Attenuation length measurement of wavelength-shifting fibers

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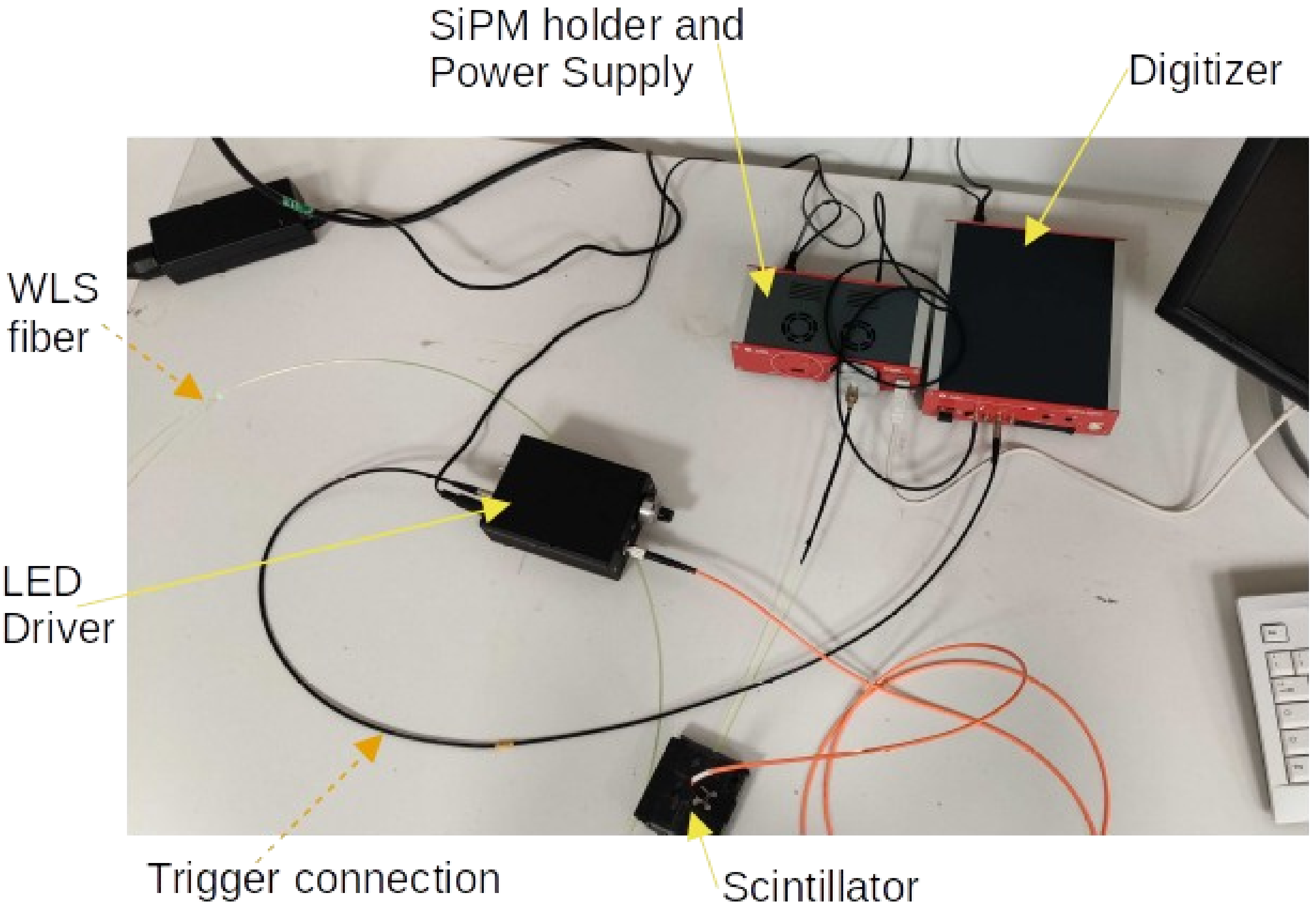
Introduction

- Measure attenuation length of wavelength-shifting fibers
  - Vary position of scintillator on 3 m fiber
    - position and heights of peak spectrum (histogram)
- Use different fibers
  - Thickness
  - Different doping materials

General setup

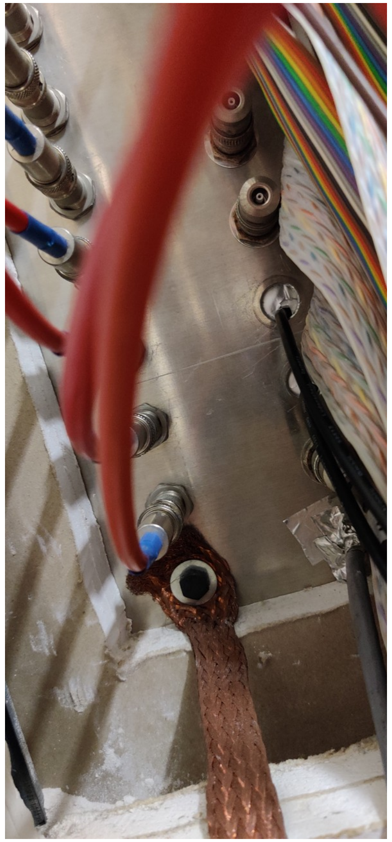
Use SP5600E Educational Photon Kit (CAEN)

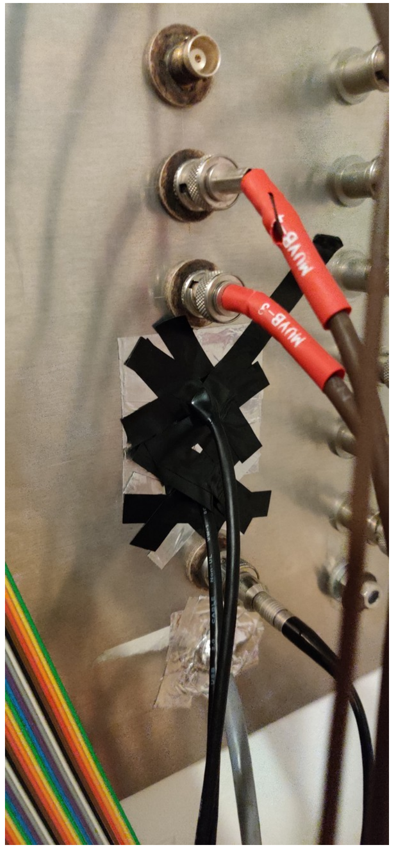
- HAMAMATSU MPPC S13360-1350CS SiPM
  - 1.3 mm x 1.3 mm
  - 3% crosstalk probability
  - Holder with temperature sensor
- LED Driver
  - typical peak wavelength 405 nm (25°C)
- Digitizer
  - takes trigger from LED Driver



