HYPER-KAMIOKANDE

OUTER DETECTOR

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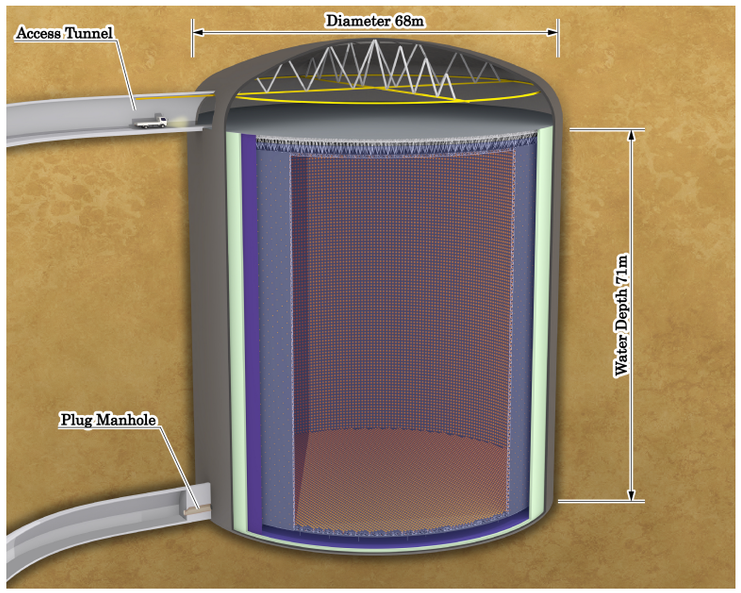
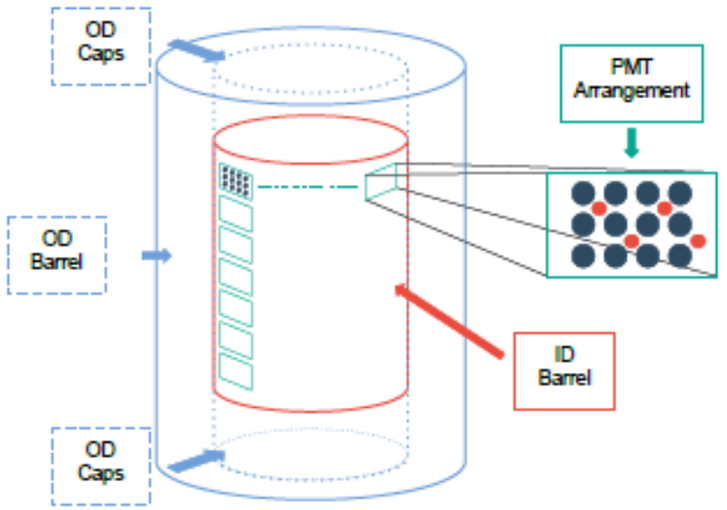
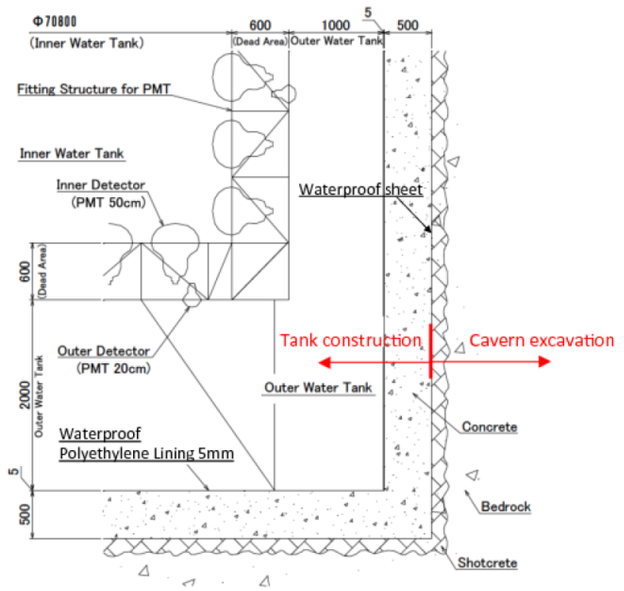
HYPER-K OUTER DETECTOR

- Nominal design based on Super-K Outer-detector
  - 6700 20cms (8”) PMTs facing outward
  - → 1% coverage
  - OD Water thickness : 1m barrel / 2m top and bottom



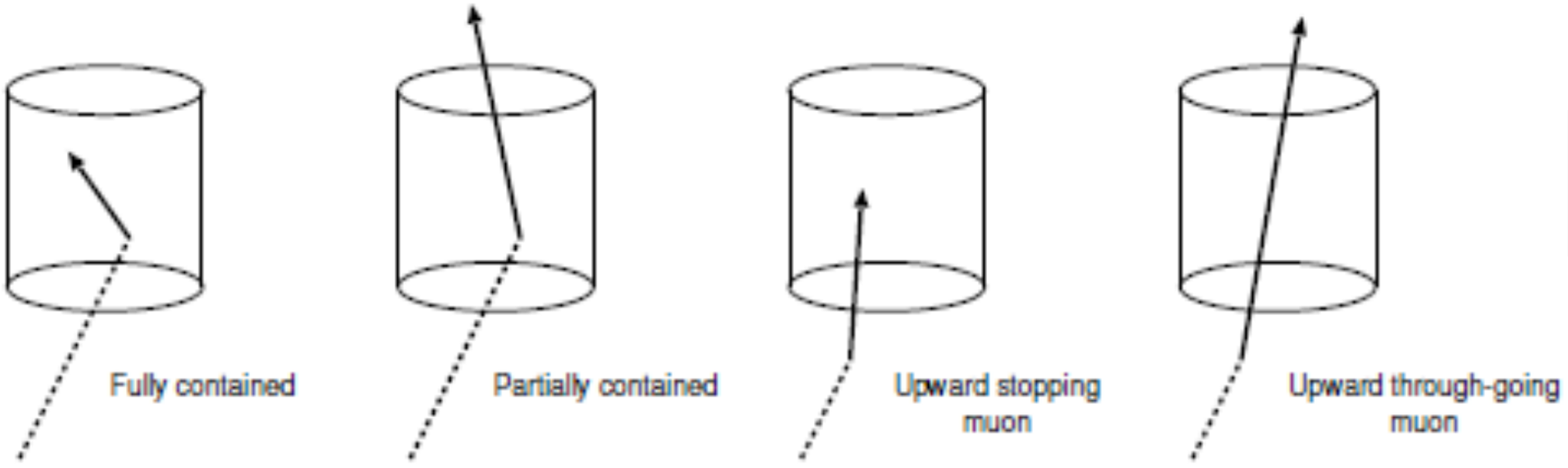




- Proposed design for improved performance
  - ~ **[13.3k, 18k] 3 or 3.5”** PMTs facing outward
  - → [0.28%, 0.42%] coverage
  - OD Water thickness : **1.5m barrel** / 2m top and bottom

PHYSICS REQUIREMENTS

- The outer-detector is a **veto** for background particles
  - Classify Fully Contained (FC), Partially Contained (PC), and Upward-going muons (UPMU)



ATMnu analysis

  - Shield from **gamma** particles

- OD hits information are use in a “binomial way”
  - We want to know if they are clusters of hits → Number of PE matters less

PHYSICS REQUIREMENTS

- The outer-detector is a veto for background particles, based on PMT triggers hits clusters above threshold
- Using Super-K experience, we can study the minimum #PMTs required to classify events
- Increasing number of PMTs linearly increase the amount of information

Increase # of PMTs

- In order to make the system to work, we need to set a system with efficient trigger

