Neutron Scattering Studies and Quenching factor measurements with SPC

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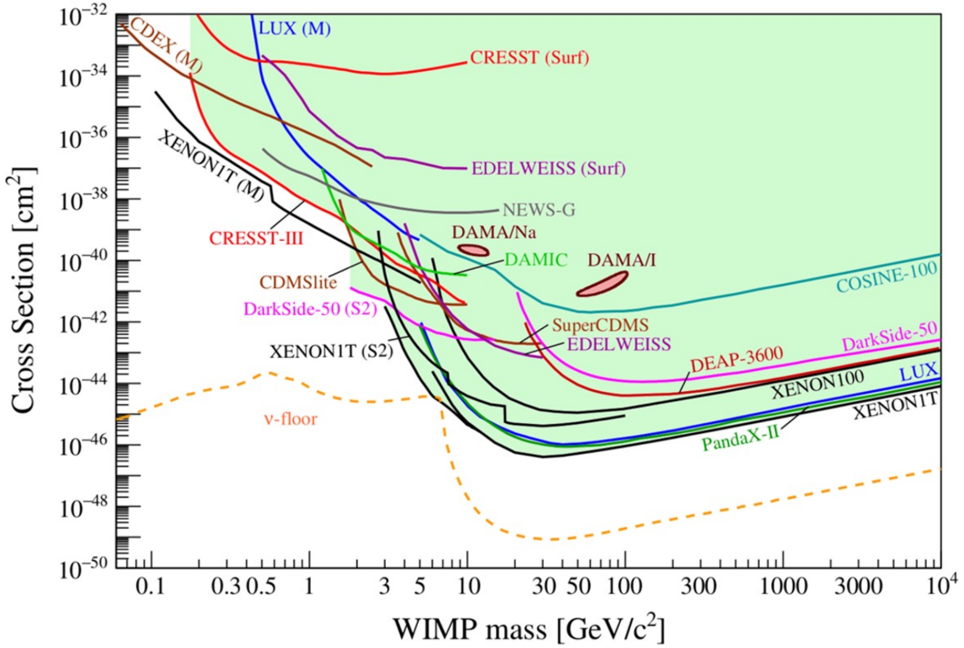
NEWS-G, Queen's University, Canada

ICHEP, Prague July 2024

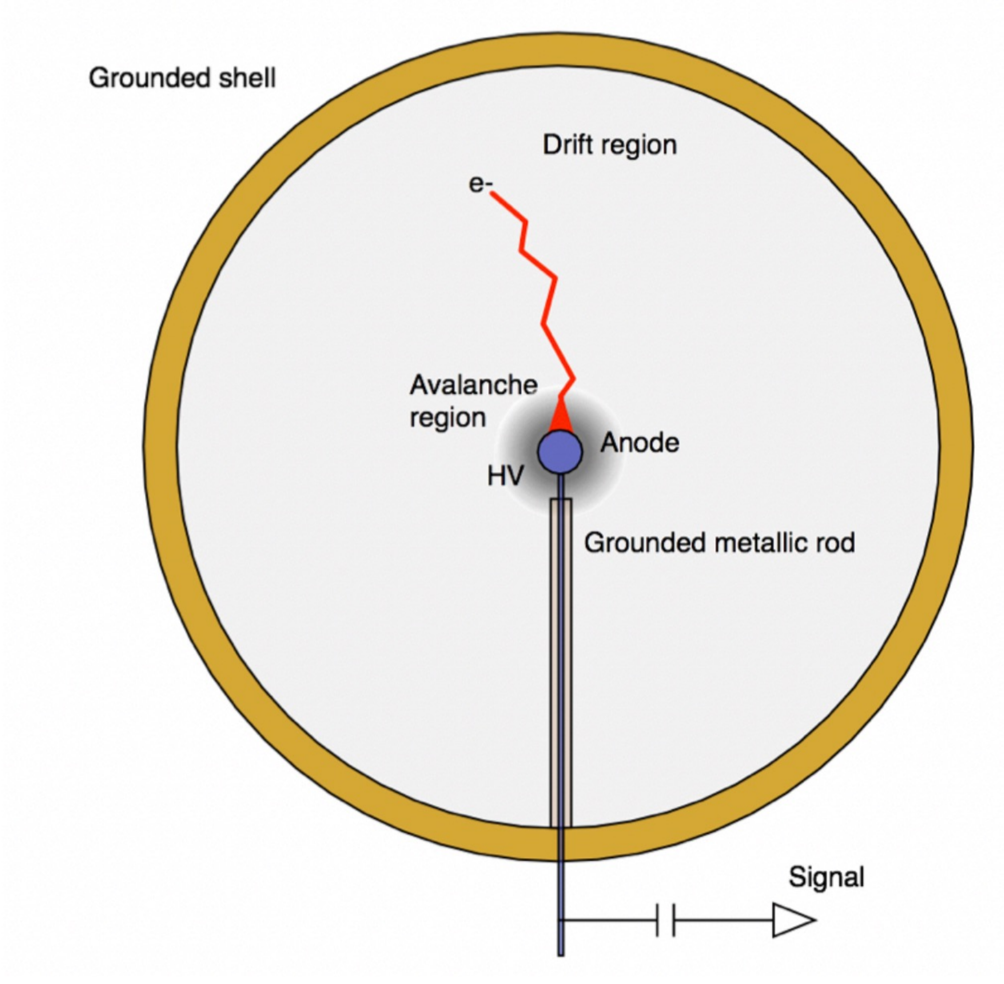
NEWS-G

- NEWS-G experiment searches for Light Dark Matter
- Uses SPCs as detector: Metallic vessel filled with a noble gas mixture, with a single high voltage anode
- Low mass target atoms increases sensitivity to low-mass dark matter
- Low capacitance (~10 pF) decreases electronic noise and Townsend avalanche provides large gain
- Single ionization detection threshold!



DOI 10.1088/1361-6633/ac5754

SPC: working principle



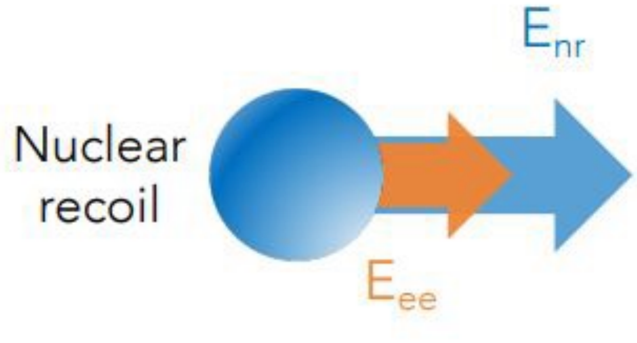
- Atomic recoil causes ionization of the gas.
- Primary electrons drift towards the central anode.
- Townsend avalanche near the anode amplifies the signal.
- Drifting secondary ions induce a current on the anode.

Quenching factor

Definition

- Dark matter sensitivity: Very important to know actual nuclear energy spectra
- As nuclear recoil and an electronic recoil of same energy do not produce same amount of primary ionization

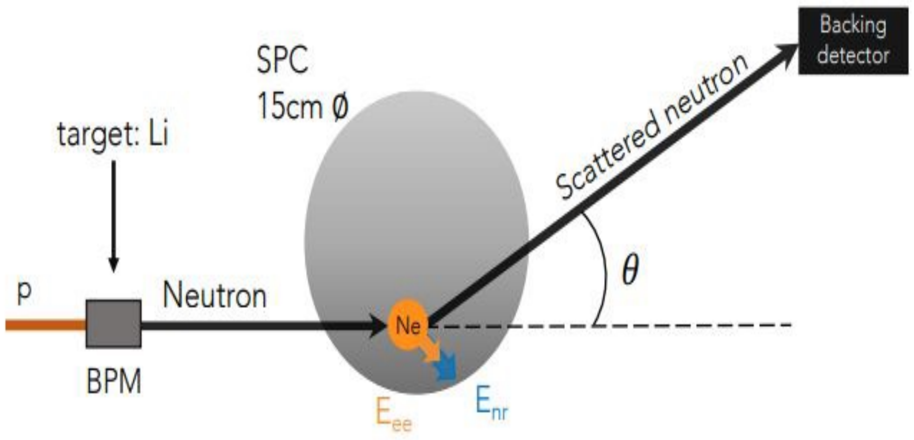
$$QF(E_{nr}) = \frac{E_{ee}}{E_{nr}}$$

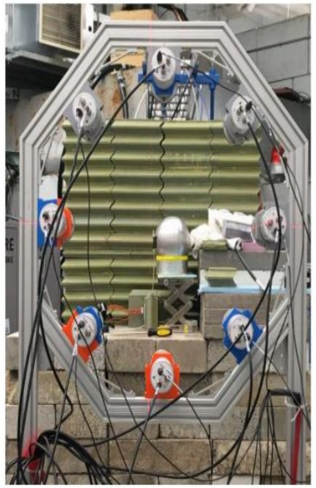


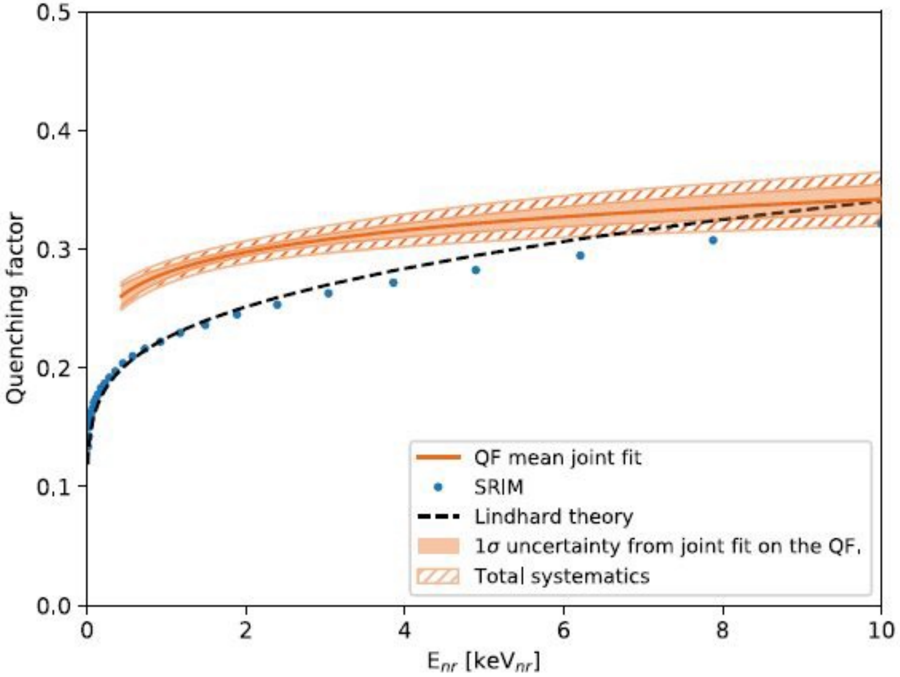
$E_{ee} < E_{nr}$

Past measurement at TUNL

- **Quenching factor measurements at TUNL (Duke tandem facility)**
- The nuclear recoil energies covered were 0.34 to 10 keVnr







