DIAMMONI: diamond-detector for beam monitoring at ultra-high dose rate

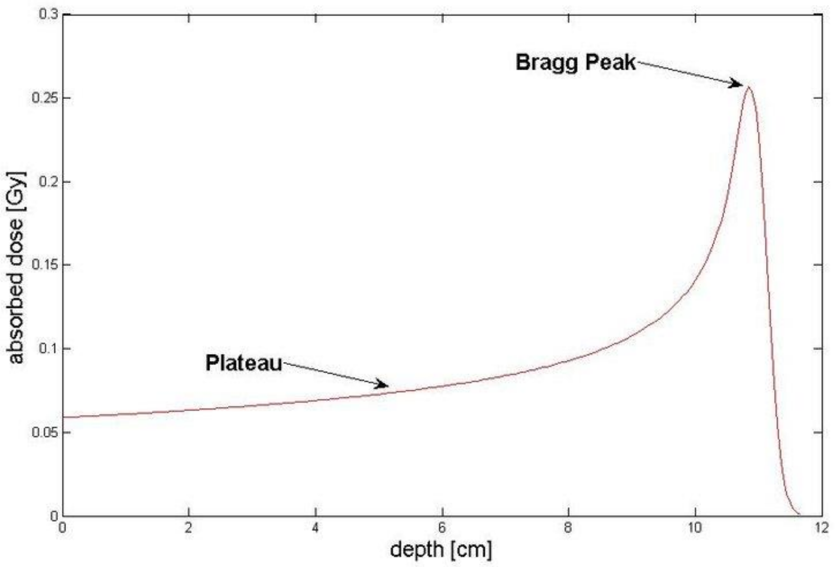
MOLLE ROBIN

Why beam monitoring?

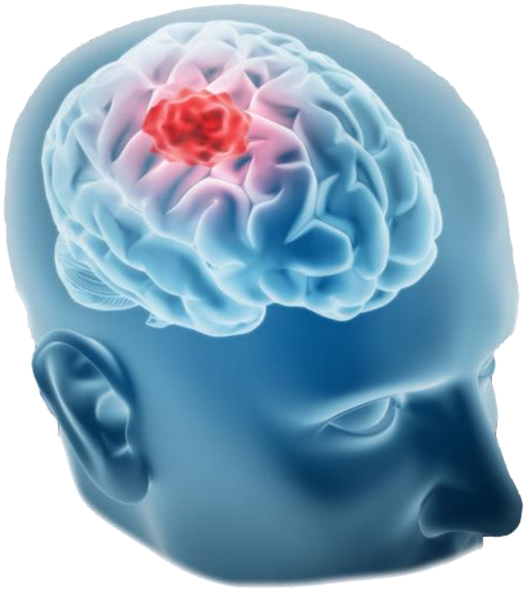
Diamond detector

Ion beam

50 MeV – 150 MeV for protons



Source : Experimental determination of absorbed dose to water in a scanned proton beam using a water calorimeter and an ionization chamber, S. Gagnebin,2010. URL : https://www.researchgate.net/publication/272623275_Experimental_determination_of_absorbed_dose_to_water_in_a_scanned_proton_beam_using_a_water_calorimeter_and_an_ionization_chamber

