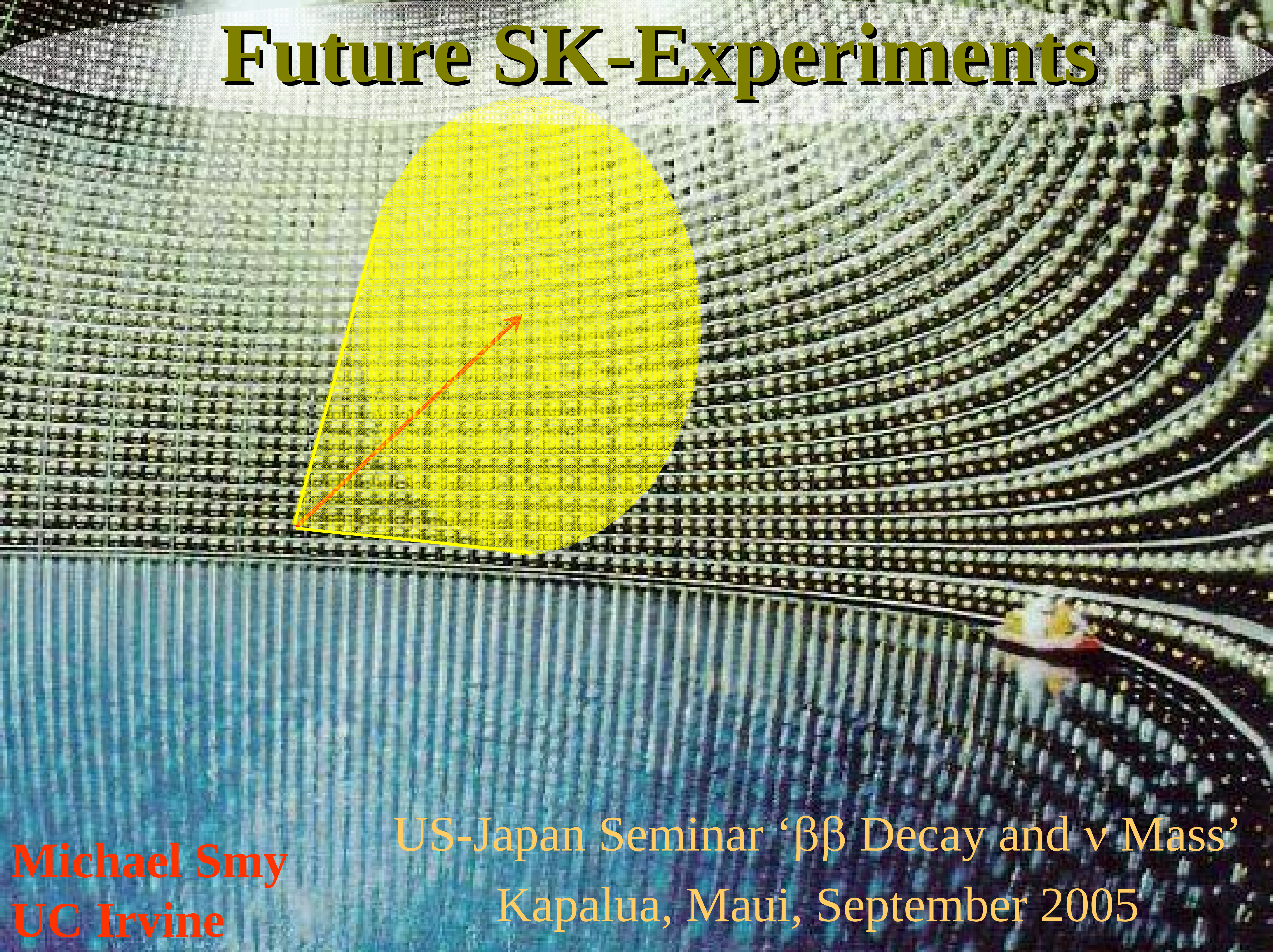
Future SK-Experiments



US-Japan Seminar ‘ββ Decay and ν Mass’

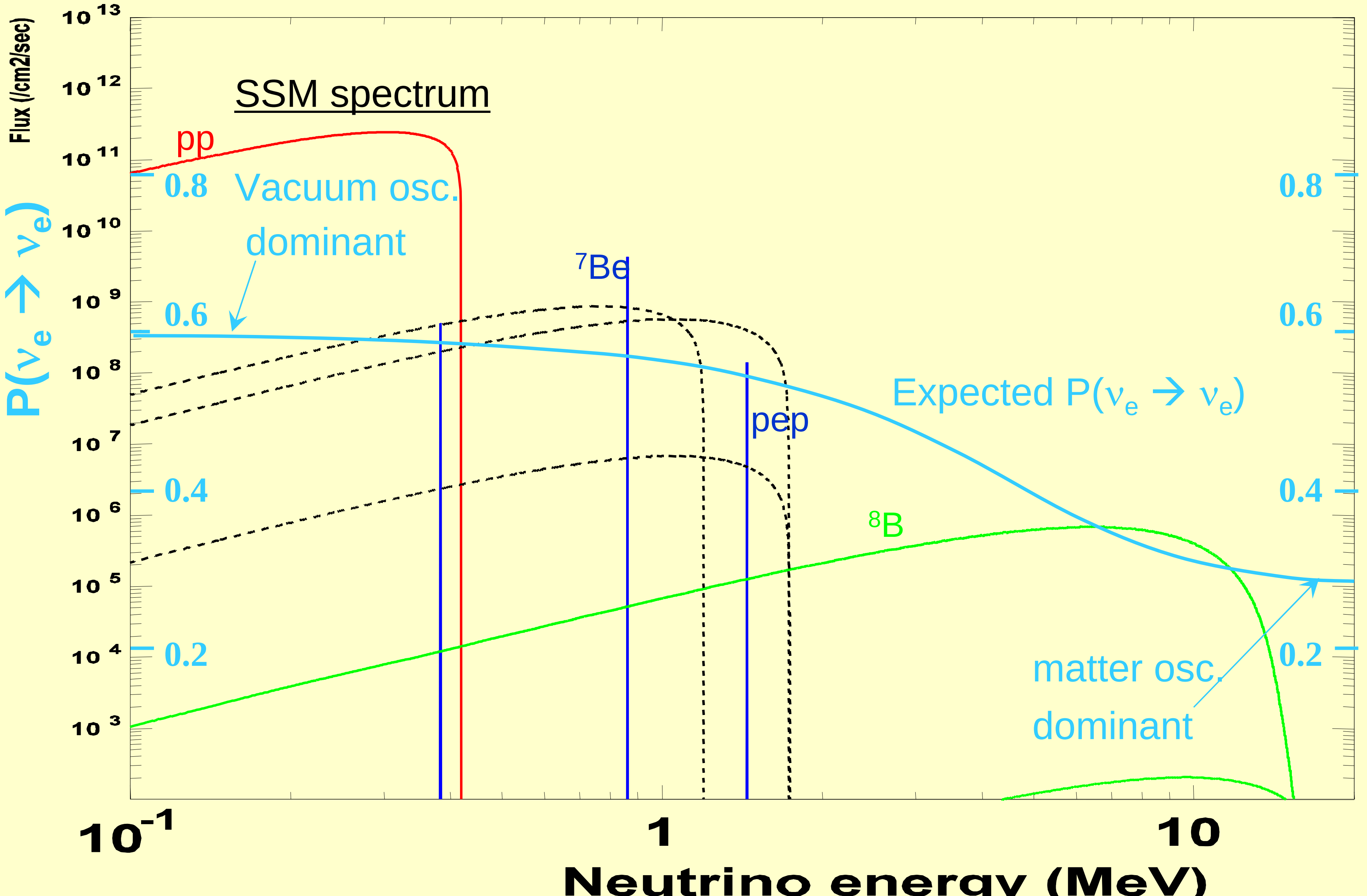
Kapalua, Maui, September 2005

Michael Smy
UC Irvine

Solar Neutrinos

Michael Smy, UC Irvine

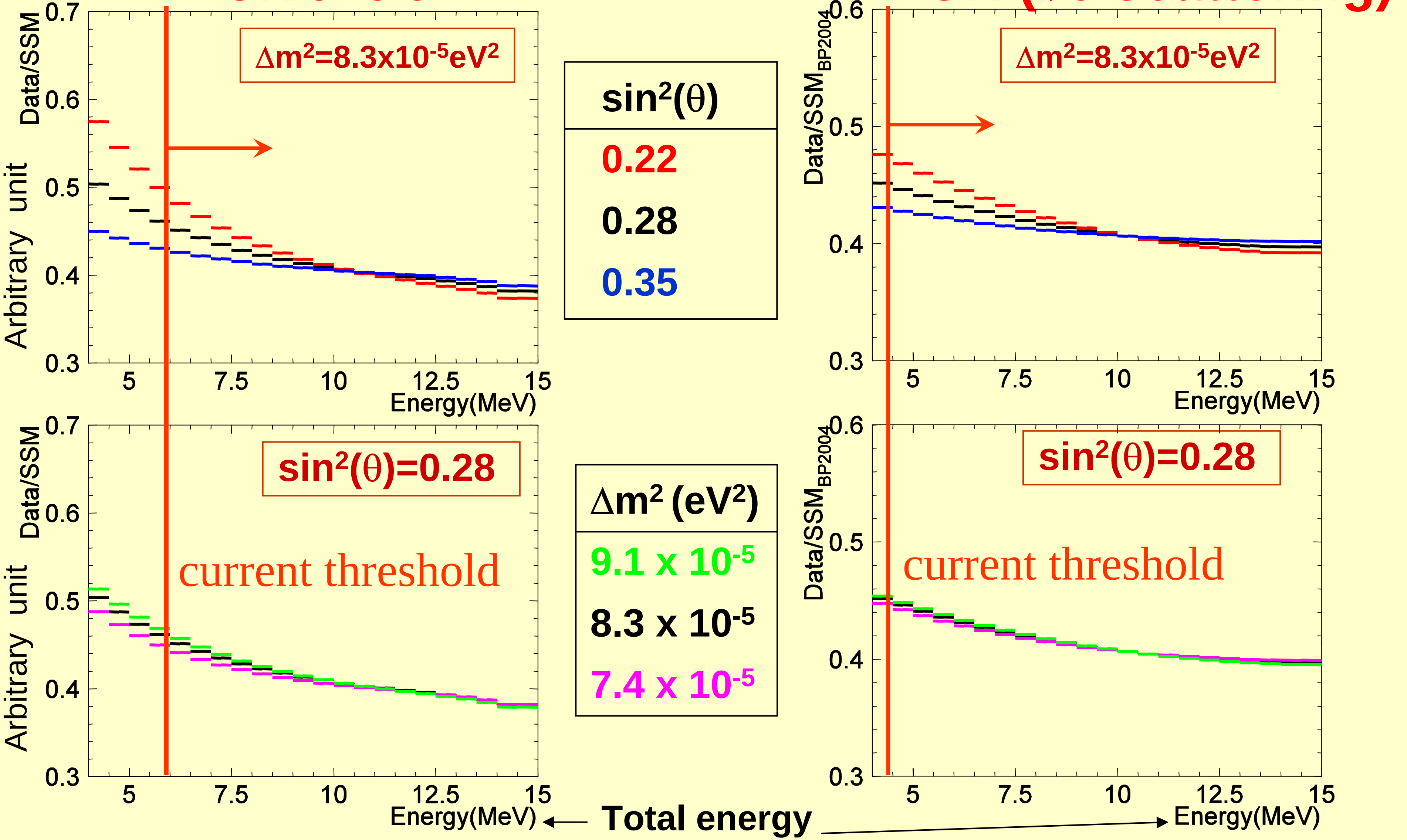
Solar MSW-Vacuum Transition



Courtesy of M. Nakahata, ICRR

Expected low energy upturn (^{8}B)

