A new low-energy plastic scintillation neutron detector for real time pulse shape discrimination

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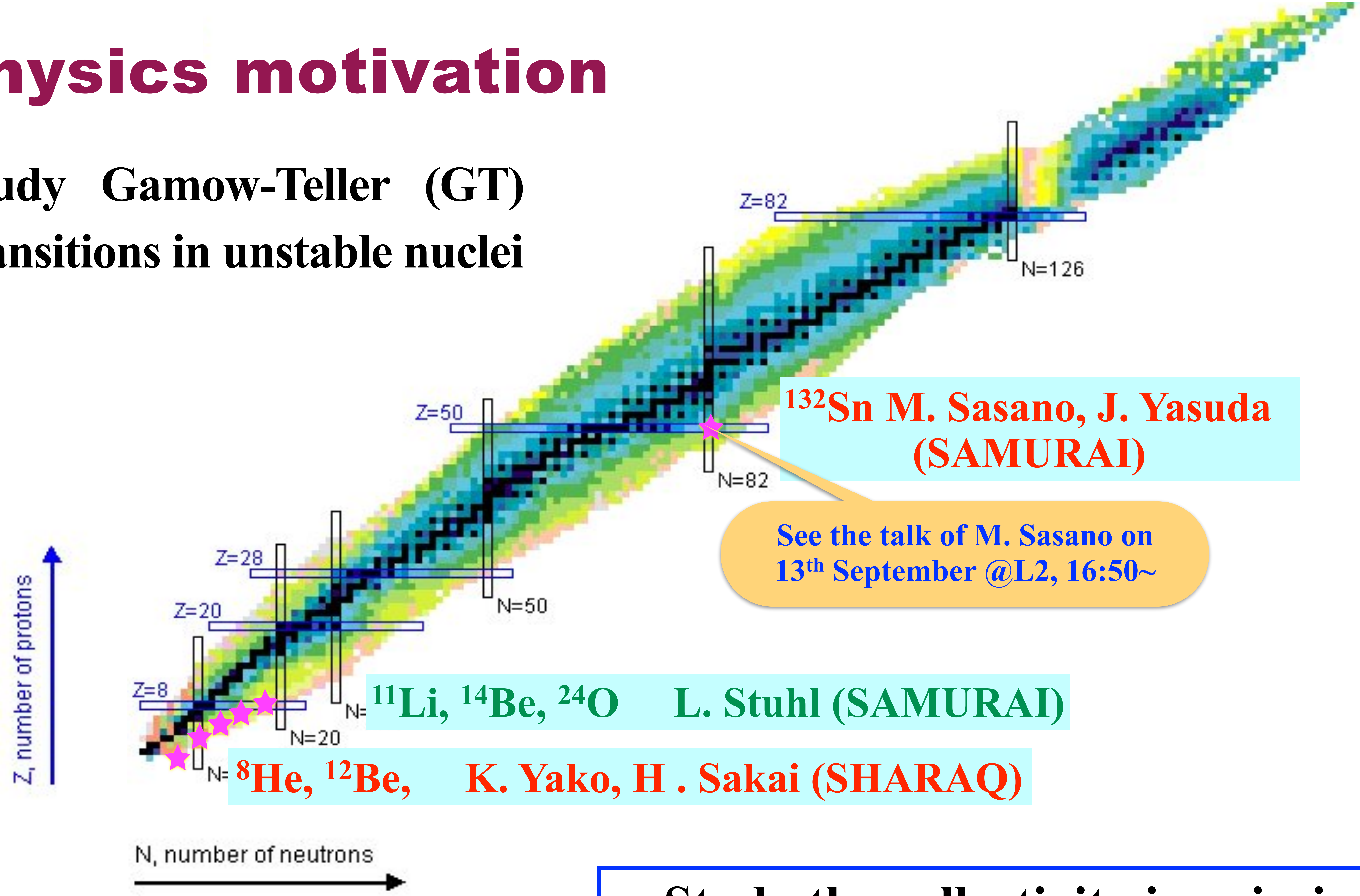
Physics motivation

Study Gamow-Teller (GT) transitions in unstable nuclei



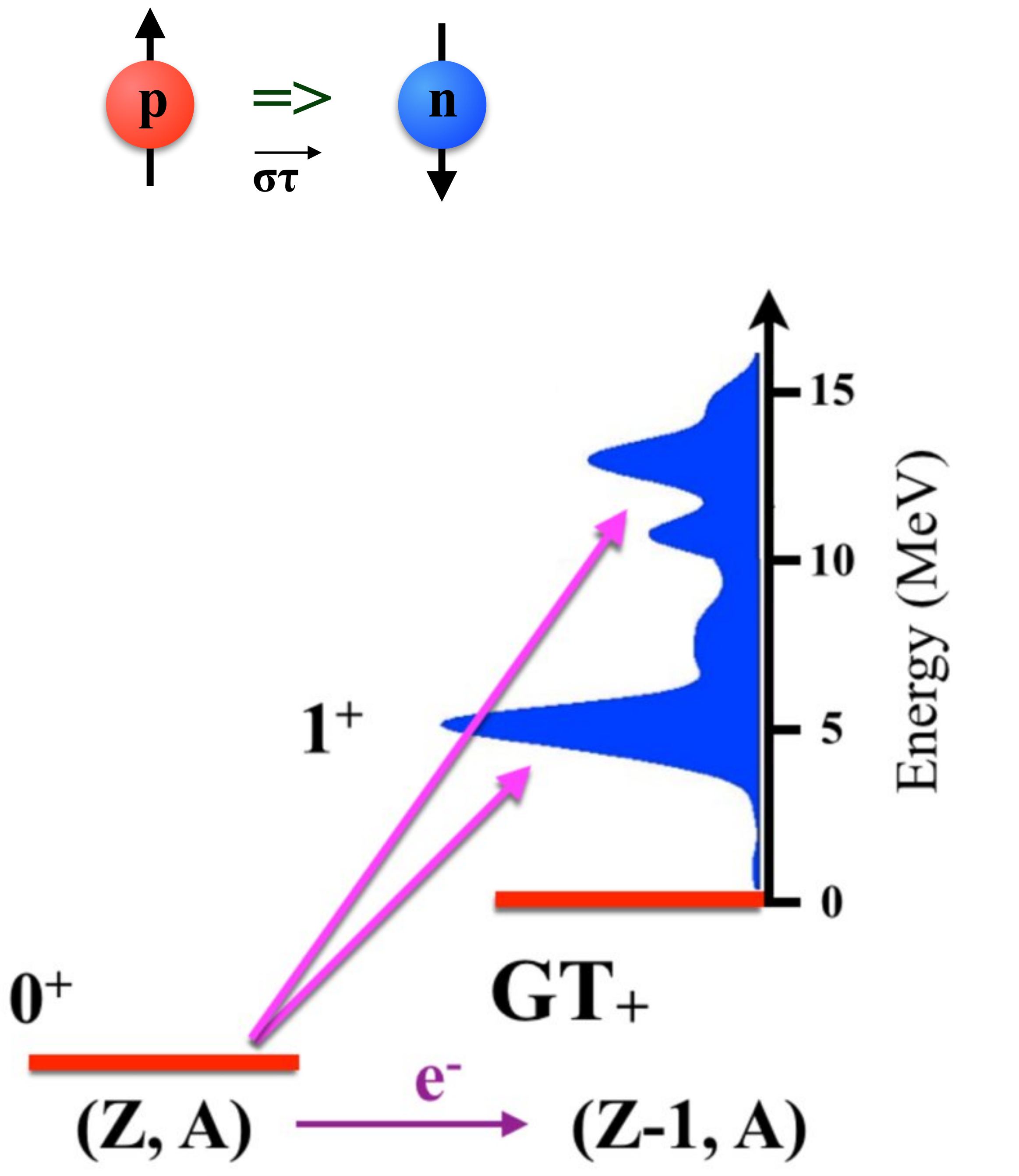
^{132}Sn M. Sasano, J. Yasuda (SAMURAI)

See the talk of M. Sasano on 13th September @L2, 16:50~

^{11}Li, ^{14}Be, ^{24}O L. Stuhl (SAMURAI)

^{8}He, ^{12}Be, K. Yako, H . Sakai (SHARAQ)

M. Sasano et al., PRL 107 (2011) 202501.

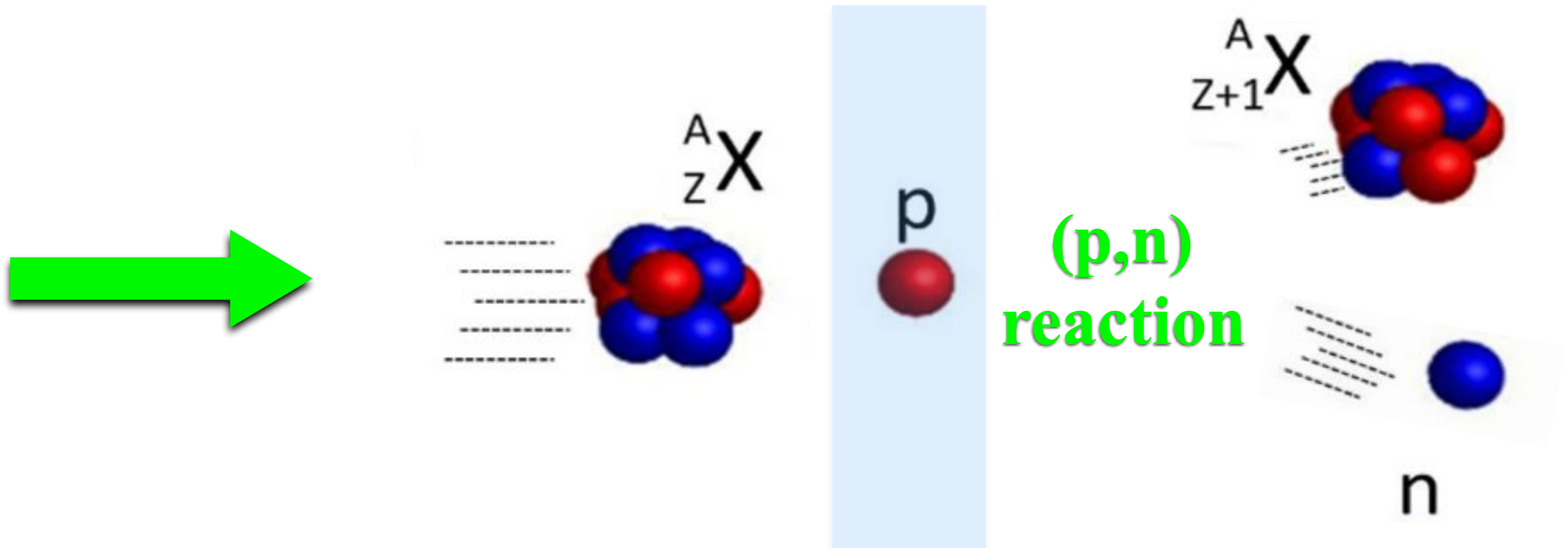


Study the collectivity in spin-isospin channel

(p,n) reaction in inverse kinematics

proton probe

RI target



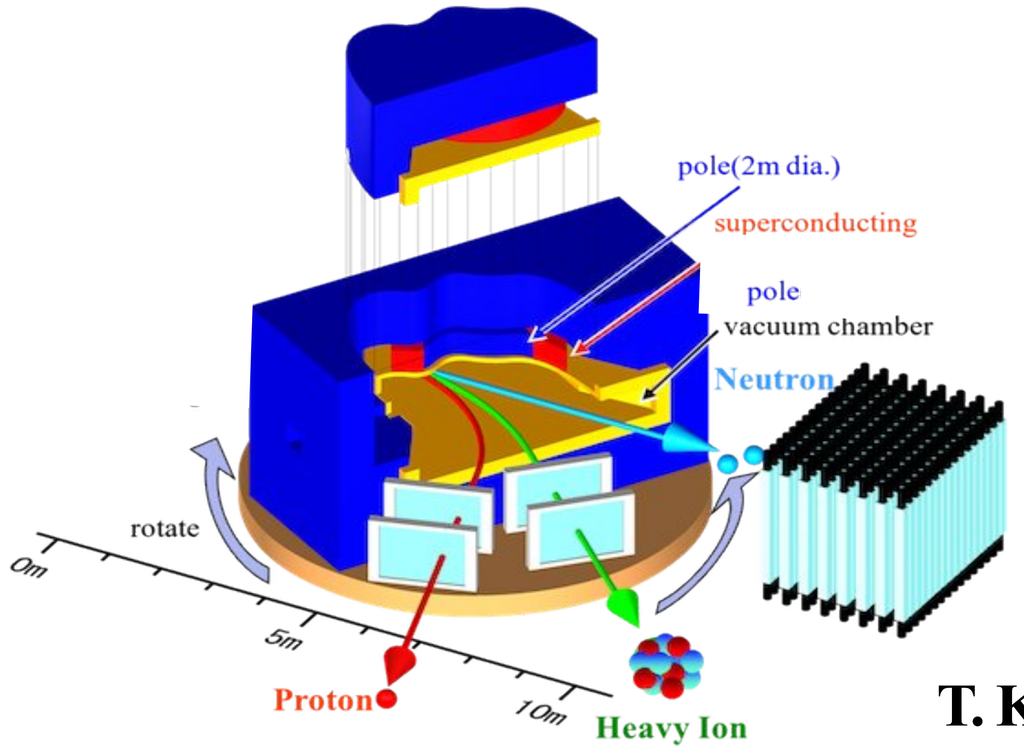
(p,n) reaction

Thick liquid hydrogen target

Typically ~1-1.5 cm

High luminosity

SAMURAI



heavy reaction residues

T. Kobayashi et al., NIM B 317 (2013) 294.

WINDS

Low-energy recoil neutrons

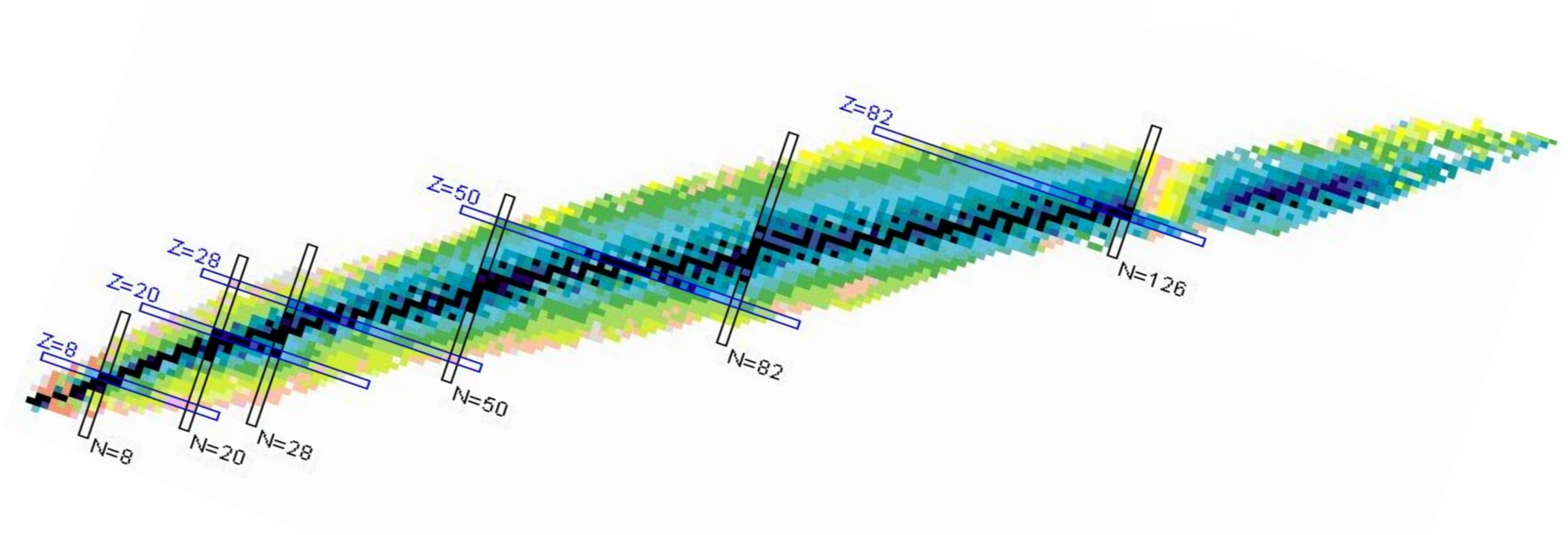
K. Yako et al., RIKEN APR 45 (2012) 137.

The best tool to study the GTGR in unstable nuclei…

The problem... ... bad result

Intensity Luminosity

Background



Secondary beam intensity

Contamination (inverse of purity)

$$R = L \cdot \sigma$$

The background limits the counting rate

Goals of our detector development

Online

- To reduce the trigger rate by removing the large background due to gamma rays

To be able to handle high intensity beam
To decrease the size of data to be stored

Offline

- To fully remove the background

Lower systematical and statistical errors

Good signal-to-noise ratio in both online and offline

Solution

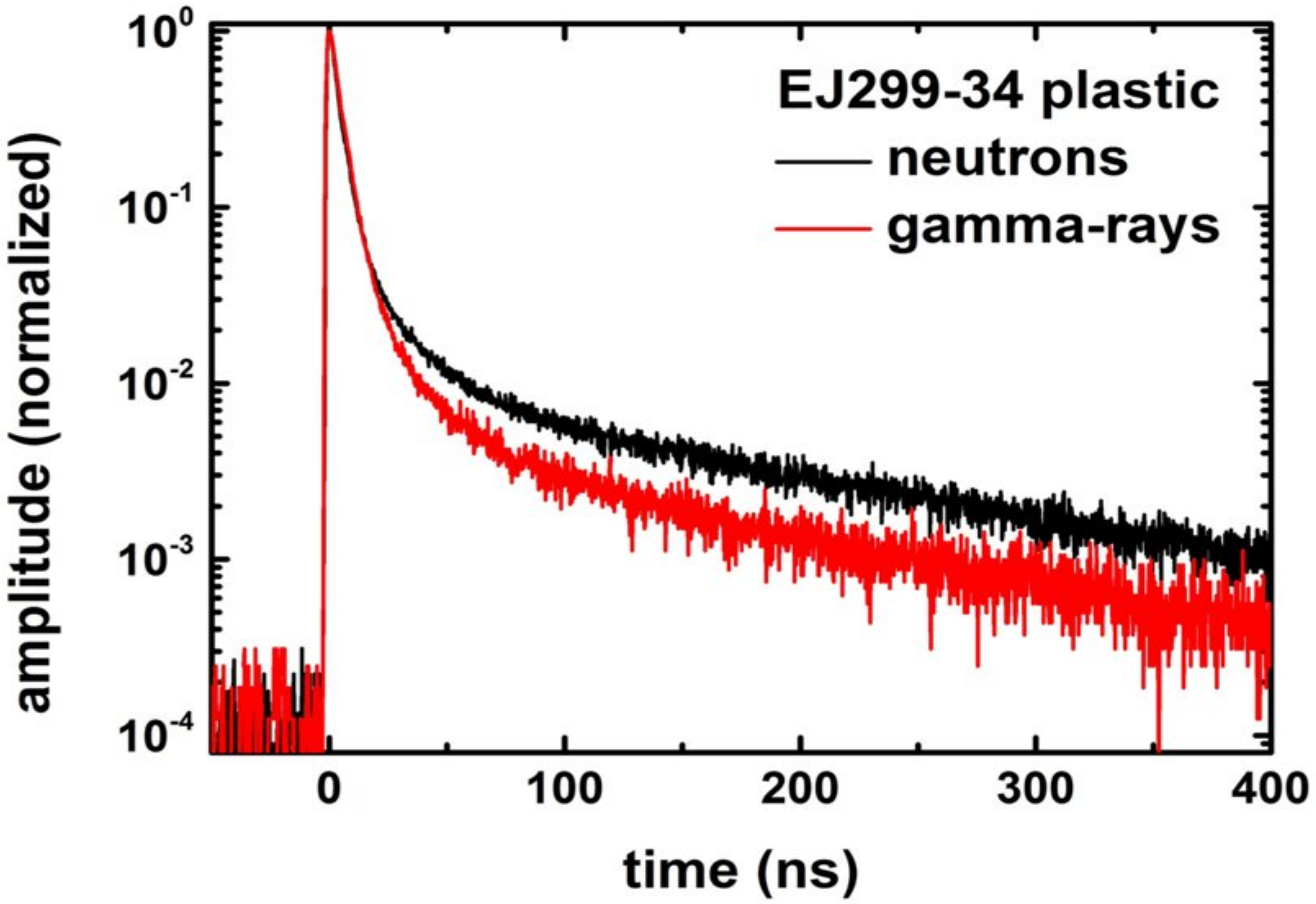
We need a detector device which provides
online particle identification!

