Characterisation of Gas Properties in a Spherical Proportional Counter

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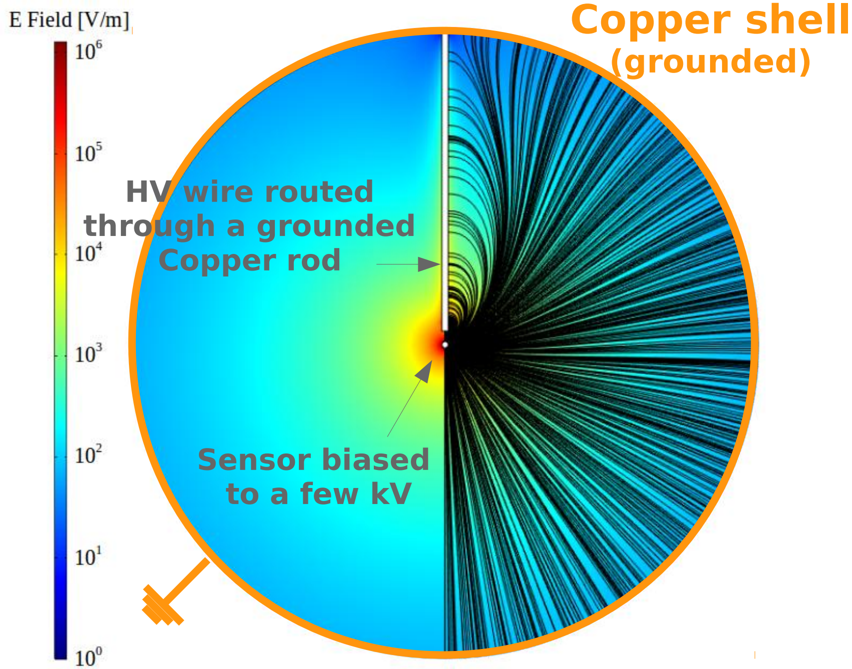
9th Symposium on Large TPCs for Low-Energy Rare Event Detection
Paris, France

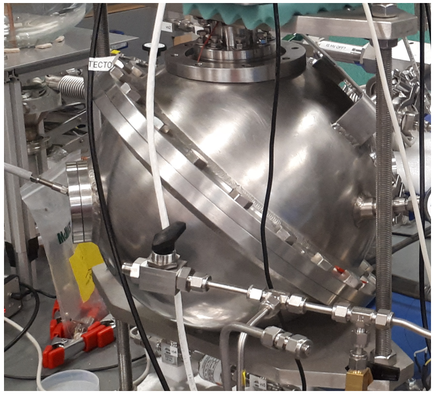
Outline

- Spherical proportional Counters
- Experimental setup with UV laser
- Analysis of Single Electron Response
- Extraction of Gas Properties

Spherical Proportional Counters (SPC)



- Gaseous proportional counter
  - Metal sphere
  - Central ball with HV
- Very low capacitance
  - <1pF
- Drifting electrons from ionisation
- Light gas optimal for low mass WIMPs
- 1 channel, 1 HV
  - drift and amplification fields linked



Vessel

30 cm ∅ Stainless Steel

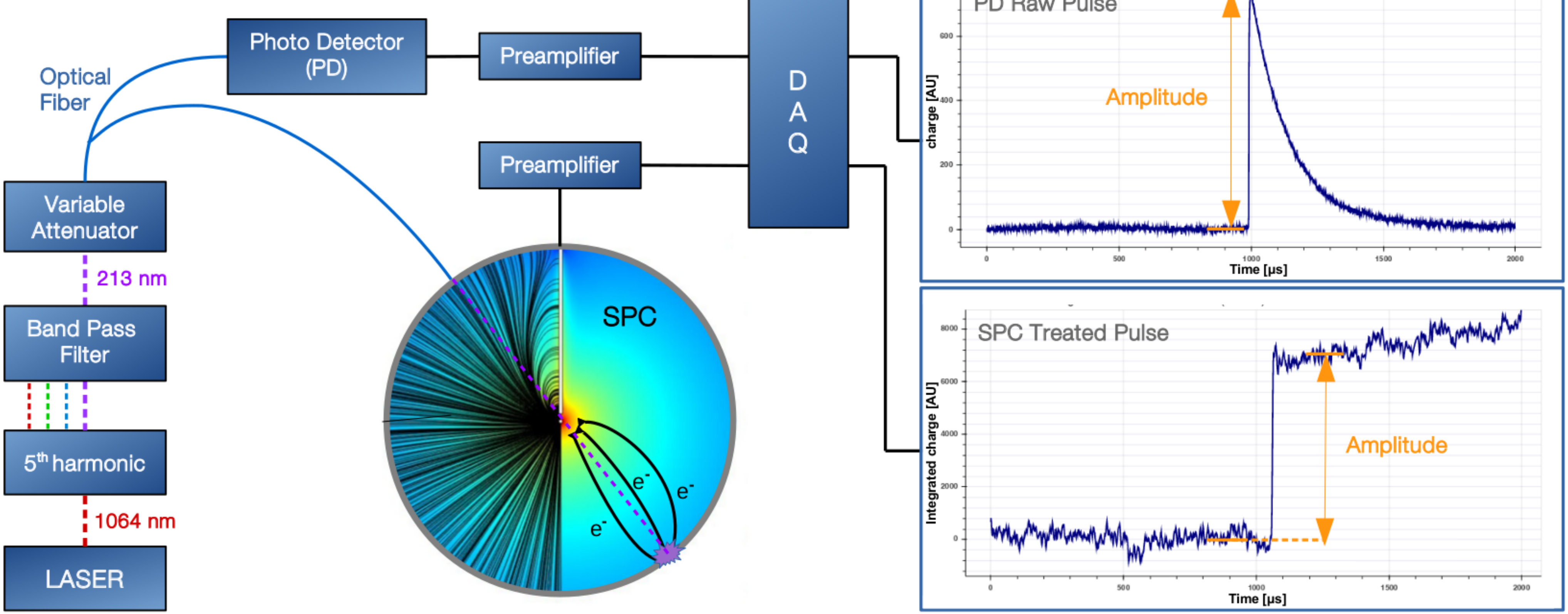
Sensor

2 mm ∅

Experimental Setup

- Characterization of the SPC response down to single electrons (SER)
  - Precision measurements of the avalanche gain
  - Drift time, Diffusion time, W-value and Fano Factor measurements
  - Monitoring of the stability of the detector response during WIMP search runs
  - Experimental measurement of the trigger threshold efficiency