SNO CC — SK (νe scattering)



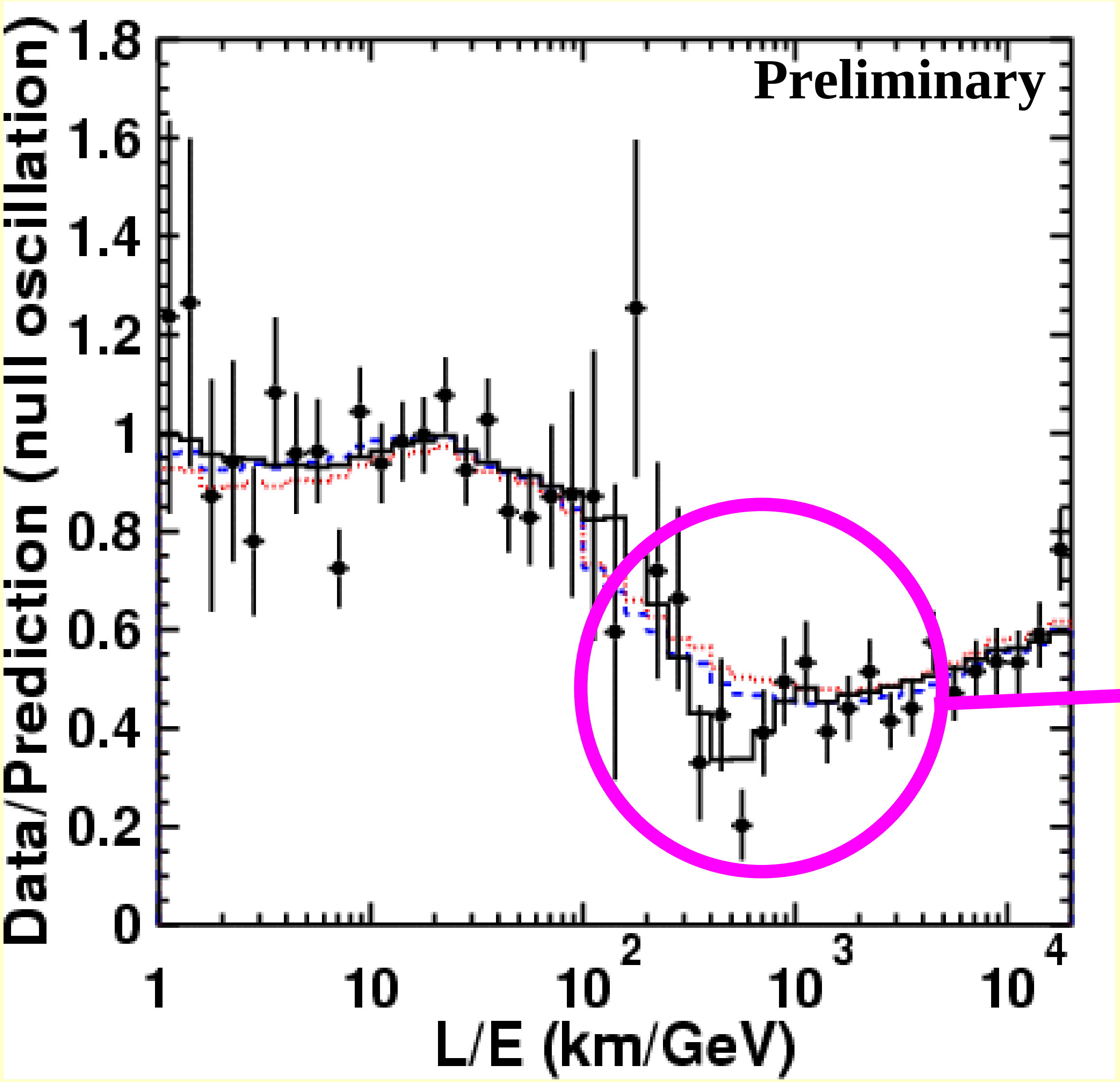
~20% in SNO and ~10% in SK distortion is expected from 4 MeV to 15 MeV

Courtesy of M. Nakahata, ICRR

Atmospheric Neutrinos

- L/E Oscillation Analysis
- Three Flavor Oscillations
- Appearance of τ leptons

Similar plot with this selected subset: (~2700 events)



decoherence

decay

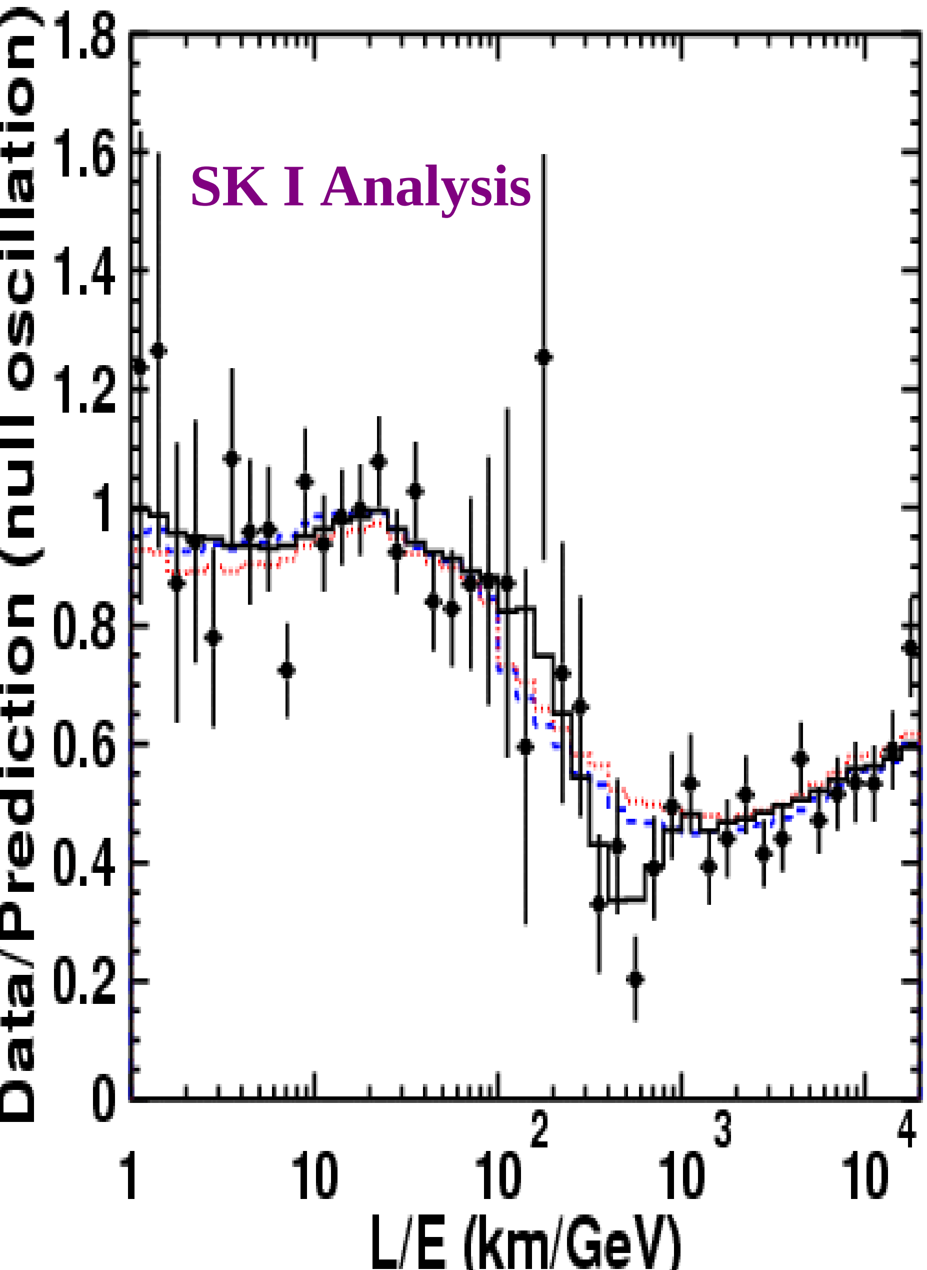
best-fit osc (favored by >3 σ)

