DATA ANALYSIS from the Bern medical cyclotron

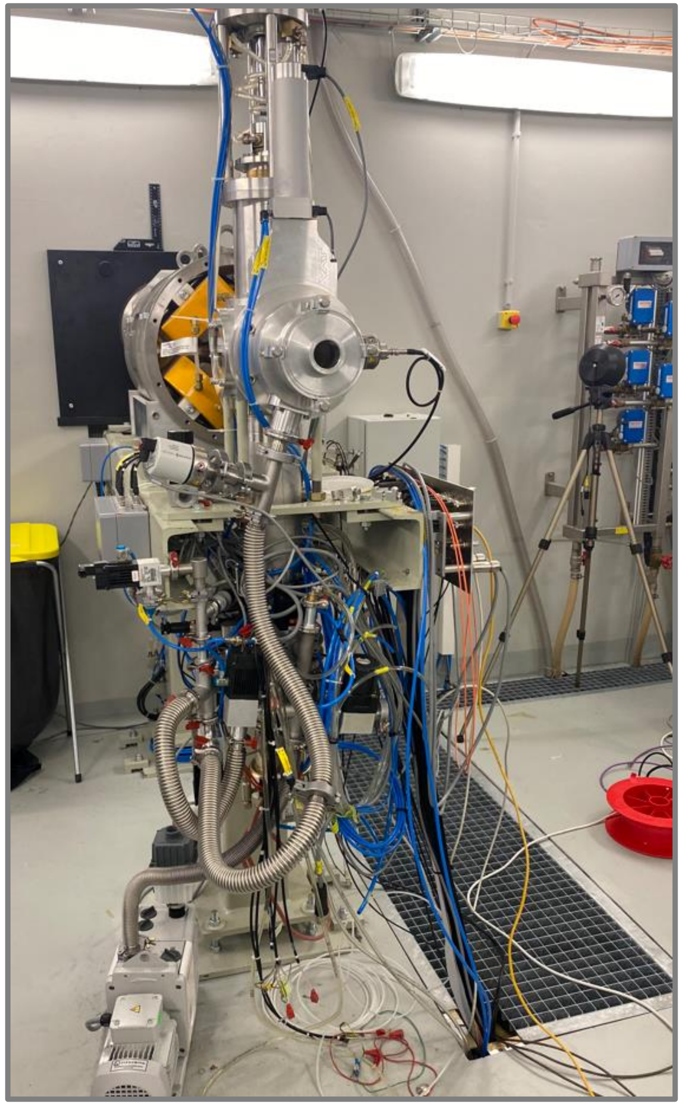
HASPIDE EXPERIMENT

Keida Kanxheri & Francesca Peverini (on behalf of the PG group) – HASPIDE general meeting

OUTLINE

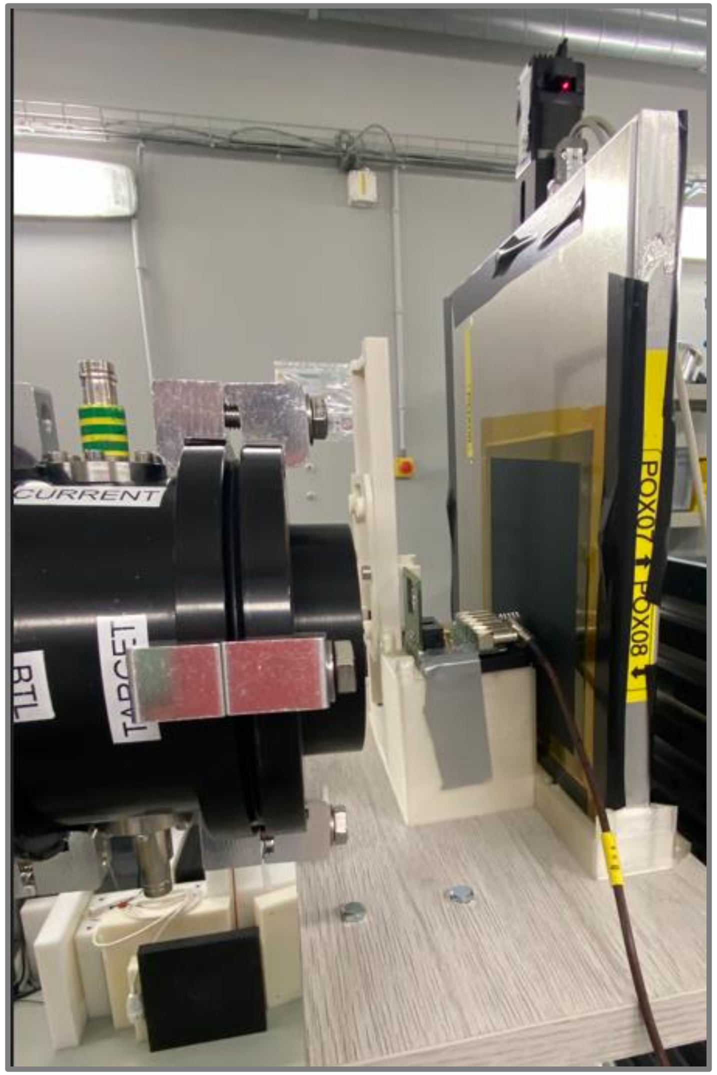
- Detectors under test and Bern cyclotron setup
- Bias voltage scan for detector working point definition
- Proton flux to dose rate conversion
- Dose rate dependence measurements
- Sensitivity calculation
- Efficiency calculation

