Conception of prompt-gamma detector for online ion therapy monitoring

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On behalf of the TIARA collaboration

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Prompt-Gamma (PG) ion therapy monitoring

Ion therapy:

- ✓ **High ballistic precision**
- ✗ **Uncertainties** on ion range estimation

Online ion therapy monitoring:

- Real time **Bragg Peak** location by detection of **secondary particles**: **Prompt Gamma**

⇒ Improvement of treatment accuracy

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PG features

- ✗ $1 < E_{P_G} < 10$ MeV
- ✗ **0.01** $\gamma.p^{-1}.cm^{-1}$
- ✓ **PG spatial correlation**
- ✓ $\langle T_{PG} \rangle < 1$ ps $\Rightarrow$ **Time correlation**

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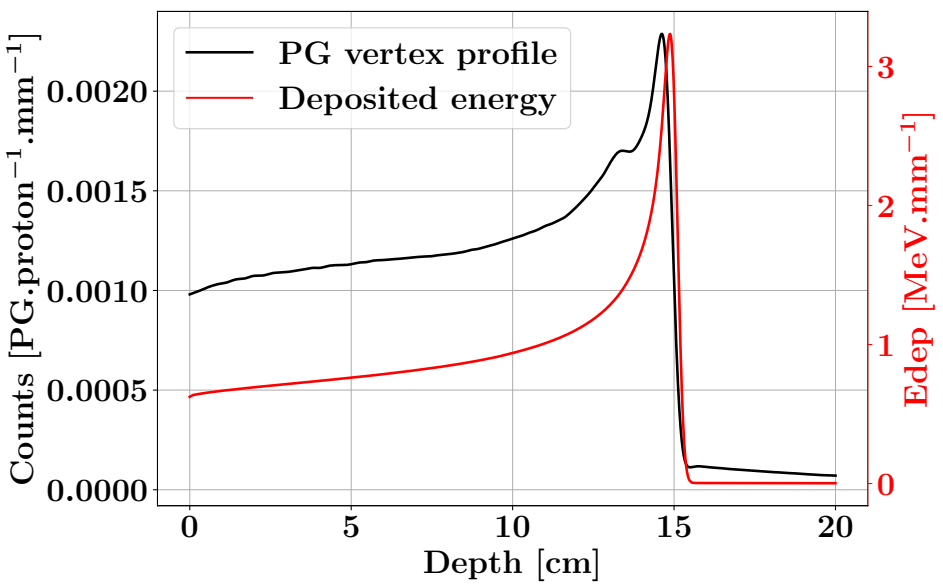

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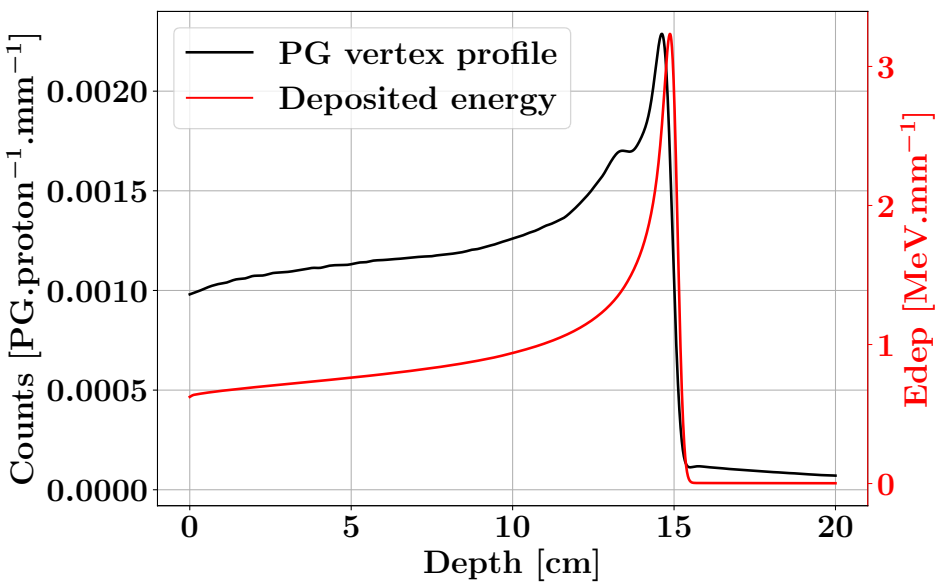
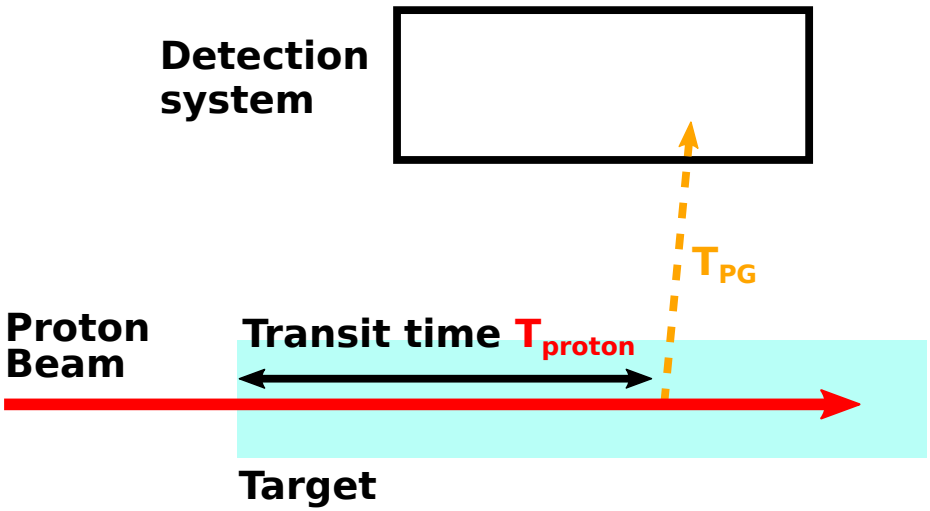


