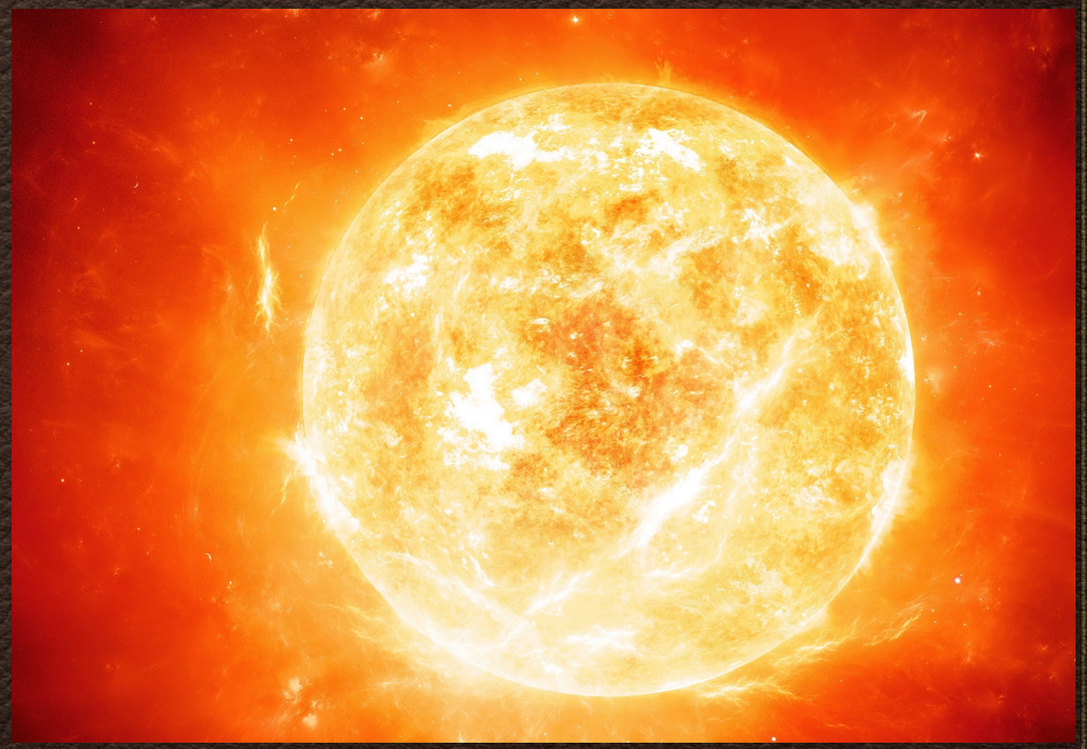
Solar Neutrinos at Water Cherenkov Detectors

Solar and Geoneutrino Workshop, December 7th, 2020

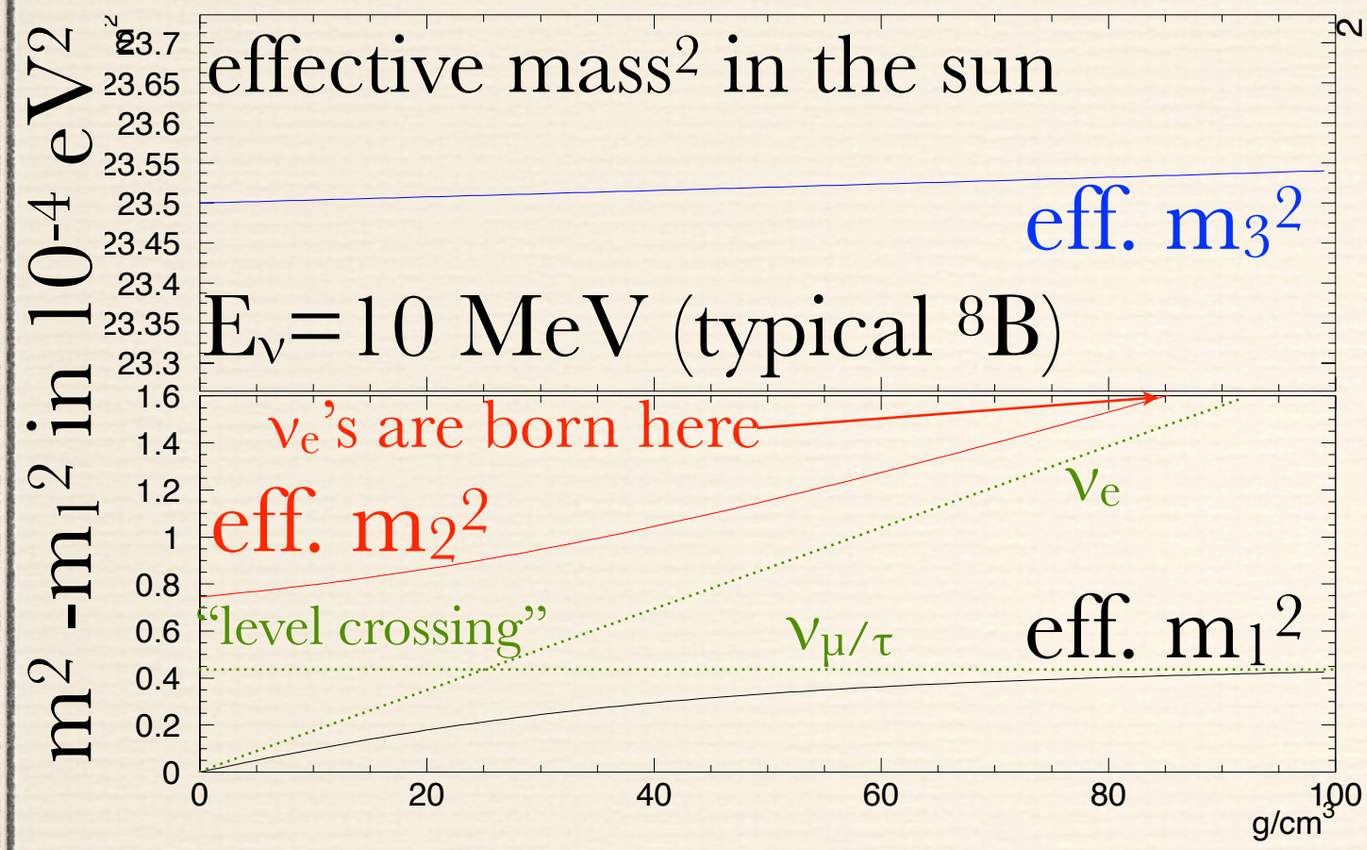
Michael Smy, UC Irvine

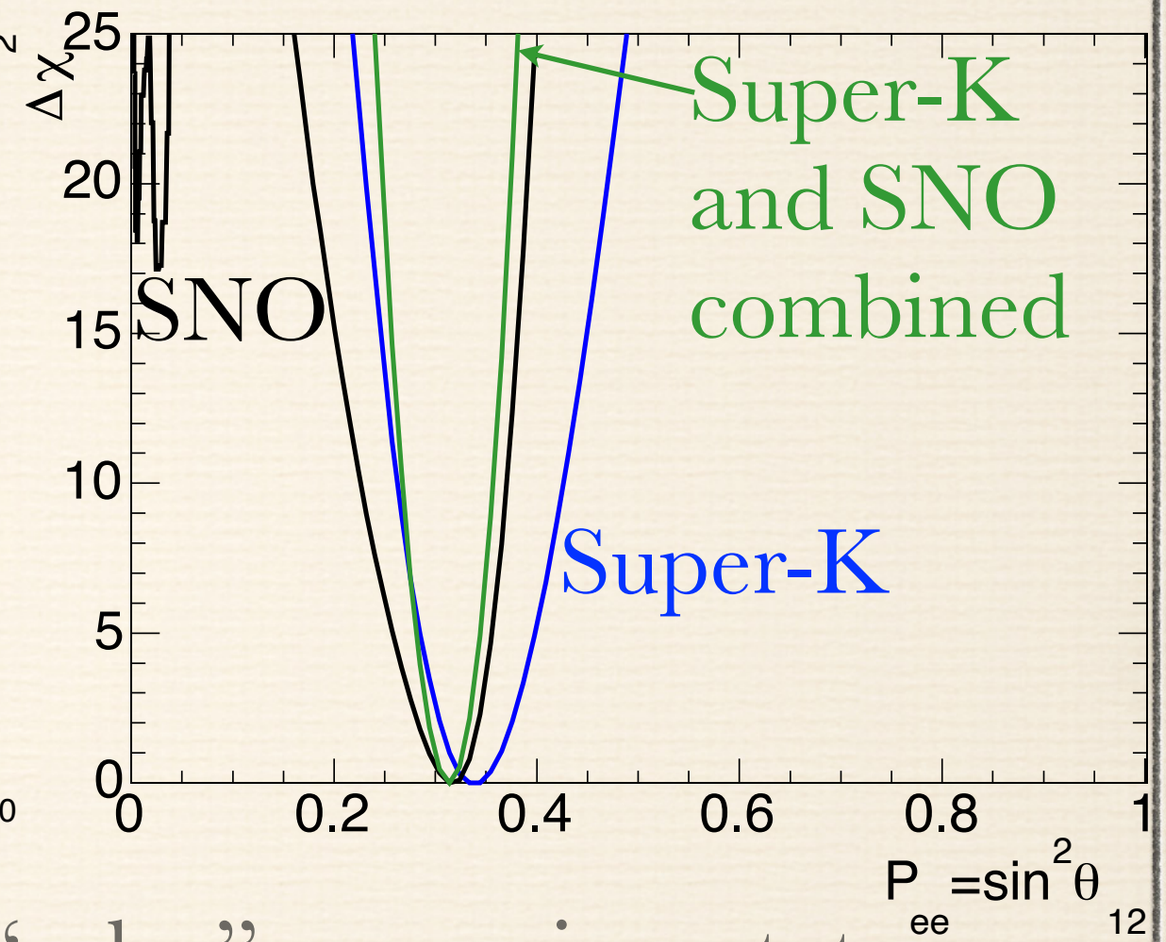


“High Energy” Solar Neutrinos

- unique laboratory: high neutrino flux, low neutrino energy, high flavor purity (all ν_e), high matter density, high magnetic fields, ^{8}B ν’s are only produced in the very center of the sun
- Cherenkov Detectors measure only ^{8}B Neutrinos, and hep neutrinos, since a few MeV of energy are needed to make sufficient amount of Cherenkov light
- high energy, O(10 MeV) solar ^{8}B and hep neutrinos are the only neutrino sources producing a defined mass eigenstate
- high energy solar ^{8}B and hep neutrinos are the only neutrino sources to directly probe Earth matter effects on neutrino oscillations: compare P_{ee} with (night time) and without (day time) the presence of Earth matter in the flight path

