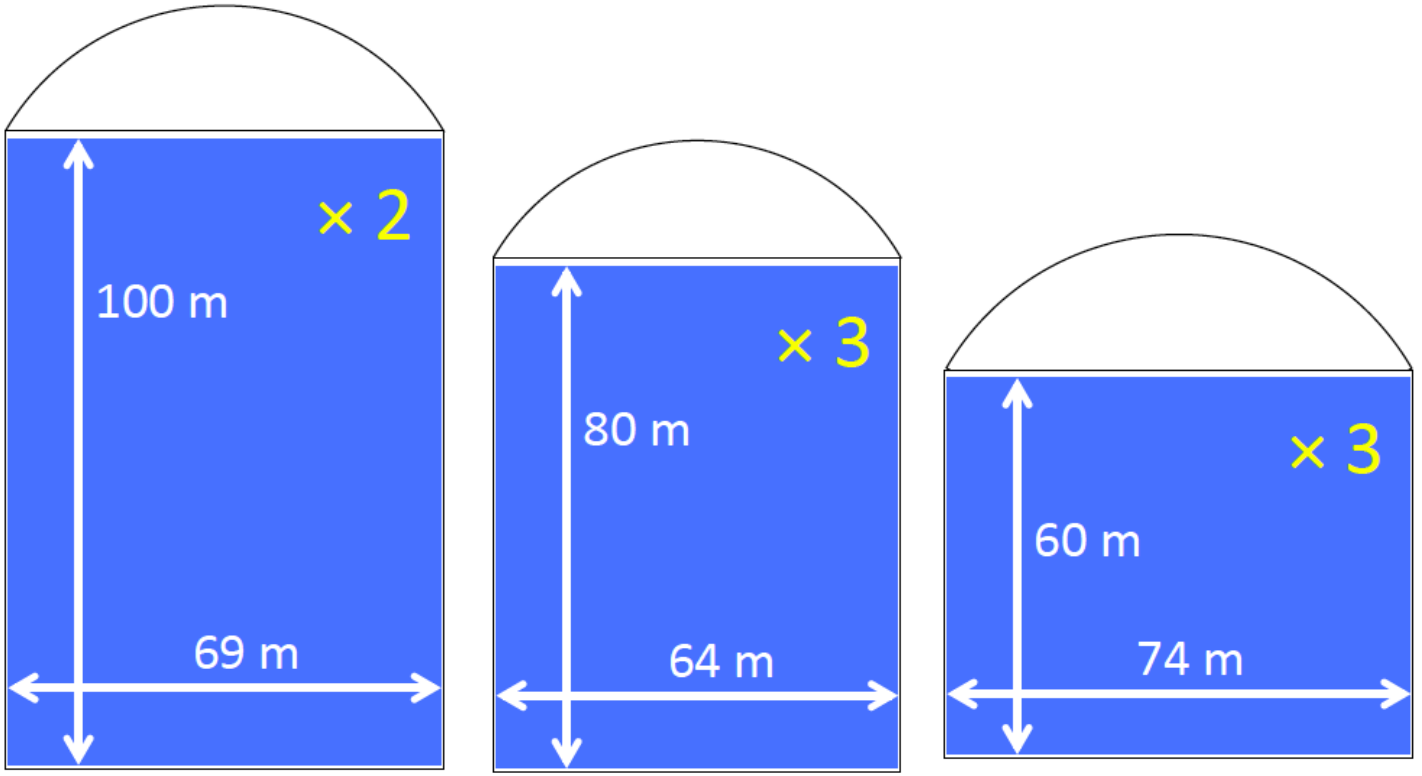
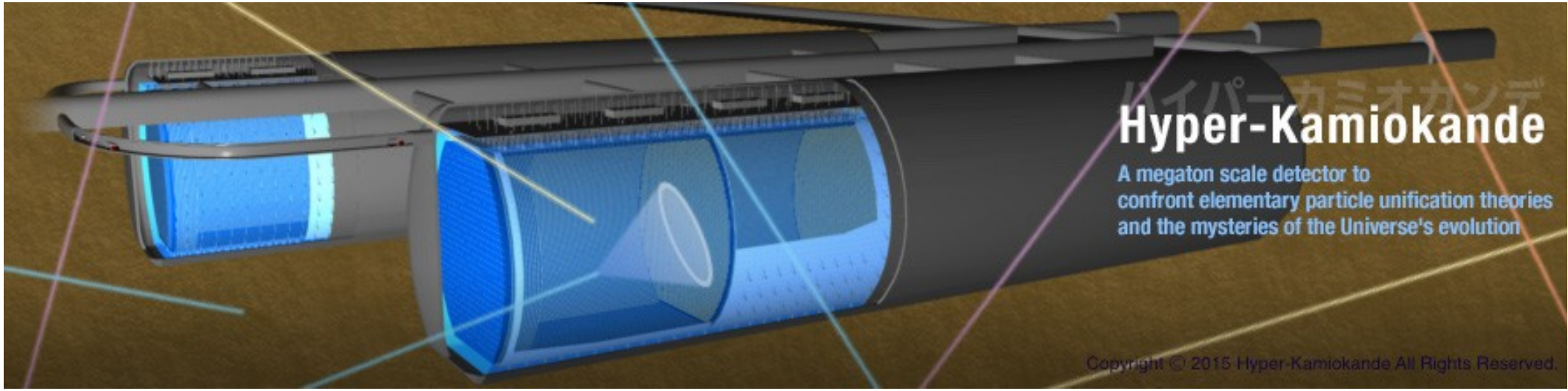
Software & Tank Studies