- Conclusions



SETUP

Bern cyclotron setup



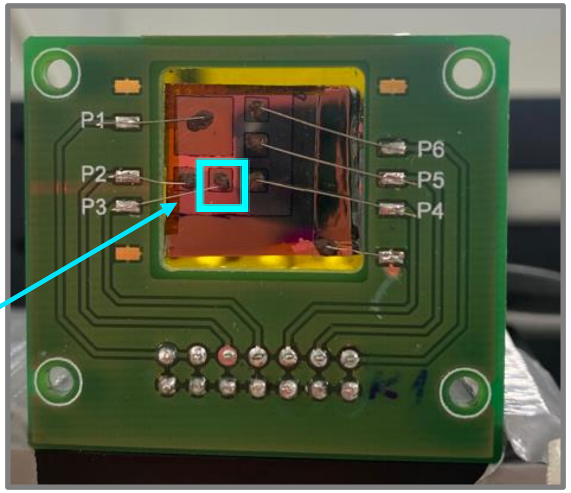
- Cyclotron: IBA Cyclone 18/18
- Proton beam at 16.7 MeV
- Beam dimension 2 cm x 2 cm

Proton Flux (p/cm^2s)
$8 \cdot 10^7$
$5 \cdot 10^8$
10^9
$5 \cdot 10^9$
10^{10}
$5 \cdot 10^{10}$
10^{11}
$5 \cdot 10^{11}$

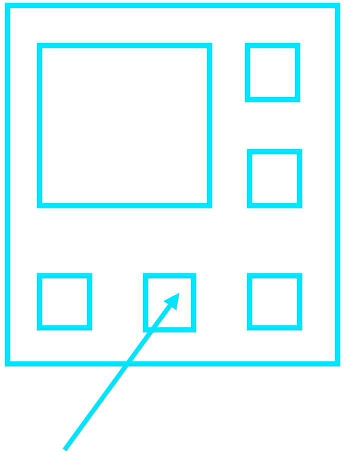
DETECTORS UNDER TEST

Detectors under test

1



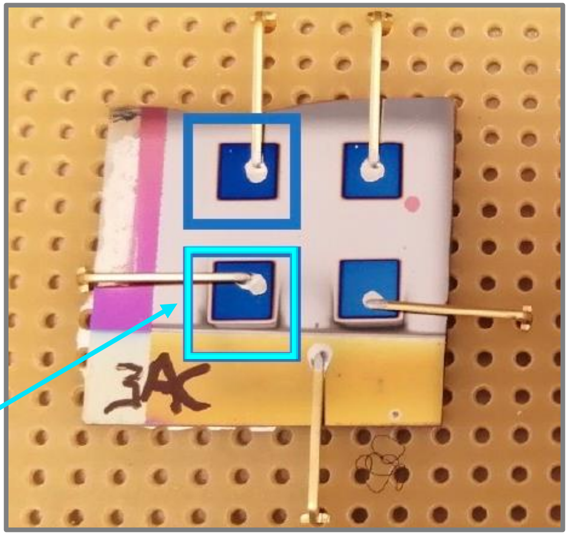
P3



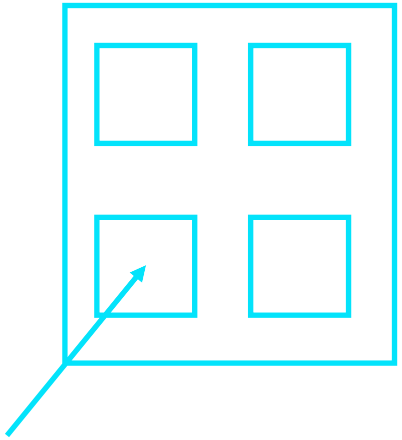
K1 P3

- Diode detector on capton substrate
- Intrinsic layer of a-Si:H of 2.5 um
- P-doped Si layer & n doped Si layer
- 2 mm x 2 mm area

