Avalanche Diodes Array – 5D
(ADA_5D)

P.S. Marrocchesi[(a)], P. Brogi[(a)], G. Bigongiari[(a)], M. Boscardin[(f)], M. Centis Vignali[(f)], C. Checchia[(a)], G. Collazuol[(d)], T. Corradino[(e)], G.F. Dalla Betta[(e)], M. Feltri[(d)], S. Giroletti[(c)], M. Grassi[(c)], O.Hammad Ali[(f)], P. Maestro[(a)], M. Maghami Moghim[(a)], P. Malcovati[(c)], M. Mattiazzi[(d)], A. Messineo[(b)], F. Morsani[(b)], J. Minga [(c)], L. Pancheri[(e)], F. Stolzi[(a)], L. Ratti[(c)], A. Taffelli[(e)], C. Vacchi[(c)]

(a) Univ. di Siena & INFN Gruppo Collegato
(b) Univ. di Pisa & INFN Sezione di Pisa
(c) Univ. di Pavia & INFN Sezione di Pavia
(d) Univ. of Padova & INFN Sezione di Padova
(e) Univ. di Trento & TIFPA
(f) Fondazione Bruno Kessler (FBK – Trento)

Proposta di nuova iniziativa CSN5 (2022-2025)

CHARGE IDENTIFICATION of cosmic-ray (CR) ions with charge $1 \le Z \le 30$ with $dE/dx \propto Z^2$ measurements in a **charge detector** (SCD) at the top of the instrument

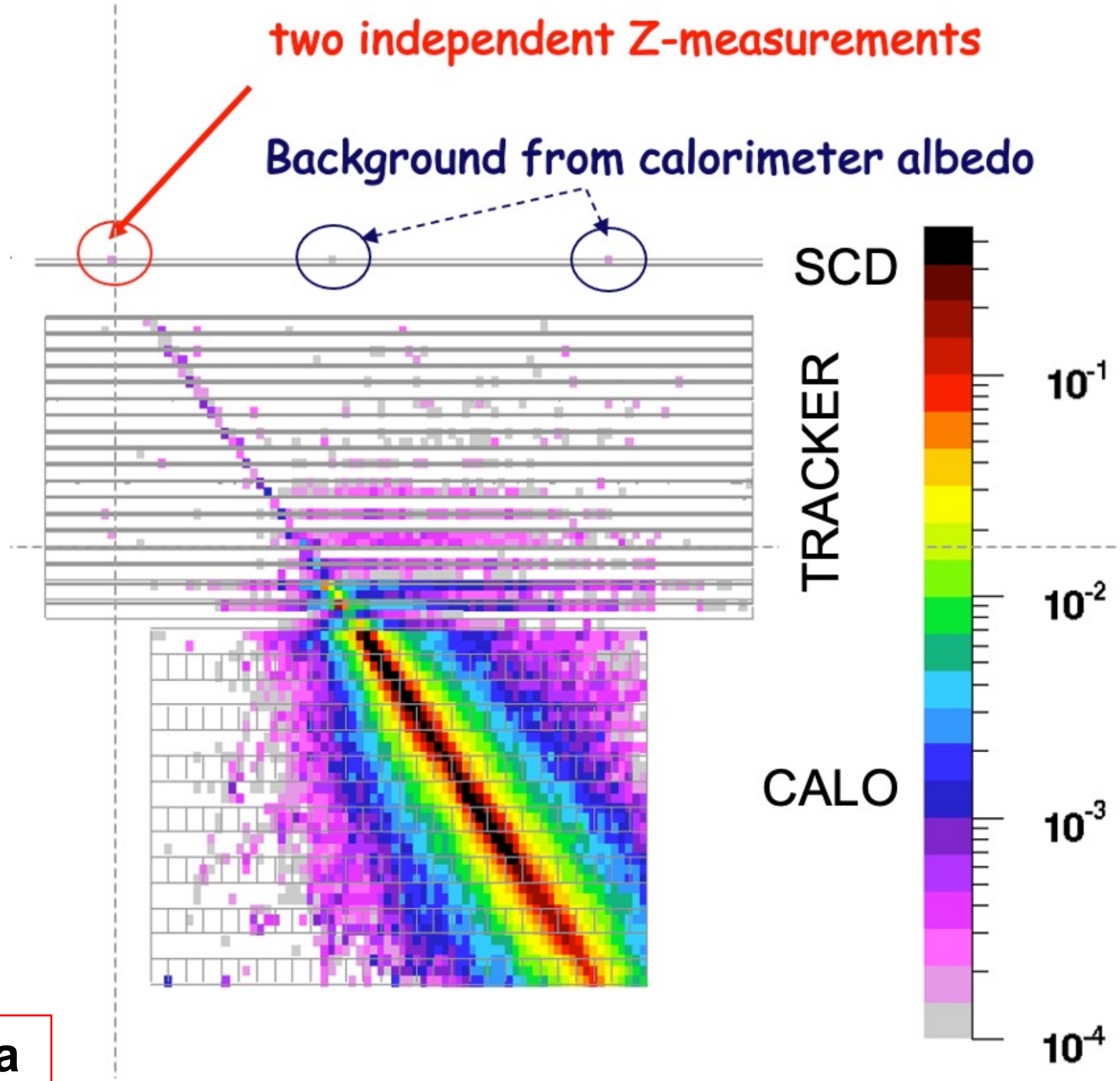
Example of a typical space-borne CR experiment with a generic charge detector (silicon pixels, scintillator paddles/tiles, etc.)

Backscattering (BS) from the calorimeter generates fake hits in the charge detectors and in the tracker.

The tracker back estrapolates to the SCD with an impact point IP residual ~ 150 - 200μm

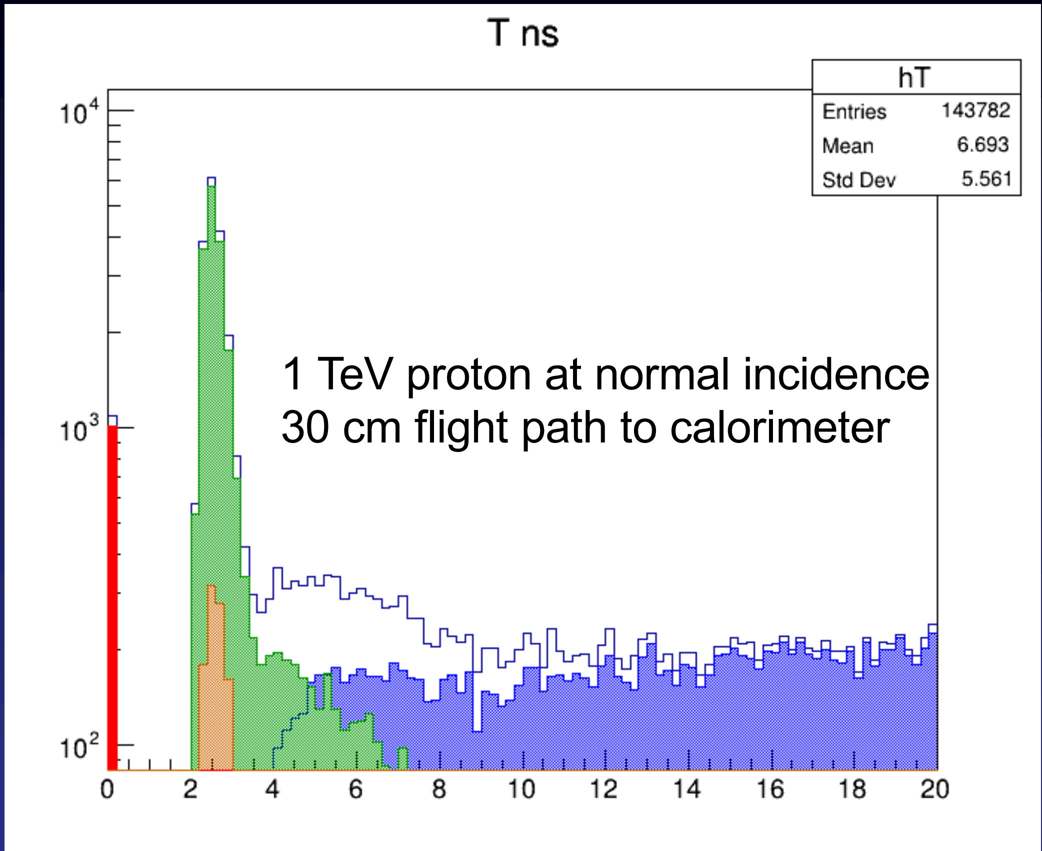
BS increases with energy and deteriorates the charge ID of individual CR elements.

