Dose monitoring with prompt gamma-rays

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AB-NCT workshop

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γ emission for neutron capture by ^{10}B and ^{157}Gd

- **Boron neutron capture**

$$^{10}B + n_{th} \rightarrow {}^{11}B^* \begin{cases} (6\%) \quad {}^{4}He + {}^{7}Li \ 2.79 \text{ MeV} \\ (94\%) \quad {}^{4}He + {}^{7}Li \ 2.31 \text{ MeV} + \gamma \ 0.478 \text{ MeV} \end{cases}$$

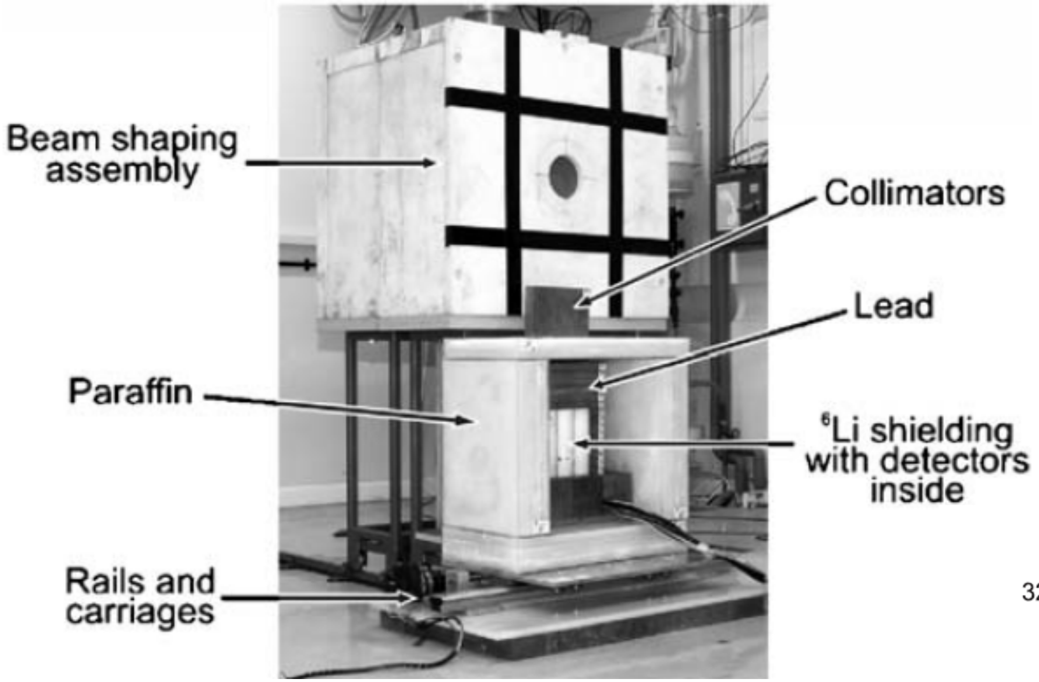
➡ SPECT imaging: boron induced dose

- **Gadolinium neutron capture**

$^{157}Gd + n_{th} \rightarrow {}^{158}Gd$ 7.9 MeV (IC and/or γ rays)

