SK Calibration Parameters and Constraints

S.Mine (UCI) for SK calibration and detector simulator groups

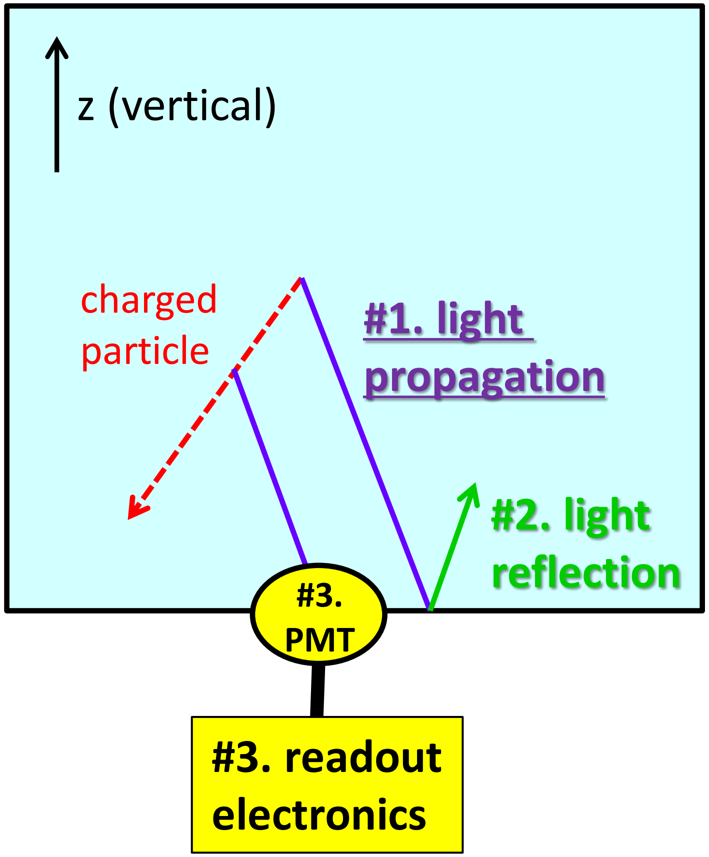
Introduction

- Requests from Mike:
  - A complete list of SK calibration parameters within SK detector simulator (SKDETSIM)
  - What calibration samples were used to constrain them, and how
- References:
  - "Calibration of the Super-Kamiokande detector", SK collaboration, **Nucl.Instrum.Meth. A737 (2014) 253-272**
  - **"**The Super-Kamiokande detector" , SK collaboration, **Nucl.Instrum.Meth. A501 (2003) 418-462**
  - "Overview of the tuning of SKDETSIM", J.Kameda, T2KSK/SKLB joint workshop on December 5th, 2009
- I will focus on ID and SK-IV.

#1. MC calibration parameters in SKDETSIM

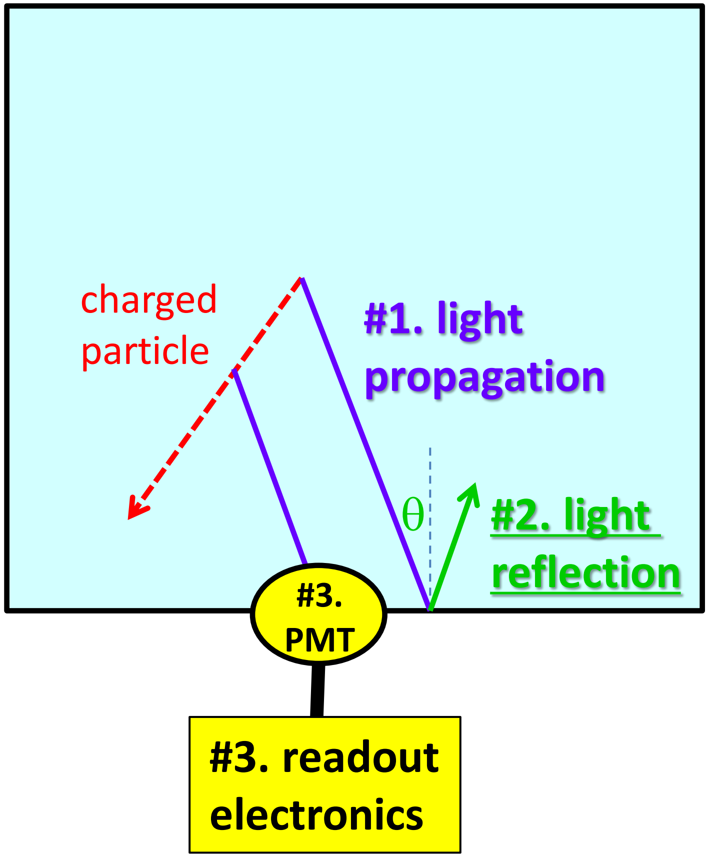
parameter	calibration
light absorption(λ, t*)	real-time laser beam
light symmetric scattering(λ, t*)	real-time laser beam
light asymmetric scattering(λ, t*)	real-time laser beam
light absorption(z, t*)	Ni and Xe

(* no time dependence used in high-E analyses,
April 2009 parameters used in high-E analyses)



#2. MC calibration parameters in SKDETSIM

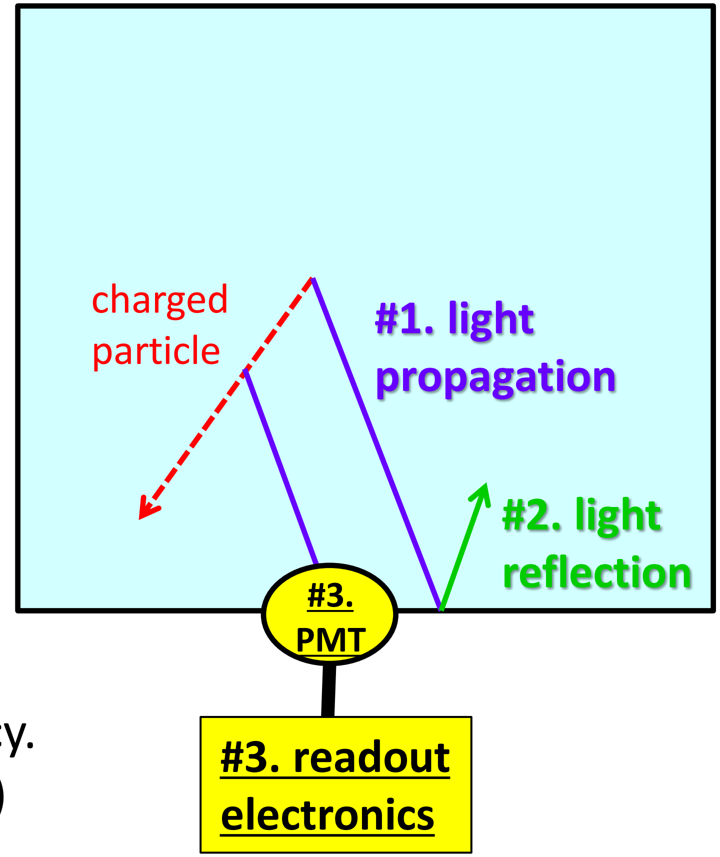
parameter	calibration
light reflection at PMT: reflective index (real and imaginary)	real-time laser beam
light reflection at black sheet: reflectivity(θ)	light injector set
light transparency and reflection at acrylic cover	spectromete r?



