Current Status of Solar Neutrinos at Super-Kamiokande

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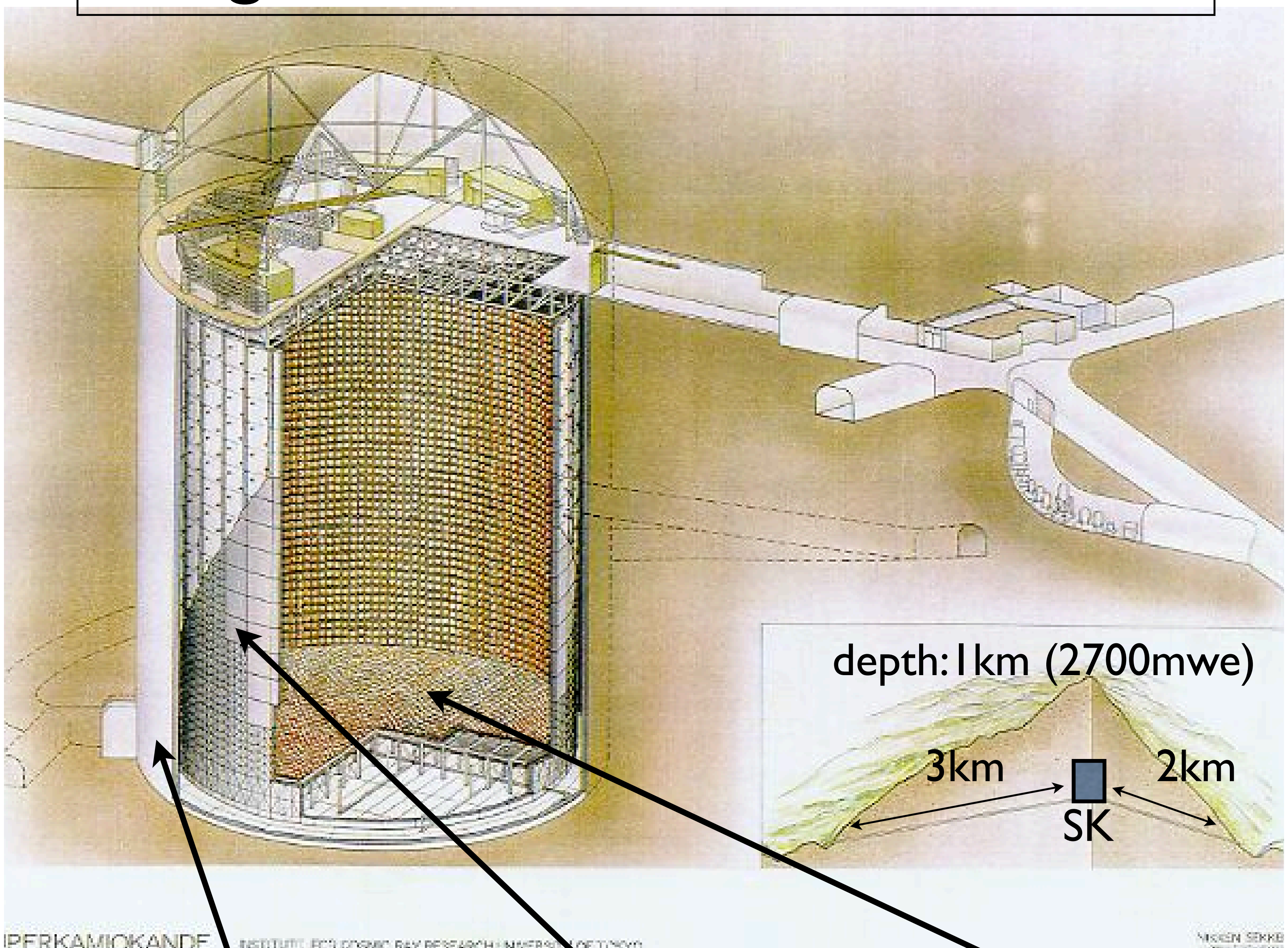
~130 collaborators
36 institutions
5 countries