Francesca Di Lodovico (QMUL)

Third Hyper-Kamiokande EU Meeting
CERN, 27-28 April 2015



Tank Design



- Horizontal double tanks is a decade long design.
- Shape based on considerations of pressure on PMTs.
- However, new photosensors are available. Further studies on cavern available => <u>needed new look at original tank design</u>.

Tank Design

- Main challenge: keep the “same” physics potential. But need careful studies.
  - But it could be challenging to keep lowE physics with larger compartments (light attenuation, more noise hits against signal hits).
- New design should be supported by pressure tolerance of photo-sensors and cavern studies.
- Optimized cost envelop for new design.
- Timescale for new tank design: Design Report => report to KEK/J-PARC in October.

Design Report

IBR report at 6th Open Meeting (T. Nakaya):

http://indico.ipmu.jp/indico/getFile.py/access?contribId=13&sessionId=0&resId=0&materialId=slides&confId=52

Detector design

- We must convince reviewers/managements that we are ready for budget request of real experiment
- Making a optimum design for the report is crucial
  - Optimum cavern location and shape
  - Liner material and design
  - Outer detector design (width, PMT density etc)
  - water system
  - PMT support structure
  - FV cut (can we reduce 2m Dwall cut?)
  - Photo-detector size, density, accessaries
  - DAQ electronics and computers
  - Calibration strategy
  - Near detector complex
  - Maximized physics potentials

Many places to contribute

The optimized experiment will constitute the content of the Design Report (DR)

A reminder of the proposed tank designs:

Shoei Nakayama
Masato Shiozawa
Hide-Kazu Tanaka
6th open meeting

Assumption for the case study

- Assume that the veto region could be reduced
  - OD thickness 2 m → 1m for barrel, 2m for top/btm
  - Insensitive region 0.9 m → 0.6 m
  - Dwall for FV 2 m → 1.5 m
- Assume that the photocathode coverage could be reduced by using improved photodetectors
  - QE (Quantum Efficiency) 22 % → 30 %
  - CE (Correction Efficiency) 80 % → 93 %

(22/30) x (80/93) = 63 %

→ Change the PD number density to 63% of current design

→ 1 PD/1.6 m^2 (cf. 1 PMT/0.5 m^2 @SK)

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Case study – Summary

	Case 1 (2 tanks)	Case 2 (3 tanks)	Case 3 (3 tanks)
Water tank size	H: 100m, D: 69m	H: 80m, D: 64m	H: 60m, D: 74m
Fiducial volume	569 kt	565 kt	561 kt
Excavation vol.	868k m^3 (72%)	915k m^3 (76%)	968k m^3 (81%)
ID surface	52800 m^2 (53%)	60300 m^2 (61%)	60200 m^2 (61%)
# of PDs (ID)	33.3k (34%)	38k (38%)	38k (38%)
FV/Excav.*	0.66	0.62	0.58

* FV/Excav. for the baseline design is 0.47.