➡ several gamma lines: position of Gd

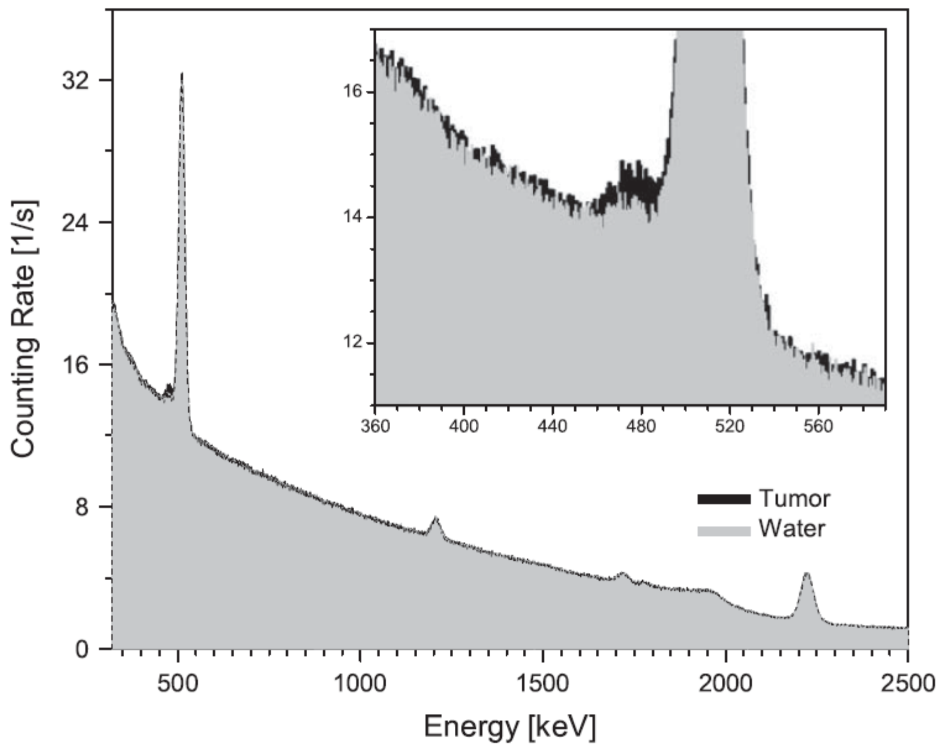
Prompt gamma monitoring of BNCT



Minsky et al (Appl Rad Isotopes 2009)

Measurements at Birmingham reactor

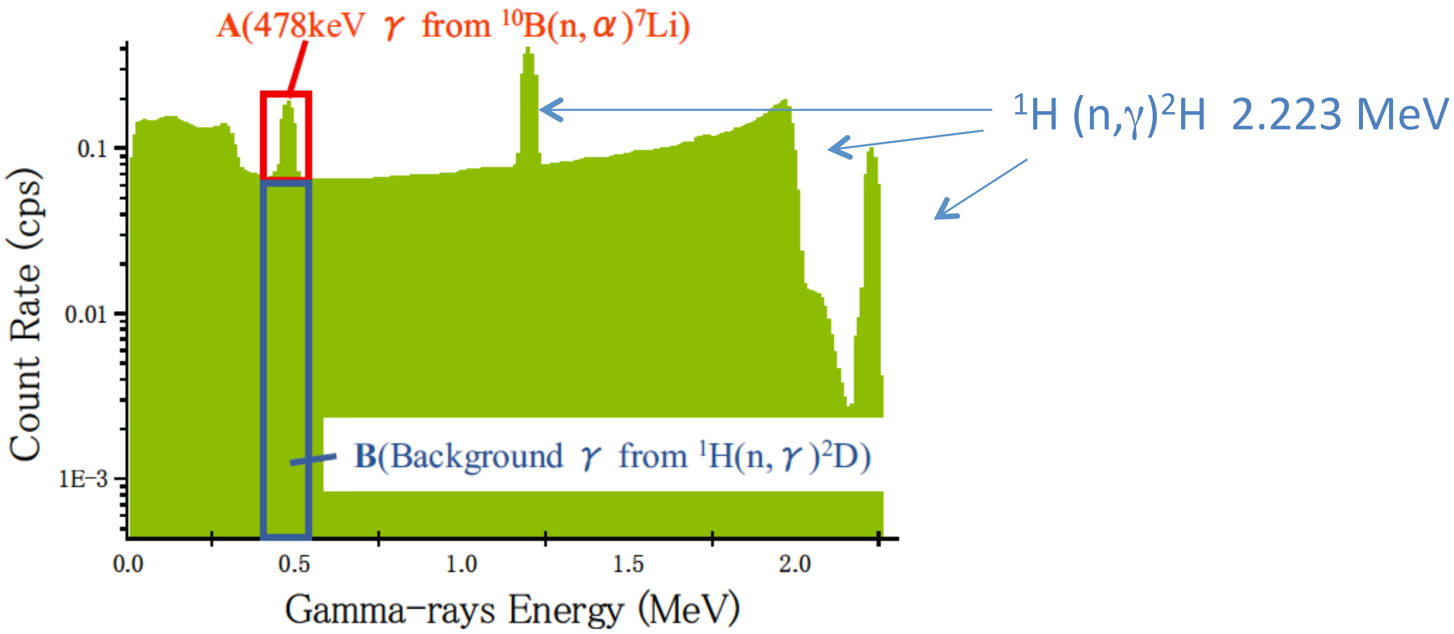
LaBr scintillator



Prompt-gamma imaging of BNCT

- Blood ^{10}B concentration follow-up (Raaijmakers Acta Onc 1995)
- First studies by Verbakel (NIMA 1997, clinical tests Int J Rad Onc Biol Phys 2003) Ge detector
- Murata et al, Prog. Nucl Science and Technology 2011

