New particle identification system for the MAGNEX magnetic spectrometer: the SiC-CsI telescope wall

7th International Conference on

Collective Motion in Nuclei under Extreme Conditions

Catania 11-16 June 2023

Diana Carbone

for the NUMEN collaboration

The LNS upgrade

Upgrade project of the LNS Cyclotron and infrastructures

funded by national grant (PON) for 19.4 M€

Triggered by the NUMEN physics case

- **Much higher beam current will be available**

  (from 100 W to 5-10 kW)

The NUMEN project

(**NU**clear **M**atrix **E**lements for **N**eutrinoless double beta decay)

F. Cappuzzello et al., EPJA 54, 72 (2018)

Cross section measurements of heavy-ion induced **Double Charge Exchange (DCE)** reactions

F. Cappuzzello et al., Prog. Part. Nucl. Phys. 128, 103999 (2023)

Extraction from measured cross-sections of *"data-driven"* information on NME for all the systems candidate for $0\nu\beta\beta$

- Constraints to the existing theories of NMEs (nuclear wave functions)
- Model-independent comparative information on the sensitivity of half-life experiments
- Complete study of the reaction mechanism

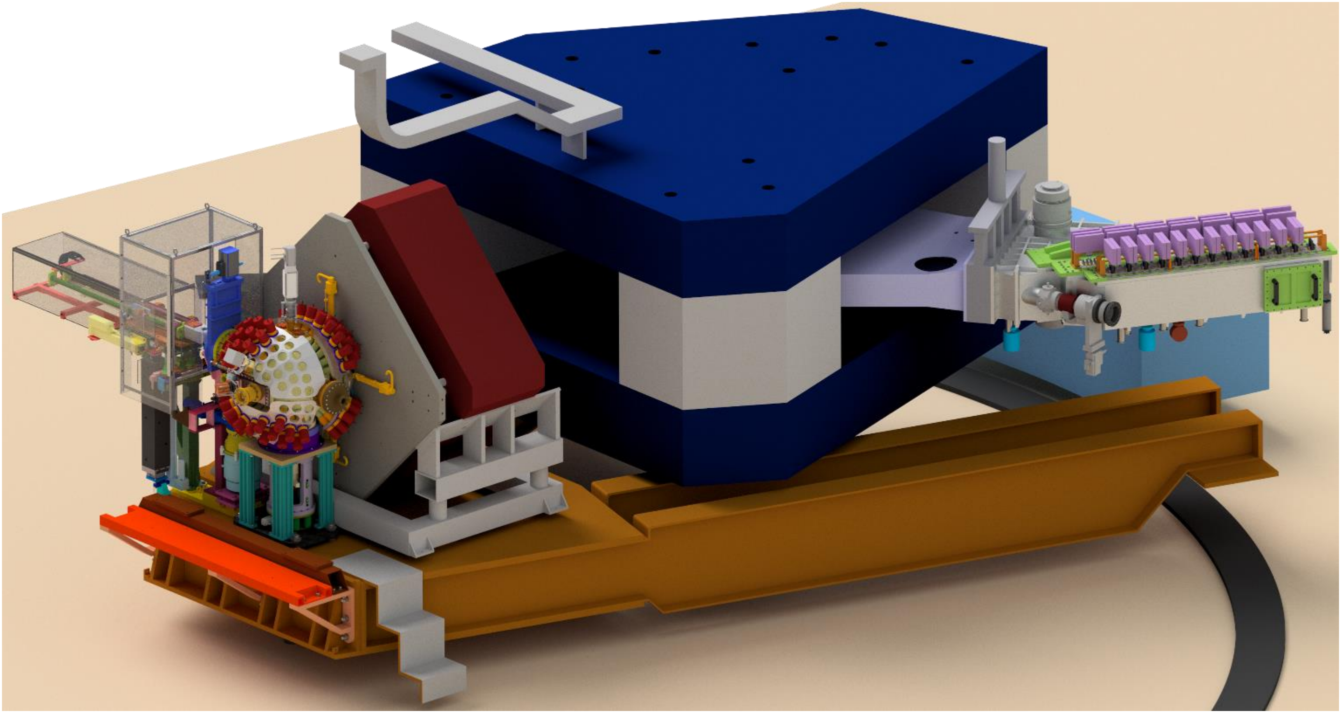
NUMEN phases			
Phase 1	**Phase 2**	**Phase 3**	**Phase 4**
Feasibility study	Study of few cases + development of theory + R&D activity	Shutdown & Upgrade of LNS facilities	Systematic study of all the targets

J. Bellone, G.A. Brischetto and I. Ciraldo talks

The MAGNEX magnetic spectrometer

MAGNEX spectrometer

Optical characteristics	Current values
Maximum magnetic rigidity (Tm)	1.8
Solid angle (msr)	50
Momentum acceptance	-14%, +10%
Momentum dispersion (cm/%)	3.68



F. Cappuzzello et al., Int. Jour. Mod. Phys. A 36, 2130018 (2021)
C. Agodi et al., Universe 7, 72 (2021)

Performances

- Energy $\Delta E/E \sim 1/1000$
- Angle $\Delta\theta \sim 0.2°$
- Mass $\Delta m/m \sim 1/300$
- From H to Zn ions detected

F. Cappuzzello et al., Eur. Phys. J. A (2016) 52: 167
M. Cavallaro et al., NIM B 463 (2020) 334
G. Souliotis et al., NIM A 1031, 166588 (2021)

Major upgrades

- New focal plane detector (gas tracker and pid wall)
- New gamma detector array (G-NUMEN)
- New exit beam lines and beam dump (for 0° measurements)
- Higher magnetic rigidity (up to 2.2 Tm)
- Suitable targets

The particle identification wall

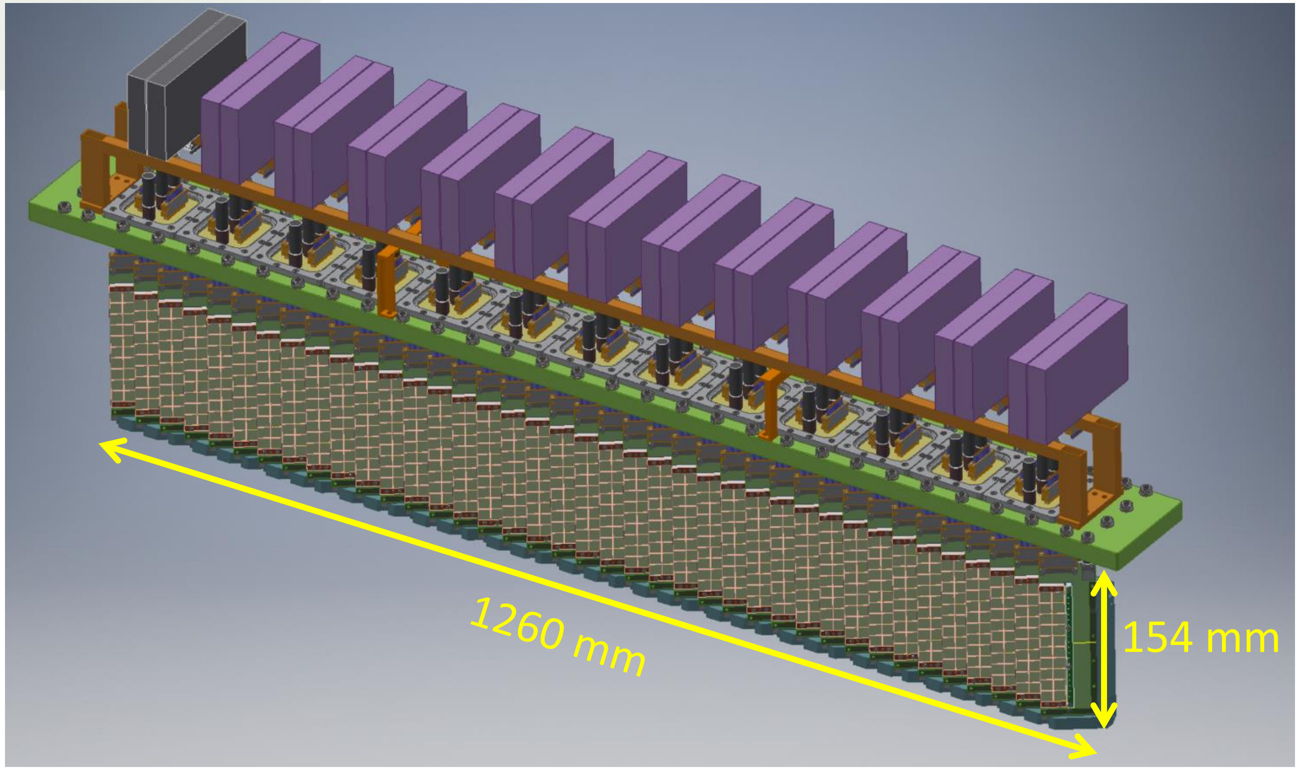
Determine the atomic number (Z) of the reaction ejectiles and provide, in connection with the gas tracker, the isotopic species (A) and its atomic charge state (q)

Requirements for new PID system

- **Radiation Hardness** of the order of 10^{11} ions/(cm^2/yr)
- Particle identification capability for identification of **Z ≈ 10 and A ≈ 20**
- **Time resolution** better than 2-3 ns
- **Double-hit** event probability **below 3%** in the whole FPD
- Woking in low pressure (tens mbar) gas environment

PID wall

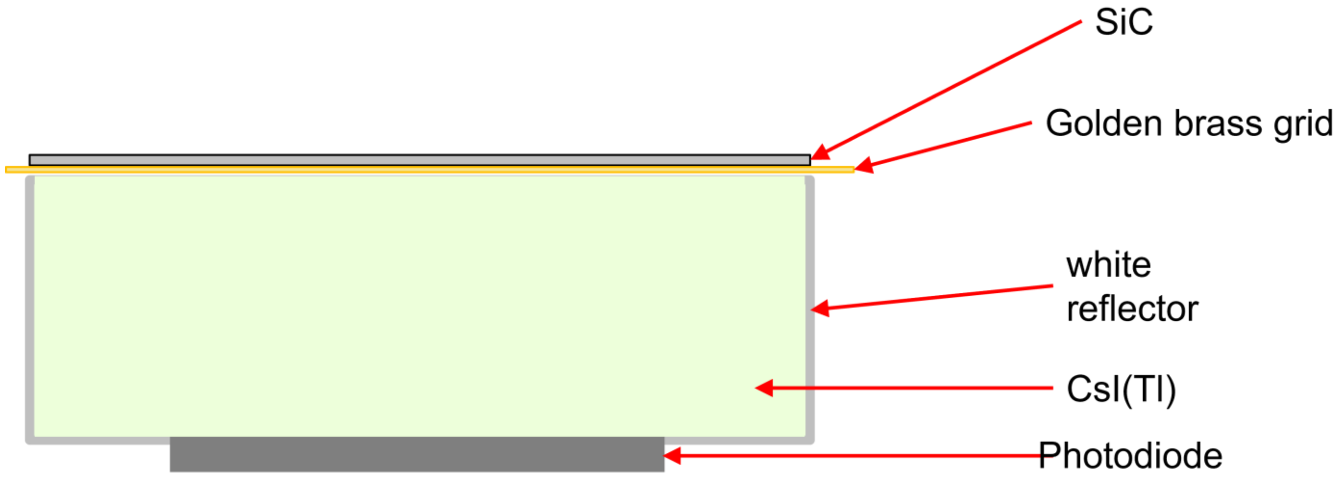
720 SiC-CsI telescopes arranged in 36 towers



Obtained performances

- ✓ Radiation hardness **10^{13} ions/cm^2 for SiC**
- ✓ Radiation hardness larger than 7.5 x 10^{11} ions/cm^2 for CsI
- ✓ **$\Delta Z/Z \approx 1/34$** and **$\Delta A/A \approx 1/47$**
- ✓ Time resolution hundreds of ps for SiC
- ✓ Double hit less than 2.5 % with the chosen granularity

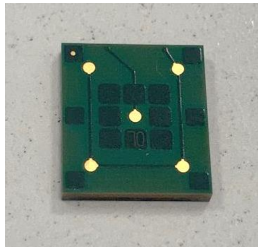
The E stage: CsI(Tl) crystals



Front view
Back view

E stage CsI (Tl)
Thickness 5 mm
Area 1.5 x 1.5 cm^2

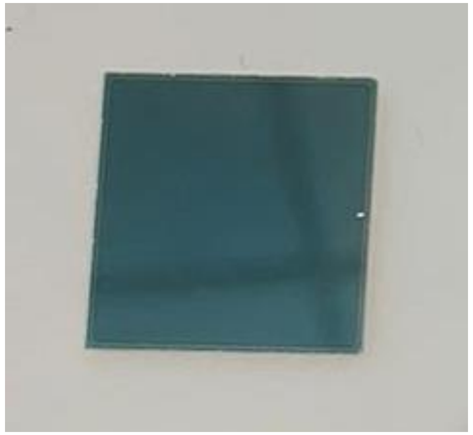
Hamamatsu Photodiode S3590-0887
Area ~ 1 x 1 cm^2
Bias -70 V

