The use of ASM board for dose control in hadrontherapy

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Laboratoire de Physique Corpusculaire de Clermont-Ferrand

Workshop on picosecond photon sensors for physics and medical applications.

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Outline

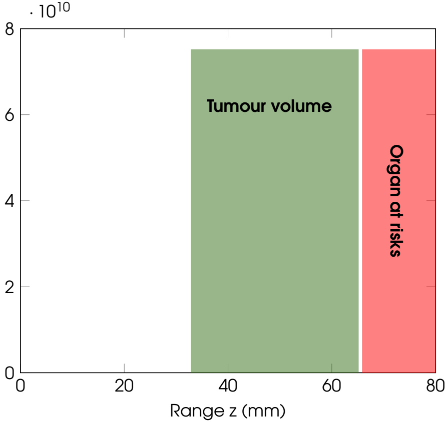
MOTIVATIONS

RETURN OF EXPERIENCE

USE OF ASM BOARDS

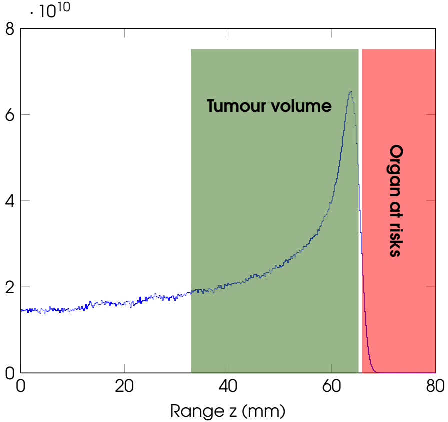
CONCLUSION & PERSPECTIVES

Hadrontherapy: ion therapy



- ⇒ Target volume: dose maximised
- ⇒ Organ at risks: dose minimised → prevent side effects

Hadrontherapy: ion therapy



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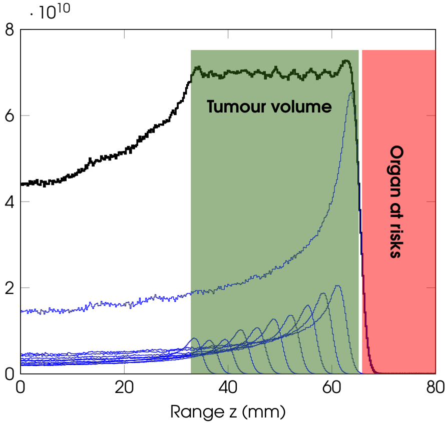
  - ≫ increasing **energy deposition** until reach a **maximum**
  - ≫ **finite range**

Hadrontherapy: ion therapy



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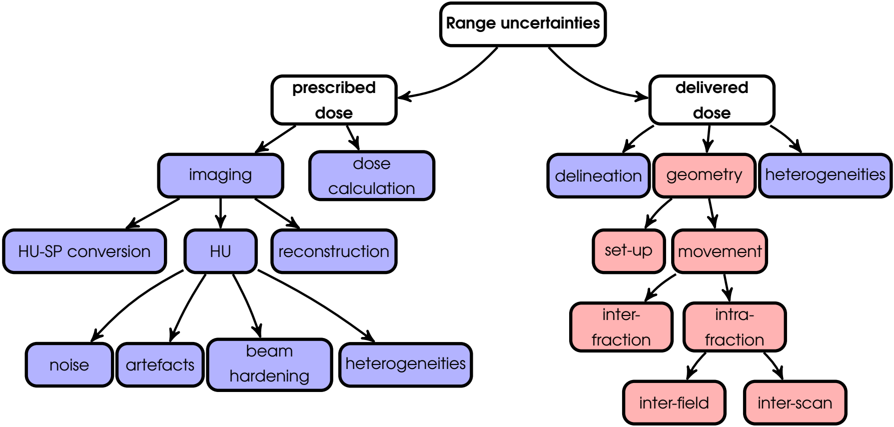
⇒ range monitoring is a key issue of hadrontherapy treatments

