PET system update and CNAO Test beam results

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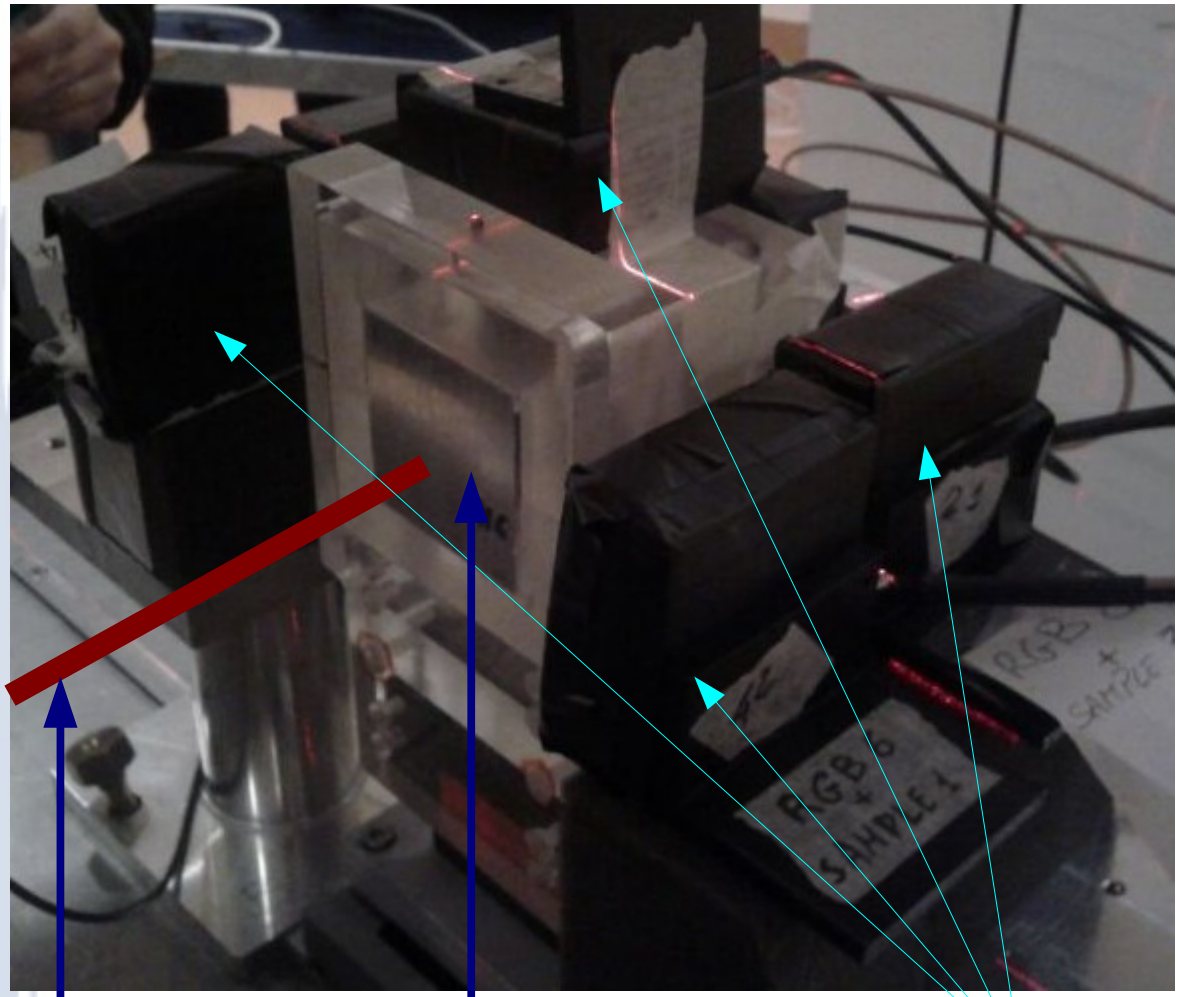
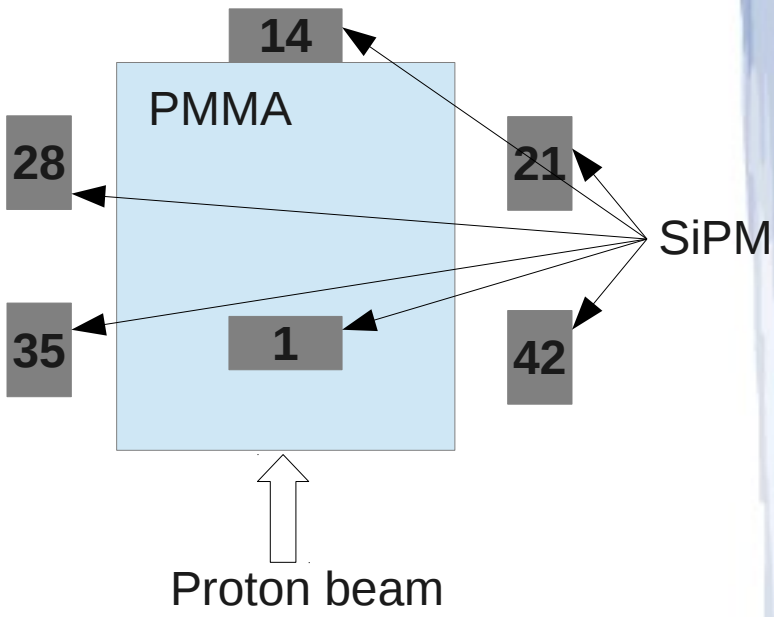
1. Experimental results of the first test beam at the CNAO facility

Experimental set up



Schematic top view of the experimental set up



- PMMA phantom: 5 x 5 x 7 cm^3
- RGB SiPM from AdvanSid
  3 x 3 mm^2
- LYSO crystal 3 x 3 x 10 mm^3
- TOFPET ASIC read out:
  SiPMs distinguished by their
  read out channel number

Data acquisition set up

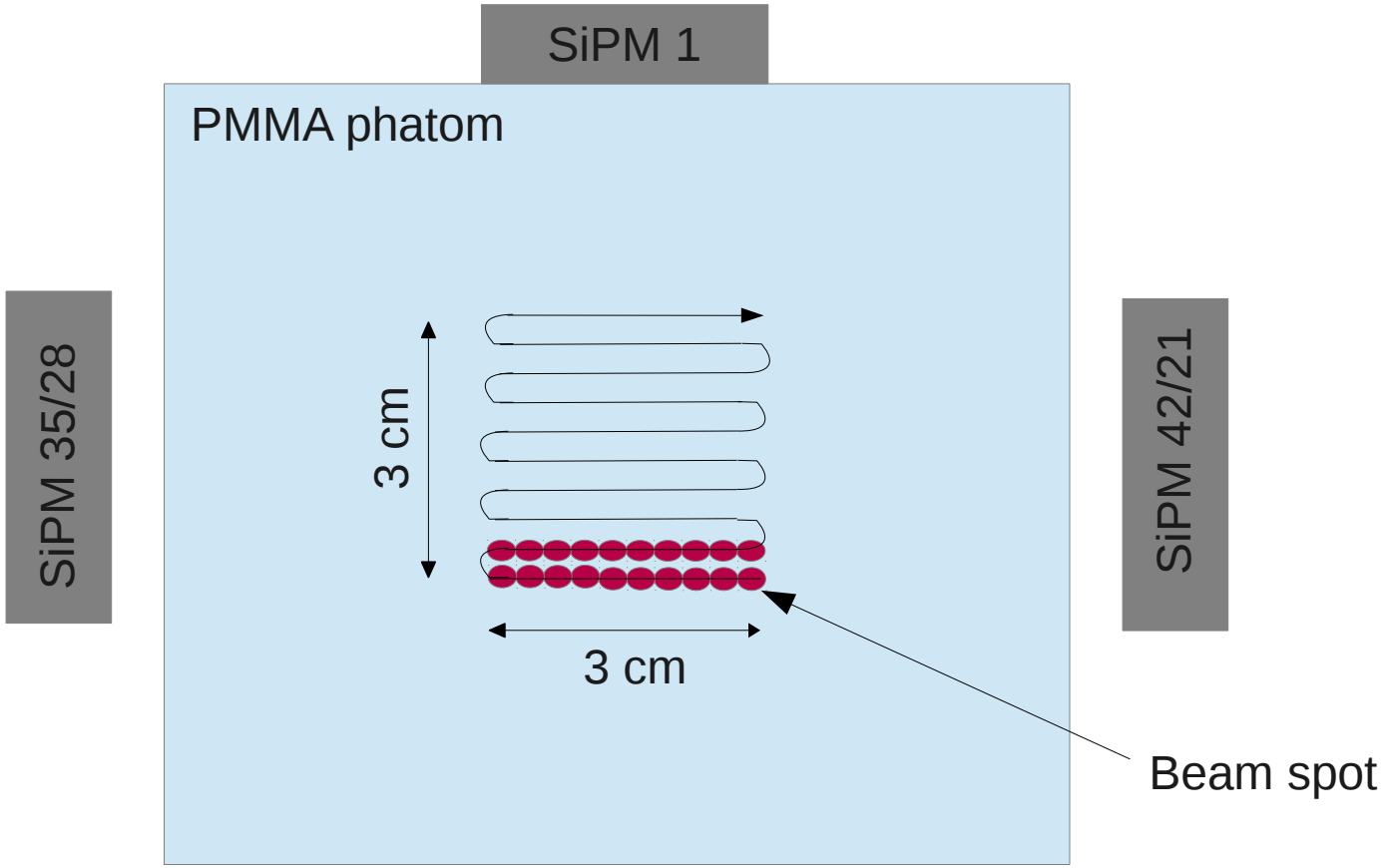
- TOFPET ASIC read out
- 4DMPET acquisition board
- Acquisition software developed in LabView code at INFN, sez. Torino

Radiation beam characteristics

- Proton beam: 95 MeV
- Beam spot size: 3 mm Ø
- Pulsed beam: 10^9 protons per spill

