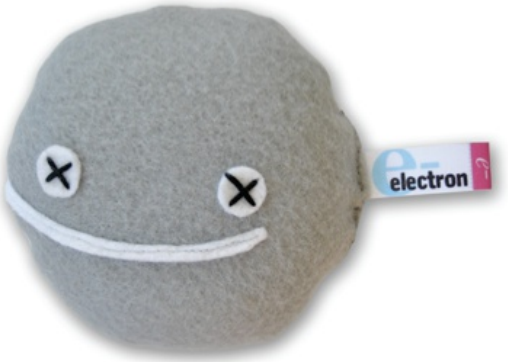
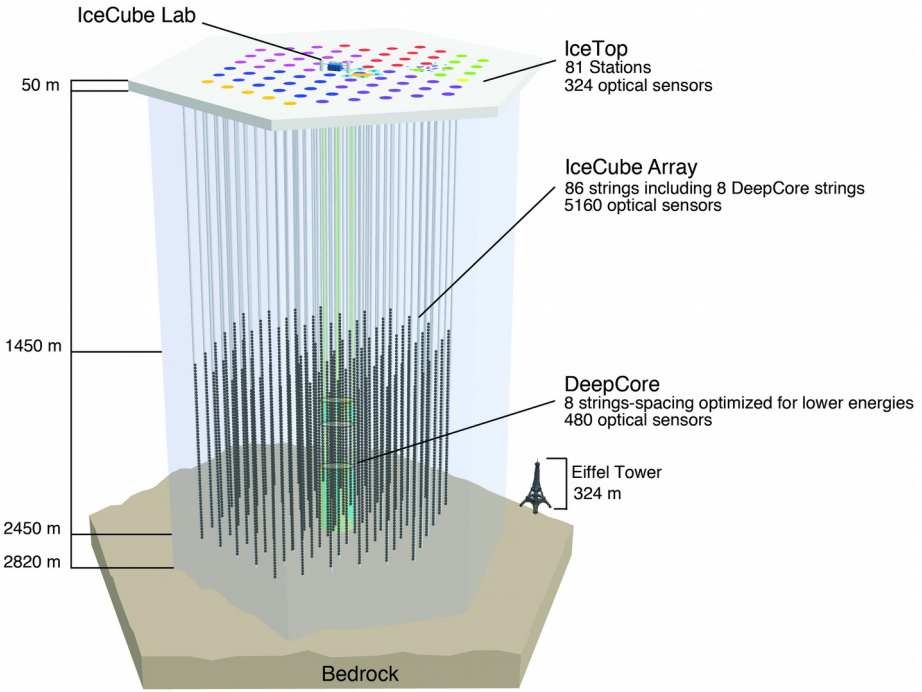
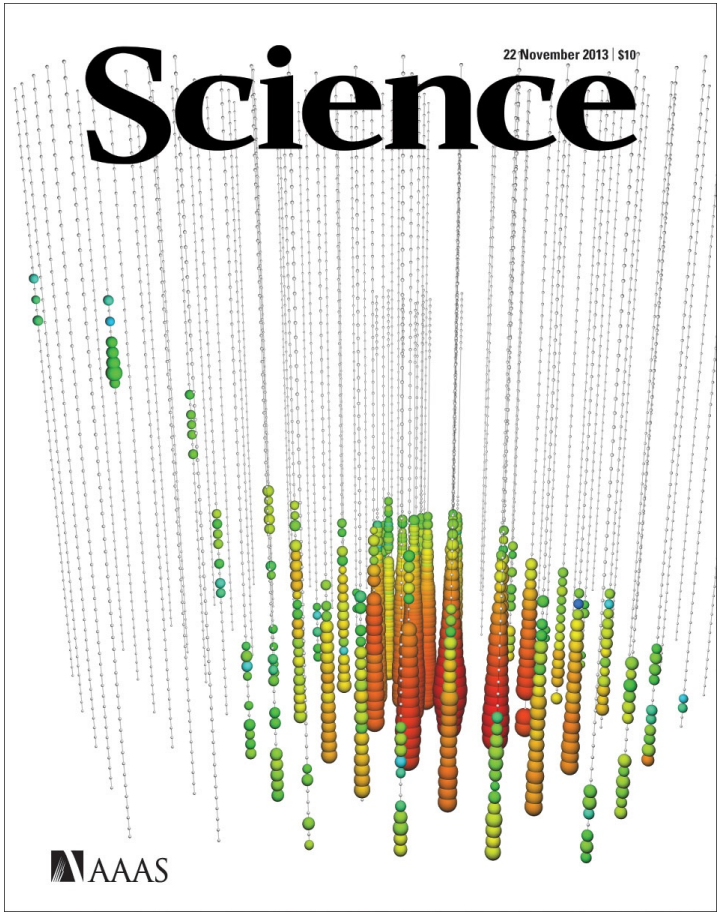
Precision lab measurements on IceCube optical modules



IceCube

- In-ice Cherenkov telescope at the geographic South Pole
- 5160 DOMs containing a 10” PMT each
- Construction: 2005 – 2011
- Discovery of extra-terrestrial neutrinos: 2013





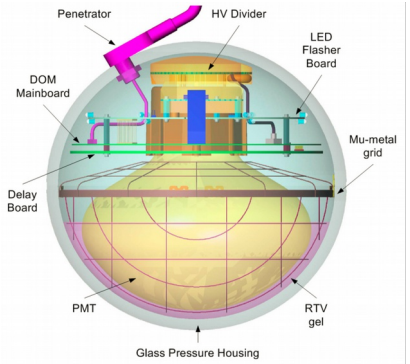
Calibrating the experiment

Hardware:

timing

gain

Quantum efficiency



noise

Dead time

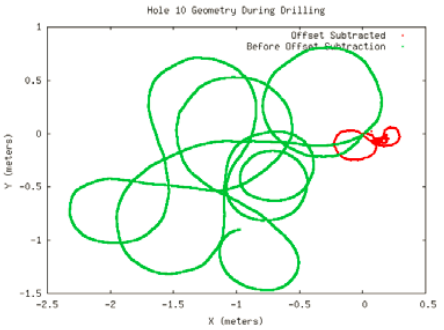
resolution

Geometry:

DOM position

orientation

Drill data



Survey data

LED data

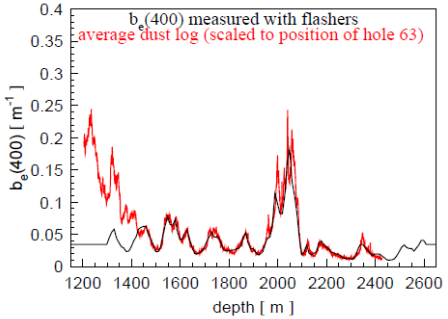
Muons

Ice properties:

Scattering

Absoption

Hole Ice



Flasher LEDs

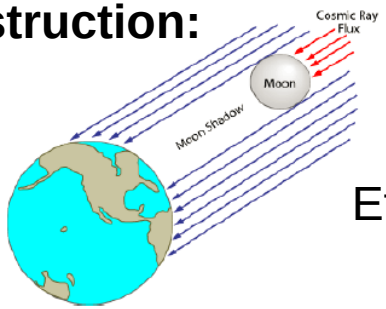
cameras

muons

Dust logger

Event reconstruction:

High level stuff...



Energy resolution

Effective area

Angular resolution

→ *science results*

Going beyond what is required/sensible for the detector calibration...

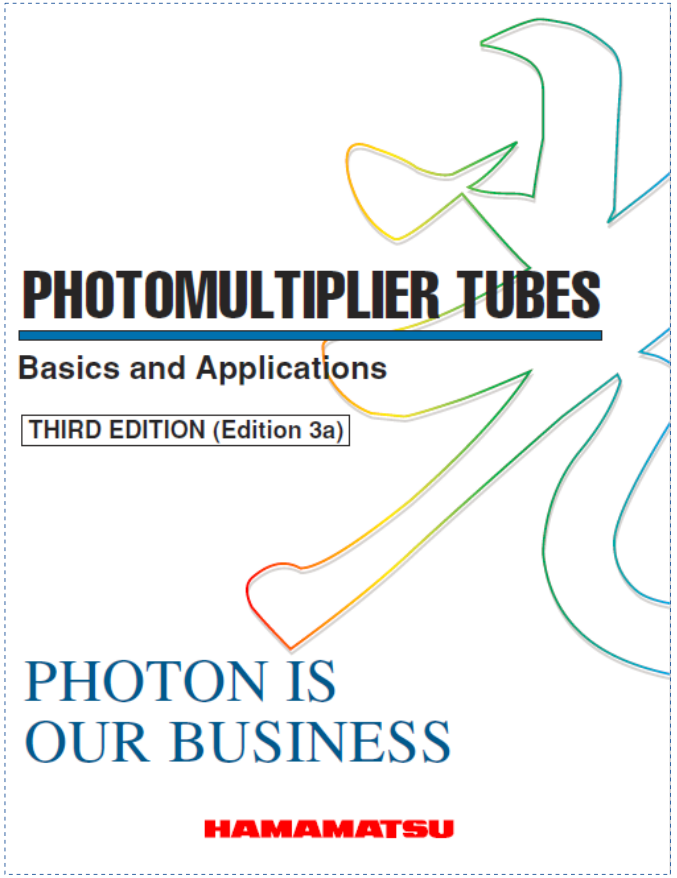
Contents:

- The hardware, the lab

Selected properties:

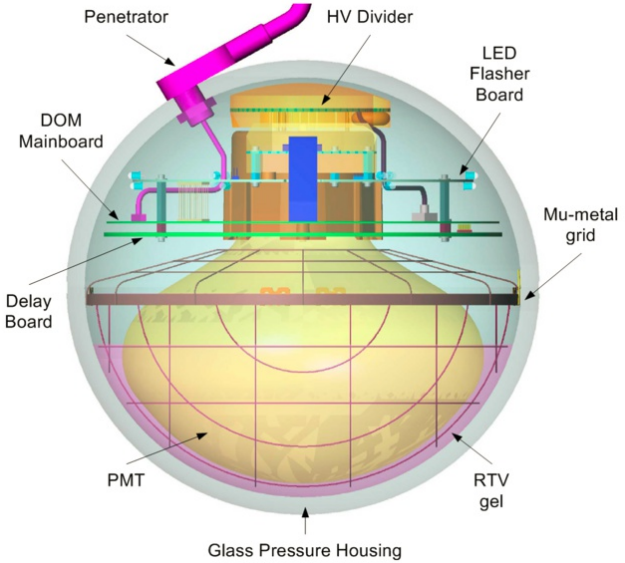
- Effects of the first dynode on ...
  - … the gain
  - … P2V ratio
  - … the late pulse probability
- Recovering PMT saturation
  - When?
  - How?

Nothing which is not described in the PMT bible, but still a good reminder.



BECAUSE WE CAN

The IceCube PMT and ASIC



Hamamatsu R7081-02 (datasheet)**:**

- 10“ large area PMT
- 10 stage Box&Line dynode chain
- 1.5 – 5% late pulsing
- Linear to 70 mA at 2%

- Contained in fully independent DOM unit
- Operated at gain 10^7

The IceCube ASIC:

Analog Transient Waveform Digitizer (ATWD) by LBNL

- 4 channels, 128 sample linear capacitor array each
- 0.3 – 3.5 analog input range
- 0.3 – 2.0 GHz sampling speed
- Acquisition triggered by comparator, digitization initialized by local coincidence → trigger
- 40 MHz, 10 bit ADC → ping-pong to reduce dead time to < 0.1‰

18y old ASIC

The Madison lab for absolute calibration

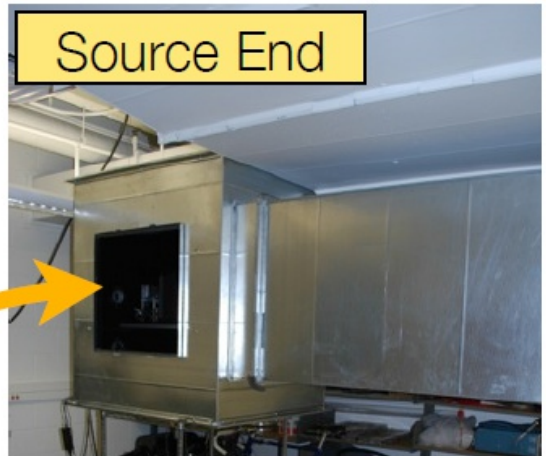
Available sources:

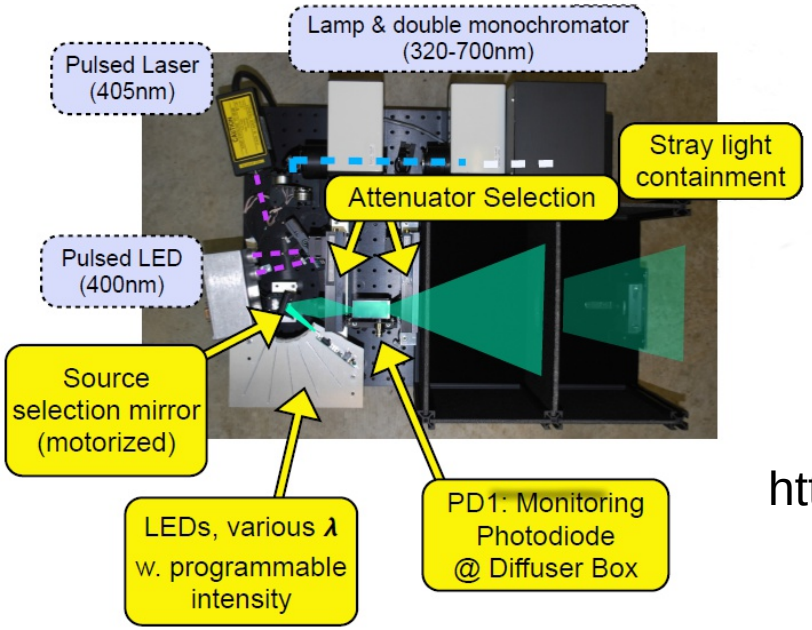
Pulsed → waveform DAQ

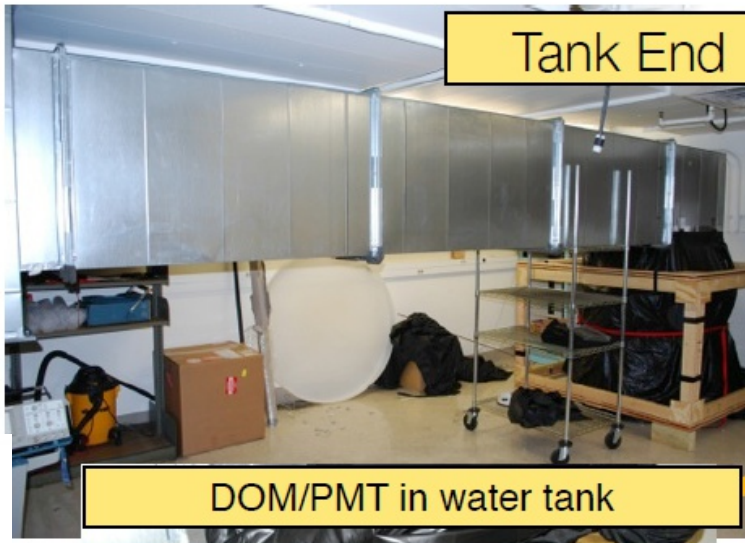
- 50ps laser with filter:
  ~3% chance of 1 PE
- Laser without filter:
  ~75 PE per pulse
- Flasher LEDs
  - High brightness
  - 30 ns
  - 1.25 us