- Reduction of excavation vol. → Thanks mostly to thinning down the veto region and removing the segmentation walls
- Reduction of ID surface → The shape diff. contributes much

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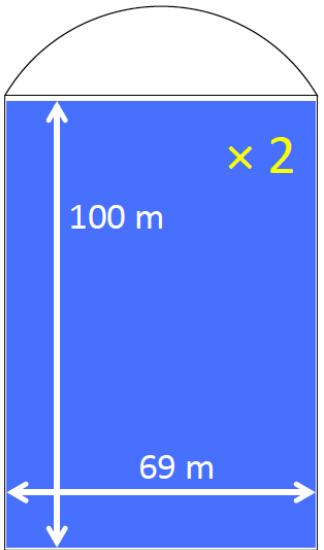

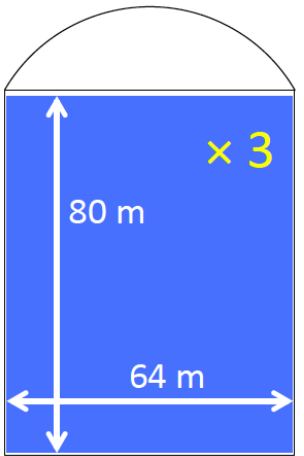

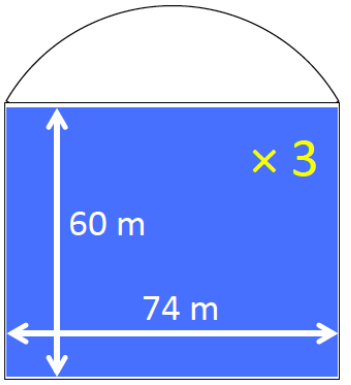

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Smaller photodetectors ?

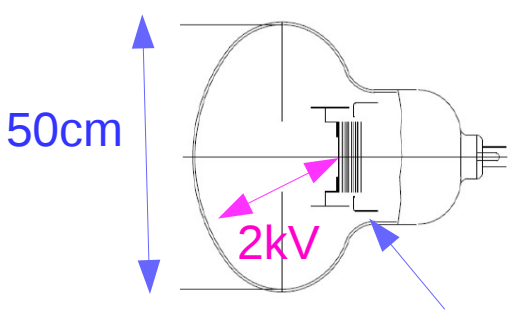
- The number density of photodetectors in case studies above is 1/3 of SK's (cf. 1/2 of SK's in the baseline design).
  - By considering an improvement of the PD efficiency (QE×CE).
  - Total photon detection efficiency may be unchanged from that of the baseline design, but the event reconstruction performance will get worse due to the smaller granularity (especially for events near the wall).

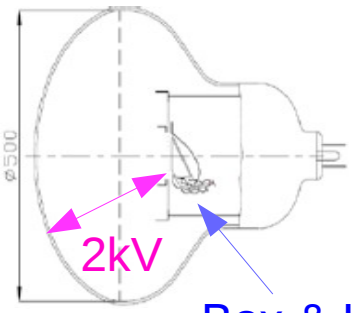
- Instead of using 20" PDs with the number density of 1/3 SK's, how about using 1/3 smaller (~12") PDs with the same number density as SK ?
  - 33k-38k 20" HQE PDs → 100k-120k ~12" HQE PDs ?

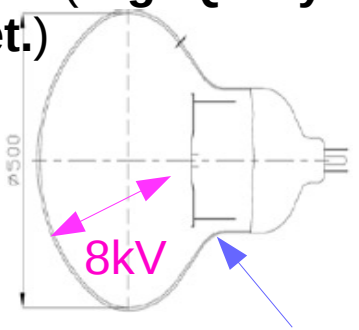
Summary of Photosensors

- Current photosensors implemented in the simulation and used for the tank studies:

R&D going to get better perfomance and lower costs







Quantum Eff. (QE)	22%	30%	30%
Collection Eff. (CE)	80%	>90%	>90%

- It was finally decided to use the Box-and-Line (BL) high QE PMTs in the tank simulation, as suggested by the photosensors group.