ADA-5D concept: reject BS with a high resolution ToF measurement



FLUKA simulation of 1 TeV incident carbon nucleus

Arrival time (ns) of BS from calorimeter on SCD: a GEANT4 simulation



Geometry

Calorimeter: 50x50 cm^2 Pb 30 X_0

300 micron Silicon array (50x50 cm^2)

e.g.: 30 cm distance to calorimeter

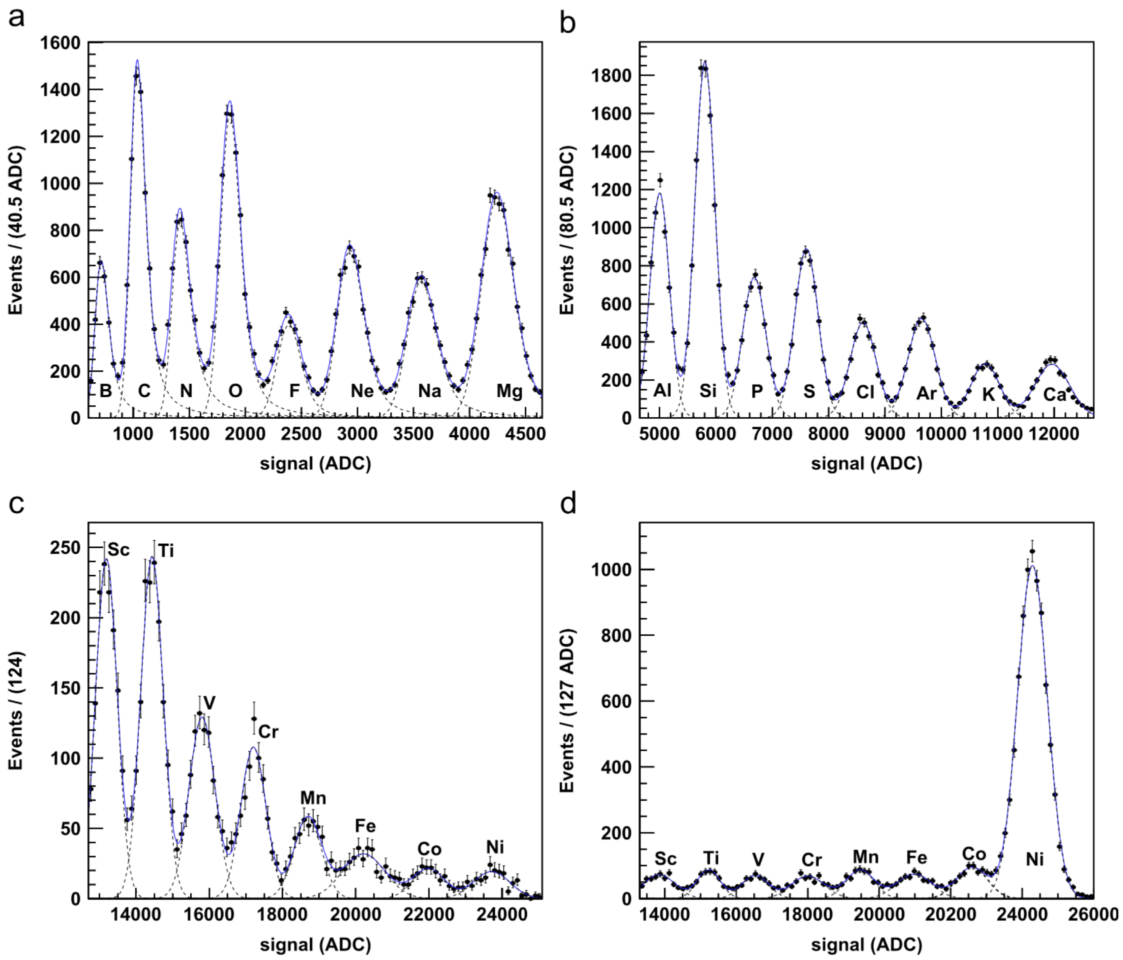
- ToF of incident particle to CALO ~ 1ns
- BS flight time:
  ~ 1ns for ultra-relativistic particles (e, γ)
  > 1ns for NR (neutrons)

Total time > 2ns

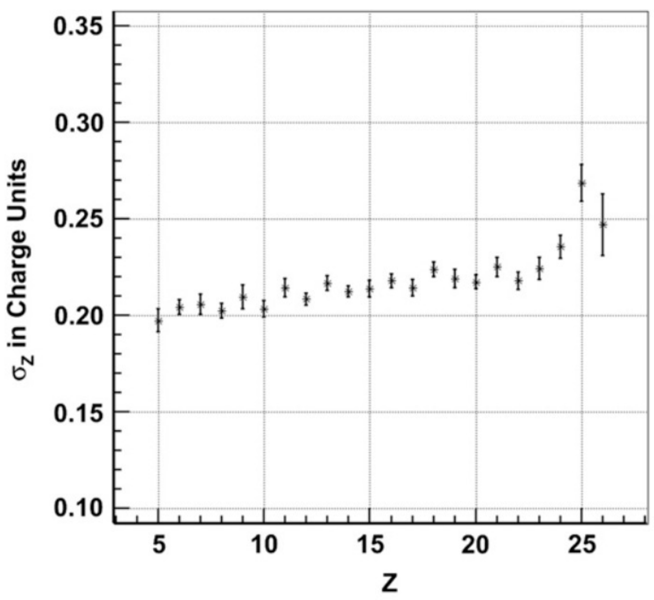
- filled-green: back-scattered **photons** (interact in SCD → ionizing secondaries → fake hits;
- filled-blue: back-scattered **neutrons**;
- filled-orange: back-scattered **electrons** (depositing energy in the charge detector);
- filled-red: **incident protons** on the charge detector (generated at t=0);
- unfilled histogram: inclusive of all above..

