Stilbene detectors: characterization, n+^{12}C preliminary results and future developments

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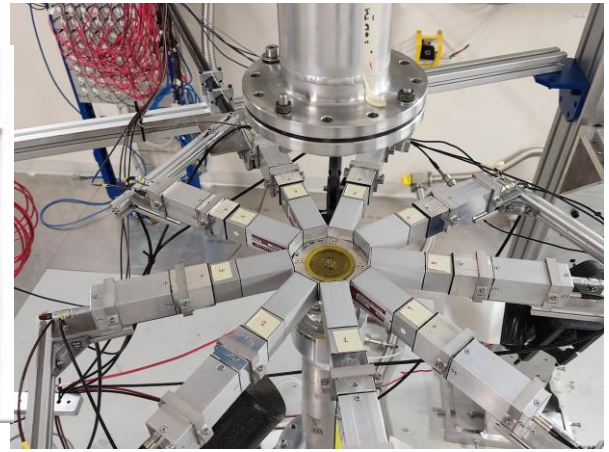
for the n_TOF collaboration

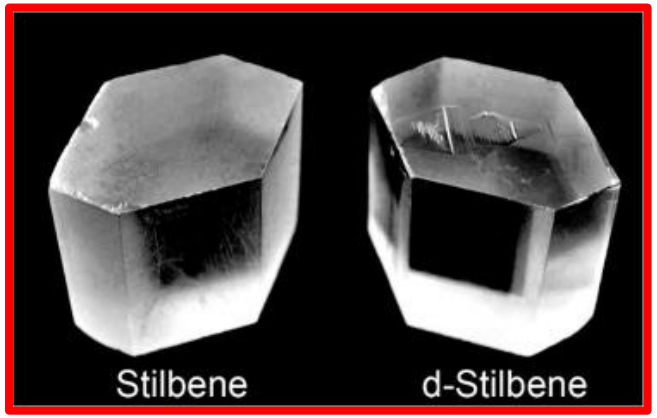
Meeting Nazionale n_TOF, Bologna 21/11/2024

OUTLOOK

1. Development motivations: (n,γ), (n,n) and (n,n’) reactions
2. Lol’s for PSTIL in-beam characterization @ n_TOF
3. PSTIL Structure and specs
4. Detector Characterization
5. Pulse Shape Discrimination (PSD)
6. Principal Component Analysis (PCA)
7. Preliminary results on $^{12}C(n,n)^{12}C$ measurement at EAR1
8. Summary of the activities in 2024
9. Status of the PSTIL set-up and Future developments

Motivation for developing the prototype: (n,γ) measurements





"Big" C_6D_6 Liquid scintillators

Large & segmented C_6D_6

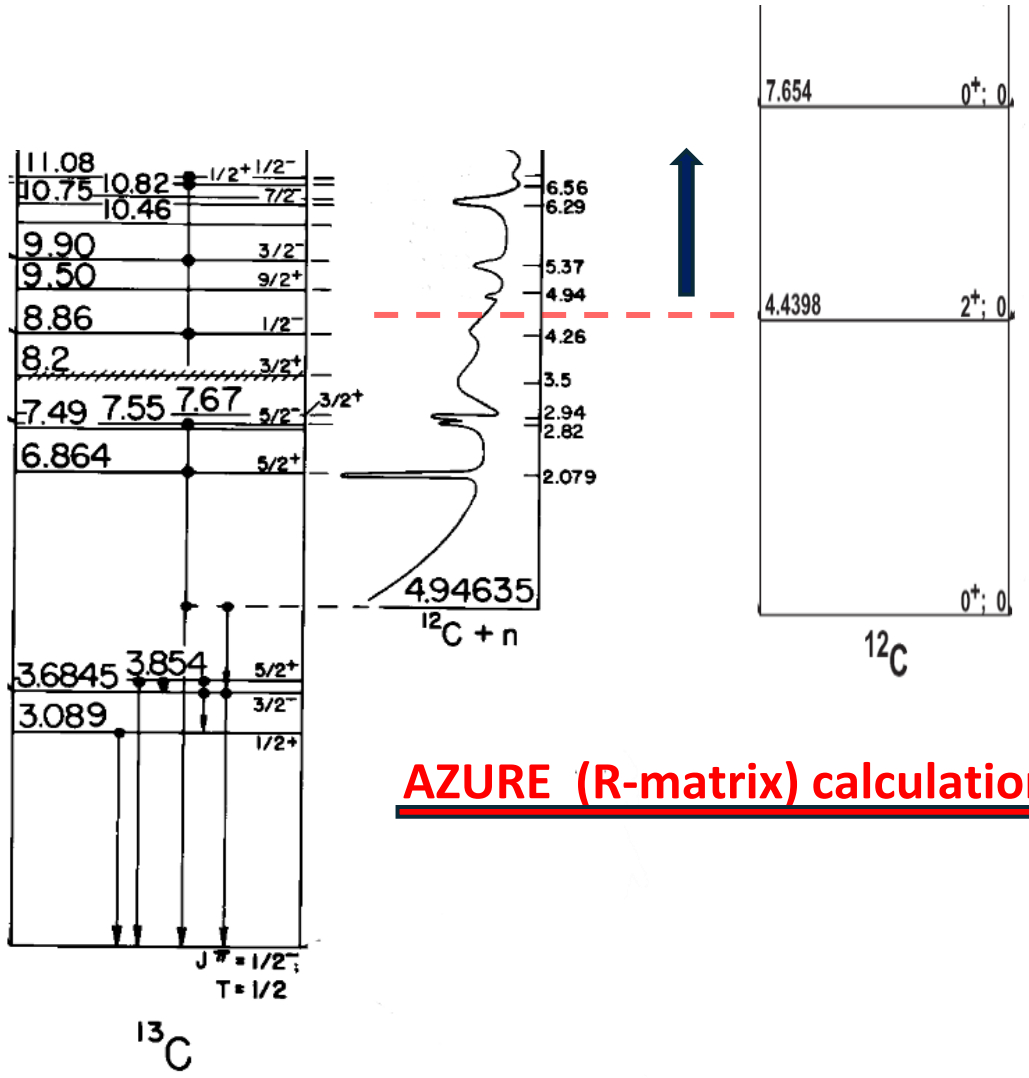
Compact array of small C_6D_6

Solid organic scintillators
Read-outs/Power supplies

Solid
Higher density
No Chemical hazard
n/γ discrimination

Motivation for developing the prototype: (n,n) and (n,n')measurements

$^{12}C(n,n)^{12}C$ and $^{12}C(n,n')^{12}C^*$ benchmark



AZURE (R-matrix) calculations

G.M. Hale, Nuclear Data Sheets 118 (2014) 165

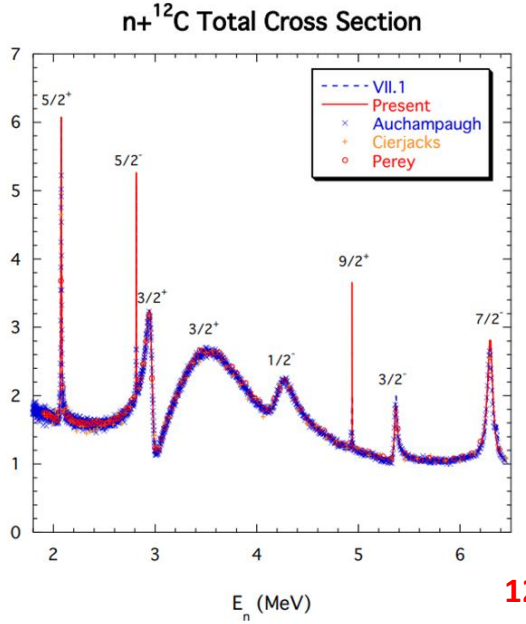
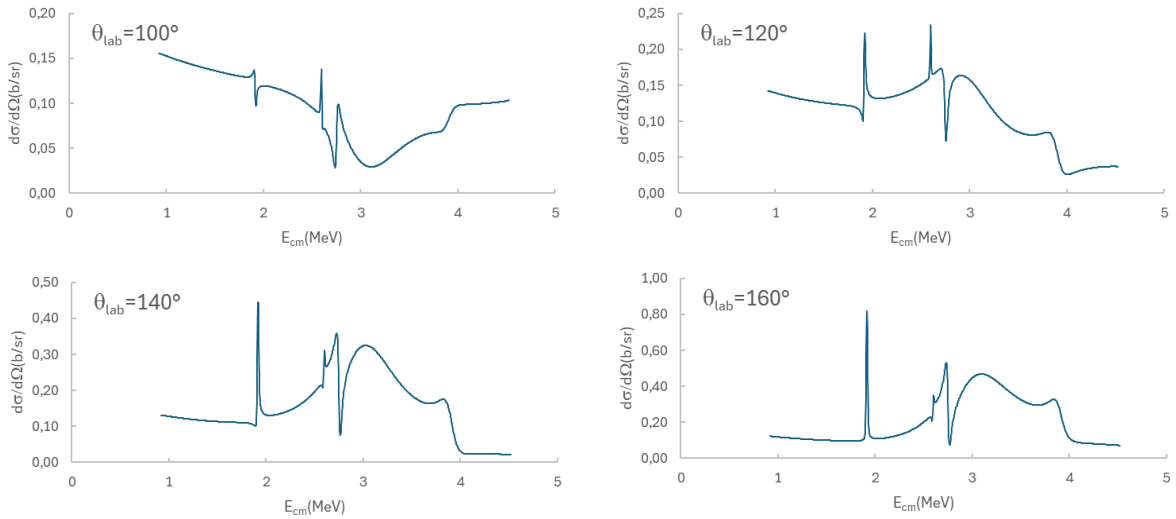


TABLE II. Resonance parameters for ^{13}C.

E_x (MeV)	J^π	Γ (keV)	Notes
3.089	$1/2^+$	0.00	Residue = 34 MeV
6.862	$5/2^+$	7.69	
7.543	$5/2^-$	1.91	
7.681	$3/2^+$	63.1	
8.073	$3/2^+$	913.	
8.849	$1/2^-$	188.	
9.501	$9/2^+$	0.57	
9.894	$3/2^-$	28.3	$\Gamma_{n_0} = 21, \Gamma_{n_1}(^4P) = 7$
10.756	$7/2^-$	61.0	$\Gamma_{n_0} = 56, \Gamma_{n_1}(^6P) = 5$

$^{12}C(n,n)^{12}C$



LoI's for PSTIL in-beam characterization @ n_TOF

INTC

PSTIL 2023

EAR 2

Informazioni | Discussioni (0) | File

Scientific Committee Paper

Report number	CERN-INTC-2023-034 ; INTC-I-254
Title	**Development of new solid-state total-energy detectors for neutron-capture measurements at CERN n_TOF**
Project Manager/Technical Coordinator	Balibrea Correa, Javier; Musumarra, , Agatino
Author(s)	Aberle, O (European Organization for Nuclear Research (CERN), Switzerland) ; Alcayne, V (Centro de Investigaciones Energ\'{e}ticas Medioambientales y Tecnol\'{o}gicas (CIEMAT), Spain) ; Bacak, M (European Organization for Nuclear Research (CERN), Switzerland) ; Balibrea-Correa, J (Instituto de F\'{\i}sica Corpuscular, CSIC - Universidad de Valencia, Spain) ; Colonna, N (Instituto Nazionale di Fisica Nucleare, Sezione di Bari, Italy) ; Cano-Ott, D (Centro de Investigaciones Energ\'{e}ticas Medioambientales y Tecnol\'{o}gicas (CIEMAT), Spain) ; Casanovas, A (Universitat Polit\`{e}cnica de Catalunya, Spain) ; Domingo-Pardo, C (Instituto de F\'{\i}sica Corpuscular, CSIC - Universidad de Valencia, Spain) ; Fjeld, O (European Organization for Nuclear Research (CERN), Switzerland) ; Gunsing, F (CEA Irfu, Universit\'{e} Paris-Saclay, F-91191 Gif-sur-Yvette, France) *Visualizza tutti i 19 autori*
Corporate author(s)	CERN. Geneva. ISOLDE and neutron Time-of-Flight Experiments Committee ; INTC
Series	(Letter of Intent)
Submitted by	javier.balibrea.correa@cern.ch on 18 Apr 2023
Subject category	Detectors and Experimental Techniques

Email contact(s) : javier.balibrea@ific.uv.es ; musumarra@lns.infn.it ; Oliver.Aberle@cern.ch

INTC

PSTIL 2024

EAR 1

Scientific Committee Paper

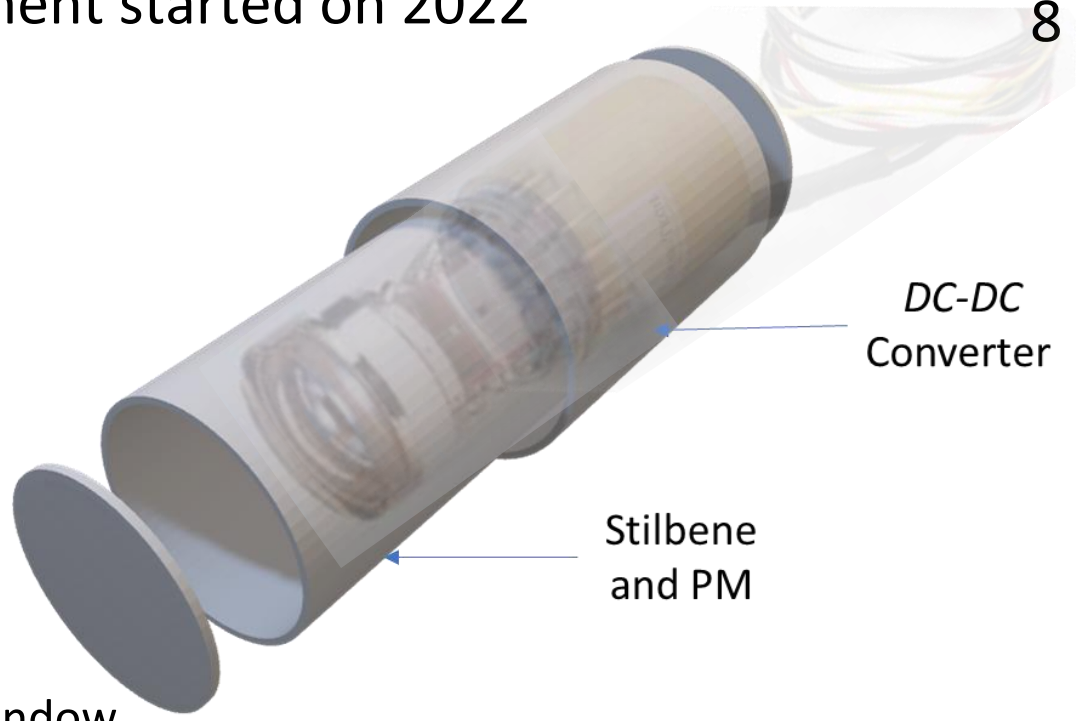
Report number	CERN-INTC-2024-028 ; INTC-I-274
Title	**Response of stilbene scintillator to (n,n) and (n,n') reaction channel in TOF experiments**
Project Manager/Technical Coordinator	Pellegriti, Maria Grazia; Sahoo, Rudra Narayan
Author(s)	Castelluccio, DM (ENEA-Bologna and INFN-Bologna, Italy) ; Console Camprini, P (ENEA-Bologna and INFN-Bologna, Italy) ; Diakaki, M (National Technical University of Athens, Greece) ; Elme, Z (University of Ioannina, Greece) ; Massimi, C (University of Bologna and INFN-Bologna, Italy) ; Mastromarco, M (University of Bari and INFN-Bari, Italy) ; Mucciola, R (INFN-Bari, Italy) ; Musumarra, A (University of Catania and INFN-Catania, Italy) ; Patronis, N (University of Ioannina, Greece) ; Pellegriti, MG (INFN-Catania, Italy) *Visualizza tutti i 11 autori*
Corporate author(s)	CERN. Geneva. ISOLDE and neutron Time-of-Flight Experiments Committee ; INTC
Series	(Letter of Intent)
Note	Requested protons: 6*10^17 protons on target
Submitted by	maria.grazia.pellegriti@cern.ch on 08 Apr 2024
Subject category	Detectors and Experimental Techniques

Email contact(s) : mariagrazia.pellegriti@ct.infn.it ; RudraNarayan.Sahoo@bo.infn.it ; Oliver.Aberle@cern.ch

Record creato 2024-04-08, modificato l'ultima volta il 2024-04-08

PSTIL structure and specs (Stilbene-cylinder 1’’x1’’)

Development started on 2022



8 modules available 4 INRAD + 4 PROTEUS

Carbon Fibre housing

PS1807 DATA SHEET
PHOTOMULTIPLIER POWER BASE (NEGATIVE)
SENS - TECH

INPUT POWER AT V MAX = -1800 V +5 V, 65 mA	INPUT POWER AT V MAX = -1800 V +12 V, 20 mA
POWER CONVERSION EFFICIENCY, P_o/P_{in} 40 % for +5 V	POWER CONVERSION EFFICIENCY, P_o/P_{in} 50 % for +12
OUTPUT VOLTAGE RANGE -100 V to -1800 V	WARM UP TIME TO 0.3 % OF FINAL O/P < 2 s
LINE REGULATION 0.05 % / V	DISCHARGE TIME TO <40 V WITH NO LOAD < 2 s
TEMPERATURE COEFFICIENT <0.02 % °C^{-1}	MAXIMUM ANODE CURRENT, CONTINUOUS 100 µA
ANODE RIPPLE WITH 100 KΩ //5 PF LOAD 100 µV	WEIGHT 60g

HAMAMATSU
PHOTON IS OUR BUSINESS
PHOTOMULTIPLIER TUBE
R7378A

Parameter		Description	Unit
Spectral response		160 to 650	nm
Peak wavelength		420	nm
Photocathode	Material	Bialkali	—
	Minimum effective area	ϕ22	mm
Window material		Synthetic silica	—
Dynode	Structure	Circular and linear-focused	—
	Number of stages	10	—
Base		14 pin glass base	—

Contents

- Detector Characterization (radioactive sources)
- Pulse Shape Discrimination (PSD)
- Principal Component Analysis (PCA)
- Preliminary results on $^{12}C(n,n)^{12}C$ measurement at EAR1
- Future Analysis

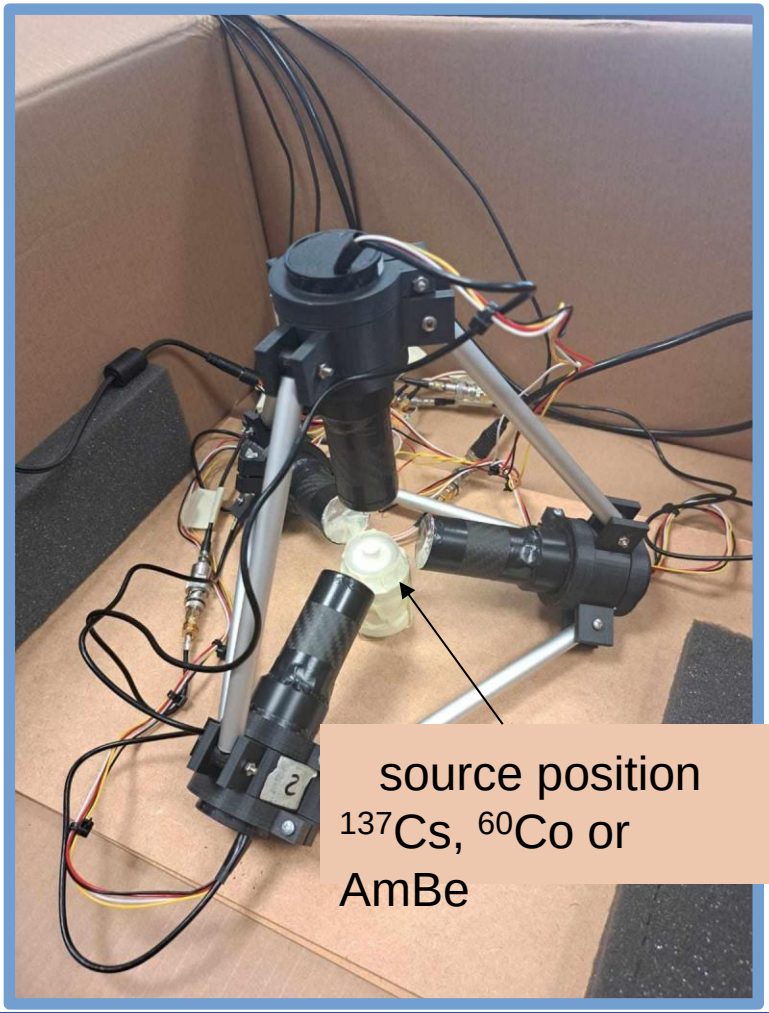
Detector Characterization

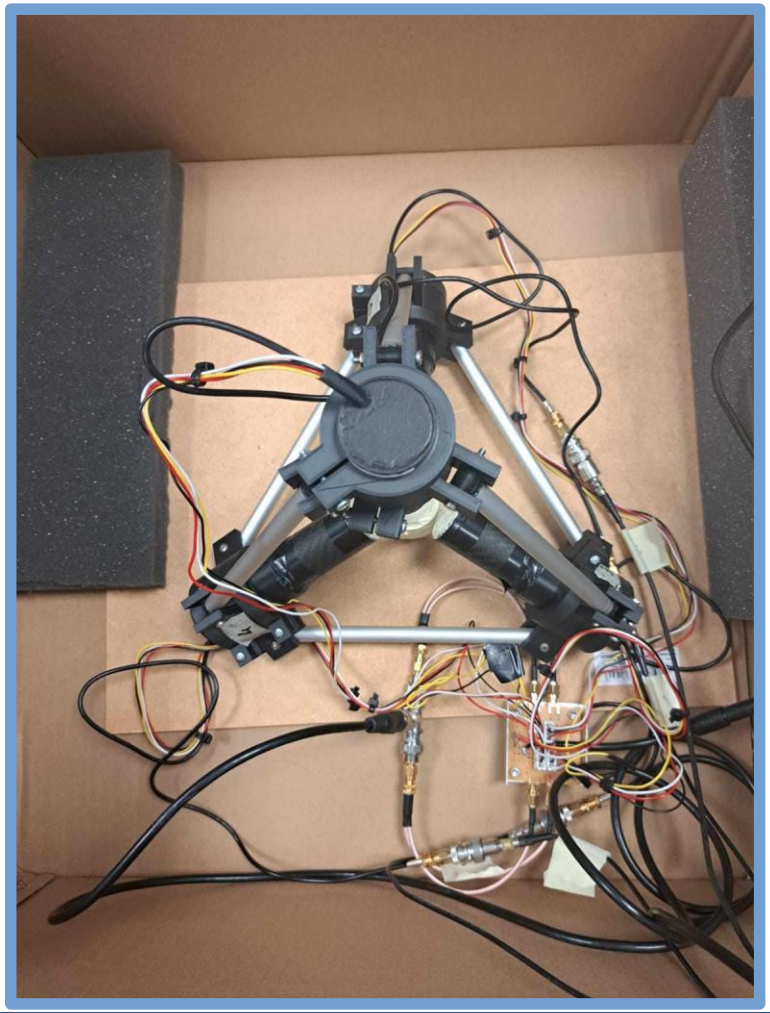
Multi-Detector Array

pStil0 (PROTEUS)

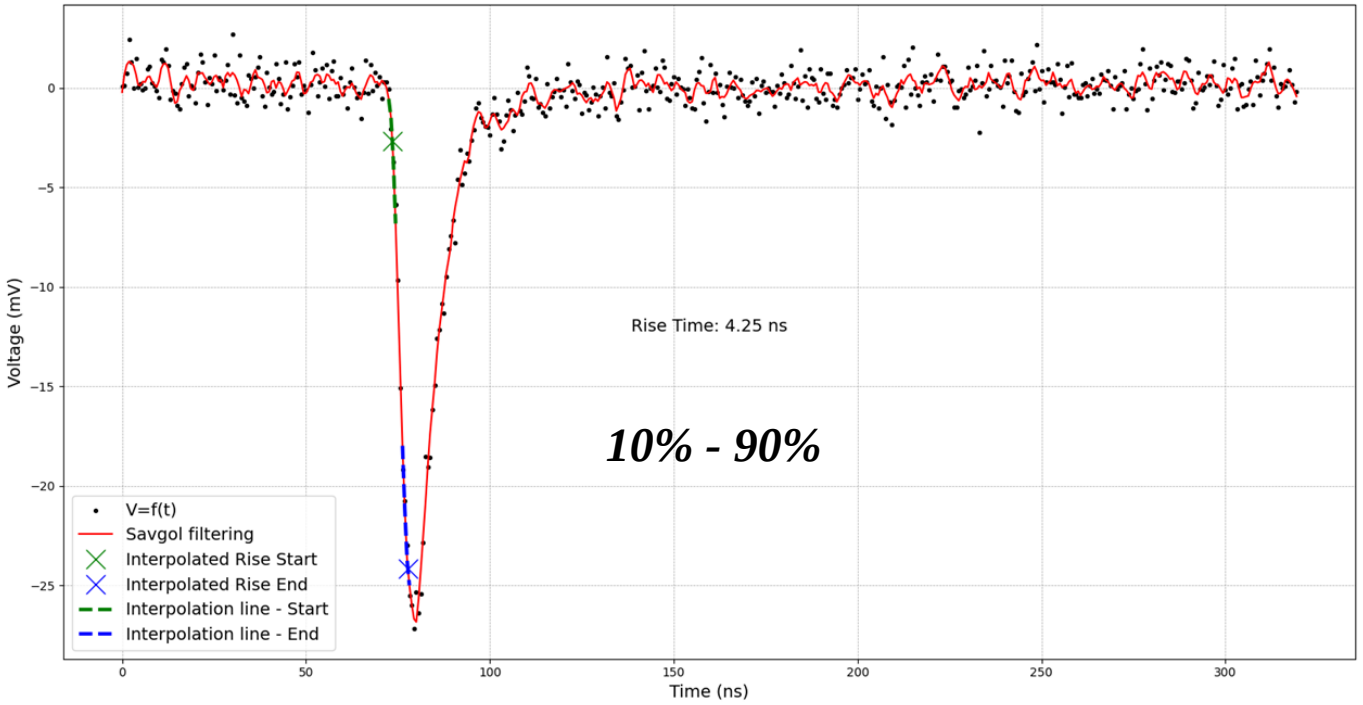
pStil1-2-3 (INRAD)

