# GAMMA CAMERA DEVELOPMENT: PRESENT STATUS

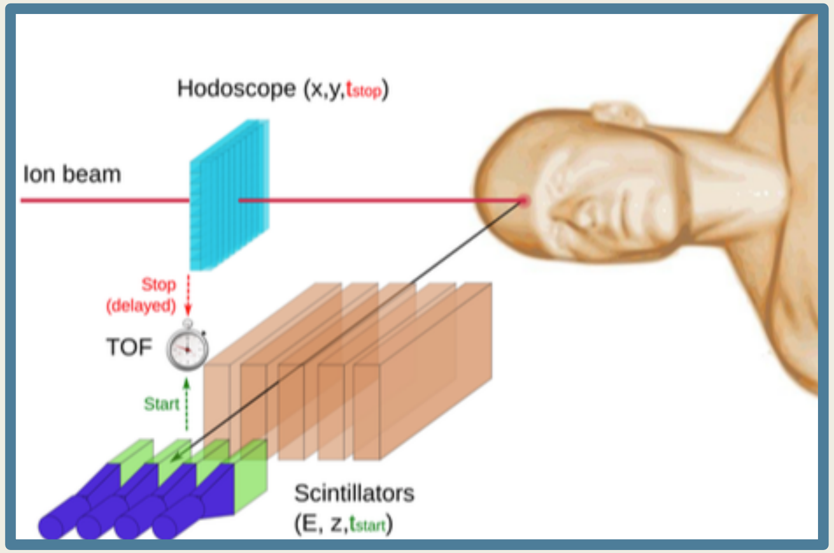
Workshop CLaRyS

Nice, 14-15 January 2016

Mattia Fontana

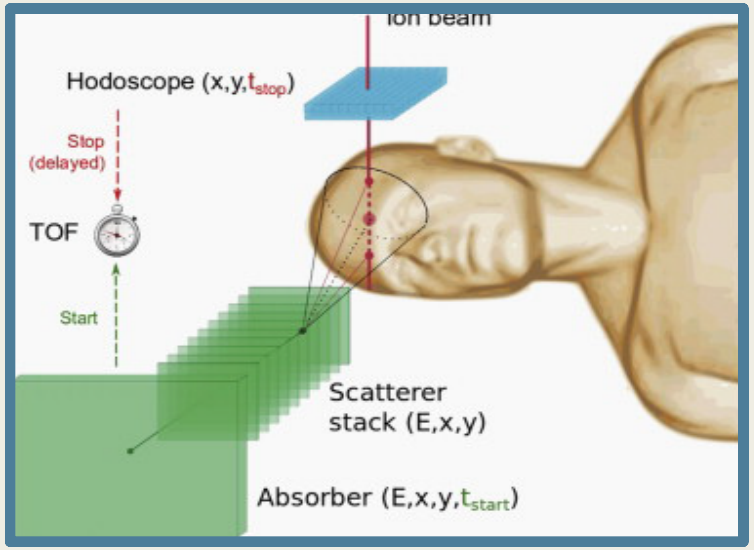
# Gamma cameras

COLLIMATED CAMERAS




- Simple detector and reconstruction
- Limited efficiency
- 1D information
- First to be tested

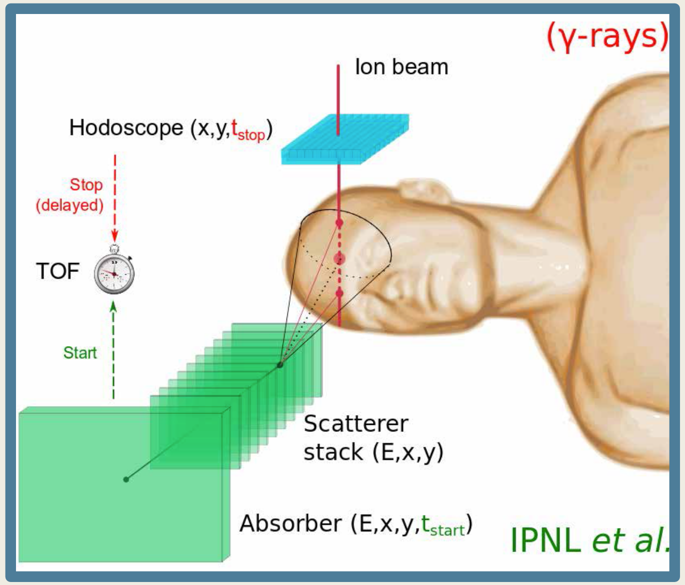
COMPTON CAMERAS




- Complex detector and reconstruction algorithm
- Increased efficiency, counting rate and spatial resolution
- 3D information (LM-MLEM)
- Longer development

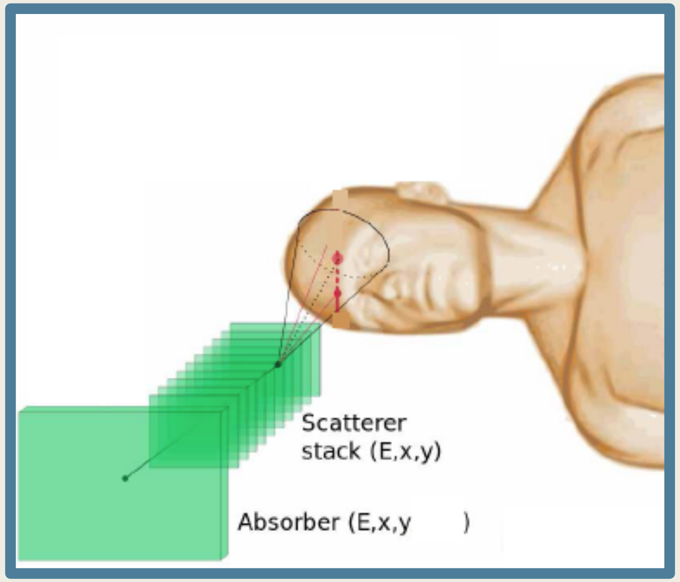
# Gamma cameras applications

ION RANGE MONITORING




- Wide gamma energy range to be handled
- Unknown primary energy
- Compton Cameras can provide 3D images and high detection efficiency
- Relevant background

NUCLEAR MEDICINE




- Fixed and well known gamma energy
- Low energy sources
- Collimated cameras employed
- Compton Cameras promising at higher gamma energies -> new radioisotopes

# Development overview

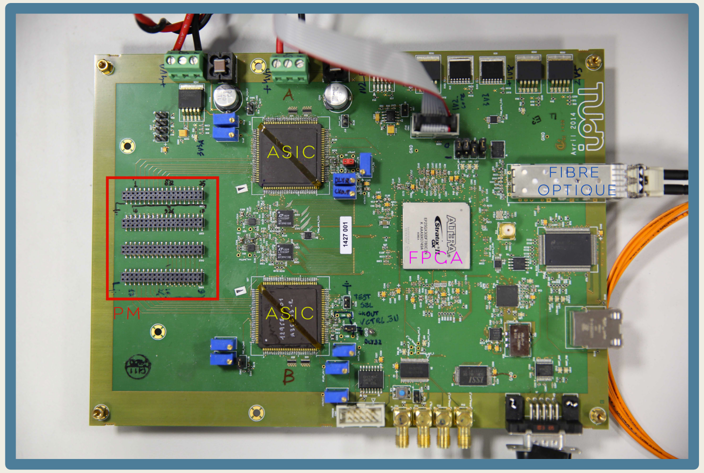
1. Prototype status
2. Mechanical structure
3. Camera simulation and data reconstruction
4. Counting rate estimate
5. Next future plan
6. S2C2 Nice

- Hodoscope
- Scatterer
- Absorber

- Compton camera performance simulation and reconstruction tests for hadrontherapy monitoring
- Nuclear medicine application

# Hodoscope

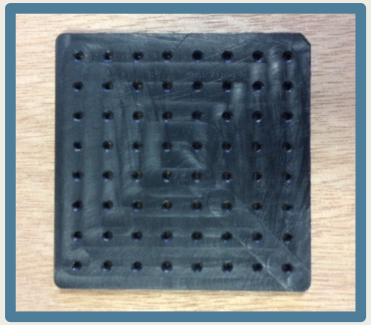
- Small hodoscope prototype already tested on beam
- Multi-anode PMs under tests
  - *“Naked” PM response characterization*
  - *PM response with custom mask (for fiber connection)*
- Electronics
  - *final version of the ASIC under test*
  - *second DAQ card version in production*
- Mechanical support ready

