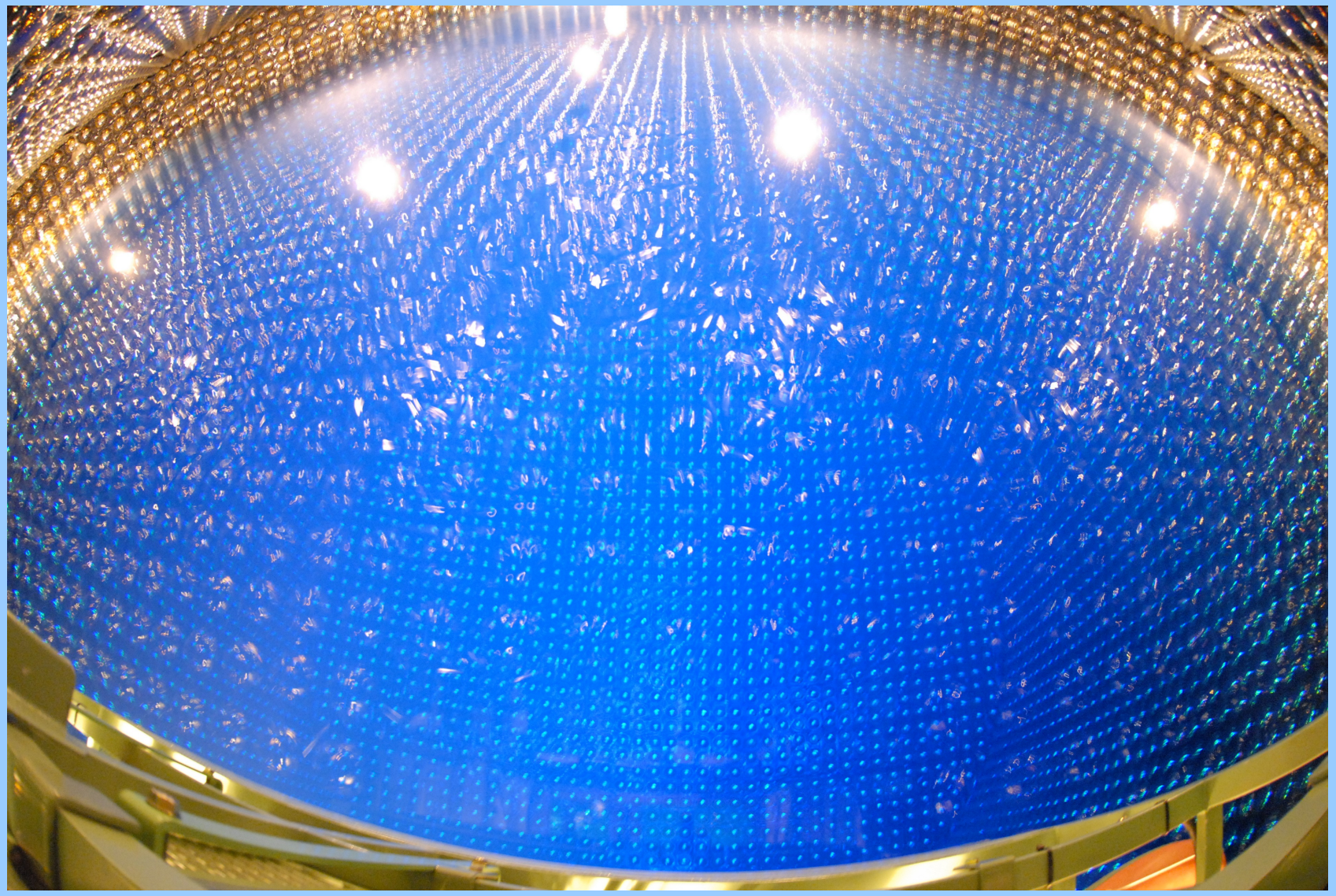
Experience from Super-Kamiokande



K. Scholberg, Duke University

Large Area Photodetector Workshop, Dec 2008

OUTLINE

- The Super-Kamiokande detector
- Reconstruction performance
    - low energy
    - high energy (atmospheric & beam)
- e vs π reconstruction issues relevant for next-generation detector
- Existing code

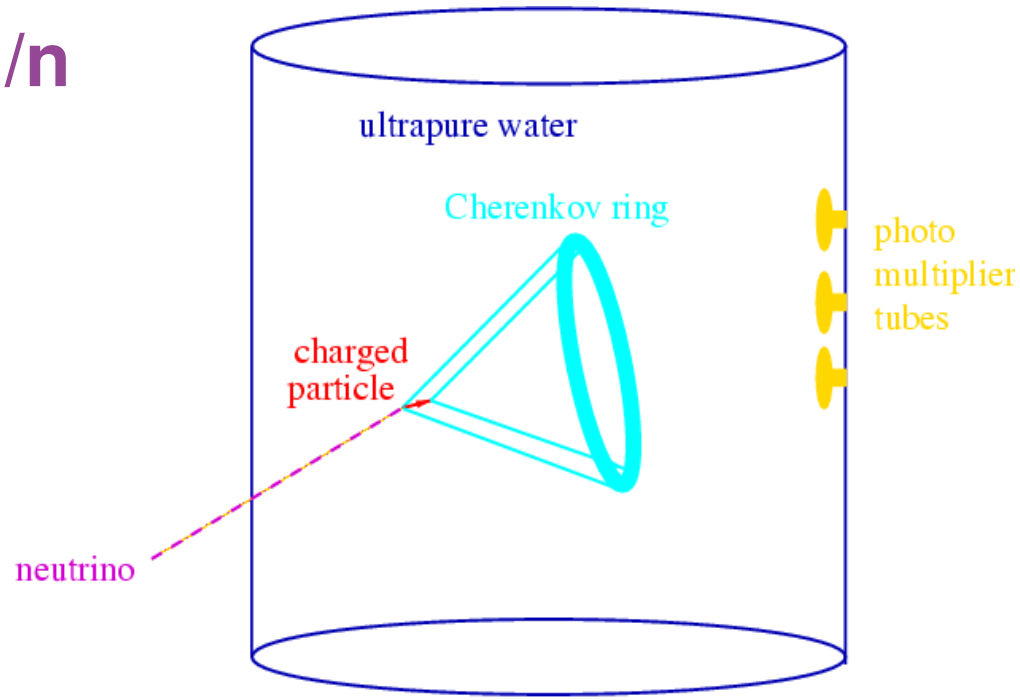
Water Cherenkov Detectors

Charged particle with $\beta > 1/n$

$$E_{th} = \frac{m}{(1 - 1/n^2)^{1/2}}$$

Thresholds (MeV)

e	0.73
μ	150
π	200
p	1350



Angle: $\cos\theta_c = \frac{1}{\beta n}$

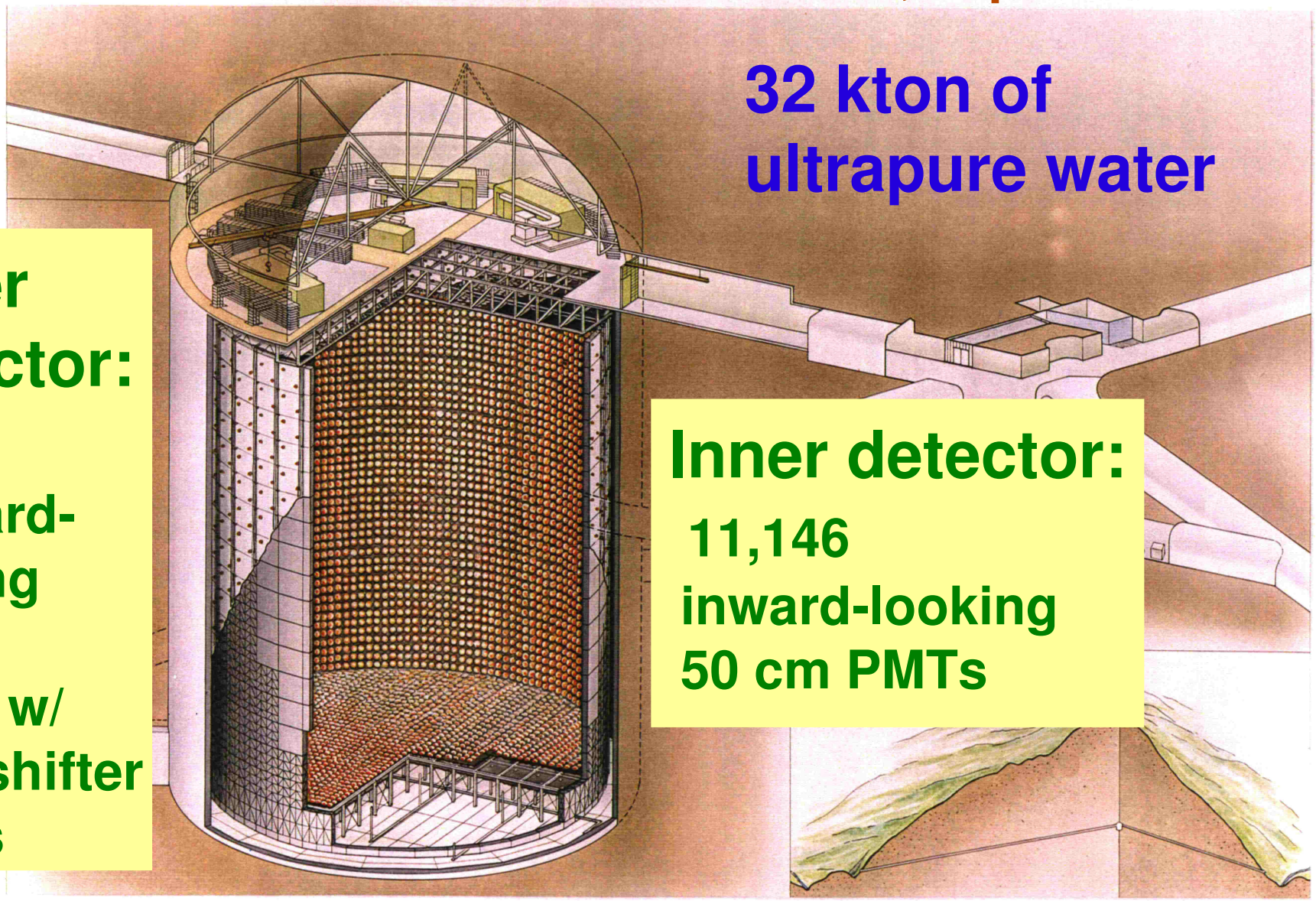
$\theta_c = 42^0$ for relativistic particle in water

No. photons $\propto$ energy loss

Photons $\rightarrow$ photoelectrons
$\rightarrow$ amplified PMT pulses
$\rightarrow$ digitize charge, time
$\rightarrow$ reconstruct energy, direction, vertex

Super-Kamiokande

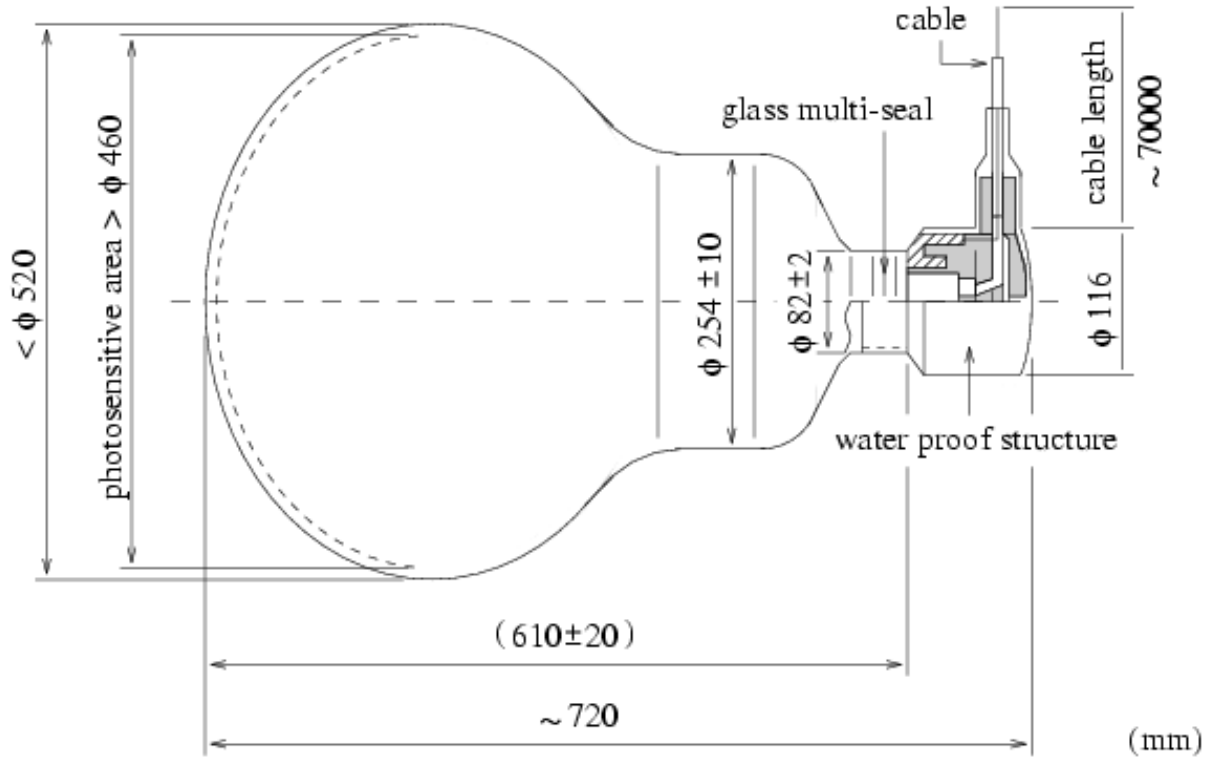
Water Cherenkov detector in Mozumi, Japan

