Super-Kamiokande Low Energy Results

-Solar neutrinos & SN neutrinos-

NOW2012 @Conca Specchiulla
14 September

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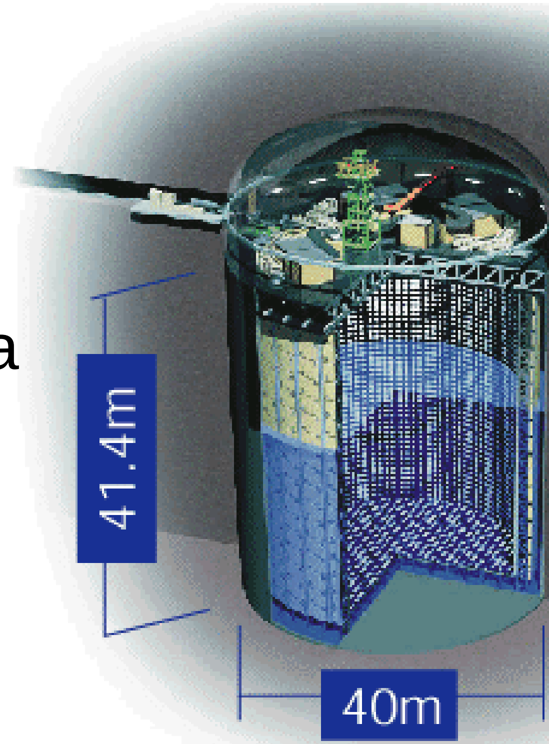
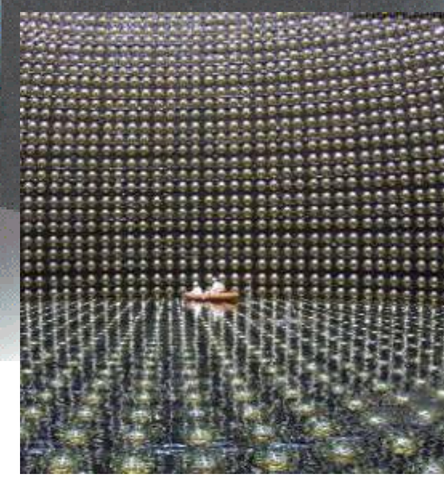
for the Super-K Collaboration

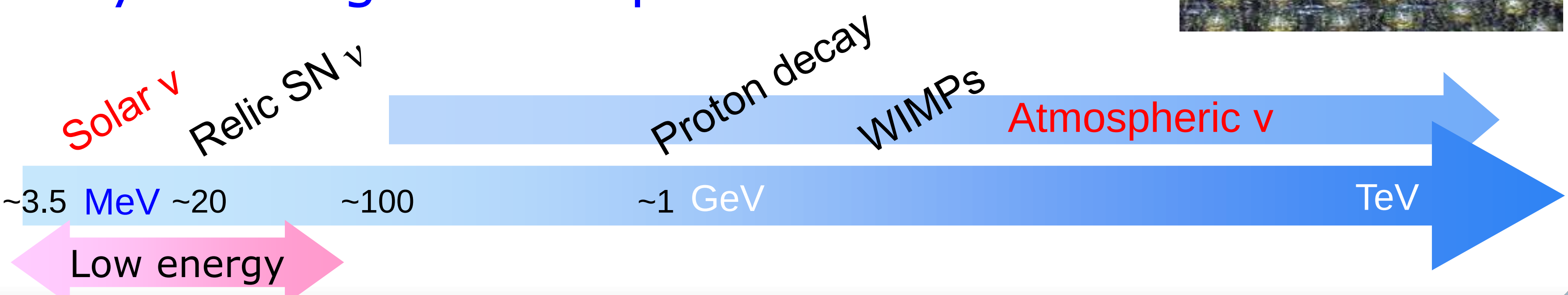
Super-Kamiokande

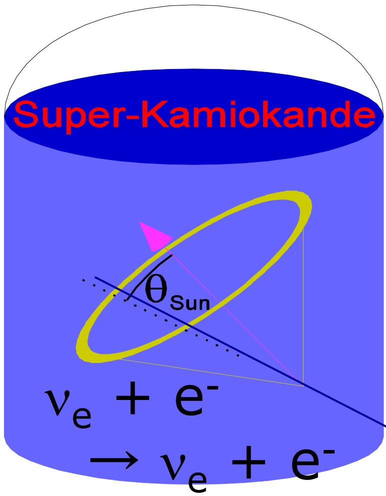
- 50kton pure water Cherenkov detector
- 1km (2.7km w.e) underground in Kamioka
- 11129 50cm PMTs in Inner Detector
- 1885 20cm PMTs in Outer Detector

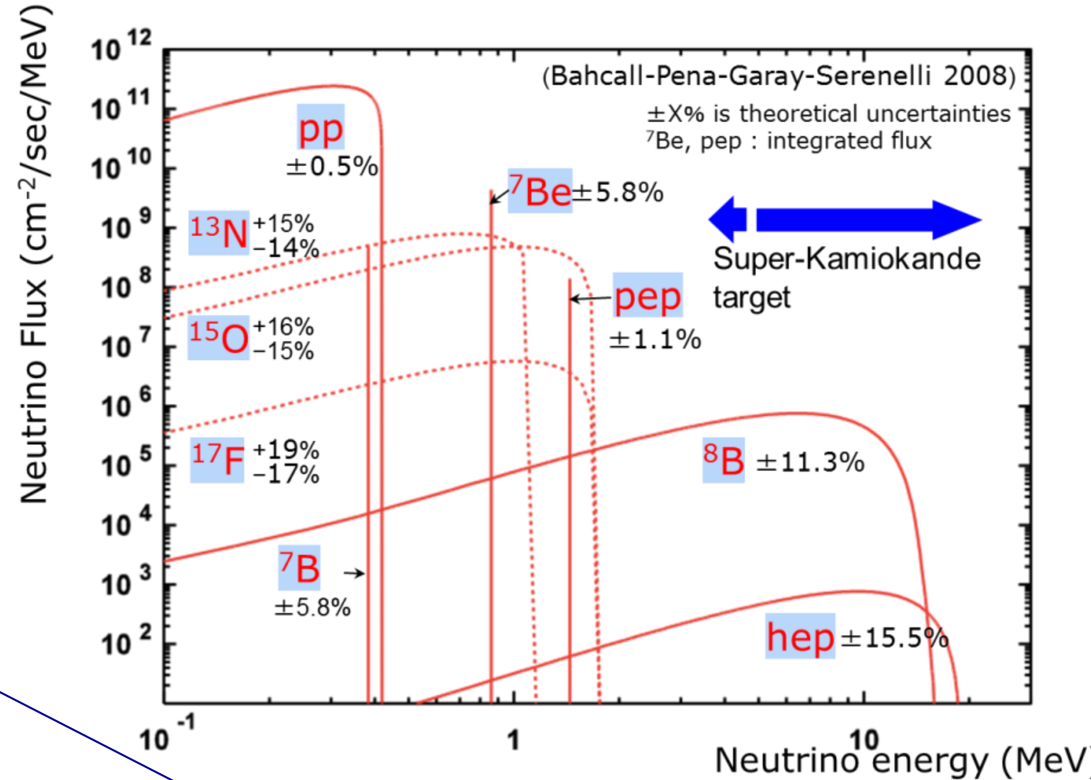




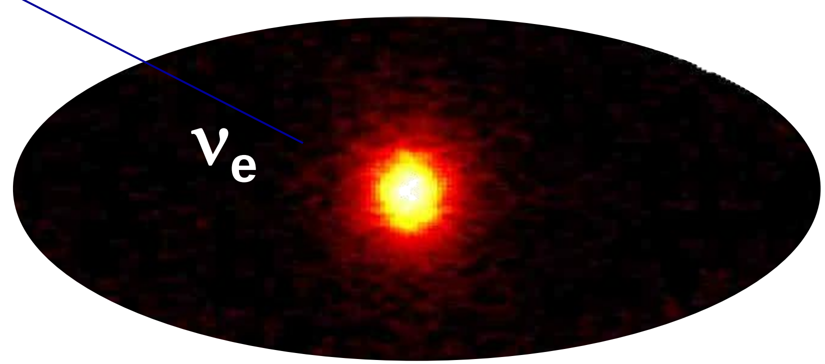
Physics targets of Super-Kamiokande







Solar neutrinos observation



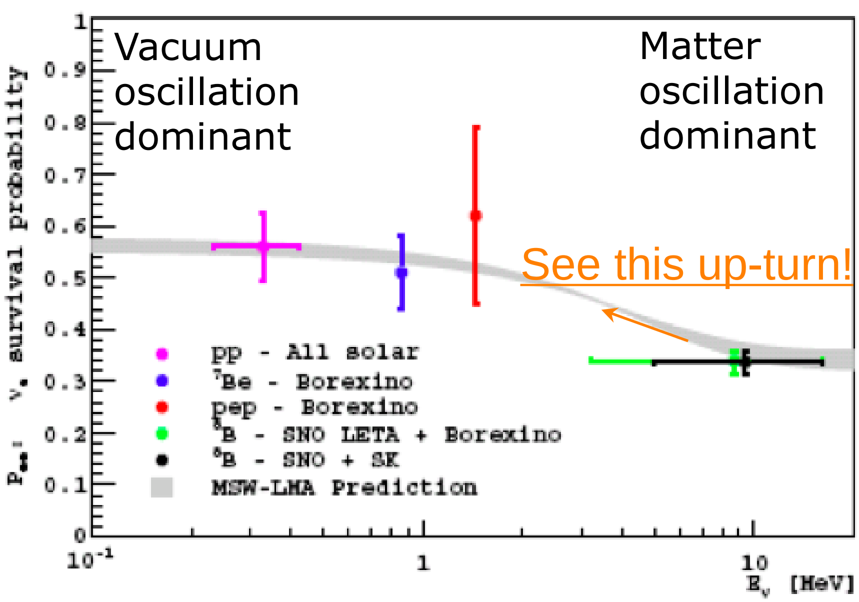
Current motivation

- Check the direct signal of the MSW effect

Solar matter effect

Energy spectrum up-turn

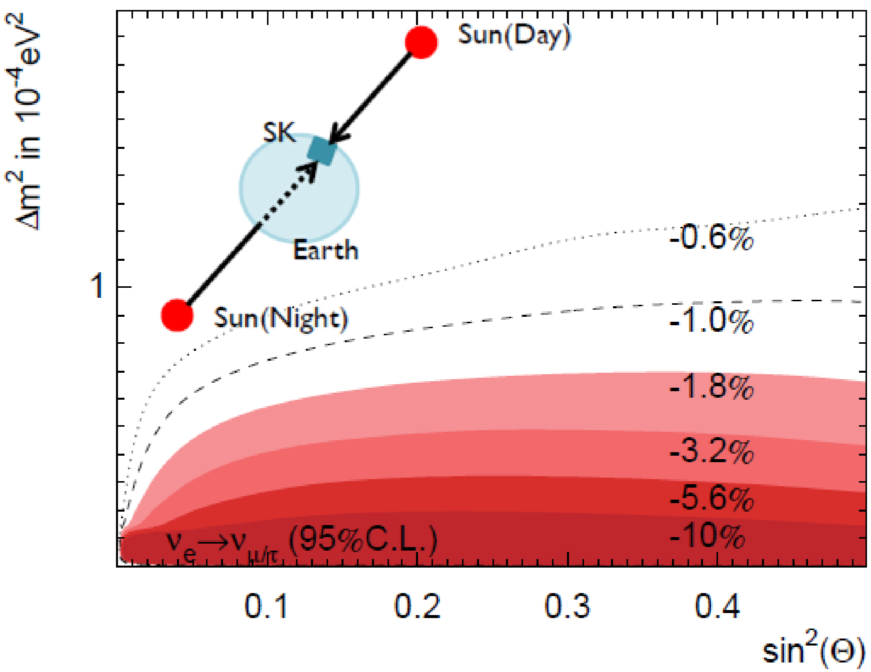
Neutrino survival probability



Earth matter effect

Flux day/nigh asymmetry

Night>Day : about 2% level



New SK-IV results are added

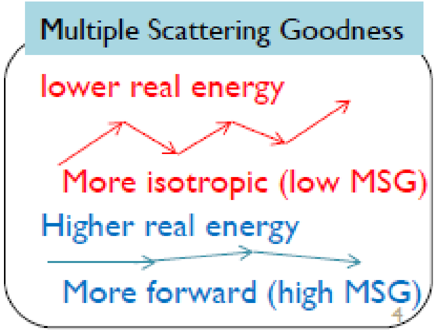
- First results from SK-IV (1069.3 days of data)

Hardware improvement

  - Better water quality control
    - Lowered threshold (~3.5MeV (kin.))
    - Large statistics with lower backgrounds.
  - New electronics
    - Better timing determination
    - Better MC model of trigger efficiency.

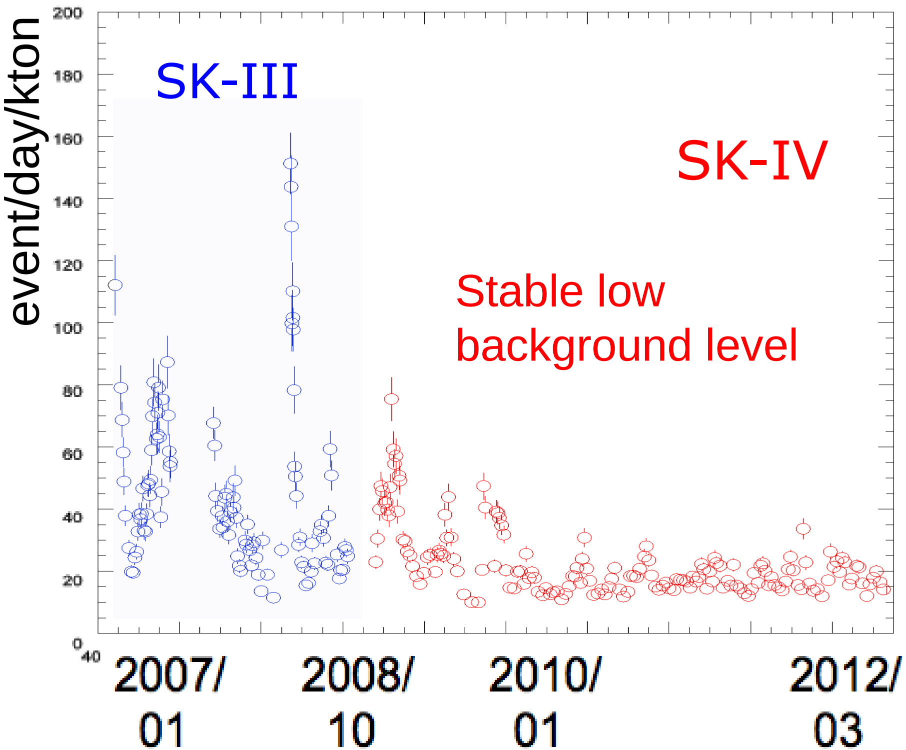
Software improvement

  - Introduce multiple scattering goodness
    - Although the ^{214}Bi decay-electrons (majority of low energy BG) fluctuate up above 5.0 MeV, they truly have energy <3.3 MeV and should have more multiple scattering than true 5.0 MeV electrons, and therefore a lower MSG
  - Reduced systematic error
    - 1.7% for flux   cf. SK-I: 3.2% SK-III: 2.1%

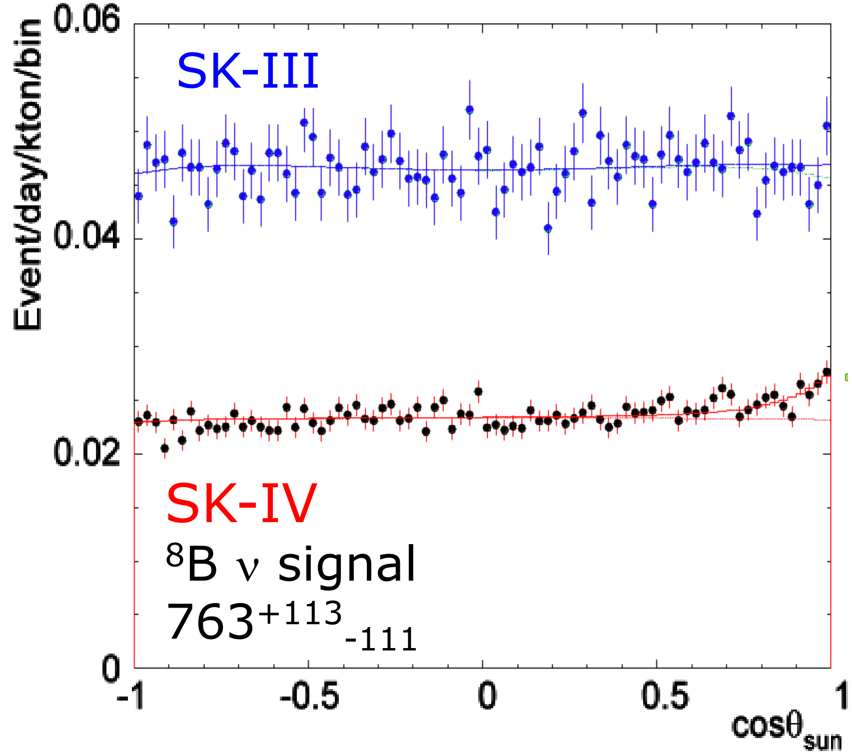


Lowered background

Event rates
4.0-4.5MeV(kin.)