Scheme of the experimental set-up

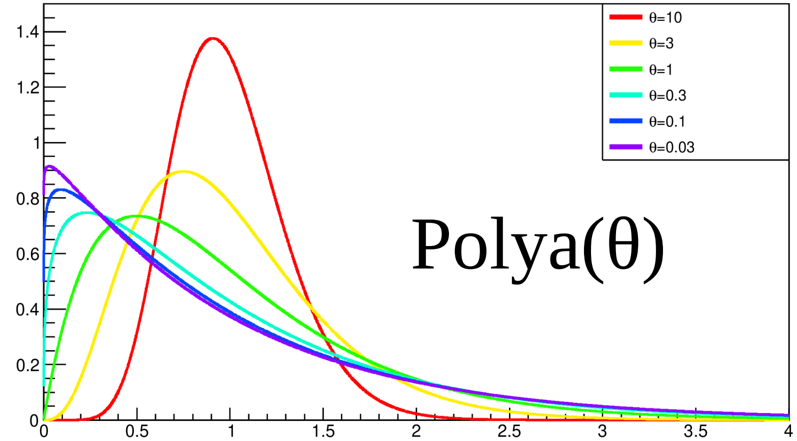


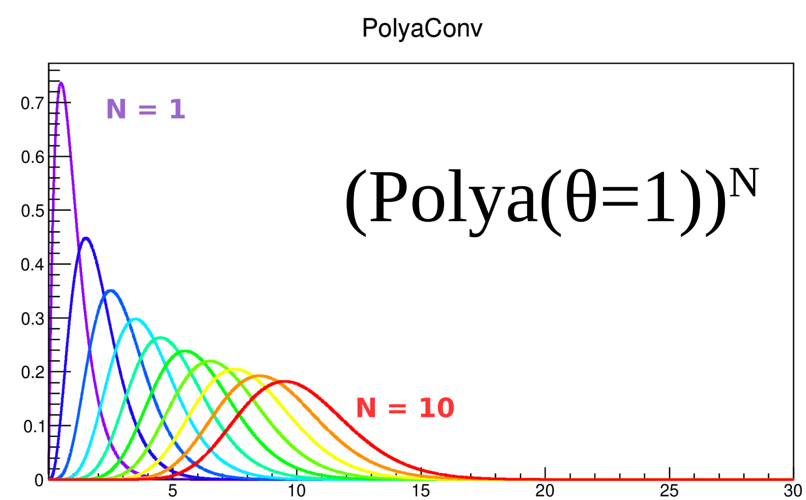
Analysis Methodology

- Single electron response
  - Polya distribution (<G>,θ)

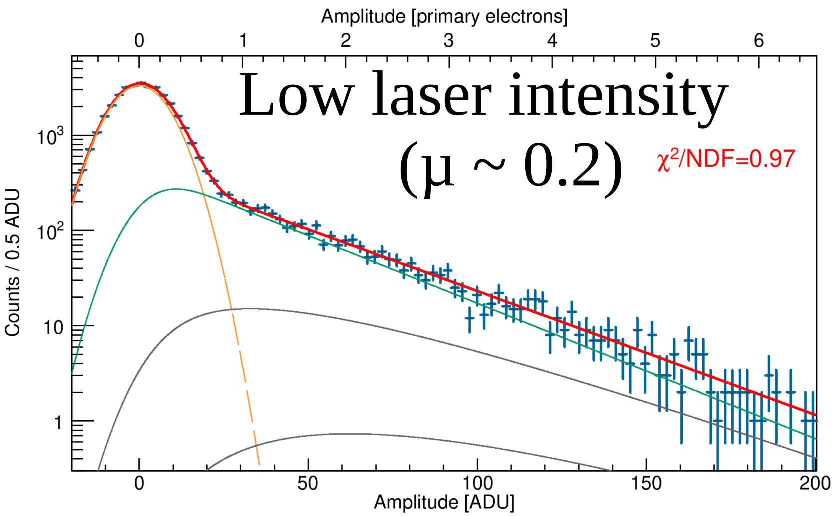
$$P_{Polya}(X) = \frac{1}{\langle G \rangle} \frac{\cdot(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{X}{\langle G \rangle}\right)^{\theta} \exp\left(-(1+\theta)\frac{X}{\langle G \rangle}\right)$$

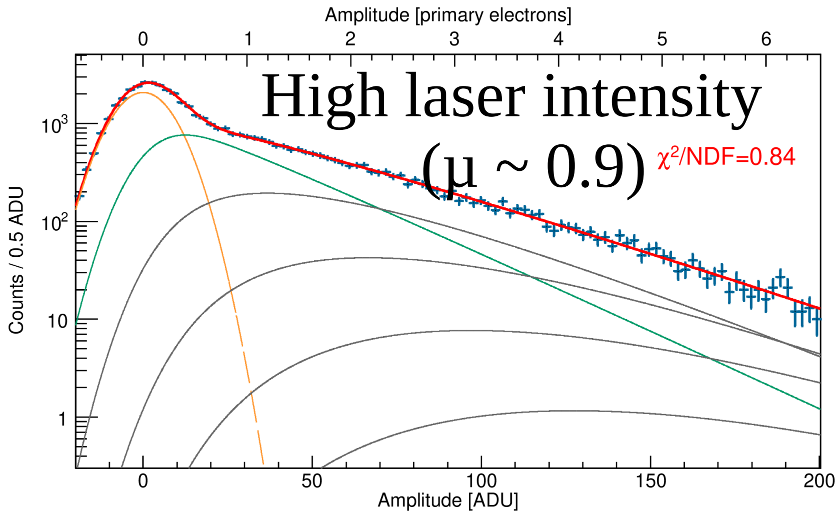
  - non correlated (true for low signal)
  - N electrons → N^{th} convolution of Polya
- N photo electrons
  - Poisson distribution (μ)