Time Of Flight(TOF) online monitoring

PG Timing (PGT): concept



$T_{proton} + T_{PG}$ distribution measurement

- ✓ **Monitoring in real time**
- ✓ High detection efficiency
- ✓ Neutron rejection by TOF
- ✗ TOF limited at the bunch width

$\Rightarrow$ Time resolution $\approx$ **1 ns** rms

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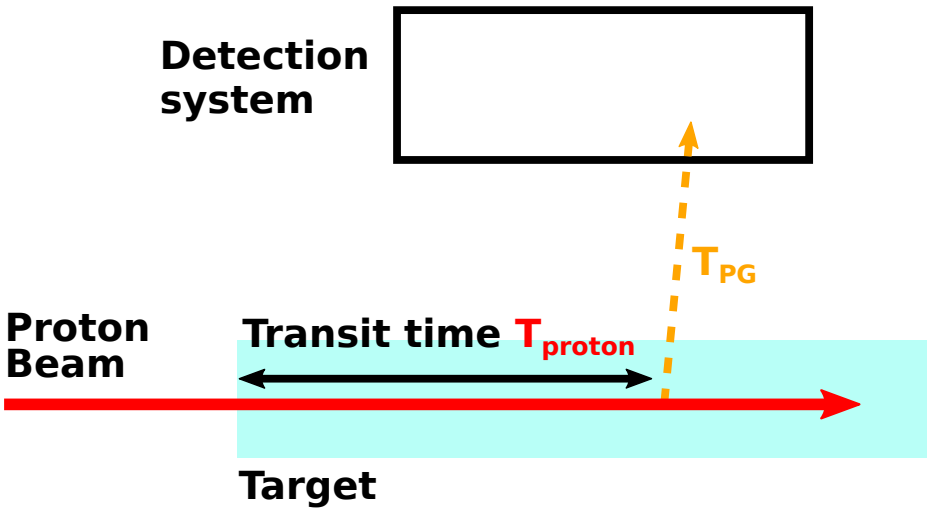

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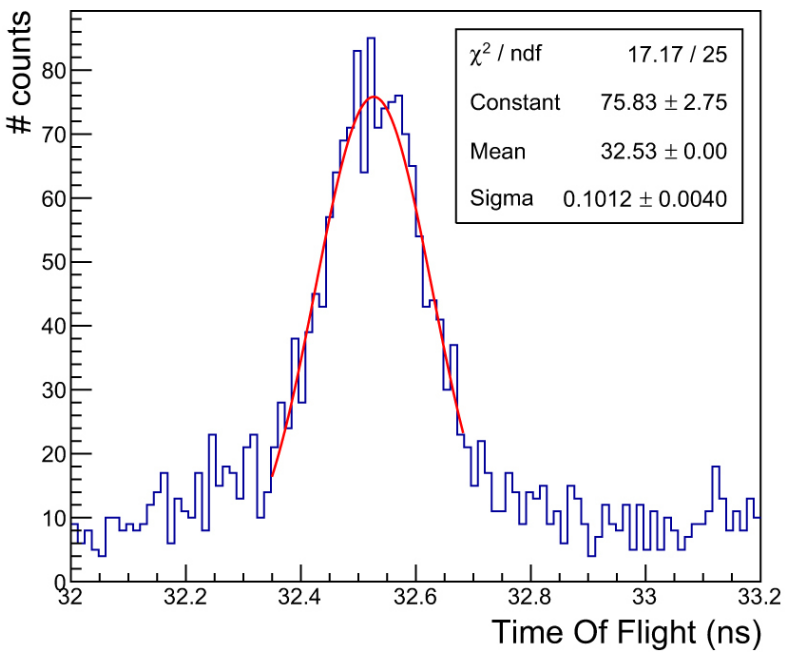

Marcatili et al 2020 Phys. Med. Biol. 65 245033

Increase PGT sensitivity:

- Single proton regime
- Diamond beam monitor

Time resolution: **101 ps rms**

Prompt Gamma Time Imaging

Goal: proton range estimation at the **very beginning of the irradiation** (10^7-10^8 protons) in single proton regime