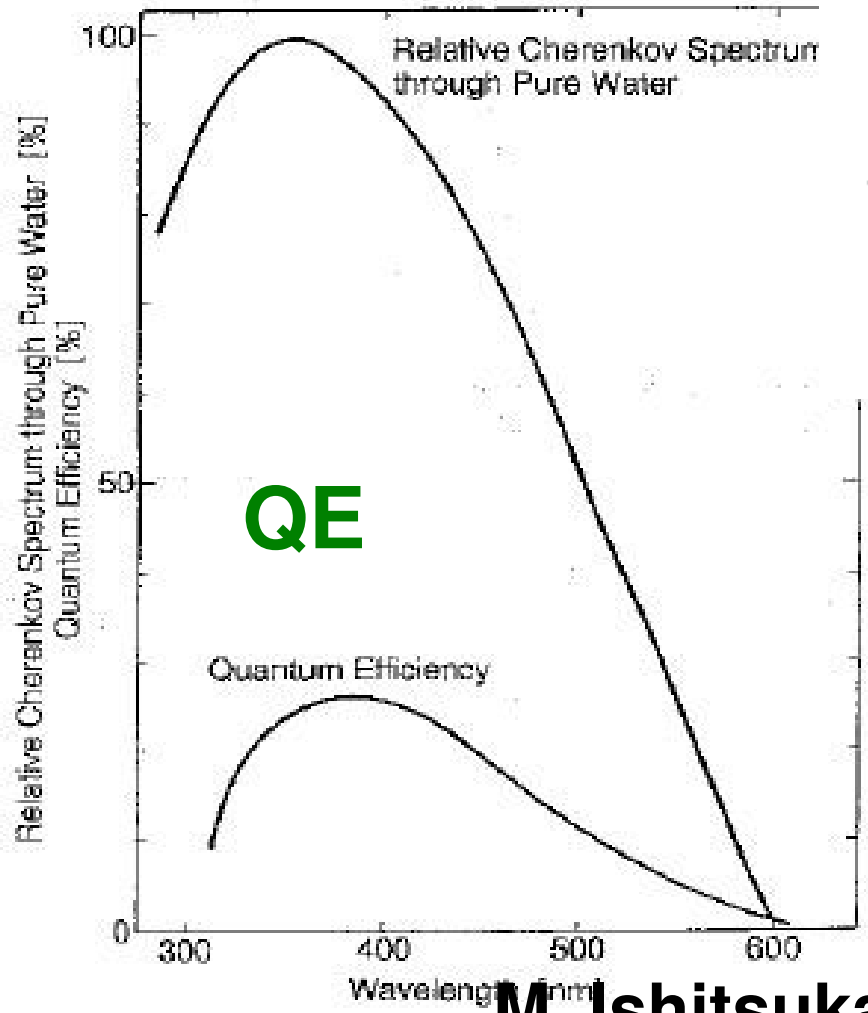


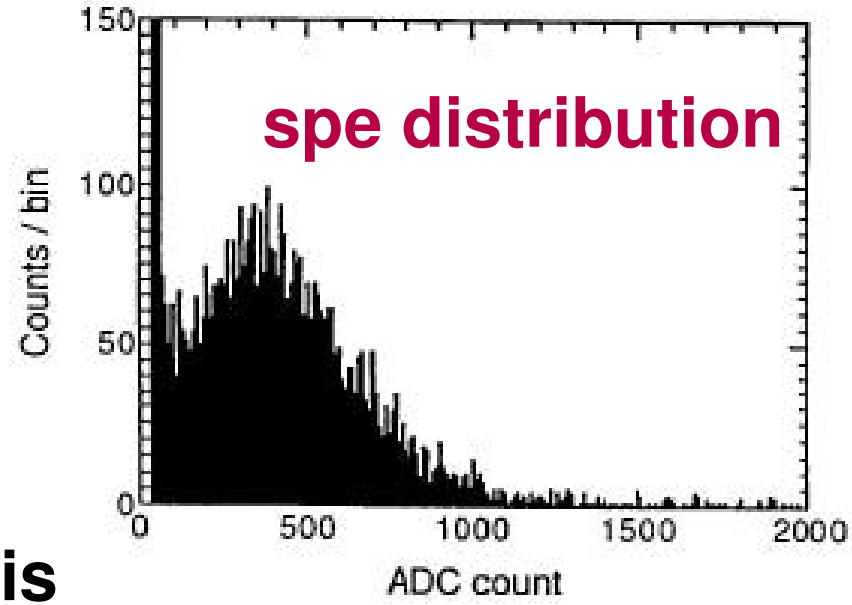
40% coverage in the ID

Photomultiplier Tubes

gain ~10^7

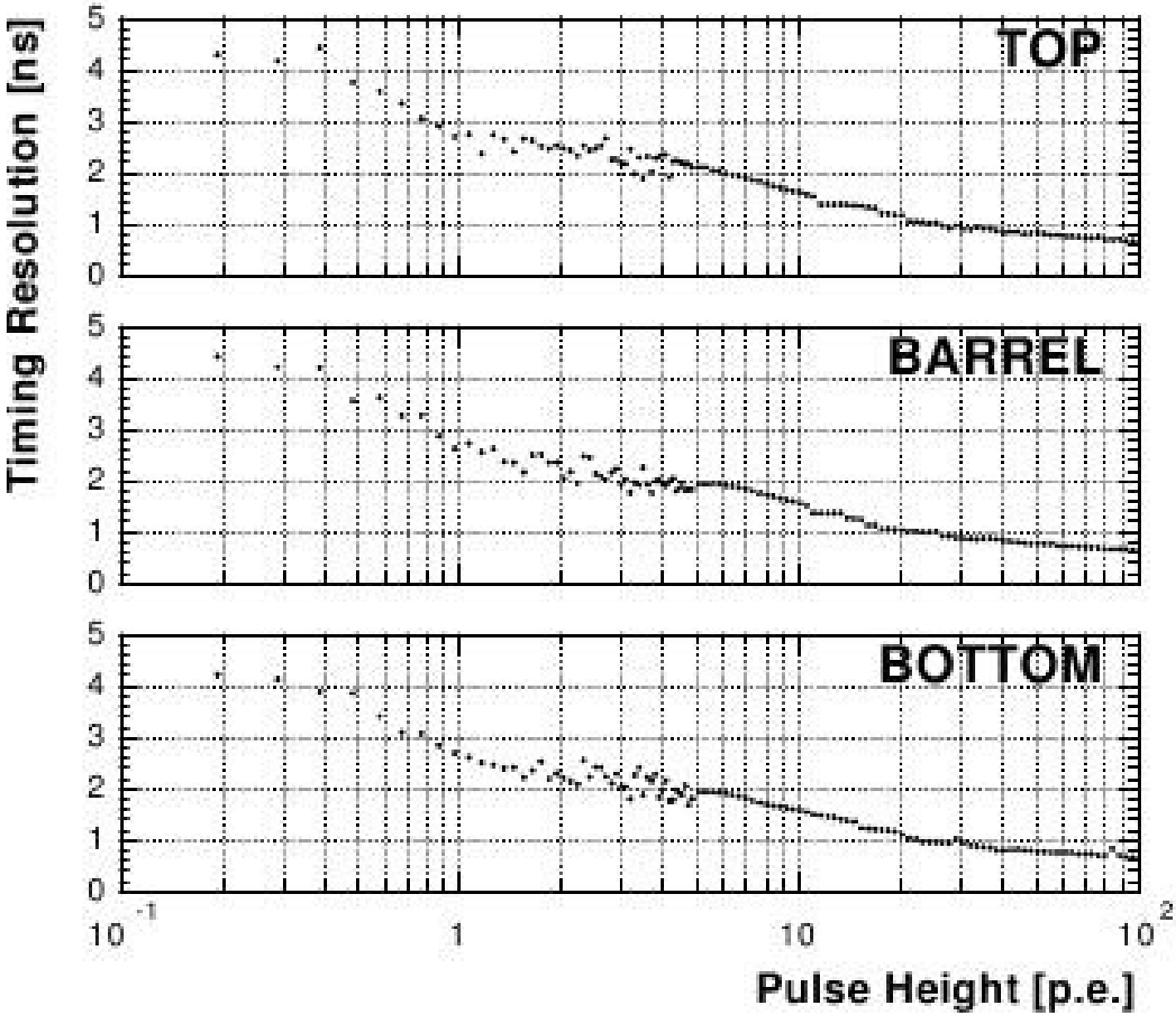




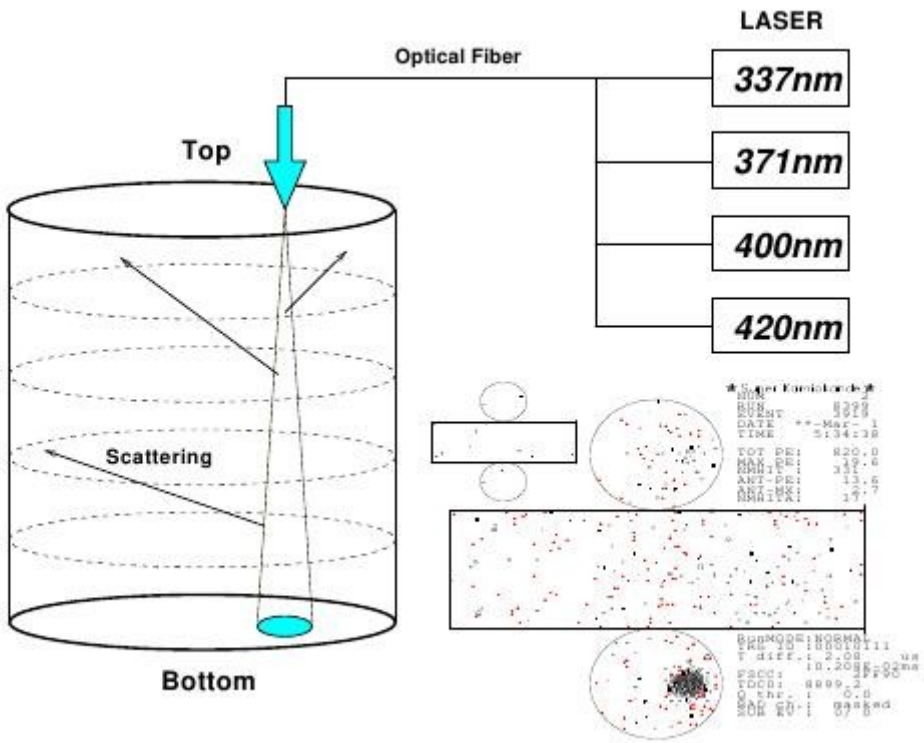


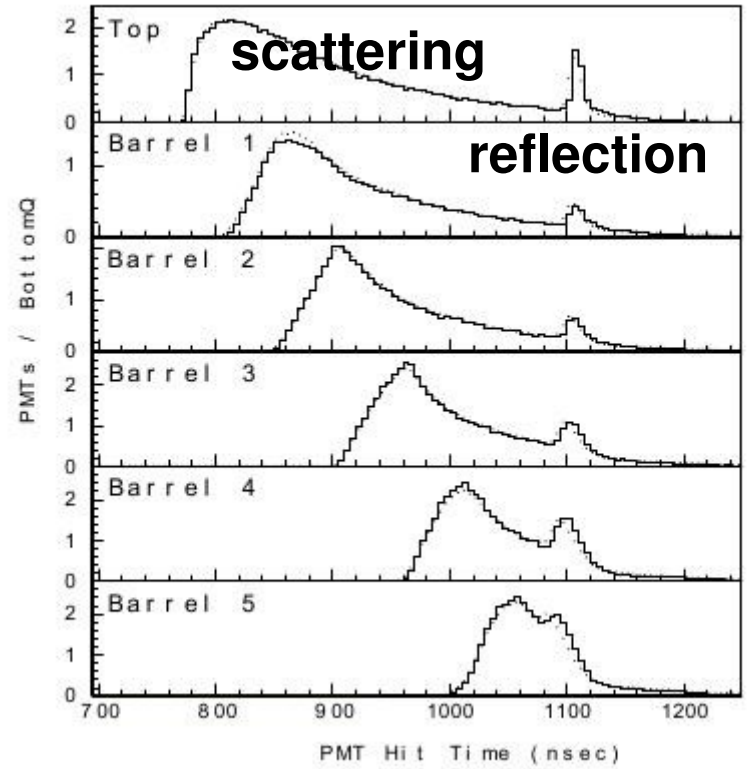
M. Ishitsuka thesis

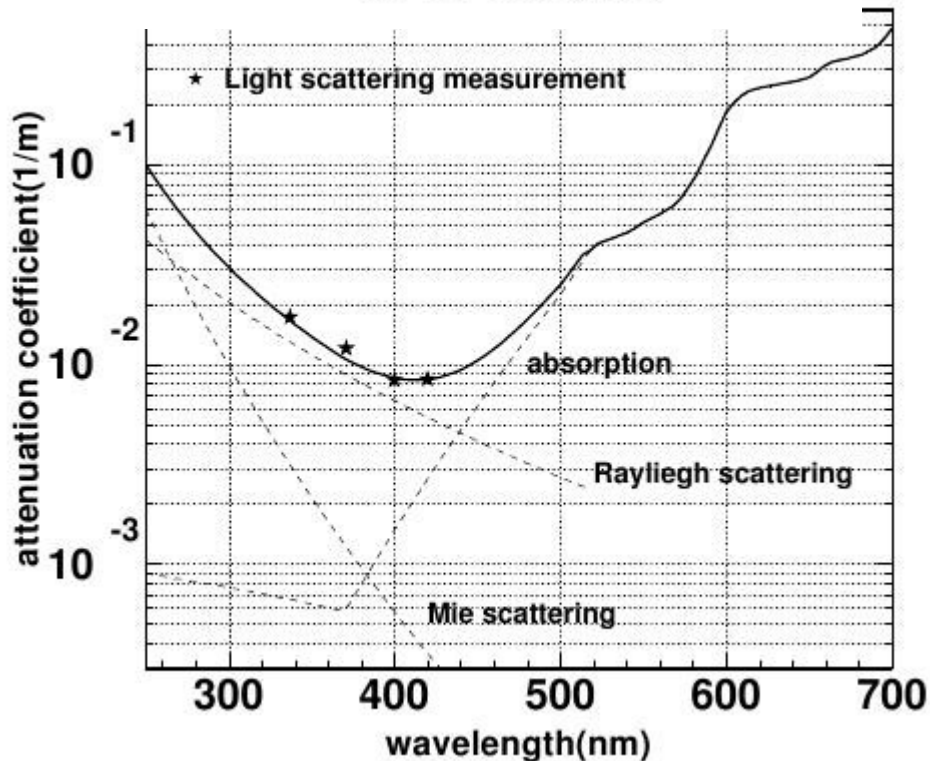
Timing resolution for SK I, measured with laser



