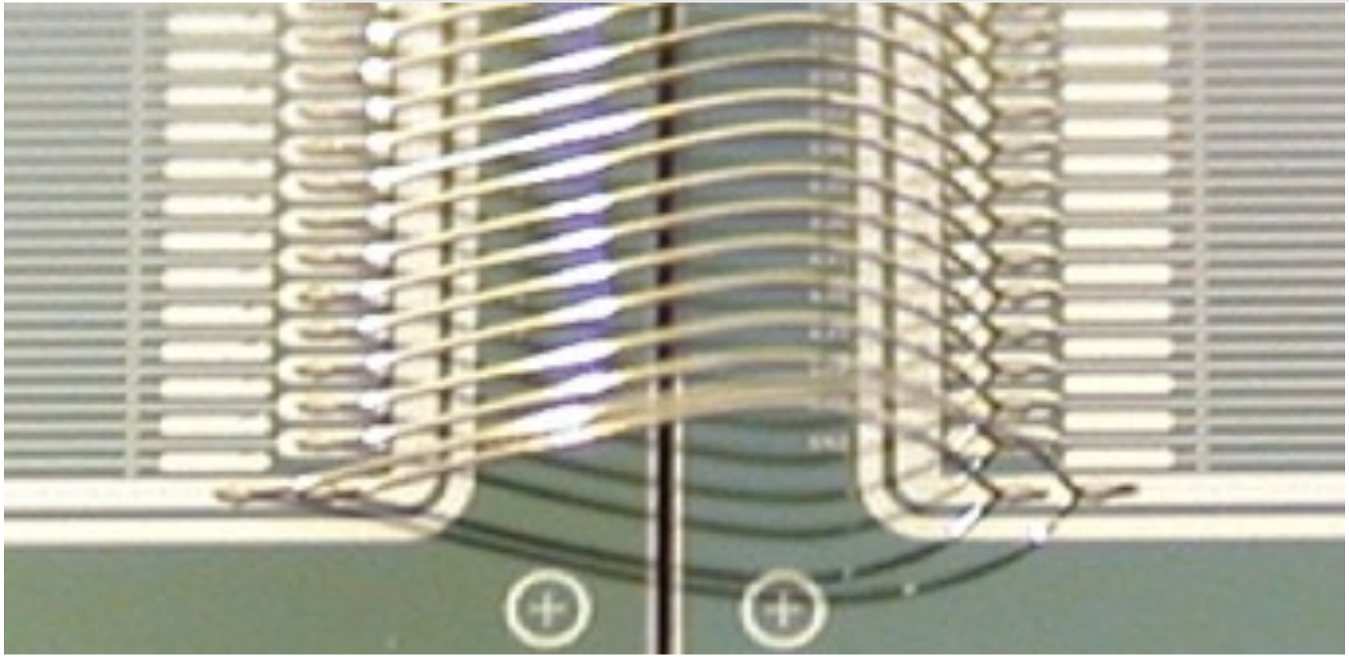
→ daisy chain (parallel!) of many wafers

→ impedance of the sensor of the order of 50-100 pF

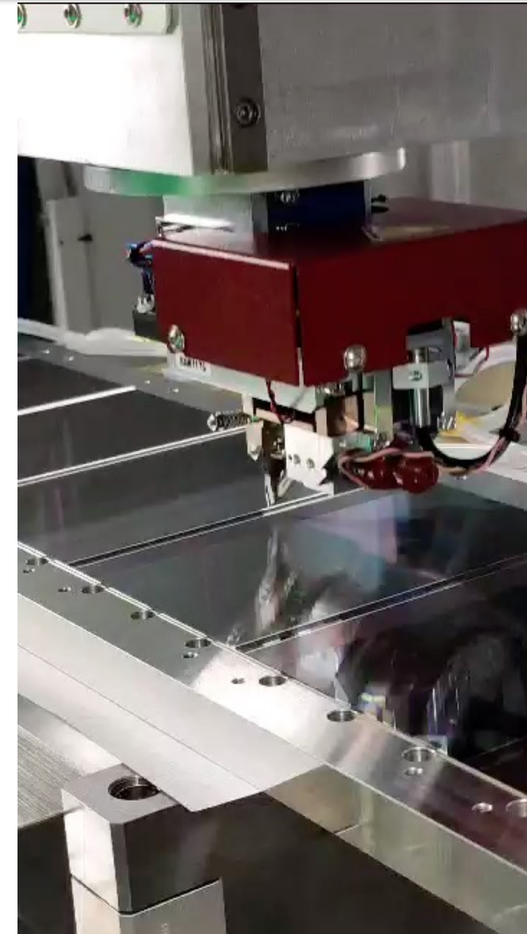


- 1024 high dynamic range, AC coupled readout channels:
  - 640 on junction (S) side
  - 384 on ohmic (K) side
- Implant/readout pitch (floating strips!):
  - 27.5/110 μm ("S"/junction/p-side/bending side)
  - 104/208 μm ("K"/ohmic/n-side/non-bending side)

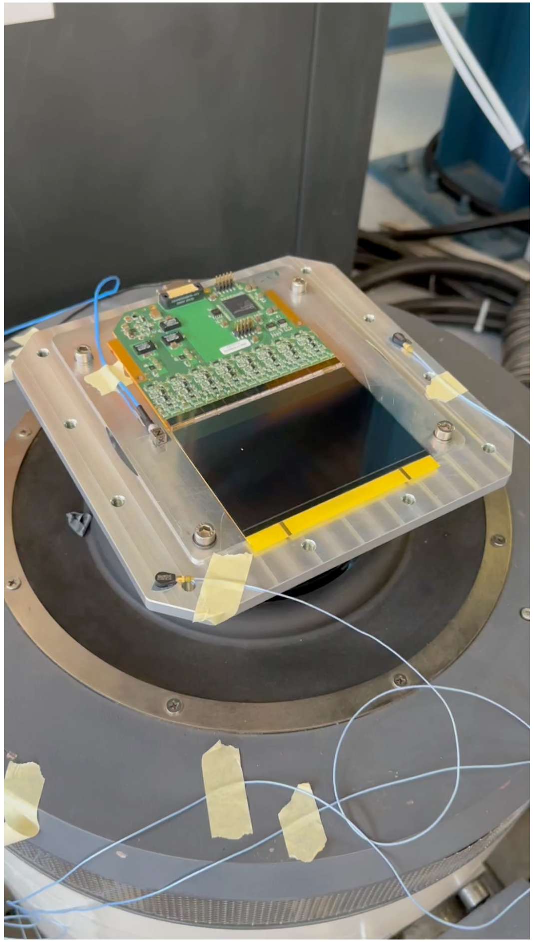
Wire bonding



- bonding wire: 25 μm
- Merino wool: 20 μm
- Human hair: 200 μm

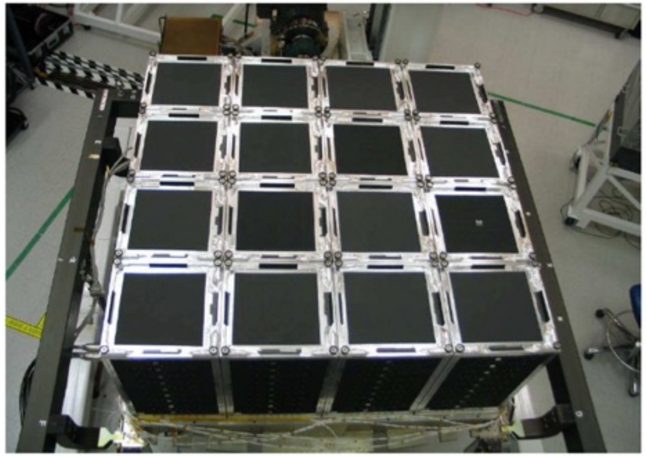


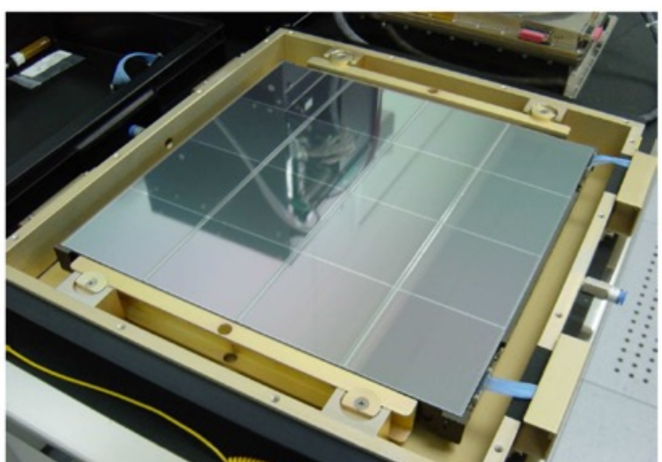
wire bonds vibration test

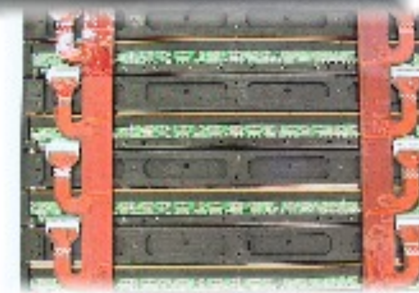


Fermi-LAT (2008)

strip pitch 230 µm
readout pitch 230 µm



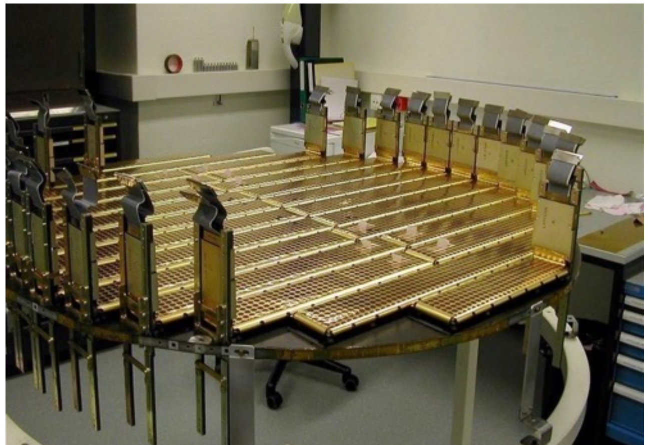




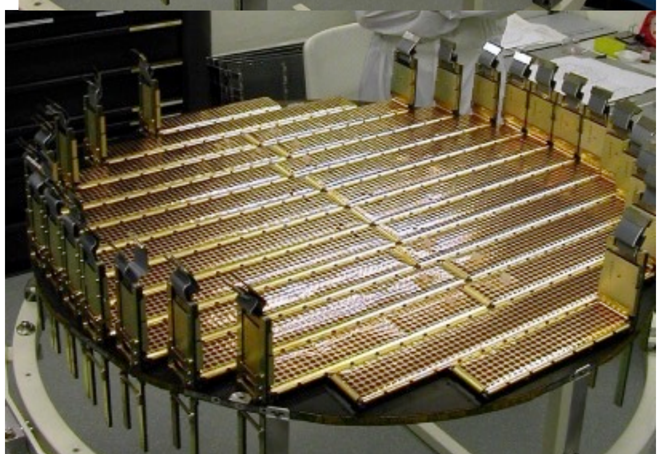
73 m^2 surface
9216 sensors
2304 ladders
221k channels

AMS-02 Silicon Tracker (2011)

strip pitch 27.5 µm
readout pitch 110 µm

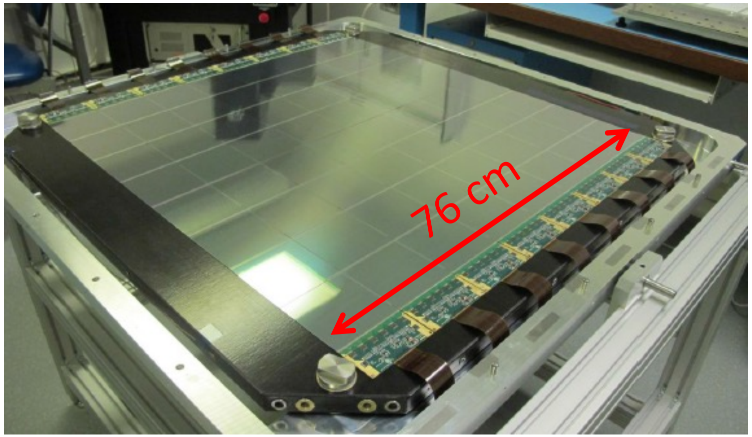


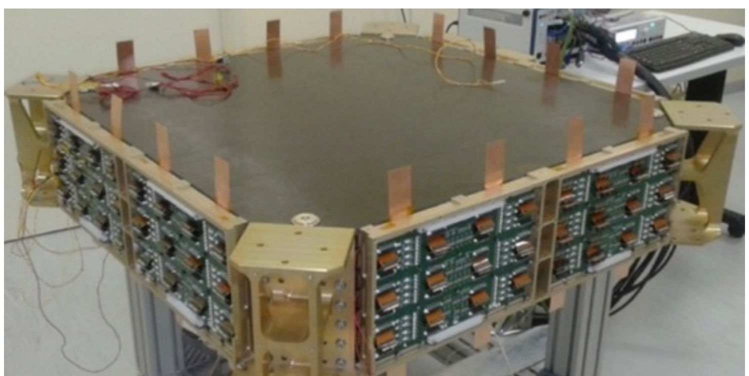
6.3 m^2 surface
2264 sensors
192 ladders
197k channels
190 W

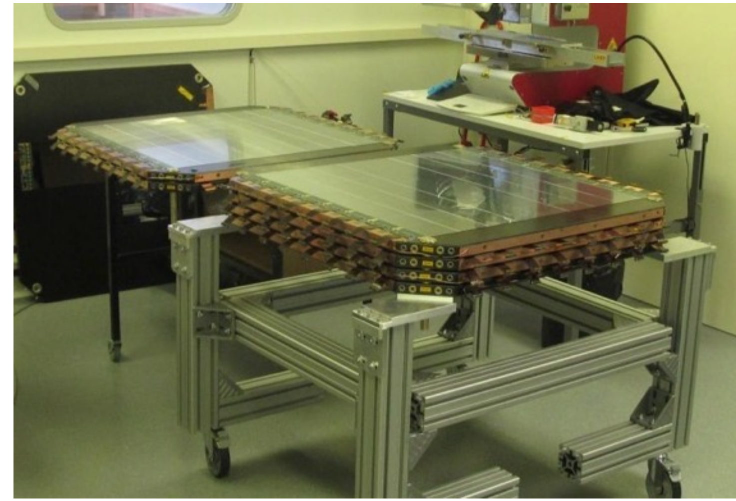


The DAMPE Silicon TracKer (2015)

strip pitch 120 µm
readout pitch 240 µm

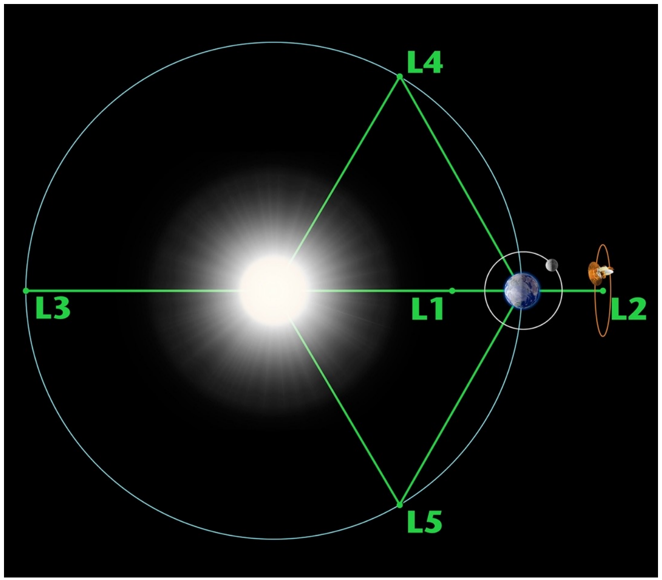


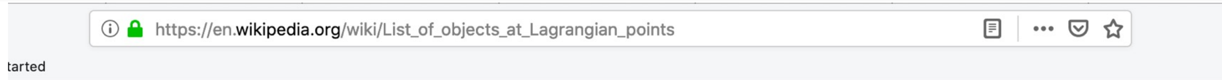




6.9 m^2 surface
768 sensors
192 ladders
74k channels
23 W

the (far) future is in L2, a nice place in space





L2 [edit]

L_2 is the Lagrangian point located approximately 1.5 million km from Earth in the direction opposite the Sun.

Past probes [edit]

- NASA's Wilkinson Microwave Anisotropy Probe (WMAP) observed the cosmic microwave background from 2001 until 2010. It was moved to a heliocentric orbit to avoid posing a hazard to future missions.
- NASA's WIND from November 2003 to April 2004. The spacecraft then went to Earth orbit, before heading to L_1.
- The ESA Herschel Space Observatory exhausted its supply of liquid helium and was moved from the Lagrangian point in June 2013.
- At the end of its mission ESA's *Planck* spacecraft was put into a heliocentric orbit and passivated to prevent it from endangering any future missions.
- CNSA's Chang'e 2[1] from August 2011 to April 2012. Chang'e 2 was then placed onto a heliocentric orbit that took it past the near-Earth asteroid 4179 Toutatis.

