SuperKamiokande

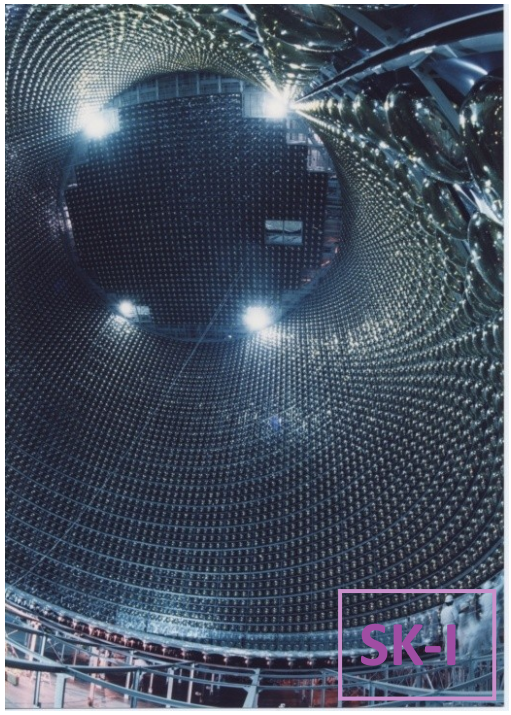
Introduction
Solar neutrinos
Supernova Relic Neutrinos
Gadzooks!

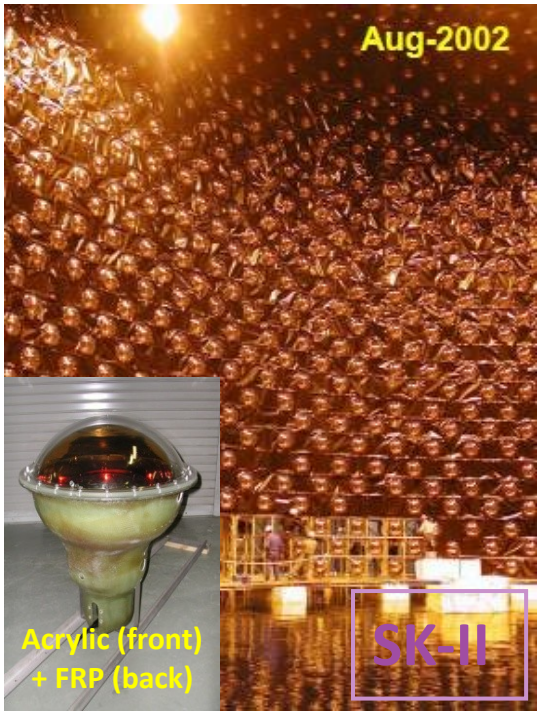
Lluís Martí Magro, UA Madrid.
Neutrino Champagne, 19th of October 2009.

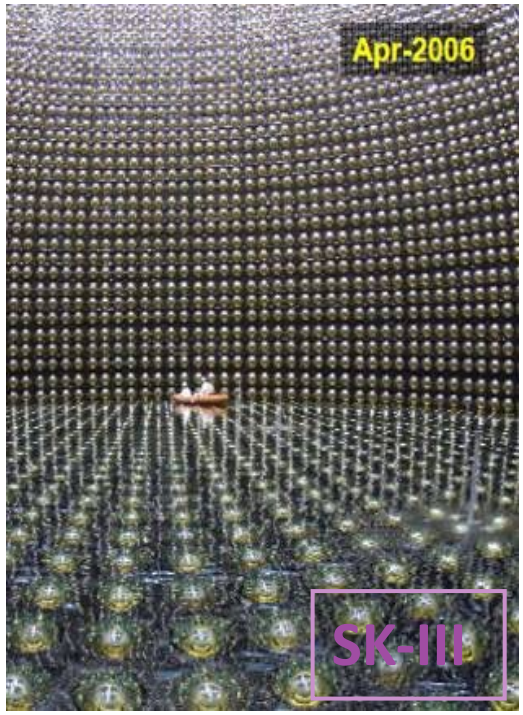
SuperKamiokande History

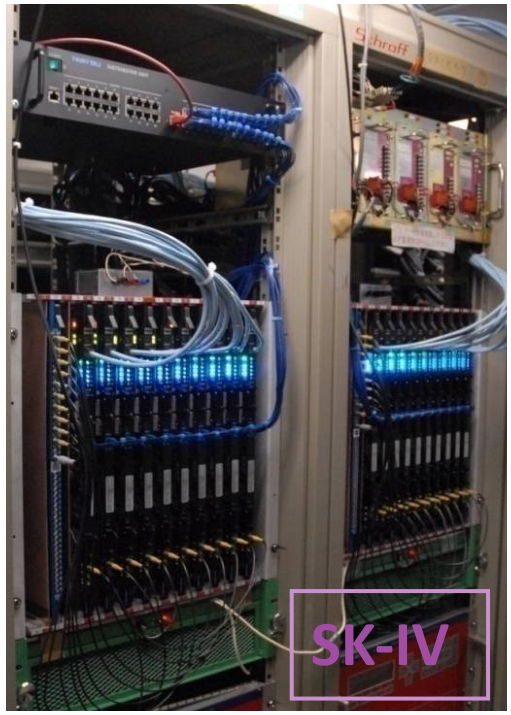
1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009

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



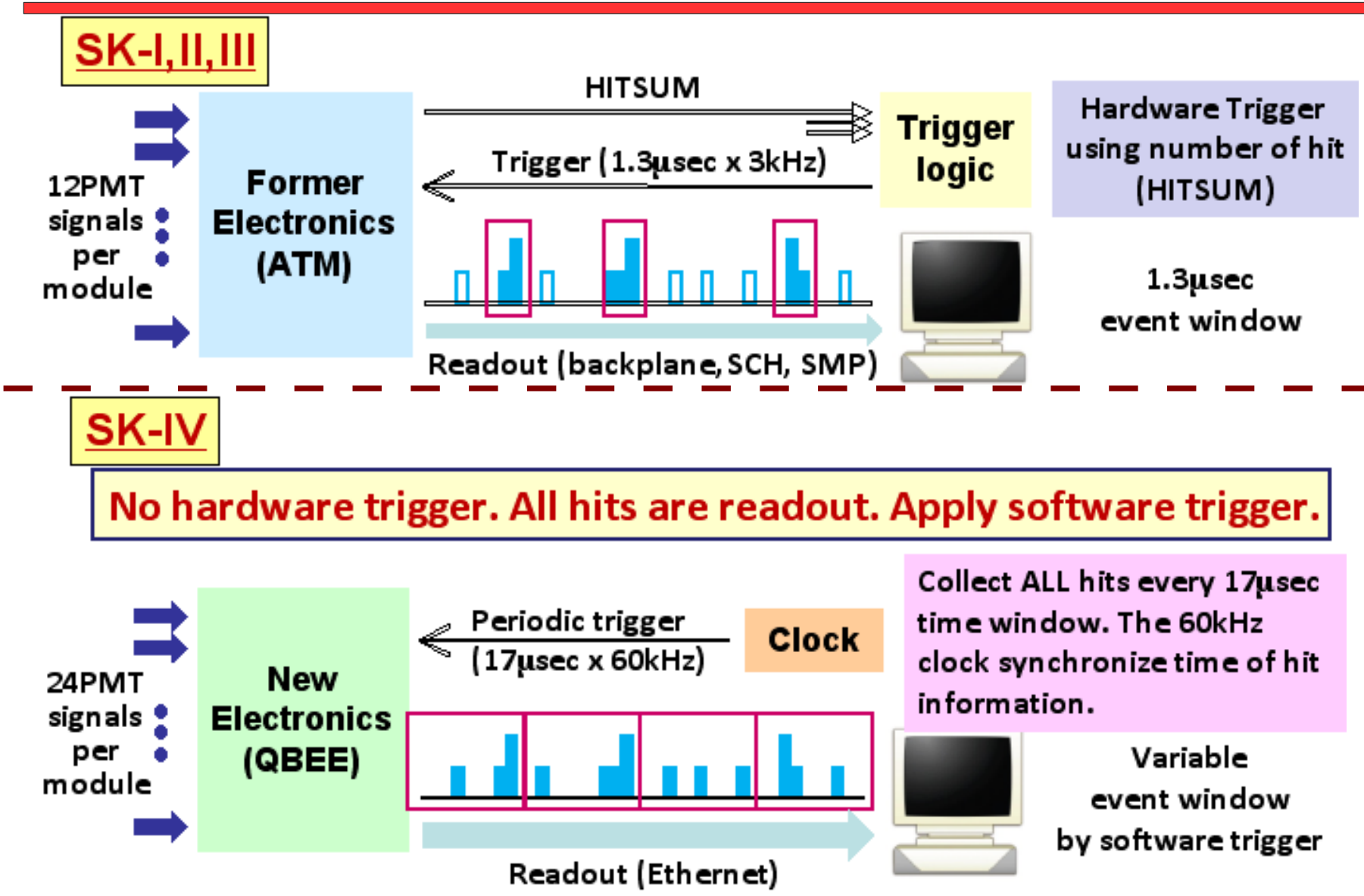






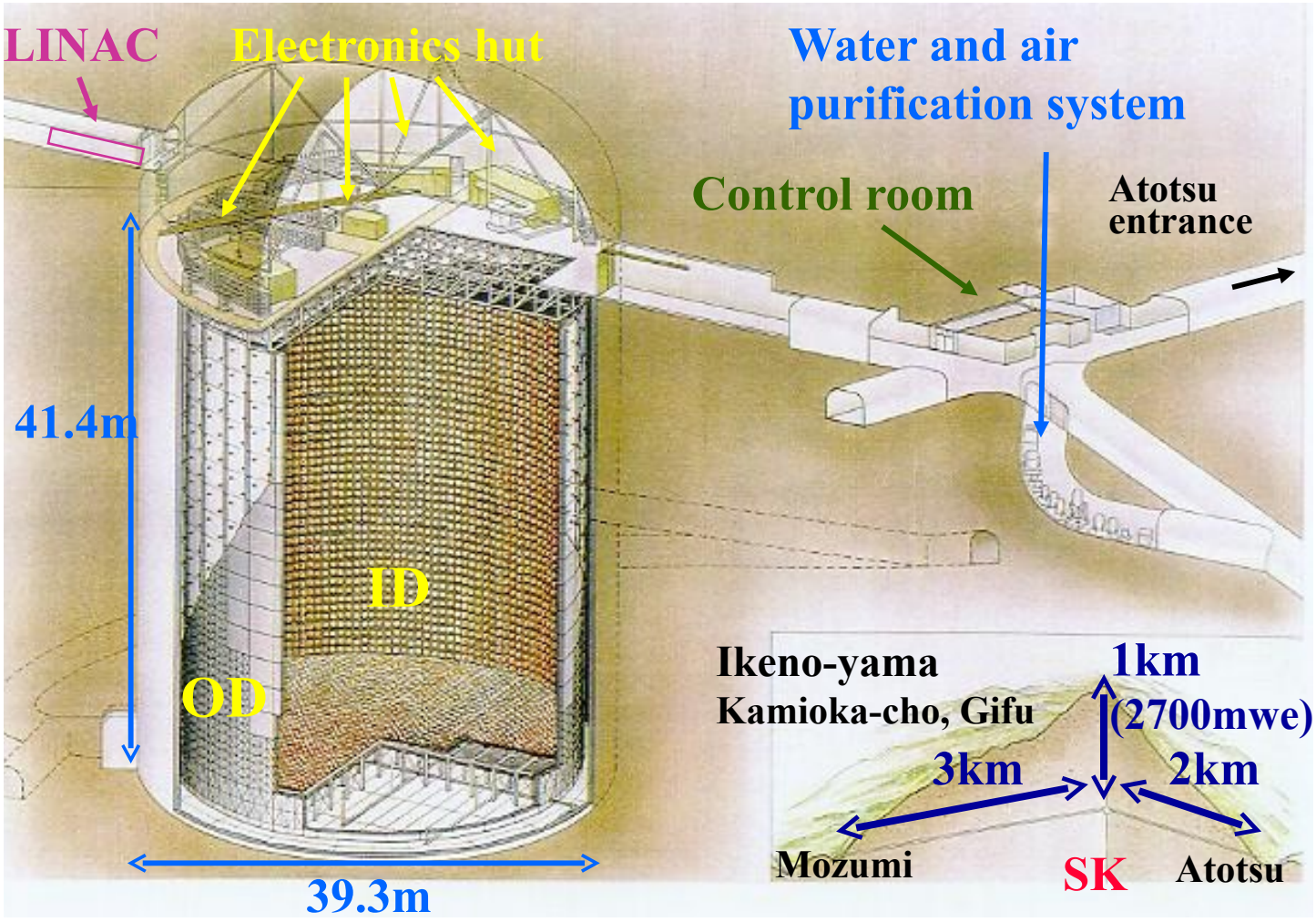
	11146 ID PMTs (40% coverage)	5182 ID PMTs (19% coverage)	11129 ID PMTs (40% coverage)	Electronics Upgrade
Energy Threshold (Total energy)	5.0 MeV	7.0 MeV	4.5 MeV	< 4.0 MeV
(Kinetic energy)	~4.5MeV	~6.5MeV	~4.0MeV	<~3.5MeV
			Work in progress	Target

SK-IV Software Trigger



More sophisticated/flexible triggering can be implemented. For example a neutron trigger: Open a time gate of 500 μs after a E_{total} >10MeV event to search for neutron capture