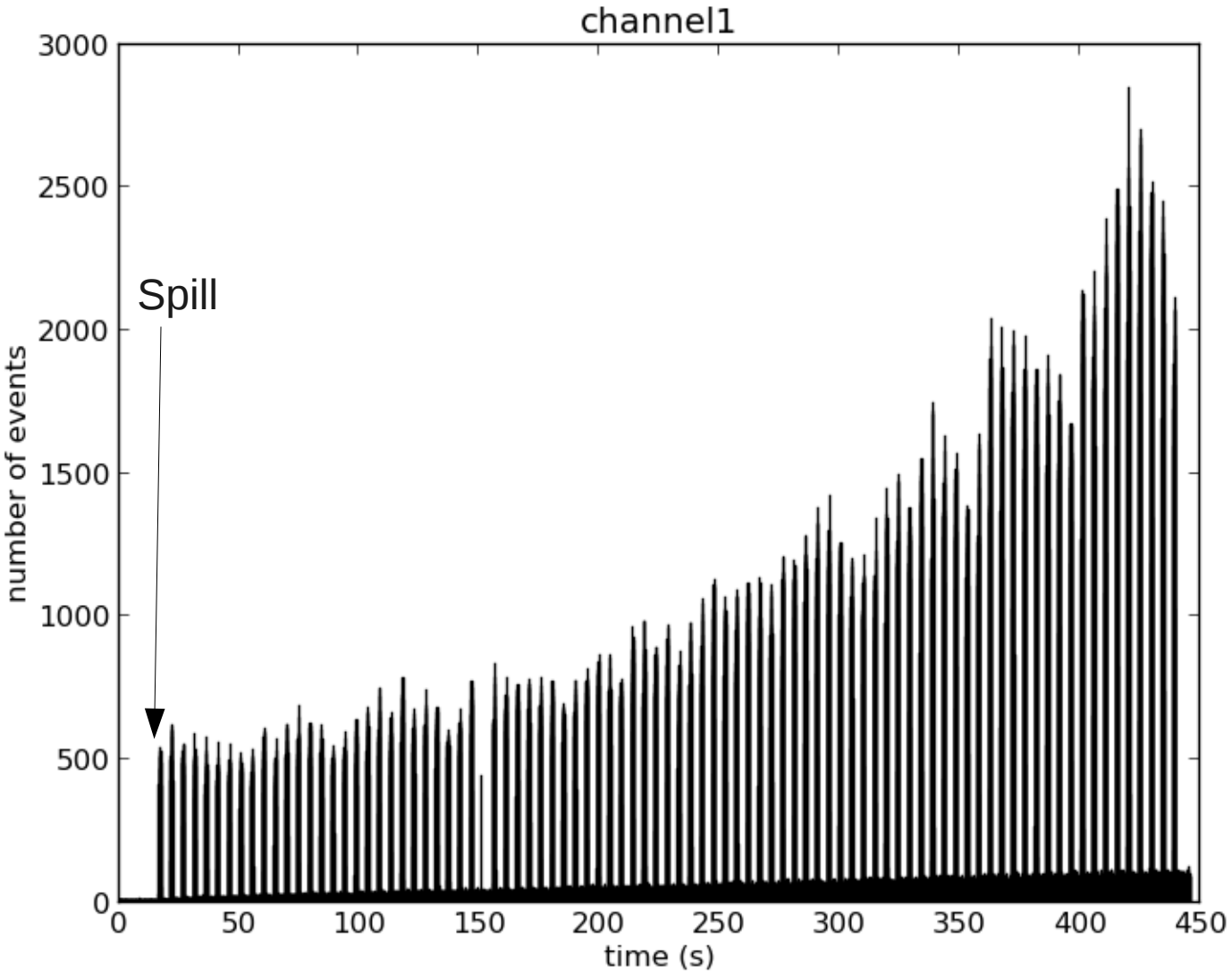
Acquisition 1

- Proton beam scanning a large region: 3x3 cm^2
- 88 spills

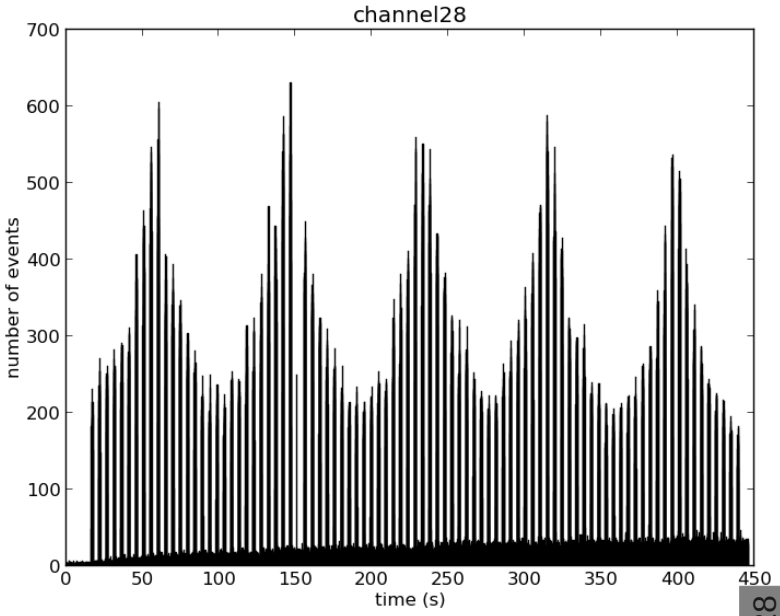


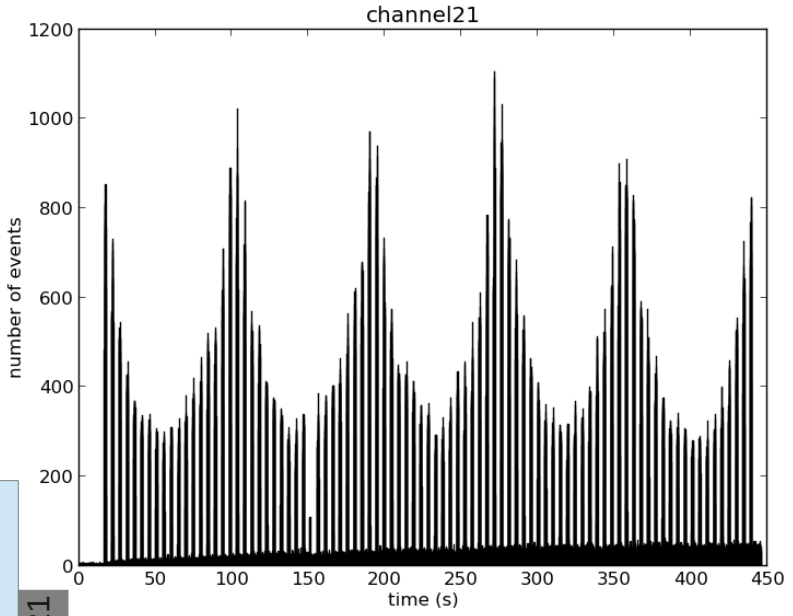
Front view of the expertimental set up

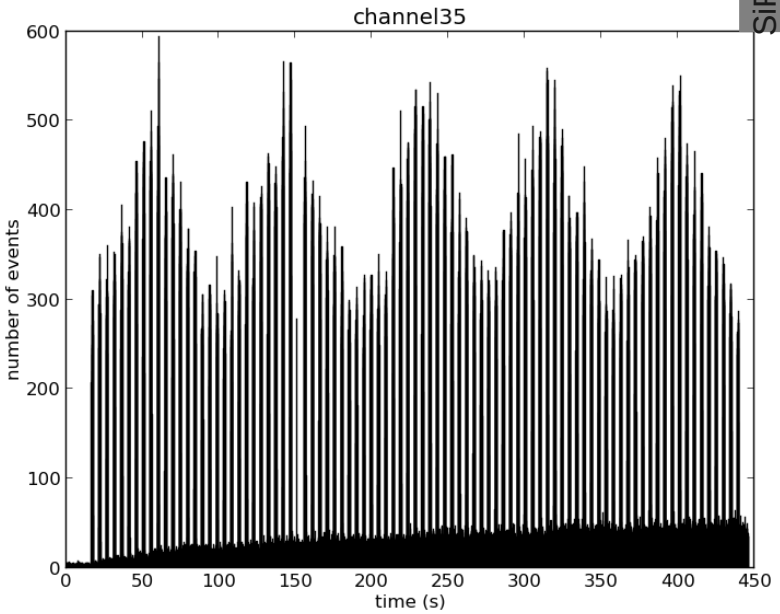
Time structure of the experimental data

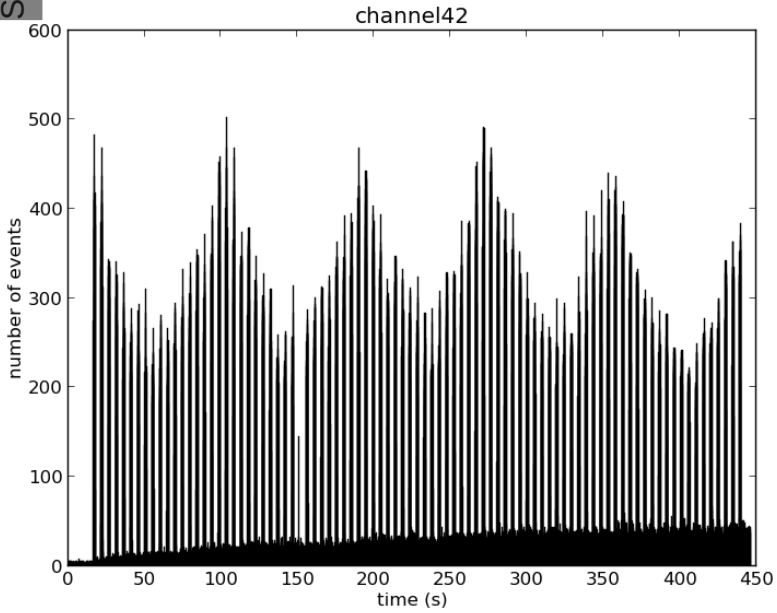


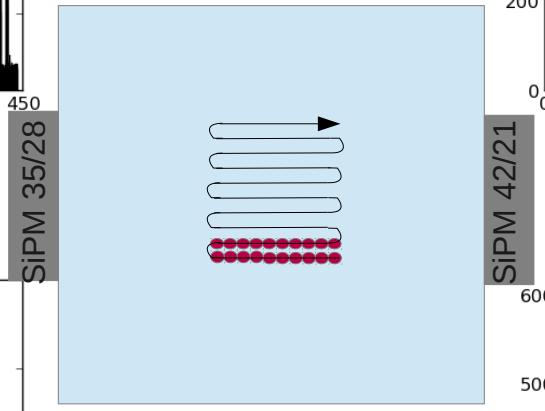
- The number of in spill events is increasing because the beam spot was moving towards the detector





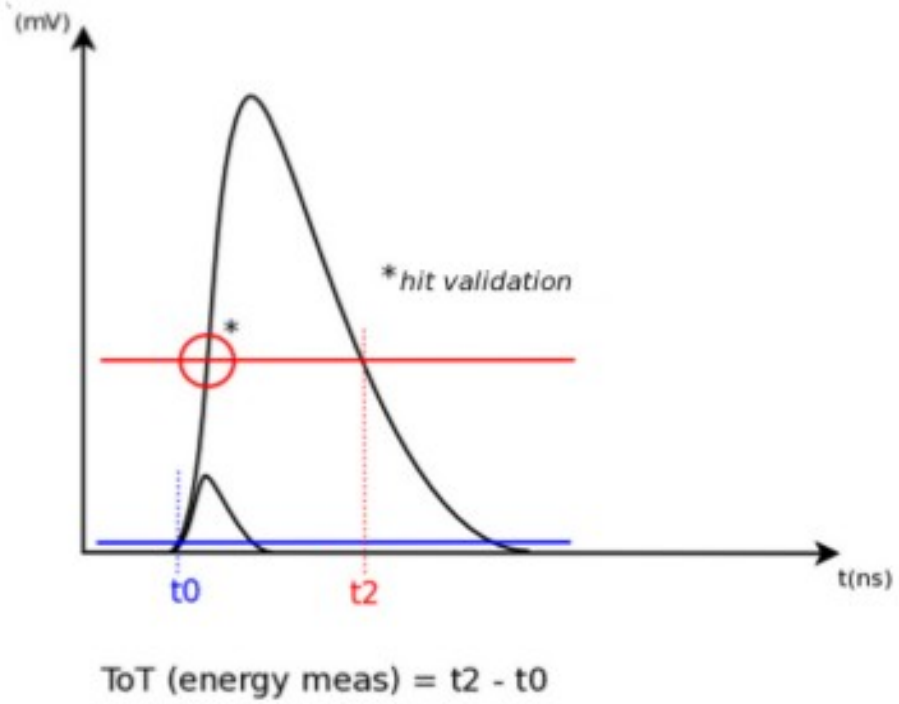






- The number of in spill events is oscillating because the beam spot was moving from right to left and back from left to right, until the 3x3 cm^2 region was irradiated

Energy spectrum measurement



- TOFPET read-out ASIC:
  - Energy measurement through the Time-Over-Threshold technique
  - Energy proportional to ToT: non-linear dependence

Rolo, M. D., et al. "TOFPET ASIC for PET applications." Journal of Instrumentation 8.02 (2013).

ToT spectra, inspill+interspill

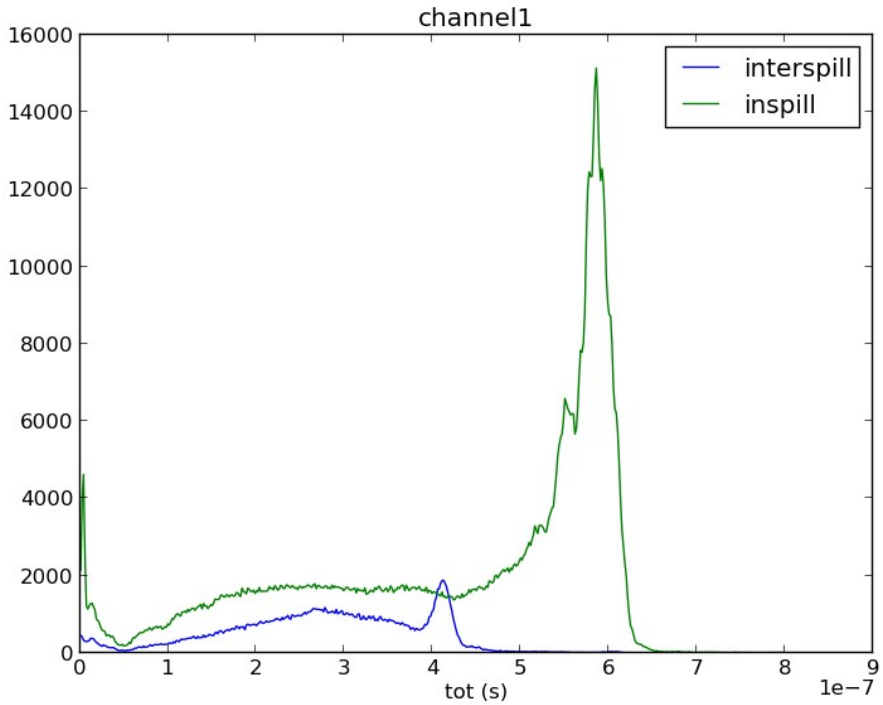
- In spill spectrum includes the contribution of:

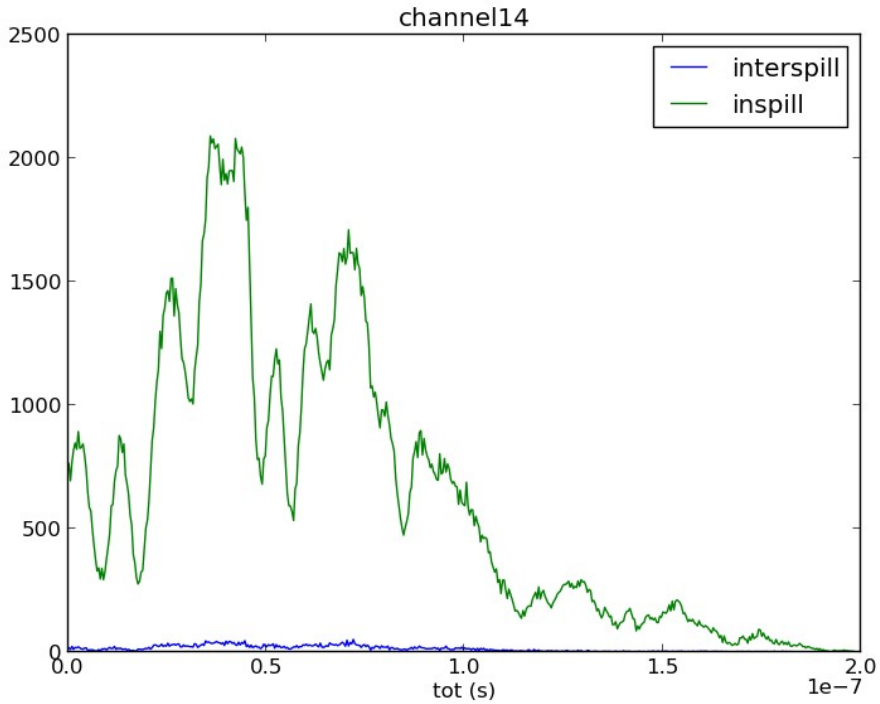
  - Neutrons

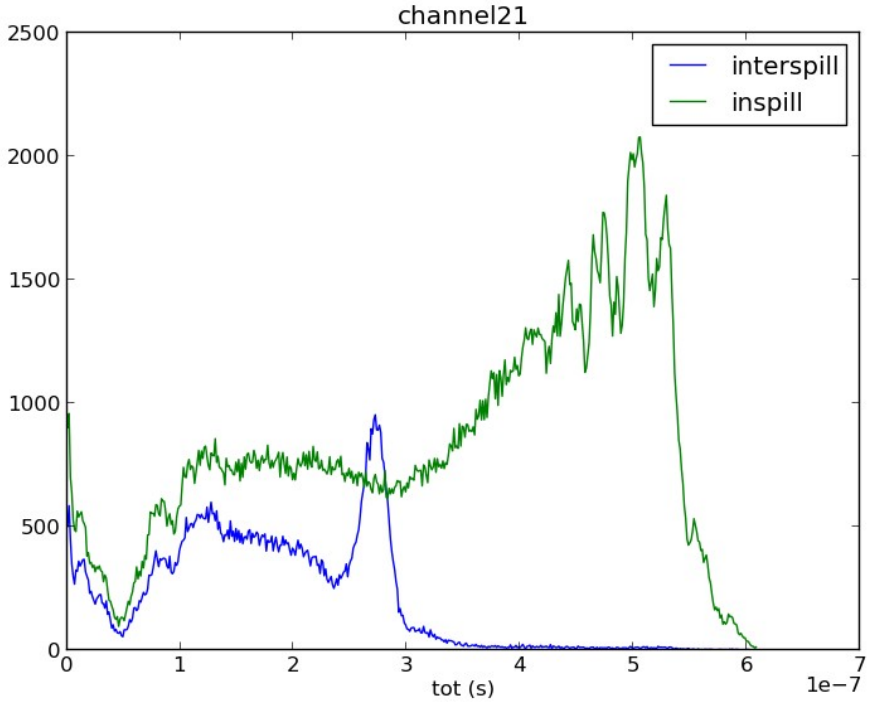
  - Prompt Gamma Rays

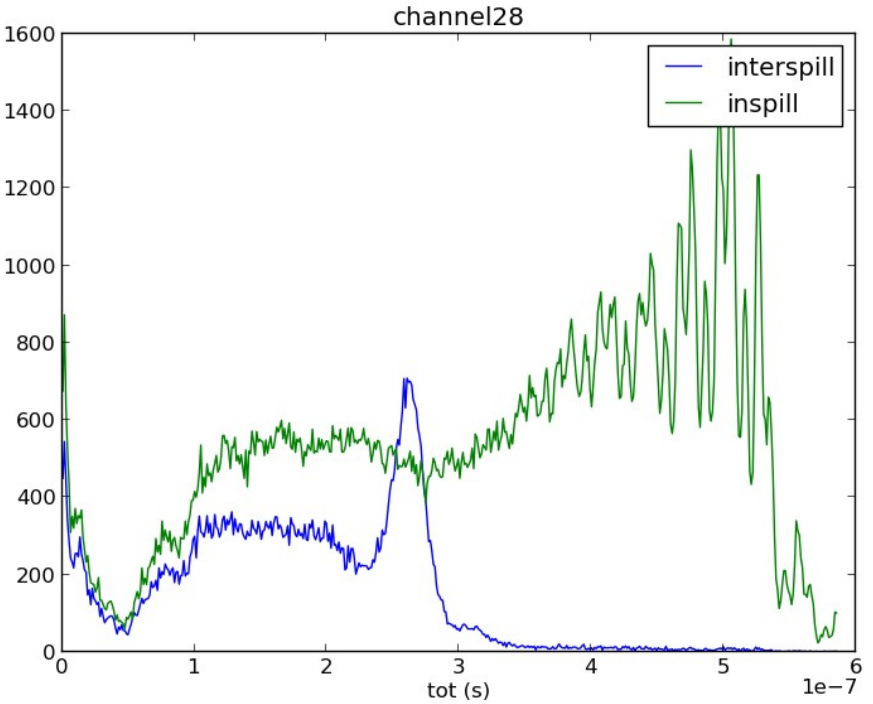
- Interspill spectrum:

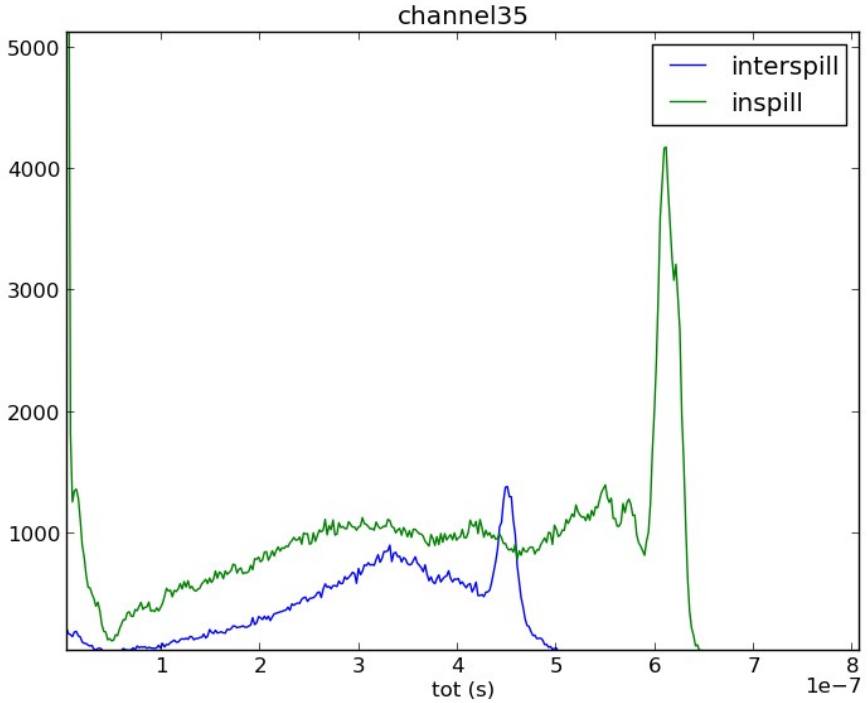
  - 511 keV photons from β^+ decays, mainly from ^{15}O and ^{11}C

