Calibrating photon detection efficiency in IceCube

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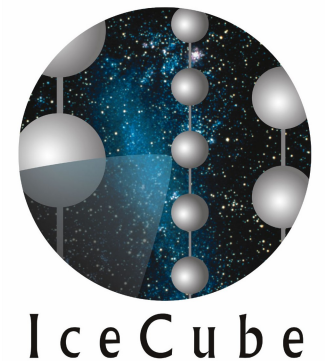
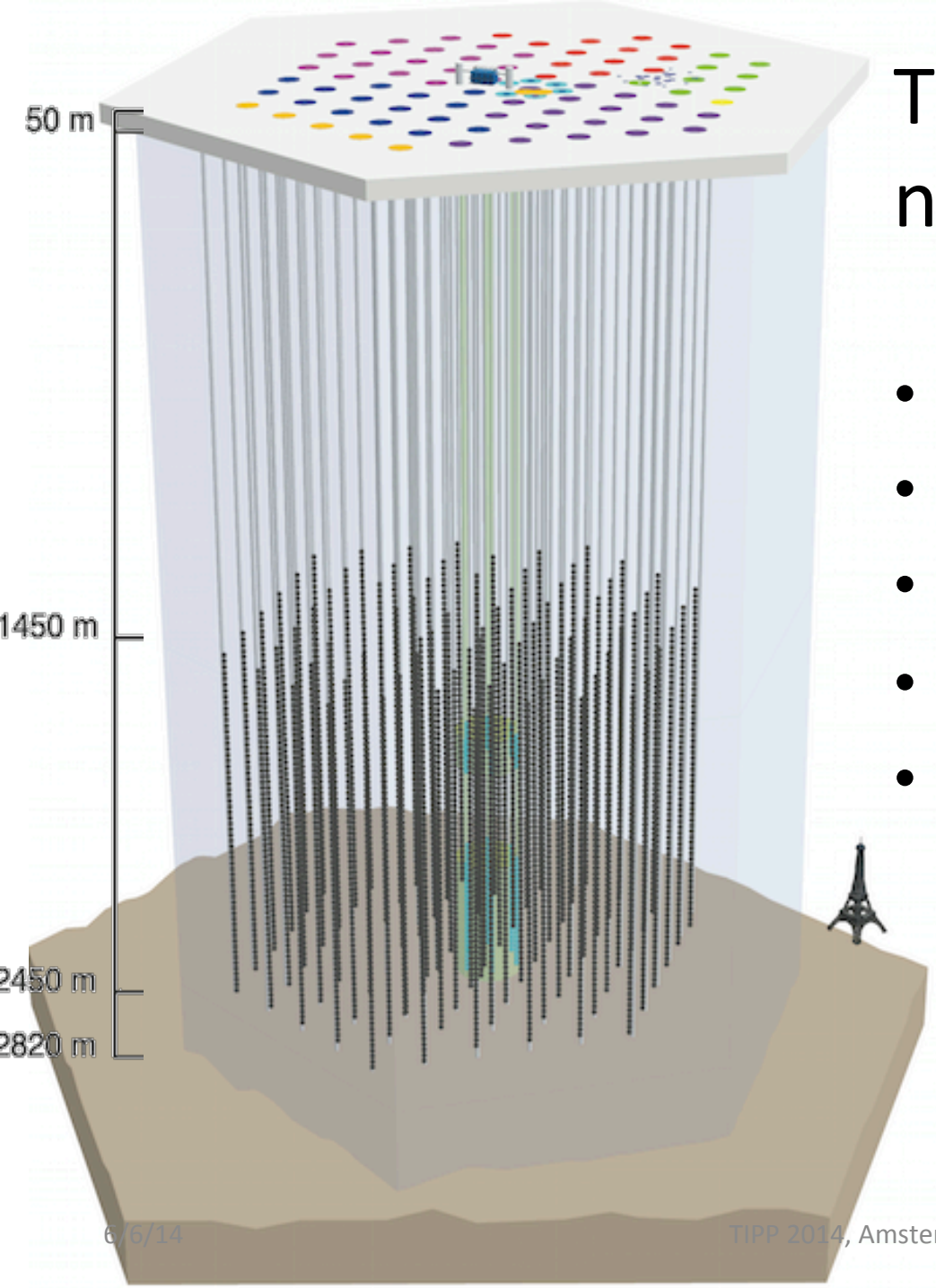


Outline

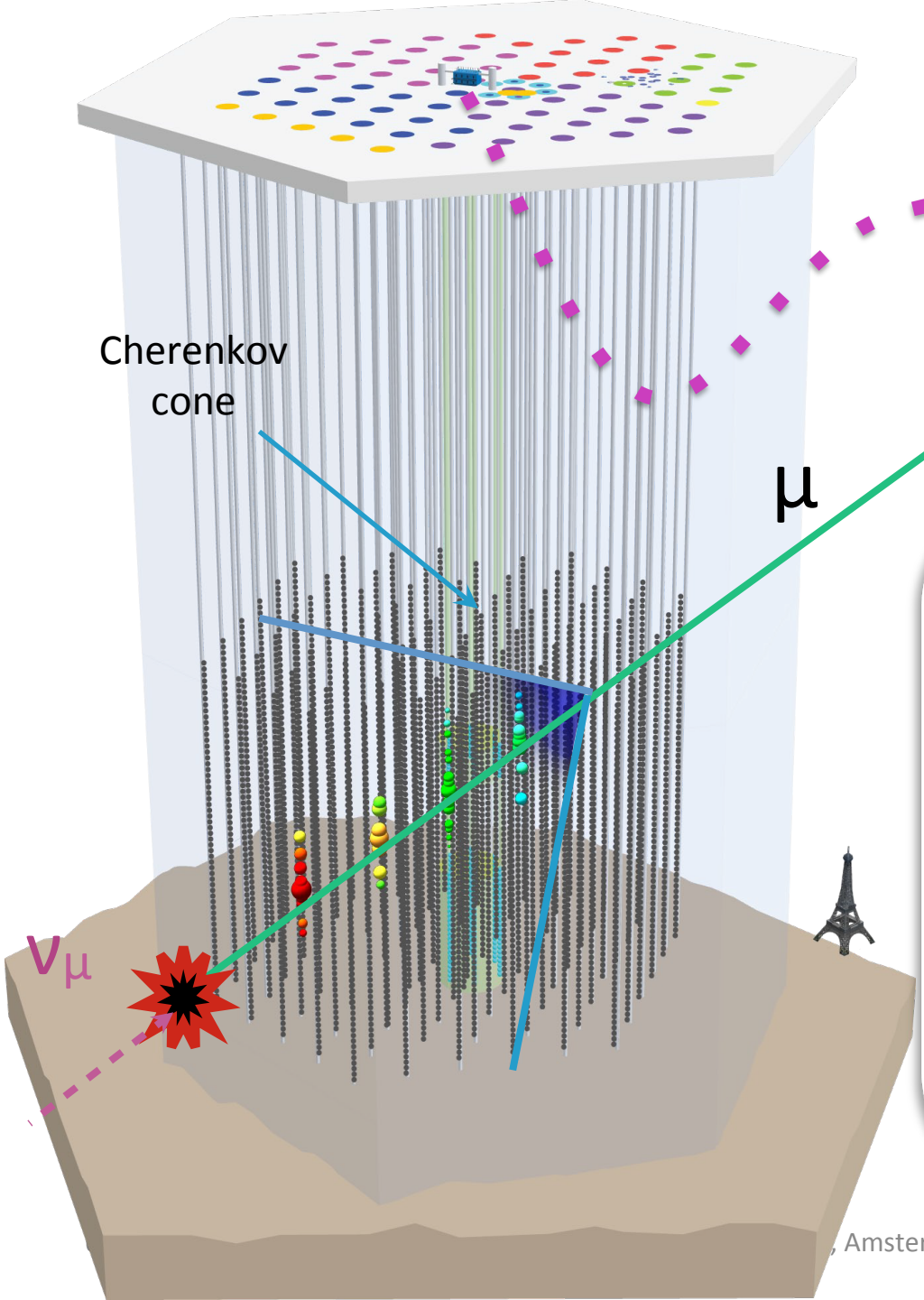
- The IceCube detector
- Neutrinos and Cherenkov light detection
- Current energy scale measurement in IceCube
- Lab setup
  - General goal
  - Description
  - Measurement method
  - Linearity check
- Summary & outlook



