Solar Neutrino Results from Super-Kamiokande

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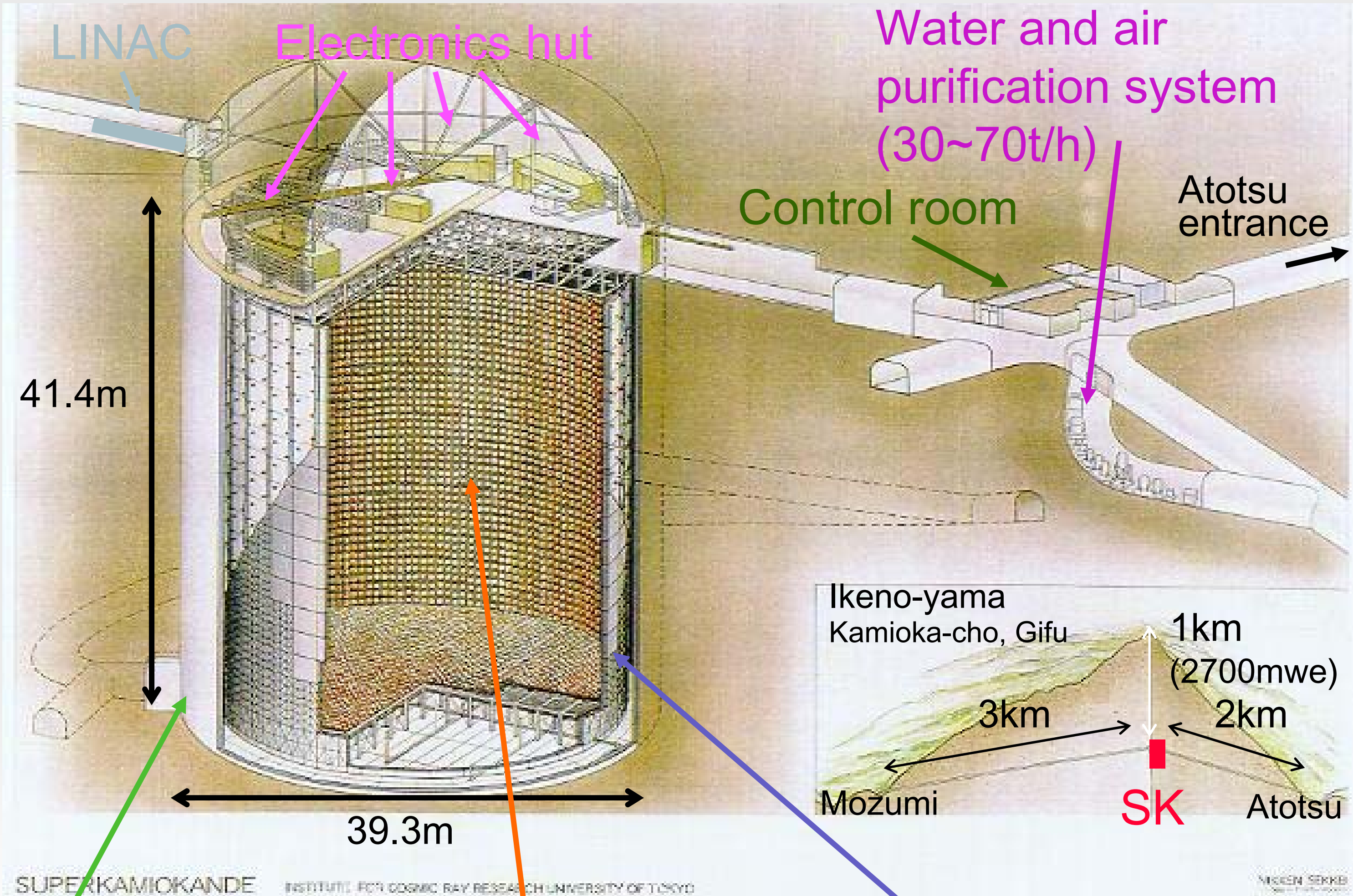
- Super-Kamiokande-I detector
- Solar neutrino results from SK-I
- Accident & reconstruction
- Prospects for SK-II
- Summary

Super-Kamiokande-I



50 kton
stainless steel tank

Inner Detector (ID)
11146 of 20 inch PMTs

Outer Detector (OD)
1867 of 8 inch PMTs

- Apr 1996 ~ Jul 2001
- fid. vol. 22.5kt
- photo coverage 40%
- $\nu + e^- \rightarrow \nu + e^-$
- resolution(10MeV e)
  - Energy: 14%
  - Vertex: 87cm
  - Direction: 26^o
- ~60% of PMTs are destroyed on Nov. 12, 2001

SK-I: Solar neutrino flux

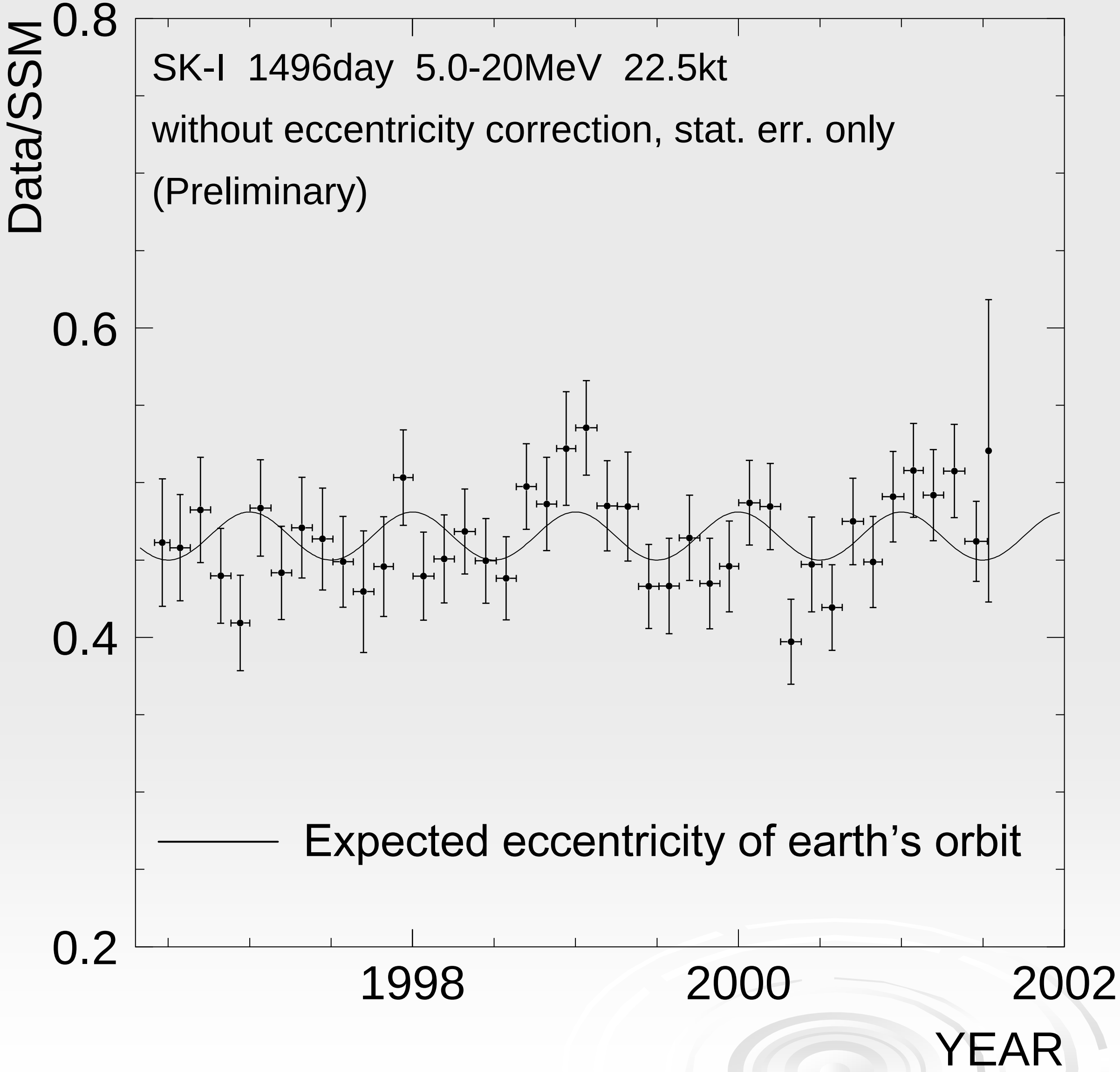
(preliminary)

- Observation period: May 31,1996 ~ July 15, 2001
- Live time: 1496days
- Analysis energy range: 5.0~20MeV
- Fiducial volume 22.5kt

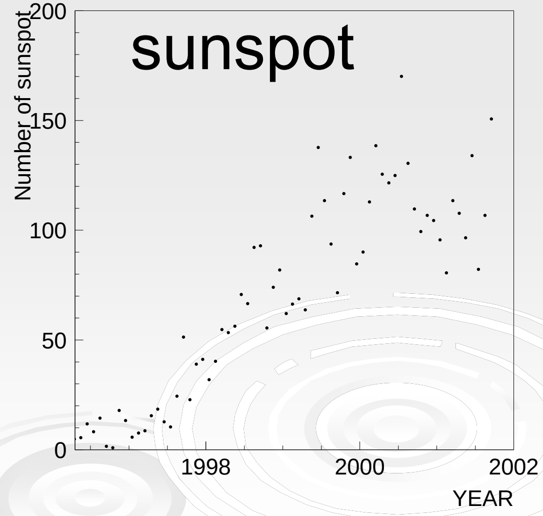
- Signal (at 1AU) = 22404 +-226(stat.) +784-717(sys.) events
- Expected = 48173 events
- Data/SSM_{BP2001} = 0.465 +-0.005(stat.) +0.016-0.015(sys.)
- Flux = 2.35 +-0.02(stat.) +-0.08(sys.) ($x10^6/cm^2/s$)