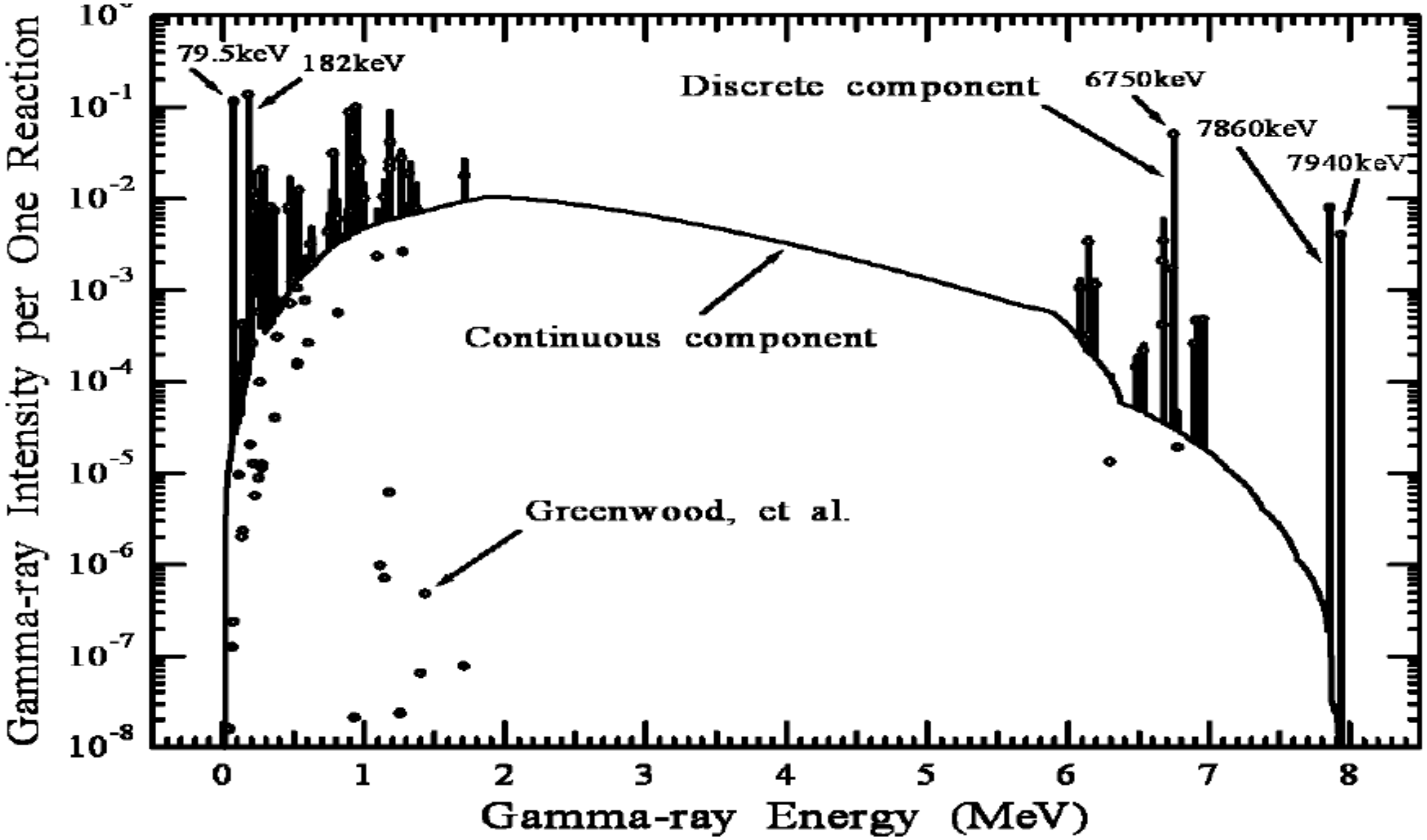
  Simulation MCNP with CdTe detector (511 keV not taken into account)



- Per Munck af Rosenschöld (JINST 2006): HPGe , Pinhole collimator

Gamma emission for (n,γ) reaction on ^{157}Gd

Sakurai, Appl Radiat Isot 2009



+ Large multiplicity (> 1 gamma/capture)