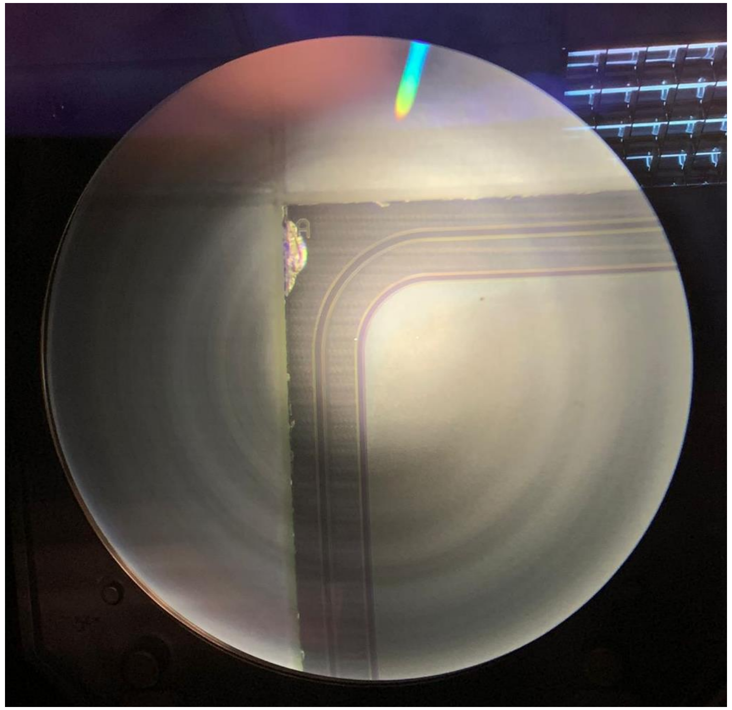


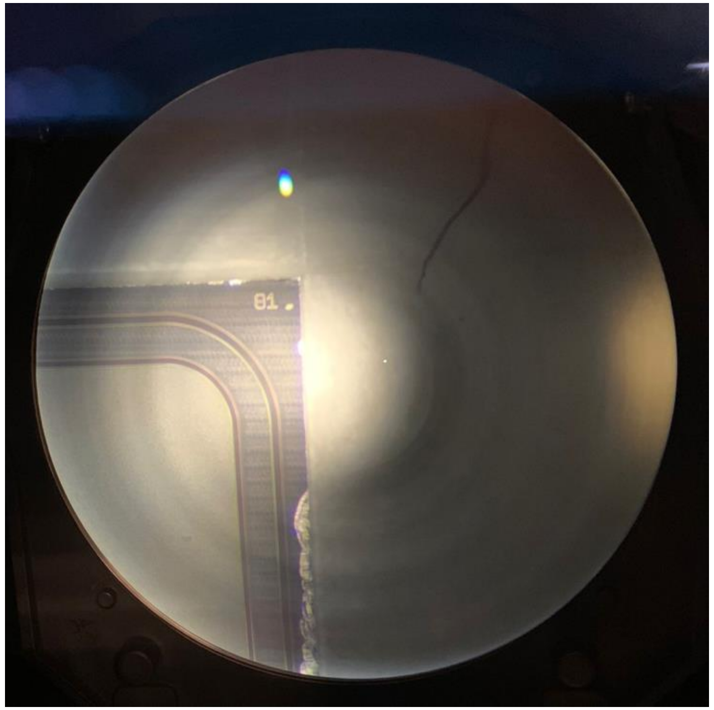
NUMEN

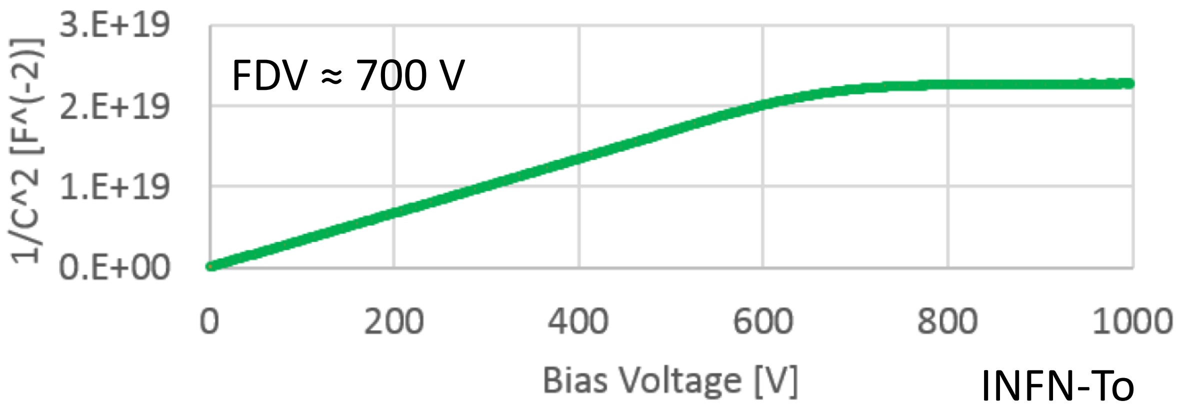
The ΔE stage: SiC detectors

ΔE stage SiC
Epitaxial layer 100 µm
Dead layer on the back 10 µm
Area 1.54 x 1.54 cm^2
Edge structure 200 µm
Full Depletion Voltage -300/-1000 V







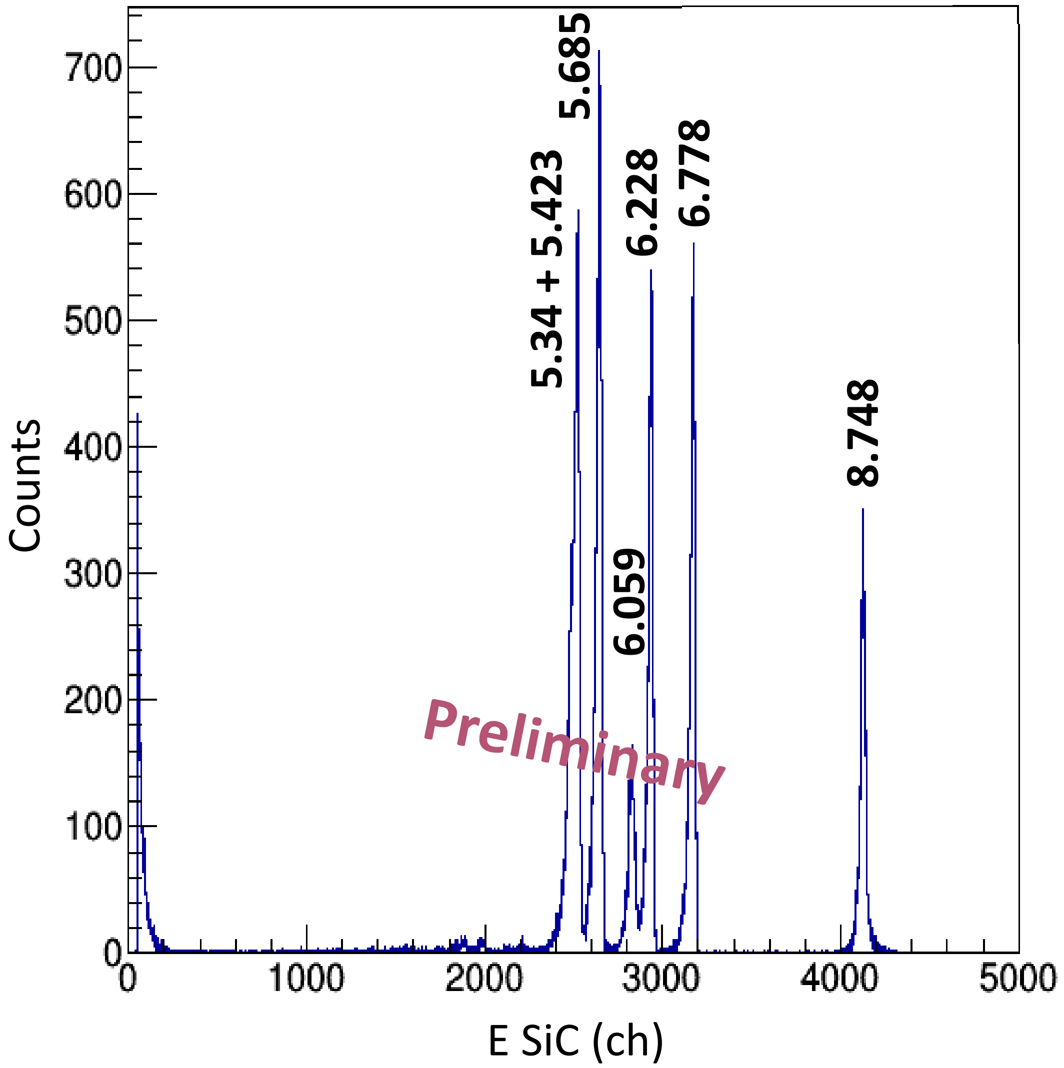


INFN-To

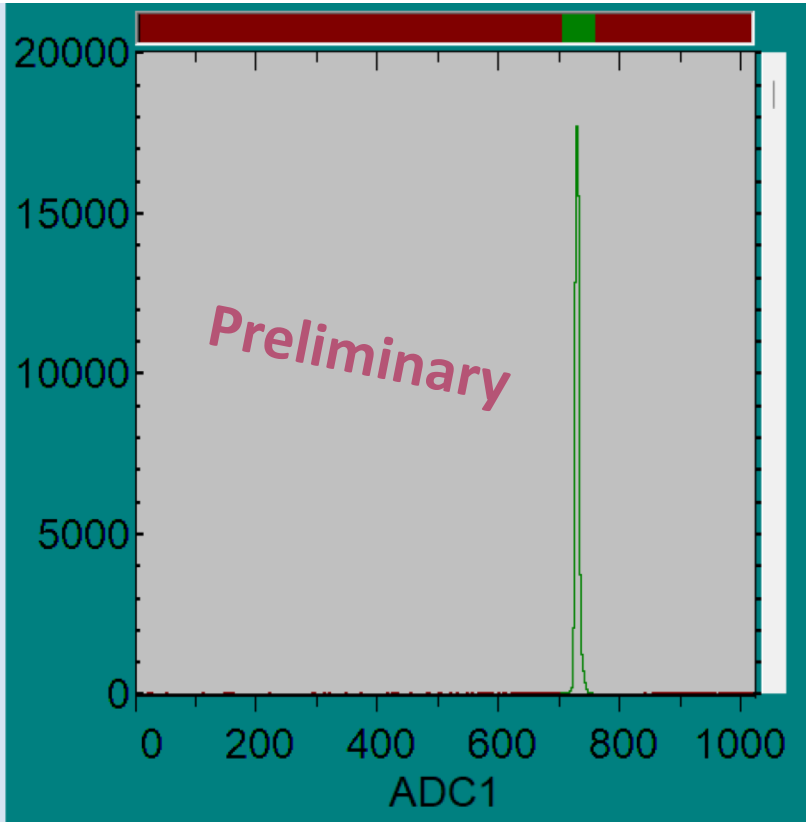
SiC Energy resolution

SiC 100 μm thick FDV ≈ 900 V

^{228}Th α-source (no collimation)