SuperKamiokande Detector



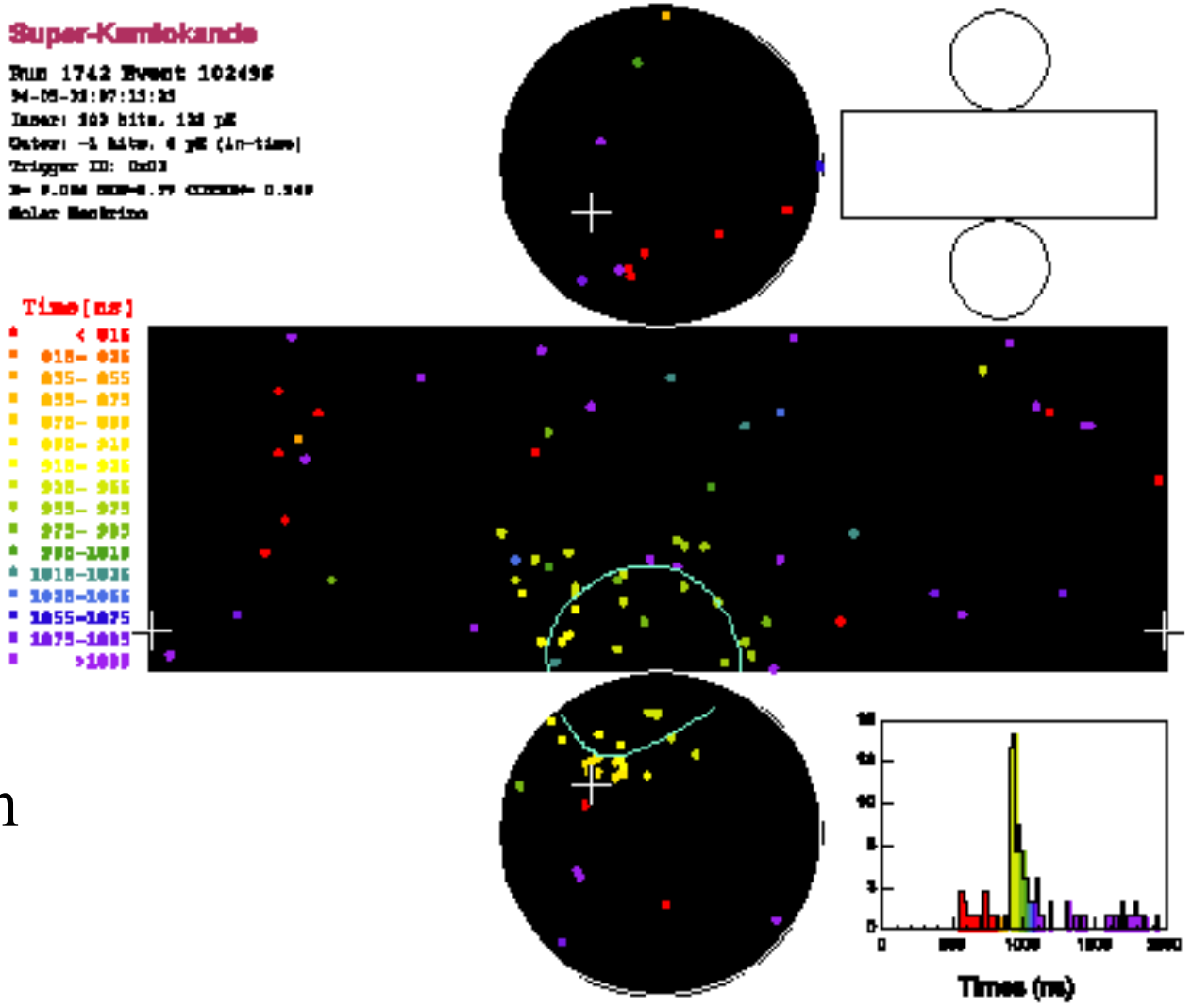
- 50kton water
- ~2m OD viewed by 8-inch PMTs
- 32kt ID viewed by 20-inch PMTs
- 22.5kt fid. vol. (2m from wall)
- ~5MeV energy threshold
- April 1996~

Inner Detector (ID) PMT: ~11100 (SK-I,III,IV), ~5200 (SK-II)
Outer Detector (OD) PMT: 1885

Event reconstruction in a Nutshell

Solar neutrino

$$\nu \; e^- \rightarrow \nu \; e^-$$



✔ Reconstruction method:

- Interaction vertex:

  ⇨ Timing information

- Electron direction:

  ⇨ Cherenkov Ring pattern

- Electron energy:

  ⇨ Number of hit PMTs, N_{eff} , (~6 hit/MeV @ SK-I, III and IV)

Resolution (10 MeV electron@SK-I)
Vertex: 87cm Direction: 26º Energy: 14%

Solar Neutrino Analysis

Analysis current status

Goal: reduce background and systematic uncertainties to further reduce the energy thresholds and improve limits.

Systematic Uncertainty Sources under improvement:

- Water quality:
  - Fine water temperature control in the tank→ Lower radon concentration in fiducial volume
  - MC position water quality parametrization: 1% position dependence in energy scale included in the MC simulation
- Fiducial volume uncertainty reduction:
  - Some non-linearity in the electronics caused a vertex shift of ~15 cm at the edge of the fiducial volume. It was taken into account and became <10cm →larger fiducial volume: correction also applicable in SK-I/II data!
- Optical properties of the detector material:
  - Precise measurement of the ID black sheet cover reflectivity included in MC
- Improved direction fitter: → 10% angular resolution

The estimation of the systematic uncertainties are currently under way

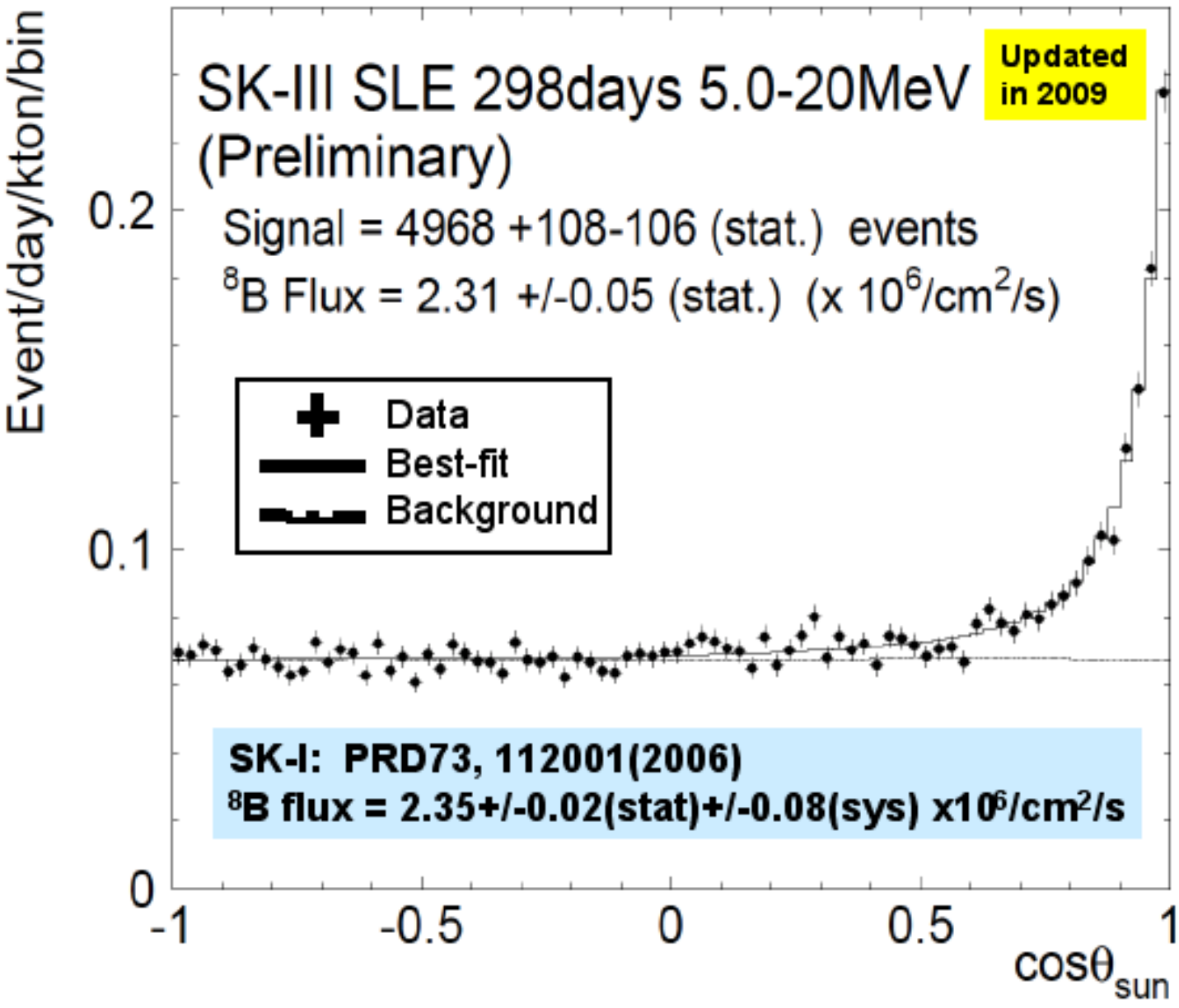
Analysis current status

Goal: reduce background and systematic uncertainties to further reduce the energy thresholds and improve limits.

For SK-IV data:

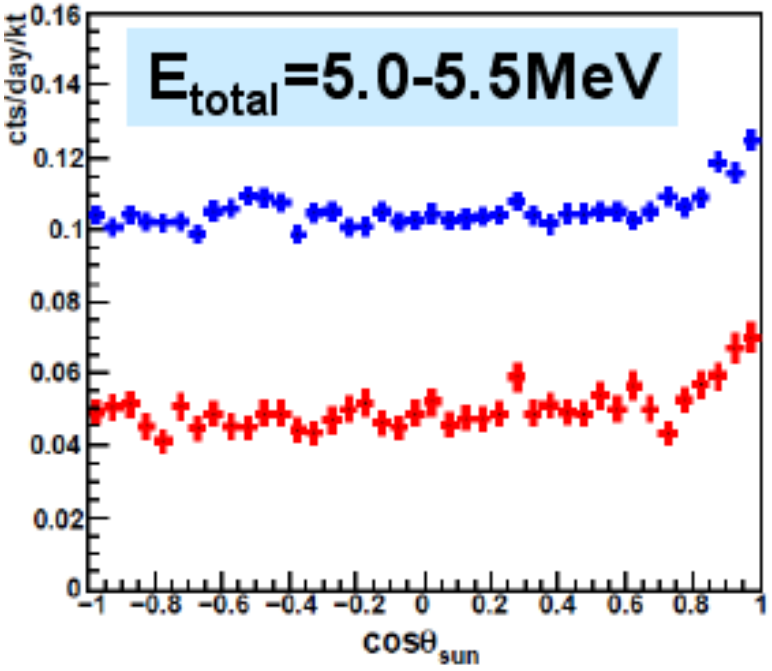
- 100% efficiency at $E_{total} = 4.5$ MeV($E_{kin} = 4.0$ MeV)
- This threshold will be lowered in the future. Current target is $E_{total} \leq 4.0$ MeV($E_{kin} = 3.5$ MeV)

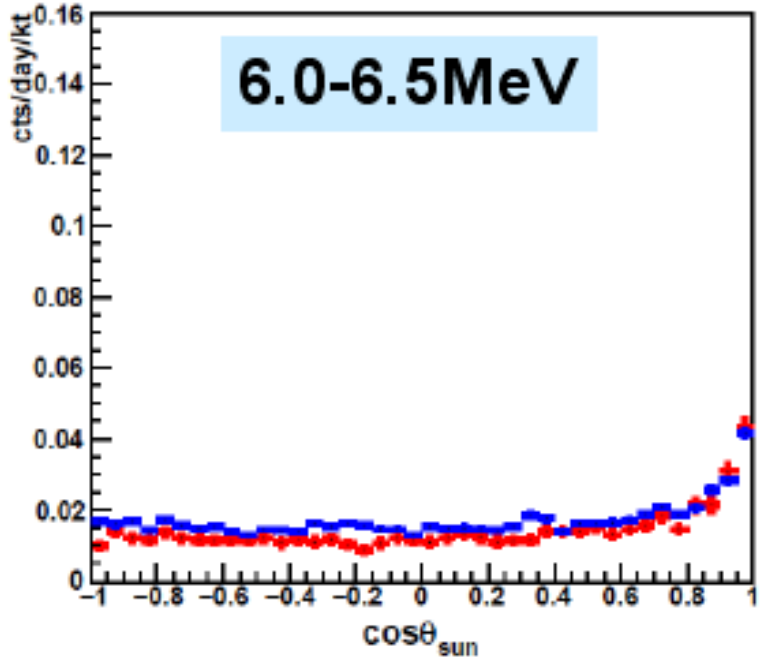
^{8}B Flux @ SK-III

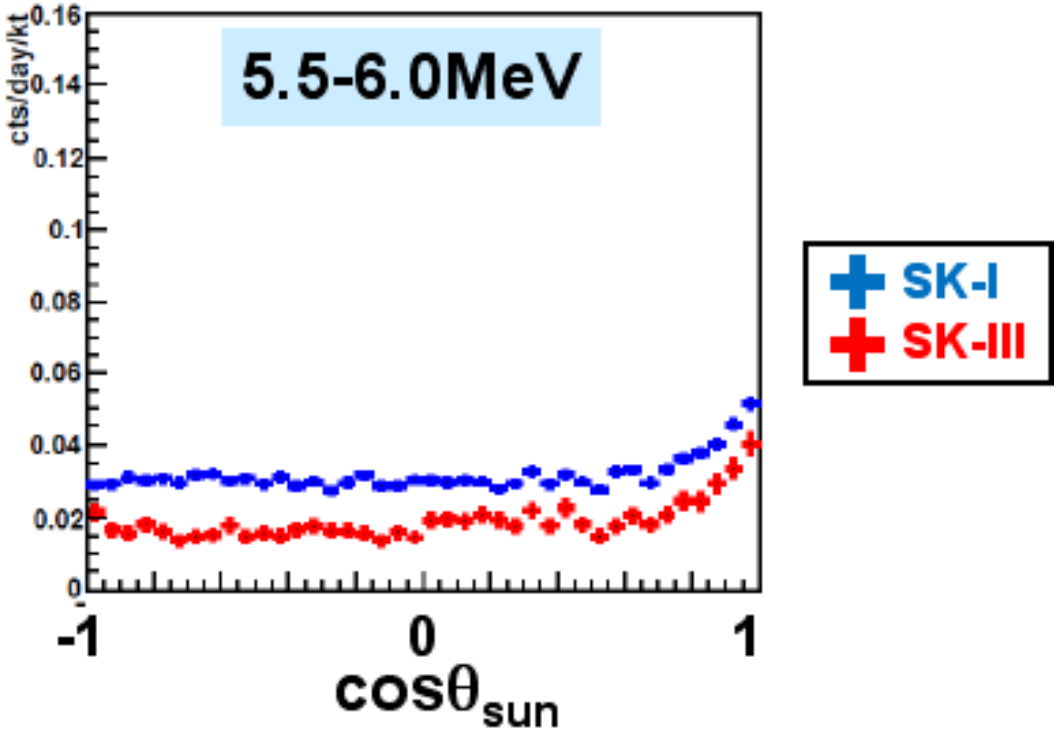


- ✔ Flux consistent with SK-I
- ✔ Better angular resolution compared to SK-I
- ◆ Systematic uncertainties are currently being estimated (trying to reduce them)

