NECTAR project

Response of solar cells to heavy ions at energies close to 10 AMeV at GANIL

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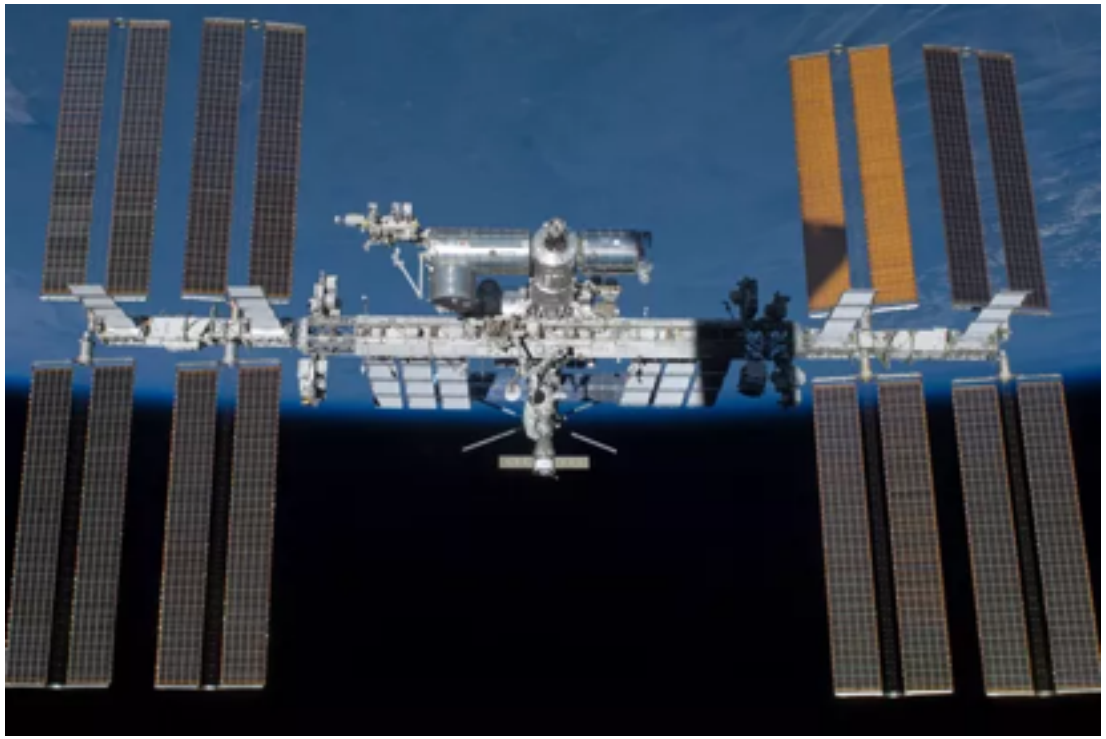
2 Grand Accélérateur National d'Ions Lourds (GANIL), Caen, France

SOLAR CELL



Silicon - Solar Cells (Earth Solar Panels)

Germanium - Solar Cells (Space Applications)

SOLAR CELLS for heavy ion detection

- 1979 Siegert → First heavy ions detection at energies about 1 AMeV

CHARGE COLLECTION PROCESS IN SOLAR CELLS IS VERY DIFFERENT

Field-funneling effect

- C. Hsieh, et al., Electron Device Lett. IEEE 2 (1981) 103–105
- F.B. McLean, et al., IEEE Trans. Nucl. Sci. 29 (1982) 2017–2023
- G.C. Messenger, et al., IEEE Trans. Nucl. Sci. 29 (6) (1982) 2024–2031

SOLAR CELLS for heavy ion detection

Main Advantages:

1) **Energy (1-2%) and time (few ns) resolution**

SOLAR CELLS for heavy ion detection

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2) Better **radiation resistance**

SOLAR CELLS for heavy ion detection

Main Advantages:

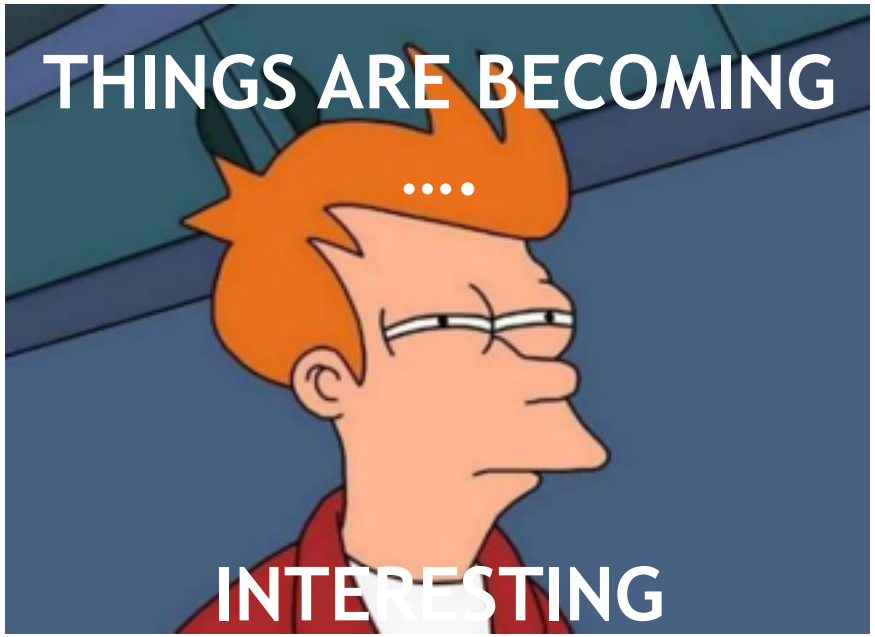
1) **Energy (1-2%) and time (few ns) resolution**

2) Better **radiation resistance**

3) **Flexible geometry, very robust**

4) Extremely **cost-efficient (5 €)**

SOLAR CELLS for heavy ion detection



Solar Cells appear a very interesting alternative to Silicons detector for Heavy ions at energies between 1 and 10 AMeV.

But…

→ high capacitance ($40\ \frac{nF}{cm^2}$, 1000 times larger than Si detector), increasing with Solar Cells surface

NECTAR Project:

Solar Cells as heavy ions detectors at energies E > 1 AMeV in UHV!

→ NO TEST HAS EVER BEEN PERFORMED!!

GANIL exploratory test experiments 2018

First irradiation experiment with Heavy ions above 1 AMeV!

CIME cyclotron was used to accelerate beams of:

- ^{84}Kr at 7, 10 AMeV
- ^{129}Xe at 10,13 AMeV

First results:

1. Best performance: company Solar Made, 10x10 mm^2, σ(E) E=1.5% (RMS) and 3.6 ns (FWHM).
2. Stable behavior during irradiation with 100 to few 10^3 pps for a minute.

→ A. Henriques et al., Nucl. Instrum. Methods A 969 (2020) 163941.

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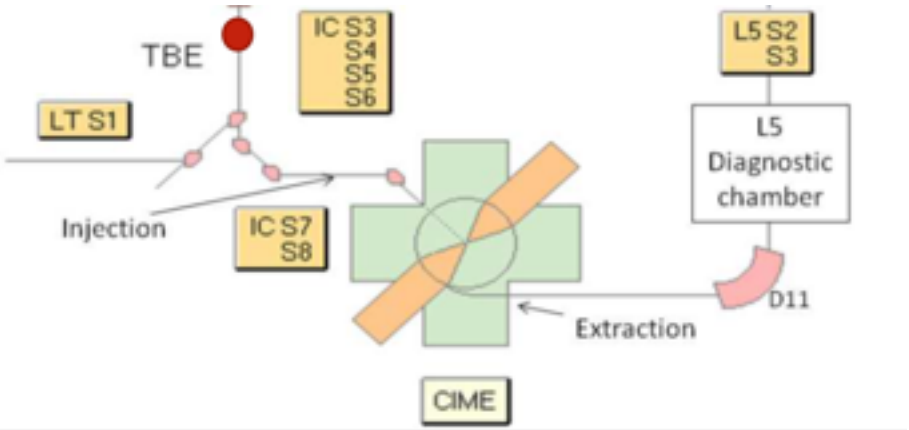
New irradiation experiment at GANIL: March 2021

GANIL experiment (March 2021)

CIME cyclotron was used to accelerate beams of:

- ^{84}Kr at 5, 10, 15 AMeV



SPIRAL facility

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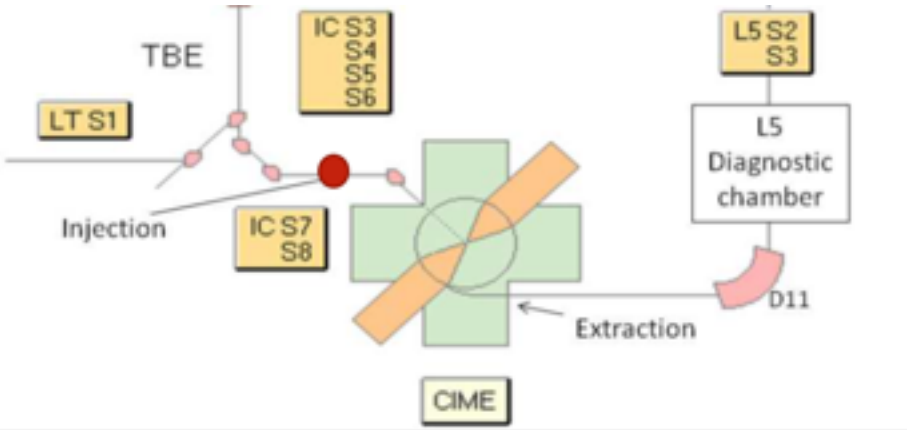

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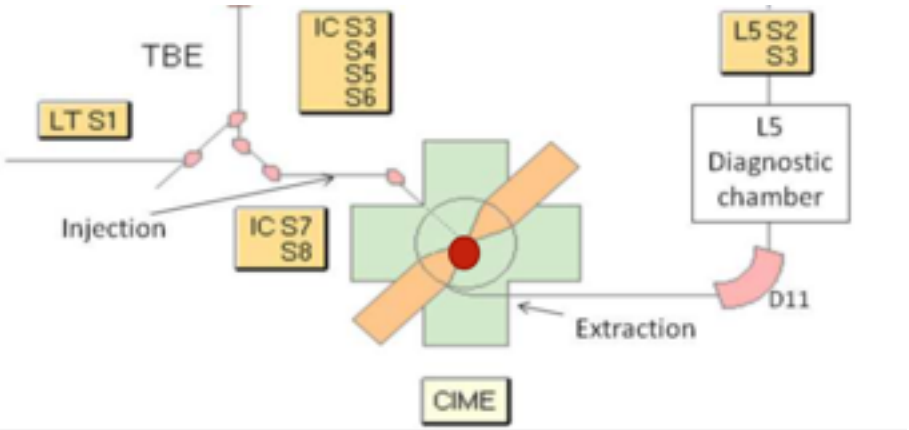

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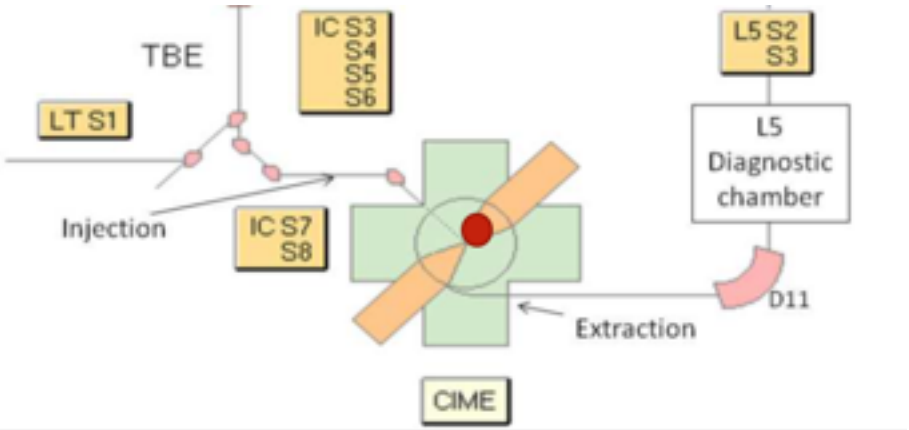

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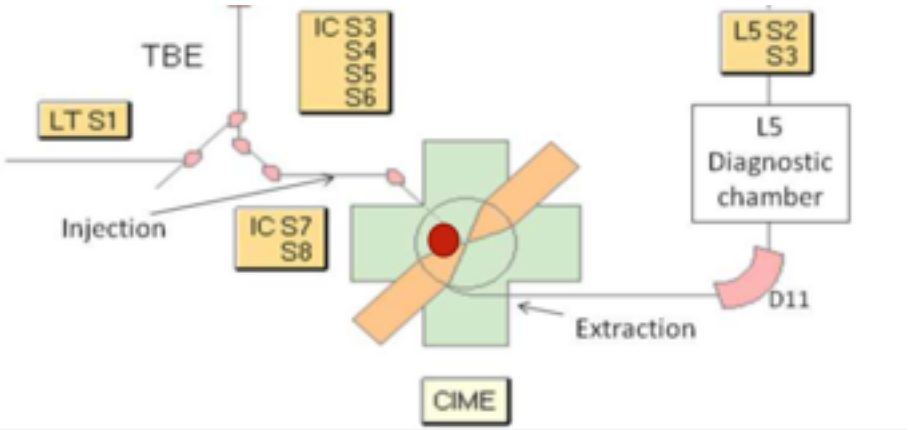

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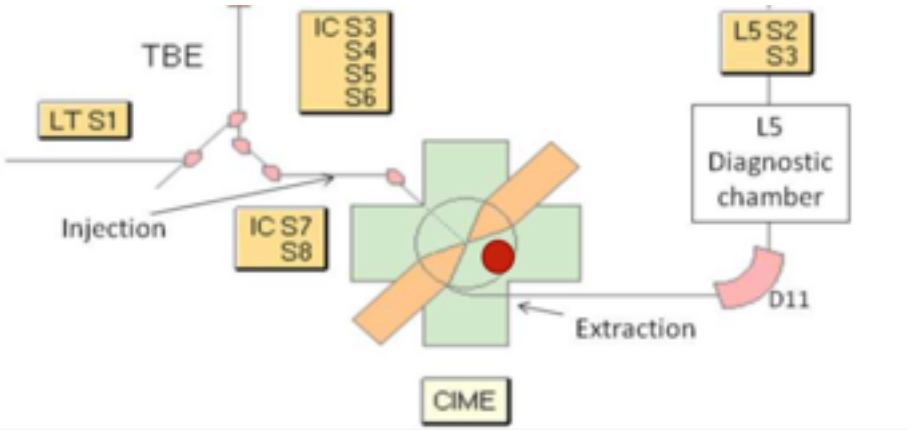

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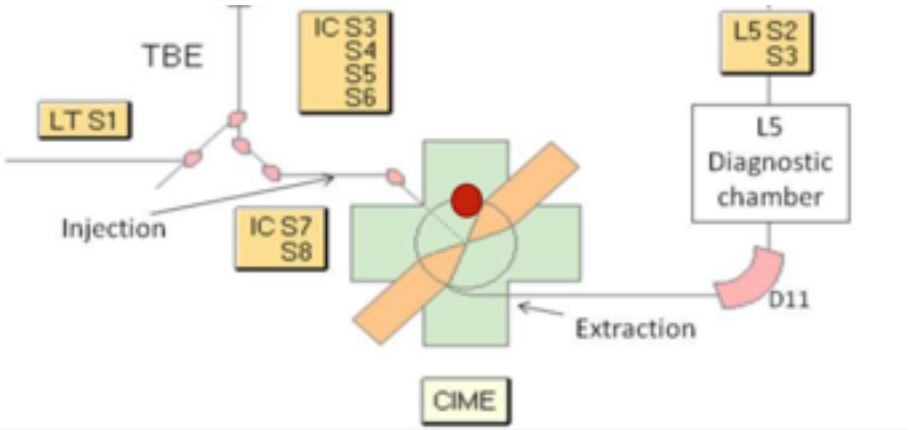

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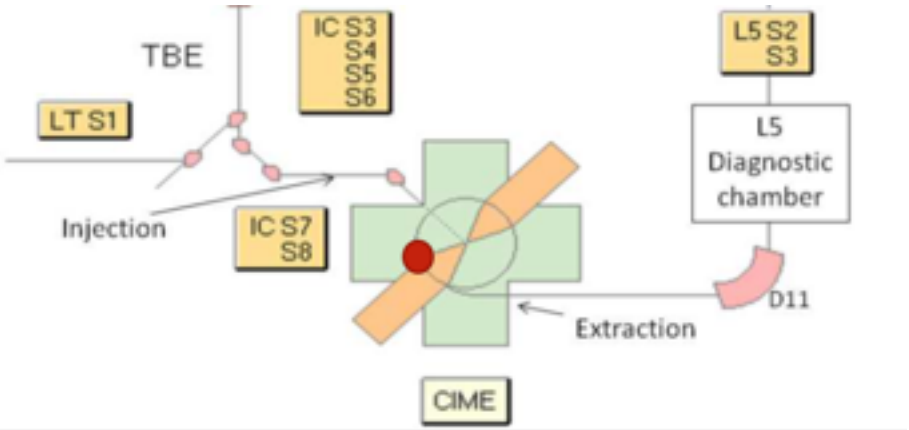

