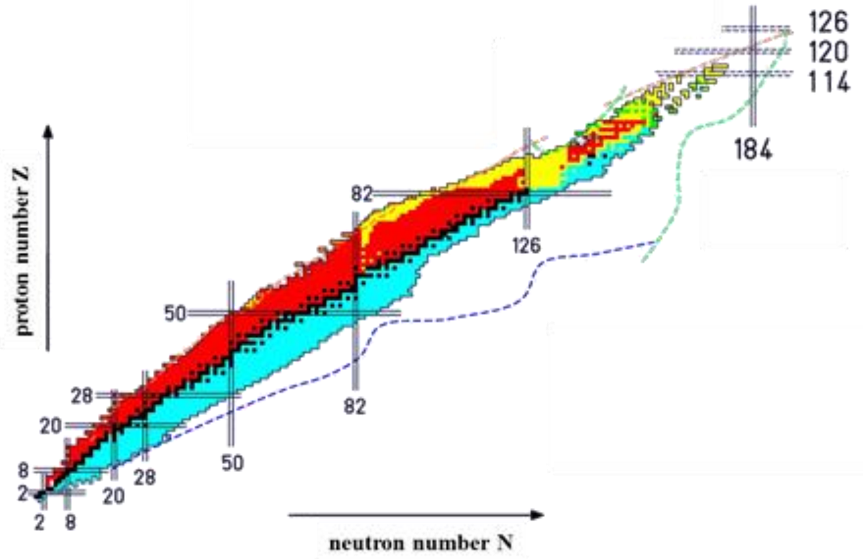
The DESPEC Fiber Implanter (FIMP)

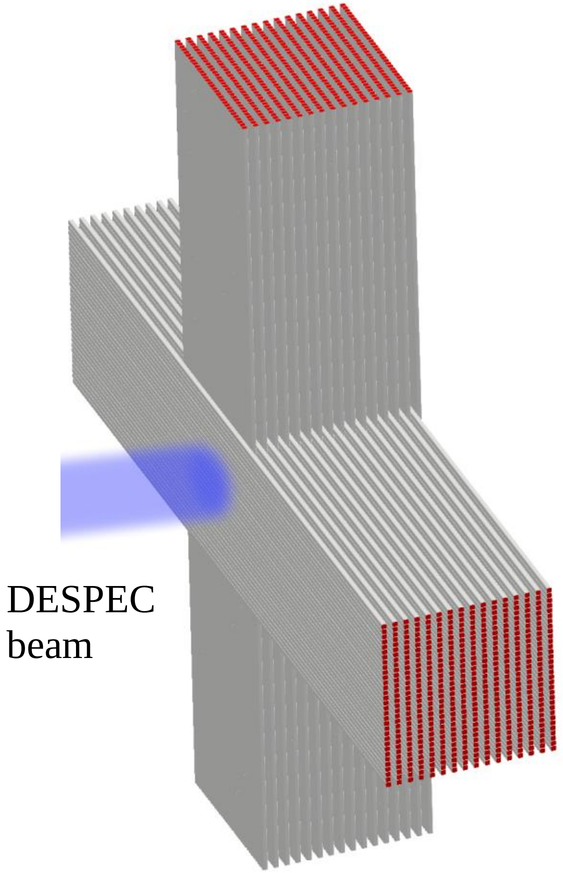
Jelena Vesić
for FIMP collaboration

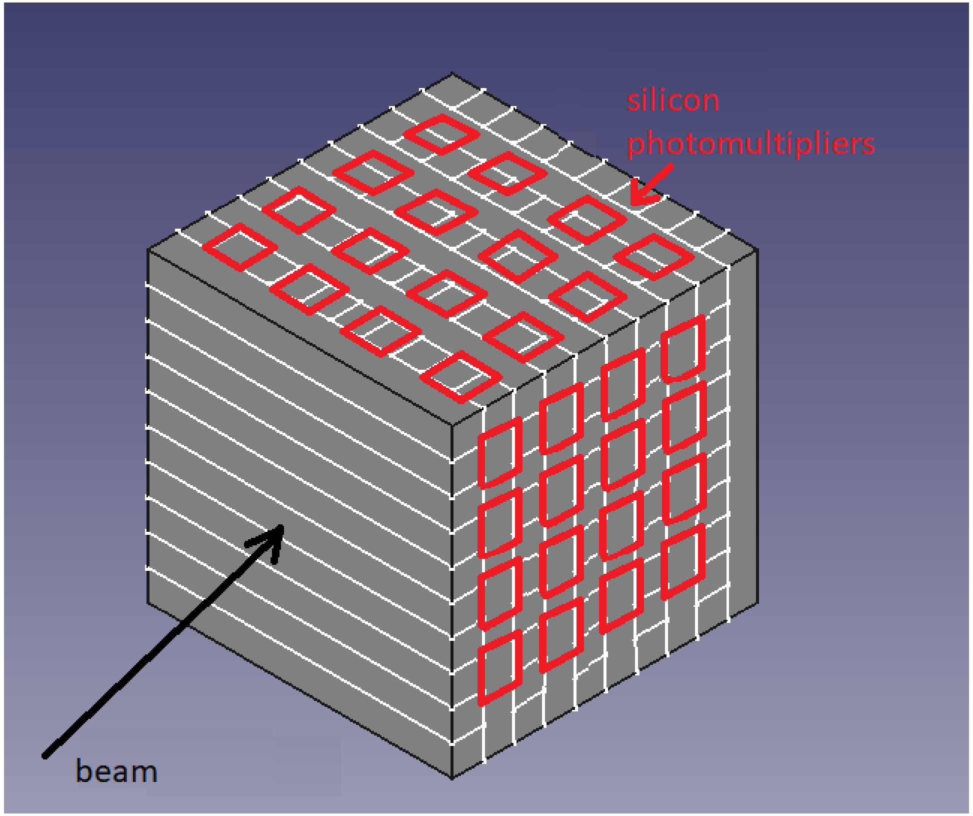
- The active implanter - Stop the isotopes produced by FRS/Super-FRS, provide the respective implantation time and position, detect the time and position of subsequent β or α decays, and provide rough energy information to enable at least distinction of β from α decays.
- Spectroscopy of nuclei far off stability based on their β, α and isomeric decays
- Active implanter + gamma and neutron-detector arrays



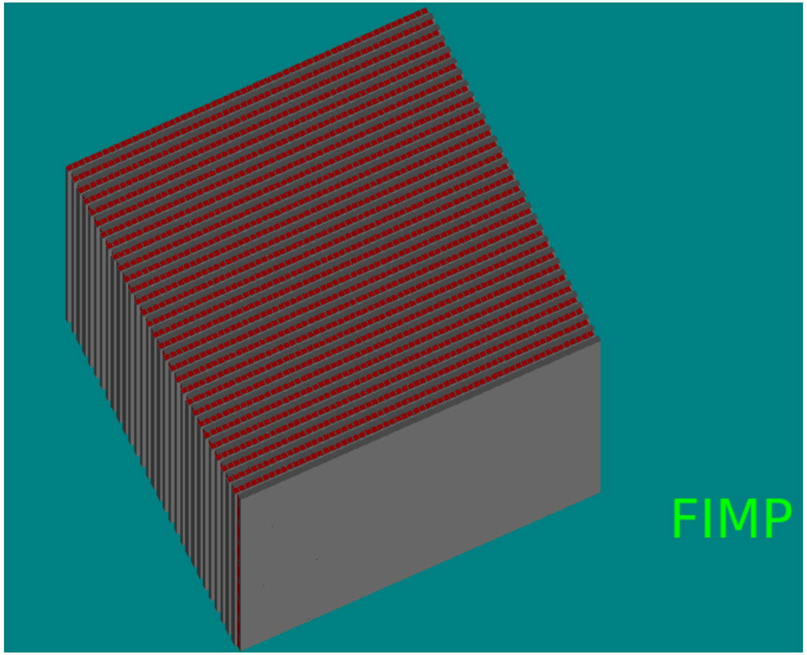
Fibre IMPlanter concept

- An implantation detector is needed with a time resolution of < 1ns and better.
- Compose the implanter from orthogonal layers of fibre mats, assuming that β and α particles (or their associated secondary electrons) will hit at least one x and one y fibre so that complete position information is available.





- The FIMP consists of scintillating fibres from polystyrene-like polymers.
- A complete position information is obtained when (beta or alpha) particles hit at least one x and one y fibre.



- Scintillating core :

  Fiber (Polystyrene, $H_8 C_8$ 1.06 g/cm^3)

  0.4 x0.4 mm^2 (cross section)

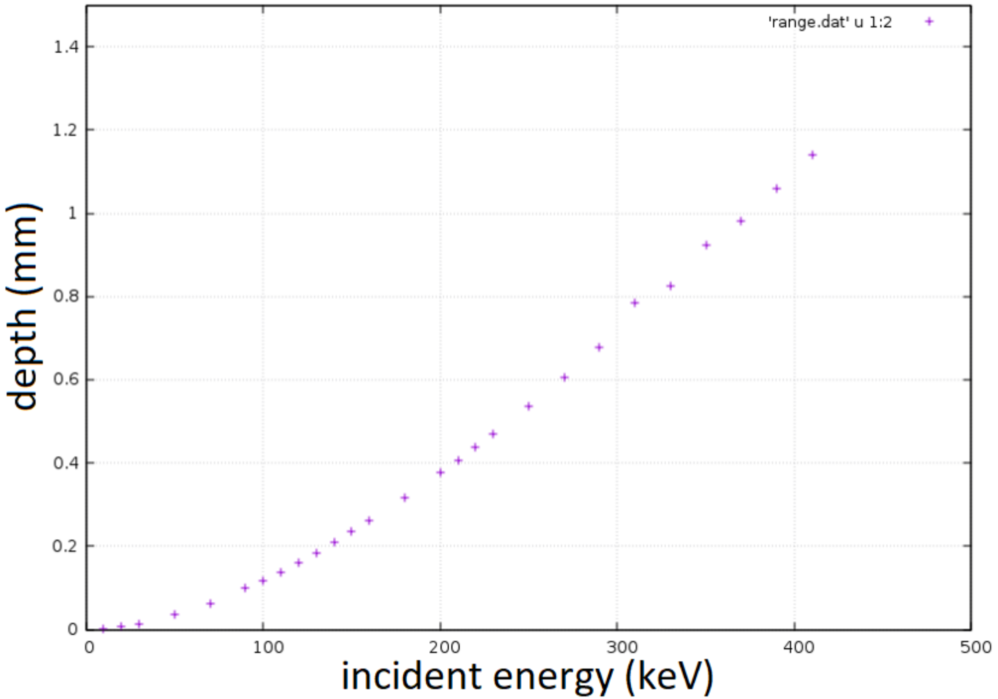
- Cladding : 0.05 mm

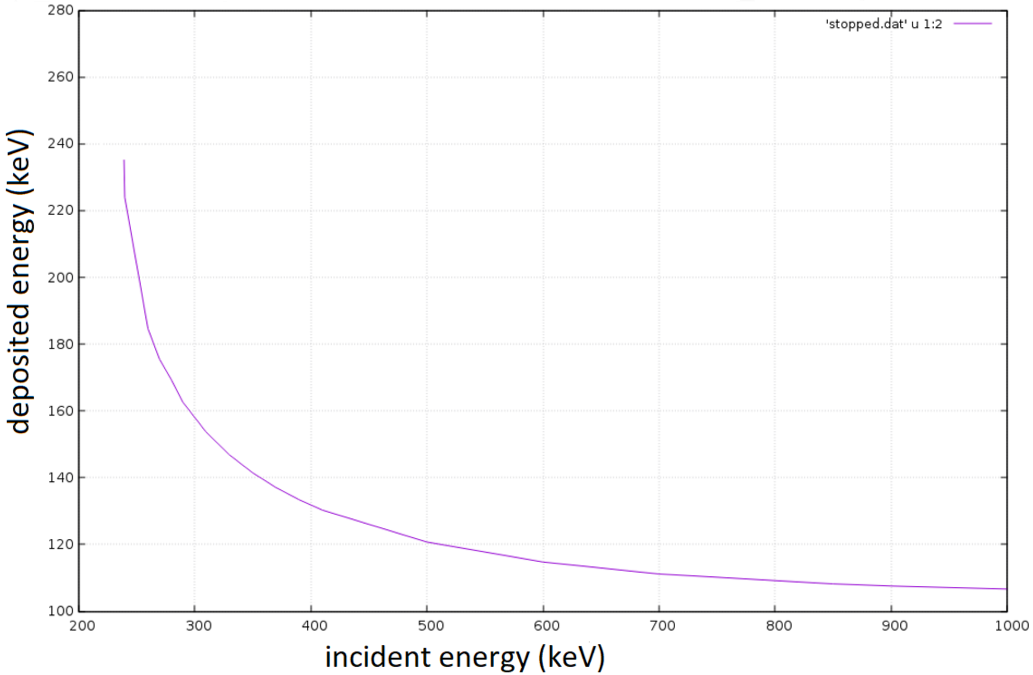
  PMMA （$H_8C_5O_2$, 0.95 g/cm^3）

- Detector:

  26 Layers × 160 Fibers

  80 mm × 80 mm × 12 mm



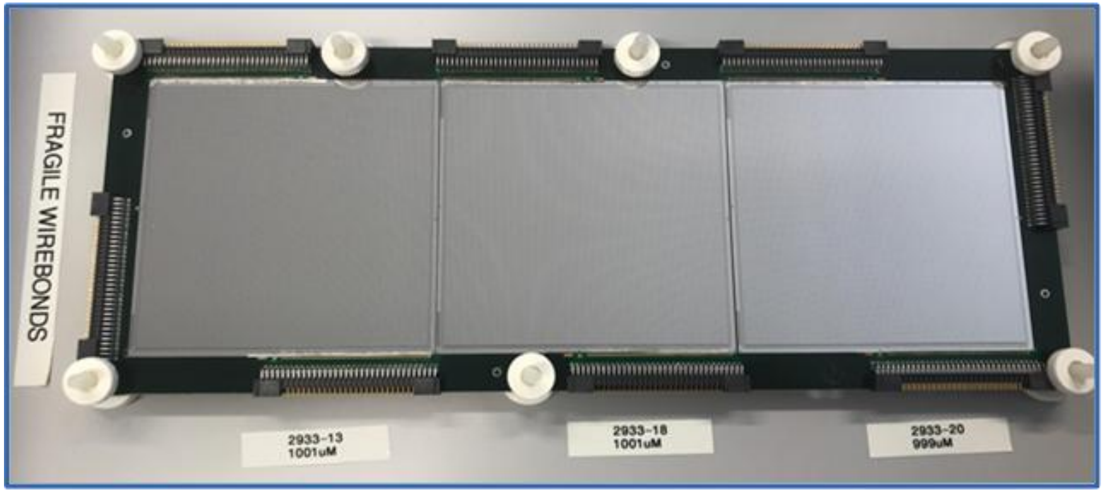


Total thickness of 30 mm would be sufficient to stop the majority of all β particles, also considering the non-straight paths.

The detection threshold of fibres read out by SiPMs is in the order of 100 keV. The optimal fibre thickness for decent signals is about 0.5 mm. Low-energy limit of about 250 keV for β particles being detected in two adjacent orthogonal fibres.

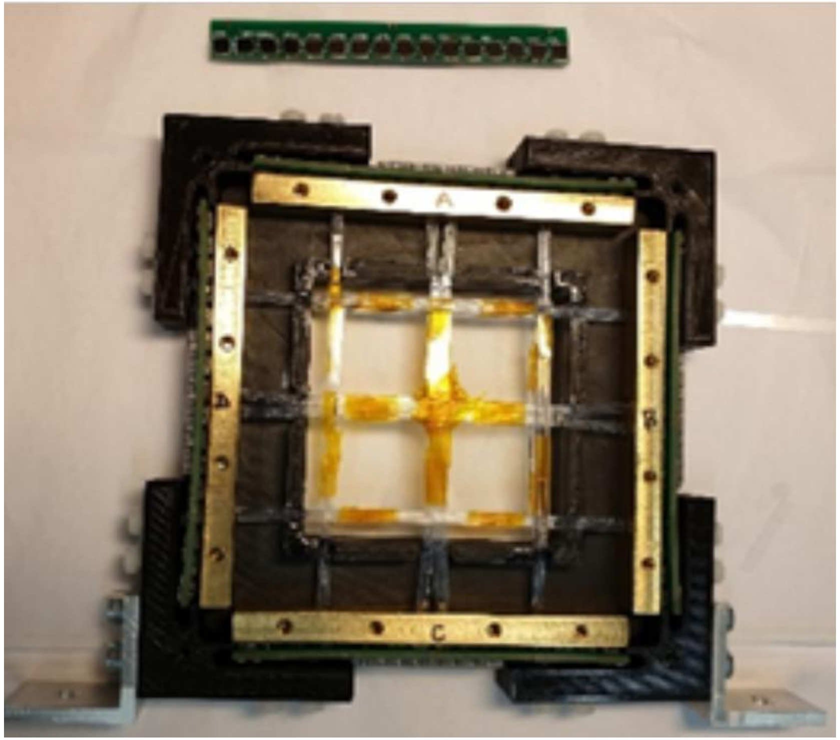
AIDA – DESPEC workhorse

- DSSSD detectors
- Detection efficiency: 25 % - 35 %
- Time resolution: > 1 µs (Drawback!)