2



A3AC



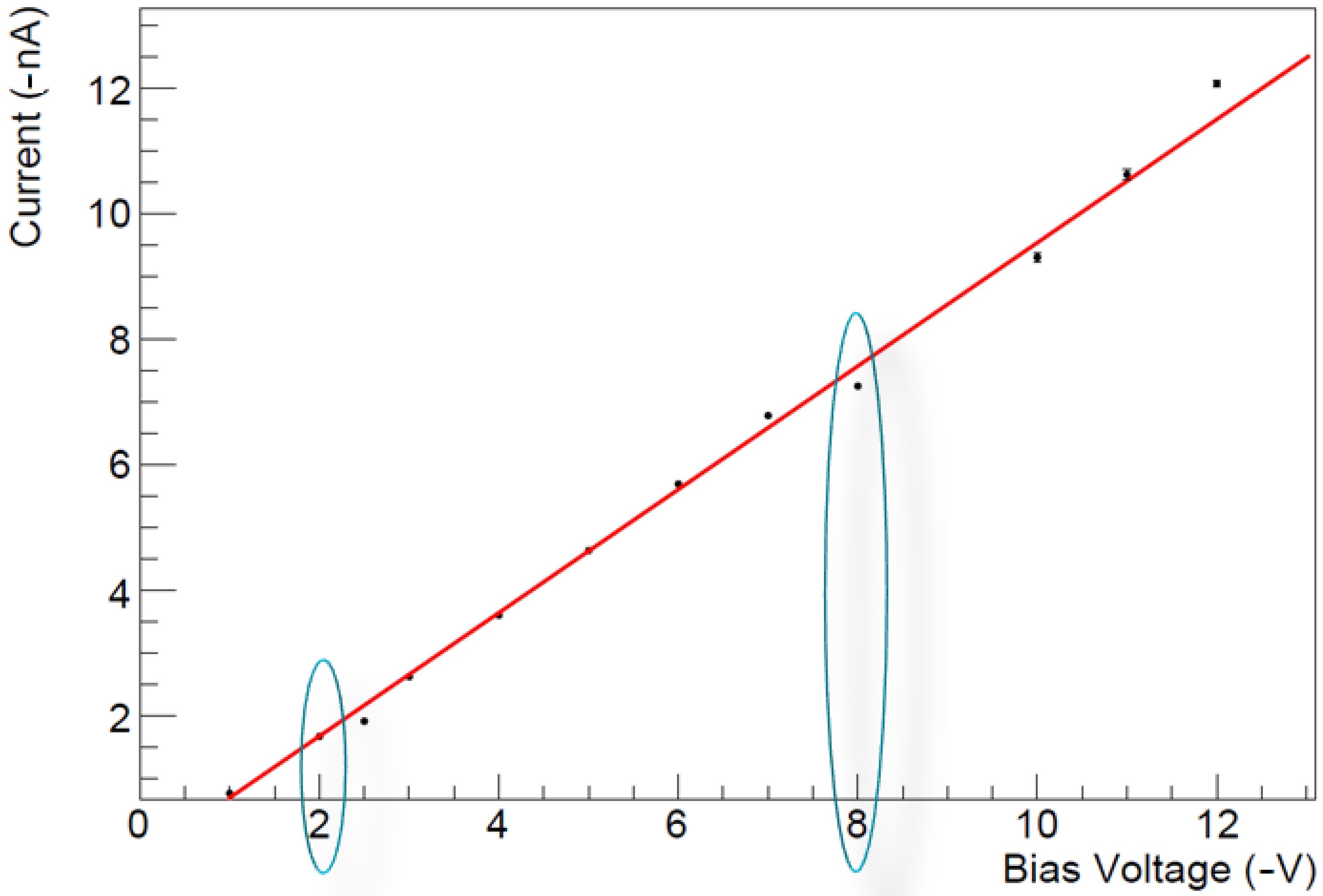
A3AC 1

- Charge selective contact detector on glass substrate
- Intrinsic layer of a-Si:H of 8.2 um
- Molybdenum oxide layer & Aluminium-doped zinc oxyde layer
- 4 mm x 4 mm area

BIAS VOLTAGE SCAN

Detector K1 P3

We initially studied the detector response with a fixed external stimulus for different bias voltage values.



- **Detector K1 P3**
- E_{Beam} = 16.7 MeV
- Beam dimension = 2x2 cm^2
- **Proton flux = $5 \cdot 10^9$ (p/cm^2s)**

The values considered for the I-V graph are parameters of the Gaussian fit, the mean value represents the measured current and the sigma value identifies the oscillation.

BIAS VOLTAGE SCAN

Detector A3AC 1

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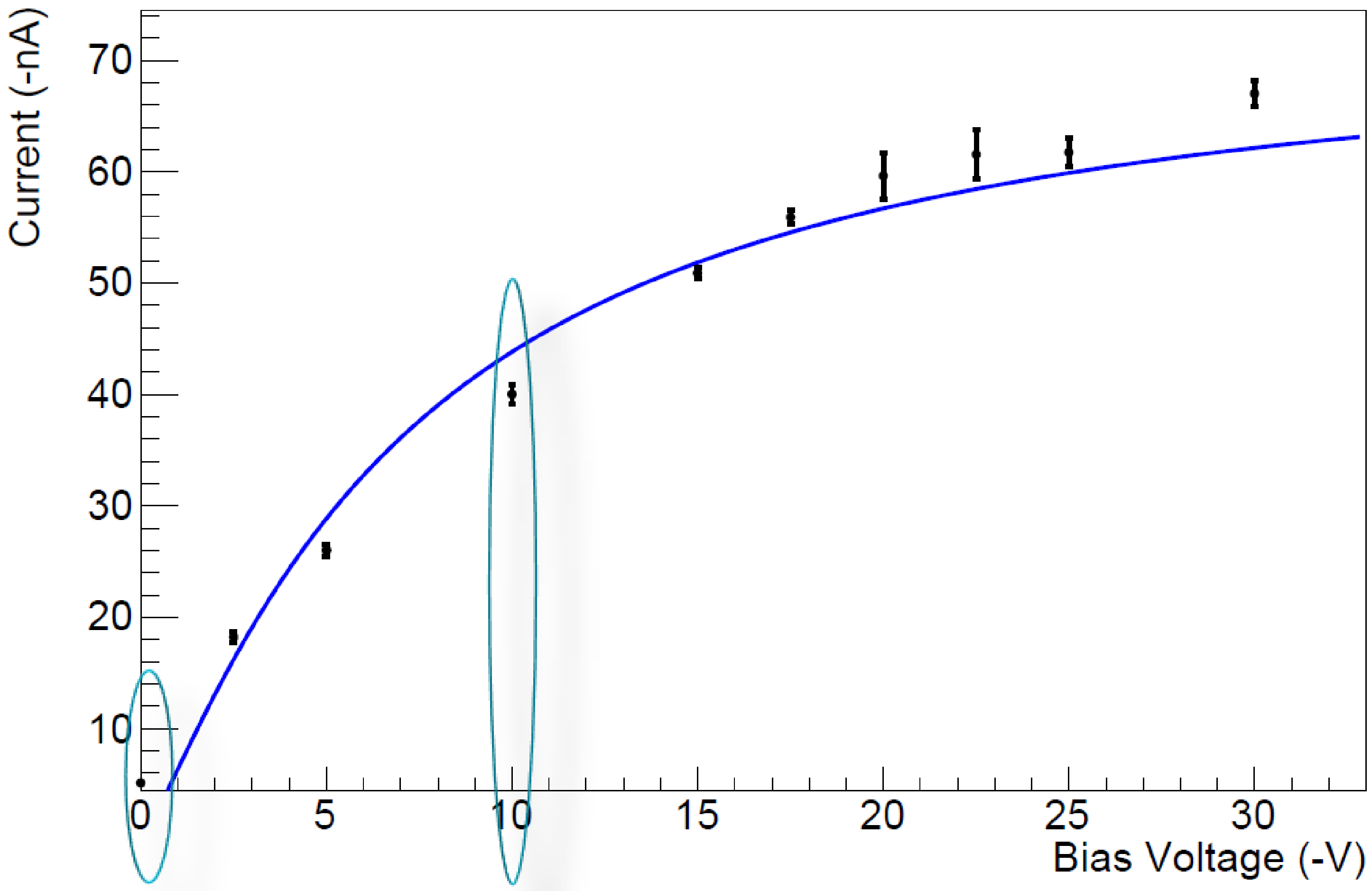


- **Detector A3AC 1**
- E_{Beam} = 16.7 MeV
- Beam dimension = 2x2 cm^2
- **Proton flux = 10^9 (p/cm^2s)**

The values considered for the I-V graph are parameters of the Gaussian fit, the mean value represents the measured current and the sigma value identifies the oscillations.

