

Single events analysis in BULLKID

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Many thanks to D'Addabbo, Castello and others
Collaboration Meeting at Grenoble, Jan. 16th, 2026



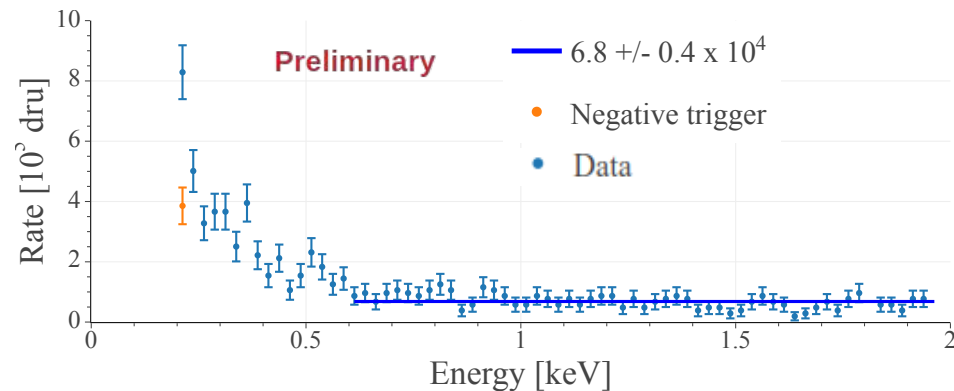
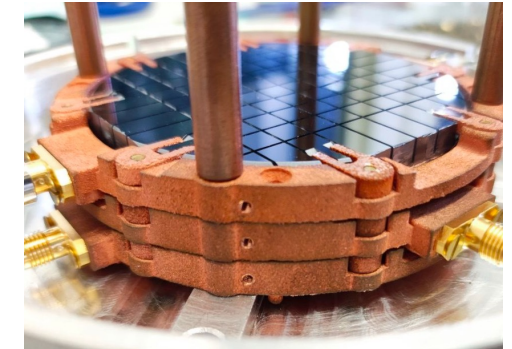
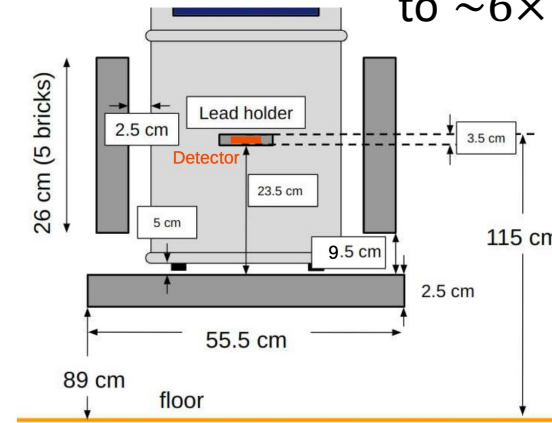
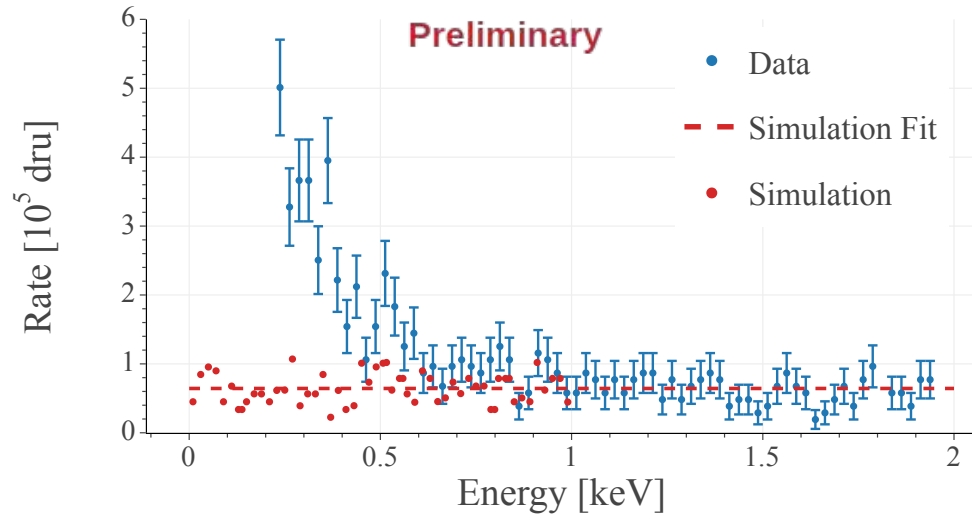
Low Energy Excess (LEE) problem

BKG reduced

 from $\sim 2 \times 10^6$ dru

 to $\sim 6 \times 10^4$ dru

Aboveground measurement with mild shield



- Excess up to a factor ~ 5 has been observed in energy < 600 eV
- Preserved with diff working conditions
- Has the basic symptoms of the LEE
 - Does not decay with time
- Not compatible with negative triggers
- Question: Shared or Singles?

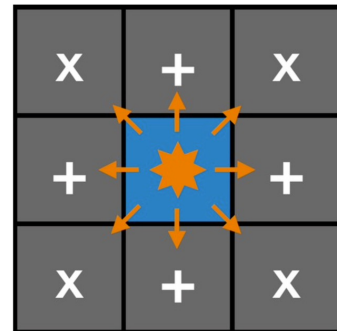
Singles in BULLKID

At higher energies:

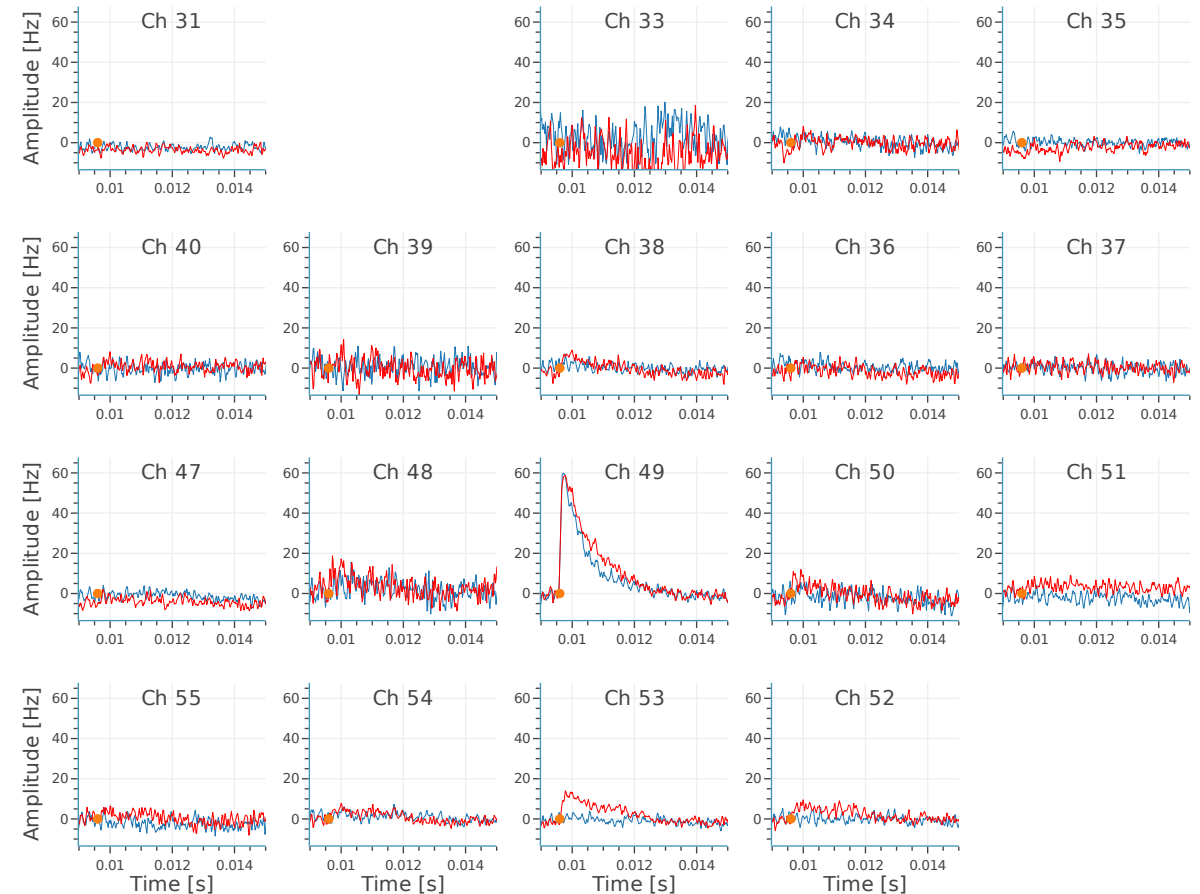
- Singles visible at $\sim 2\text{keV}$ and above
- Could be direct KID hits due to high metalized area (Al absorbs well 100 eV photons)
- Could it be that the excess is due to Singles (under investigation)?

