# Simulation for Gadolinium dissolved Water Cerenkov Detector

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In collaboration with

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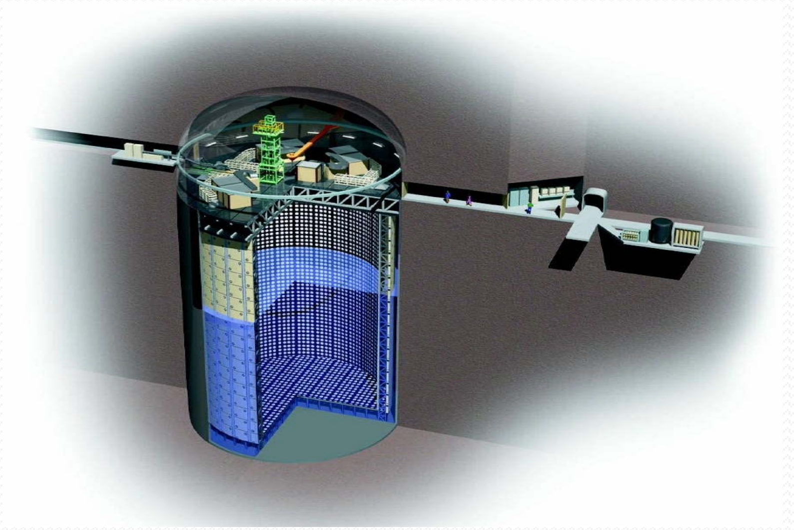
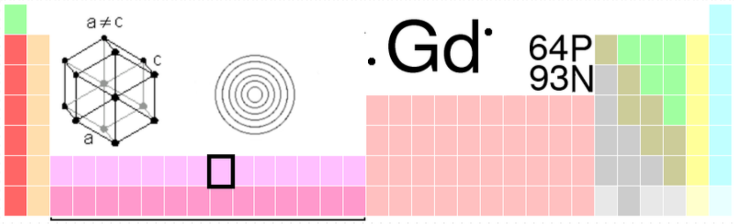
# Outline

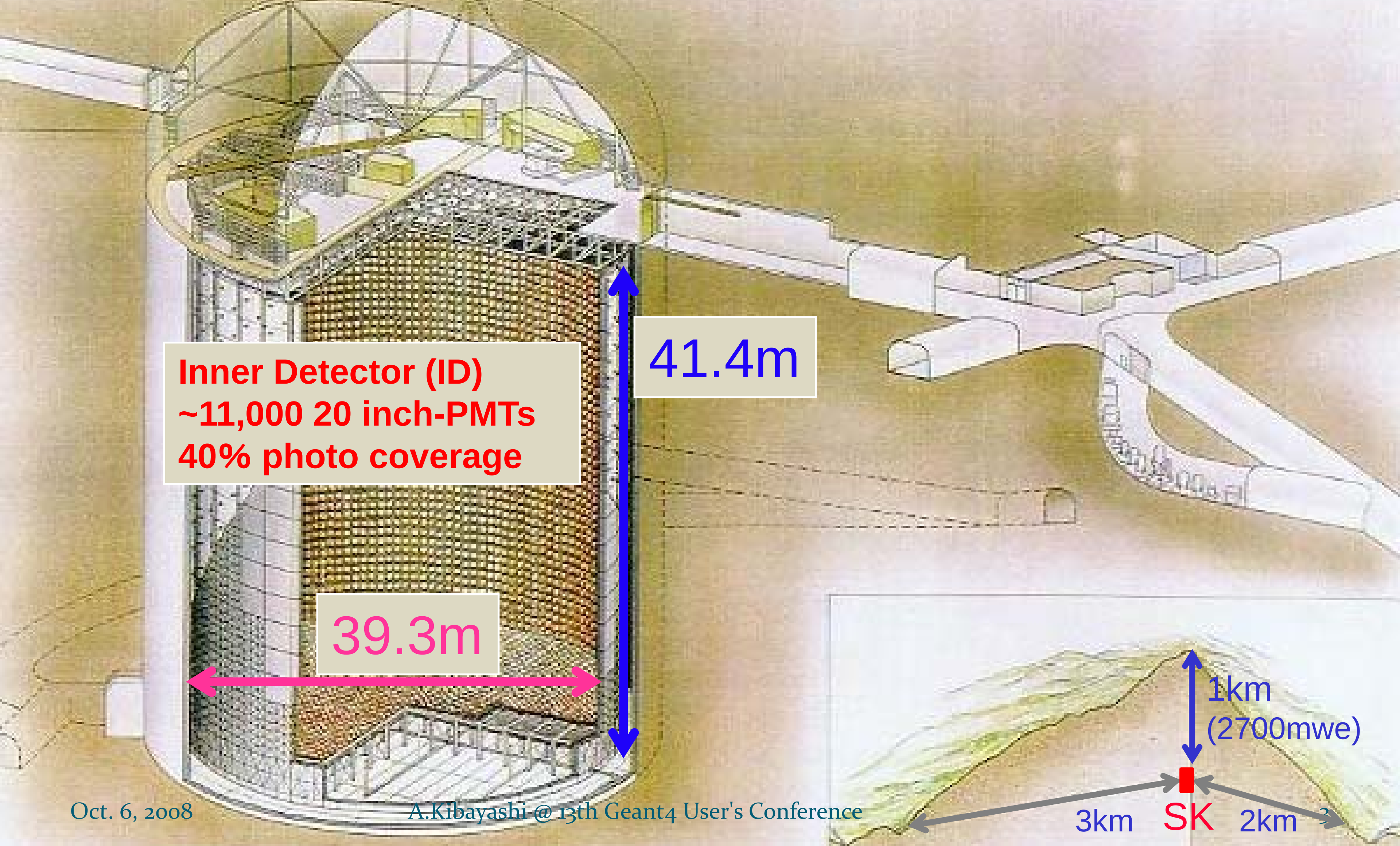
- Super-Kamiokande
  - A brief introduction
- Gadolinium
  - Why?
- Prototype Detector
  - Its purpose
- Simulation with Geant4
  - Status & ToDo
- Summary





