

Etiquetage spatio-temporel et monitoring de faisceaux pulsés : applications en hadronthérapie et thérapies « flash ».



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Context

In vivo monitoring from the use of secondary emissions

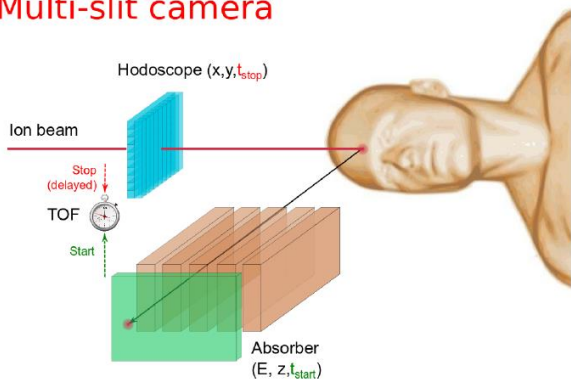
Improvement of treatment planning

Prompt Gamma Imaging

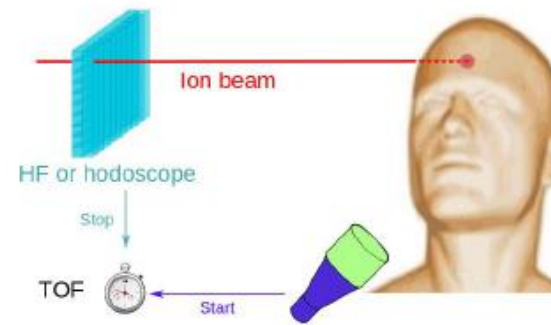
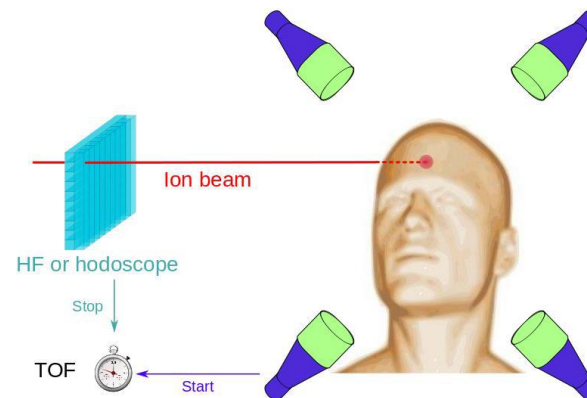
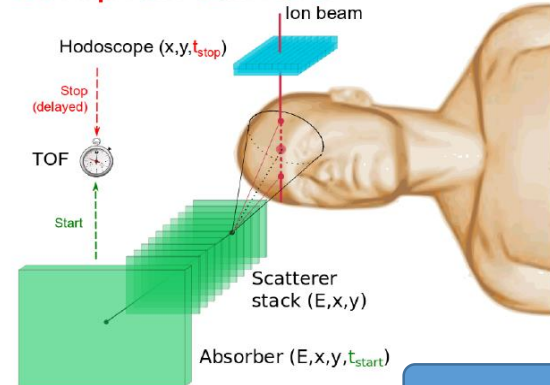
Prompt Gamma Peak Integral

Prompt Gamma Timing

Multi-slit camera



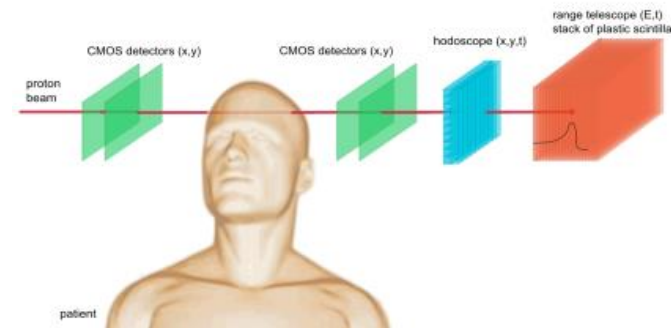
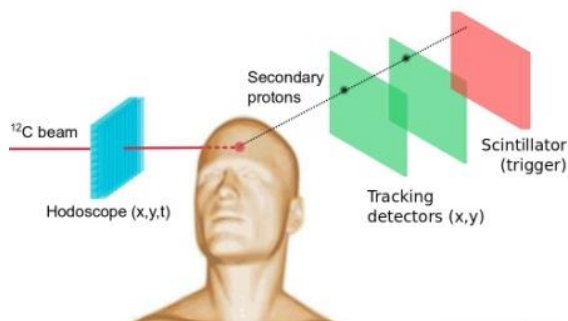
Compton camera



Talks by E. testa and S. Marcatili

Secondary proton vertex imaging in carbon therapy

Proton radiography



Context

In vivo monitoring from the use of secondary emissions

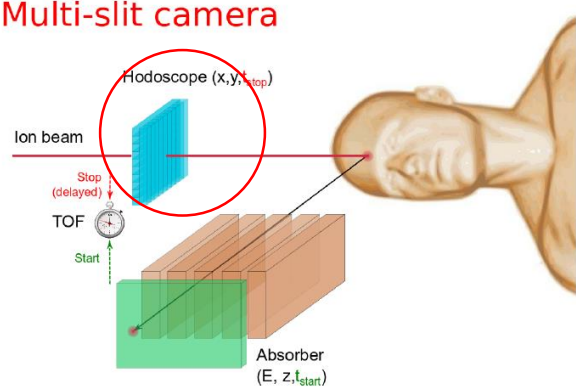
Improvement of treatment planning

Prompt Gamma Imaging

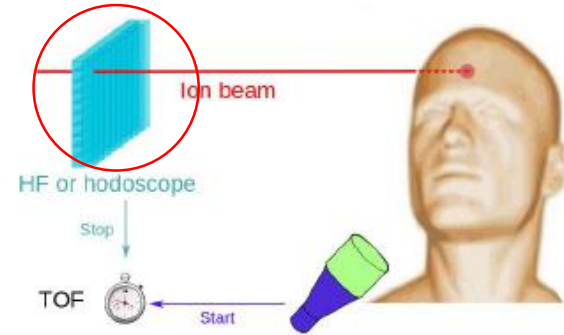
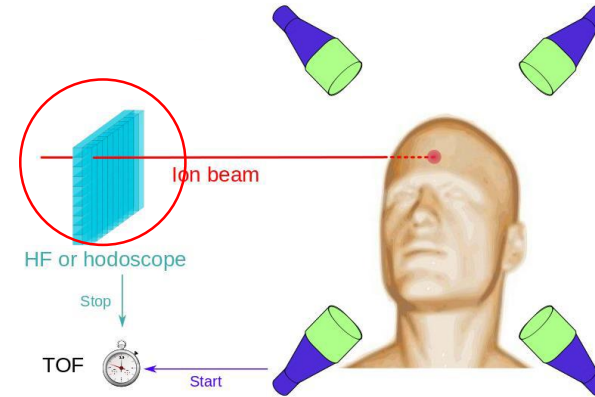
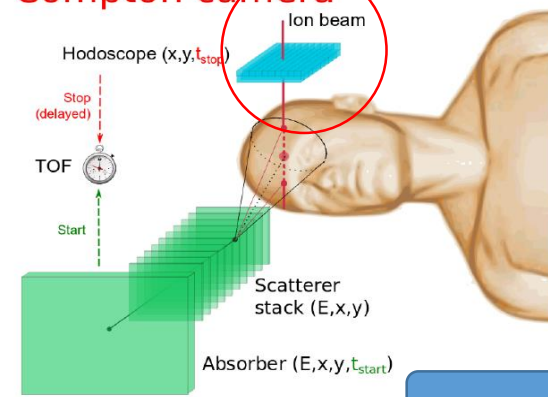
Prompt Gamma Peak Integral

