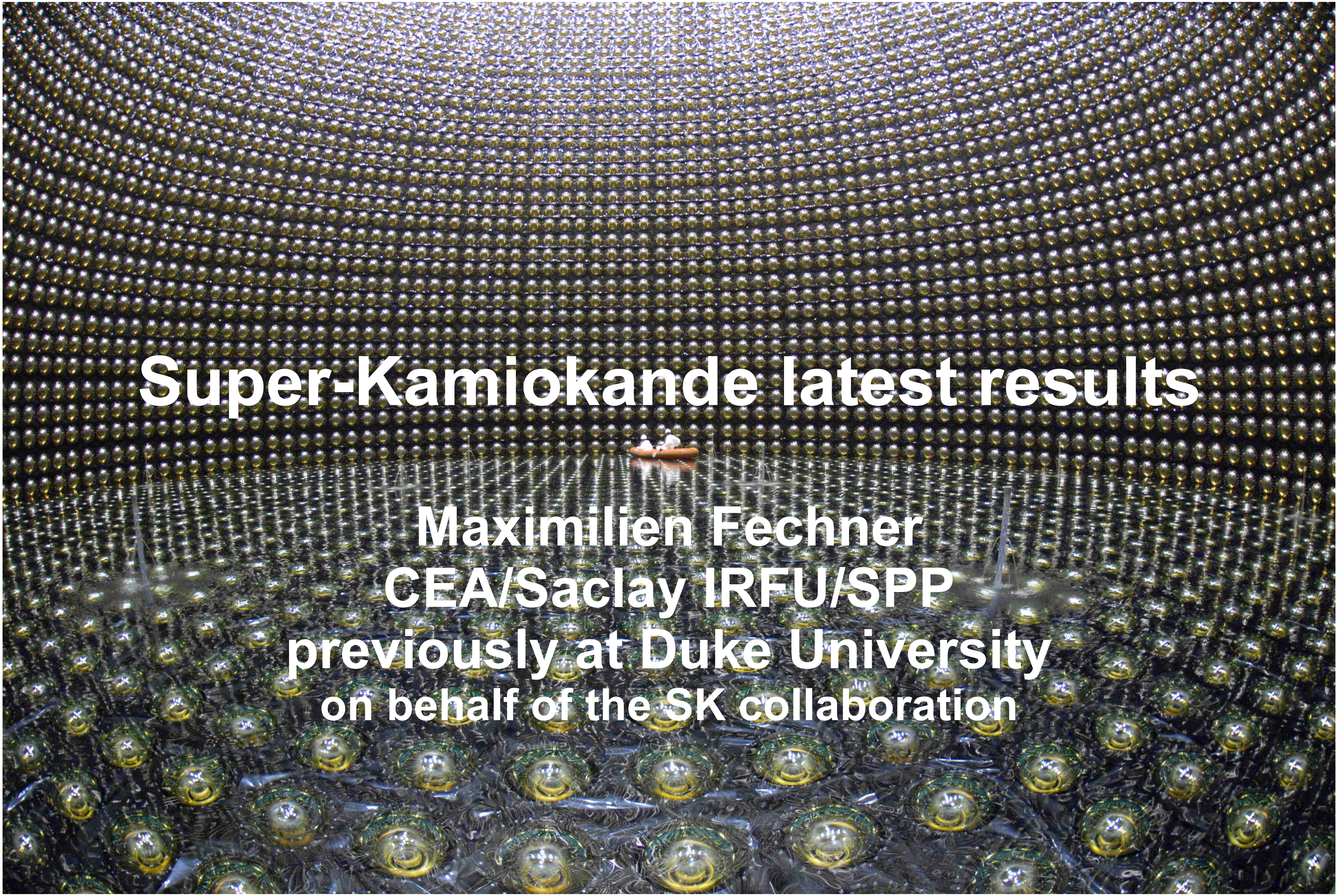

Super-Kamiokande latest results

Maximilien Fechner
CEA/Saclay IRFU/SPP
previously at Duke University
on behalf of the SK collaboration