Continuous → scalars

- LEDs:
  - 400 nm
  - 450 nm
  - 360 nm

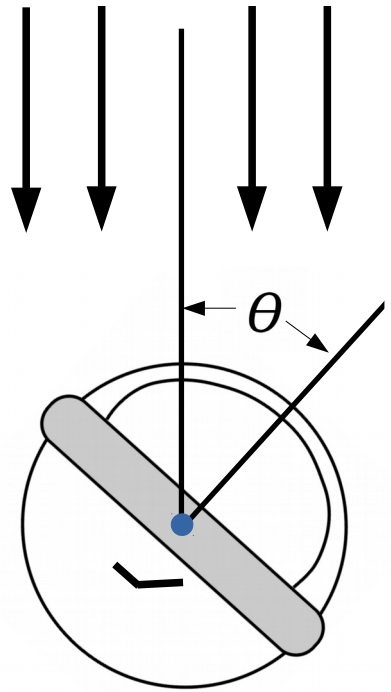


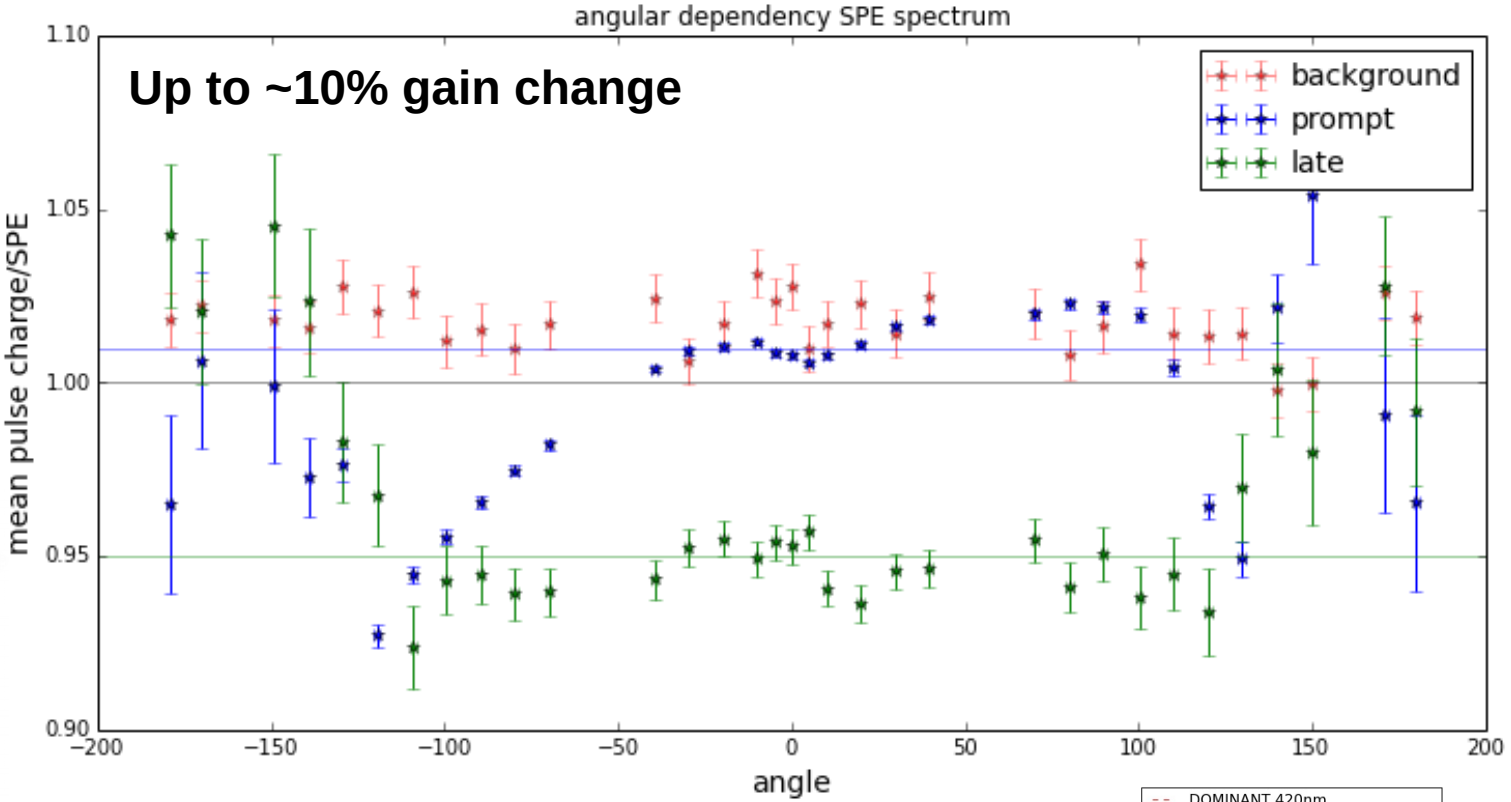


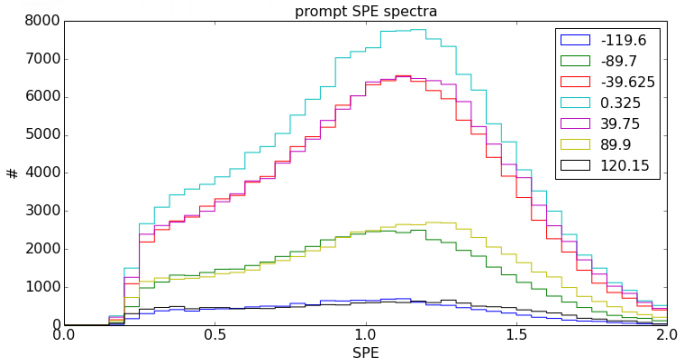


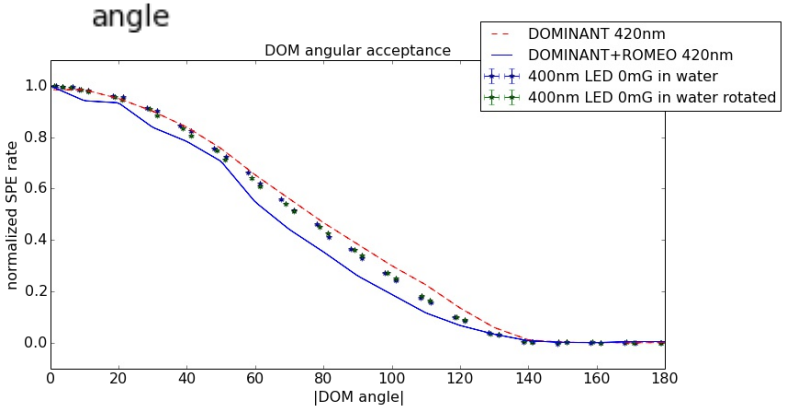
http://arxiv.org/abs/1502.03102

Rotating the DOM

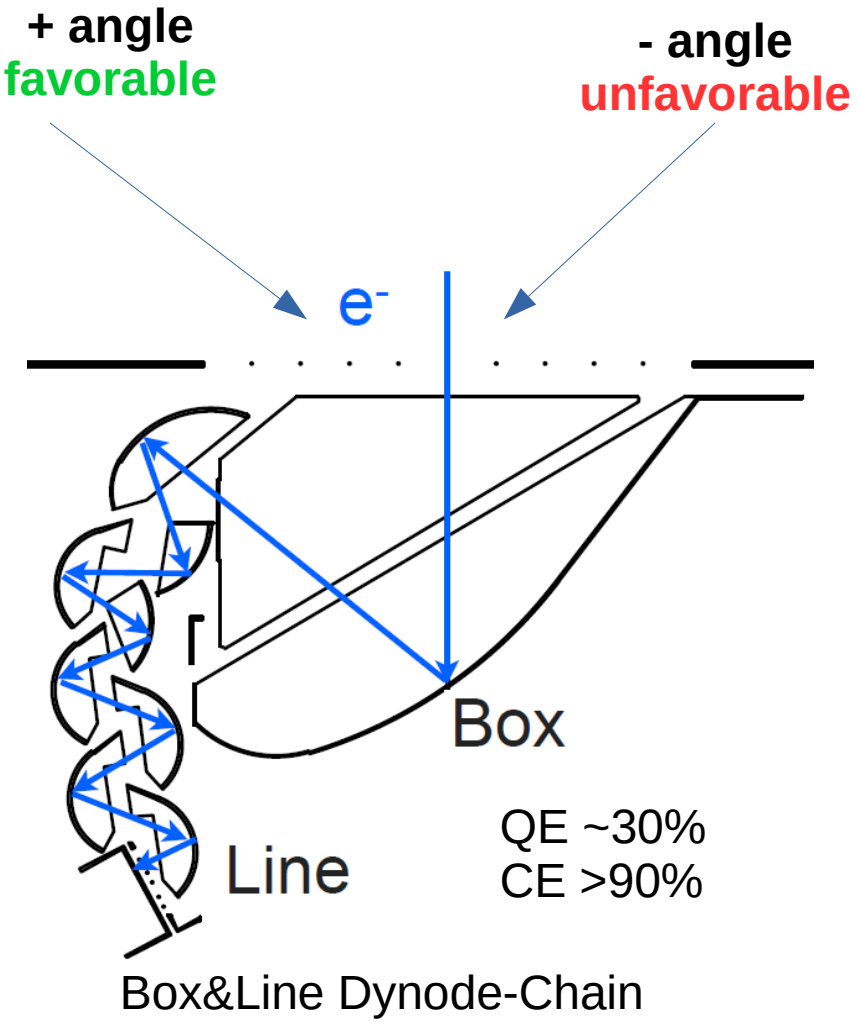




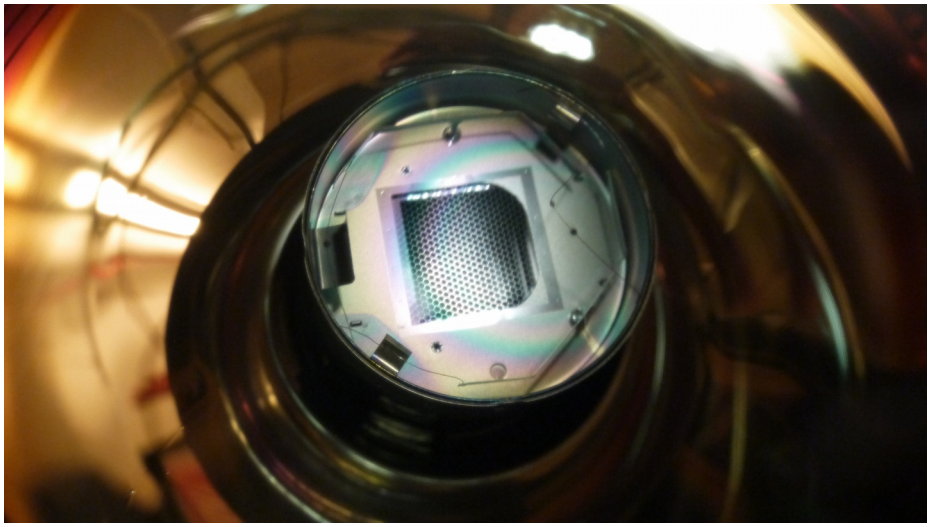