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Multi-slit camera



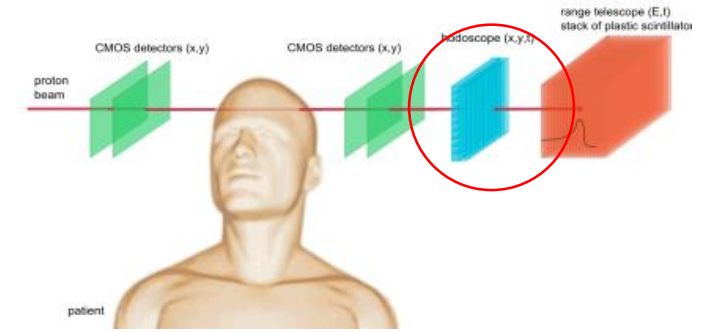
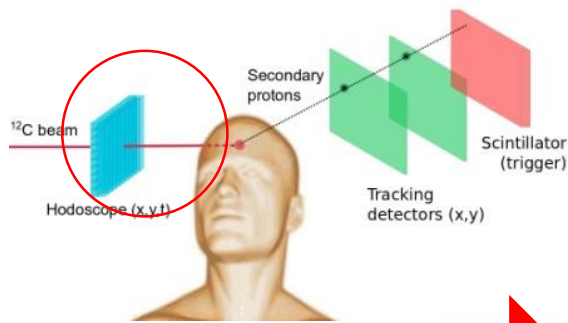
Compton camera



Talks by E. testa and S. Marcatili

Secondary proton vertex imaging in carbon therapy

Proton radiography



Beam tagging hodoscope

Role of the hodoscope

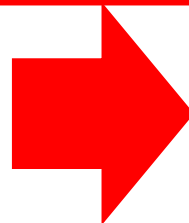
Time structure of the clinical accelerators

Talk by S. Marcatili

		synchrotron (CNAO, HIT)		cyclotron (IBA, Varian)	synchro-cyclotron (S2C2, IBA)
		ions C	Protons		
Intensité type (ions/s)		10^7	10^9	10^{10}	$\sim 10^{10}$
Macrostructure	Période (s)	1 – 10		Ø	10^{-3}
Microstructure	Largeur paquet (ns)	20 – 50		0.5 – 2	8
	Période (ns)	100 – 200		10	16 (à l'extraction)
	Ions/paquet	2 – 5	200 – 500	200	4000

J. Krimmer, D. Dauvergne, J.M. Létang, and É. Testa, *Prompt-gamma monitoring in hadrontherapy: A review.*, *Nucl. Instrum. Meth. A*, **878** (2018) pg. 58–73

Hodoscope



Provide a time tagging per bunch or per ion

Beam tagging hodoscope for online ion range verification in hadrontherapy

Prompt Gamma detection

CLaRyS

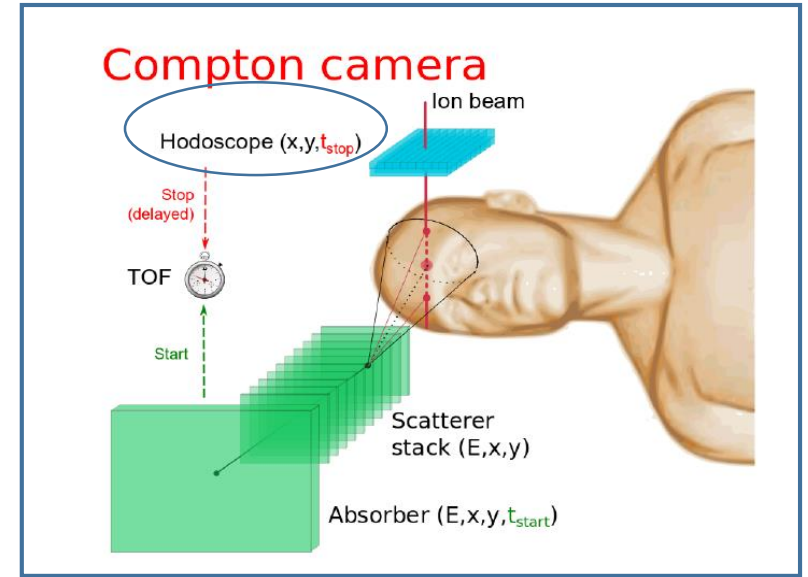
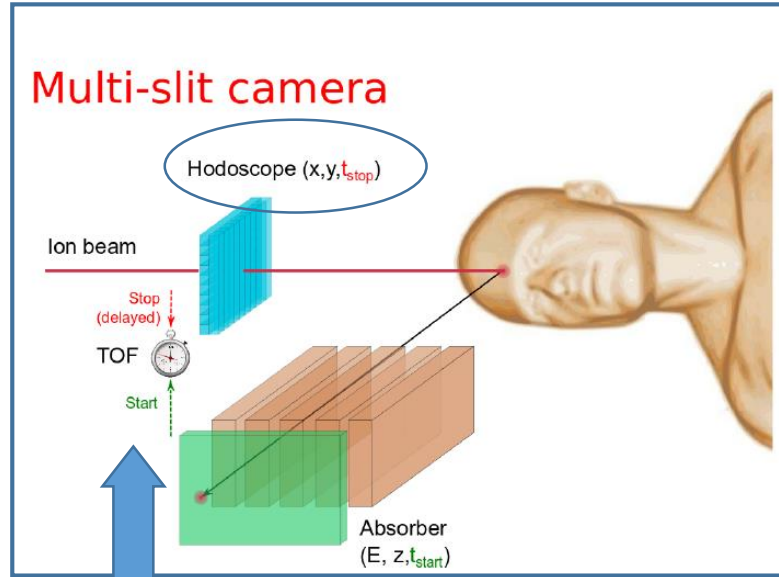
Gamma Prompt Imaging

Hodoscope Existing development :