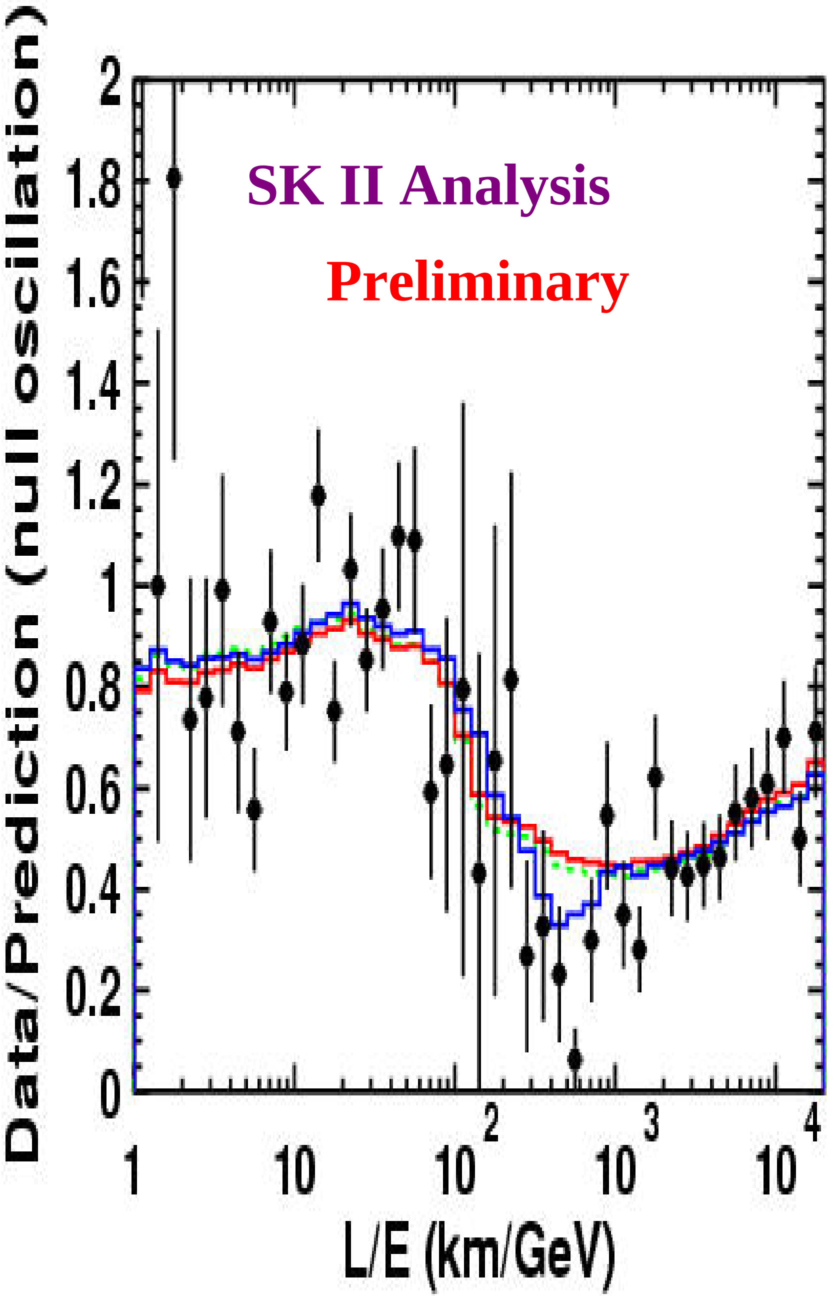
"the dip"

Seems to be really wiggling!

Courtesy of K. Scholberg, Duke University

L/E Analysis



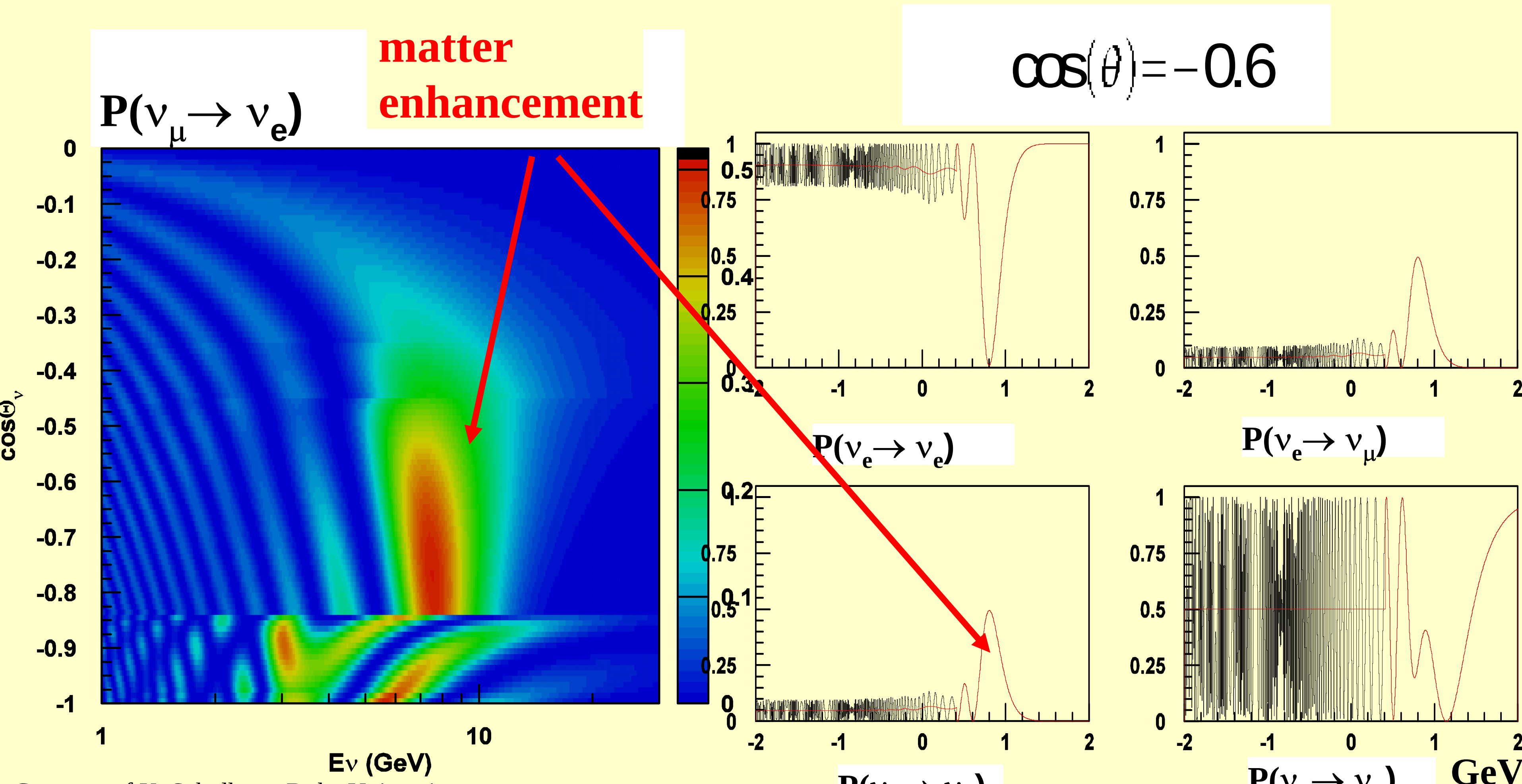


Courtesy of K. Scholberg, Duke University

Look for Non-Zero θ_{13} in Enhancement of ν_e for some Angles/Energies

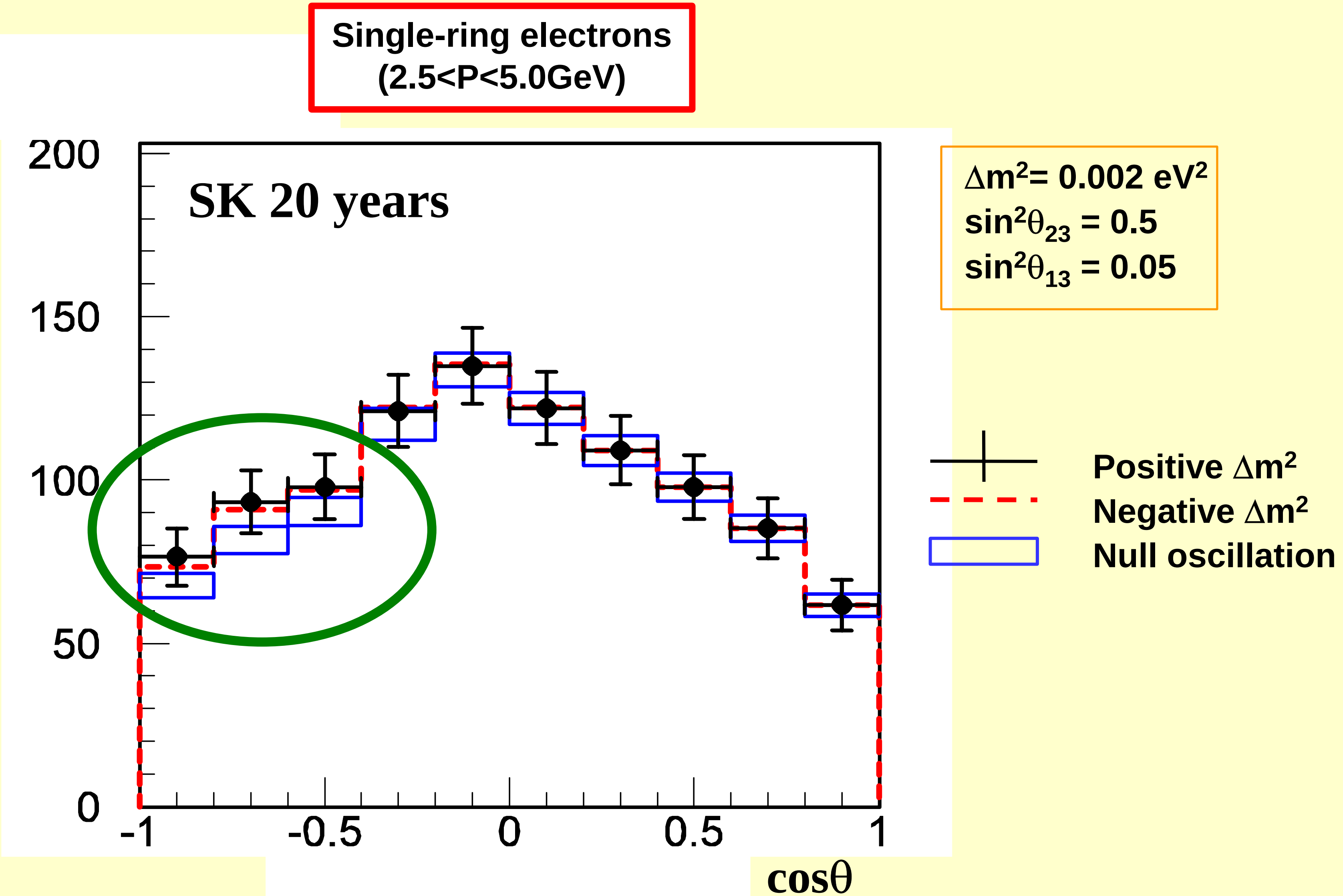
Normal hierarchy: resonance for neutrinos