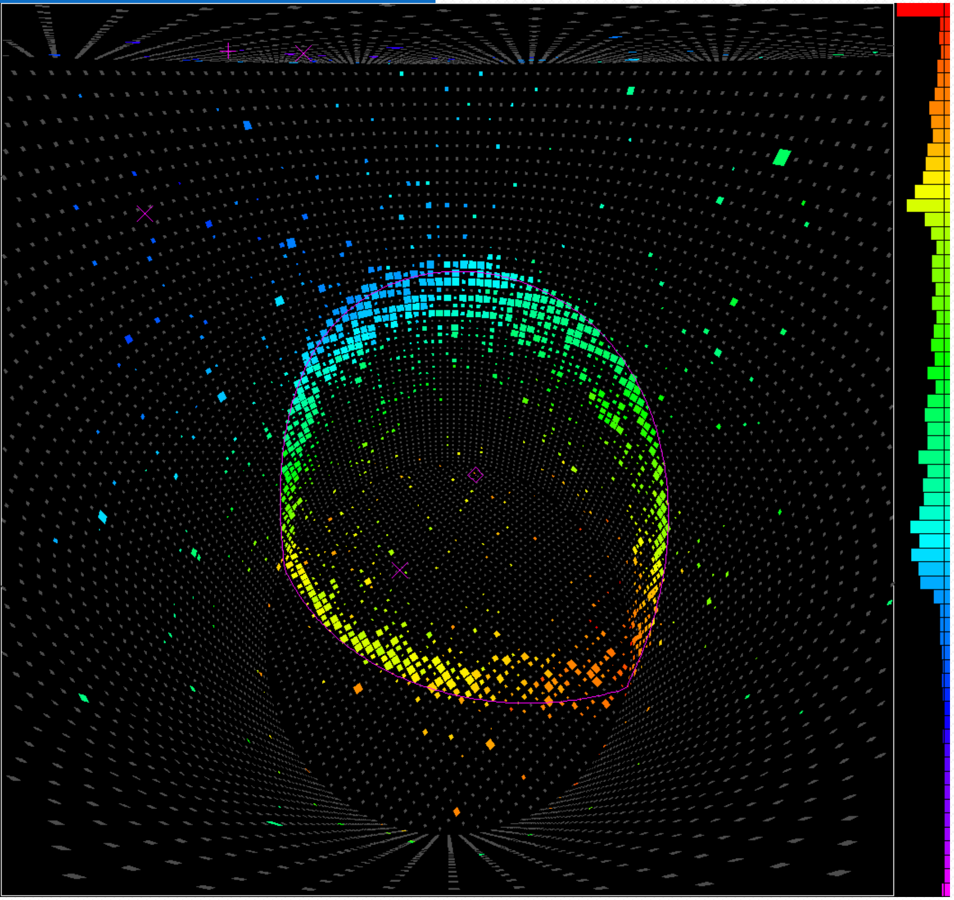
# Super Kamiokande (SK)