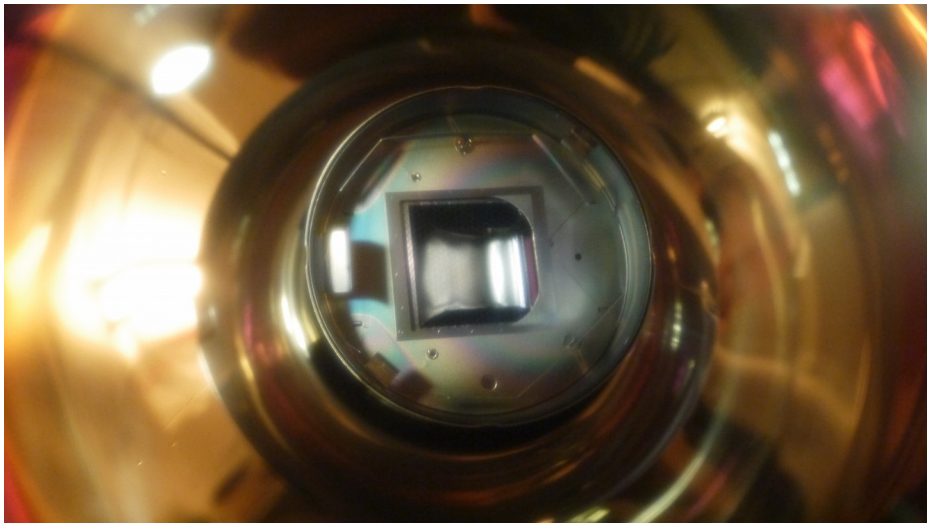


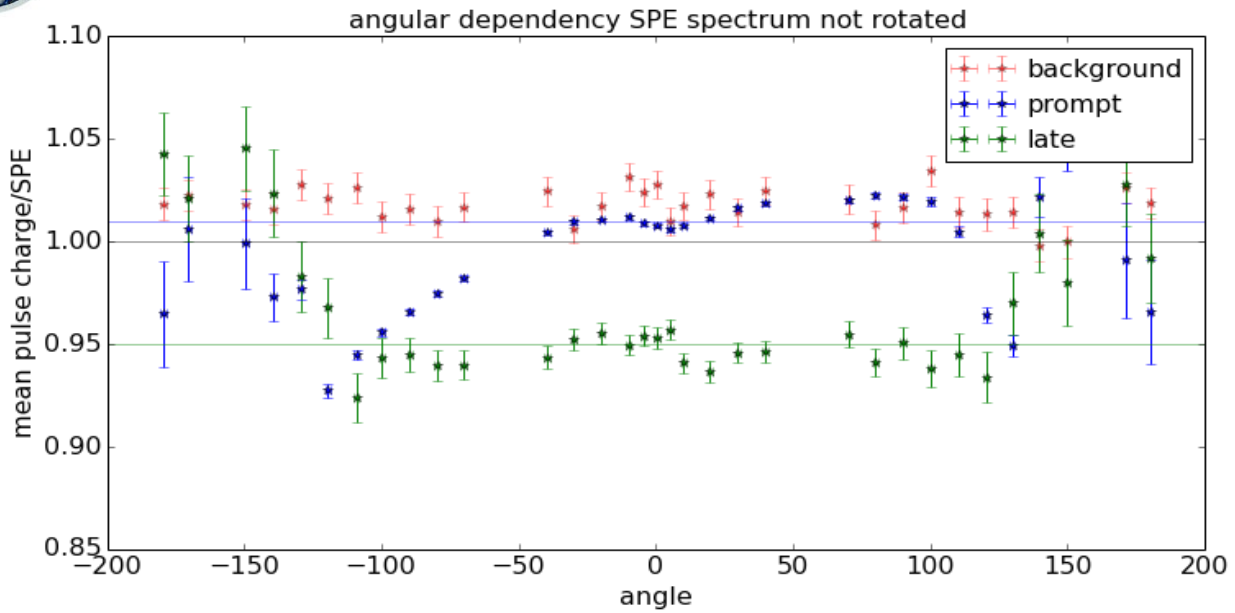
Understanding the asymmetries

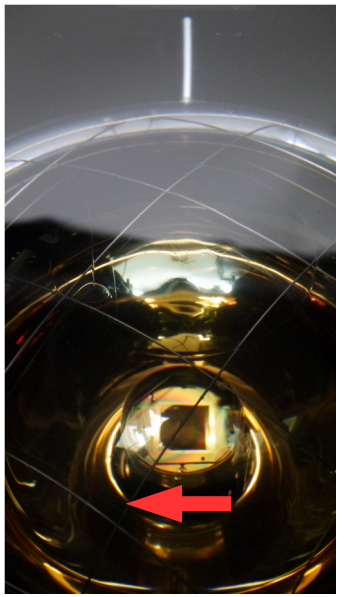


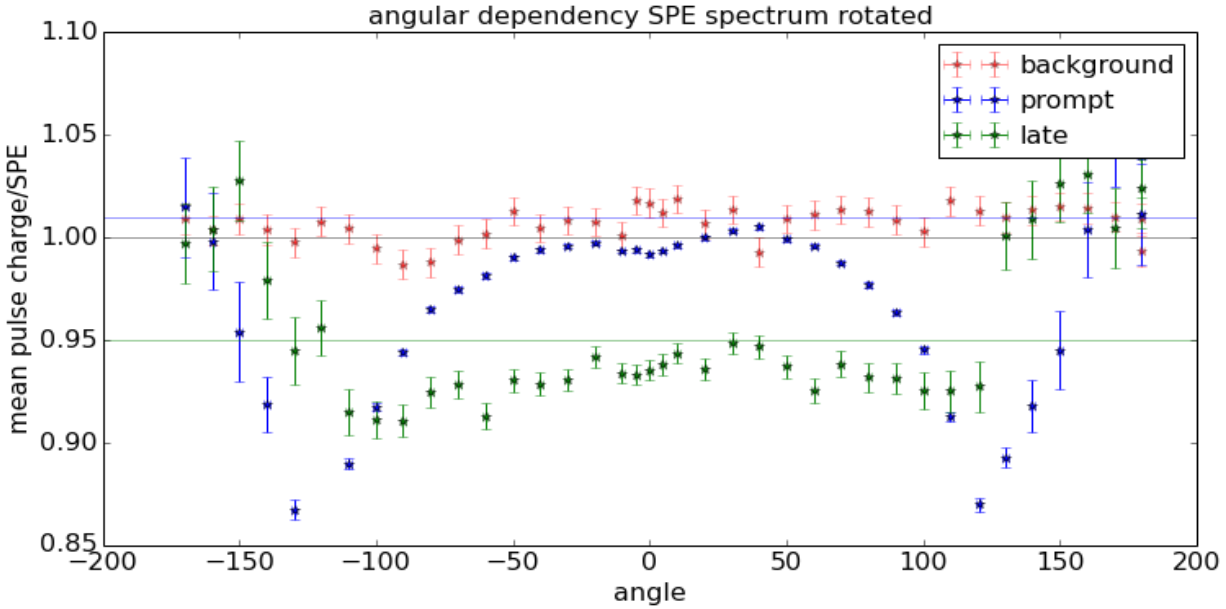
Box&Line Dynode-Chain






angular dependency SPE spectrum not rotated
background
prompt
late
mean pulse charge/SPE
angle
1.10
1.05
1.00
0.95
0.90
0.85
−200
−150
−100
−50
0
50
100
150
200