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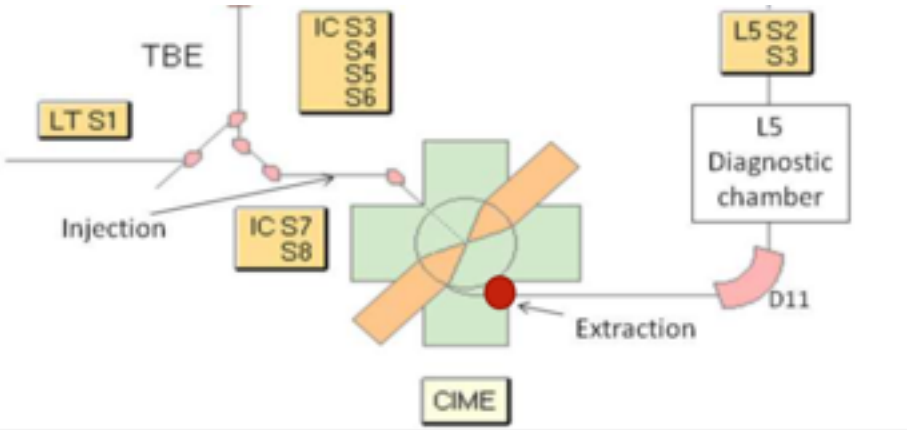

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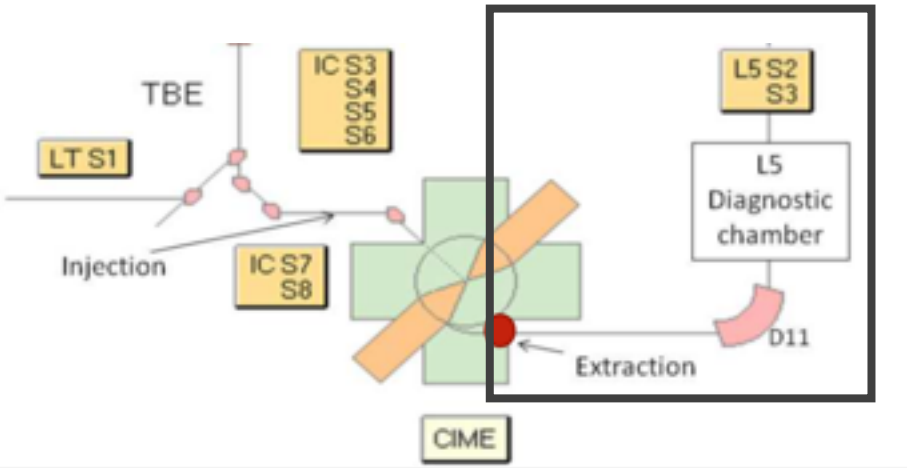

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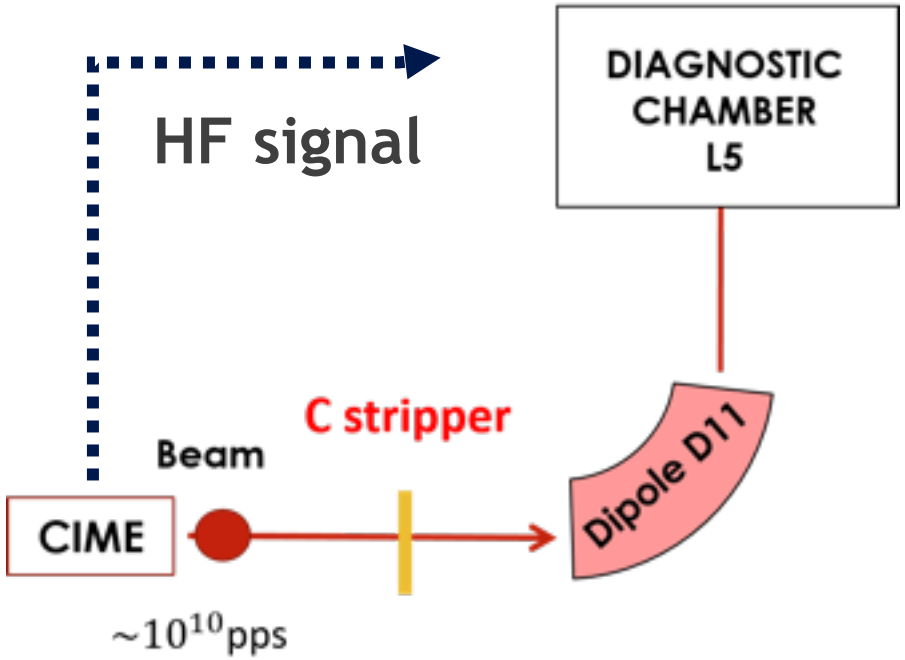

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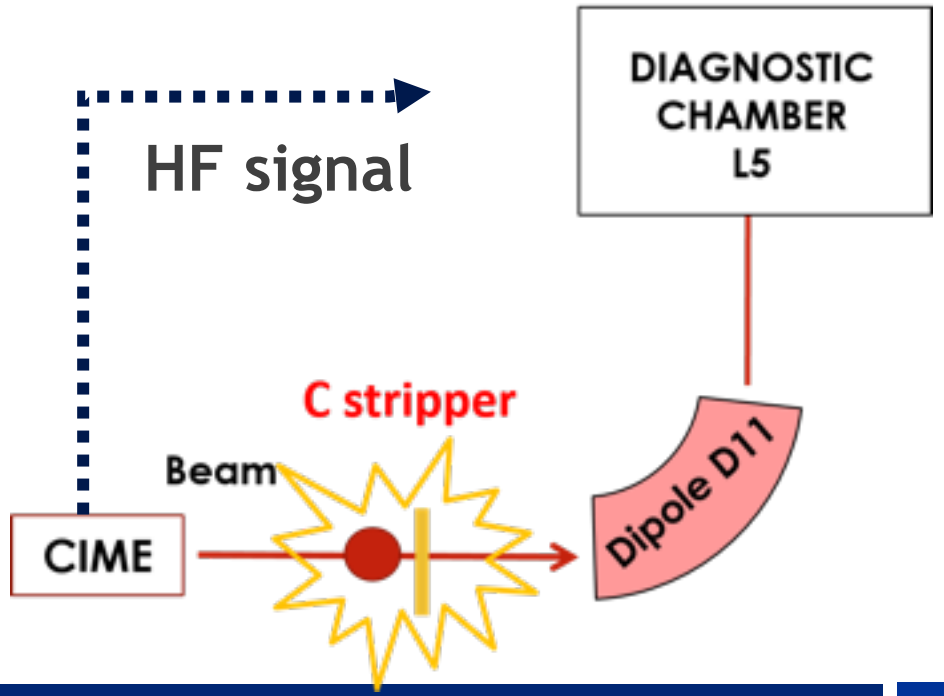

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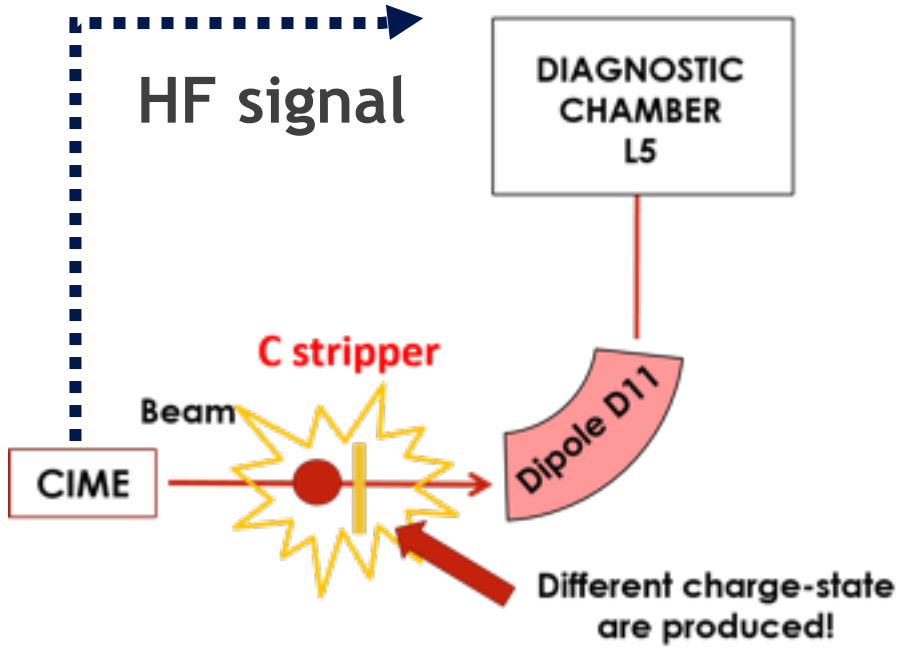

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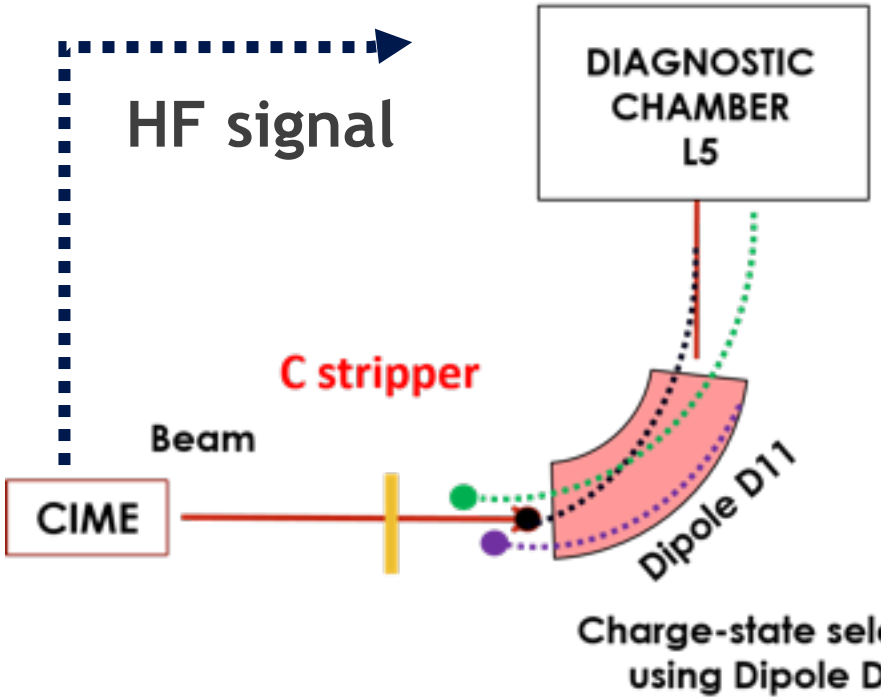

A	Z	Q1	Rate (pps)
84Kr	36	1.37e+07	
84Kr	35	1.12e+08	
84Kr	34	5.11e+08	
84Kr	33	1.31e+09	
84Kr	32	1.89e+09	
84Kr	31	1.52e+09	
84Kr	30	6.87e+08	
84Kr	29	1.74e+08	
84Kr	28	2.47e+07	
84Kr	27	1.97e+06	
84Kr	26	3.77e+04	
84Kr	25	2.19e+03	
84Kr	24	3.07e+01	
84Kr	23	2.41e-01	
84Kr	22	1.06e-03	
84Kr	21	2.62e-06	

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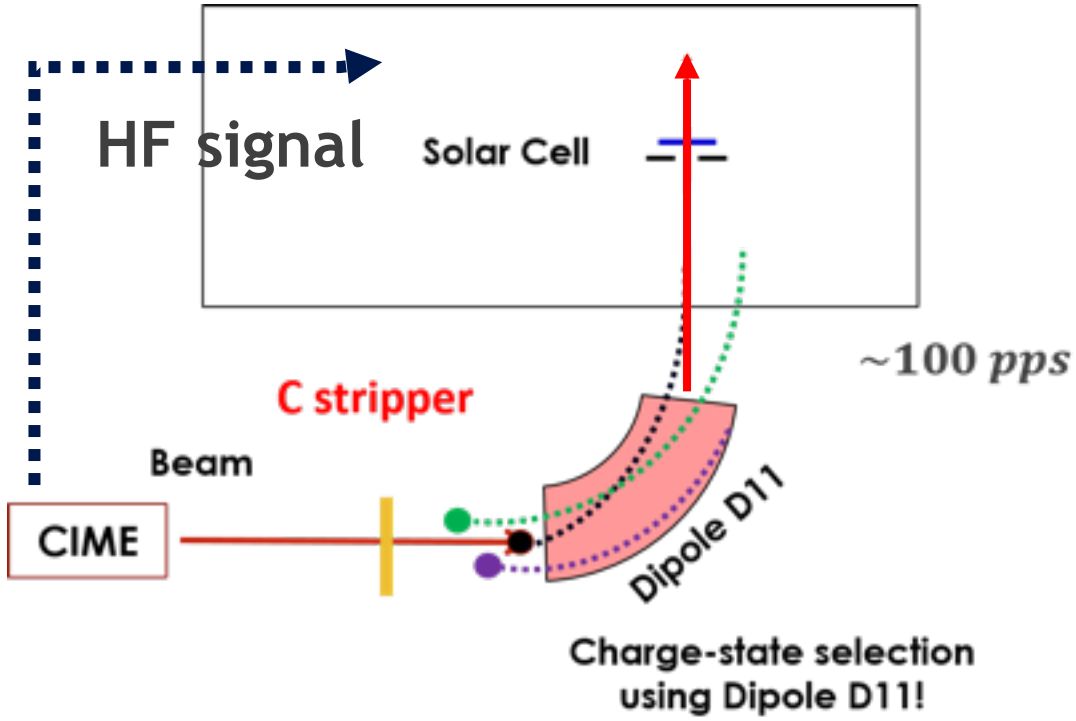

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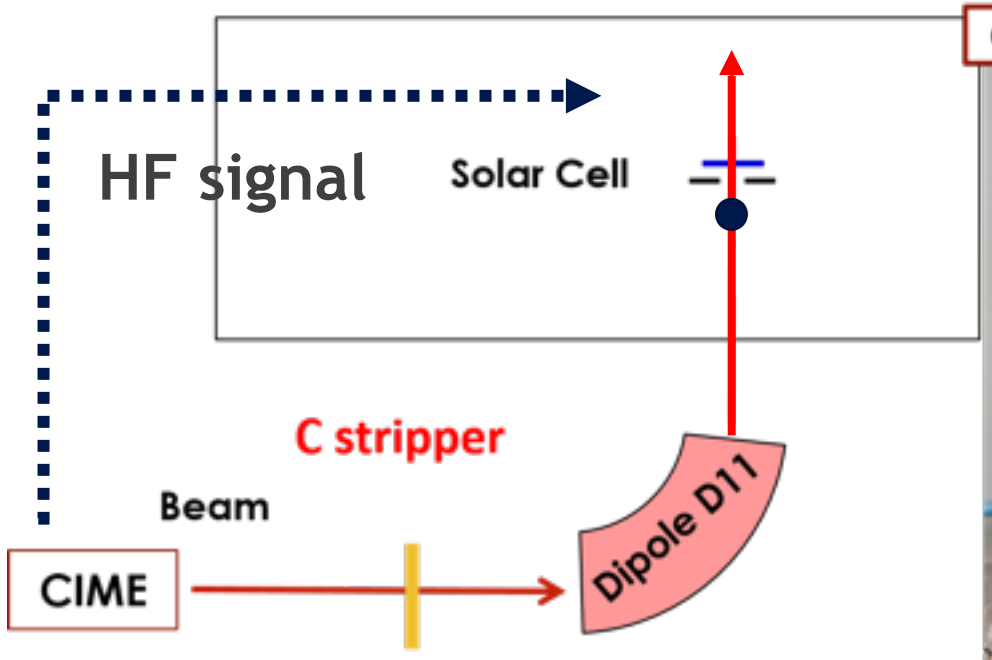
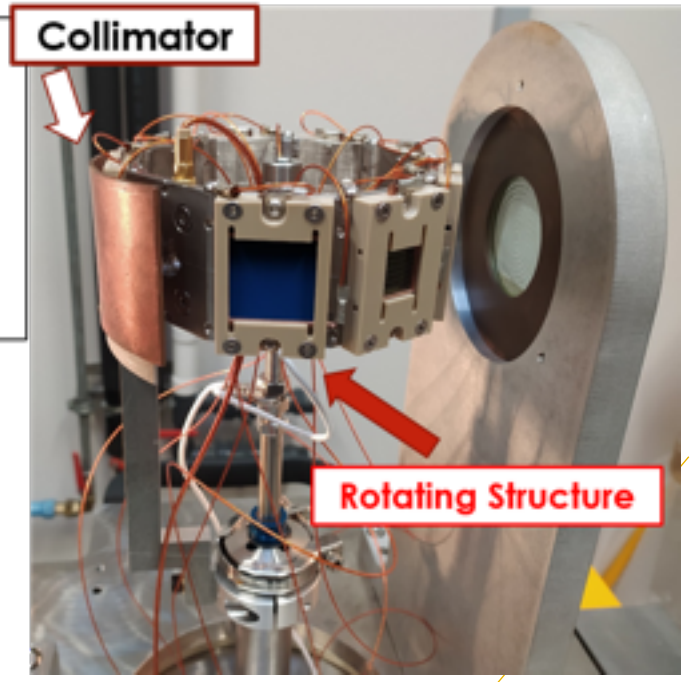