Developed at INFN-CT, Sezione di Catania



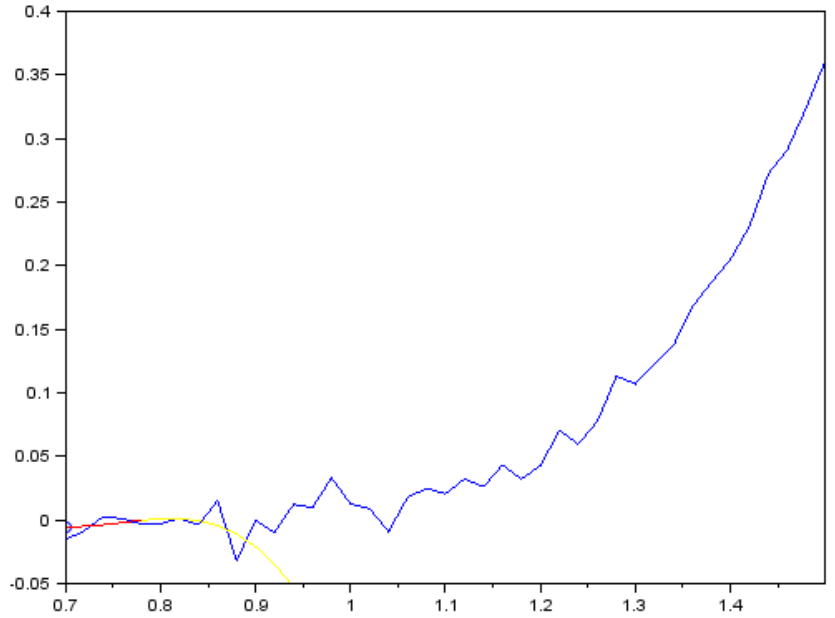


- **Regular Tetrahydron base**
- Lightweight 3D-printed **PLA holders**
- Thin hollow **Al rods**
- **Power Supply**
- **Voltage Distributor** (4 Channels)



Savitzky-Golay Filtering

Implementation of a **signal smoothing process**



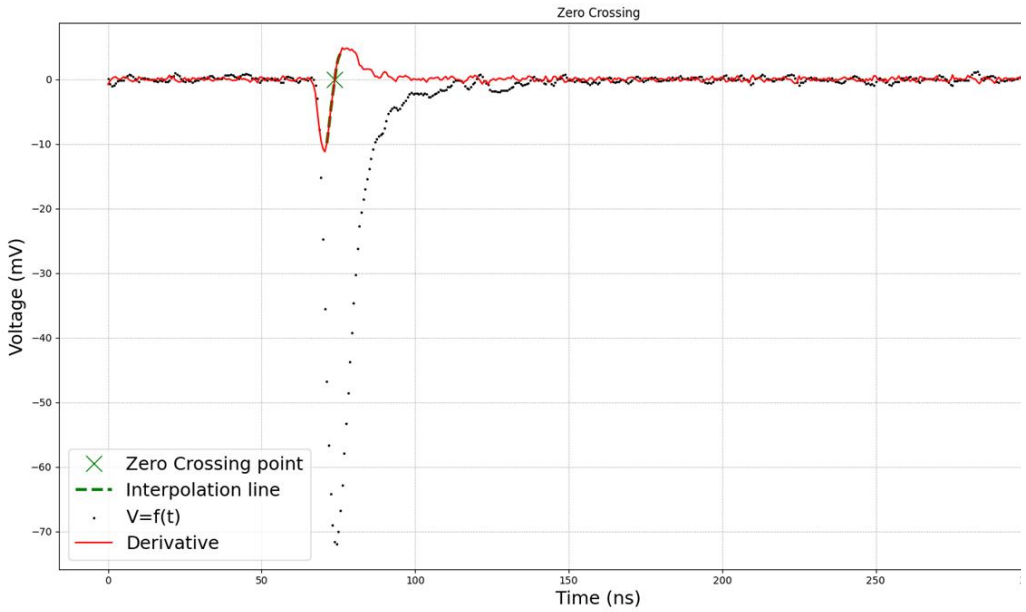
	Rise Time (ns)	Fall Time (ns)
INRAD	3.966 ± 0.003	14.13 ± 0.06
PROTEUS	4.051 ± 0.002	14.43 ± 0.05

Averaged for ~40000 events

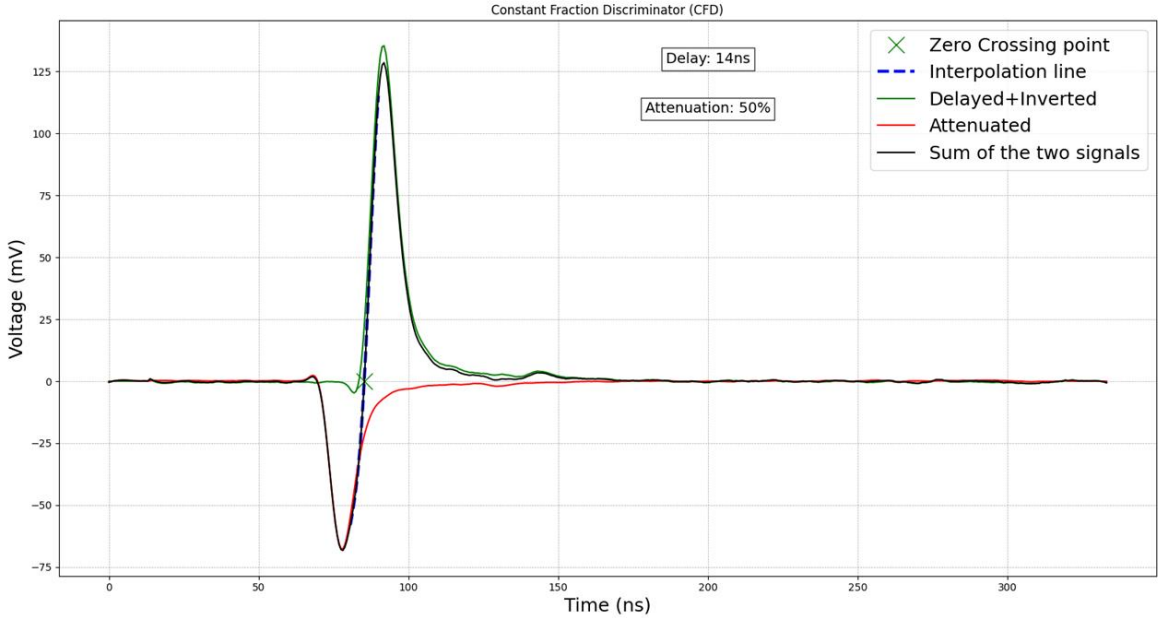
γ-γ Time Coincidence with ^{60}Co source

Time Pick-Off
Crossover Timing

Derivative *method*

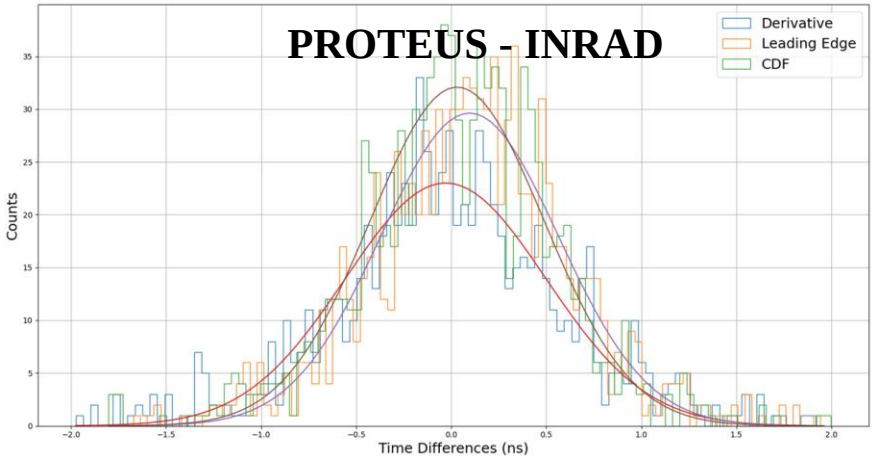


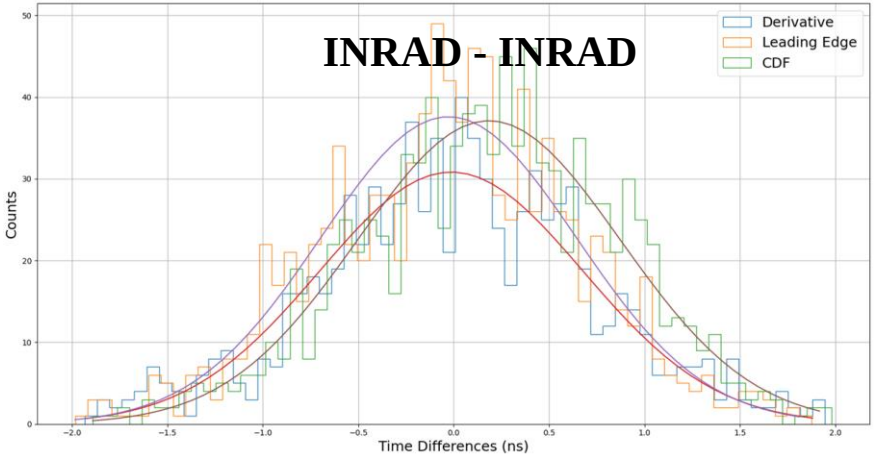
Constant Fraction Discriminator (CFD) *method*

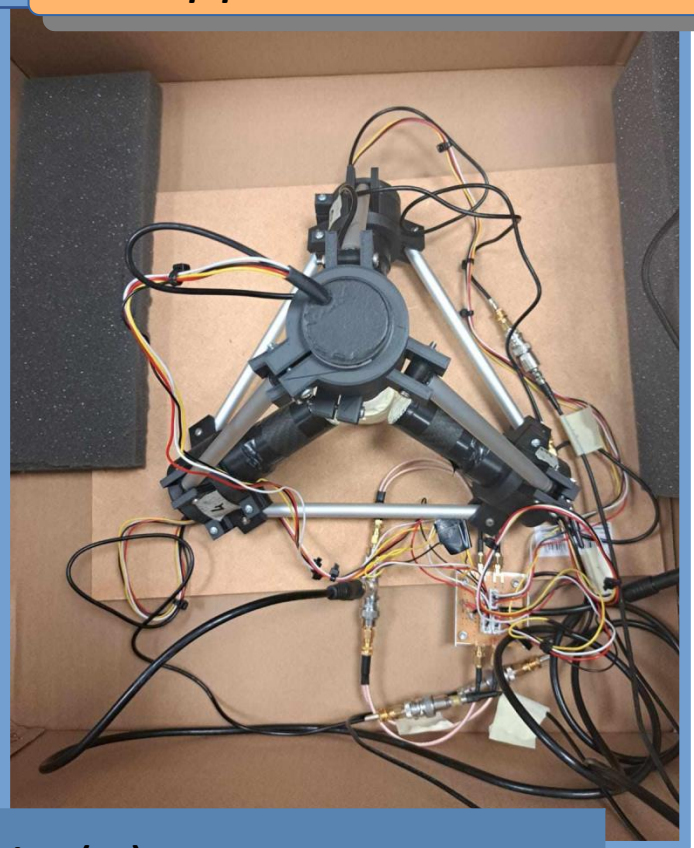


γ-γ Time Coincidence

Time Resolution







Time Resolution (ns)		
	INRAD - PROTEUS	**INRAD - INRAD**
Derivative	0.74 ± 0.03	1.08 ± 0.02
Leading Edge	0.78 ± 0.03	1.12 ± 0.02
CFD	0.73 ± 0.03	1.13 ± 0.03

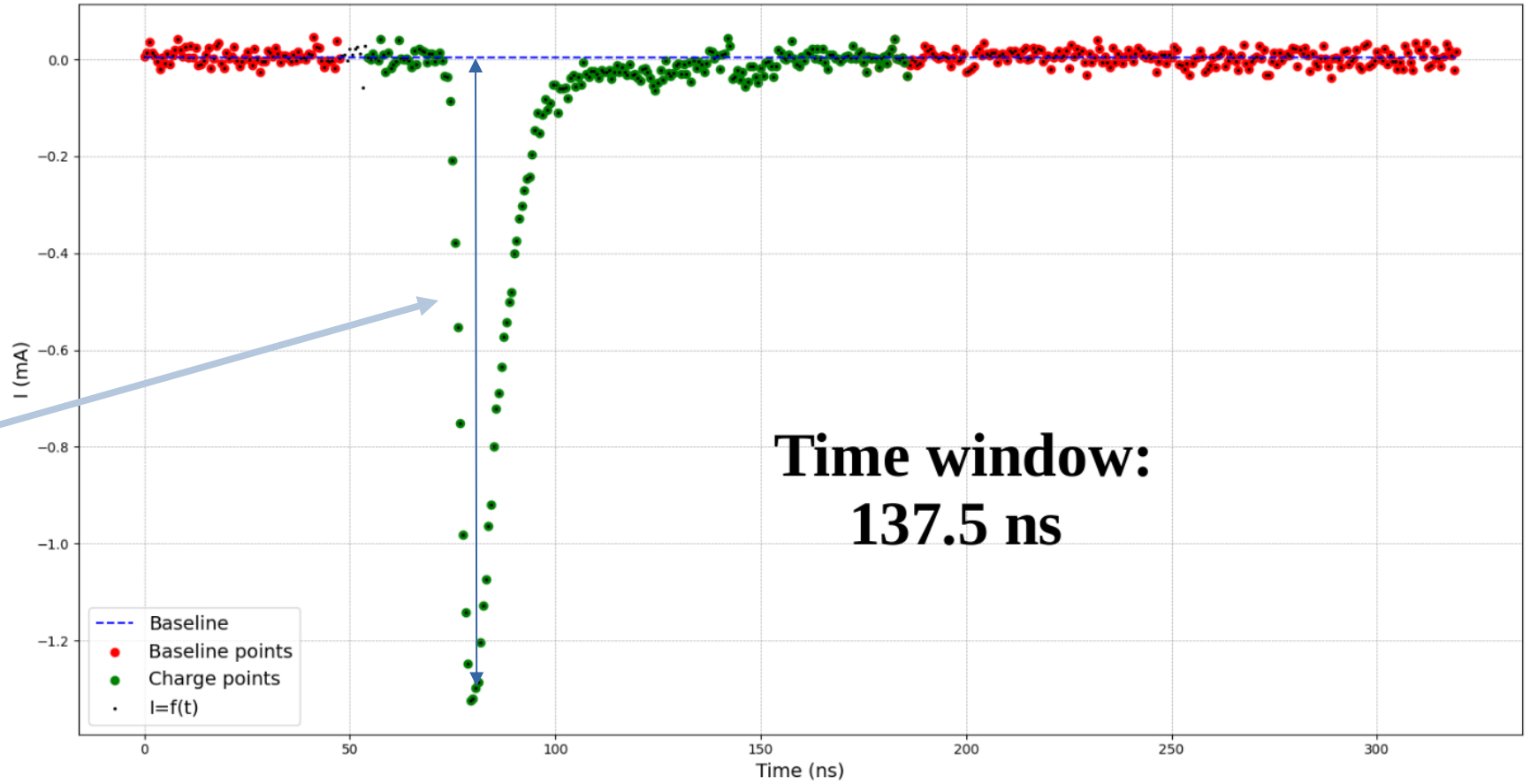
Pulse Shape Discrimination (PSD)

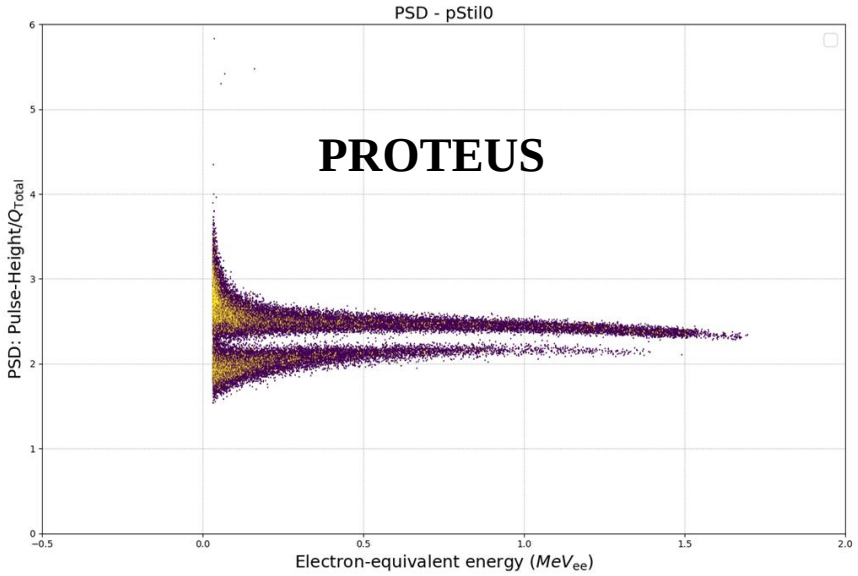
"Discrimination Ratios"

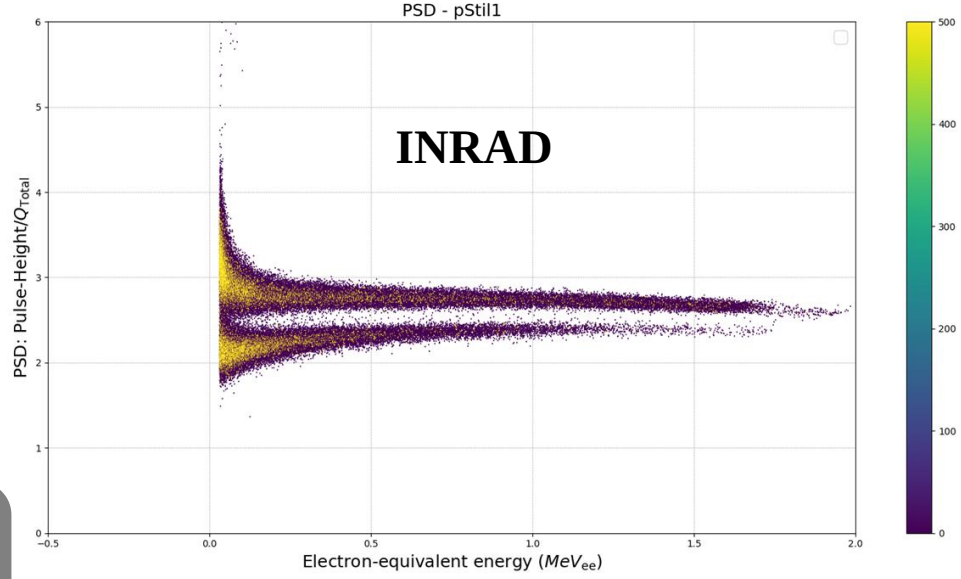
$$Q_{short}/Q_{total}, \frac{Q_{long}-Q_{short}}{Q_{long}} \ldots etc$$

$$\mathrm{PSD} = \frac{Pulse\ Height}{Q_{total}}$$

Charge Integration Method



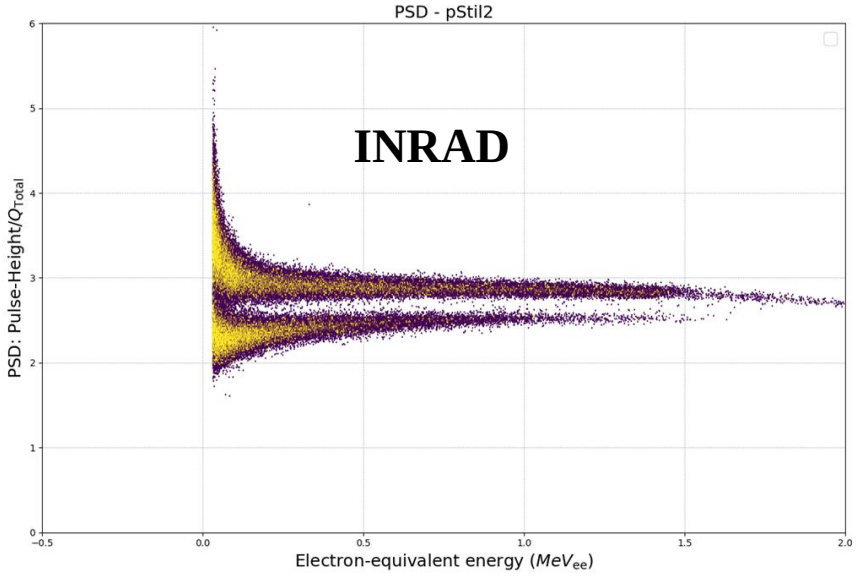


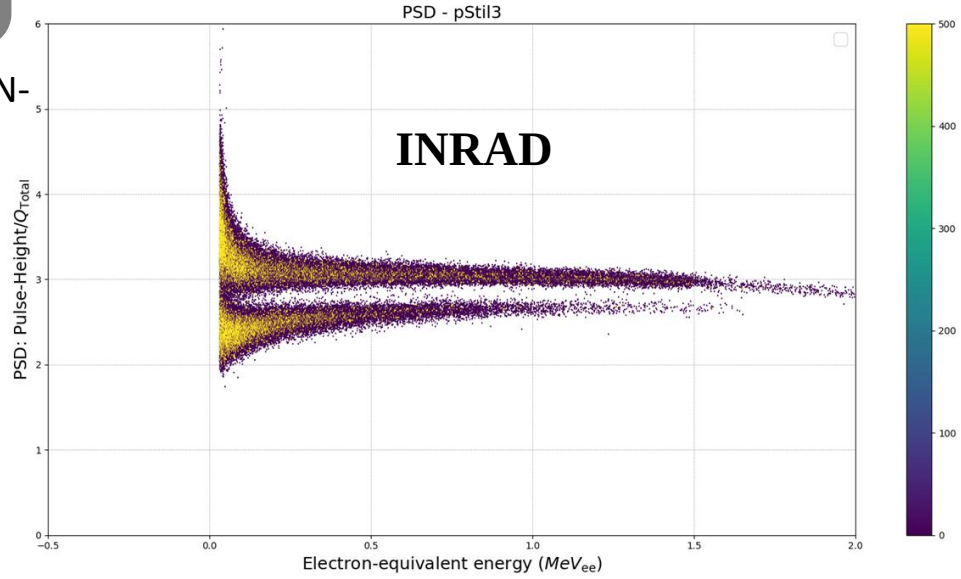


Using an ^{241}**Am-Be** source

Provided by INFN-LNS

-300 pC threshold to account for pile-up

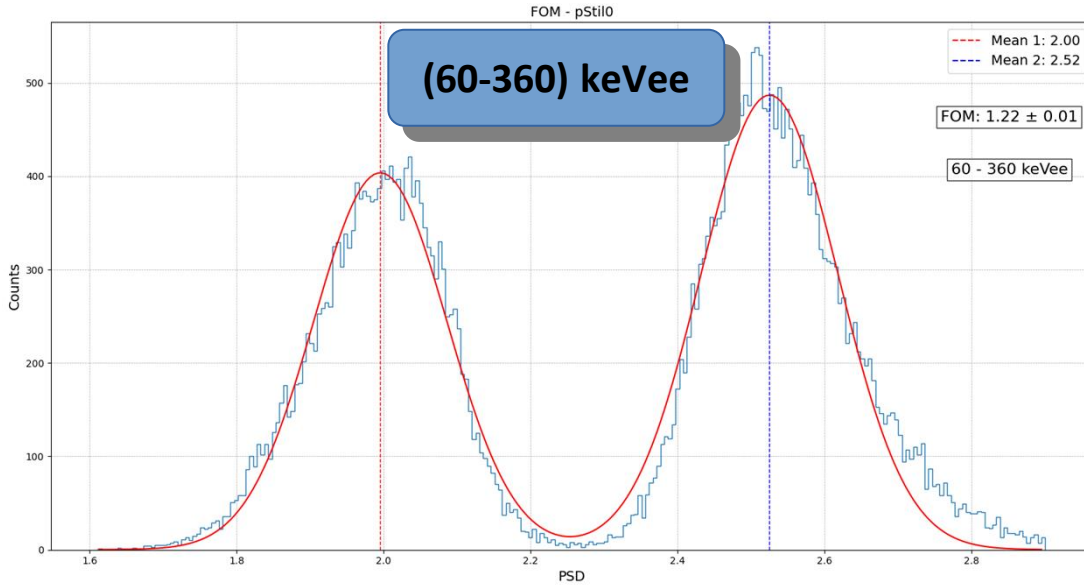


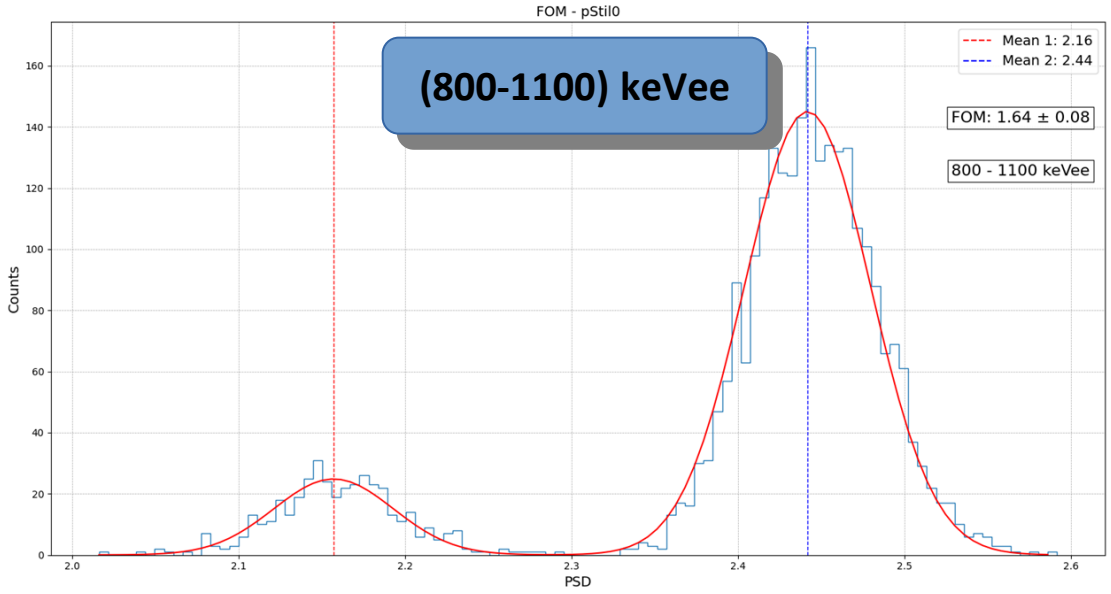


PSD FOM

Slicing the PSD Distributions

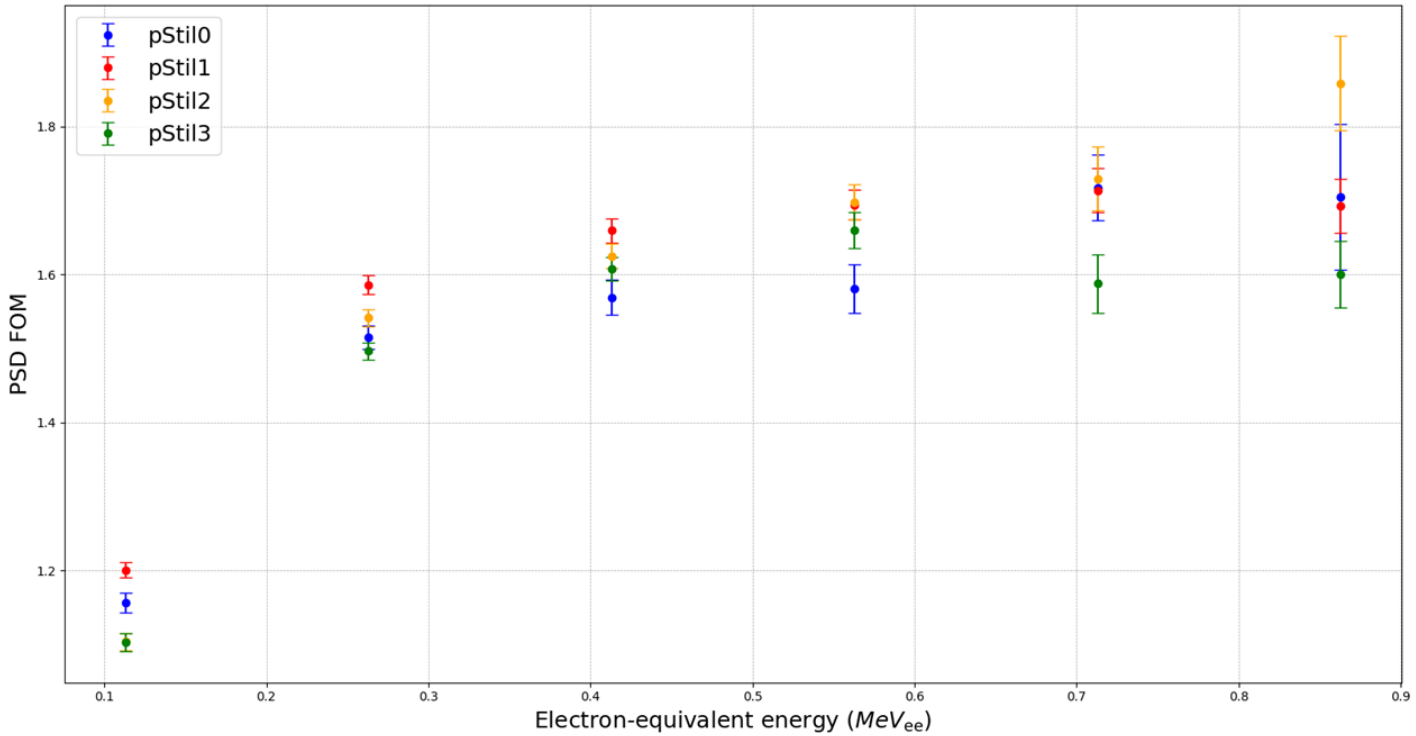
PSD FOM		
	60-360 keVee	800-1100 keVee
pStil0 - PROTEUS	1.22 ± 0.01	1.64 ± 0.08
pStil1 - INRAD	1.29 ± 0.01	1.69 ± 0.03
pStil2 - INRAD	1.22 ± 0.01	1.86 ± 0.06
pStil3 - INRAD	1.22 ± 0.01	1.60 ± 0.04





PSD FOM as a function of energy

Slicing the PSD Distributions



Difficult to comparatively assess the results!