#3. MC calibration parameters in SKDETSIM

parameter	calibration
single photo electron (SPE) charge distribution and threshold behavior	**Ni**
relative differences in QE*s	**Ni**
global photoelectron yield	**cosmic ray thru-μ**

(* "QE": collection efficiency × quantum efficiency.
QE is assumed to be constant on photo cathode)



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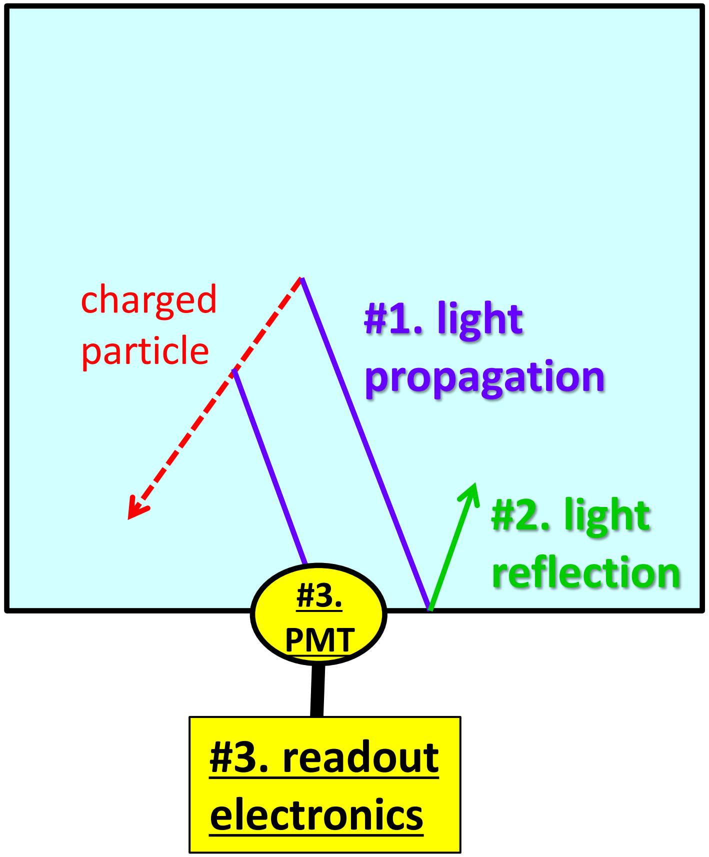
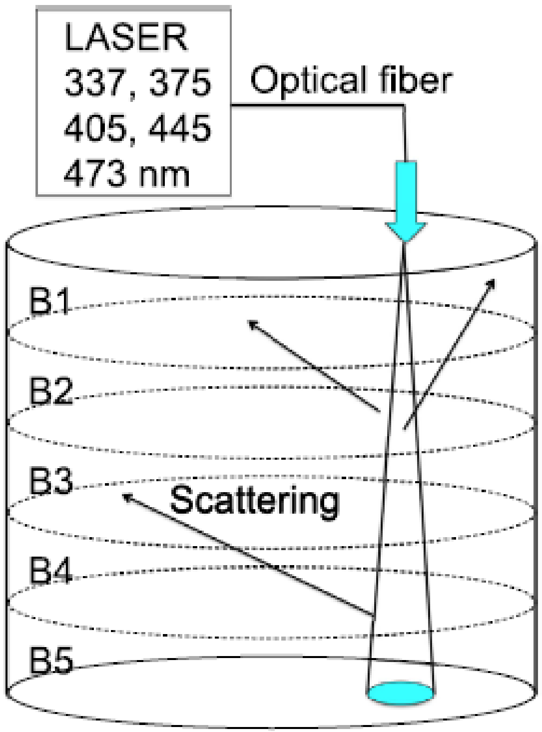
parameter	calibration
non-linearity of charge	**N+dye laser**
timing resolution: $\sigma_{earlier}$ and σ_{later} of asymmetric Gaussian	**N+dye laser**
dark noise: charge distribution* and rate**	**off timing hits**

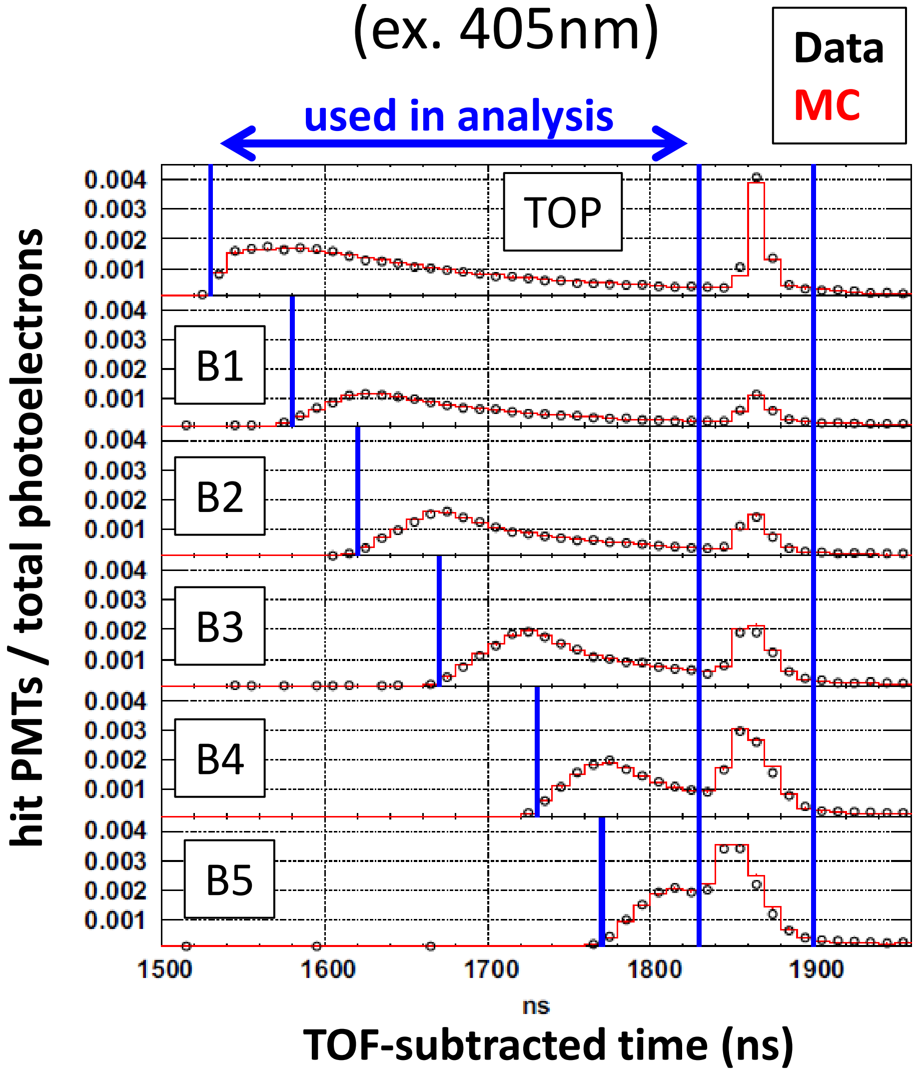
(* same as SPE from Ni data.
** 4.5kHz(fixed) for high-E analyses.
time dependent for low-E analyses?)



Light absorption and scattering



(ex. 405nm)