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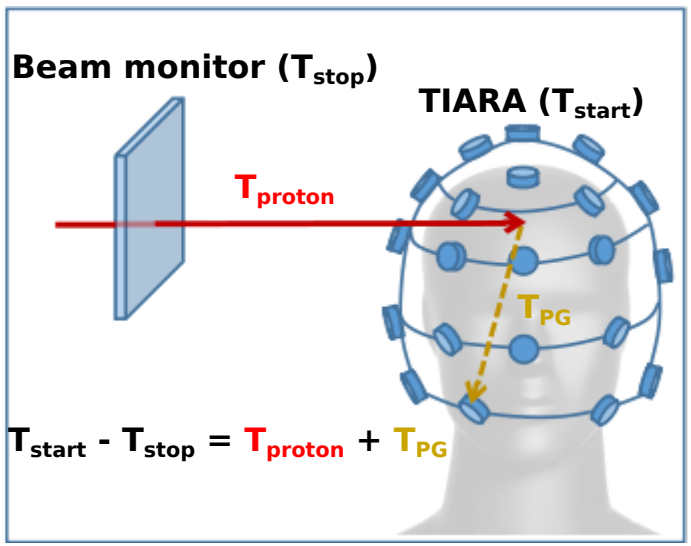
Diamond-based beam monitor

Time of flight Imaging ArRAy (TIARA):

- $\approx$ 30 small-size Cerenkov radiators

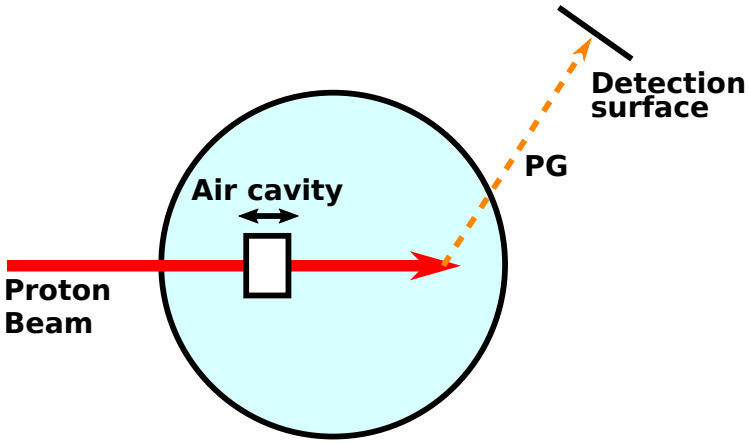
Vertex Reconstruction:

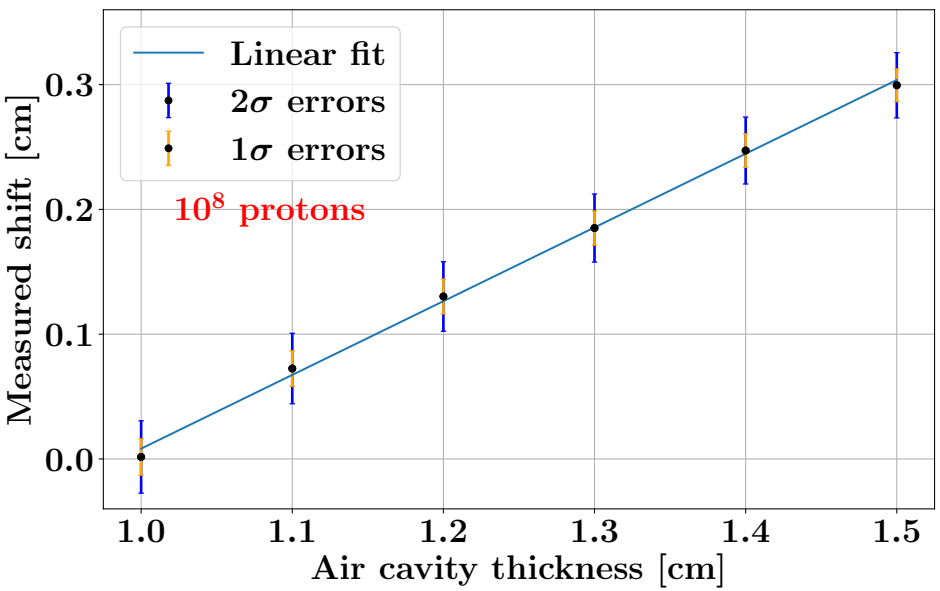
$$T_{Start} - T_{Stop} = T_{proton} + T_{PG}$$