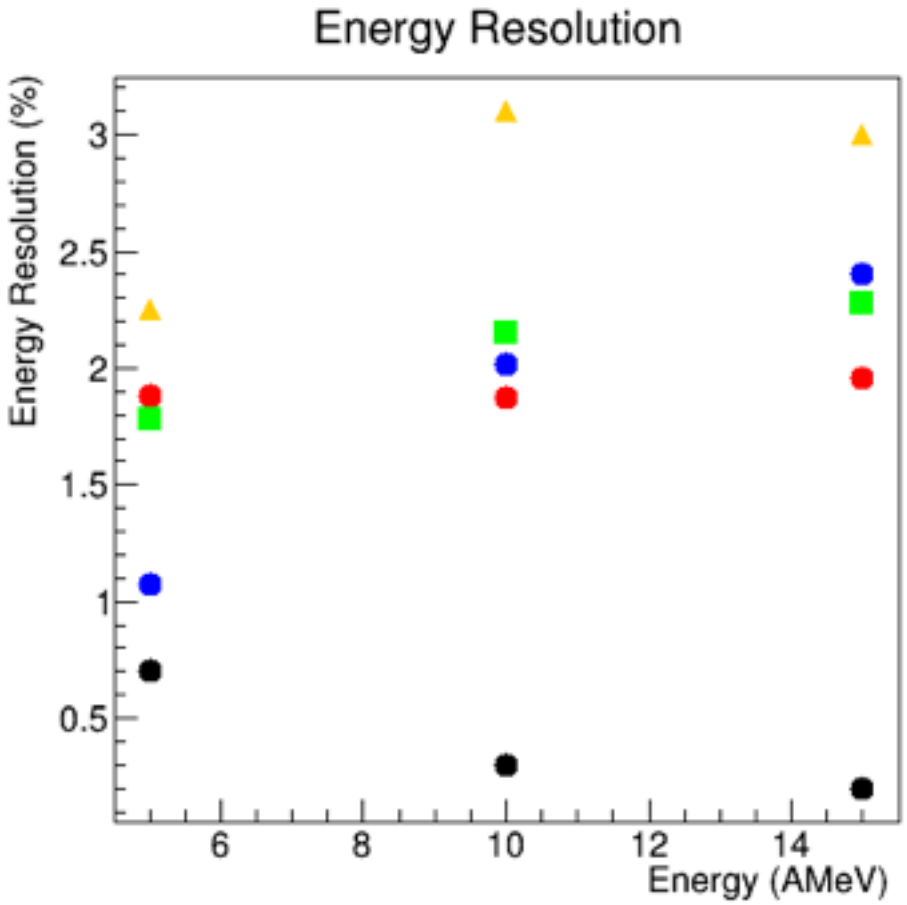


MAIN IMPROVEMENTS

- Better intensity control
- Better alignment with respect to the incoming beam

GANIL experiment (March 2021) - Final RESULT

1. Energy (σ(E)/E) and Time (FWHM) resolution

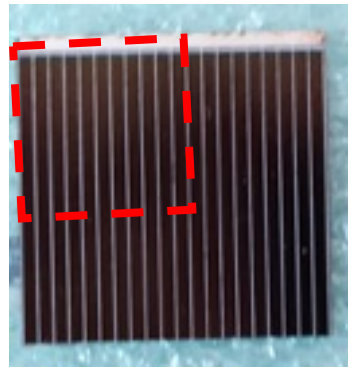


^{84}Kr beam

- Si - 10x10 mm^2
- Si - 10x10 mm^2
- Si - 10x10 mm^2
- Ge - 20x20 mm^2
- Si Detector

Si - 10x10 mm^2

Si Detector



Ge - 20x20 mm^2

GANIL experiment (March 2021) - Final RESULT

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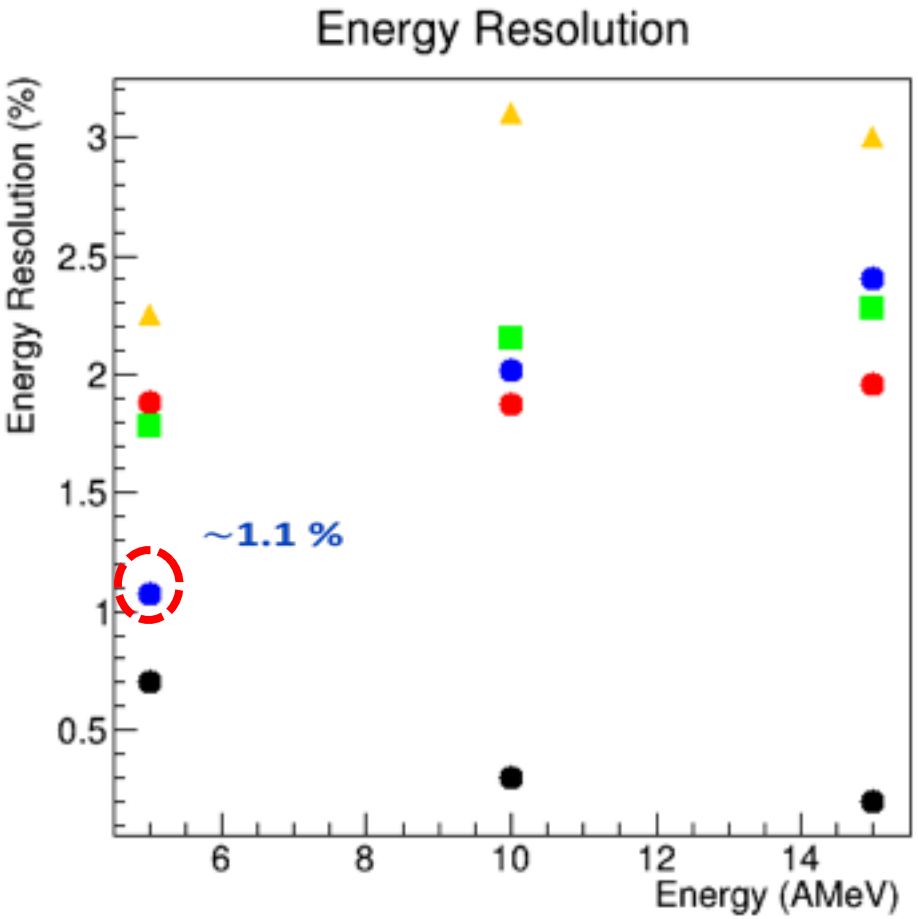
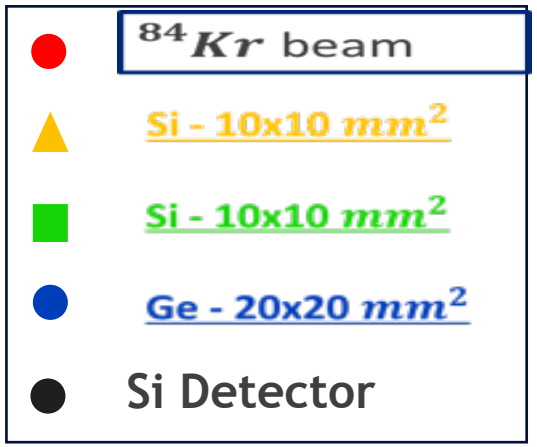
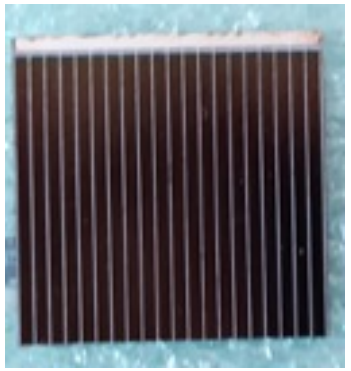


^{84}Kr beam



Si - 10x10 mm^2



Ge - 20x20 mm^2

Si Detector

GANIL experiment (March 2021) - Final RESULT

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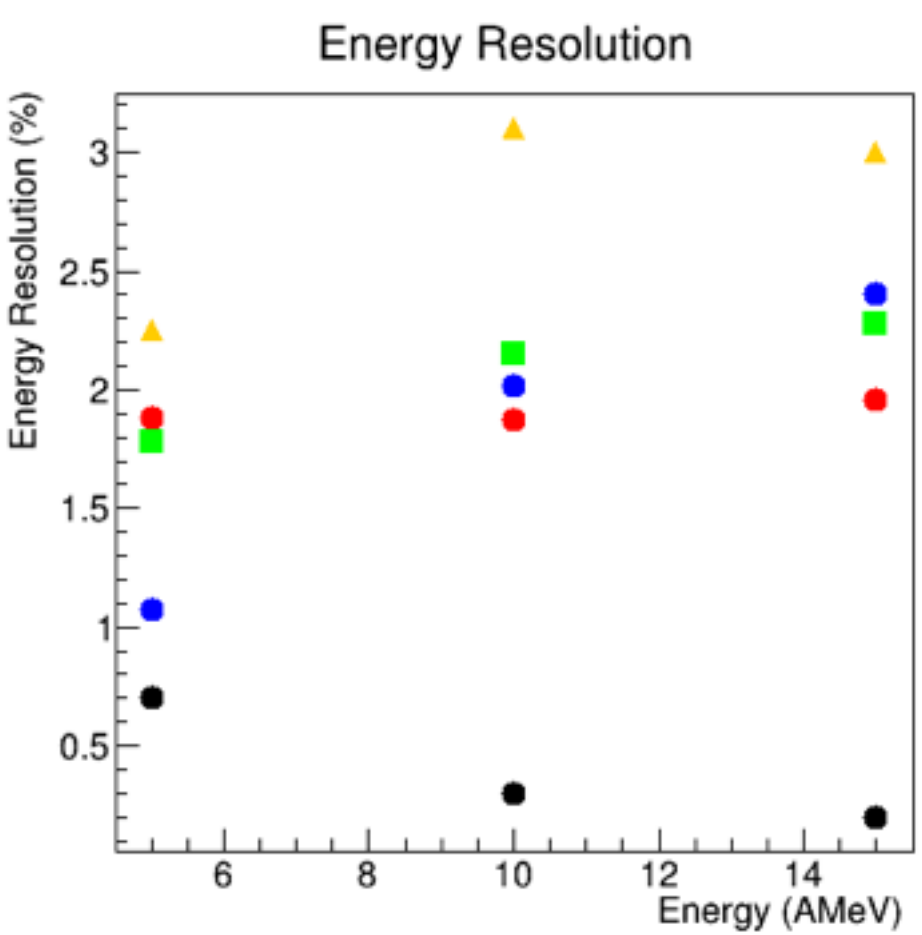

- Si - 10x10 mm^2
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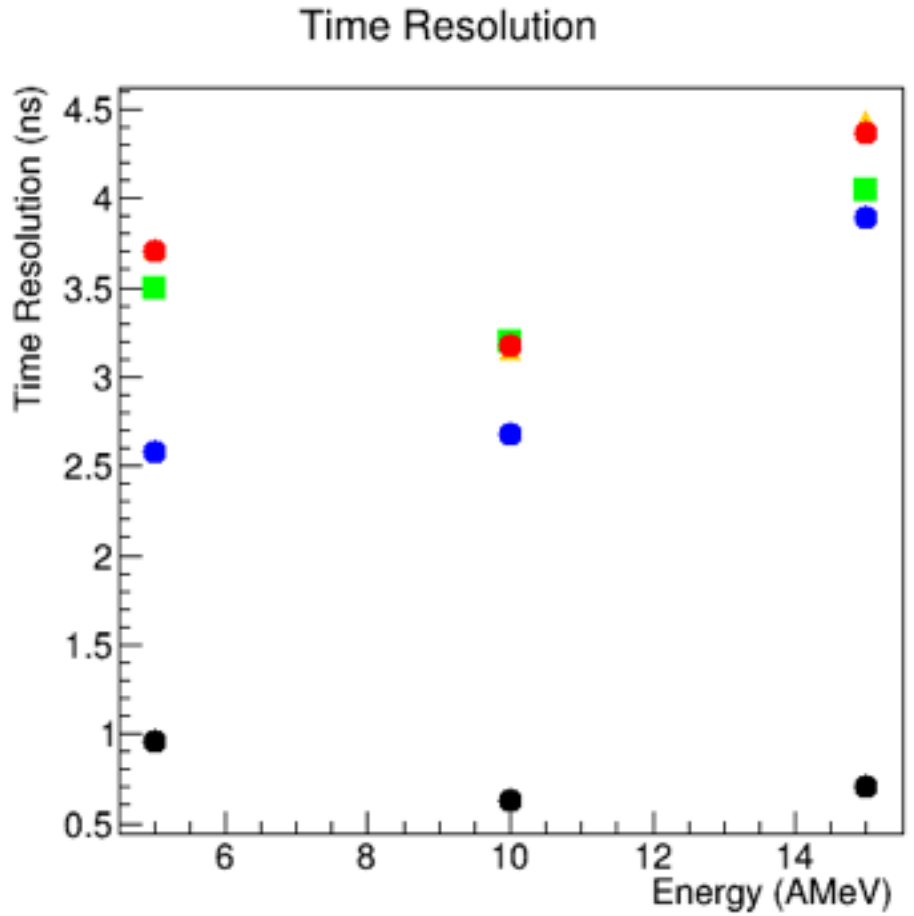
- Ge - 20x20 mm^2
- Si Detector



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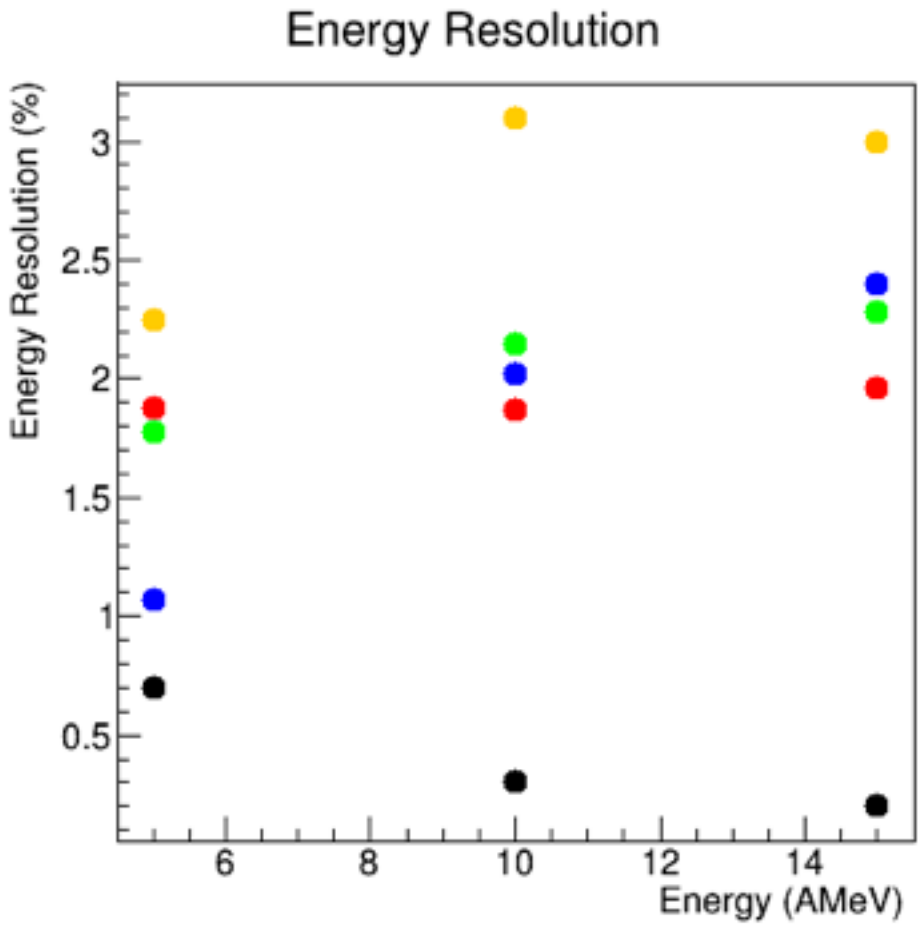

