The SiC-CsI particle identification system for the NUMEN project

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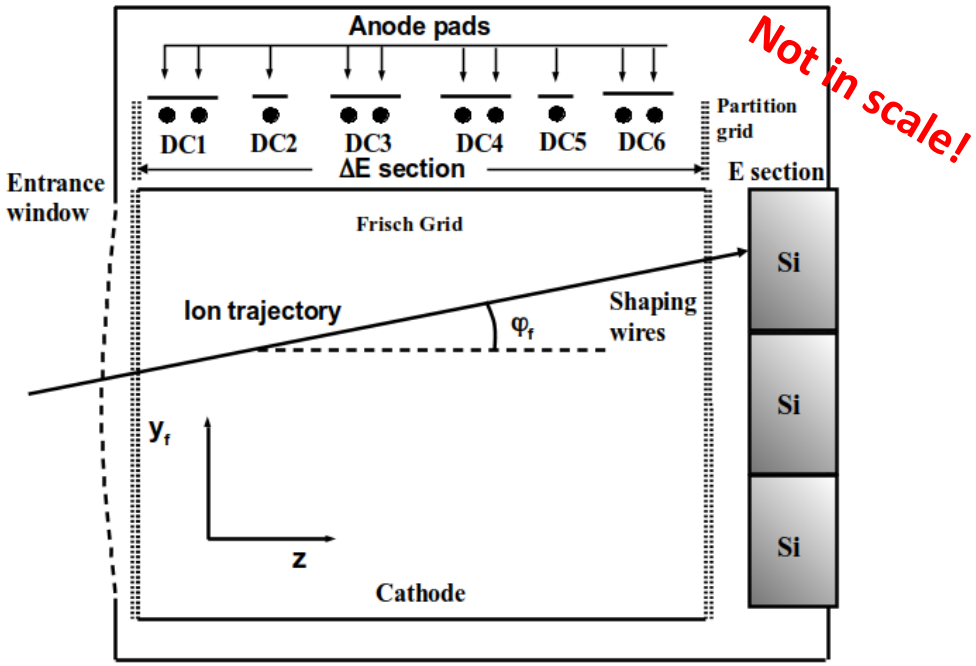
for the NUMEN collaboration

Techniques and Detectors for Heavy-ion Charge-State Identification in High-acceptance Spectrometers

16-18 December 2020

The old and the new gas tracker

The old gas tracker

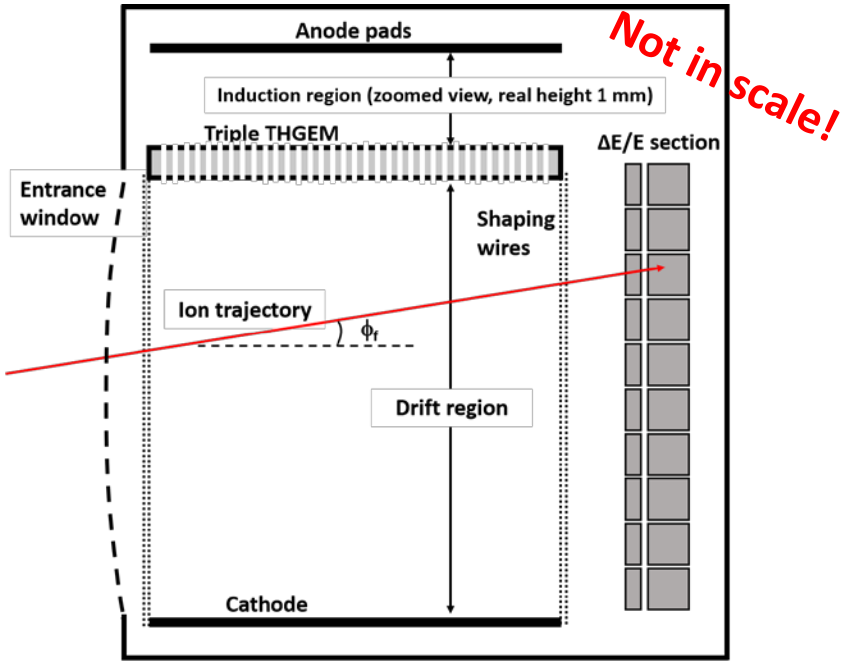


Proportional wires:

Energy-loss information used for ion Z-identification

(S. Calabrese talk)

The new gas tracker



Triple THGEM:

No accurate energy-loss information

(I. Ciraldo talk)

Need of a wall of telescope detectors

PID-system fundamental requirements

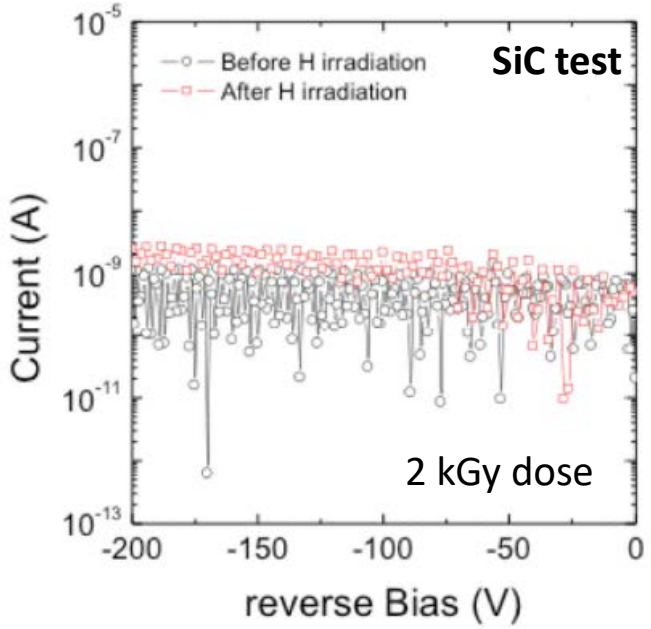
- **Unambiguous identification** of ions in the region of O, F, and Ne
- **Excellent radiation hardness**, expected overall heavy-ion fluency of $\sim 10^{12}$ ions / ($cm^2 \cdot yr$)
- **Energy resolution** better than ~2%
- **Time resolution** better than 2-3 ns
- High degree of **segmentation**
- **Scalability**

The SiC-CsI solution

ΔE → SiC

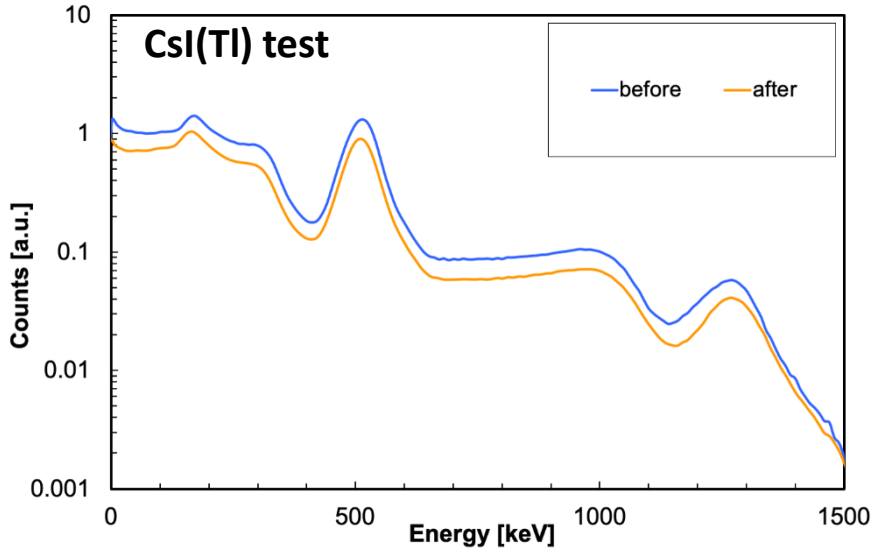
SiCILIA project [1]

- Excellent radiation hardness: test with ^{16}O at 26 MeV with fluencies as large as 10^{13} ions / cm^2 [2]
- Energy resolution: 0.4% FWHM for α-particle at 5486 keV [1];
  1.2% FWHM for ^{16}O at 26 MeV [2]
- Time resolution: hundreds of ps [3]



E → CsI(Tl)

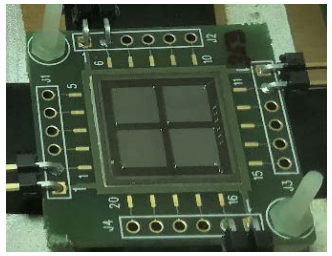
- Very good radiation hardness: specific irradiation test with ^{14}N at 62.5 MeV/amu for a total fluency of 10^{12} ions / cm^2 [4]
- PID capability: specific test done



[1] S. Tudisco *et al.*, Sensors **18**, 2289 (2018)
[2] S. Tudisco *et al.*, (in preparation)
[3] X. Zhang *et al.*, IEEE Trans. Nucl. Sci. **60**, 2352 (2013)
[4] P. Finocchiaro *et al.*, Universe **6**, 129 (2020)