Present probes [edit]

- The ESA Gaia probe

Planned probes [edit]

- The joint Russian-German high-energy astrophysics observatory Spektr-RG
- The ESA Euclid mission, to better understand dark energy and dark matter by accurately measuring the acceleration of the universe.
- The joint NASA, ESA and CSA James Webb Space Telescope (JWST), formerly known as the Next Generation Space Telescope (NGST)
- The ESA PLATO mission, which will find and characterize rocky exoplanets.
- The JAXA LiteBIRD mission.
- The NASA Wide Field Infrared Survey Telescope (WFIRST)
- The ESA ARIEL mission, which will observe the atmospheres of exoplanets.
- The ESA Advanced Telescope for High ENergy Astrophysics (ATHENA)
- The NASA Advanced Technology Large-Aperture Space Telescope, which would replace the Hubble Space Telescope and possibly the JWST.

Cancelled probes [edit]

- The ESA Eddington mission
- The NASA Terrestrial Planet Finder mission (may be placed in an Earth-trailing orbit instead)

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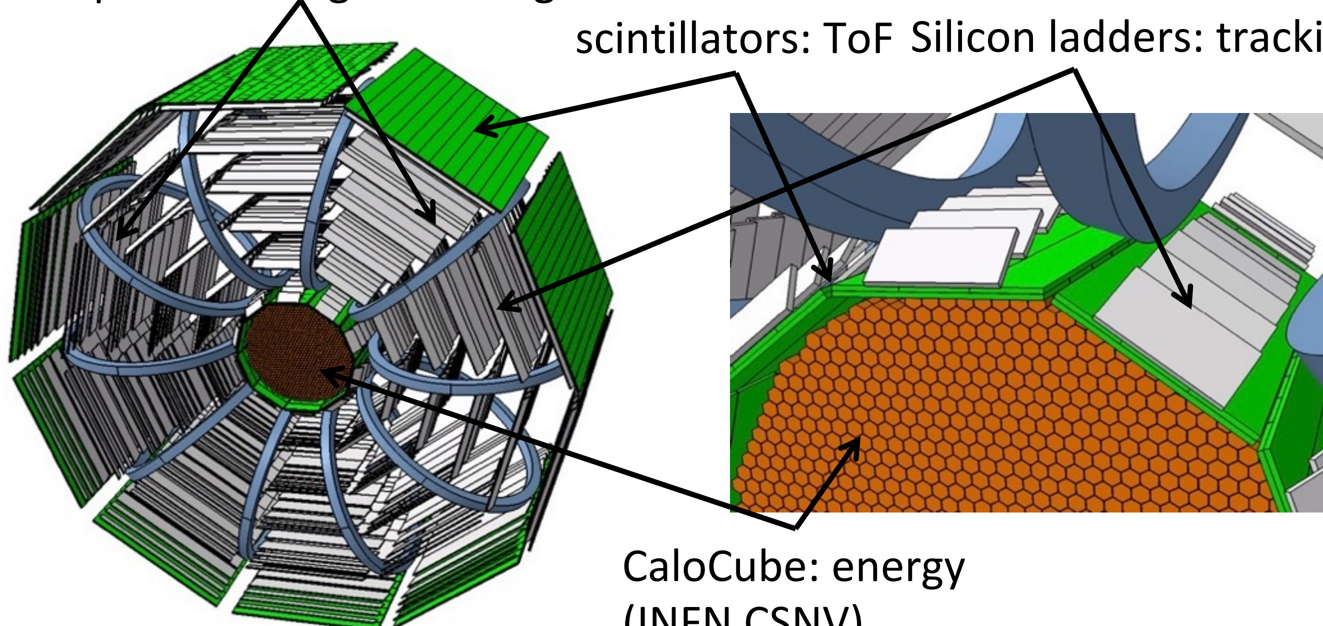
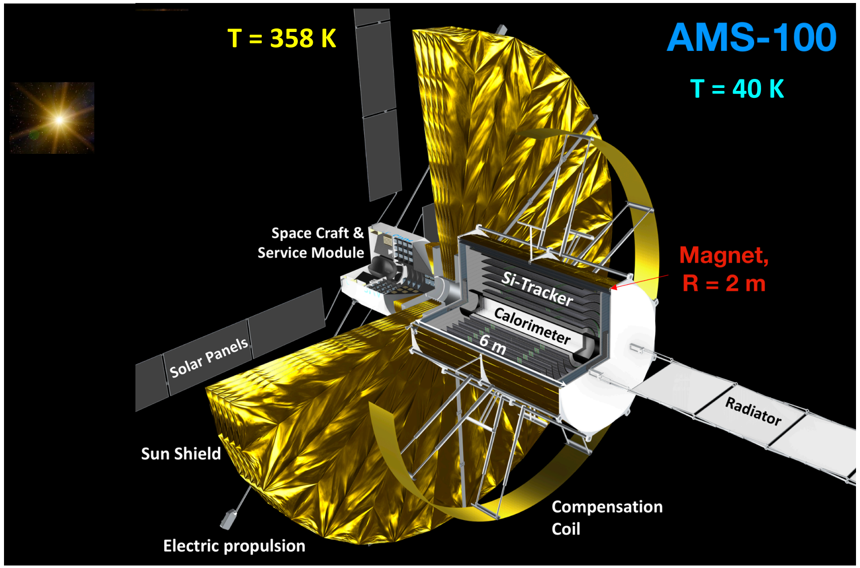
ALADInO - Antimatter Large Acceptance Detector In Orbit

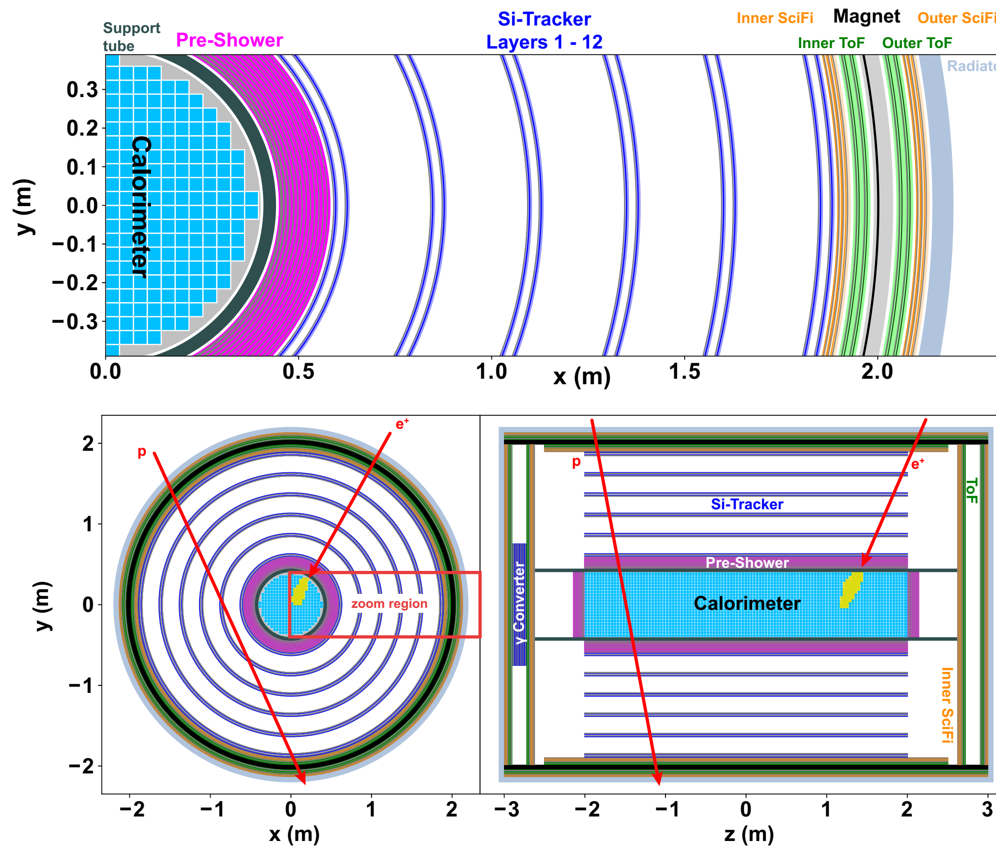


Diameter: 4.4 m
Length: 2.2 m
Acceptance: 3 m^2sr
MDR > 20 TV

~100 m^2 surface
O(5 μm) spatial resolution
2M channels
1 kW

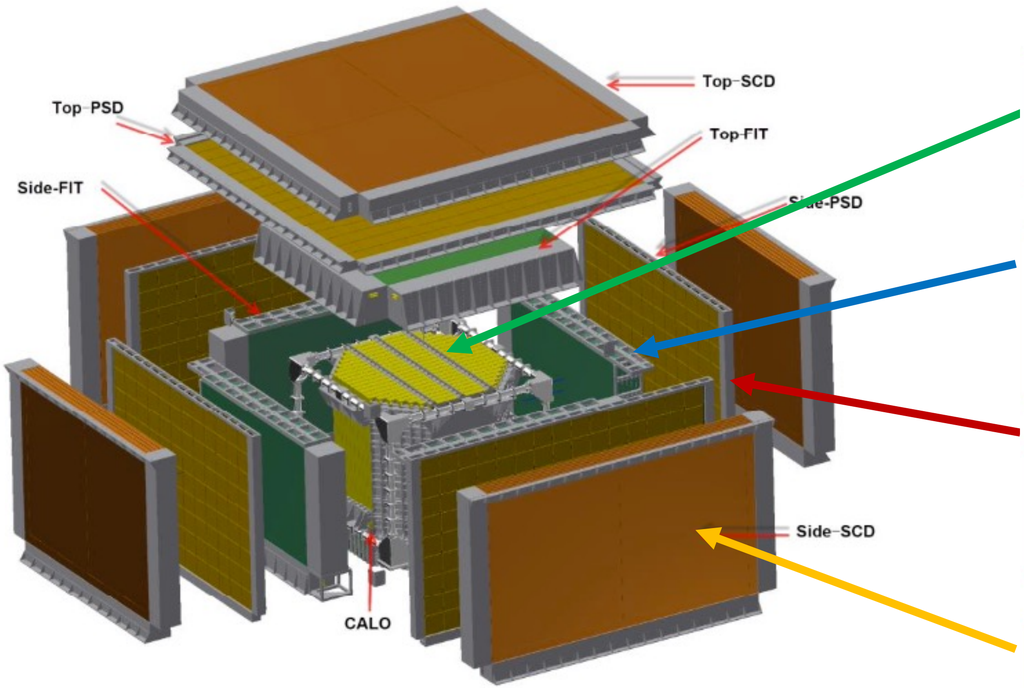
AMS-100





~200 m^2 surface
O(5 μm) spatial resolution
10M channels
5 kW

intermediate future: HERD



Field of view	+/- 70° off the zenith
Power	< 1.5 kW
Mass	< 4 t

CALO: CALOrimeter
- Energy measurement
- Electron/proton separation

FIT: FIber Tracker
- Track reconstruction
- Low energy γ ray conversion ($\gamma \rightarrow e^+ e^-$)
- Charge measurement (|Z|)

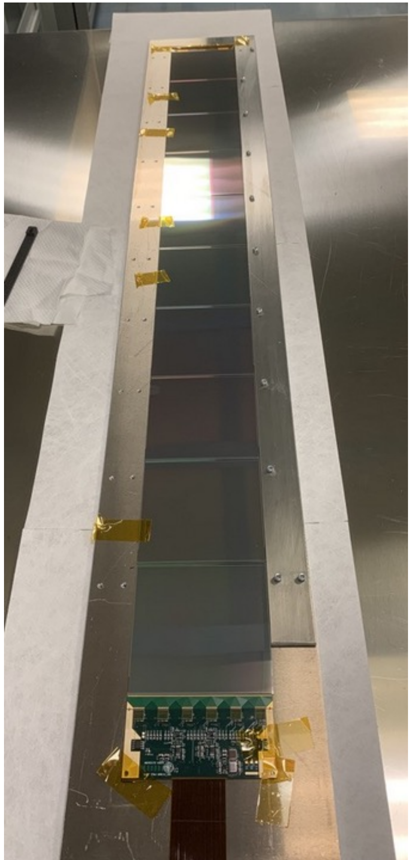
PSD: Plastic Scintillator Detector
- Charge measurement (|Z|)
- γ ray identification

SCD: Silicon Charge Detector
- Charge measurement (|Z|)

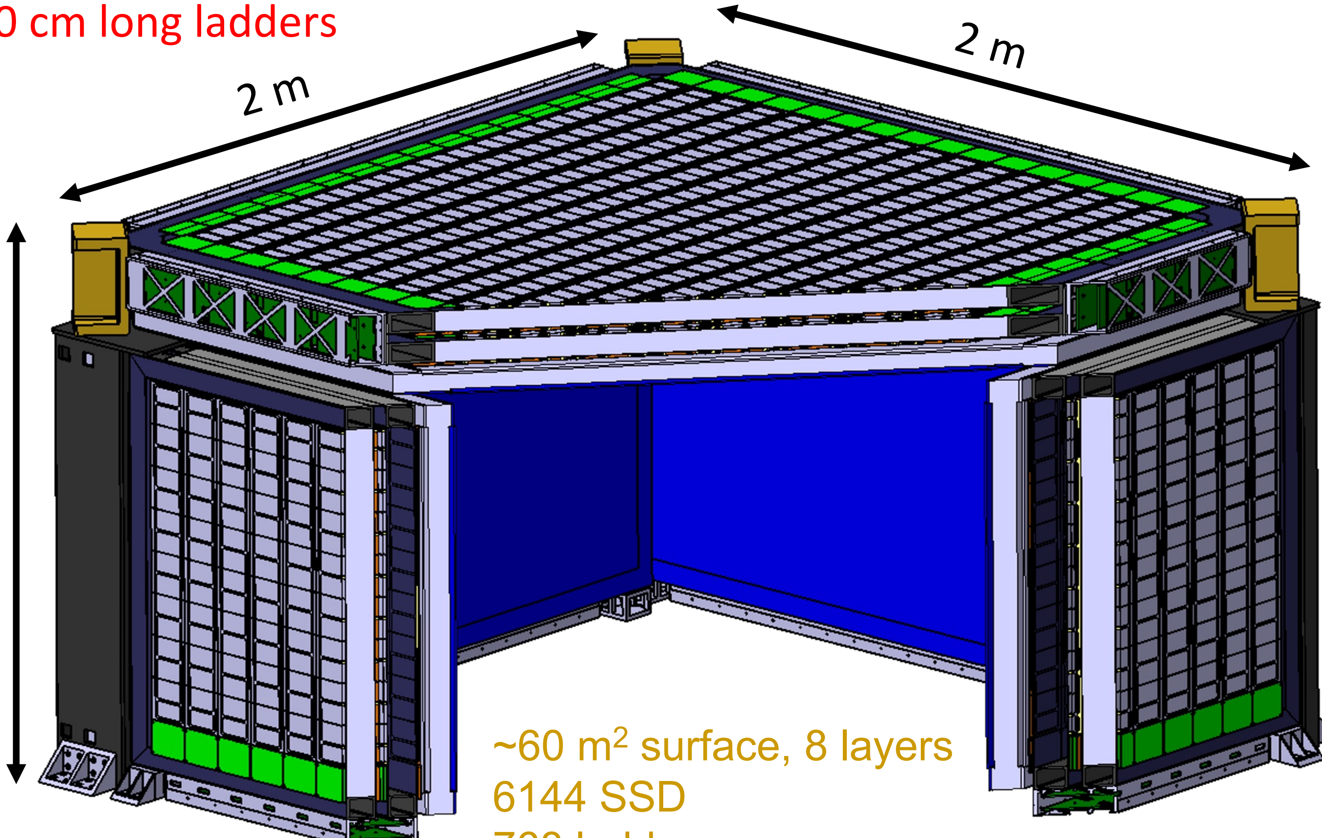
TRD: Transition Radiation Detector
- Energy calibration of TeV nuclei

to be installed on board the Chinese Space Station (2027)