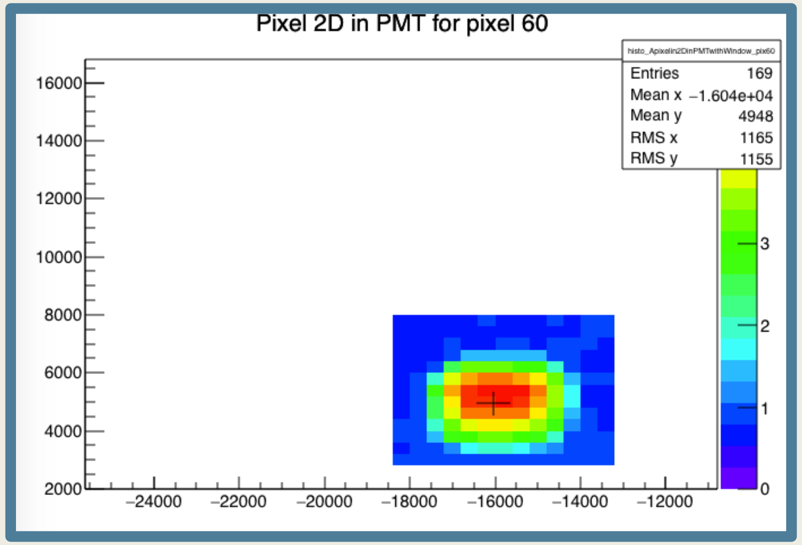


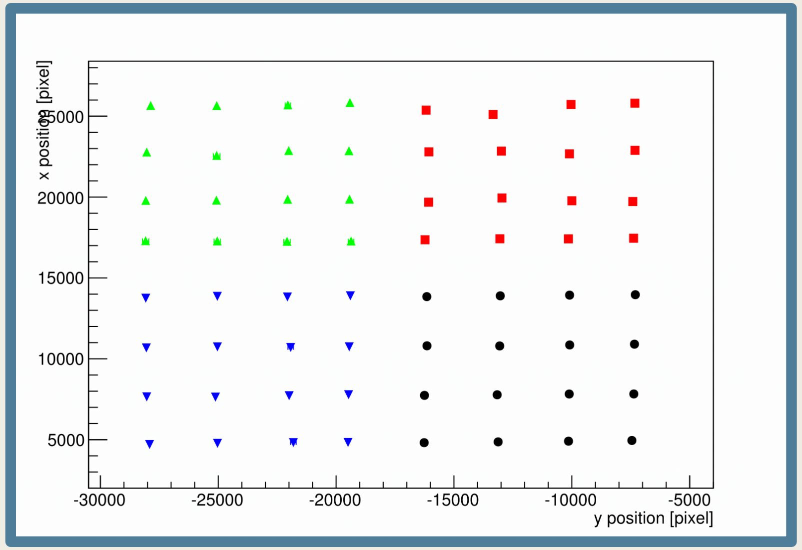
# PM characterization

- 8 Hamamatsu H8500 multianode PMs, 64 channels
- Characterization of the PM response with LED source
- Test-bench with remotely controlled moving table for automatic measurements
- Single channel response analysis

- New tests ongoing for response characterization with optical fiber mask



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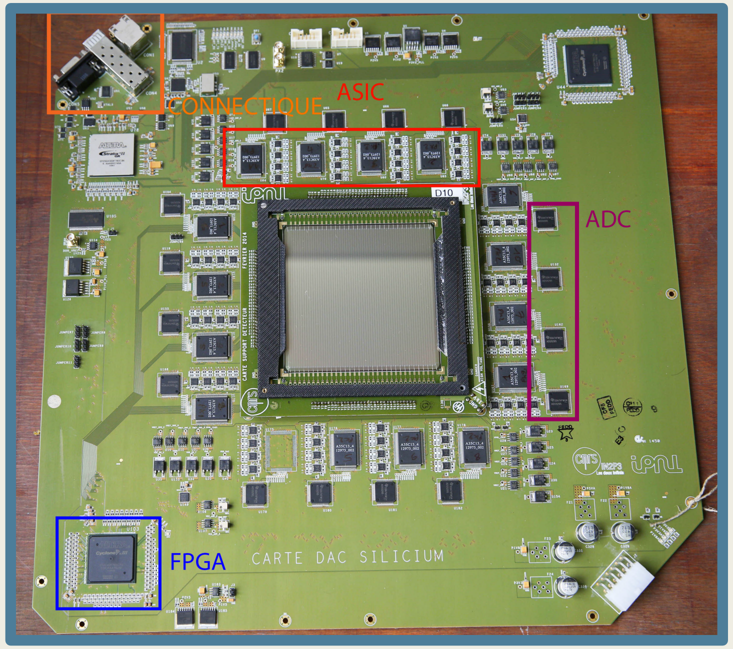
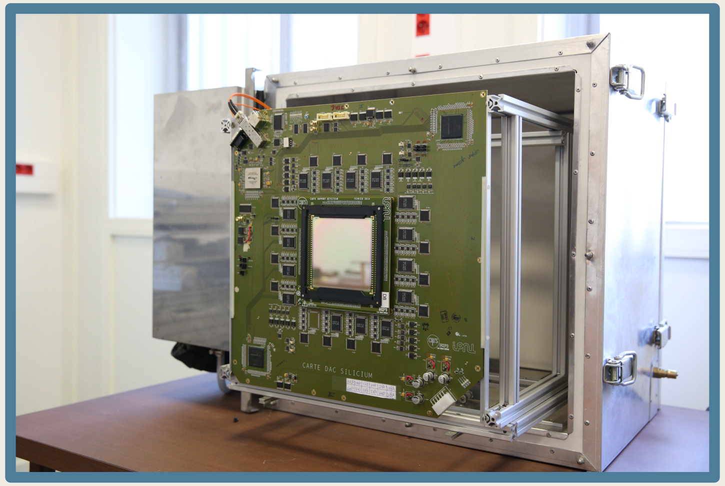
# To do list: Hodoscope

- PM complete characterization
- Single read-out channel characterization and calibration (scintillating fiber + optical fiber + PM channel)
- Connection check
- Final electronics integration and characterization
- Firmware development
- Complete detector test

# Scatterer

- 7 Silicon planes available
- Leakage currents measured for each strip as a function of temperature with an automatic system
- Small DSSD prototype tested
  - *Measurements of energy and spatial resolution*
- Final ASIC version and DAQ card tests ongoing
- Characterization tests with radioactive sources under study
- Thermic box ready



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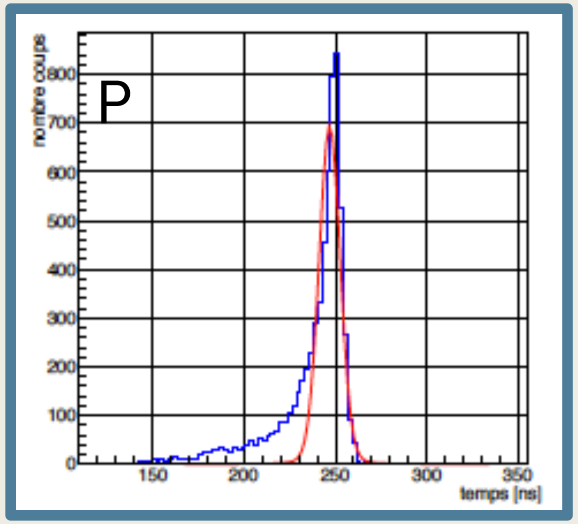
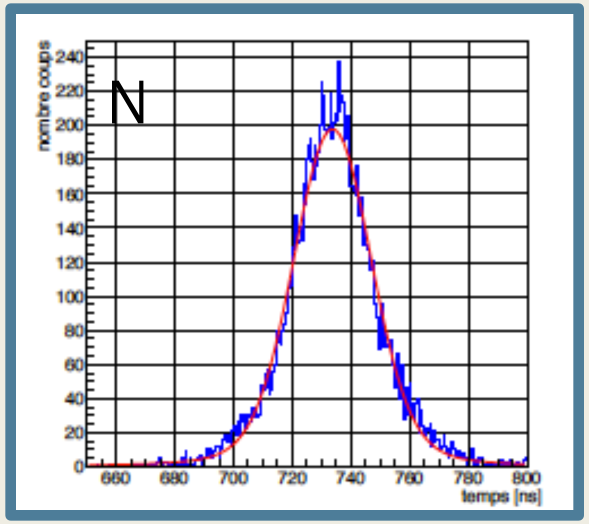
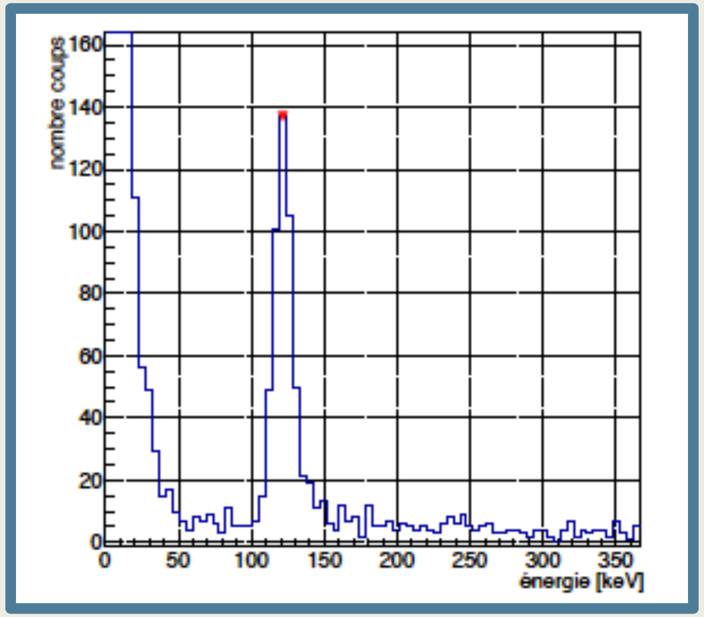
# Small prototype performance

