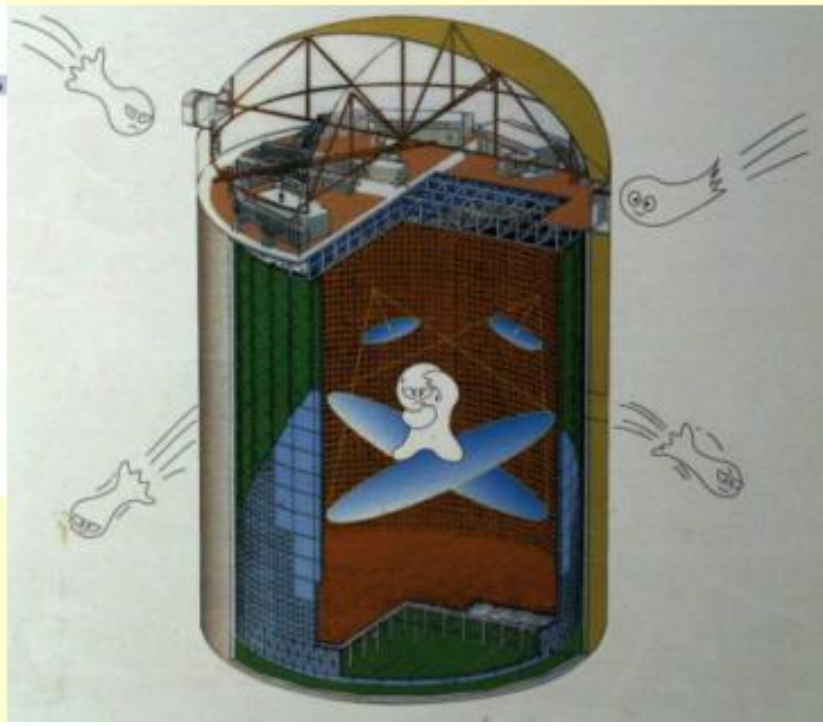
Solar ν Precision Measurements with Super-Kamiokande

At Neutrino 2002

Munich, May 25

Michael Burghard Smy,
UC Irvine



Super-K Collaboration

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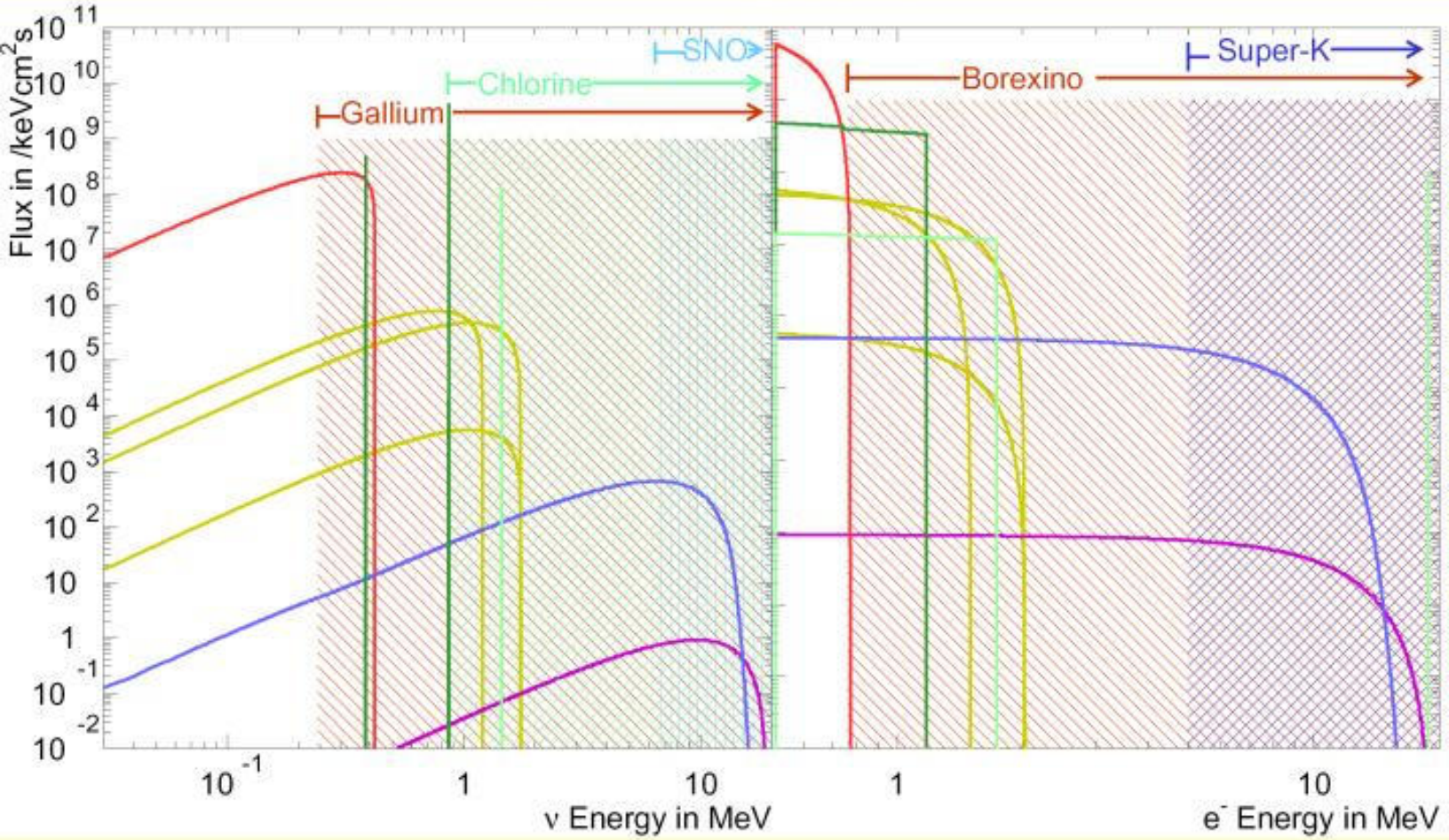
Solar ν Spectrum



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Super-K Solar Neutrinos

- 1496 Live Days between May 31st, 1996 and July 15th, 2001
- High Statistics
- Measures ^{8}B, limits *hep* flux
- ^{8}B flux time variations
- Studies energy spectrum
- Some sensitivity to other than *e*-type neutrinos

Oscillation Signatures

- Suppression of ^{8}B flux
- Appearance of other active flavors (with SNO)
- Spectral Distortion
- Daily variations of ^{8}B flux
- Anomalous yearly variations of ^{8}B flux

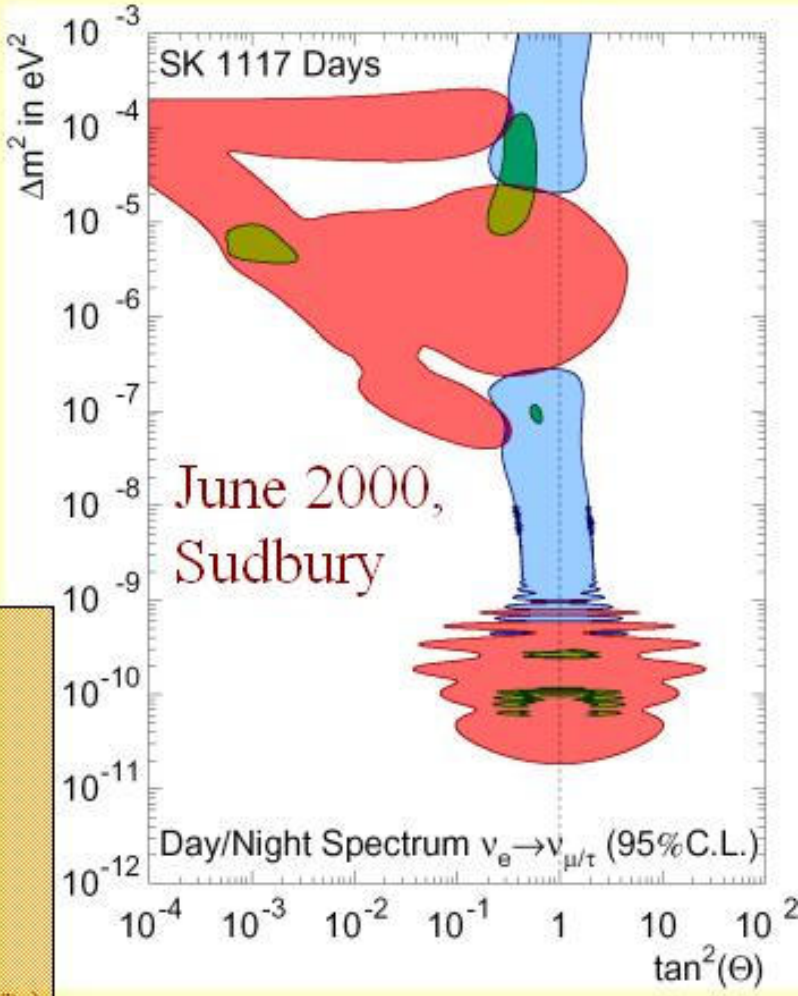
A Brief Moment of History…

Before Super-Kamiokande:

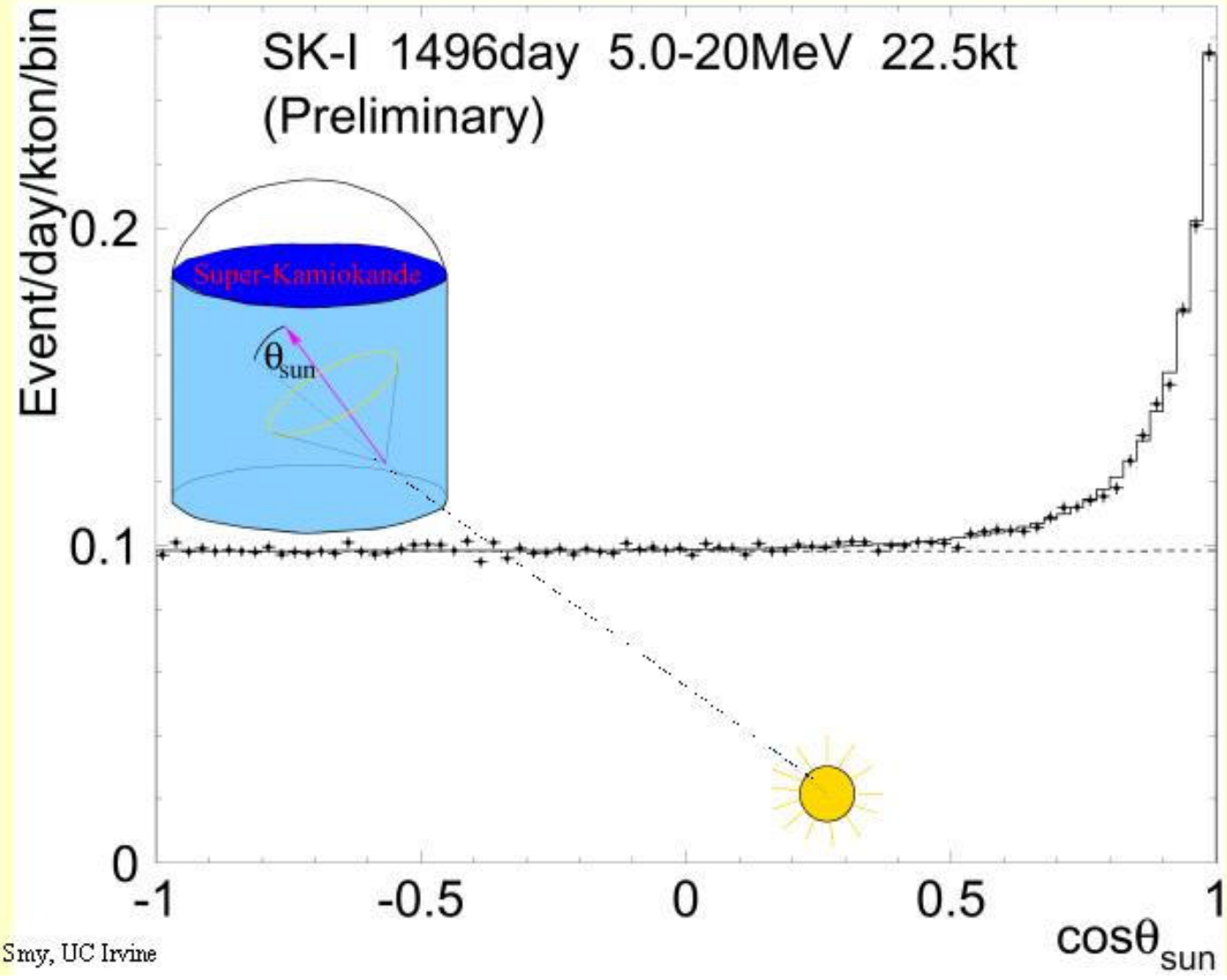
- Active or Sterile Oscillations?
- SMA, VAC, LMA, LOW?
- Really Oscillations?

After Super-Kamiokande:

- ✓ Active Oscillation!
- ✓ Large Angle Solutions!
- ➢ Not VAC, SMA!
- ➢ Not LOW!
- ✓ Really Oscillation! (with SNO)



Solar Peak above 5 MeV



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Super-K Solar Neutrino Rate

1496 Day Final Sample:

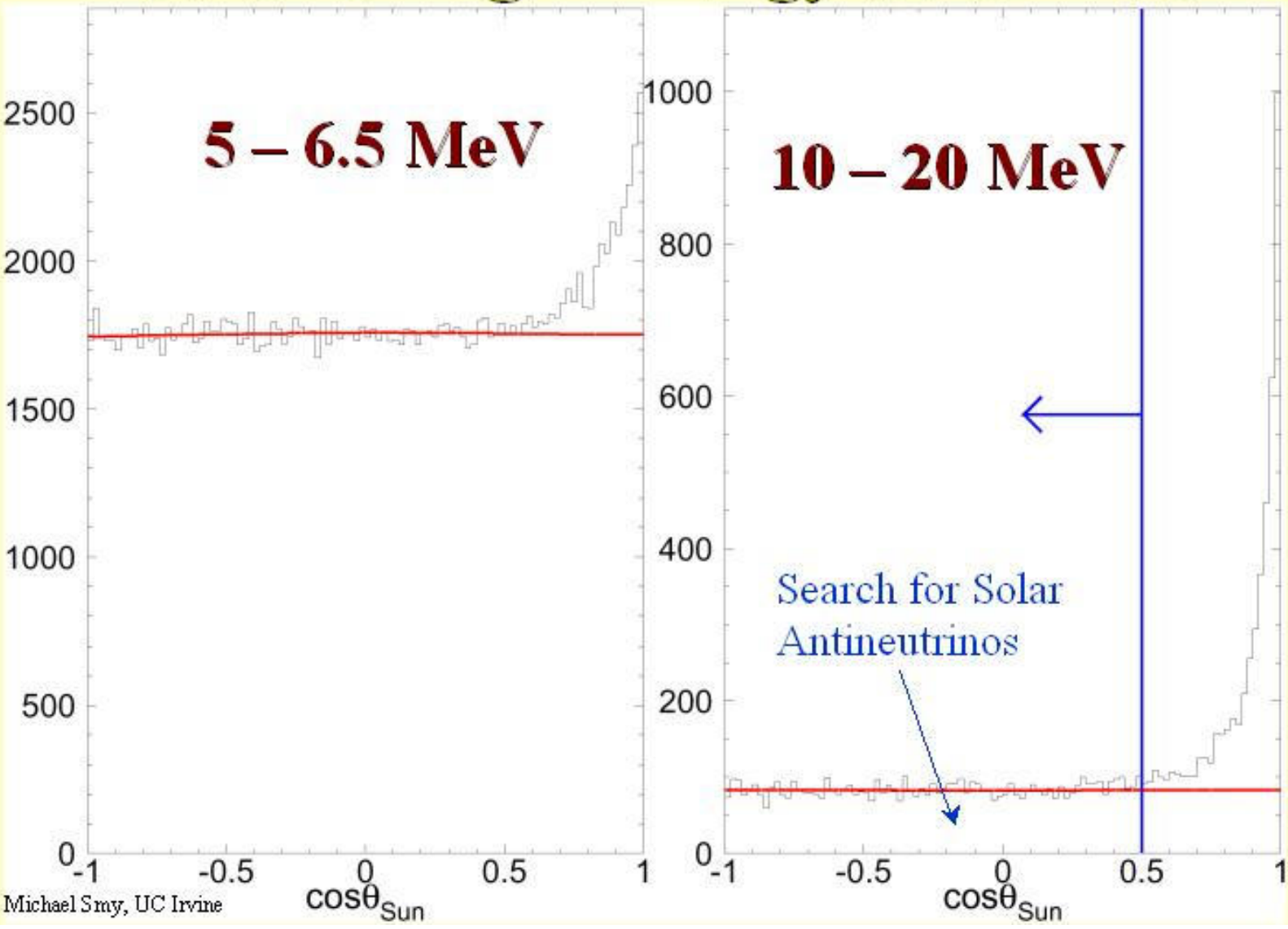
flux is
$2.35 \pm 0.02(\text{stat.}) \pm 0.08(\text{sys.}) \times 10^6/\text{cm}^2\cdot\text{s}$
or $0.465 \pm 0.005(\text{stat.})^{+0.016}_{-0.015}(\text{sys.}) \times \text{SSM}$

