スーパーカミオカンデ
太陽ニュートリノ・超新星ニュートリノ

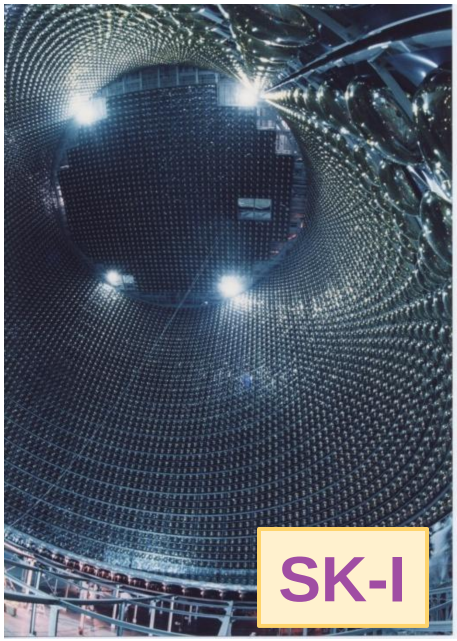
樹林敦子
岡山大学

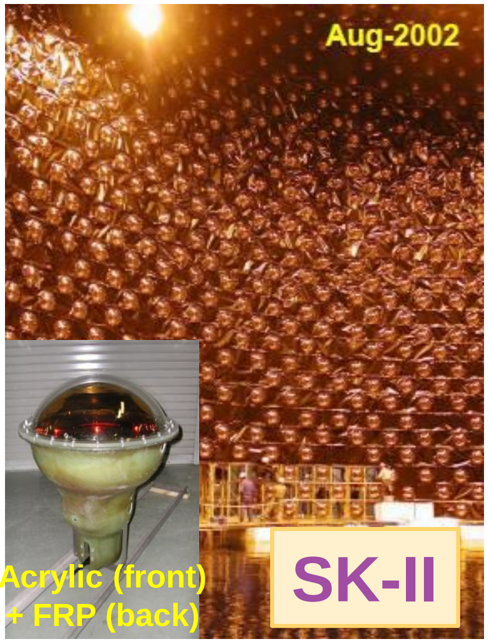
2012年12月7日
平成24年度共同利用研究成果発表会

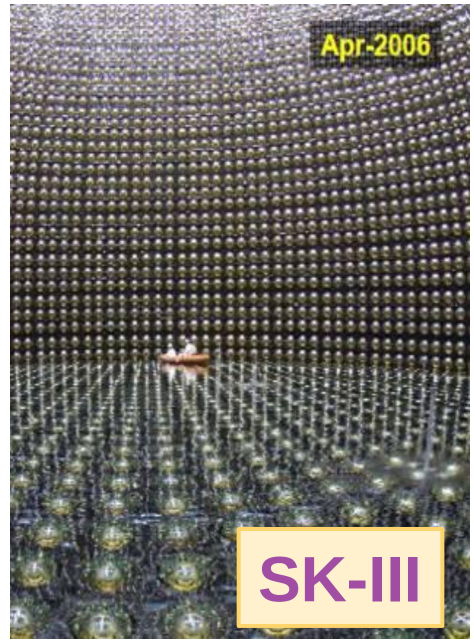
History of Super-Kamiokande

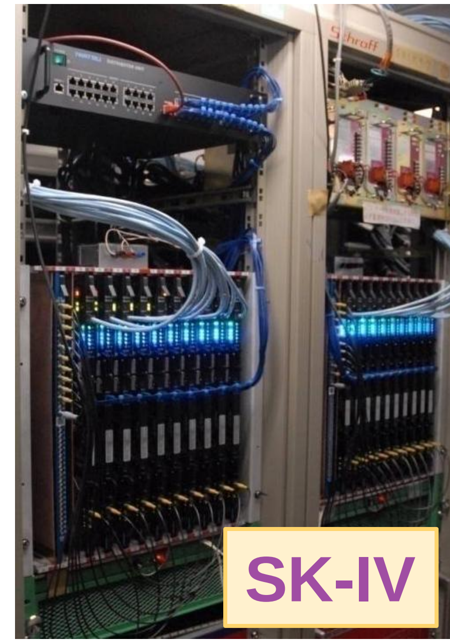
96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12

SK-I SK-II SK-III SK-IV





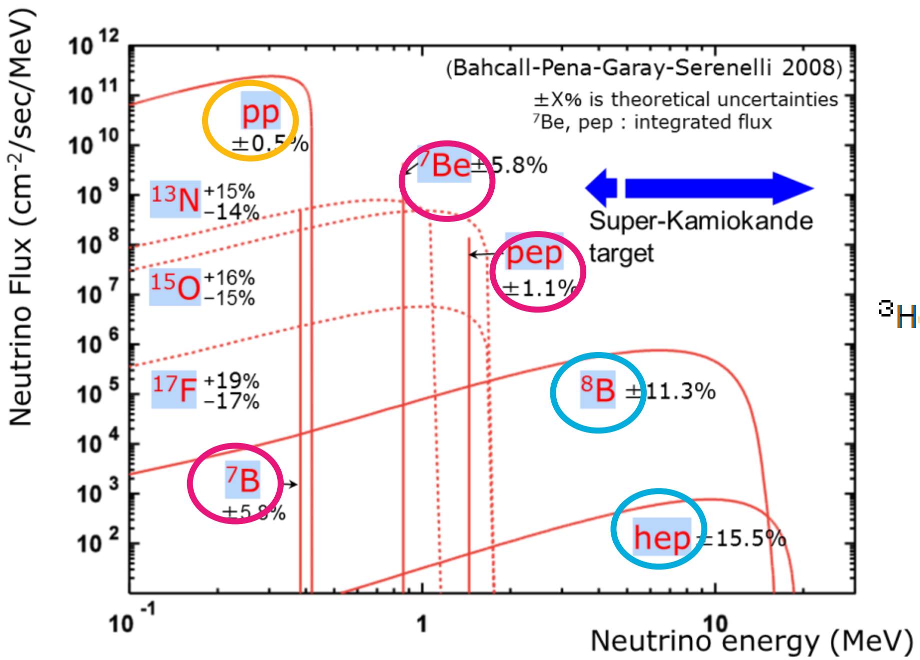


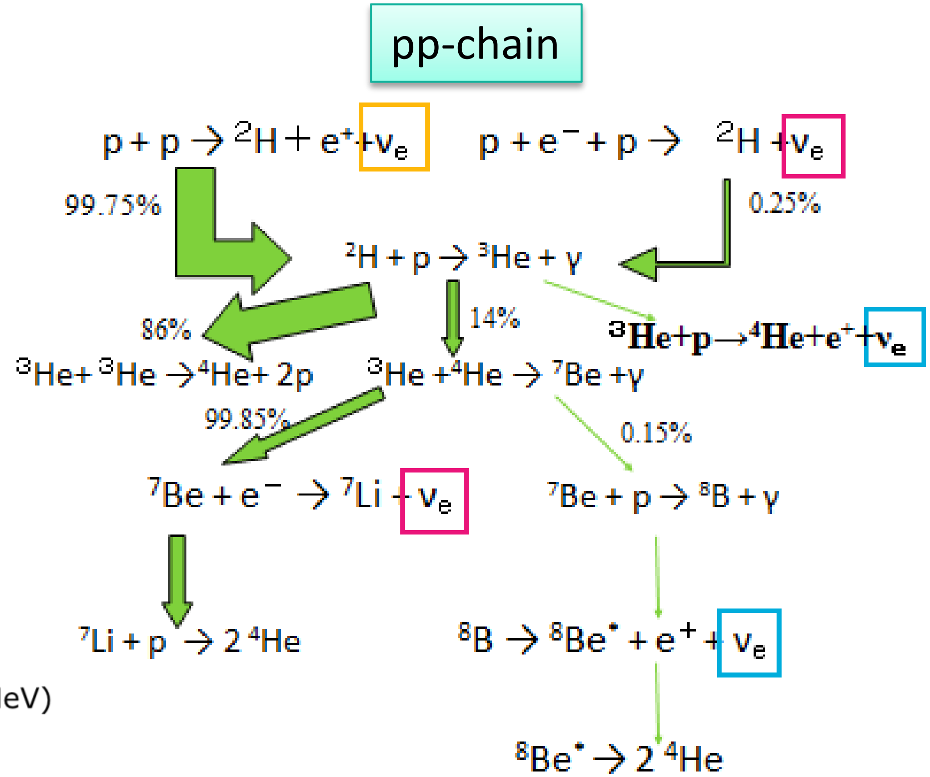


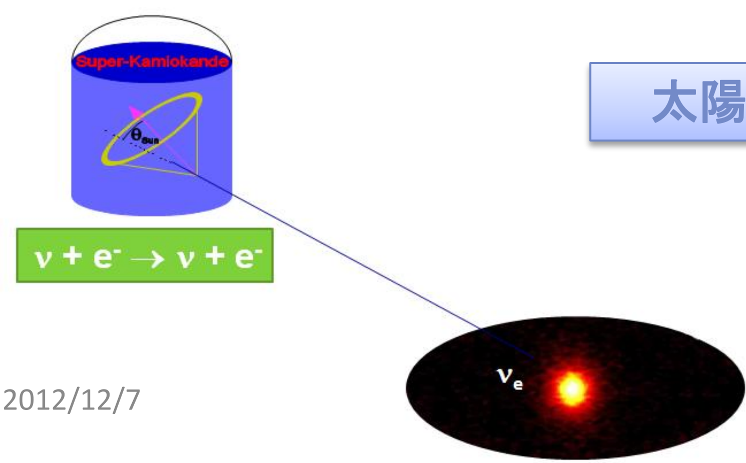
	SK-I	SK-II	SK-III	SK-IV	
	11146 ID PMTs (40% coverage)	5182 ID PMTs (19% coverage)	11129 ID PMTs (40% coverage)	Electronics Upgrade	
Energy Threshold (Total energy)	5.0 MeV	7.0 MeV	5.0 MeV	~4.5 MeV	< 4.0 MeV
(Kinetic energy)	~4.5 MeV	~6.5 MeV	~4.5 MeV	~4.0 MeV	<~3.5 MeV
				Current	Target

太陽ニュートリノ

太陽ニュートリノ







太陽ニュートリノフラックスの計　= 6.6 x $10^{10}\nu_e$/sec/cm^2

最近の進展

- 新しい事象選択のためのパラメタ
  - Multiple Scattering Goodness
- SK-IV のデータ解析結果
  - 2008/10〜2012/03 SK-IV 1069 days (cf. SK-I 1496 days)
- SK-IVでの系統誤差の改善
- SK-IVデータを含めたニュートリノ振動解析

