Progress of CsI experiment from COHERENT

Chenguang Su

University of Chinese Academy of Sciences

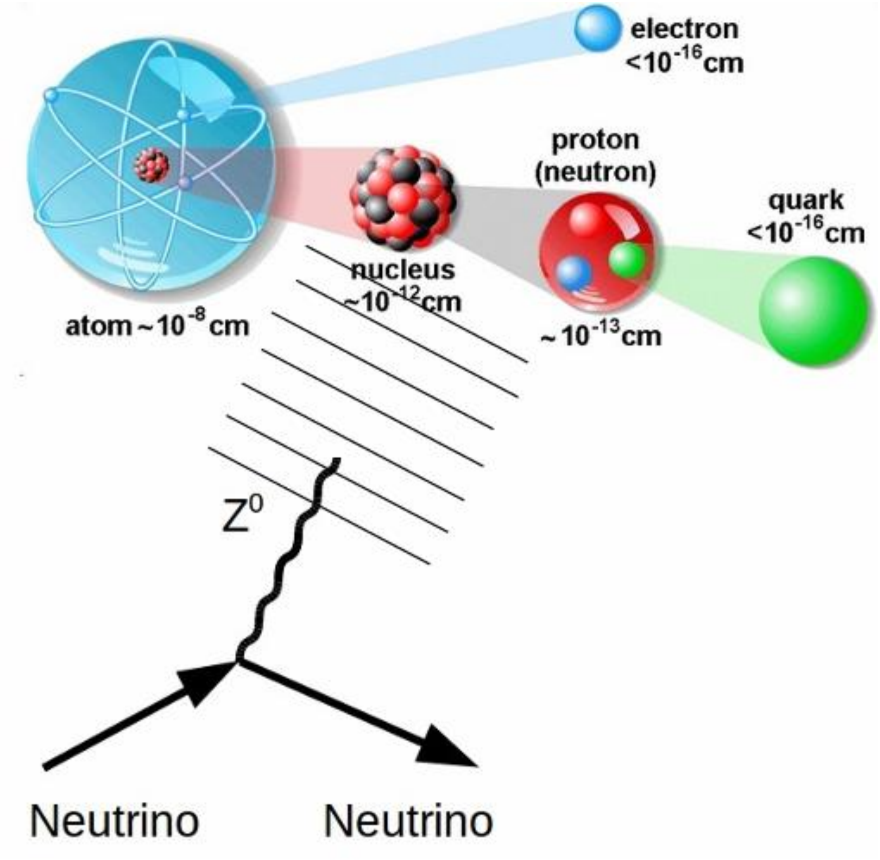
On behalf of COHERNT Collaboration

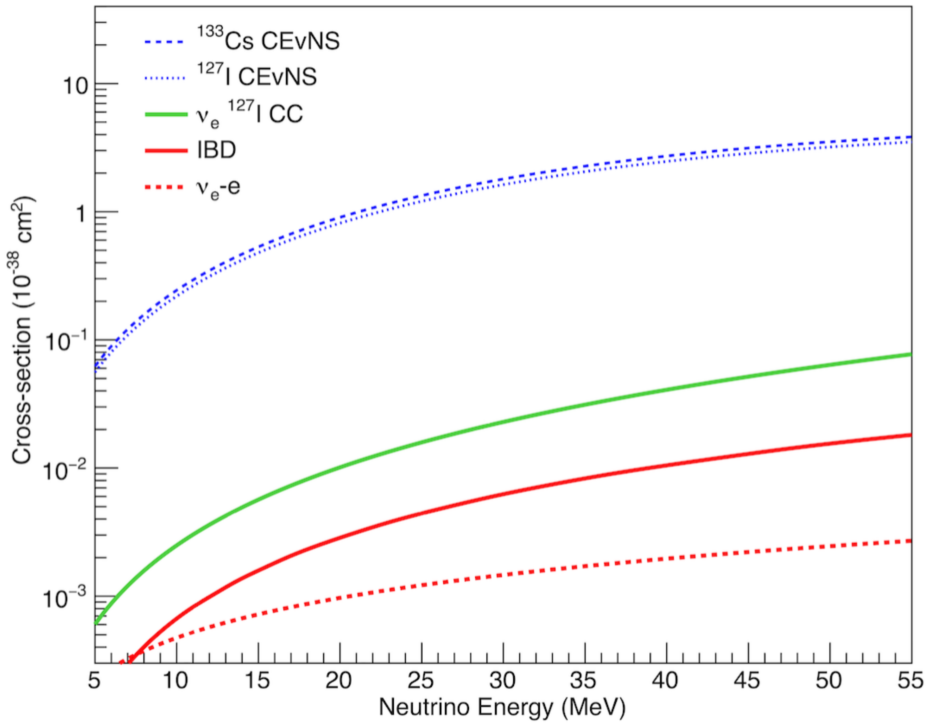
16, July, 2026, Guangzhou

suchenguang17@mails.ucas.ac.cn

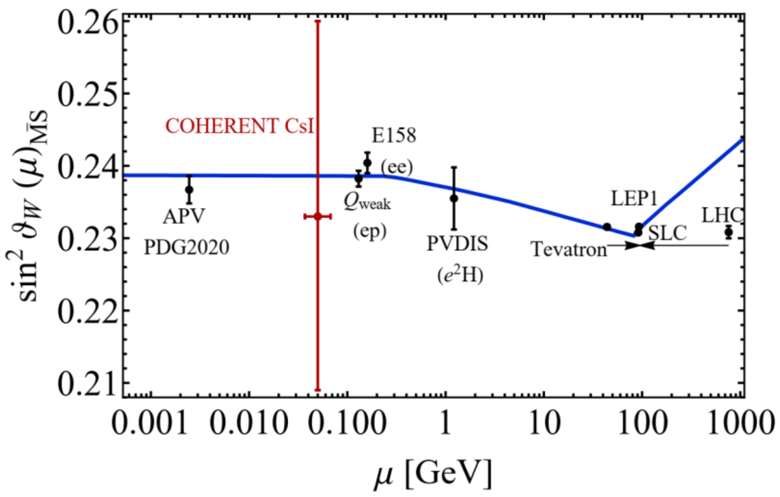
The CEvNS

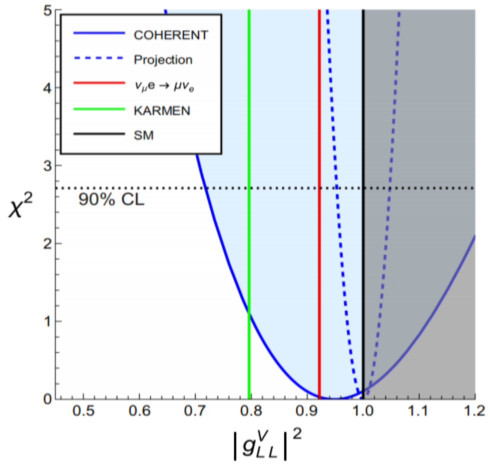
$$\frac{d\sigma}{dE_r} = \frac{G_F^2 M}{2\pi}\left[\left(\frac{1}{2} - 2\sin^2\theta_W\right) Z F^p(E_r) - \frac{1}{2} N F^n(E_r)\right]^2 \left[2 - \frac{M E_r}{E_\nu^2}\right]$$



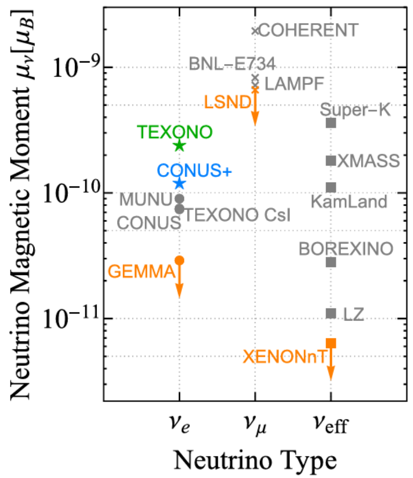


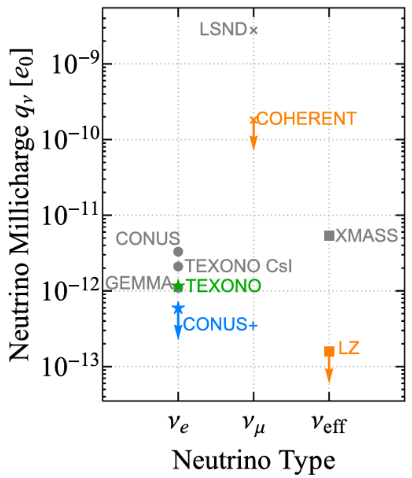
Physics to explore：Precision CEvNS!



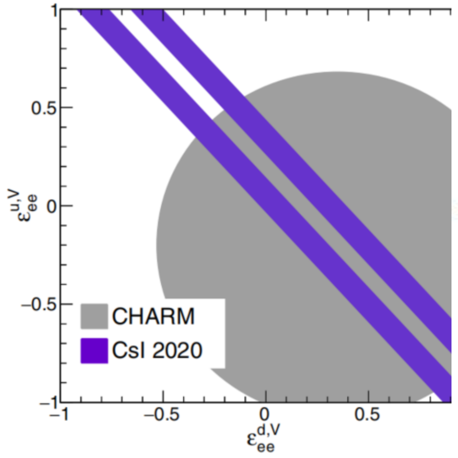


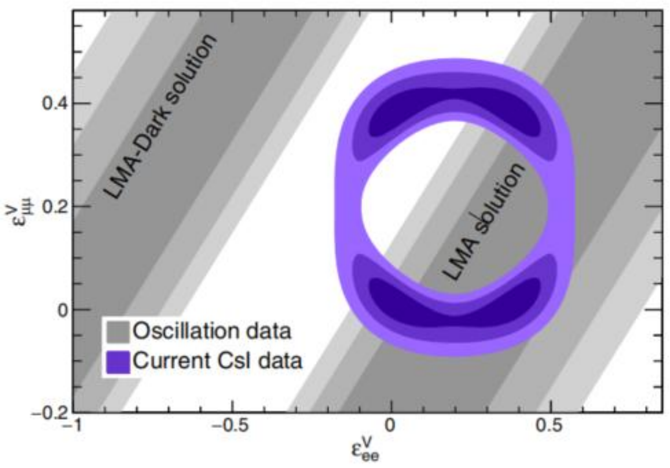
SM: $\sin^2\theta_W, \mu\ decay\ parameter$