Phonon leakage

- 50% of the phonons in central die hits
- $\sim 10\%$ in each “+” die
- $\sim 5\%$ in each “x” die
- the rest in outer dice



LED Background Preliminary



Datataking

- BULLKID architecture cannot distinguish Shared/Singles at threshold (small phonon leakage)
- Look for single events with high-energy, investigate the pulse shape difference

		1	2	3	4	5	
13	12	11	10	8	7	9	6
14	15		16	17	18		19
27	26	25	24	23	22	21	20
29	28	30	31	32	33	34	35
43	42	41	40	39	38	36	37
44	45	46	47	48	49	50	51
	57	56	55	54	53	52	

Indexes: Frequency ordering
 Triggering
 Acquired in coincidence as veto

- 15 KIDs (2 triggering + 13 as veto)
- Run time: 19 Apr 22:00 → 5 May 8:00, 2025
- Live time per cluster: 290 hours
- Events **variable** for veto selection:

$$\psi_n = \frac{A_n - A \cdot r_n}{\sqrt{\sigma_{0,n}^2 + r_n^2 \cdot \sigma_0^2}}$$

$$r_n = \left\langle \frac{A_n}{A} \right\rangle \quad \text{estimated by shining pulses of LED light on the central die}$$

- Low ψ_n expected for Singles

DataFrame

After preliminary analysis cut

- Main dice:

Run	831694
Event	1.395e+03
Channel	47
IsSignal	1.000e+00
IsSelfTrigger	1.000e+00
IsReversed	0.000e+00
IsNoise	0.000e+00
CPOF_Amplitude[mrad]	4.730e+00
CPOF_Chi2	6.875e+01
CPOF_ChiLeft	1.864e+00
CPOF_ChiRight	4.880e+00
CPOF_Jitter	-1.773e-03
CPNumberOfPulses	2.000e+00
CPBaselineSlope[RMS/Window]	-4.944e+00
CPMaxMinInWindow[RMS]	1.796e+02
CPBaseline[RMS]	8.430e+02
CPDecayTime[ms]	2.000e+05
CPRiseTime[ms]	-1.607e-01
CPMaxBaseline[mrad]	-2.129e+00
CPBaseline[mrad]	1.860e+02
CMBaseline[mrad]	-9.989e+02
Time[s]	6.053e+01
CPRightLeftBaselineInRMS	1.832e+00
CPMaxPosInWindow	1.190e+03
StartTime[s]	1.745e+09
Type	IsSignal
UnixTime[s]	1.745e+09
lin_CPOF_Amplitude[mrad]	4.736e+00
lin_CPOF_Amplitude[keV]	3.960e-01

For 13 neighbors + ch 47:

T0_Veto	-8.299e-01
P0_CPCA_Amplitude[mrad]	-9.078e-02
P0_Channel	4.900e+01
P0_leakage	-4.130e+01
psip0_Veto	-4.225e+00