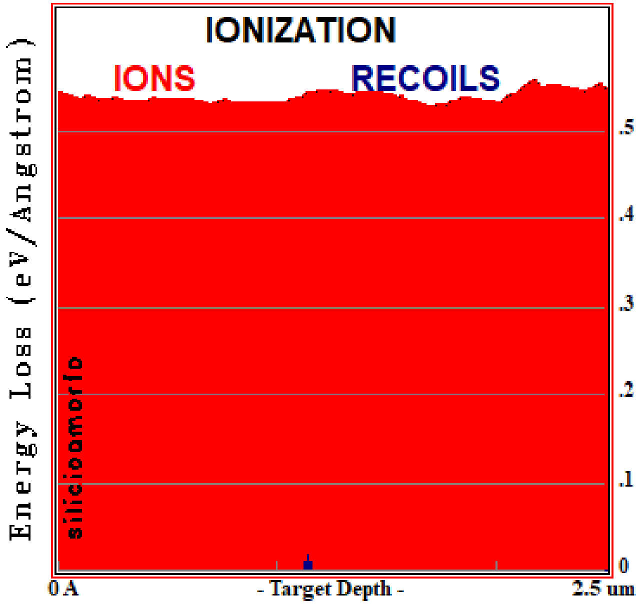
FROM FLUX TO DOSE RATE

SOME STEPS FOR DOSE RATE CALCULATION

- Detector K1 P3

- Given the energy of the protons (16.7 MeV), we evaluated the energy lost by a proton crossing the detector using SRIM:

$$5.5\ \text{keV/um} \times 2.5\ \text{um} = 1.37 \cdot 10^{4}\ \text{eV/proton}$$



- Given the volume and density of the detector we can estimate the energy
- released by 1 Gy of protons:

Volume of the detector = 2.00 x 2.00 x0.025 mm^3 = 0.01 mm^3
Density of a-Si:H = 2.1g/cm3
Energy needed to create an e/h pair ≈ 4.5 eV

$$1\ \text{Gy} = 6.25 \cdot 10^{15}\ \text{eV/g}$$

- The energy released in 0.01 mm^3 of detector volume by 1 Gy of proton dose is $1.31 \cdot 10^{11}$ eV

- To deposit 1 Gy of dose in our detector we need: $$\frac{1.31 \cdot 10^{11}\ \text{eV}}{1.37 \cdot 10^{4}\ \text{eV/proton}} = 9.6 \cdot 10^{6}\ \text{protons}$$

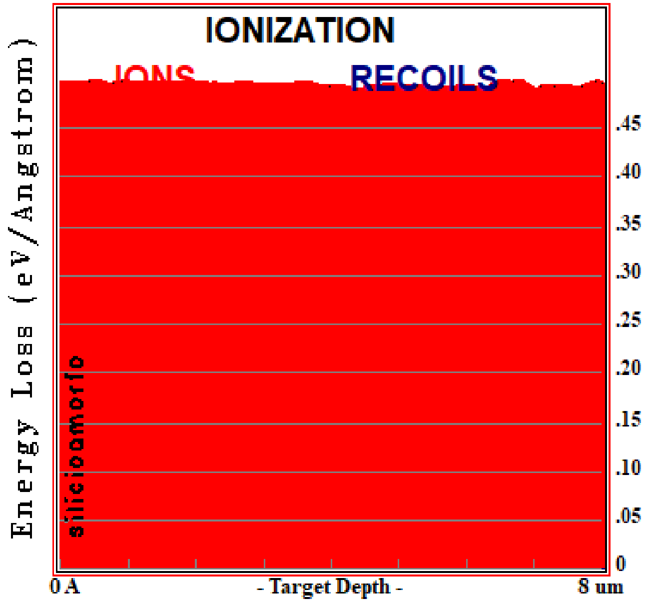
FROM FLUX TO DOSE RATE

SOME STEPS FOR DOSE RATE CALCULATION

- **Detector A3AC 1**

- Given the energy of the protons (16.7 MeV), we evaluated the energy lost by a proton crossing the detector using SRIM:

  $5\ keV/um \times 8.2\ um = 4.1 \cdot 10^4\ eV/proton$



- Given the volume and density of the detector we can estimate the energy
- released by 1 Gy of protons:

  Volume of the detector = $4.00 \times 4.00 \times 0.082\ mm^3 = 0.01\ mm^3$
  Density of a-Si:H = 2.1g/cm3
  Energy needed to create an e/h pair ≈ 4.5 eV

  $1\ Gy = 6.25 \cdot 10^{15}\ eV/g$

- The energy released in $0.13\ mm^3$ of detector volume by 1 Gy of proton dose is $1.71 \cdot 10^{12}$ eV

- To deposit 1 Gy of dose inside the detector we need: $\frac{1.71 \cdot 10^{12}\ eV}{4.1 \cdot 10^4\ eV/proton} = 4.17 \cdot 10^7$ protons