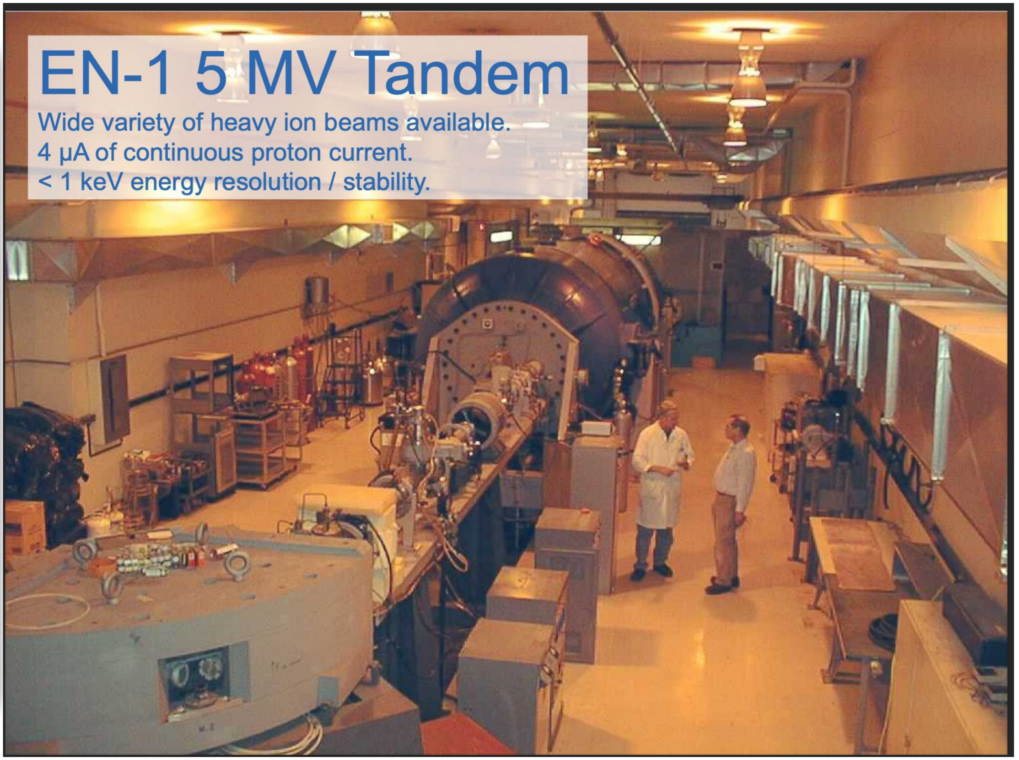
Marie et al.

Phys. Rev. D. Vol. 105, No. 5, 052004 (2022)

Current plans

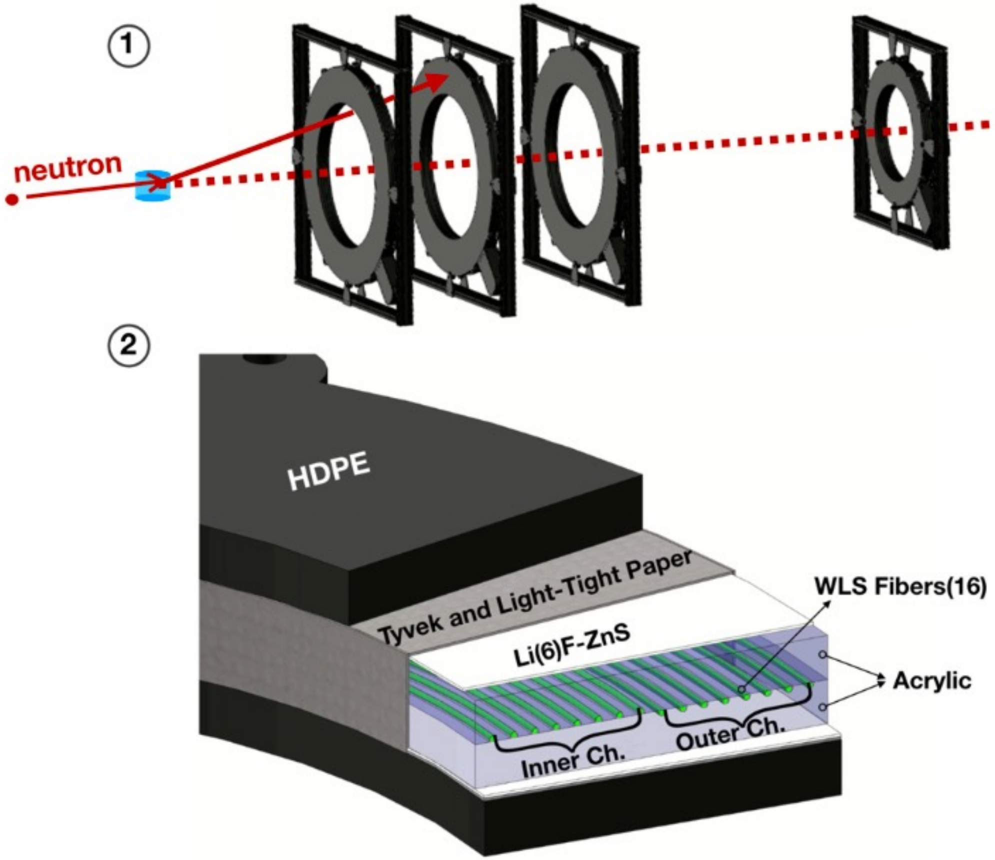
UdeM tandem accelerator: planning to do QF measurements

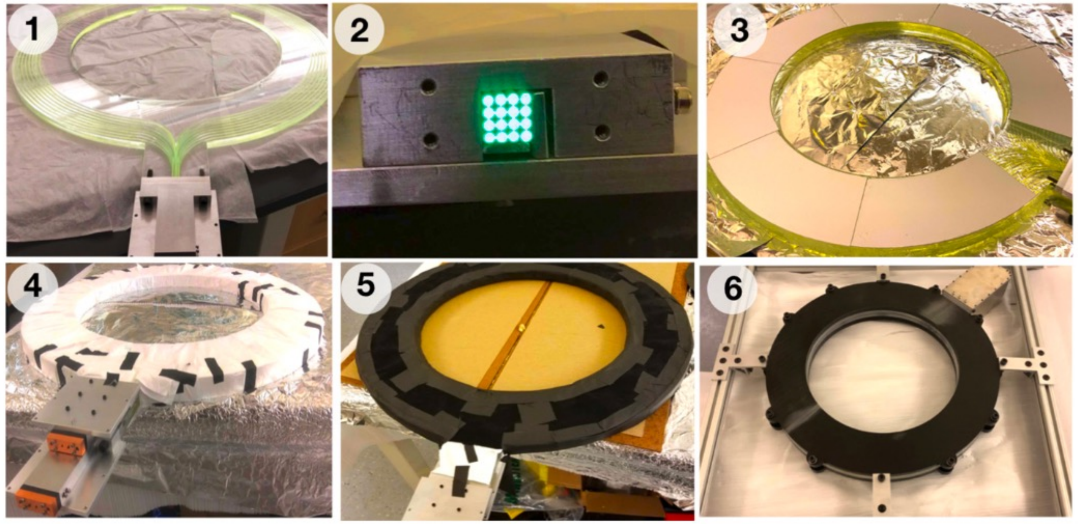
- Possibility to go to ~10 times lower energy than TUNL ~5keV
- $^{51}V(p,n)$ as target offering large number of near threshold resonances
- Better rejection to gamma background by B-10 neutron capture
- Working on building a new backing detector


EN-1 5 MV Tandem

Wide variety of heavy ion beams available.
4 μA of continuous proton current.
< 1 keV energy resolution / stability.

New Backing Detector





- The Backing Detector is an annulus structure
- Provides better angular coverage
- Based on n-capture on Li
- Detection efficiency 27% at 2keV
- Mean neutron capture time 17usec

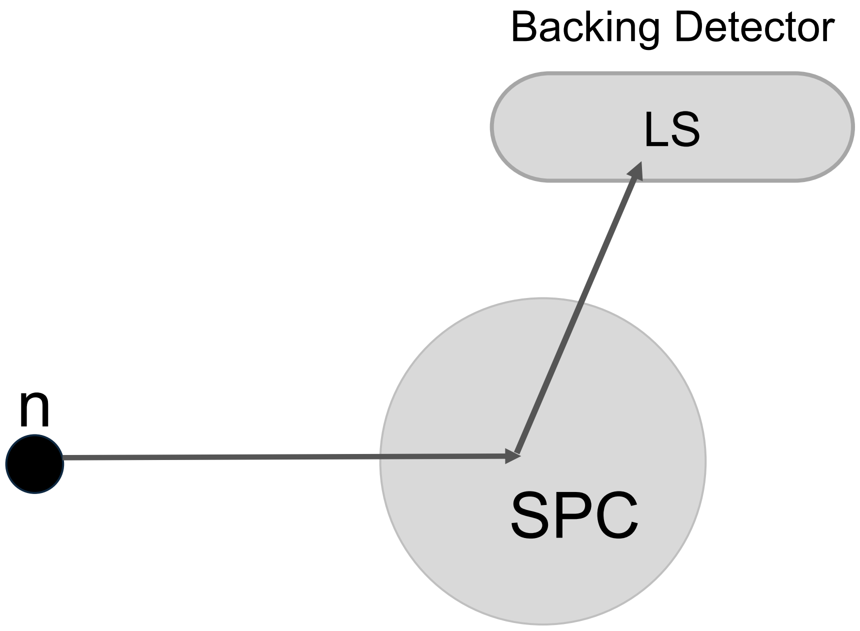
Pratyush Patel et al.

Neutron scattering @ Queen's

💡 To observe the scattered neutrons from SPC using a source in lab.