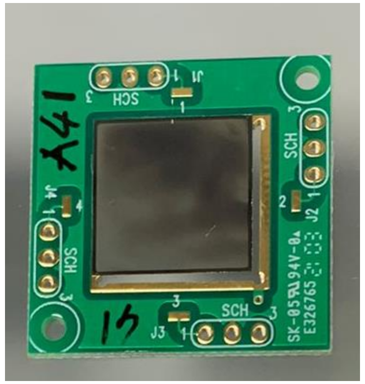


Proton microbeam @ 3.4 MeV

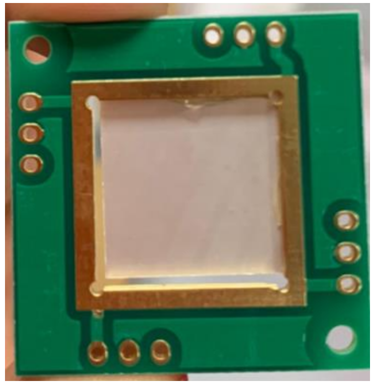


ΔE/E ≈ 0.7 %

Front



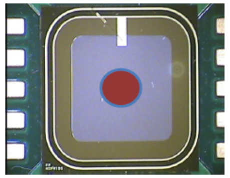
Back

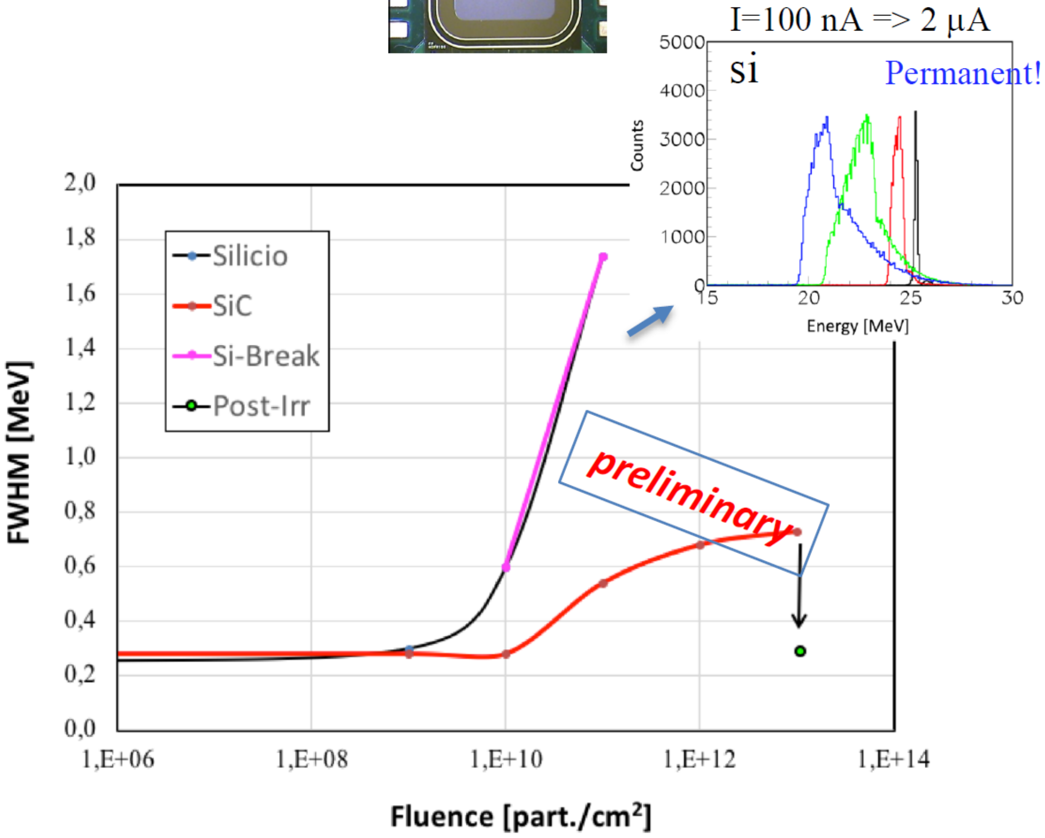


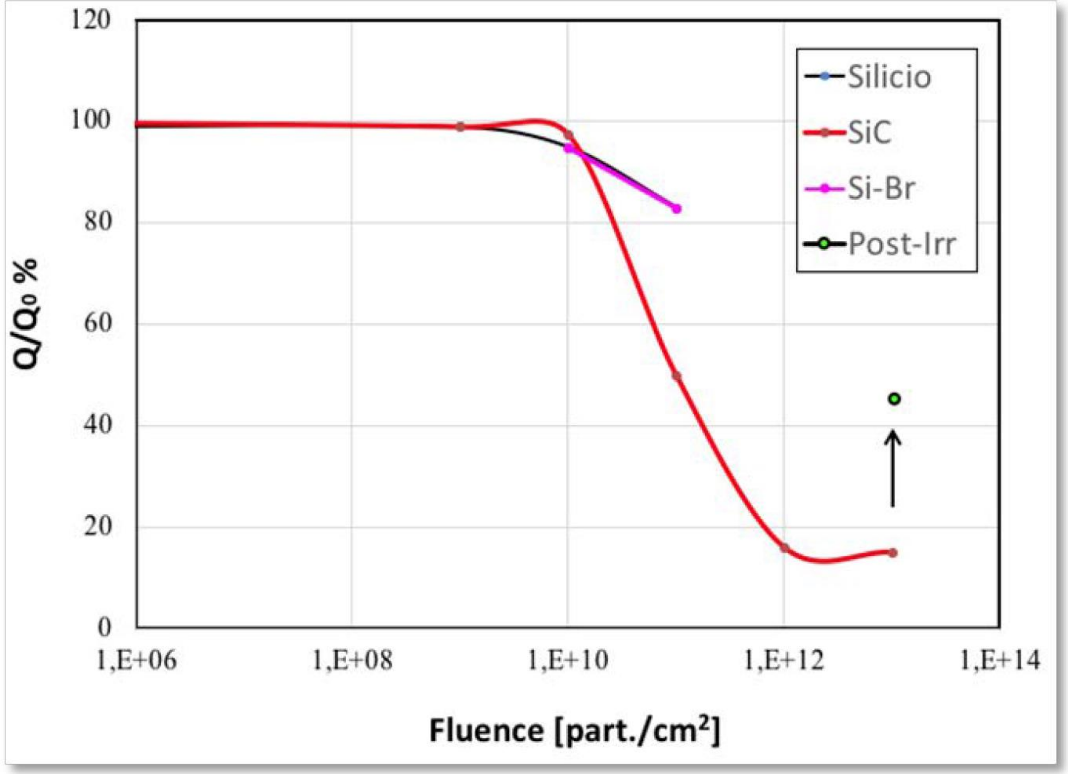
SiC Radiation hardness tests

^{16}O @ 25 MeV

SiC 10µm 5x5 mm²







NUMEN TDR F. Cappuzzello et al., Int. Jour. Mod. Phys. A 36, 2130018 (2021)

SiC microbeam characterization

Ruđer Bošković Institute, Zagreb (Croatia)

Experiment funded by EURO-LABS (EURO-LABS-RBI-2023-002)

