IEEE NUCLEAR & PLASMA SCIENCES SOCIETY
2012 Nuclear Science Symposium, Medical Imaging Conference
& Workshop on Room-Temperature Semiconductor X-Ray and Gamma-Ray Detectors
October 29 - November 3, 2012, Disneyland Hotel, Anaheim, California

Proton Interaction Vertex Imaging with Silicon-Pixel CMOS Telescopes for Carbon Therapy Quality Control

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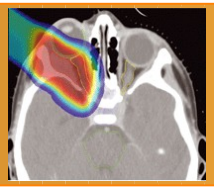
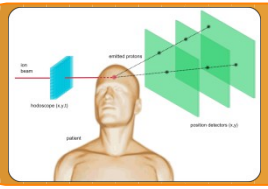
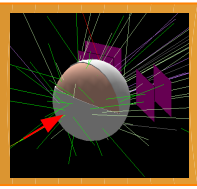
Outline



1. Ion therapy and range verification



2. Interaction Vertex Imaging principle
   Simulation results



3. Experimental results

4. Conclusion and perspectives

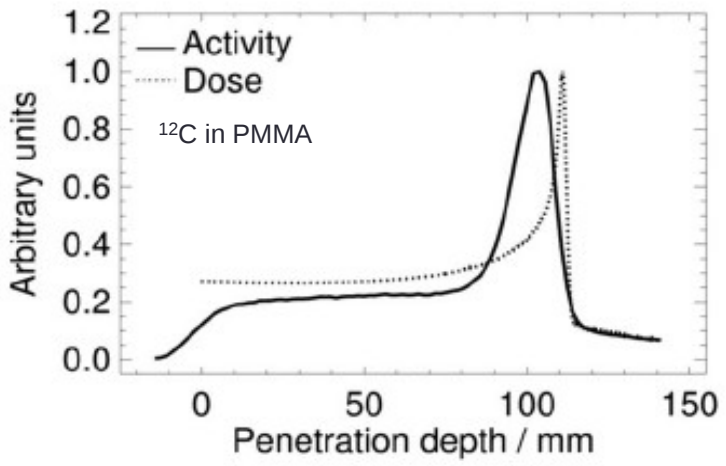
Physical principles of range verification

- Correlation between ion range and nuclear reaction depth profile

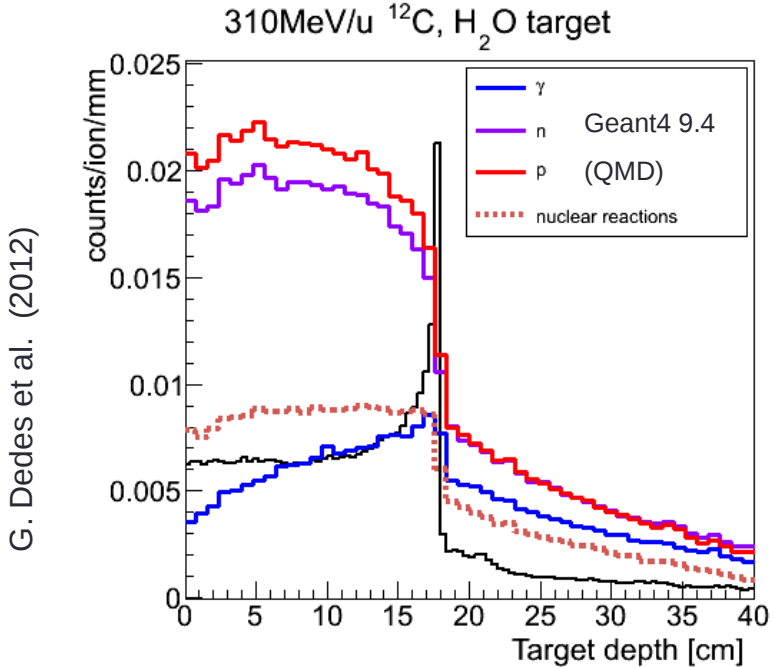
- Two kinds of radiations
  - § β^+ activity
  - § Prompt radiation
    - Ø γ-rays
    - Ø Neutron
    - Ø Proton

U. Amaldi et al., *Nucl. Instrum. Methods* **A 617** 248–9 (2010)

Parodi *et al.* (2005)



G. Dedes et al. (2012)

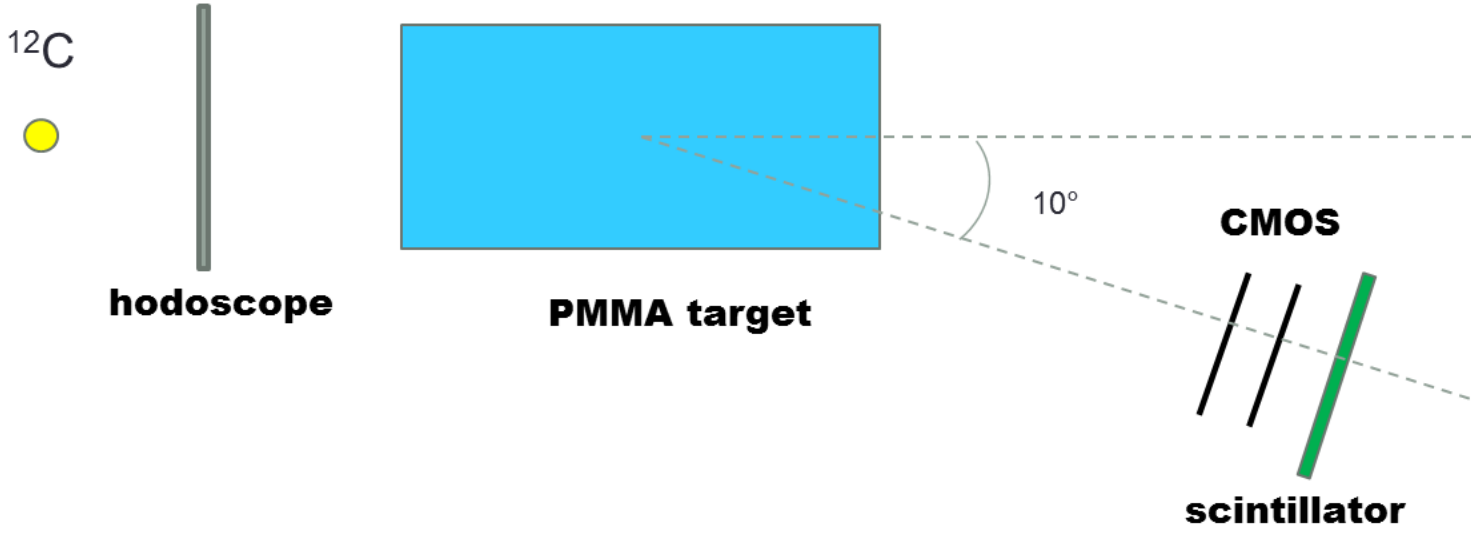


Proton Interaction Vertex Imaging

Prompt radiation for ion range verification in ion therapy

Proton Interaction Vertex Imaging

- Principle
  - § Detection of secondary protons emitted from incident ions
    ⇒ Determination of nuclear reaction positions (vertex)
  - § Detectors
    - Ø Tracker (CMOS sensors)
    - Ø Beam hodoscope (scintillating fibers)