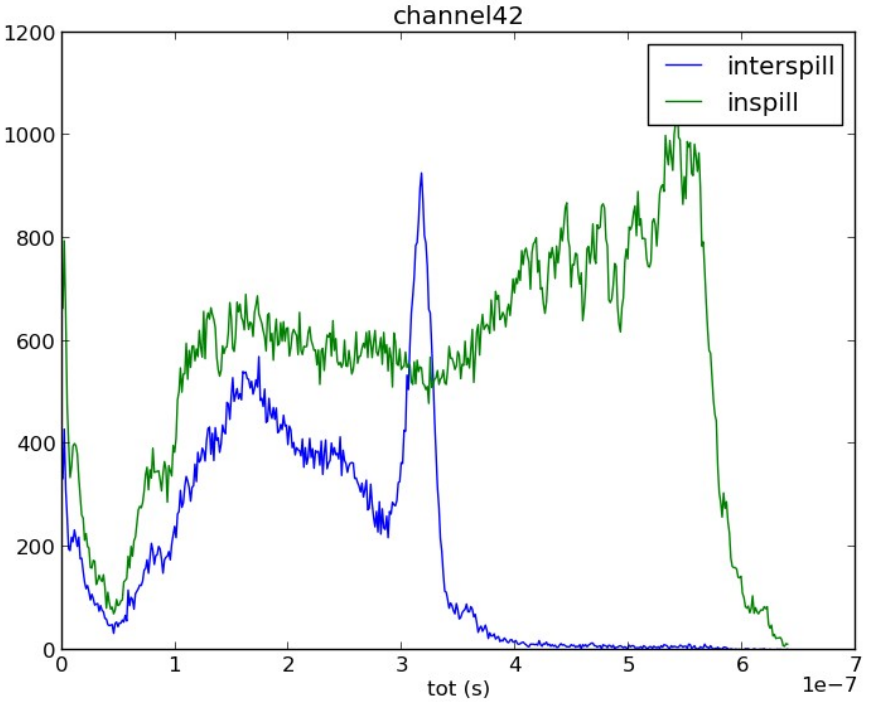




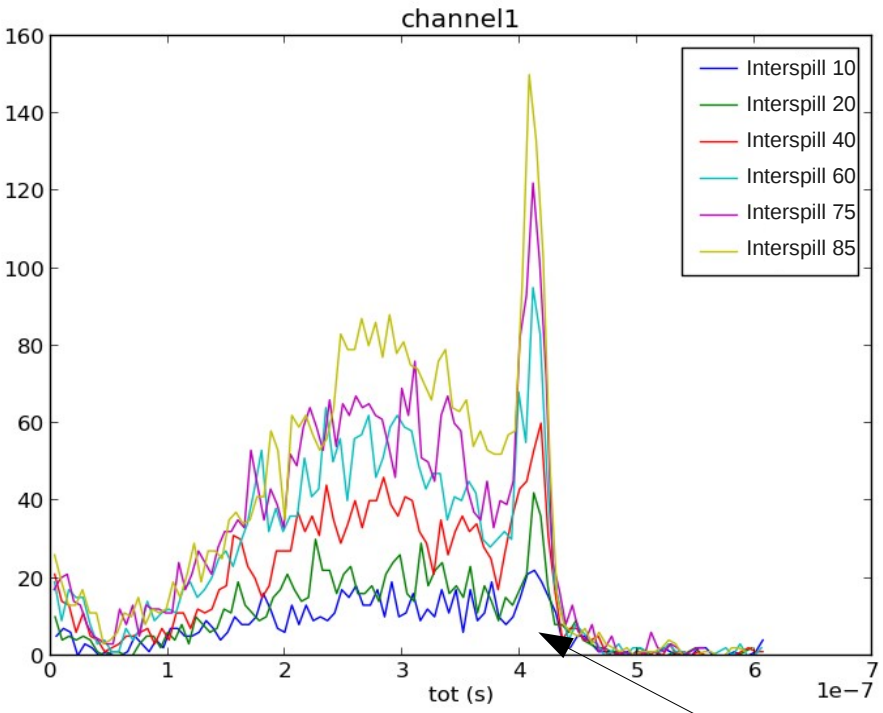

channel21
interspill
inspill
tot (s)
1e−7

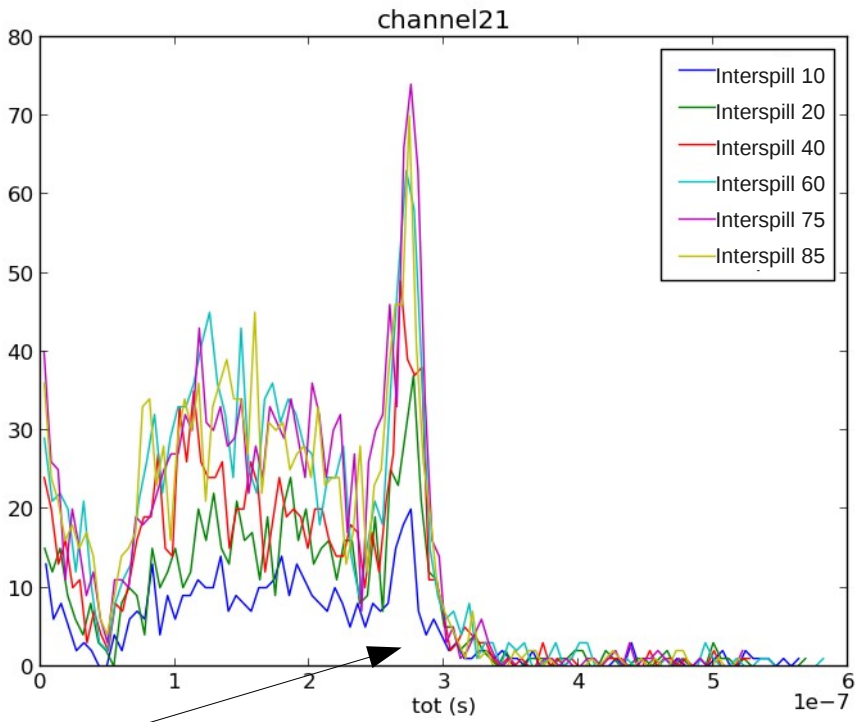

channel28
interspill
inspill
tot (s)
1e−7


channel35
interspill
inspill
tot (s)
1e−7


channel42
interspill
inspill
tot (s)
1e−7

Examples of interspill spectra

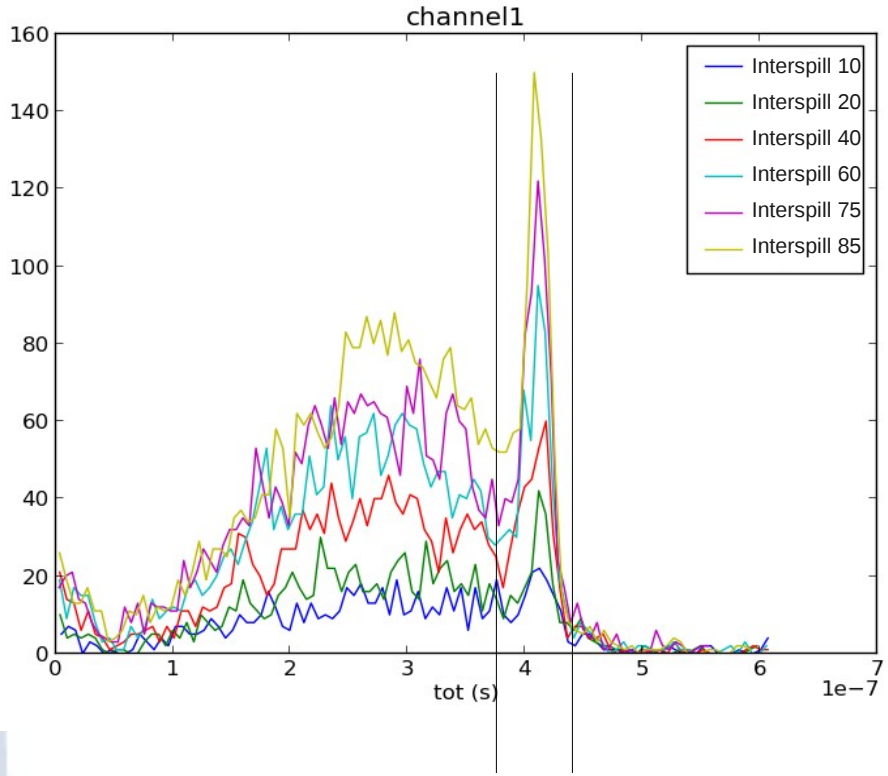




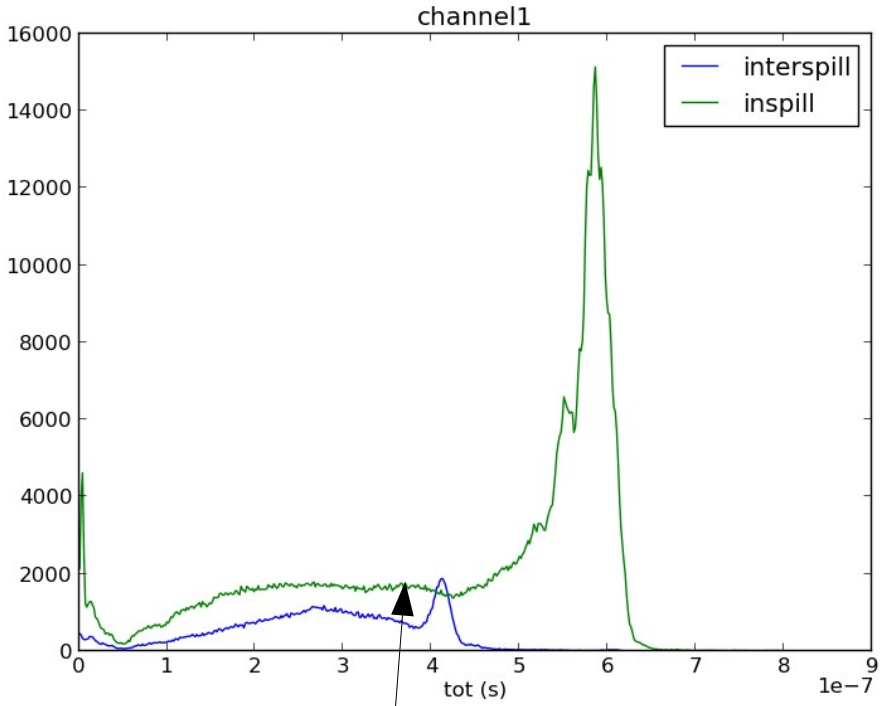
511 keV photopeak

- The position of the 511 keV photopeak is stable throughout the irradiation
- The number of events is increasing with the irradiation because of the β^{+} activation induced by the protons ^{12}

Number of events below the 511 keV photopeak



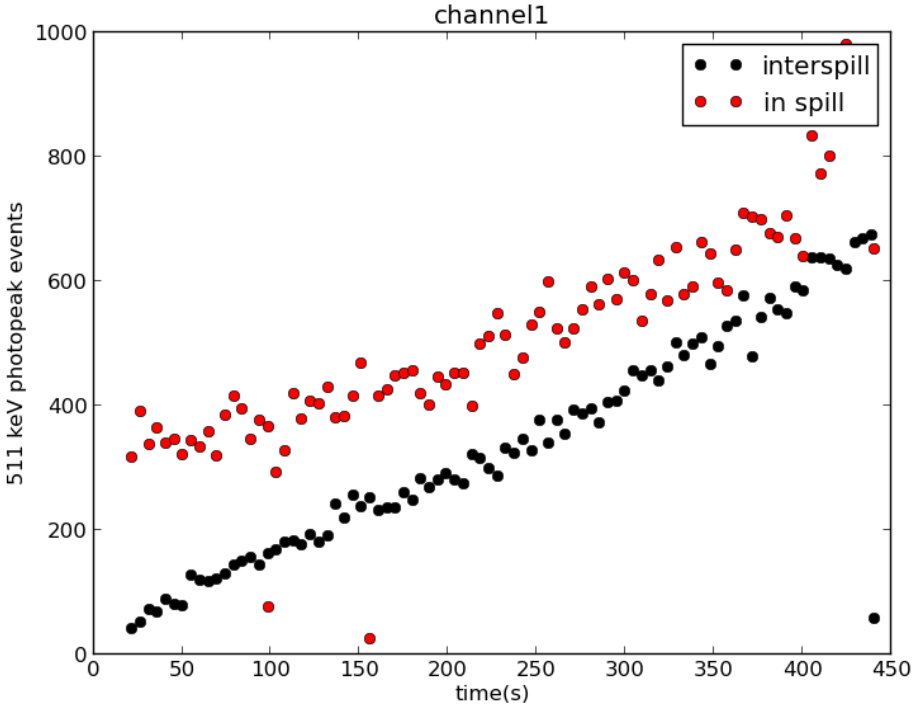
511 keV photopeak events

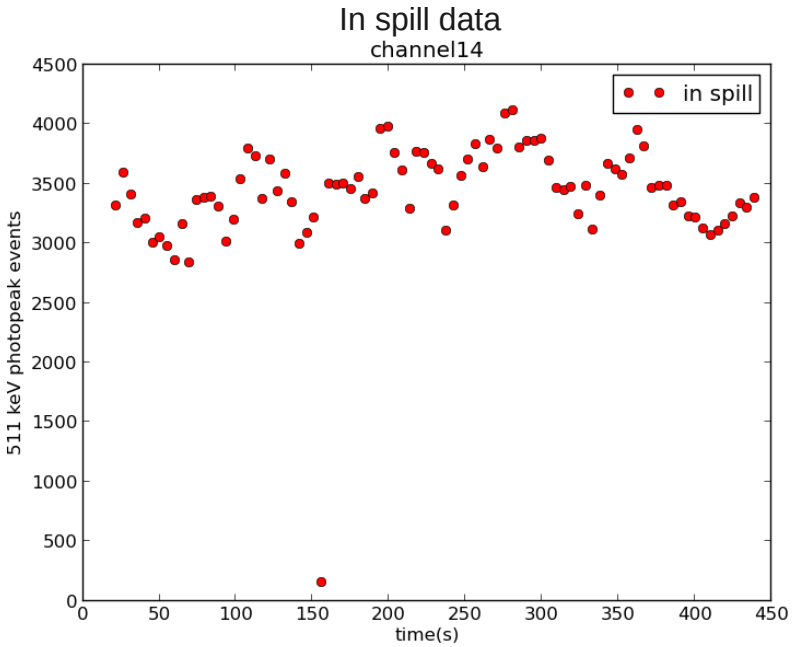


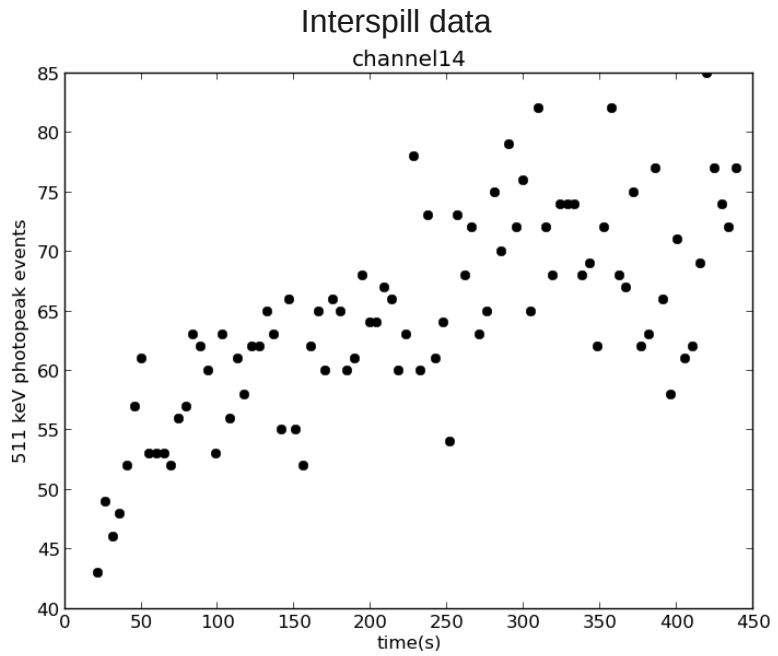
511 keV photopeak does not appear in the inspill spectra

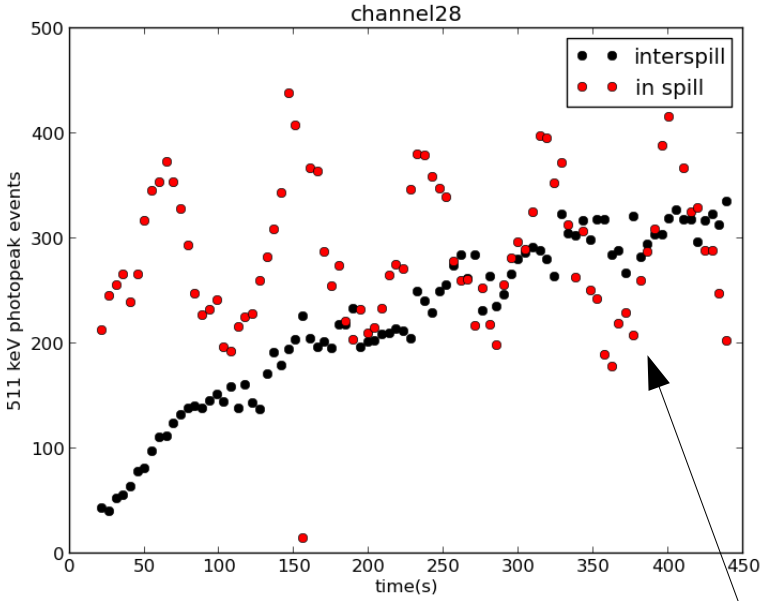
The number of event below the 511 keV photopeak was calculated by considering the same ToT interval selected in the interspill spectra