Angular distributions 1/2



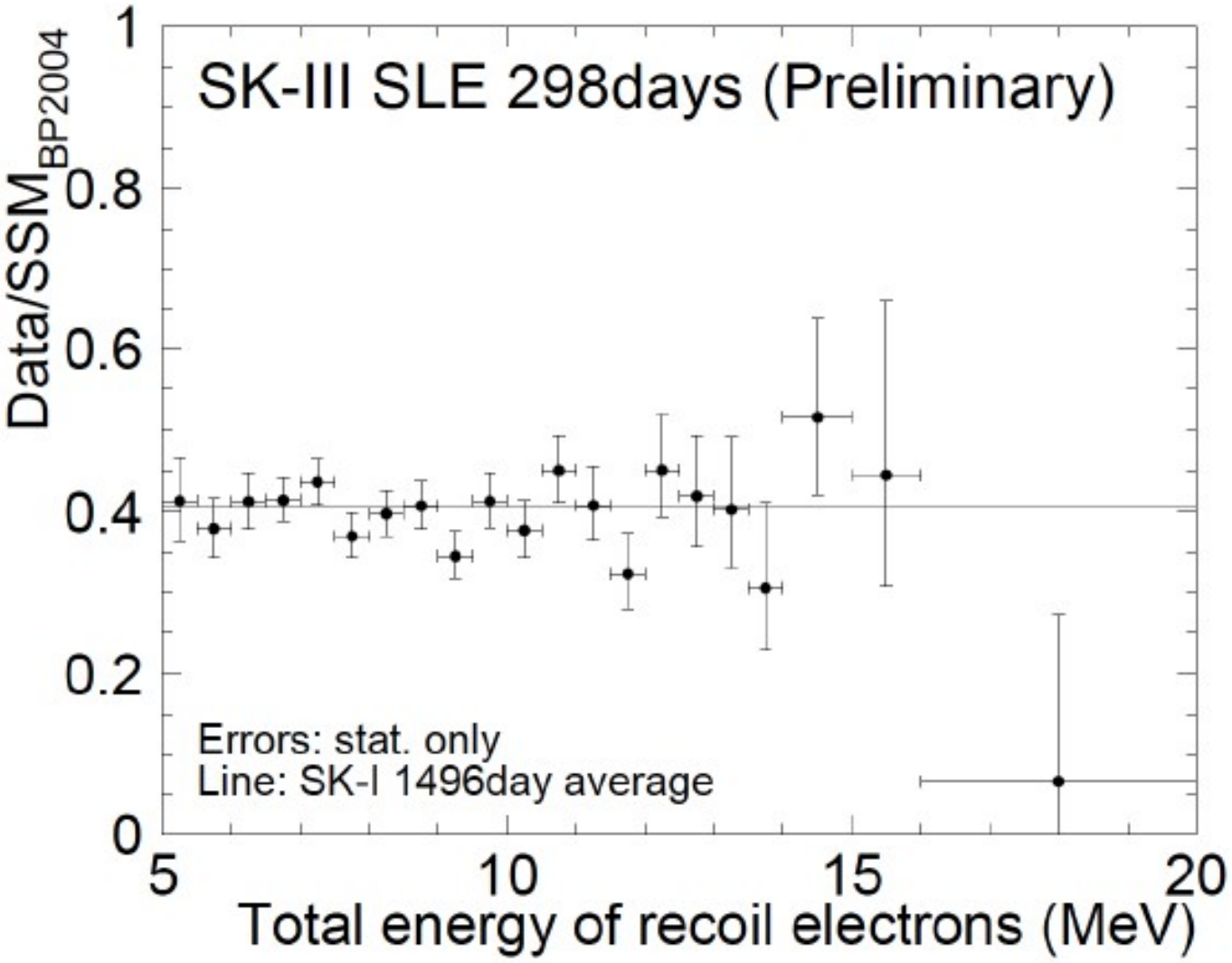




✔ Lower background level due to better water quality

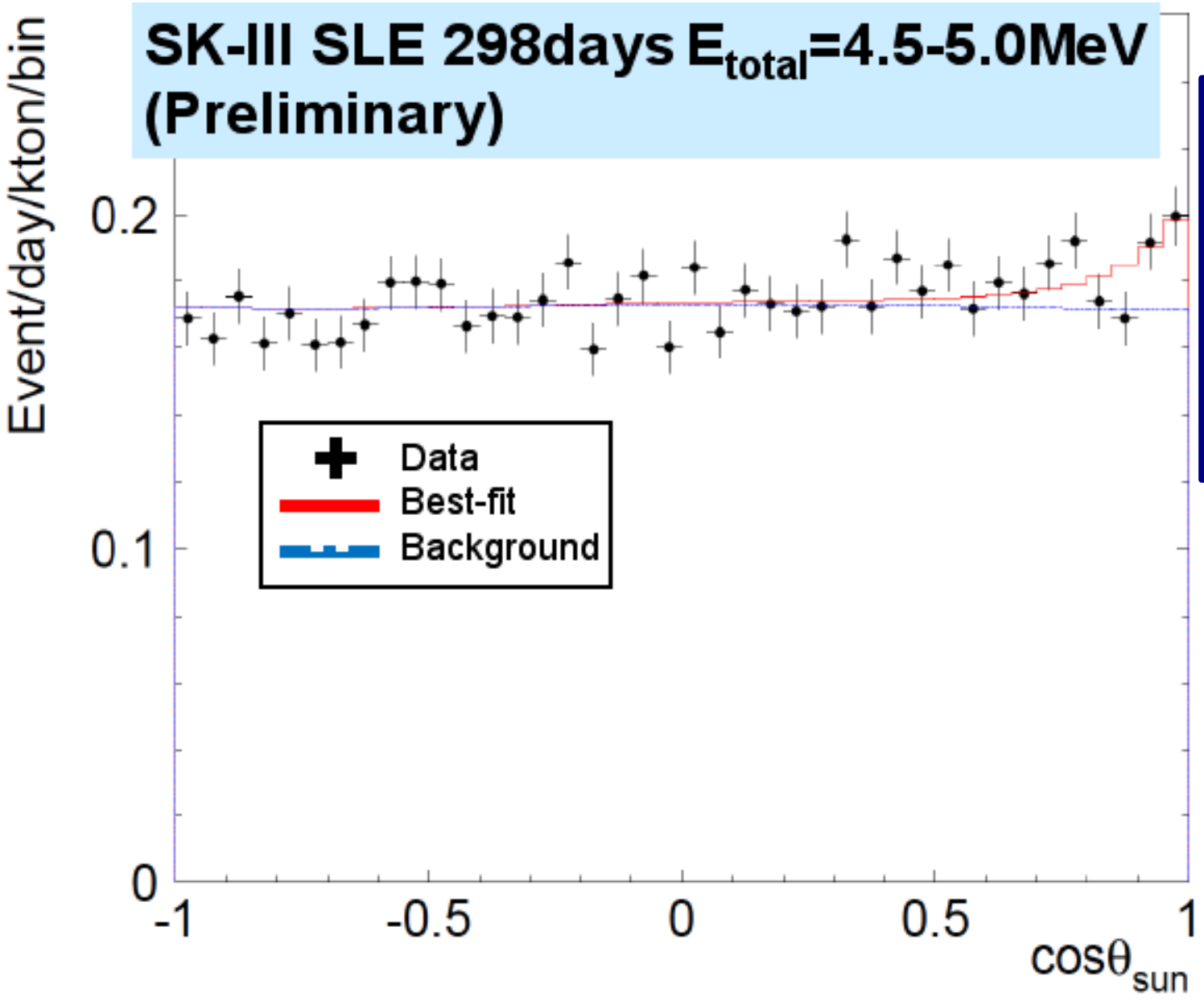
Fiducial volume is central 13.3 kton

^{8}B energy spectrum



✔Consistent with SK-I

Angular distributions 2/2

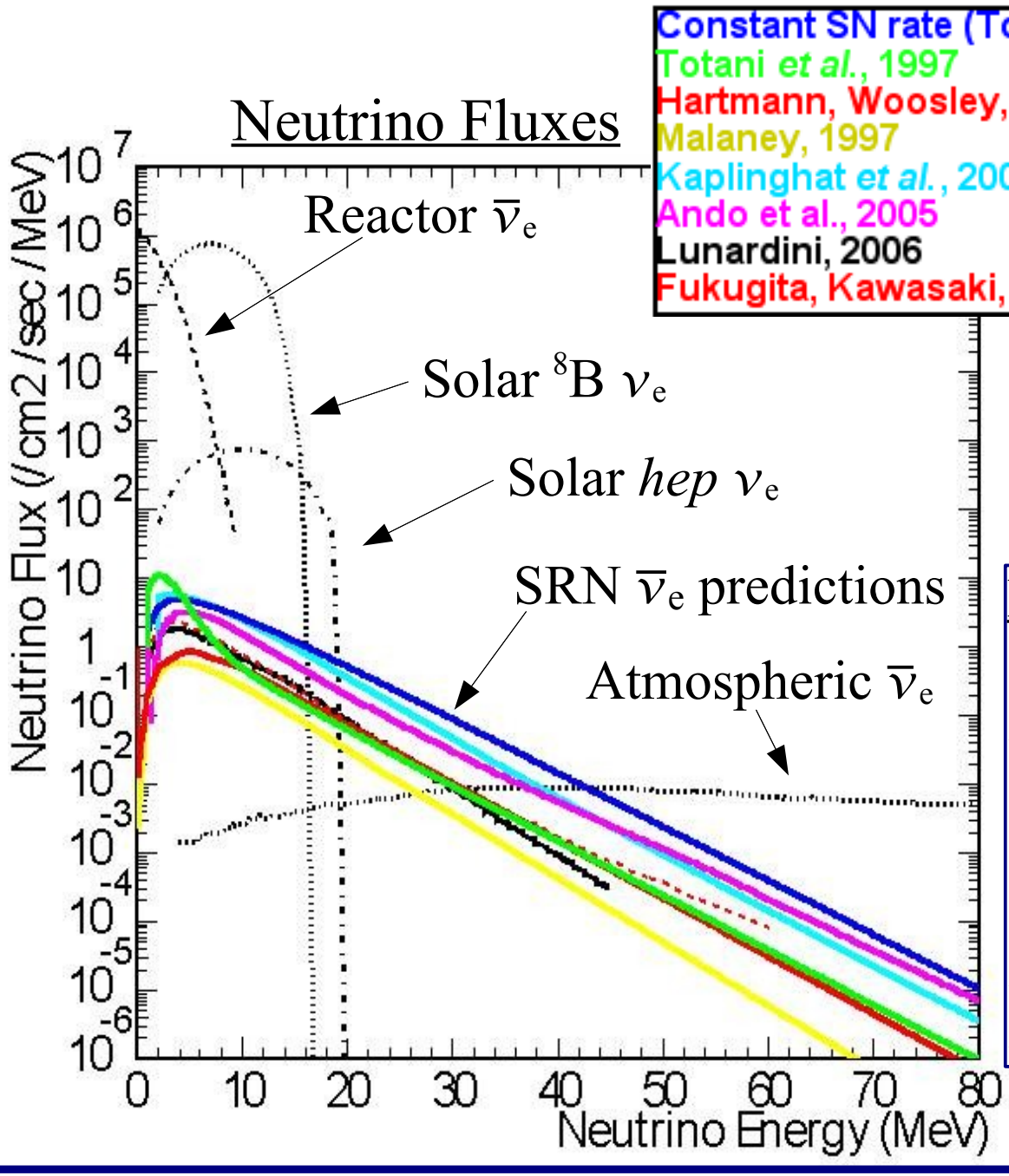


✔ Lower background due to better water quality

Fiducial volume is central 9.0 kton

Supernova Relic Neutrinos

Supernova Relic Neutrinos (SRN)



Dominant interaction@SK:

$$\bar{\nu}_e \; p \rightarrow n \; e^+$$

<u>Motivation:</u> obtain supernova and star formation rate for $M > 8\ M_\odot$ and metal enrichment rate.

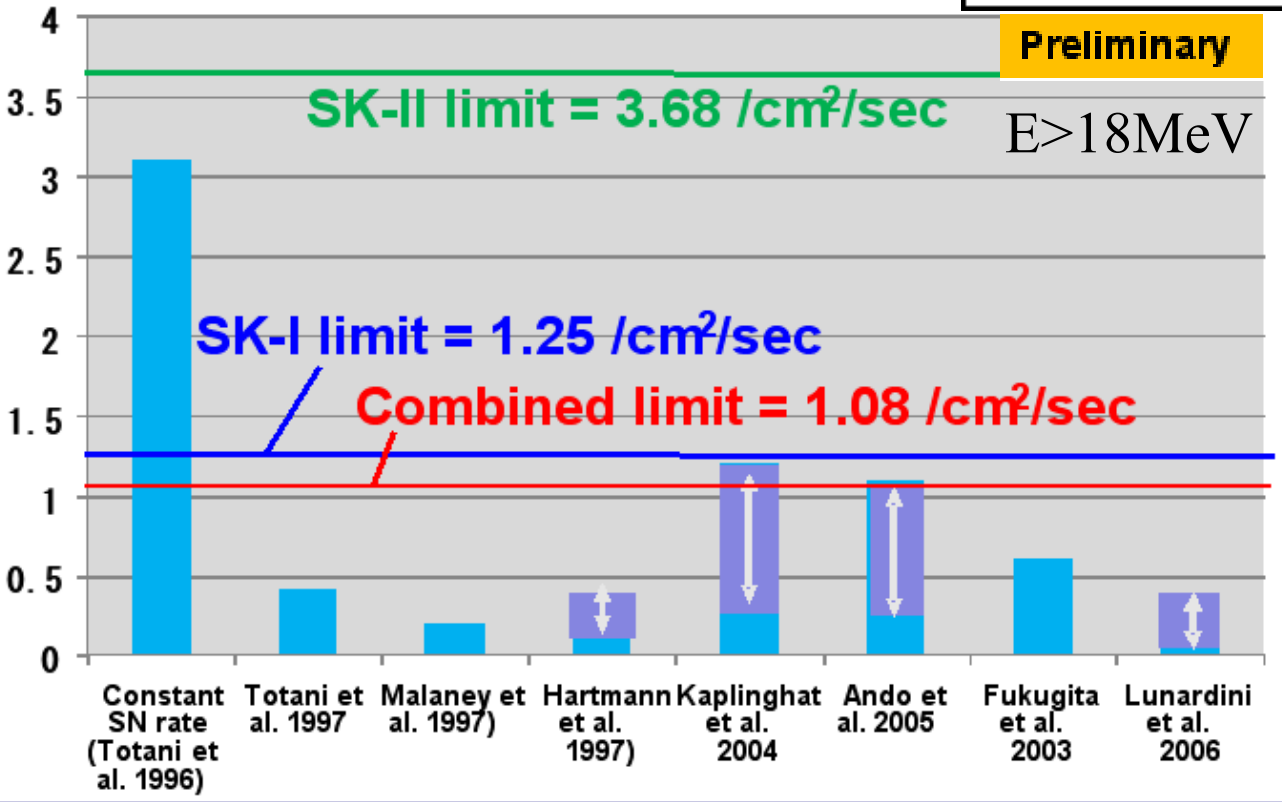
Since: $\dfrac{E_{detect}}{E_{emit}} = \dfrac{1}{1+z}$