Adiabatic Conversion of Solar ^{8}B Neutrinos

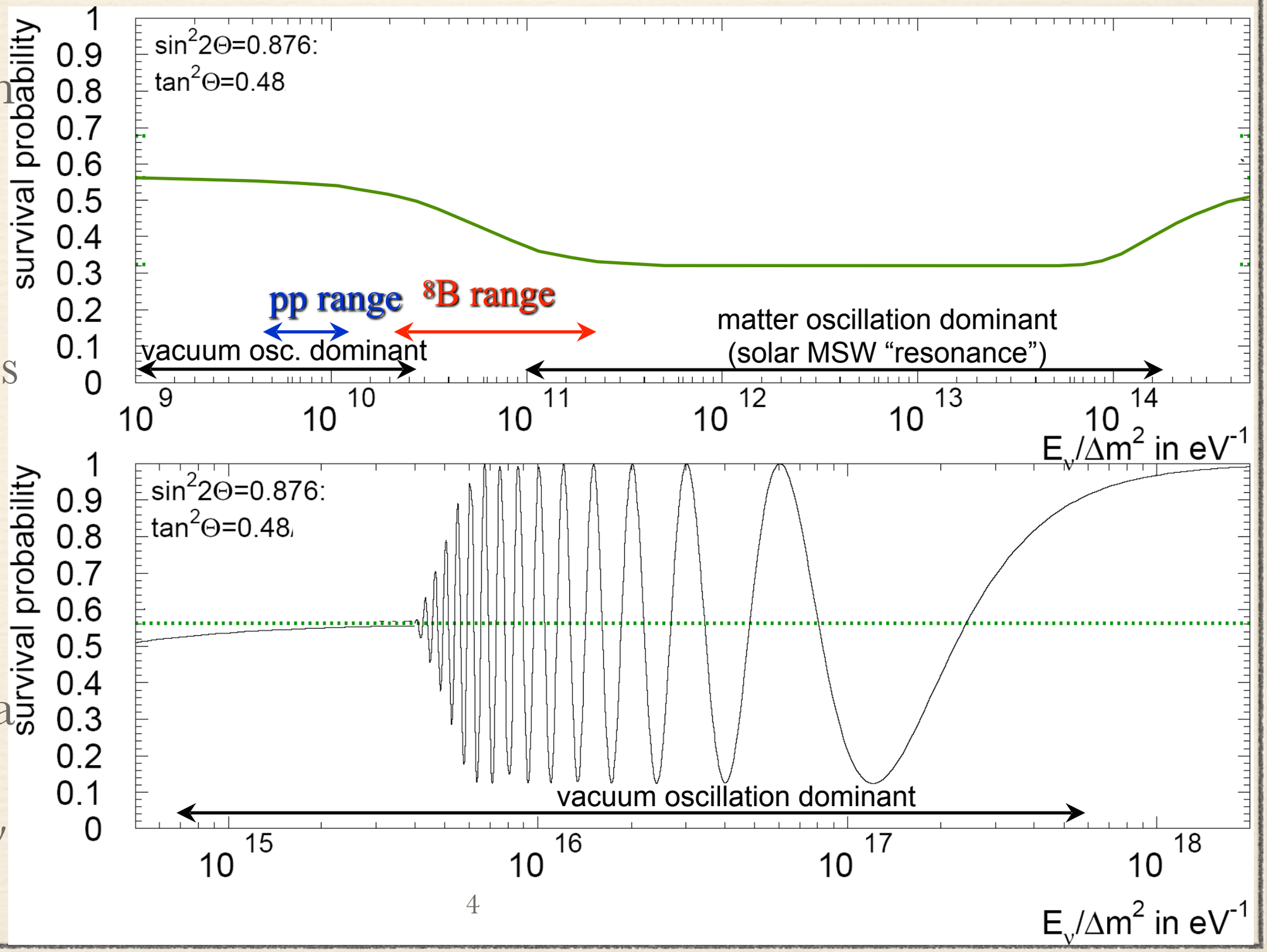




- convert ν_e's to heavier of the "solar" mass eigenstates
- survival prob. P_{ee} measures directly this eigenstate's flavor comp.: two experiments reject $\Delta m^2_{21}<0$ ($P_{ee}>0.5$) at $>5\sigma$
- … but what about the "resonance curve"?

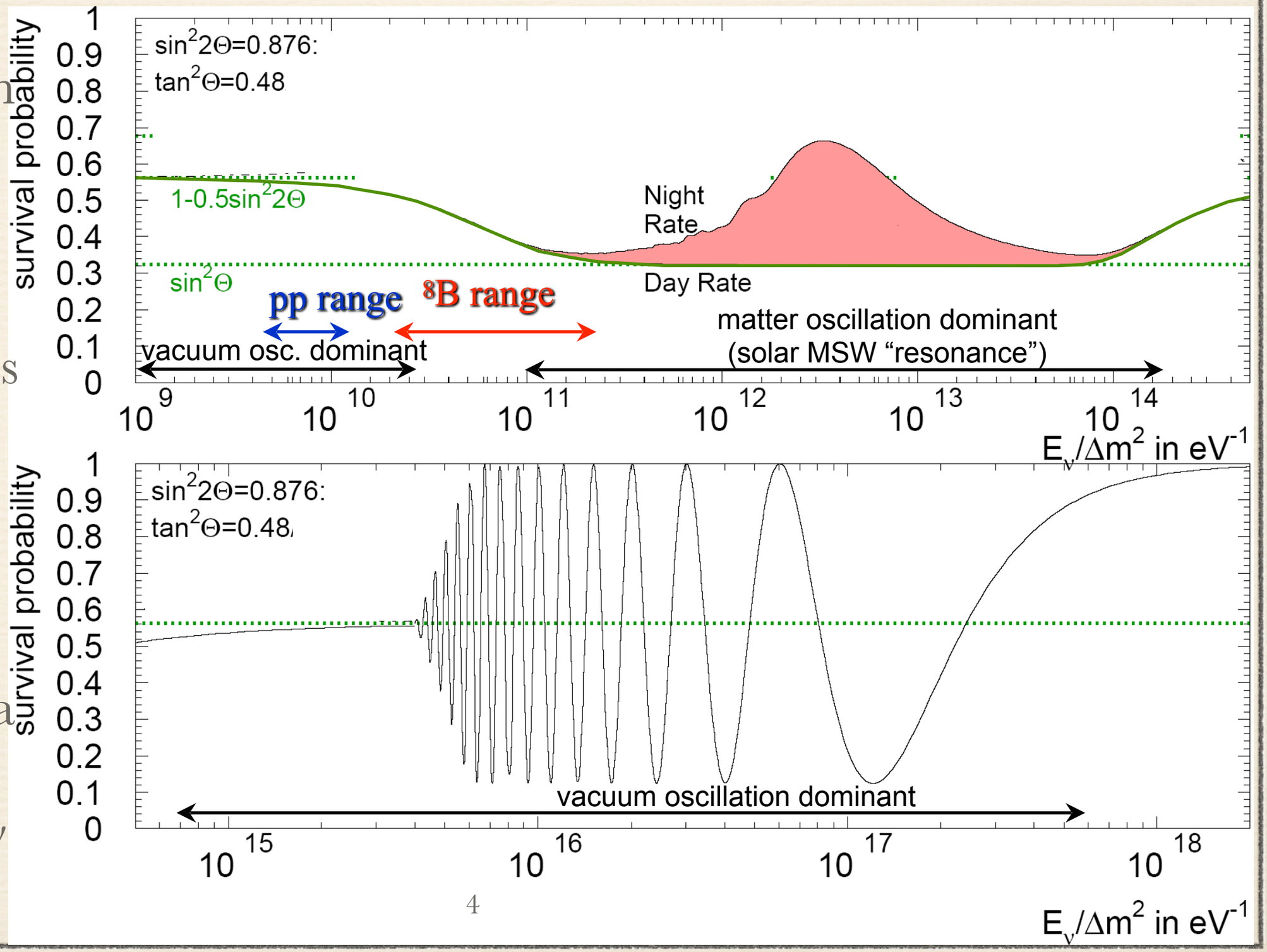
Expected "Resonance Curve"

- adiabatic conversion of ^{8}B ν's
- averaged vacuum oscillations for lower energy neutrinos
- transition region in a "hole" of the solar ν spectrum



Expected "Resonance Curve"

- adiabatic conversion of ^{8}B ν's
- averaged vacuum oscillations for lower energy neutrinos
- transition region in a "hole" of the solar ν spectrum

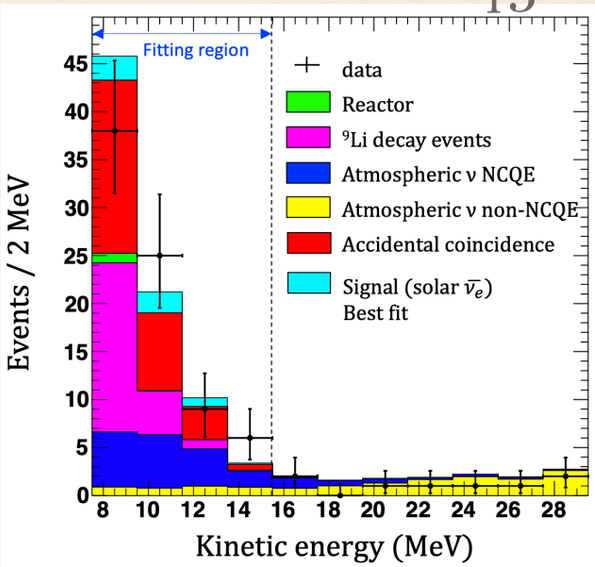


Water Cherenkov Detectors

- Kamiokande: pure light water
  - electron—neutrino elastic scattering
- Super-Kamiokande: pure light water
  - electron—neutrino elastic scattering, search for anti-neutrino IBD
- Super-Kamiokande-Gadolinium: light water with $Gd_2(SO_4)_3$ dissolved to detect neutron captures on Gd
- Hyper-Kamiokande: pure light water
- SNO: pure heavy water and heavy water with NaCl dissolved to detect neutron captures on Cl
  - deuteron break-up via CC or NC interaction, electron—neutrino elastic scattering