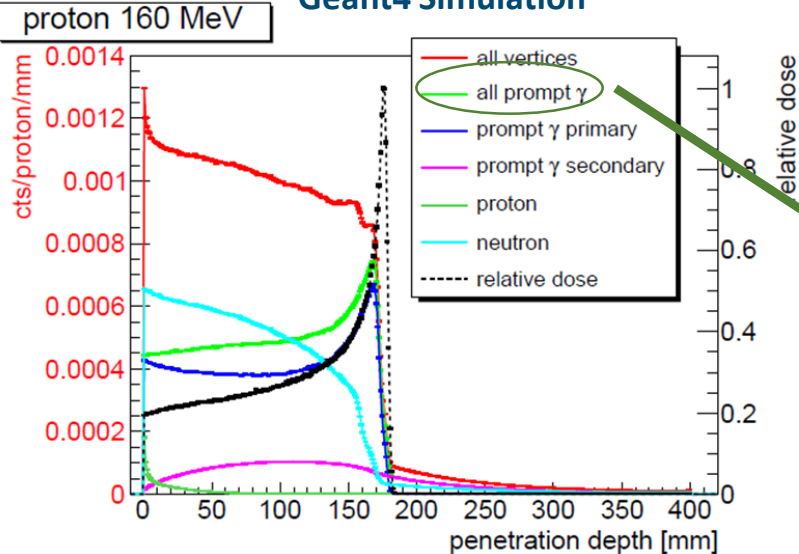


← Array of scintillating fibres + multichannel PMT

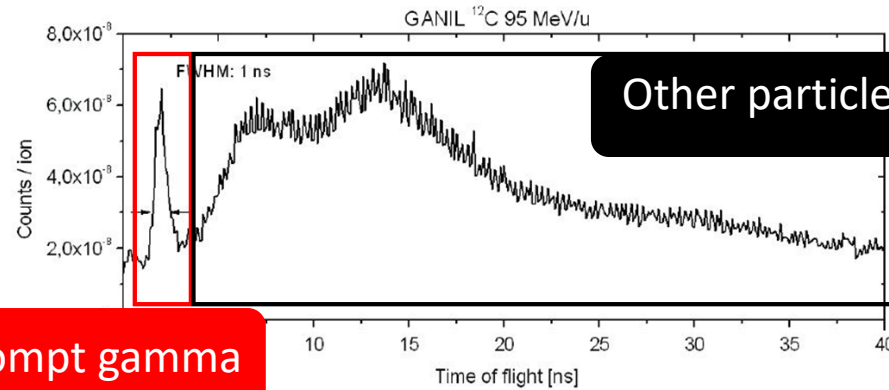
Hodoscope : Background reduction + position and time stamps for the ion beam



Geant4 Simulation



Prompt gamma detection : experiment using ^{12}C @95 MeV/u on PMMA
Time of Flight Spectrum



Prompt gamma

Mauro Testa, Thèse, Univ. Lyon, 2010

ML Gallin-Martel GDR MI2B ARCHADE

The scintillating fibres hodoscope

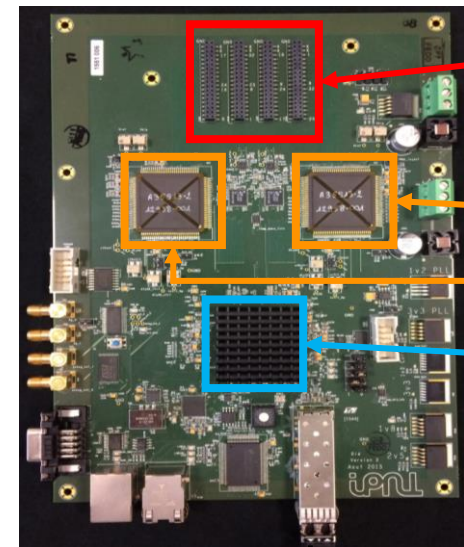


Characteristics

- 2 perpendicular planes for a 2D mapping
- 128 polystyrene scintillating fibers BCF-12 per plane
- 1 mm² squared section
- 8 multi-anode PM tubes for a two side read-out

The read-out electronics

- Each PM tube is readout by an ASIC “HODOPIC” FE board



Multi-anode PM tubes connexion with 64 input channels

ASICs

FPGA

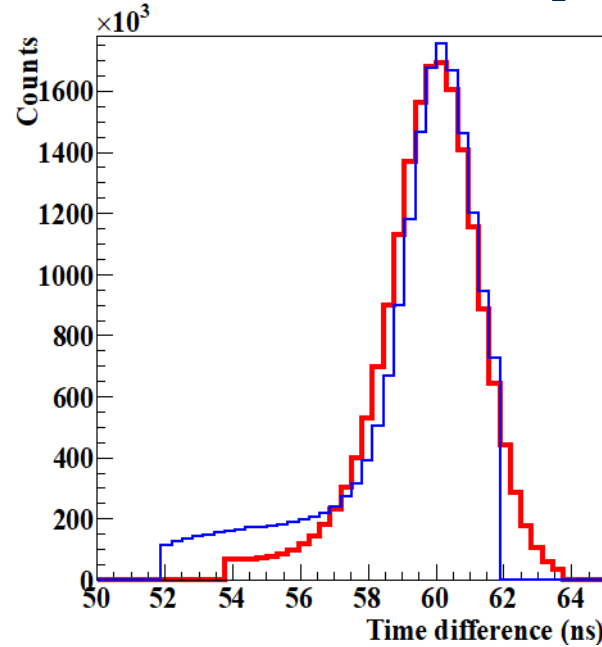


AMC40

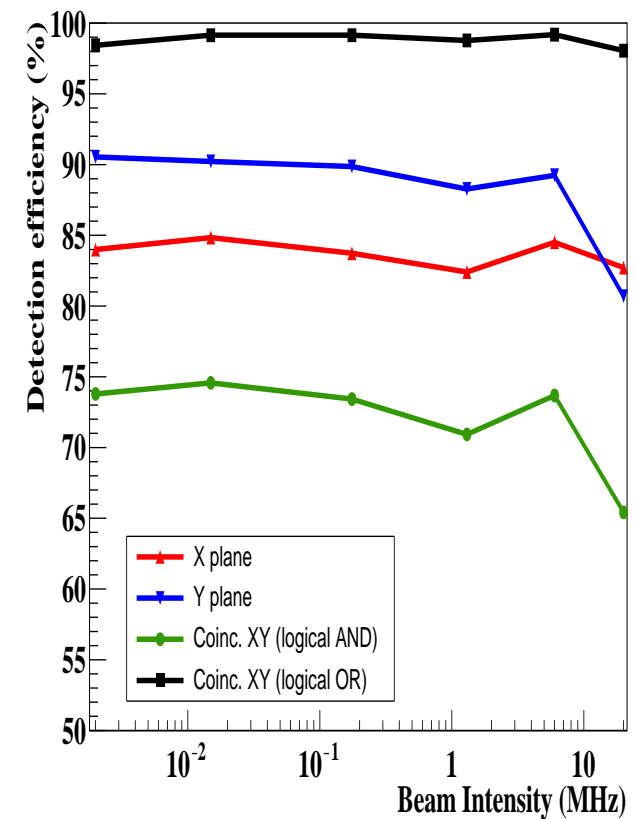
PC
Acquisition

PC
Slow control

The scintillating fibres hodoscope



O. Allegrini et al, article submitted to JINST in Sept 2020



	Specifications	Measured performance
Detection efficiency	~ 90 % (logical AND) at 100 MHz	66 % (logical AND) at 20 MHz 97 % (logical OR) at 20 MHz
Time resolution	< 2 ns	1.8 ns (10 MHz)
Radiation hardness	Operational for 1000 clinical irradiations	< 10 % loss of detection efficiency after an equivalent of 1000 clinical irradiations