SK-I: Time variation1 (1.5month)

(preliminary)

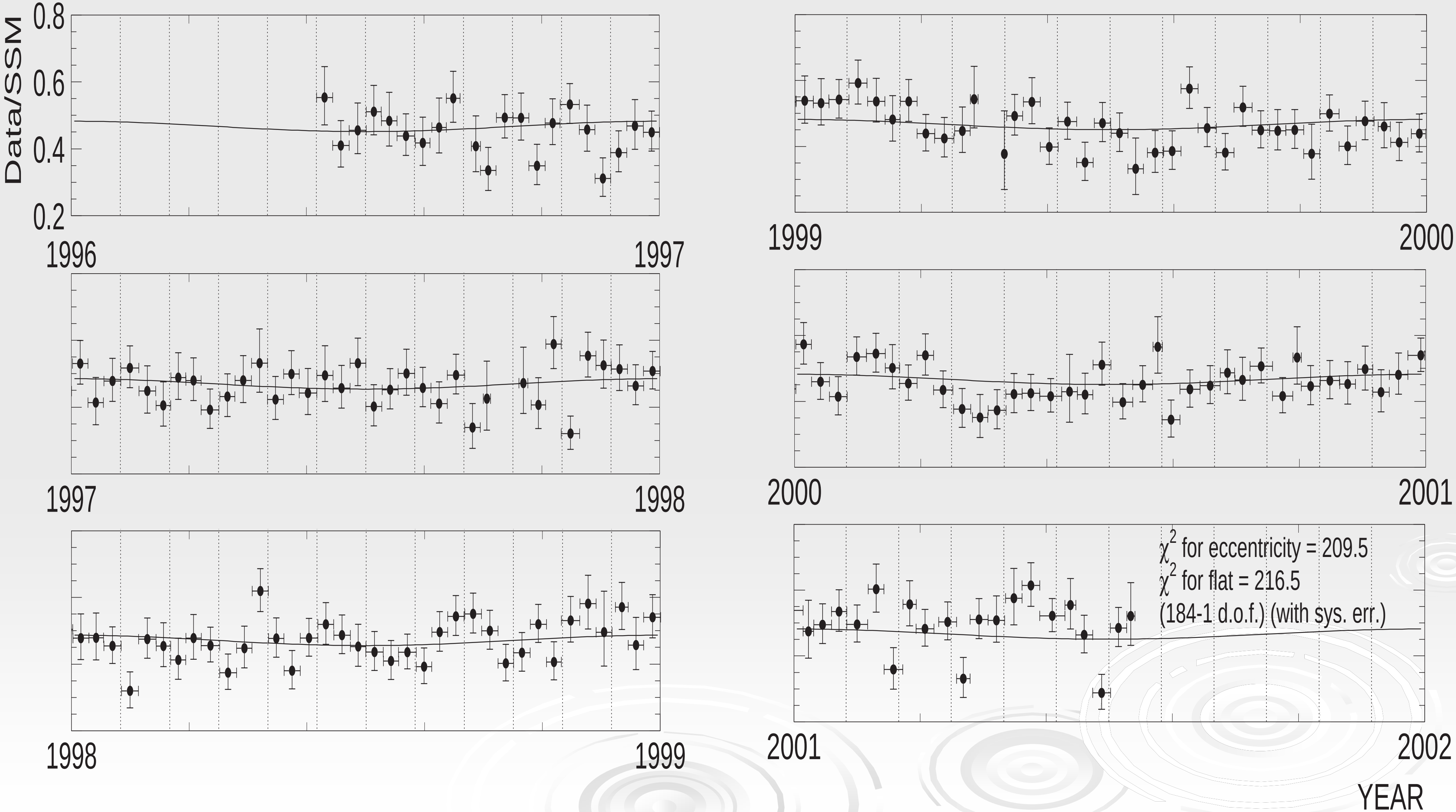


χ^2 for eccentricity 34.8
χ^2 for flat 40.1
(41d.o.f., with sys. err.)



SK-I: Time variation2 (10day)

(preliminary)



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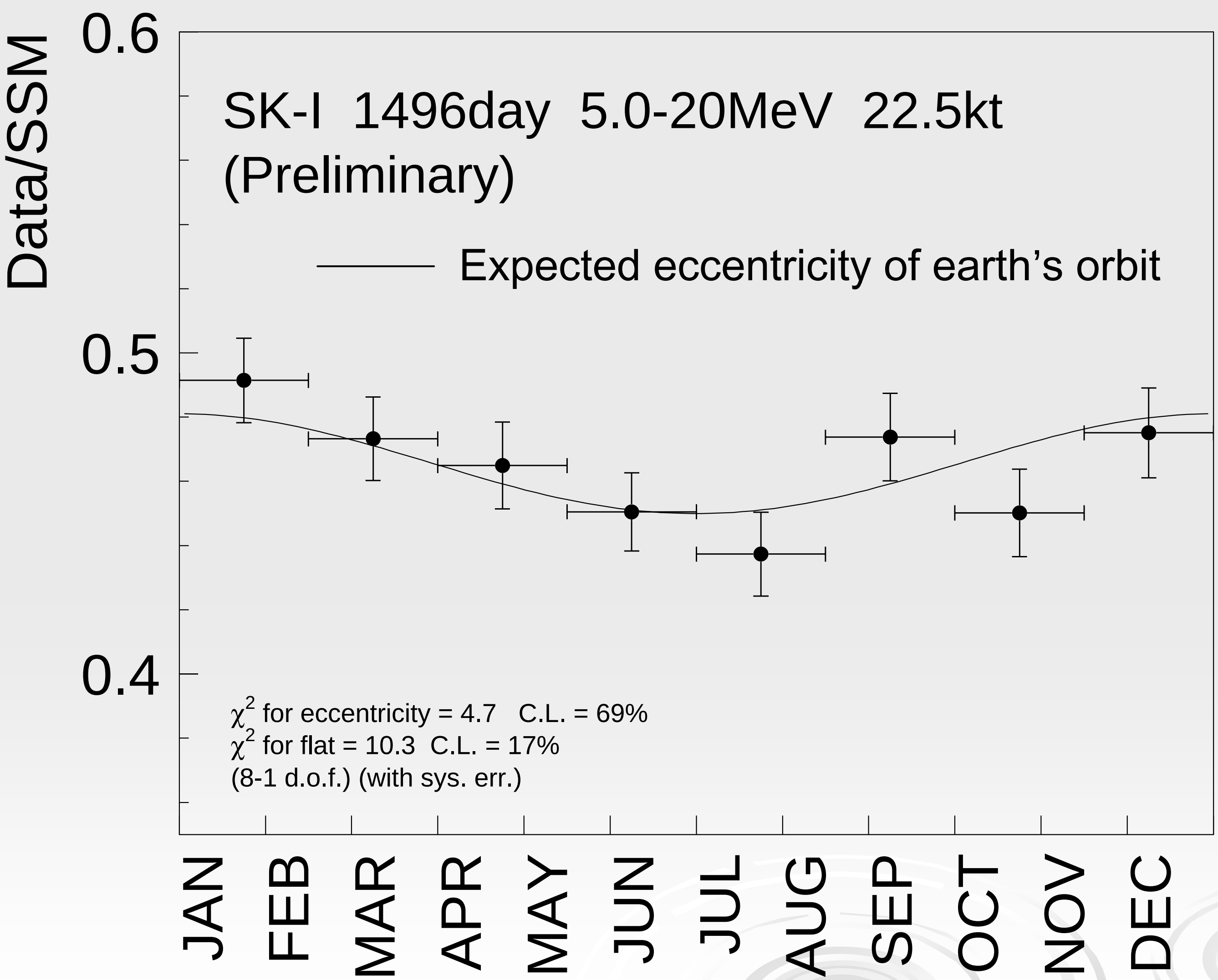
SK-I: Seasonal variation

(preliminary)