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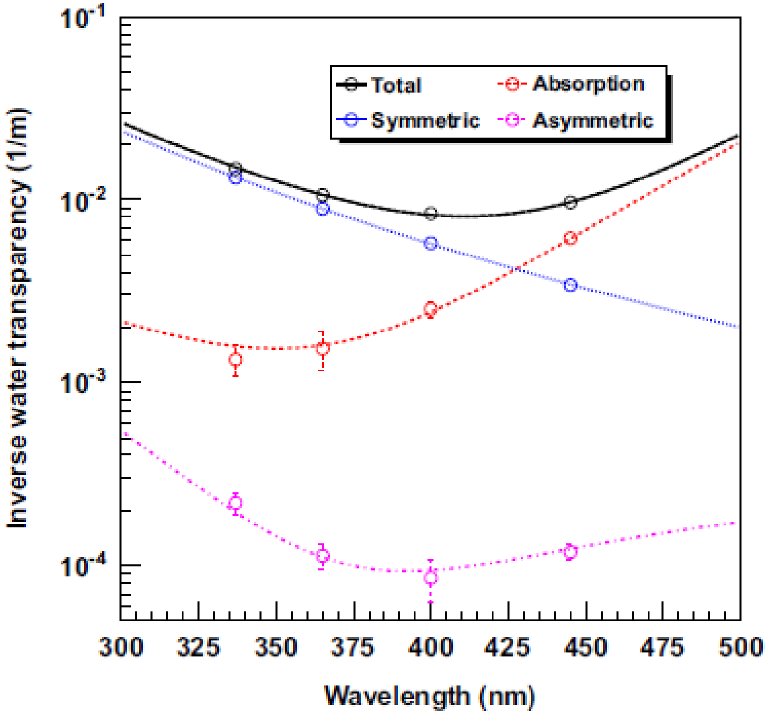
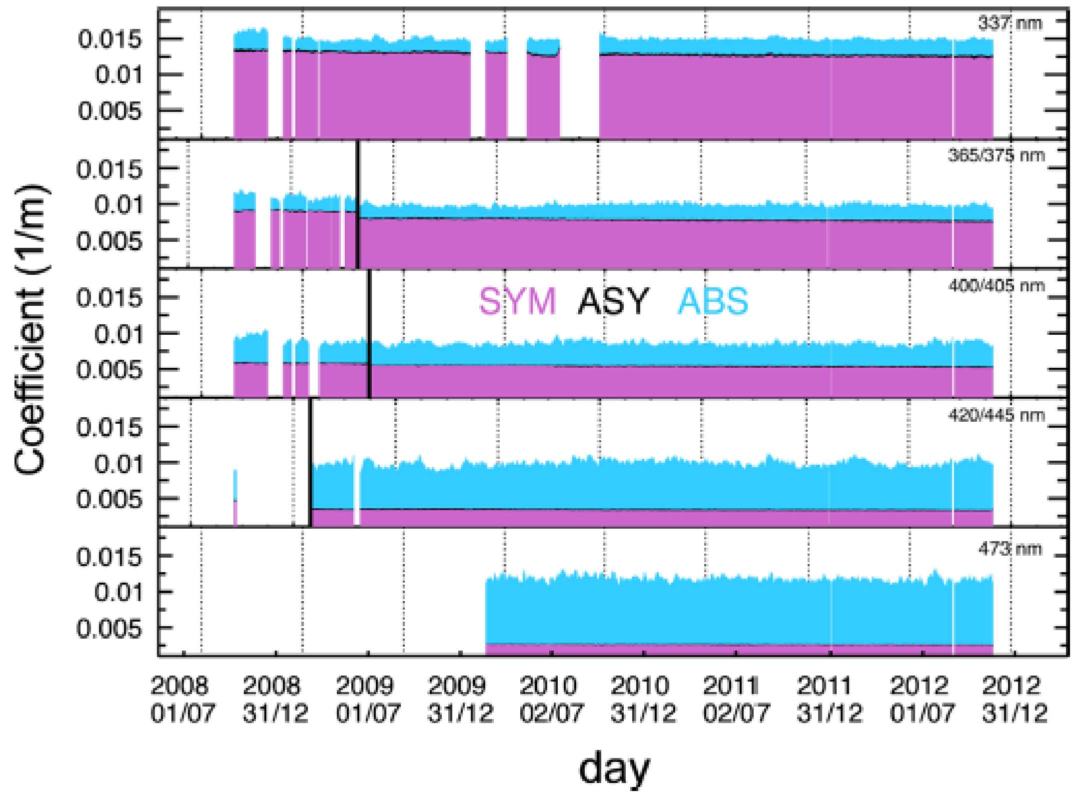




Data points (April 2009) fitted with empirical functions used in SKDETSIM

RMS/mean (Aug. 2008 – Nov. 2012):
~3% for symmetric scattering
20-40% for absorption

Z dependence of light absorption

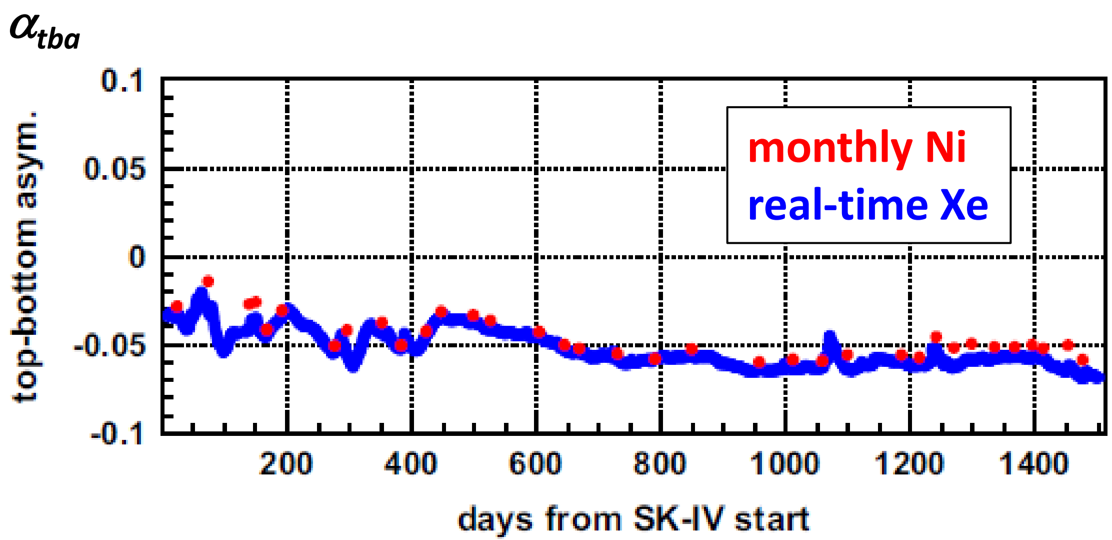
$$L(\lambda) = \frac{1}{\alpha_{abs}(\lambda) + \alpha_{sym}(\lambda) + \alpha_{asy}(\lambda)}$$

Multiplying $\alpha_{abs}(\lambda)$ by $A(z,t)$:

$$A(z,t) = 1 + z \cdot \beta(t) \quad \text{for } z \geq -11\text{ m}$$

$$= 1 - 11 \cdot \beta(t) \quad \text{for } z \leq -11\text{ m}$$

($A(z,t)$ constant for $z \leq$ -11m)

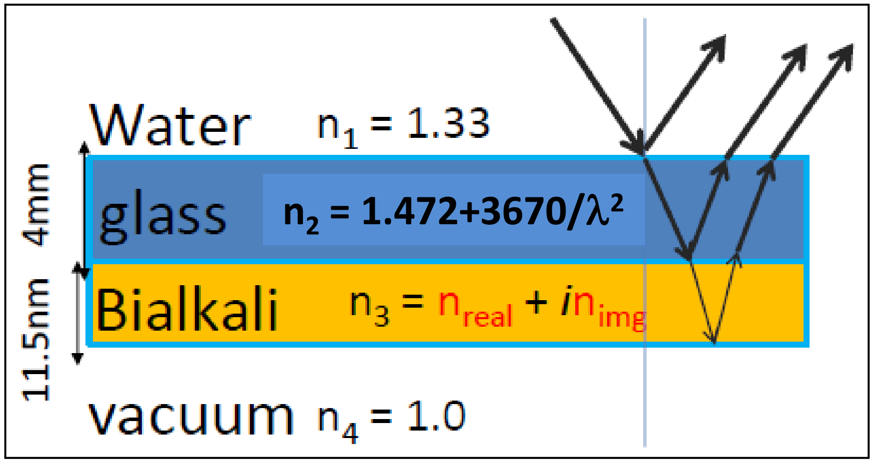


Ni data/MC used to determine slope $\beta(t)$

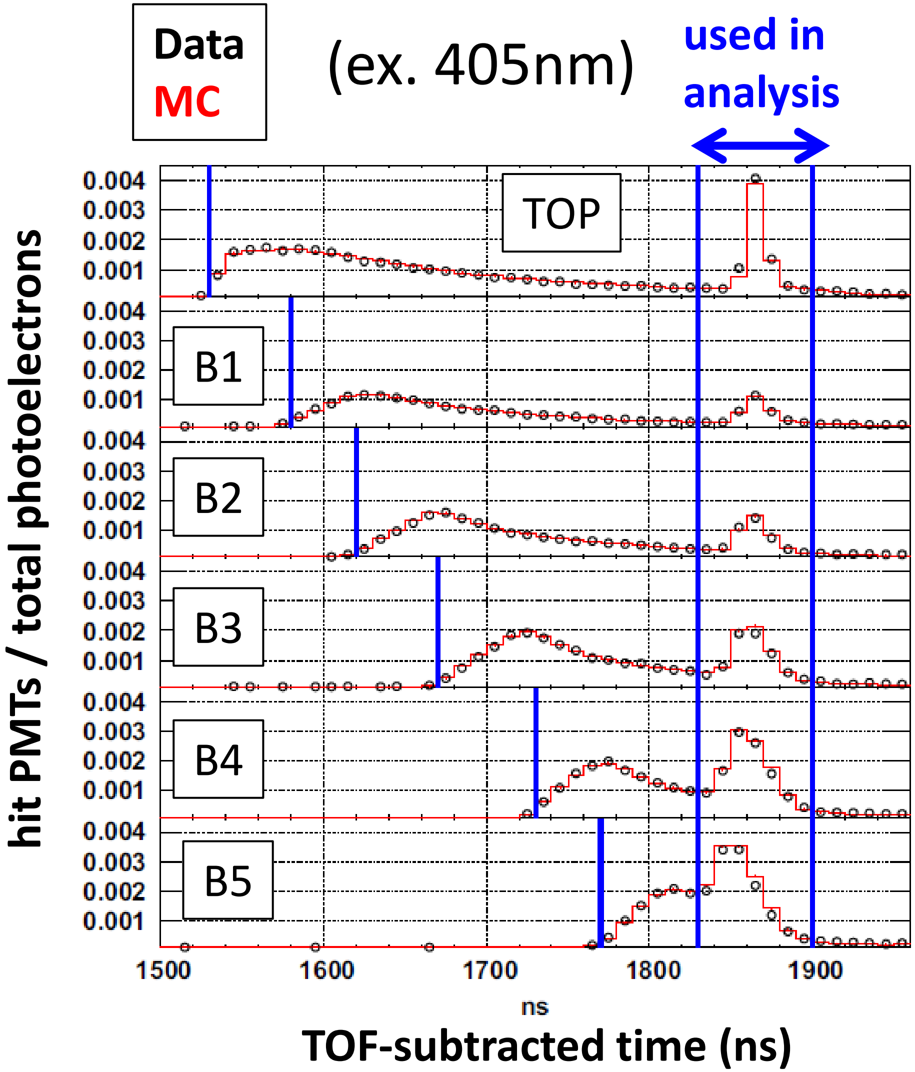
$$\beta(1/m) = (-0.163 \times (\alpha_{tba})^2 - 3.676 \times \alpha_{tba}) \times 10^{-3}$$