Current limitations : ground fluctuations in the ASICs

Beam tagging hodoscope for online ion range verification in hadrontherapy

Prompt Gamma detection

CLaRyS

Gamma Prompt Imaging

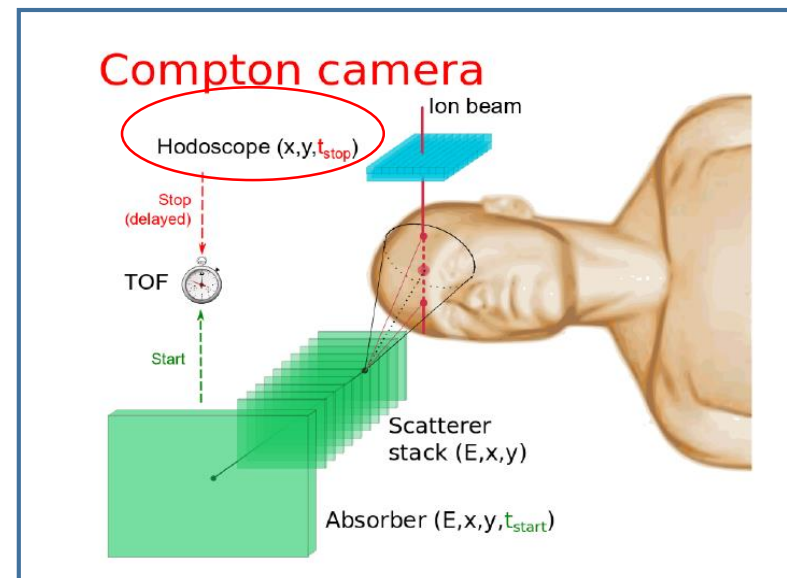
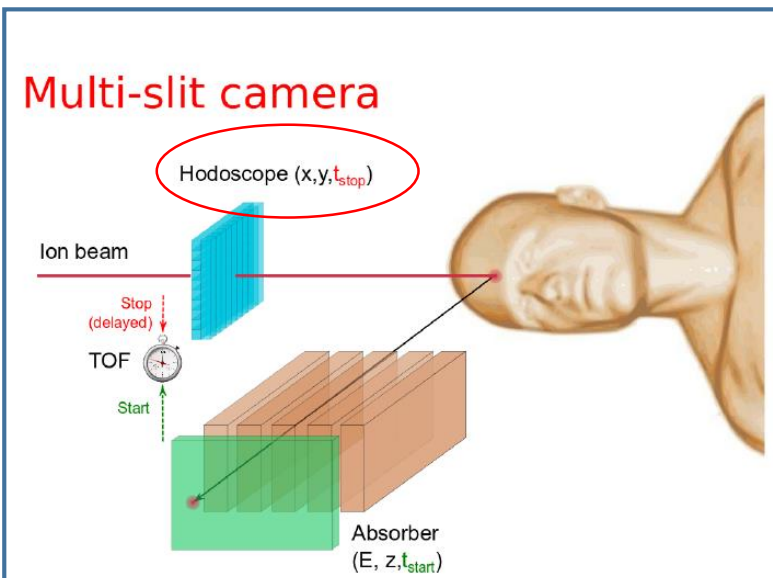
Hodoscope Existing development :



← Array of scintillating fibres + multichannel PMT

Time resolution 1.8 ns (10 MHz)

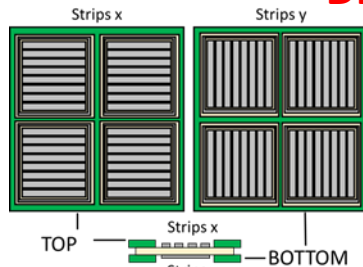
Hodoscope : Background reduction + position and time stamps for the ion beam



Ultra-Fast Timing : 100 ps resolution using diamond

Diamond hodoscope

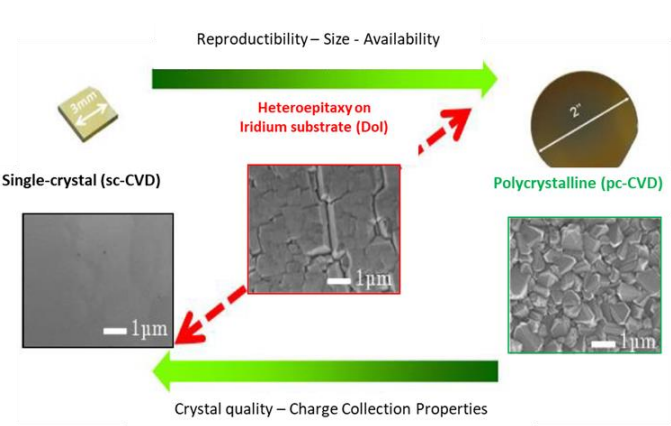
→ Imaging based on Time of Flight



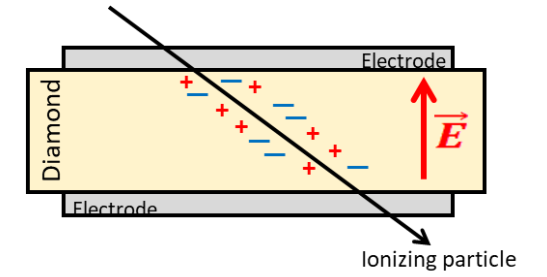
Diamond Sensor Instrumentation

Diamond a wide-bandgap semiconductor

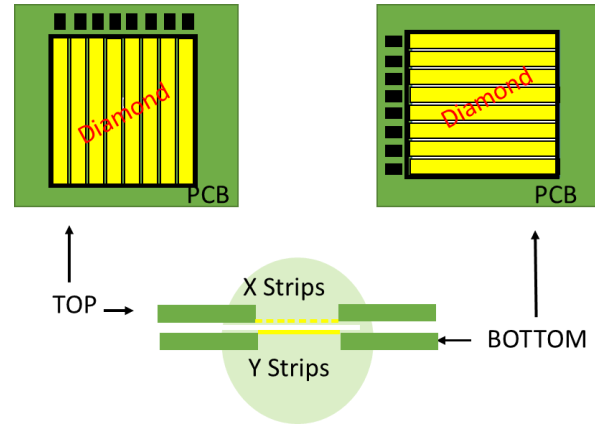
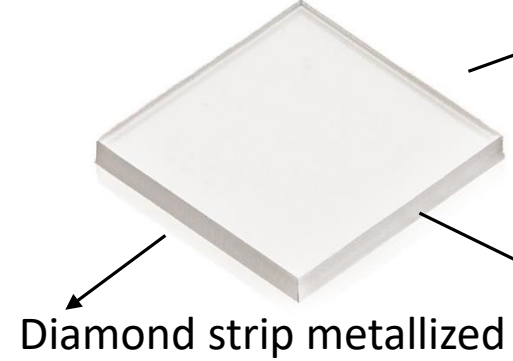
- Very low leakage current
- Low noise
- Radiation hard
- Fast timing
- Room temperature