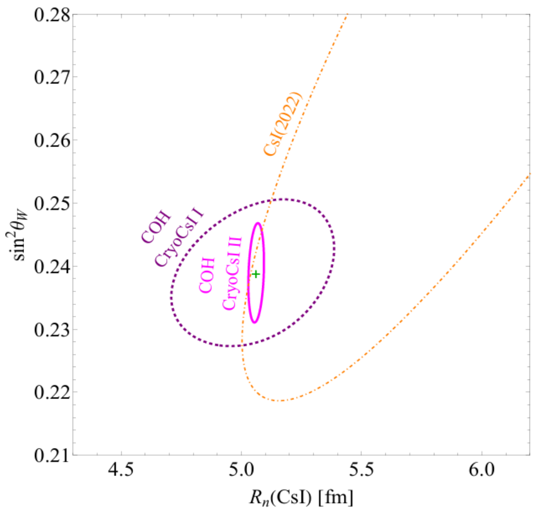


Neutrino Electromagnetic property



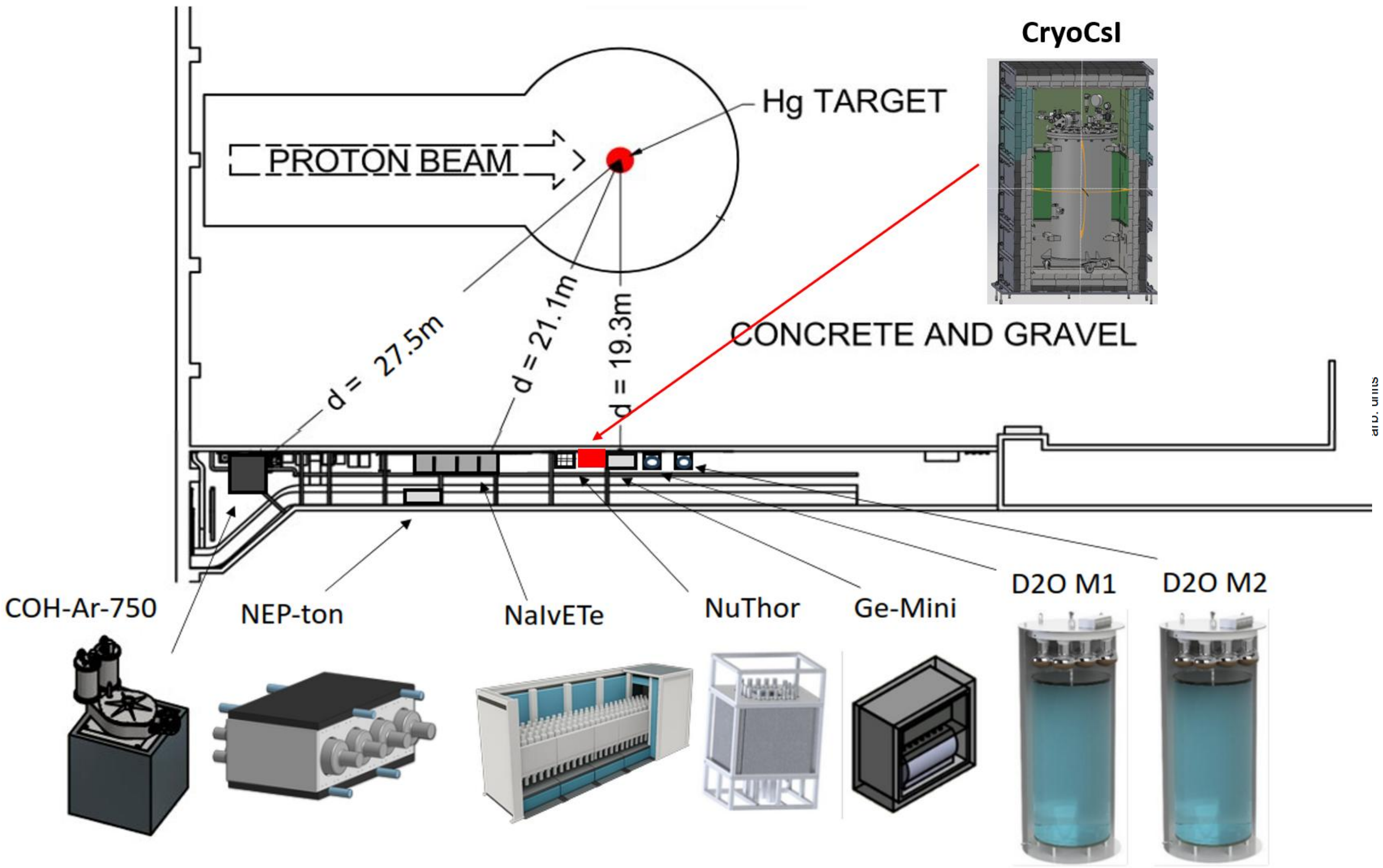


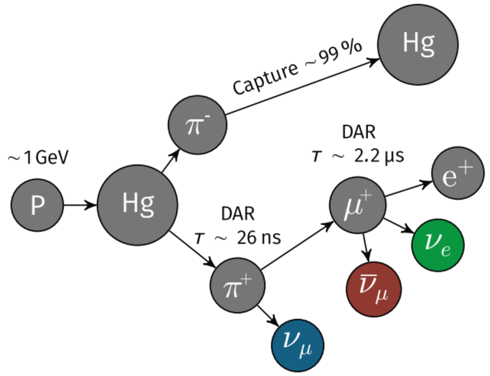
NSI

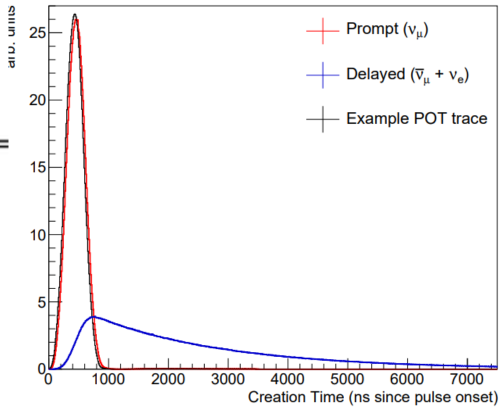


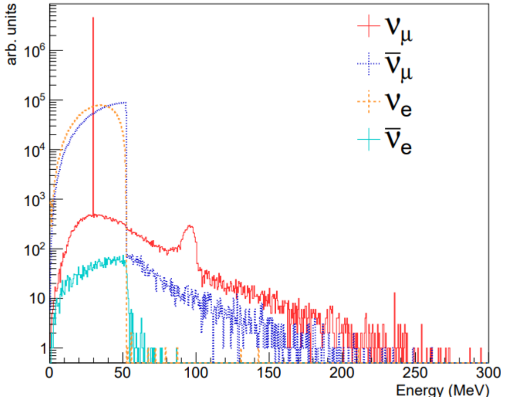
Nuclear structure

The COHERENT Collaboration



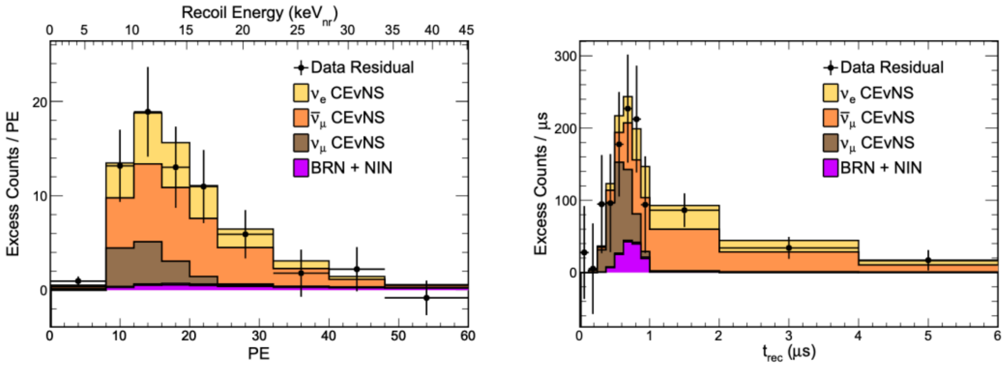




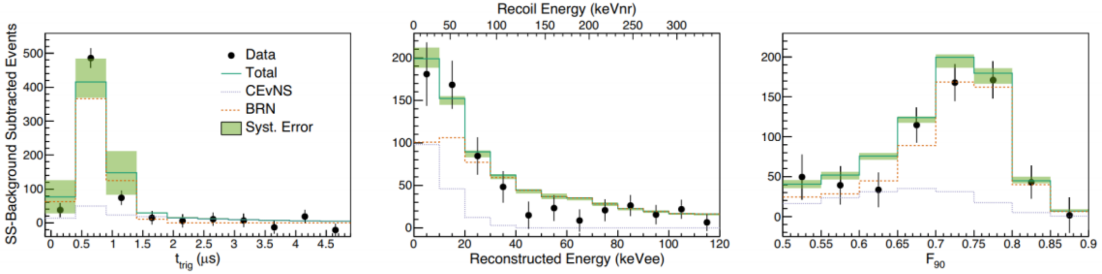


Beam Energy: 1.3GeV
Beam Power: 2MW
60Hz and 380ns FWHM

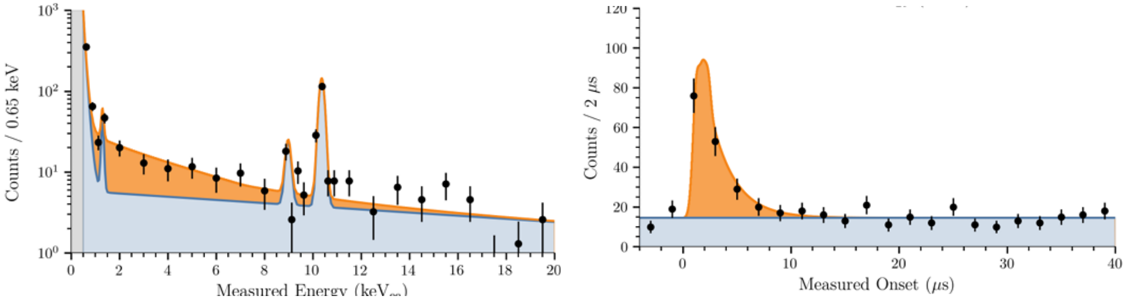
Results from COHERENT



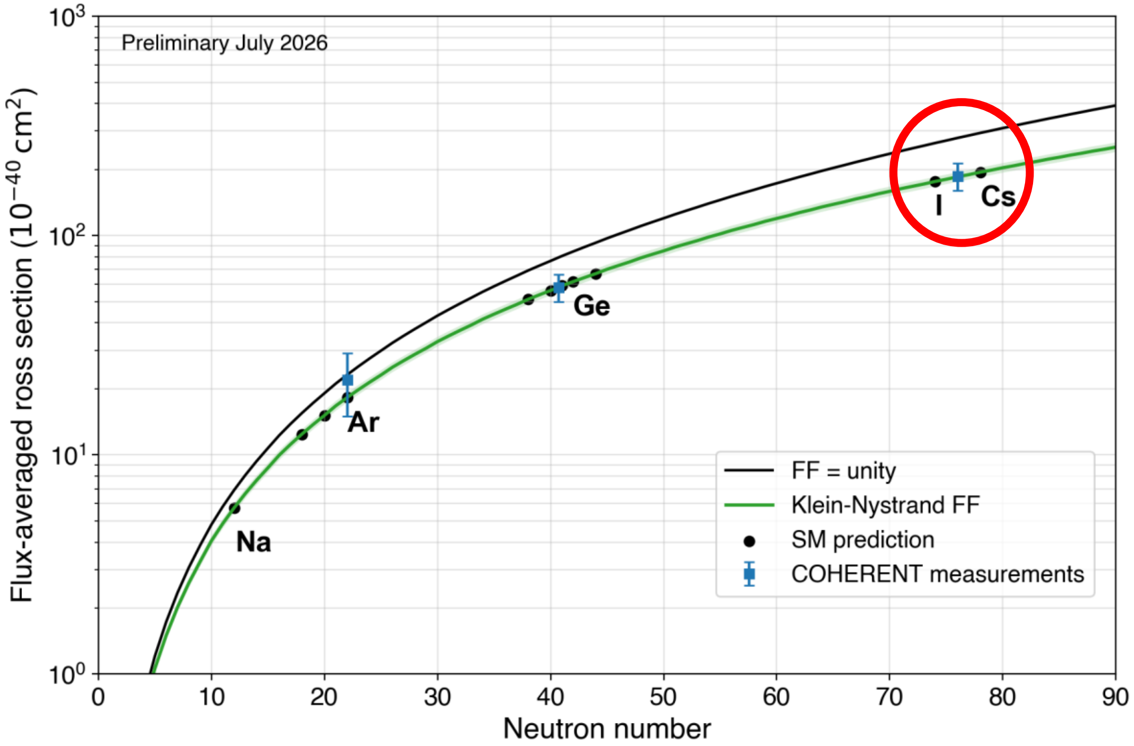
COHERENT, PRL 129 081801 (2022)



COHERENT, PRL 126 012002 (2021)



COHERENT, arxiv 2603.17951

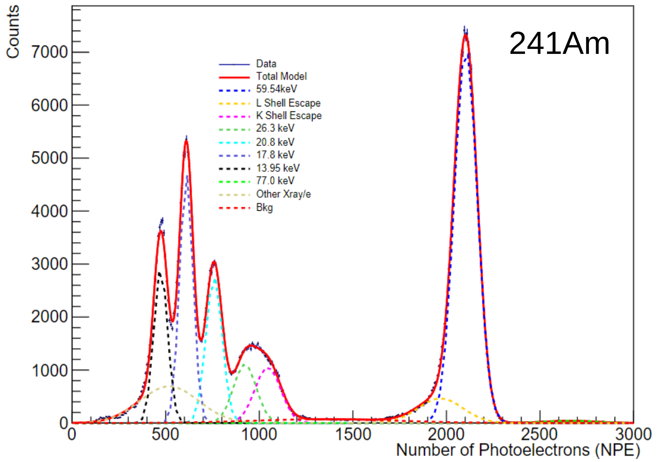


Precision CEvNS era!

The CryoCsI Detector

Nucl.Sci.Tech. 36 (2025) 5, 82

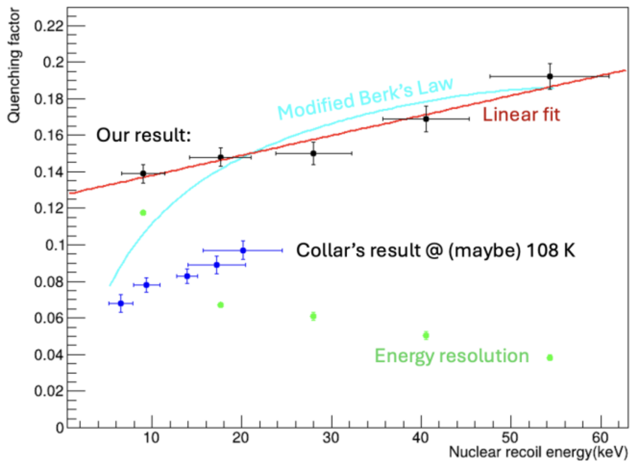
High light yield and good resolution



$LY \geq 35.2 \pm 0.6\text{PE/keVee}$

$FWHM = 6.9\%@60\text{keV}$

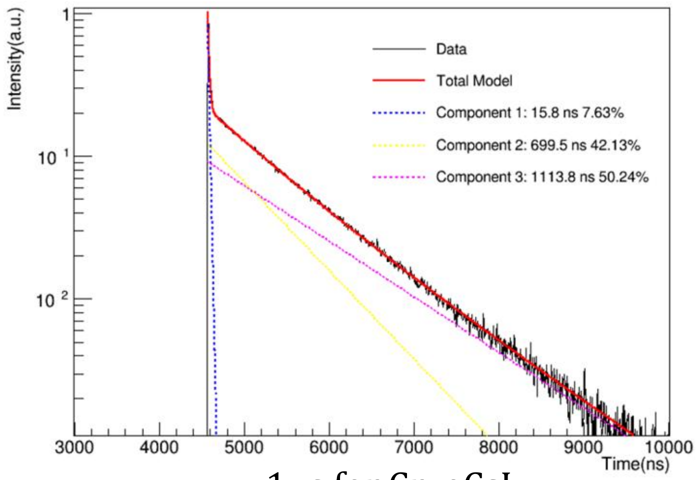
High quenching factor



$\sim 15\%@77K$

$\sim 8\%@293K$

Low afterglow



$1\mu s$ for CryoCsI

$17\mu s$ for CsI(Na)

A Lower threshold down to 1keV_{nr}

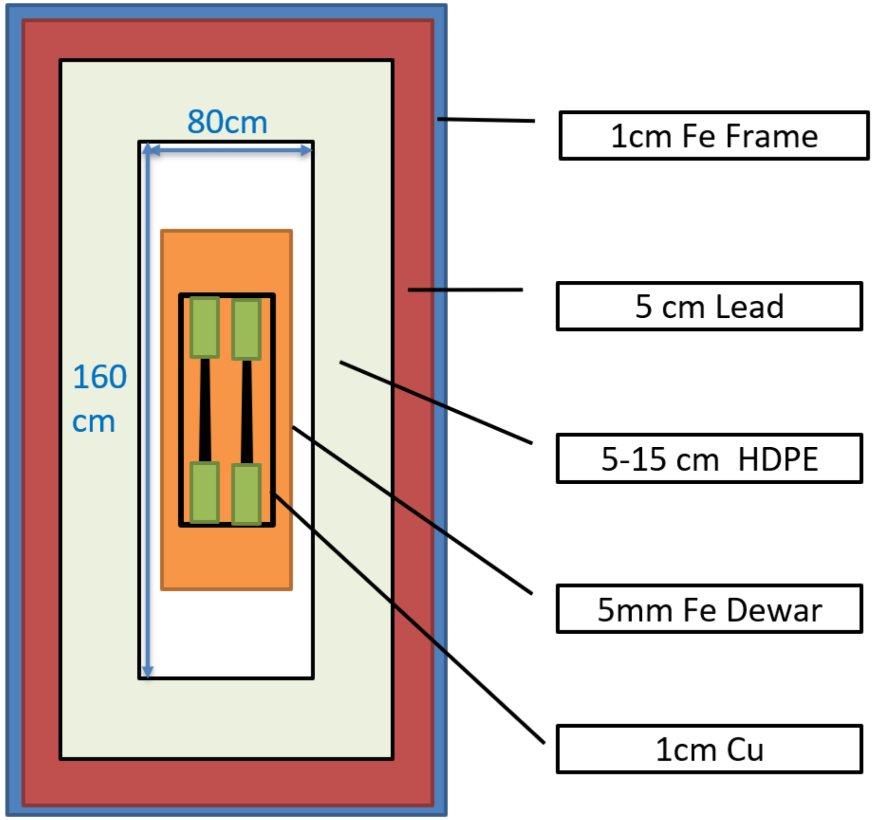
Higher statistics and better sensitivity to physics

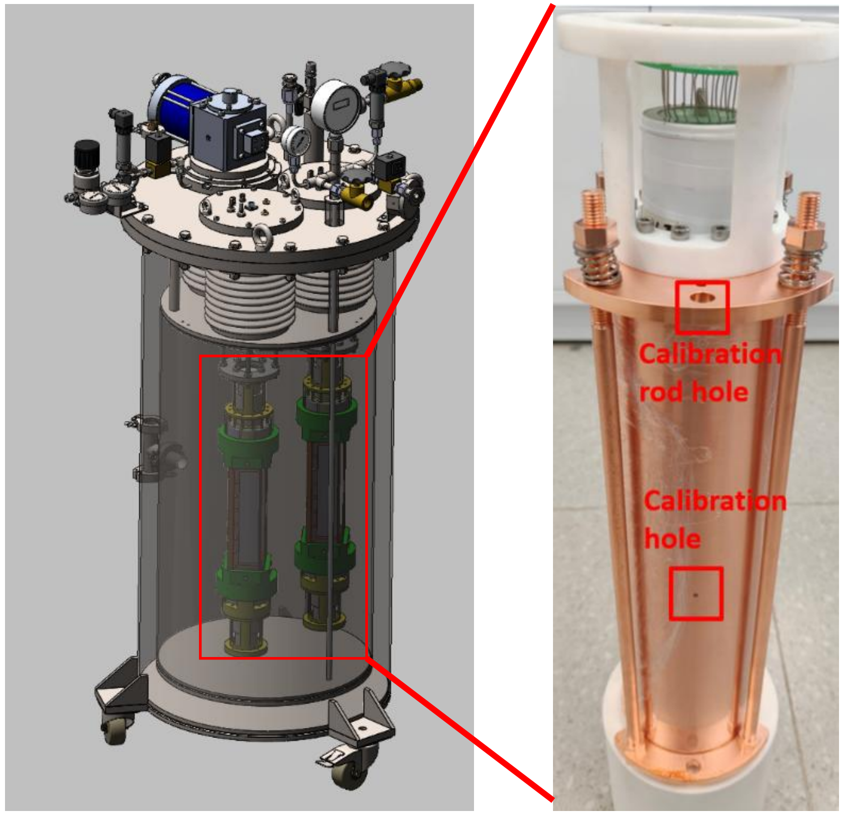
Important to precision CEvNS!