- Poly-energetic photons

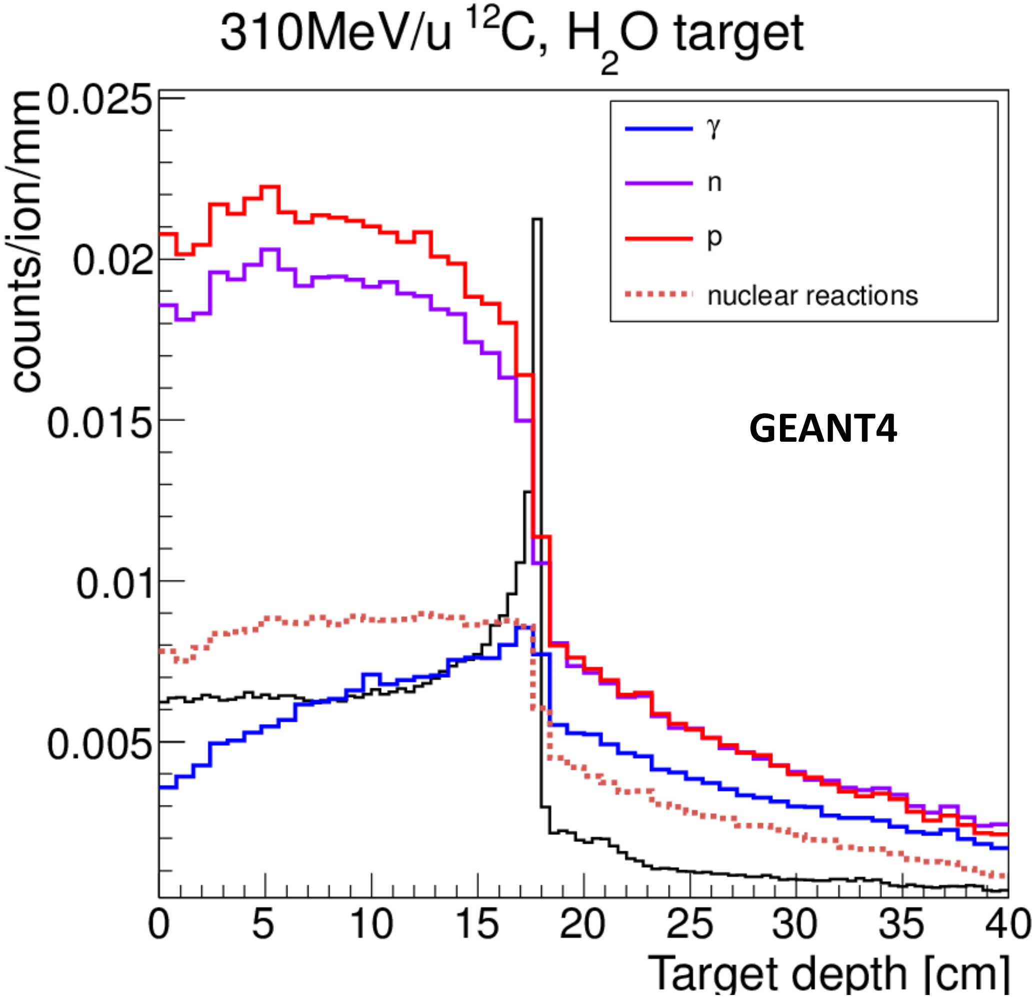
Background from CLaRyS collaboration: Prompt γ imaging of hadrontherapy

- Nuclear fragmentation
  - High probability
  - Secondary particles
    - γ, *n*, *p*, fragments
    - Radioactive Isotopes (β^+)

- Emission profiles correlated to the projectile range

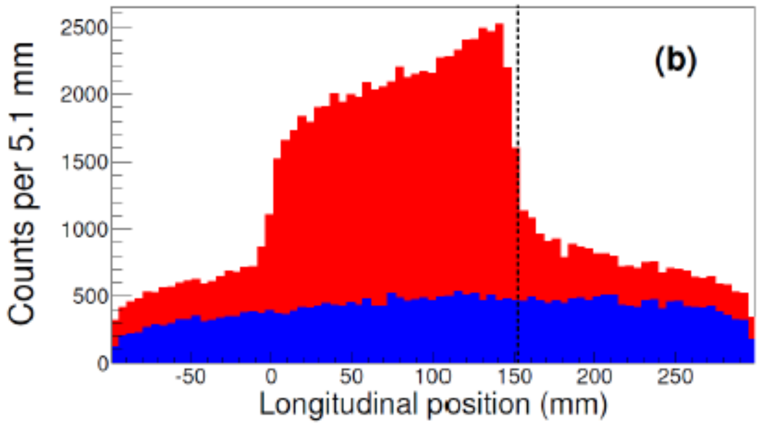
- PG yield above 1 MeV :
  ~ 0.3% /cm per proton
  ~ 2% /cm per carbon ion
  Energy range 1-10 MeV

- High background (neutrons)