- SiC CCE profile: 3D characterization
- Dead layer thickness measurement

Proton beam – 10 µm scanning pitch

Irradiation in the FRONT and BACK side

6 scanned areas

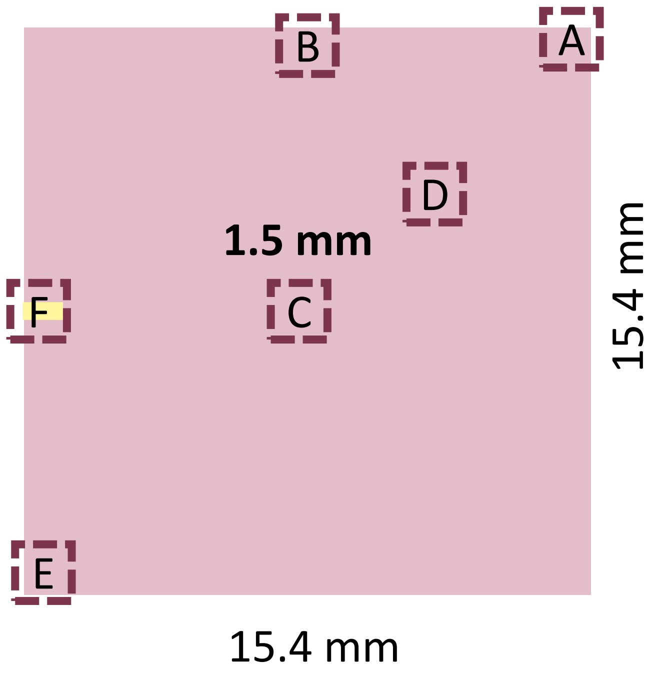
5 voltages FDV, FDV ± 15%, FDV ± 30%

4 proton energies

Different incident angles

4 SiC devices

Proton energy (MeV)	Range (µm)
1.26	15
2.50	45
3.4	75
3.92	95

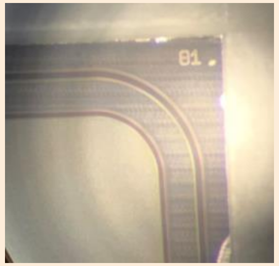


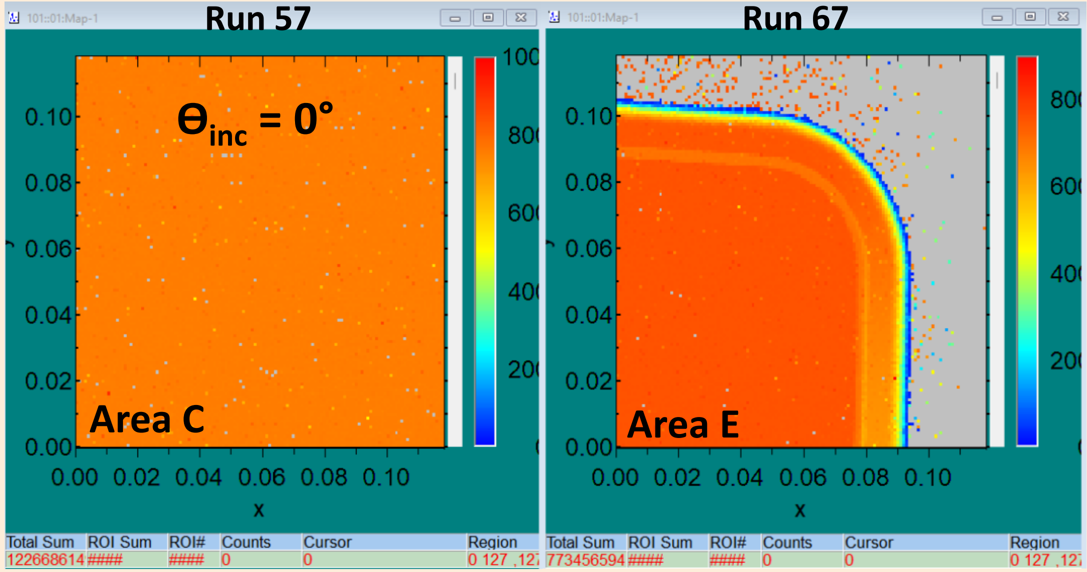
SiC microbeam characterization

Proton energy 3.4 MeV

Front irradiation

Preliminary

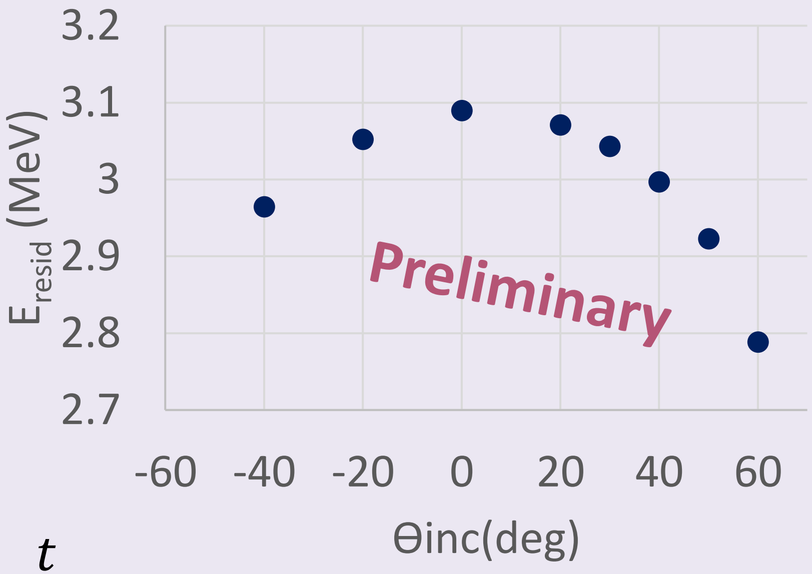




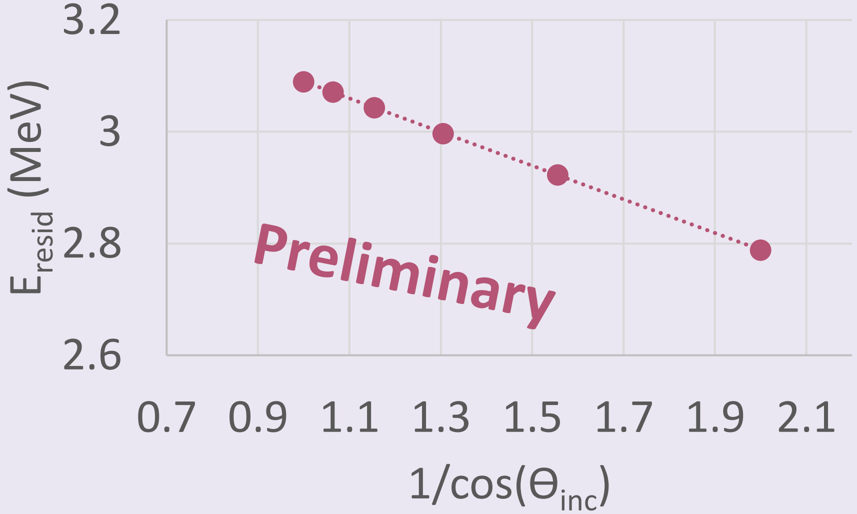
IBIC (Ion Beam Induced Charge) mode

- ➢ Good uniformity in the inner areas
- ➢ Rapid drop of the CCE at the edge

Back irradiation

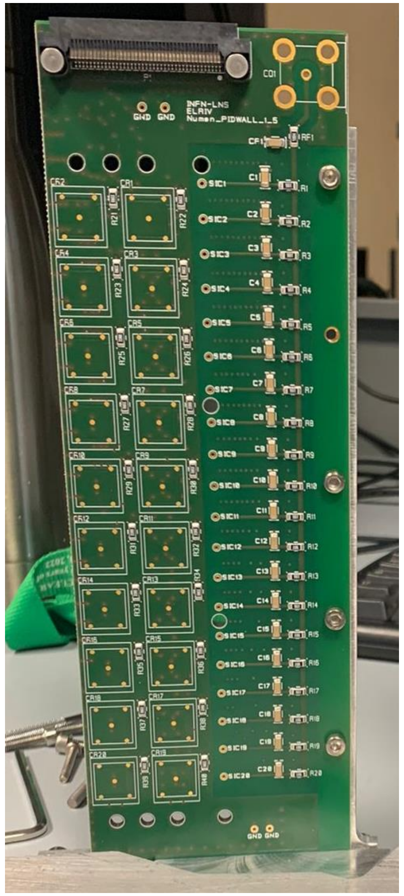


$$E = E_0 - \frac{dE}{dx}\frac{t}{cos\theta}$$

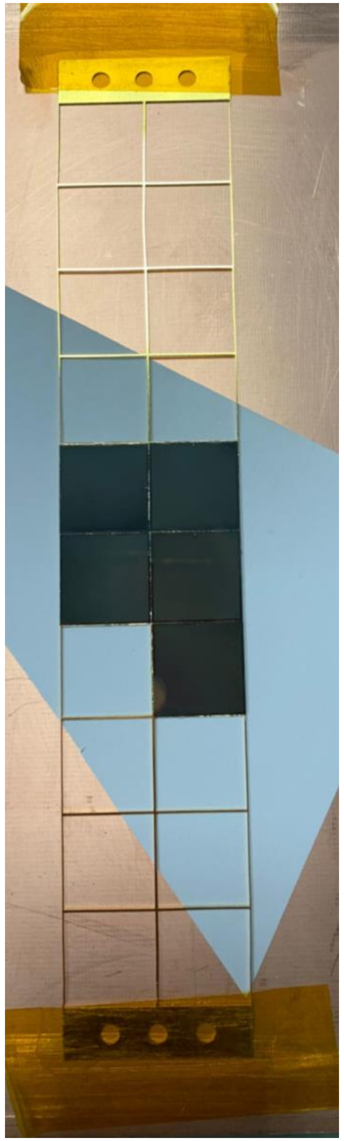


t ≈ 10.8 µm

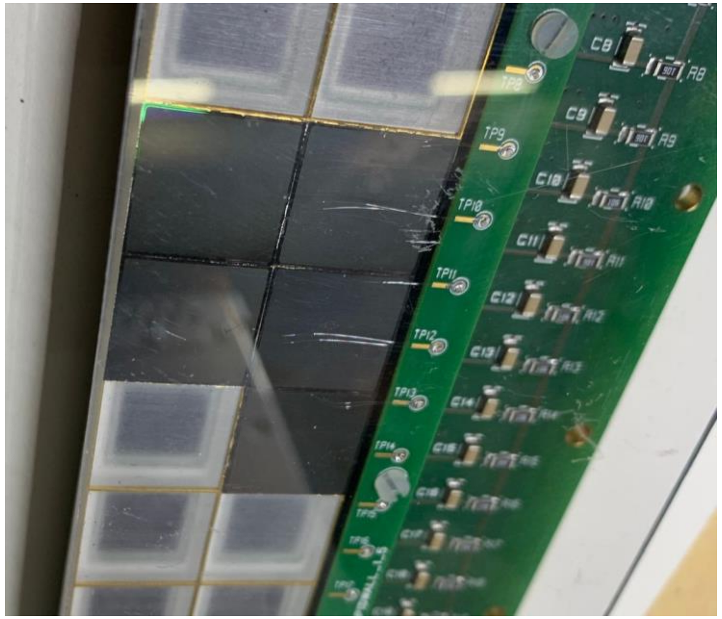
The PID tower assembly



Main PCB for the readout of the detectors

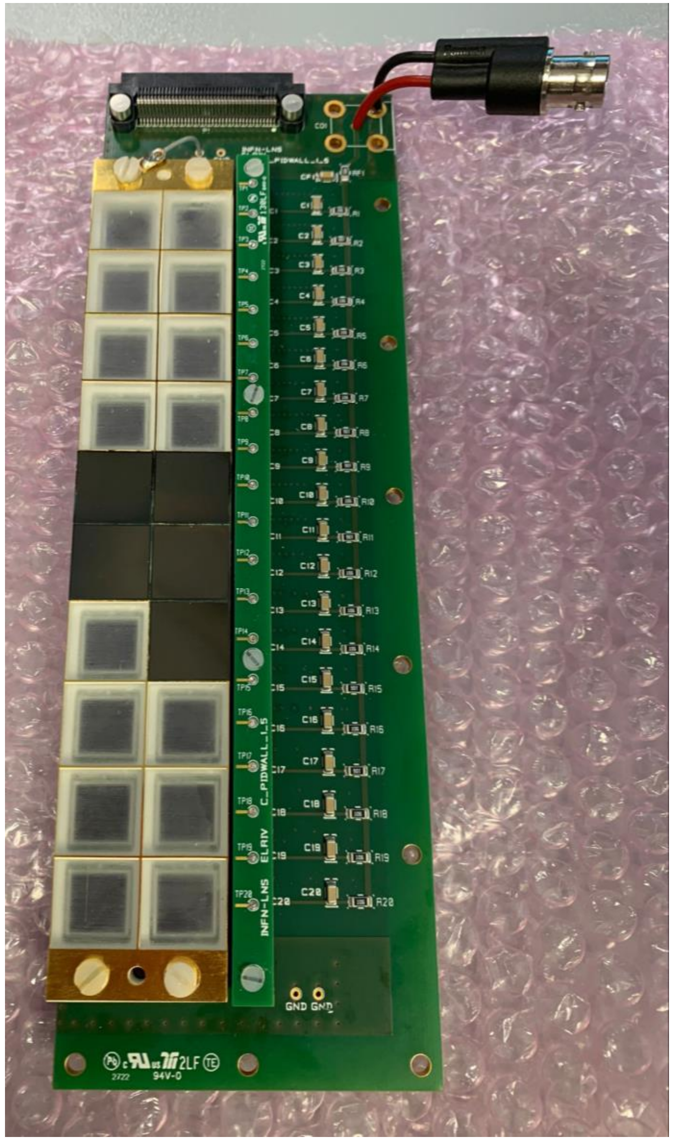


SiC glued onto a golden brass grid



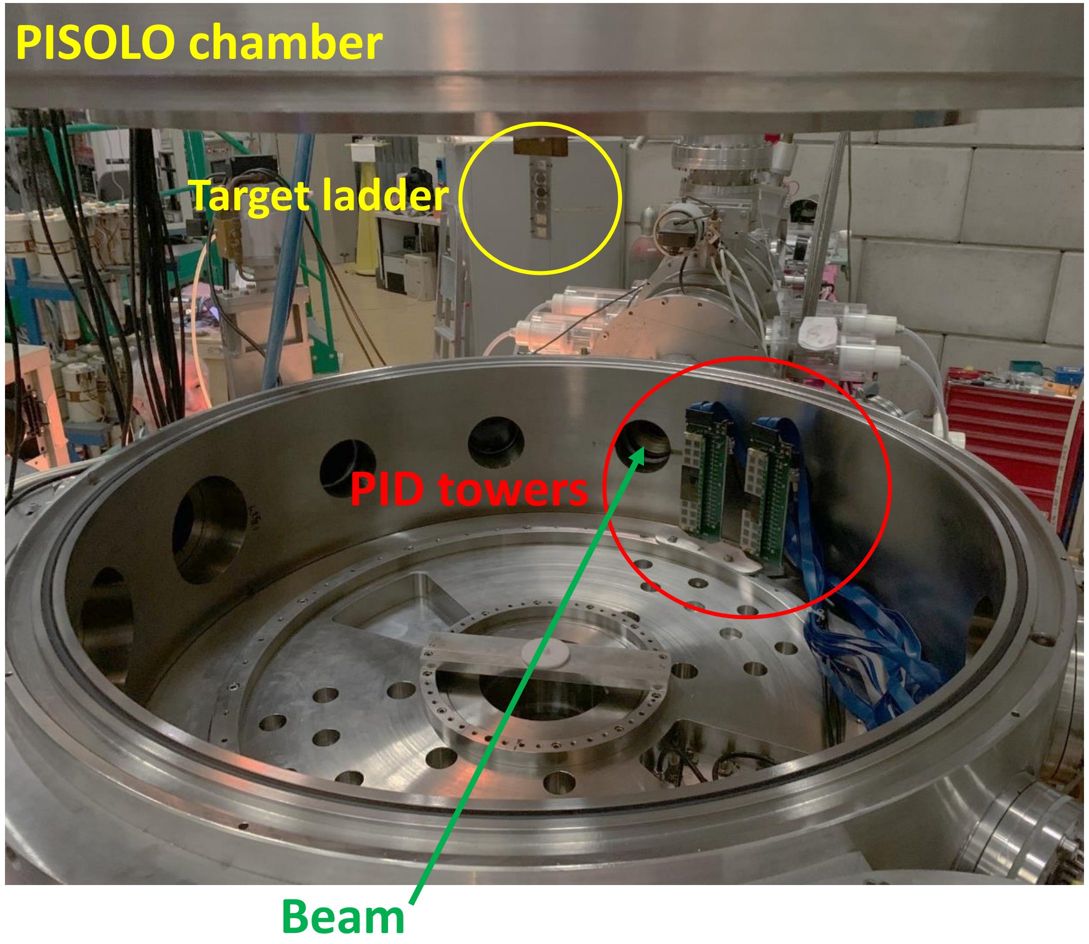
Long wire bonding (performed at INFN-To)

The first full tower



Commissioning of the PID prototype @ INFN-LNL

Proposal approved for 6 BTU ^{18}O beam @ 15 AMeV by Tandem+ALPI facility



- PISOLO chamber equipped with Au and C targets
- PID prototype (2 towers) placed at forward angles
- Readout:

  64 channels Preamplifiers (CAEN A1429) +

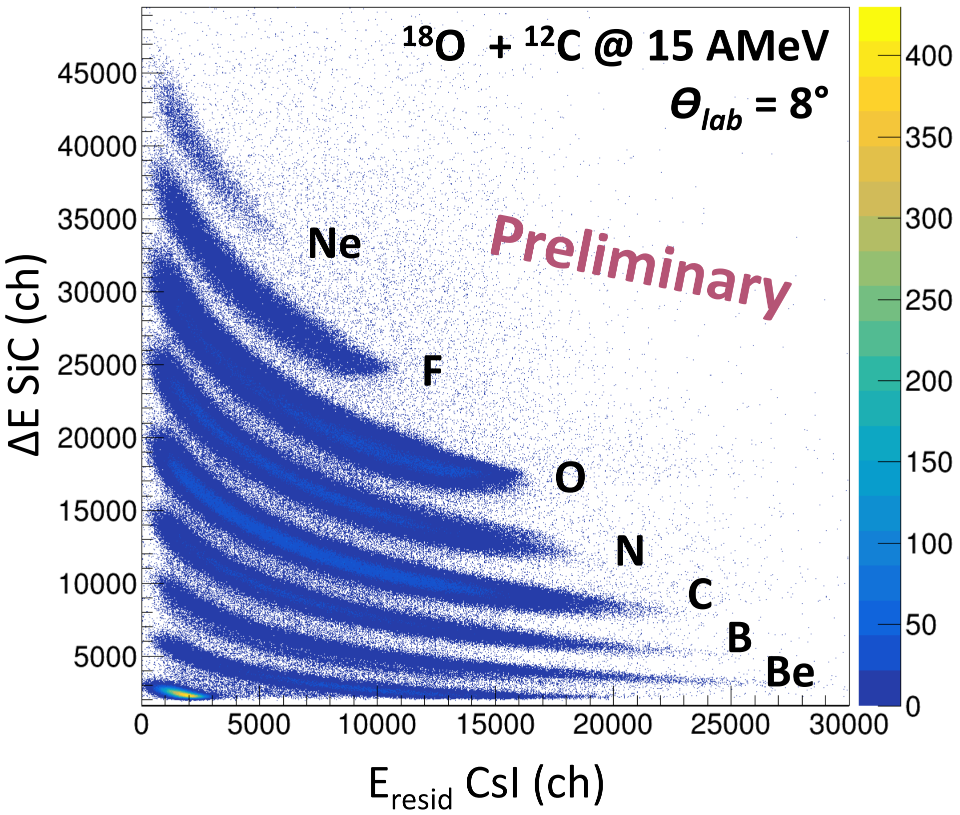
  64 channels Digitizers (CAEN VX2745) +