Light scattering measurement with laser

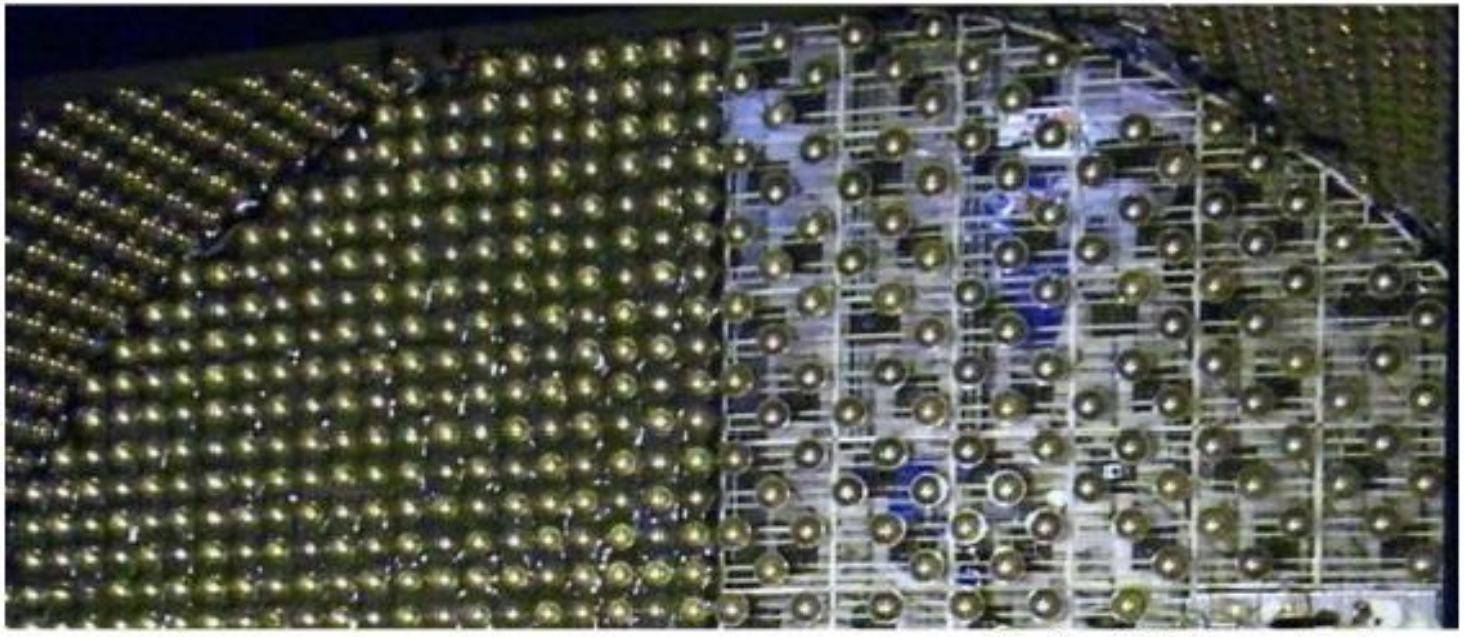






From J. Raaf, Neutrino 2008

Timeline



During SK-III construction

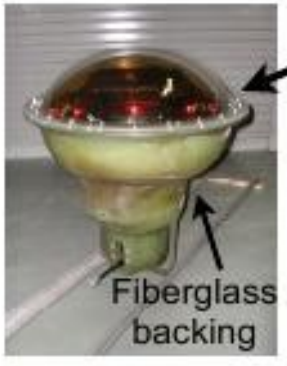
1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009

SK-I (1996-2001)
11,146 ID PMTs
(40% coverage)
1,885 OD PMTs

accident

SK-II (2003-2005)
5182 ID PMTs
(19% coverage)
Acrylic shields added

SK-III (2006-2008)
11,129 ID PMTs (40% cov.)
OD segmentation
(top/barrel/bottom)



Coming soon:
SK-IV (2008- ...)
Replace DAQ electronics

Electronics & DAQ replacement now done

Physics Goals: SK and next generation water Cherenkov detectors

"<u>High Energy</u>" 50 MeV-100 GeV

- Neutrino physics with long baseline beam

- Proton decay

- Atmospheric neutrinos

  (useful for understanding beam systematics)

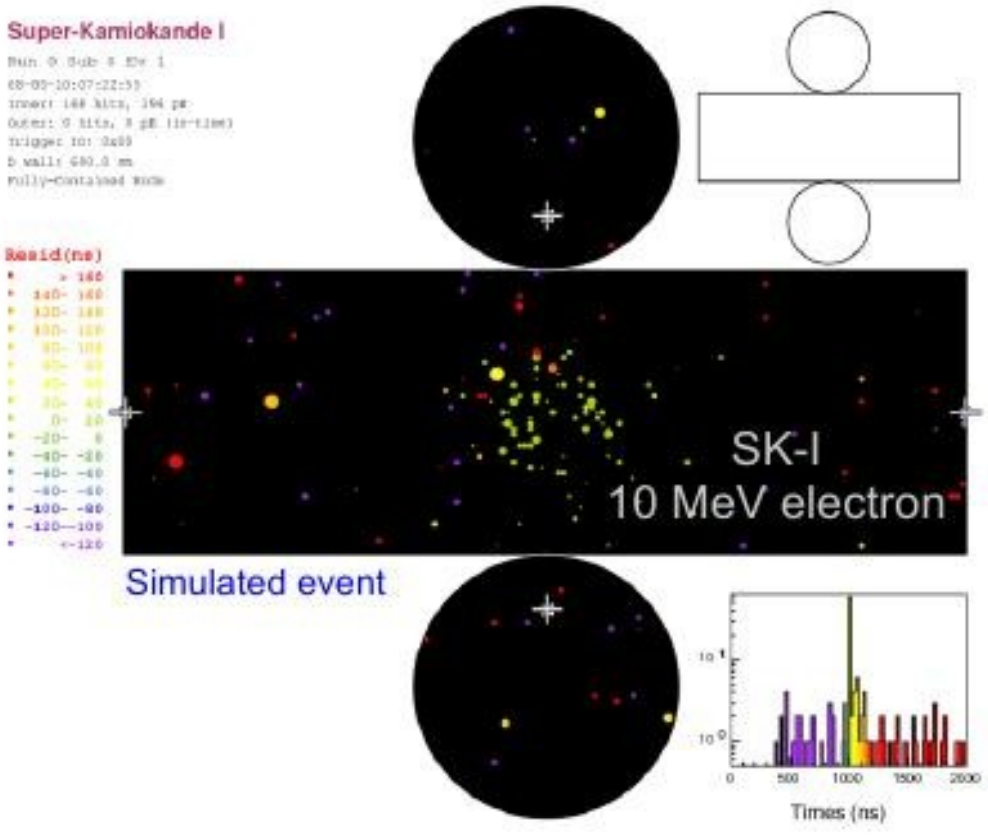
"<u>Low Energy</u>" 5-50 MeV

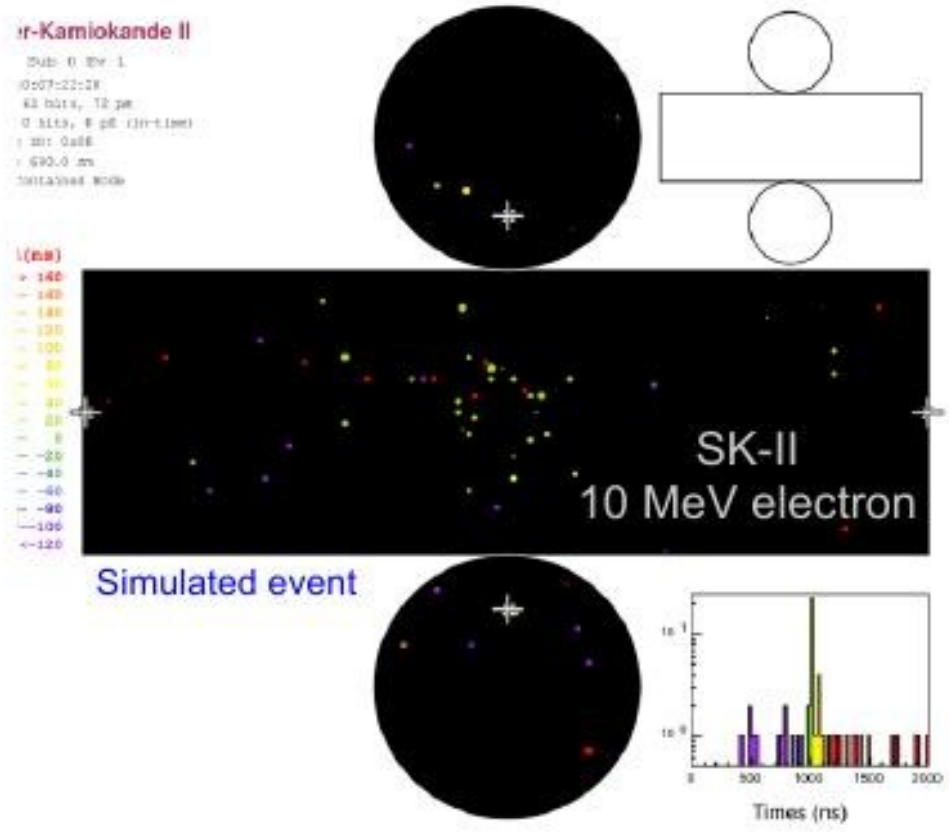
- Supernova neutrinos: relic and Galactic

- Solar neutrinos

From J. Raaf, Neutrino 2008

Low energy events in Super-K (solar & supernova)





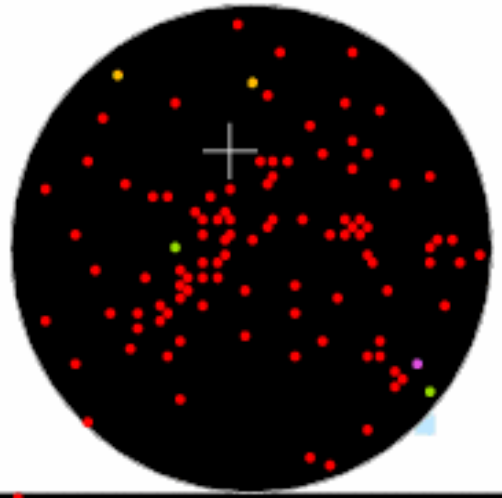
	Energy response	Vertex resolution for 10 MeV electron
SK-I	~6 p.e./MeV	~70 cm → 60 cm†
SK-II	~3 p.e./MeV	~100 cm
SK-III	~6 p.e./MeV	in preparation

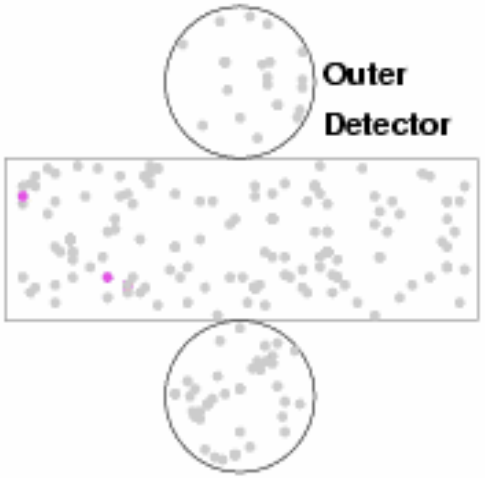
†Using SK-II improved algorithm

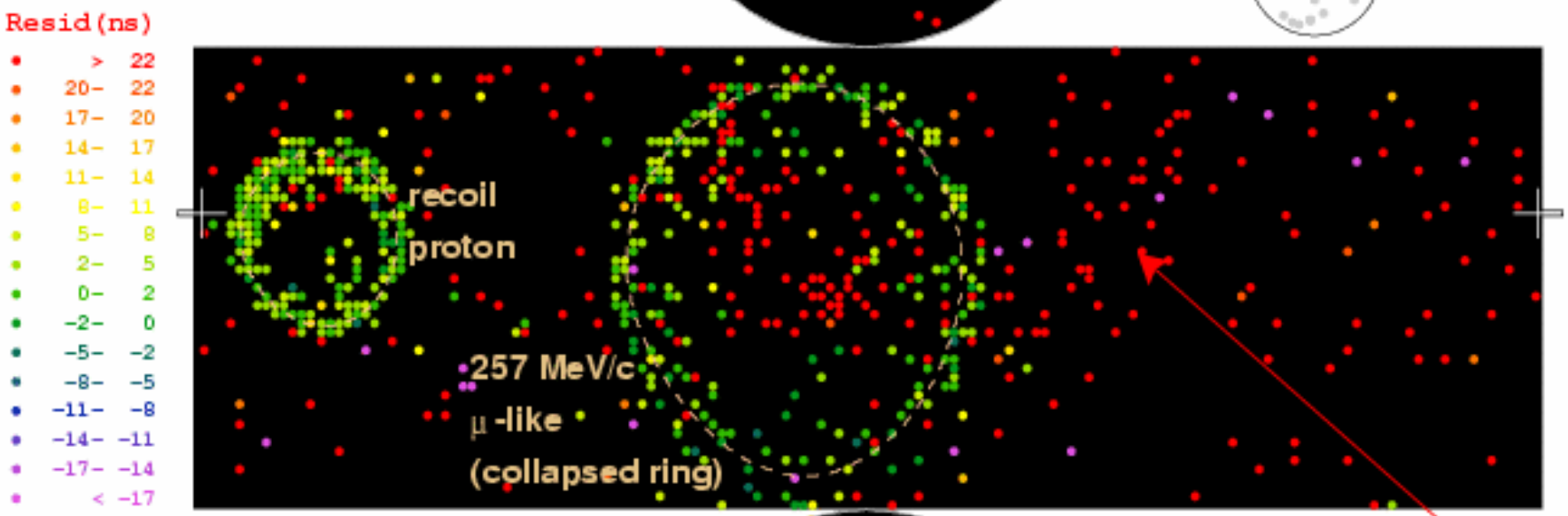
Mostly, need more photons

What about high energy events?