Simulation: Detection of a proton range shift

Longitudinal shift sensitivity





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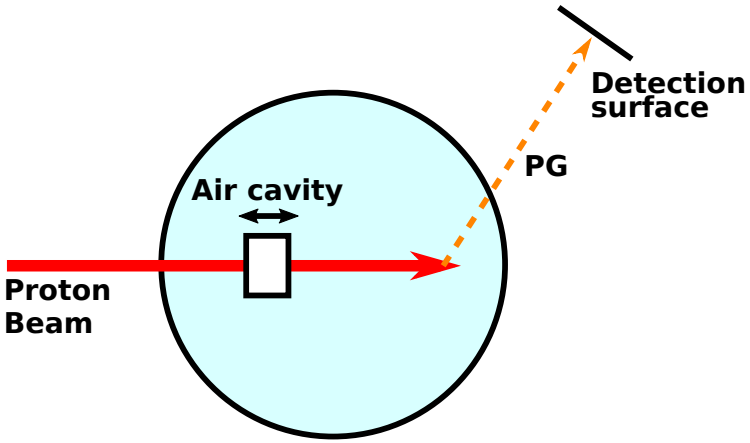
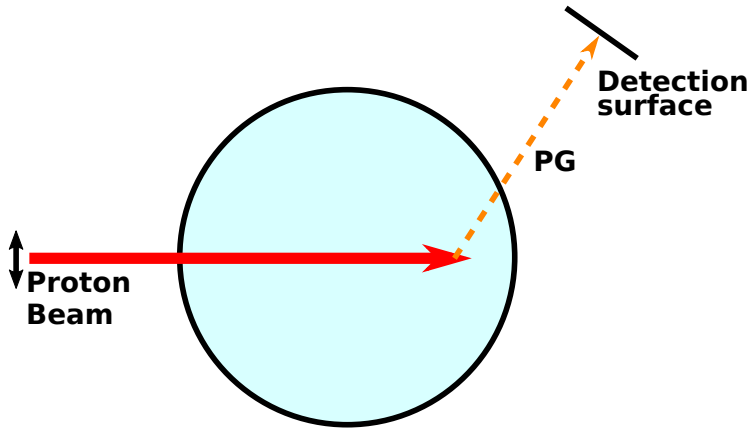
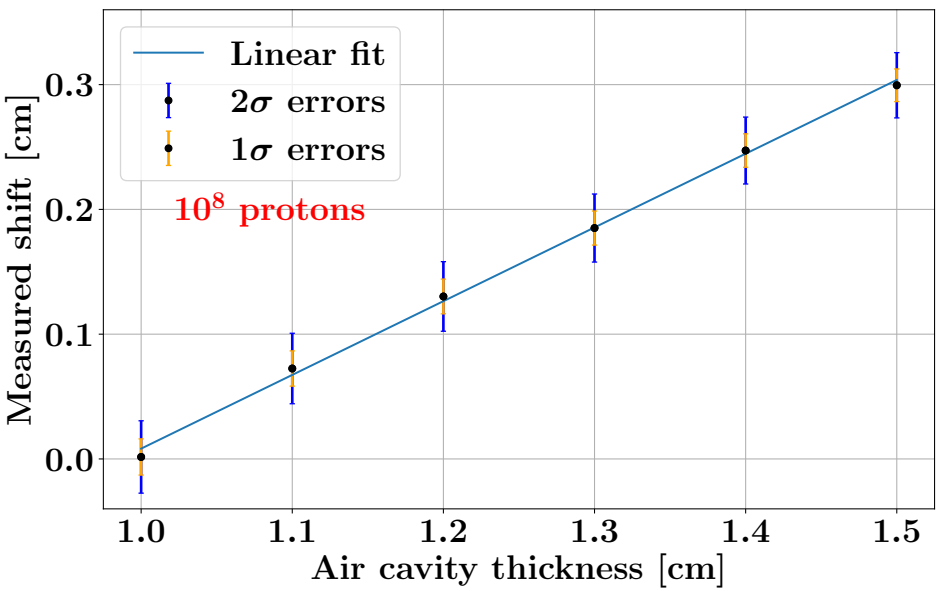
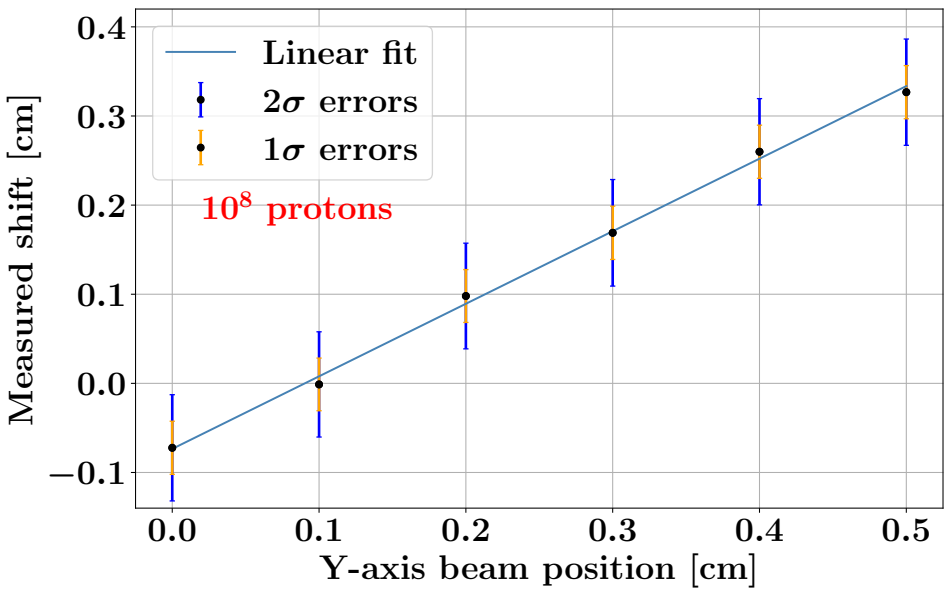