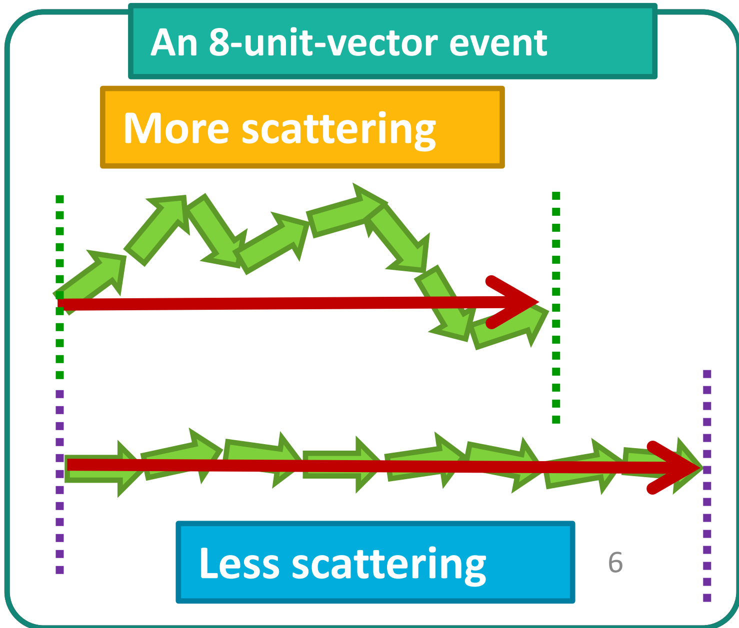
Multiple Scattering Goodness （MSG）

- 目的：**極低エネルギー背景事象の削減**
  - ^{241}Bi 崩壊の電子（3.27MeV）
- 案：
  - 低エネルギー事象は多重散乱を多く起こすため、方向の違う単位ベクトルを多くもつ。⇨**Low Goodness**
  - 高エネルギー事象は、まっすぐ進み各単位ベクトルの方向は近い。⇨**High Goodness**

“単位ベクトル” (事象の再構築された方向)

“最適方向” （単位ベクトルの和）

$$\mathrm{MSG} = \frac{\text{最適方向の長さ}}{\text{単位ベクトルの数}}$$



Systematic uncertainties on ^{8}B flux

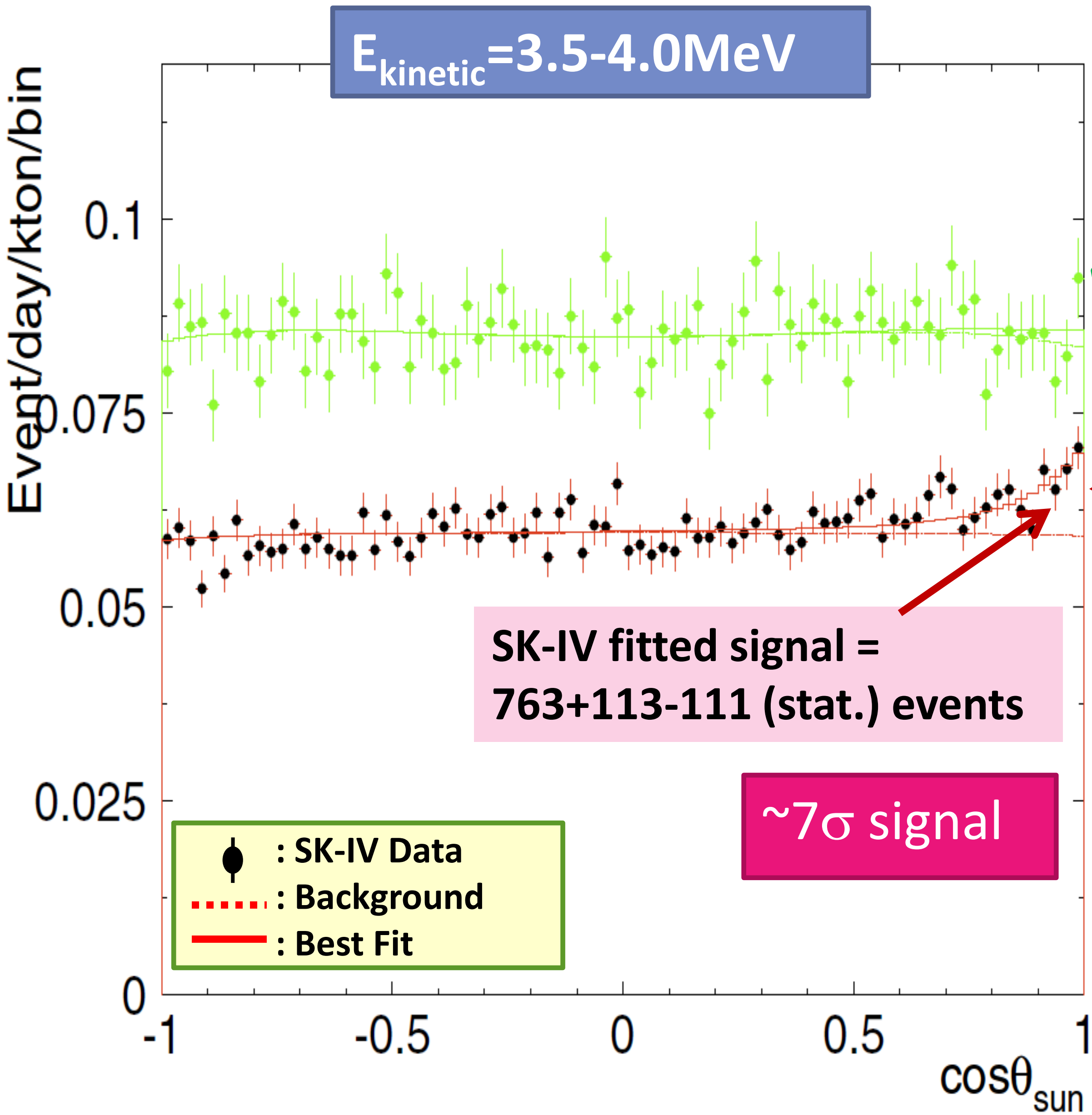
Preliminary

Source	SK-IV Flux (4.0-19.5MeV(kin)) *Preliminary*	SK-III Flux (4.5-19.5MeV(kin)) (PRD83, 052010)	SK-I Flux (4.5-19.5MeV(kin)) (PRD73,112001)
Energy Scale	±1.2%	±1.4%	±1.6%
Energy resolution	±0.15%	±0.2%	
8B spectrum	±0.33%	±0.4%	+1.1/-1.0%
Trigger efficiency	±0.1%	±0.5%	+0.4/-0.3%
Vertex shift	±0.17%	±0.54%	±1.3%
Reduction	±0.6%	±0.9%	+2.1/-1.6%
Spallation dead time	±0.1%	±0.2%	±0.2%
Background shape	±0.1%	±0.1%	±0.1%
Angular resolution	±0.36%	±0.67%	±1.2%
Signal extract method	±0.7%	±0.7%	
Cross section	±0.5%	±0.5%	±0.5%
Total	**±1.7%**	**±2.2%**	**+3.5/-3.2%**

The total systematic error on total flux in SK-IV is reduced by front-end electronics upgrade, precise calibrations, and software improvements

SK-IV: low-energy solar signal

Preliminary May 2012



SK-III SLE1+2 298days

Trigger efficiency
SLE1 (212 days)
>99%@4.5MeV$_{kin}$
SLE2 (87 days)
>98%@4.0MeV$_{kin}$

SK-IV 1069days

Trigger efficiency
>99%@4.0MeV$_{kin}$
~86%@3.5MeV$_{kin}$

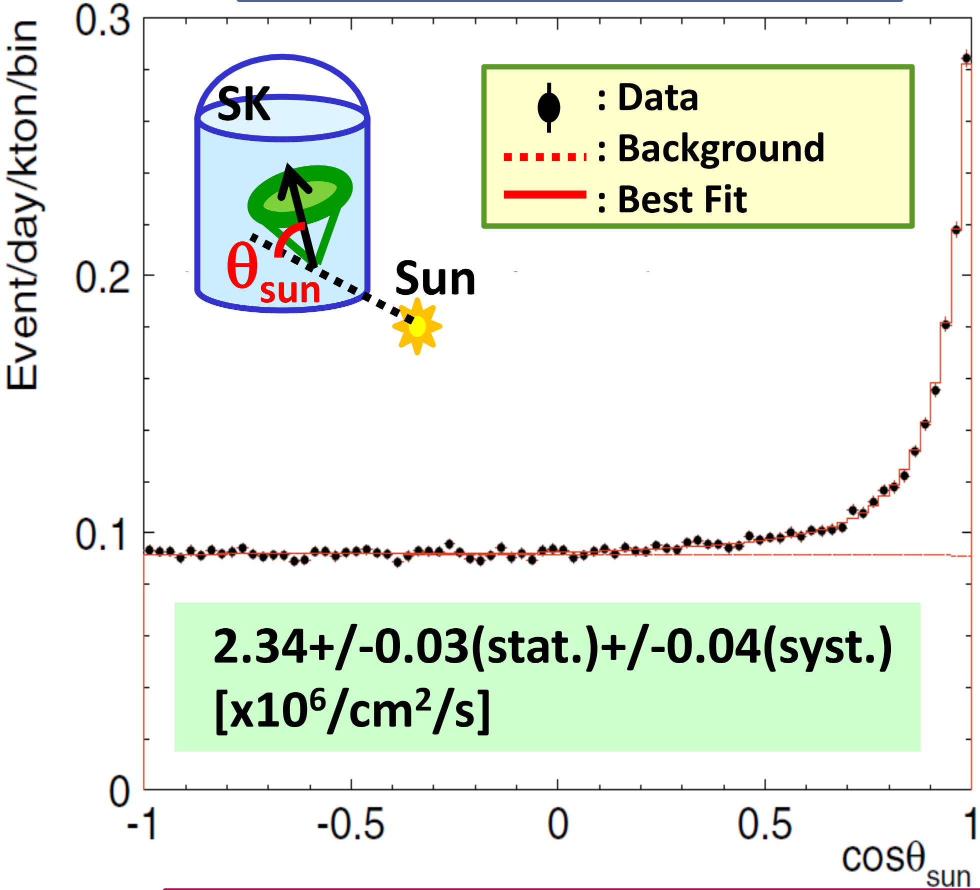
We are planning to lower the energy threshold more by a new intelligent trigger system (hardware is ready in Dec. 2012)