J. L. Ley

- Time and energy resolution characterization
- First ASIC version
- $^{22}$Na source: 511 and 1275 keV gamma
- $^{57}$Co source: 122 keV gamma
- Time resolution with time walk correction on P and N strips (511 keV photon):
  - *P 13.6 ns FWHM, worse for N (~30 ns)*
- Energy resolution: $^{57}$Co source, no cooling
  - *Between 10 and 22 % FWHM*
  - *About 15 keV on average*
  - *1 keV goal for the new prototype*



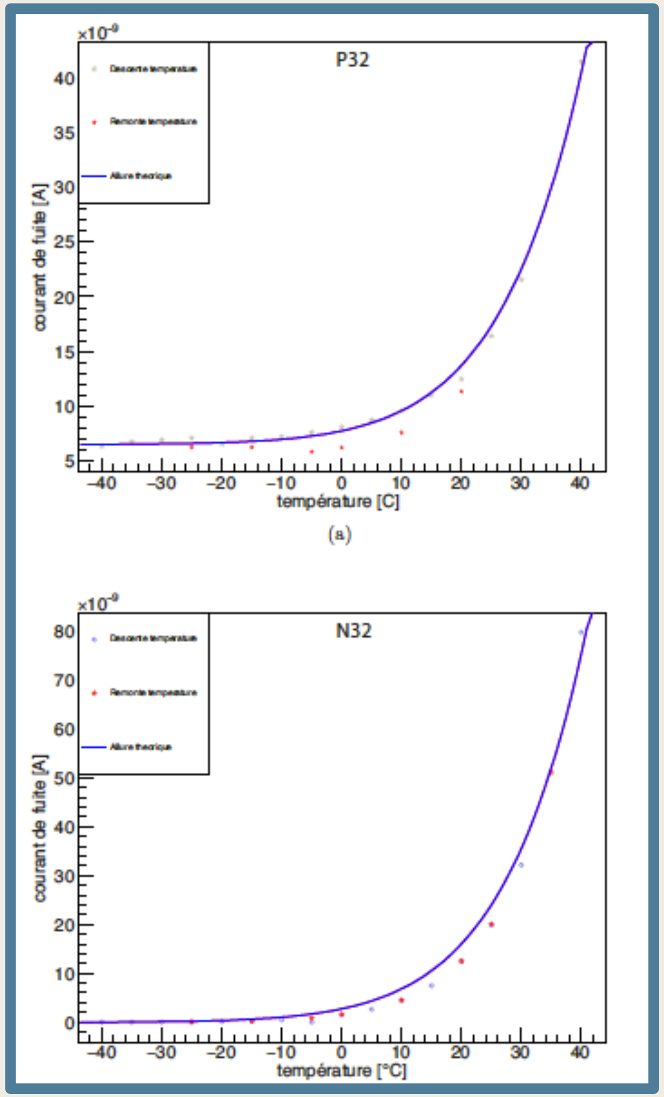



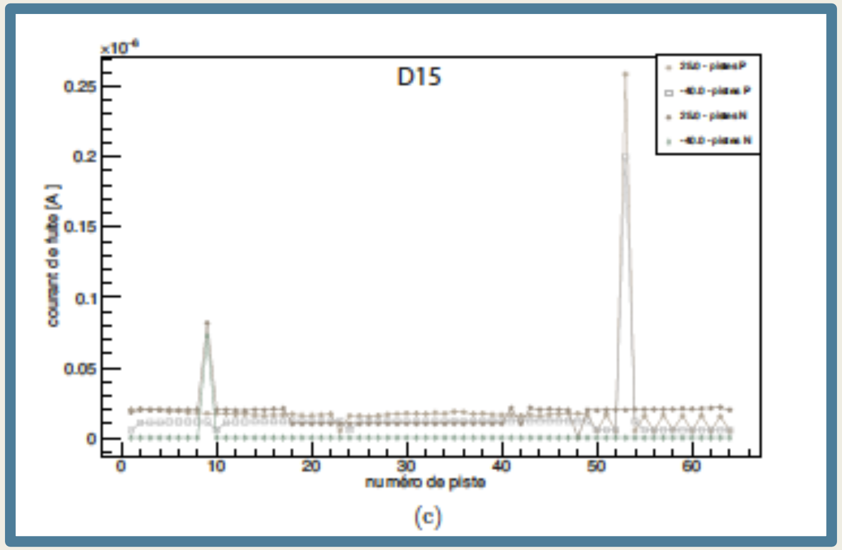

| Piste P | Énergie [keV] | Résolutions en énergie (FWHM) [keV] | [%] |
|---|---|---|---|
| 0 | 122 | 20 | 16,4 |
| 2 | 122 | 13 | 10,6 |
| 3 | 122 | 14 | 11,5 |
| 4 | 122 | 14 | 11,5 |
| 6 | 122 | 16 | 13,1 |
| 7 | 122 | 26 | 21,3 |

# Silicon detectors leakage current

J. L. Ley

- Manual measurements started in 2013
- Automatic test-bench optimization and new measurements in 2015
- 5 Silicon planes characterization
- Current measured on a single strip basis
- Measurements as a function of temperature with thermic cycles in a controlled box



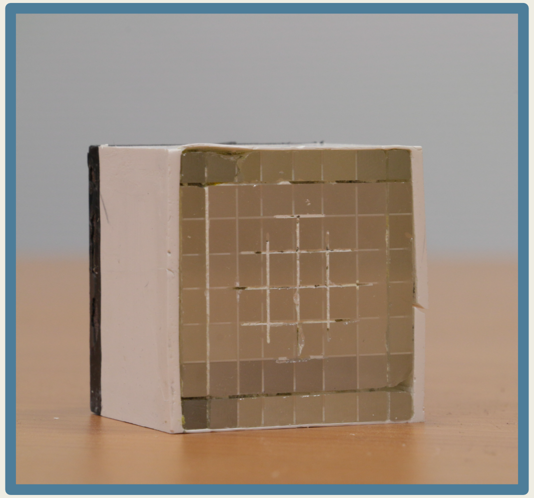
# To do list: Scatterer

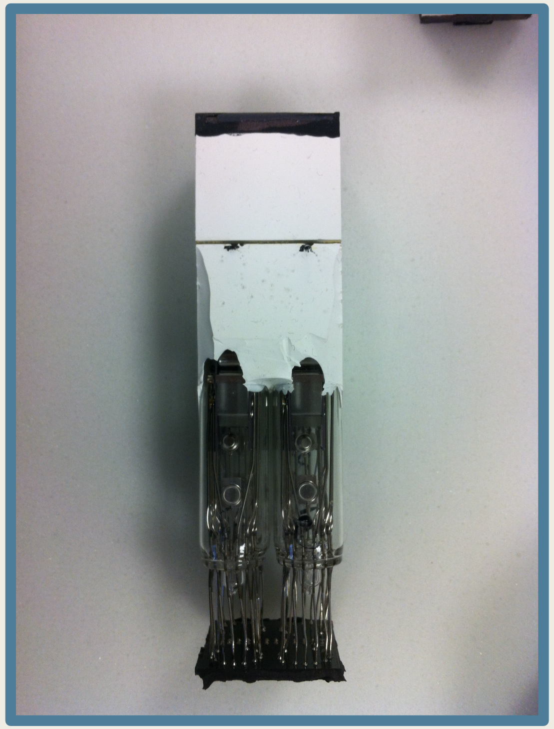
- DAQ card – ASIC coupled tests
- DAQ cards production
- Detector response test with radioactive source
- Read-out channel characterization
- Thermic box arrangement (cables, detector support rails)
- Cooling system test
- Complete detector test with cooling system

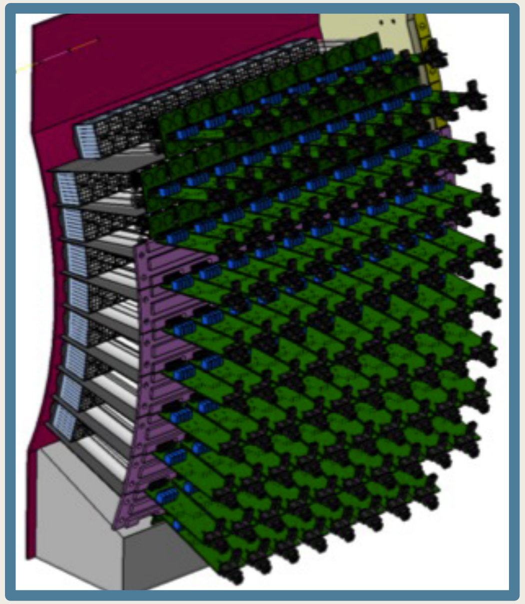
# Absorber

- Contribution from LPC Clermont-Ferrand

- Blocks ready and connected with the PMs
- Blocks classified in terms of PM gains
- ASM cards ready
- VME “carte blonde” ready
- BGO blocks characterization ongoing
- Mechanical support designed: realization ongoing