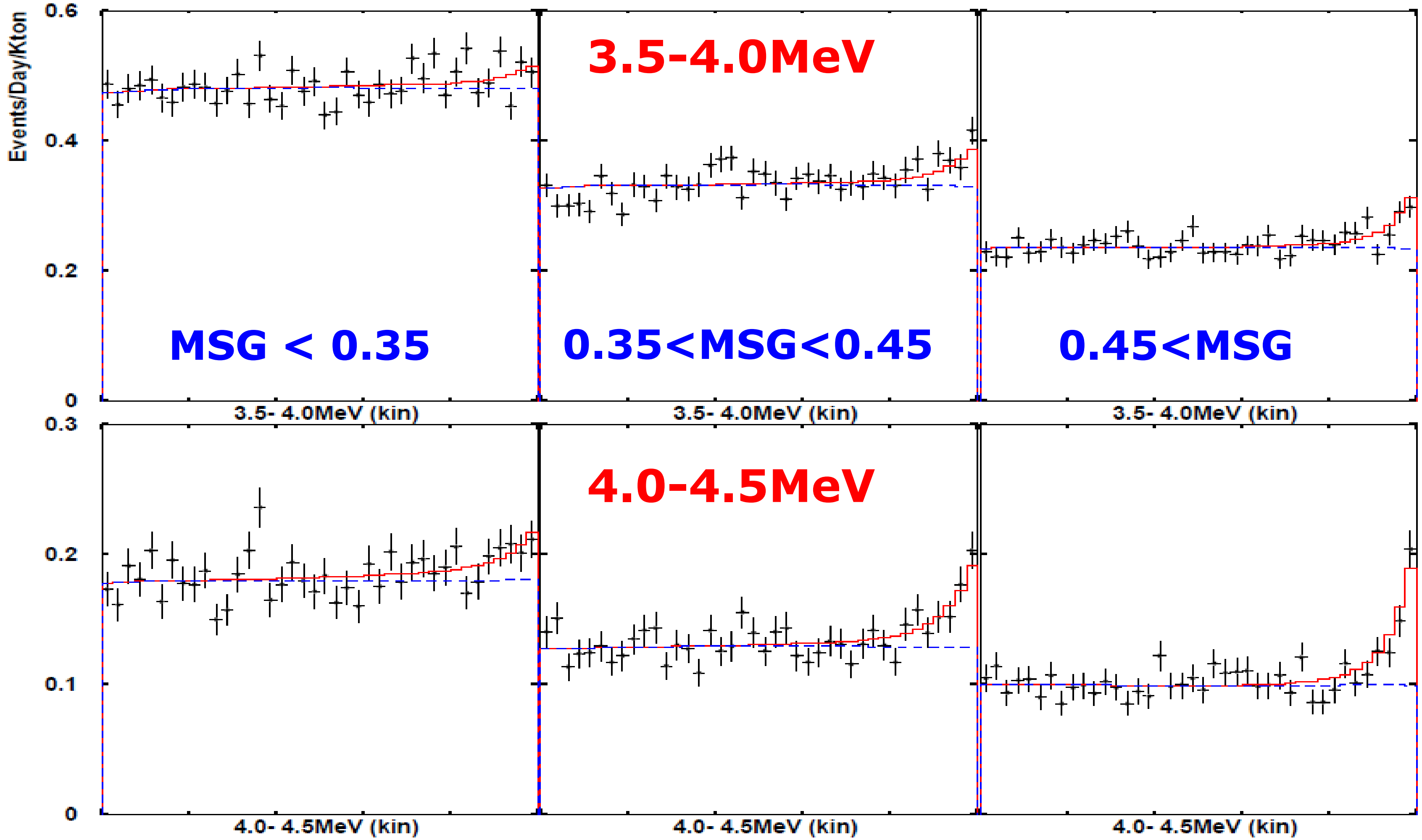


Solar angular distribution
3.5~4.0MeV(kin.)

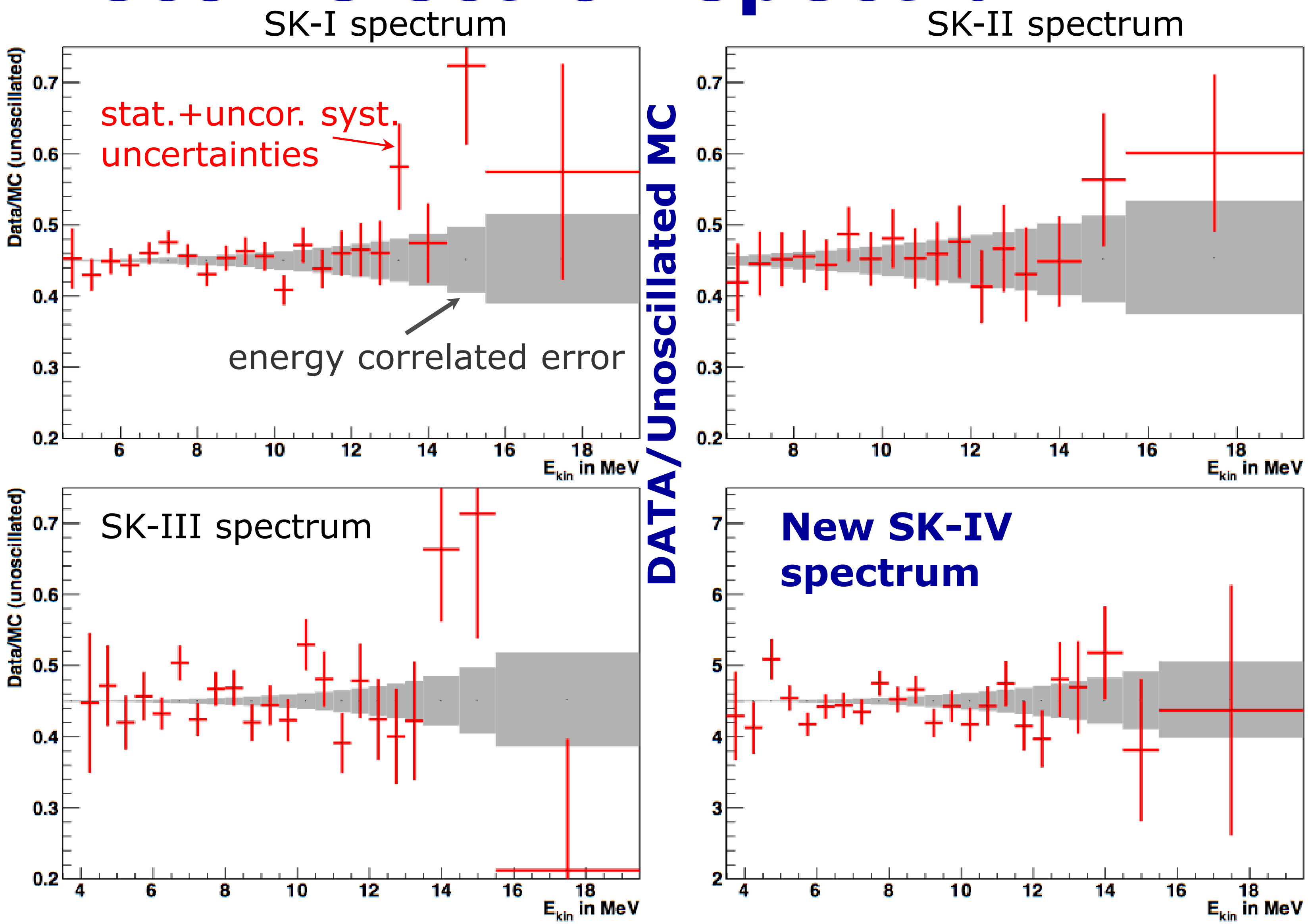


Clear Solar peak ~7σ level
3.5MeV threshold is achieved!

Solar angle distributions with MSG in low energy



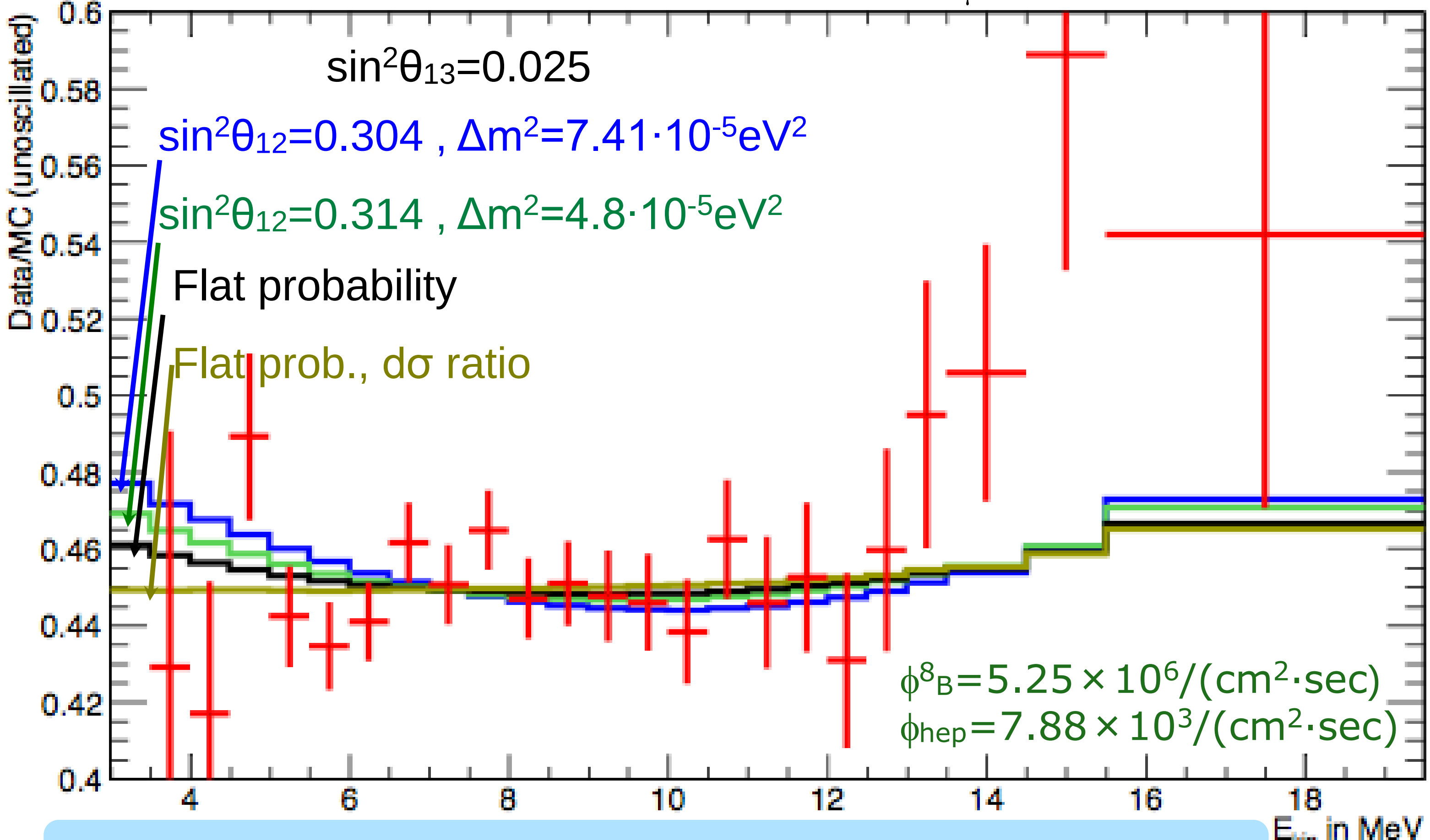
Recoil electron spectrum



Recoil electron spectrum

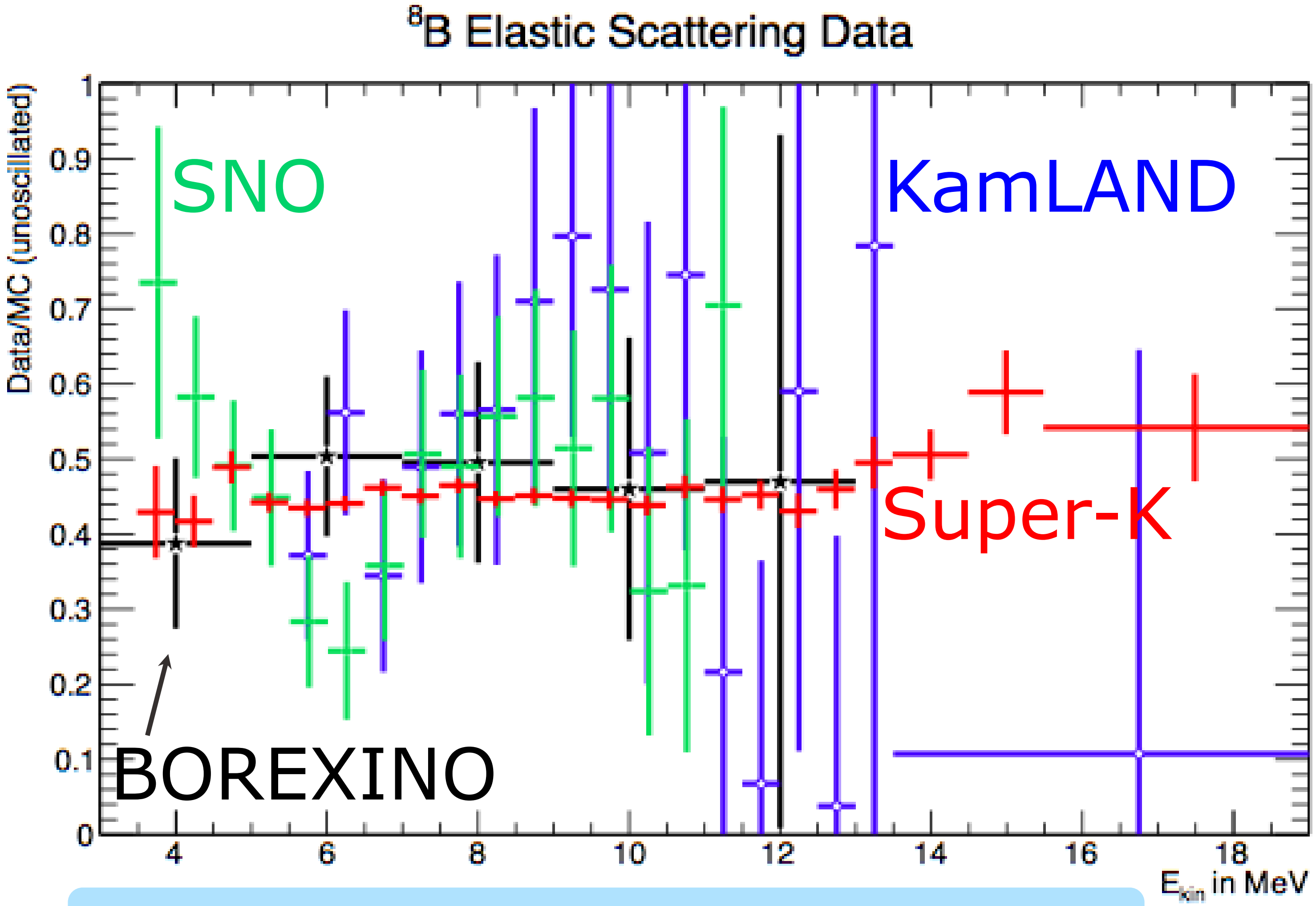
SK-I,II,II,IV
DATA/Unoscillated MC

Distortion due to E dependence of
1) Oscillation survival probability
2) $d\sigma_\mu/d\sigma_e$



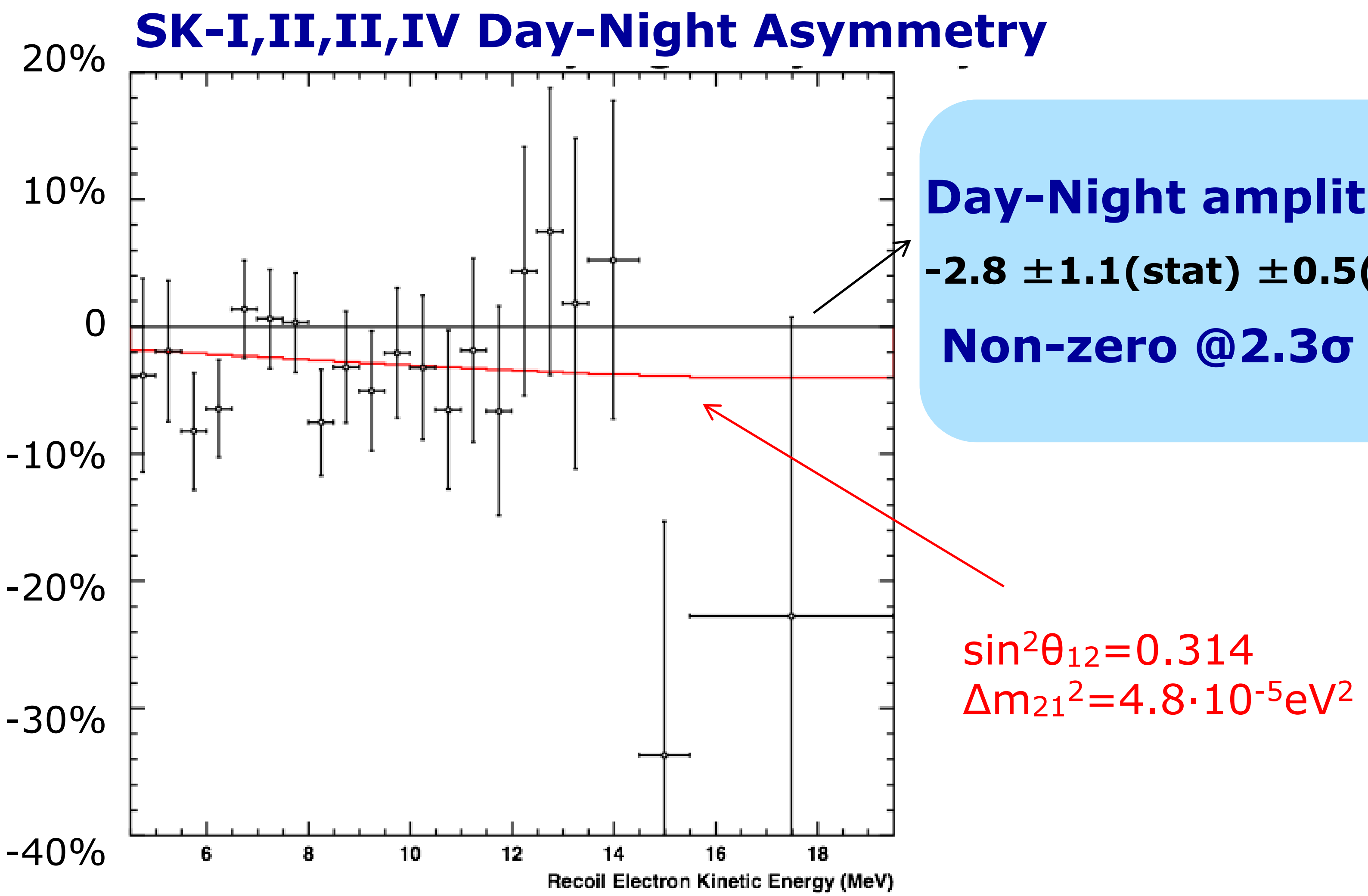
Unoscillated shape is favored ~1.1 to 1.9 σ

Comparison with others



Super-K spectrum is the most precise!