SK-IV solar neutrino flux

Preliminary

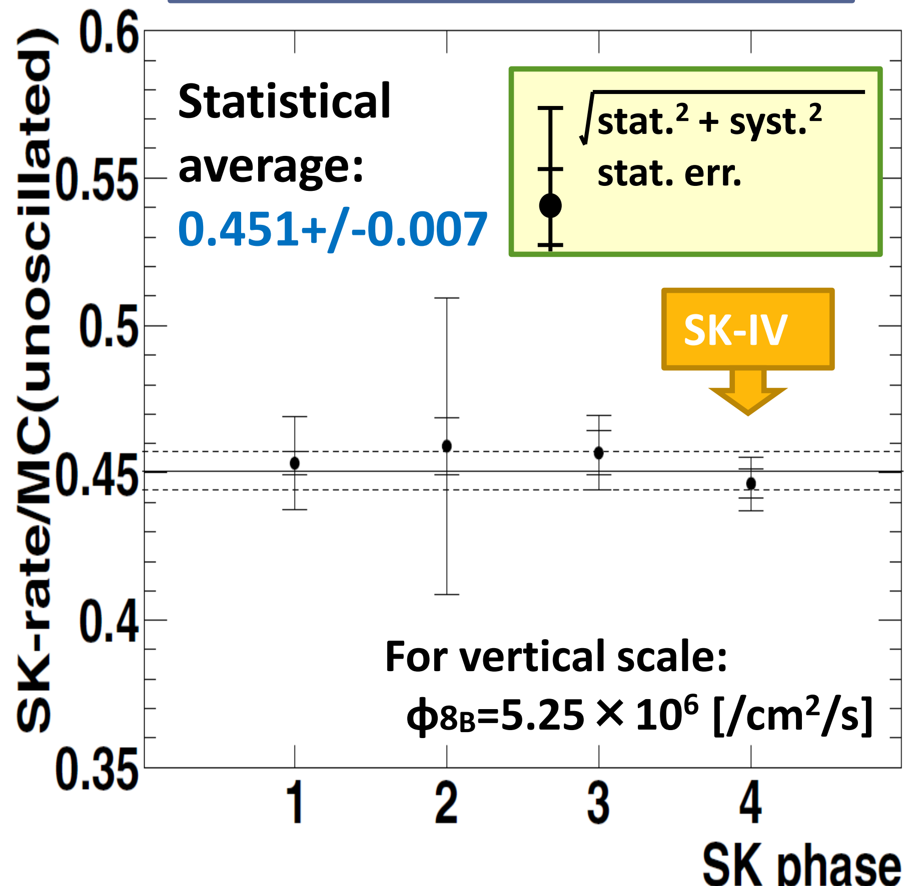
May 2012

SK-IV 4.0-19.5MeV(kin)



2.34+/-0.03(stat.)+/-0.04(syst.) [x10^6/cm^2/s]

^{8}B Flux in each SK phase



- **Consistent flux values within statistical error are observed among SK phases**

Day-Night variation

Preliminary May 2012

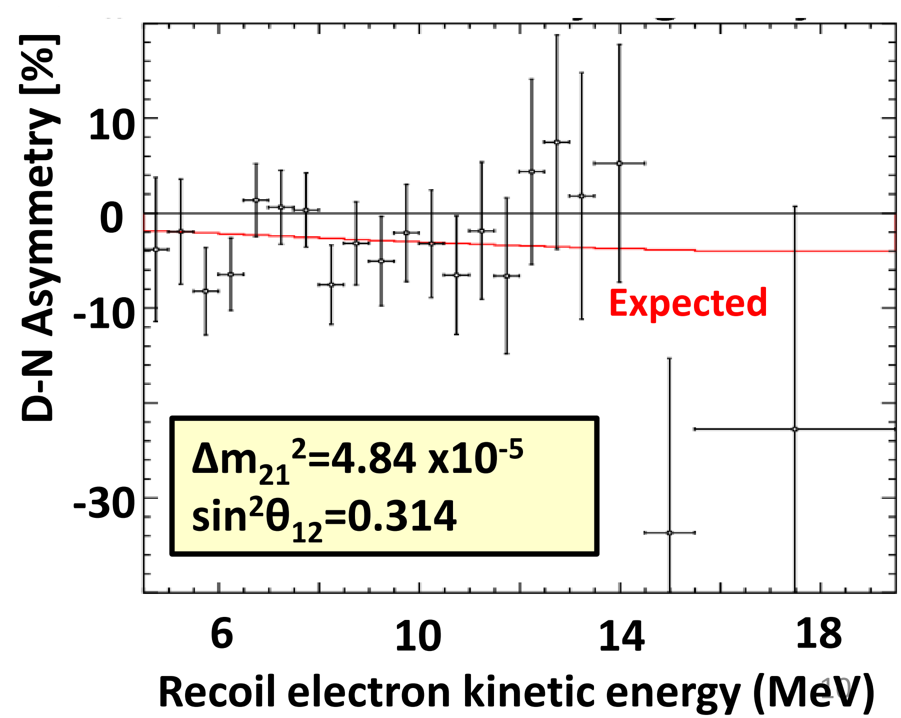
- Un-binned Day-Night analysis (PRD69, 011104) is applied in each SK phase, then obtained Day-Night asymmetry values (=A_{DN}) from fitted Day-Night amplitude parameter.
  - Consider energy and zenith angle dependence of event rate variation.

$$A_{DN} = \frac{\text{Day flux} - \text{Night flux}}{0.5\,(\text{Day flux} + \text{Night flux})}$$

	A_{DN} (±stat.±sys.)
SK-I	-2.0±1.7±1.0 %
SK-II	-4.3±3.8±1.0 %
SK-III	-4.3±2.7±0.7 %
SK-IV	-2.8±1.9±0.7 %
SK combined	-2.8±1.1±0.5 %

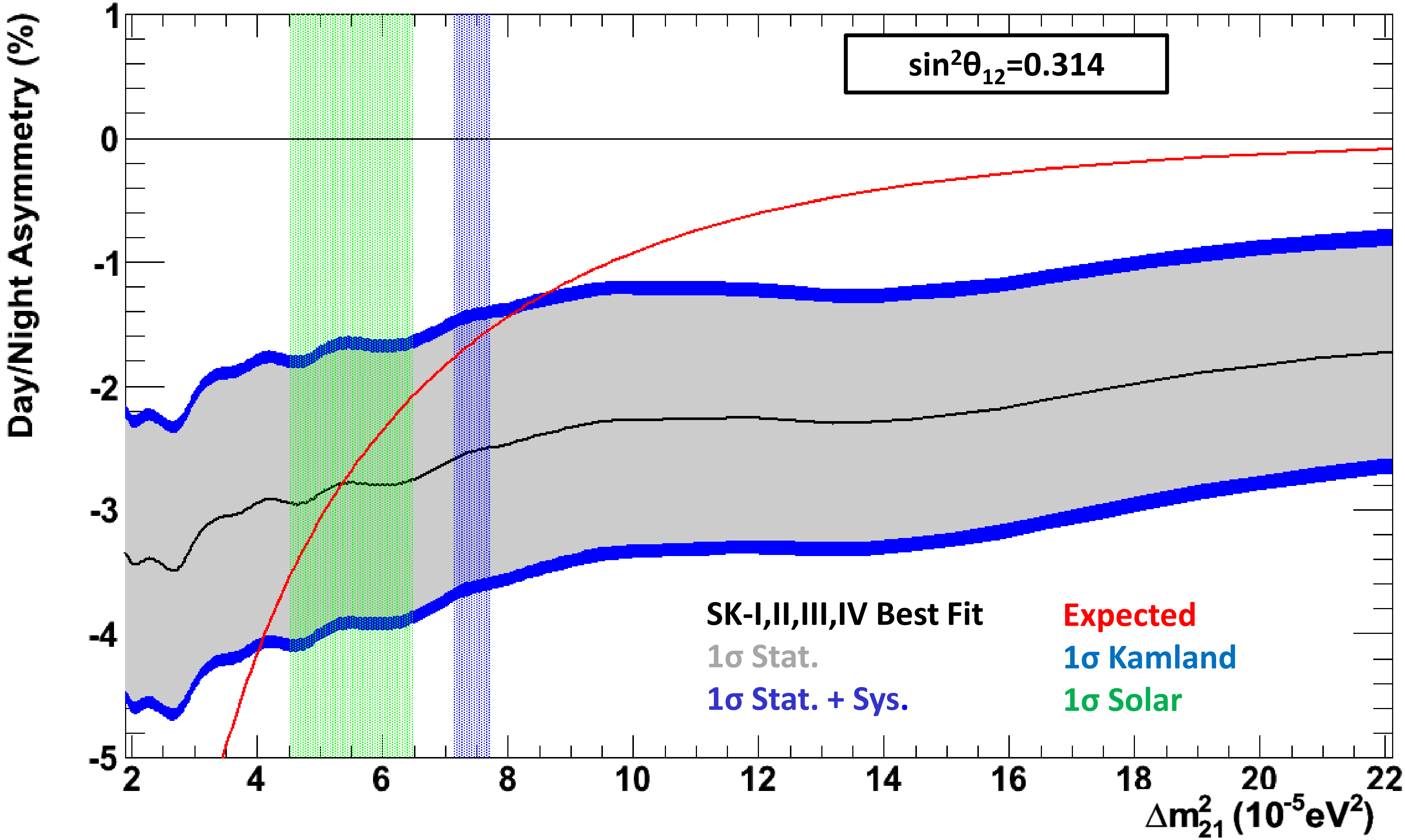
Day-Night asymmetry consistent with zero @ 2.3 σ

SK combined D-N asymmetry values



Preliminary

SK-I/II/III/IV Day/Night Asymmetry

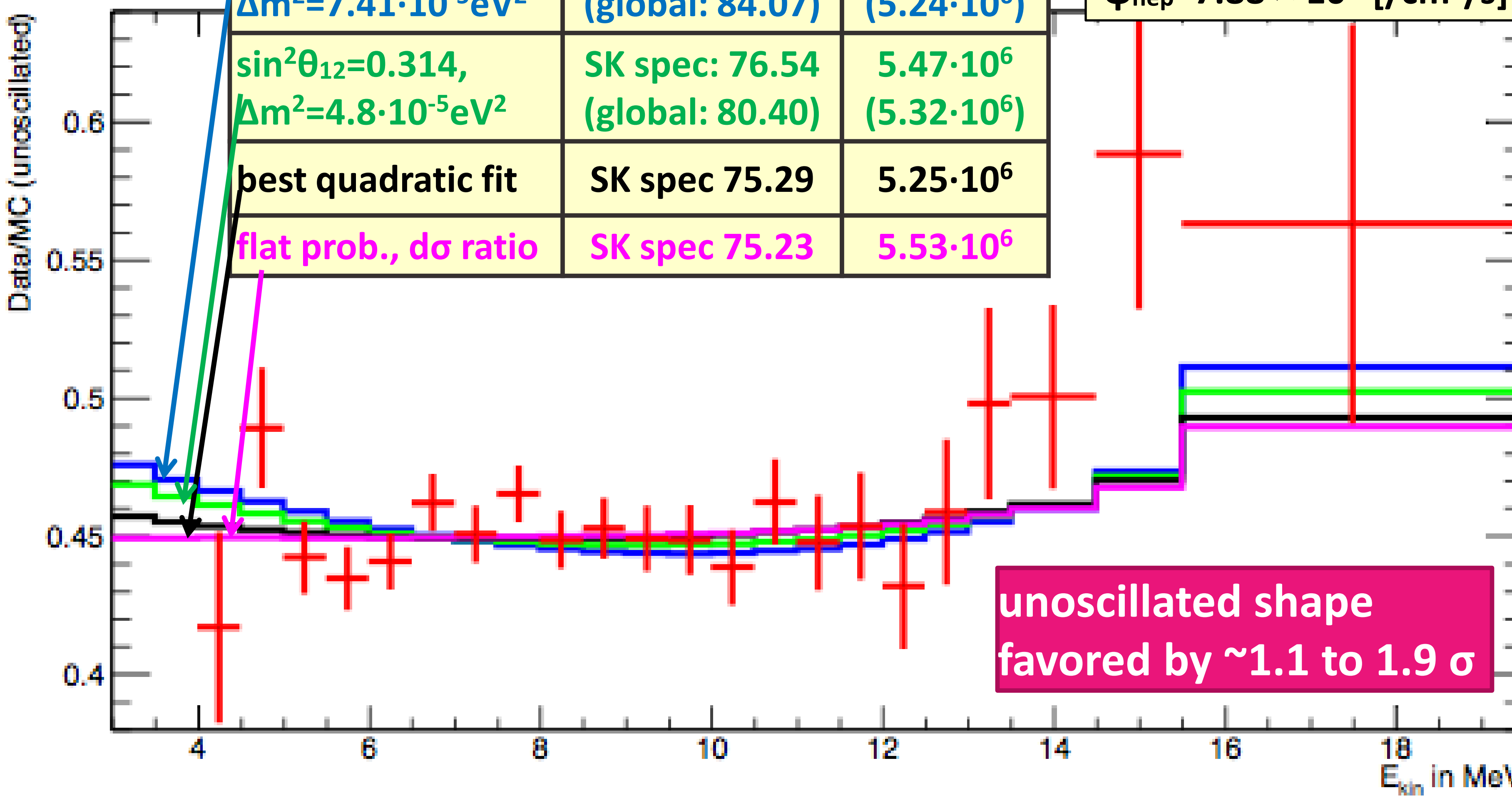


^{8}B energy spectrum (SK combined)