Nota "storica"
Matrix-CSN5-2005-7

All'epoca (~15 anni fa !) con rivelatori SILICON PAD (next slide), abbiamo misurato risoluzioni in carica fra 0.2 e 0.3 dal Boro (Z=5) fino al Fe (Z=26) al **GSI** con un fascio primario di ^{64}Ni (1.0–1.3 GeV/amu) su fragmentation target di Be.
La risoluzione in carica per protoni (Z=1) era ~0.1



risoluzione in carica vs Z

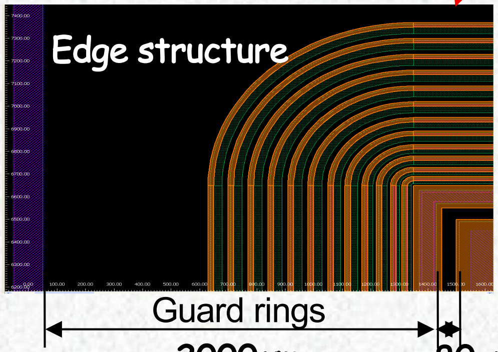


Nucl.Instrum.Meth.A.679, p. 7-13 (2012)

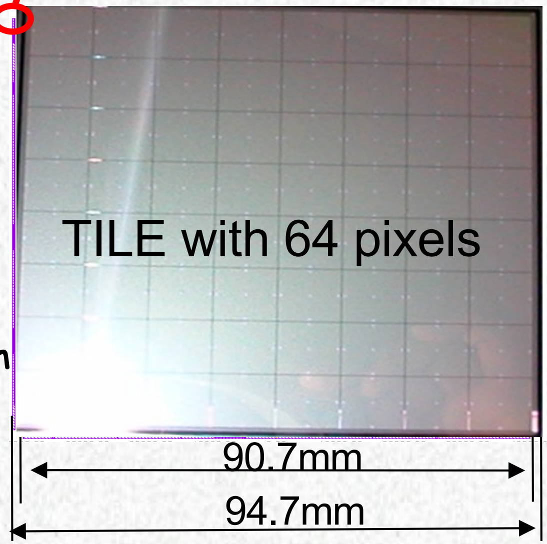
Nota "storica"
Matrix-CSN5-2005-7

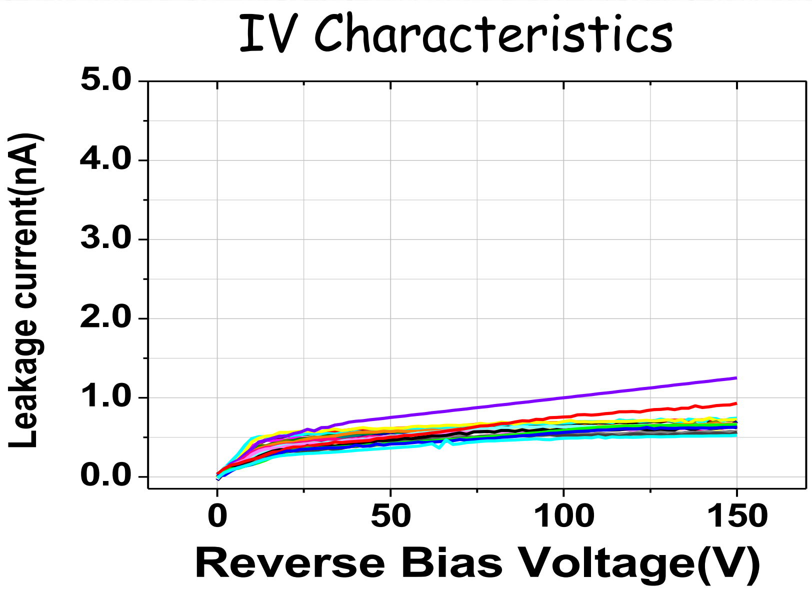
Silicon Pad Array

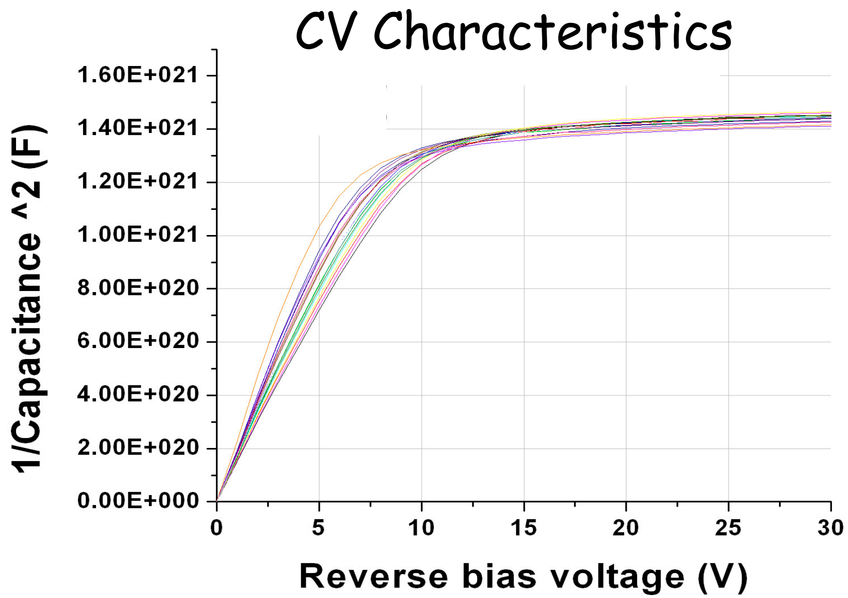
- Pixel area: 1.125 × 1.125 cm^2
- Thickness: 500 μm
- Matrix: 8 × 8 pixels
- Active area: 9.07 × 9.07 cm^2
- TILE **Full area: 9.47 × 9.47 cm^2**
- Full depletion voltage: < 30V
- Breakdown voltage: > 200V
- Dark current per pixel: < ~ 1nA
- Junction capacitance per pixel : ~ 25pF



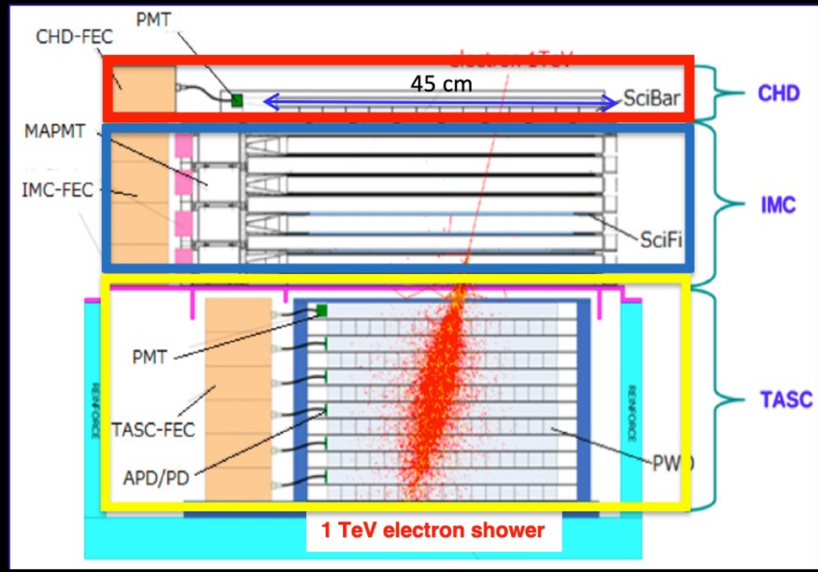
SINTEF – Norway
(MATRIX R&D – CSN5)







An example: CALET on the ISS



CHD – Charge Detector

- 2 layers x 14 plastic scintillating paddles
- single element charge ID from p to Fe and above (Z = 40)
- charge resolution ~0.1-0.3 e

IMC – Imaging Calorimeter

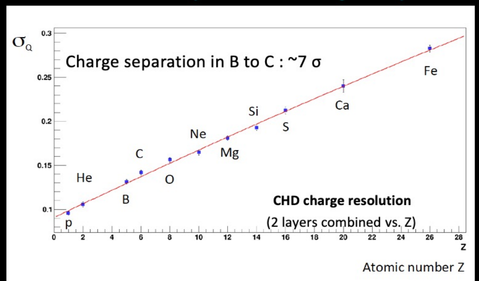
- Scifi + Tungsten absorbers: $3\ X_0$ at normal incidence
- 8 x 2 x 448 plastic scintillating fibers (1mm) **readout individually**
- **Tracking** (~0.1° angular resolution) + **Shower imaging**