Summary of Investigated HK Tanks

H(m)	D(m)	# of Tanks	ID PDs	ID PD Grid Size	ID Photocoverage	Total # of ID PDs	OD PDs	Total # of OD PDs
100	69	2	20” HQE	122.5cm	13.51%	35,196	8”NQE	17,598
100	69	2	12” HQE	70.7cm	14.59%	105,590	8”NQE	17,598
80	64	3	20”HQE	122.5cm	13.51%	40.188	8”NQE	20,094
80	64	3	12”HQE	70.7cm	14.59%	120,564	8”NQE	20.094
60	74	3	20”HQE	122.5cm	13.51%	40,125	8”NQE	20,061
60	74	3	12”HQE	70.7cm	14.59%	120,375	8”NQE	20,061

- Physics studies need to be associated to the different tank configurations to tension them and decide on the best one, together with design consideration.
- Note, Gd-specific can needs to added to the plan yet.

Software in a nutshell

- Hyper-Kamiokande software release on GitHub.
- Developing an independent code from Super-K.
- However, ND and beam codes are necessarily related to the current software.
- An automatic vector generator (C. Kachulis) created and being extended to include all the physics categories.
- WCSim is the simulation software for the WC detector.
  - An open-sourced, GEANT4-based simulation code.
  - User can define a detector configuration by choosing a PMT type, cylinder size, option to add Gadolinium loading. Also, the HK detector is defined here.
  - Currently all the needed Pds and tanks have been implemented.
  - Run particles in your detector using either a user-defined vector file or using GEANT4 particle generation.

Software in a nutshell

- Reconstruction. Two reconstructions are currently available.
  - Low energy: BONSAI
    - Based on hit time likelihoods only
    - Assumes ≤ 1 hit per PMT per event
    - Used for low energy analysis like solar neutrinos, SN.
  - FiTQun
    - Based on charge and time likelihoods
    - Used for high energy analysis
  - Both packages work for Super-K (based on skdetsim)
  - Now being adapted for Hyper-K (based on WCSim)
- Analysis software:
  - Sensitivity code: VALOR, MACH3, SimpleFitter all available in Hyper-K
  - Detailed analysis code will be developed in the near future.

Cross checks with Super-K Tank

- Initial cross checks have been performed using the Super-K tank instrumented with new photosensors.
- Configurations:

Detector size	ID PDs	ID Photocoverage	Corresponding ID Grid size	Total # of ID PDs
SK-size	20” NQE PMT	20.27%	1 PD / 1.0 m^2	5,496
SK-size	20” HQE BL	20.27%	1 PD / 1.0 m^2	5,496
SK-size	20” HQE BL	13.51%	1 PD / 1.5 m^2	3,676
SK-size	12 HQE BL	14.59%	1 PD / 0.5 m^2	11,082

- Goals:
  - Validate Hyper-K software comparing w/ SK software
  - Initial validation of new PDs

SK tank studies for sw testing

Generate event samples by particle gun with SK2 setup (size: SK tank, coverage: 20%, normal 20” PMT) and compare performance with:

- SKdetsim+Apfit
- SKdetsim+fiTQun
- WCSim+fiTQun

Event samples

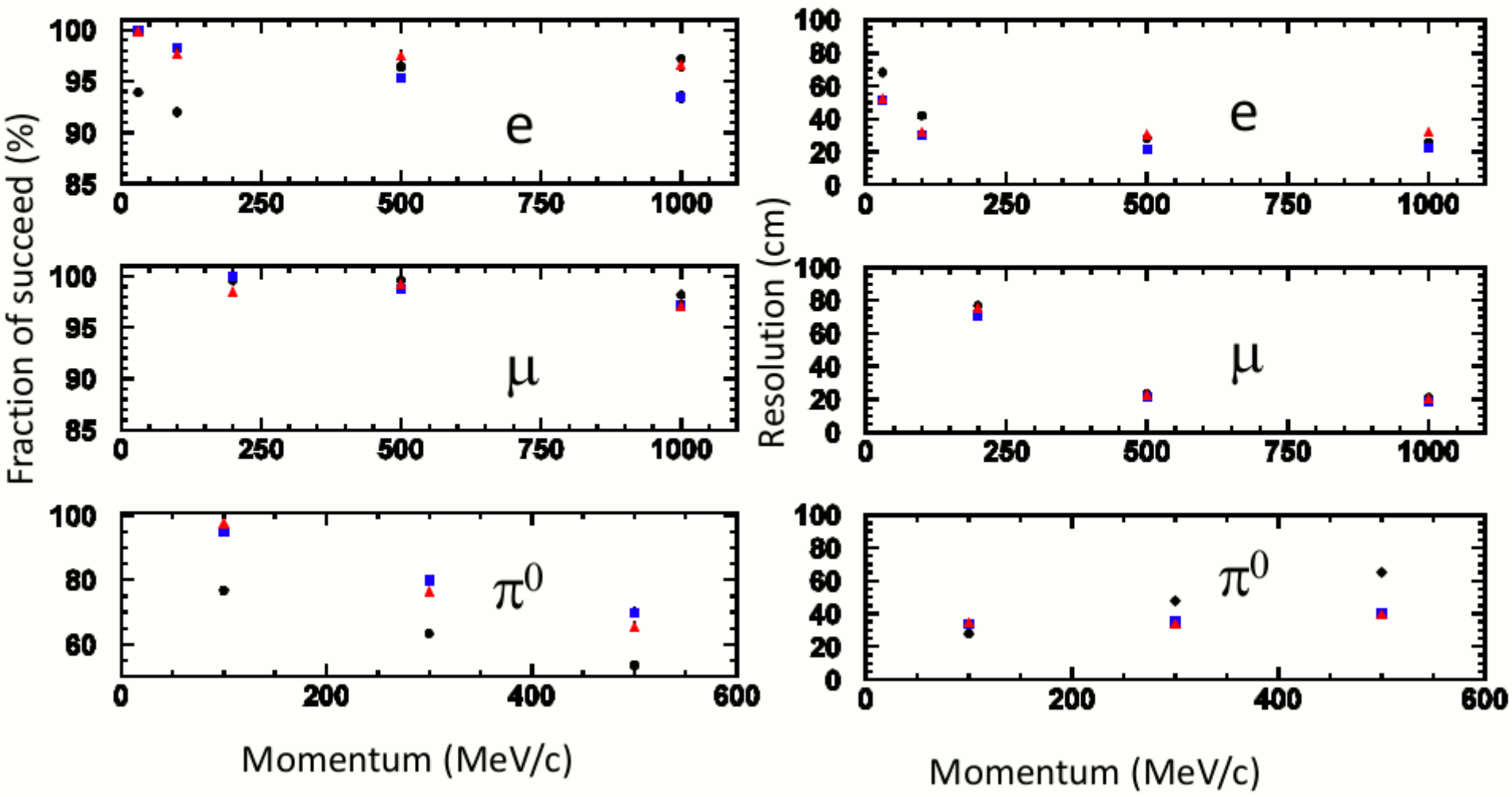
- electron: 30, 100, 500, 1000 MeV/c
- muon: 200, 500, 1000 MeV/c
- π^0: 100, 300, 500 MeV/c

Results comparing the SK and HK software show reasonable results. Note that the reconstruction has not been tuned yet.