- 22,400 solar neutrino events
- 18-21 MeV: 4.9±2.7 events
- Expect ~1 *hep* neutrino (SSM)
- Expect ~2 *hep* neutrinos (oscillation best fit: ~4x SSM)
- 90% C.L. upper limit of *hep* flux: $73 \times 10^3/\text{cm}^2\text{s}$ (7.9xSSM)

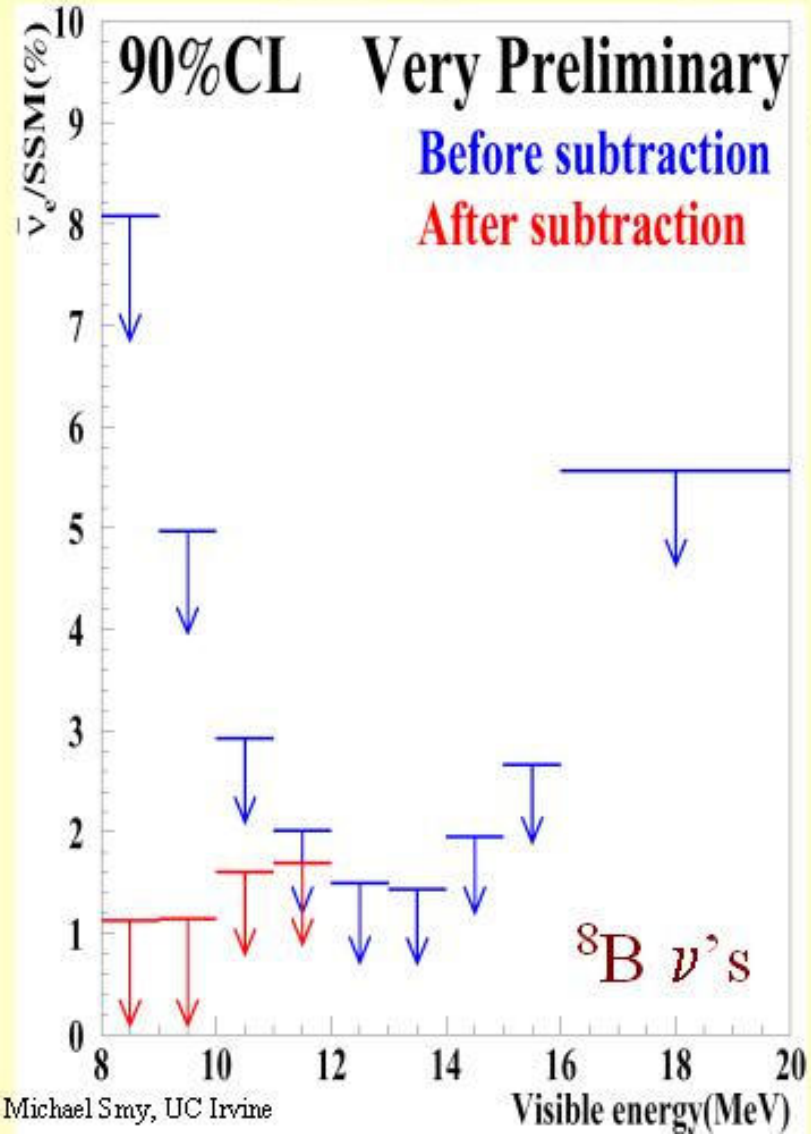
Expect:

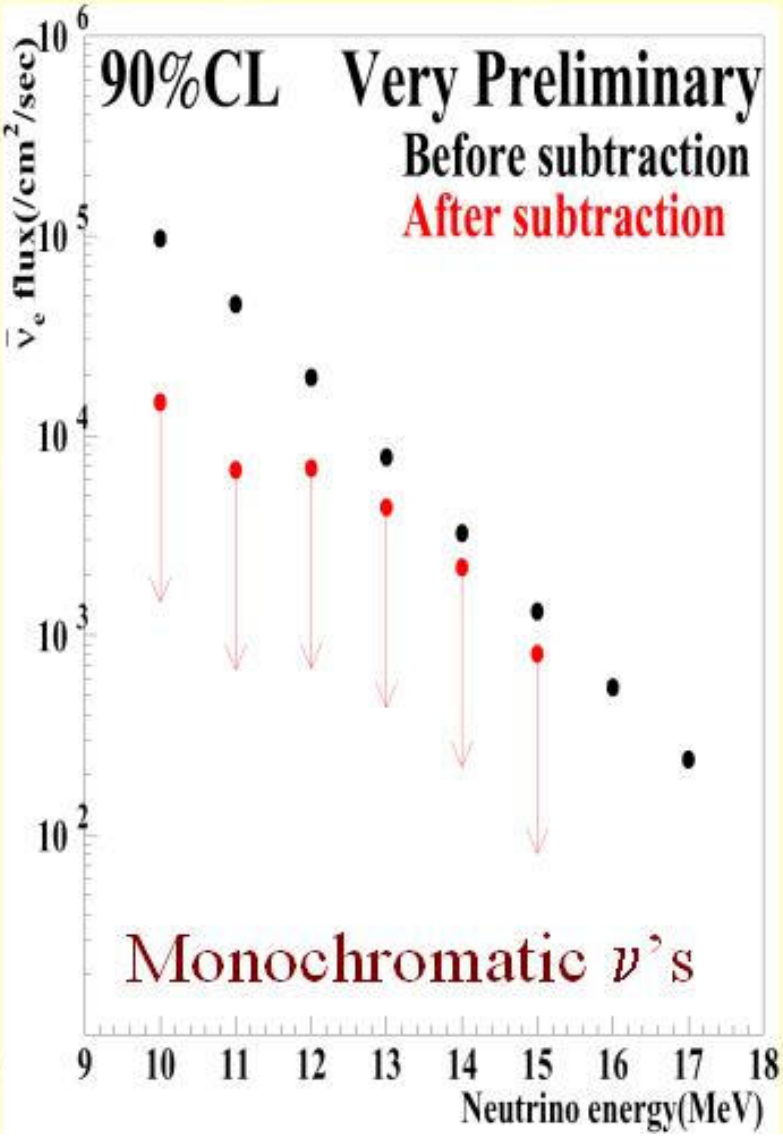
- 48,200 solar neutrinos (from SSM)
- 16,700 e-type solar neutrinos (from SNO)
- About 5,700 μ/τ-type solar neutrinos