Good light collection

Low dark rates for low PE threshold

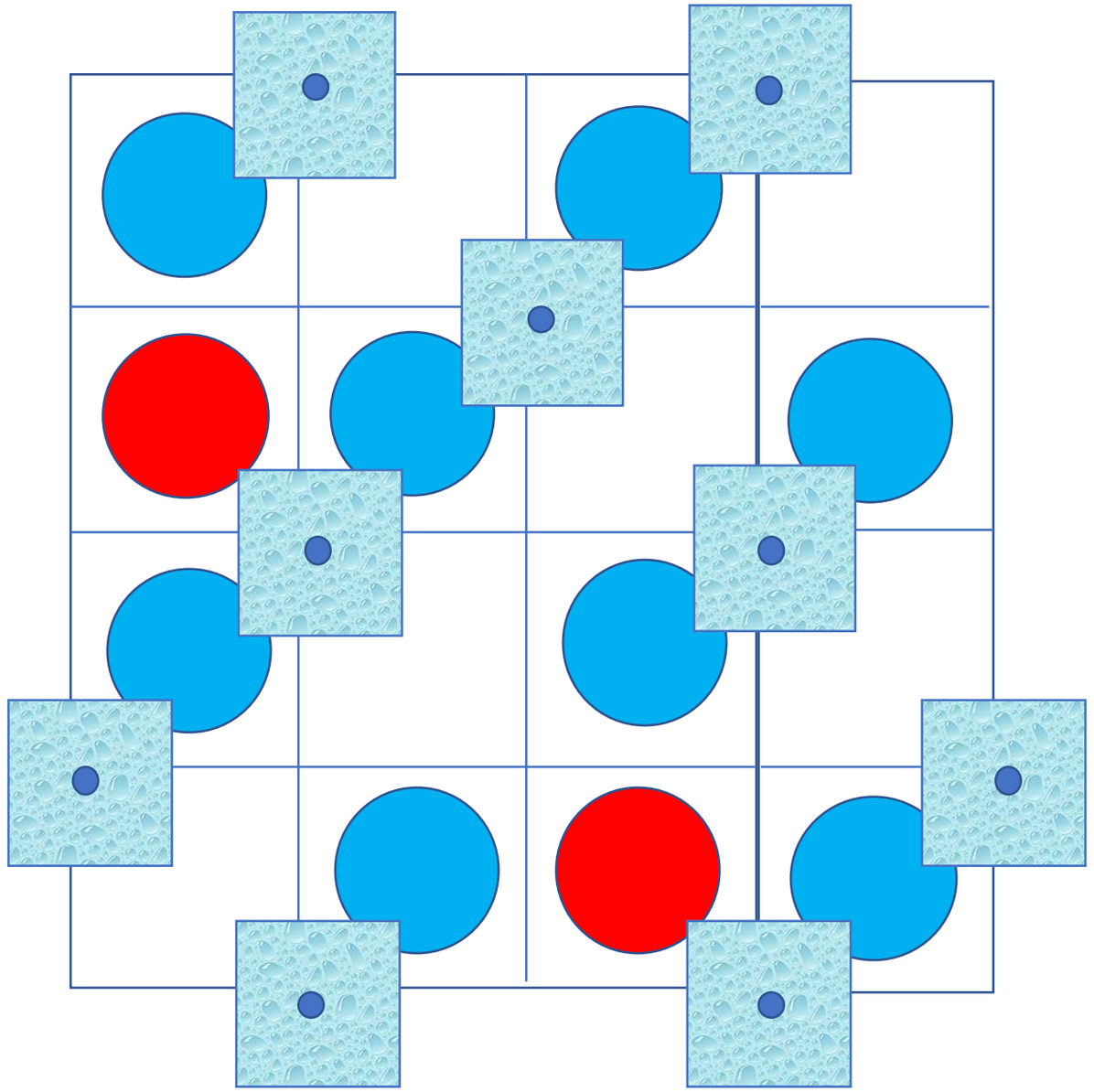
OD DESIGN WITH WLS PLATES

OD 3” PMTs (13.3k)

WLS plates (50x50cm)

ID 20” PMTs (20k)

ID mPMTs (5k)



PMT CANDIDATES FOR THE OD

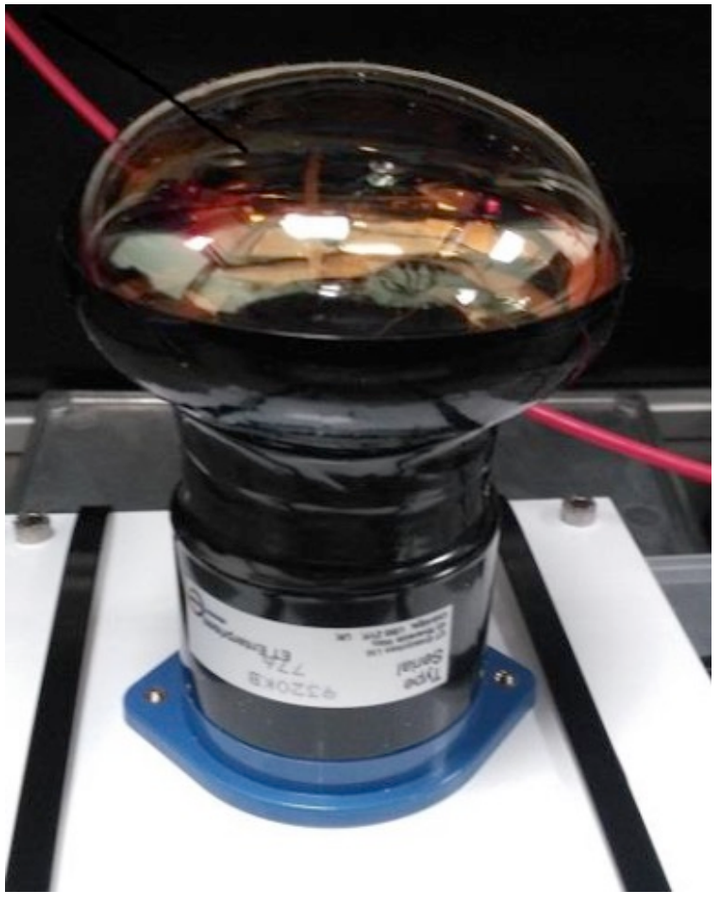
Hamamatsu 3” and 3.5”

- R14374(HA) **3”**
- R14689(HA) **3.5”**

HZC XP82B20

Cheap

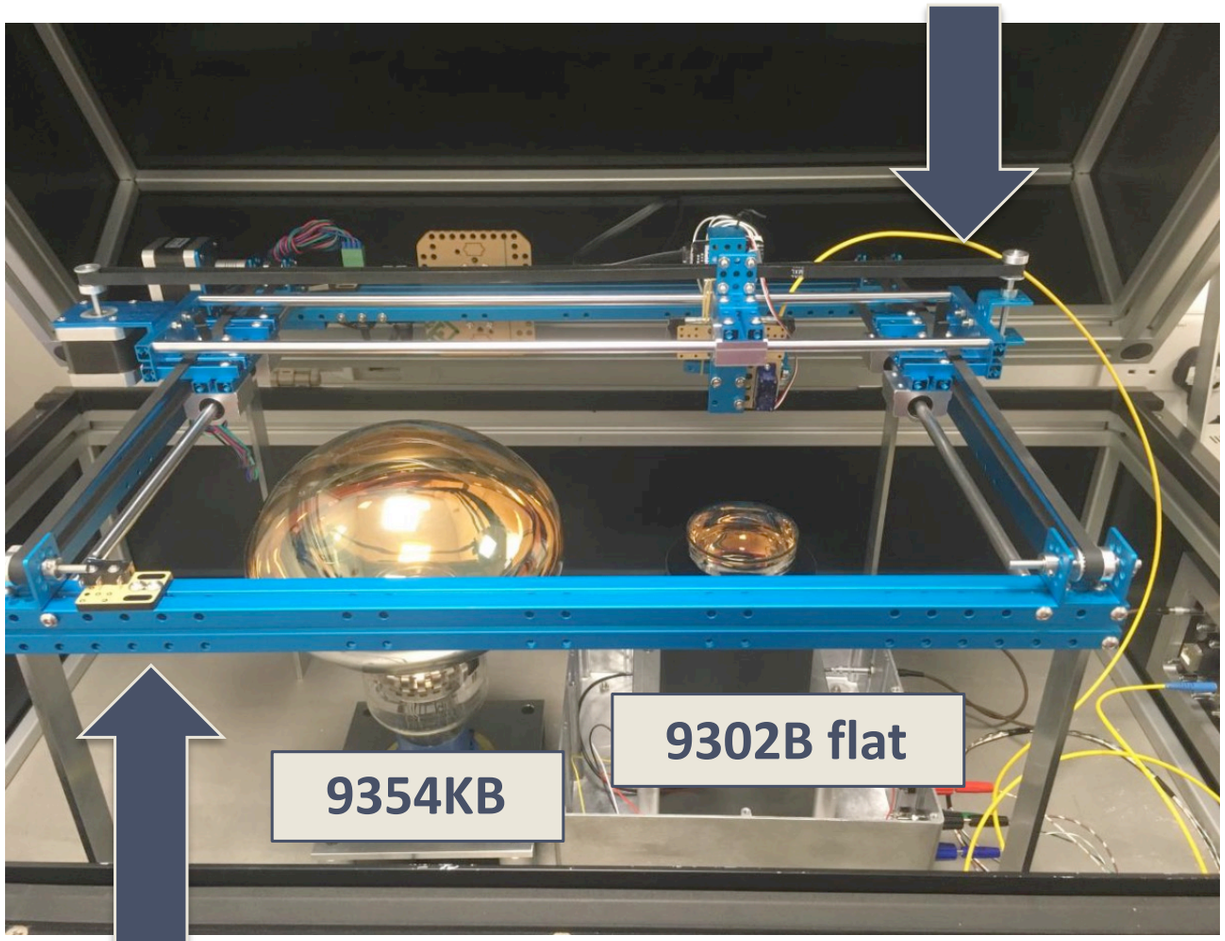
ETEL 9302KFL



Well known

SETUP AT QMUL (=> KCL)