The Super-Kamiokande Detector

Height: 41.4m Diameter: 39.3m



50,000 ton stainless steel tank

Outer Detector (OD) 1885 8in. PMTs

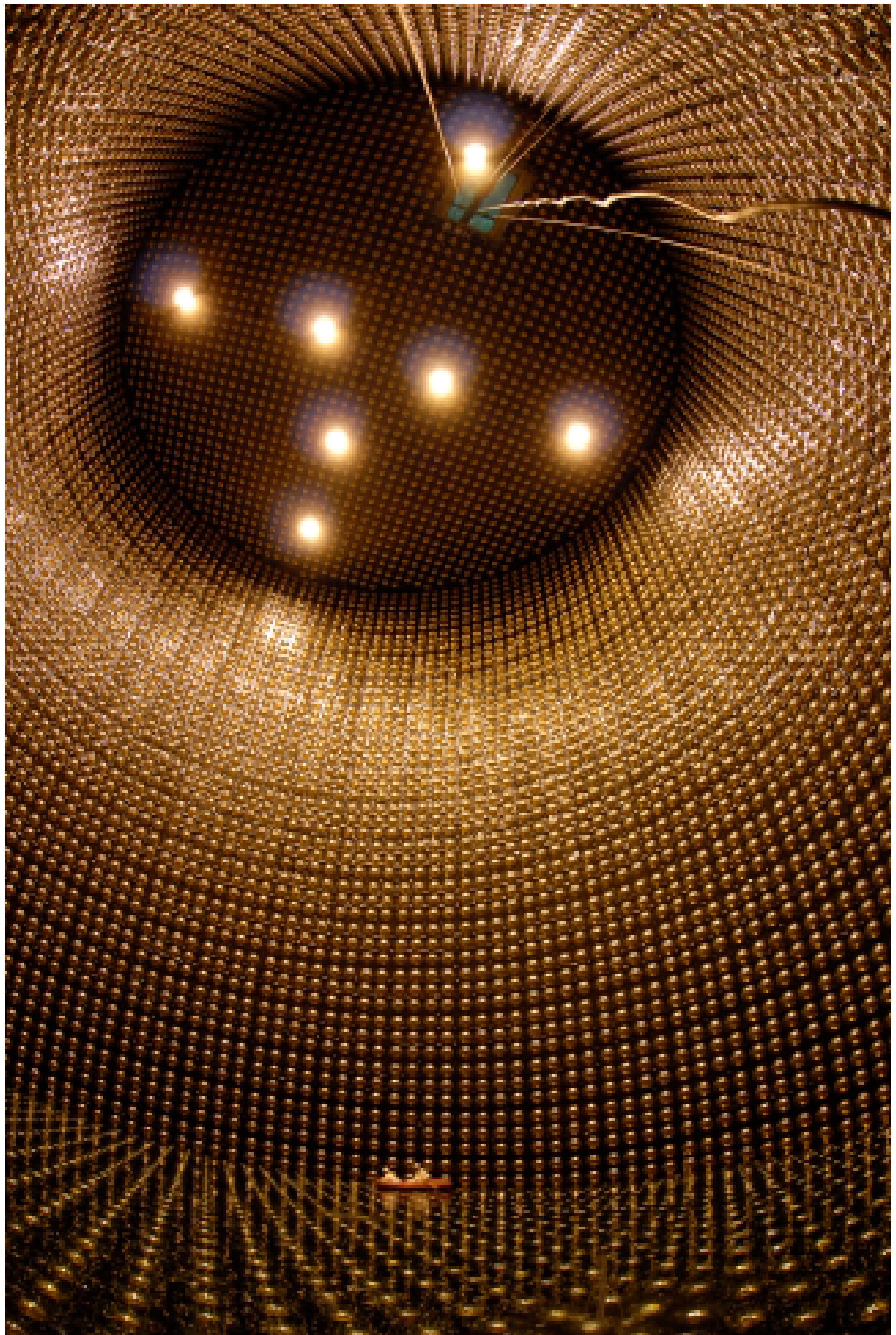
Inner Detector (ID) 11129 20in. PMTs

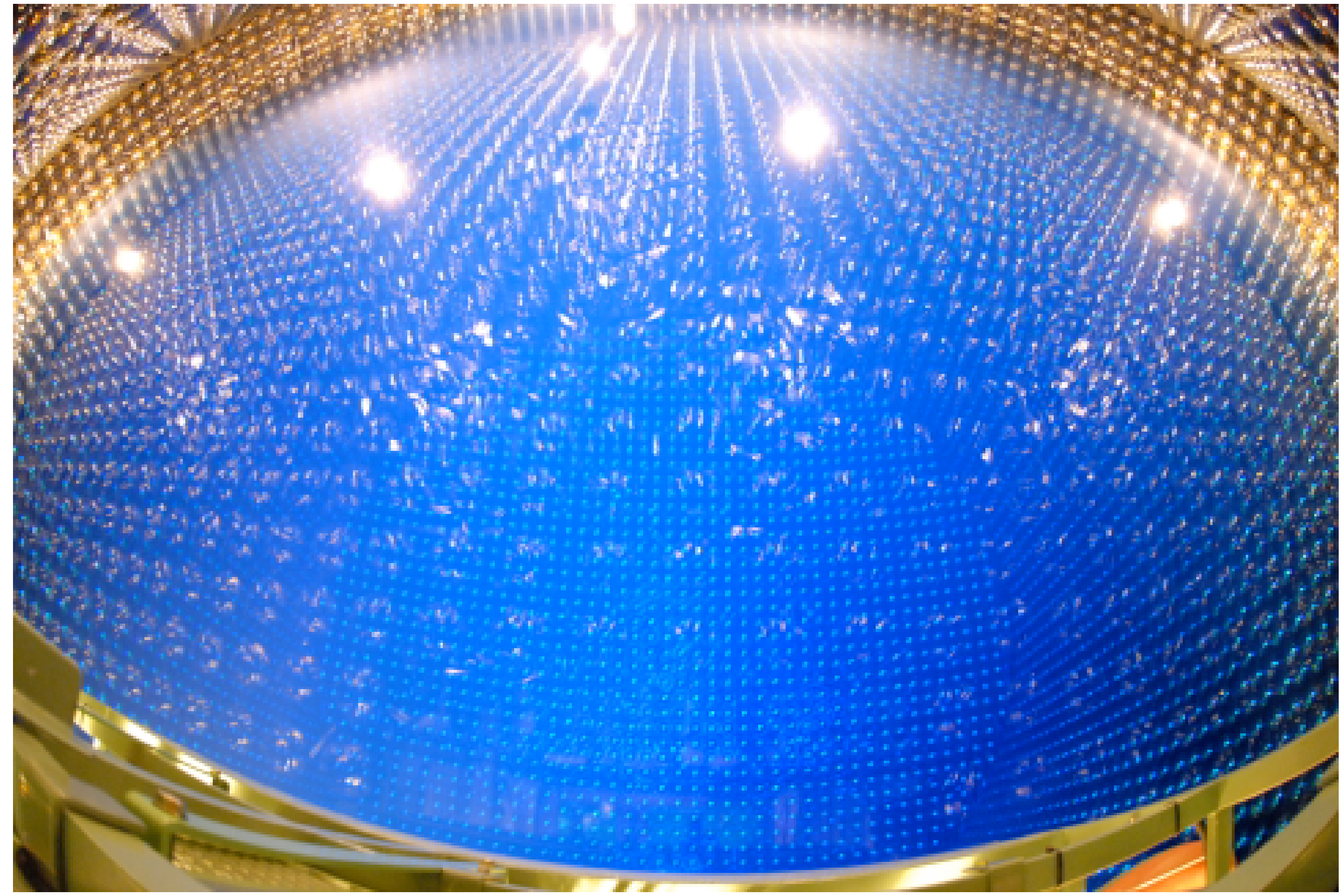
SK-I (1996~2001)
- 50000ton water
- ~11200 of 20inch PMTs
- Fid. vol. 22.5kt
- Photo coverage 40%
- Stopped by the accident in Nov. 2001

SK-II (2002~2005)
- ~5200 of 20inch PMTs
- Photo coverage 19%

SK-III (Jul. 2006~)
- 40% coverage
- OD Segmentation

The Super-Kamiokande Detector





April 12th, 2006

PMT mounting completed

July 11th

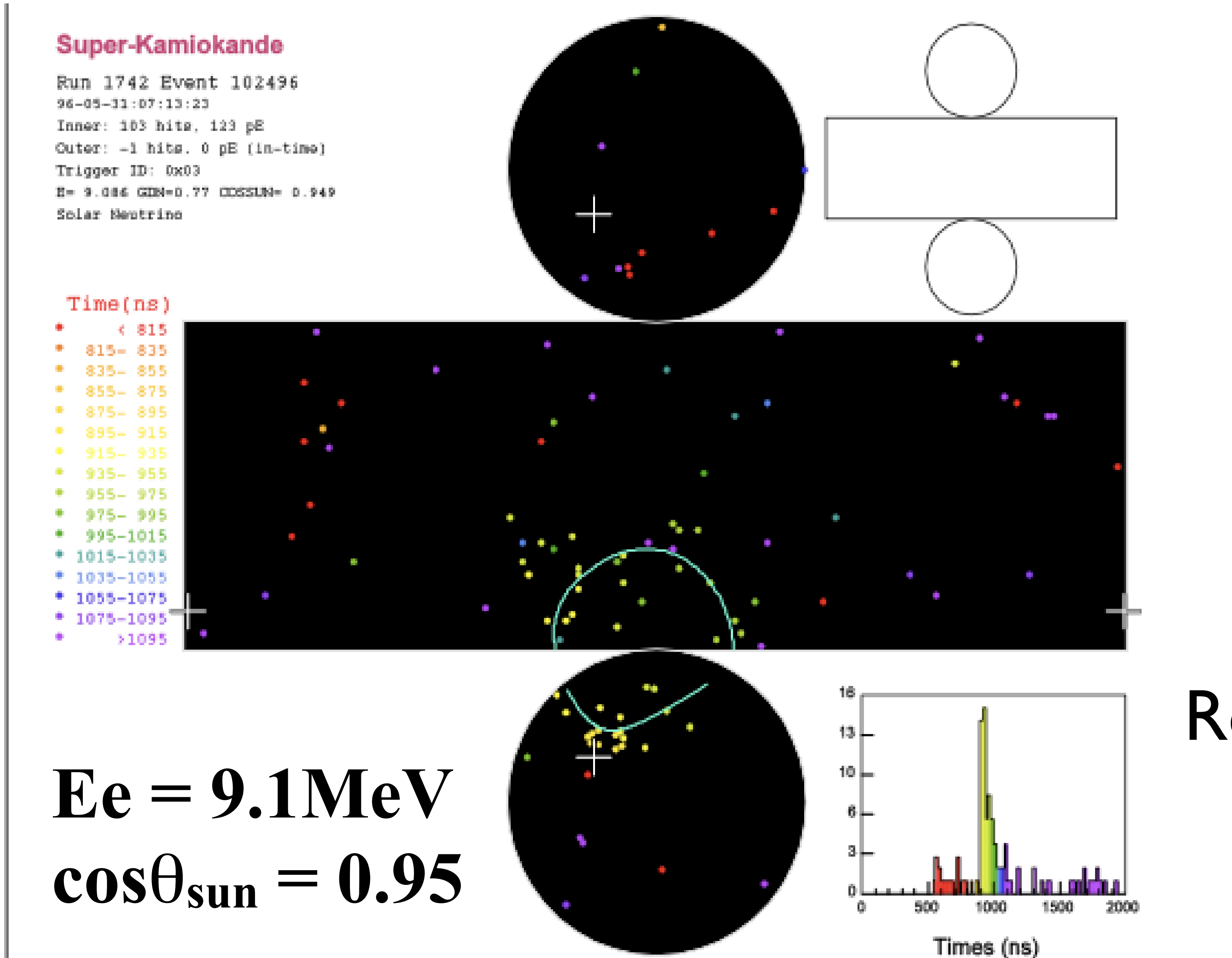
Tank filled

October 3rd

Water purification progessing

Solar Neutrinos at Super-K

Typical low energy event



Ee = 9.1MeV

$\cos\theta_{sun}$ = 0.95

$$\nu_x + e^- \longrightarrow \nu_x + e^-$$

$$\sigma(\nu_{\mu(\tau)}e^-) =\sim \mathbf{0.15} \times \sigma(\nu_e e^-)$$

Timing information
- Vertex position

Ring Pattern
- Direction

Number of hit PMTs
- Energy

Resolutions (for 10 MeV electron)