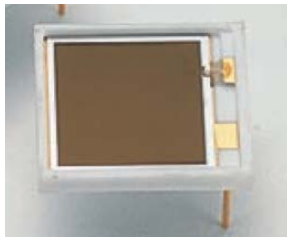
The SiC-CsI telescope features

SiC
Thickness 100 µm
Area 15.4 × 15.4 mm^2
Bias -600/-1000 V

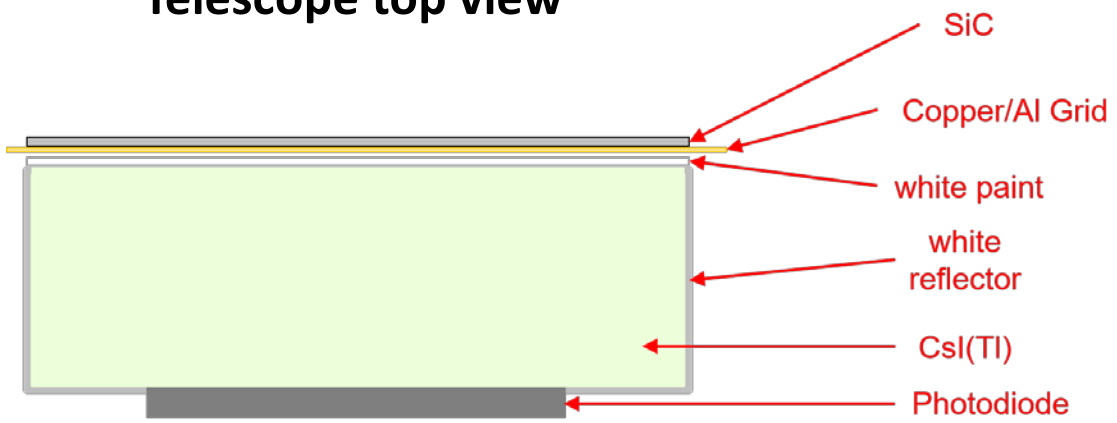


CsI (Tl)
Thickness 5 mm
Area 15 × 15 mm^2

Hamamatsu Photodiode S3590
Area ~ 10 × 10 mm^2
Bias -70 V

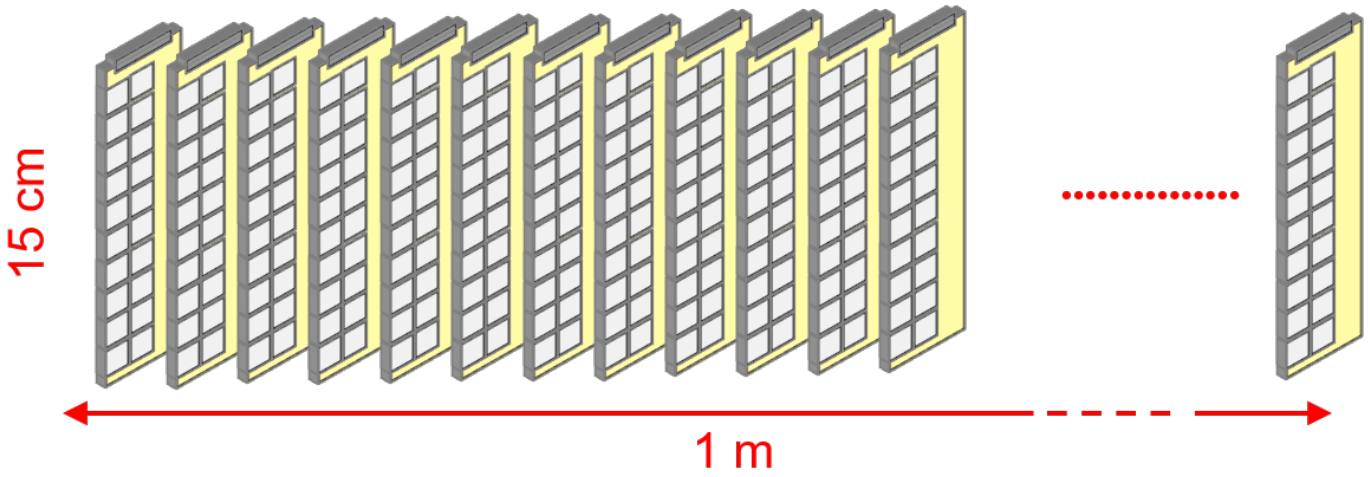


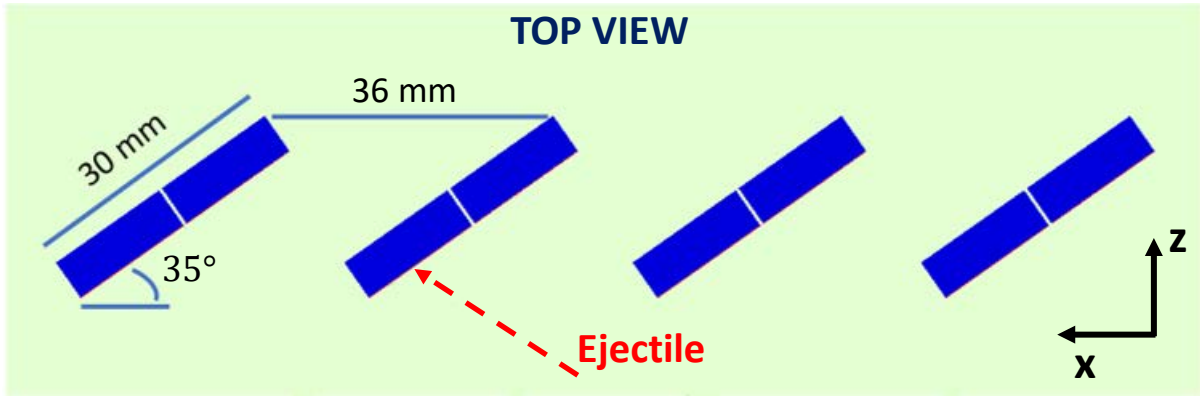
Telescope top view

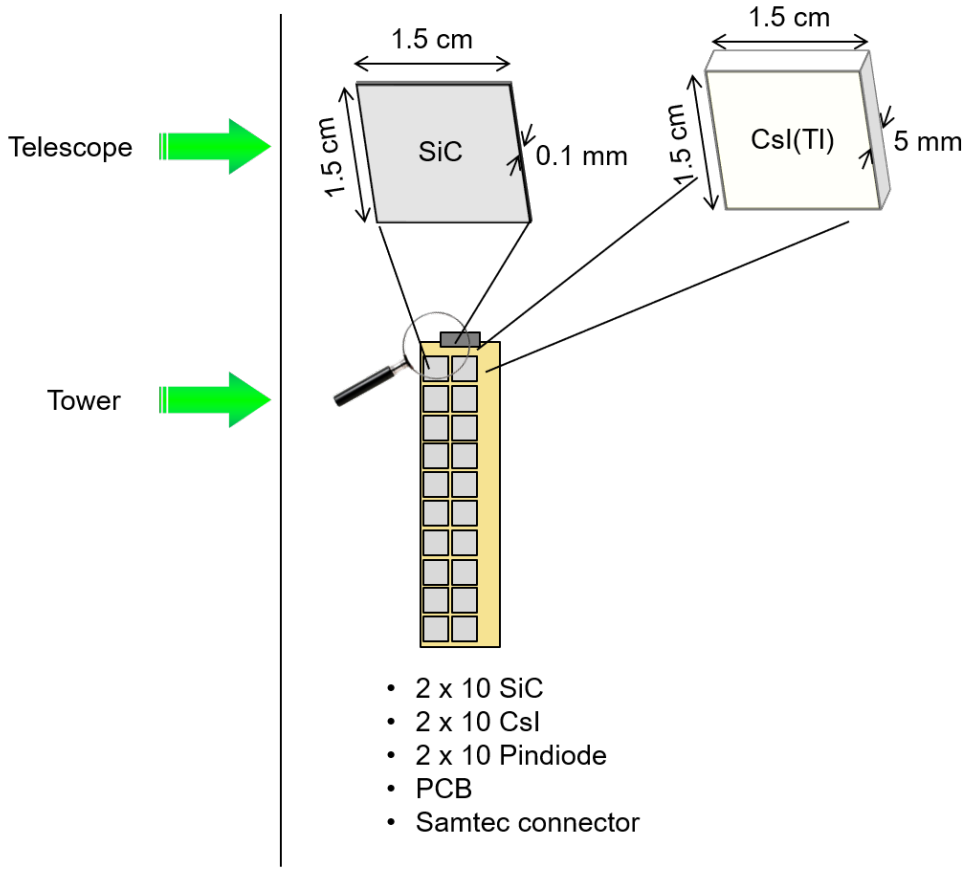


PID-wall layout

Full Focal Plane Detector
About 30 columns for 1 m coverage
600 telescopes/m







- 2 x 10 SiC
- 2 x 10 CsI
- 2 x 10 Pindiode
- PCB
- Samtec connector

Test beam of the first telescope prototype

Experimental Conditions:

^{20}Ne beam @ 20 AMeV

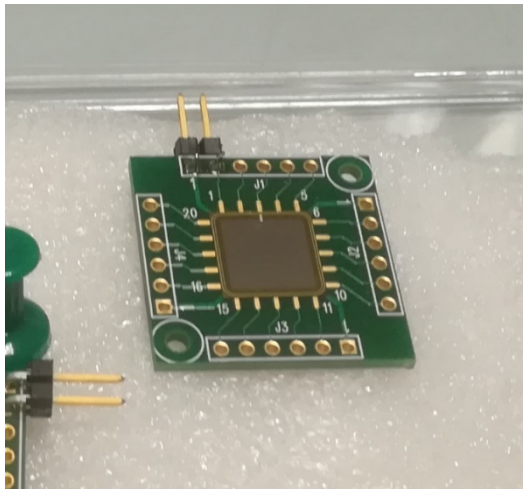
MAGNEX beam line (θ_{MAGNEX} = 10°)