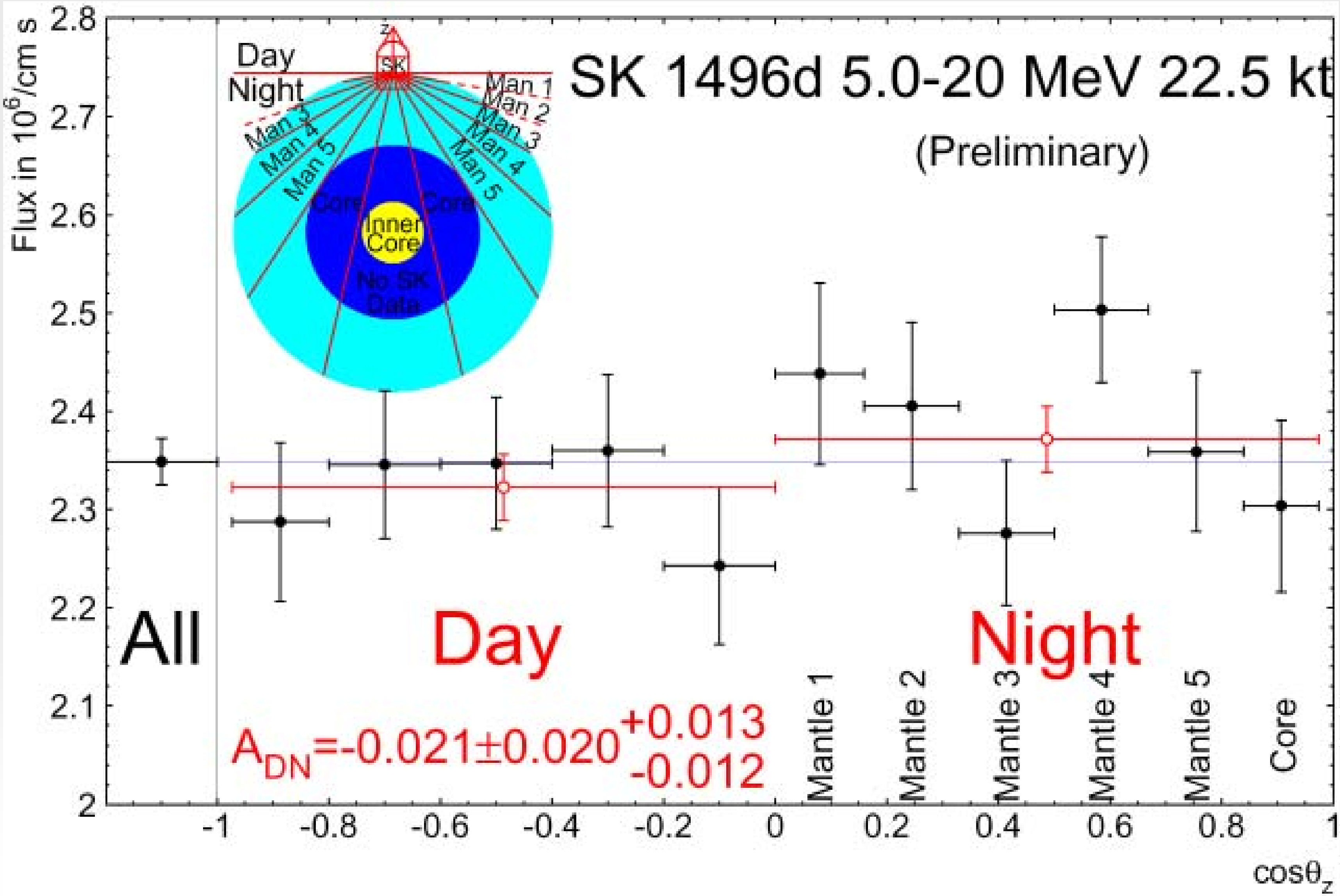
χ^2 for eccentricity
4.7 (69%)
χ^2 for flat
10.3 (17%)

$\Delta\chi^2 = 5.6$
2.4sigma difference

(7d.o.f.,
with sys. err.)

SK-I: Day / Night variation

(preliminary)



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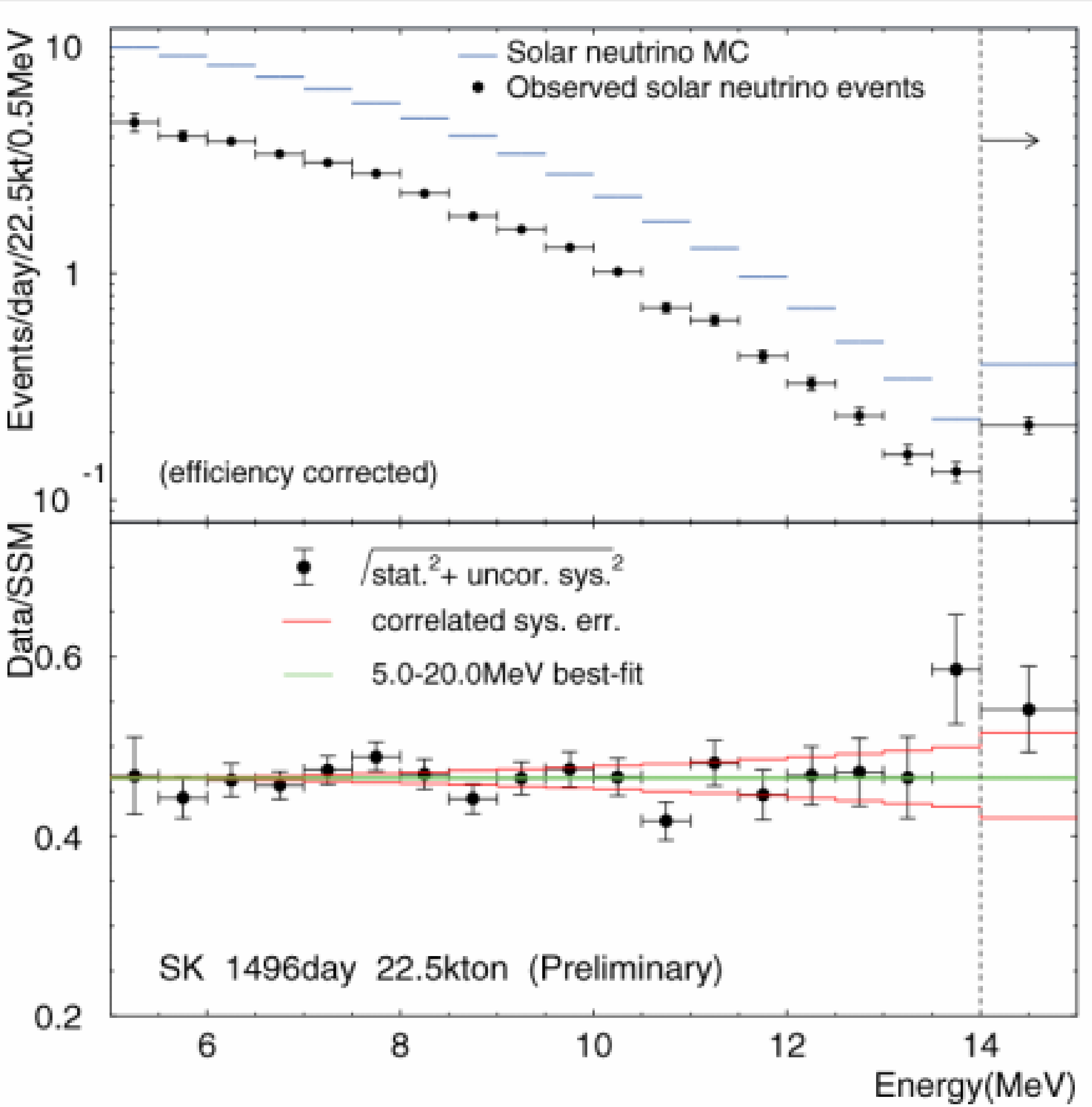
SK-I: Energy spectrum

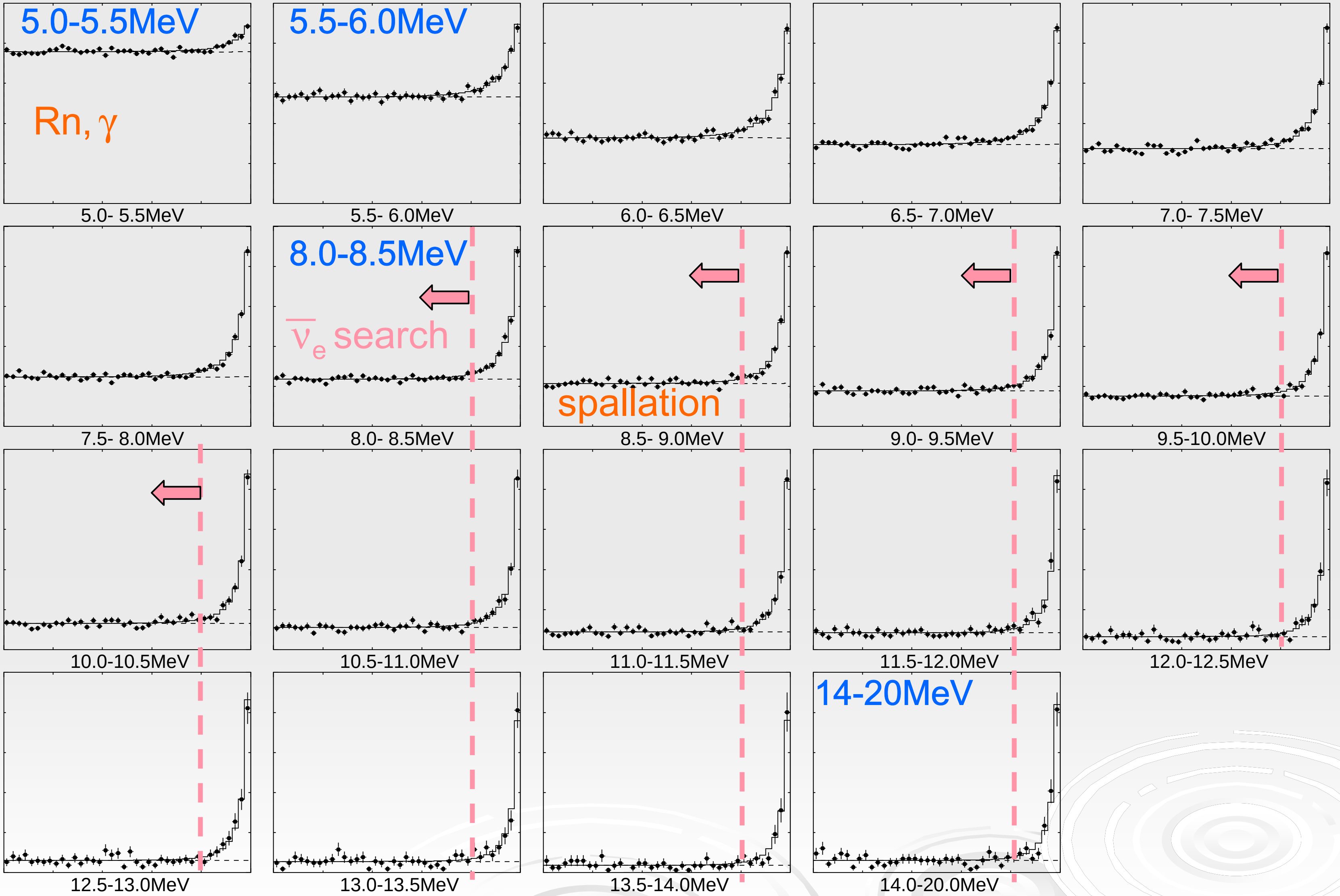
(preliminary)