- Si - 10x10 mm^2
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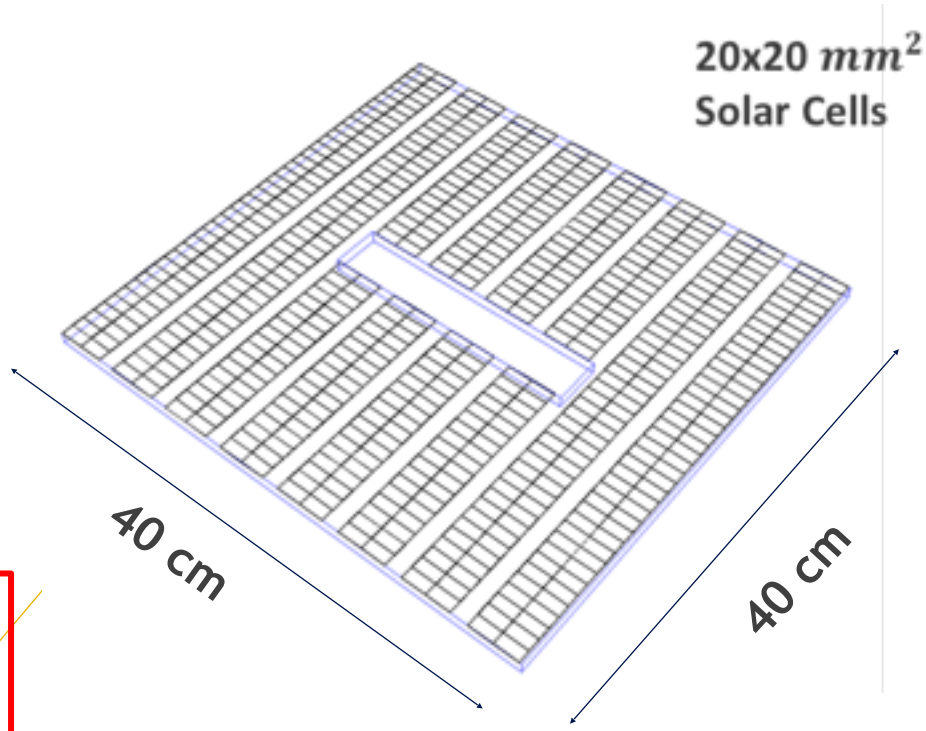
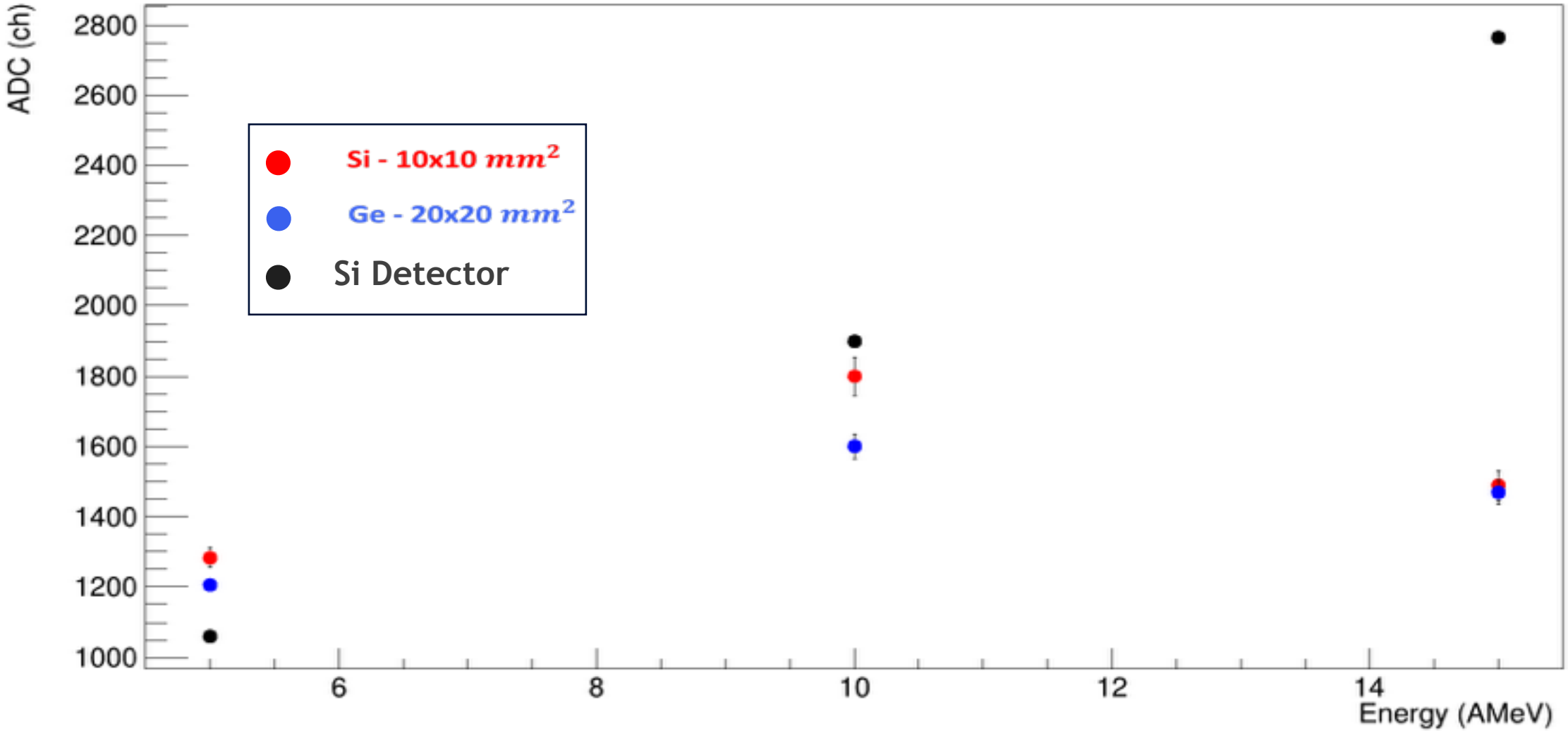
- Ge - 20x20 mm^2
- Si Detector

Very important results for NECTAR project (large detection arrays)!



GANIL experiment (March 2021) - Final RESULT

2. Characterization of solar cells linearity



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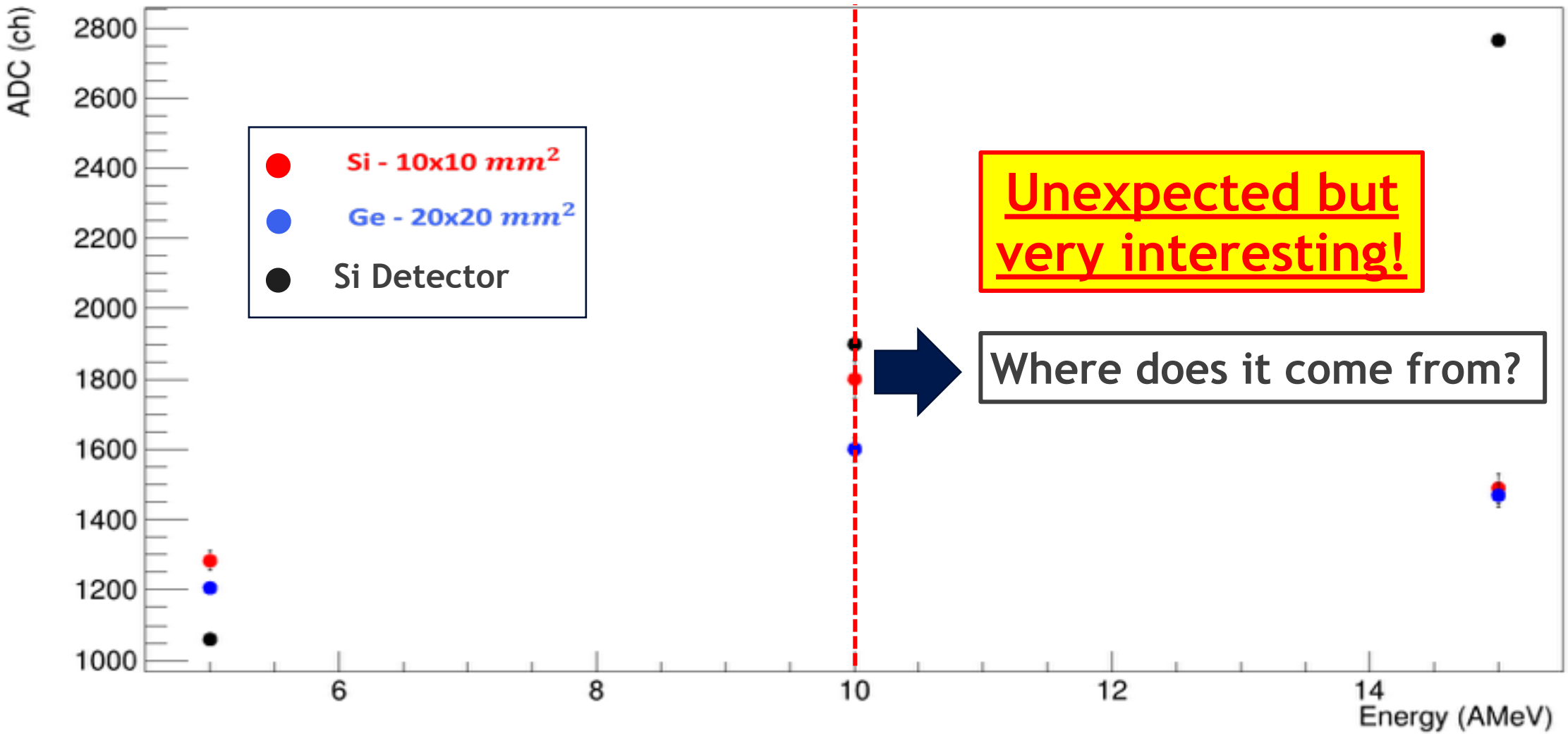


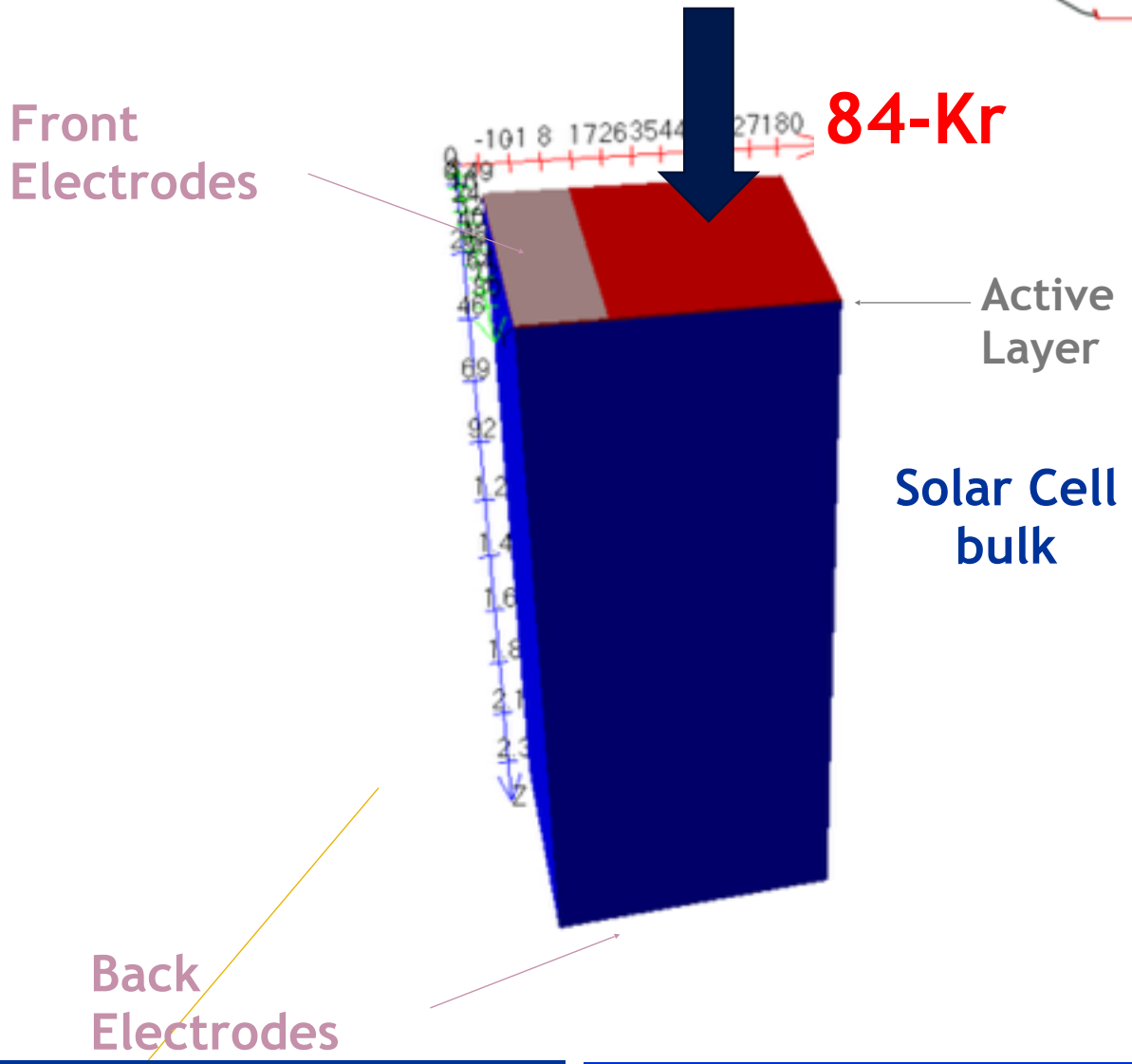
SIMULATION OF CHARGE COLLECTION

PRELIMINARY RESULTS

3. Simulation
   - 1) 84-Kr 5 AMeV
   - 2) 84-Kr 10 AMeV
   - 3) 84-Kr 15 AMeV

ATLAS Silvaco code

CHARGE COLLECTION PROCESS IN SOLAR CELLS



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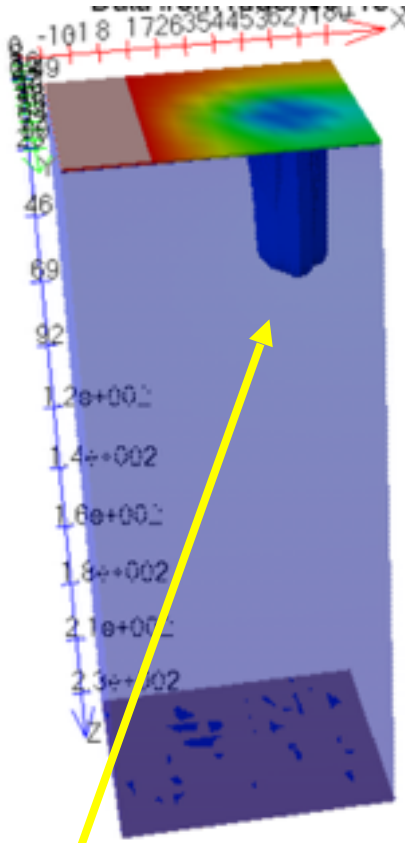
ATLAS Silvaco code

CHARGE COLLECTION PROCESS IN SOLAR CELLS

Few tens ns

84-Kr 5 AMeV



POTENTIAL DISTORTION

SIMULATION OF CHARGE COLLECTION

PRELIMINARY RESULTS

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   - 1) 84-Kr 5 AMeV
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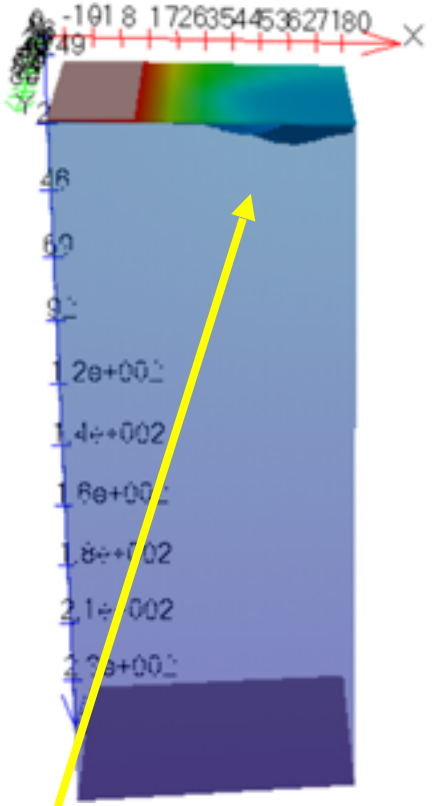
ATLAS Silvaco code

Few hundred ns

84-Kr
5 AMeV



POTENTIAL DISTORTION

CHARGE COLLECTION PROCESS IN SOLAR CELLS

SIMULATION OF CHARGE COLLECTION

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↓

ATLAS Silvaco code

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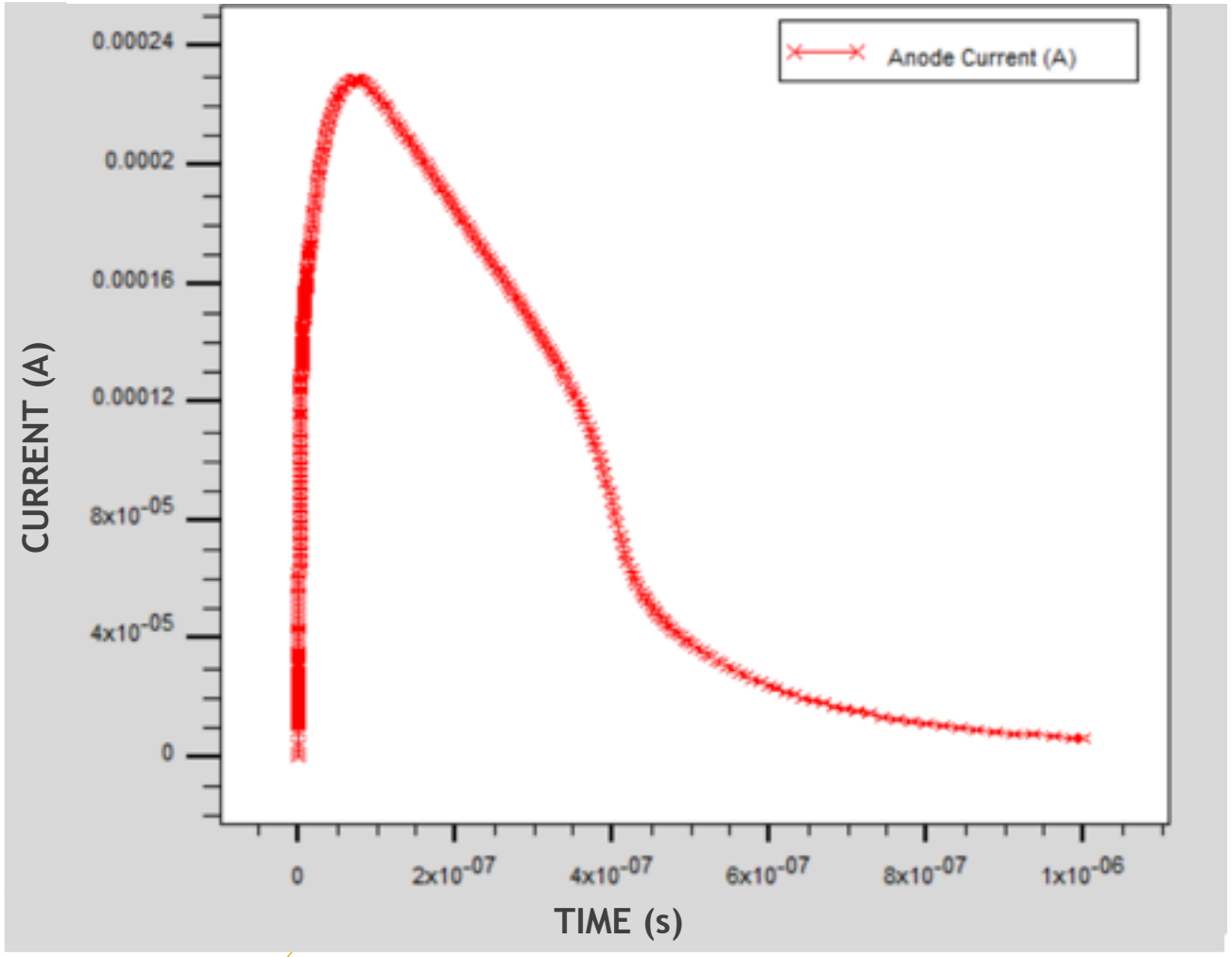