41	40	39	38	36
46	47	48	49	50
56	55	54	53	52

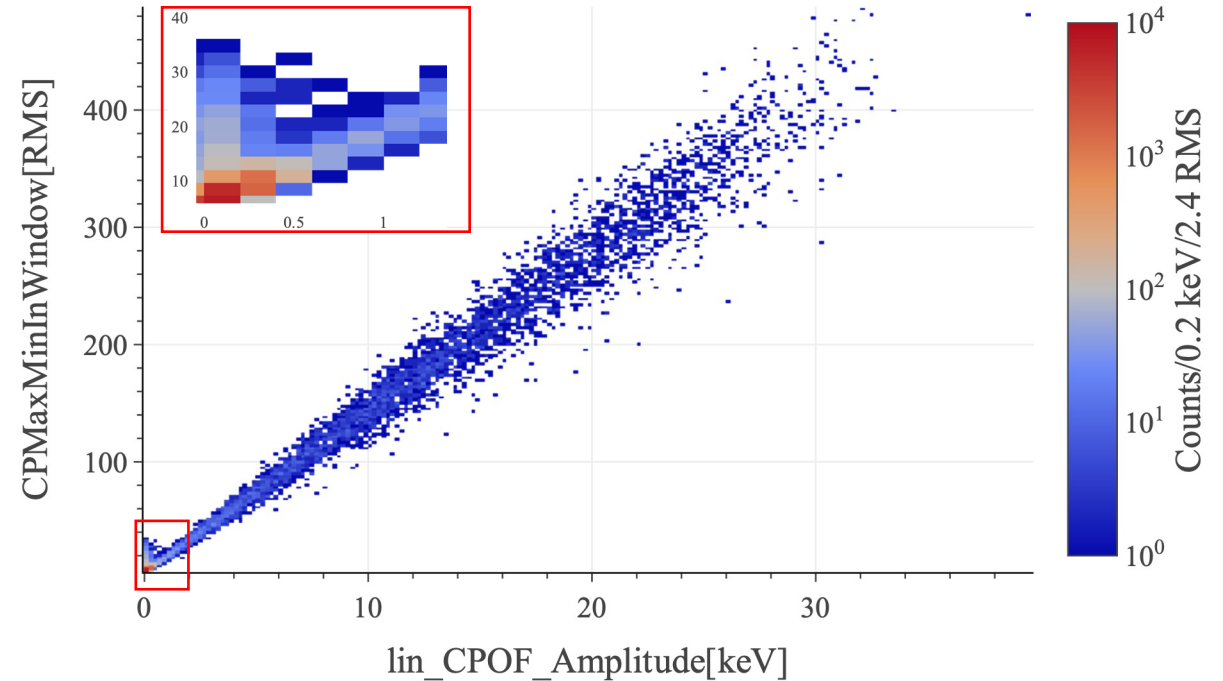
$$29 + 14 * 5 = 99$$

Basic cut

- Remove events with abnormal pulse shape

```
def CleanCut_HE(df, ch):  
    return ((df['IsSignal']==1)  
            & CH(df, ch)  
            & (df['CPBaseline[mrad]']>CP_bllow[ch])  
            & (df['CPBaseline[mrad]']<CP_bllup[ch])  
            & (df['CPBaseline[RMS]']<1000)  
            & (np.abs(df["CPBaselineSlope[RMS/Window]"]) < 25)  
            & (np.abs(df['CPRightLeftBaselineInRMS'])<5)  
            & (df['CPOF_Chi2']<2.5)  
            & (df['CPOF_ChiRight']<15)  
            & (df['CPOF_ChiRight']>-15)  
            & (df['CPOF_ChiLeft']<4)  
            & (df['CPOF_ChiLeft']>-4)  
            & (df['CPRiseTime[ms]']<0.15)  
            & (df['CPRiseTime[ms]']>0.04)  
            & (df['CPDecayTime[ms]']<2.9)  
            & (df['CPDecayTime[ms]']>0.8)  
            & (df['Time[s]']>60)  
            & (~df['Run'].isin(skip))  
            )  
    CP_bllup['47'] = 210  
    CP_bllup['49'] = 145  
    CP_bllow['47'] = 180  
    CP_bllow['49'] = 110
```

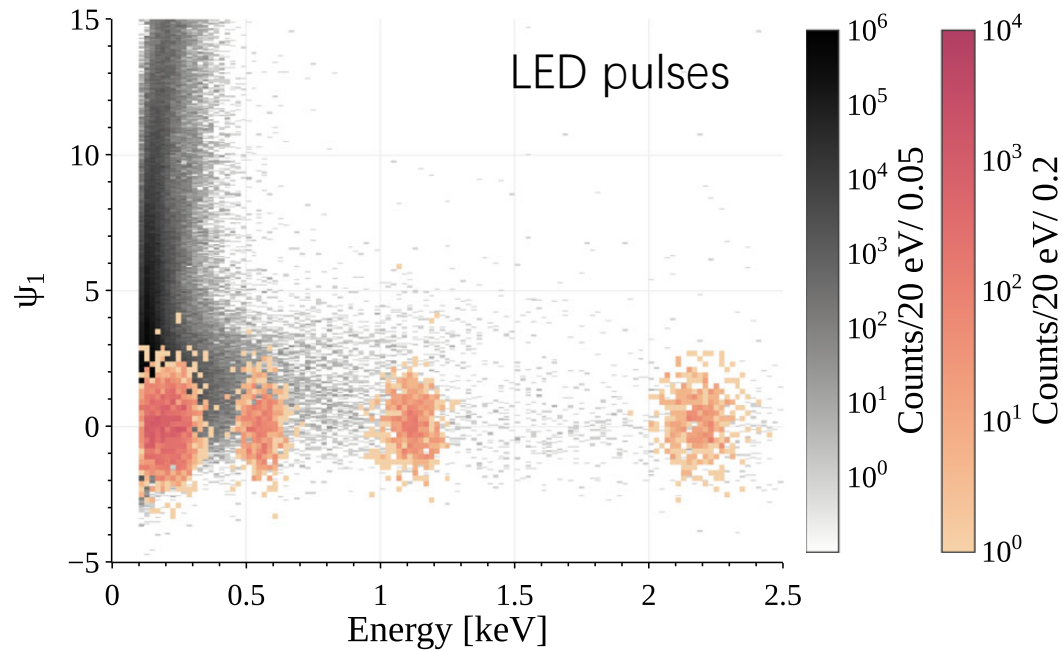
Cuts applied



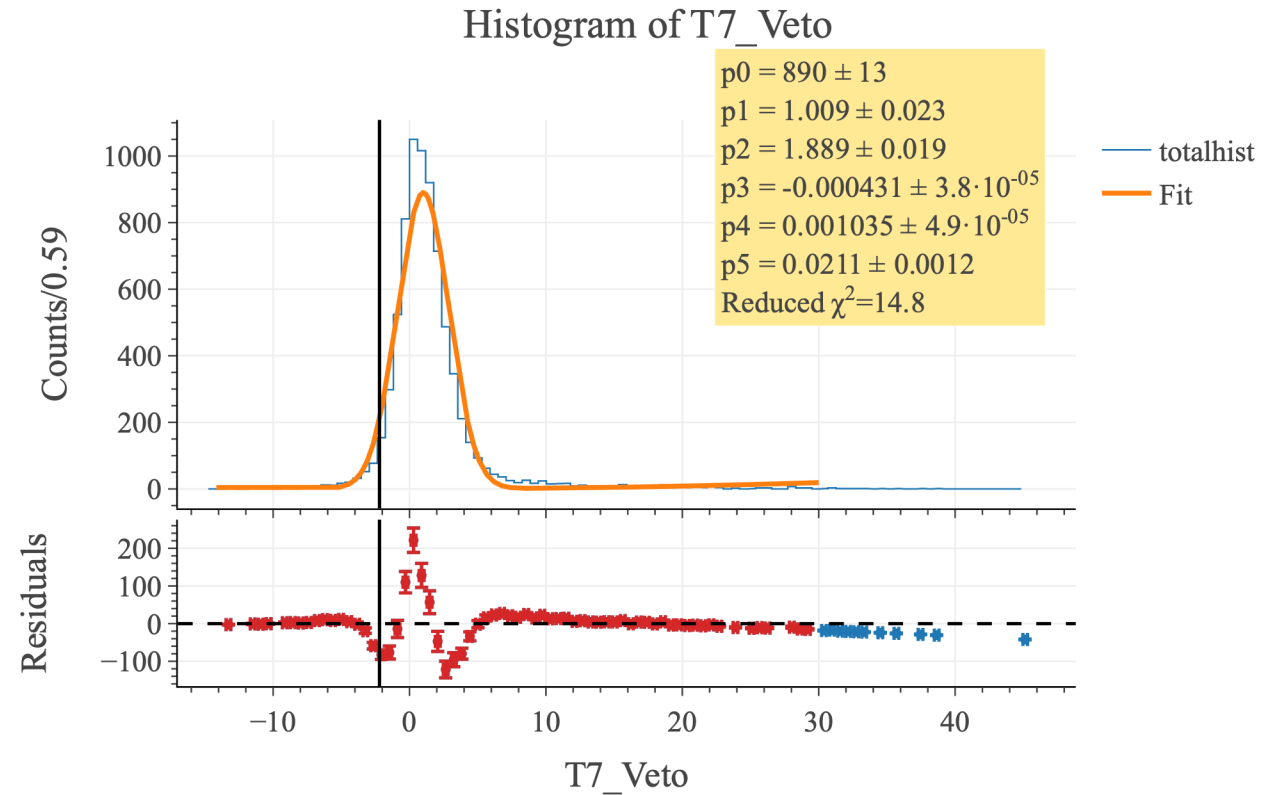
Veto cut

- Selection based on ψ_n , low ψ_n expected for Singles
- Roughly fitting to Gaussian + linear Model
- Set reasonable cut ranges for all neighbors

$$\psi_n = \frac{A_n - A \cdot r_n}{\sqrt{\sigma_{0,n}^2 + r_n^2 \cdot \sigma_0^2}}$$



