# Fermilab testbeam data analysis

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On behalf of the analysis team

Calvision meeting Nov 16 2023

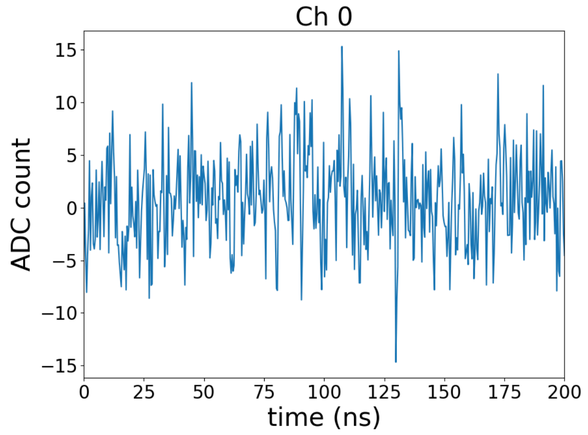
# Status

- To reduce the impacts of noisy events, a selection of amplitude > 5 times RMS(noise) is applied before the analysis.
- For events passed the above selection, a fit is performed on the time spectrum event-by-event to extract the characteristics of different kind of signals in each crystal.

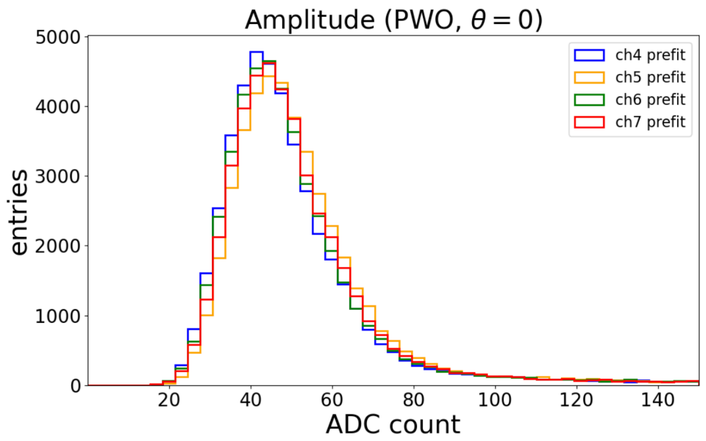
# Event selection

- Selection: amplitude > 5 times noise
- For events passing the selection in channel 4-7 (w/o filter), we see a peak ~40-50 ADCs in the amplitude distribution, which is likely due to MIPs (plot 2).
- For PWO channel 0-3 (w/ filter), the signals are generally smaller. Therefore, the pulse can't be distinguished from the noise for a large portion of events. 23% of events passed the selection for PWO channel 0-3 data.
- The 23% events are dominated by hadronic shower (10% of incident protons will produce hadronic shower at 0 degree), which results in a falling spectrum (plot 3).
- The simulation predicts to see only on average 2 Cherenkov photons with filters applied, so it would be hard to see Cherenkov contributions after the event selection.

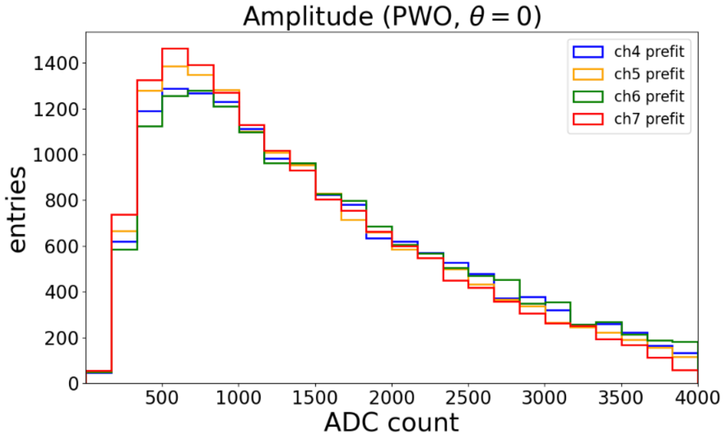
1. Noisy event in PWO data




2. MIP-like events

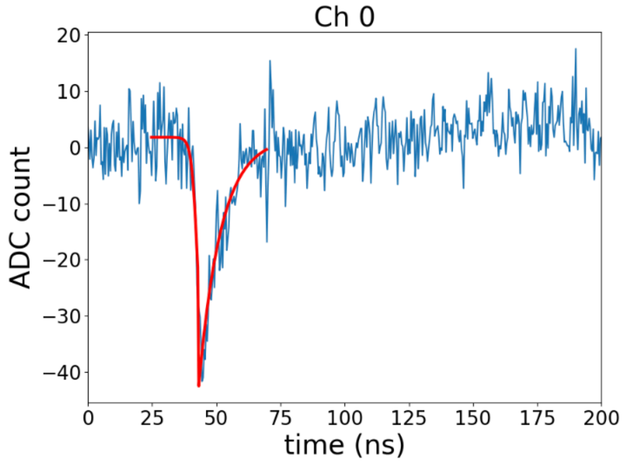



3. Shower-like events

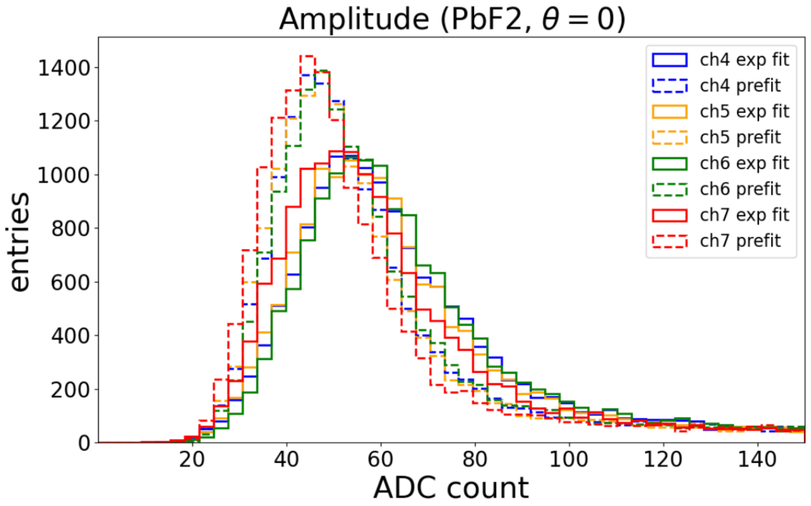


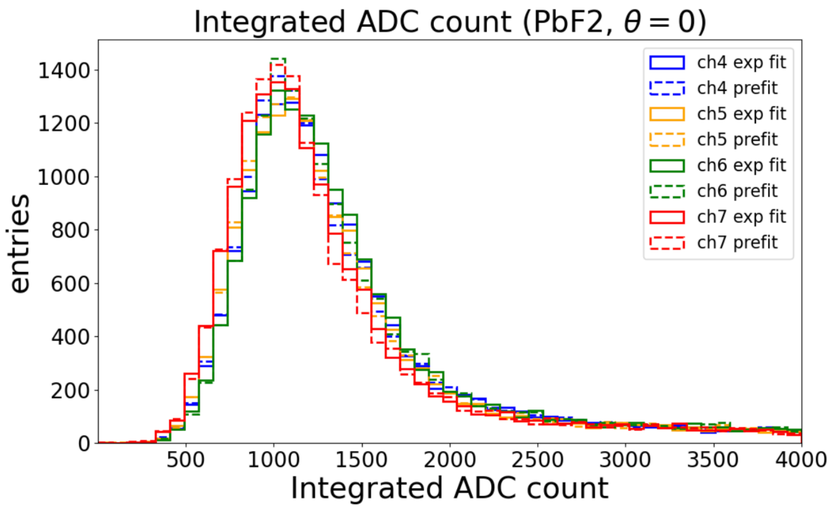
# Exponential function fit

- Before the peak: $V(t) = |A|[\frac{1}{e^{(t-t0)/\tau L}+1} - 1] + d$, where |A| is the amplitude of the peak [Eq3]
- After the peak: $V(t) = -|A|e^{(-t+t0)/\tau R} + d$
- $t_0$ / $\tau_L$ / $\tau_R$: related to peak position / rising time / decay time




- Comparison of amplitude and integrated ADCs before and after the fit:



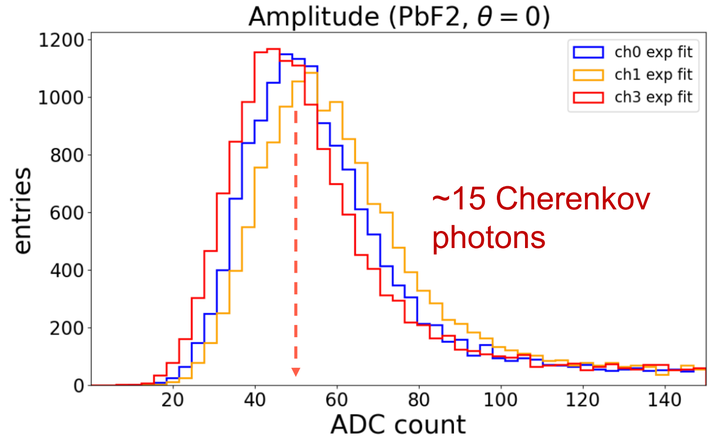
# Compare fit results of PbF2 vs. PWO (0 degree)

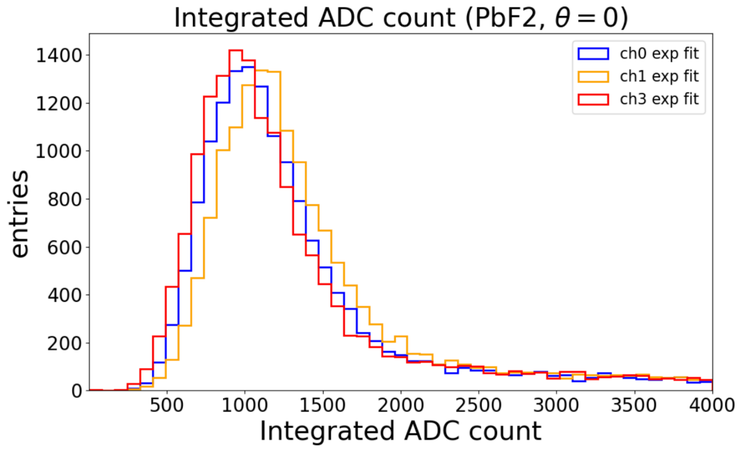
- PWO have much more counts than PbF2 since a large portion of events comes from showering [backup].

Mainly showering events

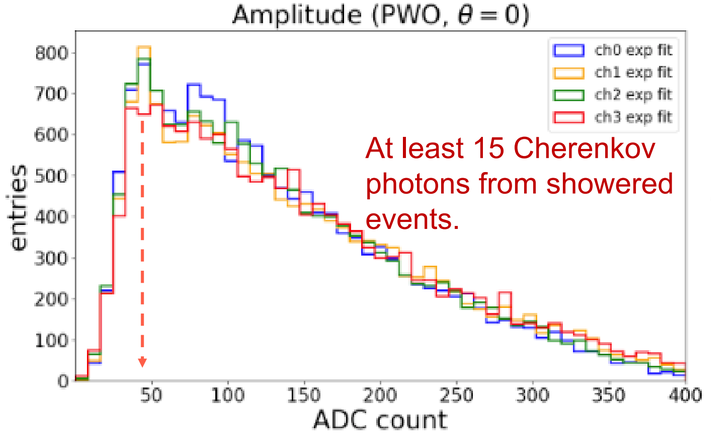
Composed by both scintillation and shower

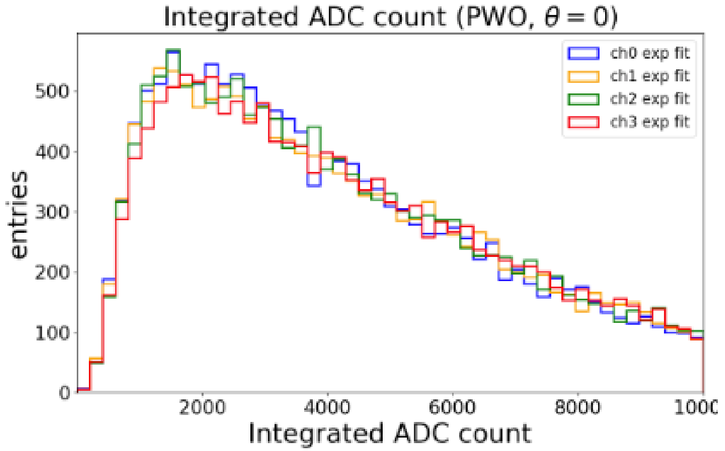
PbF2



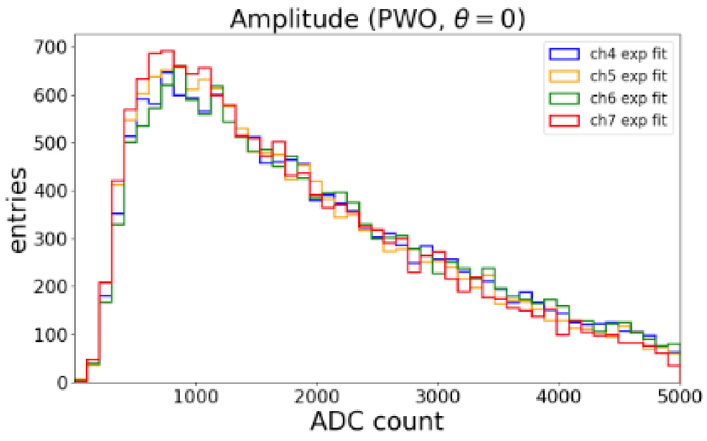



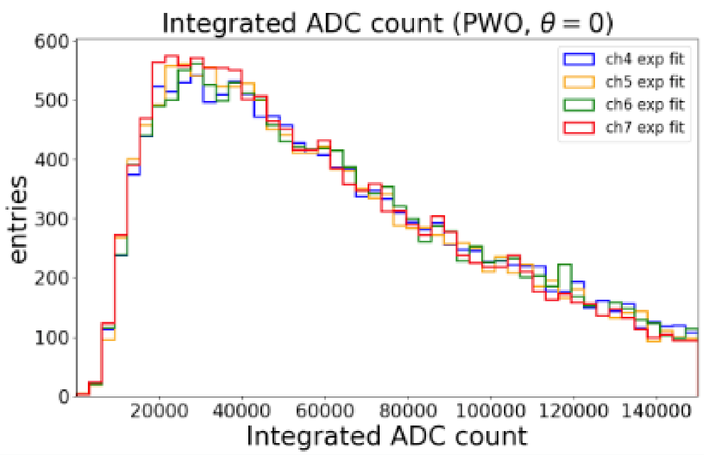

PWO w/ filter



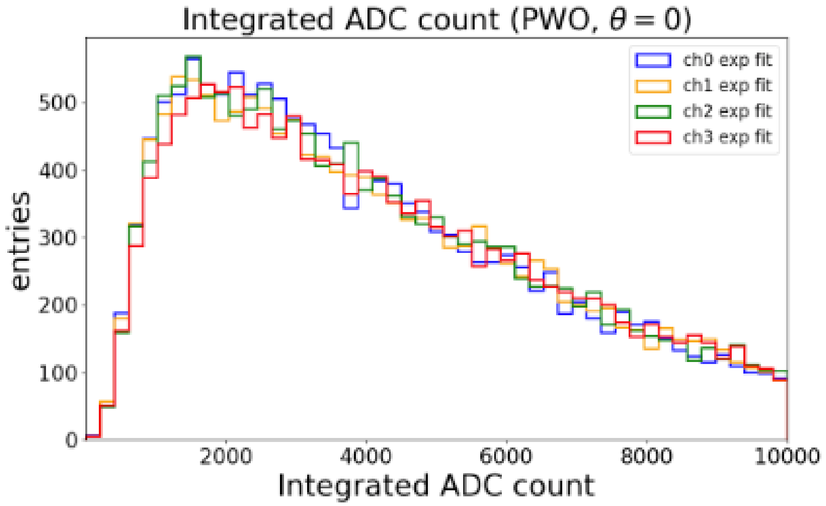

PWO w/o filter



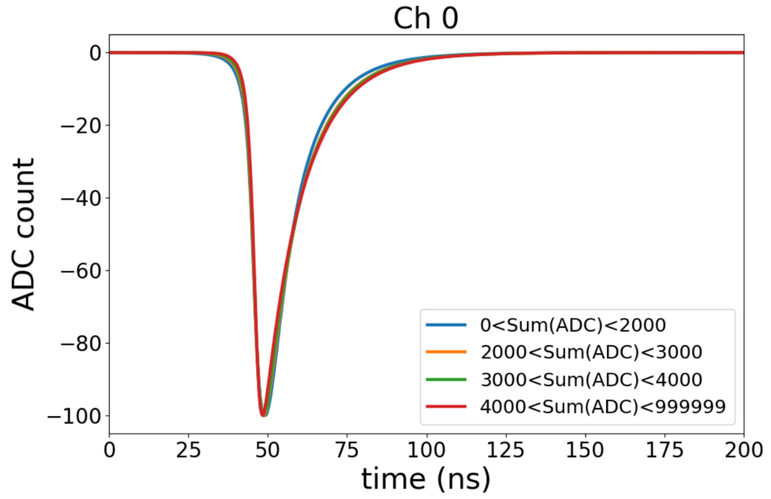



# Understand the distributions from PWO w/ filter

- Average time spectrum for events in different integrated count intervals. Small differences between events with lower and higher counts.
- Could apply a cut integrated ADC < 2000 on ch 0-3 to exclude large-signal events.



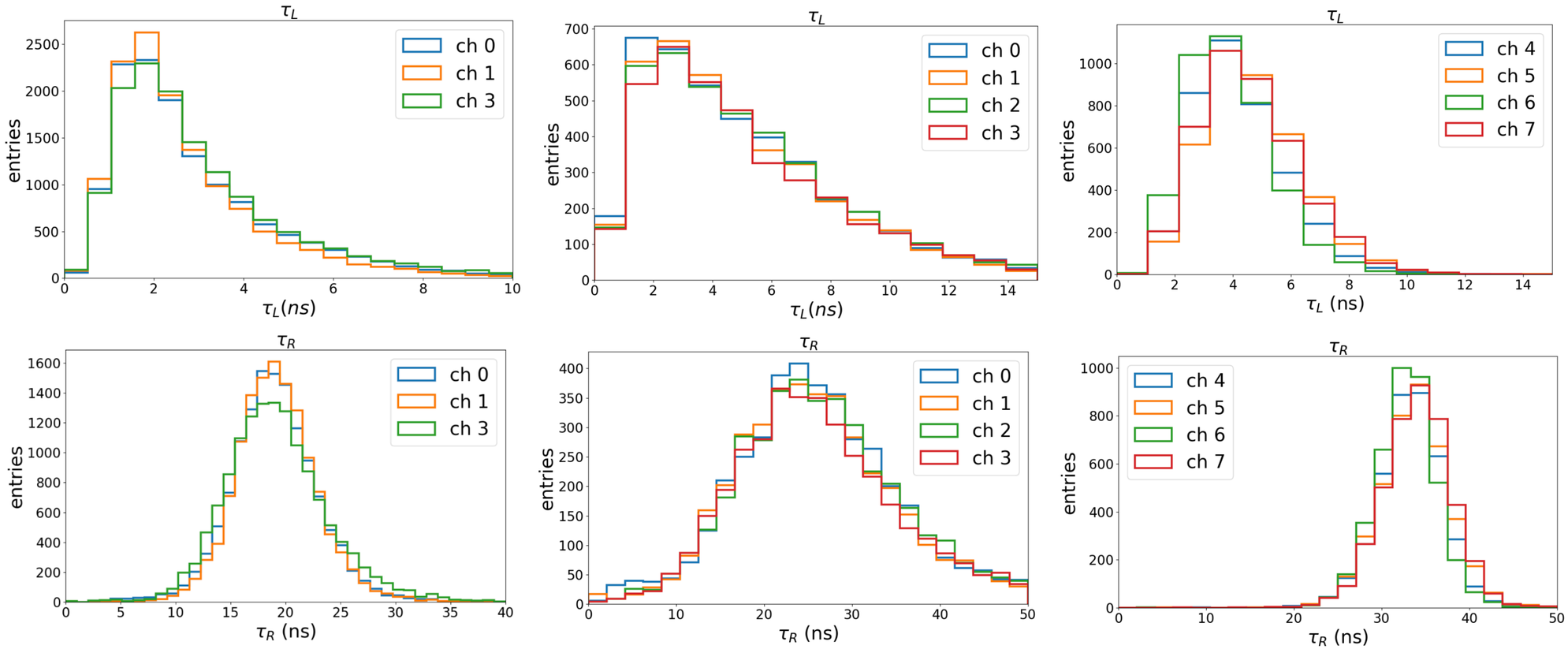

Average time spectrums



# Compare fit results of PbF2 vs. PWO (0 degree)

- $\tau_L$ (related to rising time) for PWO w/ filter is closer to PbF2 due to Cherenkov photons only.
- Slightly longer $\tau_L$ is seen in PWO w/o filters.
- $\tau_R$ is more related to SiPM and electronics response. A larger width observed for PWO w/ filter is probably due to limited statistics.
- The large $\tau_R$ observed for PWO w/o filter is due to the decay time of scintillation photons (~30 ns) plus the SiPM and electronics responses.

PbF2 | PWO w/ filter | PWO w/o filter

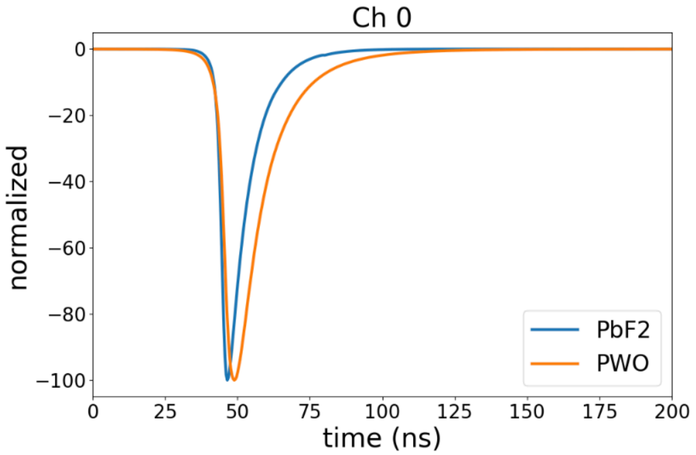


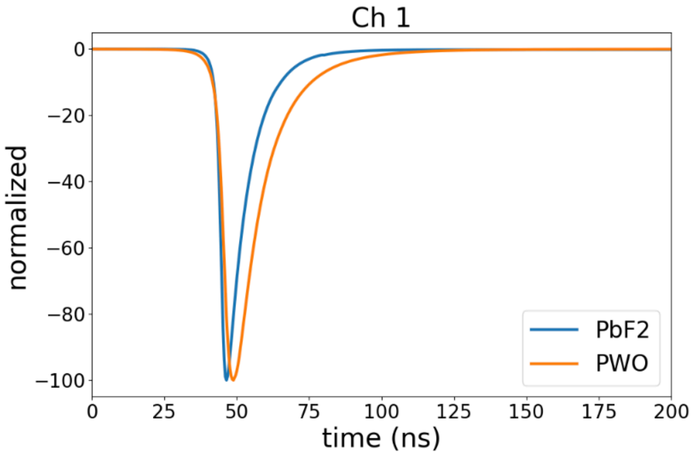

* Only select events whose integrated ADC < 2000 in ch 0-3

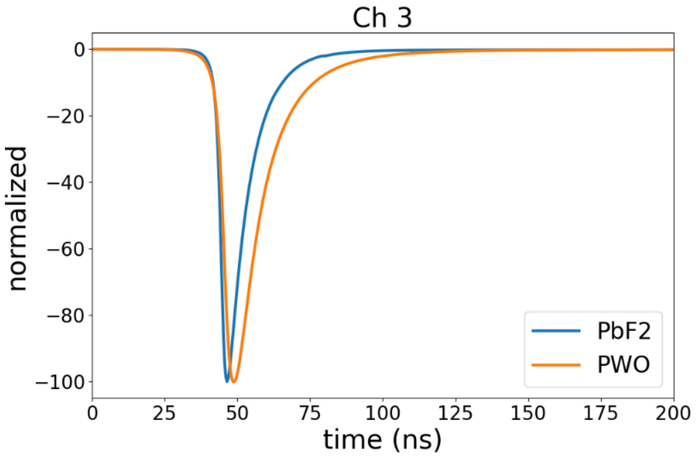
# Compare fit results of PbF2 vs. PWO (0 degree)

- Average time spectrum comparison between PbF2 and PWO w/ filter.
- Only compare the shape difference: scale the amplitudes of the two spectrums to be the same.
- The two spectrums are similar to some degree, but the rising and decay time still differ slightly (PbF2 are mainly MIP events while PWO are manly showered events).

* Only select events whose integrated ADC < 2000 in ch 0-3

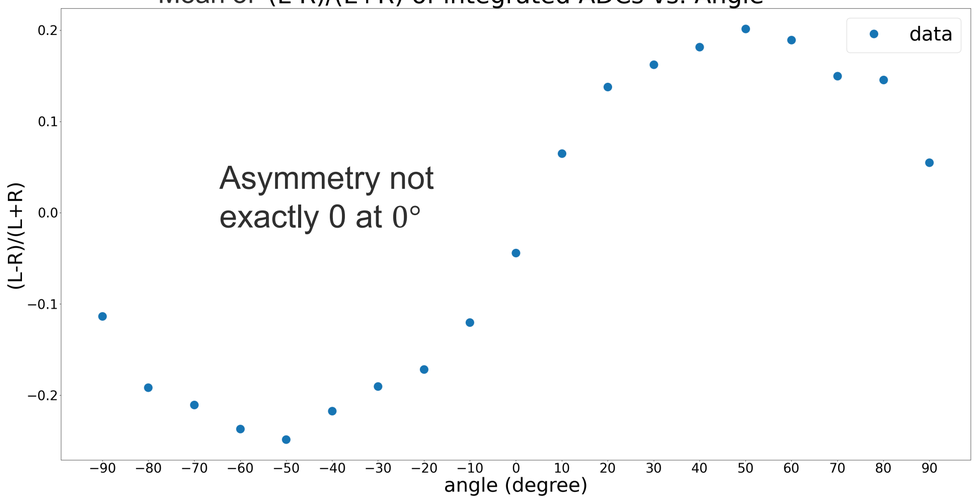


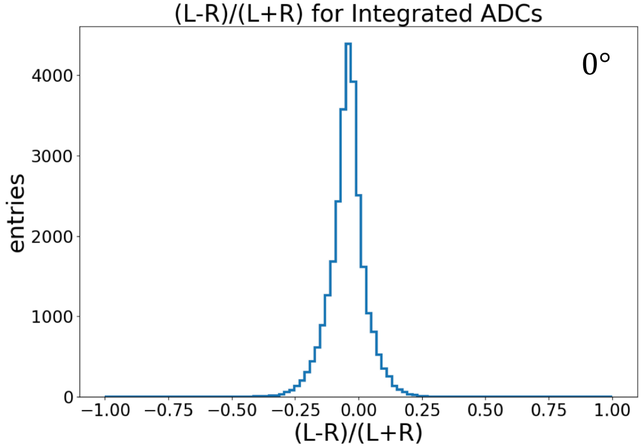



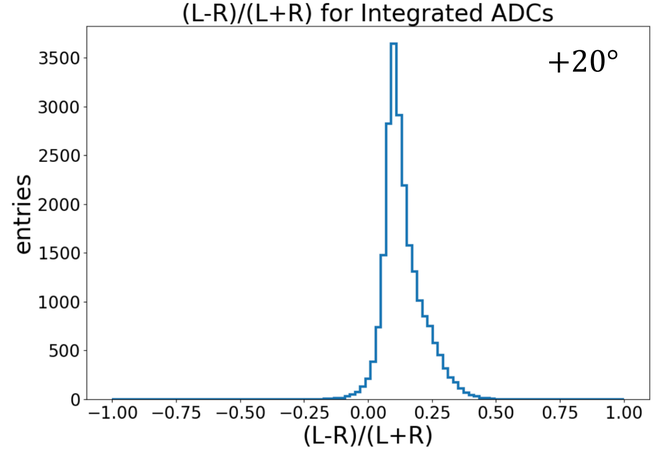
# Asymmetry between the LHS and RHS channels

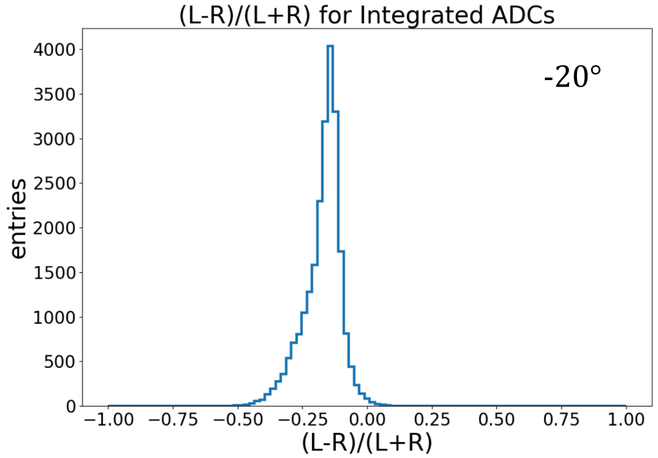
- PbF2: asymmetry is around $\pm 0.2$

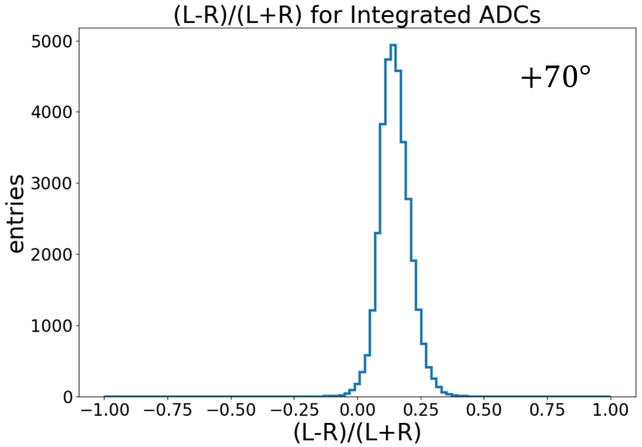


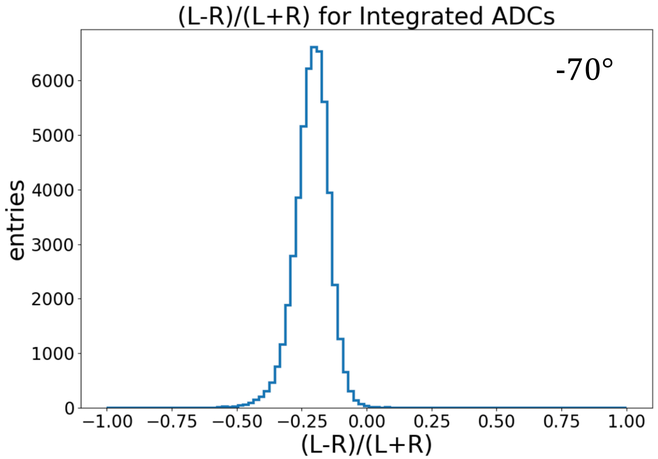

Asymmetry



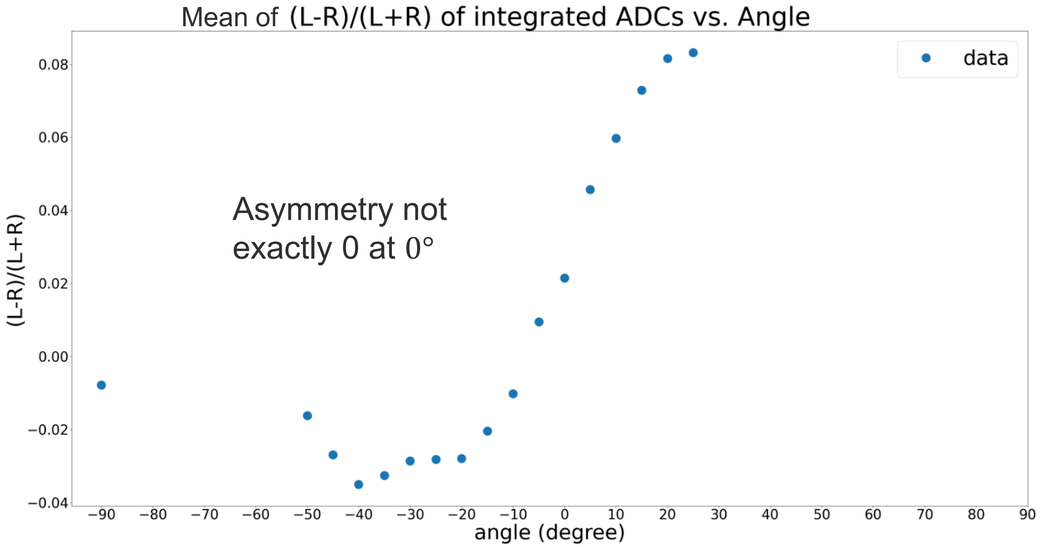



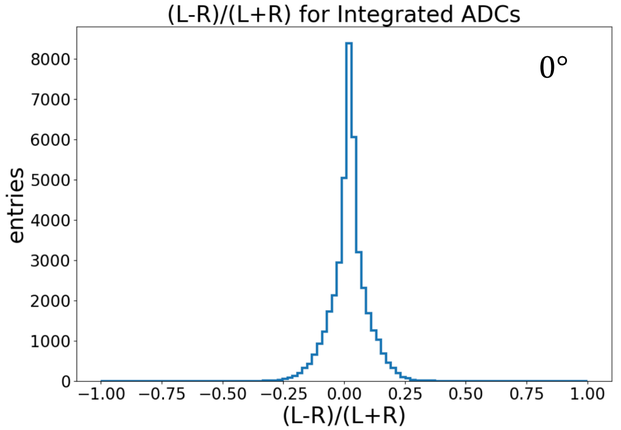



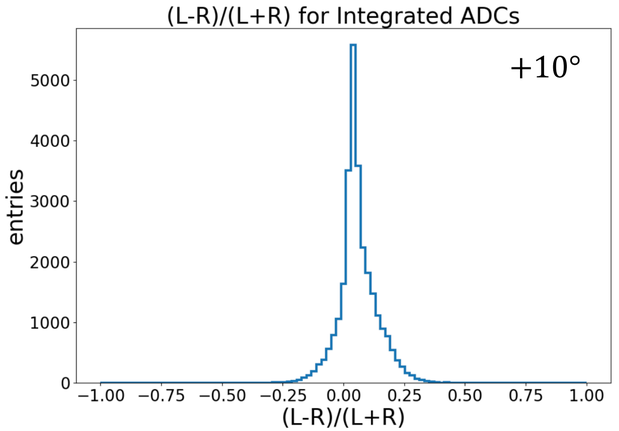



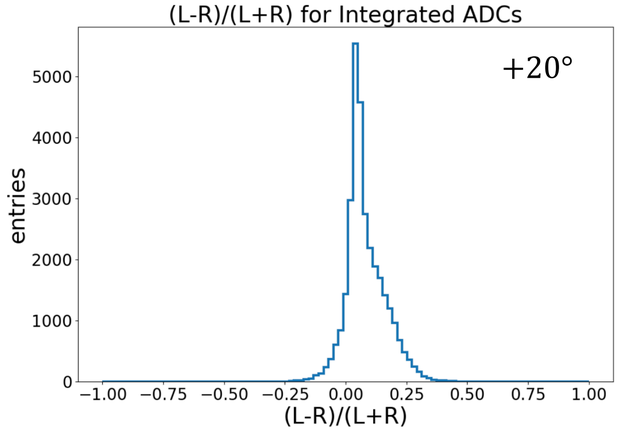
# Asymmetry between the LHS and RHS channels

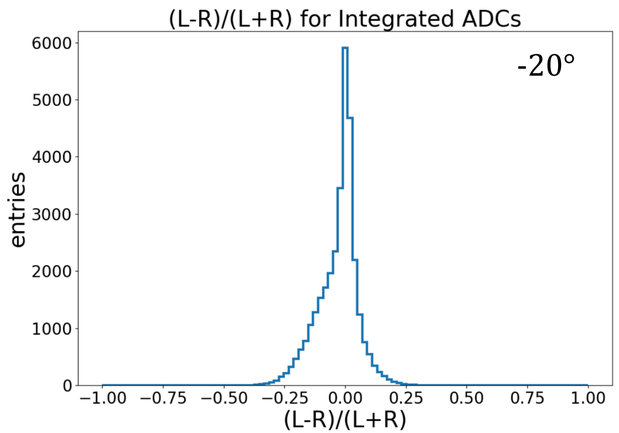
- PWO (no filters applied on ch 0-3): asymmetry ranging from -0.04 to 0.08.

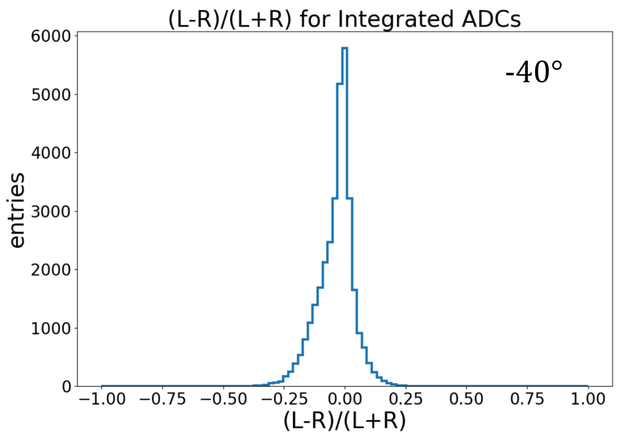


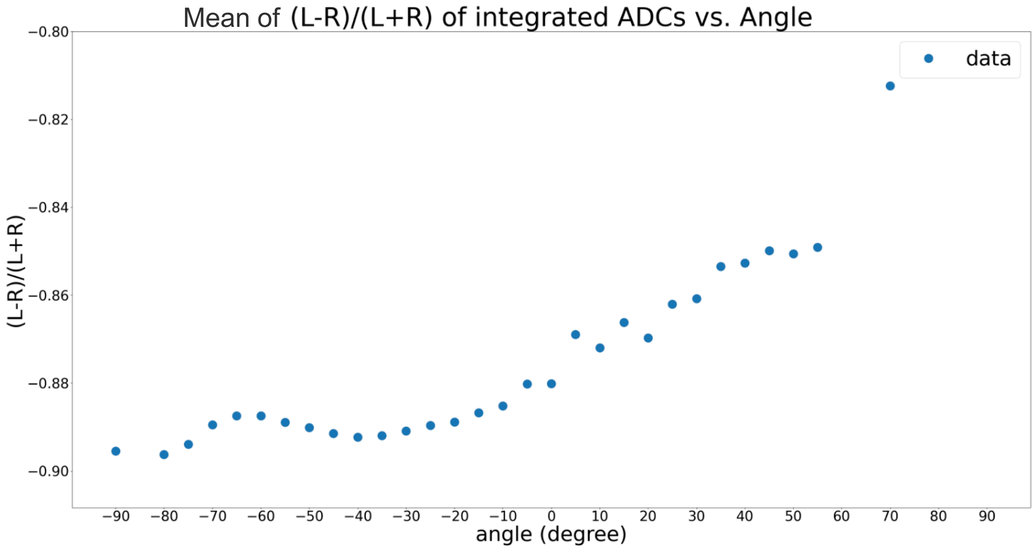



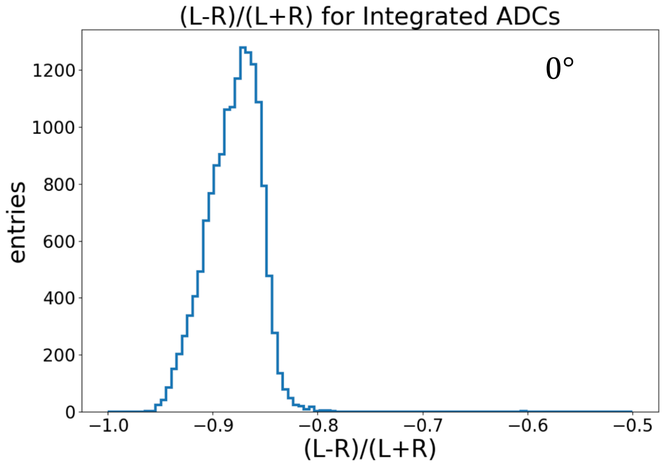



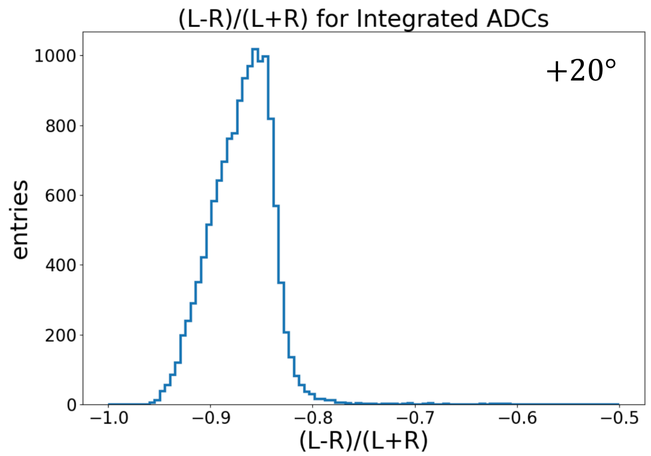



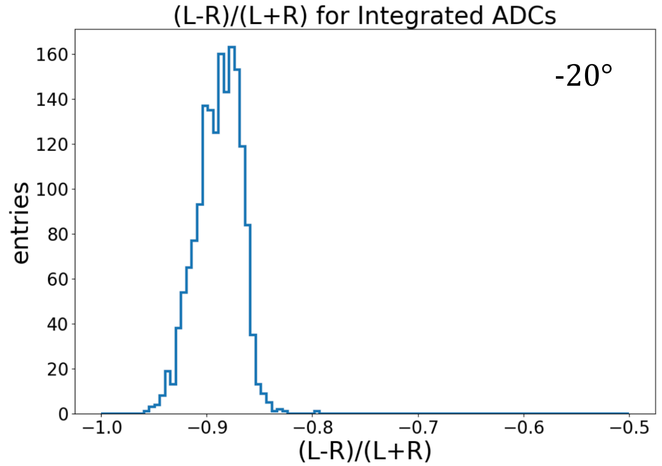
# Asymmetry between the LHS and RHS channels

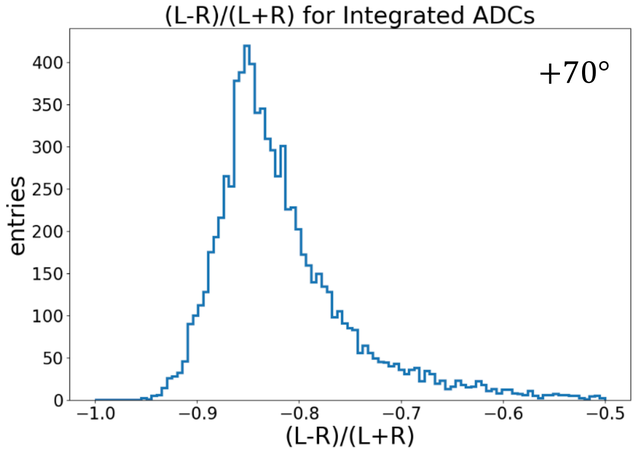
- PWO (with filters applied on ch 0-3): asymmetry ranging from -0.9 to -0.8.

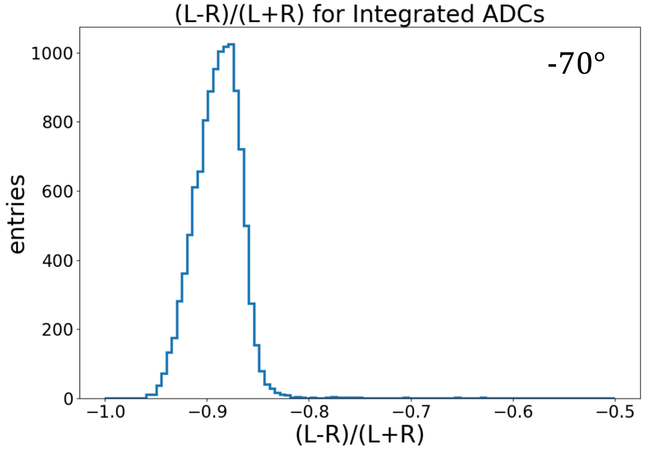


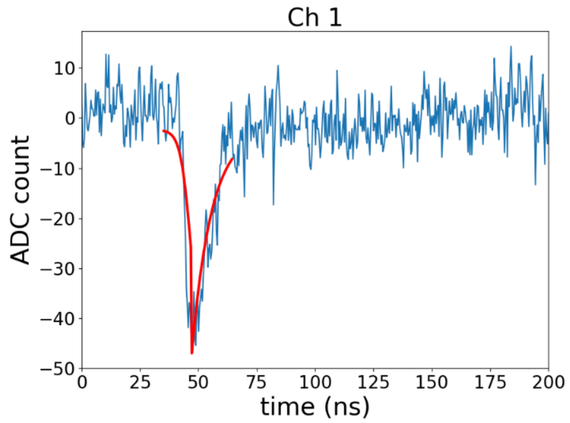
# Conclusion

- Reduction of noise by applying the event selection largely help to extract useful information from data.
- However, due to the small signals for PWO data that a filter is applied, the remaning events after the selection are mainly from showering.
- An exponential function fit is performed on the time spectrums. The fit parameters $\tau_L$ (rising time) and $\tau_R$ (decay time) have dependence on the integrated ADC.
- By selecting events with integrated ADC < 2000, we compared the time spectrum of PbF2 and PWO with a filter applied, which is similar to some degree.
- We checked distributions of the asymmetry of LHS and RHS channels for PbF2 and PWO (w/ and w/o filters), and the mean value of asymmetry as a function of angles.

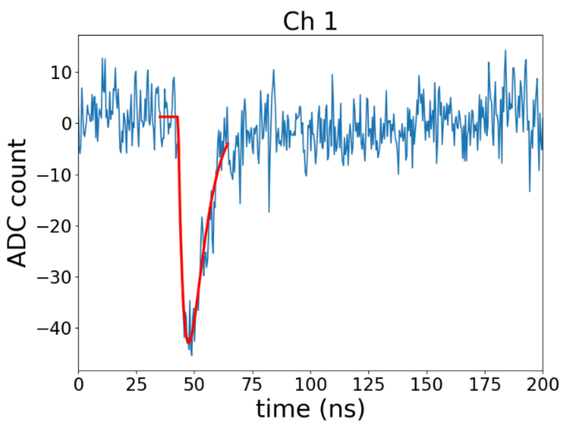
# To-do

- On-going: try a Gamma distribution to do the fitting instead of exponential functions.
- Check event-by-event asymmetry [(L-R)/(L+R)] for PWO w/ and w/o filters applied on ch 0-3.
- Build a template for Cherenkov and Scintillation spectrum from PbF2 and PWO (w/ filter) data respectively.

Exponential



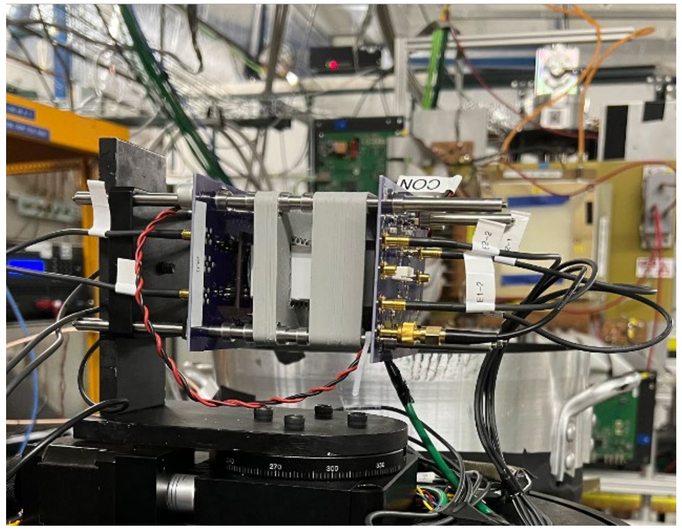

Gamma

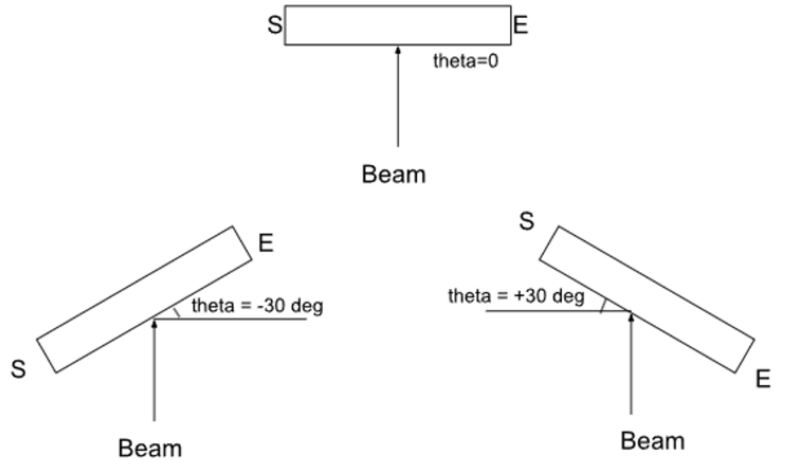


# Back up

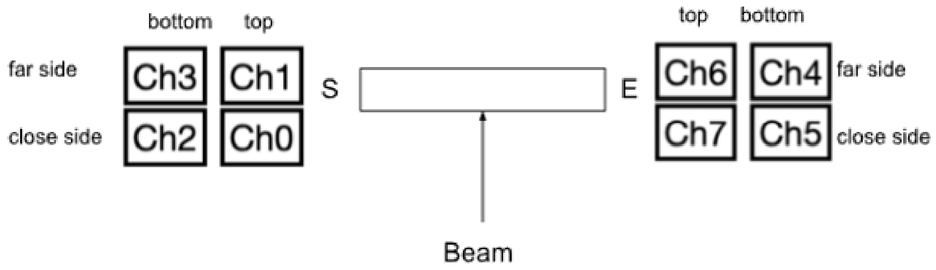
# June 2023 Test Beam @Fermilab Setup

- 120 GeV protons, ~45k protons evenly distributed in 4 s
- Only one spill per minute, 8 mm horizontally and 4 mm vertically
- Only at most one proton expected in our readout window




Four 6mmx6mm SiPMs on each side
0-3 on the S side
4-7 on the E side

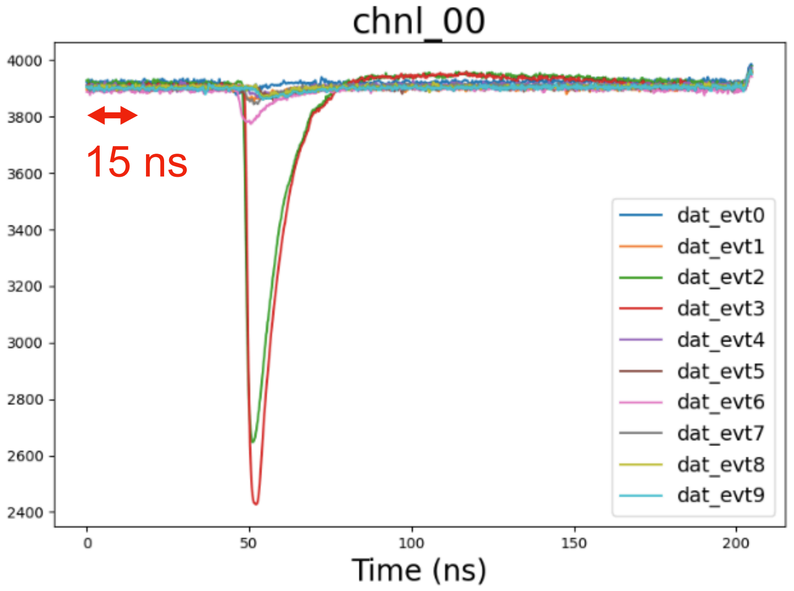


# June 2023 Test Beam @Fermilab Datasets

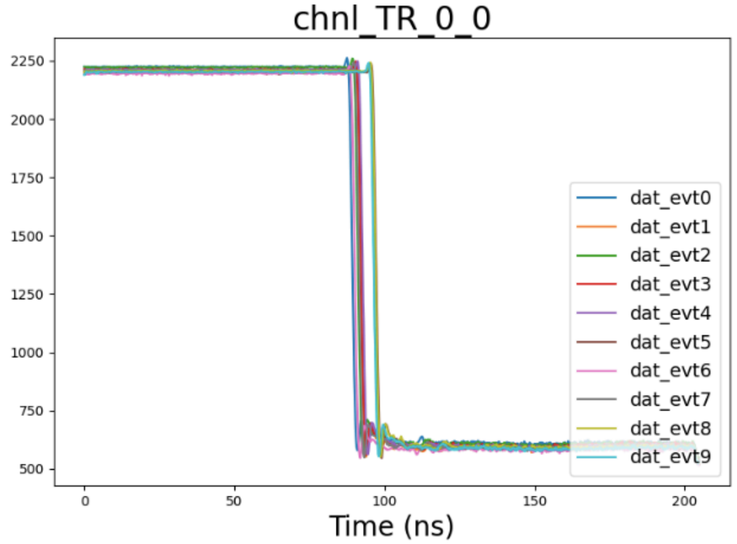
| Crystal | Size | Filter (S side only) | Run # | Angle (°) | # of events | Satuarated-event rate (%) |
|---|---|---|---|---|---|---|
| PbF2 | 6x2.5x2.5 $cm^3$ | No filter | 11-29 | 0 to ±90<br>(10° interval) | ~40k-70k | \|θ\|<30°: 2%<br>30°<\|θ\|<60°: 10%<br>60°<\|θ\|: 30% |
| PWO | | R60 | 31-66 | 0 to ±90<br>(5° interval,<br>except ±85°) | ~30k-70k | \|θ\|<30°: 2%<br>30°<\|θ\|<60°: 15%<br>60°<θ: 20%<br>θ<-60°: 35% |
| | | No filter | 103-121 | 0 to -50 (5° interval),<br>0 to +25 (5° interval),<br>±90 | ~20k-40k | \|θ\|<30°: 5%<br>30°<\|θ\|<60°: 15%<br>60°<\|θ\|: 45% |
| BGO | | U330 | 68-101 | 0 to -45 (5° interval),<br>0 to +50 (5° interval),<br>-55, -65, -75, ±90 | ~50k-60k | \|θ\|<30°: 7%<br>30°<\|θ\|<60°: 20%<br>60°<\|θ\|: 40% |

# Data pre-processing

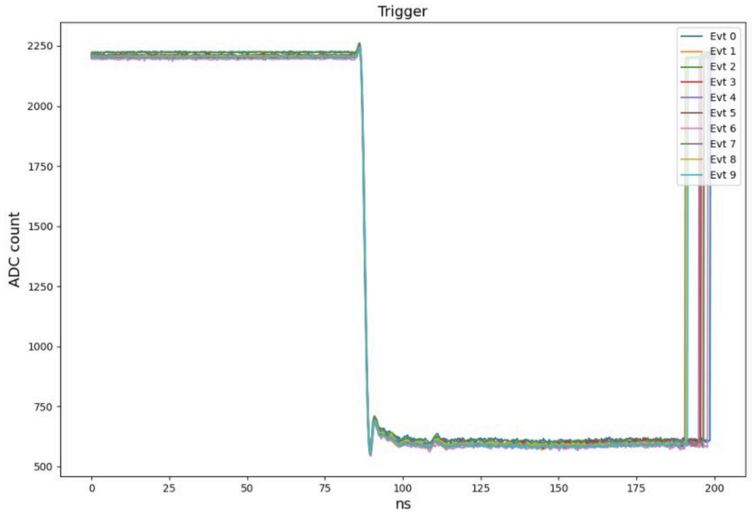
- Events with at least one channel readout value saturated are thrown away
- Pedestal correction: Average over the ADC counts in the time range (0, $t_{peak} - 20$) ns as the base count. Subtract all points in the event by the base count.
- Time correction.




**Before time shifting**




**After time shifting**

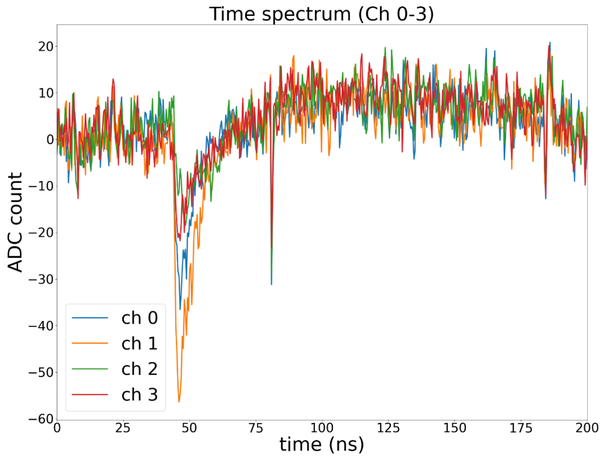


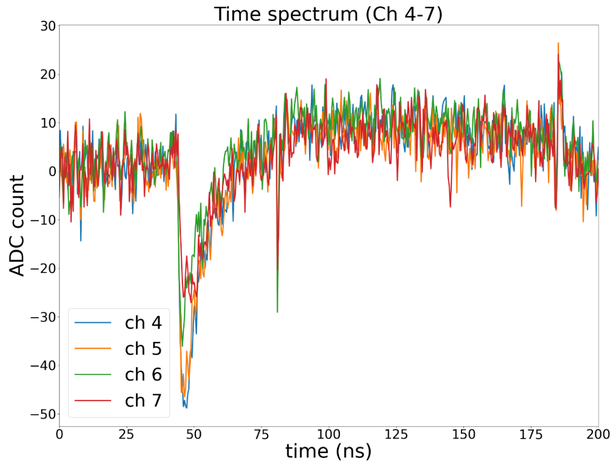
# Waveform for each crystal (θ=0°)

Show evt0 as example

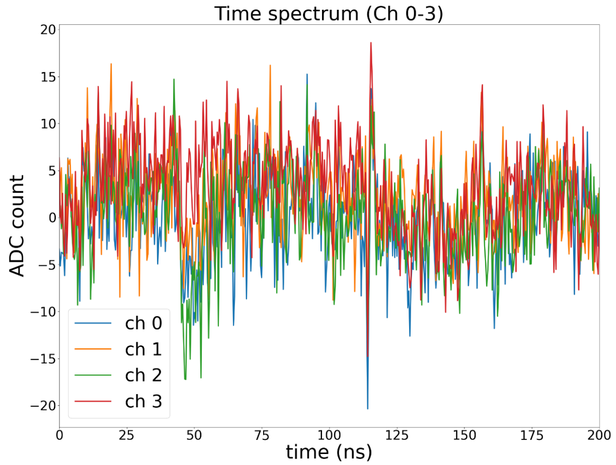
- PbF2: no filter for all channels; PWO and BGO: w/ fiter for ch 0-3, w/o filter for ch 4-7

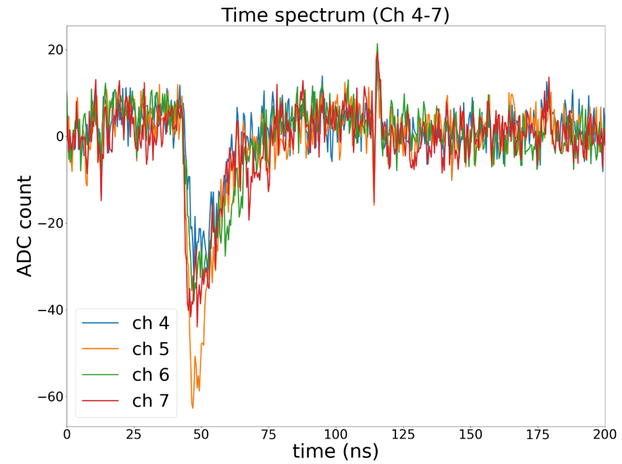
PbF2



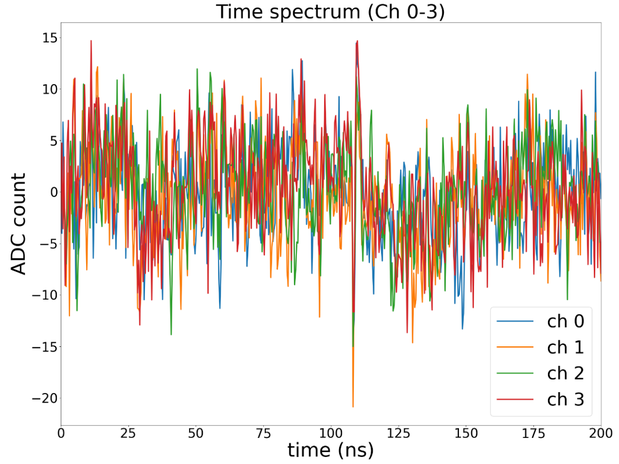



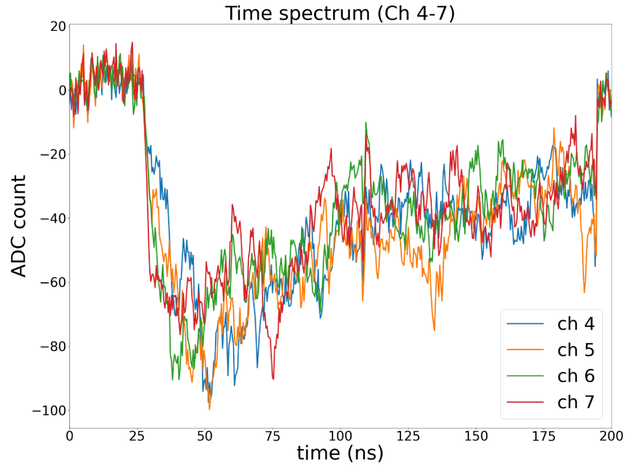

PWO



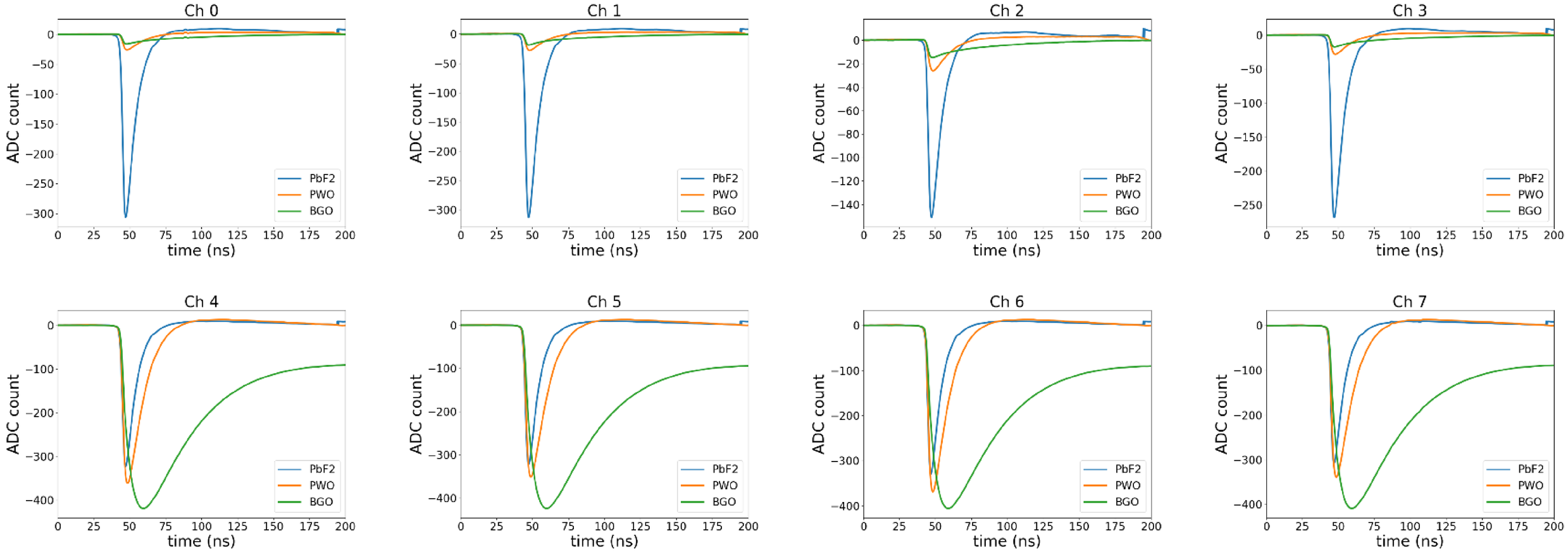

BGO



# Average Time Spectrum (θ=0°)

- The spectrums shown are the average over all events (without the saturated ones) in the same run.
- PbF2: no filter for all channels; PWO and BGO: w/ fiter for ch 0-3, w/o filter for ch 4-7



# Fit setup

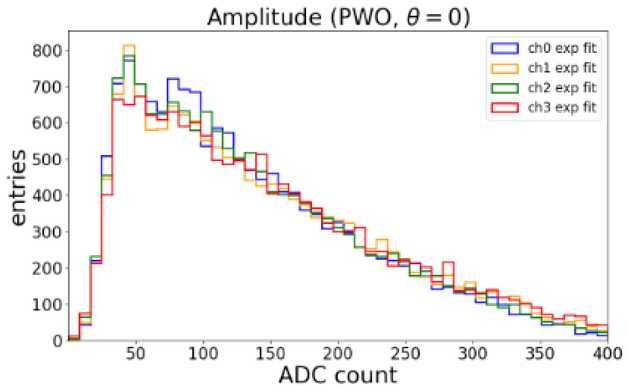
- Base count calculation: average over the first 15 ns.
- To reduce fluctuations, smooth the data by averaging two adjoint points.
- Fit range:
  - PbF2: 20-70 ns
  - PWO: 35-65 ns (LHS); 35-85 ns (RHS)
  - BGO: 20-170 ns
- Fit function:
  - Before the peak: $V(t) = |A|[\frac{1}{e^{(t-t0)/\tau L}+1} - 1] + d$, where |A| is the amplitude of the peak
  - After the peak: $V(t) = -|A|e^{(-t+t0)/\tau R} + d$

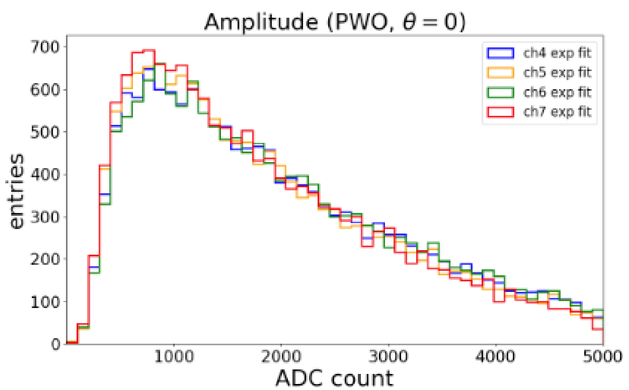
# Compare PWO Run31 vs. 103 (0 degree)

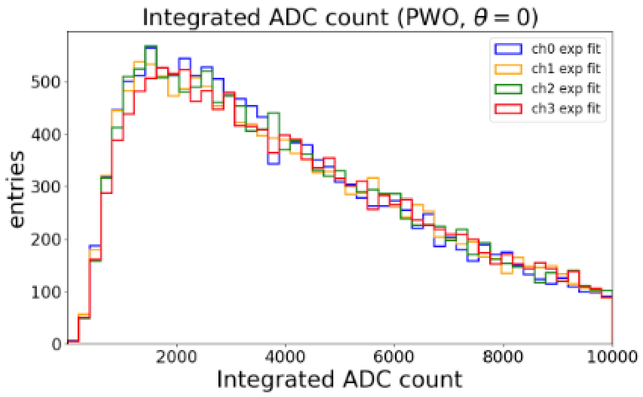
[back]

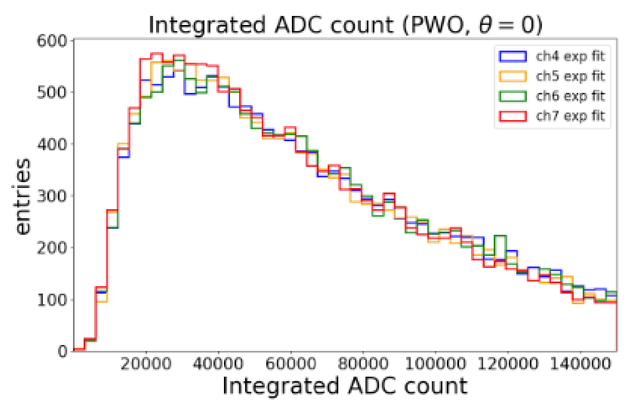
- Run31: filter applied on ch 0-3; Run103: without filter

Run31

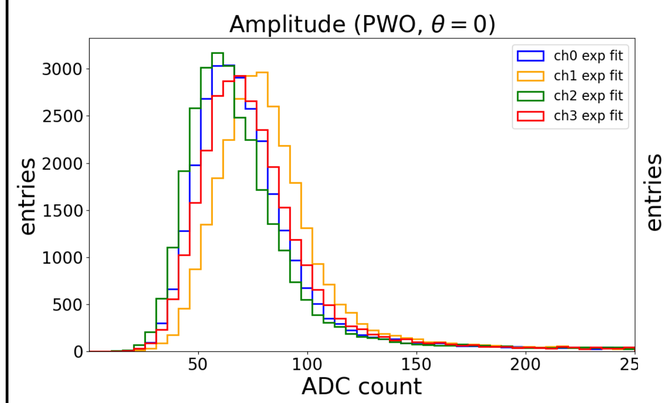


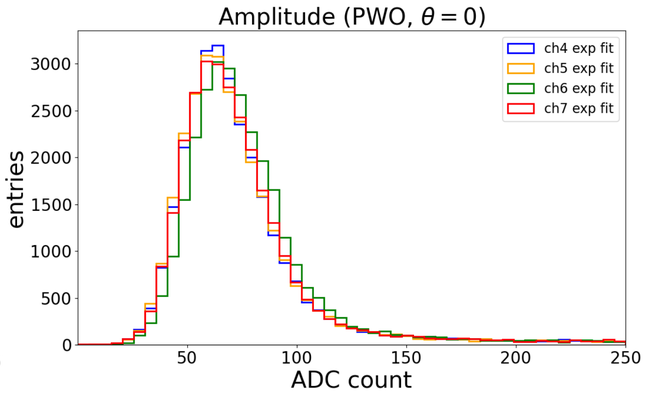



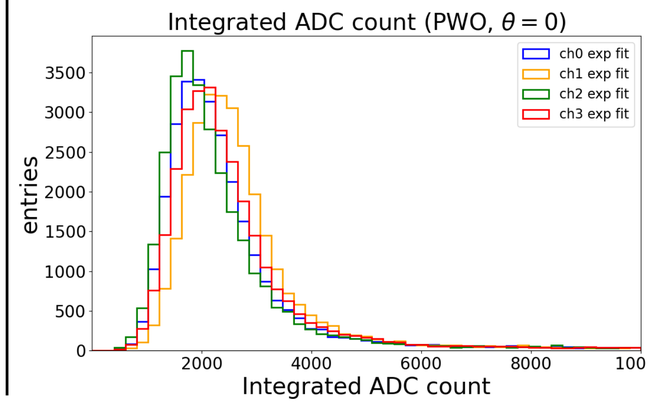



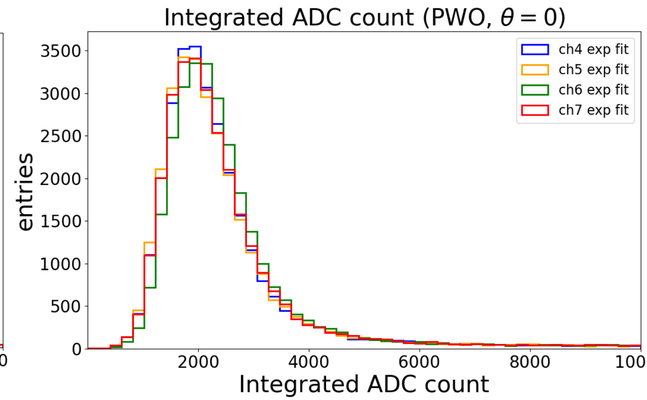




Run103



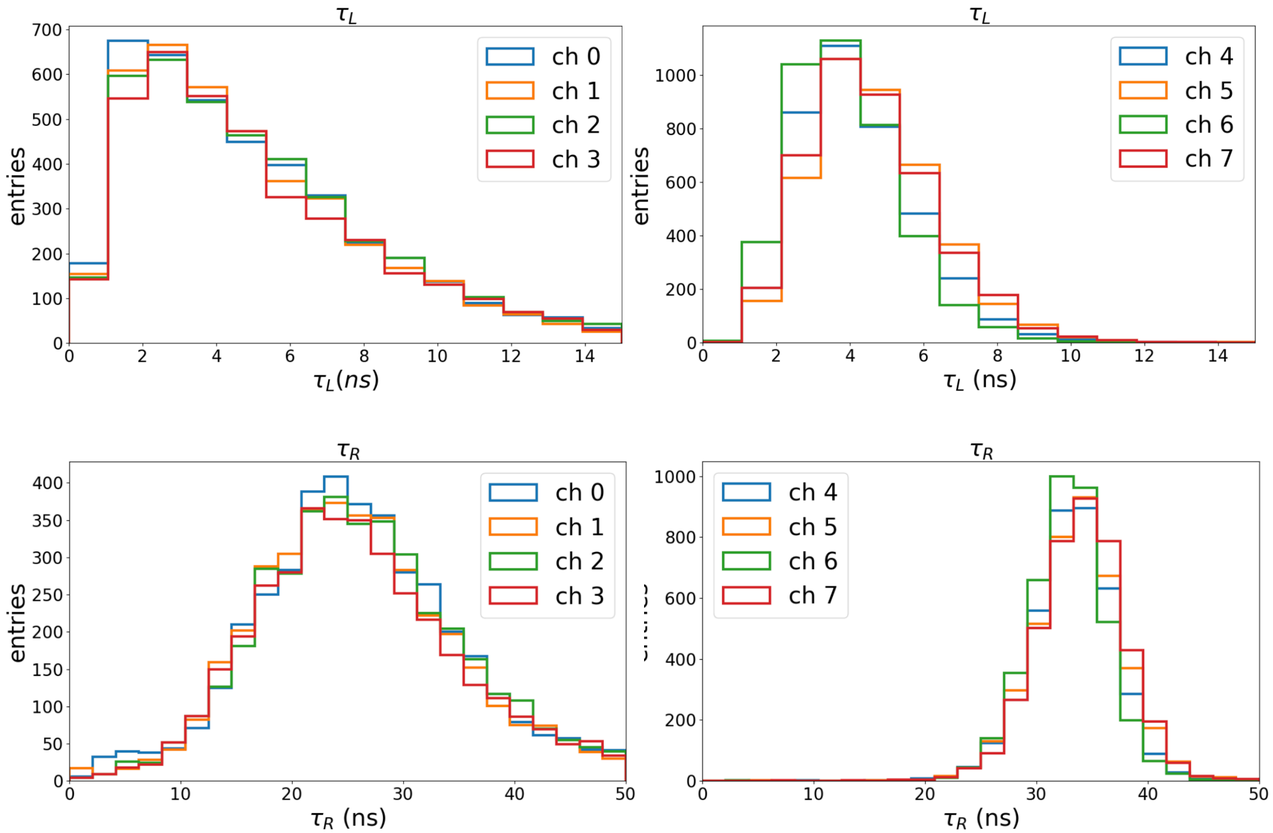
# Compare PWO Run31 vs. 103 (0 degree)

[back]

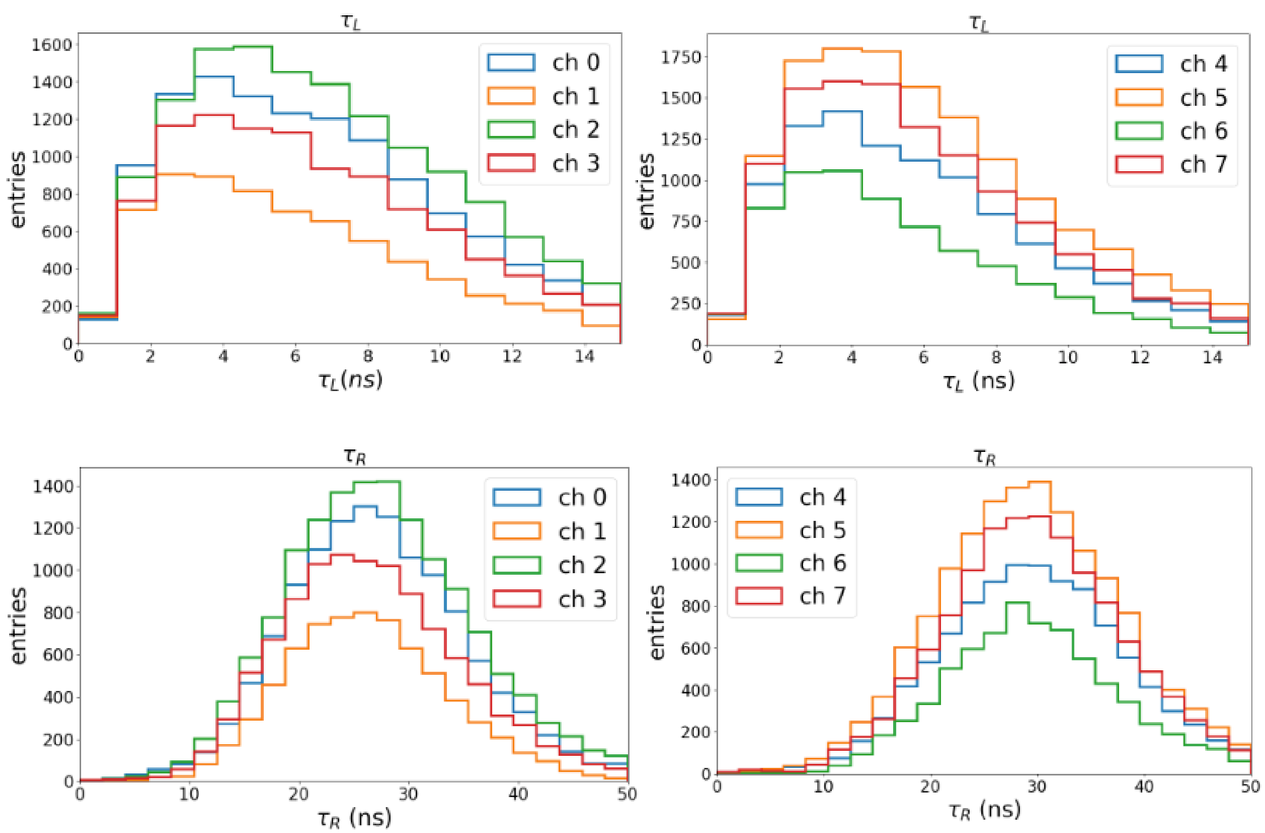
- Run31: filter applied on ch 0-3; Run103: without filter

* Only select events whose integrated ADC < 2000 in ch 0-3

Run31

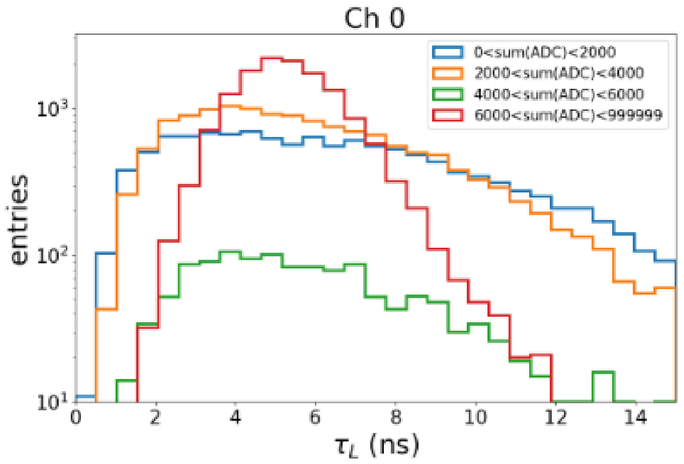


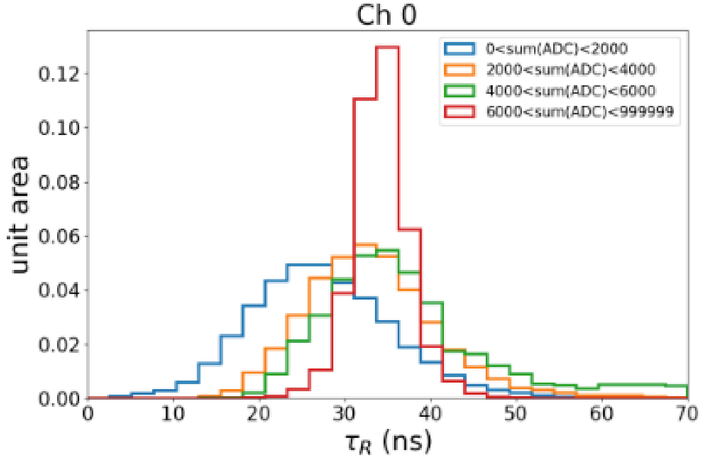

Run103

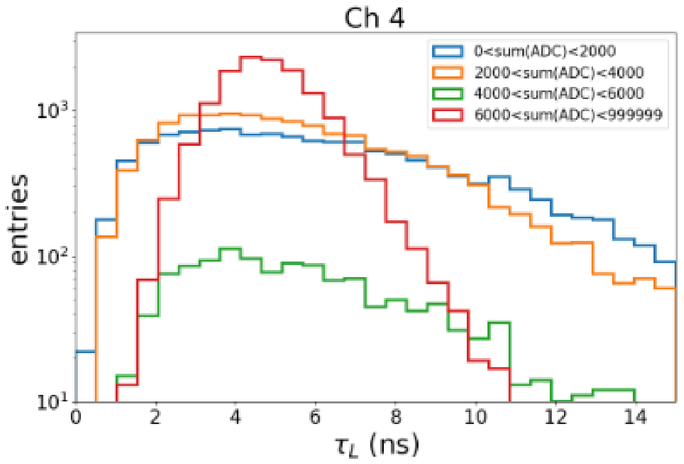


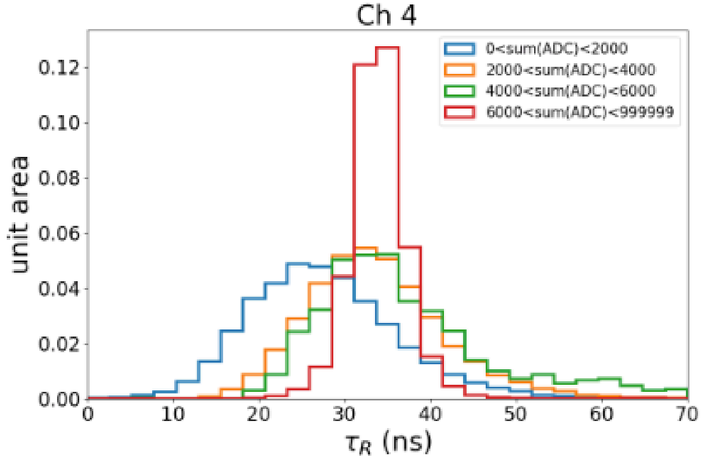
# $\tau_L$ and $\tau_R$ with different ADC cuts in Run103 [back]

- Run31: filter applied on ch 0-3; Run103: without filter



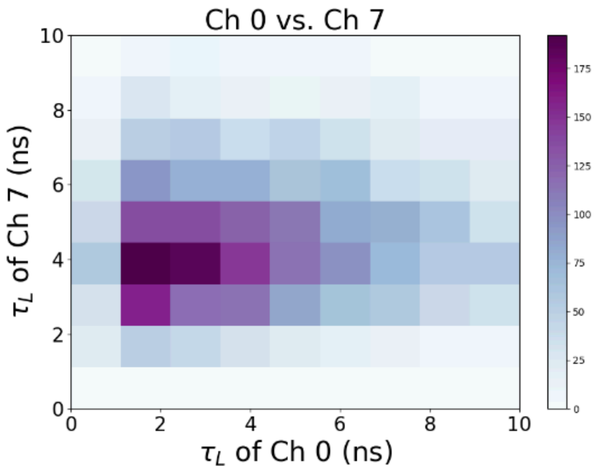



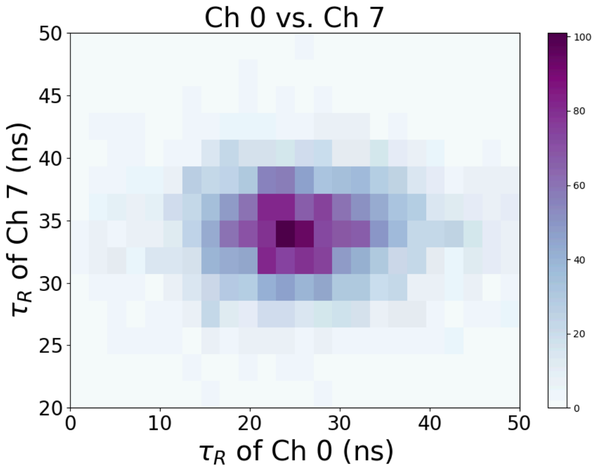
# $\tau_L$ ($\tau_R$) correlation between PWO w/ vs. w/o filter

- Weak $\tau_L$ ($\tau_R$) correlation between channels w/ and w/o filter.
- Anti-correlation between $\tau_L$ and $\tau_R$ in the same channel.

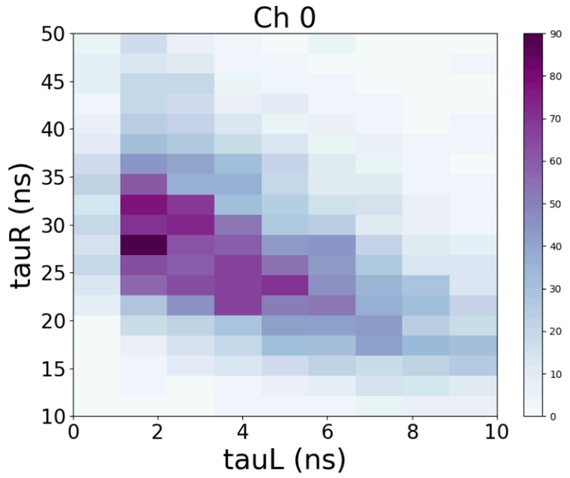
* Only select events whose integrated ADC < 2000 in ch 0-3

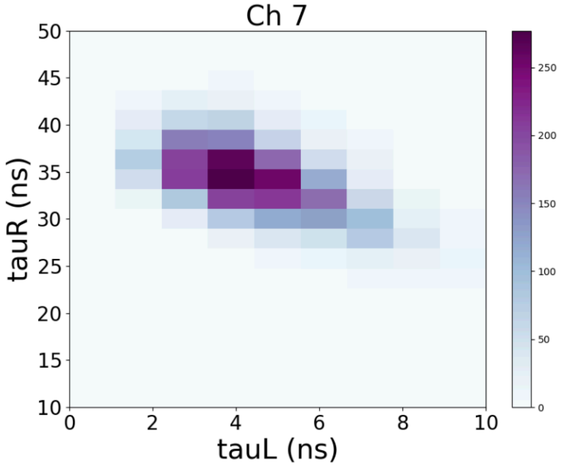
- $\tau_L$ ($\tau_R$) correlation between channels w/ and w/o filter:




- $\tau_L$ vs. $\tau_R$ in the same channel:



# ADC to p.e. conversion

- Evaluated from the LED data with #photon=5.
- For both pulse height and voltage integration, scale the x variable of the poisson distribution with mu=5 (orange) to match the distributions (blue). The scaling of x is the voltage to ADC conversion.
- Further convert voltage to ADC by 1V=4096 ADC.
- 1 p.e. = 2.9 ADC for pulse height;  1 p.e. = 67.5 ADC for integrated counts