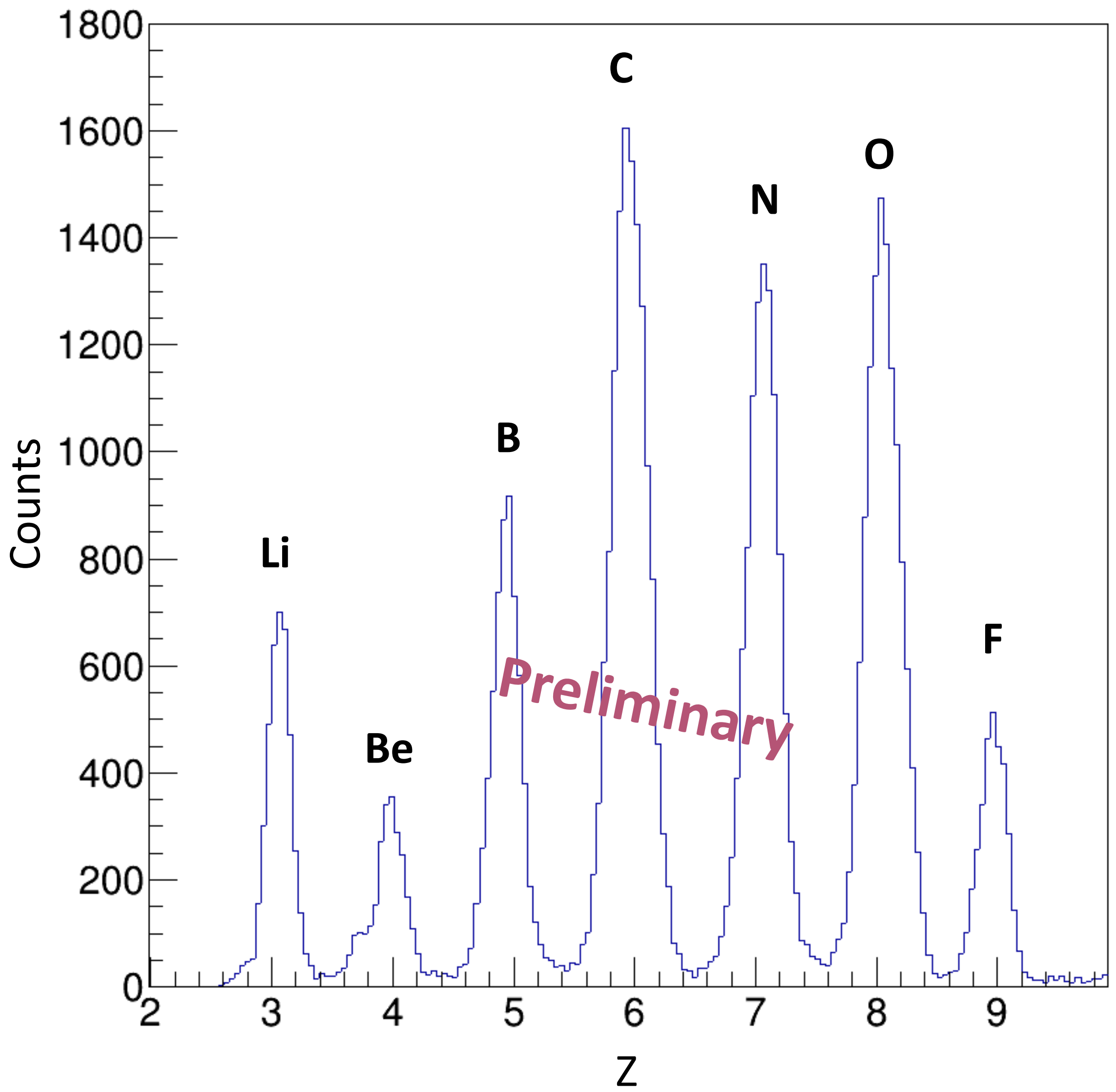
  new DAQ program developed for NUMEN

Goals

- ❑ Z identification capabilities
- ❑ Validation of the readout + DAQ
- ❑ High rates effects
- ❑ Tilt angle effects

Commissioning of the PID prototype @ INFN-LNL





Particle identification capabilities

ΔZ/Z ≈ 3 %

Conclusions and Outlooks

- High perfomances particle identification wall for the heavy-ion detection
- New large area **SiC detectors** characterized with alpha source and proton microbeam
- Construction of the first prototypes of 20 **SiC-CsI telescope towers**
- In-beam commissioning confirmed the performances in terms of particle identification

Outlooks

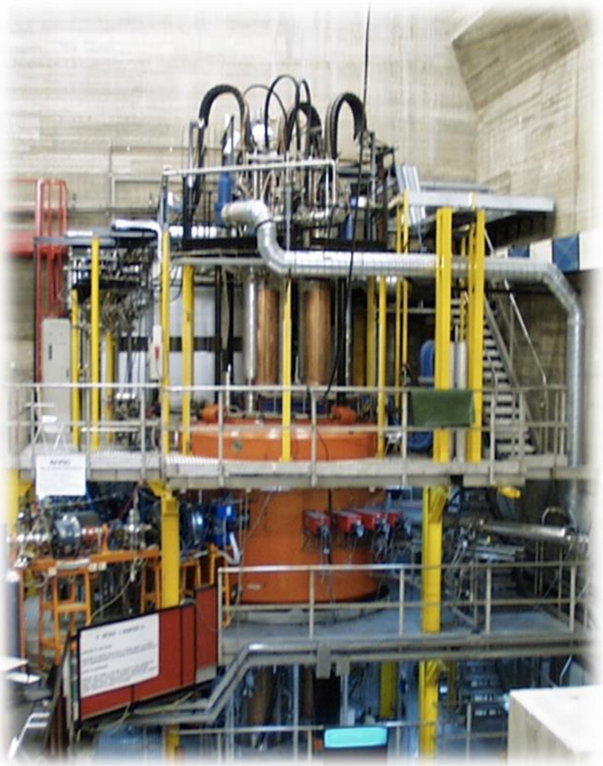
- Continue the tests in the gas environment
- Coupling with the gas tracker

- **PRIN 2022 project** just funded by Italian MUR (P.I. Diana Carbone, involved institutions: INFN-LNS and Politecnico di Torino) for the construction of SiC-CsI identification system for heavy-ion nuclear reactions

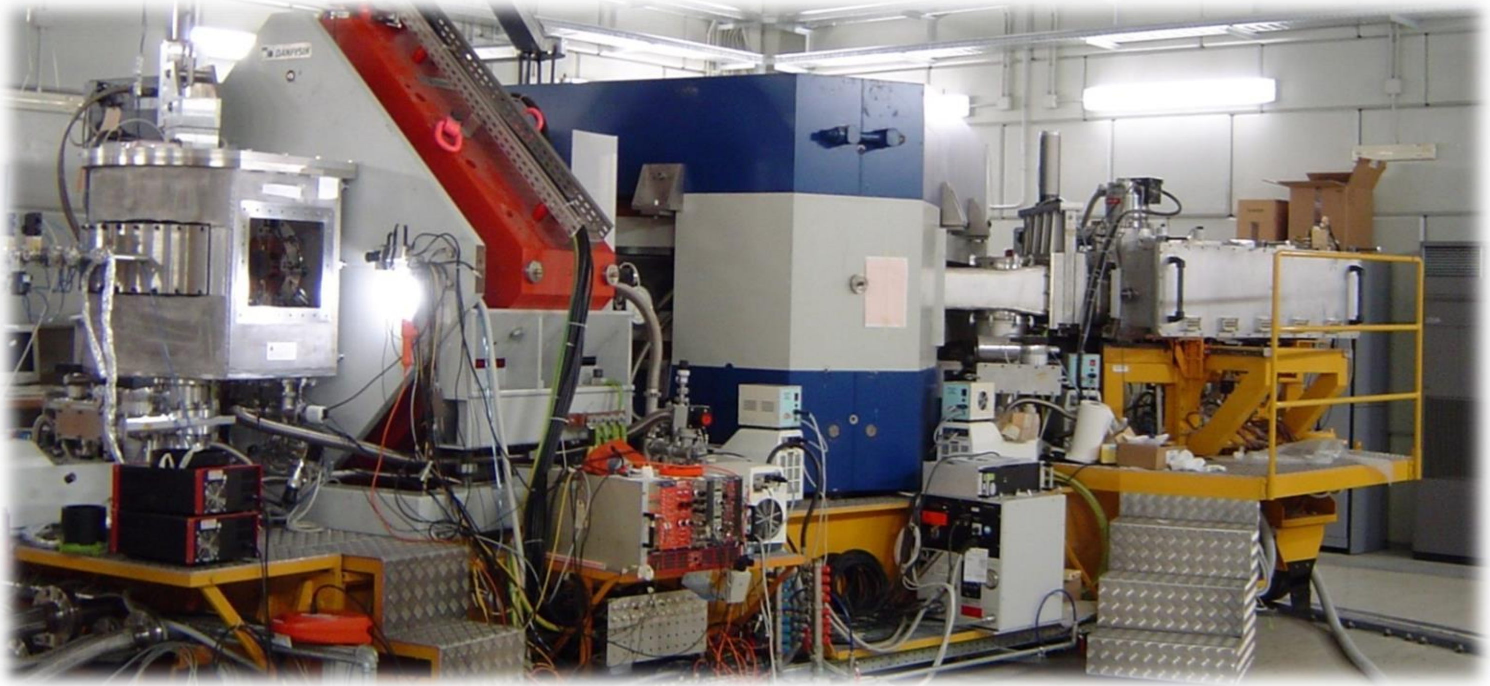
Thank you
for the attention

The NUMEN project

The experimental tools for studying **Heavy-Ion Double Charge-Exchange (HI-DCE)**



K800 Superconducting Cyclotron



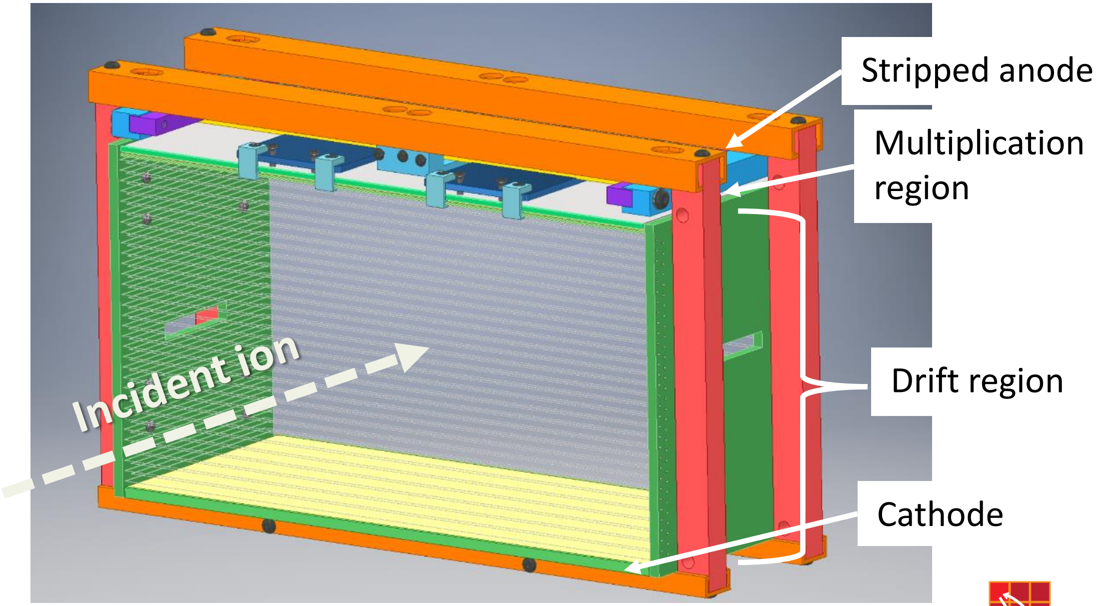
MAGNEX magnetic spectrometer

The gas tracker

Measure the three-dimensional track (X, Y, θ, ϕ) of the reaction ejectiles reaching the focal plane