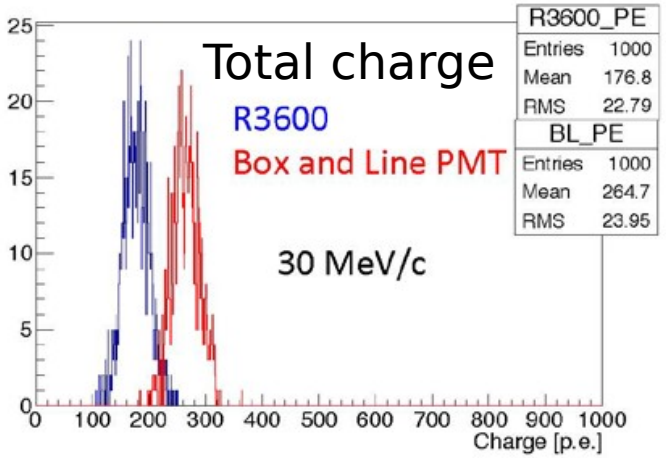
Hyper-K Software Validation

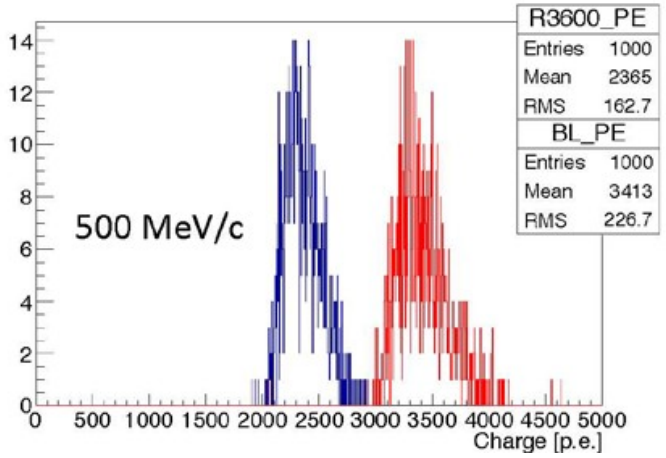
Black: skdetsim+apfit
Blue: skdetsim+fiTQun
Red: WCSim+fiTQun