- Type of **scintillator**
- **QE** of the PMT
- **Energy** of the incident particles
- Performance of **electronics**

**

Just accounting for the **QE** of a PMT, differences in FOM up to **30%** can be introduced

**

Principal Component Analysis (PCA)

So **why PCA ?**

5 Initial Parameters! ...

Pulse-height

Charge (short, long, tail)

Pulse-width

...

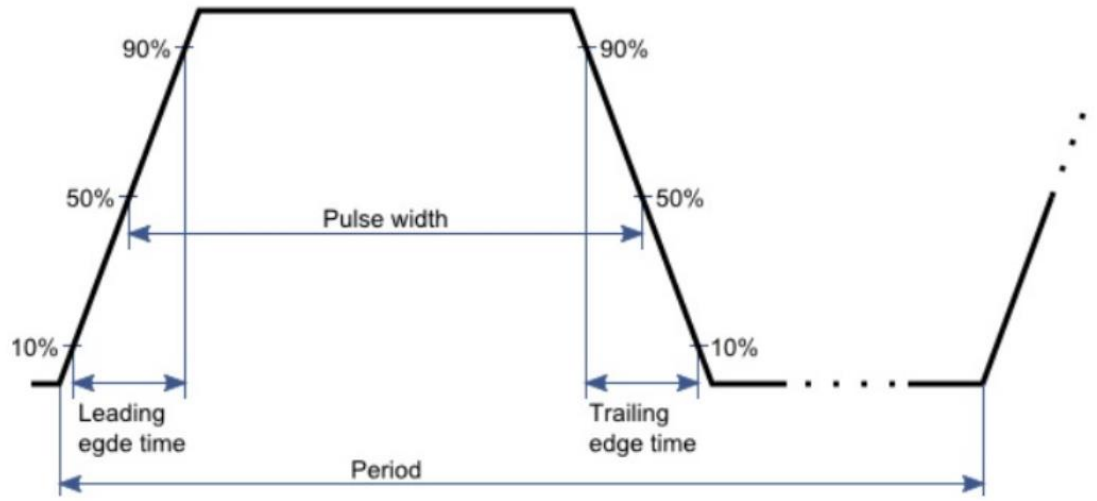
$$\mathrm{PSD} = \frac{Pulse\ Height}{Q_{total}} \quad Q_{short}/Q_{total}, \frac{Q_{long}-Q_{short}}{Q_{long}} \ldots etc$$

**

A lot of missed opportunity

**

Pulse-width



PCA – Scree Plots

% Variance				
	pStil0	**pStil1**	**pStil2**	**pStil3**
PC1	87.0	85.7	85.0	85.3
PC2	10.0	11.0	11.5	11.3
SUM	**97.0**	**96.7**	**96.5**	**96.6**

Lower the dimensionality from

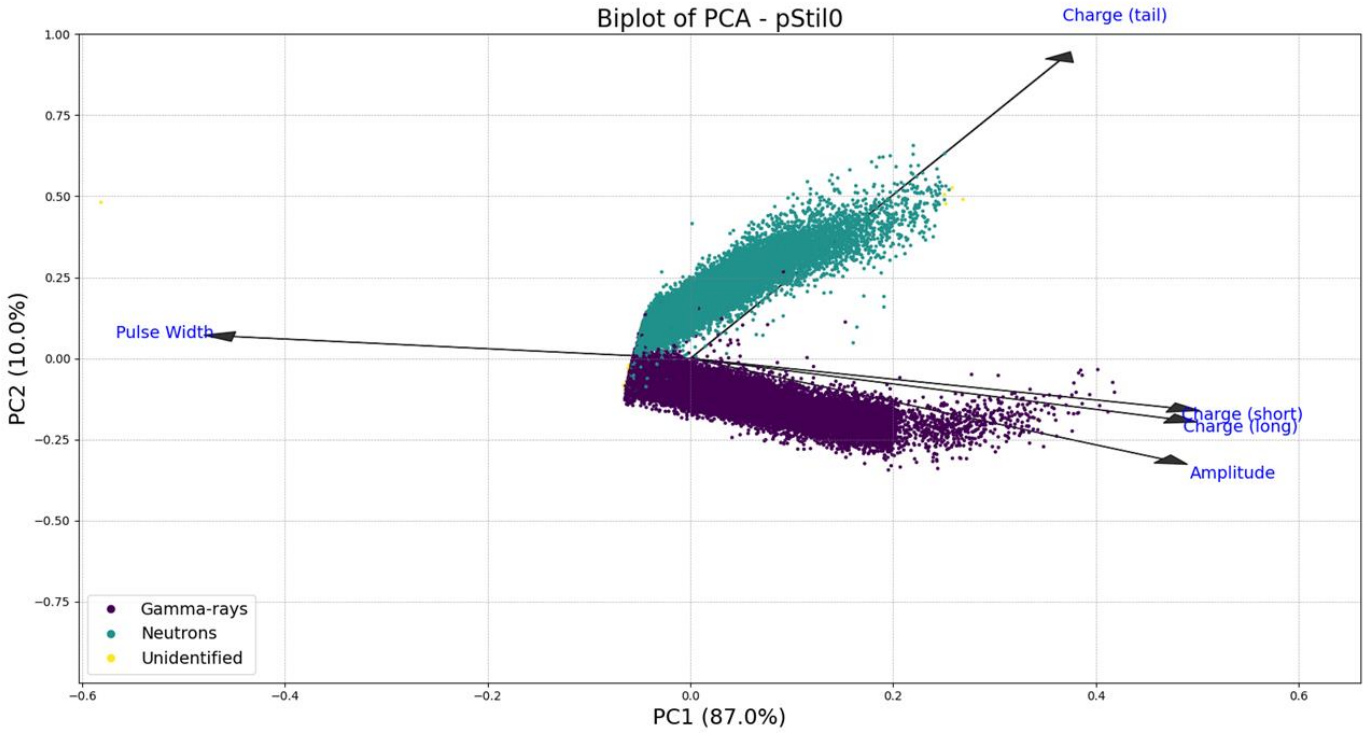
5D to 2D !

Overall, more than 96% of the variation is preserved in the first two PCs

PCA – Biplots

A biplot is another **enhanced graphical representation** used in PCA that displays both the **PC scores** of the observations **and the loadings** of the variables on the same plot

Scores represent the **transformed coordinates of the observations** in the new PC space



The **position** of each point **indicates its projection** of the original data point onto the PCs

PCA – Physical Interpretation

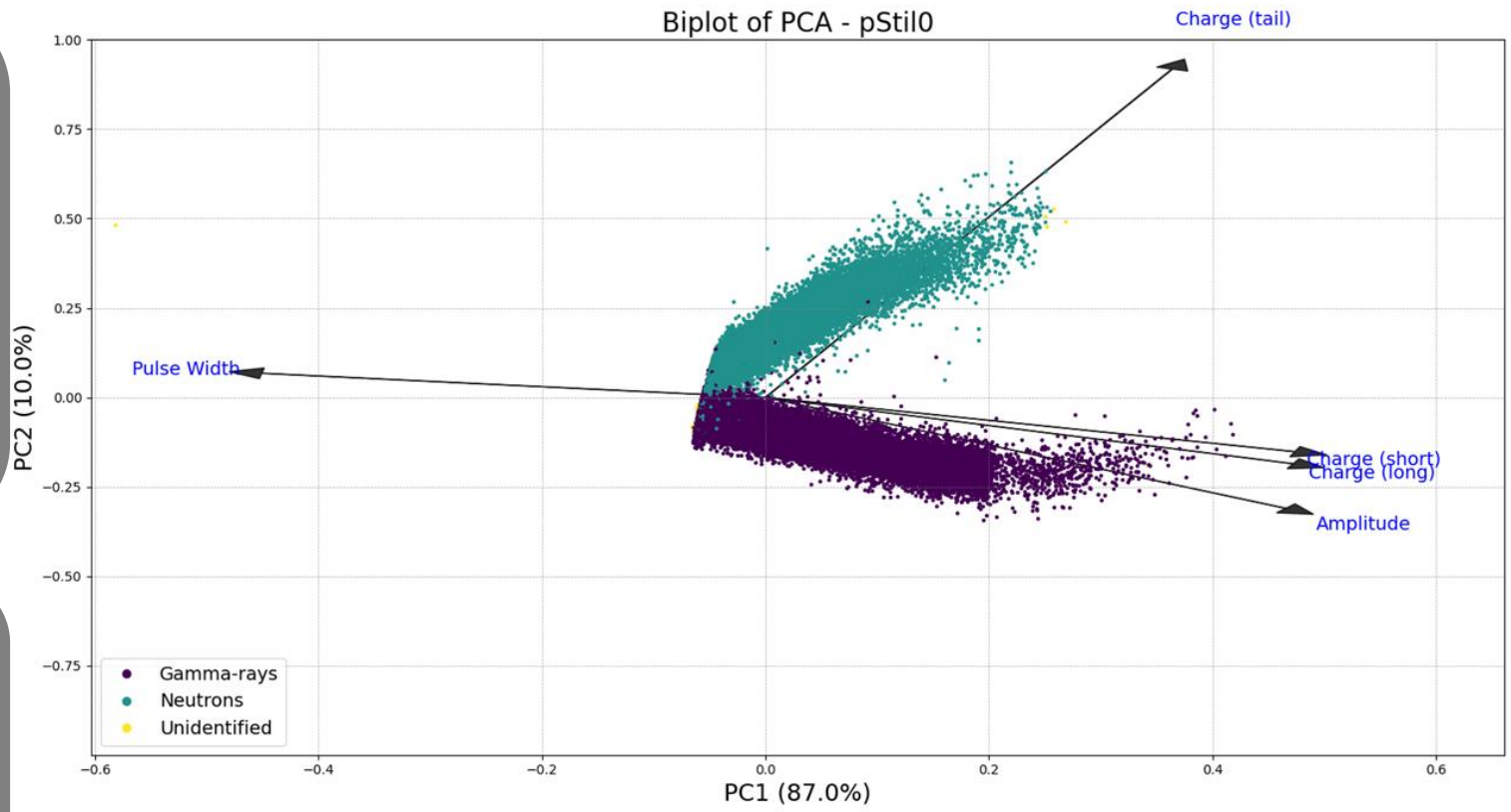
Principal Component 1
PC1

Pulse-height, Charge (short), Charge (long)

High positive loadings on PC1.
It suggests that PC1 represents the **overall signal strength or energy deposited** by the particle, as these parameters are directly related to the signal amplitude and integrated charge

Pulse-width

Negative loading on PC1.
Inversely correlated with the other variables on this component.
ToT → **proportional to energy loss**.



PCA – Physical Interpretation

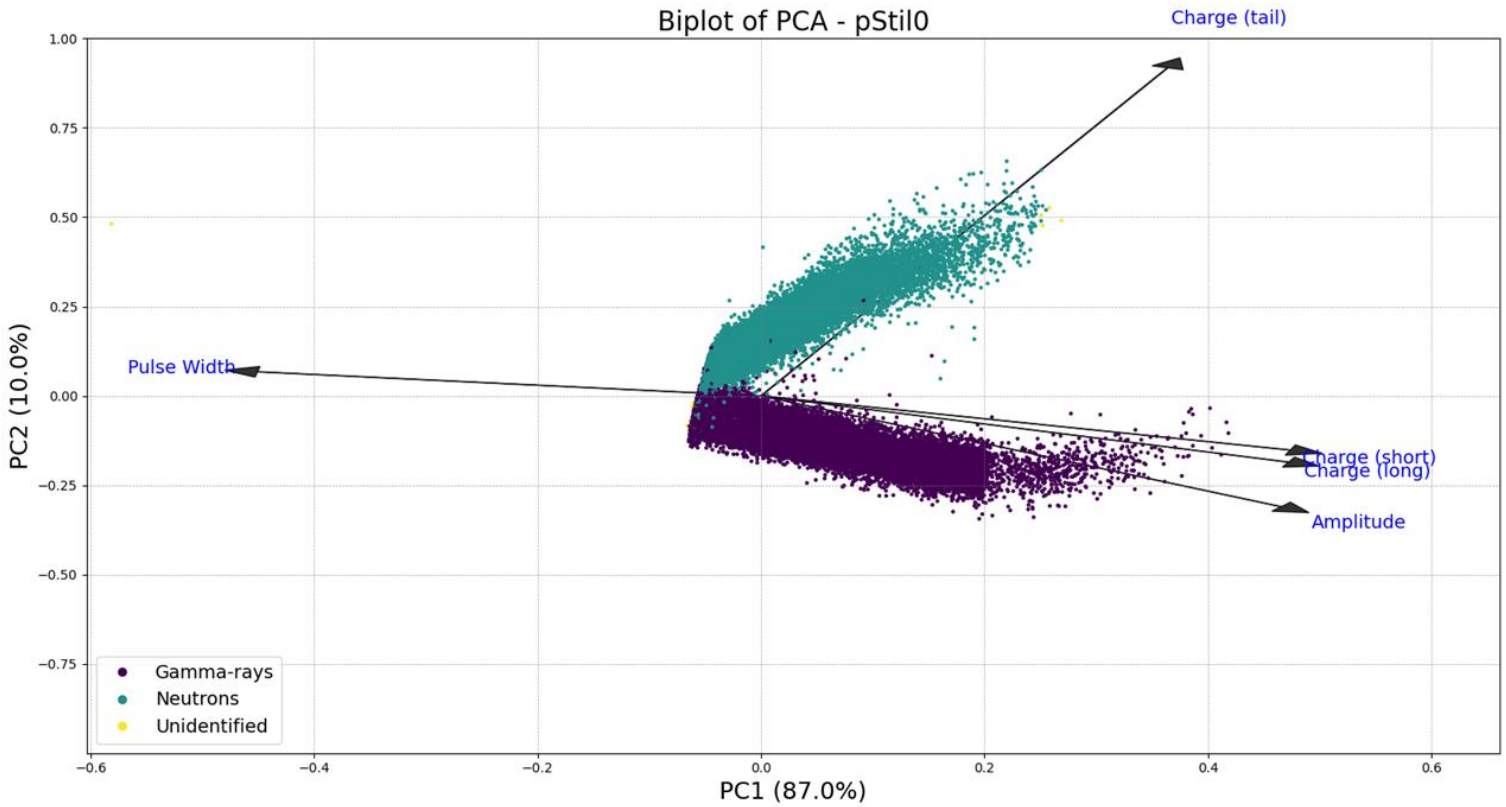
Principal Component 2
PC2

Charge (tail)

High positive loading on PC2.
Reflects PSD contribution of slower signal components, confirming the basis of PSD by charge integration

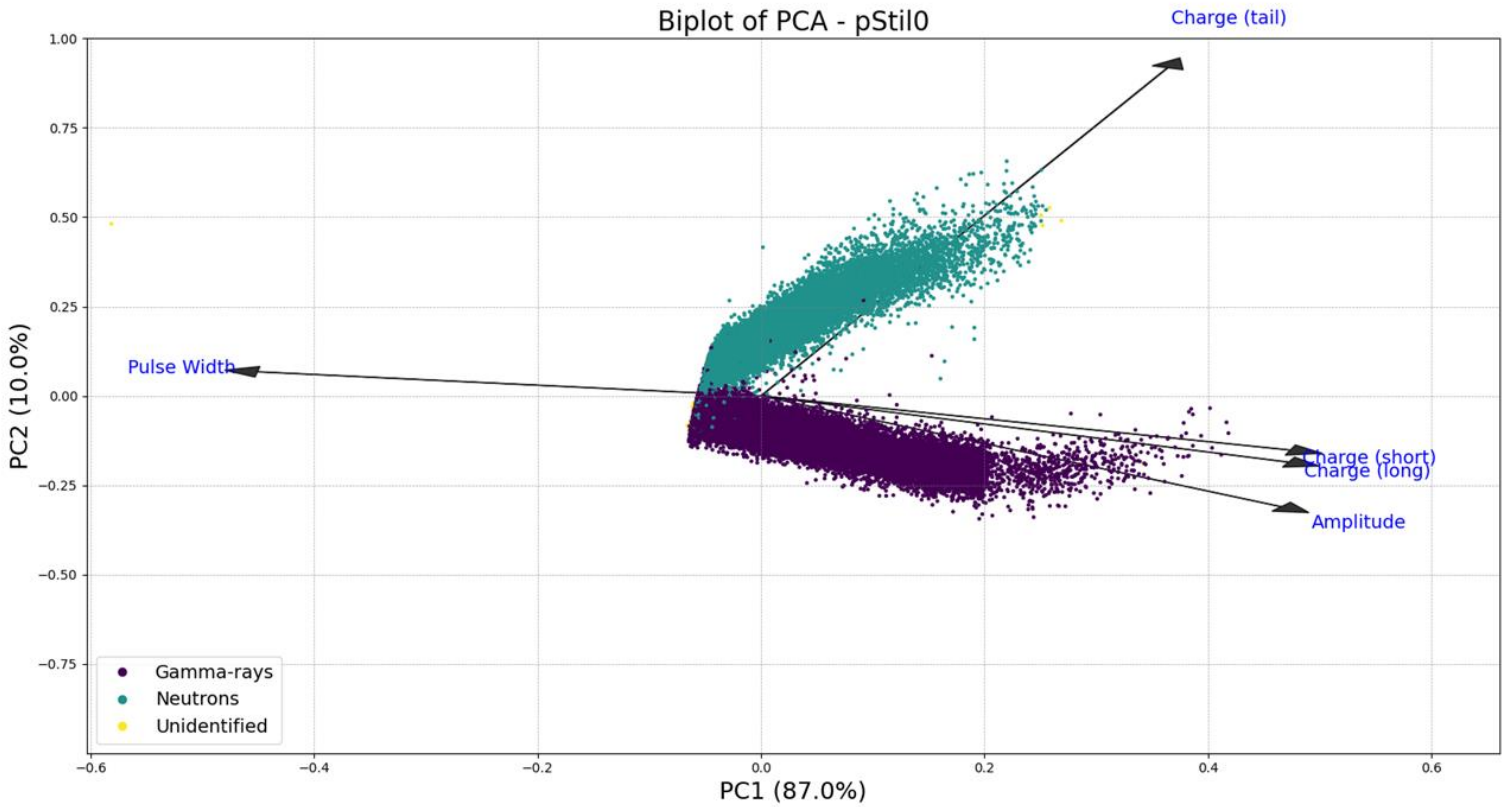
Pulse-height and Charge (long)

Relatively **small loadings on PC2,**
Suggesting they are equivalent for the purpose of discrimination, as expected