FROM FLUX TO DOSE RATE

SOME STEPS FOR DOSE RATE CALCULATION

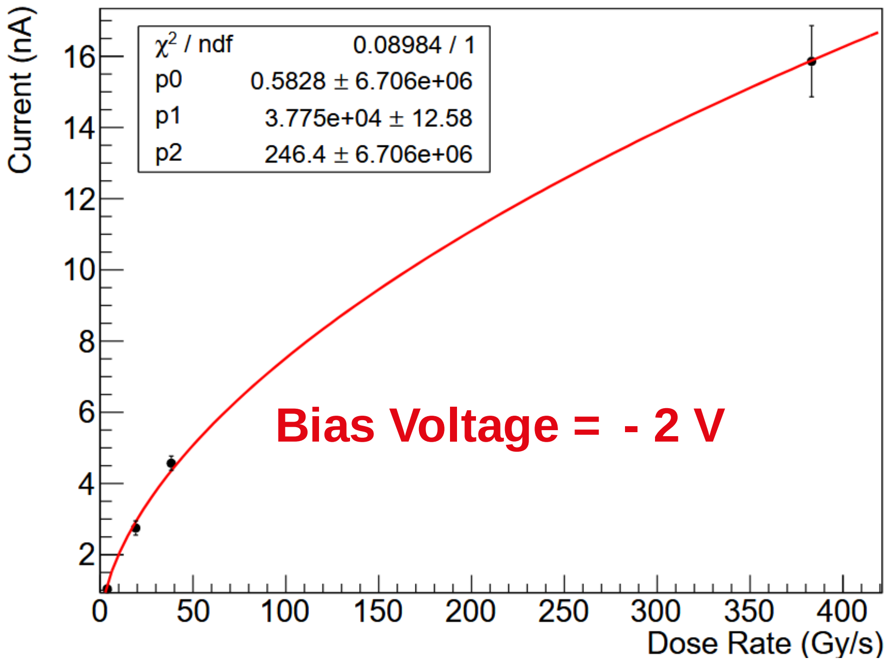
Hence, we expect $9.6 \cdot 10^6$ protons/s in 0.04 cm^2 and $4.17 \cdot 10^7$ protons/s for a 1 Gy dose deposition which corresponds to about $2.7 \cdot 10^8$ protons/cm^2

Proton Flux (p/cm^2s)	Dose Rate (Gy/s)
10^8	0.38
$5 \cdot 10^8$	1.92
10^9	3.83
$5 \cdot 10^9$	19.16
10^{10}	38.31
$5 \cdot 10^{10}$	191.60
10^{11}	383.14

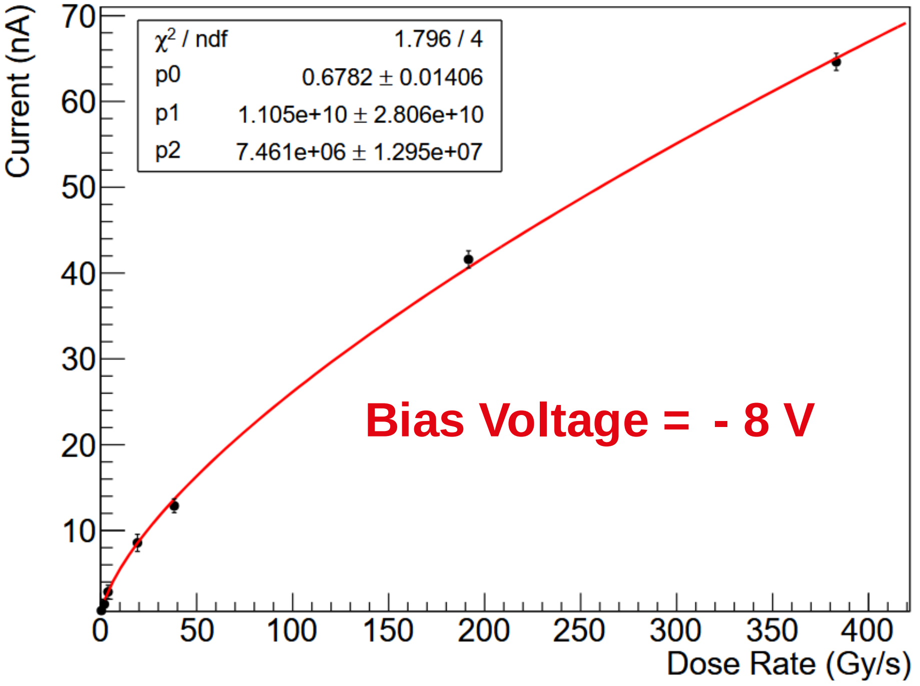
DOSE RATE SCAN

Detector K1 P3

We studied the detector response with a fixed bias voltage and different proton fluxes.



- **Detector K1 P3**
- E_{Beam} = 16.7 MeV
- Beam dimension = 2x2 cm^2
- **Bias Voltage = - 8 V & -2 V**