Ex.) (α_{tba}, β) = (-4.91%, 0.01) in April 2009

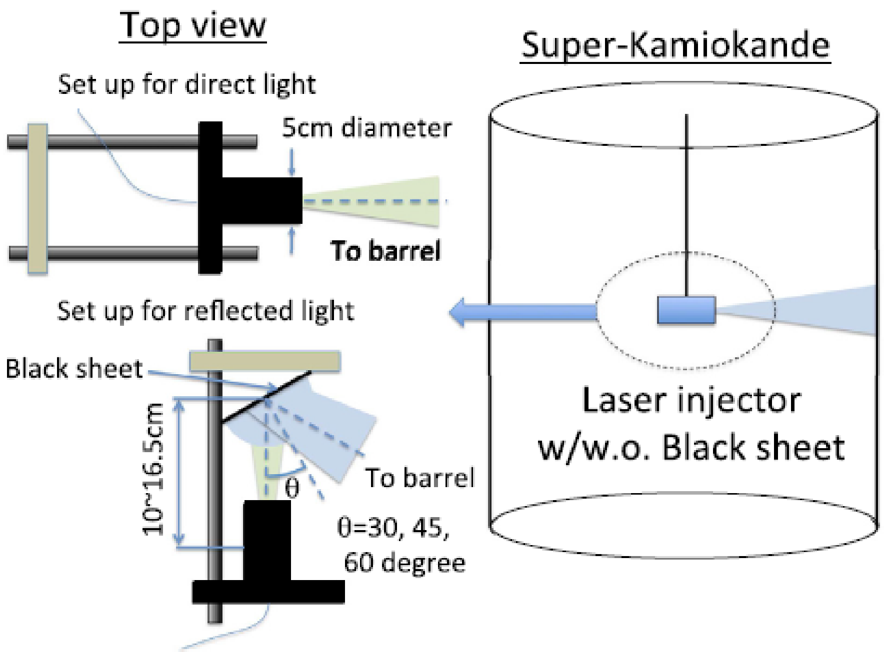
Light reflection at PMT



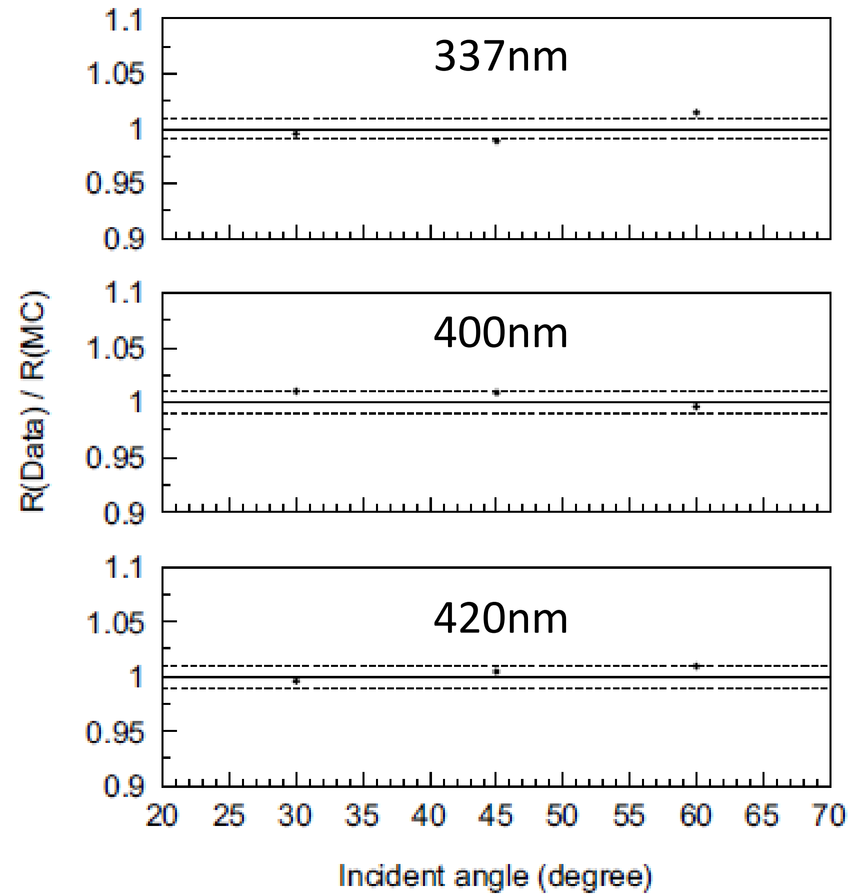
fit n_{real} and n_{img} (real and imaginary parts of complex refractive index)



Light reflection at black sheet



(for normalization of reflectivity, data were taken without black sheet)



Tune reflectivity(θ) using $R = Q_{scattered} / Q_{direct}$

SPE charge distribution

Ni source

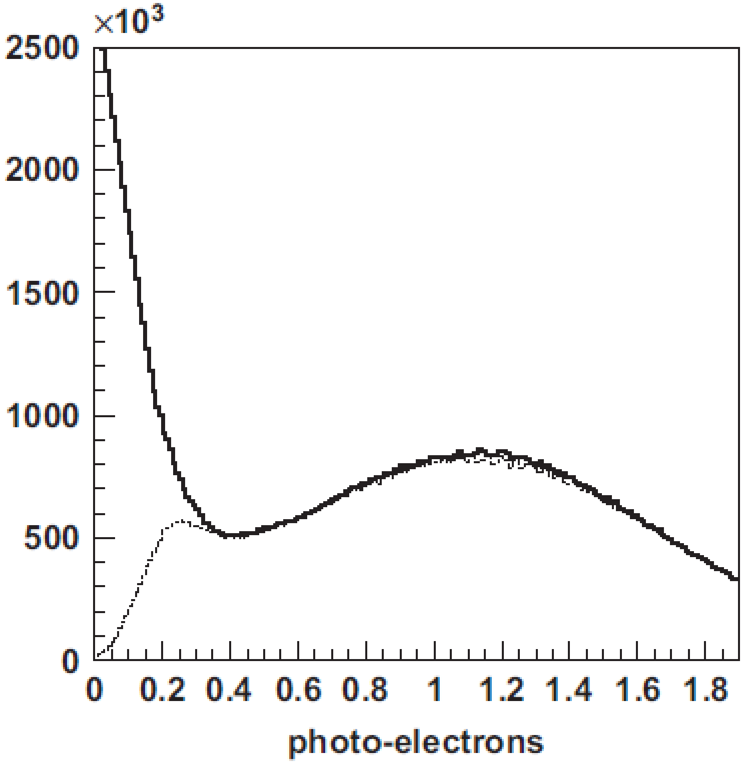
Isotropic ~9MeV γ from thermal n capture on nichel from $^{58}Ni(n,\gamma)^{59}Ni$.

^{252}Cf source provides neutrinos.