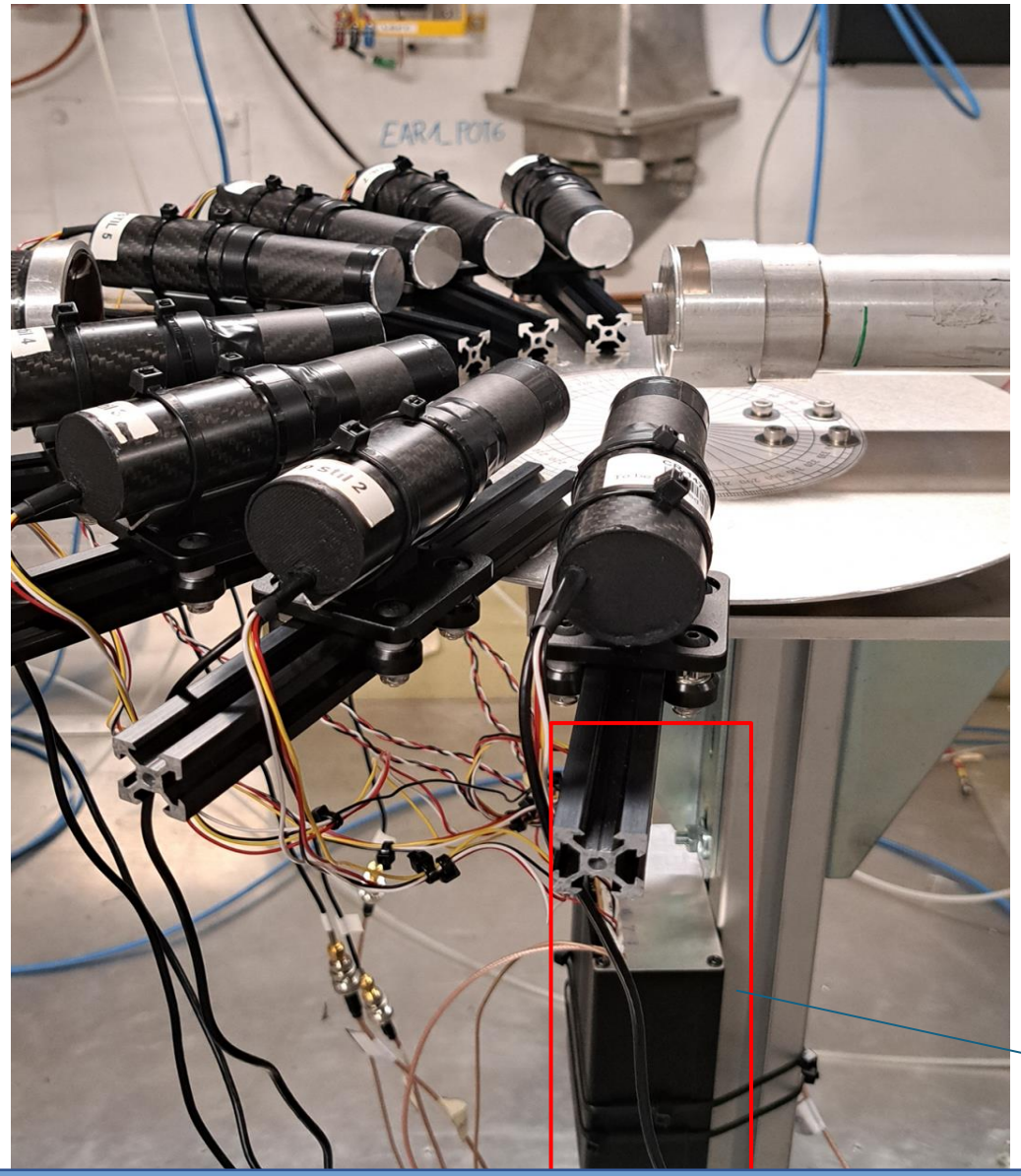
PCA – Physical Interpretation

Verifying the validity of an unsupervised technique for discrimination

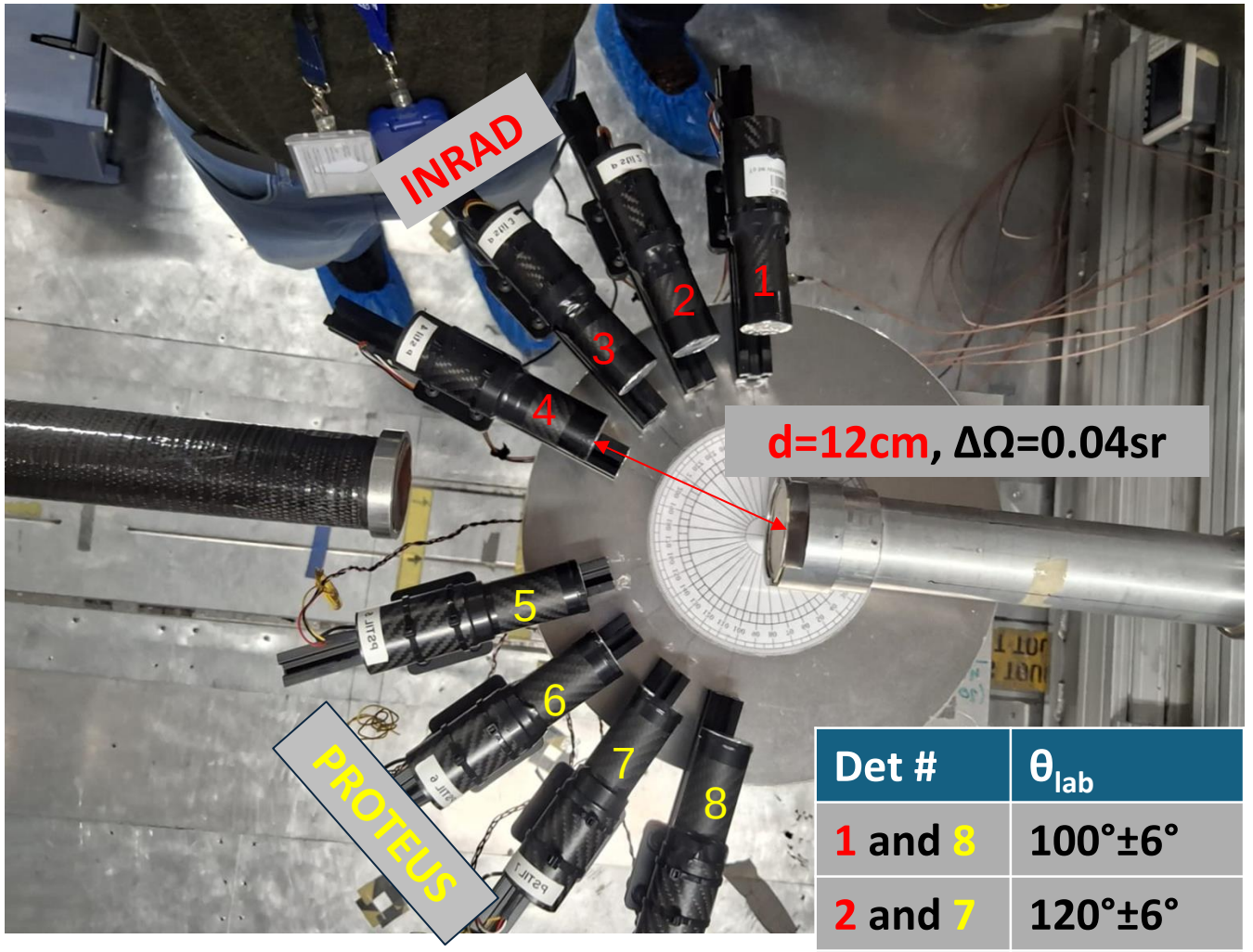


Preliminary results on ^{12}C(n,n)^{12}C measurement at EAR1

PSTIL set-up in EAR1 - October 2024



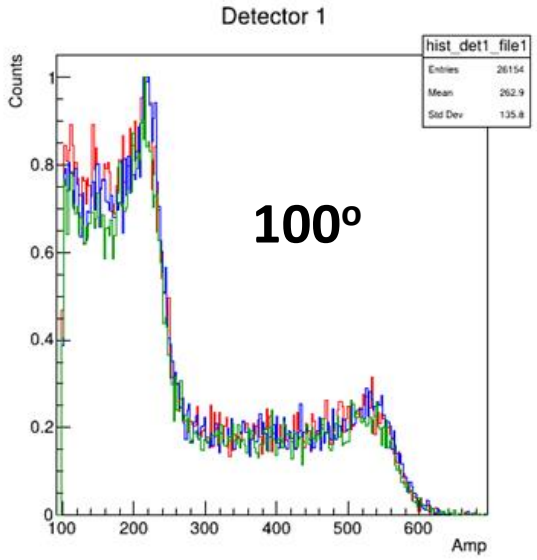
New equalization/distribution box

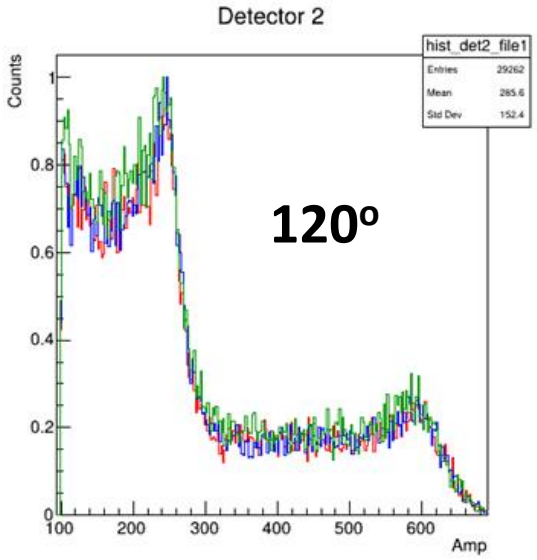


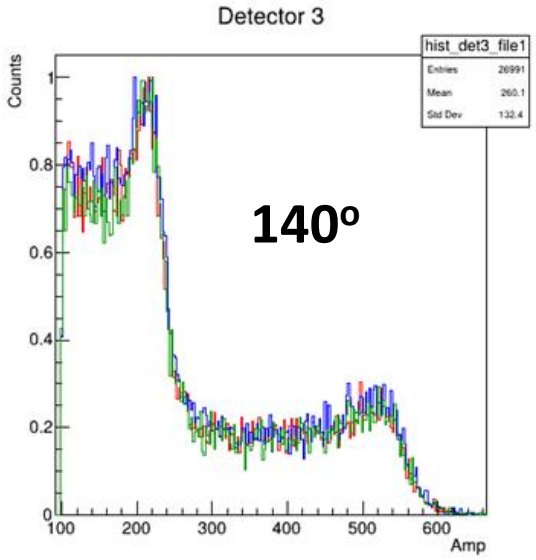
Det #	θ_{lab}
1 and 8	100°±6°
2 and 7	120°±6°
3 and 6	140°±6°
4 and 5	160°±6°

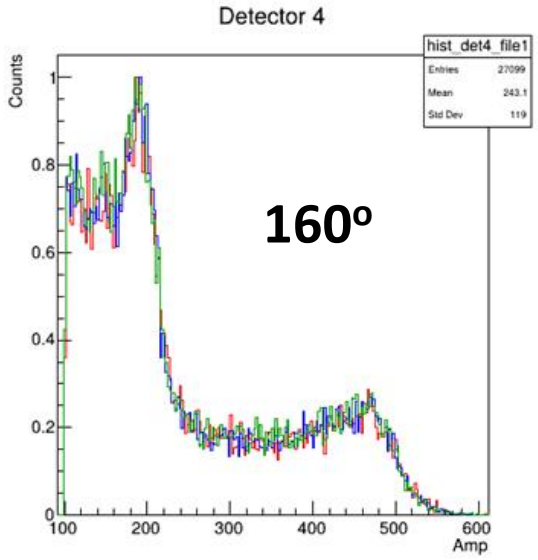
Stabilized Electronics – 3 runs

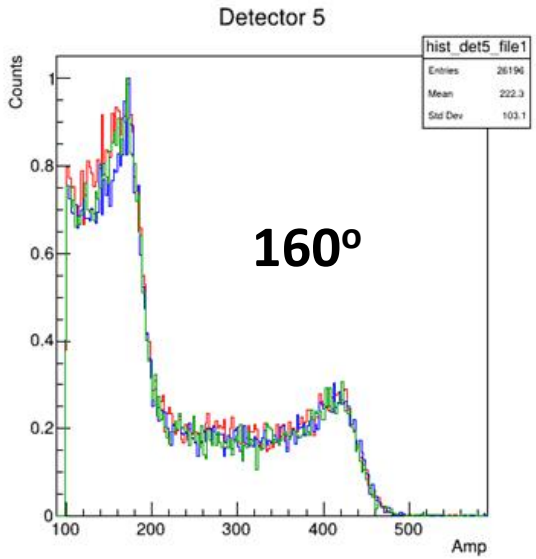
1st run | 2nd run | 3rd run

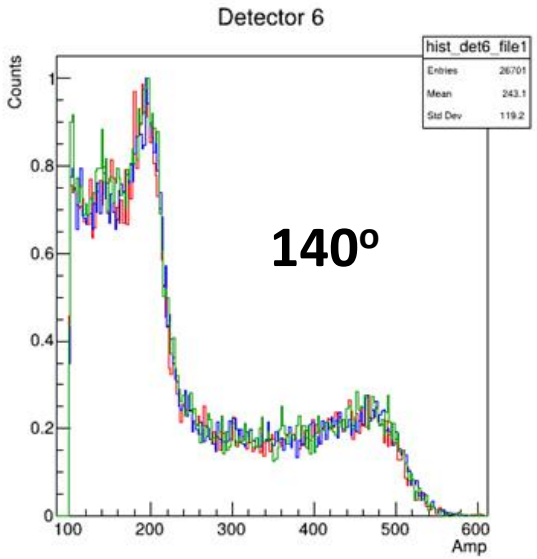


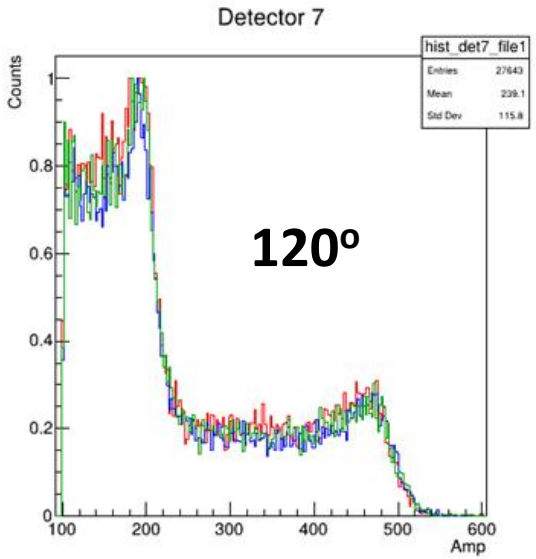


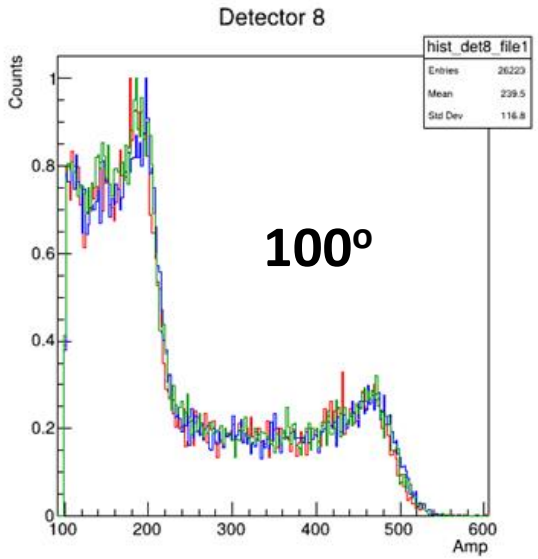








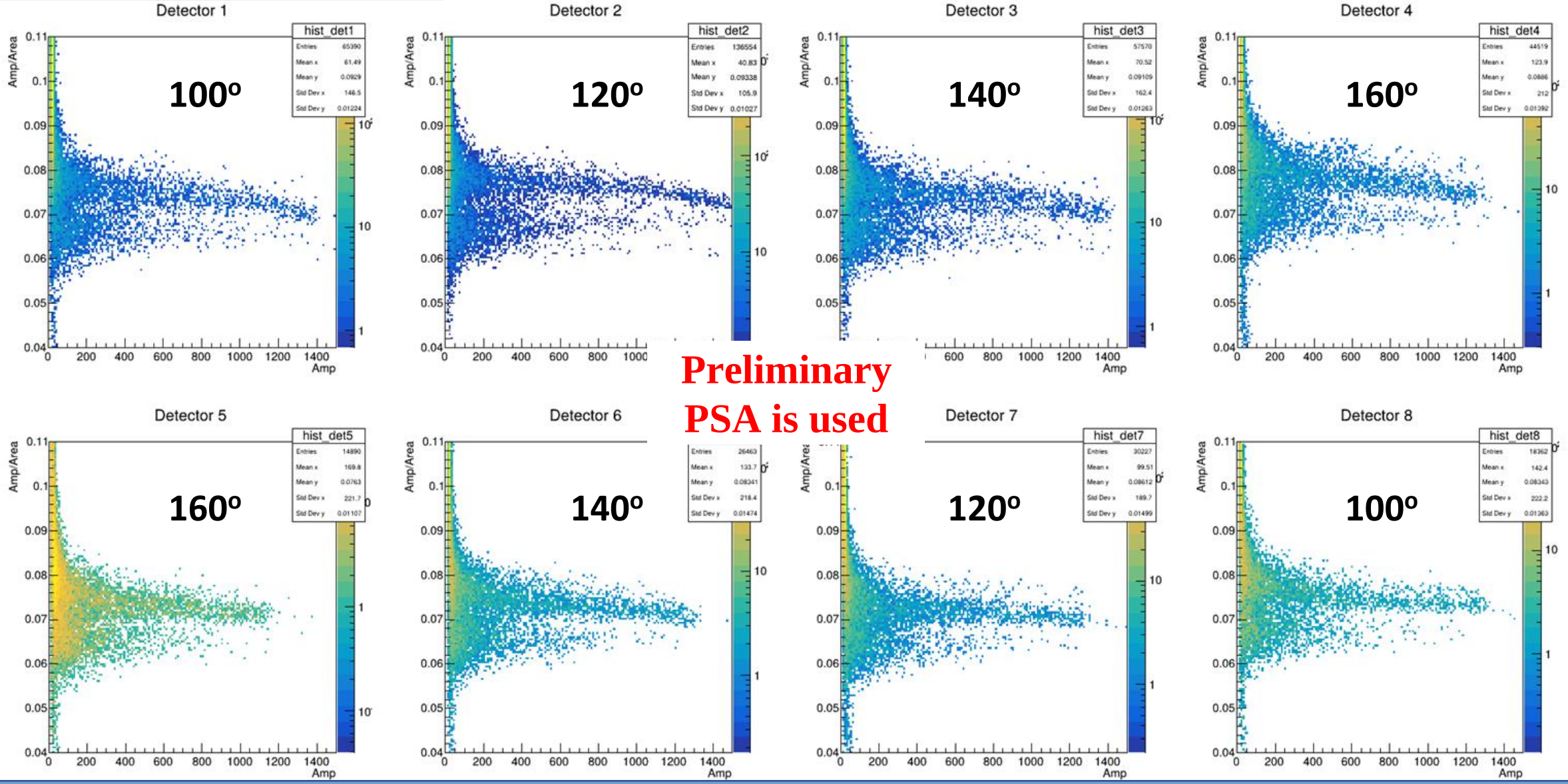




Amp/Area filtering

amp/area: 0.074 threshold to select neutrons

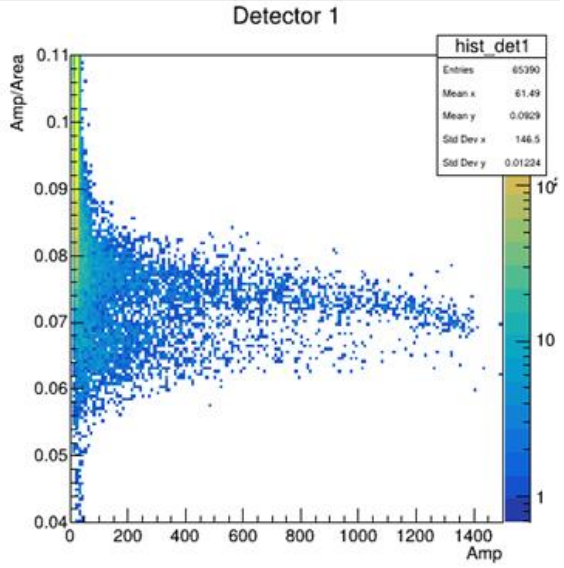
+ pile-up rejection

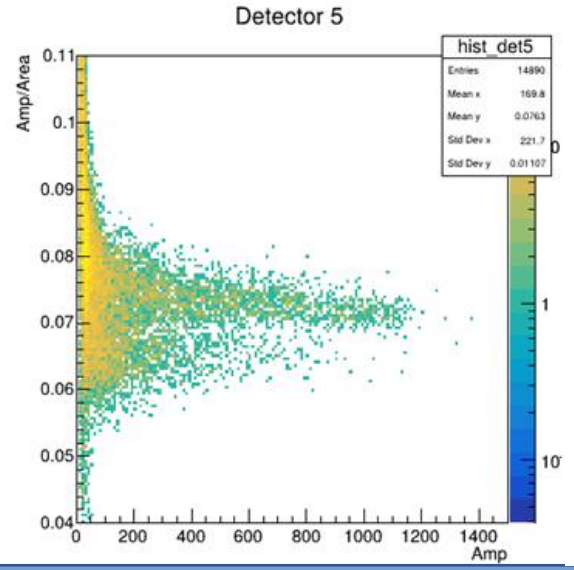


Preliminary

PSA is used

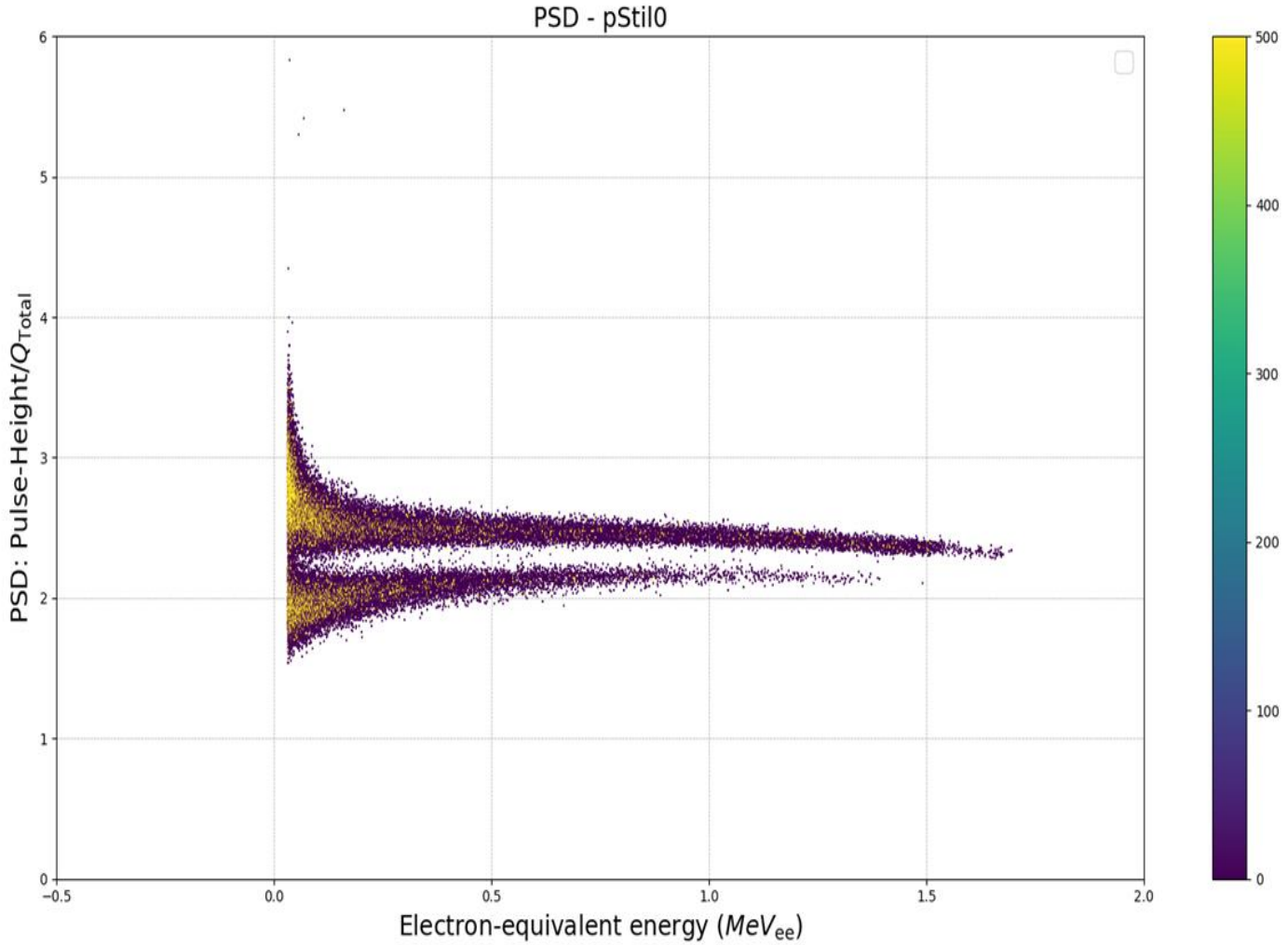
Amp/Area filtering





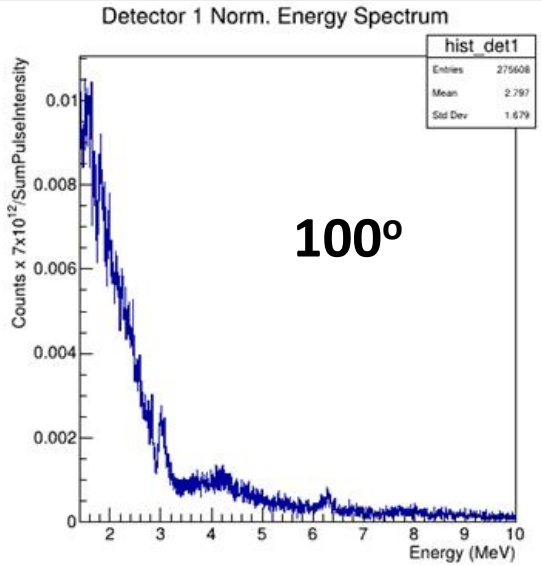
amp/area: 0.074 threshold to select neutrons