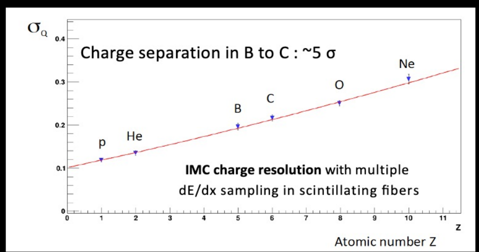
TASC – Total Absorption Calorimeter $27\ X_0,\ 1.2\ \lambda_I$

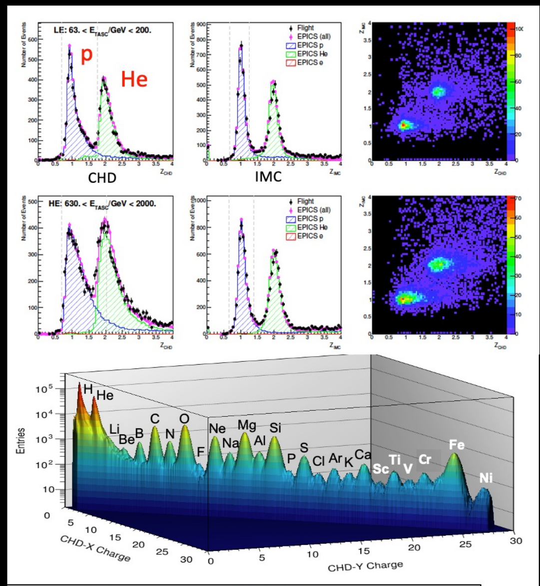
- 6 x 2 x 16 lead tungstate ($PbWO_4$) logs
- **Energy resolution:** ~2 % (>10GeV) for e , γ ~30-35% for p, nuclei
- **e/p separation:** $\sim 10^{-5}$

Charge Identification with CHD and IMC

Single element identification for p, He and light nuclei is achieved by CHD+IMC charge analysis.



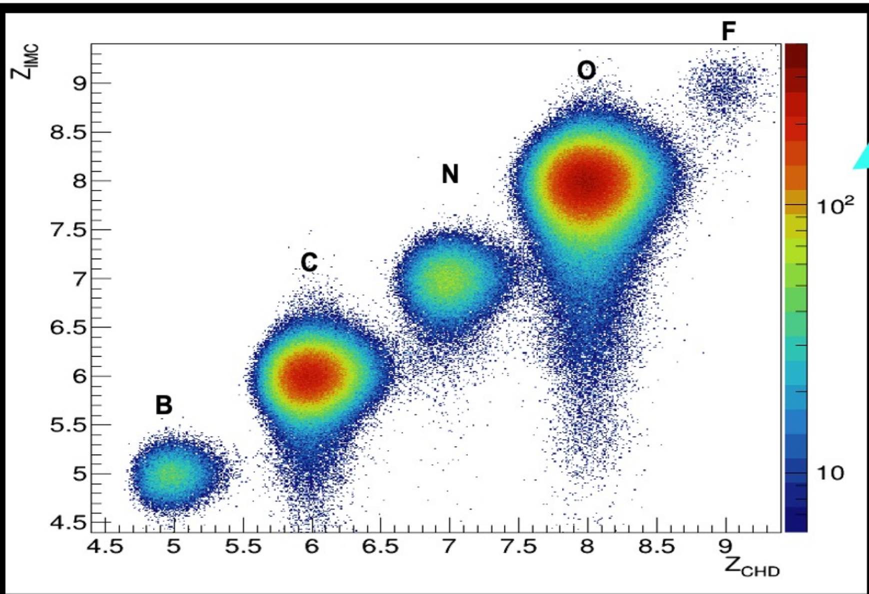


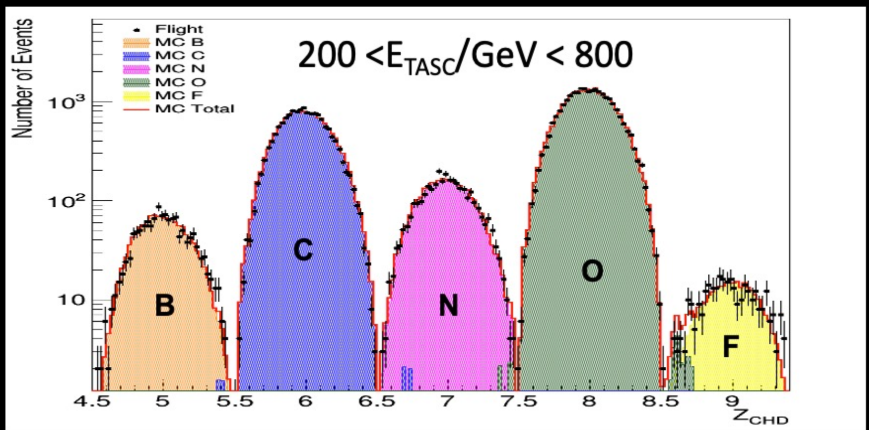


Deviation from Z^2 response is corrected both in CHD and IMC using a core + halo ionization model (Voltz)

CALET is taking data aboard the ISS since 2015

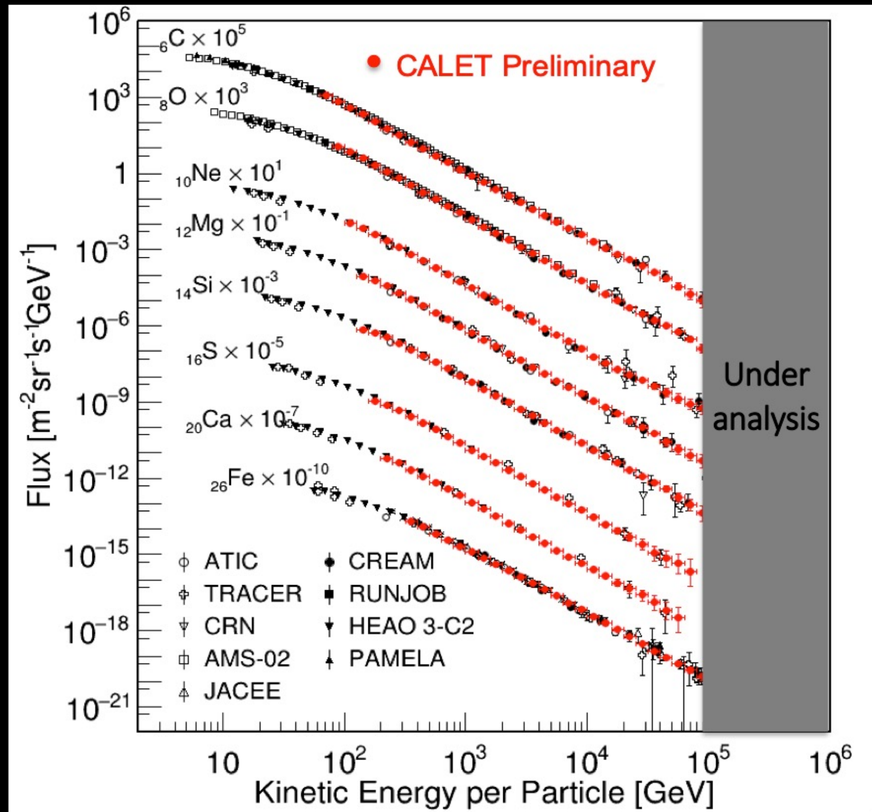
Spectra of cosmic-ray nuclei from C to Fe