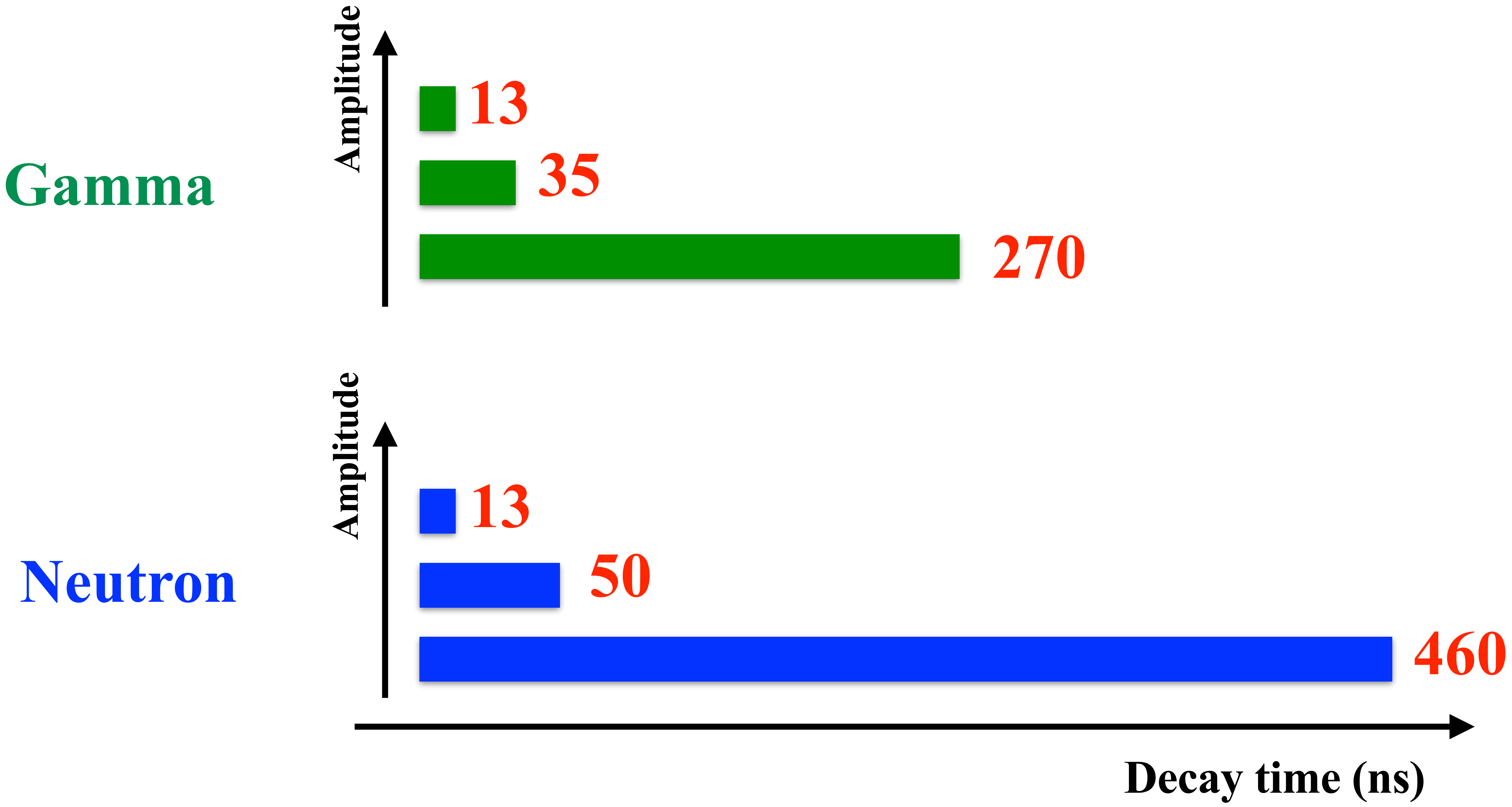
- *detector material sensitive to differences between particles*
- *system which can handle the particle discrimination real time*

Detector material

N. Zaitseva et al., NIM A 668 (2012) 88.

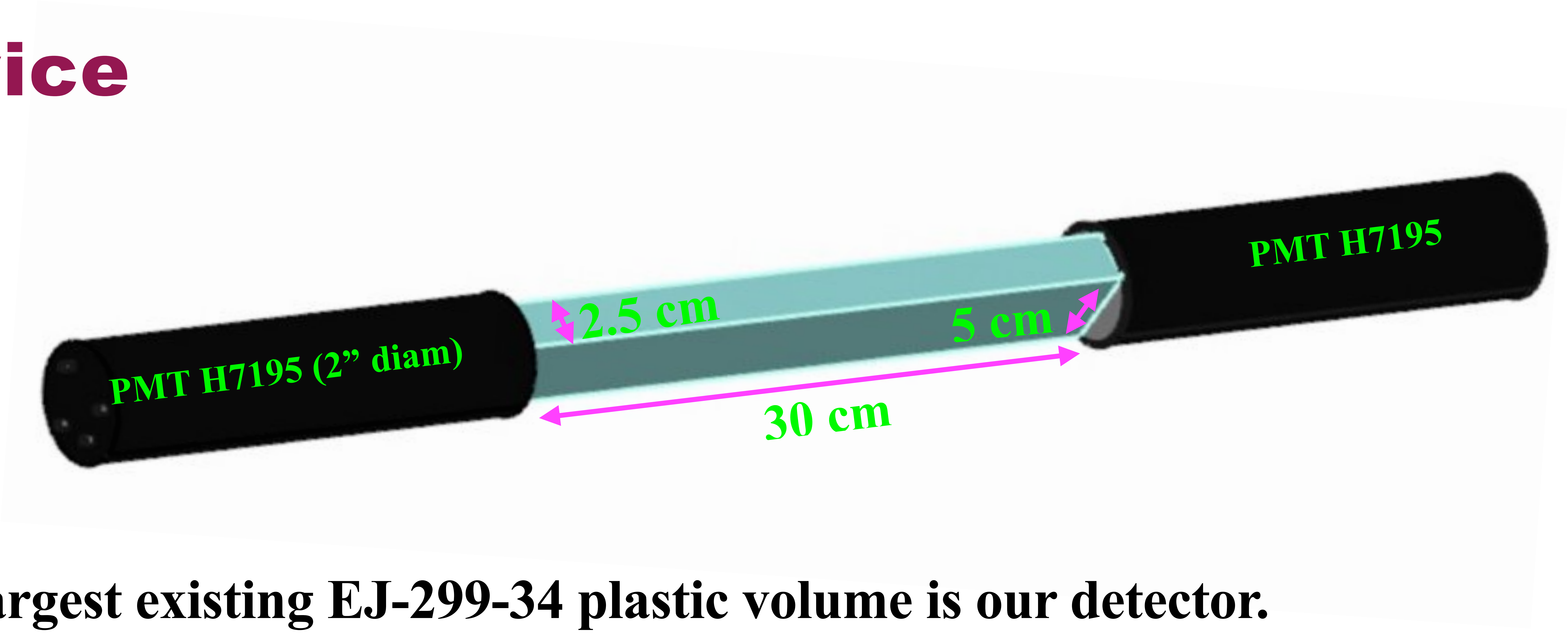
New EJ-299-34 plastic scintillator with special secondary solvent.





Pulse Shape Discrimination (PSD) capability

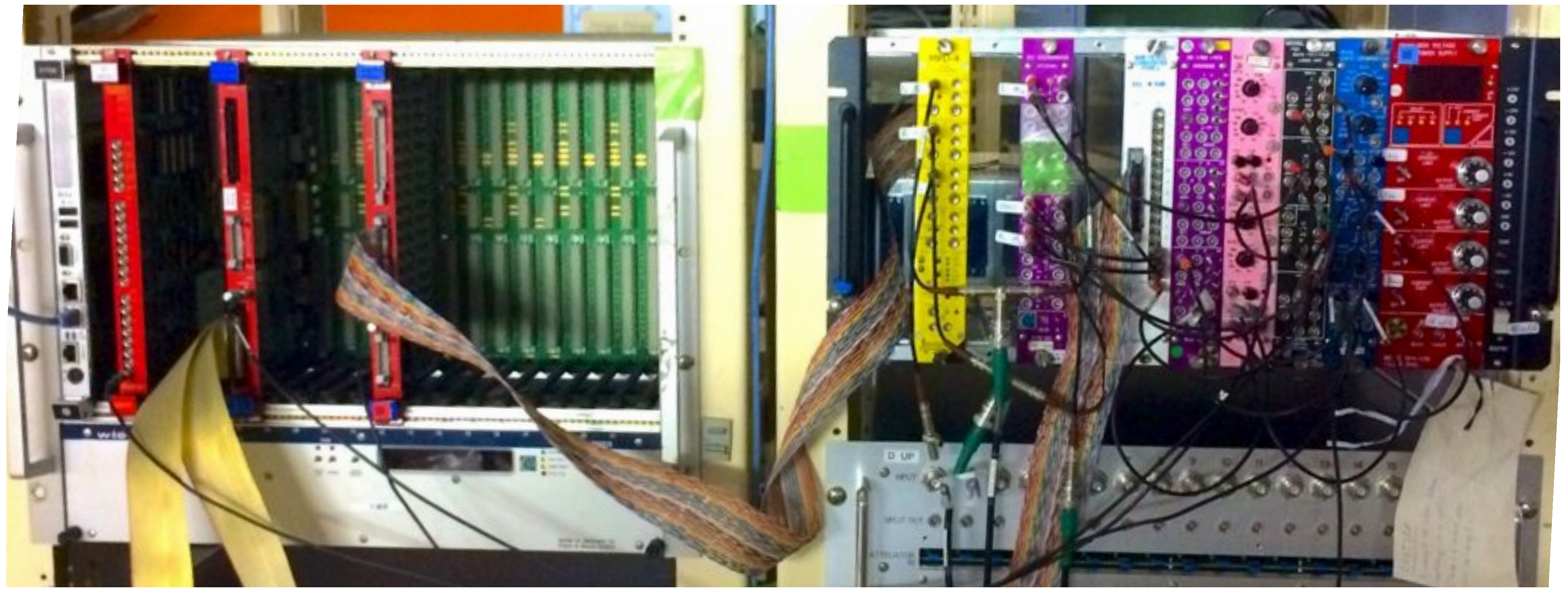
Device



- Largest existing EJ-299-34 plastic volume is our detector.
- Hamamatsu H7195 photomultipliers coupled to both ends directly (no light guide)
- Optical cement
- Wrapping: two layer of aluminised mylar + black tape
- Position sensitive device (time differences)

Sensitive signal processing is necessary

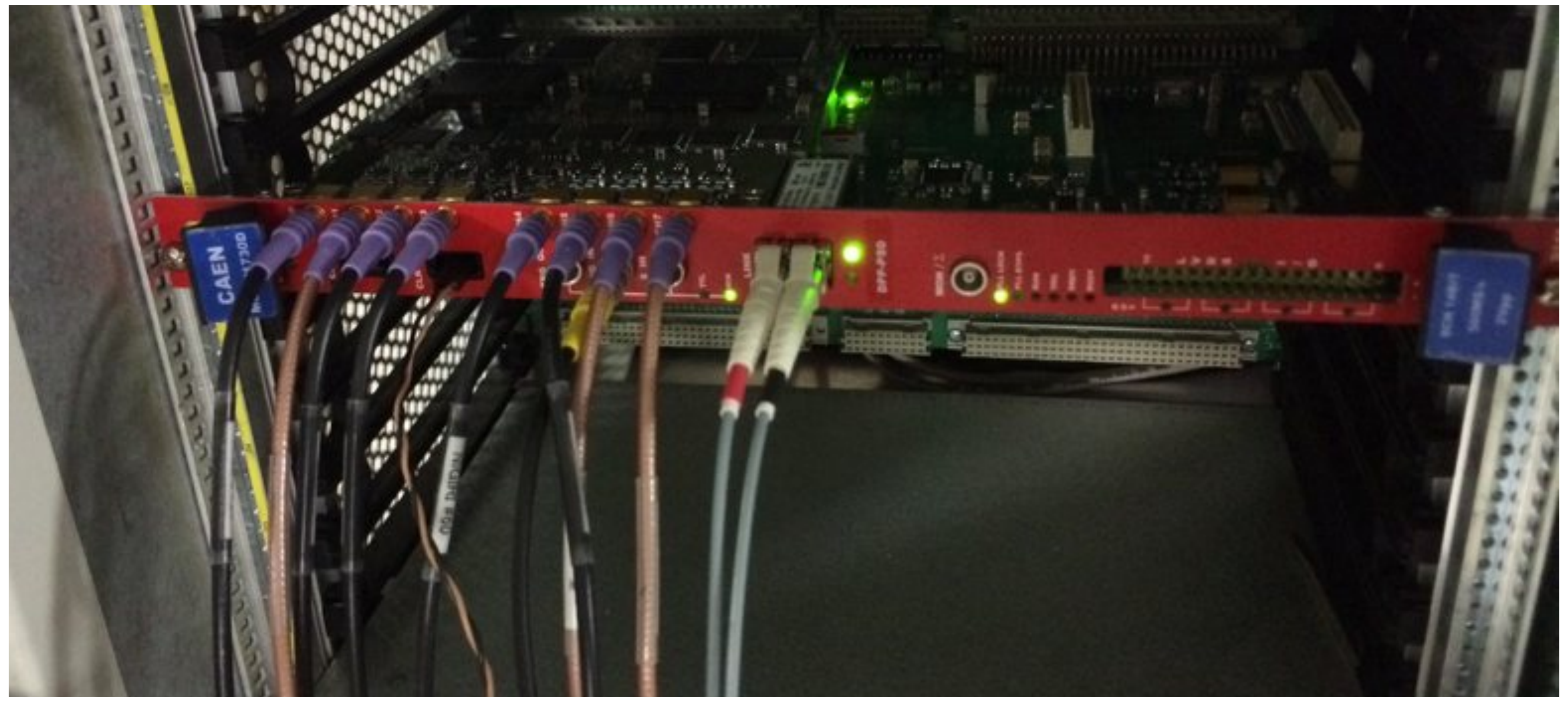
Anlog DAQ



Jungle of modules and cables.

+ *programming*
+ *programming*
+ *programming*
+ *programming*
+ *programming*
+ *programming*
+ *programming*

Digital DAQ (DDAQ)



One single board can do the job of several analog modules.

Reconfigurable

Benefits of DDAQ

- Digitising of the wave form as early as possible
- Data reduction

preserve full information

- Multi-parametric analysis: energy, timing and pulse shape on same board

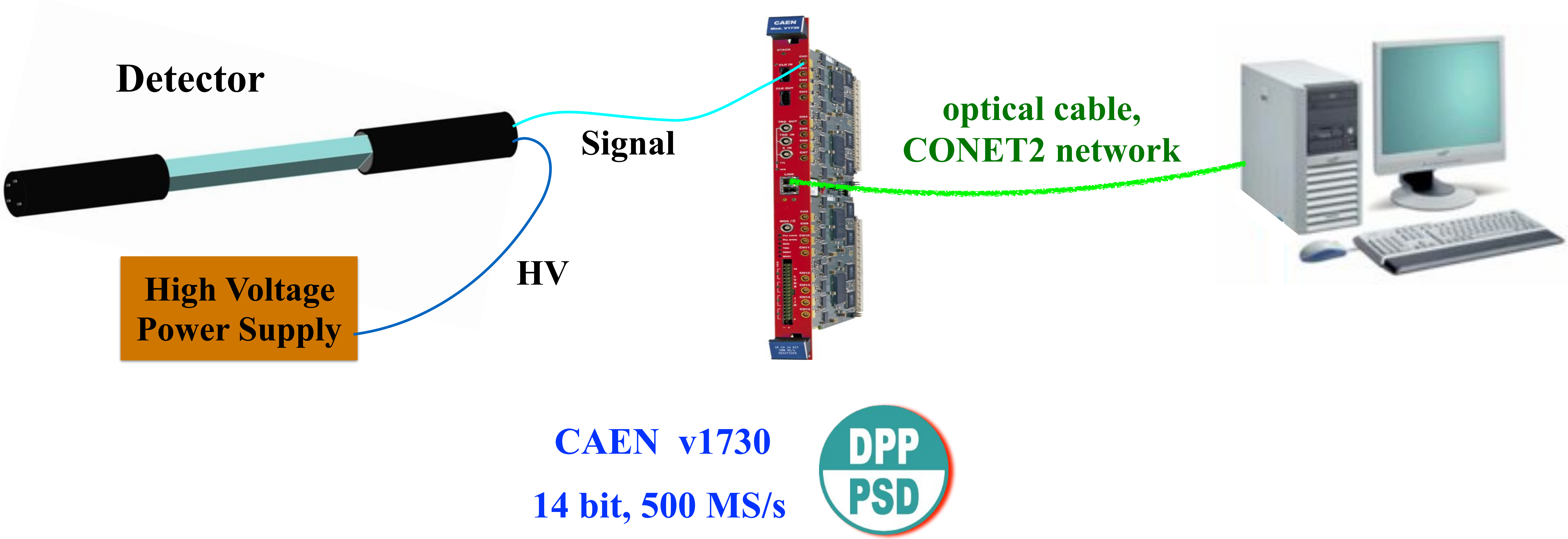
→ all correlated in the same data flow

- Reduction in size, cabling, power consumption

→ low cost per channel, high mobility, fast setup

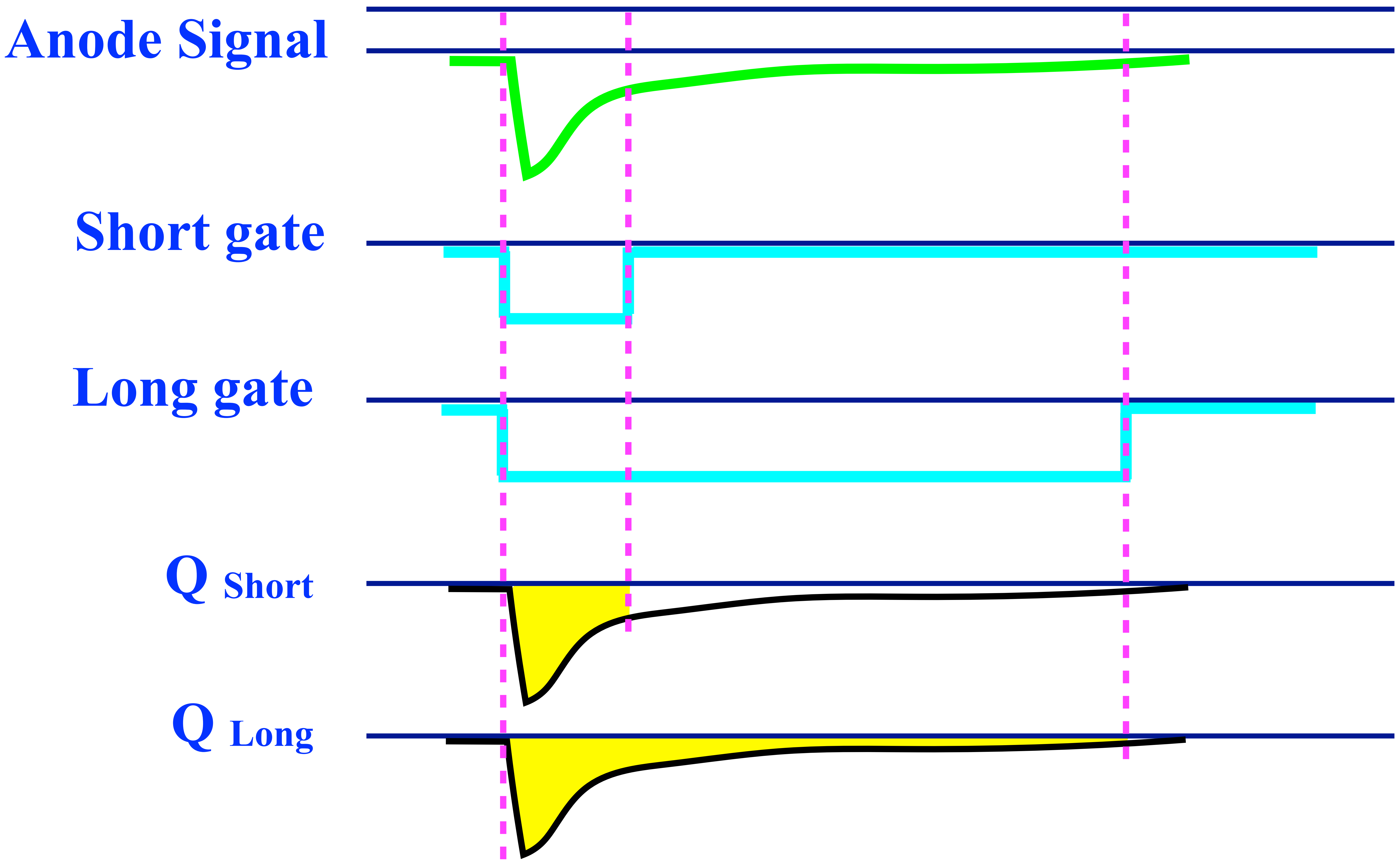
- High reproducibility of the setup (configuration of electronics)

Fully digital acquisition chain



Flexibility: different digital algorithms can be designed and loaded into the same hardware

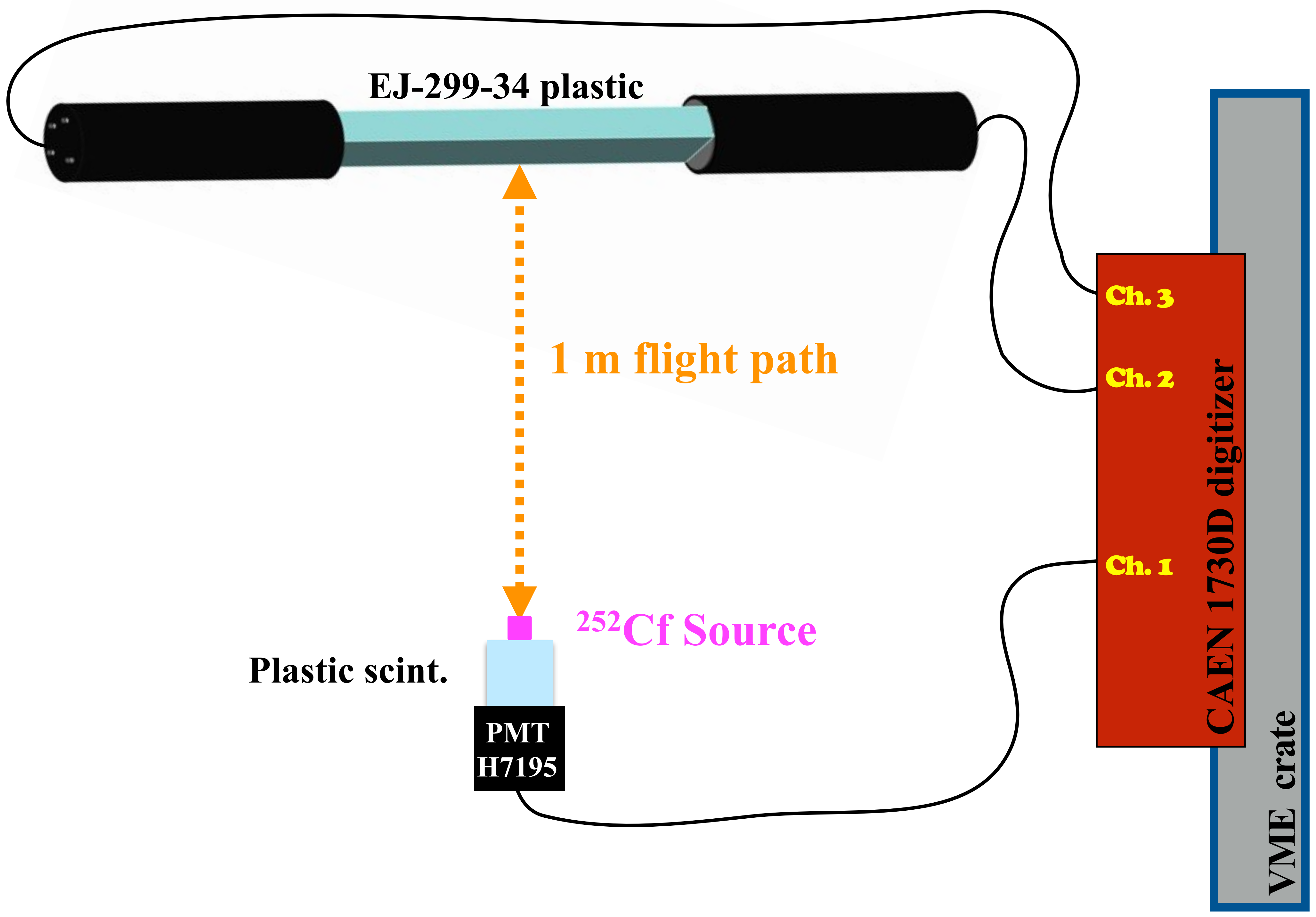
PSD capability based on charge integration method

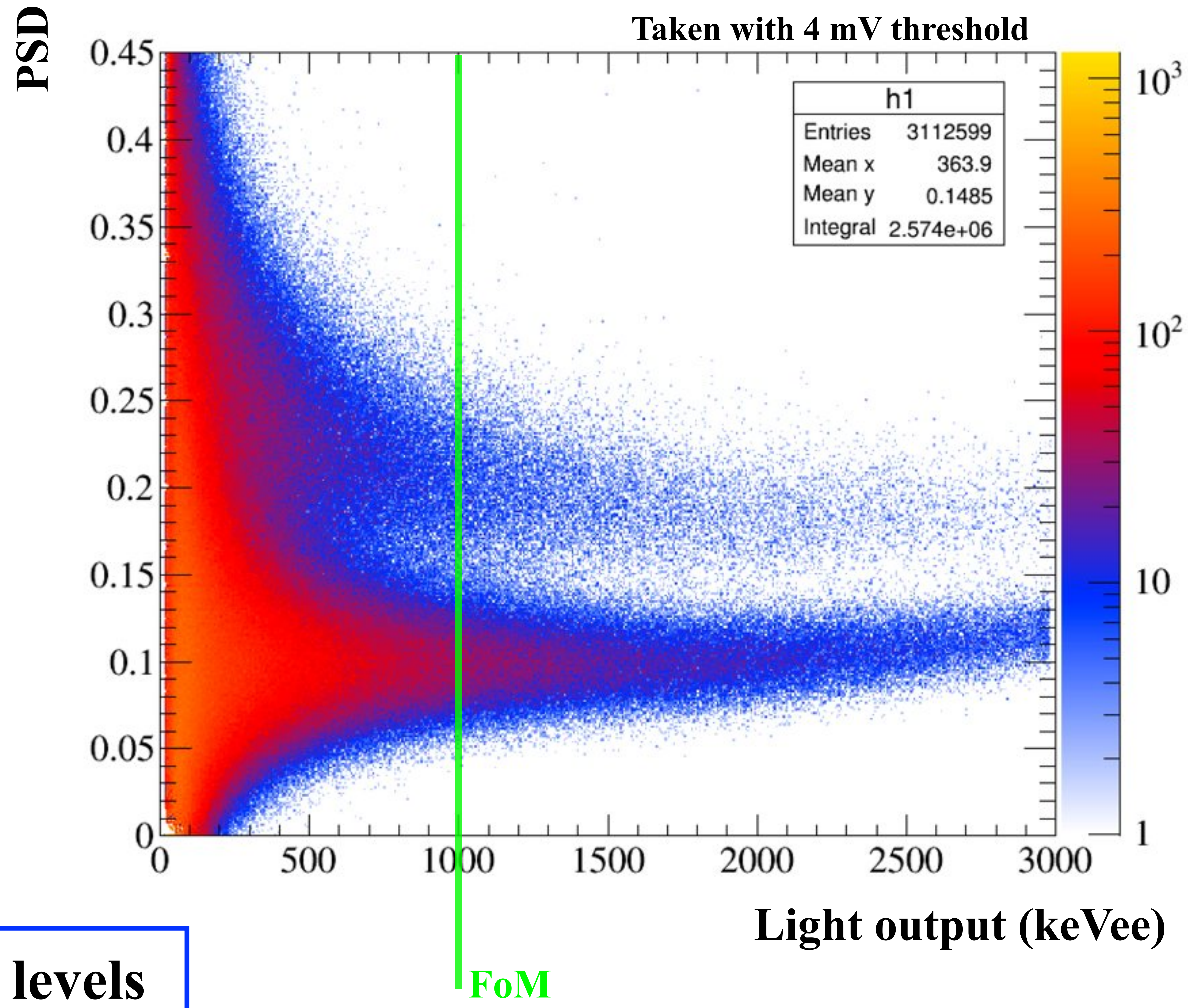


$$\mathrm{PSD} = \frac{Q_{\mathrm{Long}} - Q_{\mathrm{Short}}}{Q_{\mathrm{Long}}}$$