HERD Silicon Charge Detector



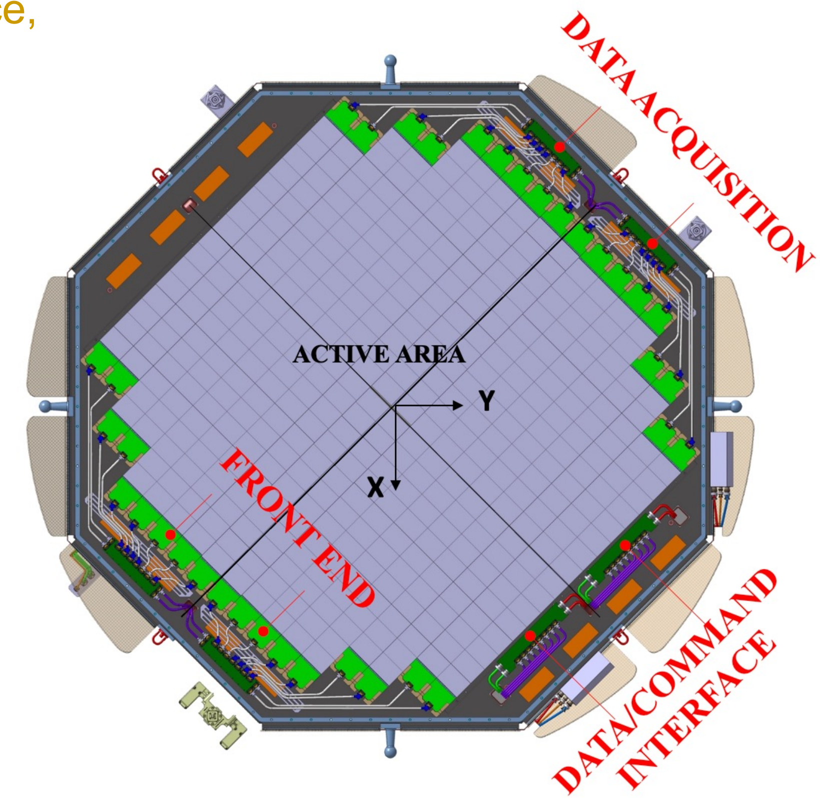
80-100 cm long ladders



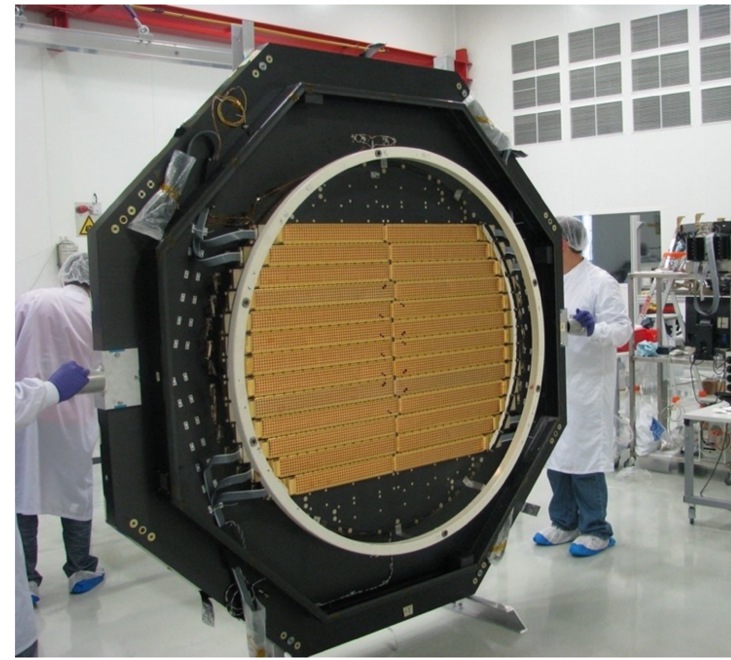
~60 m^2 surface, 8 layers
6144 SSD
768 ladders

The near future: AMS-02 L0 upgrade

~ 8 m^2 surface,
2 layers (45° stereo)
768 sensors
72 ladders
72k channels
~ 120 W



to be ready by early 2025



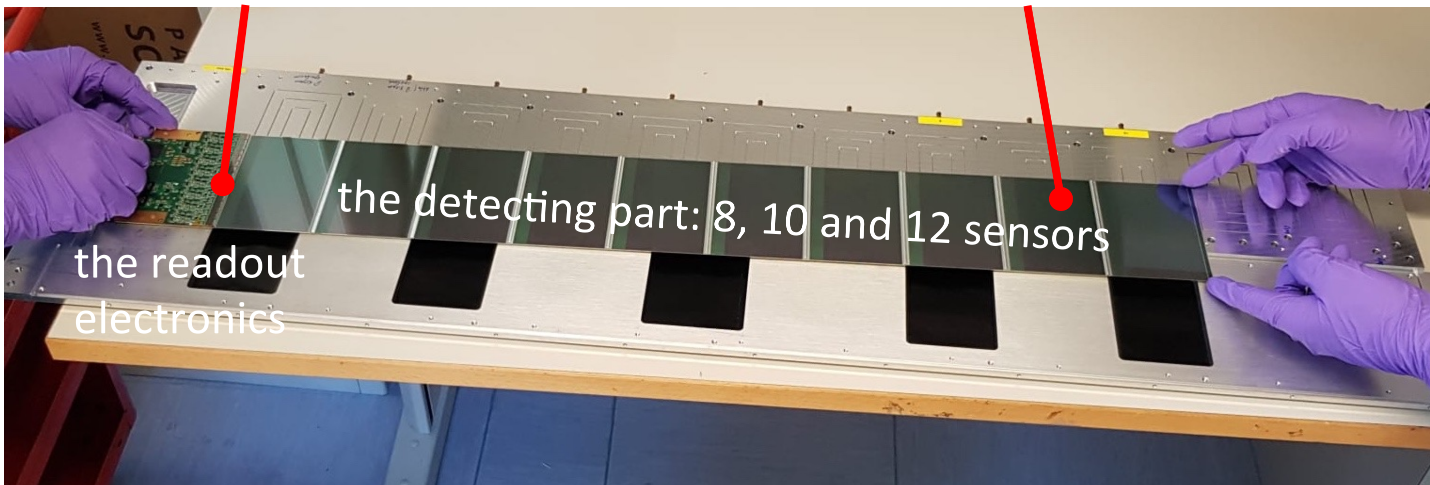
AMS-02 Layer1

The near future: AMS-02 L0 upgrade

the basic element of the detector

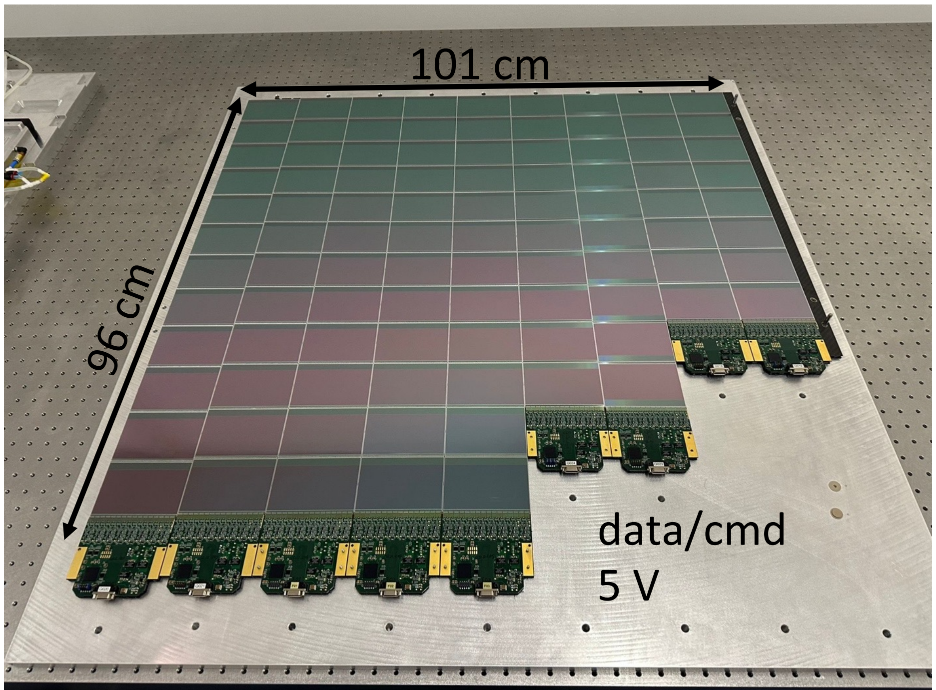
charge measurement:
high dynamic range FE

spatial resolution:
110 µm readout pitch

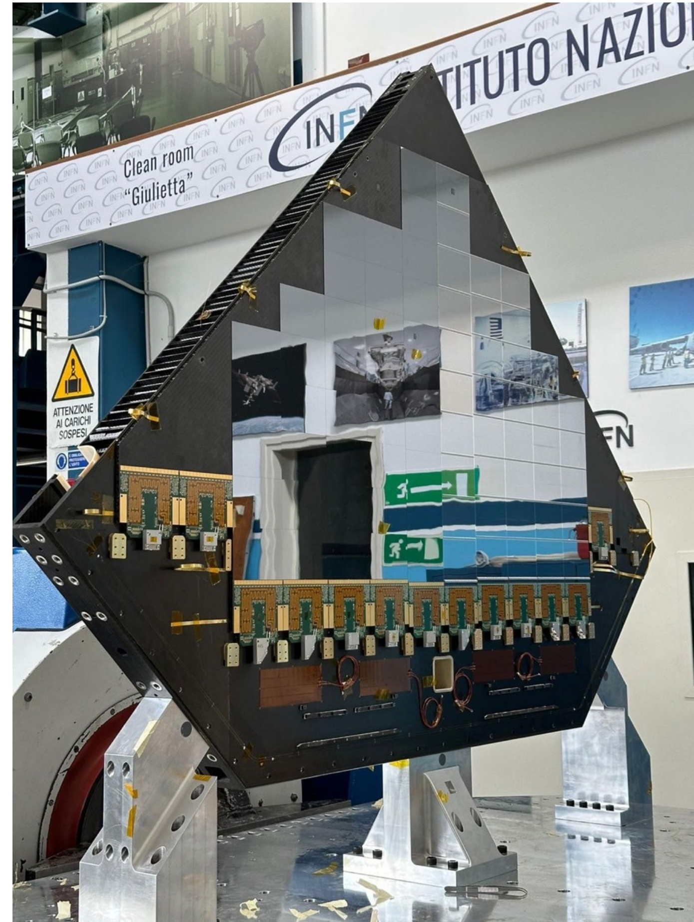


64-96 cm long ladders

AMS-02 L0 upgrade



Vibration test of a silicon detector

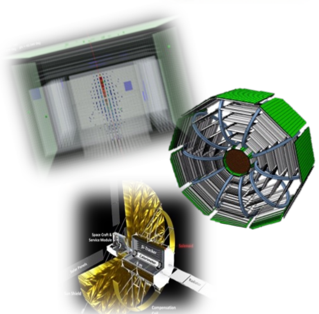


Silicon Microstrip detectors in space

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	$\sim 74\,\mathrm{m}^2$	38 cm	$\sim 880 \cdot 10^3$	228 μm	$\sim 66\,\mu$m
AMS-02	2011	$\sim 7\,\mathrm{m}^2$	29–62 cm	$\sim 200 \cdot 10^3$	110 μm	$\sim 7\,\mu$m
DAMPE	2015	$\sim 7\,\mathrm{m}^2$	38 cm	$\sim 70 \cdot 10^3$	242 μm	$\sim 40\,\mu$m



Future Missions						
	Planned operations	Si-sensor area	Strip-length	Readout channels	Readout pitch	Spatial resolution
HERD	2030	$\sim 35\,\mathrm{m}^2$	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

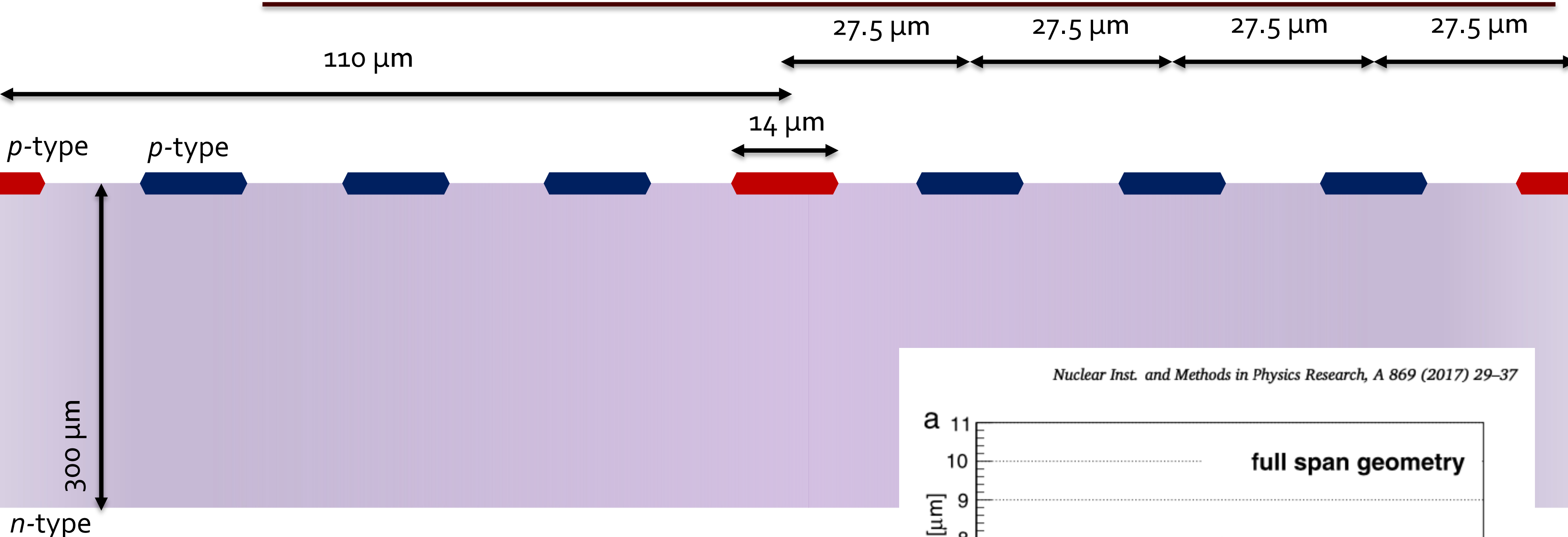
[1] HERD Collaboration. *HERD Proposal, 2018* https://indico.ihep.ac.cn/event/8164/material/1/0.pdf

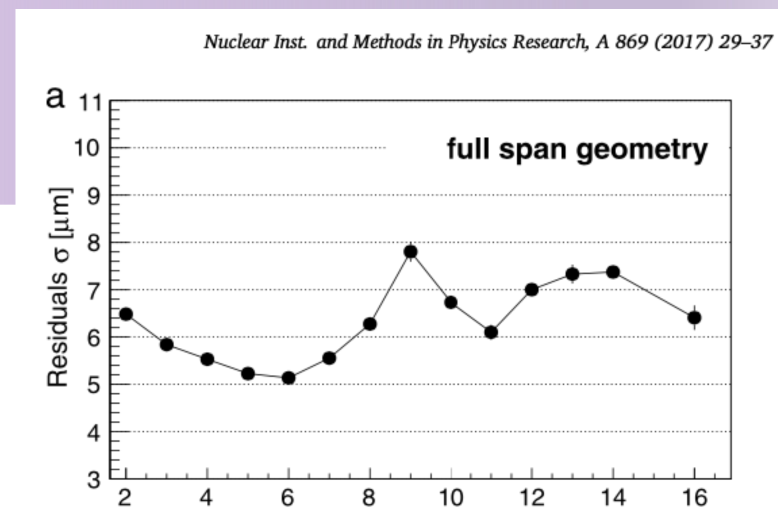
[2] Battiston, R.; Bertucci, B.; *et al. High precision particle astrophysics as a new window on the universe with an Antimatter Large Acceptance Detector In Orbit (ALADInO)*. Experimental Astronomy 2021. https://doi.org/10.1007/s10686-021-09708-w

[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

(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)

AMS-02 (junction, *"S"*, *"p-side"*, *"bending"*)





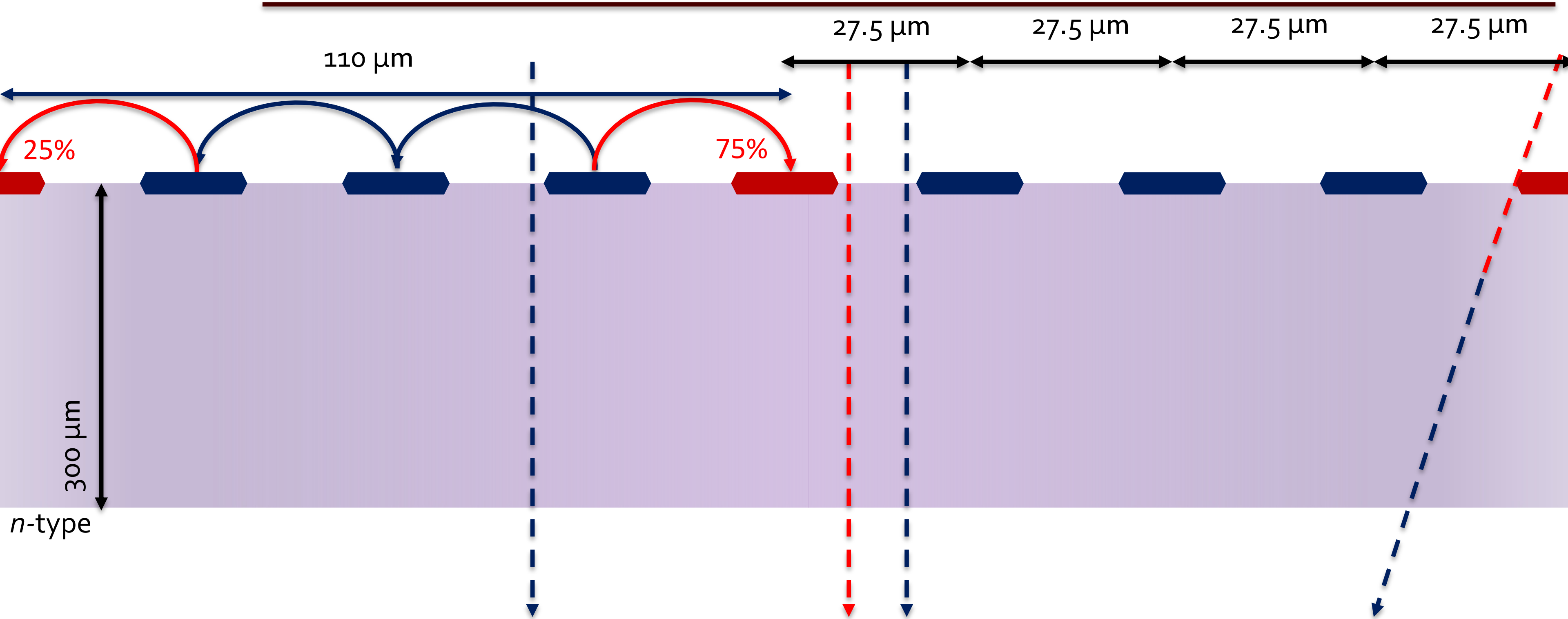
spatial resolution:
- 10 μm @ Z=1
- 5-6 μm @ Z>1

read-out strip
floating strip

to be compared with
27.5 μm /sqrt(12) ~ 8 μm

NOT
110 μm /sqrt(12) ~ 32 μm

AMS-02 (junction, *"S"*, *"p-side"*, *"bending"*)