FIMP (ver. 0) Proof-of-concept

- Square-shaped fibres of 0.5 mm thickness
- Fibre bundles of 4x4 Kuraray fibres per SiPM
- Arrays of 2x2 mm^2 SiPMs



Courtesy of J. Gerl

Challenges of Design and Construction

- Deposited energy distribution for α particles, β particles and ions
- Efficiency of detection
- Deadspace of silicon photomultipliers: placing
- Multiplexing

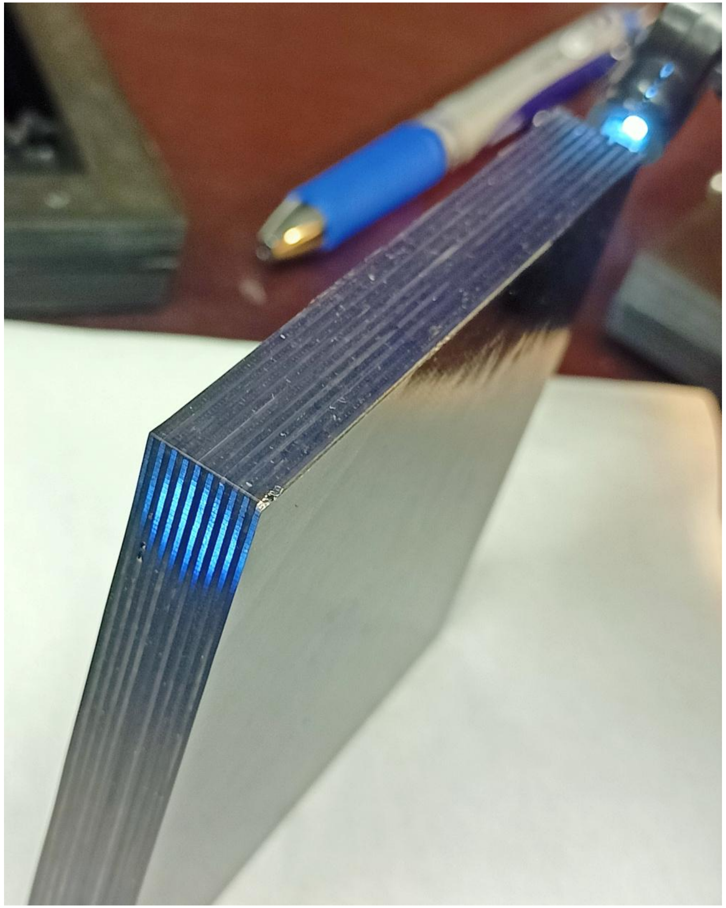
FIMP ver 1

- 80 mm × 80 mm × 12 mm
- 3x16 array of 4x4mm^2 SiPMs
- 192 readout channels

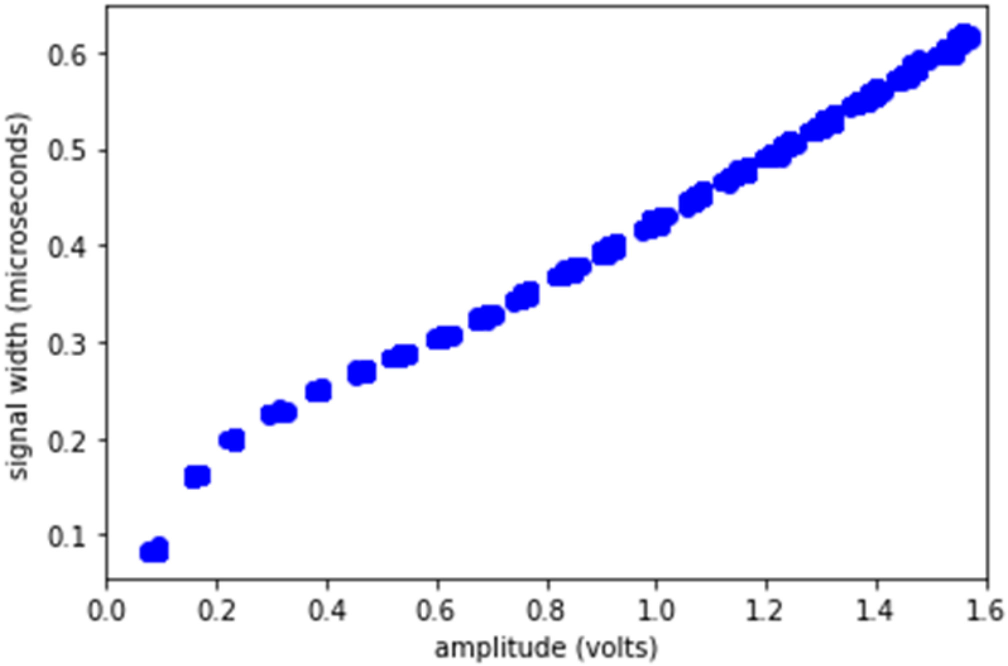
Glue between fibers:

Between different layers: ~0.1 mm

Between Fiber in the same layer: ~0.01 mm

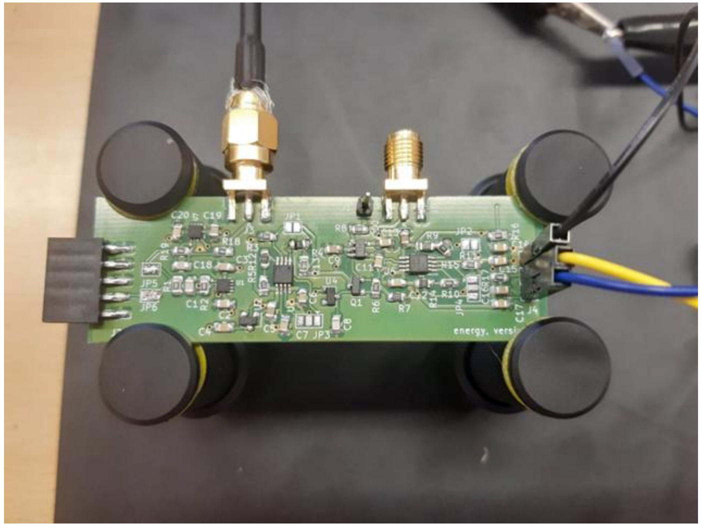


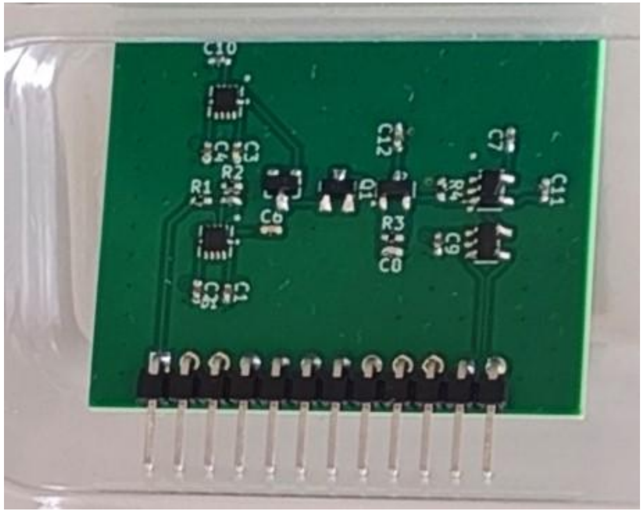
Energy determination



Output signal width vs input signal amplitude

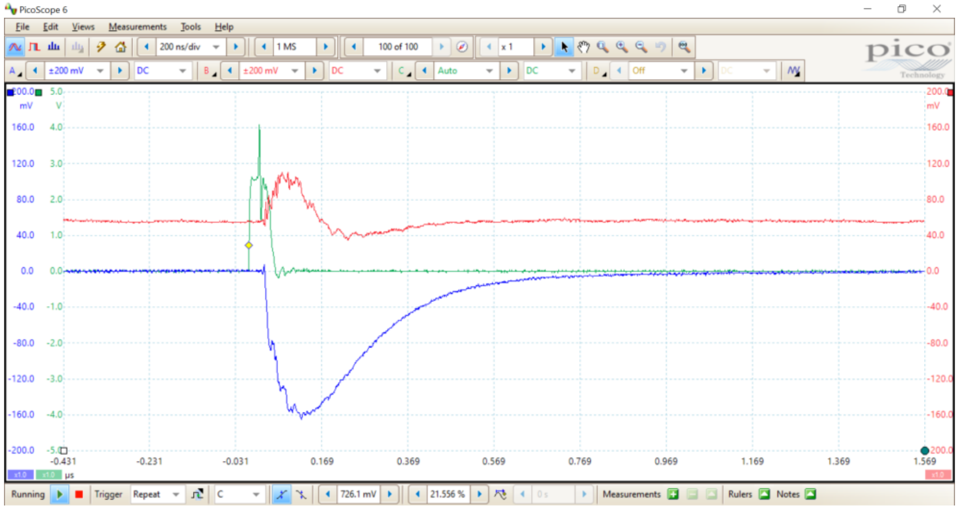
- Amplitude range of input signal: from 50 mV to 2.5 V

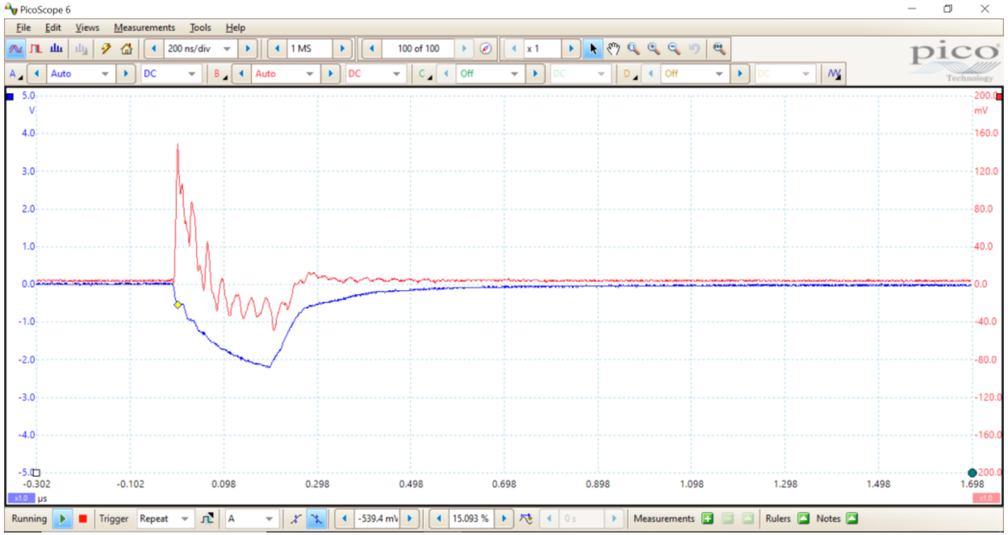




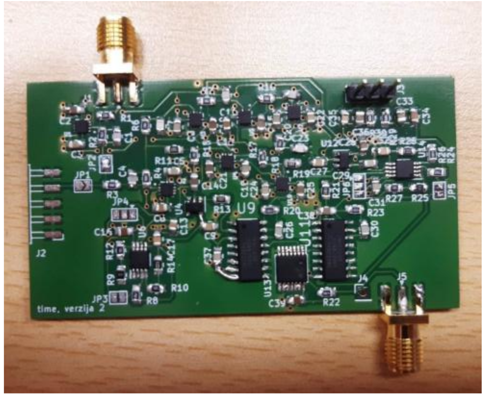
Timing test

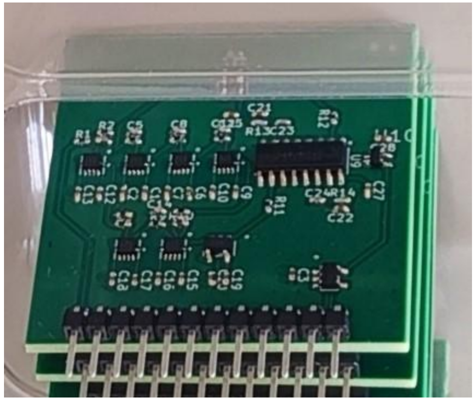
- At large amplification, signals are less steep which results in worse time resolution.

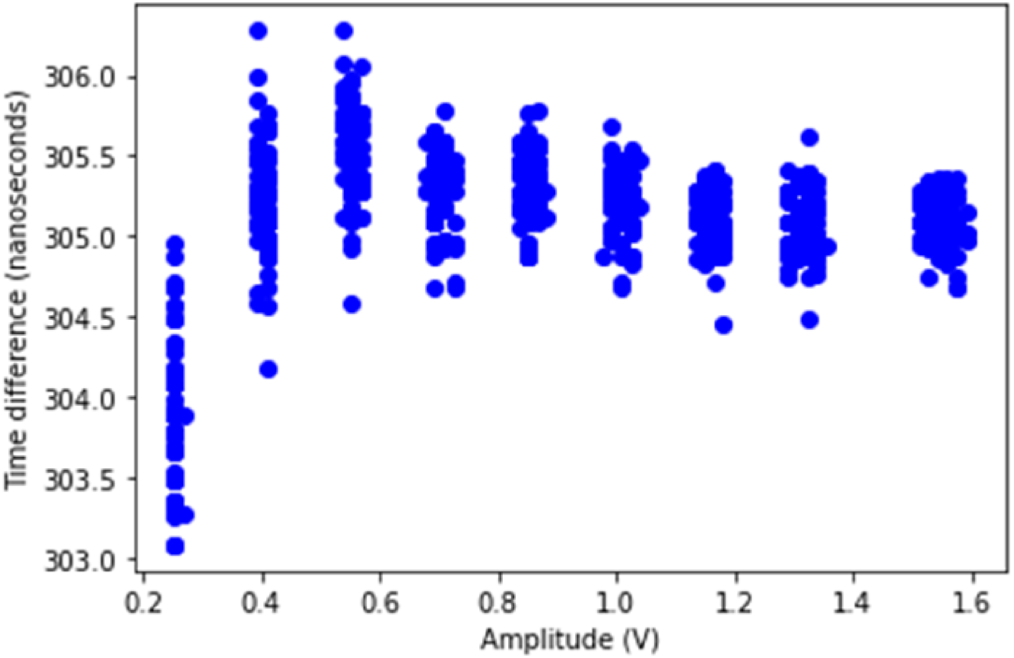




Timing determination: CFD



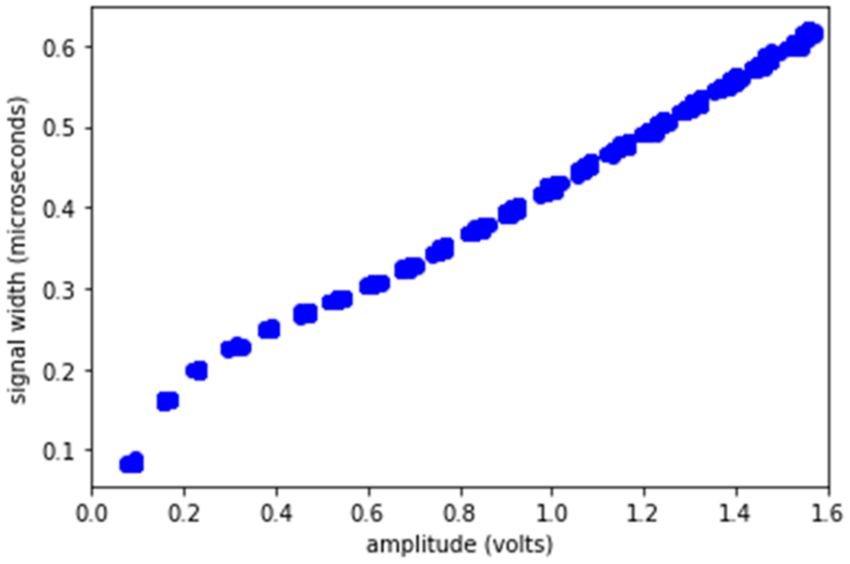




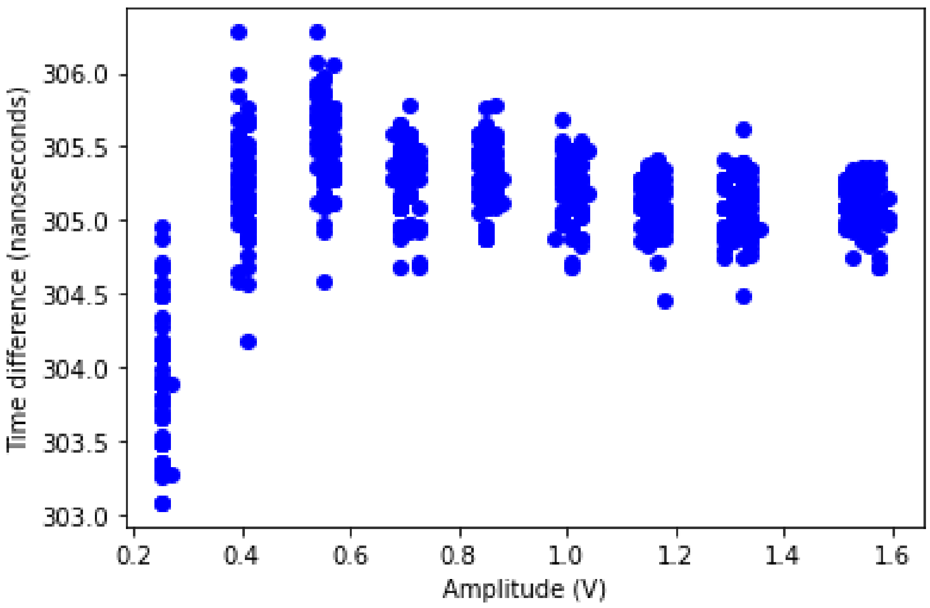
- Timing resolution: around 1 ns at large amplitudes