The Super-K collaboration

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M. Hasegawa[17], K. Hiraide[17], I. Kato[17,c], H. Maesaka[17], T. Nakaya[17], K. Nishikawa[17], T. Sasaki[17], H. Sato[17],
S. Yamamoto[17], M. Yokoyama[17], T.J. Haines[18,6], S. Dazeley[19], S. Hatakeyama[19], R. Svoboda[19], G.W. Sullivan[20],
D. Turcan[20], A. Habig[21], Y. Fukuda[22], T. Sato[22], Y. Itow[23], T. Koike[23], T. Tanaka[23], C.K. Jung[24], T. Kato[24],
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M. Ikeda[26], M. Sakuda[26], M. Sugihara[26], Y. Kuno[27], M. Yoshida[27], S.B. Kim[28], B.S. Yang[28], J. Yoo[28],
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The SK detector

World's largest water Cherenkov detector (to-date)

Located under Mt. Ikenoyama, Gifu prefecture, Japan
at 1km (2700 mwe) rock overburden

Cylindrical shape, 50 kton of purified water

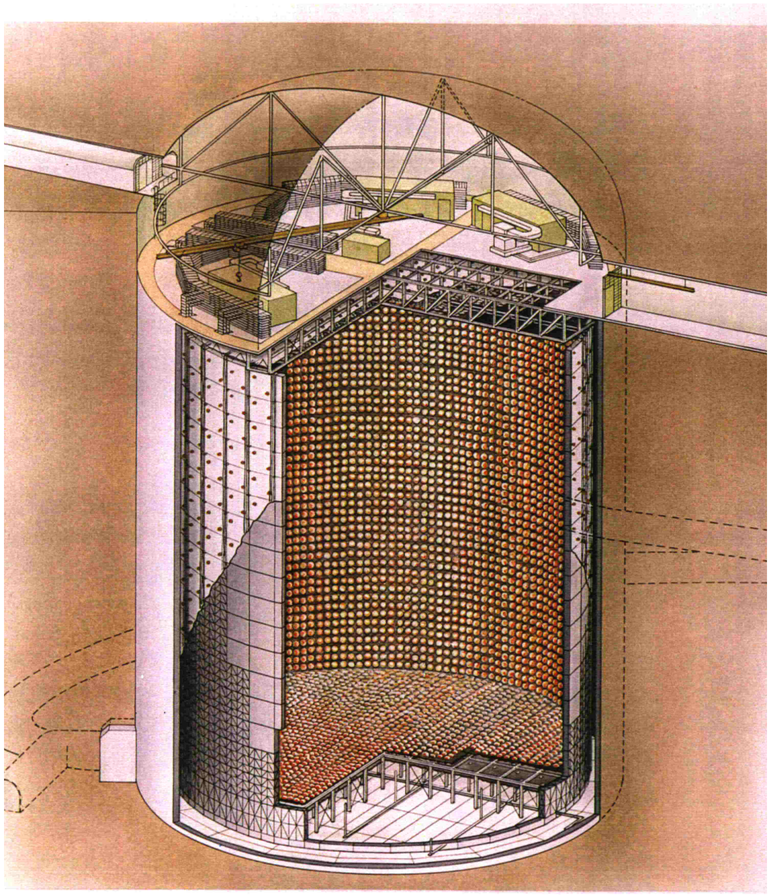
Fiducial mass : 22.5 kton

Optical separation between :

- Inner Detector (ID):
  - ~32kton
  - ~11,129 large 20 inch PMTs
- Outer Detector (OD):
  - ~1,885 smaller 8 inch PMTs
  - 2m thick veto around the ID