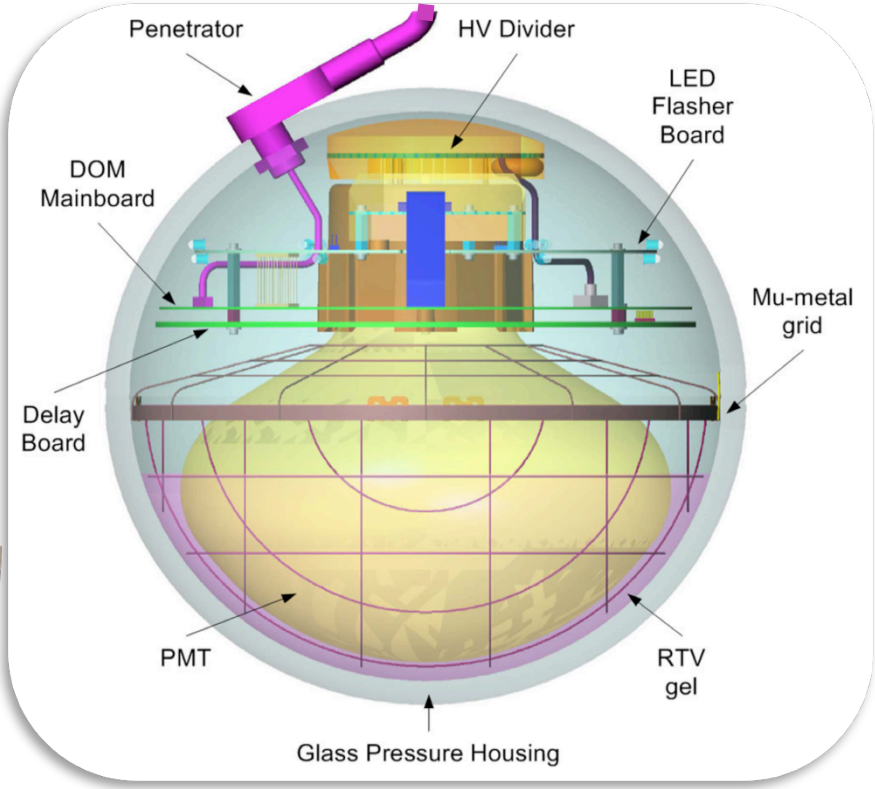
The IceCube neutrino telescope

- 1 km^3 volume
- 86 strings
- 125 m string spacing
- 5160 PMTs
- 17 m vertical spacing between PMTs

Light detection



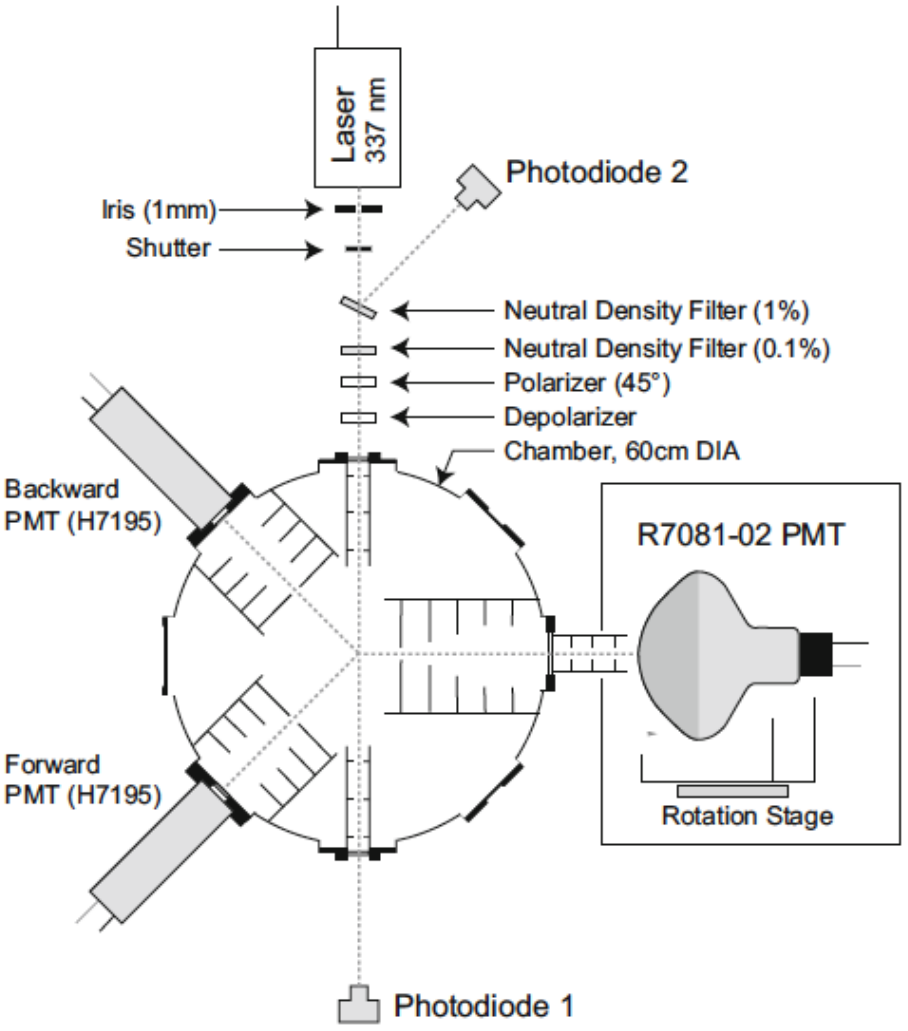
Data to surface



Energy scale calibration in IceCube (lab)

- PMT absolute efficiency calibration measured in lab (Chiba)
- A 337 nm laser emits 4 ns pulses into a ball containing nitrogen; Rayleigh scattered light at 90 degrees illuminates PMT
- Number of photons incident is calculated and measured by PD1, number of photons detected is measured
- 16 PMTs measured @ 25°C, 337 nm, gain 10^8