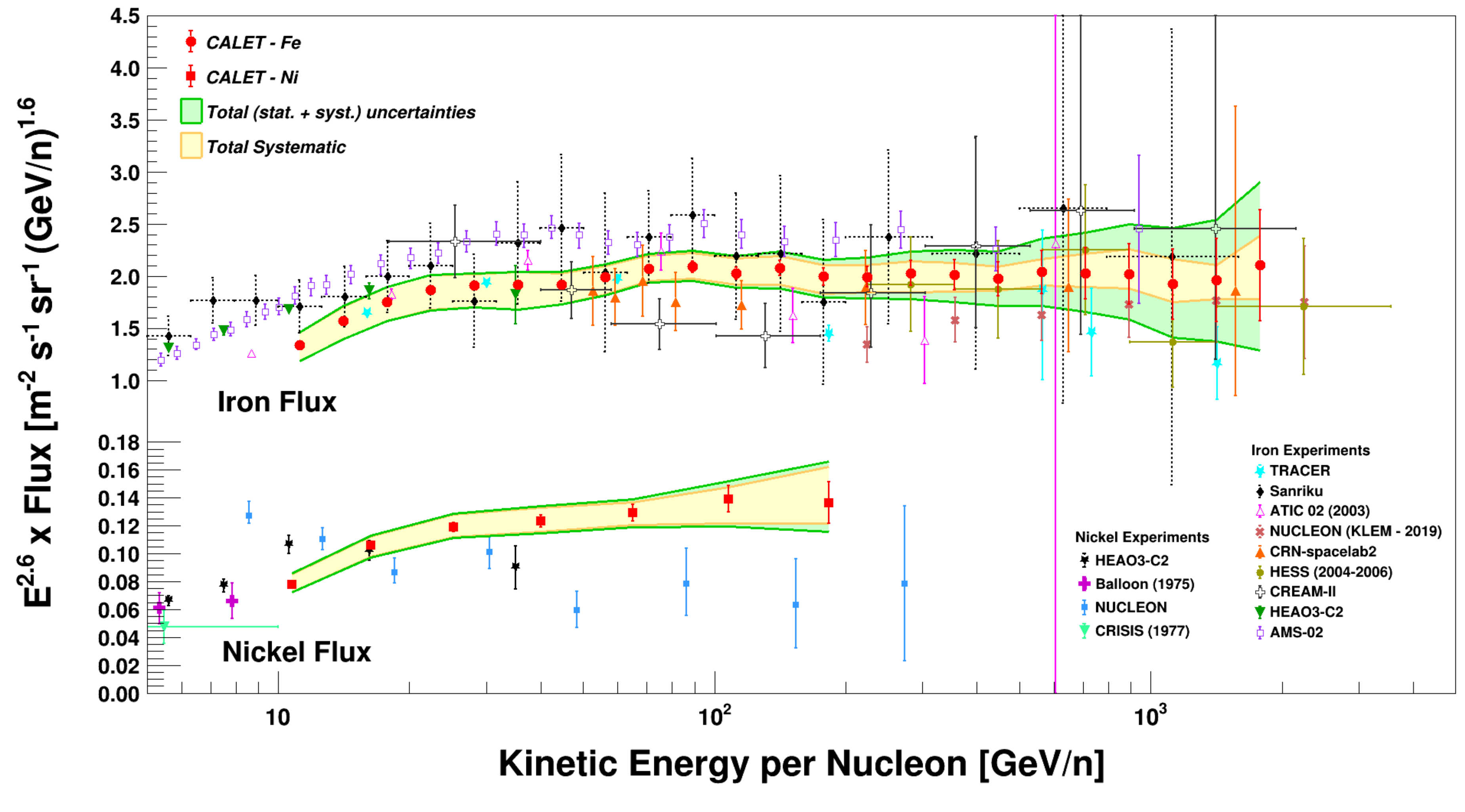


With excellent charge-ID of individual elements CALET is exploring the Table of Elements in the multi-TeV domain

Preliminary Spectra of Carbon – Iron



An example: direct measurements of Fe and Ni fluxes with CALET on the ISS



CALET Nickel paper: Physical Review Letters **128**, 131103 (2022)

CALET Iron paper: Physical Review Letters **126**, 241101 (2021)

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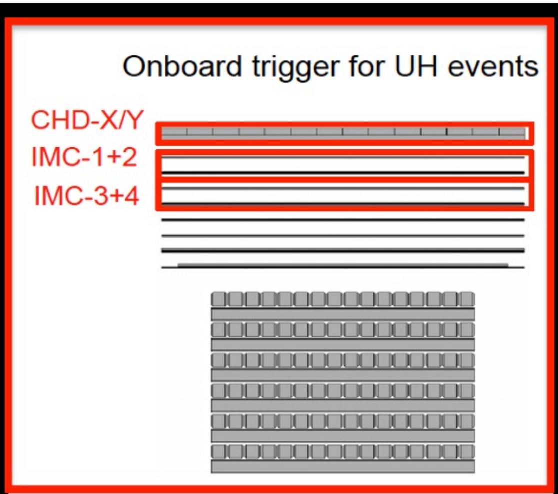
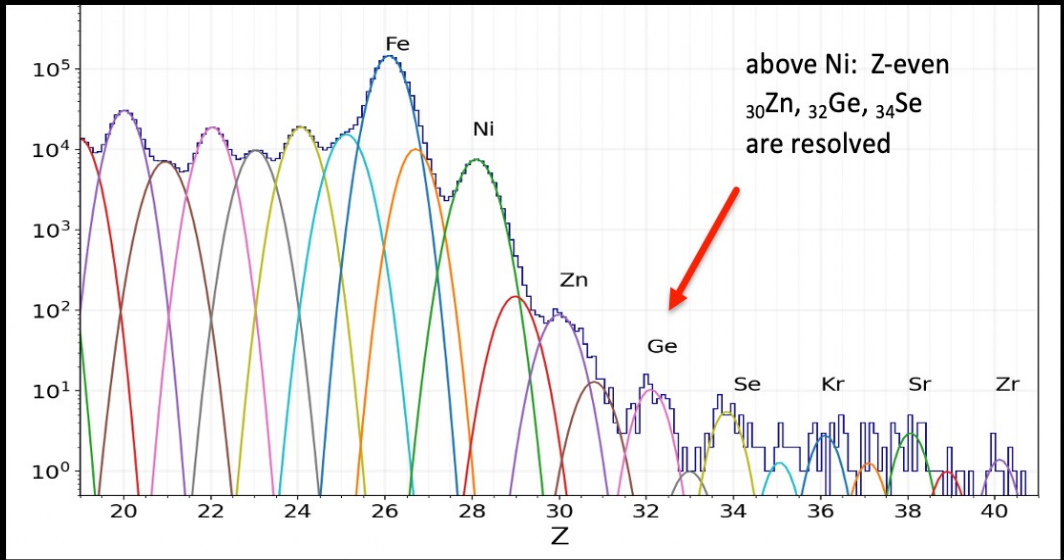
Ultra-heavy cosmic-ray nuclei (26 < Z ≤ 40)