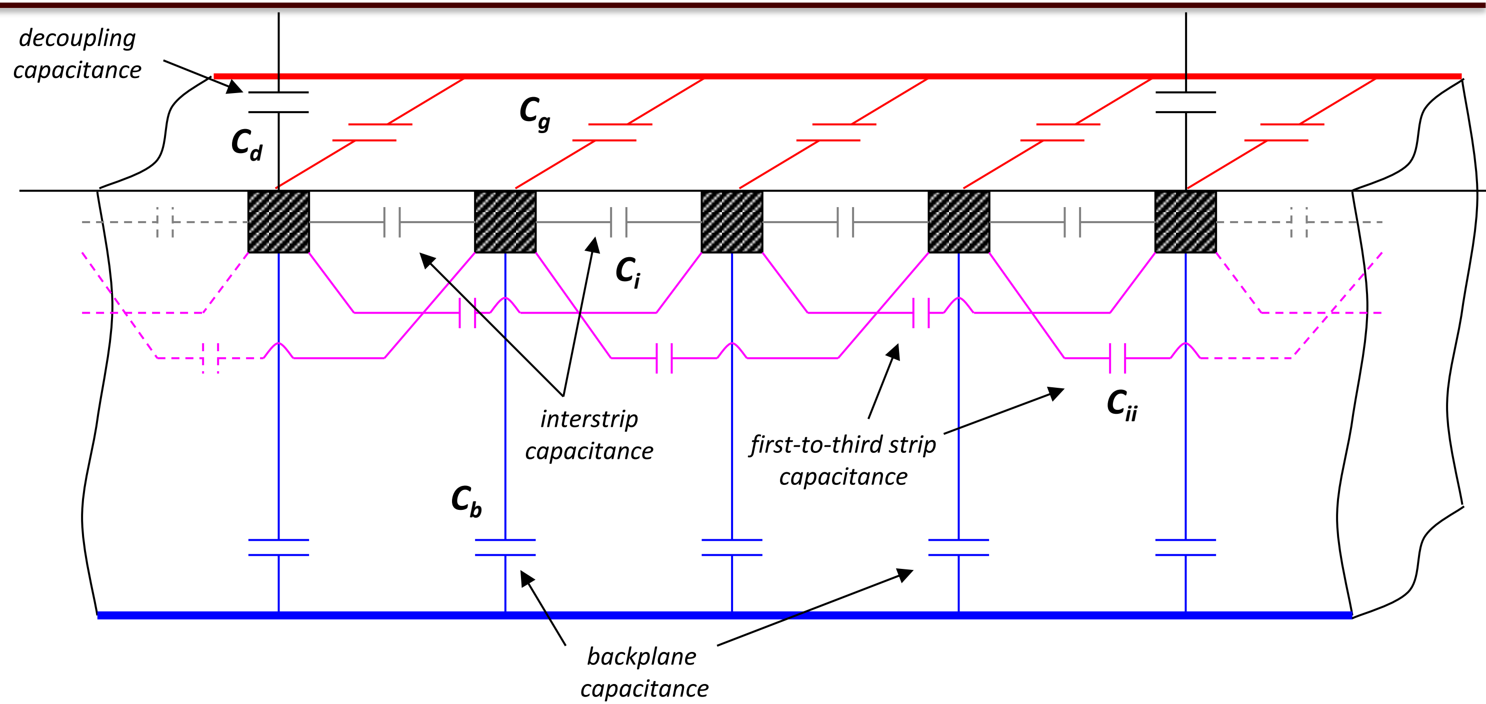
Ramo's theorem: only the closest strip (i.e. “digital")

→ capacitive coupling permits to know the fired strip

→ 27.5 µm /sqrt(12) ~ 8 µm

Thanks to *charge sharing* we can do even better than "digital"

Sensor's scheme (junction)



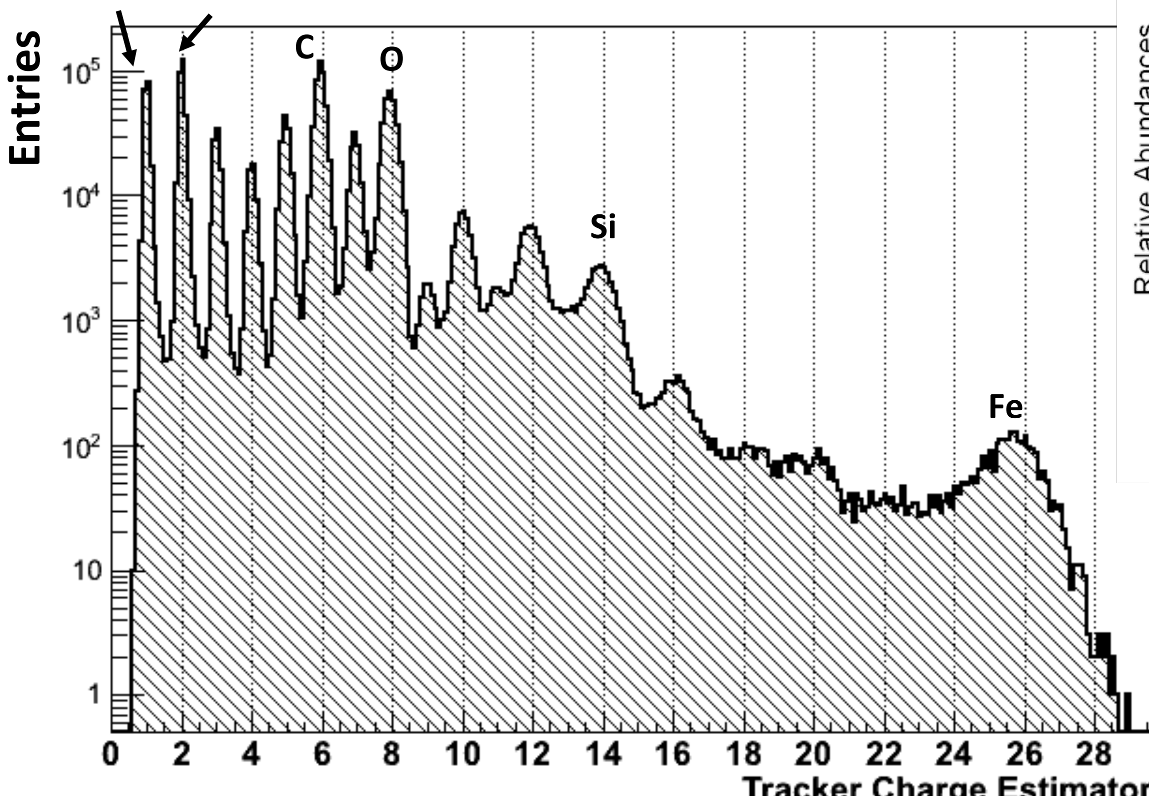
p *= pitch*
l *= strip lenght*
d *= thickness*

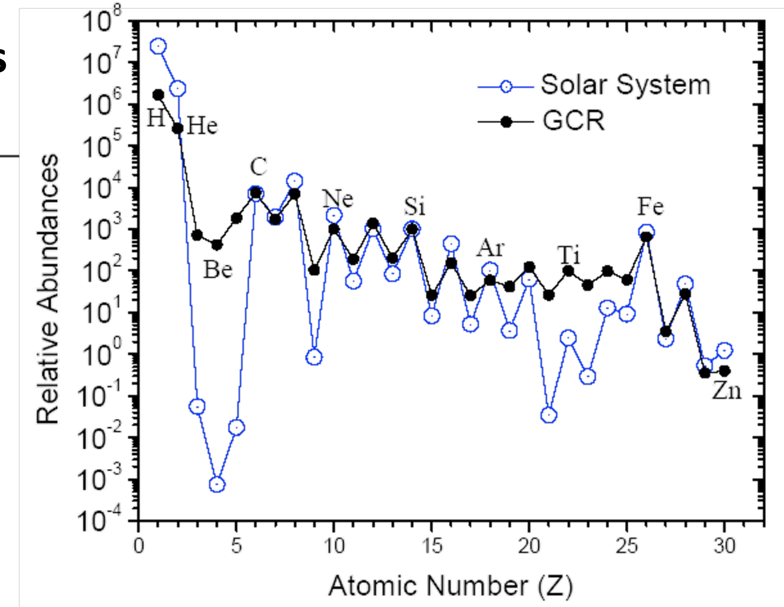
C_i = *interstrip capacitance ~ 1 pF/cm * l = 10 – 100 pF*
C_d = *decoupling capacitance ~ 1000 pF (DC sensors) or 120 pF/mm^2 (AC sensors) >* C_i C_b C_g C_{ii}
C_b = *backplane capacitance ~ 1 pF/cm * l * p/d = 0.5 – 2 * 10 – 100 pF*
C_g = *guardring capacitance << C_i*
C_{ii} = *first-to-third strip capacitance << C_i*

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

Abundances not corrected for detector efficiencies

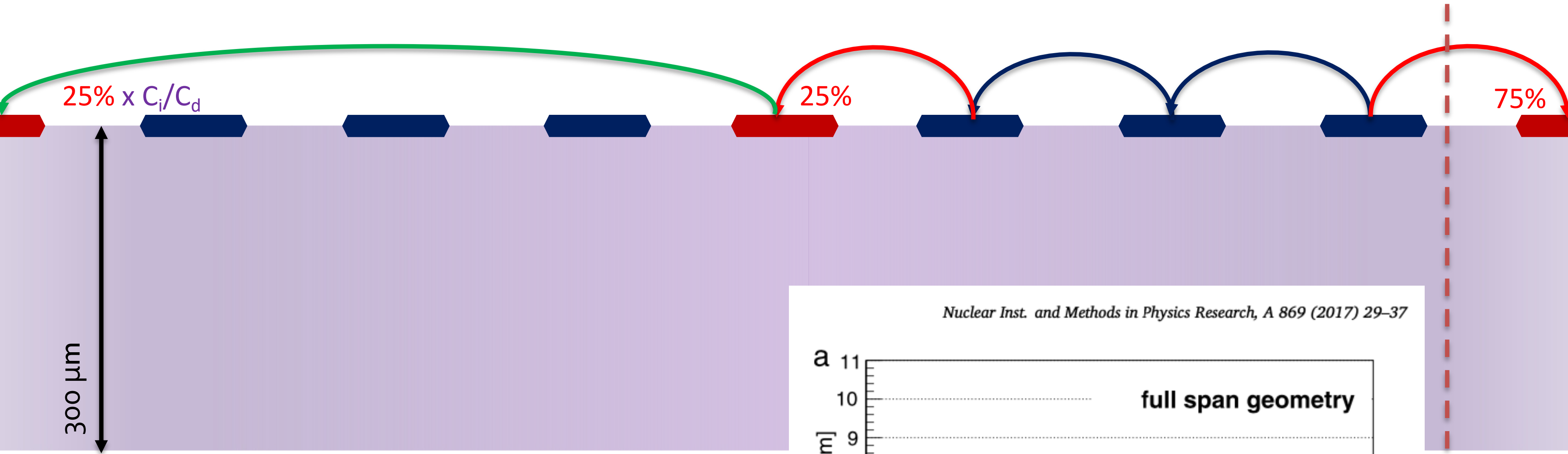
H and He prescaled



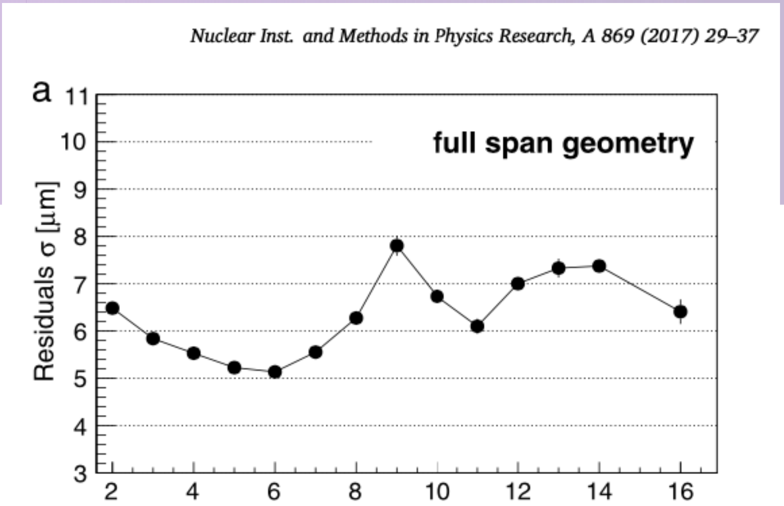


After few months of data on space the galactic cosmic rays (GCR) nuclear abundances are easily observed with an unprecedented statistics

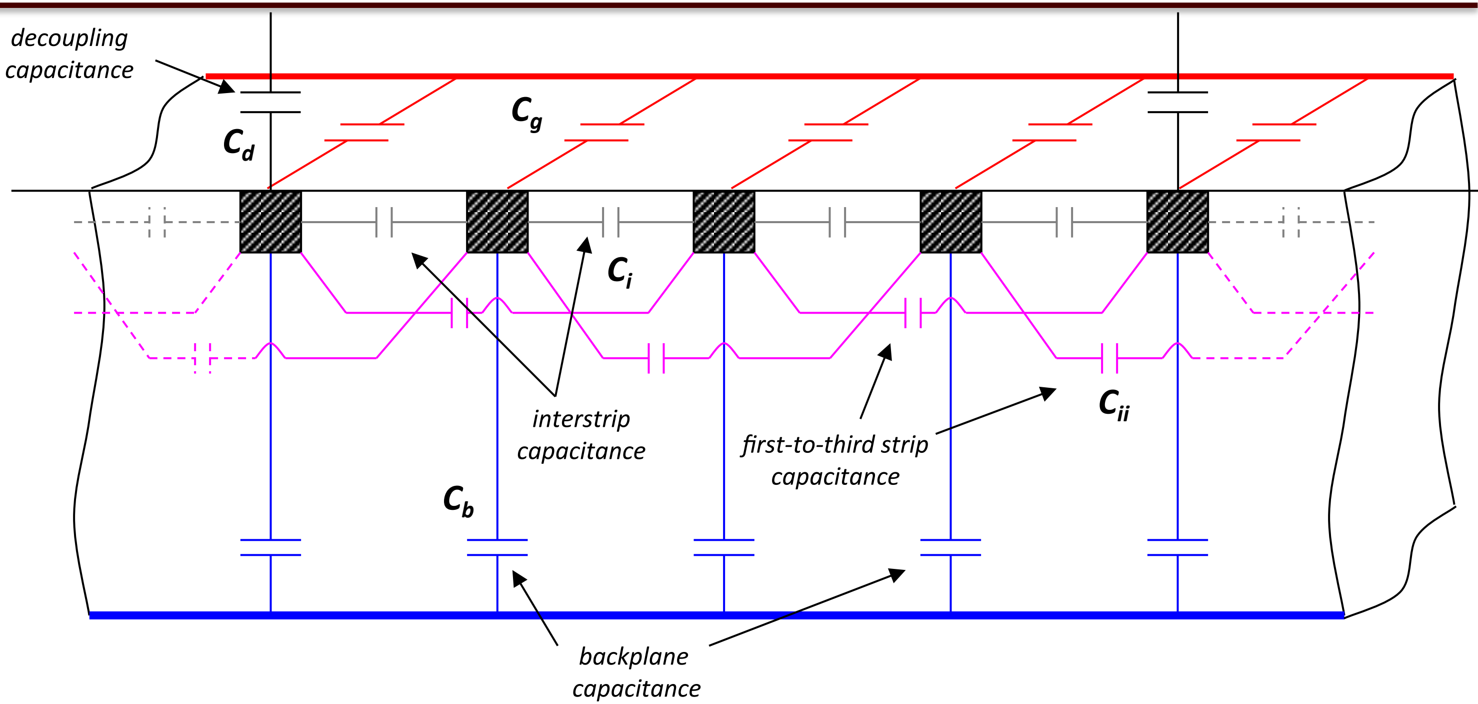
AMS-02 (junction, *"S"*, *"p-side"*, *"bending"*)



when the main two strips are saturated (at Front End level), the "overflow", towards other readout strips, allows to "recover" both the charge and the position



Sensor's scheme (junction)



p *= pitch*
l *= strip lenght*
d *= thickness*

***C**$_i$* *= interstrip capacitance ~ 1 pF/cm * l = 10 – 100 pF*

C**$_d$* *= decoupling capacitance ~ 1000 pF (DC sensors) or 120 pF/mm^2 (AC sensors) >* ***C_i C_b C_g C_{ii}

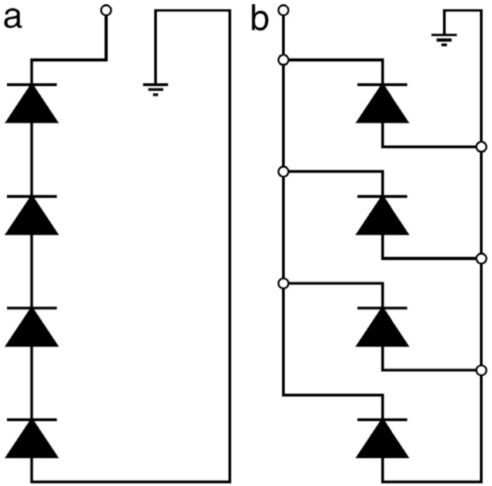
***C**$_b$* *= backplane capacitance ~ 1 pF/cm * l * p/d = 0.5 – 2 * 10 – 100 pF*