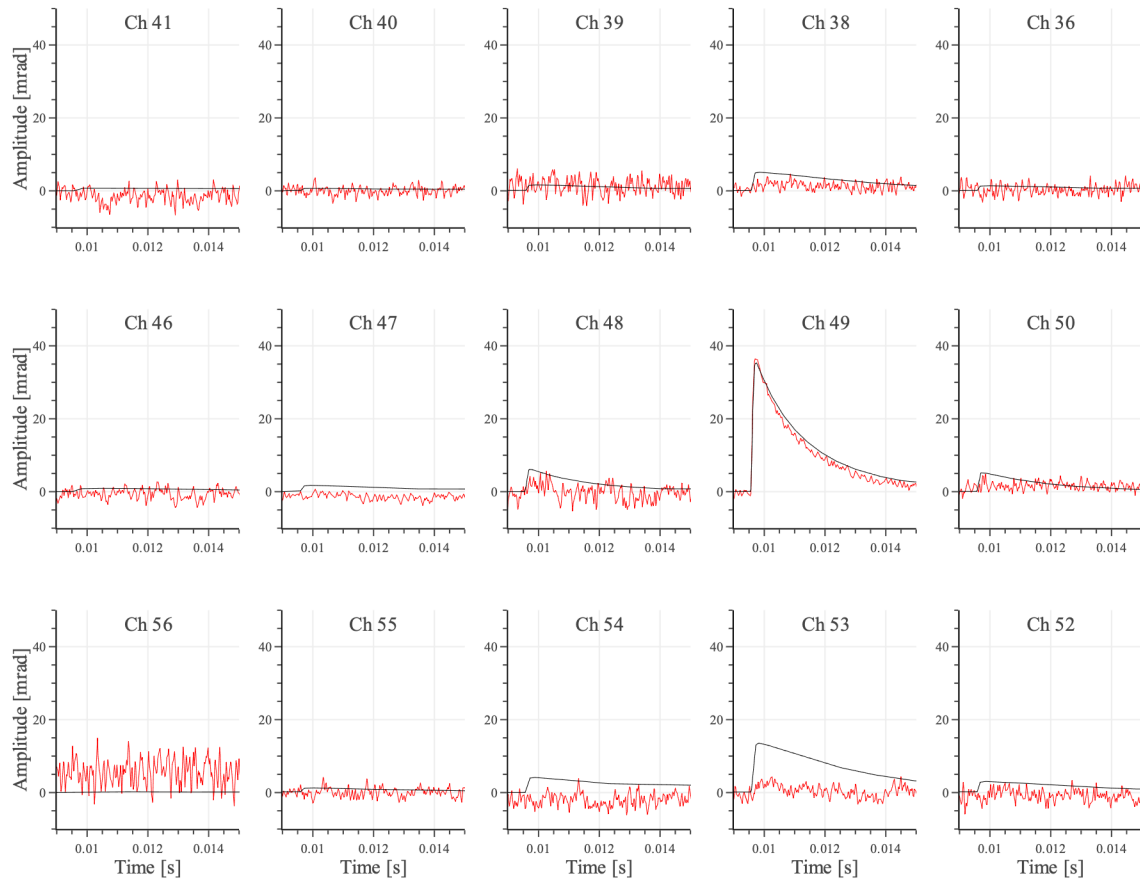
D. Delicato *et al*, Eur. Phys. J. C (2024) 84 :353