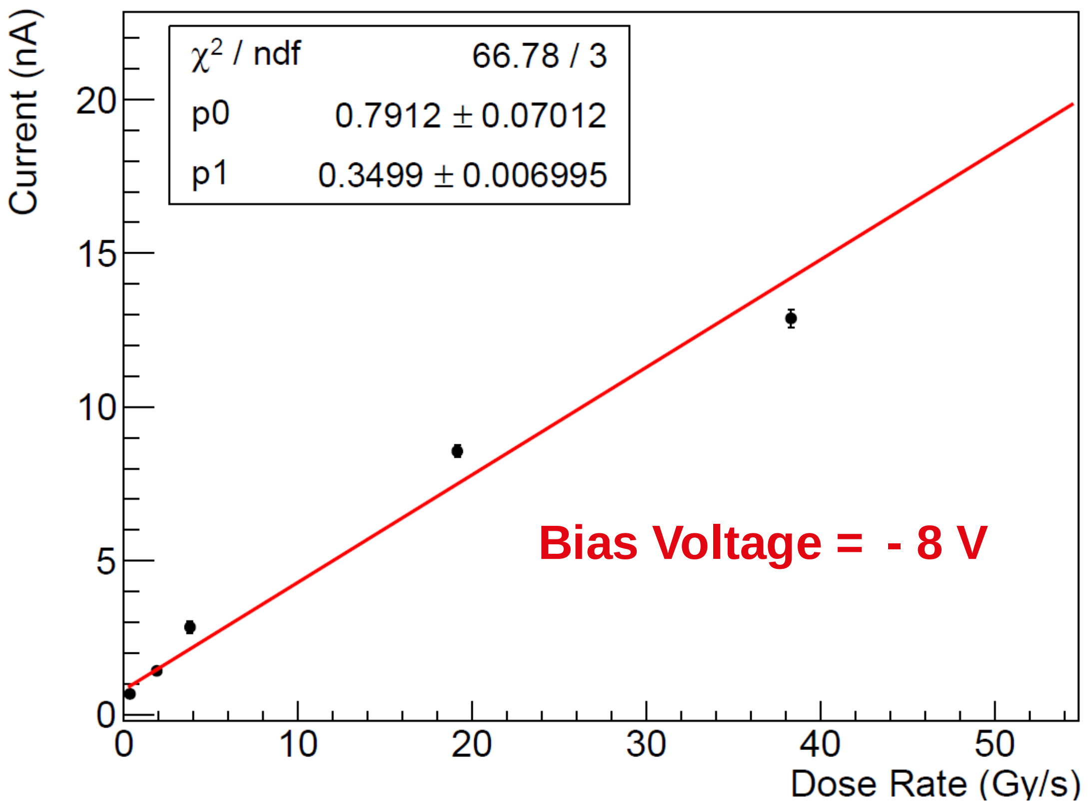


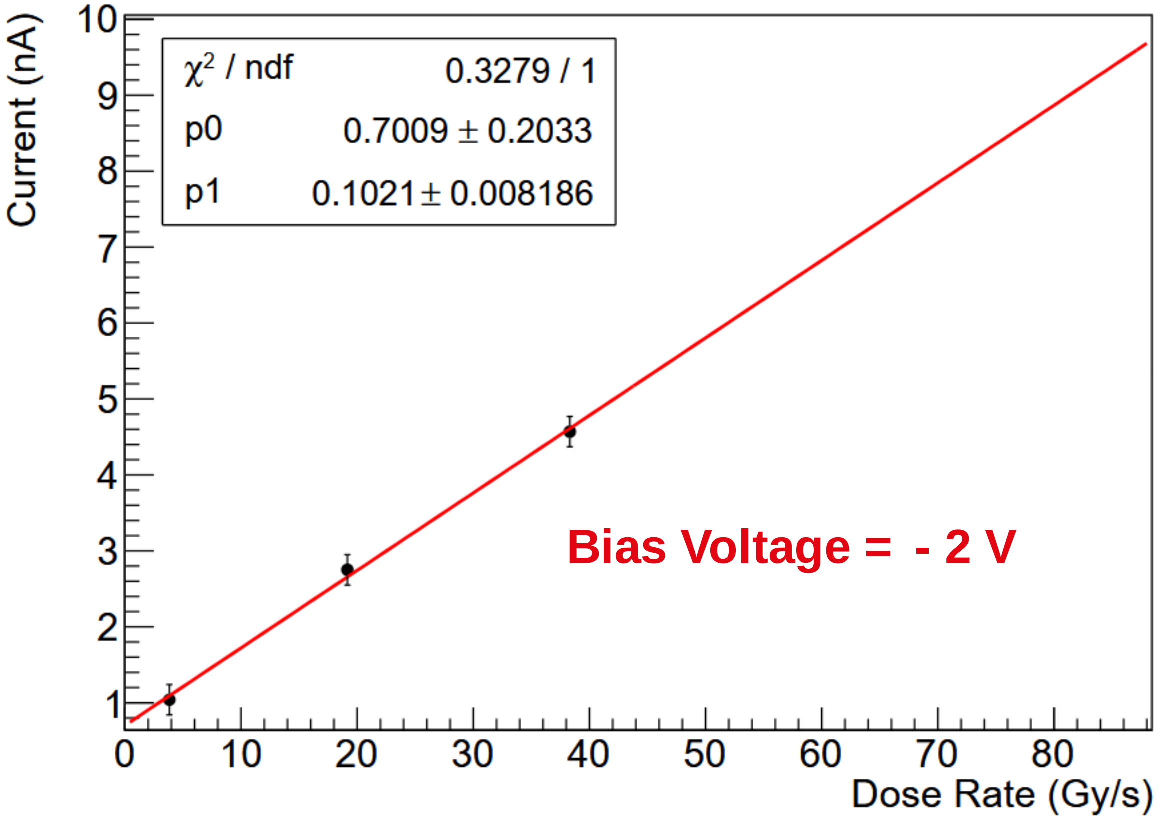
Proton Flux (p/cm^2s)
10^8
$5 \cdot 10^8$
10^9
$5 \cdot 10^9$
10^{10}
$5 \cdot 10^{10}$
10^{11}
$5 \cdot 10^{11}$

DOSE RATE SCAN

Detector K1 P3

We studied the detector response with a fixed bias voltage and different proton fluxes / **dose rates**.