$$\Delta m^2 = 0.003\,eV^2, \sin^2\theta_{23} = 0.5, \sin^2\theta_{13} = 0.026$$



Courtesy of K. Scholberg, Duke University

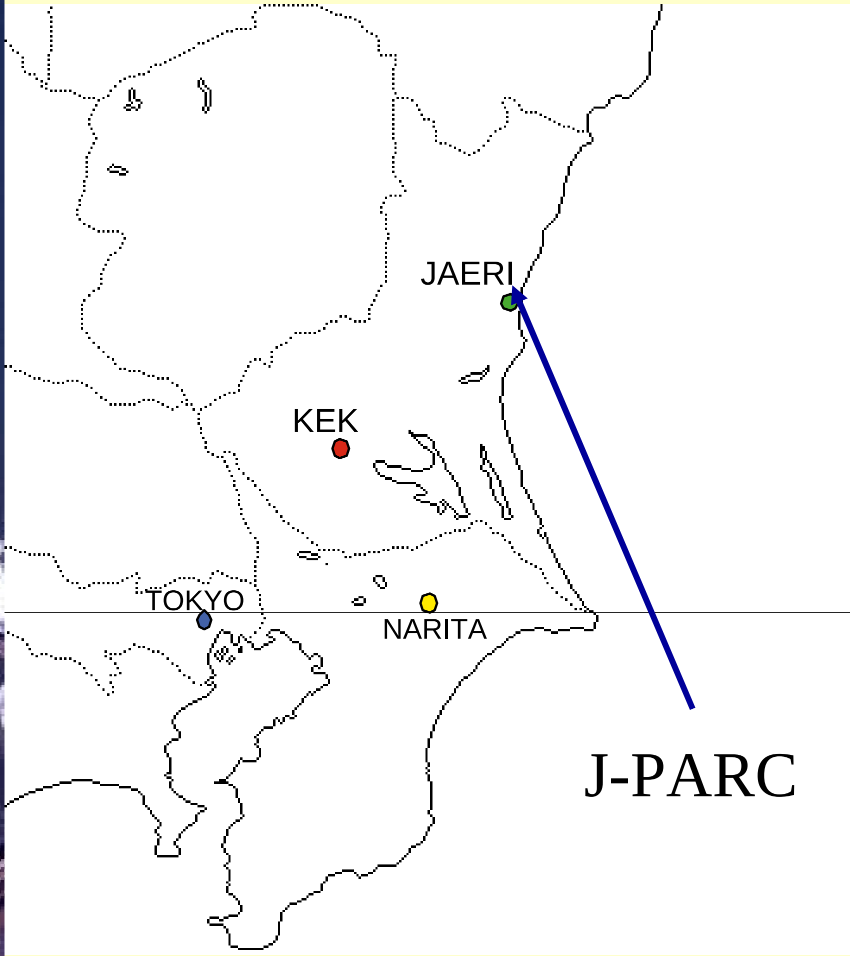
Enhancement of Upgoing Multi-GeV Single Ring Electrons



Courtesy of K. Scholberg, Duke University

Accelerator Neutrinos

Courtesy of T. Kobayashi, KEK



T2K: Search for $\nu_\mu \rightarrow \nu_e$ Appearance

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \frac{\Delta m_{31}^2 L}{4E} \times \left(1 + \frac{2a}{\Delta m_{31}^2}(1 - 2S_{13}^2)\right)$$

Main

$$+8C_{13}^2 S_{12} S_{13} S_{23}(C_{12}C_{23}\cos\delta - S_{12}S_{13}S_{23})\cos\frac{\Delta m_{32}^2 L}{4E}\sin\frac{\Delta m_{31}^2 L}{4E}\sin\frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23}\sin\delta\sin\frac{\Delta m_{32}^2 L}{4E}\sin\frac{\Delta m_{31}^2 L}{4E}\sin\frac{\Delta m_{21}^2 L}{4E}$$

CP-odd

$$+4S_{12}^2 C_{13}^2\{C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12}C_{23}S_{12}S_{23}S_{13}\cos\delta\}\sin^2\frac{\Delta m_{21}^2 L}{4E}$$

Solar

$$-8C_{13}^2 S_{13}^2 S_{23}^2 \cos\frac{\Delta m_{32}^2 L}{4E}\sin\frac{\Delta m_{31}^2 L}{4E}\frac{aL}{4E}(1 - 2S_{13}^2)$$

Matter

$\delta \rightarrow -\delta$, $a \rightarrow -a$ for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

Matter eff.:

$$a = 7.56\times10^{-5}[\mathrm{eV}^2]\cdot\left(\frac{\rho}{[\mathrm{g/cm^3}]}\right)\cdot\left(\frac{E}{[\mathrm{GeV}]}\right)$$

$$A_{CP} \equiv \frac{P - \bar{P}}{P + \bar{P}} \approx \frac{\Delta m_{12}^2 L}{E}\cdot\frac{\sin 2\theta_{12}}{\sin\theta_{13}}\cdot\sin\delta$$

\# of signal $\propto \sin^2\theta_{13}$ (Stat err $\propto \sin\theta_{13}$),
CP-odd term $\propto \sin\theta_{13}$

⇒ **Sensitivity indep. from θ_{13} (if no BG & no syst. err)**

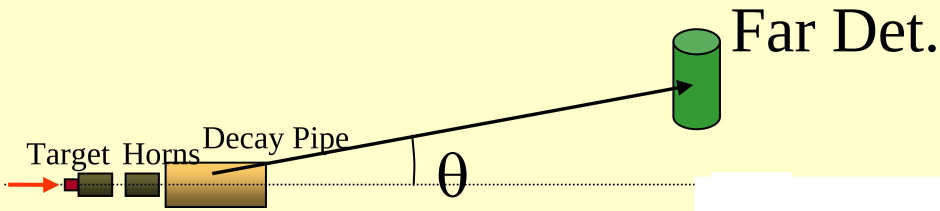
Courtesy of T. Kobayashi, KEK

- (0.75MW→)4MW 50GeV PS @ J-PARC
- Off-axis (OA) 2~3^0: E_ν^{peak}=0.5~0.8GeV
- L=295km

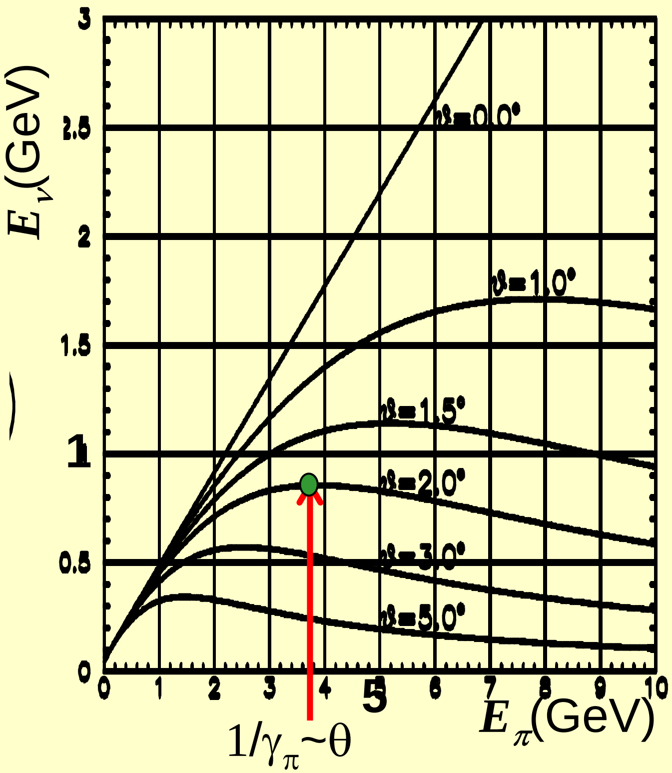
Courtesy of T. Kobayashi, KEK

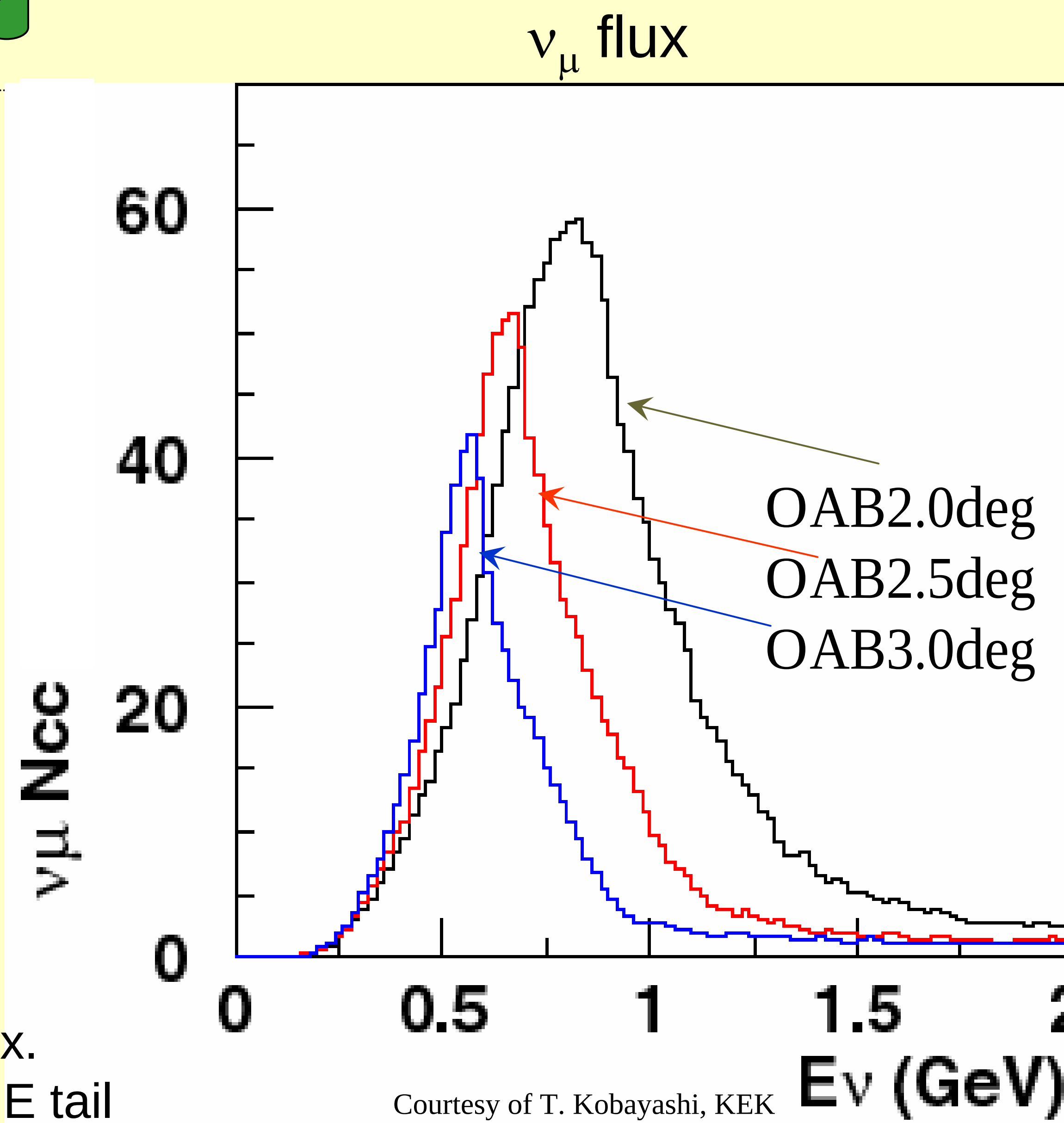
Off-Axis: High Intensity Narrow Band Beam

(ref.: BNL-E889 Proposal)