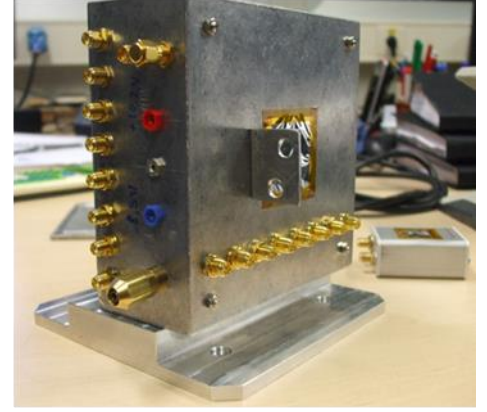
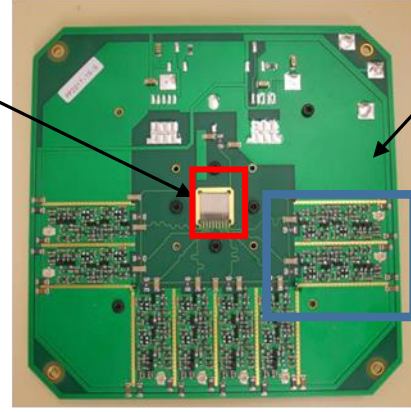
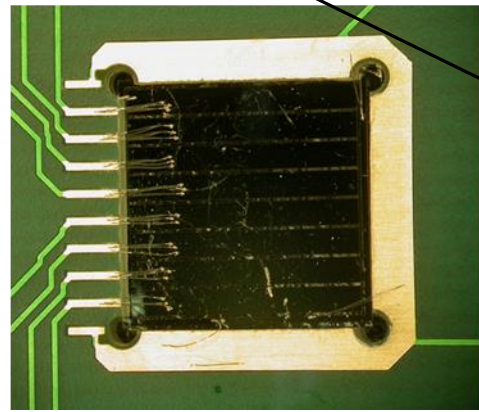
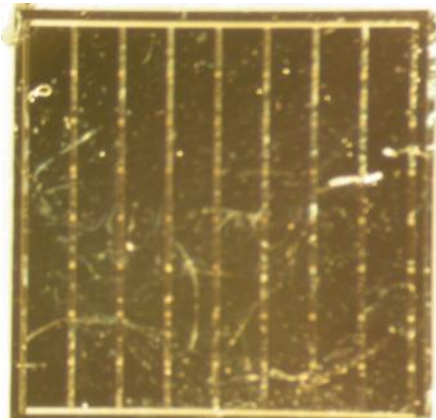
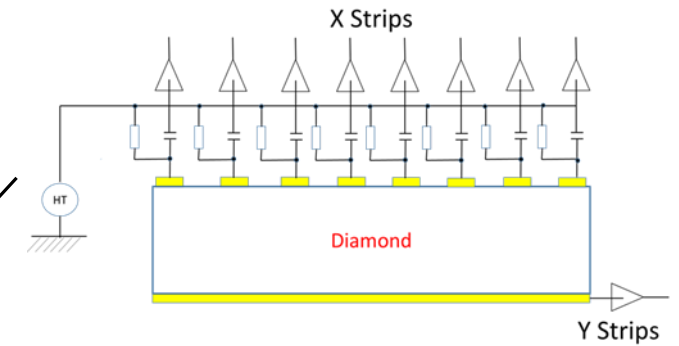
Solid state ionization chamber



Detector assembly



Read out electronics

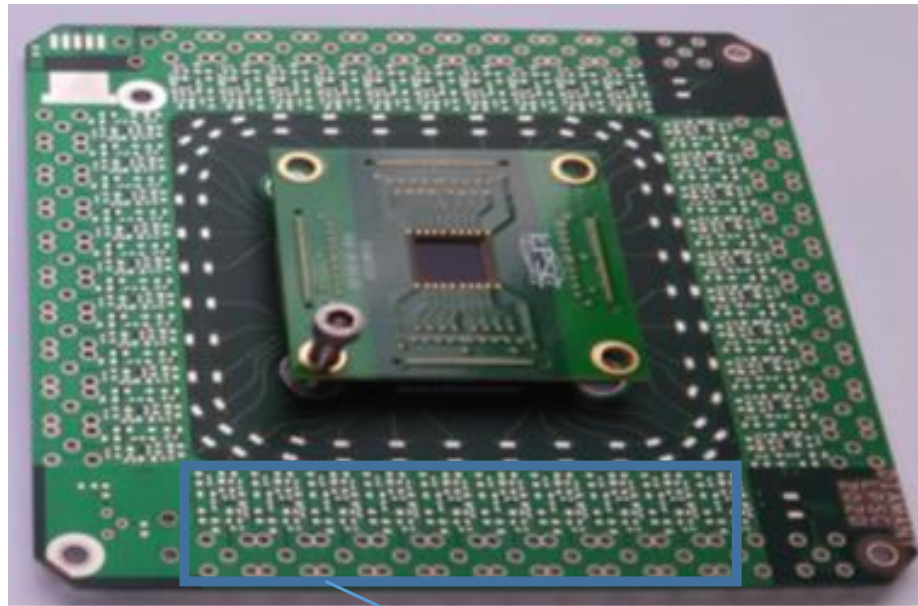
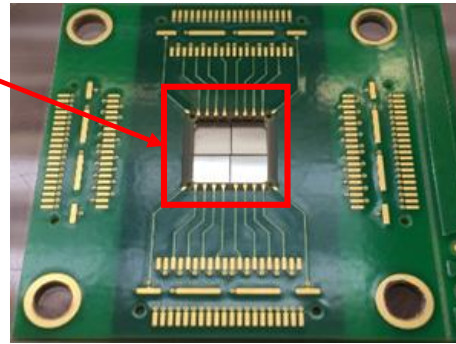


