^{79}Se(n,γ) at n_TOF EAR1 & EAR2

Status of the analysis of the measurement at EAR2

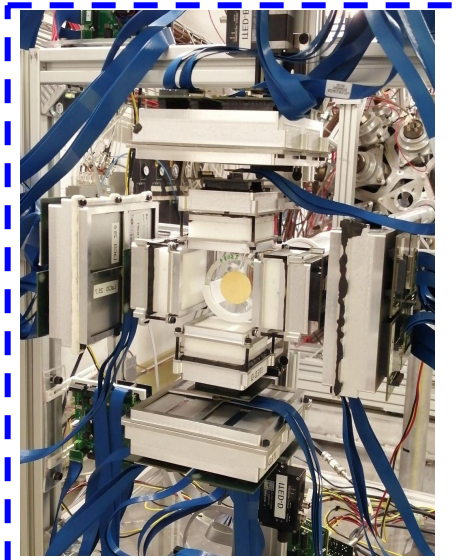
J. Lerendegui-Marco, C. Domingo-Pardo, J. Balibrea-Correa et al. and the n_TOF Collaboration

n_TOF Collaboration Meeting, Edinburgh, 13-14 Dec 2022

Outline

- **VERY Brief review of the experiment**
- Status of the analysis last meeting
- Recent progress in the analysis of EAR2:
  - Challenges of the measurement & solutions/corrections
- Outlook

Summary experiment: Setups



EAR1

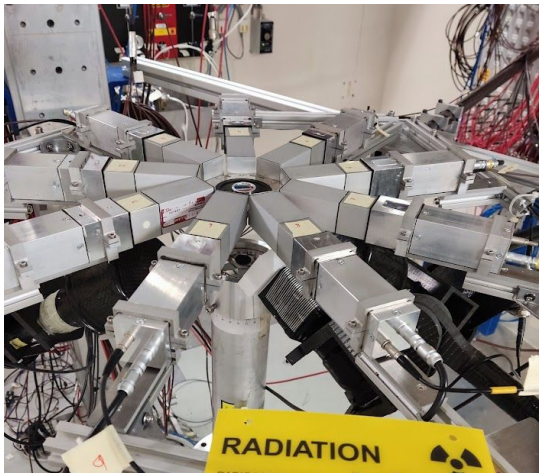
i-TED detectors @ 5 cm
Closer than C6D6 → higher SBR
High Energy resolution →Precise Cuts in Edep
Compton Imaging → Reduction Background

Ancillary: L-C6D6 detectors (old PMTs) @ 15 cm
Validation, check n-sensitivity i-TED

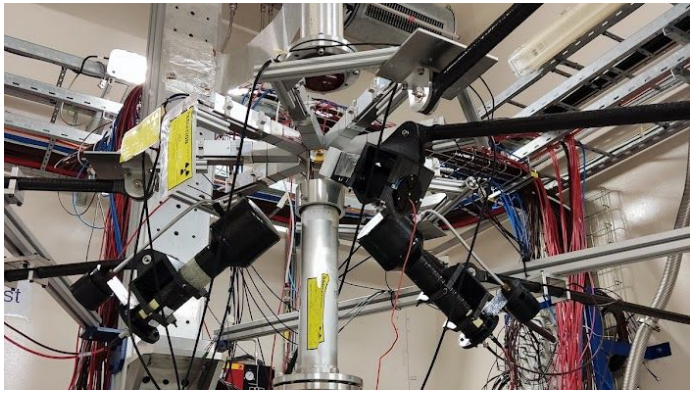
EAR2: Same Nb-94 campaign

- 9 sTEDs @ **4.5 cm**
- 2 C6D6 @ **17 cm**
- 1 LaCl3 @ **9 cm**

C6D6 + new PMTs



EAR2

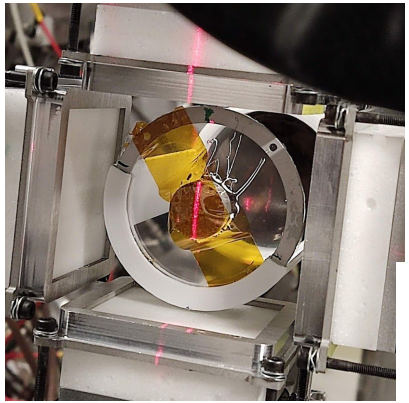


Summary experiment: samples & statistics

ISOTOPE	Protons	DIMENSIONS / MASS	REF.
Se-79 (PbSe)	2.30E+18	14 mm, 3.9g + Al casing	855
Dummy	4.50E+17	Al ring + Mylar + Al casing	856
Se-78	3.00E+17	20 mm, 1.99 g	236
Au-197	1.50E+17	20 x 0.1 mm / 0.596 g	689
Lead	3.00E+17	20 mm x 1-2 mm	184
Empty	1.00E+17	60 mm Al ring + 6 um mylar	889

REQUESTED TO INTC:
EAR1: 3.5e18
EAR2: 2.5e18

OBTAINED:
EAR1: 3.9e18
EAR2: 2.7e18



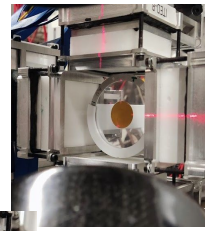
Se-79 (PbSe + Al)

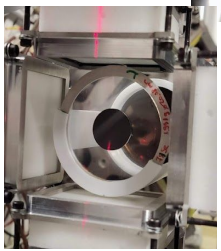
Isotope	Mass (g)
Se-78	1.064
Se-79	0.003
Pb-208	2.838
Al-27	1.0244

Only 3mg of ^{79}Se in a 3.9g sample of ^{208}Pb^{78}Se!!

Indirect absolute normalization

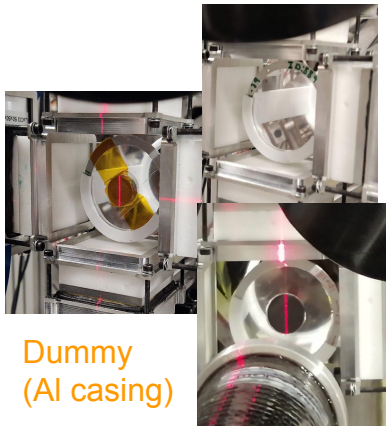
Au-197





Se-78

Beam-related background:
Contribution of Al casing and Pb



Empty

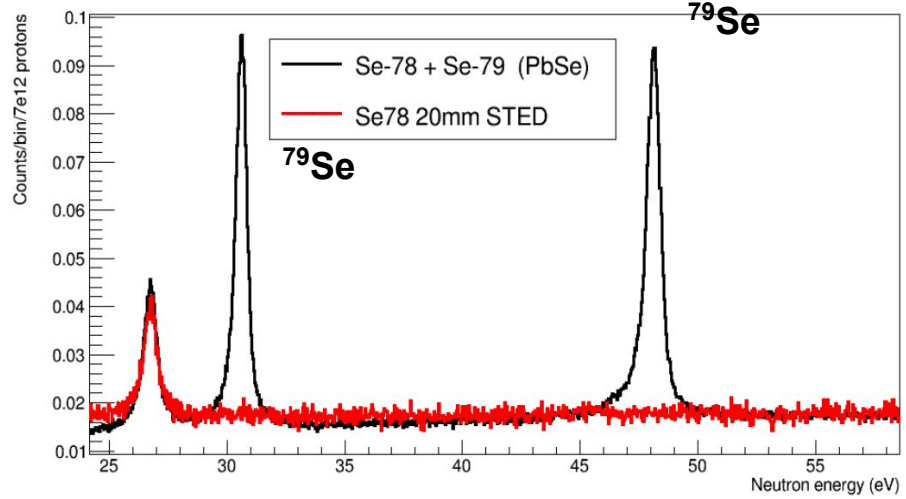
Dummy
(Al casing)

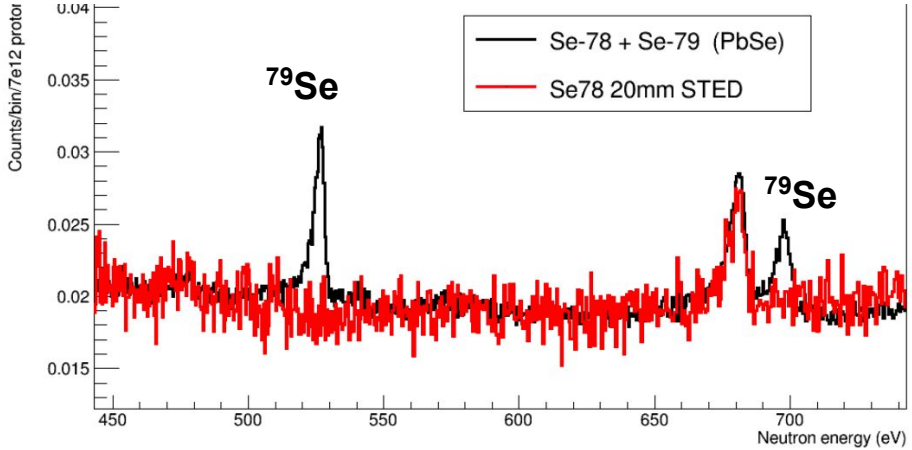
Lead

Outline

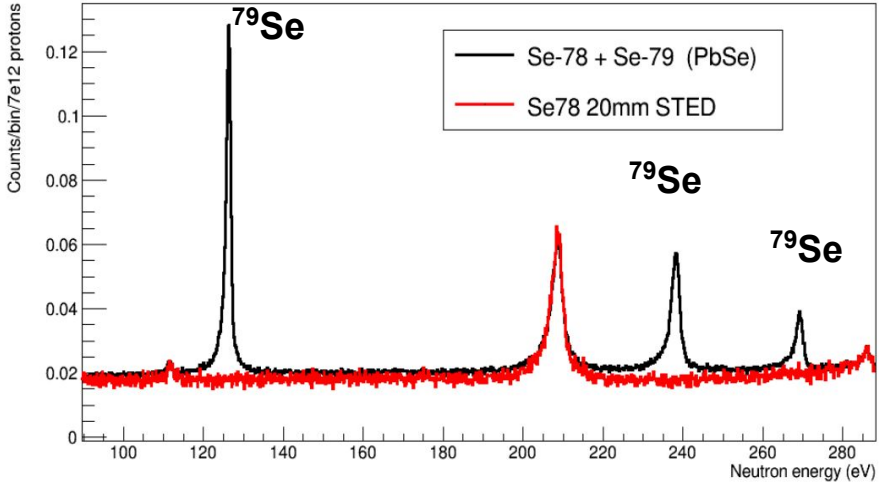
- VERY Brief review of the experiment
- **Status of the analysis last meeting**
- Recent progress in the analysis of EAR2:
  - Challenges of the measurement & solutions/corrections
- Outlook

Se-79 @ EAR1 & EAR2: June ‘22 Meeting





- **Se-78 disc** vs **Se-79 (PbSe) sample**
- Sum of the STEDs is plotted



First results indicate that it has been a **successful experiment**: 10-15 resonances observed → In very good agreement with the proposed results.