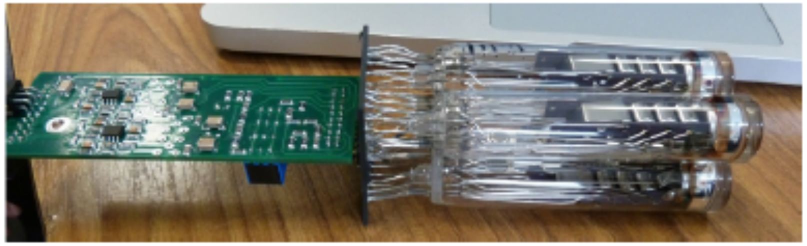


Multi-slit collimated camera

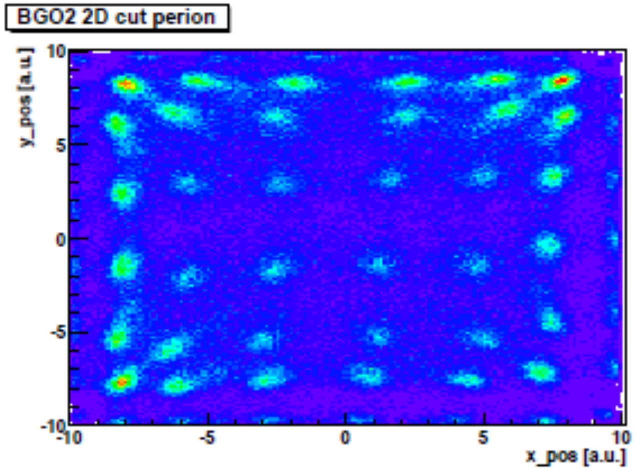
- 1D profile



Profile obtained with an optimized TOF camera for 4×10^9 protons
[Pinto. PMB 2014]



PM + BGO blocs from HR+ PET (LPC)



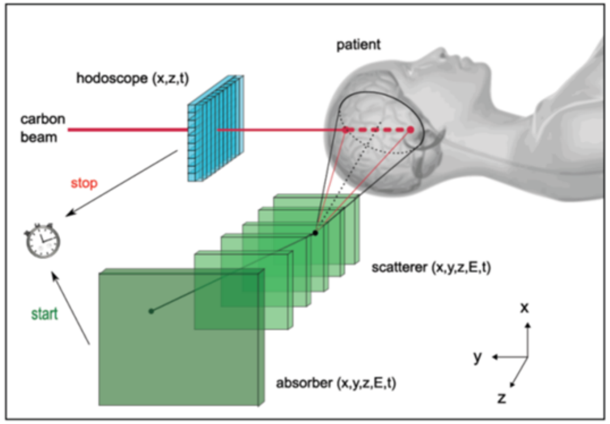
2D reconstructed position

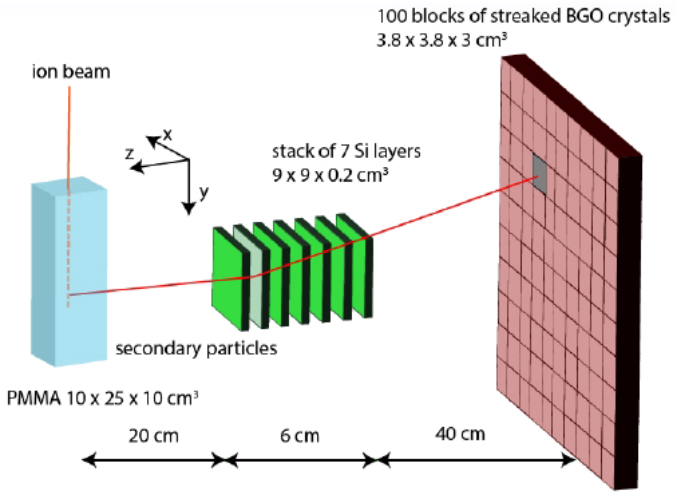
Tungsten alloy collimator (12x10x0.2 cm slabs)

[Krimmer, NIMA 2015]

- 2D profile: pinhole camera?