Decay Kinematics

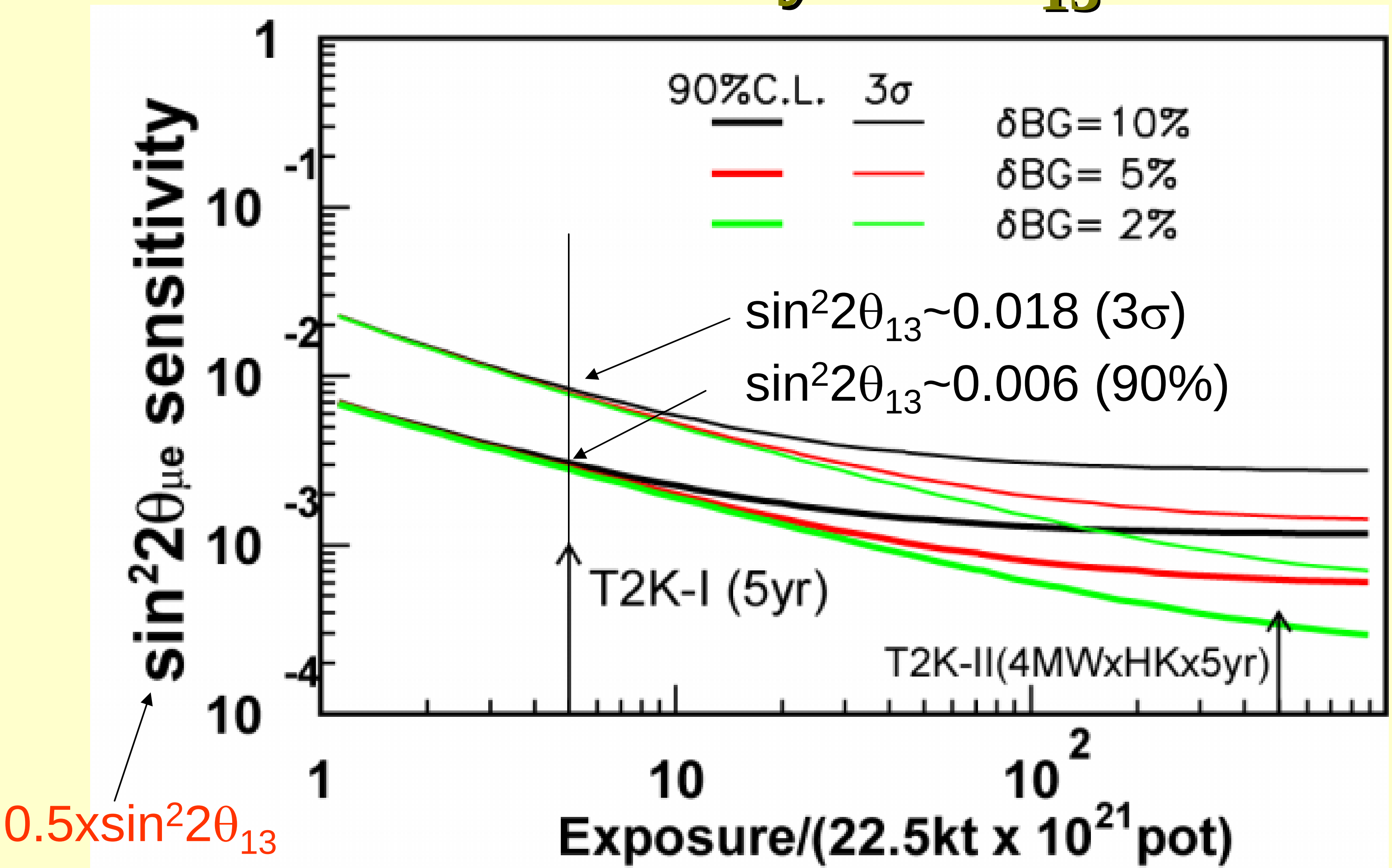




Courtesy of T. Kobayashi, KEK

- Increase statistics @ osc. max.
- Decrease background from HE tail

Sensitivity for θ_{13}



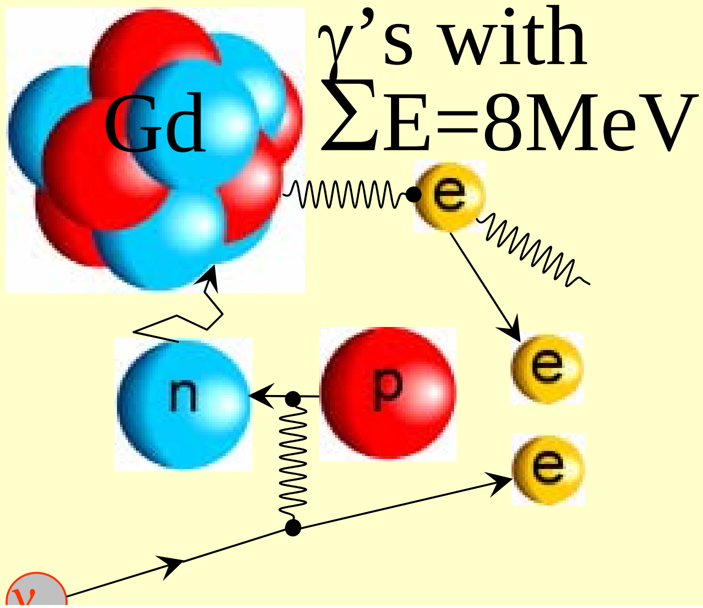
$\sin^2 2\theta_{13} < 10^{-3}$ can be searched if syst err ~ few %

Courtesy of T. Kobayashi, KEK

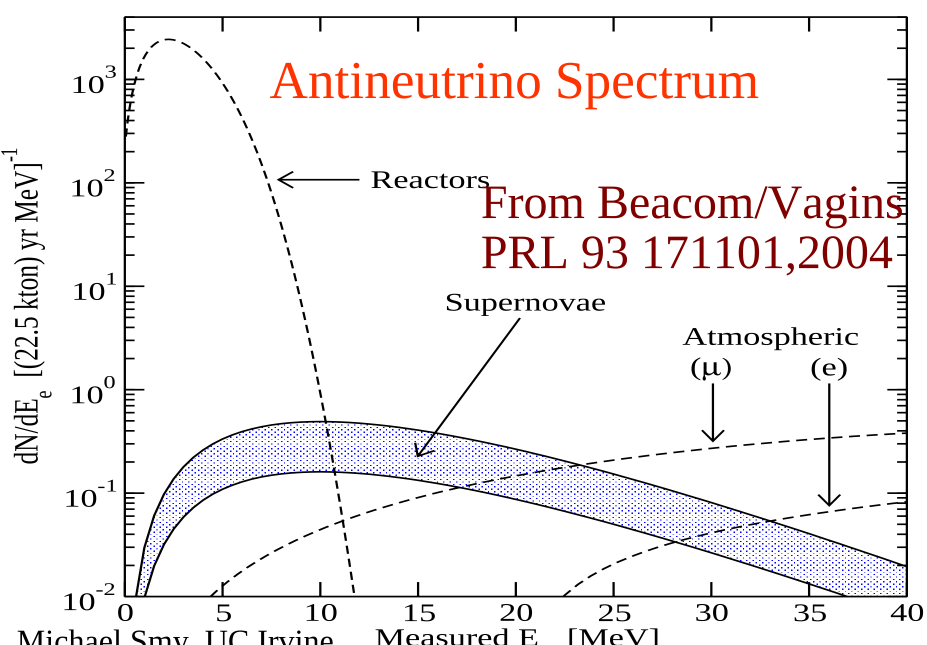
Supernova/Reactor Neutrinos

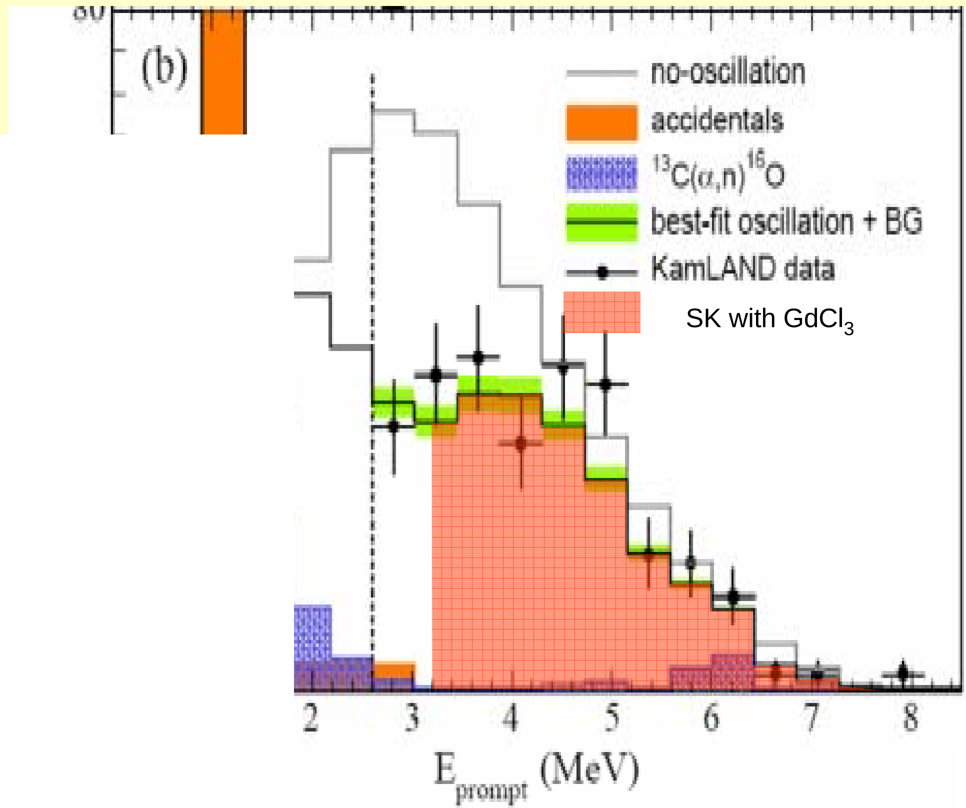
- Rests on Identification of Antineutrinos
- Beacom/Vagins: Neutrons from inverse β reaction capture on dissolved Gadolinium and produce detectable γ cascade (i.e. enough č-light for SK)
- Needs very low threshold
- Feasibility study: detector corrosion, water purification, water transparency
- MC simulation of reactor neutrino interactions