Se-79 @ EAR1 & EAR2: June '22 Meeting

i-TED & C6D6 @ EAR1

- Energy calibrations
- Gain shift study
- i-TED: Preliminary bckg subtraction in singles & coincidences
- C6D6: Preliminary bckg subtraction unweighted counts

s-TED & L-C6D6 @ EAR2

THIS TALK!

- Preliminary energy calibrations
- Gain shift study
- ToF correction for SPD2886
- STED & C6D6: Preliminary (incomplete) bckg subtraction unweighted counts

- C. Rate consistency & uncertainty related to neutron/proton beam monitors
- PHWT (i-TED, STED, C6D6): integration of simulation codes
- Normalization to Se-78 → Au-197 (SRM) & scaling of the Pb background to PbSe
- Cascade simulations: Corrections and uncertainty

EAR1:
- i-TED: Imaging applied to SBR enhancement
- ML signal/background identification

EAR2:
- Parastics vs dedicated: Gain shifts vs C. rate & dead time

-Analysis of LaCl3 for spectroscopic information of the Cascades

Outline

- Brief review of the experiment
- Status of the analysis last meeting
- **Recent progress in the analysis of EAR2:**
  - **Challenges of the measurement & solutions/corrections**
- Outlook

Se-79 @ EAR2: Analysis & challenges

Challenge	What is affected?	Work done so far
High C. rates of EAR2 (+ activity ^{79}Se sample)	Gain drifts detectors → → **PHWT (efficiency)**	Final run-by-run **gain corrections**
	Dead time in large ^{197}Au, ^{78}Se resonances → **Normalization**	Simple **Dead time** correction: dedicated & parasitic bunches
Sample: Irregular geometry, 2.8 g of Pb & difficult reproducibility	Complex **Normalization** & **Background subtraction**	Consistency of **beam monitors** & detectors
		Study & **corrections for normalization** of ^{79}Se vs ^{78}Se & ^{197}Au
		Scaling of the **Pb-related background**

Se-79 @ EAR2: Analysis & challenges

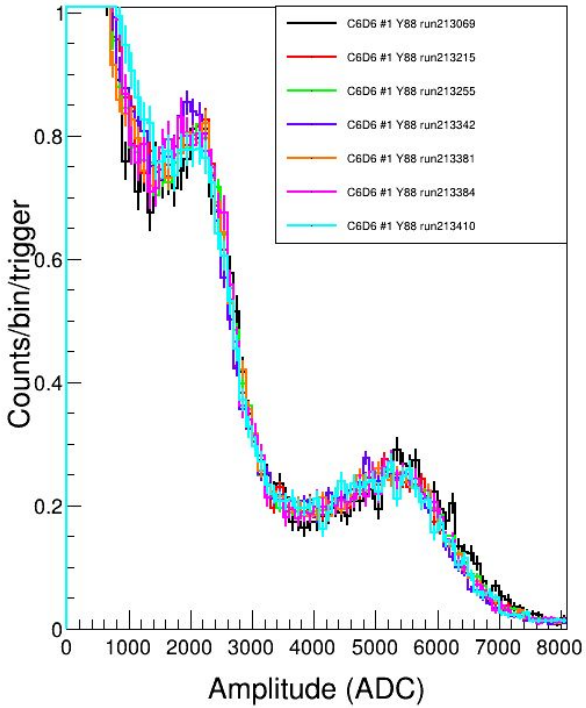
Challenge	What is affected?	Work done so far
High C. rates of EAR2 (+ activity ^{79}Se sample)	Gain drifts detectors → → **PHWT (efficiency)**	**Final run-by-run gain corrections**
	Dead time in large ^{197}Au, ^{78}Se resonances → **Normalization**	Simple Dead time correction: dedicated & parasitic bunches
		Consistency of beam monitors & detectors
Sample: Irregular geometry, 2.8 g of Pb & difficult reproducibility	Complex **Normalization** & **Background subtraction**	Study & corrections for normalization of ^{79}Se vs ^{78}Se & ^{197}Au
		Scaling of the Pb-related background

Final run-by-run gain corrections

03/05	213069	0	Y88 calibration
13/05	213215	0	Y88 calibration
13/05	213216	0	Cs137calibration
16/05	213252	0	Cs137calibration
16/05	213253	0	AmBe calibration
16/05	213254	0	AmBe calibration
16/05	213255	0	Y88 calibration
16/05	213256	0	Bi-207 calibration
16/05	213257	0	Bi-207 calibration
16/05	213259	0	Co-60 calibration
16/05	213260	0	Co-60 calibration
23/05	213342	0	Y88 calibration
23/05	213343	0	AmBe calibration
23/05	213343	0	AmBe calibration
23/05	213345	0	Cs137 calibration
27/05	213381	0	Y88 calibration
27/05	213384	0	Y88 calibration
30/05	213409	0	AmBe calibration
30/05	213410	0	Y88 calibration

16/05 → Full set: reference calibration

6 calibrations with ^{88}Y along the run

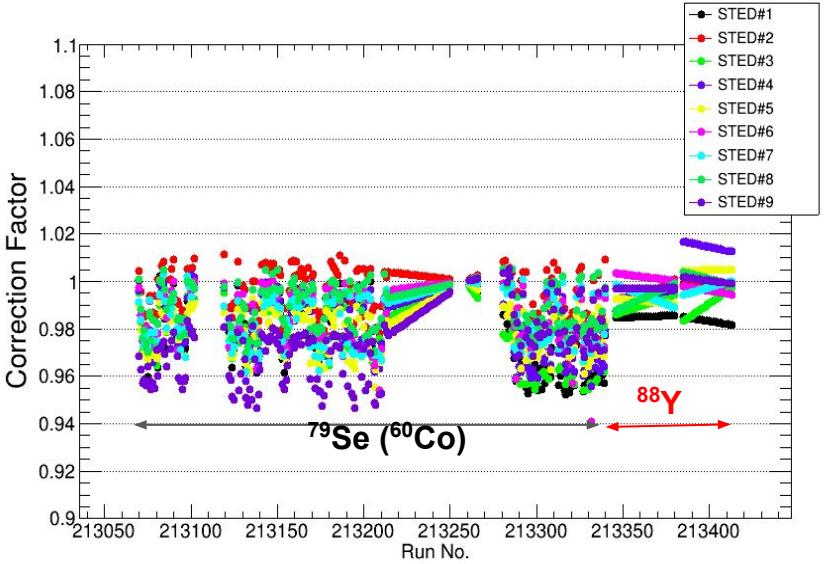


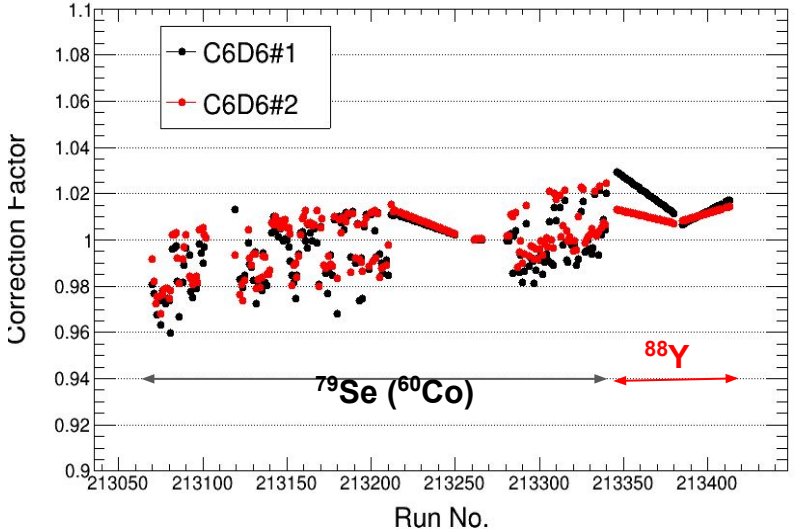
Final run-by-run gain corrections

- Gain drifts have been small (2-3%), and determined with a precision of 1-2%.

STRATEGY:

- ^{79}Se in beam →Run <= 213340 → Run-by run monitoring with ^{60}Co in ^{79}Se sample or interpolation
- ^{79}Se not in beam →Run >213340 → Interpolation ^{88}Y gain drifts