Diamond hodoscope

4 diamond detectors in a mosaic arrangement

$4 \times 4.5 \times 4.5 \text{ mm}^2 \sim 1 \text{ cm}^2$

$1 \times 20 \times 20 \text{ mm}^2 \sim 4 \text{ cm}^2$



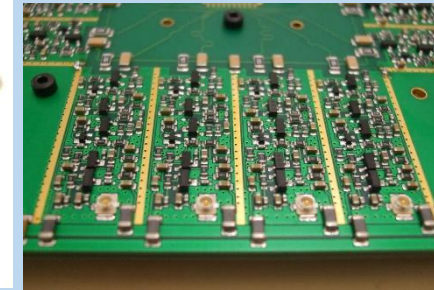
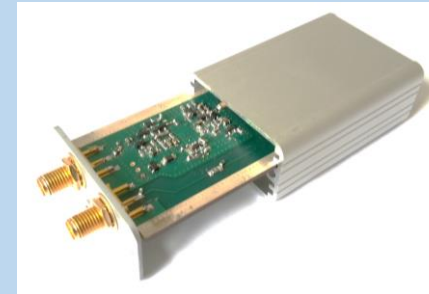
Front-End electronics

10 November

Front End electronics developed at lab

R&T IN2P3 DIAMTECH + ANR DIAMMONI 2020

Fast preamps + QDC in discrete electronics

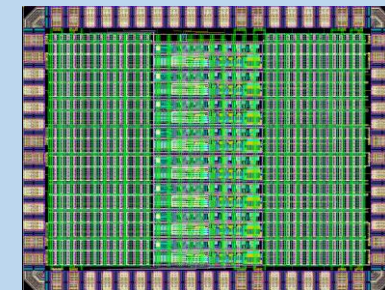
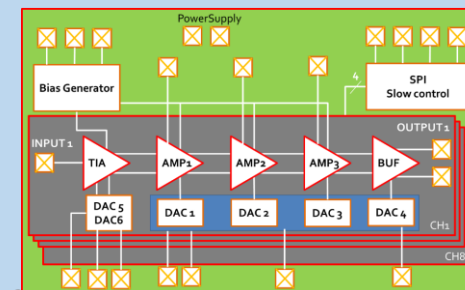


R&T IN2P3 DIAMASIC

LPSC - LPC Caen

ASIC Preamps +TDC+ QDC

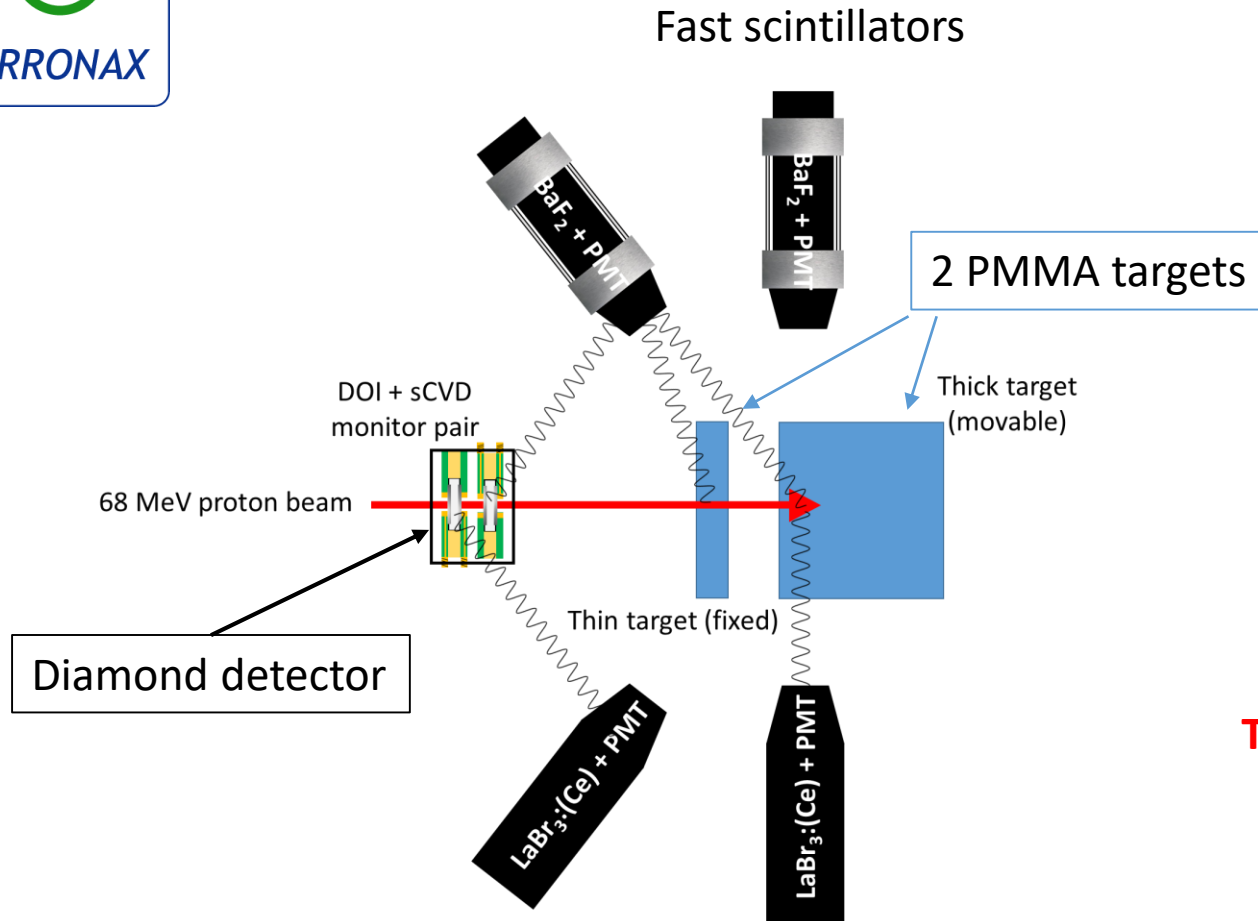
- CMOS 130 nm (CERN)
- Radiation tolerant



