3'' PMT: Performance measurements in E61 and Hyper-Kamiokande

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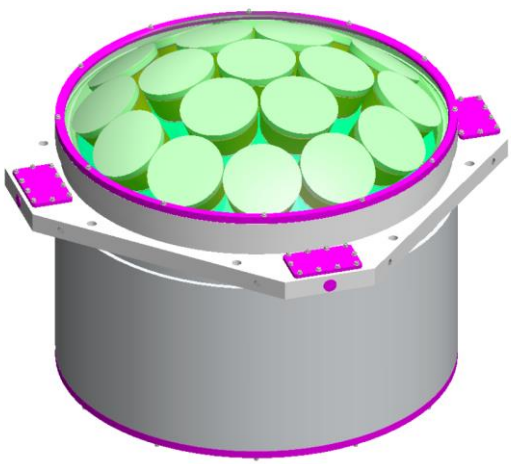
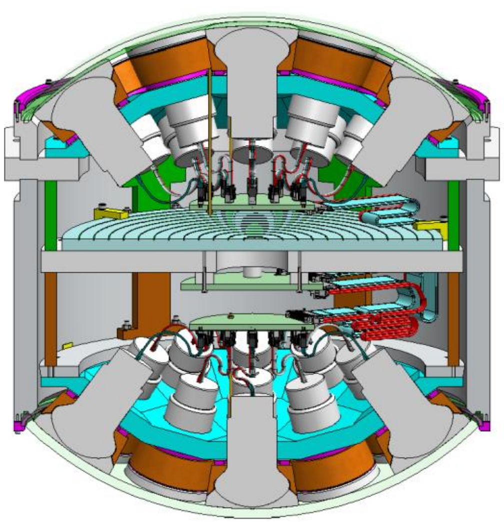
on behalf of

Hyper-Kamiokande and E61 photosensor groups

New and Enchanced Photosensor Technologies for Underground/Underwater Neutrino Experiments (NEPTUNE), July 18-21, 2018, Naples, Italy

Multi-PMT for Hyper-K and E61



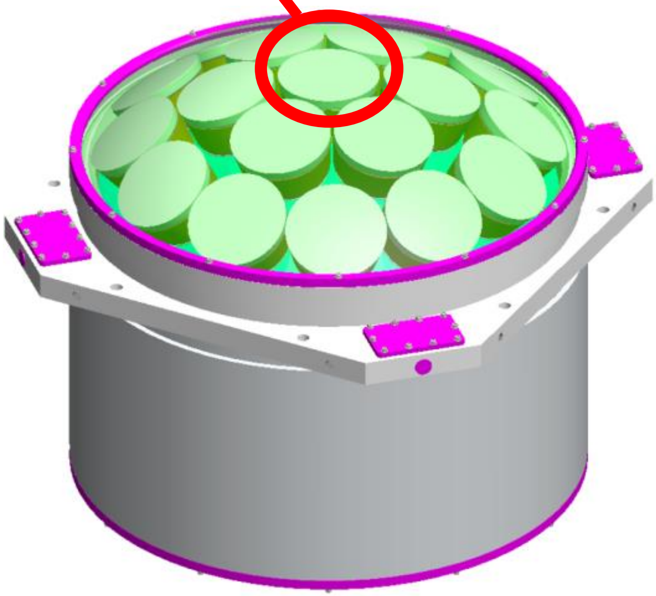


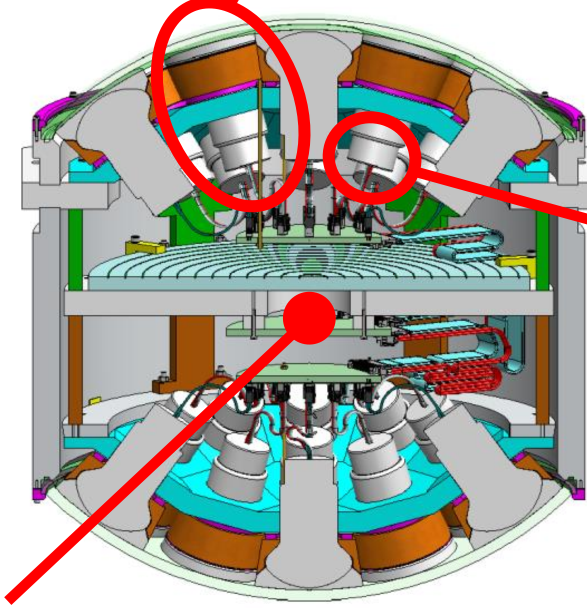
- Adaptation of concept originally invented by KM3NET
- Instead of using one large PMT (i.e. 20”), use multiple small PMTs (3” to 3.5”)
  - Small PMTs are cheap – medical industry uses a lot of them
  - **Better timing properties**
  - Better pressure rating (due to external case)
  - **Directionality of sensor** – potentially better reconstruction near walls → expanded fiducial volume
  - Larger number of channels, more **expensive and power-hungry** electronics

Multi-PMT – Key Issues

Optical coupling and reflector

Mounting, mechanical layout, shielding





HV supply

Front-end electronics

ALL STRONGLY DEPENDENT ON PHOTOSENSOR PROPERTIES!

Goals of PMT Characterization

- Fully characterize selected photosensors and select one that best fits our needs
  - TTS, gain, charge resolution, afterpulsing, position/angular dependence, dark rate
- Formulate requirements for electronics and HV supply
  - Timing resolution, dynamic range, bandwidth, charge resolution
- Provide hints as to certain aspects of mechanical design
  - Reflector geometry, photosensor arrangement
  - Is magnetic shielding needed?
- Provide relevant input for Monte-Carlo simulations
- Provide guidelines for mass-testing strategy

Candidate PMTs

mPMT for Hyper-K and E61

Outer Detector, mPMT?

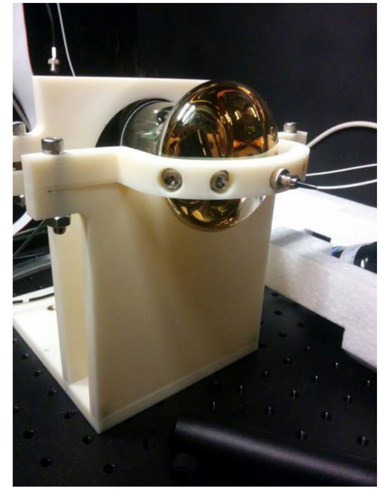
Hamamatsu
R14374

HZC XP82B20

ET Enterprise
D793KFL

Test Sites & Methods

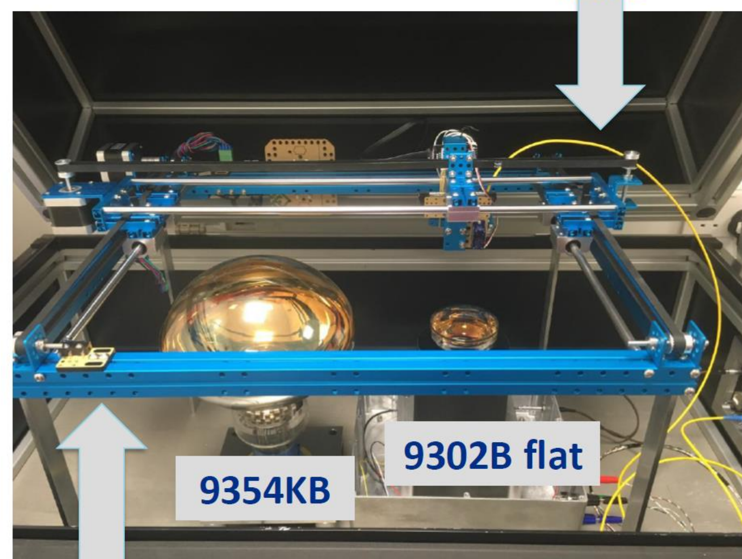
- Multiple institutions involved from Canada, Italy, Japan, Poland, UK
- All test sites use pulsed light source and high speed waveform digitizers
- For dark rate tests, setup at York University (Canada) has temperature-controlled dark box, remaining sites for now only measure temperature