χ^2 for flat = 17.4
19-1 d.o.f. 50%C.L.

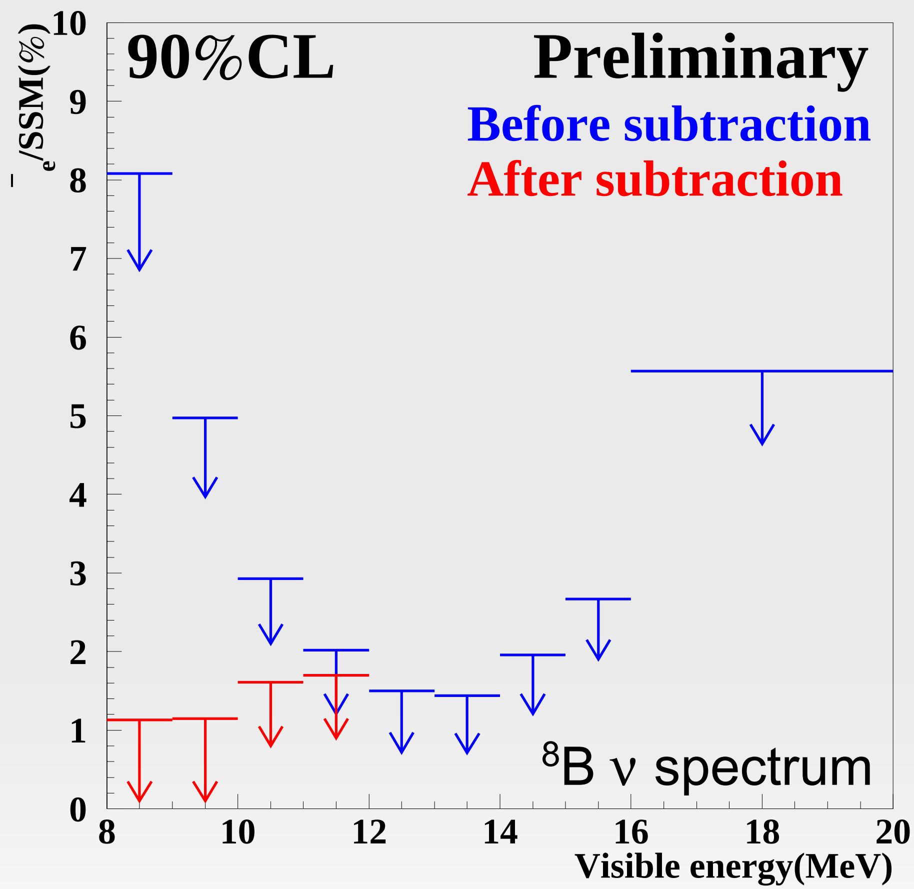
(considering correlated error)

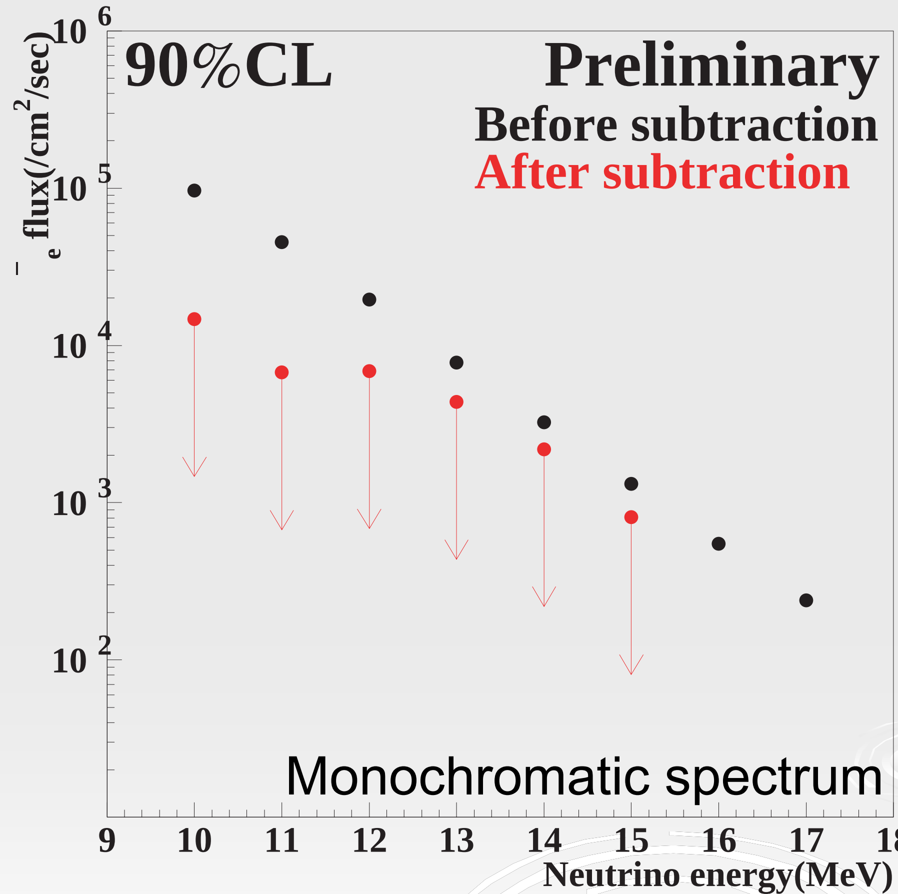
SK-I: Angular distributions



SK-I: $\bar{\nu}_e$ from Sun

(preliminary)