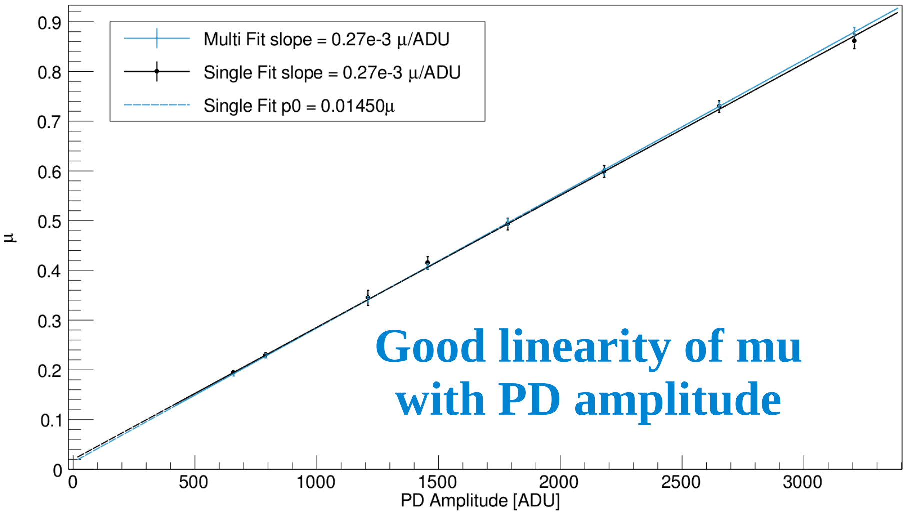
Fitting Data

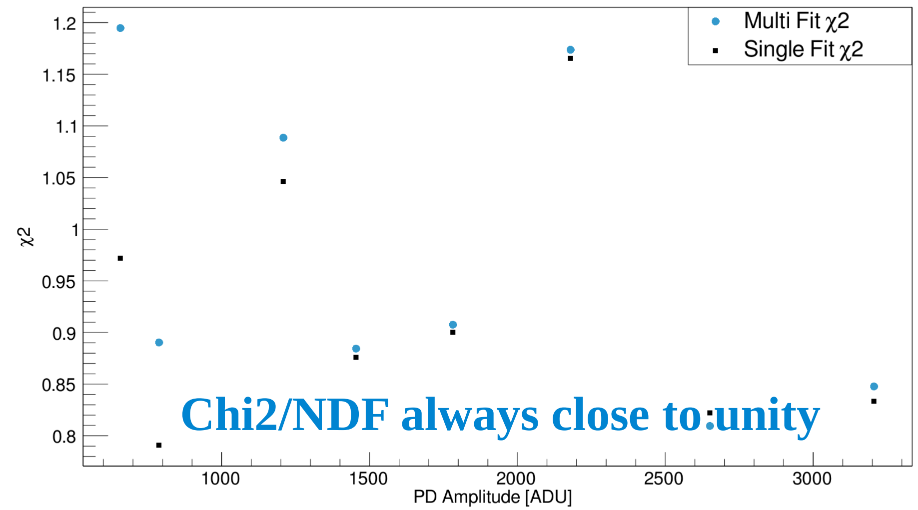


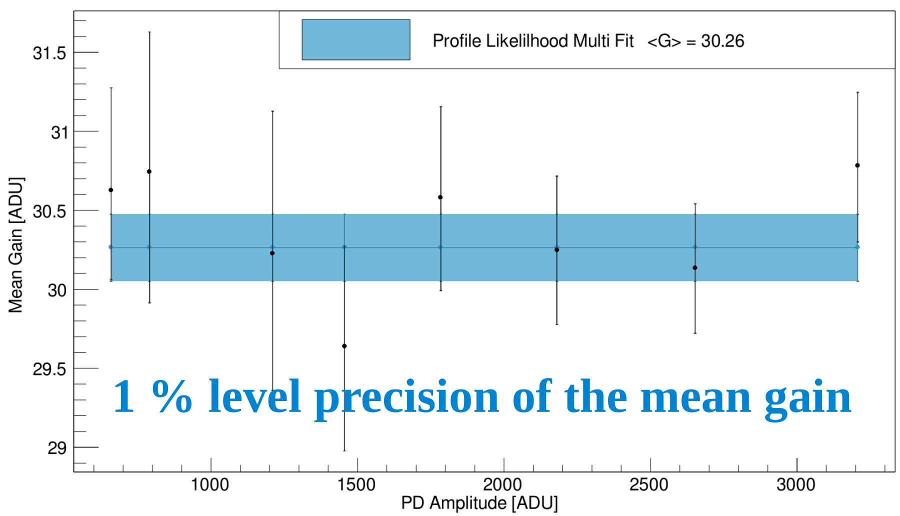


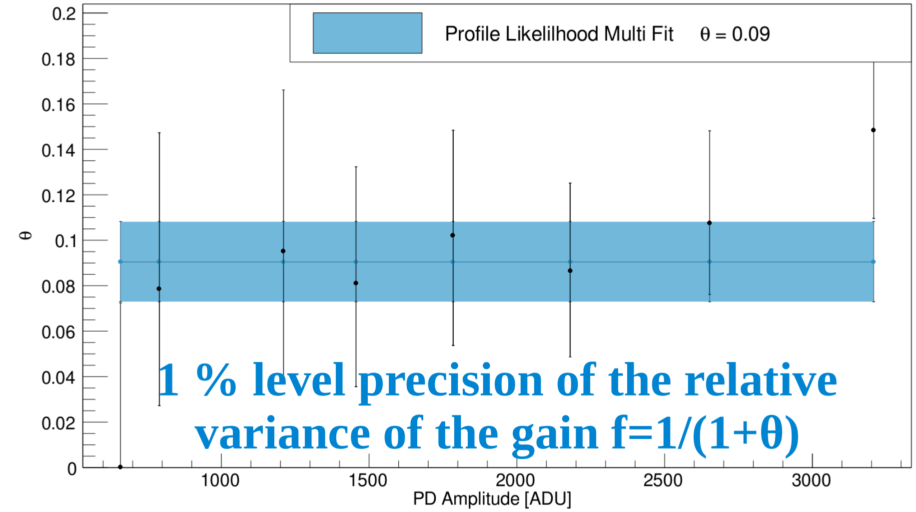
- Data triggered on photodetector
  - includes null events
  - slices of +- 5% laser intensity (PD signal)
- 4 parameters: <G>, θ, μ, σ_{Noise}
- Binned likelihood fit
  - single intensity slices
  - joint fit (multiple μ values)

Consistency check









Excellent agreement between model and data

Precision characterization of the Single Electron Response (SER)

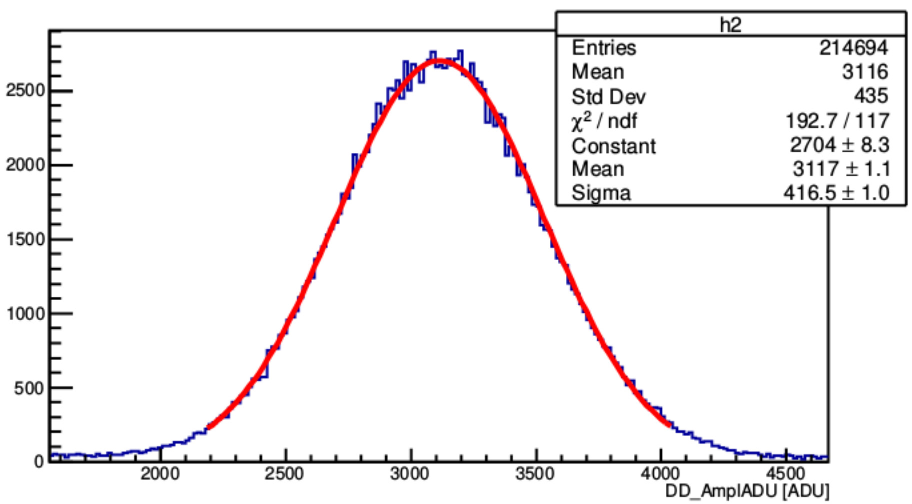
SER Characterisation

- Experimental condition
  - Ne:CH4 (98:2) at 1.5 bar
  - HV from 1100 V to 1250V → Gains 103 - 104
  - UV-pulsed Laser (10 Hz) + 37Ar (~15 Hz)
- Results
  - SER close to exponential (Fury) law $\theta \sim (0.10 \pm 0.05)$
  - Gain consistent within 1% between runs in same conditions
  - Relative gain variance $f = \frac{1}{1+\theta} \sim (0.91 \pm 0.04)$

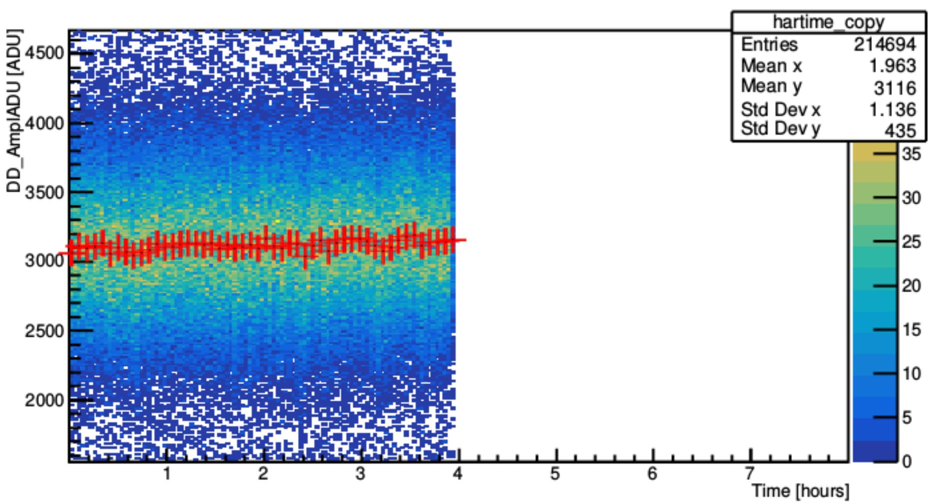
W-value from ^{37}Ar

- Simultaneous measurement of 37Ar
  - 2.83keV and 270eV Xrays
  - similar rate to laser