Requirements for new gas tracker

- Ability to cope the **rates** of particles as high as **MHz**
- **Low pressure** operation
- **High resolution measurement** of the track coordinates
  - horizontal position X_{foc} resolution **0.6 mm** (FWHM)
  - horizontal angle ϑ_{foc} resolution **0.3°** (FWHM)
  - vertical position Y_{foc} resolution **0.7 mm** (FWHM)
  - vertical angle φ_{foc} resolution **0.7°** (FWHM)



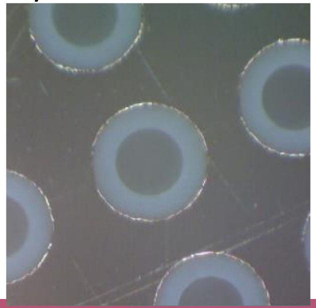
Same working principle of the present FPD tracker

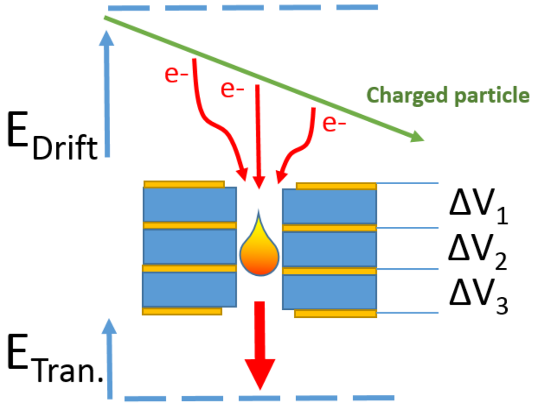
Filled with isobutane at low pressure (tens mbar)

Multiple Thick Gas Electron Multiplier (THGEM)

→ Simple and Robust

Assembly of several THGEM elements stacked together





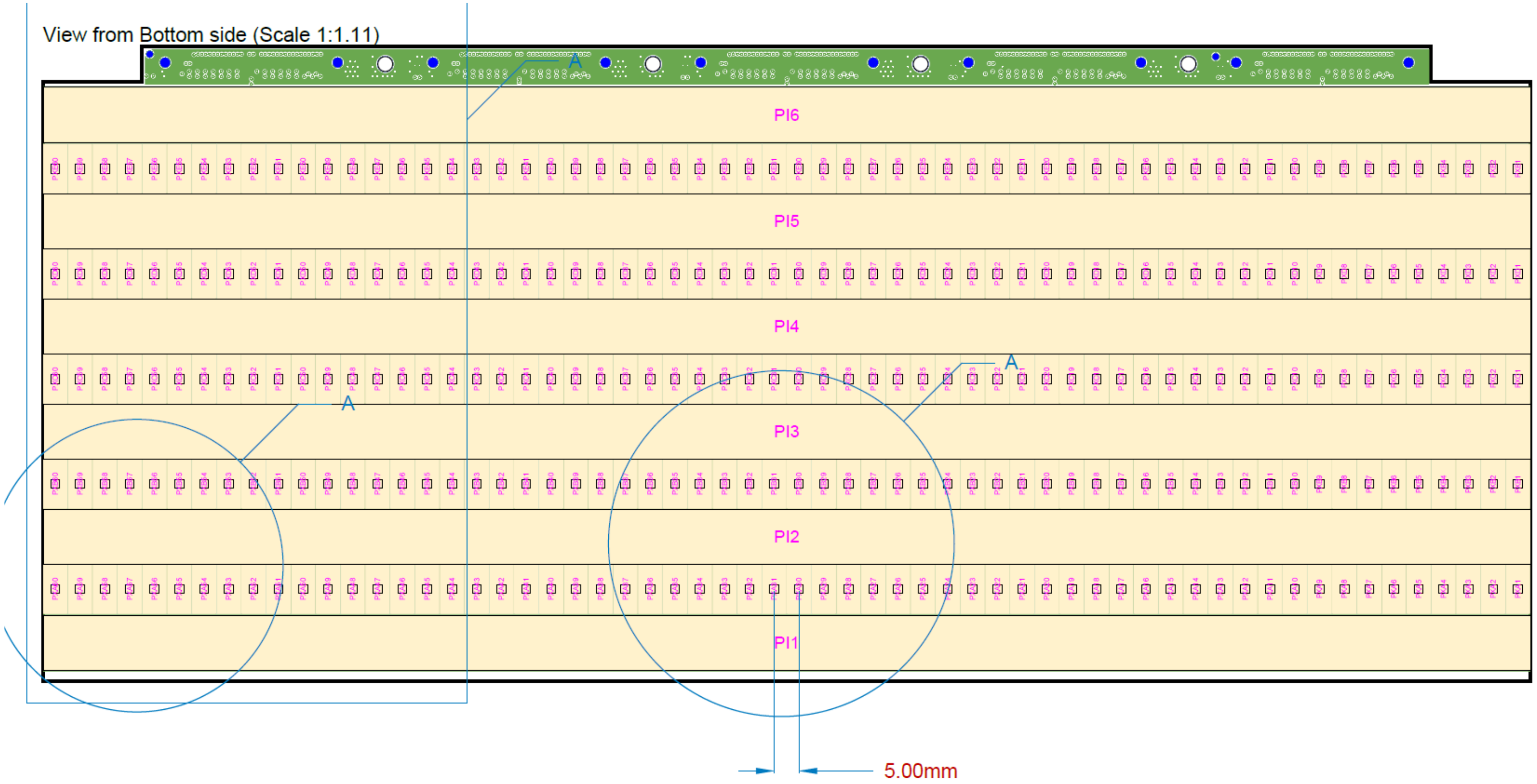
3-layer THGEM

Large gain at low pressure

The gas tracker

The stripped anode

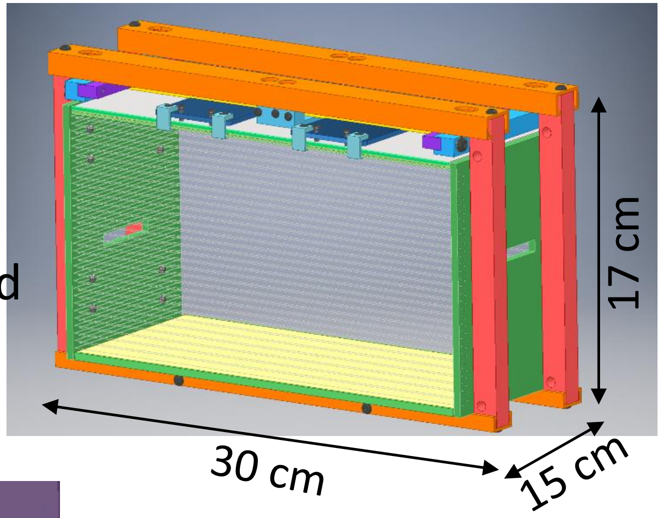
- 60 pad in 30 cm (1/4 of the full tracker)
- 5 mm x 10 mm pads
- 6 strips (11 mm height)
- Active region ≈ 110 mm

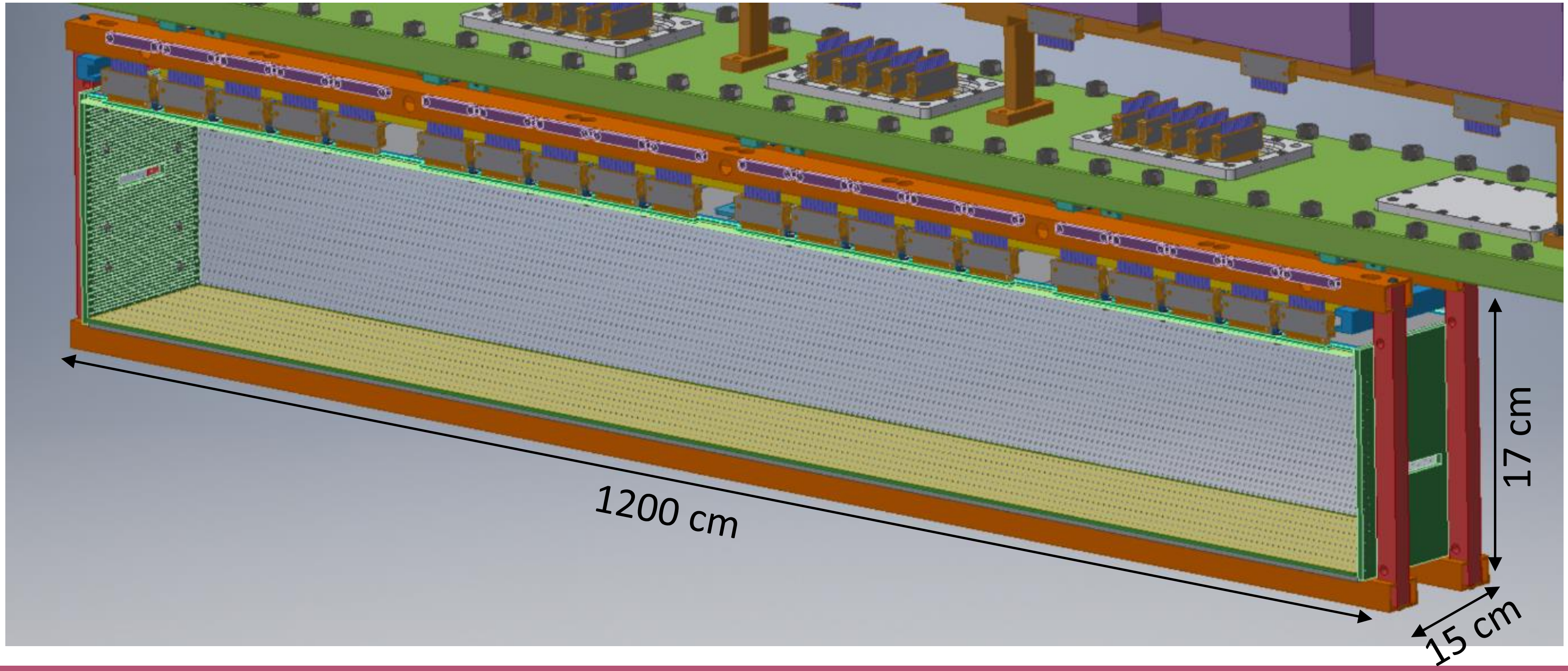


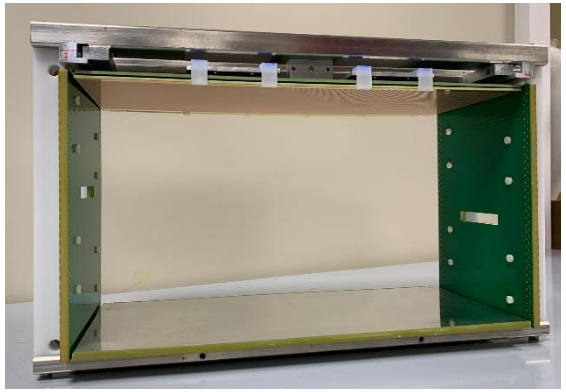
The gas tracker

The prototype

- Same design of the final tracker, just scaled in size
- 30 cm lenght (1/4 of the full tracker lenght)
- Important test bench for the final detector (performances, mechanical and electrical choices)