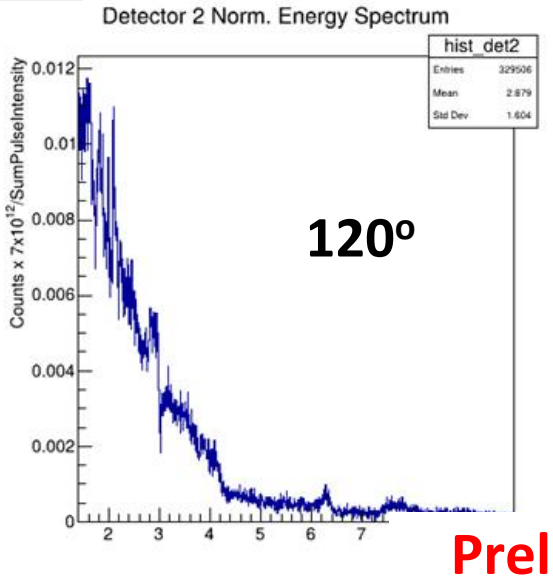
+ pile-up rejection

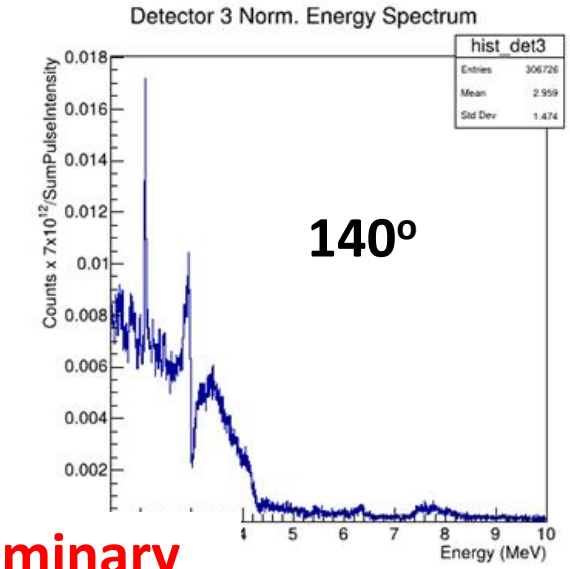


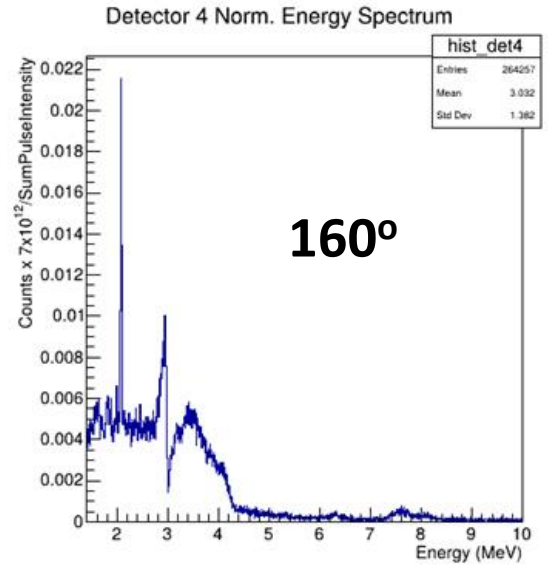
Normalized ^{12}C spectra

0.074 amp/area threshold | 5keV Binning | No pile-up | tflash range



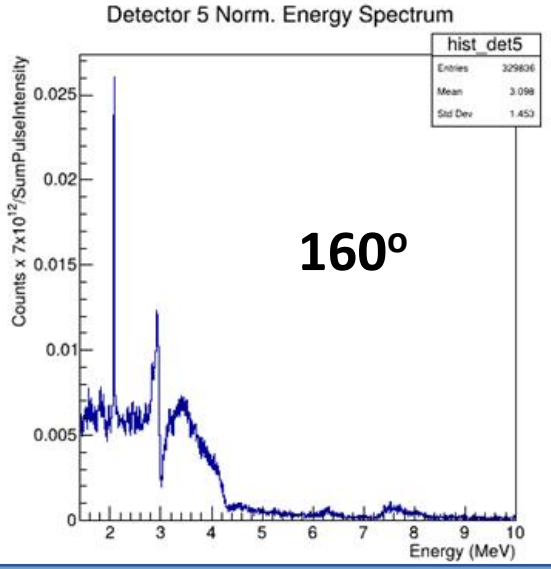


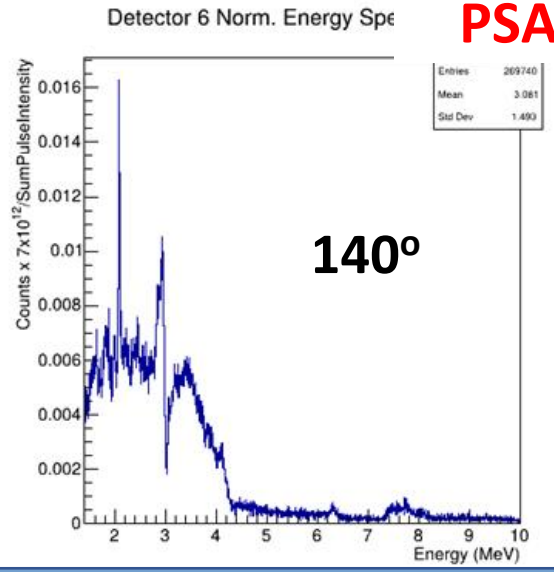


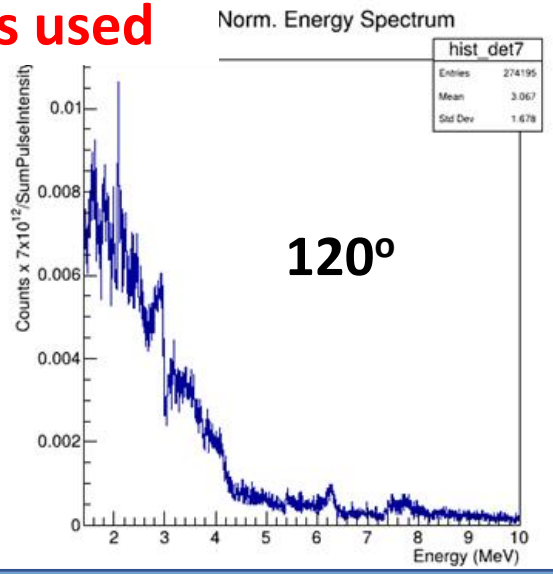


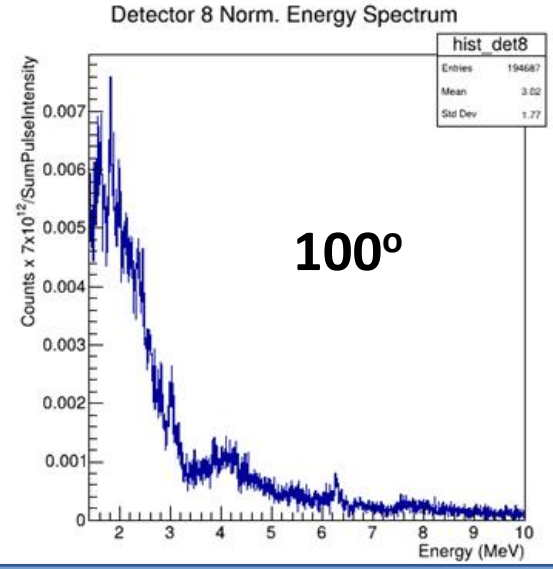
Preliminary

PSA is used



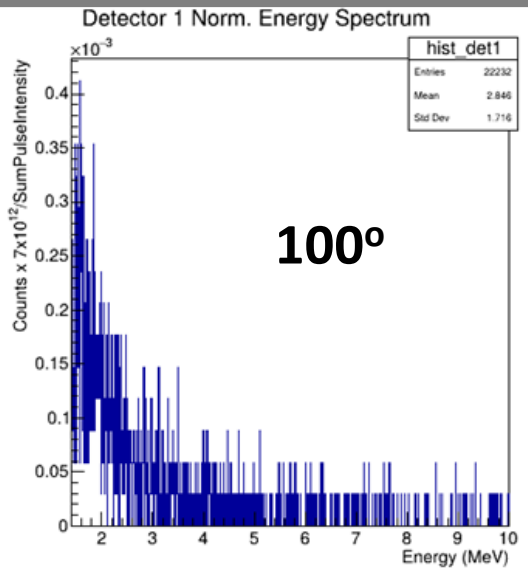


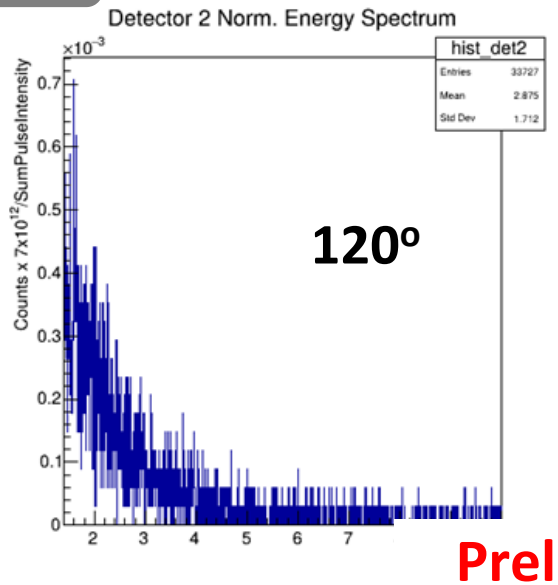


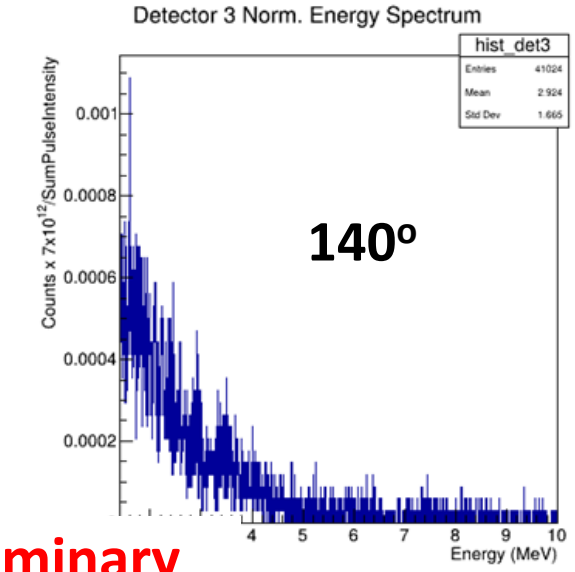


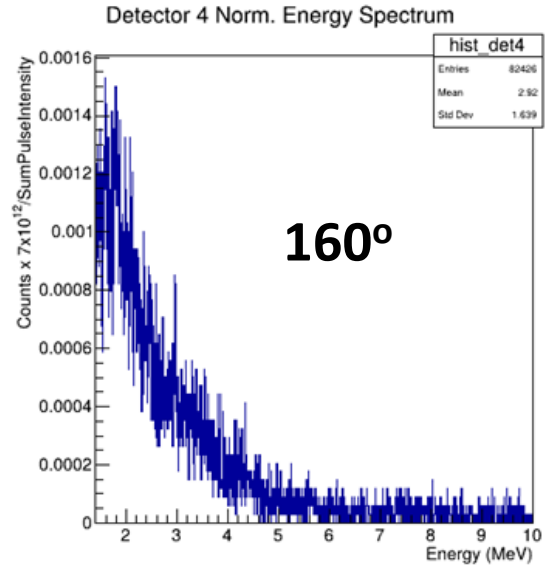
Normalized Empty Spectra

0.074 amp/area threshold | 5keV Binning | No pile-up | tflash range



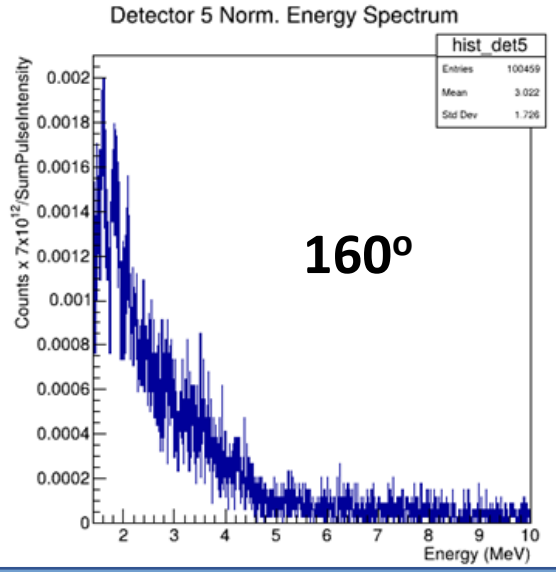


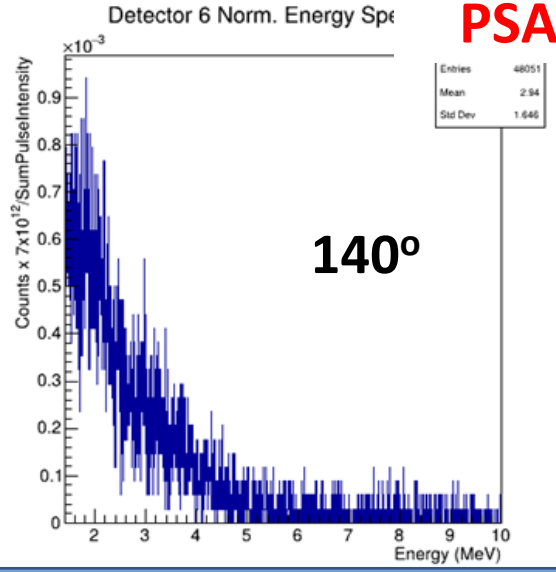


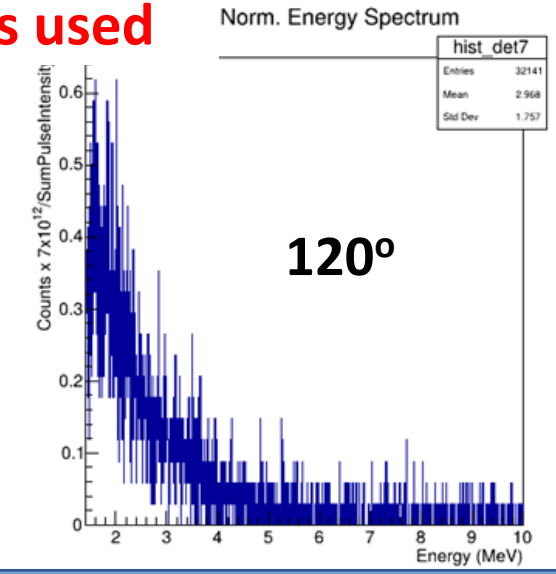


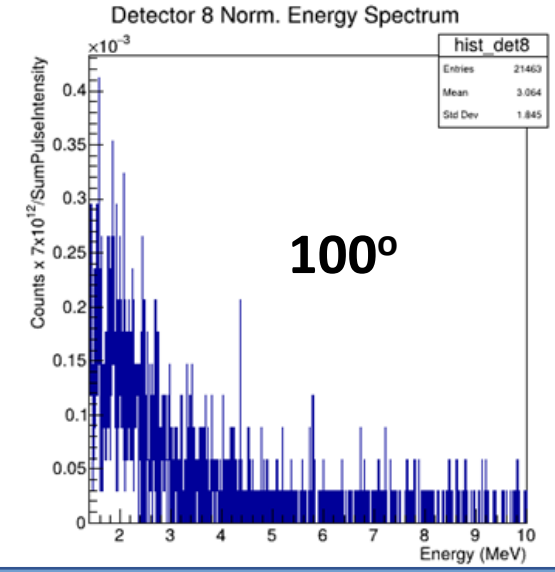
Preliminary

PSA is used



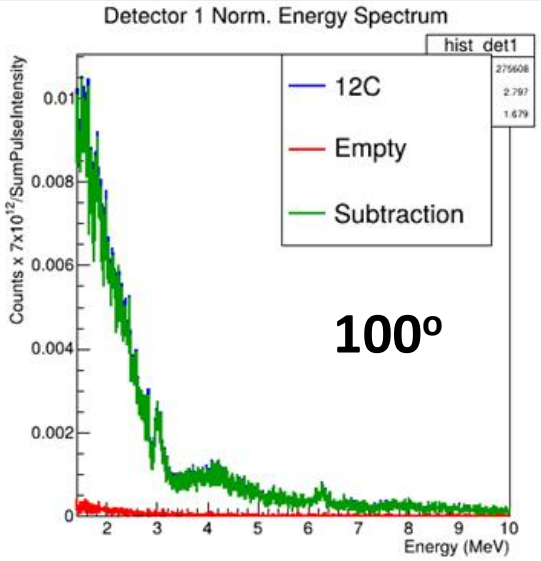


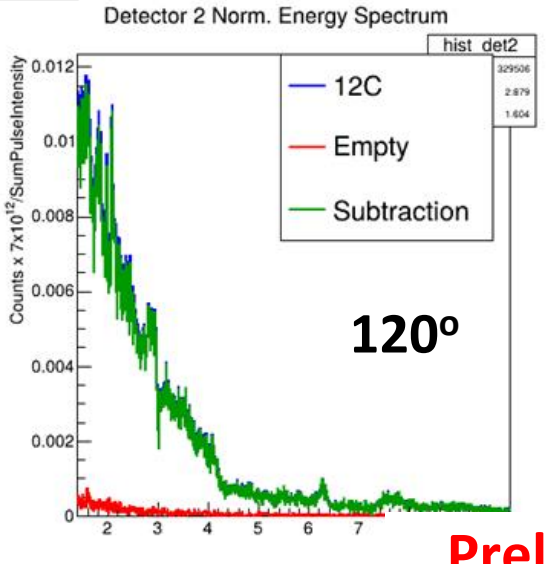


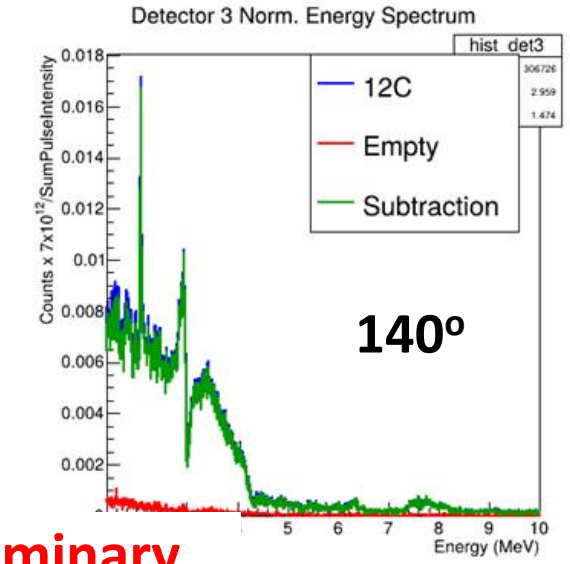


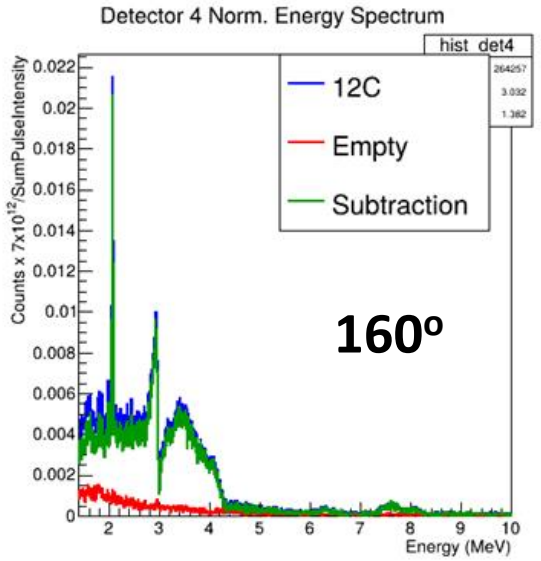
Clean Spectra

0.074 amp/area threshold | 5keV Binning | No pile-up | tflash range



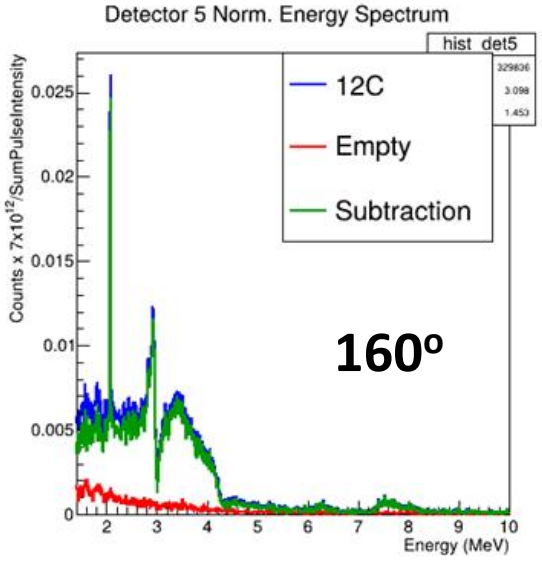


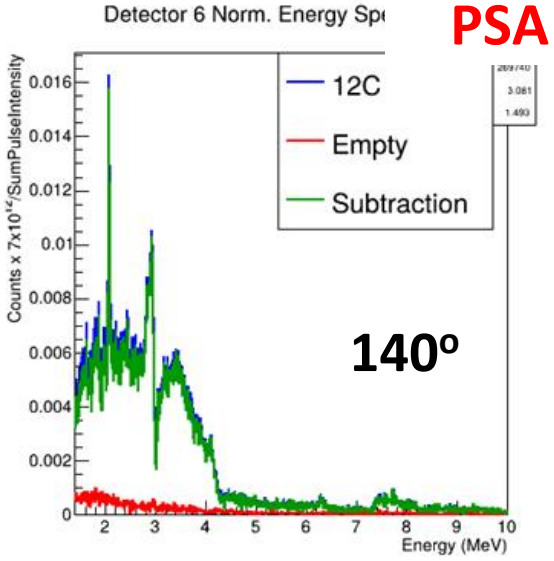


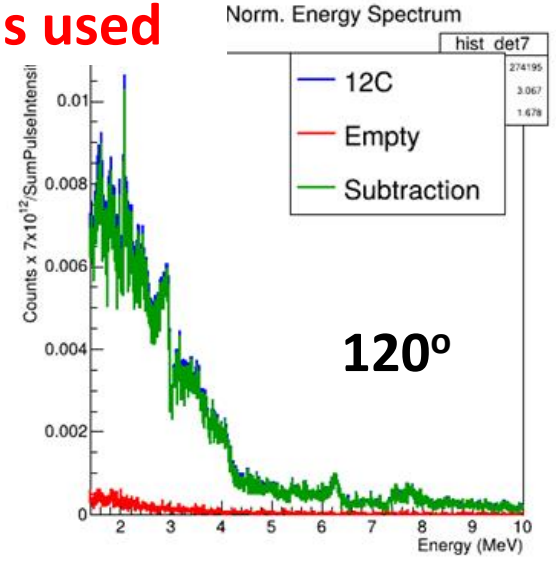


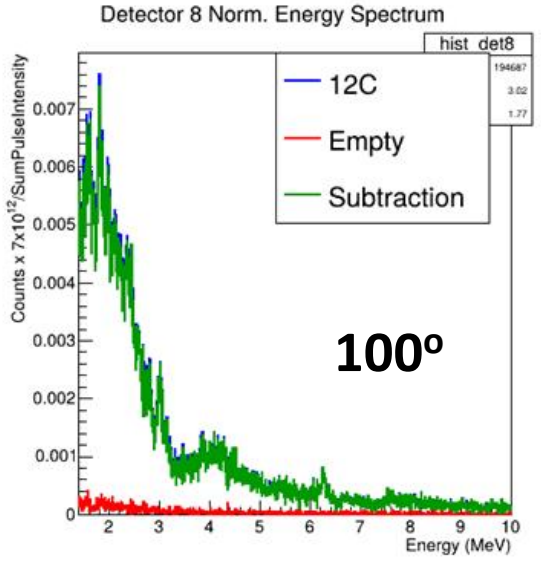
Preliminary

PSA is used



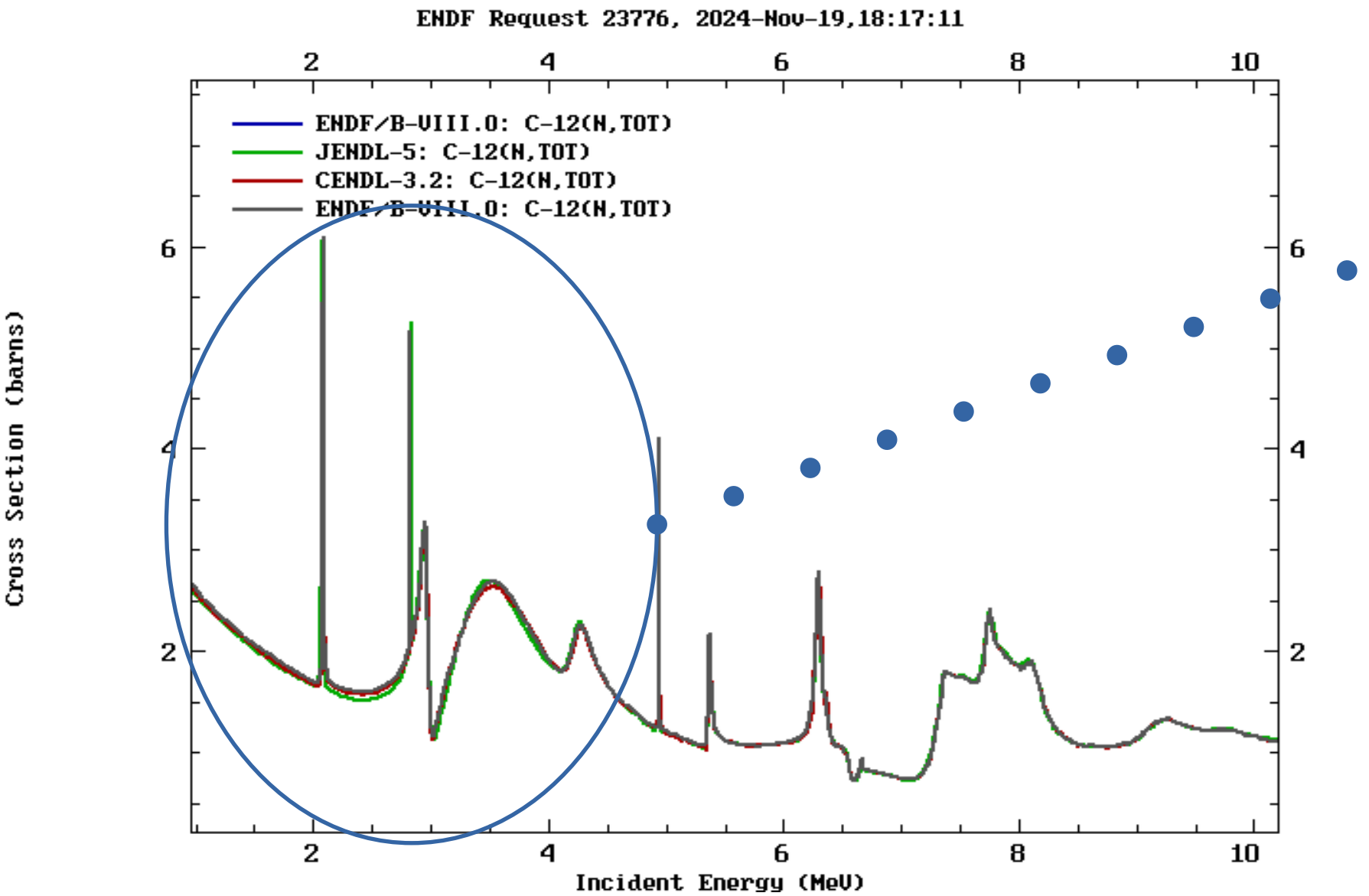


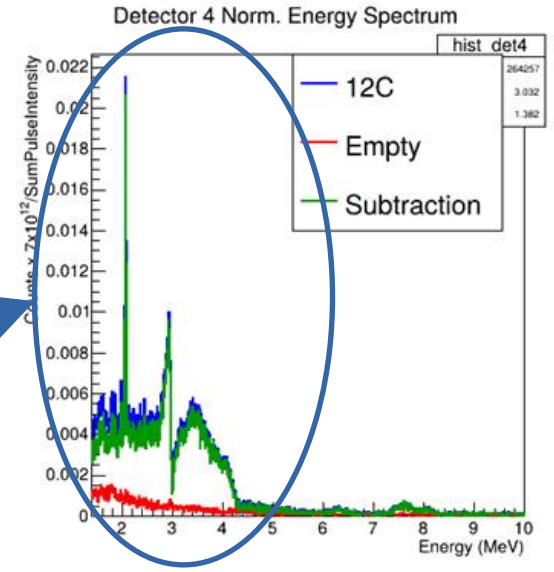


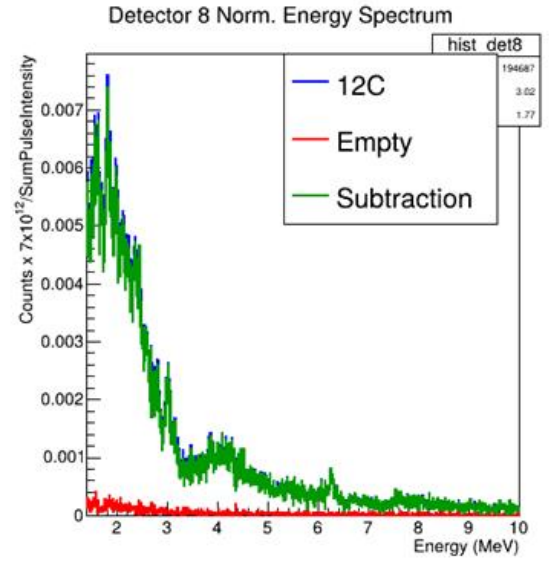


Clean Spectra

0.074 amp/area threshold | 5keV Binning | No pile-up | tflash range

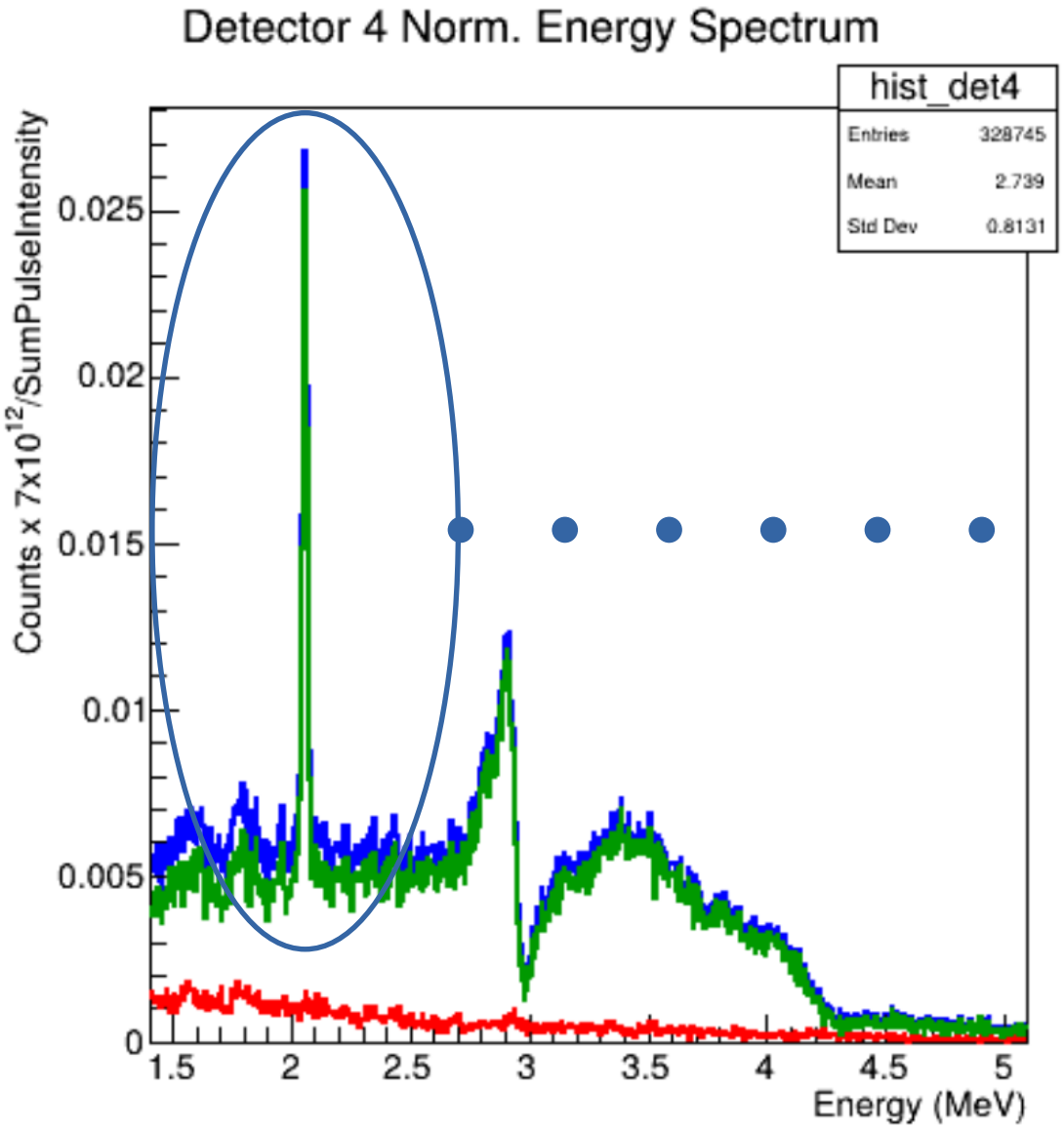




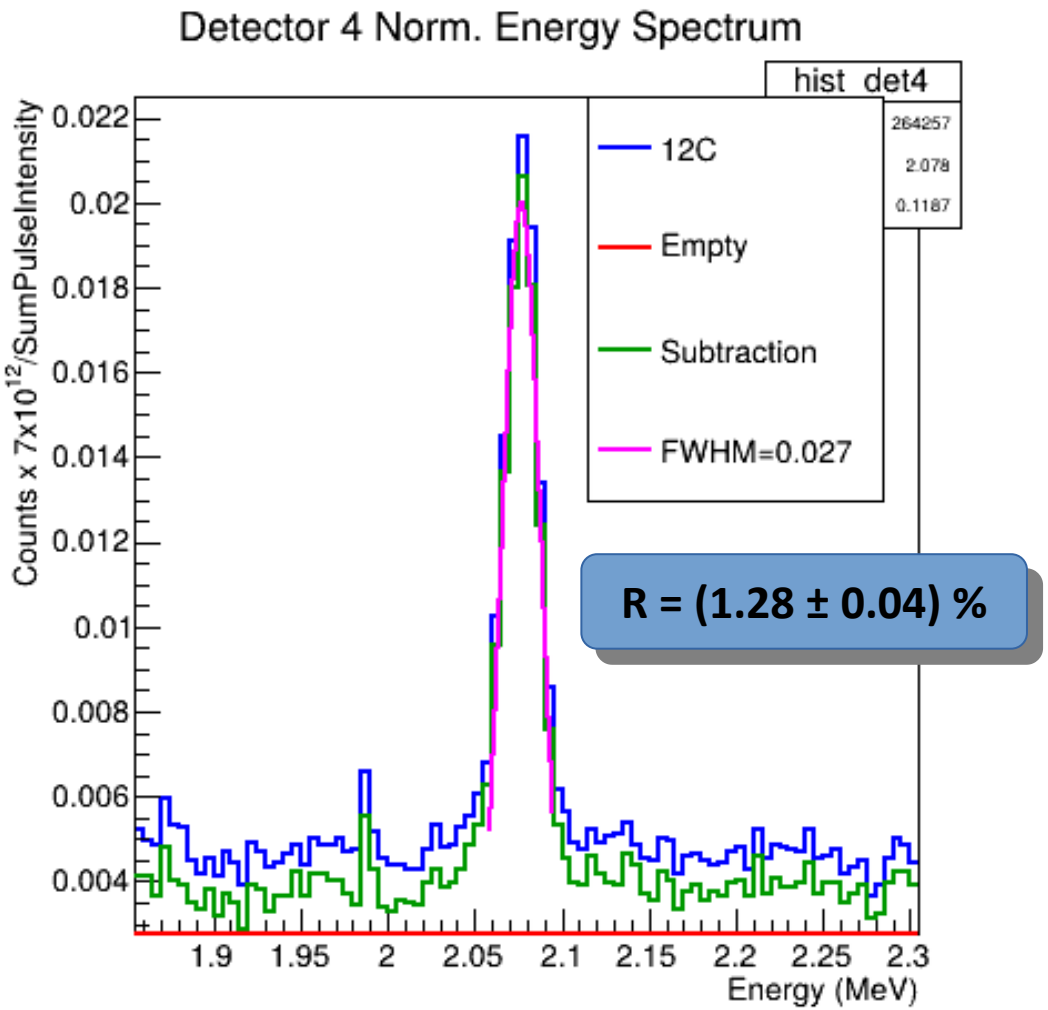


Clean Spectra

0.074 amp/area threshold | 5keV Binning | No pile-up | tflash range



preliminary estimation



R = (1.28 ± 0.04) %

Future Analysis

- Fine tune the PSA. Find the best input parameters for discrimination.
- Retrieve the flux of EAR1 and correct the normalized spectra.
- Correct for areal density and neutron efficiency.
- Compare with R-Matrix calculations.

Summary of the activities in 2024

LoI for $^{12}C(n,n)$ and $^{12}C(n,n')$ - April 2024

Preliminary Test in EAR1 with RAMEN set-up - August 2024

n. 1 detector at 10 cm

- Test with and without Energy power station
- Test with long cabling bypassing the patch panel