Low and High Energy Solar Peak

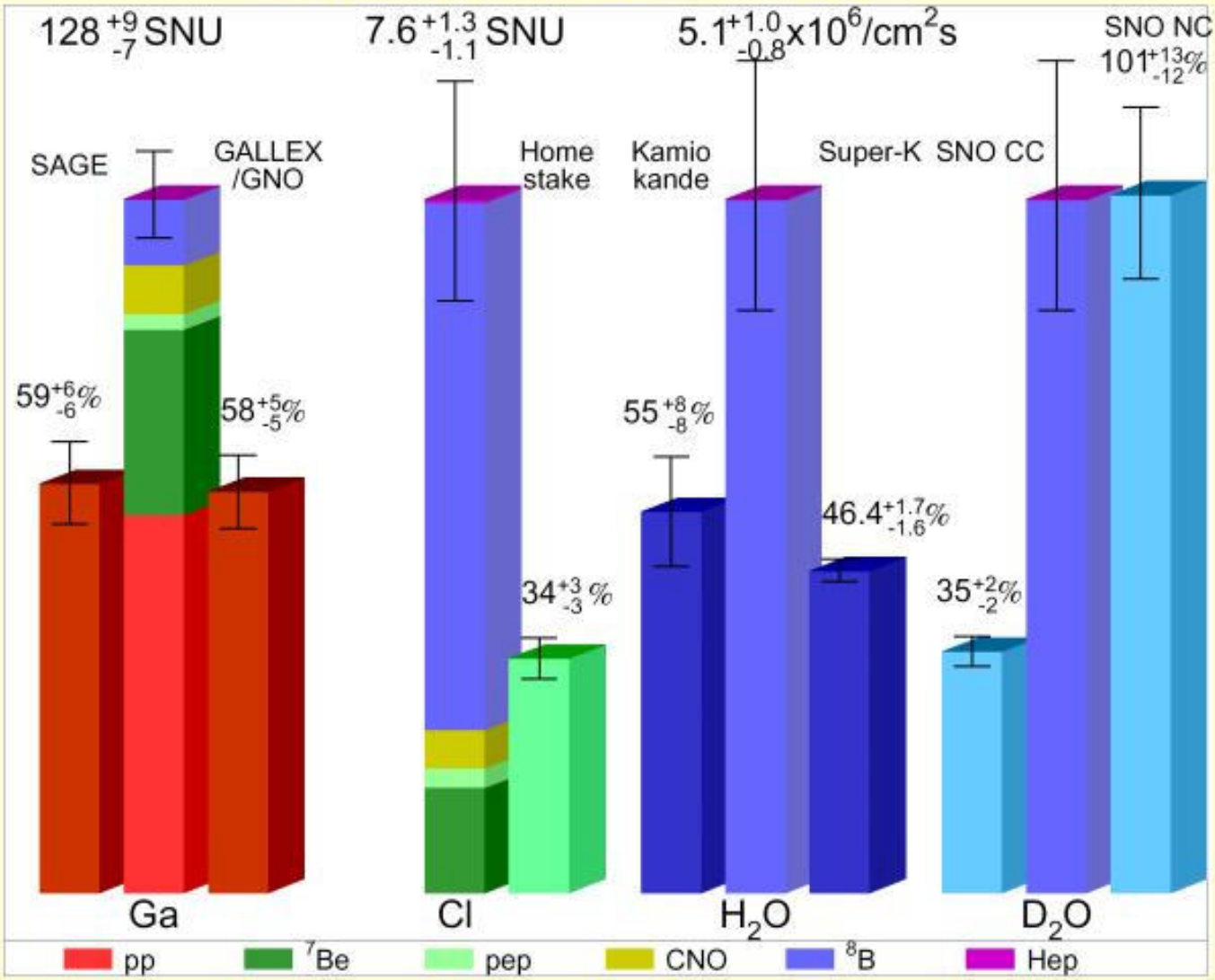


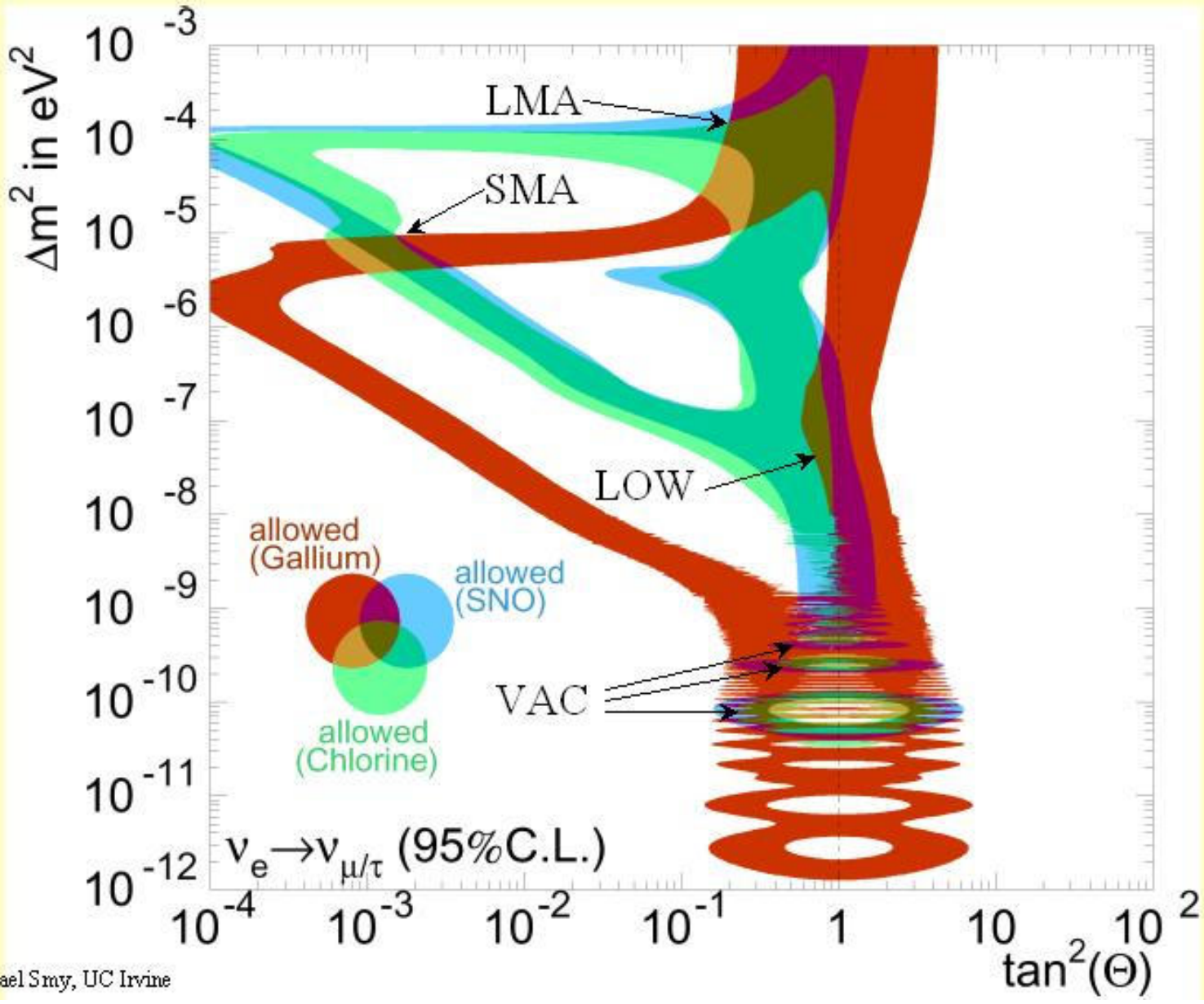
Solar Antineutrino Limit





Solar ν Problem





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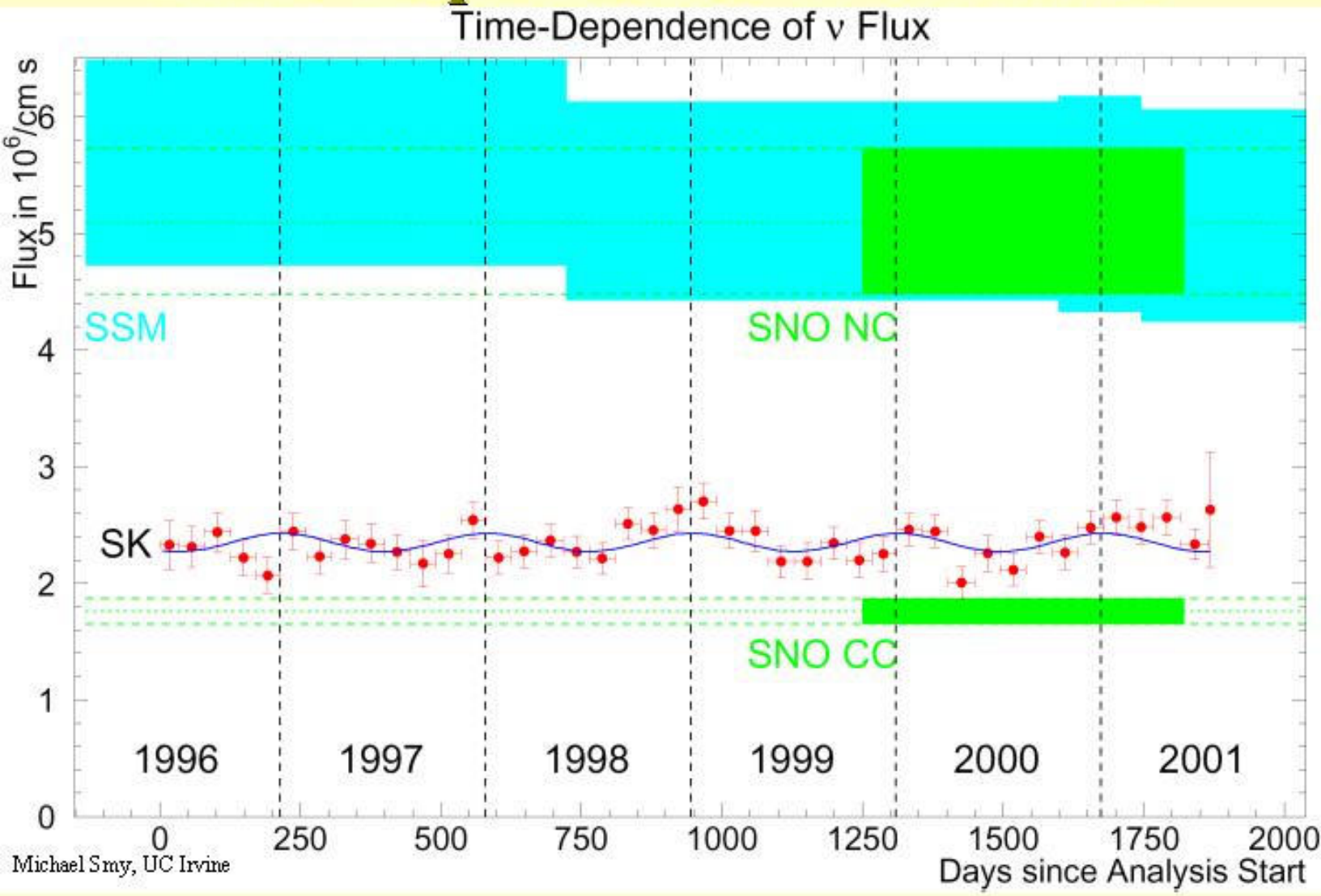
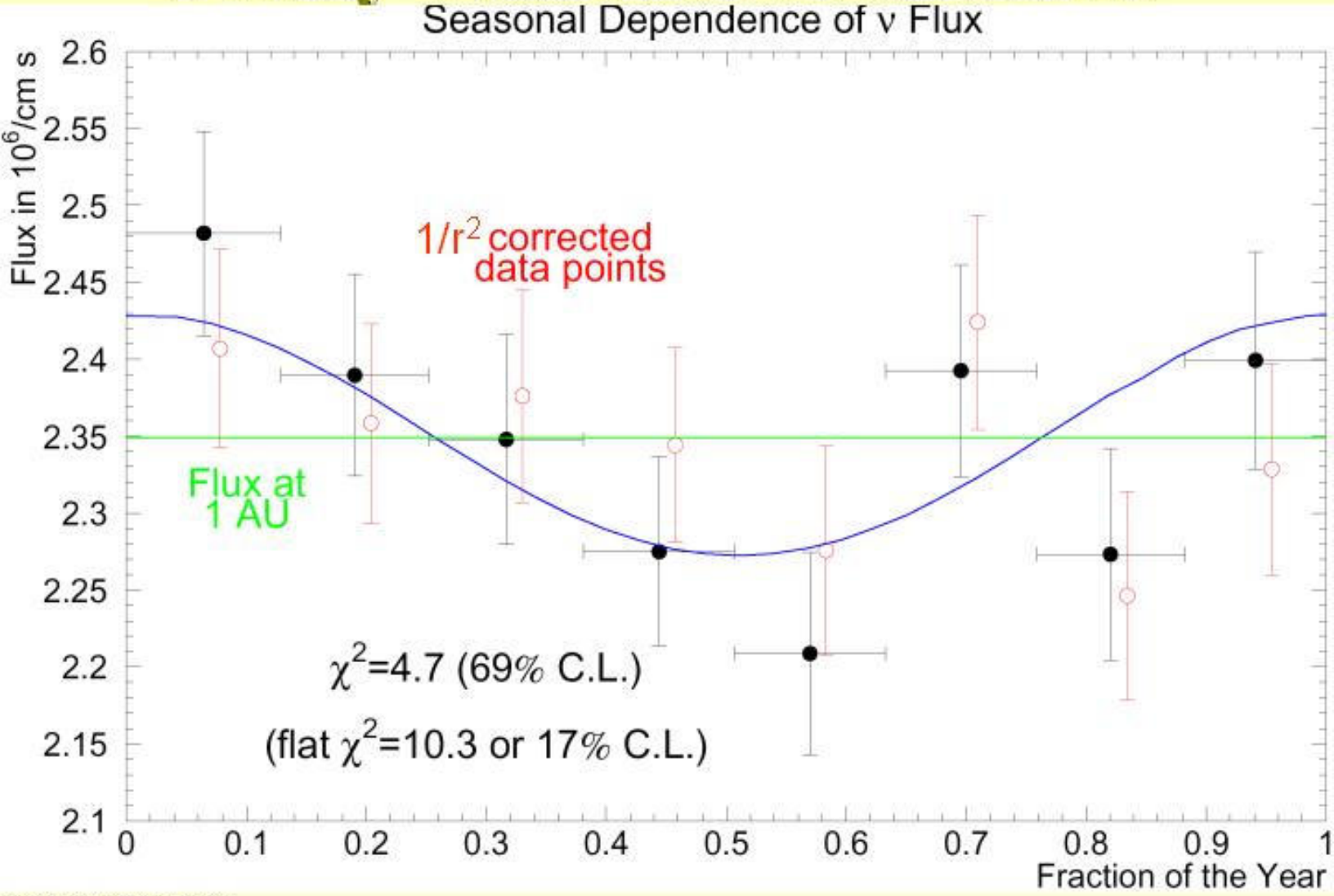
Time Dependence of SK Rate



Yearly Variation of SK Rate



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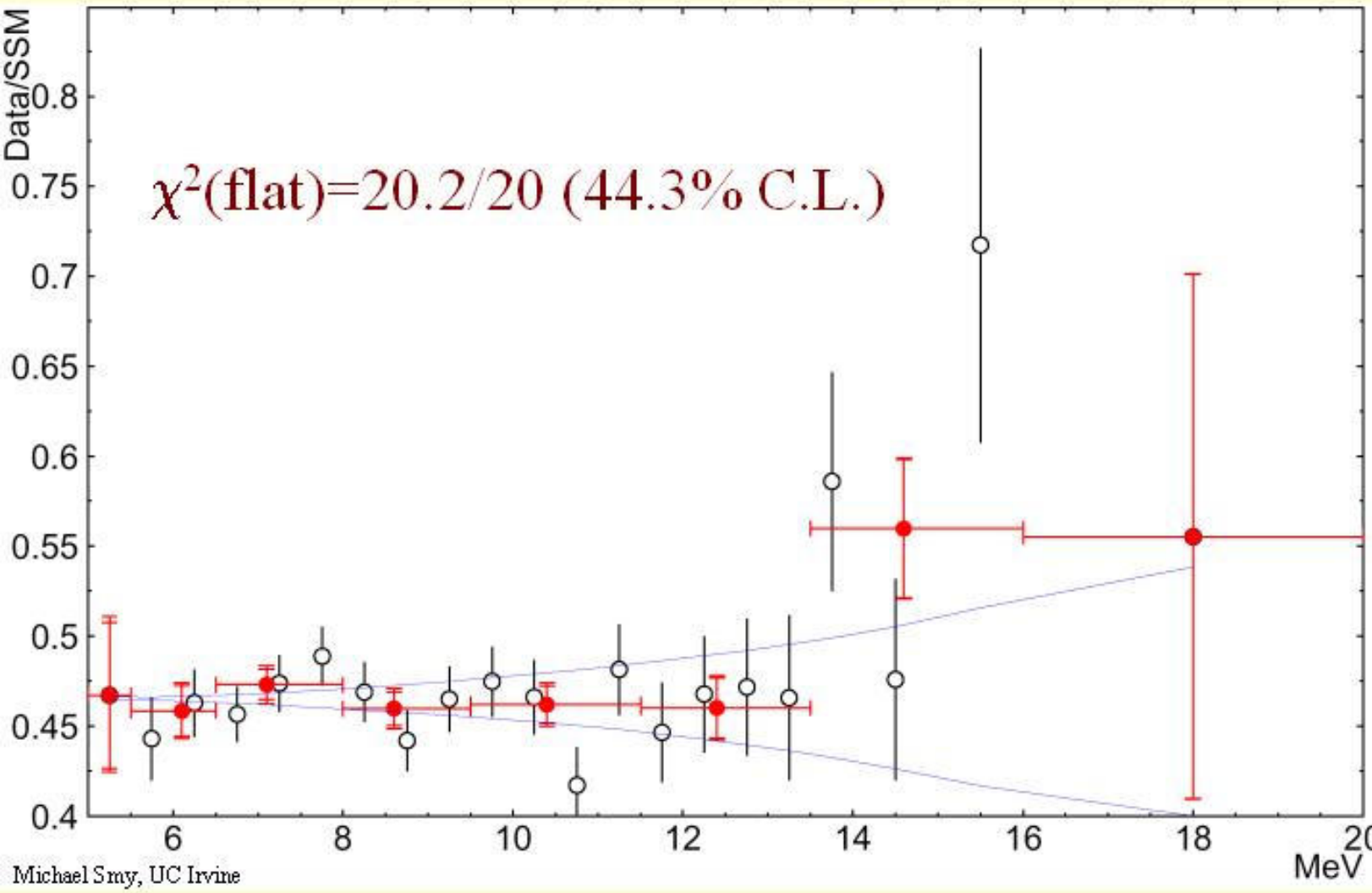
Recoil Electron Spectrum



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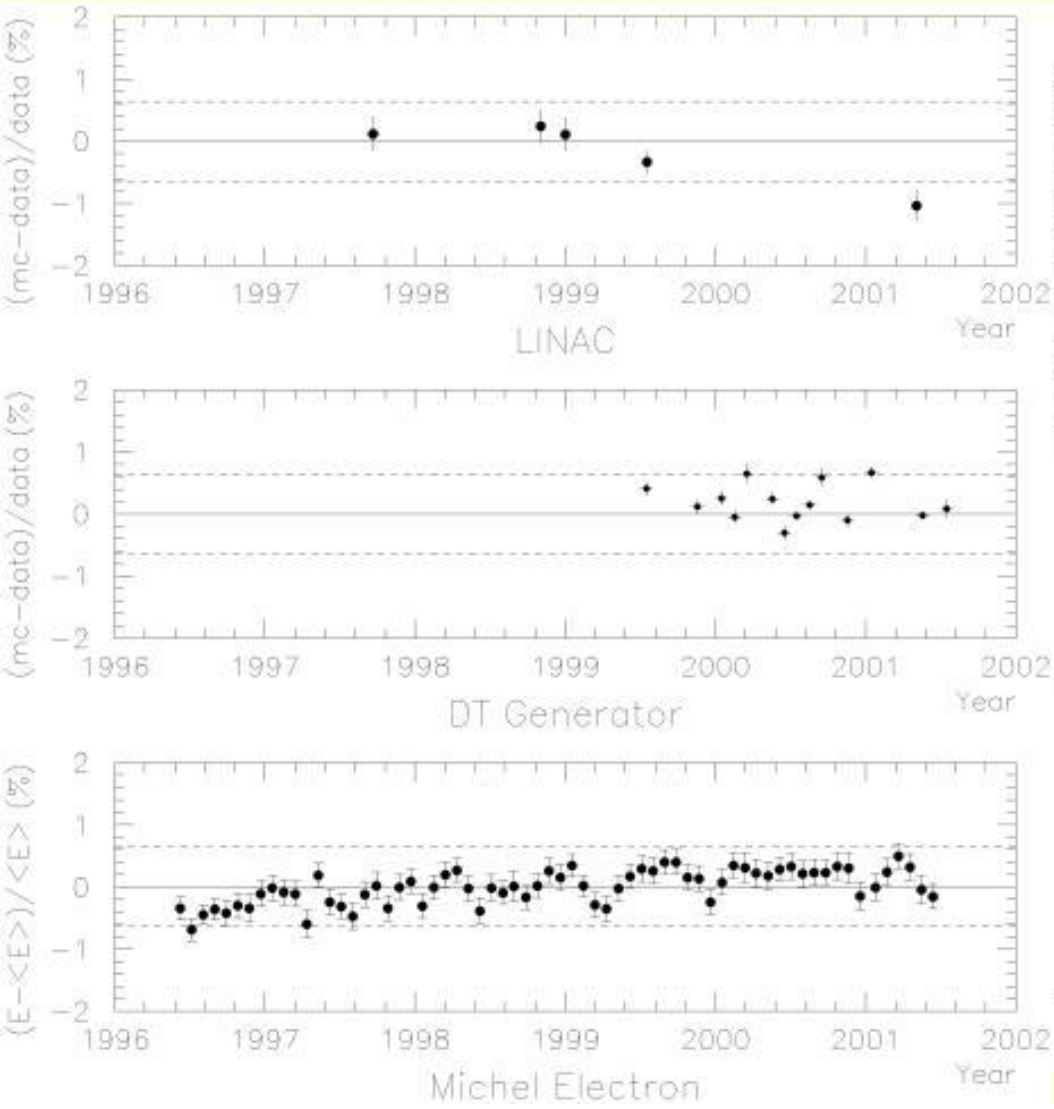
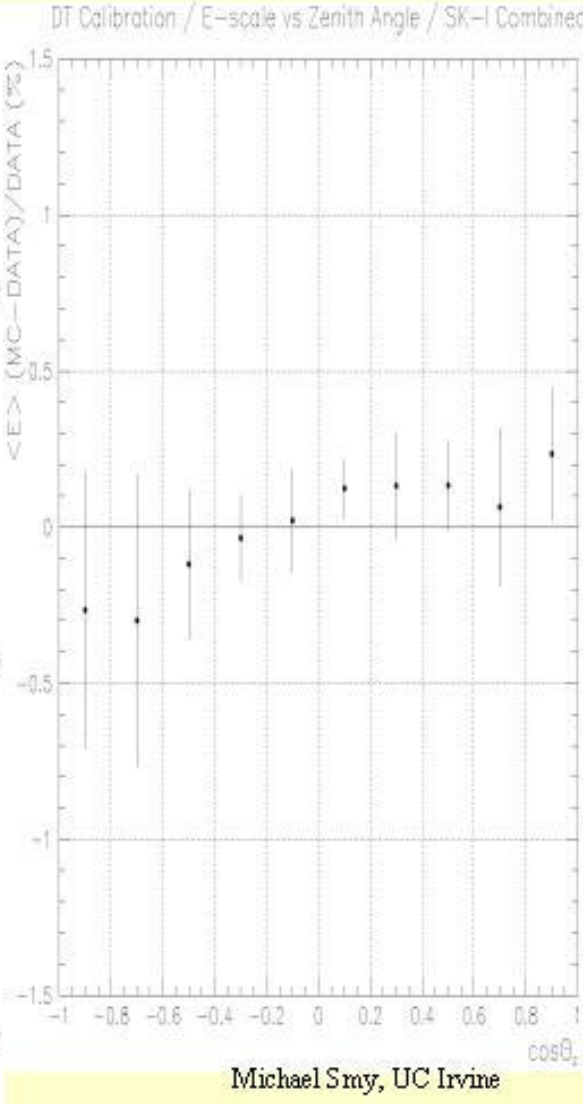
Energy Calibration Stability