~0.004pe/PMT/event at ID center

(>99% signals due to single-pe)

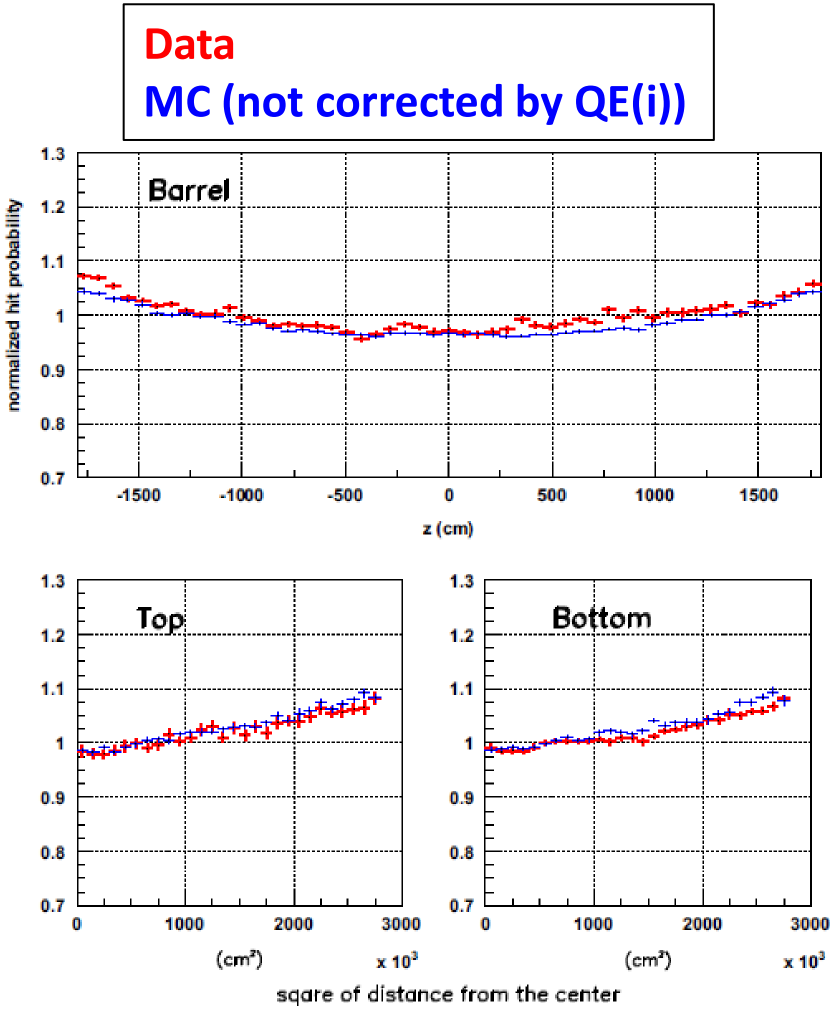
SPE in SKDETSIM



(solid from SK-III, dashed from SK-IV)

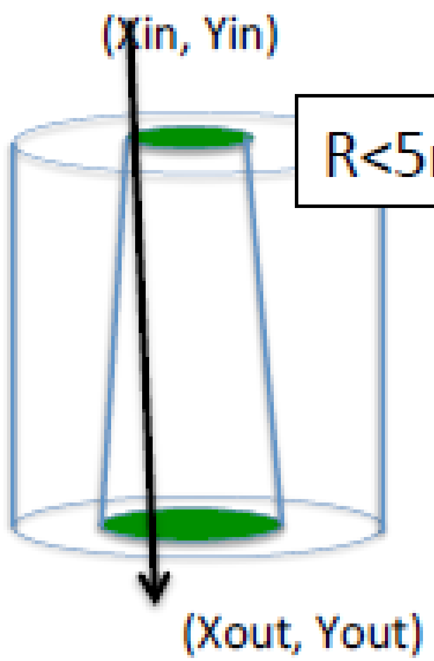
Hit probability (Ni)

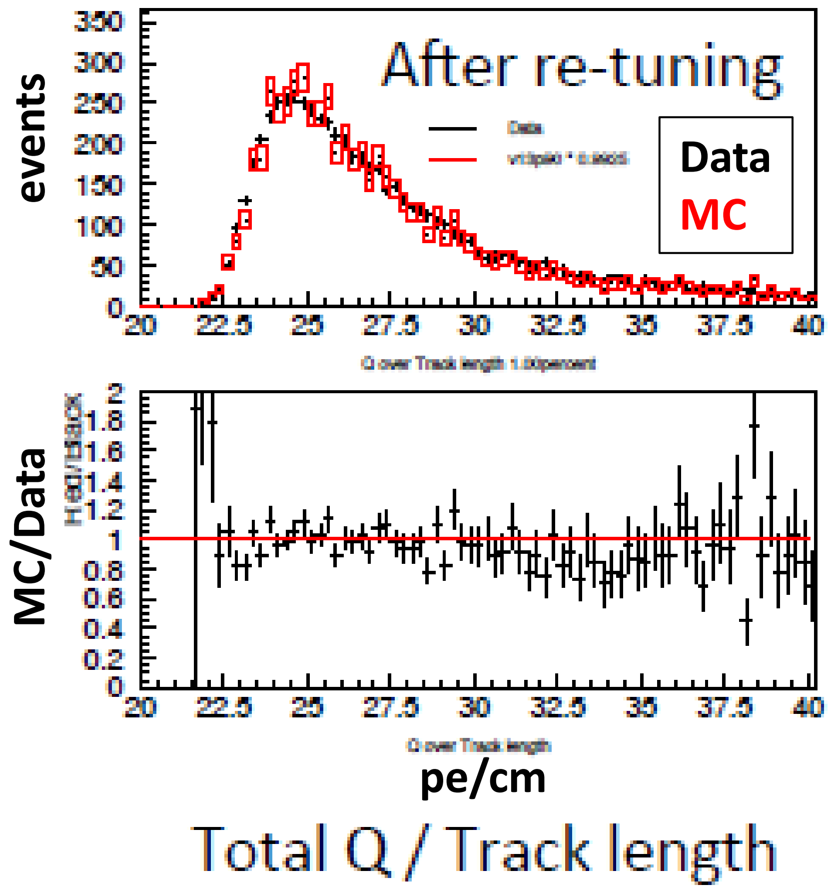
- Ni data taken when water convected over whole ID volume (no significant top-bottom asymmetry of water quality)
- Data/MC(w/o QE correction) difference is attributed to QE of individual PMTs tabulated in SKDETSIM