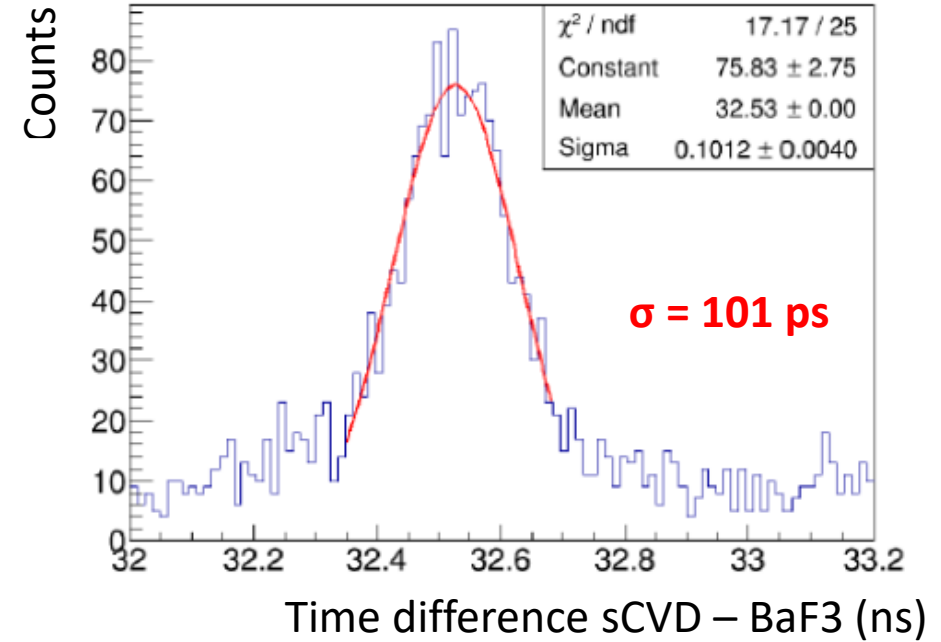
Diamond hodoscope



Beam tests in ARRONAX with 68 MeV proton beam



Talk by S. Marcatili



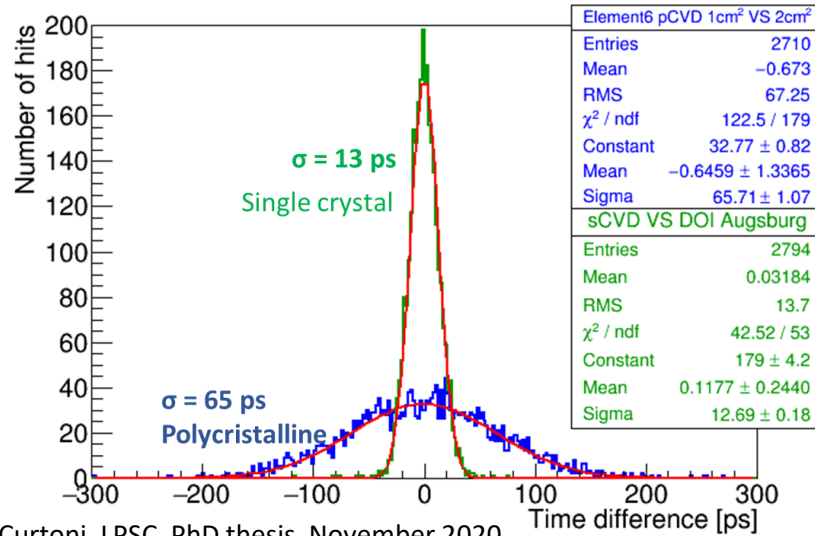
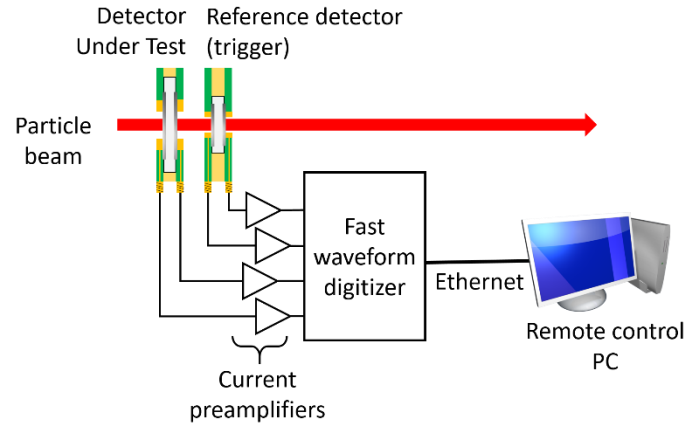
Time resolution single crystal diamond vs scintillator

S. Curtoni, LPSC, PhD thesis, November 2020

S. Marcatili et al, PMB 2020

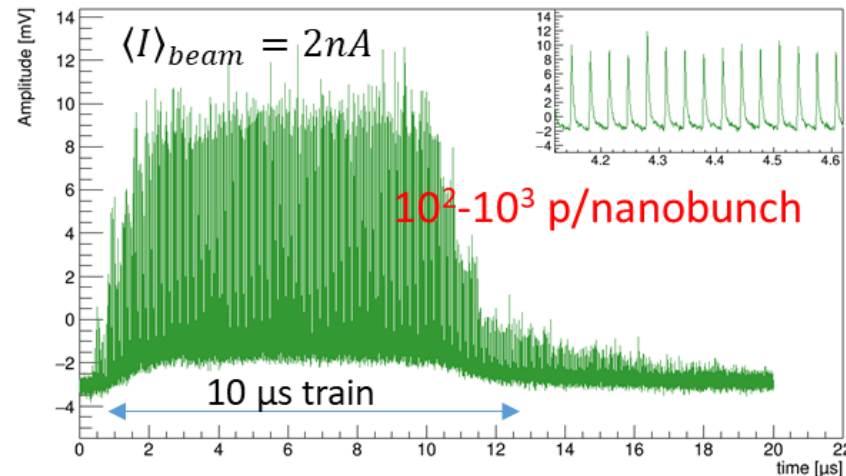
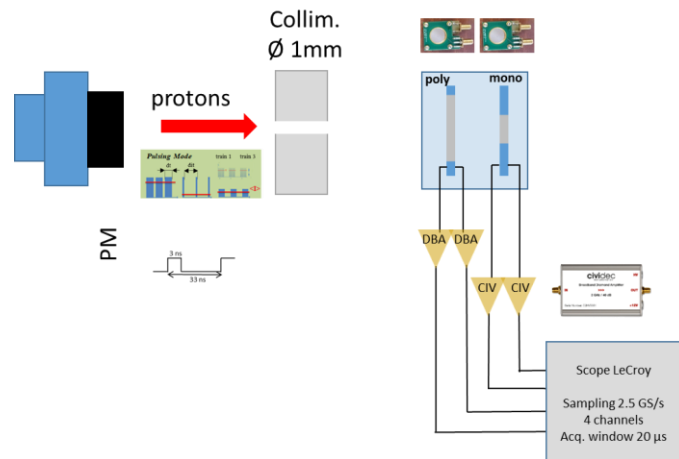
Diamond hodoscope

Beam tests in GANIL with 95 MeV/u carbon beam



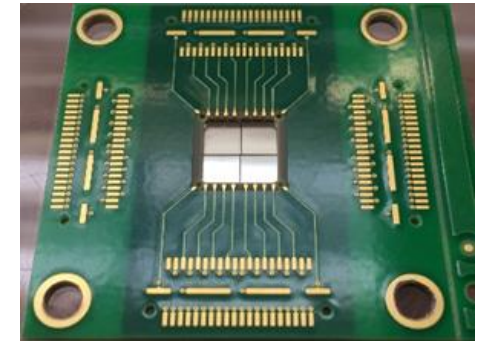
S. Curtoni, LPSC, PhD thesis, November 2020

Beam tests in ARRONAX with 68 MeV proton beam

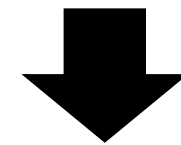


Polycrystalline diamond

- Large available surface 20 x 20 mm²
- Intrinsic radiation hardness
- Time resolution <100 ps
- High rate particle counting capabilities up to clinical intensity