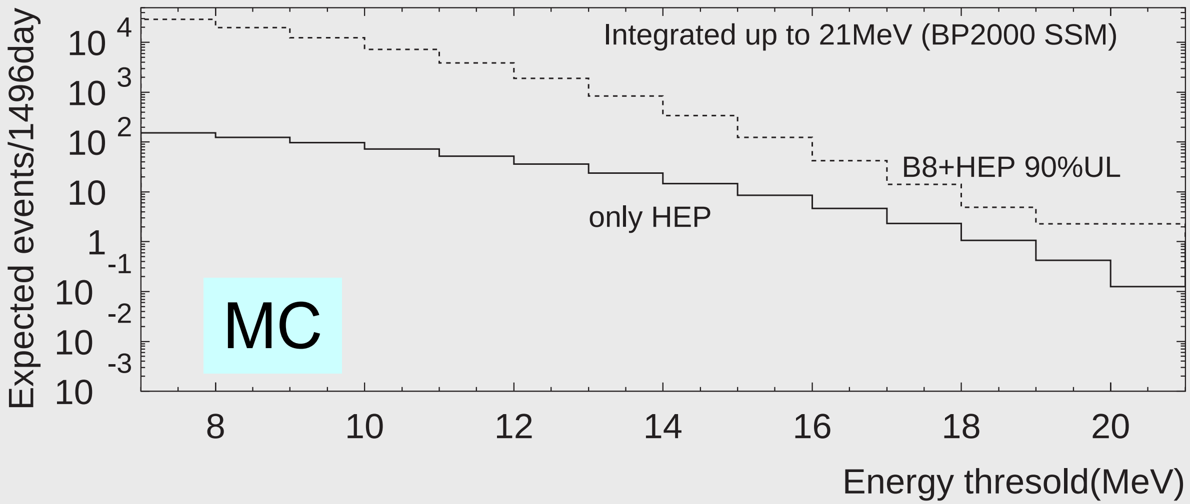


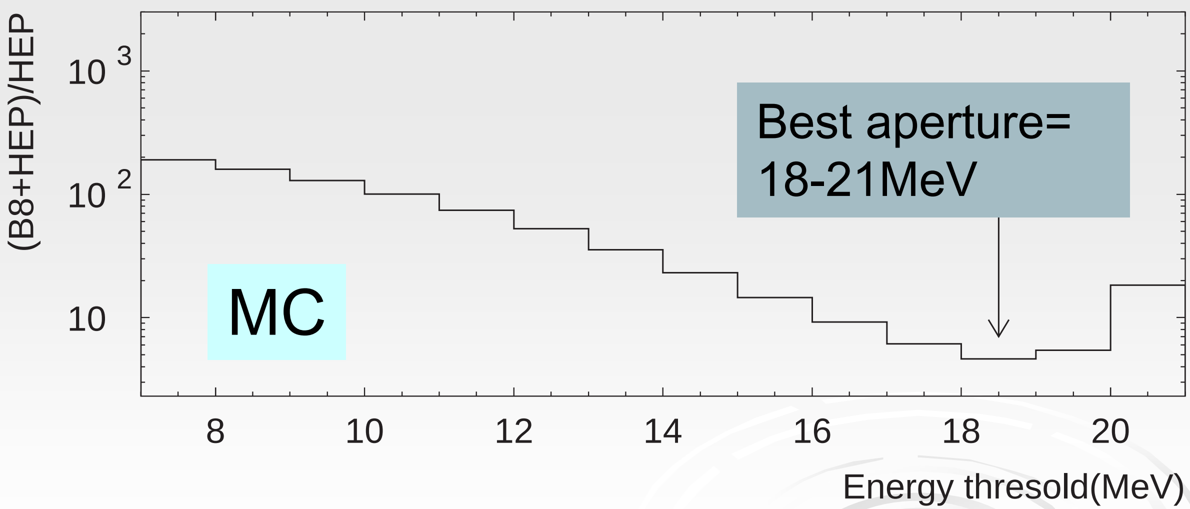


- Apply statistical subtraction of spallation events
- Assume all the remaining events in $\cos\theta_{sun}$<0.5 are solar antineutrinos

SK-I: hep neutrino

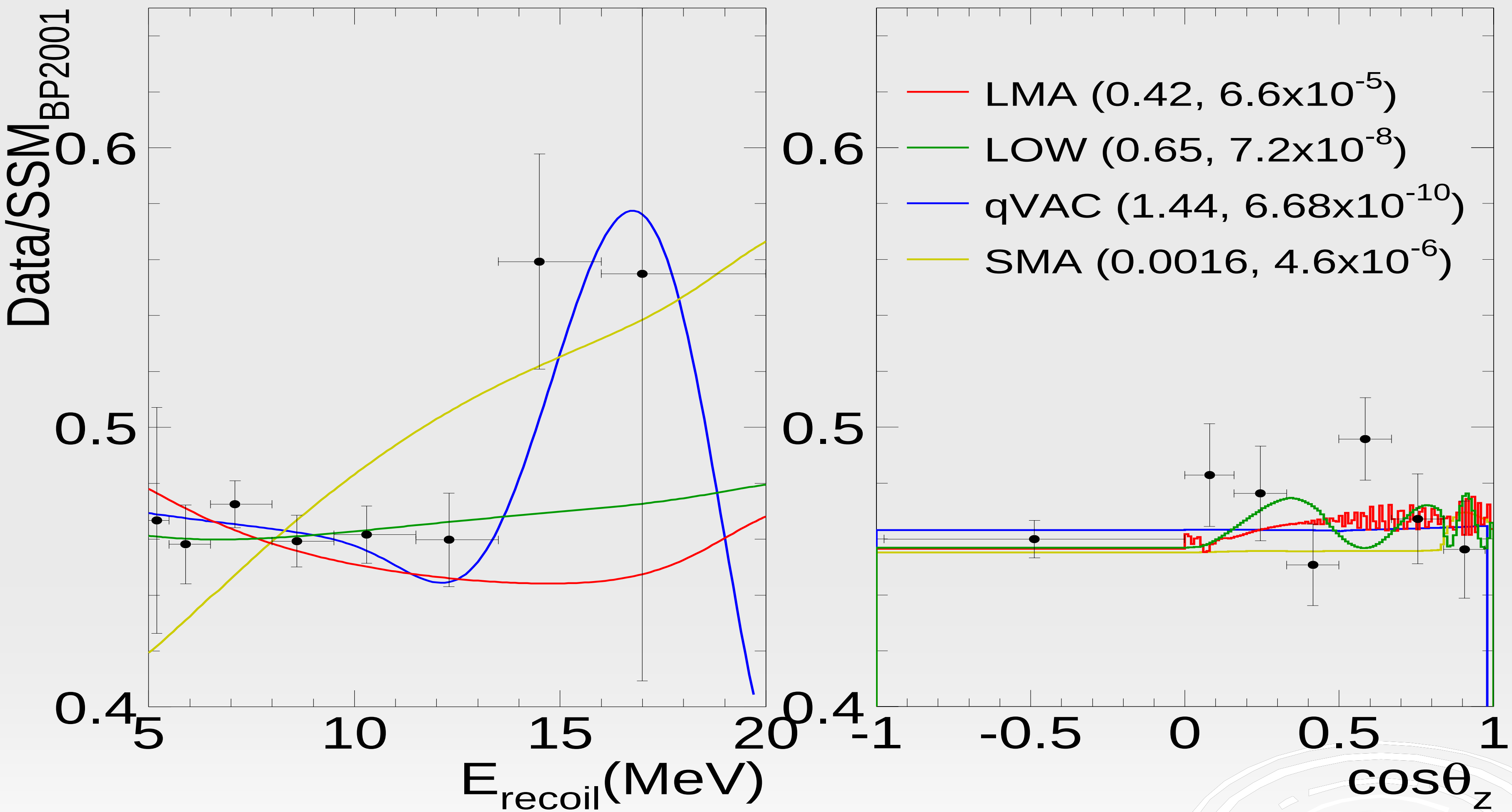
(preliminary)





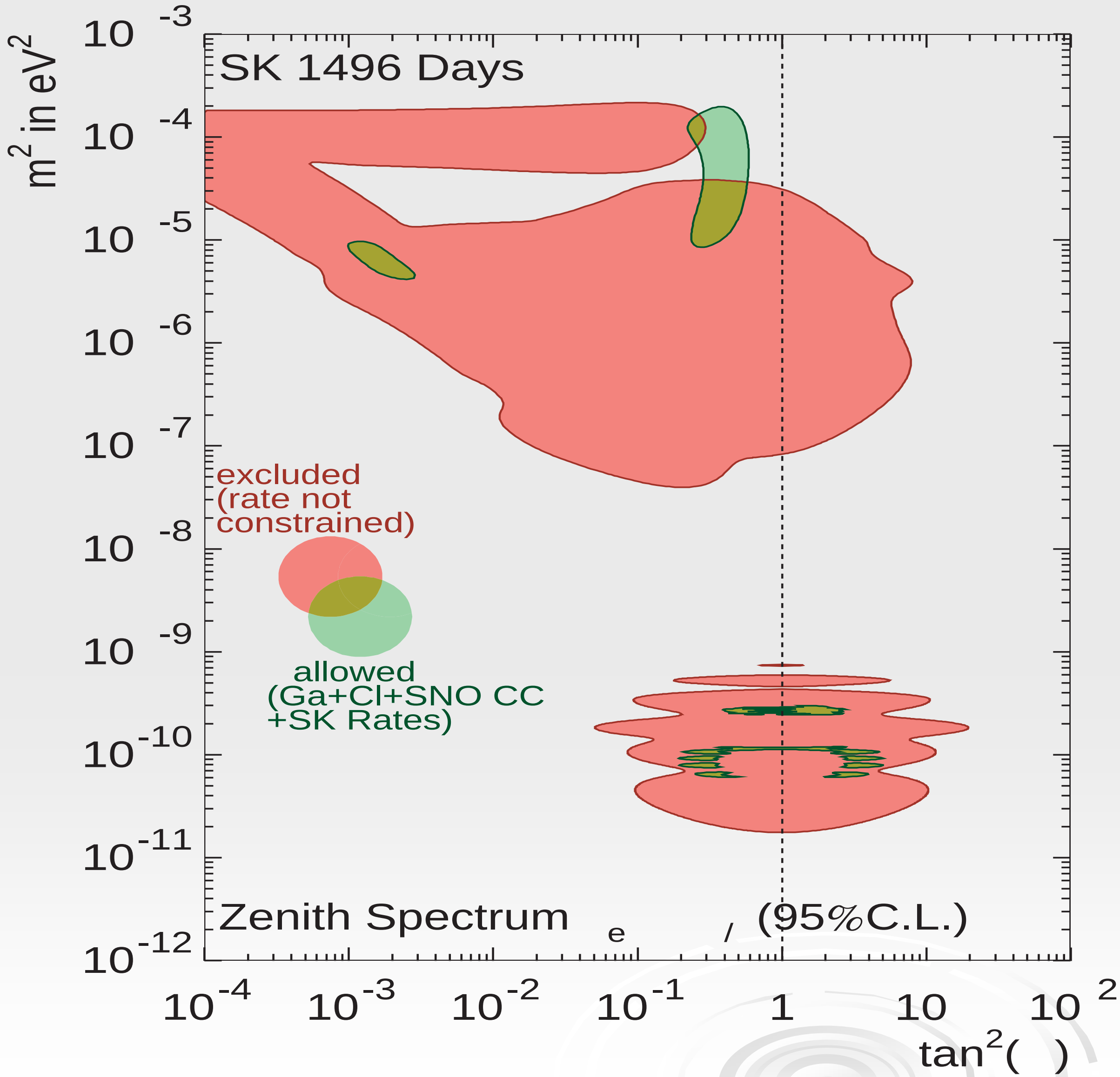
- Expected hep ν events in 18-21MeV = 1.06events
- (Expected ^{8}B ν events in 18-21MeV =1.72 events)
- Observed signal = 4.9+-2.7events
- Assuming all signals are hep ν, then hep ν flux limit (90%UL)=
  7.9 x SSM_{BP2001}
  73 x $10^3/cm^2/s$