LED-based testing

ToT vs. brightness

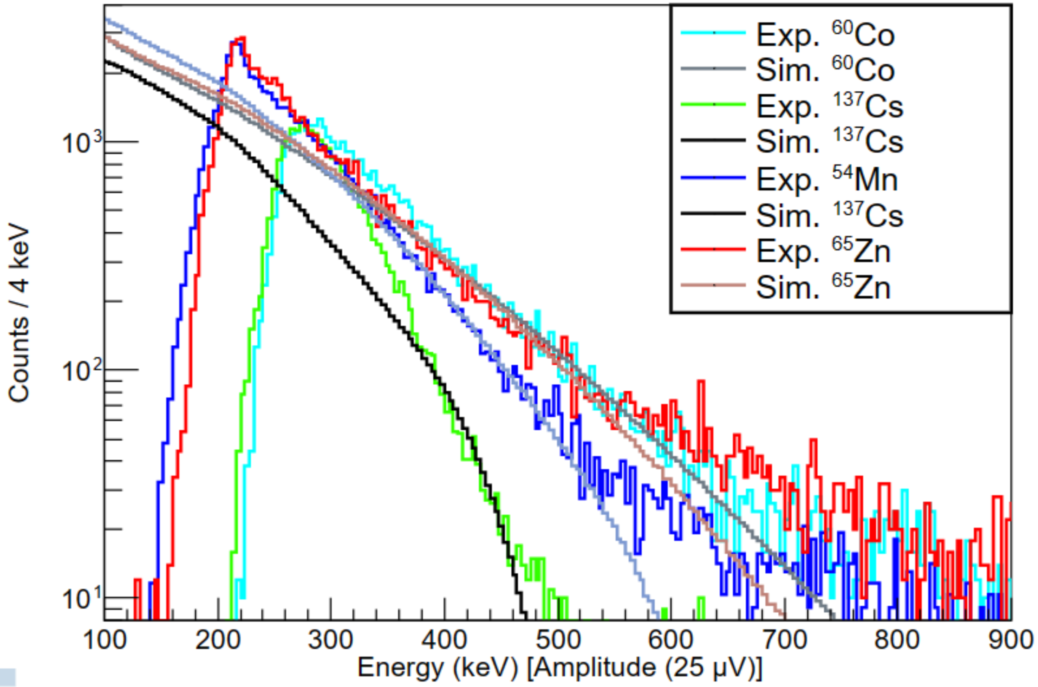


Time walk vs. brightness



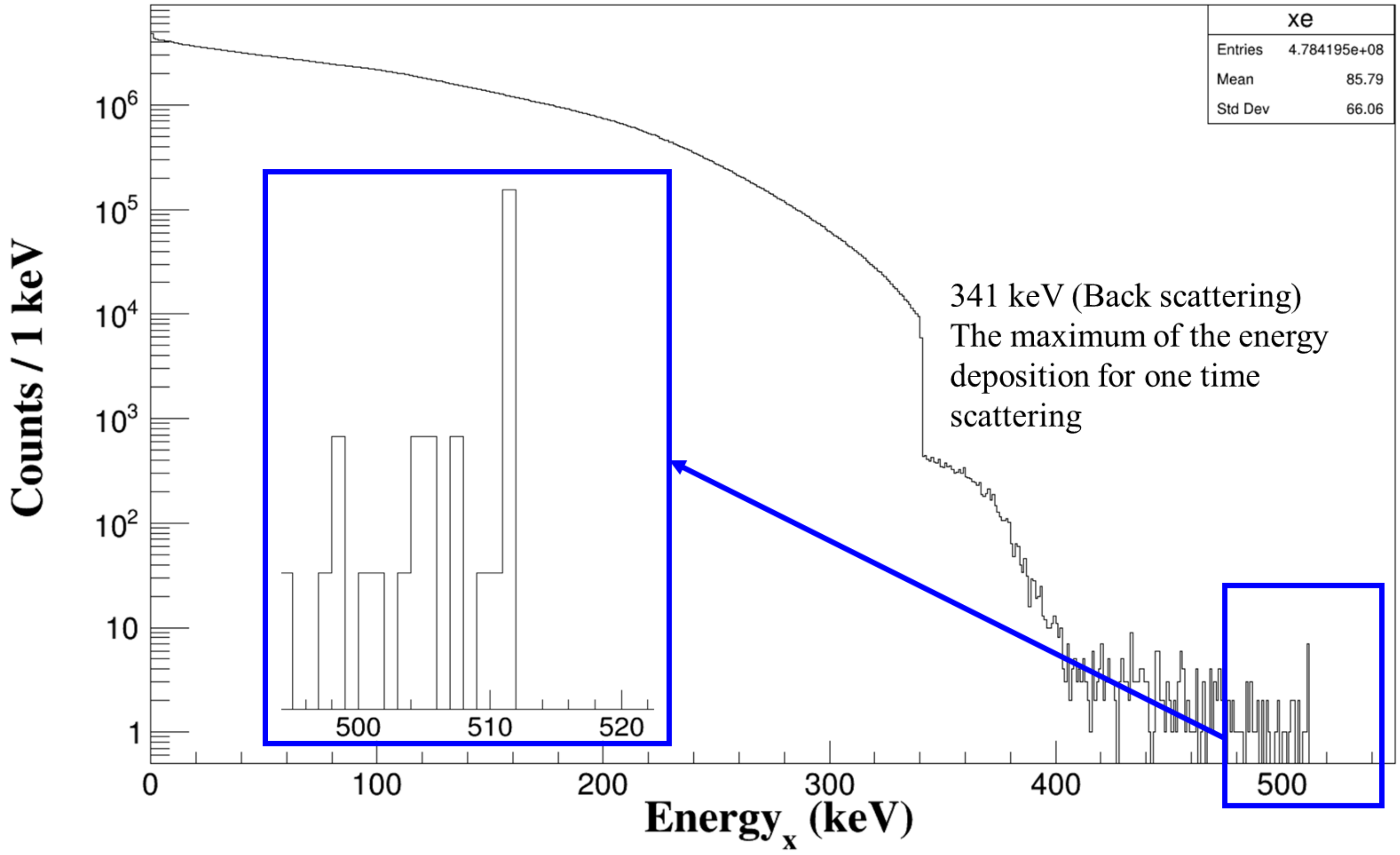
Time resolution about 1 ns

^{137}Cs, ^{60}Co , ^{54}Mn and ^{65}Zn source tests



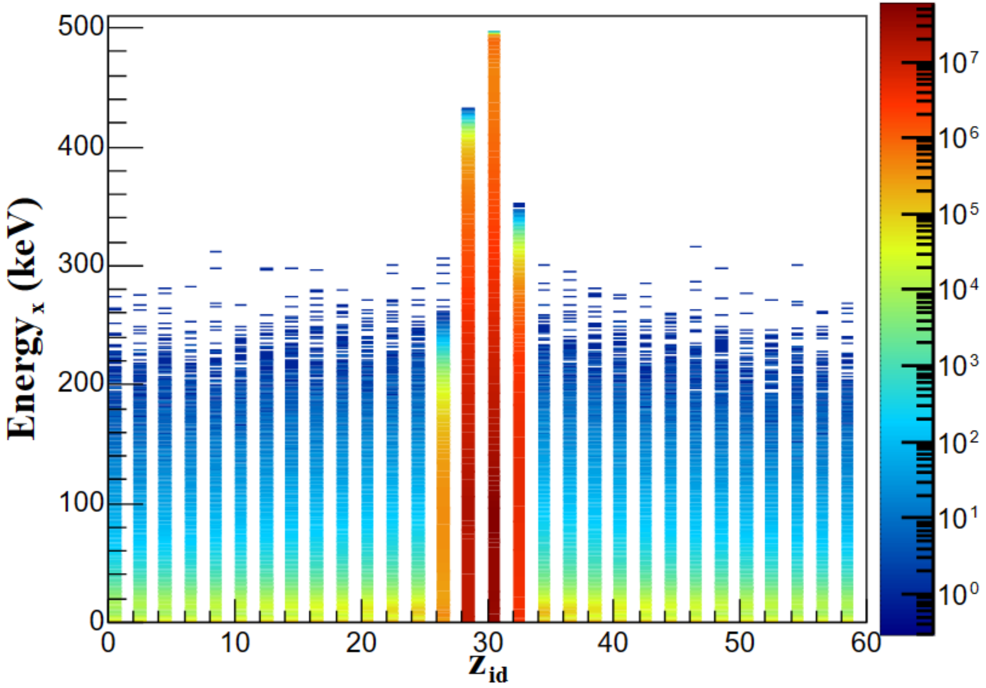
- The simulation and experimental spectra agreed excellently.

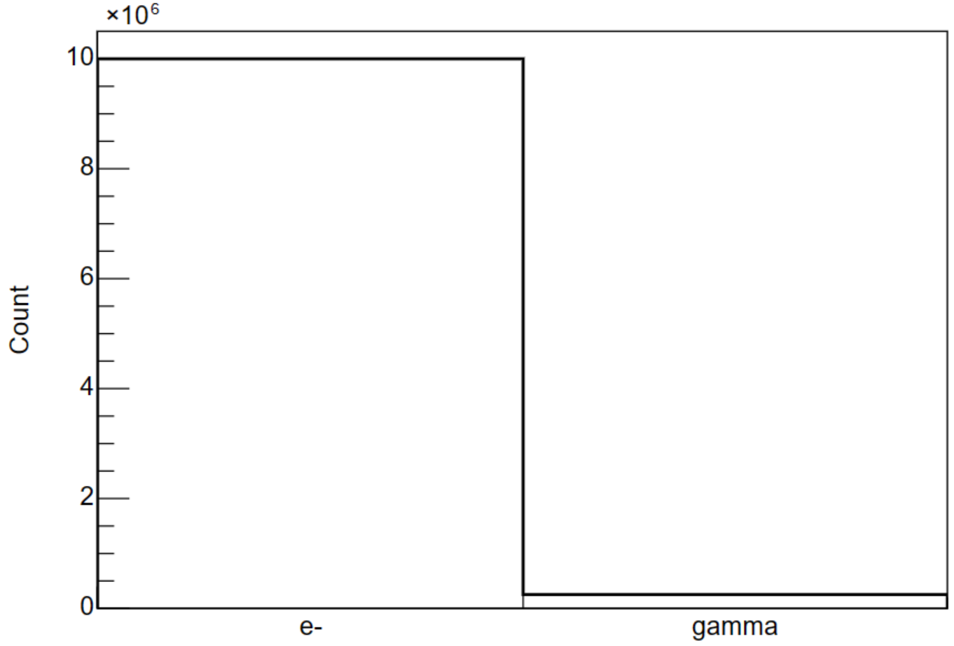
Isotropic 511 keV γ rays: Fiber



Courtesy of H. Hao

Isotropic 500 keV electron source

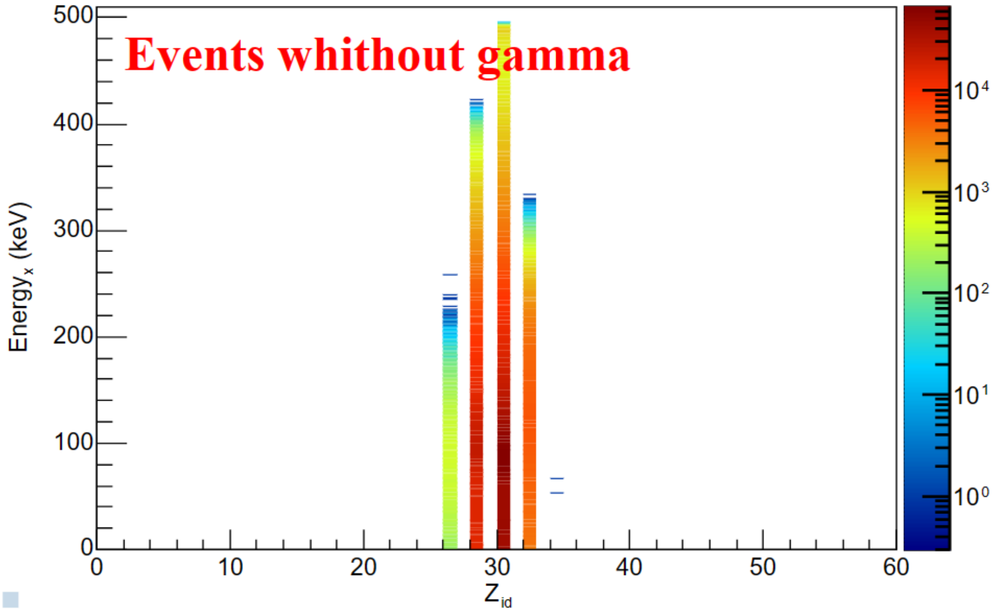


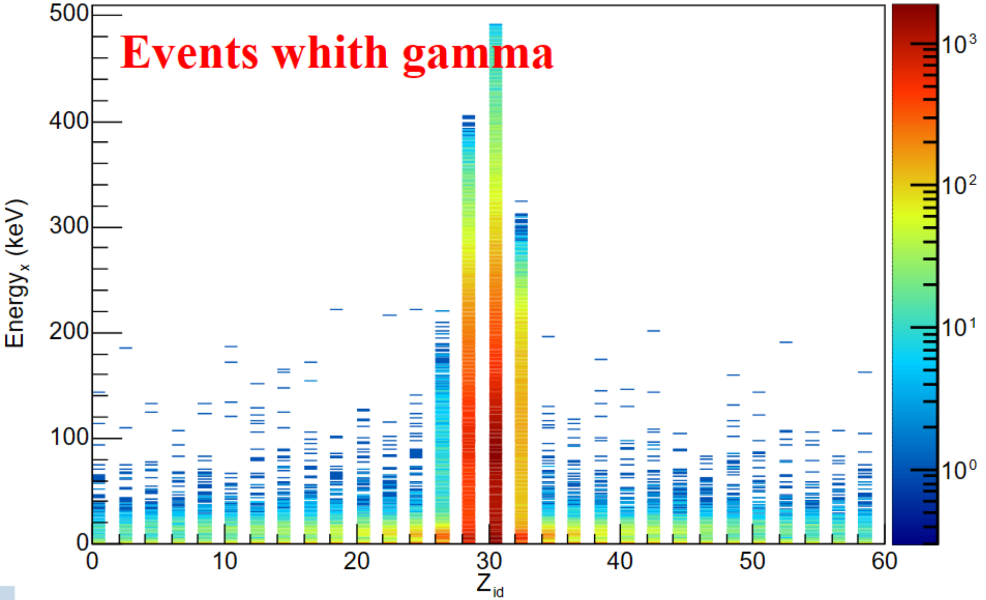


- Most energy depositions in deeper layers are lower than 10 keV
- There are a few events with the energy deposition higher than 100 keV, even 200 keV in deeper layers.
- Some gamma particles were produced: bremsstrahlung