Target: ^{12}C

Telescope placed at the focal plane of MAGNEX

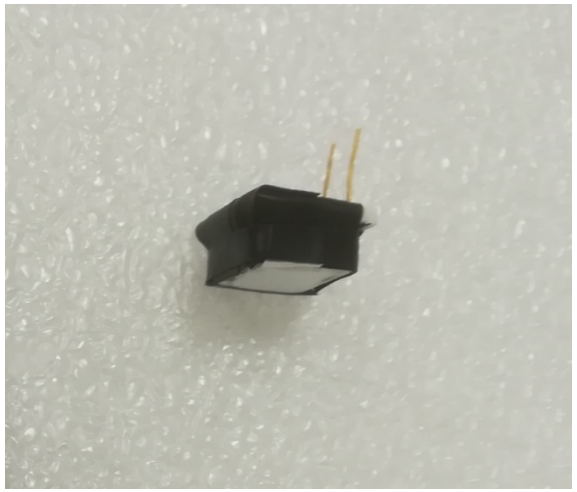
FIRST "CUSTOM-MADE" PROTOTYPE

SiC



- Area 10 × 10 mm^2
- Thickness **10 µm** + 100 µm substrate

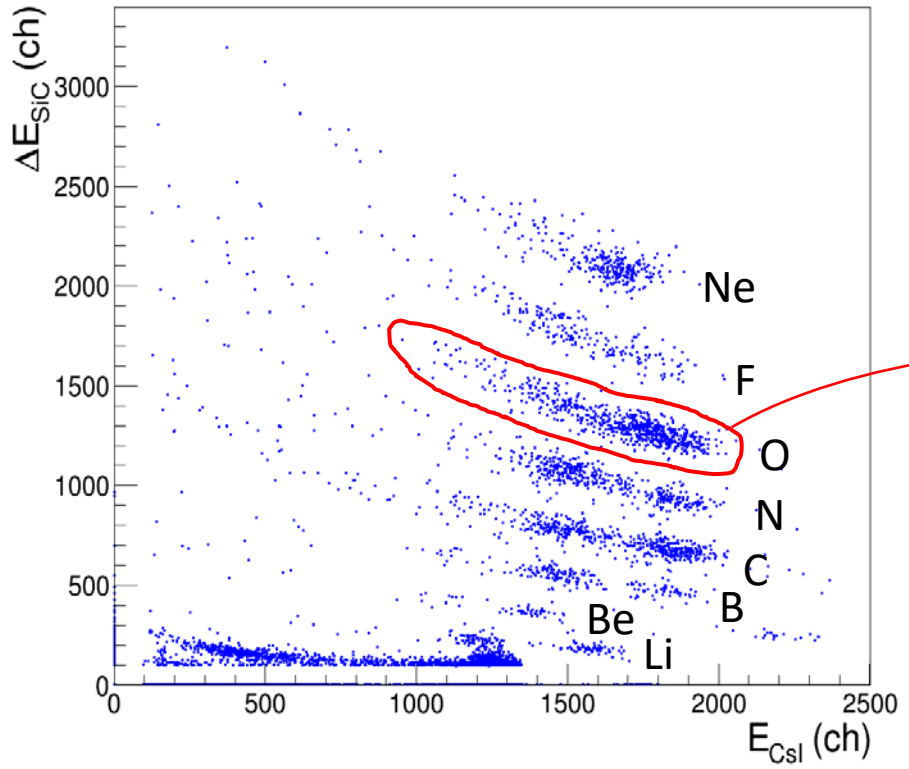
CsI(Tl)



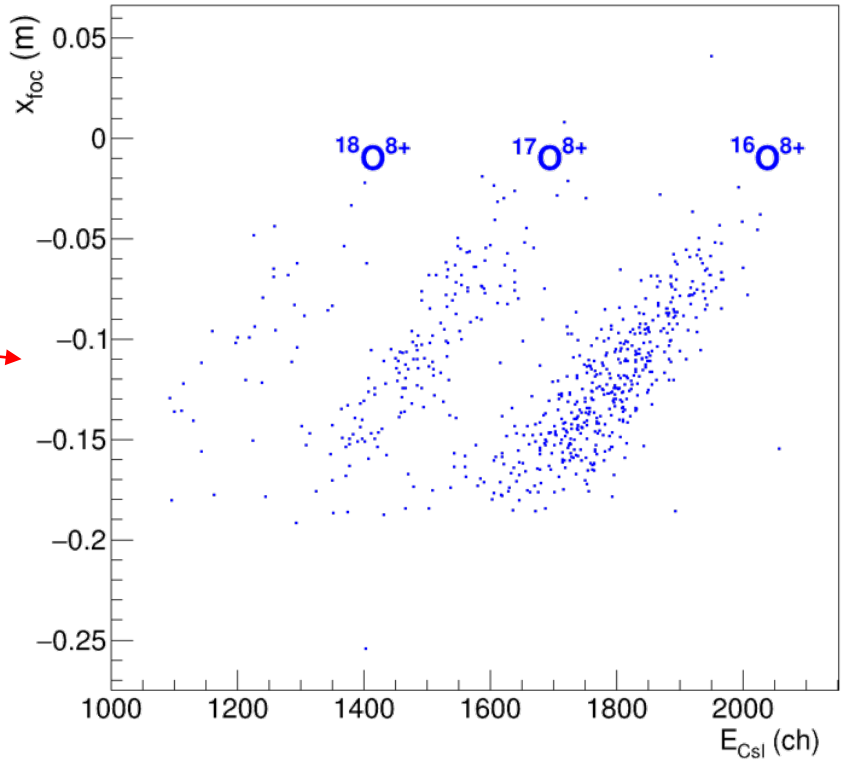
- Area 10 × 10 mm^2
- Thickness 5 mm
- Hamamatsu photodiode 10 × 10 mm^2

Test results (I)

$\Delta E - E_{resid}$ matrix

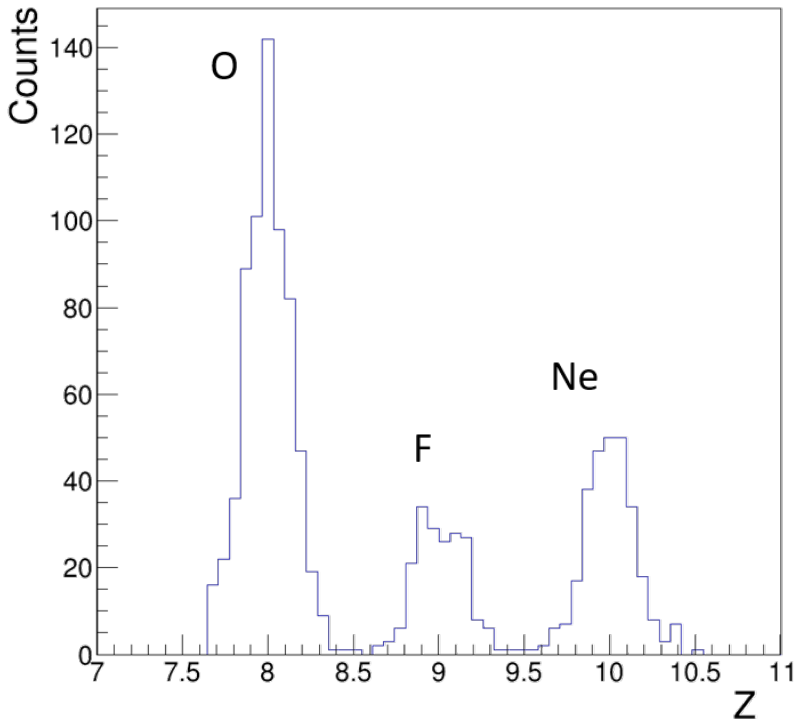


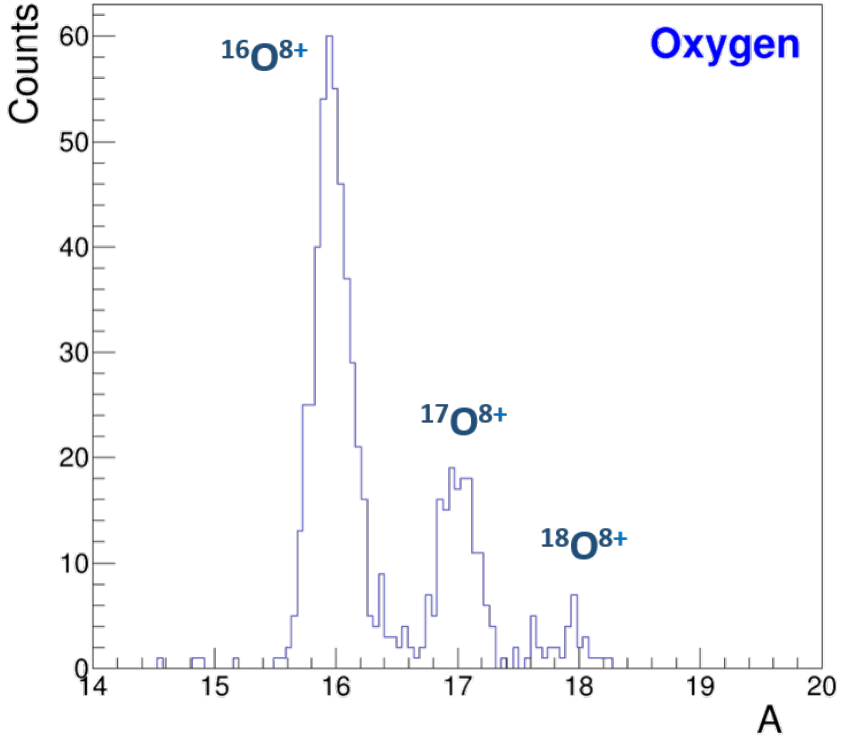
$x_{foc} - E_{resid}$ matrix



Test results (II)

Linearization and **calibration** of the two previous plots give:





ΔZ/Z ~ 4.1% FWHM

ΔA/A ~ 2.1% FWHM

The SiC-CsI PID-system satisfies the NUMEN requirements!