SK-I: Zenith spectrum



- Test spectral distortion & day/night variation
- 7 zenith angle x 6 energy +2 energy = 44bin

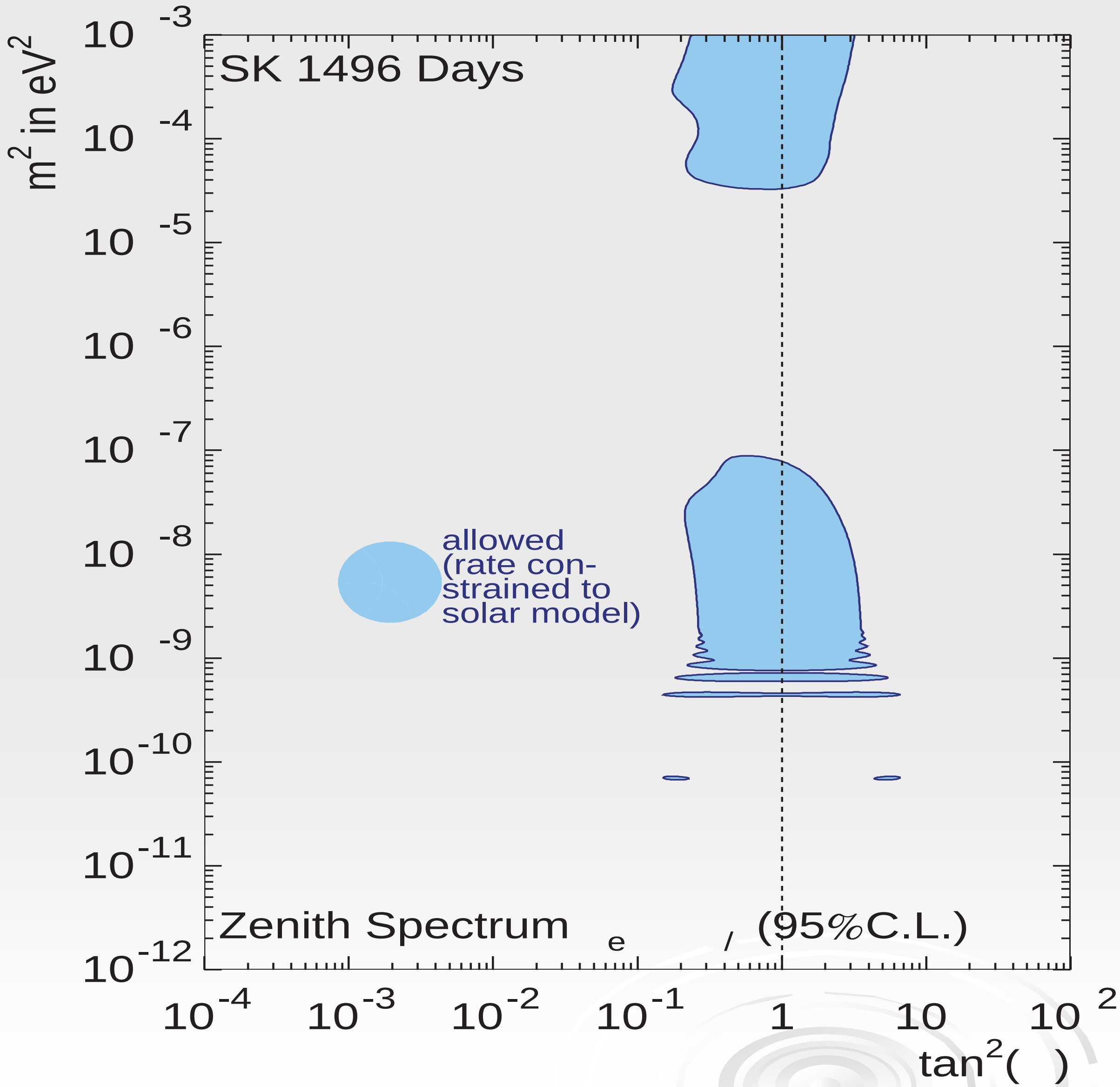
SK-I: Oscillation analysis1



SK-I zenith spectrum (no flux constraint)

Rate global

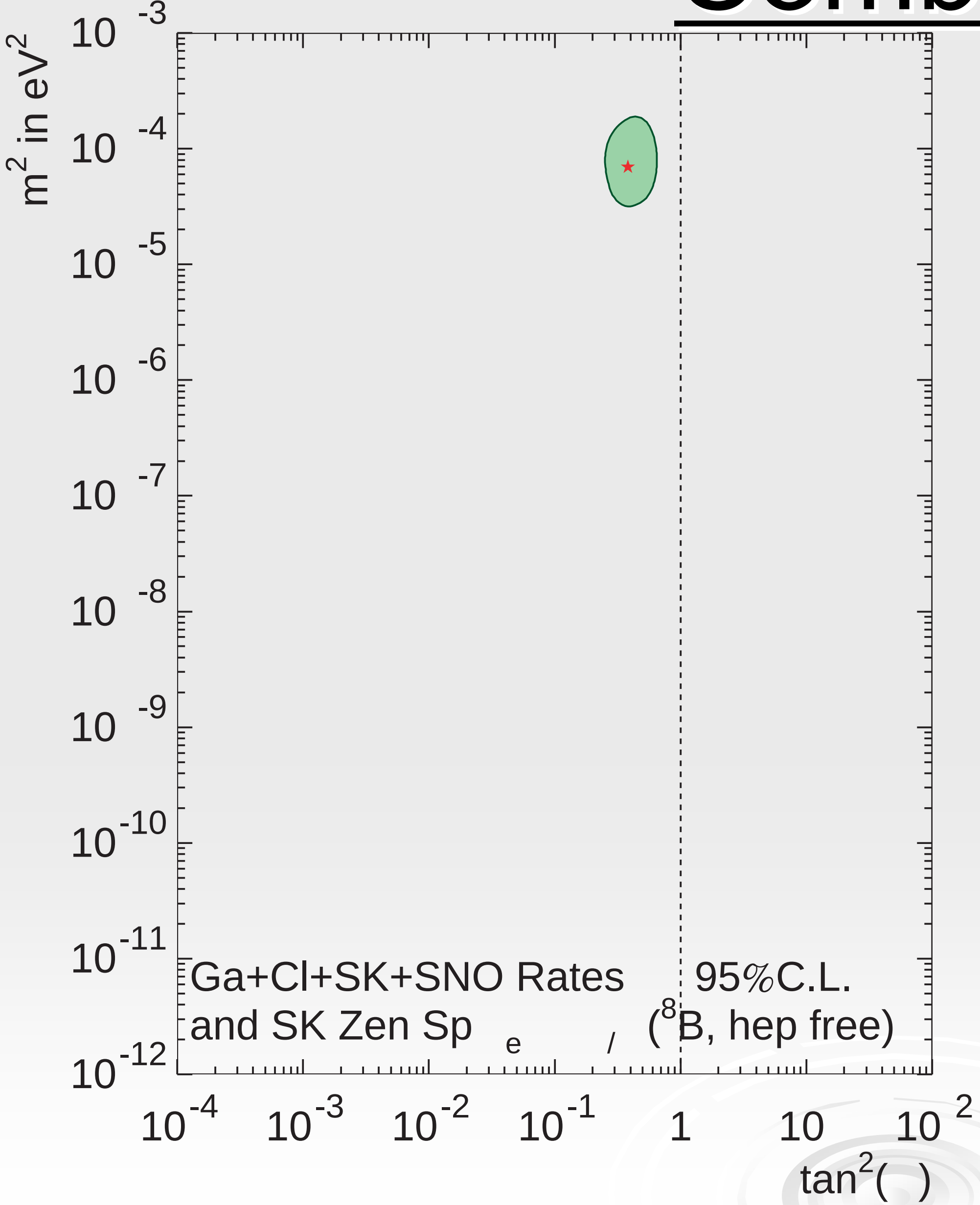
SK-I: Oscillation analysis2



All SK-I information + flux constraint by SSM

SK likes large mixing

Combined fit



PLB539 (2002)179-187

- Best fit:
  - $\tan^2\theta$ =0.38
  - Δm^2 =6.9×10^{-5} eV^2
  - ^{8}B flux =1.06 SSM_{BP2001}
  - hep =3.9 SSM_{BP2001}
  - χ^2_{min} =43.5

Quasi-VAC (1.5, 6.68x10^{-10})	χ^2=53.5
LOW (0.66, 7.2x10^{-8})	χ^2=52.5
SMA (0.0012, 6.6x10^{-6})	χ^2=58.9