Range uncertainties



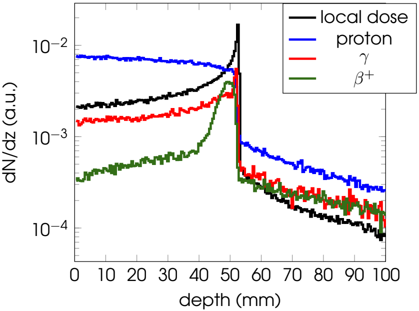
⇒ <5 mm uncertainties

⇒ systematic uncertainties: could be reduced as much as possible

⇒ random uncertainties: could not be prevented without any beam delivery monitoring

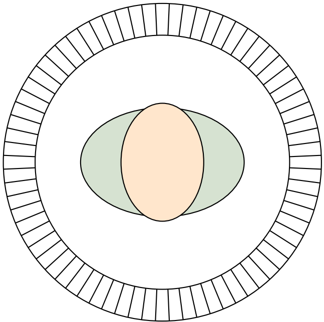
Range monitoring: detection of secondary particles

GEANT4 simulation: ^{12}C 163 MeV.u^{-1} on PMMA target



- ⇒ Induced β^+ activity measurements during irradiation:
  - ≫ annihilation photon pairs → good events ☺
  - ≫ prompt particles (mainly nuclear γ → bad events ☹)

- ⇒ $\beta^+ \rightarrow 2\times511$ keV γ (induced radioactivity)
  - ≫ ^{10}C **($T_{1/2}$=20 s)**
  - ≫ ^{11}C **($T_{1/2}$=20 min)**
  - ≫ ^{15}O **($T_{1/2}$=2 min)**
- ⇒ prompt γ: nuclear γ (1,10 MeV)



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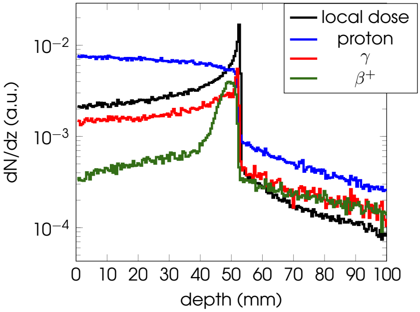

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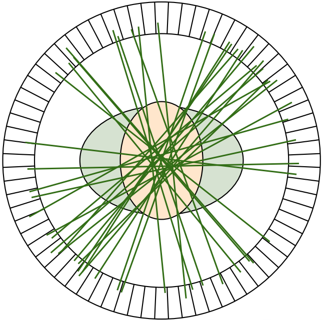

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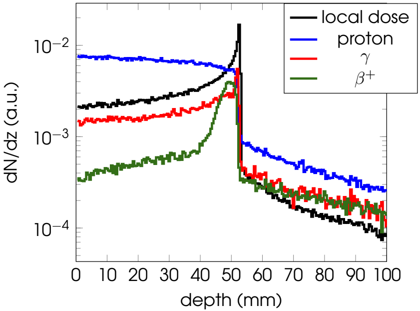

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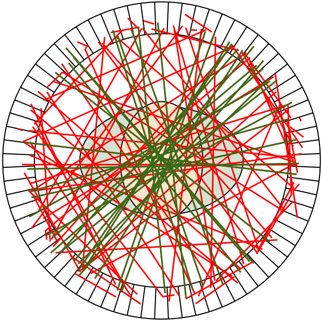

What we would like: waveform digitisation

⇒ Acquisitions during irradiation is **very noisy**: need for **random coincidences rejection**

⇒ Improve trigger selectivity: data sampling allows to **re-process and refine** trigger off-line
(not possible with TDC+QDC)

⇒ Read-out electronics should be **generic** for different photosensors

What we have

- ⇒ Since 2002, different **read-out electronics** based on **switched capacitor array** technology have been developed at LPC for physics experiments:
  - ≫ **ARS16 board** based on ARS0 chip [1]: 16 channels, buffer depth=128, F_{samp}=300 MHz-1 GHz, ADC(12 bits): 1 MHz
  - ≫ **ASM board** based on DRS4 chip [2]: 24 channels, buffer depth=1024, F_{samp}=500 MHz-6 GHz, ADC(12 bits): 33 MHz
- ⇒ 1 small solid angle detector has been developed:
  - ≫ **2×20 channels**: 1 channel = APD S 8664-55 (Hamamatsu) coupled to LYSO crystal (5×5×22 mm^3)
- ⇒ 1 larger solid angle detector is under development:
  - ≫ **2×120 channels**: 1 channel = 1/2 inch head on PMT coupled to LYSO crystal (13×13×15 mm^3)