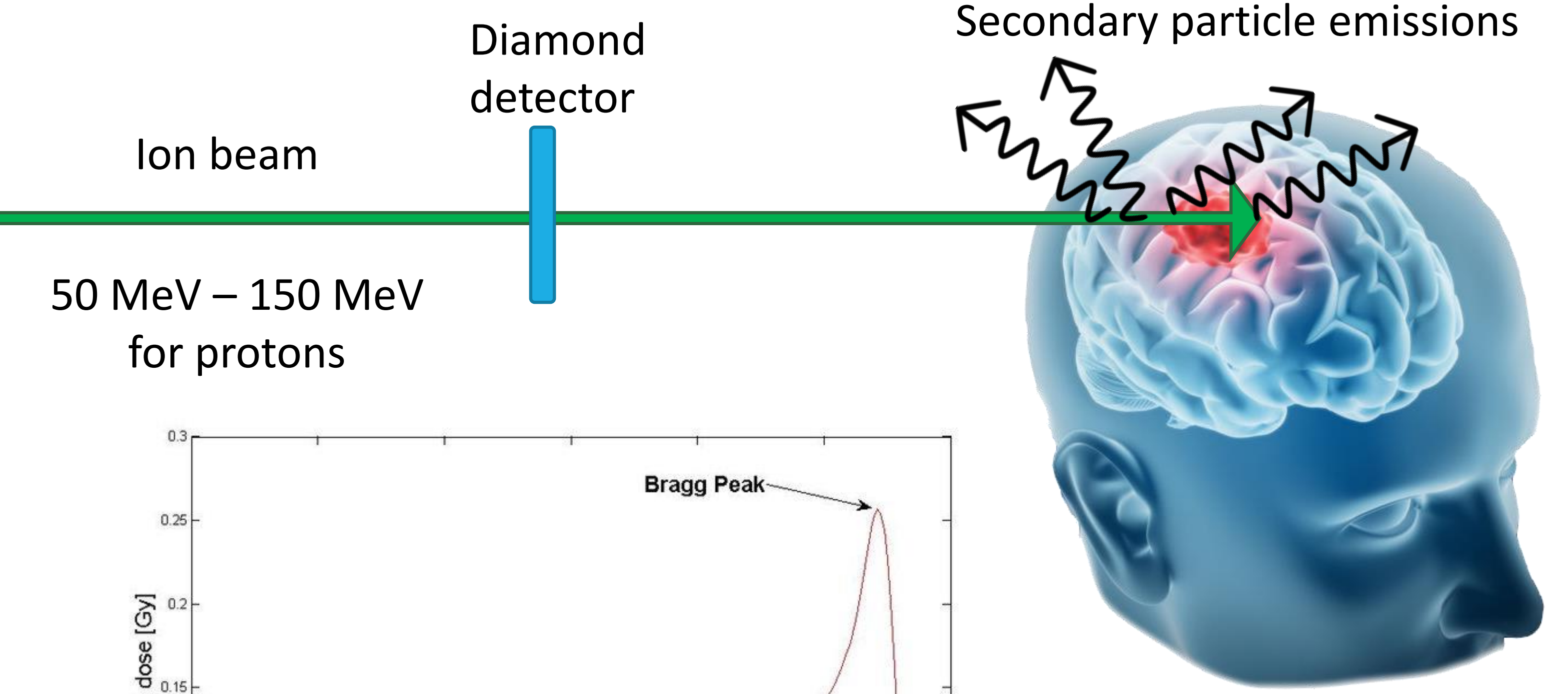


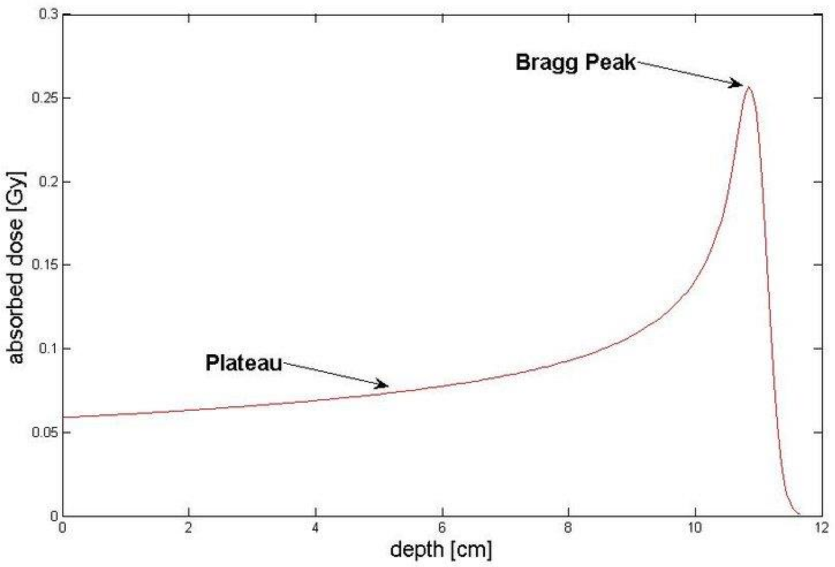
Beam monitoring

Number of particles

Time tagging for particles

Why beam monitoring?





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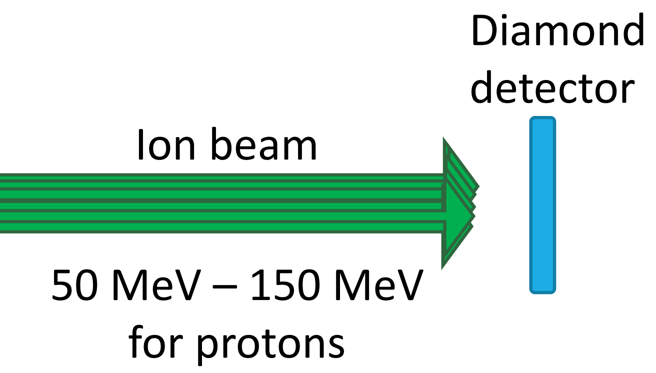
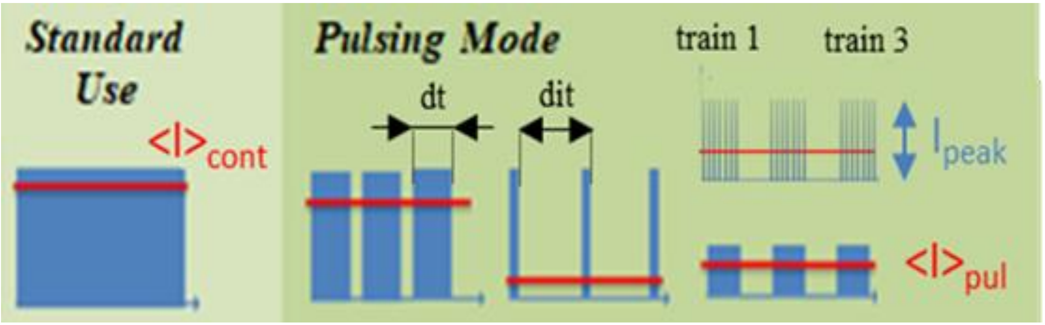