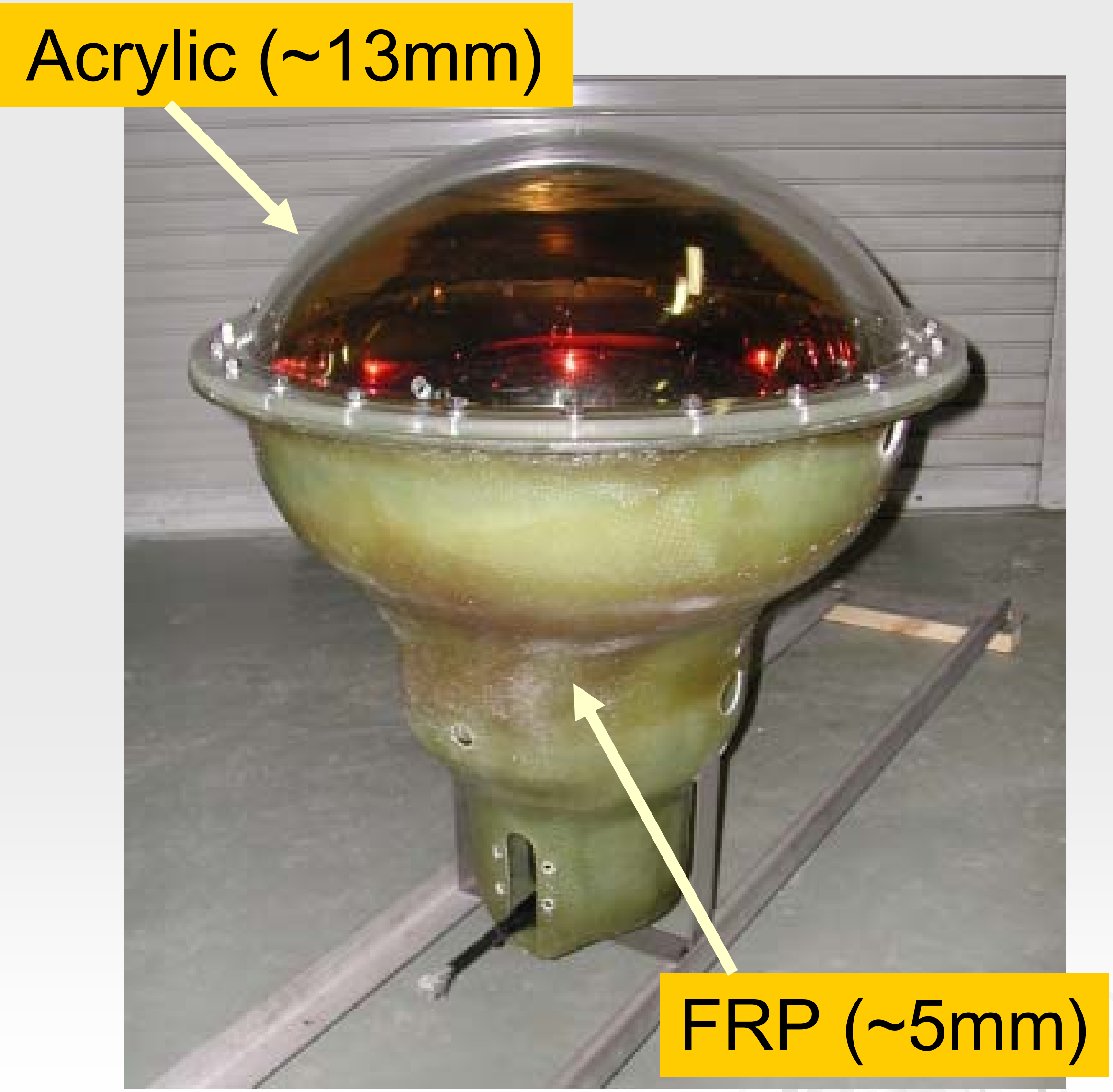
Super-Kamiokande after accident (Nov. 12, 2001)

Cause of the accident is:

- A PMT at the bottom imploded.
- Shock wave from the first implosion broke surrounding PMTs, then chain reaction started.

View from the inspection hole on the top of the detector. Most of 20inch PMT’s below water surface are broken.

PMT vessel for SK-II



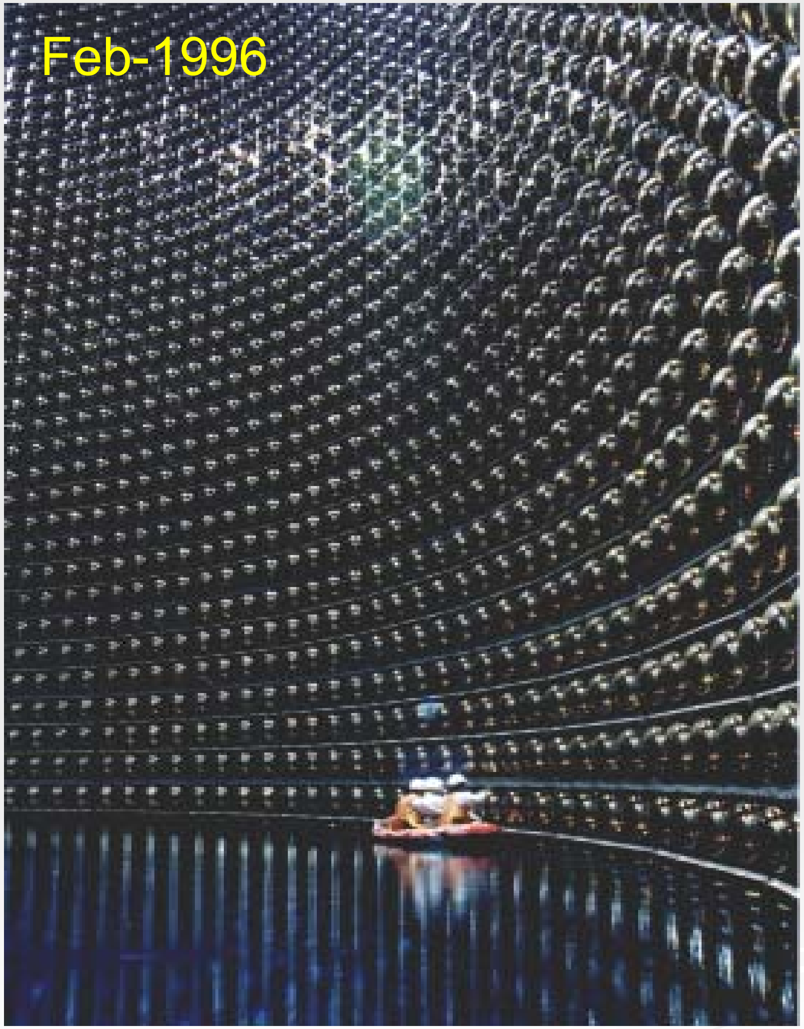
- To prevent the chain reaction, all 20inch PMTs are put into the vessel.
- PMT vessels were tested at -30m water depth.
- Radon diffusion from PMT would be stopped.

Reconstruction plan

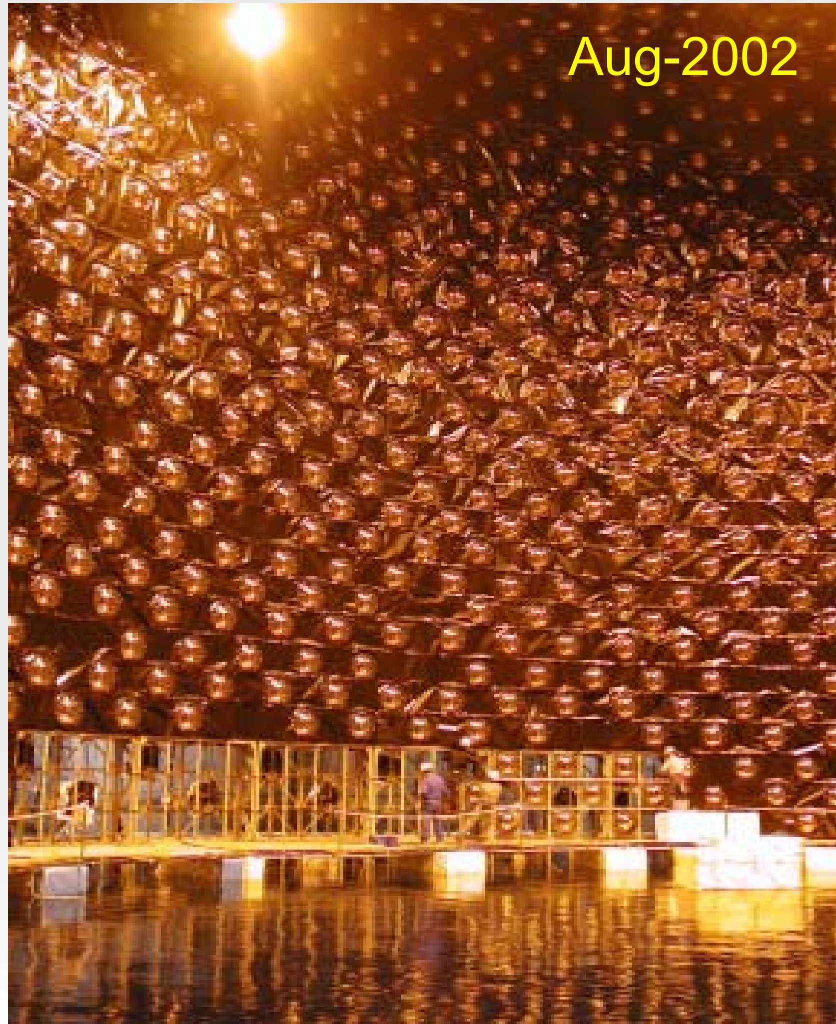
- Implosion test in the detector (~Feb. 2002)
- Drain water, clean up, remove existing 20inch ID PMTs (Mar. ~ May, 2002)
- Mount about 5200 20inch ID PMTs and full 8inch OD PMTs (May ~ Sep. 2002)
- Water filling started on Oct. 3, 2002 at 35ton/hour.
- Close top inspection hole, then start physics run (early Dec. 2002)

- We are making efforts to reconstruct ID part fully by summer 2006 (before JHF-SK start).