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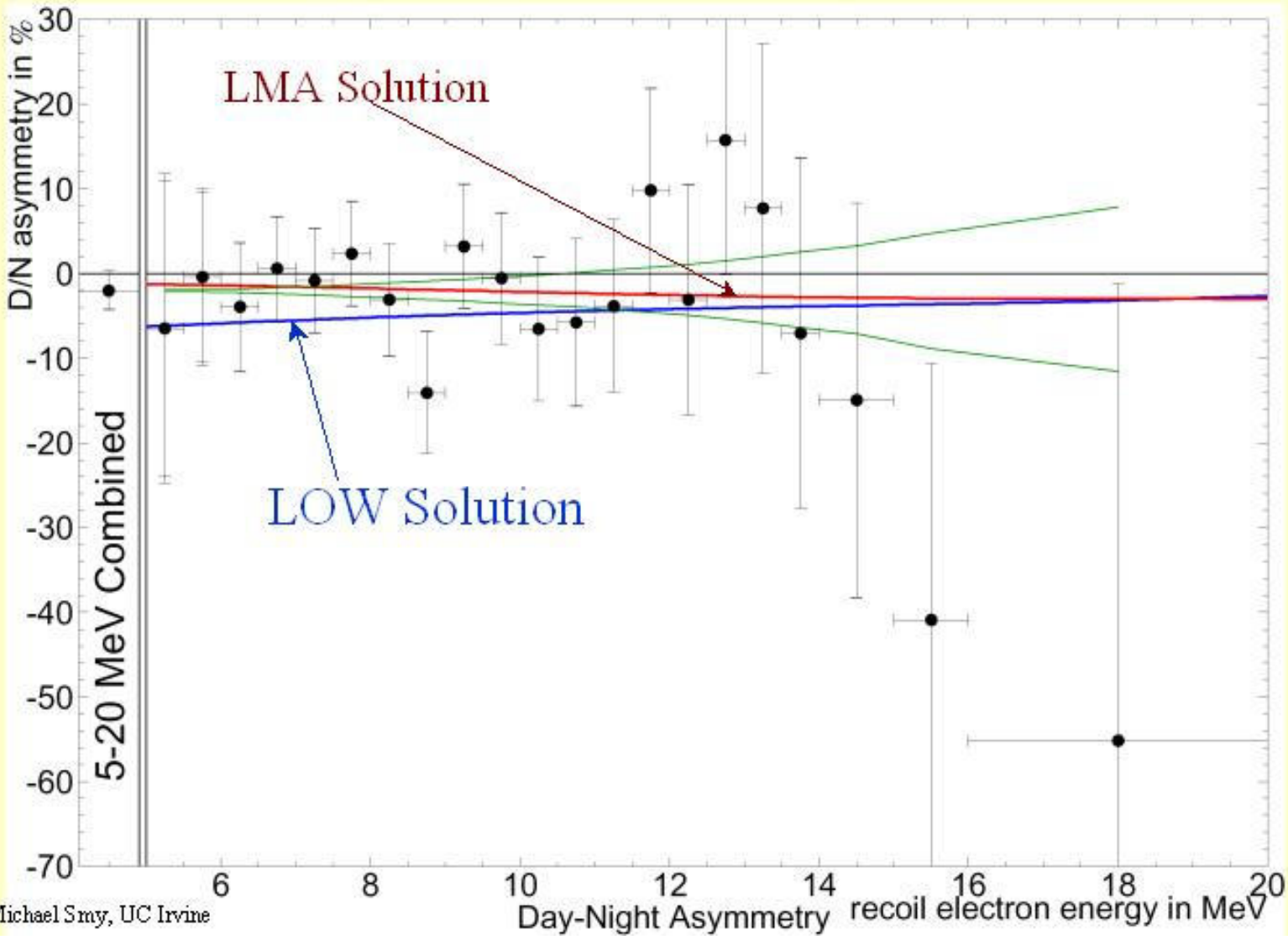
Day/Night Asymmetry



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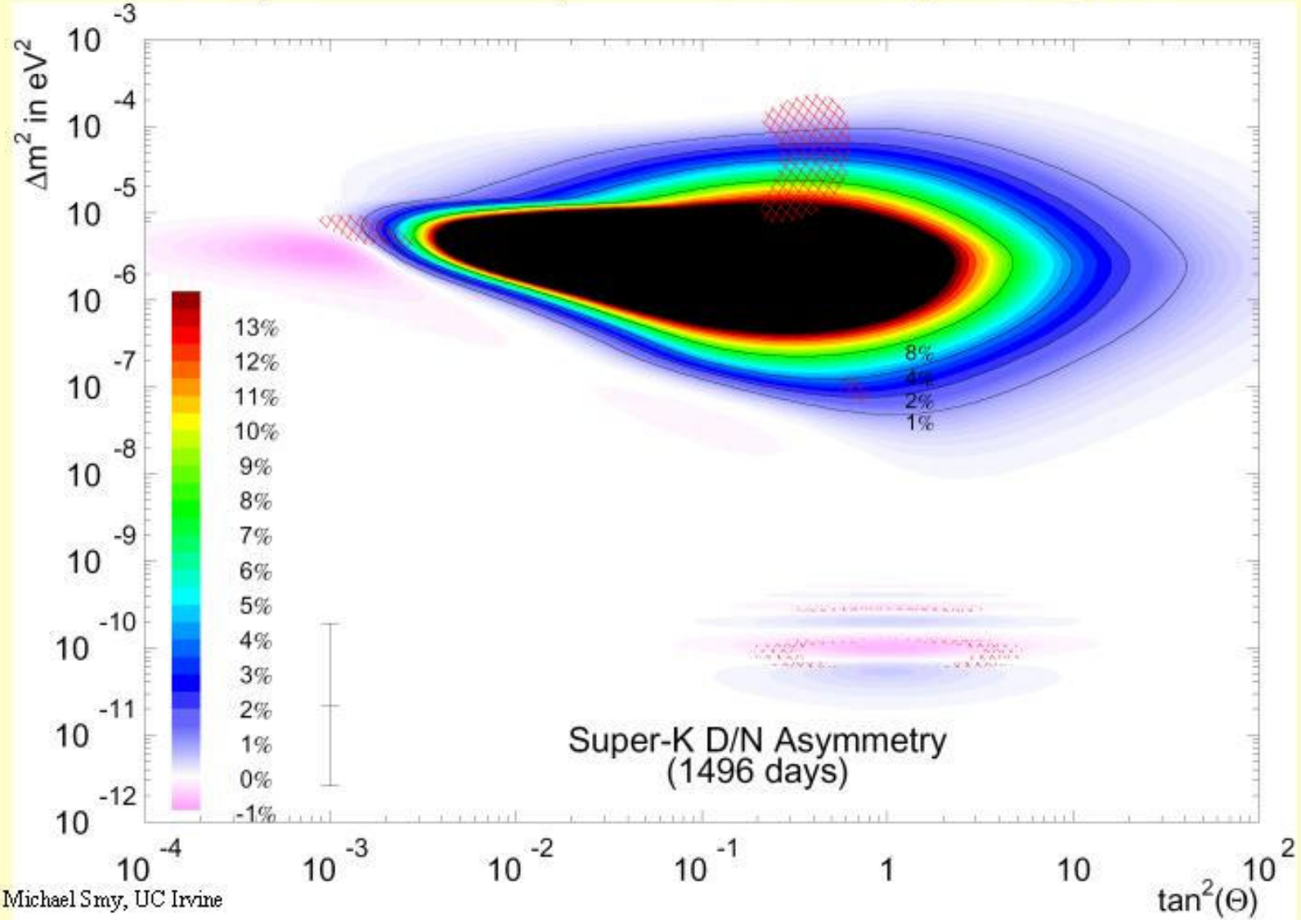
Super-K Expected Day/Night



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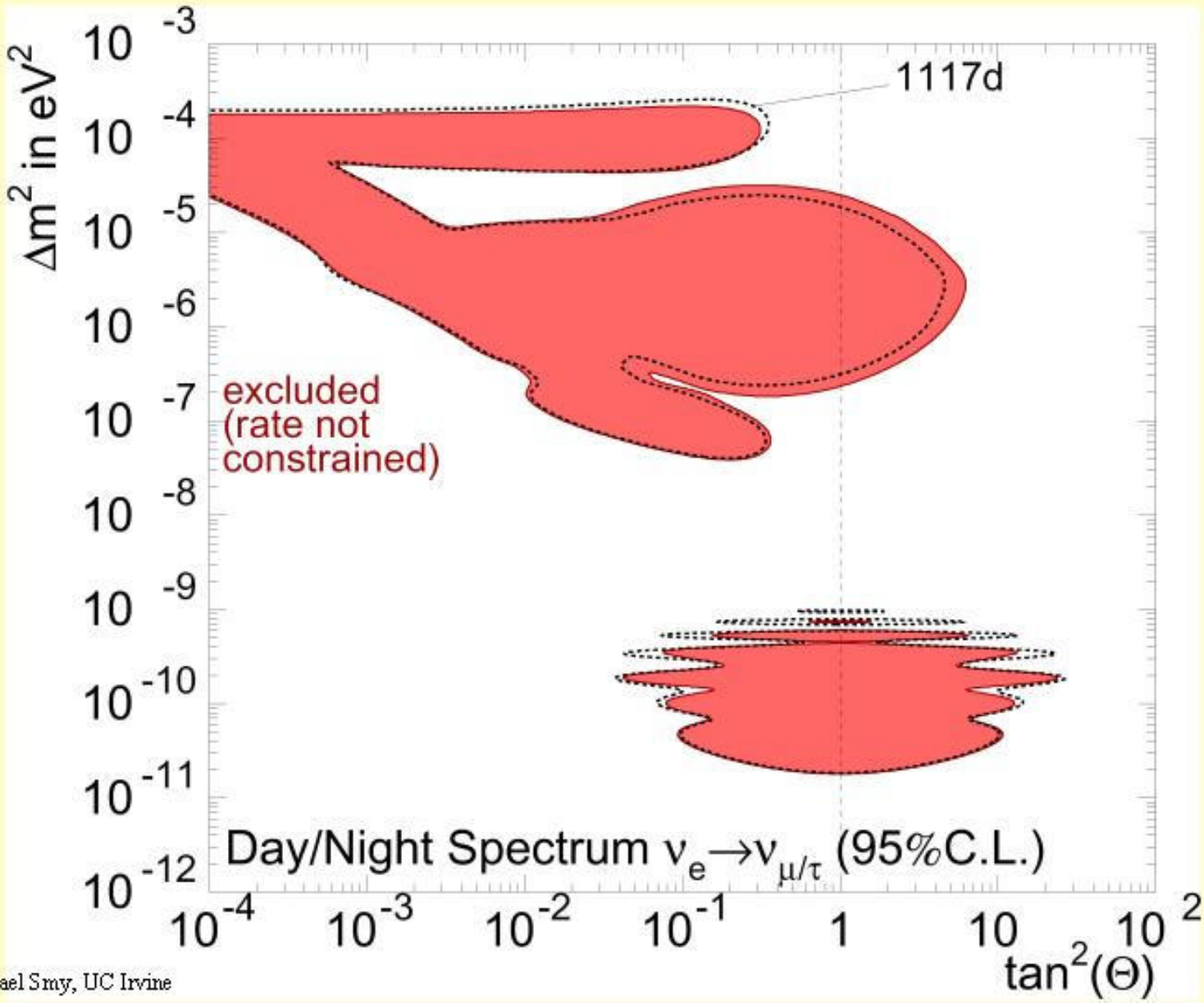

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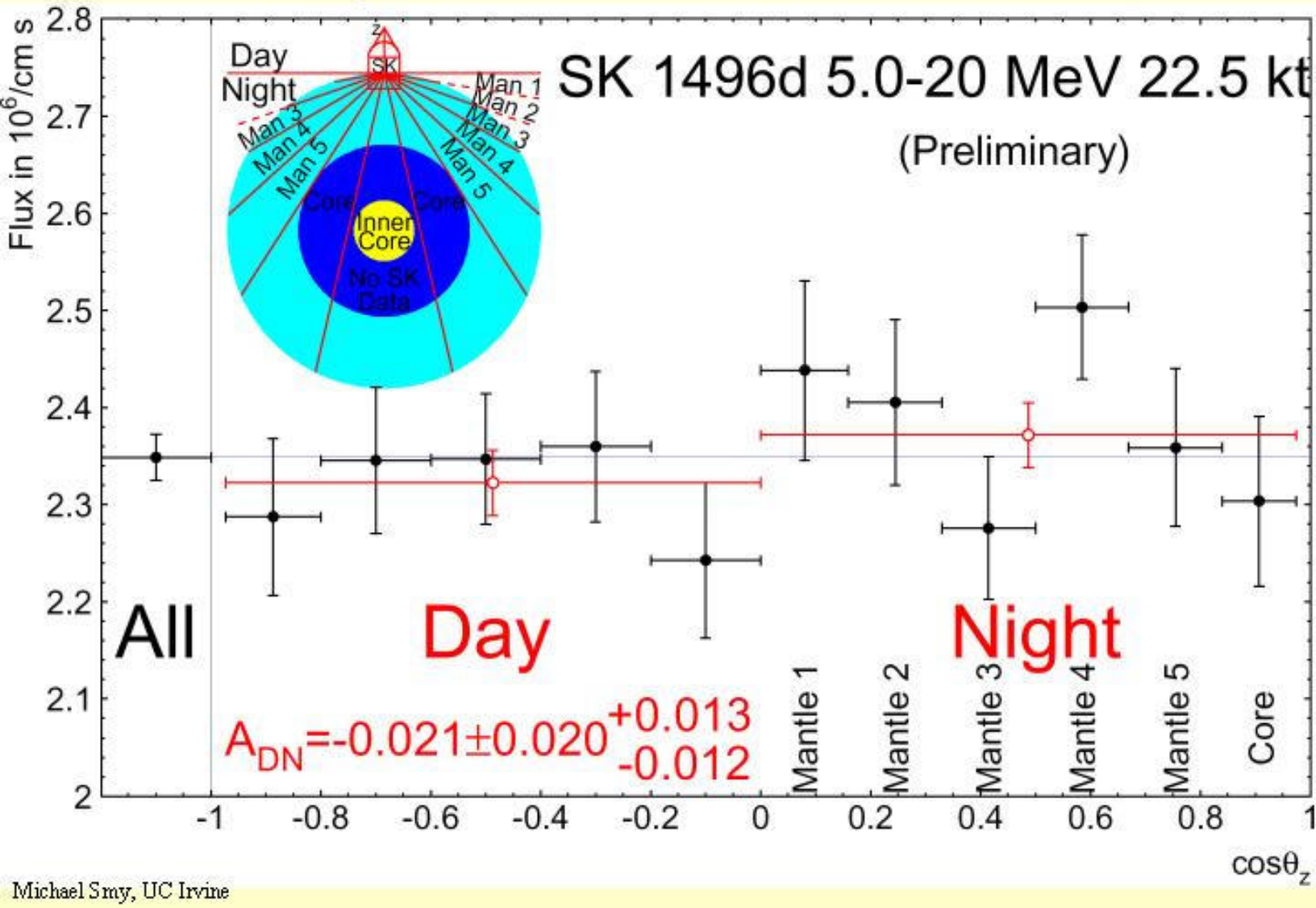
Daily Variation of SK Rate