The simulation tool

Development of a simulation of the PID-wall

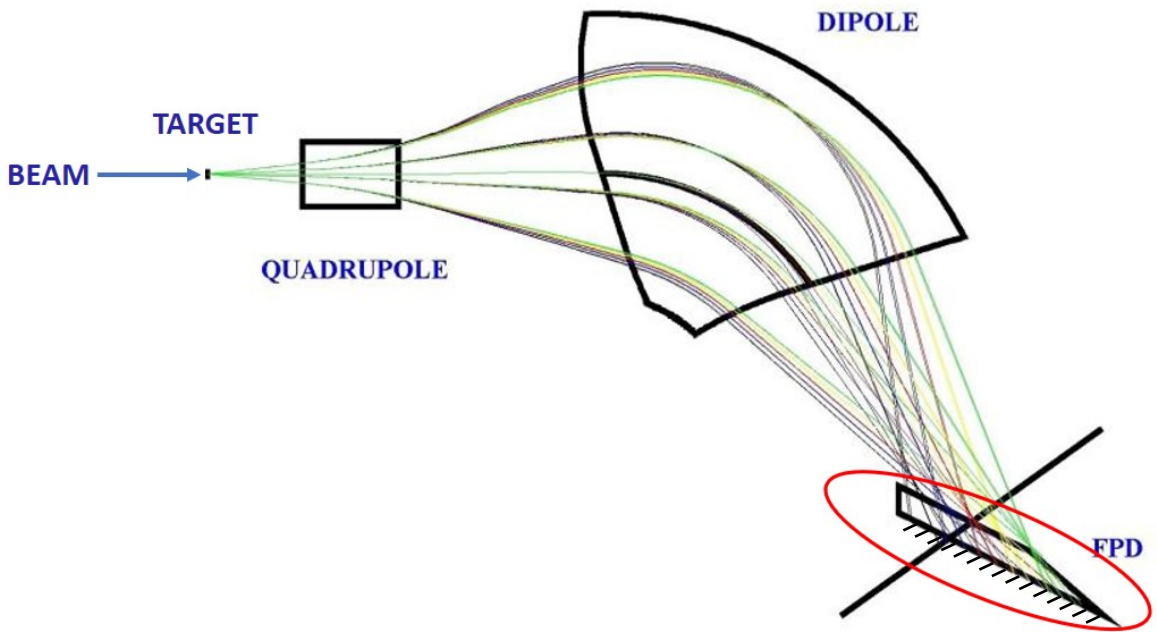
- **Design phase:**
  - Optimization of granularity conditions
  - Optimization of the towers tilt angle
  - …
- **Test phase:**
  - Analysis of the background contribution
  - Evaluation of the sensitivity
  - …
- **Operation phase:**
  - Evaluation of the overall efficiency
  - Optimization of the experimental set-up
  - …

The simulation tool

The simulation tool is made up by **two interconnected parts**:

1. The **COSY-INFINITY** software
   - Reaction kinematics
   - Ejectiles motion through MAGNEX

2. A **Geant4** specific application
   - Ejectiles-telescopes interaction



COSY-INFINITY **output** taken as **input** by the Geant4 application

Simulation main aspects

Materials

- Three parts for each telescope
  1. **SiC Active Volume (SiC AV)**
  2. **SiC Passivated Volume (SiC PV)**
  3. **CsI(Tl) crystal (CsI)**
- Realistic mechanical holder

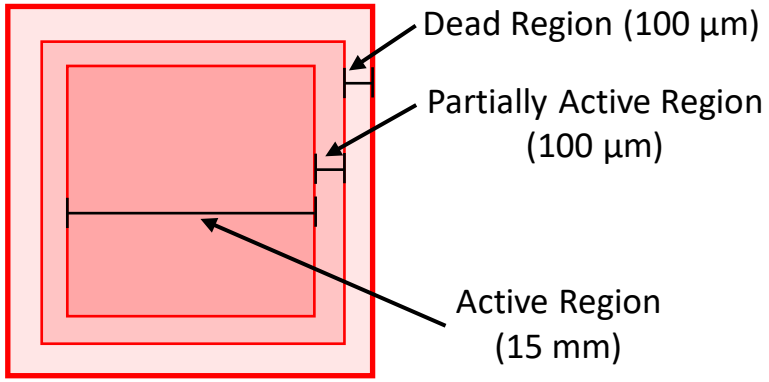
Geometry

- **SiC AV**
  - area 15.4 × 15.4 mm^2
  - thickness 100 µm
- **SiC PV**
  - area 15.4 × 15.4 mm^2
  - thickness 10 µm
- **CsI**
  - area 15 × 15 mm^2
  - thickness 5 mm

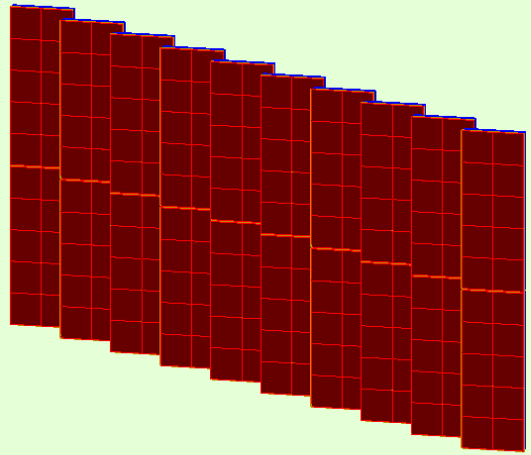
Post-processing

- **Spectra reconstruction** with the typical energy resolutions:
  - **SiC**: 0.8% FWHM @ 25.3 MeV
  - **CsI**: 2% FWHM @ 700 MeV
- Introduction of **partial charge collection effects** in the SiC detectors

SiC front view

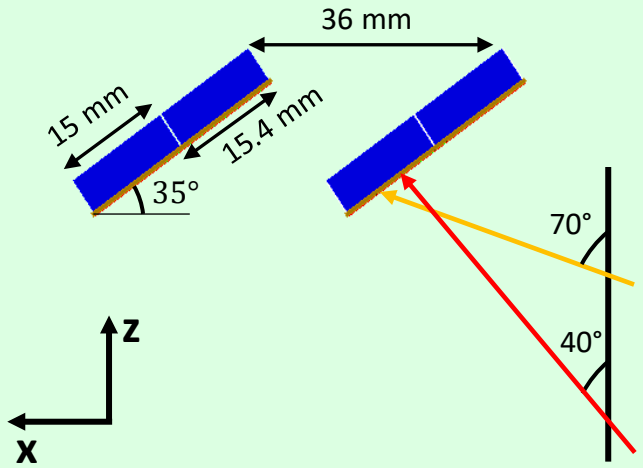


Geant4 view of the PID-wall



Just a sketch of 10 towers!

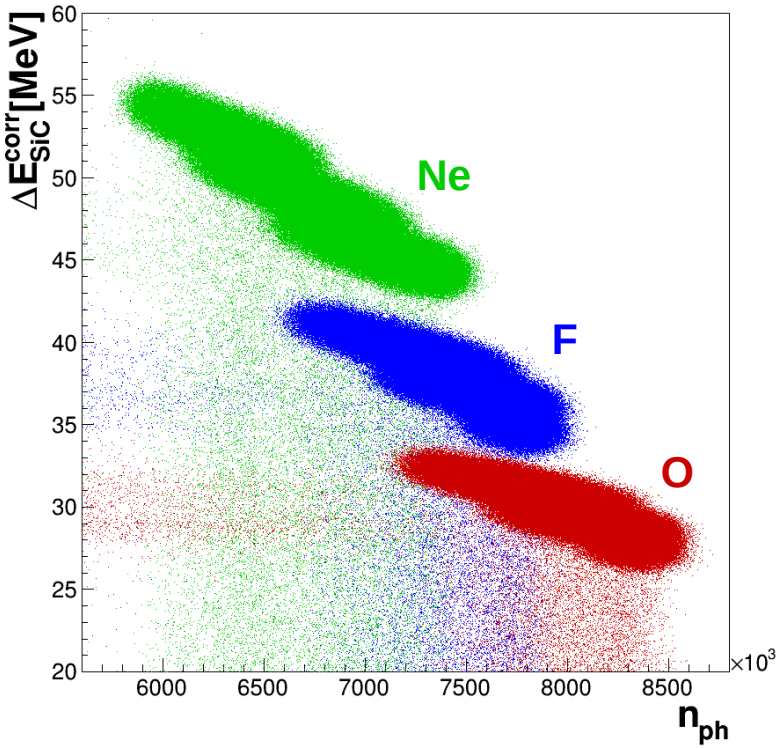
TOP VIEW



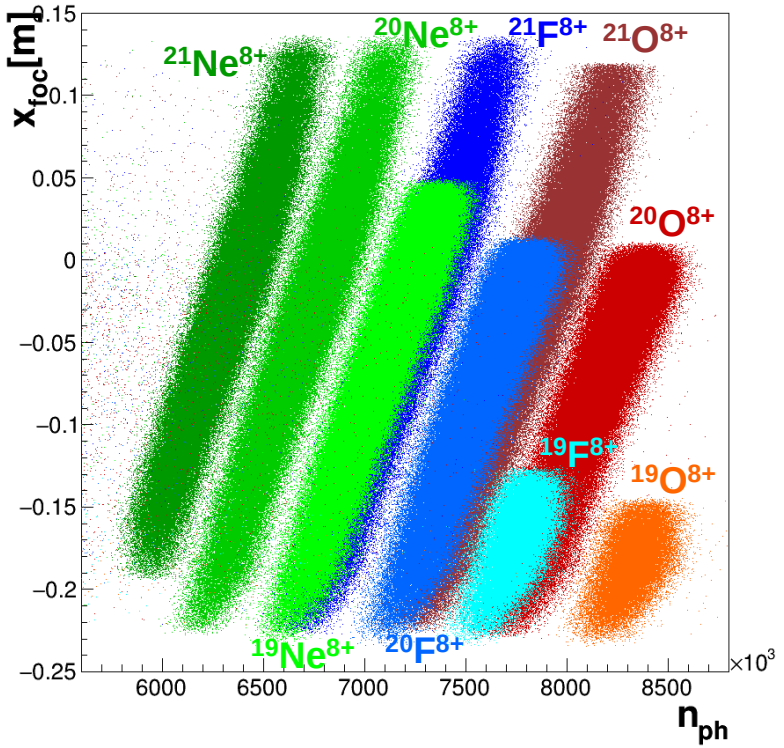
Reaction: $^{20}Ne + {}^{76}Ge$ @ 35 AMeV $\rightarrow {}^{20}O$ is the signal