Neutron Detection in SK: 0.1% $GdCl_3$



"Super-KamLAND" could collect this much data in two weeks





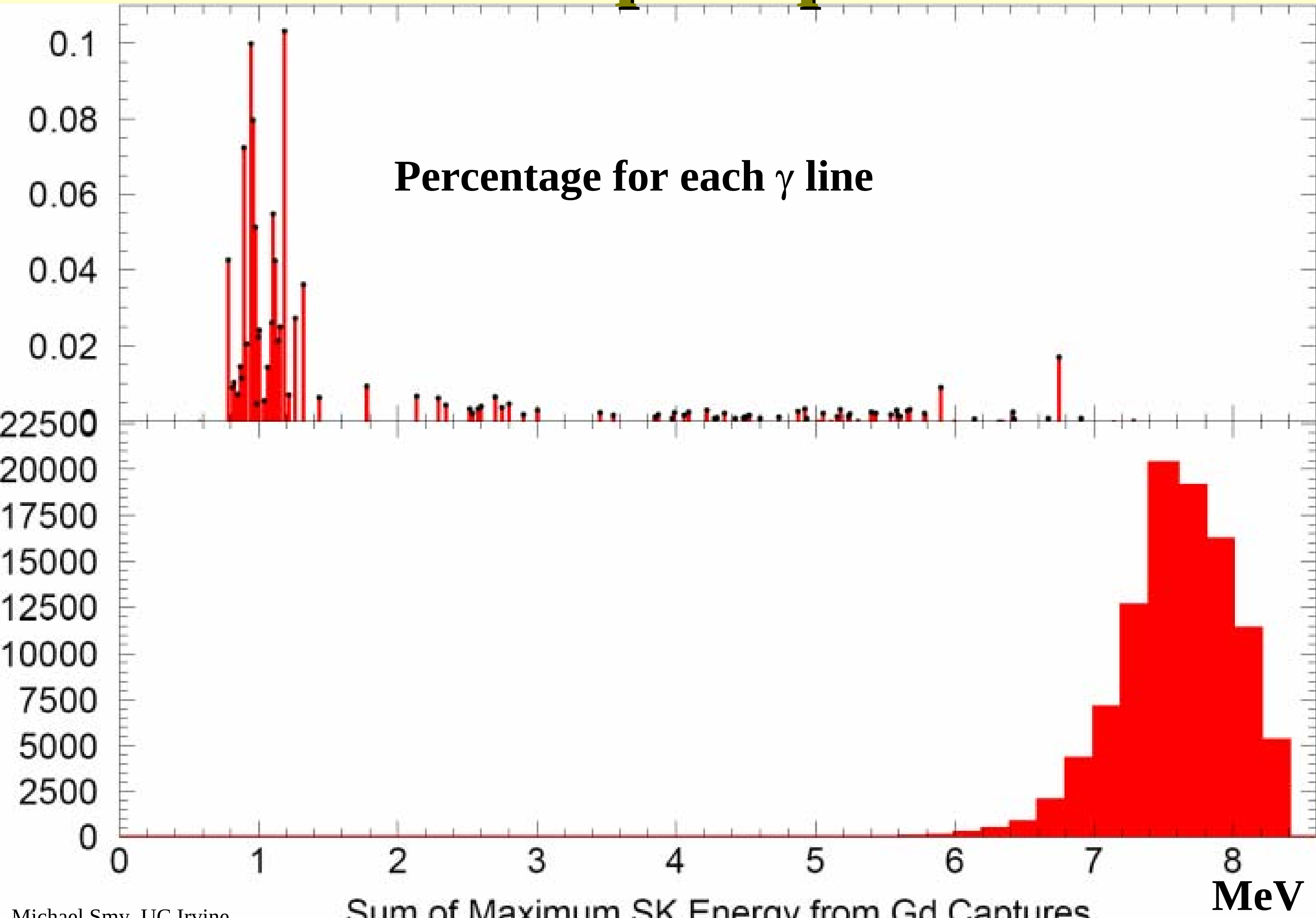
Choubey and Petcov consider the reactor signal of SK-Gd

Data set used	99% CL range of $\Delta m^2_{21} \times 10^{-5}eV^2$	99% CL spread of Δm^2_{21}	99% CL range of $\sin^2\theta_{12}$	99% CL spread in $\sin^2\theta_{12}$
only solar	3.2 - 14.9	65%	0.22 – 0.37	25%
solar+162 Ty KL	5.2 - 9.8	31%	0.22 – 0.37	25%
solar with future SNO	3.3 – 11.9	57%	0.22 – 0.34	21%
solar+1 kTy KL(low-LMA)	6.5 - 8.0	10%	0.23 – 0.37	23%
solar+2.6 kTy KL(low-LMA)	6.7 – 7.7	7%	0.23 – 0.36	22%
solar with future SNO+1.3 kTy KL(low-LMA)	6.7 – 7.8	8%	0.24 – 0.34	17%
3 yrs SK-Gd	7.2 - 7.4	1.4%	0.25 – 0.37	19%
5 yrs SK-Gd	7.0 – 7.3	< 1%	0.26 – 0.35	15%
solar+3 yrs SK-Gd(low-LMA)	7.0 – 7.4	3%	0.25 – 0.34	15%
solar+3 yrs SK-Gd(high-LMA)	14.5 – 15.4	3%	0.24 – 0.37	21%
solar with future SNO+3 yrs SK-Gd(low-LMA)	7.0 – 7.4	3%	0.25 – 0.335	14%
solar with future SNO+3 yrs SK-Gd(high-LMA)	14.5 – 15.4	3%	0.24 – 0.35	19%
3 yrs SK-Gd with Kashiwazaki "down"	6.8 – 7.6	6%	0.23 – 0.40	27%
7 yrs SK-Gd with *only* Shika-2 "up"	7.0 – 7.3	< 1%	0.28 – 0.32	6.7%

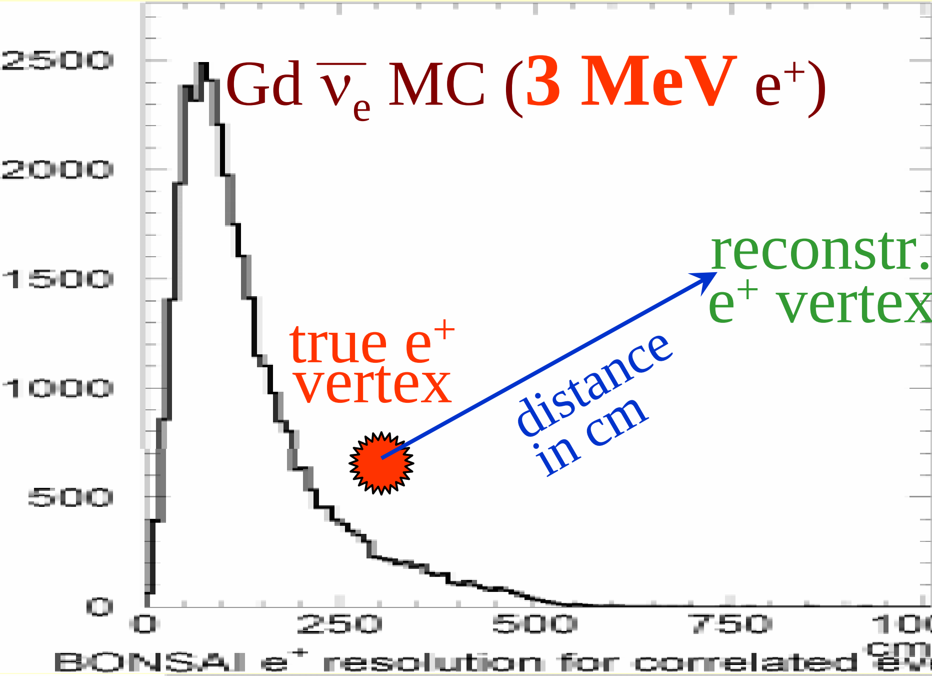
Table 1: The range of parameter values allowed at 99% C.L. and their corresponding spread.