Beam monitoring

Number of particles

Time tagging for particles

Time stamps for trains

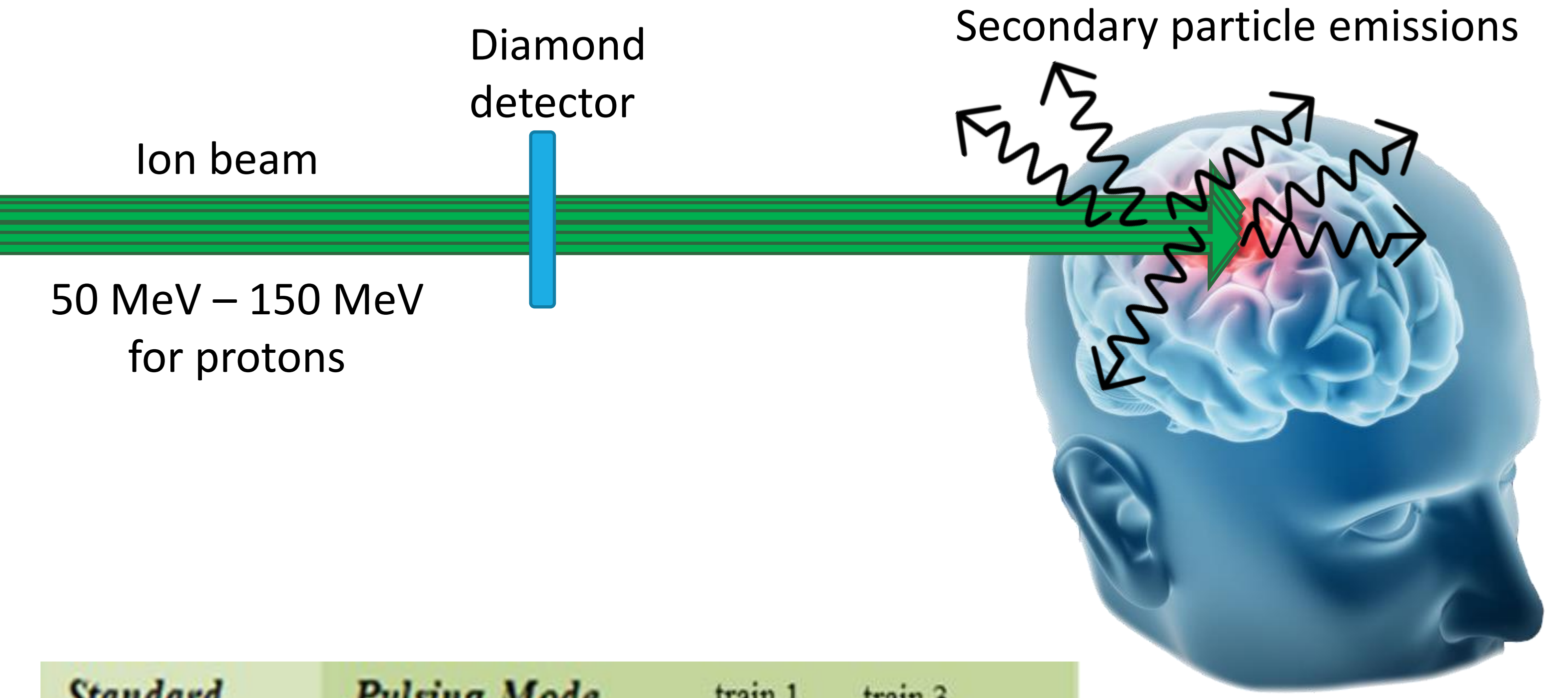


Source: The pulsing chopper-based system of the ARRONAX C70XP Cyclotron, Poirier et al., International Particle Accelerator Conference, 2019. URL https://doi.org/10.18429/JACoW-IPAC2019-TUPTS008

Beam structure:

- Microstructure : ~30 ns bunch
  (4 ns ON – 29 ns OFF for ARRONAX cyclotron)
- Macrostructure : few µs to 1 ms train
  train made of bunches
  tunable duration dt
  tunable duration between trains dit

Why beam monitoring?



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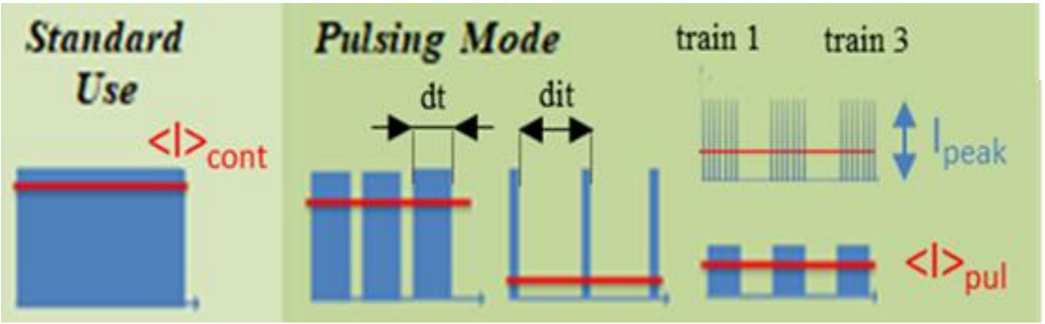

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Flash therapy vs conventionnal?
➔ high doses in a very short time: diamond beam monitoring!

Conventional X-rays
or hadrontherapy → **Gy/mn**
Flash therapies → **100 Gy/s**

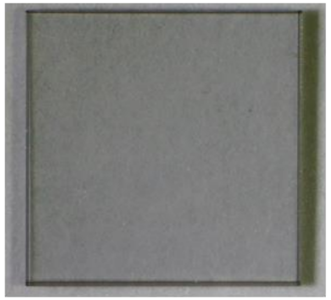
⇒ **Short pulses to be monitored** at **high beam intensity** !
⇒ **High particle couting rate capabilities** to be demonstrated
⇒ **Bunch or train of bunches time stamps**

Diamond compared to other semiconductors

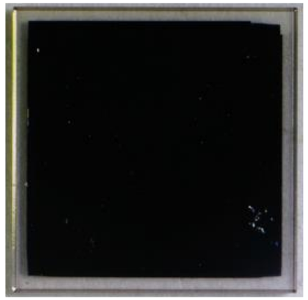
Diamond Assets :
- ❑ Intrinsic radiation hardness
- ❑ Fast signal risetime enables timing precision of a few tens of ps
- ❑ Low noise