Simulation of a single SiC-CsI telescope

$\Delta E_{SiC}^{corr} - n_{phot}$ matrix



$x_{foc} - n_{phot}$ matrix



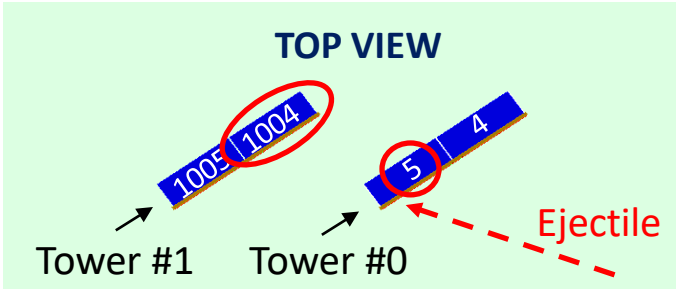
Courtesy of E. M. Gandolfo

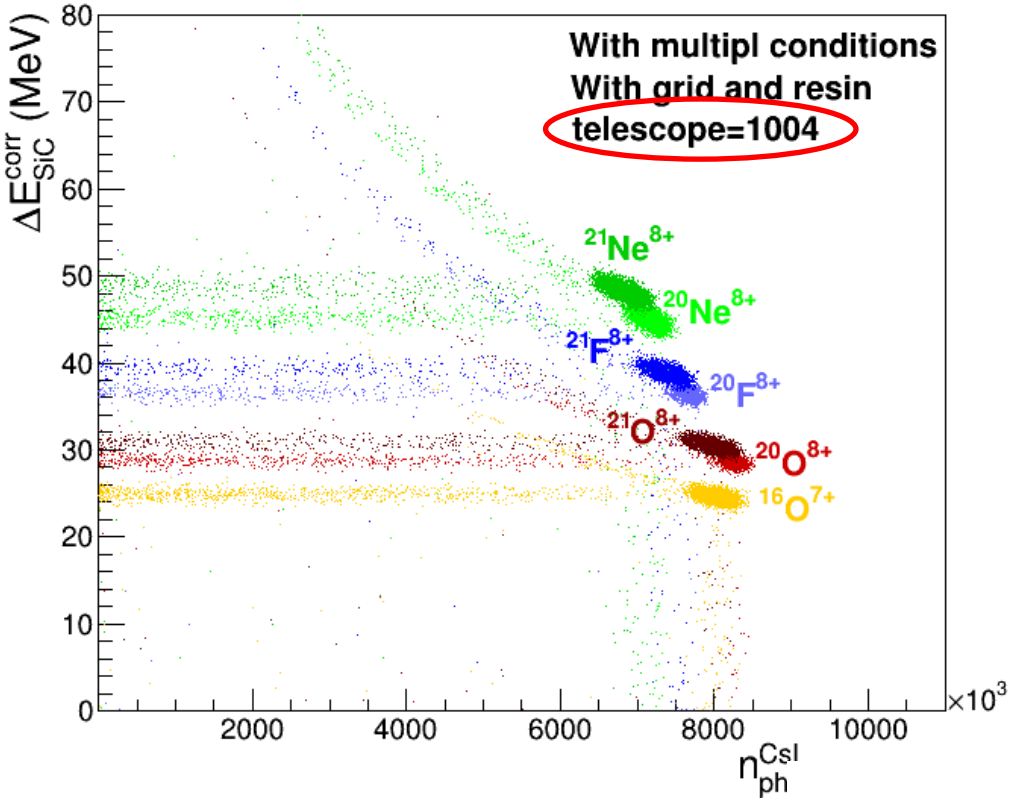
Reaction: $^{20}Ne + ^{76}Ge$ @ 35 AMeV → ^{20}O is the signal

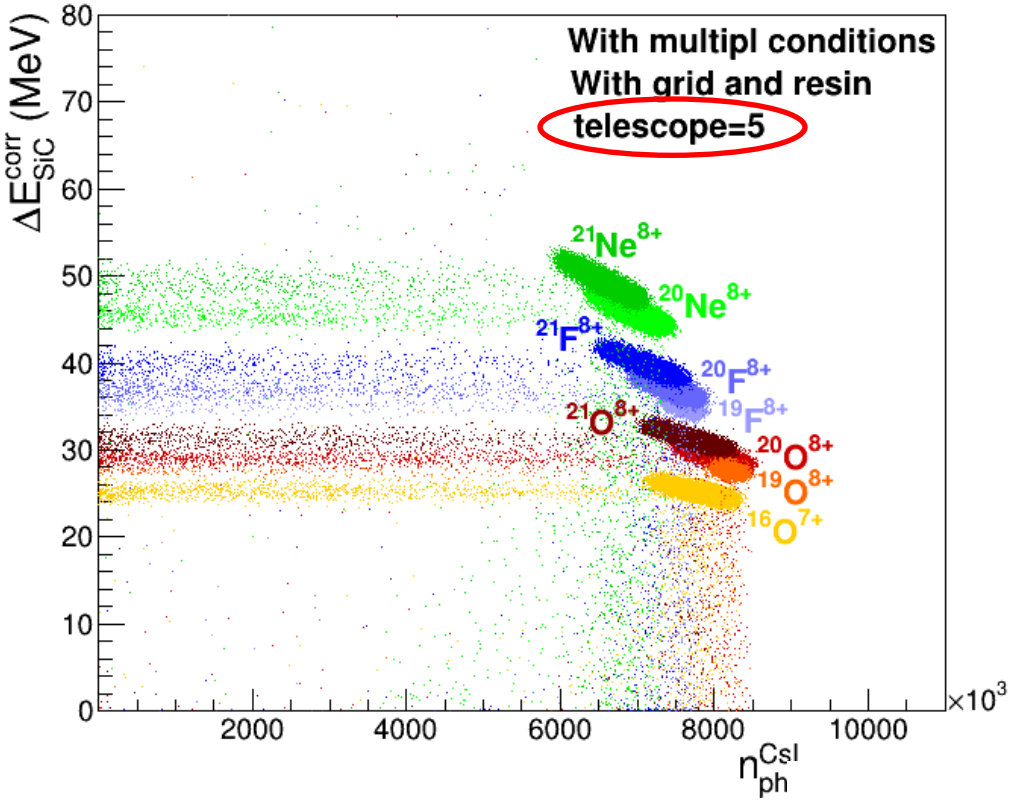
- **Good separation** in Z and in A
- Two kinds of degraded events:
  - Events affected by **partial charge collection in SiC**
  - Events due to **ions that come out from the CsI**
- Signal ($^{20}O^{8+}$) **detection efficiency** for a **single** telescope ~ 90%
- After scaling for the respective cross section:
  - $^{19}F^{8+}$ main contaminant
  - Other contribution from $^{21}O^{8+}$ and $^{19}O^{8+}$

Simulation of two towers

- **Analysis of shadowing effects**
- **Optimization of the tilt angle and distance**







Summary

Conclusions

- The radiation hardness and particle identification tests show that the **SiC-CsI(Tl) telescope detectors satisfy the NUMEN requirements**
- The **first industrial lot** of SiC detectors is in production
- A **simulation tool** of the PID-wall was developed an implemented
- Evaluation of the **partial charge collection effects** and of the **background contribution**