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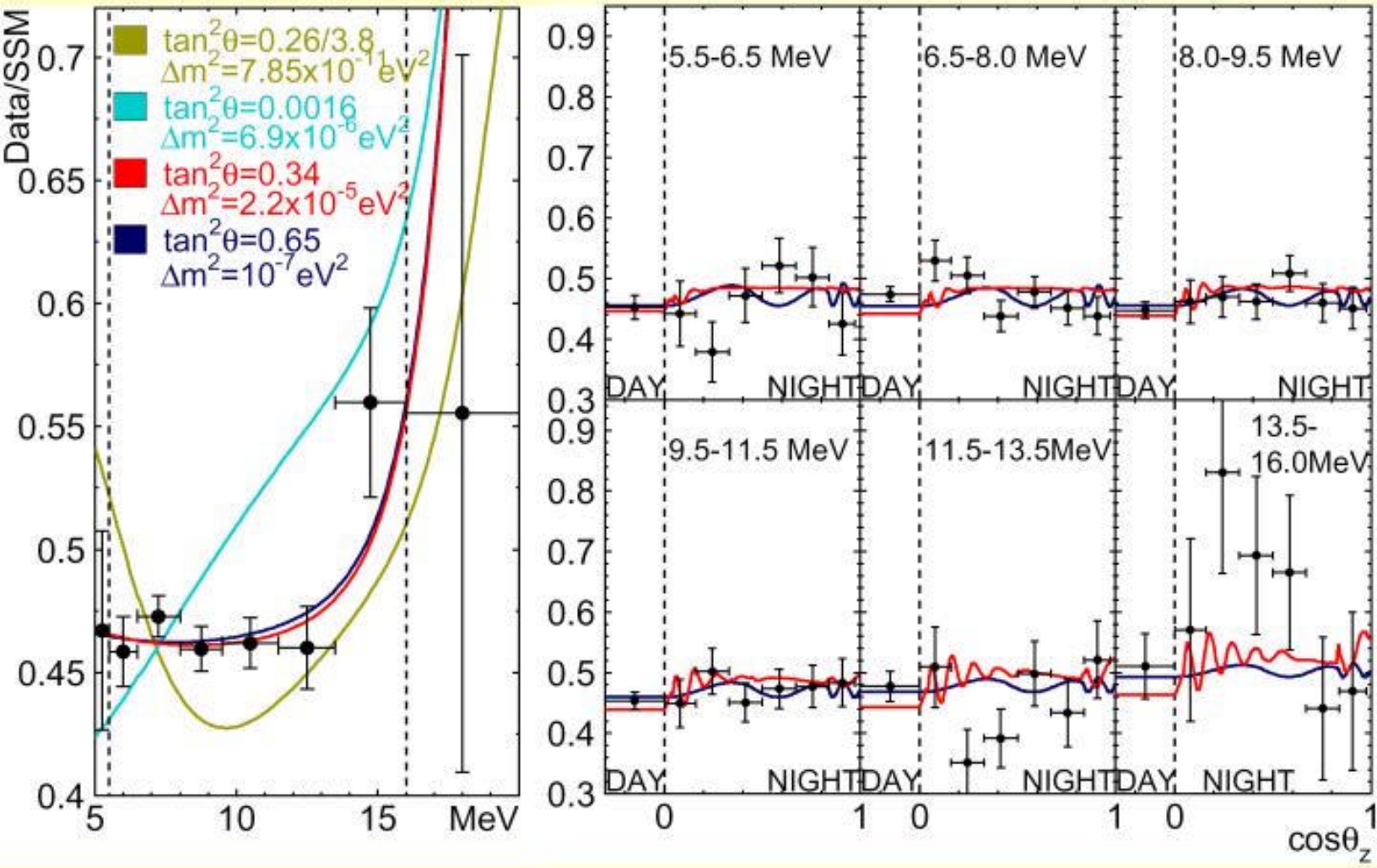
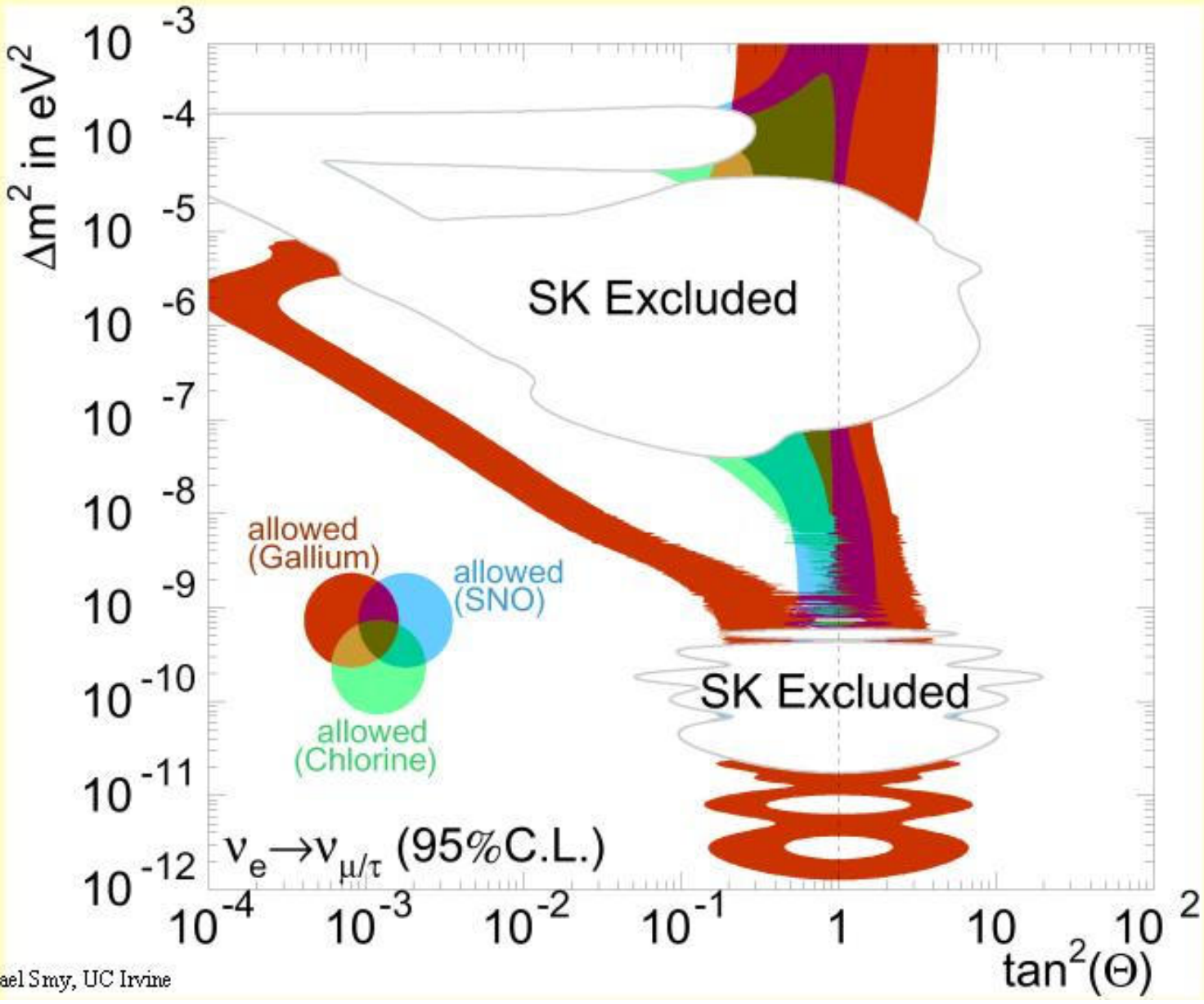
Zenith Spec: Data & Solutions





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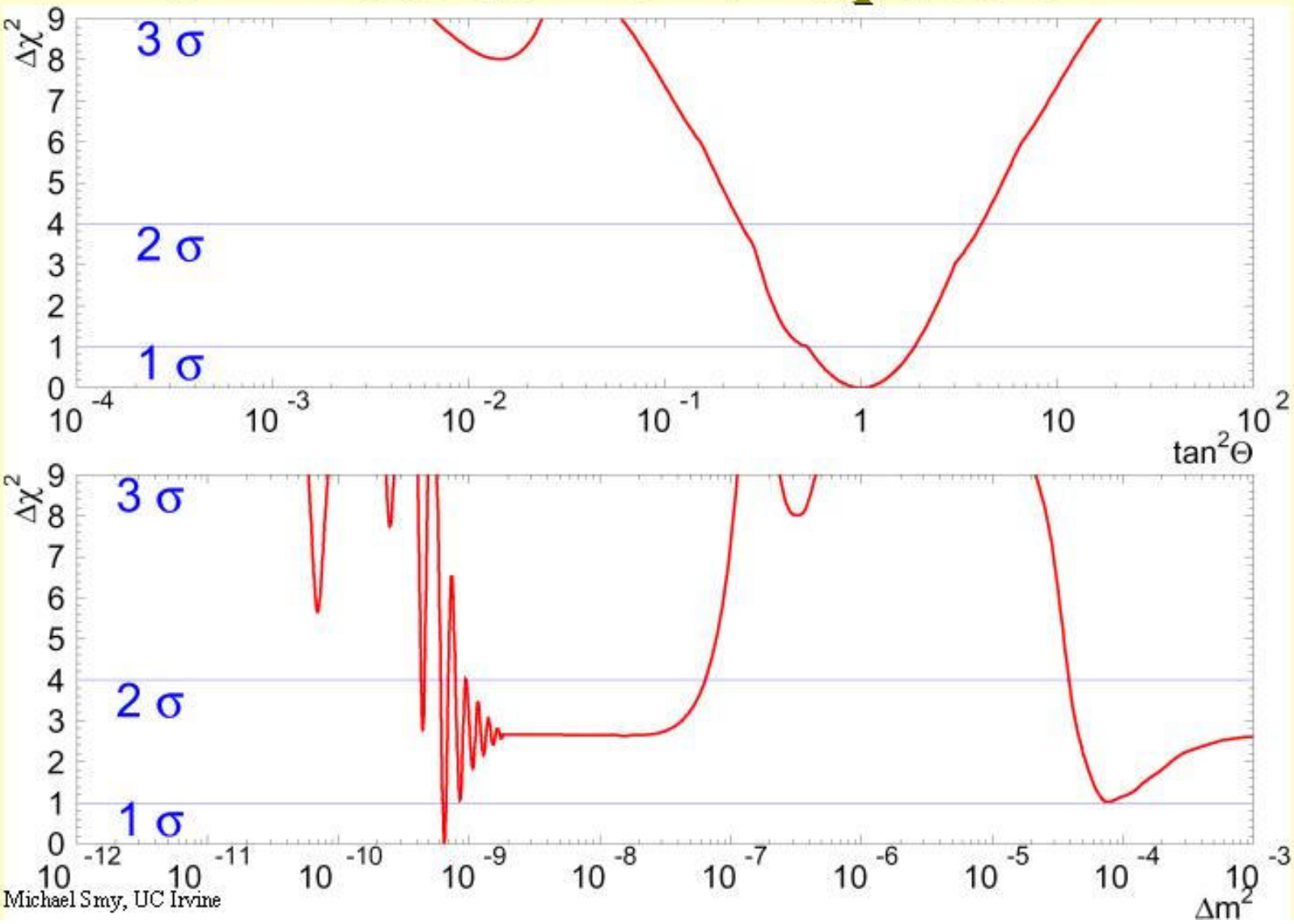
SK Rate & Zenith Spectrum



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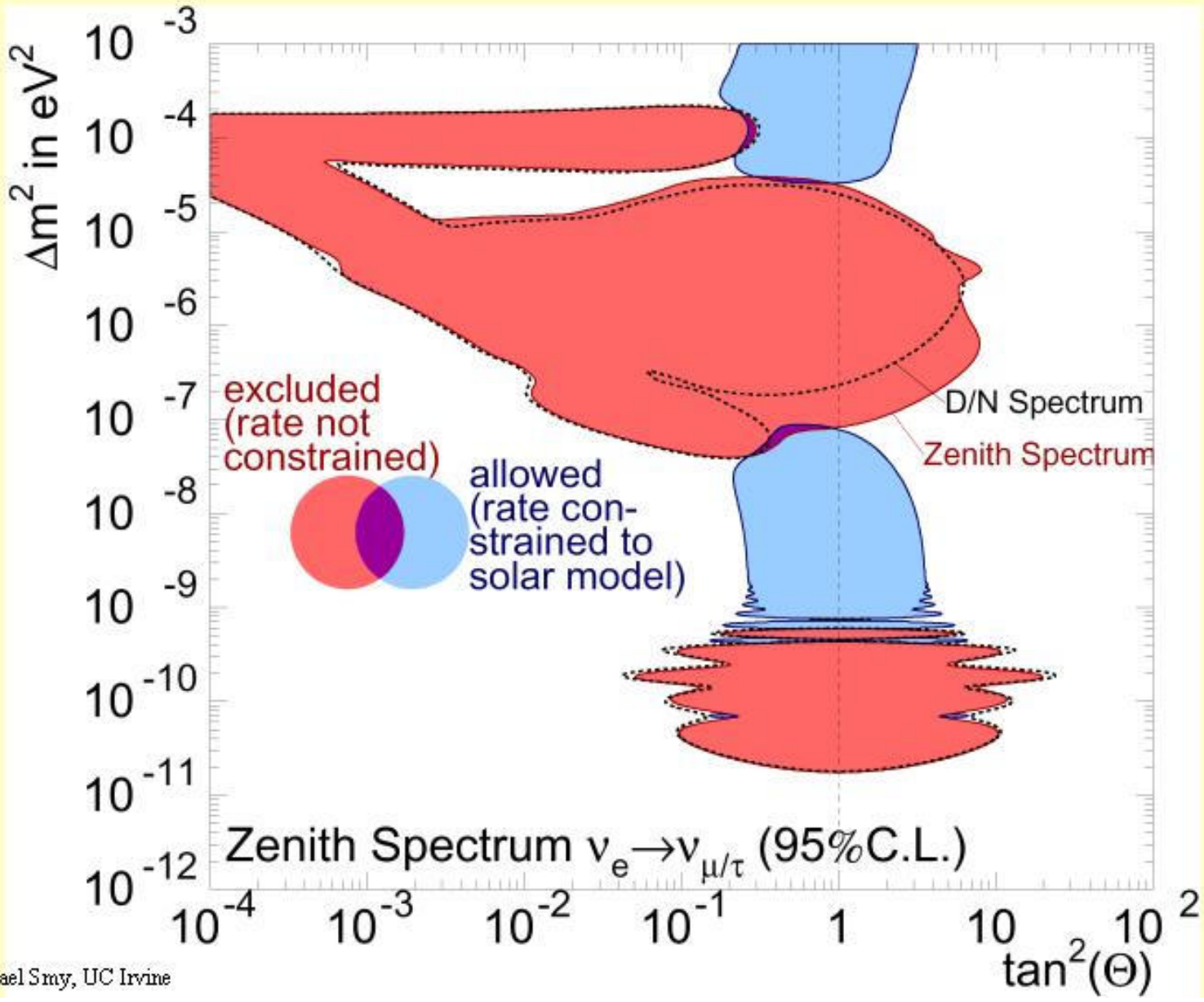