- PMT connected to HV siting outside of the dark box with panel wires
- Positive HV
- Measurements taken after a few hours with HV ON
- Dark rates measurements taken **24h** after HV ON
- 400 nm LED
- From single photon to few thousands characterization

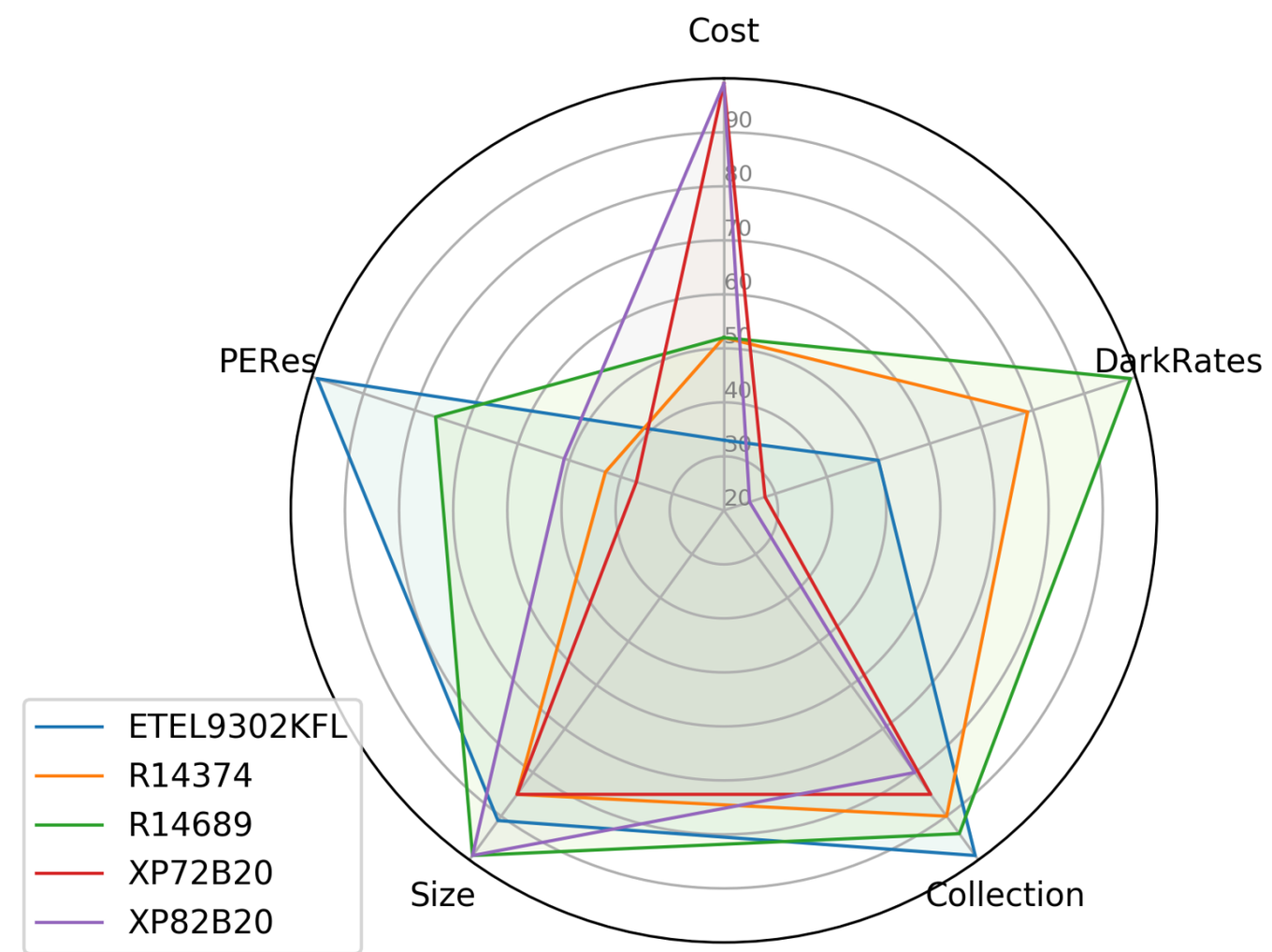


Caen SP5601 Led Driver
with a OSSV5111A High Power LED

OD PMTS CANDIDATES PRELIMINARY SUMMARY

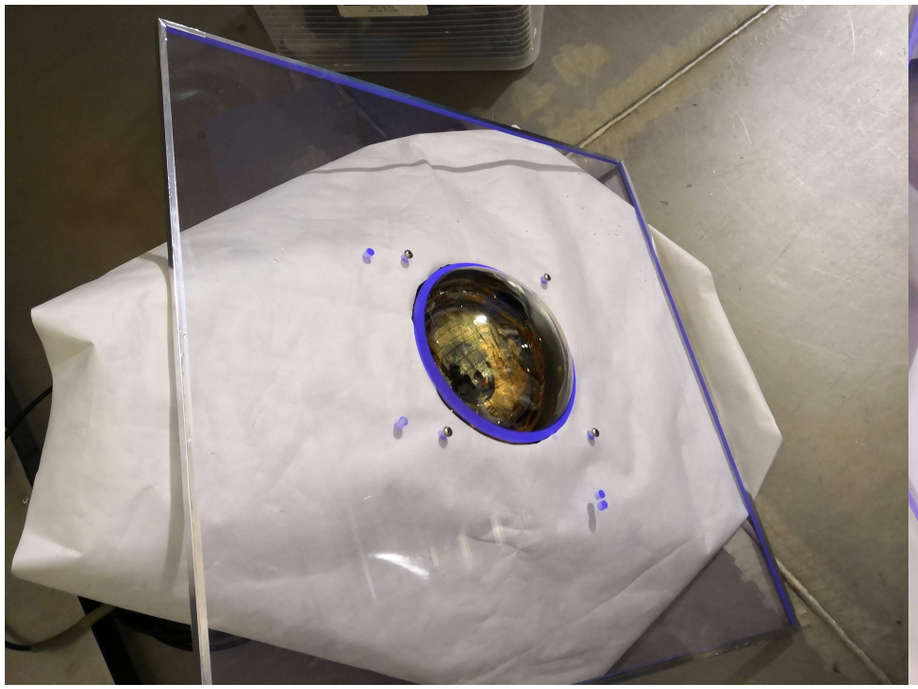
Estimates 5 key parameters estimate the best OD PMT candidate