## a water cerenkov detector

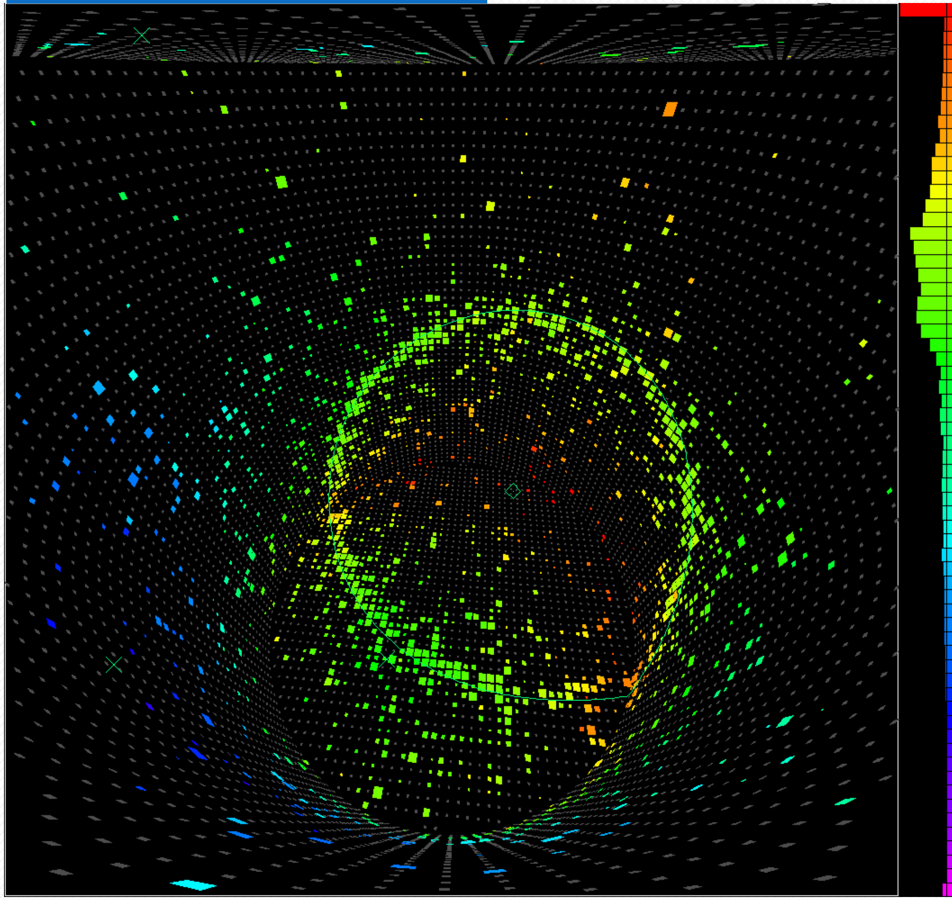


# Event Display

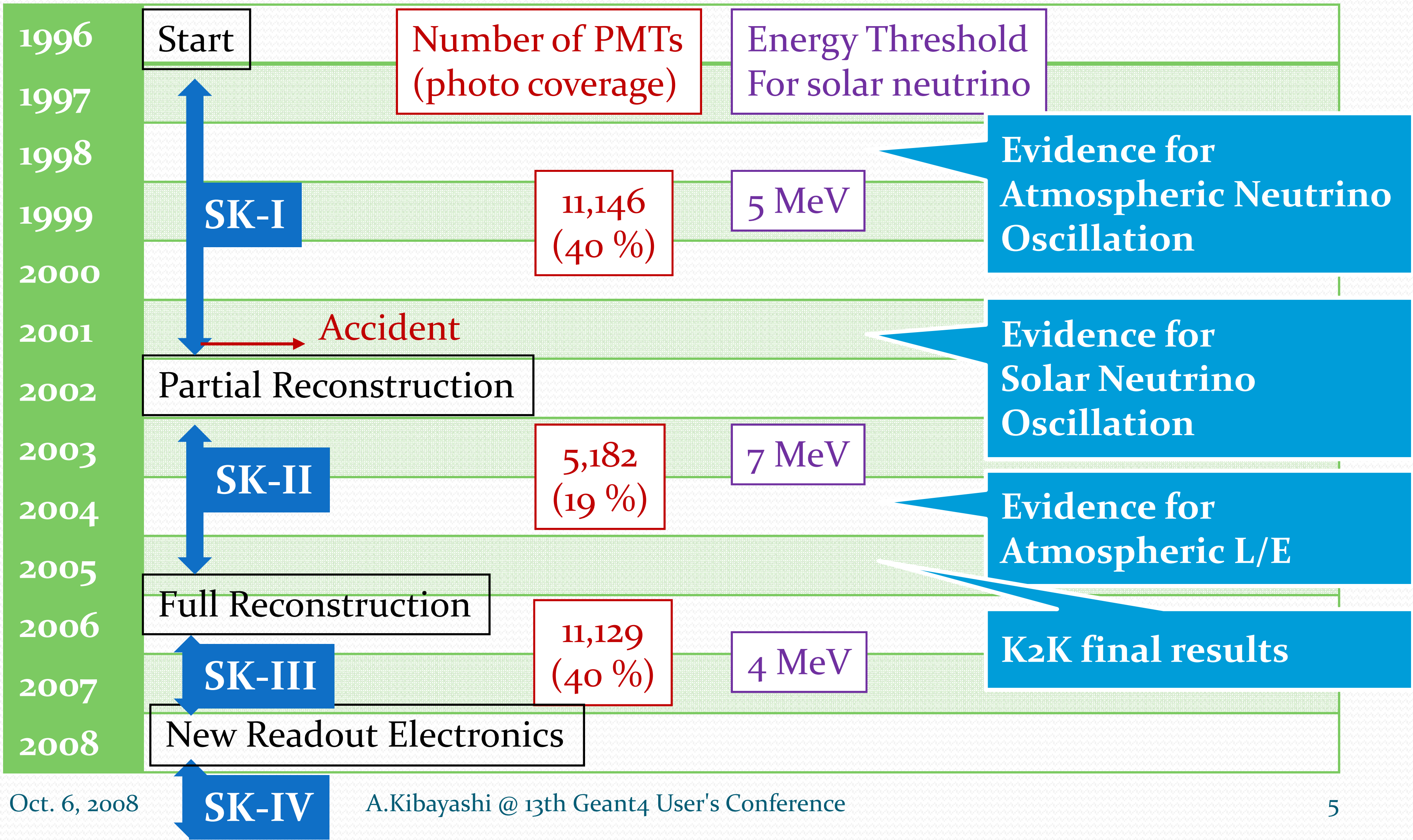
## Muon Event



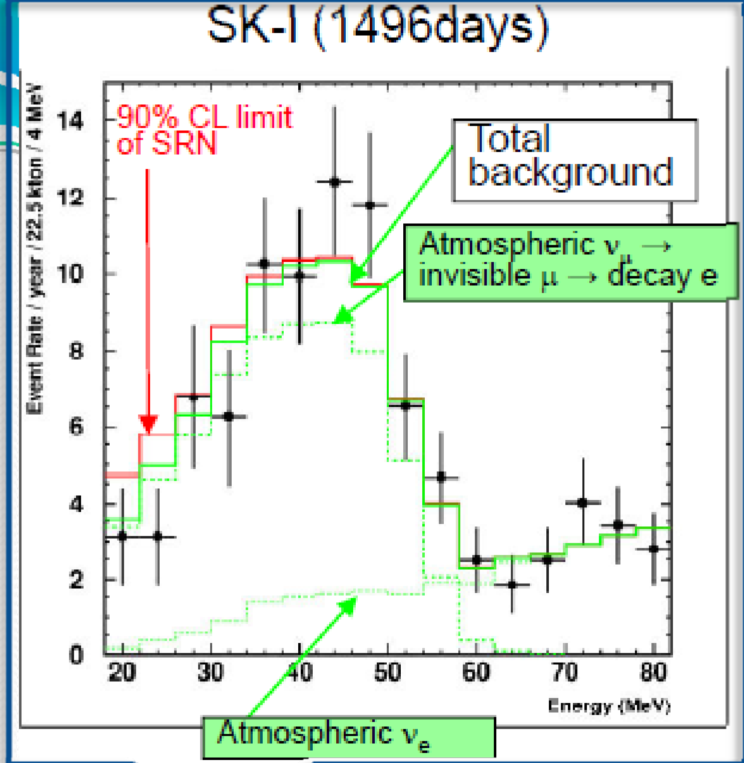
## Electron Event



# History of Super-Kamiokande



# What’s Next?

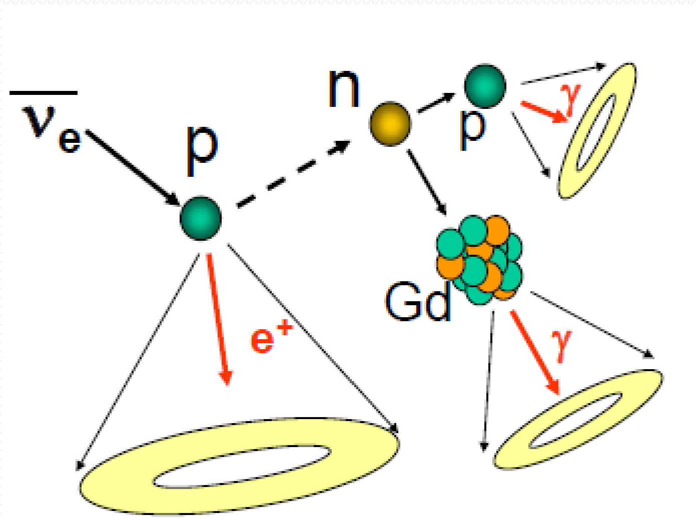



- Supernova Neutrinos?
  - Diffuse supernova neutrino background (DSNB)
- Super-Kamiokande is already the best DSNB detector, but…
  - Spectrum consistent with background
  - M. Malek et al. Phys.Rev.Lett. 90 (2003) 061101
- Is there a way to reduce the backgrounds ?
  - Tag every DSNB events in Super-K.