Rebuilding of Super-Kamiokande



SK-I: Photo coverage 40%

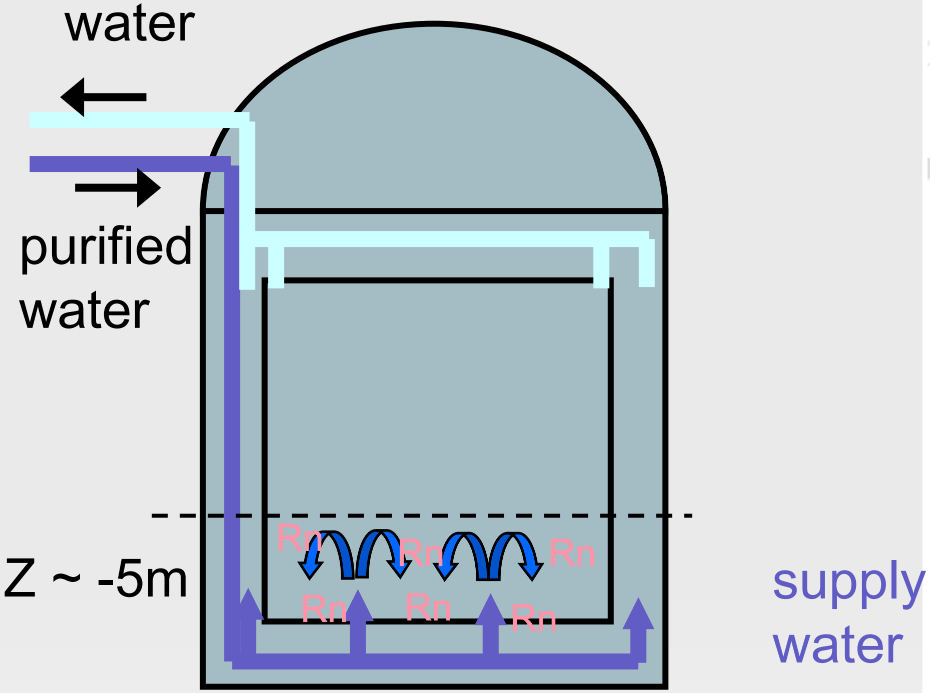


SK-II: Photo coverage 19%

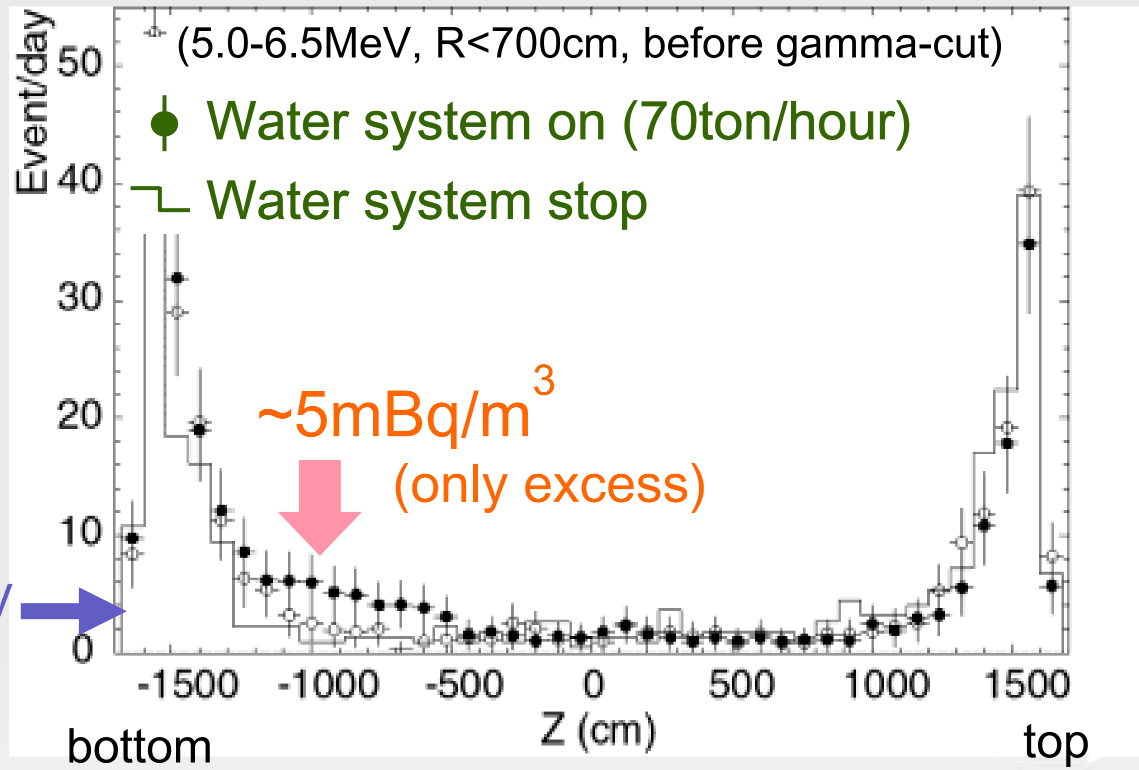
SK-II: prospects

- No serious effect for Supernova burst search, atmospheric neutrino, proton decay, and K2K.
  (except for $p \rightarrow \nu K$ mode)
- For low-energy data sample:
  - Energy resolution: ~1.4 times large
  - Energy threshold: 5MeV ⇨ 7MeV(?) because of BG increase
    (c.f. Kamiokande-III had 7MeV threshold under similar photo coverage and 100 times much radon in water)
  - Need to remake most of analysis tools
- About solar neutrino analysis:
  - Continue to measure time variation, seasonal variation, and day/night asymmetry of ^8B flux in higher energy region.
- Some amount of radon BG would be reduced.

SK-I: Radon BG



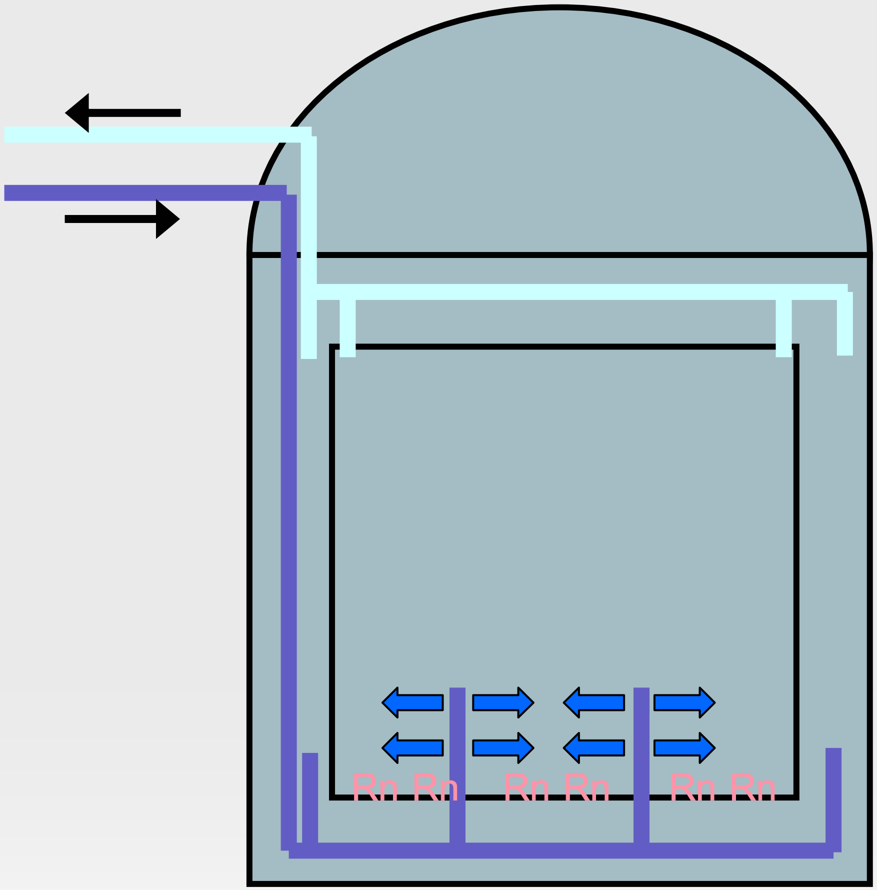
Y.Takeuchi et al., PLB452(1999)418



Vertical water flow stirs up radon on the detector bottom (emanated from PMT)

Event excess at bottom: ~40%
(5.0-5.5MeV, 22.5kt, 30ton/hour)

SK-II: improvement of Rn reduction



New water outlet (Sep. 2001)

1. Cover PMT
2. Use horizontal water outlet

Radon BG would be reduced at SK-II.

Summary

- SK-I precisely measured ^8B flux, spectrum, and time variations.
- We are still investigating data quality to obtain SK-I final results.
- Reconstruction of SK is almost finished.
- SK-II will be started in Dec. 2002.
- Radon in fid. vol. would be reduced at SK-II.
- Solar neutrino observation would be done in higher energy region in SK-II.