2.8keV peak



Stability over ~4h



W-value from ^{37}Ar

- W-value = mean energy to create e$^-$-ion pair

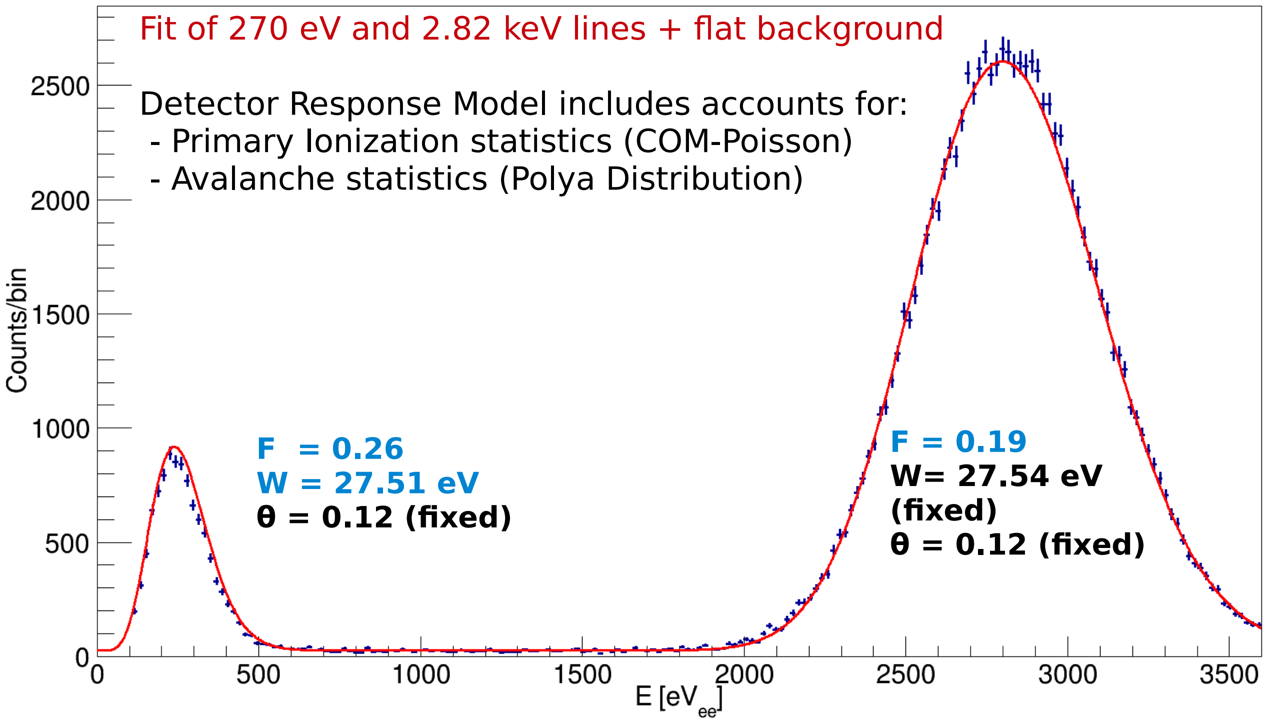
$$W = N_{electrons}/E_{peak}$$

		Gain [ADU]		W value (2820 eV)	
Run	Voltage	measure	uncertainty	measure	uncertainty
sj26g002a	1200	31.01	0.39	26.73	0.50
sj26g002b	1200	32.44	0.58	27.70	0.56
sj26g002c	1200	32.65	0.44	27.80	0.48
sj26g002d	1200	32.66	0.38	27.86	0.41
sj25g002a	1200	31.20	0.48	27.56	0.52
sj25g002b	1200	31.96	0.50	27.81	0.59
sj21g000a	1100	8.88	0.60	25.87	1.77
sj21g000b	1100	9.03	0.60	26.20	1.76
sj20g000	1150	19.44	0.20	27.47	0.46
sj18g003a	1250	69.5	0.7	27.77	0.63
sj18g003b	1250	74.5	0.67	28.10	0.41

Preliminary Conclusions

- W-value measured: $W=(27.6\pm0.2)$ eV
- W-value for pure Ne $W\sim36$ eV
- Difference expected from Penning effect with CH4
- Some systematic errors are missing

Energy Resolution



	270 eV		2820 eV	
Θ (fixed)	F	W	F	W (fixed)
0.00	0.093	27.97	0.088	27.54
0.12	0.26	27.51	0.19	27.54
0.20	0.39	26.85	0.25	27.54

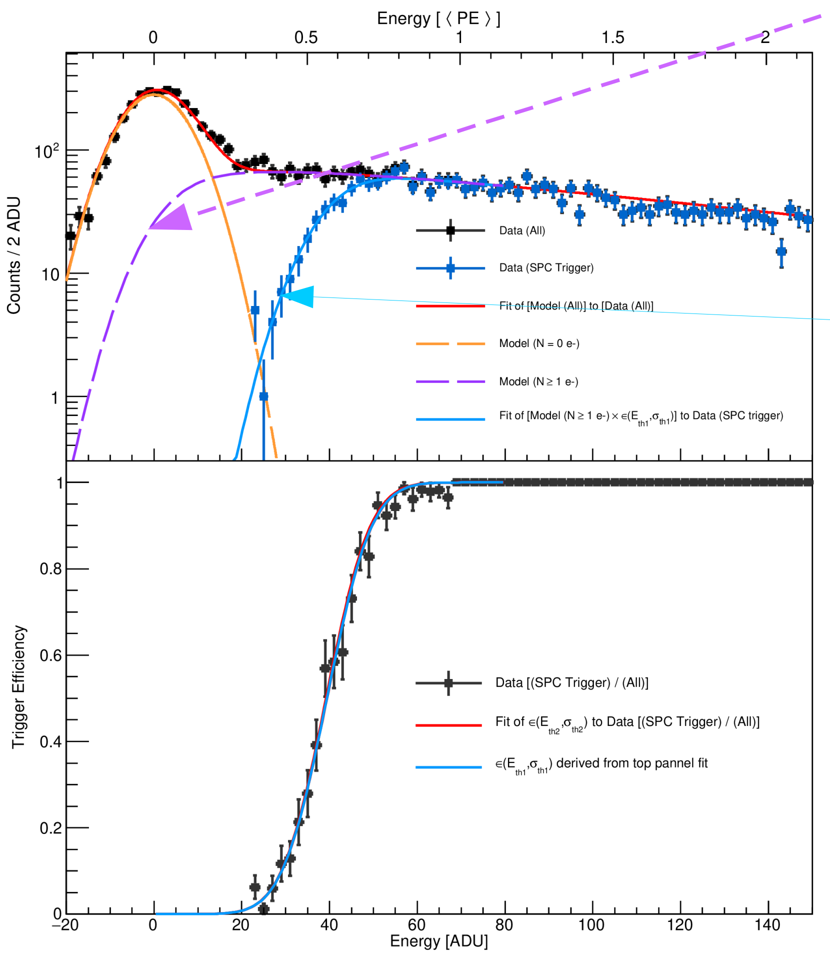
- Resolution depends on
  - W-value
  - Fano factor

$$\left(\frac{\sigma_E}{E}\right)^2 = \frac{W(E_r)}{E_r}\left(\frac{1}{1+\theta} + F(E_r)\right)$$

- Fit of ^{37}Ar spectrum
  - <G>, θ, W(2.8keV) fixed
  - Fano(270eV),F(2.8keV), W(270eV) fitted
- Preliminary conclusion:
  - W(270eV)=W(2.8keV)
  - upper value for Fano