SIMULATION OF CHARGE COLLECTION

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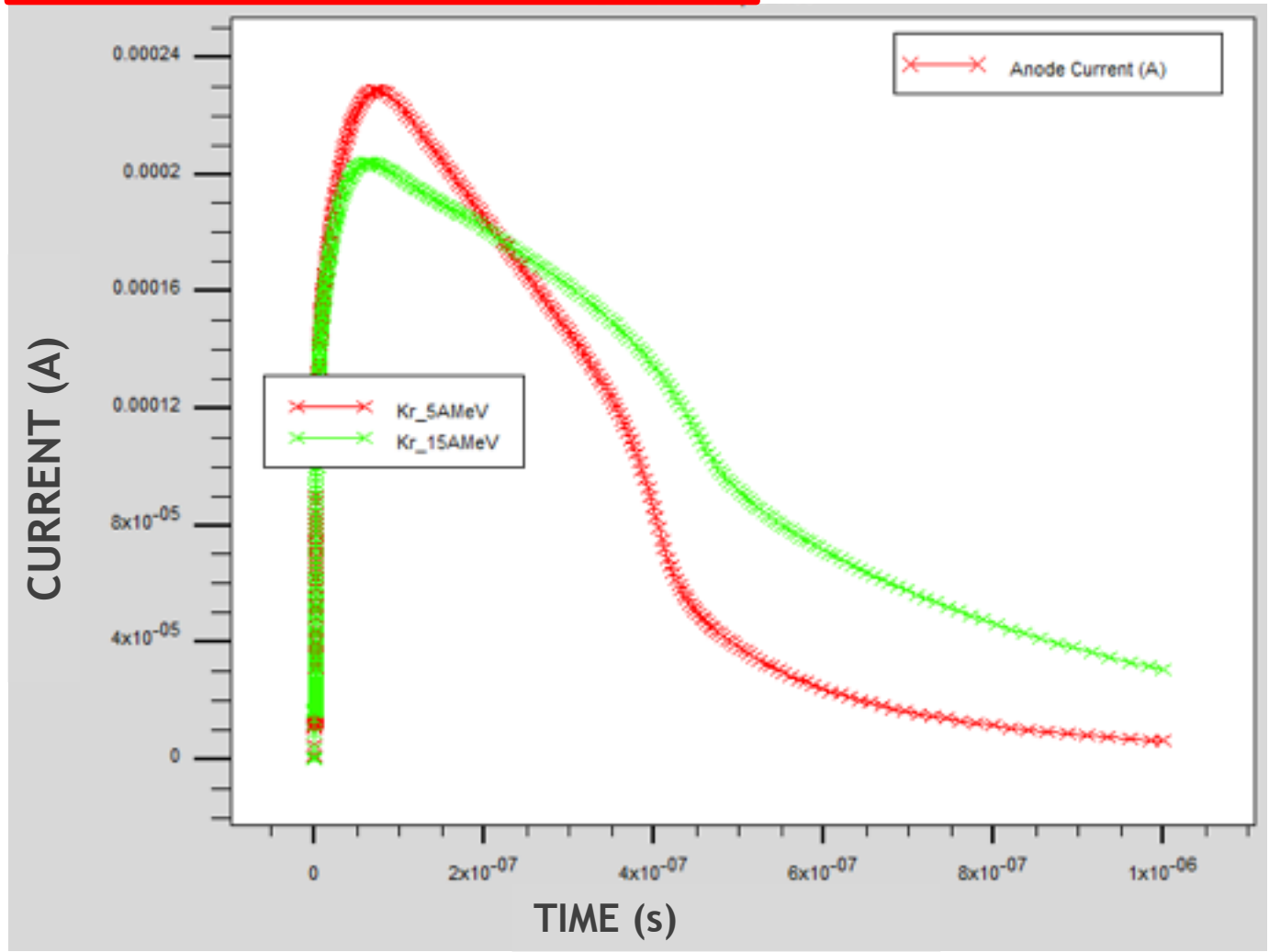
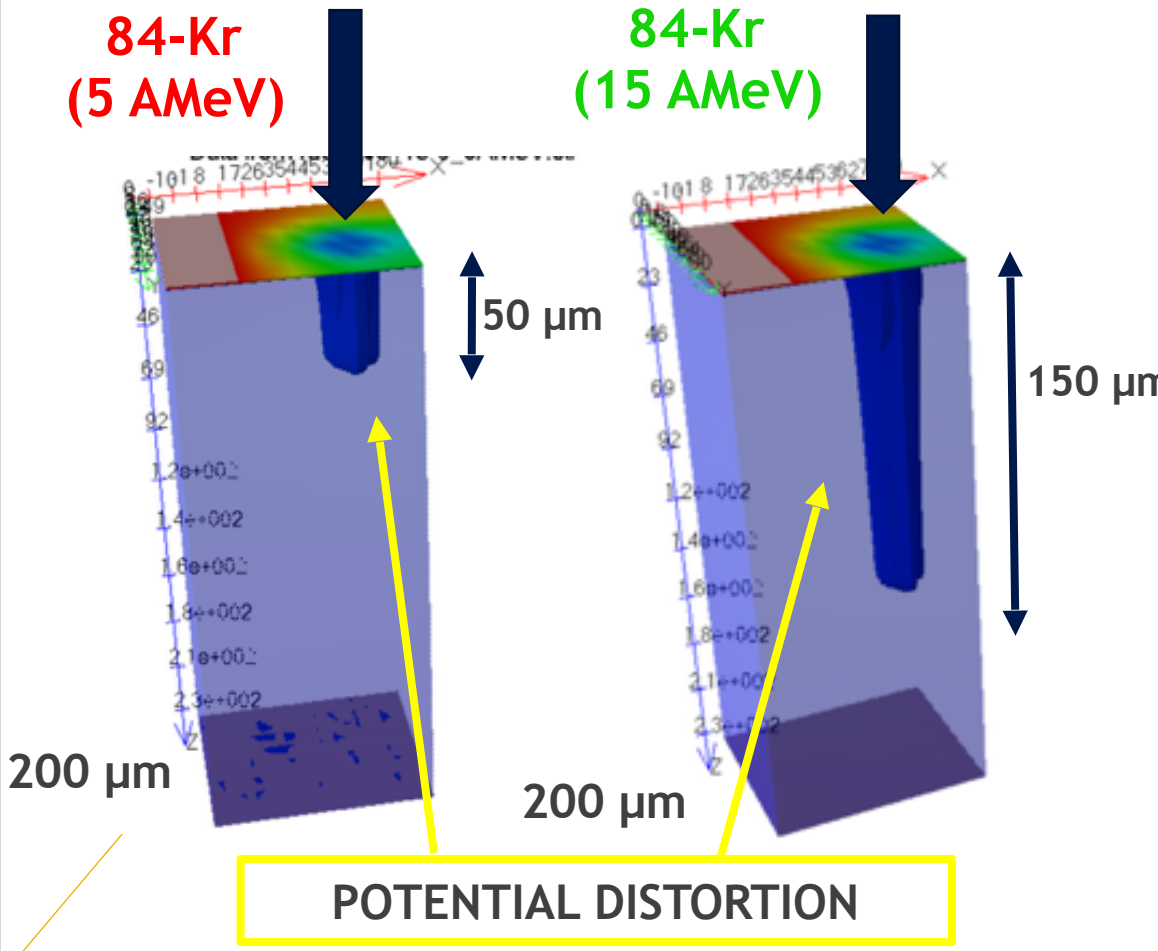


SOLAR CELLS
Interaction

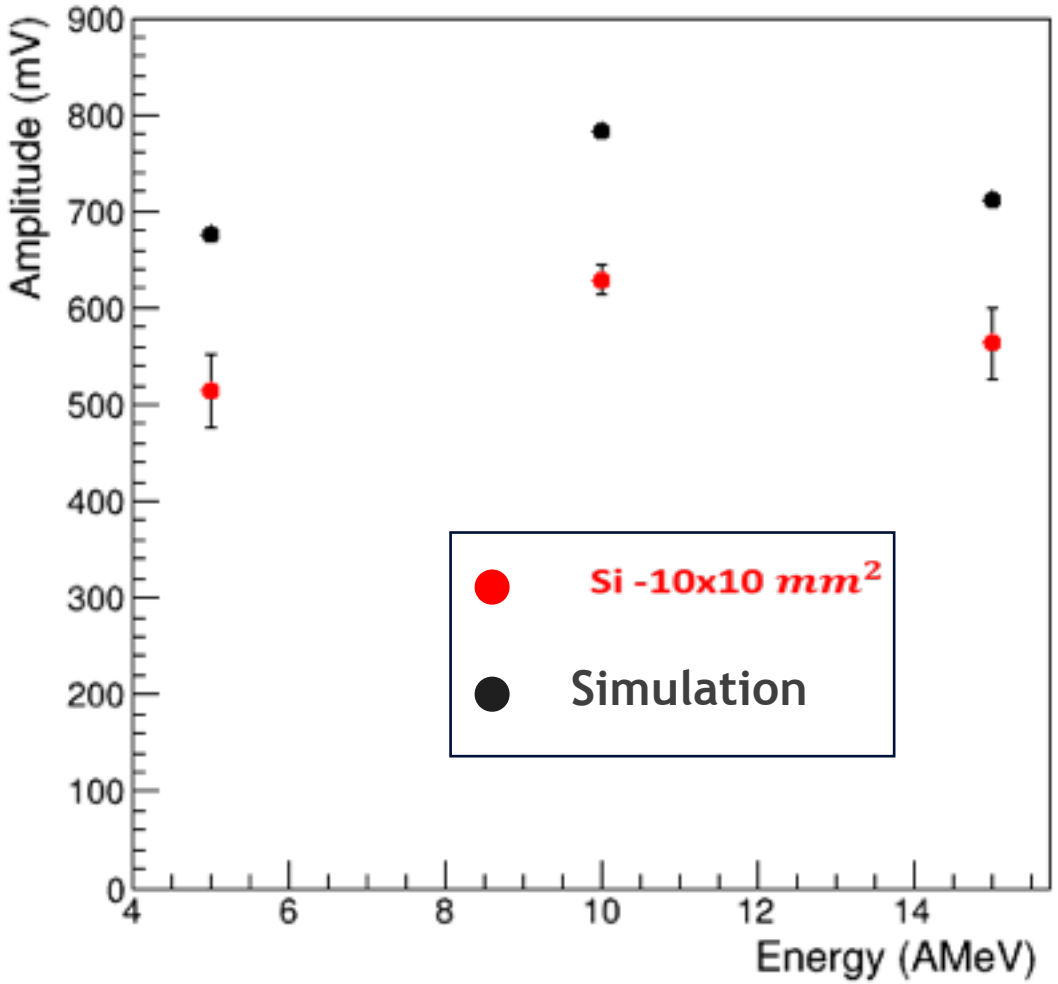


SIMULATION OF CHARGE COLLECTION

PRELIMINARY RESULTS

3. Simulation
   1) 84-Kr 5 AMeV
   2) 84-Kr 10 AMeV
   3) 84-Kr 15 AMeV

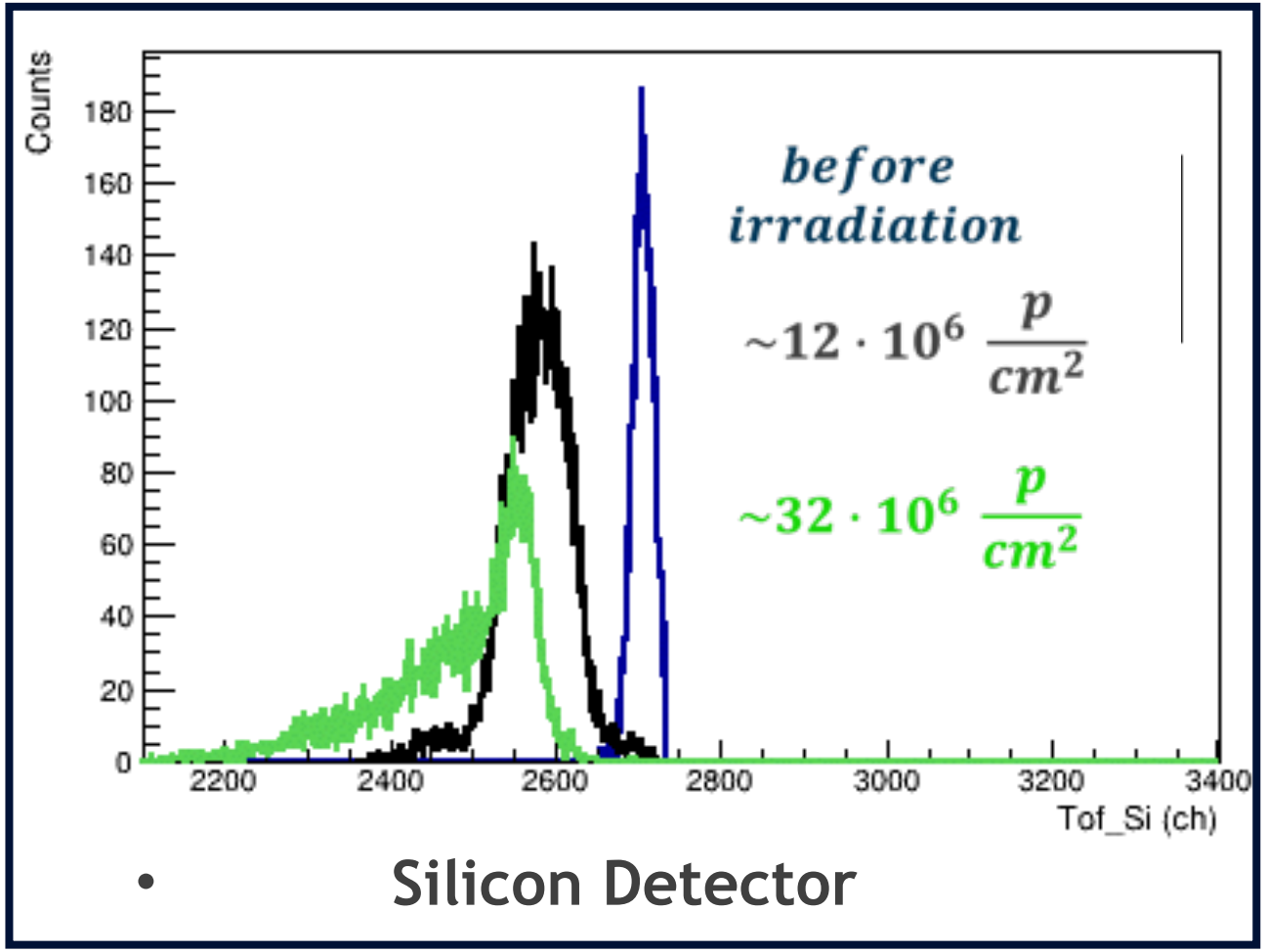
SOLAR CELL SIGNAL IS REPRODUCED but
there are still many free parameters



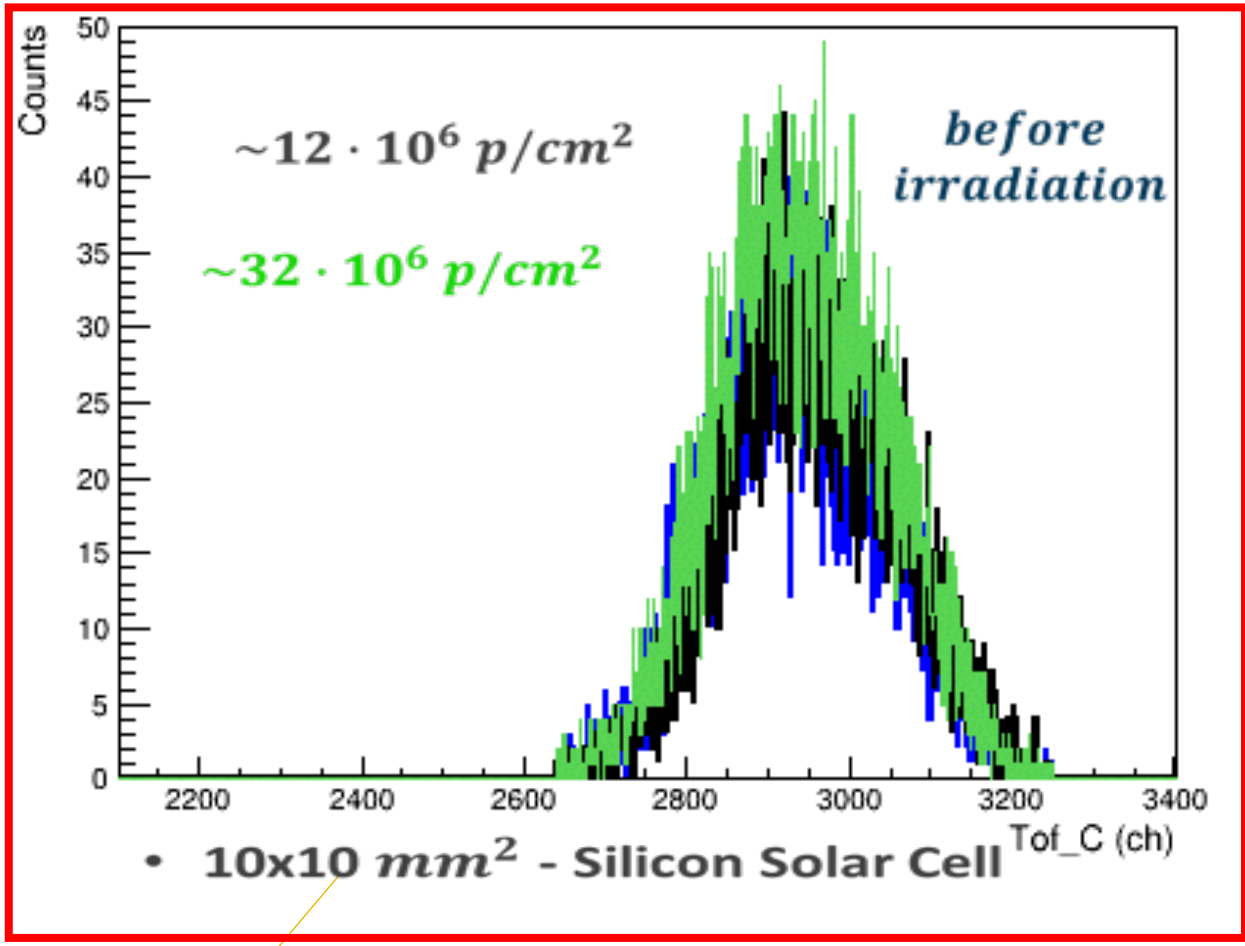
COLLECTION PROCESS IS RESPONSIBLE FOR SOLAR CELLS NON LINEARITY

GANIL experiment (March 2021) - Final RESULTS

4 - Irradiation



- Silicon Detector



- 10x10 mm^2 - Silicon Solar Cell

^{84}Kr beam at 15 AMeV

Conclusions & Future Prospectives

Solar Cells remain an interesting alternative to Silicon Detectors for heavy ions beams at energies > 1 AMeV!!