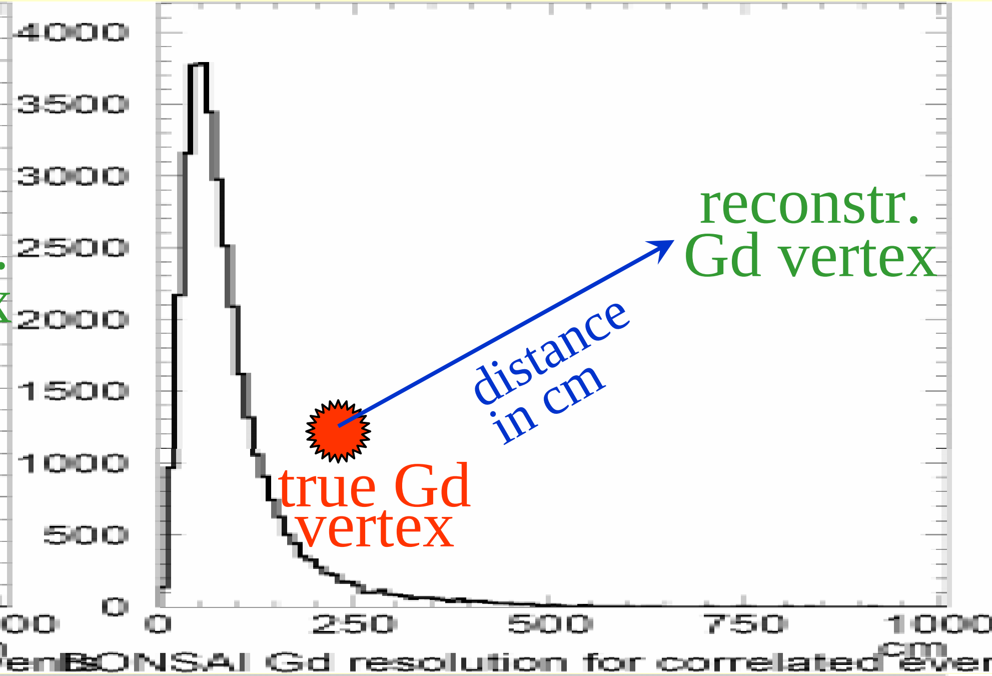
Courtesy of M. Vagins, UCI

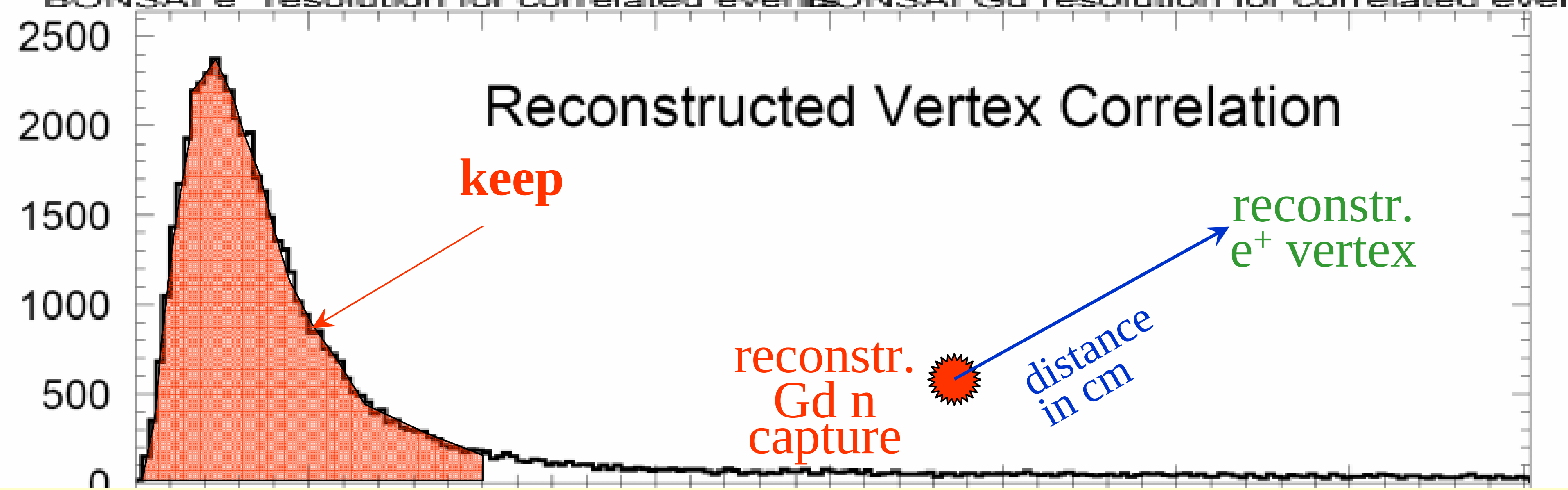
Gd MC: Input Spectrum



Event Reconstruction



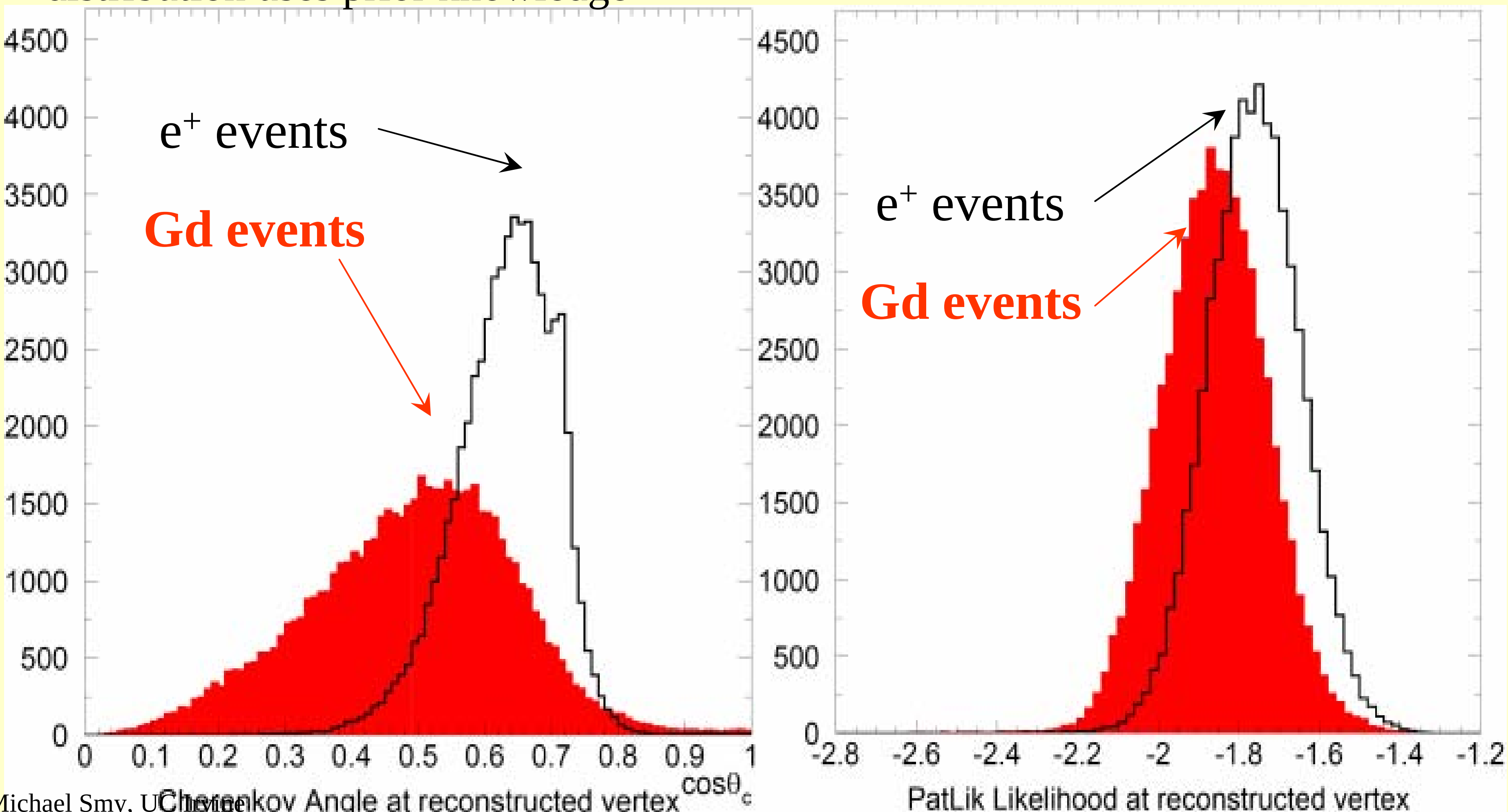




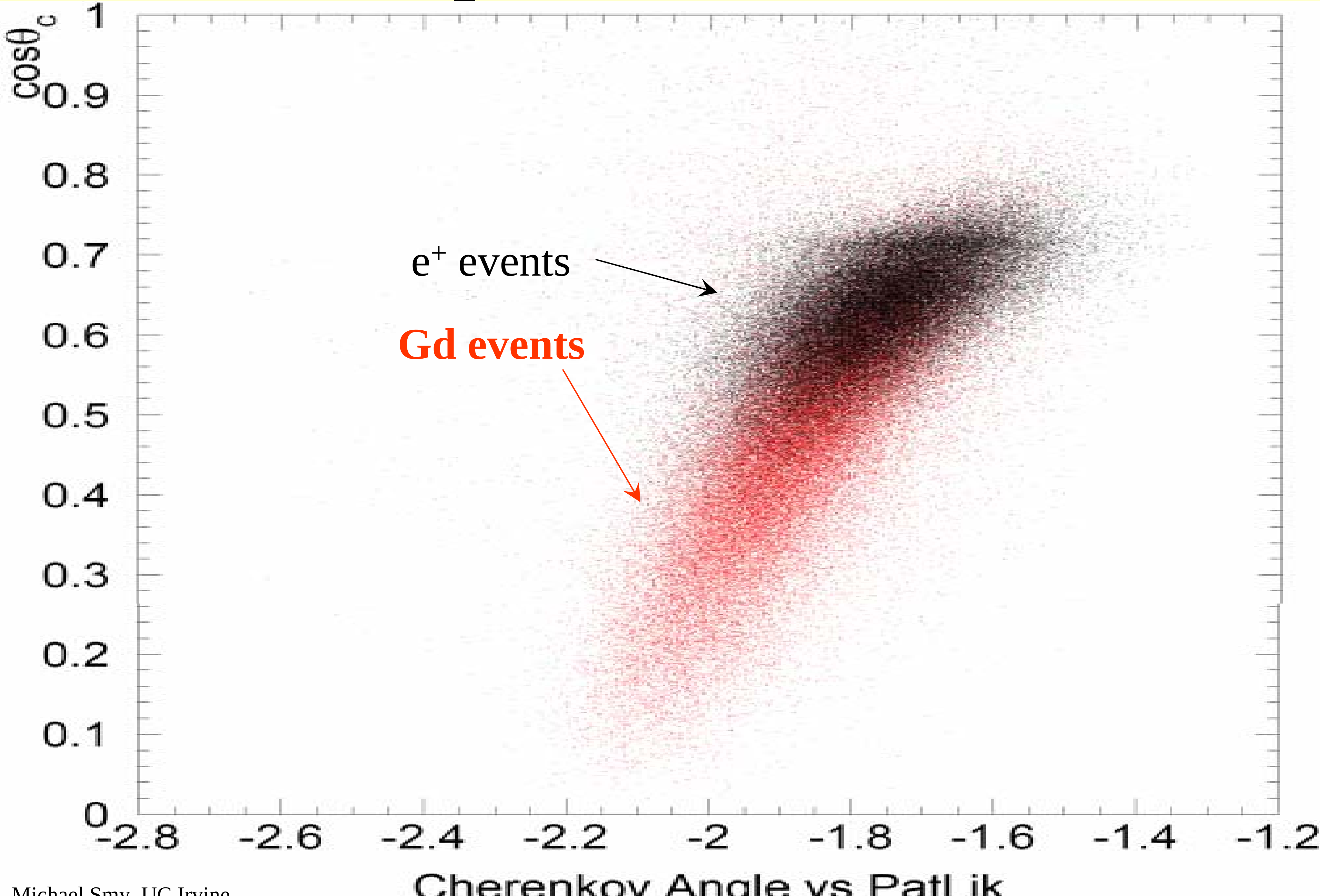
Shape of Gd Events

- Reconstructed Cherenkov Angle
- Disadvantage: already used as a "guideline" for the vertex reconstruction (of only e^+) i.e. distribution uses prior knowledge