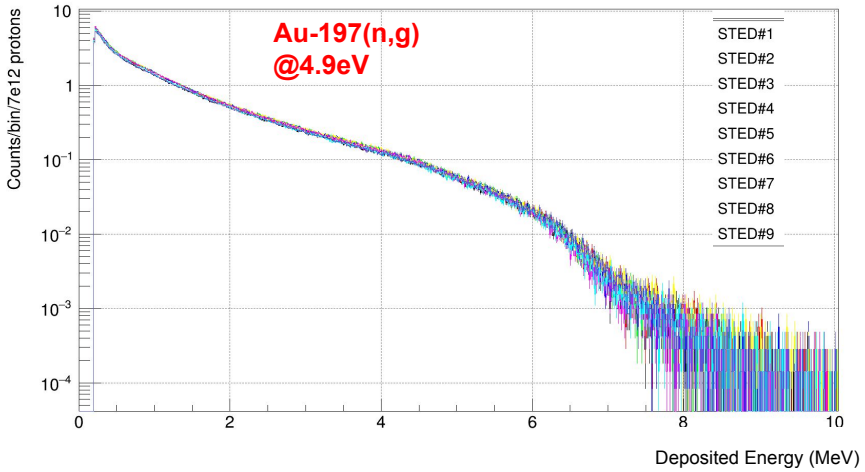


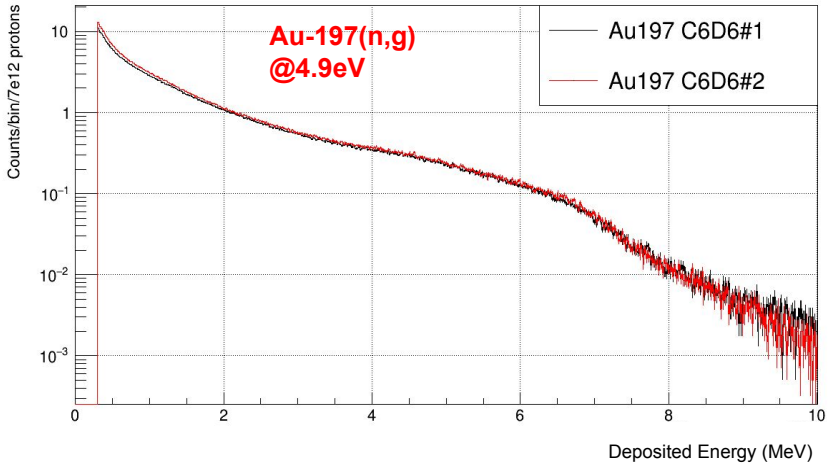


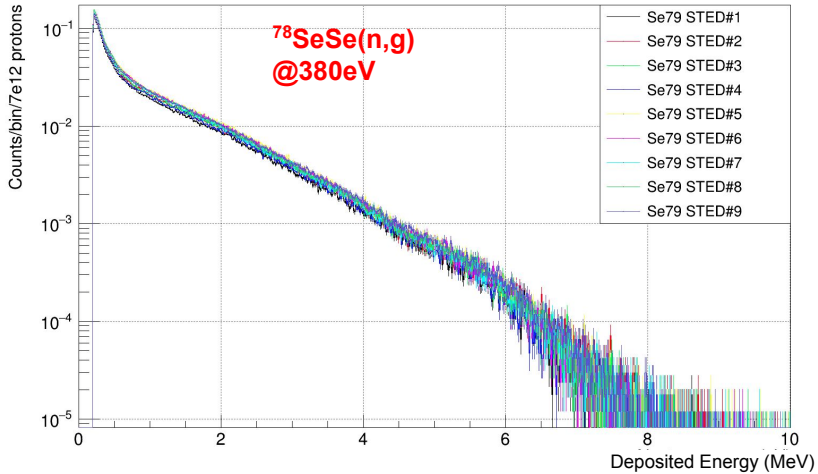
Uncertainty in the correction factors → 1% & std of fluctuations (+-1 %)

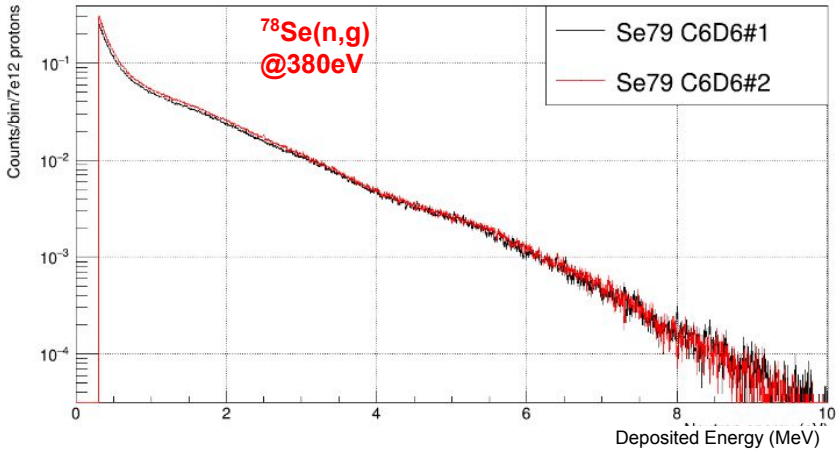
1% systematic uncertainty related to the gain drifts

Final run-by-run gain corrections: Cascades









Se-79 @ EAR2: Analysis & challenges

Challenge	What is affected?	Work done so far
High C. rates of EAR2 (+ activity ^{79}Se sample)	Gain drifts detectors → → **PHWT (efficiency)**	Final run-by-run gain corrections
	Dead time in large ^{197}Au, ^{78}Se resonances → **Normalization**	**Simple Dead time correction: dedicated & parasitic bunches**
Sample: Irregular geometry, 2.8 g of Pb & difficult reproducibility	Complex **Normalization & Background subtraction**	Consistency of beam monitors & detectors
		Study & corrections for normalization of ^{79}Se vs ^{78}Se & ^{197}Au
		Scaling of the Pb-related background

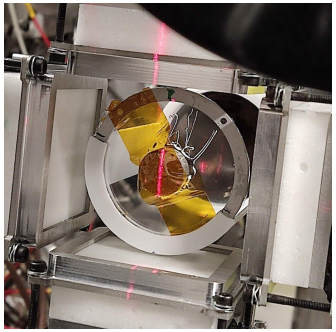
Relevance of Dead Time→ normalization

Se-79 relative to Se-78

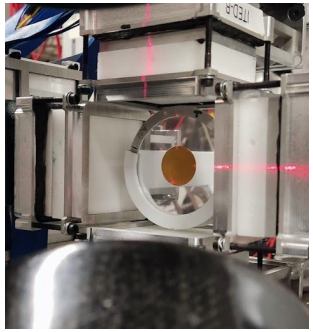
Absolute normalization

Main Sample:
Al + Pb + Se-78 + **Se-79**

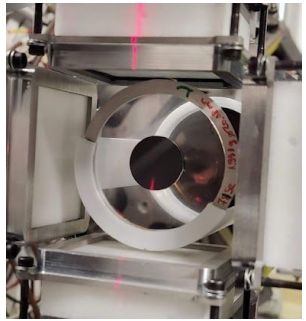
Normalization:
Se-78 & Au-197 of the same dimension



Se-79 (PbSe + Al)



Au-197



Se-78

Challenge of ^{79}Se(n,g) at EAR2:

^{79}Se→ <3mg → "Low" C. rates

BUT large resonances of…

^{78}Se in the PbSe (1.06 g) &
^{78}Se disc (20 mm, 1.9 g) &
^{197}Au (20 x 0.1mm)

… will be used for the **normalization**--
→ dead time corrections?

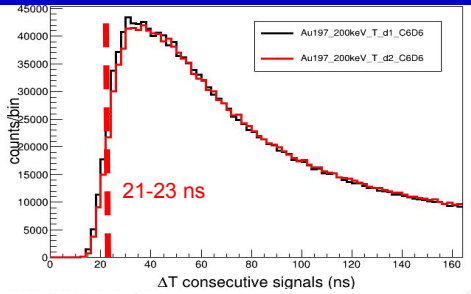
Goal: Study & correct dead time using dedicated and parasitic bunches

Dead Time: non-paralizable model

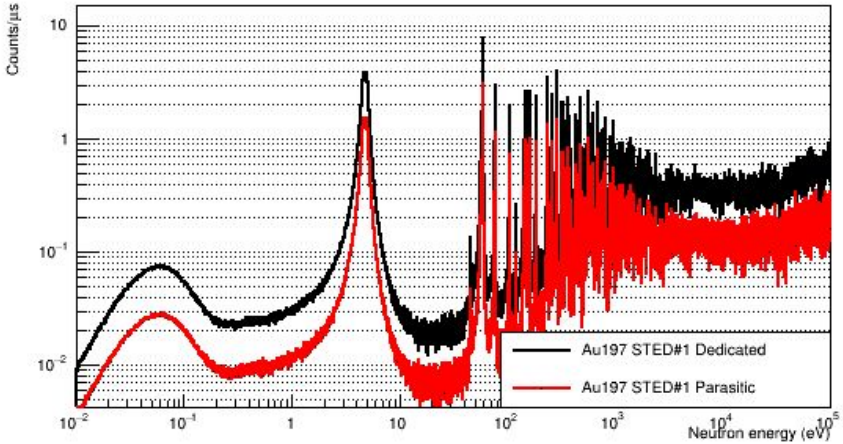
C: Real count rate
C_d: Detected count rate
F_τ: Dead time correction

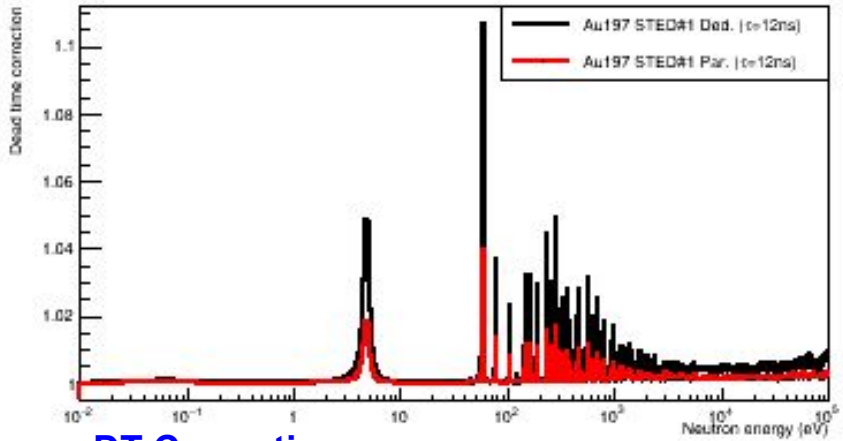
$$C = \frac{C_d}{1 - \tau \frac{C_d}{T}} = F_\tau C_d,$$

STED τ = 12 ns
C6D6 τ = 21-23 ns



STED #1: ^{197}Au 20x0.1mm





C. Rate:
Max @ 62 eV: 8 c/us (**dedicated**), 3c/us (**parasitic**)
4.9 eV: 4c/us (**dedicated**), 1.5c/us (**parasitic**)

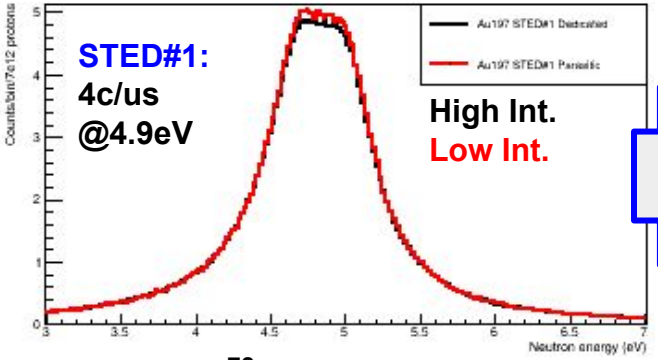
DT-Correction:
Max @ 62 eV: 10% (**dedicated**), 4% (**parasitic**)
4.9 eV: 5 % (**dedicated**), <2% (**parasitic**)

MESSAGE: STEDs also have large C. rates, even >5c/us if large masses/CS or Au for normalization!