Single event found

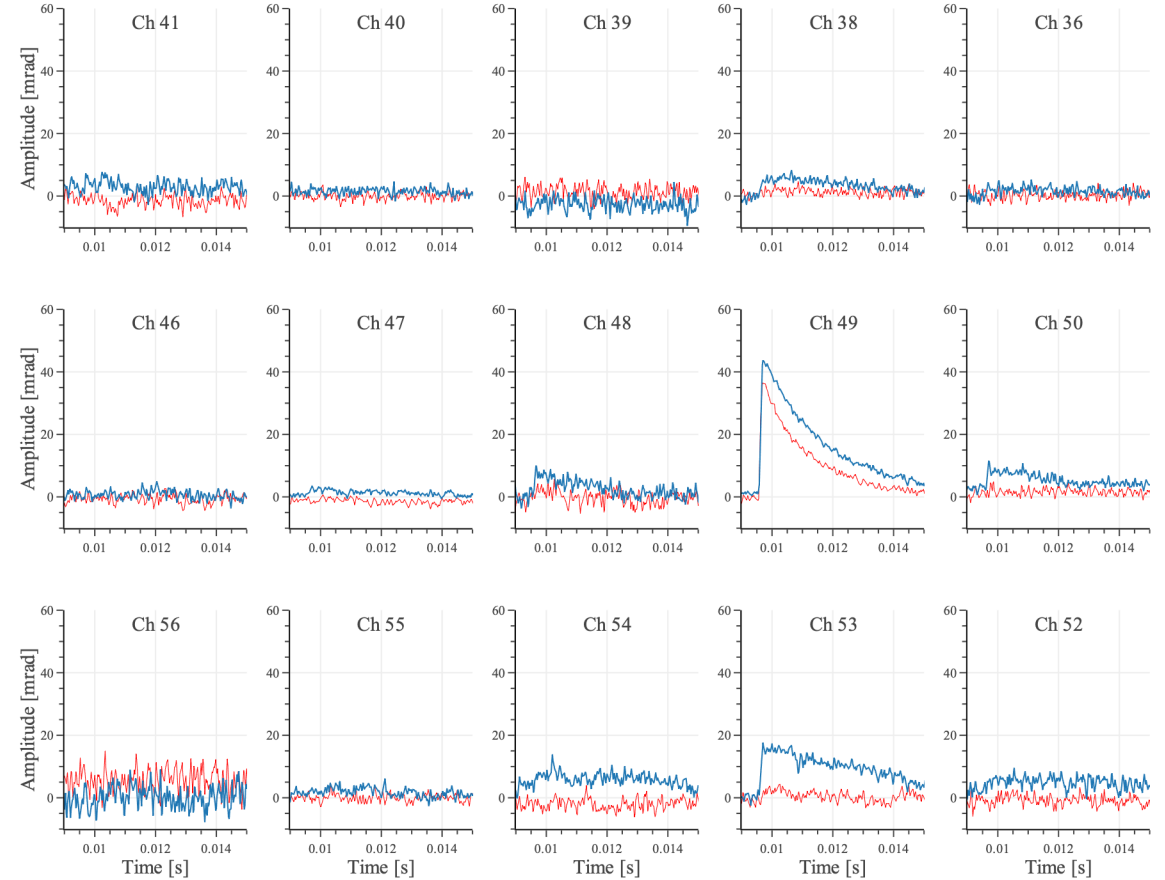
Compare with APs

Run = 831938 EventNumber = 4261 Energy=3.9 keV Ch49



Compare with one Shared

Run = 831938 EventNumber = 4261 Energy=3.9 keV Ch49

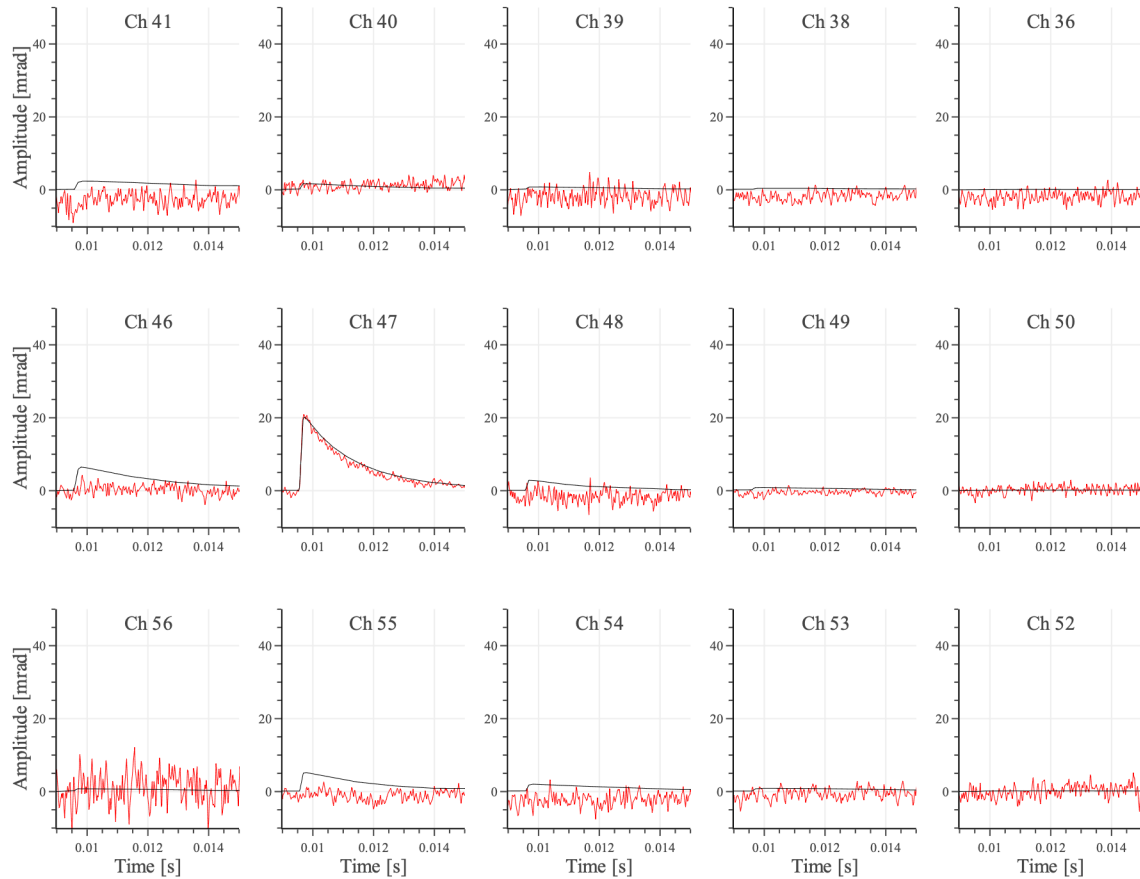


Difference on the raw amplitude height for same energy events