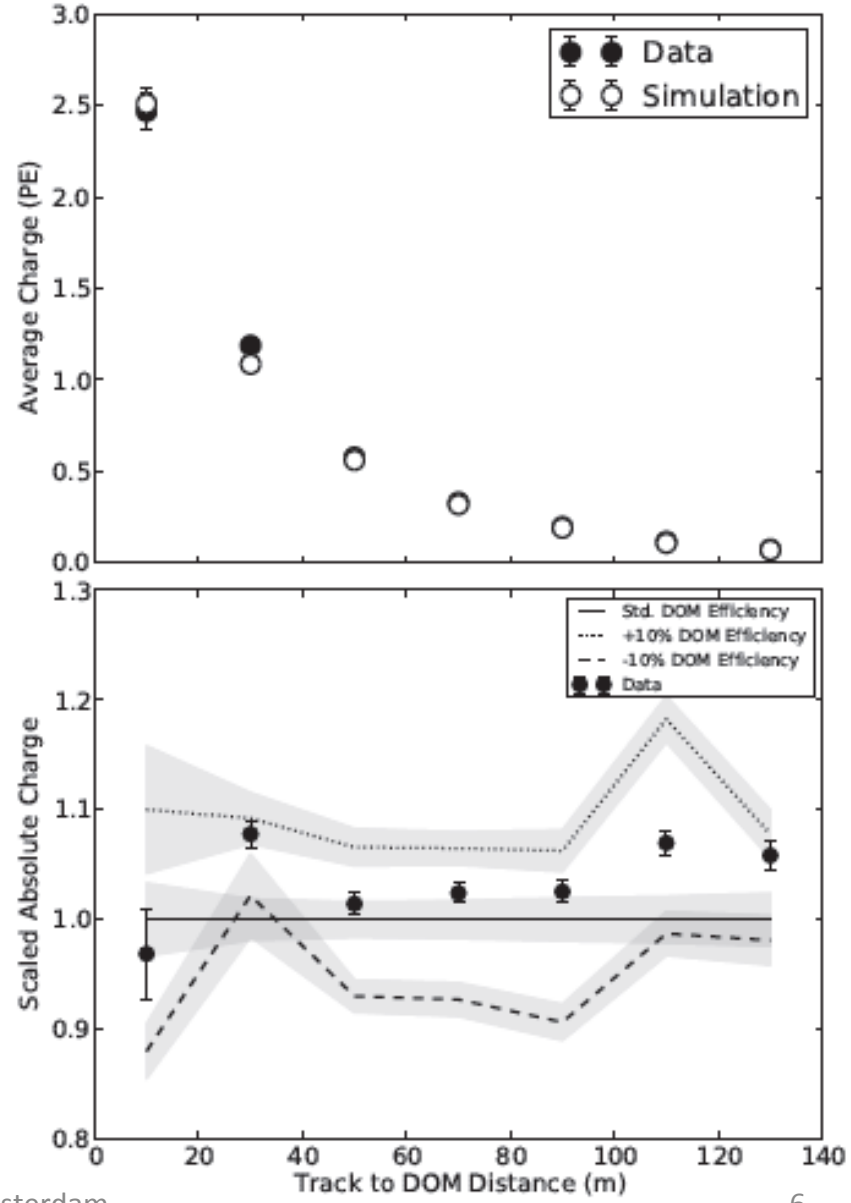
η_{whole} (%) (q_{th}=0.5 q_0)	A_{eff}(cm^2) (q_{th}=0.5 q_0)
≈13%	≈80



Calibration and characterization of the IceCube photomultiplier tube, NIMA 618 (2010) 139–152

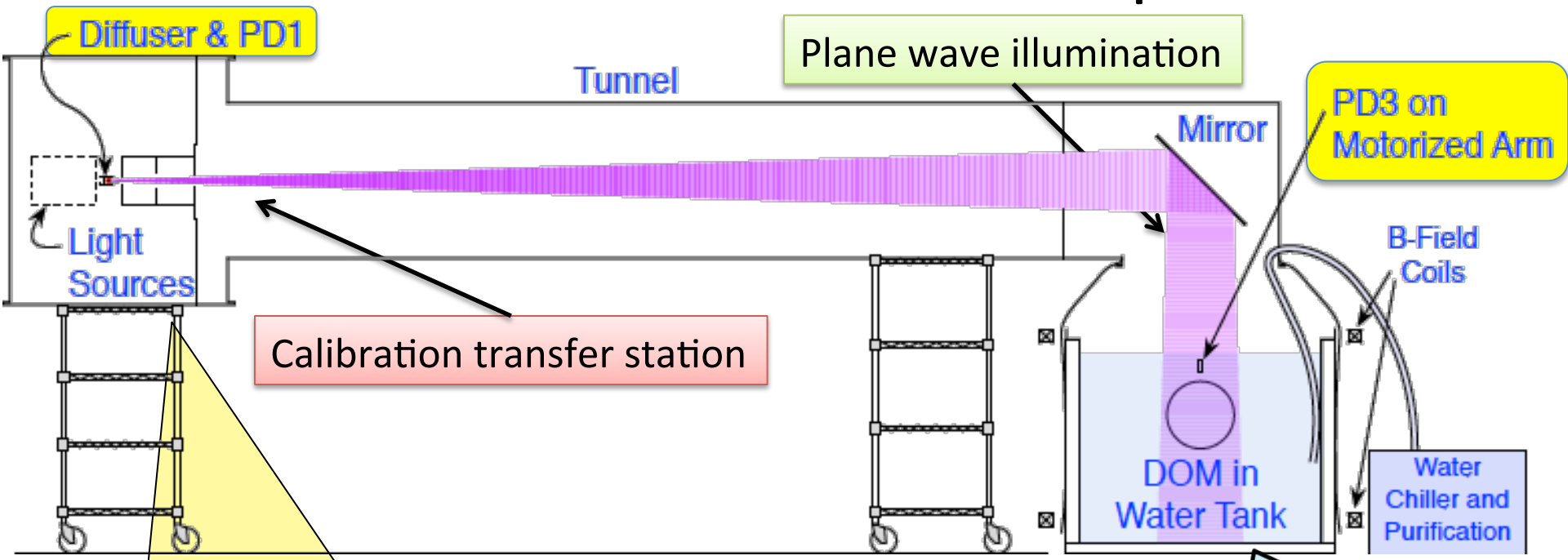
Energy scale calibration in IceCube (in situ)

- In situ verification of calibration done with:
  - in-ice light sources (flashers, standard candles), muons
  - Ice properties are fold in and may be difficult to decouple
- Minimum ionizing muons stopping in the detector
- 70k events in 30 days of IC79, well reconstructed, zenith: 45-70 degrees
- Compare light seen by DOMs in bottom clear ice in data and simulation → 5% excess



Energy Reconstruction Methods in the IceCube Neutrino Telescope, JINST 9 (2014) P03009