Day-Night amplitude

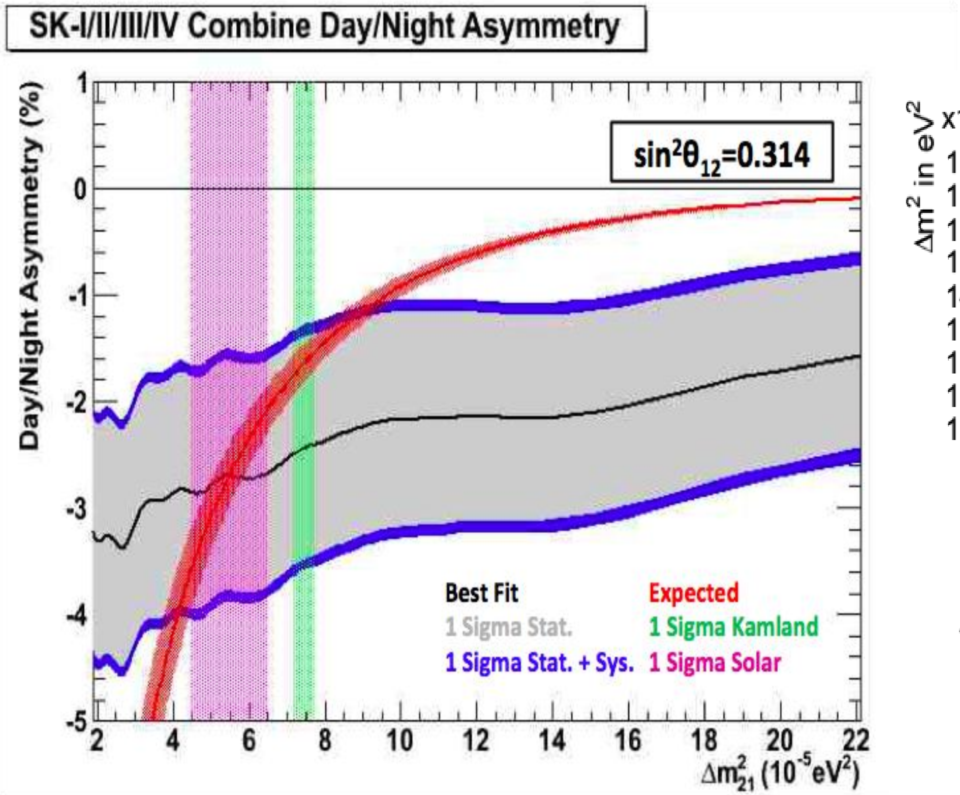


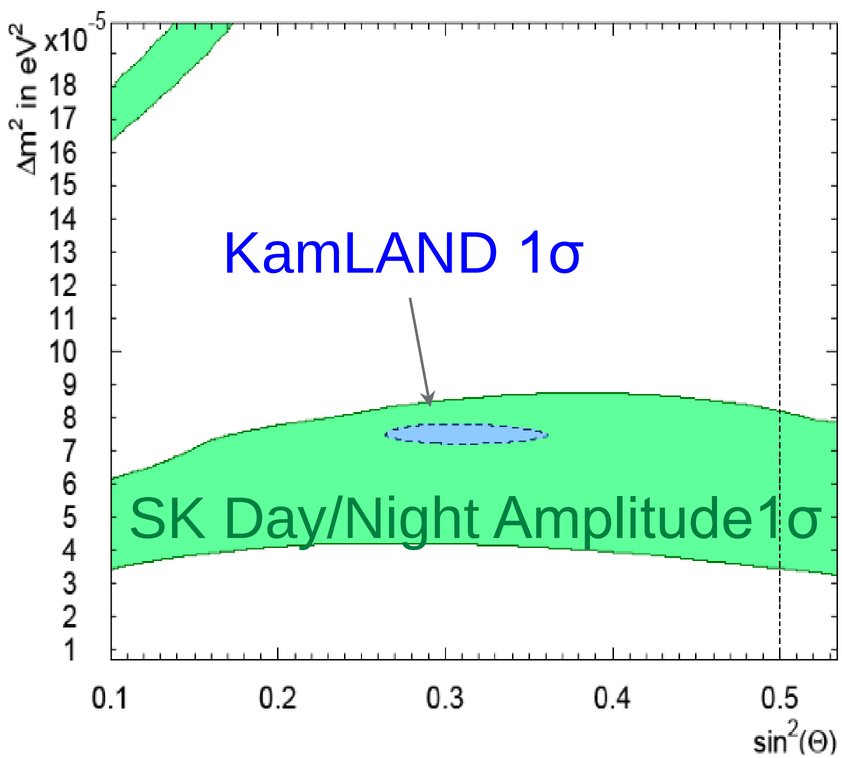
Day-Night amplitude

-2.8 ±1.1(stat) ±0.5(sys)%

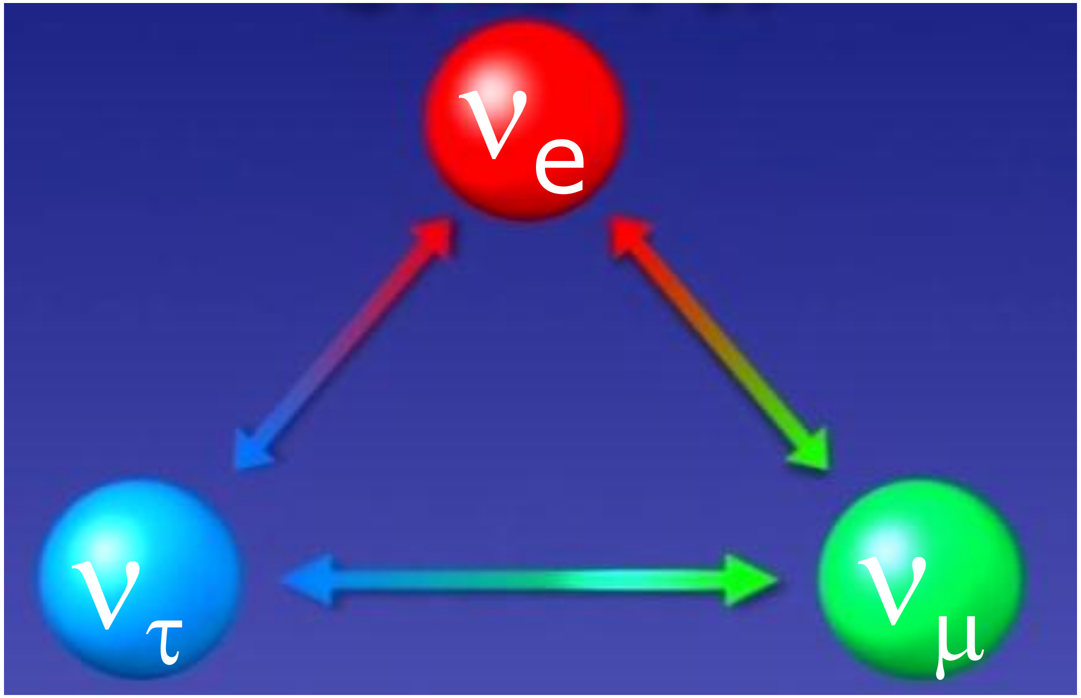
Non-zero @2.3σ level

Allowed oscillation parameter region from Day/Night data



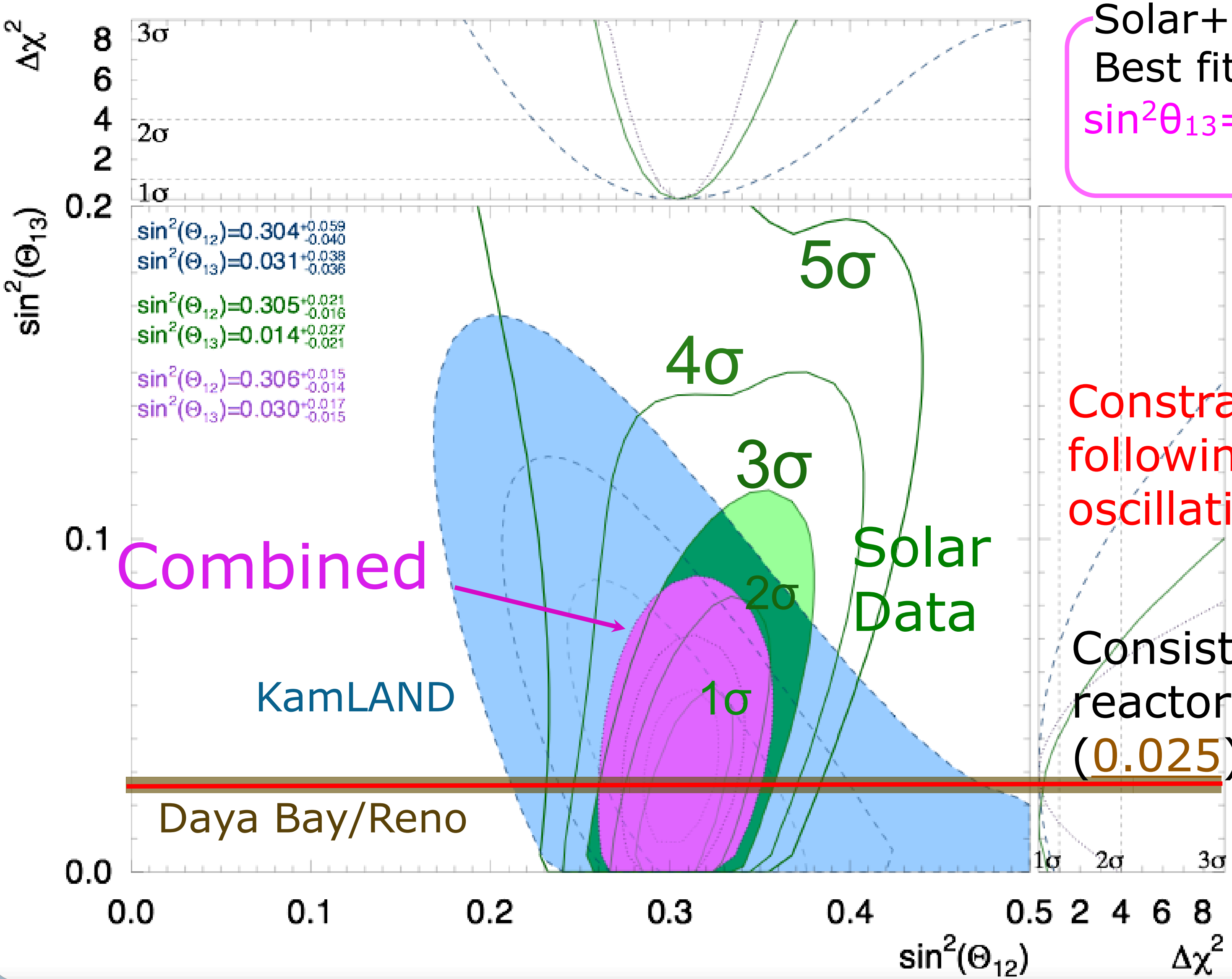


The best constraint of Δm^2_{12} among all solar neutrino measurements



Neutrino oscillation analysis

θ_{13} analysis

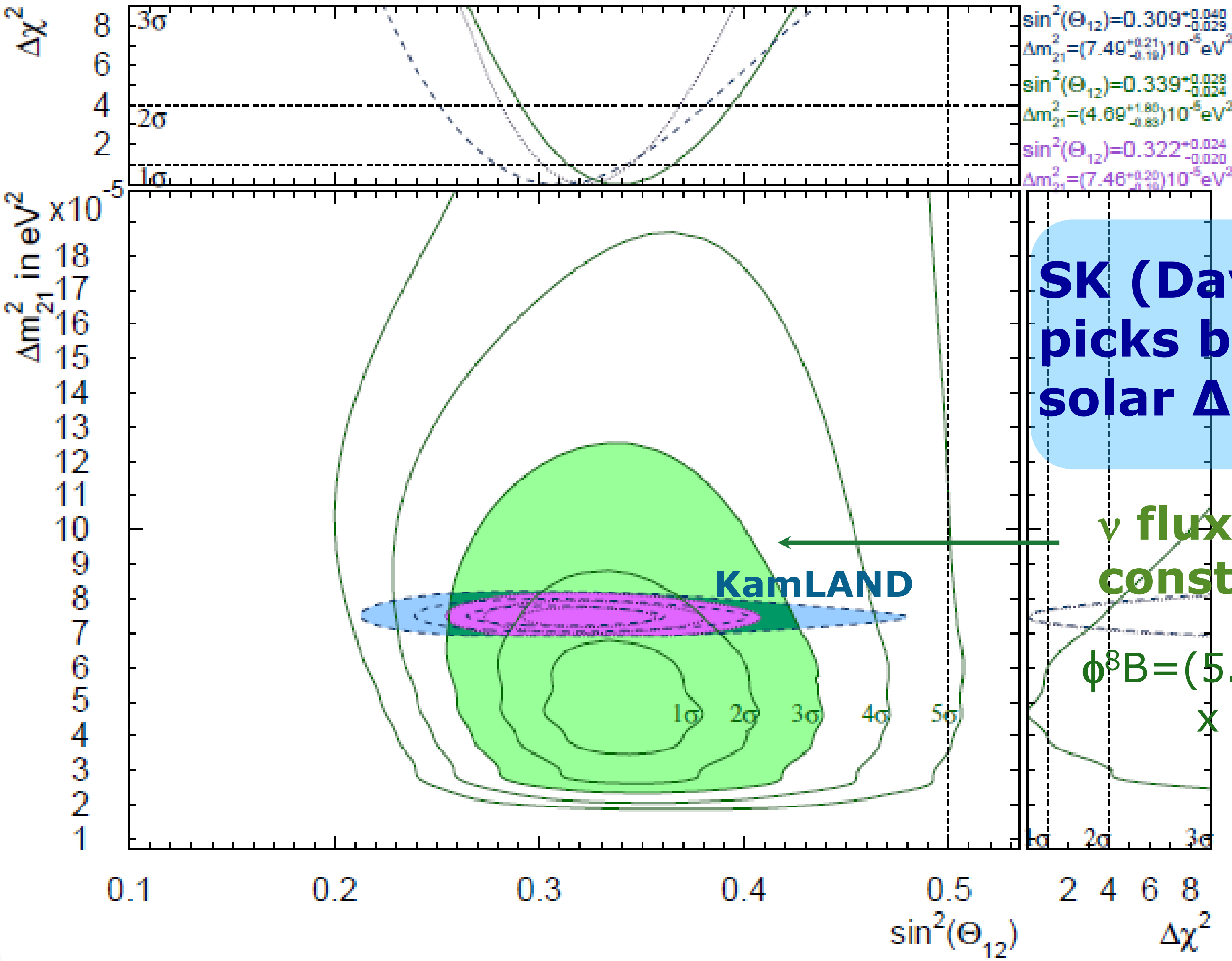


Solar+KamLAND Best fit
$\sin^2\theta_{13}=0.030^{+0.017}_{-0.015}$

Constraint to the following oscillation analyses

Consistent with reactor experiments (0.025)