Transverse shift sensitivity







Simulation results

	Longitudinal shift		**Transverse shift**
Number of protons	10^7	10^8	10^8
Number of PG detected	3×10^3	3×10^4	3×10^4
Expected sensitivity at 1σ (mm)	2	1	1
Expected sensitivity at 2σ (mm)	3	**1**	**2**

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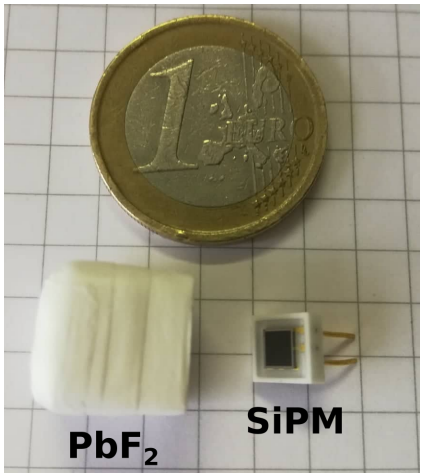
A time-of-flight-based reconstruction for real-time prompt-gamma imaging in proton therapy

https://doi.org/10.1088/1361-6560/ac03ca

Characterization of TIARA pixel detector



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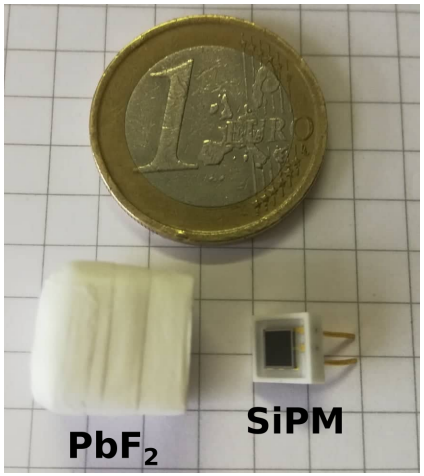
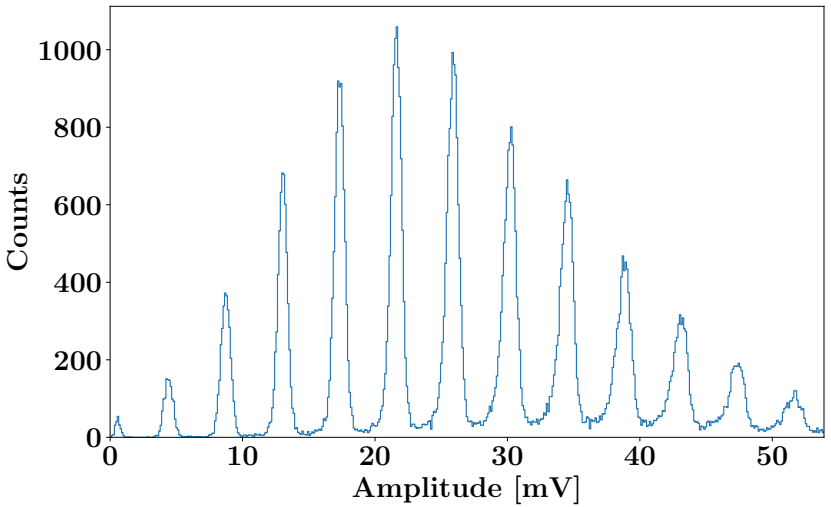


SiPM photon counting mode



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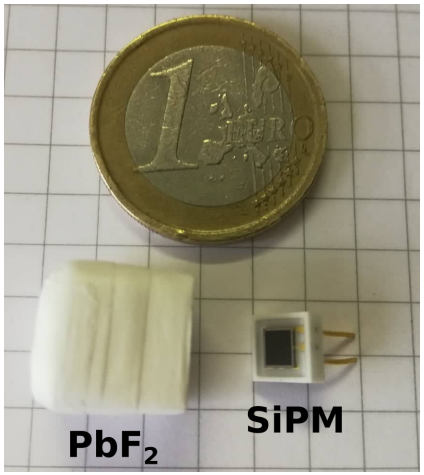