Separation

Time-of-Flight (ToF) measurement

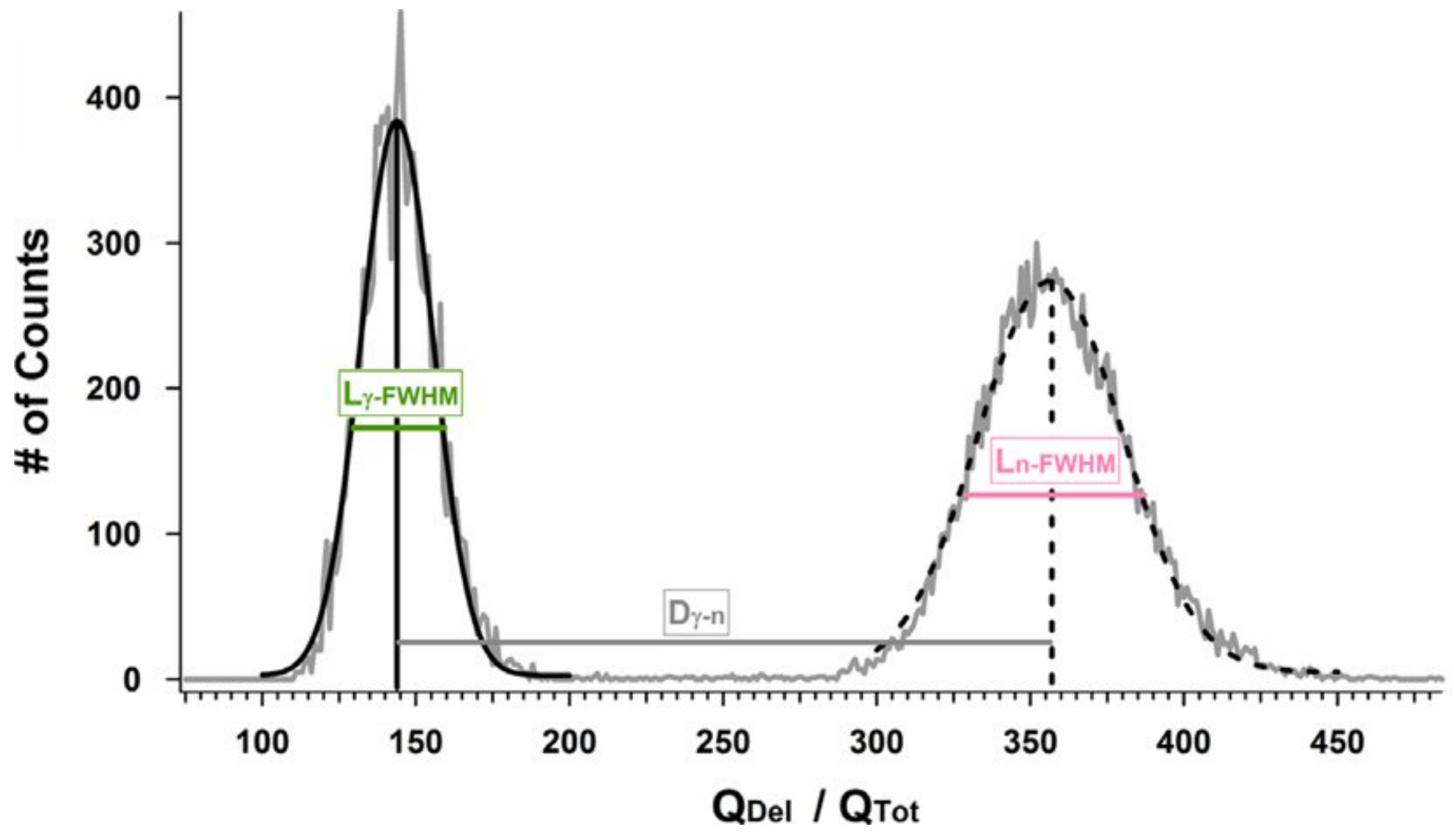




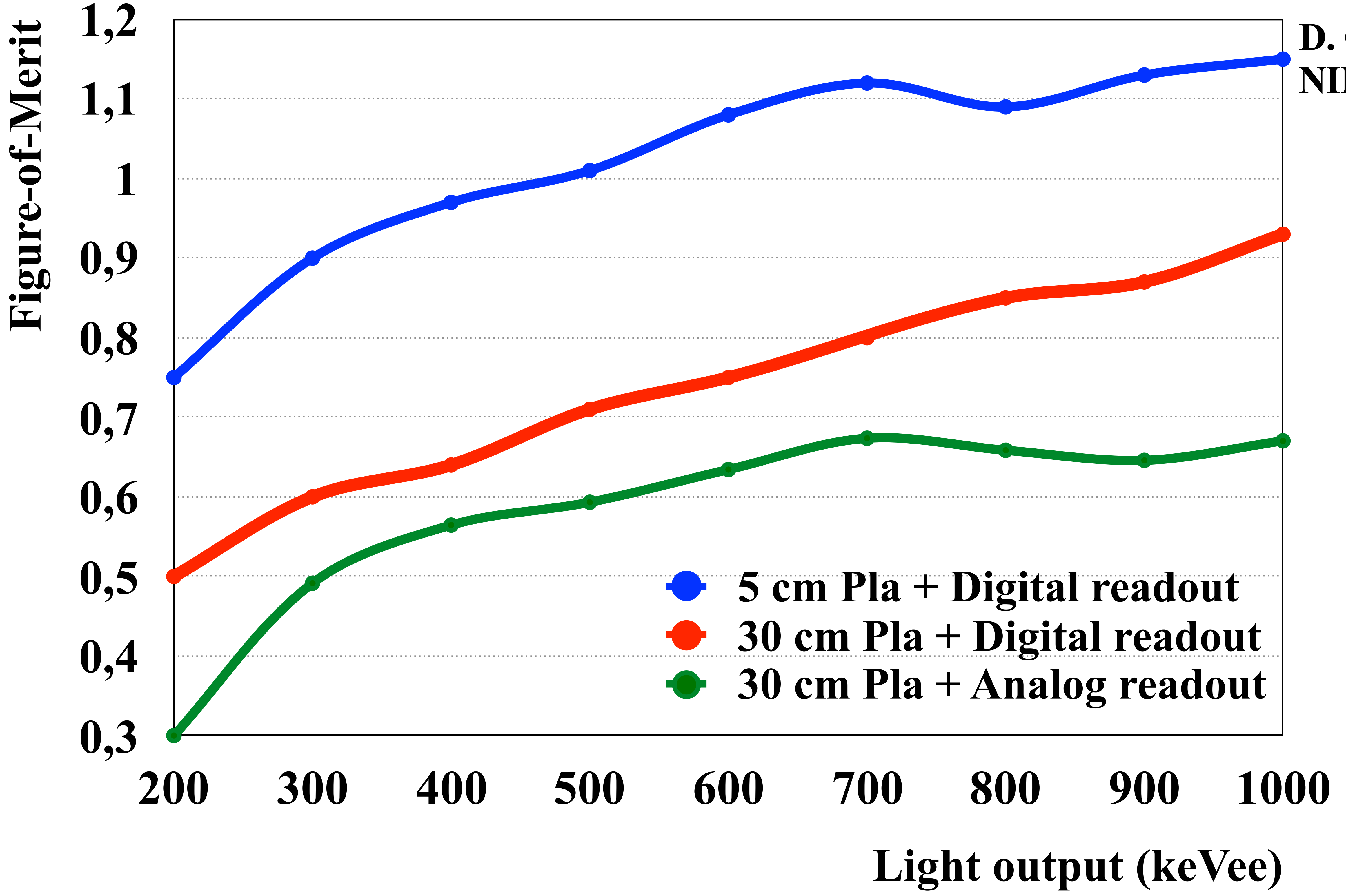
Managing triggers in "local" and "global" levels

Figure of merit (FoM) to evaluate the PSD

P. Blanc et al., NIM A 750, 1 (2014).



$$\mathrm{FOM} = \frac{D_{\gamma-n}}{L_{\gamma-\mathrm{FWHM}} + L_{n-\mathrm{FWHM}}}$$



D. Cester et al., NIM A 735, 202 (2014).

Improved FoM with digital system but the large scintillator volume blurs the light collection

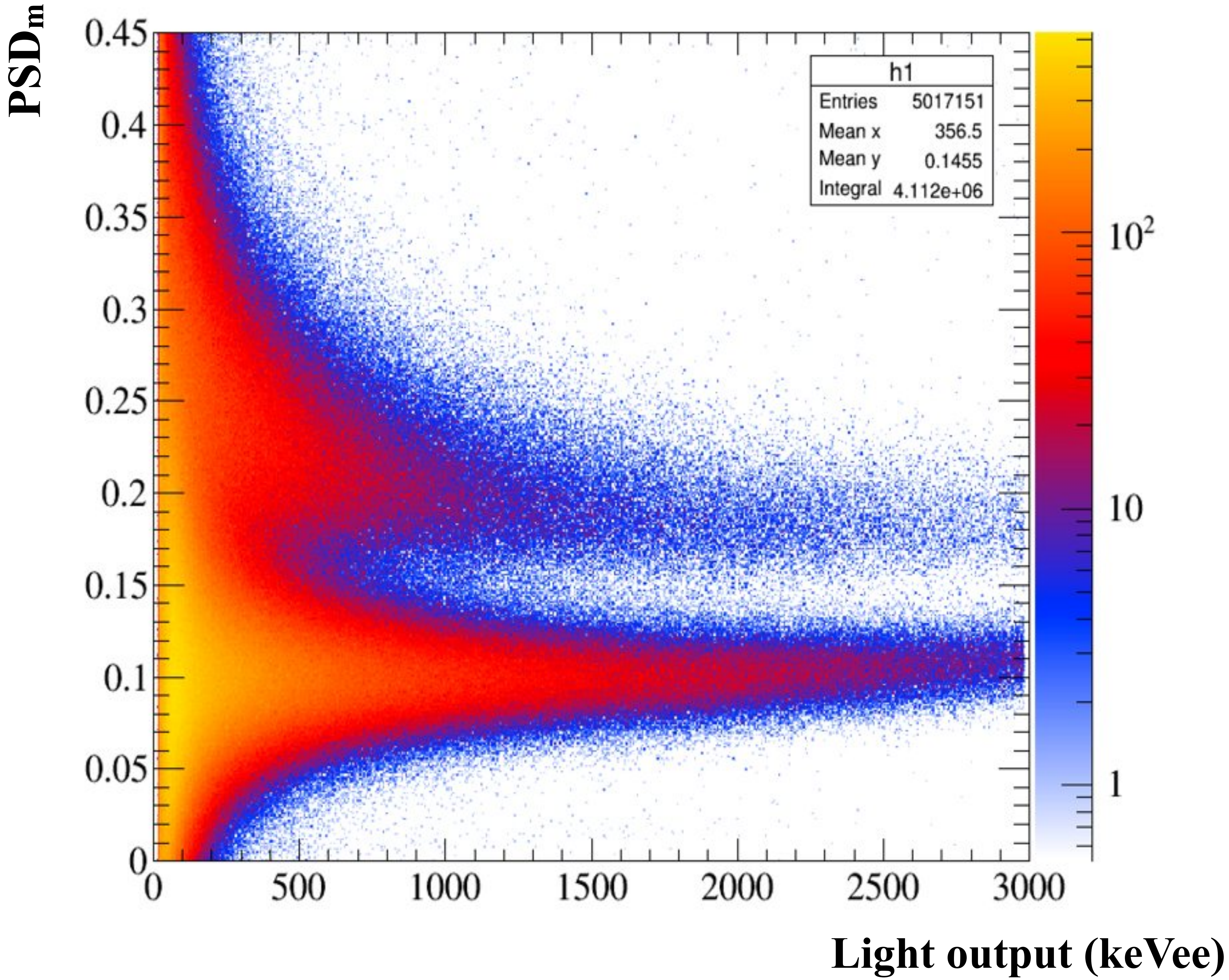
Mean PSD

Using the PSD data from both ends of the detector

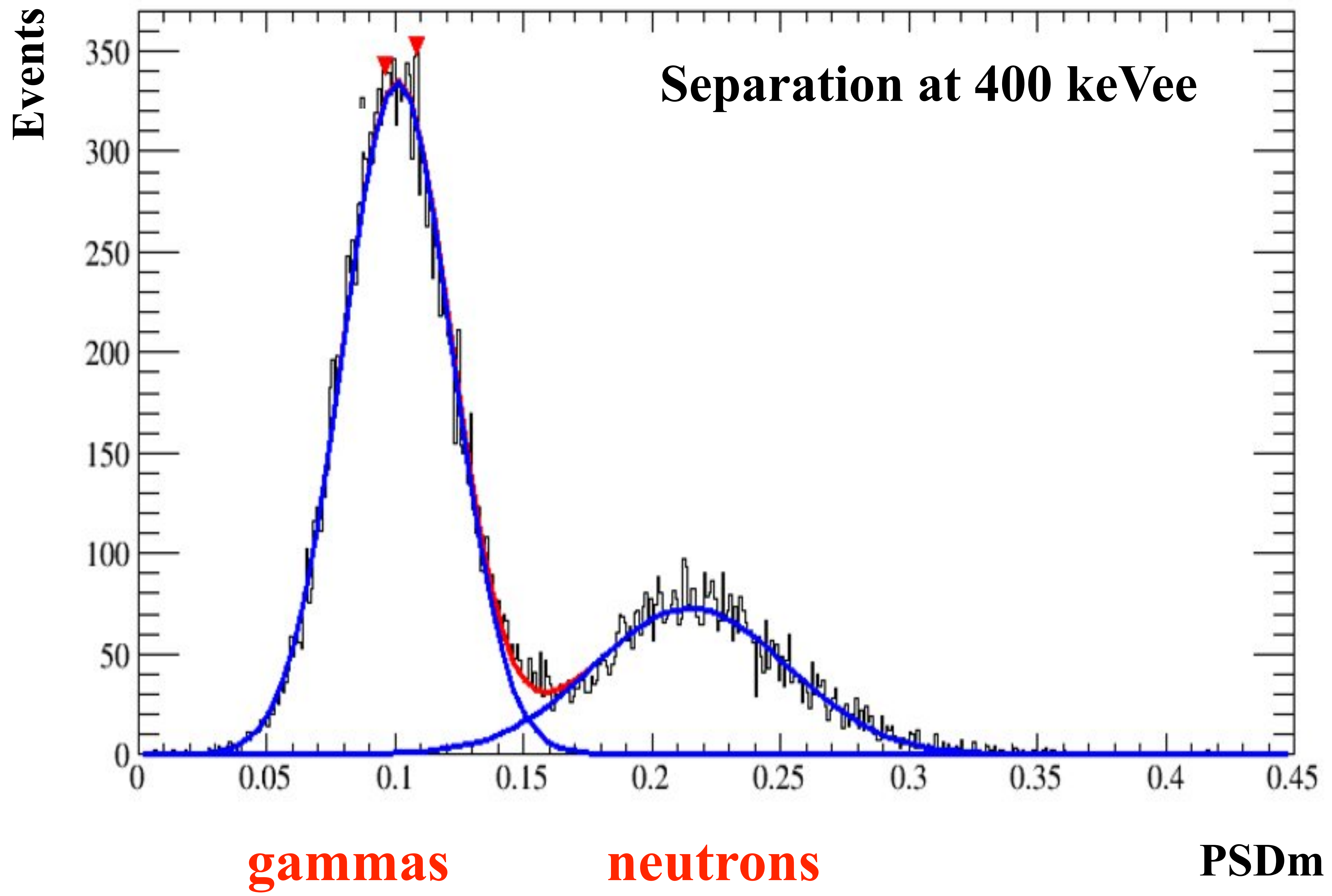
Mean PSD:

$$PSD_m = \frac{PSD_L + PSD_R}{2}$$

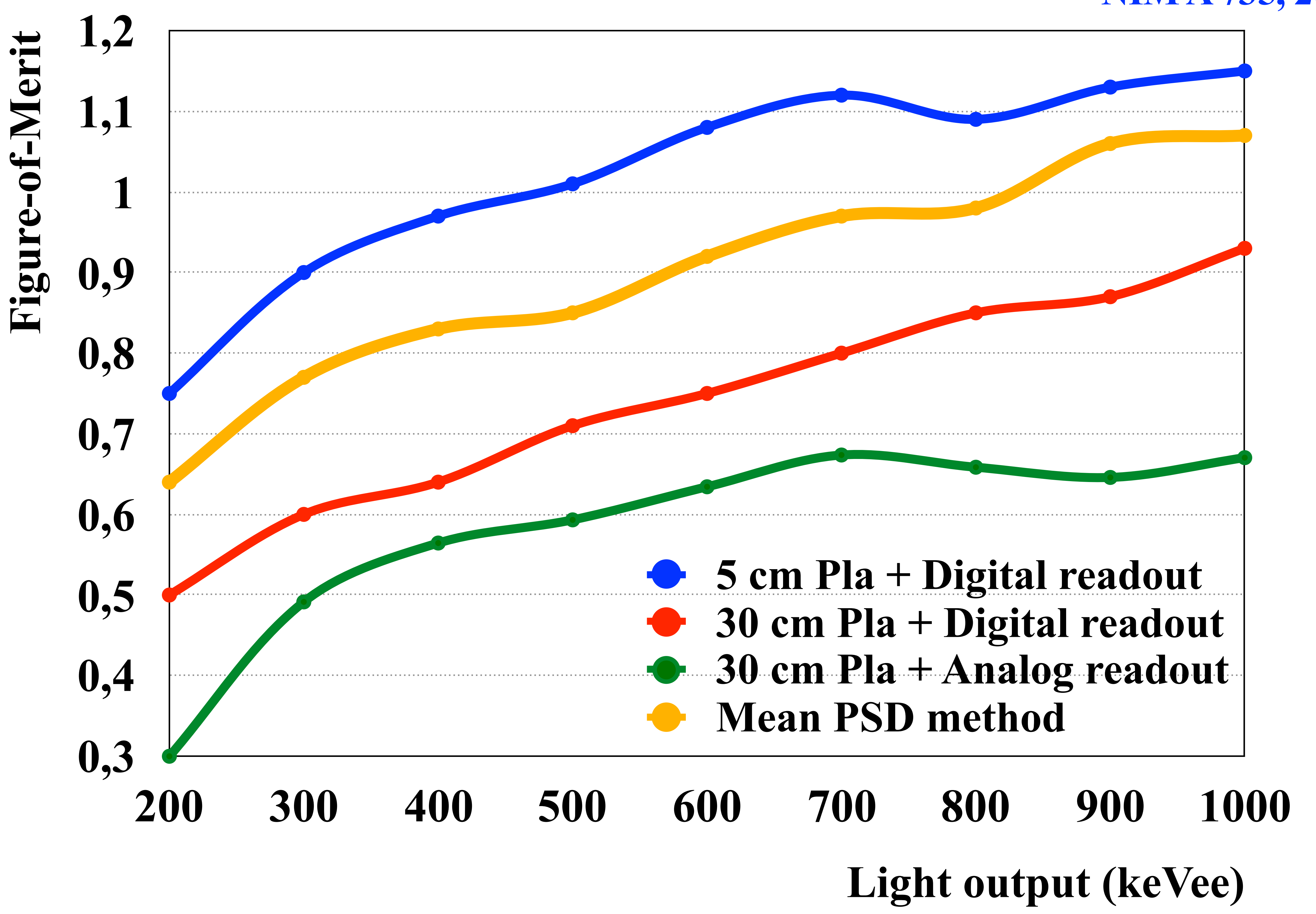
A new method results better separation



Improved FoM



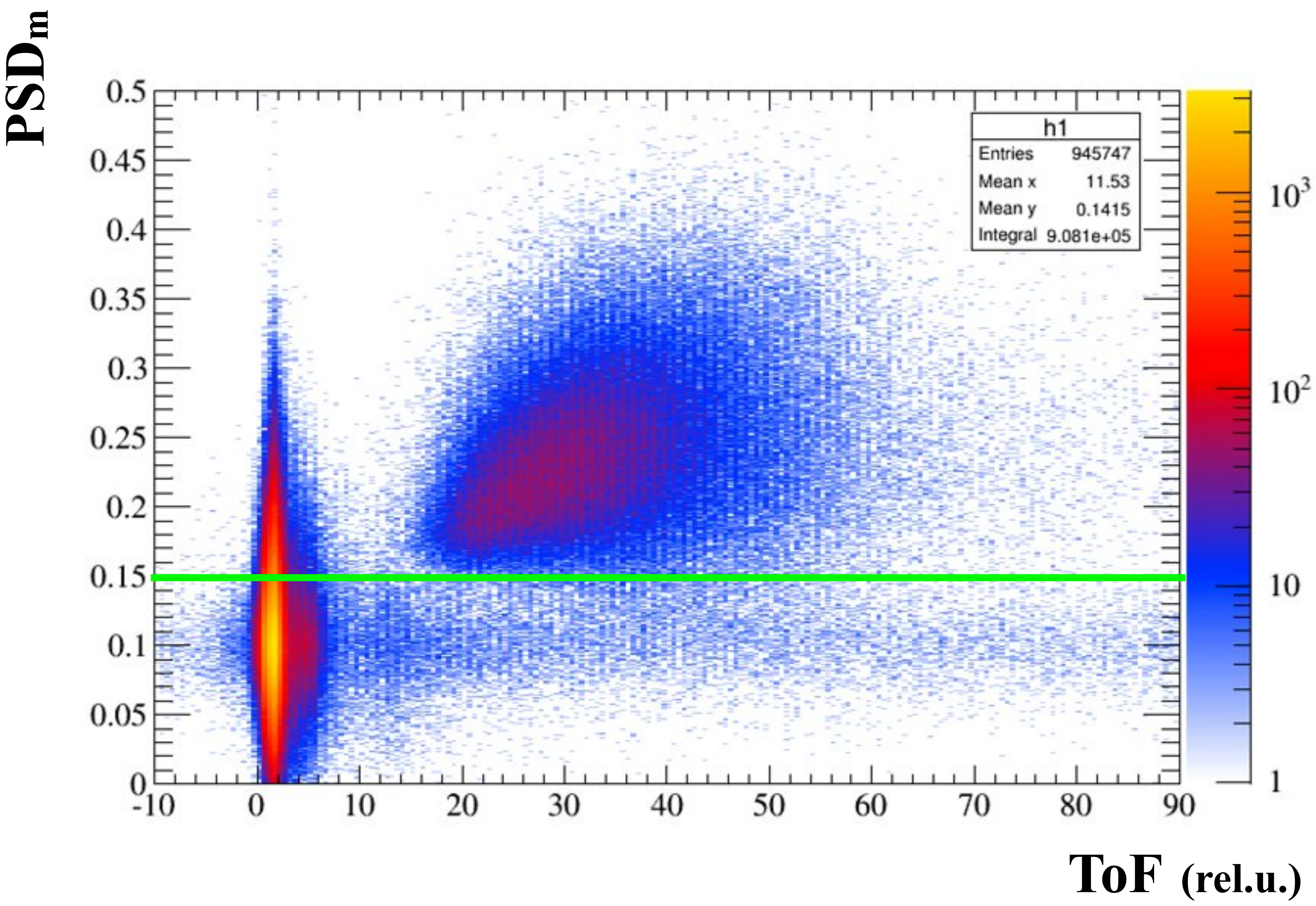
D. Cester et al., NIM A 735, 202 (2014).