$(\Delta m^2_{12}, \theta_{12})$ from Only Super-K

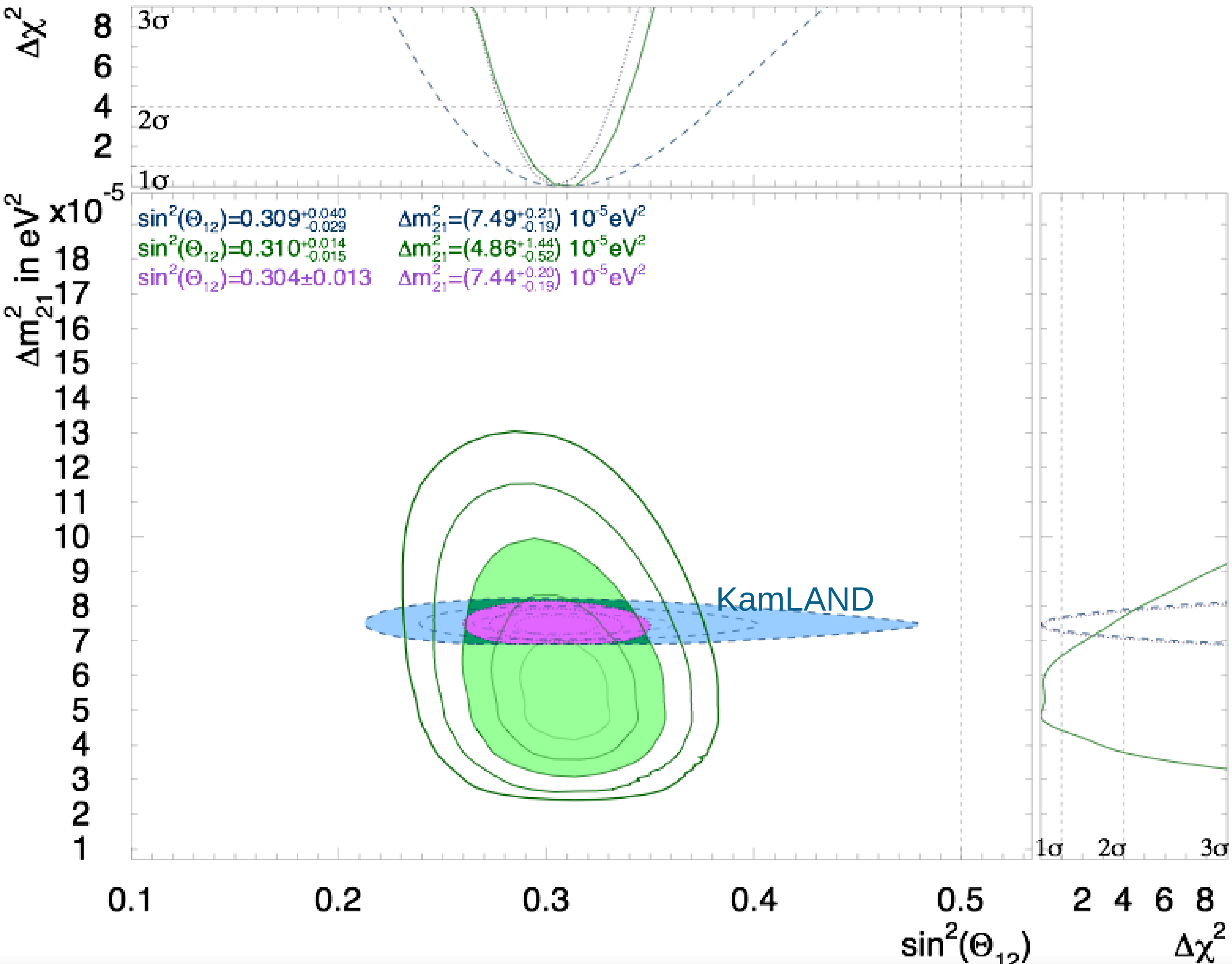


SK (Day/Night) picks best-fit solar Δm^2_{21}

ν flux constraint

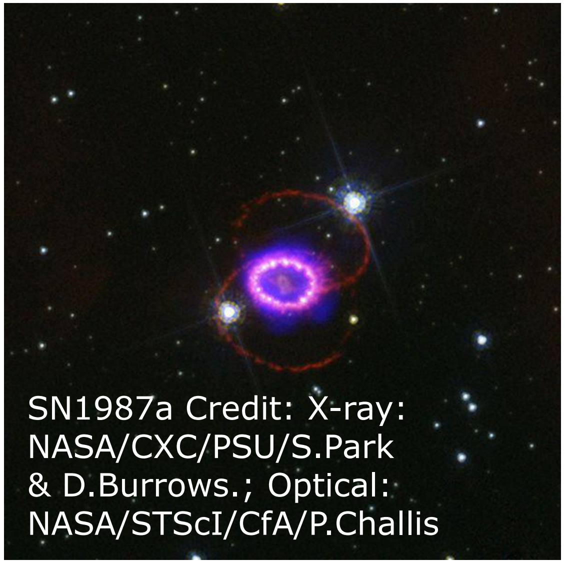
$\phi^8B=(5.25\pm0.20) \times 10^6/(cm^2\cdot sec)$

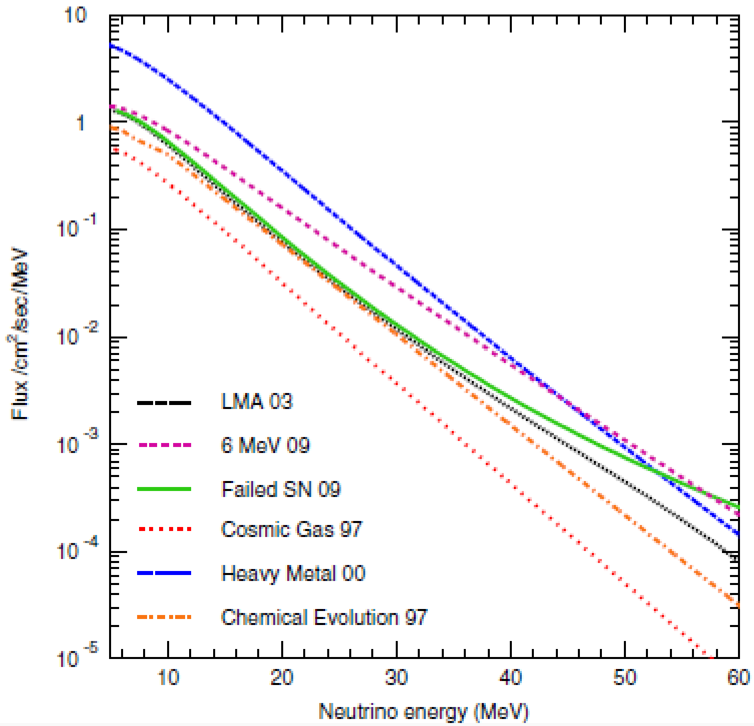
$(\Delta m^2_{21}, \theta_{12})$ from all solar data



Search for SN relic neutrinos

- All of the core collapse supernovae that have exploded throughout the history of the Universe have released neutrinos, which should still be in existence.



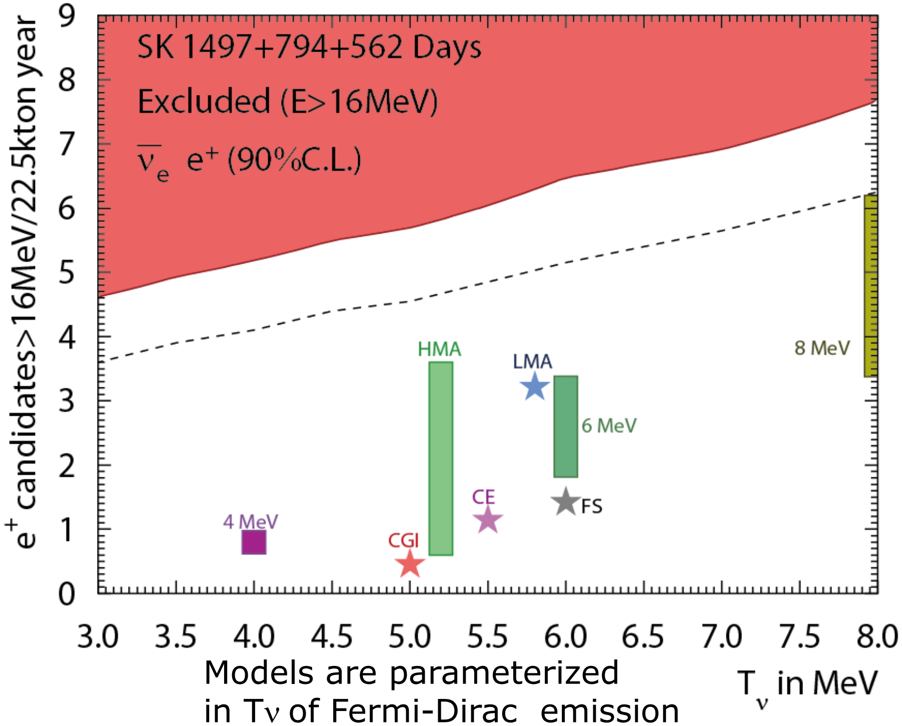


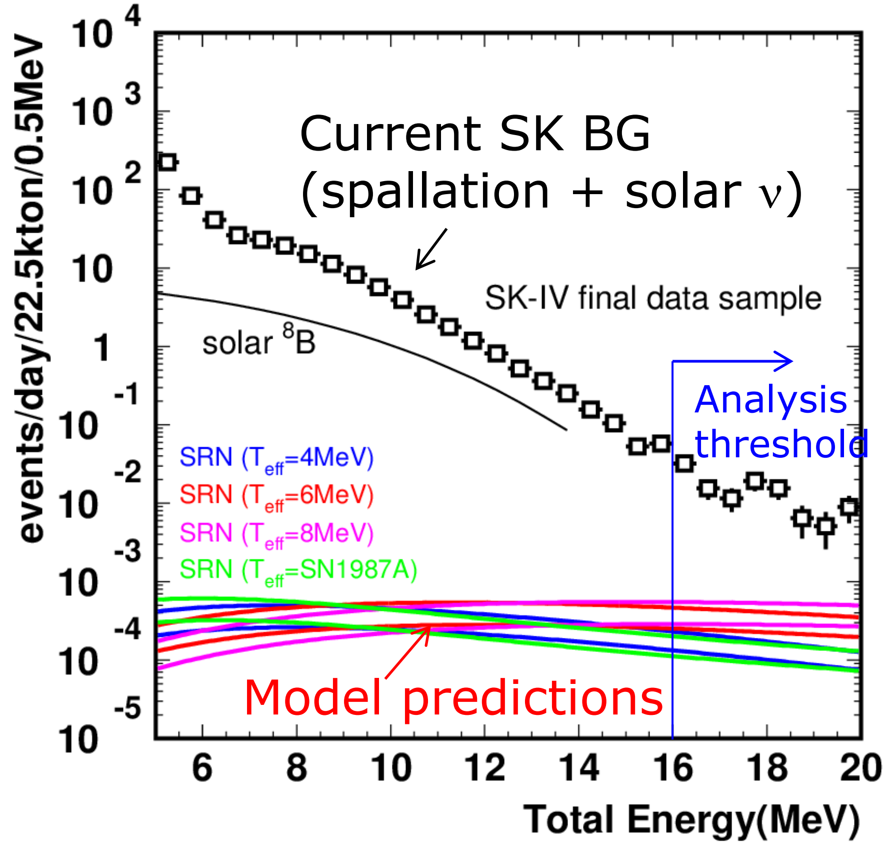
- Many SRN models that predict both the flux and the spectrum of anti-neutrino have been constructed.

Super-K sensitivity

- SK-I+II+III result is only factor 2 higher than models!

K.Bays et al., Phys.Rev.D85, 052007 (2012)





For LMA model Ando et al., (2005)
Combined 90% C.L.:
< 5.1 ev / yr / 22.5 ktons
< 2.7 /cm2/s (>16 MeV)

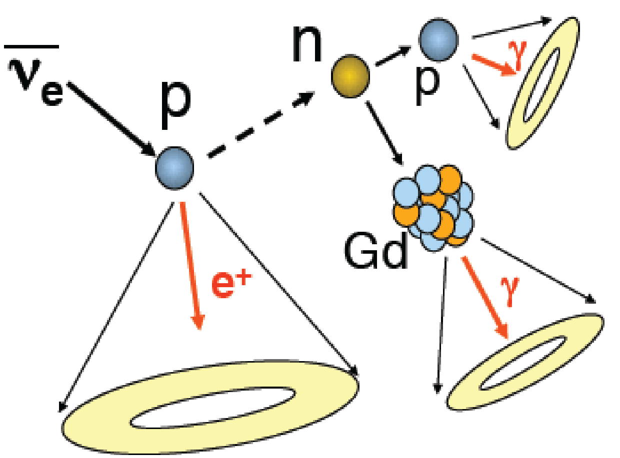
BG should be reduced ~O(10^4)

GADZOOKS! Project

Gadolinium
Antineutrino Detector
Zealously
Outperforming
Old
Kamiokande,
Super!

Beacom and Vagins, PRL, 93:171101, 2004

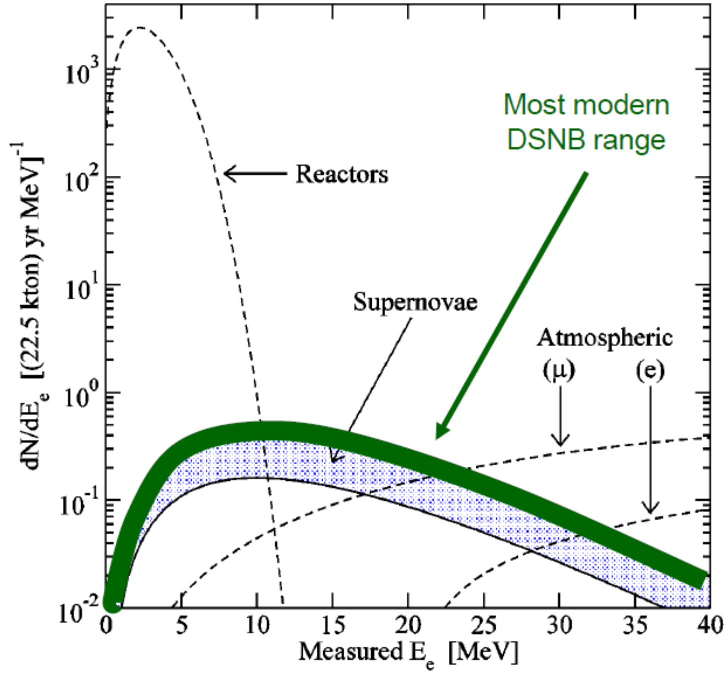
- 0.2% Gadolinium sulfate in SK
  - Neutron tag (signal) efficiency : 90%
  - Background reduction : 2×10^{-4}



Positron and gamma ray vertices are within ~50cm.

Possibility 1: 10% or less
$n+p \rightarrow d + \gamma$
2.2MeV γ-ray

Possibility 2: 90% or more
$n+Gd \rightarrow \sim 8MeV\ \gamma$
$\Delta T = \sim 30\ \mu sec$



$\overline{\nu}_e$ can be identified by the delayed coincidence technique

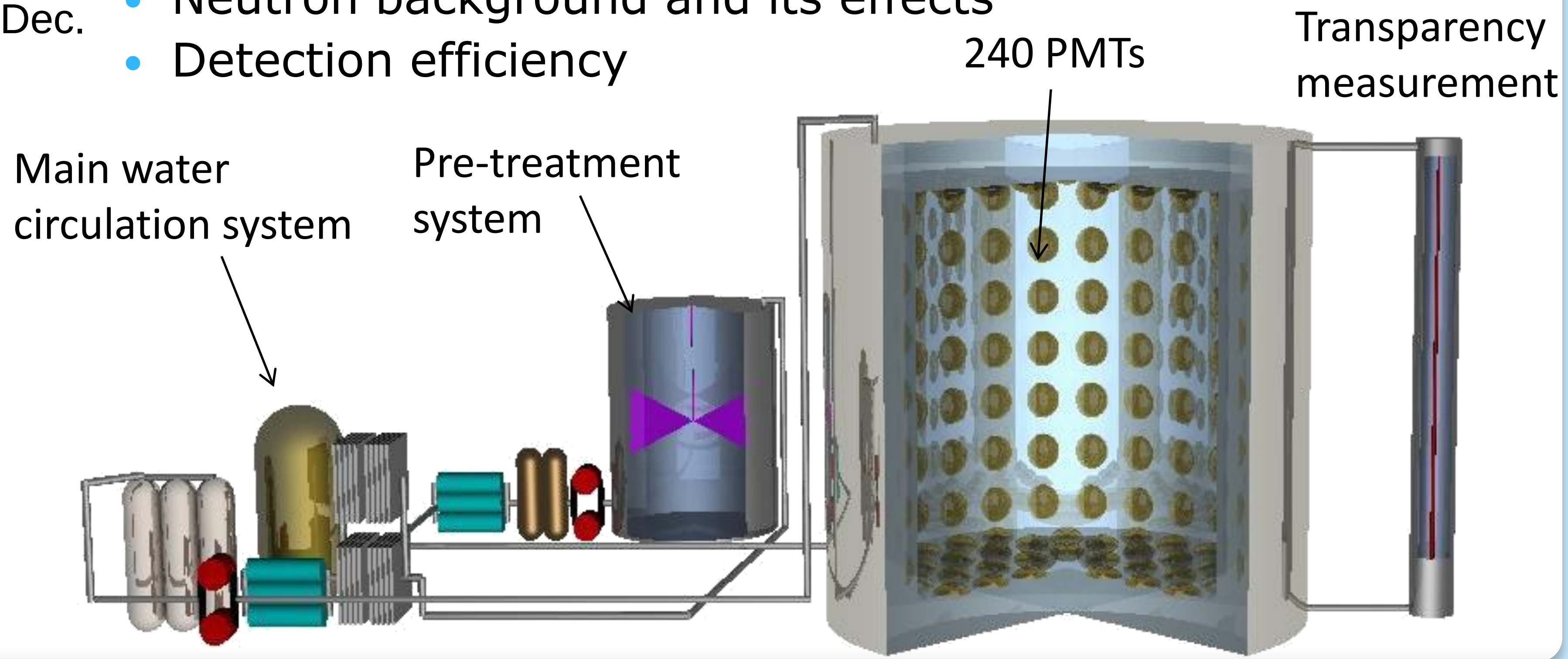
EGADS

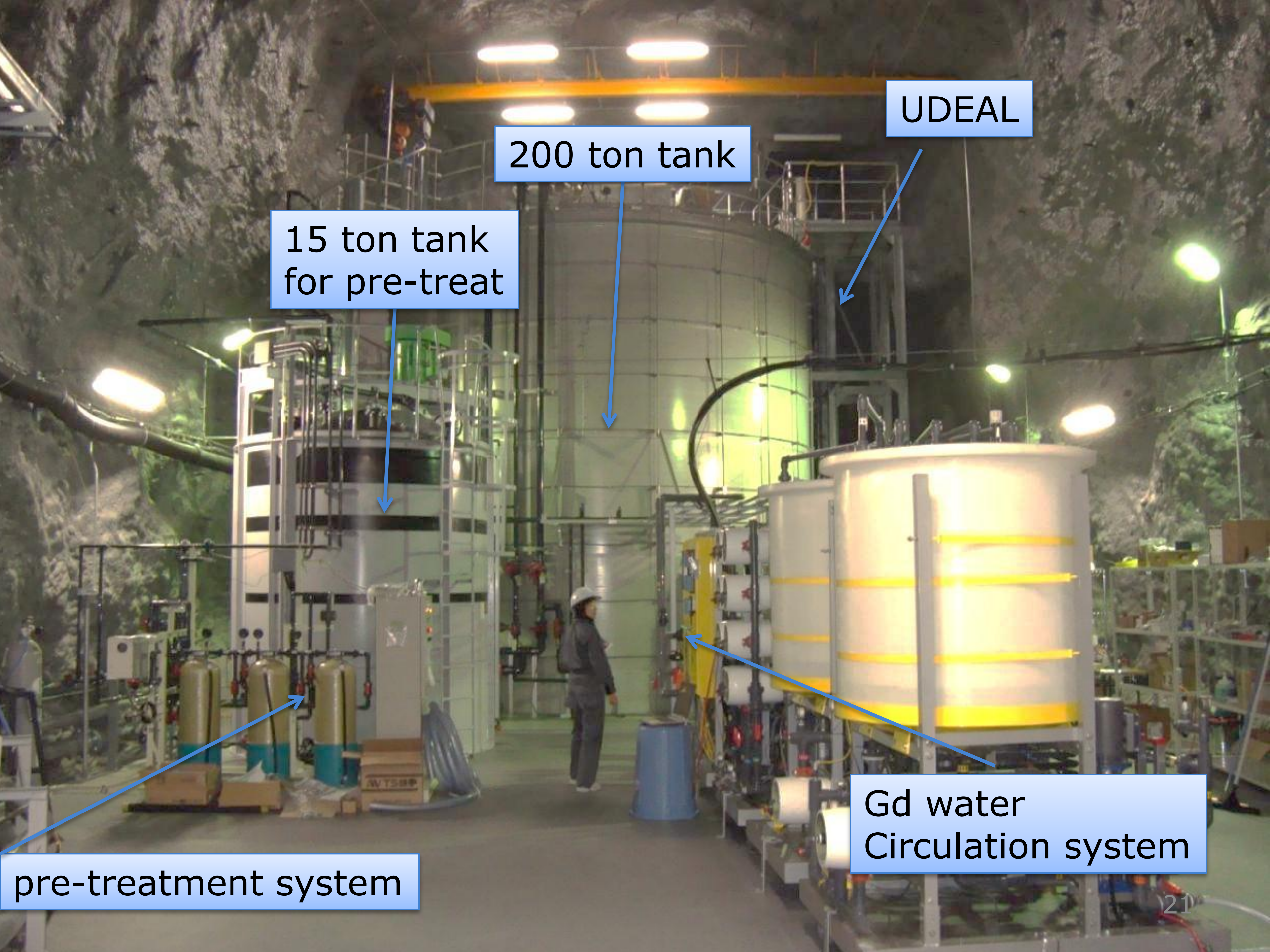
Evaluating Gadolinium's Action on Detector Systems