Issues :
- ❑ Cost
- ❑ Availability of large area

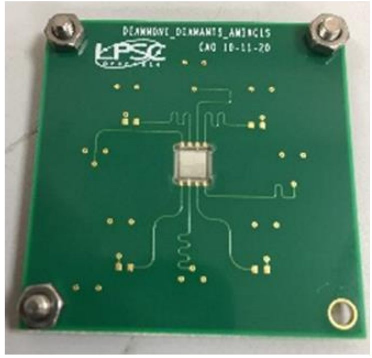
4.6x4.6 mm



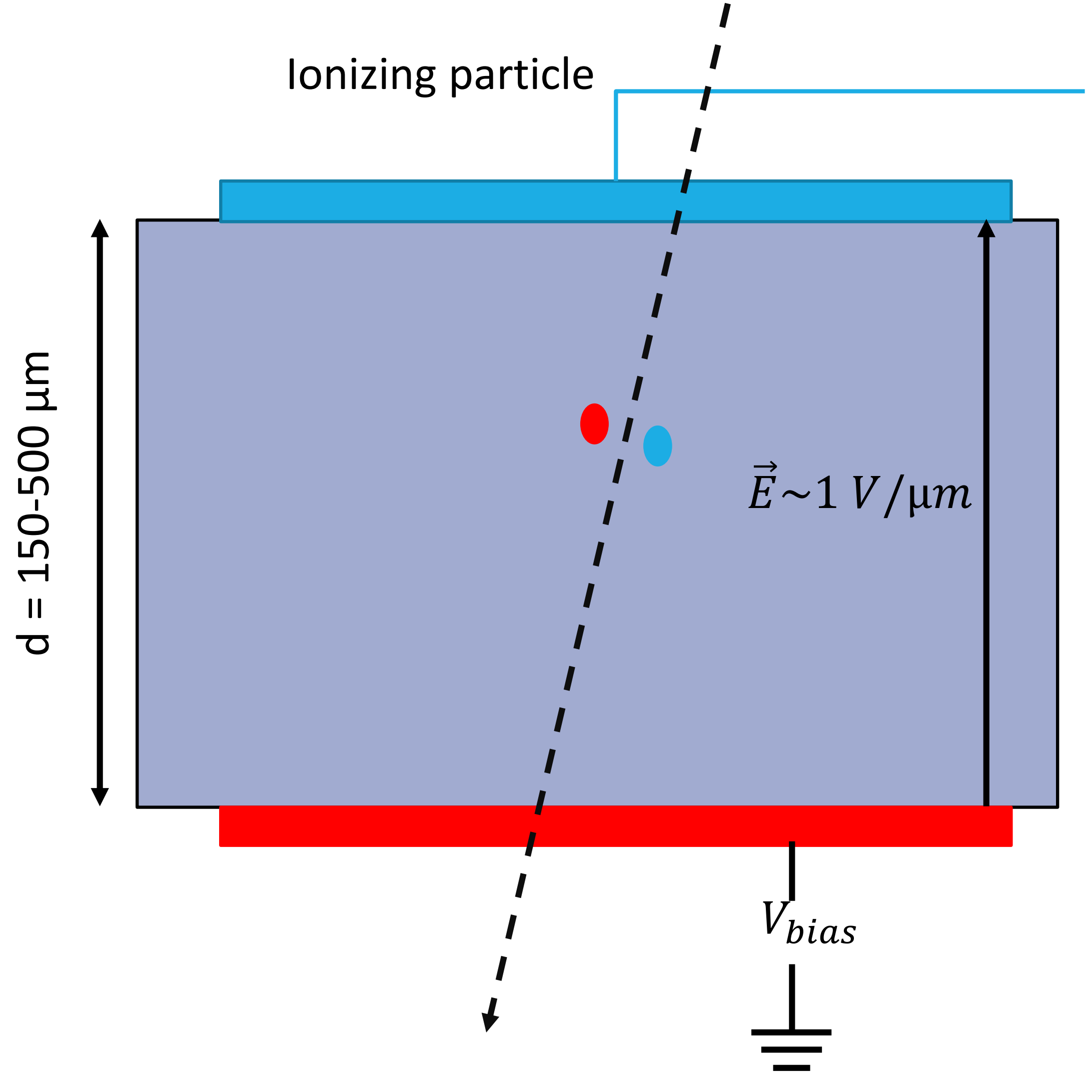
Artificial diamond



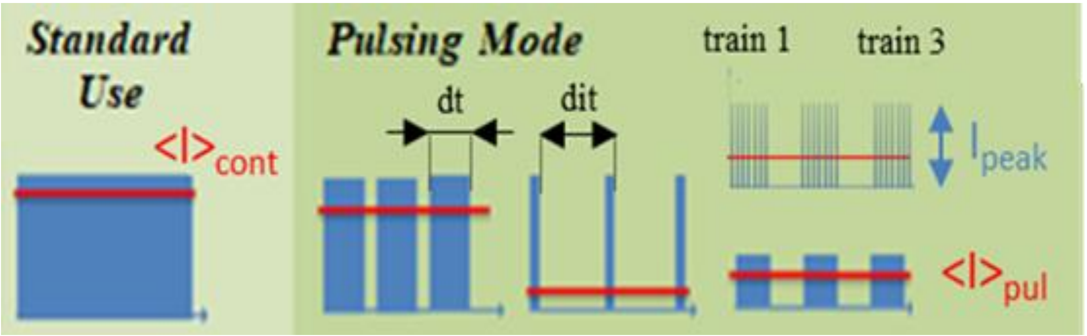
Metallized diamond
(Al 100nm)



Detector



ARRONAX cyclotron (France)