⇒ John F. Beacom and Mark R. Vagins, Phys.Rev.Lett. 93 (2004) 171101

# Key Issues

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

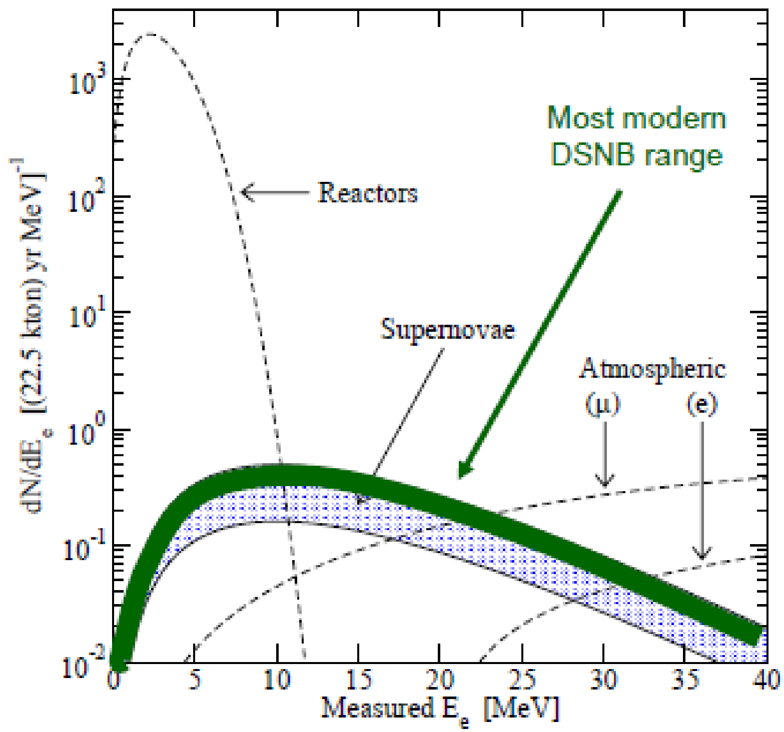



- Large cross section of Gd for neutron capture
  - ~49,000 barns (0.3 barns on free proton)
- Coincident signal detection
  - $e^+$ and gamma shower
    - $e^+$ energy 3~8 MeV peaking around 5 MeV
    - ~8 MeV shared among 3-4 gammas
- Tagging neutron with Gd will lower threshold!
- Gd is cheap and safe!

# Expected Rates
## with 100 tons of GdCl3 in Super-K

- Neutrinos from Reactors from all power reactors in Japan
  - ~5,000 events per year

- Diffuse Supernova Neutrino Background (DSNB)
  - ~ 5 events per year



# Prototype Detector

Nakahata @ Neutrino08

## Items to be studied before introducing gadolinium to SK

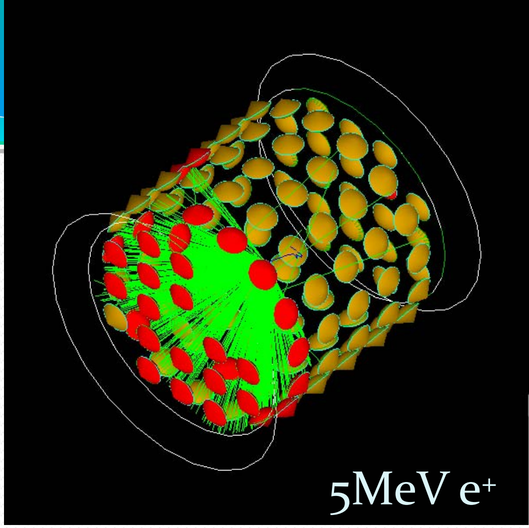
- **Effect to water transparency**
  Water transparency should be long enough to do various physics at SK.
- **Water purification system**
  Current water purification system remove ions. So, it must be modified to purify water without removing gadolinium.
- **Material effects**
  Corrosion by gadolinium solution should be checked.
- **How to introduce/remove**
  How to mix gadolinium uniformly in the tank. How quickly/economically/completely can the Gd be removed?
- **Ambient neutron level in the tank**
  Does it cause significant increase singles in trigger rate[for solar analysis]?

In order to study those things, we will construct a test tank (6~10m size) in the Kamioka mine.

# Hardware Tests

- Stainless steel corrosion tests in Gd solutions at MES (Mitsui Engineering & Shipbuilding, Co.,LTD)
  - Stainless steel (SUS304) in solutions of several types of Gd compounds.
  - Accelerated (stress+high temperature) tests , longer term tests are needed.
  - $Gd_2(SO_4)_3$ is the best so far, need tests for slightly low pH.
- Corrosion tests of other materials planned at Okayama University
  - Cables, blacksheet, PMT related materials
- Neutron tagging study conducte
  - Paper coming soon!

# Simulation with Geant4

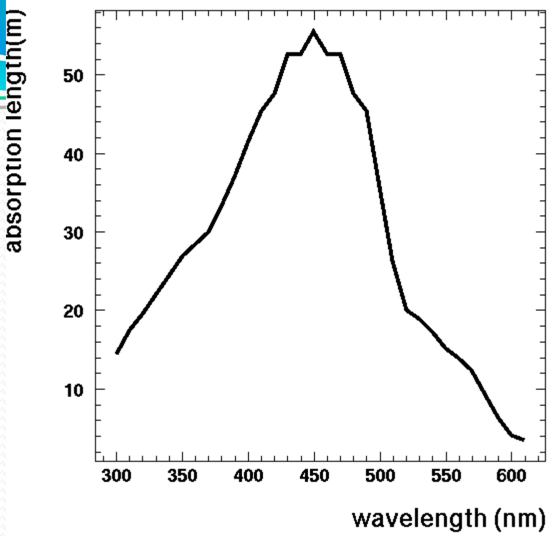


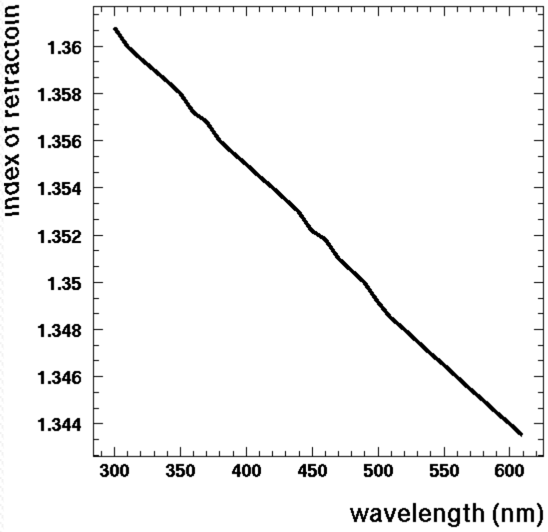

- Geant4 .9.1
- Started from extended/optical/LXe example
- Ref:
  - GLG4sim (http://neutrino.phys.ksu.edu/~GLG4sim/)

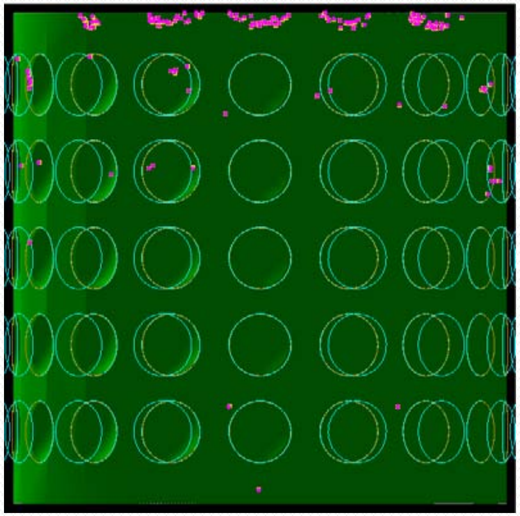
    Generic Liquid-scintillator Anti-Neutrino Detector ("GenericLAND") Geant4 simulation
  - T2K 2km water cerenkov detector simulation, M. Fechner et al.