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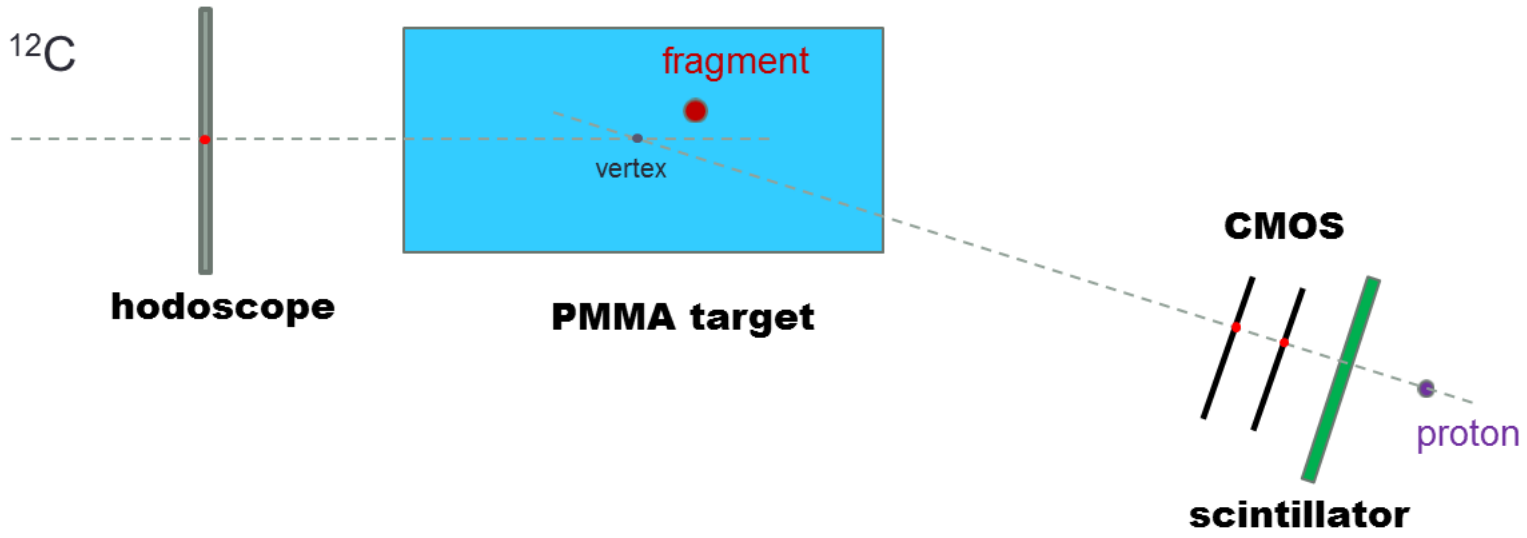
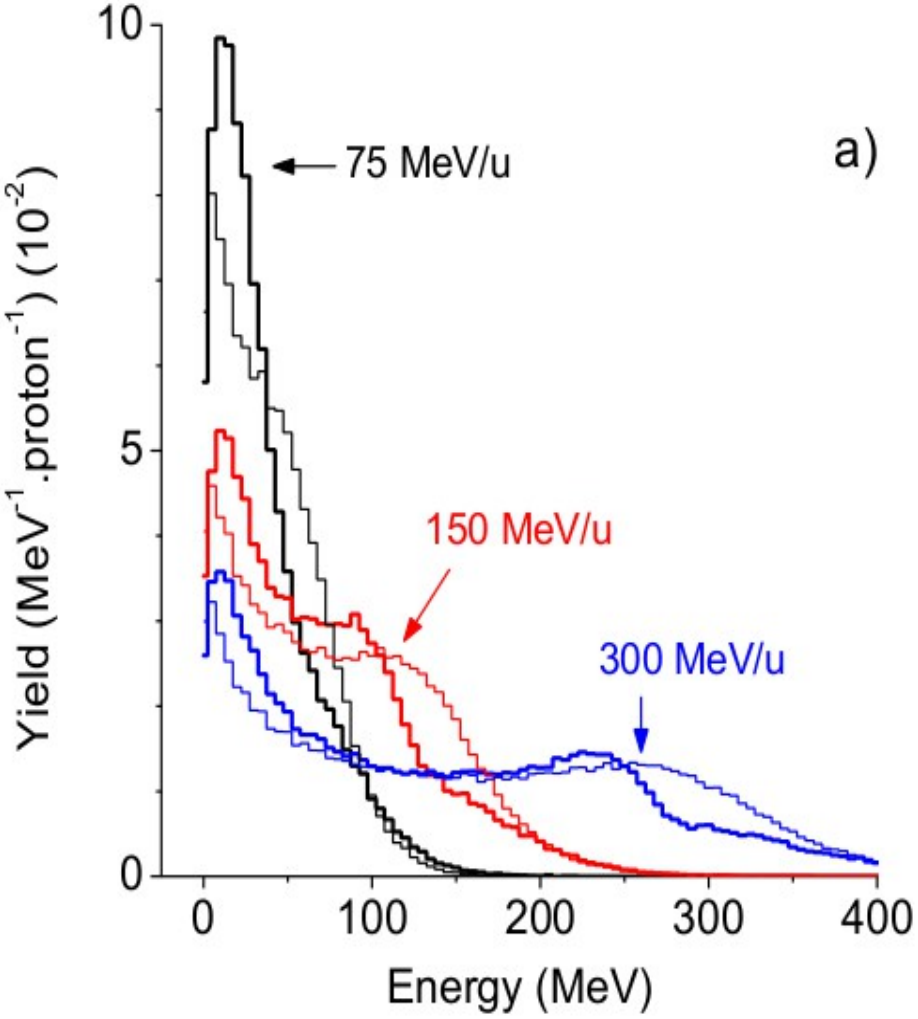
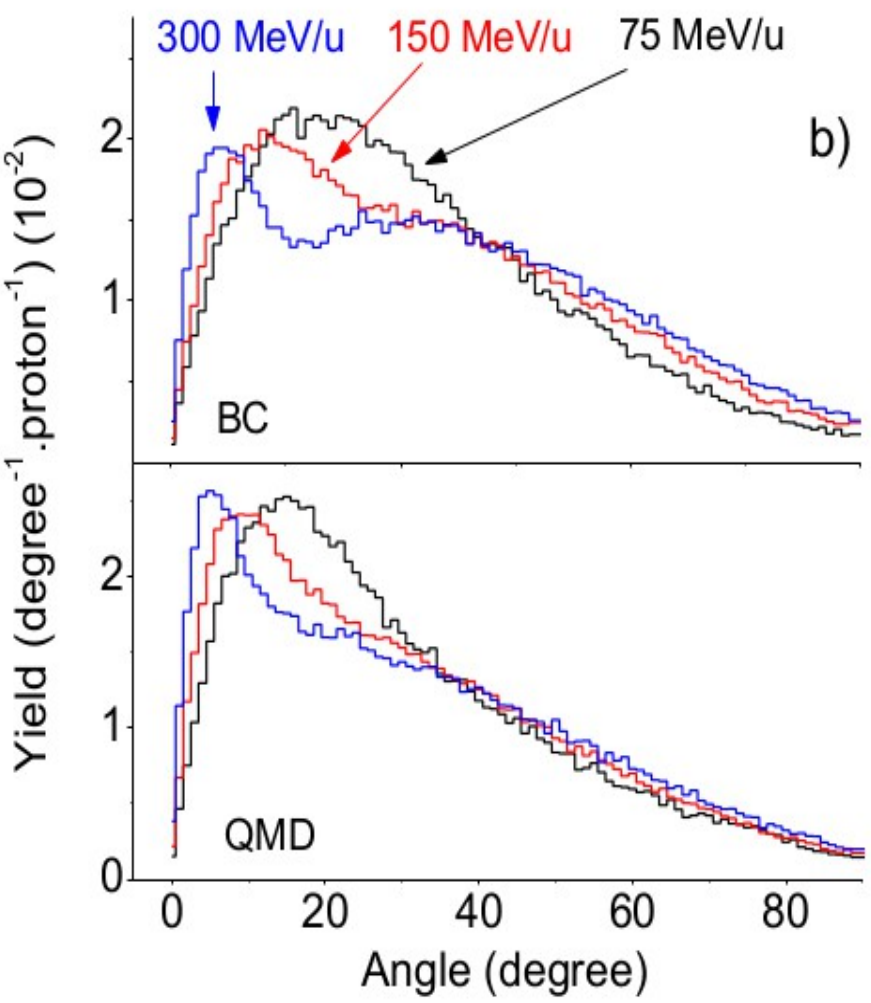