Compton camera



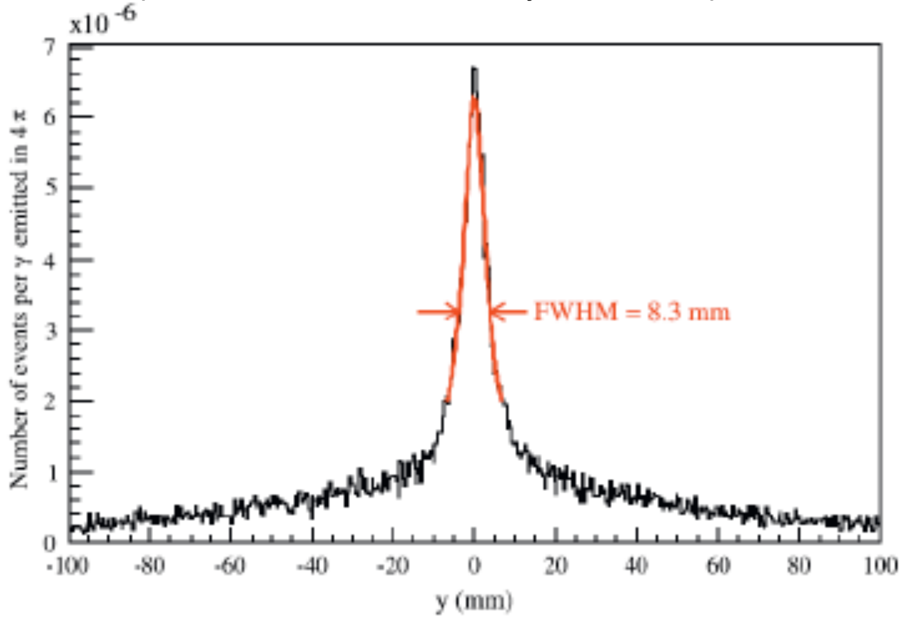


Geant4 simulations

- optimization of the setup
- check of feasibility for medical applications

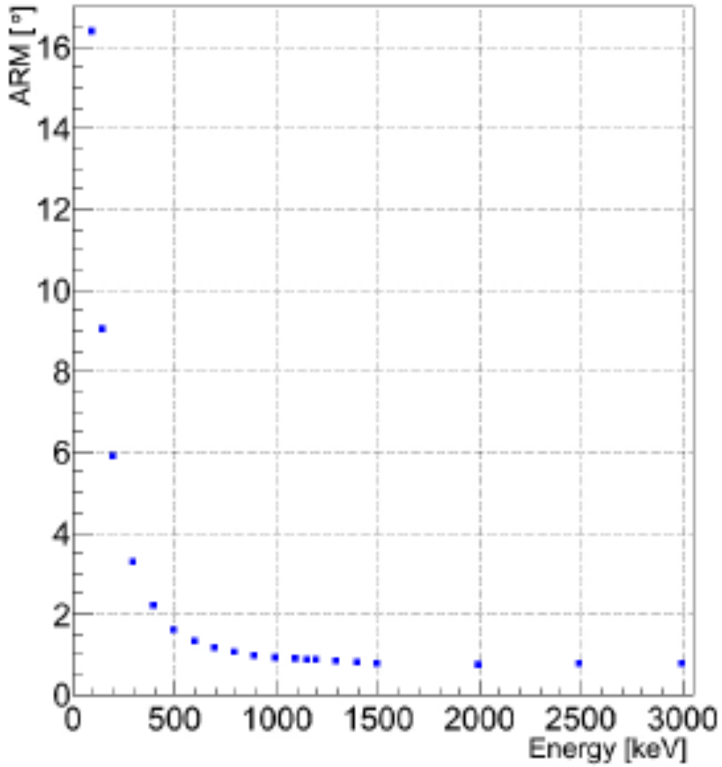
JL Ley, PhD thesis
Lyon 2015

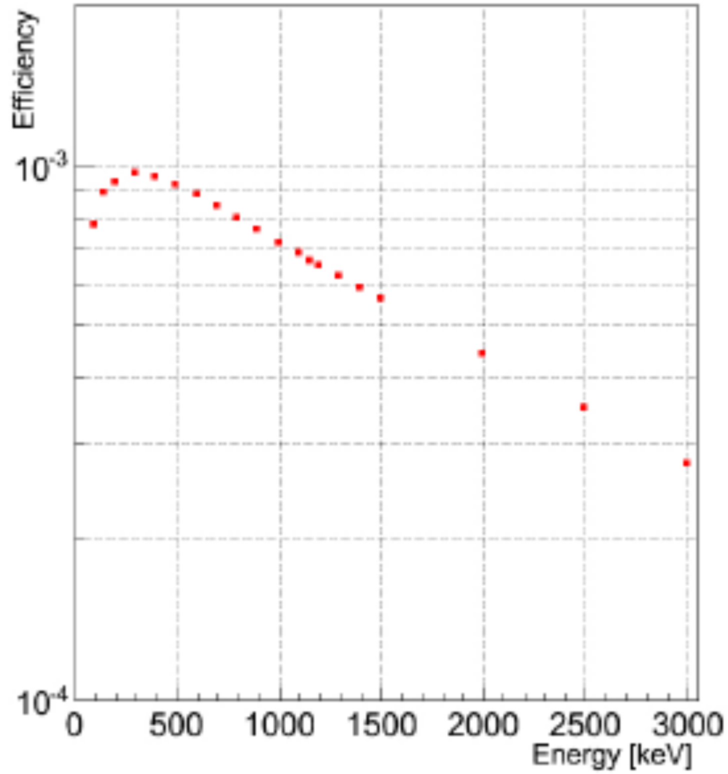
Simulation point-spread function response
(MH Richard, PhD Lyon 2012)