Global photoelectron yield

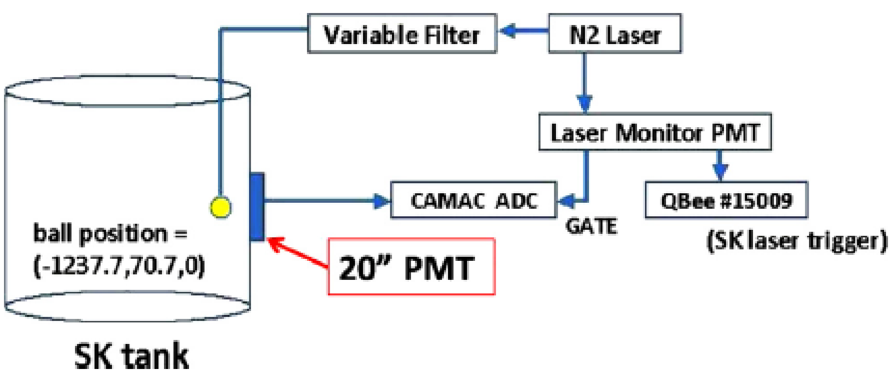
Cosmic ray thru-μ

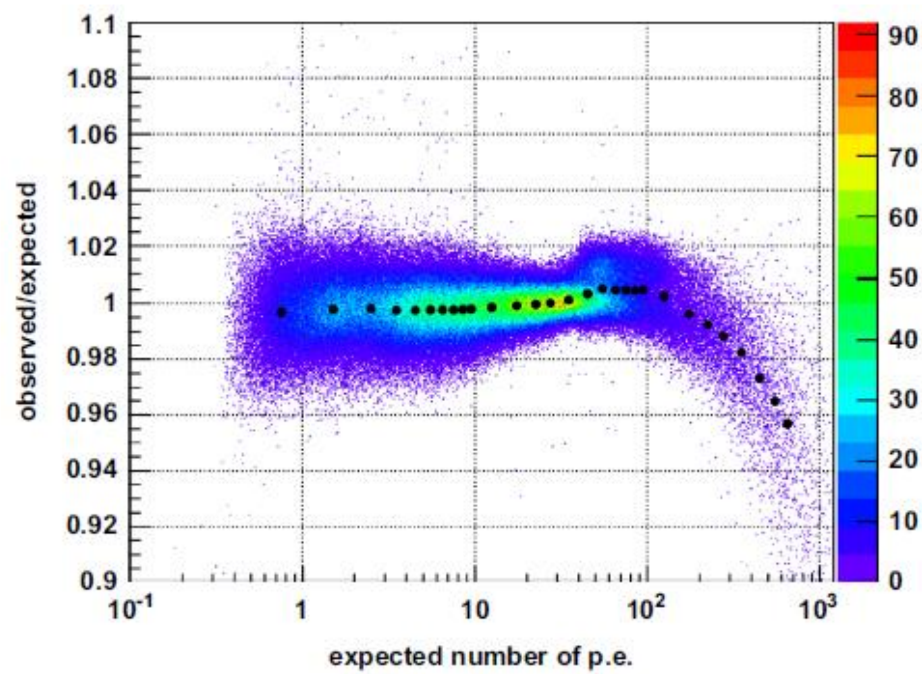




Global scale of QE for all PMTs

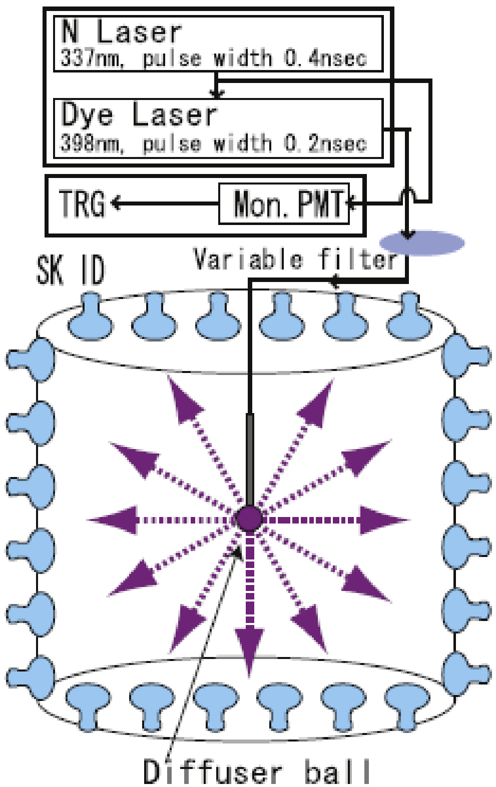
Non-linearity of charge

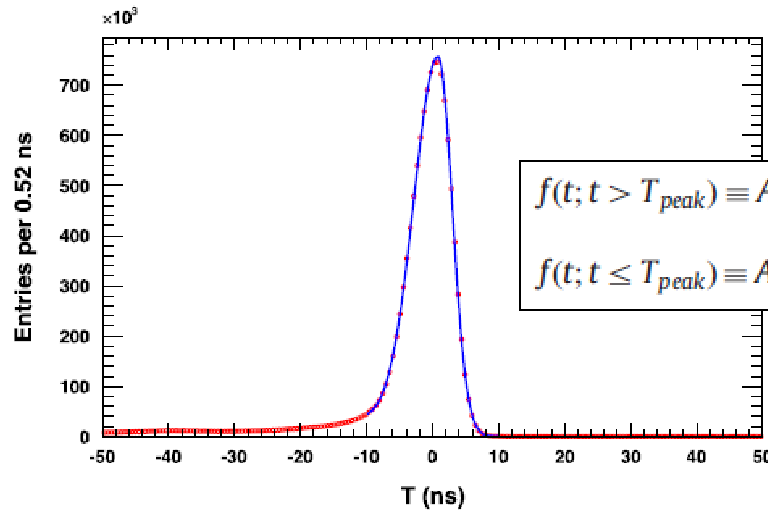




Non-linearity (averages as black points) in SKDETSIM

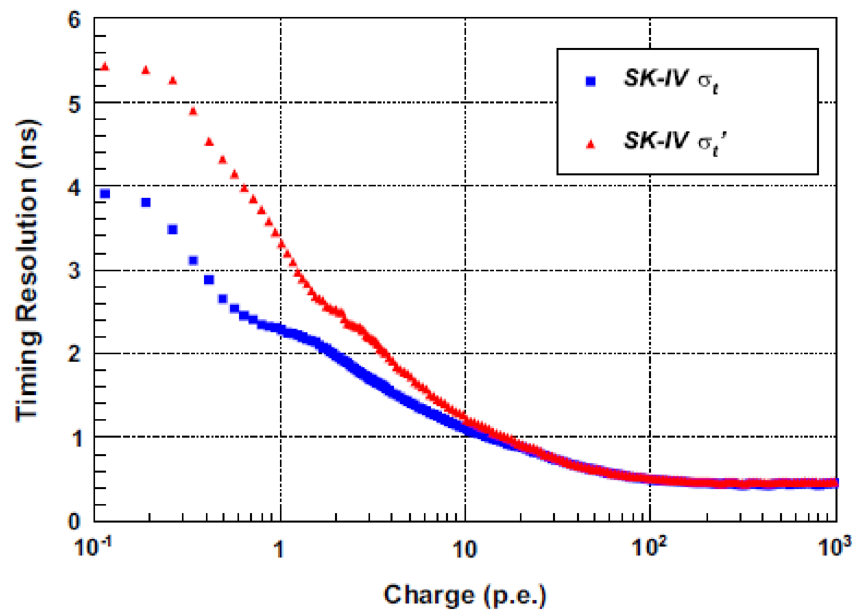
Timing resolution





$$f(t; t > T_{peak}) \equiv A_1 \cdot \exp(-(t - T_{peak})^2 / \sigma_t^2) + B_1$$

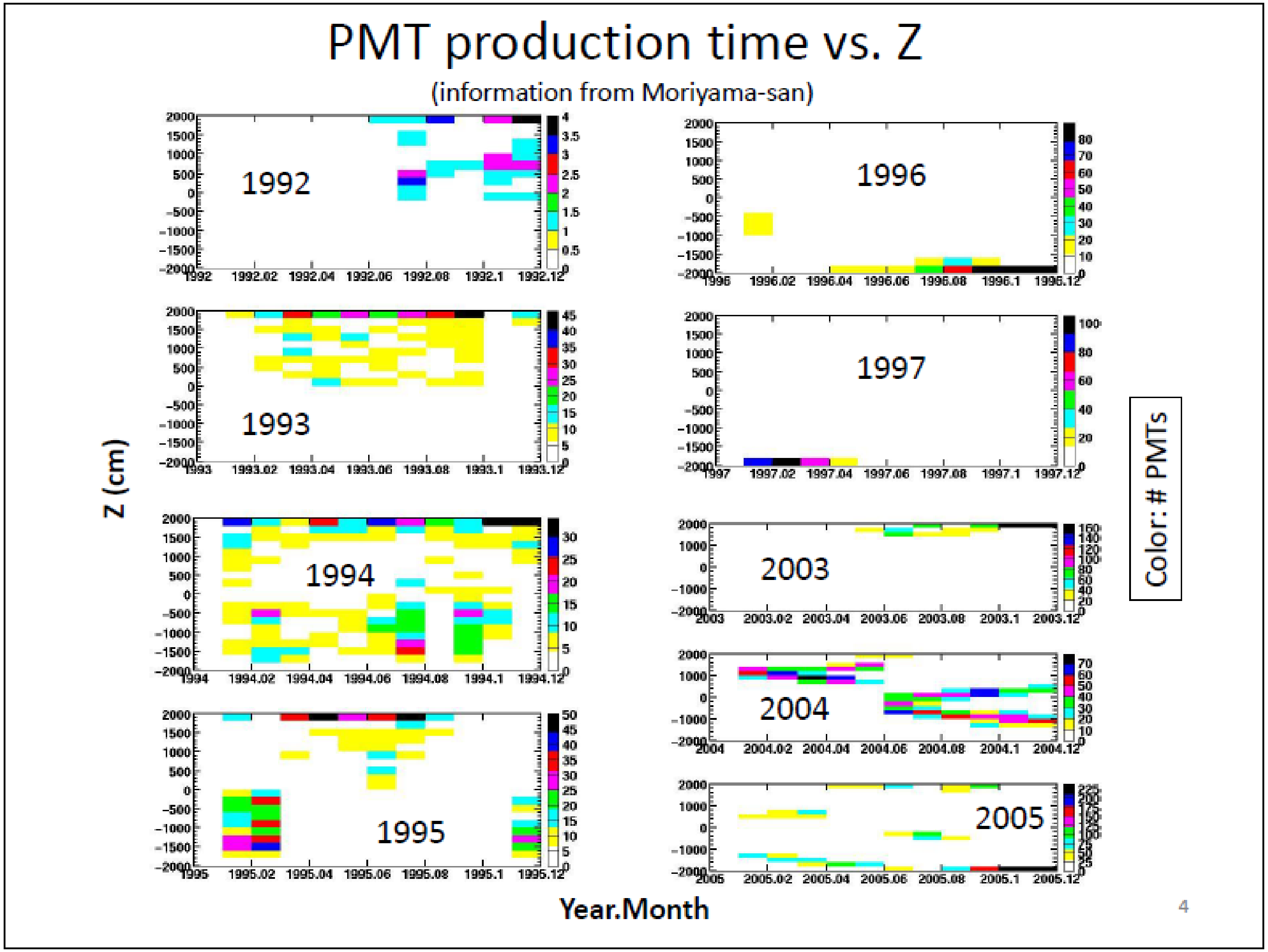
$$f(t; t \leq T_{peak}) \equiv A_2 \cdot \exp(-(t - T_{peak})^2 / \sigma_t'^2) + B_2$$