Single event found

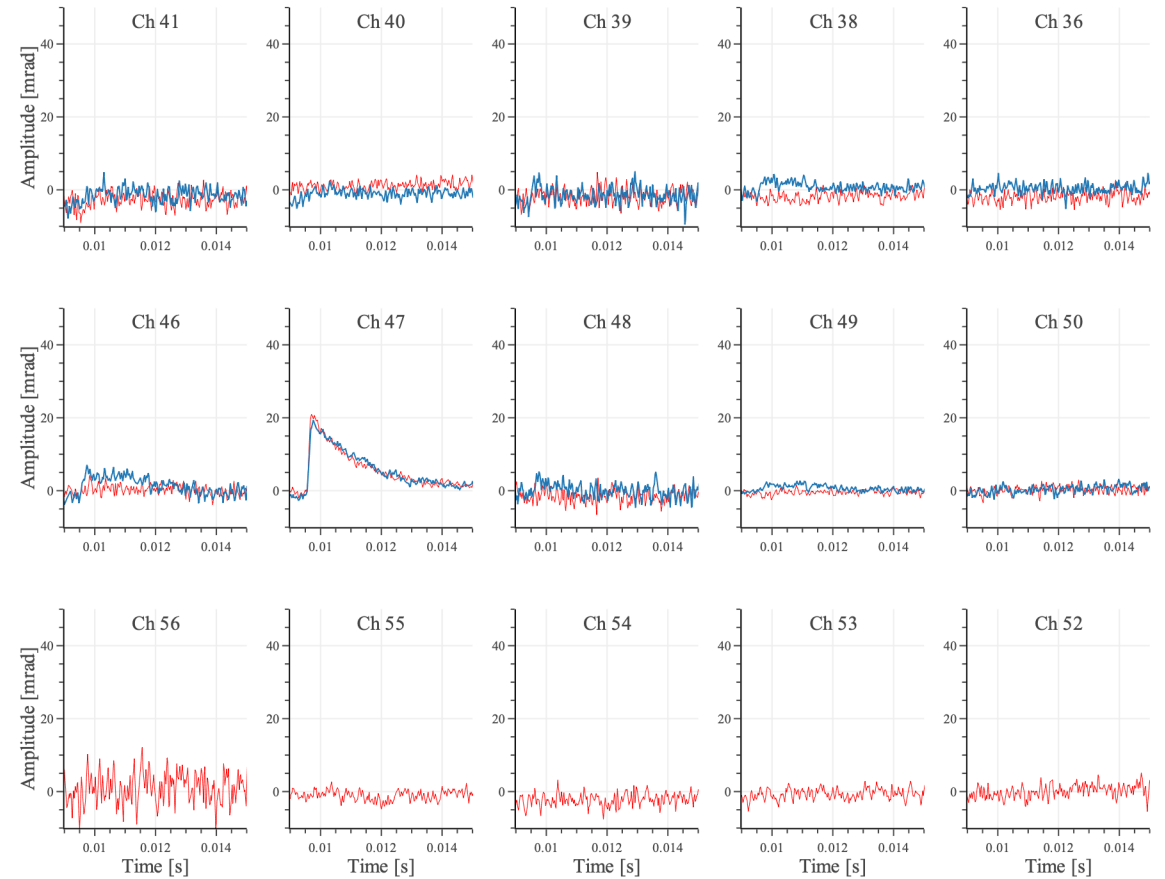
Compare with APs

Run = 831708 EventNumber = 31588 Energy=1.7 keV Ch47



Compare with one Shared

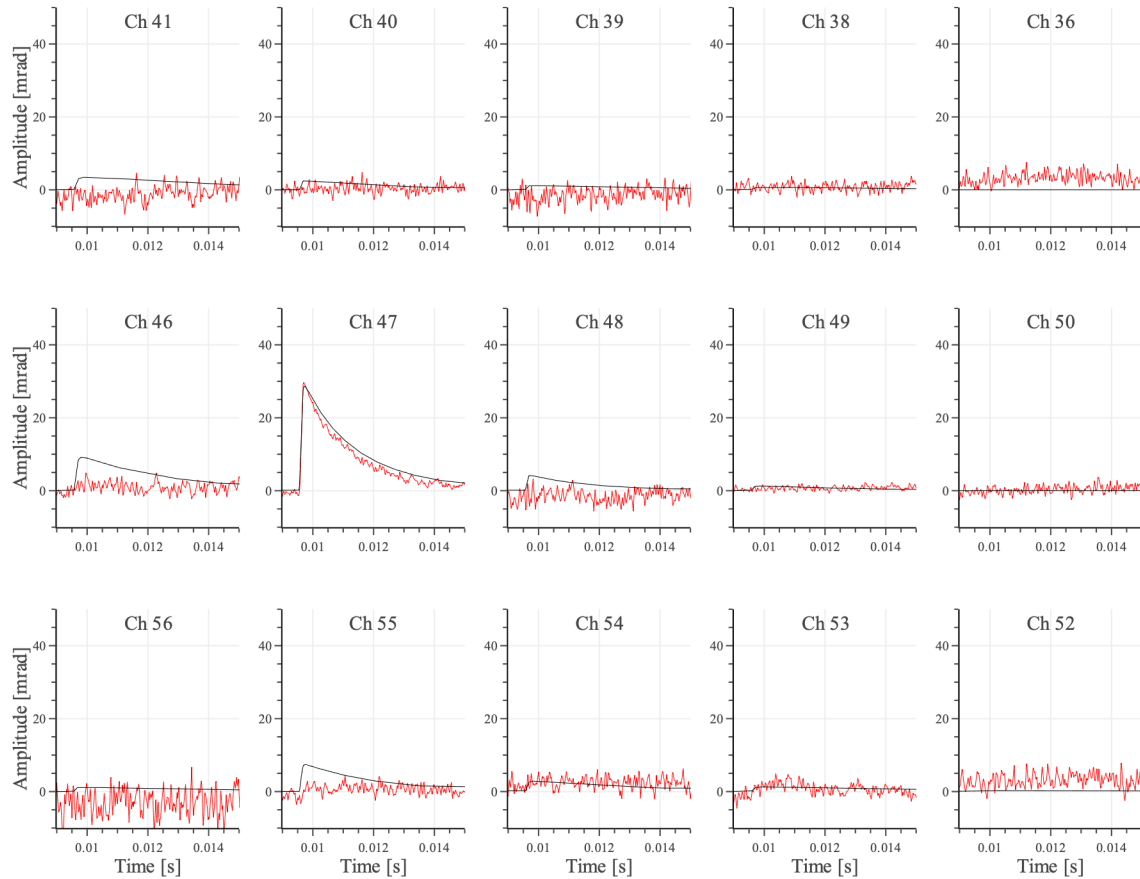
Run = 831708 EventNumber = 31588 Energy=1.7 keV Ch47