angular dependency SPE spectrum rotated
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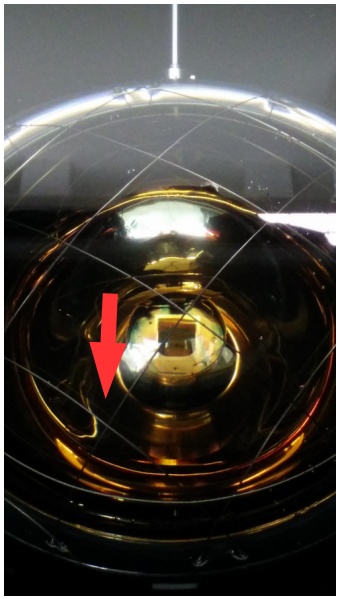
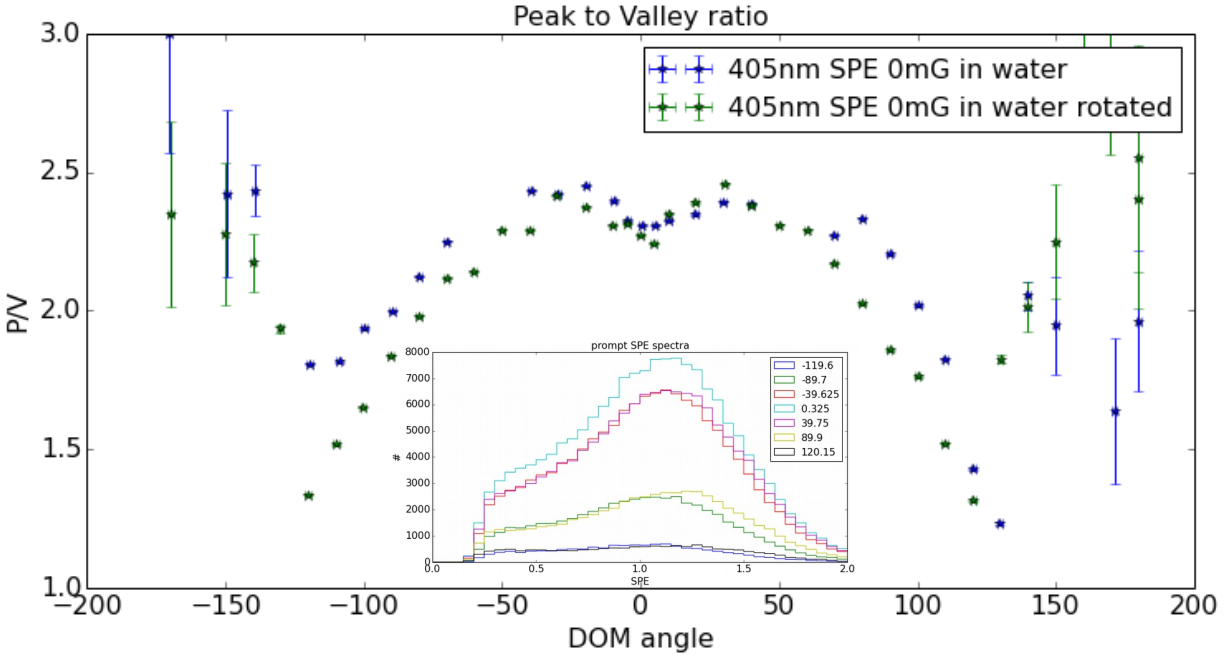
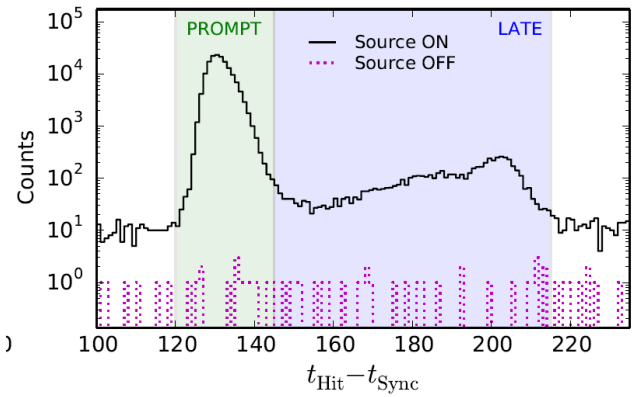
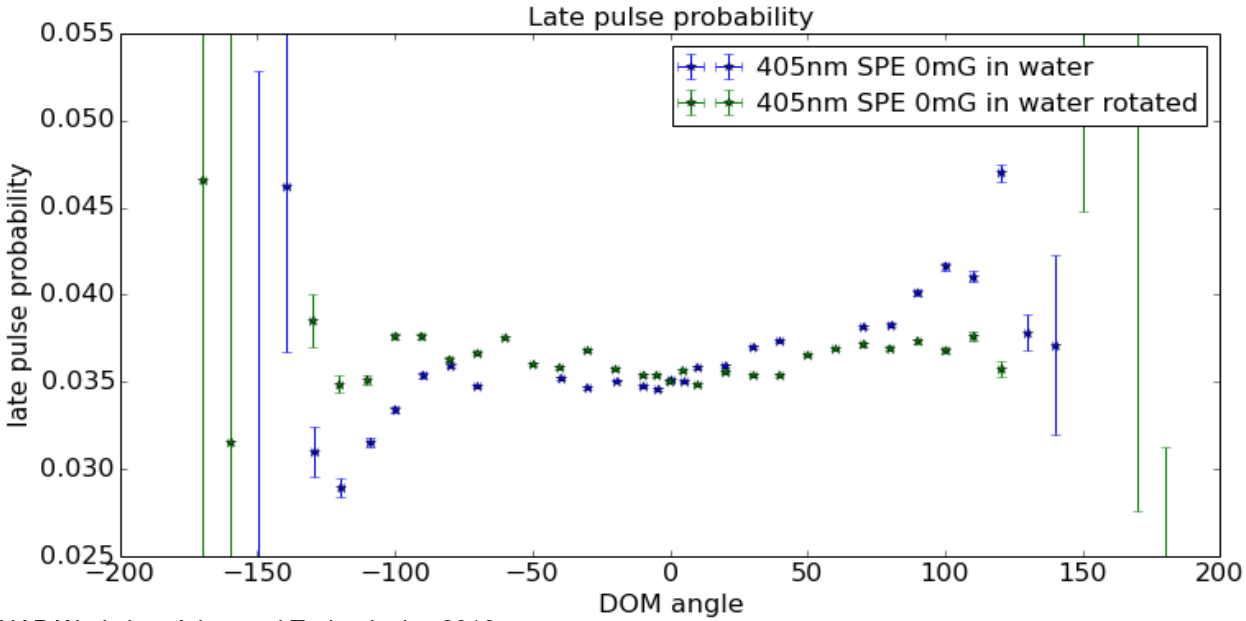