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[1] (F. Feinstein, NIM A (2006), 504)

[2] (S. Ritt, NSS Conference Record, IEEE (2008))

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Experiments

- ⇒ We have conducted several experiments on proton and carbon beams
- ⇒ GANIL[3], research facility ⇒ **75 MeV.u^{-1} carbon beams**
- ⇒ CPO[4] , clinical facility ⇒ **86 MeV proton beams**
- ⇒ **main problem**: how to **discriminate**, during *in-beam* acquisitions, annihilation photon pairs from nuclear induced background ?
- ⇒ **main hypothesis** to deal with this issue: **nuclear background is synchronous to the beam extraction** → synchronise DAQ to the accelerator frequency

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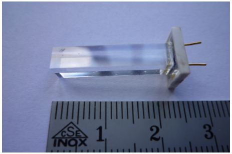
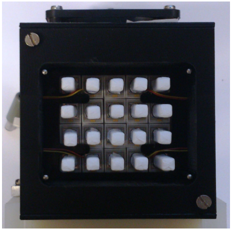
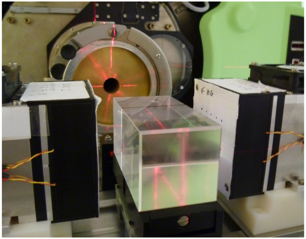
[3] Grand Accelerateur National d'Ions Lourds

[4] Centre de ProtonTherapie d'Orsay

Experiments with small solid angle detector (APD-based)

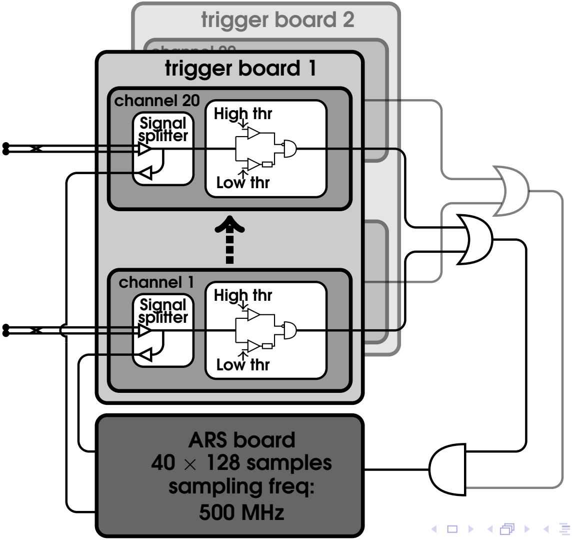






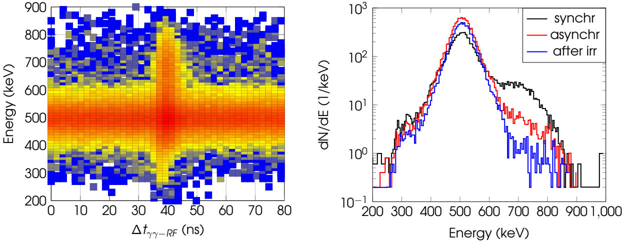
- ⇒ Custom made trigger boards: both heads operated in coincidence
- ⇒ Read-out electronics: ARS16 boards, F_{samp}=500 MHz
- ⇒ Experiments done at GANIL:
  - ≫ **^{13}C 75 MeV/n**
  - ≫ **continuous extraction**
  - ≫ cyclotron frequency: **12 MHz → 1 bunch every ∼80 ns**
- ⇒ Experiments done at CPO:
  - ≫ **p 86 MeV**
  - ≫ **continuous extraction modulated**: 50 ms extraction + 50 ms pause
  - ≫ cyclotron frequency: **106 MHz → 1 bunch every ∼9 ns**