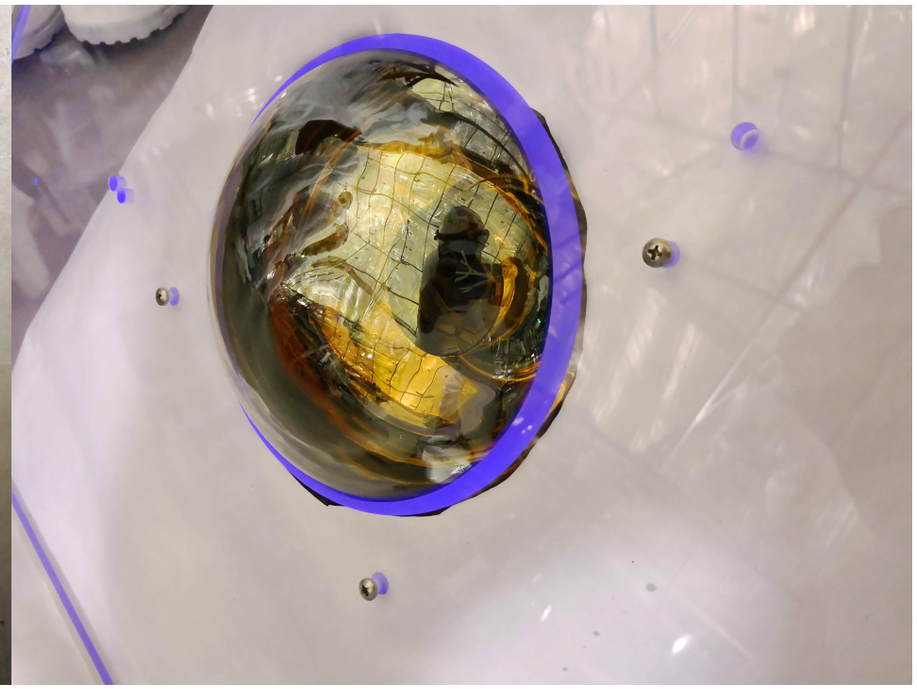
- Cost: PMT + Socket
- PERes: Photoelectron resolution defines as σ/μ
- Size: Photocathode size Collection: Relative QE from ETEL9302KFL
- DarkRates: Dark counts after 24h warming up at 20C



Best PMT = Max Score

LIGHT COLLECTION ENHANCEMENT SYSTEM



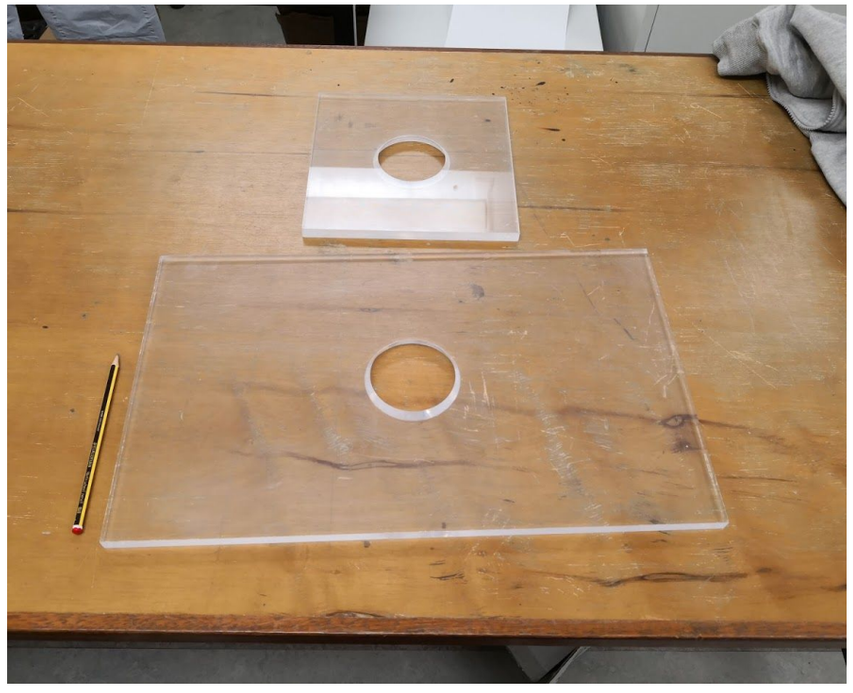


Super-Kamiokande

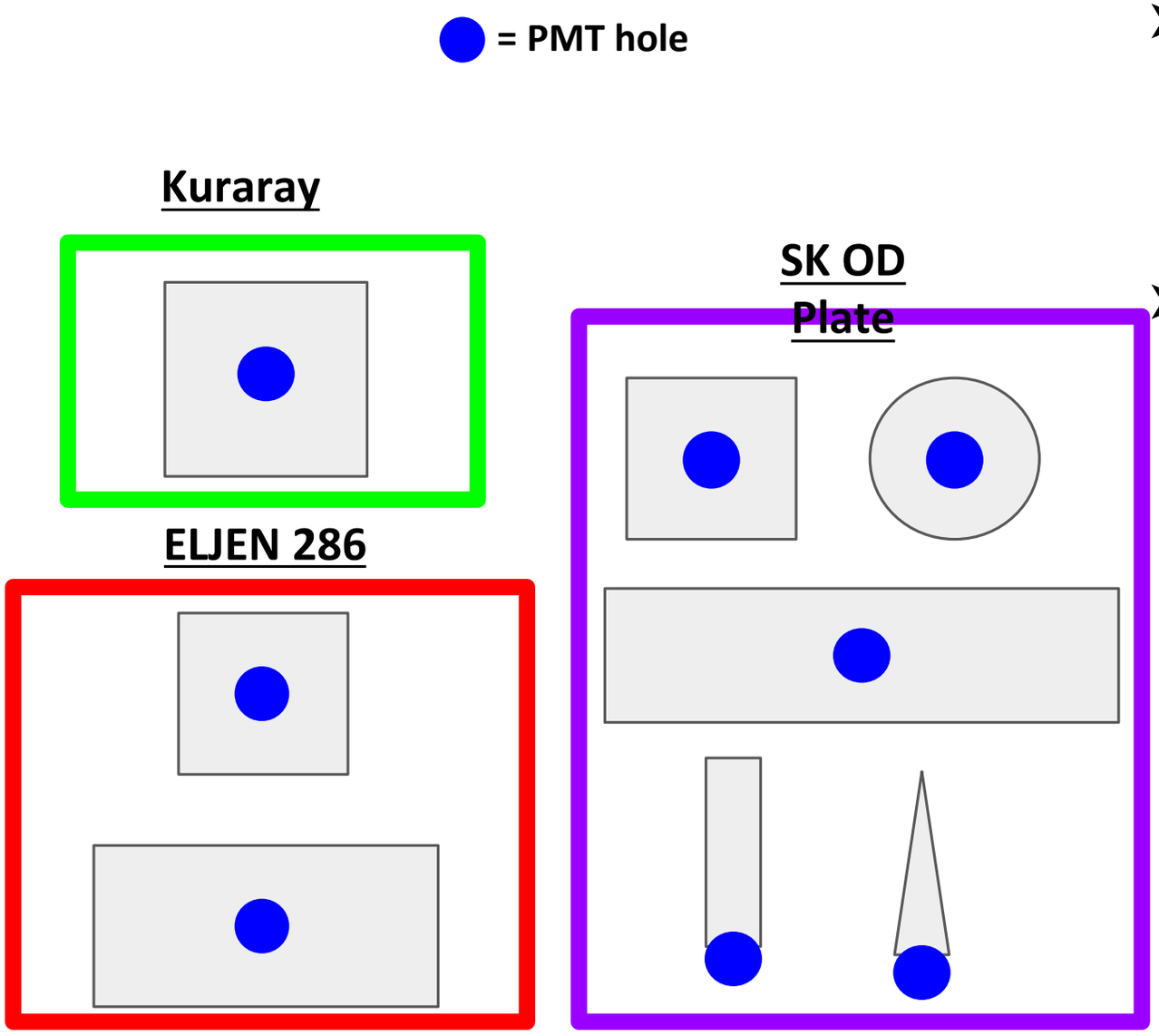
- 8” PMTs
- 60x60cm WLS plates

- Use wavelength shifting (WLS) plates to trap and reemit the light towards PMT
- We have acquired plates from three different sources:

  Eljen 286 Kuraray B2&B3 Super-K
- They have been machined into various different shapes and sizeswith holes in the centre to close fit to the ETEL PMT



ACQUIRED NEW PLATES



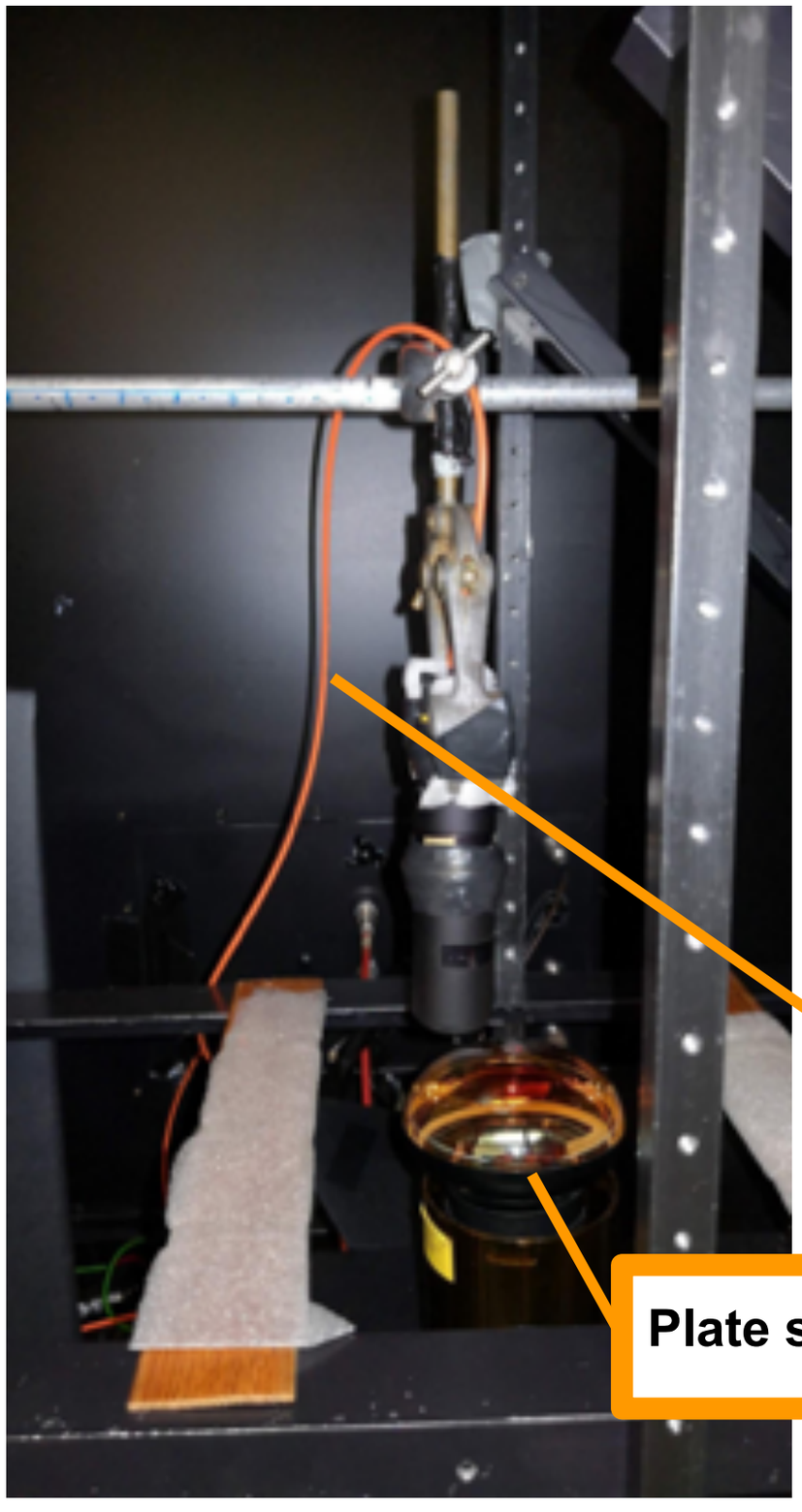
- Compare ELJEN, Super-K and Kuraray square plates to see which dopant is the most effective.
- Compare the various Super-K plates to determine which plate shape is the most effective.

Will measure the efficiency and the time spread of the plates (vs distance from the PMT)

Once the plates have been fully characterised they can be implemented into WCSim.

Default: EJ-286 50 cm plate per PMT
Other companies/sizes being considered

SETUP MEASUREMENT



- 3“ PMT (9320KFLB) and Wavelength Shifter Plate (WLS – EJ286)
- UV LED @ 375 nm
- Neutral Density filter @ 2.0
- A pulser provides signal to the UV LED with rate: ~ 10 kHz
- A fibre is used to guide the LED signal to the PMT.

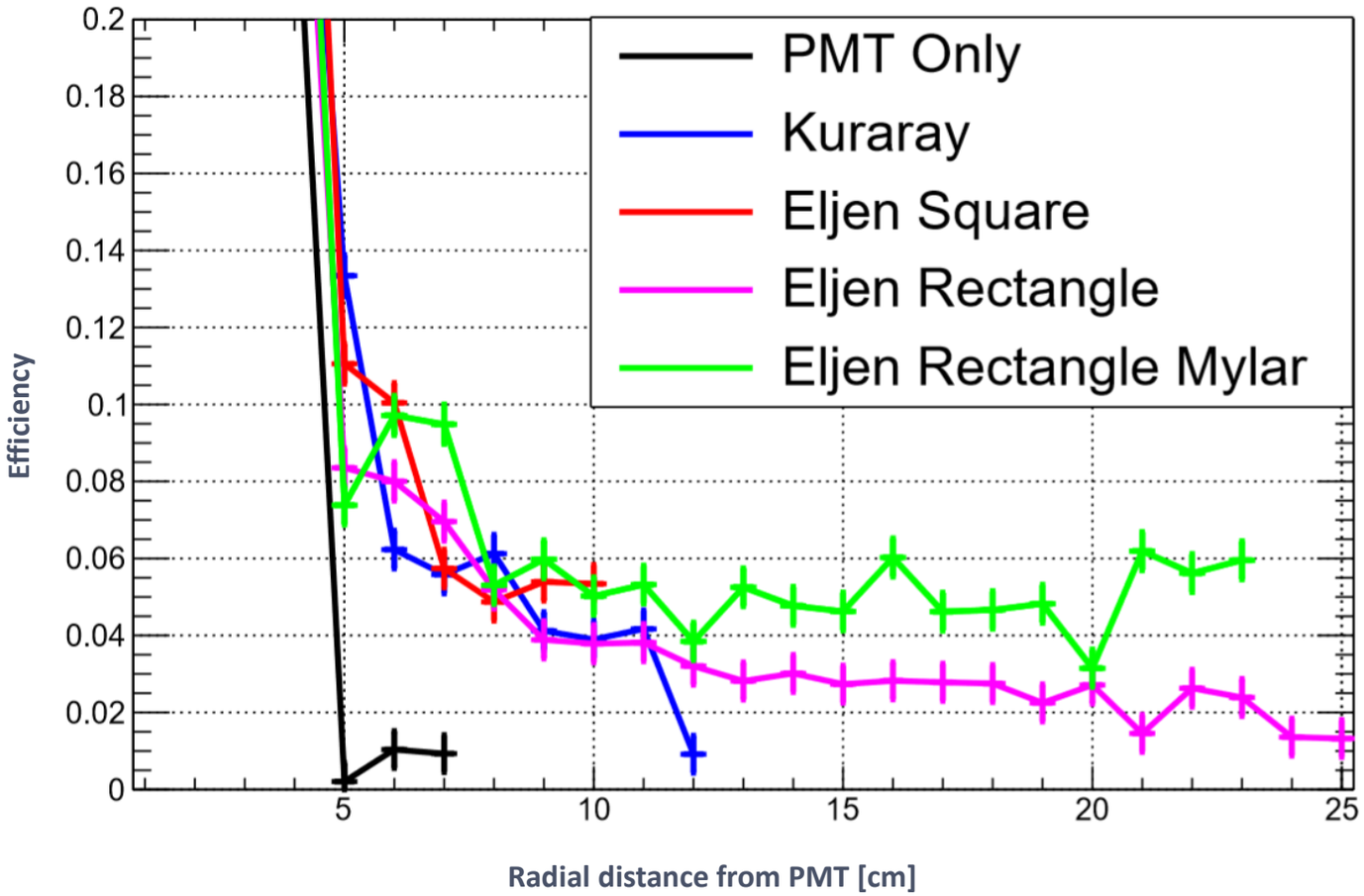
Study efficiency

- Light collected by the PMT with/wo the WLS plates
  - Ref: No WLS plate / LED centered above PMT
  - Insert WLS plate and then move LED from PMT center

$$\text{eff} = \frac{WLS_X - Bckg}{PMT_0 - Bckg}$$

LIGHT COLLECTION ENHANCEMENT FACTOR

- Use measurements in lab to evaluate enhancement factor in Hyper-K OD
- Efficiency is measured as a function of position with a 375nm UV LED
- Reflective mylar coating of edges of plate gains a factor of x2



Data fit (24x24cm)

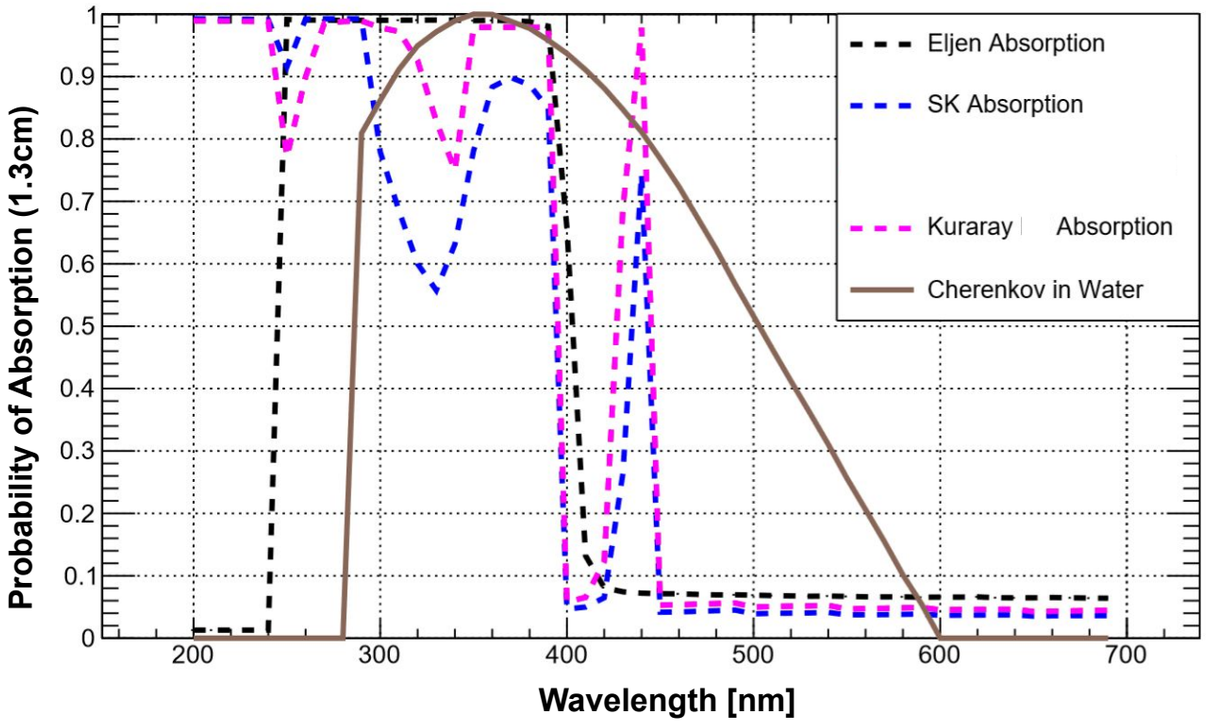
Extrapolate to 50x50cm

Convolute
- PMT QE
- WLS abs + em
- Cerenkov
- Water trans.
- Light trap factor (n)

Kuraray: 1.95x

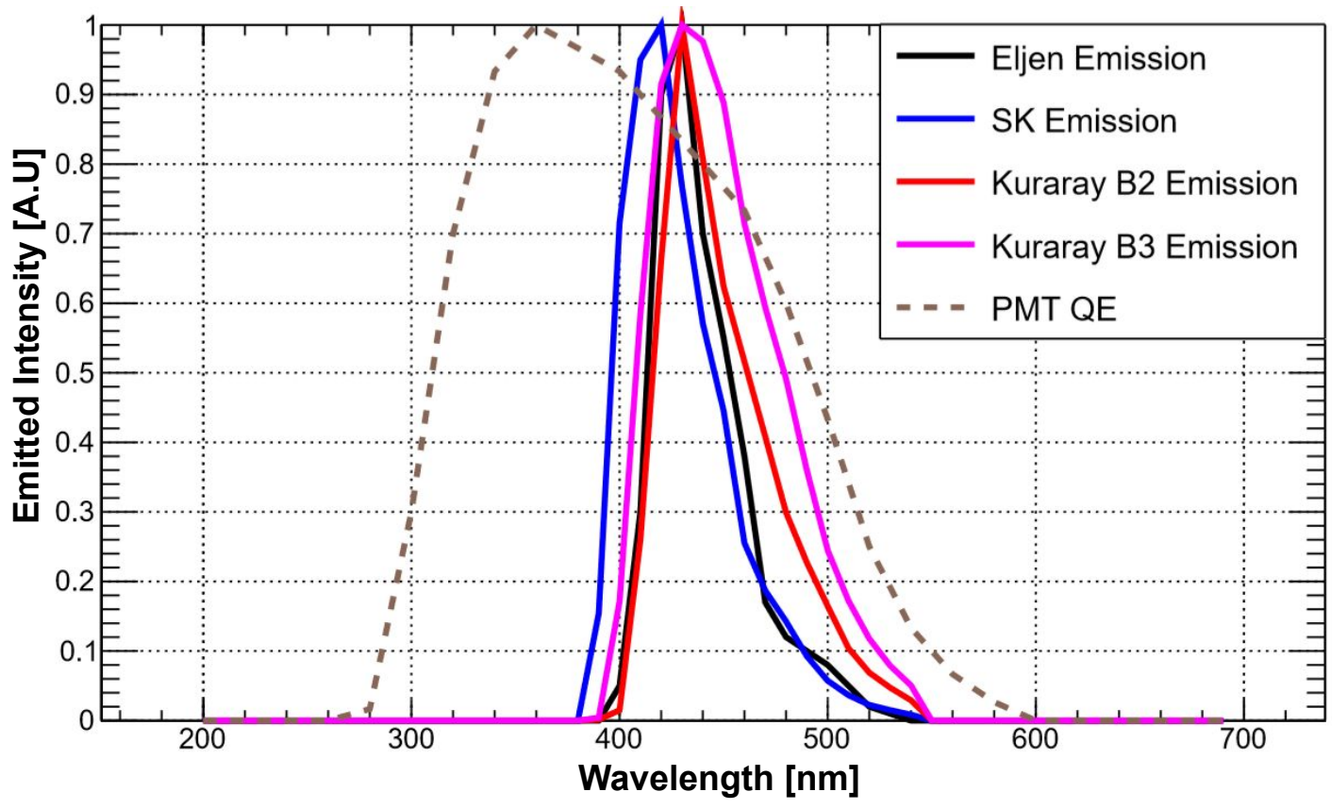
Eljen: 2.36x

ABSORPTION AND EMISSION SPECTRA

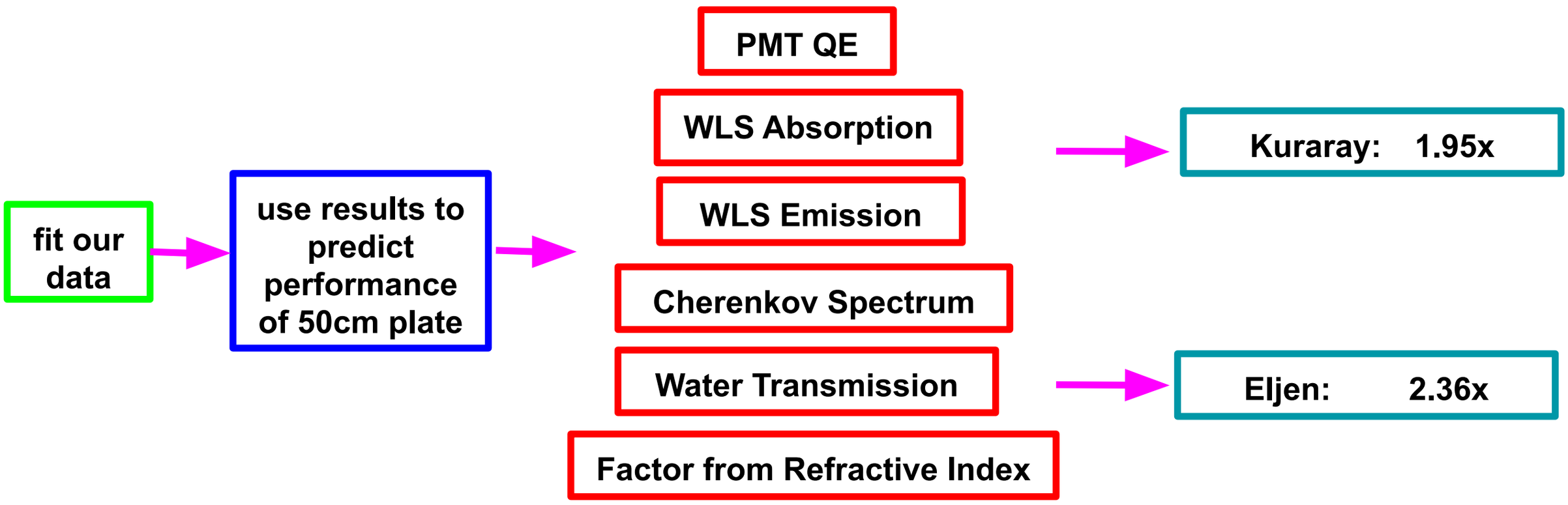


- These are been measured by us
- Eljen has best absorption in UV
- Kuraray & Super-K have a dip at 350nm and a spike at 440nm