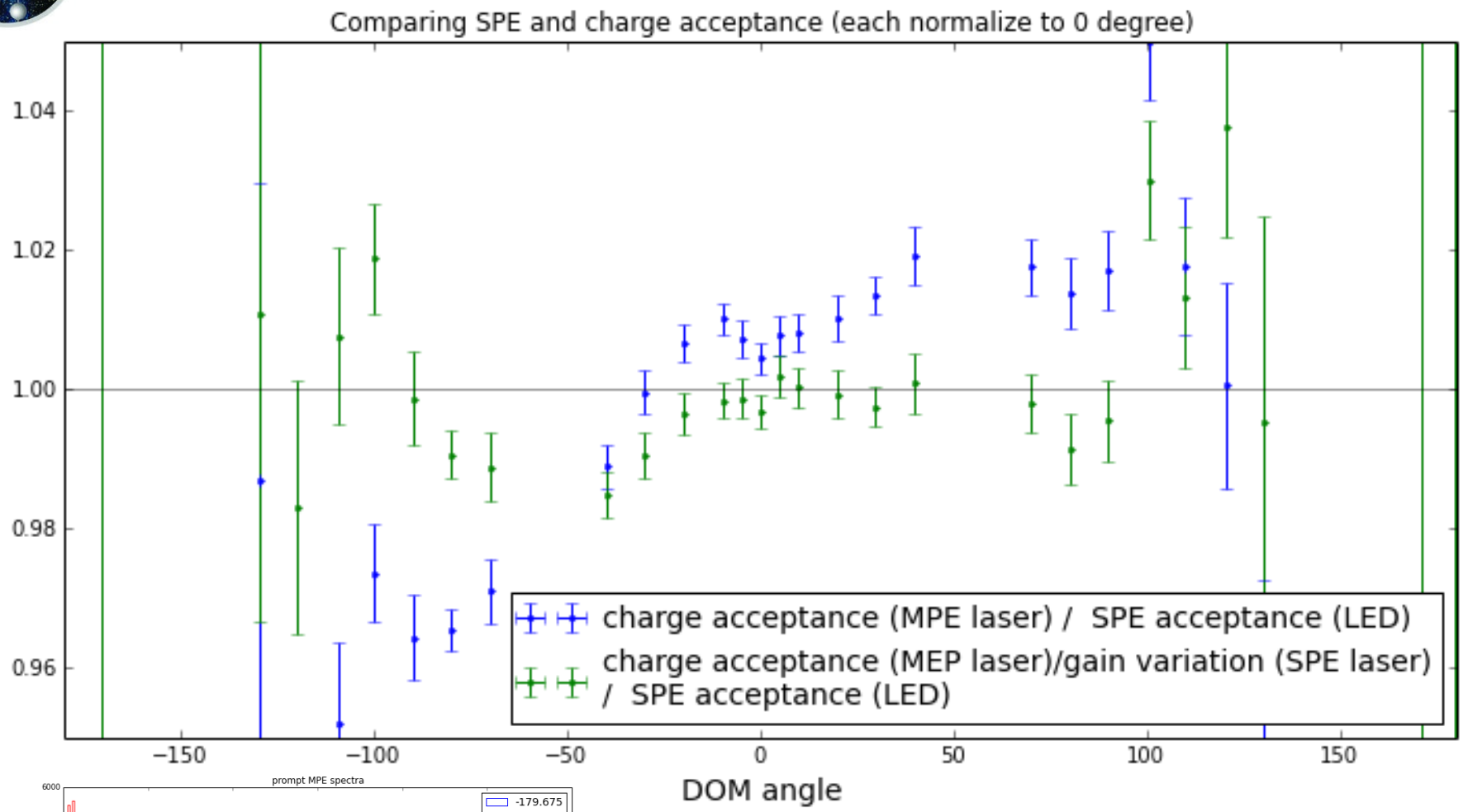


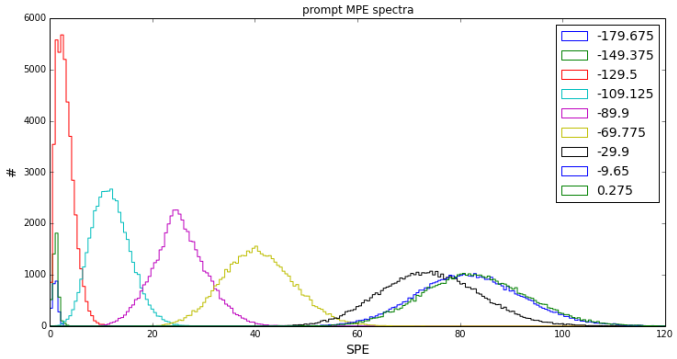
As the electron optics suffers the P2V decreases.

Depending on the incident angle the scattering likelihood changes.









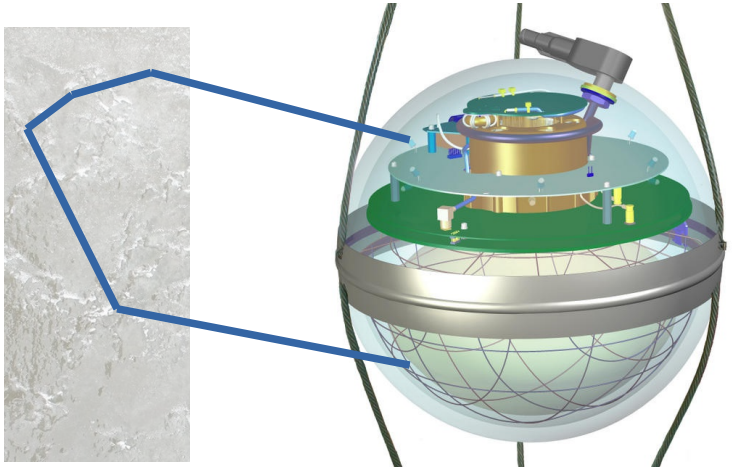
SPE acceptance ≈ QE * CE

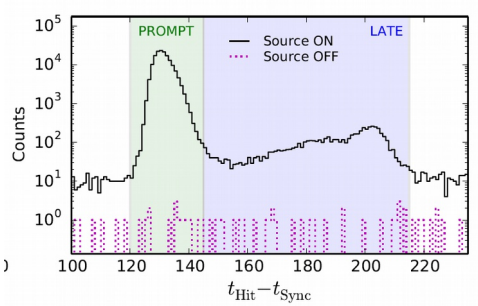
Charge acceptance = QE * CE * gain

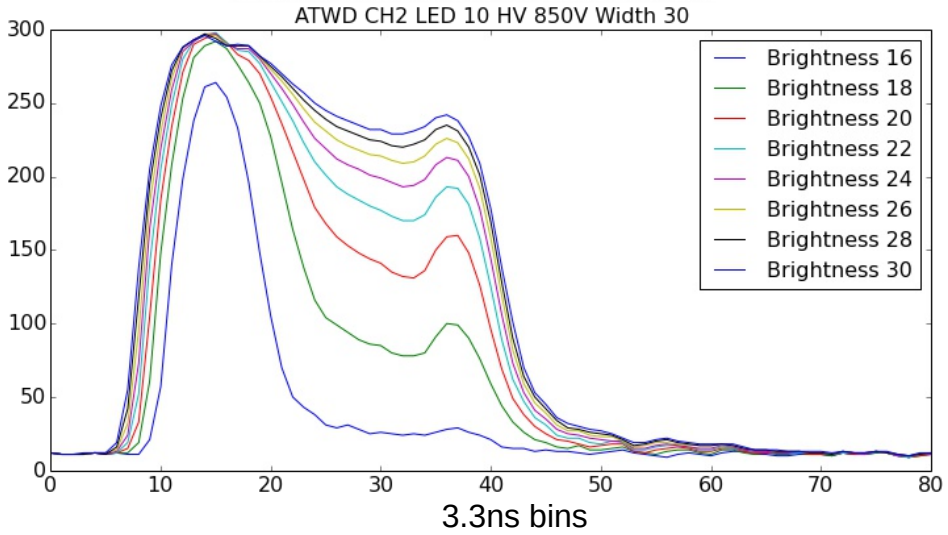
PMT saturation

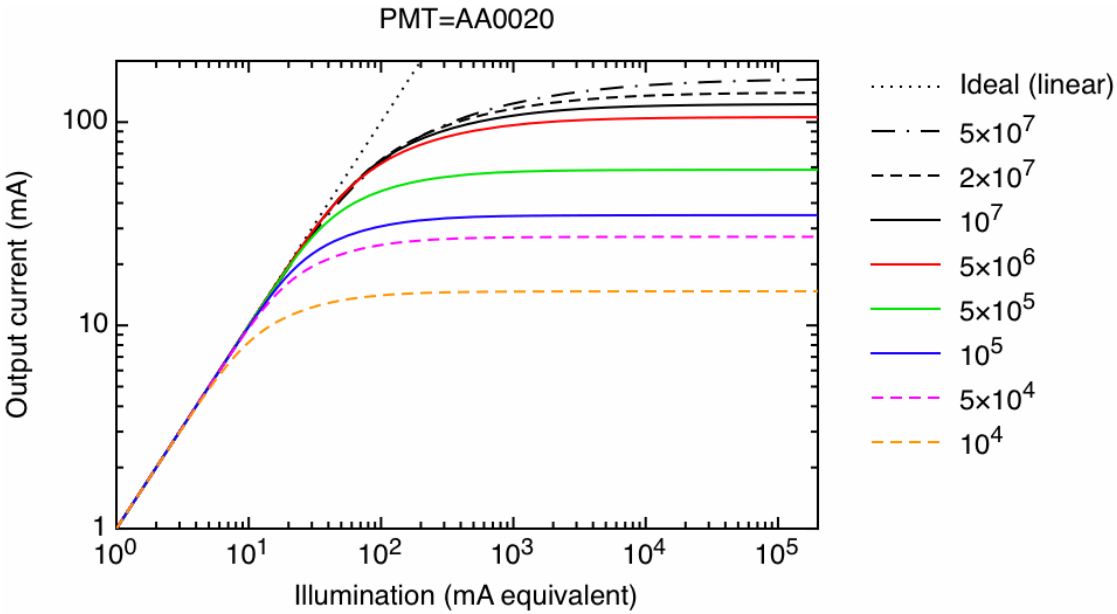
PMTs can not deliver arbitrarily large instantaneous currents (space charge effects at the dynodes)

10% non-linearity reached at 50mA (31 PE/ns)