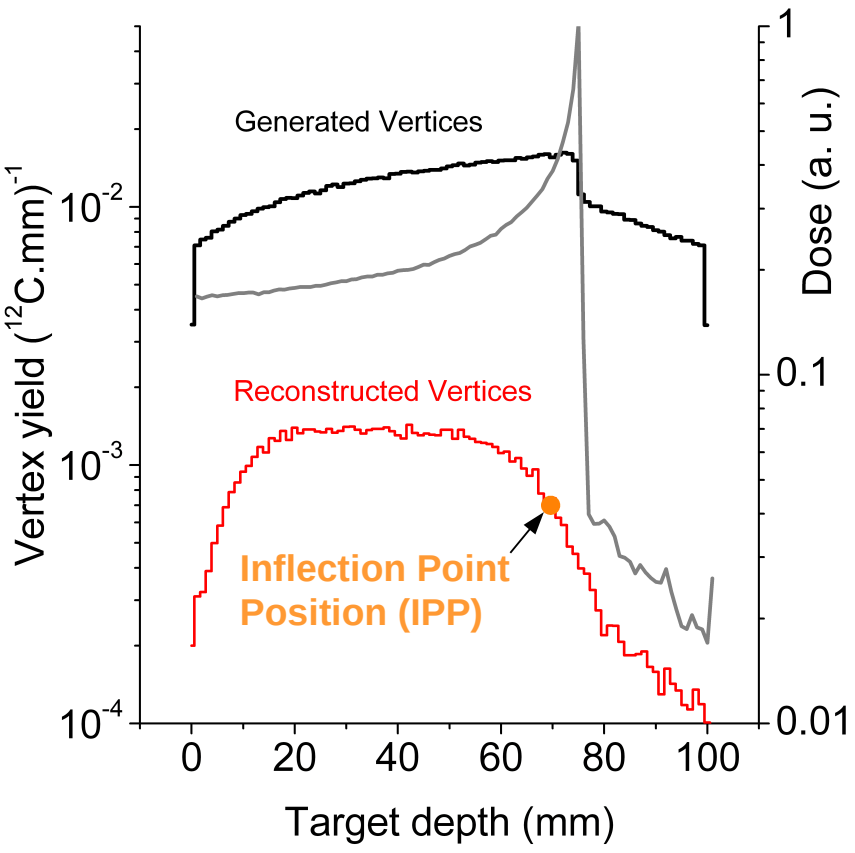
Proton Interaction Vertex Imaging



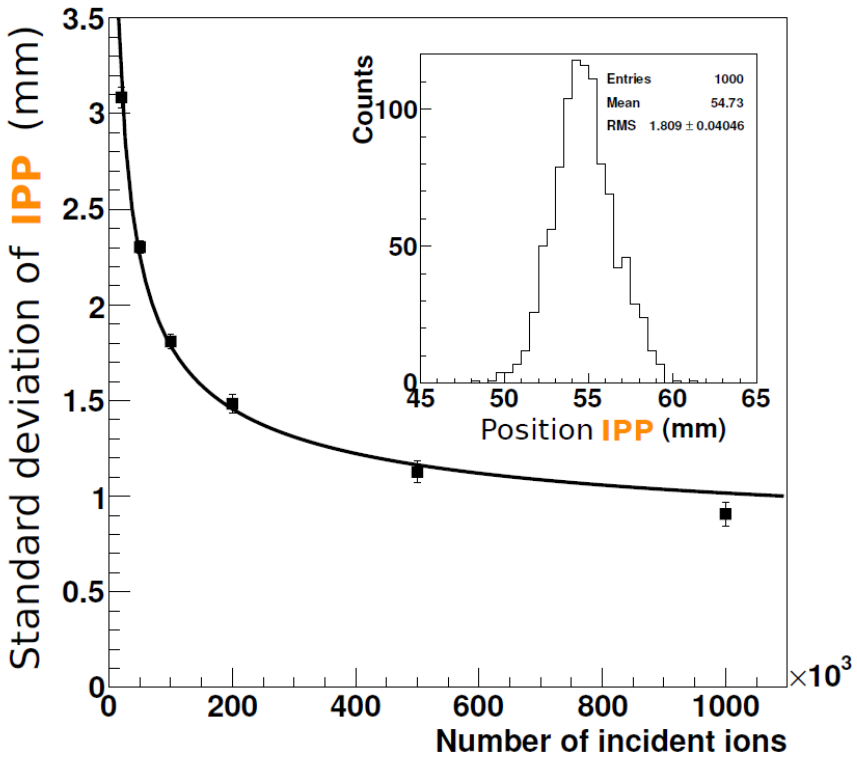


Proton Interaction Vertex Imaging

- Simulation tools
  - GEANT4 9.1 (QMD/BC)

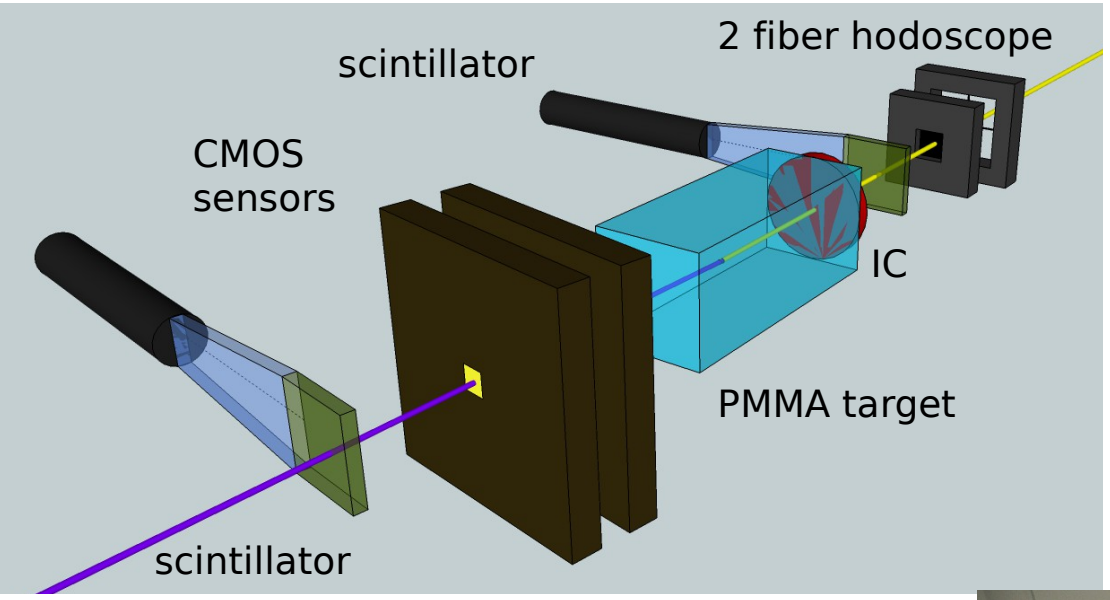


- Results (homogenous targets)
  - Ion range monitoring on pencil beam basis (10^5 incident ions)