Preliminary

	χ^2	$\phi_{^8B}$ [/cm²/s]
$\sin^2\theta_{12}$=0.304, Δm^2=7.41·10^{-5}eV^2	SK spec: 79.02 (global: 84.07)	5.34·10^6 (5.24·10^6)
$\sin^2\theta_{12}$=0.314, Δm^2=4.8·10^{-5}eV^2	SK spec: 76.54 (global: 80.40)	5.47·10^6 (5.32·10^6)
best quadratic fit	SK spec 75.29	5.25·10^6
flat prob., dσ ratio	SK spec 75.23	5.53·10^6

For vertical scale:
ϕ_{8B}=5.25×10^6
ϕ_{hep}=7.88×10^3 [/cm²/s]



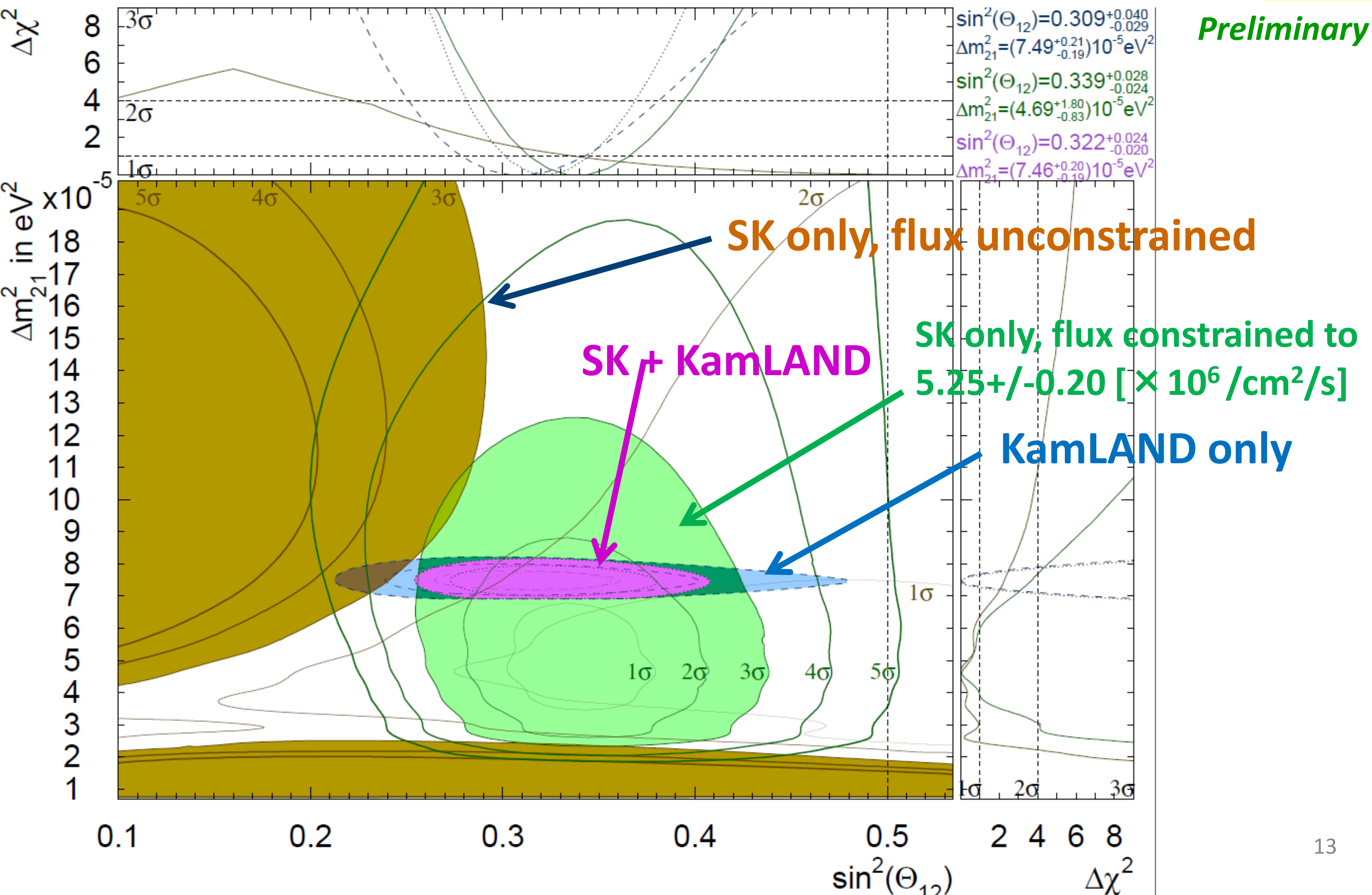
Recoil electron kinetic energy (MeV)

SK only : θ_{12} - Δm_{21}^2

- $\sin^2\theta_{13}$ is fixed at 0.025

Filled area: 3σ

May 2012



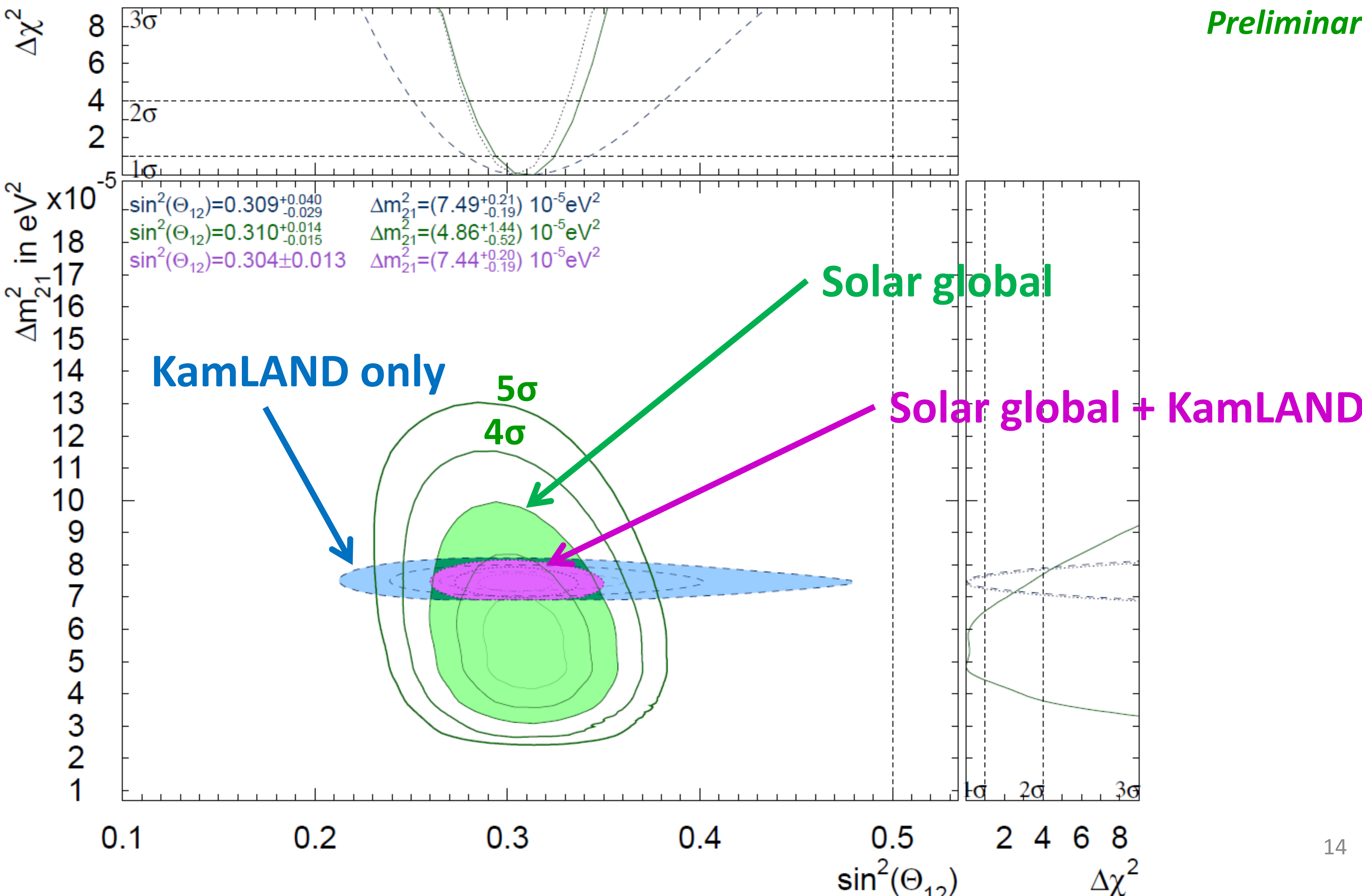
Solar global : θ_{12} - Δm_{21}^2

- $\sin^2\theta_{13}$ is fixed at 0.025

Filled area: 3σ

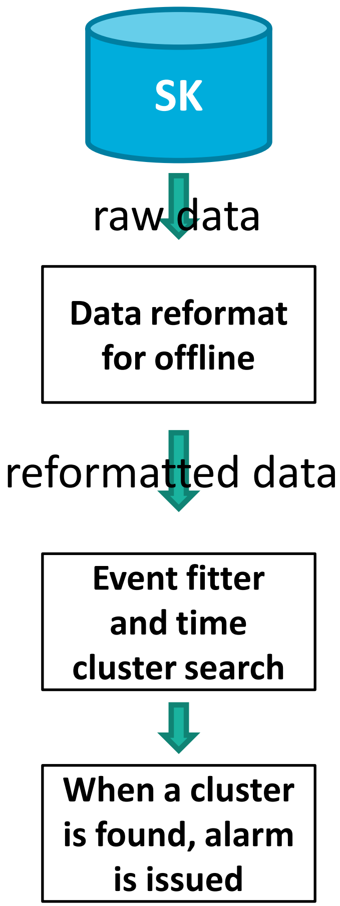
May 2012

Preliminary



超新星爆発モニター

SNwatch
Introduction



- When the alarm is issued, the experts are notified.
- Time cluster selection criteria:

	0.5 (sec)	2.0 (sec)	10.0 (sec)
Silent alarm	7	8	13
Normal alarm	23	27	39

The alarm is issued if one of the above conditions is satisfied. The **normal alarm** is issued when the cluster satisfies the **normal alarm** criteria above and R_{mean} > 900cm, where R_{mean} is an average distance between vertices. The **golden alarm** also requires 100 events in 20 sec. window, R_{mean} value greater than 550cm and vertex distribution dimension of 3.