Detector System

- **3.3kg crystal x2** (from CASSIC)
- Closed liquid nitrogen system
- Dual R11065 PMT read out
- DT5751 DAQ

- **Crystal polished**
- **4 layers of BC-642 Teflon**

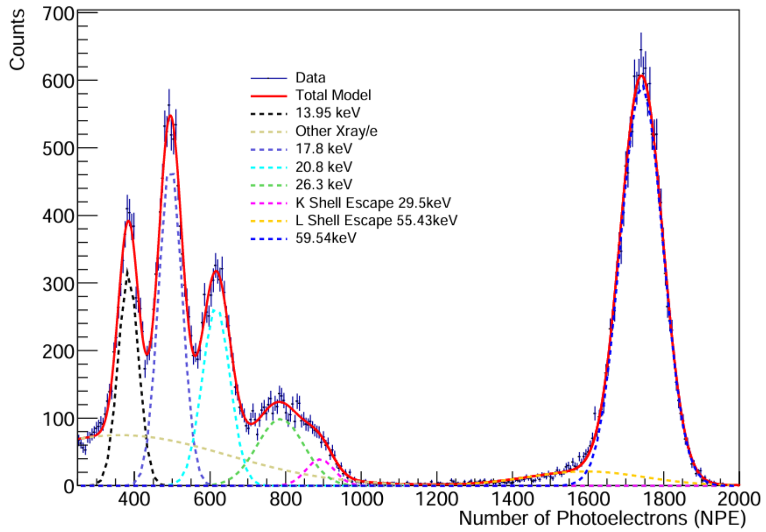




Performance

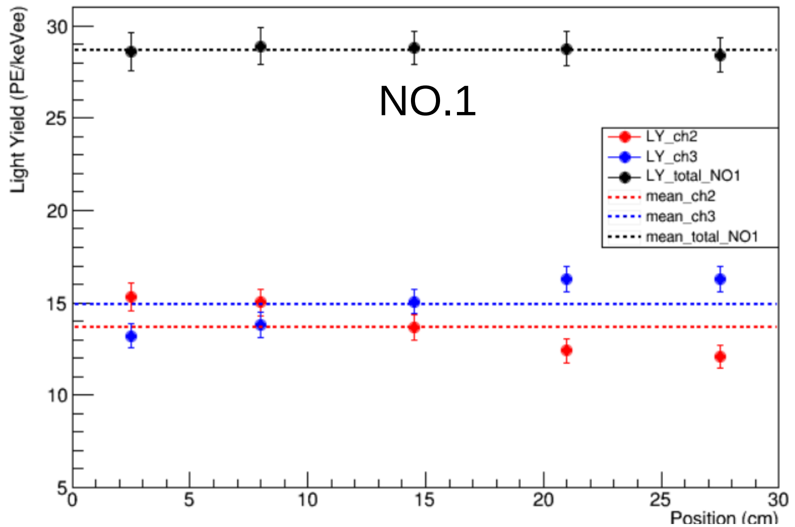
Eur.Phys.J.C 86 (2026) 2, 203

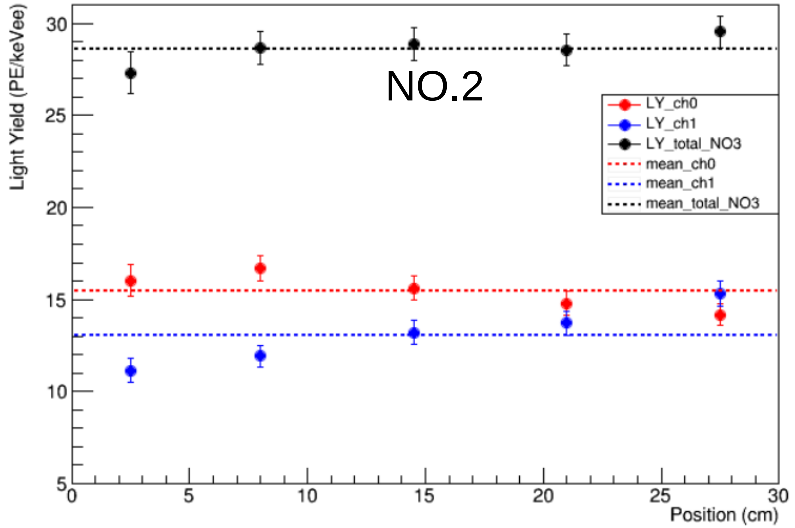
LY and energy resolution calibration



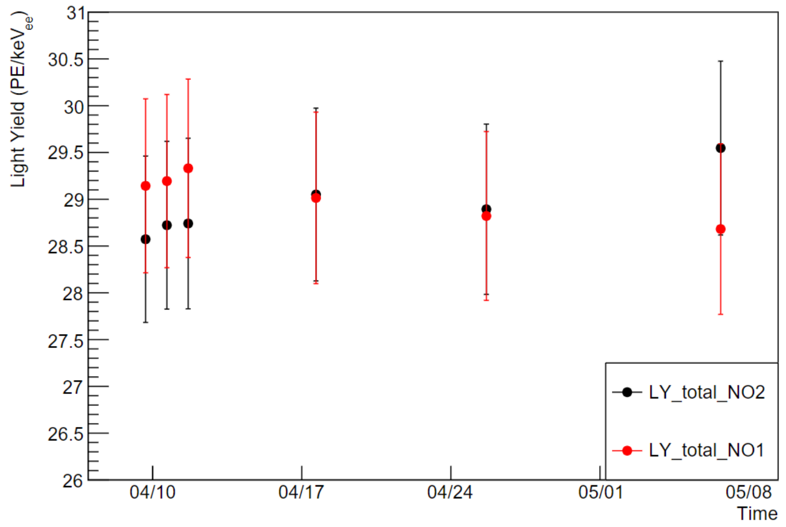
Crystal	NO.1	NO.2
LY (PE/keV_{ee})	29.3 ±1.0	28.7 ±0.9
Res. (%)		
at 13.9 keV	15.5	19.9
at 17.8 keV	15.5	14.5
at 20.8 keV	15.3	13.5
at 59.6 keV	7.7	7.2

Light collection spatial uniformity





Light Yield Long-term stability

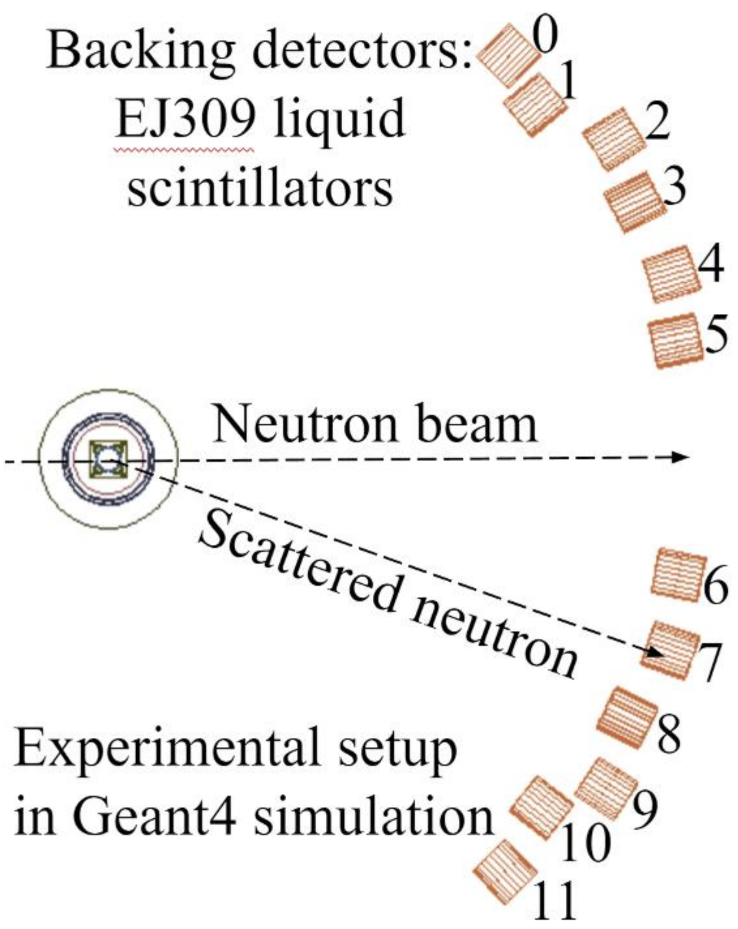


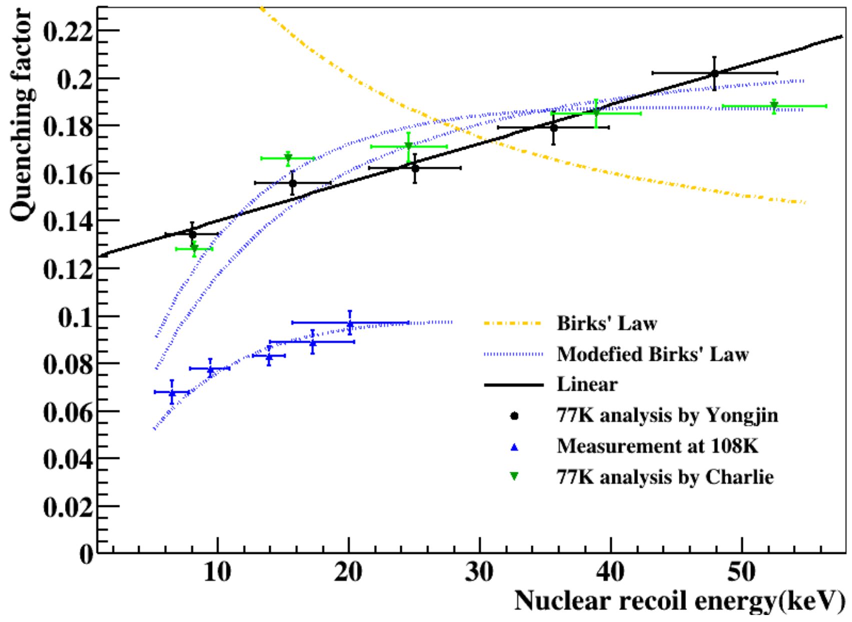
Radioactivity

Activity (mBq/kg)	^{134}Cs (796 keV)	^{137}Cs (662 keV)
No. 1	$A_U = 1.67$	$A_U = 2.91$
No. 2	$A_U = 0.87$	$A_U = 2.05$

Quenching factor

$$\mathrm{QF} = \frac{LY_{nr}}{LY_{er}}$$





- ~15% @ 77K
- Around twice as 108K
- or Room Temperature (293K)

- Help to lower the threshold

$$E_R = \frac{2(1 + A - \cos^2\theta - \cos\theta\sqrt{A^2 - 1 + \cos^2\theta})}{(1 + A)^2} E_n$$

Background

Beam related neutron

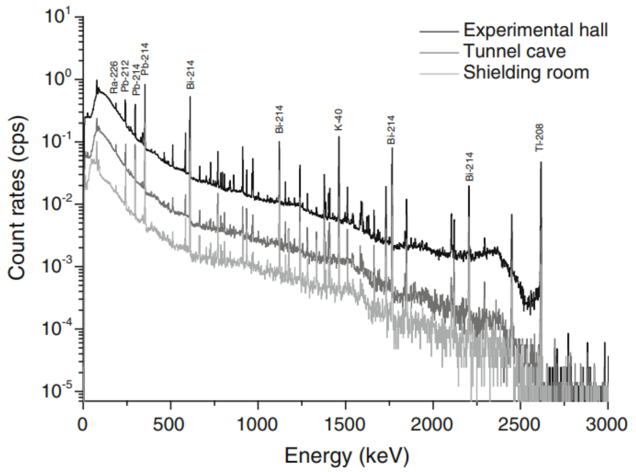
- Input:

$$P(E_n) \propto E_n[\mathrm{MeV}]^{-\alpha}$$

$$\phi_n = 1.09 \times 10^{-7} \frac{n}{\mathrm{cm}^2\,\mathrm{s}} \quad \text{and} \quad \alpha = 1.6$$

Env gamma simulation:

- Flux: 0.433 gamma/cm^2/s
- Input:

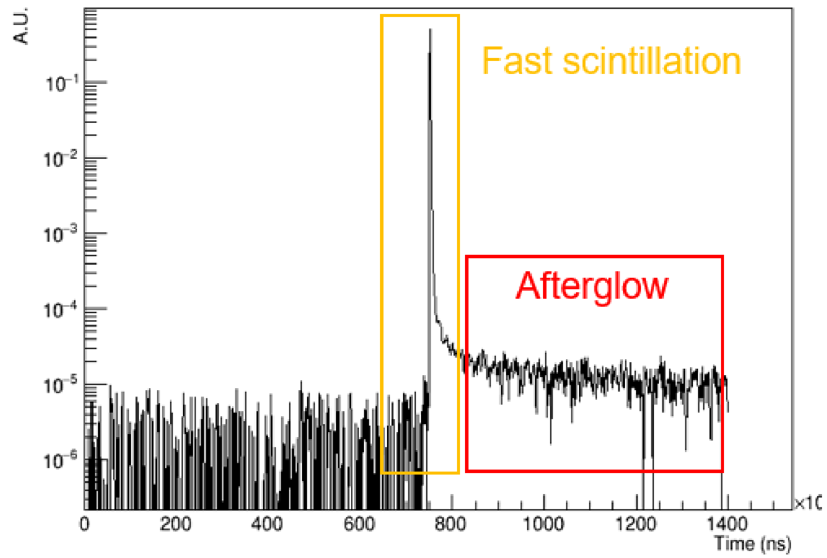


Material radioactivity

Isotope	Fe (mBq/kg)	PMT (mBq/PMT)	CsI (mBq/kg)
K40	60	37.1	-
U238	-	5.2	-
Ac228	70	-	-
Bi214	25	-	-
Pb212	70	-	-
Pb214	25	-	-
Th234	200	-	-
Tl208	70	-	-
Th232	-	13.4	-
Co60	17	-	-
Cs137	6	-	25 (γ, e)
Cs134	-	-	19
Rb87	-	-	0.63
Unit	mBq/kg	mBq/PMT	mBq/kg
Reference	ILIAS ANAIS	Taishan LAr	CJPL Jinping