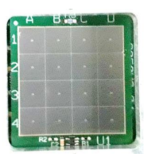
***C**$_g$* *= guardring capacitance << C_i*

***C**$_{ii}$* *= first-to-third strip capacitance << C_i*

What if we want a thin LGAD with a strip geometry?
Capacitance (C_b) become a big problem…

Serial vs parallel





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

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

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

multi-SiPM readout:

b) typical "parallel" readout

✔ bias voltage independent of number of SiPMs

✘ total capacitance seen by readout FEE scales with the number of SiPMs

a) "serial" readout

✘ bias voltage scales with of number of SiPMs

✔ total capacitance seen by readout FEE scales down (!) with the number of SiPMs

PRIN2022 - PTSD

Finanziato dall'Unione europea
NextGenerationEU

Ministero dell'Università e della Ricerca

Segretariato Generale

Direzione Generale della Ricerca

PRIN: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE – Bando 2022
Prot. 2022JNF3M4

PART A

1. Research project title

Pentadimensional Tracking Space Detector - PTSD

2. Duration (months)

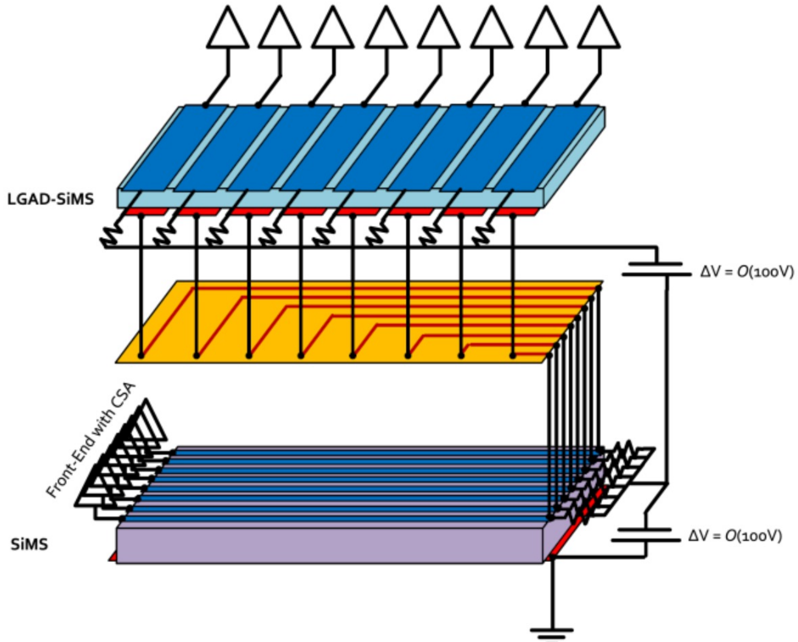
24 months

3. Main ERC field

PE - Physical Sciences and Engineering

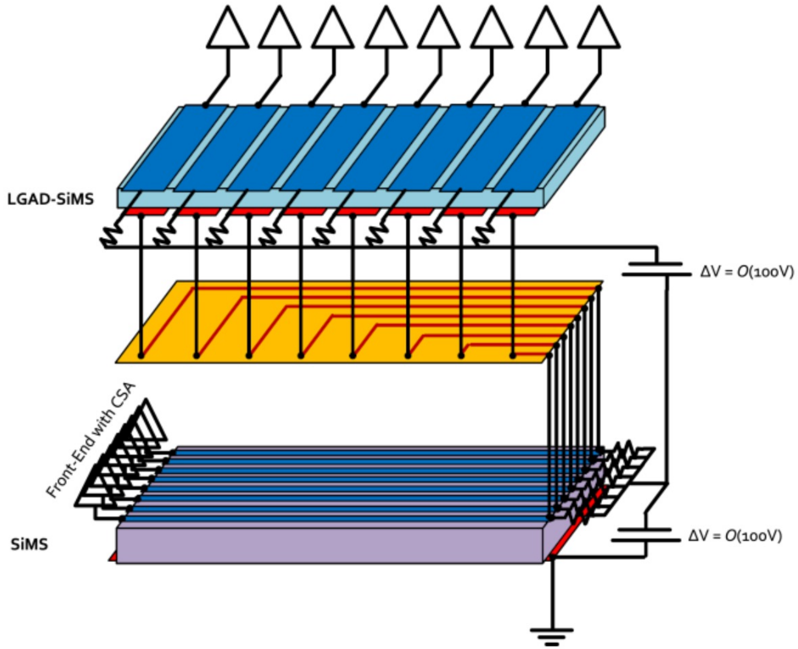
- INFN (PI M. Duranti) + ASI (Co-PI V. Vagelli)
- ~ 200 k€ received funds

Ideas behind the project



- combine a standard µstrip sensor (2D + Z) with an LGAD (2D + timing)
- serial readout of the "stack" to reduce LGAD capacitance
- use standard µtrip as "structural" material for a very thin LGAD layer

Ideas behind the project



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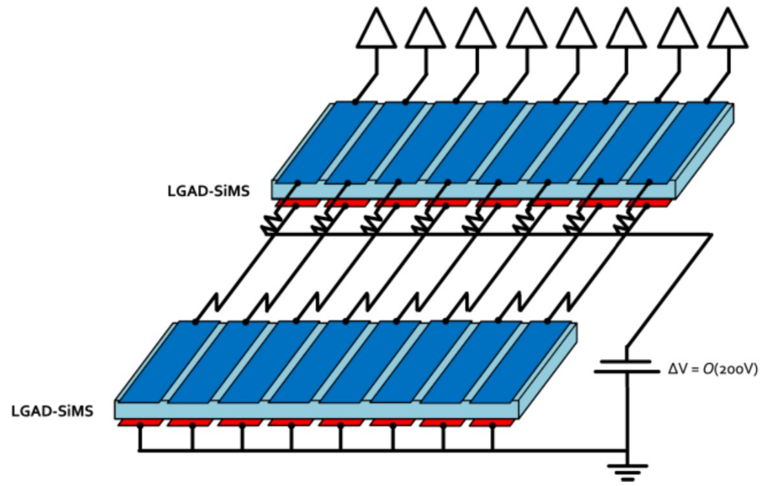


- combine a standard μstrip sensor (2D + Z) with an LGAD (2D + timing)
- serial readout of the "stack" to reduce LGAD capacitance
- use standard μtrip as "structural" material for a very thin LGAD layer

Is possible to "daisy chain" the sensors (LGAD but also standard μstrip) connecting them in series and not in parallel?

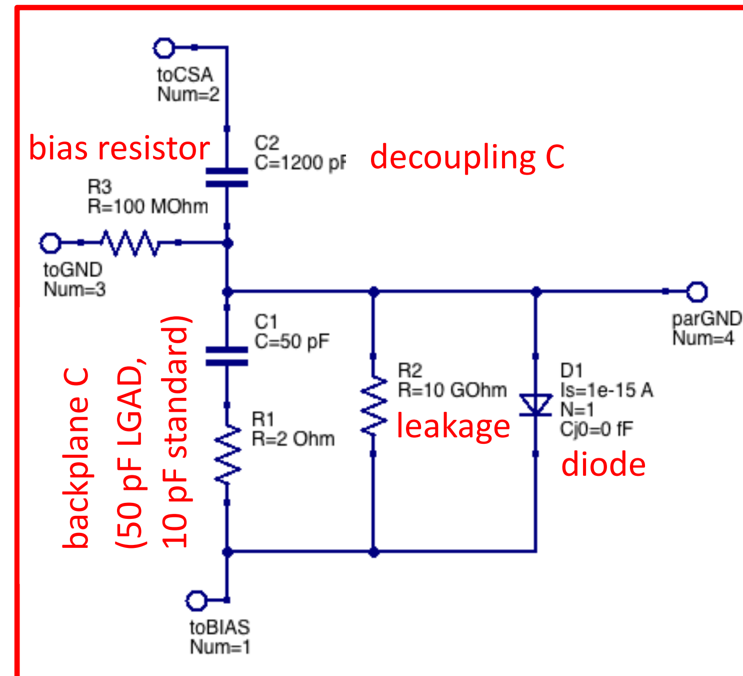
→ capacitance would decrease as the length of the sensors increases!


Si sensors
inside
STOP
CAUTION
VACUATION INSTRUCTIONS

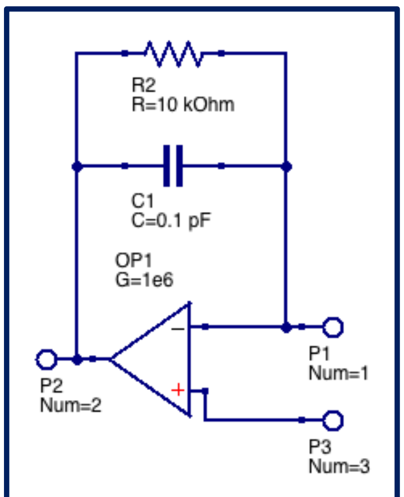
Backup

Preliminary work

Sensor (LGAD, standard)



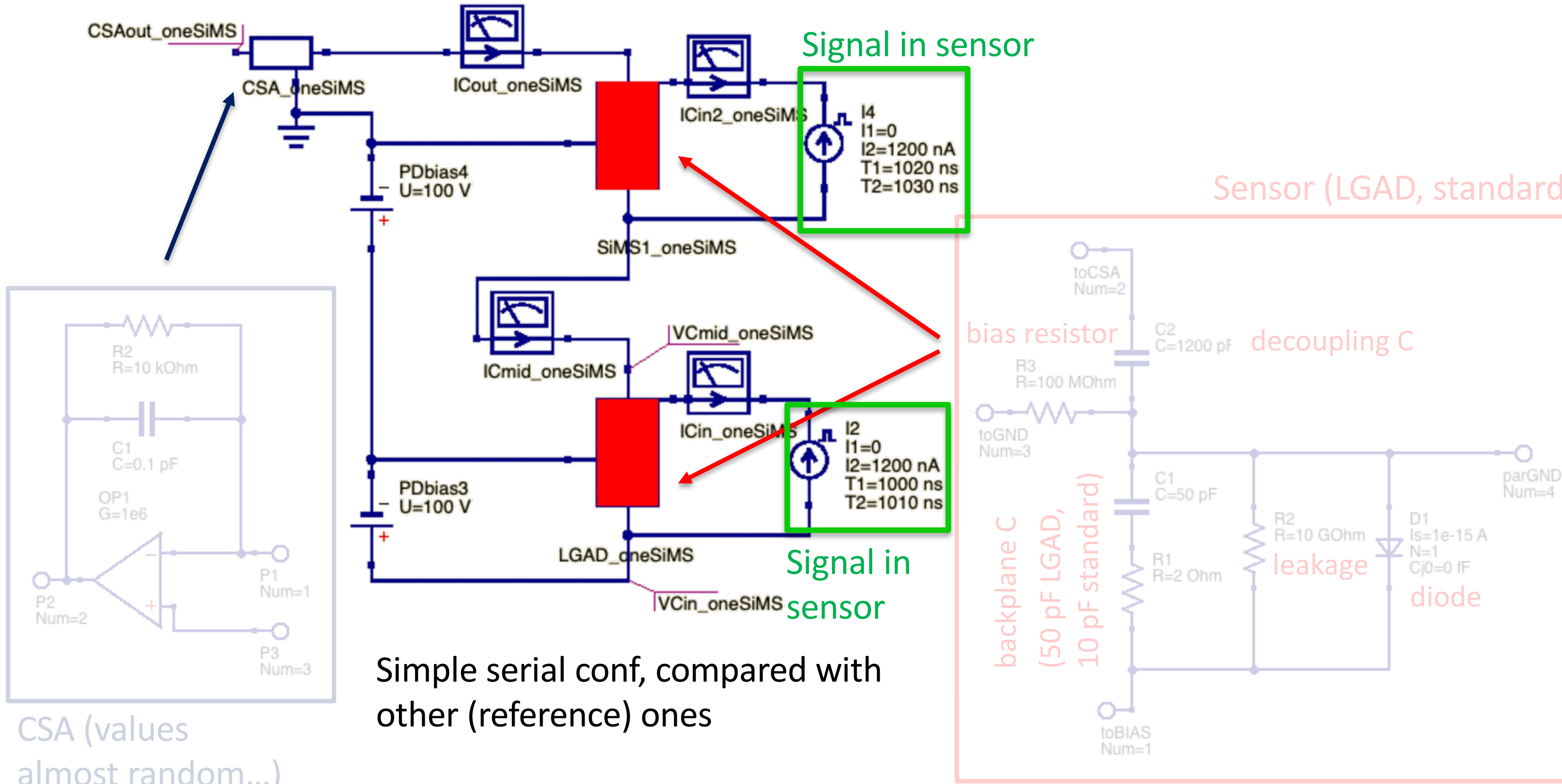
Preliminary work



CSA (values almost random…)

Sensor (LGAD, standard)

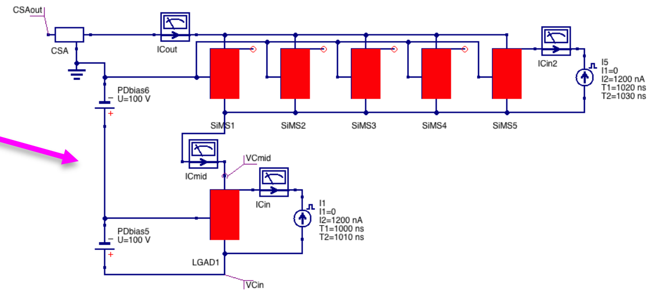
Preliminary work



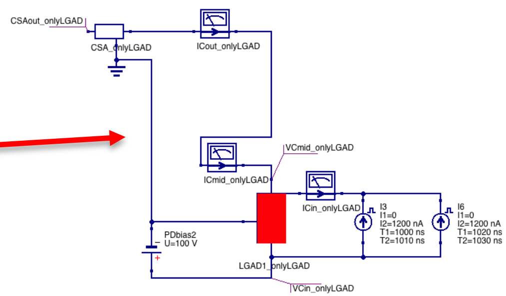
Simple serial conf, compared with other (reference) ones

Preliminary work

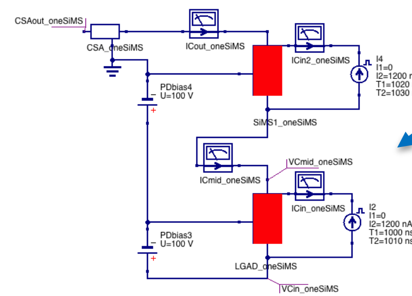
1 LGAD + 5 standard



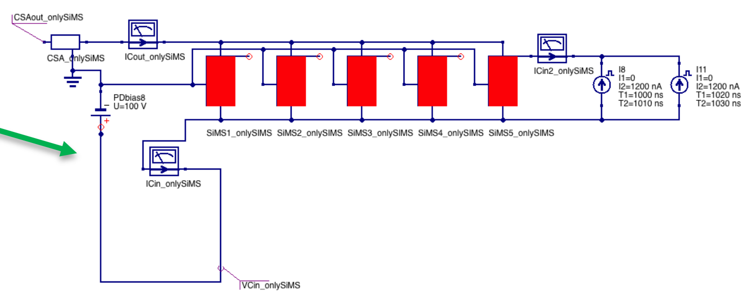
only LGAD



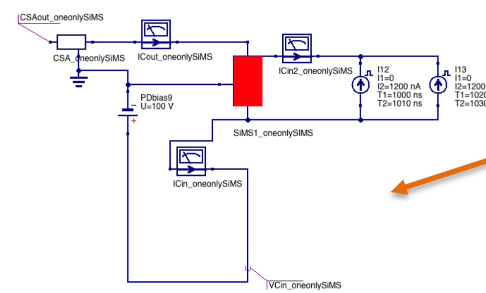
1 LGAD + 1 standard



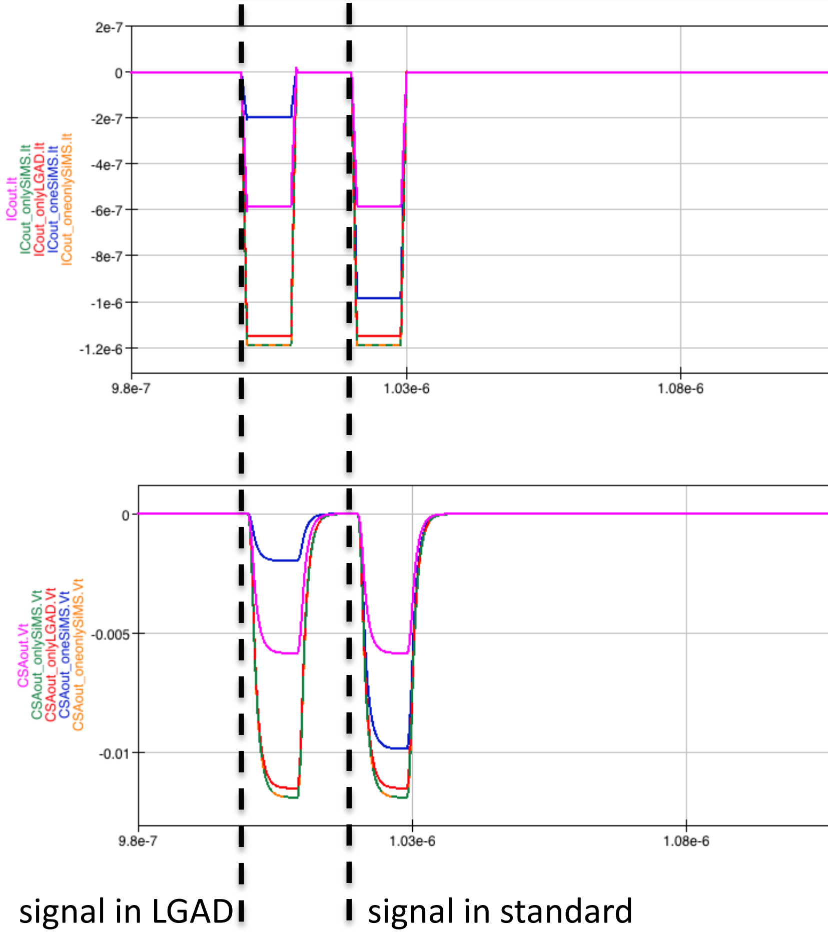
only (5) standard



only (1) standard



Preliminary work



✔ the LGAD signal is passing trough the standard sensor: seems working!