York & IPMU

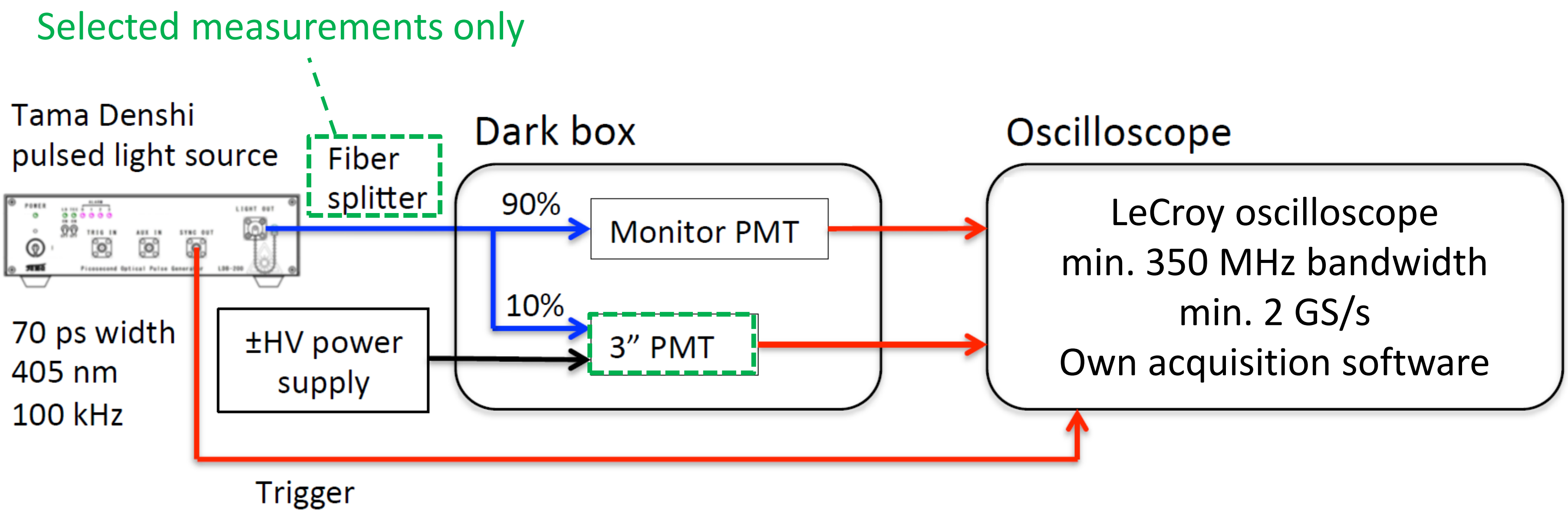
QMUL

Optical fibre



XY stage

Methods

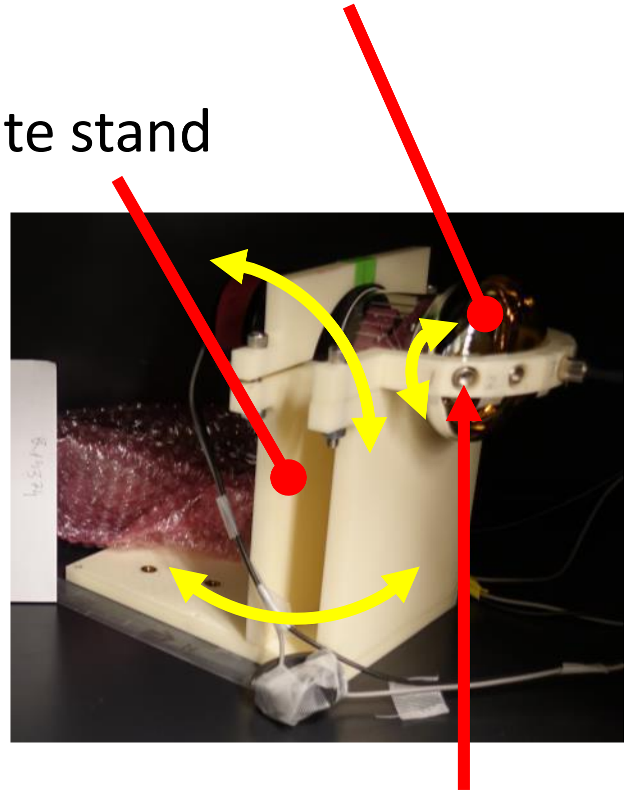


- Measurements:
  - Gain, linearity, transit time & TTS, dark rate, position dependences, afterpulsing, sensitivity to magnetic field, waveform shape
- Differences:
  - WUT uses PILAS Laser (45 ps, 375 nm) & TEK scope (1GHz, 5GS/s)
  - QMUL uses CAEN SP5601 LED Driver with OSSV5111A LED (400 nm), VME SIS3316 digitizer (charge spectrum), pico-scope (min. 1 GS/s rate) for timing measurements
- Working on code to share data between labs in order to cross-check results (almost ready)

Detailed Studies – Hamamatsu R14374

Rotate PMT around its axis

Rotate stand



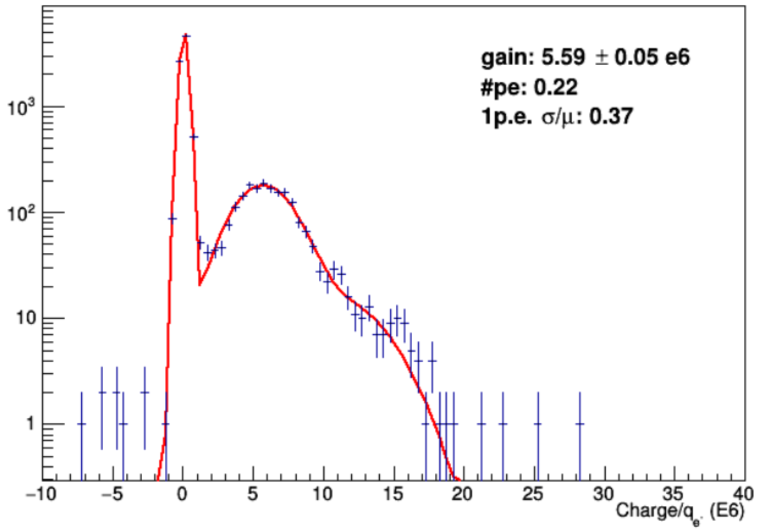
Move fiber between slots

- Passive resistive base, positive/negative HV
- Waveform shape studies:
  - Acquisition by LeCroy WaveRunner Scope, 10 GS/s, 1GHz BW
  - Template calculated by aligning multiple pulses using cross-correlation and averaging (2048 waveforms)
- Various positions on photocathode (total of 9)
- Various orientations of PMT with respect to Earth magnetic field
- Varying light intensity – 1 p.e. to 100 p.e. (logarithmic steps)

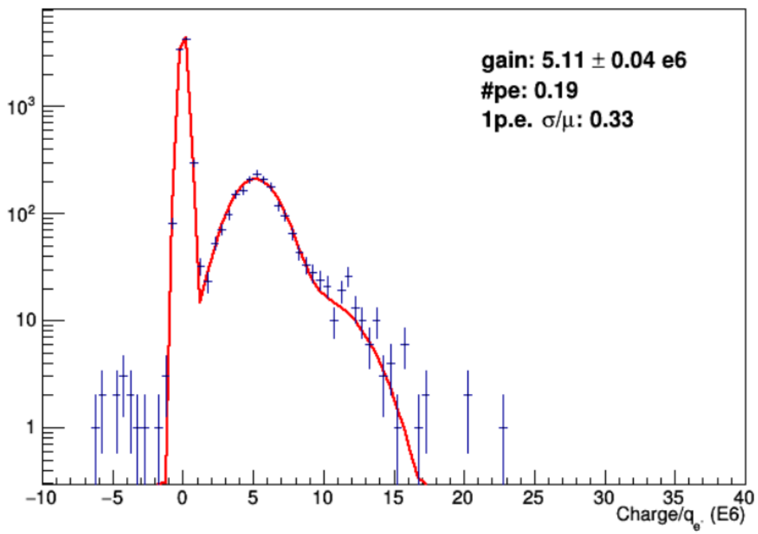
Gain

Results: A. Fiorentini (York Univ.)