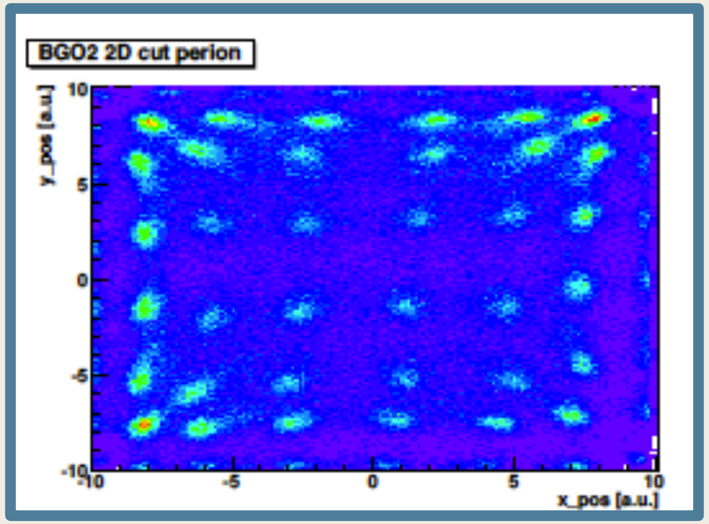


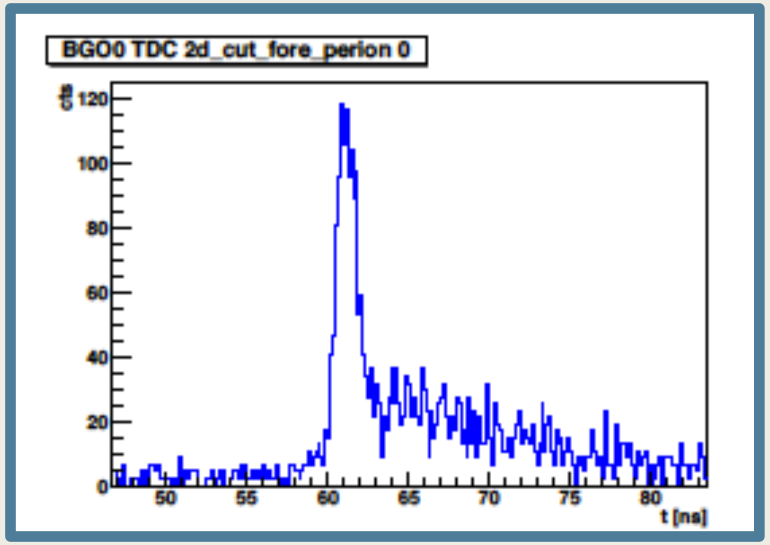


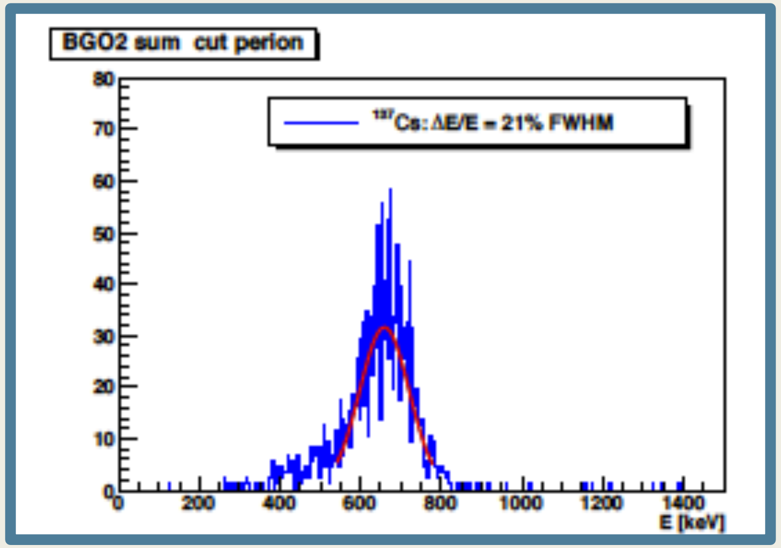
J. L. Ley

# BGO blocks measurements

- First characterization carried out in Lyon with the PET system original blocks
- Measurements at GANIL with a single BGO block with gamma from a C ion beam
- Time resolution 2-3 ns FWHM
- Energy resolution 21 % FWHM (@ 667 keV)



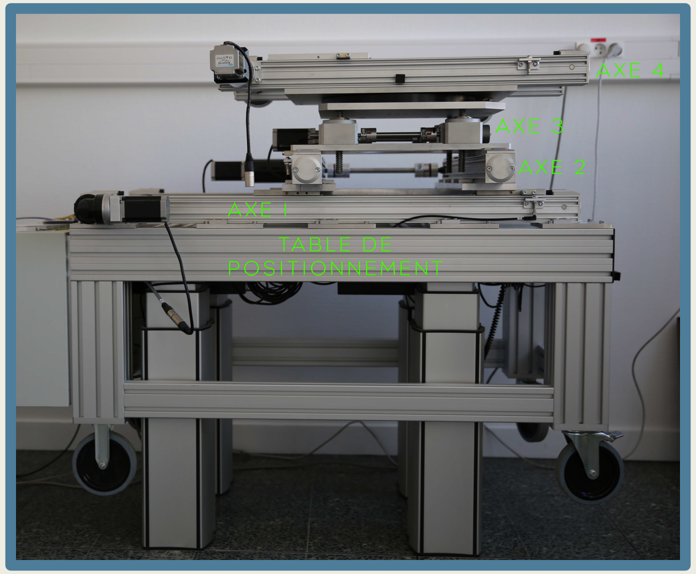



# To do list: Absorber

- Complete block characterization in terms of time and energy
- Block characterization with collimated source
- Blocks arrangement in the mechanical support
- TDC implementation in the FPGA of the ASM cards
- Slow control realization for the ASM cards
- Firmware building for the μ-TCA
- Reconstruction algorithm improvement

# Mechanical structure

- Mechanical structure needed to support the whole camera and modify its position depending on the treatment facility and on the treatment features
- Independent support for the hodoscope (slide 4)
- Support structure for the camera ready
  - *4 translation axes*
    - 3D movement of the whole camera
    - Possible modification of the distance between absorber and scatterer
- LabView slow control software ready and tested (to be tested with the detector)

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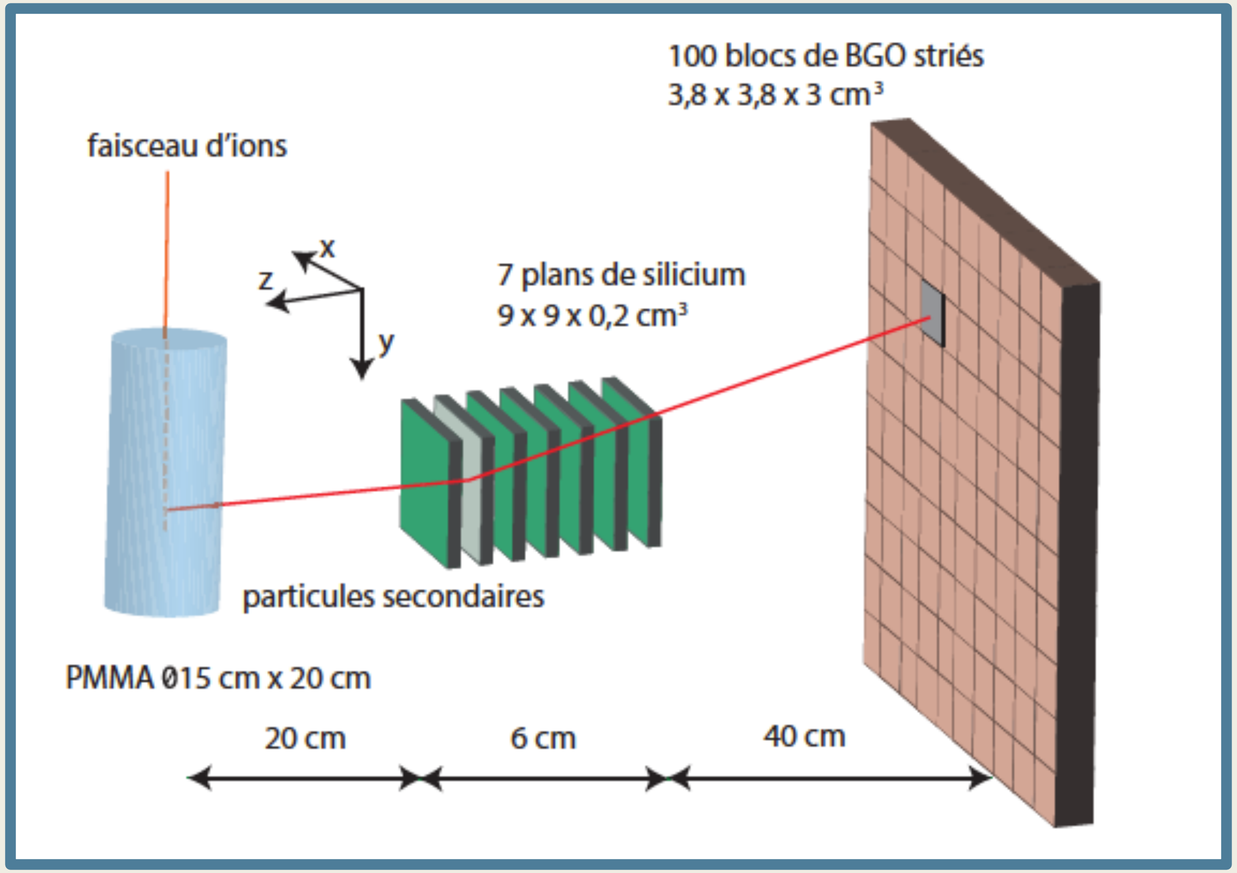
# Simulation (i)
## Geometry