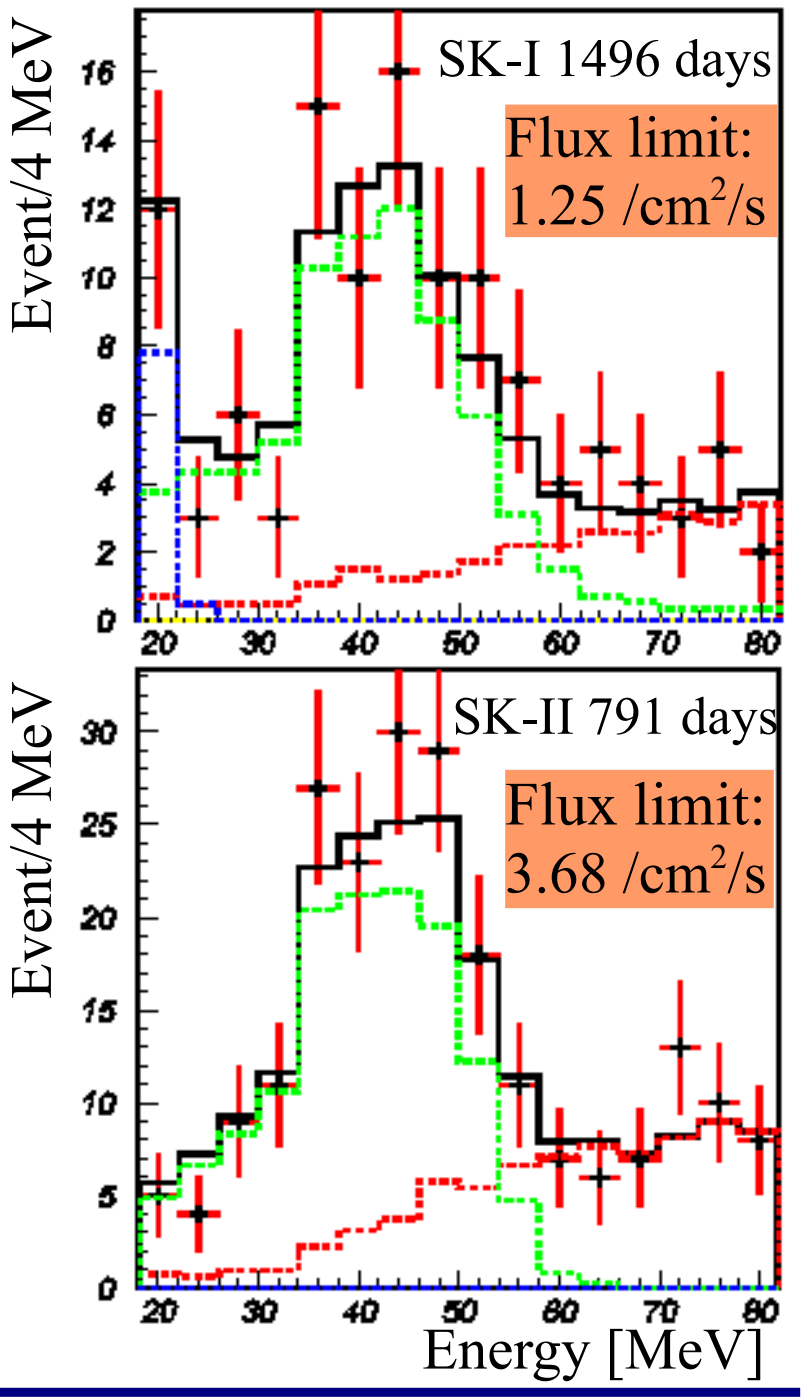
a smaller energy threshold would allow us to probe lower z values

Current results: SRN Flux Limits vs Model Predicitons

Combined SRN flux limit: < 1.08 cm^2/s

Our model exclusion and constrain power is increasing !!





Currently applied event selection

Solar neutrino cut: Reject **solar neutrinos** using direction information 7% inefficiency → improving!!

Gamma ray cut: Reject **gamma-rays** originated from outside the fiducial volume 7% inefficiency → improving!!

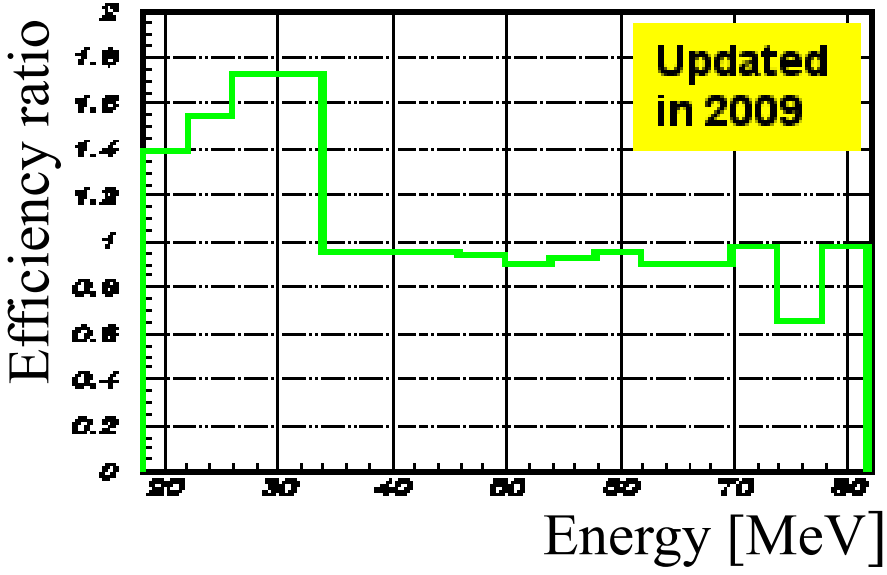
Standard spallation cut: Reject **spallation** events using Δt and Δl information from previous muons

Tight spallation cut: Reject **spallation** events using a tight Δt selection Spallation cuts total: 36% inefficiency → improving!!

Subevent cut: Reject **decay-e** by checking time correlating events 0.5% inefficiency

Ĉherenkov angle cut: Reject **low energy muons** using Ĉherenkov opening angle

- ✔Improved reconstruction tools & flux calculation
- ✔Reduction criteria are currently being improved
- ➔ The SRN signal efficiency will be improved



Currently applied event selection

In the short term:

- Finish the new event selection
- Combine the SK-I (1496 days), SK-II (791 days) and SK-III (425 days) data
- Try to enlarge the fiducial volume by ~0.5-1m
- New results will be summarized this year

Long term...

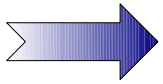
The long term future means Gadzooks!:

- The background could be reduced by neutron tagging
- The R&D program is on going

The budget for a 200-ton tank has been (EGADS) approved

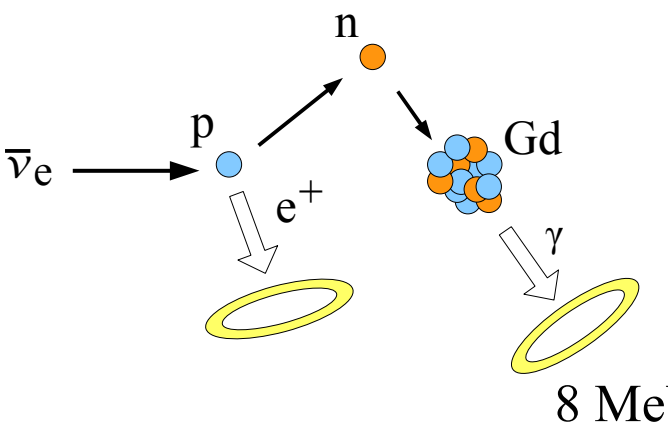
Updated in 2009

See next slides!!



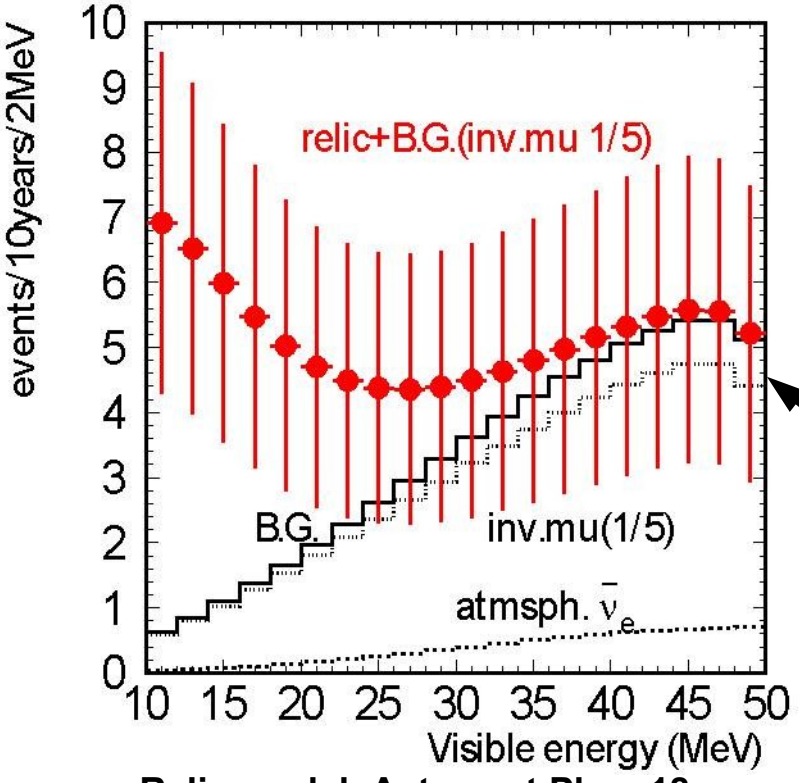
Gadzooks!

Gadzooks!



Idea: add 0.2% of Gd in the SK water
Phys. Rev. Lett. 93, 171101 (2004)
J.Beacom and M.Vagins

$\bar{\nu}_e$ signal could be separated from BG by neutron tagging, i.e. coincidence detection of positron and neutron
Vertex correlation ~50cm



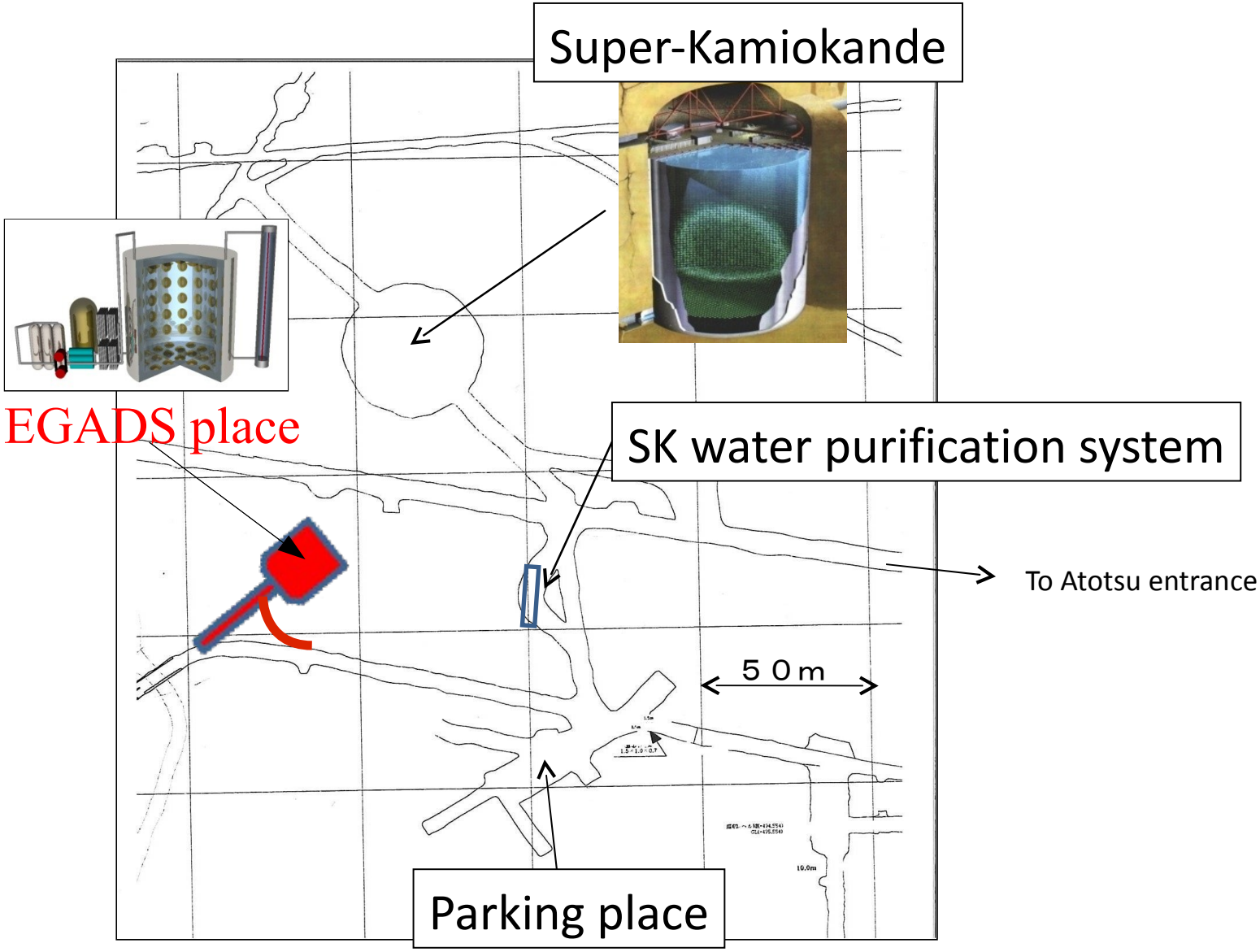
Relic model: Astropart.Phys.18, 307(2003) with flux revise in NNN05.

After 10 years of SK data taking:
Signal: 33 events; Background: 27 events
E_{vis} = 10-30 MeV

Assumption:
- 67% detection efficiency
- Invisible μ background can be reduced by a factor of 5

Evaluating Gadolinium 's Action on Detector Systems

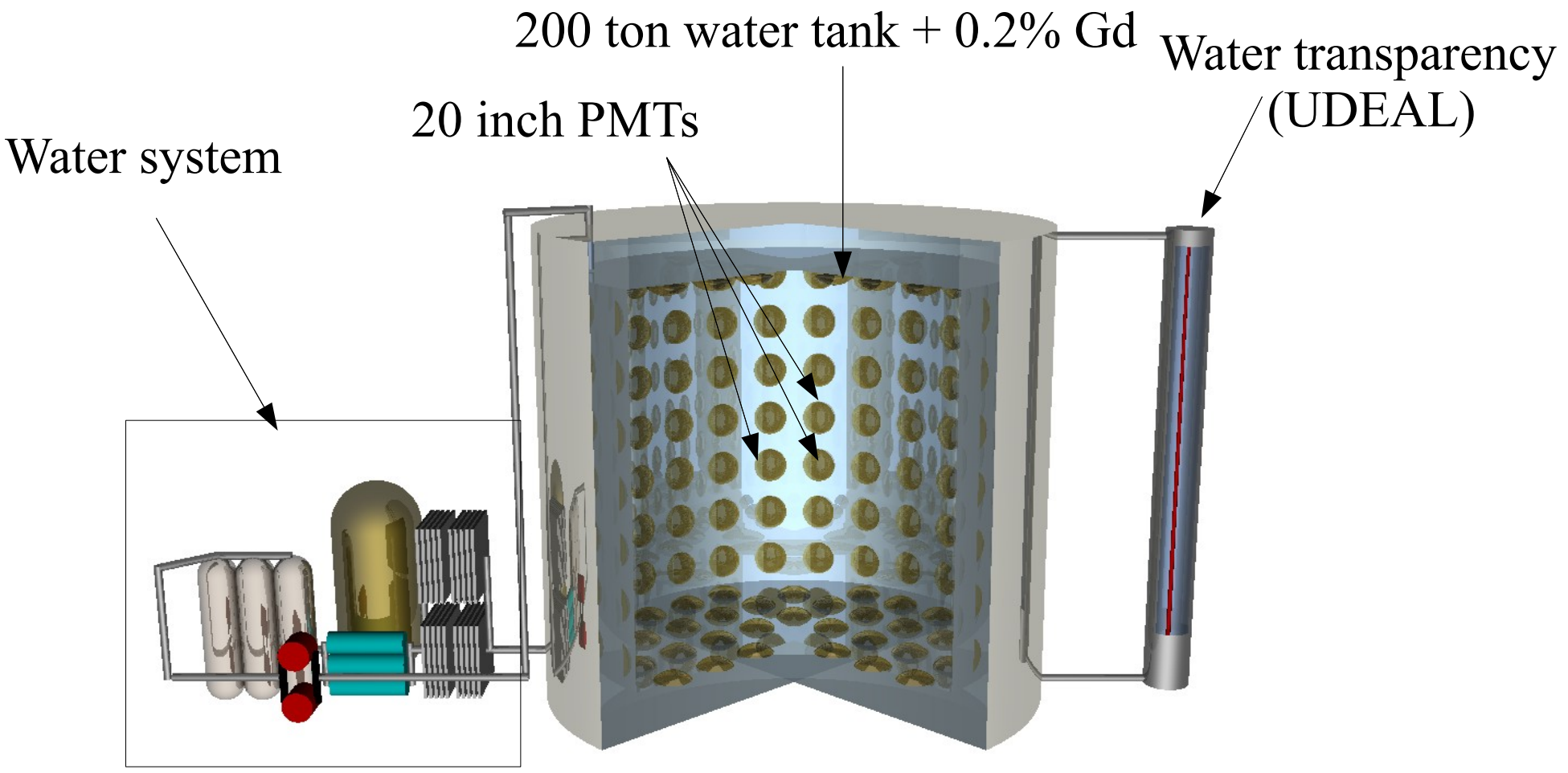
Study the effect of Gd on all the materials and the neutron background




工事名
工種 削孔工
位置 道路延伸
装薬作業

Evaluating Gadolinium 's Action on Detector Systems

Study the effect of Gd on all the materials and the neutron background



EGADS

Water Transparency: as a water Ĉherenkov detector the water transparency must be large and with no time degradation.