Trigger block diagram



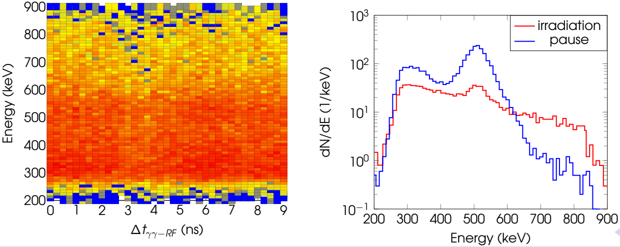
Experiment with the APD based detector

GANIL experiment results



- ⇒ GANIL experiment:
- ≫ **synchr: $\Delta t_{\gamma\gamma-RF} \in [30ns; 50ns]$**
- ≫ **asynchr: $\Delta t_{\gamma\gamma-RF} < 30ns$; $\Delta t_{\gamma\gamma-RF} > 50ns$**
- ≫ **after irr: after irradiation**
- ⇒ **Nuclear induced background well synchronised to the beam extraction**

CPO experiment results



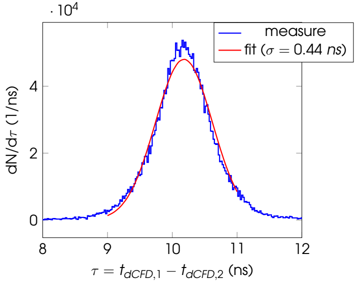
- ⇒ CPO experiment:
- ⇒ **No time correlation visible**
- ⇒ **Coincidence Resolving Time (CRT) improvement → 5.4 ns (FWHM) with this setup**
- ⇒ **use of faster photodetector than APD → PMT works well**
- ⇒ **Need for finding another selection criterion when cyclotron frequency is too high (~ 100 MHz)**

Use of PMT to improve CRT

⇒ Use of PMT from an old HR$^+$ PET system

⇒ Better timing resolution: 1 ns (FWHM)

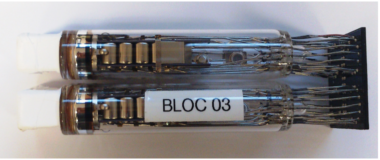
- ≫ **LaBr$_3$(5%Ce) crystal** (12.7×12.7 mm^3) coupled to a PMT Hamamatsu H6533 against **LYSO crystal** ($13 \times 13 \times 15$ mm^3) coupled to a HR$^+$ PMT
- ≫ acquisitions with Lecroy^{TM} oscilloscope (6050 A): 500 MHz analog bandwidth, 2.5 GSPS



⇒ those PMT's seems to be good enough to build a cheap large acceptance detector dedicated to *in-vivo* particle range monitoring

On-beam test with blocks of large acceptance detector

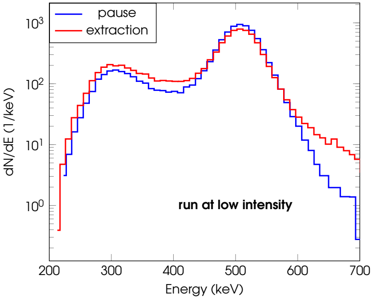
⇒ Preliminary tests with a pair of 4 channels, PMT+LYSO crystal ($13\times13\times15$ mm^3) has been made at CPO facility



⇒ Both blocks are operated in coincidence and the 8 channels are read-out by ARS16 boards

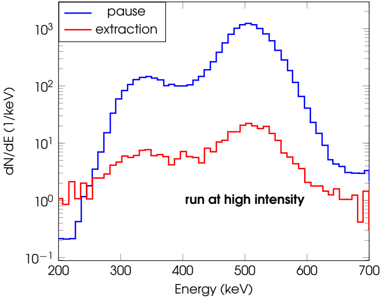
⇒ Two acquisitions have been done at two different beam intensities: low intensity ($\sim$2 10^7 p.s^{-1}) and higher intensity ($\sim$7 10^8 p.s^{-1})