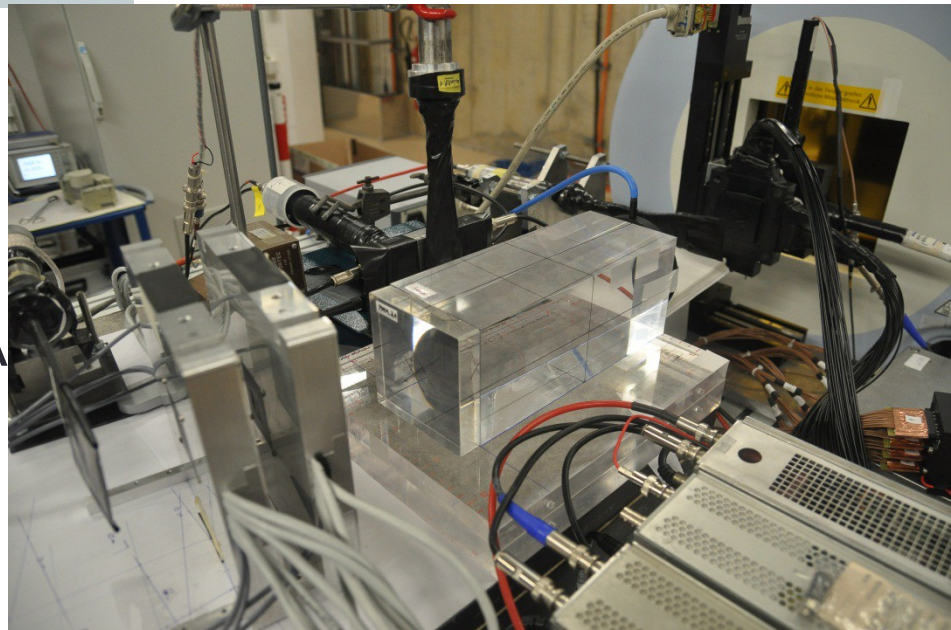


P. Henriquet et al., Phys. Med. Biol. **57** (2012) 1–15

Experimental set-up

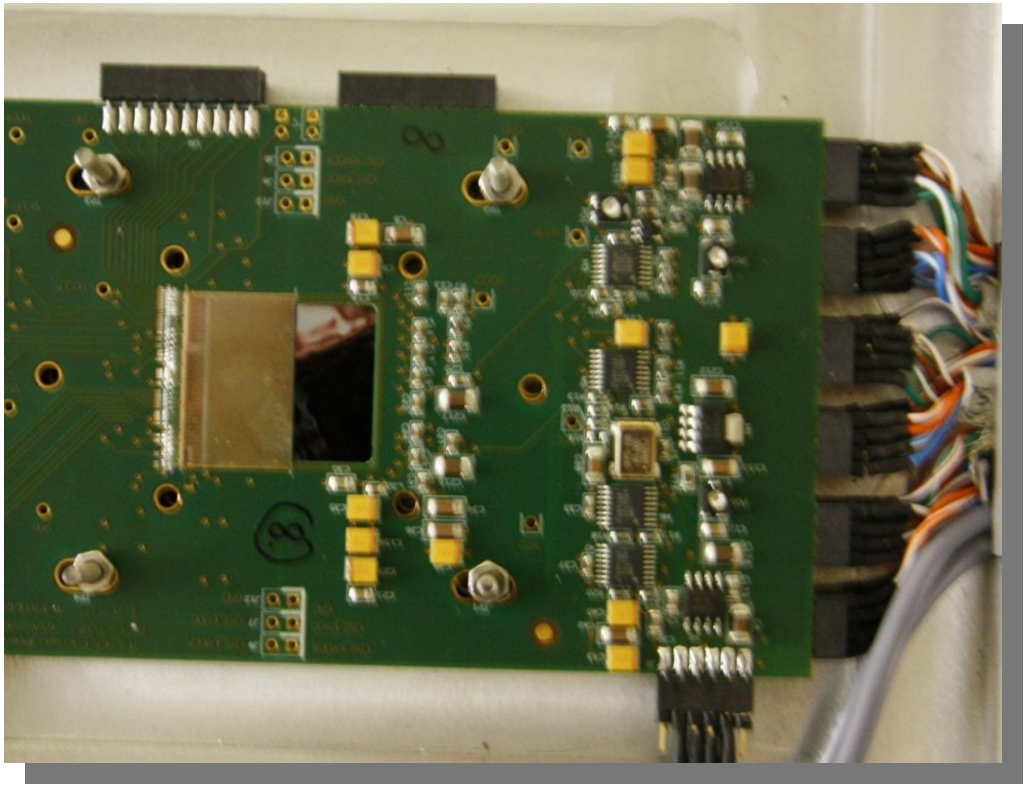


- Center: HIT (Heildelberg, DE)
- Beam: ^{12}C @ [310-395 MeV/u]
- Target: 10*10*25 cm3 of PMMA
- 4 plans CMOS 2x2 cm @ 10°
- 2 fiber scintillating hodoscope



Experimental set-up

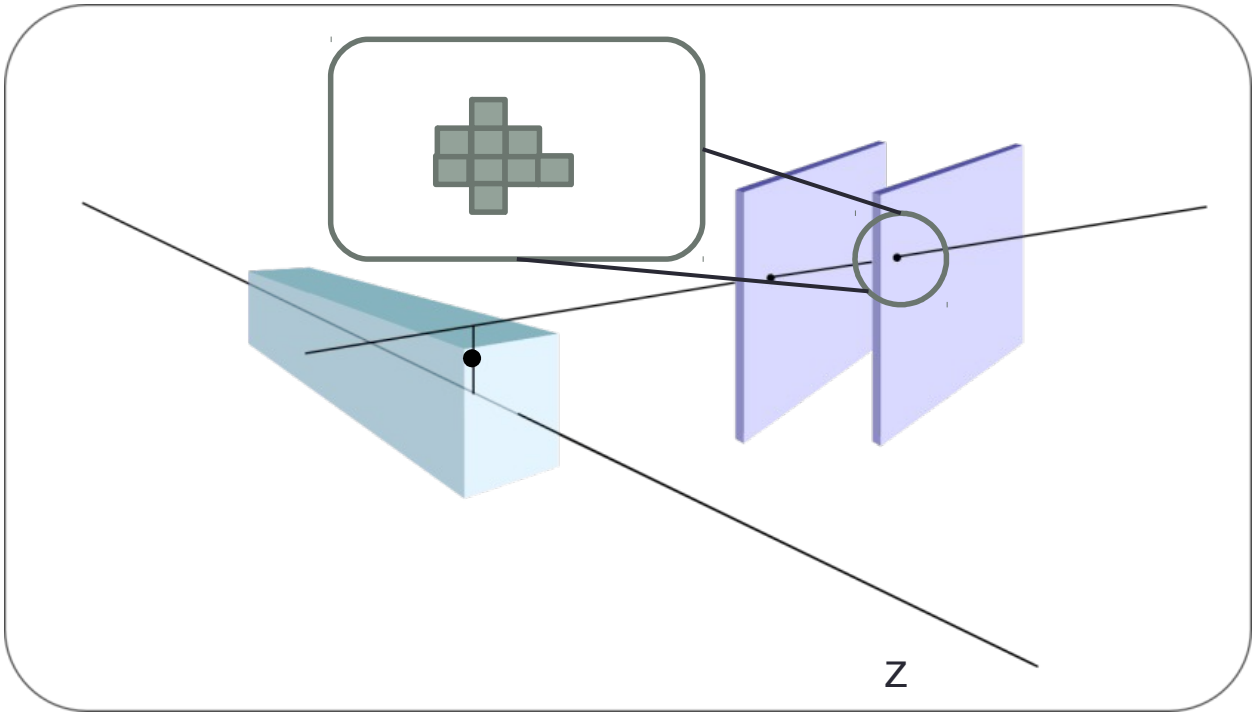
- MIMOSA26 CMOS sensors :
  - Developed in Strasbourg (IPHC)
  - Size: 2 x 1 cm
  - Thickness: 50 µm
  - Pixels: 1152 x 576
  - Pixels size: ~20µm
  - Resolution: ~ 3.2 µm
  - Integration time: 112 µs
  - Negligible dead time