Water Purification system: the new purification system should remove all ions except Gd

How to Add/Remove Gd: how uniform can be dissolve Gd? How efficient/economical can we remove Gd?

Material Effects: the addition of the Gd solution could corrode SK materials

Neutron Background: since neutron background is going to be seen, how does this will affect the trigger rates and the current analysis?

➔ No Gd should leak to the environment and therefore the SK tank has to be repaired

- EGADS will be in operation in summer 2010
- Main results will arrive in 2011

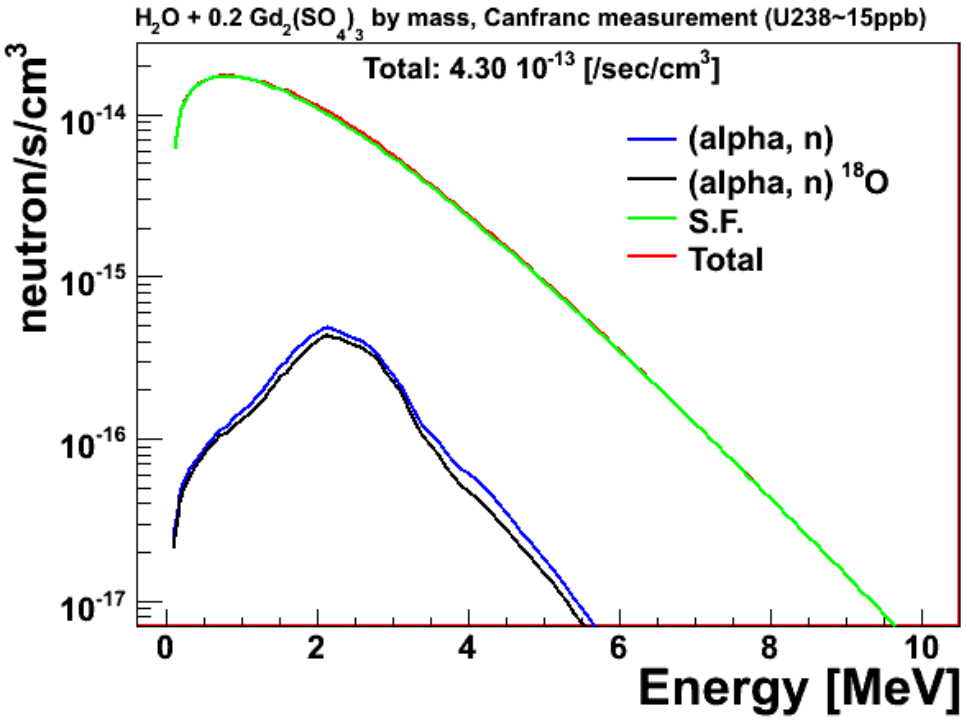
EGADS: neutron background estimation

Mass considered: 32.5kton (SK ID)

Source	neutron/s·cm^3	neutron/s
U^{238}	$4.284 \cdot 10^{-13}$	0.0139
U^{235}	$1.734 \cdot 10^{-13}$	0.0056
Th^{232}	$0.213 \cdot 10^{-13}$	0.0007
Total:	$6.231 \cdot 10^{-13}$	0.0202

neutrons/s in the ID

This is ~1750neutrons/day



Largest neutron background is expected to come from the U^{238} chain

Summary

Analyses with SK-III data are ongoing:

- Solar neutrino results will be summarized by the fall of this year. The goal is to reduce the systematic uncertainties.

- SRN search results will be finalized using SK-I, SK-II and SK-III data this year. The goal is to reduce the event selection inefficiency and therefore increase the sensitivity.

SK-IV runs with the lowest energy threshold in its history.

- Now, with 100% efficiency @ $E_{total} \leq 4.5$ MeV

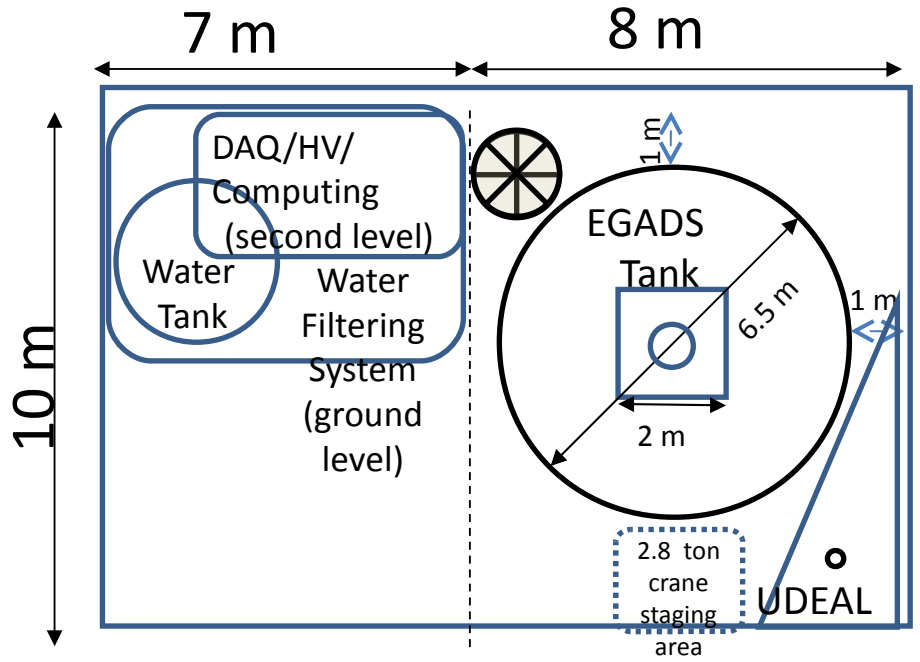
- Current target is $E_{total} \leq 4.0$ MeV

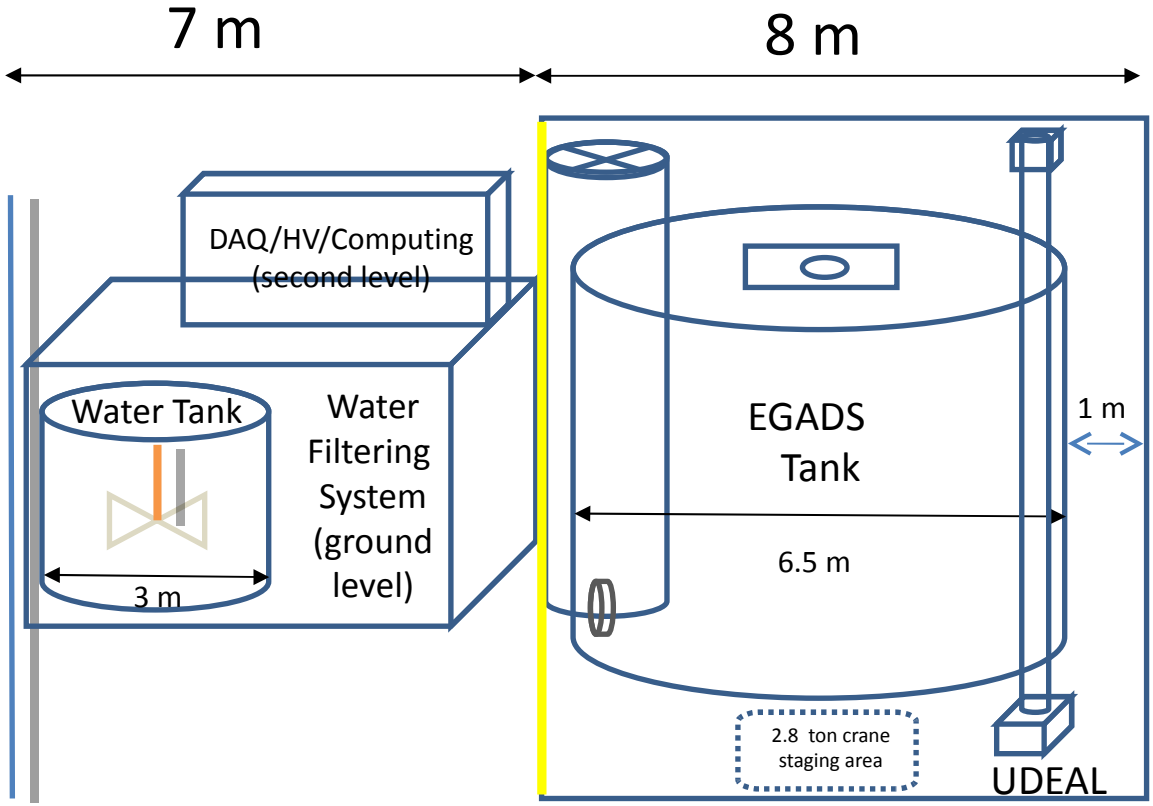
The Gadzooks! R&D project is entering into a crucial phase!

- A 200 ton test tank is going be the test field: its budget was approved!

Thank you for your attention!!

EGADS


7 m
8 m
10 m
DAQ/HV/
Computing
(second level)
Water
Tank
Water
Filtering
System
(ground
level)
1 m
EGADS
Tank
6.5 m
1 m
2 m
2.8 ton
crane
staging
area
UDEAL


7 m
8 m
DAQ/HV/Computing
(second level)
Water Tank
Water
Filtering
System
(ground
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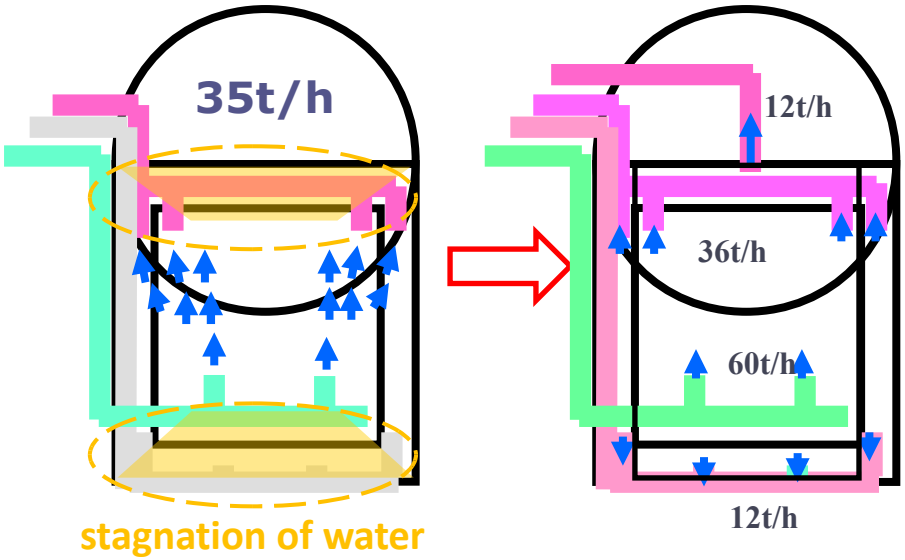
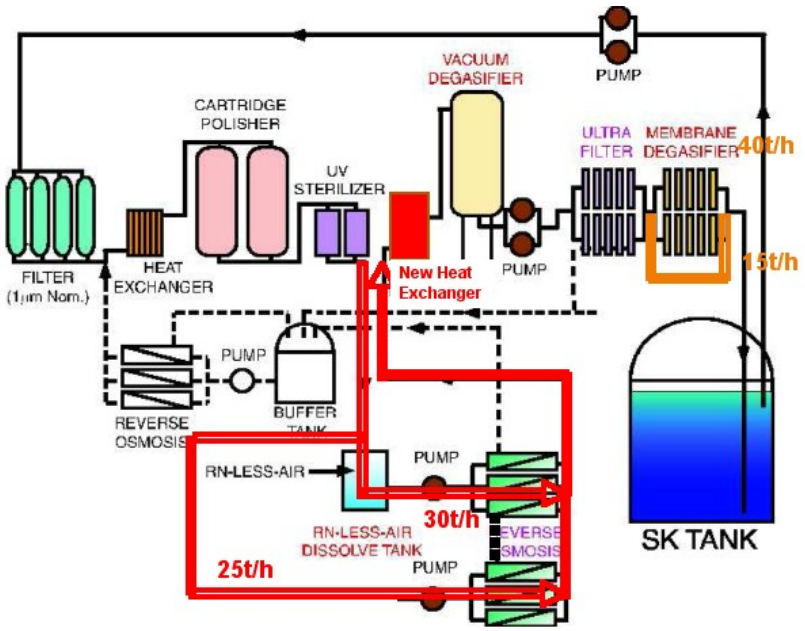
3 m
EGADS
Tank
1 m
6.5 m
2.8 ton crane
staging area
UDEAL