Courtesy of H. Hao

Isotropic 500 keV electron

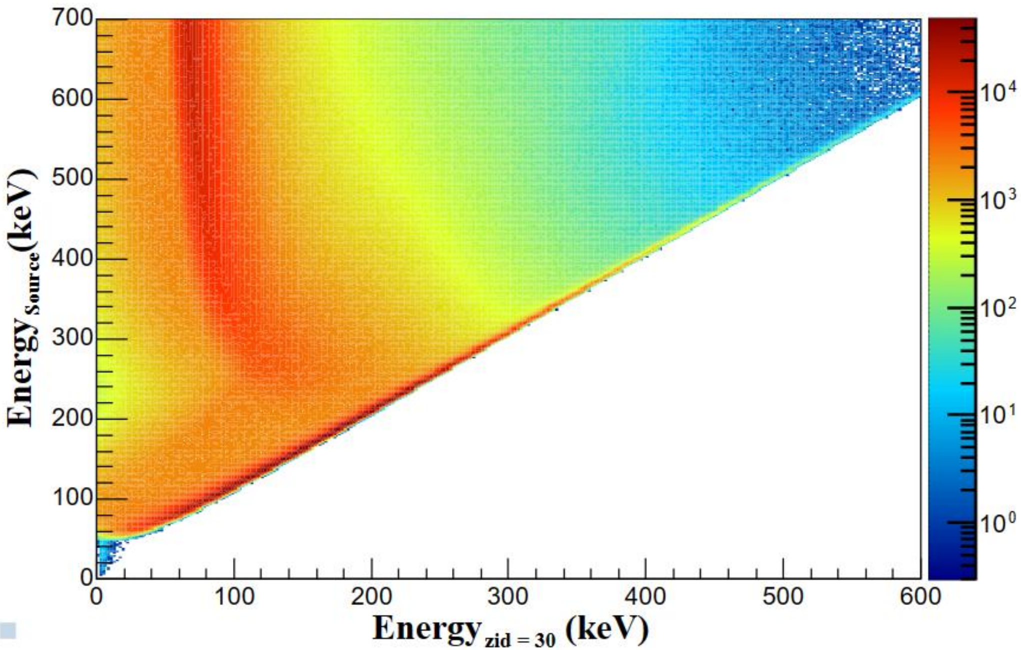


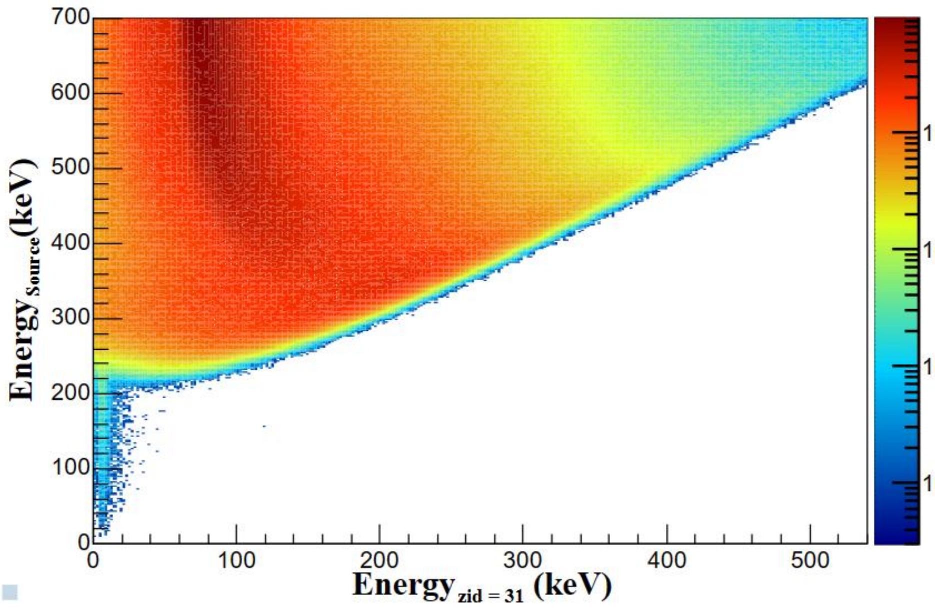


- The energy deposition in the deeper layer can be attributed to the secondary gamma rays.
- The probability for this kind of event is 2.6%;
- The probability for this kind of event with the energy deposition in deeper layer (Z_{id} < 24 || Z_{id} > 34) higher than 5 keV is 0.13 %.

Courtesy of H. Hao

0-3 MeV electron

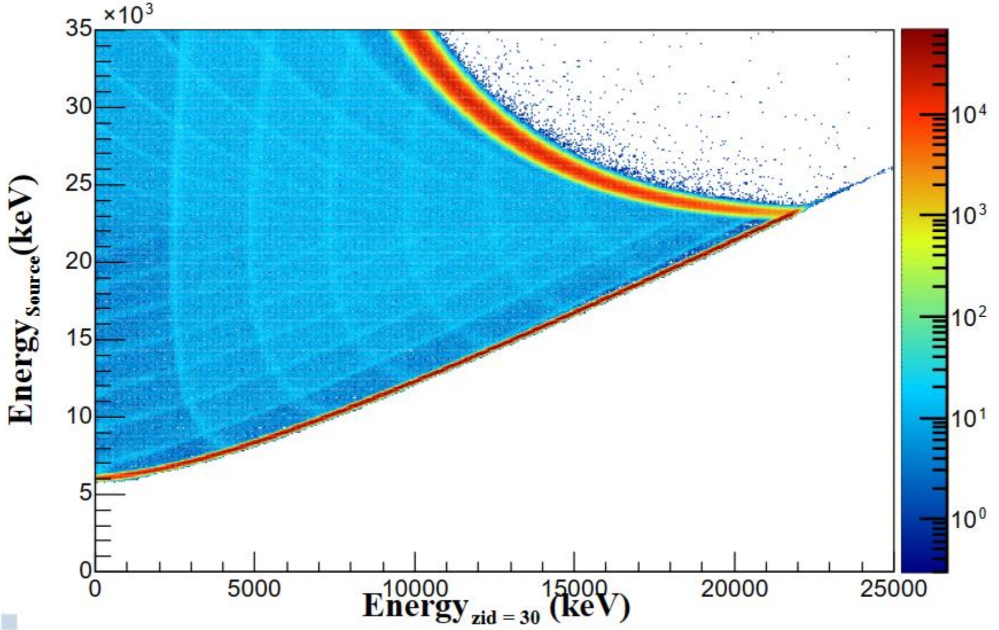


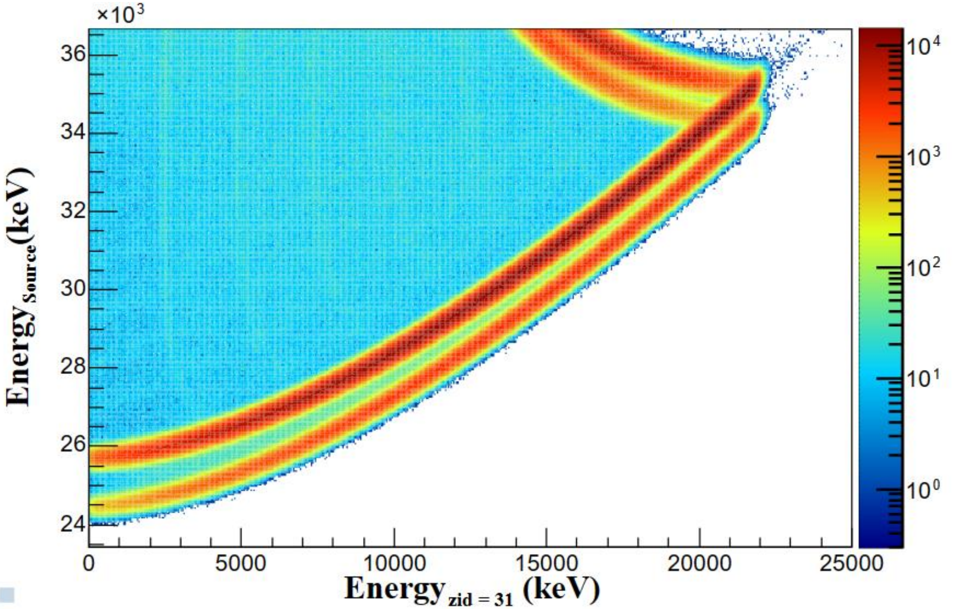


- Only the beta particles with energy higher than 50 keV can be detected with FIMP.
- Only for the beta particles with energy higher than 230 keV, precise positions can be obtained.

Courtesy of H. Hao

The Fiber IMPlanter Detector (0 -100 MeV α)

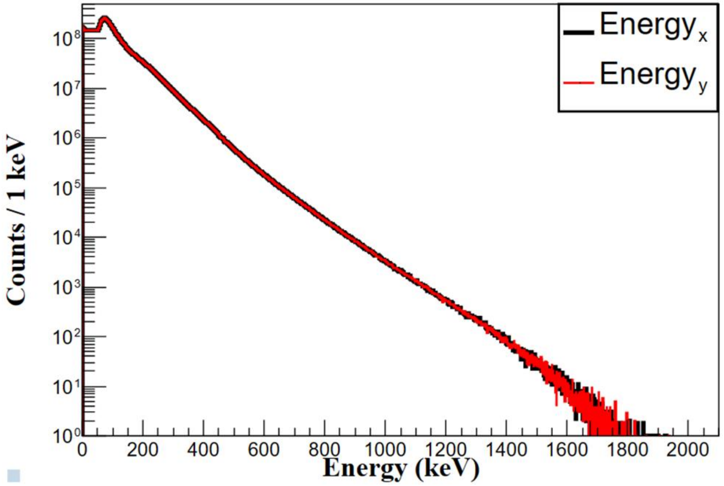


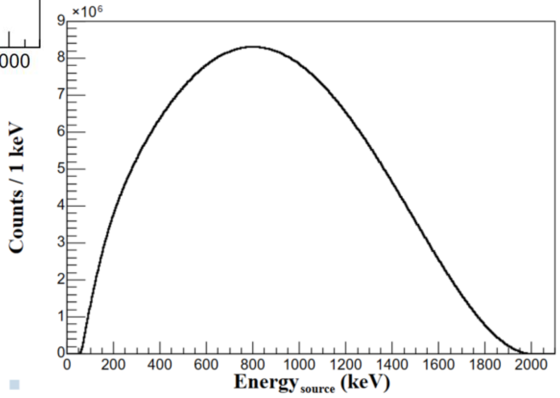


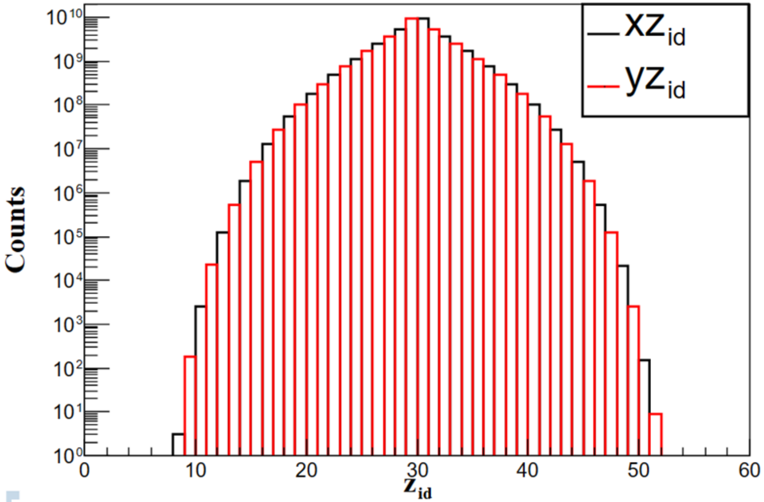
- Only the alpha particle with energy higher than 6 MeV can be detected with FIMP; 17 MeV energy will be deposited in the first layer.
- Only for the alpha particle with energy higher than 25.5 MeV, we can get their precise positions.