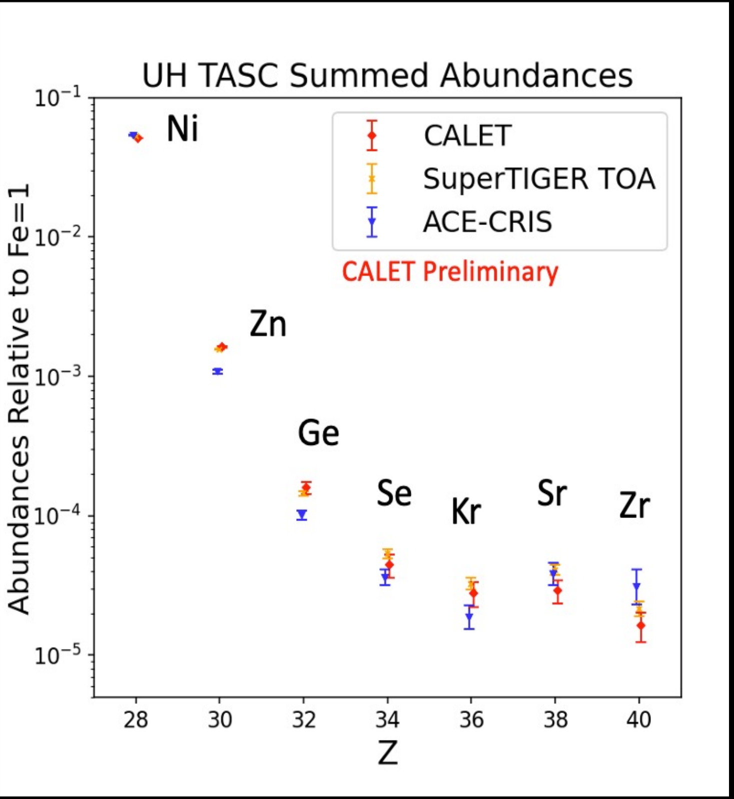
posters: CRD 1044, 657



A special UH CR trigger uses the CHD and the first 4 layers of the IMC to achieve an expanded x 4 geometric factor
GF ~ 4400 cm² sr



Measurement of the relative abundances of elements above Fe through $_{40}$Zr



The CALET UH element ratios relative to Fe are consistent with Super-TIGER and ACE abundances.

ADA_5D Charge & Timing 5D detector: x,y,z, time, charge

VERY stringent requirements for a space experiment:

Charge measurement:

- very large dynamic range > 1000 MIP (for trans-iron elements DR ~ 1600 MIP)
- charge resolution for proton < 0.1 => 200-300 um sensors for primary ionization

Timing measurement:

- sub-ns resolution (e.g., for 10 – 20 cm flight path → needs 100 ps resolution)

Space resolution and granularity:

- modest granularity (3mm x 3mm pixels) to cover large O(m^2) sensitive area)
- an independent TRACKER is in charge of the fine spatial resolution

Power budget:

- VERY challenging < 150 W/m^2

Radiation hardness:

- modest problem for space experiments < 10^{11} 1 MeV neq (TID ~100 krad)

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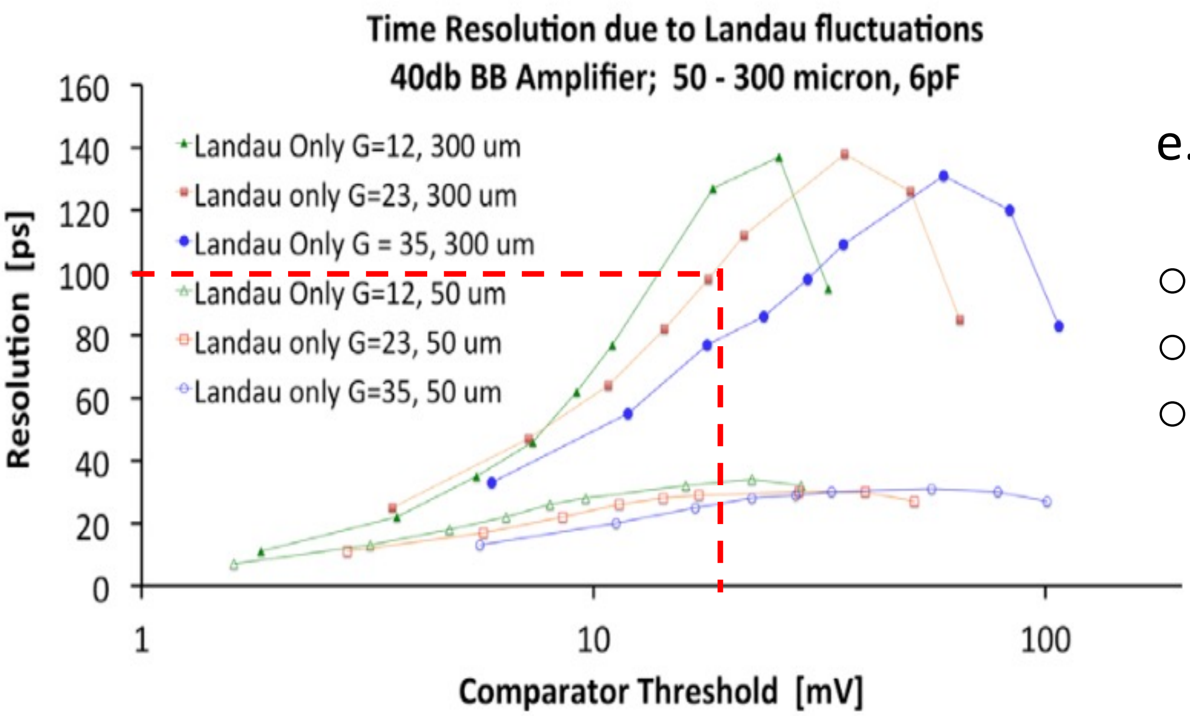
Proposed development of LGADs for ADA-5D at FBK

- large pixels (e.g.: 3mm x 3mm)
- sensor thickness 200-300 um

with G~ 10-20 the dominant term for the time resolution is the jitter => 100 ps feasible with a low threshold (realistic as S/N>30 for 1 m.i.p)

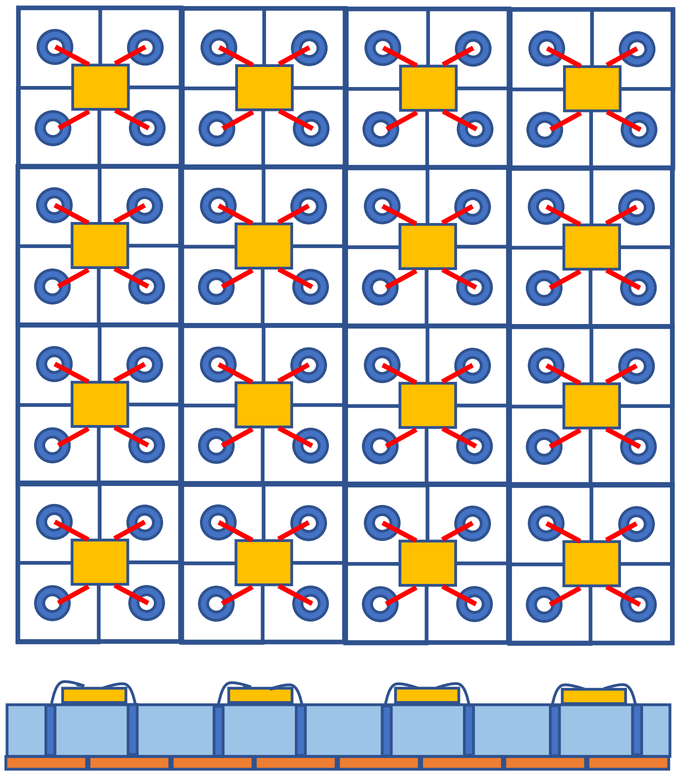


e.g.: 100 ps resolution with:

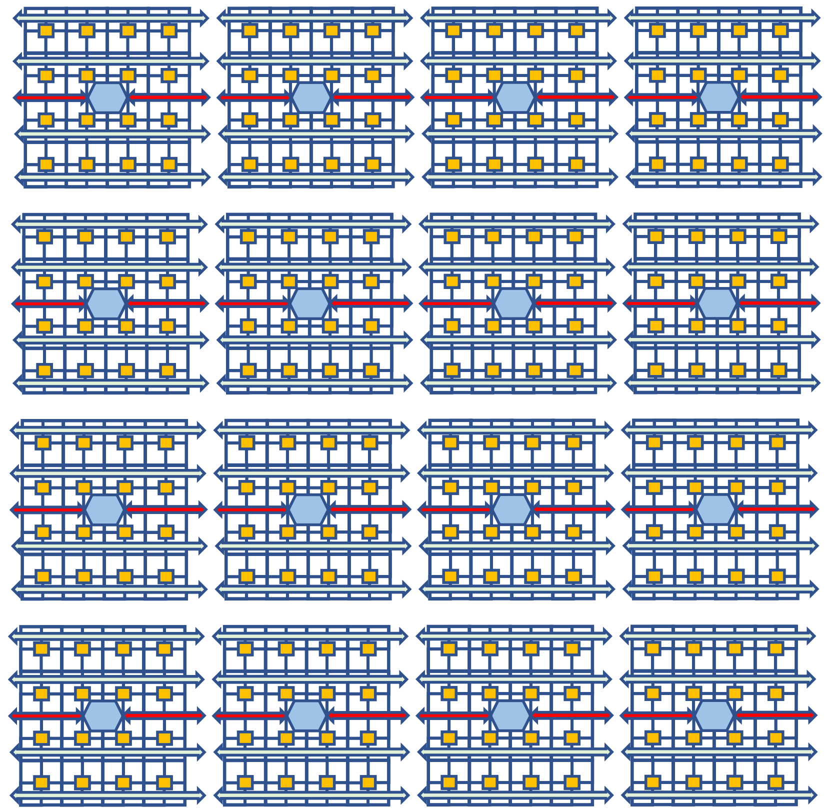
- 300 um thickness
- G=23
- threshold ~ 20 – 30 mV

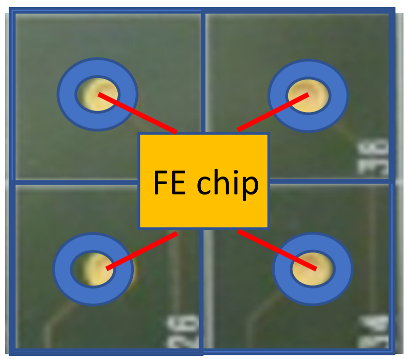
Nuclear Instruments and Methods in Physics Research A 845 (2017) 47–51

mini-TILE (2.4cm x 2.4 cm):
16 FE = 8 x 8 LGADs



TILE (9.6 cm x 9.6 cm): 16 mini-tiles
= 256 FE = 16 x 8 x 8 = 1024 LGADs

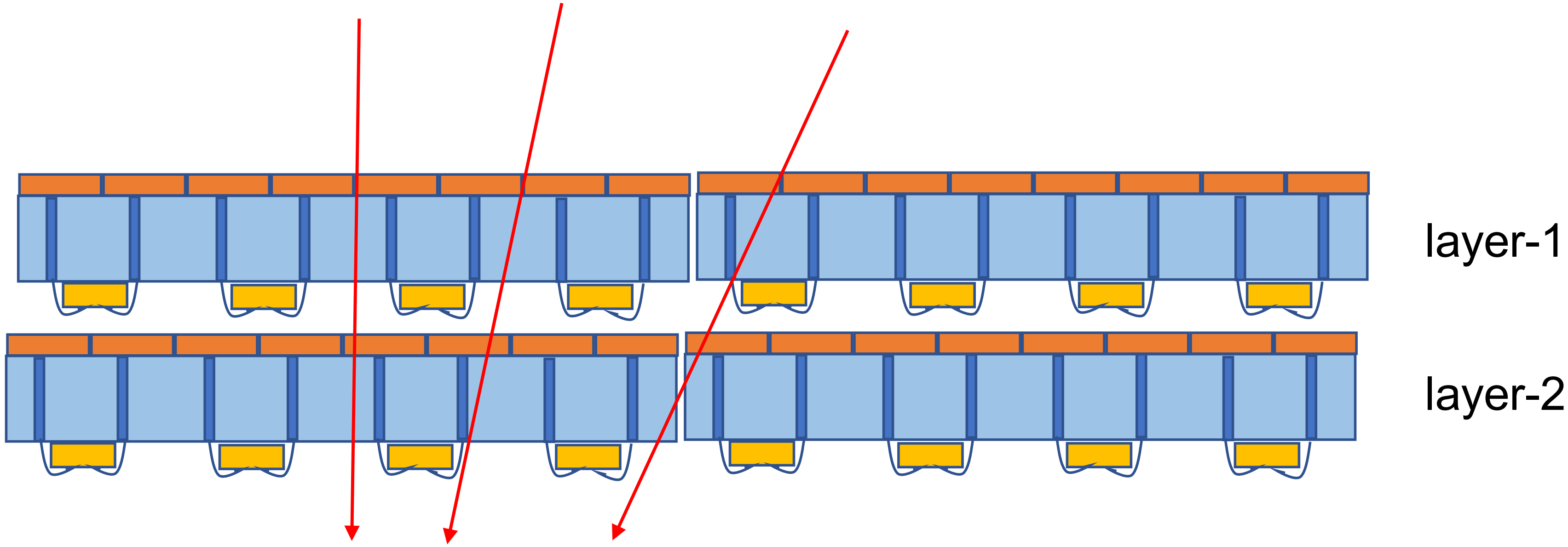




Each FE chip, connected to 4 LGADS, implements:

- double gain linear range to cover > 1000 m.i.p.
- internal ADC
- internal TAC + ADC conversion
- Track & Hold

TILE (9.6cm x 9.6 cm): 16 mini-tiles = 16 x 8 x 8 = 1024 LGADs



Example of a portion of 2 staggered layers:

- no detector material above 1st layer
- **estimate of 1st layer material budget**:
  - G10-FR4 (3mm) : 16.88 cm RL => $X_0(\%)$ = 0.03/16.88 = 0.178
  - LGAD (300μm) Si: 9.47 cm RL => $X_0(\%)$ = 0.03/9.47 = 0.317

  Worst case: LGAD+G10+FE chip ~ 0.178 x 2 + 0.317 = **0.67% RL**

- Assuming a thin window (protection of first layer LGADs) + structural stiffners => **requirement: < 1% RL**

ADA-5D Development plan (2023)

4 parallel developments:
- 300μm thick LGAD sensor (FBK, TIFPA)
- FE chip (Pavia)
- digital readout (Pisa, Padova)
- system level: DAQ and beam tracker (Siena)

- 1st LGAD run @FBK

After LGAD production:

  - lab characterization of single LGAD sensors
  - mechanical assembly and micro-bonding of 1 FE pixel (2x2 LGADs)