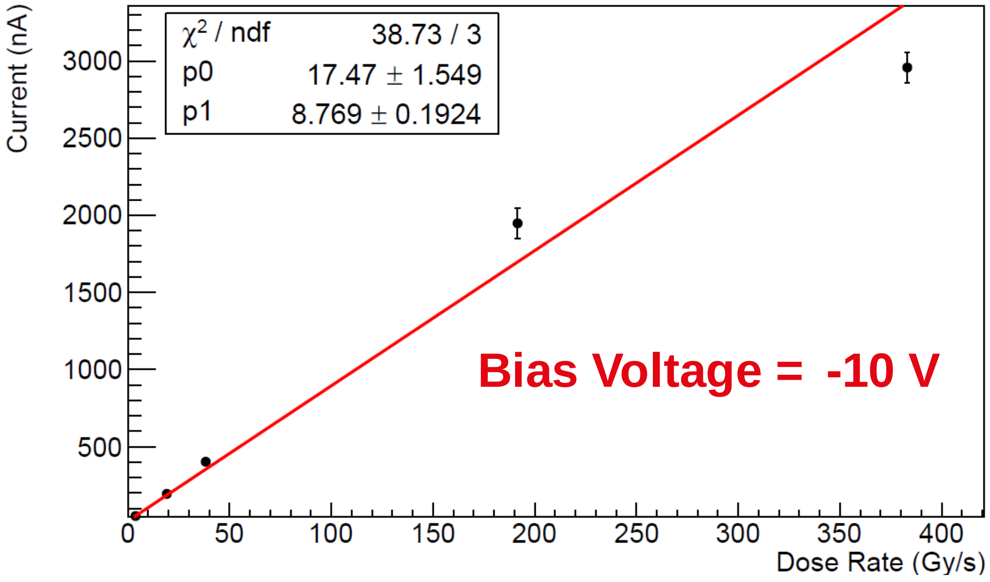




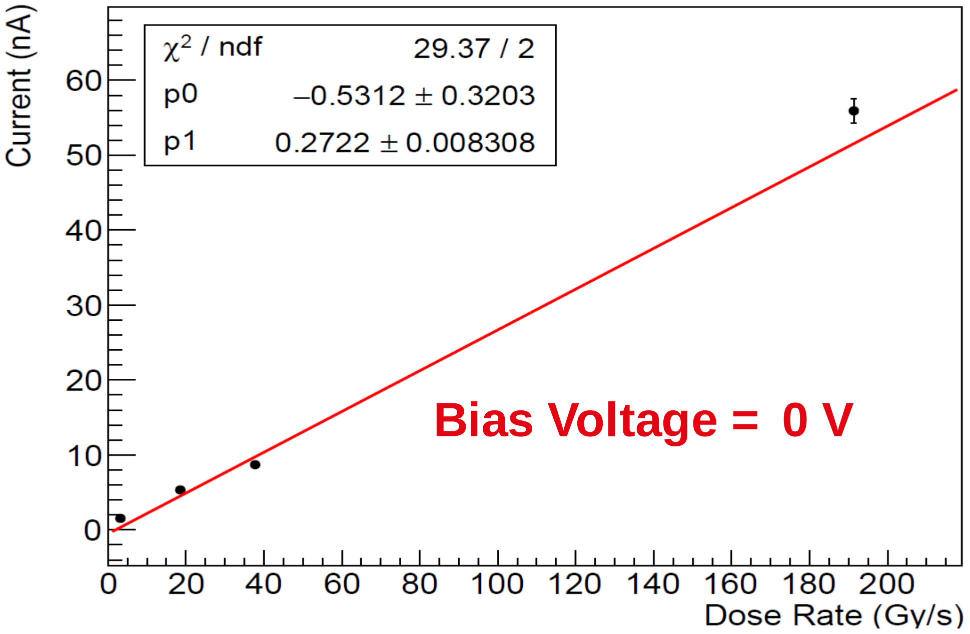
DOSE RATE SCAN

Detector A3AC 1

We studied the detector response with a fixed bias voltage and different proton fluxes / dose rates.



- **Detector A3AC 1**
- E_{Beam} = 16.7 MeV
- Beam dimension = 2x2 cm^2
- **Bias Voltage = -10 V & 0 V**



Proton Flux (p/cm^2s)
10^9
$5 \cdot 10^9$
10^{10}
$5 \cdot 10^{10}$
10^{11}

SENSITIVITY

DOSE RATE VS DETECTOR RESPONSE

1

- **Detector K1 P3**
- E_{Beam} = 16.7 MeV
- Intrinsic layer = 2.5 um
- **Bias Voltage = - 8 V**

→ ≈ 0.35 nC/Gy

- **Detector K1 P3**
- E_{Beam} = 16.7 MeV
- Intrinsic layer = 2.5 um
- **Bias Voltage = - 2 V**

→ ≈ 0.10 nC/Gy

2

- **Detector A3AC 1**
- E_{Beam} = 16.7 MeV
- Intrinsic layer = 8.2 um
- **Bias Voltage = -10 V**

→ ≈ 8.80 nC/Gy

- **Detector A3AC 1**
- E_{Beam} = 16.7 MeV
- Intrinsic layer = 8.2 um
- **Bias Voltage = 0 V**

→ ≈ 0.27 nC/Gy

EFFICIENCY

SOME STEPS FOR EFFICIENCY CALCULATION

How many e/h pairs are generated by 1 Gy of dose?

- **Detector K1 P3**

- **The energy released in 0.01 mm^3 of detector volume by 1 Gy of proton dose ≈ $1.31 \cdot 10^{11}$ eV**
- **The energy needed to create an e/h pair ≈ 4.5 eV**

$2.91 \cdot 10^{10}$ e/h pairs

The charge generated in 1s

$1.6 \cdot 10^{-19} \times 2.91 \cdot 10^{10} = 4.64 \cdot 10^{-9}$ C/s

1 Gy/s of dose rate generates a maximal current of 4.64 nA

EFFICIENCY

SOME STEPS FOR EFFICIENCY CALCULATION

- **Detector A3AC 1**

How many e/h pairs are generated by 1 Gy of dose?

- **The energy released in 0.13 mm^3 of detector volume by 1 Gy of proton dose ≈ $1.71 \cdot 10^{12}$ eV**
- **The energy needed to create an e/h pair ≈ 4.5 eV**

↓

$3.81 \cdot 10^{11}$ e/h pairs

The charge generated in 1s ↓

$1.6 \cdot 10^{-19} \times 3.81 \cdot 10^{11} = 6.08 \cdot 10^{-8}$ C/s

↓

1 Gy/s of dose rate generates a maximal current of 60.80 nA

EFFICIENCY

MAXIMAL EXPECTED CURRENT VS DETECTOR RESPONSE

1

- **Detector K1 P3**
- E_{Beam} = 16.7 MeV
- Intrinsic layer = 2.5 um
- **Bias Voltage = - 8 V**

→ ≈ 8.0 %

- **Detector K1 P3**
- E_{Beam} = 16.7 MeV
- Intrinsic layer = 2.5 um
- **Bias Voltage = - 2 V**

→ ≈ 2.2 %

2

- **Detector A3AC 1**
- E_{Beam} = 16.7 MeV
- Intrinsic layer = 8.2 um
- **Bias Voltage = -10 V**