Typical atmospheric neutrino event





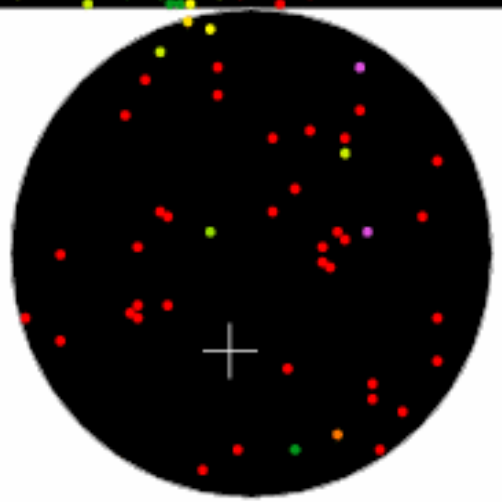


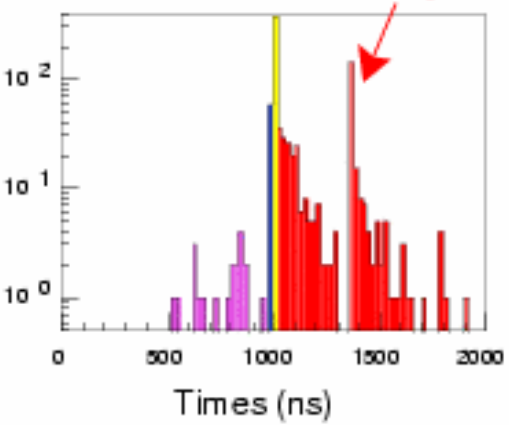
decay electron

Quasi-elastic

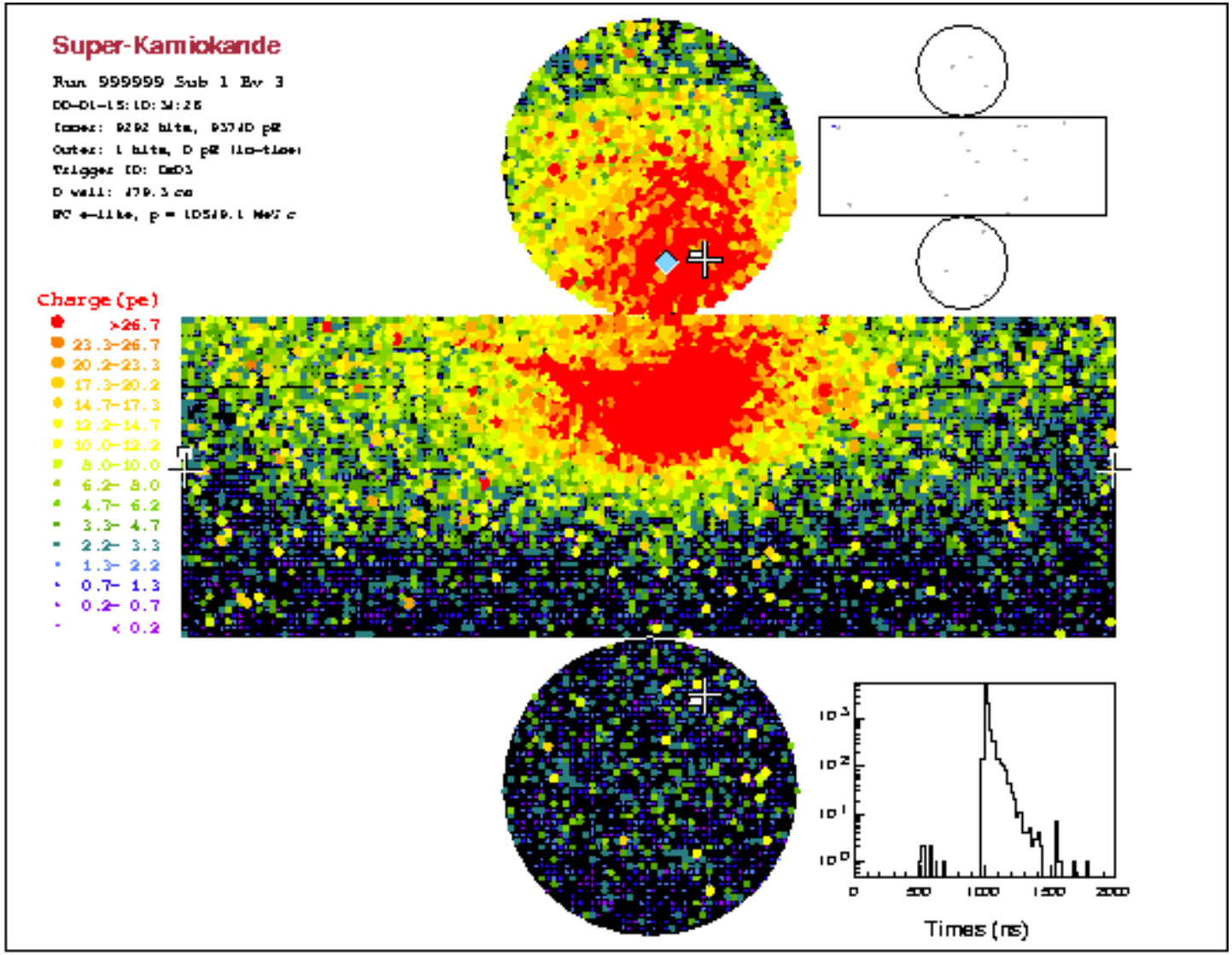
$\nu_\mu\ n \rightarrow \mu^-\ p$

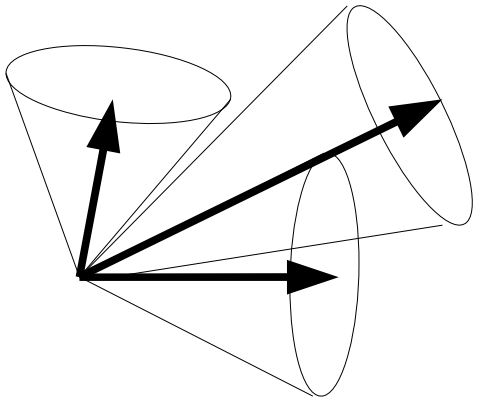
$\hookrightarrow e^-\ \nu_\mu\ \nu_e$





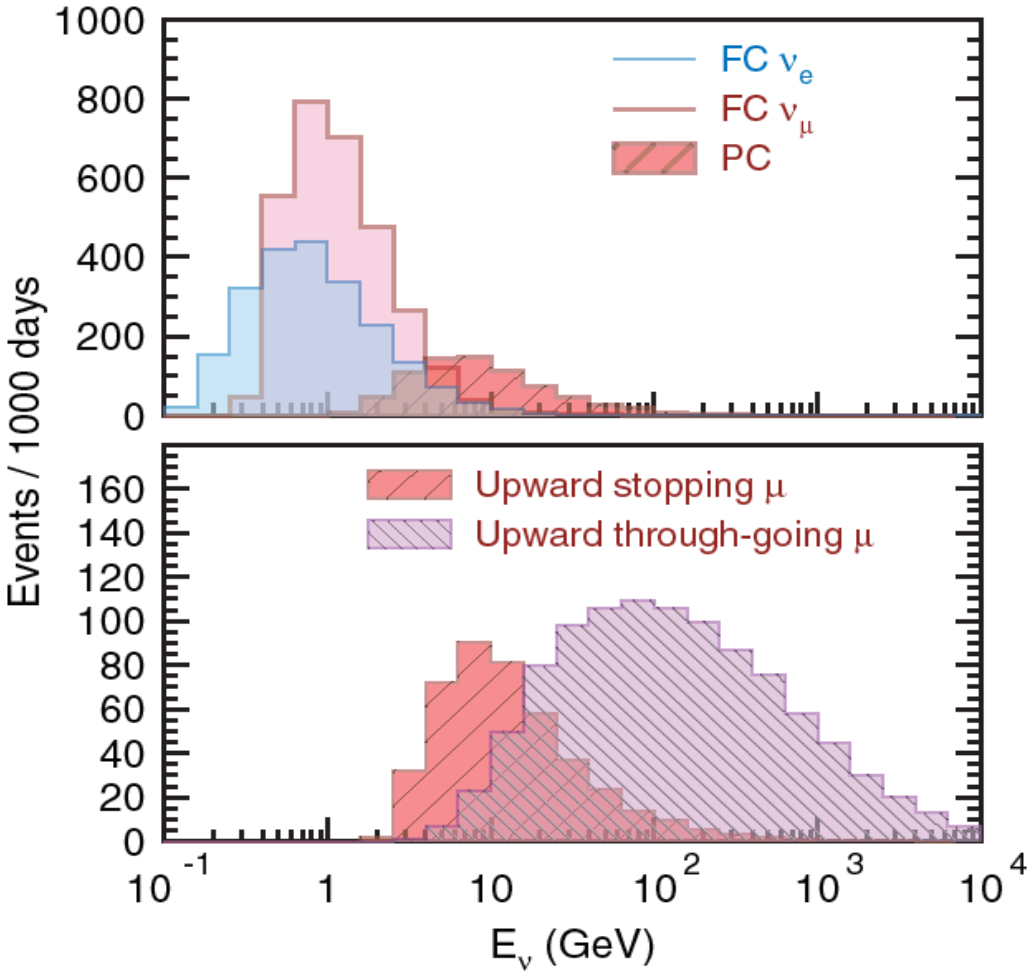
Reconstruct: vertex, energy, direction, PID; count and fit multiple rings