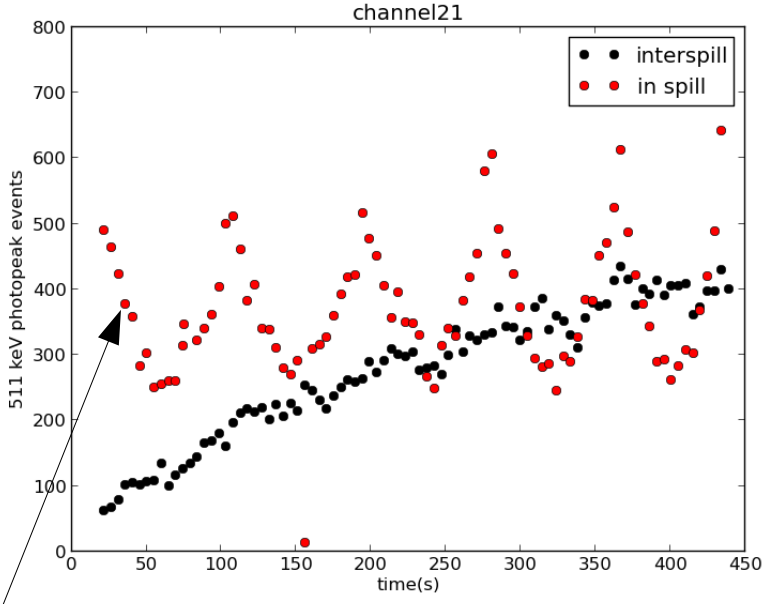
Variation of the number of events below the 511 keV photopeak with time

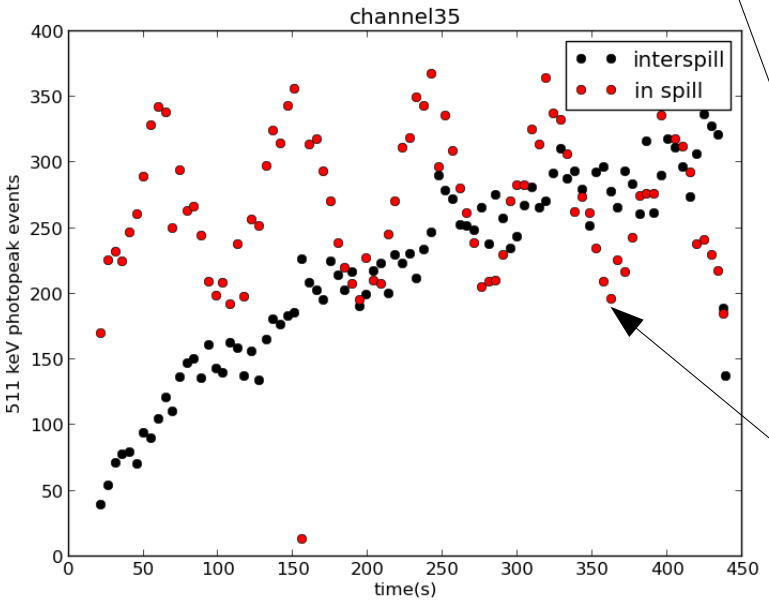


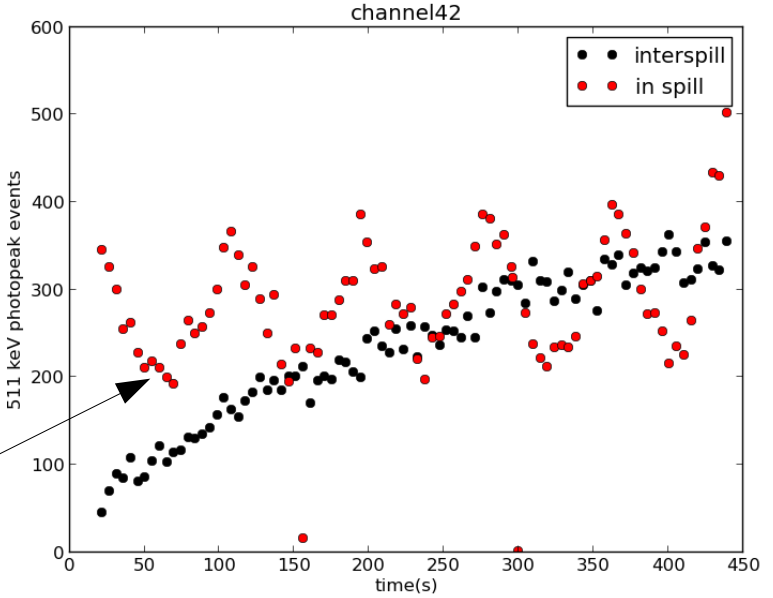






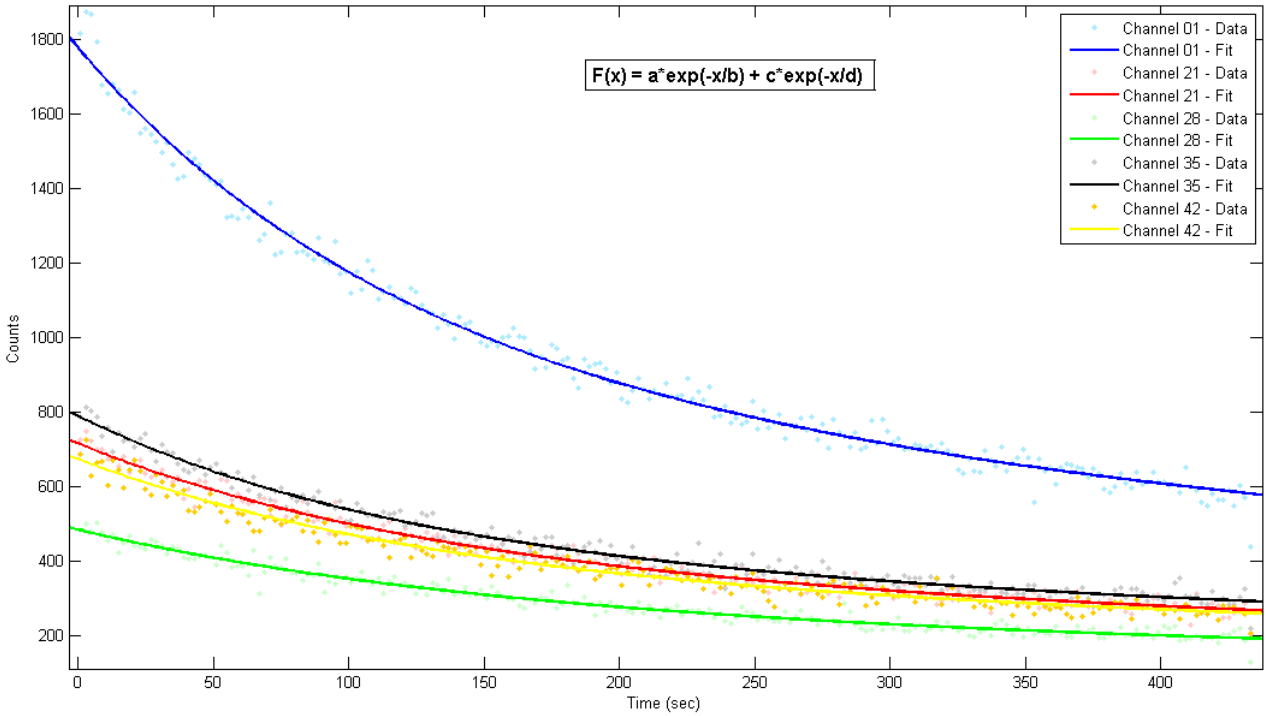






- Oscillating trend of the number of events due to the radiation beam scanning the 3x3 cm^2 area
- This effect probably depends on the presence of the prompt gamma rays rather than the 511 keV photons from the β^+ decays. Infact the same trend can be observed by considering ToT intervals other than the one relative to the 511 keV

Off beam data, after proton irradiation

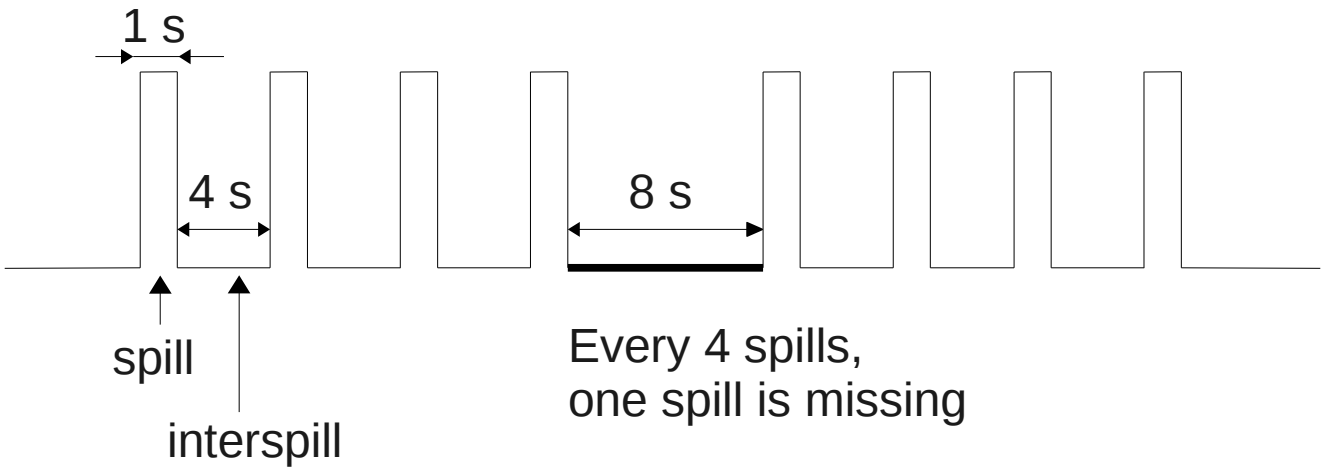


- Decay of β^+ activated isotopes, mainly ^{11}C and ^{15}O:
  - ^{11}C half life: 1200 s
  - ^{15}O half life: 122.24 s

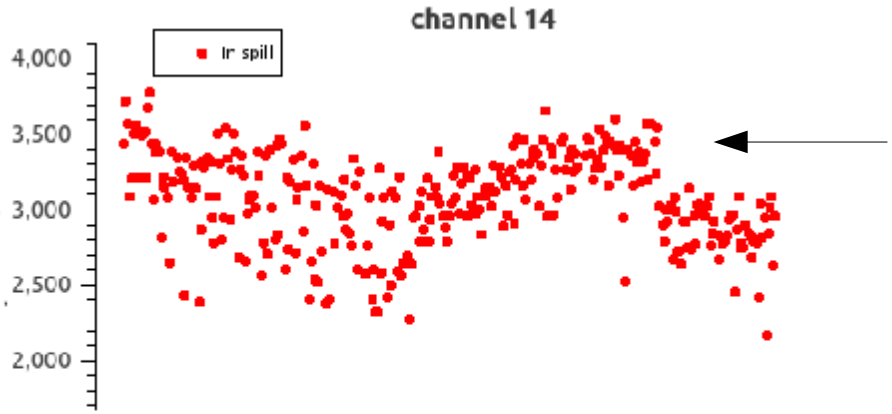
	^{15}O half life (95% confidence interval) [s]	^{11}C half life (95% confidence interval) [s]
Channel 01	**116.3** (110.2, 122.5)	**930** (892, 967.9)
Channel 21	**133** (122.4, 143.6)	**1259** (1156, 1362)
Channel 28	**154** (138.8, 170.2)	**1377** (1209, 1546)
Channel 35	**120.9** (112.1, 129.6)	**1263** (1174, 1333)
Channel 42	**131.3** (120, 142.5)	**1391** (1261, 1522)

Acquisition 2

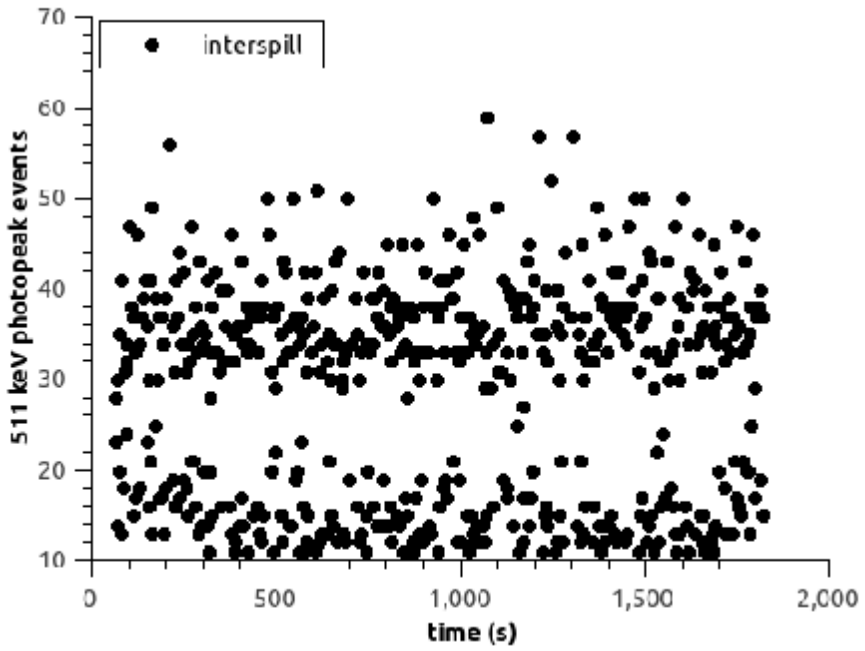
- PMMA phantom from previous irradiation
- Experimental set up as previuos irradiation
- Proton beam irradiating a fixed point, in the middle of the PMMA phantom
- Time structure of the beam:

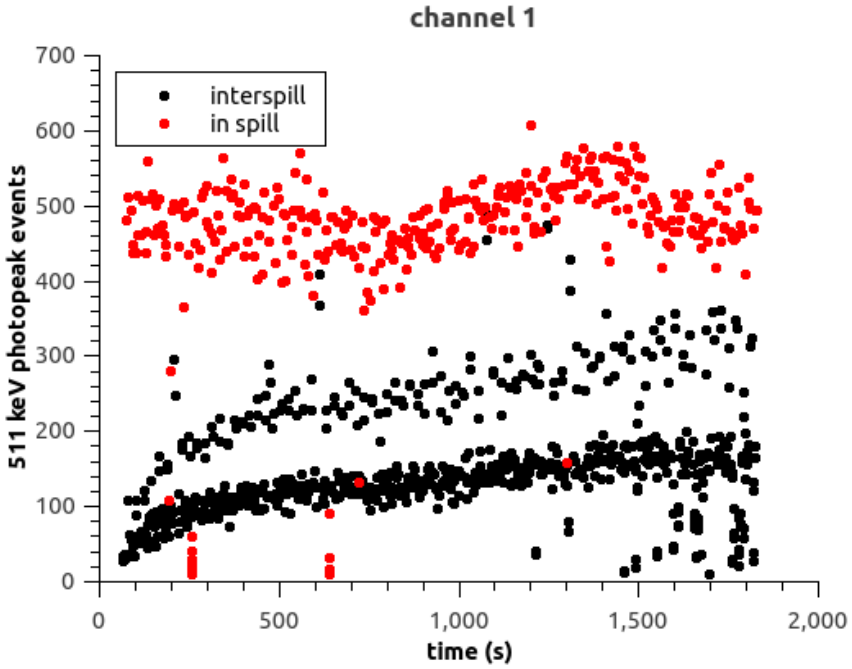


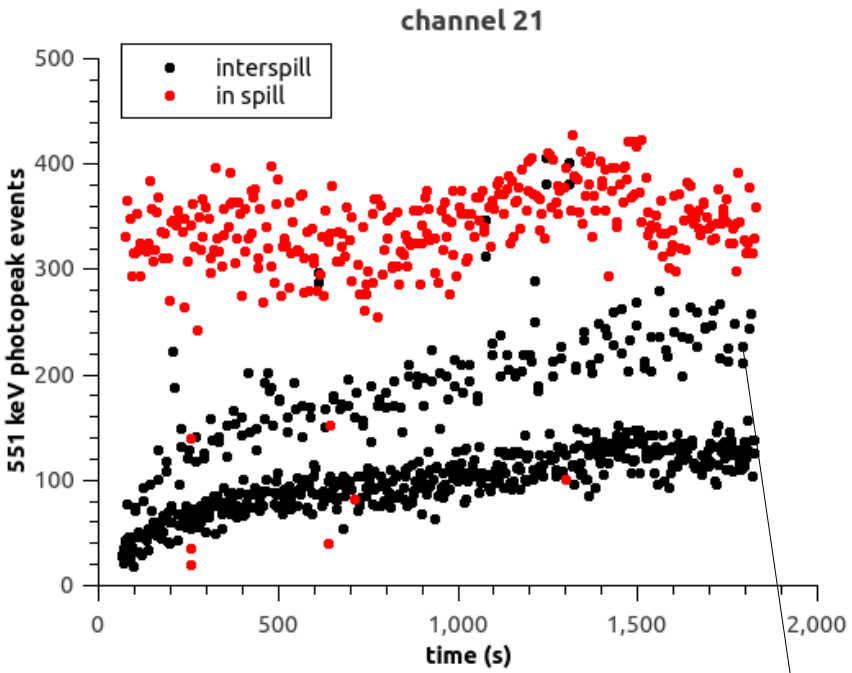
Variation of the number of events below the 511 keV photopeak with time

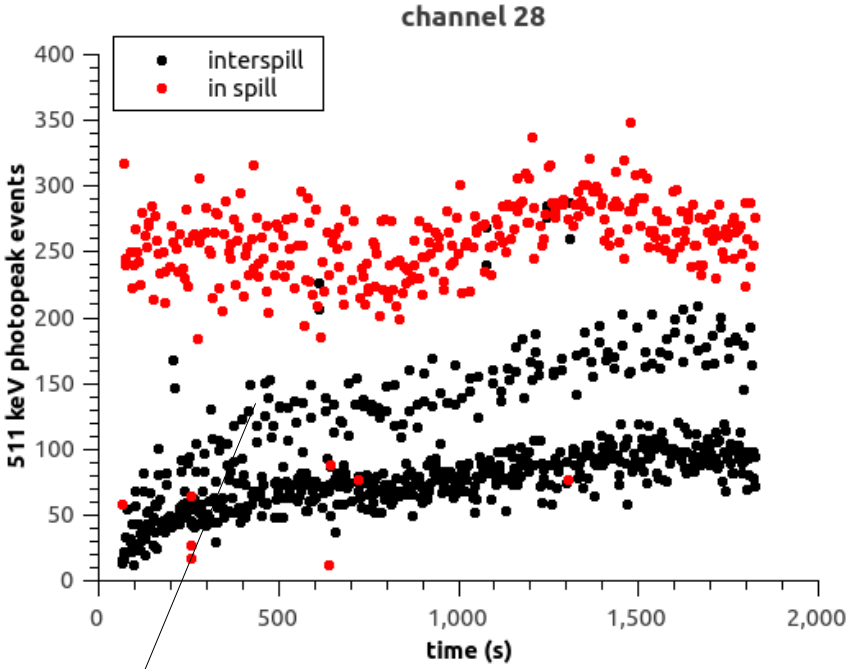


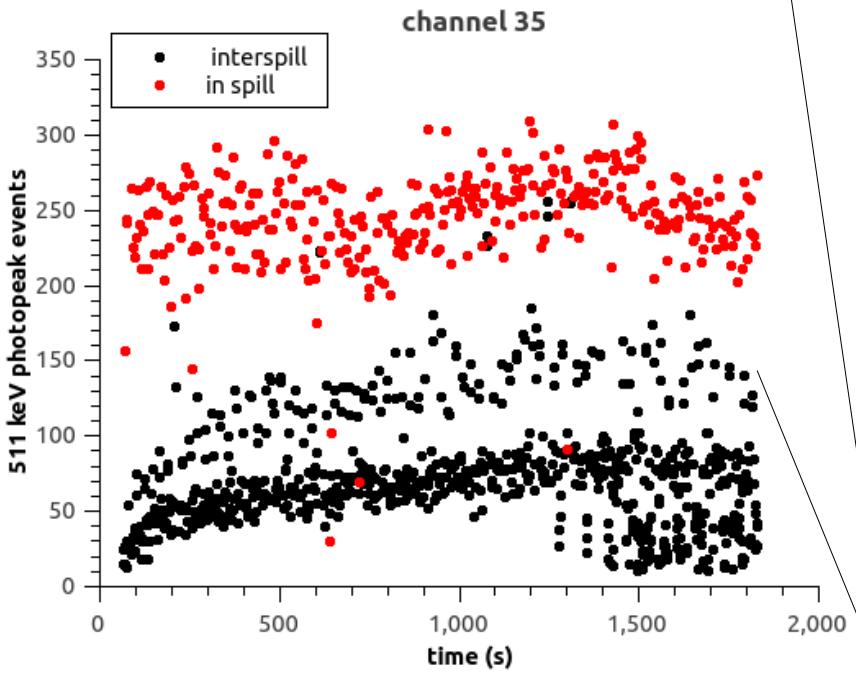
- In spill counts much higher than interspill counts probably due to higher neutron flux compared to the other SiPMs

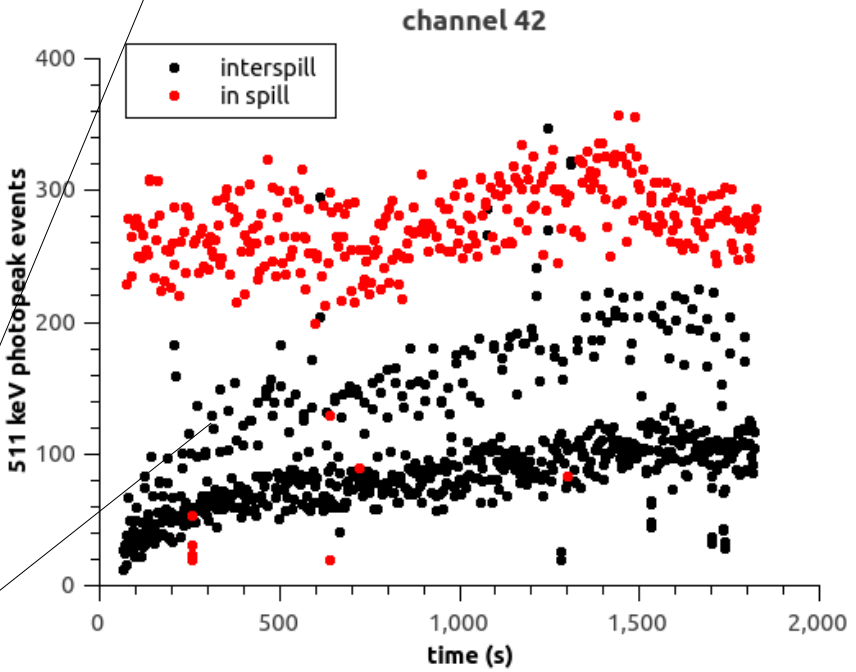




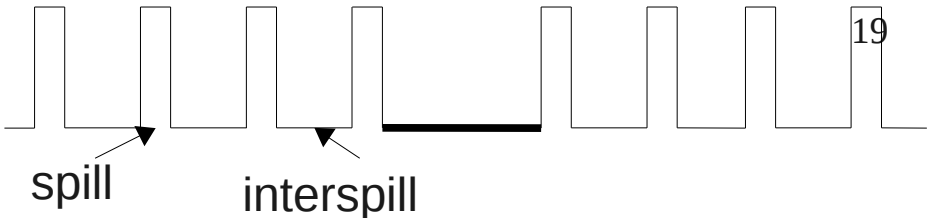








The interval between two consecutive spills doubles every 4 spills, therefore the counts double:



Damage to SiPMs after the test beam

channel	Current **before** CNAO (um)	Current **3** days after CNAO (um)	Current **9** days after CNAO (um)	Current **46** days after CNAO (um)	Current **58** days after CNAO (um)
1	1.2	7	4.4	4	3.5
14	1.3	40	Not working	12	22
21	7.9	10 um at 1V	10 um at 1V	10 um at 1V	10 um at 1V
28	6.4	8.4	8.3	Not working	Not working
35	2.0	2.9	2.6	INFN-Torino	INFN-Torino
42	7.2	8.6	8.3	4.5	6.5

- Leakage current slightly increased or SiPM not working
- Radiation damage? → FLUKA simulations ongoing to compare our results with literature

ToT-Energy calibration

- The calibration was realized after the data acquisition at CNAO

Radioactive sources:

- ^{22}Na:

  511 keV (beta+ annihilation)

  1275 keV

- ^{137}Cs:

  662 keV

- ^{57}Co:

  122 keV 85.6%

  136 keV 10.6%

- ^{133}Ba:

  35 keV 22.6%

  53 keV 2%

  79.6 keV 3%

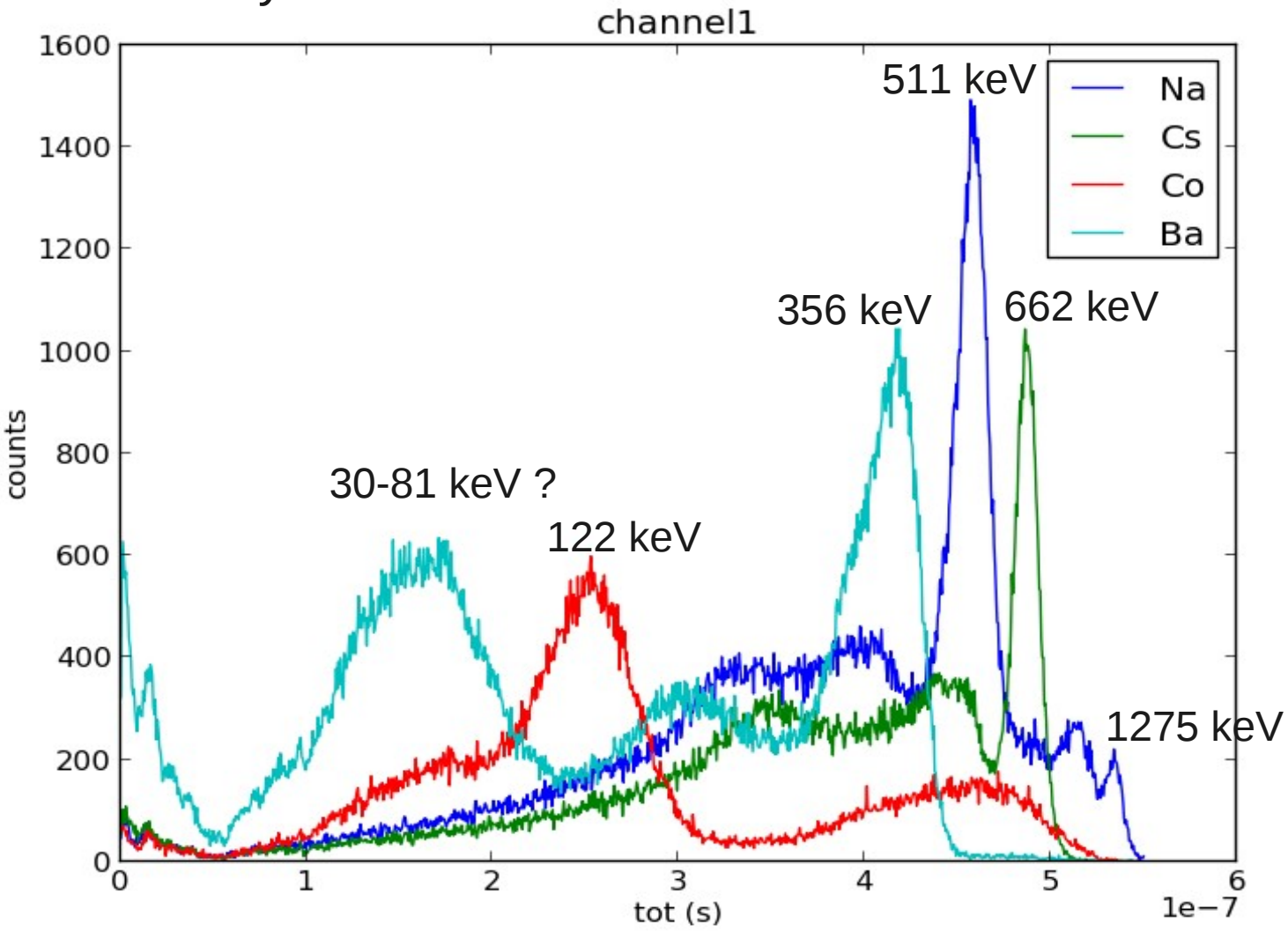
  81 keV 34%

  276 keV 7%

ToT spectrum

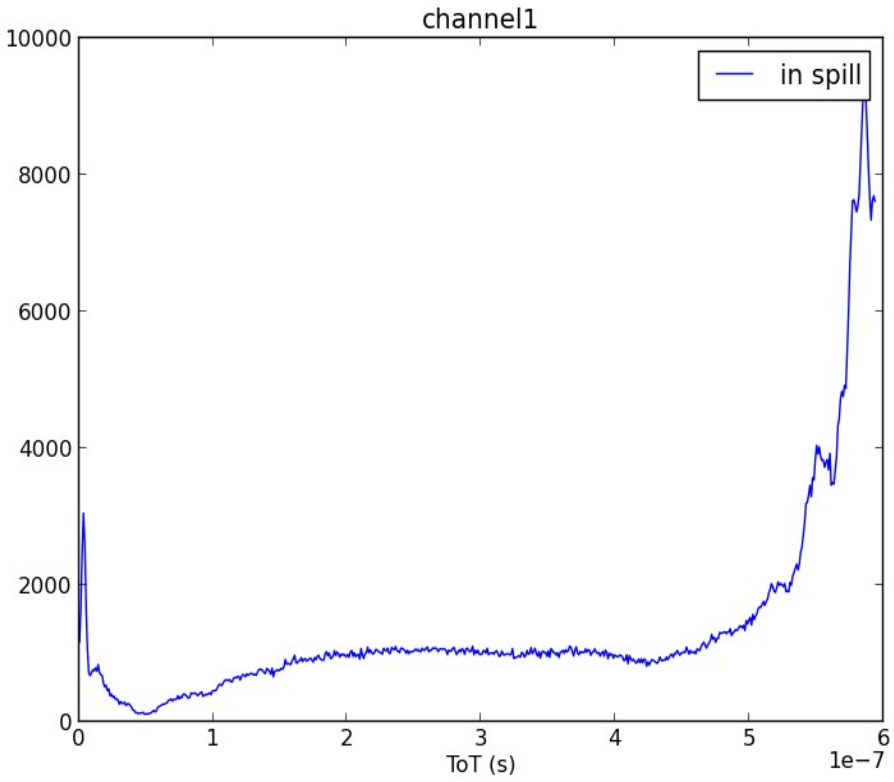
- TOFPET settings: CNAO test beam settings

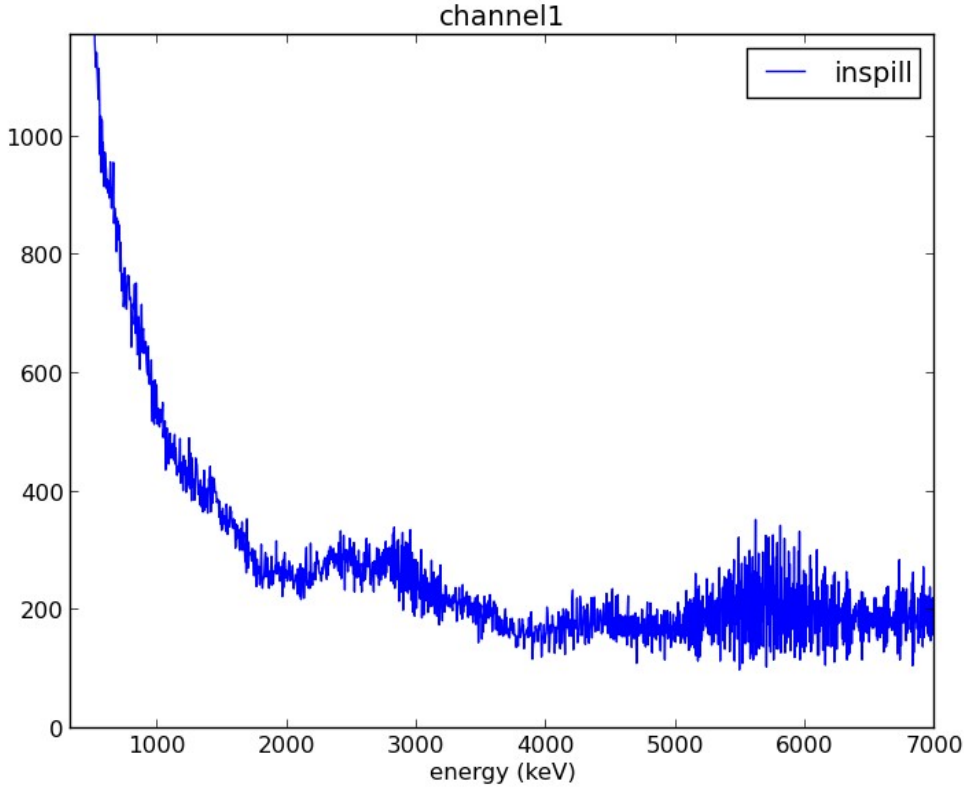
- At time of calibration, 3 out of 6 SiPMs worked. However we were able to acquire the energy spectrum of the radioactive sources with the SiPM on channel 1 only



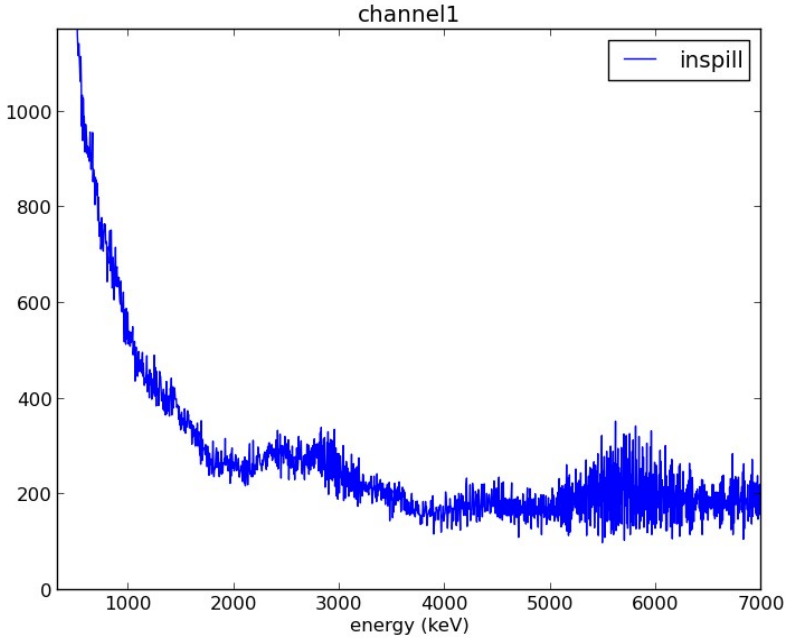
In spill energy spectrum

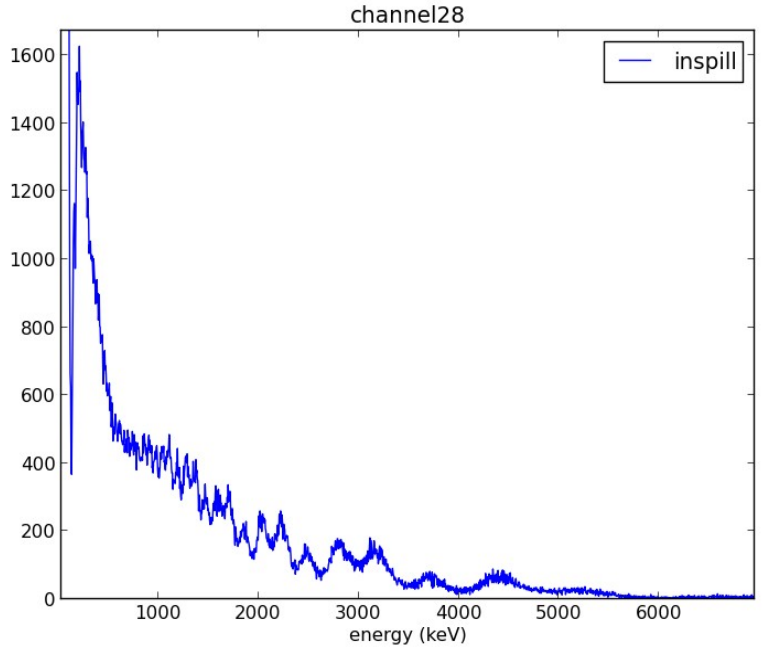
(Acquisition 1, channel 1)