J. L. Ley

- PMMA homogeneous target, cylinder d = 15 cm, h = 20 cm
- Proton or carbon ion beam on y direction, centered in x = 0, z = 0
- Scatterer and Absorber reproduced, Hodoscope neglected
  - *7 silicon planes $90x90x2\ mm^3$, 1 cm distance in between – no strips*
  - *Single BGO absorber block $380x380x30\ mm^3$ – no block segmentation*

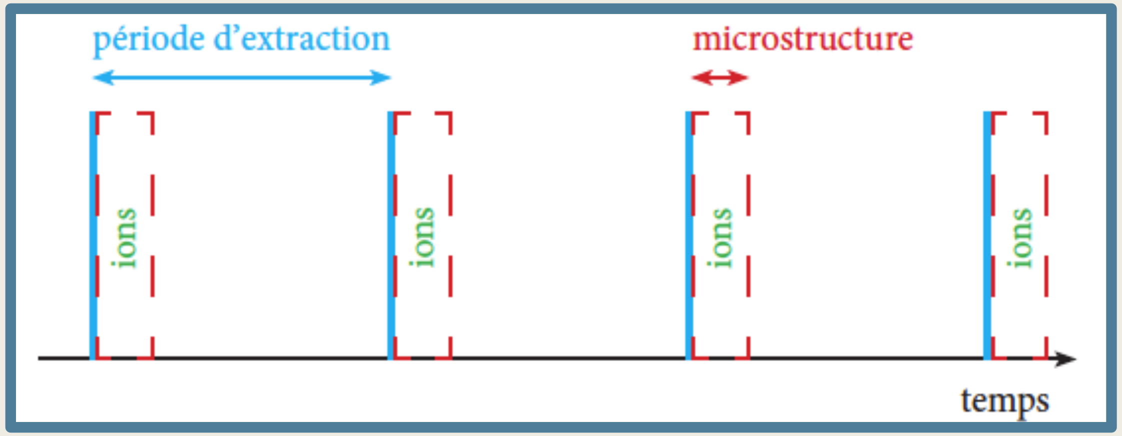


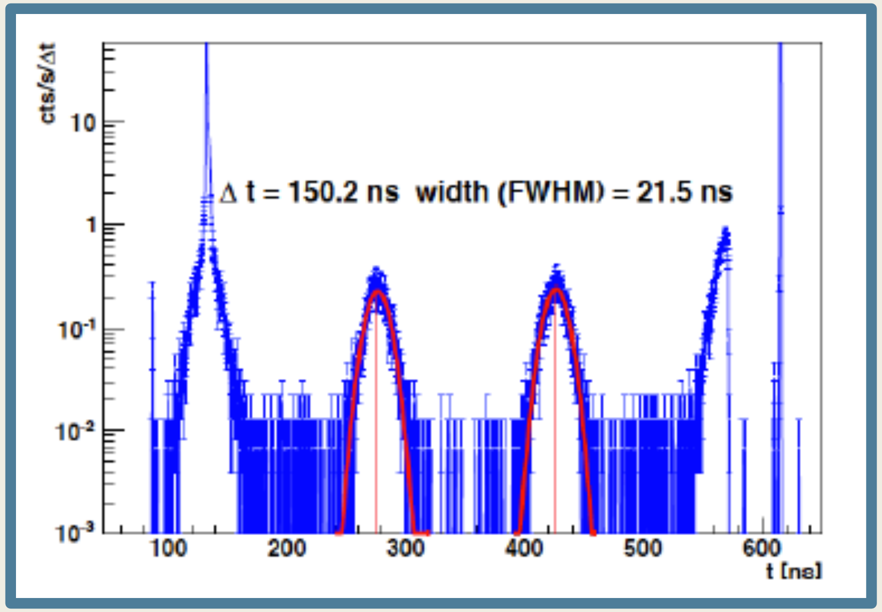

| Résolution (FWHM) à 1 MeV | Diffuseur Si | Absorbeur BGO | Hodoscope |
|---|---|---|---|
| spatiale [mm] | 0,9 | 5 | / |
| énergie [%] | 2,3 | 17 | / |
| temporelle [ns] | 15 | 3 | 1 |

# Simulation (ii)
## Beam

J. L. Ley

- 160 MeV protons, gauss distribution
  10 mm FWHM, based on C230 IBA cyclotron
  – *9.42 ns (106 MHz) period for 2 ns bunch*
  – *3.2 nA maximum intensity (2 x$10^{10}$ protons/s)*
  – *$10^8$ protons simulated*
- 305 MeV/n carbon ions, gauss distribution
  3.5 mm FWHM, based on HIT Siemens synchrotron
  – *170 ns (5.9 MHz) period for 30 ns bunch (estimate for applied energy by interpolation on 200 MeV/n and 400 MeV/n measurements)*
  – *Maximum intensity 5 x$10^7$ ions/s*
  – *2 x$10^5$ ions simulated*