- Eljen & Super-K have best emission matched to PMT
- Kuraray extends further into the red



MODEL PERFORMANCE OF WLS PLATES IN WATER



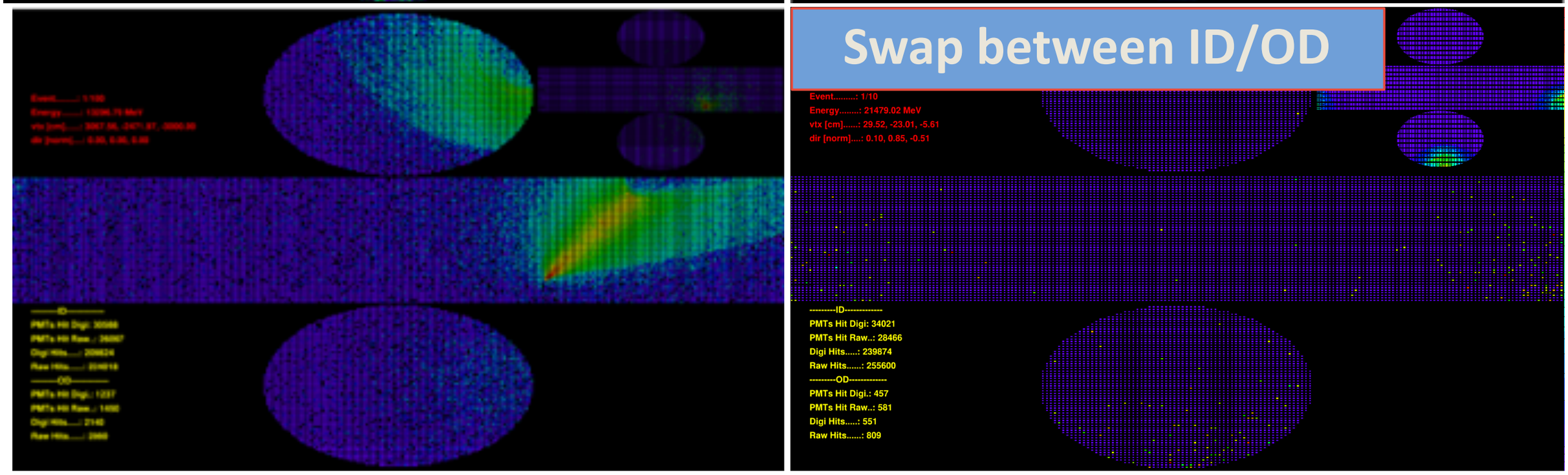
Eljen/Kuraray efficiency difference of 20% is due to:

- Different refractive index of plate n=1.58/1.49
- Better UV absorption
- Narrower emission spectrum

SIMULATION : CONFIGURATION IN WCSIM

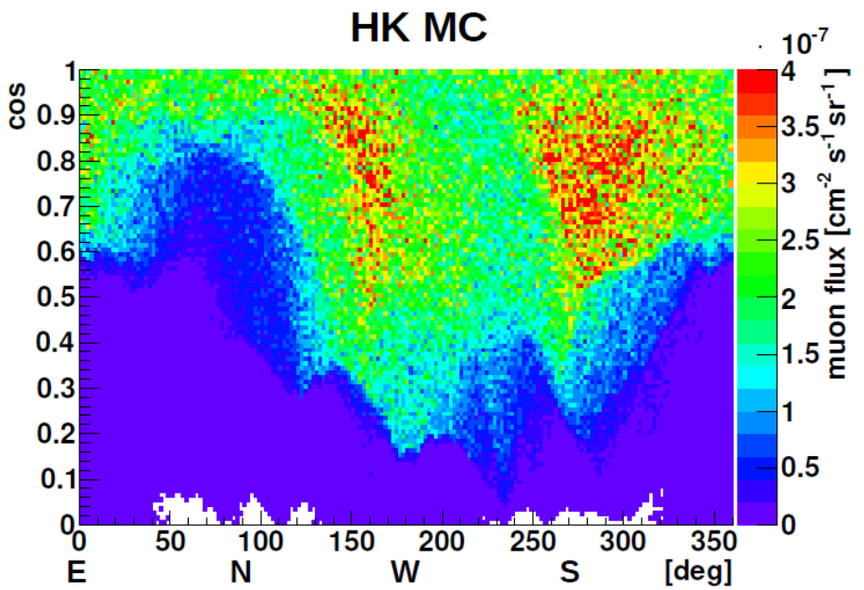
- 3 configurations are considered:
  - 2x2 3” PMTs per supermodule (0.28% photocoverage)
  - 3x2 3” PMTs per supermodule (0.42% photocoverage)
  - 2x1 8” PMTs per supermodule (1% photocoverage)
- OD structure covered with Tyvek, also cave walls
- WLS plates are simulated using Geant4 optical simulations
  - This is not yet understood how G4 process WLS absorption/ emission. G4 produces a ~20% increase in light collection, whereas from Super-K we calculated an increase of ~300% for 3” PMTs
  - Please consider the number presented here as lower boundaries on photon collection for 3” geometries
- OD lateral thickness considered: 100cm
  - Our previous studies shows how to extrapolate to 150cm and 200cm

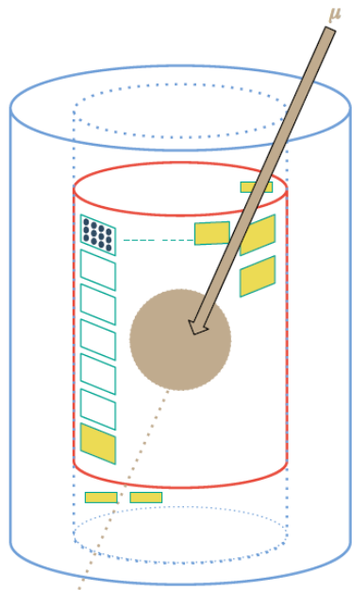
AN EVENT INSIDE THE OD



COSMIC MUONS

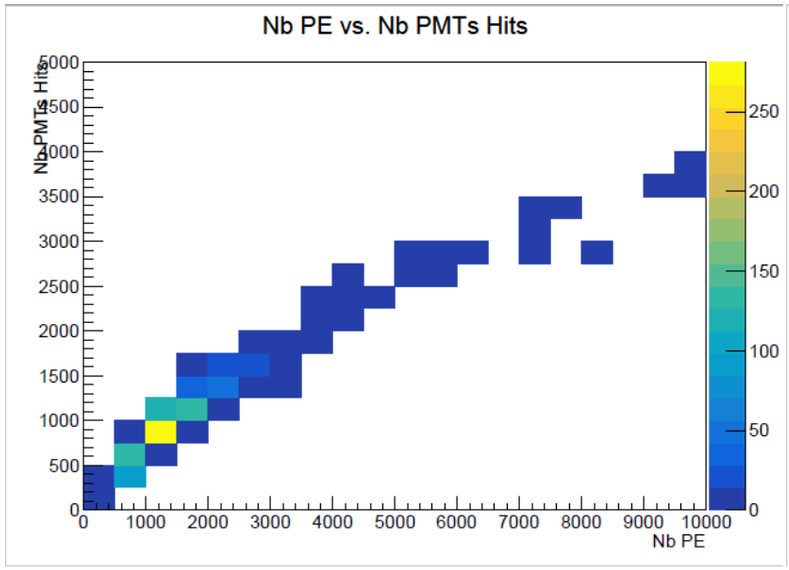
- Cosmic muons generator
  - Muons selected in a 10m sphere around centre of tank
  - Energy and impulsion are randomly generated accorded to Super-K flux extrapolated at Hyper-K
  - Then vertex generated outside Hyper-K
- 1000 events produced
- Results:
  - Total Number of photoelectrons digitized per events collected by all the PMTs
  - Total Number of PMTs with a true hits **(NO DARK RATES)**
  - Efficiency: request any event produced 50hits with at least 1 detected photoelectron per PMT