Motivation

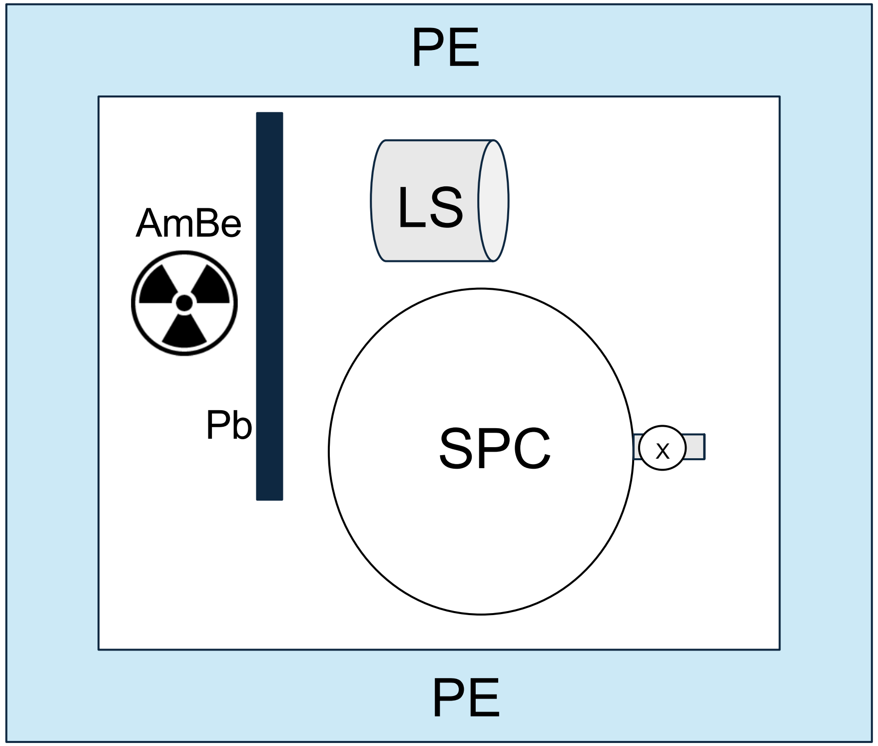
- **A crucial step towards in-beam experiment**
- Establishing the DAQ and analysis tools
- Easy access to systematic investigation:
    - different gas mixture
    - gas pressure
    - gas volume (sphere size)
    - ionization voltage
- Characterization tool for new gases and sensor designs in the future



Experiment

Setup

- **Detector:** S15/S30
- **Backing detector:** EJ-309 Liquid Scintillator
- **Source:** 30 mCi AmBe (7x10^4 n/s)
- **Shield:**
  - A layer of few mm of Pb for gammas
  - 5 cm PE for neutrons