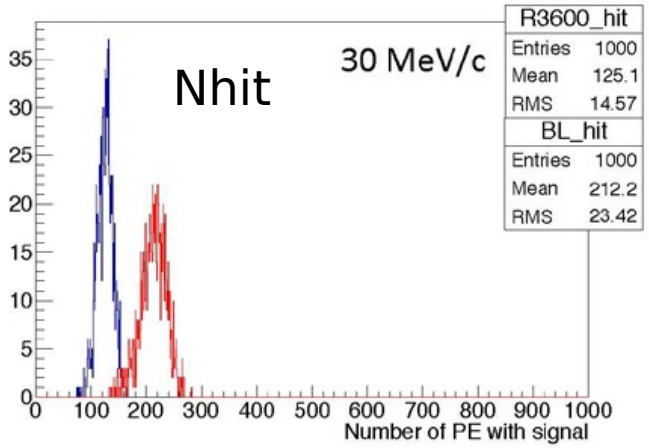
Yoshida, Okajima, Miura



Validation of B&L in WCSim





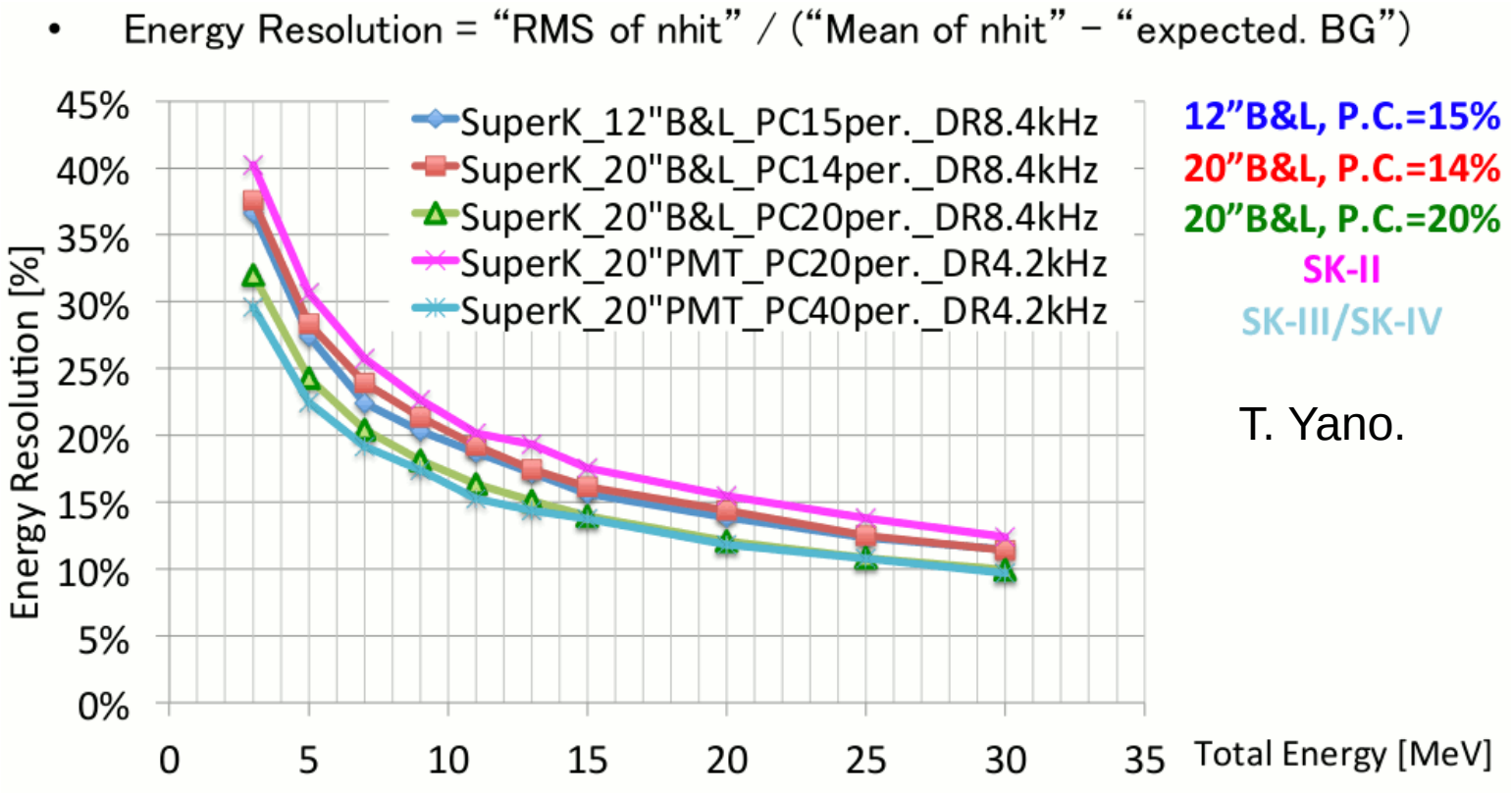


Jiang, Okajima, Yoshida, Miura

- Generate some events with 20% photo-coverage+20'B&L , and SK size tank.
- Compare number of hits and total charge.
- Increased by ~1.5 times, corresponding to higher QE and CE, as expected.
- Reconstructed momentum shifts as expected, as reconstruction fit not tuned => being done.

BONSAI fit of B&L PMTs

- Bonsai fit study with B&L started.
  - Momentum resolution: 20” B&L +14% coverage and 12” B&L+15% coverage are similar, better than 20” PMT+20% slightly.
  - Vertex resolution improved with B&L due to better time resolution.



Studies for the Different Tank Options

A large number of studies planned – mainly personnel limited.

Topics	Requirements	Comments
PDs in WCSim, update fiTQun	Parameters of Pds, Implementation in WCSim	Current status: fiTQun being update before production. Need personnel for checks.
Implementation OD in WCSim	Define strategy, start to implement in WCSim	Needed personnel for implementation.
Sensitivity Studies: accelerator	Production files, it depends on first two items	Some work can be started now using non reconstructed files. People needed.
Sensitivity Studies: atmospherics	Production files, it depends on first two items	Some work can be started now using non reconstructed files. People needed.
Sensitivity Studies: proton decay	Production files, it depends on first two items	Some work can be started now using non reconstructed files. People needed.

Studies for the Different Tank Options

A large number of studies planned – mainly personnel limited.

Topics	Requirements	Comments
WCSim	Improved handling of noise/radiative background	Being done mainly within the UK DAQ physics studies
PDs in WCSim, integration Bonsai	PDs in WCSim (done)	Current status: integrating BONSAI in HK release
Sensitivity Studies: supernova	Above two topics, vector files (being implemented), production	Personnel needed.
Sensitivity Studies: solar neutrinos	Above two topics, vector files (being implemented), production	Personnel needed.
Sensitivity Studies: others	Above two topics, vector files (being implemented), production	Personnel needed.

Conclusion

- Studies on the tanks are needed for the design report – submissions to the KEK/ICRR reviewers in October.
- Implementation of the tanks in the code almost ready.
- Once the reconstruction code is ready, the production will start.
- It is an area whether more personnels is needed both for WCSim (eg OD implementation) and physics studies.