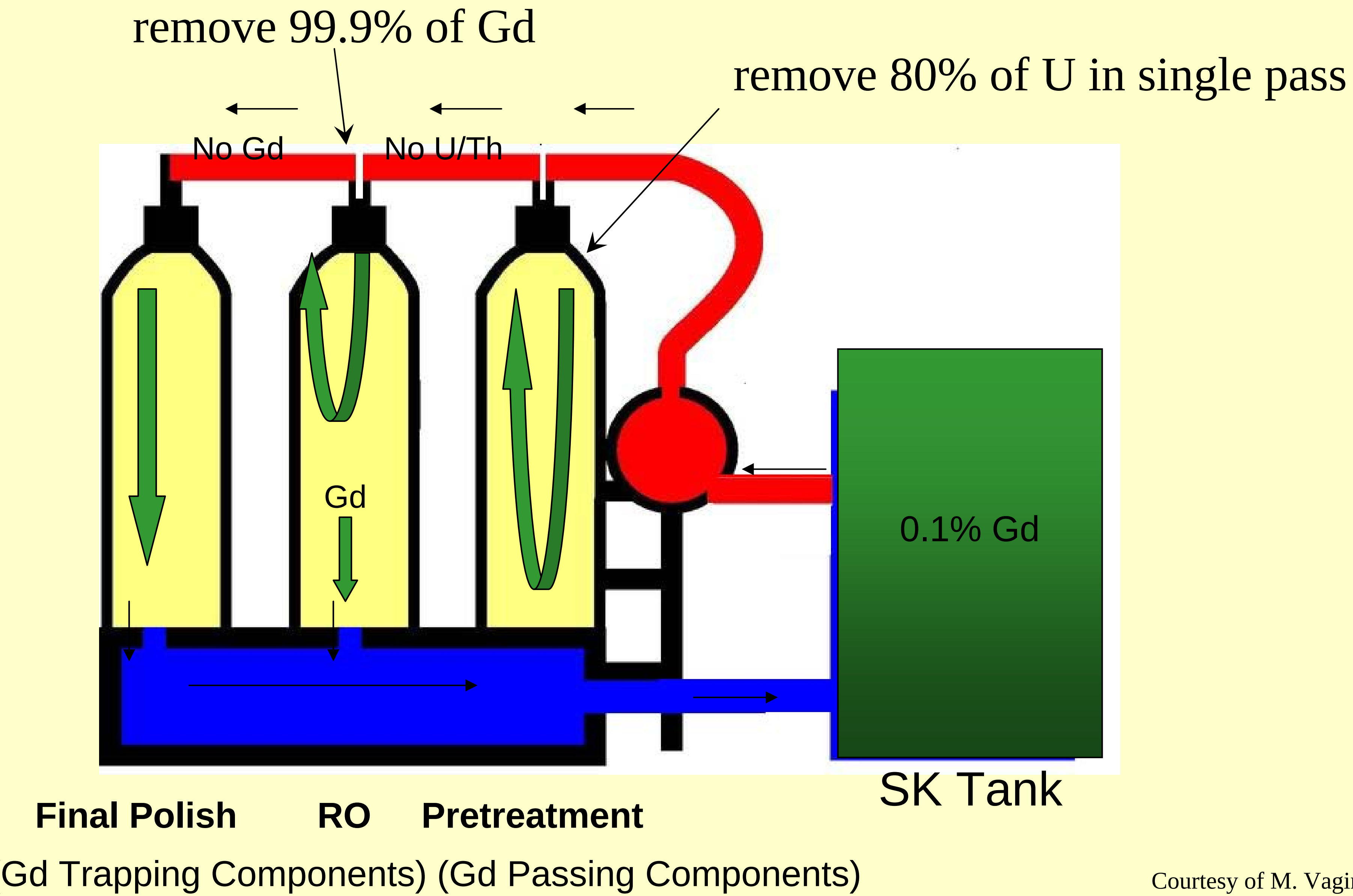
- "Patlik" variable to remove residual βγ spallation events from solar ν sample
- Disadvantage: needs direction from low energy direction fit, which assumes a single e-like Cherenkov Ring



Shape of Gd Events

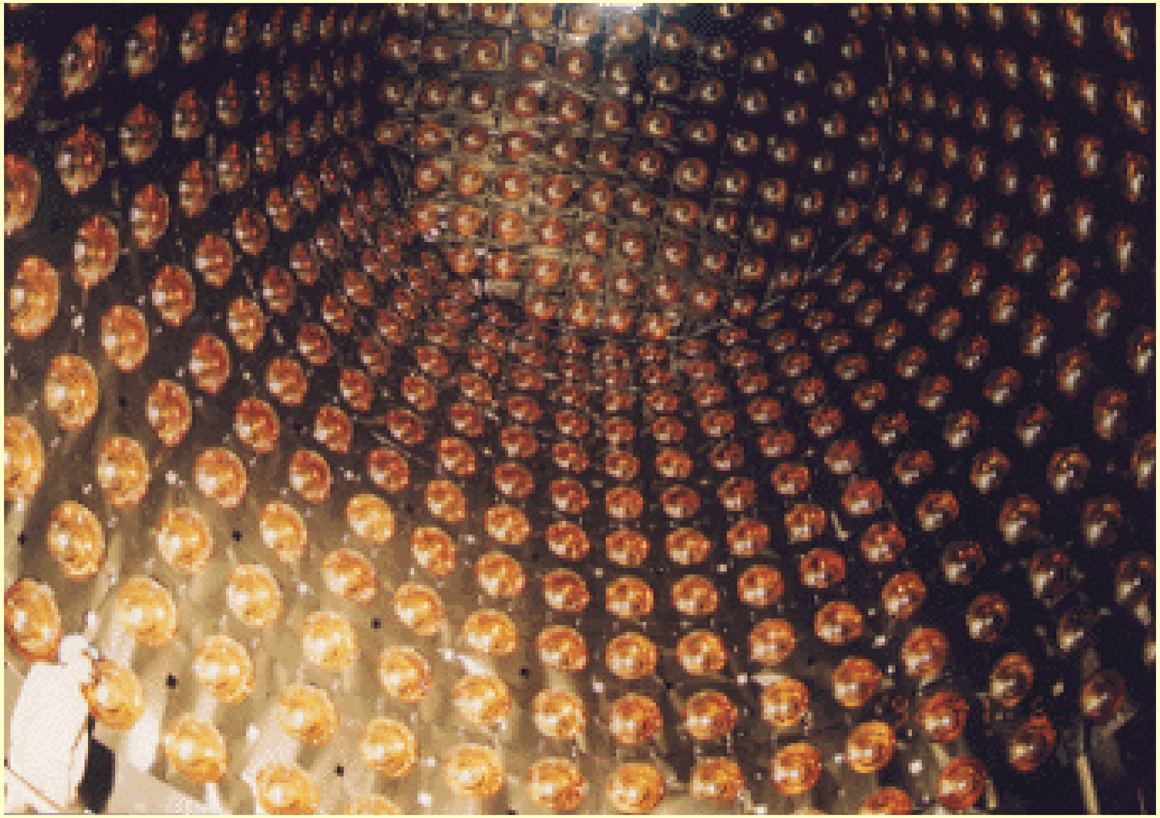


New Super-K-Water Purification System



Courtesy of M. Vagins, UCI

October 2005: Test using K2K's Near Detector

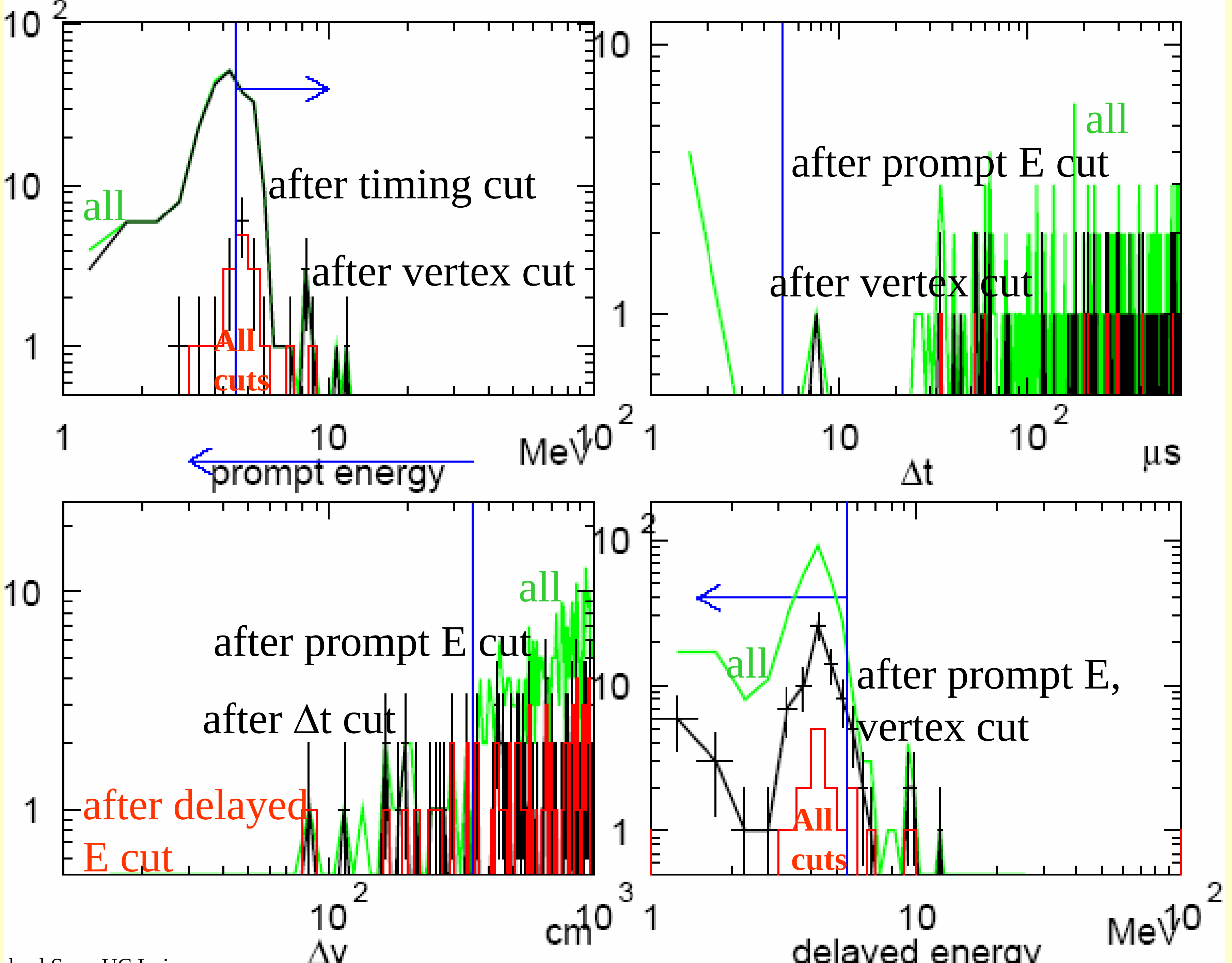


<u>K2K's 1 kiloton tank is available for large-scale studies of</u>

- Gd Water Filtering – UCI built and maintains this water system
- Gd Light Attenuation – using real 20" PMTs
- Gd Materials Effects – many similar detector elements as in SK

Courtesy of M. Vagins, UCI

Correlated (Background-) Events in SK-I


all
after timing cut
after vertex cut
All cuts
prompt energy
MeV
after prompt E cut
all
after vertex cut
Δt
μs
all
after prompt E cut
after Δt cut
after delayed E cut
Δv
cm
all
after prompt E, vertex cut
All cuts
delayed energy
MeV

Conclusion

- Hope to see distortion of solar ν recoil e^- spectrum in SK-III
- Gain more statistics for atmospheric L/E analysis
- Search for ν_e appearance with intense beam
- Plan to add neutron detection to SK-III for reactor $\bar{\nu}$'s, SN relic $\bar{\nu}$'s