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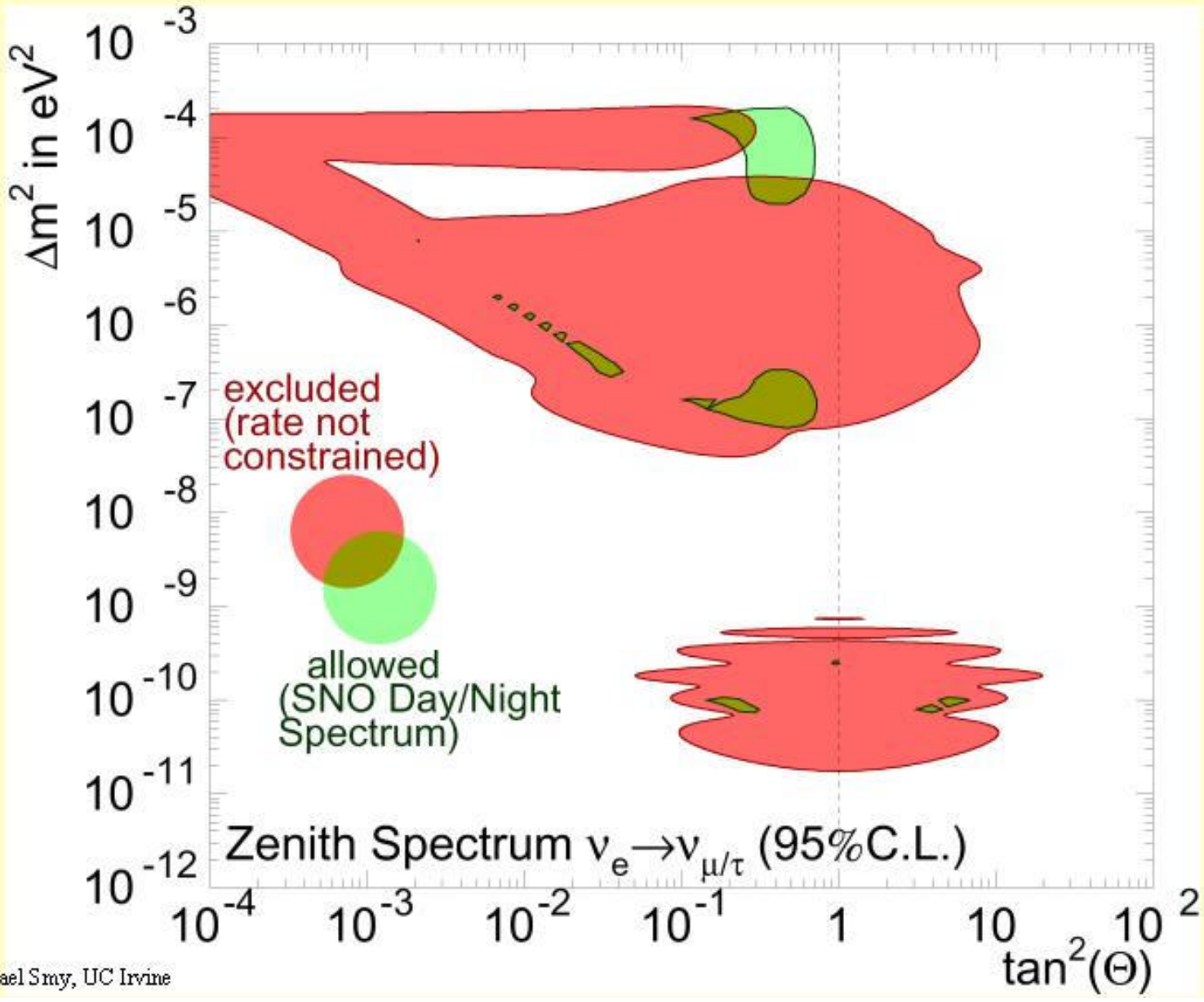

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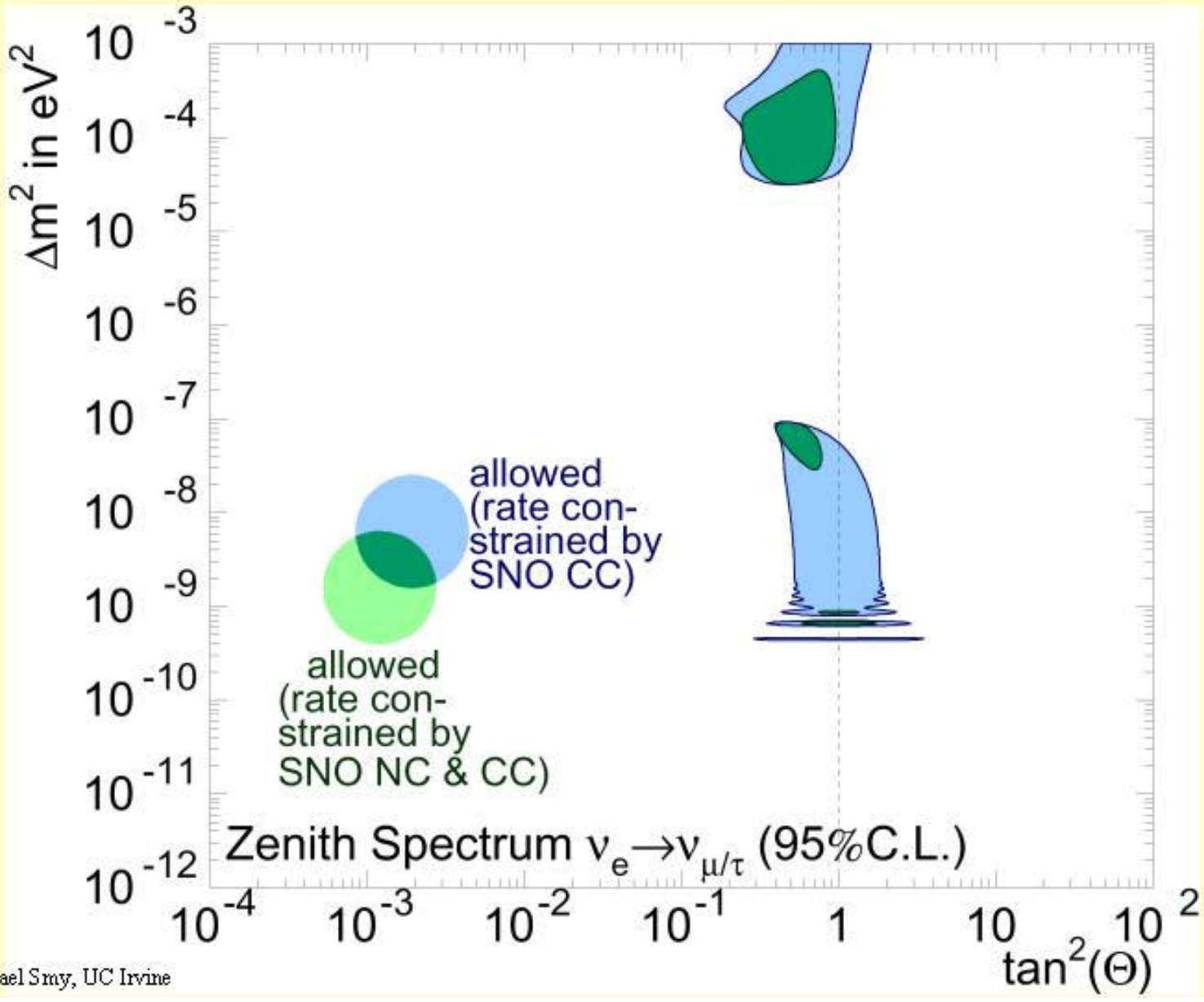
Combined Fits



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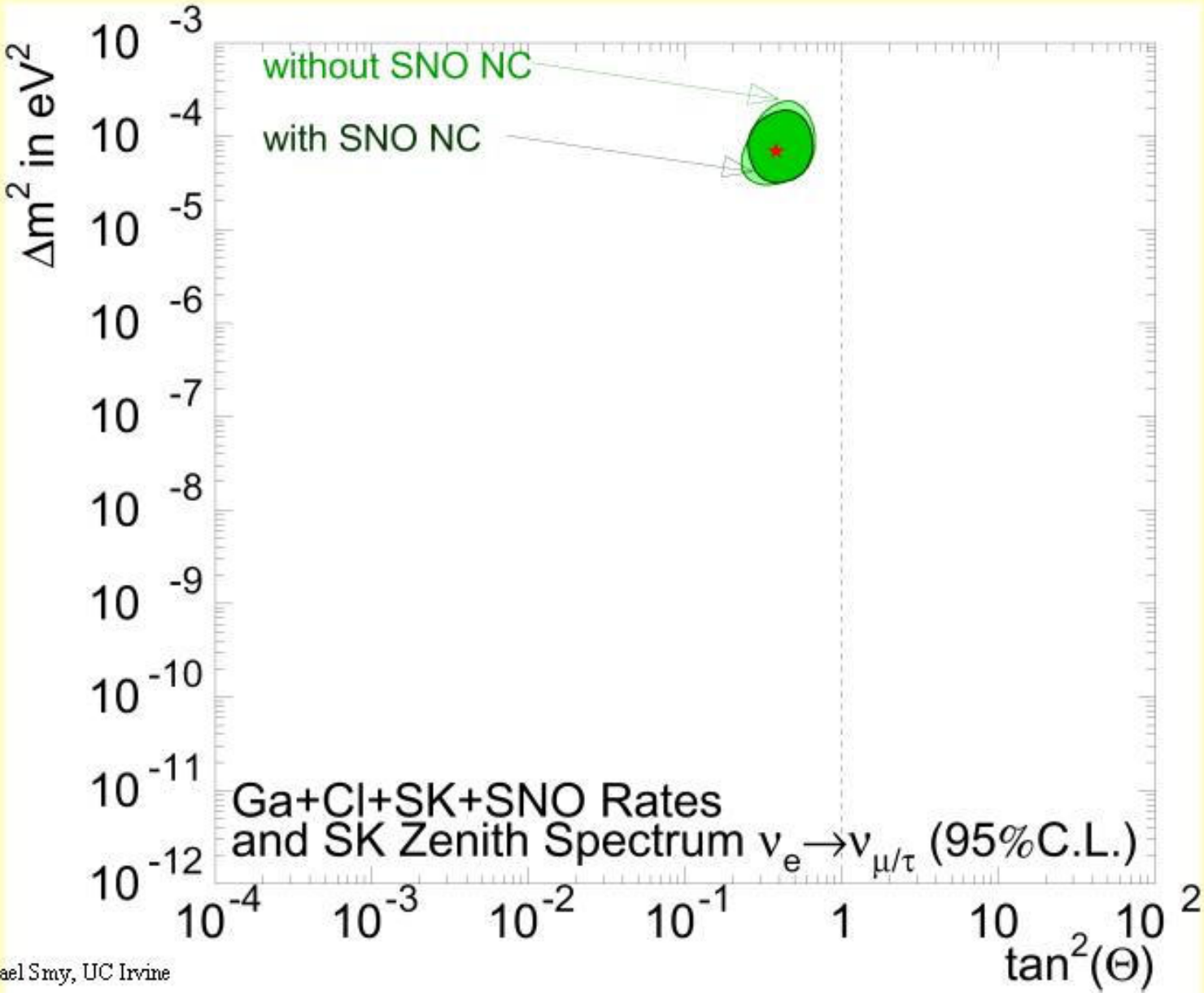
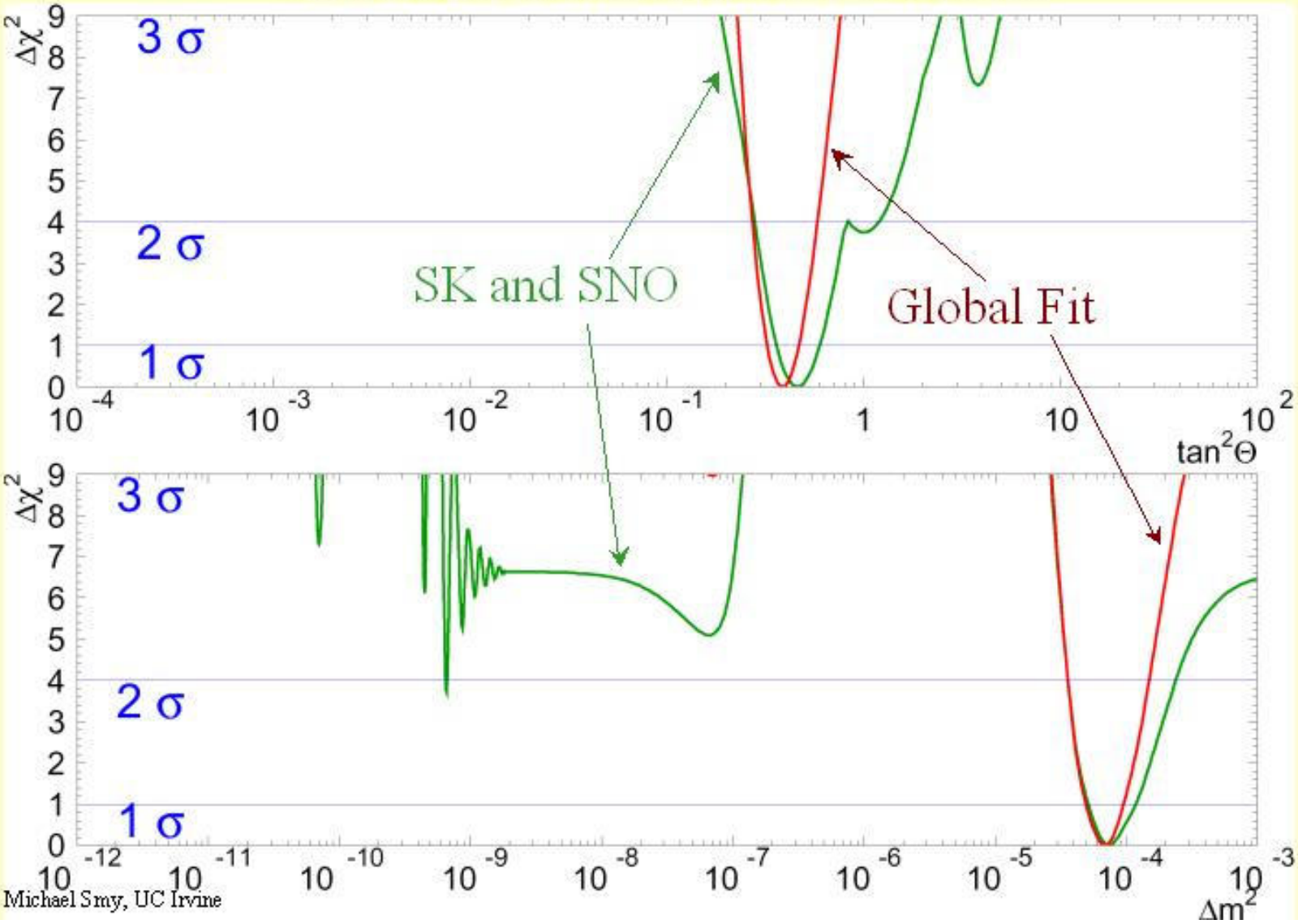

without SNO NC
with SNO NC
Δm^2 in eV^2
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
Ga+Cl+SK+SNO Rates
and SK Zenith Spectrum $\nu_e \rightarrow \nu_{\mu/\tau}$ (95%C.L.)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^2
$\tan^2(\Theta)$

Conclusions

- Super-Kamiokande has measured precisely ES Flux, Recoil Electron Spectrum and Time Variations of its Interaction Rate
- Precise, Stable Detector Calibration
- Neutrino Oscillation Studies:
  Active, Large Angle Solution,
  Flavor Conversion (with SNO),
  Selection of LMA
  (with other solar experiments)