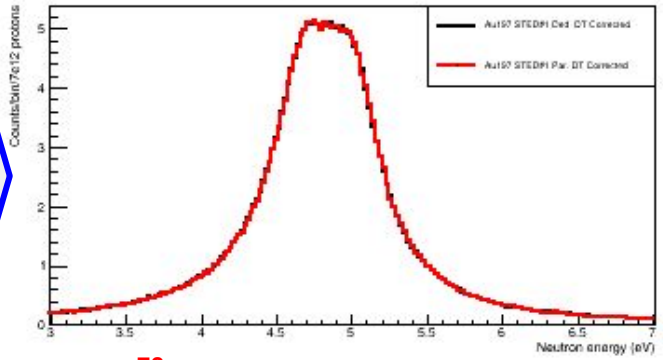
DT correction: High vs Low intensity

Low Int.: <4e12 ppp **High Int.: >8e12 ppp**

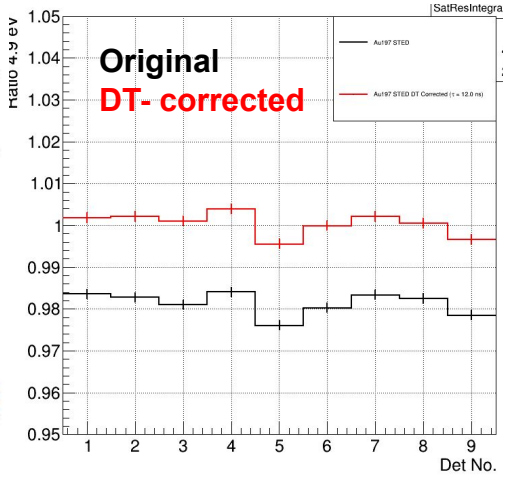
^{197}Au, 4.9 eV



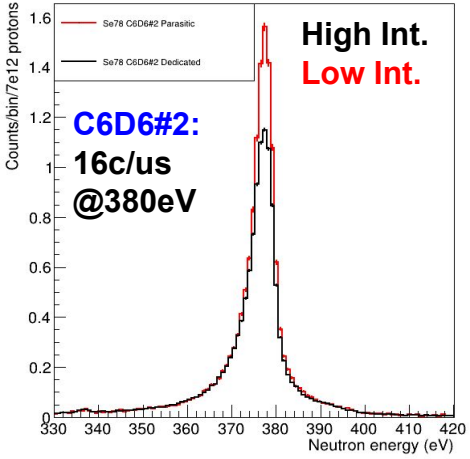
^{197}Au, 4.9 eV, DT- corrected



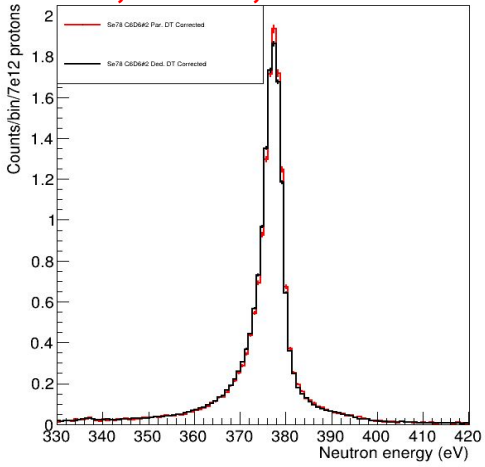
STED #1-9 Low/High Int. (3-7 eV)



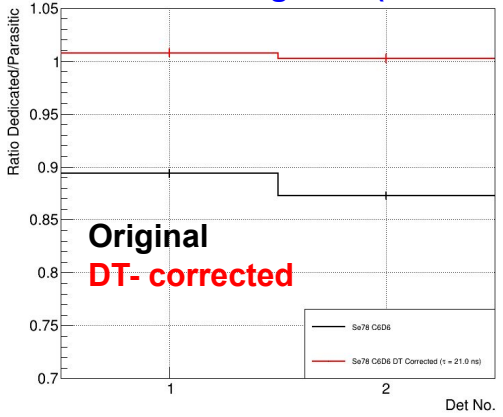
^{78}Se, 380 eV



^{78}Se, 380 eV, DT- corrected



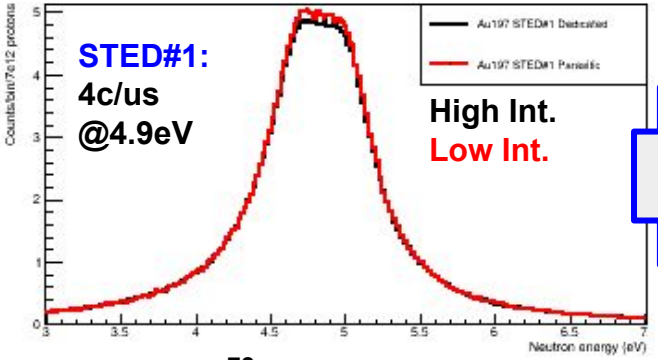
C6D6 #1-2 Low/High Int. (330-420 eV)



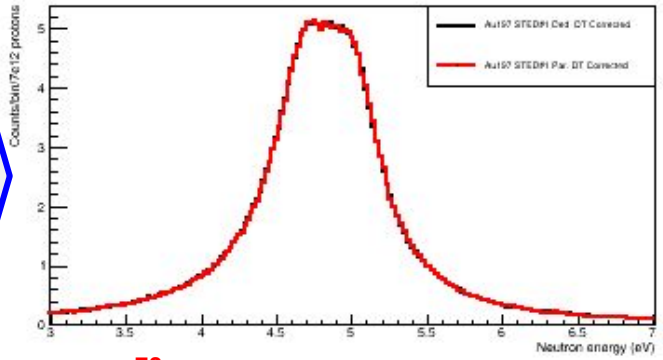
DT correction: High vs Low intensity

Low Int.: <4e12 ppp **High Int.: >8e12 ppp**

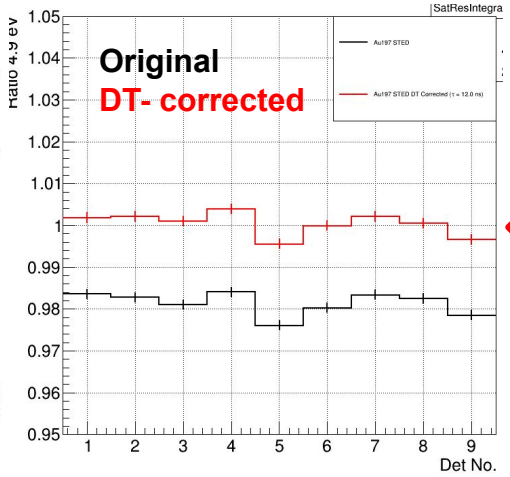
^{197}Au, 4.9 eV



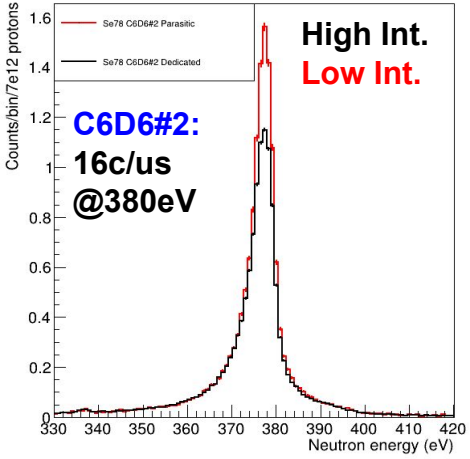
^{197}Au, 4.9 eV, DT- corrected



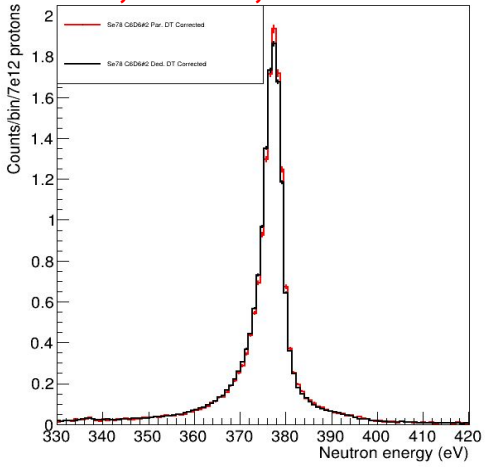
STED #1-9 Low/High Int. (3-7 eV)



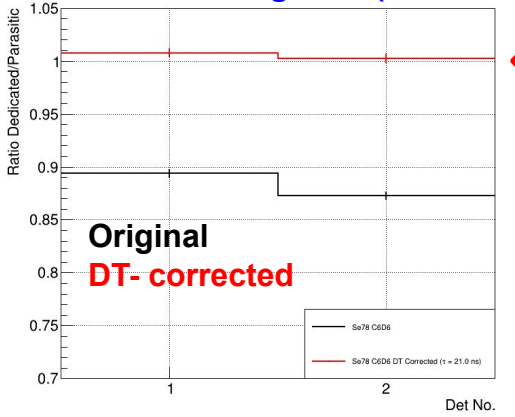
^{78}Se, 380 eV



^{78}Au, 380 eV, DT- corrected

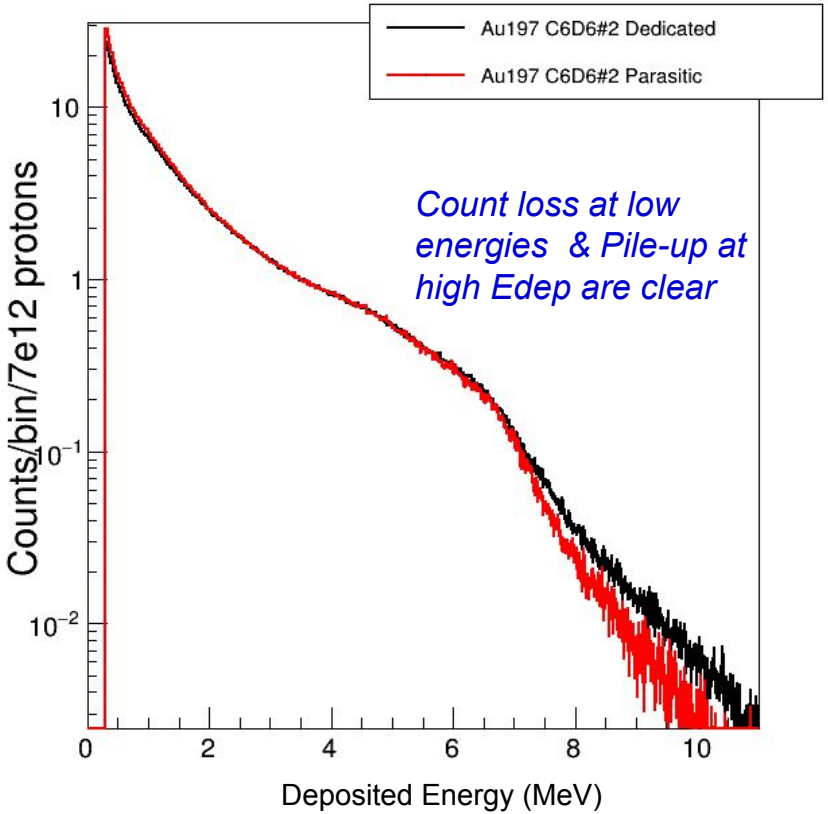


C6D6 #1-2 Low/High Int. (330-420 eV)



non-paralizable model: limitation

High C. rates of EAR2 → Large dead time corrections → DT correction seems to work consistently for dedicated and parasitic **BUT… also significant Pile-up → deposited energy spectrum changes**