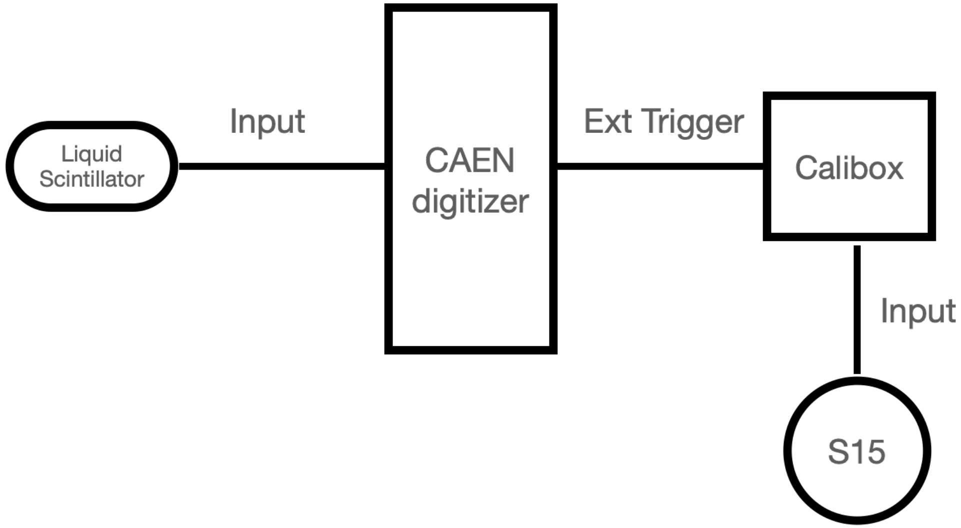


Experiment

Setup: Pictures

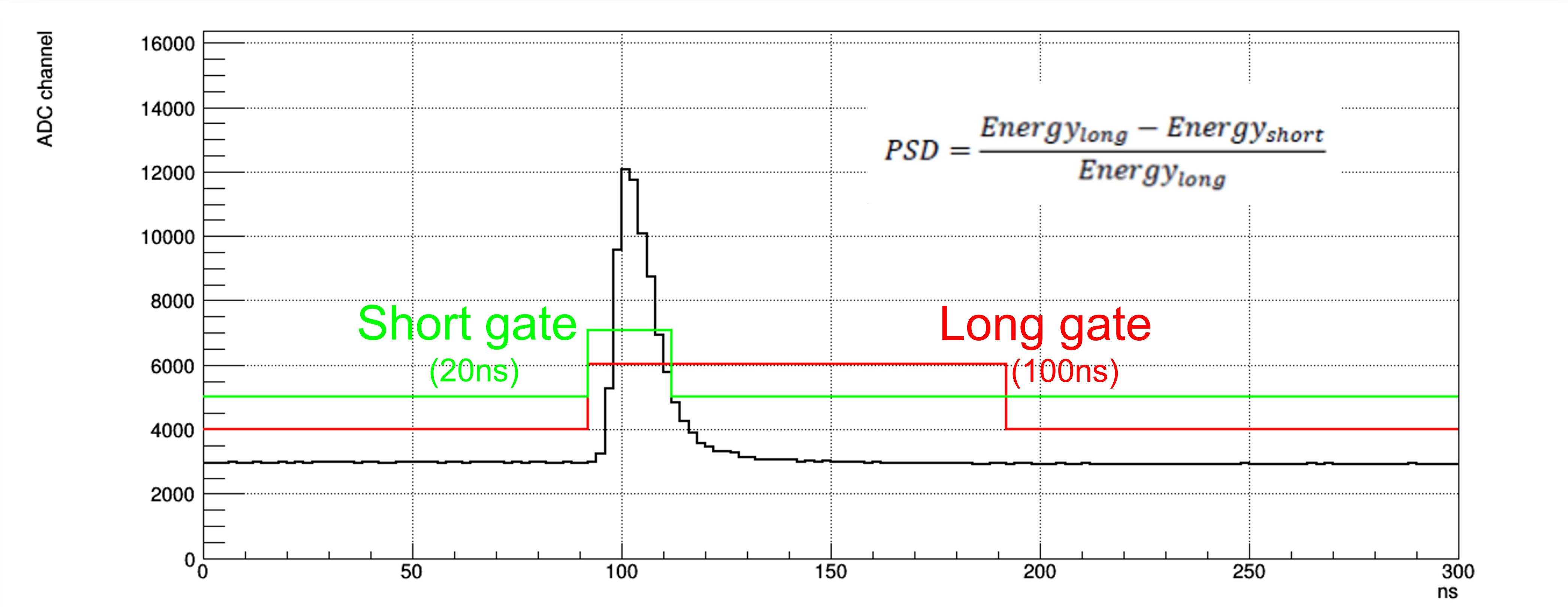
Experiment

Setup: DAQ



CAEN V1730S Digitizer
16 Channel 14 bit 500 MS/s
CoMPASS DAQ

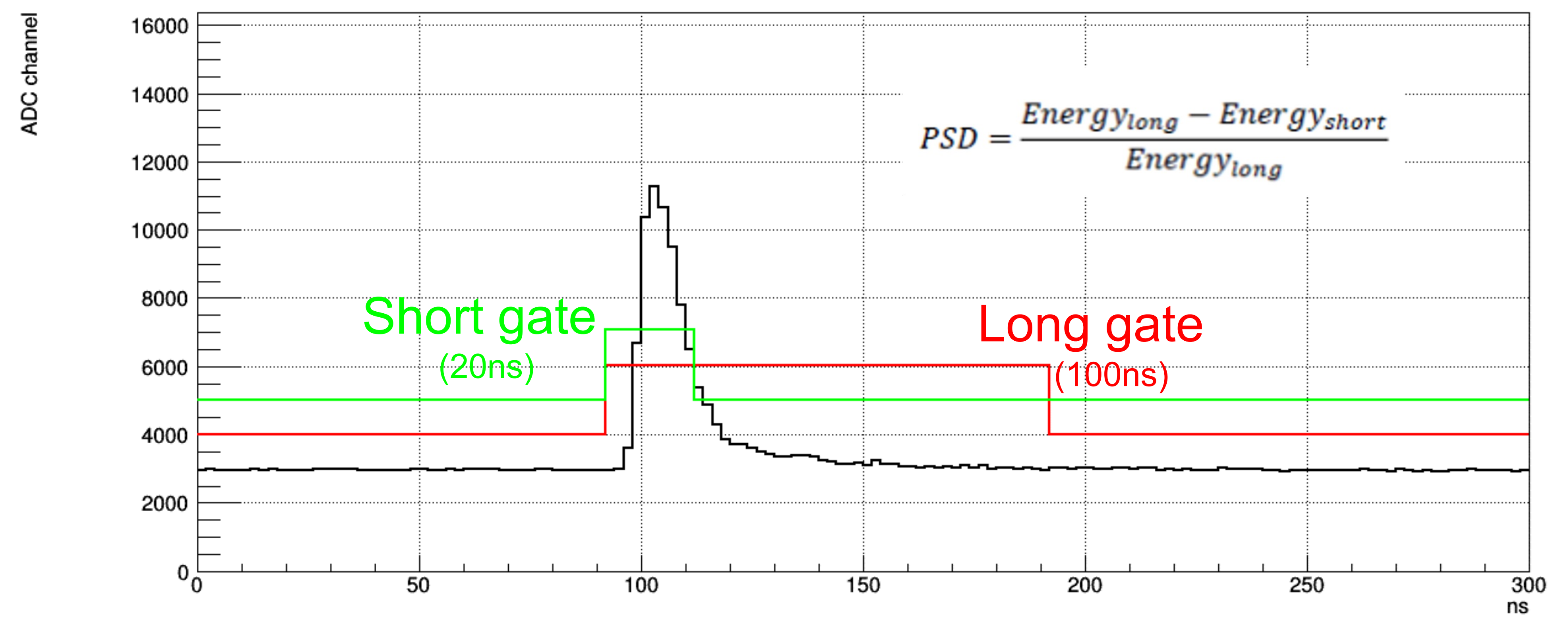
Sample pulse



$$PSD = \frac{Energy_{long} - Energy_{short}}{Energy_{long}}$$

Sample **gamma** pulse acquired with CoMPASS

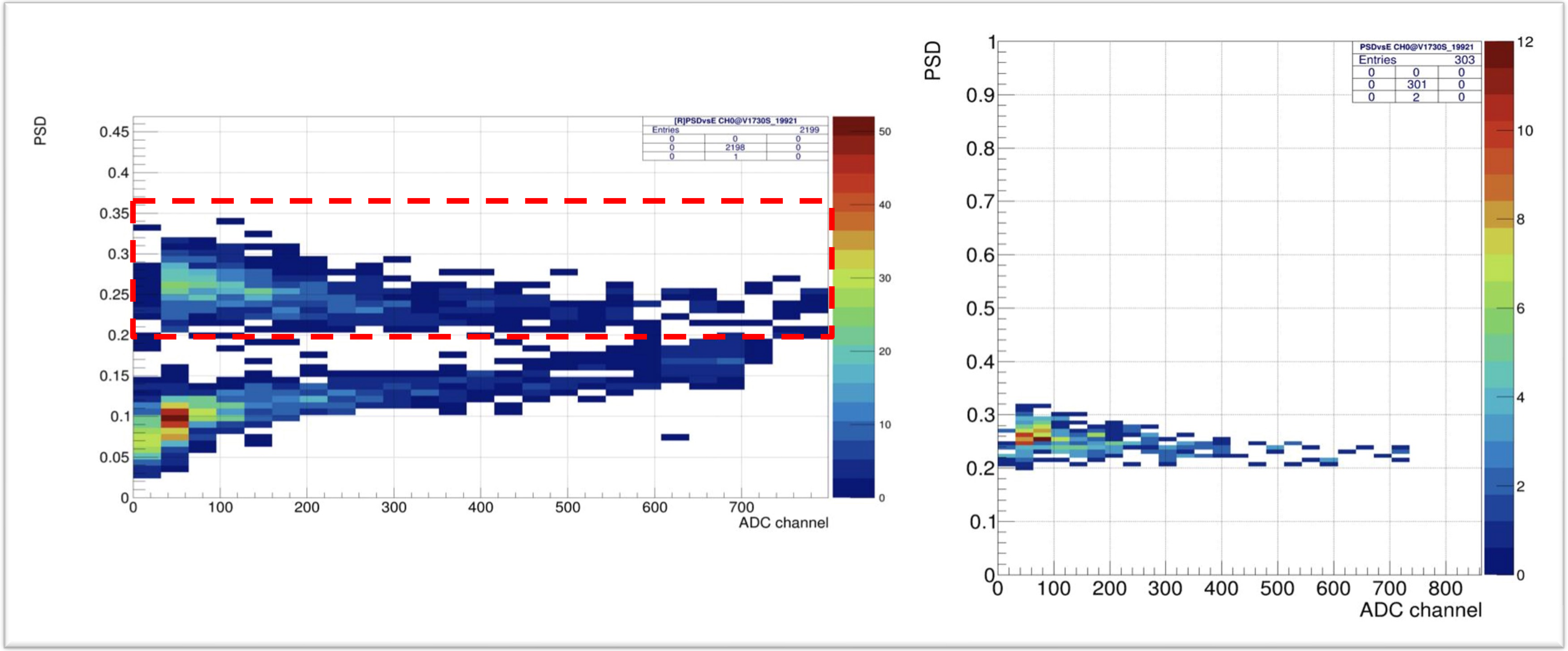
Sample pulse



$$PSD = \frac{Energy_{long} - Energy_{short}}{Energy_{long}}$$

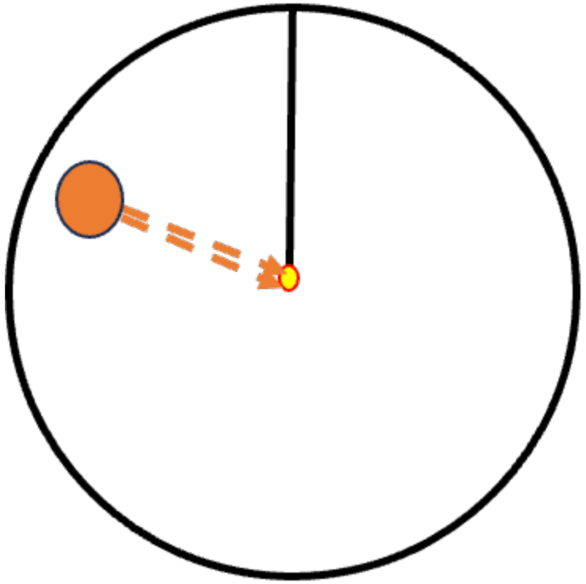
Sample **neutron** pulse acquired with CoMPASS

PSD cut


PSD
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
100
200
300
400
500
600
700
ADC channel
[R]PSDvsE CH0@V1730S_19921
Entries 2199
0 0 0
0 2198 0
0 1 0
50
40
30
20
10
0
PSD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
700
800
ADC channel
PSDvsE CH0@V1730S_19921
Entries 303
0 0 0
0 301 0
0 2 0
12
10
8
6
4
2
0

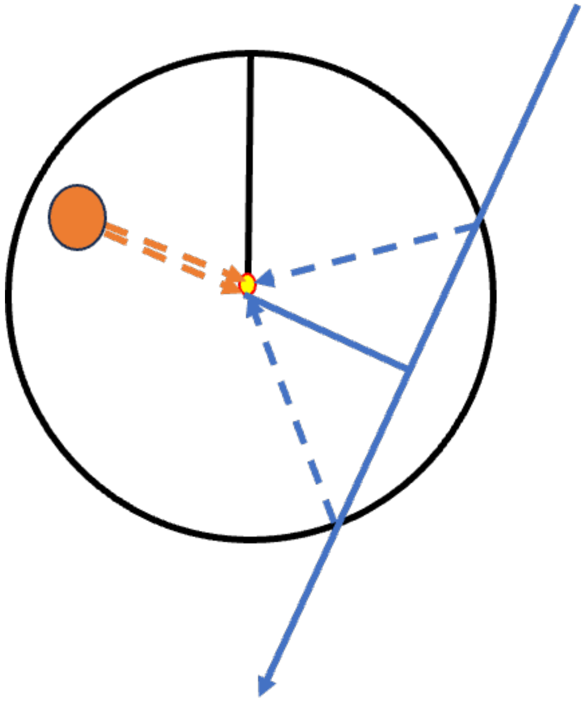
Event Discrimination in SPC

- Drift time in an SPC is proportional to the radial position of the event
- Two types of events: point-like and track-like
- Point-like event:
  - risetime is an indicator of the diffusion of electrons moving towards anode
  - **Risetime is proportional to drift-time**

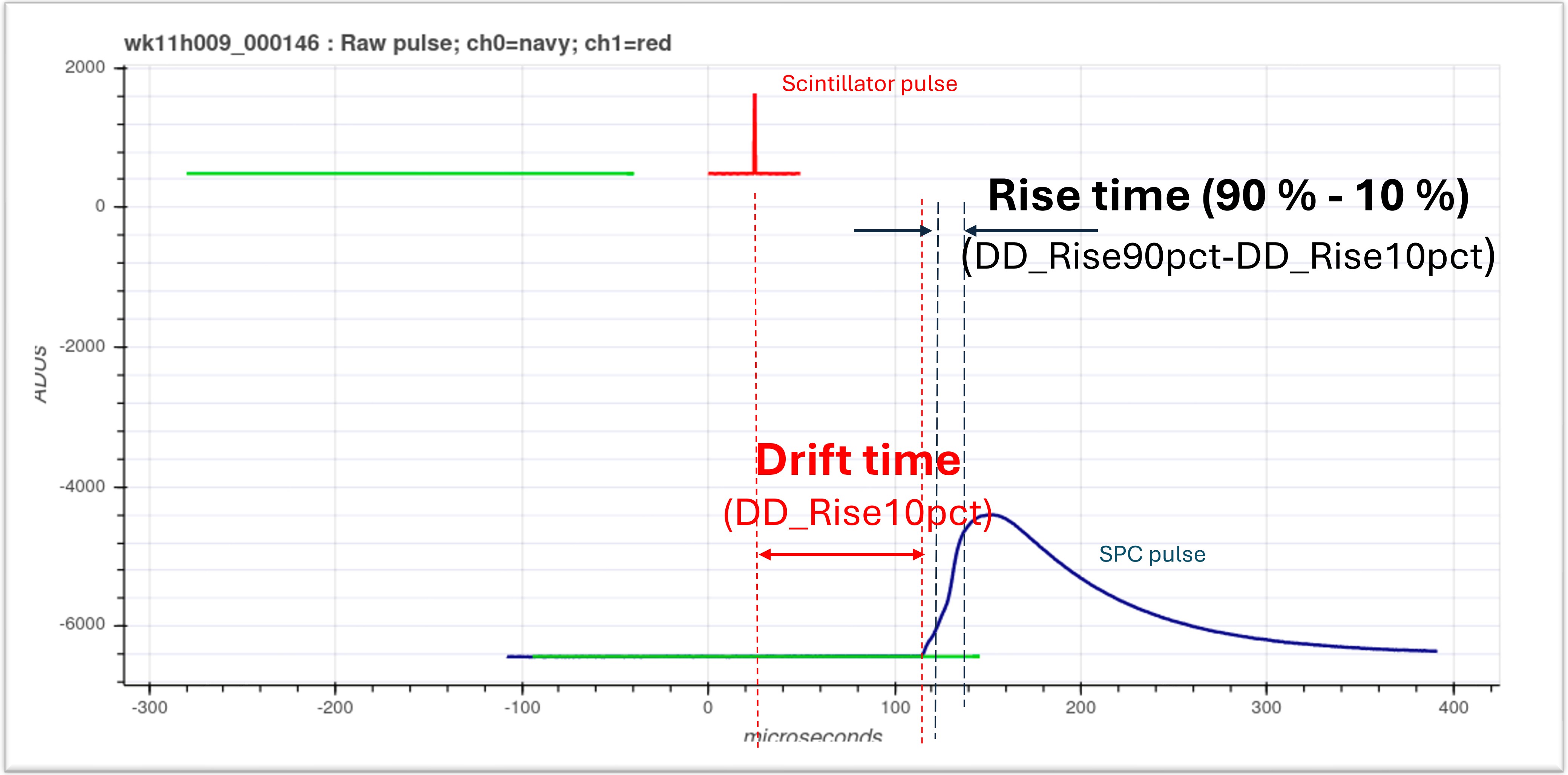


Event Discrimination in SPC

- Drift time in an SPC is proportional to the radial position of the event
- Two types of events: point-like and track-like
- Track-like events:
  - risetime is no longer governed by the diffusion time of the electrons
  - difference in the arrival time of the e- closer and farther to the anode
  - **Risetime is higher than the point-like case**