Hamamatsu R14374, S/N BC0032



HZC XP82B20, S/N 80148



Hamamatsu R14374

PMT (HV)	Gain ($x10^6$)	Q resolution
BC0032 (+1159V)	5.59 +/- 0.05	0.37
BC0032 (-1159V)	5.19 +/- 0.07	0.36
BC0036 (+1113V)	5.12 +/- 0.04	0.37
BC0036 (-1113V)	5.09 +/- 0.05	0.37

HZC XP82B20

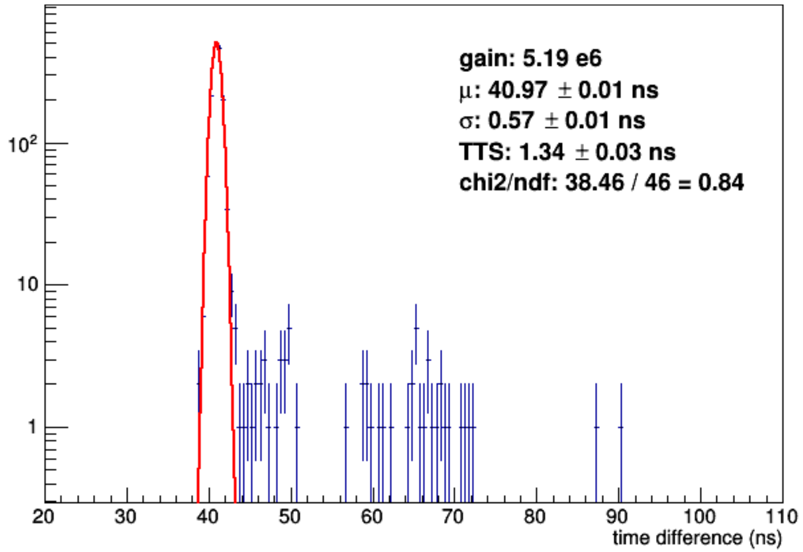
PMT (HV)	Gain ($x10^6$)	Q resolution
80148 (+1324V)	5.11 +/- 0.04	0.33 +/- 0.01
80148 (-1324V)	4.88 +/- 0.04	0.33 +/- 0.01
80149 (+1229V)	5.34 +/- 0.05	0.35 +/- 0.01
80149 (-1229V)	5.16 +/- 0.05	0.33 +/- 0.01

- Temperature = 25 °C
- No difference between positive/negative HV

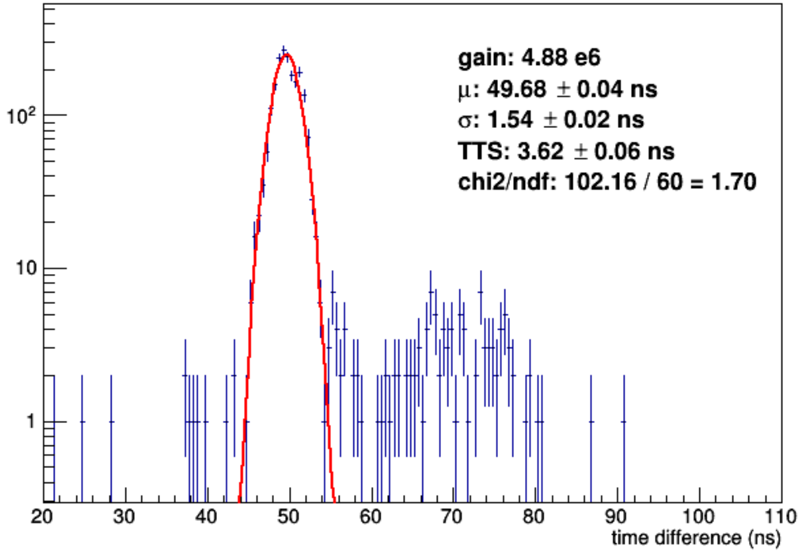
Transit Time Spread

Results: A. Fiorentini (York Univ.)

Hamamatsu R14347, S/N BC0032, -HV



HZC XP82B20, S/N 80148, -HV



Hamamatsu R14347

PMT	TT	TTS (FWHM)
BC0032, -HV	40.97 ns	1.34 ns
BC0036, +HV	45.88 ns	1.52 ns

HZC XP82B20

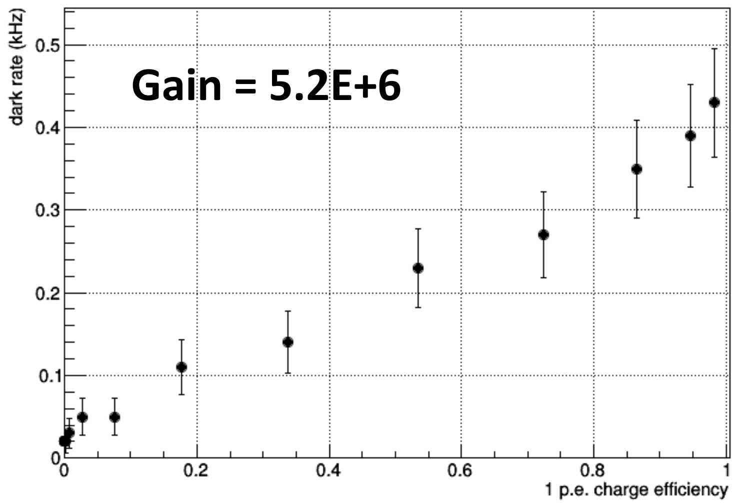
PMT	TT	TTS (FWHM)
80148, -HV	49.68 ns	3.62 ns
80149, +HV	51.26 ns	3.75 ns

- Time difference between monitor and tested PMT.
- Light splitting: 90% monitor PMT, 10% PMT under test
- Central point of the photocathode

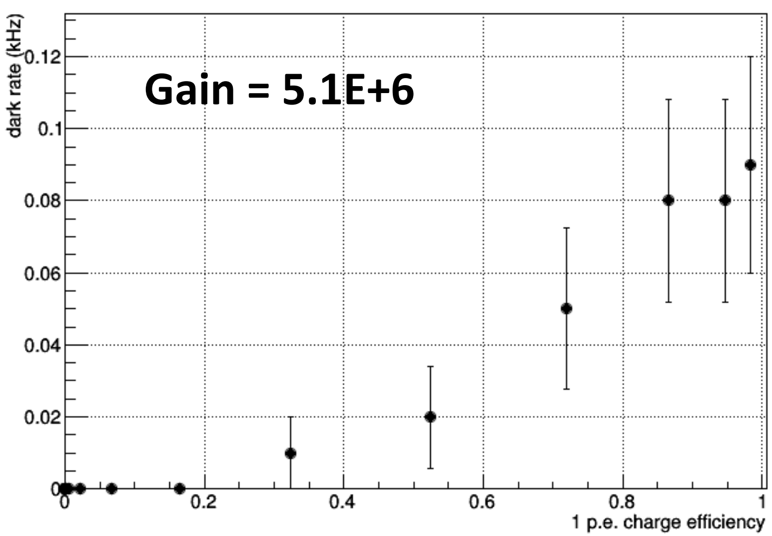
Dark Rate (R14347)

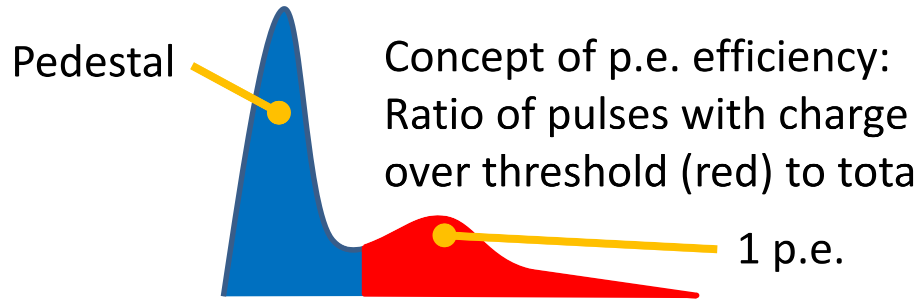
Results: A. Fiorentini (York Univ.)