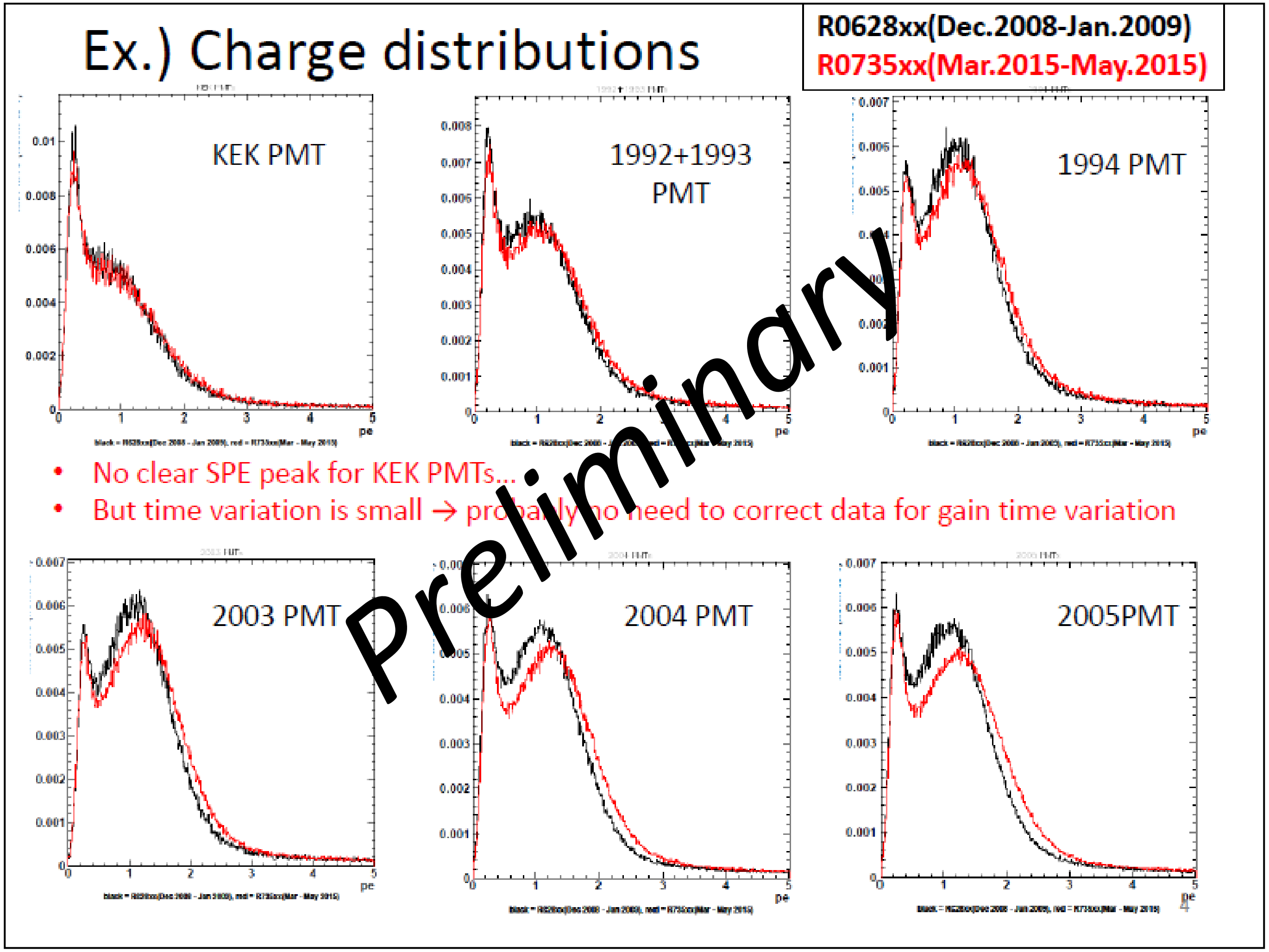
On-going SK calibrations

- Rayleigh scattering measurement with polarized laser
  - Rayleigh scattering amplitude
  - angular distribution of scattering
  - EGADS and Gd impact study (T2K TN-256)
- PMT gain time variation study with Ni, dark noise, etc.
  - dependence on PMT production year (see also Roman's talk)
  - aiming to implement in real time process and provide new data base for event reconstructions soon
- Photo-sensor Test Facility at TRIUMF
  - position/angle dependence of QE, etc.
- Dark noise rate measurement (see Shimpei/Suda's talks)
- and so on.

PMT production time vs. Z

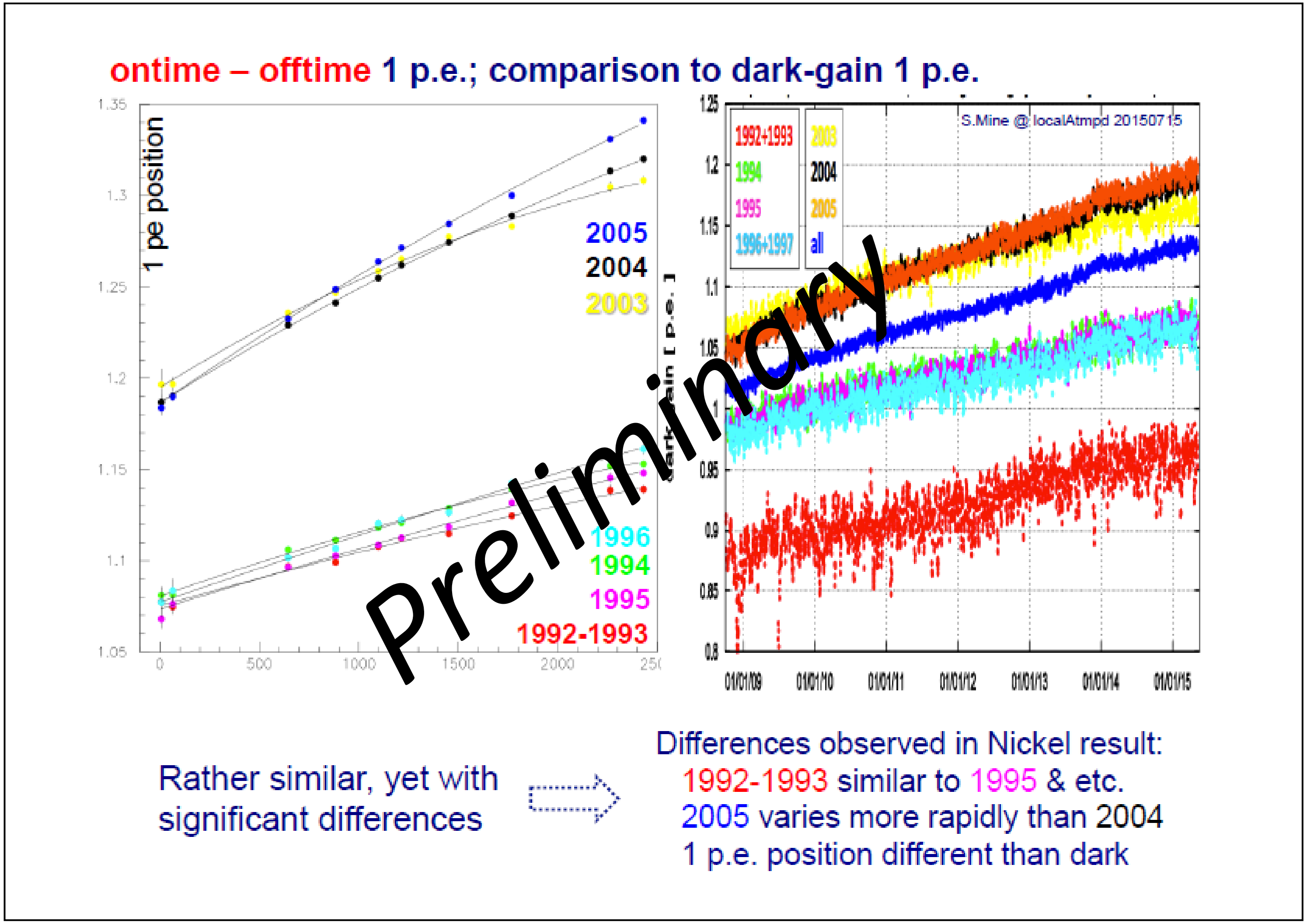


Dark noise charge distributions



- Shape is changing?