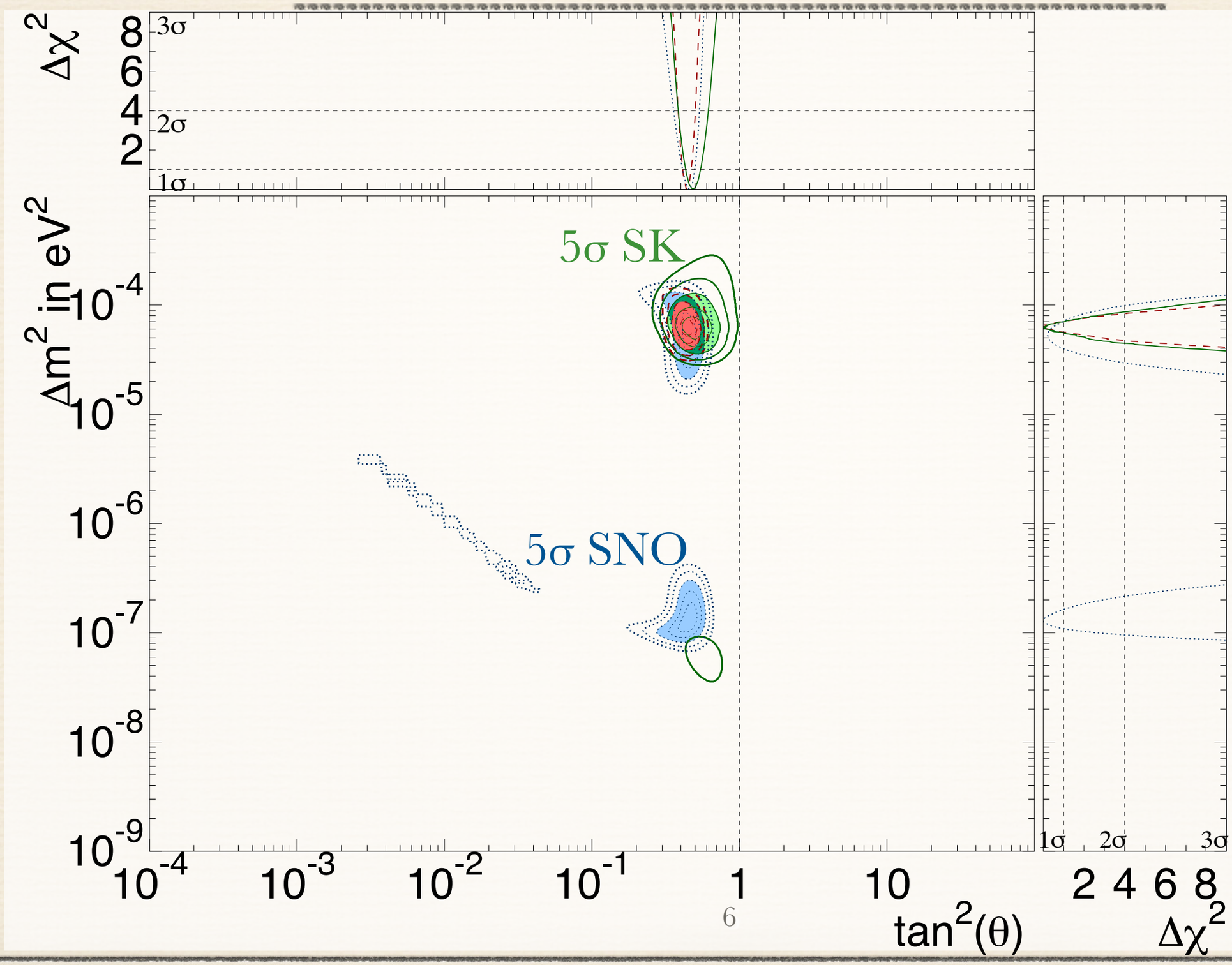
Water Cherenkov Detectors

submitted to ApJ



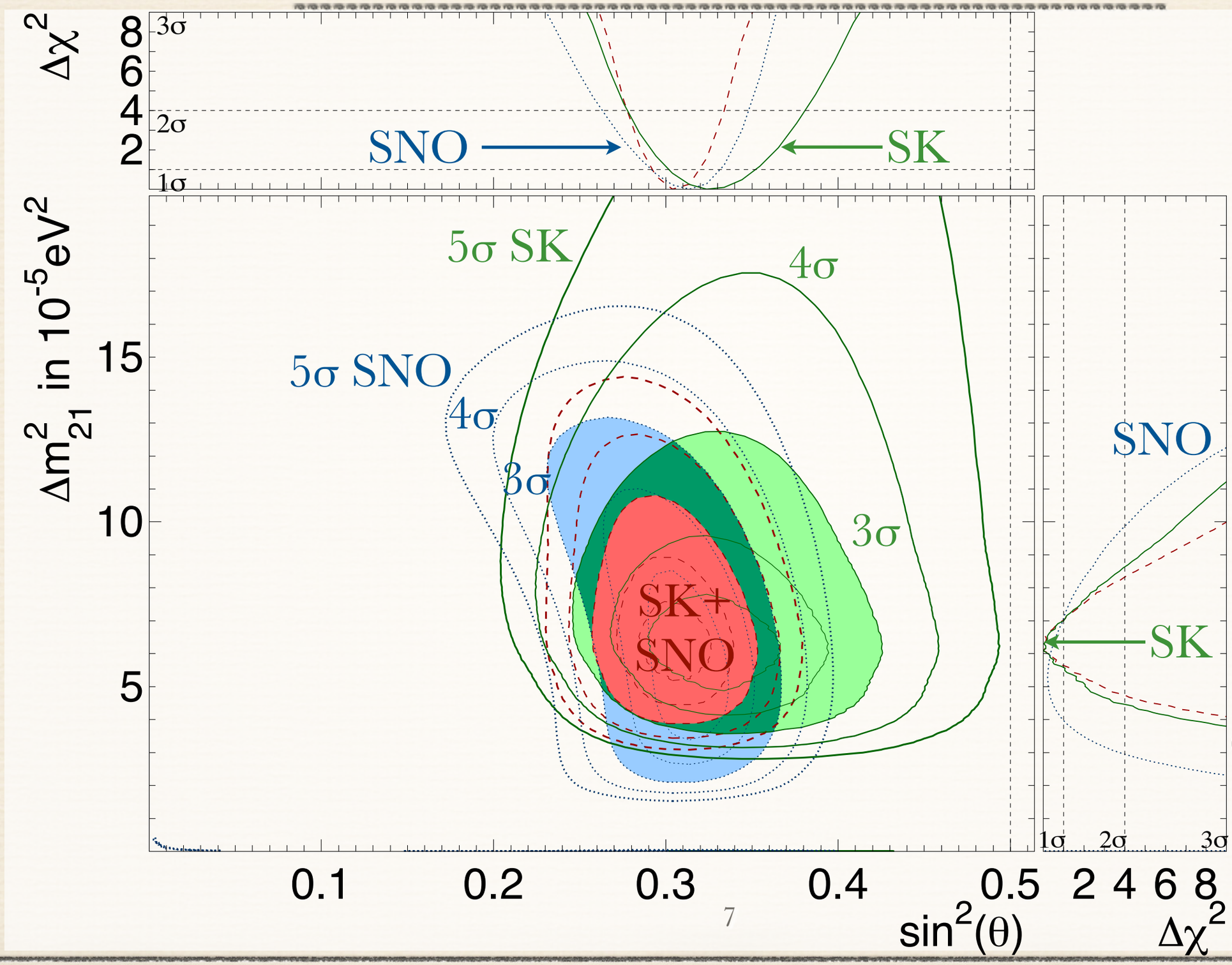
- Kamiokande: pure light water
  - electron—neutrino elastic scattering
- Super-Kamiokande: pure light water
  - electron—neutrino elastic scattering, search for anti-neutrino IBD
- Super-Kamiokande-Gadolinium: light water with $Gd_2(SO_4)_3$ dissolved to detect neutron captures on Gd
- Hyper-Kamiokande: pure light water
- SNO: pure heavy water and heavy water with NaCl dissolved to detect neutron captures on Cl
  - deuteron break-up via CC or NC interaction, electron—neutrino elastic scattering

SK and SNO Oscillation Parameters



Michael Smy, UC Irvine

SK and SNO Oscillation Parameters



SK measures

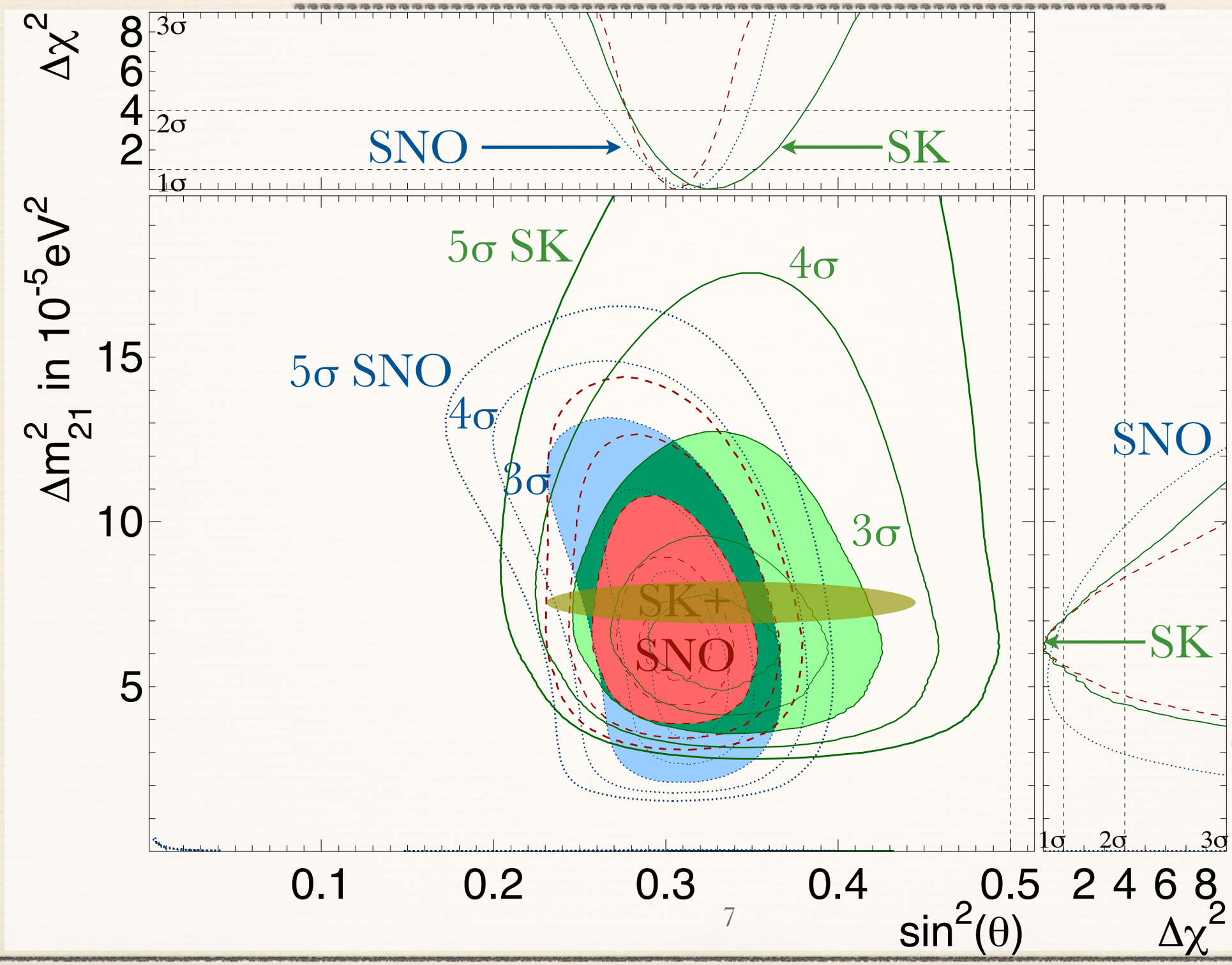
$$A_{DN}=\frac{R_D - R_N}{0.5(R_D + R_N)}$$