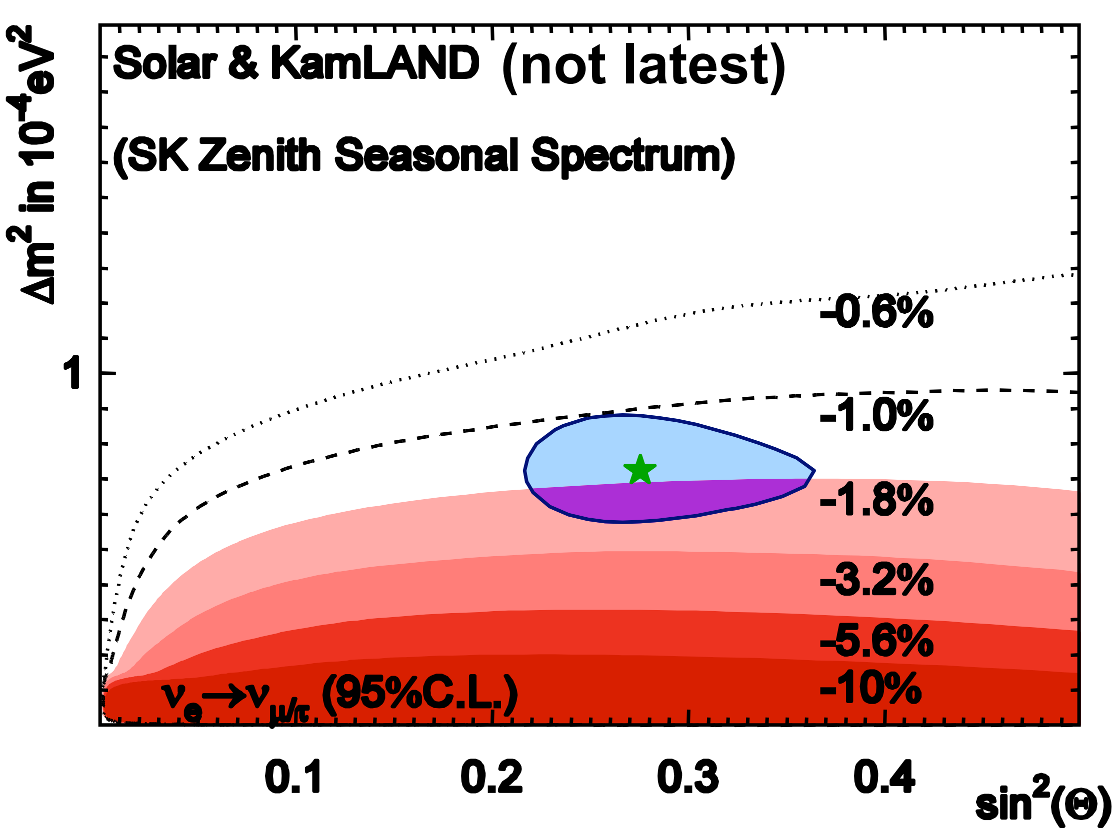
Energy: 14%

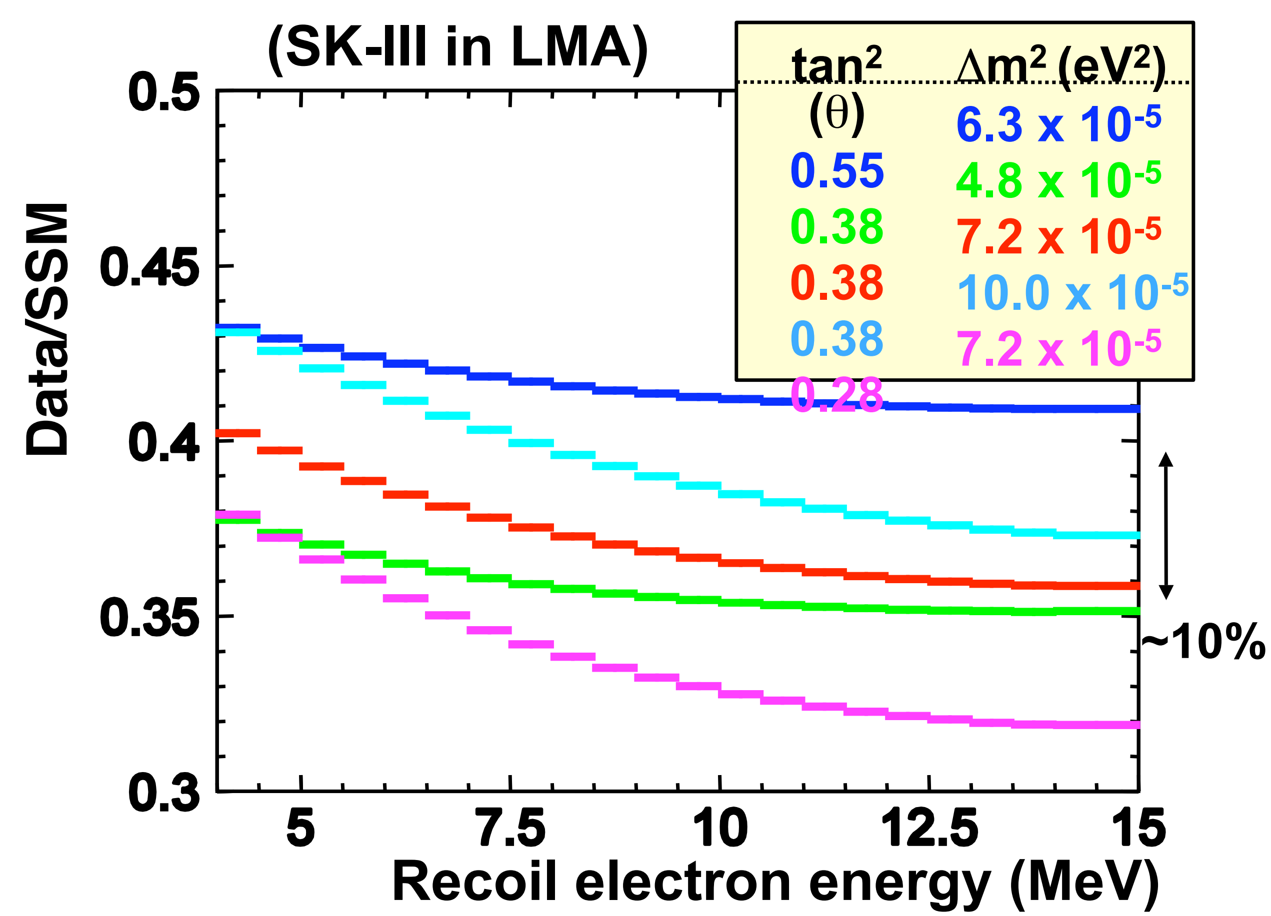
Vertex: 87 cm

Direction: 26 deg.

Solar Neutrinos at Super-K

- **High Statistics** ~15 events/day with Ee > 5 MeV (^{8}B & hep)
- **Time Variations** Day/Night, Seasonal
- **Energy Spectrum** Sensitive to ν oscillation parameters
- **Precise Energy Calibration** by electron LINAC
- **Flux Independent Analysis**





SK-II Latest Results

<u>Full SK-II run period</u>

Analysis periods & energy thresholds

Dec. 24th, 2002 - July 15th, 2003 (159 days)

8.0 - 20. MeV

July 15th, 2003 - Oct. 5th 2005 (631 days)