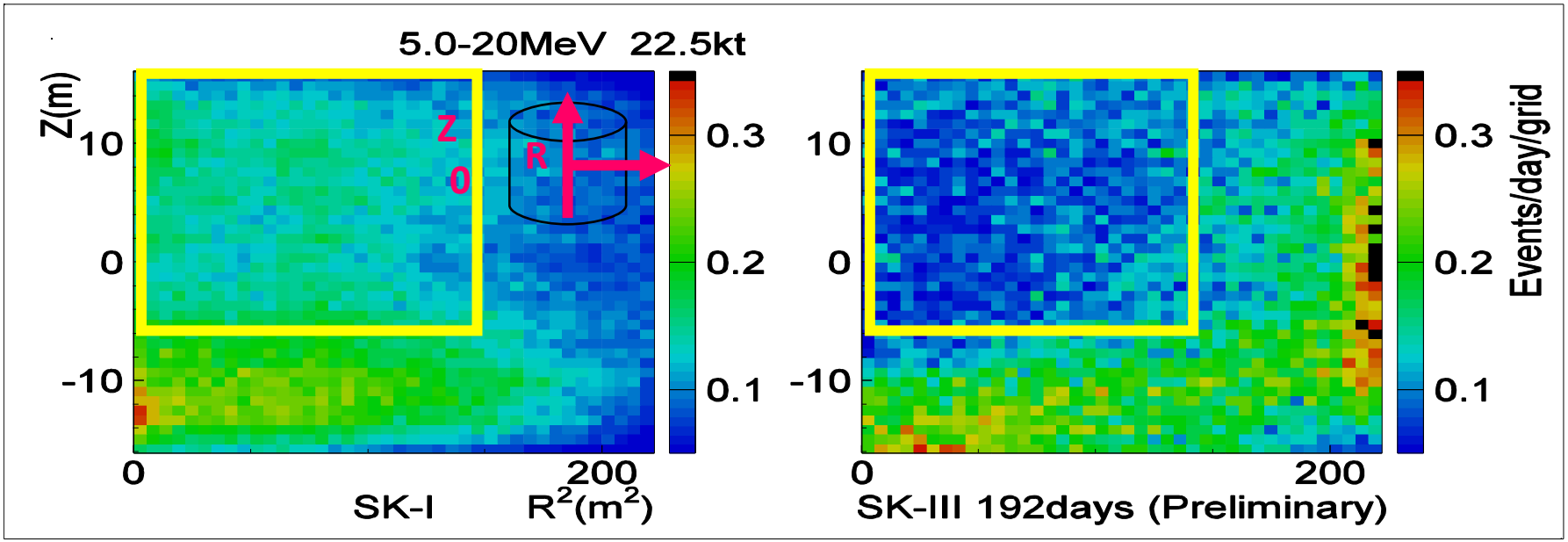
Current systematic uncertainty estimation

	SK-I Flux(%)	SK-III Flux(%) (underway)
Energy Scale	± 1.6	Can be smaller (?)
Trigger efficiency	+0.4 -0.3	
Spallation cut	± 0.2	
Reduction	+2.0 -1.6	Trying to reduce
Gamma cut	±0.5	Trying to reduce
Vertext shift	±1.3	Can be smaller
Angular resol.	±1.2	Can be smaller
BG shape	±0.1	
Livetime calculation	±0.1	
Total	+3.5 -3.2	