Single event found

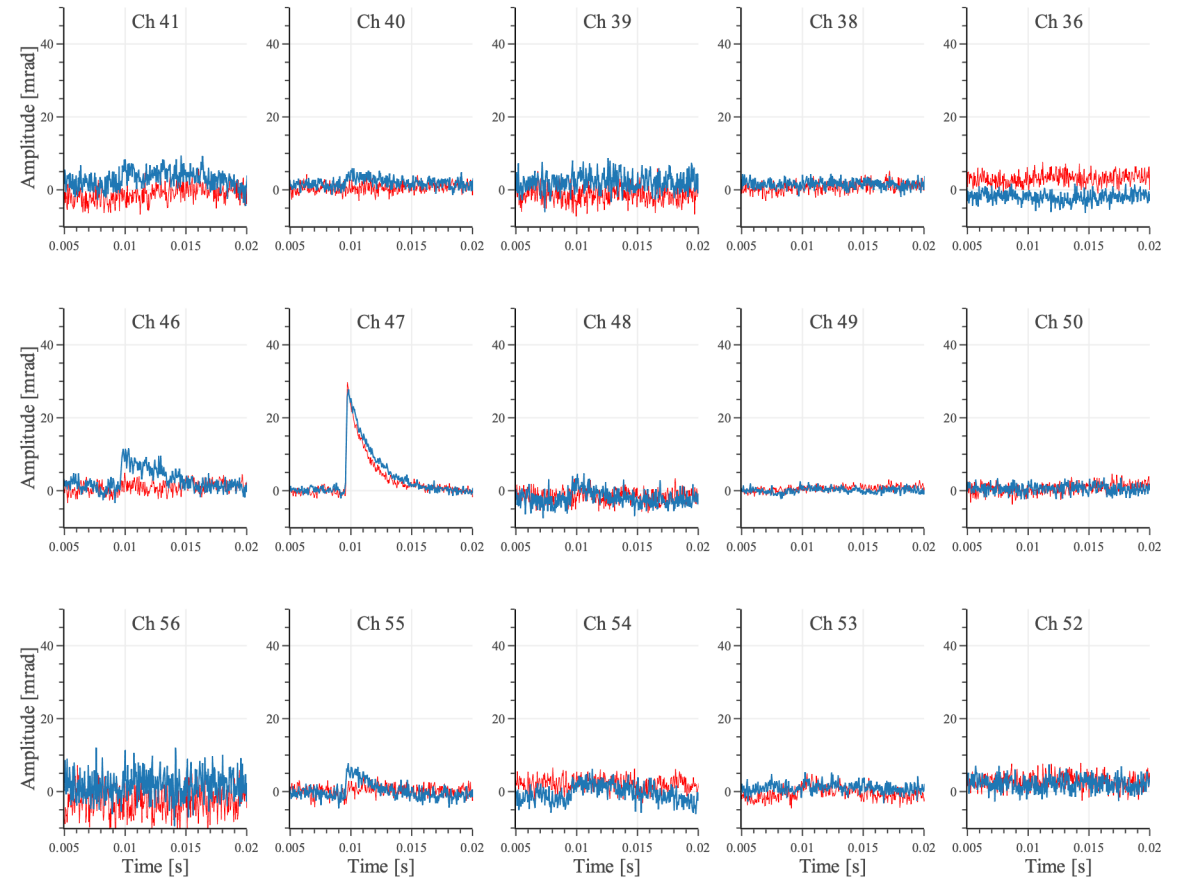
Compare with APs

Run = 832358 EventNumber = 23366 Energy=2.4 keV Ch47



Compare with one Shared

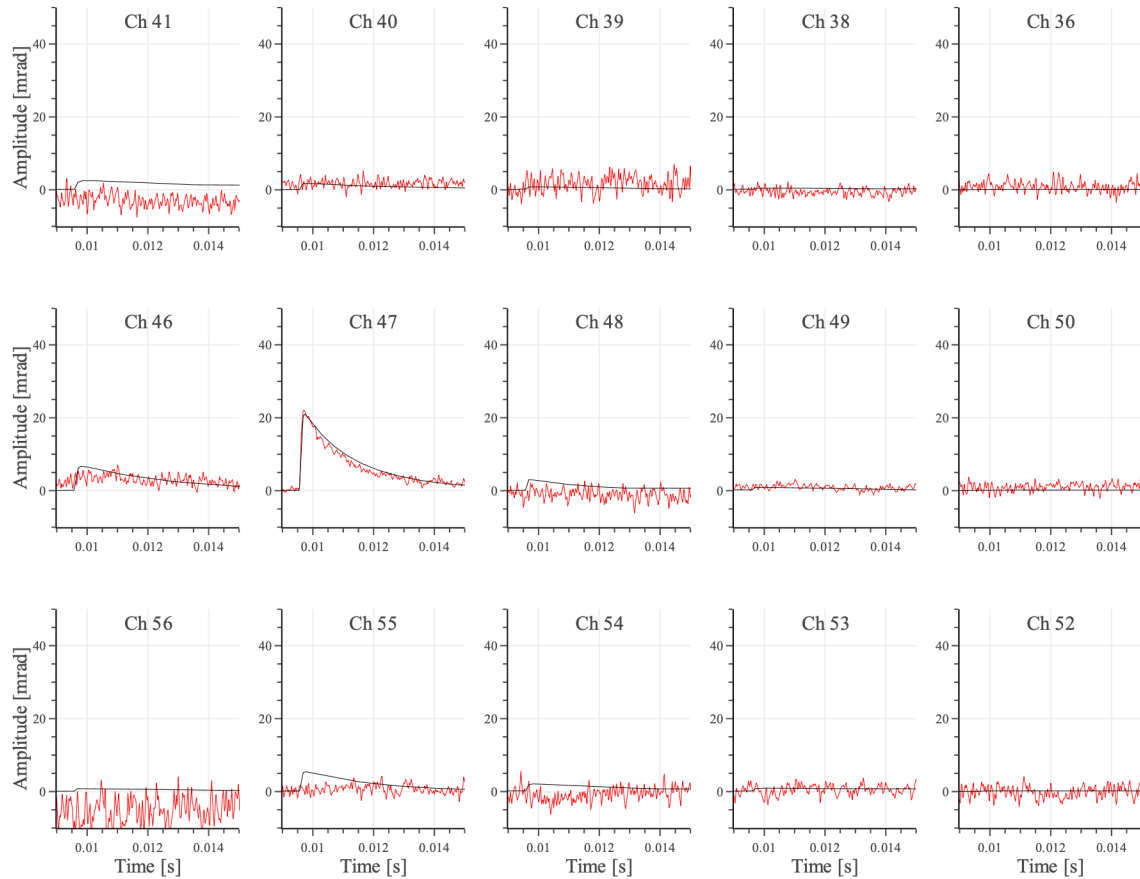
Run = 832358 EventNumber = 23366 Energy=2.4 keV Ch47