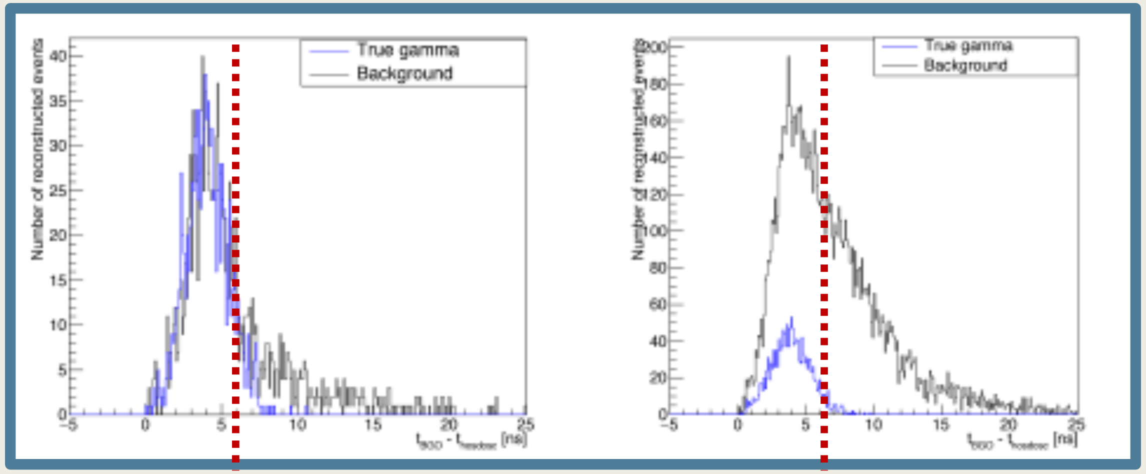



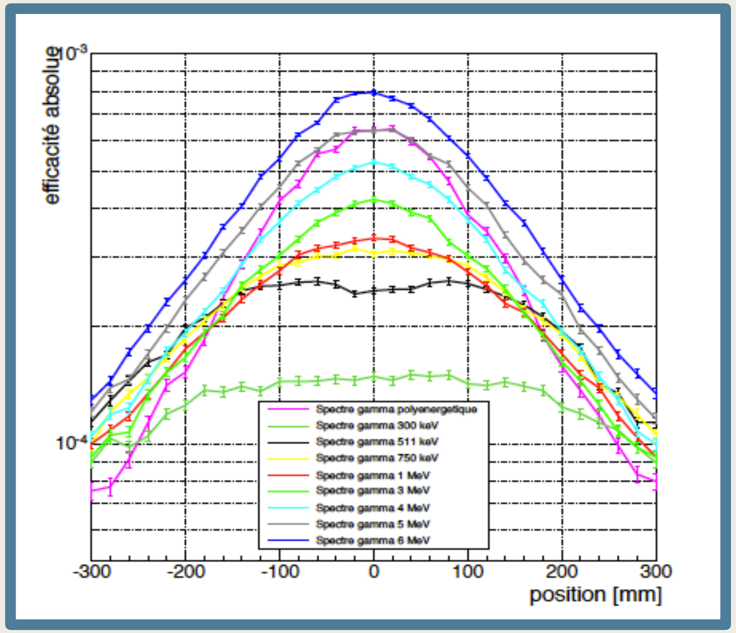

*400 MeV/n C ion beam measured time structure*

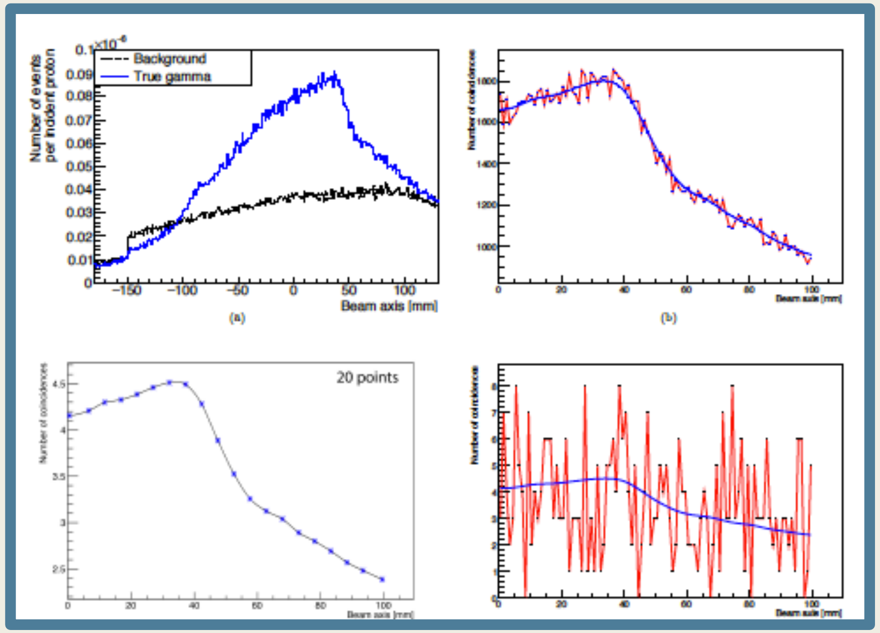
J. L. Ley

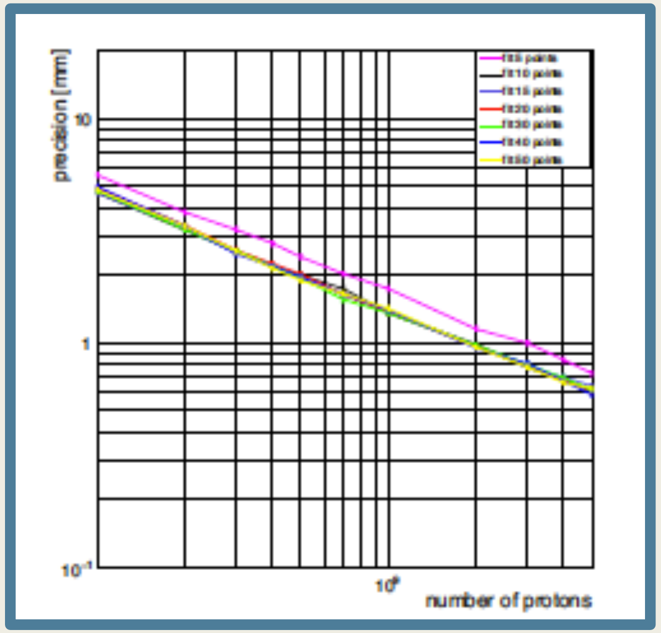
# Simulation results (i)
## Camera performance

- TOF spectra analyzed - 6 ns cut applied
- Falloff identification precision tested with reference simulated profile
- Absolute efficiency as a function of point-like source position (with respect to the camera center)



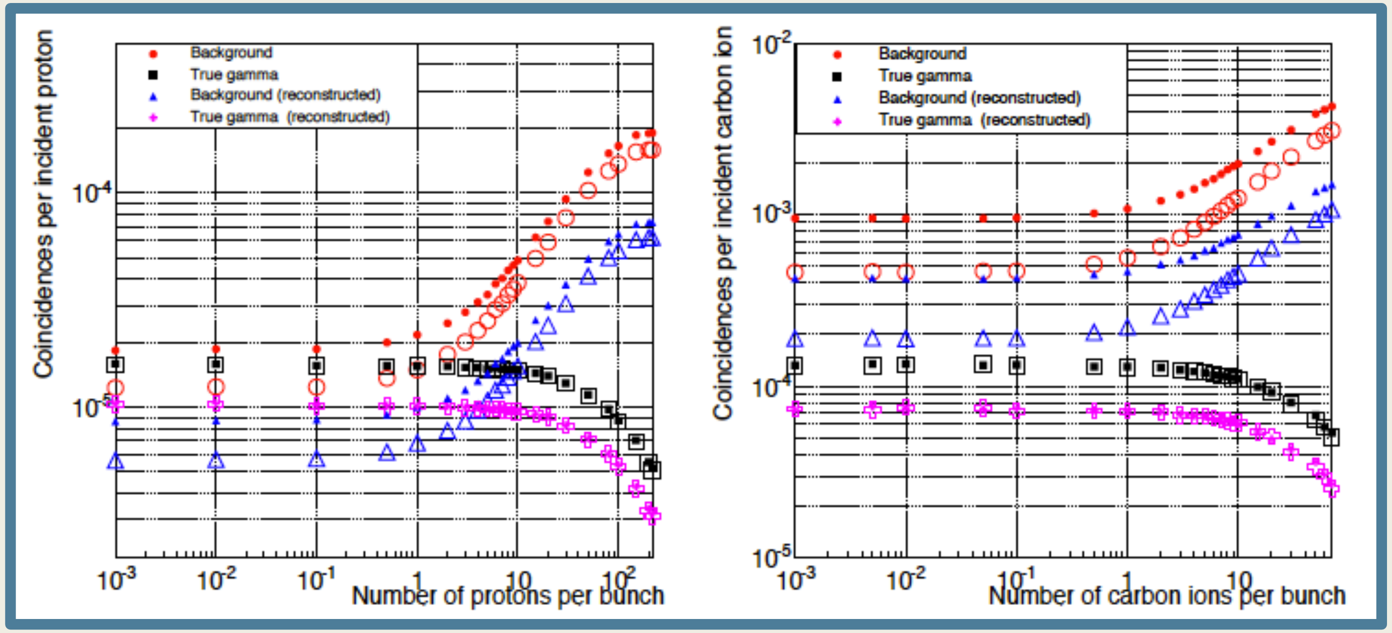



# Simulation results (ii)
## Hadrontherapy monitoring

J. L. Ley

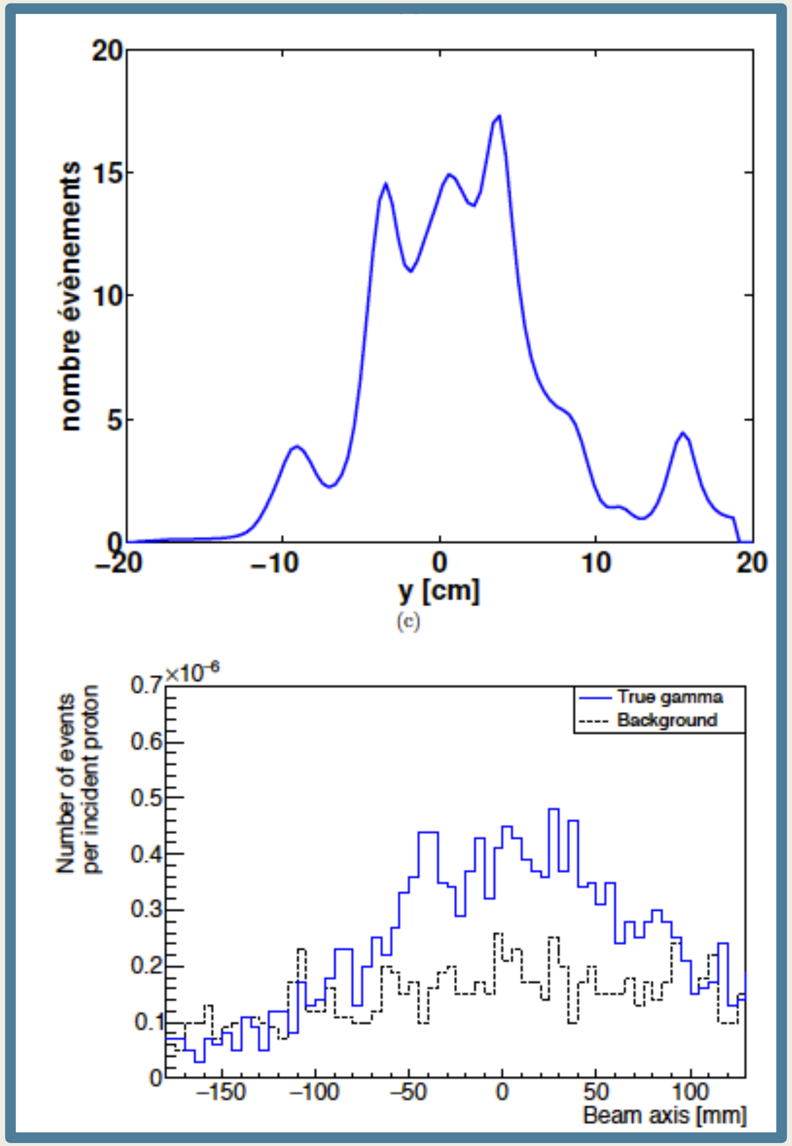
- Coincidence rate estimate for proton and carbon ions
- At clinical intensities, signal over background ratio unfavorable
- Reconstructed data promising for protons at reduced intensity (1 p/bunch)
- Further improvement with TOF information
- Possible application for proton beam at reduced intensity
- Not feasible for C ion beam