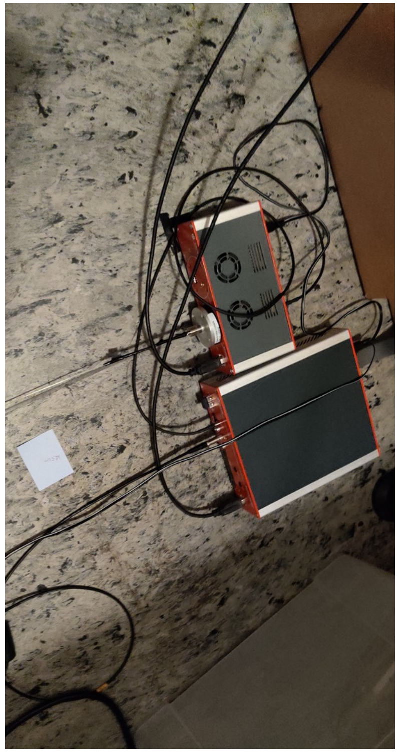
Setup in dark room

Cable feed-through



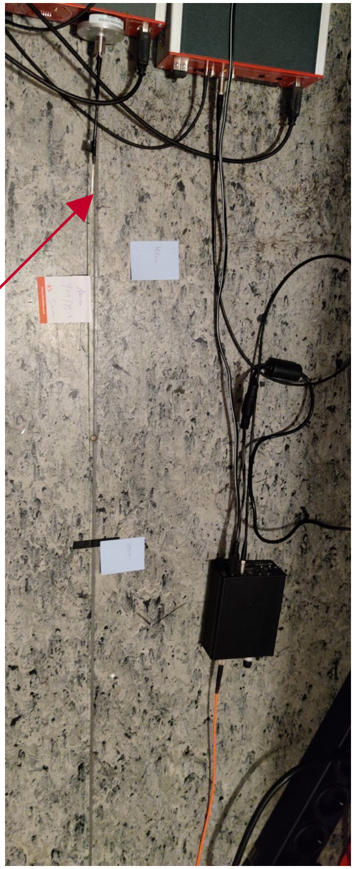


SiPM and Digitizer

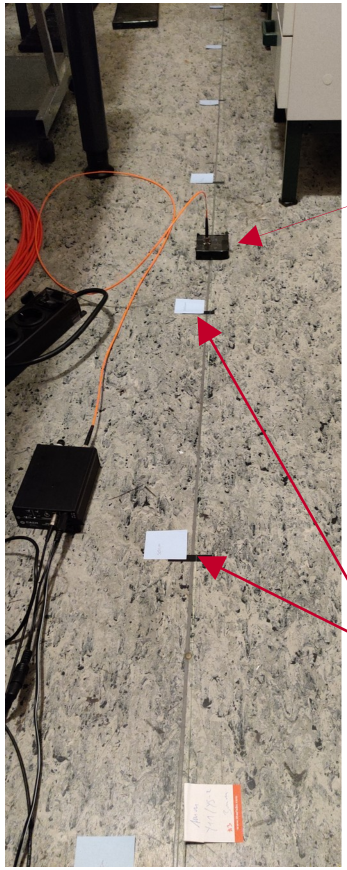


LED Driver

fiber



Fiber and Scintillator



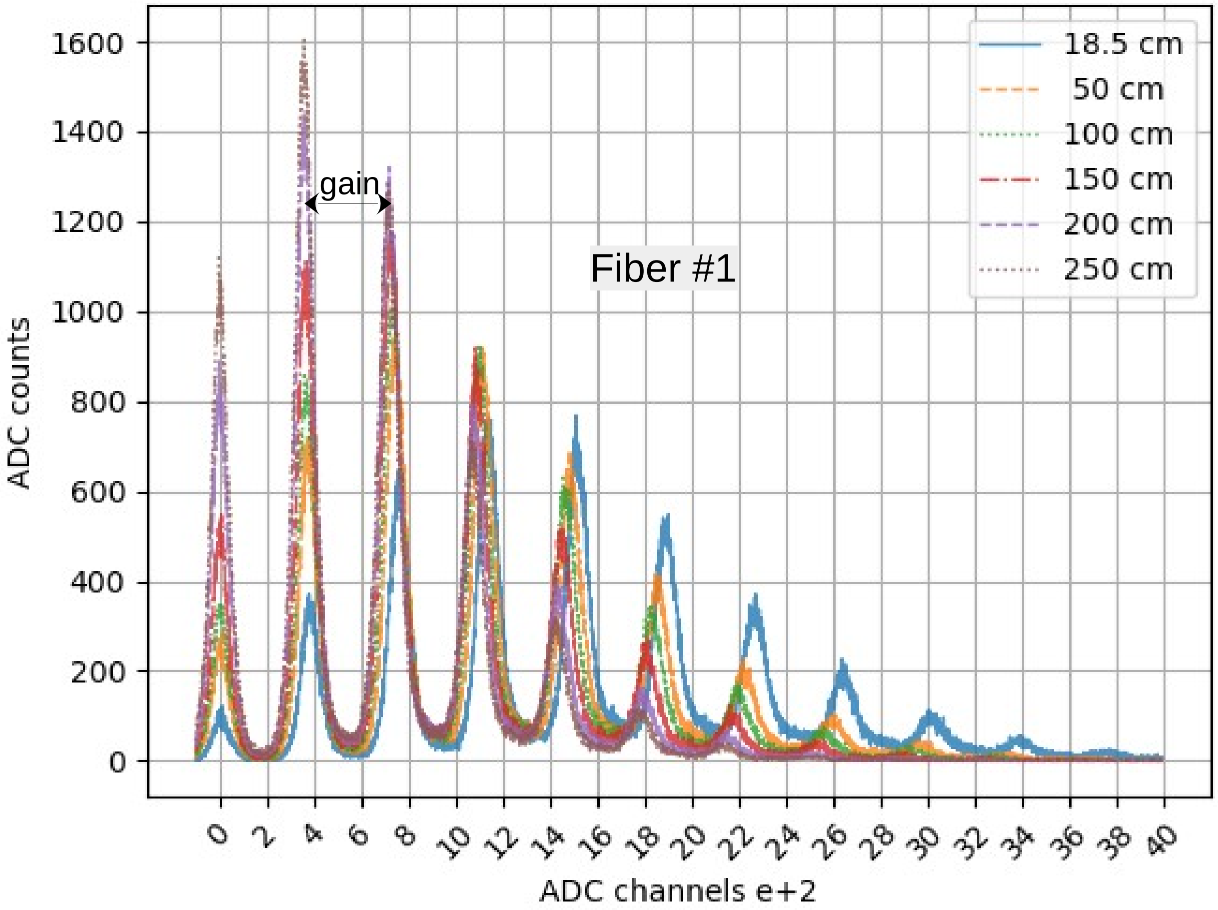
scintillator

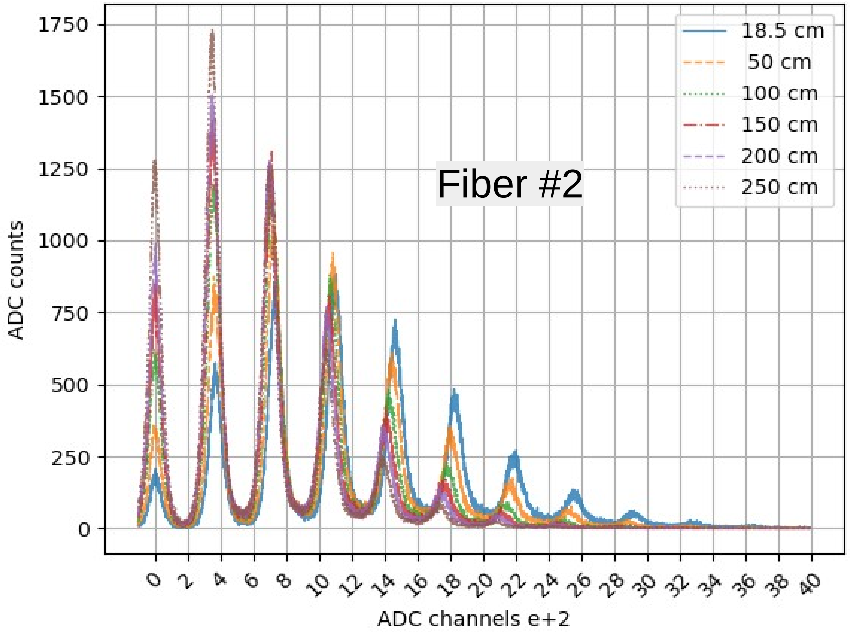
50 cm
markings

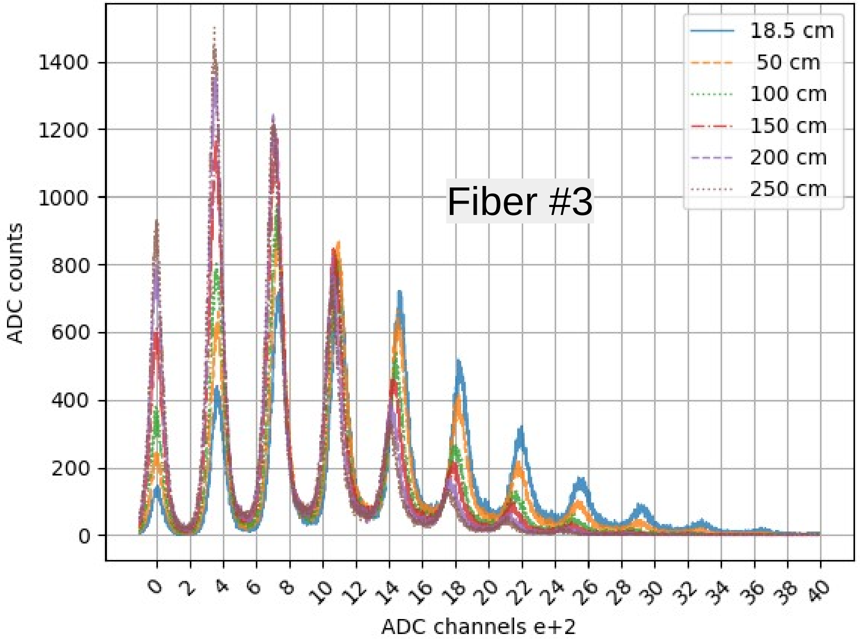
First measurements

- LED position in scintillator at 18.5, 50, 100, 150, 200 and 250 cm
- Took data for 100 s (O(500k) events per position)
- 3 fibers of 1.0 mm diameter
  - 2 are YS-2, 1 is Y11 (Kuraray fibers)
  - Temporary names now #1, #2 and #3 in order of measurement
- Took data in histogram mode (ADC counts – ADC channel)