Spectrum change may change the correction after the PHWT → Need to account for the change in the energy spectrum due to the pile-up for a proper DT correction of the weighted counts → **See J. Balibrea's (Nb-94) talk!!**

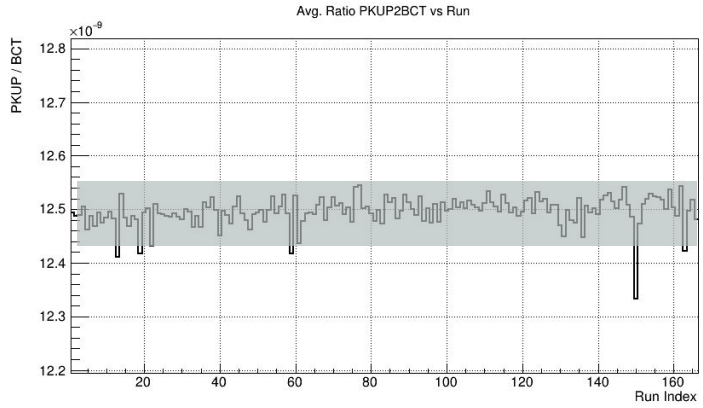
Se-79 @ EAR2: Analysis & challenges

Challenge	What is affected?	Work done so far
High C. rates of EAR2 (+ activity ^{79}Se sample)	Gain drifts detectors → → **PHWT (efficiency)**	Final run-by-run gain corrections
	Dead time in large ^{197}Au, ^{78}Se resonances → **Normalization**	Simple Dead time correction: dedicated & parasitic bunches
		Consistency of beam monitors & detectors
Sample: Irregular geometry, 2.8 g of Pb & difficult reproducibility	Complex **Normalization** & **Background subtraction**	Study & corrections for normalization of ^{79}Se vs ^{78}Se & ^{197}Au
		Scaling of the Pb-related background

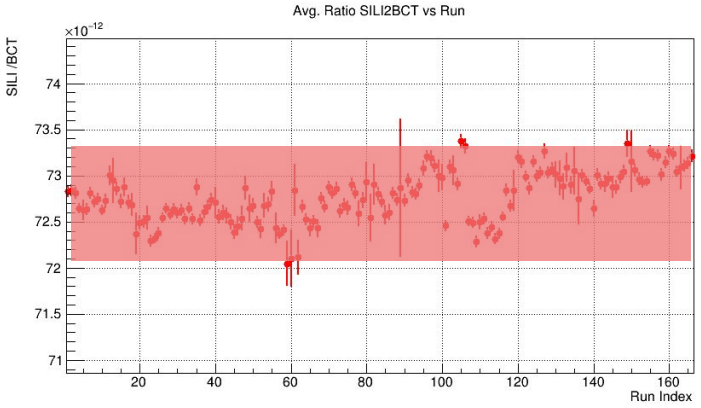
Beam-monitors per run: Full campaign

Full campaign

+-2.5%

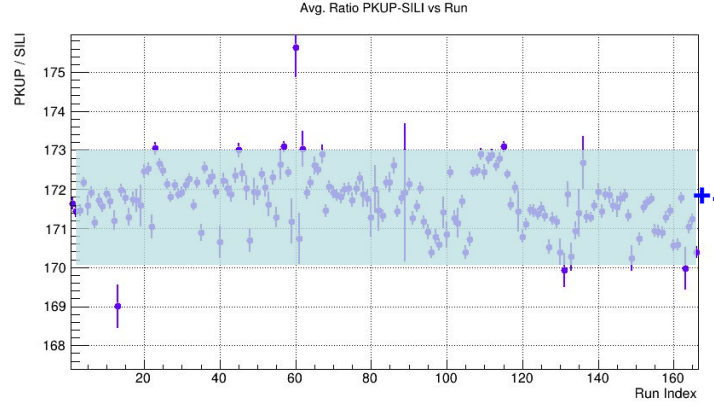


+-0.5%



+-0.8%

+-2.5%



+-0.8%

PKUP/BCT
SILI/BCT
PKUP/SILI

Overall good agreement. All within 1 %

Excluded a negligible (<2%) fraction of the statistics

Beam-monitors per bunch: Indiv. samples

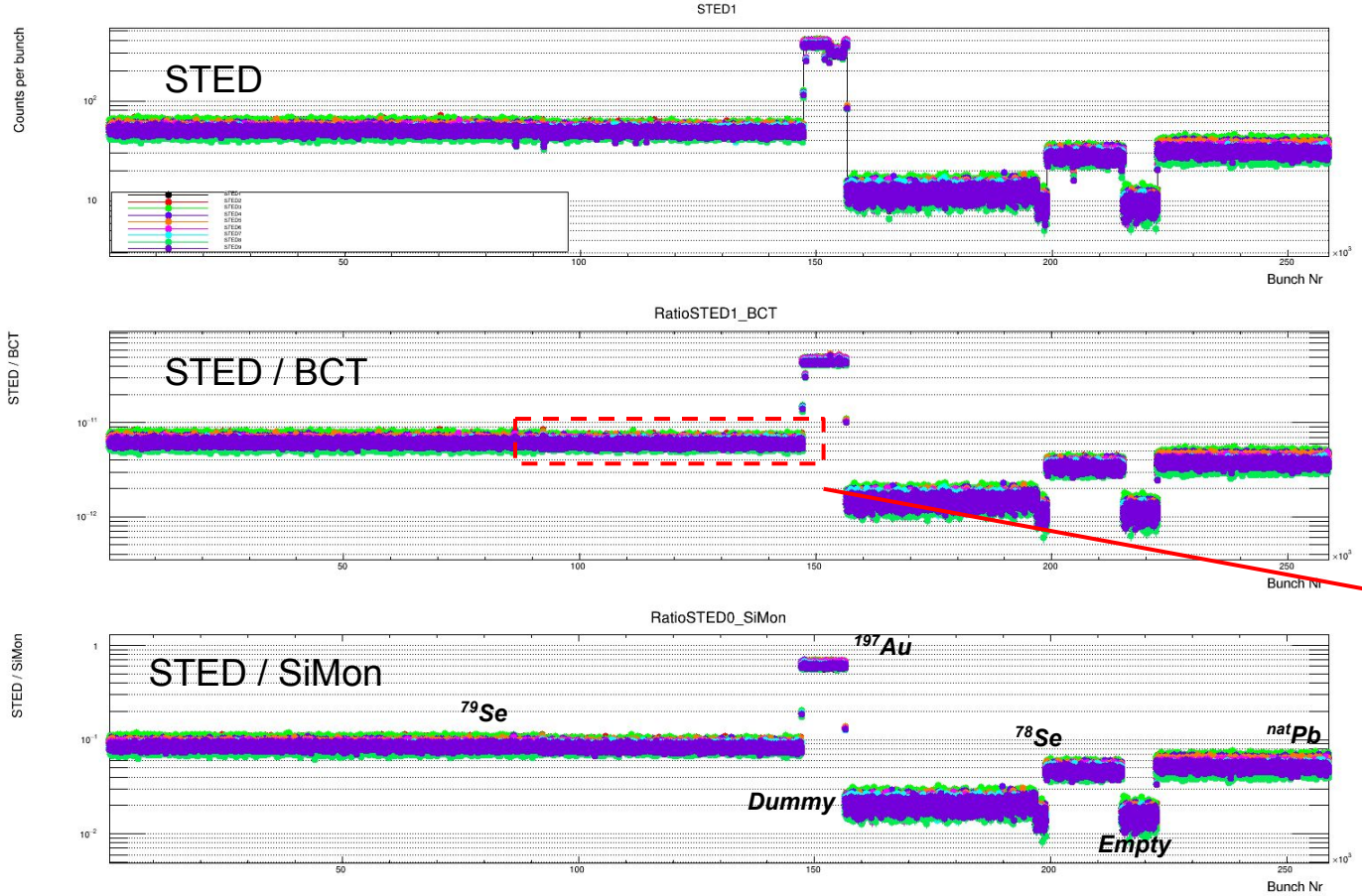
Data set	PKUP / BCT			SiMon / BCT			PKUP / SILI		
	Ratio to Avg	Rel. Unc Average Fit	Rel. Std. Dev Fit	Ratio to Avg	Rel. Unc Average Fit	Rel. Std. Dev Fit	Ratio to Avg	Rel. Unc Average Fit	Rel. Std. Dev Fit
Se-79 #1	0.999	0.001%	0.72%	0.998	0.013%	4.12%	1.002	0.025%	4.08%
Se-79 #2	1.000	0.001%	0.80%	1.001	0.017%	4.26%	1.000	0.032%	4.09%
Dummy #1	1.001	0.002%	0.72%	**0.996**	0.025%	4.43%	**1.005**	0.045%	4.12%
Dummy #2	1.000	0.003%	0.72%	1.002	0.034%	4.23%	**0.996**	0.064%	4.10%
Au #1	1.000	0.007%	0.65%	0.998	0.087%	4.07%	1.003	0.163%	4.06%
Au #2	1.001	0.008%	0.66%	1.003	0.110%	4.06%	0.995	0.204%	4.06%
Au #3	1.001	0.004%	0.67%	0.998	0.057%	5.13%	0.993	0.101%	4.36%
Se-78	0.999	0.002%	0.81%	1.001	0.421%	4.16%	0.996	0.178%	4.09%
Empty	1.000	0.004%	0.77%	1.000	0.048%	4.39%	0.997	0.089%	4.08%

PKUP / BCT → Fit to the ratio is in agreement with the average of the whole campaign <=0.1%
SiMon / BCT → Fit to the ratio is in agreement with the average of the whole campaign <=0.4%
SiMon / PKUP→ Fit to the ratio is in agreement with the average of the whole campaign <=0.5%

Conclusion: 0.5% assumed as a conservative uncertainty in the normalization to neutrons/protons for each sample

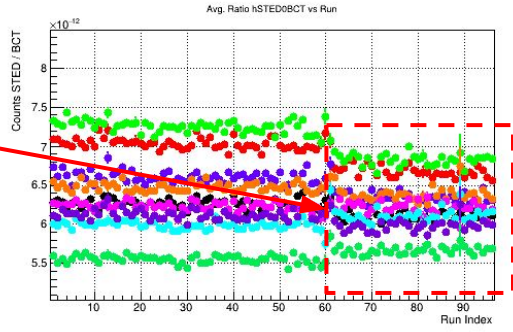
Consistency of beam-monitors and detectors