Absolute DOM calibration lab setup



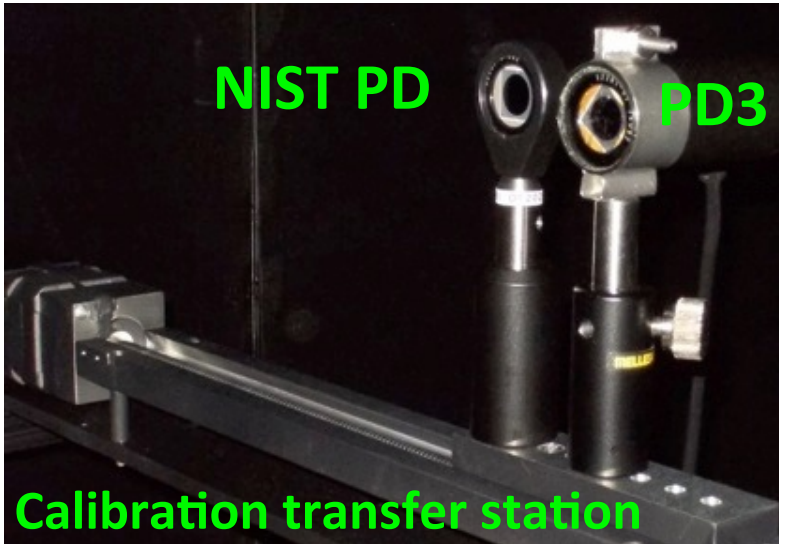
Light sources (steady and pulsed):

- Lamp + monochromator wave selection (320 – 700 nm)
- Laser (405 nm)
- LEDs at λ= 370, 400, 450 nm
- Fast switching LED @ 400 nm

+Filter wheels with attenuators

- DOM rotated with motor
- B field maintained relative to rotated DOM
- Inside tank lined with black fabric to absorb reflected light

Measurement method



- Calibrate PD3 vs NIST photodiode
  - NIST accuracy 0.2% @ 400 nm (Hamamatsu S2281)
- PD3 moved into water near DOM
  - Directly measures photon flux to DOM
    - *Only useful when source is bright*

	PD1 current	PD3 current	DOM rate
Bright for PD3	~ 50 nA	~ 100 fA	Too high
Dim for DOM	~ 500 fA	Too low	100-1000 Hz

- PD1 close to source
  - Good for both bright and dim sources
  - Scales with PD3, extends photon flux measurement to low brightness
- Measure DOM rate, obtain photon flux from PD1 current

➡ *Measure PD3/PD1 scale factor with source bright*

- Flux = 0.0226 photons/cm^2/sec * (PD1 current / fA)

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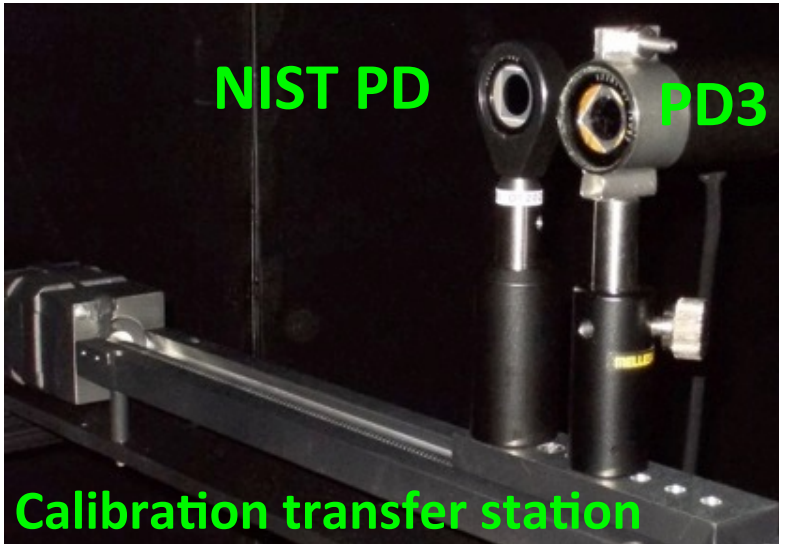

	PD1 current	PD3 current	DOM rate
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➡ *PD1 linearity crucial*

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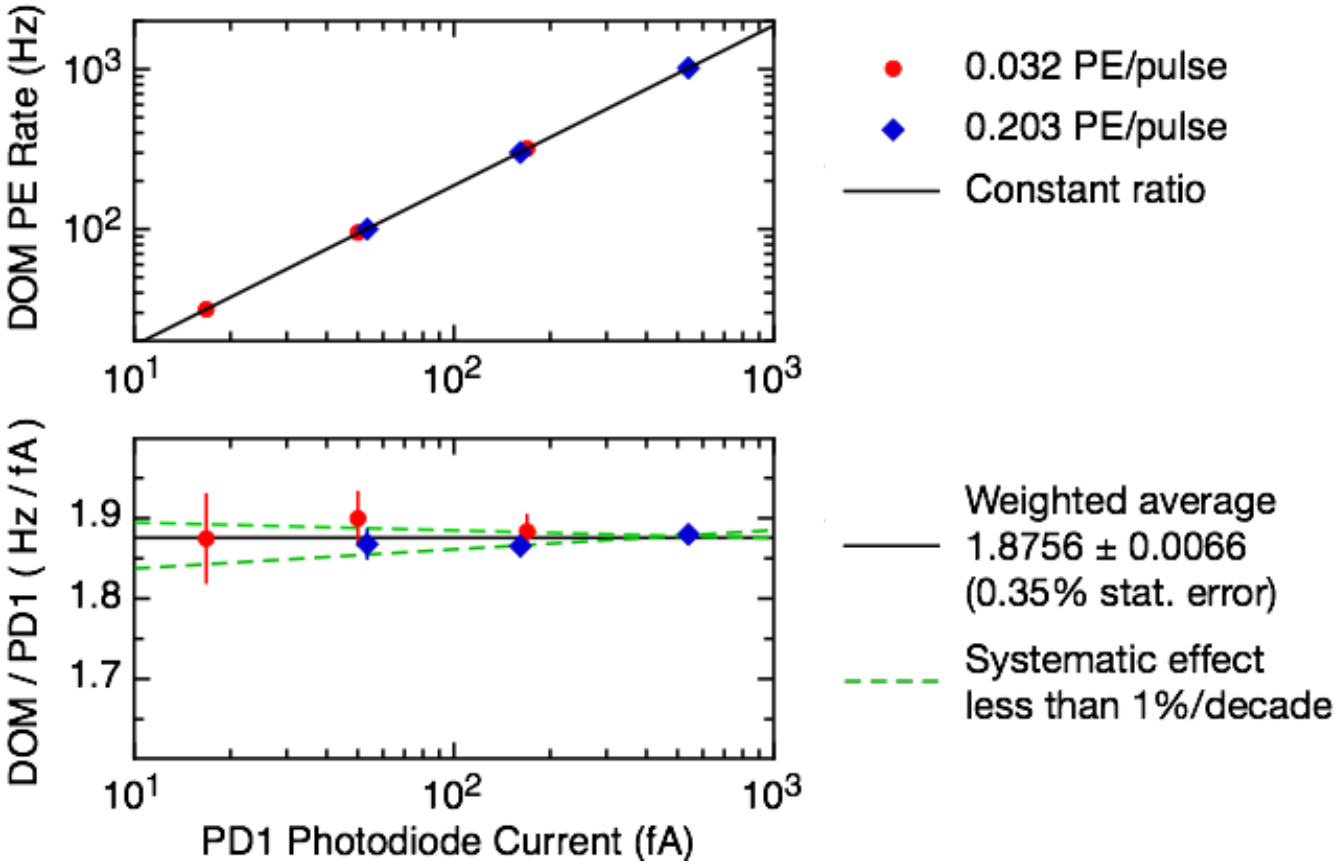
Data sample from DOM (data taken in air)