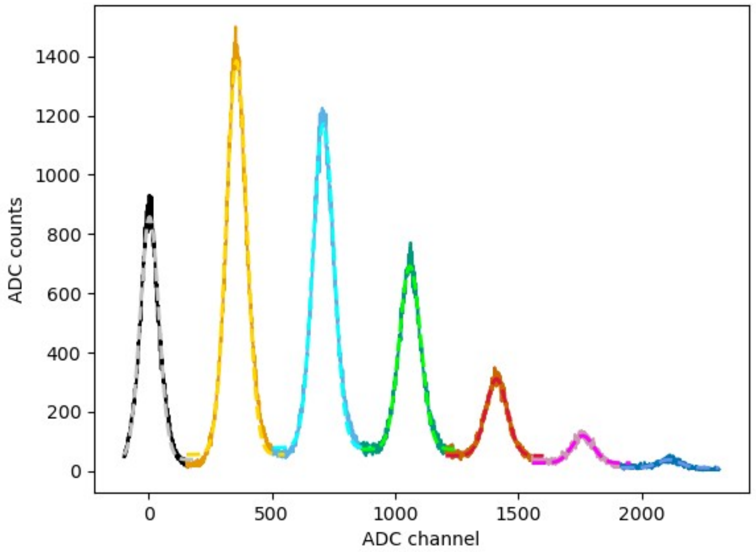
Visualization of measurements



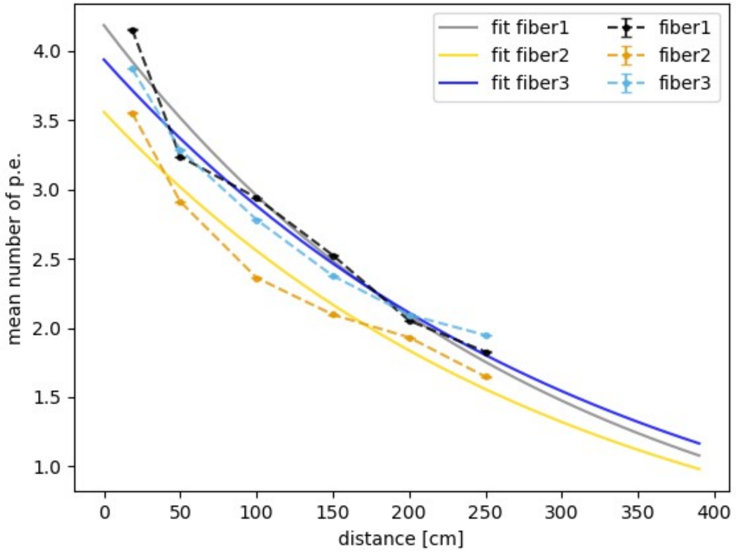




First detailed look

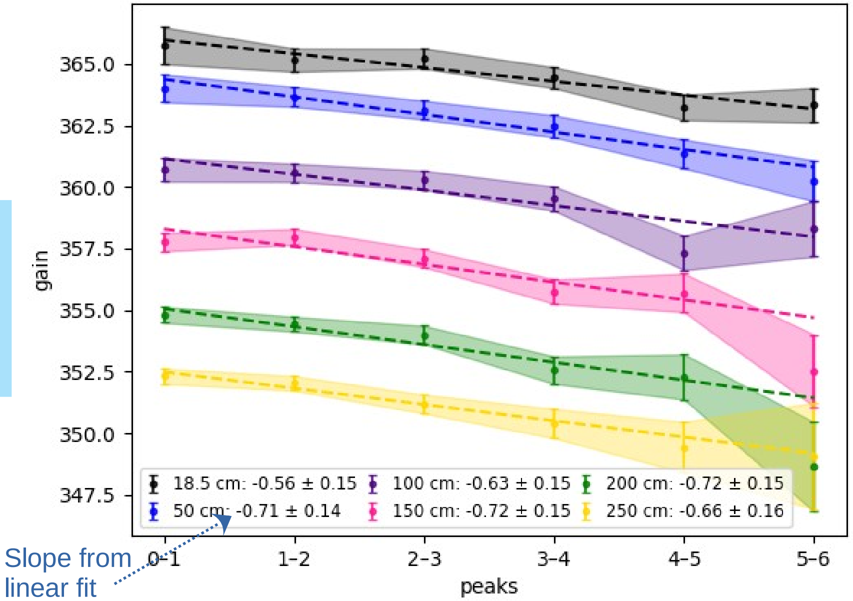


Fit individual peaks with gaussian



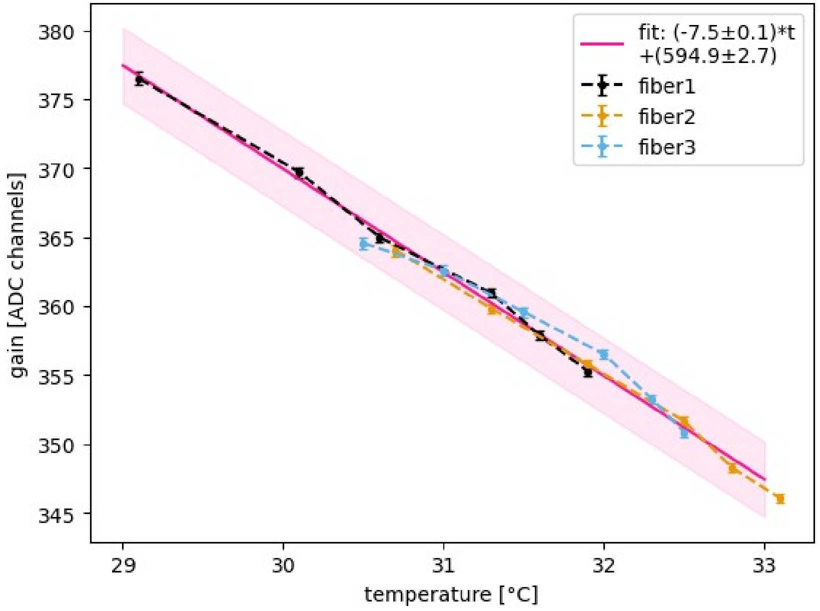
YS-2: fiber 1&3
Y11: fiber 2

Calculate gain between peaks

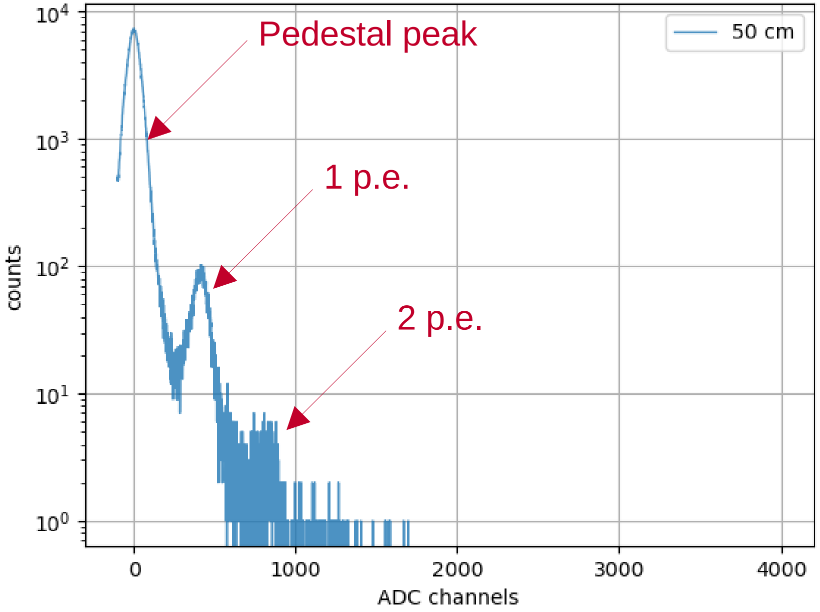


Slope from linear fit

Gain depends linearly on temperature
→ repeat measurements with stable temperature

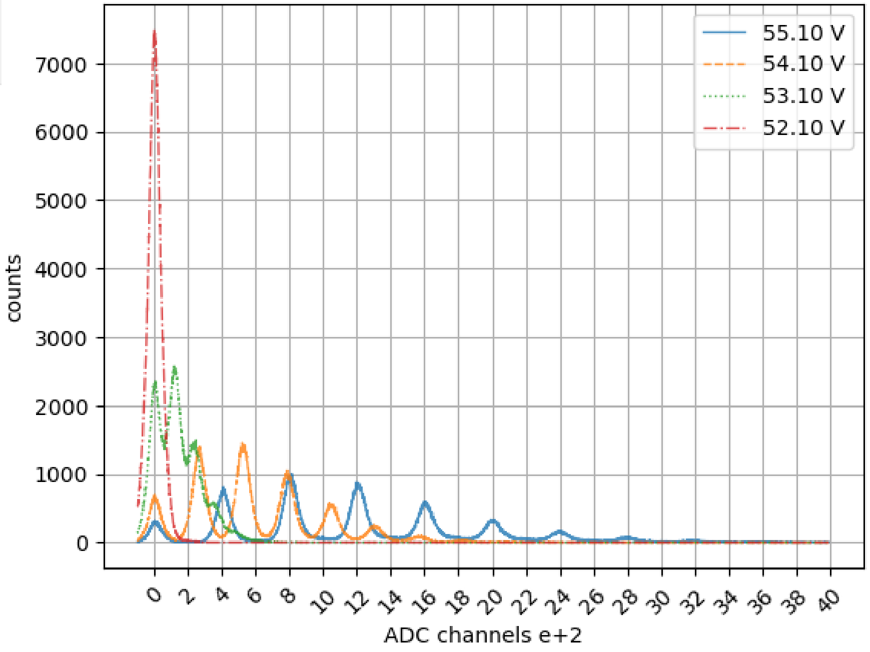


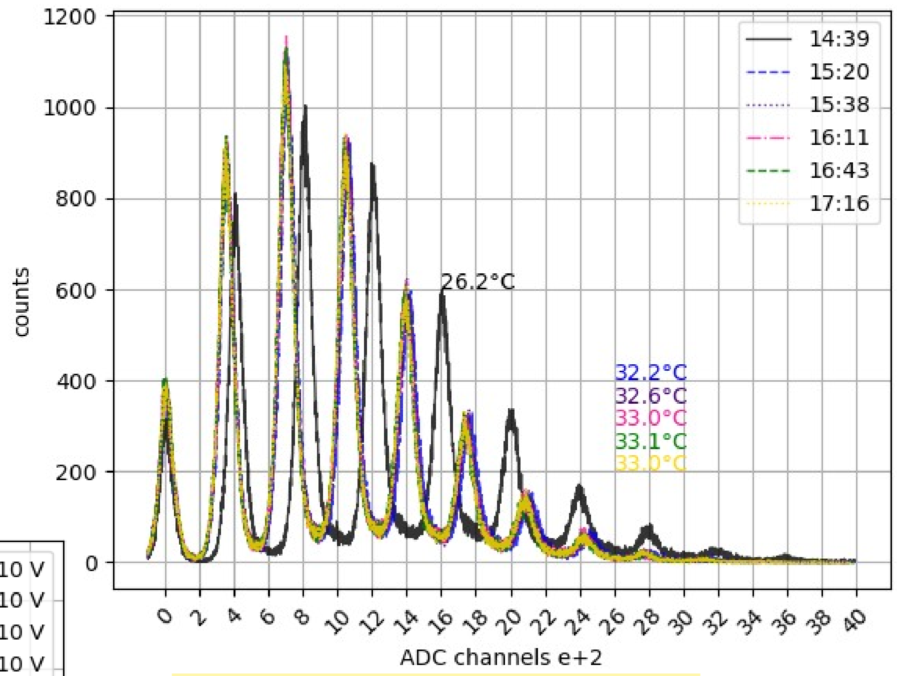
Additional measurements



Without signal

Changing the SiPM voltage

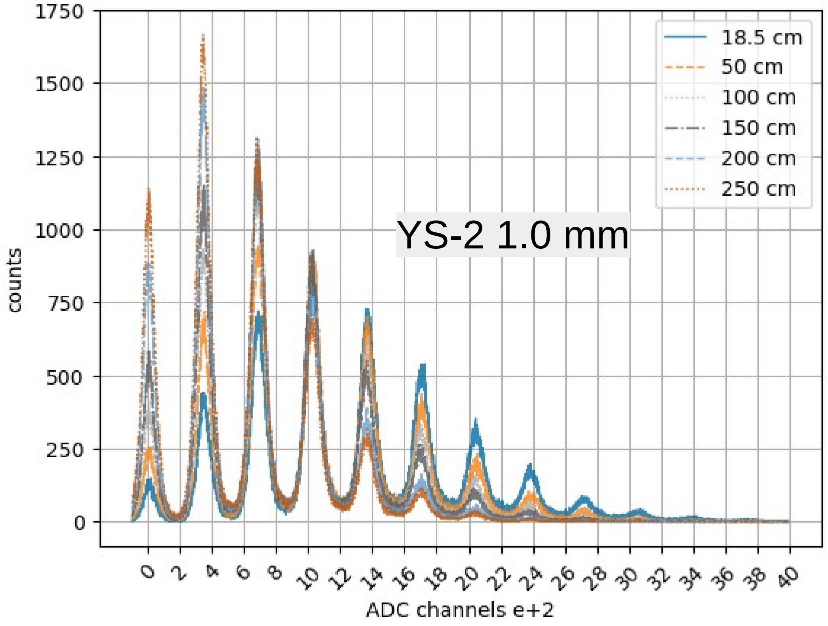


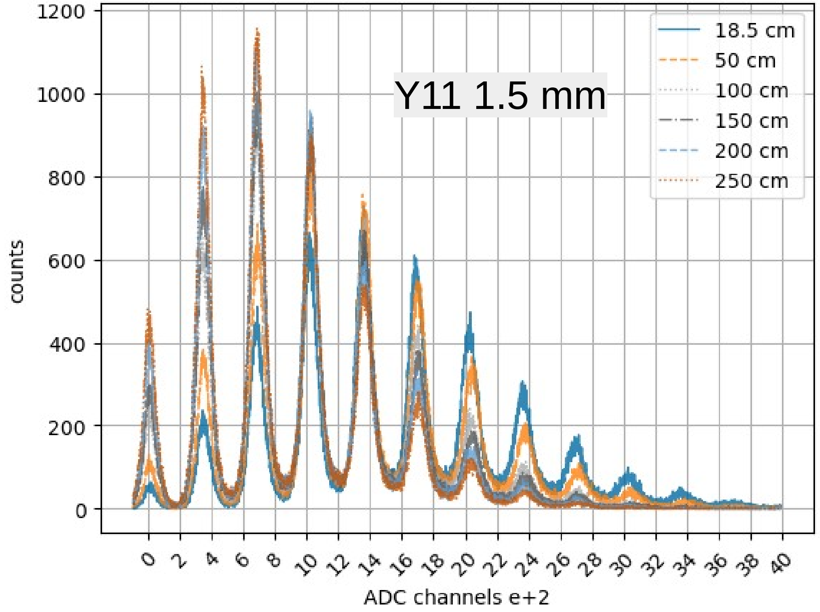


Medium-long term LED stability check
→ Expected number of p.e. stays roughly constant

New measurements with stable temperature and additional fibers

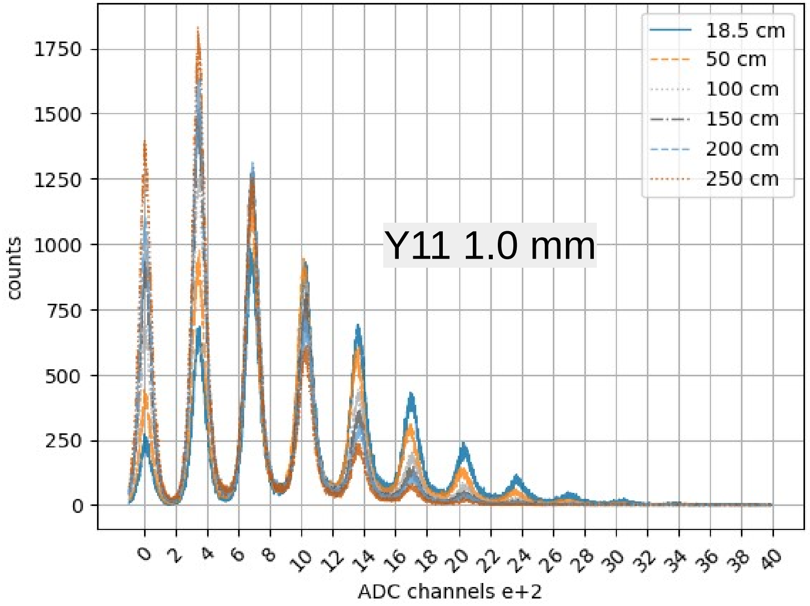
- Fiber #3 snapped in roughly half → no additional measurements could be taken
- 2 measurements per fiber (250 → 18.5 cm [r] and 18.5 → 250 cm)
- New fibers with higher diameters
  - 1.5 mm Y11
  - 2.0 mm Y11 (measured twice)

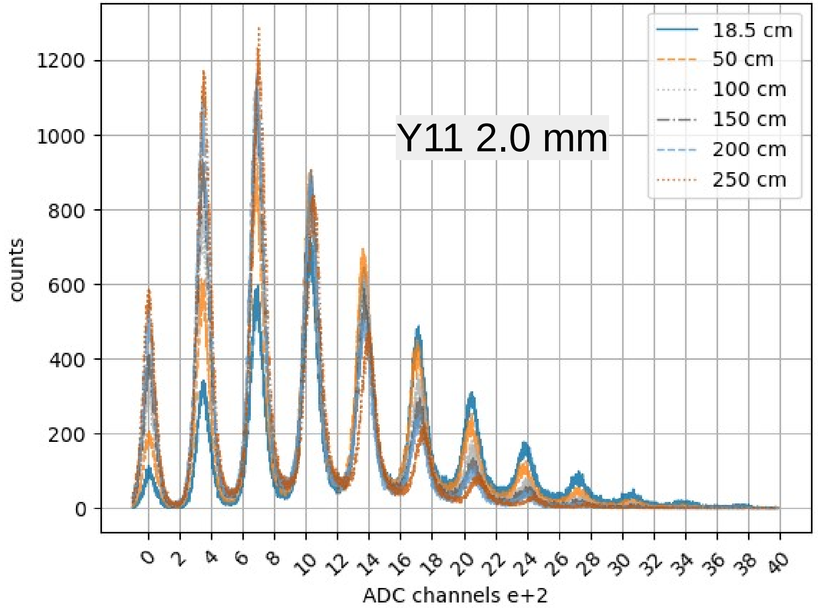




Visualization of measurements

Much less peak wandering due to temperature





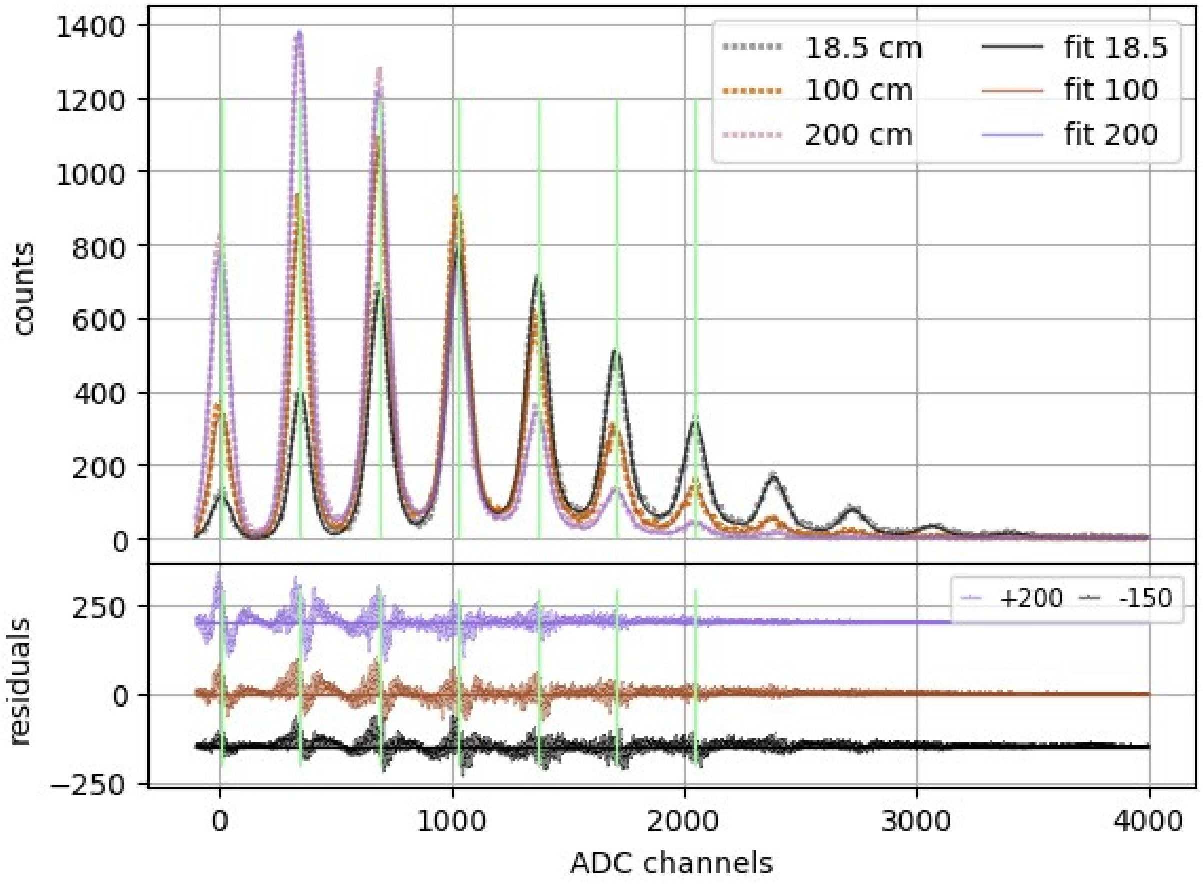
Analysis procedure: Fit peaks

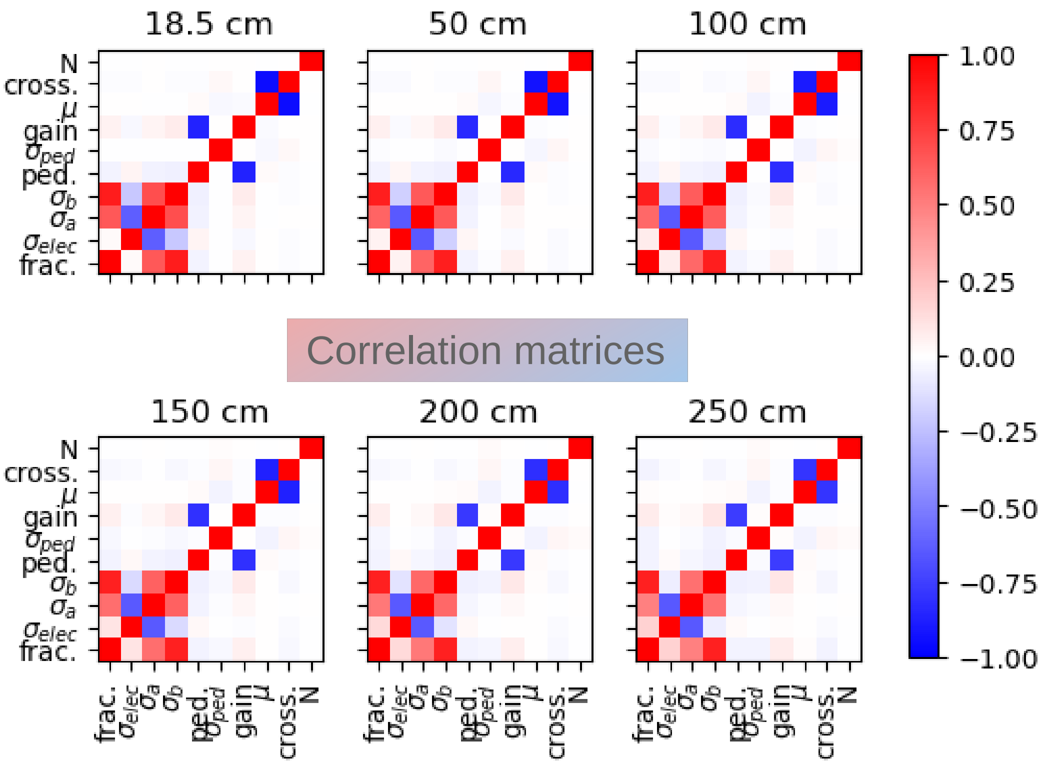
$$f(ADC,g,\sigma,\mu)=N_{trigger}\cdot[(\sum_{i=1}^{11}\{\frac{f}{\sqrt{2\pi}\sigma_1}e^{\frac{-(ADC-ped-i*g)^2}{2\sigma_1^2}}+\frac{1-f}{\sqrt{2\pi}\sigma_2}e^{\frac{-(ADC-ped-i*g)^2}{2\sigma_2^2}}\}\cdot(\frac{e^{-\mu\cdot(1+k)}\cdot(\mu\cdot(1+k))^i}{i!}))\cdot(\frac{1-e^{-\mu}}{1-e^{-\mu\cdot(1+k)}})+\frac{e^{-\mu}\cdot e^{\frac{-(ADC-ped)^2}{2\sigma_{ped}^2}}}{\sqrt{2\pi}\sigma_{ped}}]$$

Double-gaussian for peaks $\sigma_{1/2}^2=\sigma_{elec}^2+i\cdot\sigma_{a/b}^2$

poisson

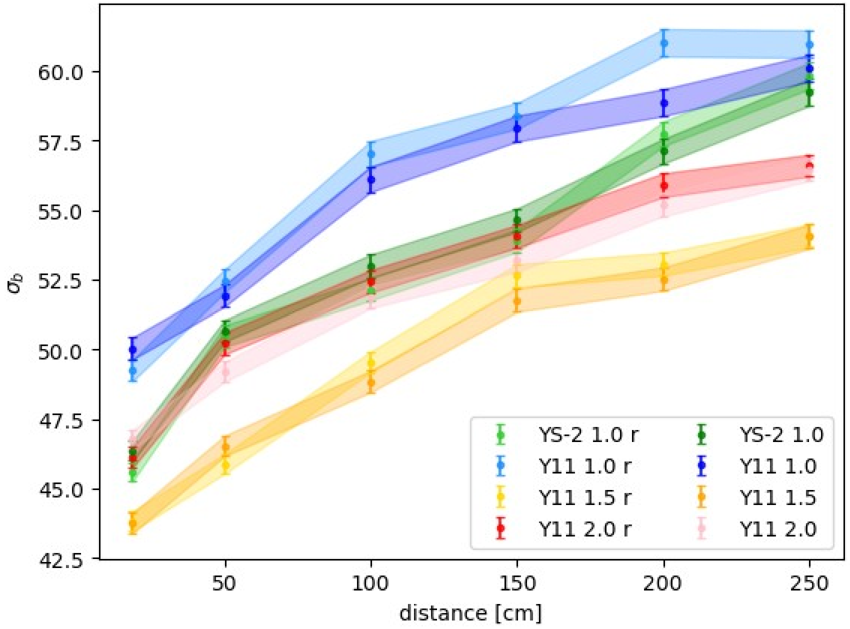
Single gaussian for pedestal peak



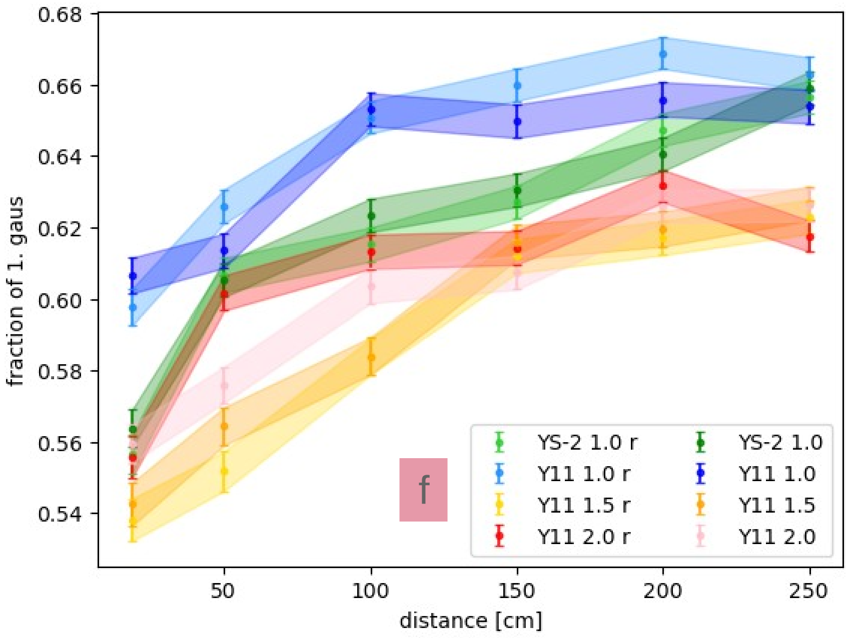


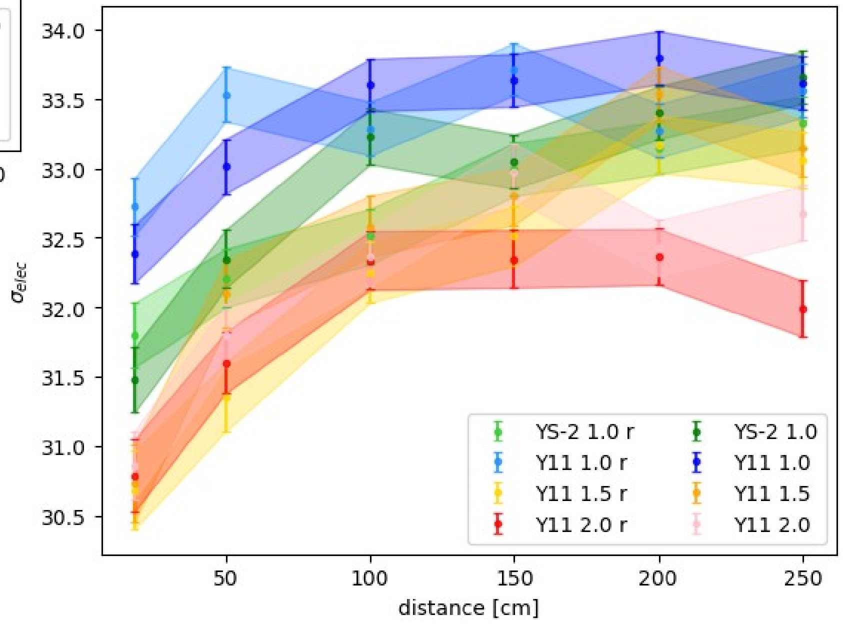
Correlation matrices

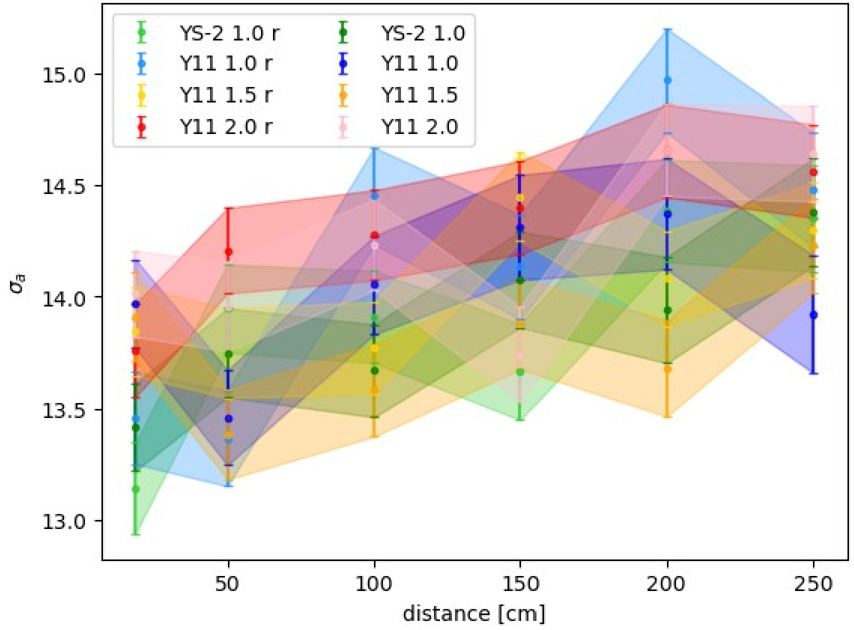
Look at fit parameters



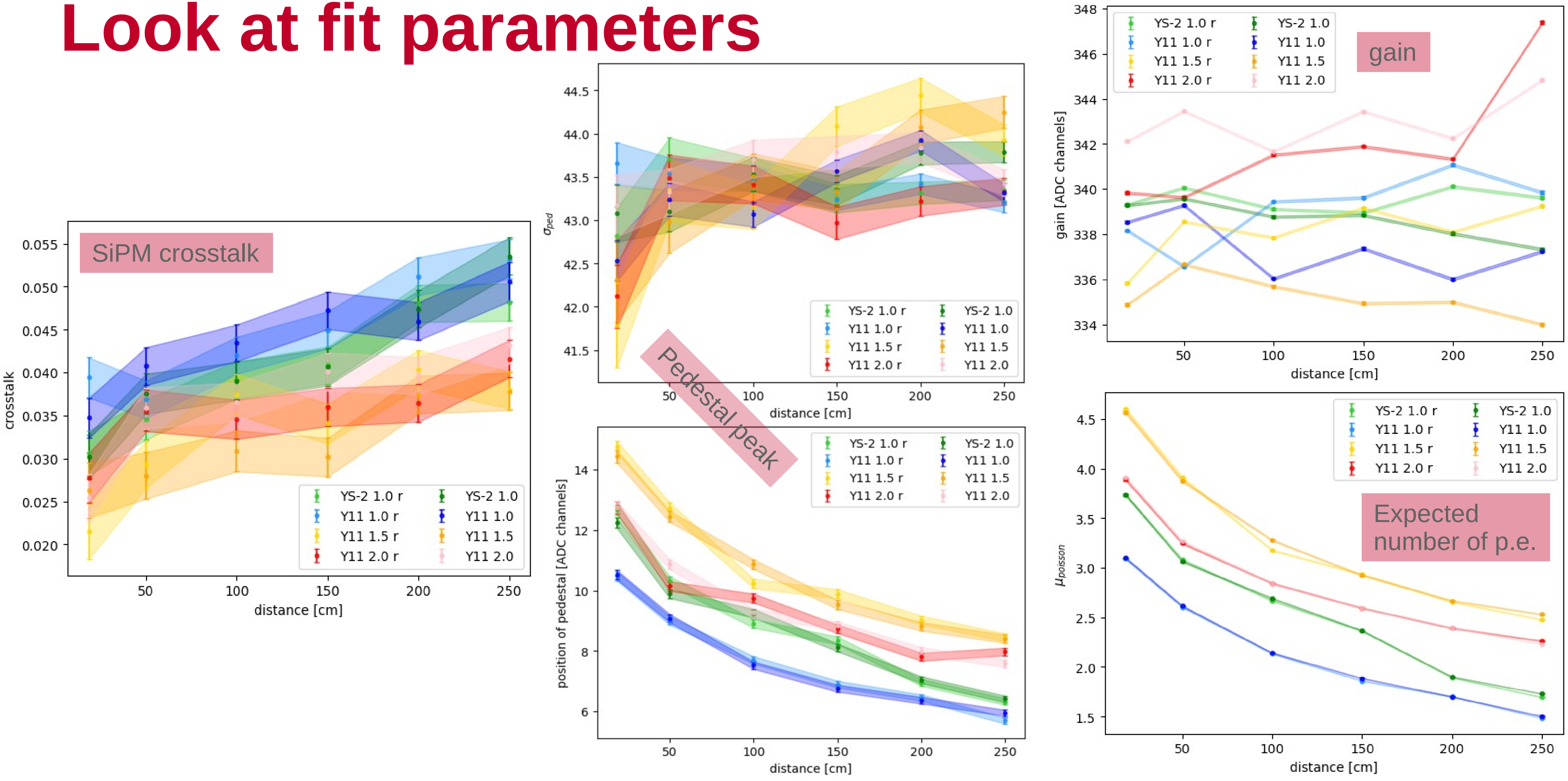
Parameters for double-gaussians



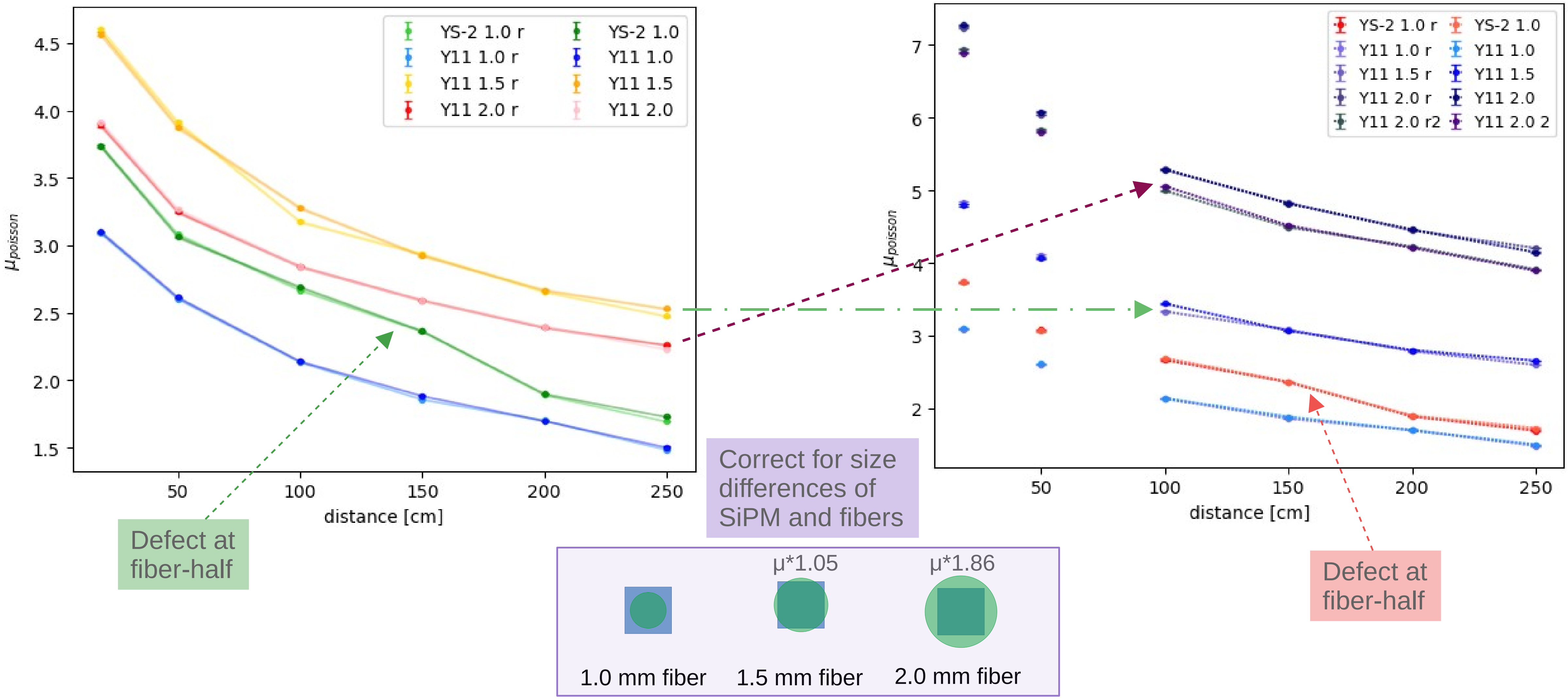




Look at fit parameters



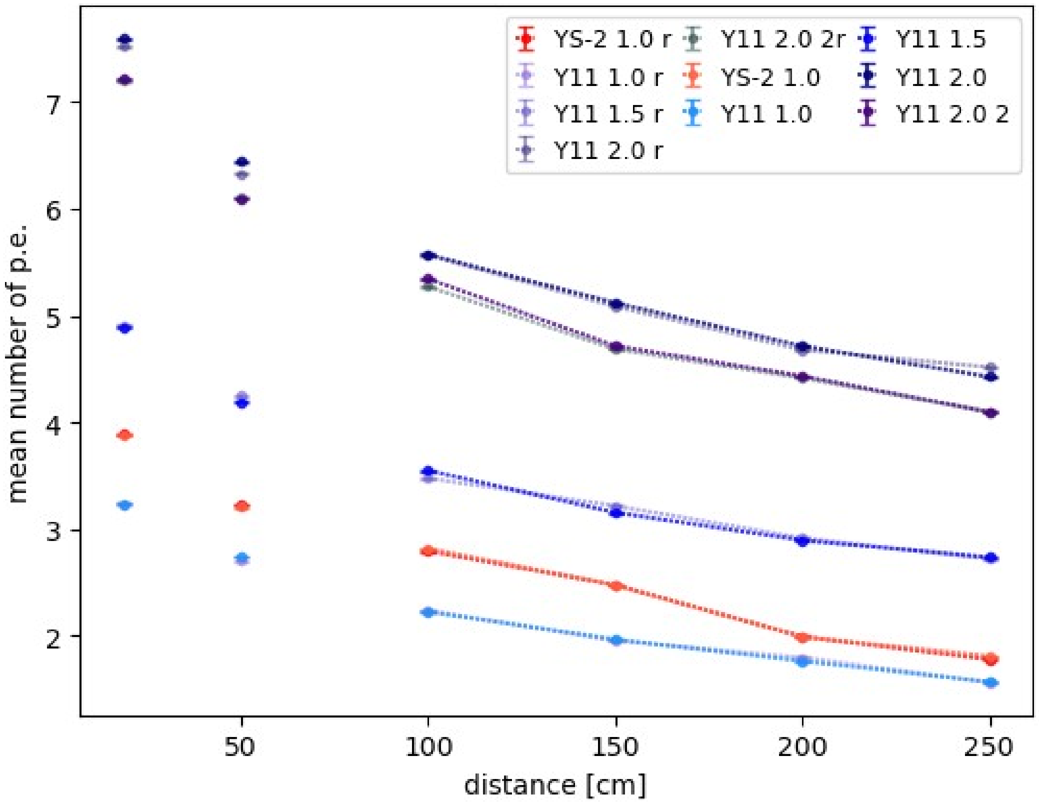
Attenuation length fit preparation: geometry

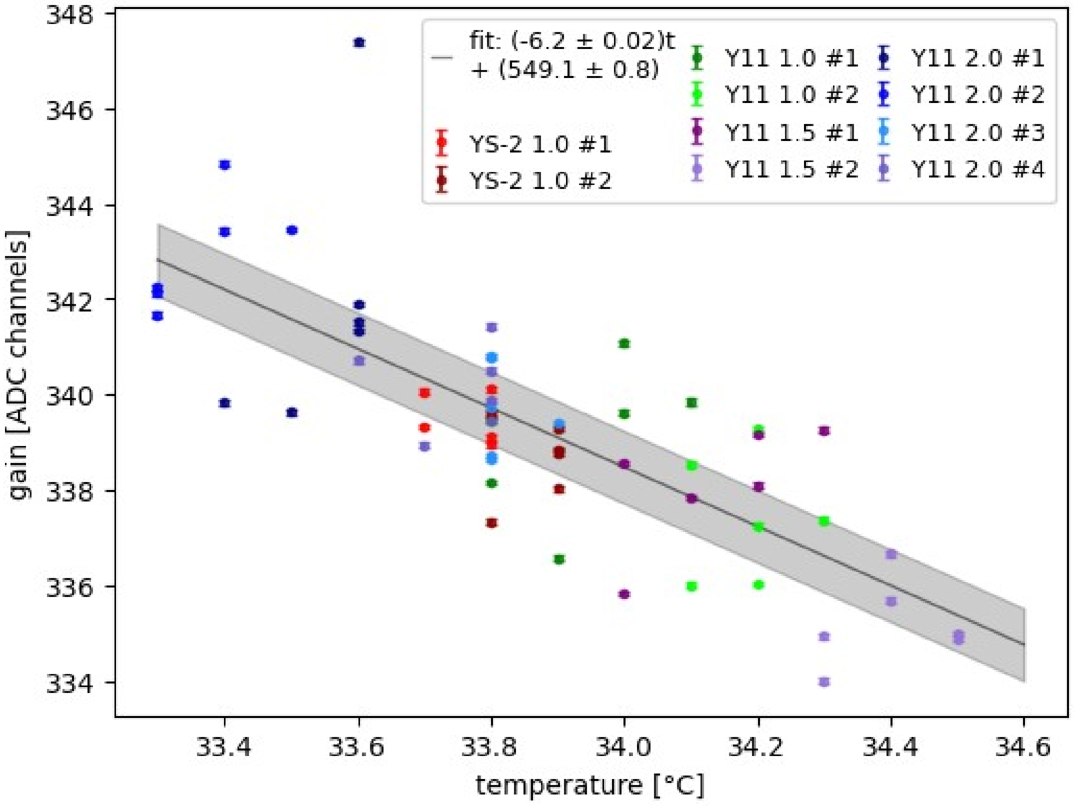


Attenuation length fit preparation: gain

Mean number of p.e. = mean(data) / gain

Correct gain for temperature (set gain for 33.9°C)

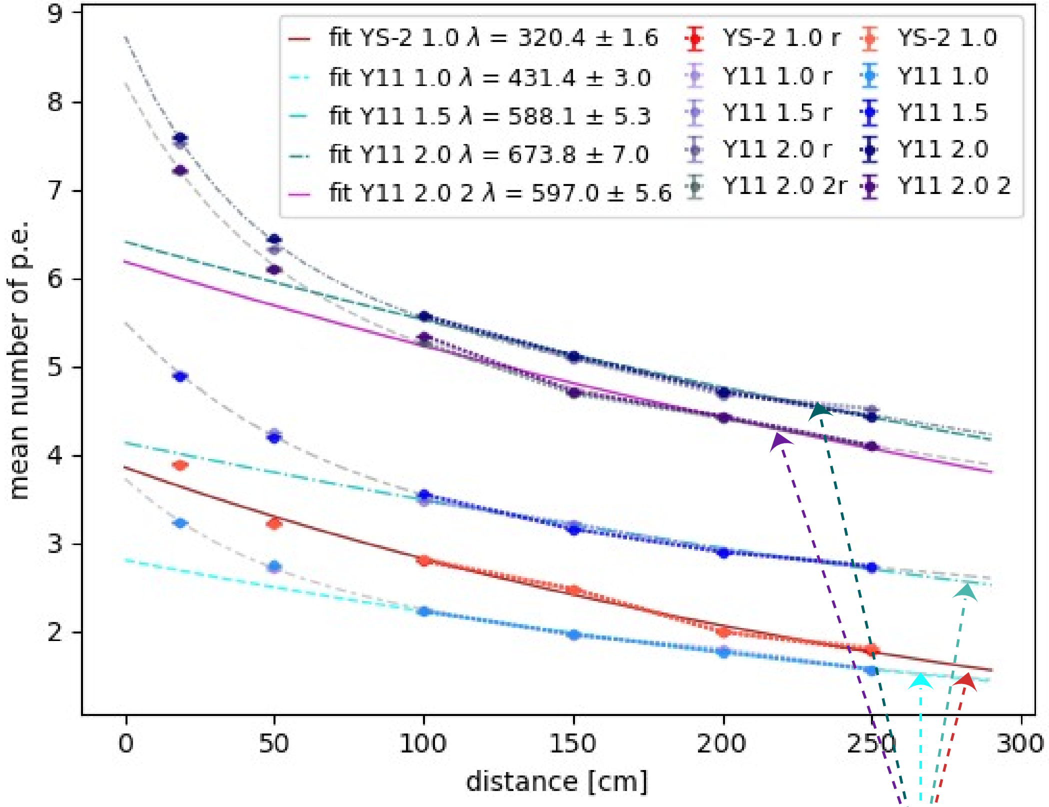


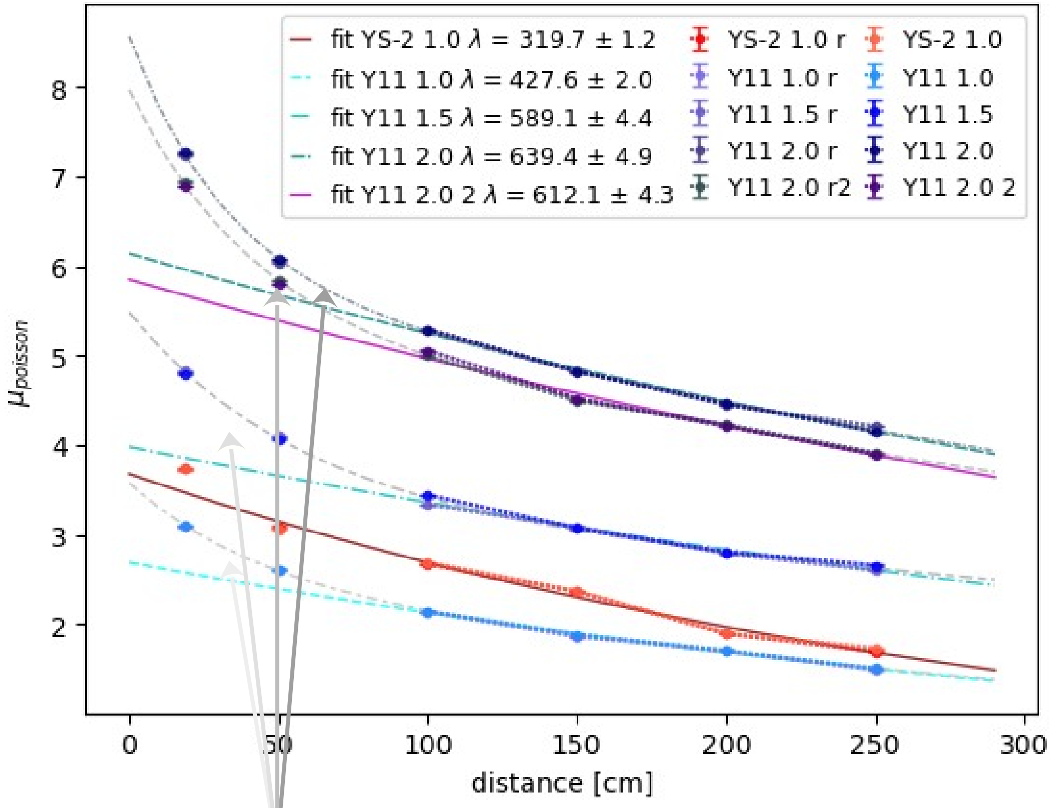


Attenuation length fit : mean number and μ

Attenuation length of fibers
- Short part by losses of cladding light and non-meridional rays
- Long part by losses of light that propagates in a regular manner in the core

[LHCb-PUB-2015-011]

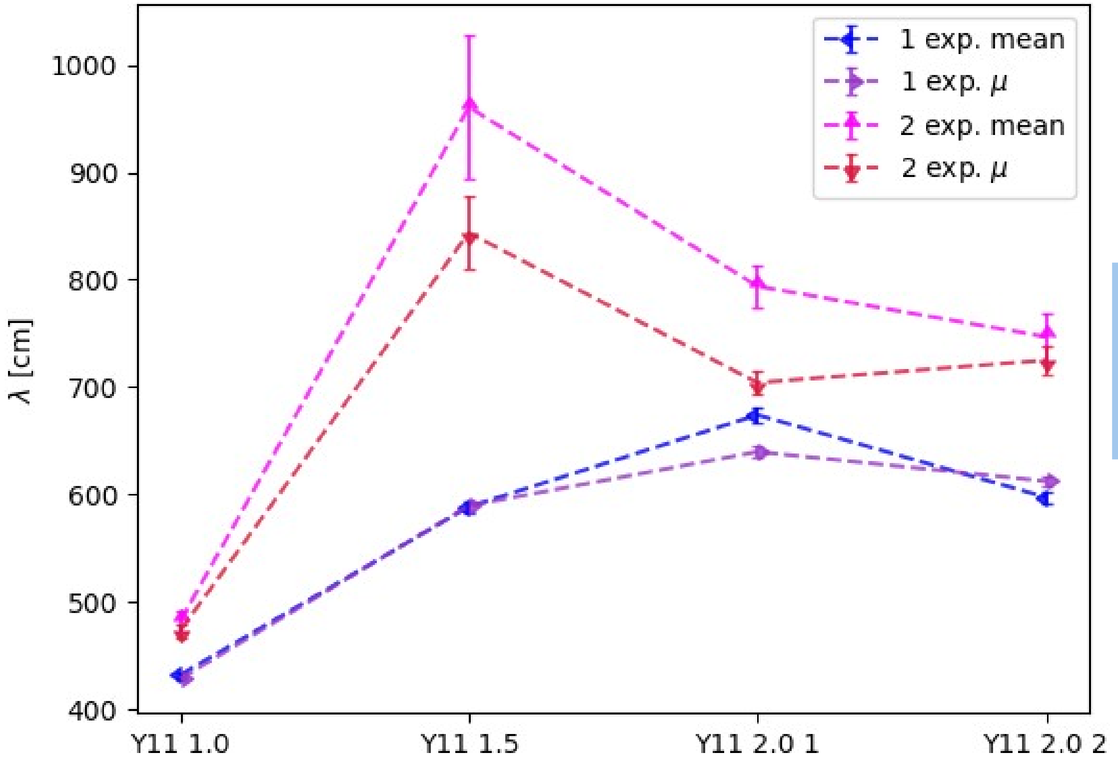




Fit single exponential decay starting from 100 cm to avoid short part

Fit two-component exponential decay for both parts $a \cdot e^{\frac{-d}{\lambda_1}} + b \cdot e^{\frac{-d}{\lambda_2}}$

Attenuation length fit: comparison



Defect at fiber-half

Single exponential decay		
Fiber	from mean/gain [cm]	from μ [cm]
YS-2 1.0 mm	320.4 ± 1.6	319.7 ± 1.2
Y11 1.0 mm	431.4 ± 3.0	427.6 ± 2.0
Y11 1.5 mm	588.1 ± 5.3	589.1 ± 4.4
Y11 2.0 mm (1)	673.8 ± 7.0	639.4 ± 4.9
Y11 2.0 mm (2)	597.0 ± 5.6	612.1 ± 4.3

Kuraray data sheet (1.0 mm)
- YS-2 390 cm
- Y11 440 cm

Two-component exponential decay (long)		
Fiber	from mean/gain [cm]	from μ [cm]
YS-2 1.0 mm	–	–
Y11 1.0 mm	481.5 ± 9.5	472.7 ± 6.0
Y11 1.5 mm	960.7 ± 66.5	843.5 ± 34.3
Y11 2.0 mm (1)	793.8 ± 20.0	703.8 ± 10.2
Y11 2.0 mm (2)	746.7 ± 22.3	724.8 ± 13.9

Attenuation length increases with increasing diameter of fiber, compare [Transmission loss measurements of plastic scintillating optical fibers]

Conclusion

- Gain is highly dependent on the temperature of the SiPM
  → temperature control!!!
- Use thicker fibers for read-out of long scintillator bars as those have longer attenuation lengths
  - But appropriate for the SiPM area as most light is emitted from the fiber at the outer part of the core and/or use specific SiPM-fiber coupling described by Sebastian Ritter

[Measurement of the exit characteristics of light from optical multimode plastic fibers]

Thank you for your attention :)
Questions?

Backup

LED stability mean/gain

2.831 ±0.096

time	mean/gain
14:39	3.045 ± 0.002
15:20	2.805 ± 0.003
15:38	2.794 ± 0.003
16:11	2.781 ± 0.003
16:43	2.779 ± 0.003
17:16	2.782 ± 0.003

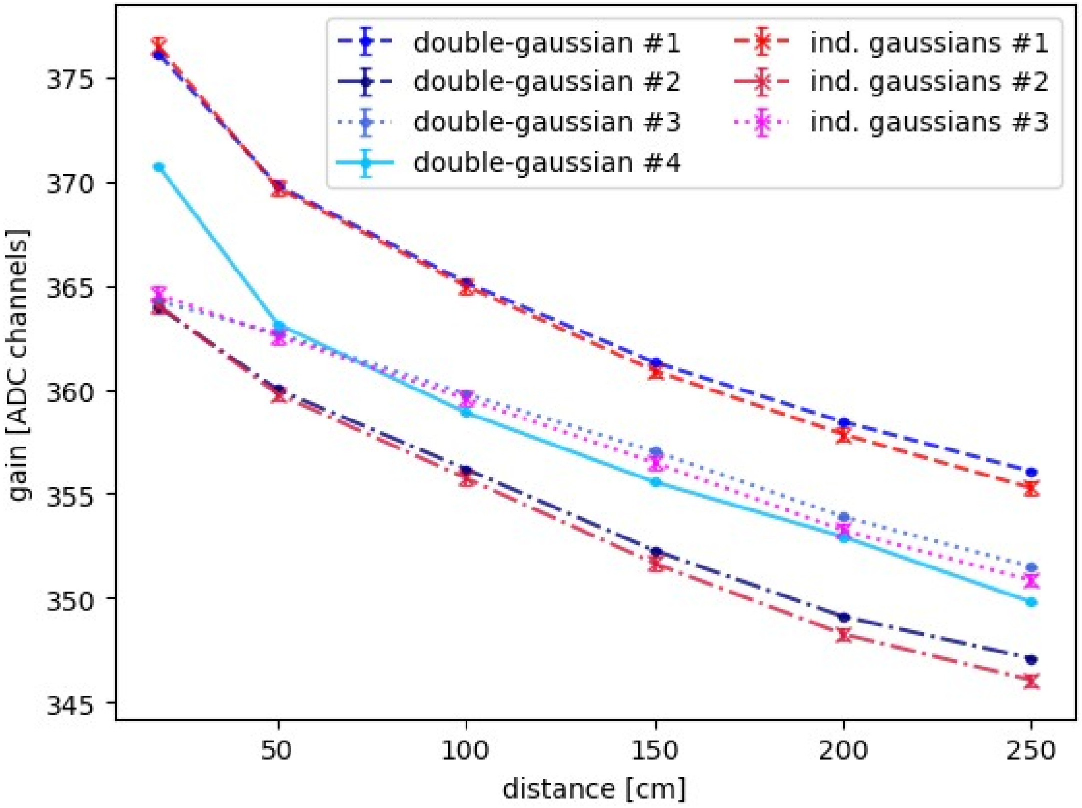
2.788 ±0.010

Chisquare per n_dof of double-gaussian poisson fit

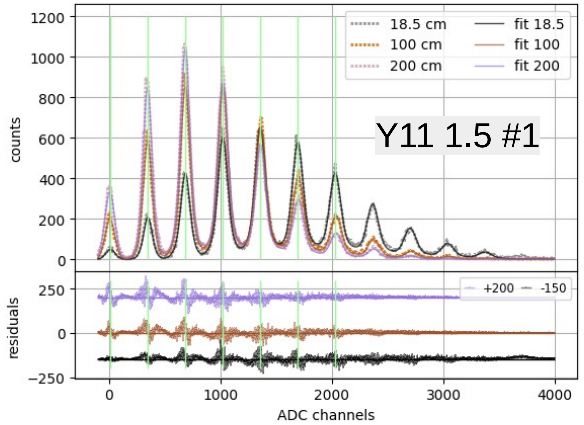
YS-2 #1	YS-2 #2	Y11 1. #1	Y11 1. #2	Y11 1.5 #1	Y11 1.5 #2	Y11 2. #1	Y11 2. #2	Y11 2. #3	Y11 2. #4	Distance [cm]
1.82	1.80	1.65	1.57	2.31	2.32	1.77	1.88	1.81	1.81	18.5
1.63	1.64	1.47	1.54	1.81	1.82	1.64	1.68	1.62	1.61	50
1.52	1.51	1.44	1.37	1.56	1.66	1.63	1.58	1.50	1.51	100
1.48	1.54	1.39	1.37	1.56	1.54	1.48	1.58	1.52	1.49	150
1.46	1.44	1.40	1.36	1.53	1.43	1.45	1.52	1.43	1.40	200
1.45	1.36	1.38	1.33	1.41	1.39	1.50	1.54	1.47	1.44	250

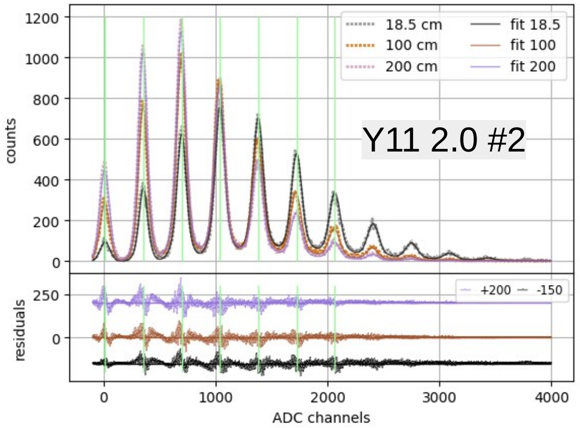
n_dof = 4096 – 9 = 4087

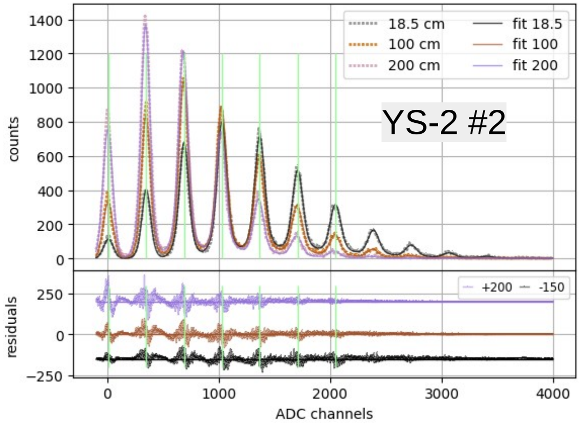
Comparison ind. gauss vs. gauss-poisson

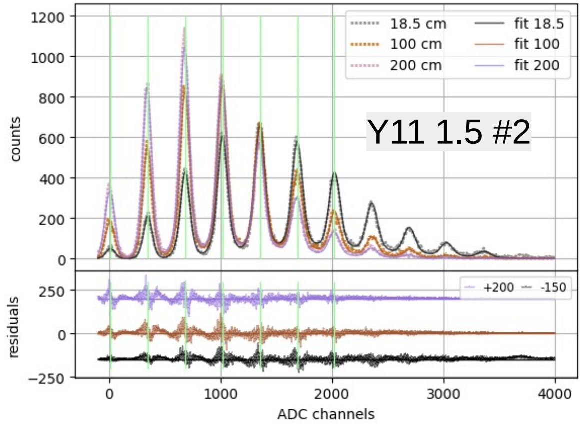


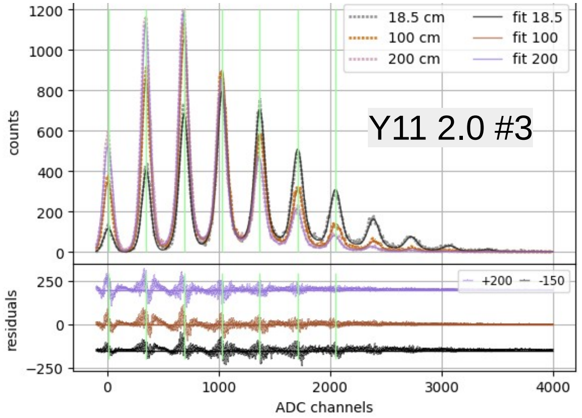
Other fits+residues

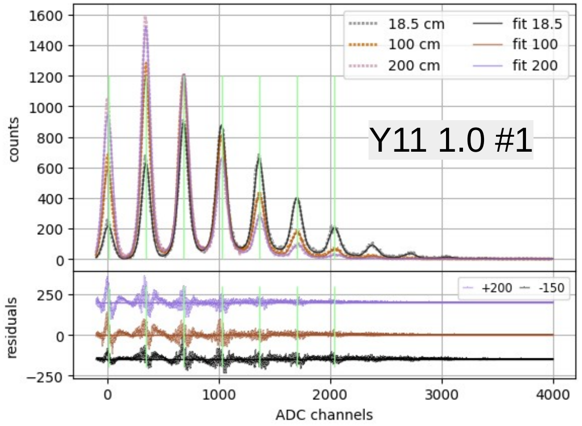


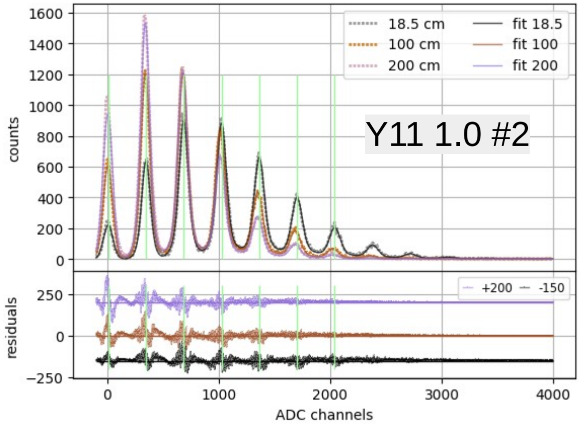


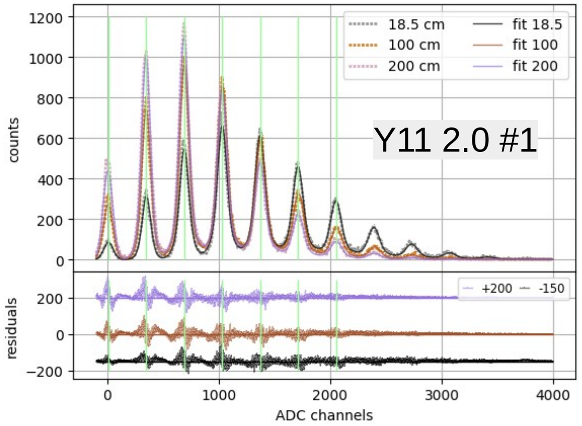


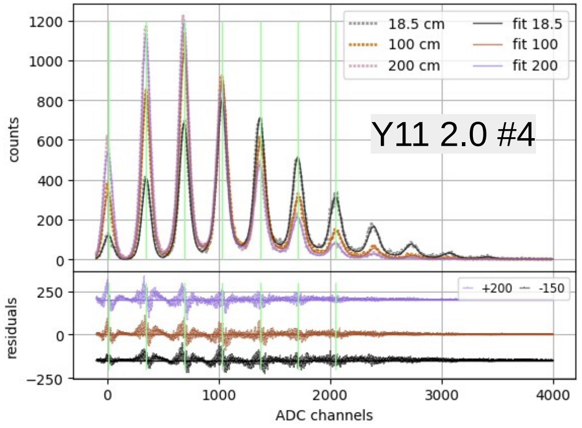




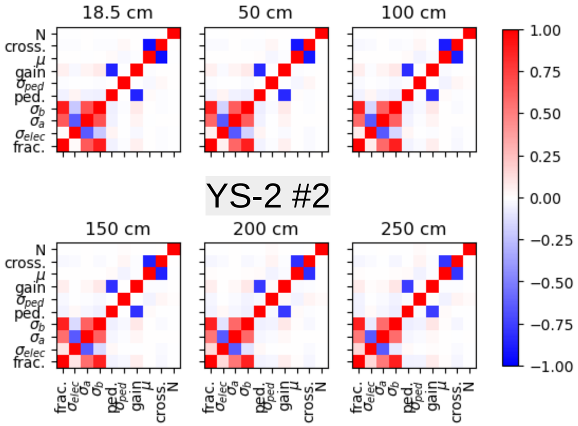


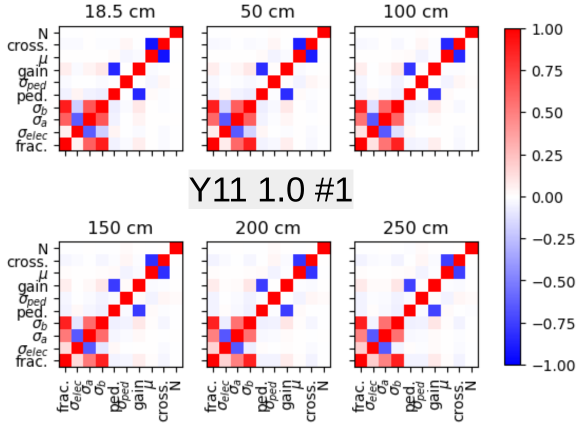


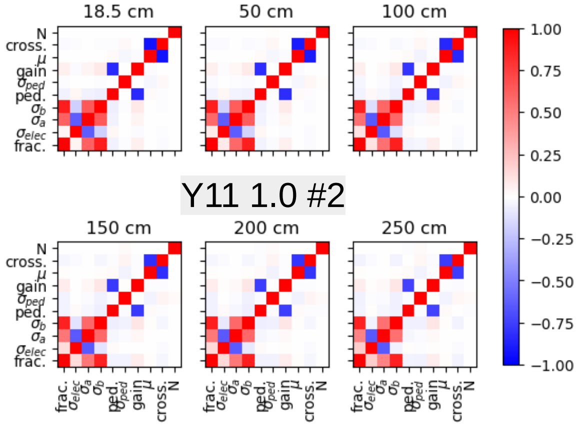


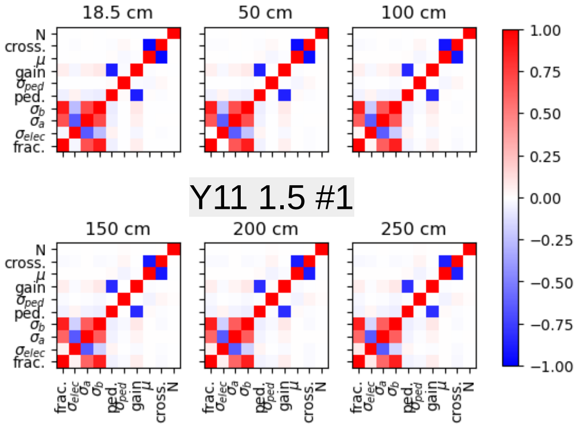


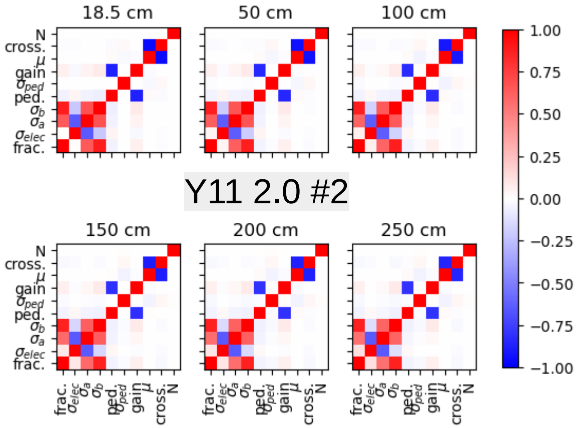
Other corr. matrices

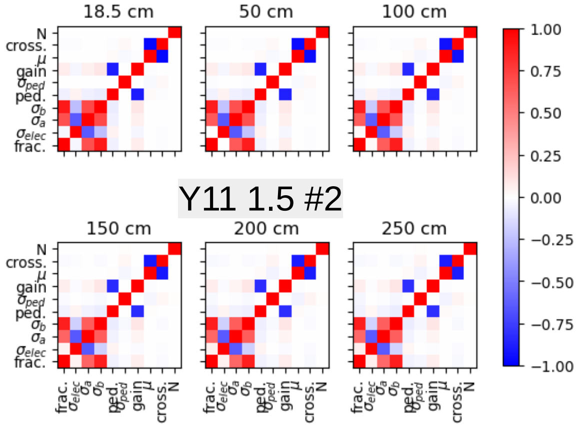


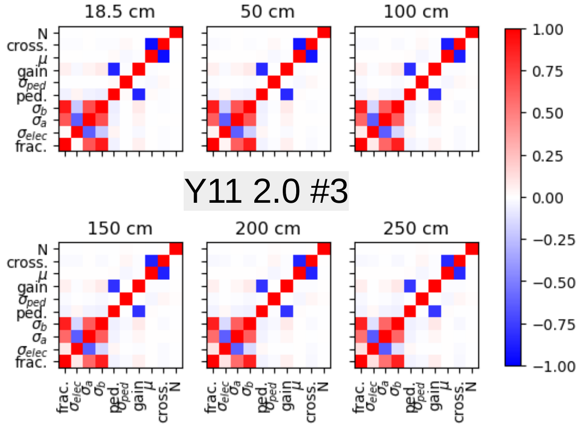


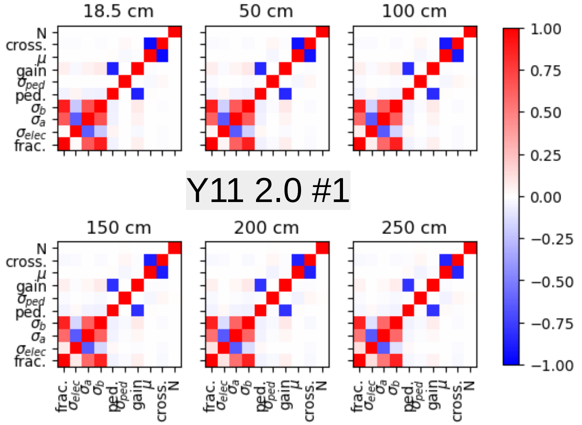


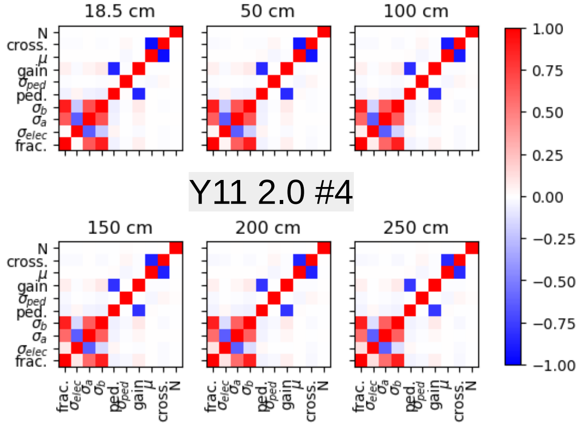












Temperature (in)dependence mu_poisson