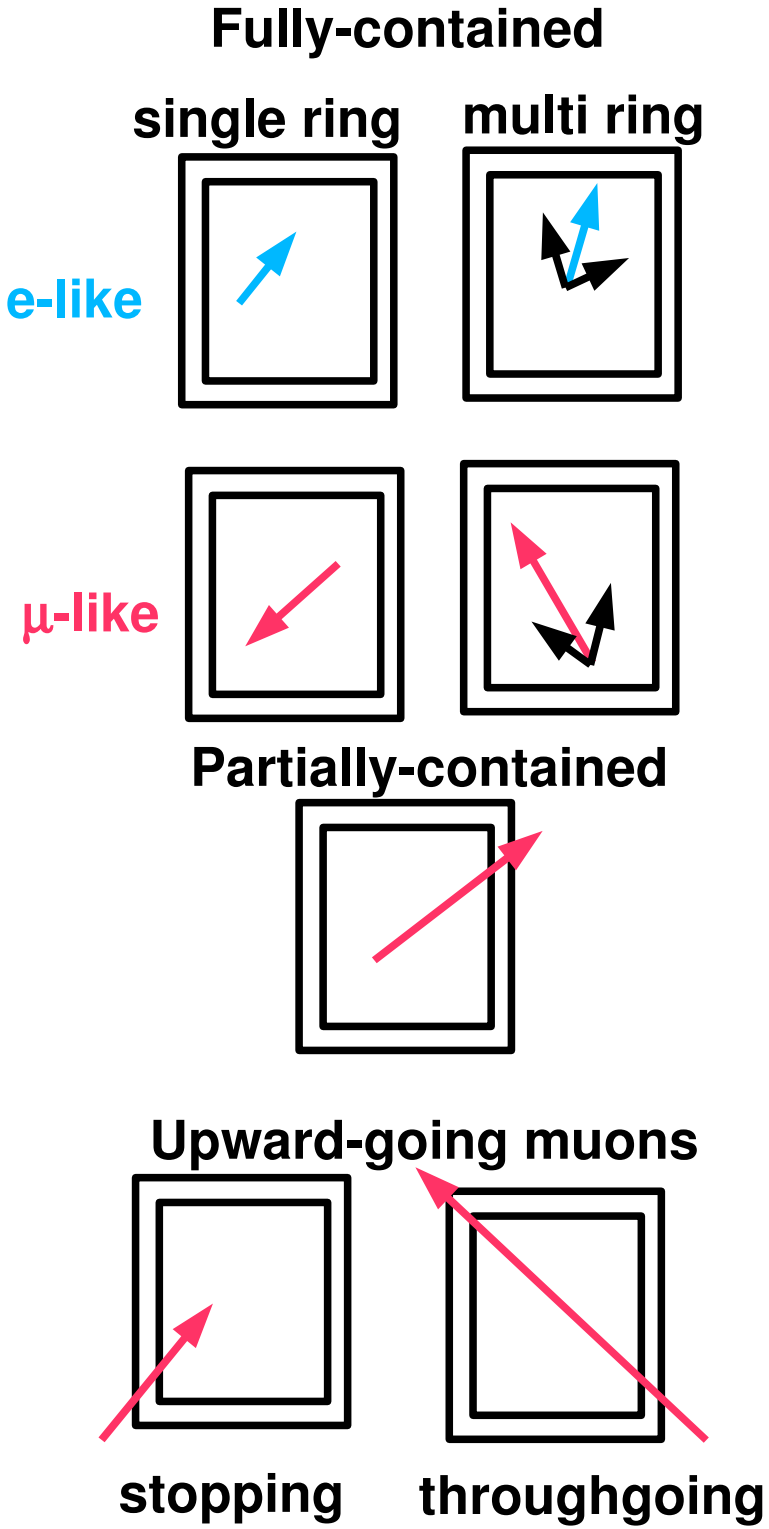




Many fitters in use for different purposes

Atmospheric Neutrinos:
parent ν energies for subsamples





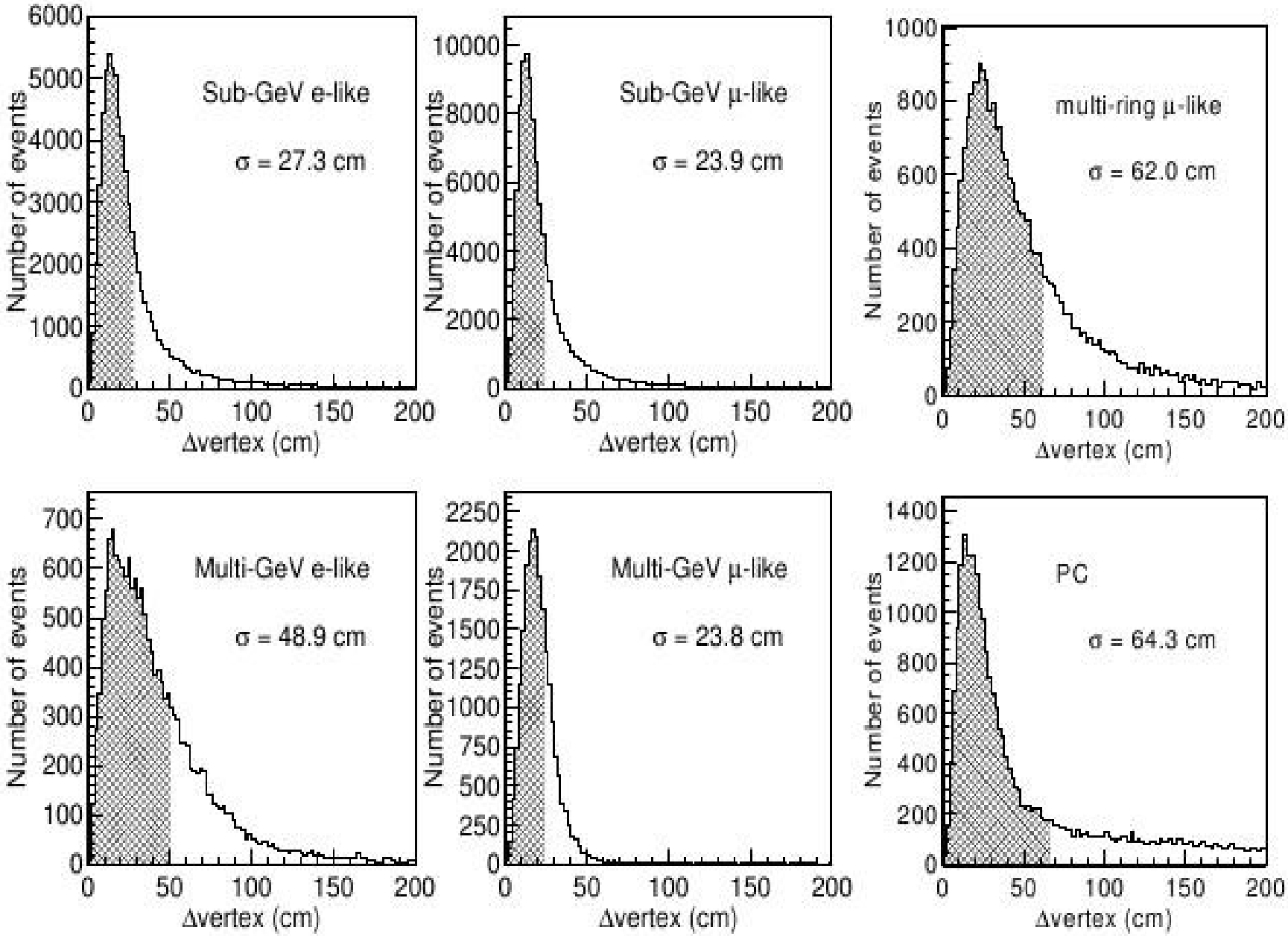
High energy neutrino reconstruction

SK-I, see M. Ishitsuka thesis

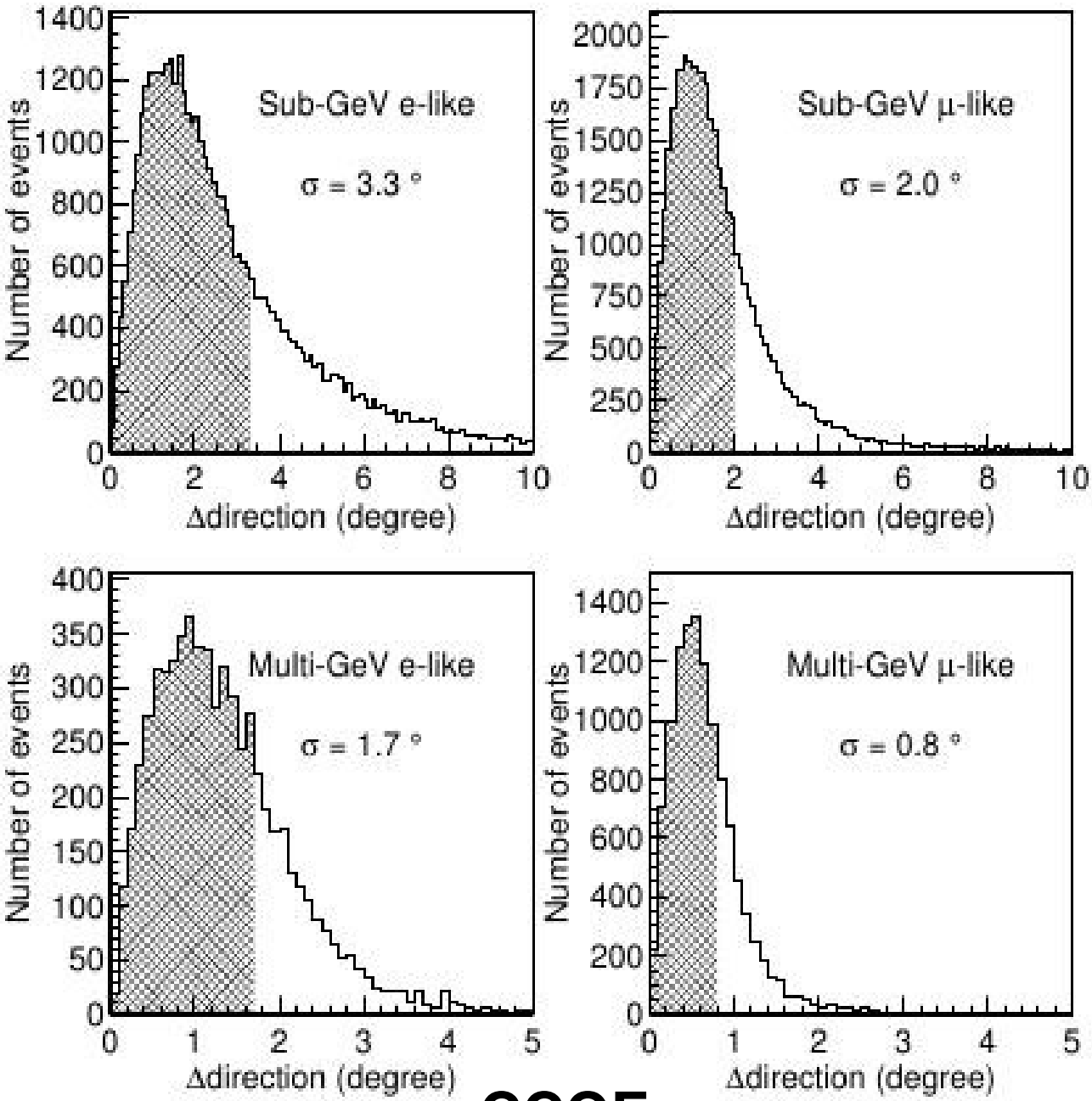
- vertex and direction fit
  - by timing residual
- ring counting
  - Hough transform for seed, likelihood method
- particle ID (e vs μ)
  - likelihood method by comparing to expected charge
- precise fitting
  - for 1-ring, using particle ID info
- momentum for each ring
  - charge inside Cherenkov cone

Vertex resolution

M. Ishitsuka thesis

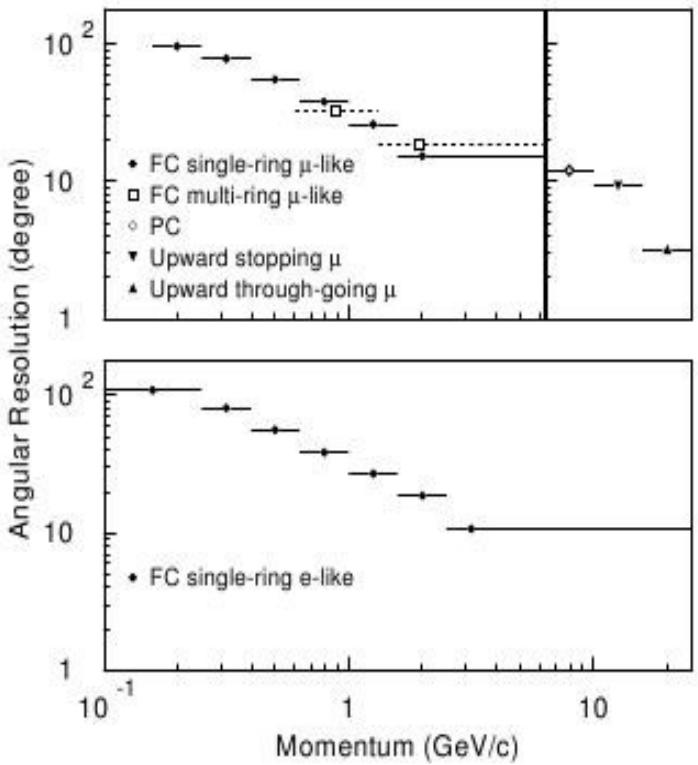


Angular resolution for lepton

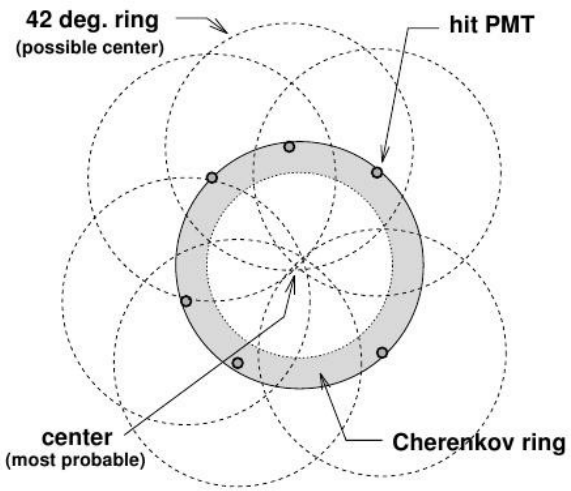


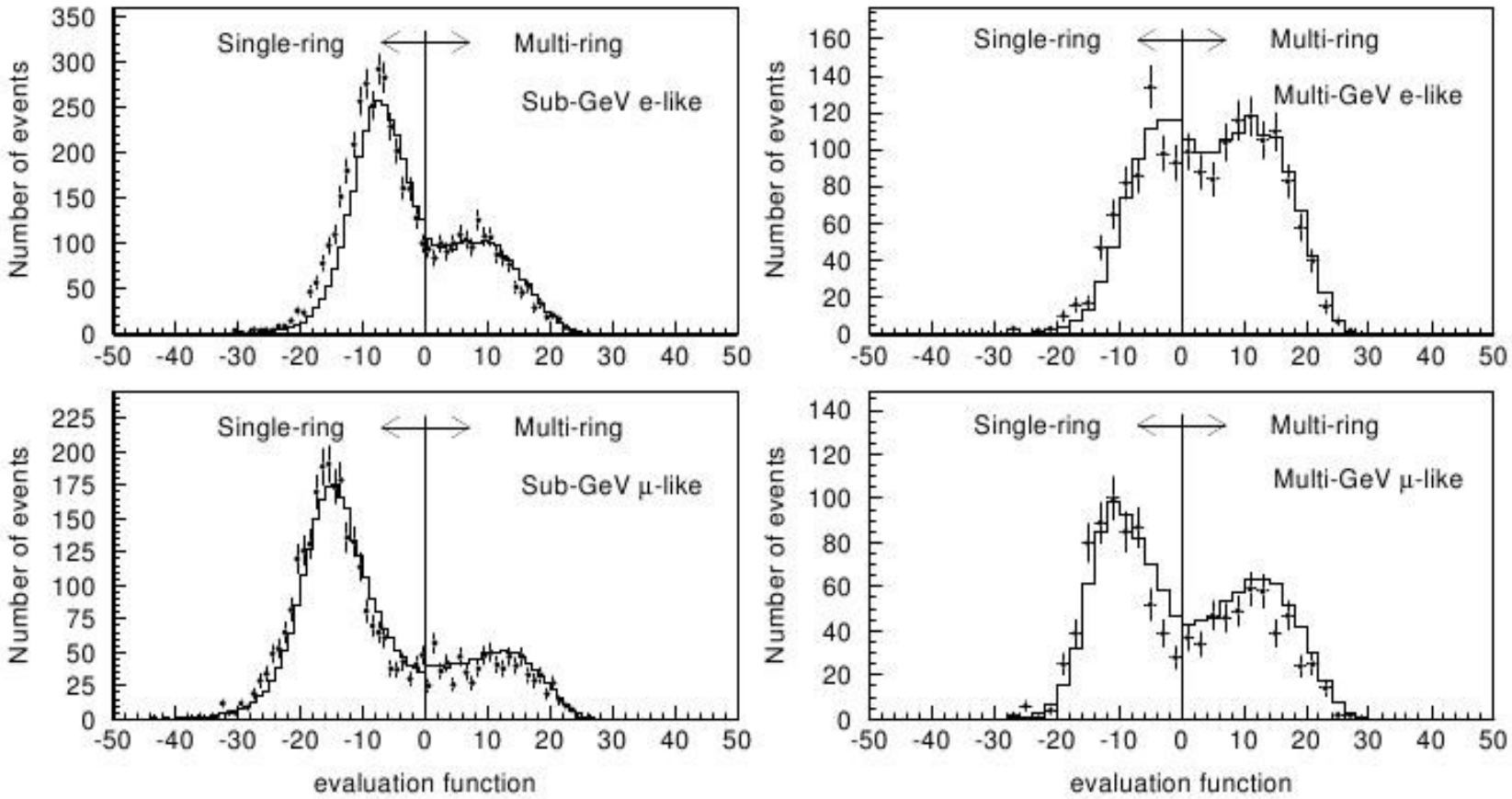
CCQE

For neutrino: not as good due to missed particles (Cherenkov threshold, non-contained)