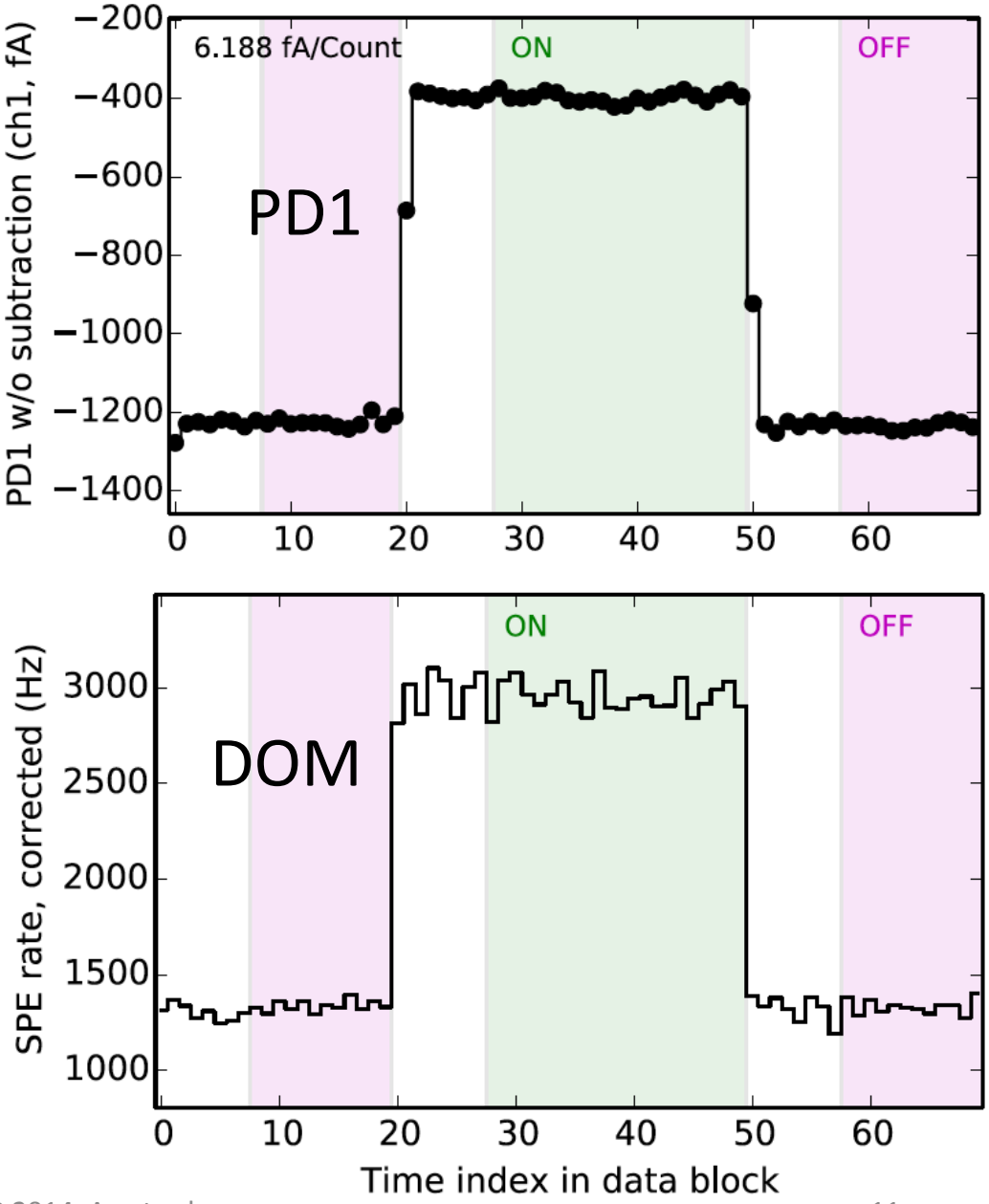
Example calculation

$$\frac{\text{DOM PE Rate}}{\text{PD1 Current}} \Rightarrow \text{DOM efficiency}$$

- Flux = 0.0226 photons/cm^2/sec * (PD1 current / fA)
- DOM rate = 1.88 Hz * (PD1 current / fA)
- DOM rate / flux = (1.88/0.0226) = 83 cm^2 counts / photon

Example of signal of PD1 and DOM

- Remove transients
- Average during “on” time and subtract baseline (average in “off” time)
- Very low noise



Photodiodes/readout linearity

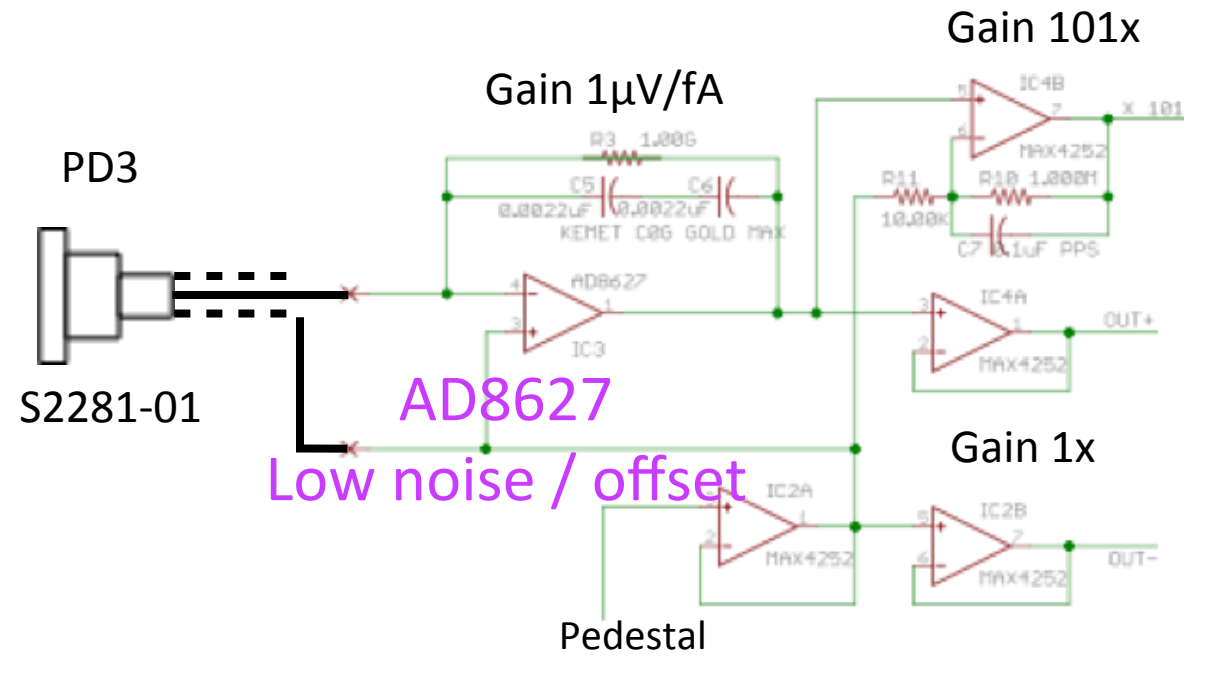
- The DOM measurement is done at much lower light level than directly measured with PD3