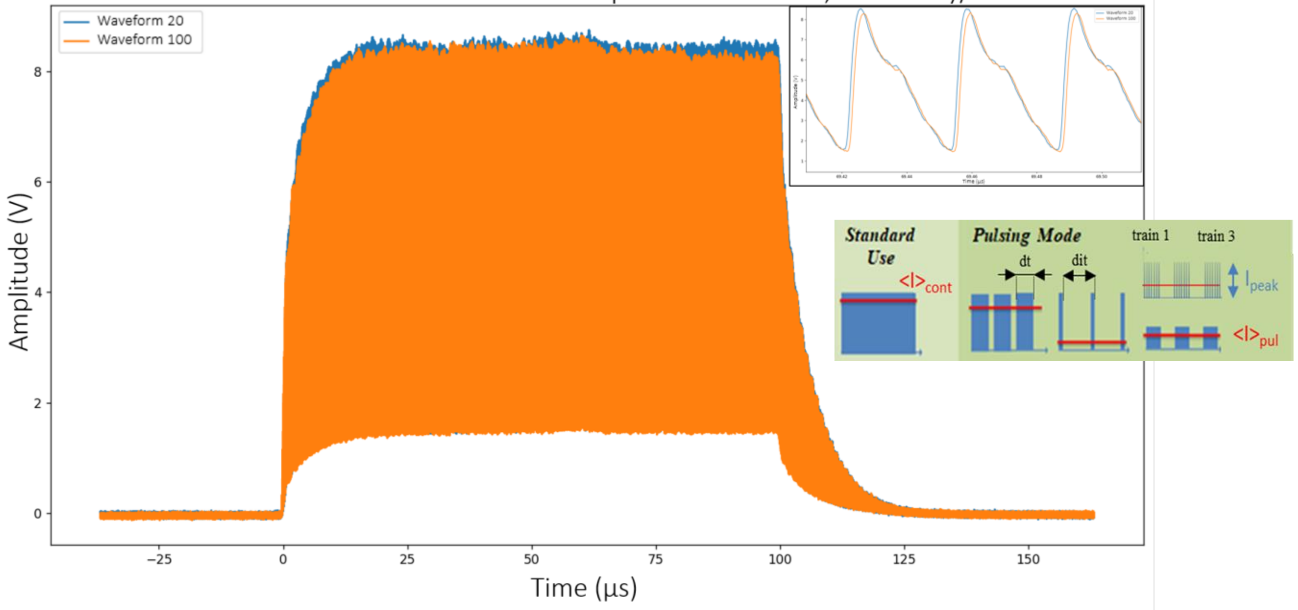


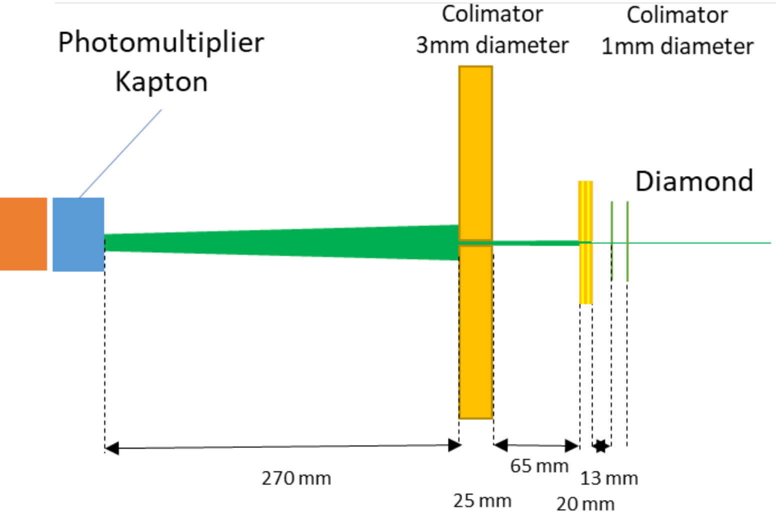
- 68 MeV proton / 70 MeV alpha particles cyclotron
- Beam intensity up to 20 µA
- Continuous or pulse mode beam delivery with tunable dt and dit time duration
- Bunch : 4ns ON, 29ns OFF (f = 30,45 MHz)

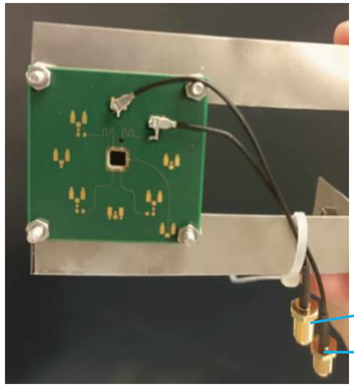
Source: The pulsing chopper-based system of the ARRONAX C70XP Cyclotron, Poirier et al., International Particle Accelerator Conference, 2019. URL https://doi.org/10.18429/JACoW-IPAC2019-TUPTS008