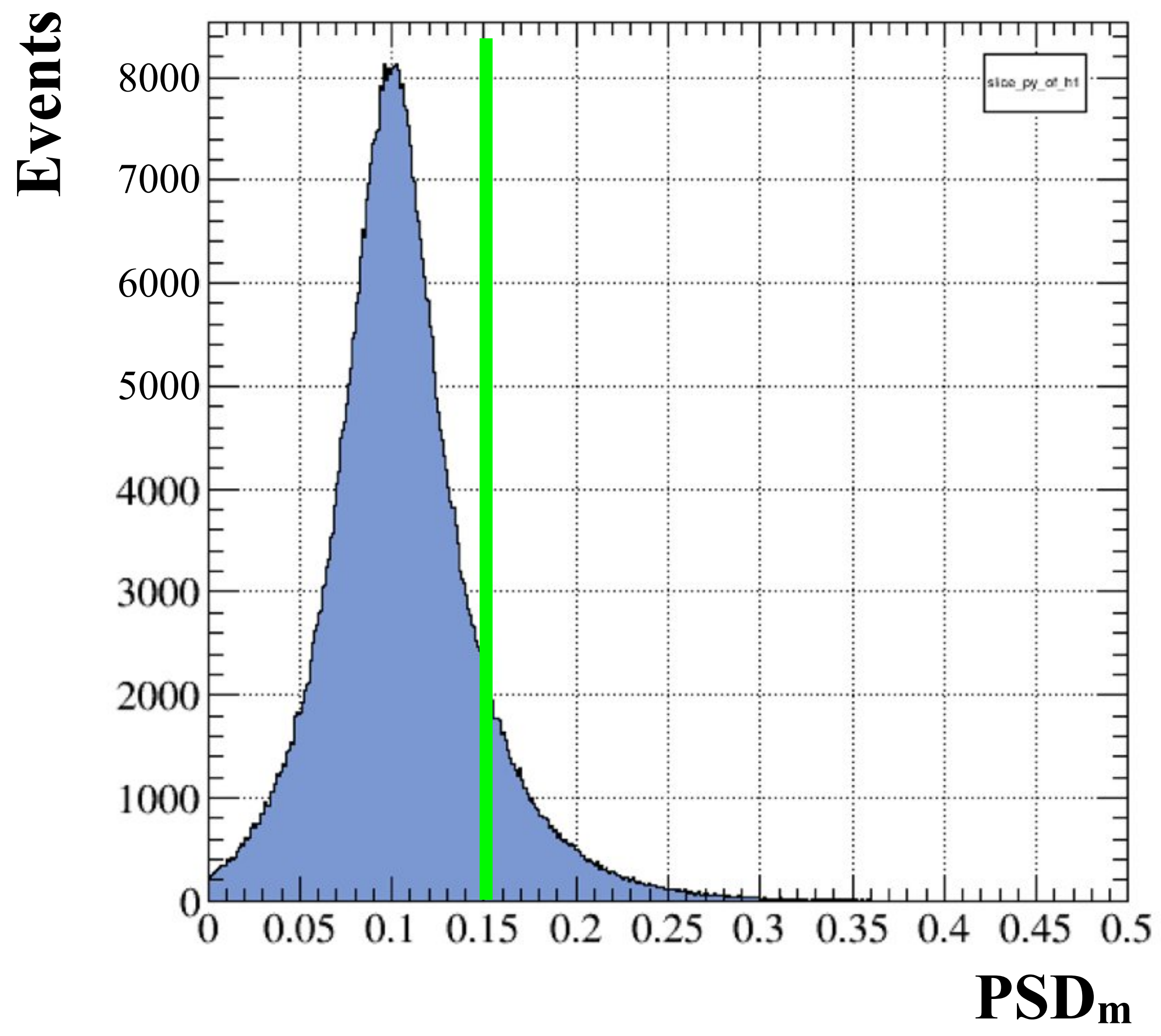


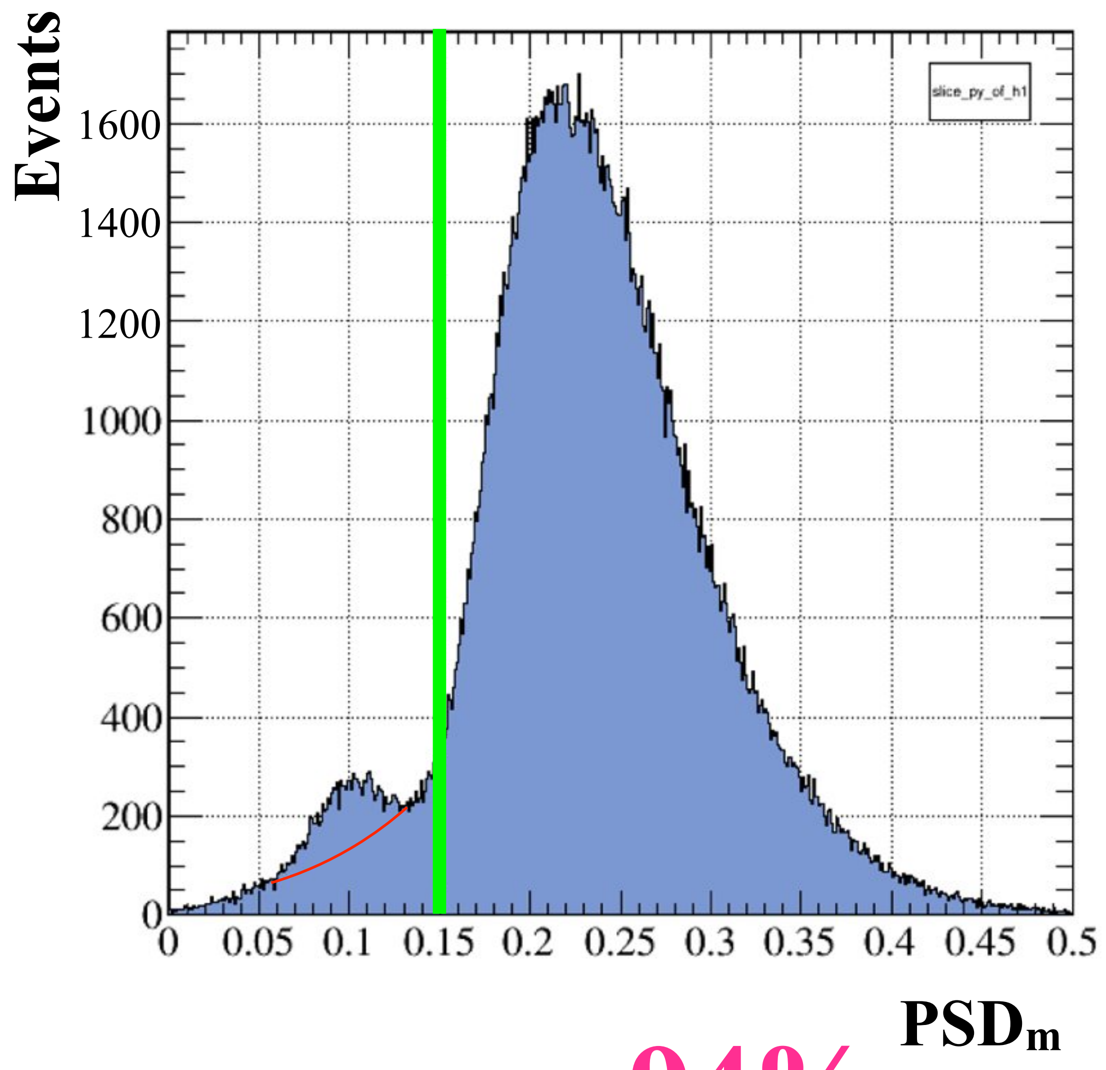
We improved further the separation using digital system

Study of the performance

The separation can be checked by ToF







~9%

gammas

~94%

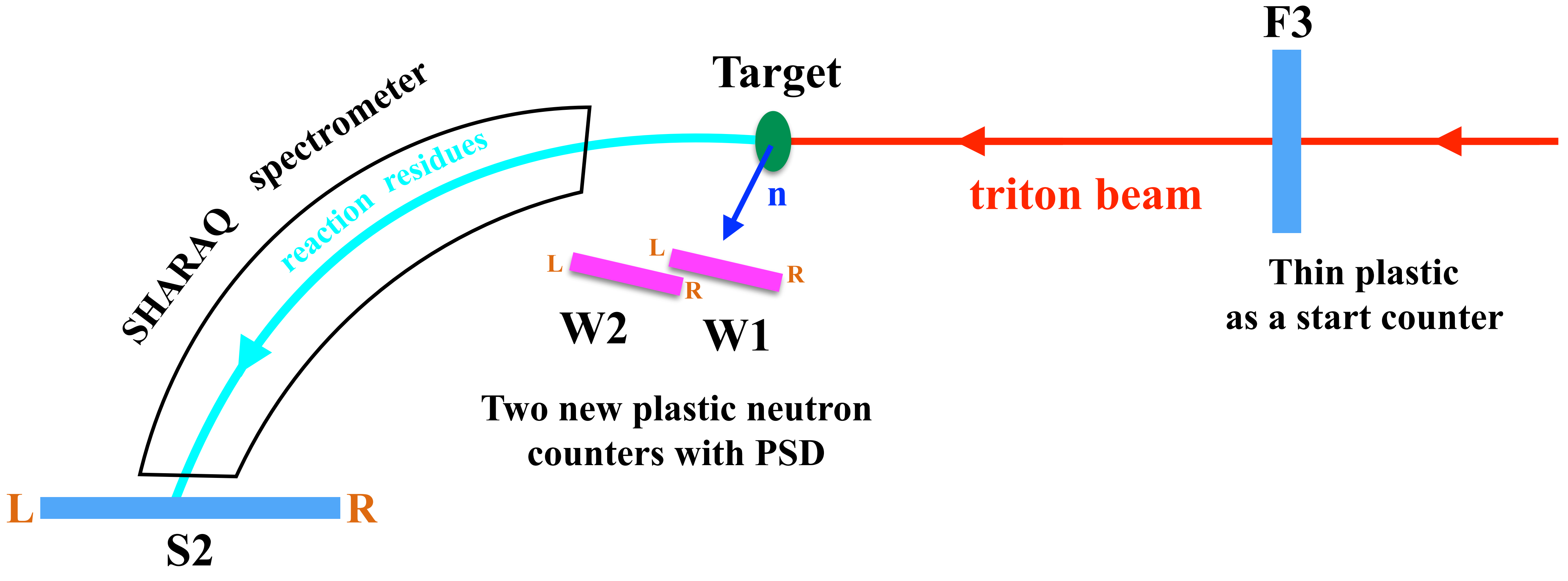
neutrons

By setting the PSD threshold at 0.15, 94% of the neutrons will be detected and only 9% of gammas.

First test experiment

Parasitic measurement during SHARAQ10 experiment at RIBF.

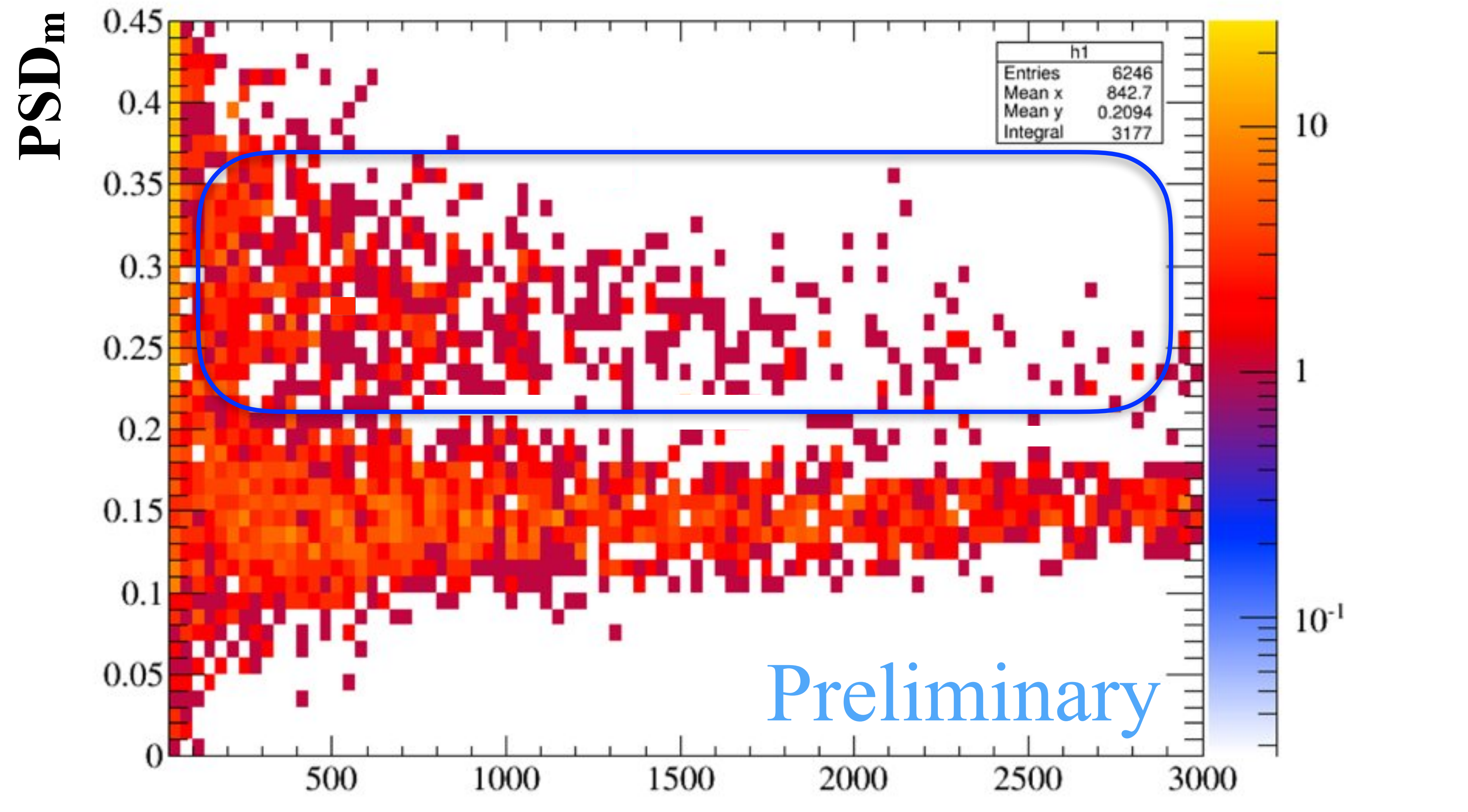
p(t,n)^{3}He inverse kinematics @ 310MeV/u. Only couple of hours.

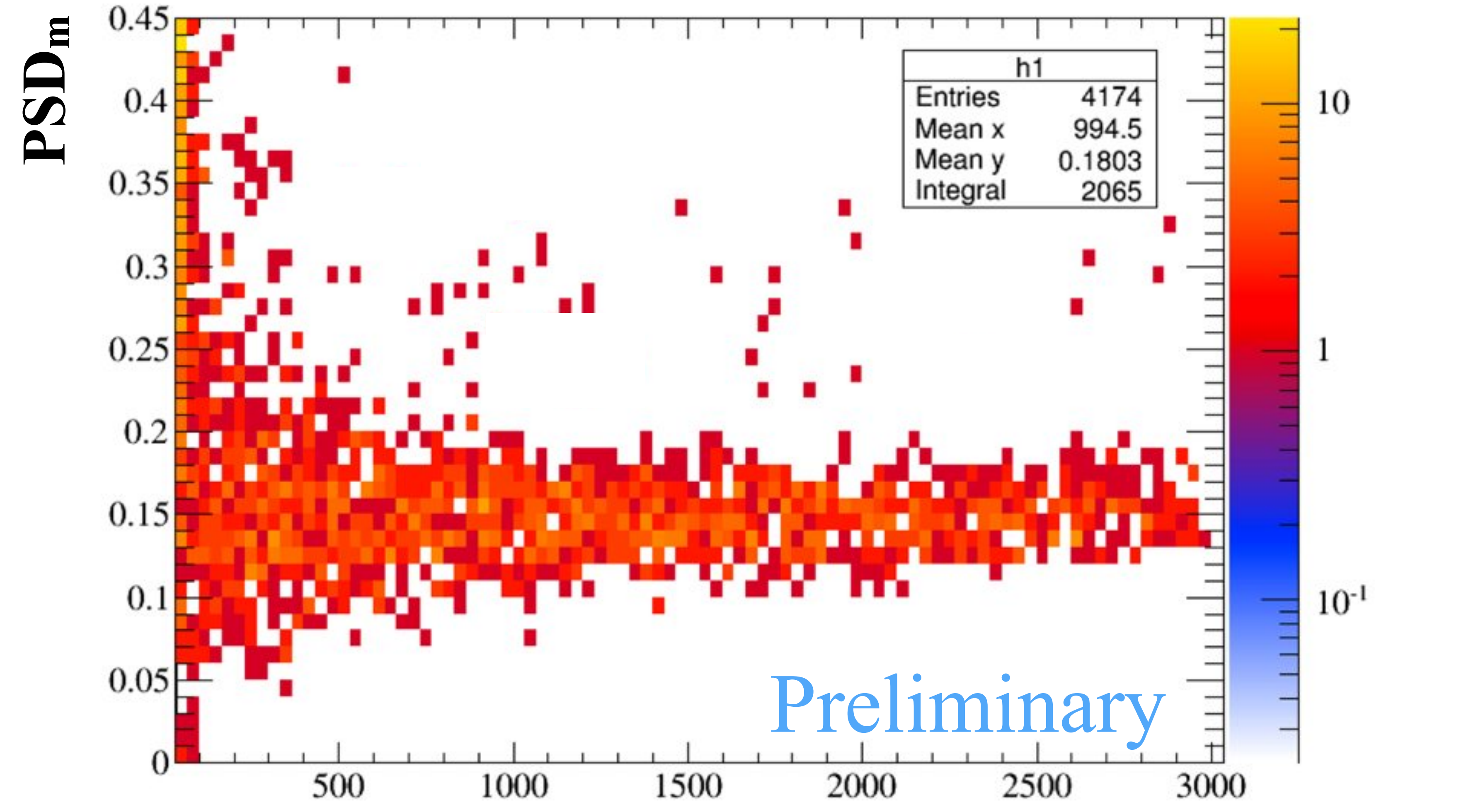


Triggering only on triple coincidence events.

Neutrons coming from the (p,n) reaction were identified

Different cuts in ToF spectra.





Summary and outlook

Good signal-to-noise ratio in both online and offline in (p,n), (d,n) reaction

A large volume low-energy neutron detector with online particle identification.

Successful online separation by using a new method.

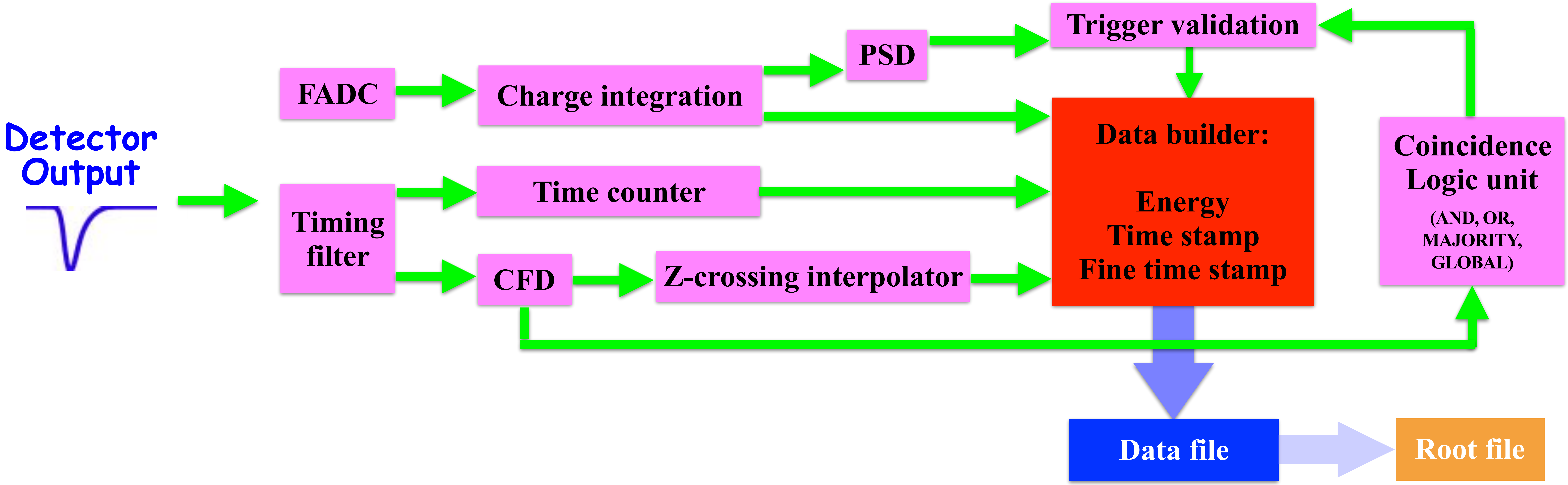
Further improvement of FoM, study of effect of wrapping and time parameters.

Testing a new version of DPP-PSD firmware and the COMPAS program with CAEN.

Thank you for your attention!