Simulation: nuclear medicine

- simulation: point source
- Angular Resolution Measure: ARM = $\Theta_{compton} - \Theta_{geom}$
- $\Theta_{compton}$ from Compton kinematics
- Θ_{geom} from (known) geometrical source





J.L. Ley PhD thesis

Compton camera scatter detector realization (2)

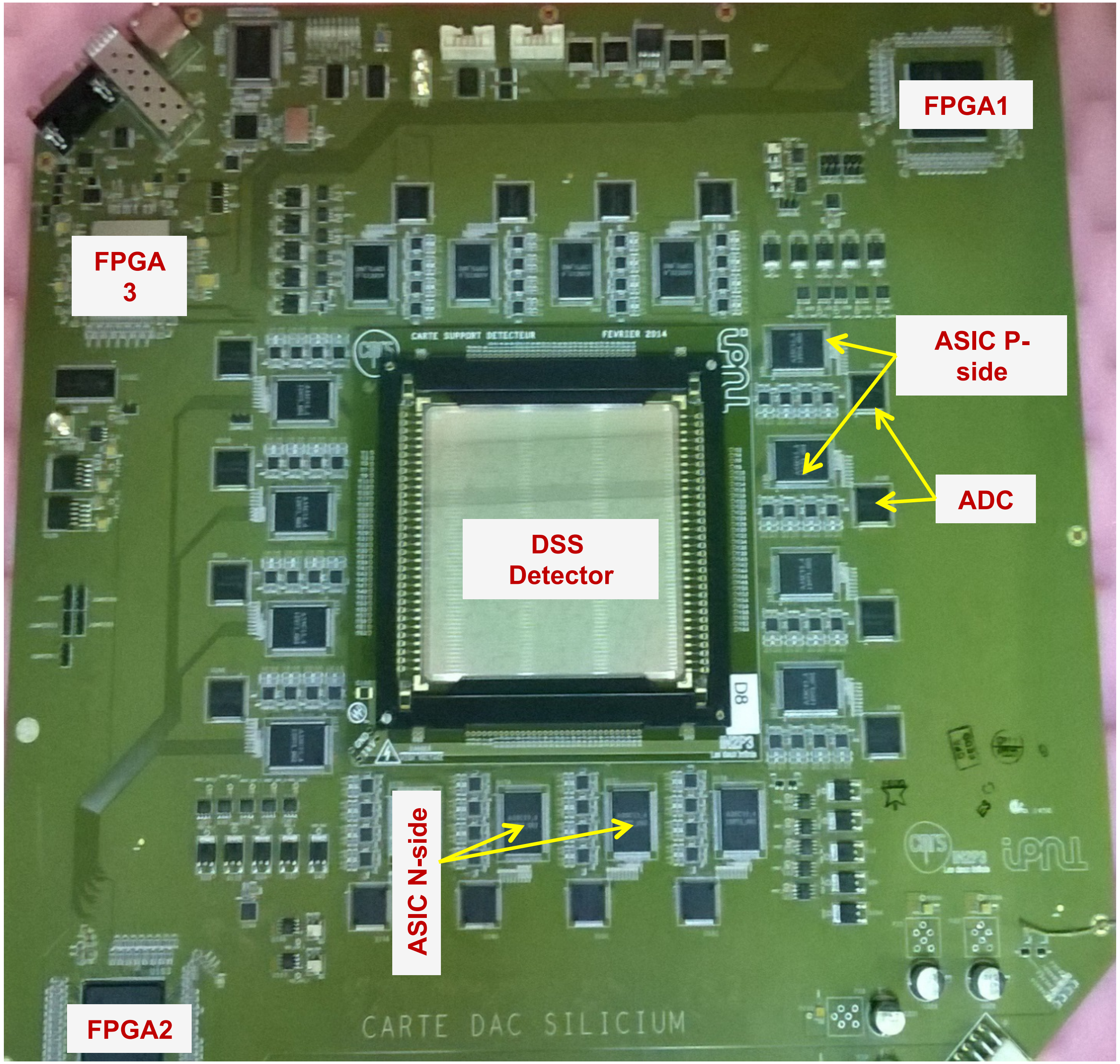
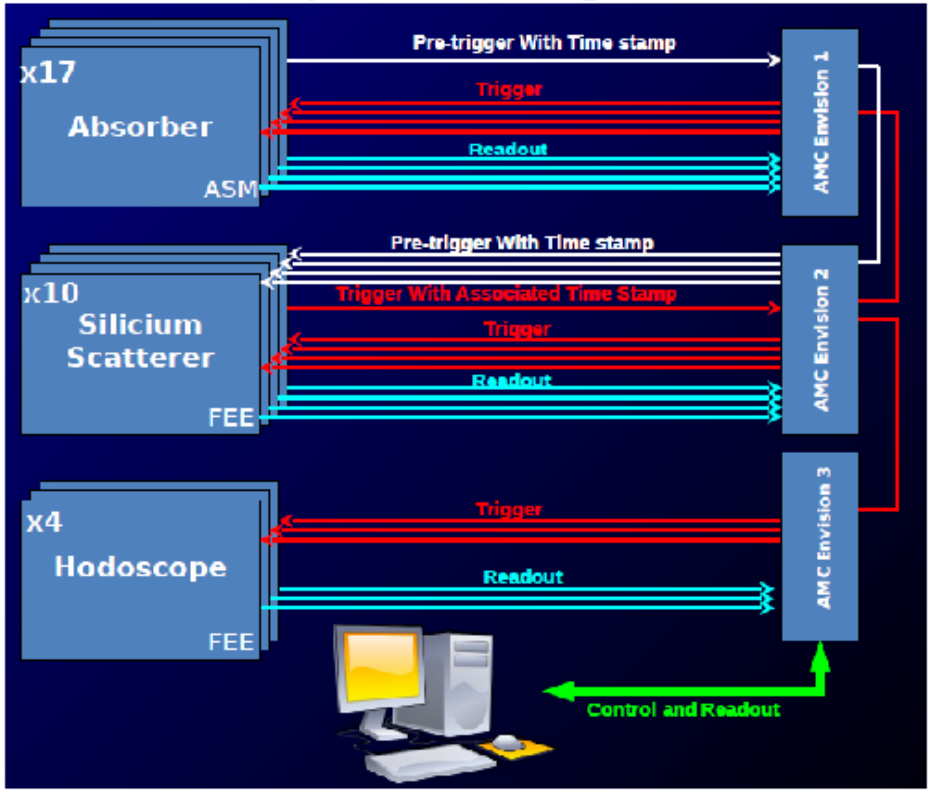