# Gadolinium dissolved Water

- Water property
  - Same data as current SK simulation
  - Wavelength dependent
    - index of refraction
    - absorption length
- Gd compound
  - 0.2 % solution
  - All Gd isotopes included

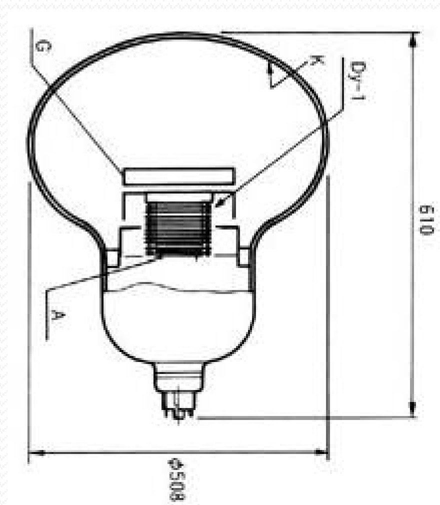


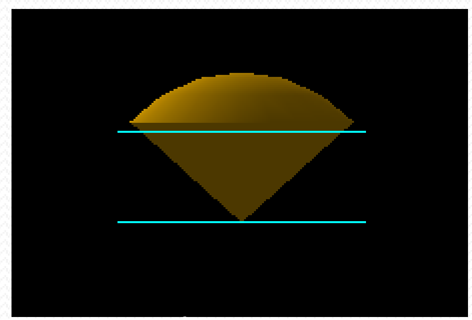



# 20 inch Hamamatsu Photo-multiplier Tube (PMT)

- Geometry simplify as sphere + tube

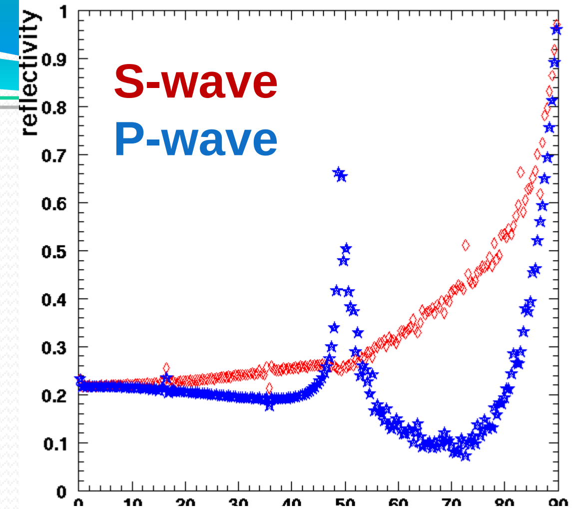


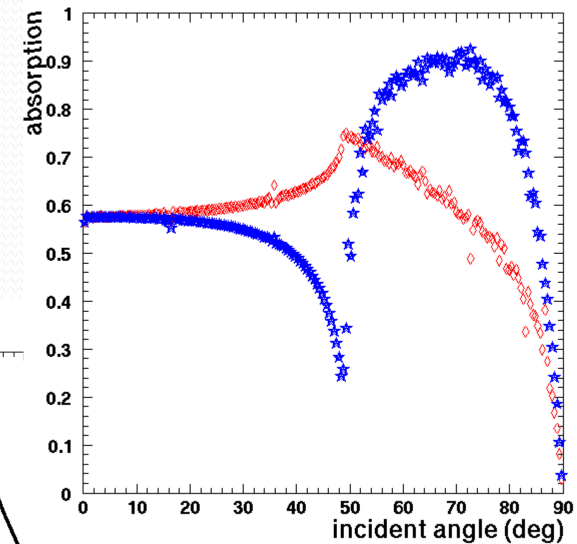



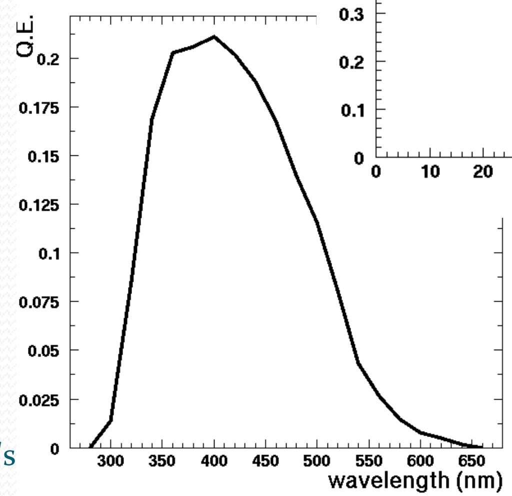
Blue (invisible):
glass surface
Orange: photo-cathode
behind glass

# PMT Properties

- Use the same data used in the current SK simulation
- PMT surface properties
  - Incident angle dependent Reflection & Absorption
  - 50% s-wave and 50% d-wave
- Quantum Efficiency
  - Depends on the wavelength

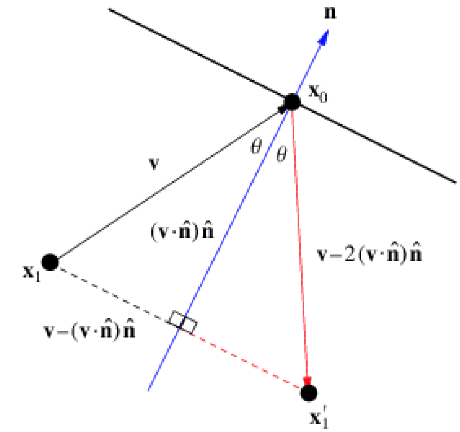


# Technical Note

## Use of FastSimulationModel




Transmission & Reflection

### Review

- Can be triggered in two possible regions
  - The primary 'mass' geometry
    - Set the region (pmt glass) in DetectorConstruction
    - Ref: ExN05EMShowerModel
  - A parallel (ghost) geometry
    - Need to build a separate parallel world which is exactly the same as the 'mass' region
    - RegisterParallelWorld in the main program.
    - Ref: ExN05PionShowerModel