R14374, S/N BC0032, -HV



R14374, S/N BC0036, +HV





R14374, S/N BC0032 (-HV)

Gain (HV)	Dark rate (kHz)		
	@ 0.5 eff.	@ 0.85 eff.	@ 0.9 eff.
1.9e6 (-1000V)	0.20 +/- 0.03	0.32 +/- 0.06	0.34 +/- 0.06
5.2e6 (-1159V)	0.21 +/- 0.03	0.34 +/- 0.06	0.37 +/- 0.06
6.5e6 (-1200V)	0.50 +/- 0.05	0.70 +/- 0.08	0.73 +-/ 0.09

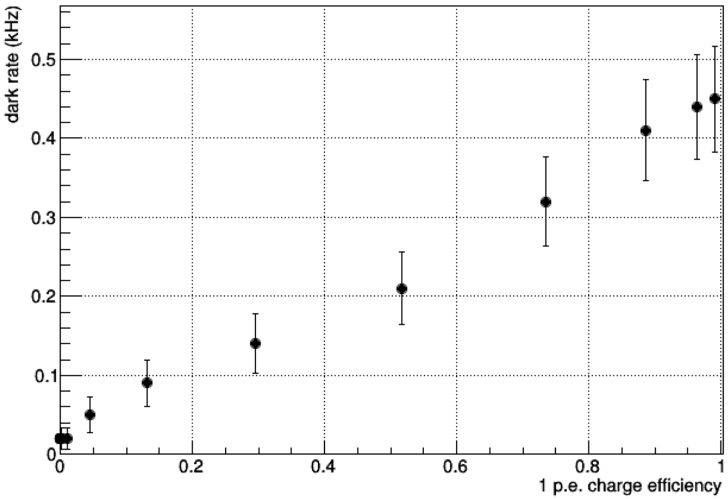
R14374, S/N BC0036 (+HV)

Gain (HV)	Dark rate (kHz)		
	@ 0.5 eff.	@ 0.85 eff.	@ 0.9 eff.
2.4e6 (+1000V)	0.08 +/- 0.03	0.19 +/- 0.04	0.21 +/- 0.05
5.1e6 (+1113V)	0.02 +/- 0.02	0.04 +/- 0.03	0.05 +/- 0.03
8.6e6 (+1200V)	0.03 +/- 0.02	0.06 +/- 0.03	0.07 +/- 0.03

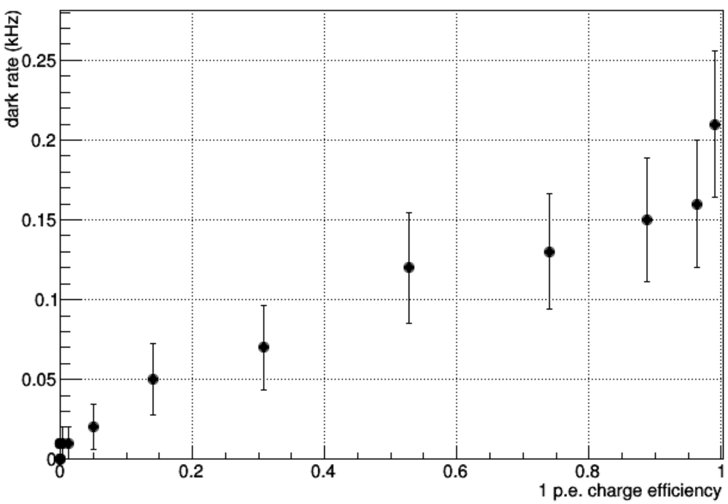
Dark Rate (XP82B20)

Results: A. Fiorentini (York Univ.)

XP82B20, S/N 80148, -HV



XP82B20, S/N 80149, +HV



XP82B20, S/N 80148, -HV

Gain (HV)	Dark rate (kHz)		
	@ 0.5 eff.	@ 0.85 eff.	@ 0.9 eff.
2.7e6 (-1200V)	0.12 +/- 0.03	0.24 +/- 0.05	0.26 +/- 0.05
5.1e6 (-1324V)	0.20 +/- 0.03	0.39 +/- 0.06	0.42 +/- 0.06
7.3e6 (-1400V)	0.18 +/- 0.03	0.35 +/- 0.05	0.35 +/- 0.06

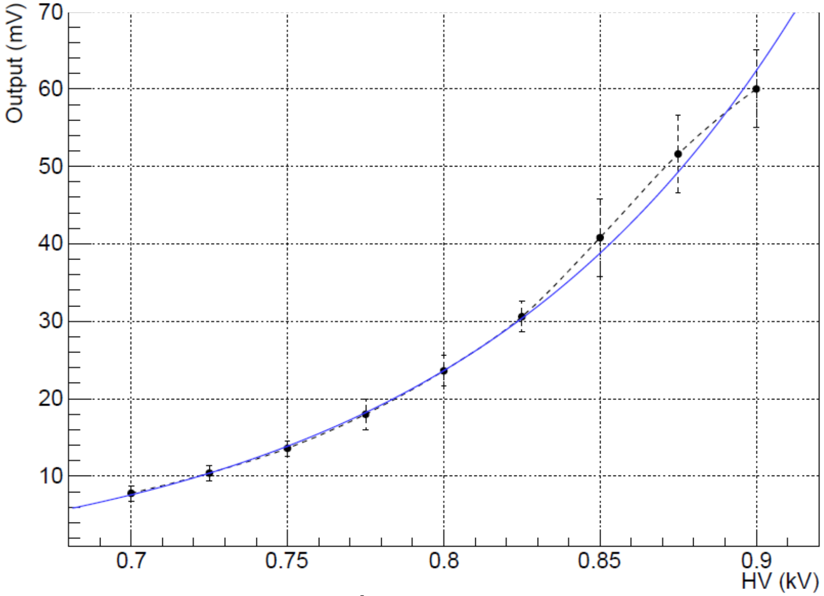
XP82B20, S/N 80149, +HV

Gain (HV)	Dark rate (kHz)		
	@ 0.5 eff.	@ 0.85 eff.	@ 0.9 eff.
2.4e6 (+1100V)	0.08 +/- 0.02	0.17 +/- 0.04	0.19 +/- 0.04
5.1e6 (+1229V)	0.11 +/- 0.02	0.14 +/- 0.04	0.15 +/- 0.04
7.5e6 (+1300V)	0.06 +/- 0.02	0.09 +/- 0.04	0.10 +/- 0.04

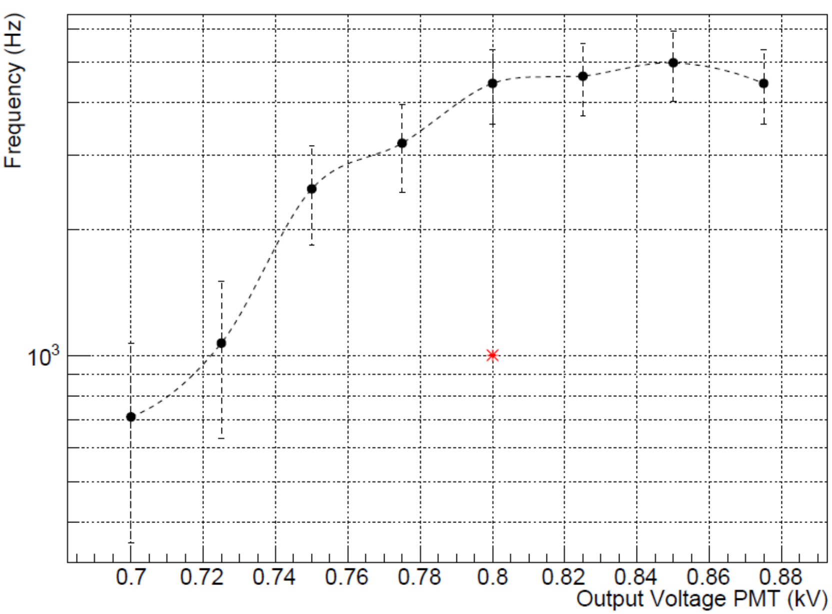
- All PMTs in dark for 48 hours, T = 9 °C
- Take multiple waveforms with random trigger, then find and count pulses