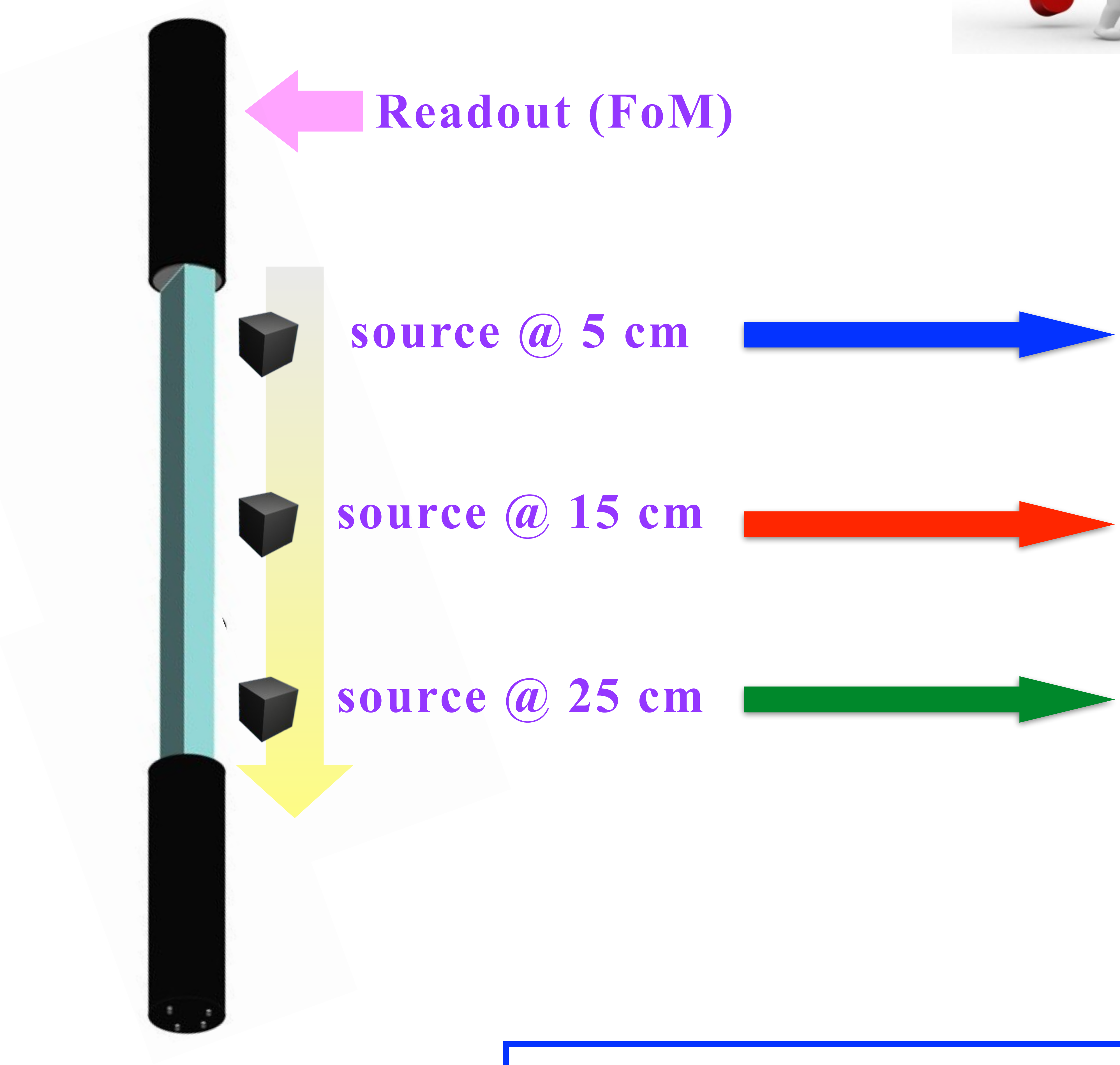
Backup

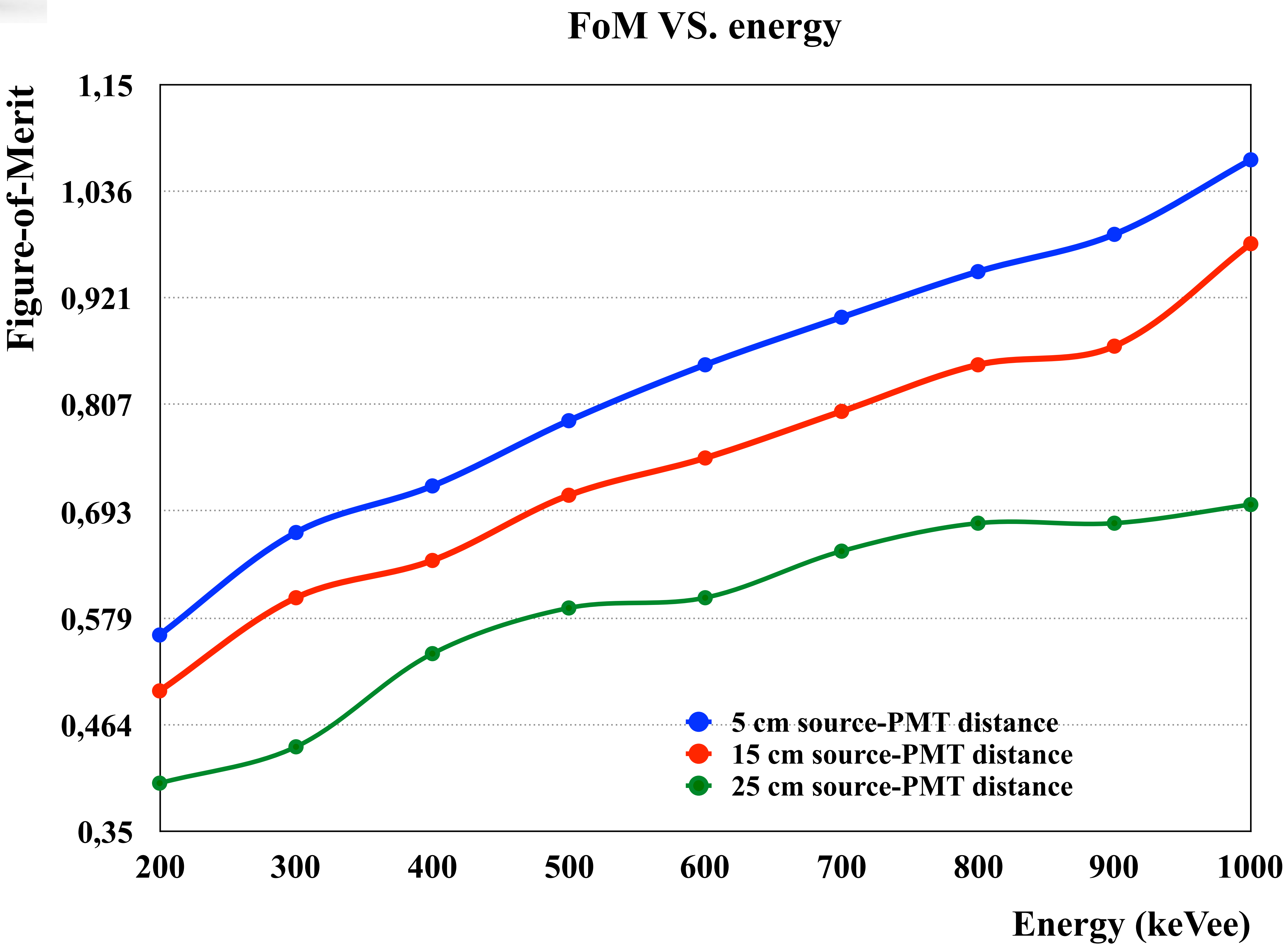
PSD capability based on charge integration method



Two different programable trigger levels.
Managing triggers in “local” (couple) or “global” levels in selected relations.

Change of FoM





The efficiency of the PSD drastically changing along the bar…

PSD optimisation

Very rough energy calibration, large uncertainty

HV optimisation

↓ FoM

QDC gate optimisation

↓ FoM

Tail delay optimisation

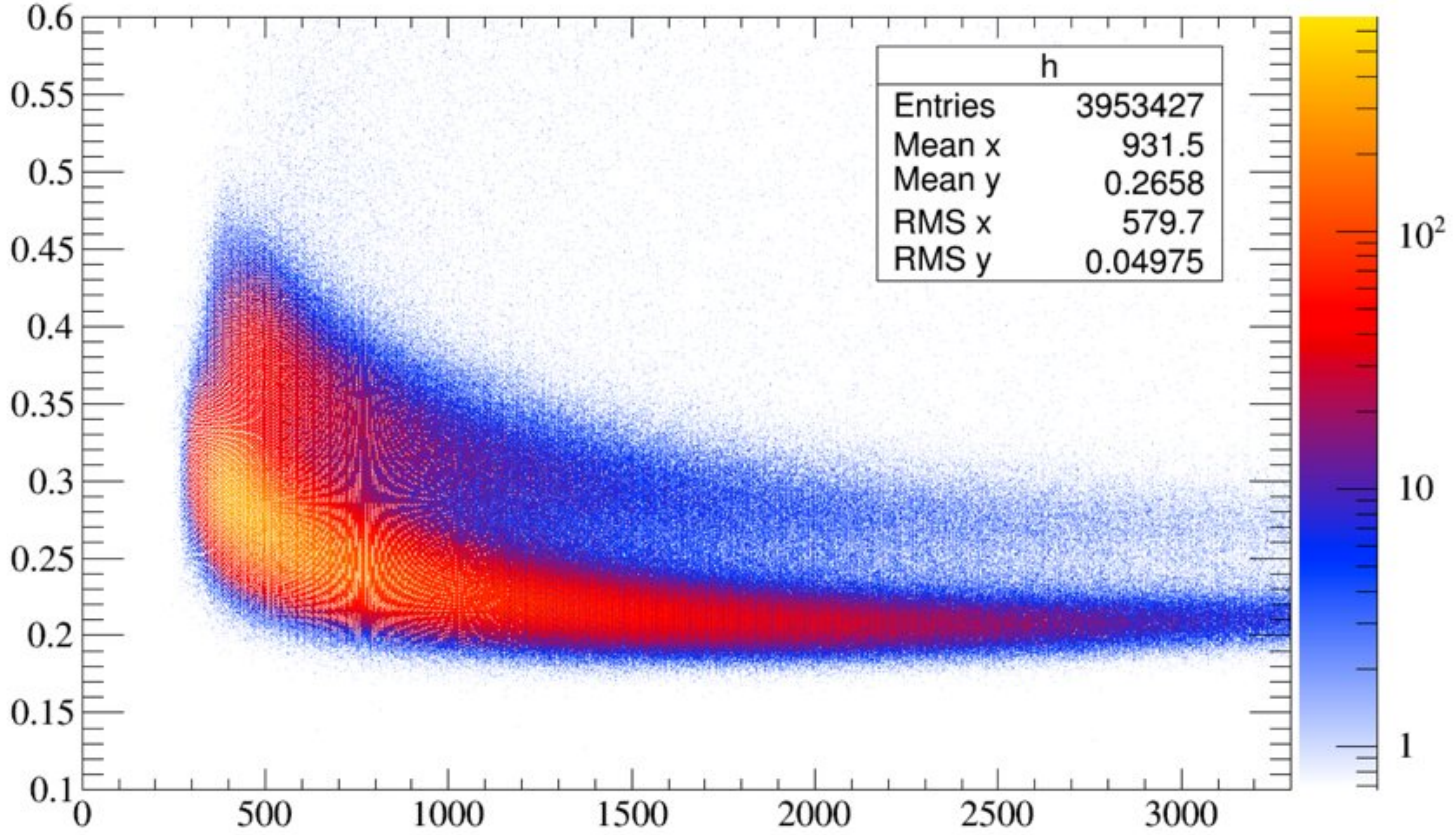
↓ FoM

Energy calibration

↓

Calibrated

Final PSD spectra → final FoM



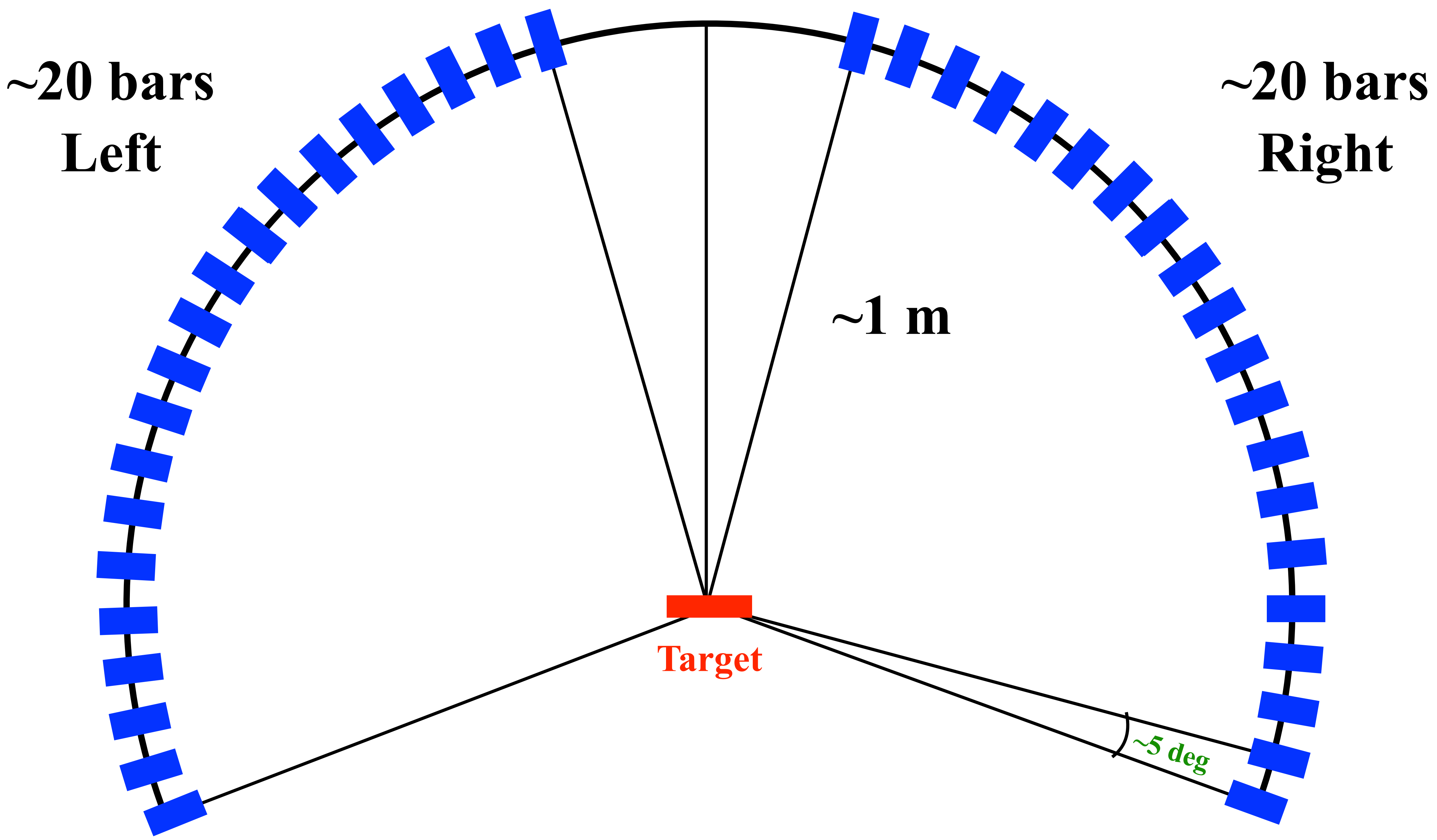
1 detector bar = 2 PMT + Plastic

Price for one detector bar: 492 000 ¥

Name	Price/pcs
EJ-299-34 plastic scintillator	¥ 272.000
Hamamatsu PMT (H7195)	¥ 110.000

Example for the experimental setup.

The frame of samurai17 can be modified and used for this system also.



Right side is shifted with 2.5 deg. compared to Left side

Triggering

CAEN

PSD "NEUTRON" or for all ch available
2 Ch coincidence of PSD "NEUTRON" also

Possibility to propagate a trigger to the TRG-OUT connector and provide it to an external board, while the TRG-IN connector is used to trigger the board from an external trigger source.

It is possible to set the coincidence of two channels and acquire them according to a PSD value. Coincidence and PSD settings can be adjusted via software.

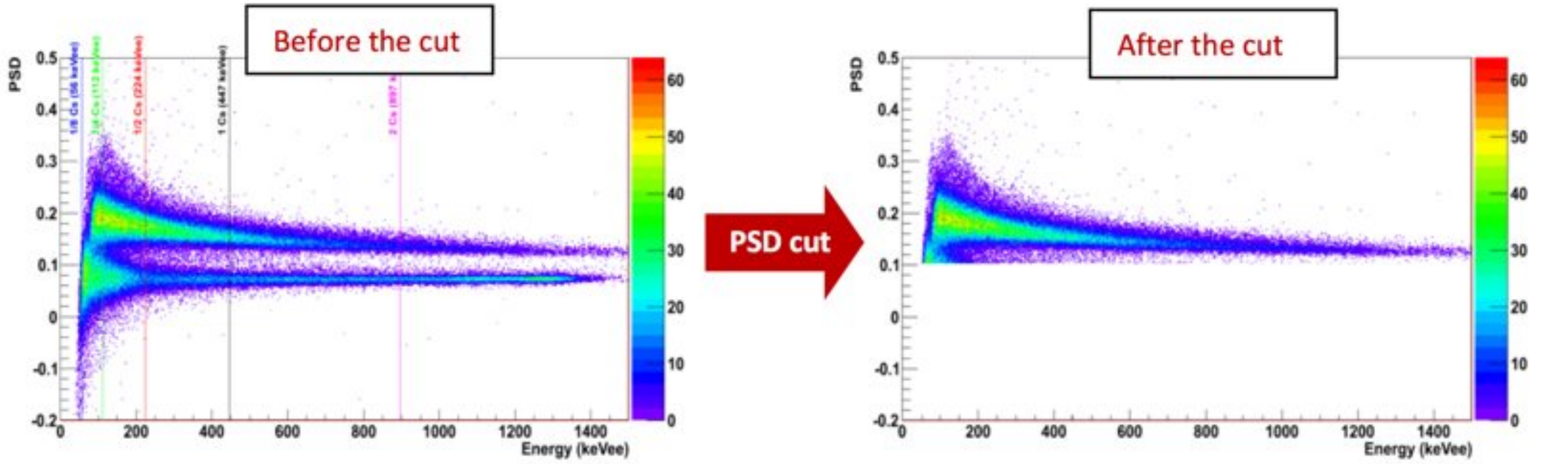
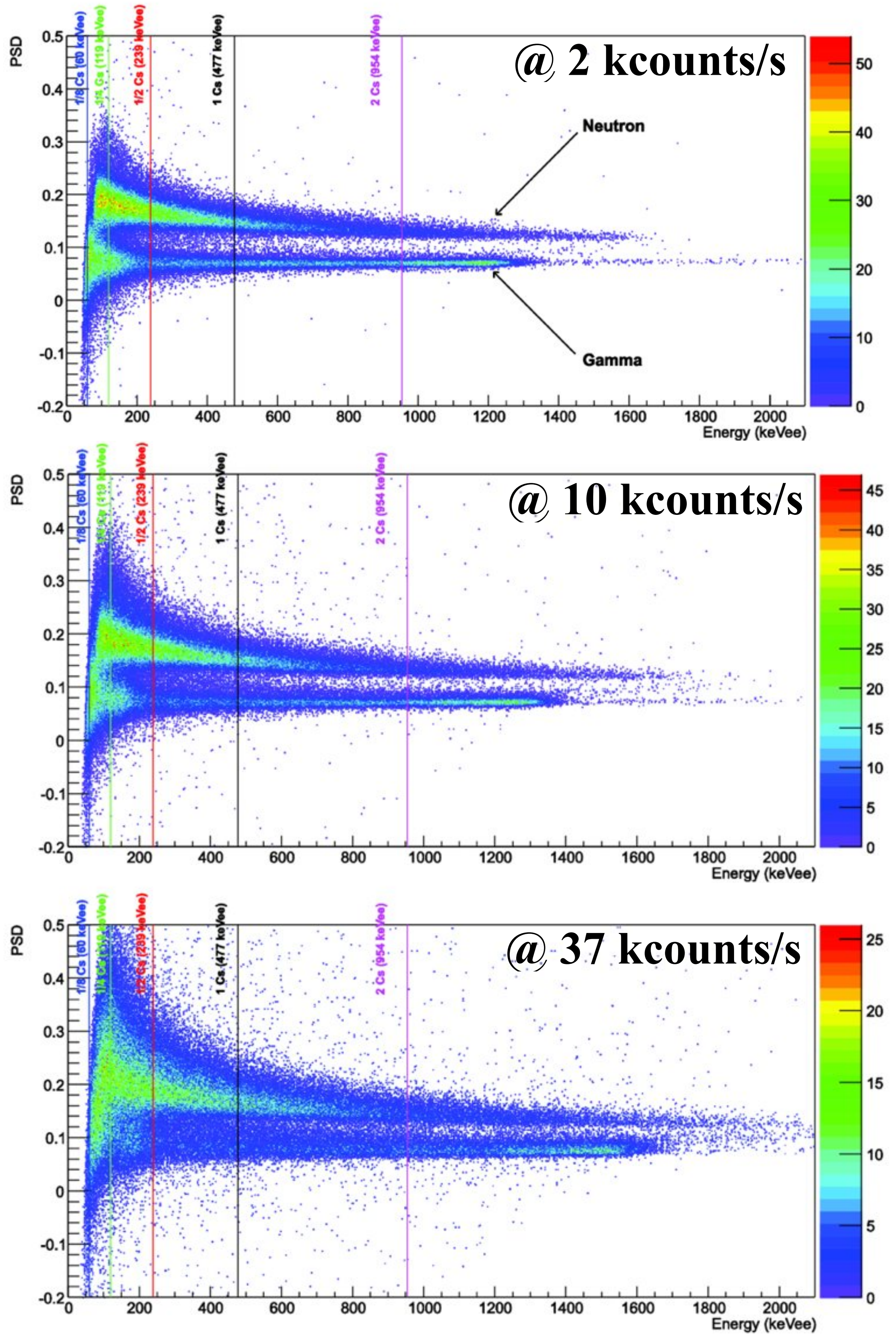


Fig. 2.9: 2D scatter plot of PSD parameter vs Energy in a neutron-gamma application. On the left the 2D plot before the cut, on the right the plot after the cut on PSD

FoM VS. cont rate

CAEN

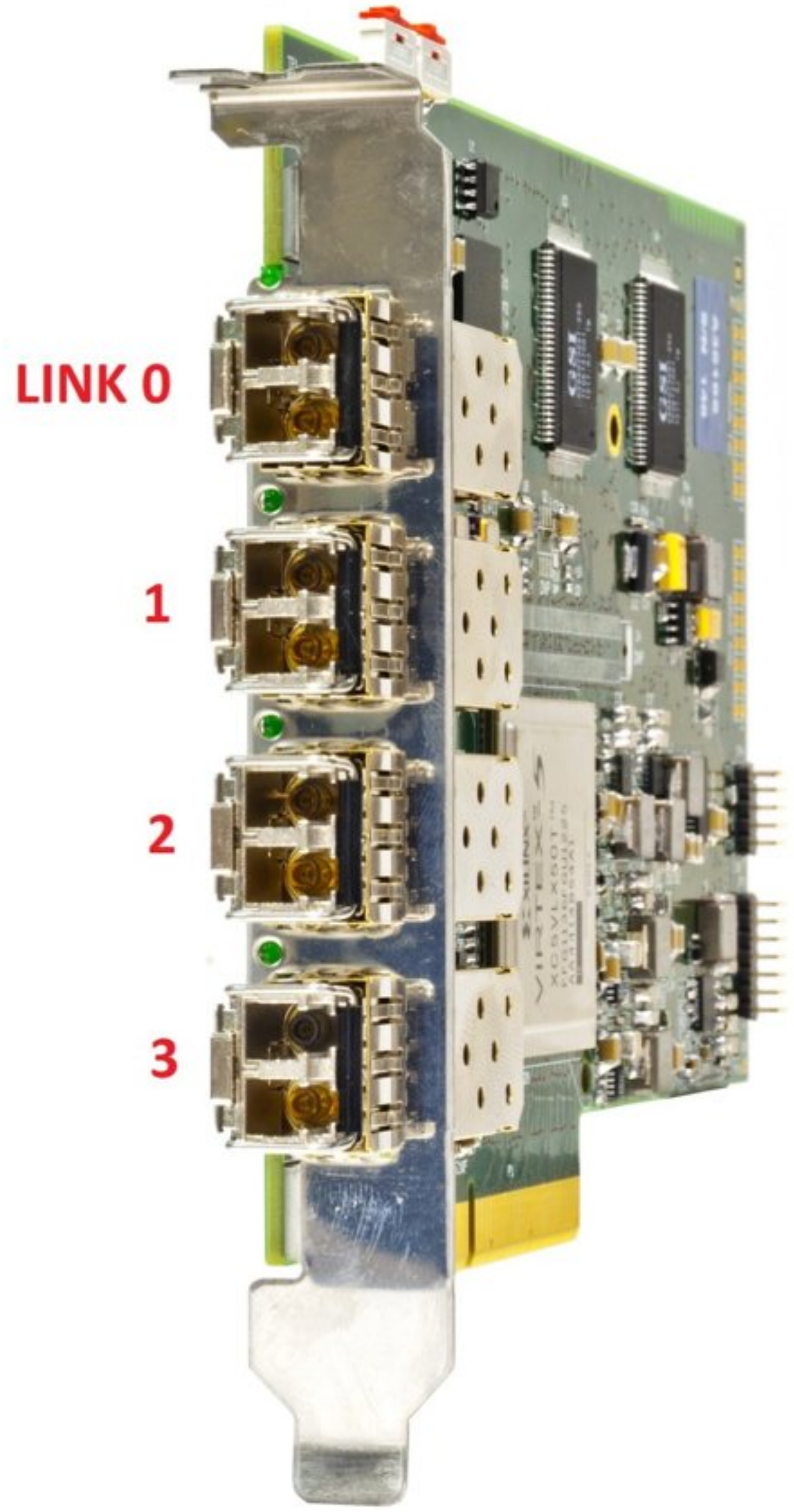
5" dia., 2" thick liquid scintillator (BC501-A) + Hamamatsu R1250 PMT. @ -1430V.