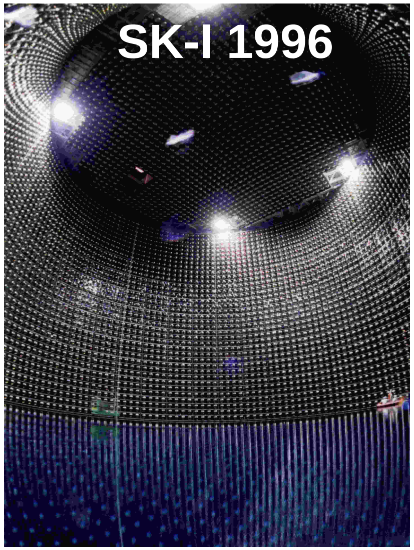
Physics : MeV to TeV scale

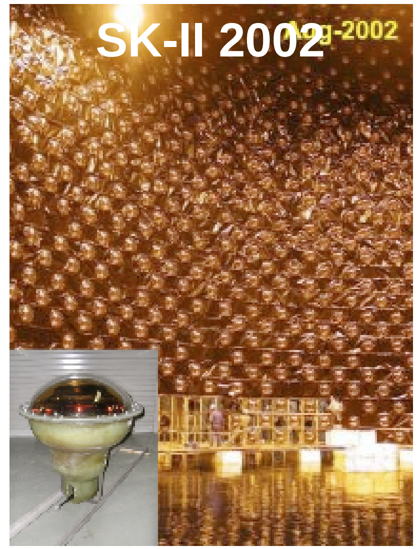
- Solar neutrinos
- Supernovae (and relic SN)
- Atmospheric neutrinos
- Proton decay [H. Nishino's talk]

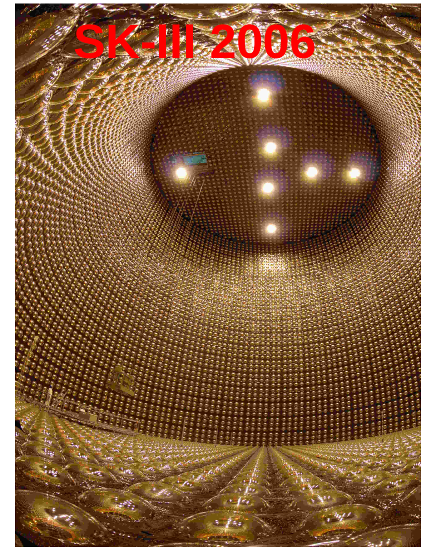


PERKAMIOKANDE INSTITUTE FOR COSMIC RAY RESEARCH UNIVERSITY OF TOKYO

12 years since first data !







SK-I (1996 to 2001)   40% photo-cathode coverage
Nov 2001 : accident...

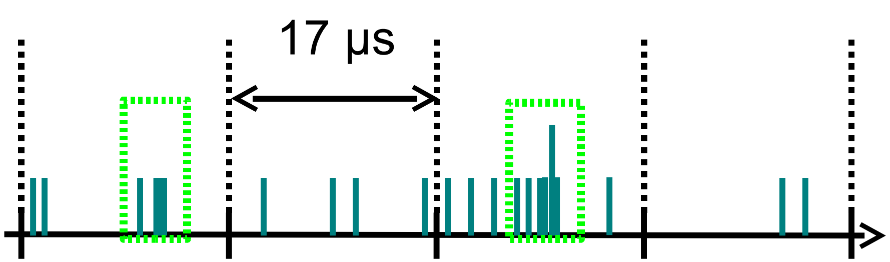
SK-II (2003 to 2005)   20% photo-cathode coverage

SK-III (2006-2008)   Full reconstruction, back to 40%

NEW: SK-IV (fall 2008-....)   Electronics upgrade in Sept

Electronics upgrade : new DAQ system

- Same readout for ID & OD
- Better performance :
  - Dynamic range
  - Multi hits
  - Reduce SPE threshold
- Use ethernet for read out
- No hardware trigger :
  - record every hit by periodic clock signal
    60 kHz x 17 μs TDC window
  - Apply software triggers : variable event window