✔ the CSA should see only the standard sensor capacitance, being the lower

✘ the LGAD sees, as effective "decoupling capacitance", the standard sensor capacitance: the collected signal is depressed by the ratio of standard/LGAD capacitance (see violet and blue curves vs red one, and blue curve vs violet one)

✔ the standard sensor sees its whole decoupling capacitance, but also a "complex" (a network, including the LGAD) backplane capacitance: the signal is not severely but still depressed (blue curve vs green or orange). To be understood completely…

Cosmic Rays

$$N_{obs}(E, E+\Delta E) \propto \int_{T_0}^{T_0+\Delta T} \int_{E}^{E+\Delta E} A(E)\, \Phi(E)\, dE\, dT$$

if:

$$\Phi(E) \sim E^{-3}$$

what we get is something like:

$$N_{obs}(E, E+\Delta E) \propto \int_{E}^{E+\Delta E} E^{-3}\, dE$$

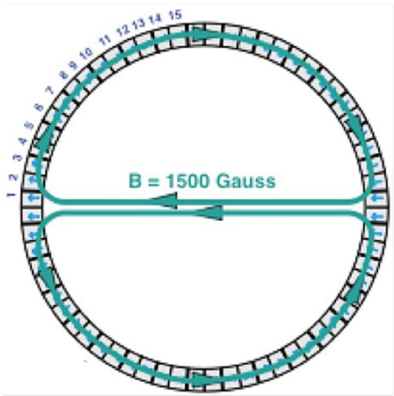
$$N_{obs}(E, E+\Delta E) \propto E^{-2}$$

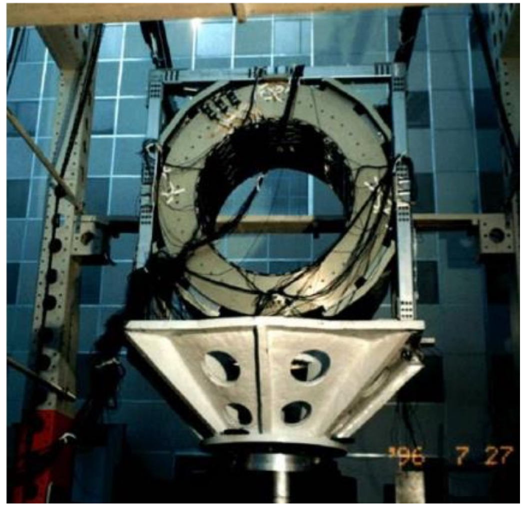
and this is what we use for the flux measurement

$$\Phi(E, E+\Delta E) = \frac{N_{obs}(E, E+\Delta E)}{A(E)\, \Delta T\, \Delta E}$$

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

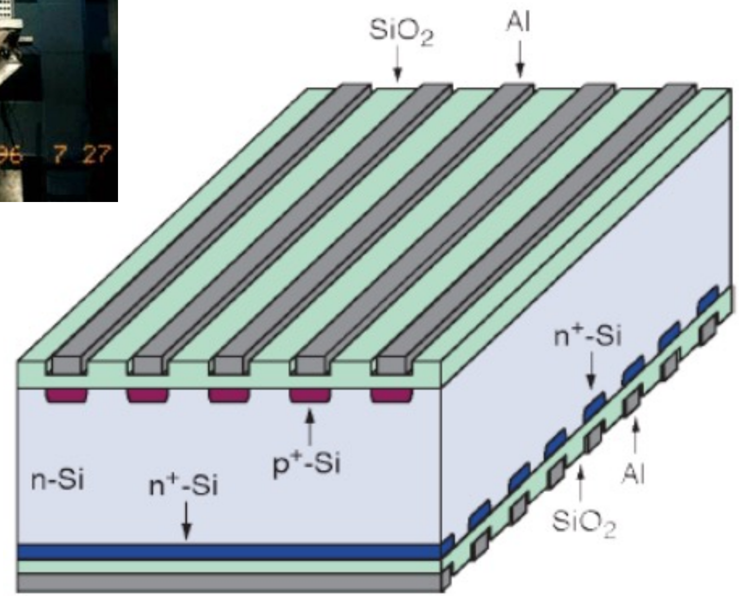
Spectrometer power consumption mitigation (AMS)





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

- bending direction
- non-bending (*) direction



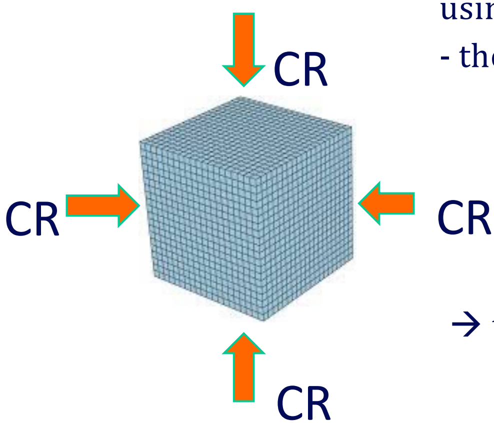
This allow to push the spatial resolution (and so the power consumption) only in one direction.

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...

Astro-particle detectors – planned and dreamed

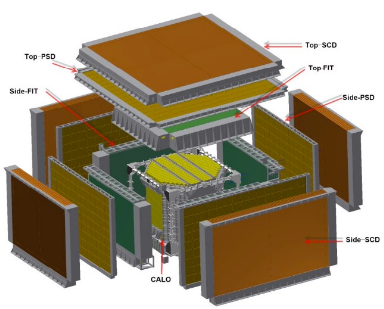


- exploit the CR "isotropy" to maximize the effective geometrical factor, by using all the surface of the detector (aiming to reach $\Omega = 4\pi$)
- the calorimeter should be highly isotropic and homogeneous:
  - the needed <u>depth</u> of the calorimeter must be guaranteed for all the sides (i.e.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

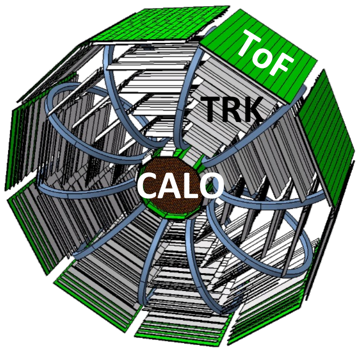
→ this is in general doable just with an homogeneous calorimeter

→ CaloCube

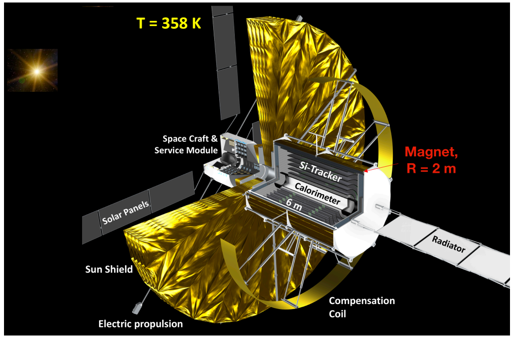
HERD on the CSS (2027):



ALADInO @L2 (2050?):

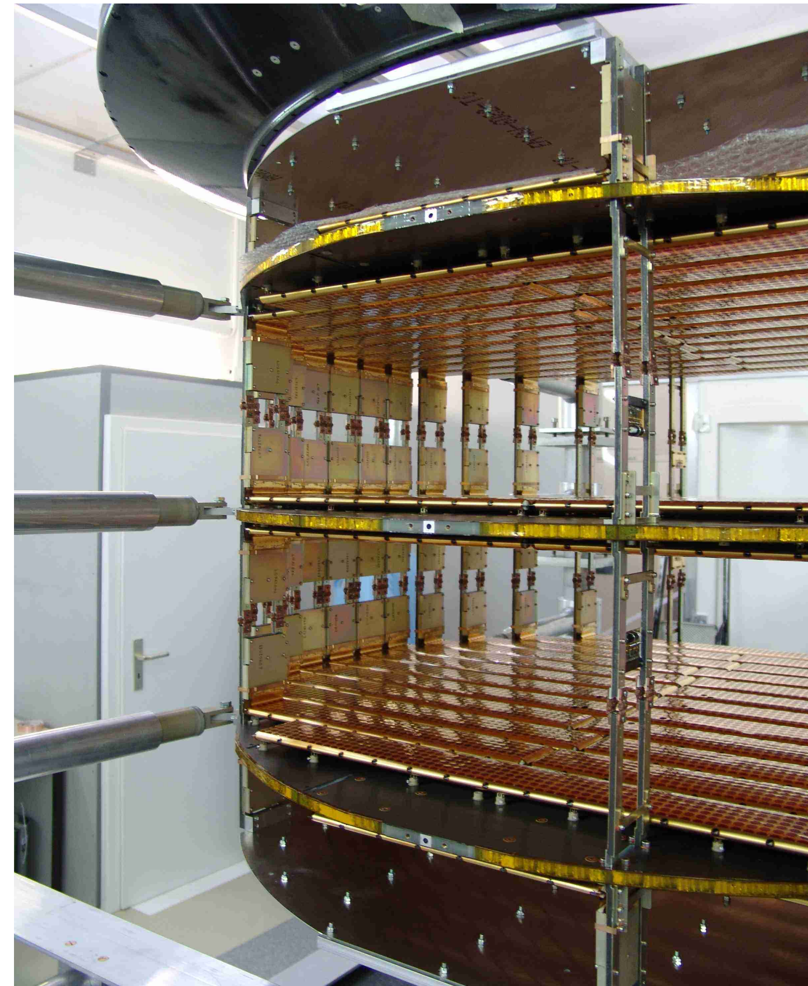


AMS-100 (2050?):

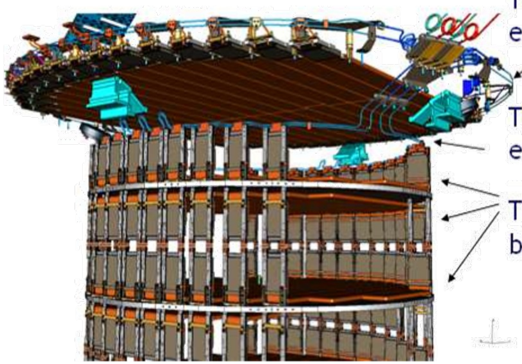


AMS-02: Silicon Tracker

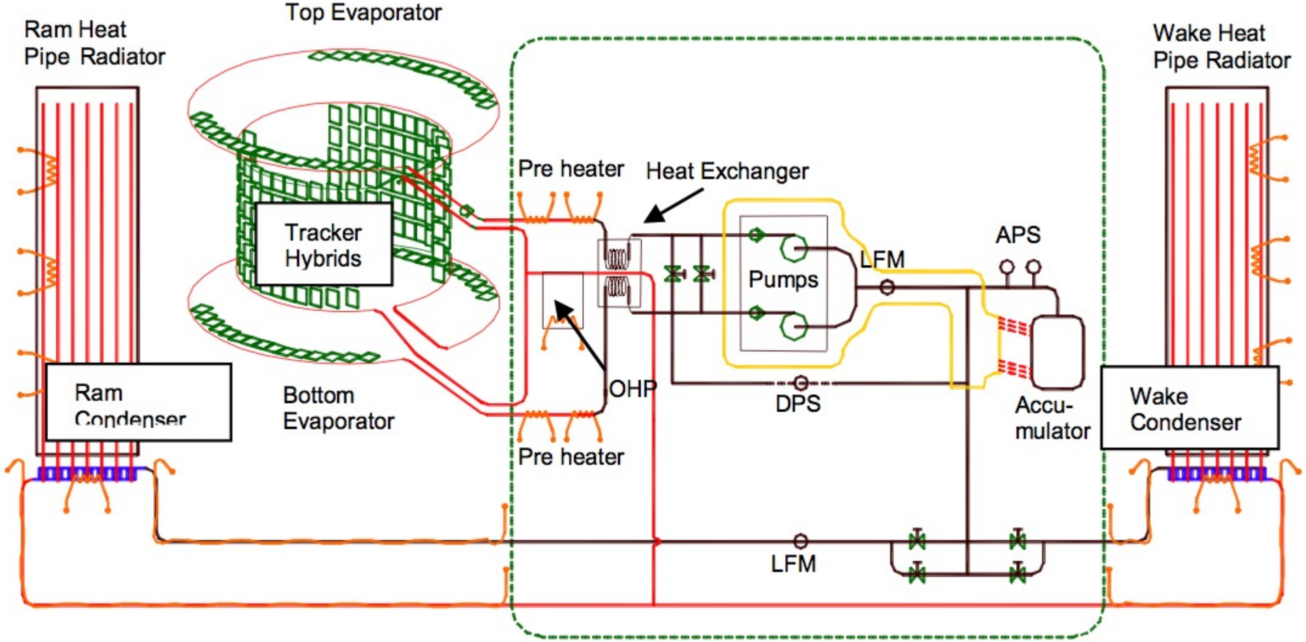
- 9 layers of double sided silicon detectors arranged in 192 ladders
- ~6 m^2
- total of 200k channels for ~ 200 watt
- 10 μm (30 μm) spatial resolution in bending (non bending) plane
- momentum resolution ~10% @10 GeV
- high dynamic range front end for charge measurement
- wide temperature range (-20/+40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



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



Tracker Thermal Cooling System (TTCS)



AMS-02: Silicon "ladder"

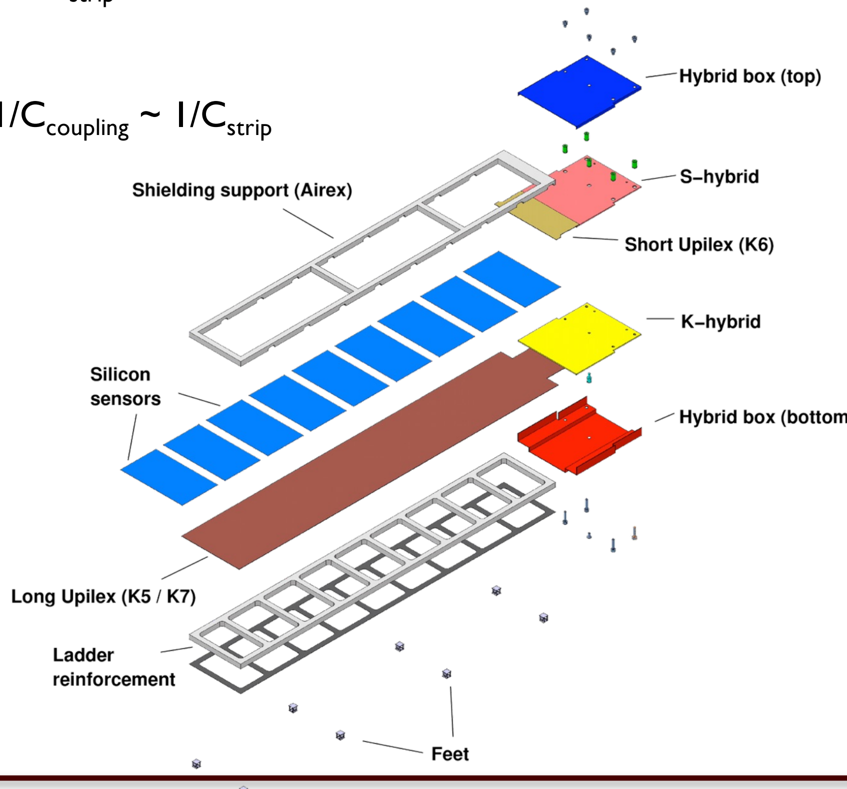
- C_b = 7pF
- C_{strip} = 1.2pF/cm

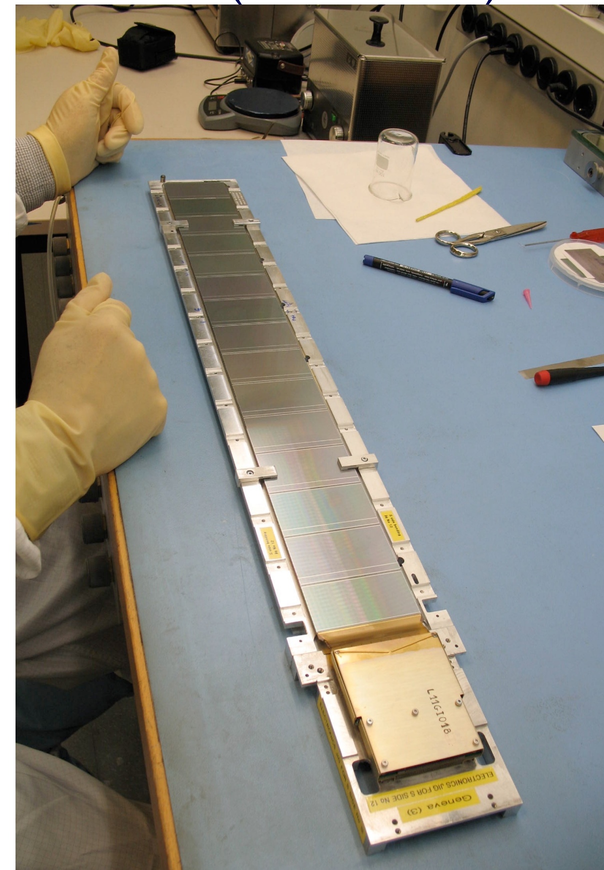
  → $C_b + C_{strip} \sim C_{strip}$
- $C_{coupling}$ = 700pF