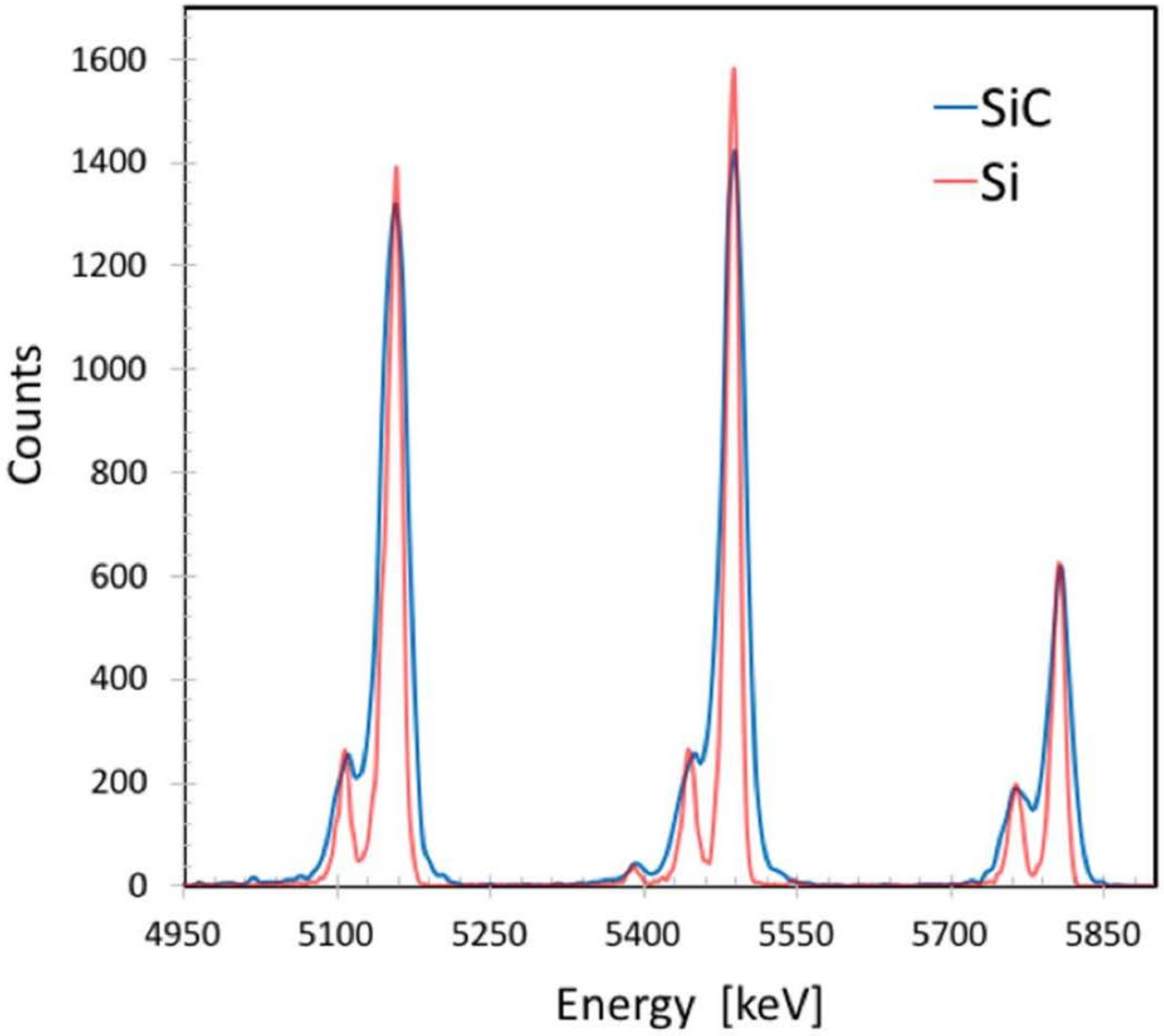
Outlooks

- **Construction** of (at least) **3 complete towers** equipped with the read-out electronics
- **In-beam test** of the first towers
- **Validation** of the the simulation tool and **optimization** of the **PID-wall layout**
- **Efficiency** evaluation and correction through simulation

Thank you for your attention

Back up

SiC energy resolution



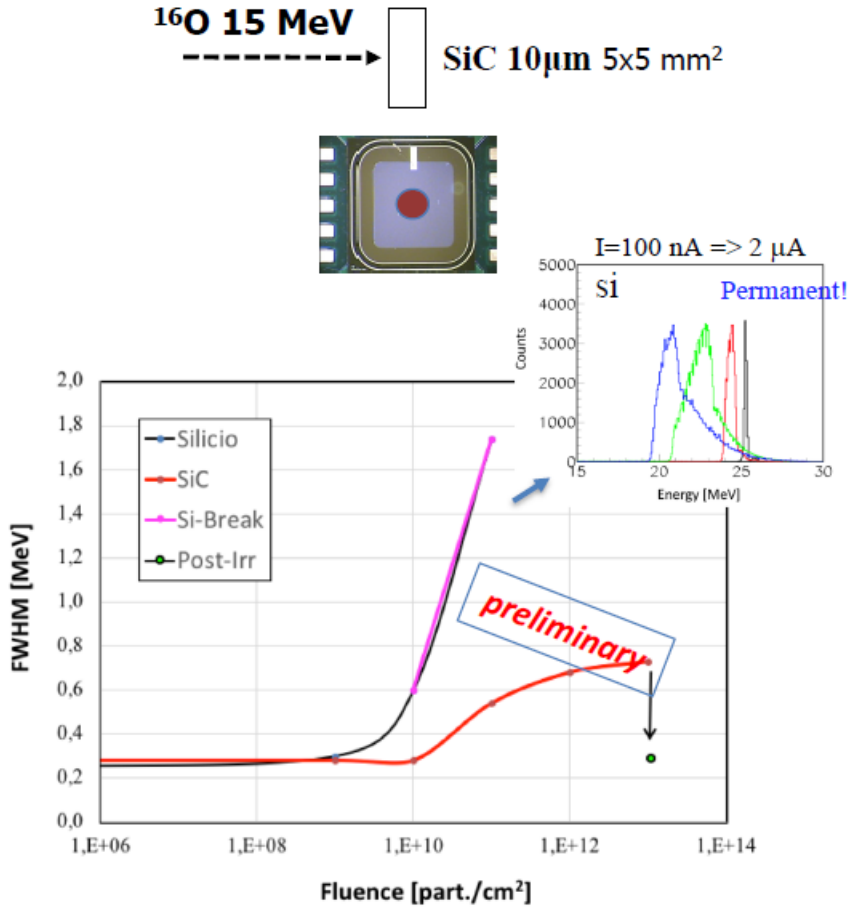
SiC prototype, 100 µm thick

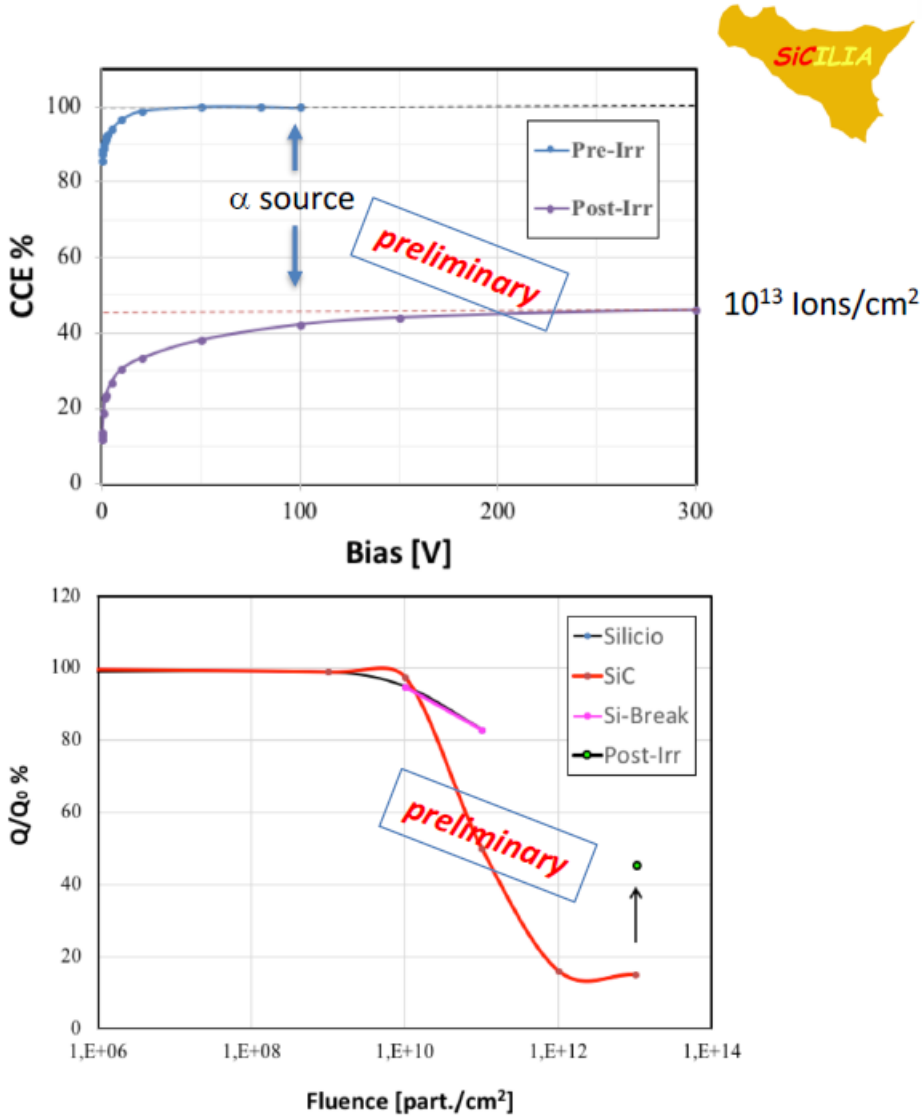
Si detector Hamamatsu S3590, 300 µm thick

Resolution

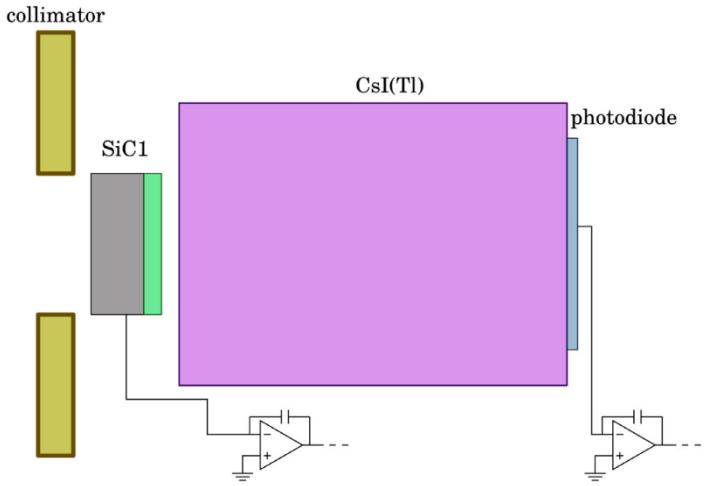
- **SiC:** 0.4% FWHM
- **Si:** 0.22% FWHM