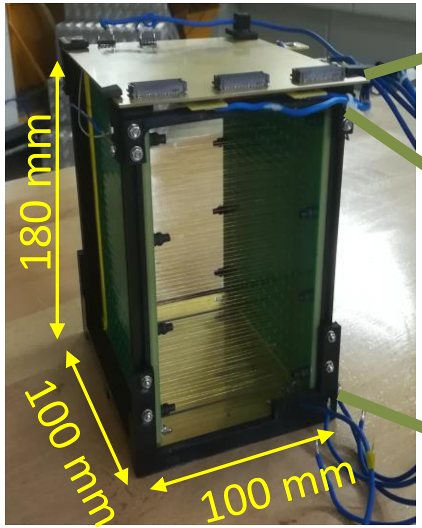


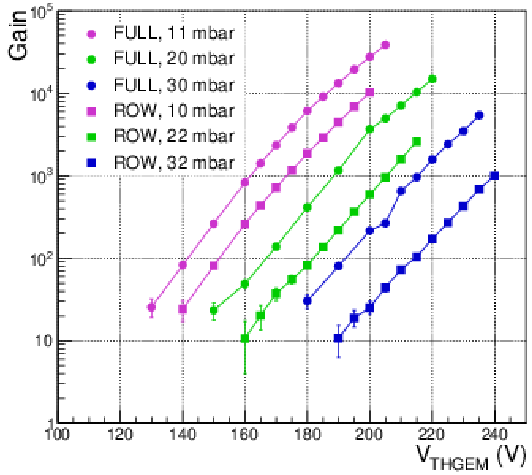



Prototype ready

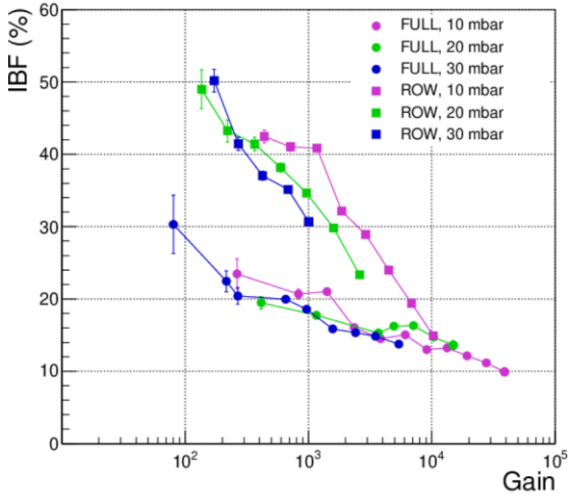
The gas tracker

The prototype characterizations





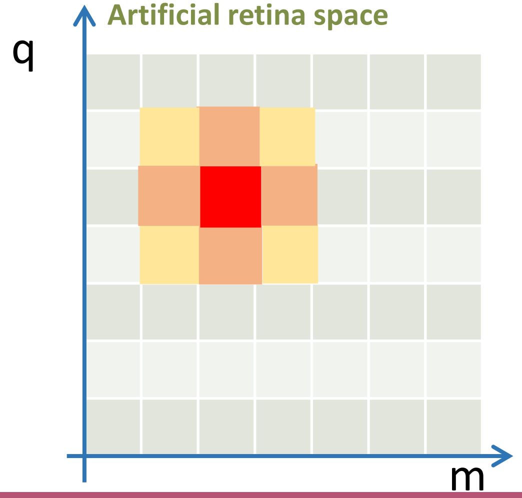
High gain at low voltage and pressure



Ion Back Flow

I. Ciraldo, G.A. Brischetto et al., accepted

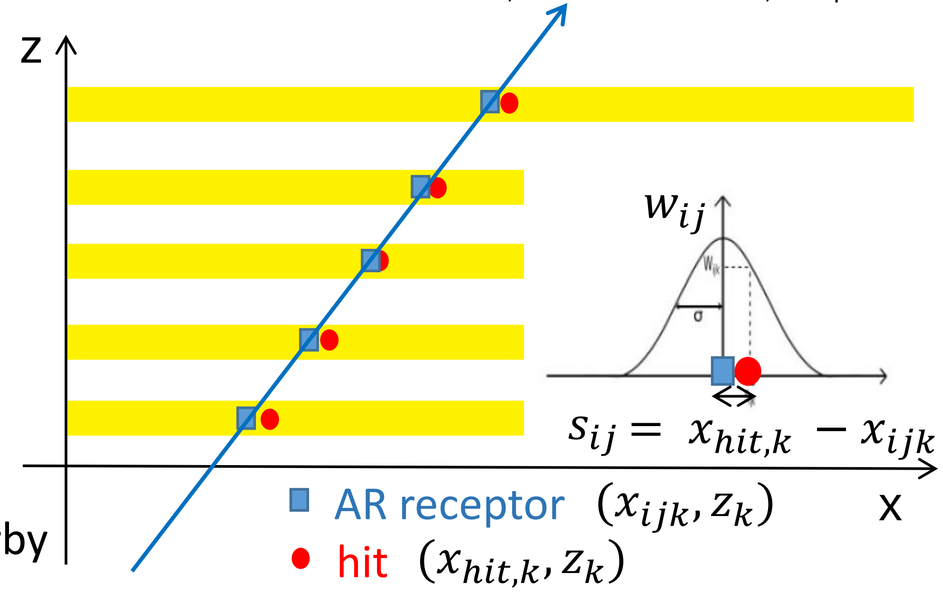
Track reconstruction



Artificial retina algoritm

Inspired by INFN RETINA project

- A AR cell represents a track in the anode
- Weight proportional to the distance beetween receptor and hit
- Real track parameters from weighted sum of nearby AR cells

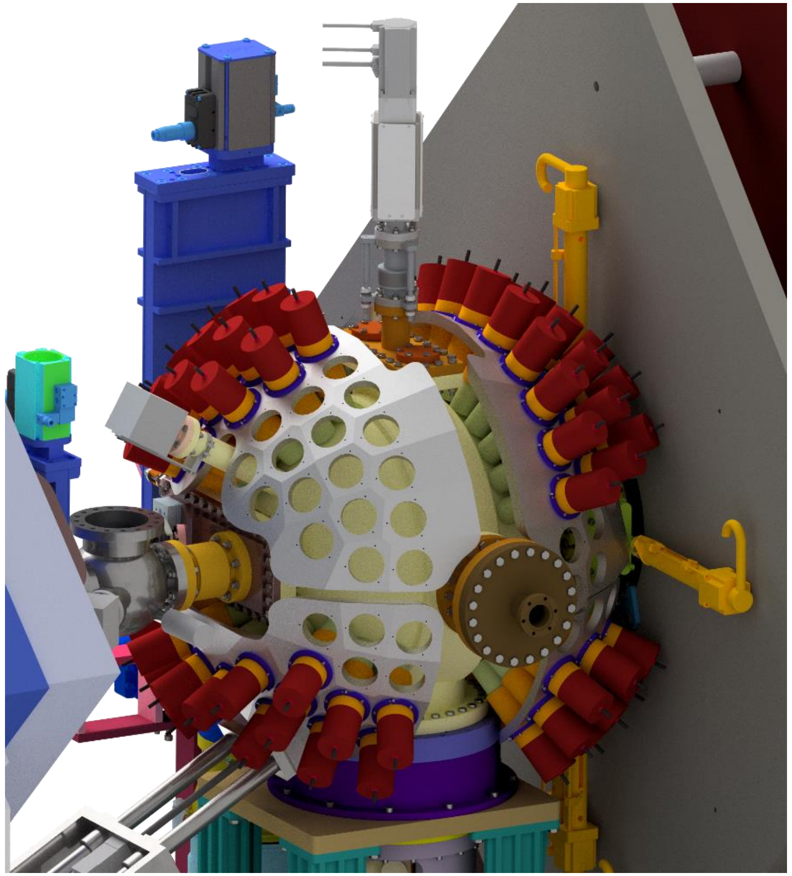


The G-NUMEN array

Measure the low-lying gamma-ray transition in coincidence with the DCE FPD events when the MAGNEX energy resolution is insufficient to isolate the g.s. to g.s. transition

Requirements for gamma array detector

- **Energy resolution <** 3-25 % (FWHM) depending on the nucleus
- **Time resolution** better than 5 ns (FWHM)
- Observational limit σ_{DCE}/σ_R less than 10^{-8}
- Radiation tolerance 10^{10} n/cm^2



G-NUMEN

≈ 110 LaBr3(Ce) crystal scintillator detectors

Expected performances

- ✓ Total photopeak efficiency of ≈ 4% at 1 MeV
- ✓ Energy resolution up to 2% (FWHM)
- ✓ Time resolution better than 1 ns (FWHM)
- ✓ Observational limit 0.3 x 10^{-8}
- ✓ Radiation tolerance better than 10^{10} n/cm^2

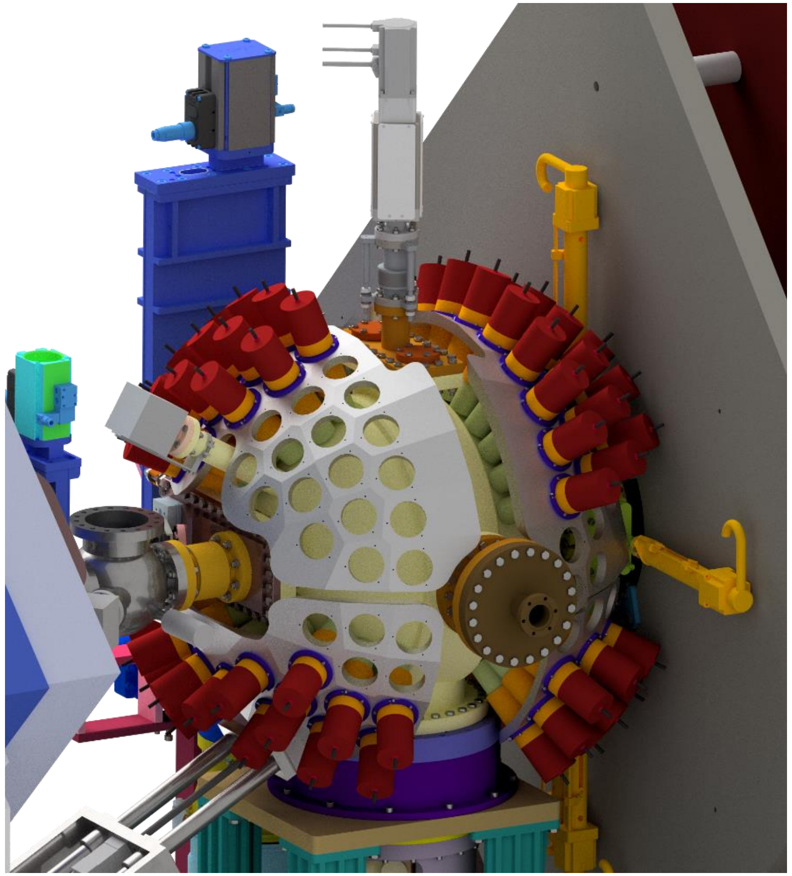
Very high rate of signals over which distinguish very few good DCE events in the region of interest

The G-NUMEN array

J.R.B. Oliveira et al, EPJA 56, 153(2020)

G-NUMEN

- ≈ 110 LaBr3(Ce) crystal scintillator detectors
- distributed in 7 rings around the beam axys
- 24 cm distance from the target
- Single crystal size 38 mm diameter and 50 mm length (compromise of increasing the photopeak efficiency while keeping the count rate per detector limited, to avoid excessive pile up)

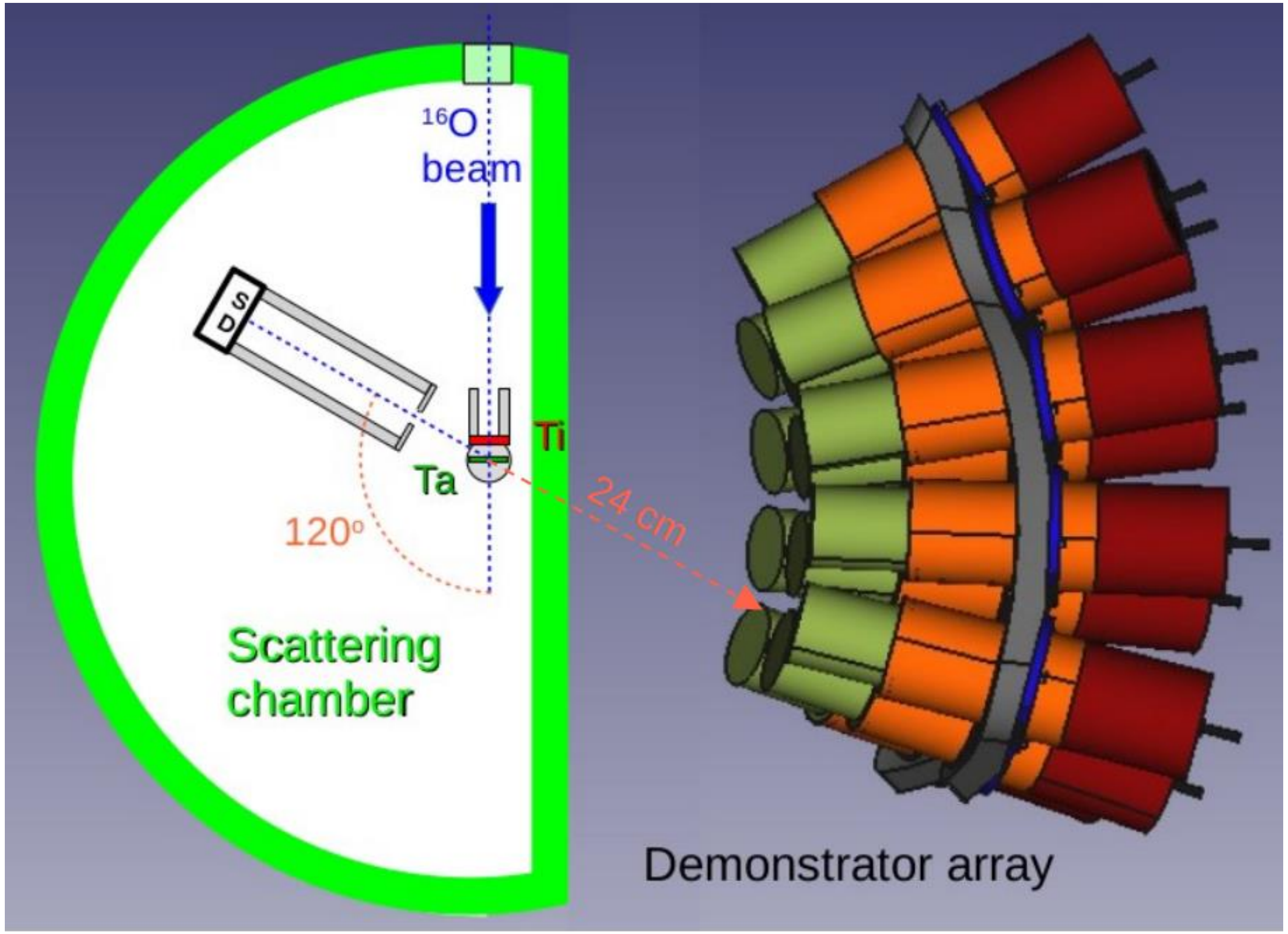


New MAGNEX scattering chamber

- Aluminum sphere of ≈ 500 mm diameter, 6 mm thickness and 6 apertures
- Aluminum shell, 15 mm thick, surrounding the scattering chamber that opens up in five pieces