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

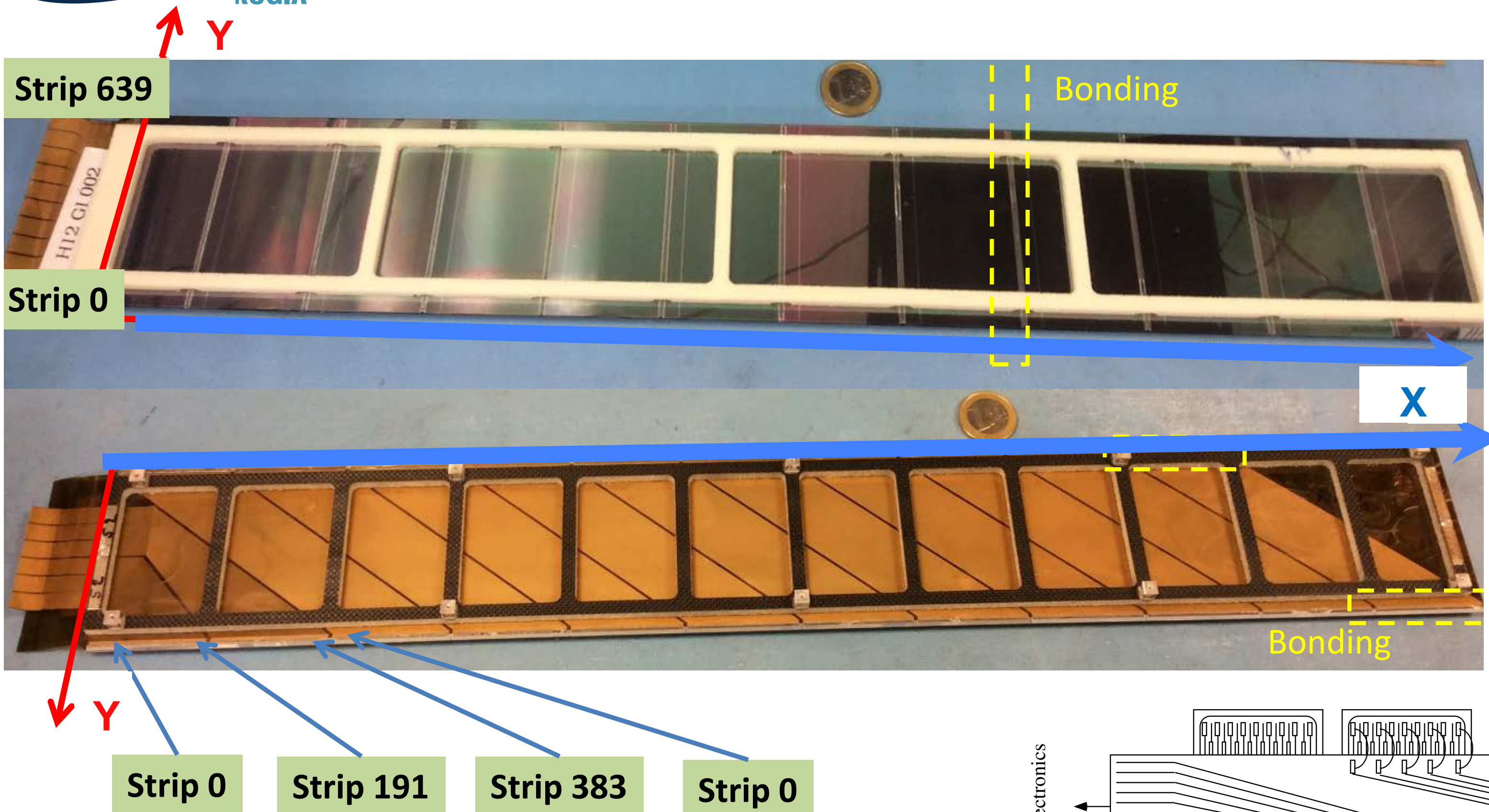
•192 flight units

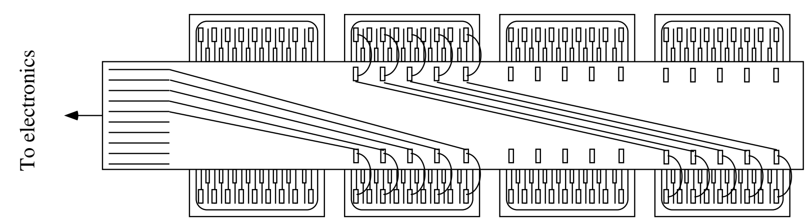
7 – 15 wafers (28 – 60 cm) each





AMS-02: Silicon "ladder"

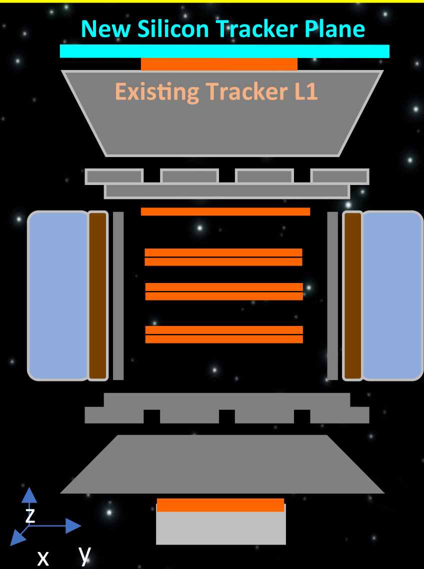


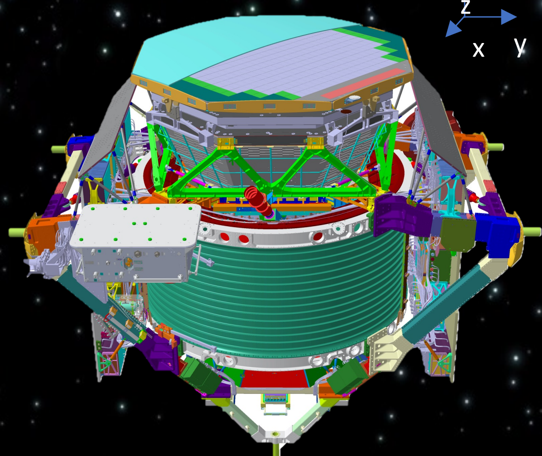


"multiplicity" (or "ambiguity"): the 1500-3000 K-side channels needed for each ladder are "merged" into 384.

AMS-02 upgrade "L0"

New Silicon Tracker Layer: one plane, two layers, each ~ 4m^2

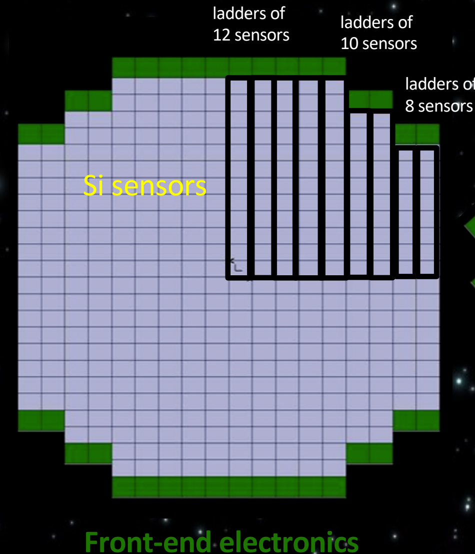




L0-Y

bending direction

7 micron

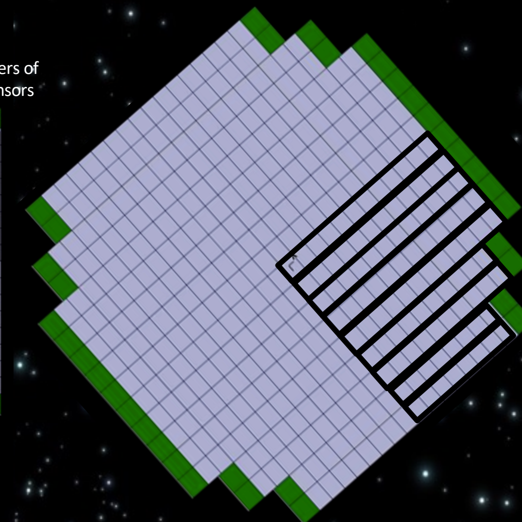


L0-U

rotated 45°

10 micron bending

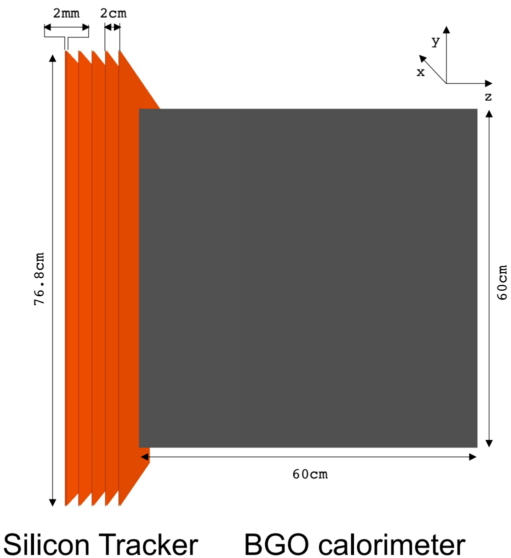
10 micron non-bending

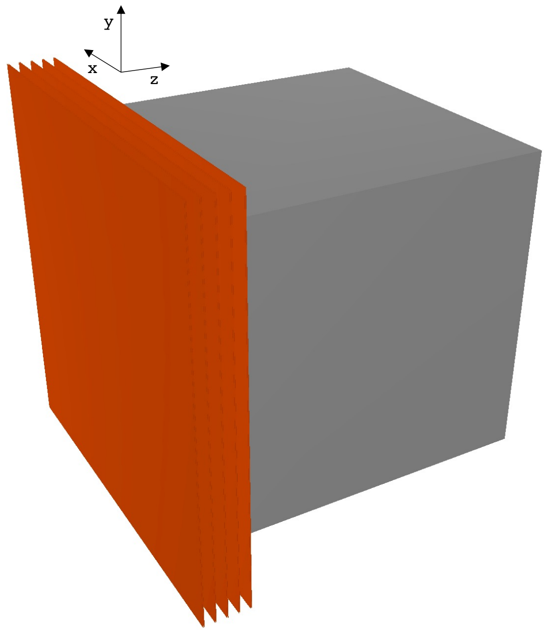


Acceptance increased to 300% (10 years data becomes 30 years data)

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



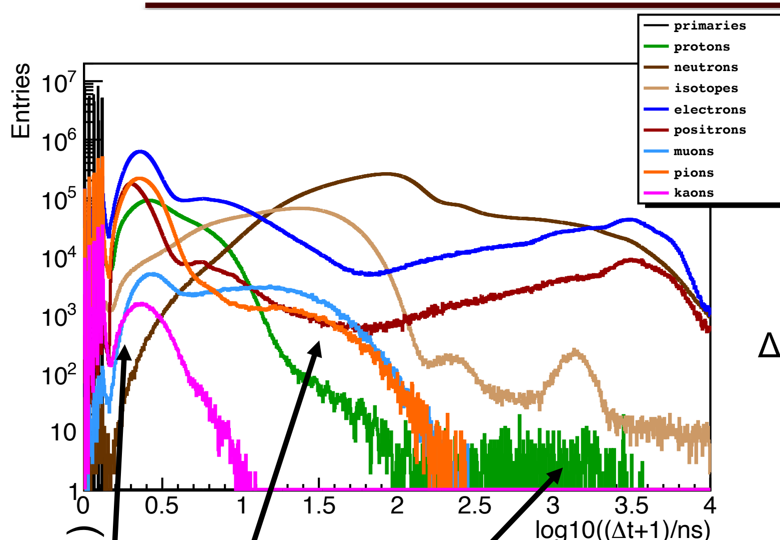


Informations saved:
- energy lost and deposited
- spatial coordinates
- timing
- …

Back-scattering

1 TeV protons

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



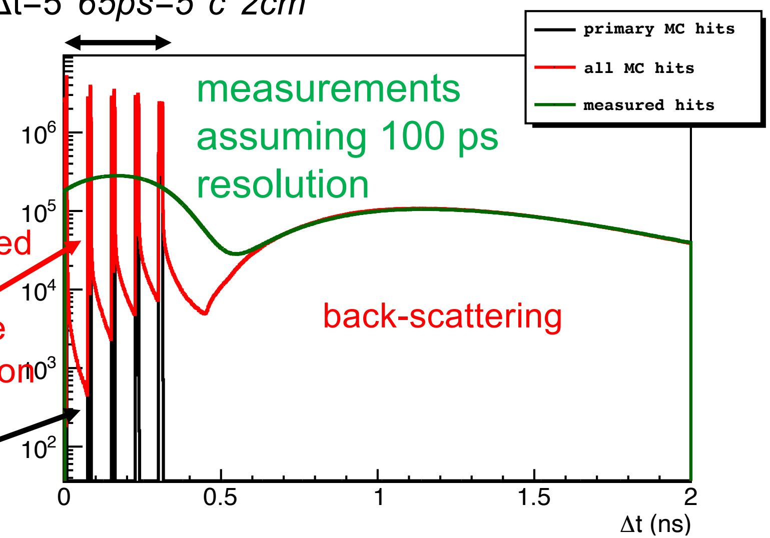
Δt=O(100ps)

Δt=O(10ns)

Δt=O(10μs)

Hits from back-scattering

Δt=5*65ps=5*c*2cm



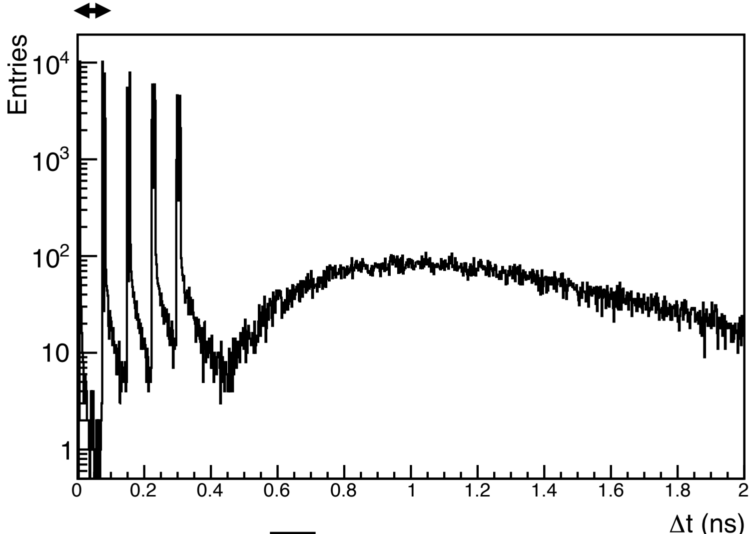
particles produced from the interaction of the CR with the silicon detectors

tracker layers

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

Back-scattering

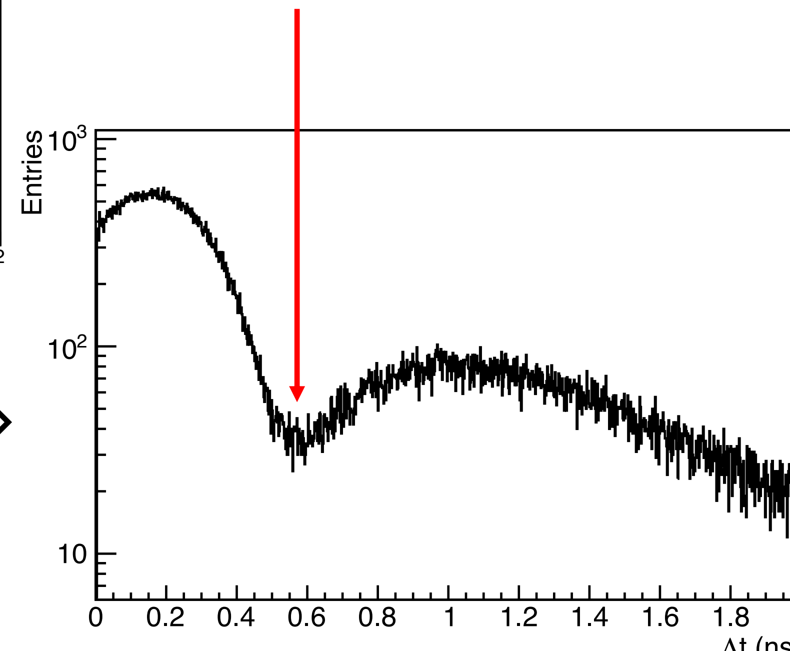
Δt=*65ps=c*2.2cm*



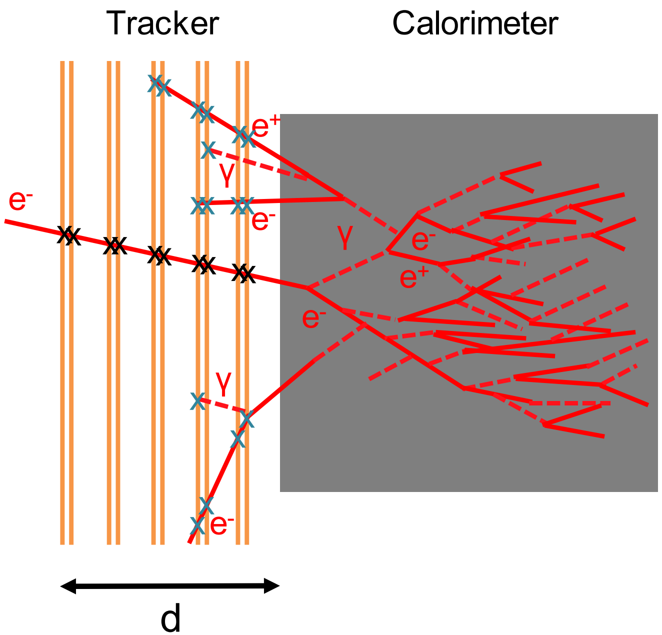
A simple cut (e.g. *550* ps from the first), removes:

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

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

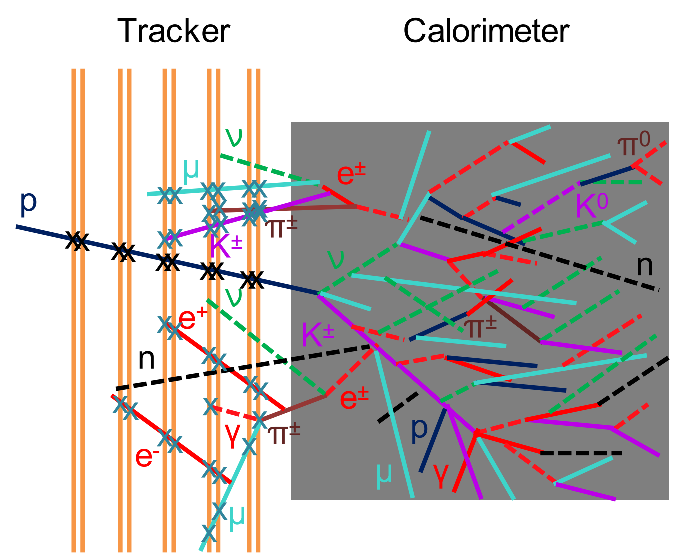


e/p identification



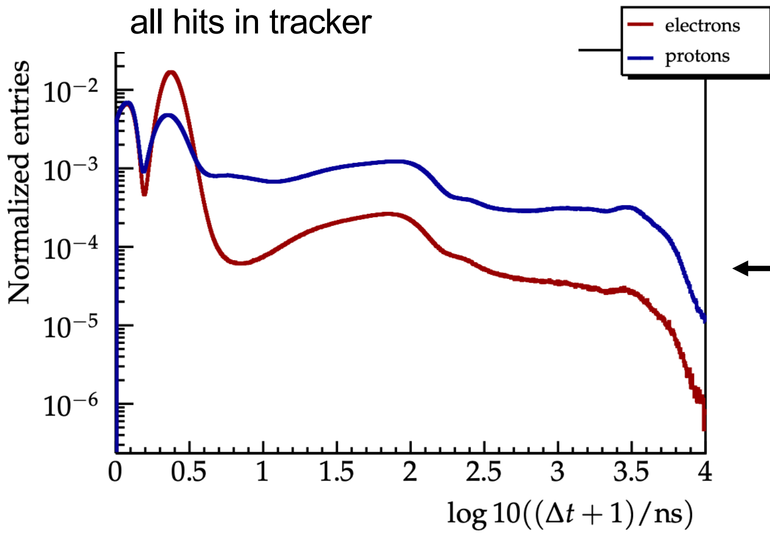
the electromagnetic shower is composed only by "ultra-relativistic" particles
→ the time arrival in the tracker is (at most):

~ 2d / c



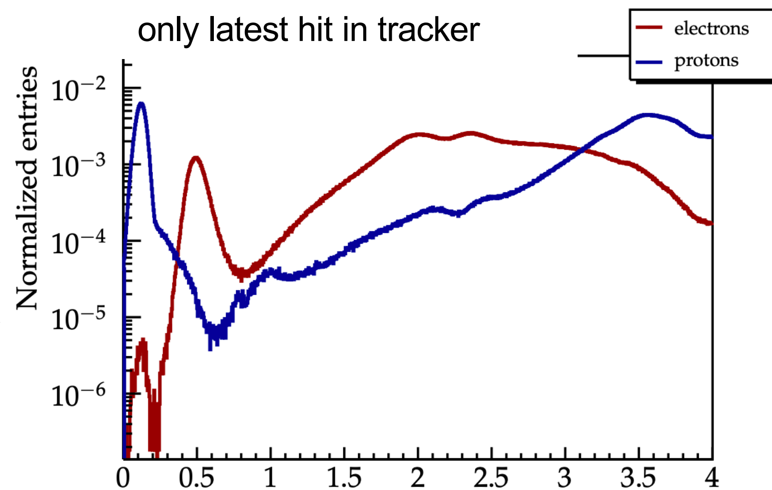
the hadronic shower could be composed by "slow" particles
→ the time arrival in the tracker could be delayed

e/p identification



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

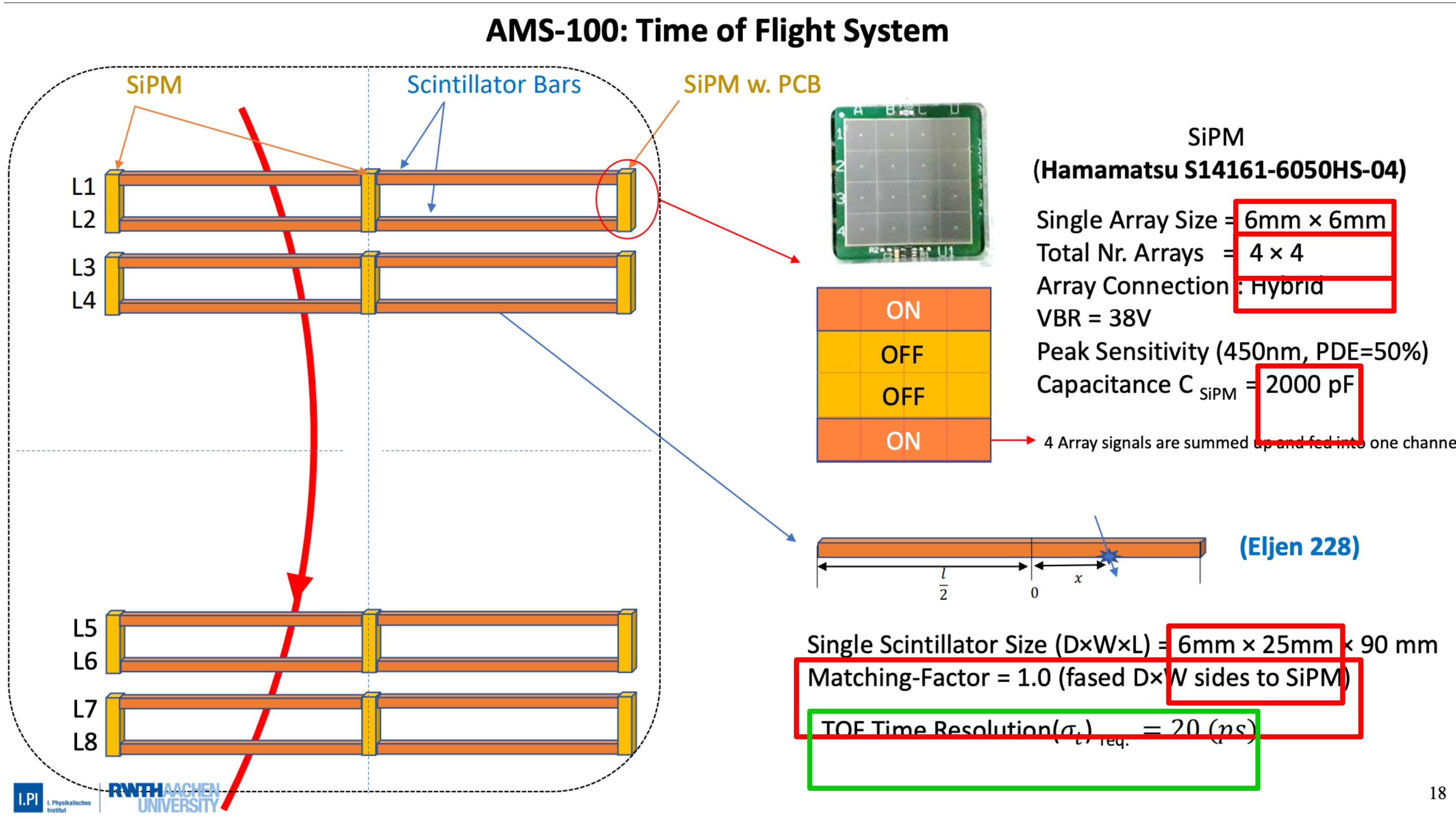
looking at all the hits in tracker offers an "high statistic" tool to, for example, train a Multi-Variate algorithm



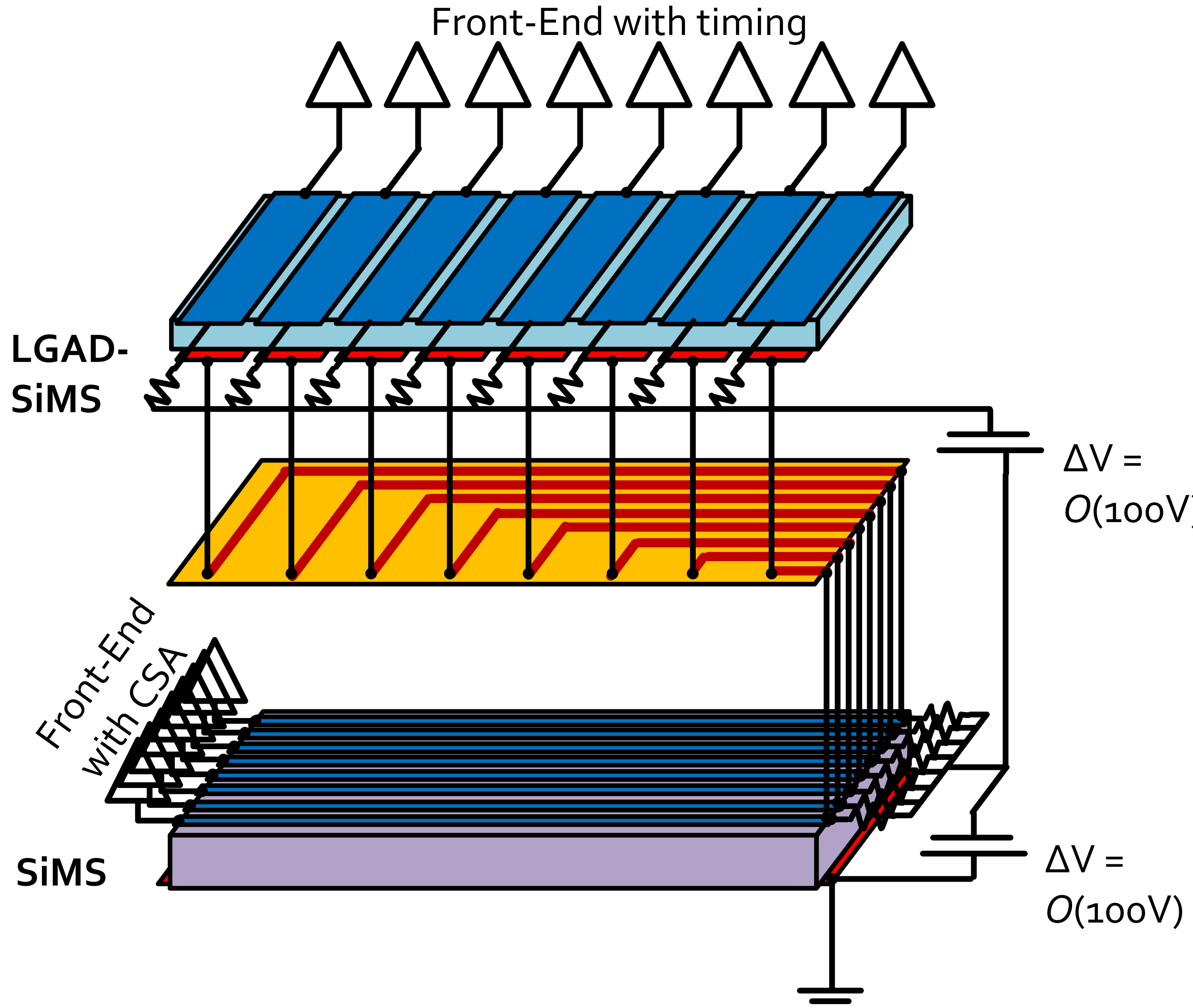
even the naive idea to look only at the "slower" hit in tracker shows two populations crearly distinct

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

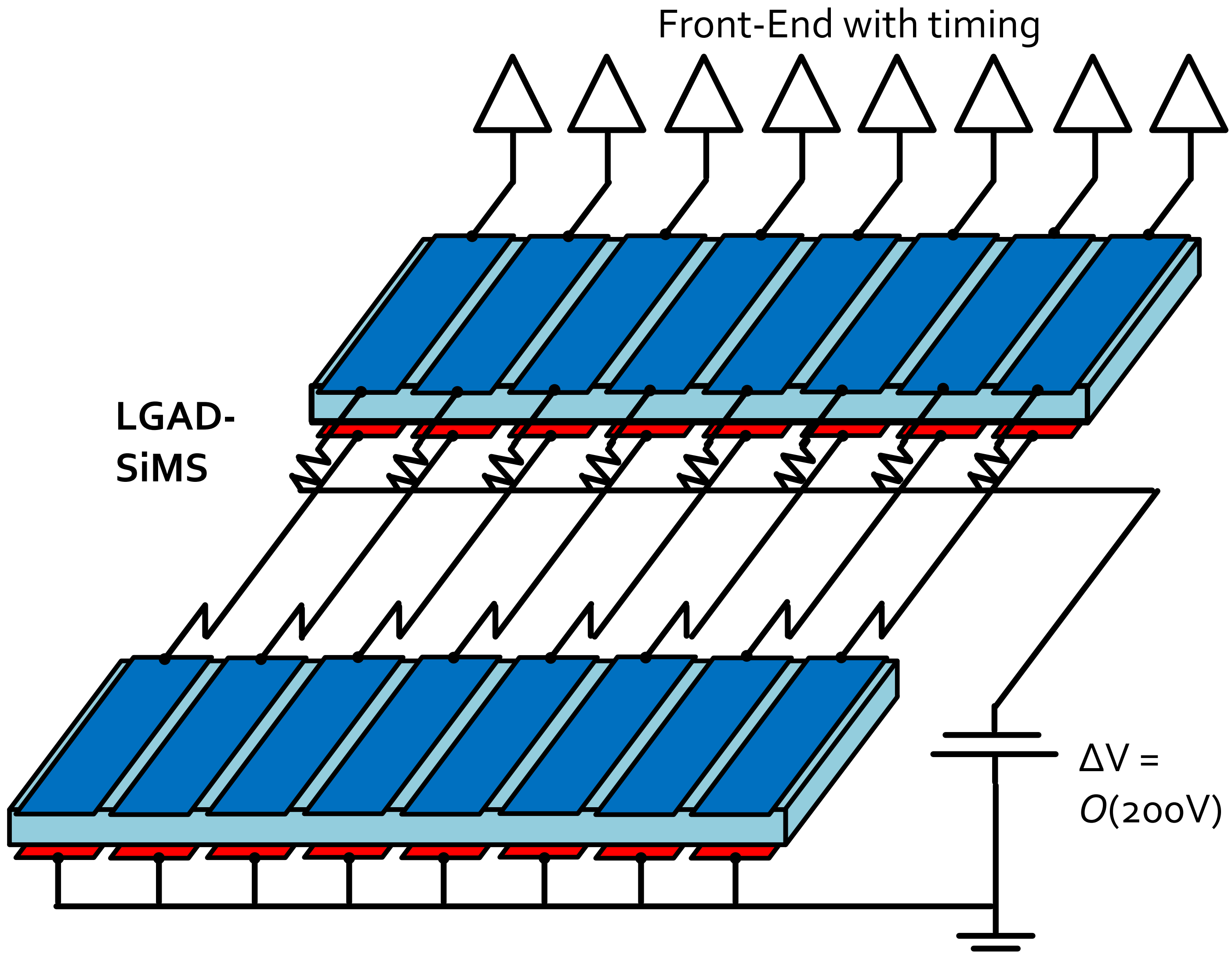
Ideas behind the project



from: https://indico.cern.ch/event/1044975/contributions/4663642/attachments/2394145/4094091/VCI-AMS-100-TKirn.pdf



Front-End with timing
LGAD-
SiMS
ΔV =
O(100V)
Front-End
with CSA
SiMS
ΔV =
O(100V)



Front-End with timing
LGAD-
SiMS
LGAD-
SiMS
ΔV =
O(200V)