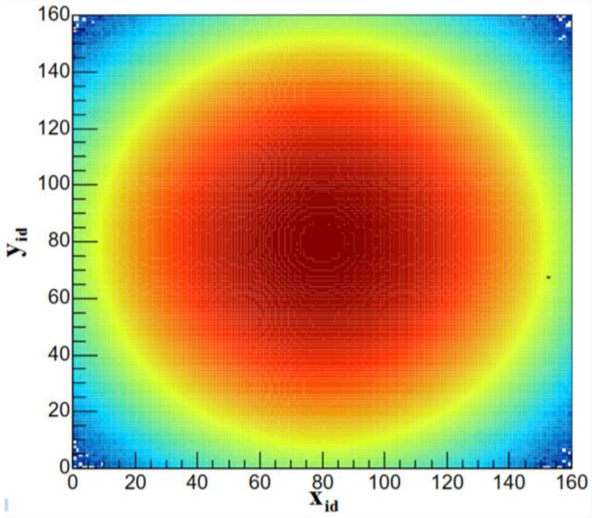
Courtesy of H. Hao

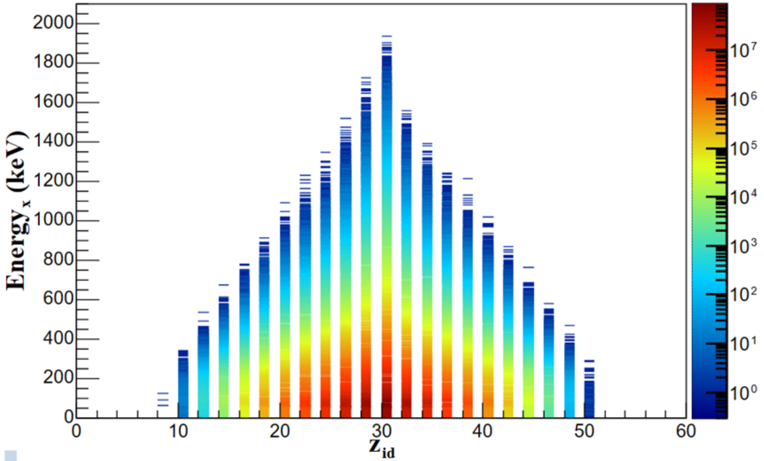
2 MeV Beta Decay





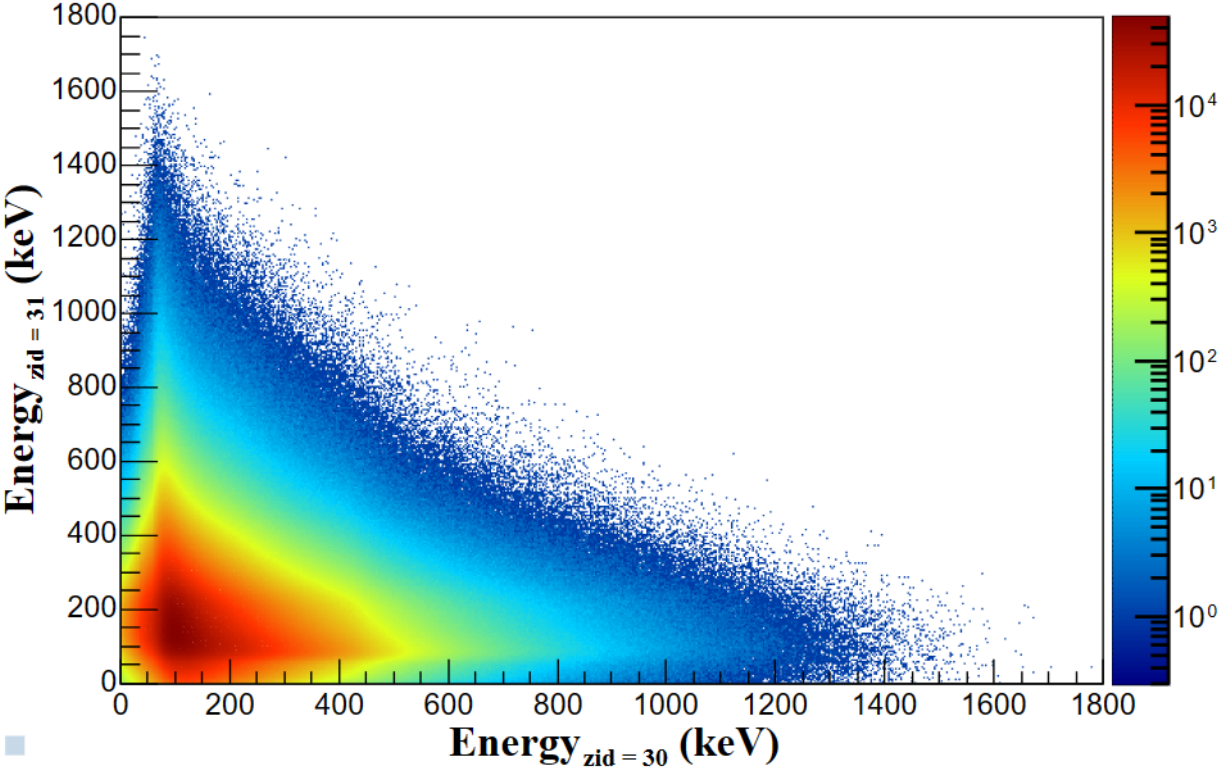


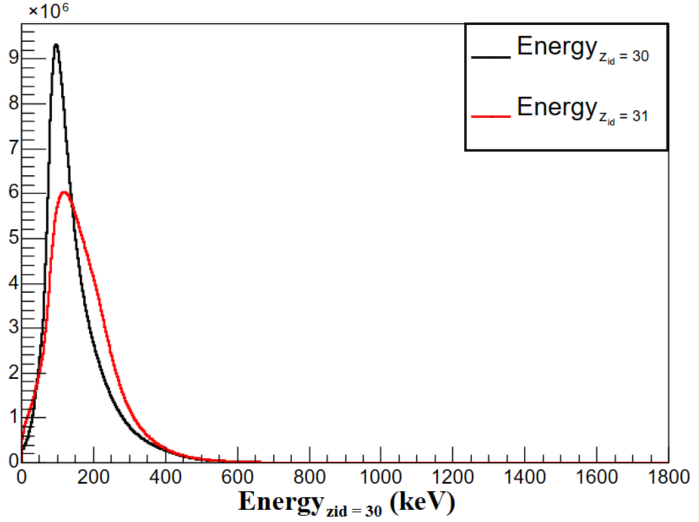


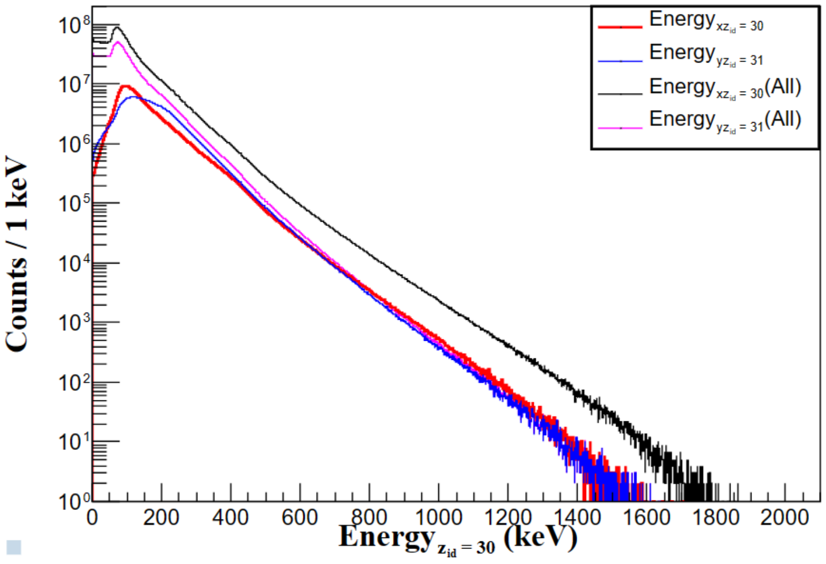


Courtesy of H. Hao

2 MeV Beta Decay

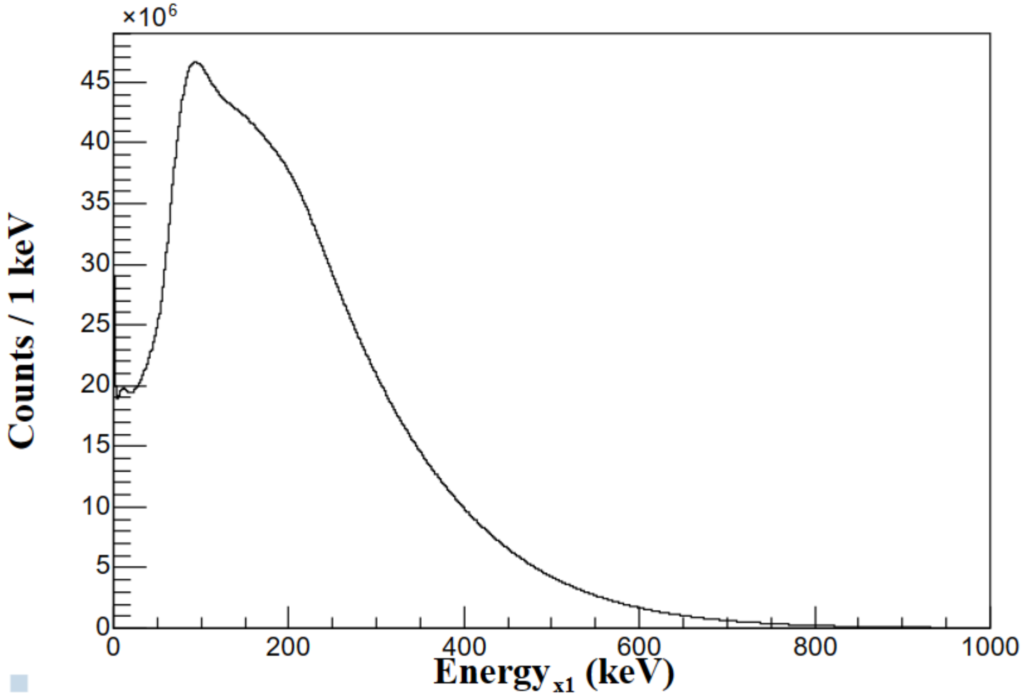


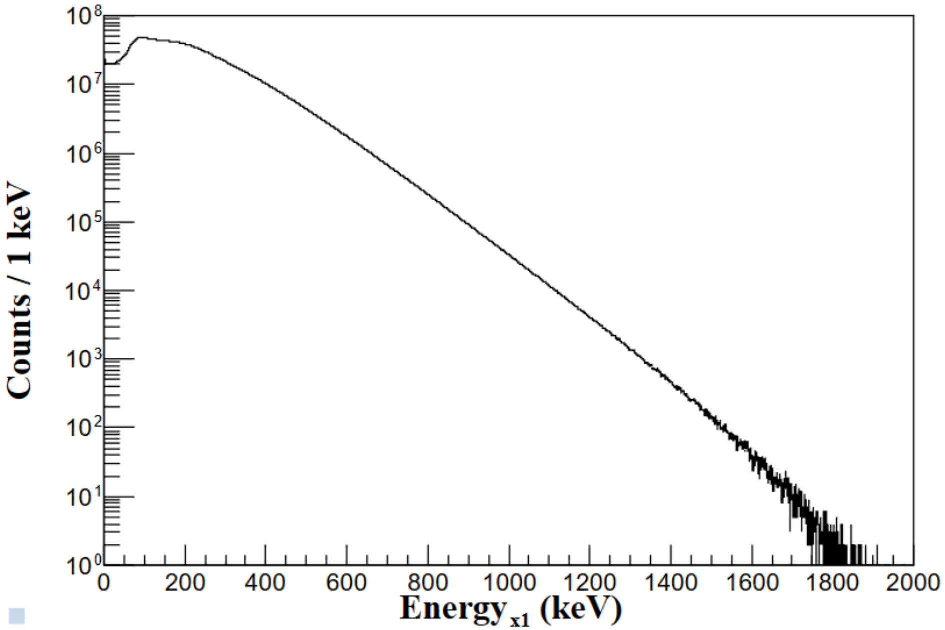




Courtesy of H. Hao

2 MeV Beta Decay: SiPM

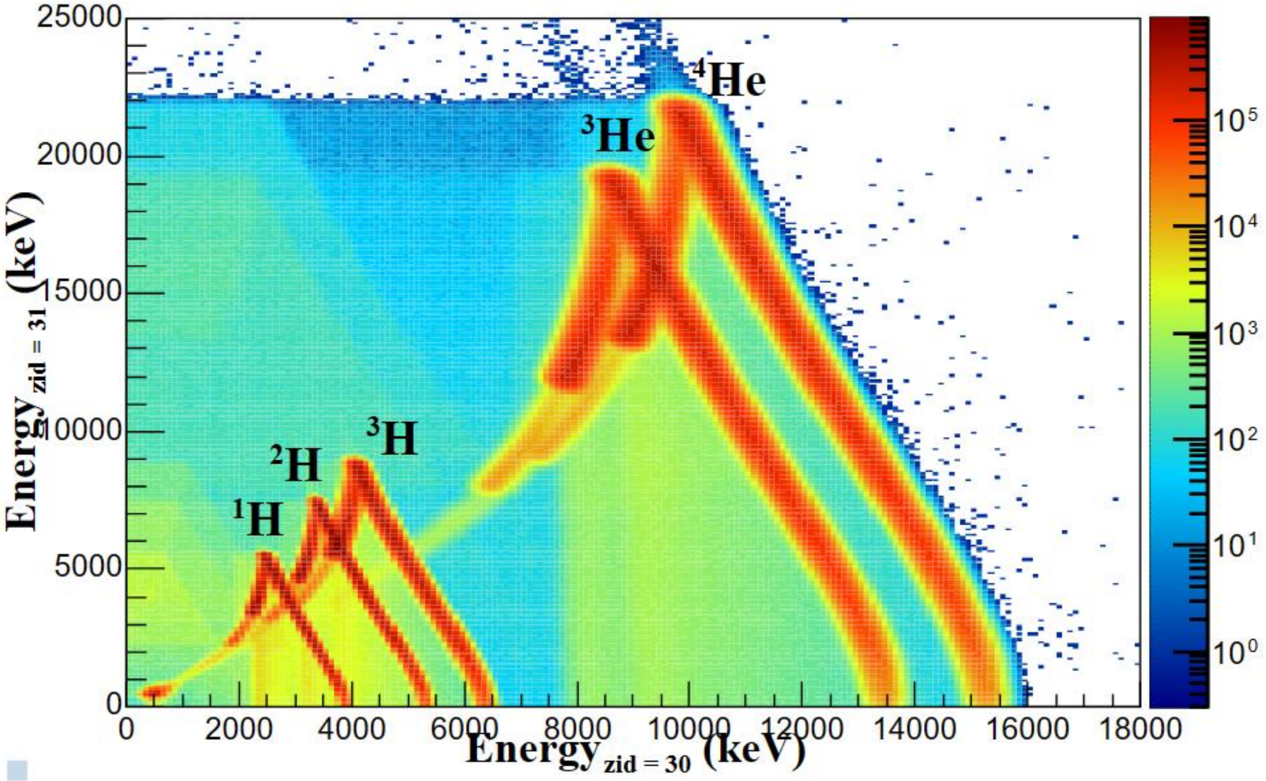




Energy spectrum from SiPM with resolution of 10 % (FWHM).

Courtesy of H. Hao

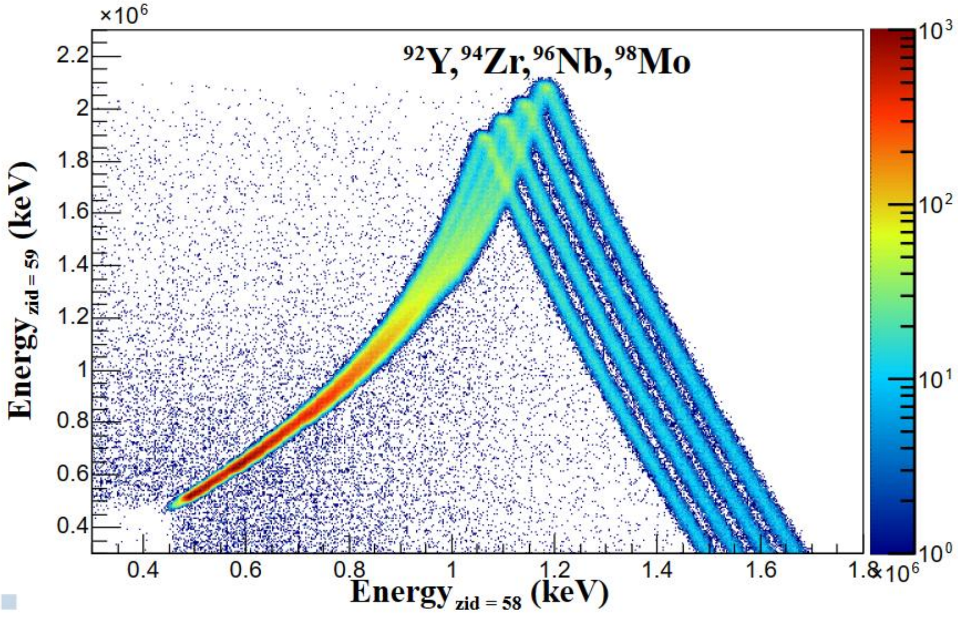
0-100 MeV p, H_2, H_3, He_3, He_4

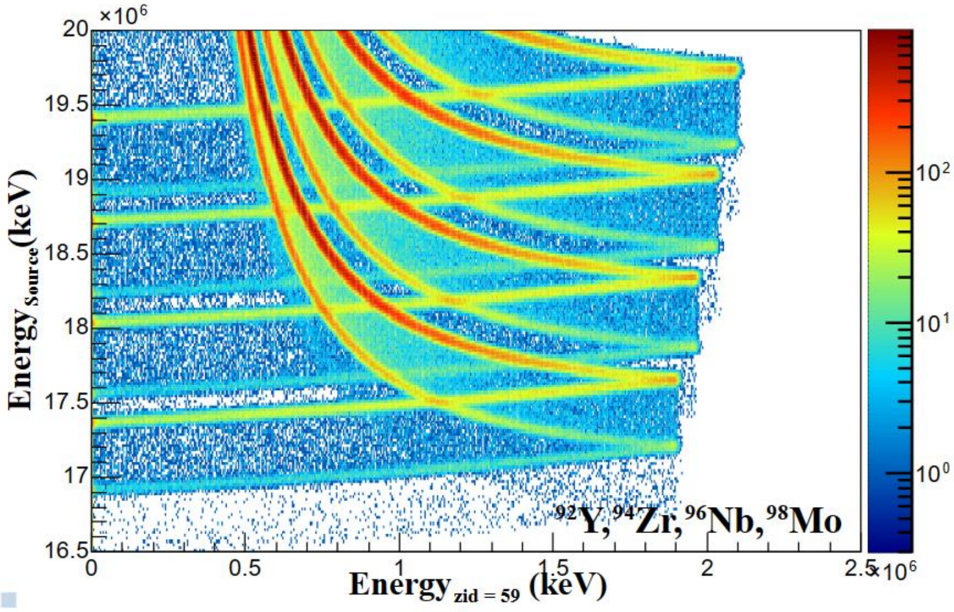


- PID by using two layers.

Courtesy of H. Hao

0-20 GeV ^{92}Y, ^{94}Zr,^{96}Nb,^{98}Mo

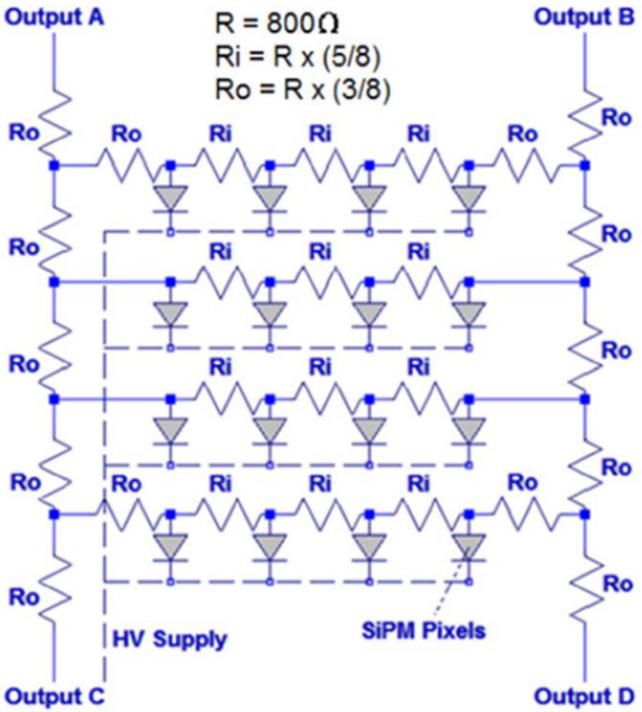


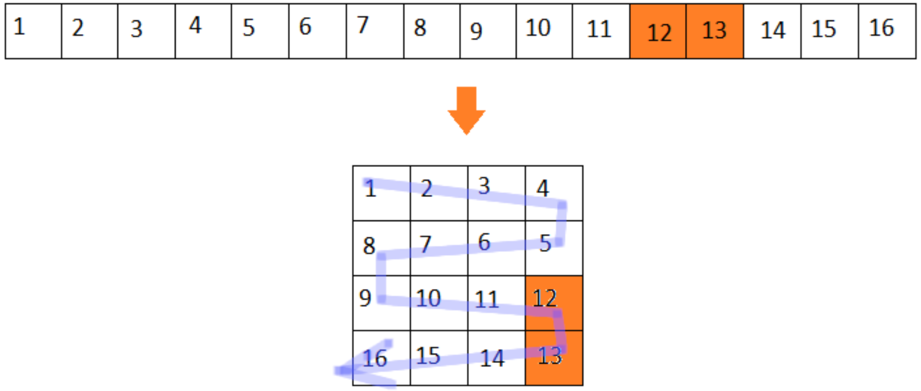


- Only the nuclei with the kinetic energy lower than ~200 MeV/u and stopped in the last layer (Zid = 59) can be identified.
- The different "bands" for each nucleus are due to the nuclei passing through the scintillators and claddings (different stopping powers).