SPC signal



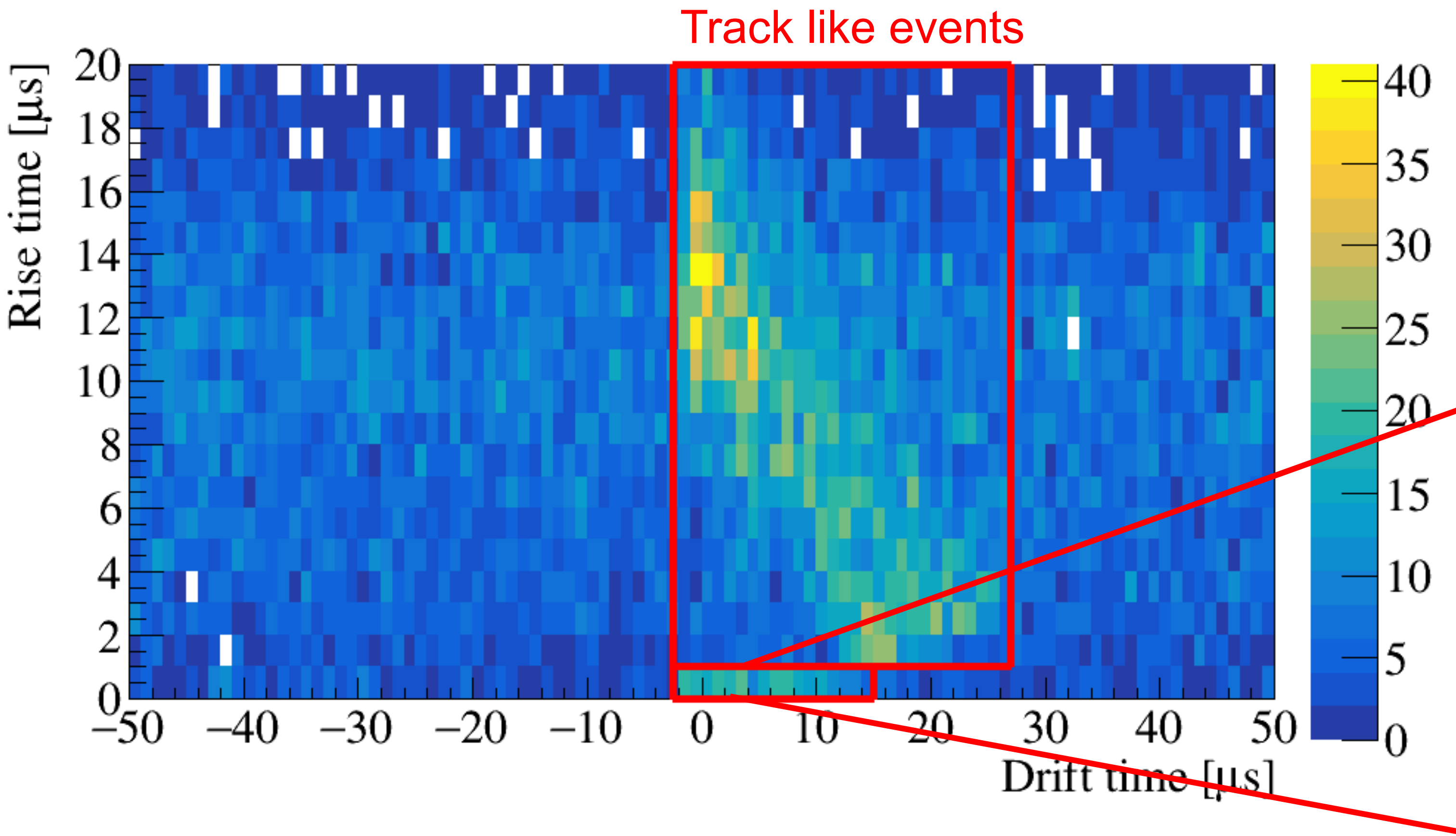
Rise time (90 % - 10 %)

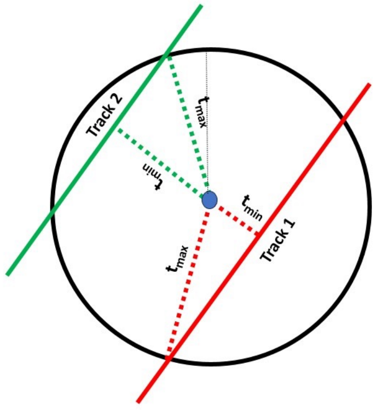
(DD_Rise90pct-DD_Rise10pct)

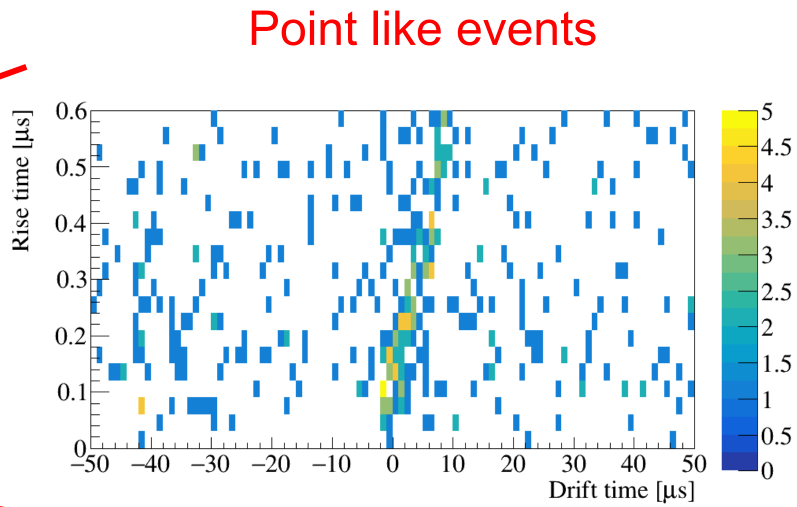
Drift time

(DD_Rise10pct)

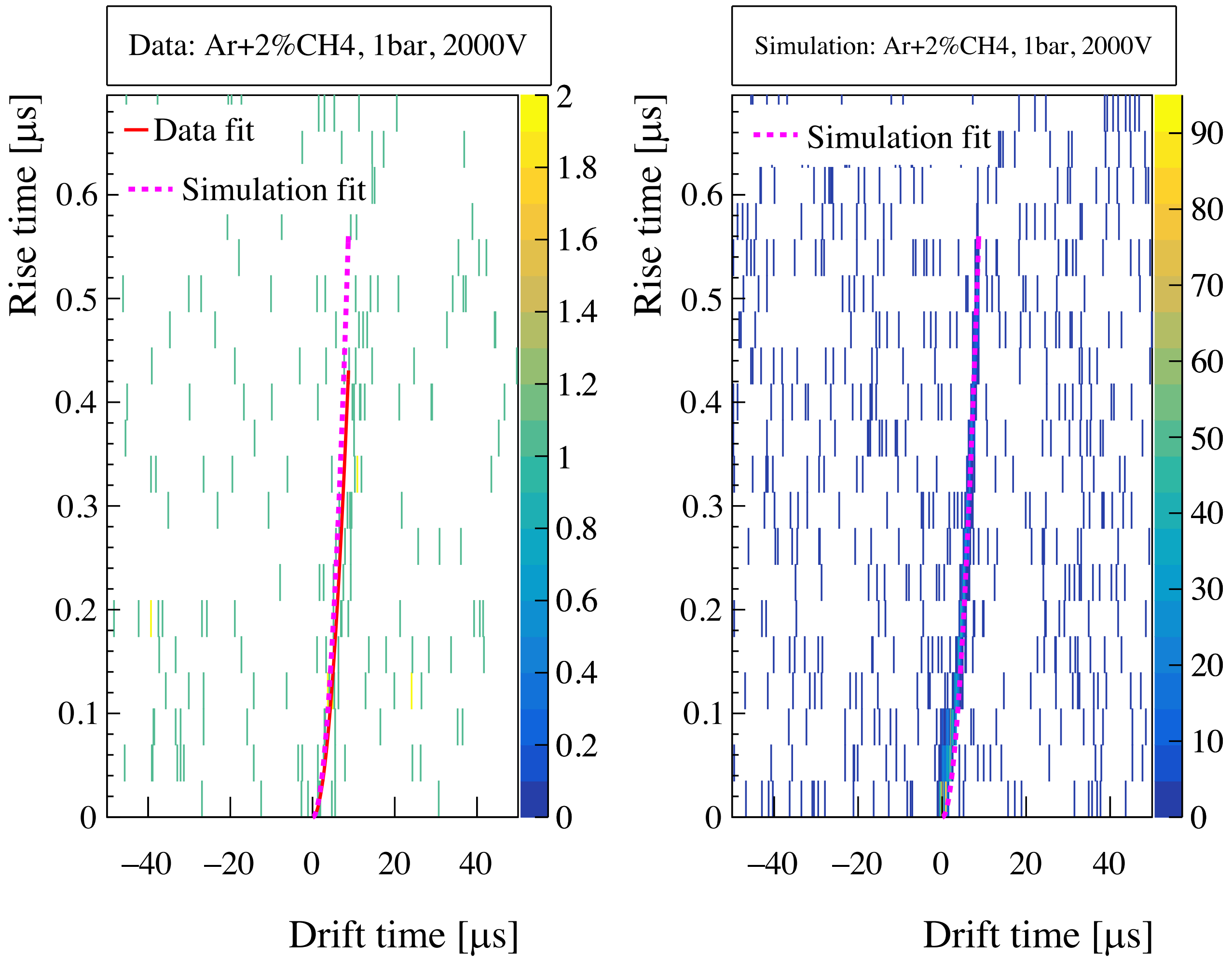
Results from Ar mixture (S15)





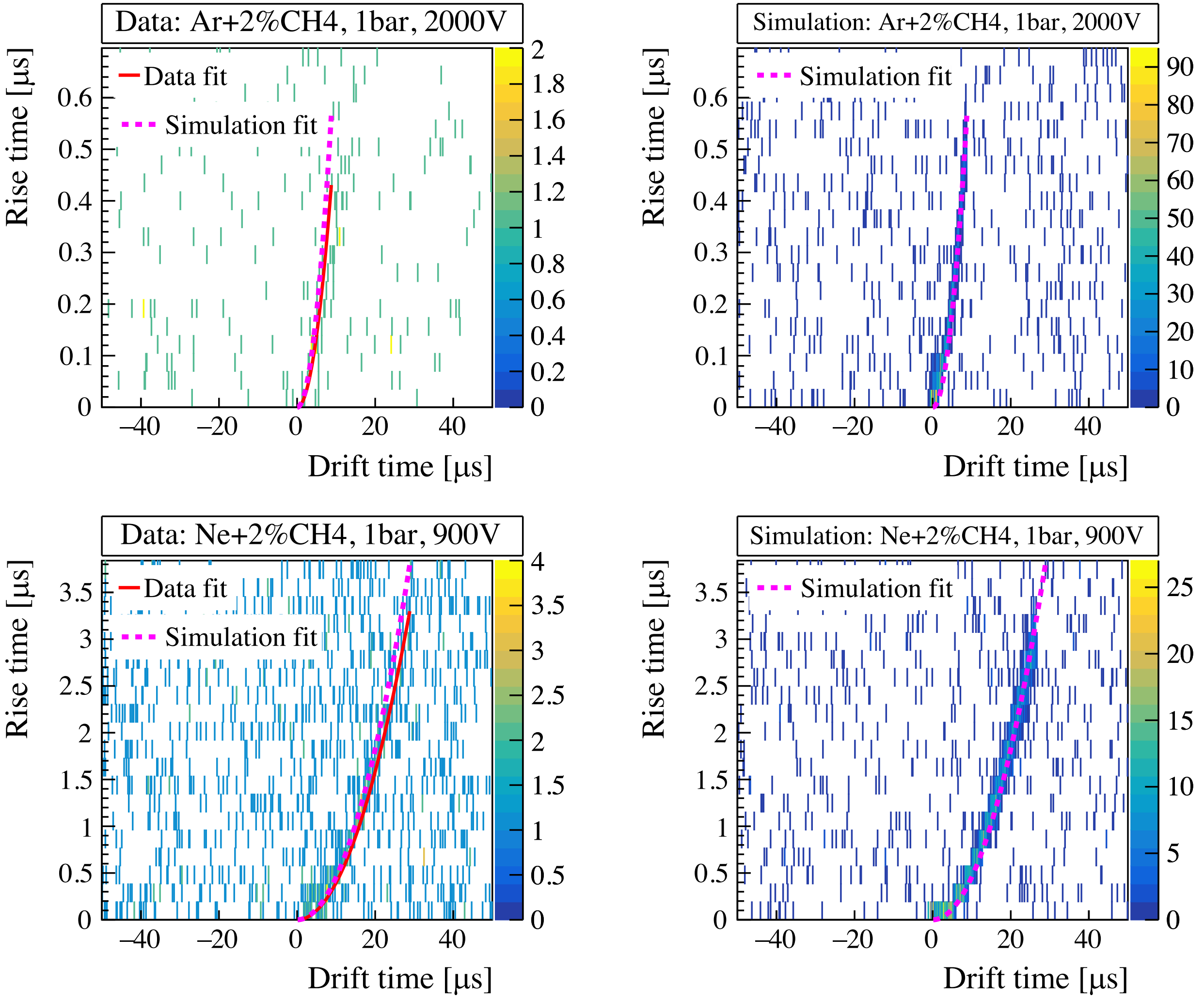


First observation in Ar (+ simulation)