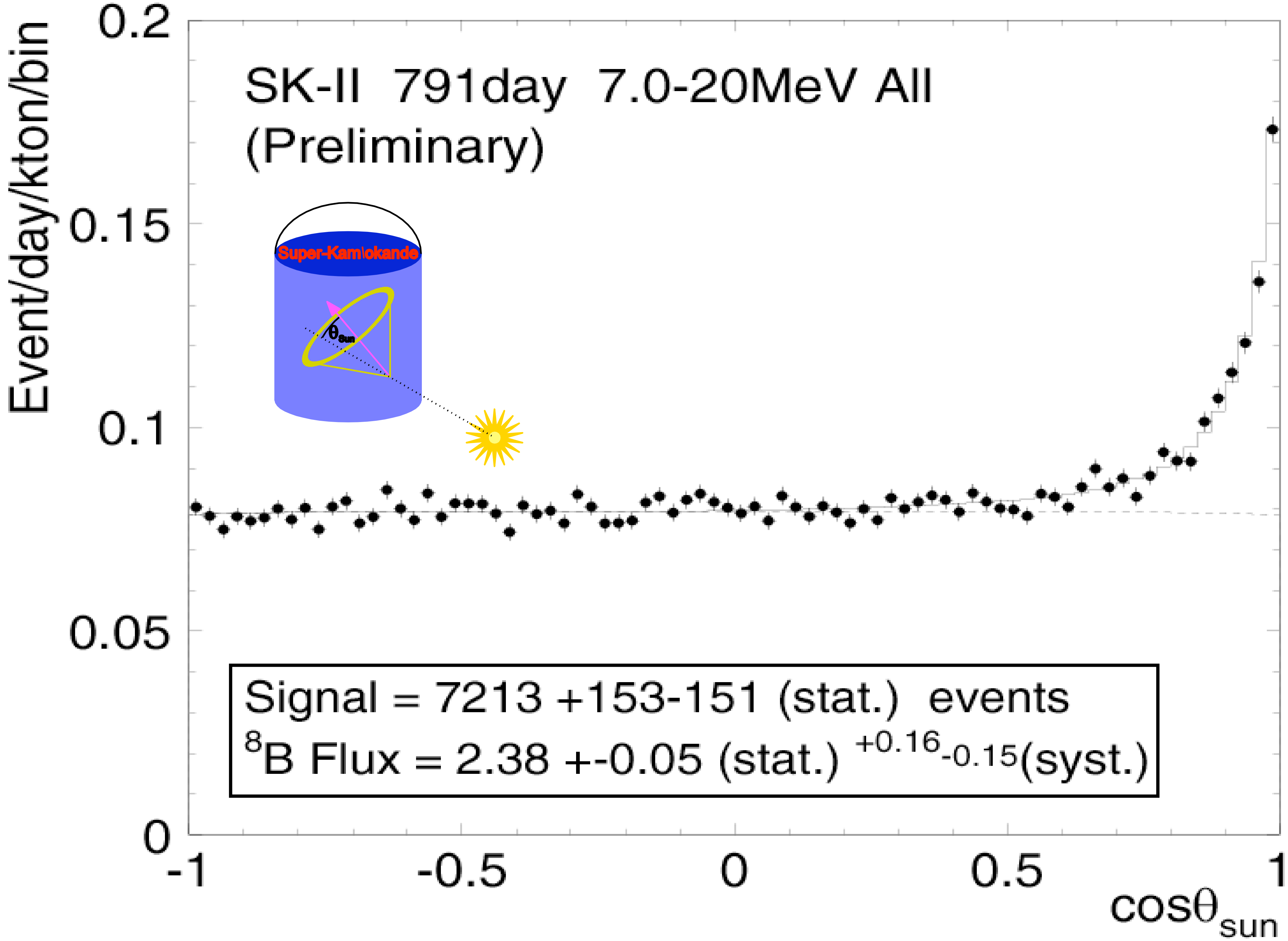
7.0 - 20.0 MeV for total flux

7.5 - 20.0 MeV for day/night

Total live time: 791 days

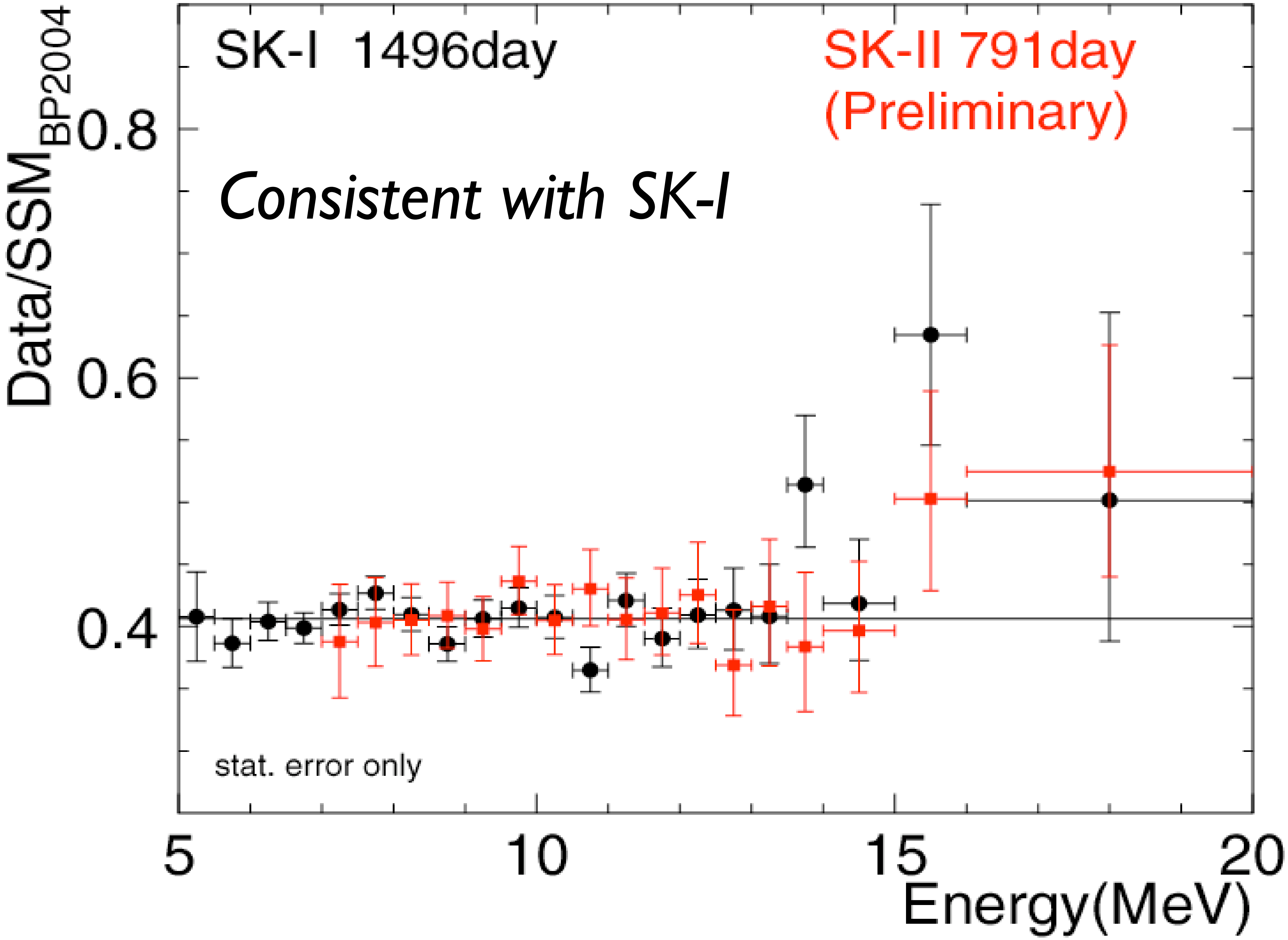
Systematic errors are under study

SK-II Flux

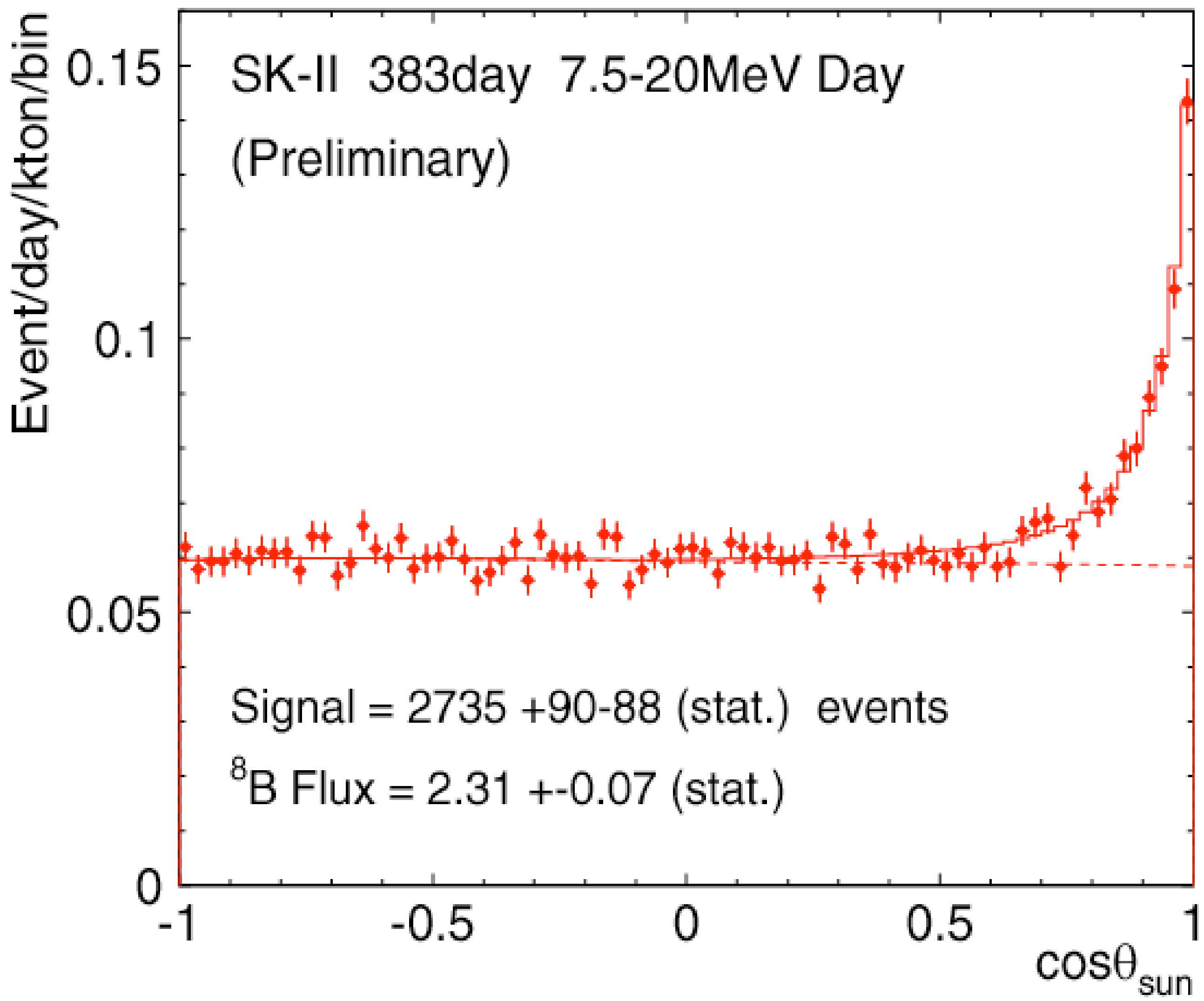


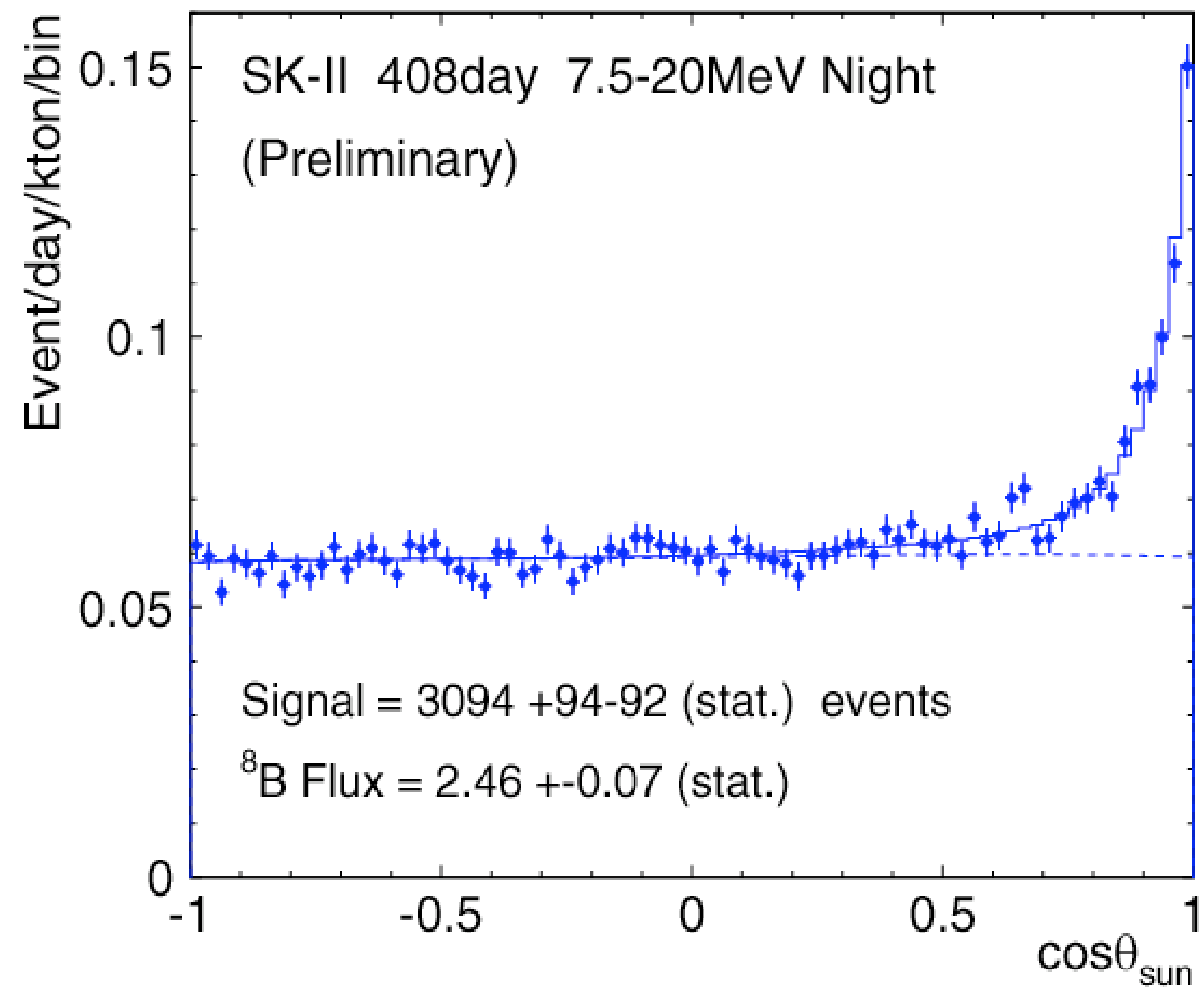
SK-I result: 2.35 +/-0.02(stat.) +/-0.08(syst.)