- ***No ringing***
- ***Comparison with C6D6 available****: reduced pile-up, baseline recovering and no saturated gamma-flash*

Final Test in EAR1 (^{12}C and ^{11}B samples) – October 2024

n. 8 detectors at 12 cm distance from target

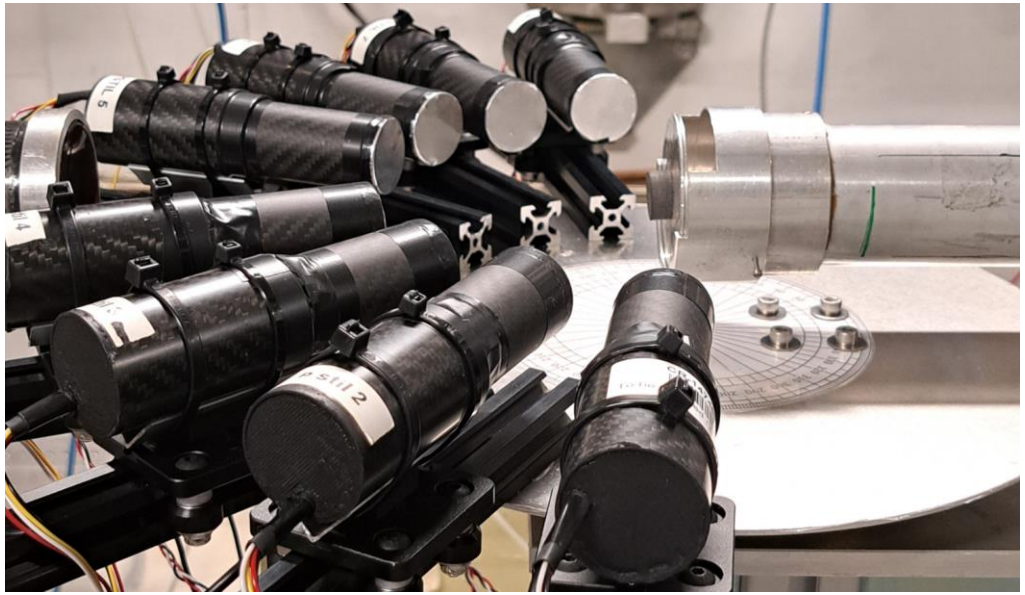
-Angular distribution available (n.4 angles)

-on-going analysis

New target development at CERN and LNS lab target

Status of the PSTIL set-up and future developments

8 Modules ready and tested



+

ITEM	n.	PROVIDER	STATUS
1''x1'' crystal	10	PROTEUS	Expected to arrive at INFN-CT this week
PMT	10	Hamamatsu	Sub judice 2025
Power base	10	Sens-Tech	Sub judice 2025

→Mechanical arrangement for 18 modules and new target holder in carbon fiber (coll. Trieste)

→Ancillary detectors for (*n,cp*): small-volume, low-power.
One PSTIL module power: ***5Vx50mA* suitable for in-vacuum applications**

→Ancillary detectors for (*n,n'*) measurements: coupling with LaBr3

THANKS!

BACK-UP SLIDES

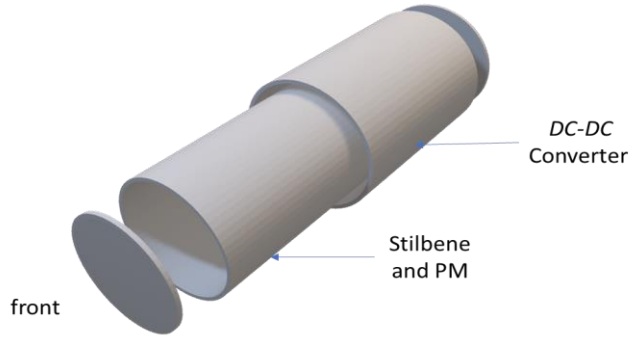
pStil Modules

Stilbene Detector Modules
(pStil)
Solid-State Organic Scintillators

Developed at INFN-CT, Sezione di Catania

Currently used & tested at nTOF/CERN

High counting rate
with **no HV** needed



p-Stil module

(x3) *1"x 1"* cylindrical ***INRAD*** trans-stilbene detector

(x1) *1"x 1"* cylindrical ***PROTEUS*** trans-stilbene detector

Carbon fiber housing

Aluminium cover in the front window

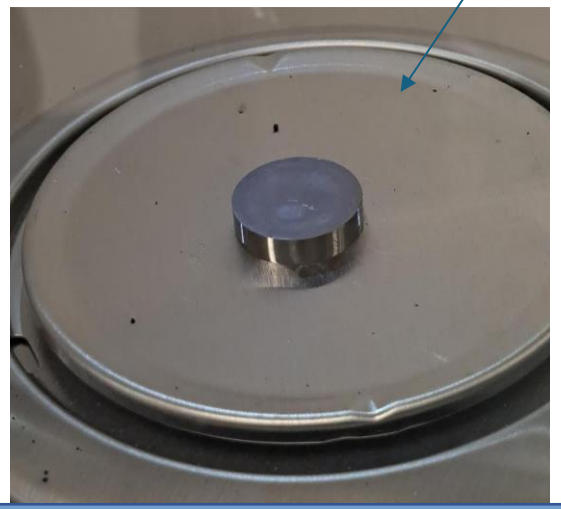
New targets: ^{13}C and ^{12}C target

^{12}C for target preparation test @ CERN

goodfellow

Item number	Description	Quantity
1000036935	Carbon Powder C 99.996% Mean Particle Size: 7.73 micron	1.00
1000001902	Carbon Powder Graphite C 99.997%	1.00

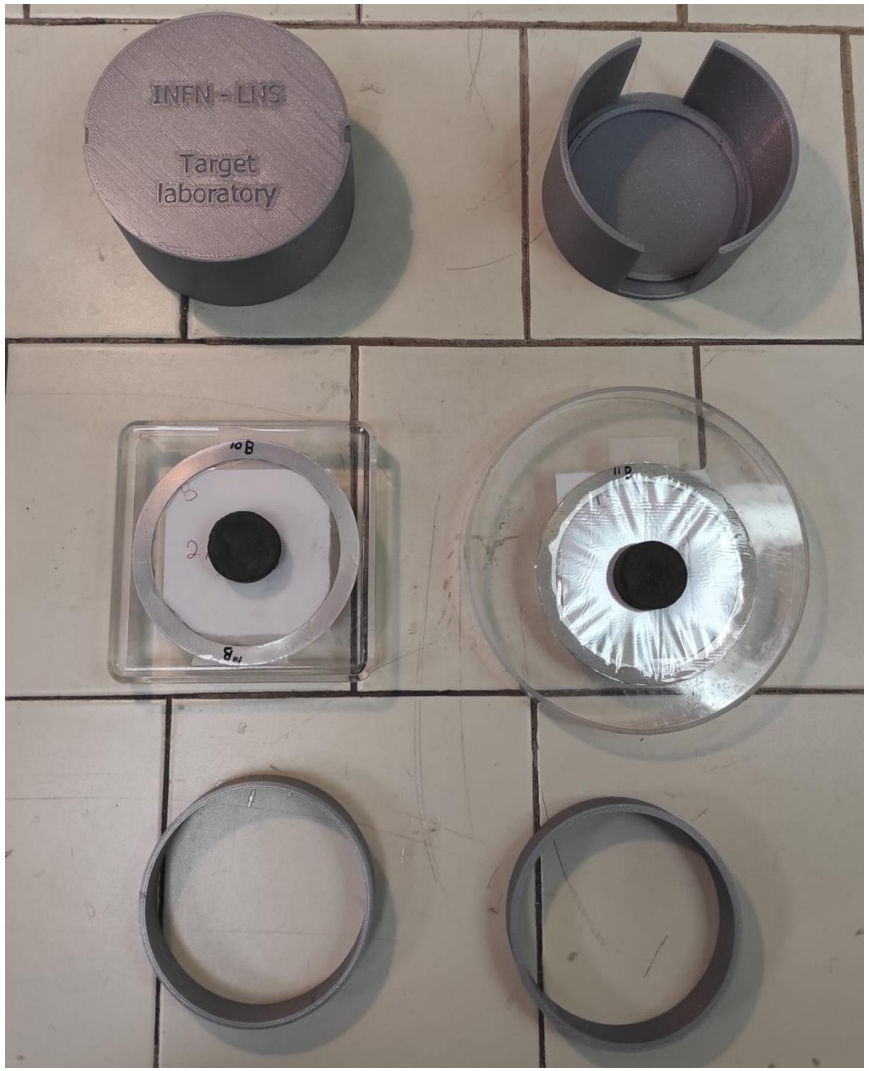
75 micron



ICON ISOTOPES

99.2% enrichment

New Targets: ^{10}B and ^{11}B target

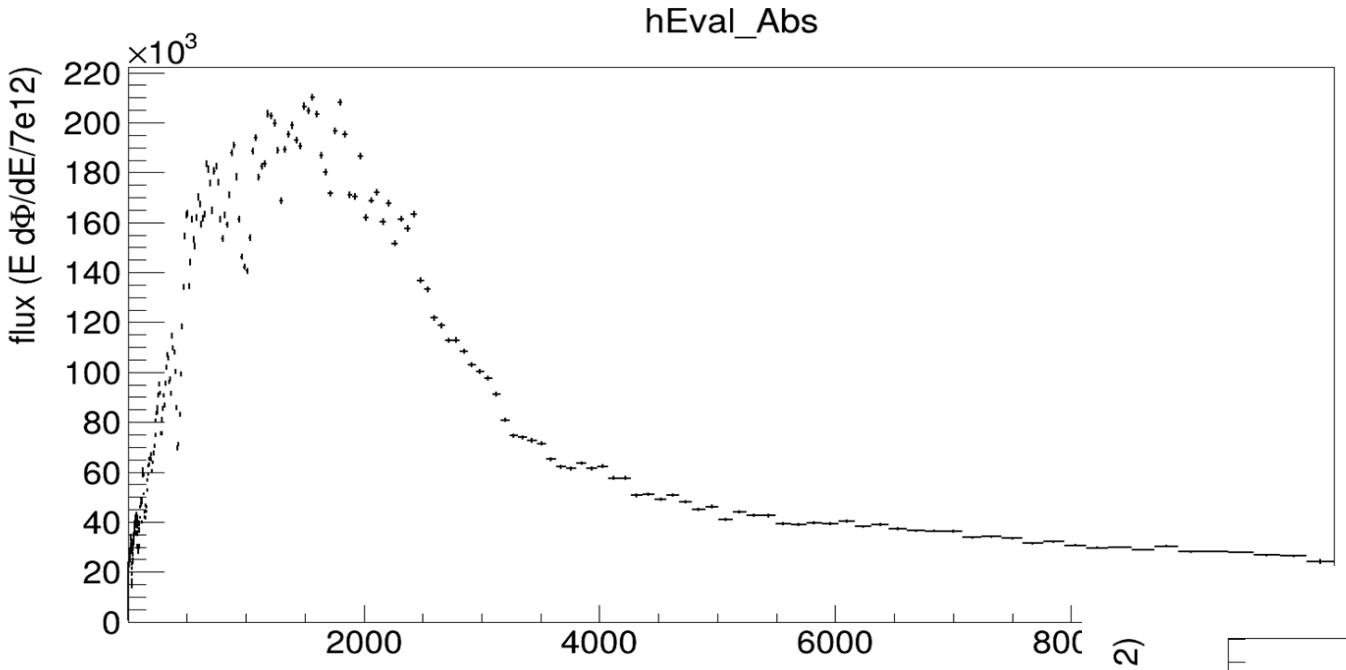


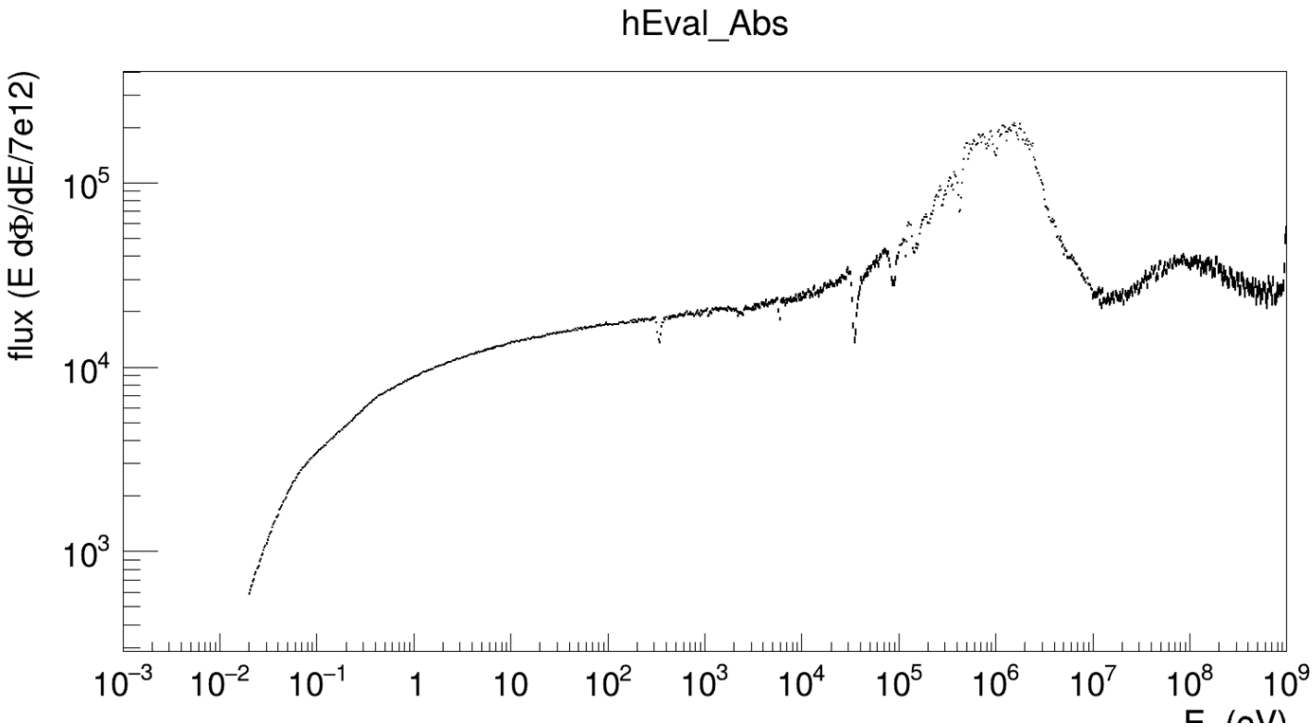
Laboratori Nazionali del Sud
Istituto Nazionale di Fisica Nucleare
Target Laboratory

List	1	N°1 pasticca di ^{10}B fi 18 mm , peso 2,8851 g , spessore 9 mm su mylar 6 µm
	2	N°1 pasticca di ^{11}B fi 18 mm , peso 2,9930 g , spessore 8 mm su mylar 6 µm
	3	

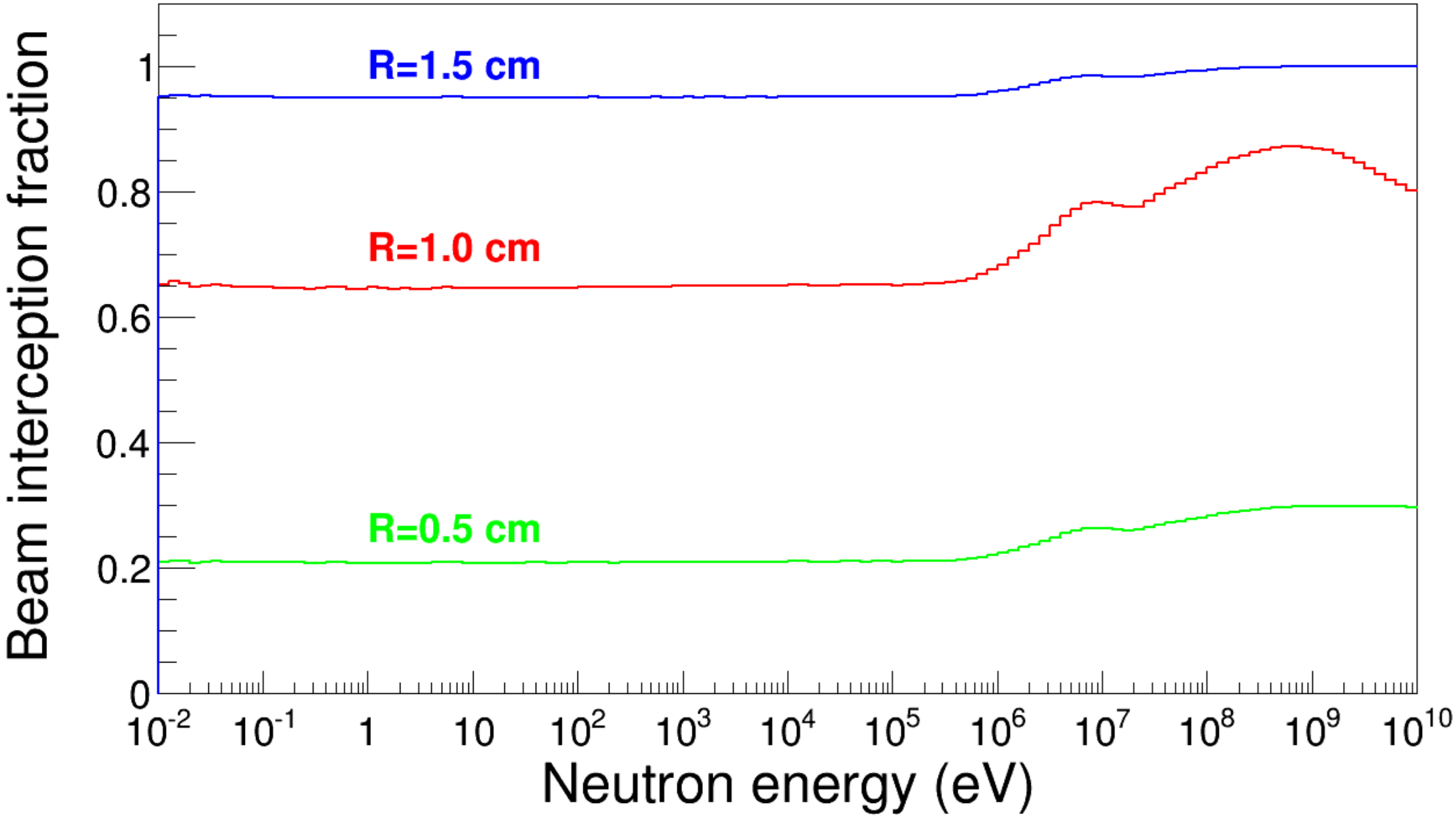
Antonio Massara and Martina Ursino

Flux Distributions (in eV)