-3.1±1.0±0.5%

-3.3±1.0±0.5%

(w/o SK-IV update from this summer)

SK and SNO Oscillation Parameters



SK measures

$$A_{DN}=\frac{R_D - R_N}{0.5(R_D + R_N)}$$

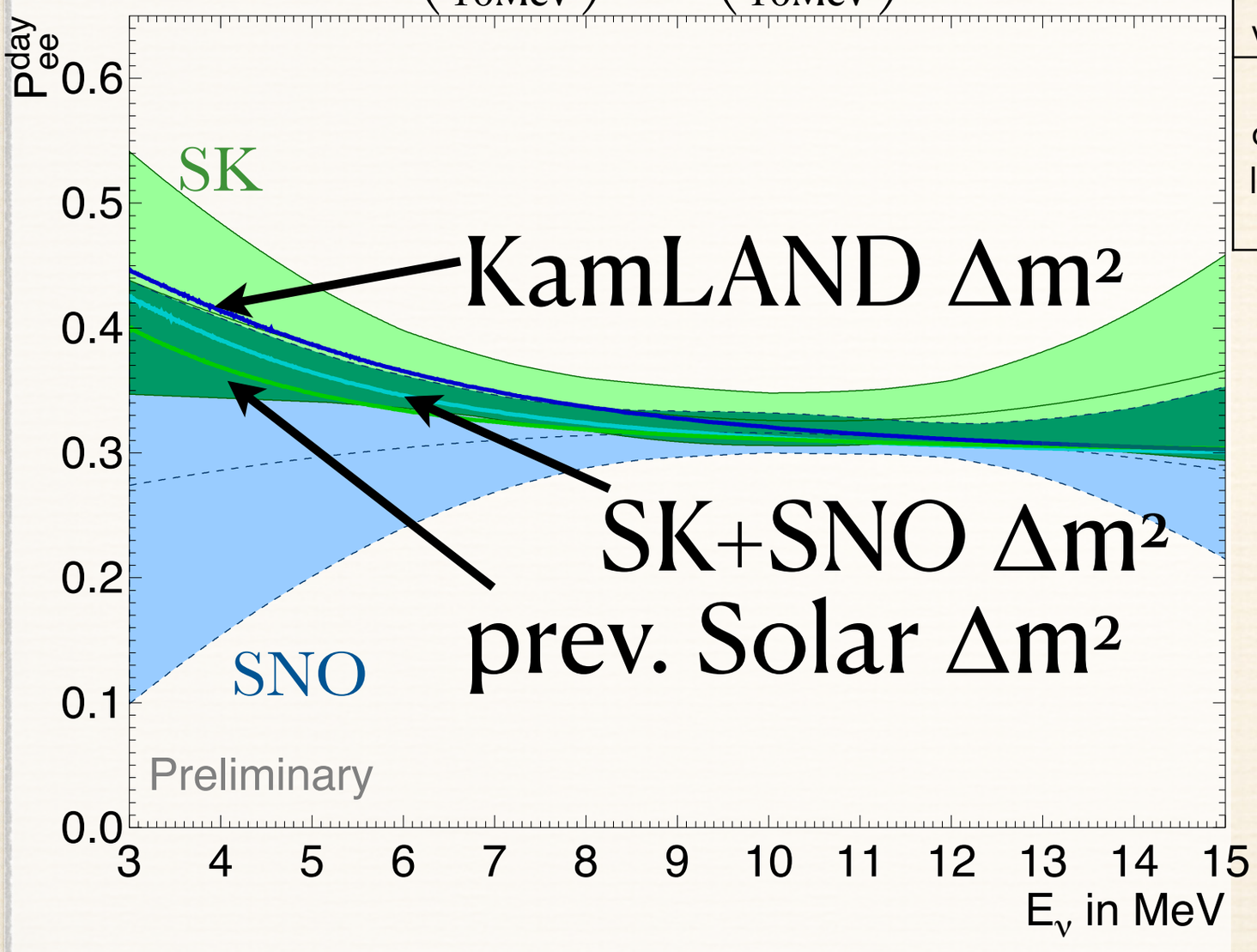
-3.1±1.0±0.5%

-3.3±1.0±0.5%

(w/o SK-IV update from this summer)

SK and SNO Survival Probability

$$P_{ee} = c_0 + c_1\left(\frac{E_\nu}{10\text{MeV}}\right) + c_2\left(\frac{E_\nu}{10\text{MeV}}\right)^2$$

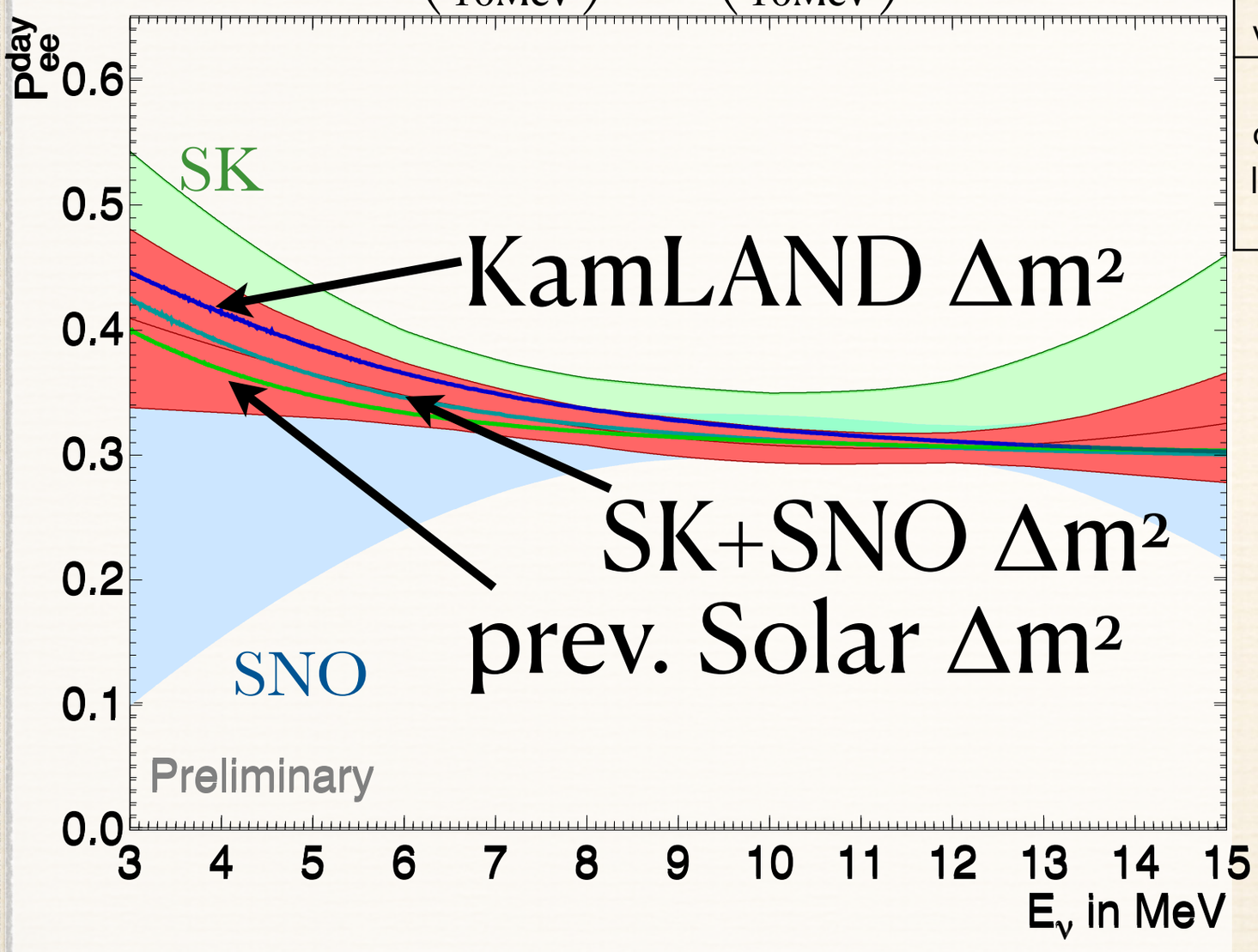


	c_0	c_1	c_2
value	0.309±0.015	-0.0045±0.0035	0.0014±0.0017
correlation	1	-0.472	-0.390
	-0.472	1	0.371
	-0.390	0.371	1

SK-I 4.49-19.5 MeV
SK-II 6.49-19.5 MeV
SK-III 3.99-19.5 MeV
SK-IV 3.49-19.5 MeV
SNO-I/II/III

SK and SNO Survival Probability

$$P_{ee} = c_0 + c_1\left(\frac{E_\nu}{10\text{MeV}}\right) + c_2\left(\frac{E_\nu}{10\text{MeV}}\right)^2$$



