KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

Hyper-Kamiokande

Multi-PMT modules for the Hyper-Kamiokande project

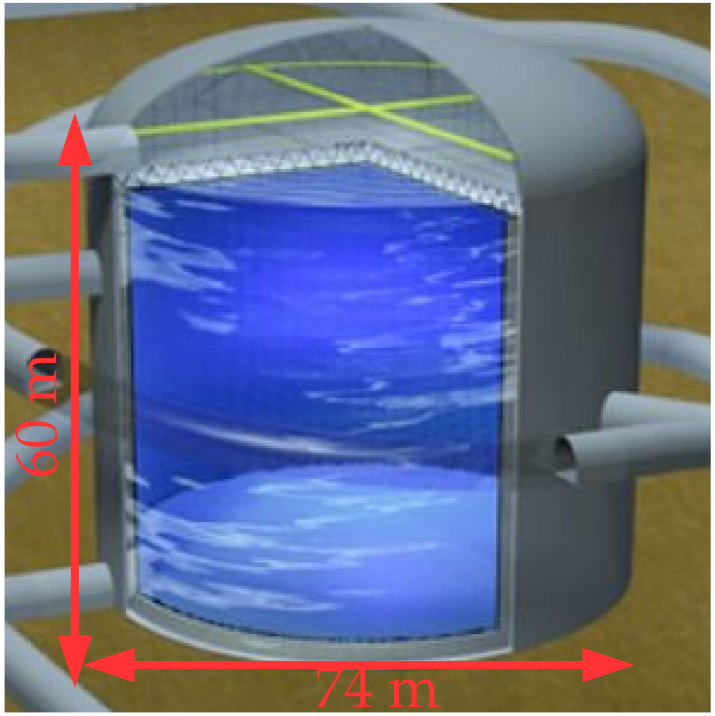
Benjamin Quilain (Kavli IPMU, The University of Tokyo)
for the Hyper-Kamiokande proto-collaboration

1. Introduction
2. multi-PMT for HK near detector : E61
3. Multi-PMT for HK
4. Measurement of their characteristics

PD18 workshop, the University of Tokyo 2018/11/29

The Hyper-Kamiokande experiment

- 260 kton water Cherenkov detector.
  → FV mass = 186 kton ~ 8 x SK



Astrophysics

Constrains Supernovae models.

Constrains cosmic star formation history.

Solar ν physics

MSW effect in the Sun

Non-standard interactions in the Sun

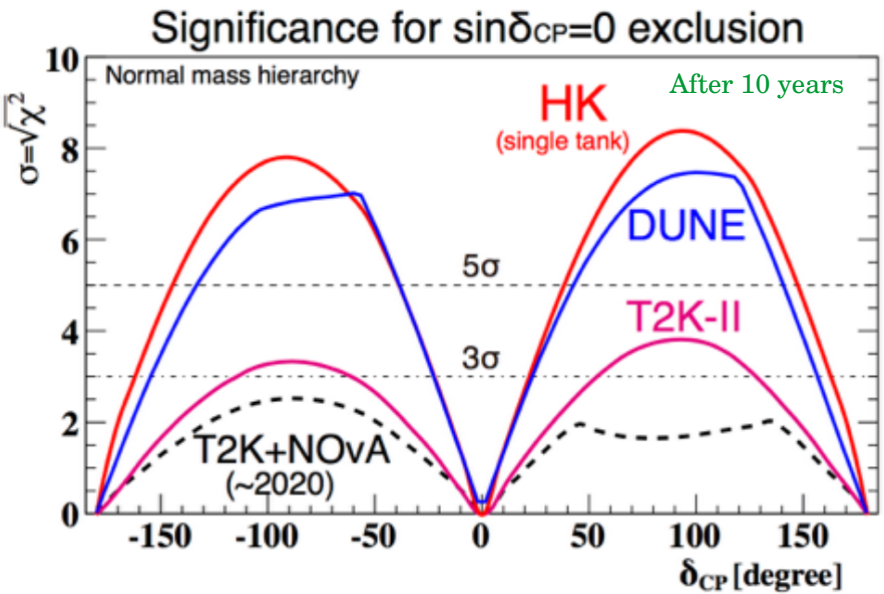
GUT

Probe GUTs through proton decay

CP violation

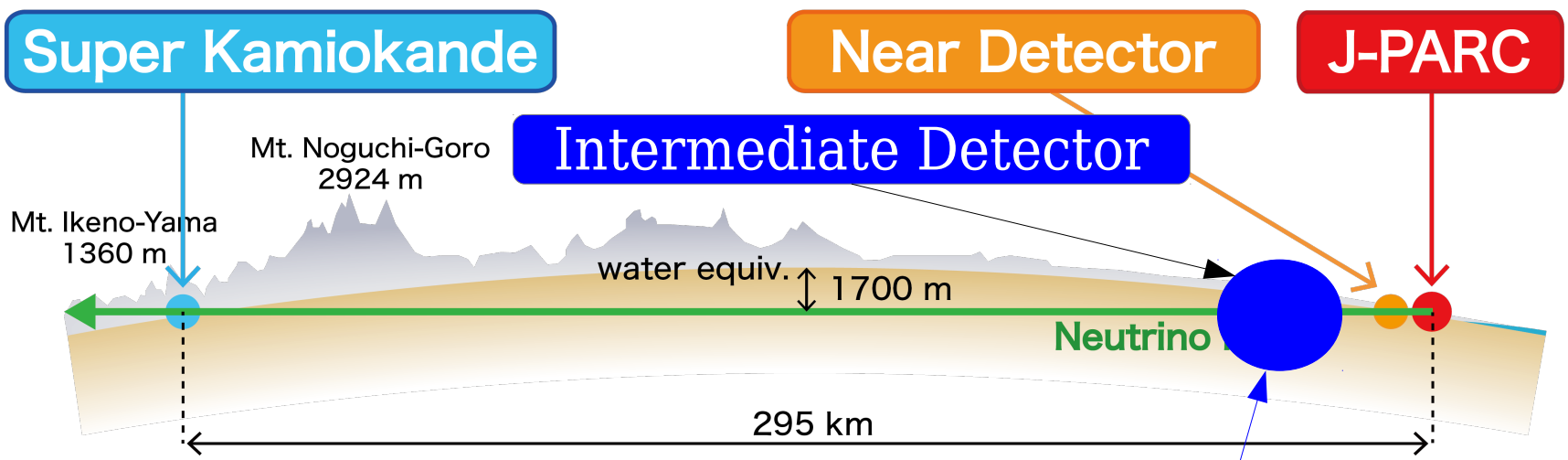
<u>Observe CP violation in the lepton sector</u>

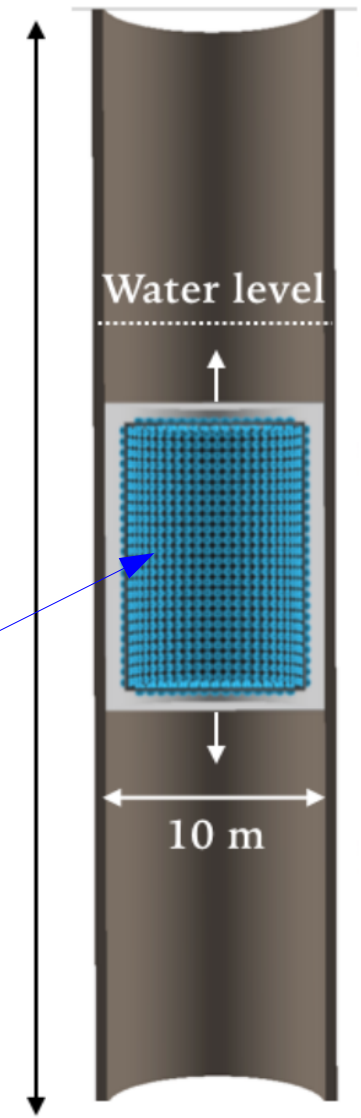
High sensitivity to ν mass ordering.



The E61 intermediate detector

- CP violation search based on accelerator ν : T2HK
  → ν_e appearance in a ν_μ beam and ν_μ disappearance & $\bar{\nu}$ equivalents.





- Use near detector to constraint the ν event rate & flux before oscillation.

- To reach the goal of 3 % systematics
  → Needs a new intermediate detector : E61.

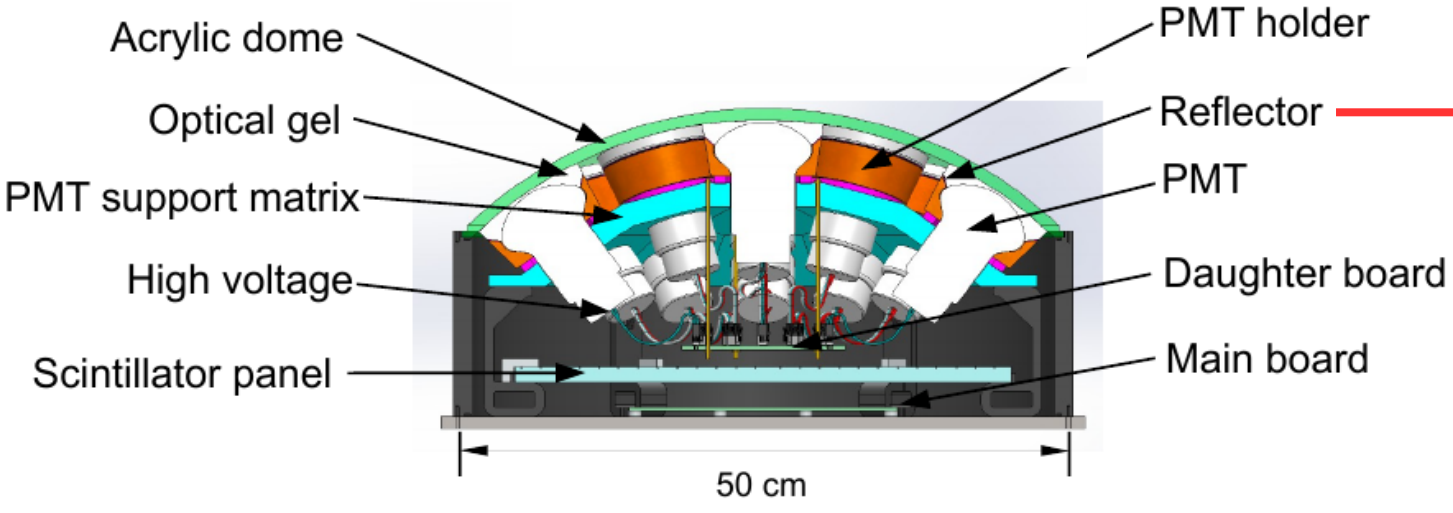
- ~1 kton water Cherenkov detector

Multi-PMT modules for E61

- E61 inner detector will be exclusively instrumented with ~500 multi-PMT modules.

- 19 x 3'' PMTs (Hamamatsu 14374)

- <u>Current prototype (will be updated) :</u>

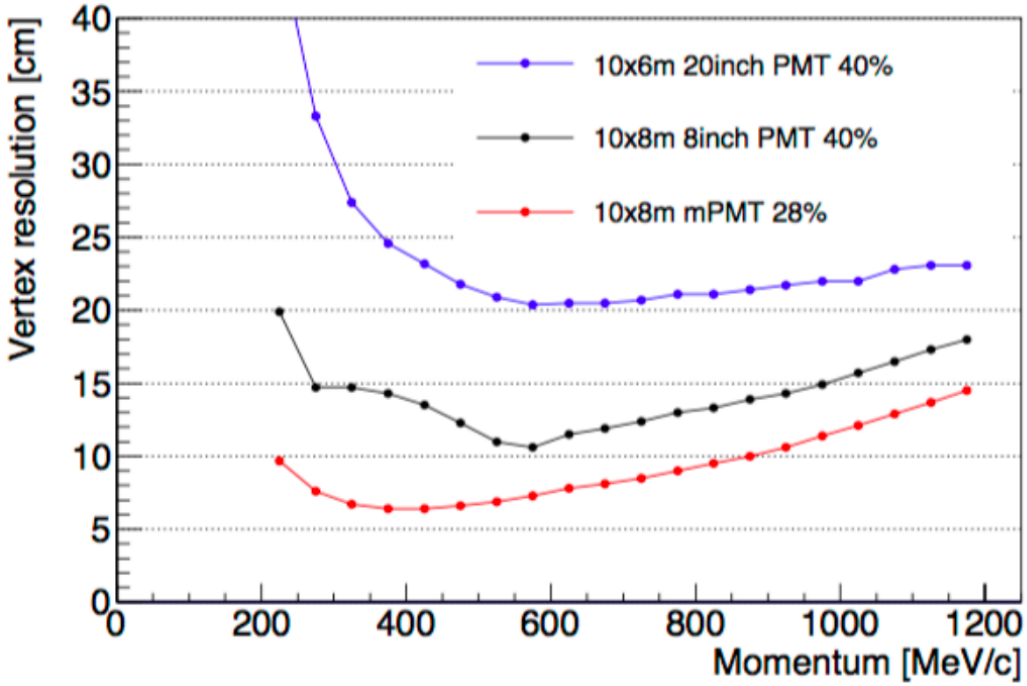


PMT top view

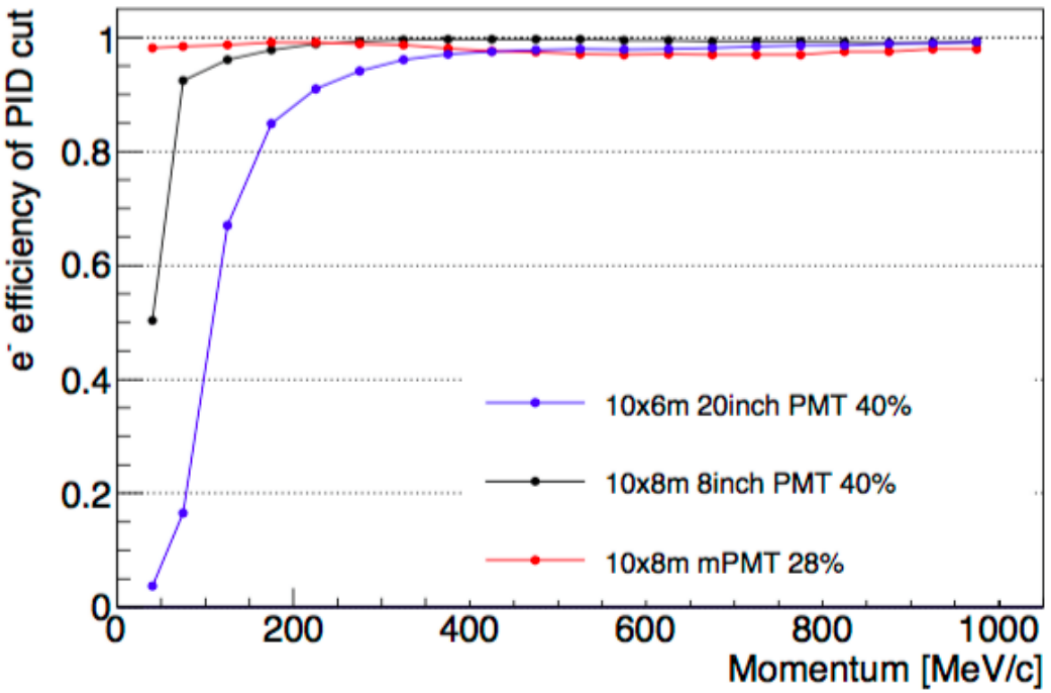
Impact of mPMT on E61 performances

- Goal : constrain the ν_μ, ν_e energy spectra before oscillation. It requires :

1. High FV (normalization) resolution



2. High e/μ separation

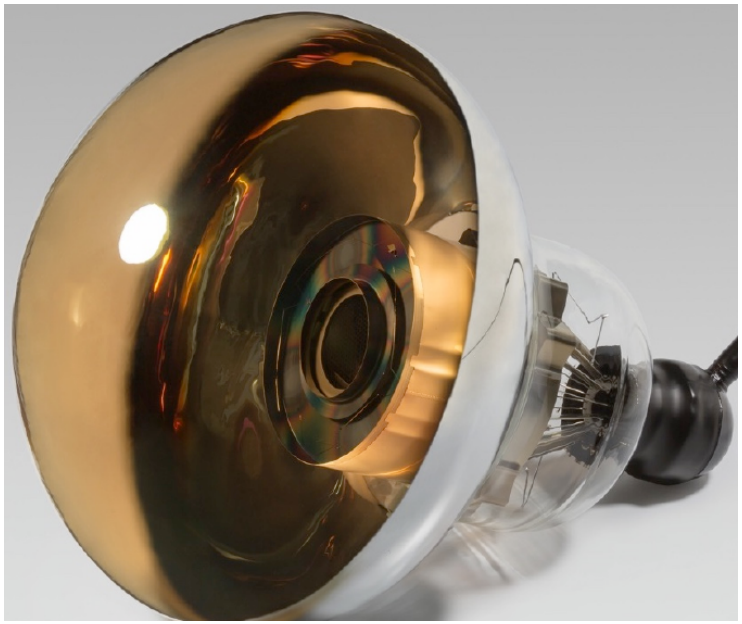


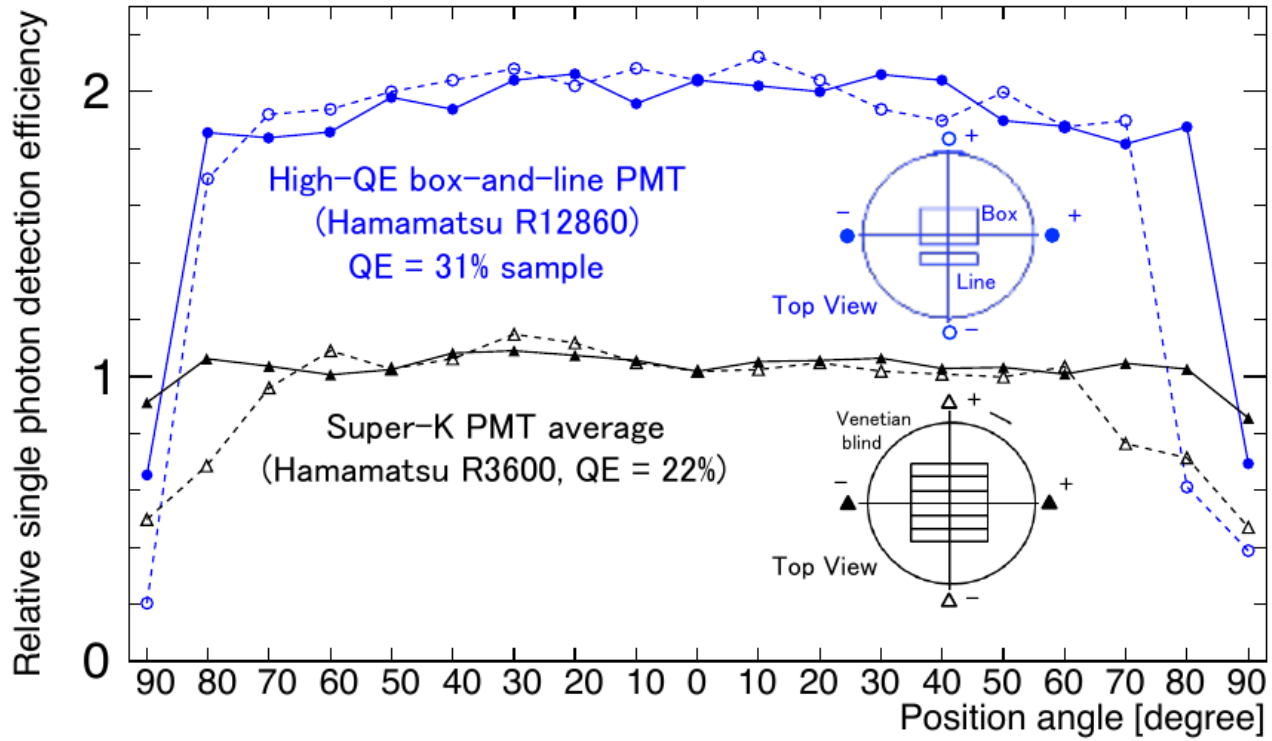
- mPMT results are not optimized (PMT directionality not implemented)

- Still, 3'' multi-PMT modules highly increases E61 abilities !

HK photo-detectors

- <u>New 20'' High-quantum efficiency Box&Line PMT :</u> See C. Bronner's talk

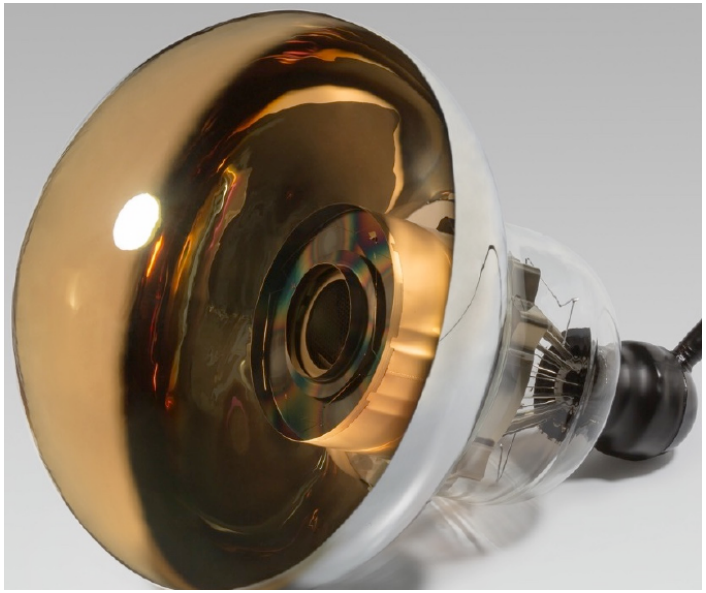




	SK PMTs	HK B&L PMT	
Photo-cathode diameter	20''	20''	
Quantum efficiency	22 %	31 % (QE x CE = 2 x SK)	✓
Transit Time spread (TTS)	> 5 ns	2.6 ns	✓
Dark rate @13 degrees	4 kHz	8.4 kHz (<u>goal :</u> 4 kHz)	✗

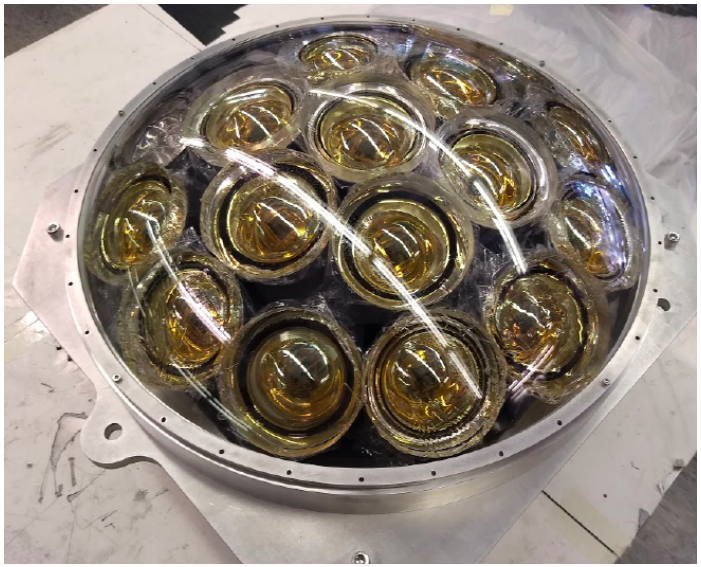
mPMT modules for Hyper-K

- Can mPMTs enhance HK physics as a complement of 20'' PMTs ?



- Smaller size : Better PID,
  Better reconstruction near wall → Increase FV.

- Better timing resolution: better vertex resolution → enhanced momentum resolution.

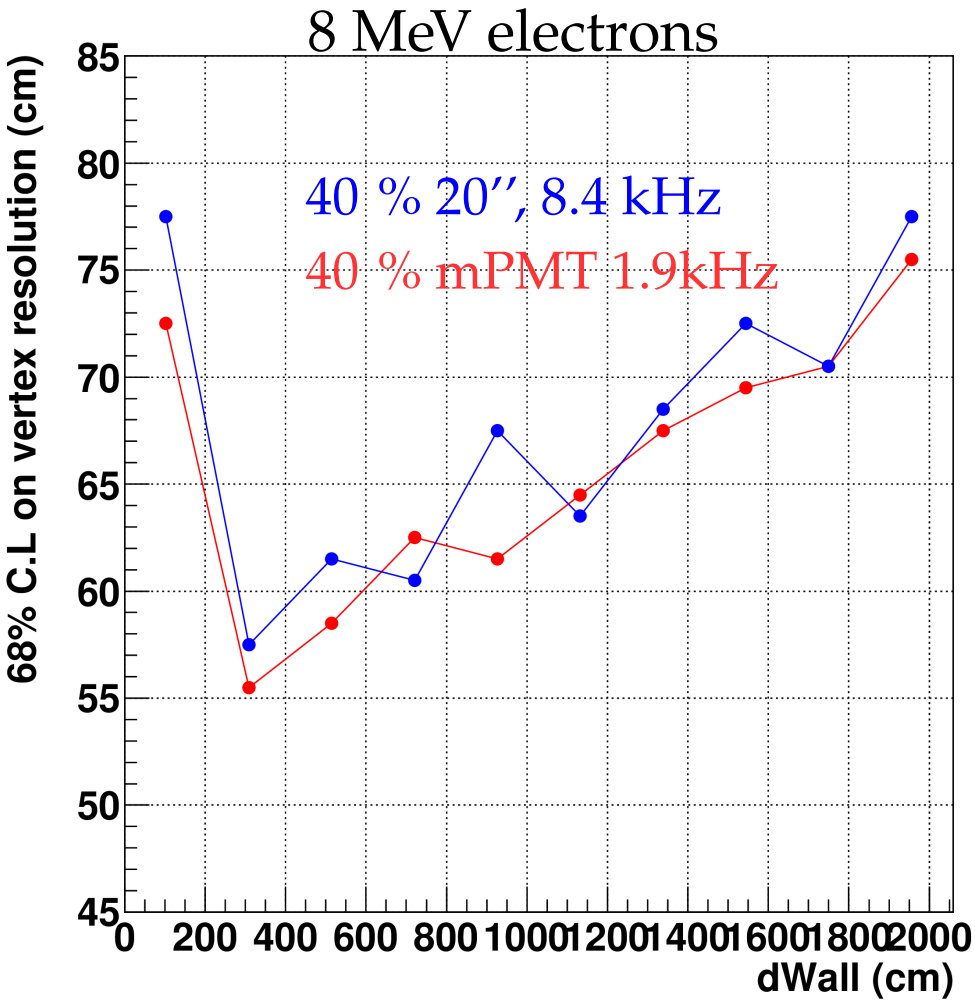


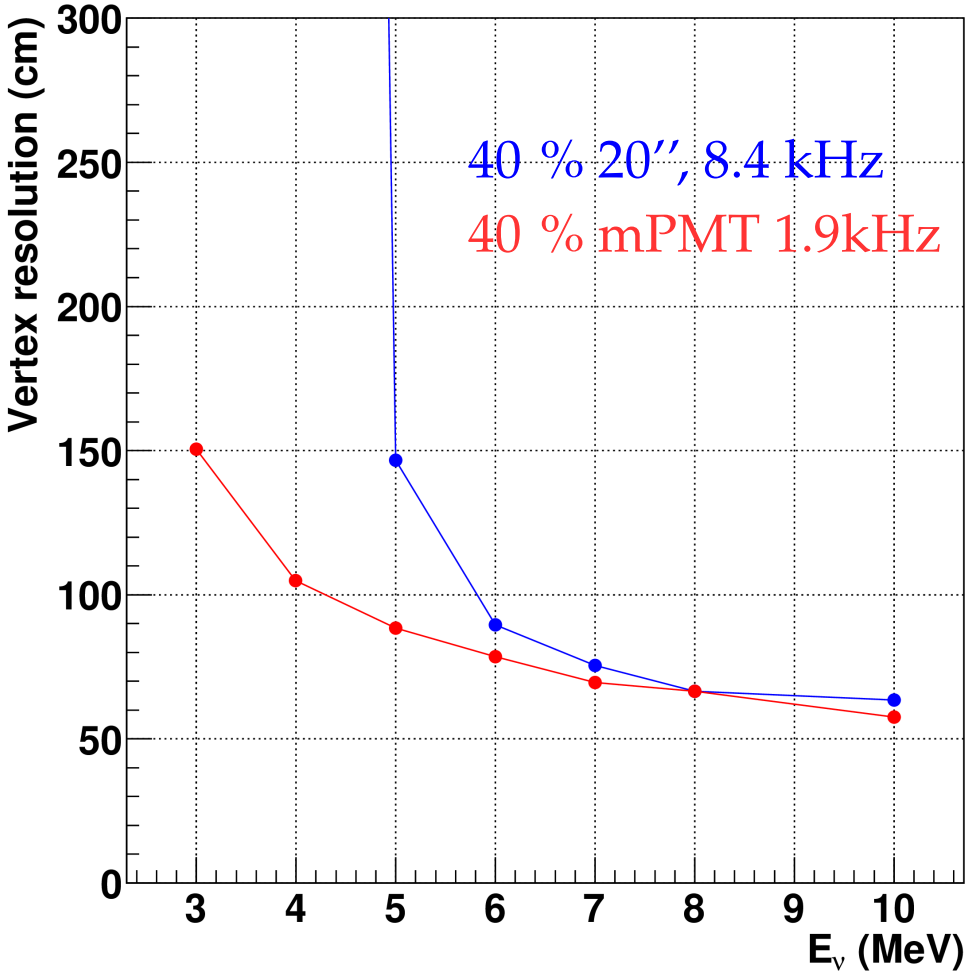
- Dark rate in negative HV = 200Hz:
  → Signal/Noise ratio ~ 20''.

- Dark rate in positive HV ≤ 100Hz:
  S/N ~ 2 x 20''→ Can probe lower energies ?

- Cons : → Less effective coverage than 20''.

mPMT low energy performances

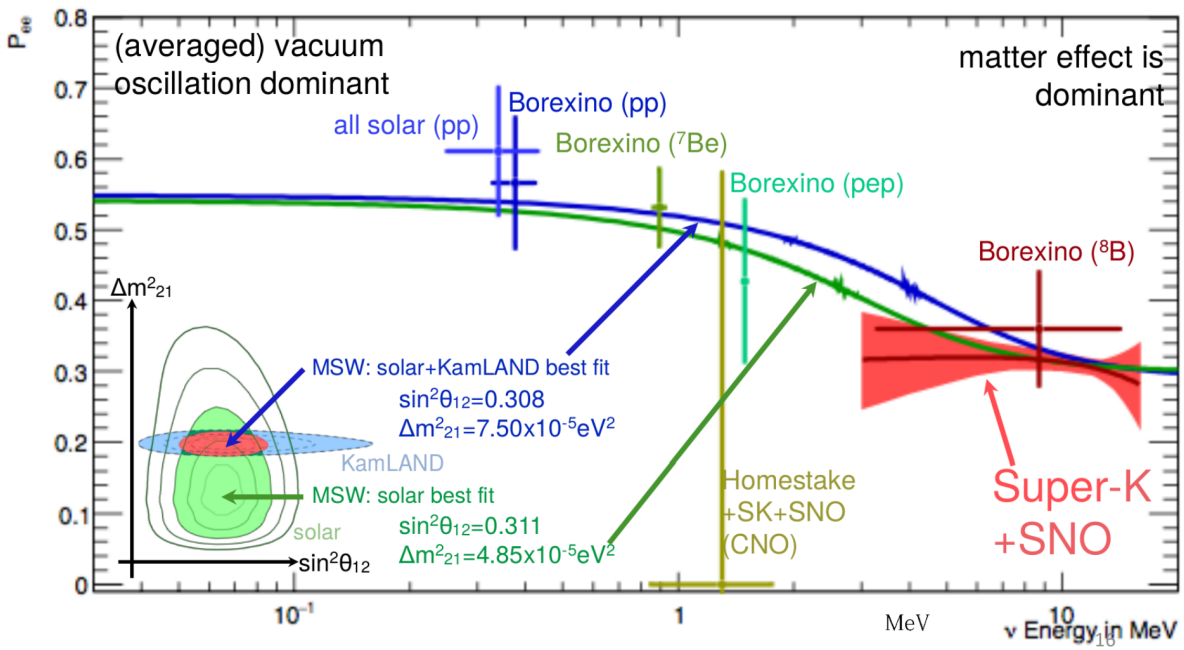


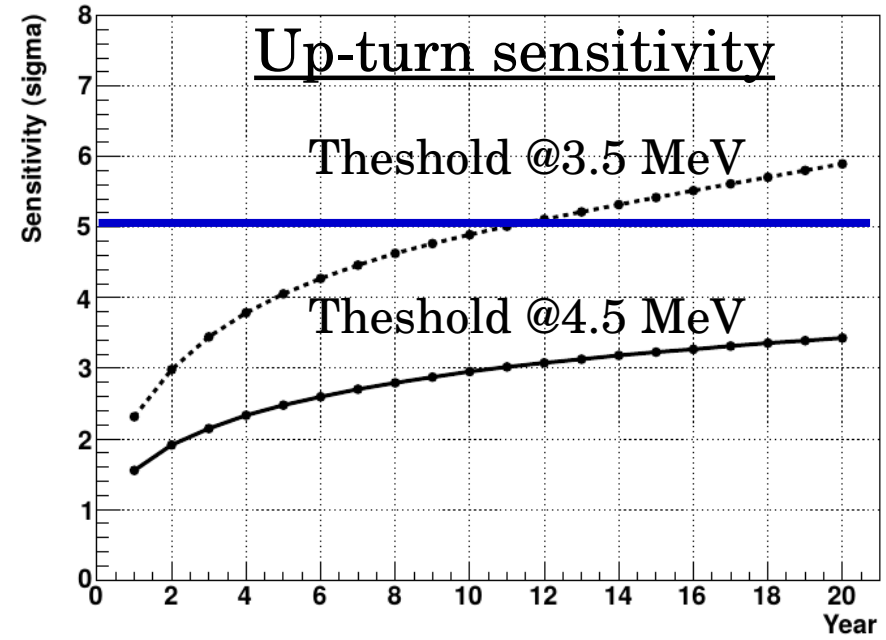


- Vertex resolution improved w/ mPMT for dWall ≤ 8m → FV expansion
- mPMT allows to explore < 5 MeV region.

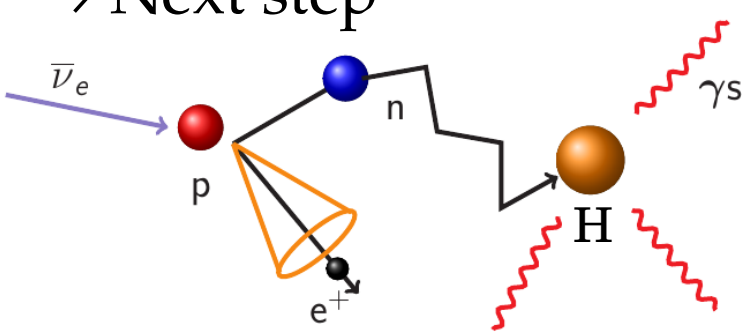
One example of impact on physics

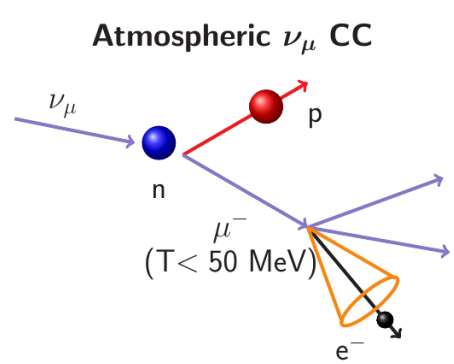
- Improved S/N : Probe low energy (3 MeV) → detect Solar up-turn ?





- Higher n tagging efficiency/purity on H? → Crucial for SNR ν
  → Next step

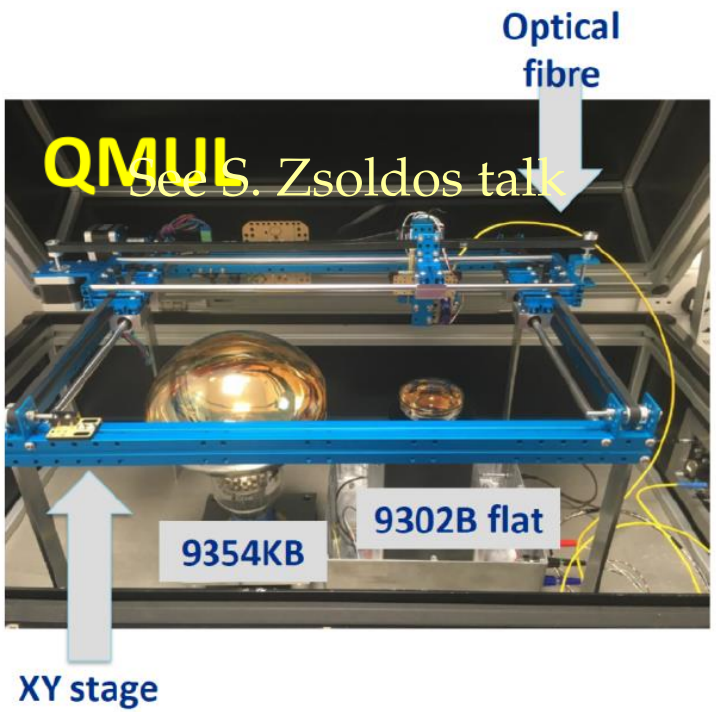


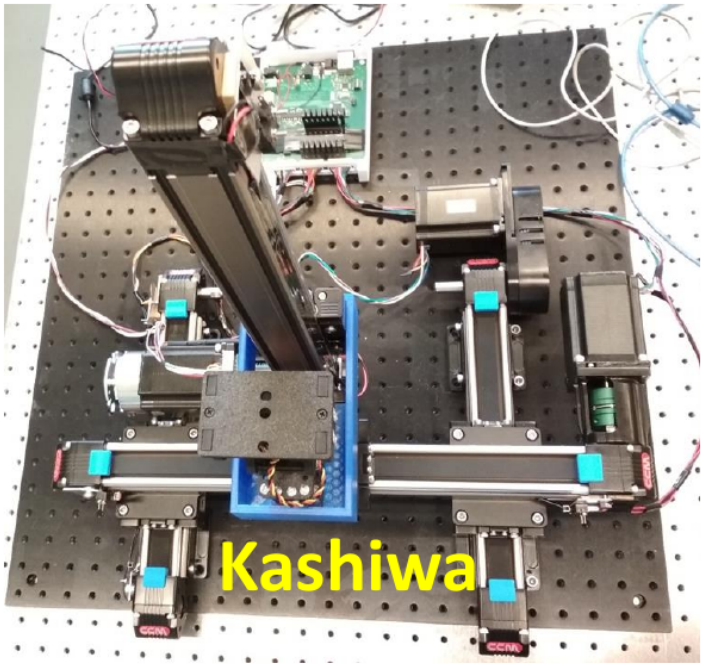


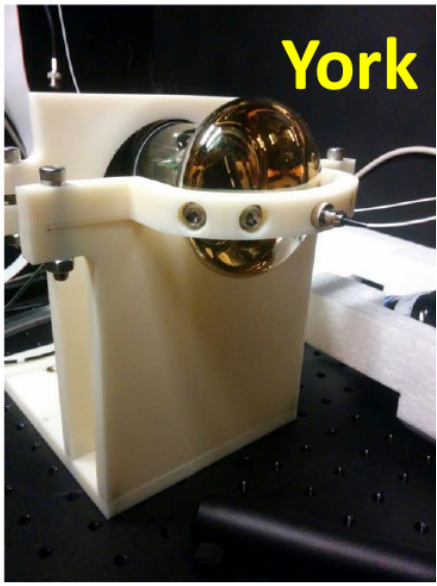
- Less noise in 100μs (capture on H)
- 3'' PMTs can enhance HK physics

Testing of 3'' PMTs in the world

- Currently tested in the UK, Canada, Poland, Italy and Japan.

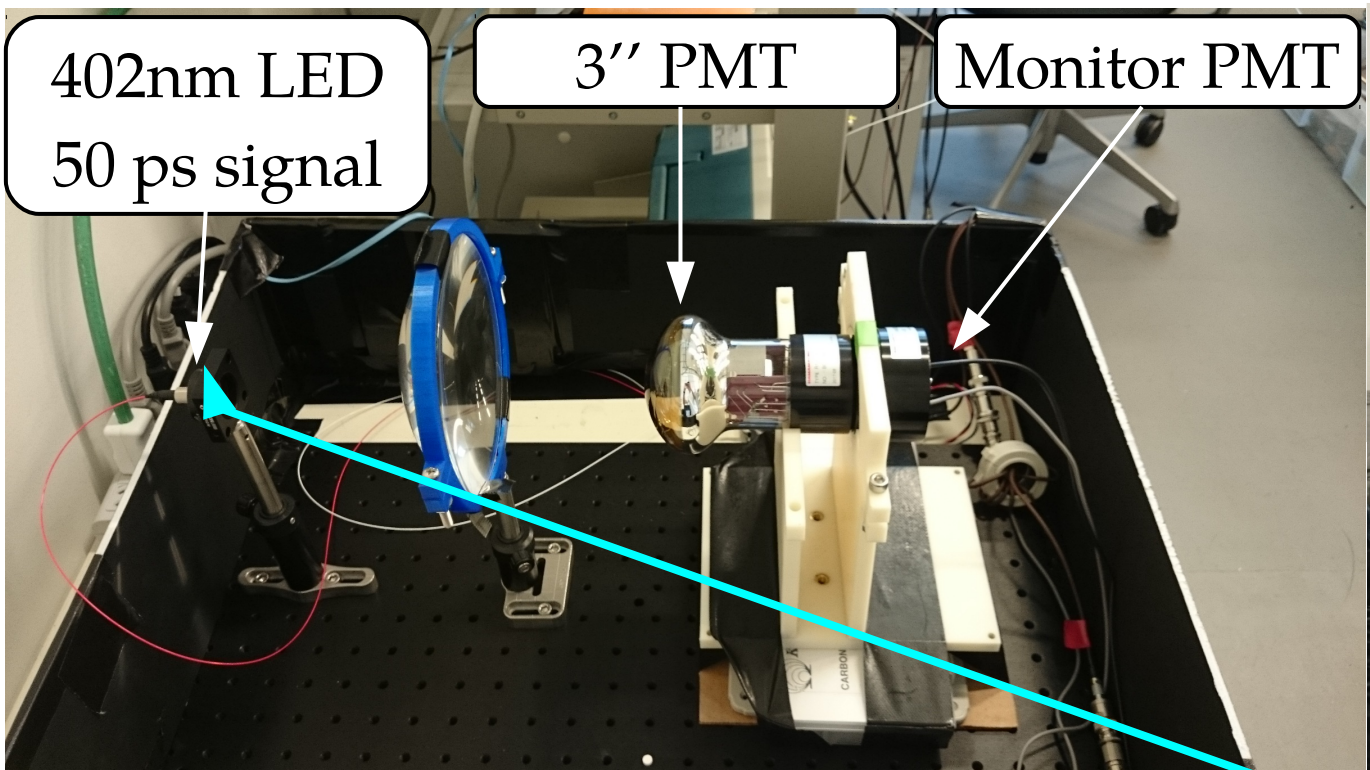


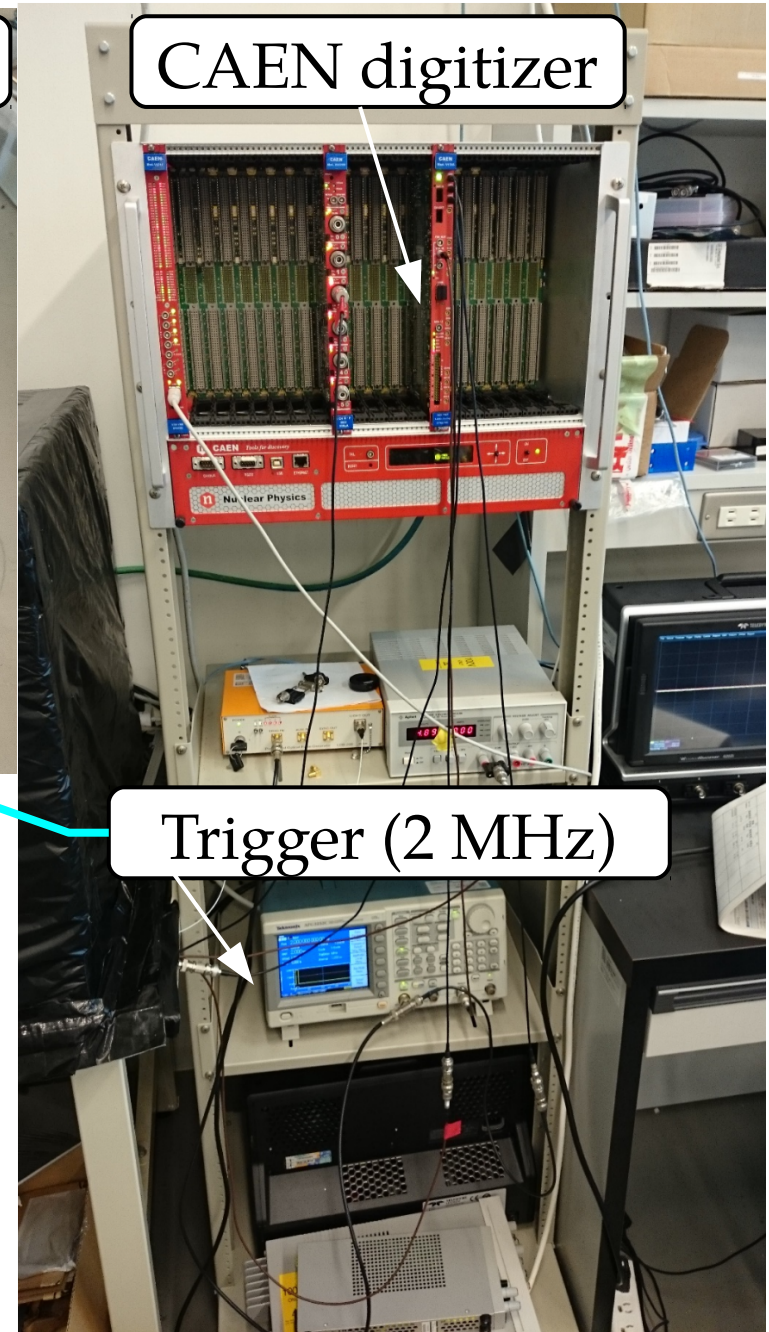


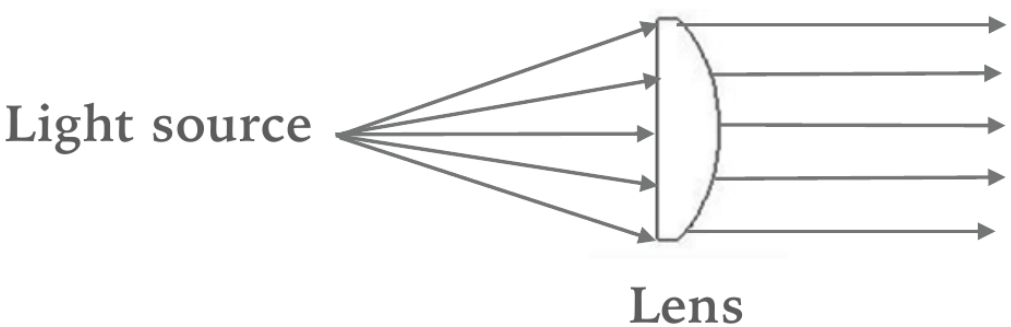


- I will focus on measurements at IPMU, which provided latest results.

Measurement setup at IPMU







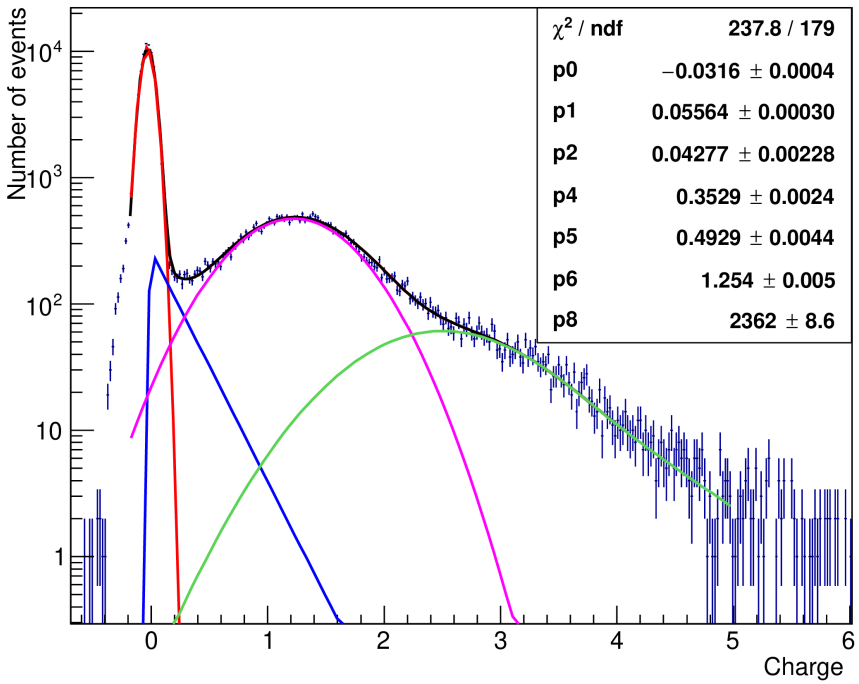
Uniform parallel light source is generated

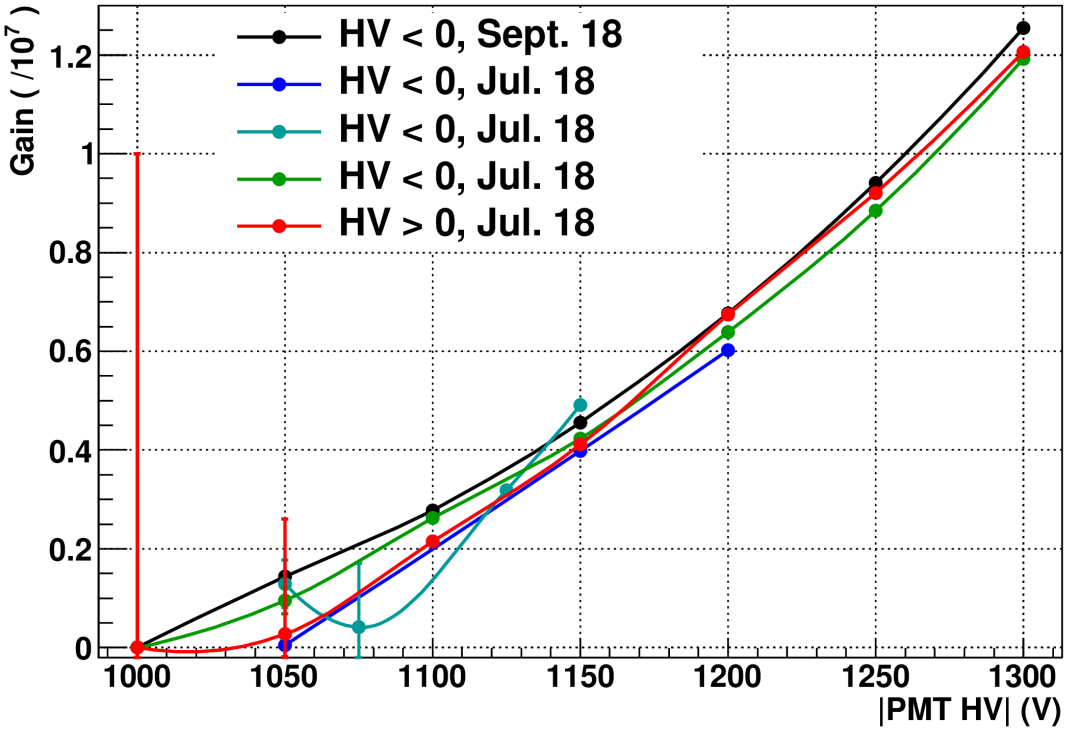
→ 15cm ring shape source (> PMT diameter)

H. Morikawa (TIT)
B. Quilain
M. Hartz

Gain measurement

- Both negative and positive high voltage are tested.





- Gain measurement is :
  1. = 10^7 @ 1265V.
  2. stable (confirms our IPMU setup stability).
  3. compatible between positive and negative HV

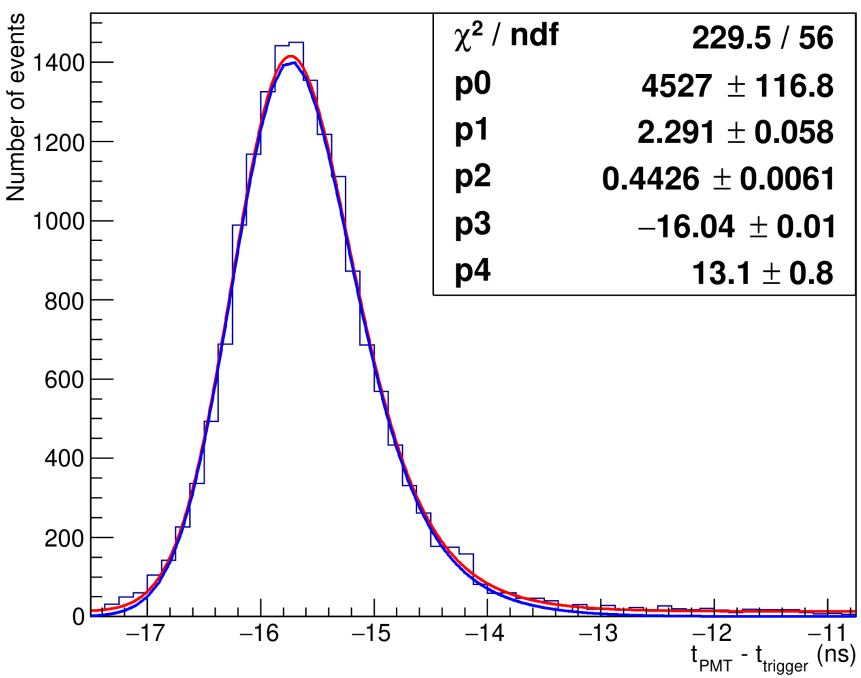
H. Morikawa (TIT)
B. Quilain
M. Hartz

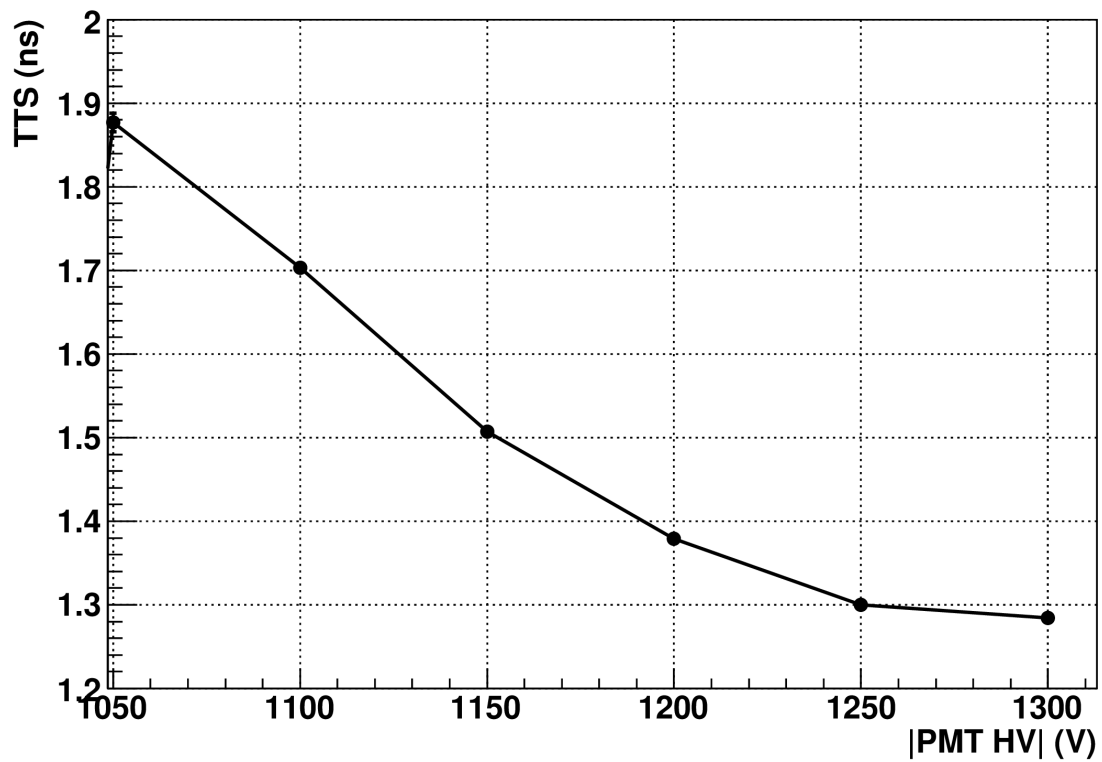
Timing measurement

- Transit time spread (TTS) is measured as a function of HV.

- $T_{PMT} - T_{trigger}$ fitted with a gaussian convoluted with exponential :

  → $I(y) = F(x) * G(x)$ TTS = I(y) FWHM





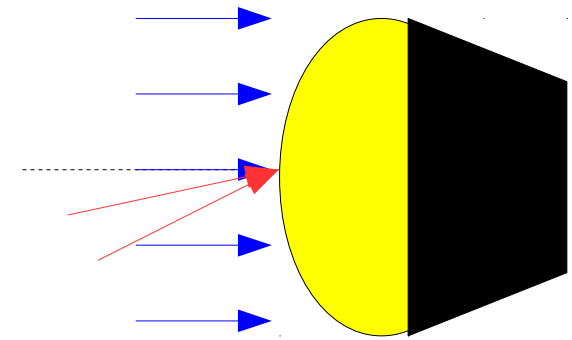
- Excellent TTS (<1.5ns) , smaller than assumed in simulation (2.0 ns)

  → Reduced to 1.3 ns @1265V (gain = 10^7)

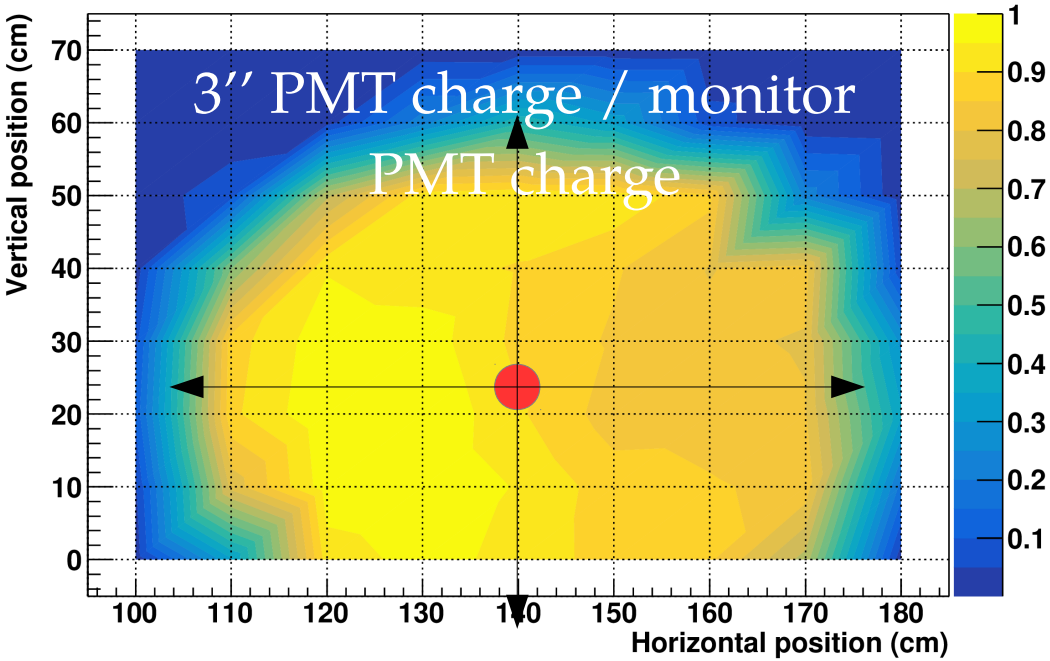
N.Izumi (TUS)
B. Quilain
M. Hartz

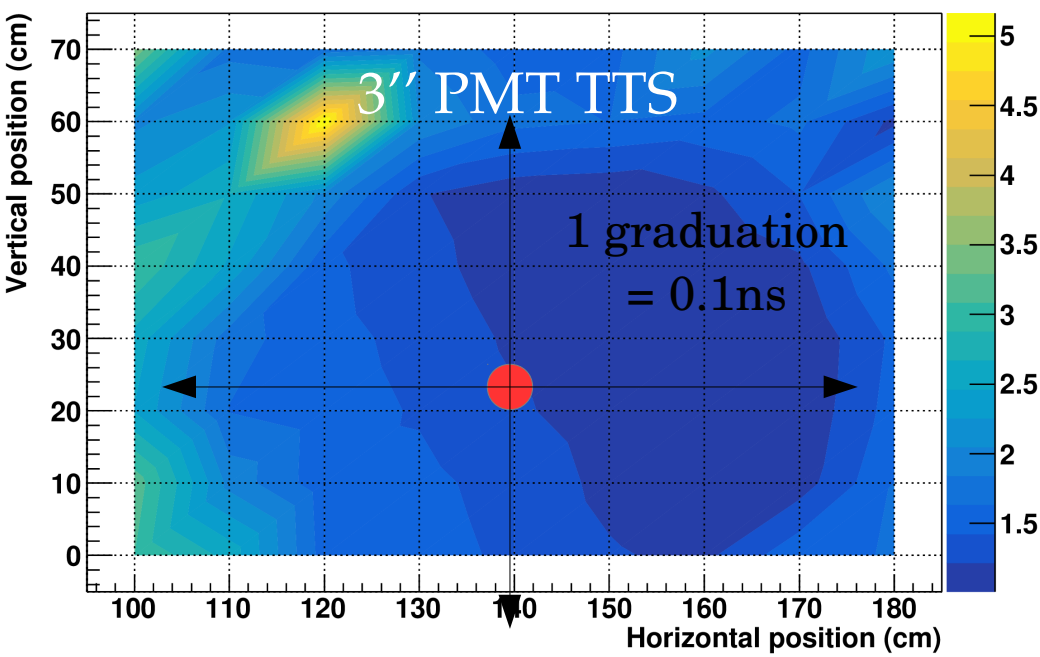
Asymmetry measurement

- Variation of TTS as a function of the photon :
  1. Incident position on PMT photocathode.
  2. Incident angle with the PMT photocathode.



- Designed motorized stage to move LED



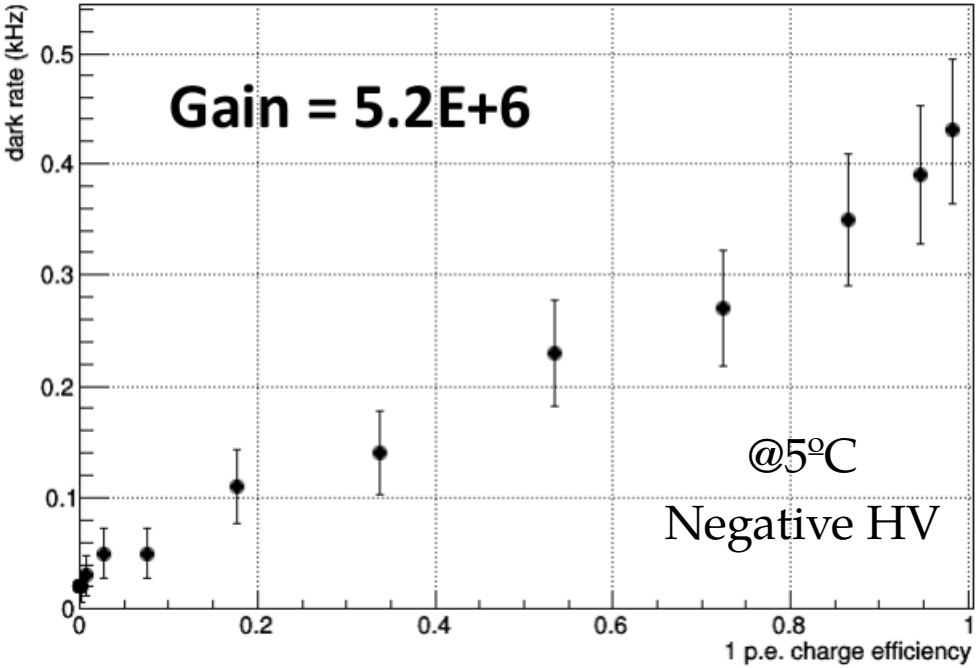


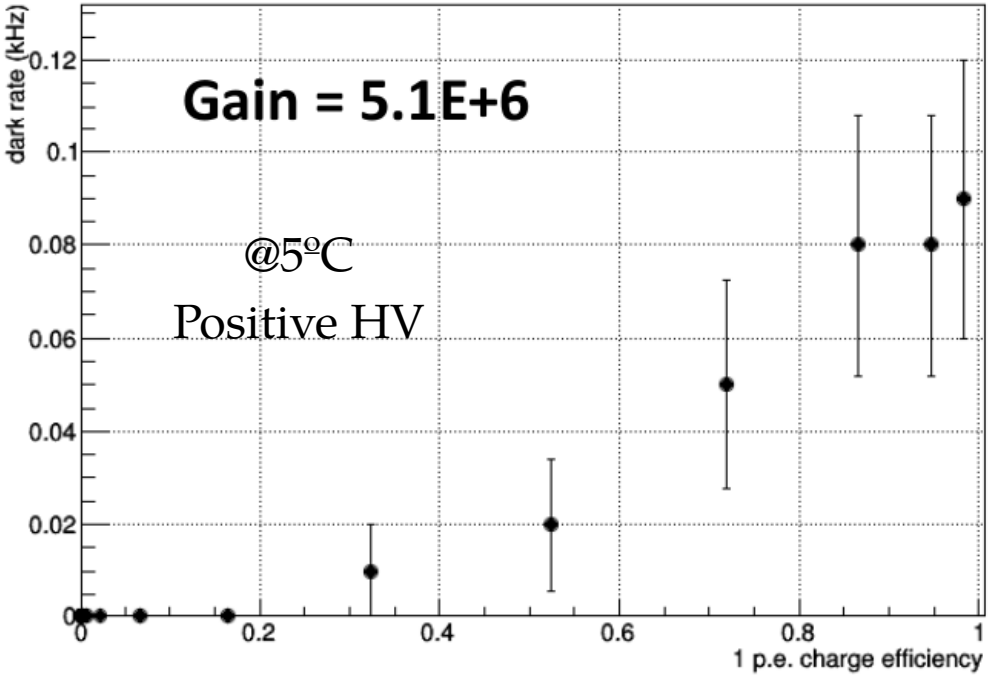
- Small efficiency asymmetry → under study.
  TTS almost flat except for 1 point→ under study.

Time walk corrected

On-going measurements

- Impact of reflector on detection efficiency → On-going @IPMU
- B-field impact on 3'' PMT → On-going @TUS.
- Dark rate → Cannot be done @IPMU with current setup → In Canada ? Upgrade our setup ?





Conclusions and future

- 3'' multi-PMT modules largely increases Hyper-K near detector abilities
  → Represents E61 baseline PMT.

- Their use in Hyper-K far detector is under study → Complementary to 20'' PMT : Very high timing resolution + Low dark rate.
  → Increased Fiducial Volume, vertex resolution & energy threshold
  → I showed you very first results. Many other studies are incoming.

End of 2018

- Simulation will be updated to an hybrid detector : 20'' PMT + 3'' PMT.

- A large measurement campaign is currently undertaken world-wide
  → Measurements so far : characteristics>expectations/simulation

- mPMT electronics is under-development

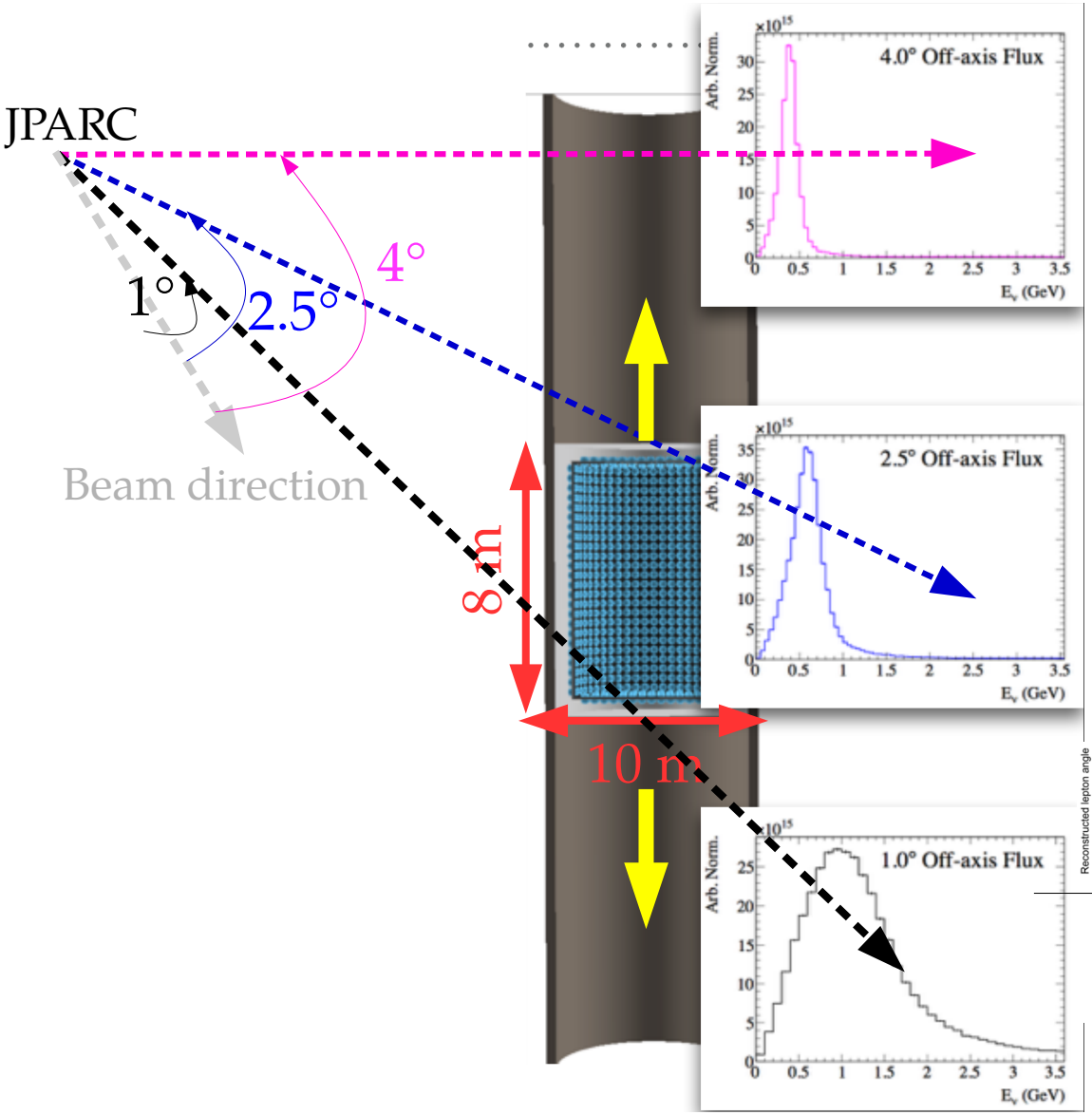
First in-situ test coming soon

  → Available prototype in Italy. 1st Canadian prototype next summer

Additional slides

2nd : Systematic error reduction

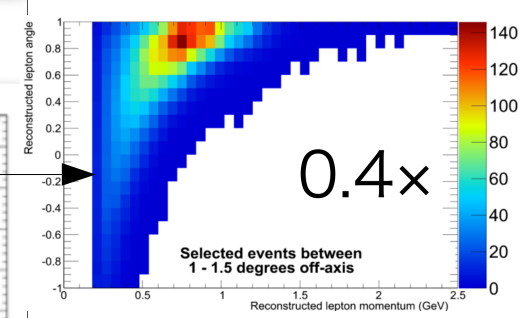
- 2. b : Requires a new intermediate detector : E61



1. HK flux = linear combination of different off-axis angles.

2.Take same combination of reconstructed number of neutrinos (e.g. in p_μ/θ_μ)

→ Drastically reduce use of cross-section models !



- Measure ν_e background & XS

Results using the high energy fitter

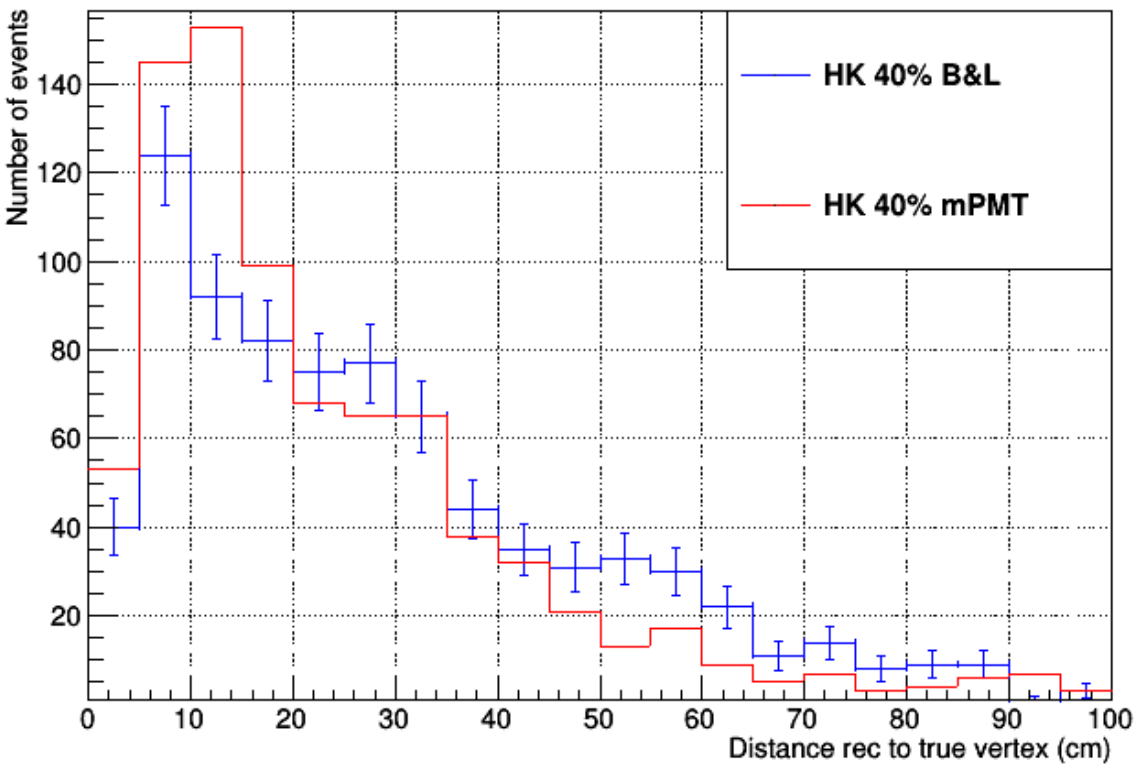
- Relies on fiTQun high energy fitter

PMT unhit probability PMT hit probability PMT charge pdf

$$L(\mathbf{x}) = \prod_{j}^{\text{unhit}} P_j(\text{unhit}|\mu_j) \prod_{i}^{\text{hit}} \{1 - P_i(\text{unhit}|\mu_i)\} f_q(q_i|\mu_i) f_t(t_i|\mathbf{x})$$

PMT timing pdf

- <u>Re-generated the tables for mPMT HK :</u>



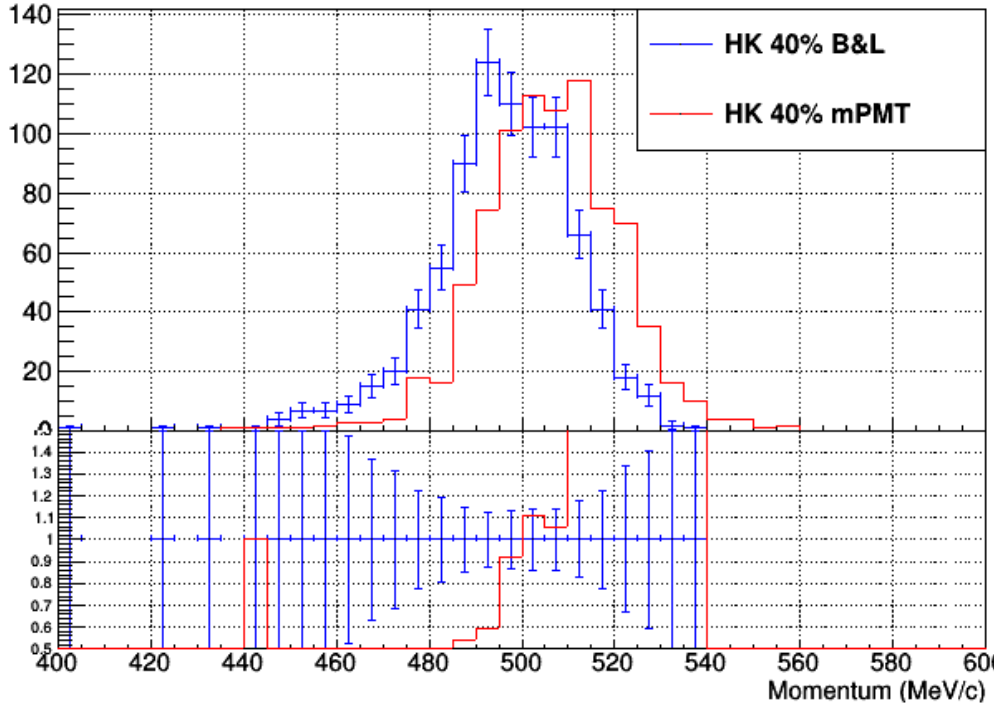
<u>Note :</u> scattering tables are not used in this 1st result

	20” PMT	3” PMT
Vertex resolution (cm)	34 ± 2 cm	27 ± 2 cm

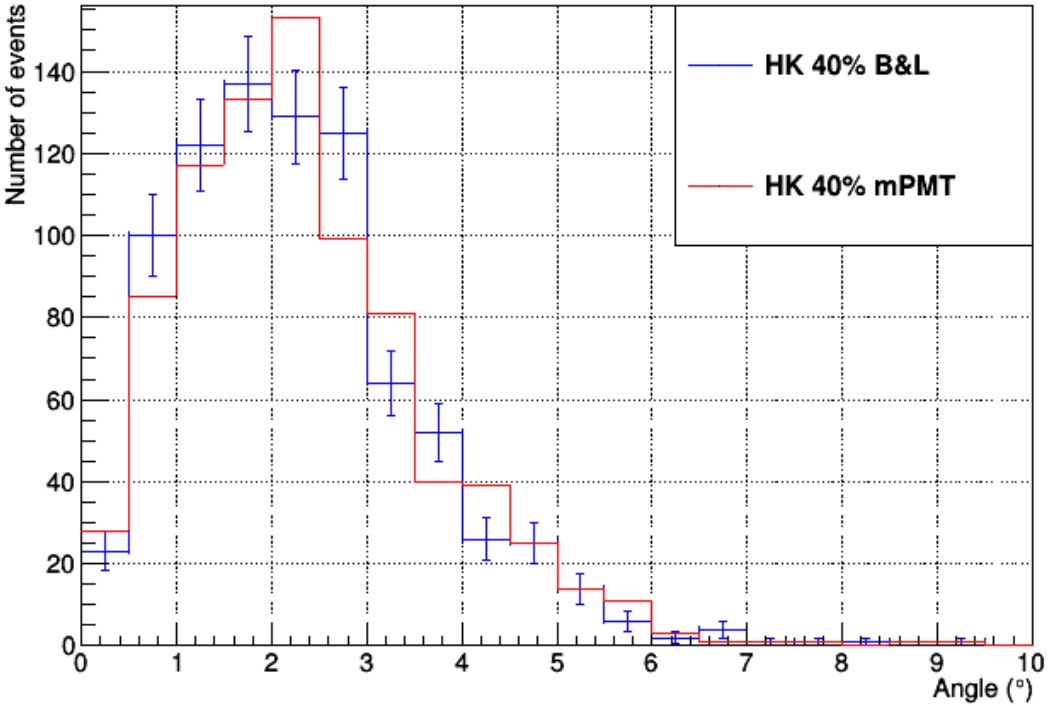
- Vertex resolution sensibly improved at the tank center ! → Reduced TTS.

Results using the high energy fitter

Momentum reconstruction



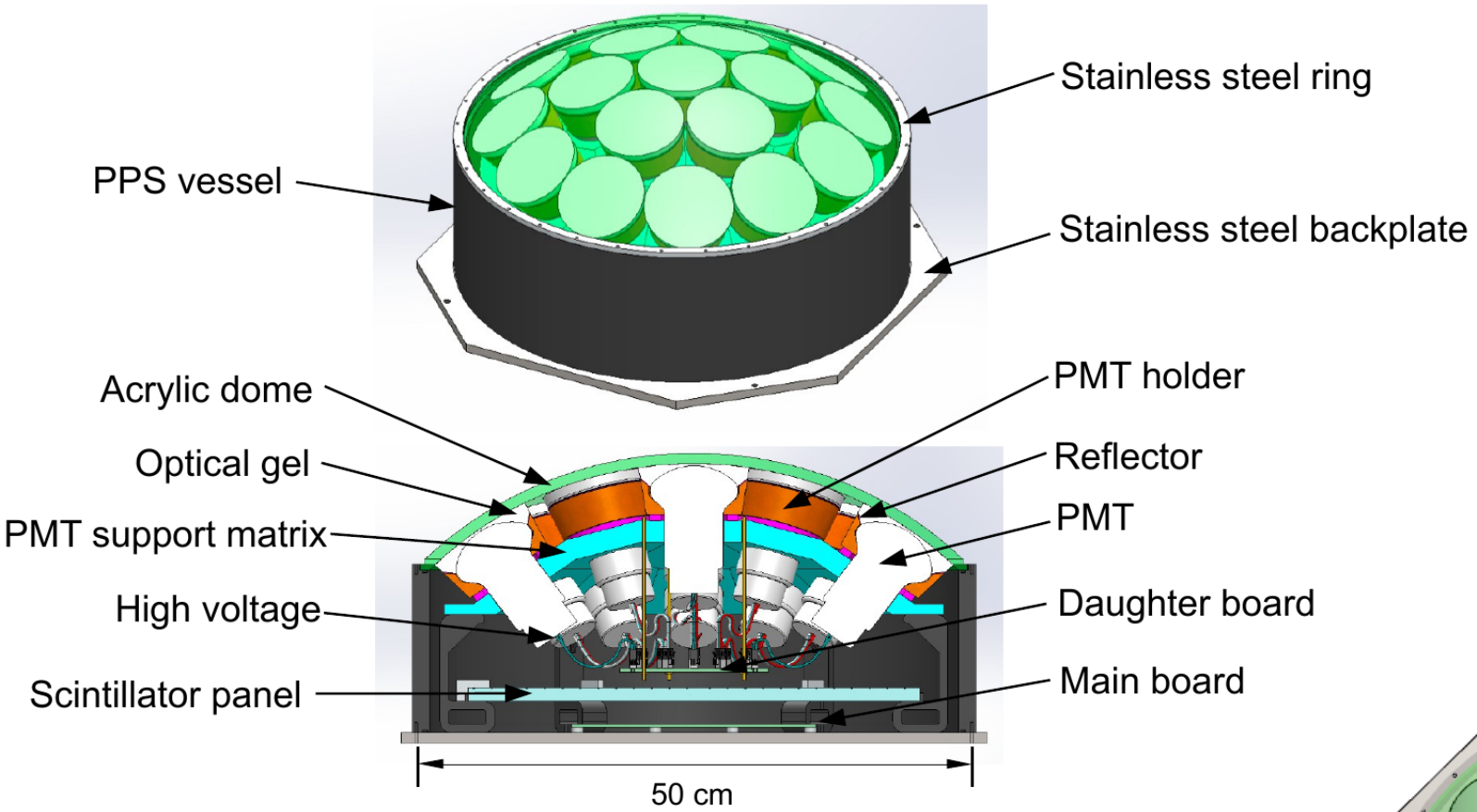
Direction reconstruction



	20” PMT	3” PMT
Direction resolution (deg)	2.5 ± 0.2 deg	2.7 ± 0.2 deg
Momentum resolution (%)	2.8 ± 0.3 %	2.8 ± 0.3 %

- Momentum resolution unchanged @ 500 MeV/c.
- Direction resolution slightly reduced → Fluctuation ?

MPMT design


Stainless steel ring
PPS vessel
Stainless steel backplate
Acrylic dome
PMT holder
Optical gel
Reflector
PMT support matrix
PMT
High voltage
Daughter board
Scintillator panel
Main board
50 cm