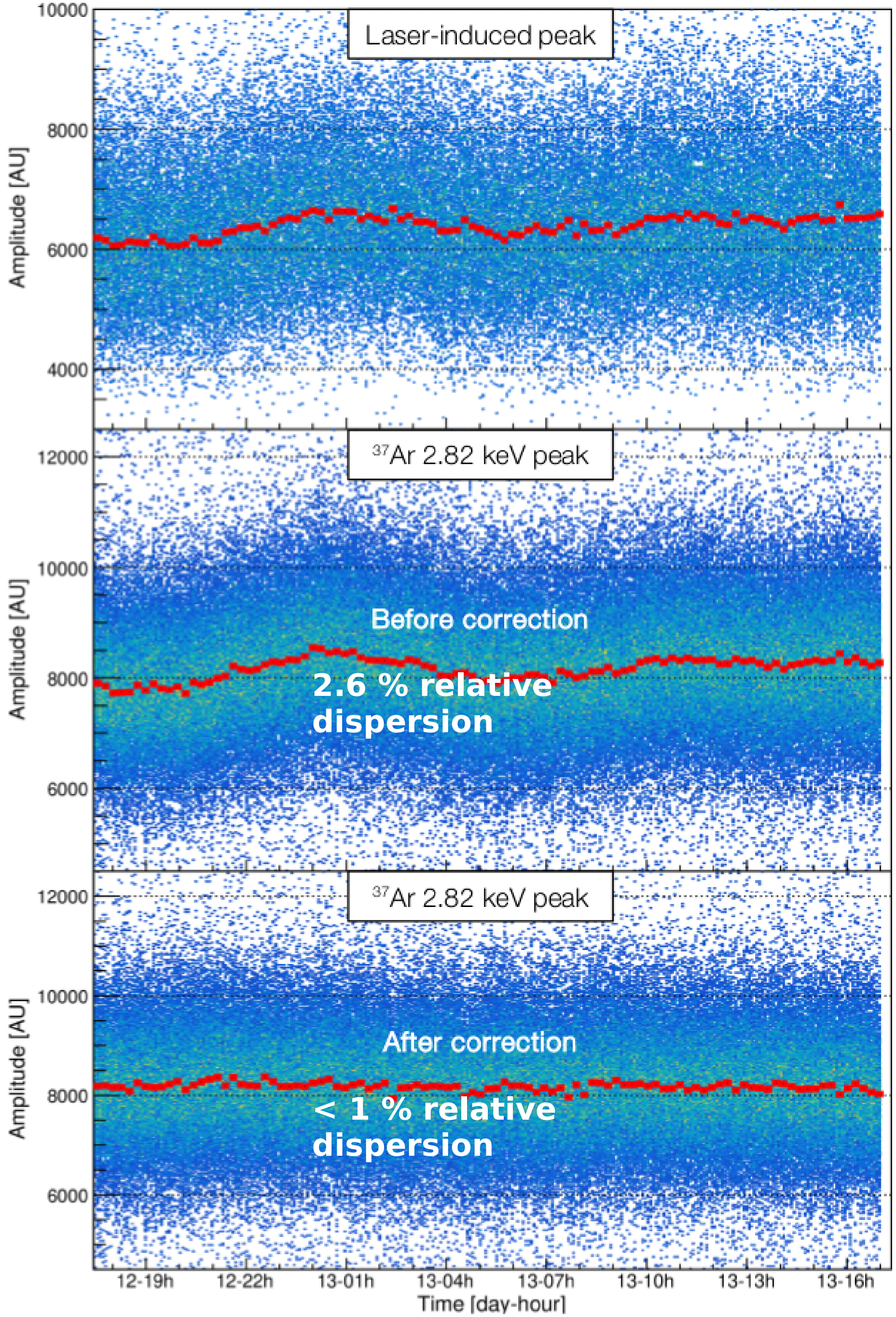
F(2.8keV) < 0.25, F(270eV) < 0.39

Experimental Measurement of Trigger Efficiency



- Events with signal from fit
  - Ne≥1
  - external trigger (PD)
- Triggered events
  - offline trigger
- Efficiency measurement
  - from fit (exact)
  - $N_{trigger}/N_{tot}$ simpler and accurate for our threshold

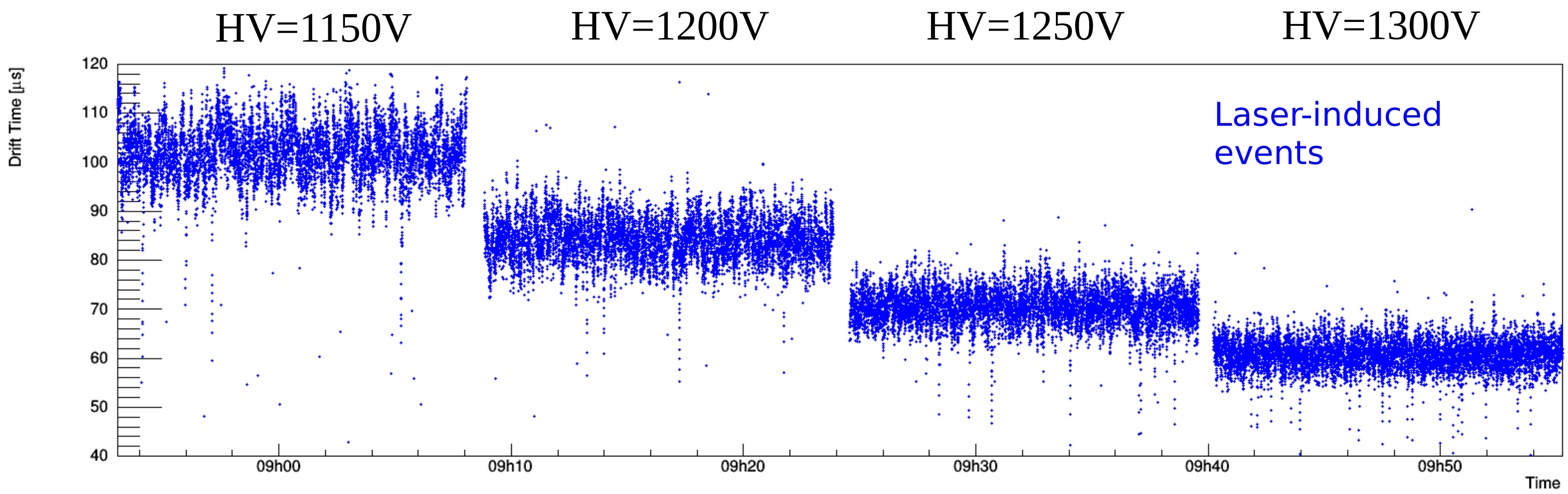
Monitoring over time



Laser can be operated continuously during WIMP search runs

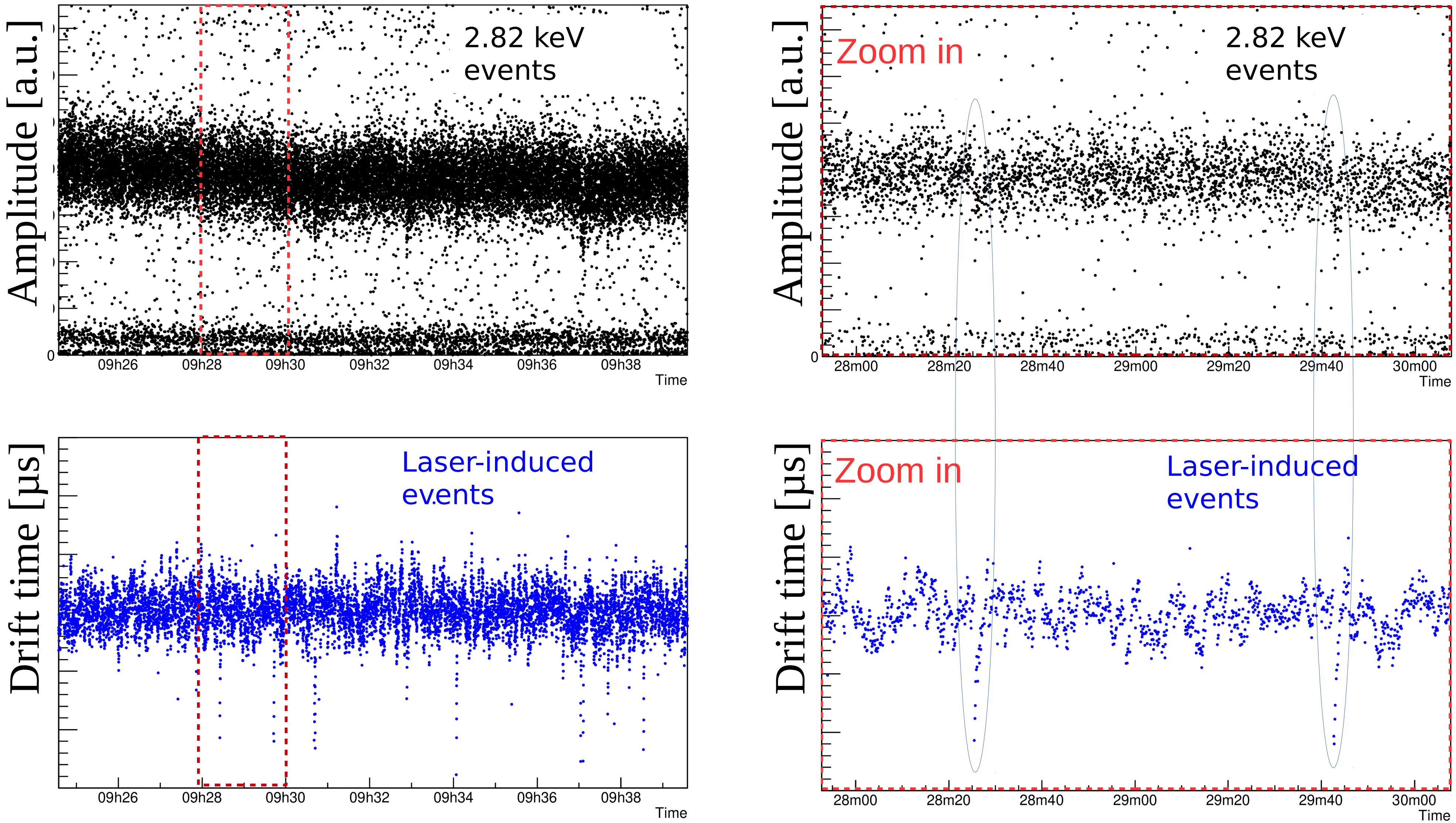
- Ensure the detector is “alive”
- Reject highly unstable periods
- Correct for variations of the gain over time (here, x3 reduction of the relative dispersion of the 2.82 keV peak)
- Cancels possible rate effect (fixed rate ~10Hz)
- No additional background
- Only 2% dead time for 10Hz (2ms event window)