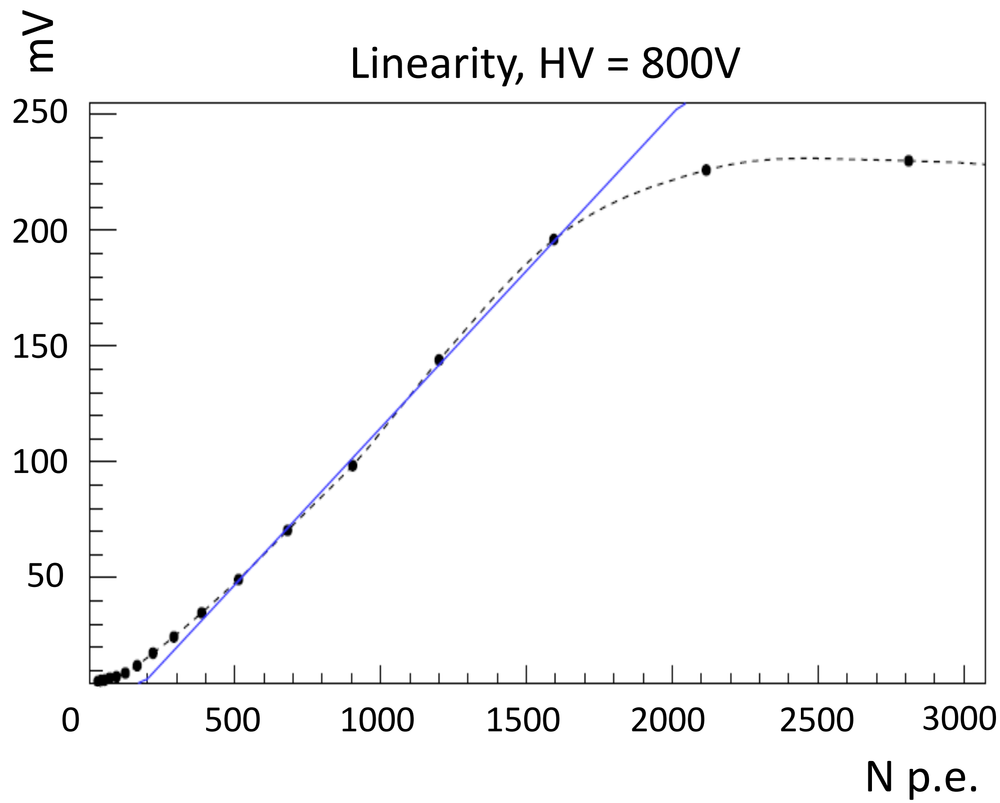
Tests of ET D793KFL

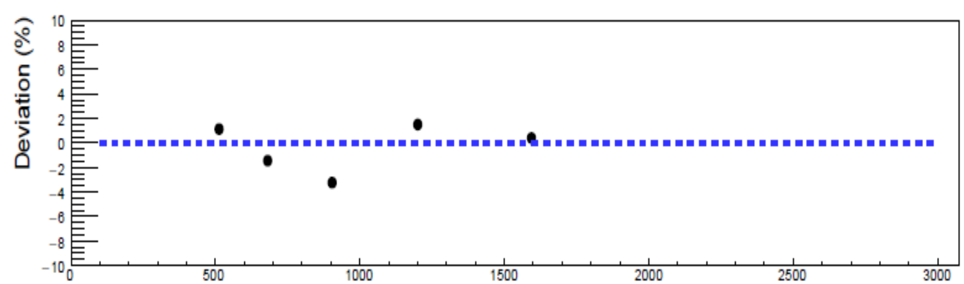
Pulse Amplitude vs HV



Dark Rate vs HV

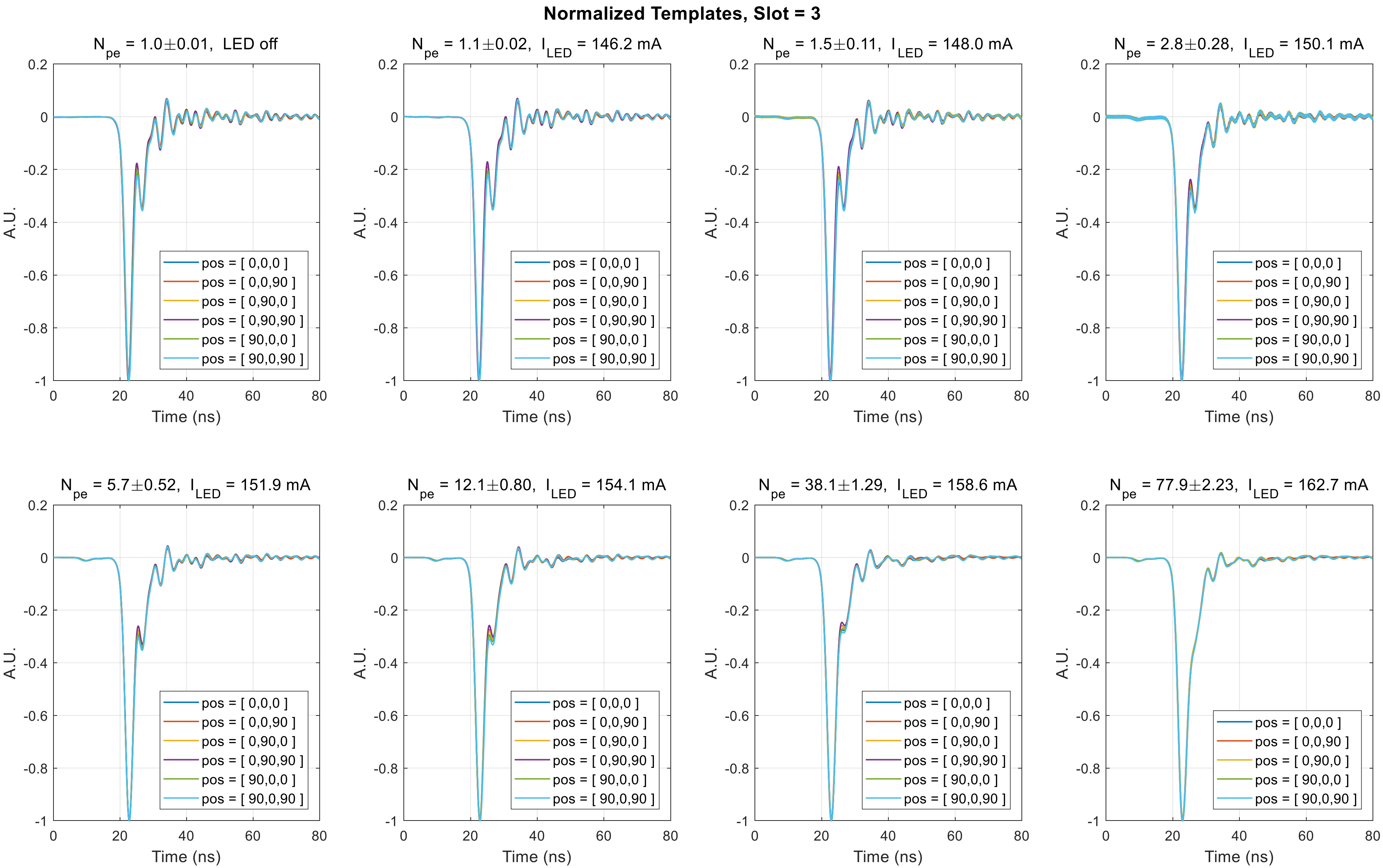




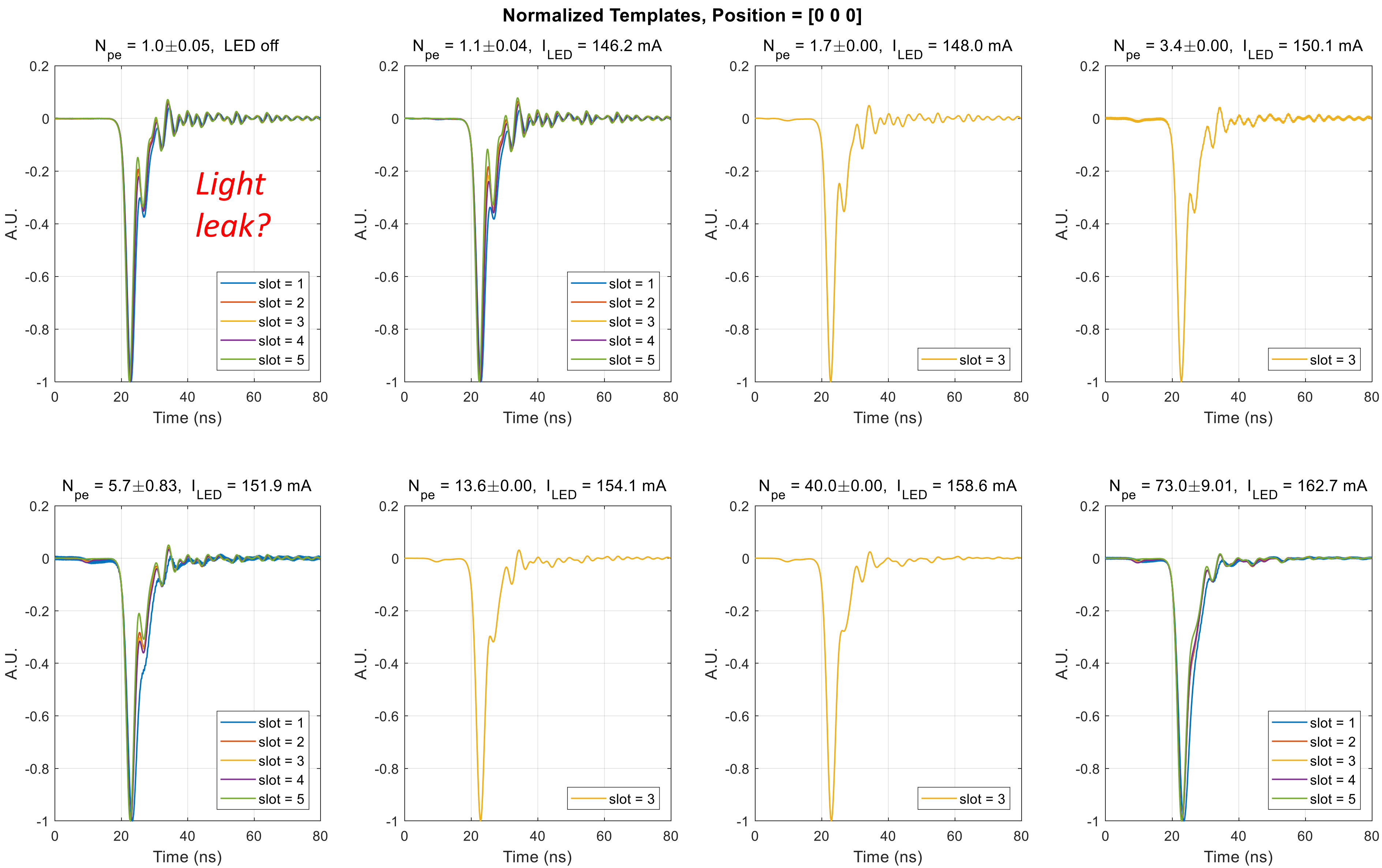


Results: S. Zsoldos (QMUL)