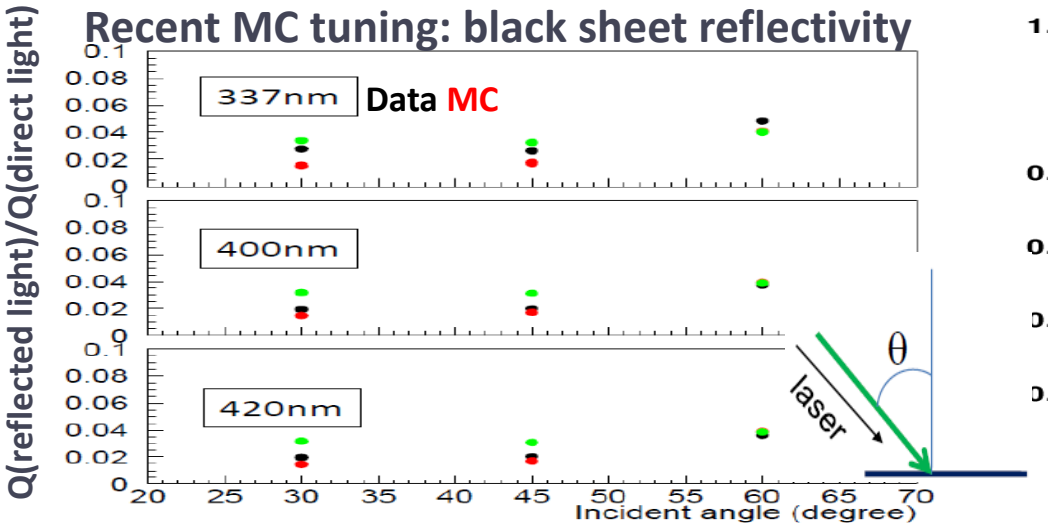
Water system

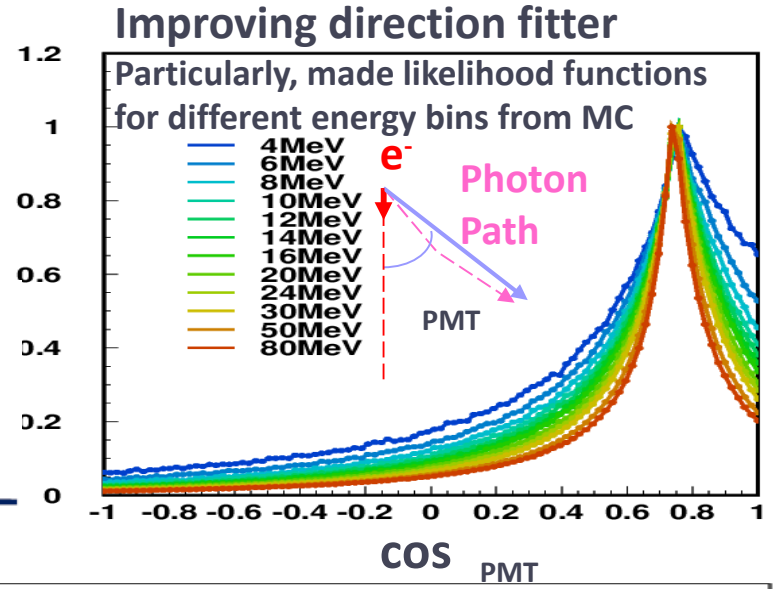


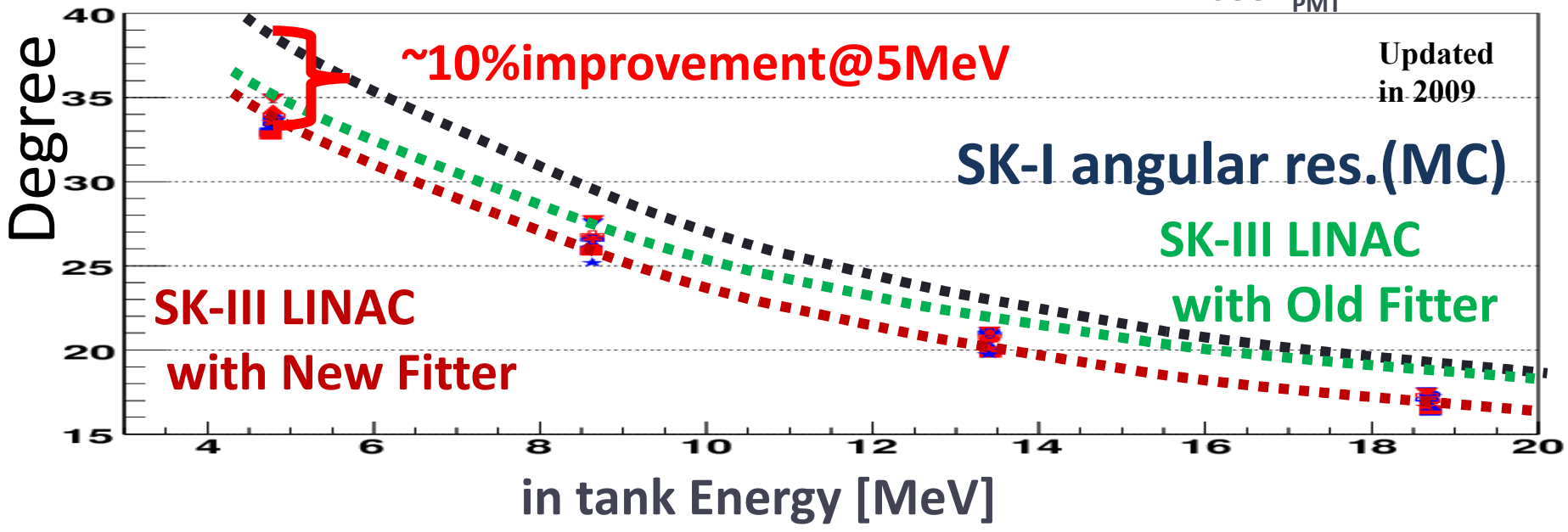




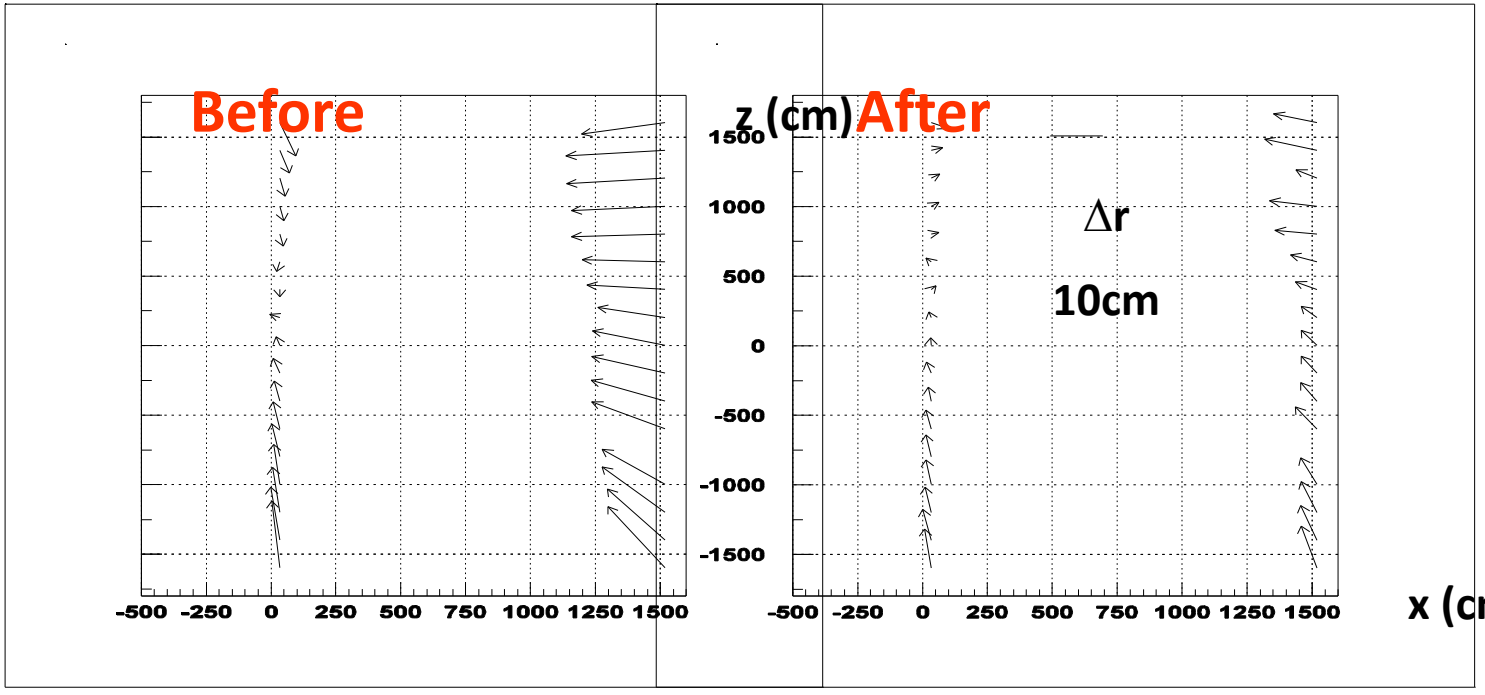
Better angular resolution



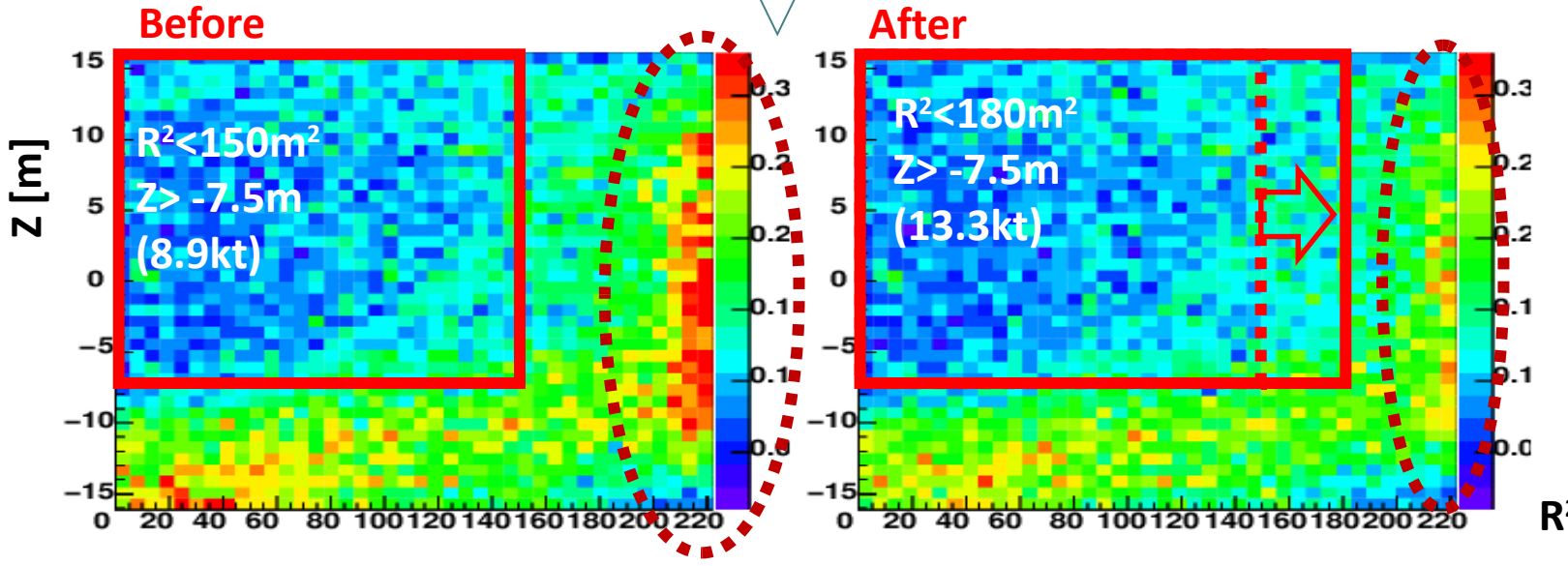




Shift Vertex Correction



R31851-33899(192days) 5-20 MeV

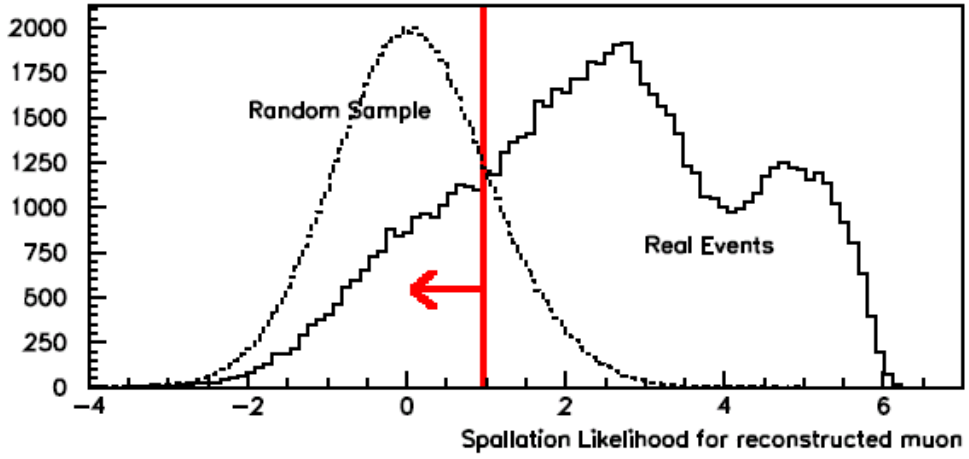


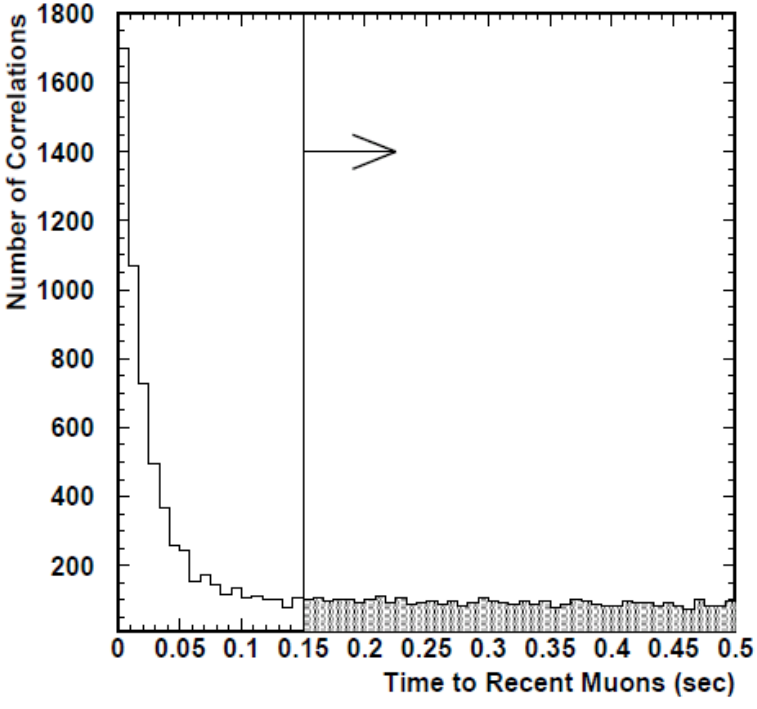
Old Spallation selection

Spallation likelihood (spalike)

$$L = L(dt)\, L(dl)\, L(resQ)$$

dt: time difference from preceding muons.
dl: distance from preceding muon track.
resQ: muon measured pulse height minus pulse height expected from track length.





dt>0.15sec cut is also applied.
Basically all the spallation BG is removed.

Total inefficiency 36%

New Spallation Cut

- 4 variable likelihood cut
- 4 variables:
  - dt
  - $dl_{transverse}$
  - $dl_{longitudinal}$
  - Q_{peak}
- We apply cut up to 24 MeV
- Improvements allow lowering the energy threshold

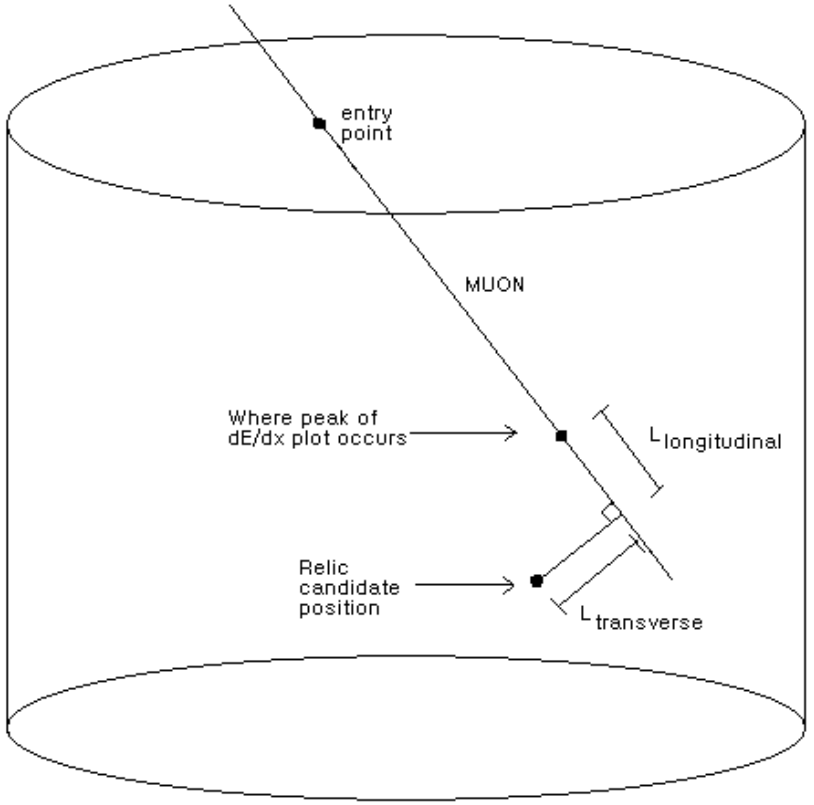
Inefficiency

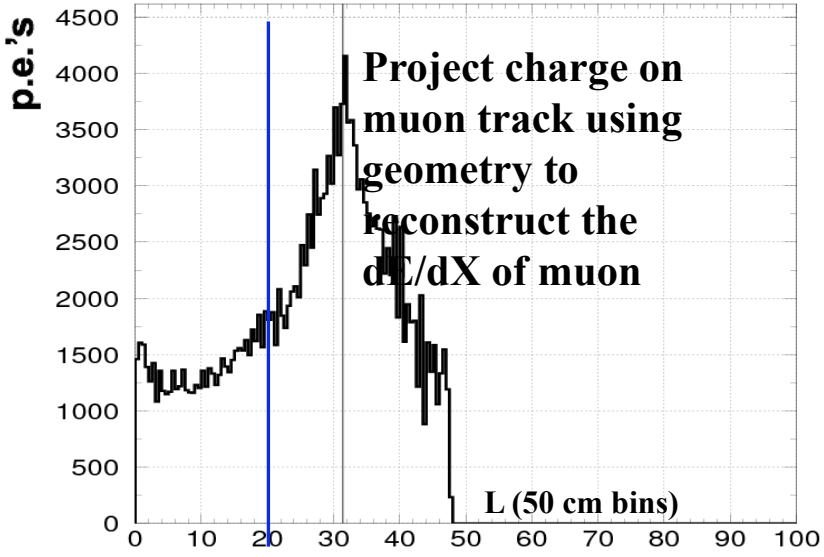
22.5% for 16-18MeV

18.5% for 18-24MeV

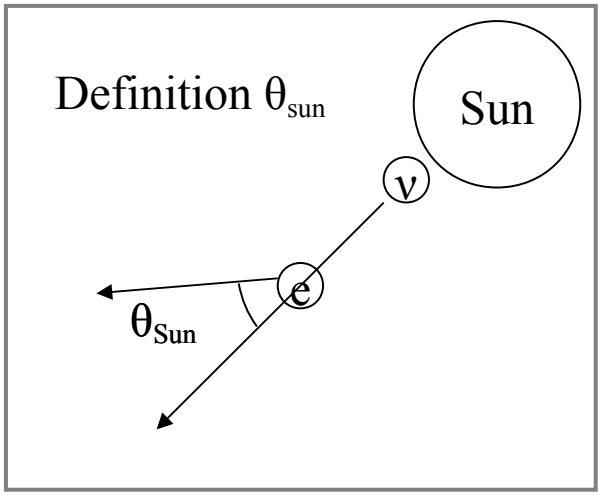
(36% for 18-34MeV in OLD)

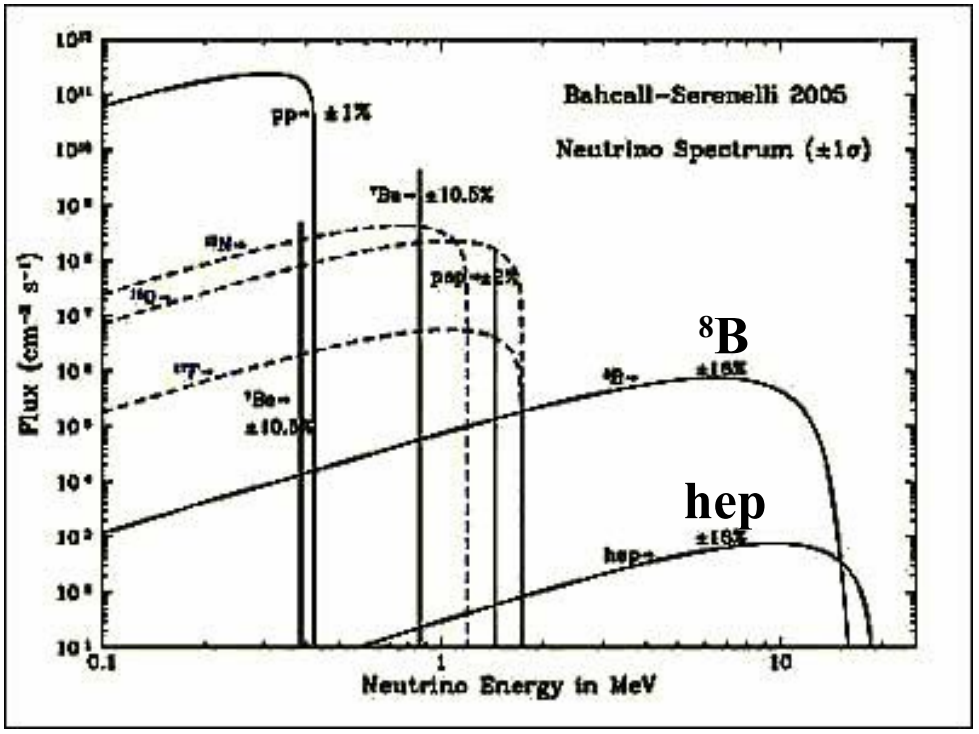
Improved!!





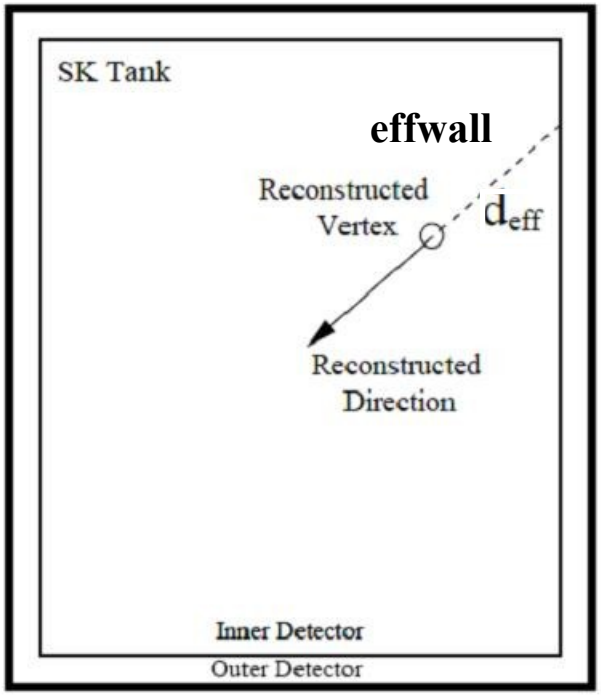
New Solar neutrino cut





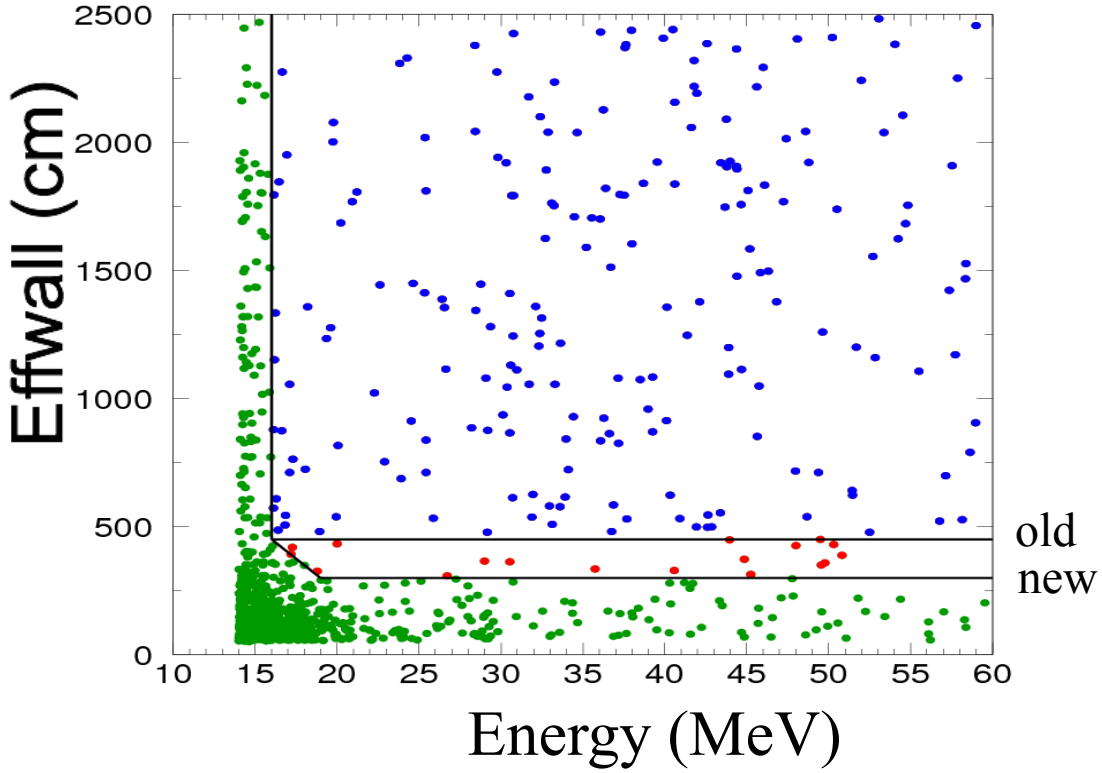
- Solar B8 and hep neutrino can be BG of SRN search due to energy resolution.
- Angle between solar direction and reconstructed direction (θ_{sun}) is used to separate SRN and Solar ν
- Cut criteria is optimized using B8/hep MC

Effective wall selection



Some ray events originating from outside of fiducial volume have possibility of being reconstructed within fiducial volume of SK.
In order to remove these events, an effwall cut is applied which uses the travel distance from tank wall.