See also: hep-ex/0205075

Global Solution: LMA



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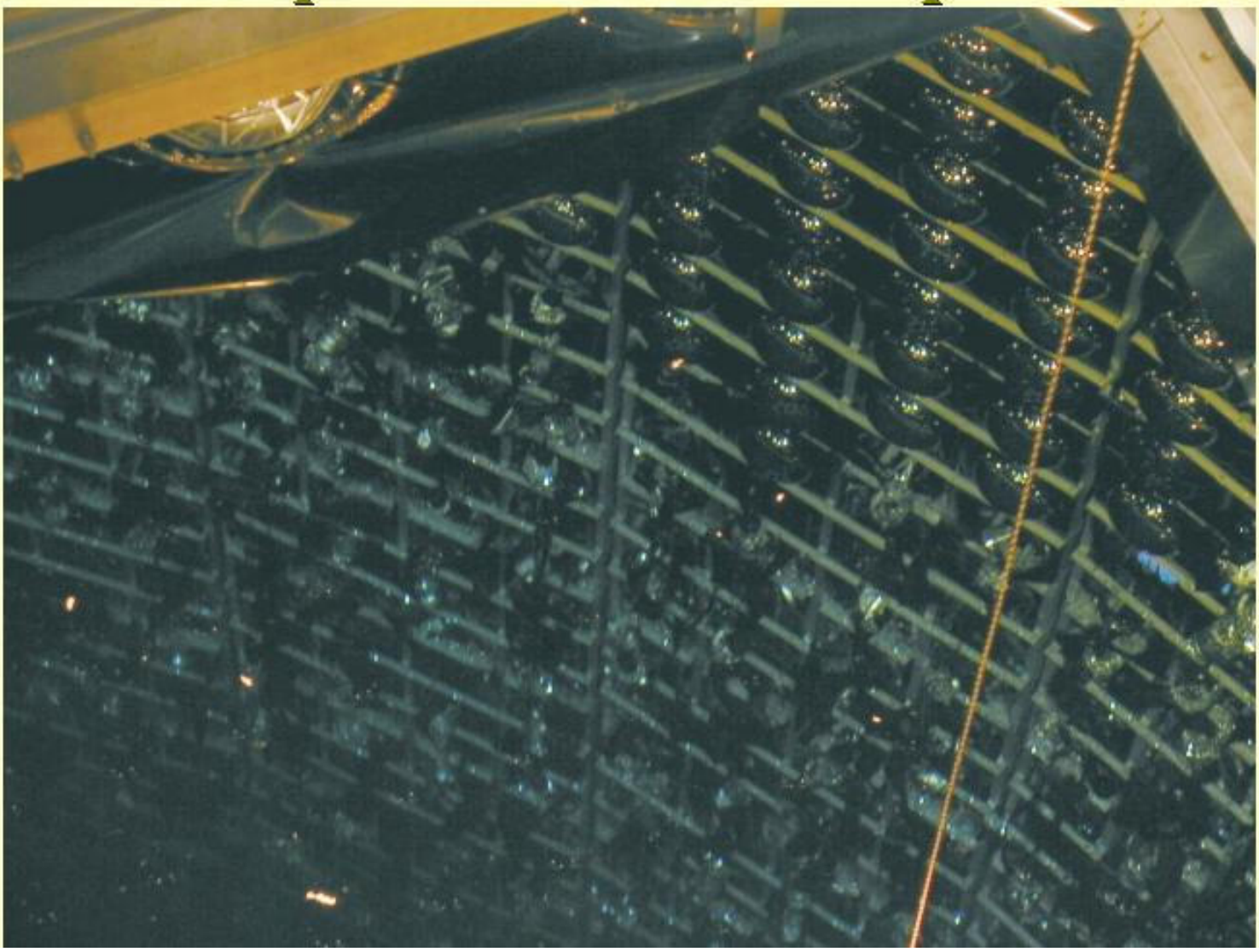
Super-Kamiokande Accident and Future Plans

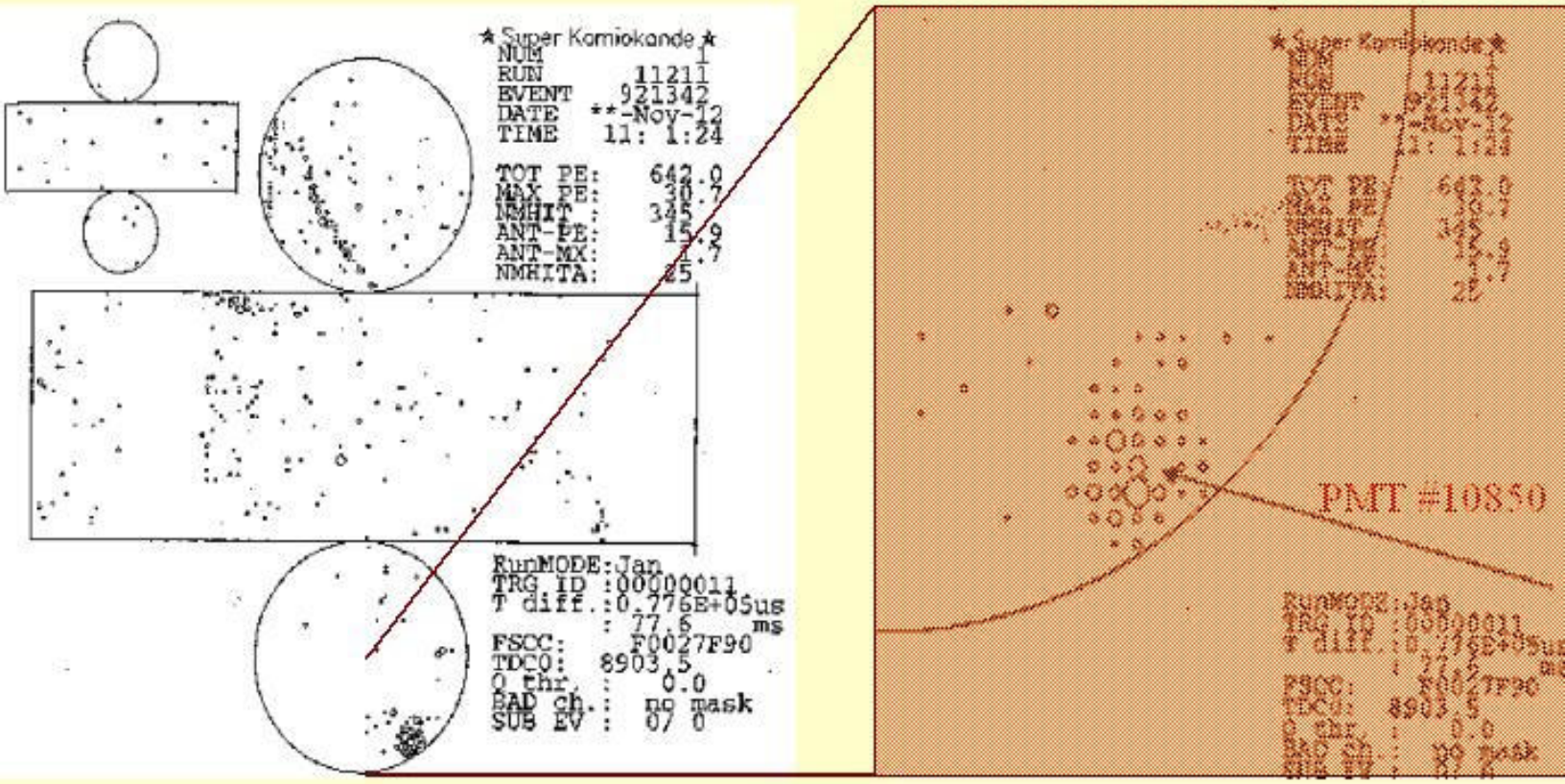
Super-K after Collapse



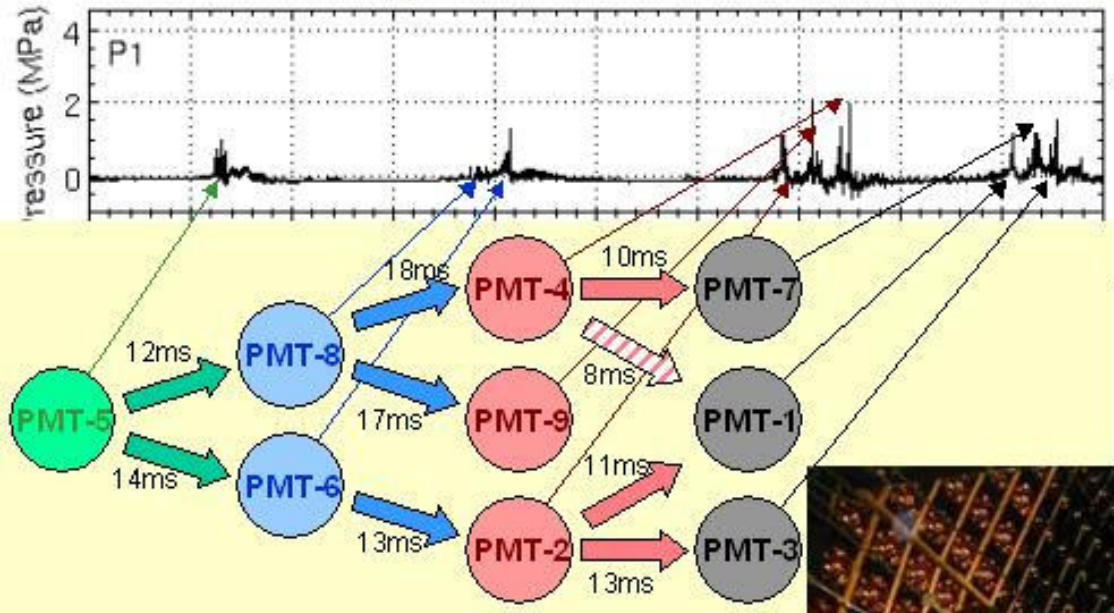
Super-K Damage Summary

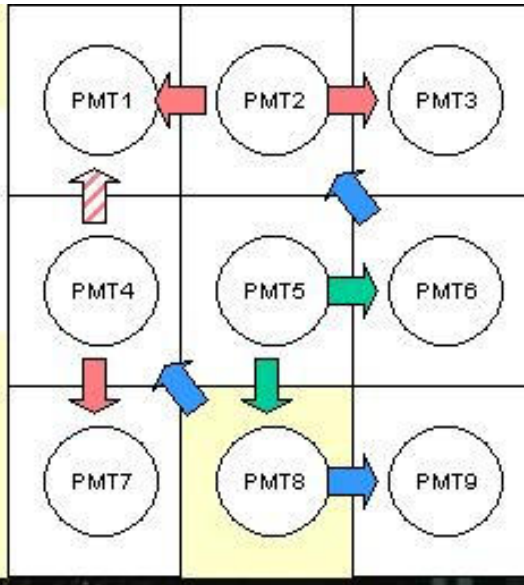
Damaged PMT's	6777 (out of 11146 20" tubes 1149 (out of 1885 8" tubes)
Electronics damage	none
High voltage damage	negligible
Wavelength shifting plates	700 (out of 1885 damaged)
Plastic, Tyvek sheeting	Needs total replacement
Cables	Still undetermined
Tube frames/housings	Extensive damage
Small water leak	4.2 tons/hr
Damage to detector structure	none

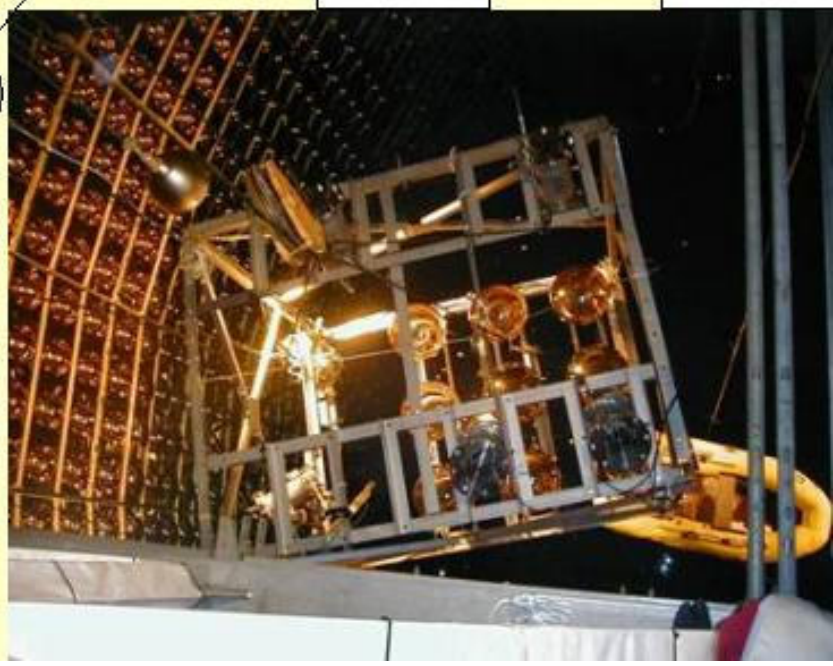
First Imploding PMTs



Implosion Tests







Observed pressure pulse at 0.45m from tube center is about 5.6 MPa.
Idealized simulation predicts about 13 MPa.

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Rebuilding Super-Kamiokande

- It takes several years to rebuild 20" PMTs
- Take existing 20" PMTs and redo ID with about 50% coverage in one year
- Design PMT enclosures to prevent chain reaction
- Rebuild OD with full coverage in one year
- Rebuild ID with full coverage in 4-5 years
- Old Super-K back in time for JHF turn-on

PMT Enclosure Designs

Acrylic (10 mm; front) and
Fiberglass (5mm; back) Design

All-Acrylic Design

Test at 30m Depth

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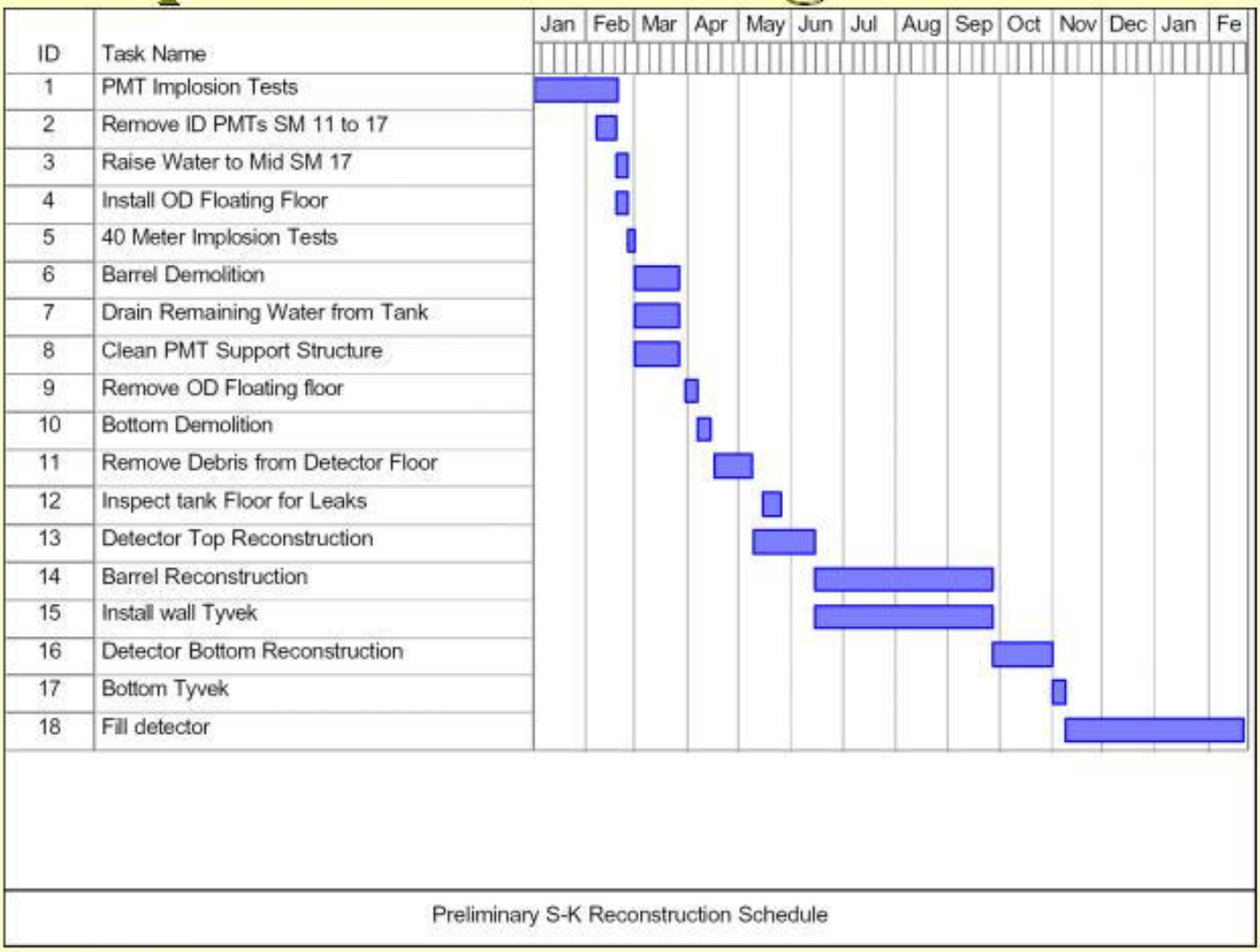
Super-K Rebuilding Schedule