Photo of the DAQ card which will compose plans of the silicon scatter detector

Data acquisition

- 400 channels (absorber), 1000 channels (Si)
- Trigger rate ~ 10^5 coinc/s

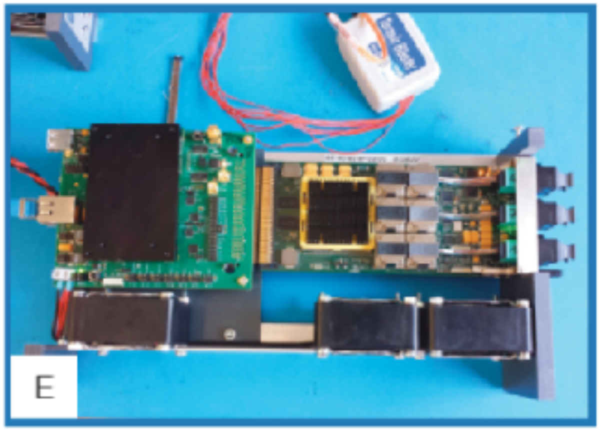
acquisition diagram



[C. Abellan ICTR-PHE 2014]

μ-TCA crate

AMC board (CPPM)



Concluding remarks

- 10^9 incident neutrons/cm^2/s → ~10^9 γ emitted in 4π /s
- ^{10}B monitoring: high resolution needed
  - CdTe, HPGe or LaBr materials are preferred to differenciate 478keV and 511 keV
  - High count rates: **3D quantitative imaging of the dose during the treatment**
  - Spatial resolution < 1 cm
- ^{157}Cd monitoring
  - Energy resolution less crucial → Compton camera could be adapted (energy and spatial resolutions OK)
  - Control of the position of the deposited dose (not quantitative?)
- More simulations are required
  - 2D collimation solution
  - Geometry optimization
  - Neutron backround
- Background issue
  - No rejection : bottleneck?