CAEN

Highlights

- 14-bit @ 500 MS/s
- Analog inputs on MCX coaxial connectors
- 16/8 channels, 1-unit wide 6U VME64 module
- 0.5 and 2 Vpp selectable input dynamic range with programmable DC offset adjustment
- Algorithms for Digital Pulse Processing
- VME64 (VME64X compliant) and Optical Link communication interfaces
- Multi-board synchronization features
- 16 programmable LVDS I/Os
- Daisy chain capability
- Demo software tools, DPP Control Software, C and LabVIEW libraries



CAEN

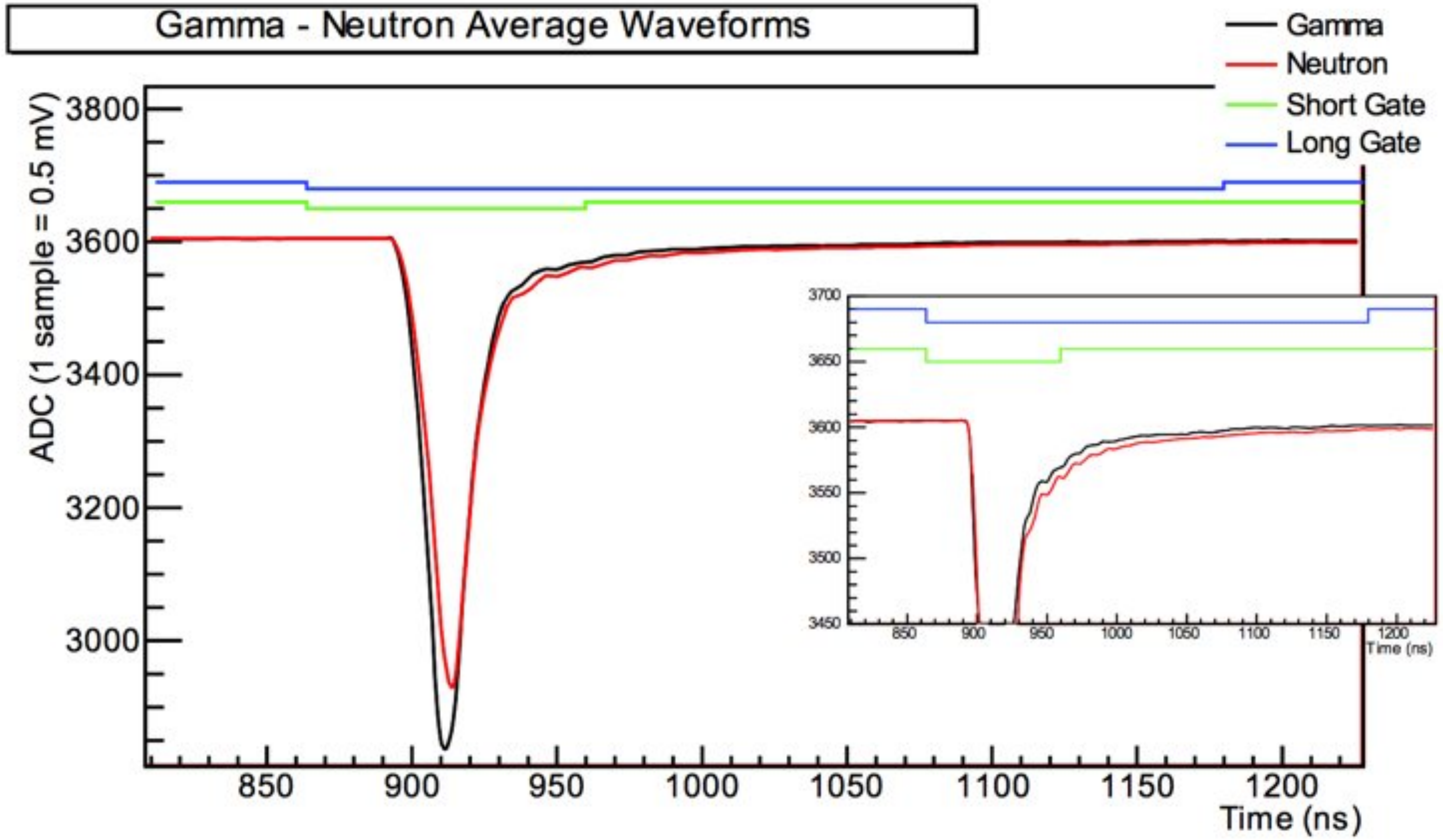
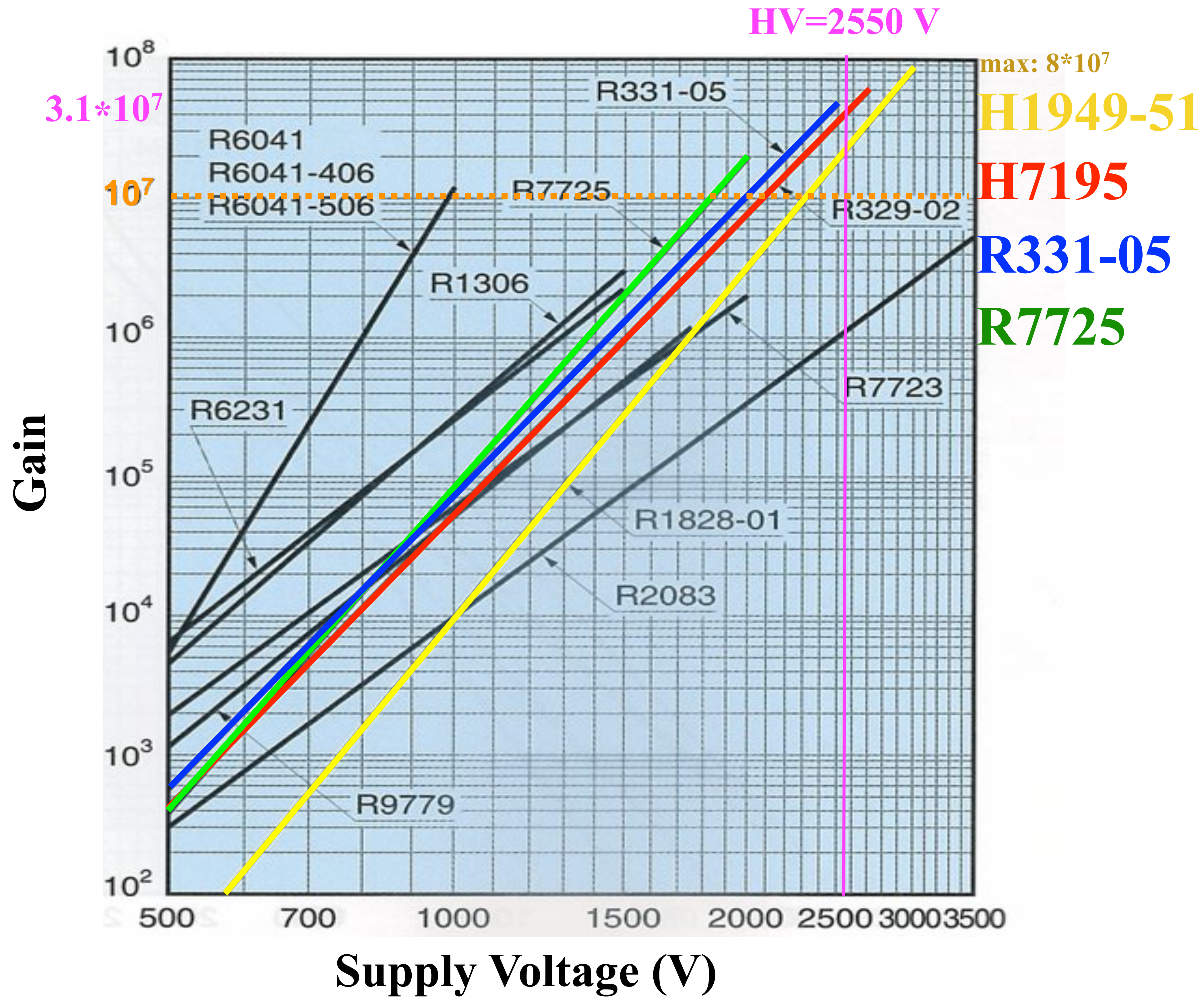


Fig. 1.1: Plot of typical Gamma-Neutron waveforms

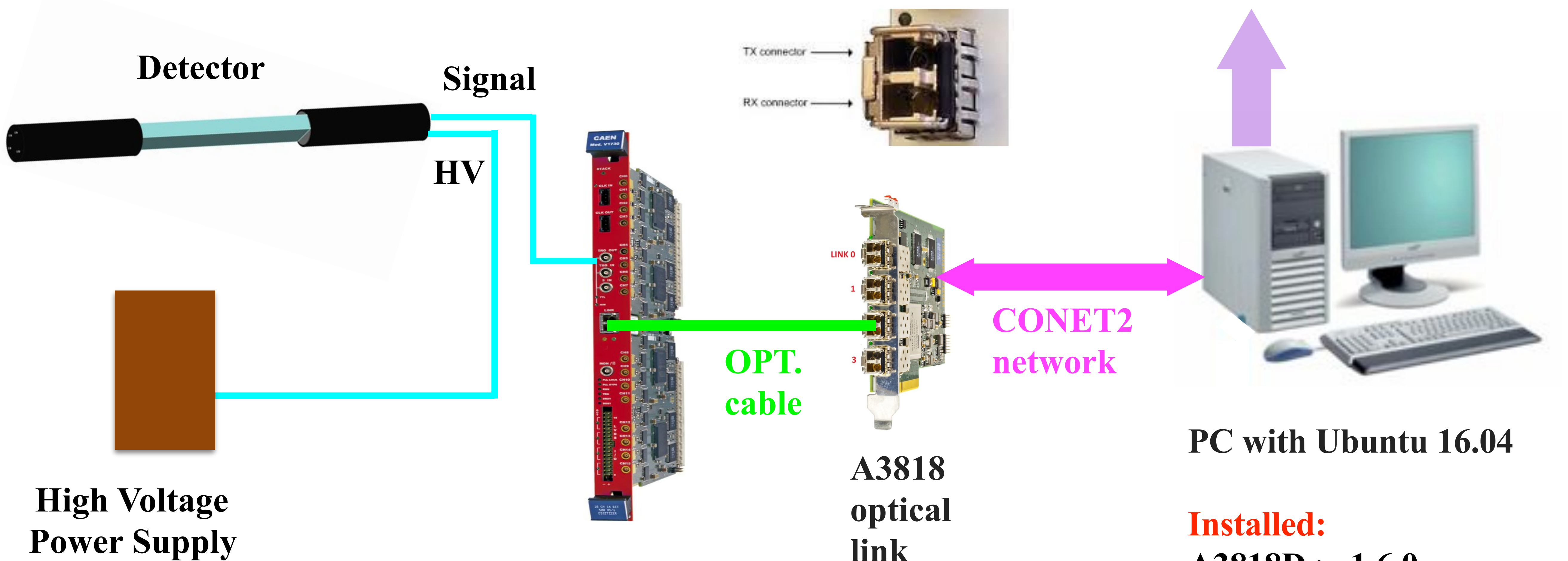
Typical Gain Characteristics for 51mm (2”) diam. types



1. DDAQ Standalone DAQ

List mode for
Energy, PSD, Time

RIBF DAQ



PC with Ubuntu 16.04

CAEN v1730D
+
DPP-PSD Firmware
+
Configuration file

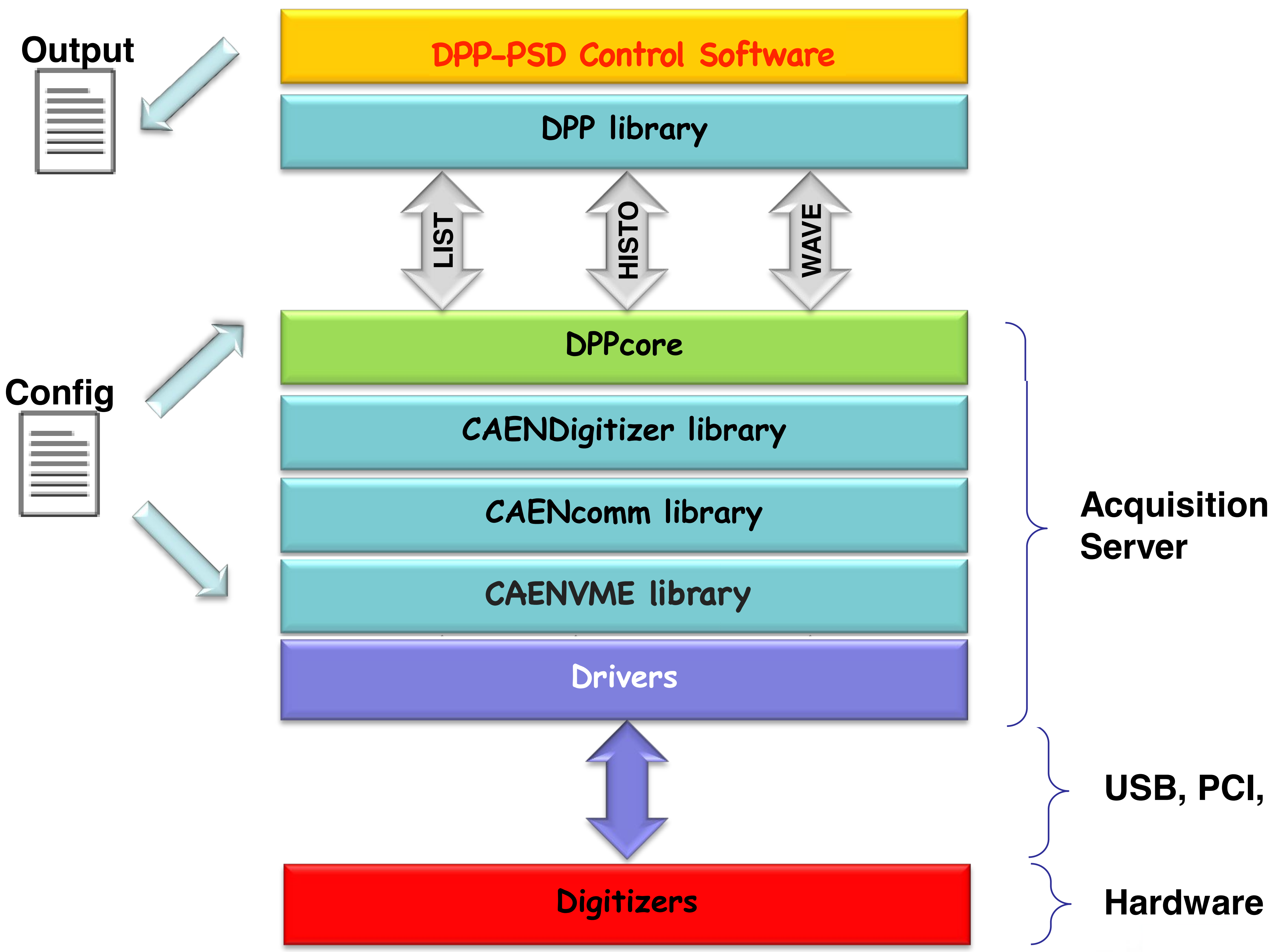
Installed:
A3818Drv-1.6.0

CAENVMELib-2.50
CAENComm-1.2
CAENDigitizer_2.7.2.
glibC
Java 8 JRE
CAENUpgrader-1.5.2

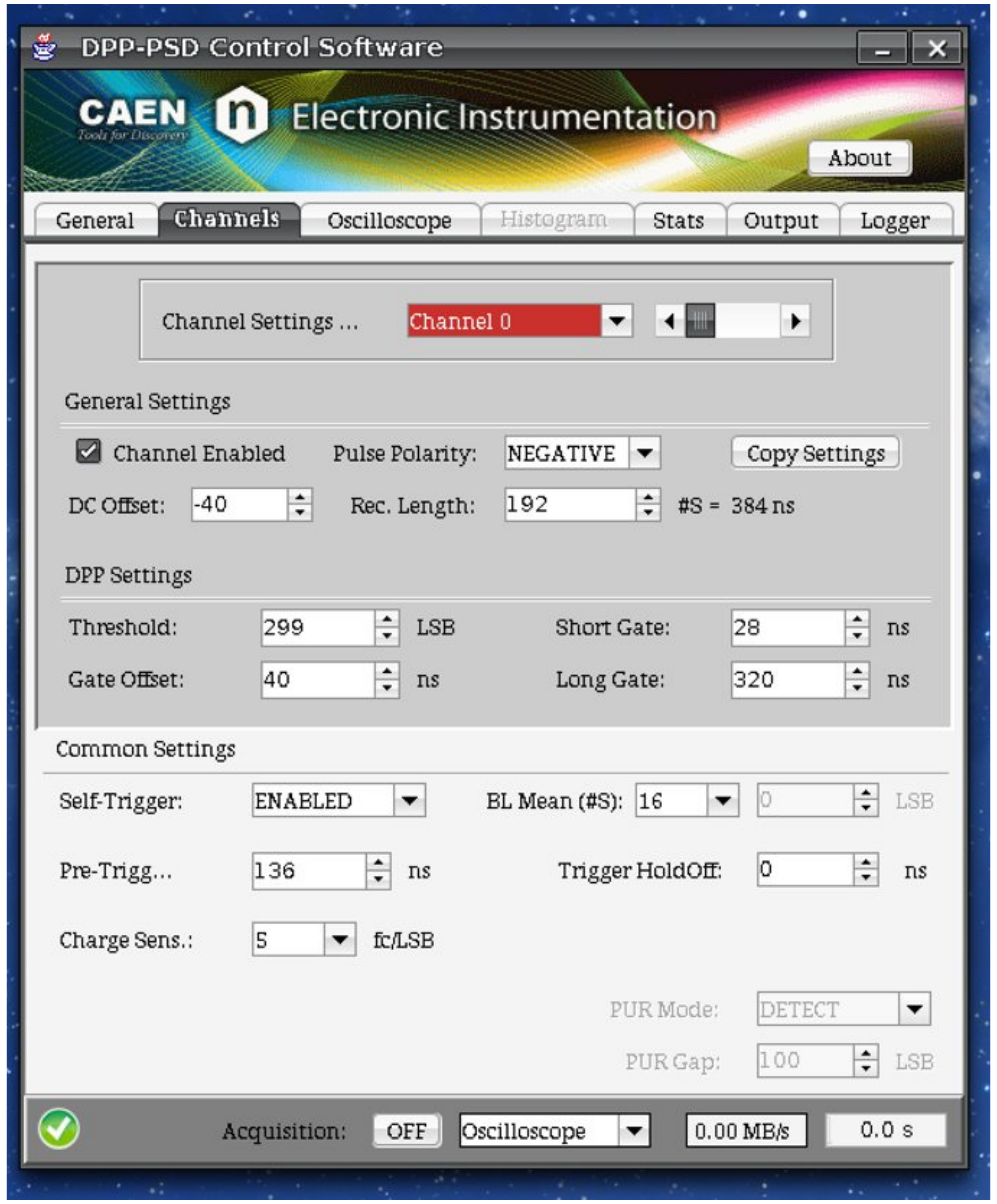
DPP-PSD_ControlSoftware-1.3.3.