J. Baudot *et al.*, *IEEE Trans. Nucl. Sci.* pp 1169–73 (2009)

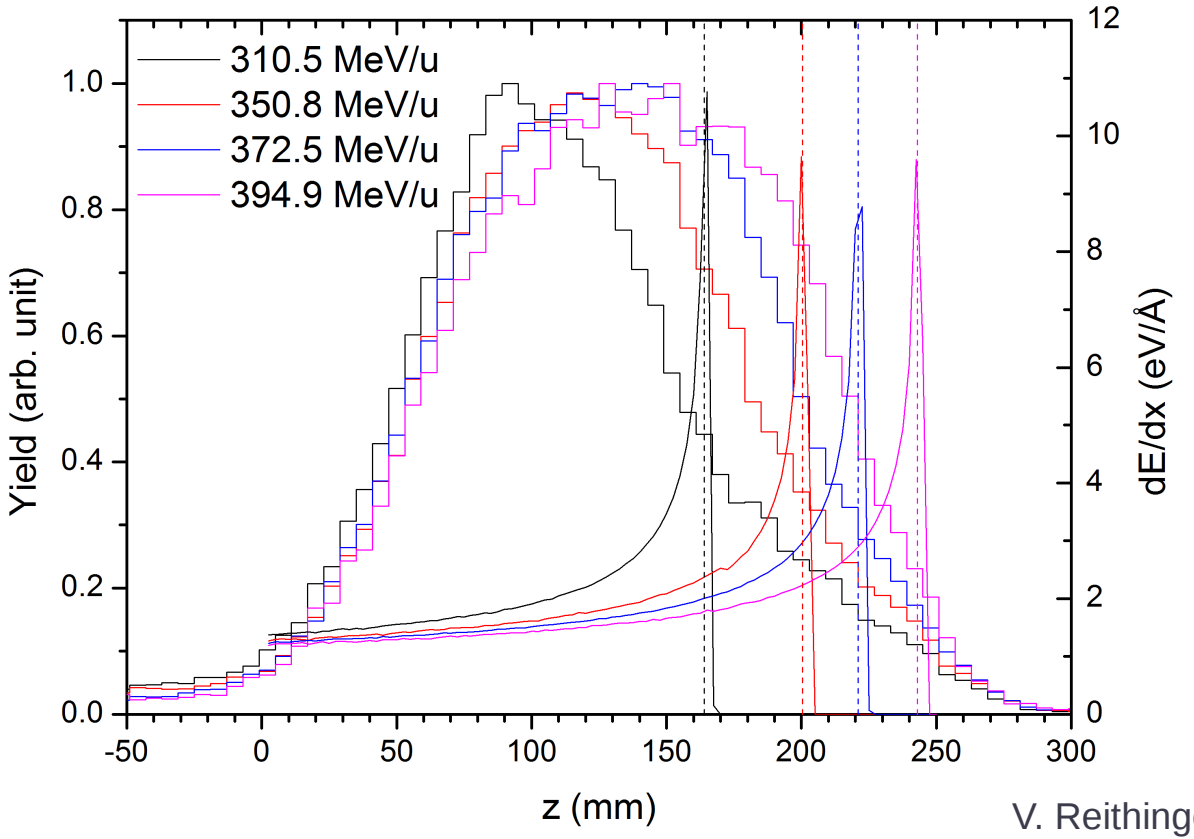
Reconstruction procedure

Pixels → Hits → Tracks → Vertexes



Ion range control (energy dependence)

- Conditions:
  - Carbon beam 310-395 MeV/u -> PMMA target (25 cm)
- Fall-off position dependent on the ion range



V. Reithinger (PhD)

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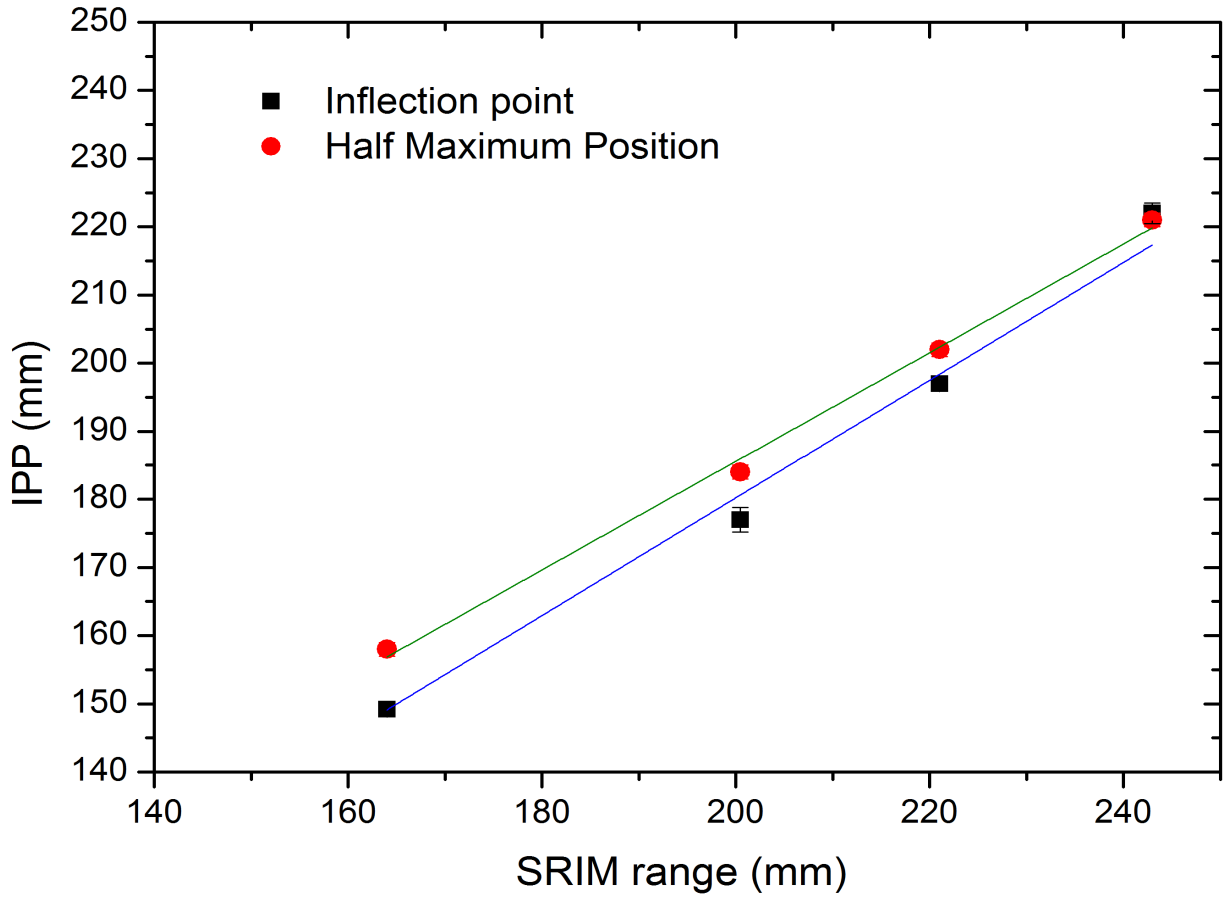
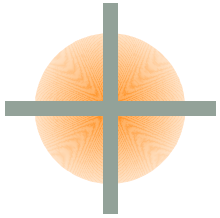
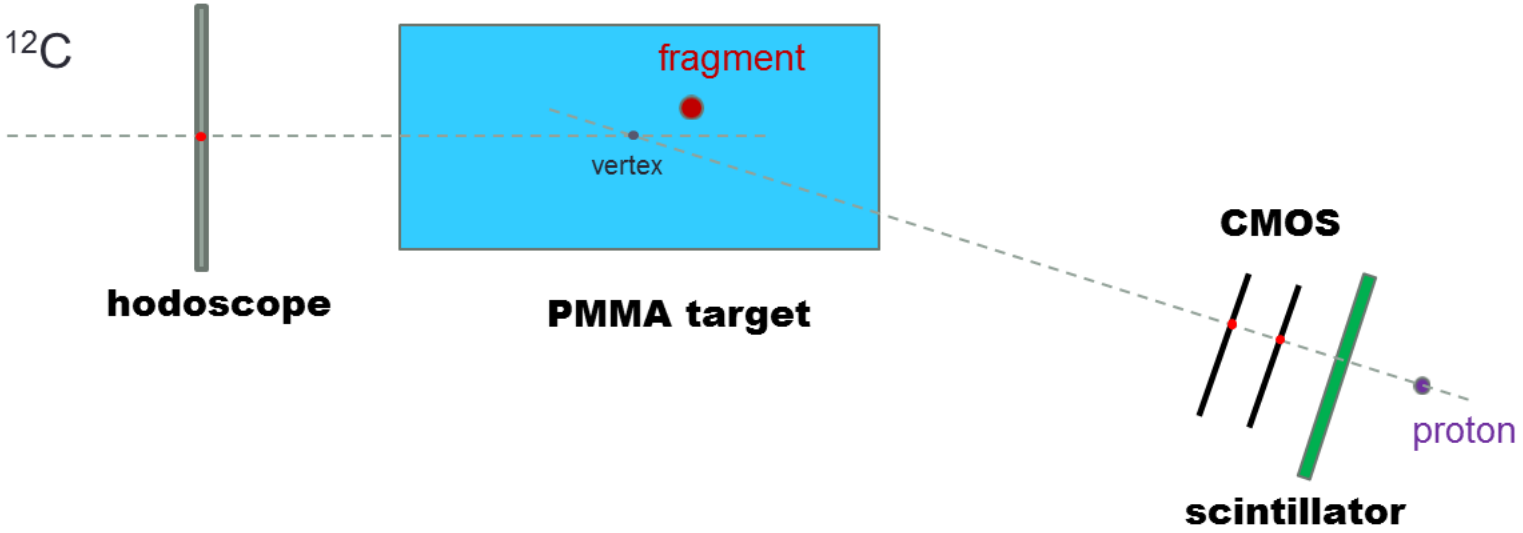