Experimental set-up

Current induced on one side of a 150 µm sCVD diamond, at 410 kGy/s







Oscilloscope

Voltage bias

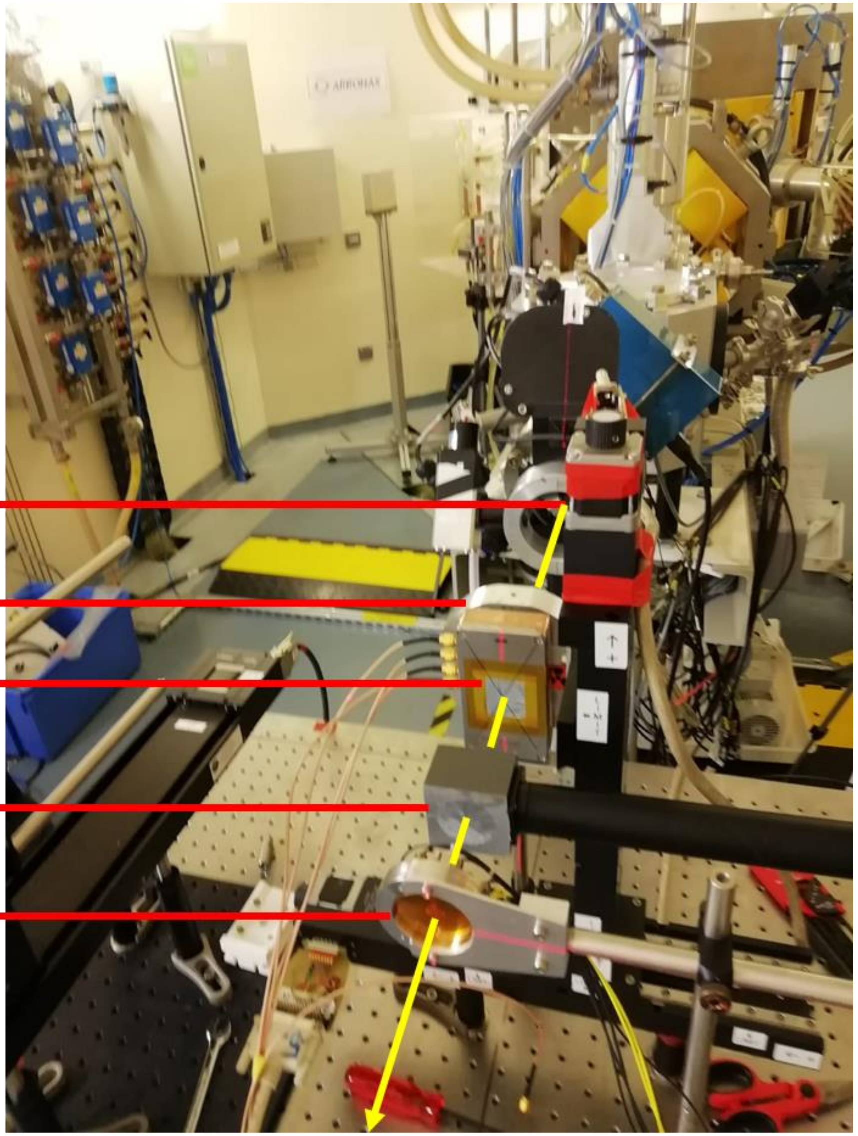
Beam output

Collimator 3 mm

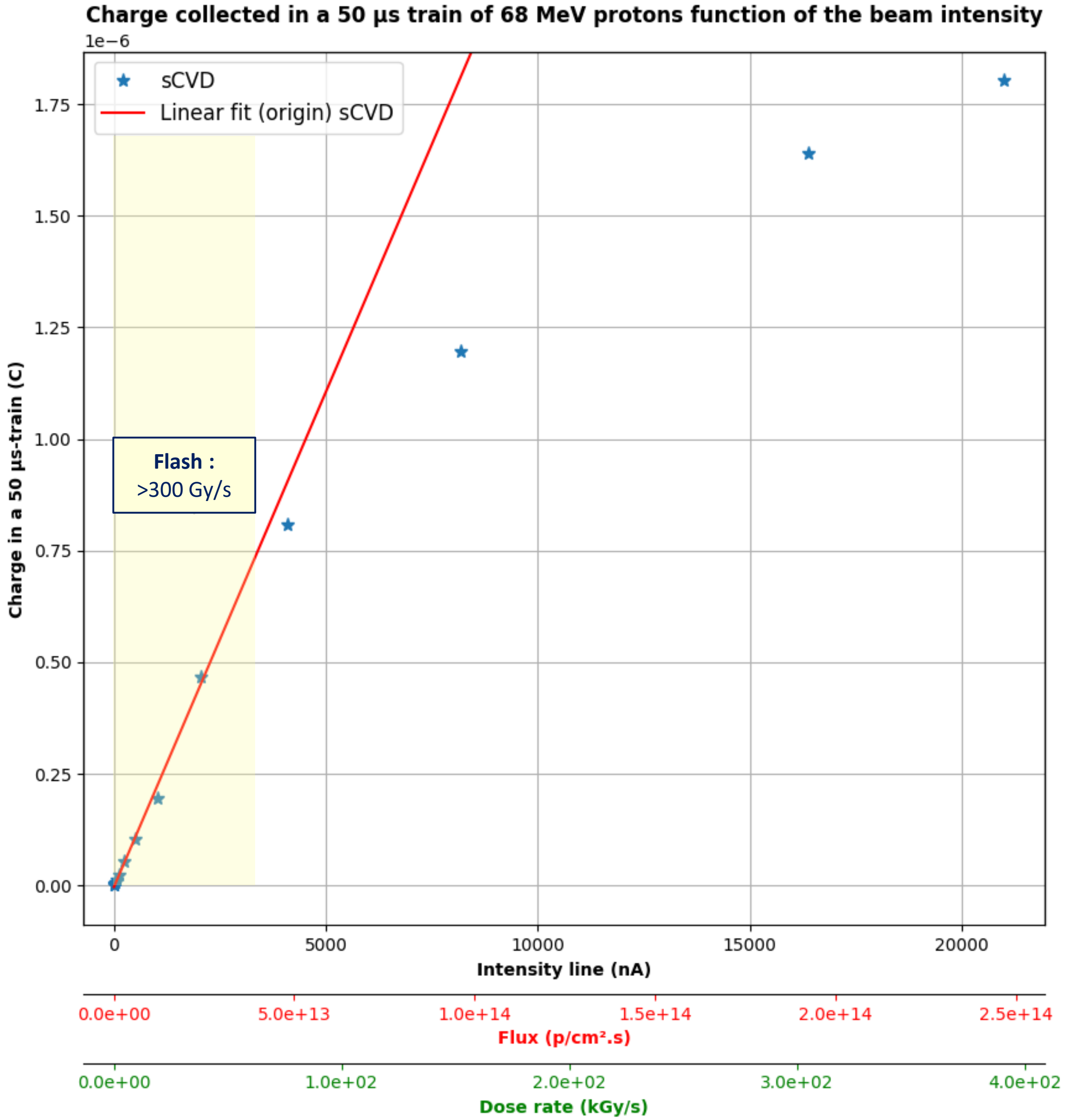
Diamonds

PM Alu

Ionisation chamber



Diamond response with proton flux



For each beam intensity:
1 train of 50 µs of 68 MeV protons

Linearity of sCVD diamond until a flux of ~2.5^{E}13 p/cm²

Saturation effect for higher fluxes :

- at high flux, an amount of e-h pairs created
- can disturb the electric field applied
- lifetime of e-h in diamond longer

➔ more risk of trapping and recombination

➔ saturation effect

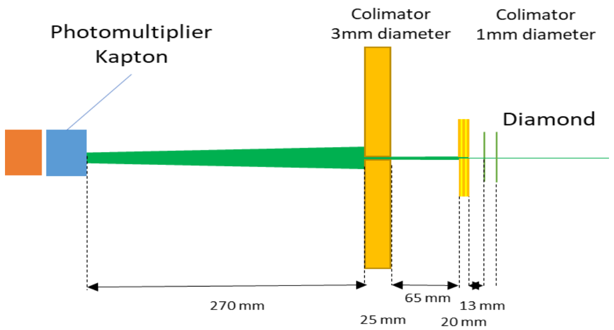
☺ for beam monitoring in FLASH conditions

What about lifetime of the detector?

➔ towards aging studies in **extreme** conditions in terms of flux and fluence

Aging studies (flux and fluence)