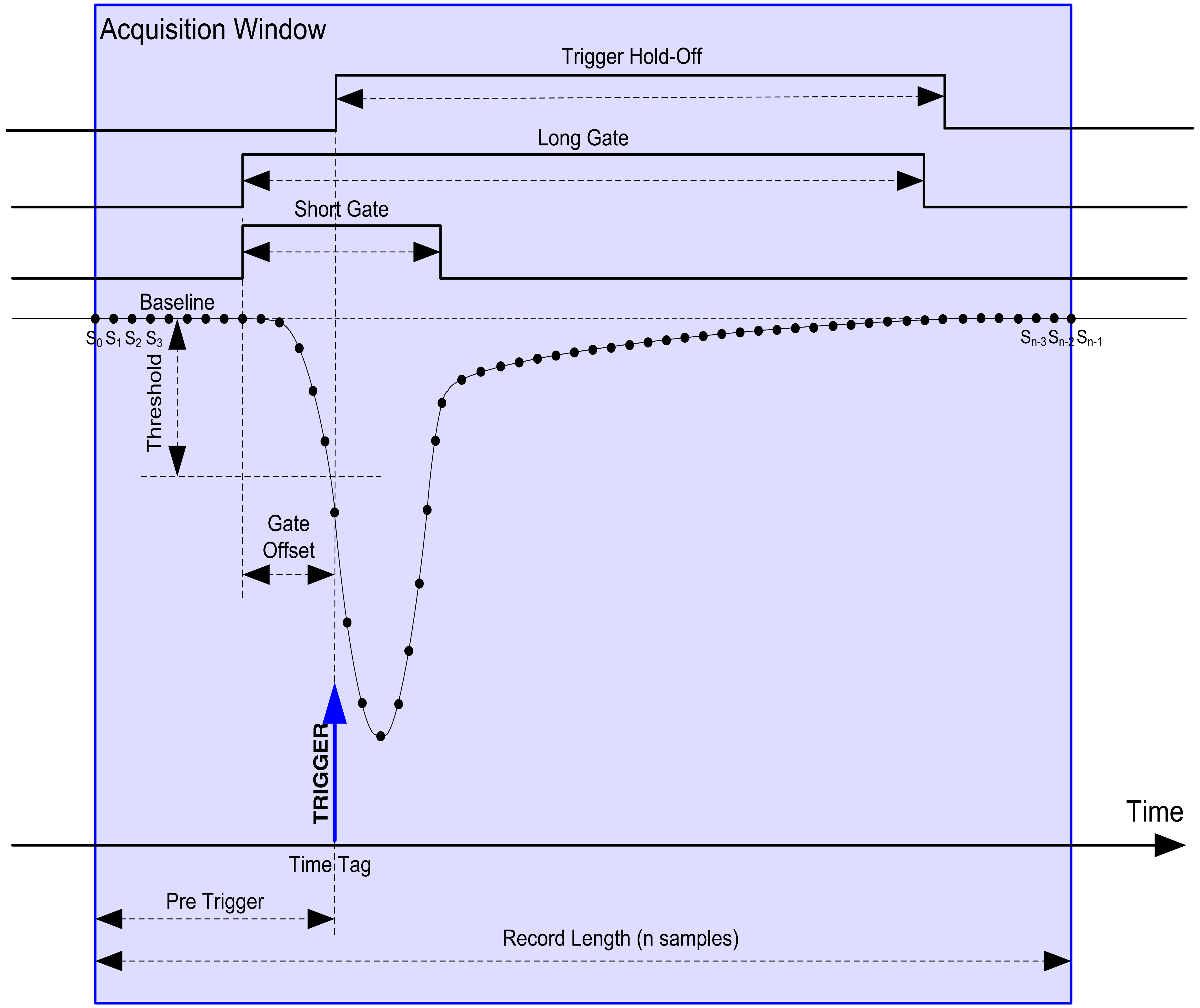
Motivation

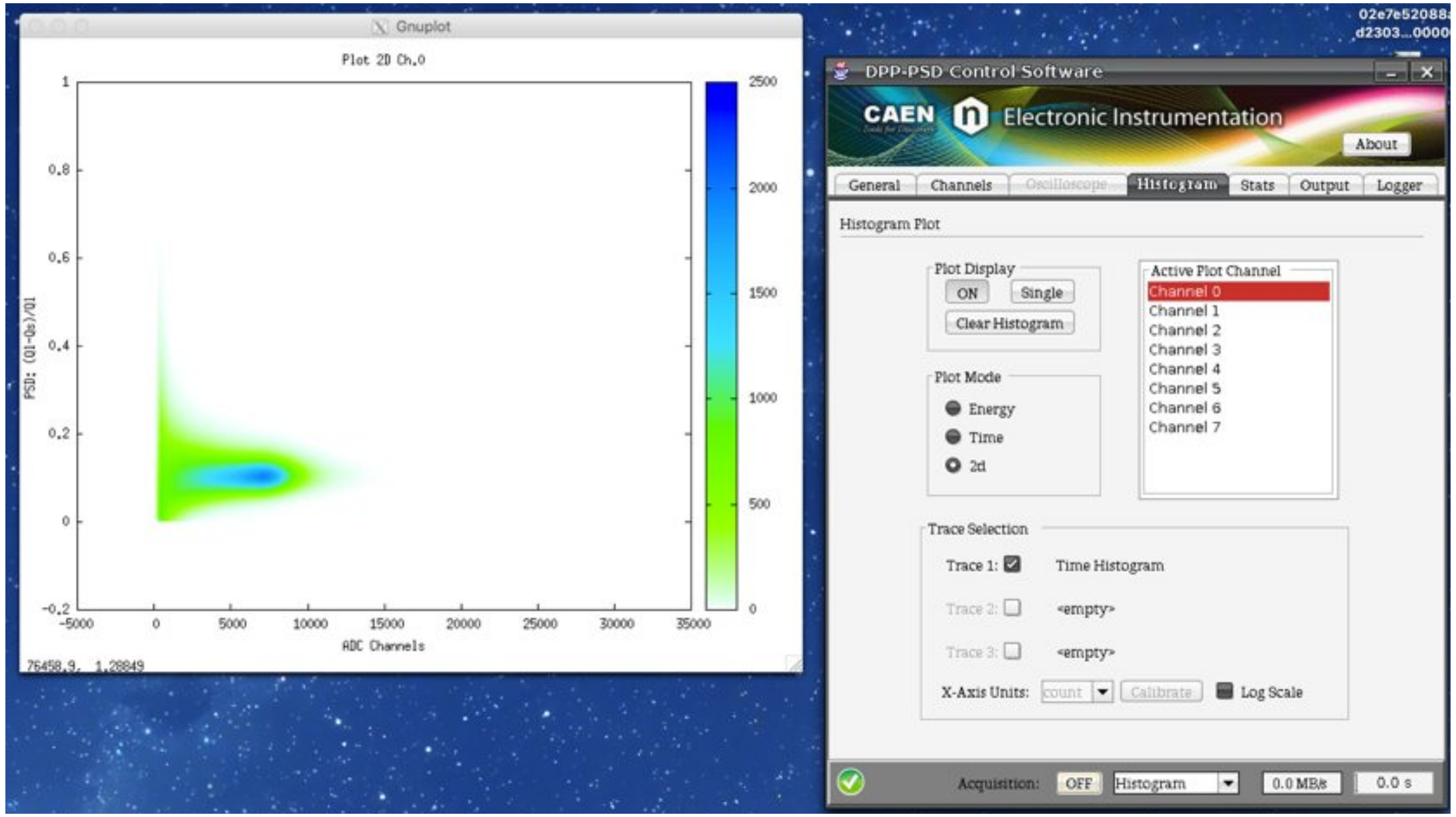
1. DDAQ



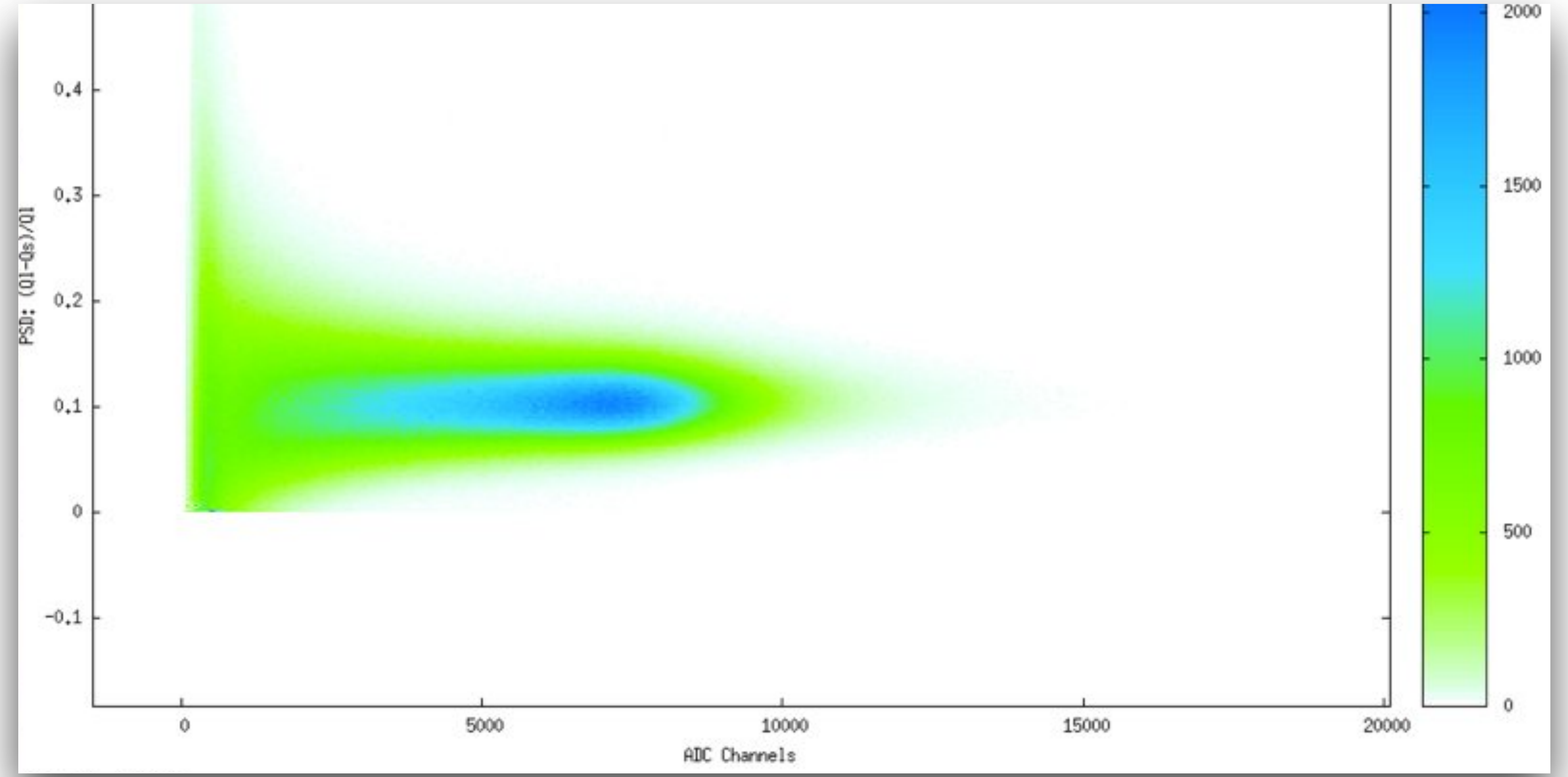
DDAQ

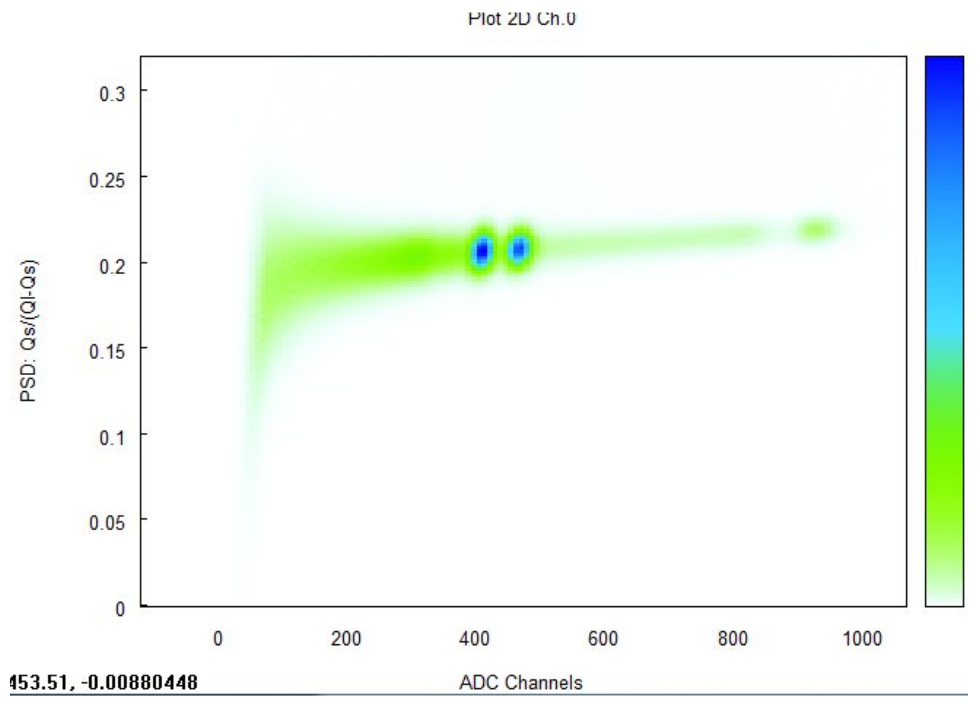

DPP-PSD Control Software
CAEN
Electronic Instrumentation
About
General
Channels
Oscilloscope
Histogram
Stats
Output
Logger
Channel Settings ...
Channel 0
General Settings
Channel Enabled
Pulse Polarity:
NEGATIVE
Copy Settings
DC Offset:
-40
Rec. Length:
192
#S = 384 ns
DPP Settings
Threshold:
299
LSB
Short Gate:
28
ns
Gate Offset:
40
ns
Long Gate:
320
ns
Common Settings
Self-Trigger:
ENABLED
BL Mean (#S):
16
0
LSB
Pre-Trigg...
136
ns
Trigger HoldOff:
0
ns
Charge Sens.:
5
fc/LSB
PUR Mode:
DETECT
PUR Gap:
100
LSB
Acquisition:
OFF
Oscilloscope
0.00 MB/s
0.0 s

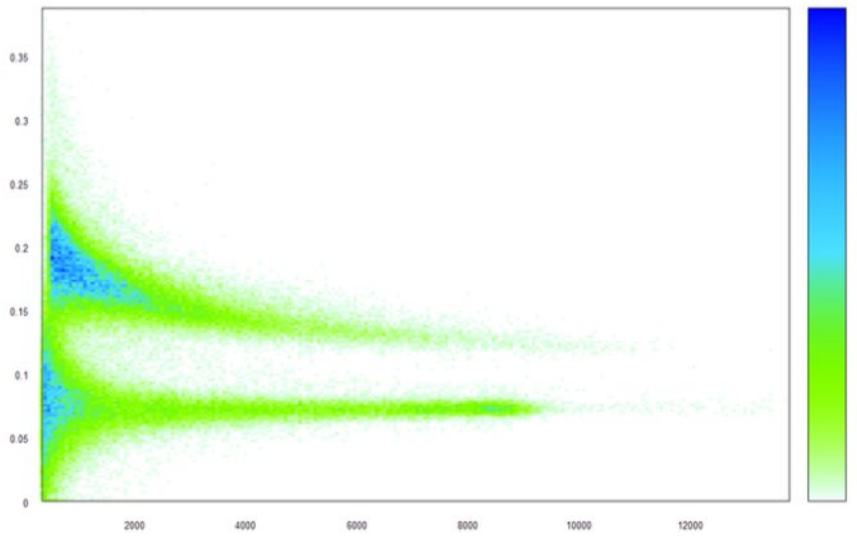

Acquisition Window
Trigger Hold-Off
Long Gate
Short Gate
Baseline
S_0 S_1 S_2 S_3
S_{n-3} S_{n-2} S_{n-1}
Threshold
Gate
Offset
TRIGGER
Time
Time Tag
Pre Trigger
Record Length (n samples)



^{137}Cs source at 5cm from PMT window

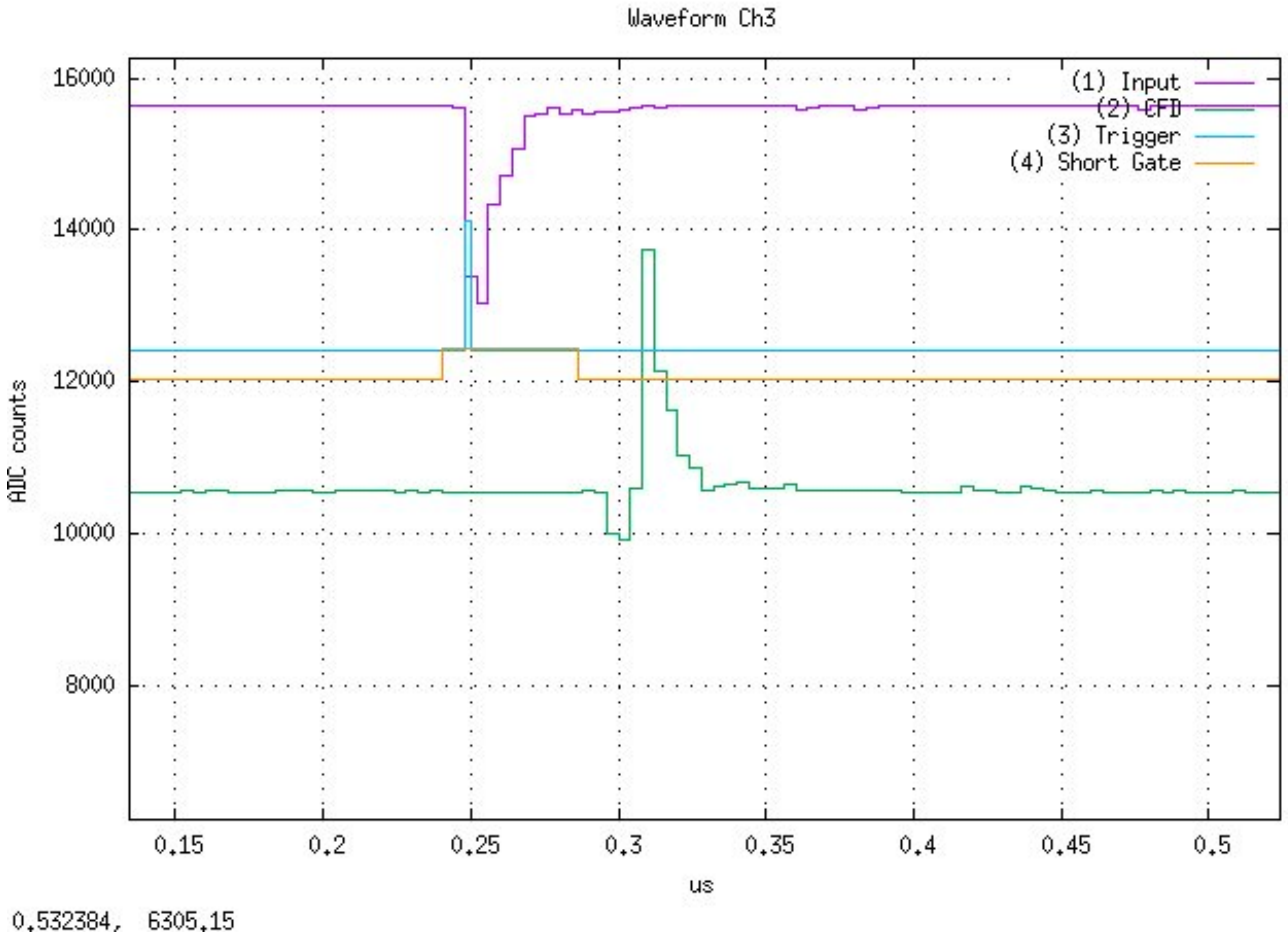






First results on PSD

Oscilloscope mode



To study the efficiency of the PSD

from the shaped pulse allowed to determine the decay time independent from the pulse amplitude.

Fig. 2. 4 channel pulse shape discrimination module MPD-4.

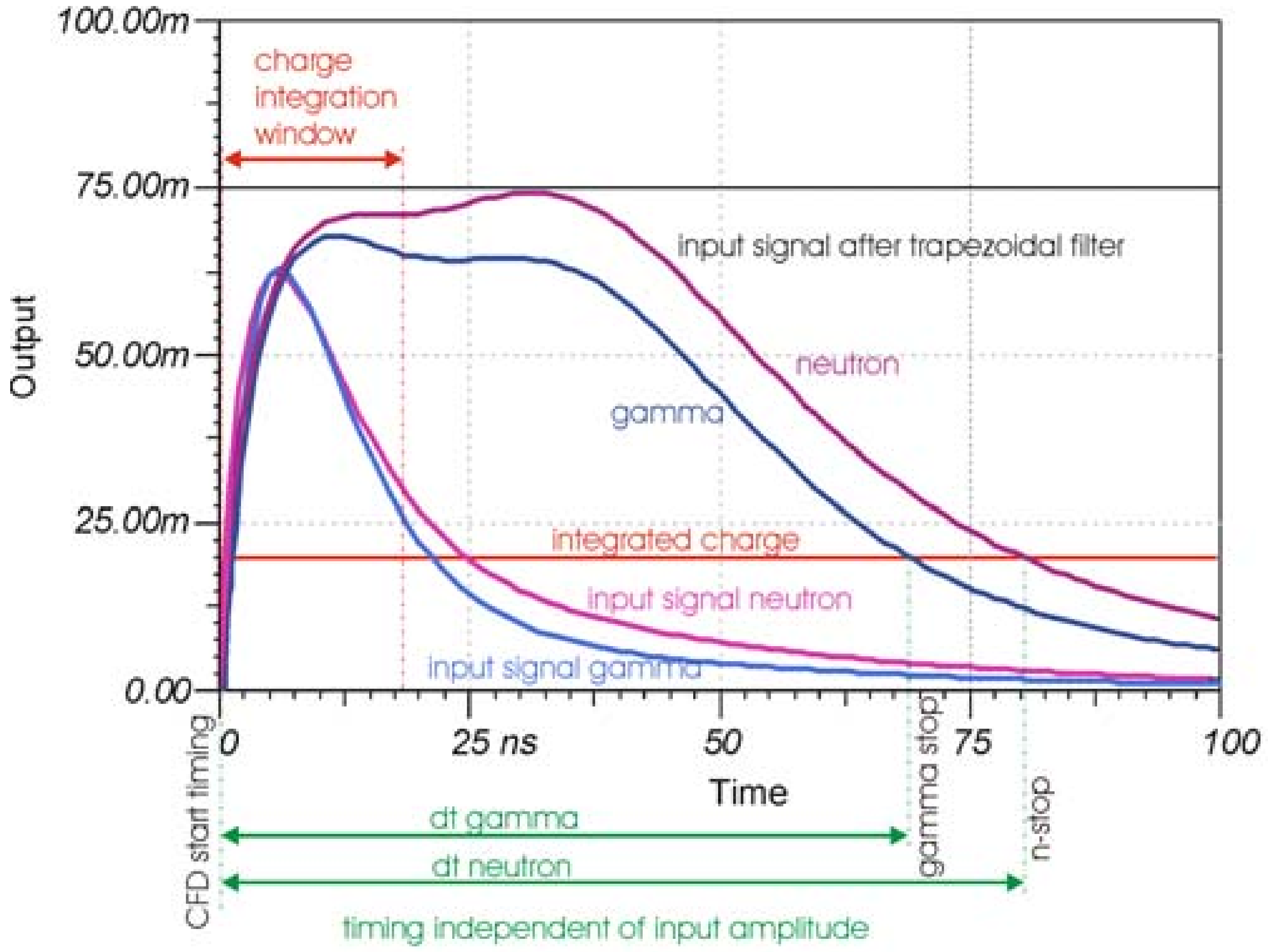
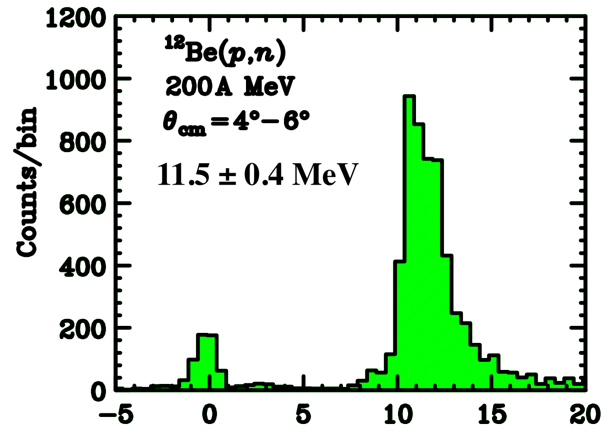


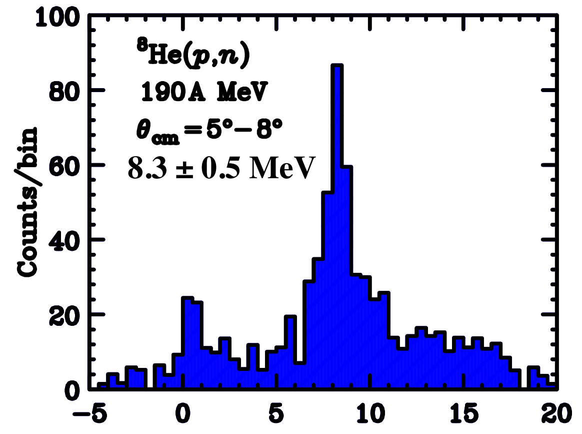
Fig. 4. Timing diagram with input pulses (light color) and shaped pulses (dark) for a typical neutron (purple) and gamma (blue) event. All timing signals are shown in green. The integral of the fast component is indicated by the red horizontal line.