$$t_{rise} = a \cdot t_{drift}^2$$

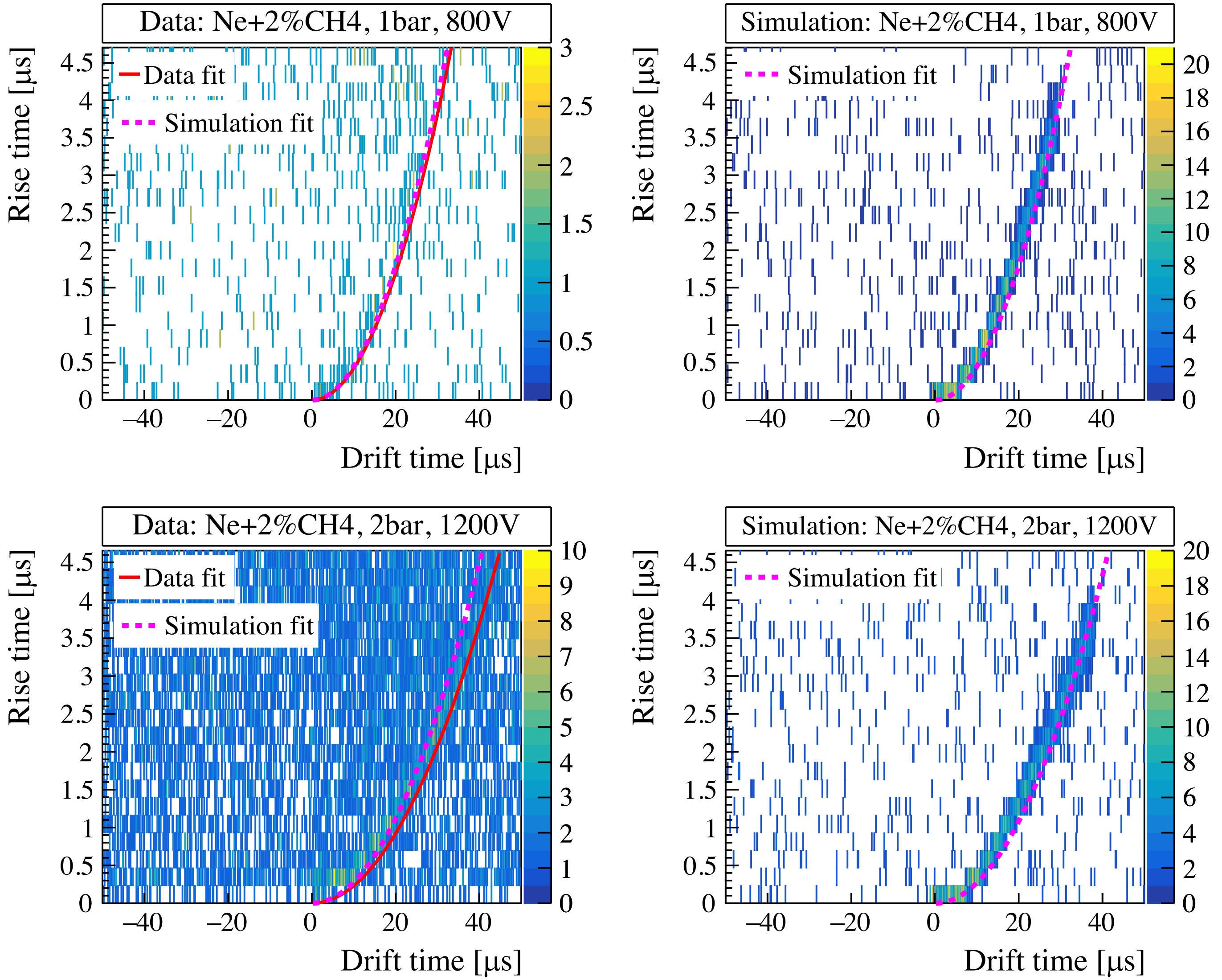
Different gases: Ne and Ar @ 1 bar



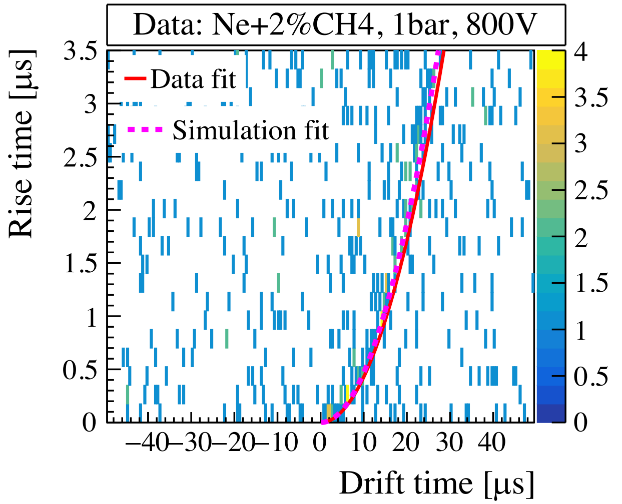
Note
Scale for risetime is different

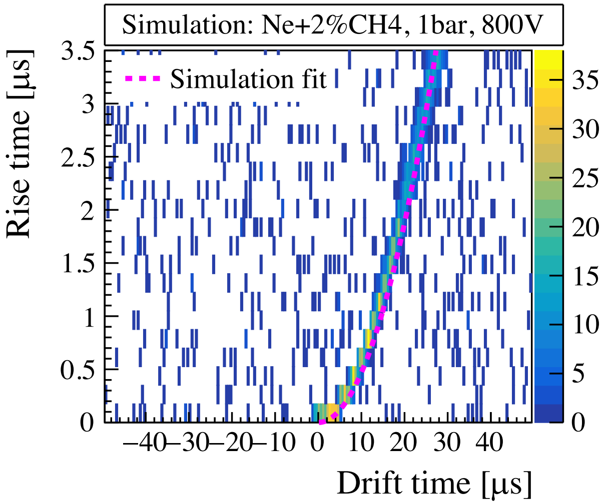
Observed Rate
~ 30 mHz

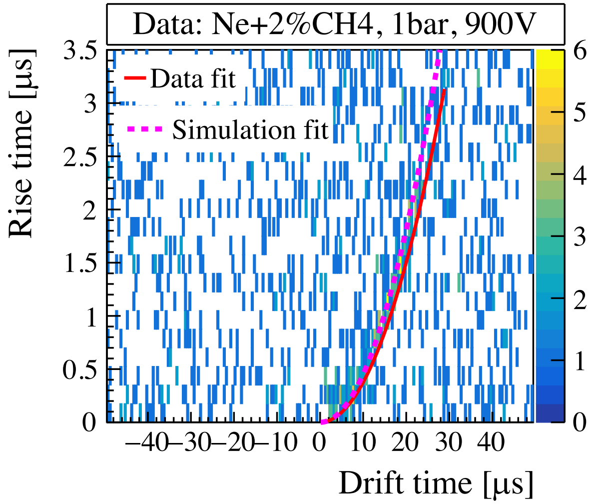
Different pressures: Ne @ 1 and 2 bar

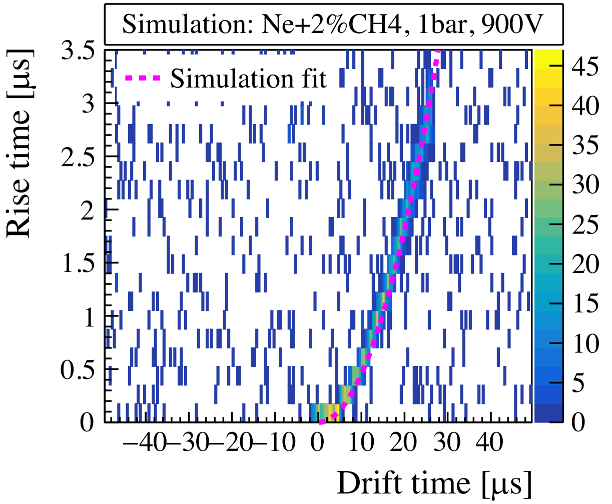


Different HV: Ne (1 bar)

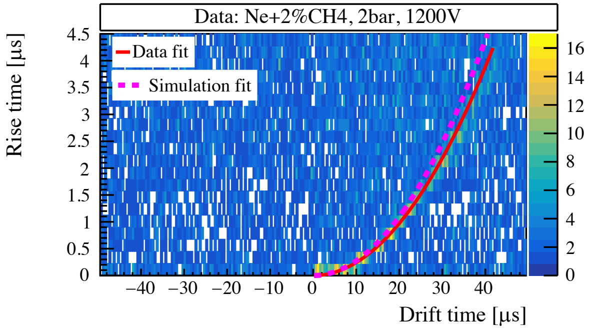

Data: Ne+2%CH4, 1bar, 800V

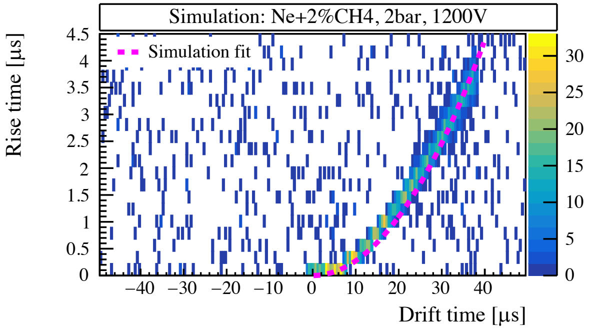

Simulation: Ne+2%CH4, 1bar, 800V

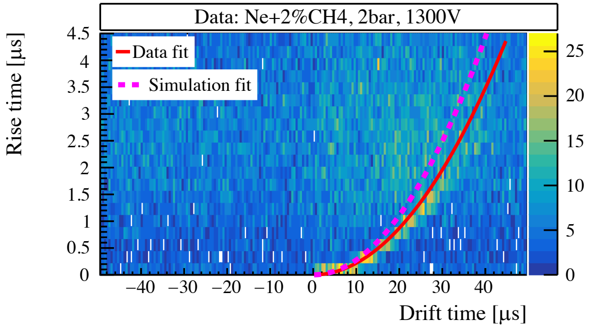

Data: Ne+2%CH4, 1bar, 900V

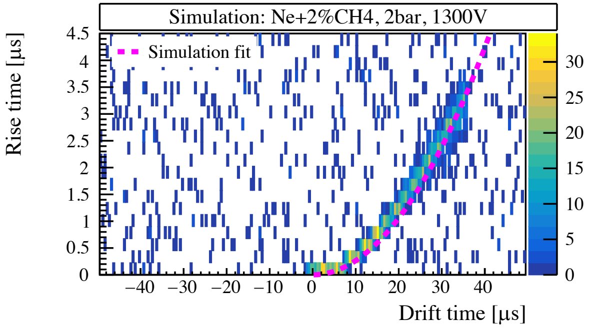

Simulation: Ne+2%CH4, 1bar, 900V

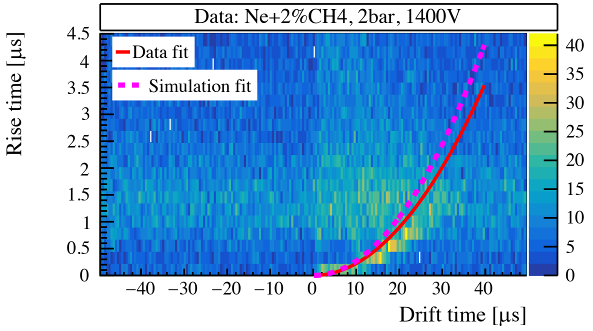
Different HV: Ne (2 bar)