SK-II Energy Spectrum



Day/Night



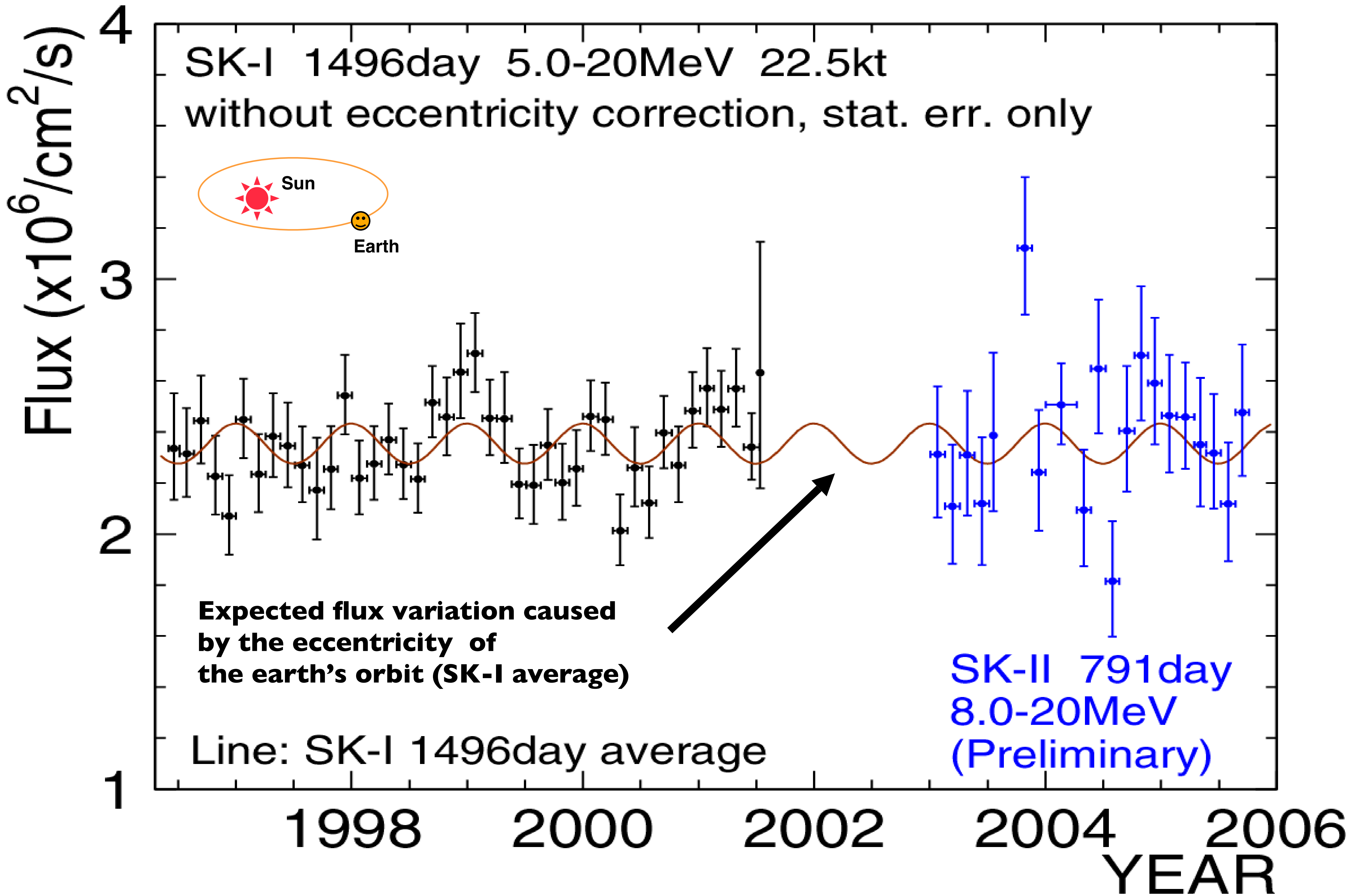


$$\frac{\text{(Day-Night)}}{\text{(Day+Night)/2}} = -0.064 +/- 0.043\text{(stat.)}$$ **Preliminary**

(systematic errors are under study)

SK-I D/N Asymmetry: $-0.021 +/- 0.020^{+0.013}_{-0.012}$

Time Variation



SK Oscillation Analysis

$$\chi^2_{SK}(\beta, \eta, \delta_B, \delta_{SK1,S}, \delta_{SK1,R}, \delta_{SK2,S}, \delta_{SK2,R})$$

$$= \sum_{i=1}^{21} \frac{(d_{SK1,i} - (\beta_m b_{SK1,i} + \eta_m h_{SK1,i}) f(E_i, \delta_B, \delta_{SK1,S}, \delta_{SK1,R}))^2}{\sigma^2_{SK1,i}}$$

$$+ \sum_{i=1}^{17} \frac{(d_{SK2,i} - (\beta_m b_{SK2,i} + \eta_m h_{SK2,i}) f(E_i, \delta_B, \delta_{SK1,S}, \delta_{SK1,R}))^2}{\sigma^2_{SK2,i}}$$

$$+ \left(\frac{\delta_B}{\sigma_B}\right)^2 + \left(\frac{\delta_{SK1,S}}{\sigma_{SK1,S}}\right)^2 + \left(\frac{\delta_{SK1,R}}{\sigma_{SK1,R}}\right)^2 + \left(\frac{\delta_{SK2,S}}{\sigma_{SK2,S}}\right)^2 + \left(\frac{\delta_{SK2,R}}{\sigma_{SK2,R}}\right)^2$$

$$+ 2\Delta \log(\mathscr{L})$$

$$\boxed{\mathrm{d_i} = \frac{\mathrm{Data}_i}{{}^8\mathrm{B}_i^{\mathrm{SSM}} + hep_i^{\mathrm{SSM}}}, \quad b_i = \frac{{}^8\mathrm{B}_i^{\mathrm{osc}}\left(\Delta m^2, \tan^2\theta\right)}{{}^8\mathrm{B}_i^{\mathrm{SSM}} + hep_i^{\mathrm{SSM}}}, \quad h_i = \frac{hep_i^{\mathrm{osc}}\left(\Delta m^2, \tan^2\theta\right)}{{}^8\mathrm{B}_i^{\mathrm{SSM}} + hep_i^{\mathrm{SSM}}}}$$

SK Oscillation Analysis

$$\chi^2_{SK}(\beta, \eta, \underbrace{\delta_B, \delta_{SK1,S}, \delta_{SK1,R}, \delta_{SK2,S}, \delta_{SK2,R}}_{\text{energy correlated systematic error}})$$

flux factors

energy correlated systematic error

$$= \sum_{i=1}^{21} \frac{(d_{SK1,i} - (\beta_m b_{SK1,i} + \eta_m h_{SK1,i}) f(E_i, \delta_B, \delta_{SK1,S}, \delta_{SK1,R}))^2}{\sigma^2_{SK1,i}}$$

SK-I energy spectrum

$$+ \sum_{i=1}^{17} \frac{(d_{SK2,i} - (\beta_m b_{SK2,i} + \eta_m h_{SK2,i}) f(E_i, \delta_B, \delta_{SK1,S}, \delta_{SK1,R}))^2}{\sigma^2_{SK2,i}}$$

SK-II energy spectrum

$$+ \left(\frac{\delta_B}{\sigma_B}\right)^2 + \left(\frac{\delta_{SK1,S}}{\sigma_{SK1,S}}\right)^2 + \left(\frac{\delta_{SK1,R}}{\sigma_{SK1,R}}\right)^2 + \left(\frac{\delta_{SK2,S}}{\sigma_{SK2,S}}\right)^2 + \left(\frac{\delta_{SK2,R}}{\sigma_{SK2,R}}\right)^2$$

$$+ 2\Delta \log(\mathscr{L})$$

time variation

predicted oscillated spectrum

$$\boxed{d_i = \frac{\text{Data}_i}{{}^8\text{B}_i^{\text{SSM}} + hep_i^{\text{SSM}}}, \quad b_i = \frac{{}^8\text{B}_i^{\text{osc}}\left(\Delta m^2, \tan^2\theta\right)}{{}^8\text{B}_i^{\text{SSM}} + hep_i^{\text{SSM}}}, \quad h_i = \frac{hep_i^{\text{osc}}\left(\Delta m^2, \tan^2\theta\right)}{{}^8\text{B}_i^{\text{SSM}} + hep_i^{\text{SSM}}}}$$