Influence of the acquisition trigger : beam position

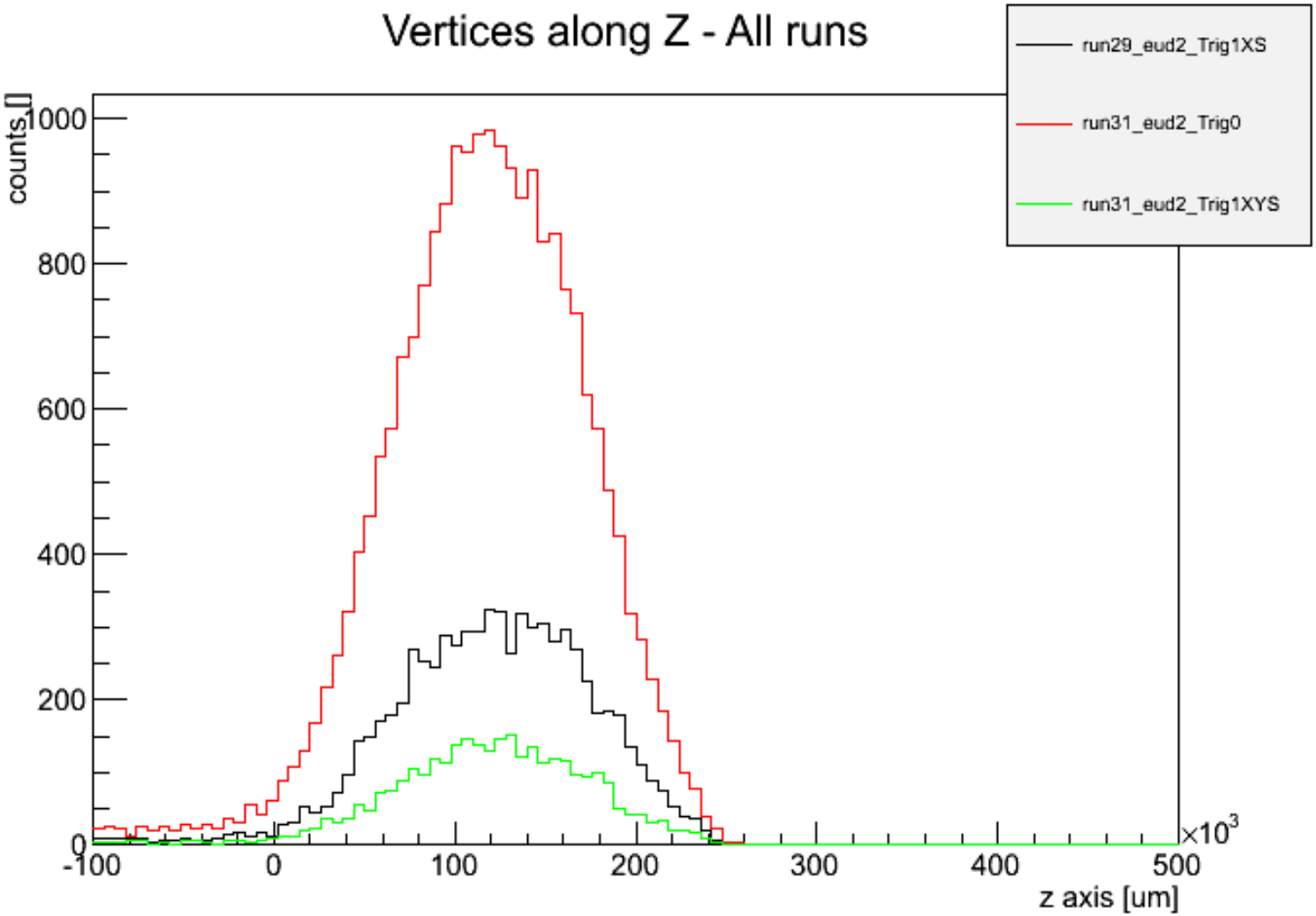
- 3 different types of trigger (same conditions) :
  - No trigger : beam (3.6 mm FWHM)
  - 1 hodoscope fiber (1 mm) + scintillator
  - 2 hodoscope fibers (1 x 1 mm²) + scintillator