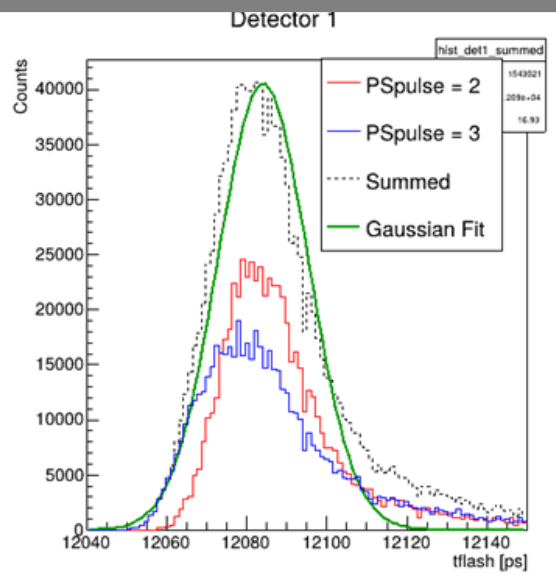


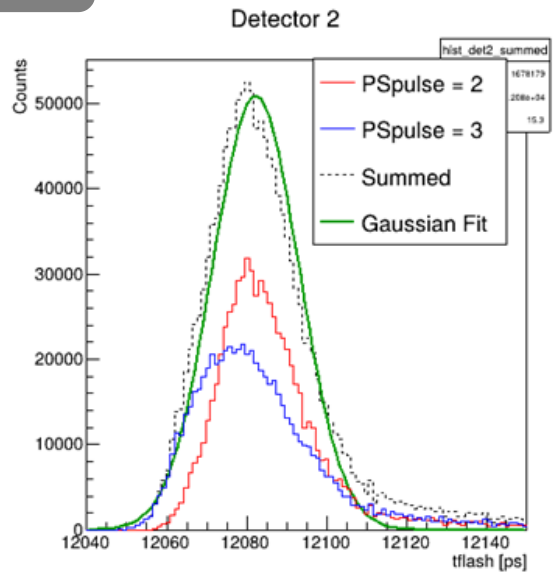
Beam size vs neutron energy

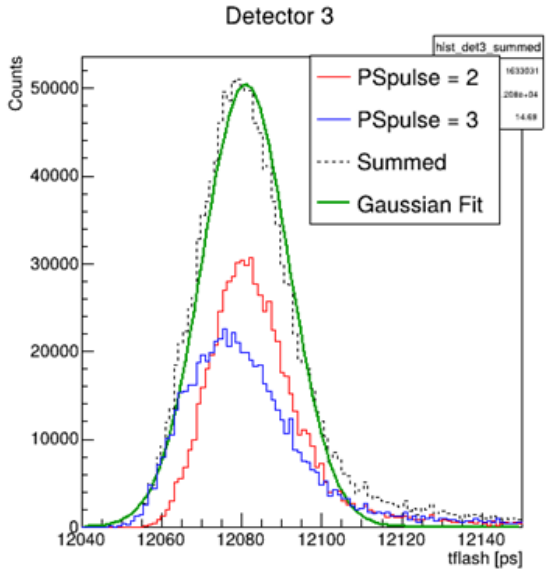


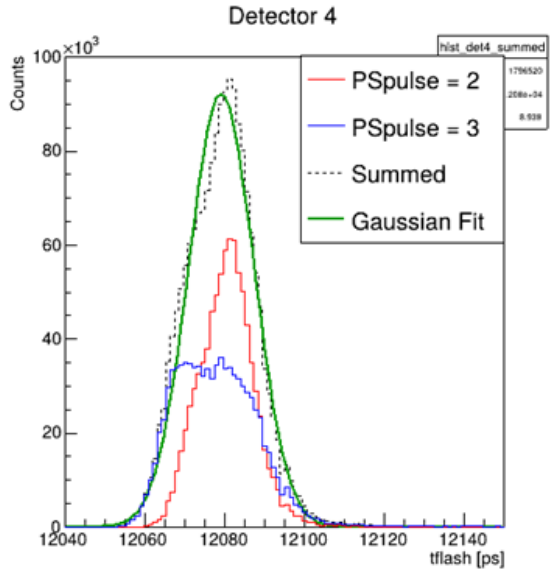
tflash filtering

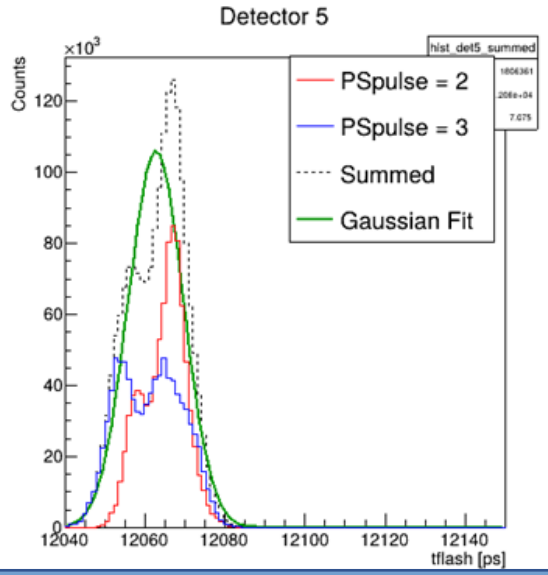
tflash: ± FWHM x-values range for each detector

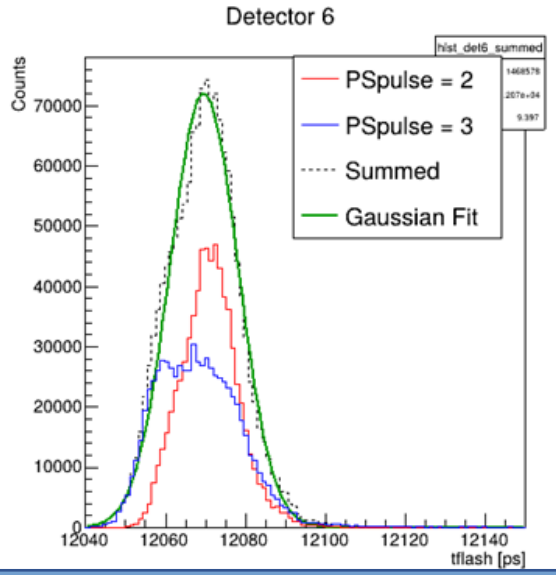


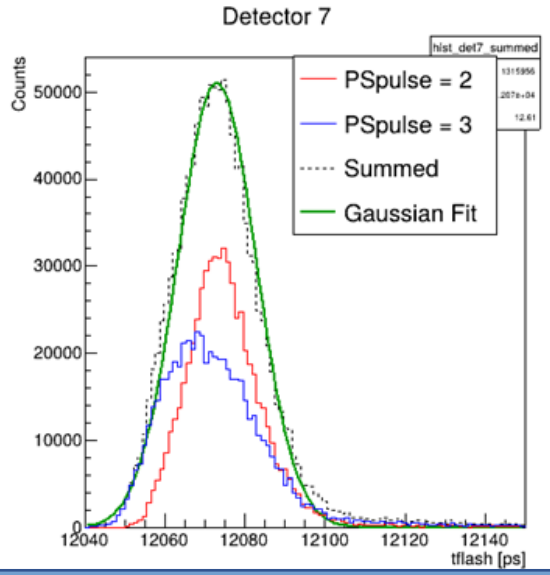


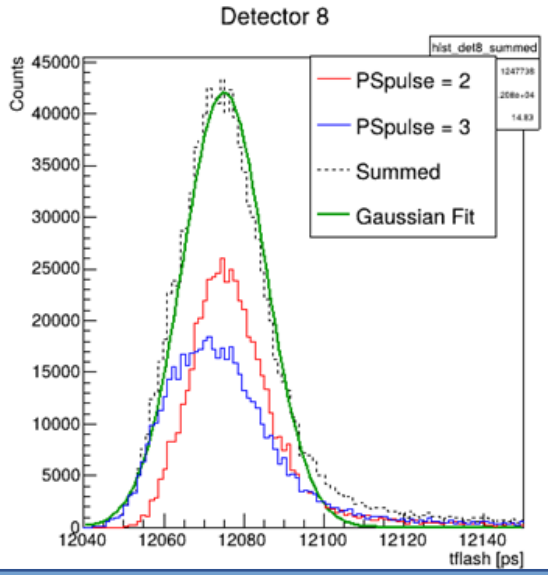












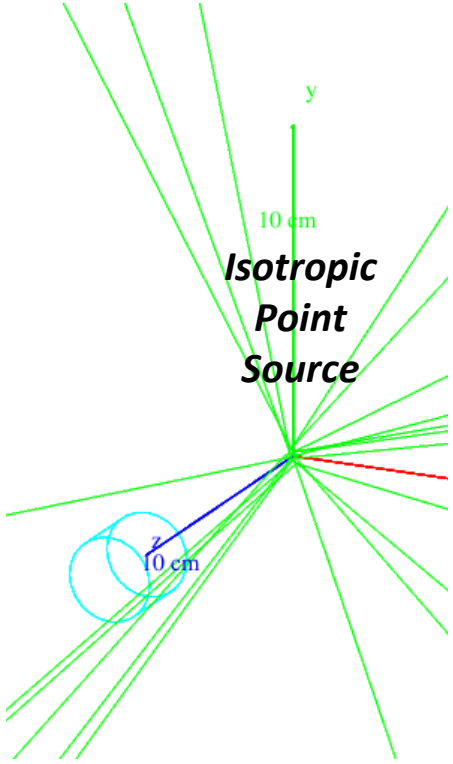
tflash filtering

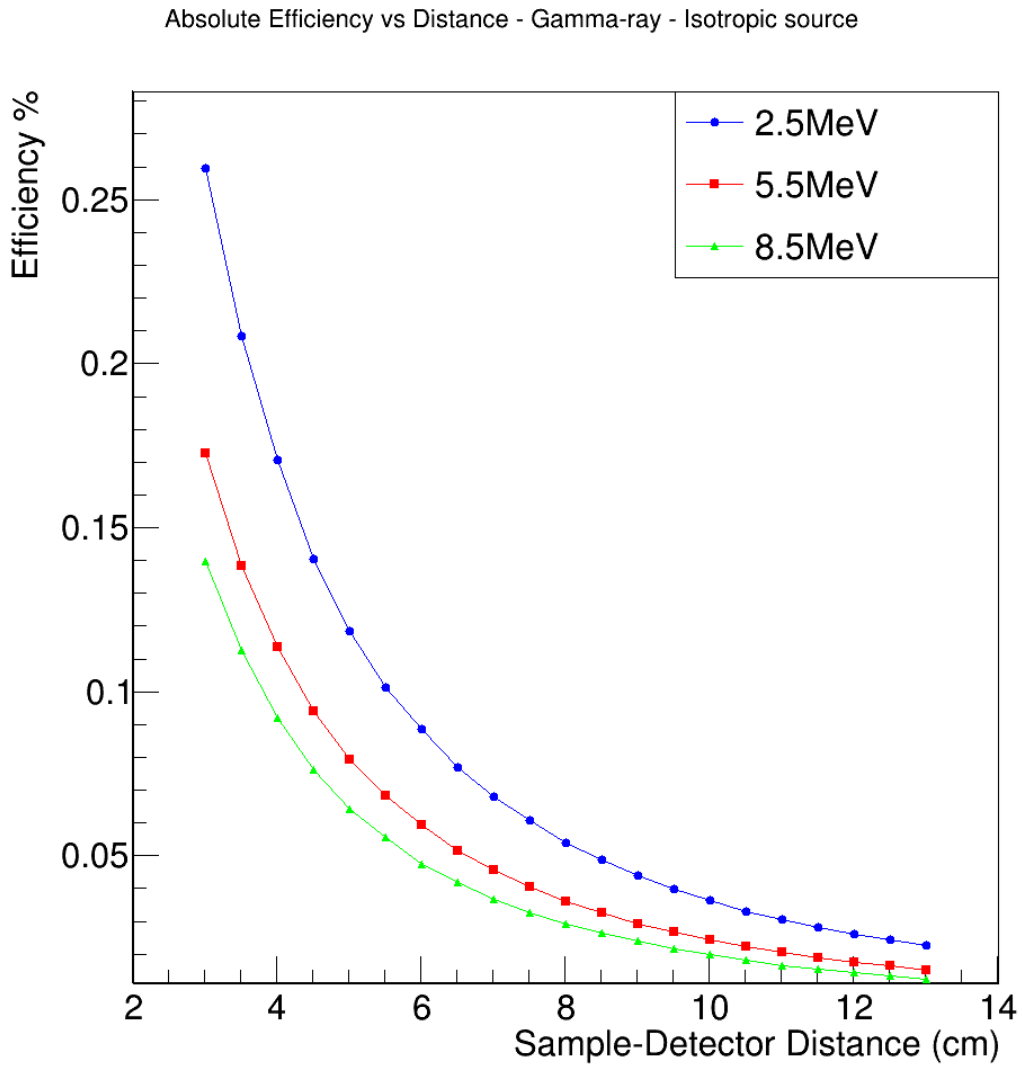
tflash: ± FWHM x-values range for each detector

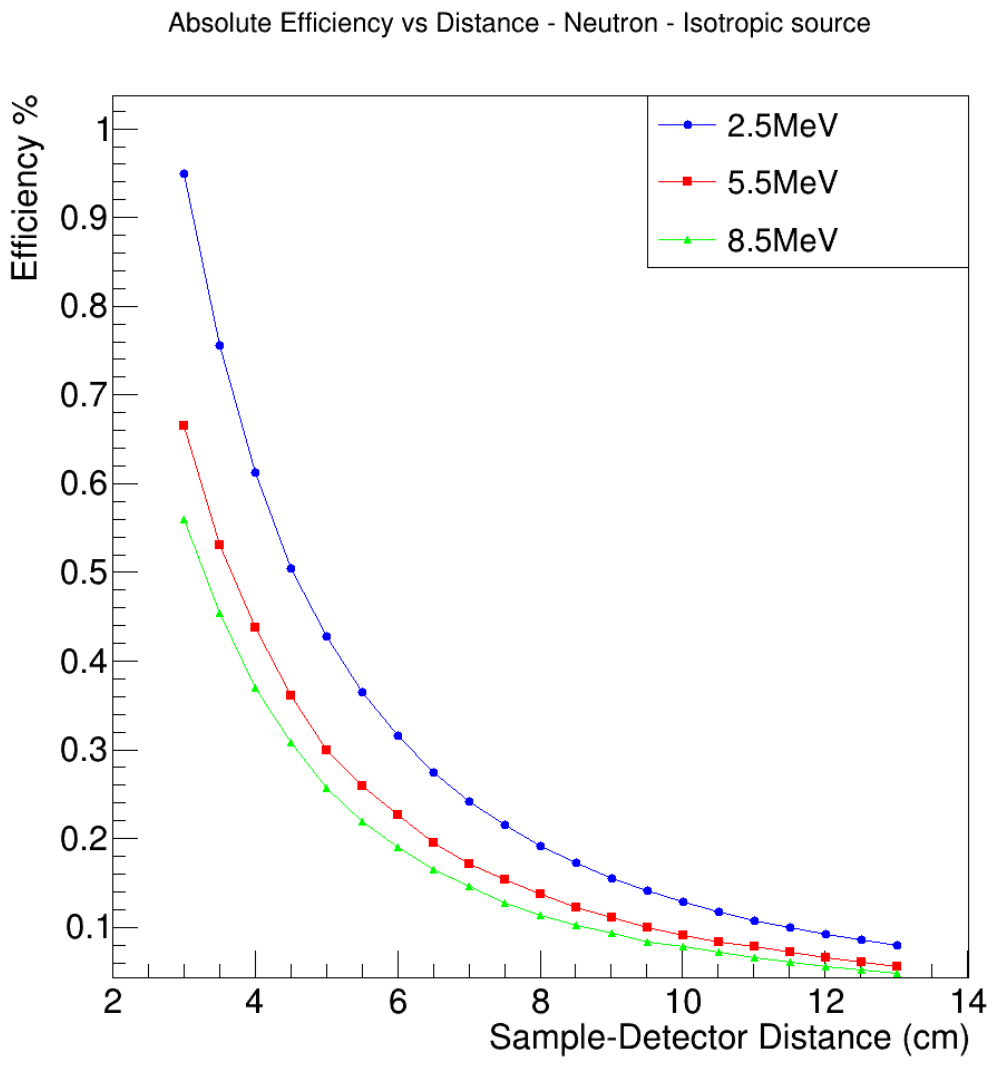
	FWHM (ns)	σ (ns)
pStil1 - INRAD	26.57 ± 0.02	11.28 ± 0.01
pStil2 - INRAD	25.42 ± 0.02	10.79 ± 0.01
pStil3 - INRAD	25.32 ± 0.02	10.75 ± 0.01
pStil4 - INRAD	19.16 ± 0.02	8.14 ± 0.01
pStil5 - PROTEUS	16.22 ± 0.02	6.89 ± 0.01
pStil6 - PROTEUS	19.97 ± 0.02	8.48 ± 0.01
pStil7 - PROTEUS	23.00 ± 0.02	9.77 ± 0.01
pStil8 - PROTEUS	24.45 ± 0.02	10.38 ± 0.01

Simulated Detection Efficiency using GEANT4 simulation toolkit

** Preliminary**







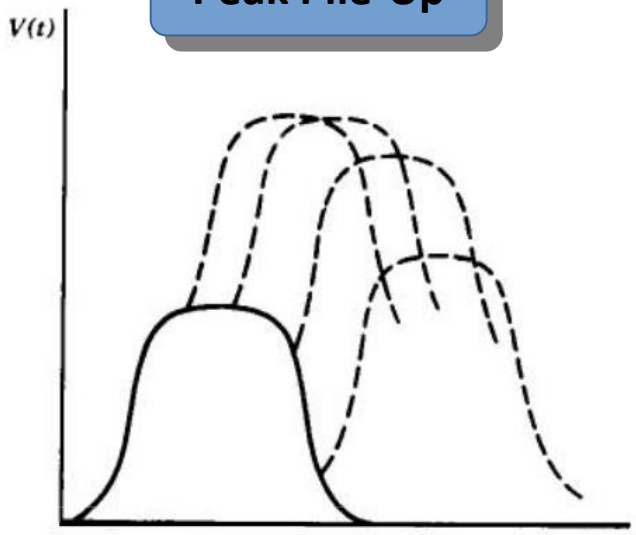
Higher counting rates can cause overlap between pulses

For a time window of **320ns** and a rate of **1kHz**

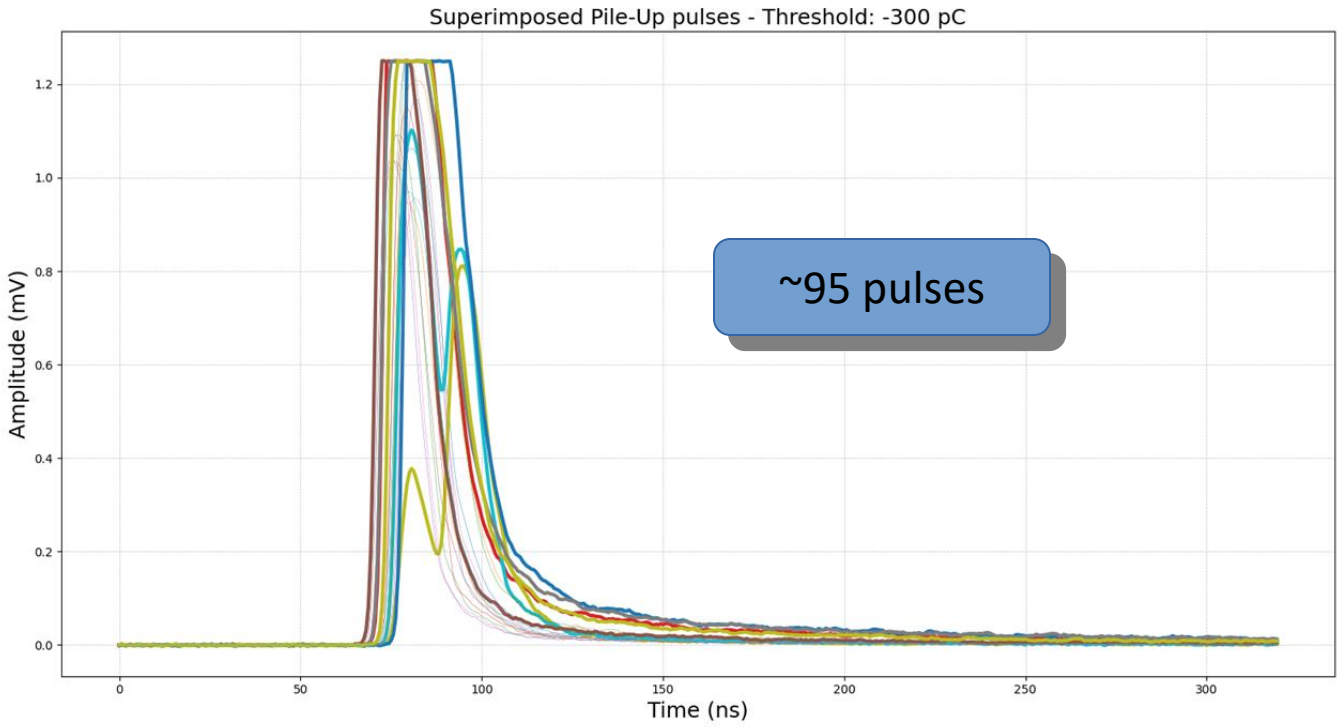
$$P(>\tau)=e^{-n\cdot\tau}$$

For **~10^6 events** we expect **~300-400 pile-up events**

Peak Pile-Up



*G. F. Knoll, Radiation Detection And Measurement, John Wiley and Sons, 2000



~95 pulses

So **why PCA ?**

5 Initial Parameters! ...

Pulse-height

Charge (short, long, tail)

Pulse-width

...

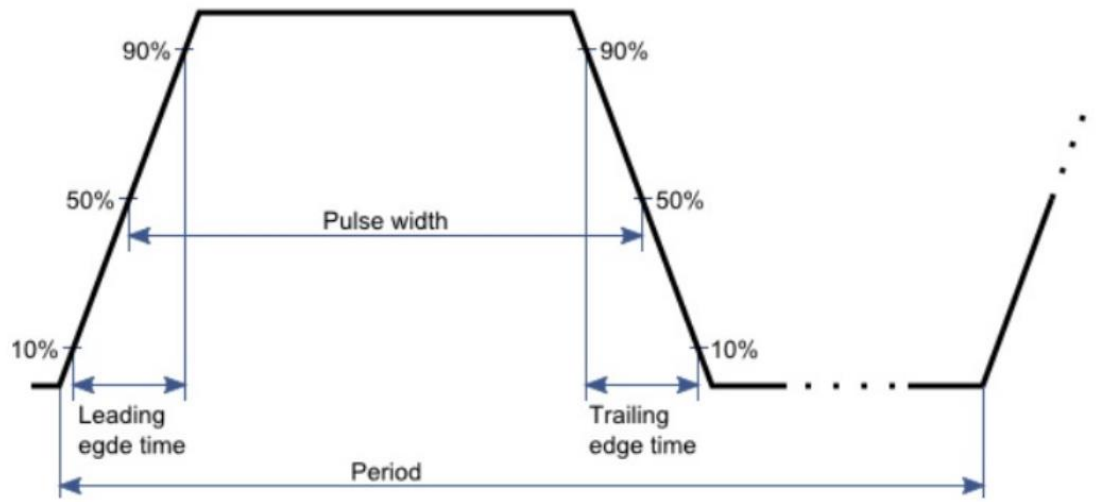
$$\mathrm{PSD} = \frac{Pulse\ Height}{Q_{total}} \quad Q_{short}/Q_{total}, \frac{Q_{long}-Q_{short}}{Q_{long}} \ldots etc$$

**

A lot of missed opportunity

**

Pulse-width



Data Standardization

**

PCA is affected by the scales of the variables. Normalizing the data to have a mean of 0 and a variance of 1

**

Computing the **Covariance Matrix**

$$S(x,y)=cov(x,y)=\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})$$

** Captures the correlations between pairs of variables **

Computing the **Eigenvalues and Eigenvectors**

$$S\cdot \boldsymbol{v_k}=\lambda_k\cdot \boldsymbol{v_k}$$

**

The **eigenvectors (PCs)** determine the **directions** of the new feature space, and the **eigenvalues** determine their **magnitude (variance)** along these new axes

**

Sorting the Eigenvalues and Eigenvectors

**

Sorted in descending order. The top k-eigenvalues and their eigenvectors are selected to form the PCs

**

Transforming the data

$$Z=X\,V$$

**

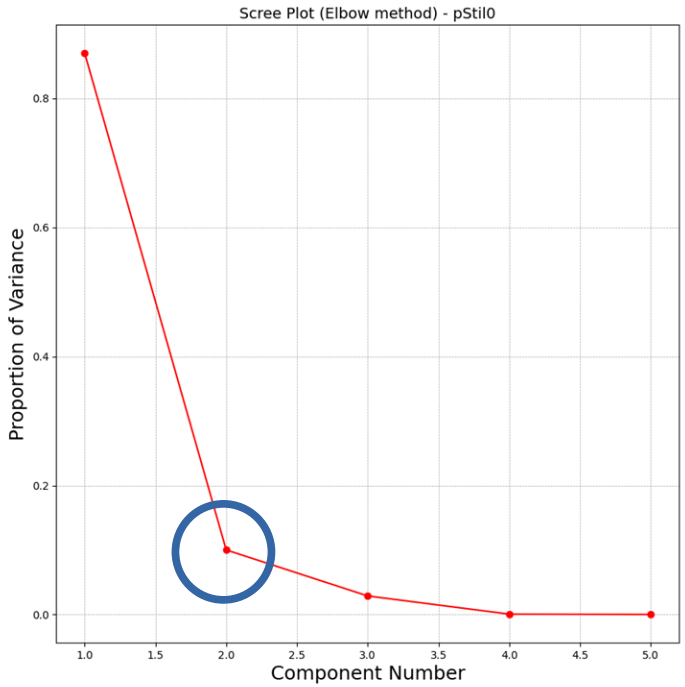
The original data is projected onto the new PC axes

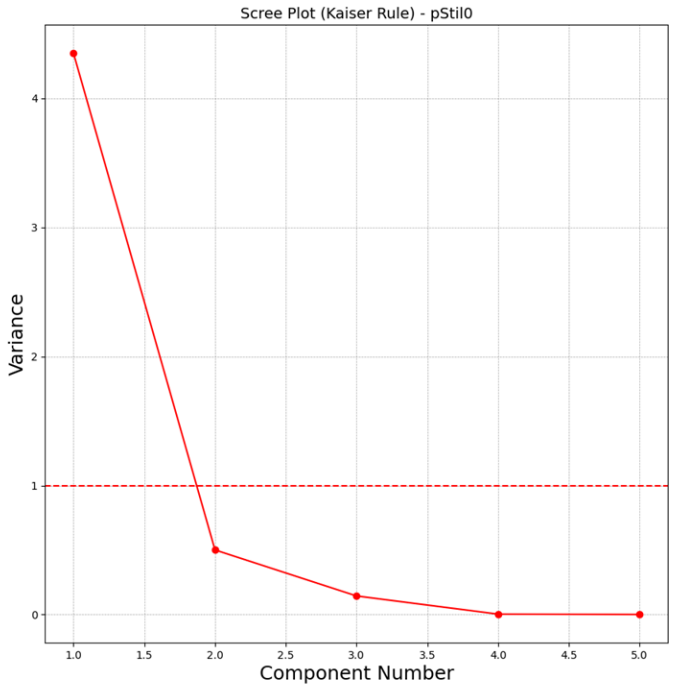
**

PCA – Scree Plots

"Elbow" Method

Kaiser-Guttman criterion





Subjective methods

The value of k, defining an **'elbow' or 'knee' or 'point of inflexion'** in the graph, is then taken to be the number of PCs to be retained