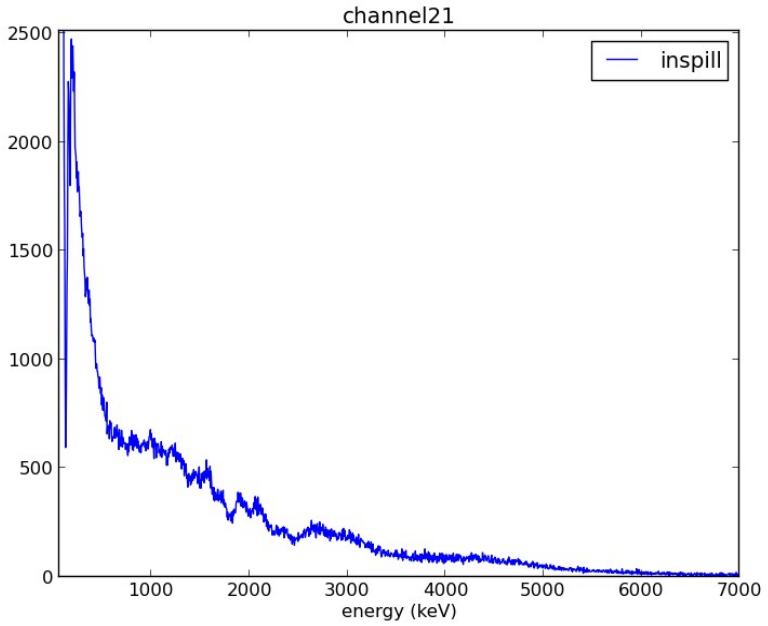




Comparison of in spill energy spectrum with literature data







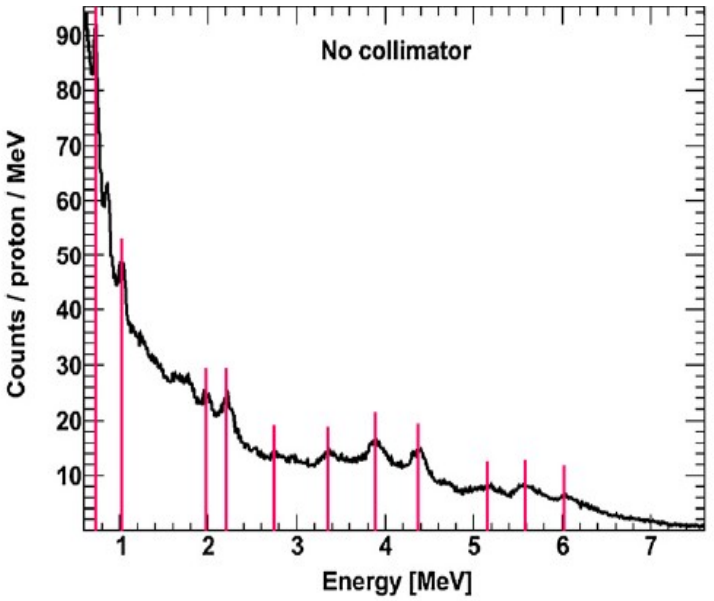


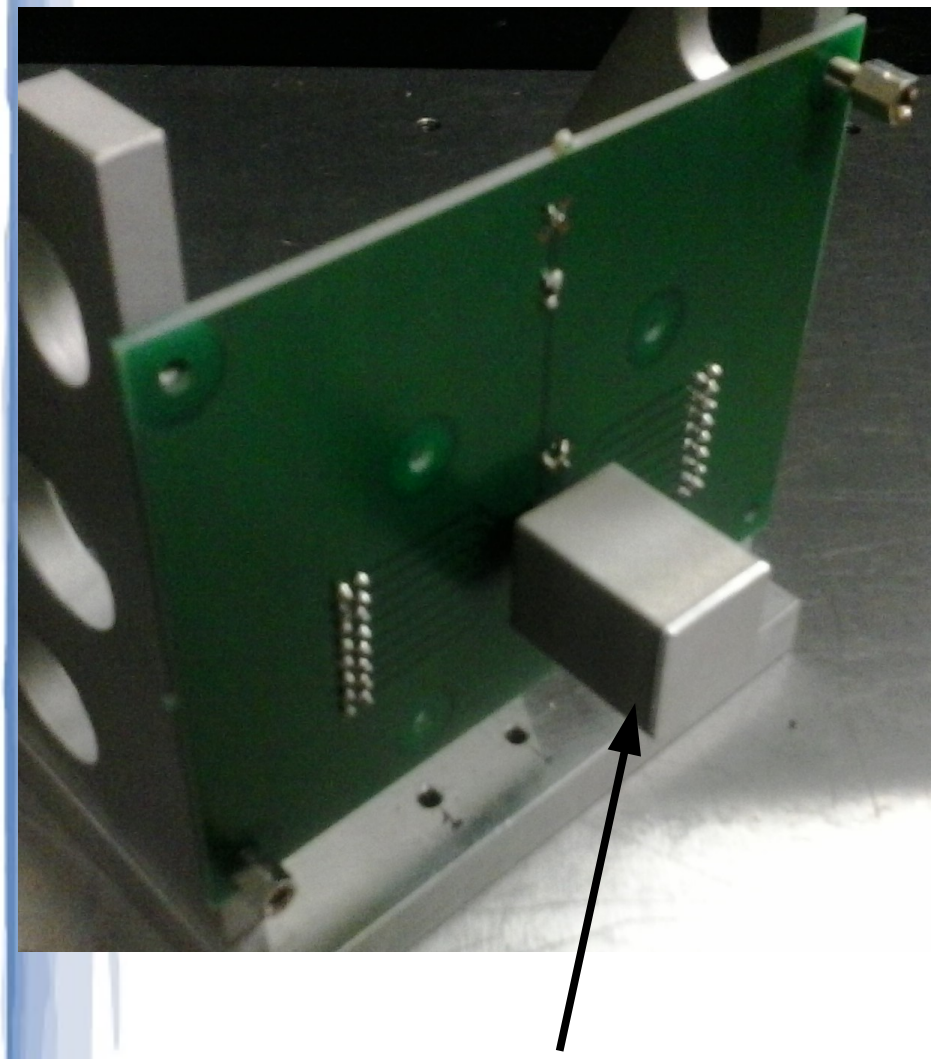
Figure 22. Spectrum measured at 50 cm distance for 160 MeV protons without a collimator. Measured gamma peak energies marked with a bar are interpreted in table 3.

Conclusions: test beam at CNAO

- The system is able to keep pace with the prompt gamma emission rate
- Clear energy spectrum of the inter spill radiation
- Stable system response
- Possible radiation damage: FLUKA simulations are ongoing

2.Preparing the next test beam

First prototypes of the HAMAMATSU matrices



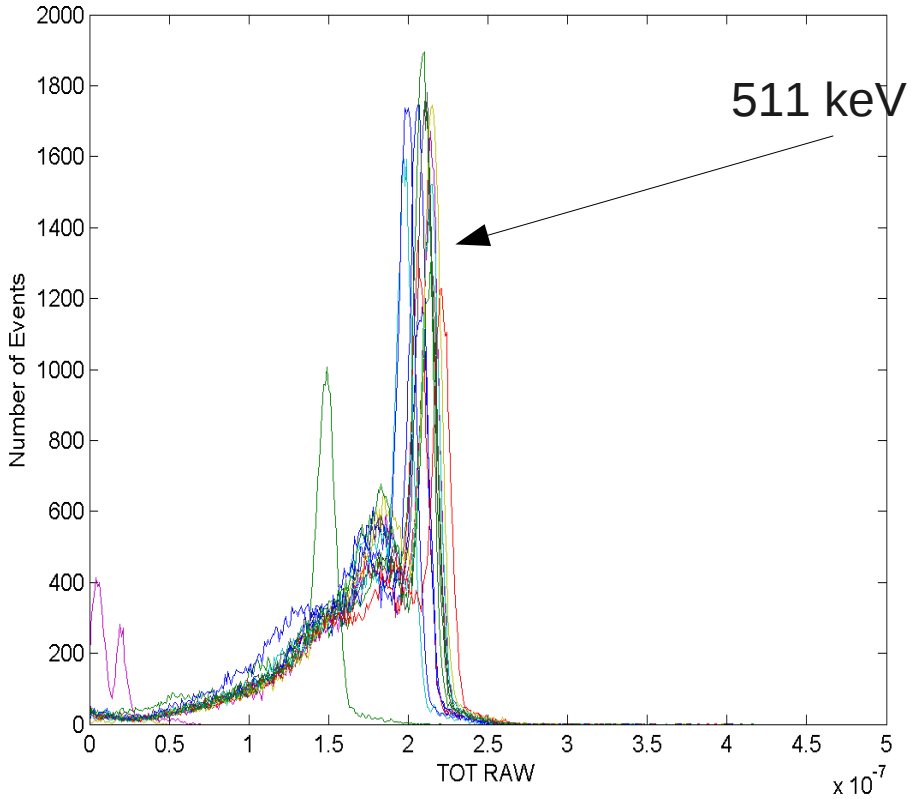
4x4 SiPMs matrix coupled to LYSO crystal

- 2 matrices:
  - 4x4 SiPMs
  - 3x3 mm2 each SiPm
- 1 matrix coupled to LYSO crystal
- 1 matrix coupled to LSF crystal
- Read-out ASIC: TOFPET

Energy spectra

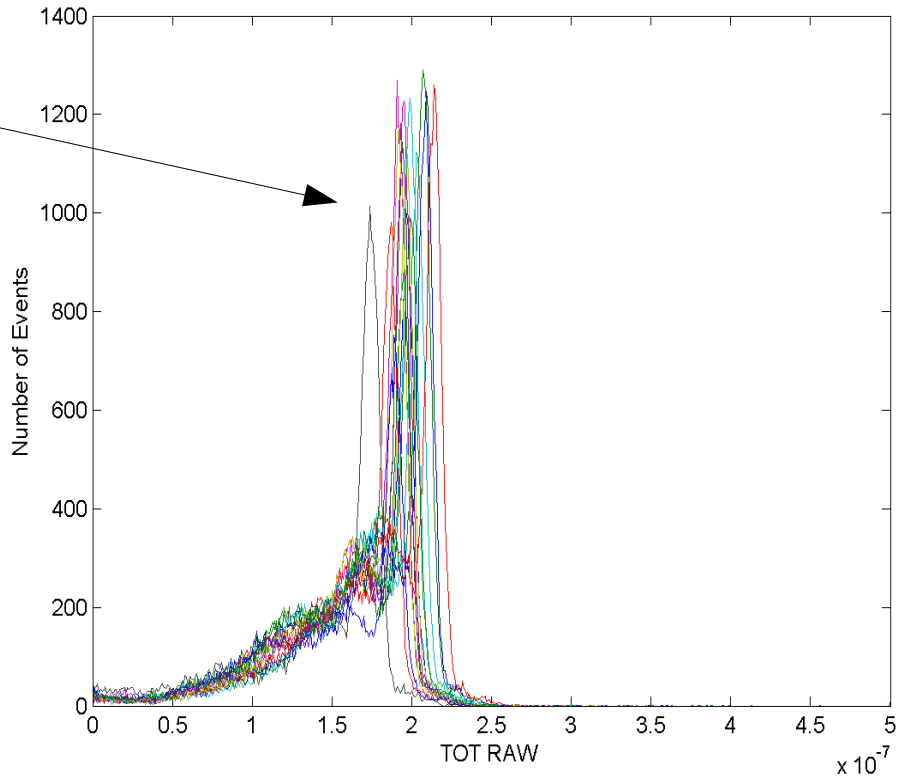
- Radiation source: ^{68}Ge
- Same bias voltage applied to all SiPMs

Matrice 1: cristallo LYSO



511 keV peak

Matrice 2: cristallo LSF



- Almost uniform response among the SiPMs within the same matrix
- It can be optimized

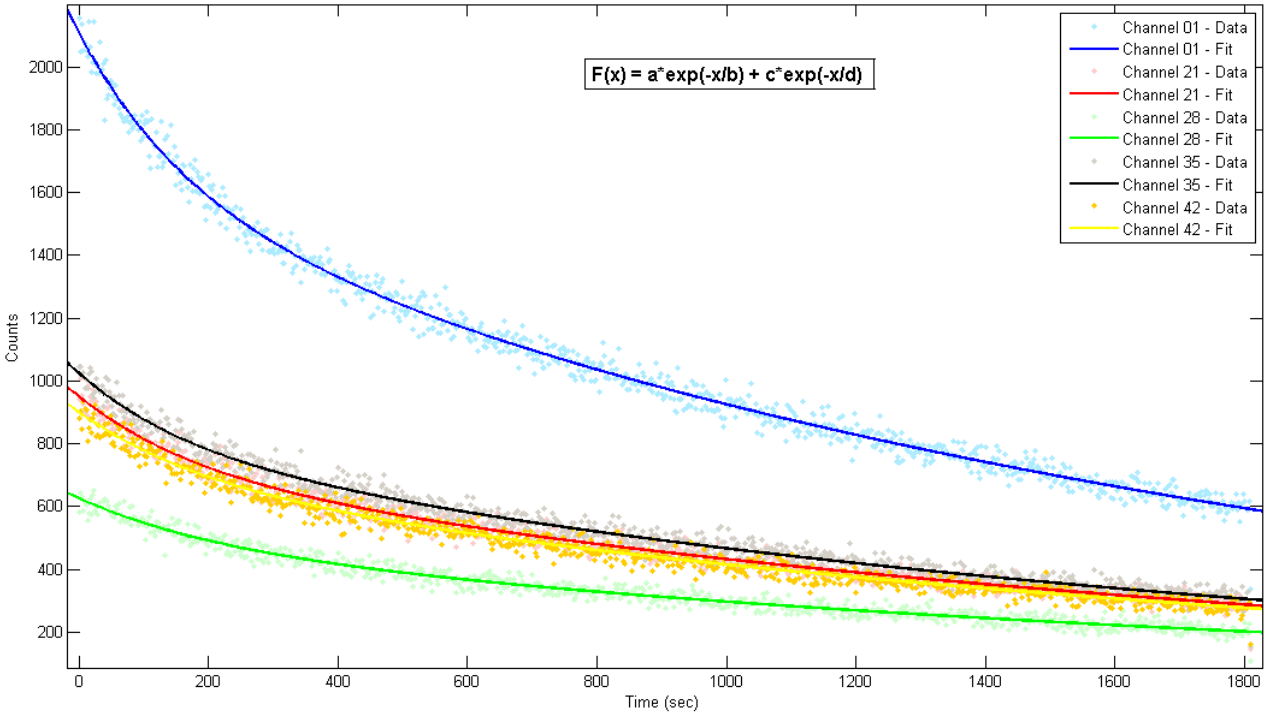
Measurements next test beam

- 511 keV photons coincidences
- Radiation damage assessment

- FLUKA simulations of the next test beam set up are ongoing

Thank you

Off beam data, after proton irradiation



- Decay of β^+ activated isotopes, mainly ^{11}C and ^{15}O:
  - ^{11}C half life: 1200 s
  - ^{15}O half life: 122.24 s

	^{15}O half life (95% confidence interval) [s]	^{11}C half life (95% confidence interval) [s]
Channel 01	**164.5** (151.2, 177.8)	**1813** (1780, 1846)
Channel 21	**180** (158.2, 201.9)	**1972** (1910, 2034)
Channel 28	**211.4** (177.1, 245.6)	**2093** (1996, 2191)
Channel 35	**169.4** (144.7, 186.1)	**1894** (1843, 1946)
Channel 42	**192.9** (167.2, 218.6)	**1996** (1925, 2066)