Drift Time Monitoring



- Drift time = Signal time – PD time
- Strong dependence on HV as expected
  - non trivial due to non uniform field
- Short term fluctuation
  - O(1s) time constant
  - probably correlated to gain variations (moving charges)

Drift Time Monitoring



One would expect drift time and gain variations to be anticorrelated (higher drift time = lower electric field = lower gain)
but these are postively correlated ..... to be discussed...

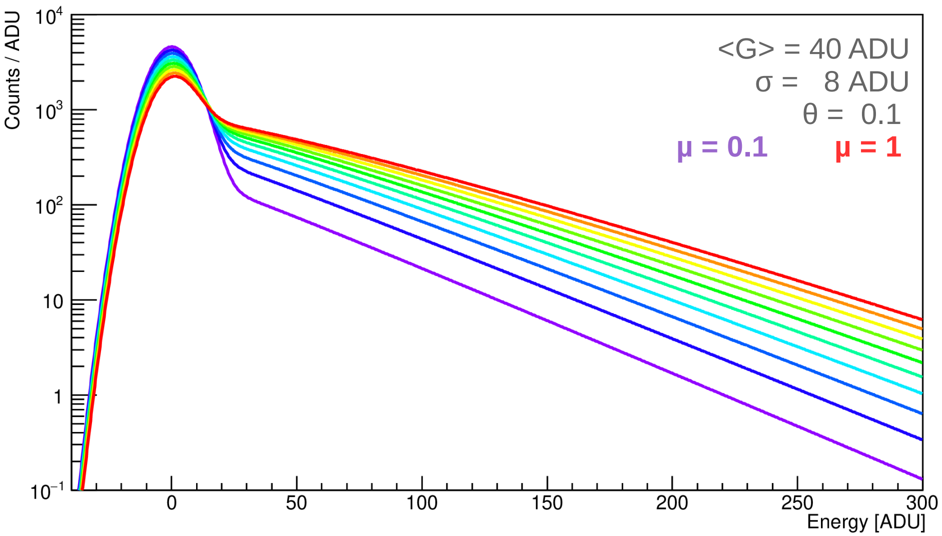
Conclusions

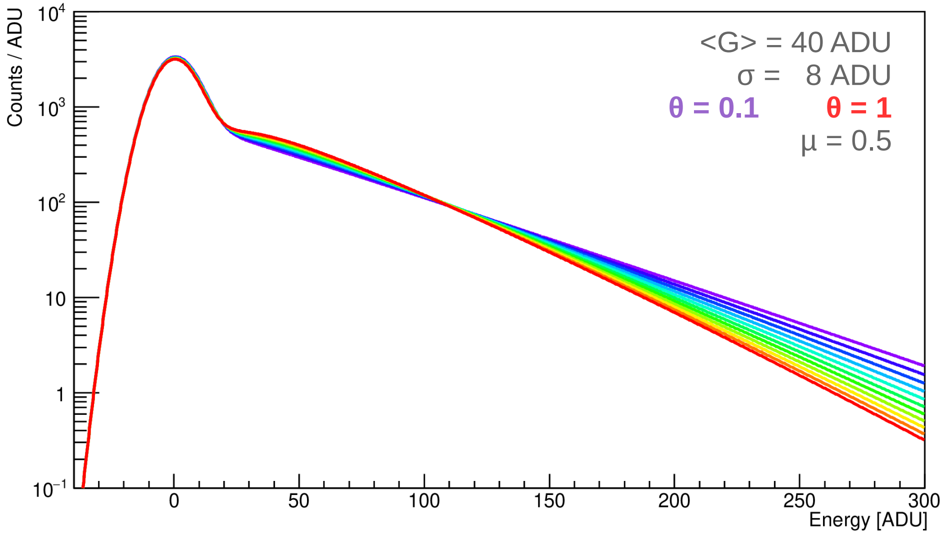
- A UV laser can be used for precise measure of Single Electron Response in SPCs
- The laser signal is well described by Polya and Poisson
  - potential measurement of W and Fano factor
  - calibration of critical parameters in actual gas mixture
- Extra information on drift velocity and diffusion
  - monitoring during DM physics run!
  - potential monitoring at very short time scale (~1s)

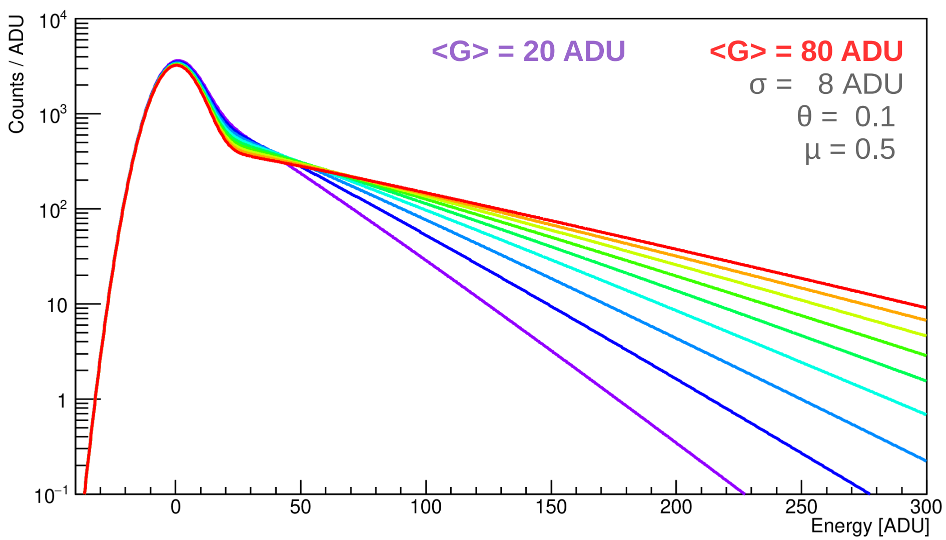
UV laser is a powerful tool for detector characterisation and monitoring in rare event search