Afterglow :

Averaged Waveform



physical evt ~ 1us
afterglow ~ 1.3ms

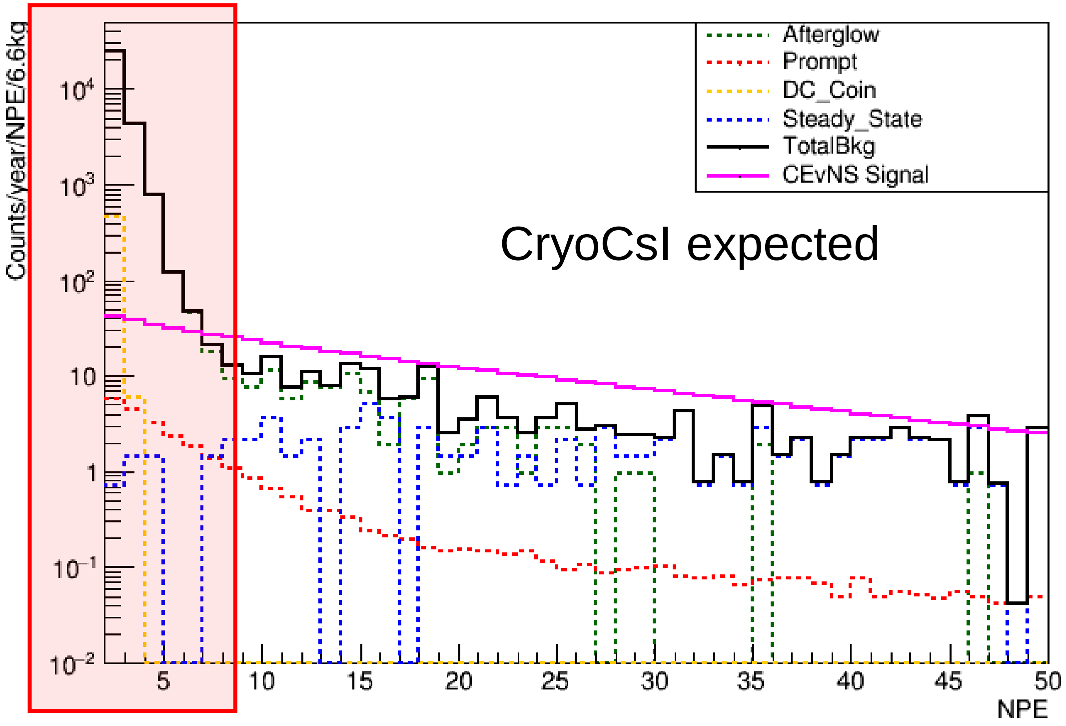
→ PSD to suppress

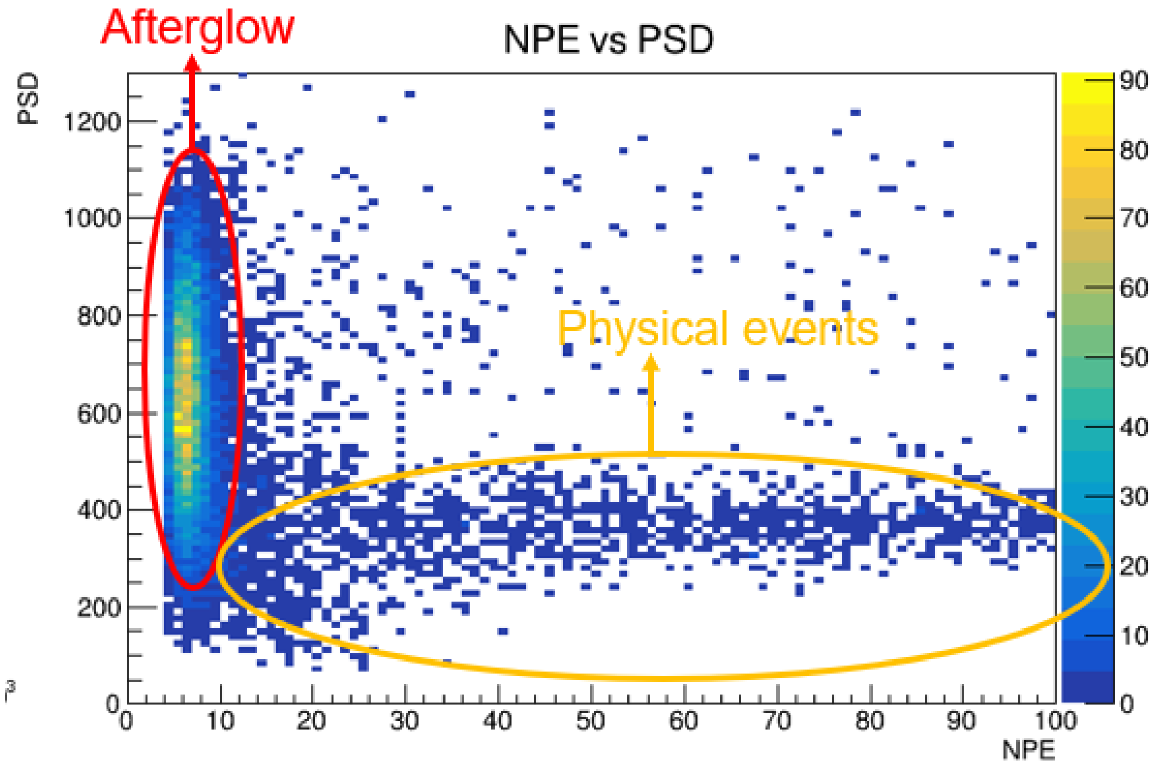
Afterglow and PSD

Afterglow dominate the low PE background

Lower threshold?
Suppress afterglow!

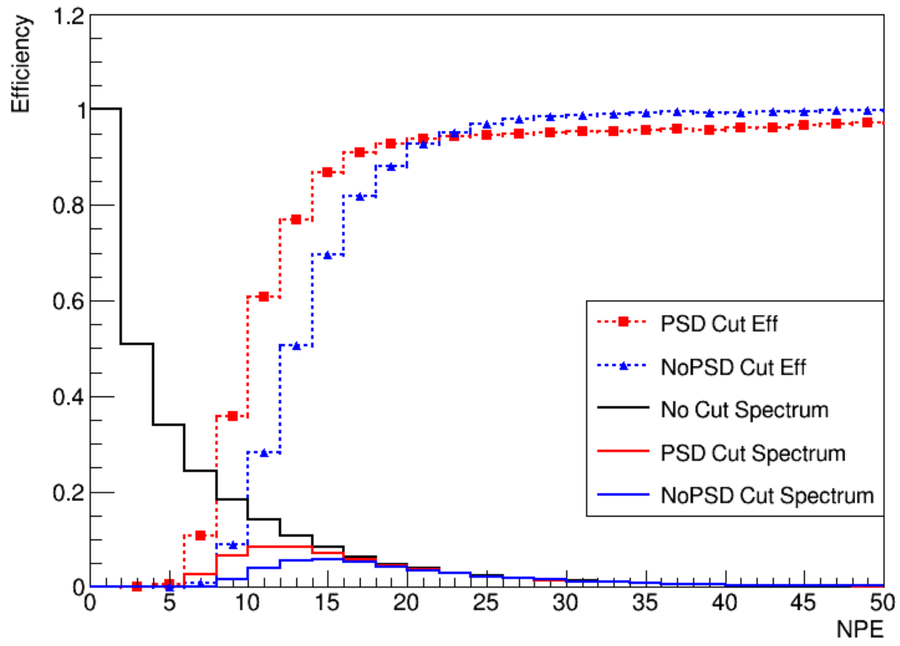
$$PSD = \frac{\sum_i^N A_i \times (T_i - T_0)}{\sum_i^N A_i}$$



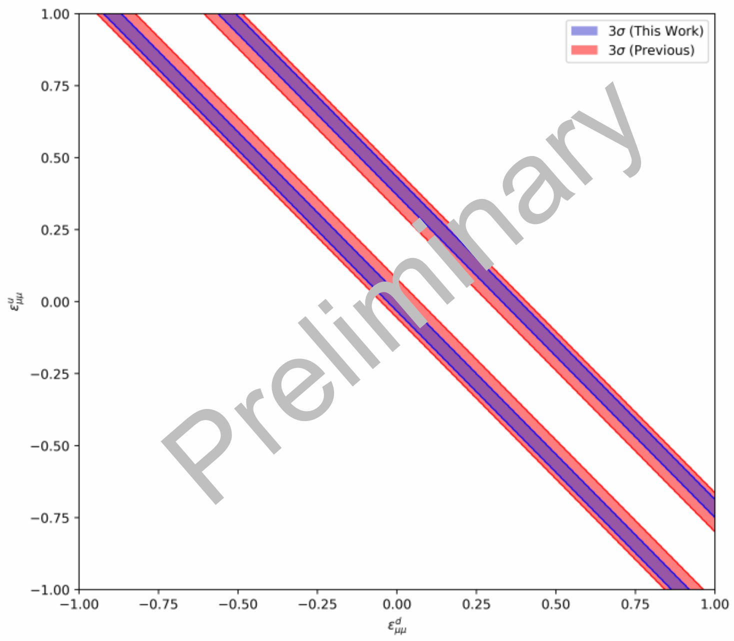


Reanalysis of CsI(Na) with PSD

Physics	Cross section $(10^{-38}\ cm^2)$	Stats Error	Total Error	WMA	WMA Error
This work	1.87 ± 0.27	7.8%	14.4%	0.238 ± 0.025	10.5%
2022 PRL	$1.65^{+0.30}_{-0.25}$	10.8%	16.7%	$0.220^{+0.028}_{-0.026}$	12.3%
SM	1.89 ± 0.06	–	–	0.239	–



Threshold lowered by 2 PE

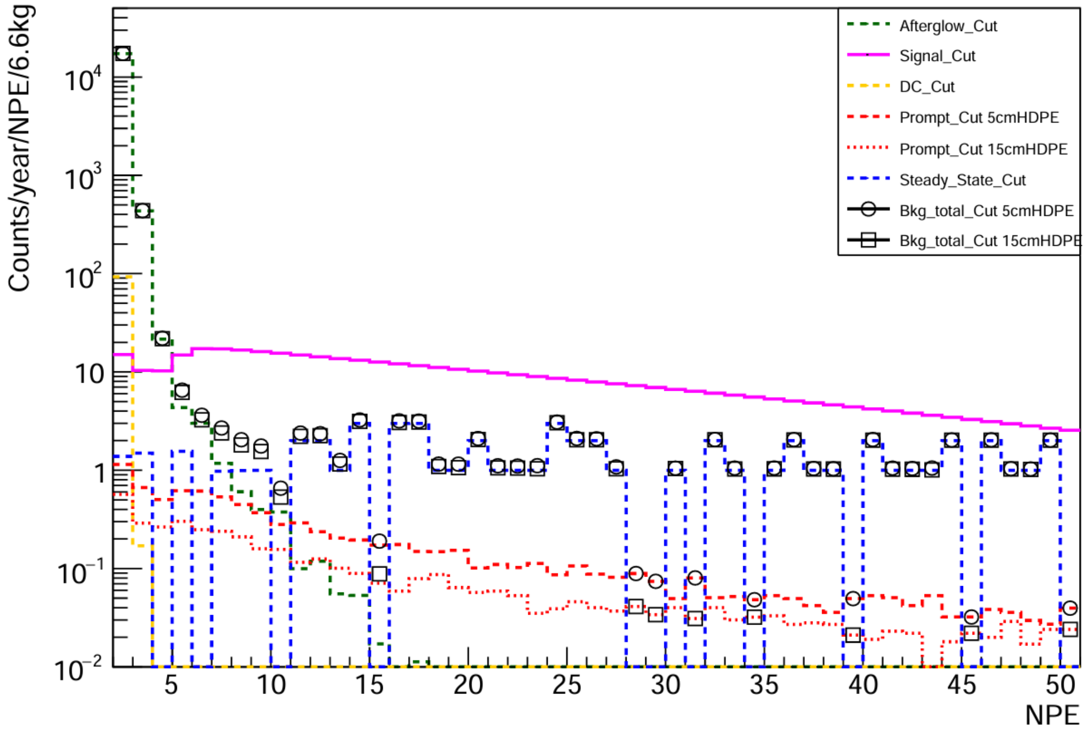


Coming Soon!