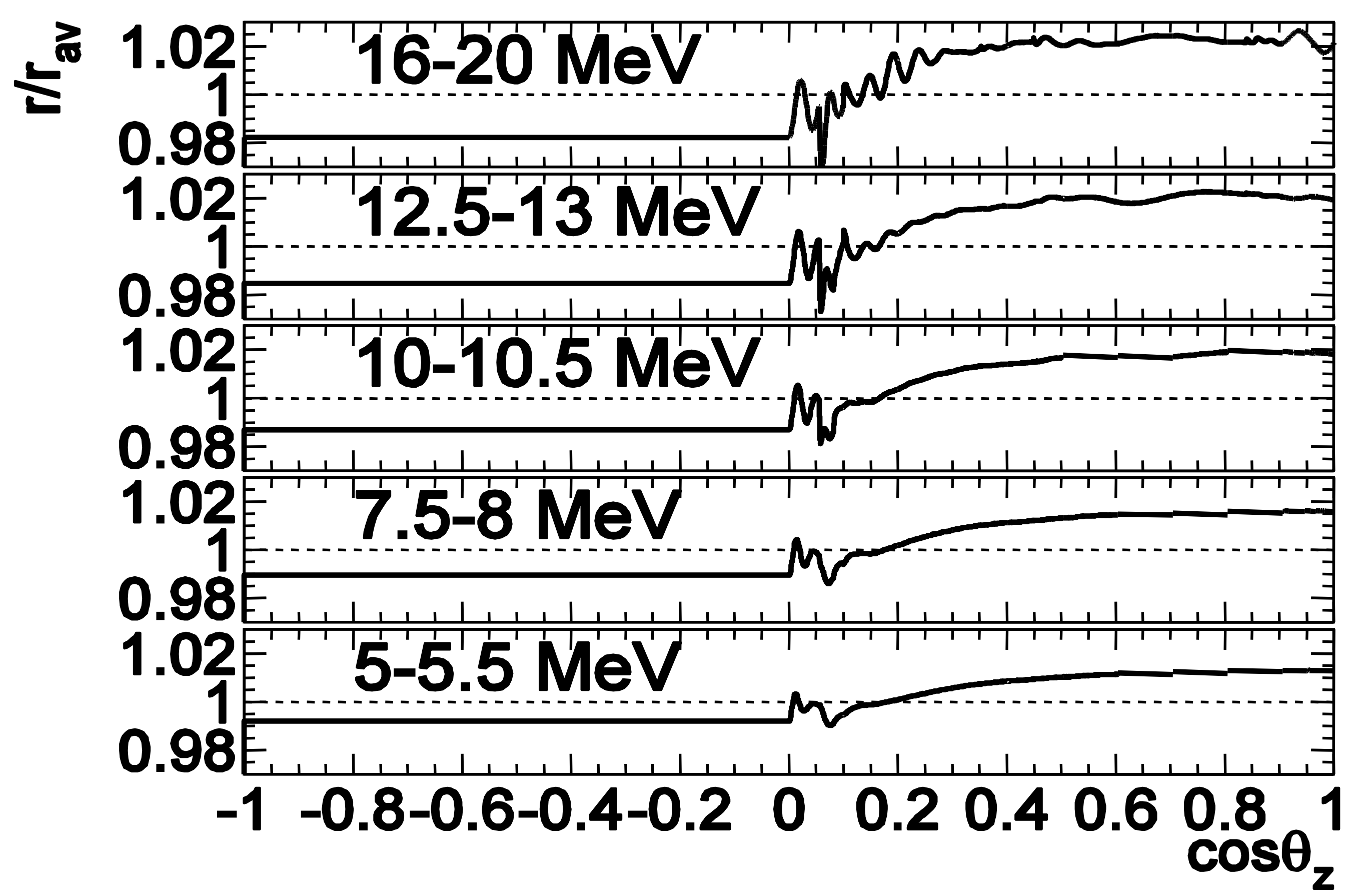
unoscillated spectrum

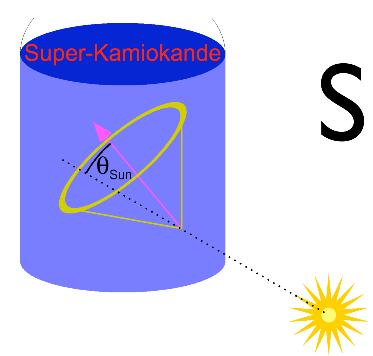
Unbinned Time Variation

$$2\Delta\log(\mathscr{L})$$

$$\mathscr{L} = e^{-(\Sigma_i B_i + S)} \prod_{i=1}^{N_{bin}} \prod_{j=1}^{n_i} (B_i \cdot b_{ij} + S \cdot Y_i \cdot p(\cos\theta_{ij}, E_j) \cdot z_i(t_j))$$

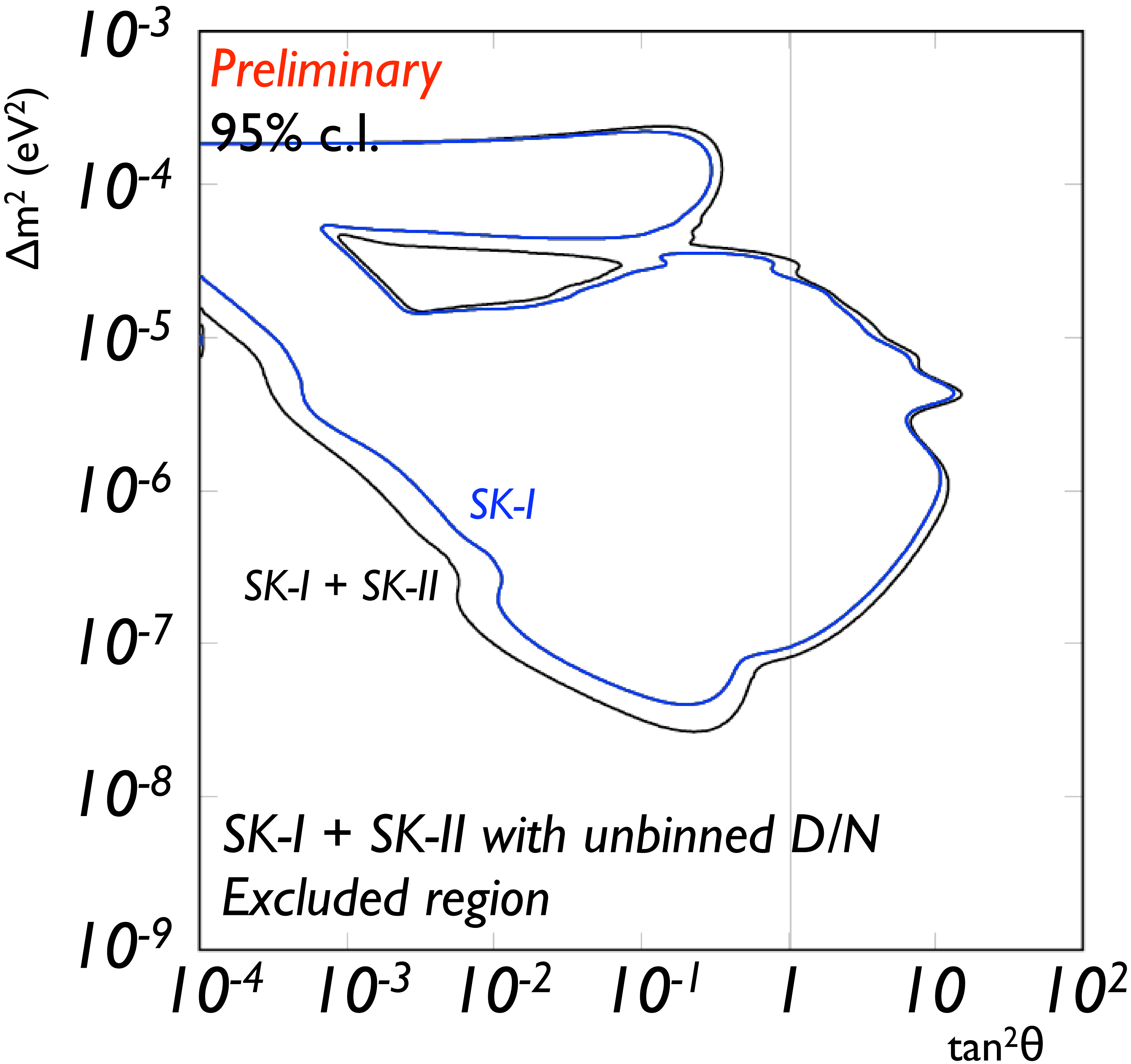
Predicted solar zenith angle variations (Δm^2=6.3x10^{-5} eV^2, $\tan^2\theta$=0.55)





SK zenith angle $\cos\theta_{ij}$ of the jth event in the ith *E* bin

SK-I, SK-II Oscillation Analysis



^{8}B, hep free fit

Common:
- ^{8}B flux scale
- Hep flux scale
- ^{8}B shape error

SK-I only:
- Energy resolution
- Energy scale

SK-II only:
- Energy resolution
- Energy scale

SK-I, SK-II Global Analysis

$$\chi^2_{global}(\beta,\eta) = \chi^2_{SK}(\beta,\eta) + \chi^2_{SNO}(\beta,\eta) + \frac{(ADN_{CC} - ADN_{pred})^2}{\sigma^2_{ADN_{CC}}} + \chi^2_{radiochem}(\beta,\eta)$$