Time variation of charge distribution peak Ni vs. dark noise



- Need to understand difference of slopes between Ni and dark noise

Issues and To-do

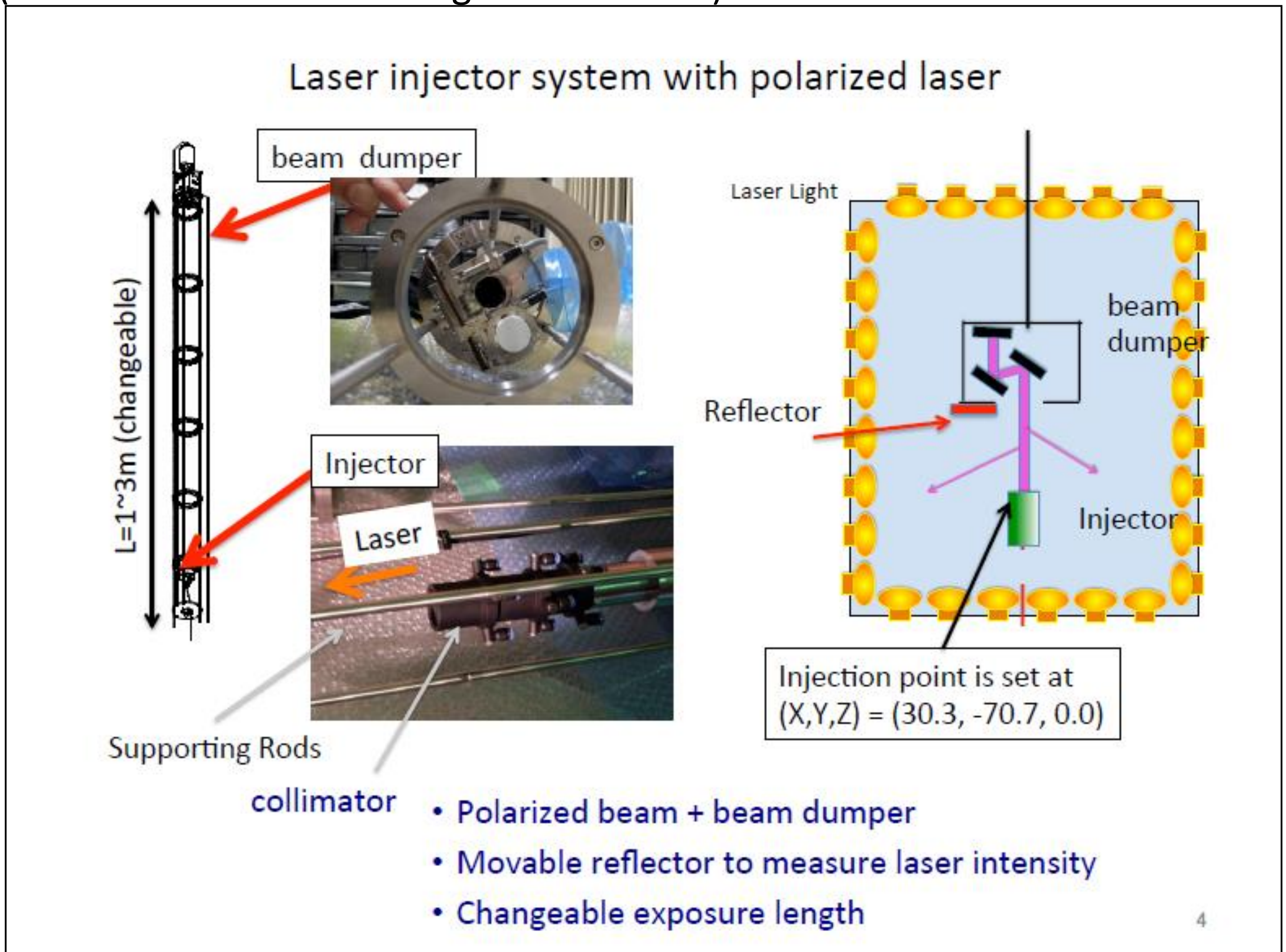
- Uncertainty of each existing parameter?
- No-missing major parameter to make "a complete list" for "bottom-up" systematics study?
- On-going calibrations

(join SK calibration group?)

Supplement

Rayleigh scattering measurement

(Kameda-san at SK meeting in June 2015)



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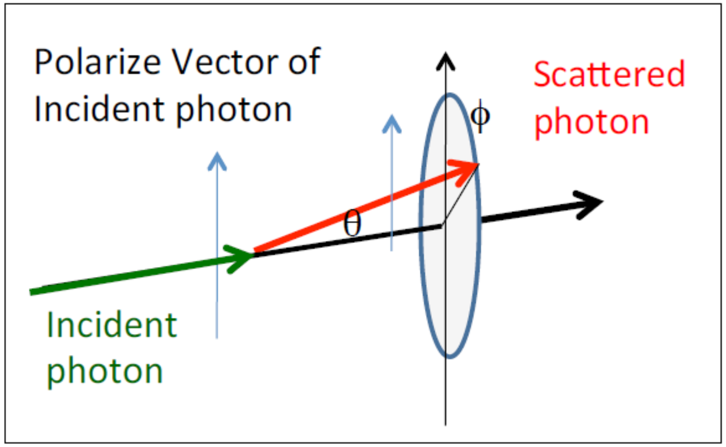
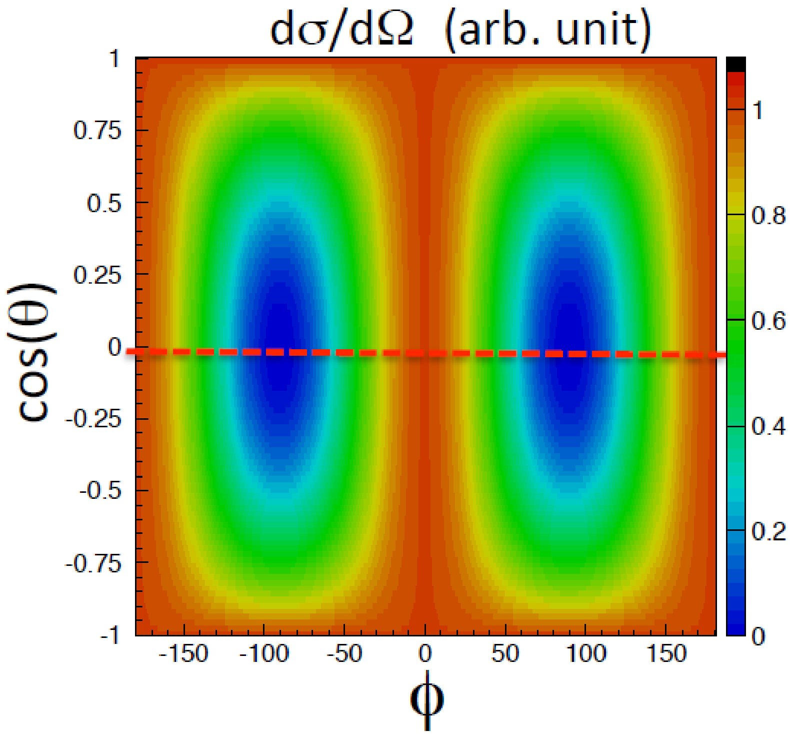


Polarize Vector of
Incident photon
Scattered
photon
ϕ
θ
Incident
photon



dσ/dΩ (arb. unit)
cos(θ)
ϕ
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-150
-100
-50
0
50
100
150
1
0.8
0.6
0.4
0.2
0