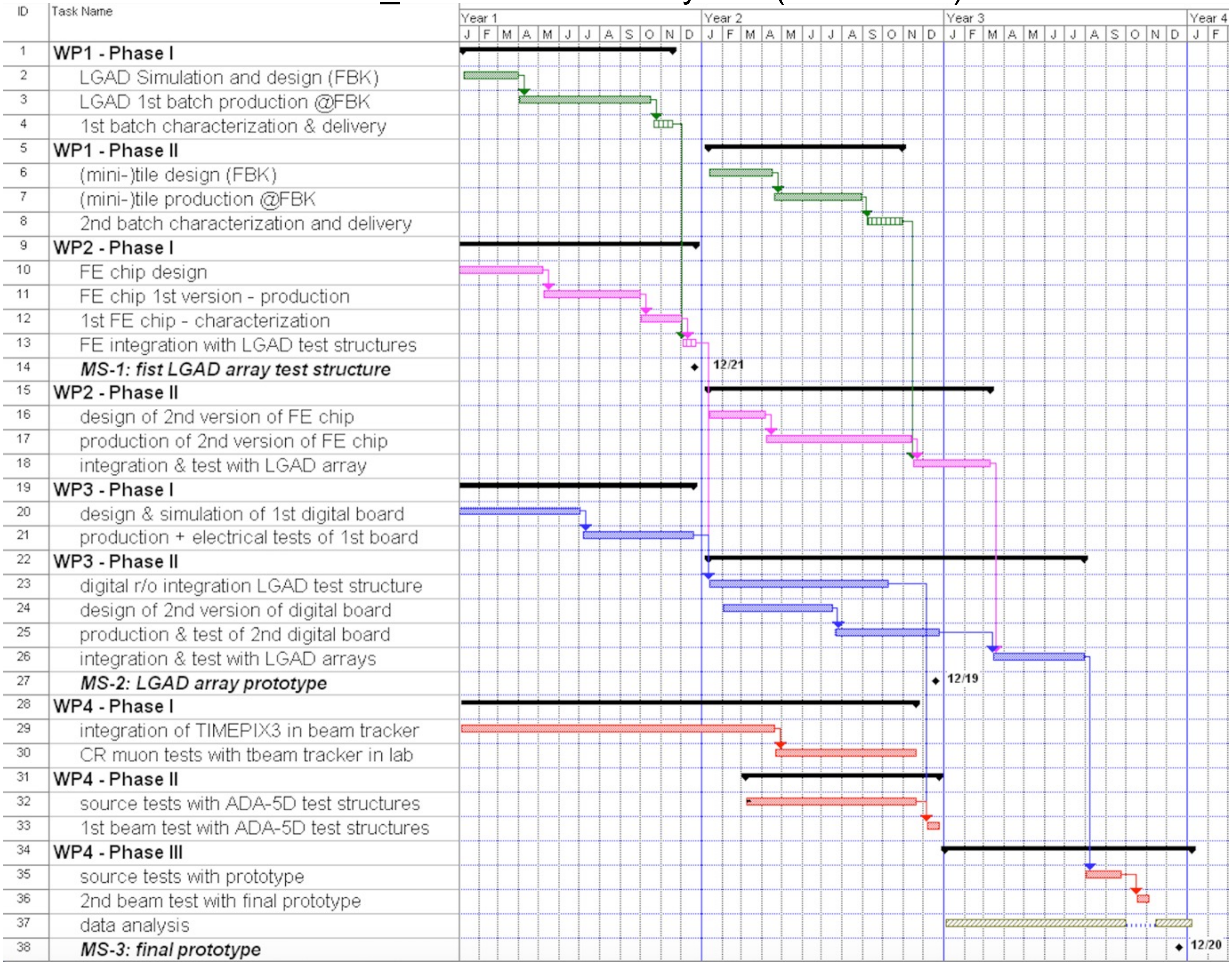
- 1st submission of r/o chip

After 1st r/o chip production:

  - lab characterization of FE chip
  - 1st prototype of 1 PIXEL (2x2) LGADs
  - characterization and beam test (with ions) of PIXEL

- development of MINI-TILE prototype (16 pixels)
- characterization and beam test (with ions) of MINI-TILE

ADA_5D timeline over 3 years (Gantt chart)



	ADA-5D 2023 - FTE	PI/SI	PV	TIFPA	PD
Pier Simone Marrocchesi	PO Univ. di Siena + INFN Gruppo Collegato	0.7			
Paolo Maestro	PA Univ. di Siena + INFN Gruppo Collegato	0.4			
Gabriele Bigongiari	PA Univ. di Siena + INFN Gruppo Collegato	0.6			
Caterina Checchia	Assegno di ricerca - Univ. di Siena - Associaz. INFN Pis	0.6			
Mina Maghami Moghim	Dottoranda Univ. di Siena - Associaz. INFN Pisa	1.0			
Paolo Brogi	RTDA Univ. di Siena + INFN Gruppo Collegato	0.8			
Francesco Stolzi	RTDA Univ. di Siena + INFN Gruppo Collegato	0.6			
Alberto Messineo	PA Univ. di Pisa + INFN Pisa	0.1			
Lodovico Ratti	PO Univ. di Pavia		0.3		
Piero Malcovati	PO Univ. di Pavia		0.3		
Marco Grassi	RTDB Univ. di Pavia		0.5		
Joana Minga	Dottoranda (associata sez. Pavia)		1.0		
Simone Giroletti	Dottorando (associato sez. Pavia)		1.0		
Carla Vacchi	RC Univ. di Pavia		0.4		
Lucio Pancheri	PA Univ. di Trento			0.4	
GianFranco Dalla Betta	PO Univ. di Trento			0.1	
Thomas Corradino	Dottorando (associato TIFPA)			0.5	
Alberto Taffelli	Dottorando (associato TIFPA)			0.8	
Maurizio Boscardin	FBK Ricercatore Senior (associato TIFPA)			0.1	
Matteo Centis Vignali	FBK (associato TIFPA)			0.1	
Omar Hammad Ali	FBK (associato TIFPA)			0.2	
Gianmaria Collazuol	PA Univ. di Padova				0.2
Marco Mattiazzi	Dottoranda (associata sez. Padova)				0.7
Matteo Feltri	Post-doc (associato sez. Padova)				0.3
TOTALE FTE	**11.7**	**4.8**	**3.5**	**2.2**	**1.2**
F.Morsani	Tecnologo INFN Pisa	0.1			
Stiaccini Leonardo	Tecnico Università di Siena	0.5			

	ADA_5D 2023 - PREVENTIVI	PI/SI	PV	TIFPA	PD	TOT
Missioni	missioni in Italia (no beam test nel 2023)	4.5	2	2	2	10.5
Consumo	elettronica	11.5	4	4	10	29.5
Costruzione Apparati	LGAD (FBK) + FE ASIC (PV)		24	27.5		51.5
Inventariabile						0
TOTALE richieste x 2023		**16**	**30**	**33.5**	**12**	**91.5**

	ADA_5D 2023 - 2025	2023	2024	2025
Missioni	beam tests (sj)		15	15
	missioni in italia	10.5	6	6
Consumi	componentistica elettronica + meccanica + schede	26	25	28
	tracker upgrade	3.5	6	
Apparati	runs di produzione del chip di front-end	24	42	
	runs di produzione di LGADs a FBK	27.5	26	
	TOTAL 260.5	**91.5**	**120**	**49**

ADA-5D: Richieste di servizi in sezione per il 2023

- Supporto gruppo alte-tecnologie (micro-bonding)
- Supporto progettazione elettronica (2 mesi uomo)
- Eventuale uso della stampante 3D (A. Basti)
- utilizzo del laboratorio di HERD/ASAP (ASAP in chiusura nel 2022)