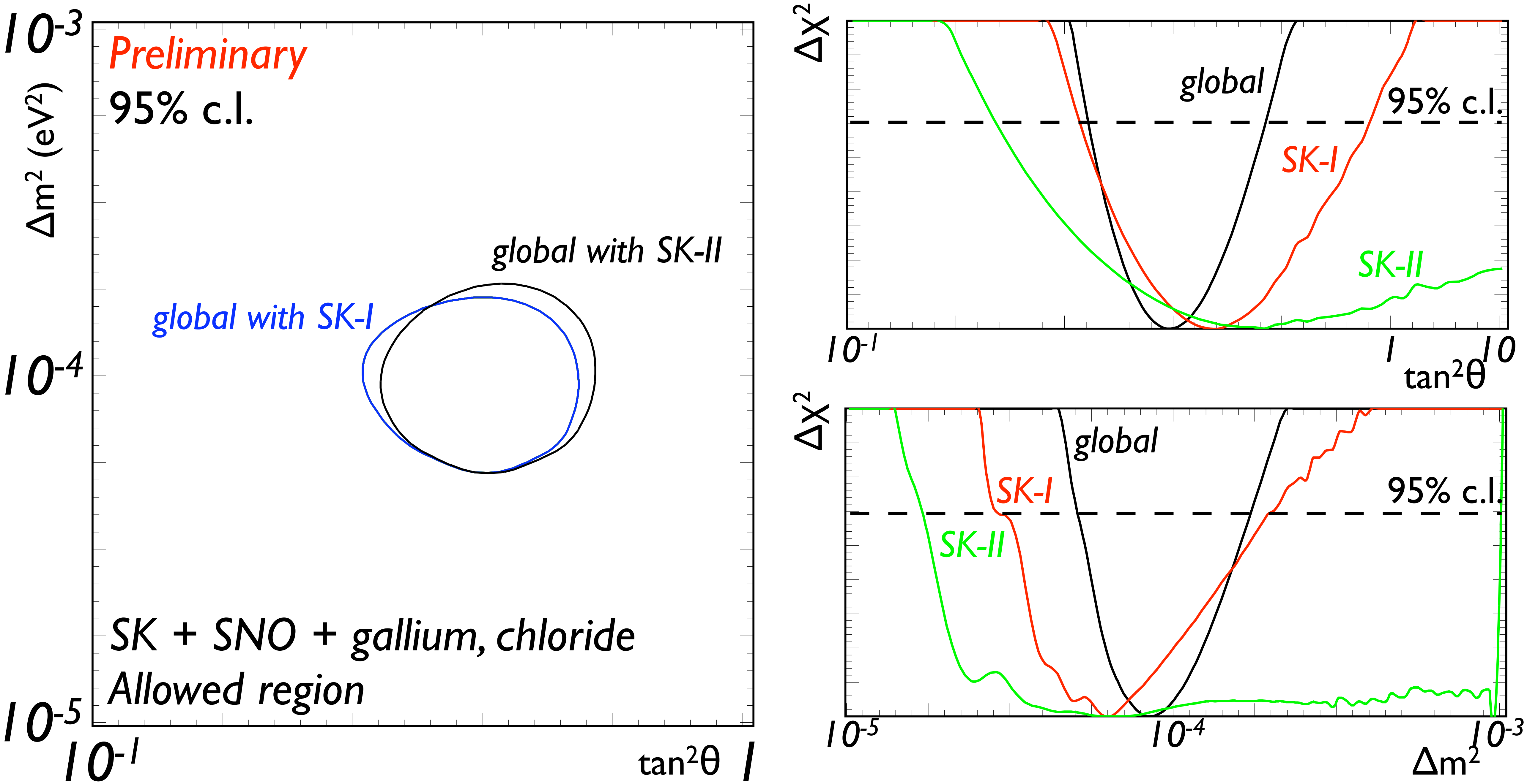
SNO data:

Absolute flux fit (spectrum information summed)

Fluxes from 371-day Salt Phase (CC & NC)

ADN from 306-day pure $D_2 0$ Phase with NC=0

SK-I, SK-II Global Analysis



SK-I, SK-II global fit: $\Delta m^2 = 8.71\times10^{-5}$ (eV^2)

$\tan^2\theta = 0.38$

Future Plan In SK-III

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

SK-I SK-II SK-III

Water filling was finished on July 11th, 2006

Now, detector calibration is taking place

ID PMT:

SK-II = ~5,200

SK-III = 11,129

Original energy & vertex resolutions for low-energy events is restored

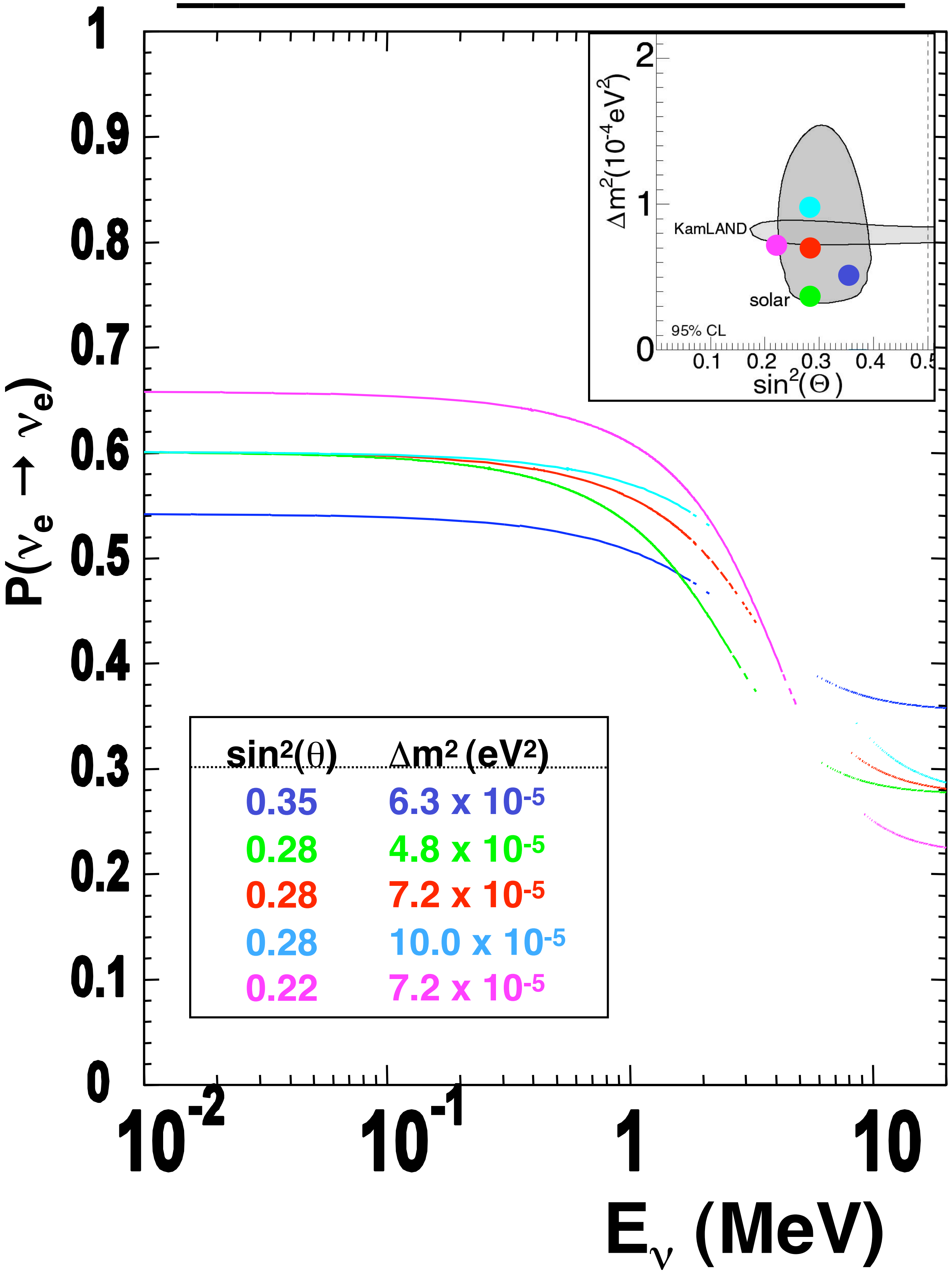
Goals

Solar neutrinos below 5.0 MeV with improved analysis tools and lower Rn background