Constraint on ν_μ related NSI parameters improved by 50%

Sensitivity of CryoCsI after PSD

Background type		Events in 5 – 50 NPE / year
Prompt neutron		17
Steady state	Env gamma	2
	Material rad	42
	CsI self-rad	10
	afterglow	21
Total bkg		92
CEνNS		532



$$SN = \frac{N_{sig}}{\sqrt{N_{tot} + N_{bkg}}}$$

- Beam power: 2.0MW
- Distance: 20m
- Crystal mass: 6.6kg

- **5σ detection** in 1 month beam time (counting only)
- **One year stats:** 5% counting only.
- Better if Energy vs Time 2D fitting considered

COHERENT Collaboration

Oak Ridge National Laboratory
Duke University
TUNL Triangle Universities Nuclear Laboratory
서울대학교 Seoul National University
Los Alamos National Laboratory EST. 1943
Laurentian University Université Laurentienne
岡山大学 Okayama University
NC State University
The University of Tennessee Knoxville
NC Central University
ICRR Institute for Cosmic Ray Research University of Tokyo
Sandia National Laboratories
Carnegie Mellon University
University of South Dakota
東京大学
Tufts University
Canadian Nuclear Laboratories Laboratoires Nucléaires Canadiens
UF University of Florida
Concord U
SLAC National Accelerator Laboratory
Virginia Tech
Washington & Jefferson College

COHERENT SNS

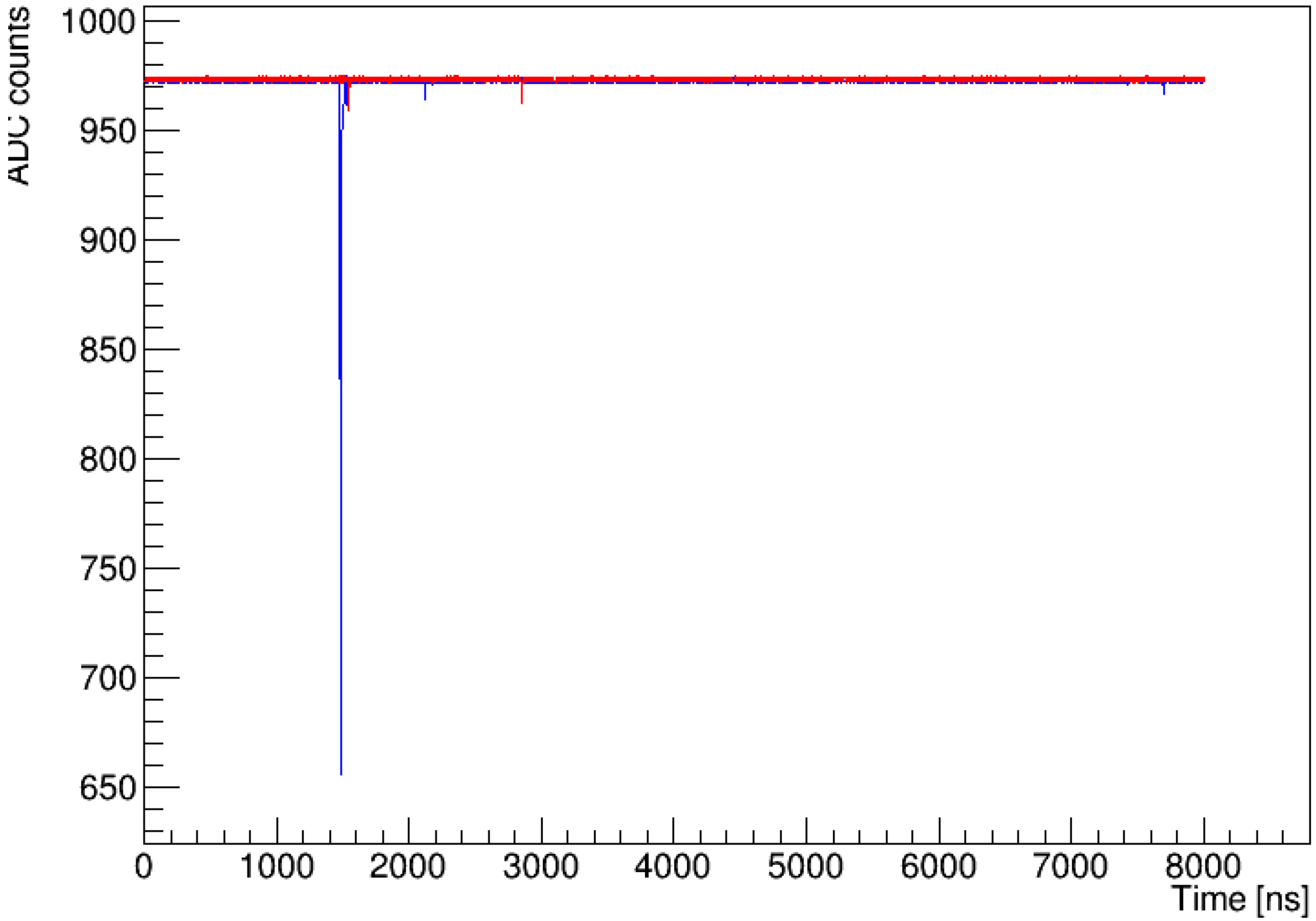
Summary

- A 6.6kg CryoCsI detector working very well
- Quenching ~15% @ 77K
- PSD suppress the afterglow background, lower the threshold
  - PSD Validated with CsI(Na) data!
- Sensitivity:
  - Threshold down to 0.8keVnr with 15% QF
  - Expected detected event rate: 530/year in 2MW

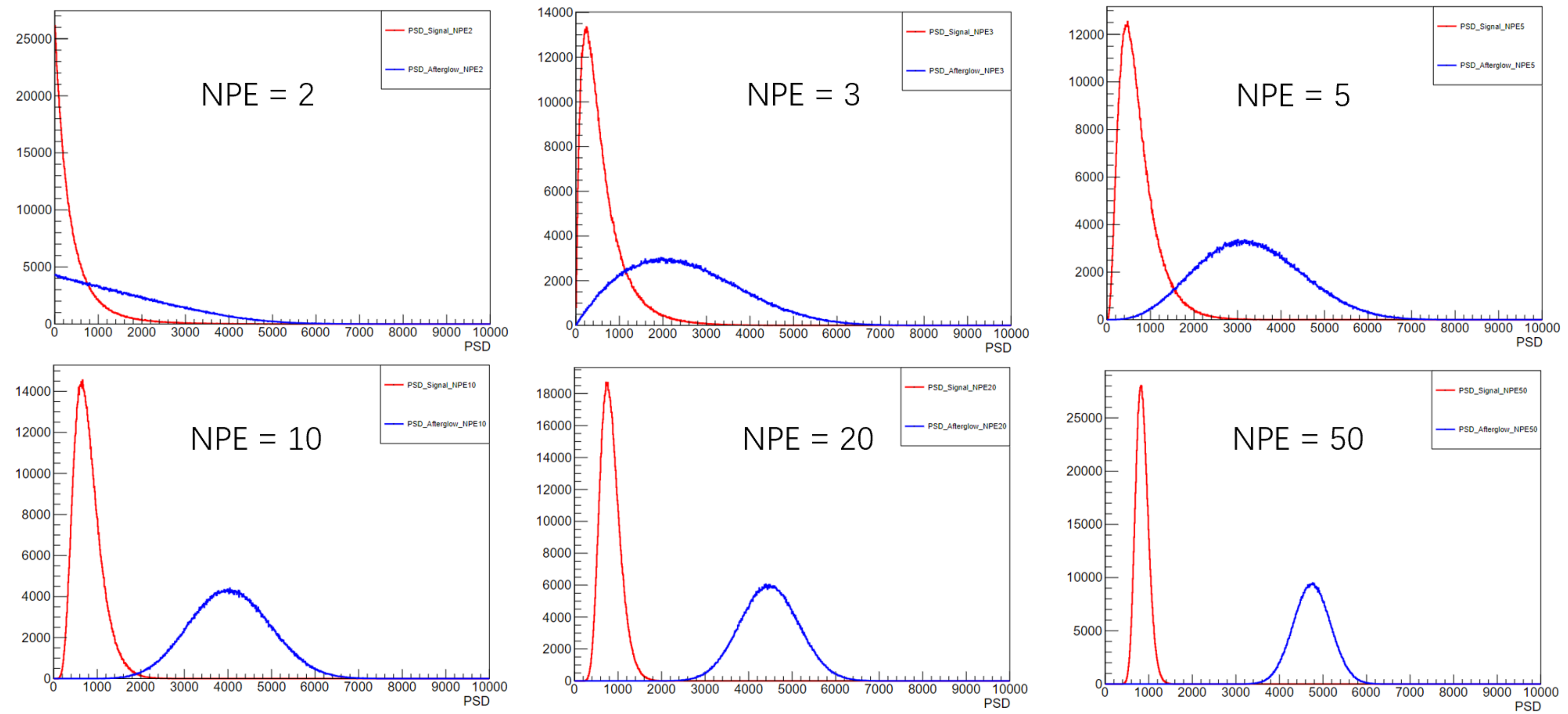
- Future Upgrades:
  - Larger mass -> 100kg
  - SiPM readout -> Higher QE
  - Crystal shape improvement -> Better light collection
  - TPB/NOL coating -> Better spectrum matching
  - Aiming at 50PE/keVee (Maybe 100?)

Deploying Soon!

Cherenkov event



MC of PSD for afterglow and physical events



Red: Physical Events
Blue: Afterglow

Very distinguishable for NPE >= 10

Would be beneficial

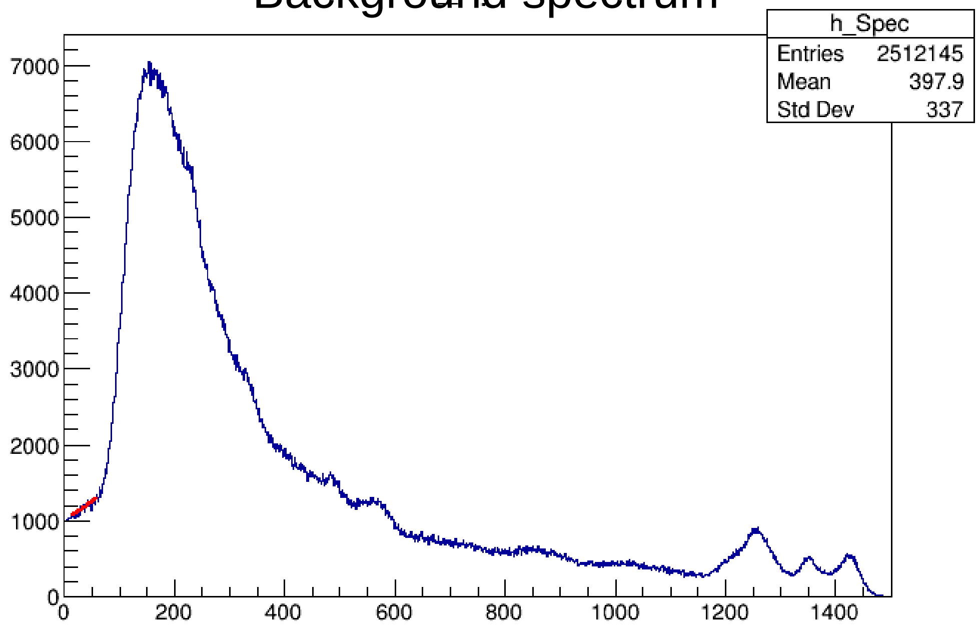
University of Chinese Academy of Sciences

Afterglow MC Simulation

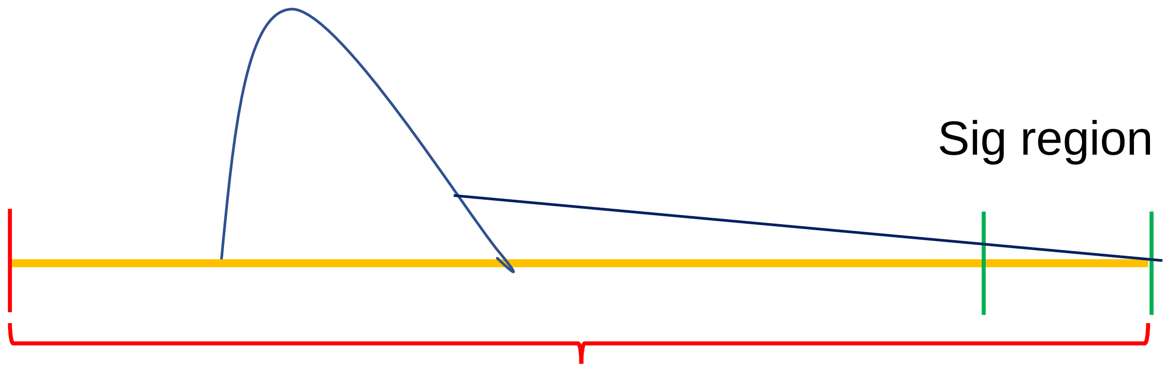
Self Trigger Run:

Background Event rate: 500Hz

Background spectrum



E(keV)



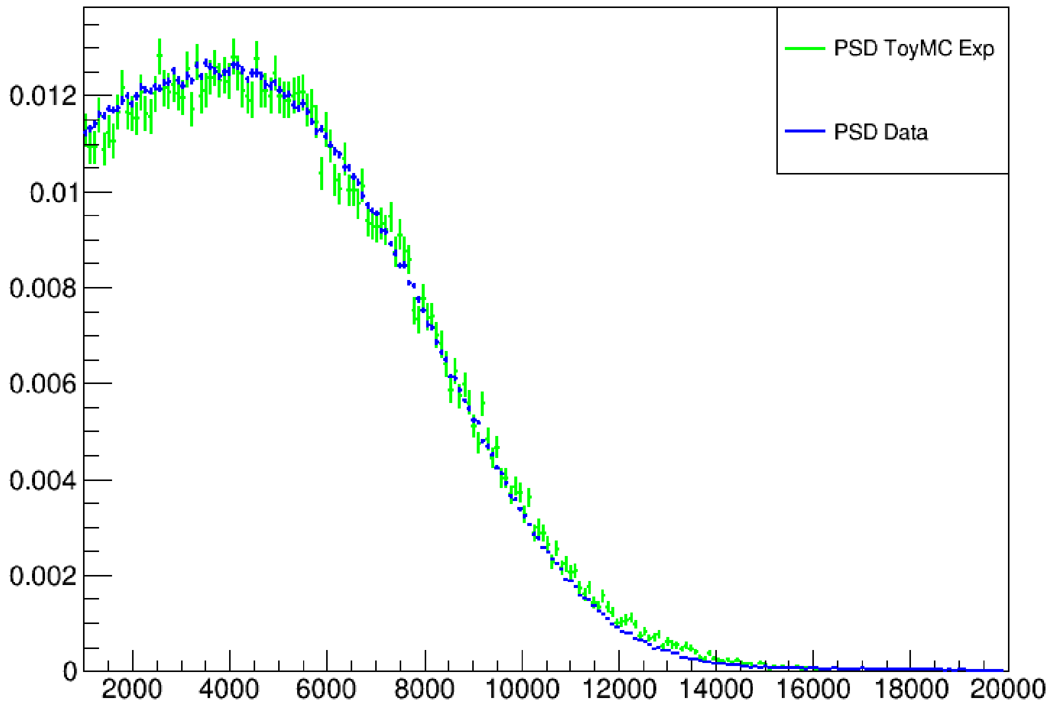
1. Randomly generate physical signal with Poisson distribution (Mean: 6.3Events) in this time window
2. Sampling PE time according to the decay time, PE number according to Energy and LY
3. One afterglow event is generated