Main Results:

1) • 20x20 Ge substrate the best performances in Energy (σ(E)/E=1.1% RMS) and Time Resolution (2.6 ns)

2) The Response of Solar Cells have been characterized up to 15 AMeV for ^{84}Kr :
   - Simulations are able to reproduce Solar Cells signal

3) Long Irradiation Test : Better behaviour of Solar Cells with respect to Silicon Detector (for time response)
   - VERY IMPORTANT FOR USE IN UHV!

SOLAR CELLS ARE WELL SUITED FOR NECTAR project but also for other experiments with heavy ions

FUTURE PROSPECTIVES

- Xe & Kr beams → Confirm experimentally our predictions; Digitize Solar Cells signal; Preamplifier system: Final optimization stage
- U beam → explore Solar Cells possibilities as beam like residues detectors

……Thank you for your work ……

Collaborators:

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……Thank you for your attention

……

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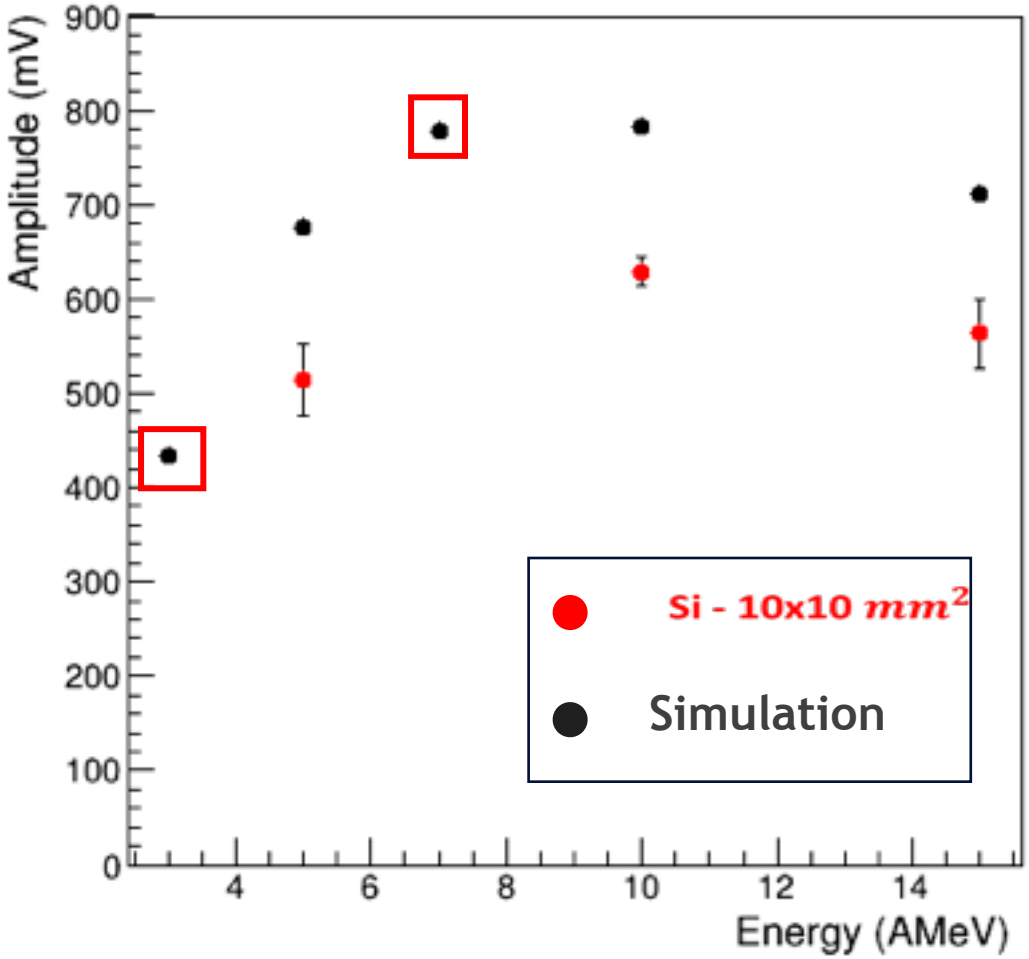
Backup Slides

E809 experiment(March 2021) - RESULTS

PRELIMINARY RESULTS

3. Simulation
   1) 84-Kr 3 AMeV
   2) 84-Kr 5 AMeV
   3) 84-Kr 7 AMeV
   4) 84-Kr 10 AMeV
   5) 84-Kr 15 AMeV

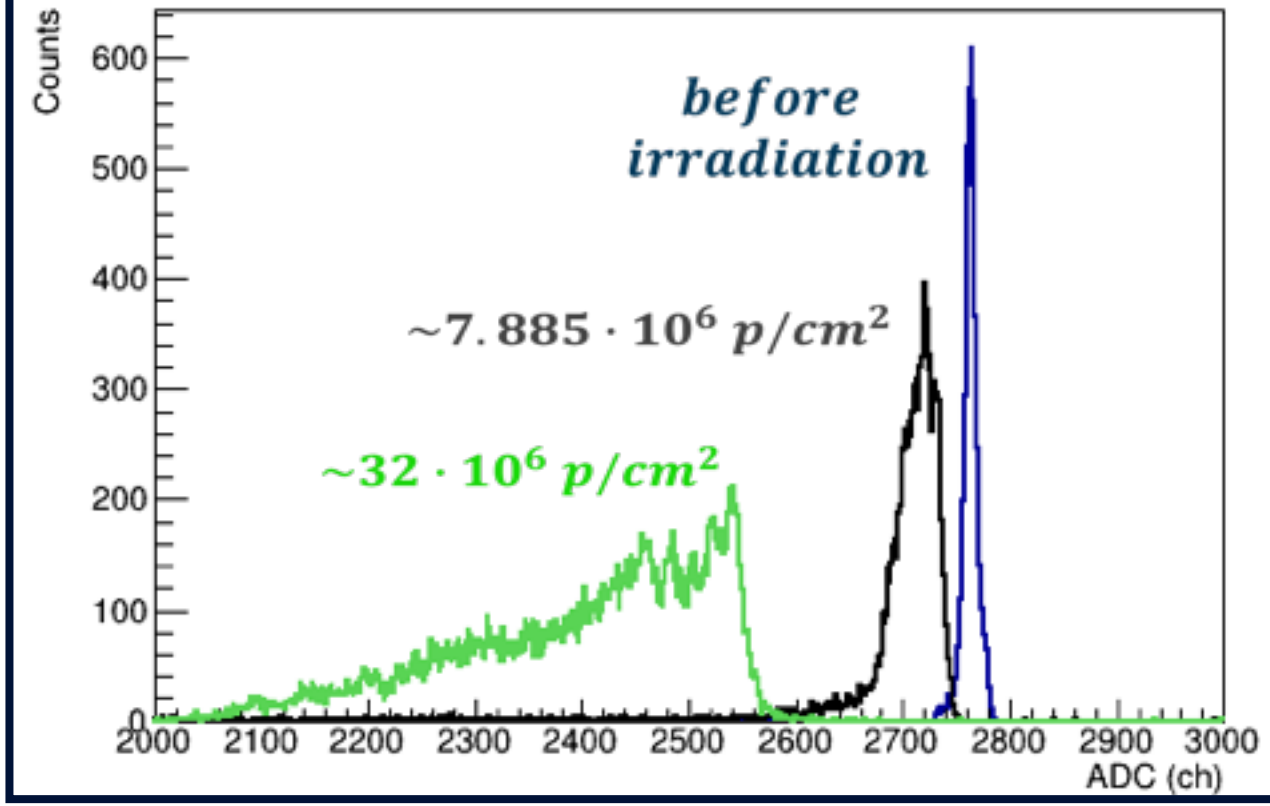
ATLAS Silvaco code

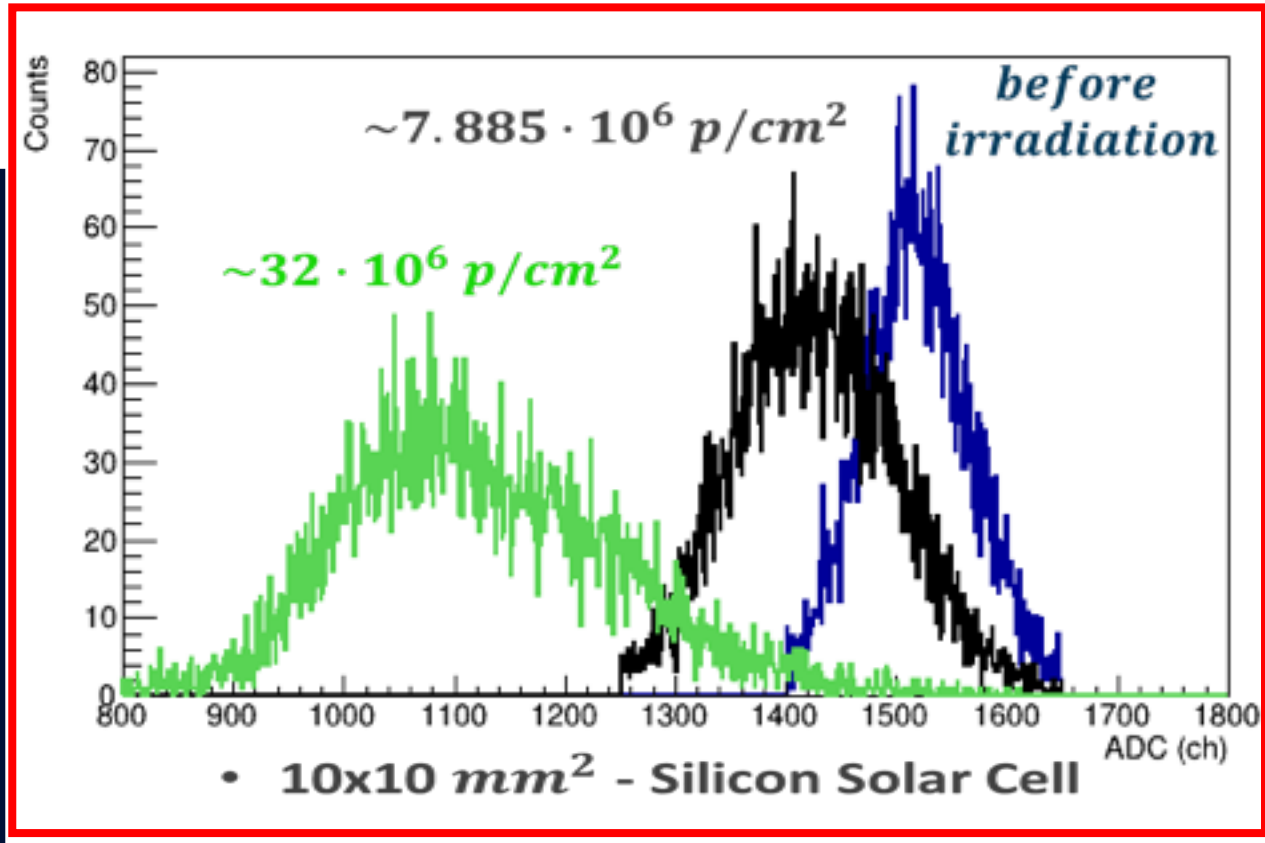


E809 experiment(March 2021) - RESULTS

4 - Irradiation

- Silicon Detector



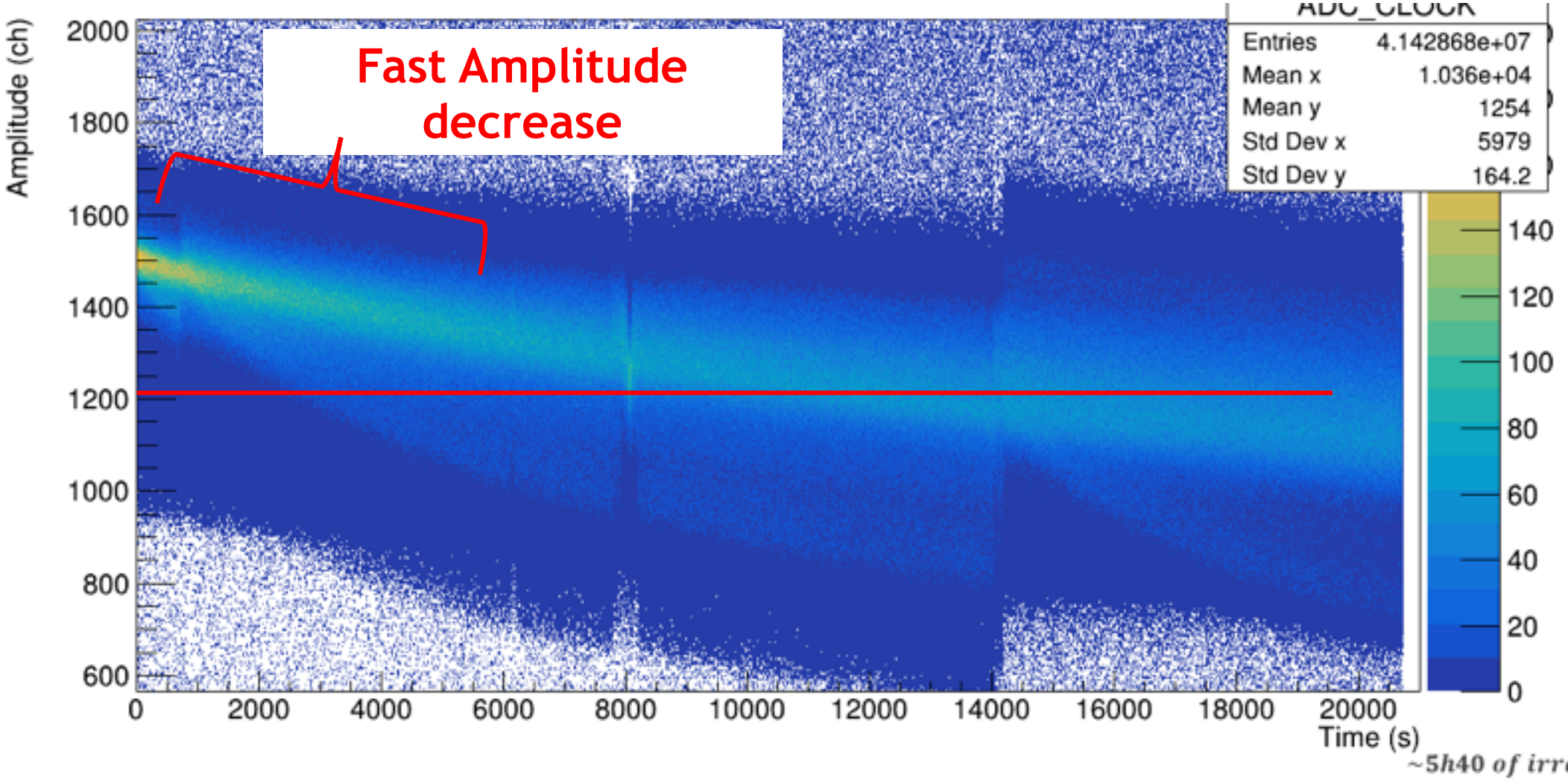


- 10x10 mm^2 - Silicon Solar Cell

^{84}Kr beam at 15 AMeV

Amplitude Spectra as function of real time

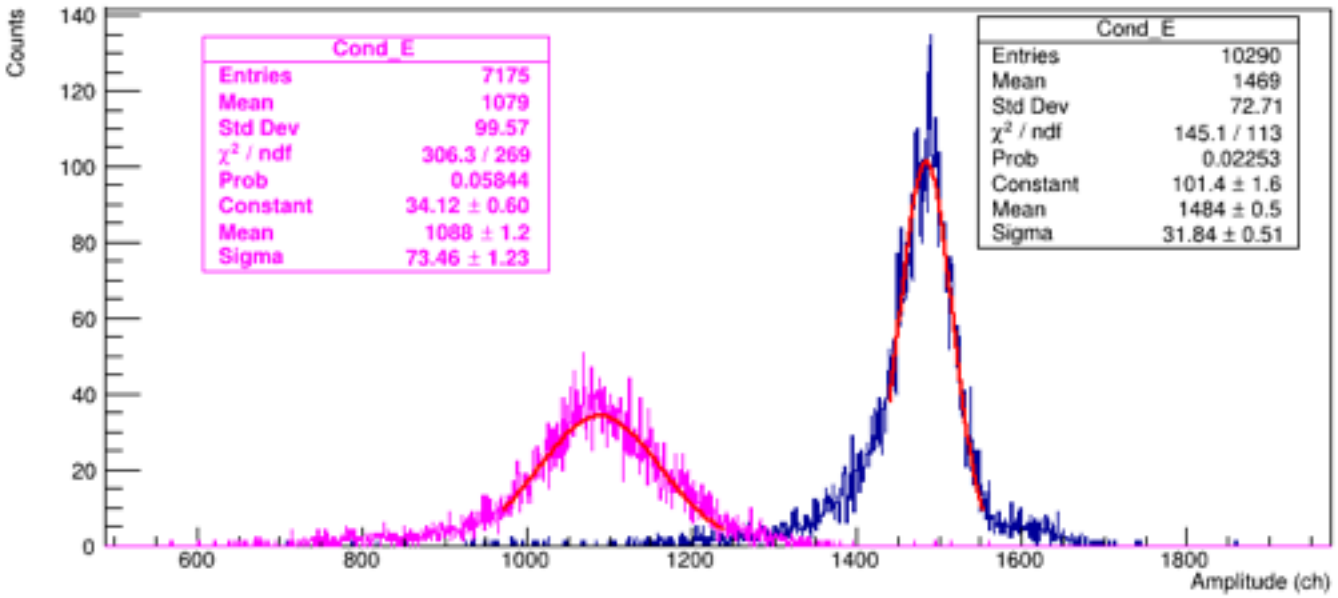
- **Solar Cells: Ge 20x20 mm2 ----> rate 5 KHz**