SN direction fit

- Based on Maximum Likelihood method:

$$L = \exp\left(\sum_{k,r} N_r^k\right) \prod_i L_i$$

where,

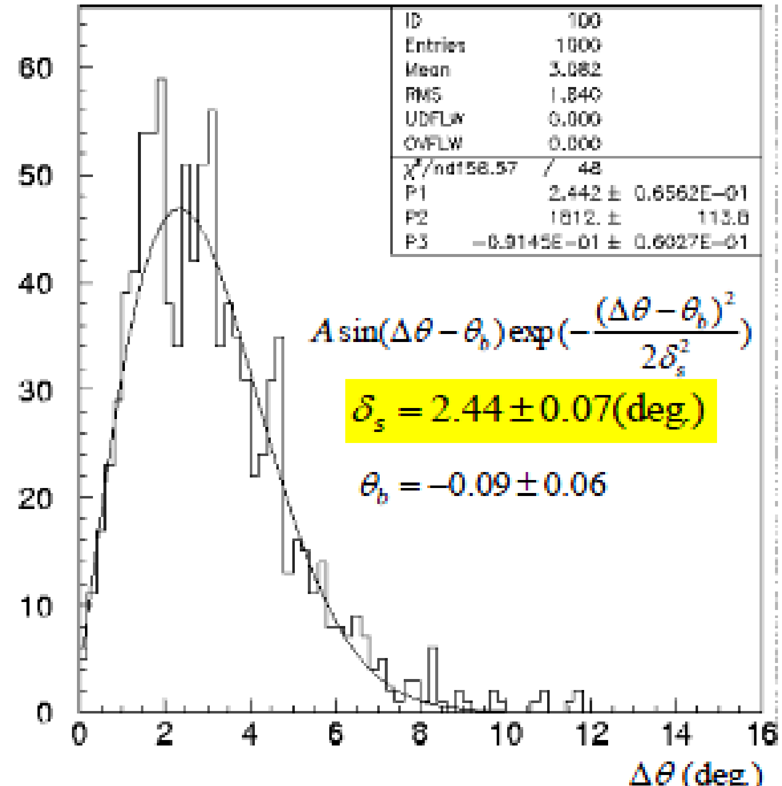
$$L_i = \sum_r N_r^k p_r(E_i, \hat{d}_i; \hat{d}_{SN}) \qquad r = \bar{\nu}_e p, \nu e, \text{and } \bar{\nu}_e e$$

$k = 1 \sim 5$ is the energy binning. $i = \text{event index}$

- Pr is probability density function, obtained using MC.
- The likelihood function is maximized so that:

$$\frac{\partial L}{\partial N_r^k} = \frac{\partial L}{\partial \hat{d}_{SN}} = 0$$

- 12 variables total are varied.



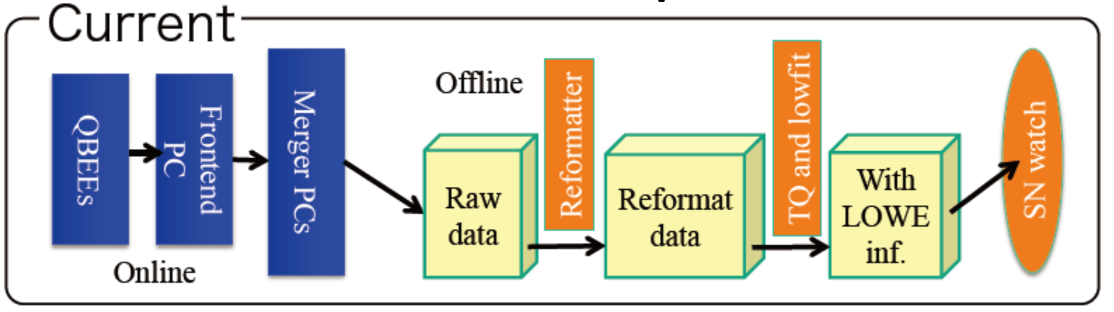
Direction difference between fitted and generated at 10kpc SN obtained with 1000 MC samples.

MC w/o neutrino oscillation based on a model [1], fitter is applied.

[1] T. Totani *et al.*, ApJ 496, 216 (1998)

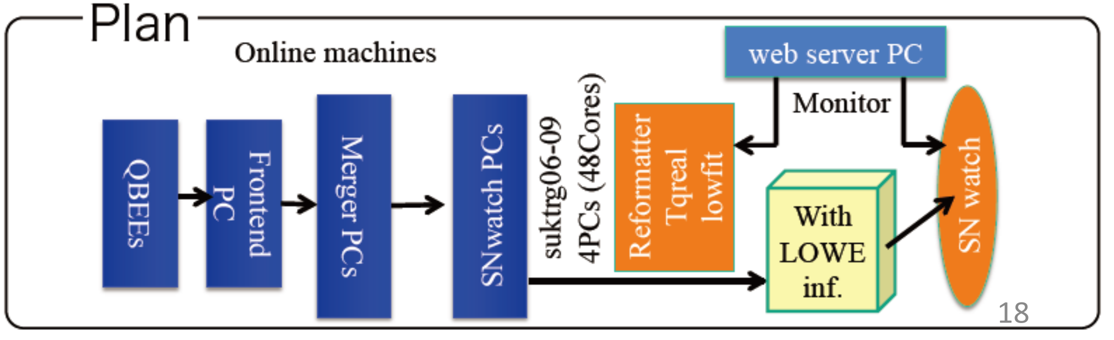
SNwatch Summary

- SNwatch system has been in operation
  - No SN has been found.
- SN direction can be determined
  - 2.4 degrees precision, for SN at 10kpc.

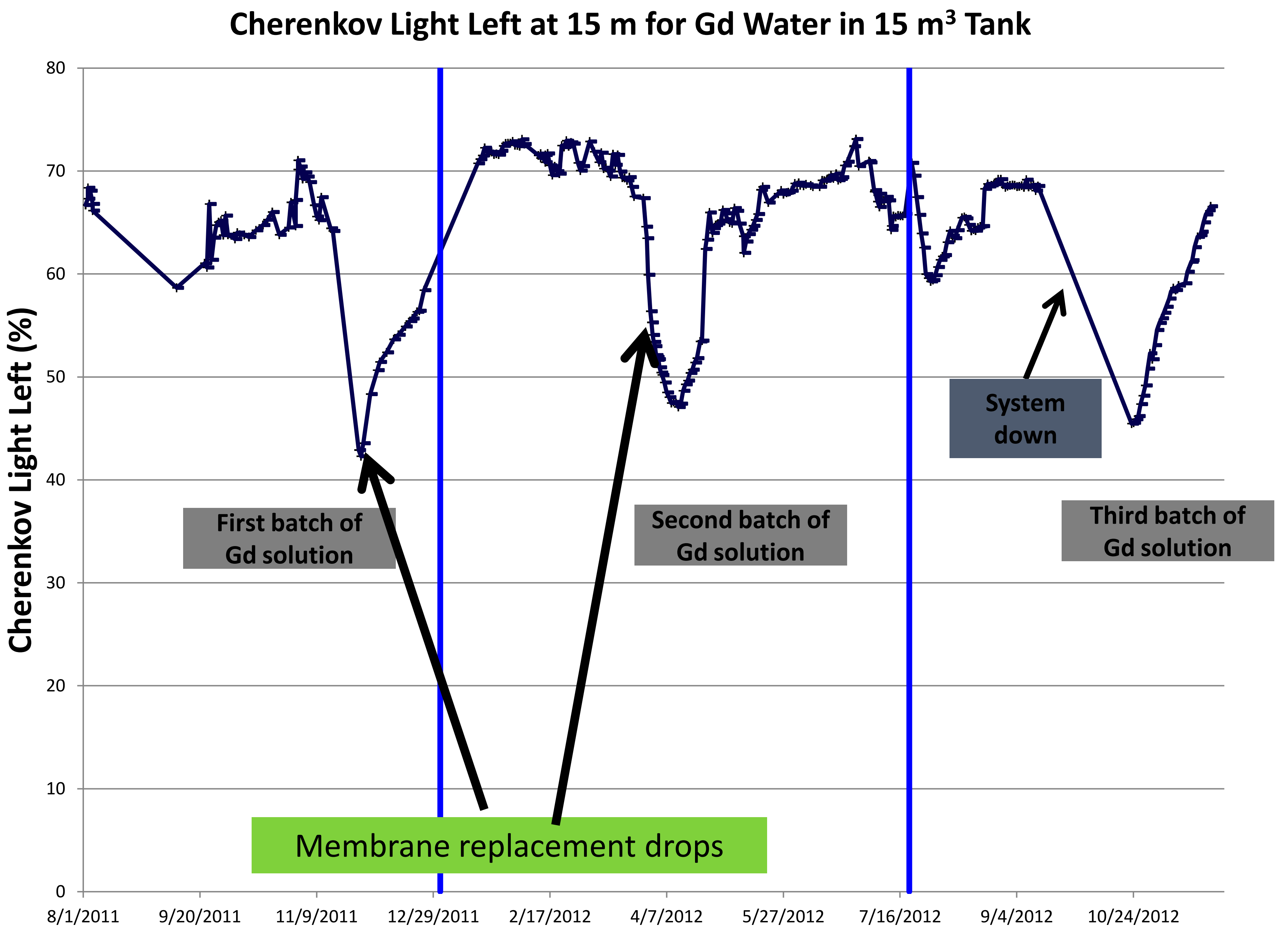


Plan:

- Install online machines for dedicated for SNwatch (4pcs, 48cores)
  - during T2K off-time in Dec., 2012
- Web server machine for monitoring SNwatch
- Vertex fitter improvement (faster)