### In MyCode

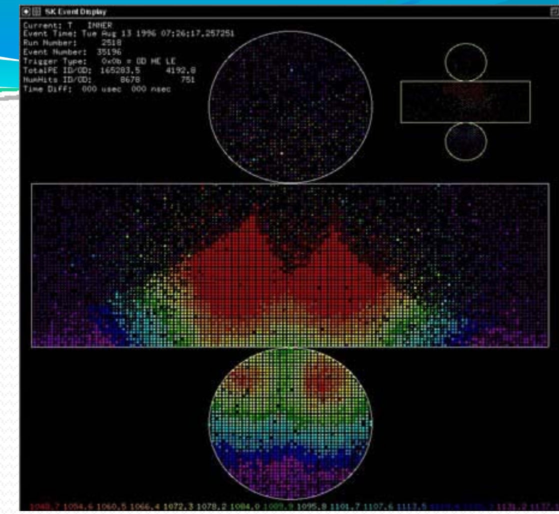
- Ref: GLG4PMTOpticalModel
- G4bool ModelTrigger
  - Trigger the FastSimulationModel when local position of G4FastTrack on G4LogicalVolume ( my glass pmt region) is in the spherical region of PMT.
- G4bool IsApplicable
  - Apply when G4ParticleDefinision is a photon.
- Void DoIt
  - Read the PMT property table.
    - Incident angle dependent Reflection (R) and Absorption(A)
  - Apply to all tracks.
    - A track hits PMT surface

if( G4UniformRand()<R) Reflect the track
if( G4UniformRand()<A) { Detect on cathode }
else{ Kill; }

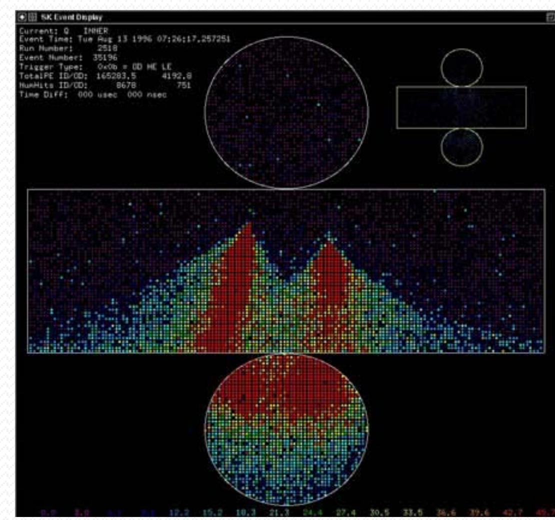
# Digitization

## Outputs

- Time (T) information
  - Gate 1.3 microsec
  - Dark noise at 4 kHz rate
    - No. of dark photon per PMT ~ Poisson
    - Randomly assign time in the gate window for the no. of dark photons
  - Photon arrival time smeared by 2.5 ns with Gaussian
- Charge (Q) information
  - No. of photons detected in 400 ns gate for each PMT

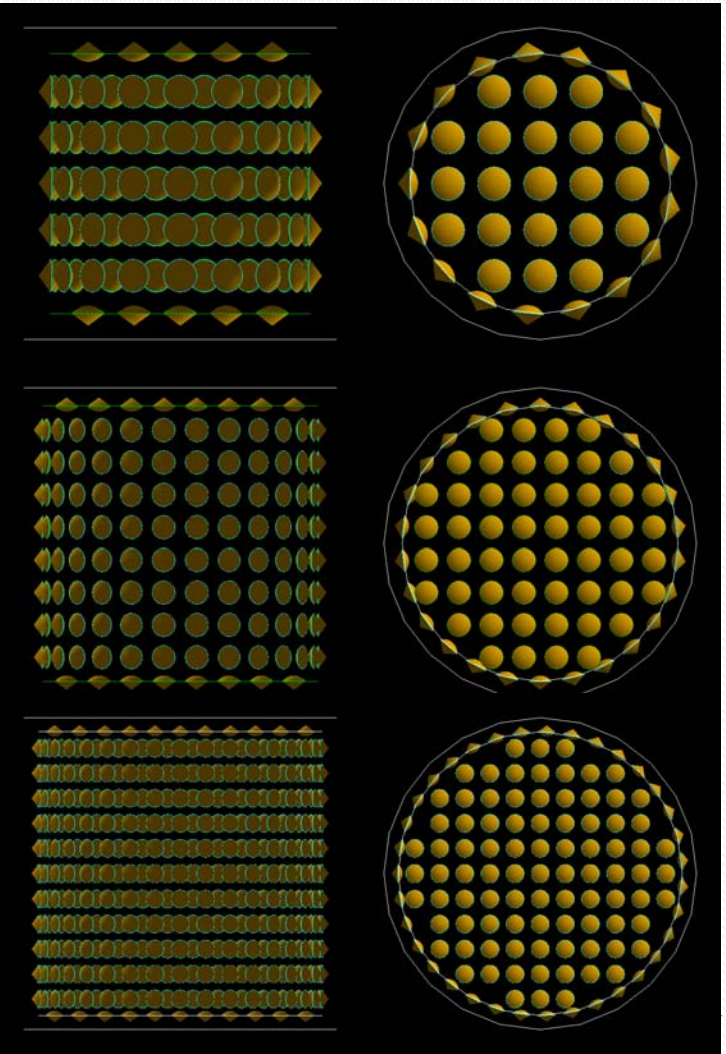


Double muon event
in T mode ↑
in Q mode ↓



# Minimum tank size allowed?

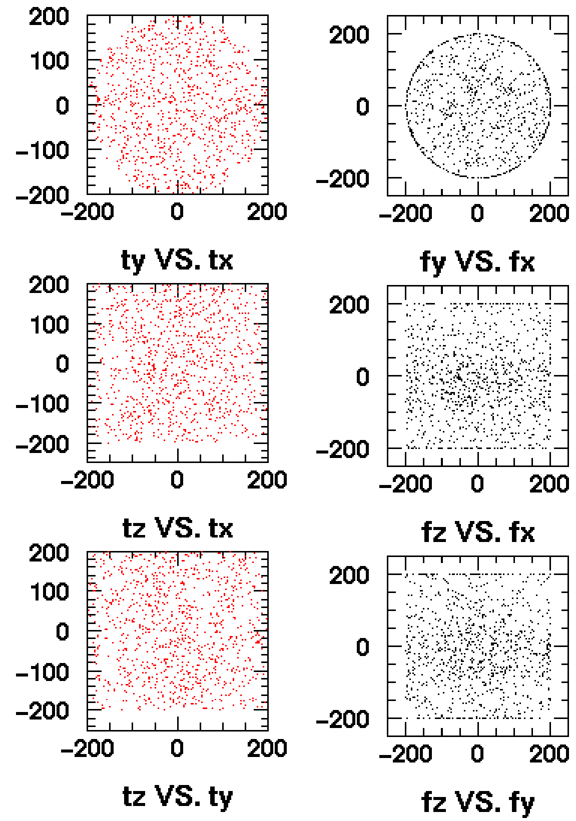
## check in terms of vertex resolutions



- Change size of the tank
  - Place max. number of PMTs automatically
- Geom:
  - Diameter of PMT = 50.8 cm
  - Spacing between PMTs = 70.7 cm
  - Blacksheet covering between PMTs
  - Stainless steel tank frame structure
- Size of the inner volume (tank size is +2 x 0.5 m)
  - 4m h x 4m ϕ
  - 6m h x 6m ϕ
  - 8m h x 8m ϕ