Single event found

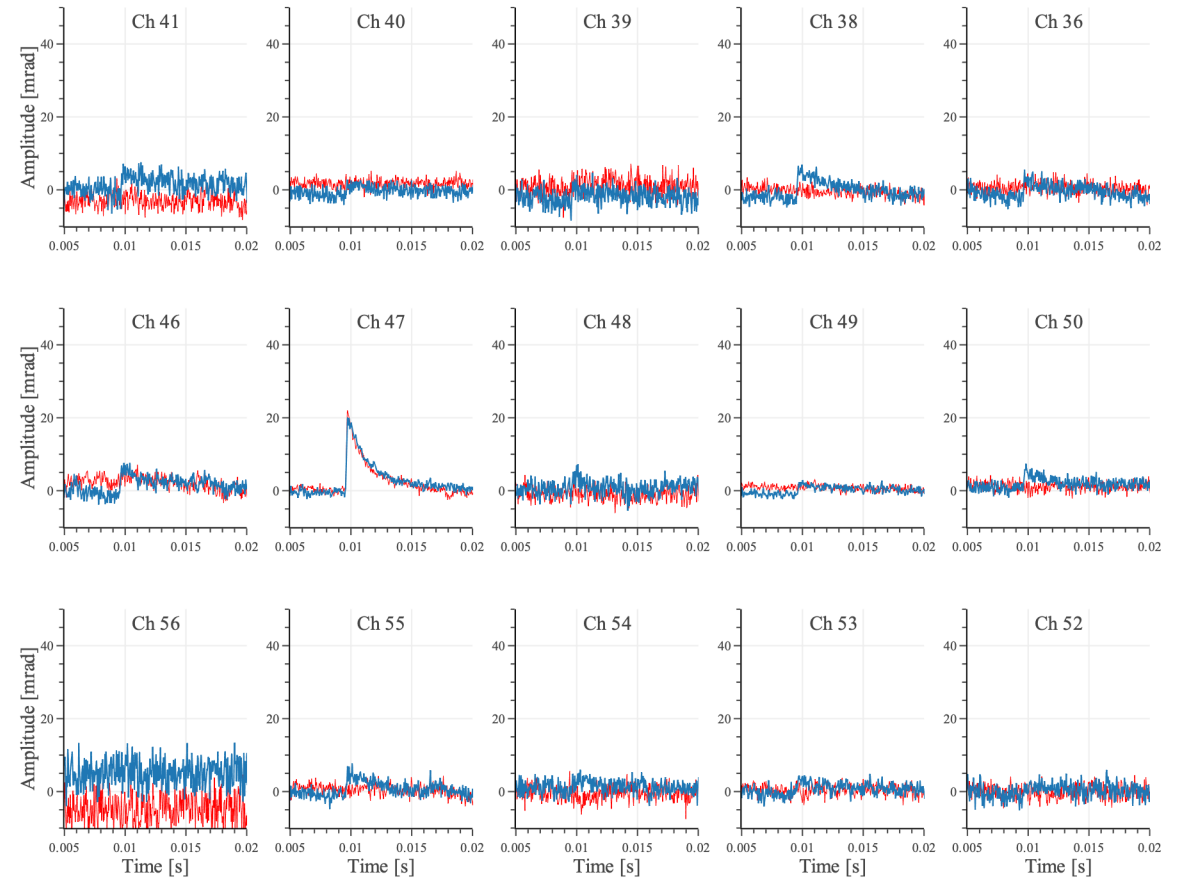
Compare with APs

Run = 831888 EventNumber = 73201 Energy=1.8 keV Ch47



Compare with one Shared

Run = 831888 EventNumber = 73201 Energy=1.8 keV Ch47



Difference on pulse shapes

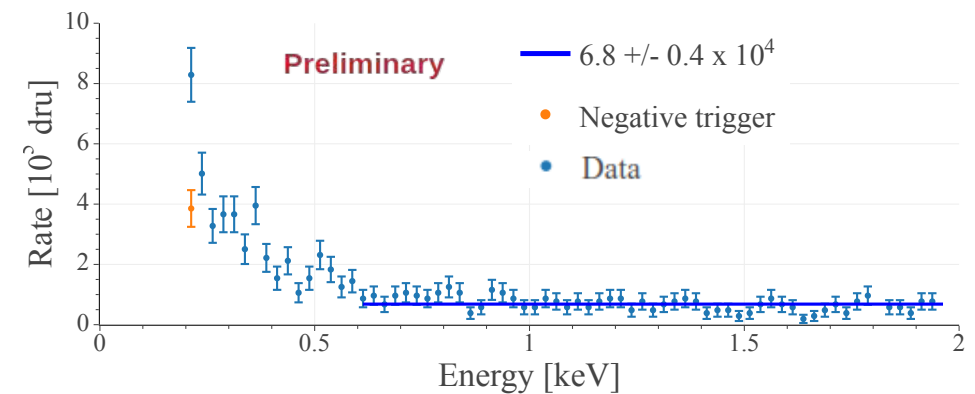
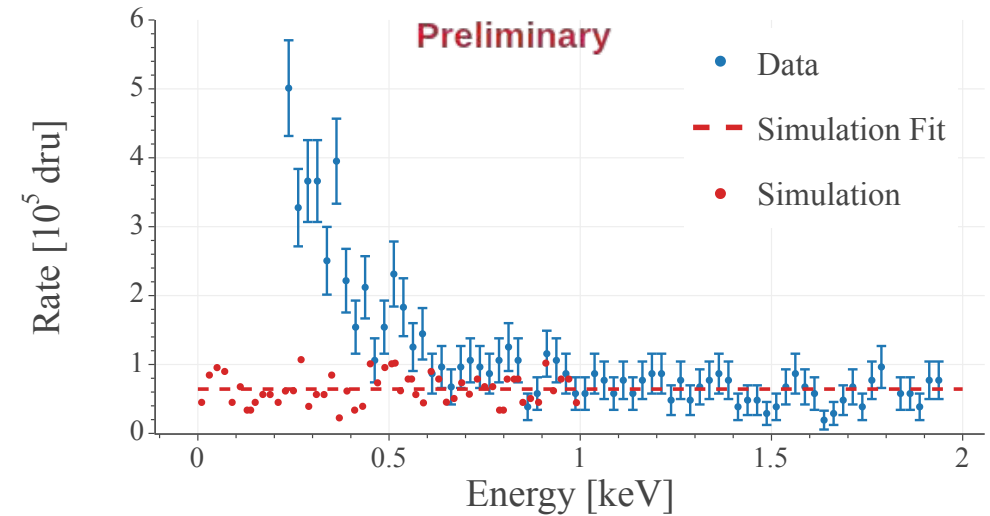
- Compared to the rise time and decay time of shared events in 5-20 keV
- Singles show decay times shorter by more than 5 sigma
- Shared events with same energy as Singles show less than 1 sigma discrepancy on decay time

ch47	Shared		Singles			Delta/sigma		
	5-20 keV		run = 832358	run = 831888	run = 831708			
	mean	sigma	ev = 23366	ev = 73201	ev = 31588			
RT	0.083	0.003	0.075	0.074	0.082	2.566	2.938	0.210
DT	2.133	0.084	1.640	1.340	1.240	5.833	9.385	10.569

ch49	Shared		Singles	Delta/sigma
	5-20 keV		run = 831938	
	mean	sigma	ev = 4261	
RT	0.083	0.003	0.075	2.589
DT	2.129	0.079	1.640	6.171

Summary

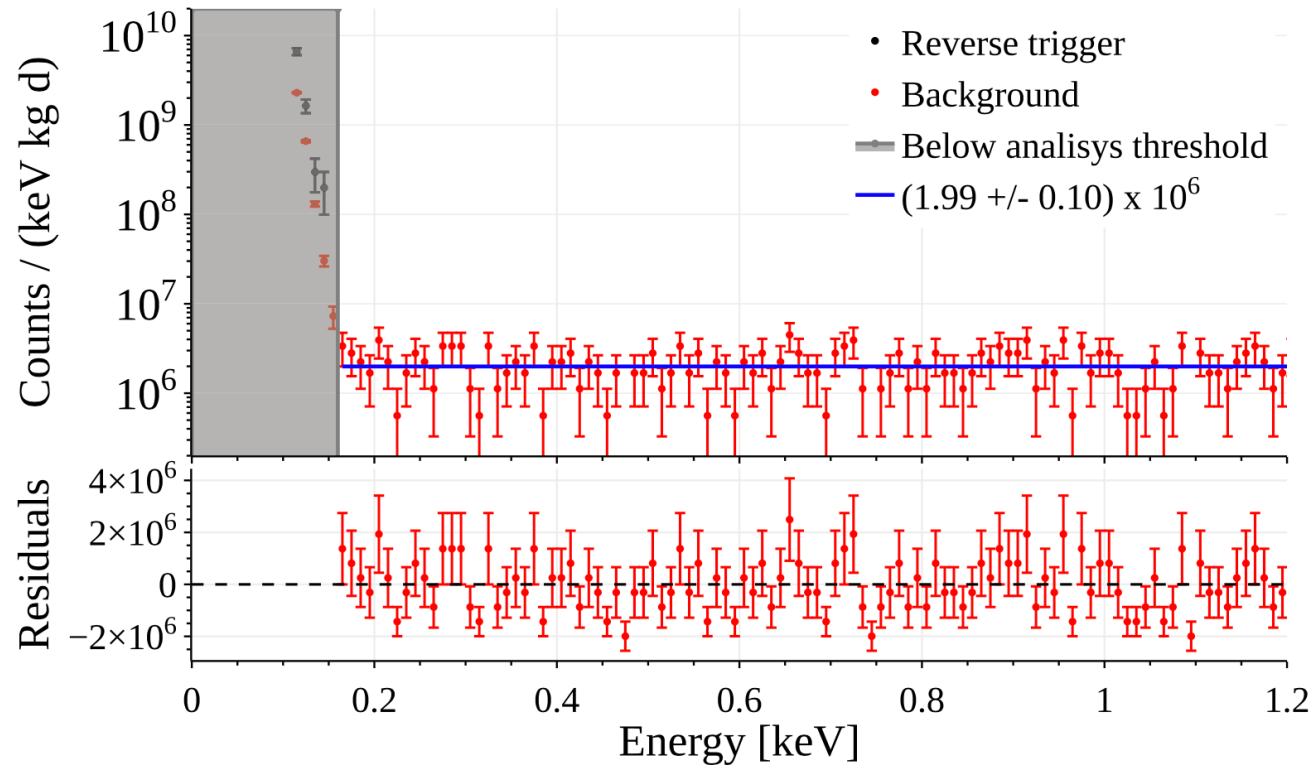
- Just started the single events searching
- 4 singles have been observed till now (low statistics)
- Further work needed to investigate the rise
 - Analyze more datasets,
 - Look into the pulse shape in low energy range (< 600 eV)



Backup slides

Previous measurement without shields

D. Delicato *et al*, Eur. Phys. J. C (2024) 84 :353



- Not able to state whether there is LEE
- Operation aboveground
- Absence of shields against ambient radioactivity

Basic cuts