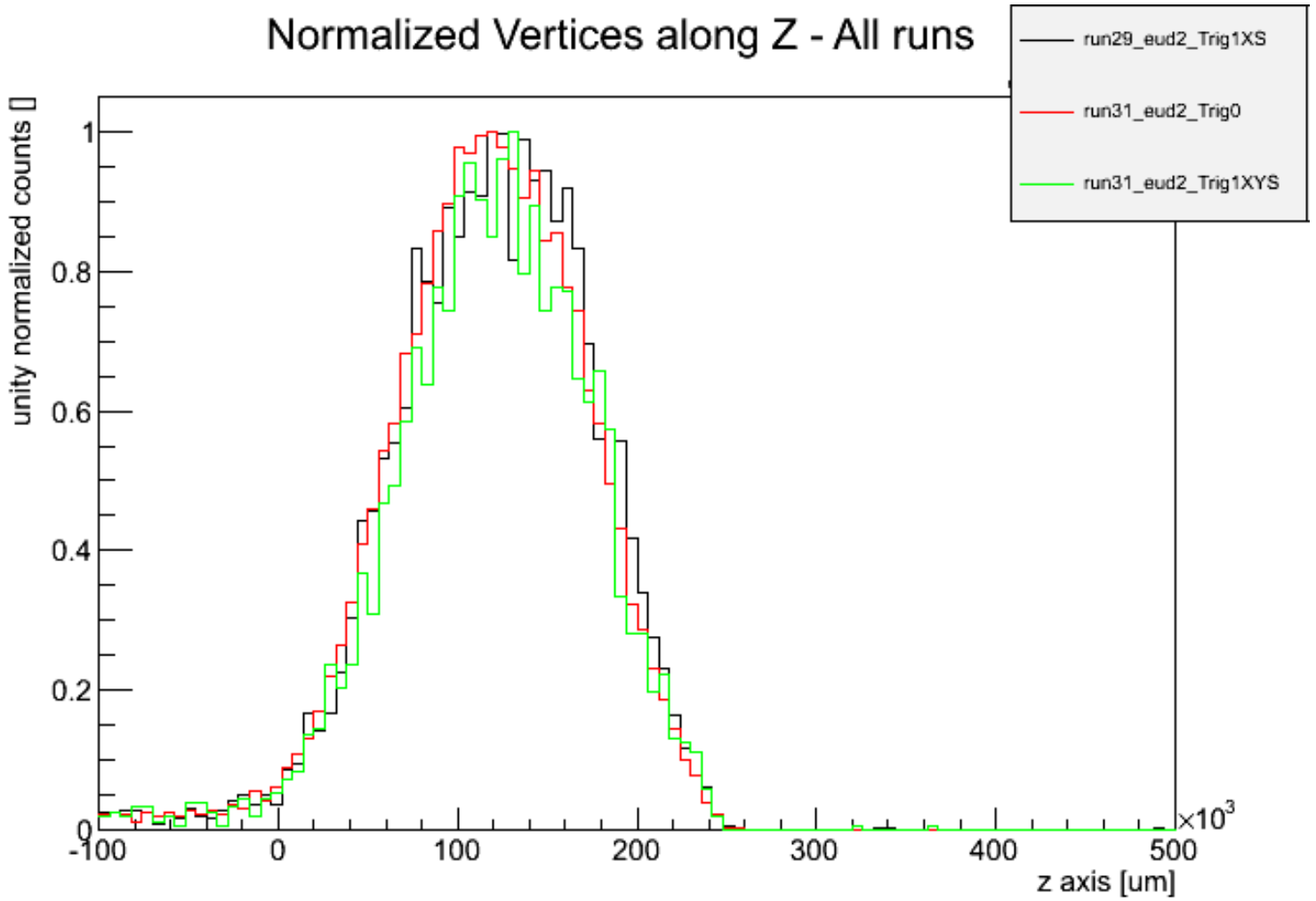
Influence of the acquisition trigger : beam position

- 3 different types of trigger (same conditions) :

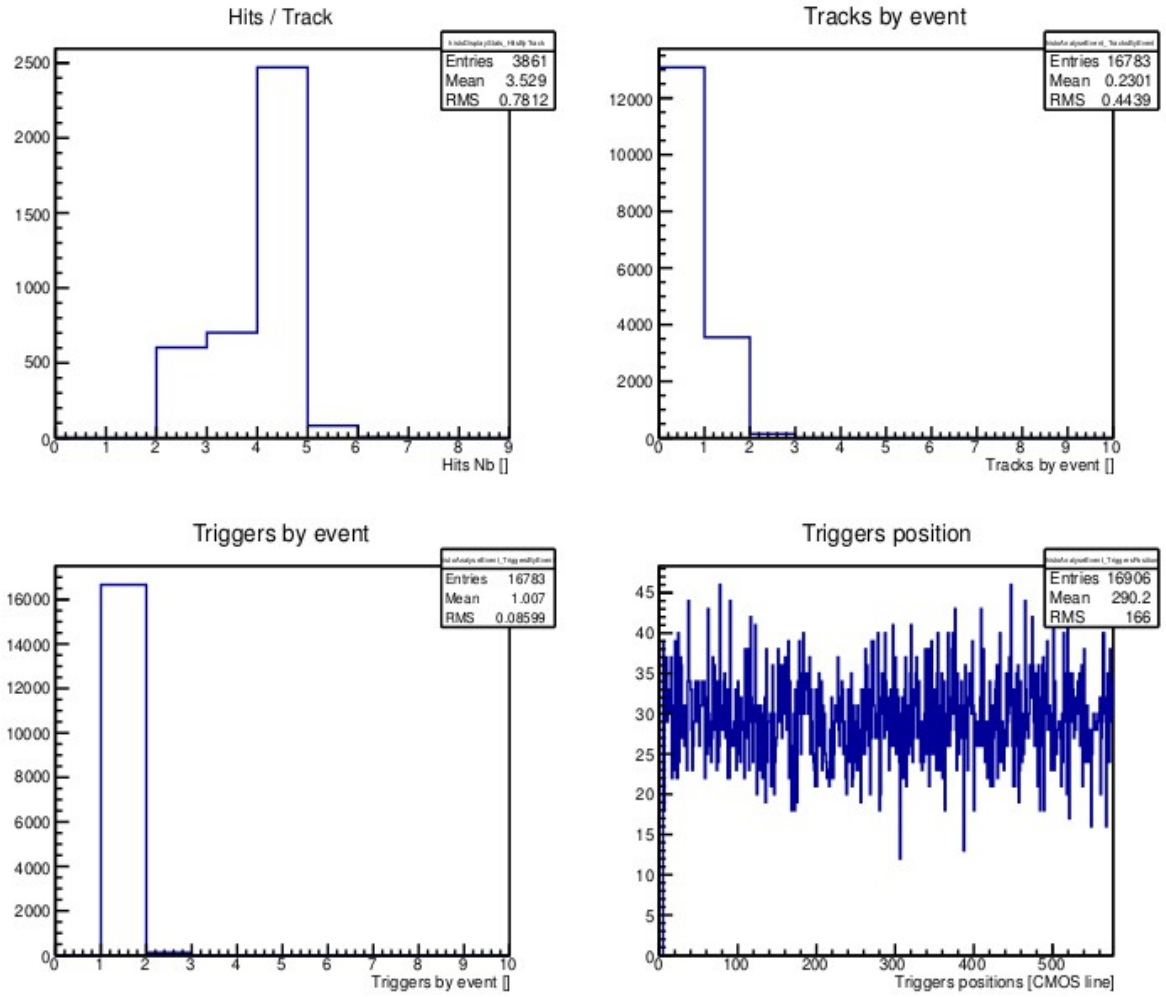


Influence of the acquisition trigger : beam position

- 3 different types of trigger (same conditions) :
  protons diffusion + reconstruction “issue”