- We measure this change in flux using PD1, so we need to be sure this PD & readout is linear over many orders of magnitude

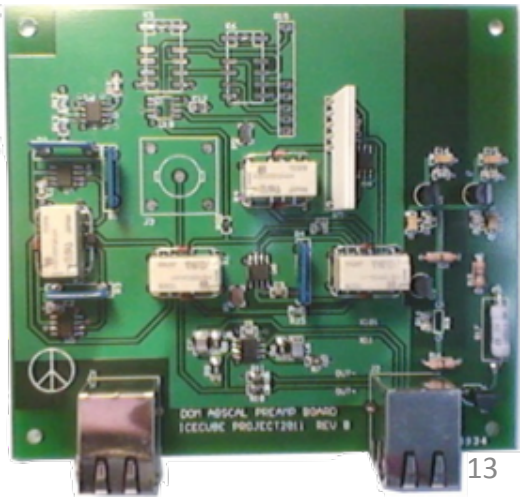
- Even the bright flux at PD3 is much dimmer than used for NIST PD calibration

→ Need to measure linearity of photodiodes and amplification chain at multiple light levels.

Photodiode amplification circuit



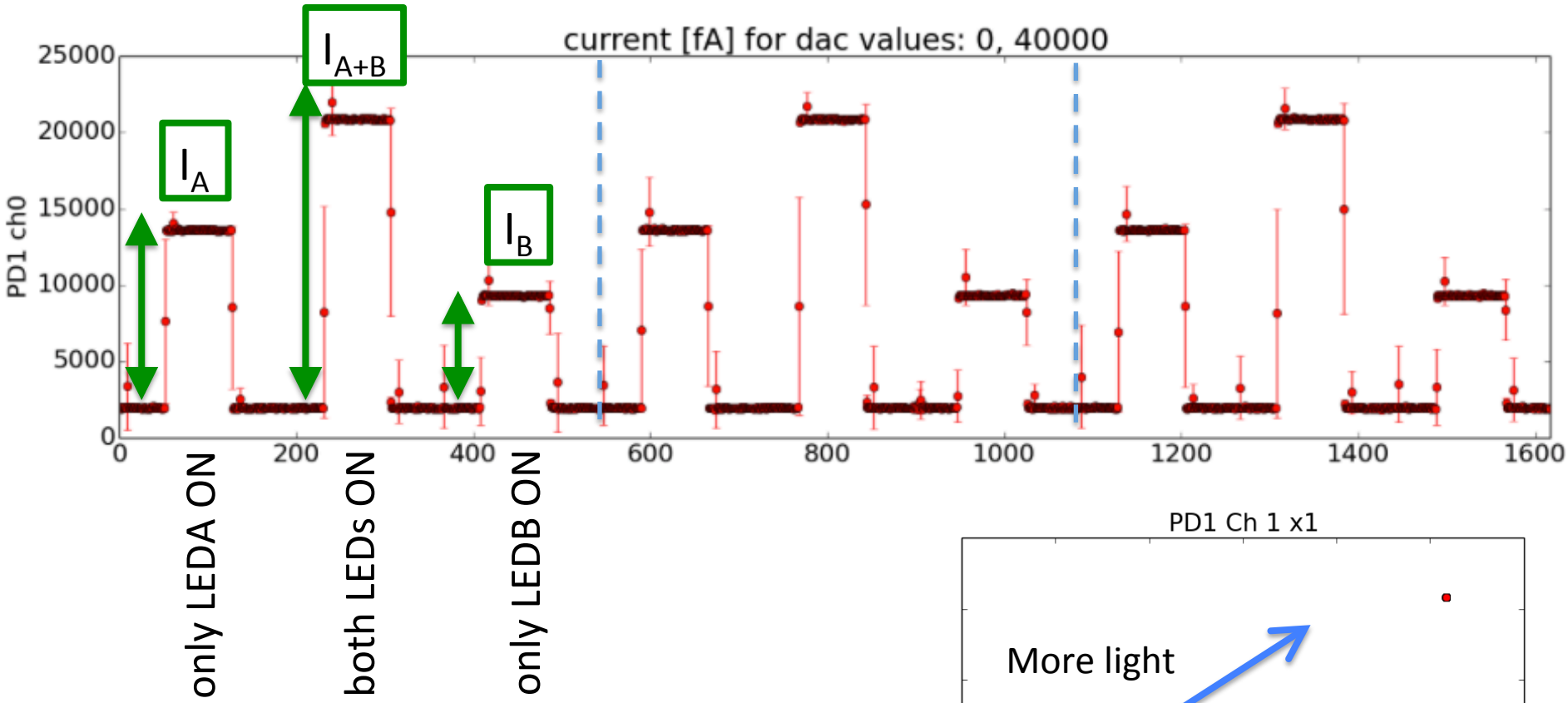
16 bit ADCs
ADS1110
LSB=8—63µV

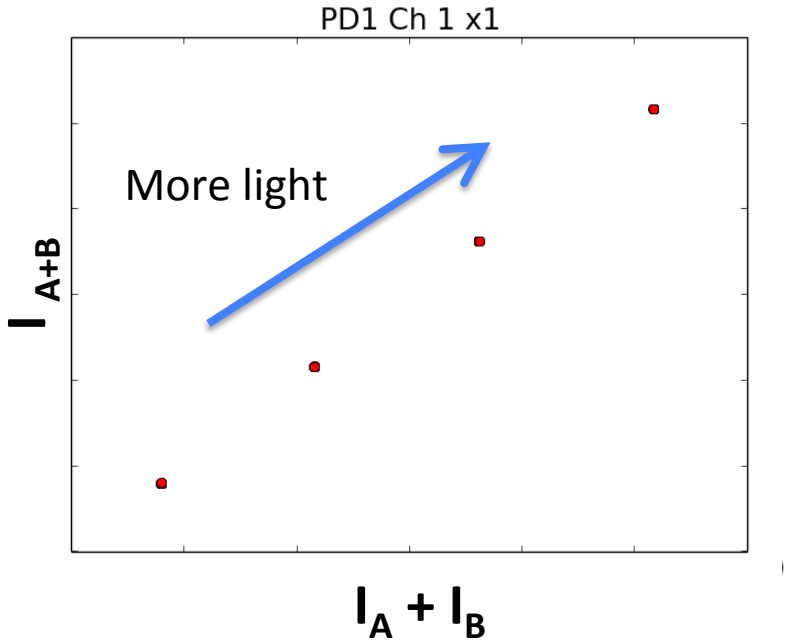


PD1 circuit similar

- 6 gains available, selected by relays (Panasonic ASX220A4H)
  10µV/nA, 100µV/nA, 1µV/pA, ... , 1µV/fA