SiC radiation hardness



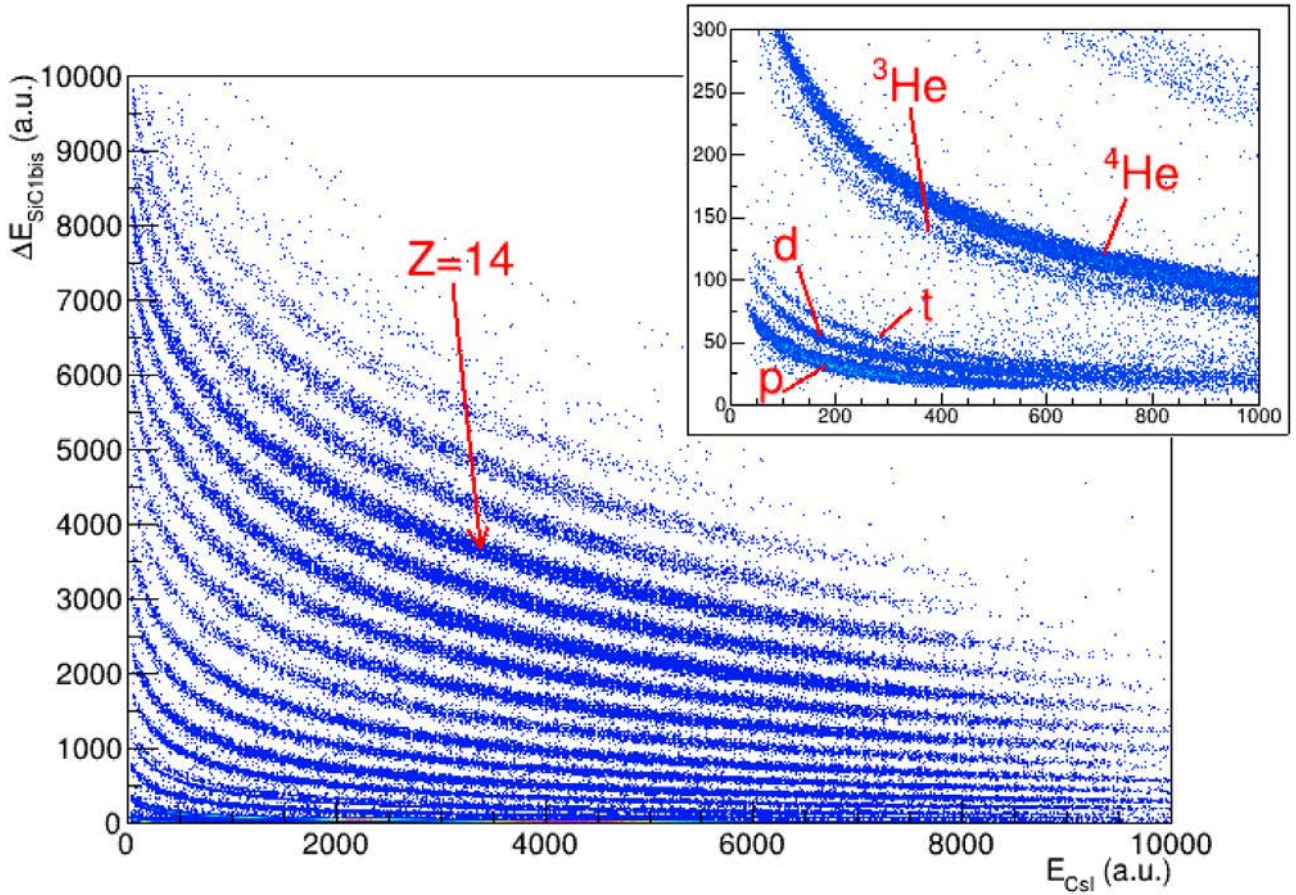


SiC particle-identification test



Telescope characterics:

- **SiC:**
  - area 10 × 10 mm^2
  - thickness 100 µm
- **CsI(Tl):**
  - area 20.5 × 20.5 mm^2
  - thickness 10 cm



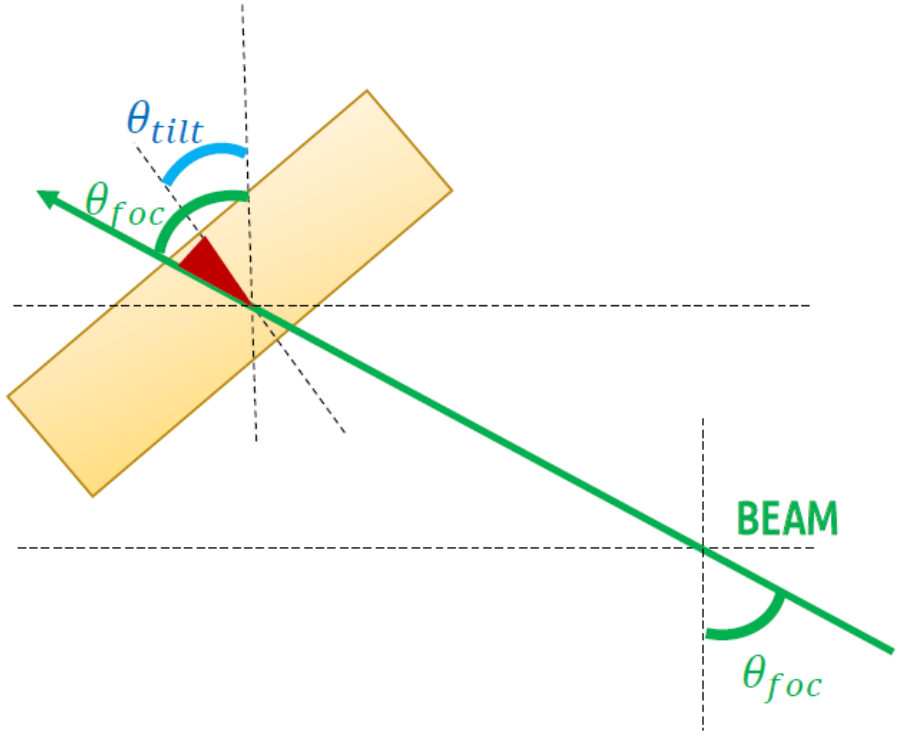
Ciampi *et al.*, Nucl. Instrum. Meth. A **925**, 60 (2019)

Clear charge identification up to Z ~ 20!

ΔE_{SiC}^{corr} and n_{ph}

$$\Delta E_{Sic}^{corr} = \Delta E \cdot \cos(\theta_{foc} - \theta_{tilt})$$

Energy lost in SiC corrected for the direction of the beam



Courtesy of E. M. Gandolfo

$$n_{ph} = \mathrm{norm(A, Z)} \cdot \mathrm{L(E)}$$

Number of photon detected from the CsI

PARAMETRIZATION:

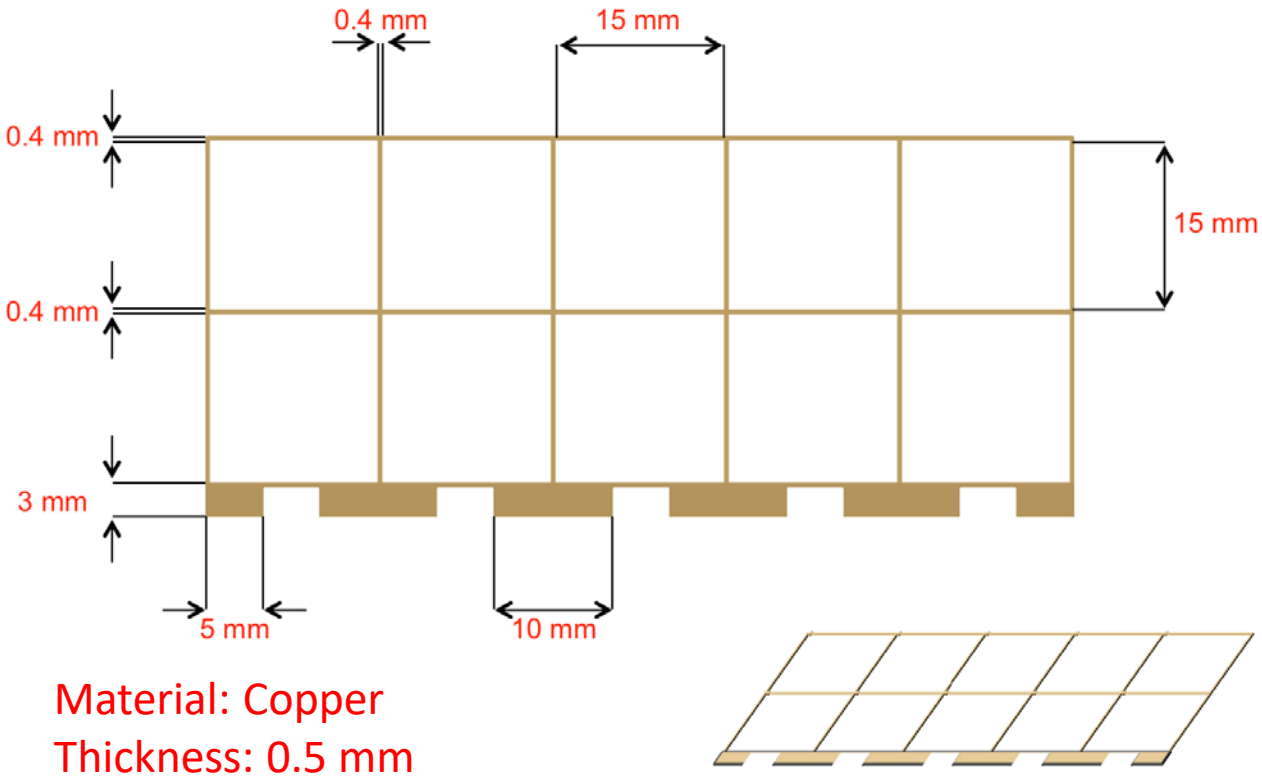
$n_{ph}^{Finocchiaro} = n_{ph}(Z)$ | Birks + Becchetti [1]