The new criteria depends on the energy



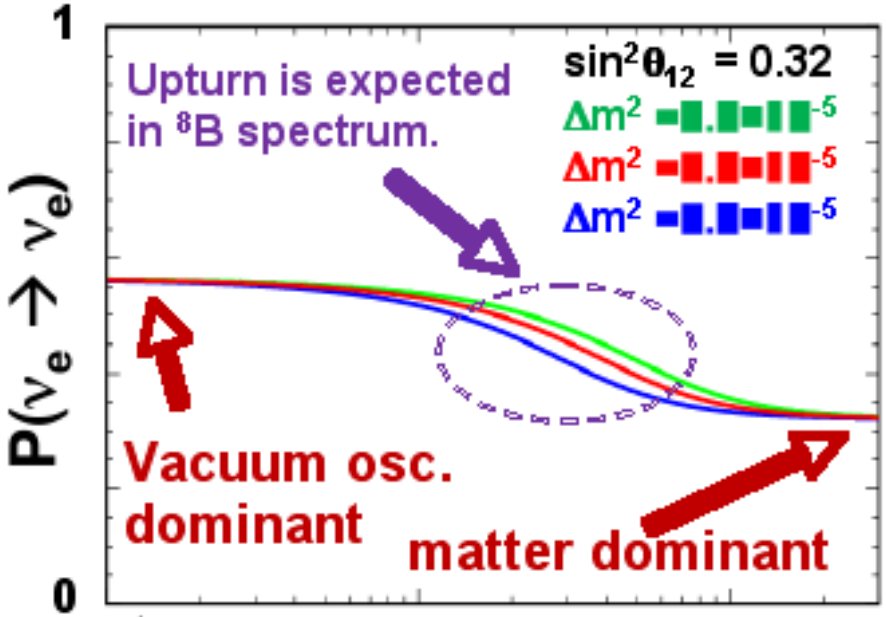
Inefficiency for signal

Old: 7% **18-34MeV**

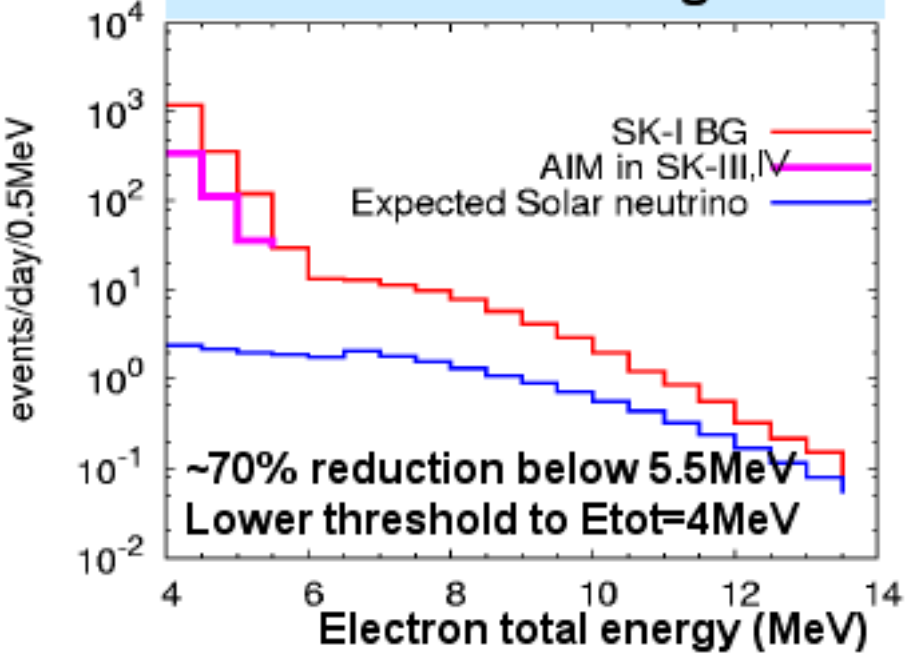
New: 2.5% *Improved!!*

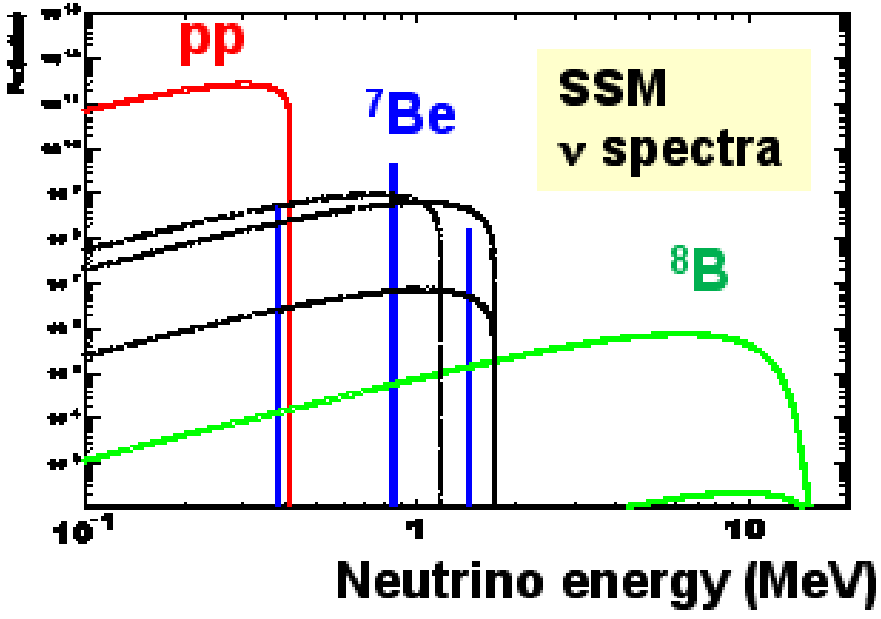
Solar Neutrino Prospects

ν_e survival probability

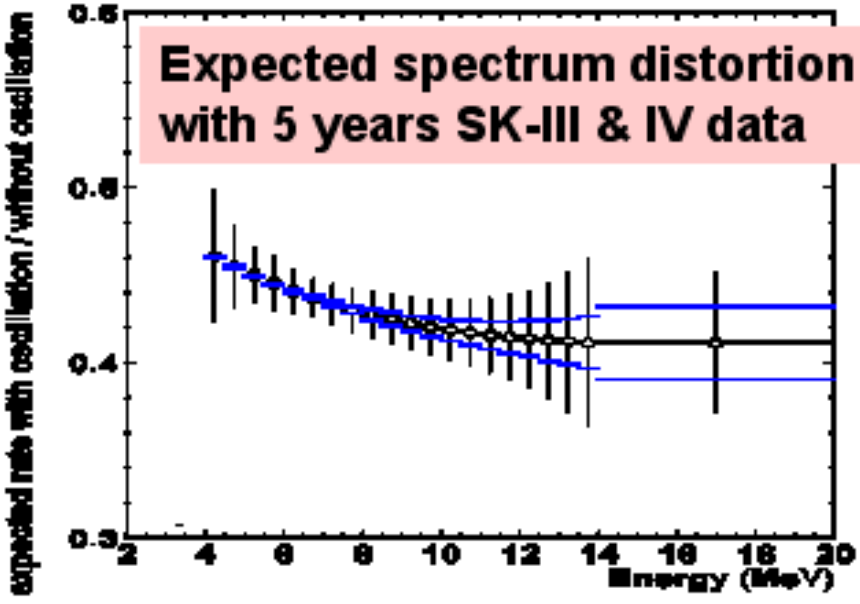


Aim to reduce background

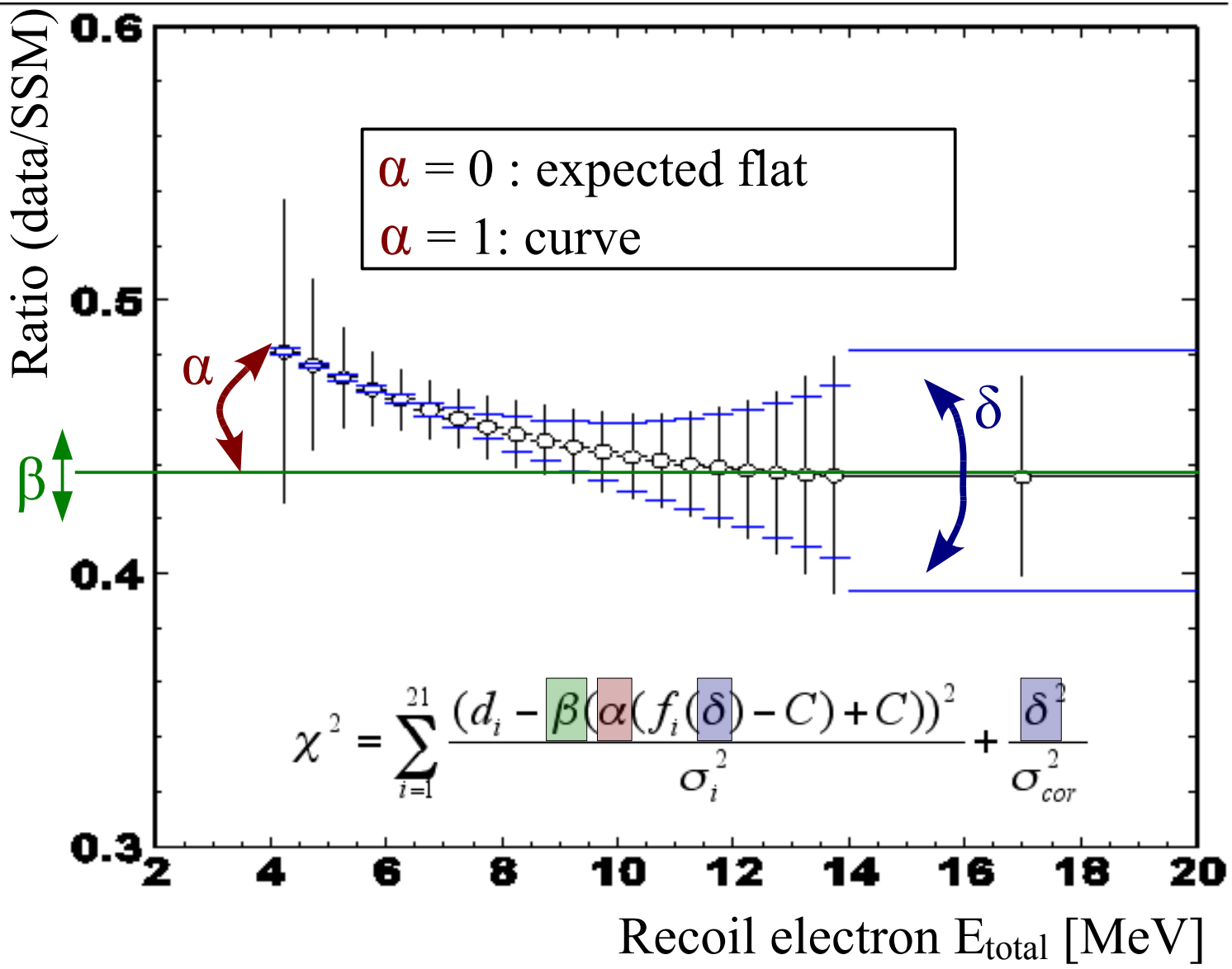




Expected spectrum distortion with 5 years SK-III & IV data

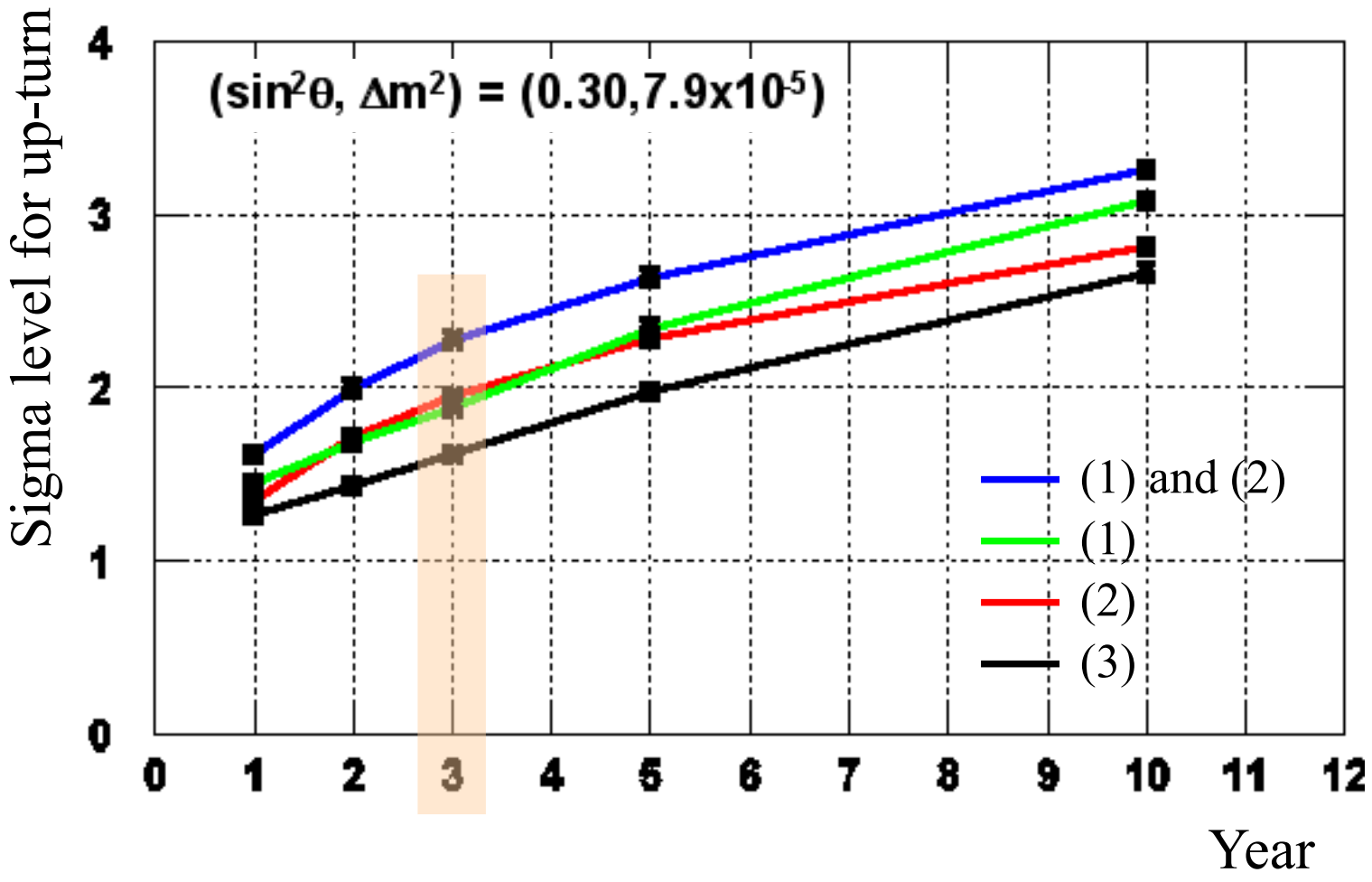


Upturn Sensitivity Estimation



$$\chi^2 = \sum_{i=1}^{21} \frac{(d_i - \beta(\alpha(f_i(\delta) - C) + C))^2}{\sigma_i^2} + \frac{\delta^2}{\sigma_{cor}^2}$$

Upturn Sensitivity



- First target: 2 sigma level up-term discovery after 3 years observation (or its exclusion)
- Enlarge fiducial volume and while keeping control of BG
- Reduction of the energy correlated systematic uncertainty

(1) Enlarge fiducial volume to 22.5kton (low BG)
(2) Half energy correlated systematics as SK-I
(3) 13.3 kton E<5.5 MeV and 22.5 kton E>5.5MeV and same energy correlated uncertainty as SK-I