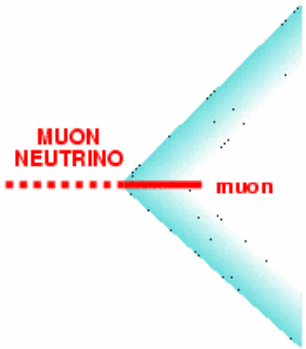


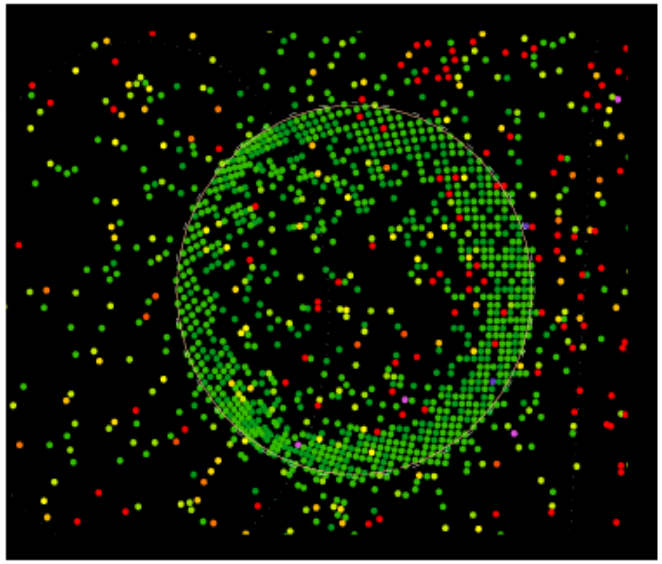
Ring-counting

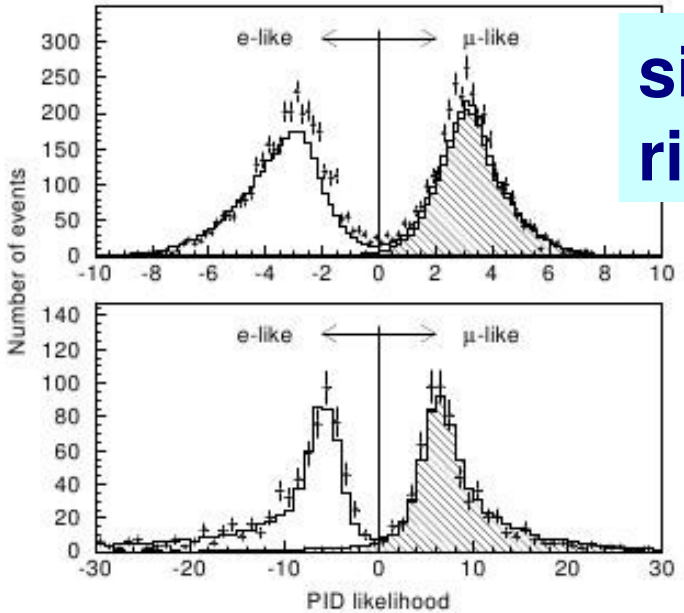




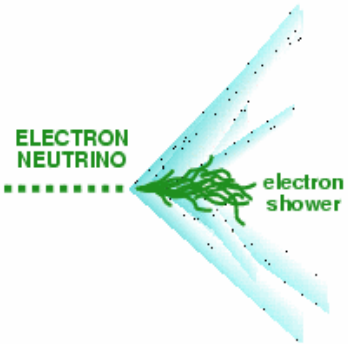
Particle ID based on likelihood w/expected light

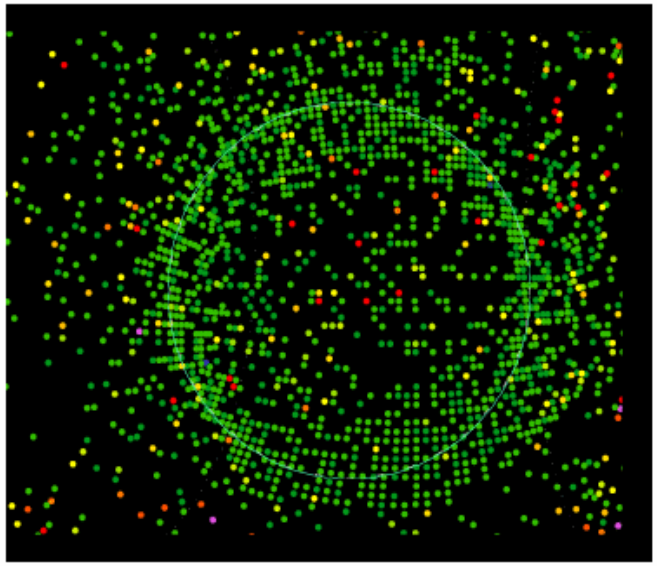


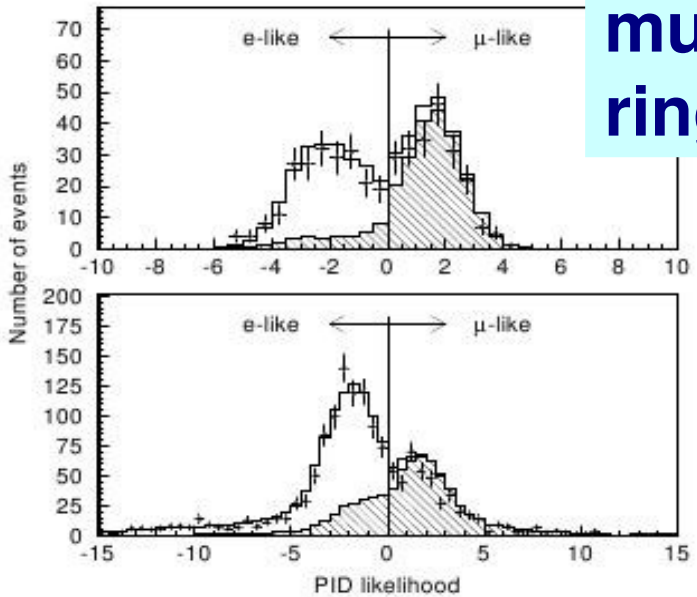




single ring

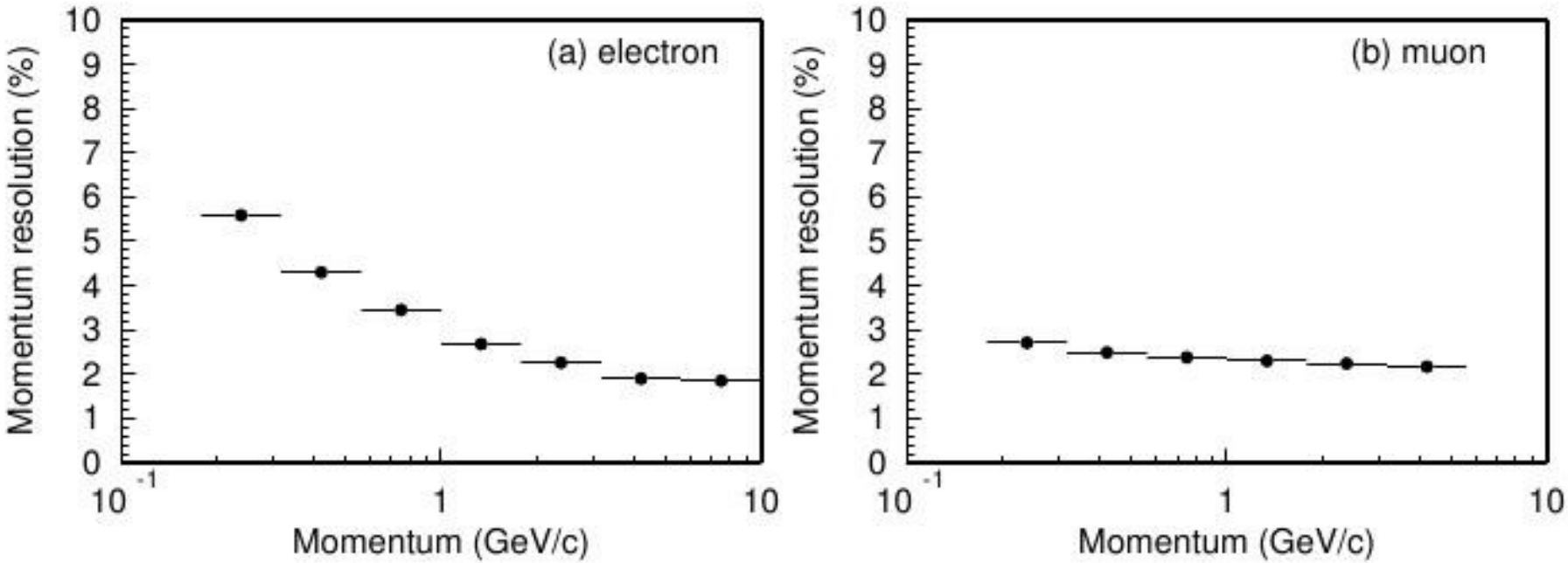






multi ring

Momentum resolution for lepton



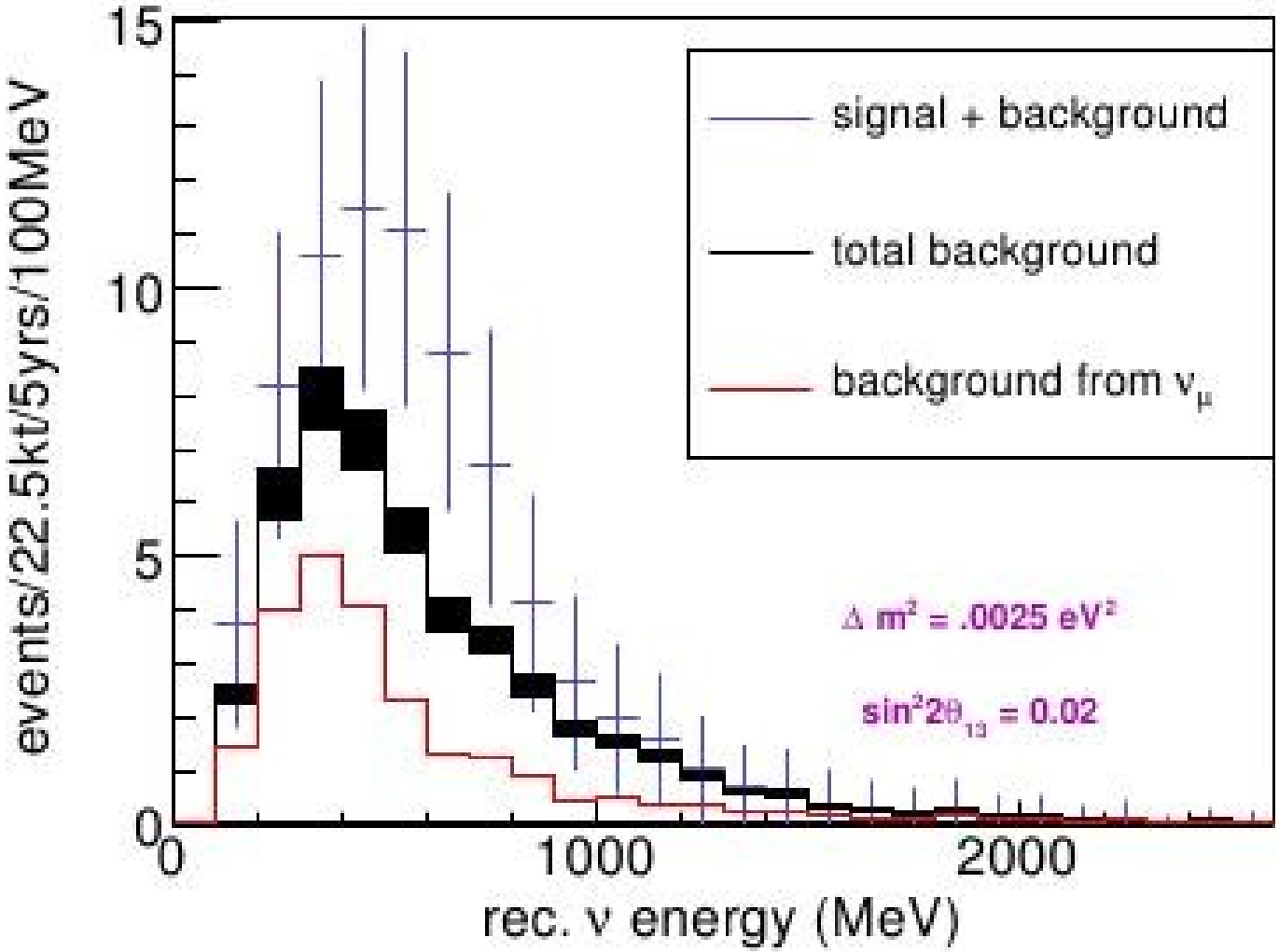
Energy scale (<~2%) set using: - decay electrons