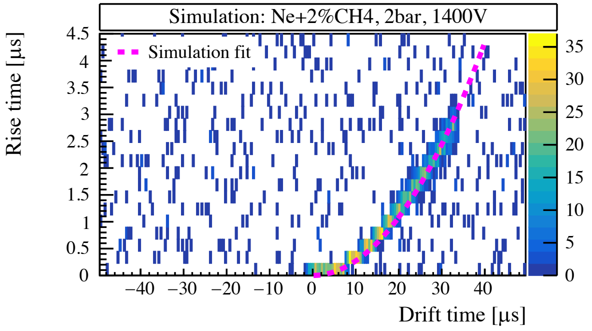

Data: Ne+2%CH4, 2bar, 1200V


Simulation: Ne+2%CH4, 2bar, 1200V

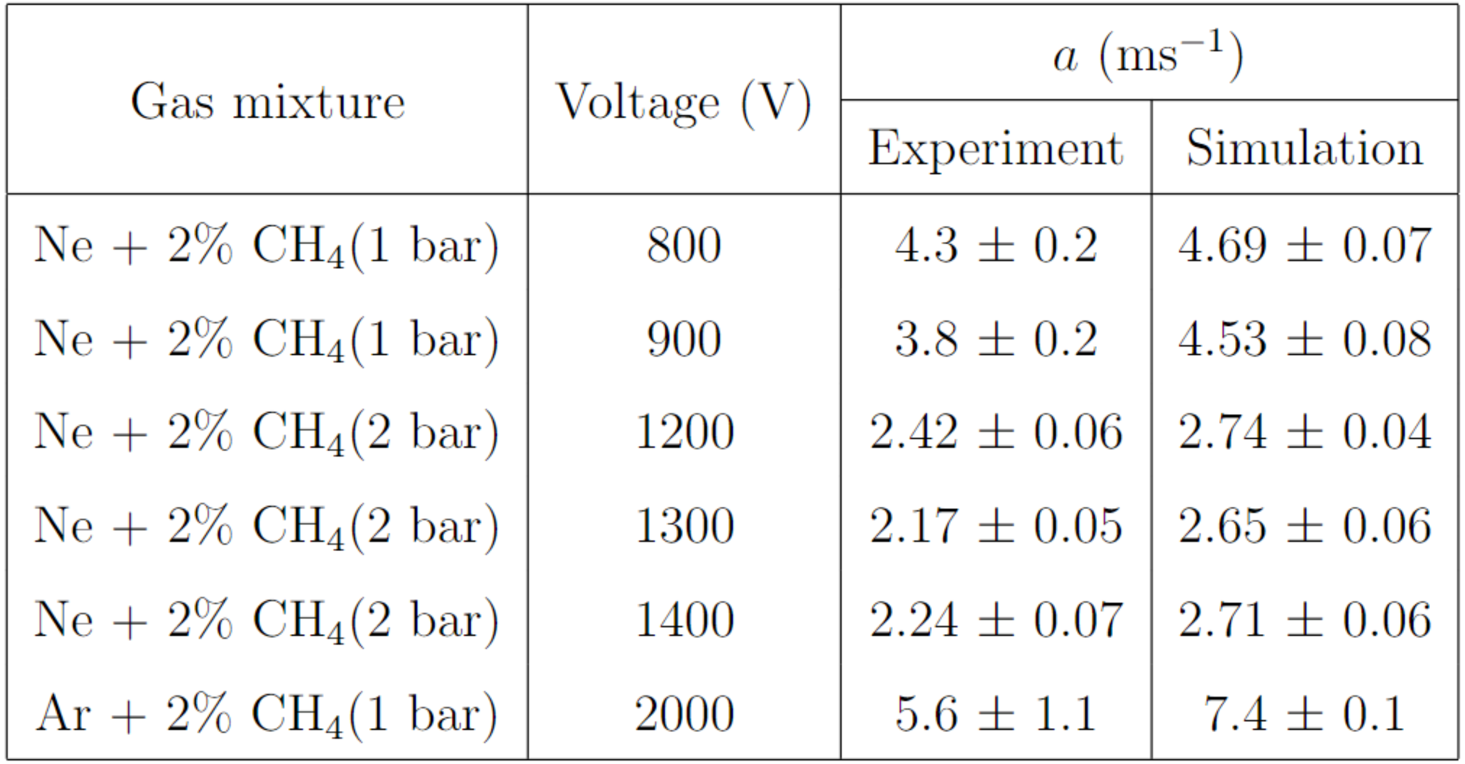

Data: Ne+2%CH4, 2bar, 1300V


Simulation: Ne+2%CH4, 2bar, 1300V


Data: Ne+2%CH4, 2bar, 1400V


Simulation: Ne+2%CH4, 2bar, 1400V

Summary of measurements



Gas mixture	Voltage (V)	a (ms^{-1})	
		Experiment	Simulation
Ne + 2% CH_4(1 bar)	800	4.3 ± 0.2	4.69 ± 0.07
Ne + 2% CH_4(1 bar)	900	3.8 ± 0.2	4.53 ± 0.08
Ne + 2% CH_4(2 bar)	1200	2.42 ± 0.06	2.74 ± 0.04
Ne + 2% CH_4(2 bar)	1300	2.17 ± 0.05	2.65 ± 0.06
Ne + 2% CH_4(2 bar)	1400	2.24 ± 0.07	2.71 ± 0.06
Ar + 2% CH_4(1 bar)	2000	5.6 ± 1.1	7.4 ± 0.1

Conclusions

- Past measurements at TUNL in Ne + CH4 by Marie et al.,
- Working towards QF measurements at UdeM
- New backing detector is being built
- Neutron scattering observed in a table top experiment with AmBe source as a crucial step towards QF measurement with neutron beam
- The manuscript for neutron scattering work is accepted for publication in NIM-A

Backup slides

Rate Estimation

Monte Carlo simulation

- Simple MC simulation by Irina to calculate the geometric factor
- Assumed Isotropic distribution of neutron-gas interactions in SPC
- **10%** total interactions in SPC will be recorded in the liquid scintillator

$$\text{rate} = (\text{neutron rate}_{\text{source}})\sigma_{Ar} l (\frac{N_A}{V_{m,stp}})(\frac{\Omega_{\text{source}\rightarrow\text{sphere}}}{4\pi})$$