R&D items

Done
- ✓ Water purification with gadolinium sulfate
- ✓ Keep water transparency with gadolinium sulfate

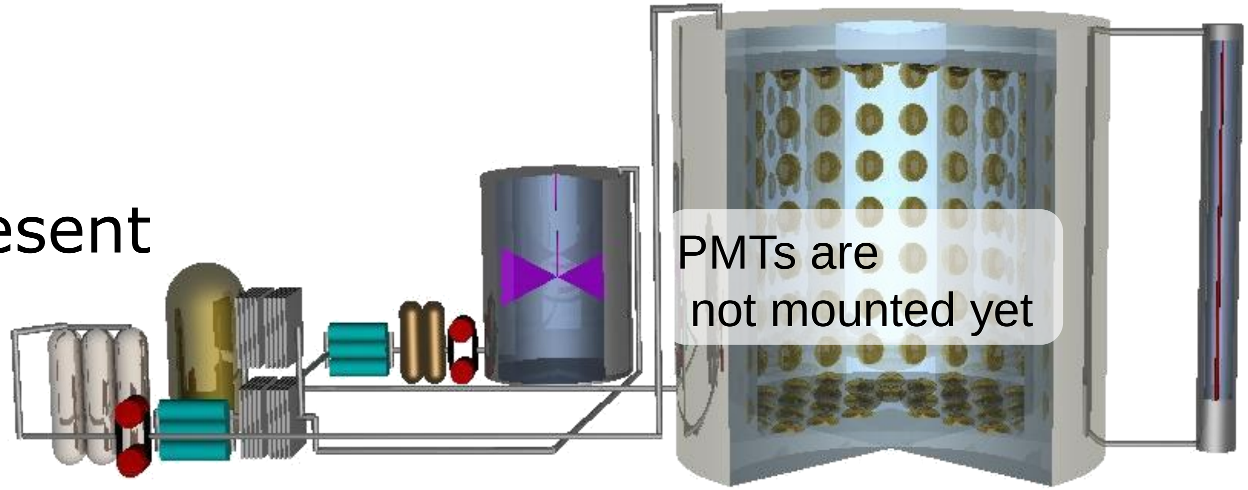
From Dec.
- Effects on Super-K components/materials
- Neutron background and its effects
- Detection efficiency




UDEAL
200 ton tank
15 ton tank
for pre-treat
Gd water
Circulation system
pre-treatment system

Status

- Aug.2011- Present



Long term stability and quality check

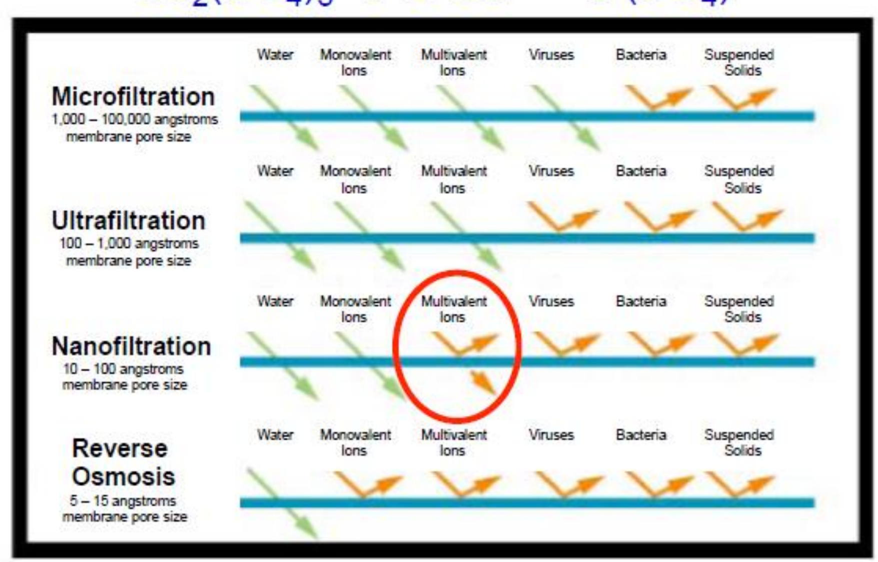
- 0.2% Gd-loaded water circulation (w/o 200t tank)

Selective filtration system

uses a molecular size band-pass scheme to filter the water.

Confirmed Gd-kept eff. > 99.9%

$Gd_2(SO_4)_3 \rightarrow 2\ Gd^{3+} + 3\ (SO_4)^{2-}$

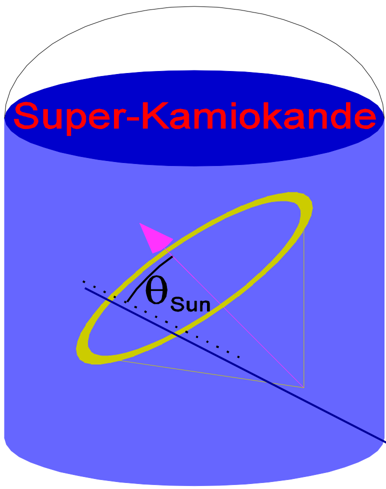


Conclusion

- Solar neutrino measurement in Super-K keeps improving.
  - lower threshold, lower BG, smaller errors, and larger statistics
- No significant spectrum distortion.
- Asymmetry in day/night flux @2.3σ, hint of non-zero?
- Neutrino oscillation parameters are updated from global fit;
  - $\Delta m^2_{12}=7.44^{+0.2}_{-0.19}\times10^{-5}eV^2$, $\sin^2\theta_{12}=0.304\pm0.013$, $\sin^2\theta_{13}=0.030^{+0.017}_{-0.015}$
- Adding 0.2% Gadolinium sulfate to SK, SRN event rate is expected to be 0.8 – 5.0 events/year/22.5kt (10 – 30 MeV)
  - EGADS, the R&D project is ongoing.
  - Neutron tagging efficiency measurement with 200t test tank and 240 PMTs will be done.

Extra slides

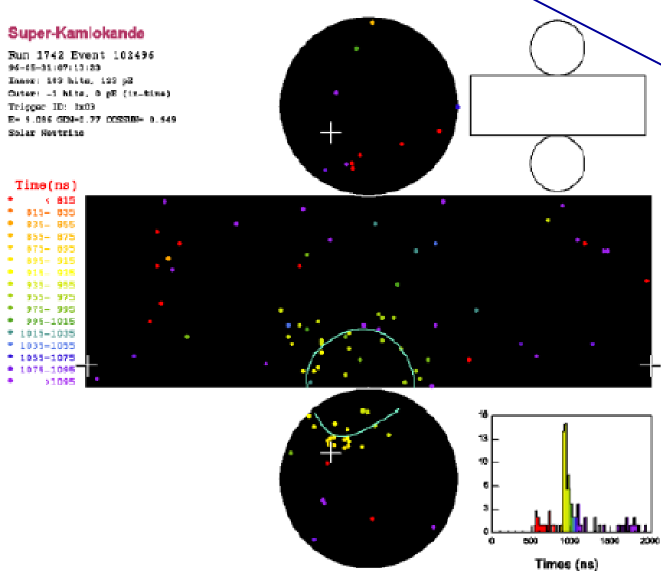
Solar neutrinos observation

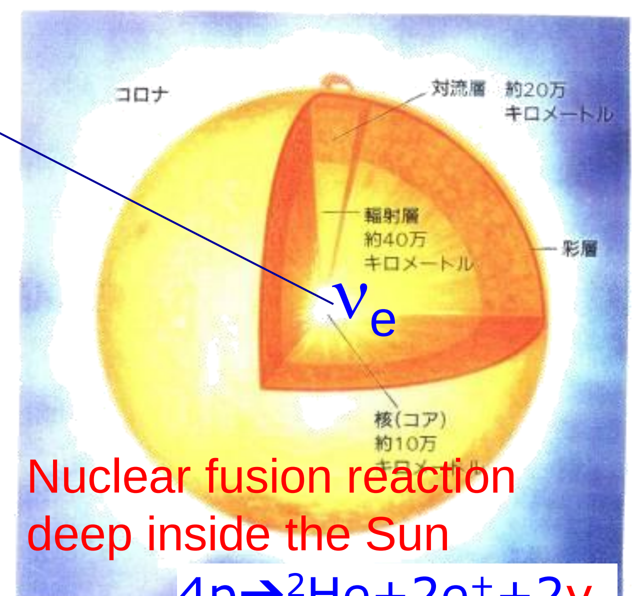


Neutrino-electron elastic scattering

$$n + e^- \rightarrow n + e^-$$

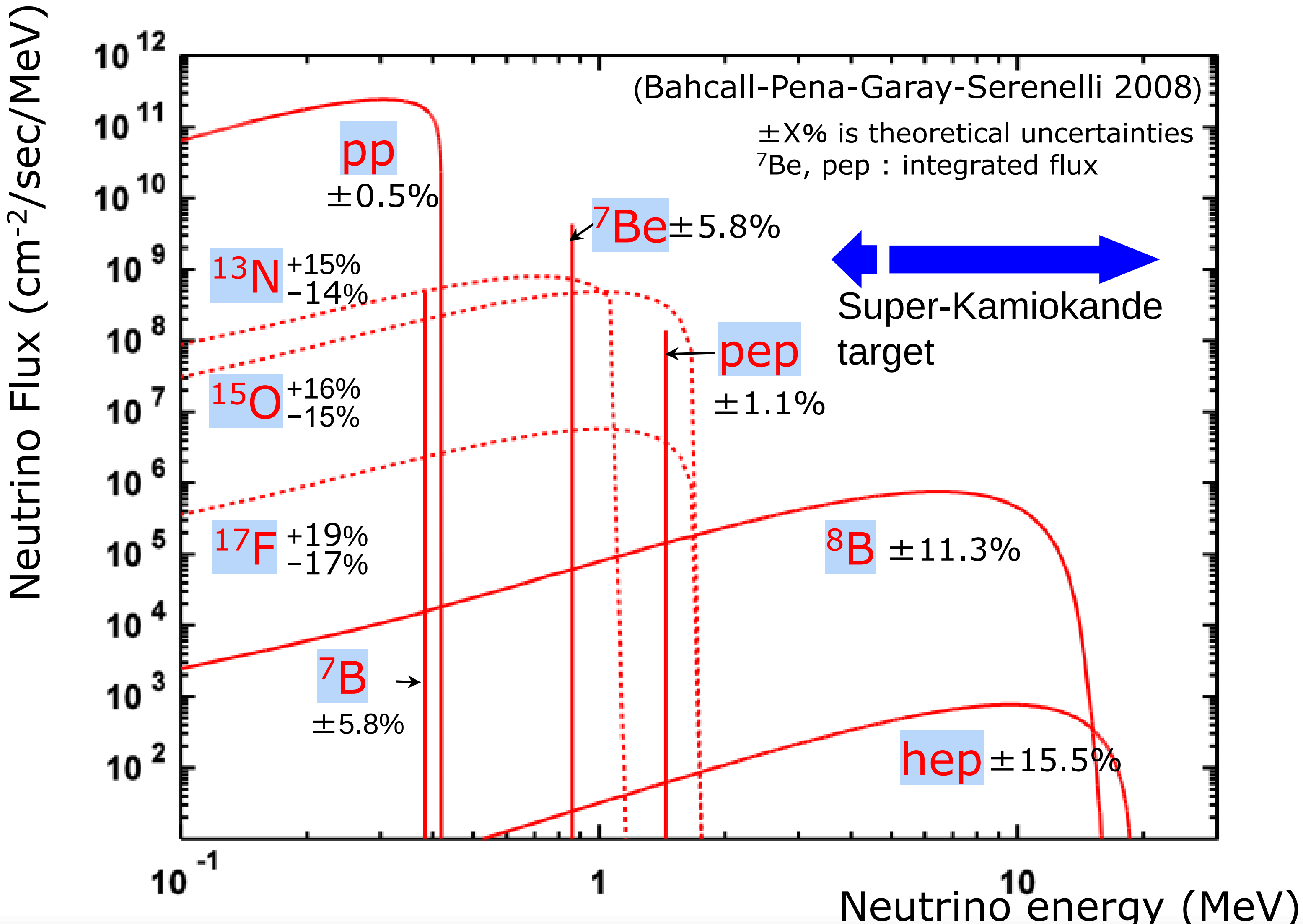
- Solar direction sensitive
- Realtime measurements
  - Energy spectrum
  - day/night flux differences
  - Seasonal variation