- π^0 mass peak

- CR muon dE/dx

Example of physics question for next generation:

Electron neutrino appearance for θ_{13}, CP violation

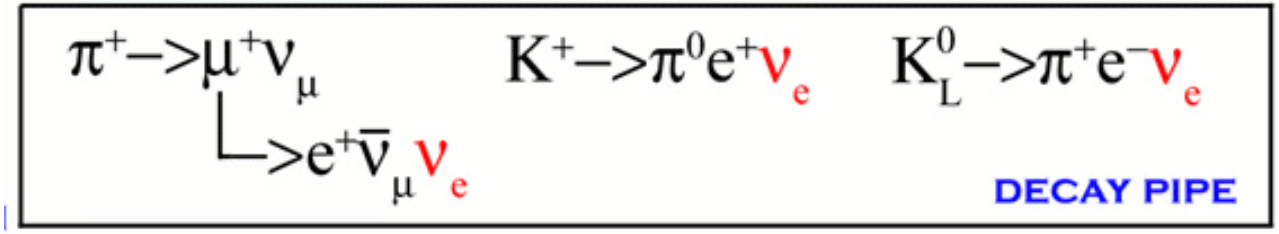


SK/T2K

Look for tiny e-like signal on non-negligible background

Background for ν_e appearance

Intrinsic beam ν_e contamination



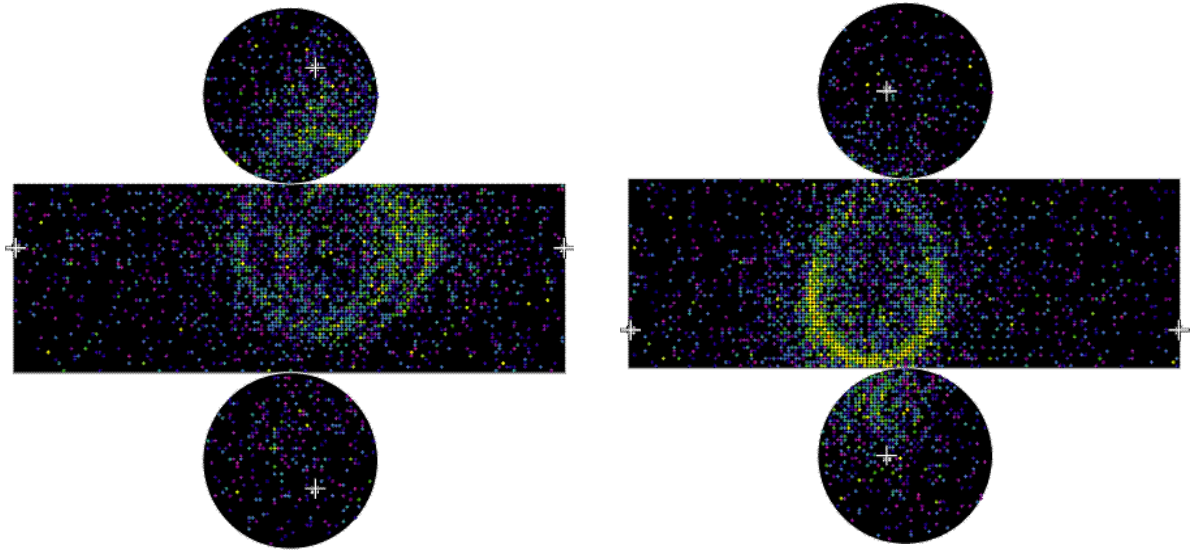
NC single pions

$\pi^0 \to \gamma\gamma$

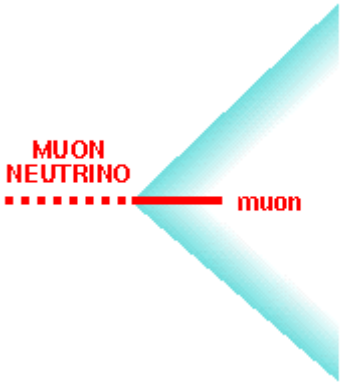
-asymmetric decay

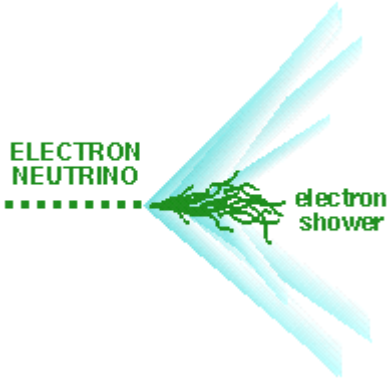
-both γ boosted forward

-one γ near wall



ν_μ mis-id

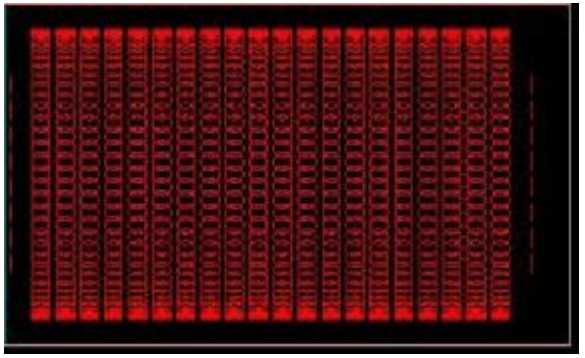




SK background for ν_e appearance

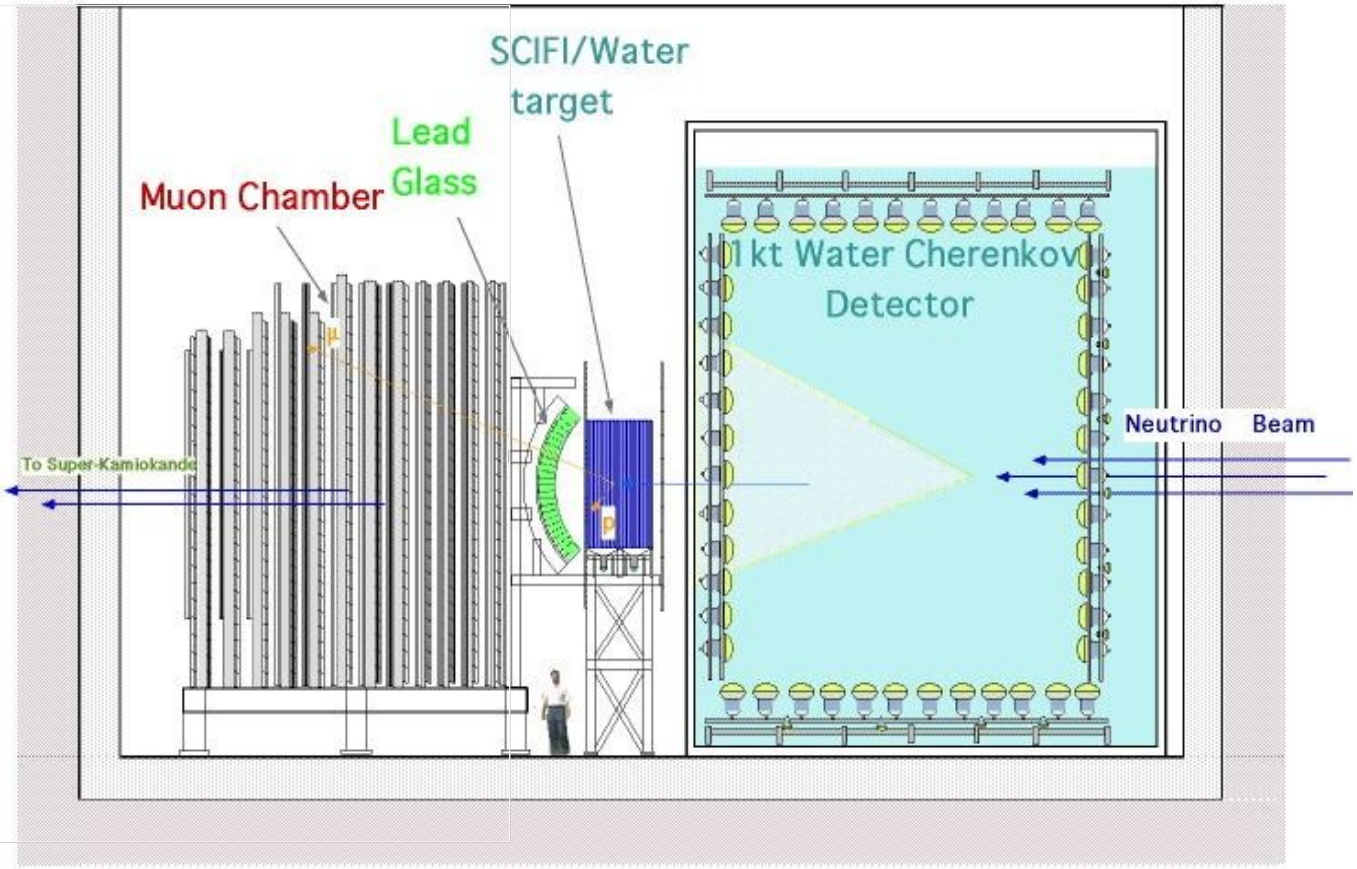
	NC	beam ν_e	CC-ν_μ
1) FCFV, E_{vis} >100 MeV	93805	20250	564229
2) 1-ring e-like	20971	10113	12264
3) no decay-e	17241	8045	3284
4) 0.35 GeV < $E_{\nu e}^{rec}$ <0.85 GeV	6939	2430	1223
5) e/π^0 separation	1122	1551	469

Existing WC simulation code:
T2K 2KM G4 sim,
tuned with K2K
1 kton near detector data