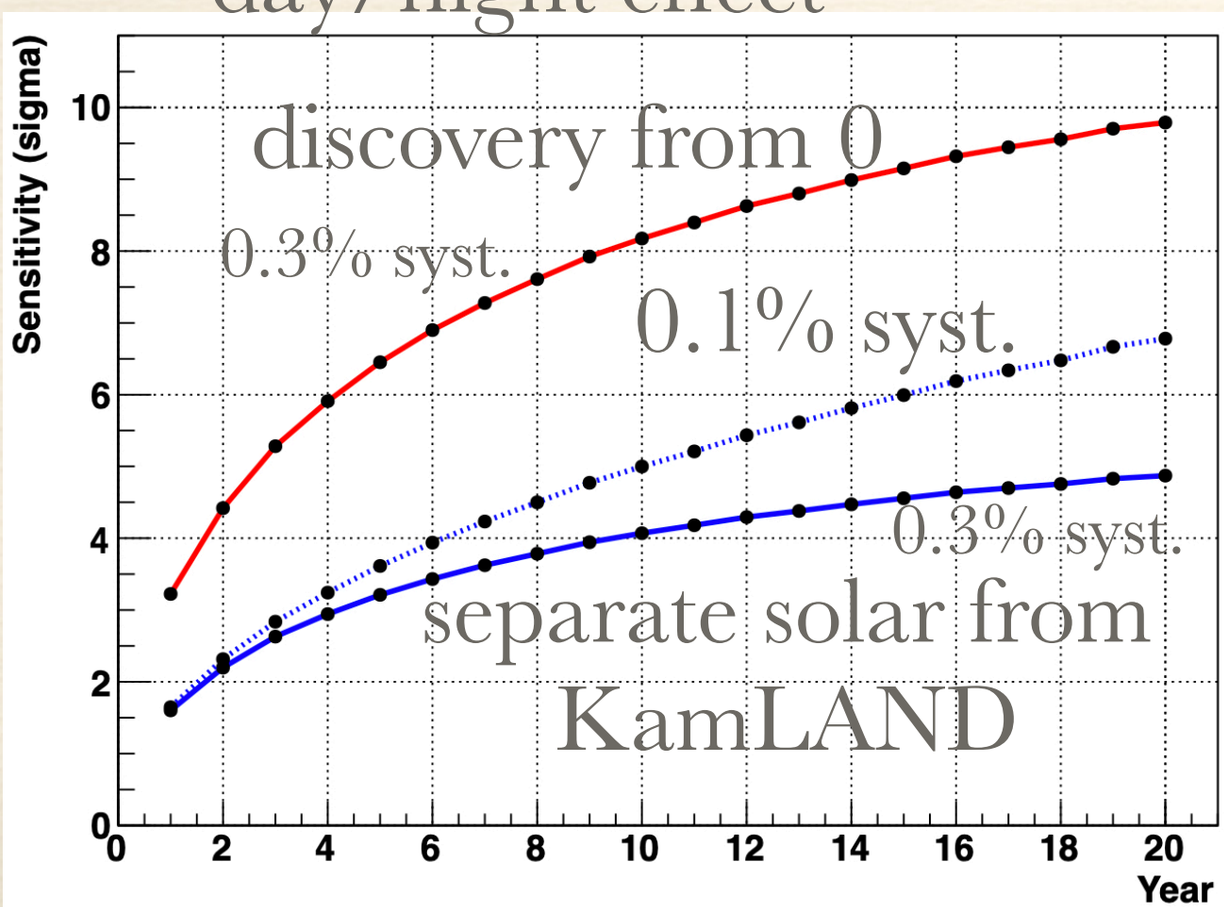
	c_0	c_1	c_2
value	0.309±0.015	-0.0045±0.0035	0.0014±0.0017
correlation	1	-0.472	-0.390
	-0.472	1	0.371
	-0.390	0.371	1

SK-I 4.49-19.5 MeV
SK-II 6.49-19.5 MeV
SK-III 3.99-19.5 MeV
SK-IV 3.49-19.5 MeV
SNO-I/II/III

Future Water-Cherenkov Detectors

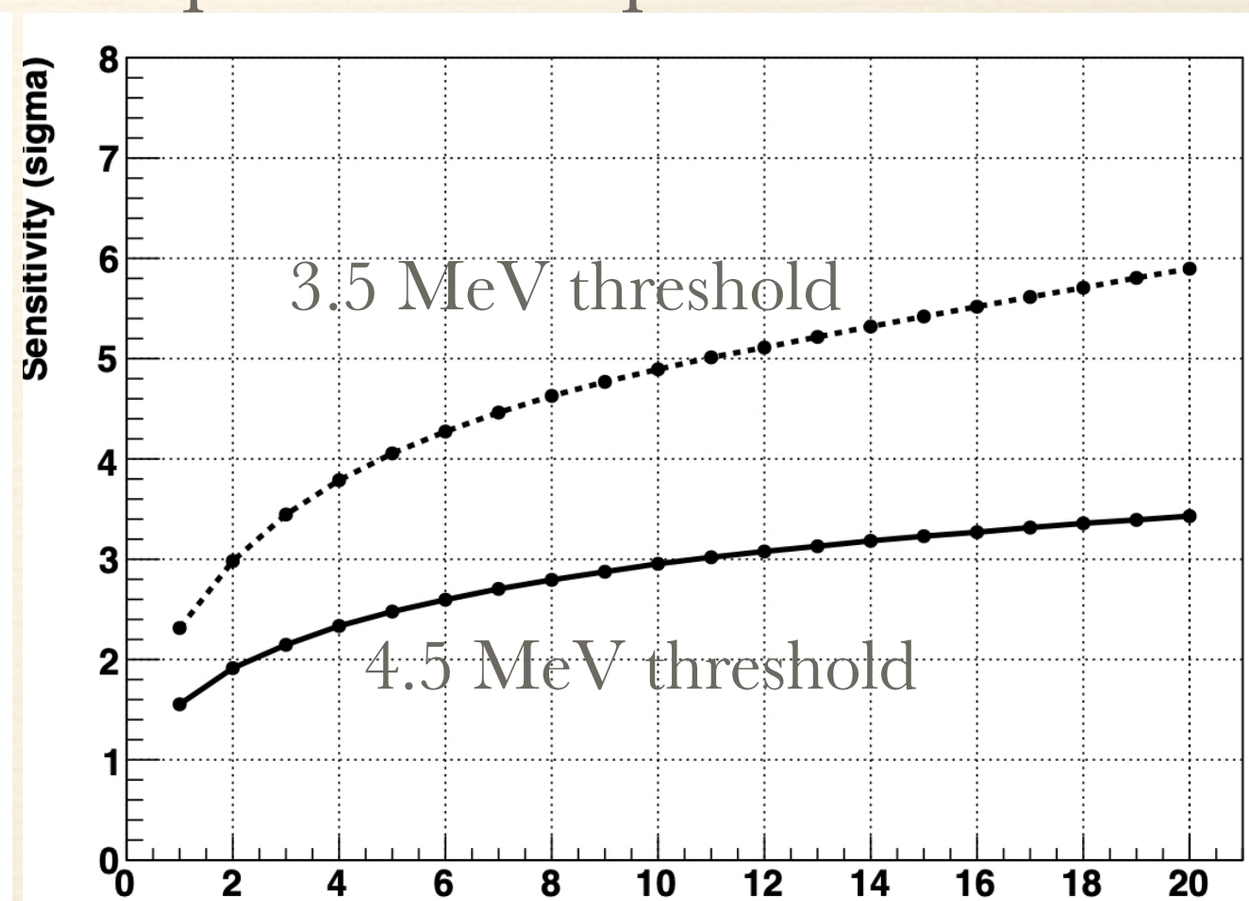
- Theia (see next talk)
- WATCHMAN (ignore for this talk)
- Hyper-Kamiokande:

day/night effect



Courtesy Takatomi Yano (ICRR)

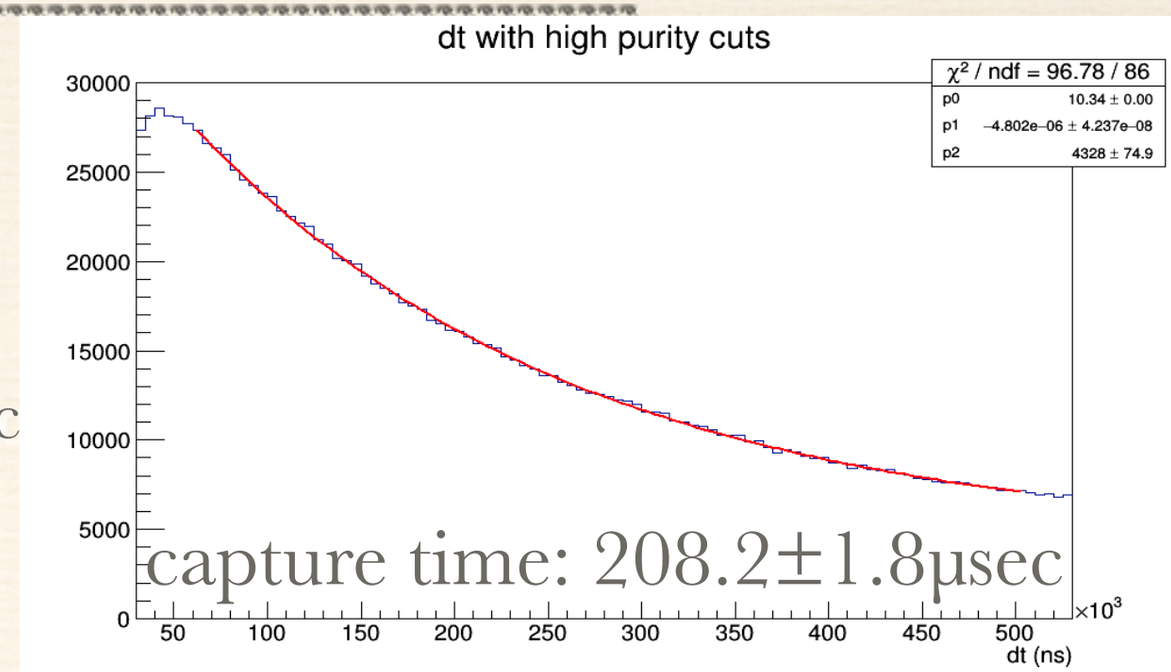
spectrum "upturn"