Courtesy of H. Hao

Multiplexing



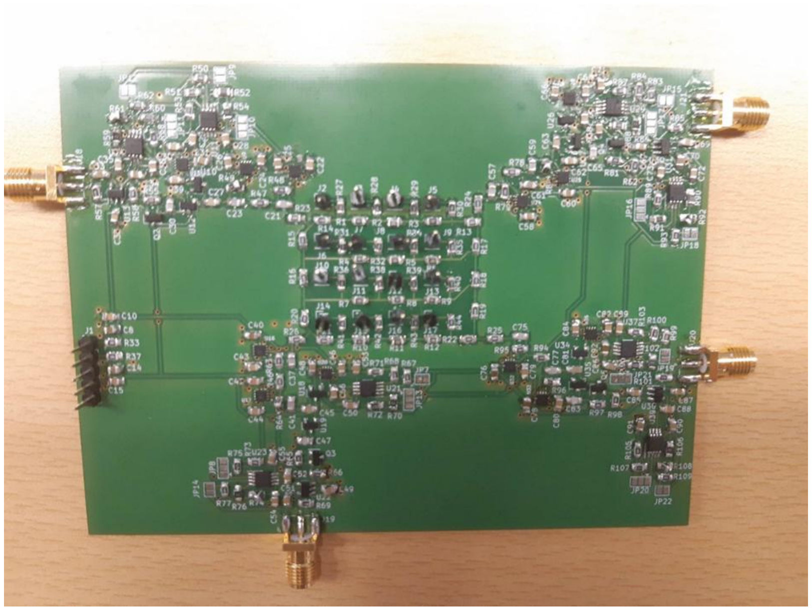


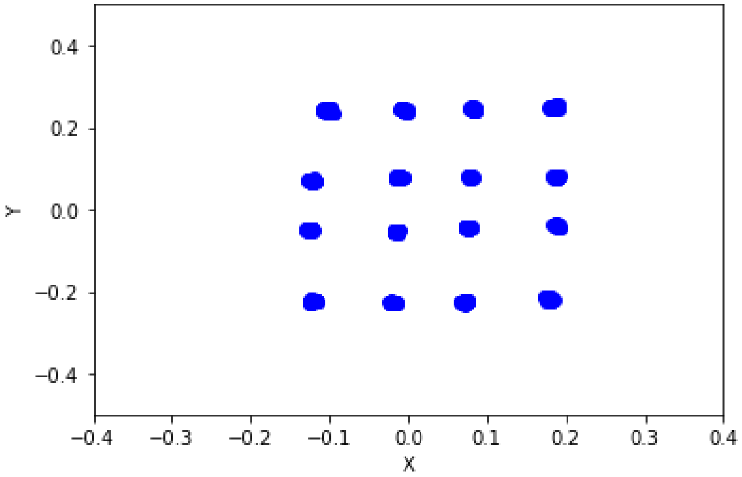
Position of the particle can be calculated as:

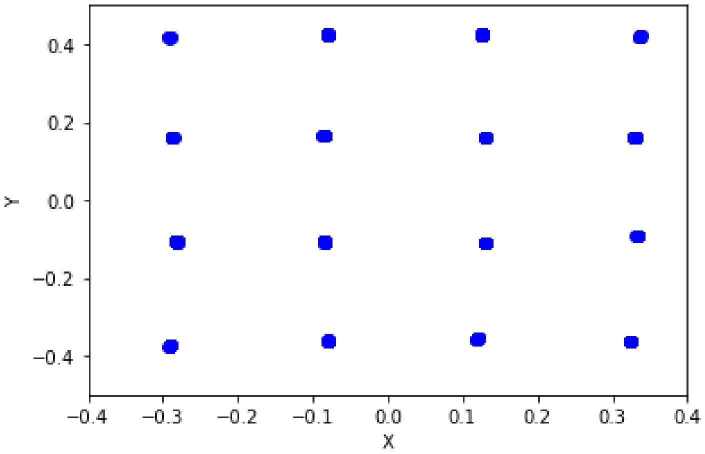
$$X = \frac{B + D}{A + C} \qquad Y = \frac{A + B}{C + D}$$

- Same readout channel for several silicon photomultipliers
- Reducing cost, saving space
- Determining the position of the particle

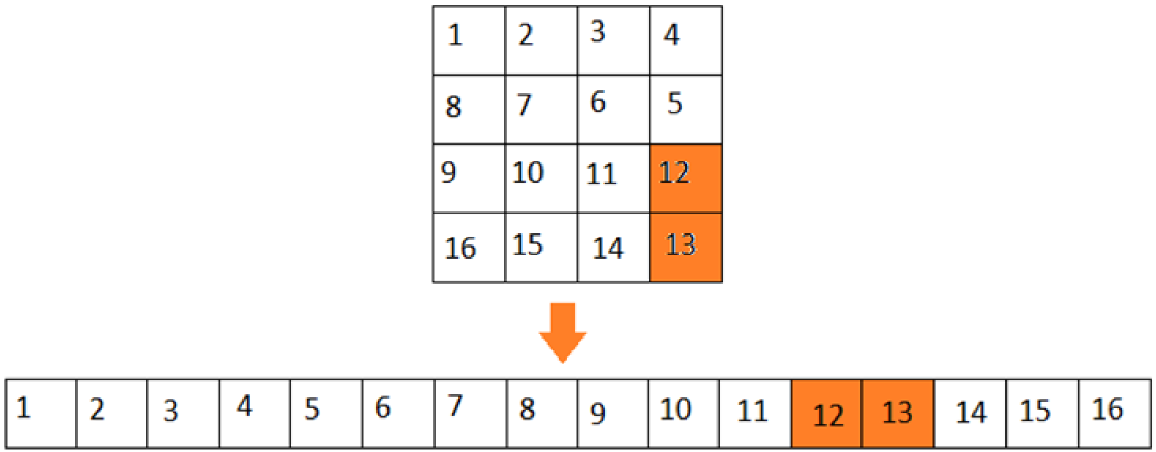
Multiplexing

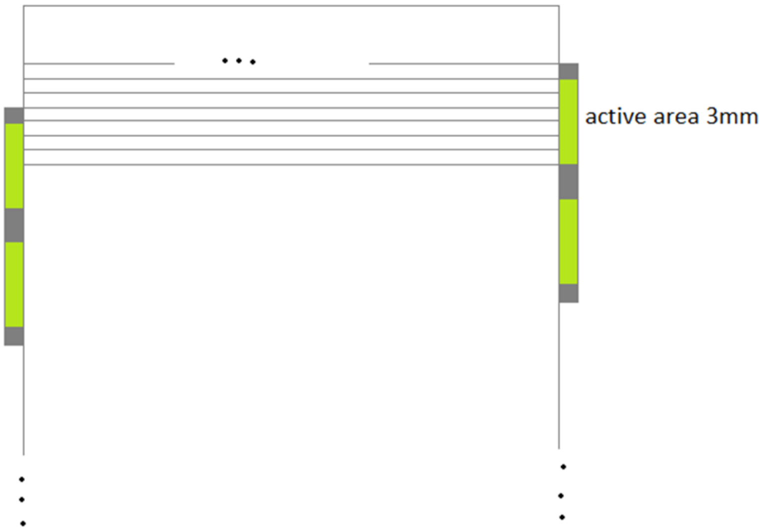




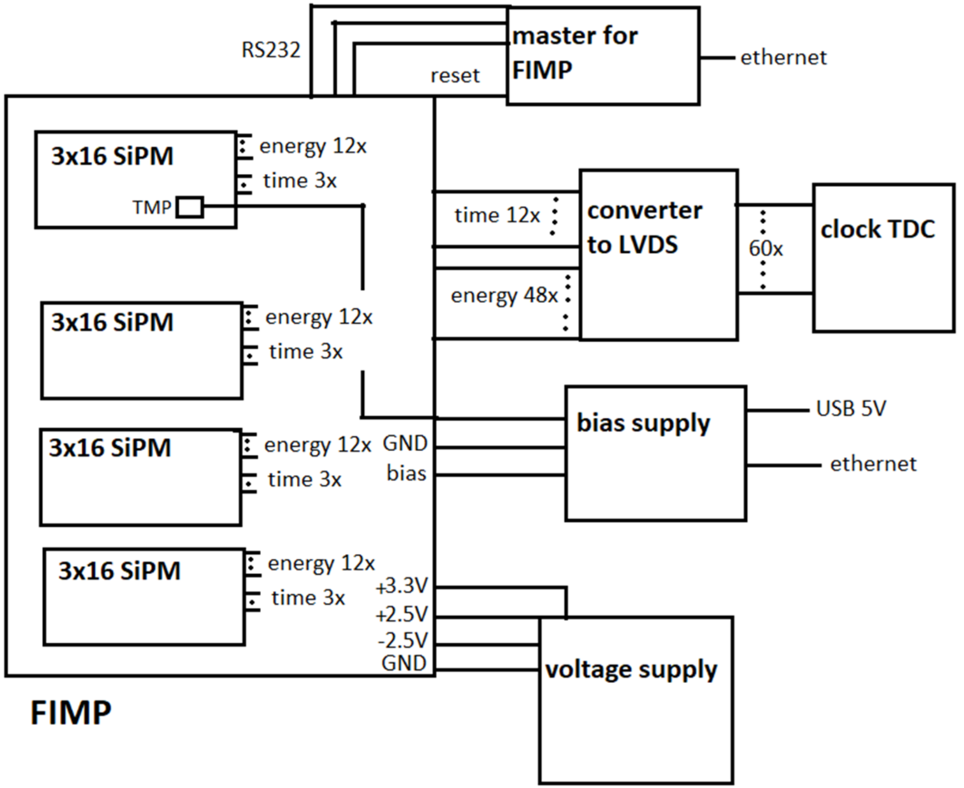


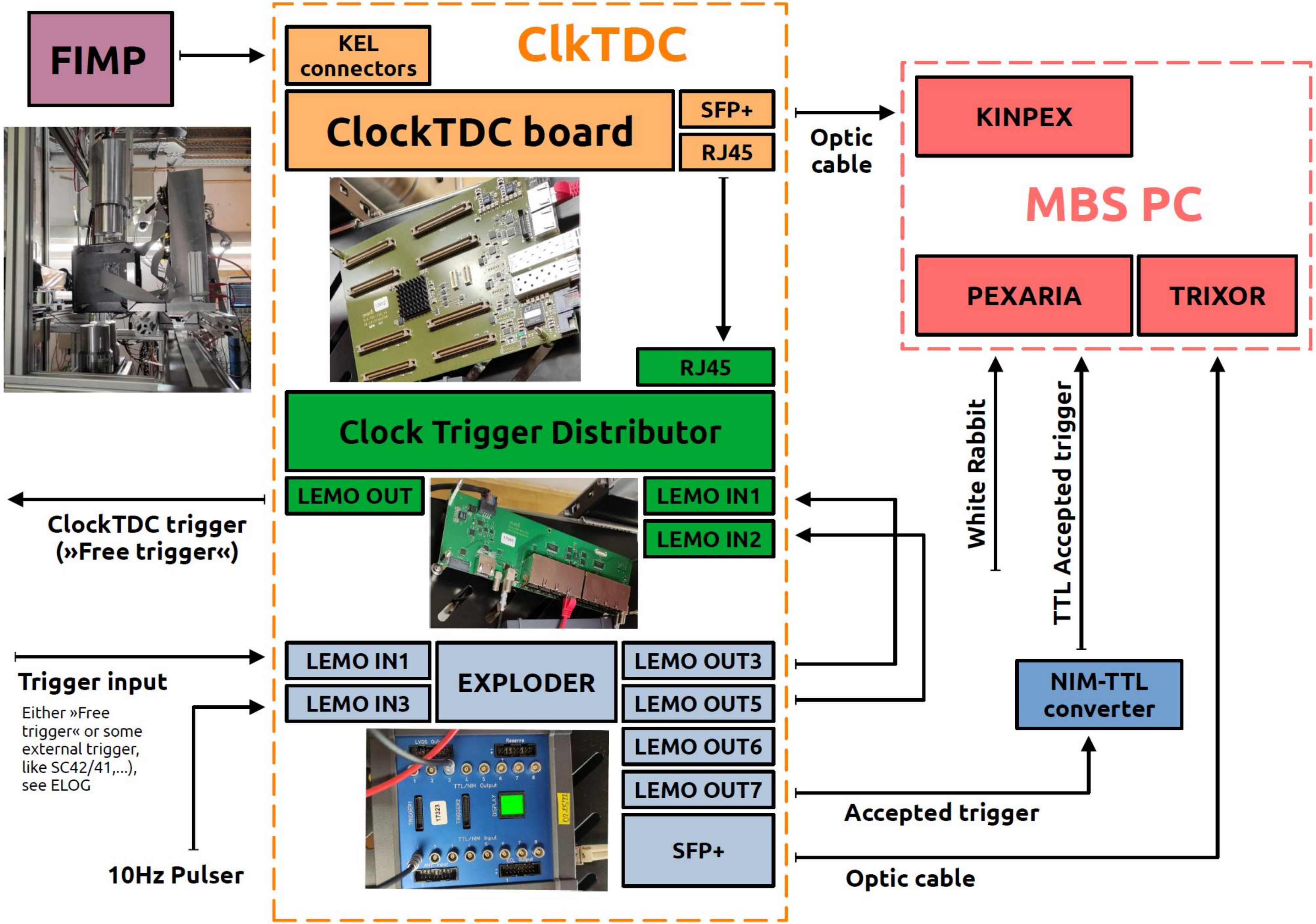
- There are 3 rows on each side of the detector, each with 16 SiPM-s.
- Each row was multiplexed into 4 outputs using a resistive scheme as schematically shown.



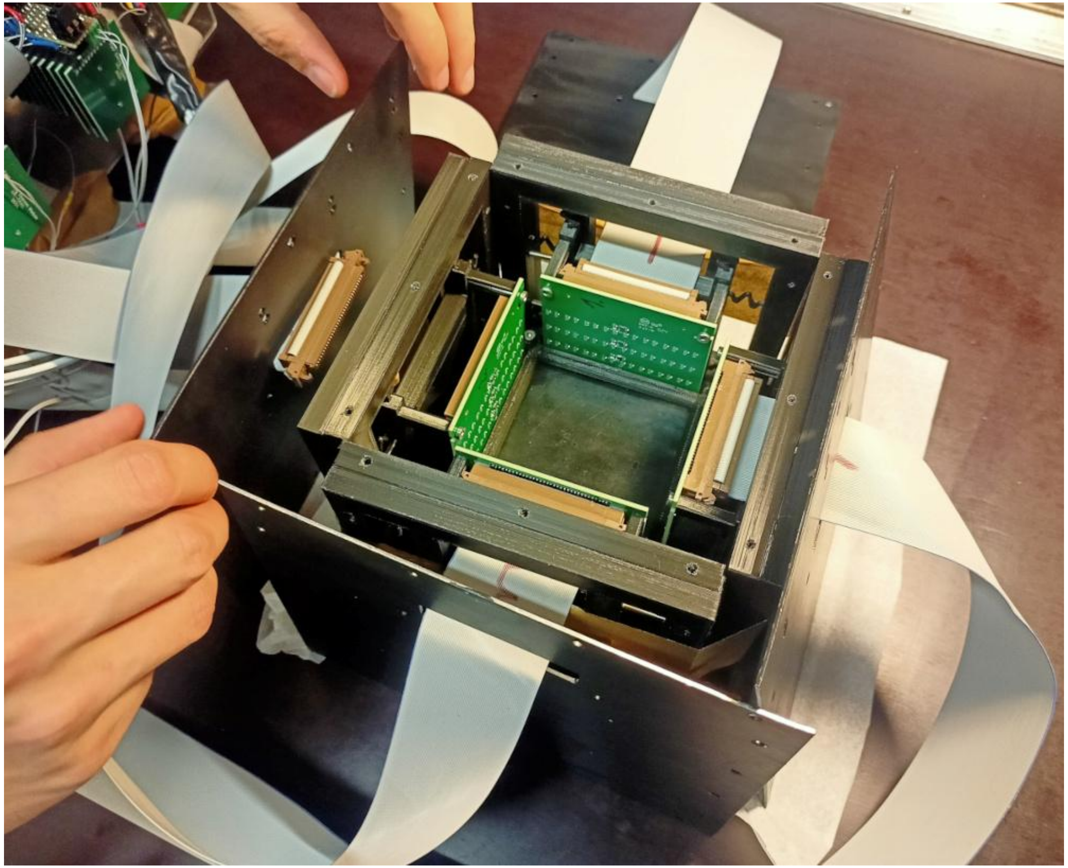


System view

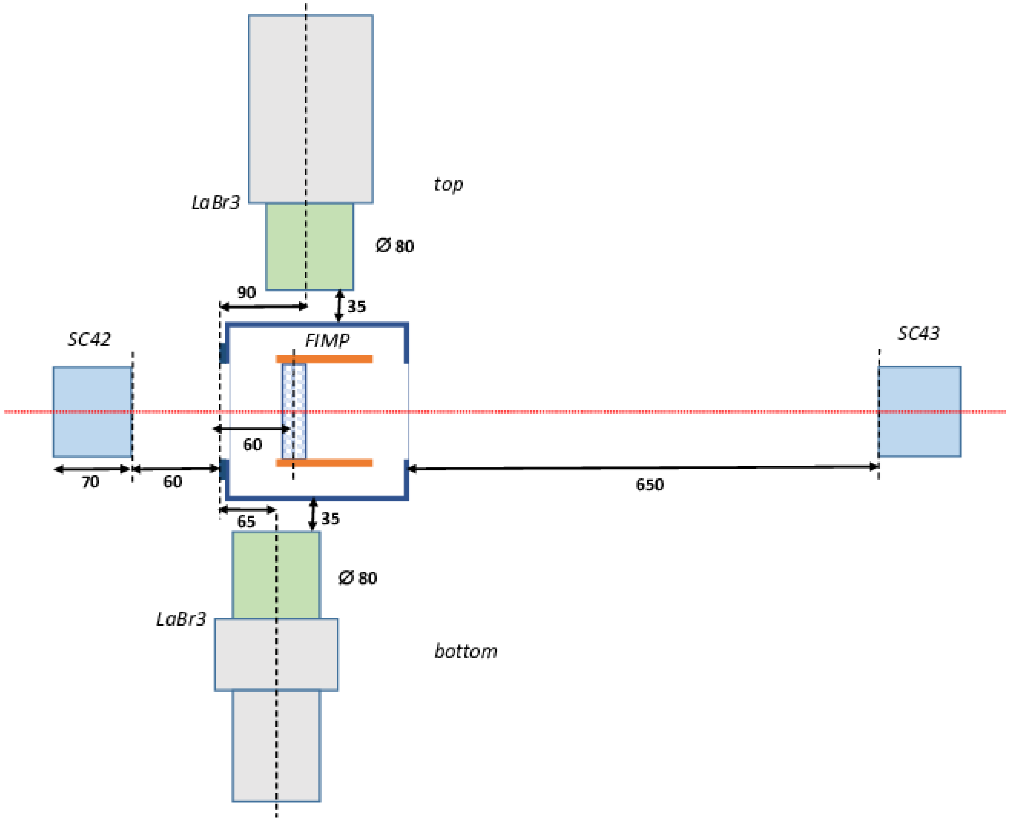

RS232
reset
master for FIMP
ethernet
3x16 SiPM
energy 12x
time 3x
TMP
time 12x
converter to LVDS
60x
clock TDC
energy 48x
3x16 SiPM
energy 12x
time 3x
bias supply
USB 5V
ethernet
3x16 SiPM
energy 12x
time 3x
GND
bias
3x16 SiPM
energy 12x
time 3x
+3.3V
+2.5V
-2.5V
GND
voltage supply
FIMP