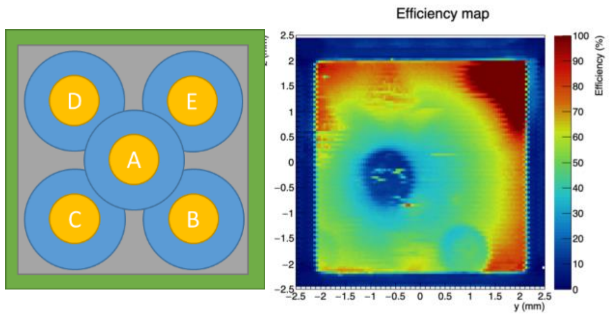
PRELIMINARY

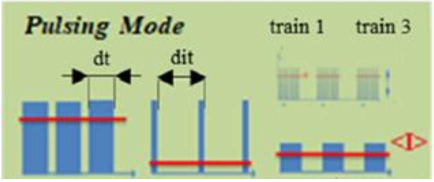


70-MeV protons

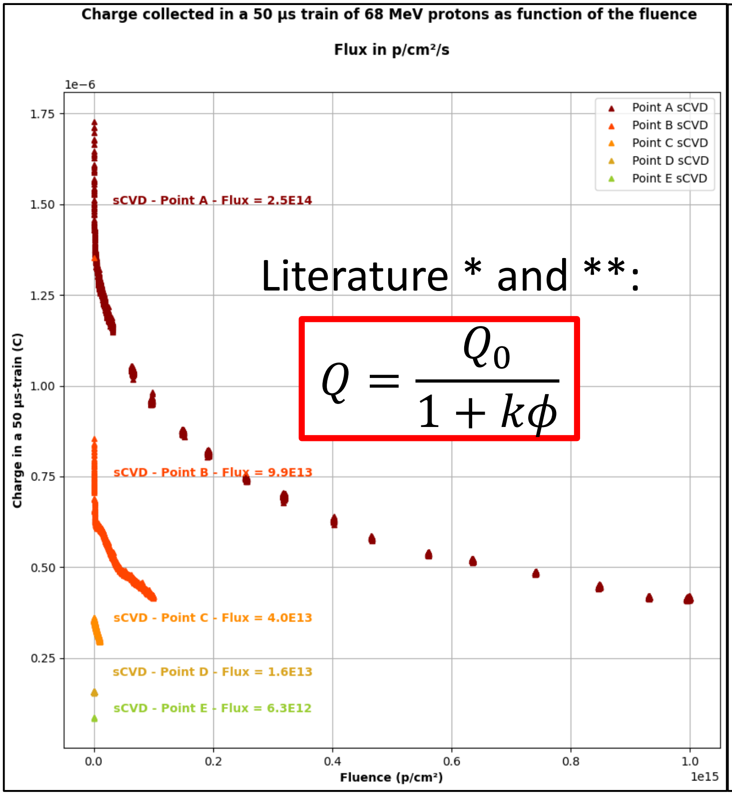
Point	Fluence	Flux
A	~10^{15}	2,5 10^{14}
B	~10^{14}	9,9 10^{13}
C	~10^{13}	4 10^{13}
D	~10^{12}	1,6 10^{13}
E	~10^{11}	6,3 10^{12}

sCVD results



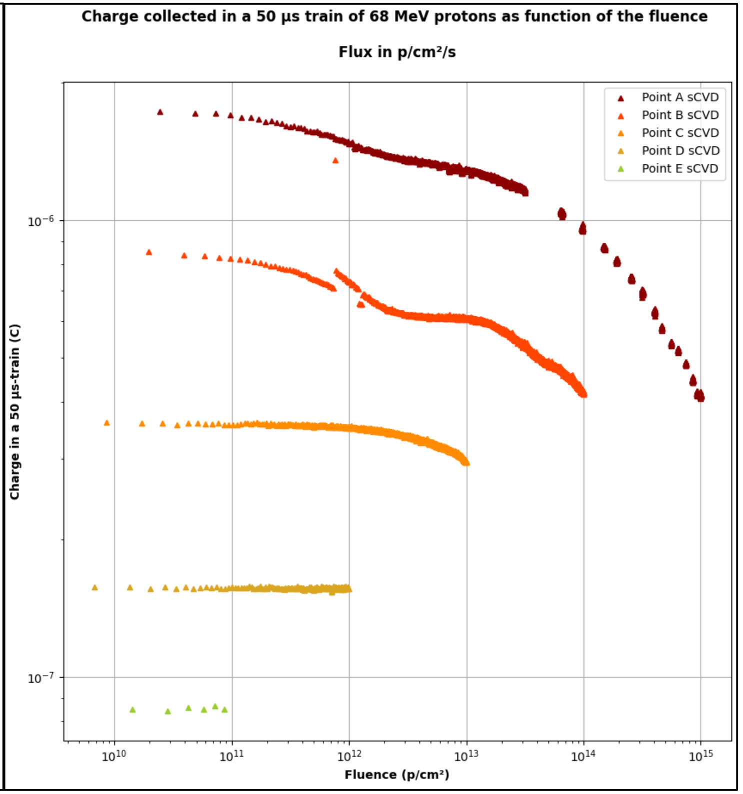


dt = 50µs
dit : variable => <I> = cste



Literature * and **:

$$Q = \frac{Q_0}{1 + k\phi}$$



$Q = charge$ ϕ = fluence Q_0, k = Cste = fit parameters

RD42 CERN coll. results:**

→k is decreasing with proton energy

Question to be answered:

→k = k (φ) with φ = flux?

Ongoing studies!

Ref.	Proton energy (MeV)	k cm²/p/µm
RD42 coll.	25	4,4 10^{-18}
RD42 coll.	70	2,6 10^{-18}
This work	70 (A point)	3,1 10^{-18}
RD42 coll.	800	1,67 10^{-18}
RD42 coll.	24000	1,0 10^{-18}

* A. Bhattacharya et al, « Degradation of single crystal diamond detectors in swift heavy ion beams, Diamond and related Materials 70 (2016) 124-131

**L. Bäni et al, RD42 coll. , « A study of the radiation tolerance of CVD diamond to 70 MeV protons, fast neutrons and 300 MeV pions », Sensors 2020, 20, 6648

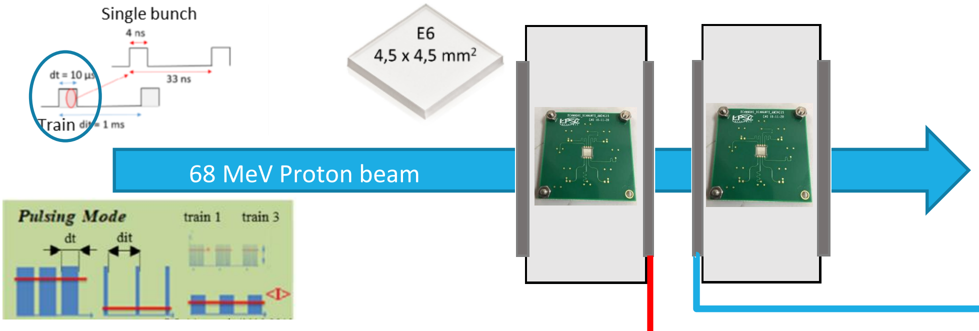
Remind proton therapy:

~10^{10} protons/cm²/treatment

~20 patient/day

~10^{13} proton/cm²/year

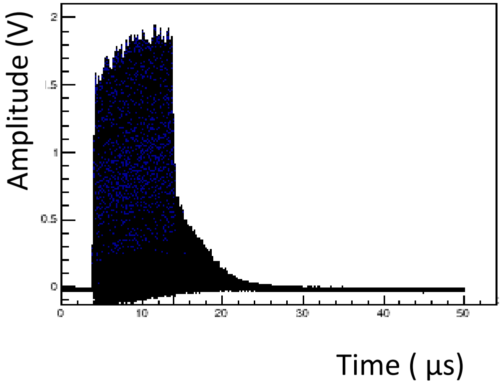
DIAMMONI detector development



I = 10nA, dt = 10µs, dit = 1s

DSO Lecroy
2 GHz; 10 or 20 GS/s

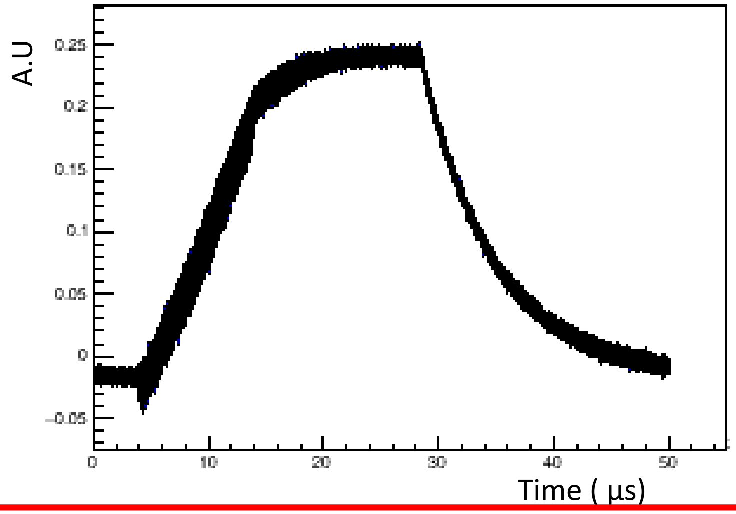
Signal of 10µs train of protons



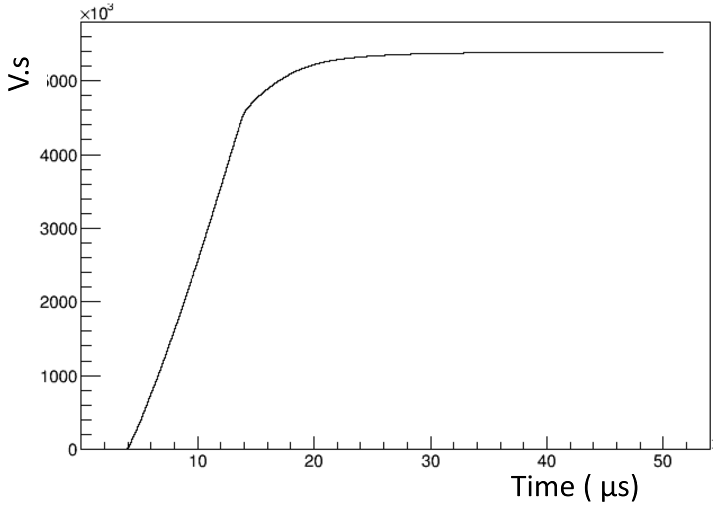
QDC board
developped @ LPSC

DAQ
developped @ LPSC

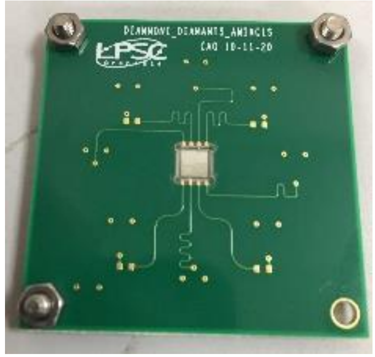
Train integral = on line measurement with LPSC QDC



Train integral = DSO post analysis

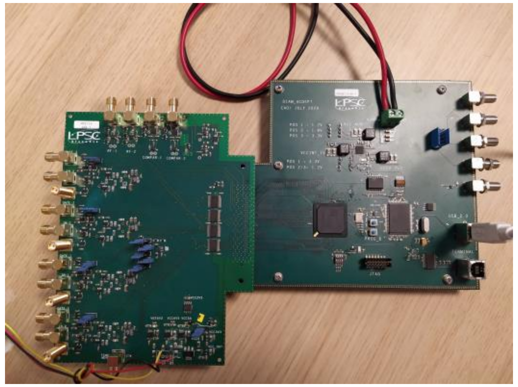


Conclusion



DIAMMONI: Diamond detector for pulsed beam monitoring in FLASH conditions

- diamond used as solid-state ionizing chamber
  - studies function of
    - flux (up to very high dose rate beyond FLASH conditions)
    - fluence (lifetime of the detector under extreme radiation conditions)
- front-end and back-end electronic developments (current integration in proton trains)



Further studies function of

- ionizing particle type
- signal formation (simulation)

Thank you for your attention !

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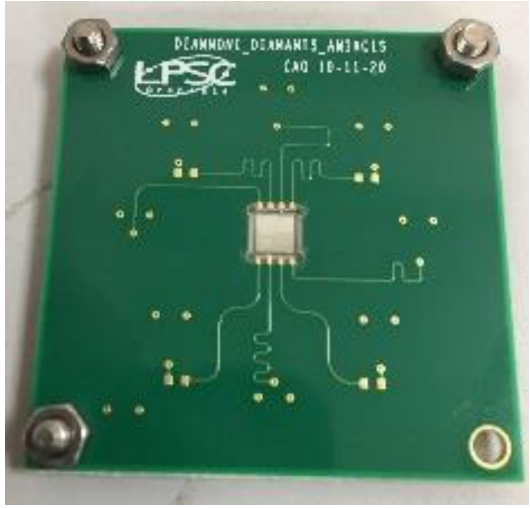

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