The integrated fast component, which is proportional to the

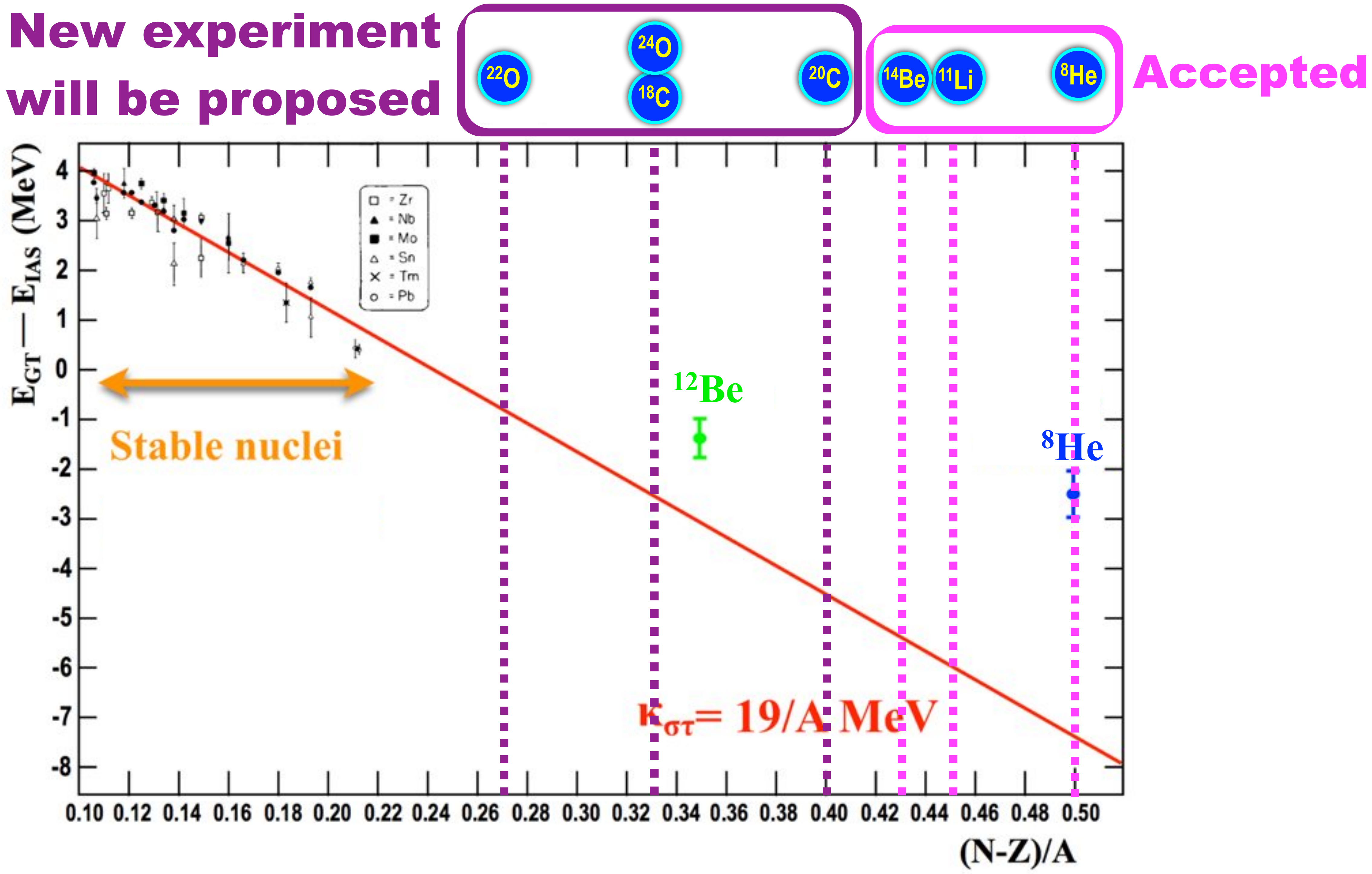
The goal of this project



H. Sakai et al., in preparation

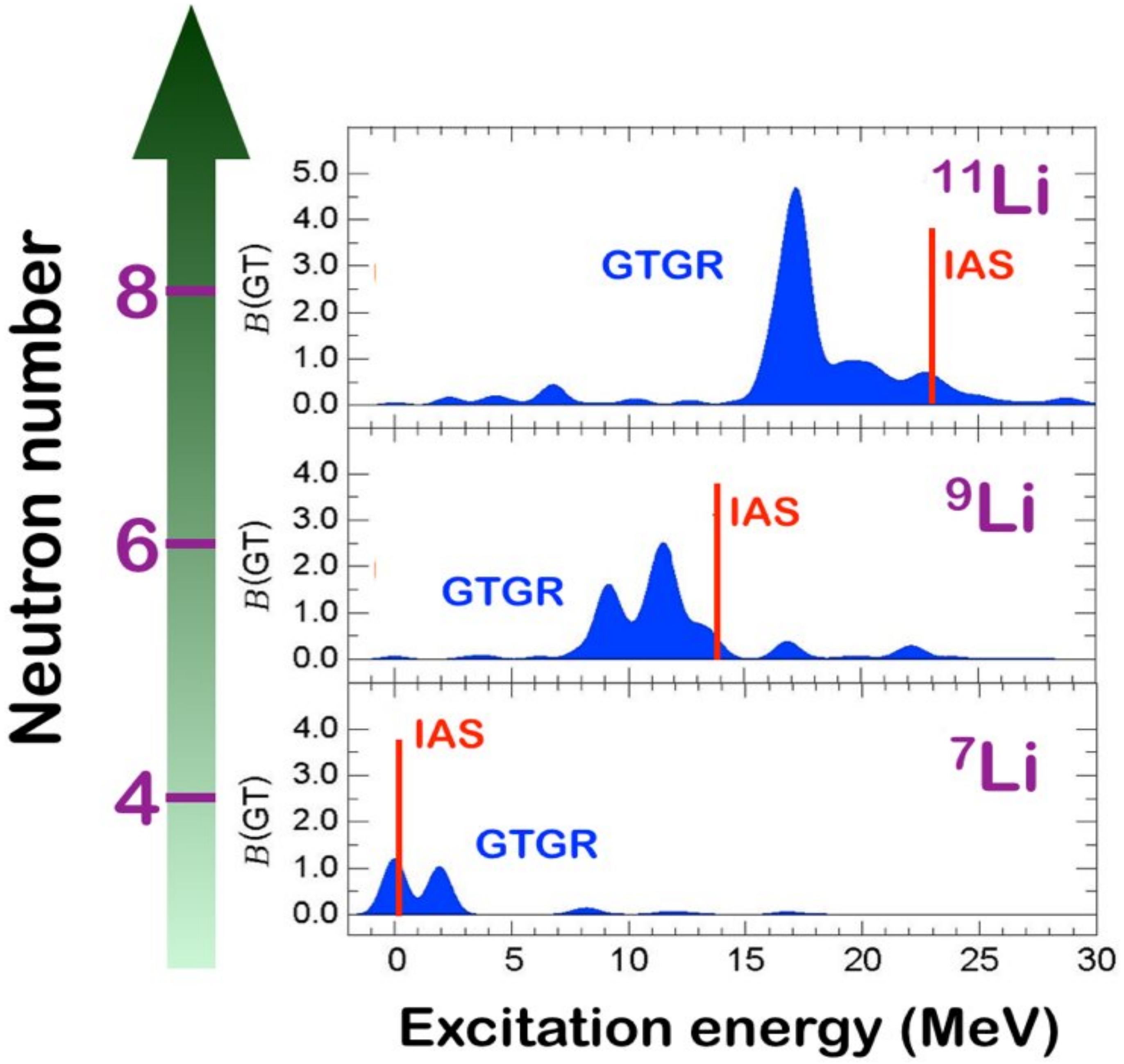


M. Kobayashi et al, JPS Conf. P. 1 (2014) 013034.



Expected: large set of experimental data in a wide (N-Z)/A range

Measurement of GTGR and IAS as a function of (N-Z)/A

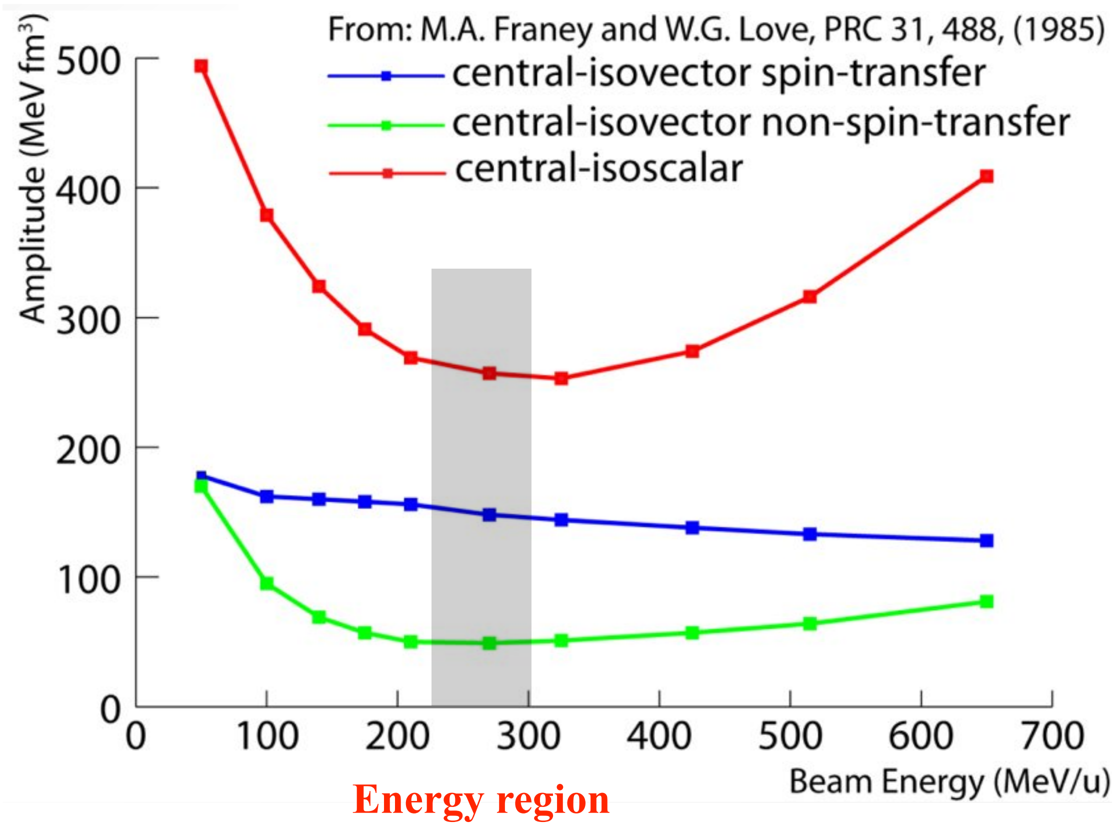


$$\langle E_{GT}\rangle - \langle E_{IAS}\rangle = \Delta E_{ls} + 2(\tilde{\kappa}_{\sigma\tau} - \tilde{\kappa}_{\tau})\frac{N-Z}{A}$$

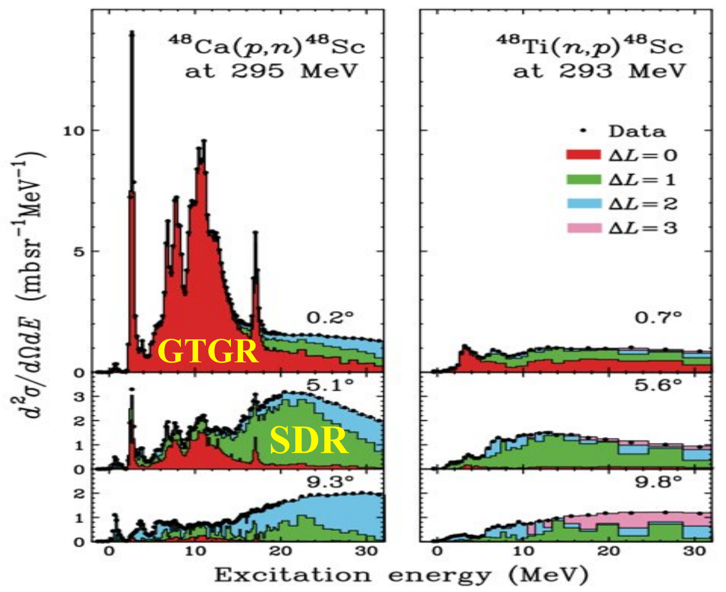
it is not known
for unstable nuclei

A good tool exists to investigate the spin isospin interaction

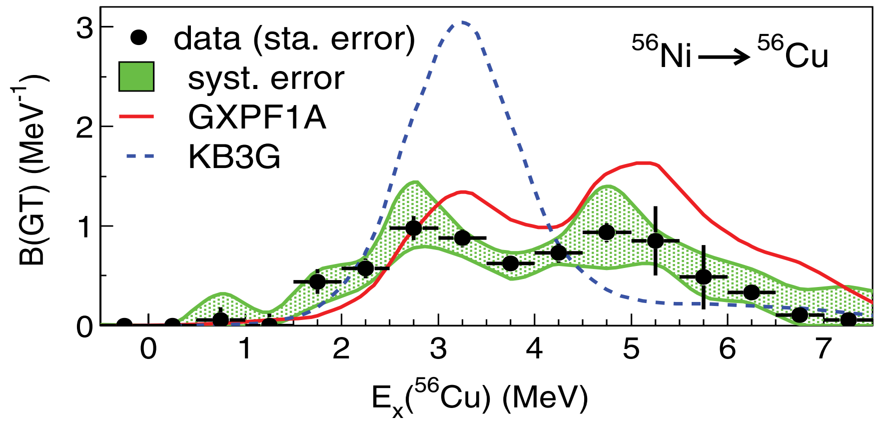
Charge exchange reactions



Energy region
of our proposed
experiment



K. Yako et al., Phys. Rev. Lett. 103 (2009) 012503.

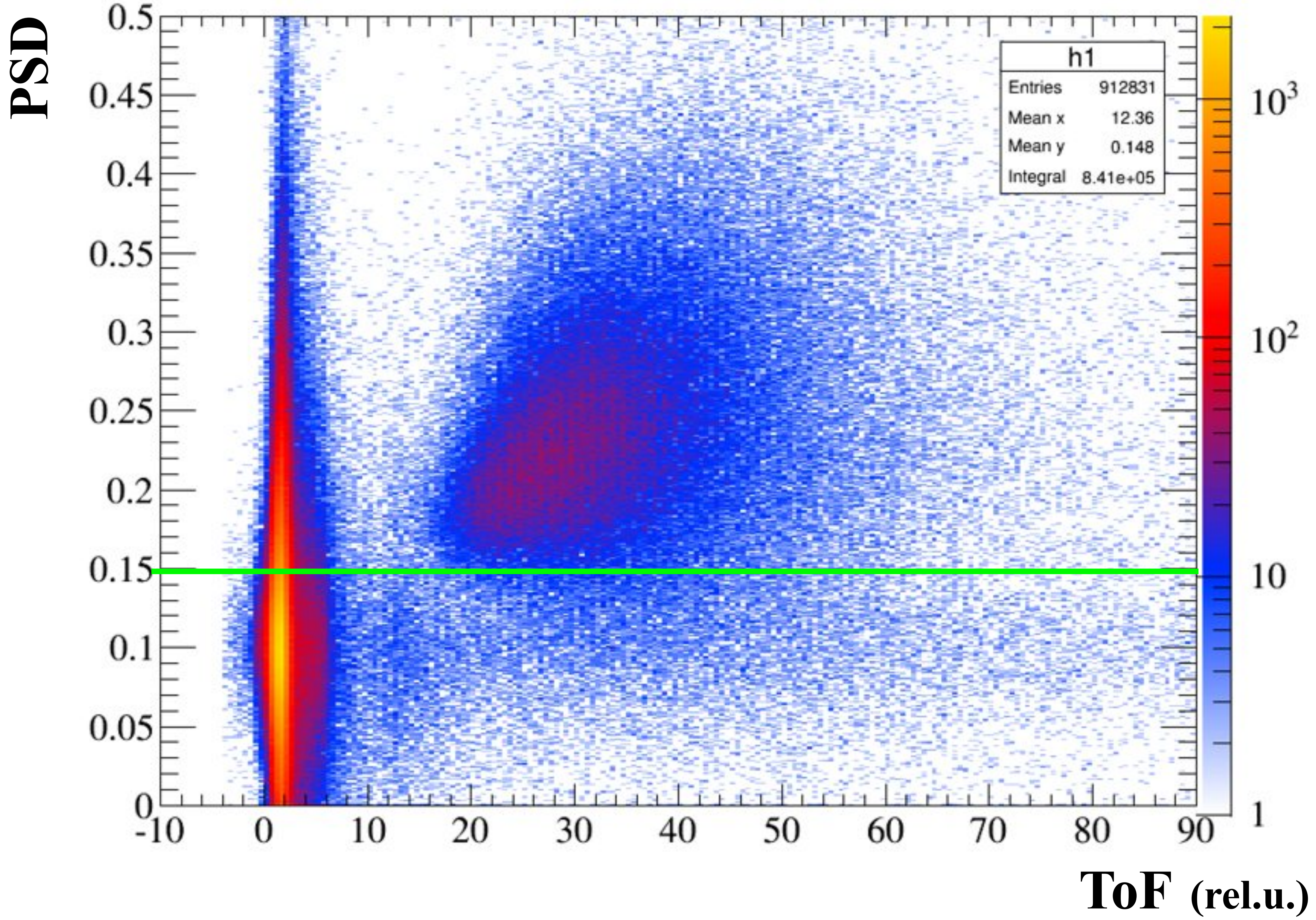


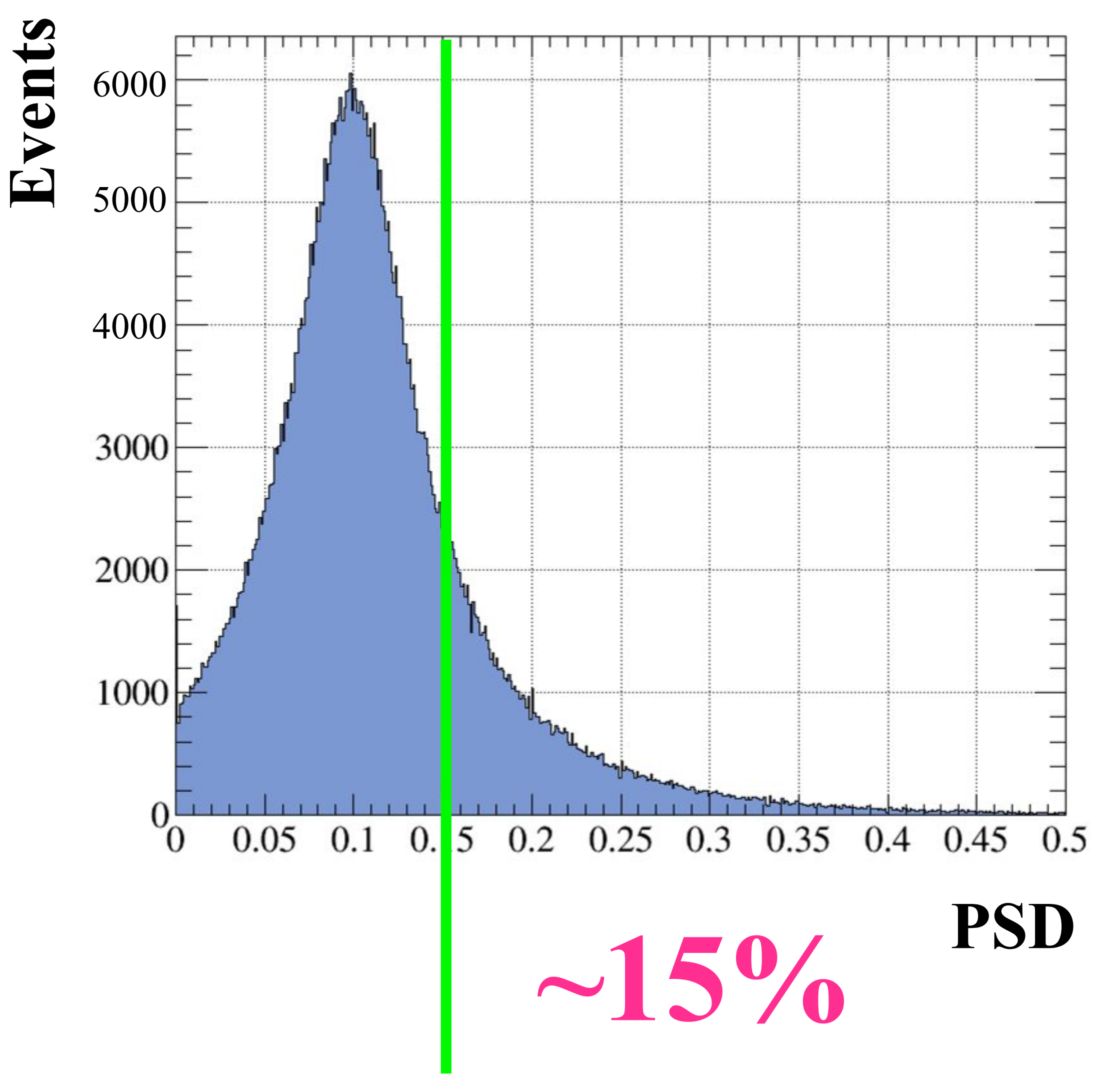
M. Sasano et al., Phys. Rev. Lett. 107 (2011) 202501.

The (p,n) reaction at intermediate energies is the best probe
to investigate the GT and SD strengths distributions
in a large excitation energy region.

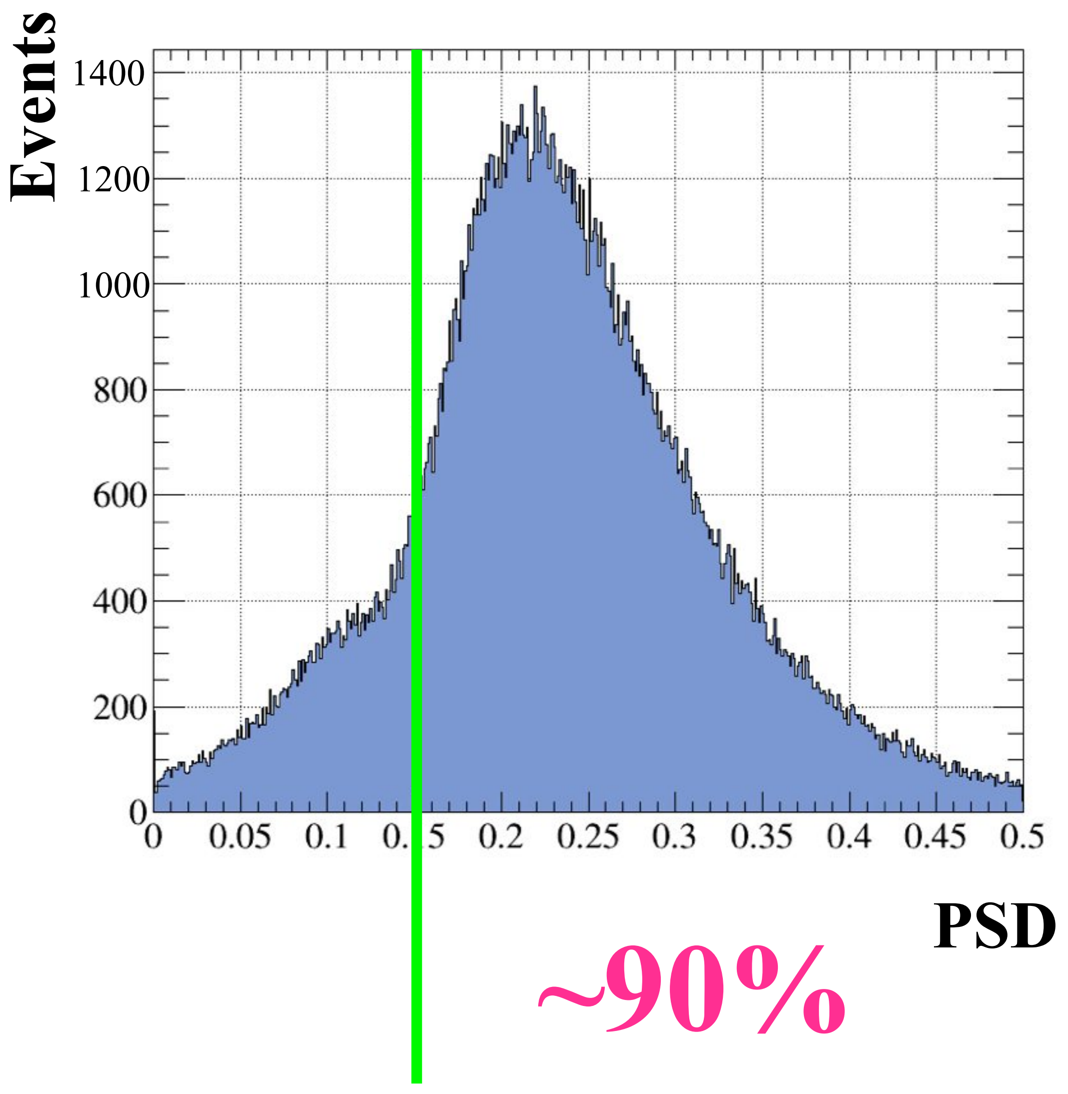
Study of the performance

The separation can be investigated by ToF





gammas



neutrons

By setting the PSD threshold at 0.15, 90% of the neutrons will be detected and only 15% of gammas.