C. Rates (Edep >200 keV, En<100 keV) vs Bunch No



After normalization to BCT or SiMon:

- Detectors counting rates consistent
- Except the two sub-sets of ^{79}Se → **Discussed in the next point!**



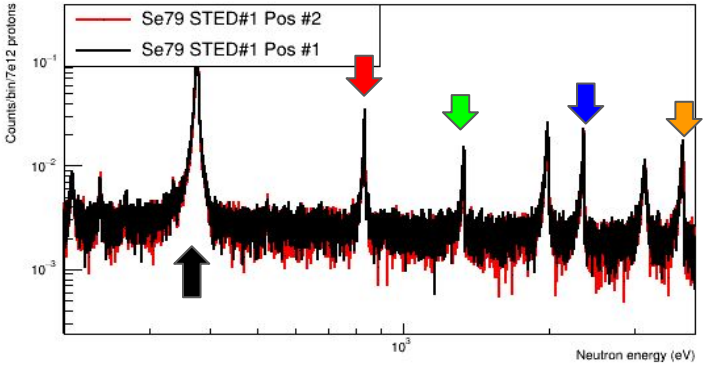
Se-79 @ EAR2: Analysis & challenges

Challenge	What is affected?	Work done so far
High C. rates of EAR2 (+ activity ^{79}Se sample)	Gain drifts detectors → → **PHWT (efficiency)**	Final run-by-run gain corrections
	Dead time in large ^{197}Au, ^{78}Se resonances → **Normalization**	Simple Dead time correction: dedicated & parasitic bunches
		Consistency of beam monitors & detectors
Sample: Irregular geometry, 2.8 g of Pb & difficult reproducibility	Complex **Normalization** & **Background subtraction**	**Study & corrections for normalization of ^{79}Se vs ^{78}Se & ^{197}Au**
		Scaling of the Pb-related background

Normalization of PbSe(^{79}Se) vs ^{197}Au and ^{78}Se

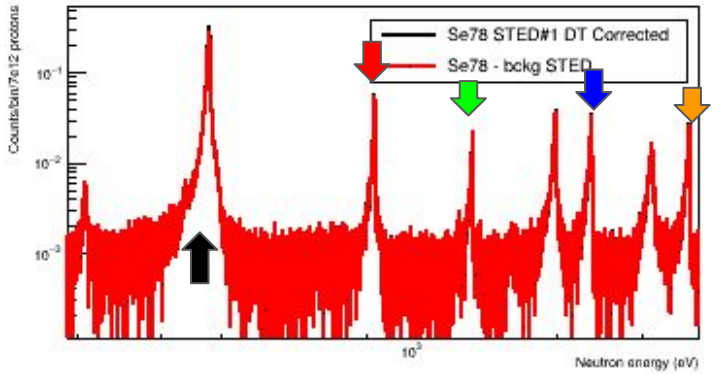
^{79}Se divided in two sub-sets : Check consistency with ^{78}Se & ^{197}Au (both used in the absolute normalization

^{79}Se sample: Part# 1 vs Part#2



Ratio of 5 ^{78}Se res. to:

^{78}Se disc: Same 5 resonances



^{197}Au: 4.9eV (SRM)

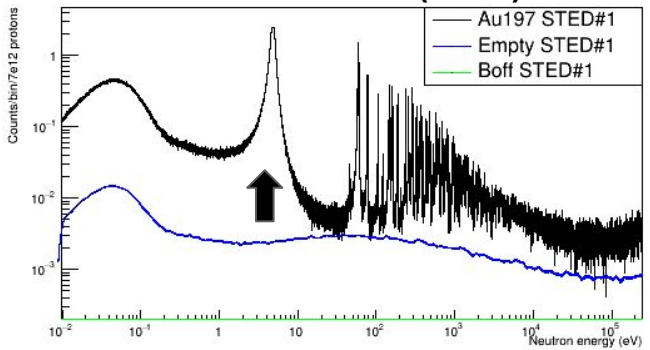
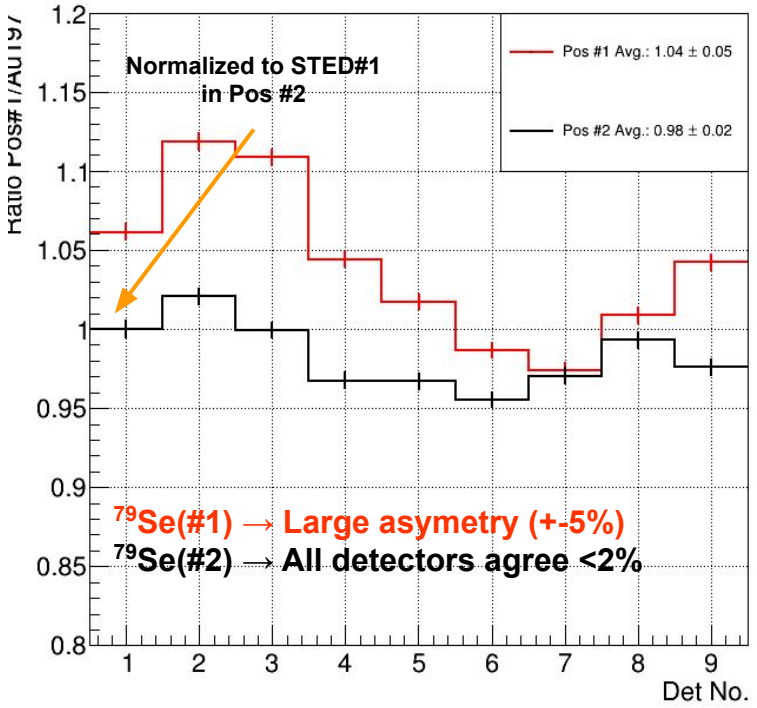


Figure-of-merit: Average Integral ratio of the 5 resonances / Reference sample

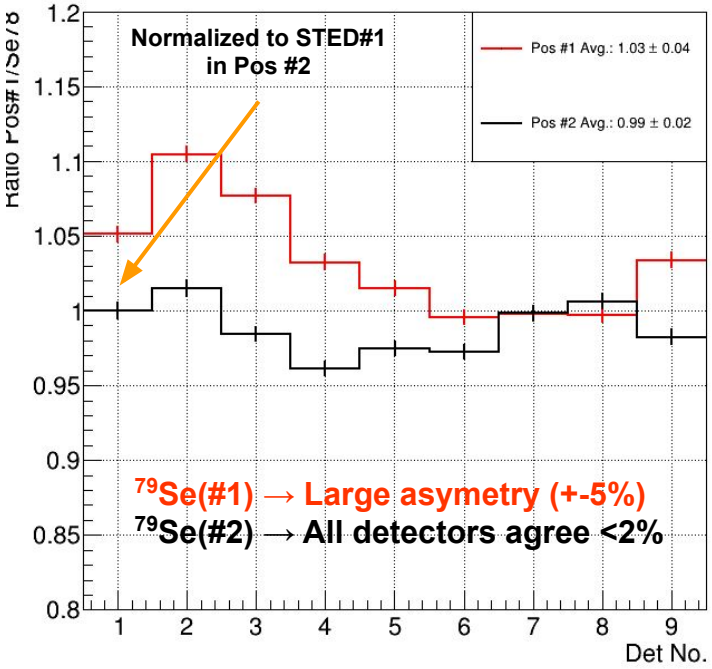
Normalization of PbSe(^{79}Se) vs ^{197}Au and ^{78}Se

^{79}Se divided in two blocks: Check consistency with ^{78}Se & ^{197}Au (both used in the absolute normalization)

^{78}Se (PbSe)/^{197}Au (4.9eV) for individual STEDs



^{78}Se (PbSe)/^{78}Se (disc) for individual STEDs

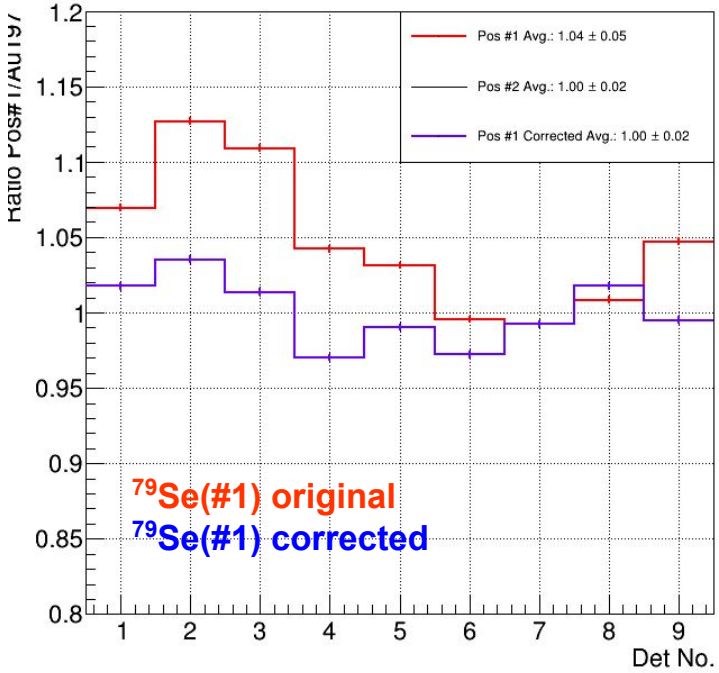


PROBLEM FOUND! →C. Rates **^{79}Se (#1)** not consistent to ^{78}Se and ^{197}Au samples (**asymmetry**) → **Conclusion**: sample was slightly shifted from the center → **Correction**: Scale each detector to **Pos #2**

Normalization of PbSe(^{79}Se) vs ^{197}Au and ^{78}Se

Consistency after the correction (scaling) of the data of ^{79}Se(part#1)