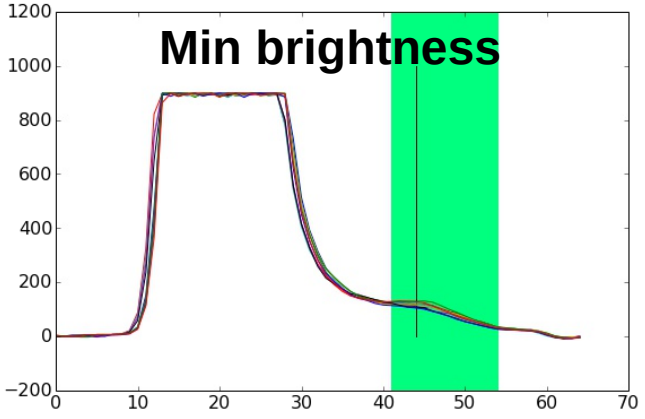


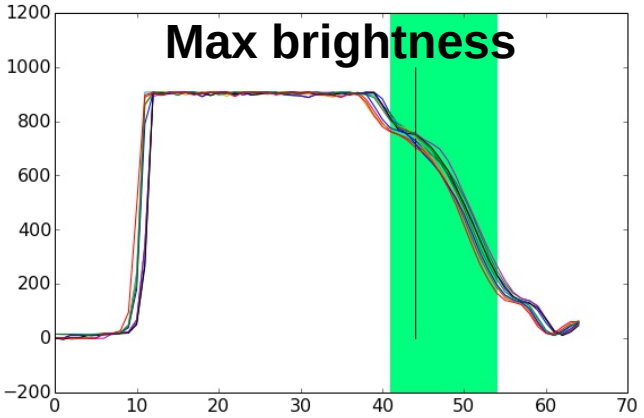


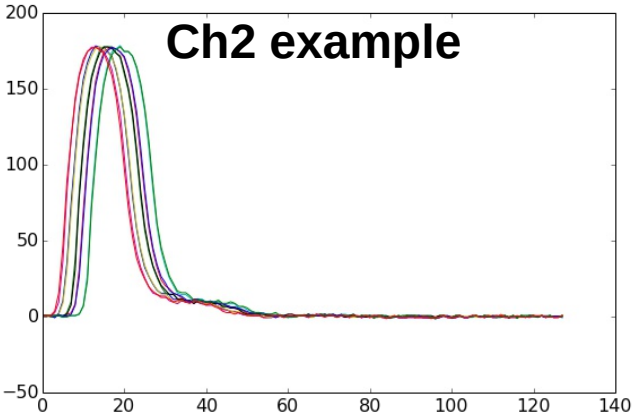


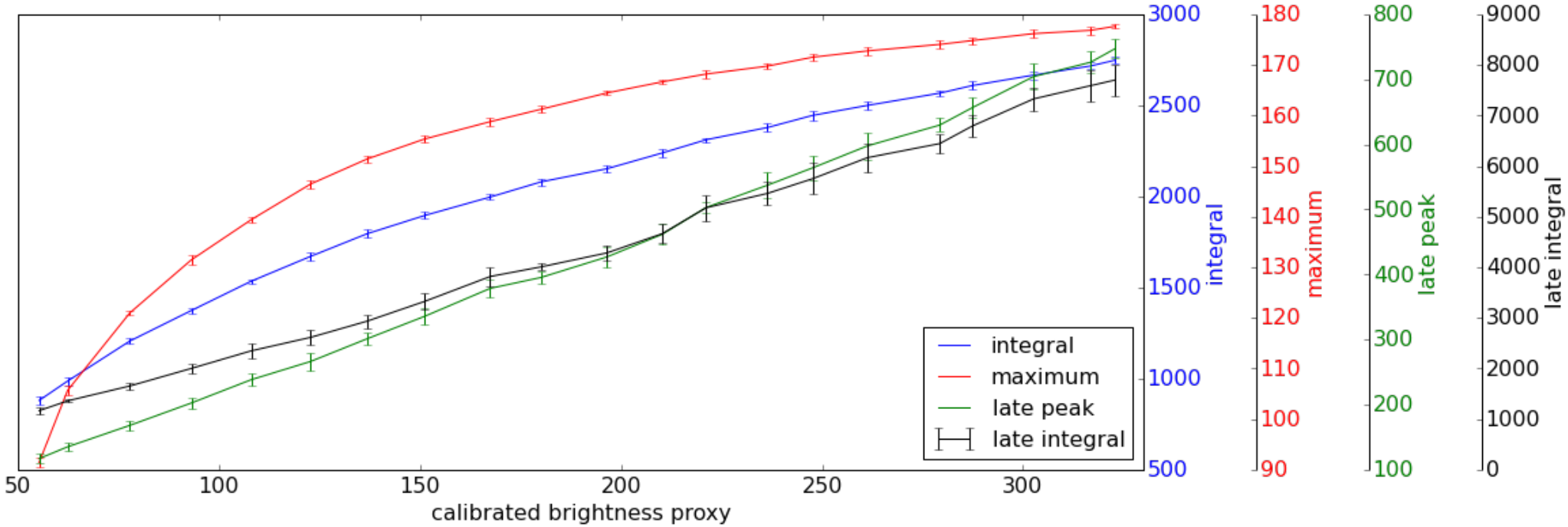


http://arxiv.org/abs/1002.2442

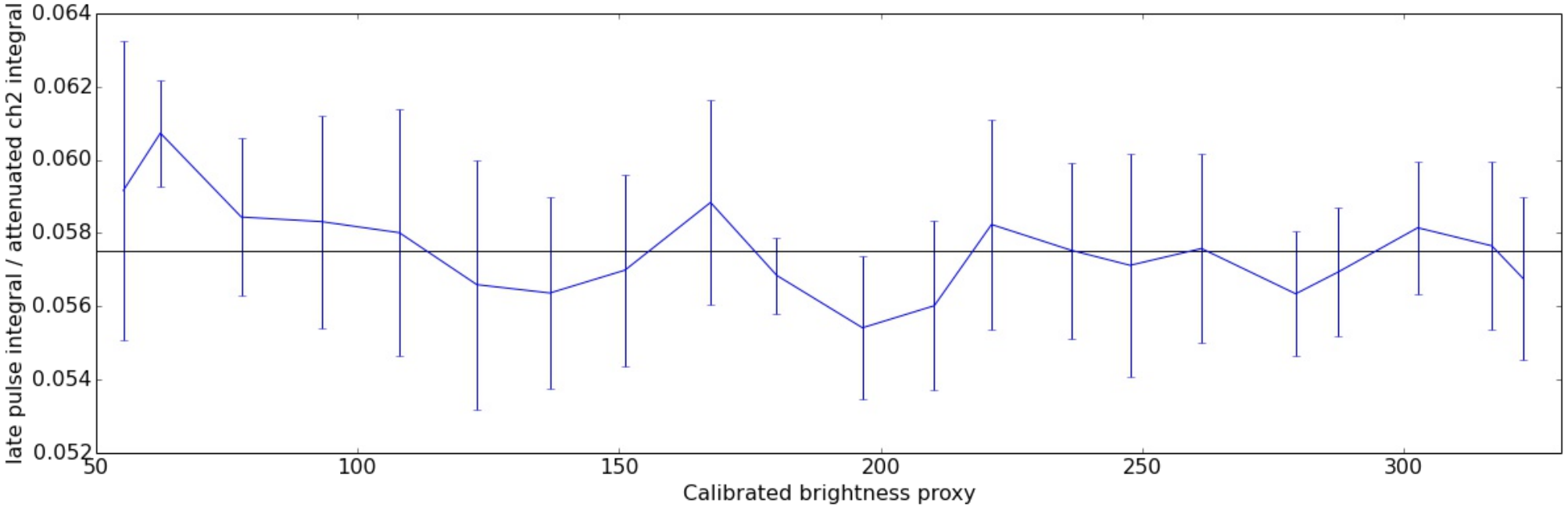








from attenuated light signal



→ the late pulse contains a constant fraction of the arriving photons
→ recover ~ a factor 40 in pulse linearit

(But the late pulse fraction needs to be calibrated for each PMT individually...)

Thank you for your attention!
Questions are welcome

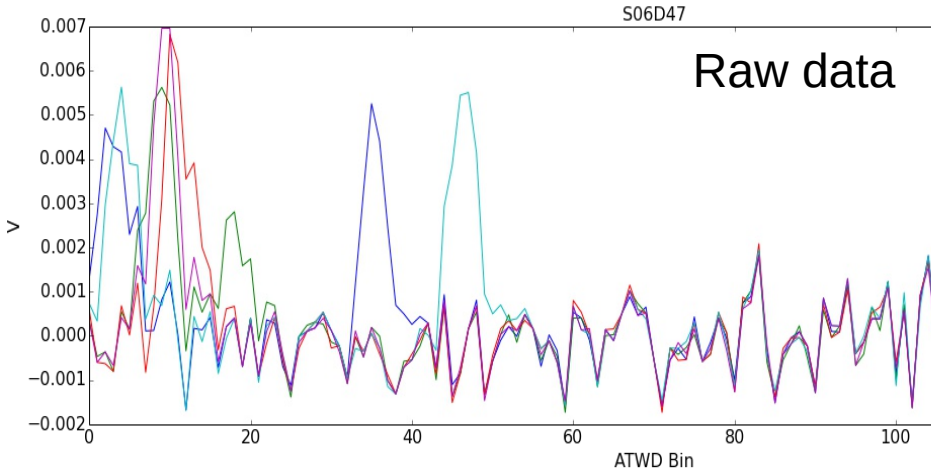
Backup

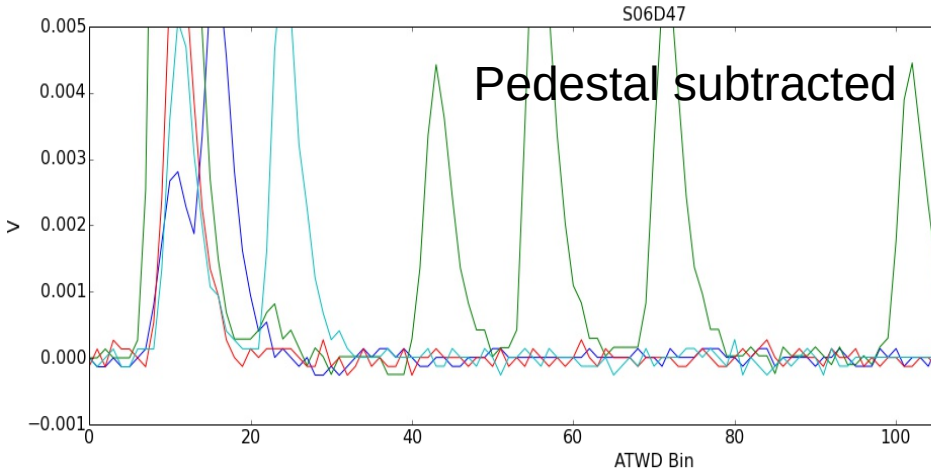
ATWD pedestals (both of them...)