# Reconstruction
## Hadrontherapy monitoring

J. L. Ley

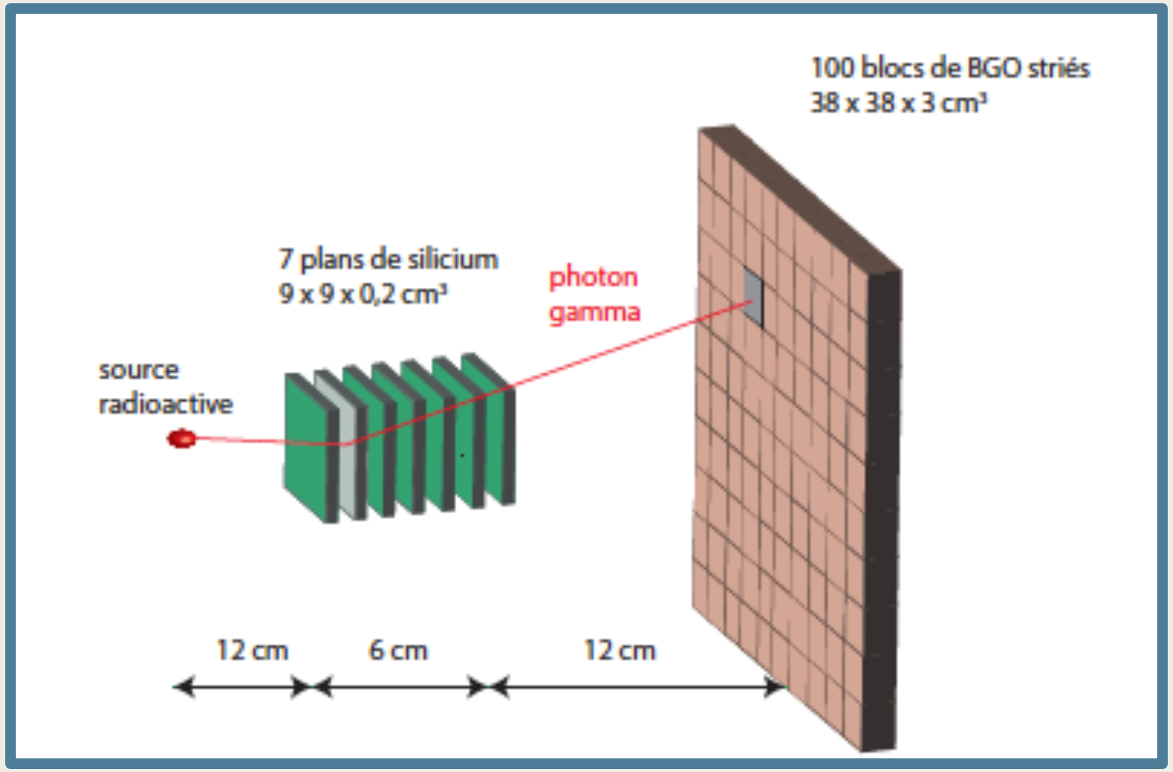
- Data reconstruction tests for
  - *$10^8$ 160 MeV protons*
  - *1 ion/bunch*
- Analytical reconstruction method: simple, fast, 1D information, low falloff identification accuracy
- Iterative algorithm LM-MLEM: complex, slow, 3D potential information, better falloff identification
- Tested with success for point-like and linear sources (0-10 MeV)
- Compared to analytical method for proton beam monitoring application



# Nuclear medicine application (i)

J. L. Ley

- Mono-energetic gamma source
  0.1x0.1x0.1 mm$^3$
  511 keV – 3 MeV
- Angular distribution studied as a function of
  - *Gamma energy*
  - *Electronic noise*
  - *Silicon and BGO spatial resolution*
  - *Camera geometry*
- Better performance than a collimated camera for gamma energy > 300 keV
  - *Better efficiency*
  - *Better spatial resolution*
- Simulations with phantoms and with more than one camera still needed



# Nuclear medicine application (ii)

J. L. Ley

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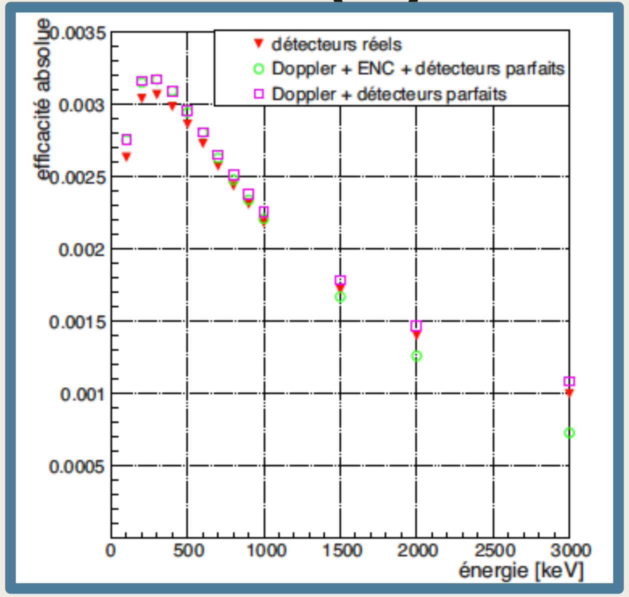


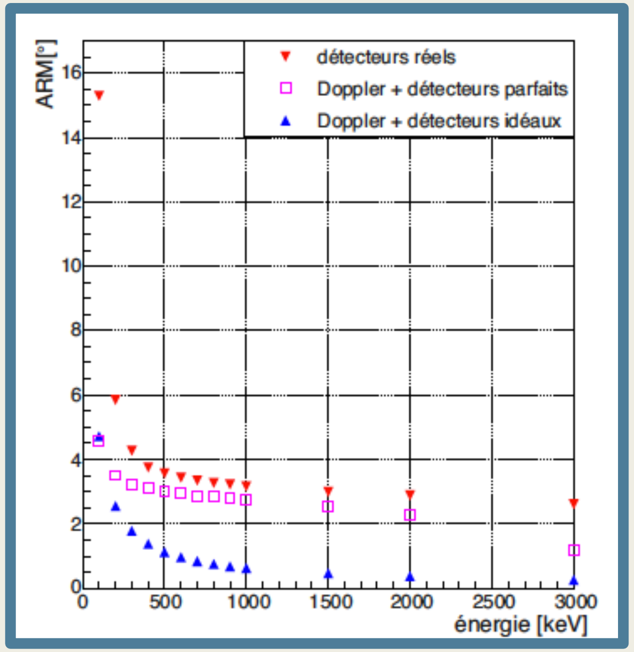


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# Counting rate
## Compton Camera

J. L. Ley

- Counting rate estimation based on MC simulation as a function of the beam intensity

| | Intensité clinique | | Intensité réduite | |
|---|---|---|---|---|
| | Protons | Ions carbone | Protons | Ions carbone |
| Intensité [ions/s] | $2 \times 10^{10}$ | $5 \times 10^{7}$ | $1 \times 10^{8}$ | $5 \times 10^{6}$ |
| Taux de coïncidences par ion incident | $9 \times 10^{-4}$ | $8 \times 10^{-4}$ | $9 \times 10^{-4}$ | $8 \times 10^{-4}$ |
| Taux de coïncidences [Hz] | $1{,}8 \times 10^{7}$ | $4 \times 10^{4}$ | $9 \times 10^{4}$ | $4 \times 10^{3}$ |
| Taux de singles BGO 96 blocs [Hz] | $7{,}8 \times 10^{7}$ | $1{,}4 \times 10^{6}$ | $3{,}9 \times 10^{5}$ | $1{,}4 \times 10^{5}$ |
| Taux de singles BGO 1 carte ASM [Hz] | $4{,}9 \times 10^{6}$ | $8{,}7 \times 10^{4}$ | $2{,}4 \times 10^{4}$ | $8{,}7 \times 10^{3}$ |
| Taux de singles BGO 1 bloc [Hz] | $8{,}1 \times 10^{5}$ | $1{,}5 \times 10^{4}$ | $4 \times 10^{3}$ | $1{,}5 \times 10^{3}$ |