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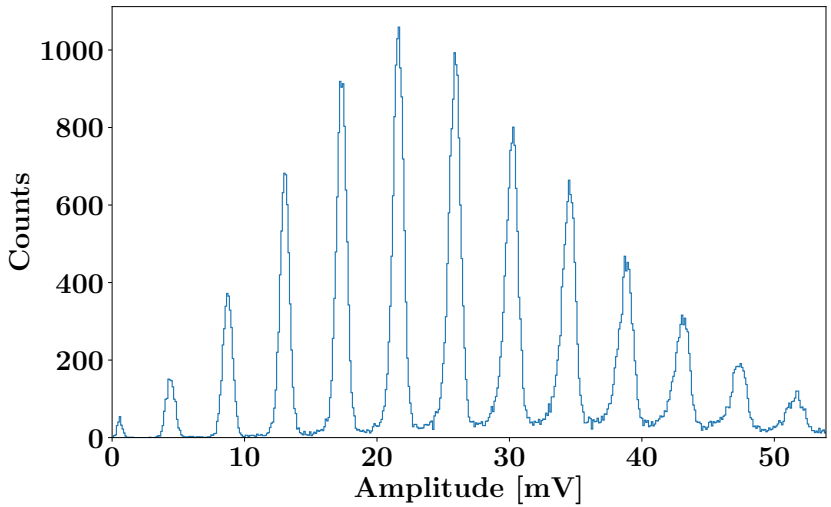
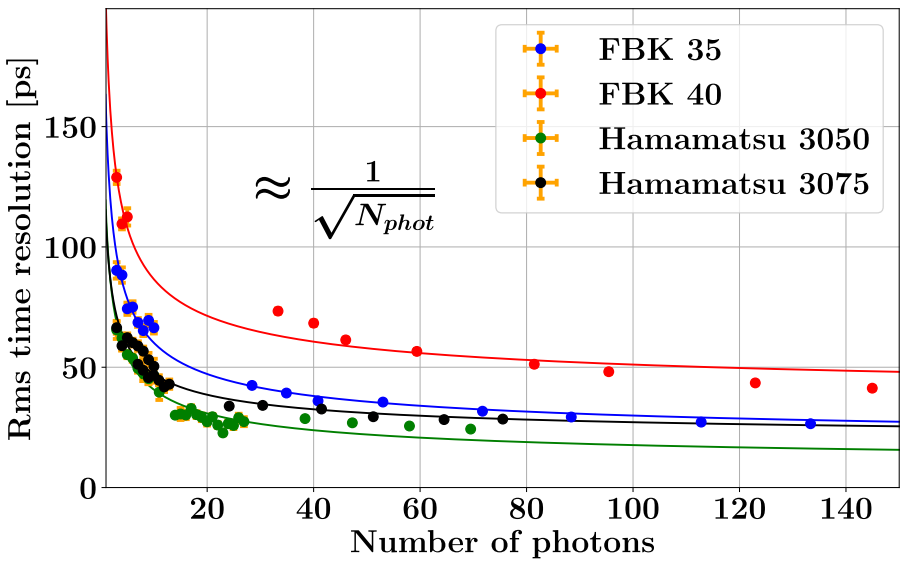


Intrinsic SiPM time resolution



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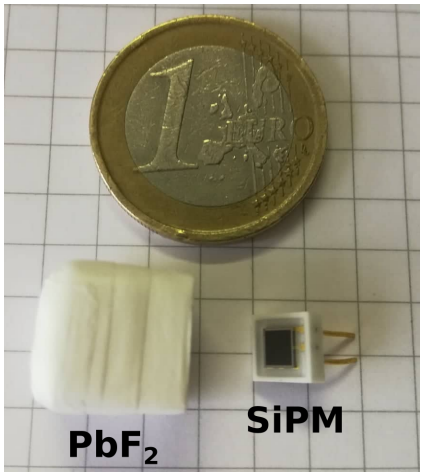

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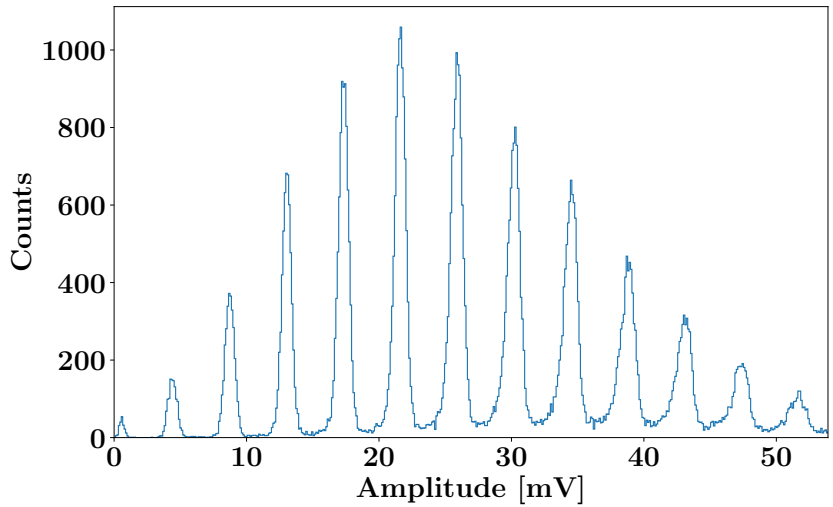