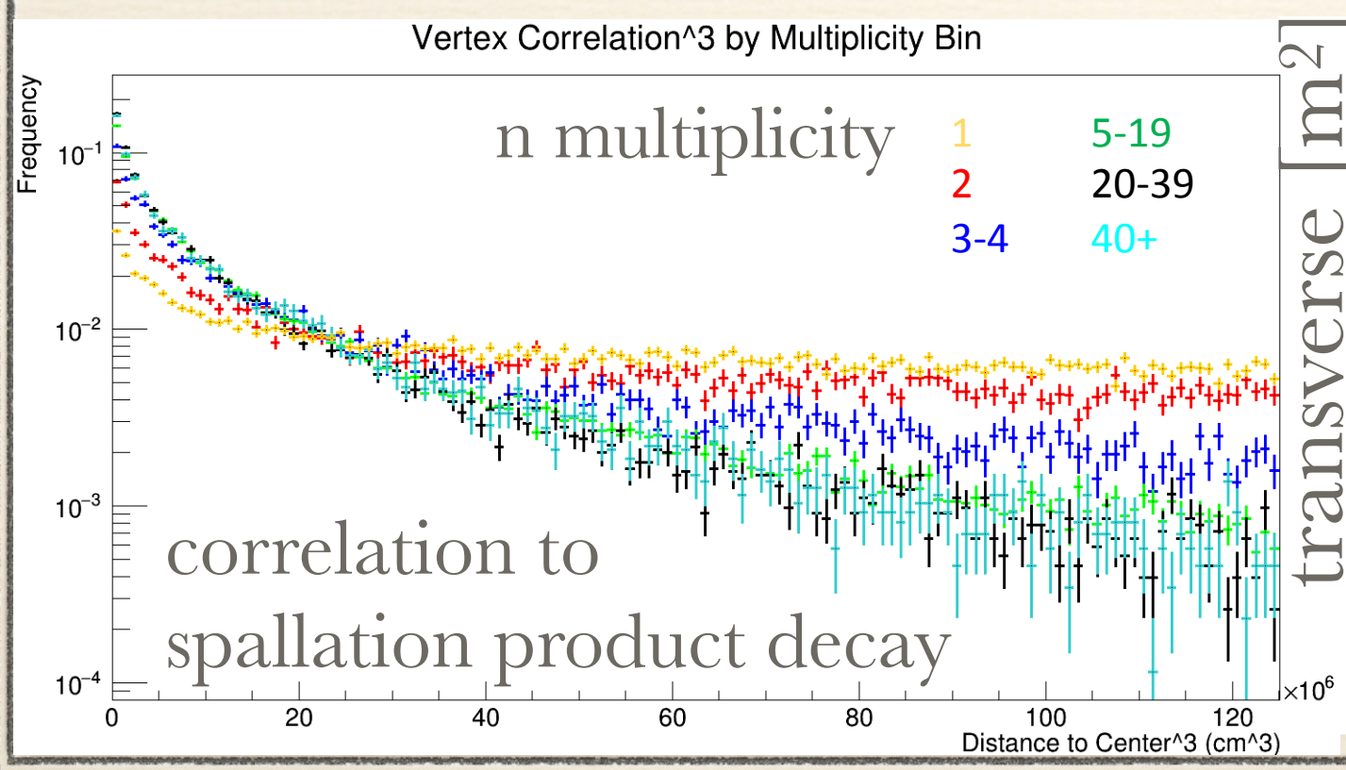


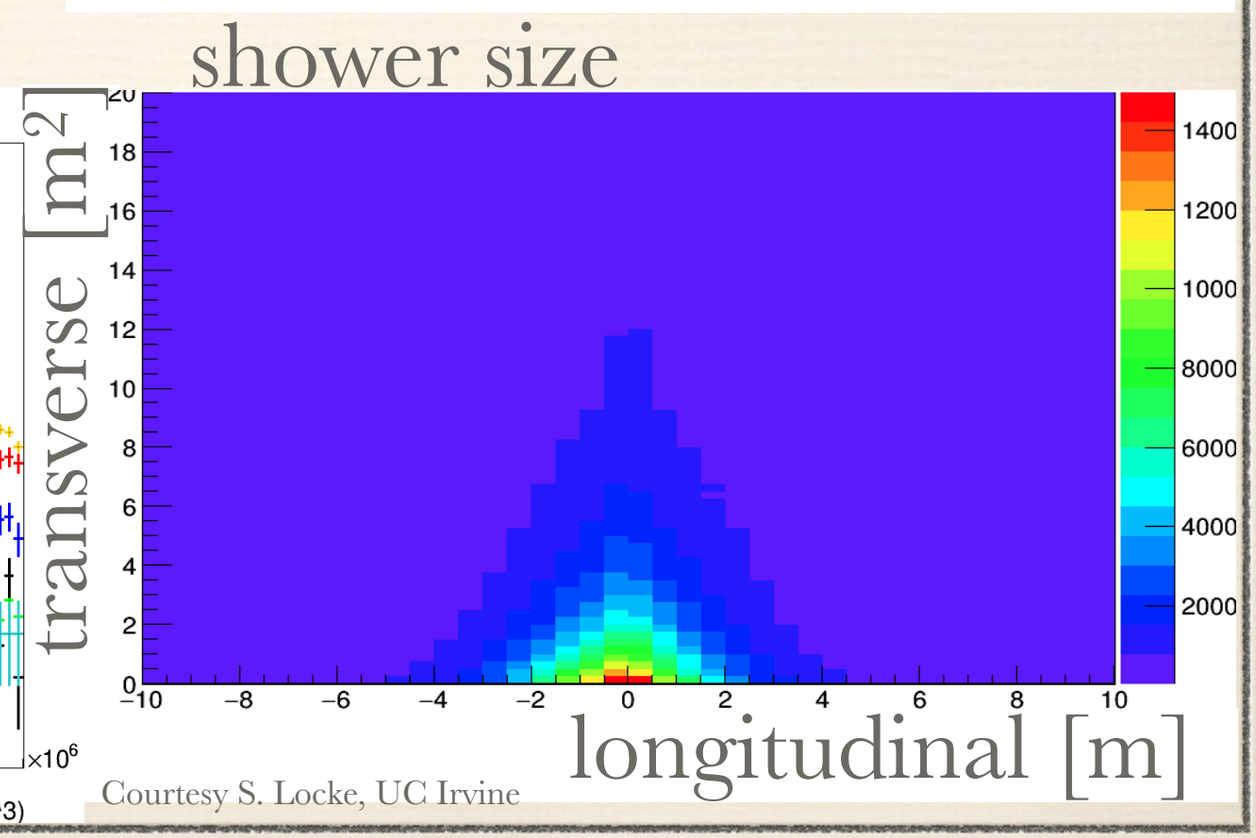
Courtesy Takatomi Yano (ICRR)

Reduce Spallation Background: Tagging Hadronic Showers

- very low threshold WIT system triggers on 2.2 MeV γ's from hadronic shower neutrons **capturing on hydrogen**
- multiple spallation: several events >5.49 MeV within 60sec and 4m tag a hadronic shower, even without a detected muon
- ~45% of spallation background is from multiple spallation