Considering **eigenvalues**. According to this rule, only the **PCs with eigenvalues greater than 1 should be retained**

% Variance				
	pStil0	**pStil1**	**pStil2**	**pStil3**
PC1	87.0	85.7	85.0	85.3
PC2	10.0	11.0	11.5	11.3
SUM	**97.0**	**96.7**	**96.5**	**96.6**

Lower the dimensionality from

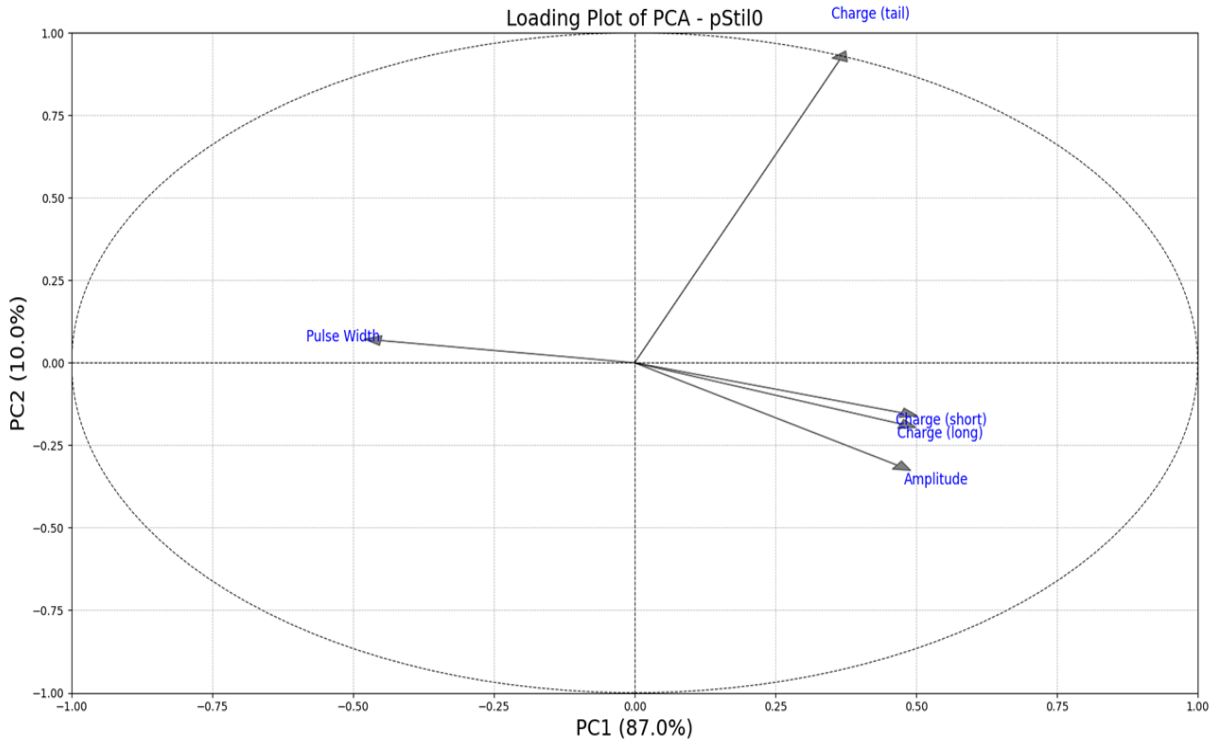
5D to 2D !

Overall, more than 96% of the variation is preserved in the first two PCs

PCA – Loadings Plots

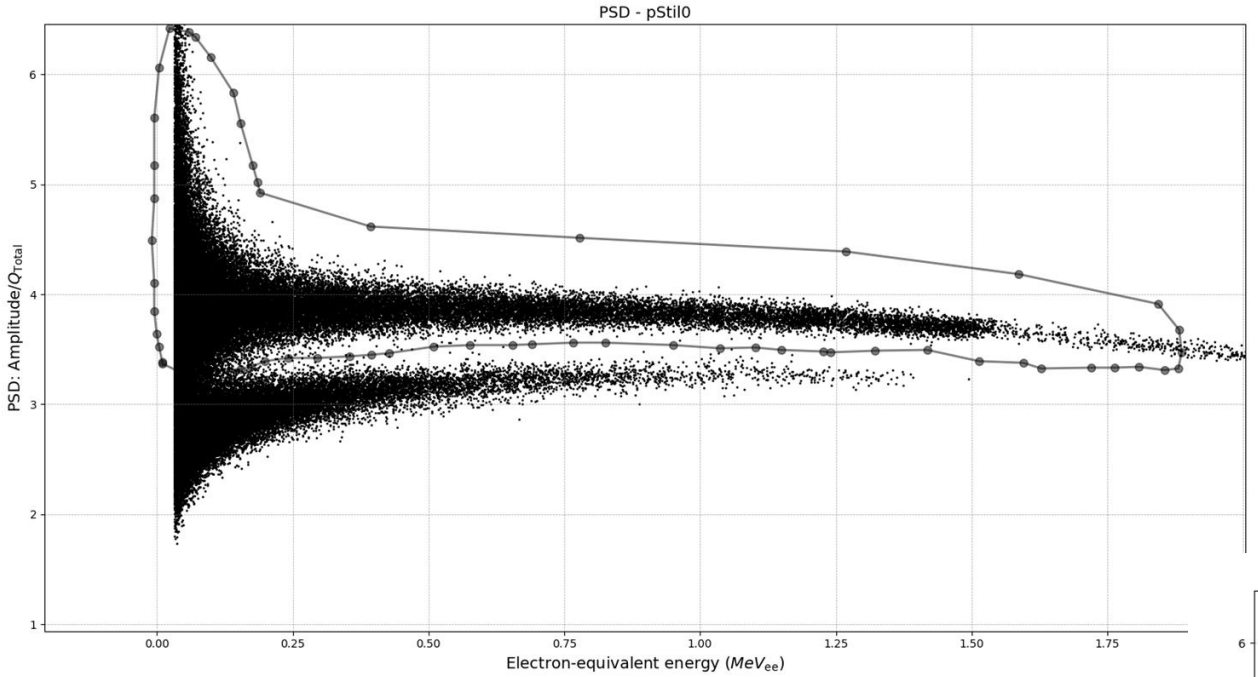
Graphical representation used in PCA to visualize the **relationships between the original variables and the PCs**

Mathematically speaking, **loadings are the coefficients of the original variables** in the linear combinations that define the PCs



For a given PC z_k, the loadings are given by the eigenvectors v_k is the eigenvector (loading) corresponding to the k-th PC

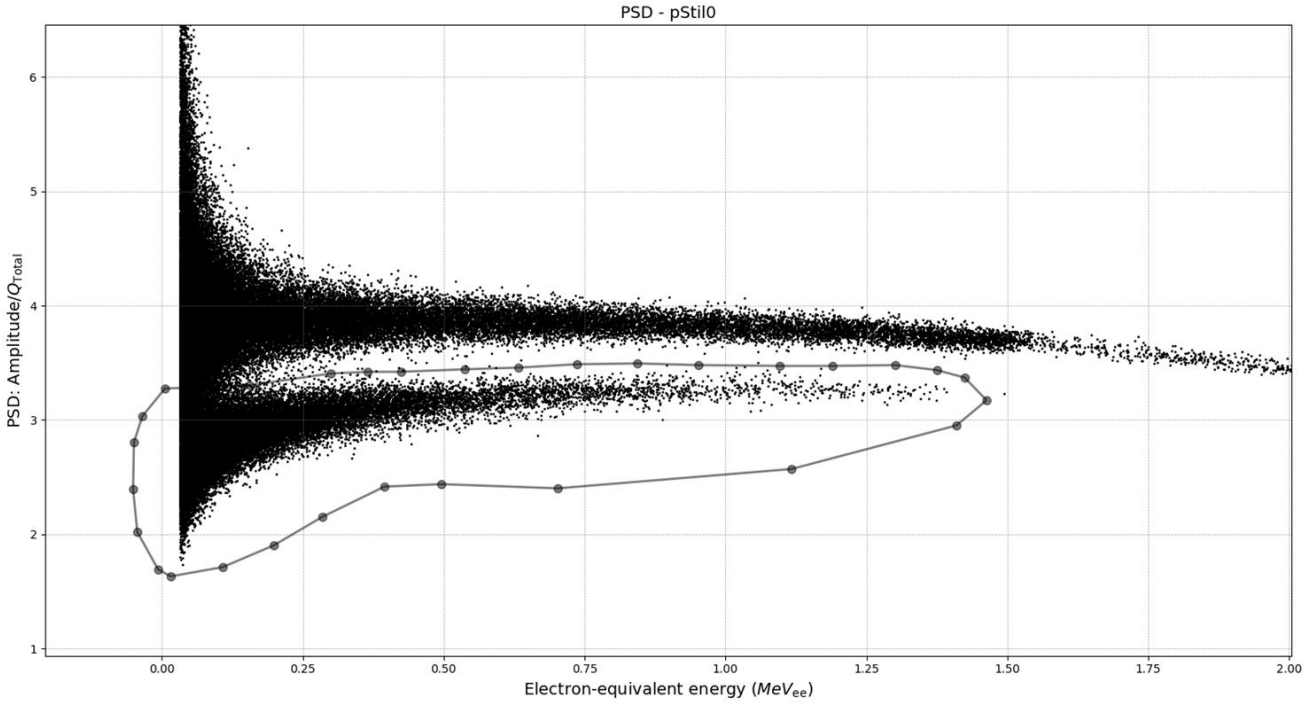
PCA – Biplots – Target Groups



Custom class for the selection of indices, from the PSD distributions, corresponding to **gamma-rays** and **neutrons**

Flexible selection using the left mouse button

PSD + PCA



PCA – Physical Implication

Energy Deposition

High positive loadings of **pulse-height and charge parameters** on PC1 indicate that this component captures the energy deposition characteristics of the particles

Tail Charge

Strong positive loading of charge (tail) on PC2 highlights the importance of the signal's tail in identifying **slower processes or particles with extended interaction times**

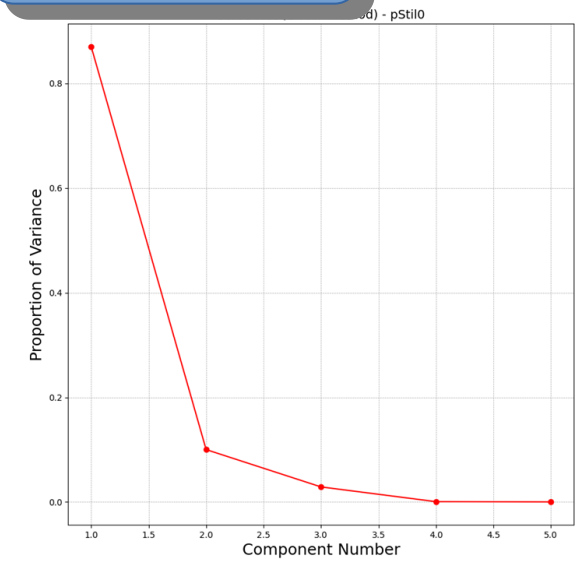
Signal Shape and Duration

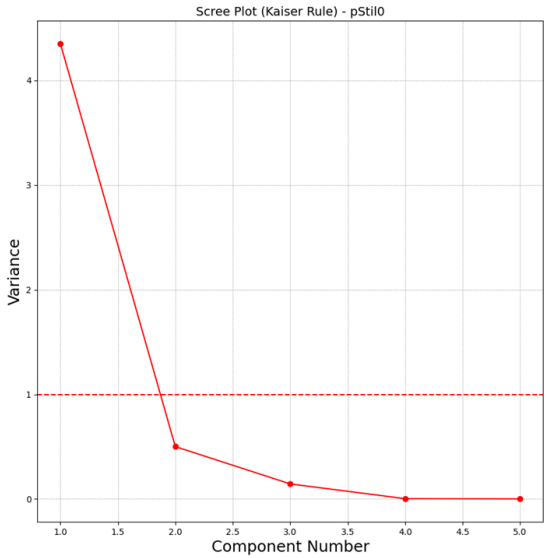
Negative correlation of pulse-width with PC1 and its small positive loading on PC2 suggests that the **pulse width is related to the pulse amplitude.**

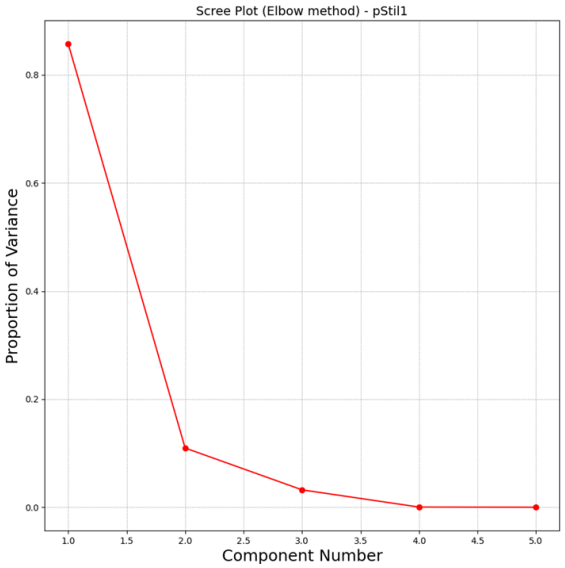
Anti-correlation could be associated to the fact that the pulse width is calculated at **50% of the signal** (more investigation on that).

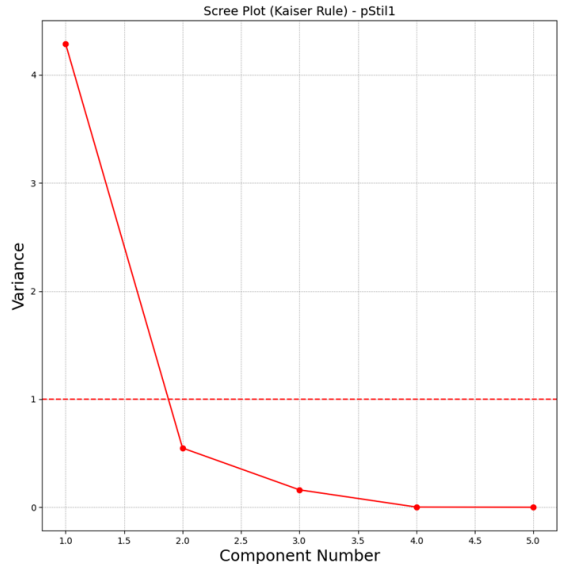
PCA – Scree Plots

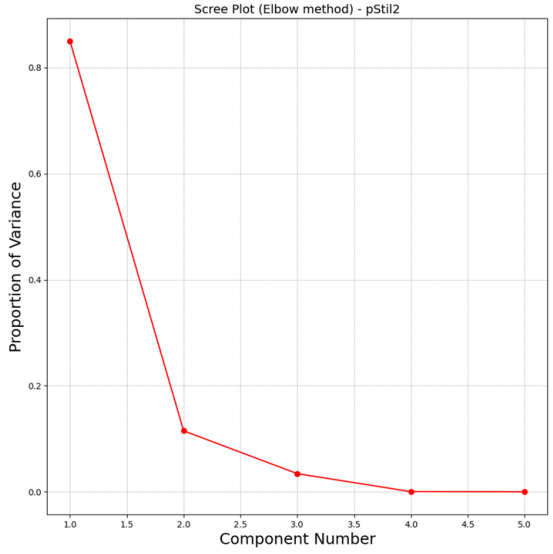
4 Detectors

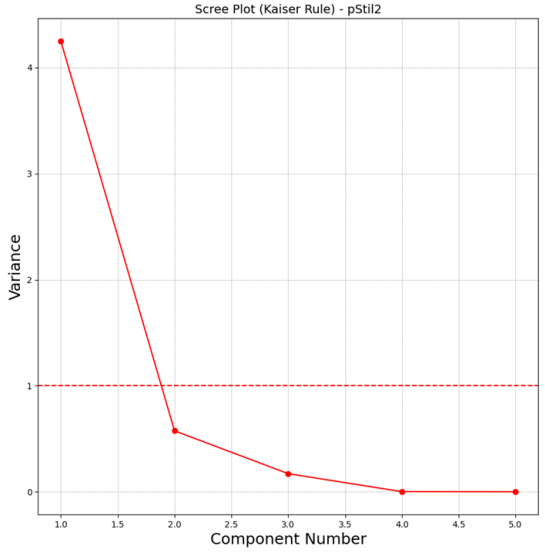


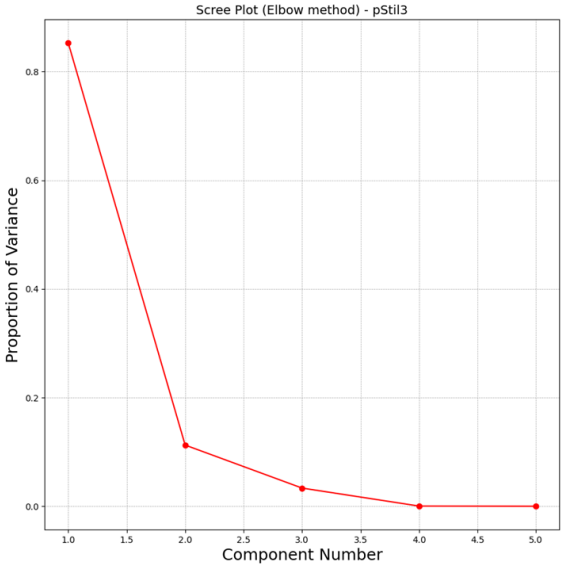


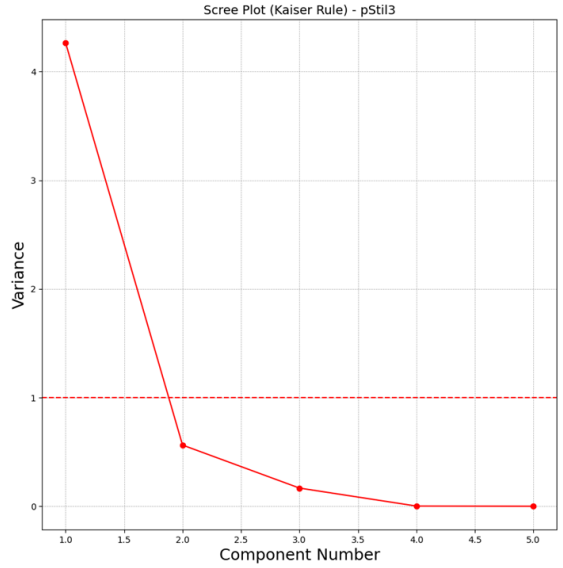






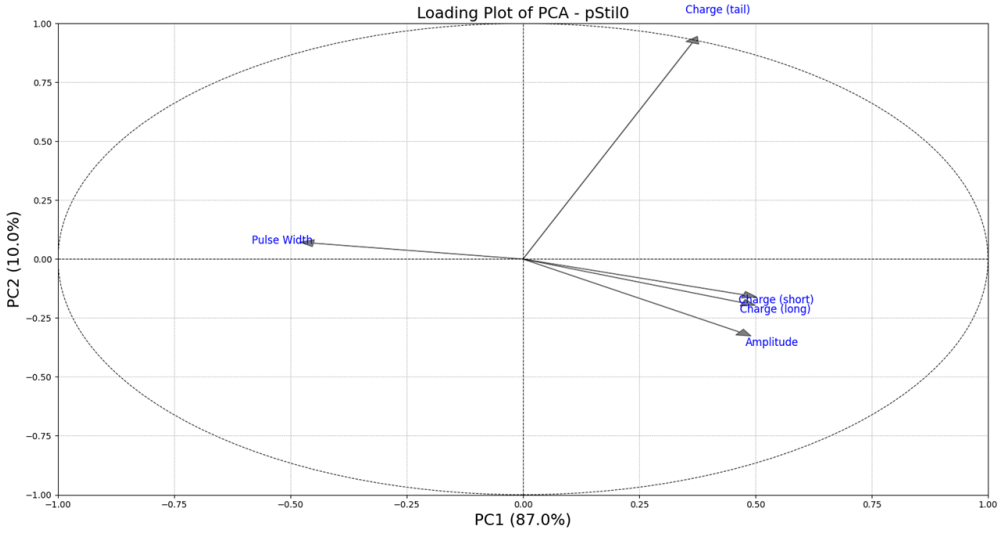


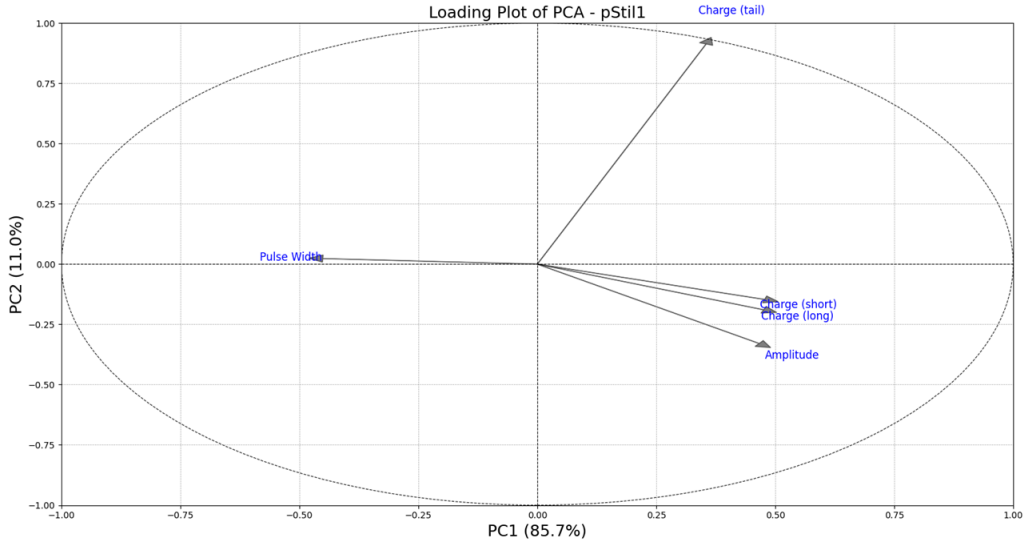


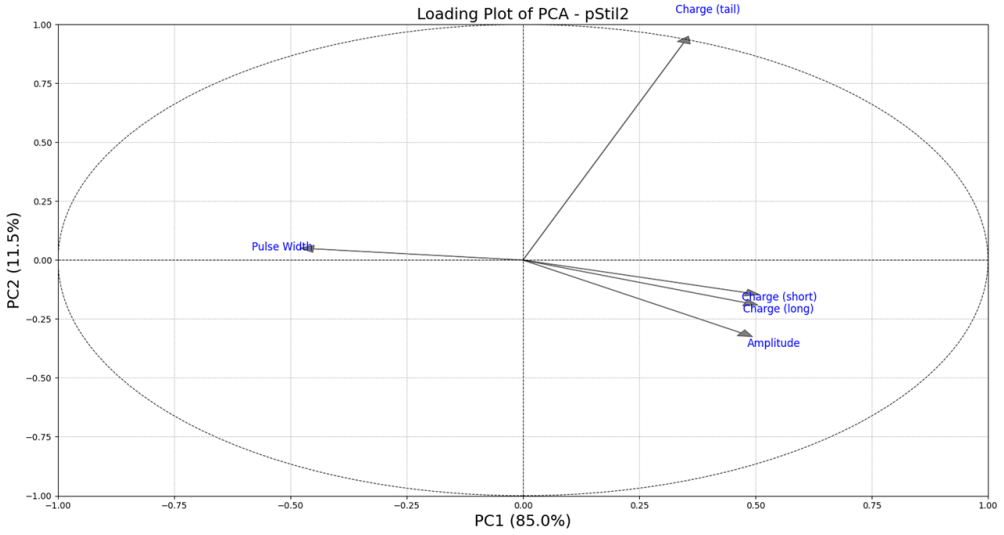


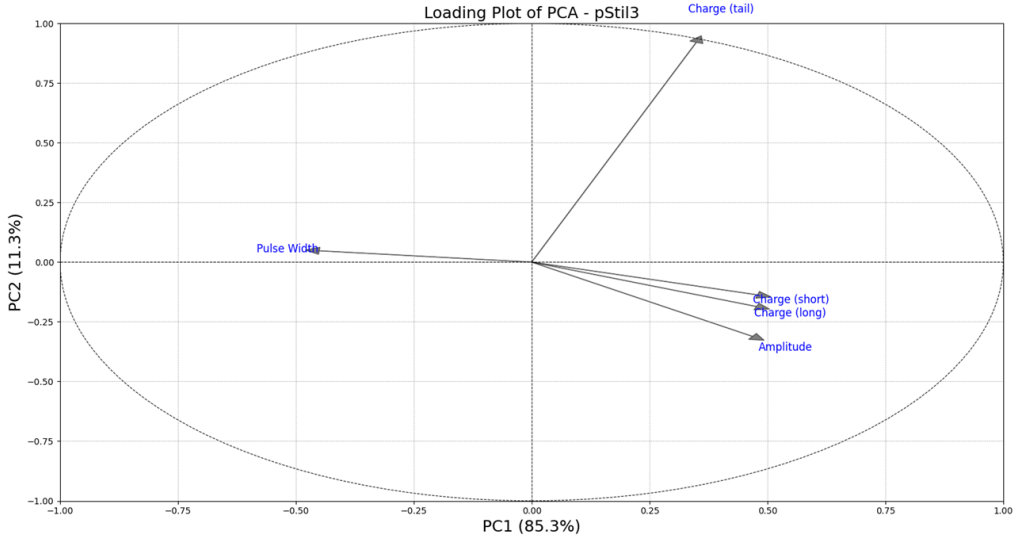
PCA – Loadings Plots

4 Detectors









PCA – Biplots

4 Detectors