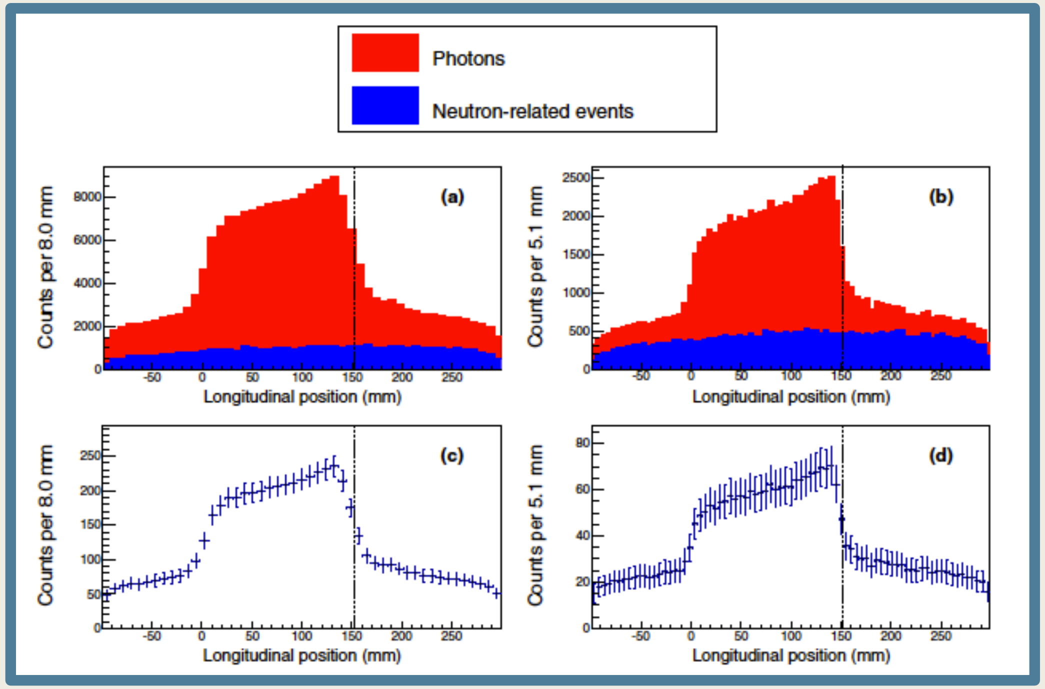
- Counting rate extracted from the small prototype tests at GANIL

| Voie détecteur | Taux de comptage coups.ions carbone$^{-1}$ | Simulation coups.ions carbone$^{-1}$ |
|---|---|---|
| OU pistes N | $4{,}1 \times 10^{-6}$ | / |
| OU pistes P | $1{,}6 \times 10^{-6}$ | / |
| OU silicium | $4{,}7 \times 10^{-6}$ | $5{,}8 \times 10^{-6}$ |
| Absorbeur | $8{,}5 \times 10^{-5}$ | $7{,}6 \times 10^{-5}$ |
| Coïncidences | $3{,}9 \times 10^{-9}$ | $3{,}8 \times 10^{-10}$ |

# Counting rate
## Collimated Camera

- Different camera geometries analyzed, with different:
  - *Slit width*
  - *Slab width*
  - *Collimator thickness*
  - *Distance collimator-beam axis*
  - *Distance detector-beam-axis*

M. Pinto



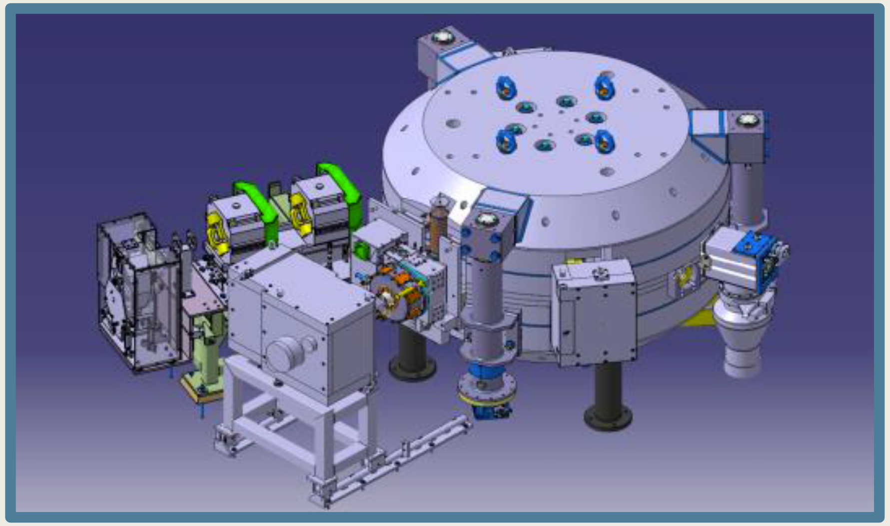

| Case | Precision fall-off | Precision entrance | Precision profile length | FOV | Slit | Slab | Thickness | Distance axis-collimator | Distance axis-detector |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.59(0.06) | 0.66(0.09) | 0.88(0.11) | 23.6 | 5.4 | 2.6 | 180.2 | 303.7 | 485.3 |
| 2 | | | | –same as case 1– | | | | | |
| 3 | 0.70(0.08) | 0.87(0.12) | 1.12(0.14) | 13.1 | 3.0 | 2.1 | 190.9 | 322.3 | 516.5 |

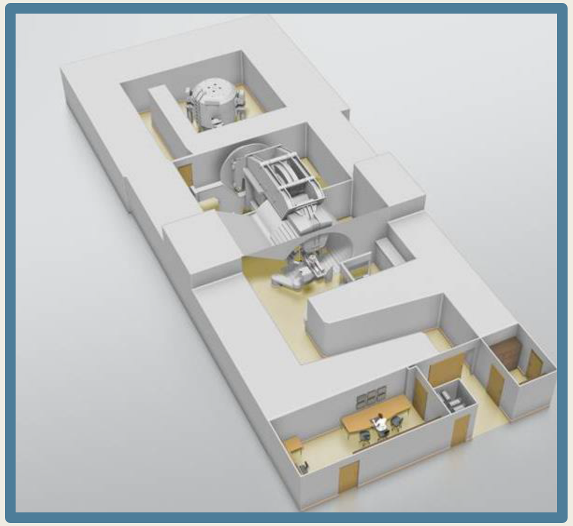
Expected counting rate

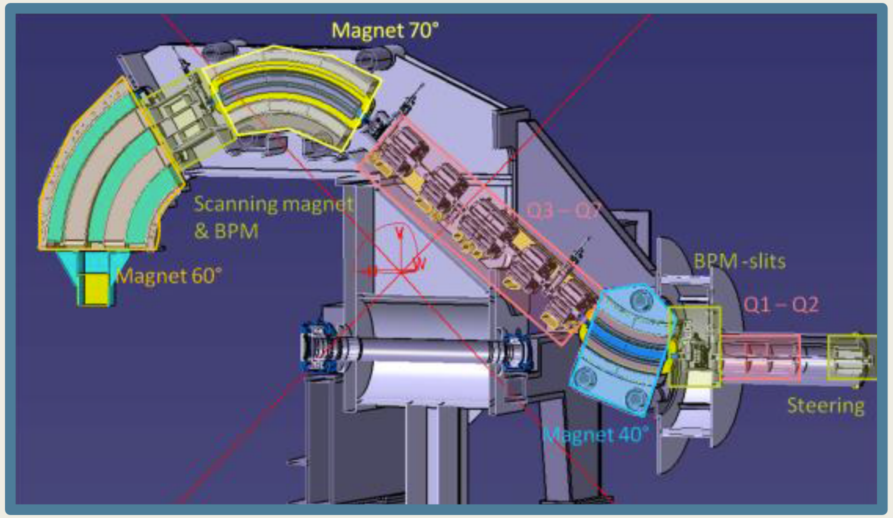
- based on the camera geometry n. 3
  - *~1.25 x $10^{-6}$ hit/ion/block*
- With the S2C2 beam time structure : ~ 16 ns period
  - *~1.56 x $10^{6}$ hit/s during extraction*

# S2C2 Nice

- S2C2 superconducting synchrocyclotron – IBA
- Accelerator main parameters:
  - *Extracted beam current : ~ 400 nA*
  - *Extraction time : ~ 20 μs*
  - *Repetition rate : 1 kHz*
  - *RF: 92-62 MHz*







# Next future plan

- Final tests on silicon detectors DAQ cards: start production foreseen for the beginning of March 2016
- BGO blocks characterization
- Hodoscope PMs complete characterization with optical fiber mask

- Possible beam time at GANIL in July : C ion beam
  - *Absorber test? Collimated camera ready?*

… towards clinical tests

*Thanks for your attention*