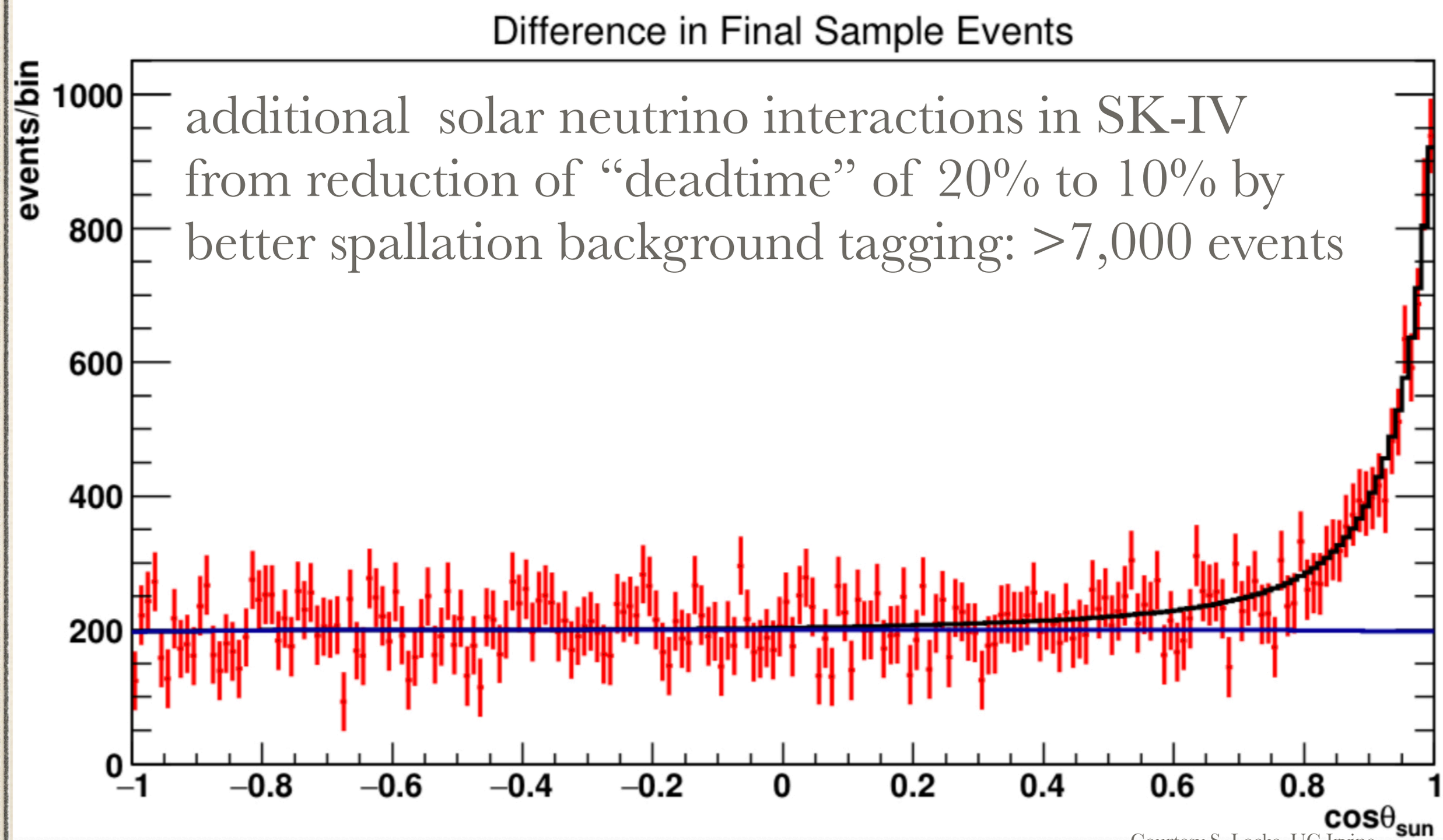






Courtesy S. Locke, UC Irvine

Reduce Spallation Background: Tagging Hadronic Showers

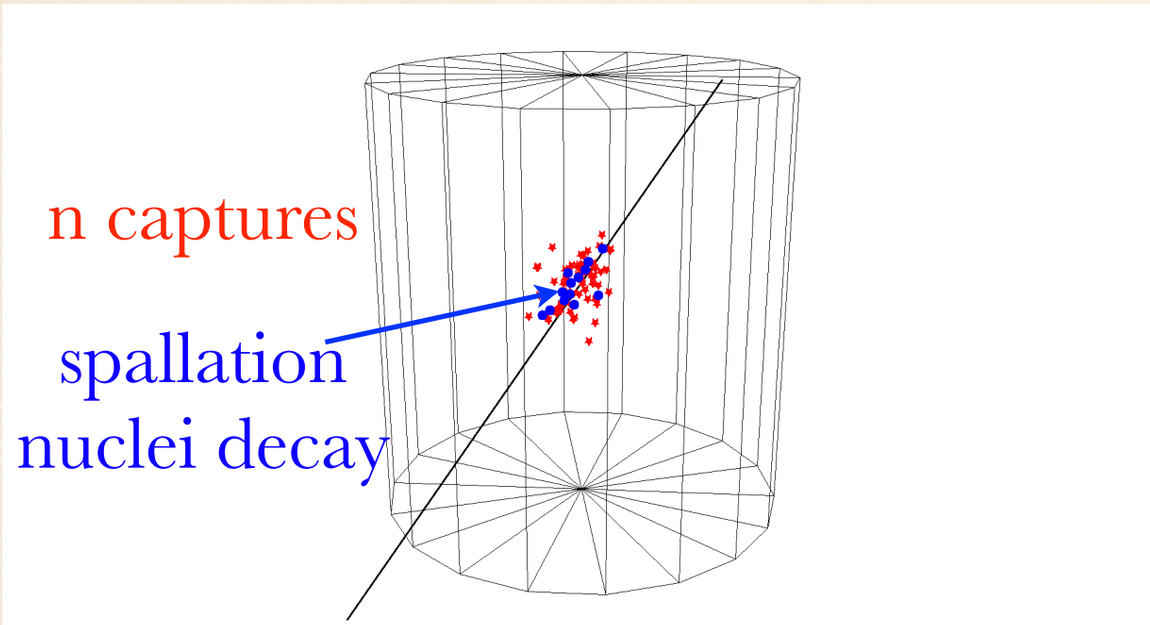


additional solar neutrino interactions in SK-IV from reduction of "deadtime" of 20% to 10% by better spallation background tagging: >7,000 events