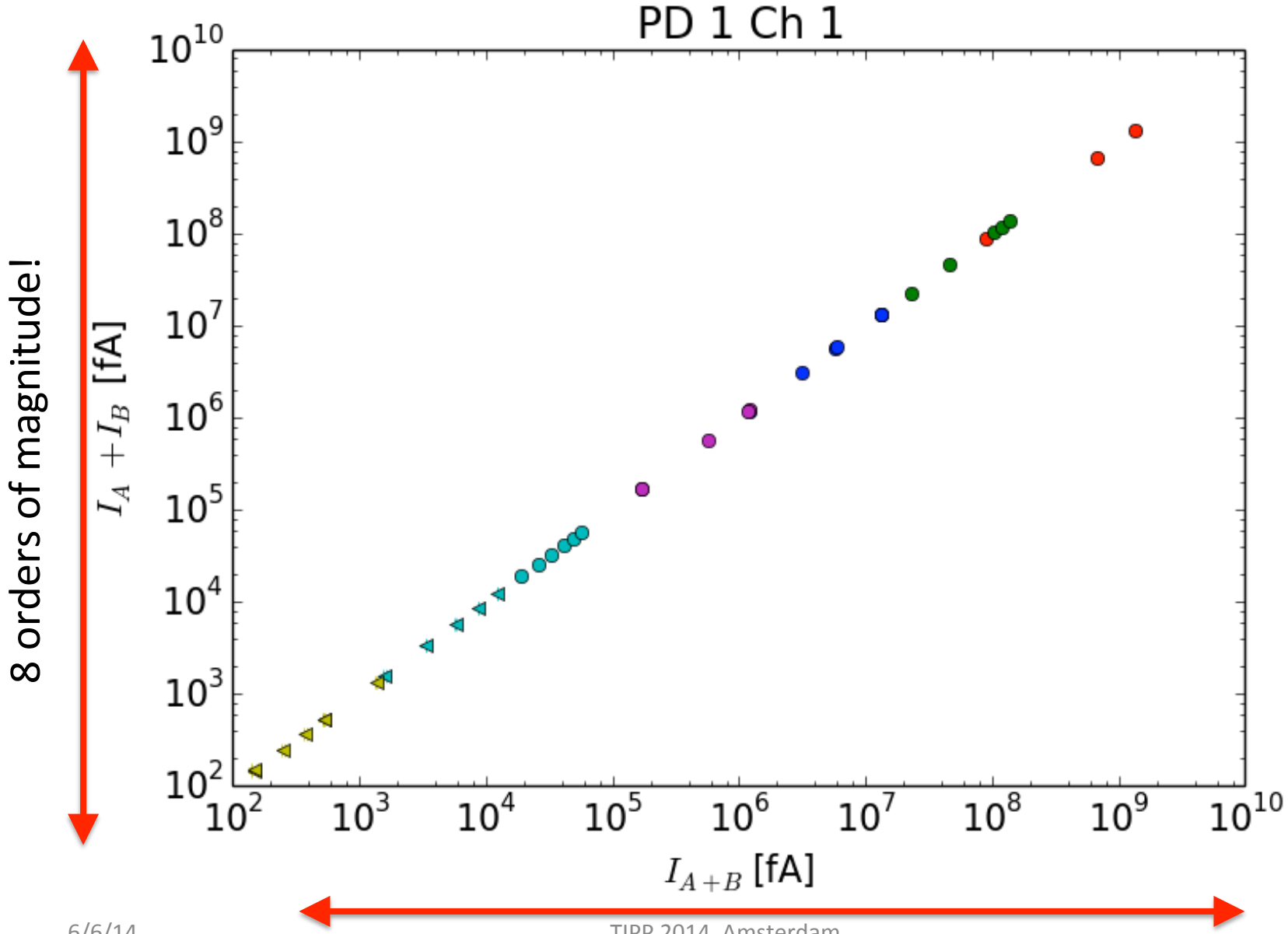
Linearity measurement method



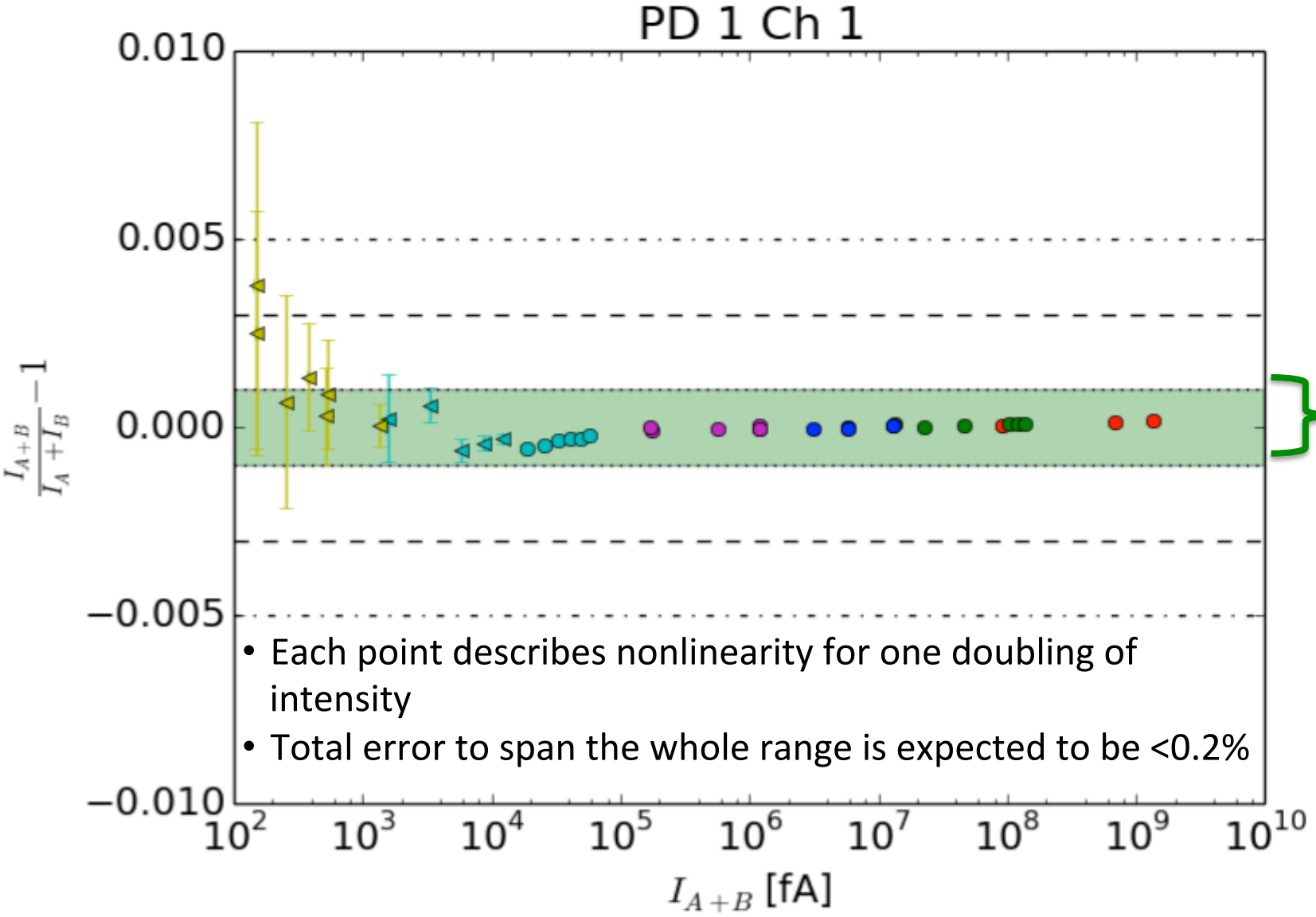


- For every cycle, measure $I_A + I_B$, I_{A+B} and calculate mean ratio
- Repeat for several light levels
- Adjust for amplification as needed