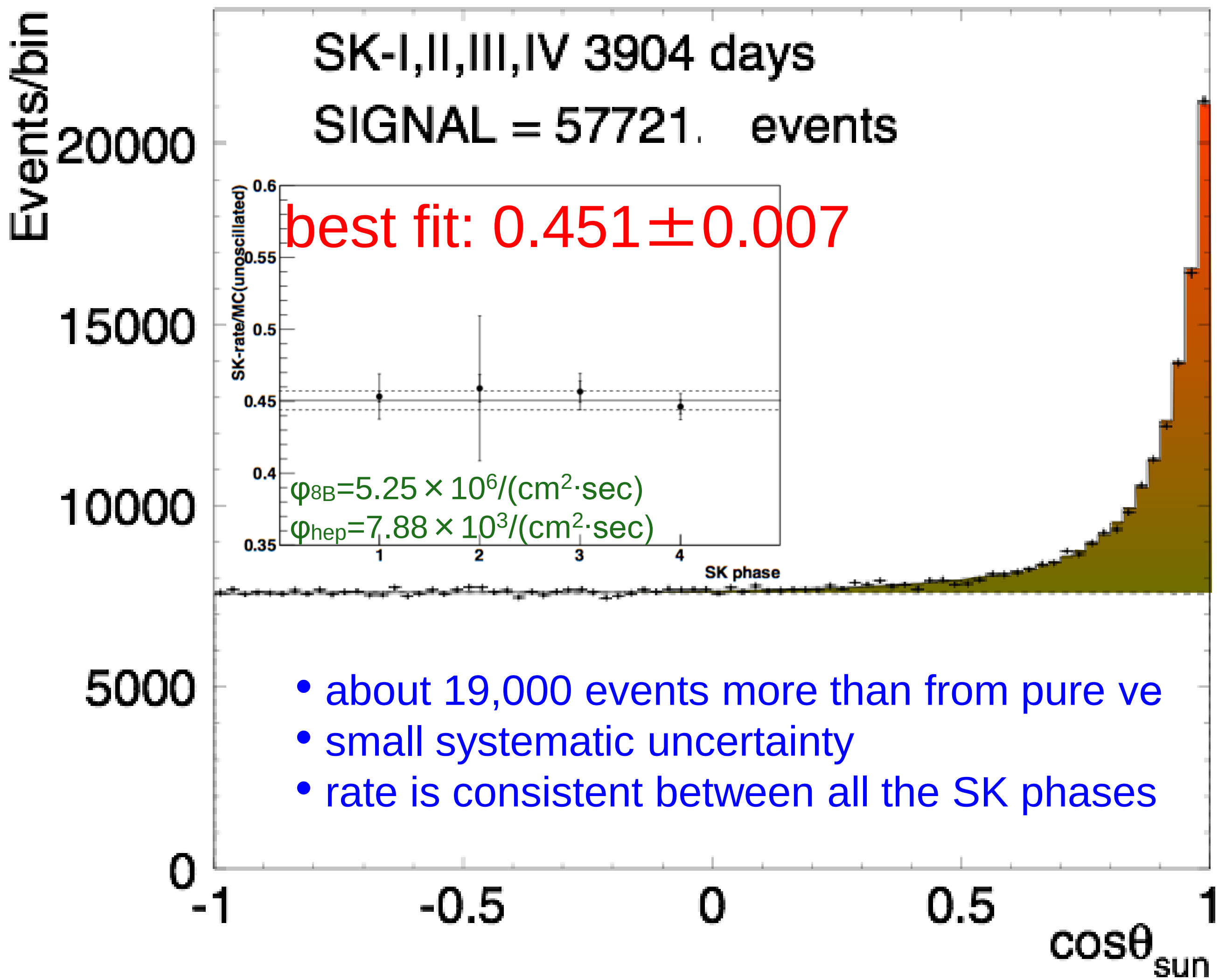


$4p \rightarrow {}^2He + 2e^+ + 2\nu_e$

Solar neutrino spectrum

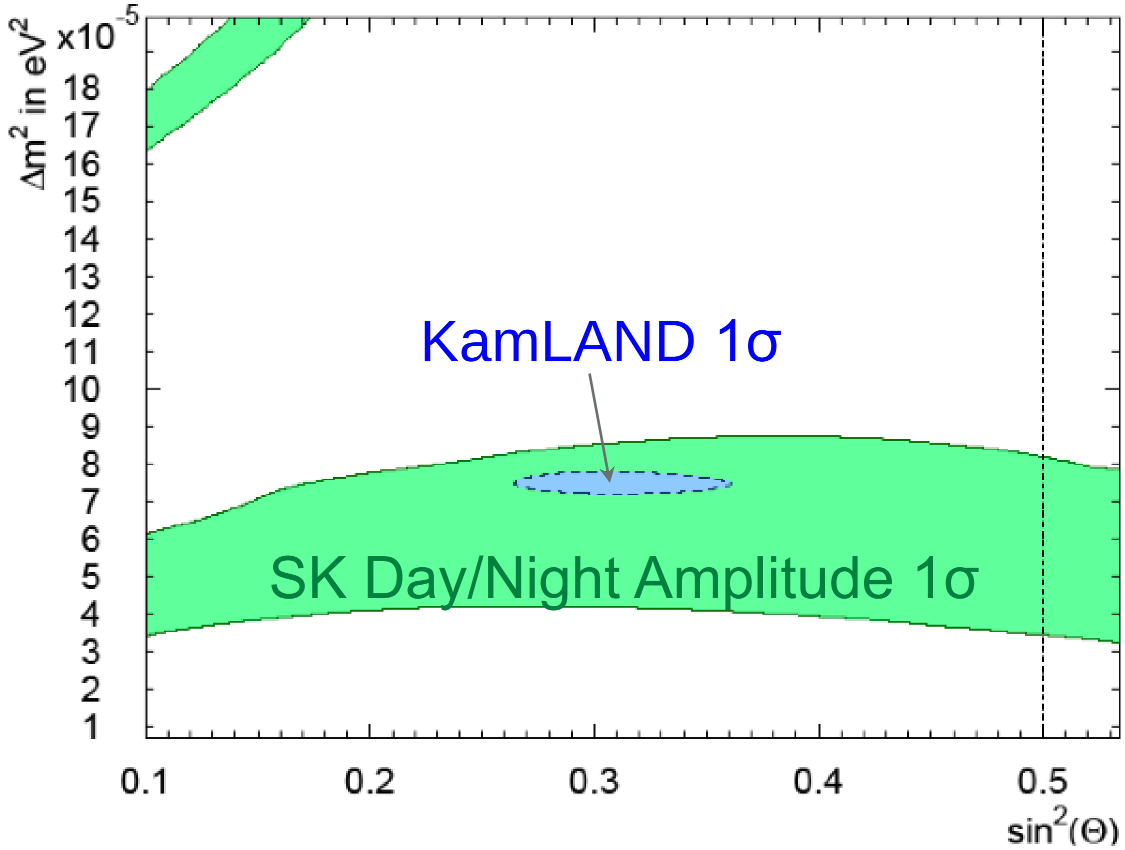


Total solar neutrino event



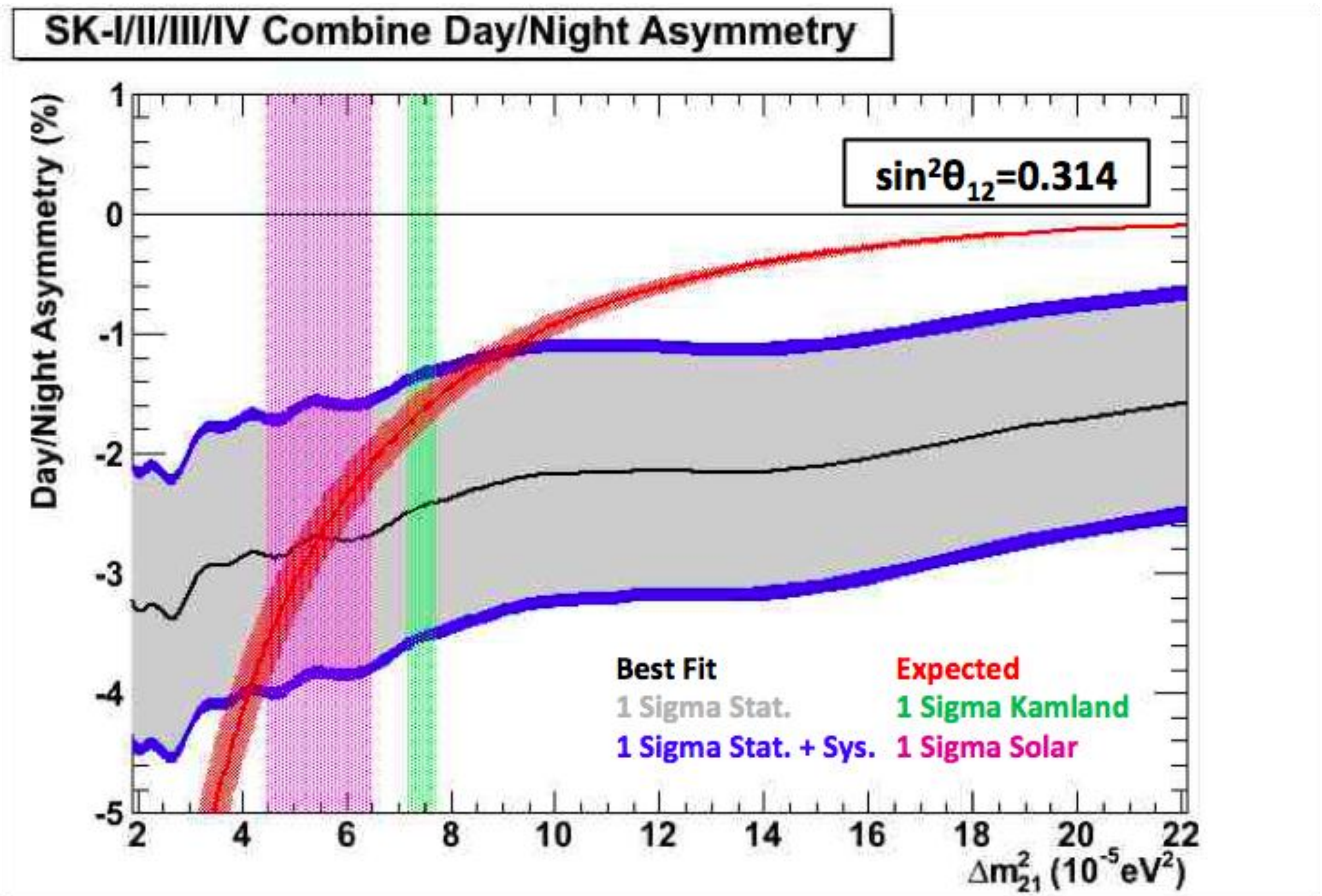
- about 19,000 events more than from pure ve
- small systematic uncertainty
- rate is consistent between all the SK phases

Allowed oscillation parameter region from Day/Night data



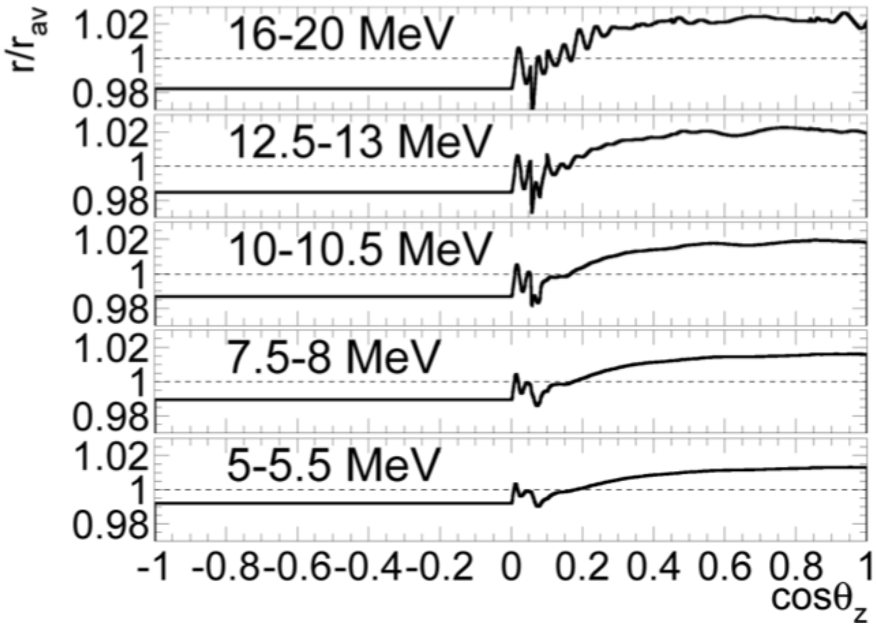
The best constraint of Δm^2_{12} among all solar neutrino measurements

Day/Night amplitude fits as a function of Δm^2



Day/Night variation

Expected rate variation
Earth "matter" model



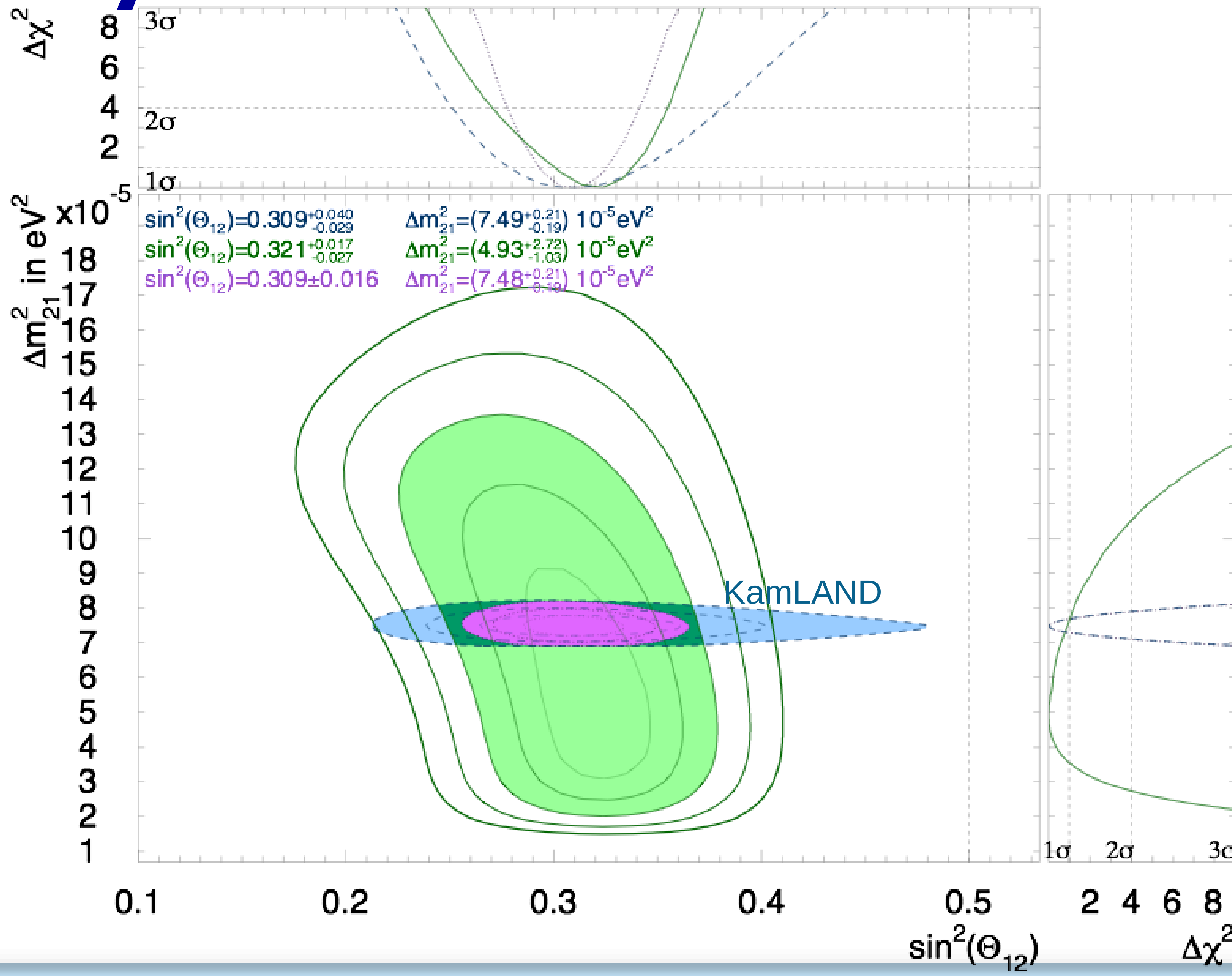
from Phys.Rev. D69 011104 (2004): $\Delta m_{21}^2=6.3\cdot 10^{-5} eV^2$

we assumed this kind of zenith angle shape from the neutrino oscillation parameter, and fit to the data.

Day/Night Asym.:
$A_{DN}=2(\varphi_D-\varphi_N)/(\varphi_D+\varphi_N)$

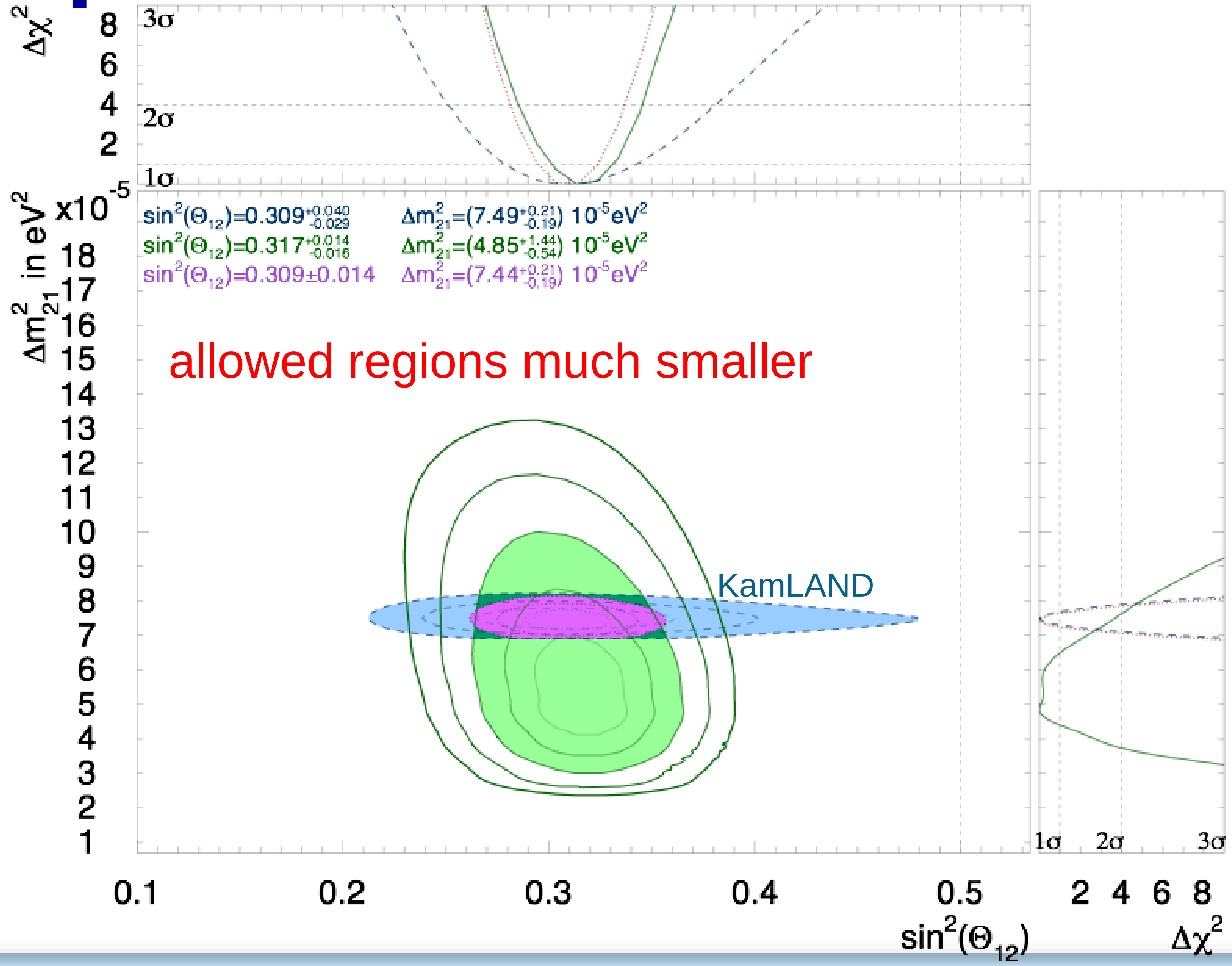
Phase	D/N amplitude	A_{DN}
SK-I	-2.0±1.7±1.0%	-2.1±2.0±1.3%
SK-II	-4.3±3.8±1.0%	-6.3±4.2±3.7%
SK-III	-4.3±2.7±0.7%	-5.9±3.4±1.3%
SK-IV	-2.8±1.9±0.7%	-5.2±2.3±1.4%
SK comb.	-2.8±1.1±0.5%	-4.0±1.3±0.8%