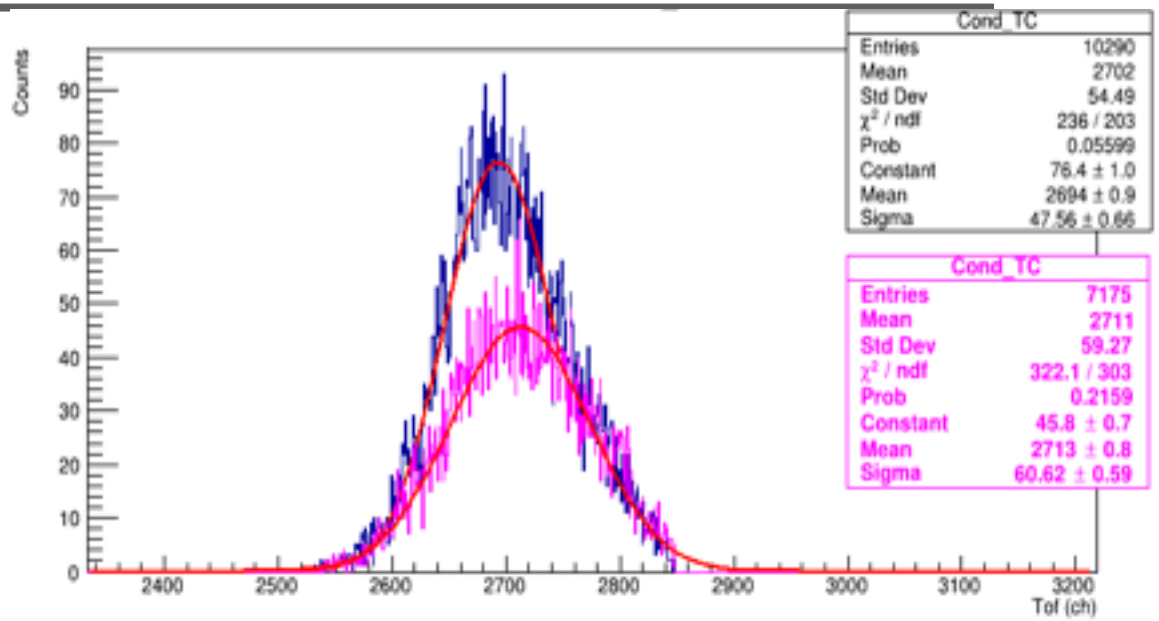


~5h40 of irradiation

Amplitude & Time Spectra before and after the irradiation

Solar Cells: Ge 20x20 mm2 ----> rate 5 KHz

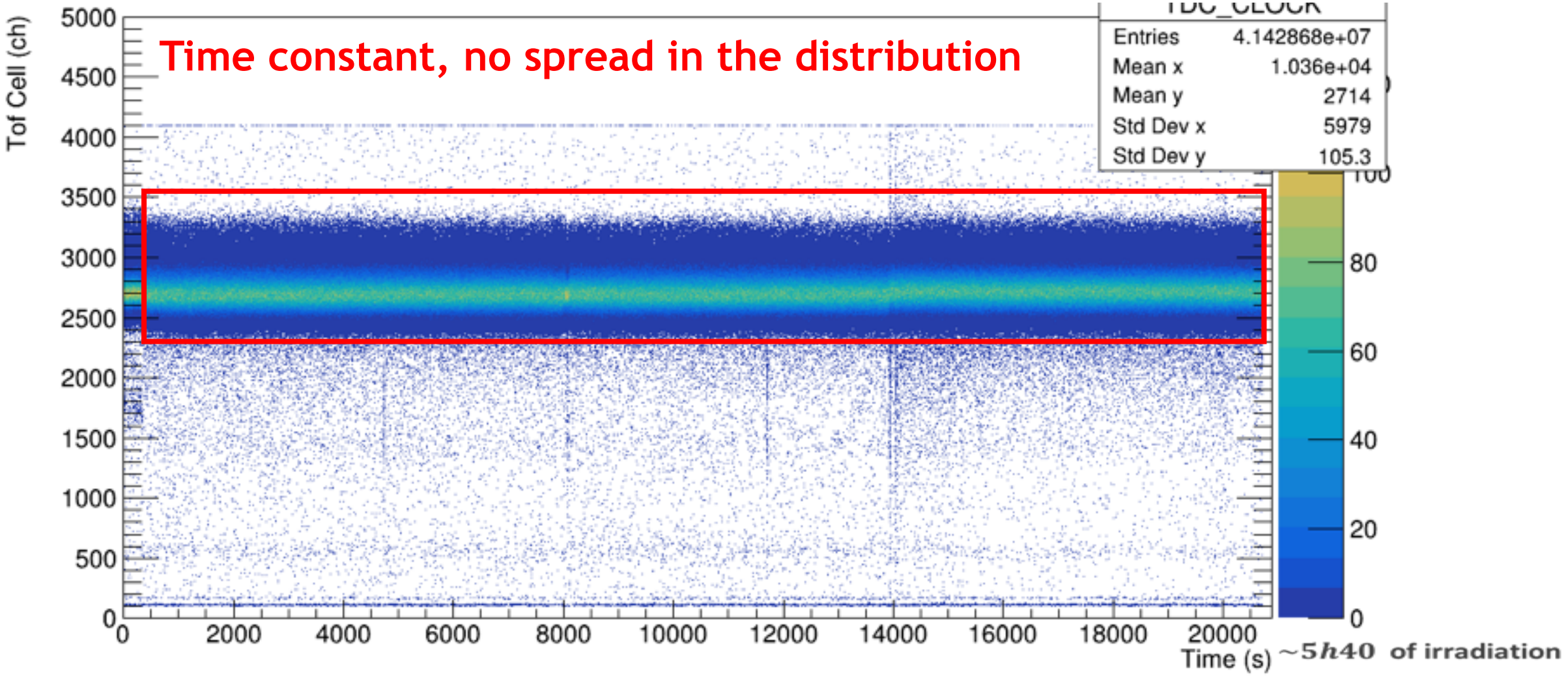


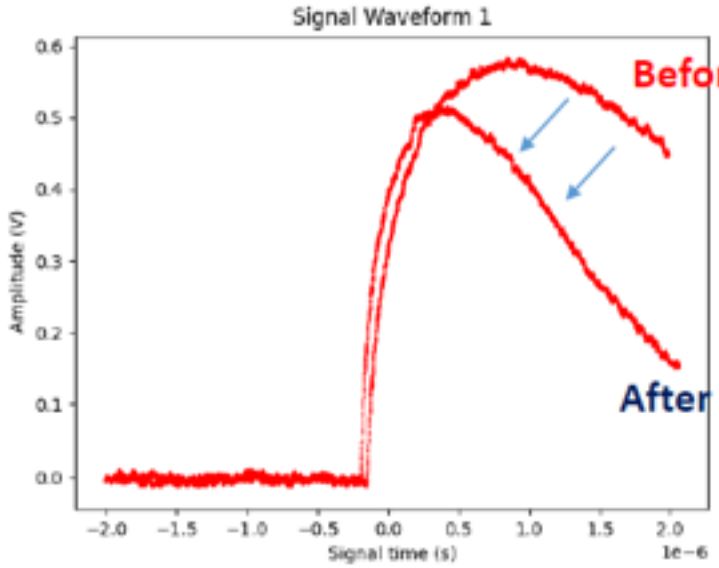


Measurements realized at low rate ~ 50 *Hz*

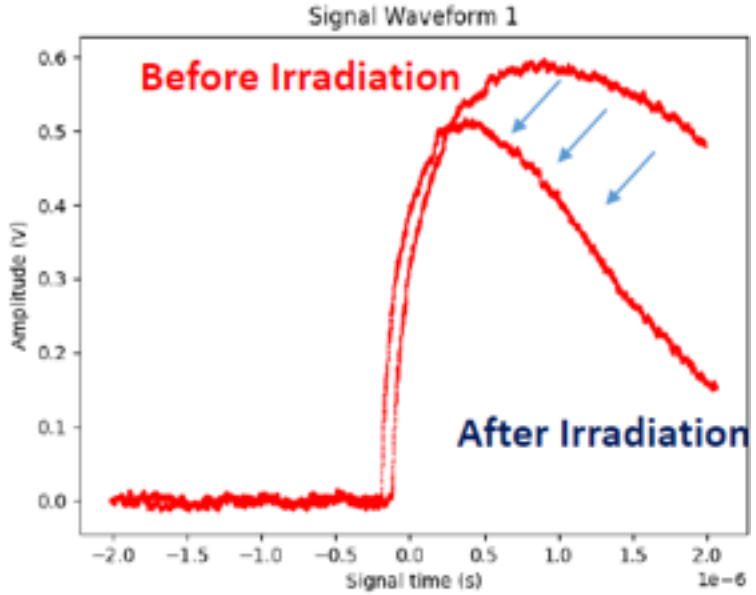
Time Spectra as function of real time

- **Solar Cells: Ge 20x20 mm2 ----> rate 5 KHz**

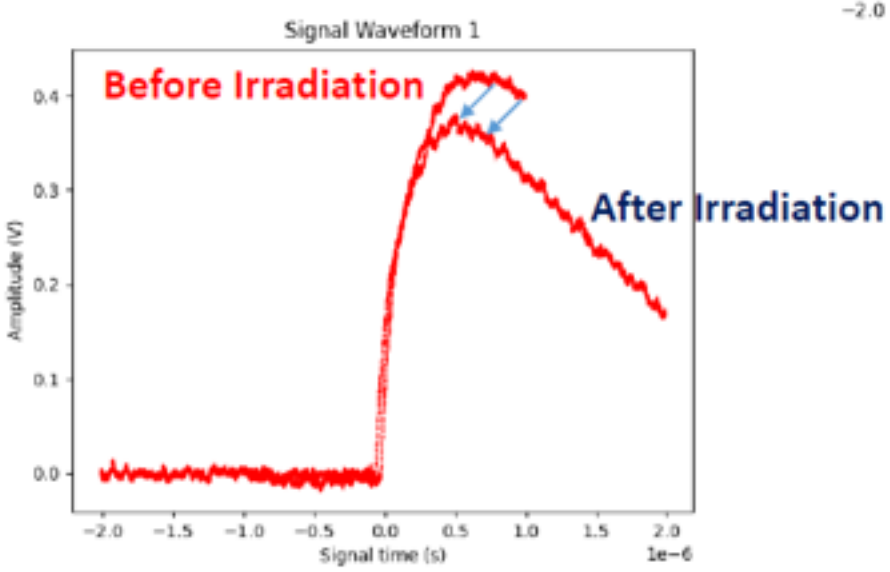


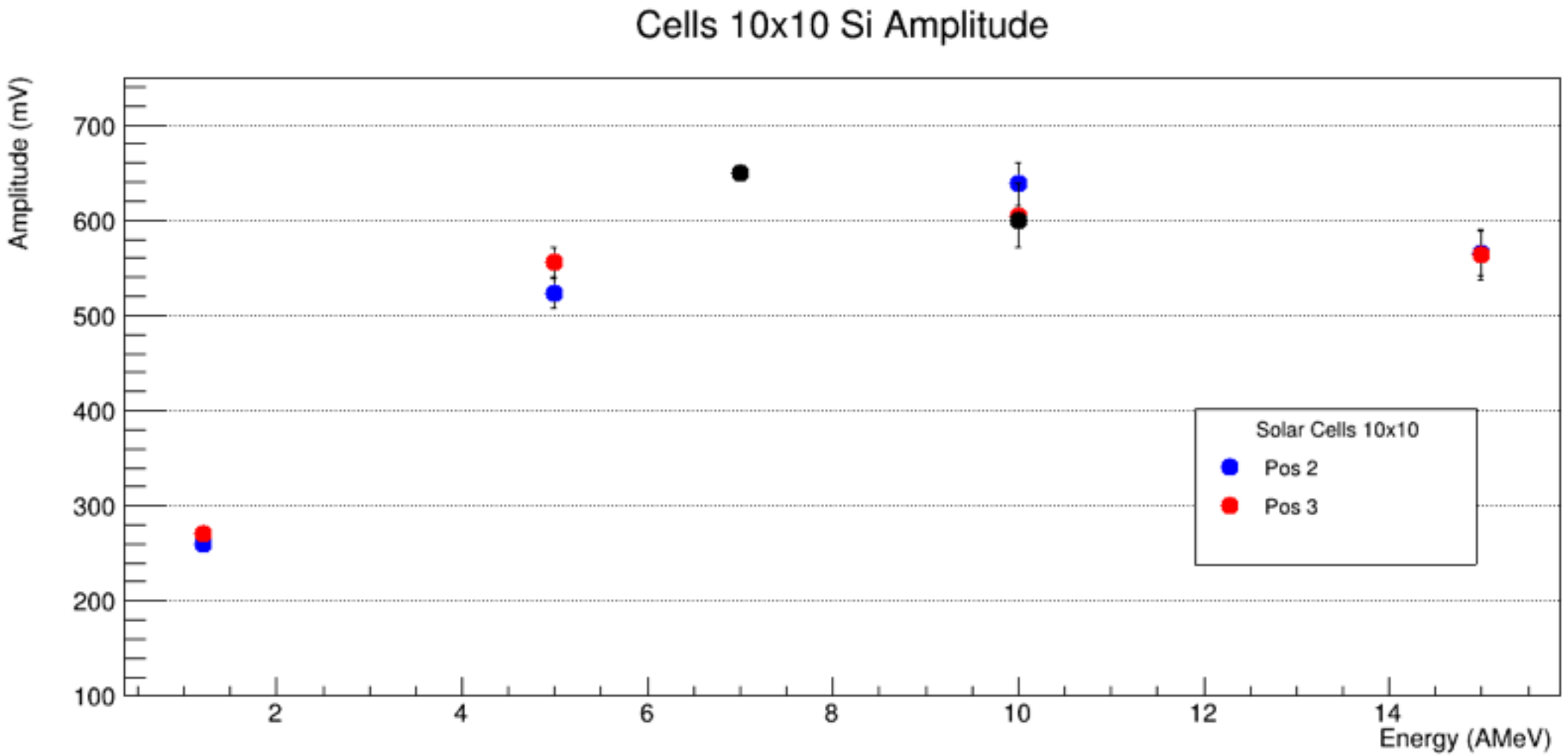


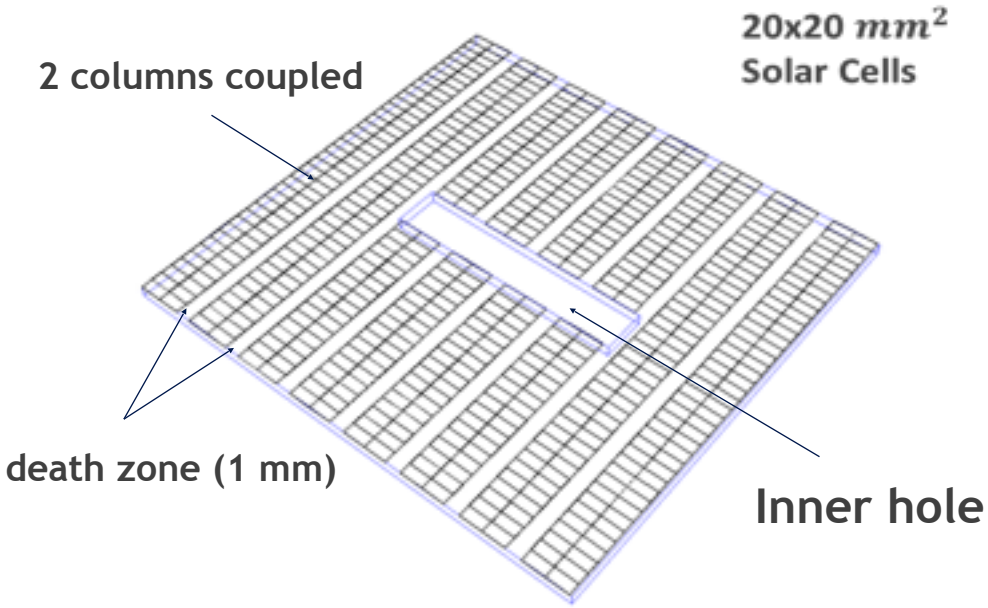
Solar Cells (Si) 10x10 mm2

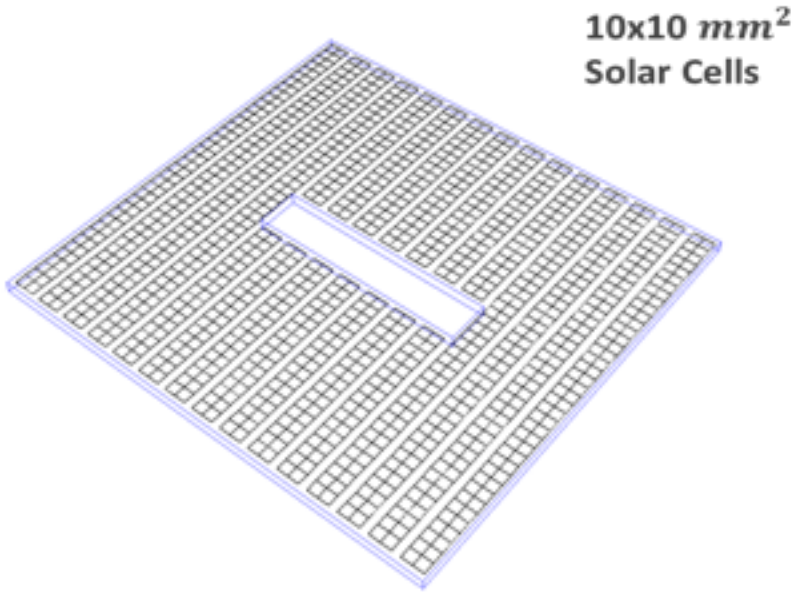


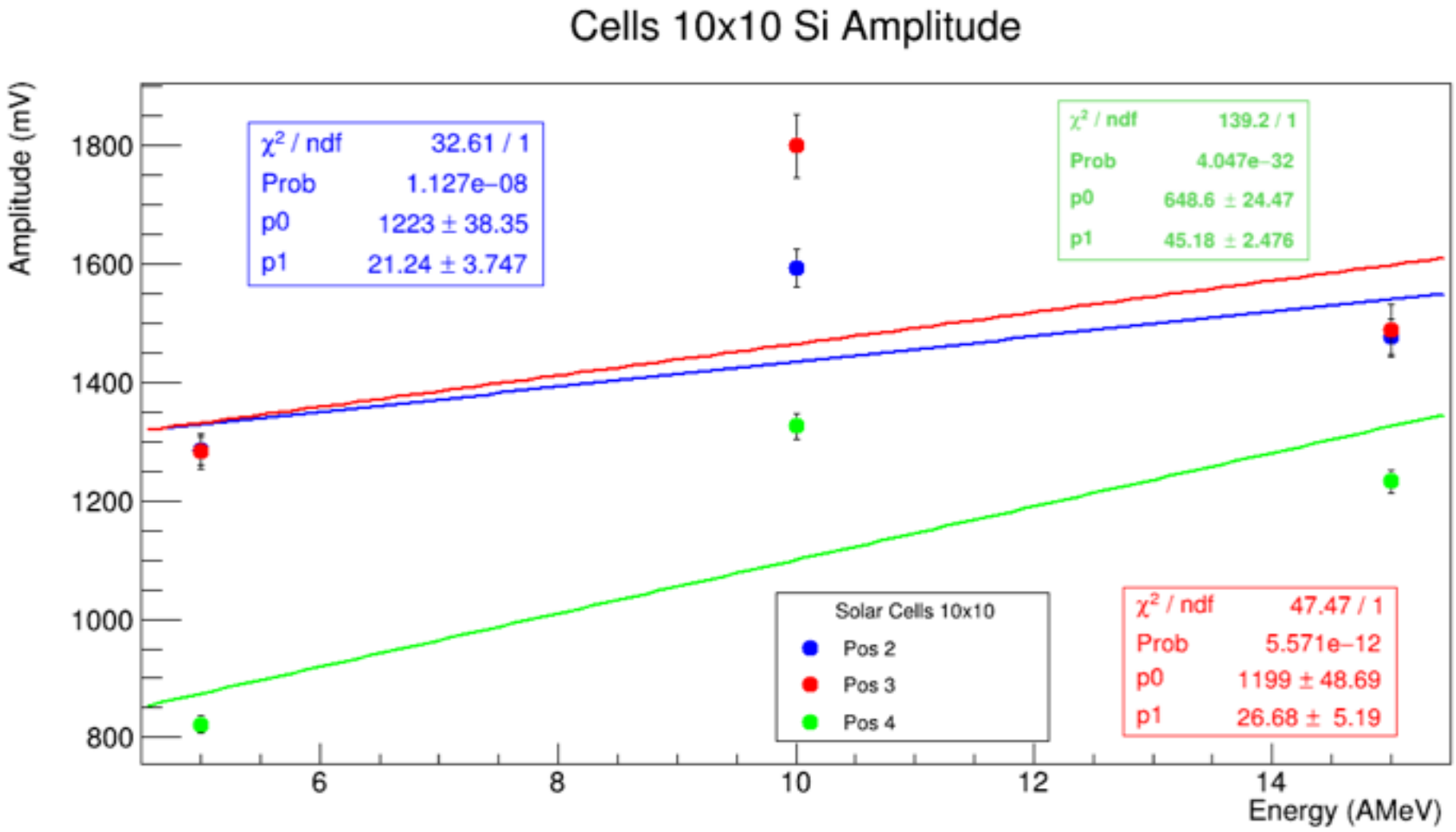
Solar Cells (Ge) 20x20 mm2

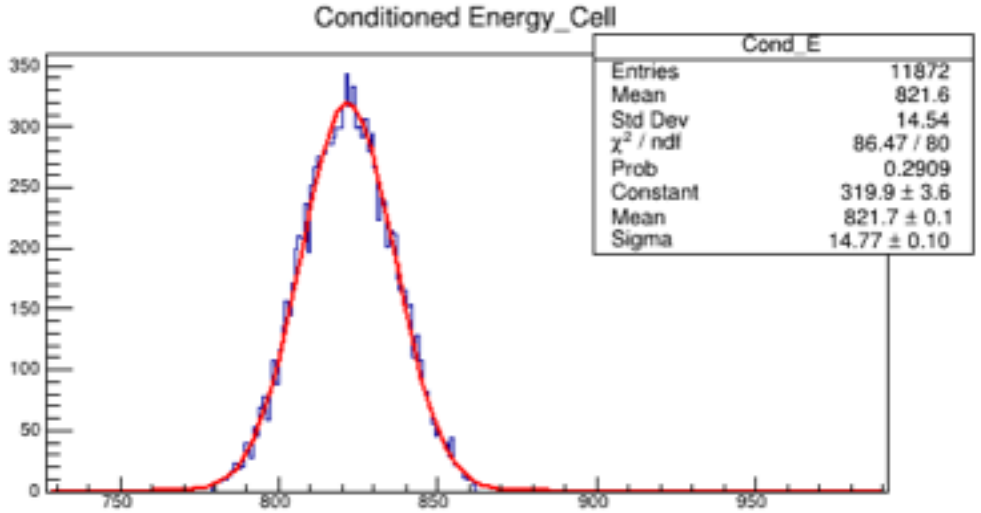


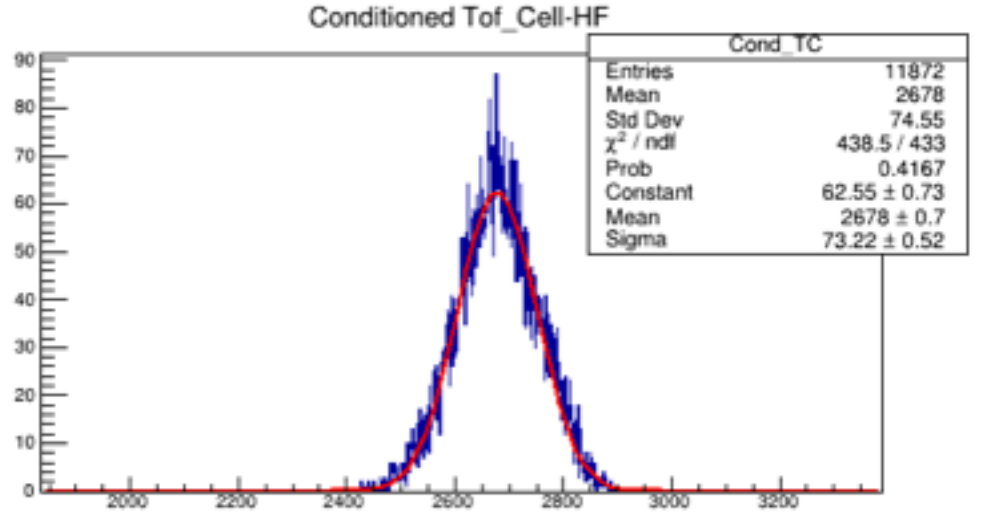

Cells 10x10 Si Amplitude
Amplitude (mV)
700
600
500
400
300
200
100
2
4
6
8
10
12
14
Energy (AMeV)
Solar Cells 10x10
Pos 2
Pos 3

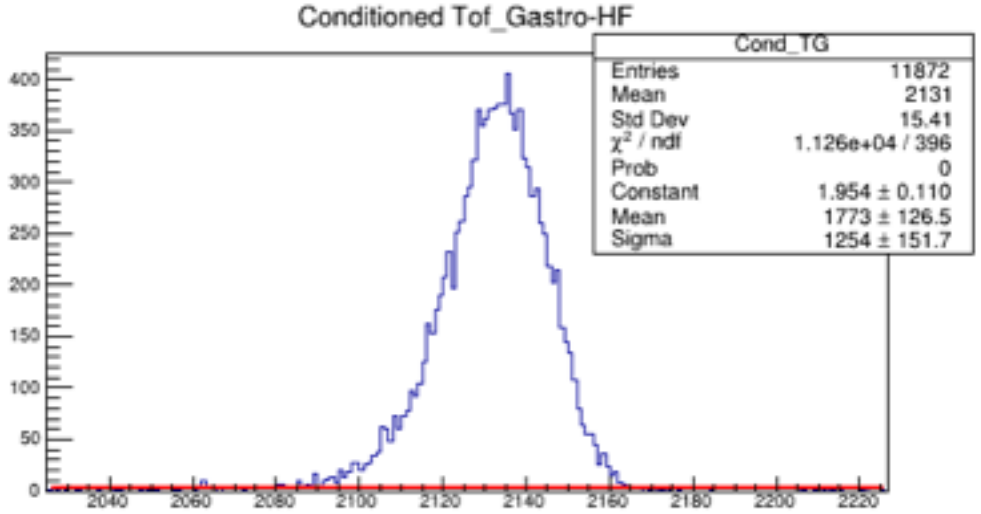

2 columns coupled
20x20 mm^2
Solar Cells
death zone (1 mm)
Inner hole

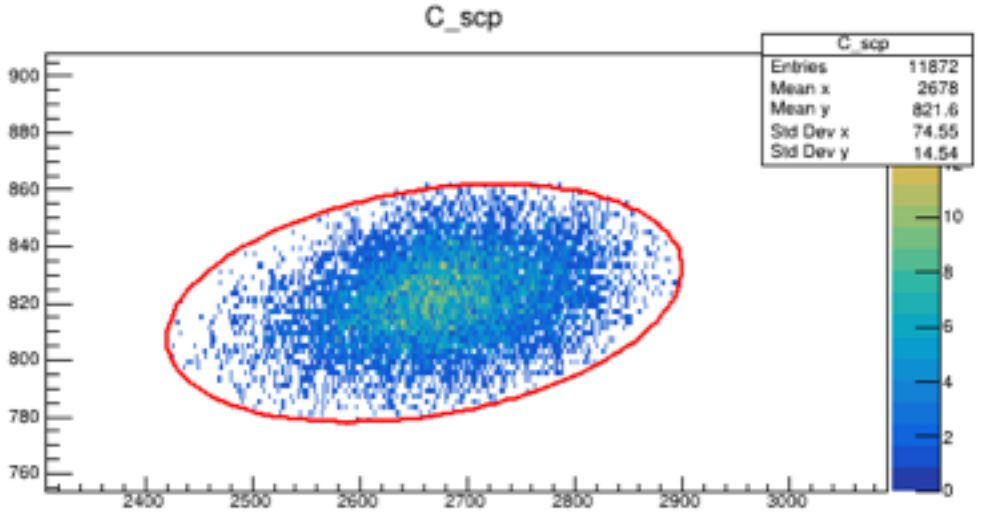

10x10 mm^2
Solar Cells

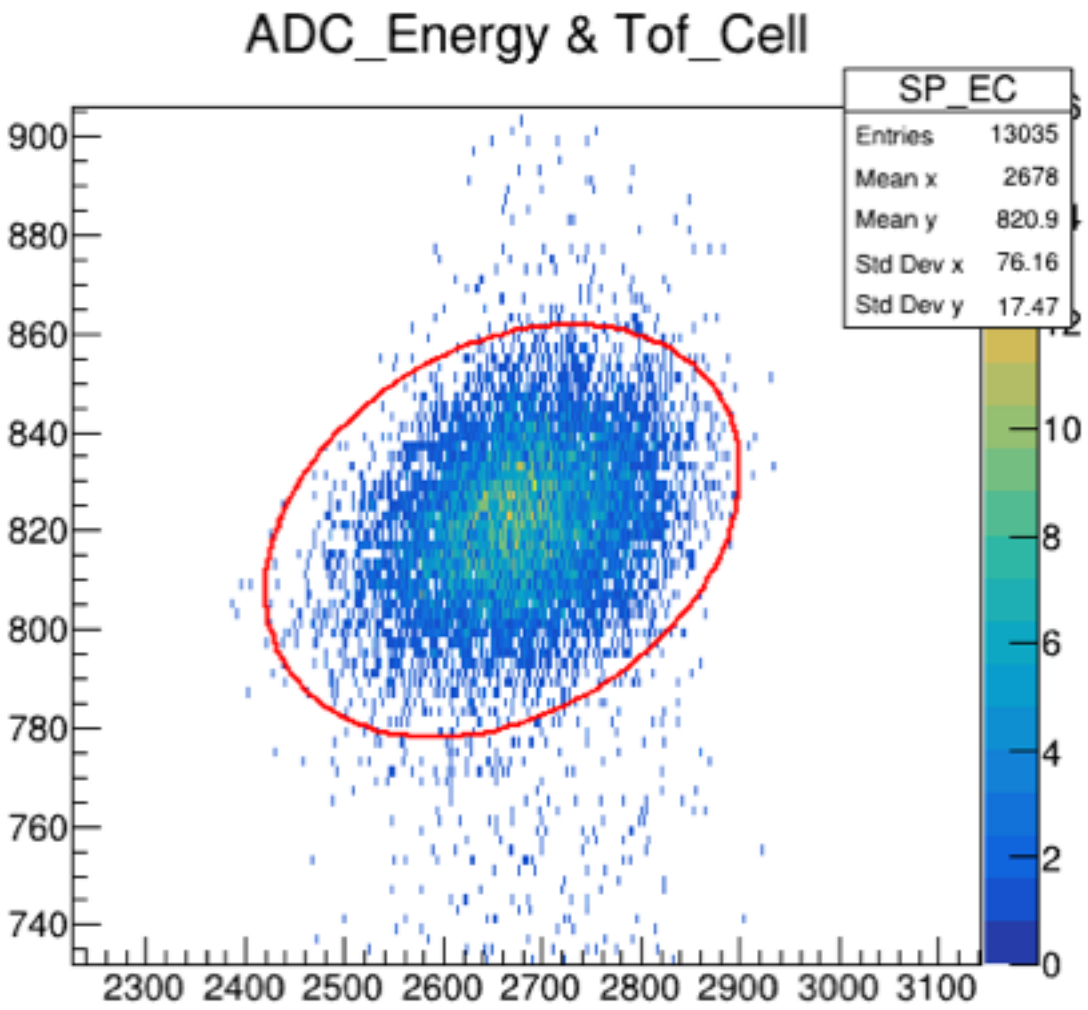