ガドリニウム実験



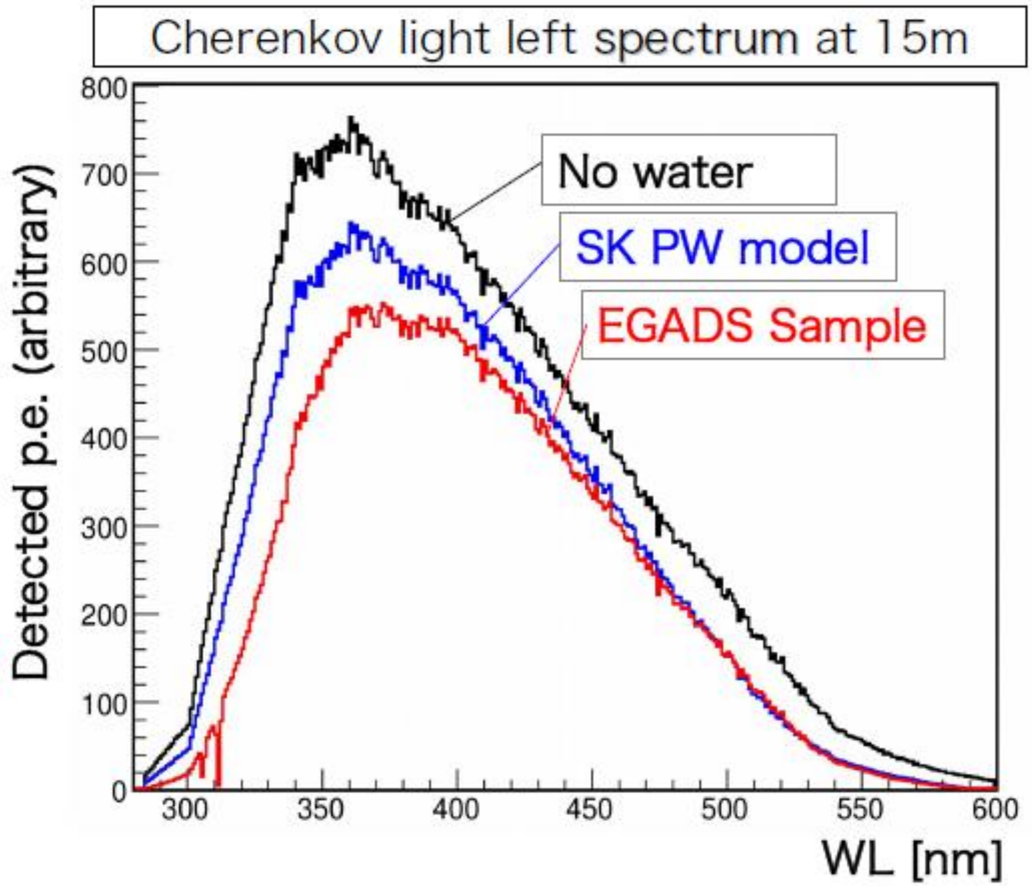
Cherenkov Light Left at 15 m for Gd Water in 15 m³ Tank
Cherenkov Light Left (%)
80
70
60
50
40
30
20
10
0
8/1/2011
9/20/2011
11/9/2011
12/29/2011
2/17/2012
4/7/2012
5/27/2012
7/16/2012
9/4/2012
10/24/2012
First batch of Gd solution
Second batch of Gd solution
Third batch of Gd solution
System down
Membrane replacement drops

Cherenkov Spectrum at 15m

Cherenkov light left at 15m

	SK PW	EGADS
光強度	81.4 %	70.2 +1.2 -1.5%

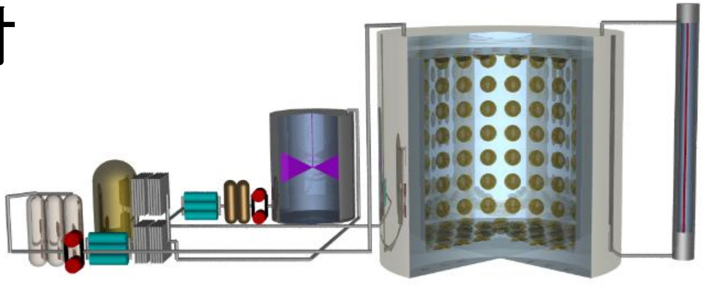
86.2 +1.5 -1.8 %



Cherenkov light left become 70.2 $^{+1.2}_{-1.5}$% after 15m.
This is 86.2 $^{+1.5}_{-1.8}$ % of pure water case.

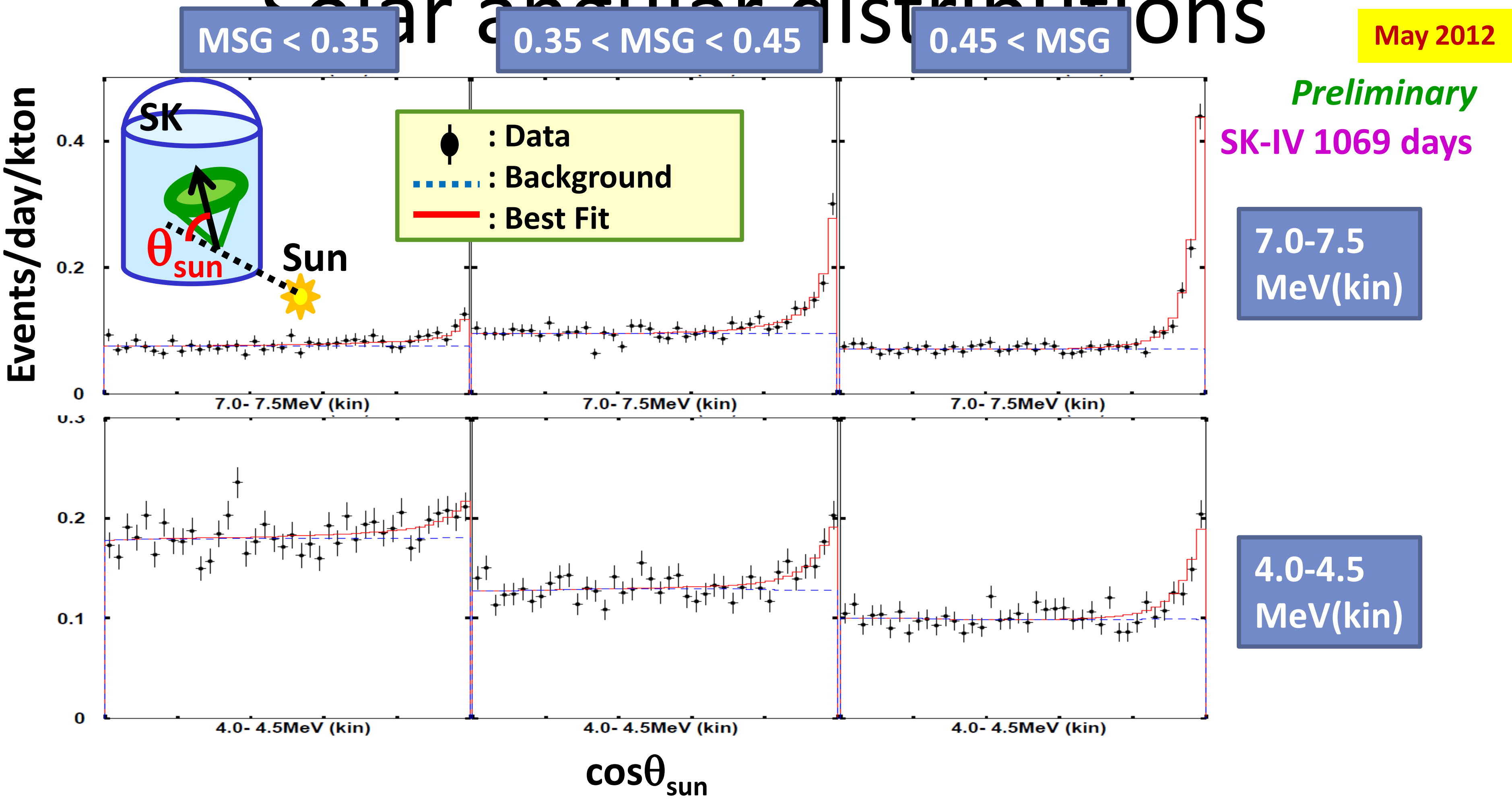
ガドリニウム実験 まとめ

- GdWaterの透過率
  - 現在超純水の86%まで到達
  - 物理からの要請(90-92%)の近くまで来ている
- DAQ/Online/MC ready
- 予定:
  - 来年1月、200トンタンクにGadolinium投入
  - ~4月200トンタンクにPMTを取付



BACKUPS

Solar angular distributions



- Better signal-to-noise ratio in the higher MSG data set.
- Signal extraction with MSG is used below 7.5 MeV(kin) in SK-III and SK-IV in the energy spectrum analysis and the oscillation analysis.

Recent solar neutrino results

- **See also following reports:**
  - **M. Smy, "Results from Super-Kamiokande" @NEUTRINO2012**
  - **Y. Koshio, "Solar neutrino results from Super-Kamiokande" @ICHEP2012**
  - **H. Sekiya, "Super-Kamiokande low-energy results" @NOW2012**

SK-IV solar neutrino flux

May 2012

Preliminary

- Total live time : 1069.3 days (2008/10-2012/03)
- Energy region for flux: $E_{kinetic}$ = 4.0 – 19.5 MeV
- Winter06 ^{8}B spectrum is used.
- ^{8}B Flux in ES reaction, without ν oscillation:
  - SK-IV: 2.34+/-0.03(stat.)+/-0.04(syst.) [x10^{6}/cm^{2}/s]
  - SK-I: 2.38+/-0.02(stat.)+/-0.08(syst.) **4.5 – 19.5 MeV(kin)**
  - SK-II: 2.41+/-0.05(stat.)+0.16/-0.15(syst.) **6.5 – 19.5 MeV(kin)**
  - SK-III: 2.40+/-0.04(stat.)+/-0.05(syst.) **4.5 – 19.5 MeV(kin)**

    (SK-I,II are recalculated with the Winter06 ^{8}B spectrum.)

    (The problem in SK-III is fixed.)

SK-I: PRD73, 112001
SK-II: PRD78, 032002
SK-III: PRD83, 052010

- 3.5-4.0MeV(kin) in SK-IV is used for oscillation analysis.
  - Energy threshold is lowest in SK-IV