Only SNO



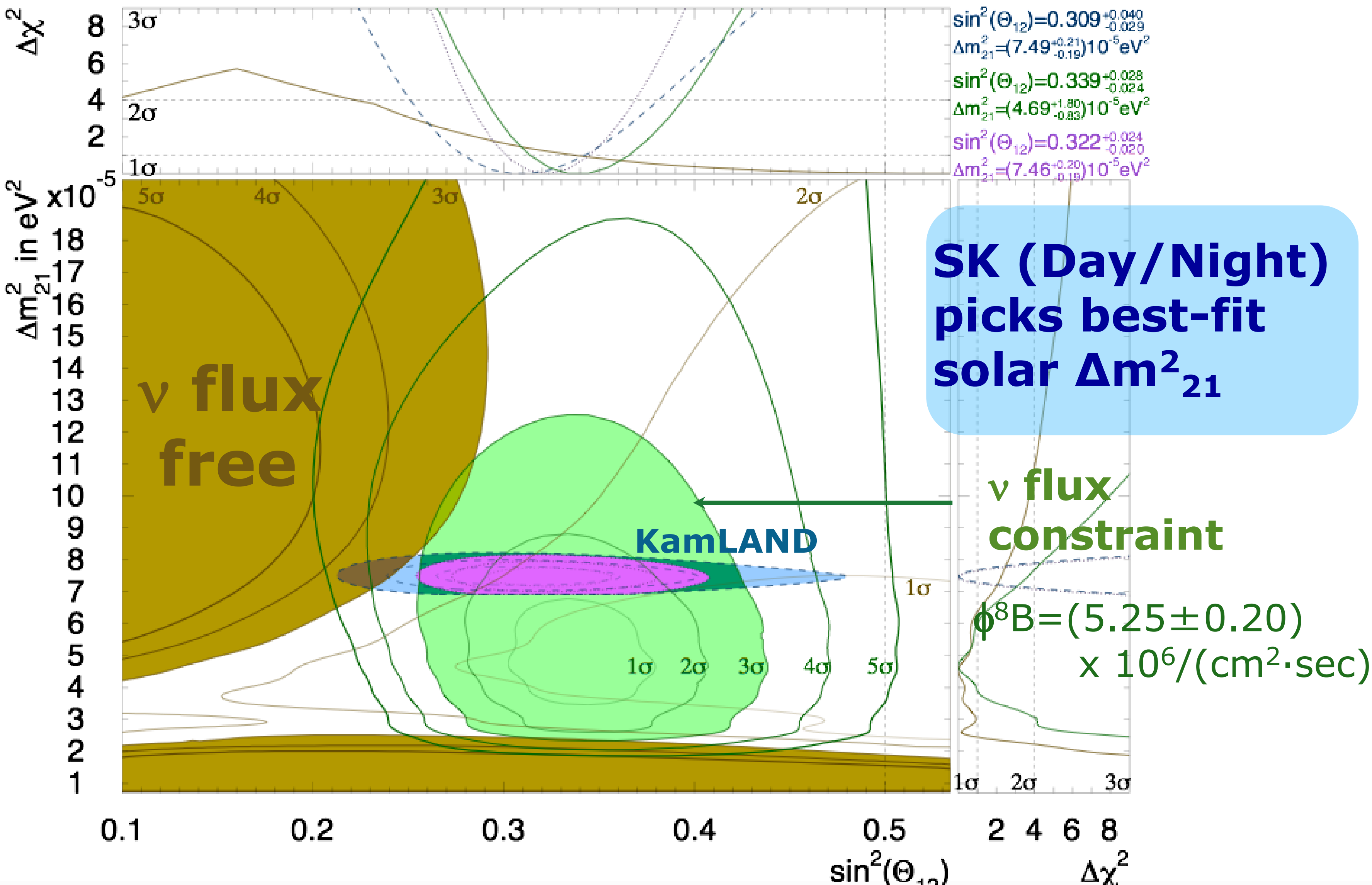
sin²(Θ12)=0.309 +0.040 -0.029
Δm²21=(7.49 +0.21 -0.19) 10⁻⁵eV²
sin²(Θ12)=0.321 +0.017 -0.027
Δm²21=(4.93 +2.72 -1.03) 10⁻⁵eV²
sin²(Θ12)=0.309±0.016
Δm²21=(7.48 +0.21 -0.19) 10⁻⁵eV²
KamLAND
Δχ²
3σ
2σ
1σ
Δm²21 in eV²
x10⁻⁵
sin²(Θ12)
0.1
0.2
0.3
0.4
0.5
2 4 6 8

Super-K + SNO

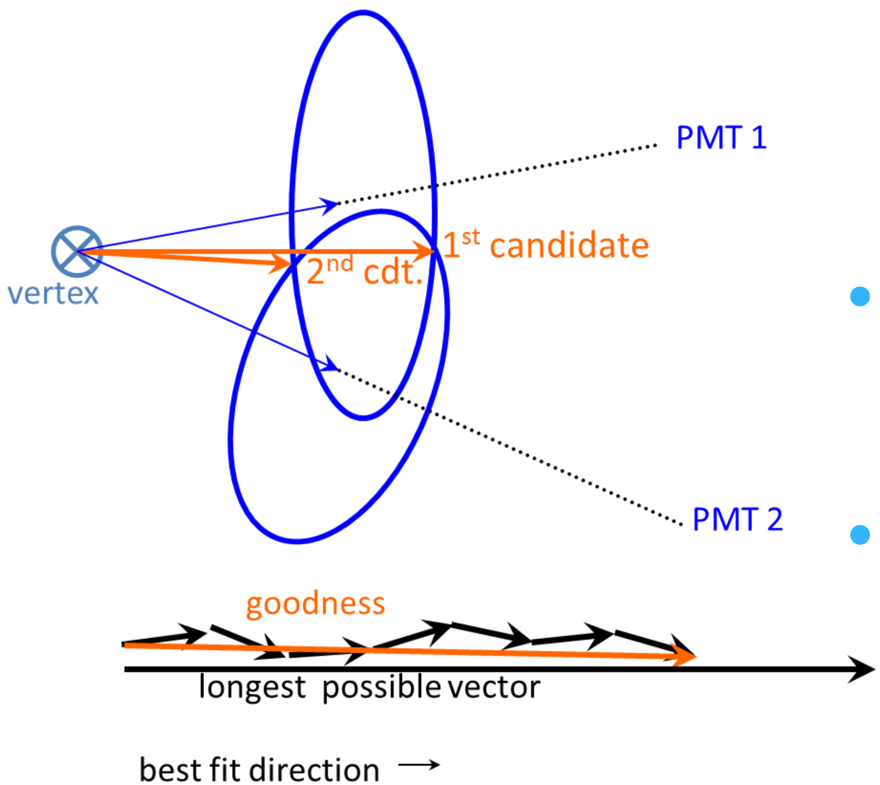


allowed regions much smaller
KamLAND
sin²(Θ12)=0.309+0.040-0.029 Δm²21=(7.49+0.21-0.19) 10⁻⁵eV²
sin²(Θ12)=0.317+0.014-0.016 Δm²21=(4.85+1.44-0.54) 10⁻⁵eV²
sin²(Θ12)=0.309±0.014 Δm²21=(7.44+0.21-0.19) 10⁻⁵eV²
Δm²21 in eV² x10⁻⁵
sin²(Θ12)
Δχ²
1σ
2σ
3σ

(Δm^2_{12} ,θ_{12}) from Only Super-K



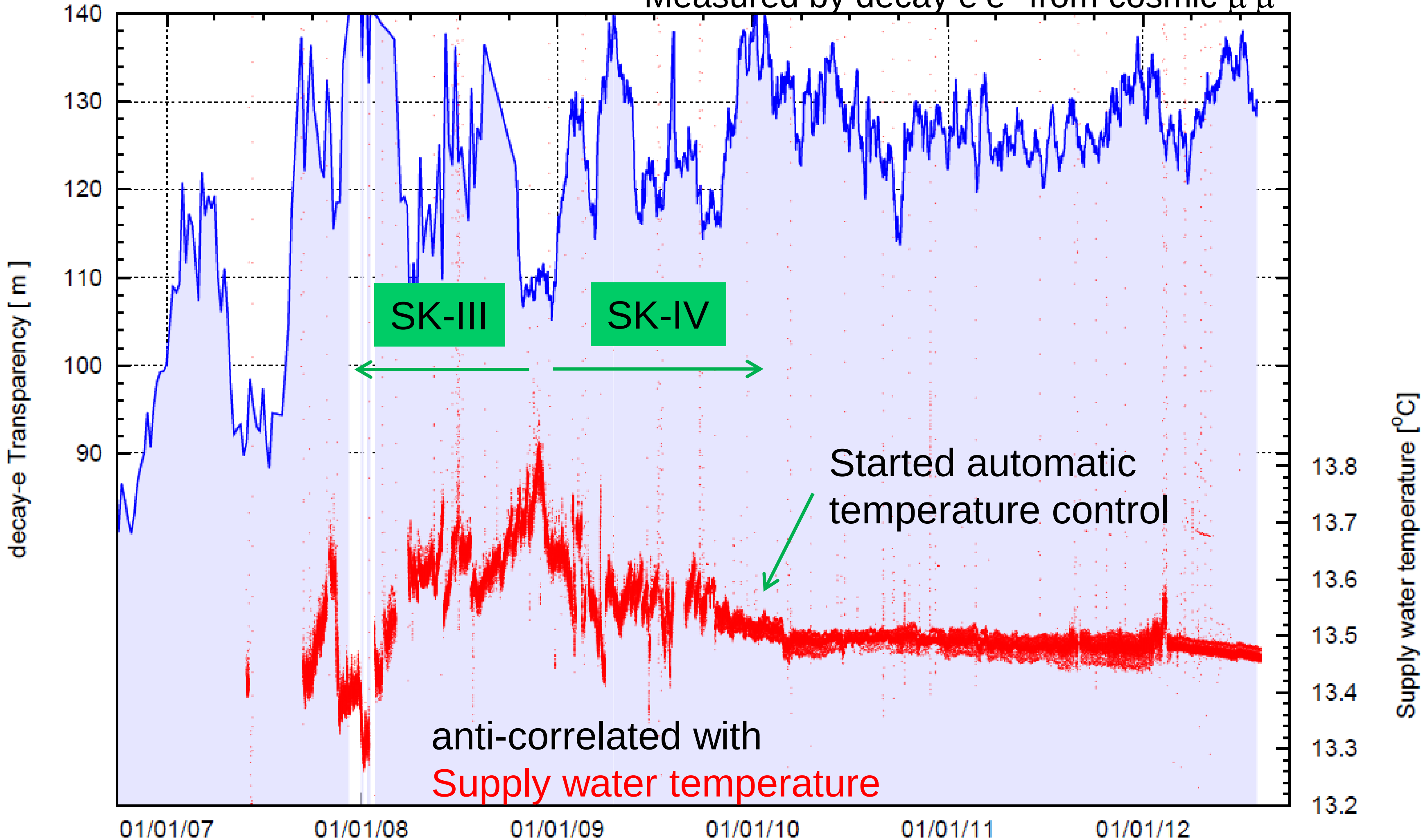
MSG



- For each PMT hit pair, the vectors to the Chrenkov ring cross points are the direction candidates
- MSG = vector sum of the candidates/ scalar sum of the candidates
- MSG of multiple scattering events should be small

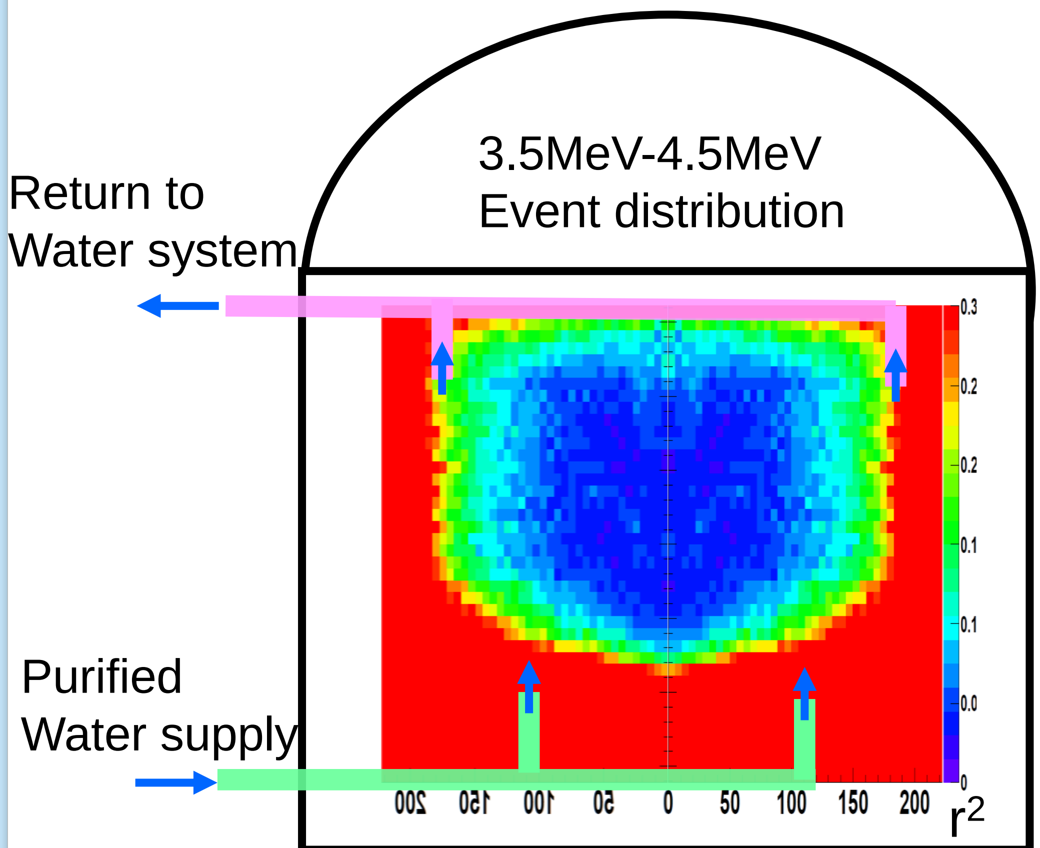
Super-K water transparency

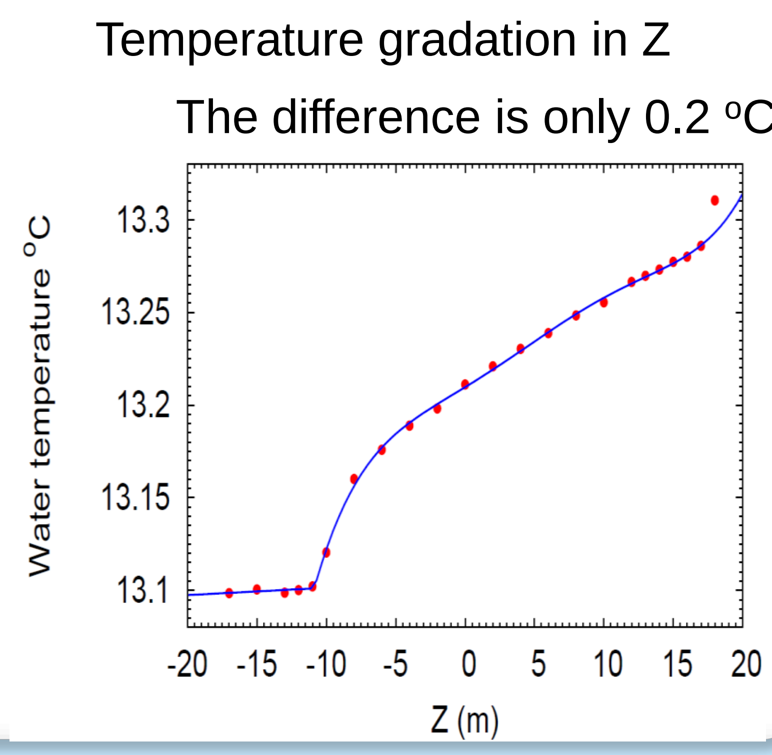
@ Cherenkov light wavelength
Measured by decay e^-e^+ from cosmic $\mu^-\mu^+$



Convection suppression in SK

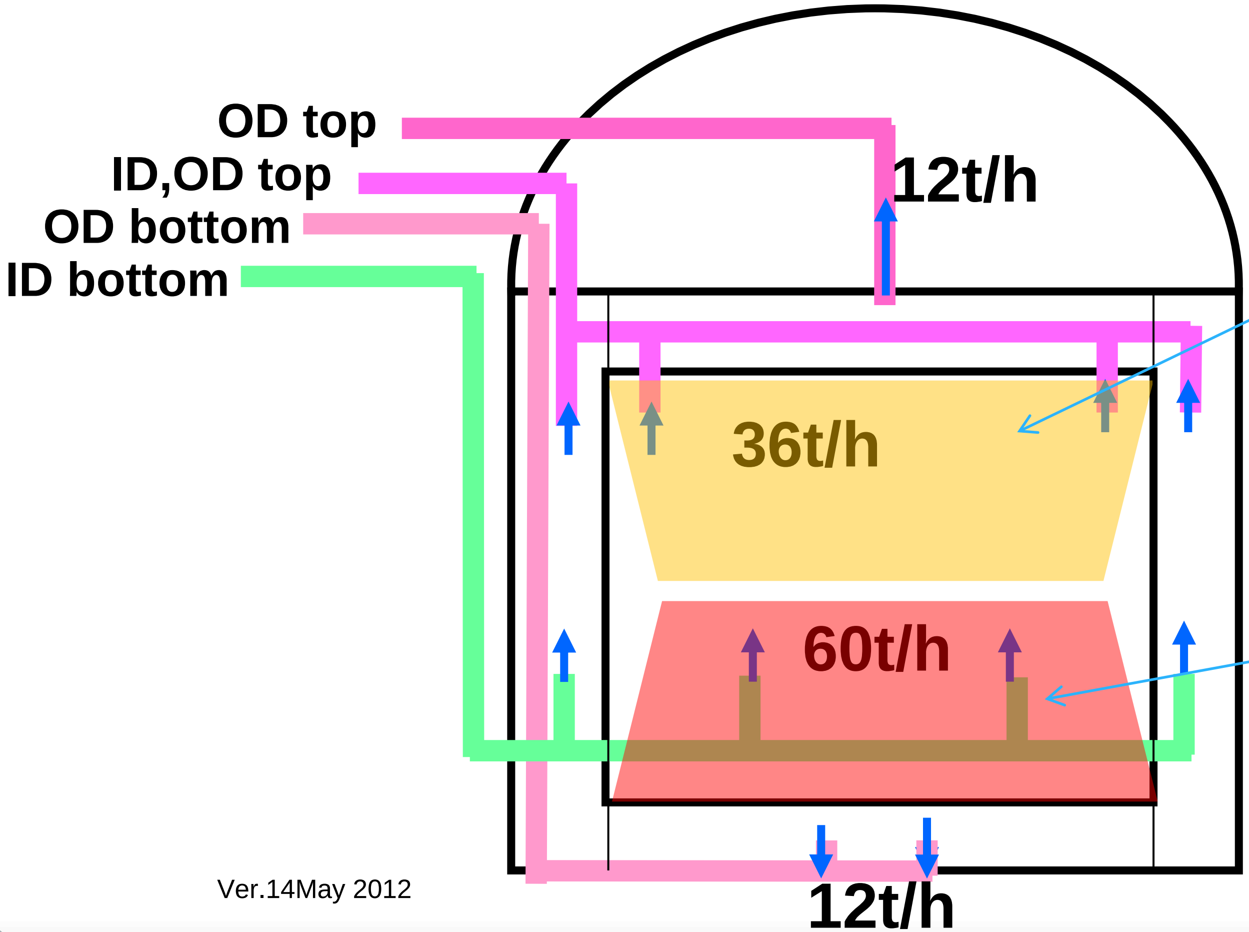
- Very precisely temperature-controlled ($\pm 0.01^{o}C$) water is supplied to the bottom.