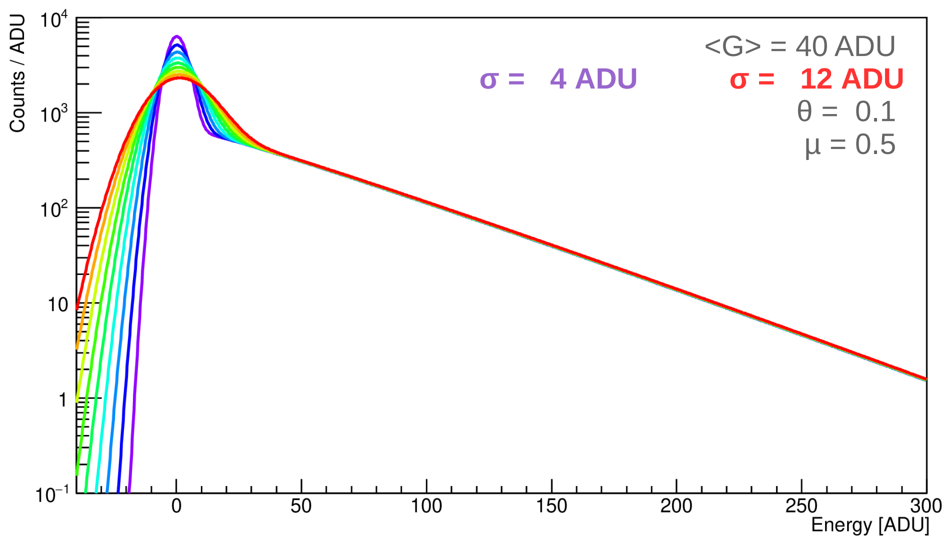
Back-up

Effect of the parameters on the energy spectrum measured





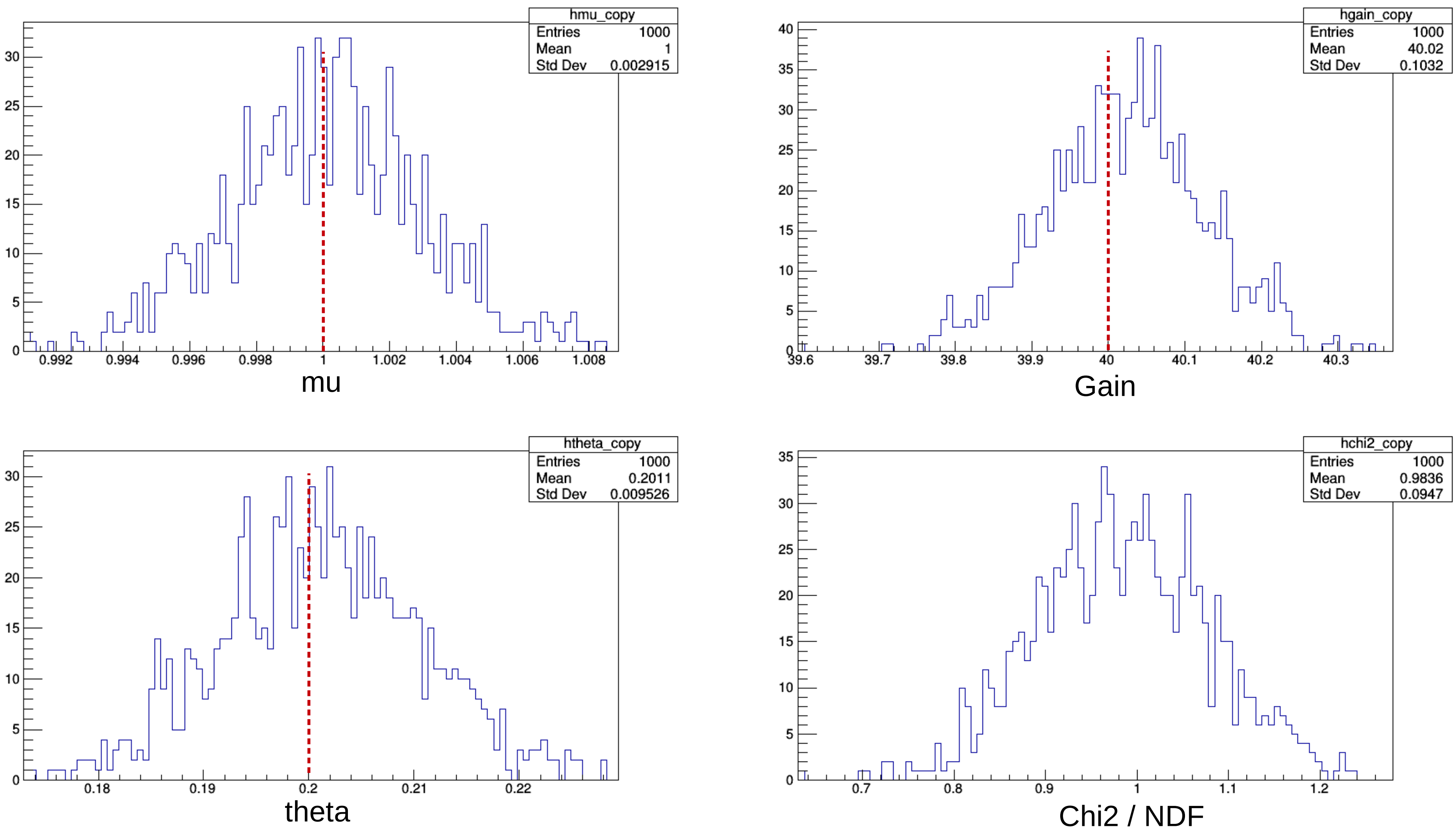




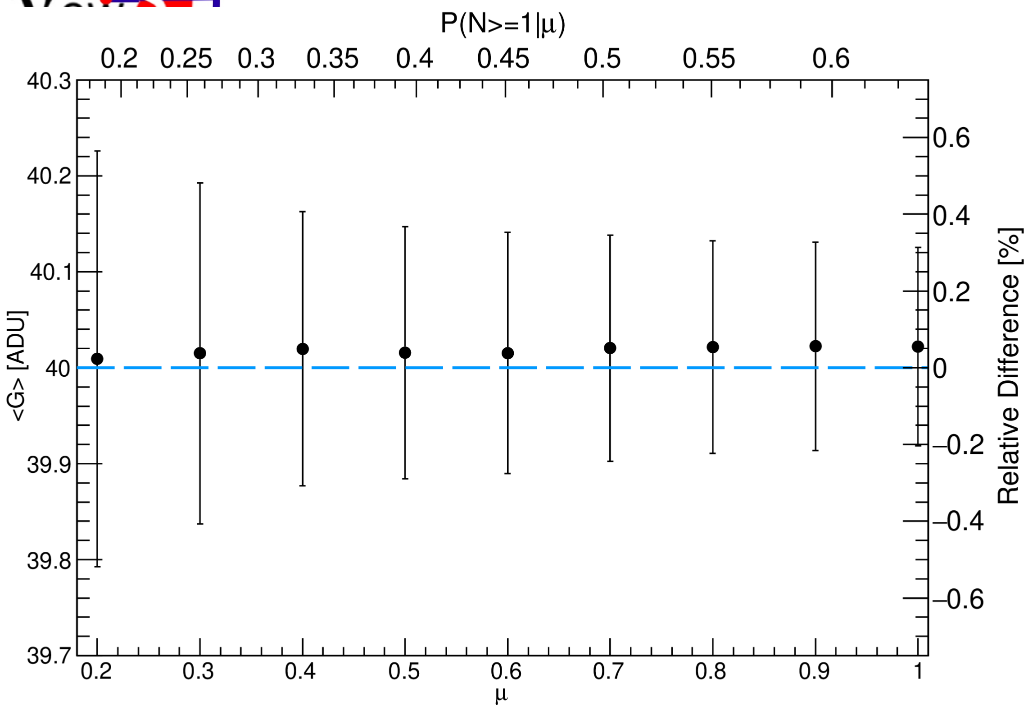
Assess the systematic uncertainty associated with non-fixed mu