SK-IIIにおけるフラックスの誤計算

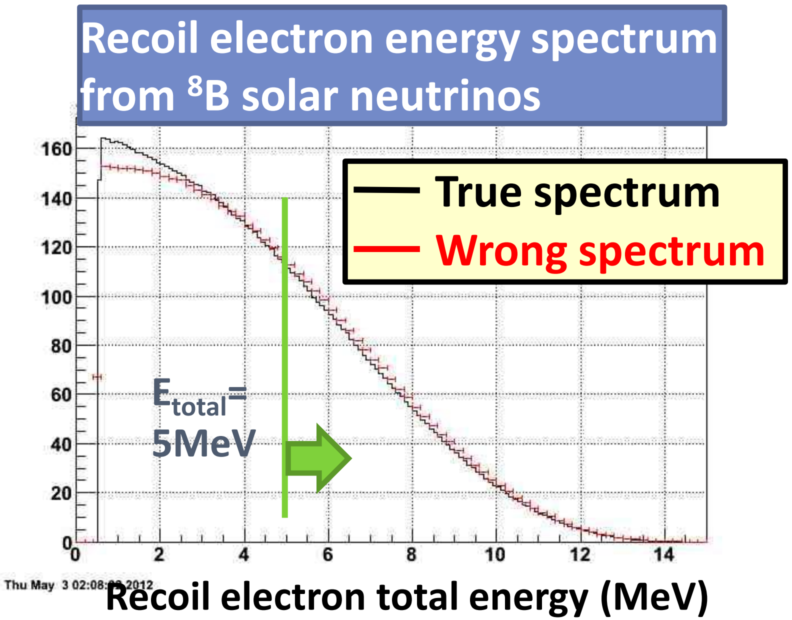
May 2012

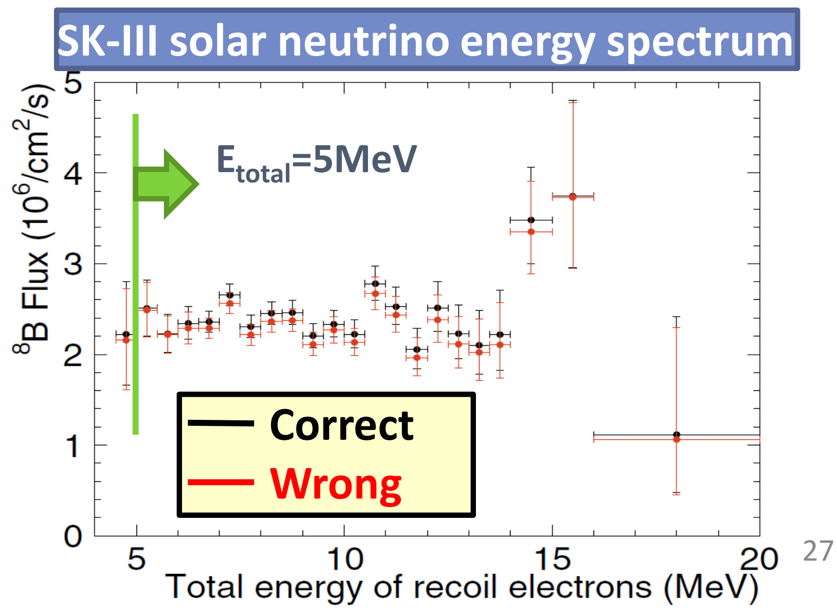
Preliminary

- SK-IIIだけ、Nueの微分断面積のエネルギー依存がflux計算から抜けていた （PRD83, 052010 (2011)）
- ^{8}Bのエネルギースペクトルの形が違っていた。
- 弾性散乱におけるSK-III ^{8}B flux 値を E_{total}=5.0-20MeVで

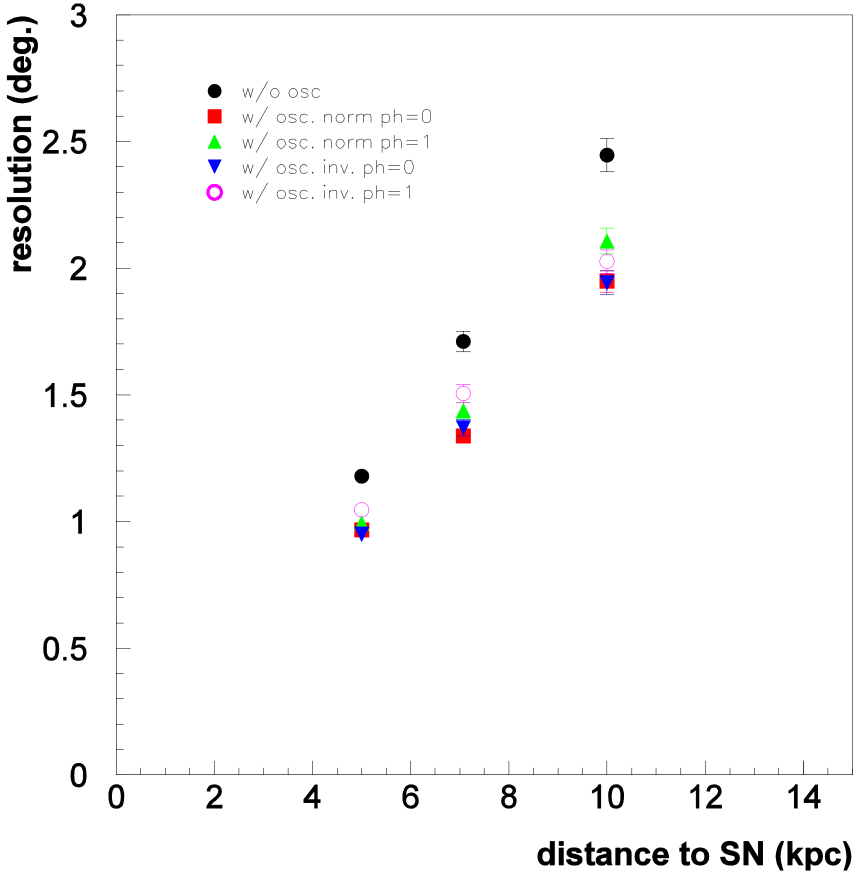
2.32 (誤)から 2.40 (正) [x10^6/cm^2/sec]　に変更

- エラッタ作成中





SNwatch direction fit



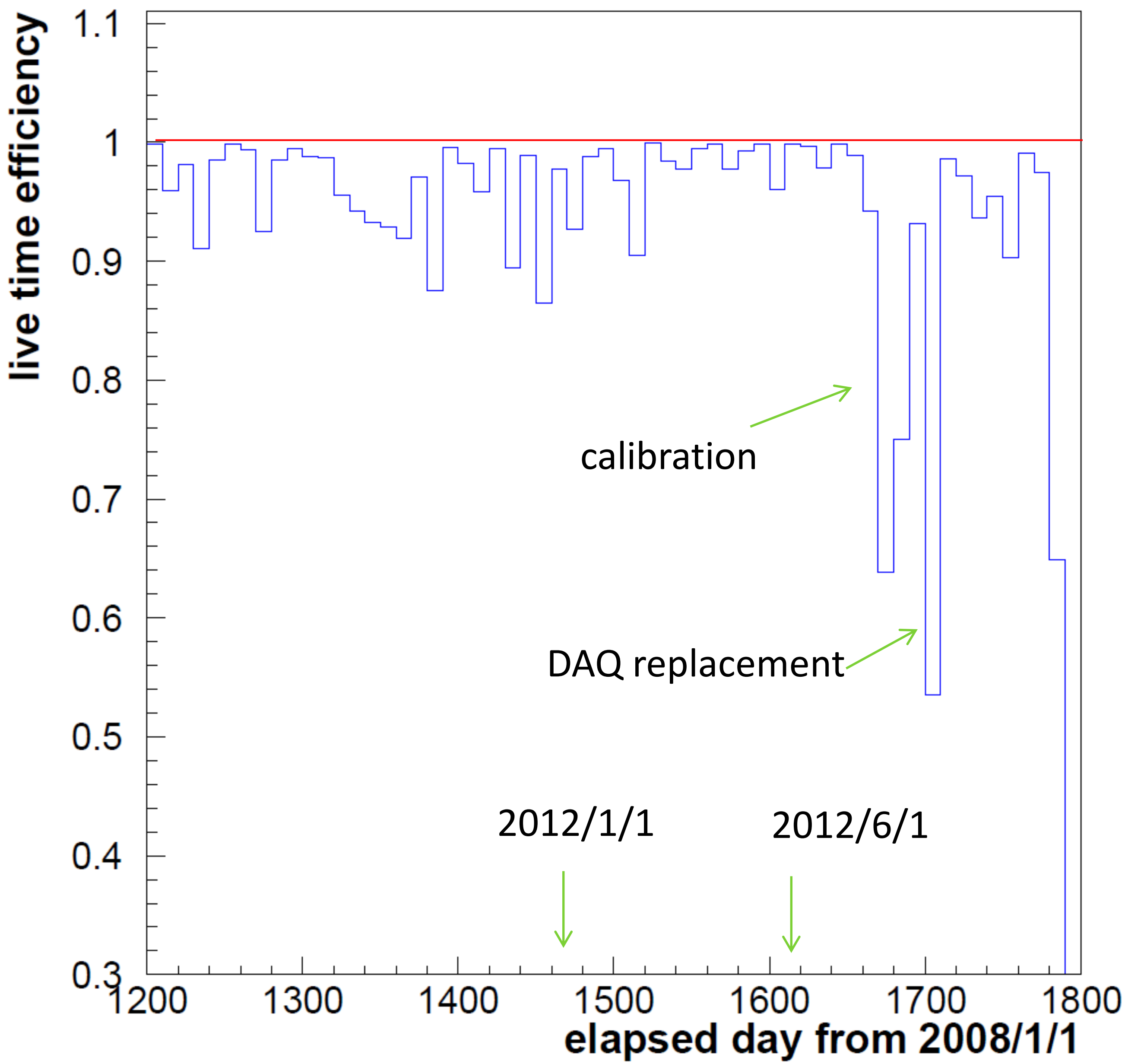
- Direction determination precession for various distances and neutrino oscillation models[2].
- [2] A. S. Dighe and A. Y. Smirnov PRD 62, 033007 (2000)

SN direction error

- fit the SN direction
  - the method was presented in the previous meeting.
- rotate all the event direction so that the fitted SN direction becomes the north pole ($\theta=0$).
- we define the direction error:

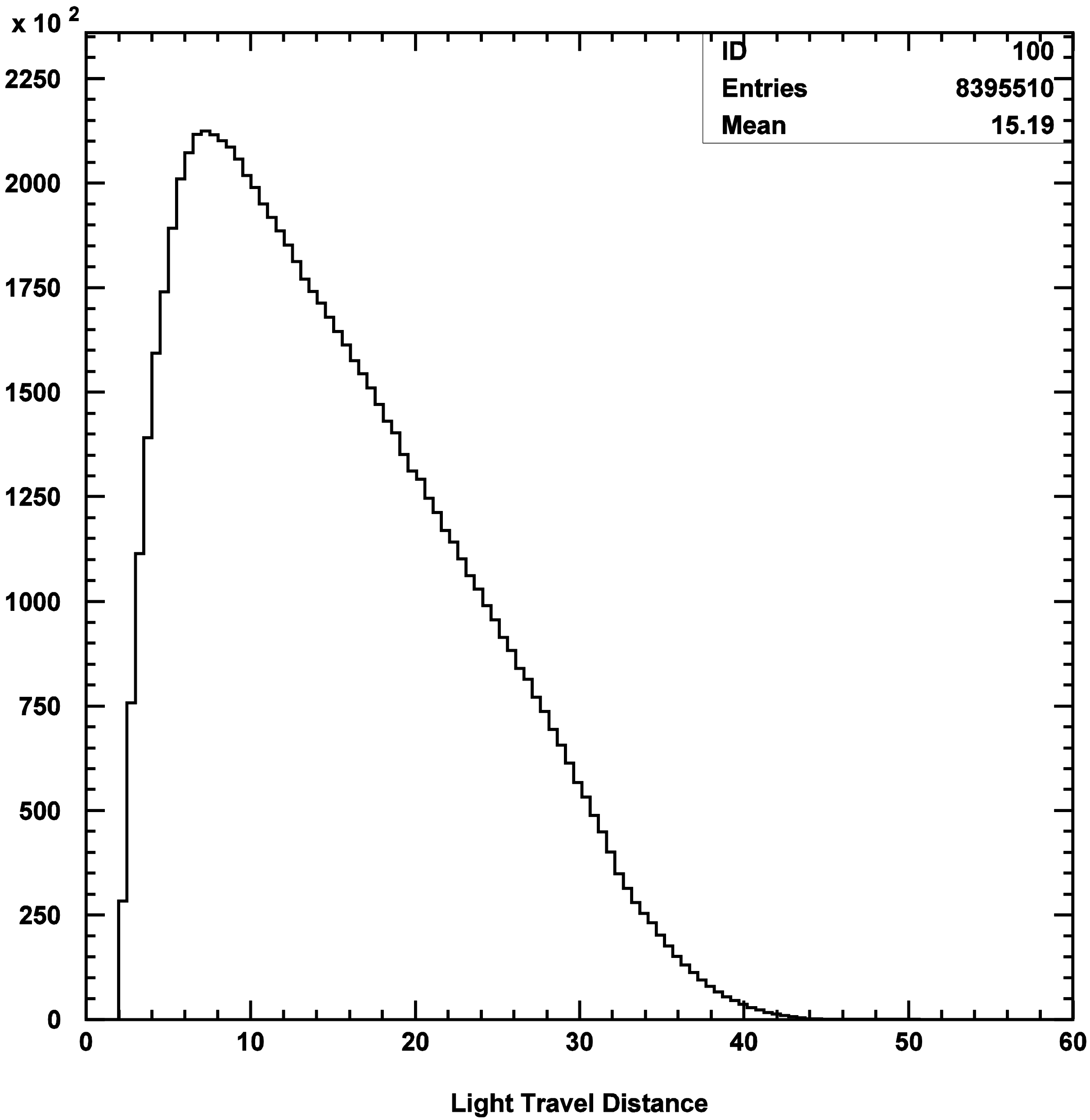
$$\sigma_\theta = \sqrt{\frac{2}{\frac{\partial^2 \chi^2}{\partial \theta^2}}} \qquad \chi^2 = -2 \ln \mathcal{L}$$