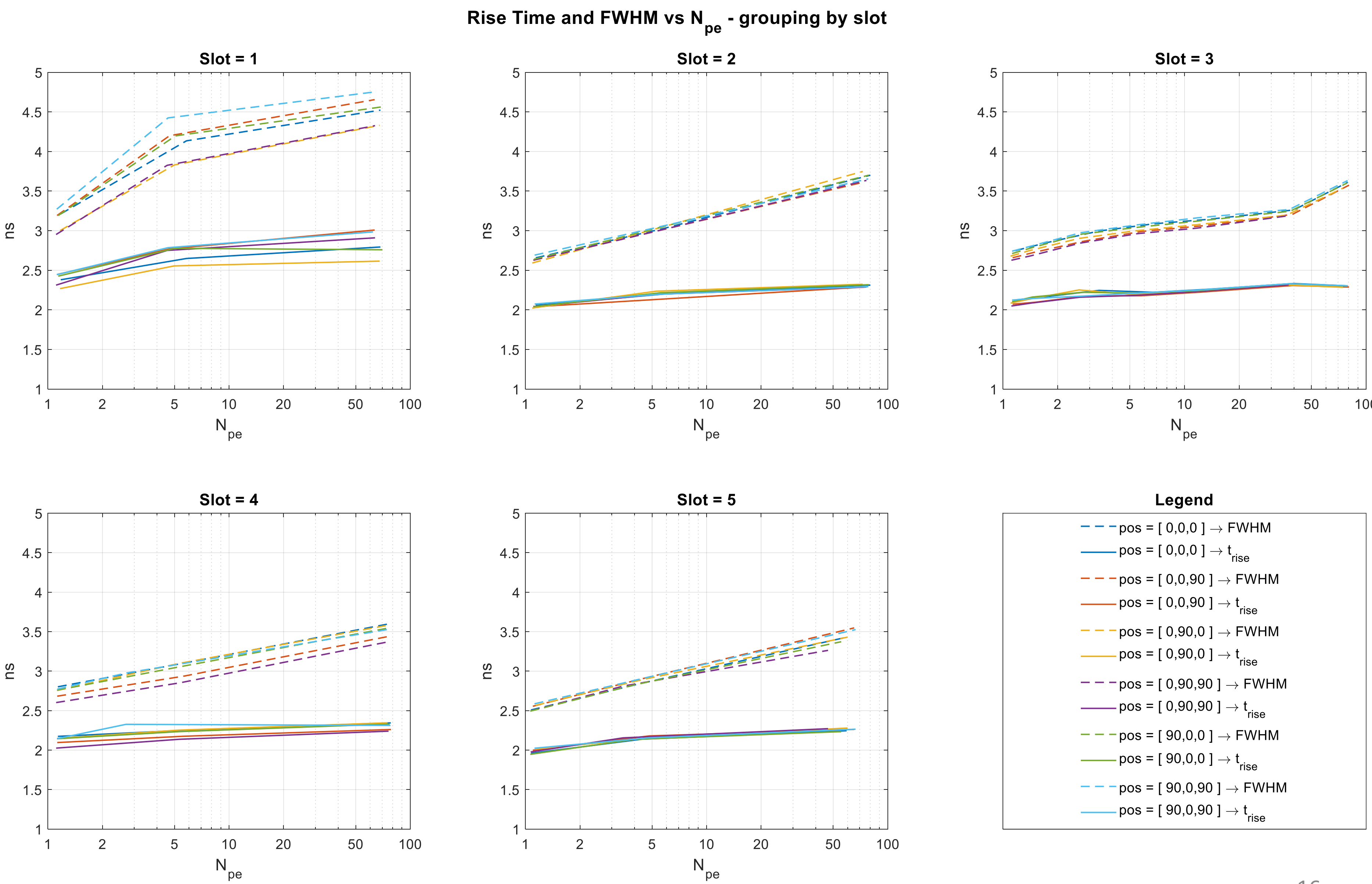
Waveform Shape vs Orientation



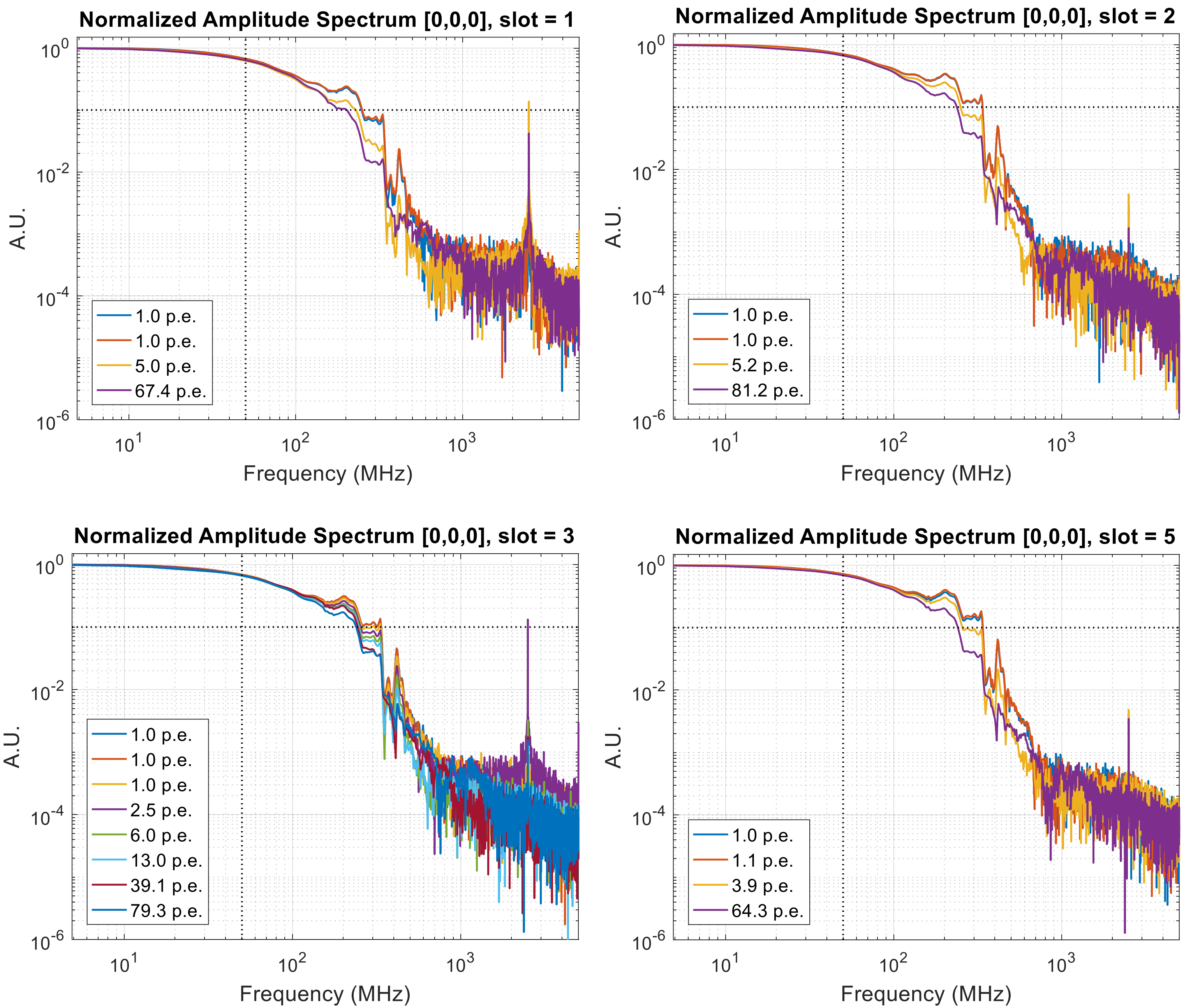
Waveform Shape vs Fiber Slot



Waveform Shape – Summary



Pulse Bandwidth



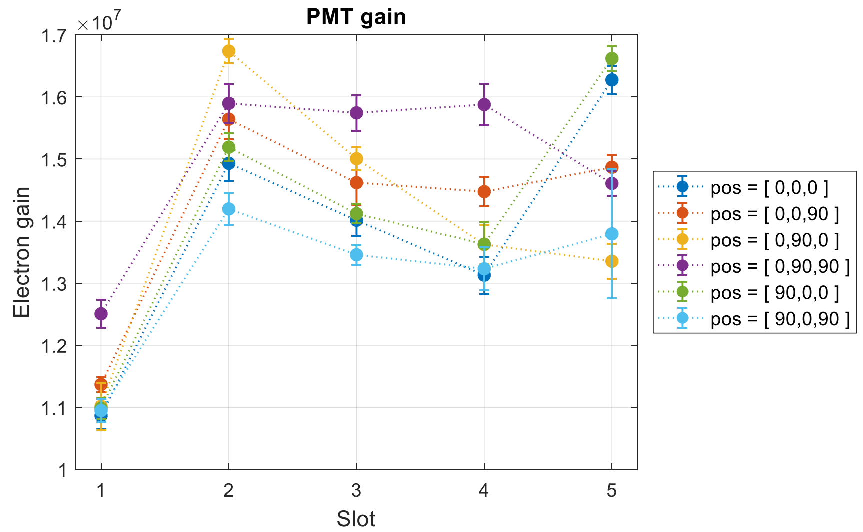