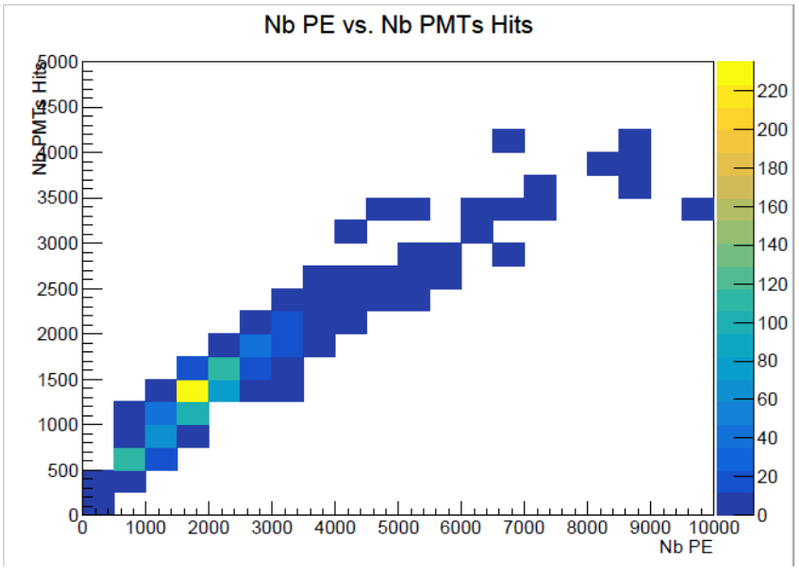


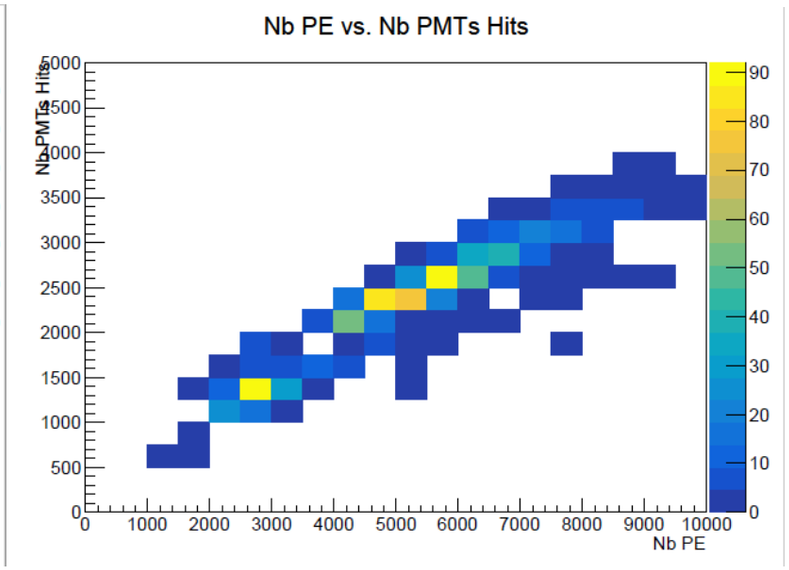


RESULTS

- 2D plot of Nb of photoelectrons collected per event VS Nb of PMTs tube hits







Geometry	Mean PE	Mean #PMTs	Efficiency
3” 0.28%	1473±933	1033±465	**100%**
3” 0.42%	2019±1115	1378±548	**100%**
8” 1%	5102±1699	2294±632	**100%**

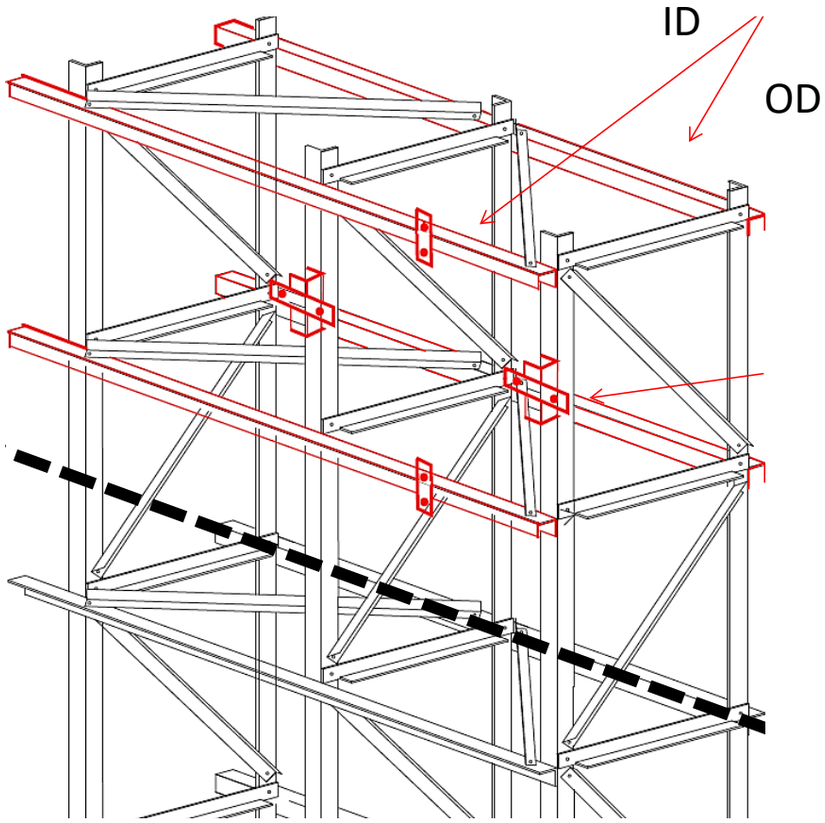
Most common OD rejection cut (50 PMTs hits) is **100%** efficient with **both 3” and 8”** geometries

OD CLUSTERS LINEAR FITS TO CLASSIFY EVENTS

- We have developed a simple charge clustering algorithm which we will tune and use to compare different geometry options
- The algorithm:
  - Splits the detector into 10m x 10m squares
  - Sums up the charge in each square
  - Looks for peaks (defined as all neighbouring squares having a lower charge)
  - Ignores peaks where the total charge is < 15% of the highest peak charge (arbitrary)
- Next steps:
  - Include timing information in the algorithm
  - Tune some of the arbitrary parameters

Event Type	Mean
FC	0.00 ± 0.00
PC	1.00 ± 0.00
UPMUS	1.04 ± 0.34
UPMUT	2.09 ± 0.85

PHOTOSENSOR MOUNTING AND ID/OD SEPARATION



- No cross-struts in the OD side.
- Can put 3” PMT anywhere there isn’t an ID cover in the way.
- The corner positions are simplest for attaching to the frame.

- We need a set of black/white reflecting plates or sheets on the OD side
- We would like these to be a bit more robust than in Super-K to simplify installation and help with Radon mitigation
- The OD PMT+WLS are made into a sub-assembly on a frame, then mounted on the outside of the OD plates and attached to the support structure (the plates have holes for the PMTs)
- Installation procedures under discussion
- Will be tested on ID/OD mock-up

SUMMARY

- OD PMTs candidates have been characterized and discussions between groups (mPMTs) are on-going to prepare bid to manufacturers (Hamamatsu)
- Kuraray provided a prototype WLS plates and it has been tested
  - We affined our predictions for the light collection enhancement factor in Hyper-K
  - On-going work to fully implement the model in WCSim
  - Discussions with manufacturers will start soon
- Veto performance to cosmic events have been evaluated:
  - –100% rejection for each geometries to cosmics events with standard threshold (50 PMTs hits)
- Small correlation between cosmic muon energy and number of hits in the OD
  - **Favoured the 0.42% 3” geometry** but even the 0.28% 3” shows correlation with performance comparable to the 8” 1% geometry
- Designing a OD clustering algorithm and tests are on-going

Next Steps

- WCSim production with full OD light collection implementation
- Define entry and exit points using clusters
  - Center of mass of Q collected per PMT
- Compare distribution between 3” and 8” OD geometries