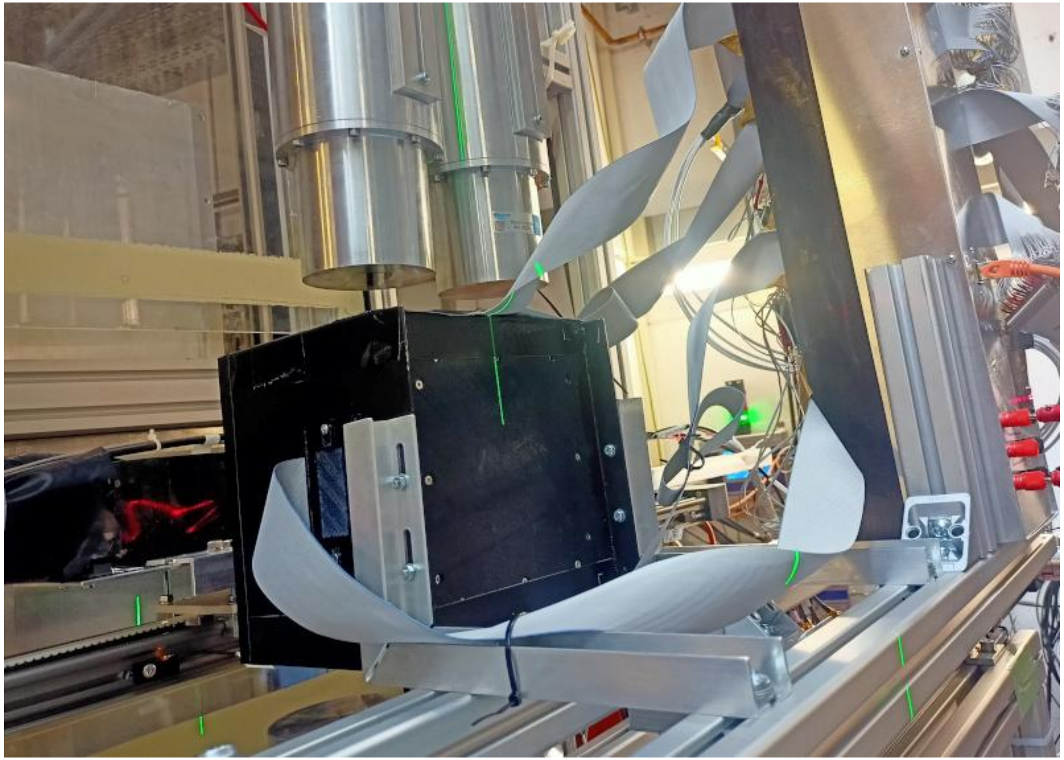

FIMP
ClkTDC
KEL connectors
ClockTDC board
SFP+
RJ45
Optic cable
KINPEX
MBS PC
PEXARIA
TRIXOR
RJ45
Clock Trigger Distributor
LEMO OUT
LEMO IN1
LEMO IN2
ClockTDC trigger
(»Free trigger«)
White Rabbit
TTL Accepted trigger
LEMO IN1
LEMO IN3
EXPLODER
LEMO OUT3
LEMO OUT5
LEMO OUT6
LEMO OUT7
SFP+
Trigger input
Either »Free trigger« or some external trigger, like SC42/41,...), see ELOG
10Hz Pulser
NIM-TTL converter
Accepted trigger
Optic cable

Assembly



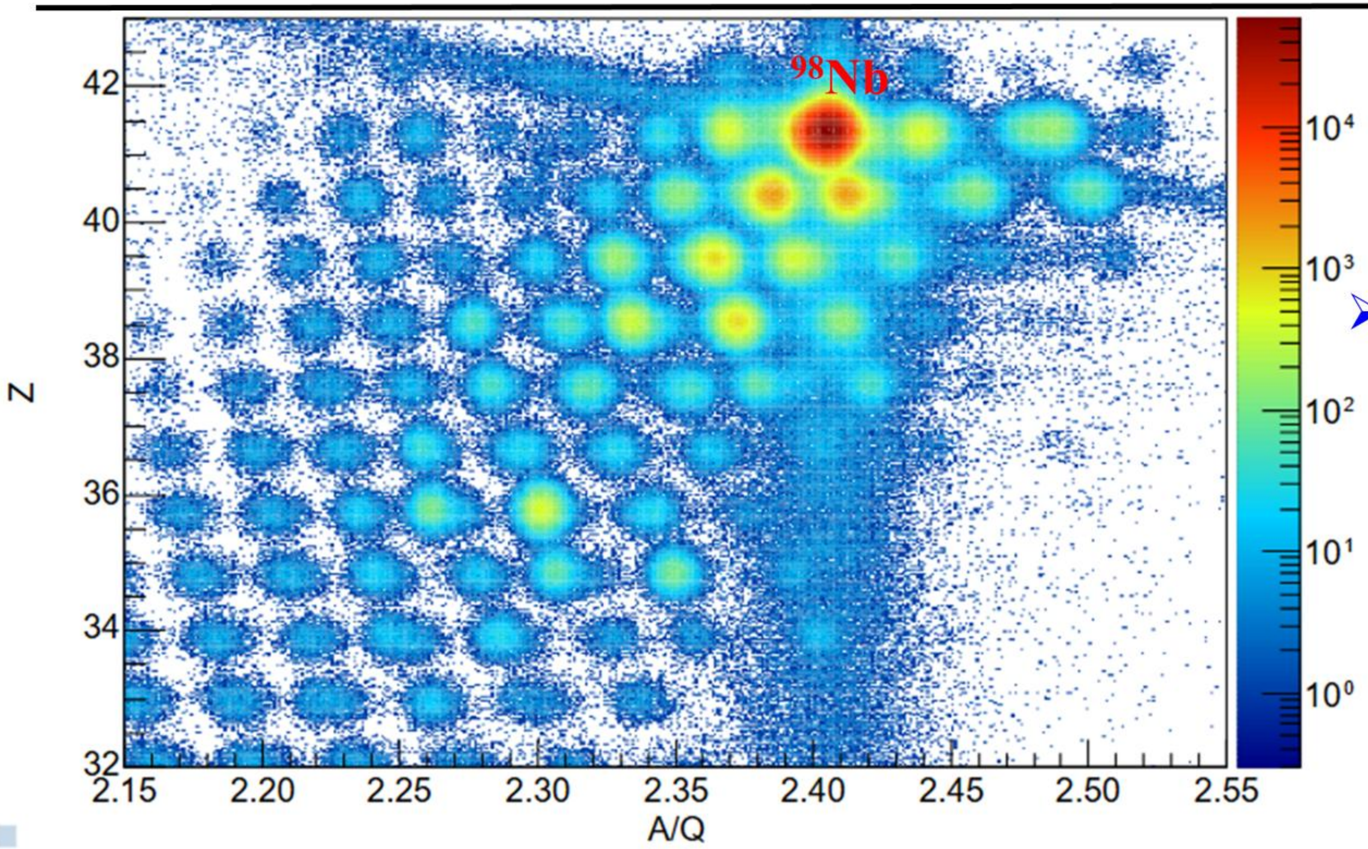
Setup in S4 for G-22-00143/2024





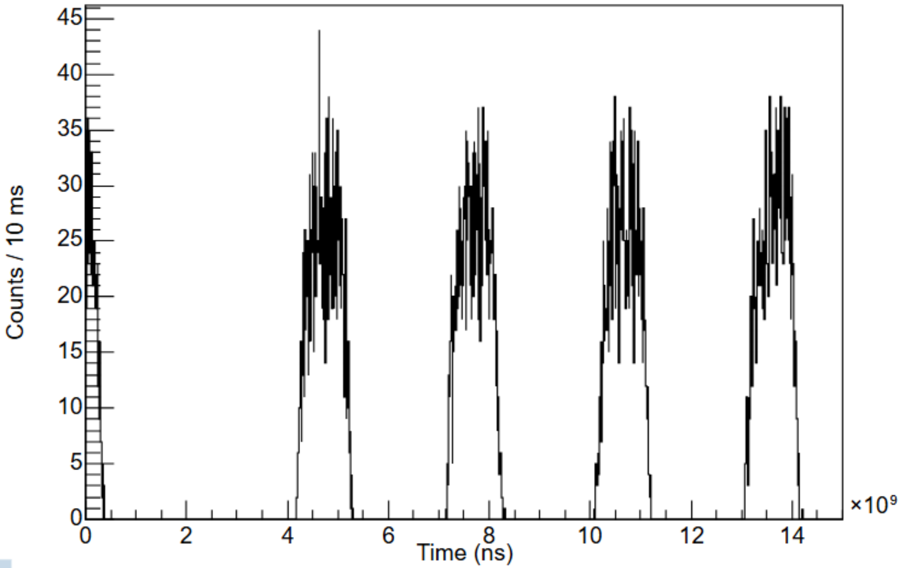
Courtesy of H. Hao

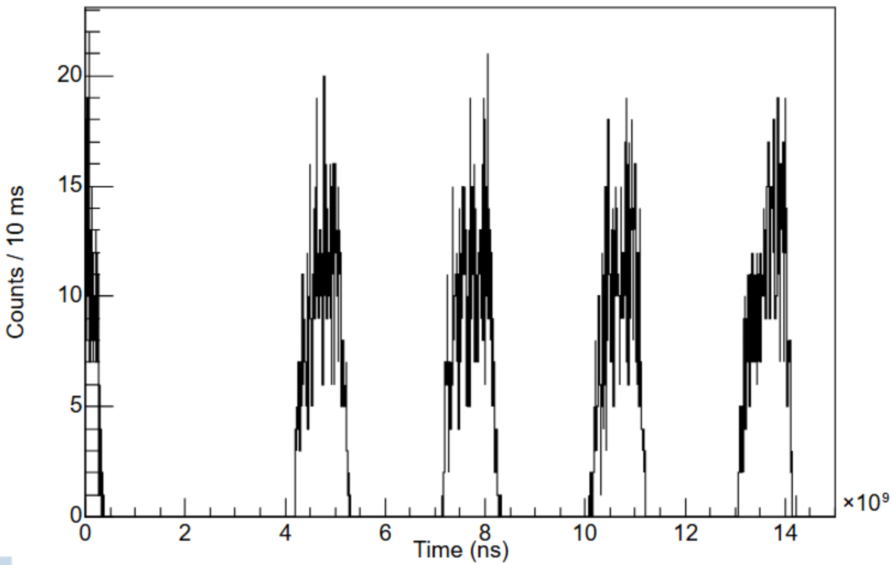
PID



- FWHM
  - Z : 0.17
  - A/Q : 0.01

Courtesy of H. Hao

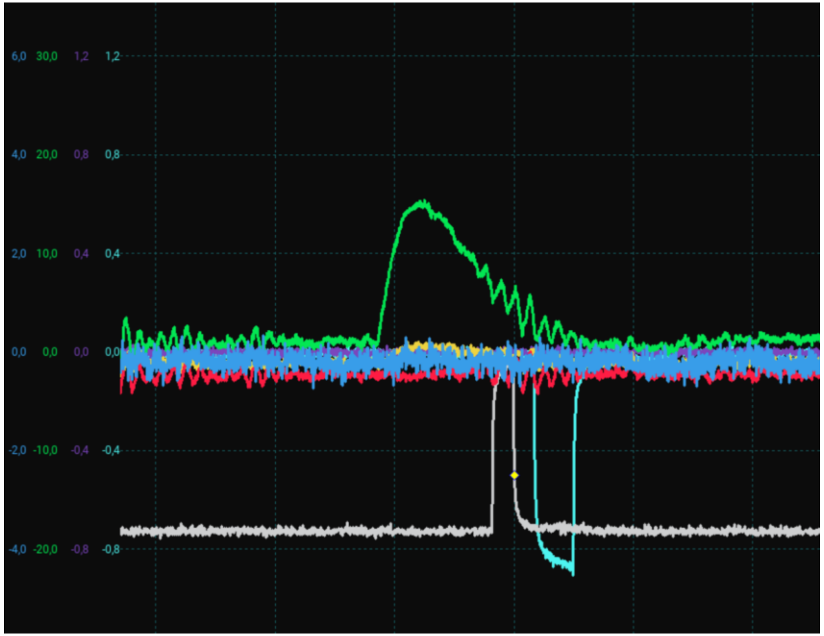


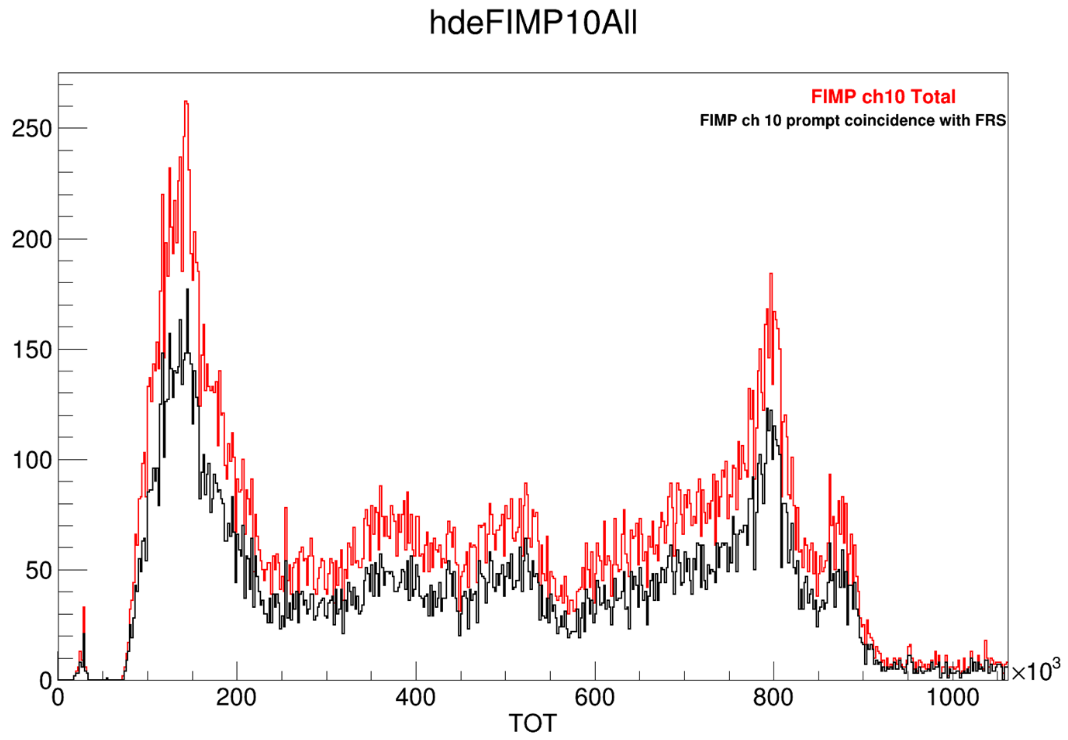


- Implantation rate: 2.5 kHZ
- ^{98}Nb : 1 kHZ (40%)