Bandwidth: ≈350 MHz

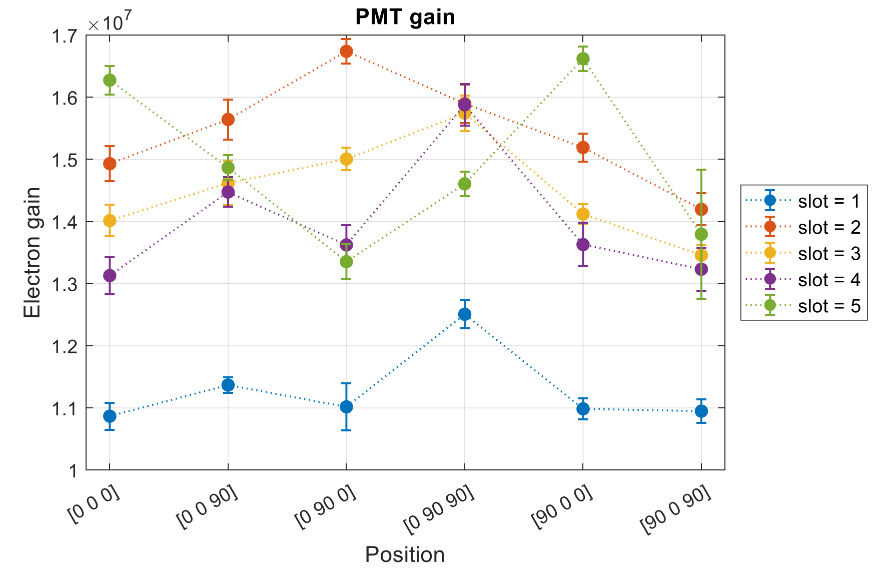
Faster than the old PMT

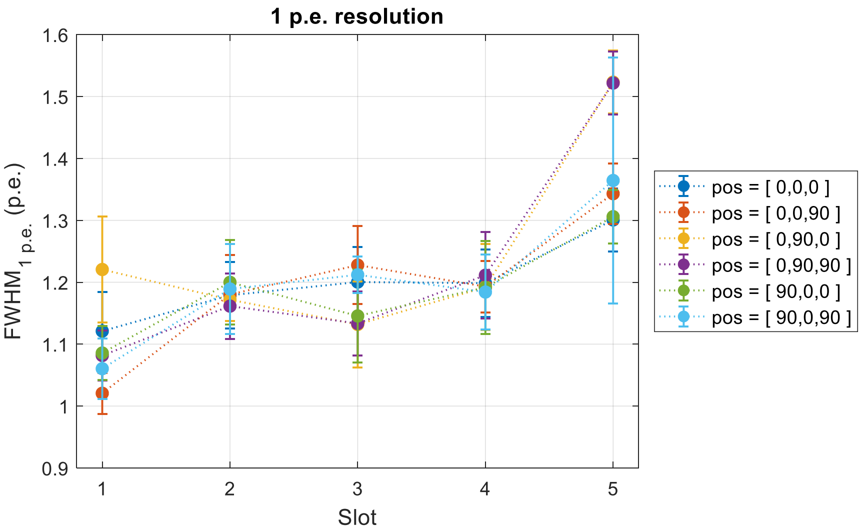
Bandwidth almost unchanged with moving light spot on the photo-cathode