Preliminary *in-beam* results



- ⇒ at low intensity, annihilation photon pairs are **easily detected**
- ⇒ **CRT = 3 ns (FWHM)**
- ⇒ CRT should be better with faster sampling

- ⇒ at higher intensity → high dead time
- ⇒ Nevertheless, we are able to **more efficiently extract** annihilation photon pairs during *in-beam* acquisitions



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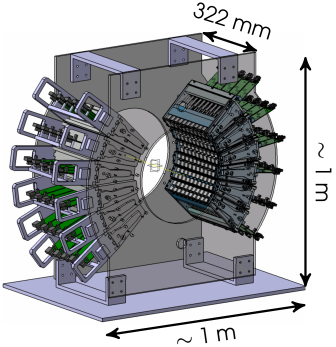
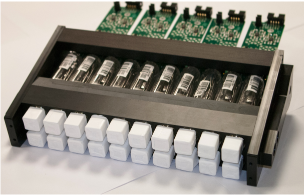
Use of ASM boards

- ⇒ **Analog Sampling Module (ASM)** boards, based on DRS4 chip, have been developed at LPC (cf. talk M.Magne)
- ⇒ able to sample analog waveforms **up to 6 GHz**
- ⇒ well adapted to read-out **fast photodetectors** such as MCP-PMT, SiPM, dSiPM: at least 5 samples on the rising edge if rising time is $\sim$ 1 ns
- ⇒ should **improve CRT** of our PMT-based detector
- ⇒ these boards are also able to **generate a first level trigger**
- ⇒ **scalable system** to read-out several hundreds of channels

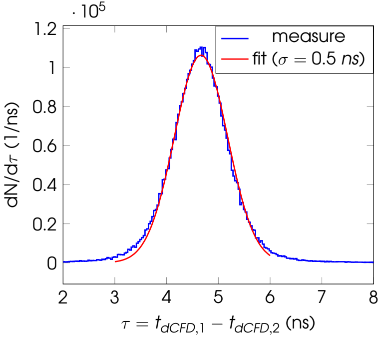
A 240 channels detector



- ⇒ 2 heads: 120 channels per head
- ⇒ a channel: 1 PMT+1 LYSO crystal ($13 \times 13 \times 15$ mm^3)
- ⇒ intern diameter: 322 mm
- ⇒ axial FOV: 188.5 mm
- ⇒ total weight: ~ 70 kg
- ⇒ 12 ASM boards to read out all the 240 channels
- ⇒ DAQ μTCA



Timing resolution



- ⇒ CRT measured :**2 LYSO crystals** ($13 \times 13 \times 15$ mm^3) coupled to HR^+ PMT
- ⇒ ASM board read-out each channel: 4.1 GSPS
- ⇒ Acquisitions performed via custom made C++ program (CPU VME)
- ⇒ **CRT reached: 1.2 ns (FWHM)**

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Conclusion

- ⇒ We would like to **monitor ion range during treatment** by measuring induced β^+ activity
- ⇒ We need to **extract annihilation photon pairs** from induced nuclear background
- ⇒ Several experiments have been done on proton and carbon ion beams
- ⇒ We conclude that **extraction of good events** is possible if **timing resolution is good enough** comparing to the mean time between two ion bunches
- ⇒ A **fast sampling read-out electronics**, based on DRS4 chip, has been espacially developped for this purpose
- ⇒ A **CRT of 1.2 ns (FWHM)** has been measured which should be enough to **improve** good events extraction during acquisition
- ⇒ This read-out electronics is also **well adapted** to fast photodetectors

Perspectives

- ⇒ Next step: **first in-beam** test with at least 80 channels (4 ASM boards)
  - ≫ GANIL: end of April
- ⇒ Then: *in-beam* tests with the **whole detector**: 240 channels (12 ASM boards)
  - ≫ CPO: end of May
- ⇒ Work on fast **photodetector** (MCP-PMT, 16 anodes (R10754X-01-M16, Hamamatsu) is on progress
- ⇒ For now characterisation with femtosecond laser
- ⇒ then timing measurement with ASM board