The G-NUMEN array

G-NUMEN demonstrator

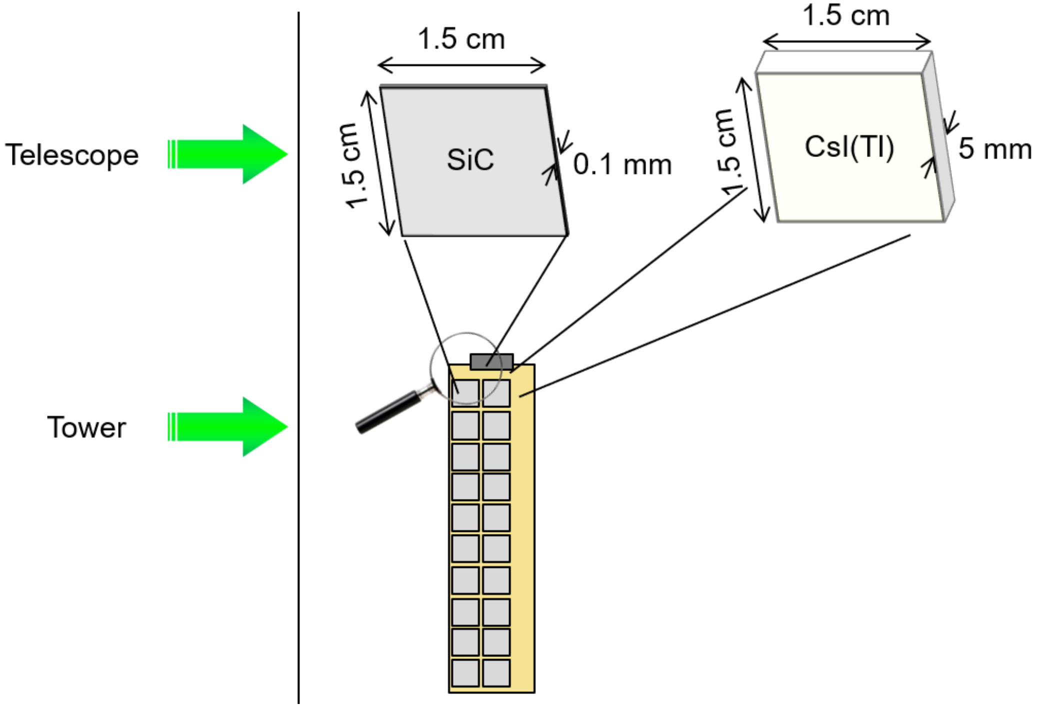


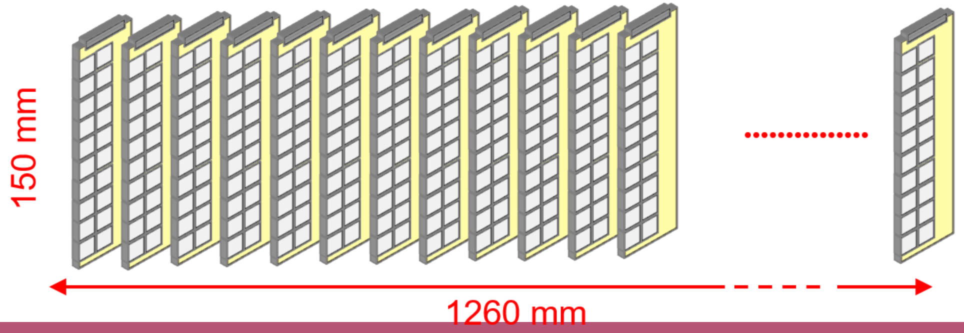
15 LaBr3(Ce) crystal scintillator detectors

Ready to be assembled and tested

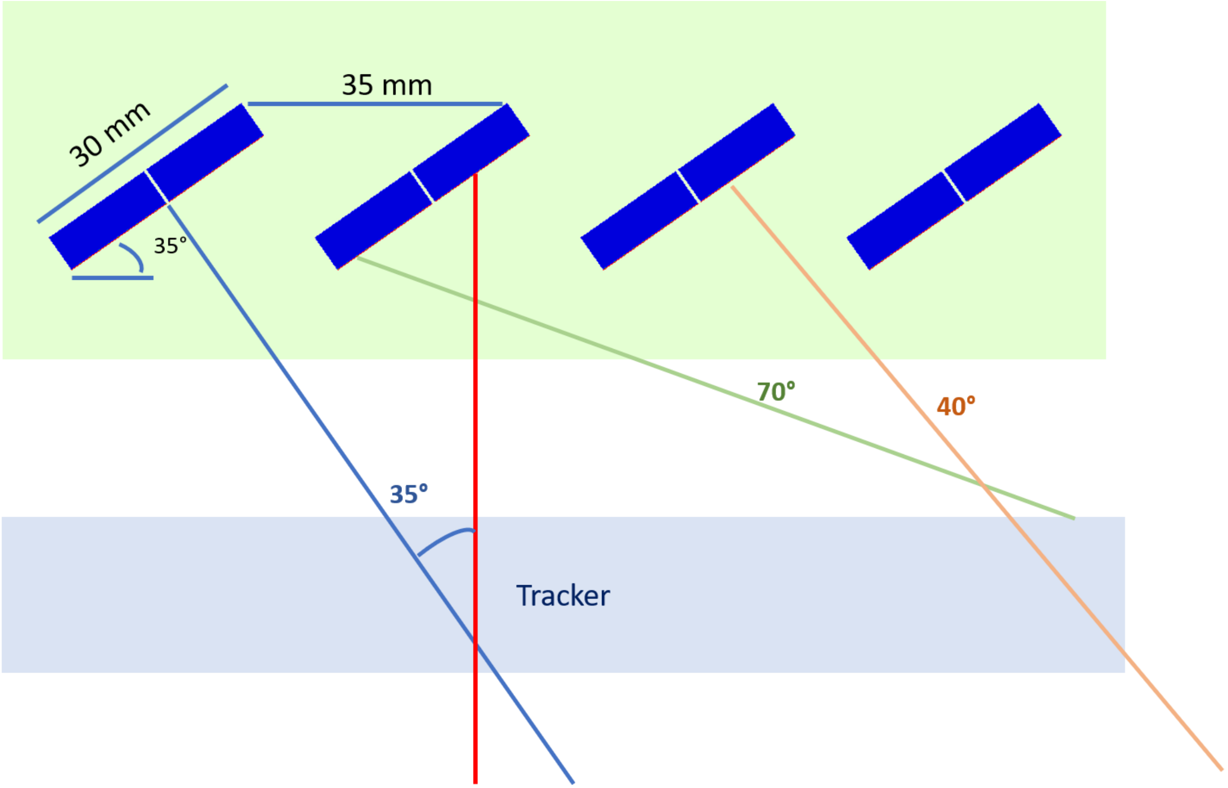
The particle identification wall

The PID tower

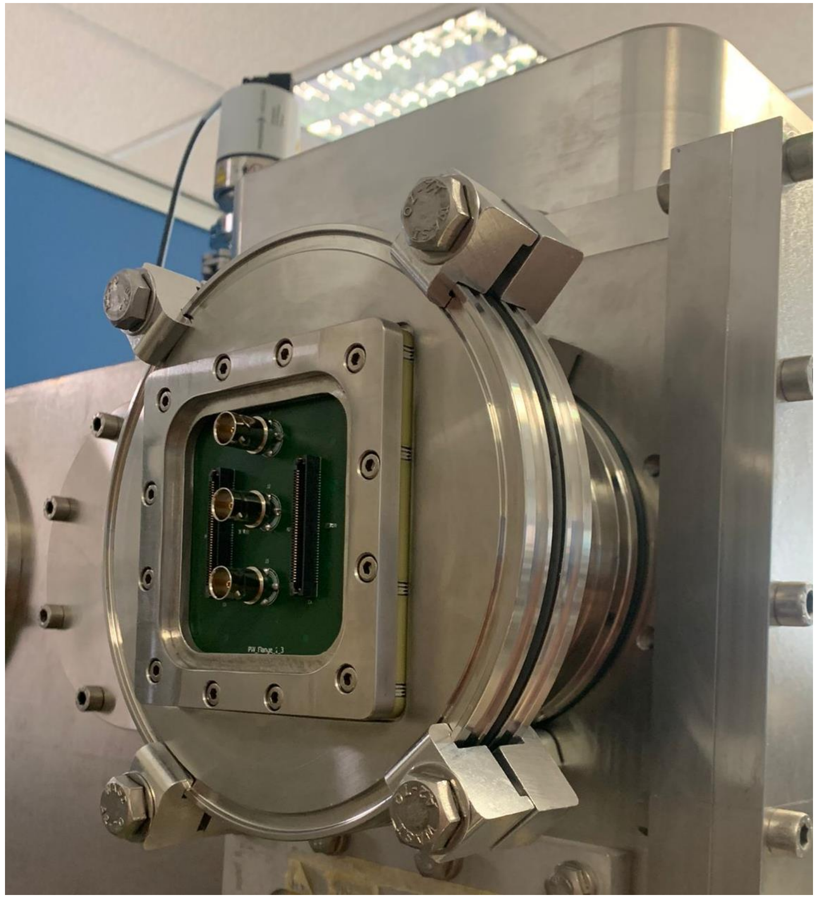




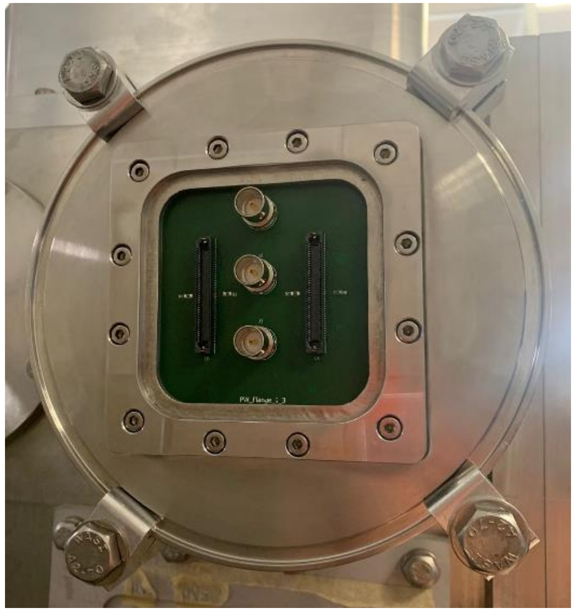
20 elements in each tower
35° angle of the towers



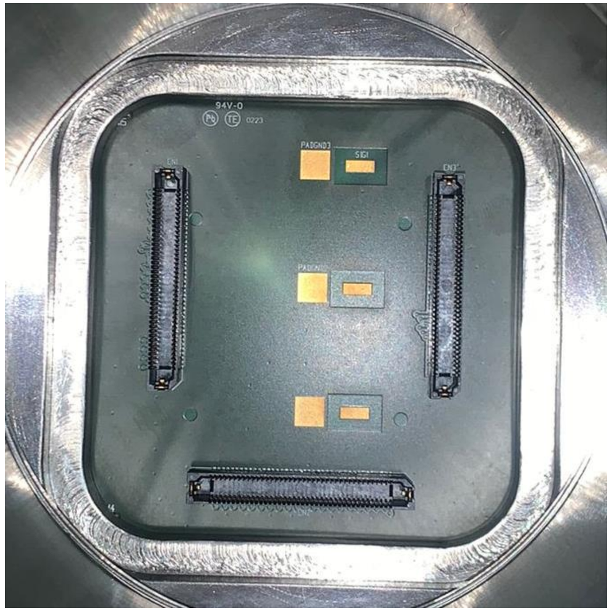
The PID flange for readout



PCB flange



Air side



Vacuum side