Cells 10x10 Si Amplitude
Amplitude (mV)
1800
1600
1400
1200
1000
800
6
8
10
12
14
Energy (AMeV)
χ² / ndf 32.61 / 1
Prob 1.127e−08
p0 1223 ± 38.35
p1 21.24 ± 3.747
χ² / ndf 139.2 / 1
Prob 4.047e−32
p0 648.6 ± 24.47
p1 45.18 ± 2.476
χ² / ndf 47.47 / 1
Prob 5.571e−12
p0 1199 ± 48.69
p1 26.68 ± 5.19
Solar Cells 10x10
Pos 2
Pos 3
Pos 4


Conditioned Energy_Cell
Cond_E
Entries 11872
Mean 821.6
Std Dev 14.54
χ² / ndf 86.47 / 80
Prob 0.2909
Constant 319.9 ± 3.6
Mean 821.7 ± 0.1
Sigma 14.77 ± 0.10


Conditioned Tof_Cell-HF
Cond_TC
Entries 11872
Mean 2678
Std Dev 74.55
χ² / ndf 438.5 / 433
Prob 0.4167
Constant 62.55 ± 0.73
Mean 2678 ± 0.7
Sigma 73.22 ± 0.52


Conditioned Tof_Gastro-HF
Cond_TG
Entries 11872
Mean 2131
Std Dev 15.41
χ² / ndf 1.126e+04 / 396
Prob 0
Constant 1.954 ± 0.110
Mean 1773 ± 126.5
Sigma 1254 ± 151.7


C_scp
C_scp
Entries 11872
Mean x 2678
Mean y 821.6
Std Dev x 74.55
Std Dev y 14.54


ADC_Energy & Tof_Cell
SP_EC
Entries 13035
Mean x 2678
Mean y 820.9
Std Dev x 76.16
Std Dev y 17.47
900
880
860
840
820
800
780
760
740
2300 2400 2500 2600 2700 2800 2900 3000 3100
10
8
6
4
2
0