$n_{ph}^{Horn} = n_{ph}(Z, A)$ | Horn [2]

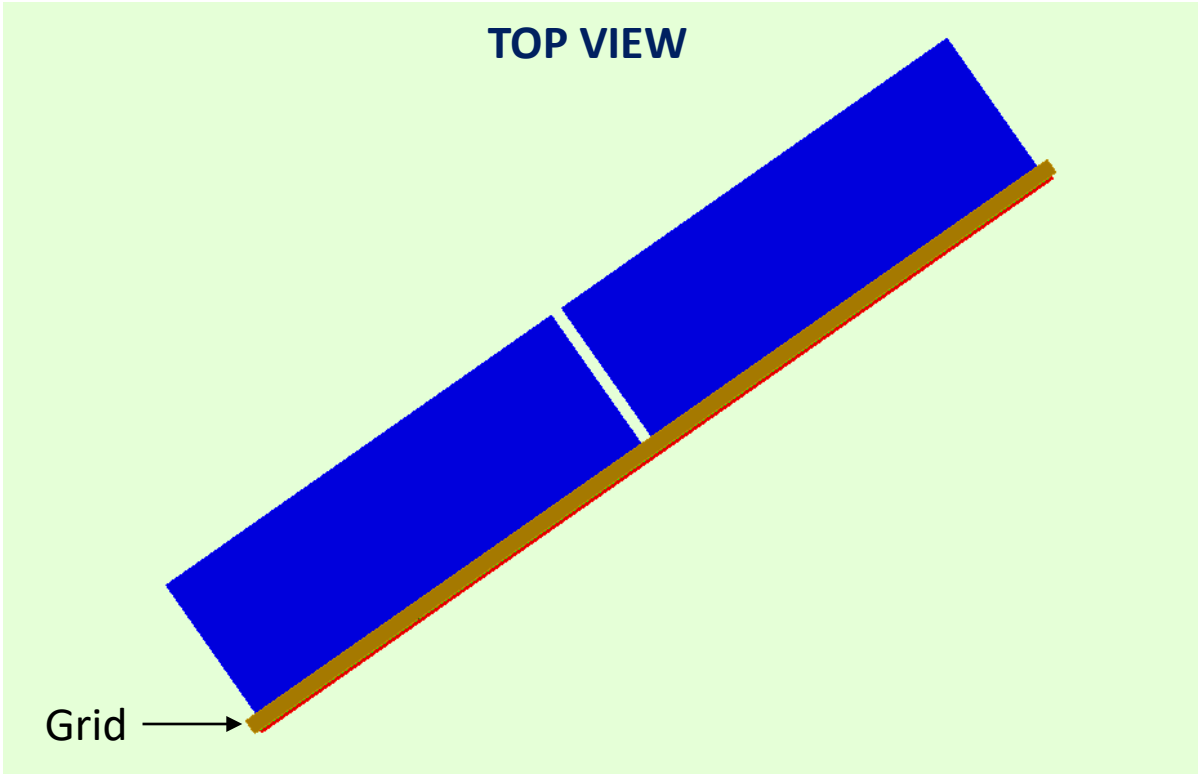
Courtesy of E. M. Gandolfo

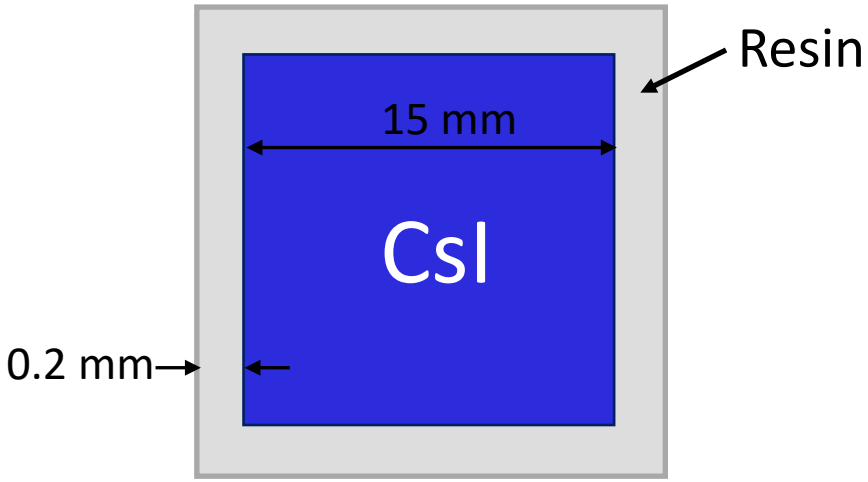
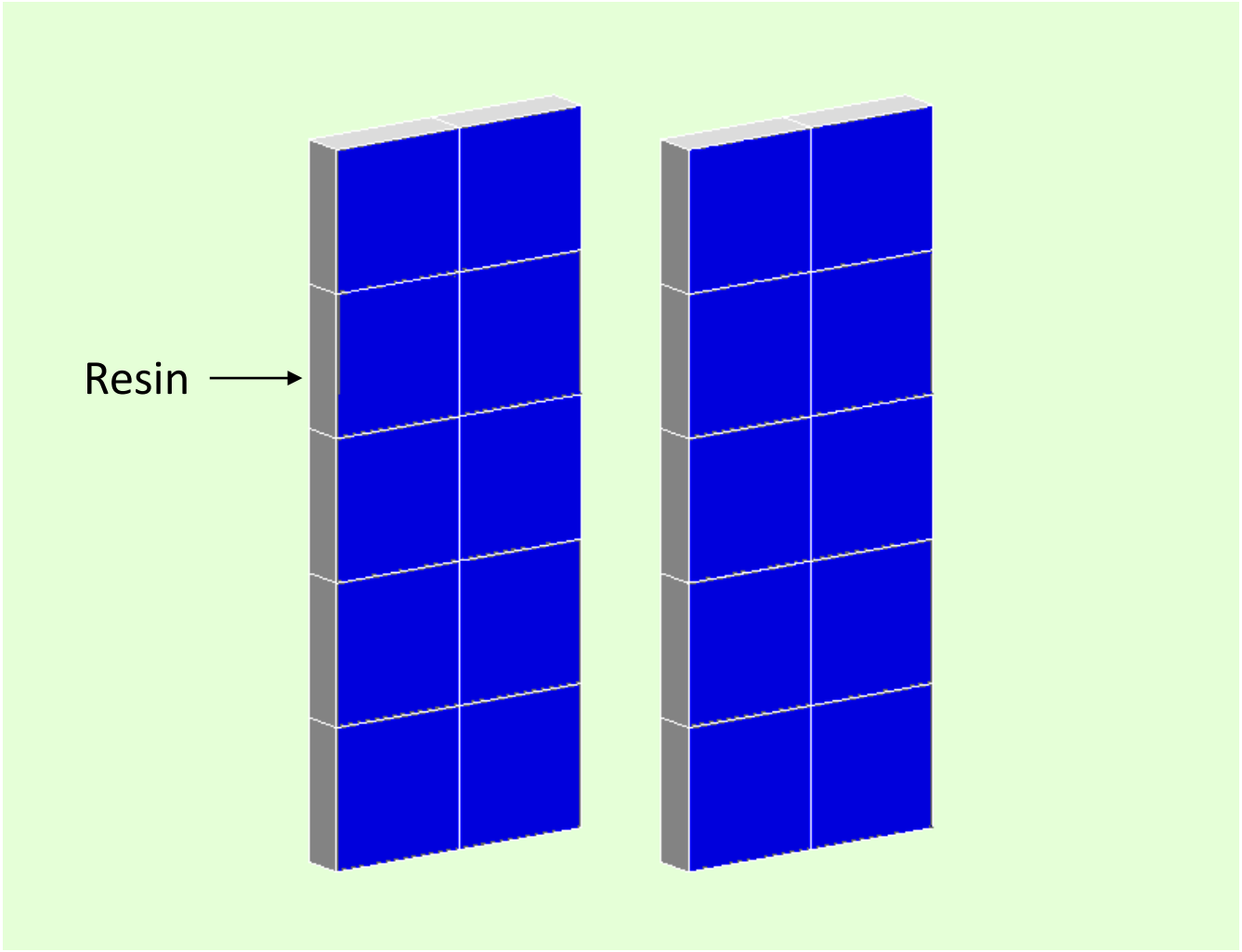
[1] A. Pappalardo *et al.*, Rev. Sci. Instrum. **81**, 033308 (2010)
[2] D. Horn *et al.*, Nucl. Instrum. Meth. A **320**, 273 (1992)

Grid



Material: Copper
Thickness: 0.5 mm



Resin

Material: Diglycidyl Ether of Bisphenol A →
$C_{19}H_{20}O_4$