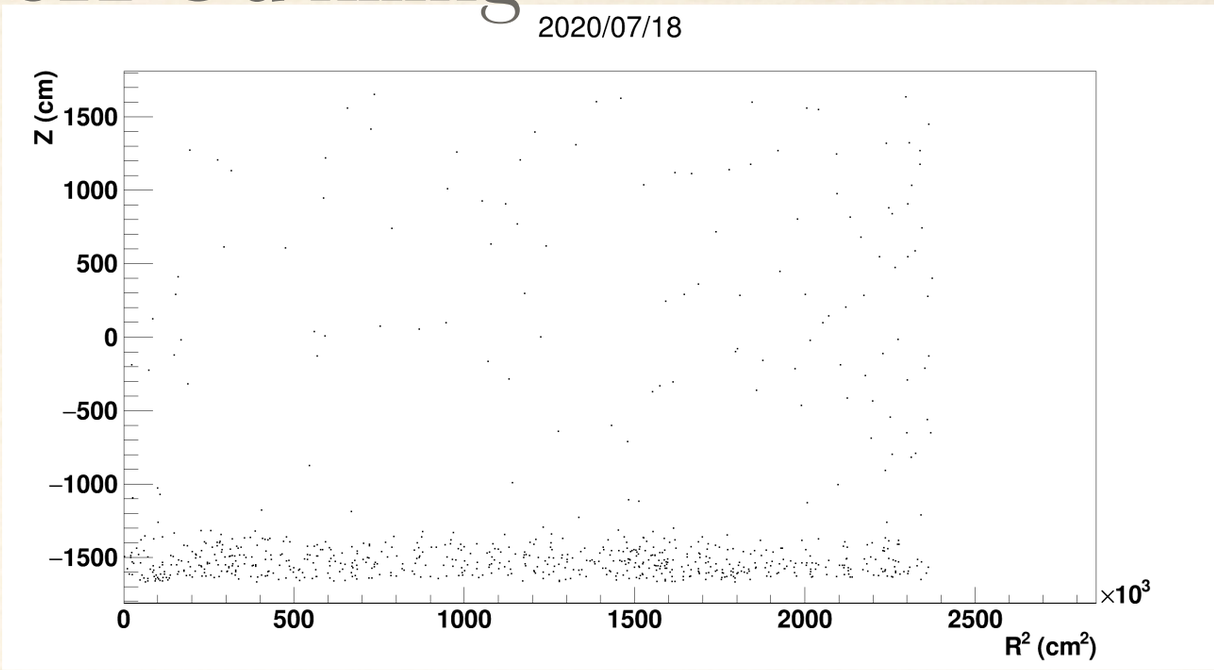
Courtesy S. Locke, UC Irvine

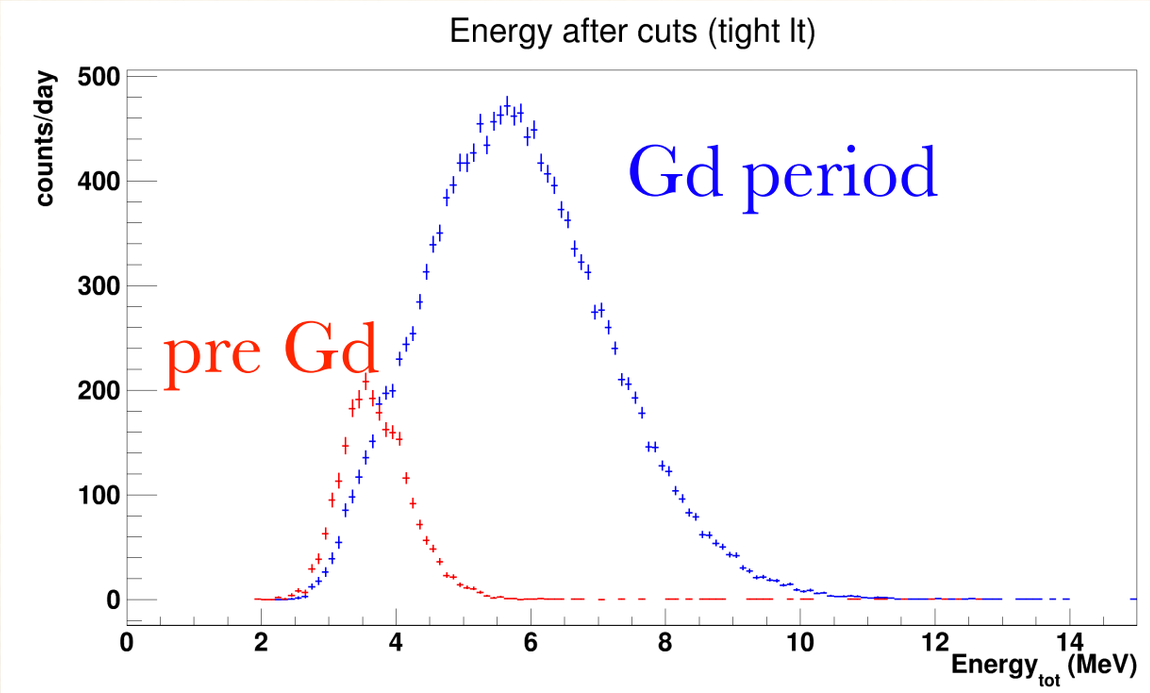
Study with Super-K Gadolinium

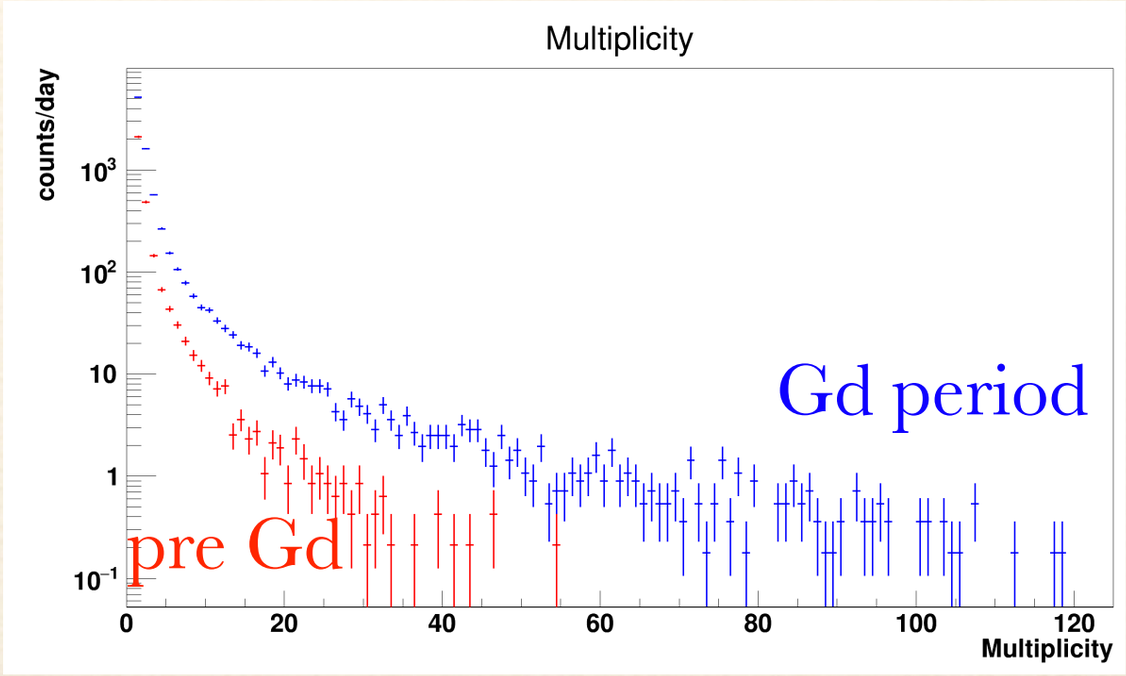
example hadronic shower



SK-Gd filling



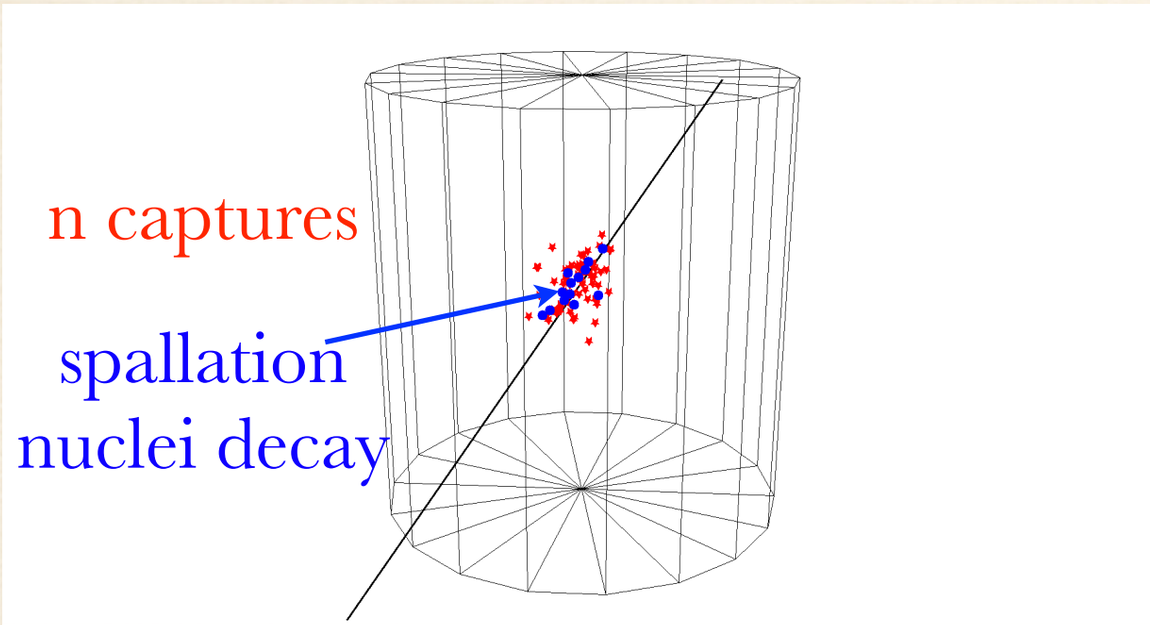




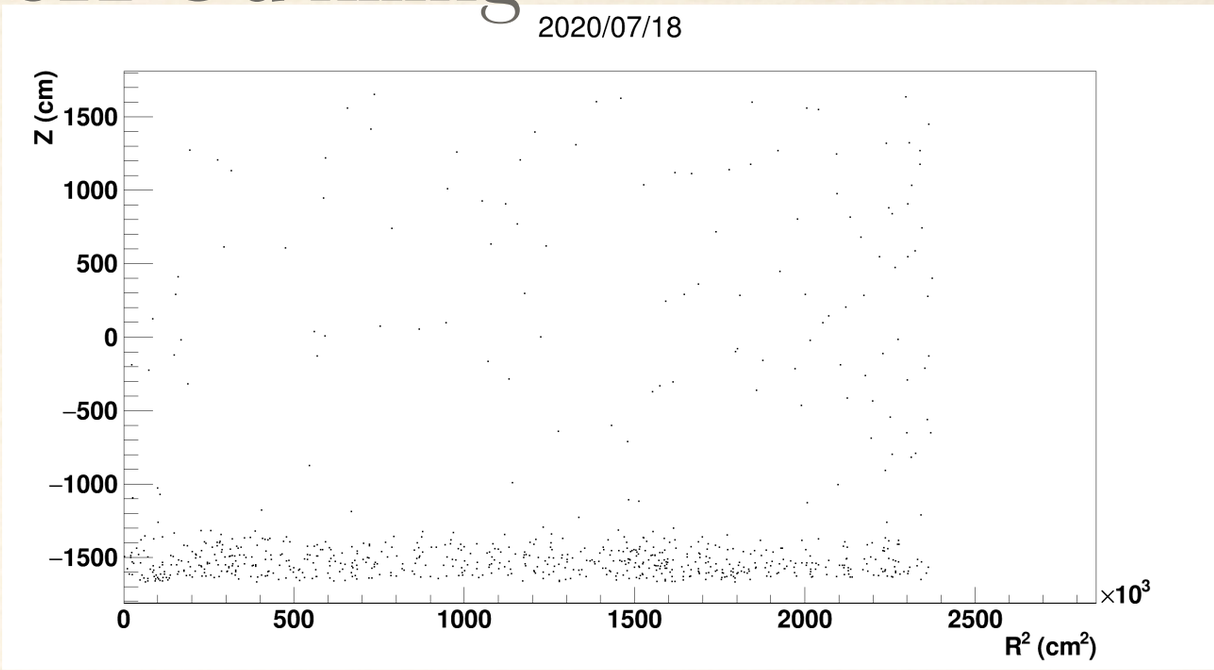
Courtesy S. Locke, UC Irvine

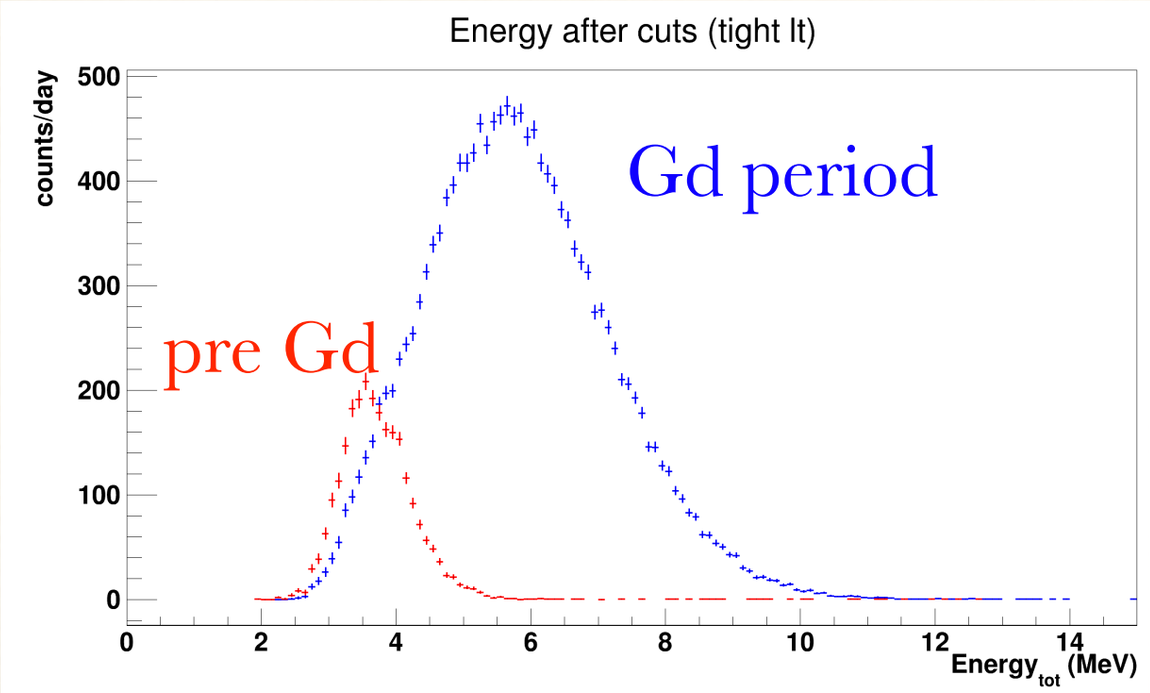
Study with Super-K Gadolinium

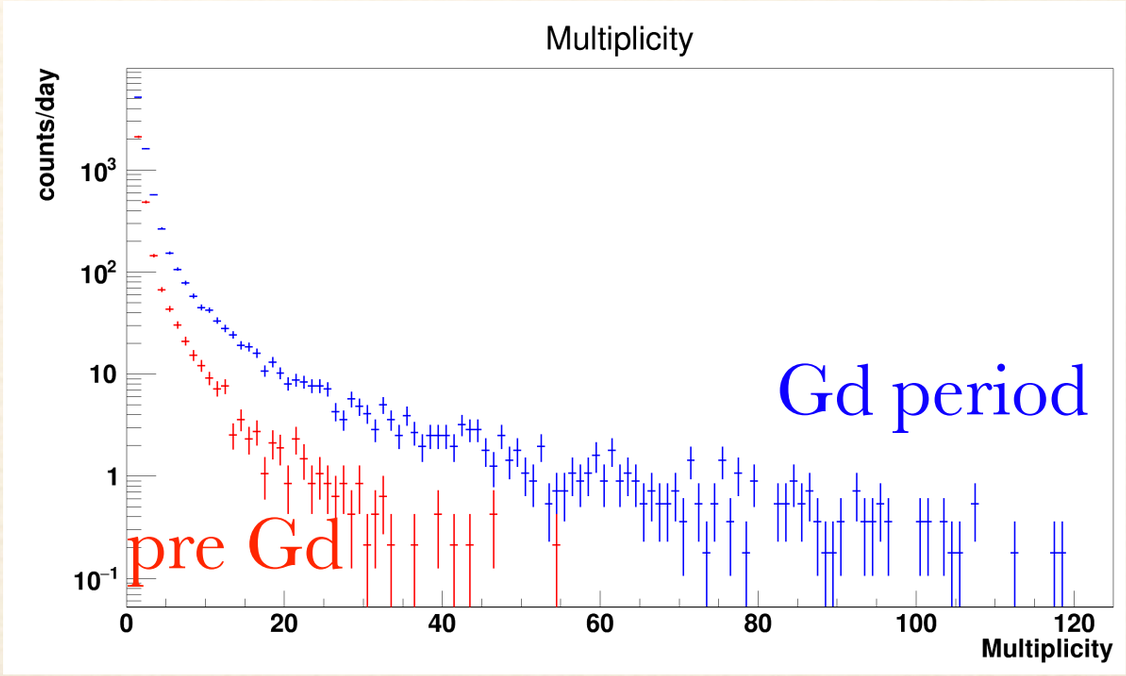
example hadronic shower



SK-Gd filling







Courtesy S. Locke, UC Irvine

Conclusions

- solar ^{8}B neutrinos still have a role to play
- water Cherenkov detectors remain the cheapest way to get to large target masses and exposure
- Hyper-Kamiokande, the largest O(MeV) water Cherenkov detector, is located at shallow depth, rejection of cosmogenic radioactive background is critical