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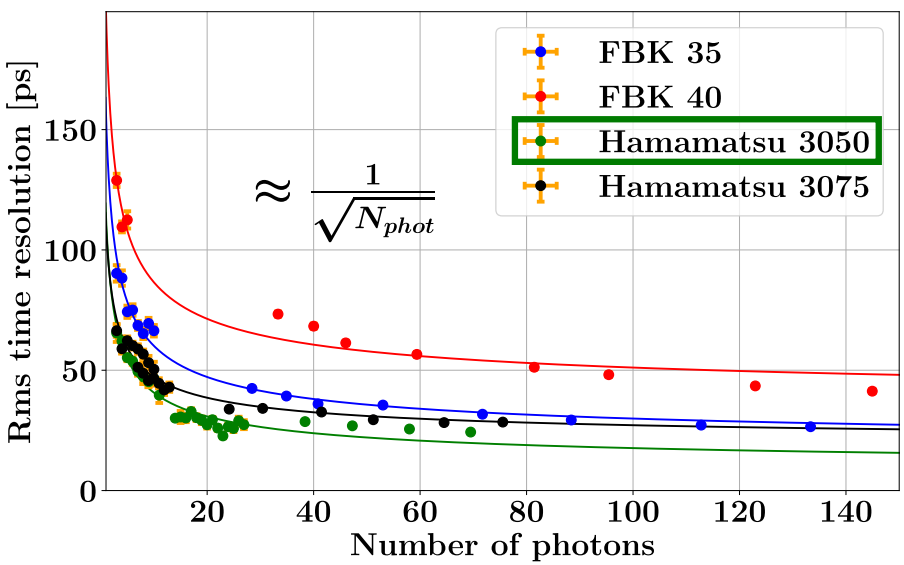
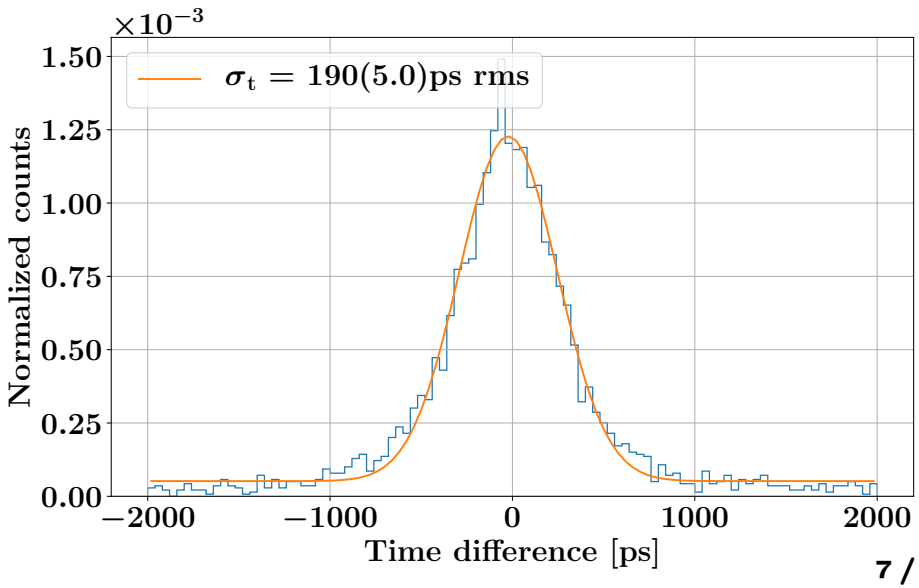


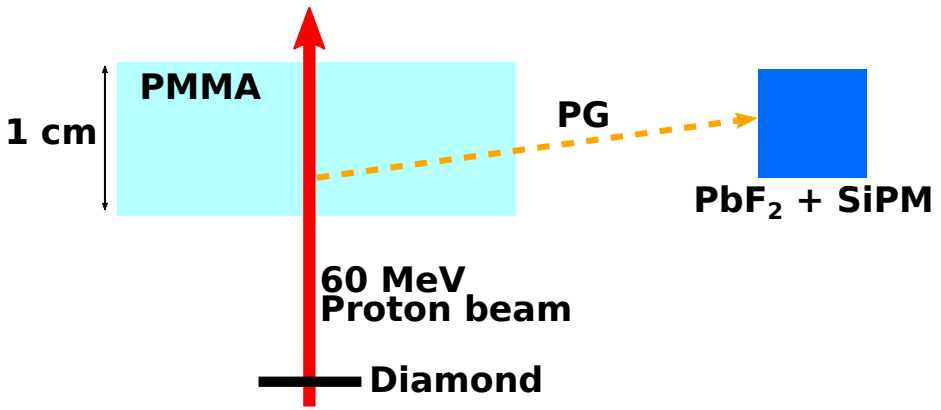
Time resolution of Cerenkov + SiPM with ^{60}Co



Experiments: performance of our detection system

Experiment 1 of June 2021:

- 60 MeV proton beam irradiation
- 1 cm thick PMMA



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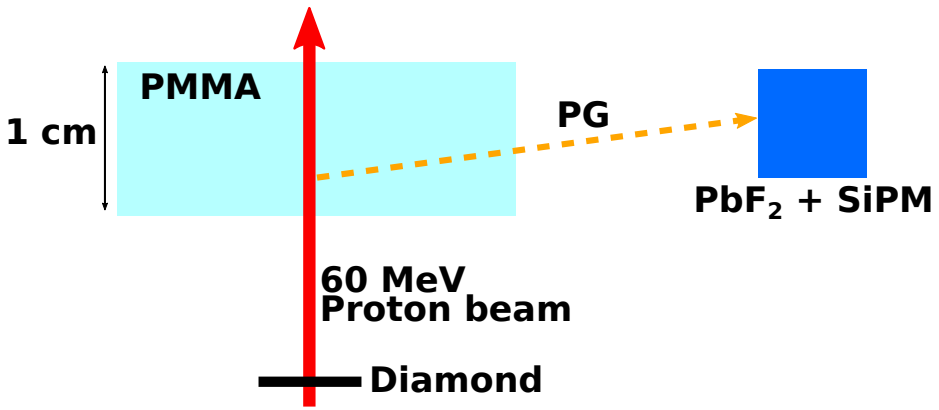