University of Chinese Academy of Sciences

中国科学院大学

Validation of MC Simulation

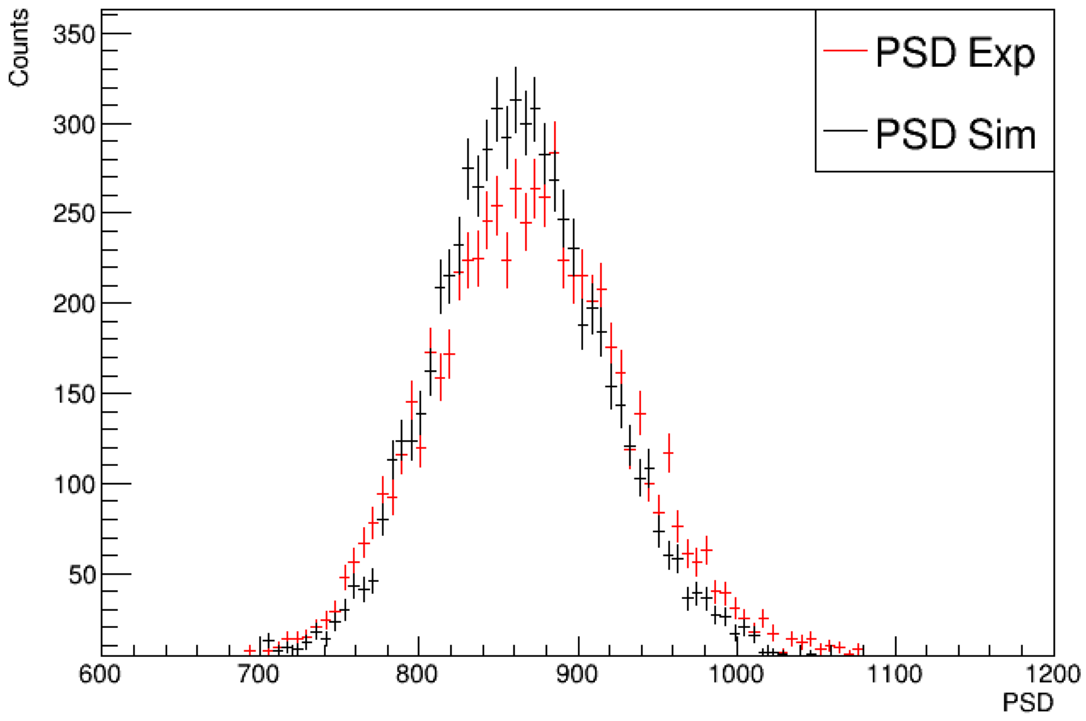
External Trigger Data NPE: 2-10



PSD(ns)

Afterglow events

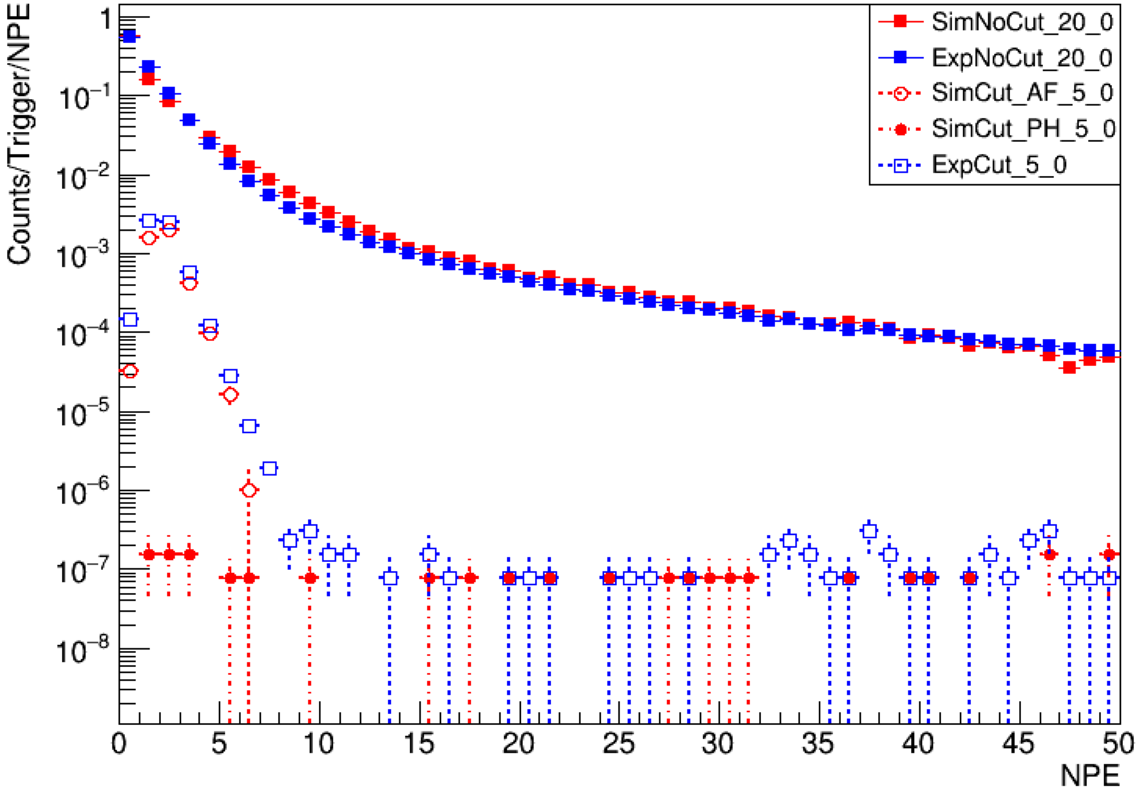
Self Trigger data: 3-20keV



Physical events

The MC modeling is reliable

Compare between Exp and Sim



Sim Results = Physical events + Afterglow Events

Cuts Applied

1. PMT Coincidence
2. Cherenkov cut (data)
3. Pre-trace No-PE cut
4. For sim data, additionally require the Signal time is 60us away from sig region to veto the strong light from the main part which not considered in simulation.

Simulation and experiment agrees very well.
The method has been proven reliable.

Radioactivity Estimation

Total peak area method: standard method for peak area estimation for single un-interfered peak

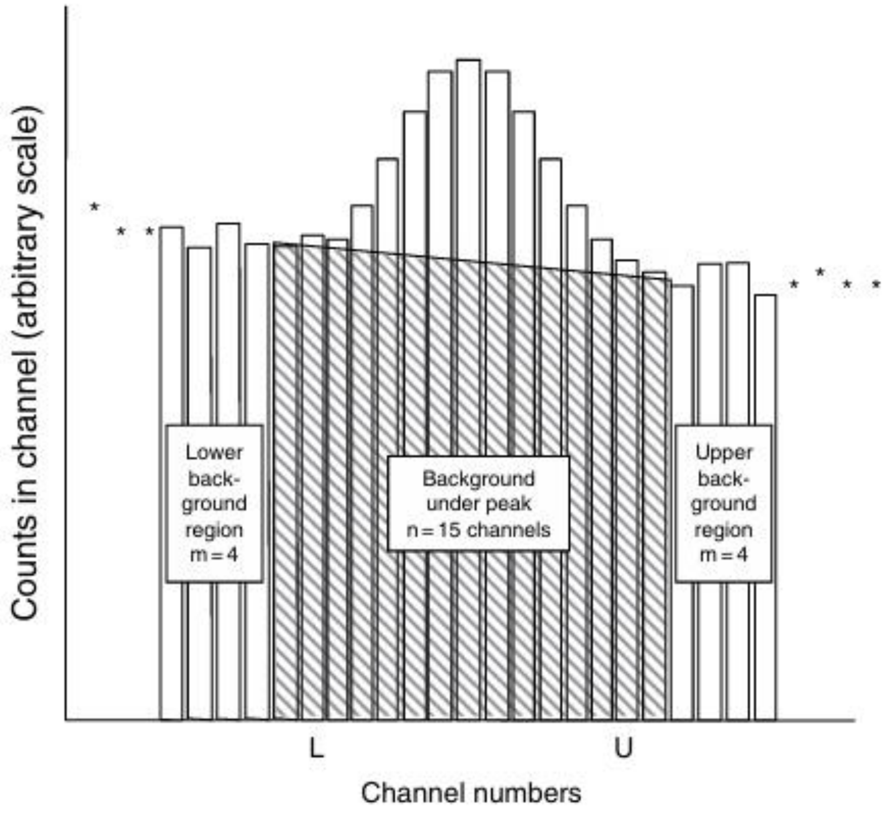
- Background: Compton continuum
- Assumption: continuum is linear

$$A = \sum_{i=\mathrm{L}}^{\mathrm{U}} C_i - n\left(\sum_{i=\mathrm{L}-m}^{\mathrm{L}-1} C_i + \sum_{i=\mathrm{U}+1}^{\mathrm{U}+m} C_i\right)/2m$$

Total counts: G

Background counts: B

- Small peak and large bkg: bkg estimation uncertainty dominates total uncertainty of peak area measurement

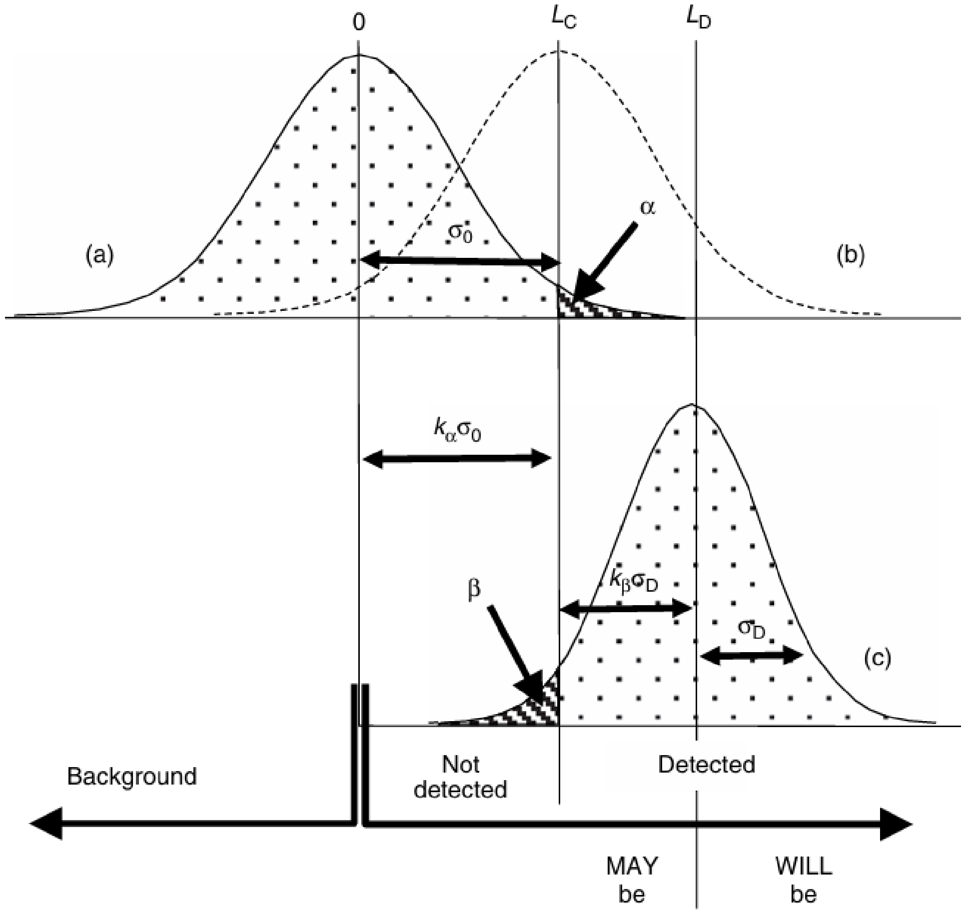


Gilmore, Gordon, and David Joss. *Practical gamma-ray spectrometry*. John Wiley & Sons, 2024.

Radioactivity Estimation

Some statistically determined levels:

- Critical limit (L_C)– a decision level: ‘Is the net count significant?’
- Detection limit (L_D)–‘**What is** the minimum number of counts I can be confident of detecting?’
- Upper limit (L_U)–‘Given that this count is not statistically significant, **what is** the maximum statistically reasonable count?’
- Minimum detectable activity (MDA)–‘What is the least amount of activity I can be confident of detecting?’



Radioactivity Estimation

- Critical limit:

$$L_C = 1.645\sigma_0 = 1.645\sqrt{B(1+\frac{n}{2m})}$$

- Detection limit:

$$L_D = 2.71 + 3.29\sqrt{B(1+\frac{n}{2m})}$$

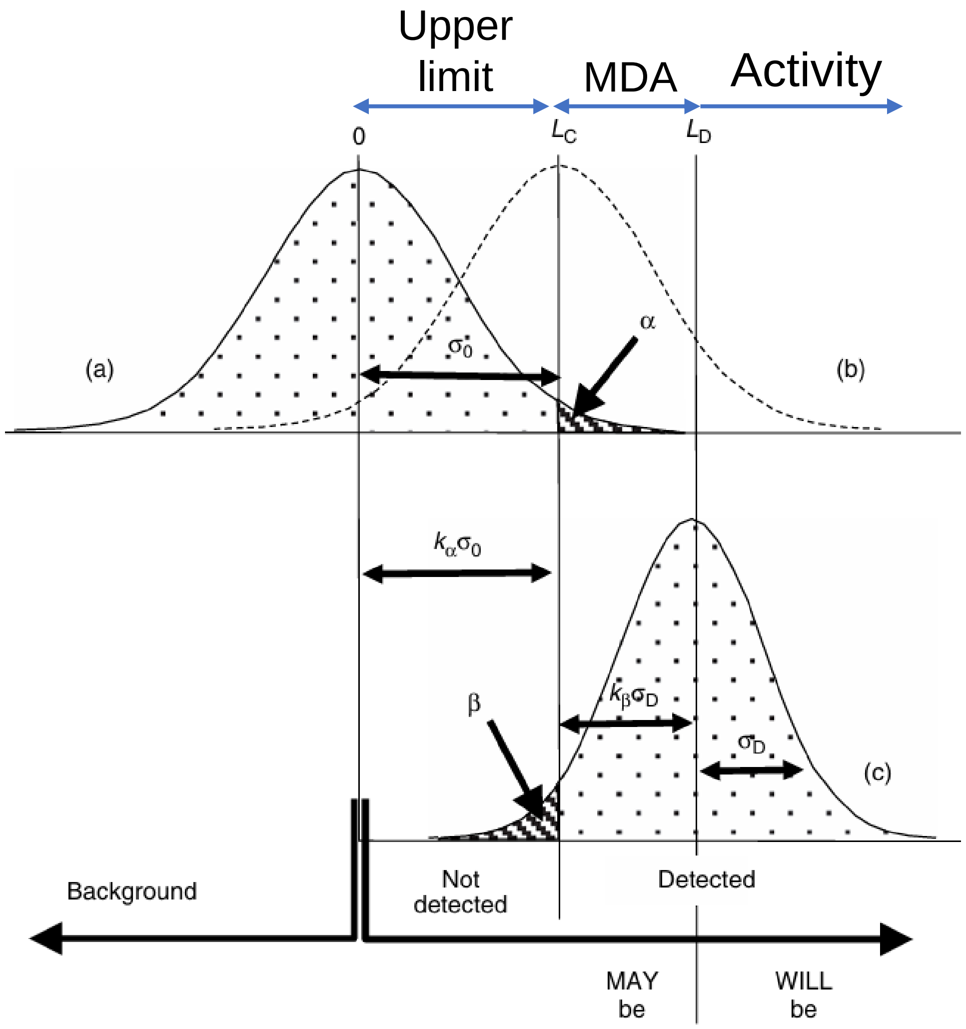
- Upper limit:

$$L_U = A + 1.645\sqrt{A + B(1+\frac{n}{2m})}$$

- MDA: minimum detectable activity

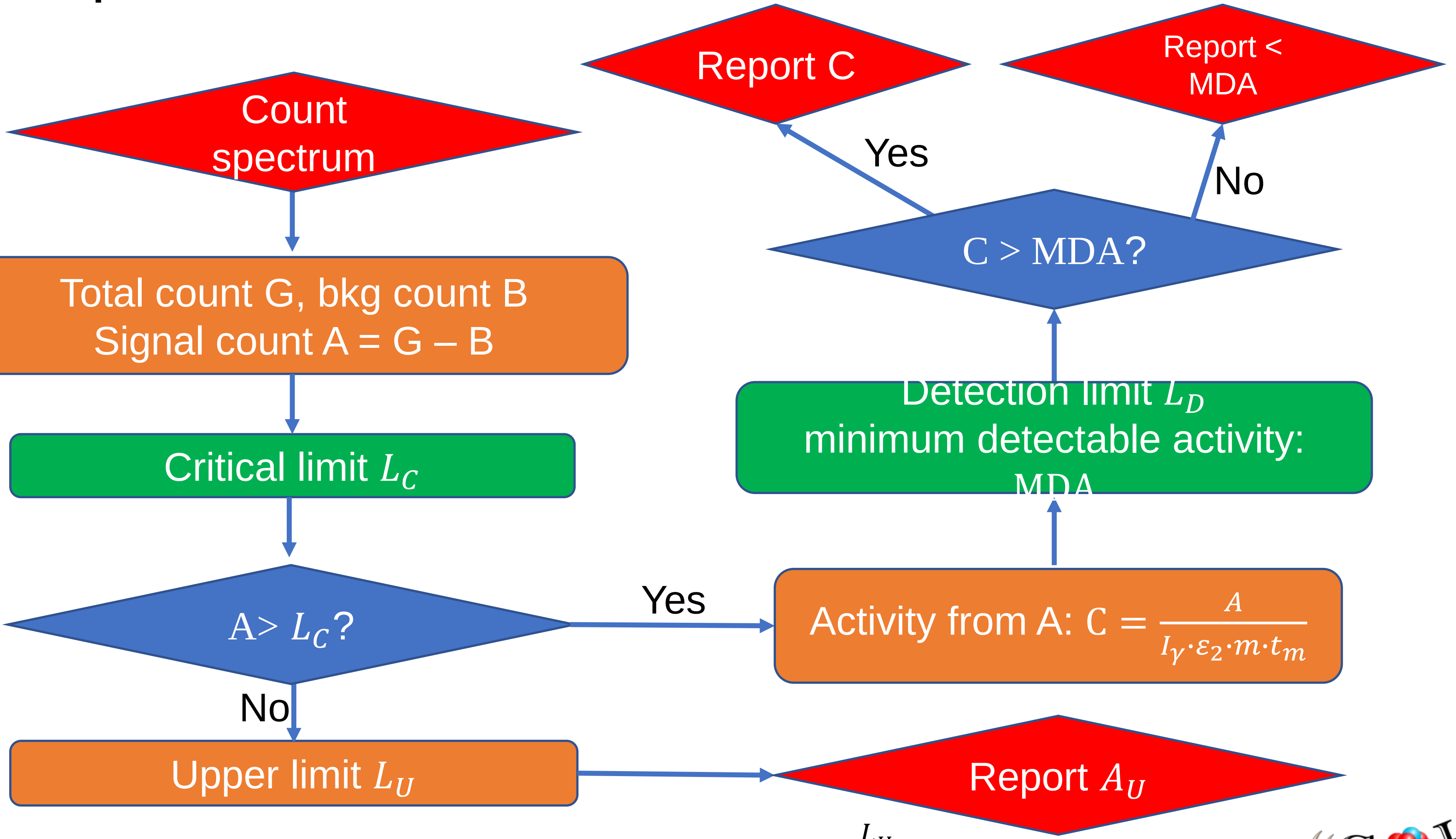
$$\text{MDA} = \frac{L_D}{I_\gamma \cdot \varepsilon \cdot m \cdot t_m}$$

- Uncertainty: $u_A^2 = \text{A} + \text{B}\left(1 + \text{n}/2\,\text{m}\right)$ $\quad u_C = \sqrt{u_A^2 + u_\varepsilon^2}$



Radioactivity Estimation

- **Total peak area method：**



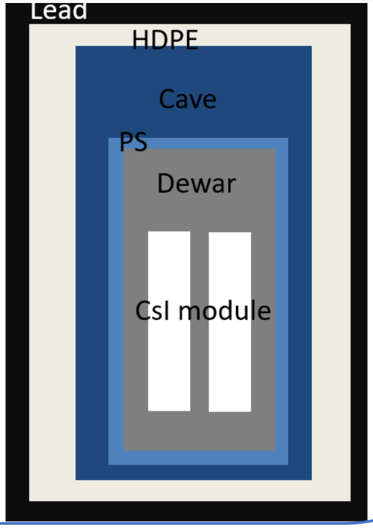
$$A_U = \frac{L_U}{I_\gamma \cdot \varepsilon \cdot m \cdot t_m}$$

Detector Perfor

Method:
- Geant4 simulation
- Data driven analysis

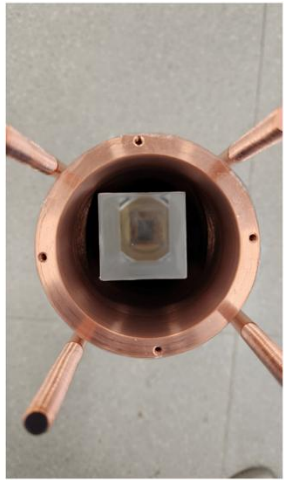
Bkg type		
Steady state background (Reducible)	Cosmic muon (vetoed, negligible)	
	Radioactivity	Env gamma
		CsI self-rad
		material rad
	Afterglow	
Prompt neutron (irreducible)		

- Full modeling of detector in simulation



Muon bkg: Simulation + self trigger data

Shielding: 5cm Pb + 5cm HDPE



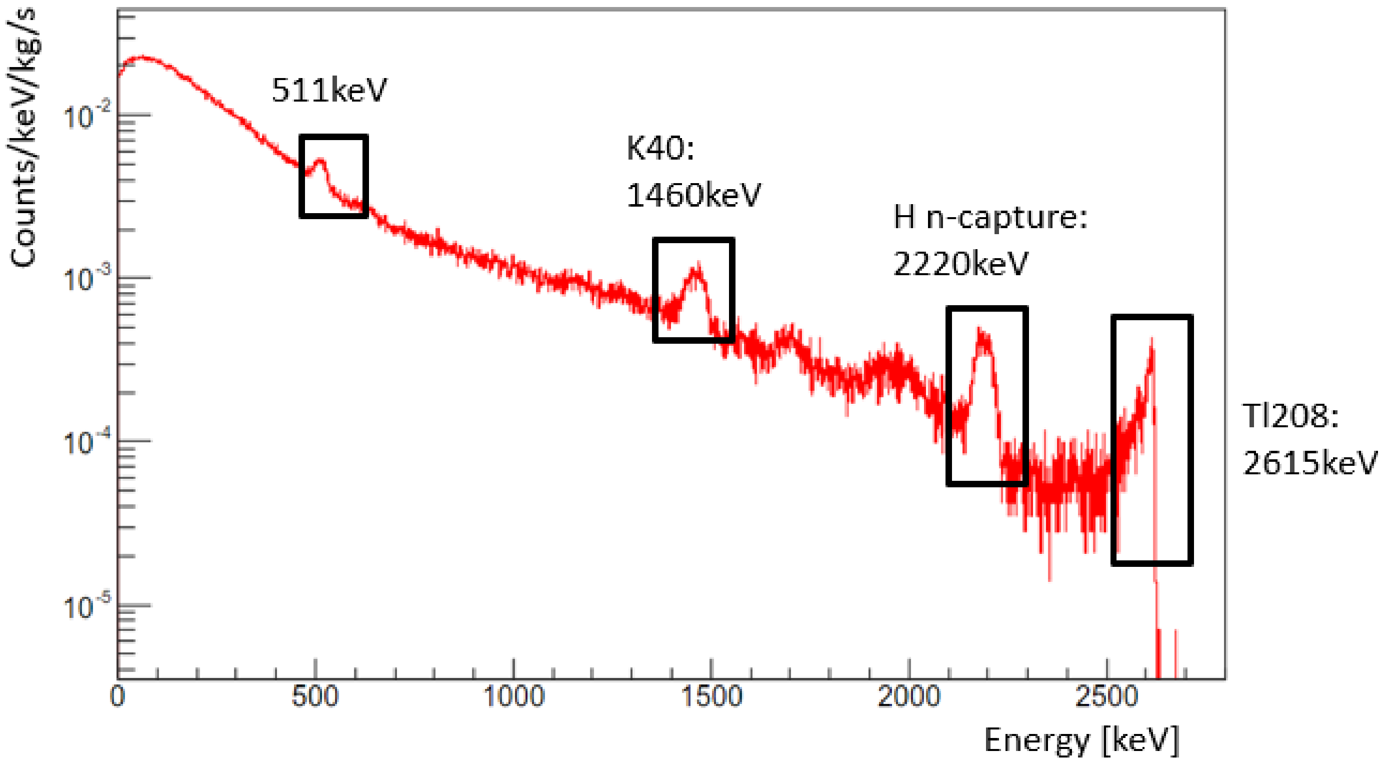
Cosmic muon trigger rate

Sim	Sim + self-trig data
5.9Hz	5.8Hz

Lab test	Self trigger rate
No shielding	~500Hz
With shielding	~30Hz
With shielding + Cu cover	~17Hz
With shielding + Cu + PS	Estimated ~11Hz

Radioactive background of crystal (SICCAS)

Self Trigger Data of 24h



Background peaks for energy and resolution calibration

Unit: mBq/kg

Crystal	Cs134 (796 keV)	Cs137 (662 keV)
NO. 1	<4.45	4.8 ± 1.5
NO. 3	4.6 ± 1.4	<1.31

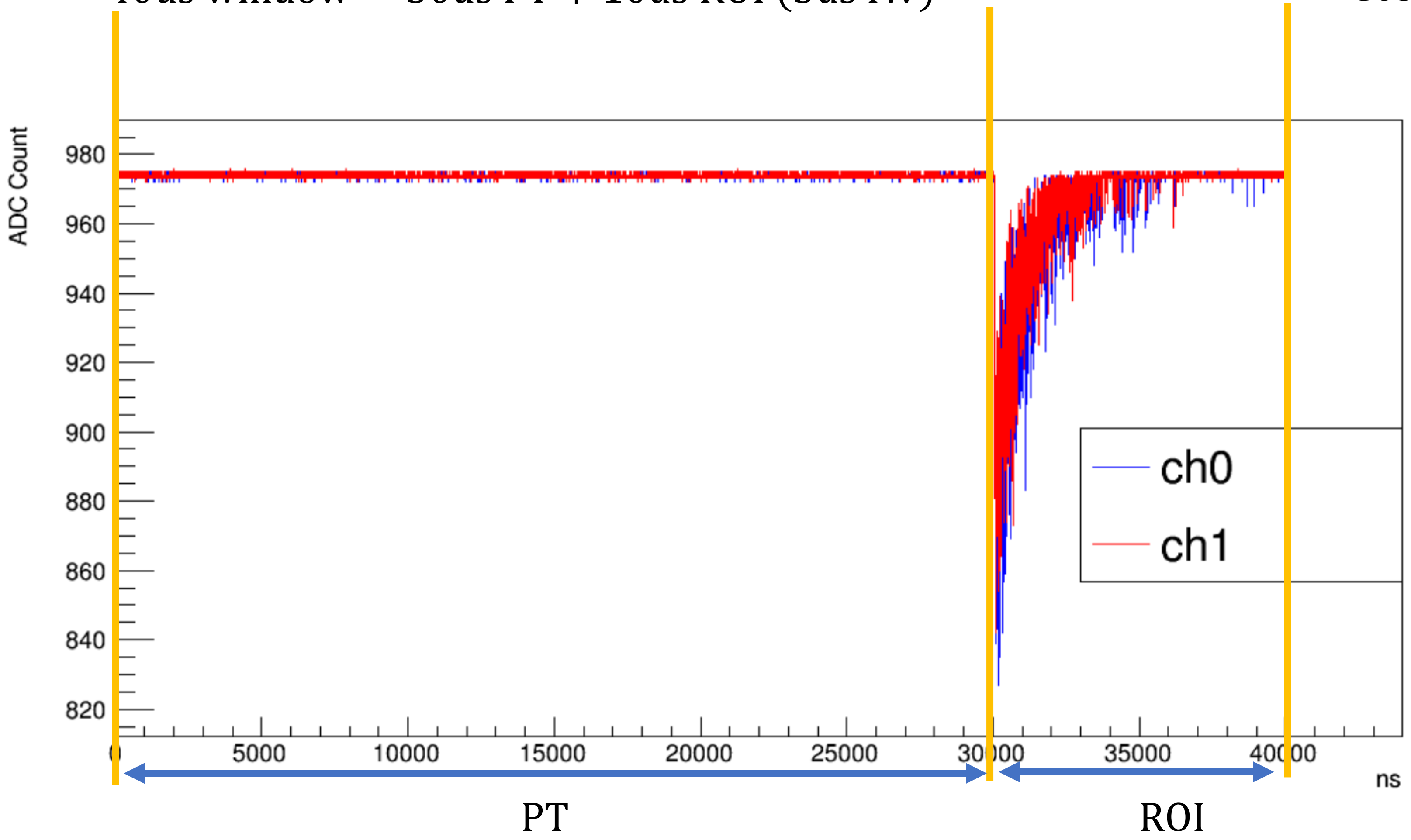
Much better than CsI(Na) from AMCRY

Material	Date Screened	Sample Mass (kg)	Activity (mBq/kg)
Amcrys-H CsI(Na) boule slice	April 2014	0.366	2.38 ± 2.17 ^{238}U <0.53 ^{232}Th 16.67 ± 15.85 ^{40}K 27.87 ± 3.28 ^{137}Cs 25.87 ± 1.96 ^{134}Cs 6.59 ± 3.47 ^{126}I

The External trigger run in UCAS:

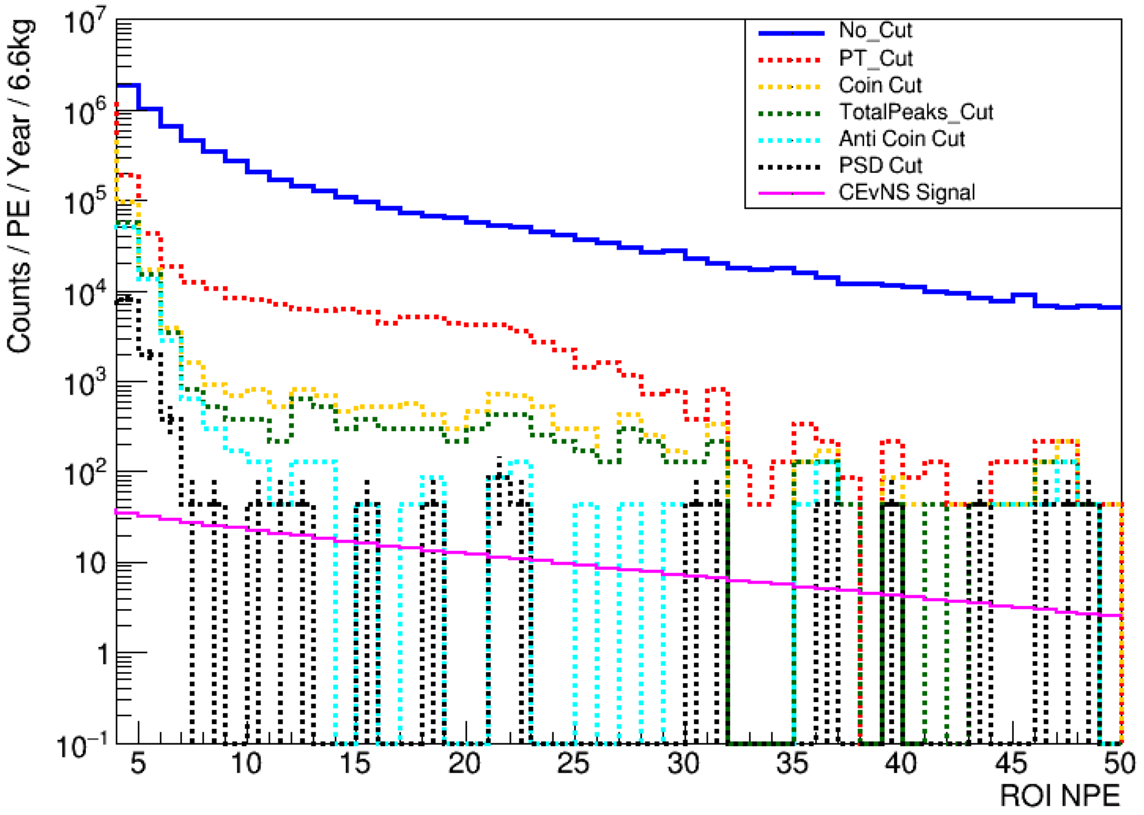
Forced Trigger Run 60Hz, 3 weeks:
40us window = 30us PT + 10us ROI (5us IW)

All Bkg are Steady – State Background
Cosmogenic background is higher in UCAS
No Muon Veto Applied
A convervative estimation



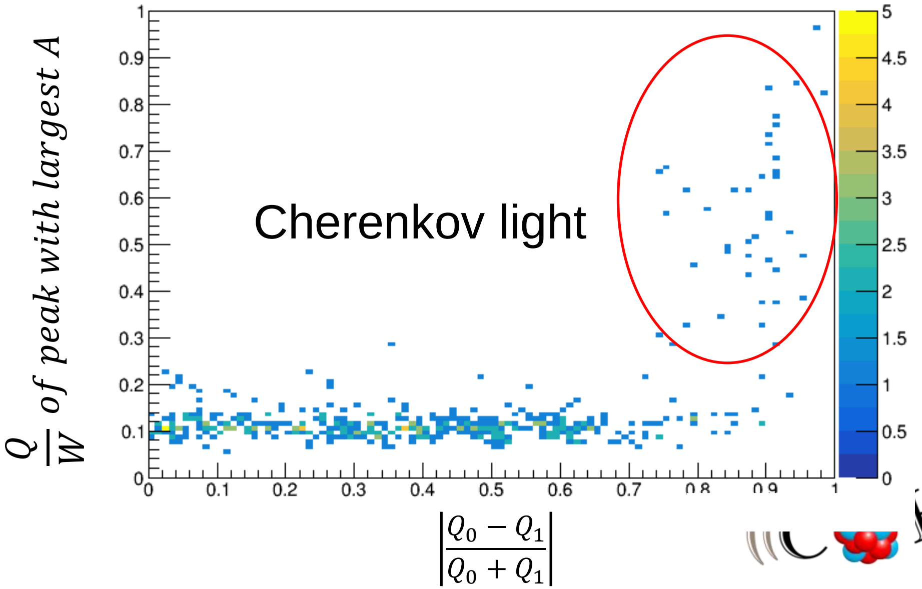
COHERENT SNS

Cuts to suppress background



S/B ~ 1 for NPE ≥ 7

Cut Name	Condition
PT Cut	$N_{pt} \leq 1$
Coin Cut	$N_{iw}^{0} \geq 1$ && $N_{iw}^{1} \geq 1$
Total Peaks Cut	$N_{iw}^{total} \geq 4$
Cherenkov Cut	See picture below
Anti Coin Cut	Only one crystal pass cuts above
PSD Cut	PSD ∈ [600,1000]



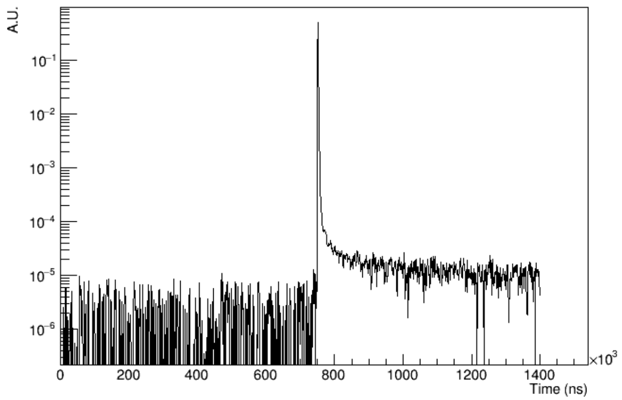
University of Chinese Academy of Sciences

TUNL Triangle Universities Nuclear Laboratory

University of South Dakota

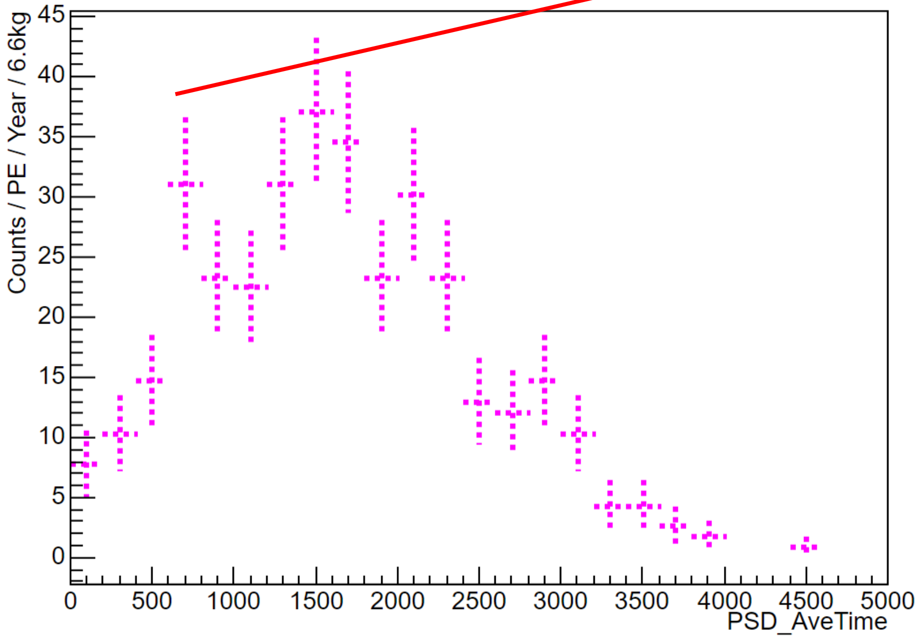
PSD method to suppress afterglow

$$PSD = \frac{\sum_i^N A_i \times (T_i - T_0)}{\sum_i^N A_i}$$, The mean arrivle time of PEs

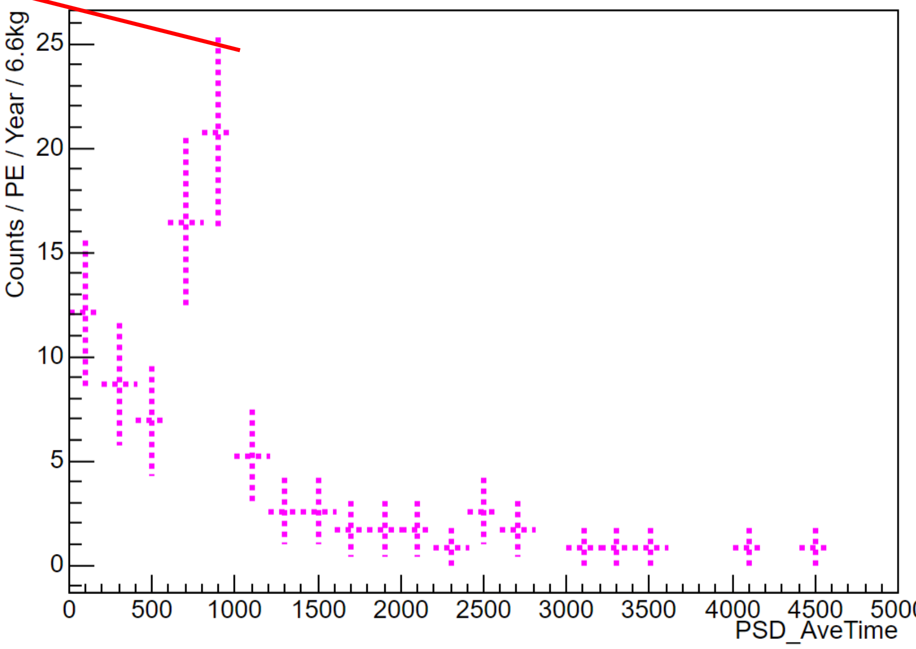


Actual Physical signal

NPE 5-7



NPE 7-100



Physical signal ~ 1us

Afterglow ~ 1.3ms

COHERENT SNS

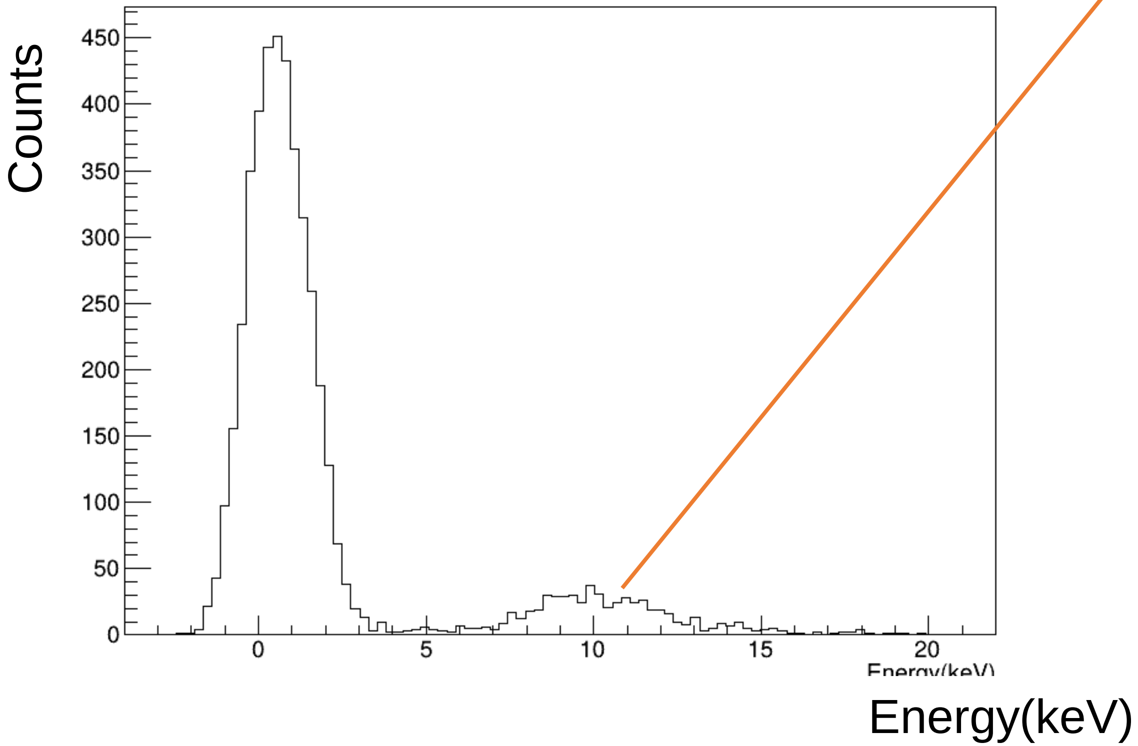
University of Chinese Academy of Sciences

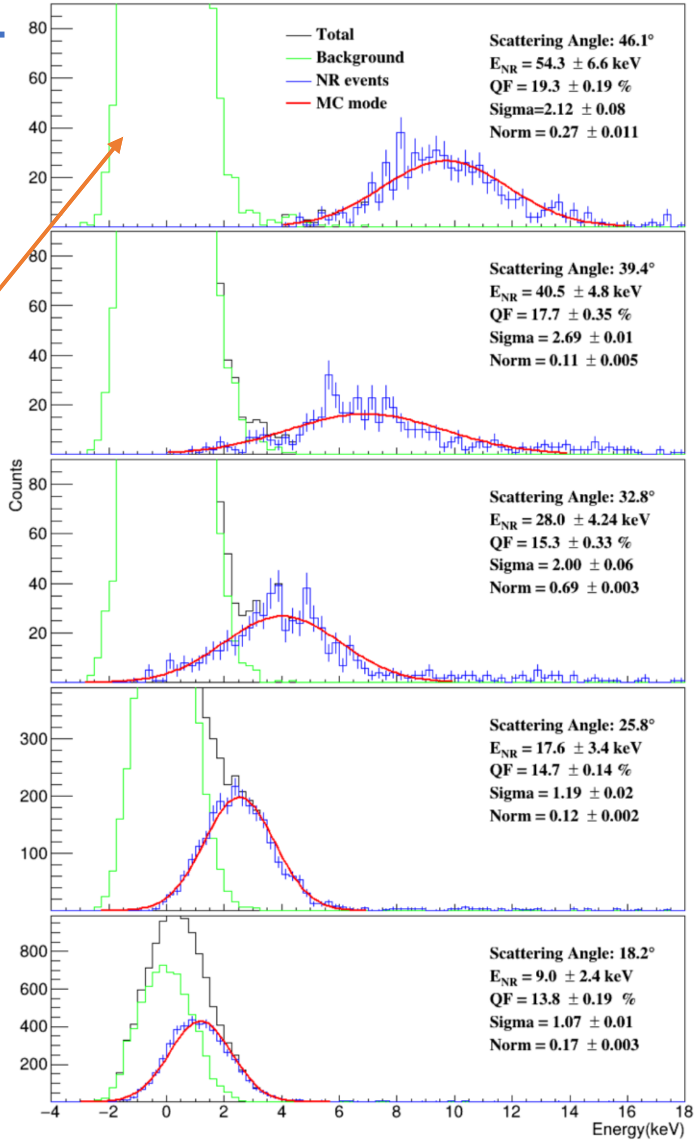
TUNL
Triangle Universities Nuclear Laboratory

University of South Dakota

Quenching factor Fitting

QF: adjust position of the model
Sigma: width of the model
Norm: height of model





COHERENT SNS