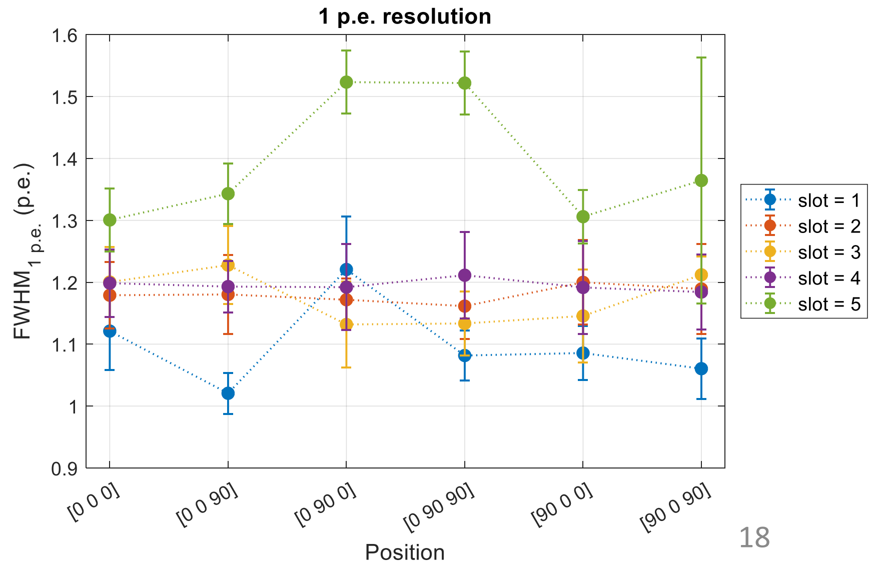
Small change with changing orientation

PMT gain and Charge Resolution (Constant HV)





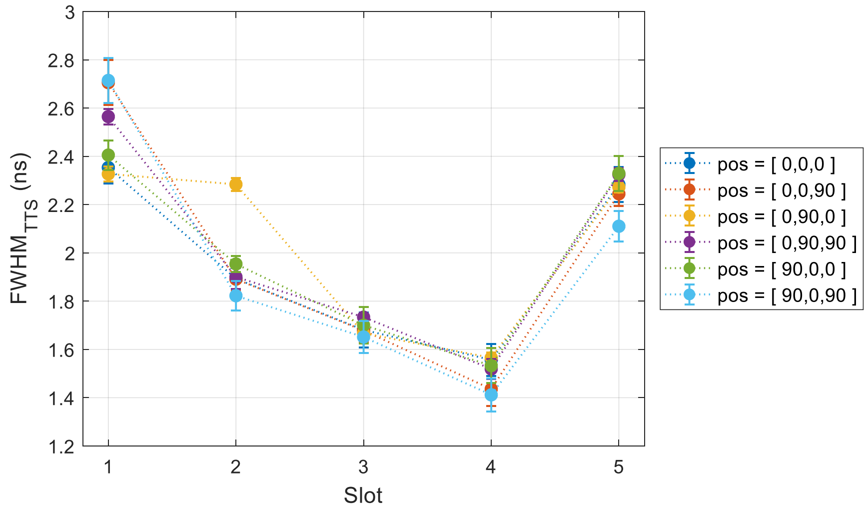




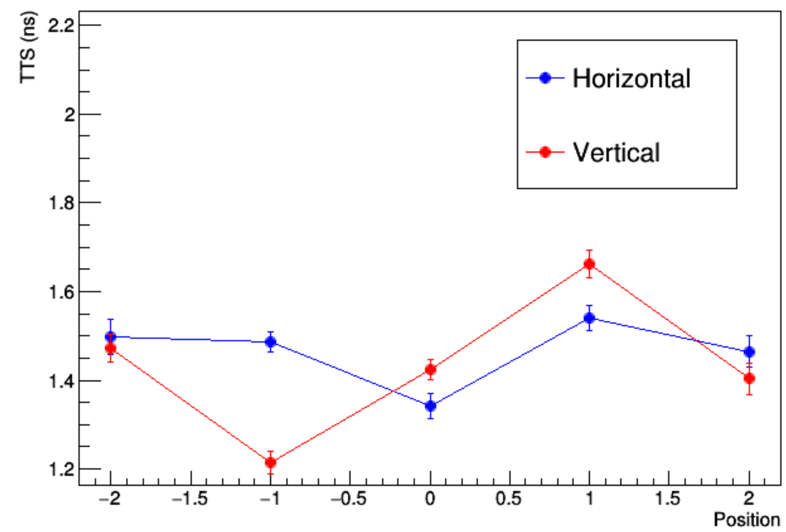
1 p.e. charge estimated using a double-Gaussian fit

Transit Time and TTS

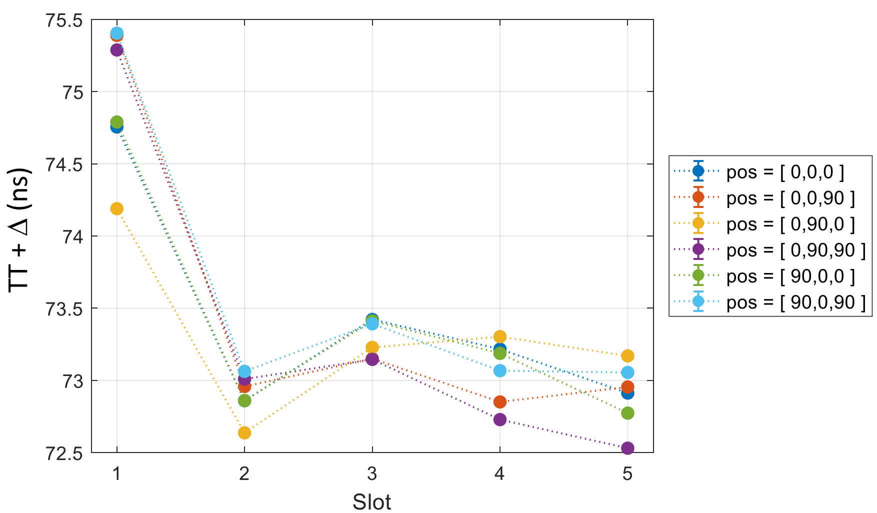
TTS (Kashiwa)



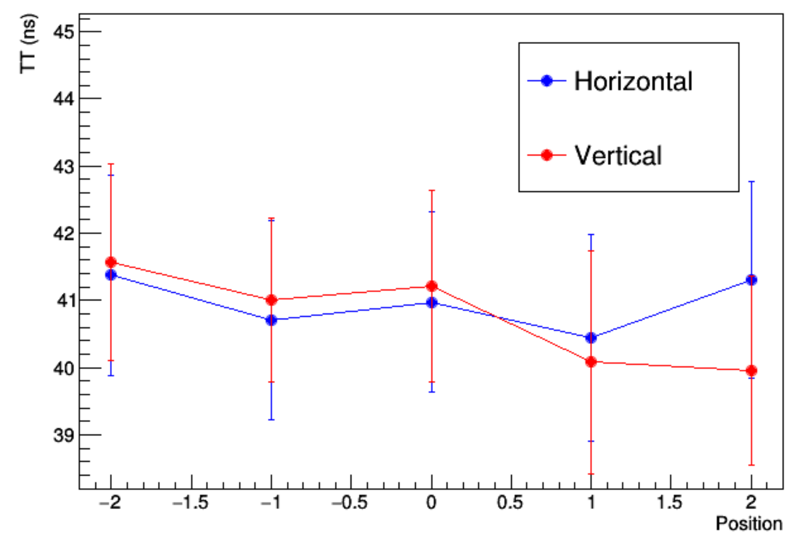
TTS (York, BC0042)



Transit Time* (Kashiwa)



Transit Time (York, BC0042)



Kashiwa - pulse timing using a digital constant fraction algorithm;
York – pulse timing at exactly ½ of pulse amplitudę
Δ - trigger to laser pulse delay

Summary

- Done measurements of gain, dark rate and timing resolution
  - Currently, Hamamatsu PMT seems to have better timing than HZC. ET PMT not tested yet for TTS.
  - Timing accuracy and transit time itself depend on the position on photocathode
- Waveform studies show some change in shape with changing the p.e. level – possibly it can be parameterized
  - Some dependence on the position on photocathode is also observable – maybe we can use it to correct for transit time differences.
- No visible dependence of gain curves on HV polarity
- Slight dependence on magnetic field
- Positive HV provides lower dark rate than negative HV. Still investigating if we can use negative HV.
  - Advantages of negative HV are better noise performance of the electronics and DC coupling (no baseline shifts). Base already available from INFN. (revision of KM3NET design) …
  - But we need to have dark rate comparable to positive HV case, otherwise we will not be able to use negative HV for Hyper-K (goal: ≈100 counts/s)
- Soon we will be able to share data and cross-check results between sites.
- Lot’s of work ahead…

BACKUP

Effects of PMT Orientation on Waveform