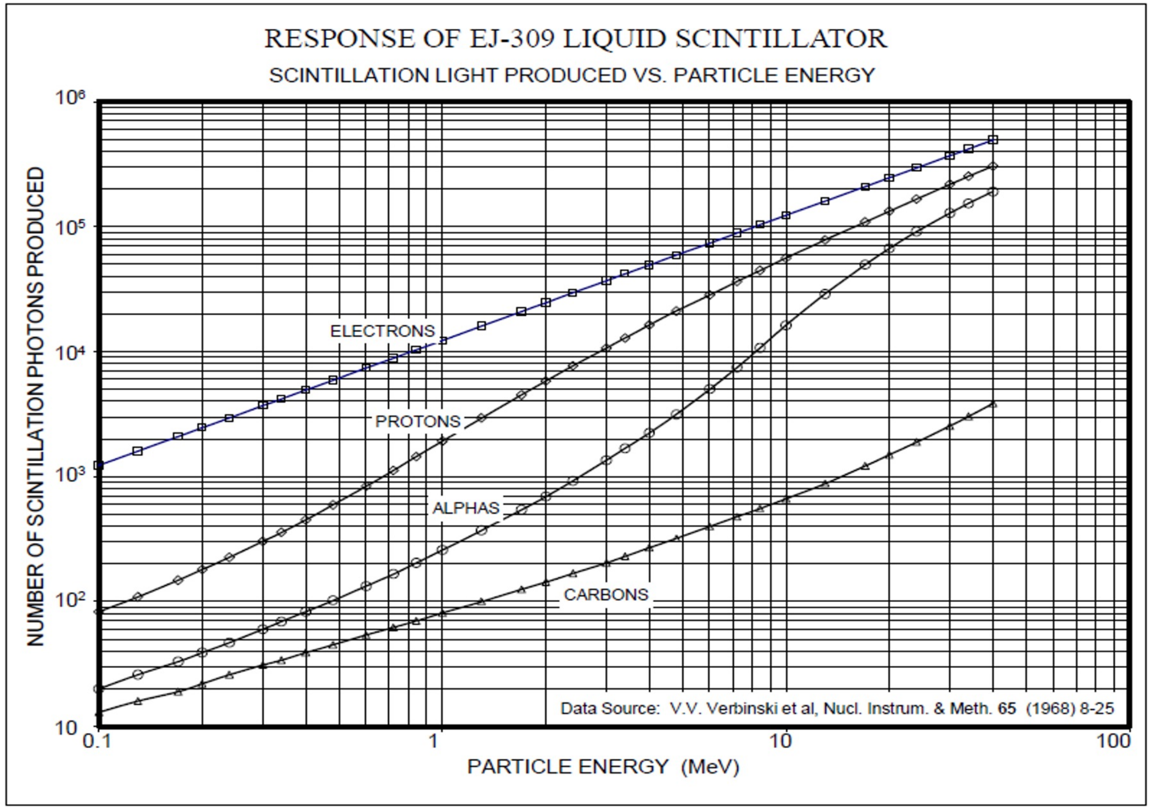
Rate ~ 300 mHz
for 1 bar Ne

Rate ~ 30 mHz

Irina Babayan

ELJEN TECHNOLOGY

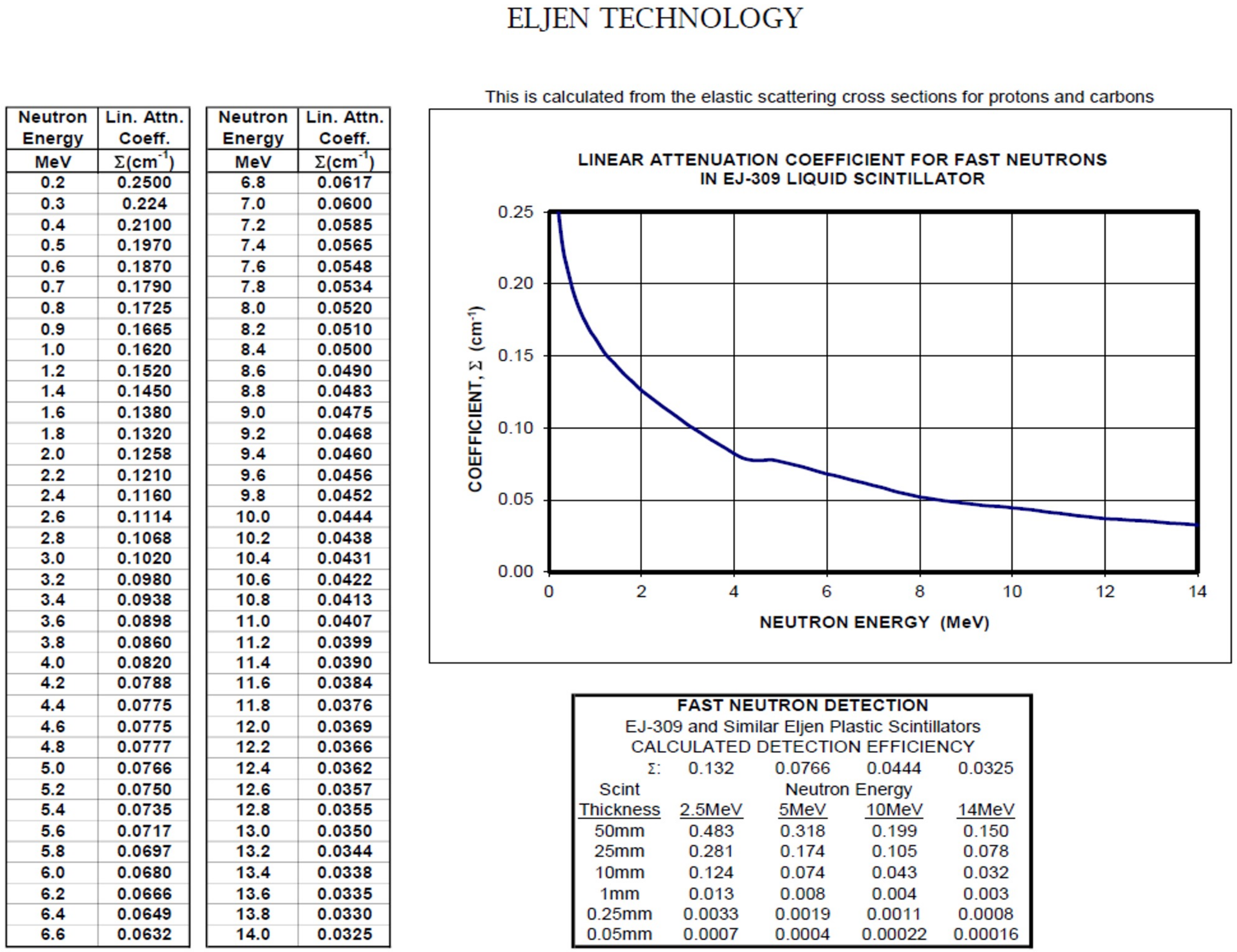
Electrons		Protons		Alphas		Carbon	
MeV	# Photons	MeV	# Photons	MeV	# Photons	MeV	# Photons
0.10	1,230	0.10	83	0.10	20	0.10	13
0.13	1,600	0.13	109	0.13	26	0.13	16
0.17	2,090	0.17	148	0.17	33	0.17	19
0.20	2,460	0.20	180	0.20	39	0.20	22
0.24	2,950	0.24	226	0.24	47	0.24	26
0.30	3,690	0.30	303	0.30	60	0.30	31
0.34	4,180	0.34	357	0.34	69	0.34	34
0.40	4,920	0.40	449	0.40	83	0.40	39
0.48	5,900	0.48	594	0.48	102	0.48	45
0.60	7,380	0.60	834	0.60	133	0.60	54
0.72	8,860	0.72	1,119	0.72	166	0.72	62
0.84	10,330	0.84	1,445	0.84	204	0.84	70
1.00	12,300	1.00	1,921	1.00	258	1.00	81
1.30	15,990	1.30	2,934	1.30	371	1.30	100
1.70	20,910	1.70	4,502	1.70	542	1.70	125
2.00	24,600	2.00	5,812	2.00	691	2.00	143
2.40	29,520	2.40	7,688	2.40	923	2.40	168
3.00	36,900	3.00	10,652	3.00	1,353	3.00	204
3.40	41,820	3.40	12,817	3.40	1,679	3.40	230
4.00	49,200	4.00	16,322	4.00	2,232	4.00	269
4.80	59,040	4.80	21,131	4.80	3,143	4.80	320
6.00	73,800	6.00	28,413	6.00	5,006	6.00	398
7.20	88,560	7.20	36,285	7.20	7,466	7.20	477
8.40	103,320	8.40	44,526	8.40	10,701	8.40	555
10.00	123,000	10.00	55,965	10.00	16,236	10.00	664
13.00	159,900	13.00	78,228	13.00	28,905	13.00	878
17.00	209,100	17.00	108,609	17.00	49,569	17.00	1215
20.00	246,000	20.00	132,840	20.00	66,912	20.00	1494
24.00	295,200	24.00	166,050	24.00	91,143	24.00	1888
30.00	369,000	30.00	217,710	30.00	128,166	30.00	2539
34.00	418,200	34.00	252,150	34.00	153,012	34.00	3028
40.00	492,000	40.00	305,040	40.00	190,650	40.00	3843



RESPONSE OF EJ-309 LIQUID SCINTILLATOR

SCINTILLATION LIGHT PRODUCED VS. PARTICLE ENERGY

Data Source: V.V. Verbinski et al, Nucl. Instrum. & Meth. **65** (1968) 8-25



ELJEN TECHNOLOGY

Neutron Energy MeV	Lin. Attn. Coeff. $\Sigma(cm^{-1})$
0.2	0.2500
0.3	0.224
0.4	0.2100
0.5	0.1970
0.6	0.1870
0.7	0.1790
0.8	0.1725
0.9	0.1665
1.0	0.1620
1.2	0.1520
1.4	0.1450
1.6	0.1380
1.8	0.1320
2.0	0.1258
2.2	0.1210
2.4	0.1160
2.6	0.1114
2.8	0.1068
3.0	0.1020
3.2	0.0980
3.4	0.0938
3.6	0.0898
3.8	0.0860
4.0	0.0820
4.2	0.0788
4.4	0.0775
4.6	0.0775
4.8	0.0777
5.0	0.0766
5.2	0.0750
5.4	0.0735
5.6	0.0717
5.8	0.0697
6.0	0.0680
6.2	0.0666
6.4	0.0649
6.6	0.0632

Neutron Energy MeV	Lin. Attn. Coeff. $\Sigma(cm^{-1})$
6.8	0.0617
7.0	0.0600
7.2	0.0585
7.4	0.0565
7.6	0.0548
7.8	0.0534
8.0	0.0520
8.2	0.0510
8.4	0.0500
8.6	0.0490
8.8	0.0483
9.0	0.0475
9.2	0.0468
9.4	0.0460
9.6	0.0456
9.8	0.0452
10.0	0.0444
10.2	0.0438
10.4	0.0431
10.6	0.0422
10.8	0.0413
11.0	0.0407
11.2	0.0399
11.4	0.0390
11.6	0.0384
11.8	0.0376
12.0	0.0369
12.2	0.0366
12.4	0.0362
12.6	0.0357
12.8	0.0355
13.0	0.0350
13.2	0.0344
13.4	0.0338
13.6	0.0335
13.8	0.0330
14.0	0.0325

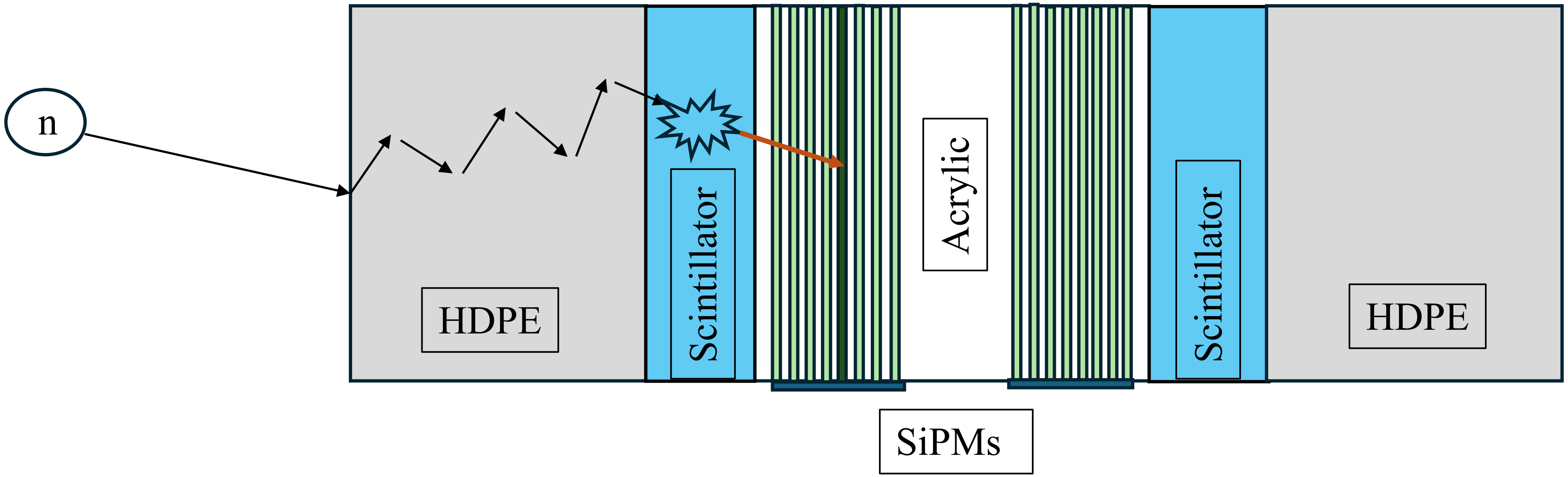
This is calculated from the elastic scattering cross sections for protons and carbons

FAST NEUTRON DETECTION
EJ-309 and Similar Eljen Plastic Scintillators
CALCULATED DETECTION EFFICIENCY

	2.5MeV	5MeV	10MeV	14MeV
Σ:	0.132	0.0766	0.0444	0.0325
Scint Thickness	Neutron Energy			
50mm	0.483	0.318	0.199	0.150
25mm	0.281	0.174	0.105	0.078
10mm	0.124	0.074	0.043	0.032
1mm	0.013	0.008	0.004	0.003
0.25mm	0.0033	0.0019	0.0011	0.0008
0.05mm	0.0007	0.0004	0.00022	0.00016

How the detector works

$^{6}Li + n \rightarrow {}^{4}He + {}^{3}H$



Moderated

HPDE & Acrylic Hydrogenous material

Neutron Capture in Li

^{6}Li-containing ZnS(Ag) scintillator

Scintillation in Zn(Ag)

Scintillation light propagates in clear Acrylic

Light capture

Captured in WLS fibers

SiPM