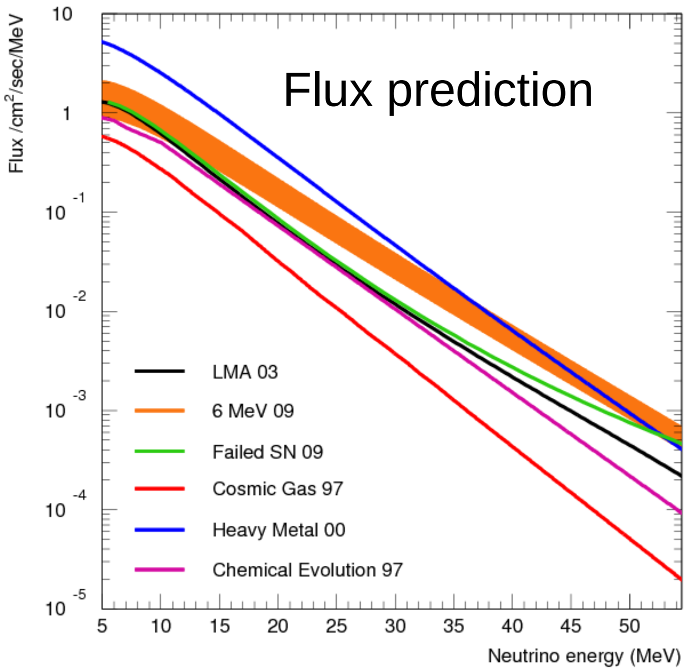
Current SK situation

- Stagnation and top-bottom asymmetry.

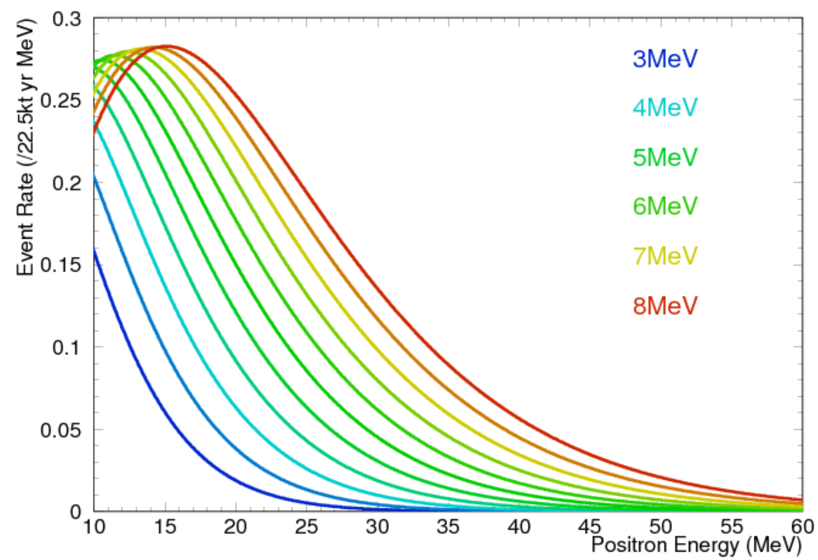


SRN models

- Cosmology(cosmic star formation history, initial mass function, Hubble expansion, etc) is establised, so we can simply parameterize with
  - $\bar{\nu}_e$ luminosity of typical supernova
  - Average $\bar{\nu}_e$ energy $\rightarrow$ $\bar{\nu}_e$ Temp. (Fermi-Dirac emission)

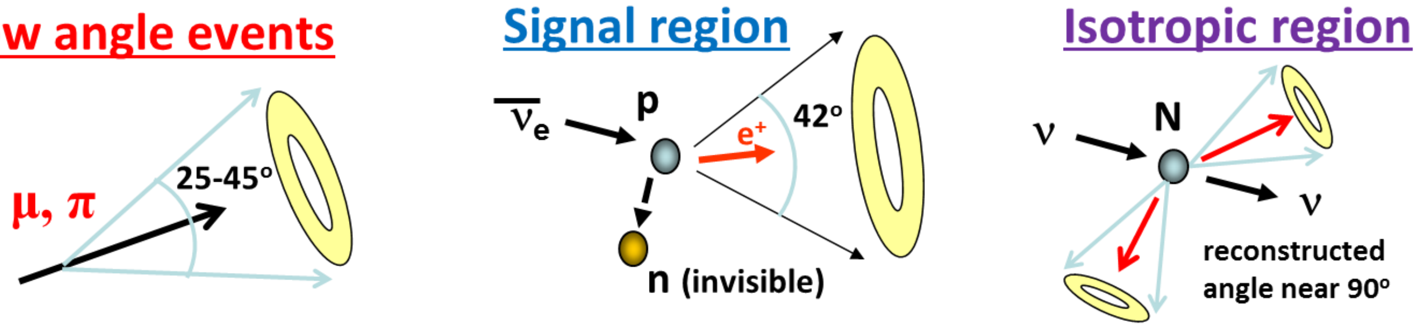


SK rate prediction

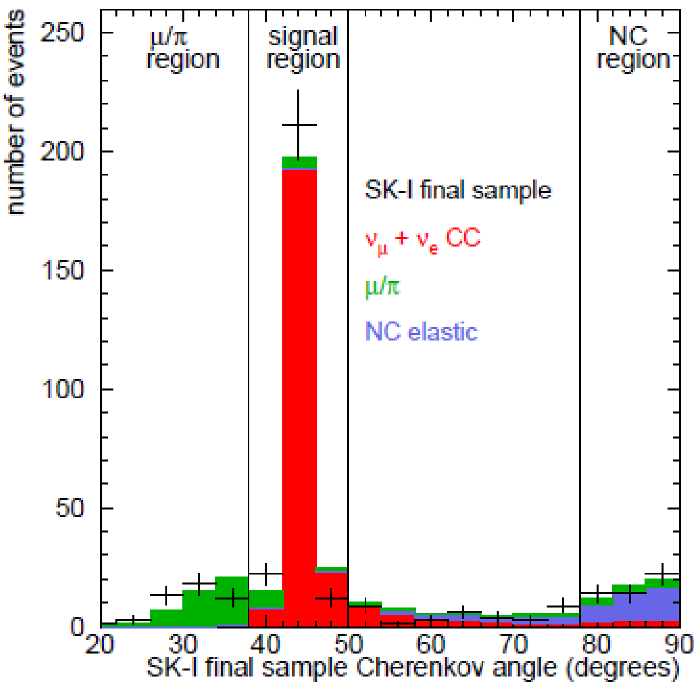


BG Cherenkov angle distribution

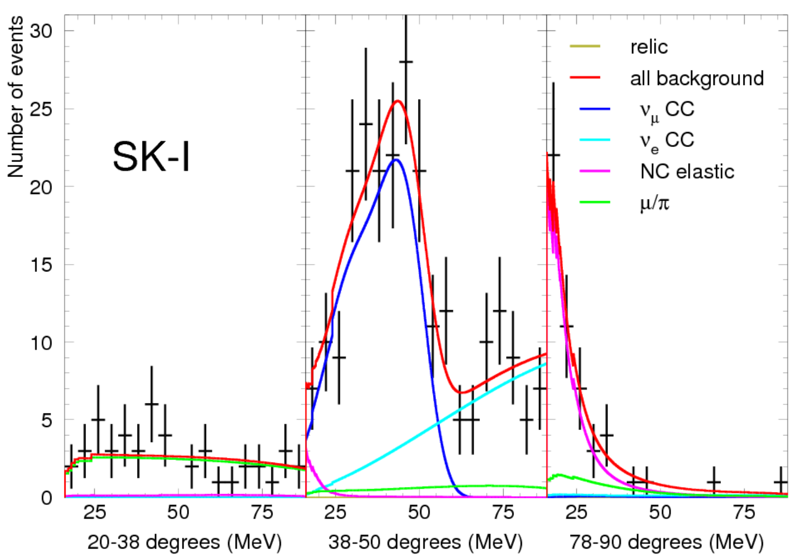
- Dominant BGs are atomospheric $\nu_e \nu_\mu$ CC



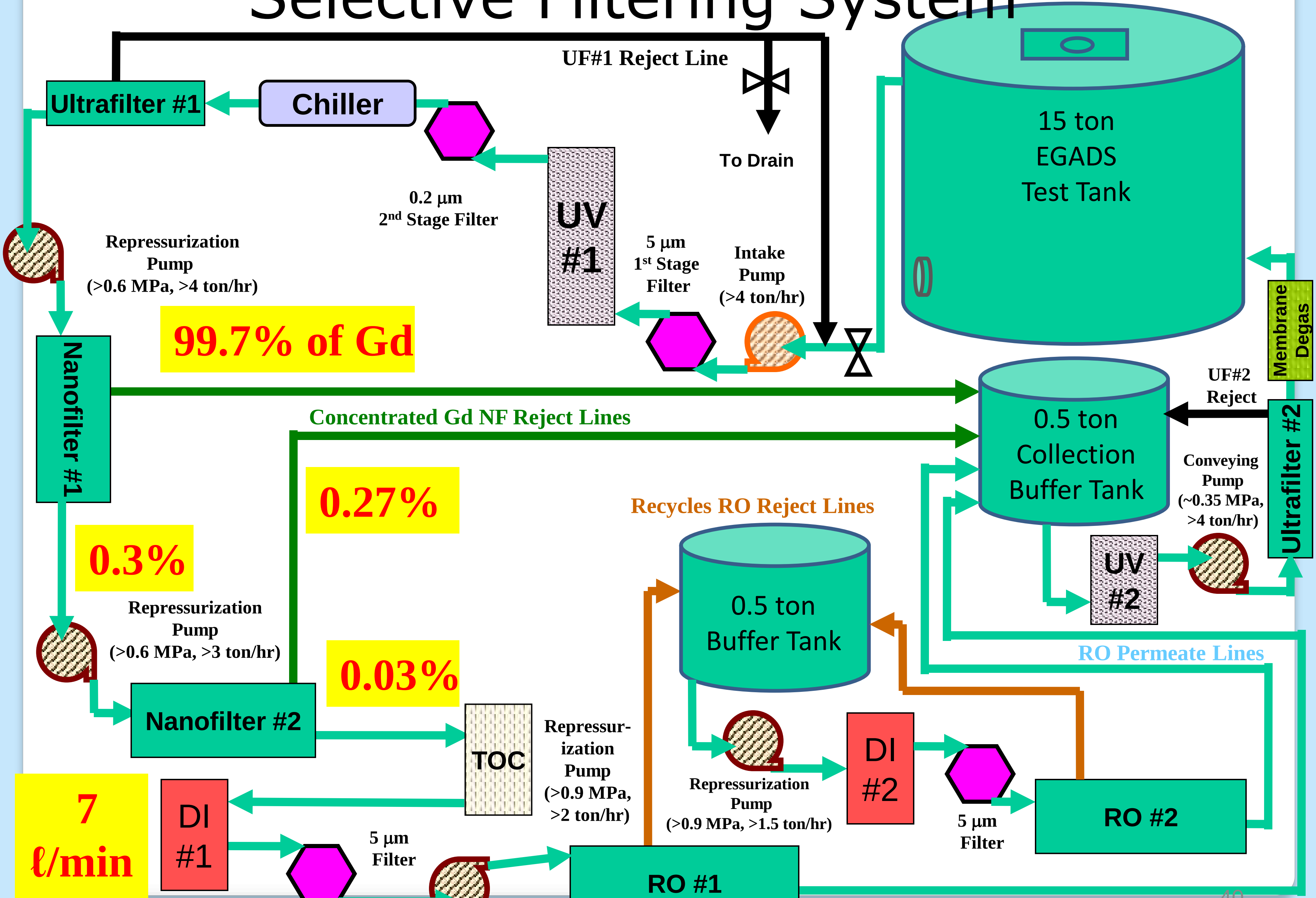
- SK-I data/MC



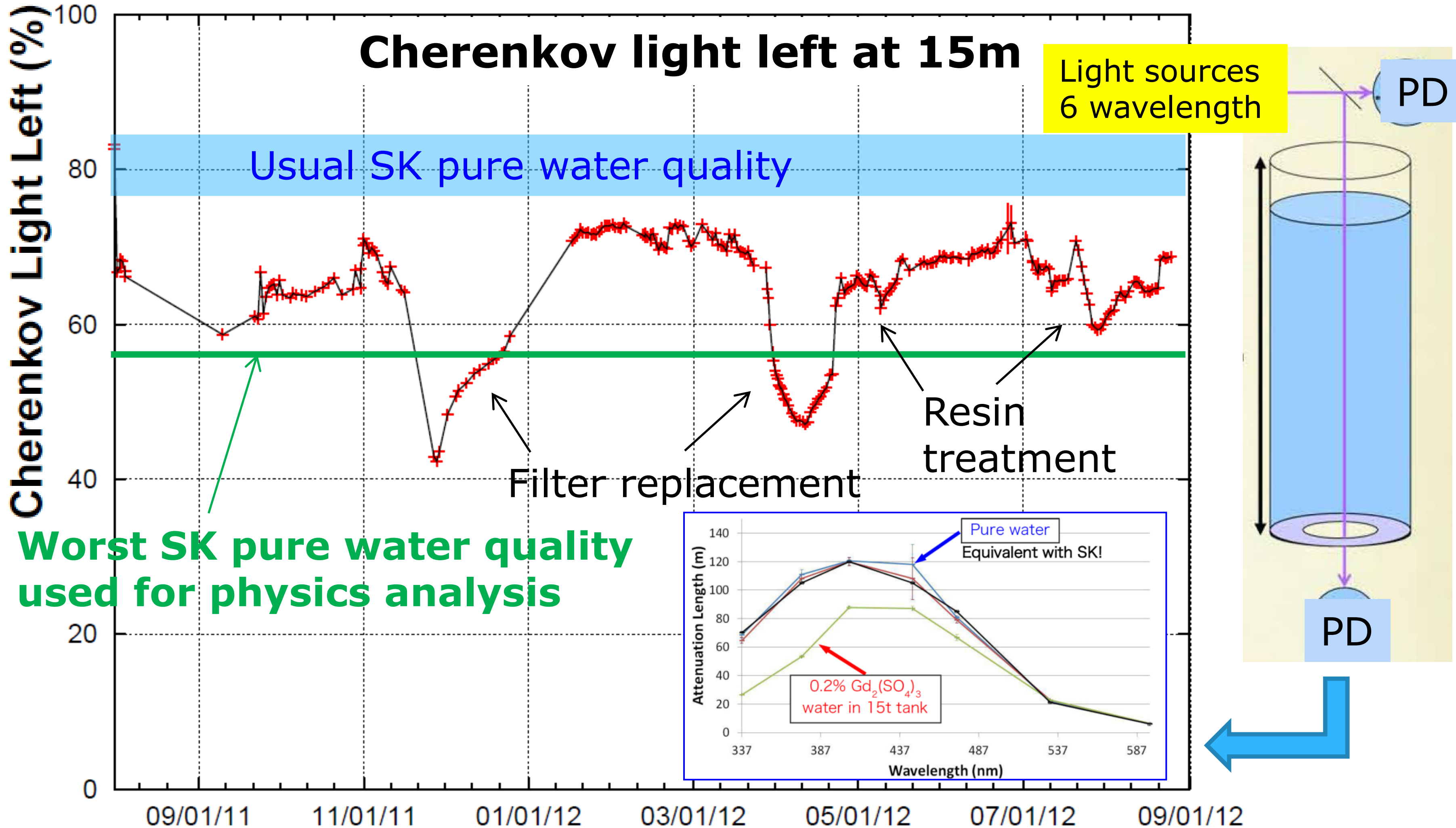
- Signal+BG fitting



Selective Filtering System



Gd-loaded water transparency



0.2% Gd-loaded water is OK for Cherenkov detector