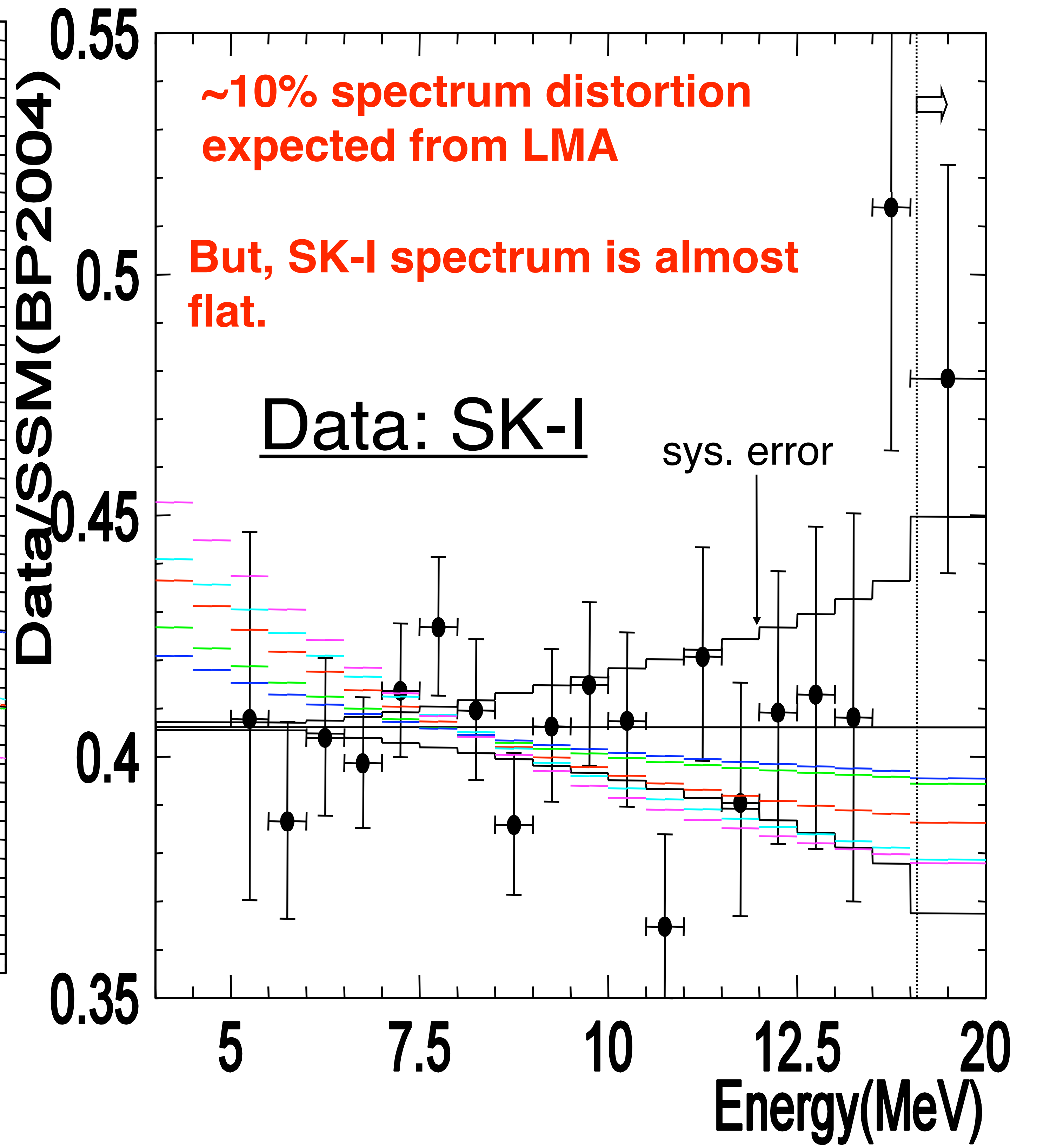
Precise study on spectrum distortion

Energy Spectrum Distortion

ν_e survival probability

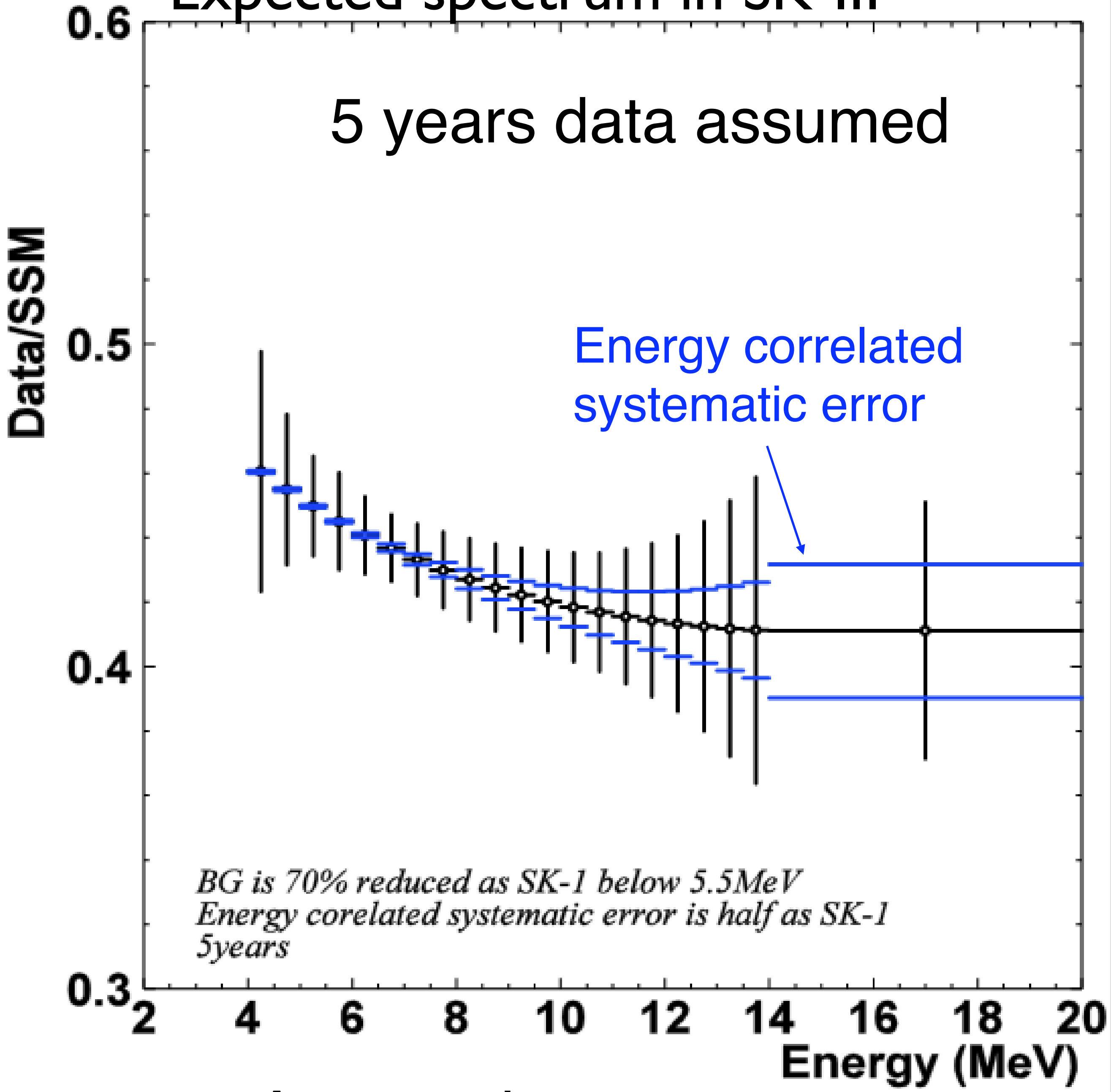


Recoil electron spectrum

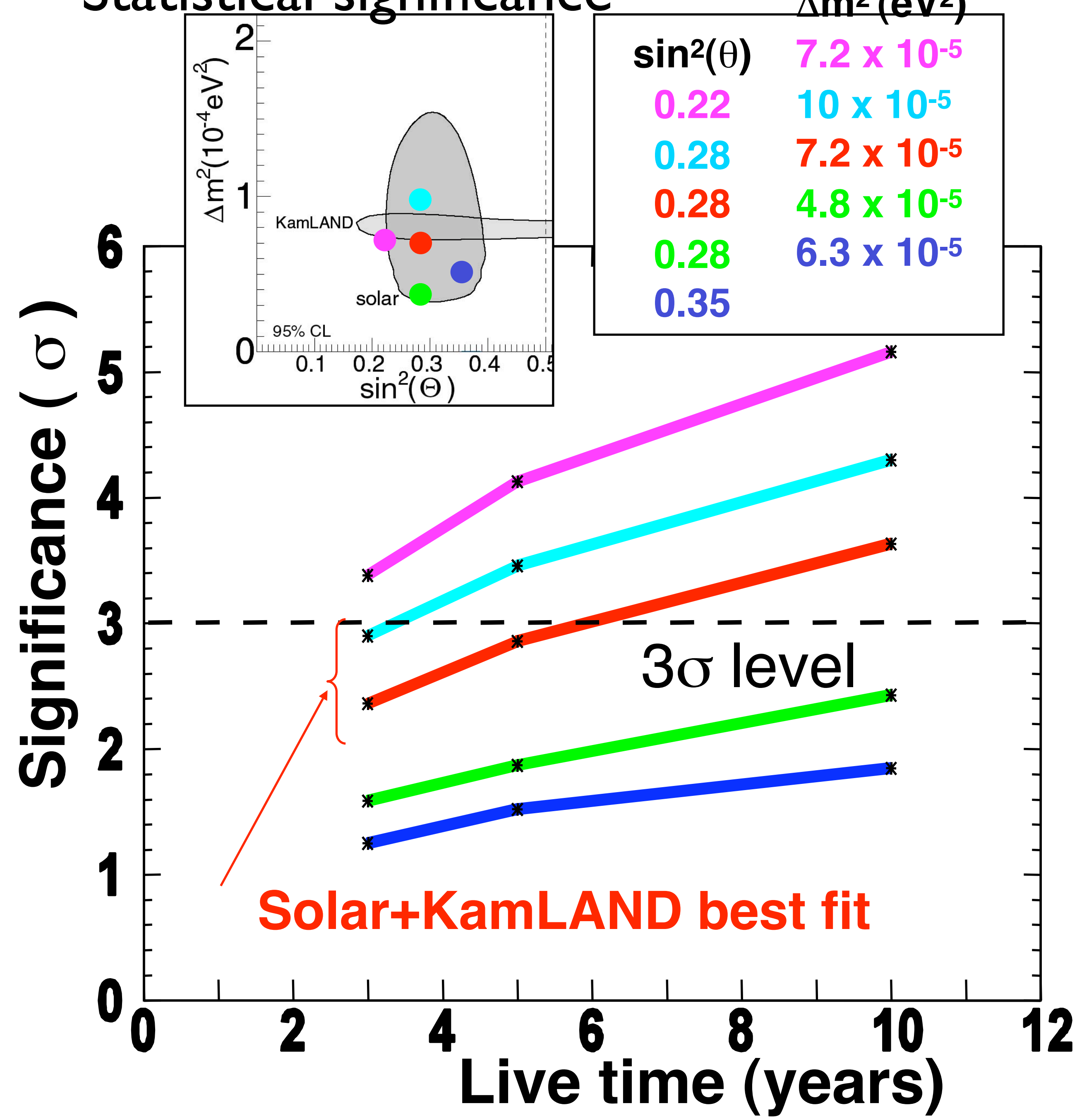


Energy Spectrum Distortion

Expected spectrum in SK-III



Statistical significance



<u>Assumption:</u>

Correlated systematic error: x 0.5

4.0-5.5MeV background : x 0.3 of SK-I

(> 5.5MeV is same as SK-I)

Summary

- SK-III has been started and is taking data
- SK-II data has been updated to its final 791d
- Oscillation analysis with SK-I, SK-II data has been performed and shows consistency with final SK-I data set
- SK-II shows consistency within the global analysis
- Hope to see energy spectrum distortion in SK-III

thank you