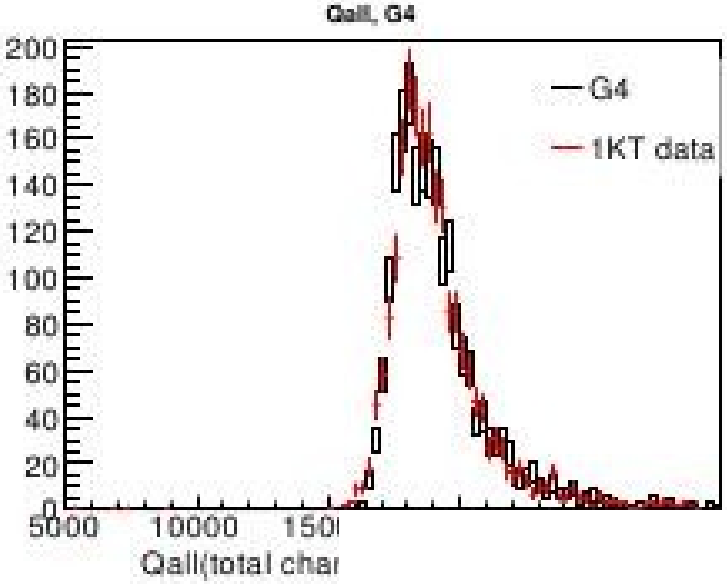


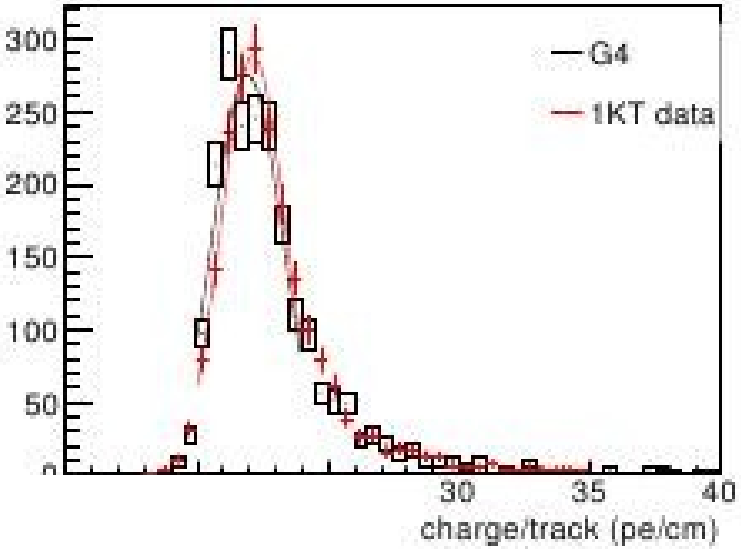
T2K 2km

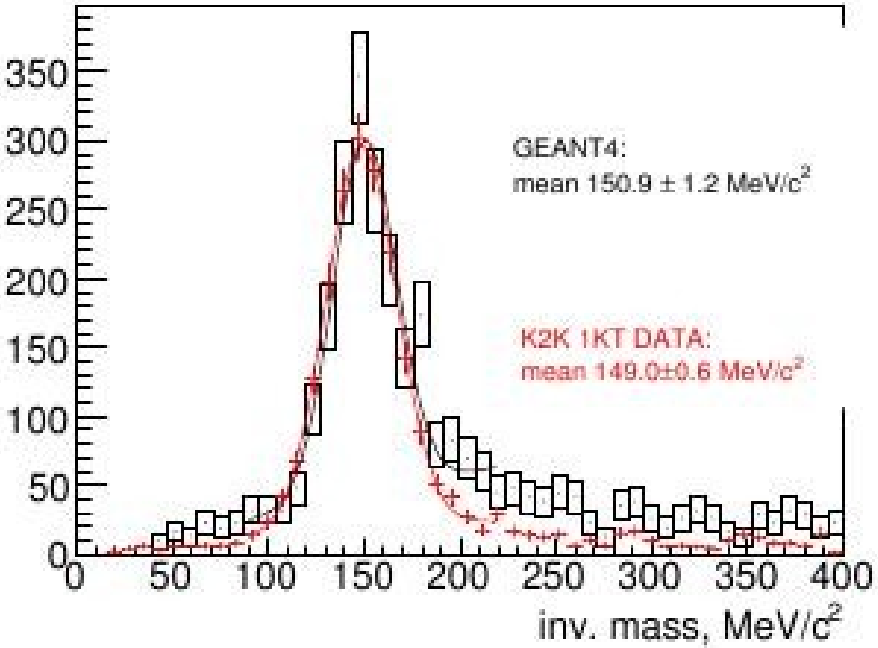
K2K 1kton



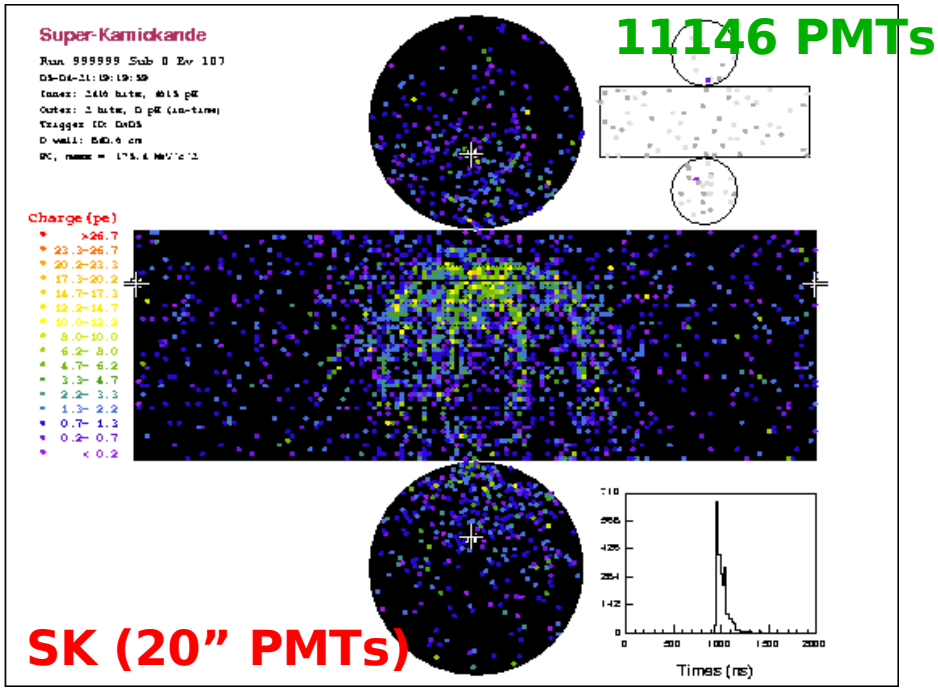
Tuning WC w/1kton data

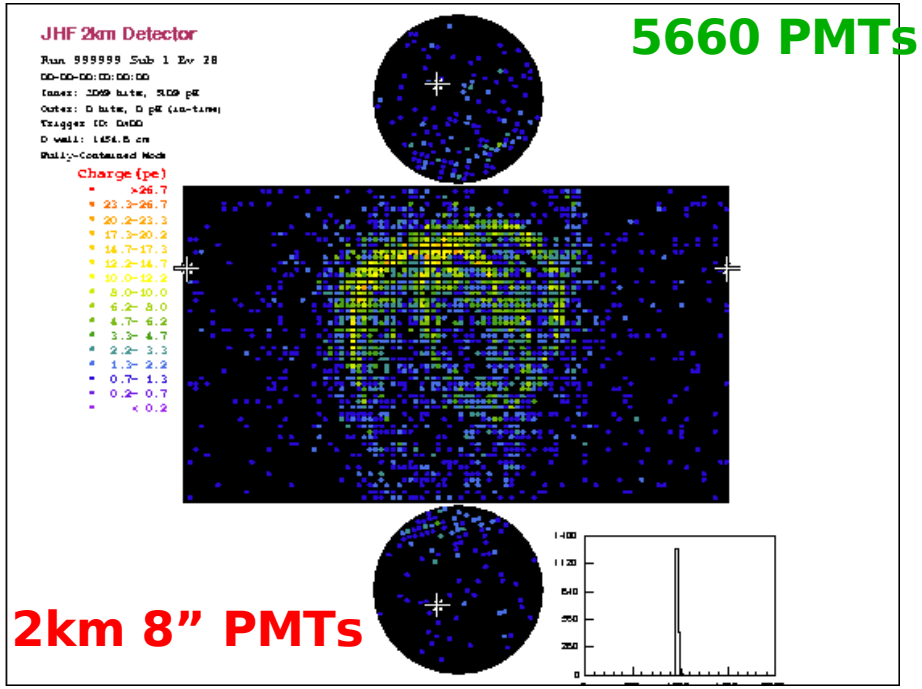


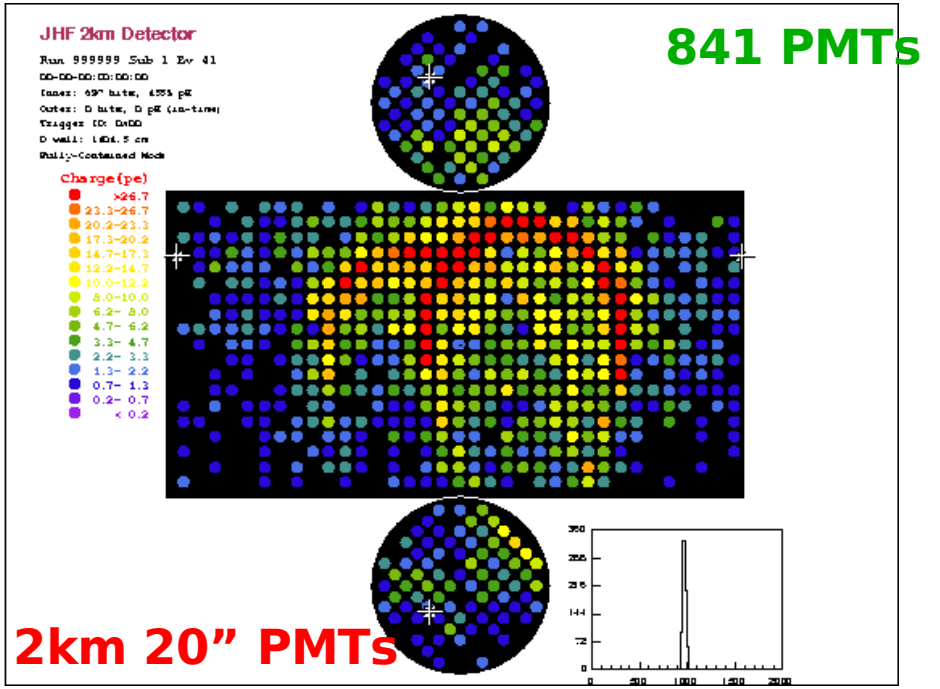




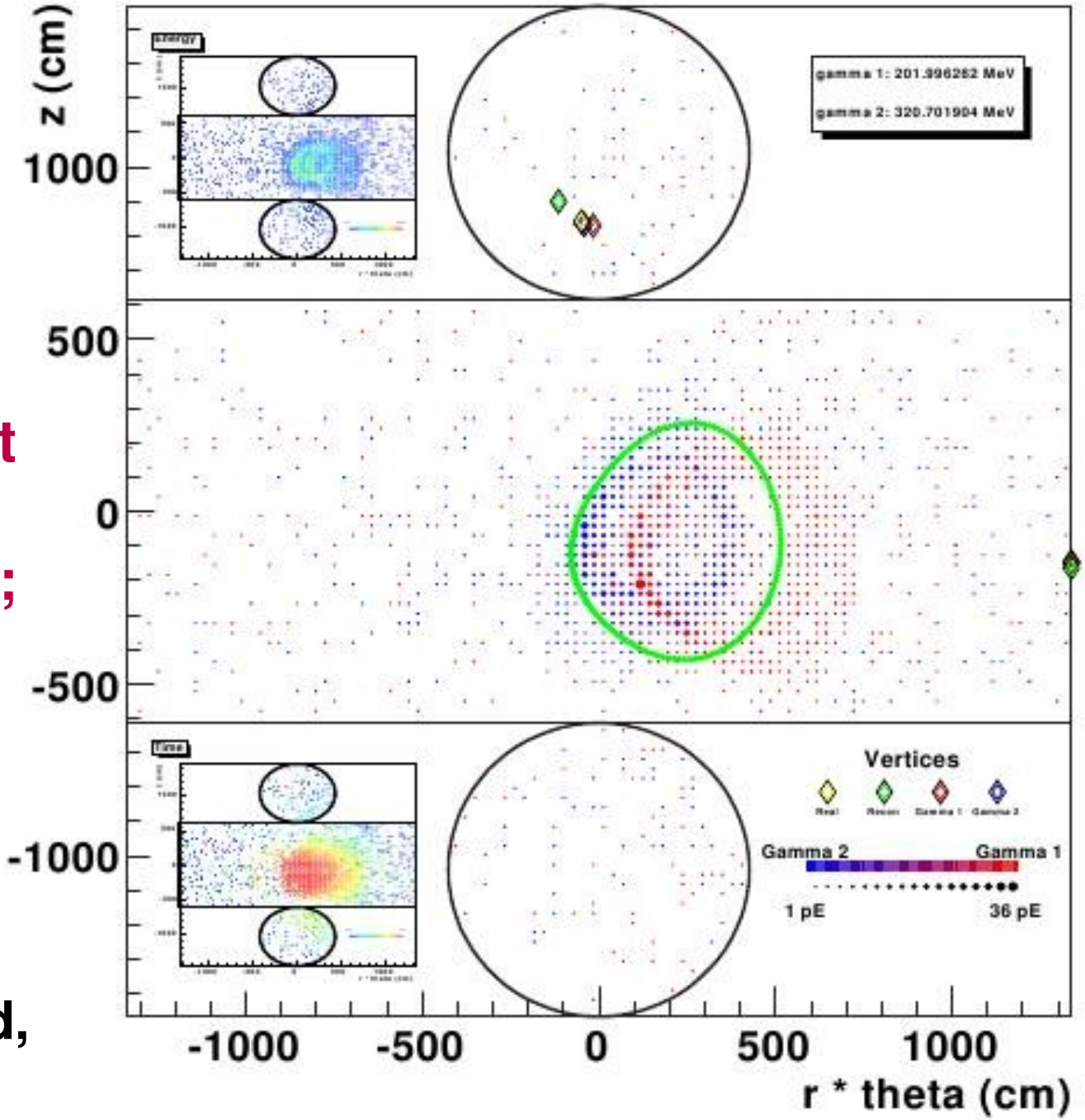
Example studies for detector configuration







Example of MC π^0 event w/overlapping rings

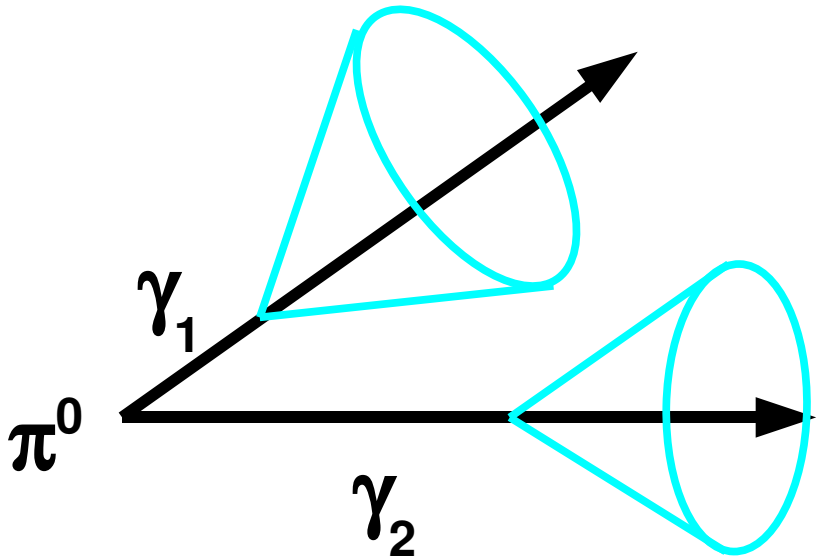


Info about gamma parent of detected photon saved; indicated in color

TJ Corona, Duke undergrad, 2006 thesis

Specialized π^0 fitters: (used for K2K) currently look for double rings

Work underway to improve, e.g. consider conversion of gammas at different times



What can be improved for high energy neutrino event reconstruction?

more photons=better
(assuming no saturation)

better coverage/pixelization is good

timing?

PMTs: so far have worked well,
but expensive and fragile
(can be deployed only at limited depth)

Lots of room for improvement...

Wish List:

- more detected photons
  (especially for low energy physics)
- more coverage, more pixelization
- better timing might help a bit
  (photon detection time resolution may be dominated by scattering)
- cheaper !

Detector simulation studies can answer:

How much will better

- timing
- pixelization
- coverage,
- quantum efficiency

improve reconstruction,
and sensitivity for various physics goals?
Tradeoff with cost?

A generic simulation may answer these, and may also guide direction for R&D
(which of these characteristics is most important?)

Now discussion within DUSEL-WC simulation group on best approach