1 x 20 x 20 mm² ~ 4 cm²

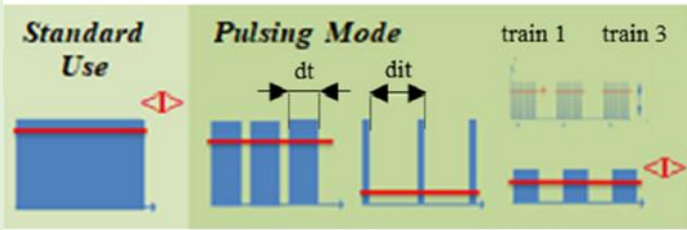


Designed to be used right now with carbon ions

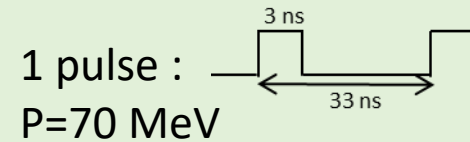
Diamond hodoscope application to « Flash Therapy »

R&T transverse IN2P3 DIAMTECH + ANR DIAMMONI

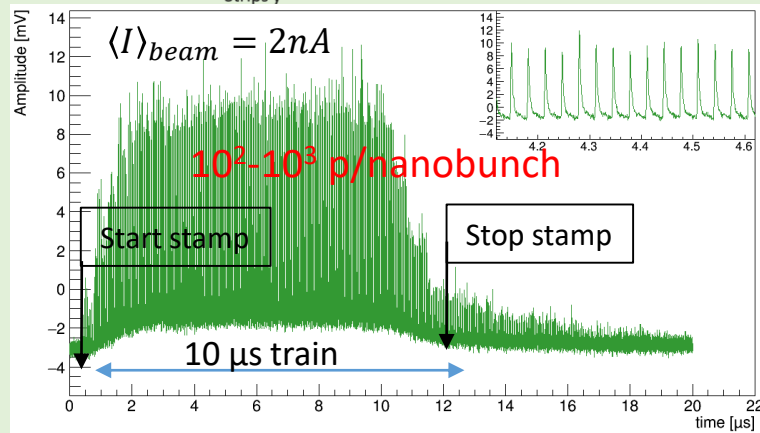
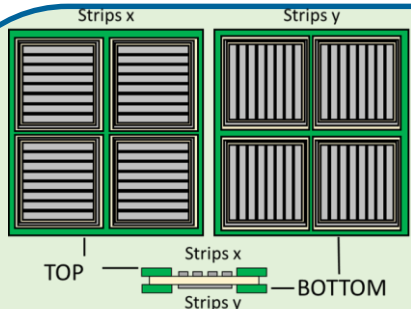
Pulsed beam monitoring in Flash Therapy



Collaboration
LPSC – SUBATECH-ARRONAX



Strip metallized diamond + FE elec + data acquisition for integration @ ARRONAX 2024



Preliminary Study

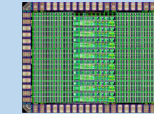
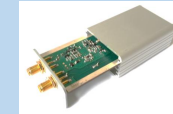
Proton counting in pulses or in train

« Start » and « stop » time stamps

ML Gallin-Martel GDR MI2B ARCHADE

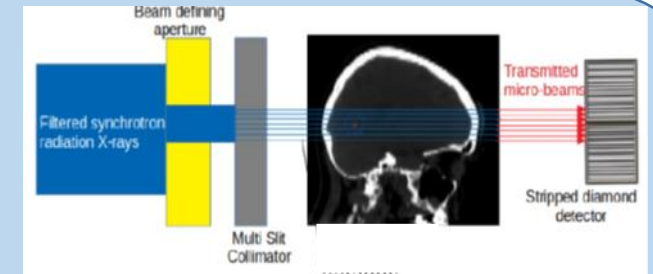
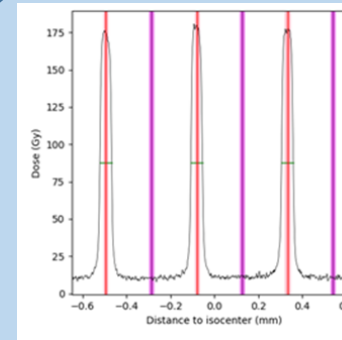
R&T IN2P3 DIAMTECH + ANR DIAMMONI 2020

QDC: in discrete electronics + ASIC electronics

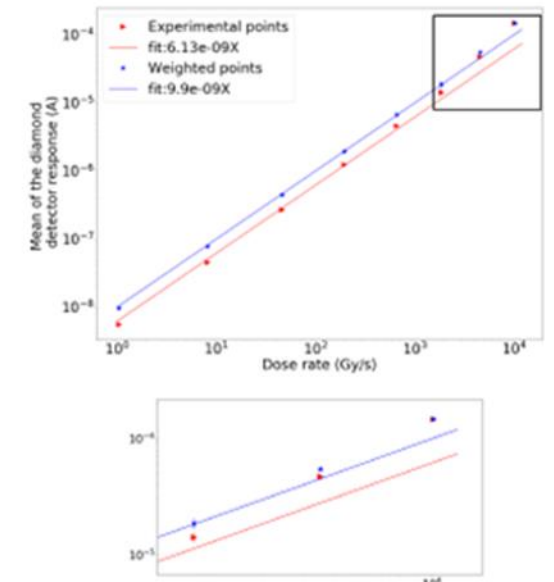


- CMOS 130 nm (CERN)
- Radiation tolerant

Ch. Hoarau et al., article submitted to JINST, Sept 2020



Linearity already tested up to 10^4 Gy/s at ESRF (X-rays) in Micro beam Radiation Therapy on ID-17 with single crystal



N. Rosuel PhD thesis

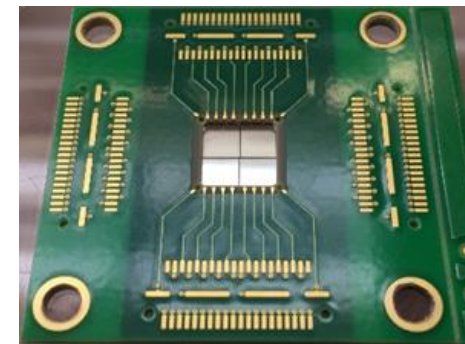
Conclusion

➤ Fibre hodoscope:

- ❖ beam hodoscope could be used at ARCHADE to provide clinical intensity mm and ns spatio-temporal labeling

➤ Diamond hodoscope:

- ❖ at ARCHADE cyclotron C400 for 10^8 ion C/s it would be undubitably possible to make beam time stamped and ion/ion particle counting
- ❖ with different types of ions ($Z > 1$), we can reach few tens of ps of resolution (in any case significantly < 100 ps)
- ❖ the diamond hodoscope can be integrated into a detection system, as part of a collaborative work, 16 cm² sensitive surface can be reached using polycrystalline diamond sensors in a 2 x 2 mosaic arrangement



4 x 20 x 20 mm² ~ 16cm²