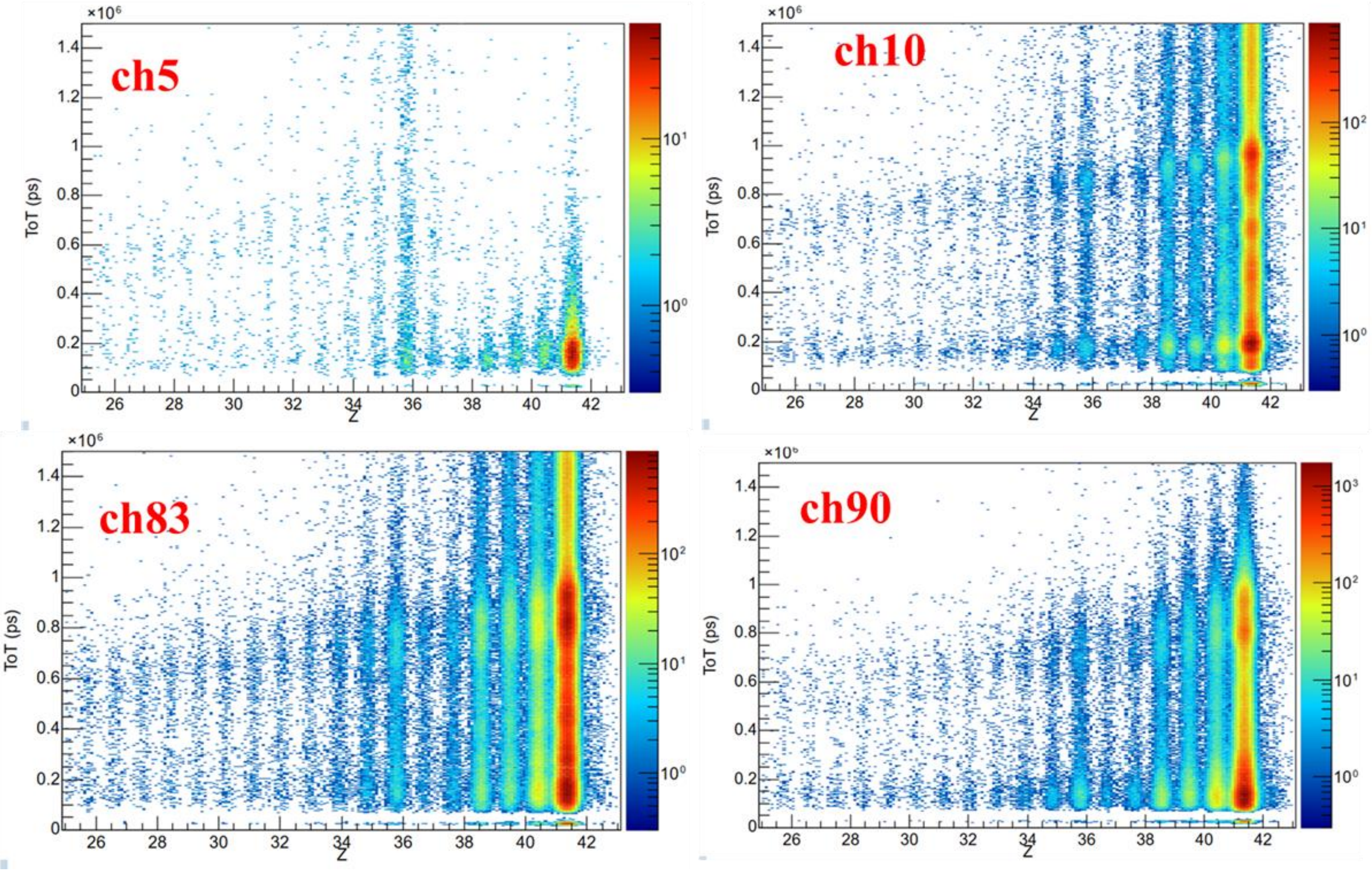
Courtesy of H. Hao

Online: first waveforms and ToT spectra



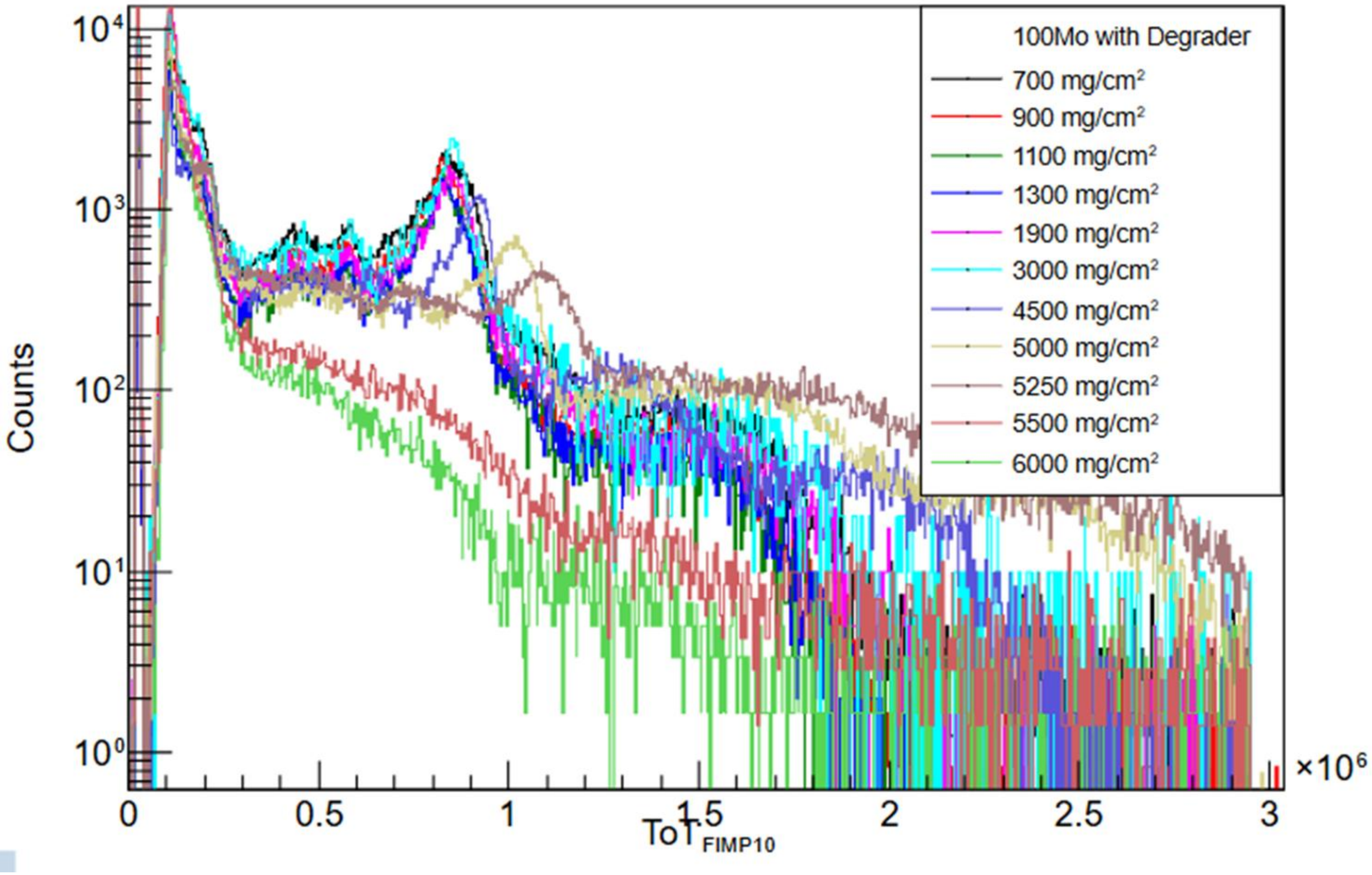


Courtesy of H. Hao



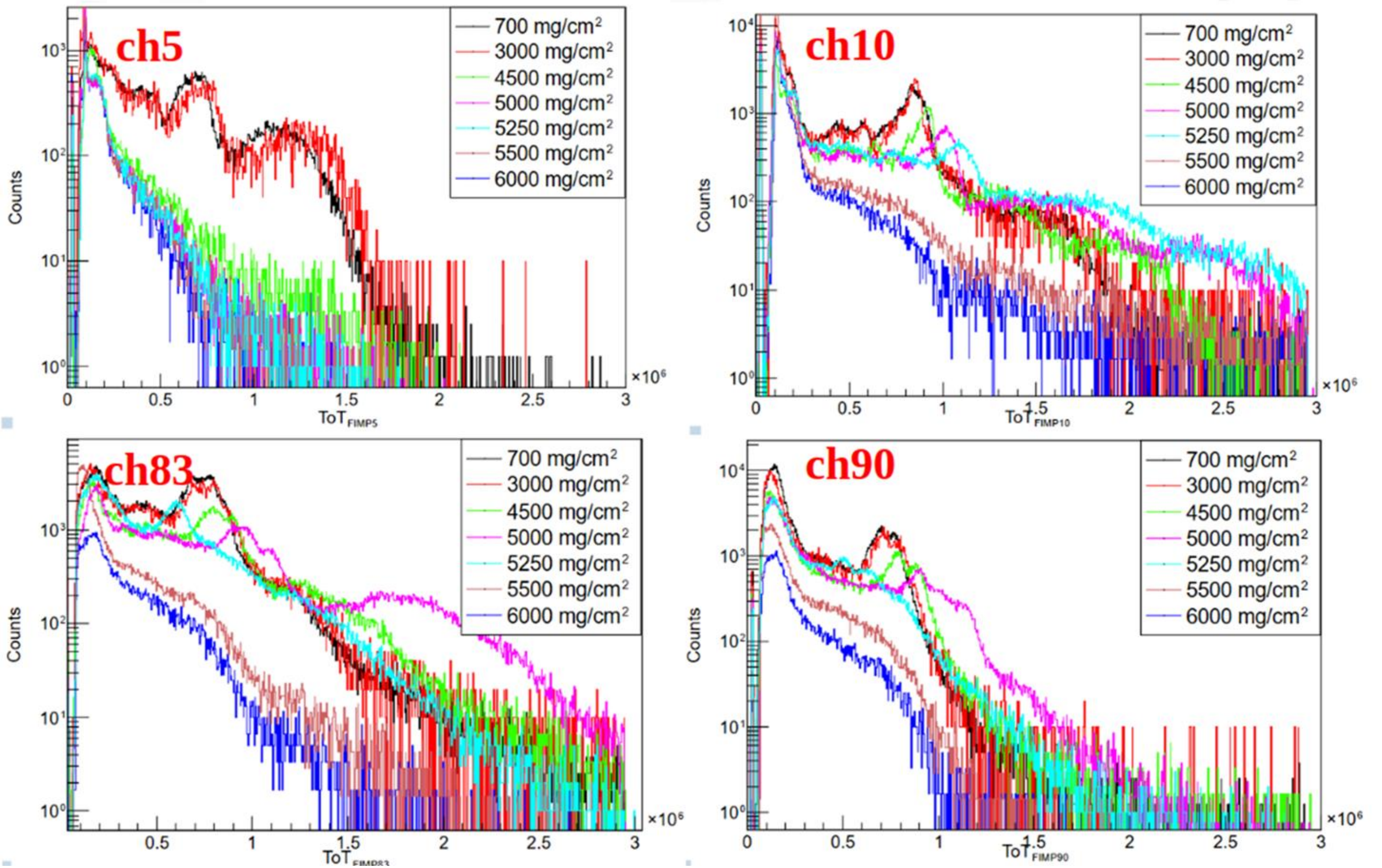
Courtesy of H. Hao

ToT spectra of FIMP for ^{100}Mo



Courtesy of H. Hao

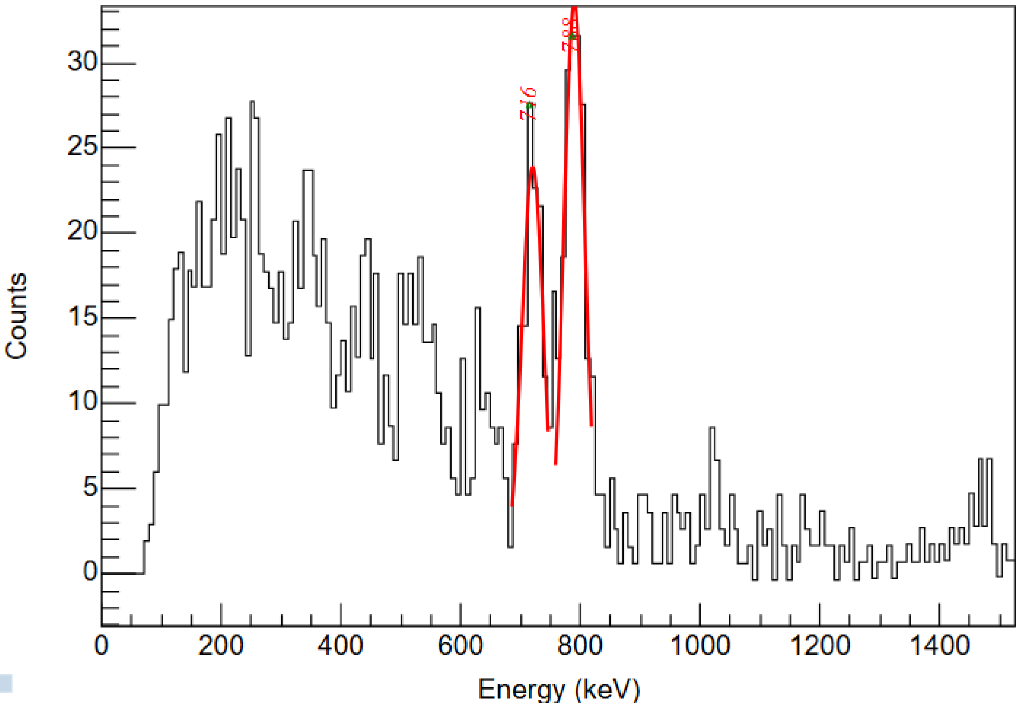
ToT spectra for ^{100}Mo

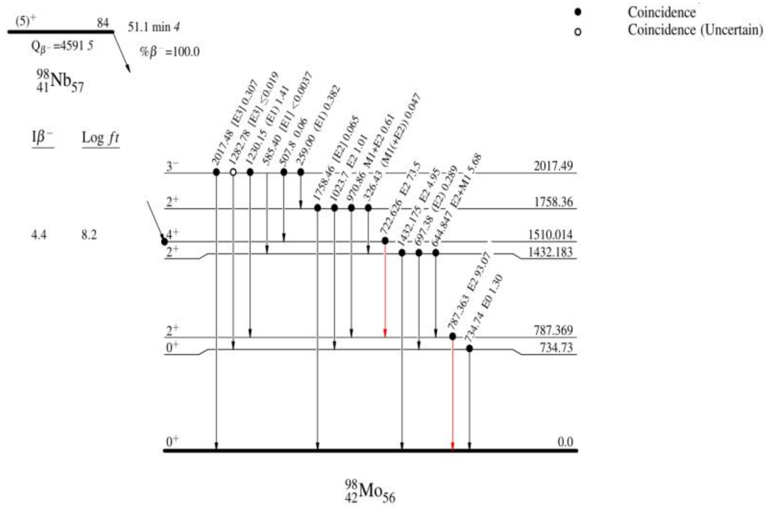


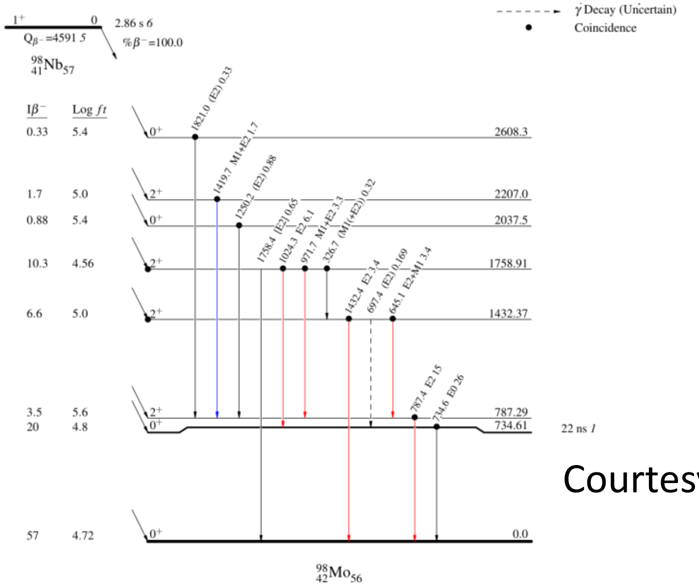
Channel 5; back
Channel 10; front
Channel 83; middle
Channel 90; middle

Courtesy of H. Hao

Fibre IMPlanter







Courtesy of H. Hao

- Both gammas can be associated with the β-γ coincidence of ^{98}Nb

Plans for FIMP'

- Multiplexing will be abandoned
- Back wall will be thinner
  (better Sc43 use)
- Use differential analog signals
- Power supply segmentation & remote control
- Gating of TOT circuit

- Double cladding fibres from Kuraray type SCSF-81, round
- Replace the black foil between the layers of the current FIMP design by aluminized mylar

- Improve the sensitivity and thereby reduce the energy threshold for beta detection.