Live time efficiency



month	ε(%)
2011/11	97.9
2011/12	91.9
2012/01	96.4
2012/02	95.6
2012/03	95.9
2012/04	99.0
2012/05	98.4
2012/06	99.1
2012/07	95.7
2012/08	73.6
2012/09	97.6
2012/10	93.6

Average Photon Travel Distance in SK



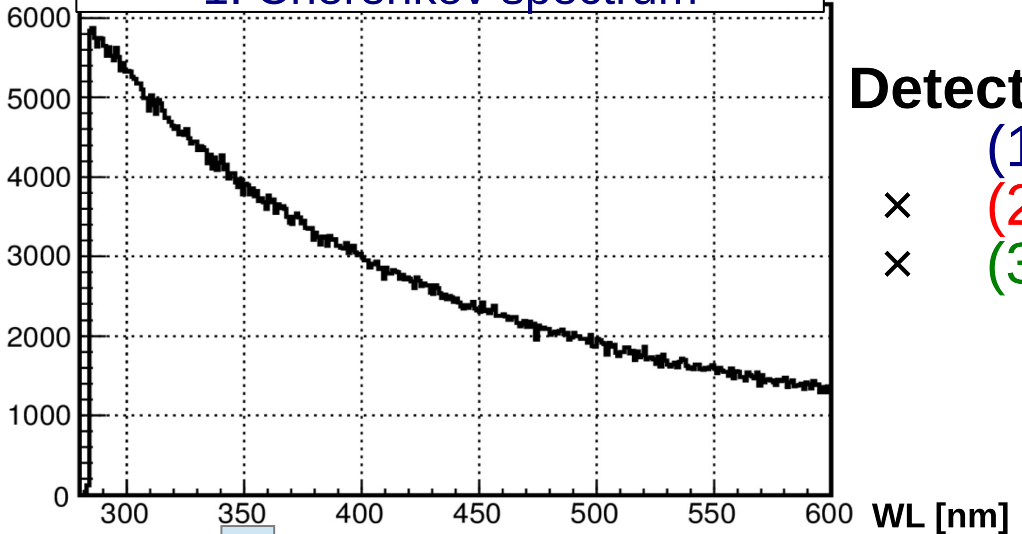
SK-IV solar final data sample used

Calculated the distance from each PMT hit to the vertex position, take this as the photon travel distance

The average photon travel distance in SK-IV is estimated to be 15.19±3.9 meters

5. Effect on water Cherenkov light

1. Cherenkov spectrum



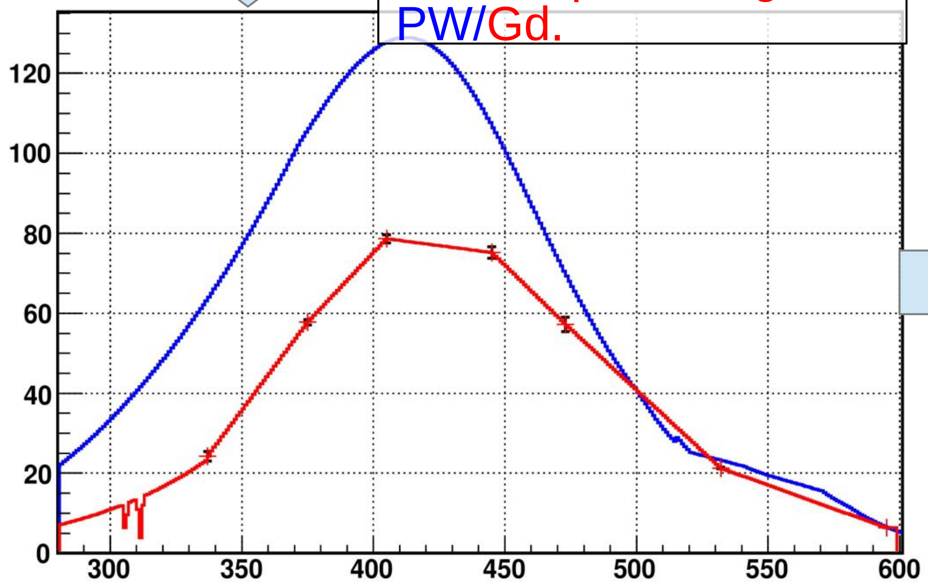
Detected Cherenkov =

(1. Cherenkov spectrum)

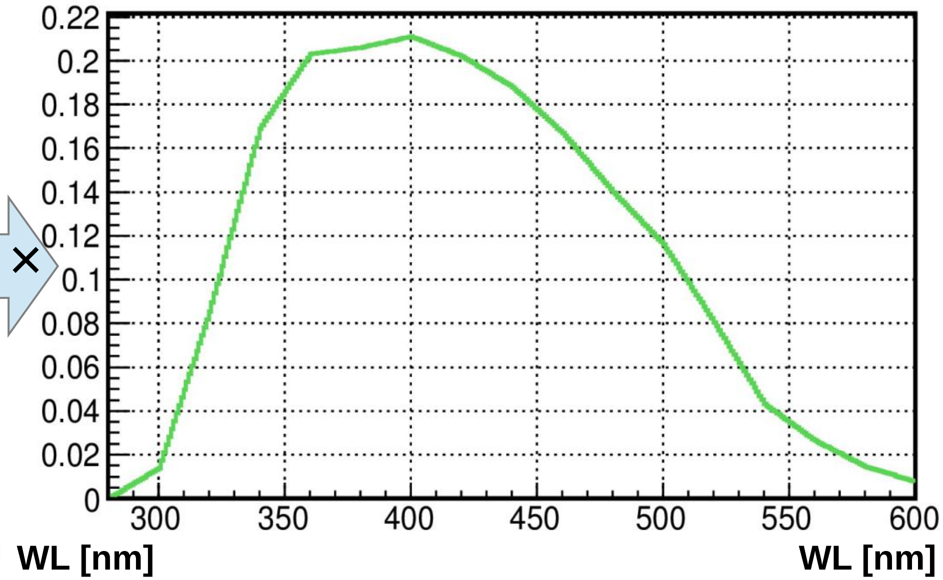
× (2. Absorption length of PW/Gd)

× (3. QE of PMT)

2. Absorption length of PW/Gd.

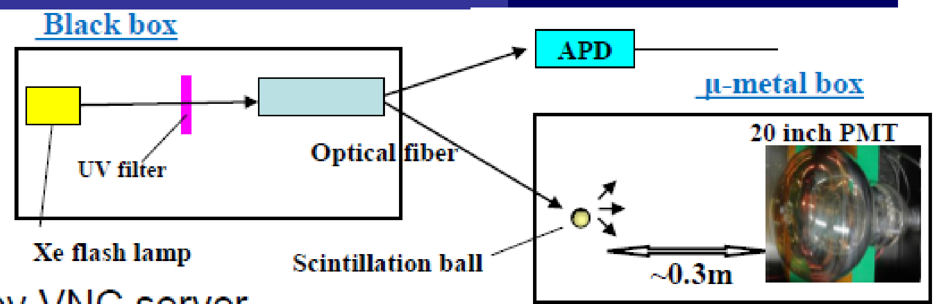


3. QE of SK PMT

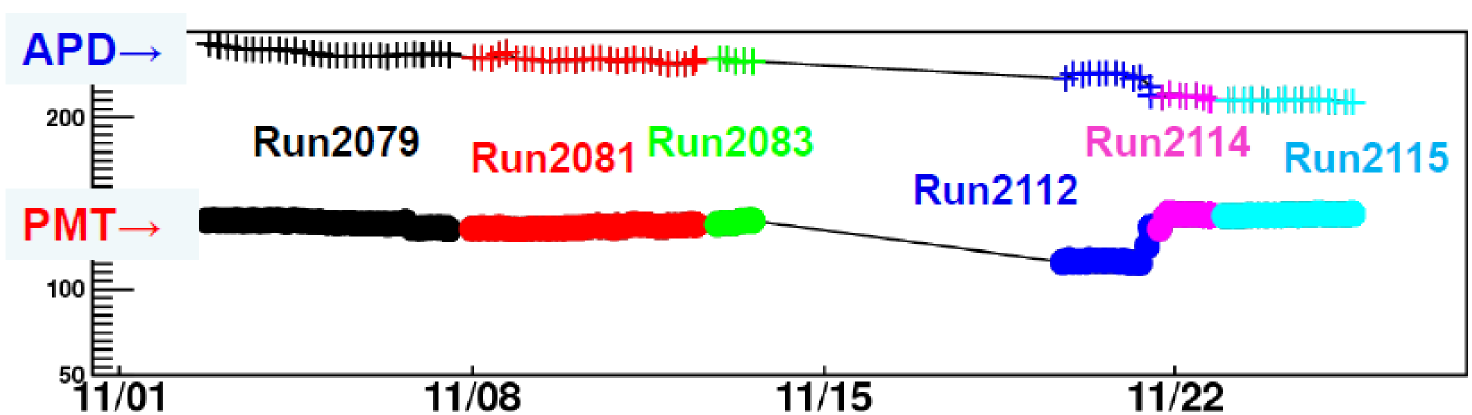


EGADS DAQ

DAQ test (with new SK HV test :Tomura-san presented)



- Purpose : Test for operation in long term
- Same setup as pre-calibration setup using Xe lamp
- DAQ can be monitored remotely by VNC server
- Data can be checked by online monitor (Event rate, ADC distribution..).
  - The online monitor system is based on the XMASS system.
- Pedestal measured every 5min.
- Trigger rate is 10 Hz.



DAQ system is working w/o errors so far !!