Linearity summary



Linearity summary

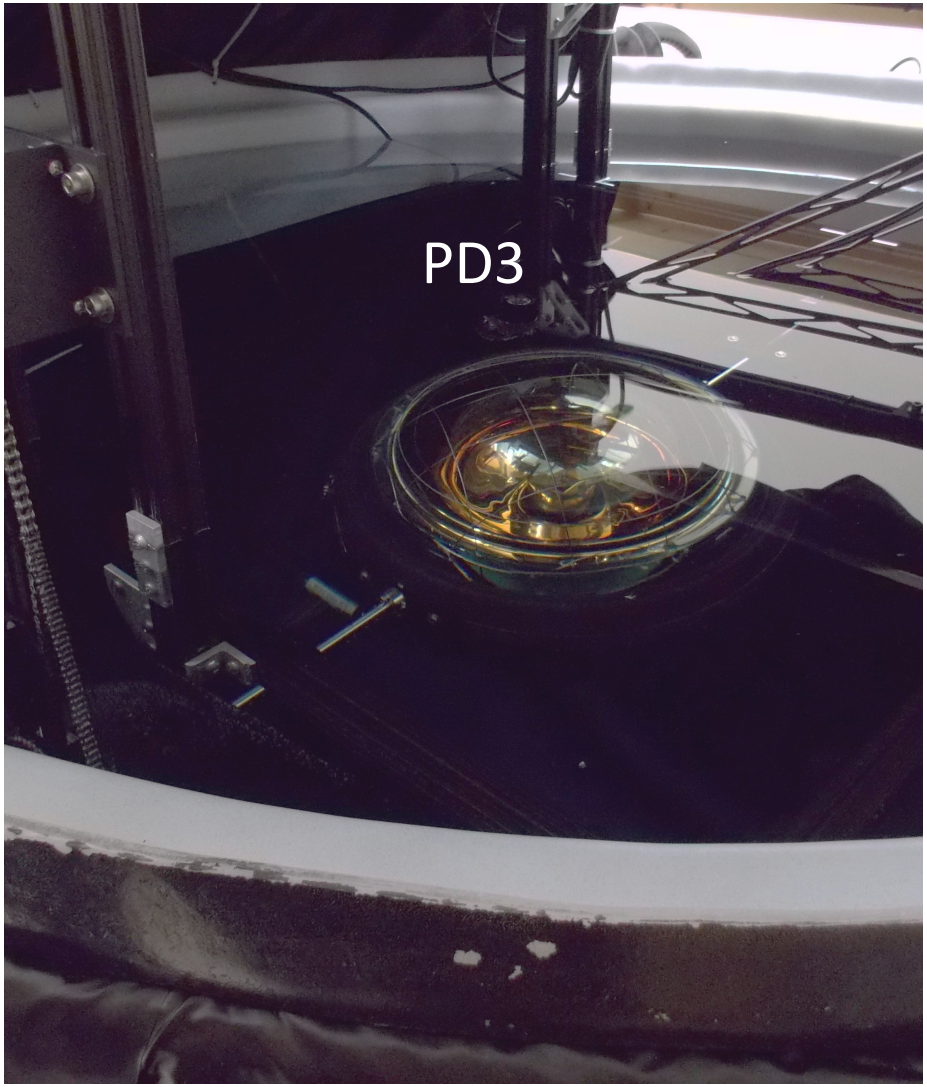


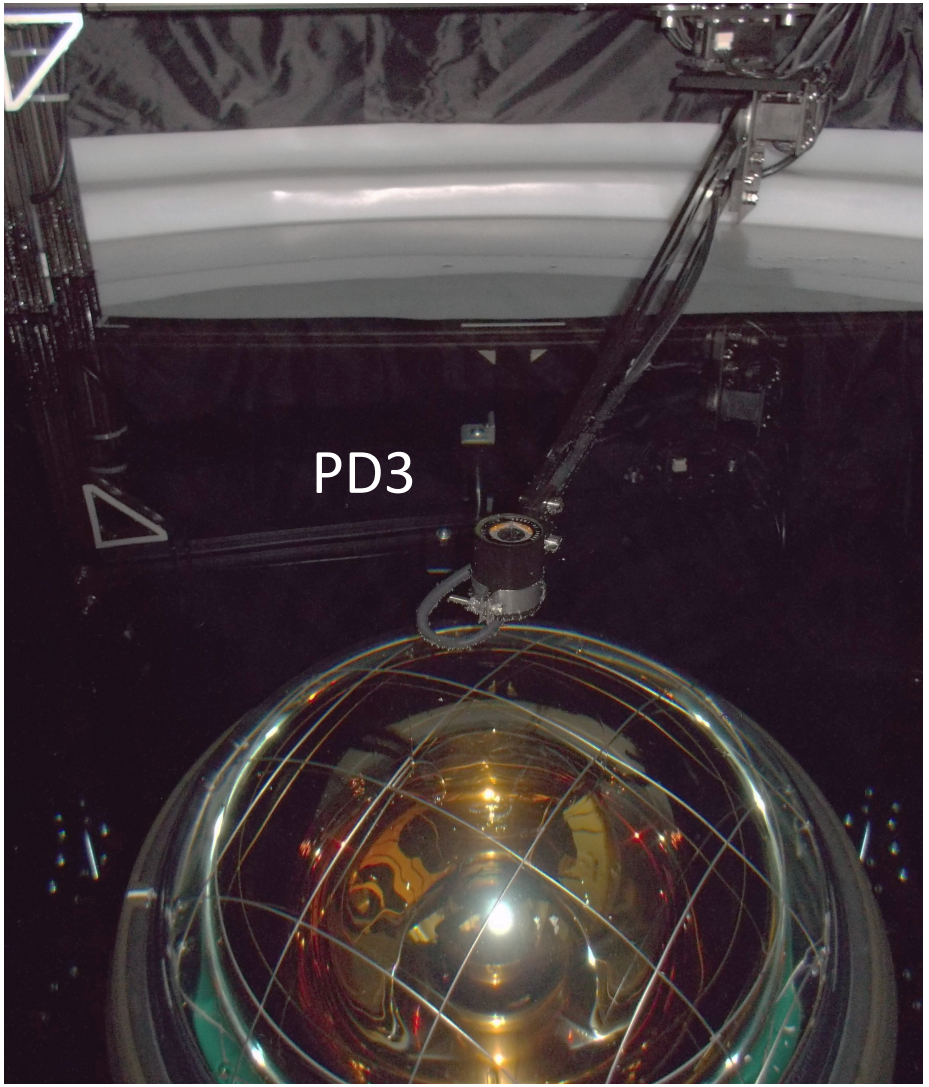
Summary

- Absolute DOM calibration lab setup has been now developed to measure the DOM optical sensitivity as a function of angle and wavelength, in temperature controlled purified water, with several light sources available.

- Strategy: calibrate 10 to 20 of 100 leftover DOMs (time estimate: <1 week/DOM)
- Relative sensitivity of all DOMs deployed is known, so we could correct for it

- Proof of understanding and tool for future development (calibrated sensors in new detectors like PINGU, or HAWC)


PD3


PD3