# Vertex Resolutions

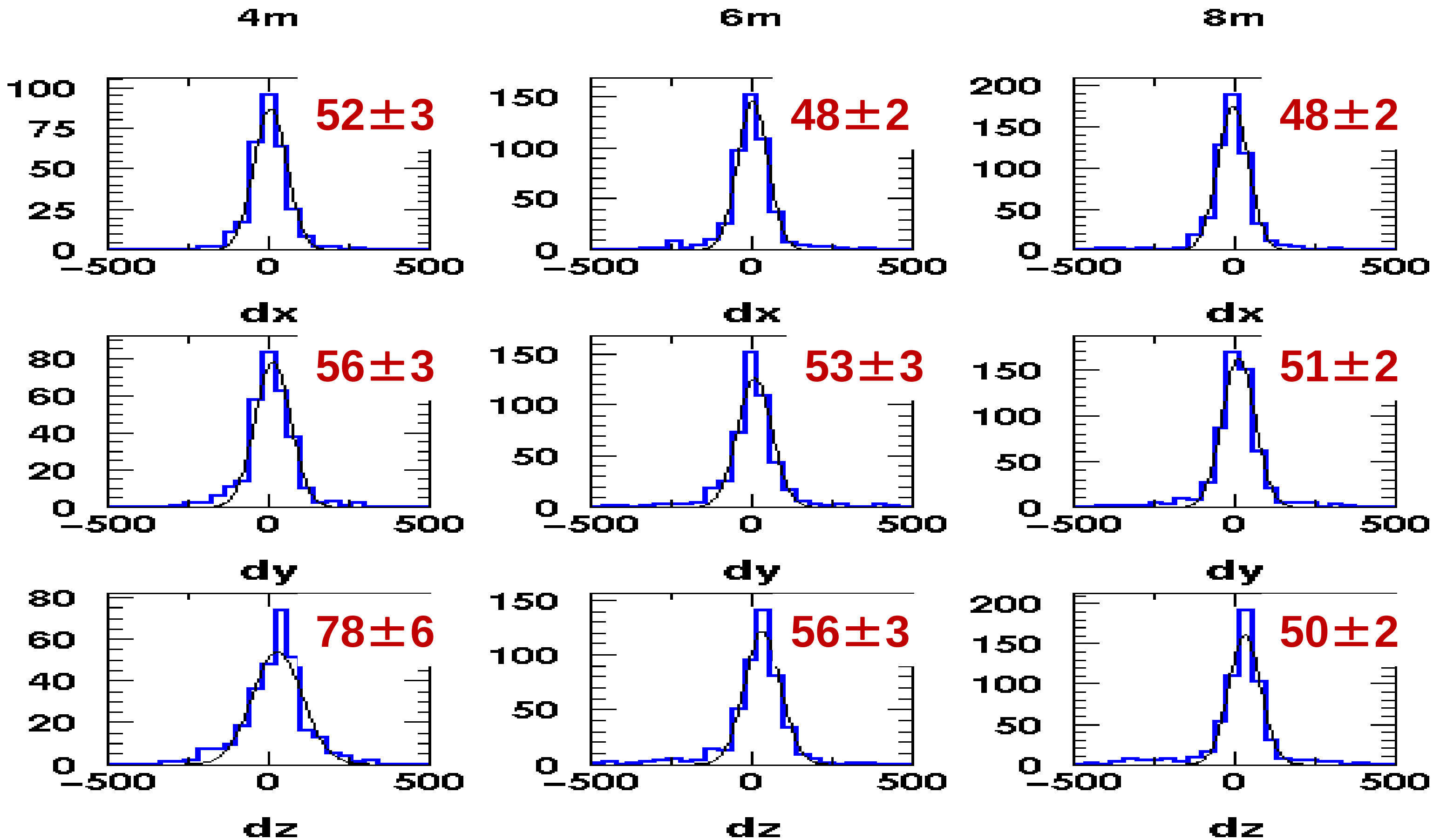
- Fitter : SK standard fitter used for low energy events
  - Still needs fine tuning for the much smaller prototype detector
- Fiducial volume cut
  - Removes badly fitted events
  - Removes environmental neutrons and gammas
  - Needs to be optimized




Vertex Positions
true(random) & fitted
Fitted vertex tend to be near the wall

# True Vertex - Fitted Vertex

## w/ f.v. 0.5m from wall cut



# Summary

- Geant4 simulation package is being built for a small scale prototype Gadolinium dissolved water cerenkov detector.
- Optical properties of the Super-Kamiokande detector are installed.
- Output is the time and charge information for each PMT.
- SK fitter for low energy events works for vertexing.
  - Fine tuning still needed.
- Next: Add neutron capture simulation (G4NDL)

Stay Tuned for More!