Trigger rate / reconstruction efficiency

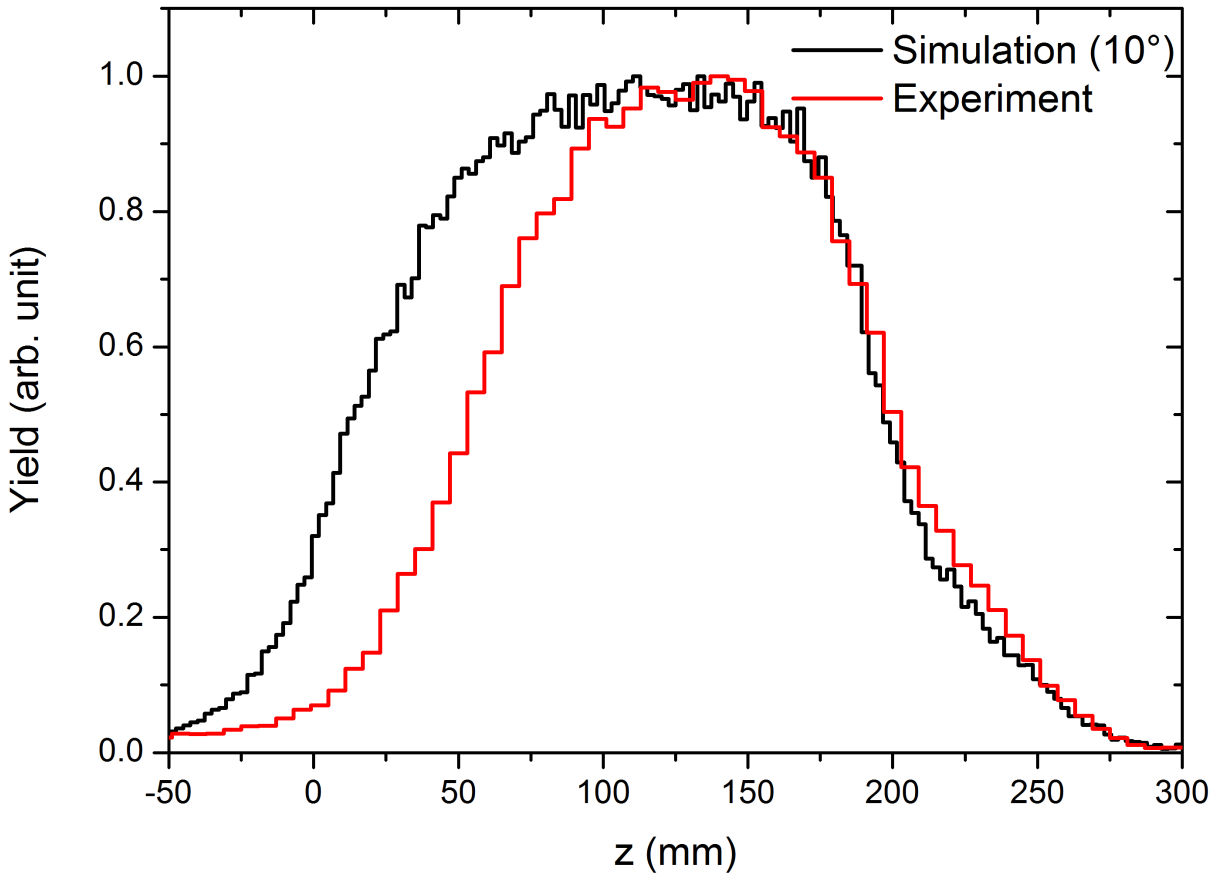


Favorable acquisition conditions for an (actual) basic (no-robust) tracking method

Comparison with simulation

- GEANT4 simulation
  - Good agreement for the fall-off
  - No detector response modeling

A.-L. Pequegnot (Master student)



Conclusion and perspectives

- Conclusions
  - § PIVI first experimental results with CMOS detectors
    - Ø Ion range verification in homogenous targets
  - § Vertexes transverse size dominated by reconstruction/scattering
  - § Good agreement with simulation (except for target entrance)

- Perspectives
  - § Realistic simulations
    - Ø Sensitivity with heterogeneities ⇒ anthropomorphic phantom
  - § Prototype specifications

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Thank you for your attention

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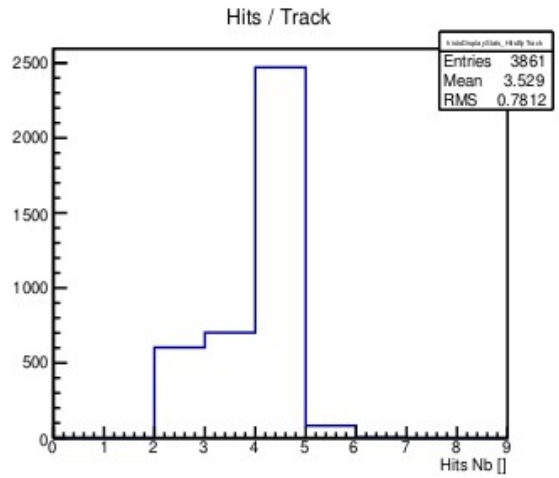
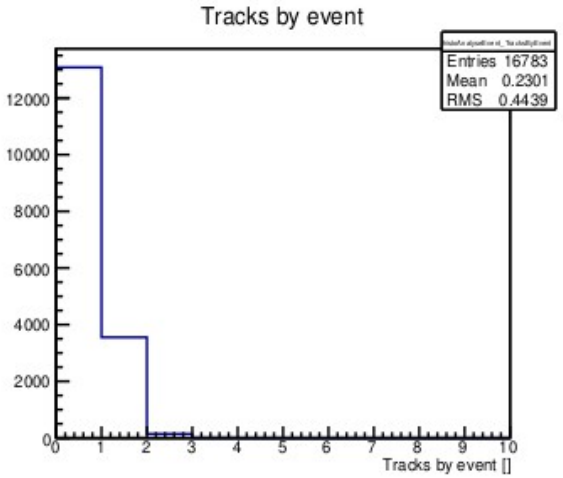
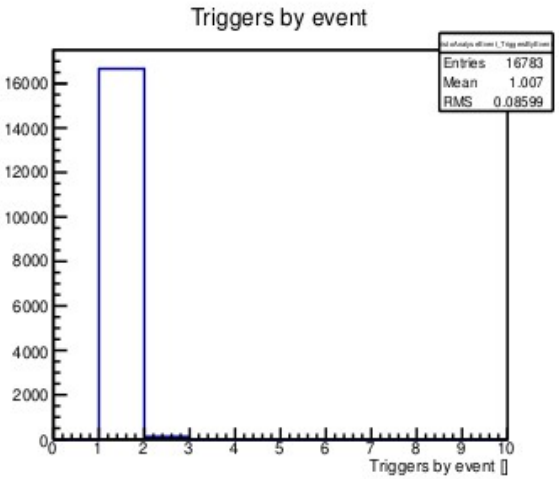
- Programme Régional de Recherche en Hadronthérapie (Rhône-Alpes)
- ITMO Cancer et Technologie pour la Santé within the 'Plan cancer 2009-2013'
- ENVISION, FP7 European program

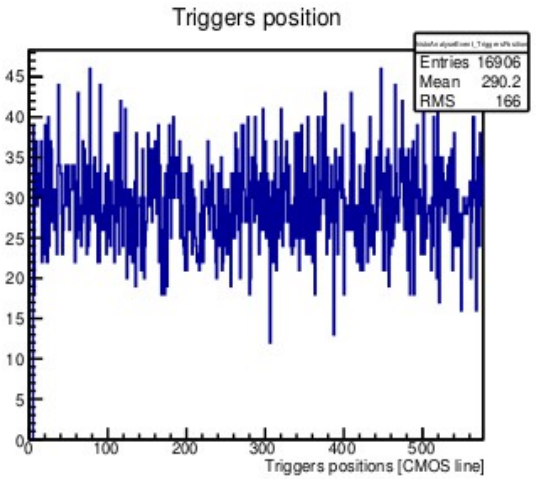
ANSWERS

Trigger rate / reconstruction efficiency









Run 31 :

- 17 388 triggers
- S = 125 000 counts
- X = 830 000 counts
- Y = 670 000 counts

- No trigger :
  29 300 tracks
- With trigger :
  3 860 tracks
  = T/4 : scintil. surface

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