^{78}Se (PbSe)/^{197}Au (4.9 eV) for individual STED

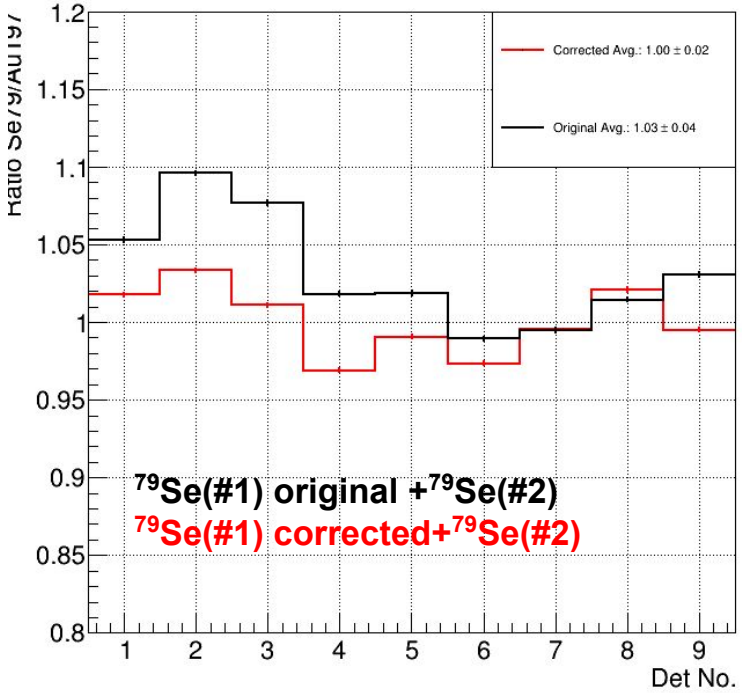


Impact of scaling of ^{79}Se (#1)

^{79}Se /^{197}Au →6% deviation

Corrected: ^{79}Se /^{197}Au →2% deviation

^{78}Se (PbSe)/^{197}Au (4.9 eV) for individual STED



After Correction → Whole campaign:

^{79}Se /^{197}Au STEDs within <2%

Se-79 @ EAR2: Analysis & challenges

Challenge	What is affected?	Work done so far
High C. rates of EAR2 (+ activity ^{79}Se sample)	Gain drifts detectors → → **PHWT (efficiency)**	Final run-by-run gain corrections
	Dead time in large ^{197}Au, ^{78}Se resonances → **Normalization**	Simple Dead time correction: dedicated & parasitic bunches
Sample: Irregular geometry, 2.8 g of Pb & difficult reproducibility	Complex **Normalization** & **Background subtraction**	Consistency of beam monitors & detectors
		Study & corrections for normalization of ^{79}Se vs ^{78}Se & ^{197}Au
		Scaling of the Pb-related background

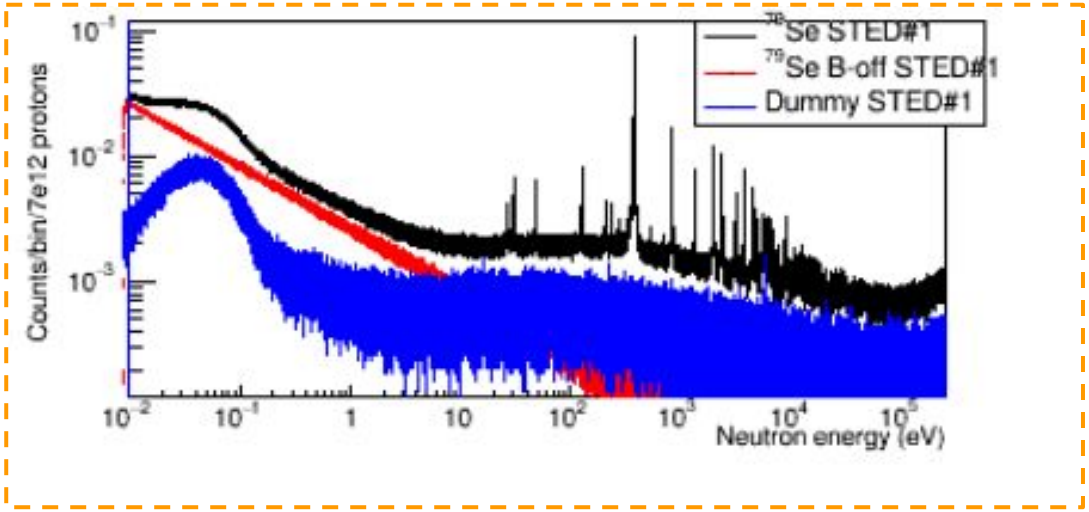
Background subtraction in a “nutshell”

Main Sample:
Se-78 + **Se-79**
+ Pb + Al casing

Direct assessment

^{79}Se Beam-off:
Room + sample activity

Dummy (Al Casing):
Beam-related background
setup + casing



Background subtraction in a “nutshell”

Main Sample:
Se-78 + **Se-79**
+ Pb + Al casing

Direct assessment

^{79}Se Beam-off:
Room + sample activity

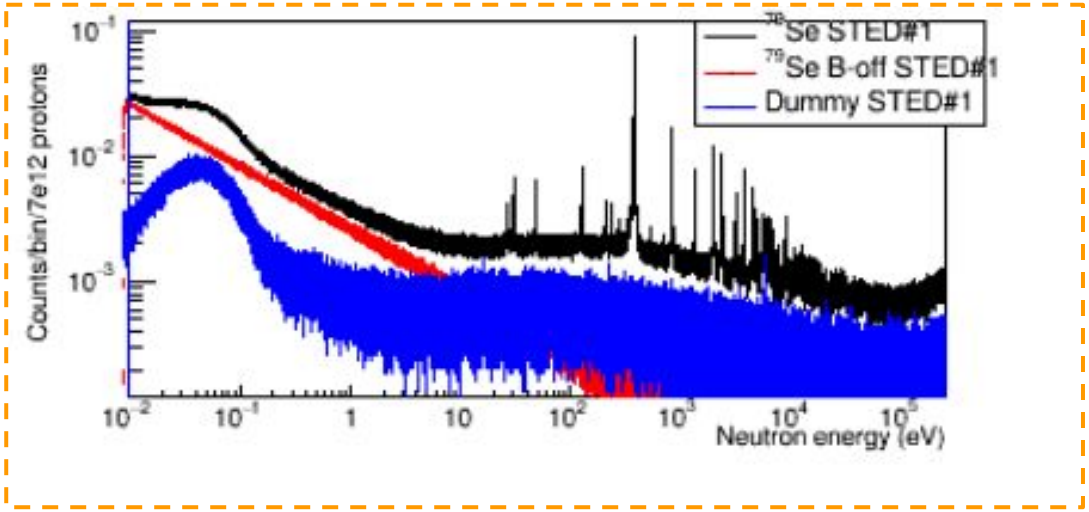
Dummy (Al Casing):
Beam-related background
setup + casing

Indirect assessment:

Neutron and g-ray scattering: dominated by Pb in the sample (2.8 g)

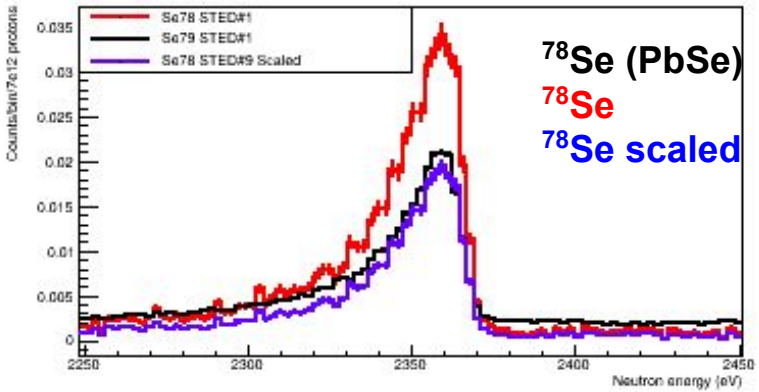
Pb Background shape:
Pb disc 20 mm →
Scaled to PbSe Sample.

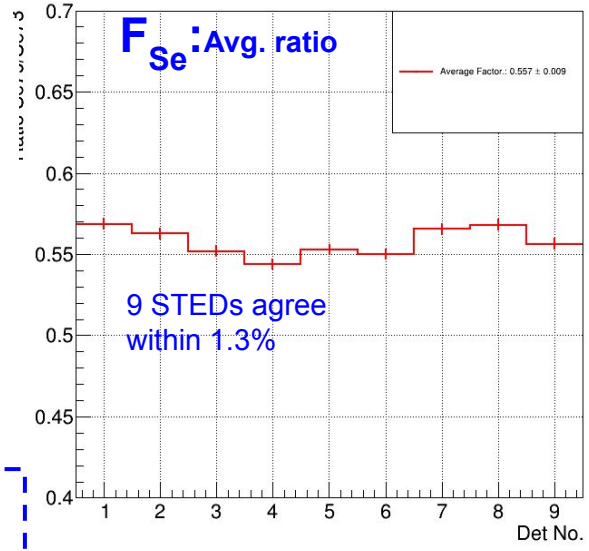
Scaling factor:
^{78}Se disc 20 mm



Determination & scaling of the Pb background

1) $Pb^{79}Se$ sample → $n_{Se78} = n_{Pb}$
2) BIF Pb sample (20 mm) = BIF ^{78}Se sample (20 mm)
3) **F_{Se}: Scaling ^{78}Se disc → ^{78}Se ($Pb^{79}Se$)**
4) F_{Pb}: Scaling Pb disc → Background ($Pb^{79}Se$) → $F_{Pb} = F_{Se} \times n_{Se} / n_{Pb}$



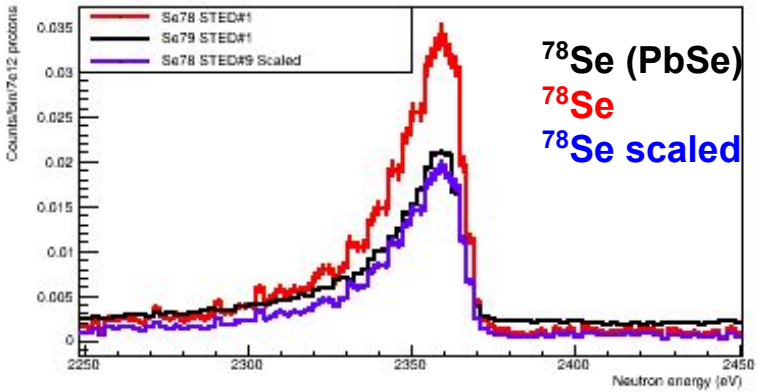


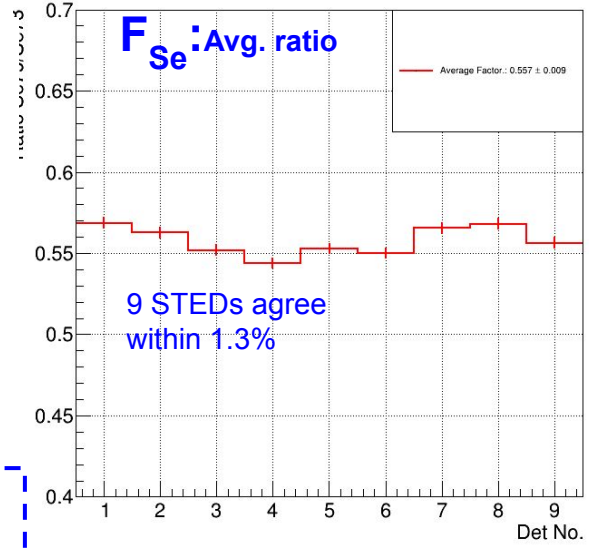
Ratio for 4 resonances (**excluded the largest**)