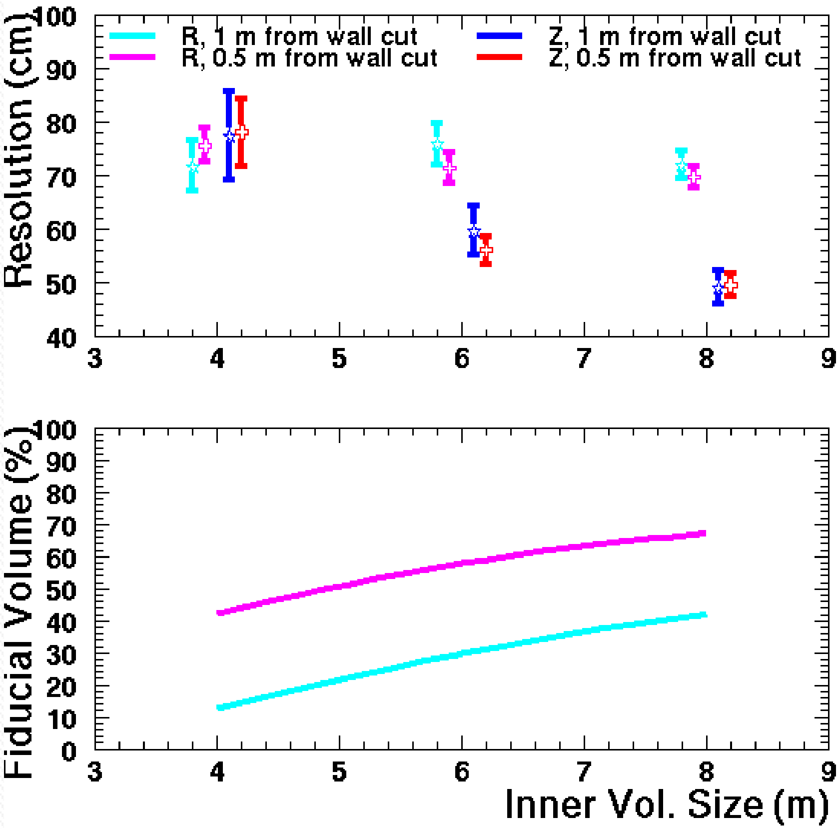
# Backups

# Expected Rates

| Inner volume | 1 m cut F.V. (ton) | 0.5 m cut F.V. (ton) | No F.V. cut (ton) | PMT coverage | Reactor nu rate w/ 1 m cut /year | Reactor nu rate w/ 0.5 m cut /year |
|---|---|---|---|---|---|---|
| 4m x 4m | 6.3 (12.5 %) | 21.2 (42.1 %) | 50.3 | 34.1 % | 1 | 5 |
| 5m x 5m | 21.2 (21.5 %) | 50.3 (51.2 %) | 98.2 | 39.2 % | 5 | 11 |
| 6m x 6m | 50.3 (29.7 %) | 98.2 (57.9 %) | 169.6 | 37.3 % | 11 | 22 |
| 8m x 8m | 169.6 (42.2 %) | 269.4 (67.0 %) | 402.1 | 37.8 % | 38 | 60 |

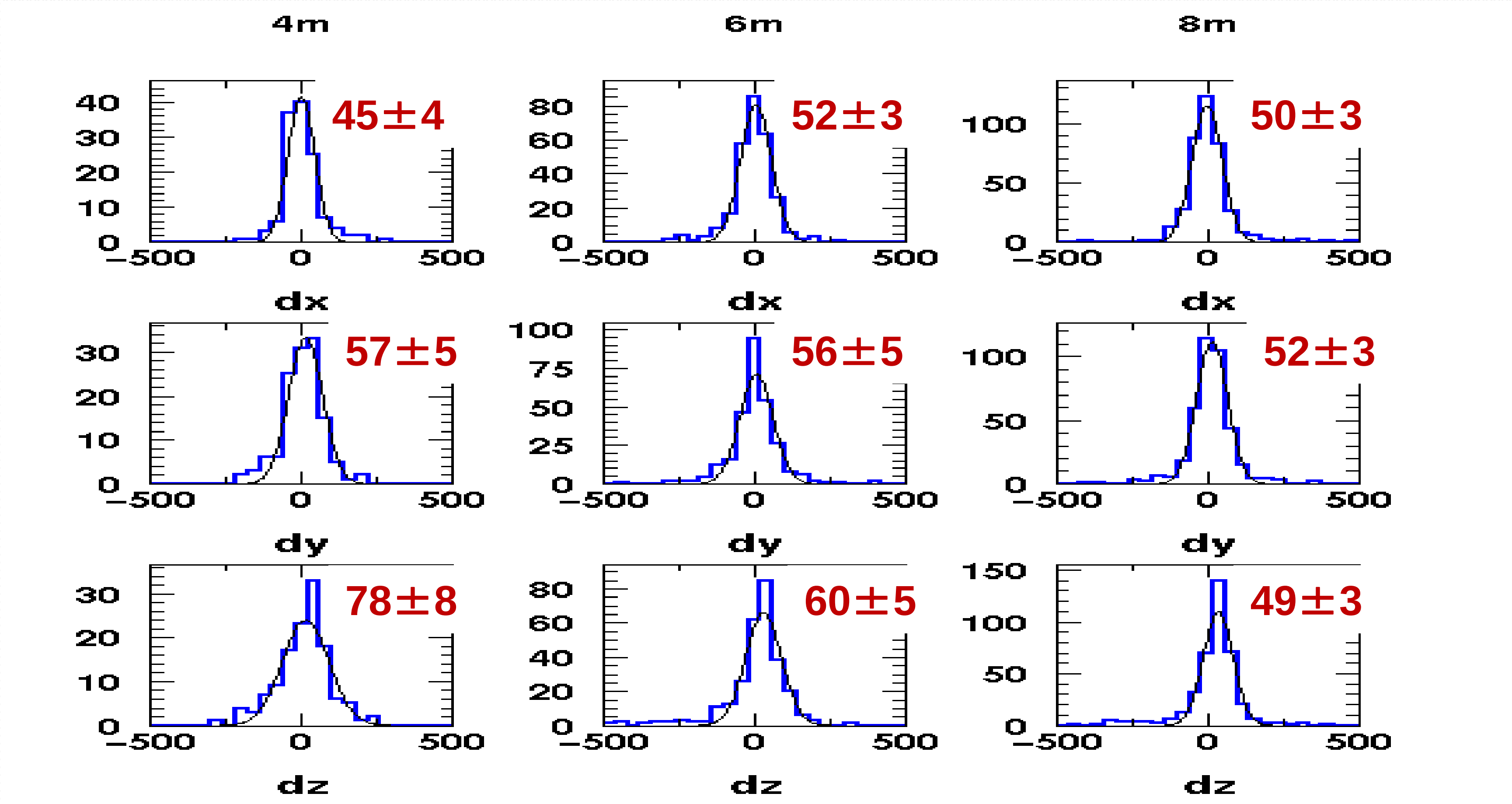
# Vertex Resolutions vs. Size

5 MeV $e^+$



# True - Fitted Vertex

## w/ f.v. 1m from wall cut

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# No. of PMTs

- Diameter of PMT = 50.8 cm
- Spacing between PMTs = 70.7 cm

| Tank Size (mxm) | Barrel | Top/Bottom | Total |
|---|---|---|---|
| 4 x 4 | 85 | 21 x 2 | 127 |
| 6 x 6 | 208 | 52 x 2 | 312 |
| 8 x 8 | 385 | 89 x 2 | 563 |
| 10 x 10 | 616 | 148 x2 | 912 |

# True - Fitted Vertex

## No cuts