Antoine Lacassagne
CENTRE DE LUTTE CONTRE LE CANCER
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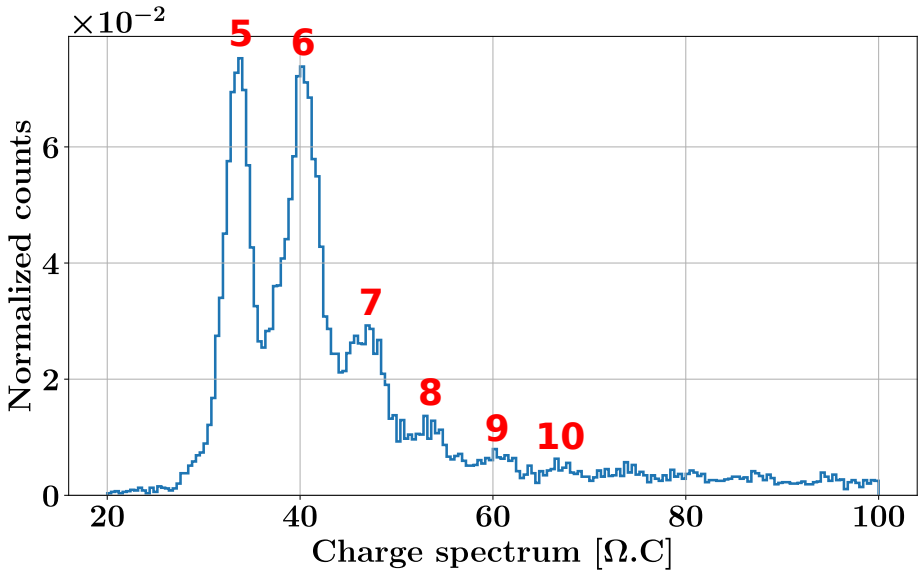
Number of detected optical photons



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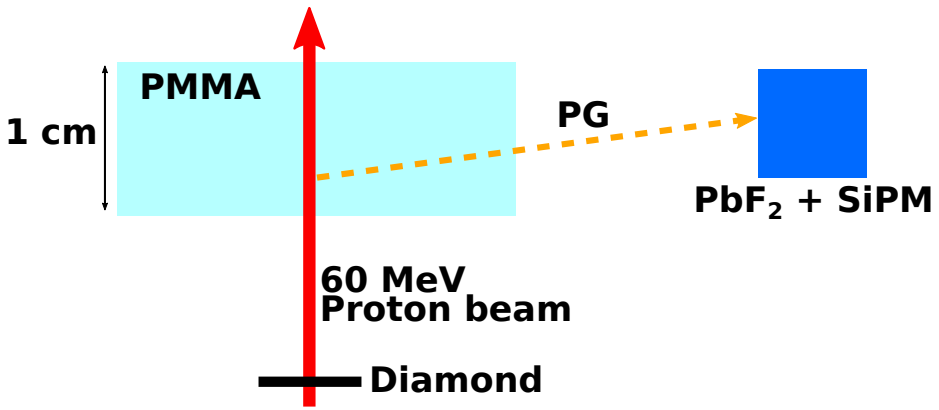

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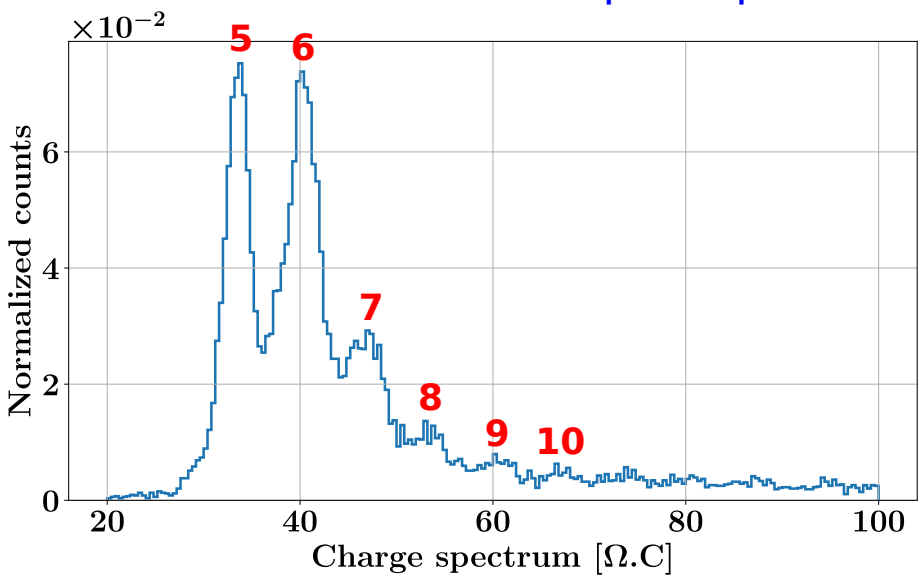

Pixel time resolution