ID	Task Name
1	PMT Implosion Tests
2	Remove ID PMTs SM 11 to 17
3	Raise Water to Mid SM 17
4	Install OD Floating Floor
5	40 Meter Implosion Tests
6	Barrel Demolition
7	Drain Remaining Water from Tank
8	Clean PMT Support Structure
9	Remove OD Floating floor
10	Bottom Demolition
11	Remove Debris from Detector Floor
12	Inspect tank Floor for Leaks
13	Detector Top Reconstruction
14	Barrel Reconstruction
15	Install wall Tyvek
16	Detector Bottom Reconstruction
17	Bottom Tyvek
18	Fill detector

Preliminary S-K Reconstruction Schedule

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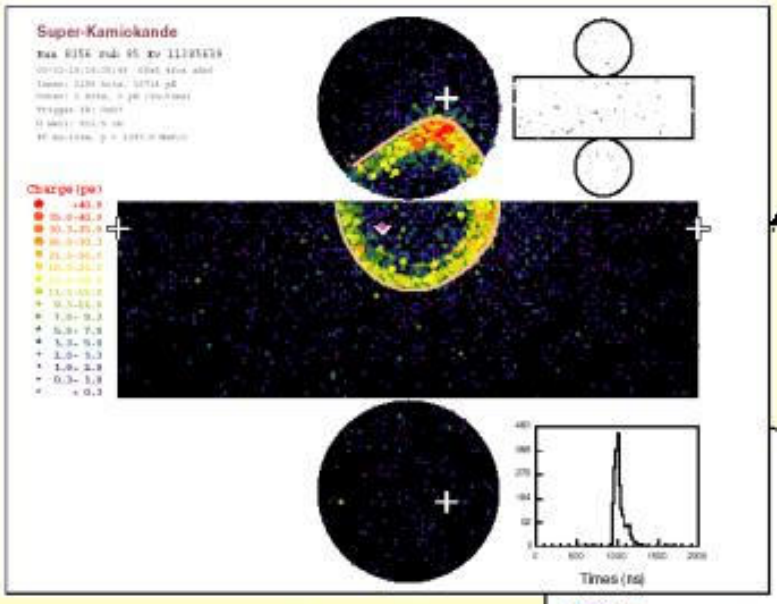
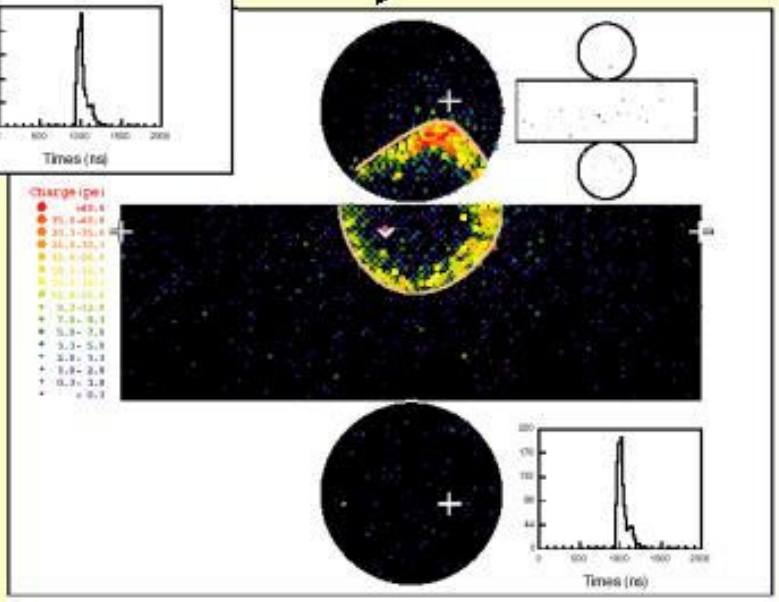
Real K2K Event



1.3 GeV Single Ring μ

As recorded

50% of PMTs masked



Momentum and angle from beam should be measurable with negligible loss of accuracy

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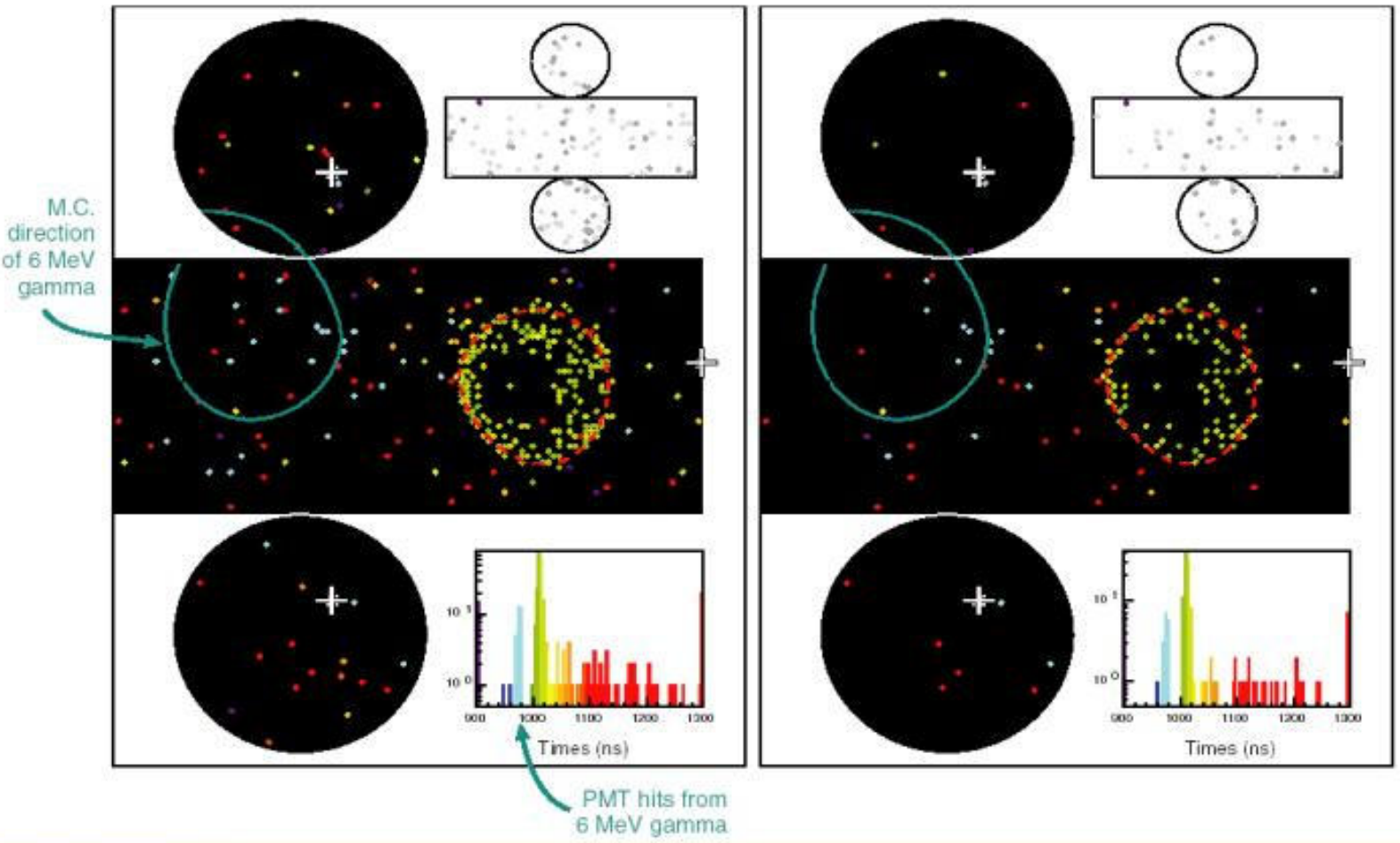
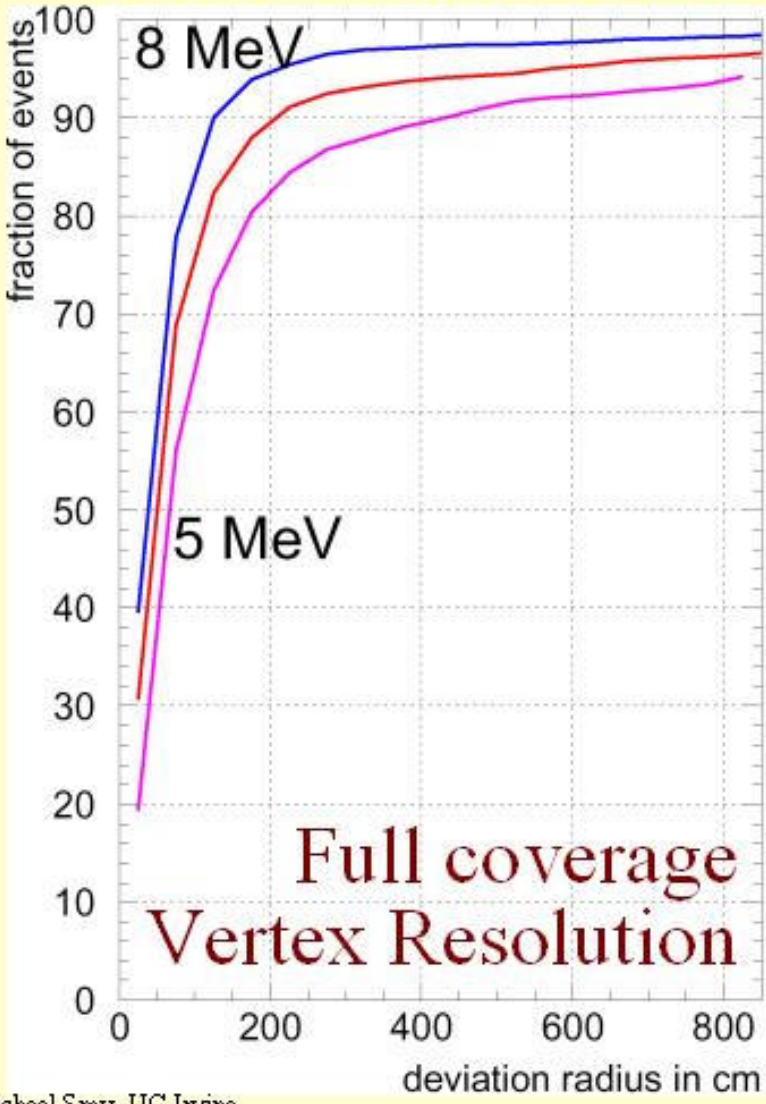
Proton Decay

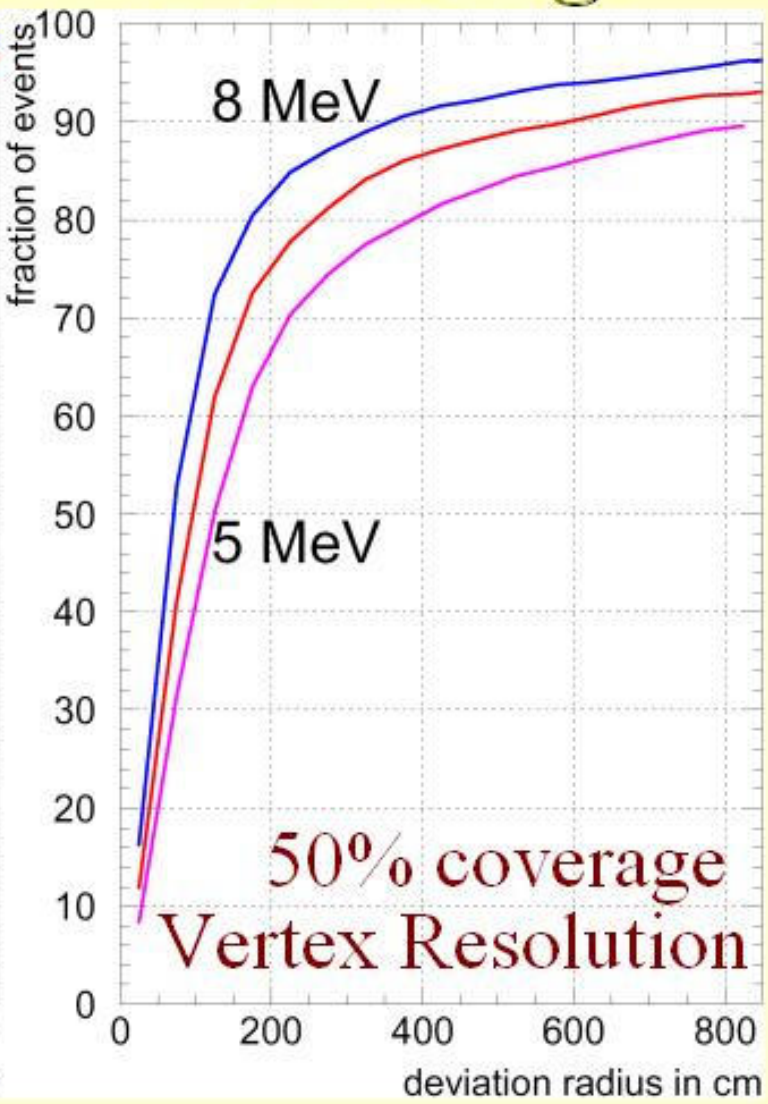
Proton Decay to $K^+ \nu$: $K^+ \rightarrow \mu\nu$ with prompt tag from $^{16}N^* \rightarrow {}^{16}N + \gamma$

8 or more hits in 12 ns sliding window preceding muon (K^+ is below Cherenkov threshold)



Threshold with 50% Coverage





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Further Impact of SK Solar Data

- Continue to watch the long-term time stability of ^{8}B flux
- Search for anomalous yearly variation to limit quasi-vacuum oscillation possibilities
- Improve high-energy spectrum shape precision to limit quasi-vacuum oscillation possibilities
- Improve day-night asymmetry precision at high energy and limit LMA oscillation possibilities
- Increase precision of high-energy flux (to test if large *hep* neutrino flux of LMA is really there)
- Increase the solar neutrino μ/τ appearance sample; do spectral analysis (with SNO)