Obtained for each STED and C6D6 individually and calculated the average

Determination & scaling of the Pb background

1) $Pb^{79}Se$ sample → $n_{Se78} = n_{Pb}$
2) BIF Pb sample (20 mm) = BIF ^{78} disc sample (20 mm)
3) F_{Se}: Scaling ^{78}Se disc → ^{78}Se ($Pb^{79}Se$)
4) **F_{Pb}: Scaling Pb disc → Background ($Pb^{79}Se$)** → $F_{Pb} = F_{Se} \times n_{Se} / n_{Pb}$





ISOTOPE	Mass (g)	at/b
Se-78	1.989	4.844E-03
Lead	7.281	6.697E-03
	Ratio nSe / nPb	0.72340

$n_{Se} / n_{Pb} = 0.723$

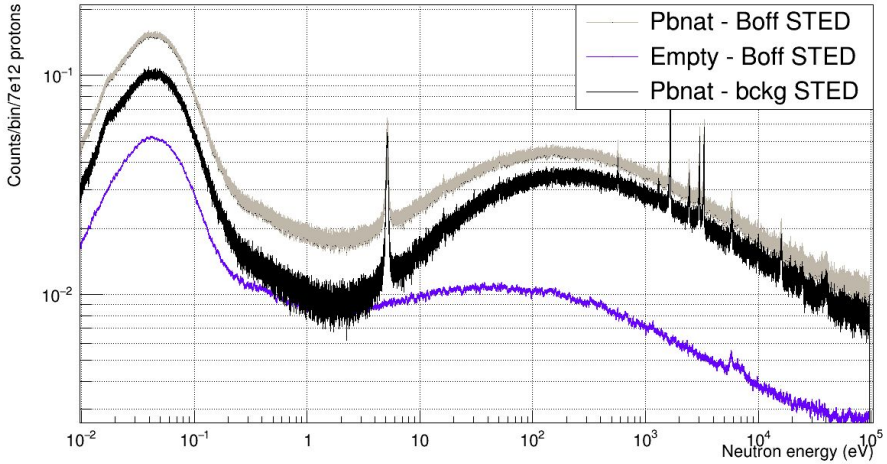
Ratio for 4 resonances (**excluded the largest**)

Obtained for each STED and C6D6 individually and calculated the average

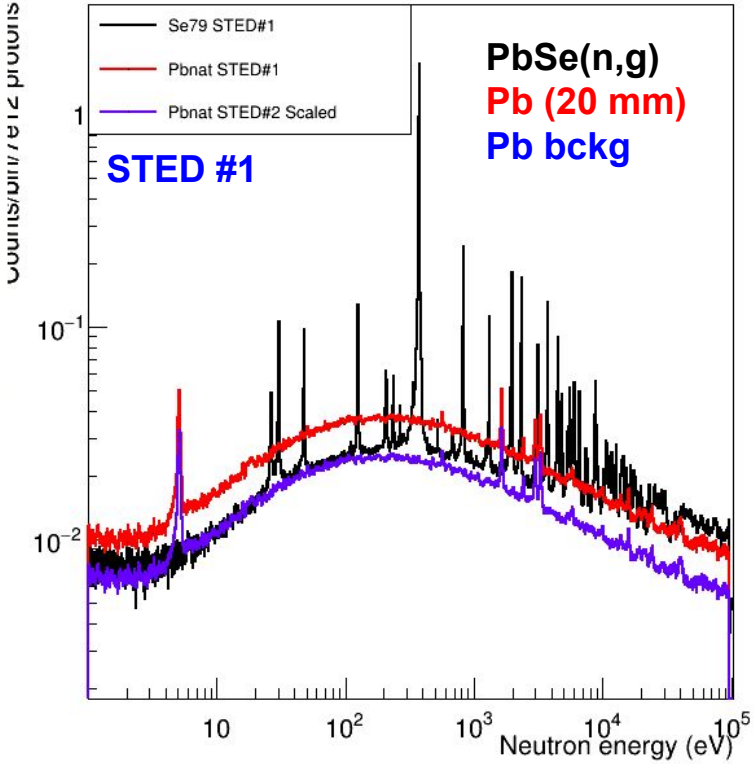
	FSe	unc_FSe	FPb	unc_FPb	Rel Unc.
Dedicated	0.557	0.008	0.403	0.006	1.4%
Parasitic	0.555	0.007	0.401	0.005	1.3%

Determination & scaling of the Pb background

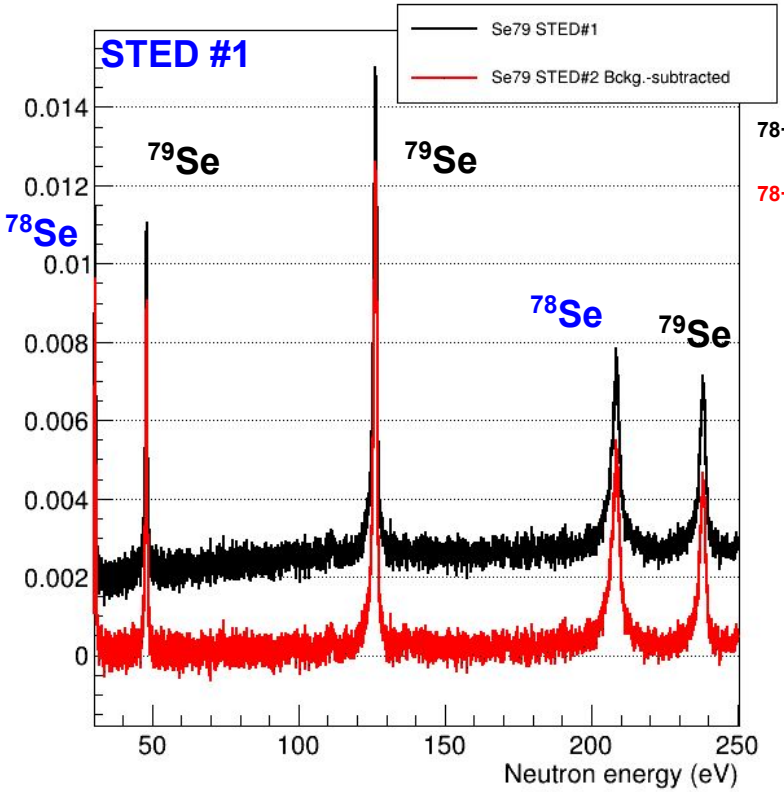
Shape of the Pb background:
Measurement of the Pb disc



1) Subtract boff → **Pb-Boff**
2) Subtract **empty** → **Pb - bckg**
3) Scale Pb by F_{Pb}

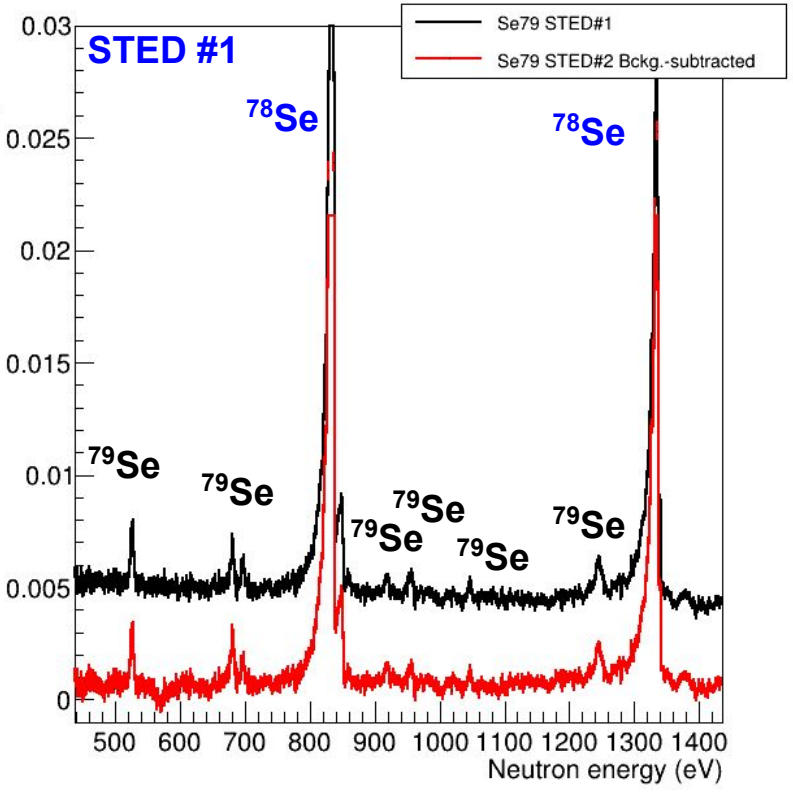


Final background subtraction: RRR



78+79Se(n,g) + Pb

78+79Se(n,g)



After Pb-background subtracted:

Residual background in the RRR of ^{79}Se Successfully subtracted

^{79}Se @ EAR2: Status & Outlook

- Energy calibrations
- Final run-by run gain corrections
- ToF correction for SPD2886
- STED & C6D6: Direct background assessed and subtracted
- C. Rate consistency & uncertainty related to neutron/proton beam monitors
- Corrections in the normalization to ^{197}Au & ^{78}Se → Absolute normalization (SRM)
- Background subtraction: Scaling of the Pb background to PbSe

s-TED & L-C6D6 @ EAR2

- Dead-time study, corrections & validation w/ low/high intensity bunches (**+ work need after PHWT**)

MC simulations: PHWT (STED, C6D6) + Cascade simulations (Milan/Standa?): Corrections and uncertainty

Analysis of LaCl3: spectroscopic information of the Cascades?

Calculation of the yield: Evaluated Flux needed

R-Matrix analysis of ^{78}Se + ^{79}Se → Effective geometry in SAMMY?

European Research Council
MINISTERIO DE CIENCIA E INNOVACIÓN
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
AGENCIA ESTATAL DE INVESTIGACIÓN

THANK YOU FOR YOUR ATTENTION!

nTOF

n_TOF Collaboration Meeting, Edinburgh, 13-14 Dec 2022

IFIC INSTITUT DE FÍSICA CORPUSCULAR
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS