# Fermilab testbeam data analysis

Hui-Chi Lin
On behalf of the analysis team

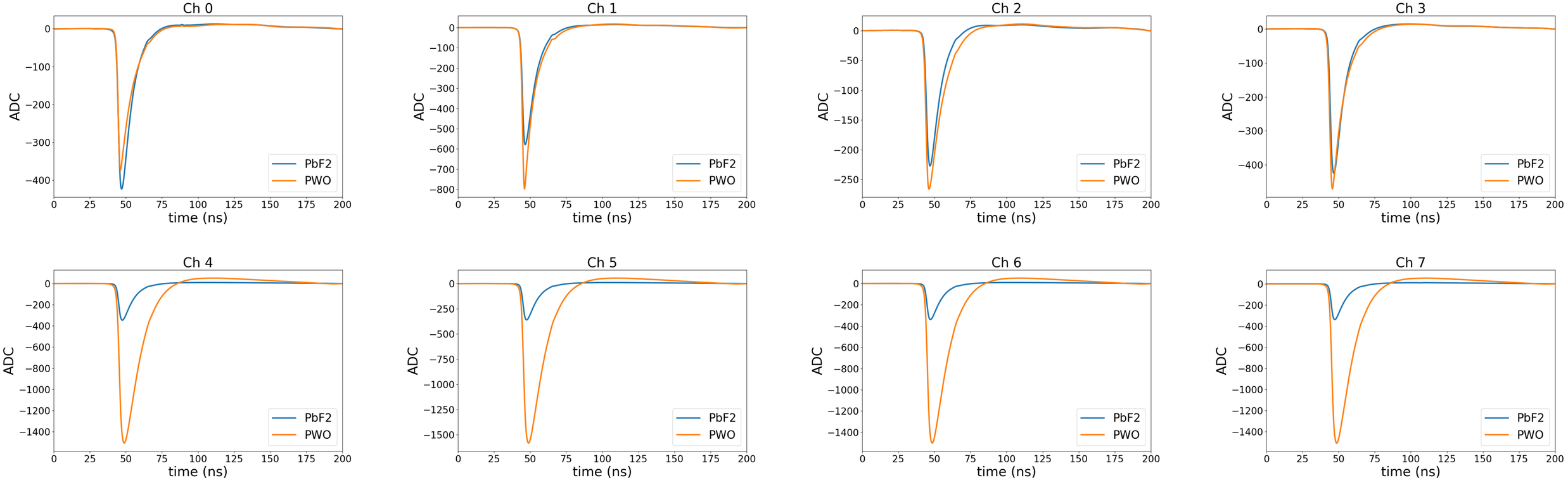
Calvision meeting Jan 18 2024

# Introduction

- Last time we saw that the PWO time spectrums at 0 degree are similar between the filtered and non-filtered sides, and therefore hard to distinguish the Cherenkov component [slides].
- At 0 degree, the thickness that the protons pass through is 2.5 cm and we only expect on average 2 Cherenkov photons after the filter is applied, it's hard for us to detect.
- Therefore, this time we analyzed the data of larger angles (longer lengths that protons can pass through). We see starting from +80 degree there are larger differences between filtered and non-filtered sides.

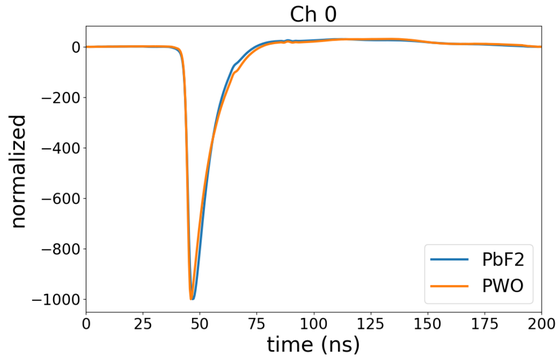
# PbF2 vs PWO time spectrums (real size) at +90 degree

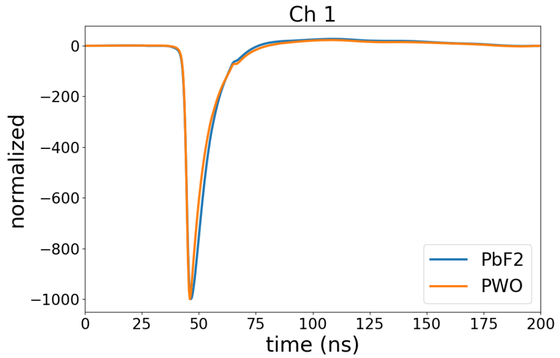
- PWO/PbF2 spectrum comparison at large angles [80 degree result].
- Filters are applied on PWO for ch0-3. No filters are applied on PbF2.
- Amplitude of average spectrum is comparable to or even larger for PWO than PbF2 on the filtered side. This trend is related to the long tail of the amplitude distribution for PWO [backup]. In addition, the PWO events are also mainly from showering [backup].

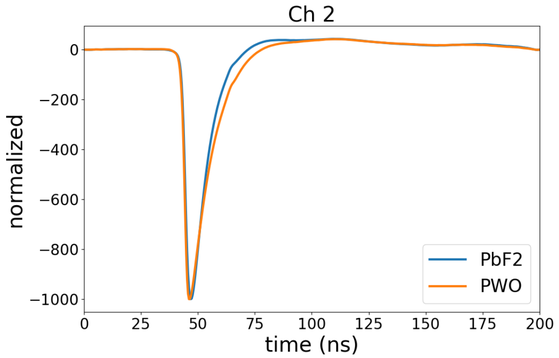


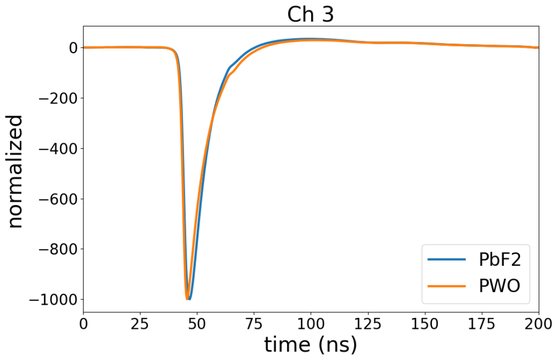
# PbF2 vs PWO time spectrums (normalized) at +90 degree

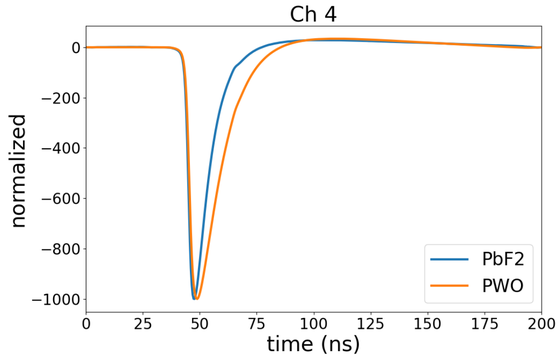
- At large angles, the shape of PWO spectrums for the filtered side matches the PbF2 spectrum! [80 degree result]

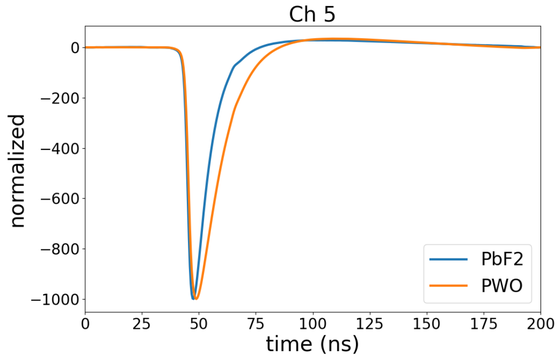


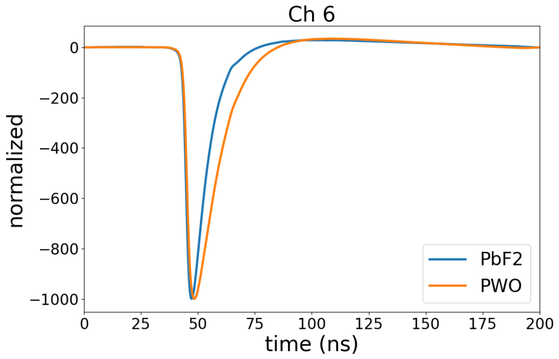



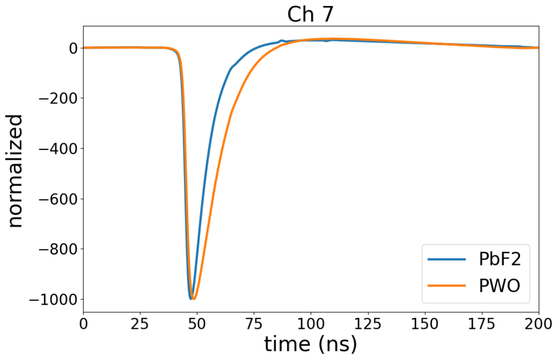



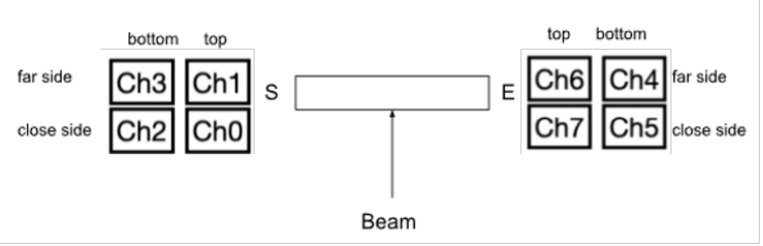



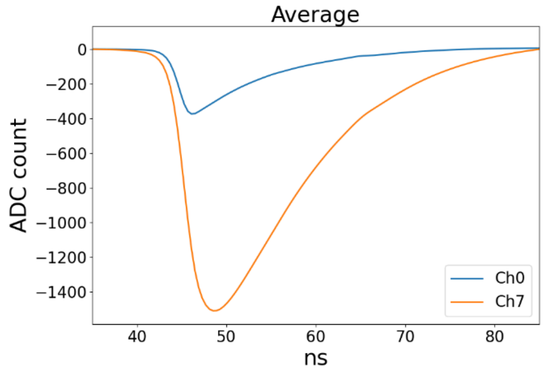
# Compare the time spectrums from filtered and non-filtered sides

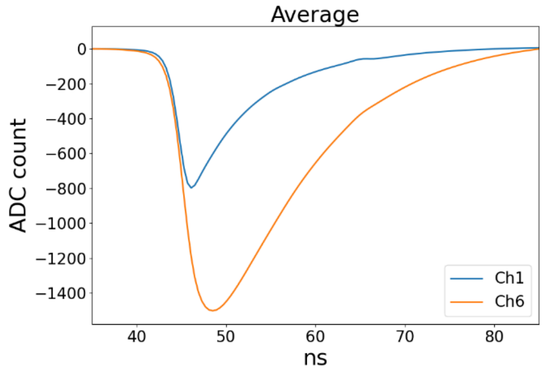
Check if the spectrums from both sides are distinguishable

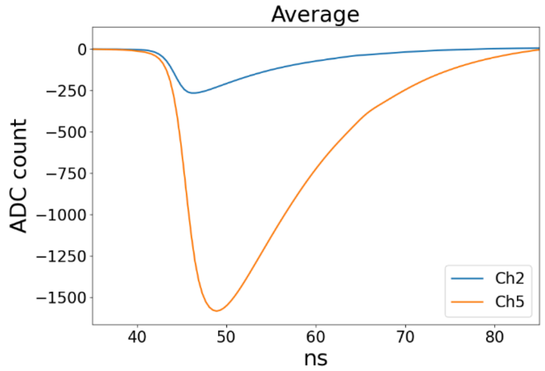
# PWO time spectrums at +90 degree (real size)

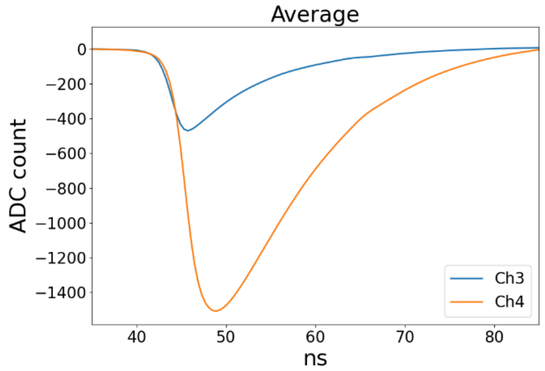


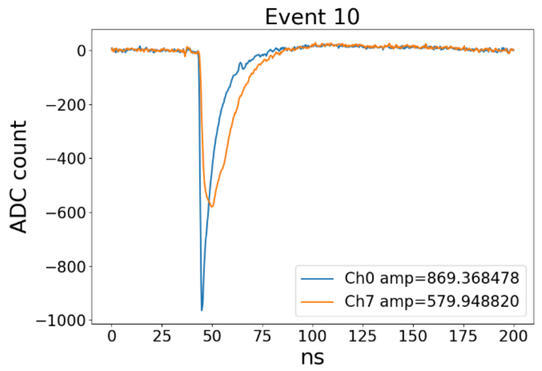

- Time spectrum comparison of channels w/ and w/o filters at 90 degree.
- Ch 0,1,2,3 are compared to Ch7,6,5,4 respectively as they are symmetric across the line perpendicular to the crystal surface.
- Amplitude of ch0-3 (w/ filters) is on average smaller than that of ch4-7. However, for some individual events amplitude from the filtered side is larger (5%) [other examples].

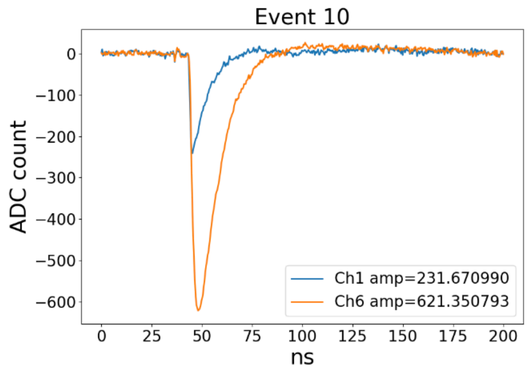


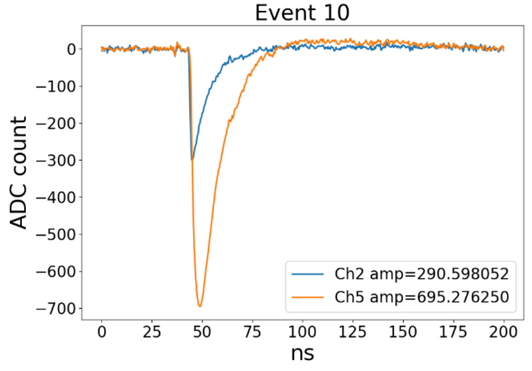



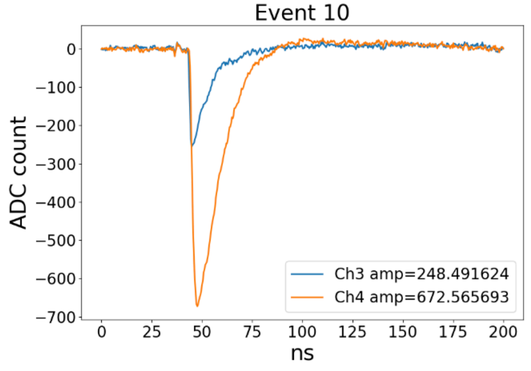



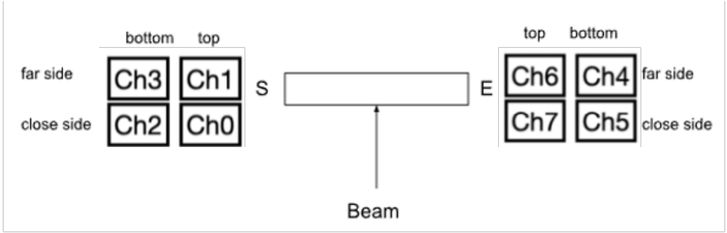



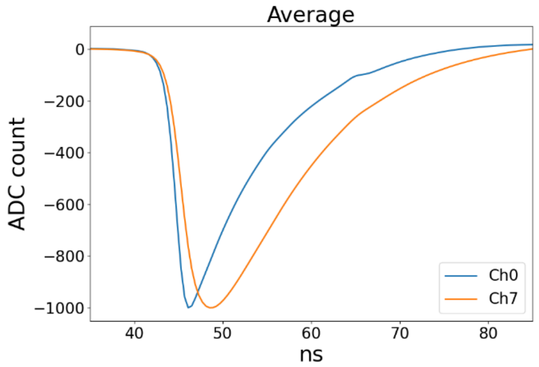



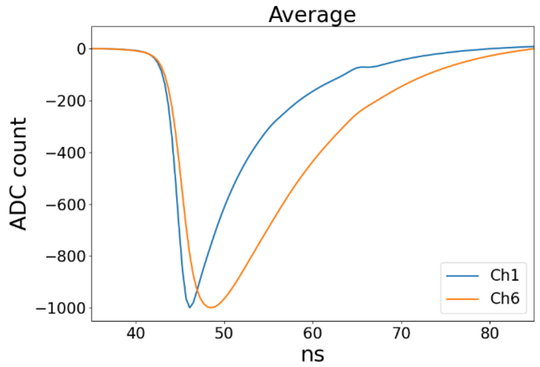



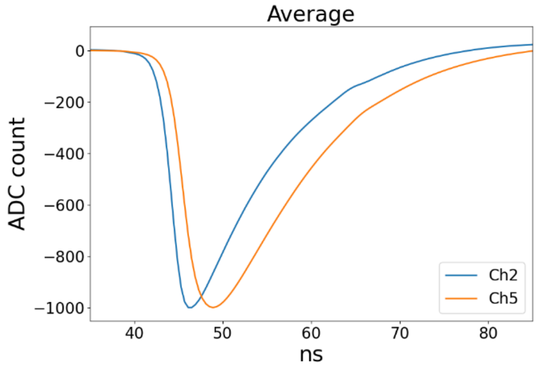
# PWO time spectrums at +90 degree (normalized)

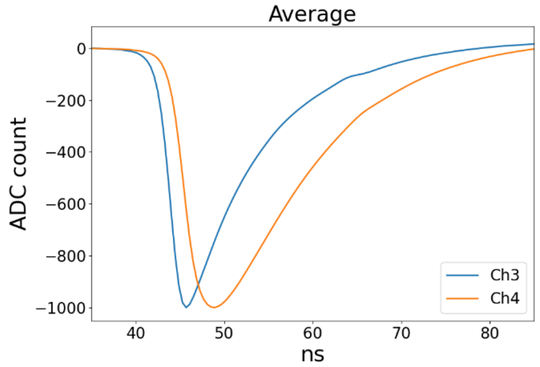
- Time spectrum (normalized to the same height) comparison of channels w/ and w/o filters at 90 degree.
- Differences are proportional to amplitude.

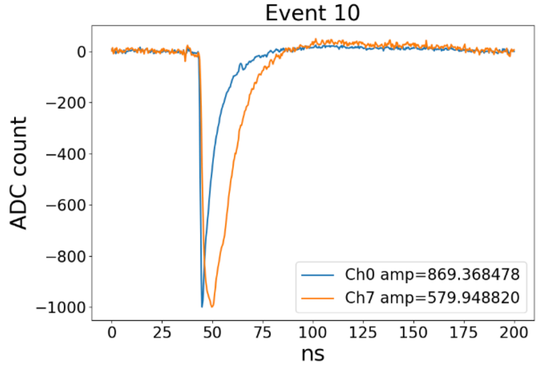


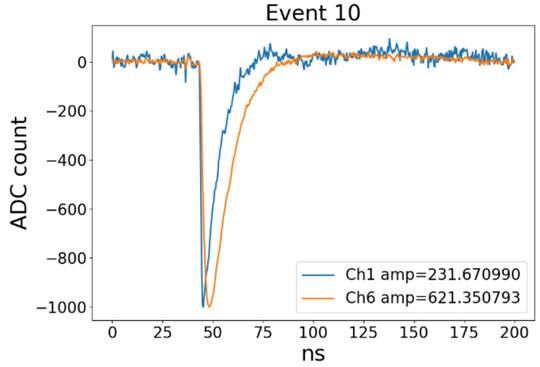



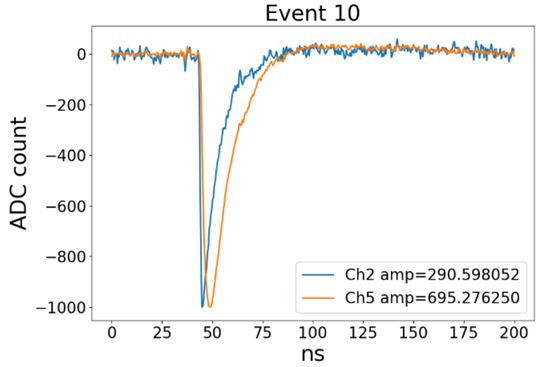



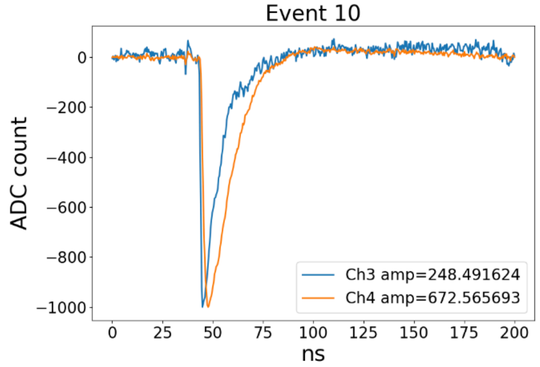



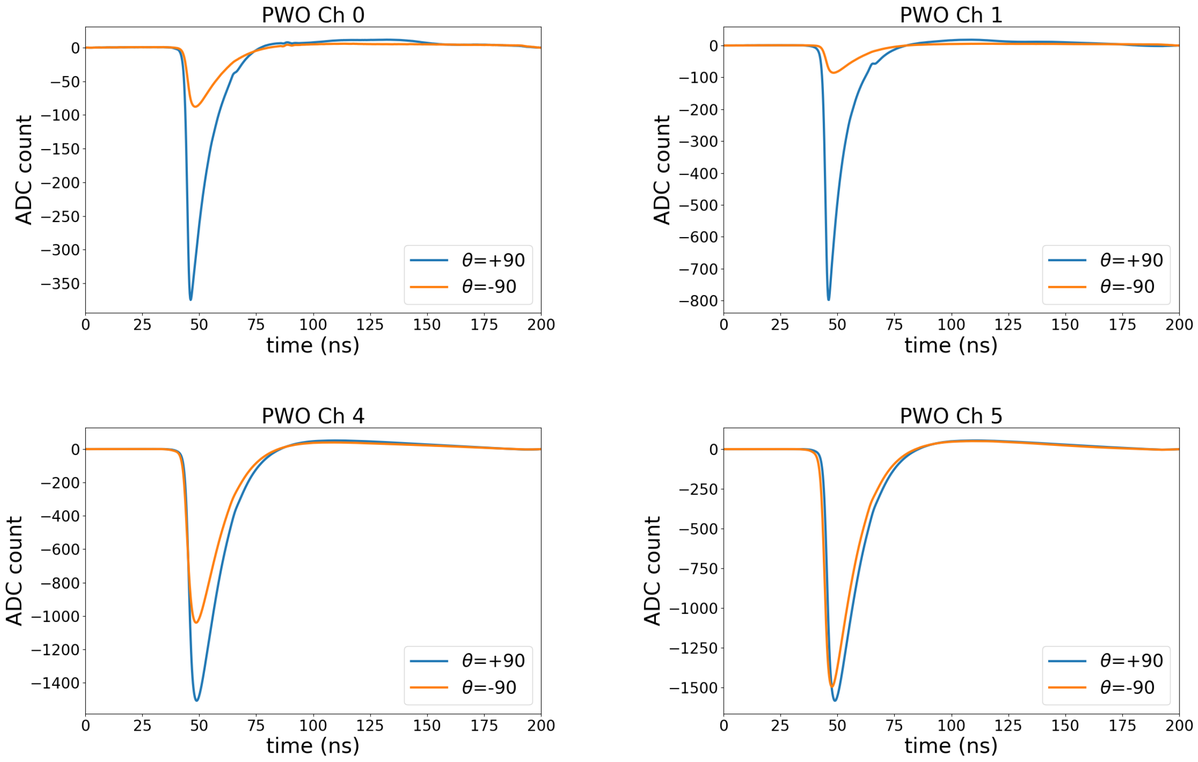
# Compare the time spectrums at ±90 degree

Check the directionality of the Cherenkov light

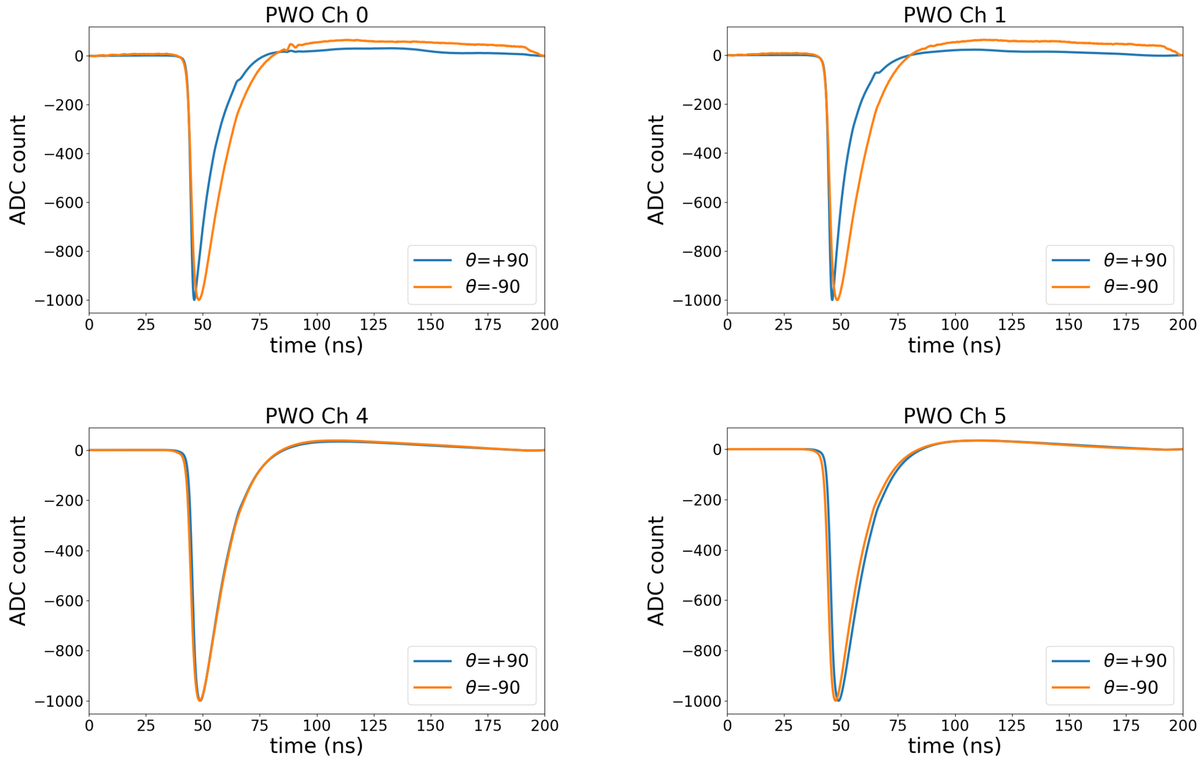
# PWO average time spectrum comparison of ±90 degree

- Amplitude: events of +90 degrees have much larger amplitude than -90 degrees on the filtered side (ch0-3), which is consistent with the property that Cherenkov is directional. [80 degree result]
- Shape: Larger differences between events of +90 and -90 degrees on the filtered side.

Real size




Normalized

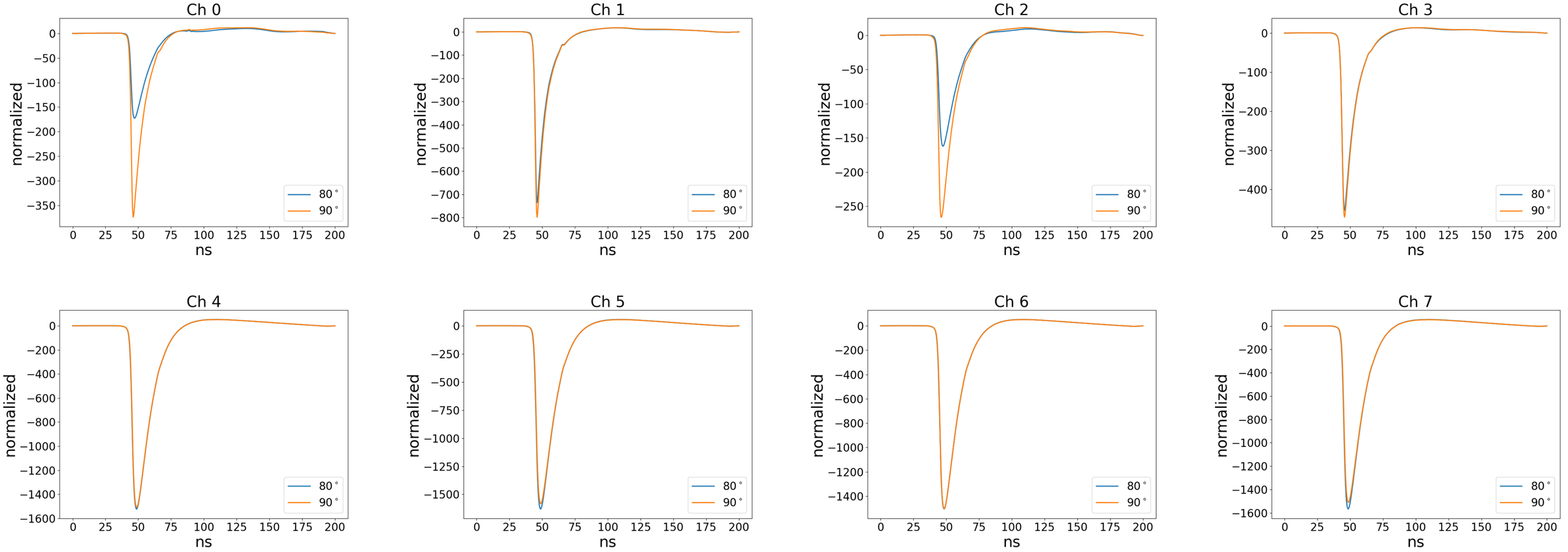


# Compare the time spectrums at +80 and +90 degree

Check how the size of the amplitude changes w.r.t angles for filtered and non-filtered side.

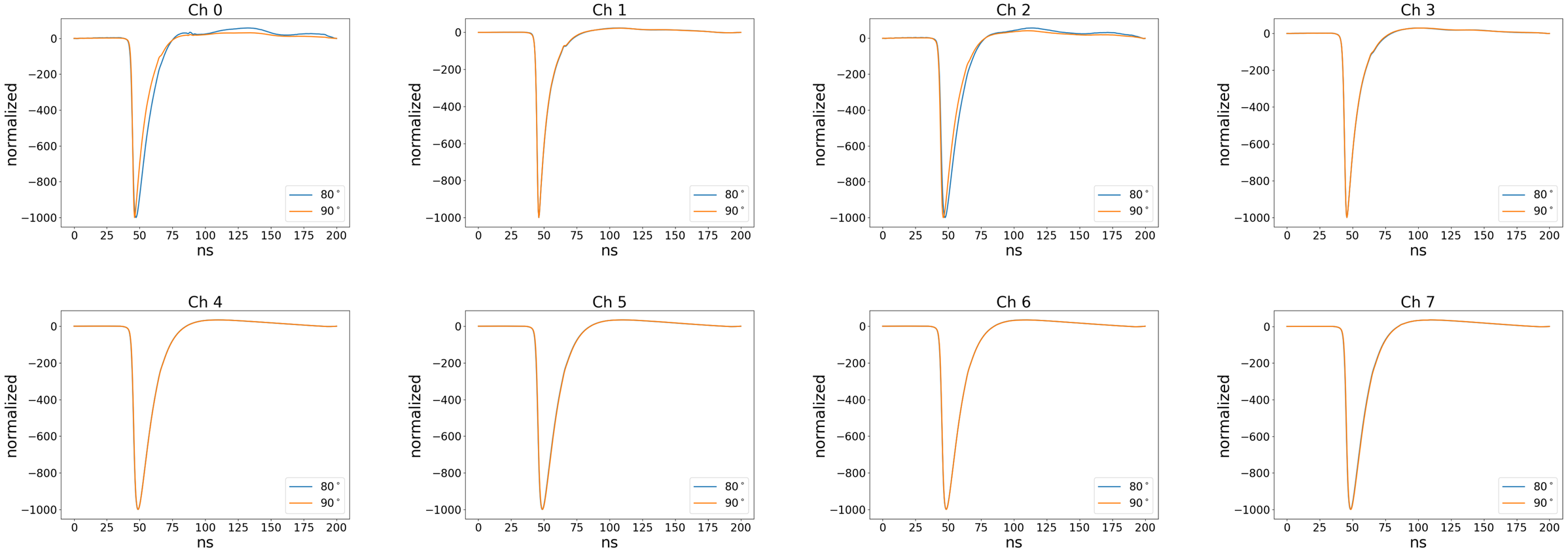
# Comparison between 80/90 degrees (Real Size)

- Filtered side: amplitude is similar between 80 and 90 degrees for ch 1 and 3, while for ch 0 and 2 the amplitude of 90 degree is larger.
- Non-filtered side: amplitude is similar between 80 and 90 degrees for all channels (can tell us that the scintillation light is isotropic).



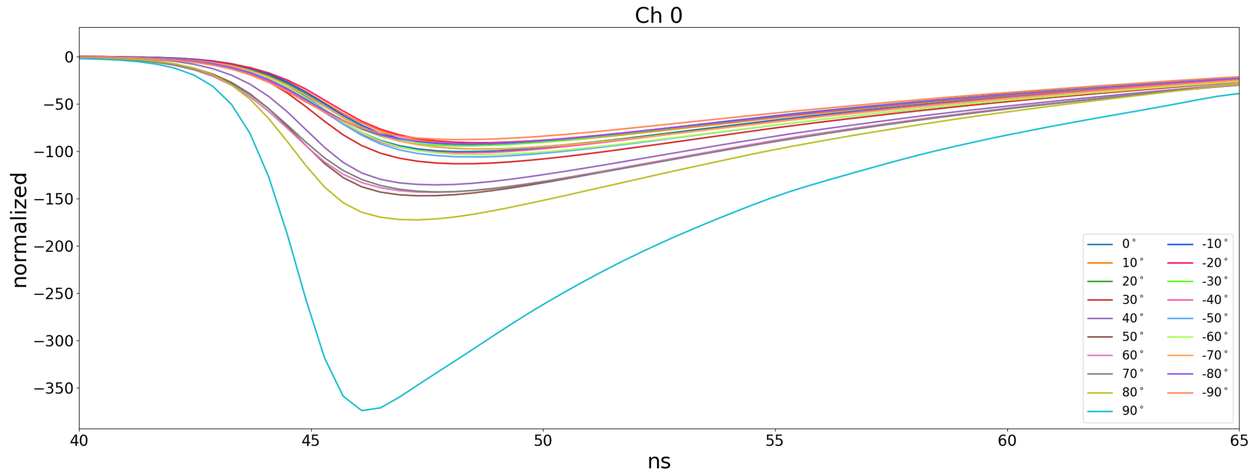
# Comparison between 80/90 degrees (normalized)

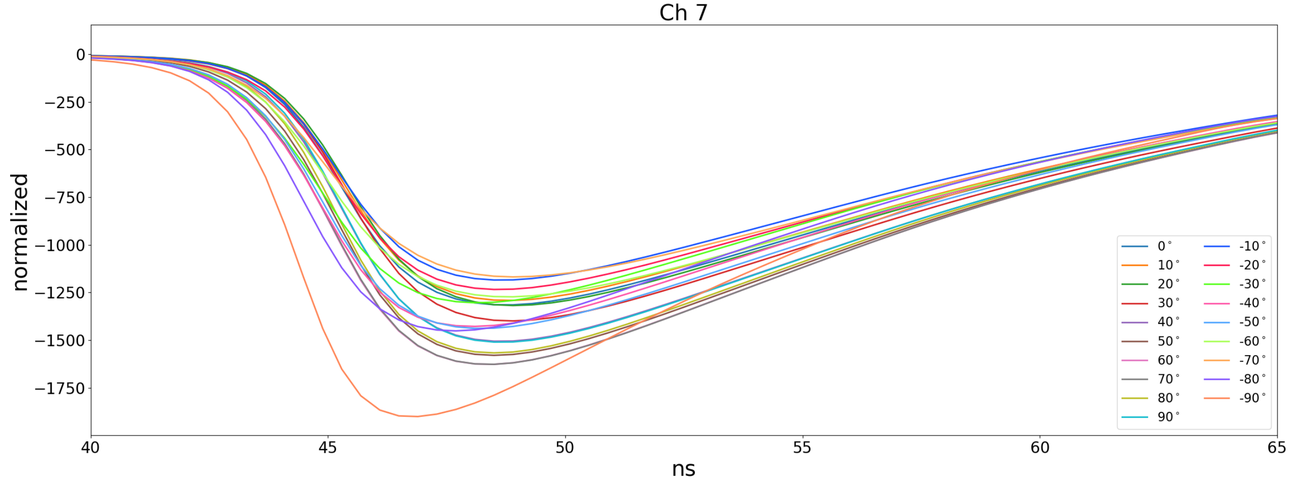
- Shape of time spectrums is similar between 80 and 90 degrees.



# PWO time spectrums at different angles (Real Size)

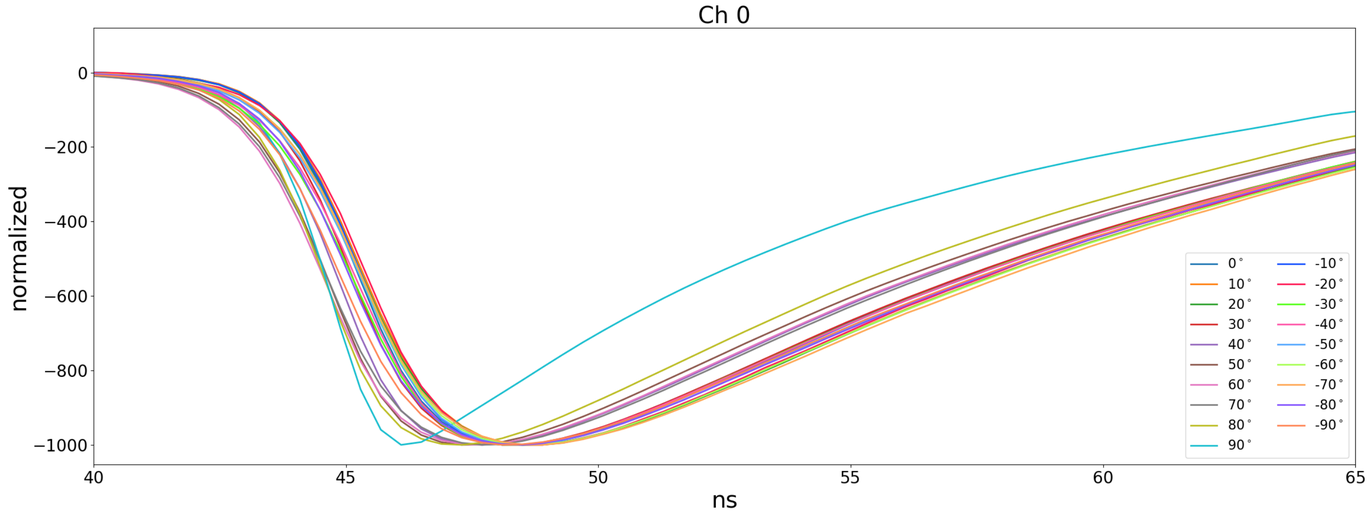
- Time spectrums of larger positive angels have larger amplitude on the filtered side.

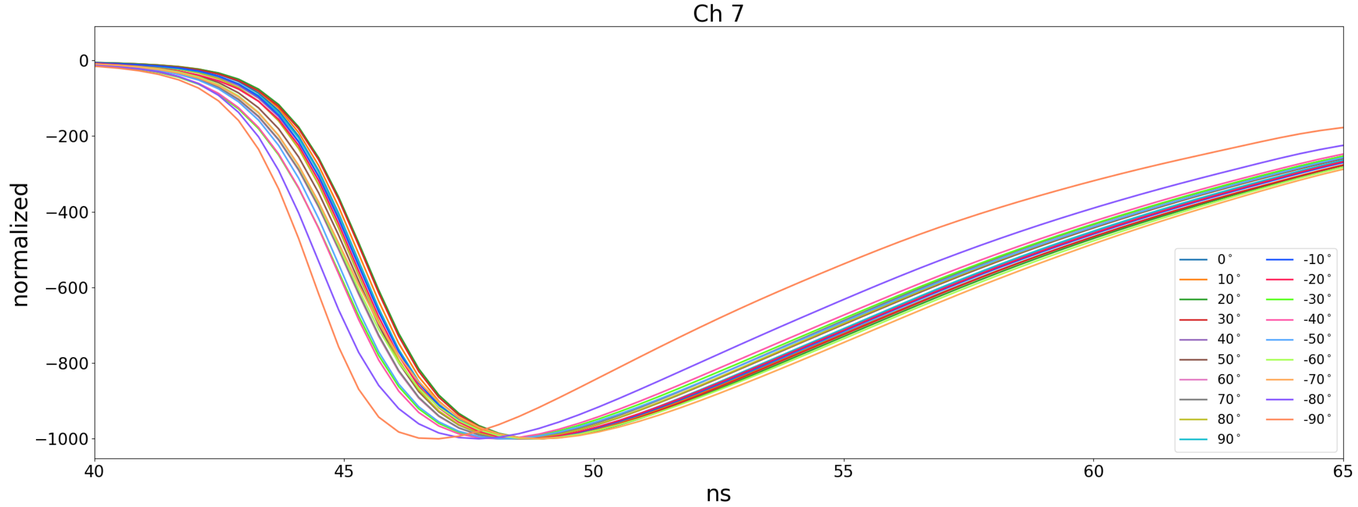


# PWO time spectrums at different angles (normalized)

- Time spectrums of larger positive angels have narrower spectrums on the filtered side.



# Conclusion

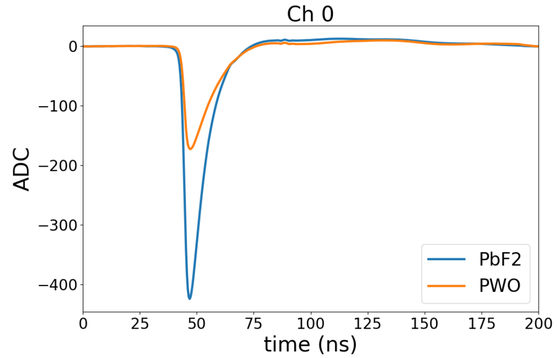
- Time spectrums from the filtered and non-filtered side are possible to be distinguished at large angles (+80 and +90) degrees.
- Checked that the shape of PWO spectrums (filtered side) is consistent with that of PbF2 spectrums.
- From the comparison between +90 and -90 degrees, the PWO events from the filtered side seem to have the directional property of Cherenkov light.
- In addition, we will in parallel work on re-analyzing the PbF2 data (e.g. with more appropriate fit function) for a potential publication.

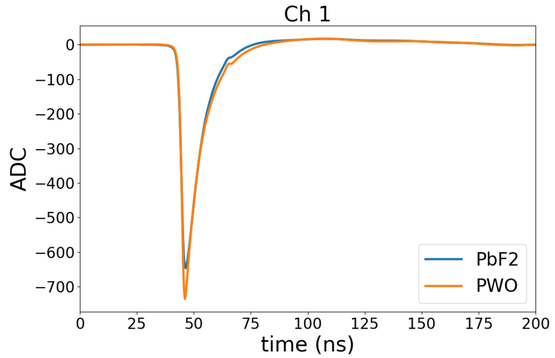
# Back up

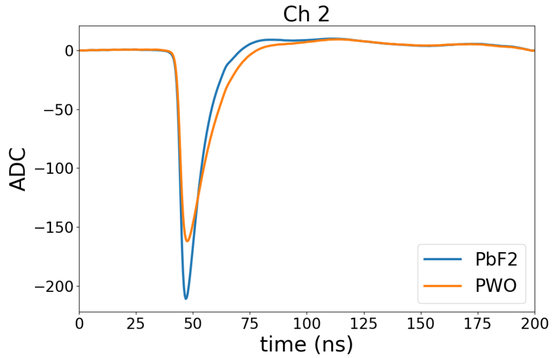
# PbF2 vs PWO time spectrums (real size) at +80 degree

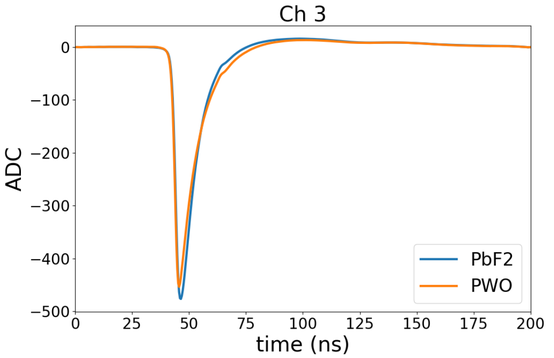
- PWO/PbF2 spectrum comparison at large angles.

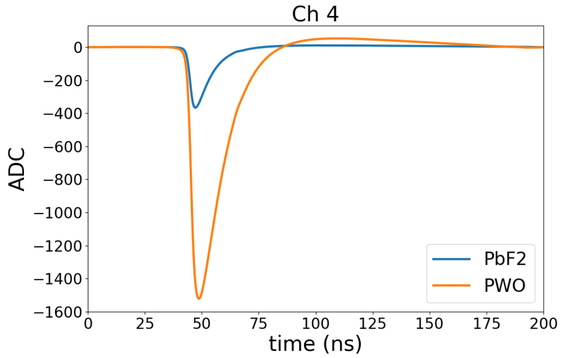
[back]

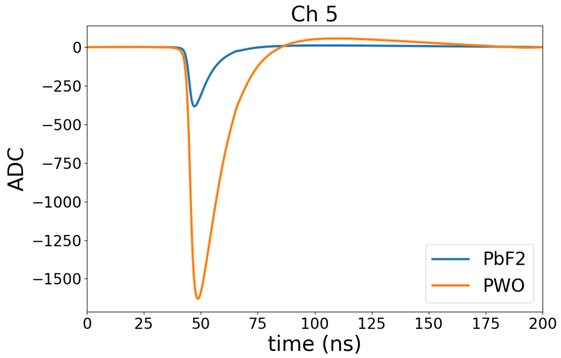


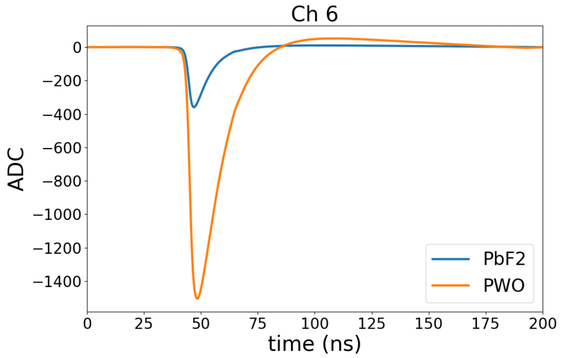



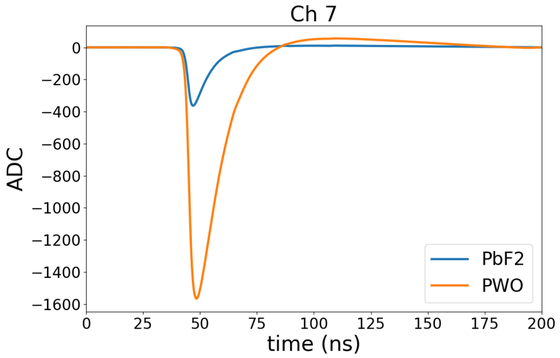



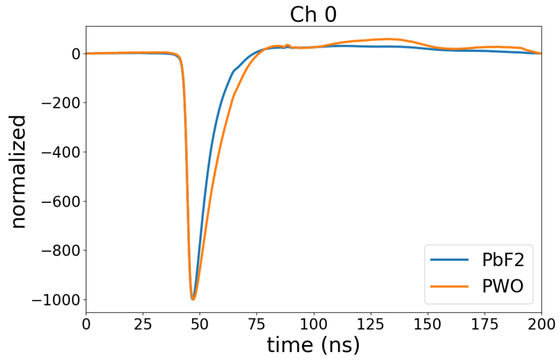



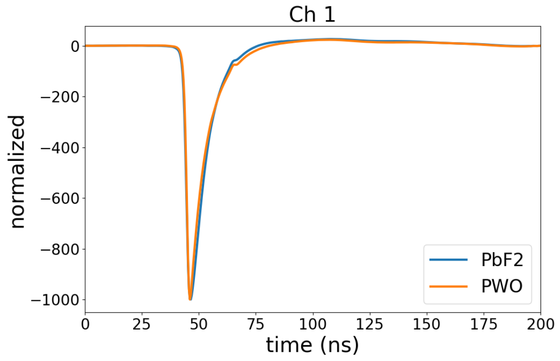



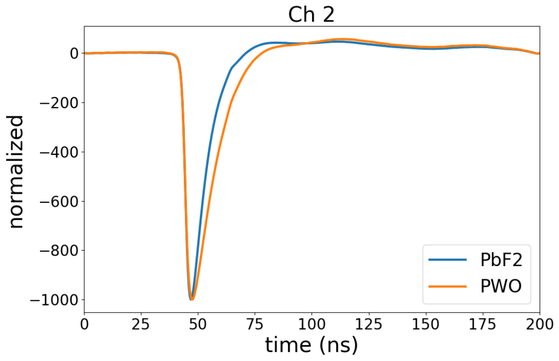
# PbF2 vs PWO time spectrums (normalized) at +80 degree

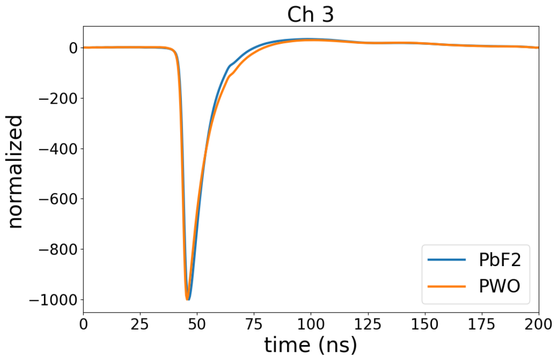
- At large angles, the shape of PWO spectrums for the filtered side matches the PbF2 spectrum!

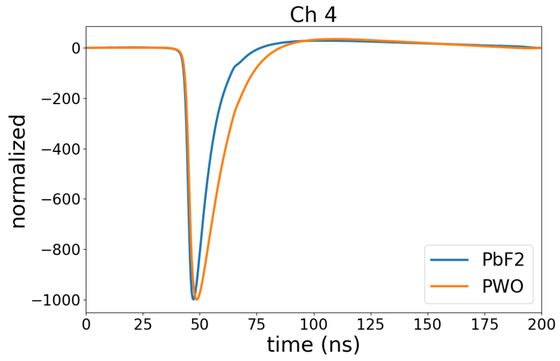
[back]

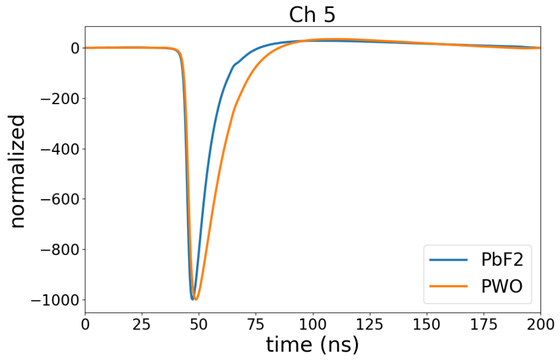


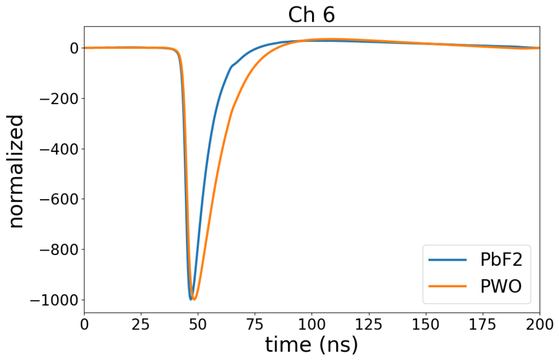



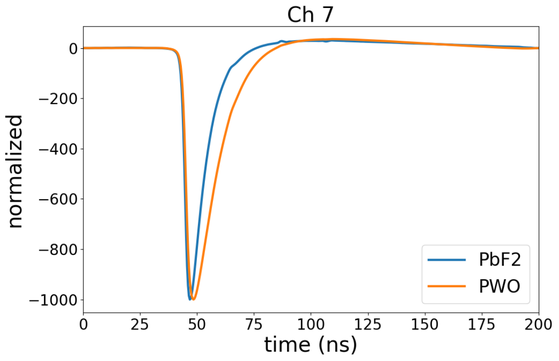



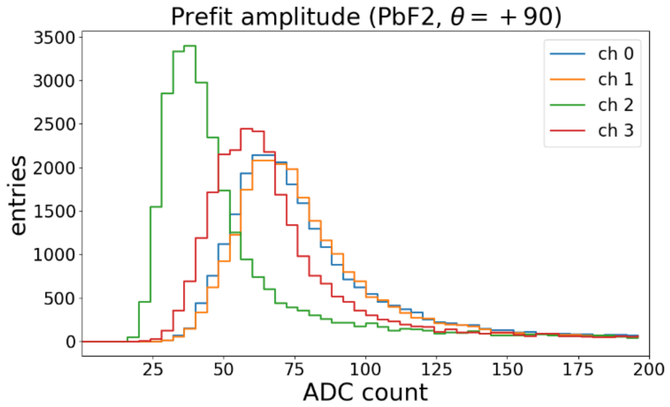



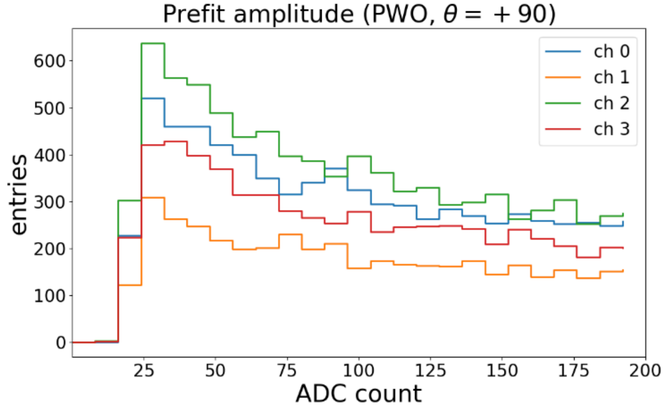



# Amplitude of PbF2 and PWO at +90 degree

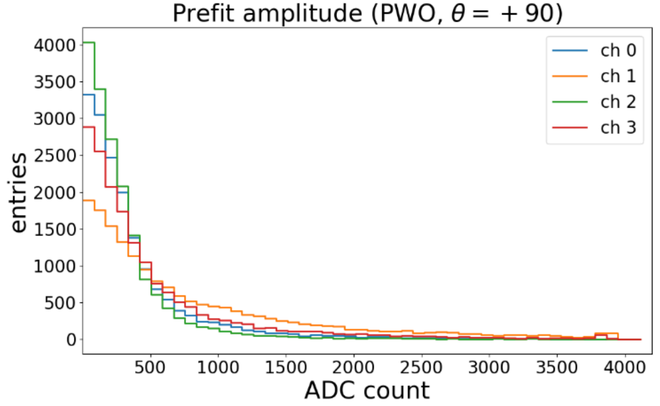
[back]

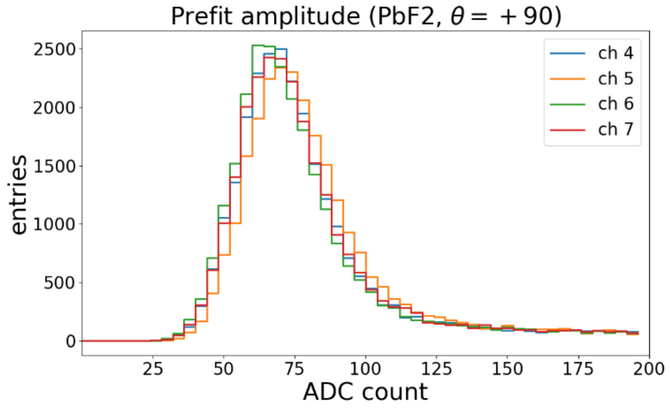
- PbF2 peaks around 70 ADC while PWO is only a decaying spectrum (showering events).
- The amplitude of the average time spectrum is affected largely by the large amplitude events, especially for PWO.

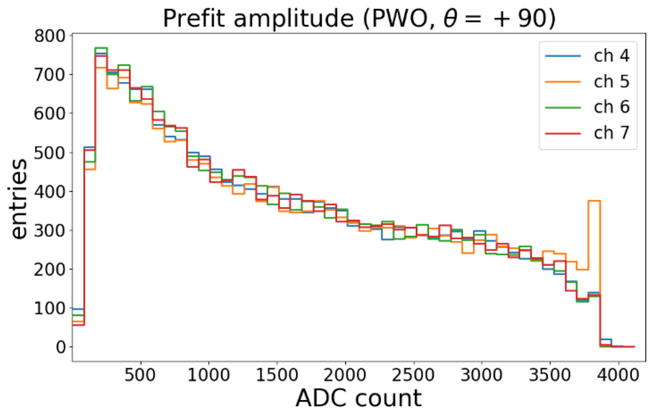


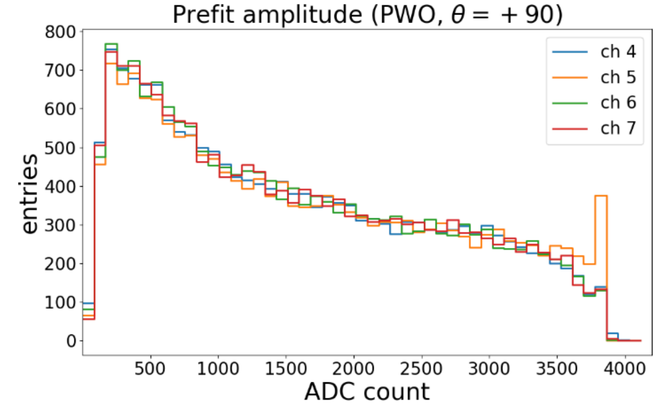




Broaden the range →



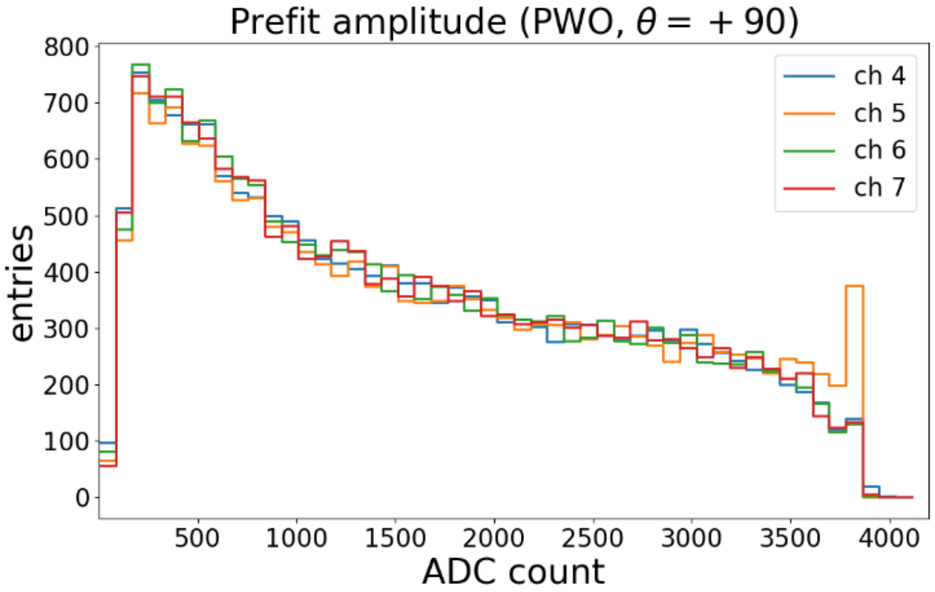



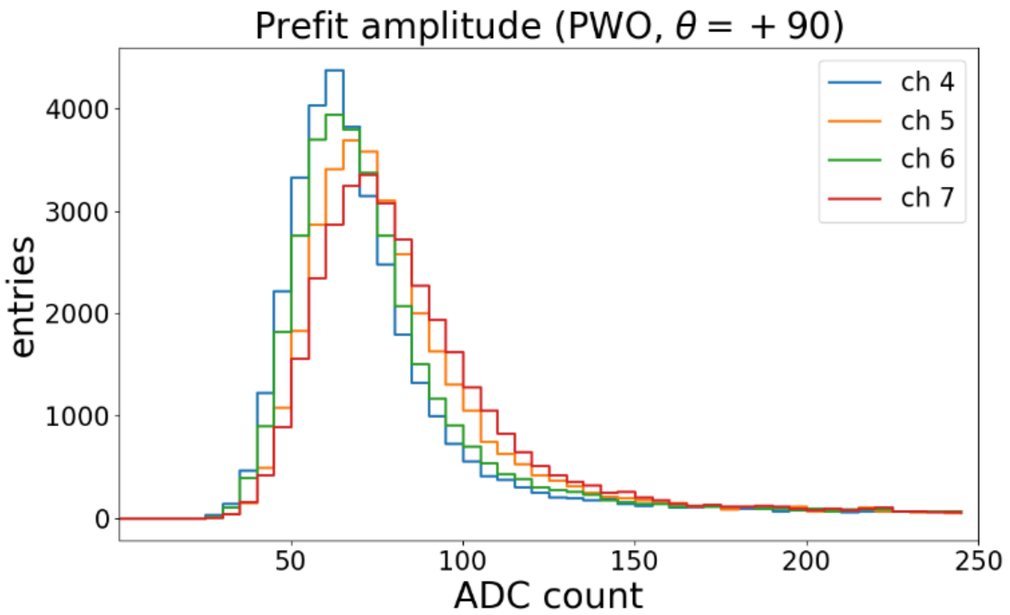



# Amplitude of PWO at +90 degree

[back]

- Left: events passing amplitude>5*noise for ALL channels →shower-like
- Right: events passing amplitude>5*noise for Ch4-7 ONLY →MIP-like

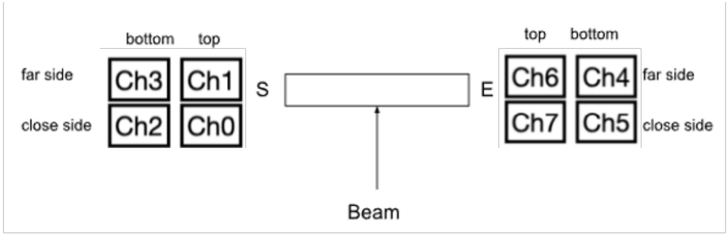


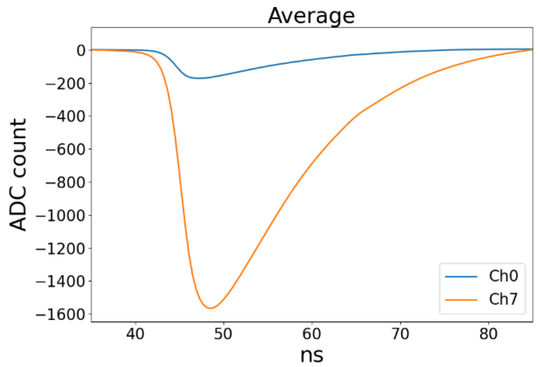



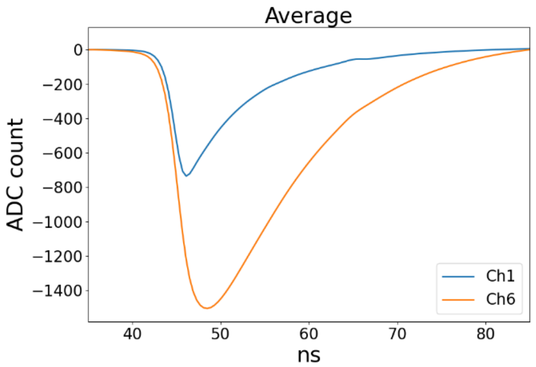
# PWO time spectrums at +80 degree (real size)

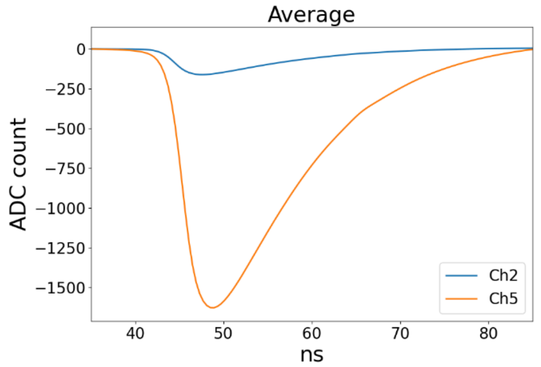
[back]

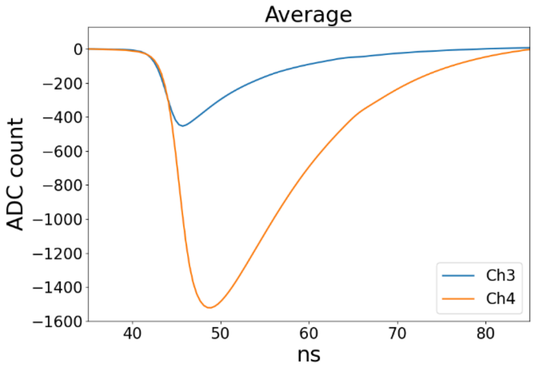
- Time spectrum comparison of channels w/ and w/o filters at 80 degree.
- Amplitude is larger at ch1&3 than ch0&2.

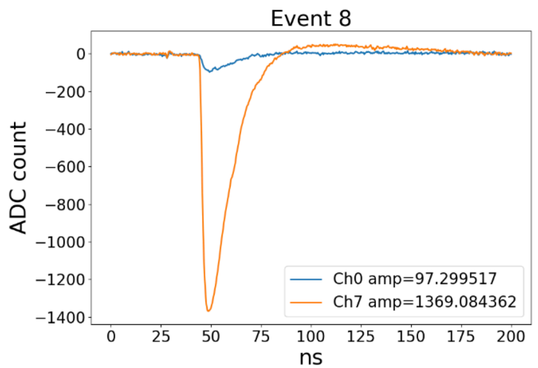


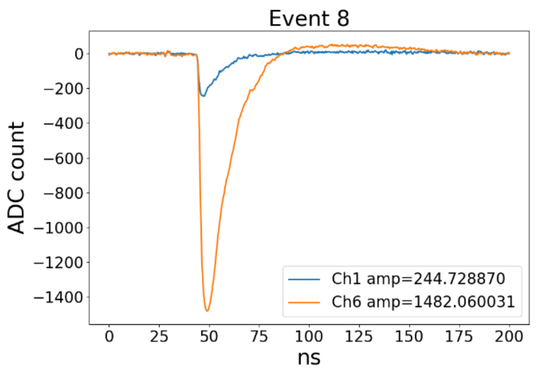



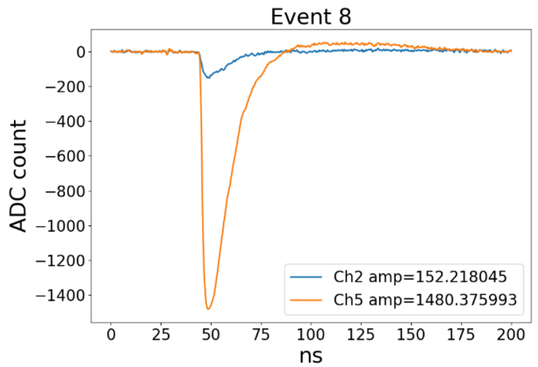



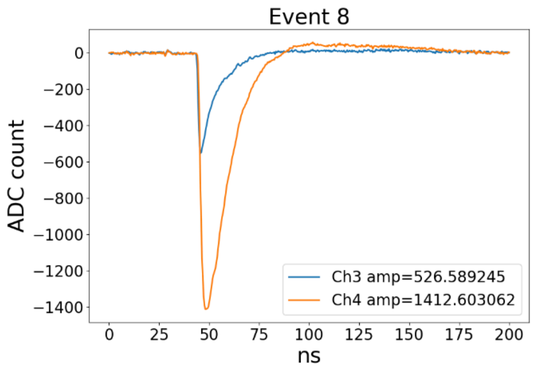



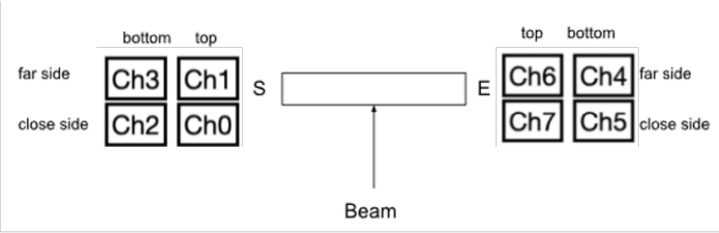



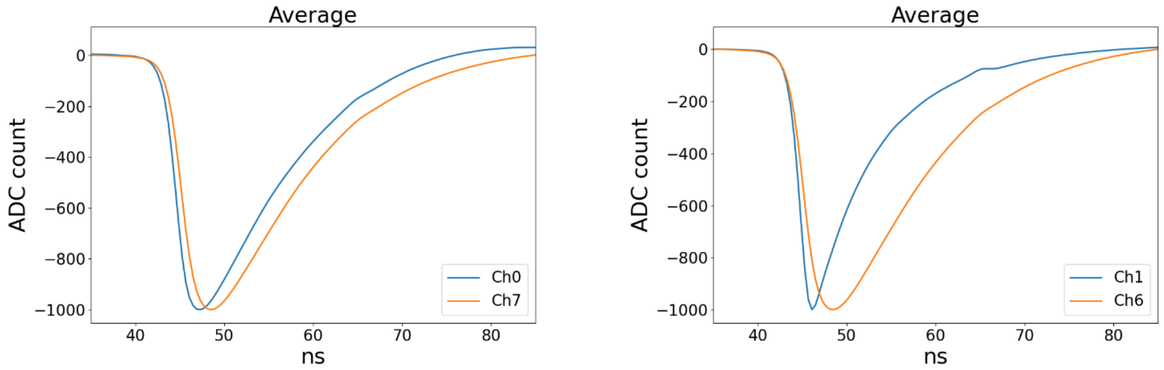



# PWO time spectrums at +80 degree (normalized) [back]

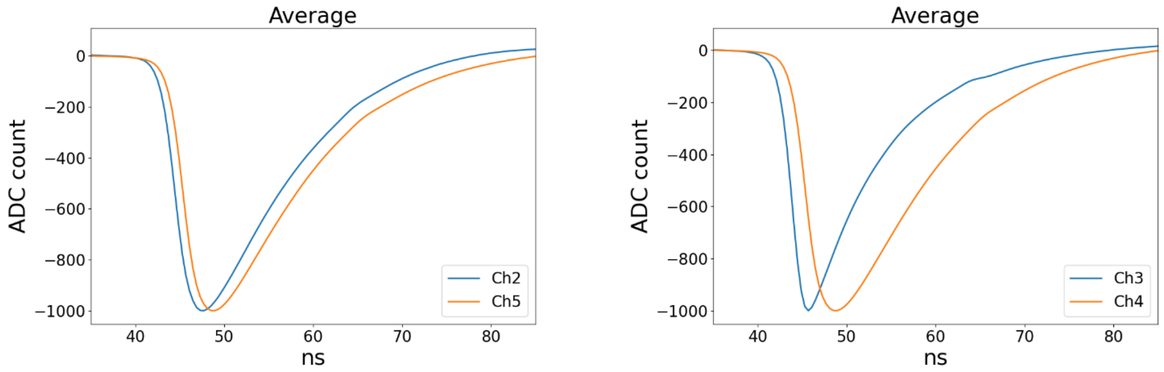
- Time spectrum (normalized to the same amplitude) comparison of channels w/ and w/o filters at 80 degree.



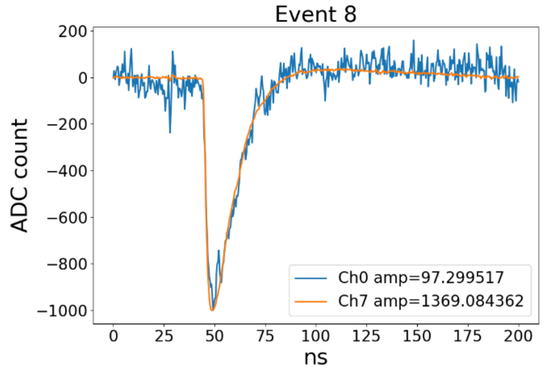


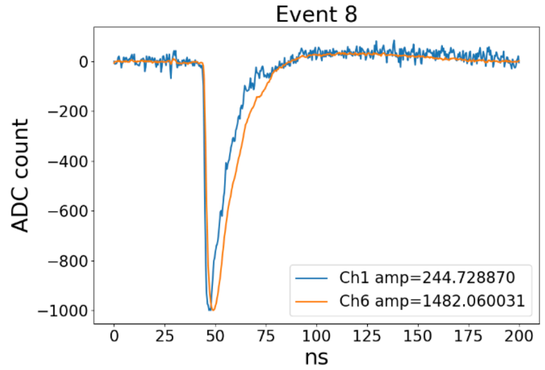


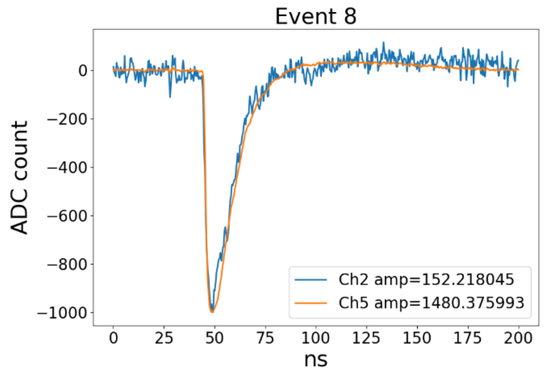


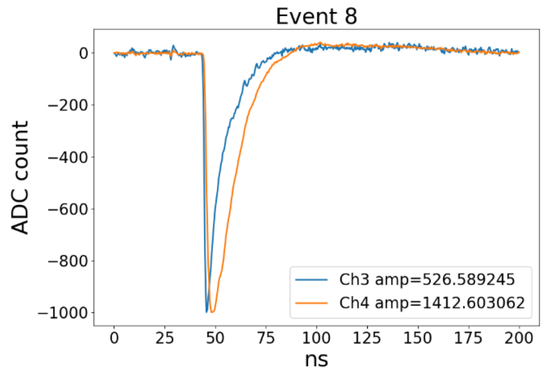






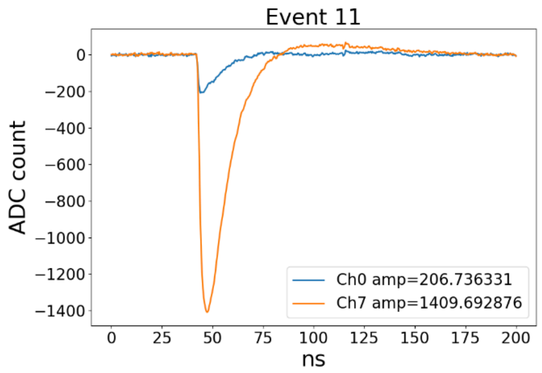



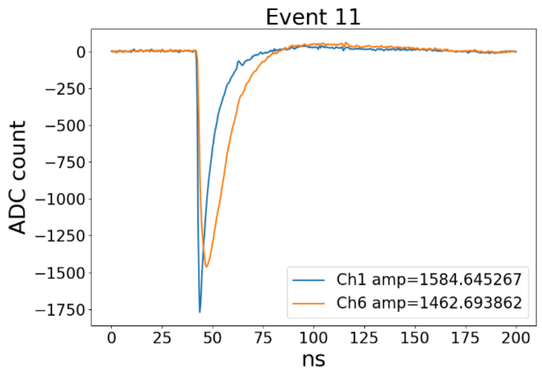



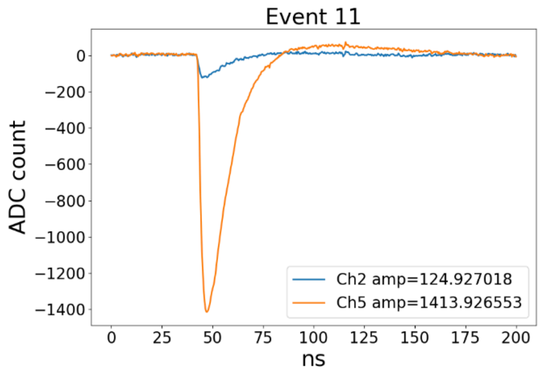
# PWO time spectrums at +90 degree (real size)

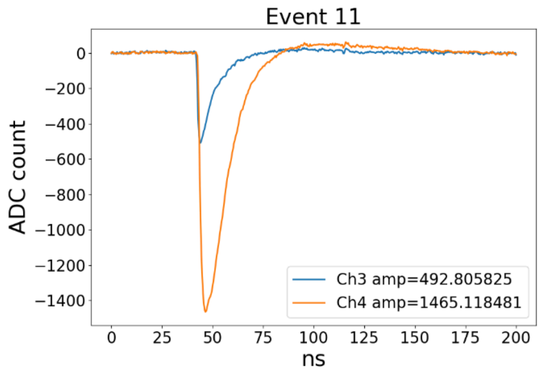
[back]

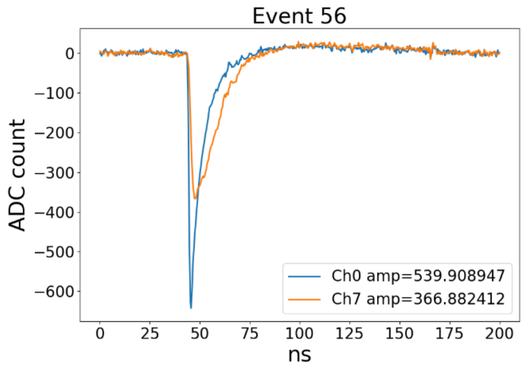
- Events whose amplitude from the filtered side is larger than that from the non-filtered side.

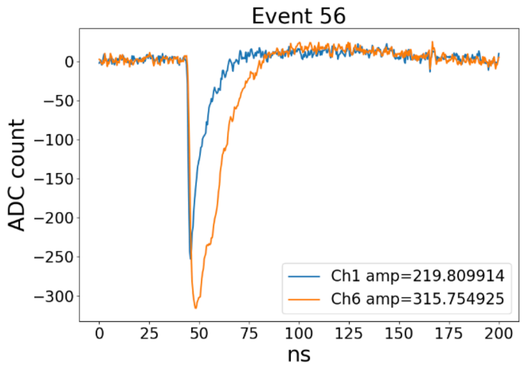


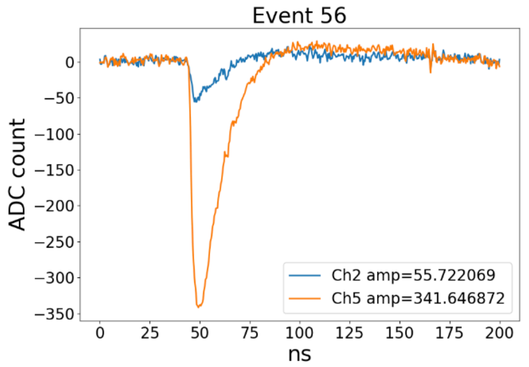



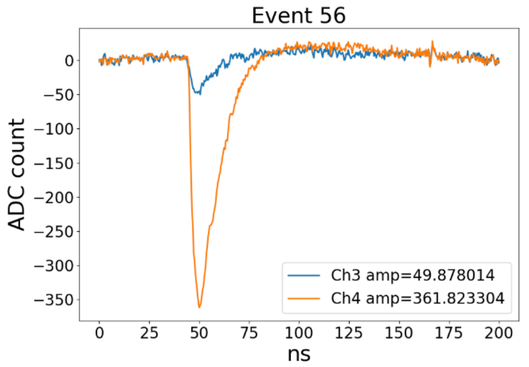



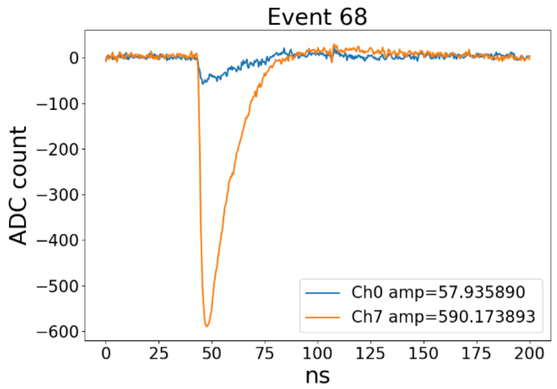



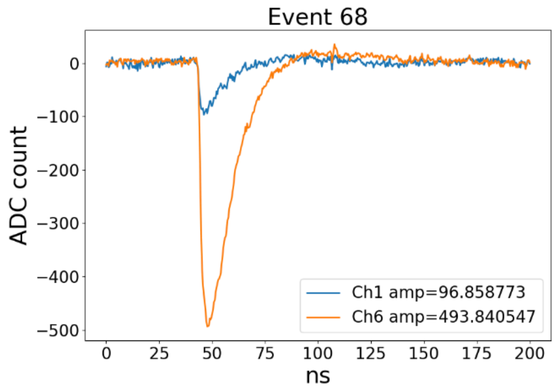



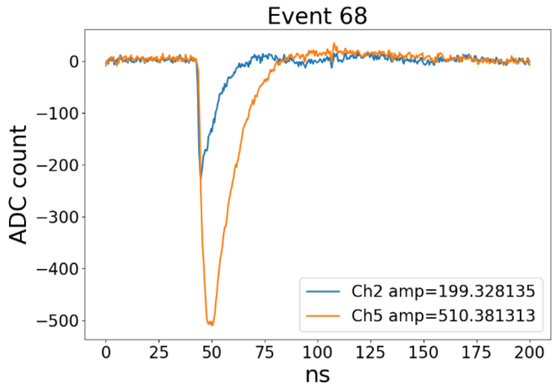
# PWO time spectrums at +90 degree (real size)

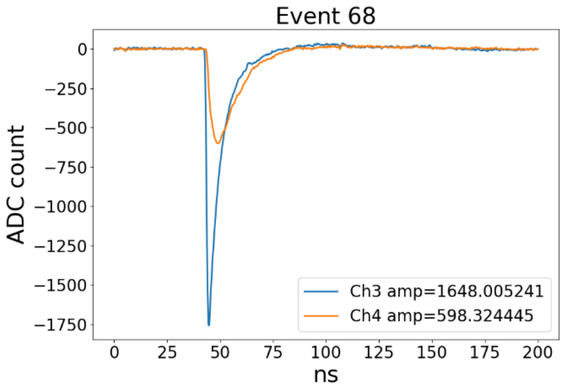
[back]

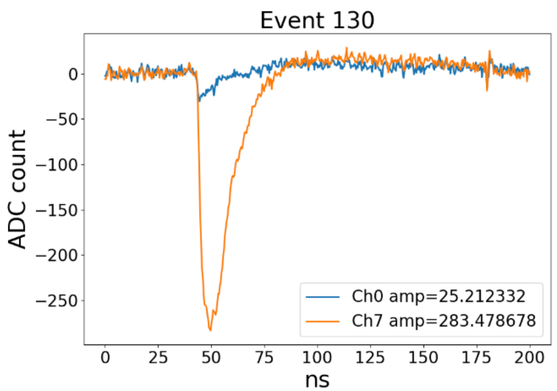
- Events whose amplitude from the filtered side is larger than that from the non-filtered side.

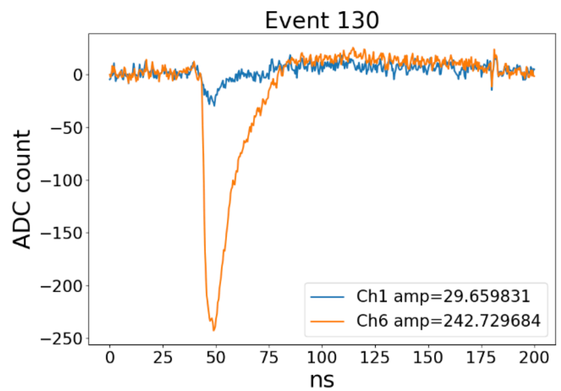


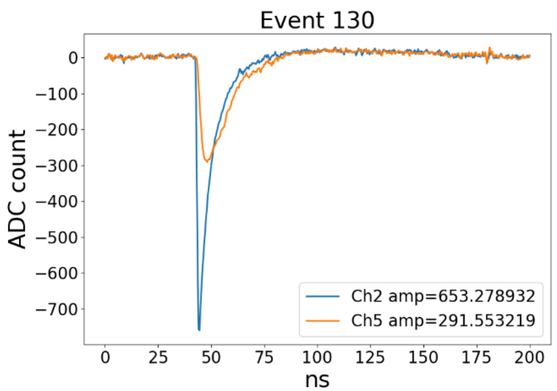



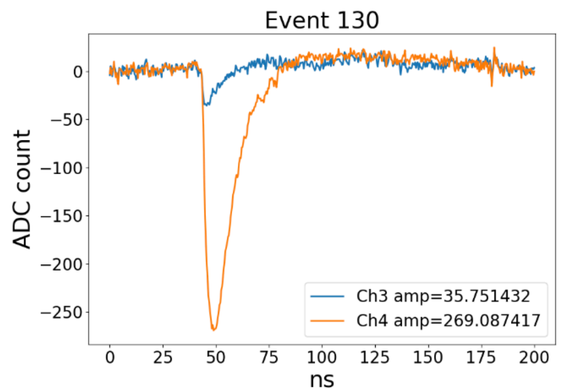



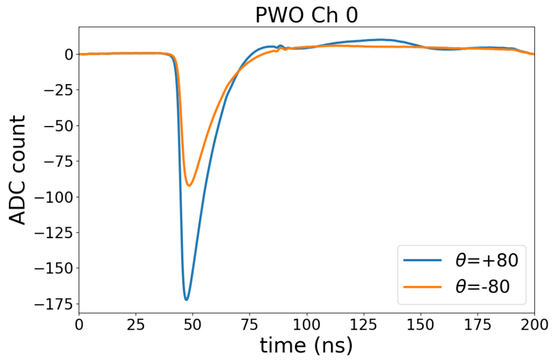



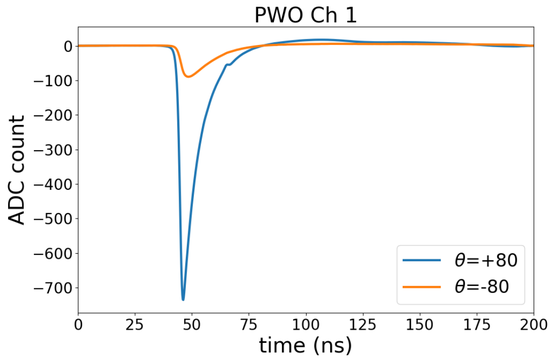



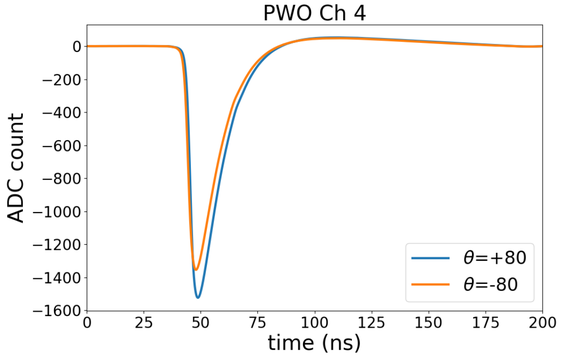
# PWO spectrum comparison of ±80 degree

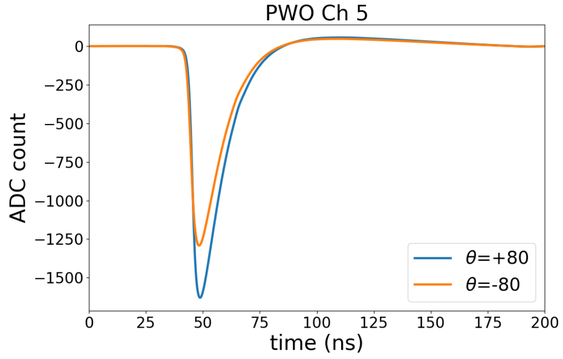
[back]

## Real size

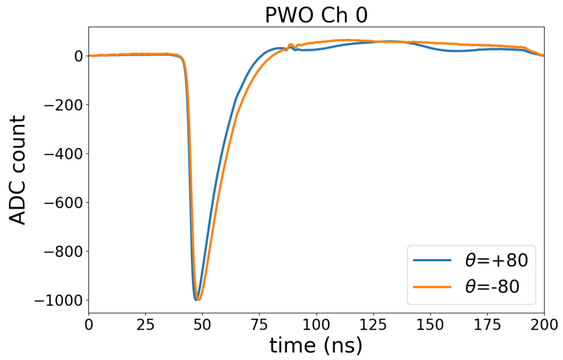


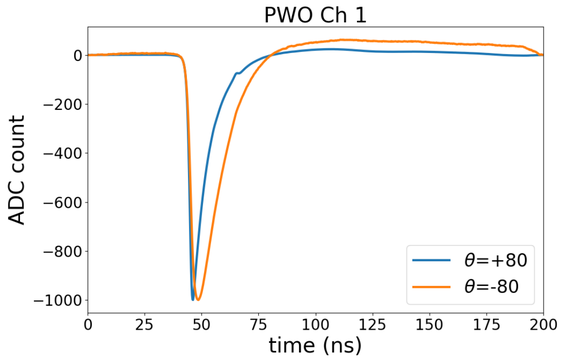



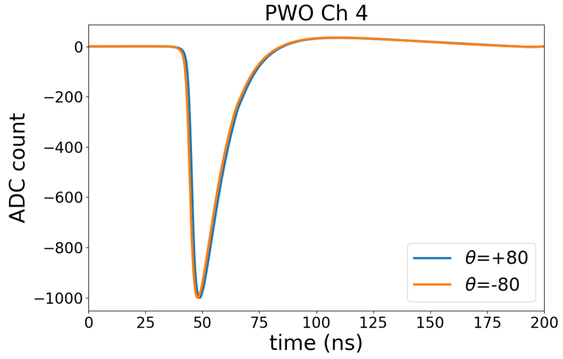



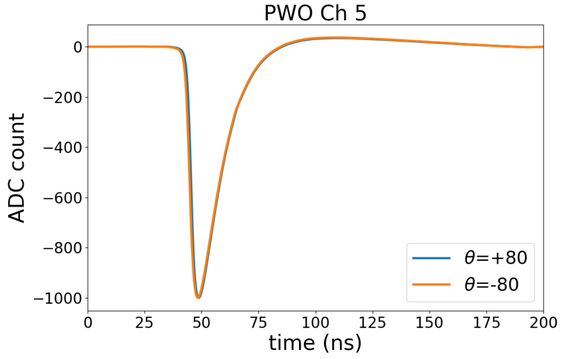




## Normalized



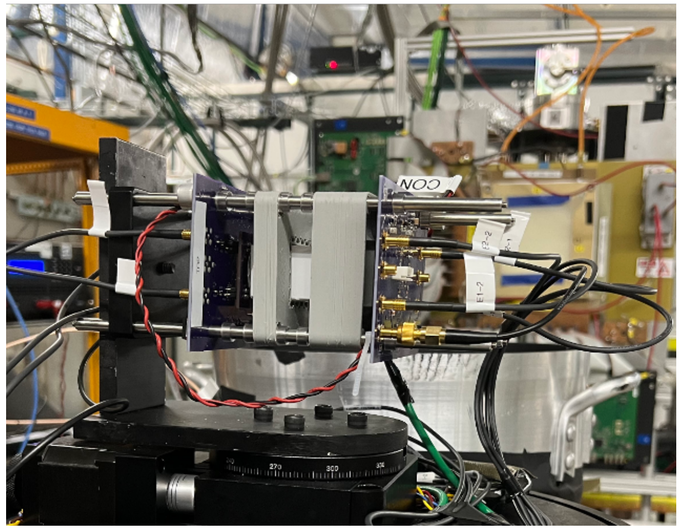



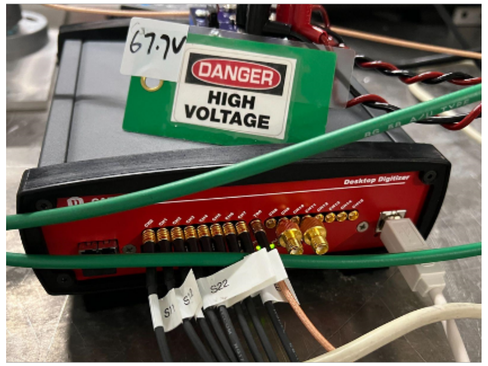



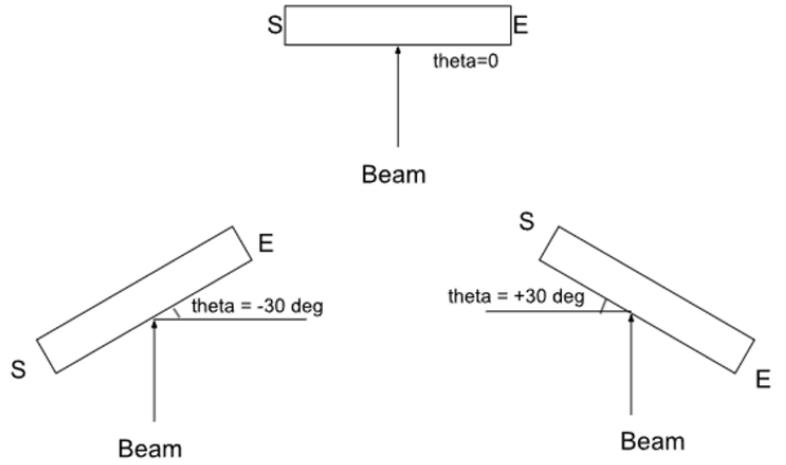



# June 2023 Test Beam @Fermilab Setup

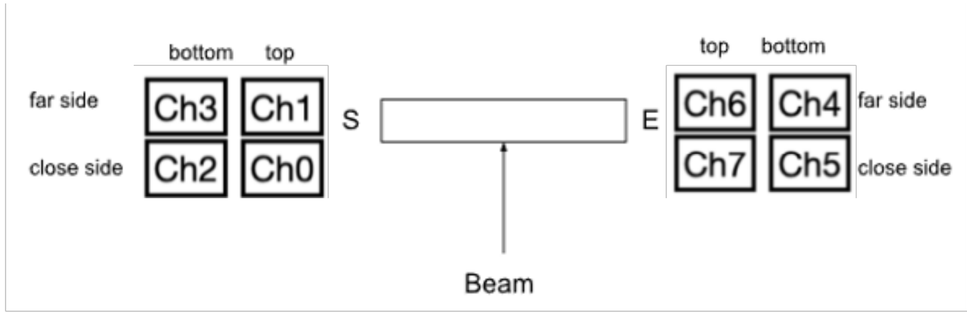
- 120 GeV protons, ~45k protons evenly distributed in 4 s
- Only one spill per minute, 8 mm horizontally and 4 mm vertically
- Only at most one proton expected in our readout window






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

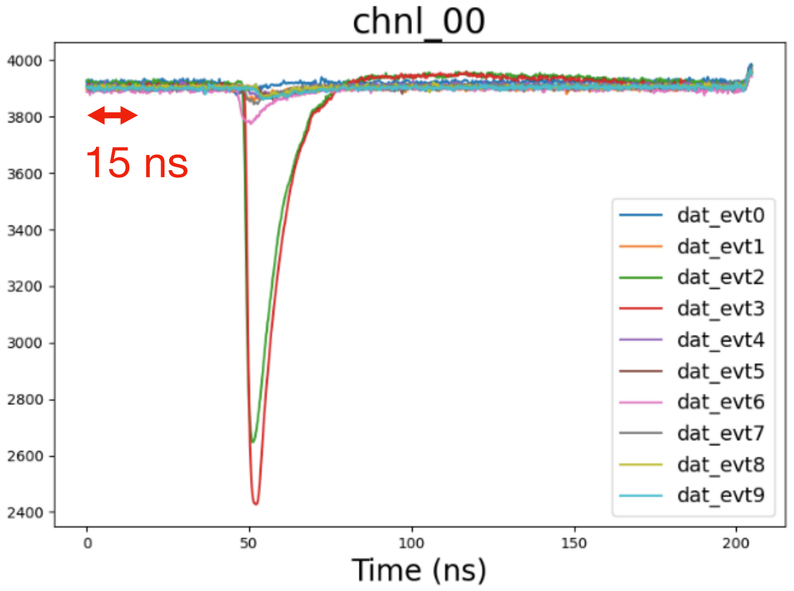


# June 2023 Test Beam @Fermilab Datasets

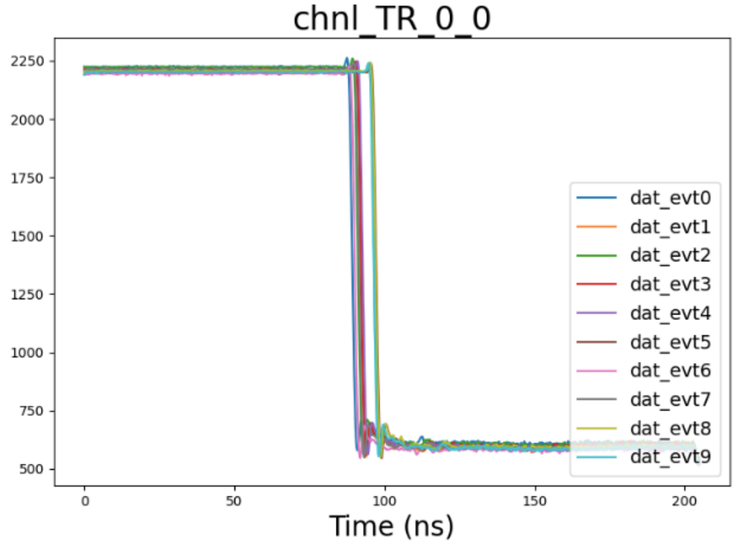
| Crystal | Size | Filter (S side only) | Run # | Angle (°) | # of events | Satuarated-event rate (%) |
|---|---|---|---|---|---|---|
| PbF2 | 6x2.5x2.5 $cm^3$ | No filter | 11-29 | 0 to ±90<br>(10° interval) | ~40k-70k | \|θ\|<30°: 2%<br>30°<\|θ\|<60°: 10%<br>60°<\|θ\|: 30% |
| PWO | | R60 | 31-66 | 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

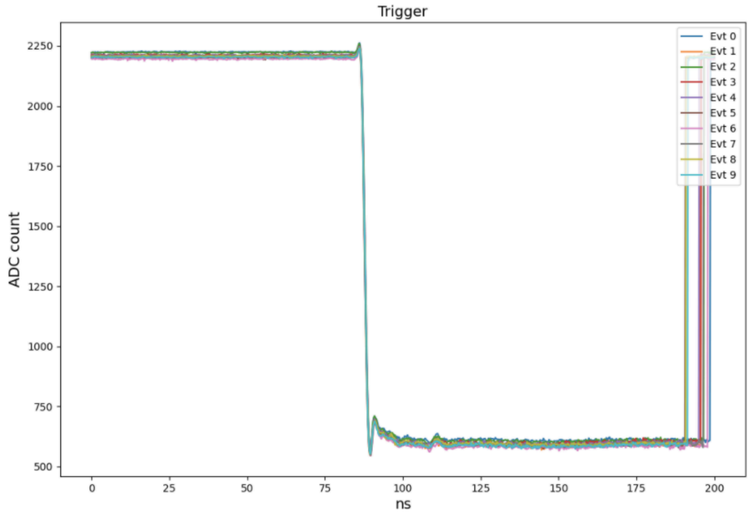
- Events with at least one channel readout value saturated are thrown away
- Pedestal correction: Average over the ADC counts in the time range (0, $t_{peak} - 20$) ns as the base count. Subtract all points in the event by the base count.
- Time correction.




**Before time shifting**




**After time shifting**

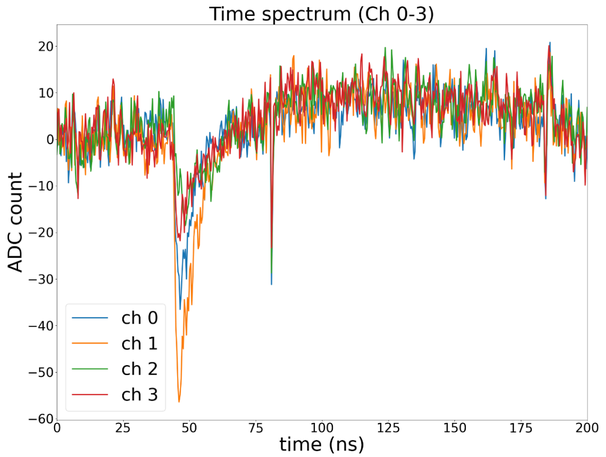


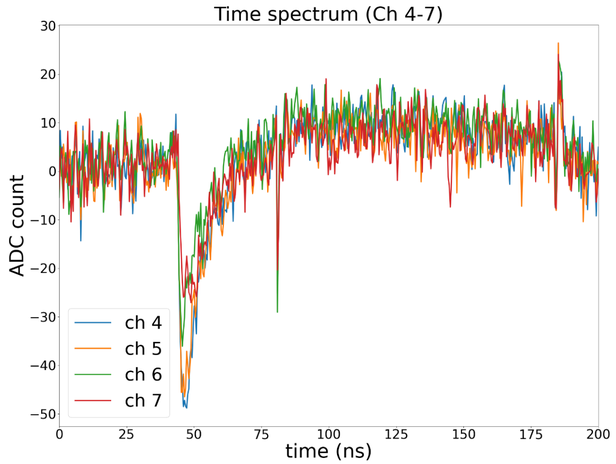
# Waveform for each crystal (θ=0°)

Show evt0 as example

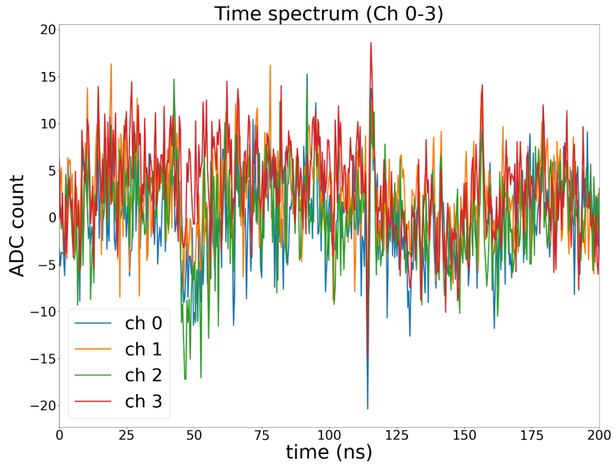
- PbF2: no filter for all channels; PWO and BGO: w/ fiter for ch 0-3, w/o filter for ch 4-7

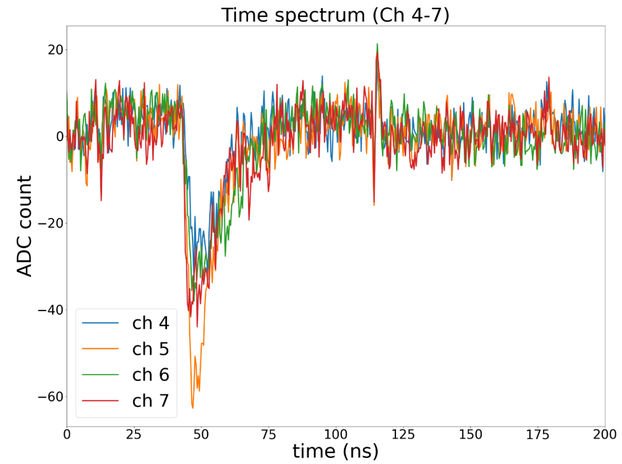
PbF2



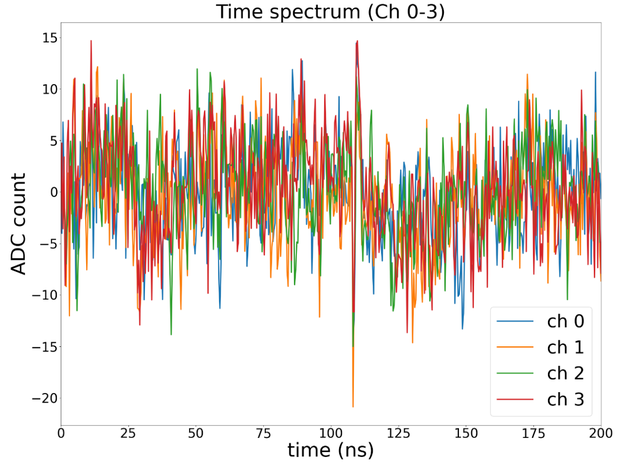



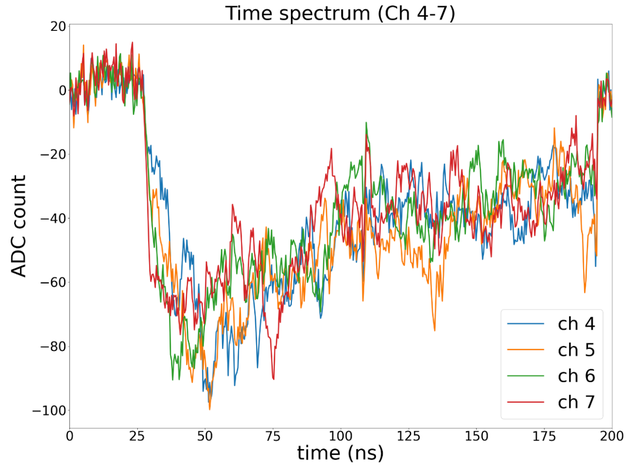

PWO




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