ADCs work best at the mid-point of the digitization range. → A bias voltage is added to the analog signal which needs to be subtracted off. Easy!

Each capacitor in the ATWD has a slightly different parasitic charge / capacitance. The resulting constant pattern needs to be subtracted from the waveforms.
The pattern changes slightly with temperature / time. Pattern is validated with CPU clock trigger waveforms.

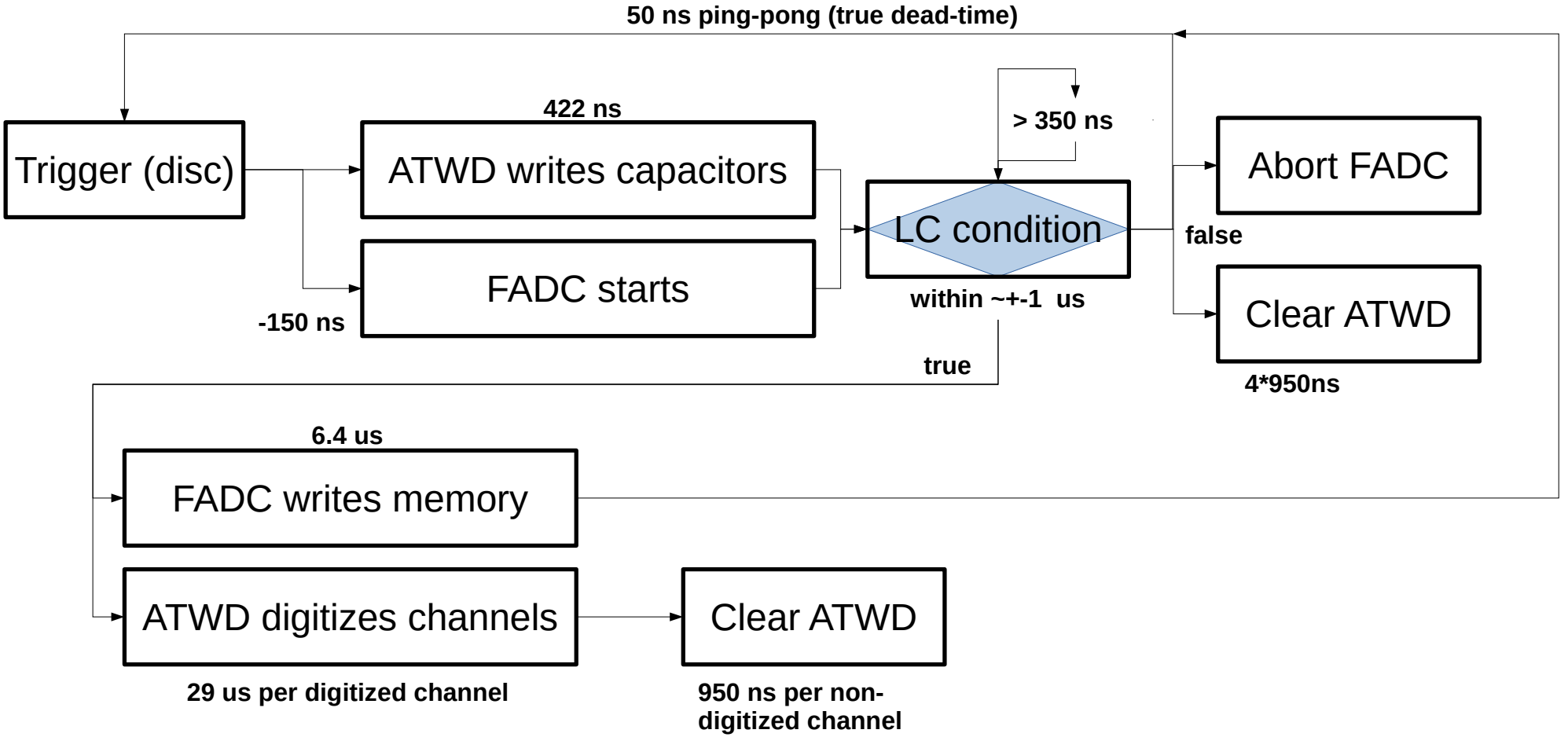
Ask Marius if you want to know what can go wrong here ;)





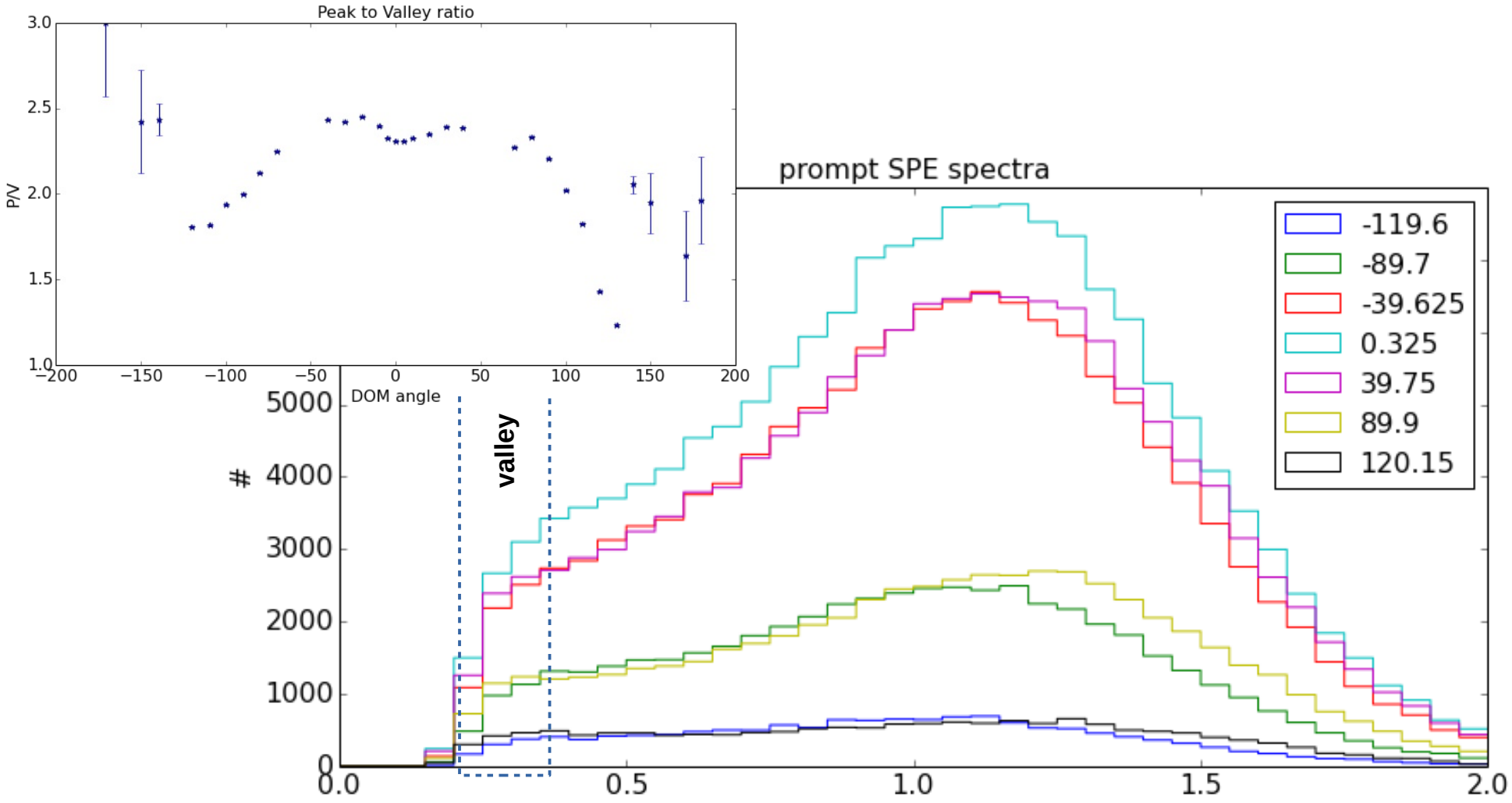
DAQ timing sequence

https://docushare.icecube.wisc.edu/dsweb/Get/Document-28424



Confusing stuff. There might be details wrong here!!

SPE charge spectra



SPE = the charge we have identified as a SPE during DOMCal