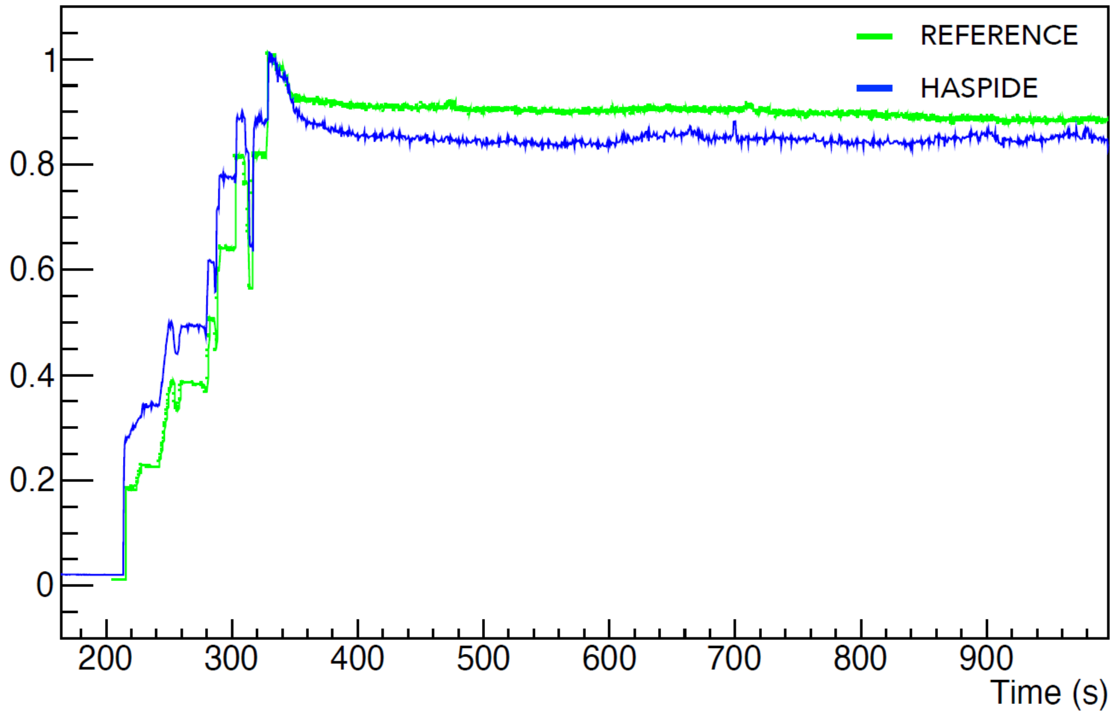
→ ≈ 14.5 %

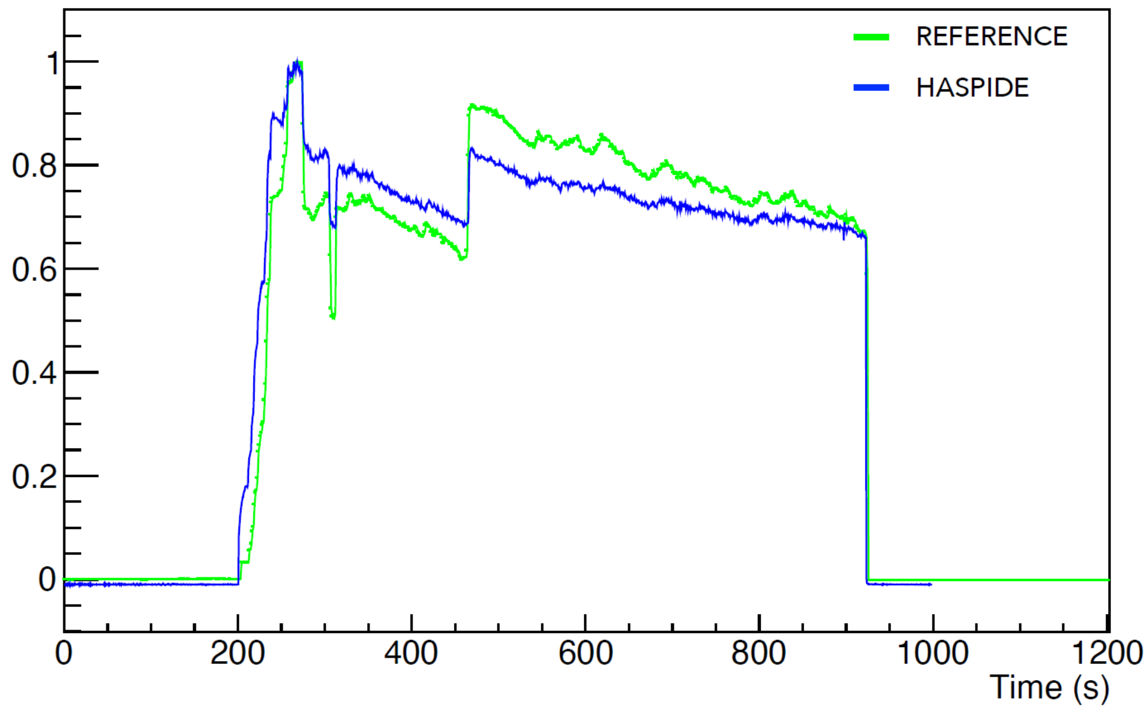
- **Detector A3AC 1**
- E_{Beam} = 16.7 MeV
- Intrinsic layer = 8.2 um
- **Bias Voltage = 0 V**

→ ≈ 0.5 %

BEAM VS DETECTOR

COMPARISON BETWEEN BEAM AND DETECTOR RESPONSE





The detector was able to follow the beam with a good approximation. In some of the runs it was impossibile to define a precise dose rate (proton flux) for a given time interval.

CONCLUSIONS

Detector K1 P3

- Linear detector response with the bias voltage
- Approximately linear response as a function of dose rate (up to 50 Gy/s)
- Higher sensitivity for the highest bias voltage (0.35 nC/Gy at -8 V)
- Higher efficiency at the highest bias voltage (8.0 % at -8 V)

Detector A3AC 1

- Saturation of the current response with the bias voltage
- Approximately linear response as a function of dose rate (up to 200 Gy/s)
- Higher sensitivity for the highest bias voltage (8.80 nC/Gy at -10 V)
- Higher efficiency at the highest bias voltage (14.5 % at -10 V)

RESULTS

It seems that a thicker a-Si intrinsic layer results in better linearity and higher sensitivity and efficiency for a certain range of dose rates.

The linearity and sensitivity of the tested detectors can be improved by optimizing the material properties, the device structure and the operating conditions.

Thank you

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