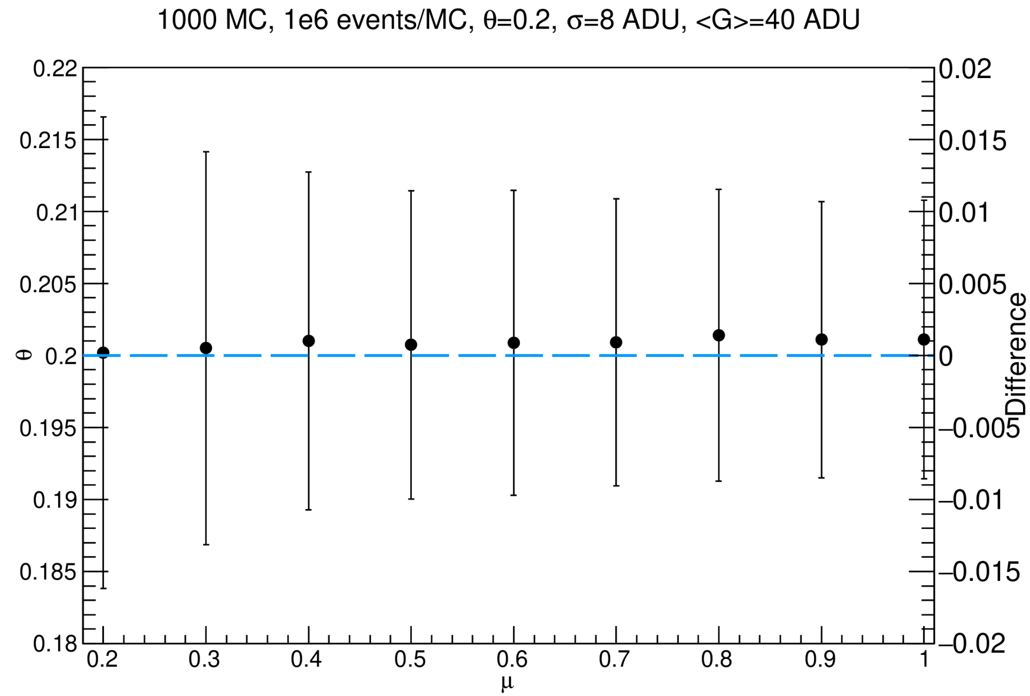
Simulate 1000 MC (toy data sets) {
For each MC, Simuate 1e6 events{
For each event{
Amplitude simulated with fixed Gain, theta and sigma
but with mu drawn randomly between 95% and 105% of mu
}
}
Fit the data and save best fit values
}

Distribution of best fit values



Assess the systematic uncertainty associated with non-fixed mu





The bias induced by +-5 % fluctuations of mu on the reconstruction of the mean gain is extremely small

$$\frac{P(N|\mu(1+\epsilon))+P(N|\mu(1-\epsilon))}{2} \sim P(N|\mu)\times\left(1+\frac{\epsilon^2}{2}(N^2-3N+1)\right)$$

For +- 5 % fluctuations :

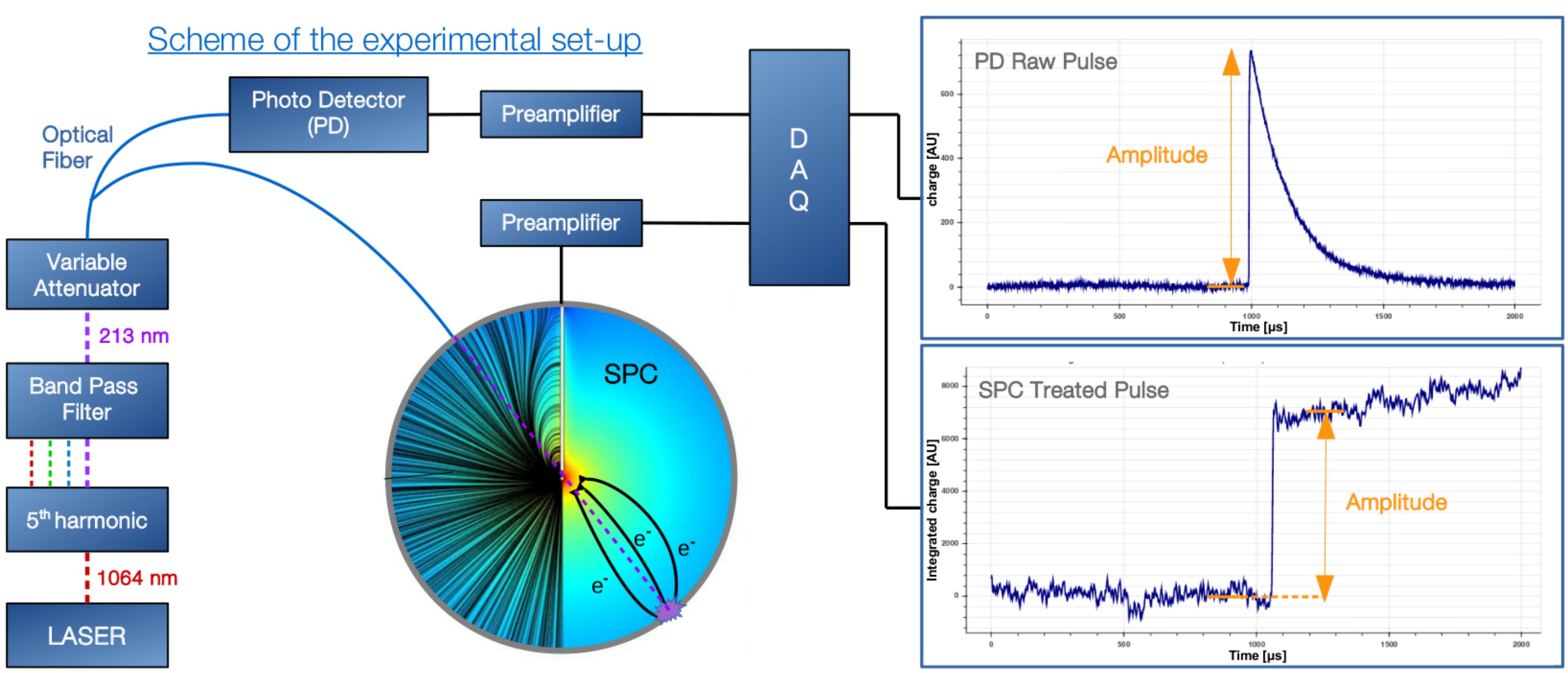
$$\frac{P(N|1.05\mu)+P(N|0.95\mu)}{2} \sim P(N|\mu)\times\left(1+0.00125\times(N^2-3N+1)\right)$$

Experimental approach

The inner surface of the vessel is illuminated with a UV laser to extract a tunable number of photo-electrons down to a single quanta !

Applications:

Characterization of the SPC response down to single electrons
Precision (1 % level) measurements of the avalanche gain and of the relative gain variance
Study of gas properties : Drift time, Diffusion time, W-value, Fano Factor
Monitoring of the stability of the detector response during WIMP search runs
Experimental measurement of the trigger threshold efficiency



UV-Laser beam (213 nm)

Compact diode-pumped solid state active Q-switched laser (1064nm) coupled with a fifth harmonic generator : output beam 213 nm
Left-over radiation (1064 nm, 532 nm, 355 nm, 266 nm) supressed by a 213 nm band-pass filter
Neutral Density variable attenuator : tunable transmission from 1 % to 100 %

PhotoDetector (PD)

Si Biased PD (Thorlabs, DET10 A, ~0.02 A/W) + CREMAT Preamplifier (CR-110, RC=140 µs)
- relative resolution of the PD to a fixed laser power measured to be always of ~ 1 % or better

Spherical Proportional Counter (SPC)

30 cm diameter stainless steel vessel, 2 mm diameter sensor with Bakelyte umbrella