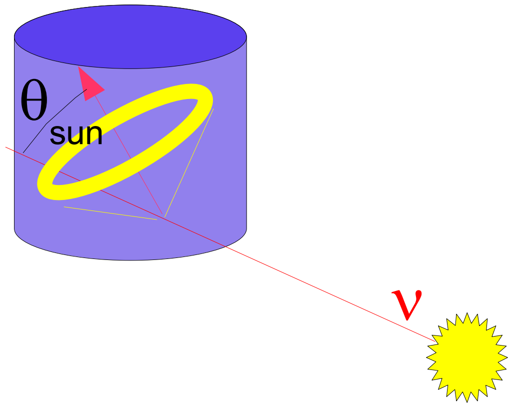
- Being installed as we speak (sept 2008)
- ~ 6 months of commissioning

FULLY READY FOR FIRST T2K BEAM IN 2009

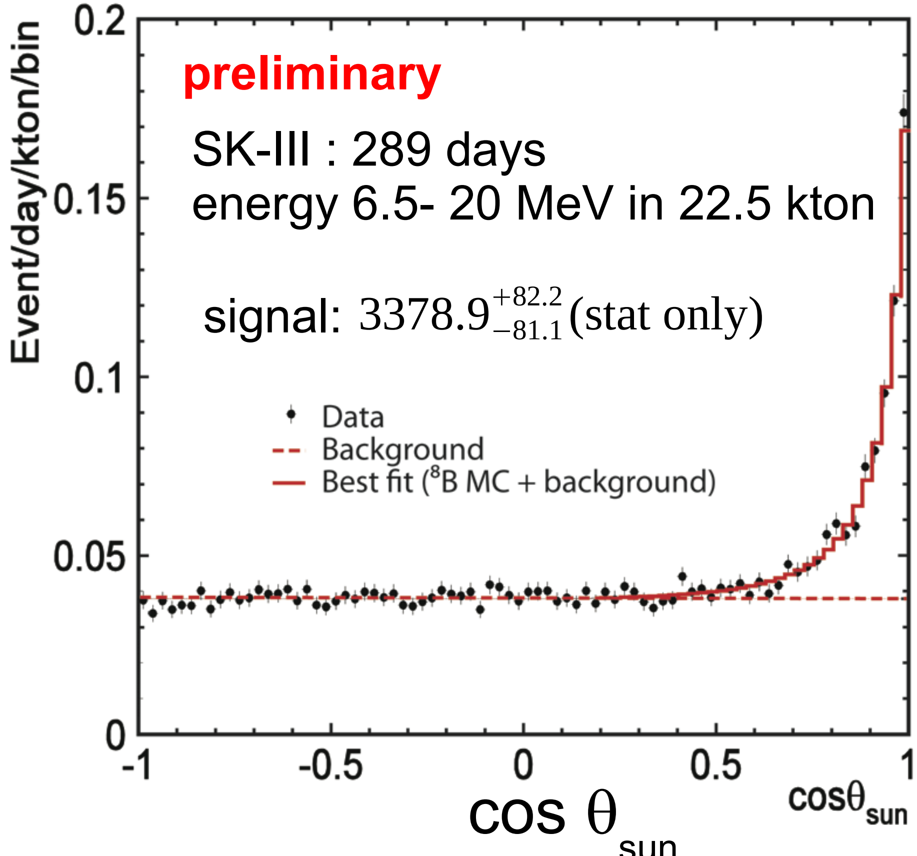
Solar neutrino results

Solar ν at SK

- Detection of solar ^{8}B neutrinos via $\nu + e \rightarrow \nu + e$
- Sensitive to all neutrino flavors, but mostly ν_e
- Reconstruct recoil electrons : energy & angle wrt sun



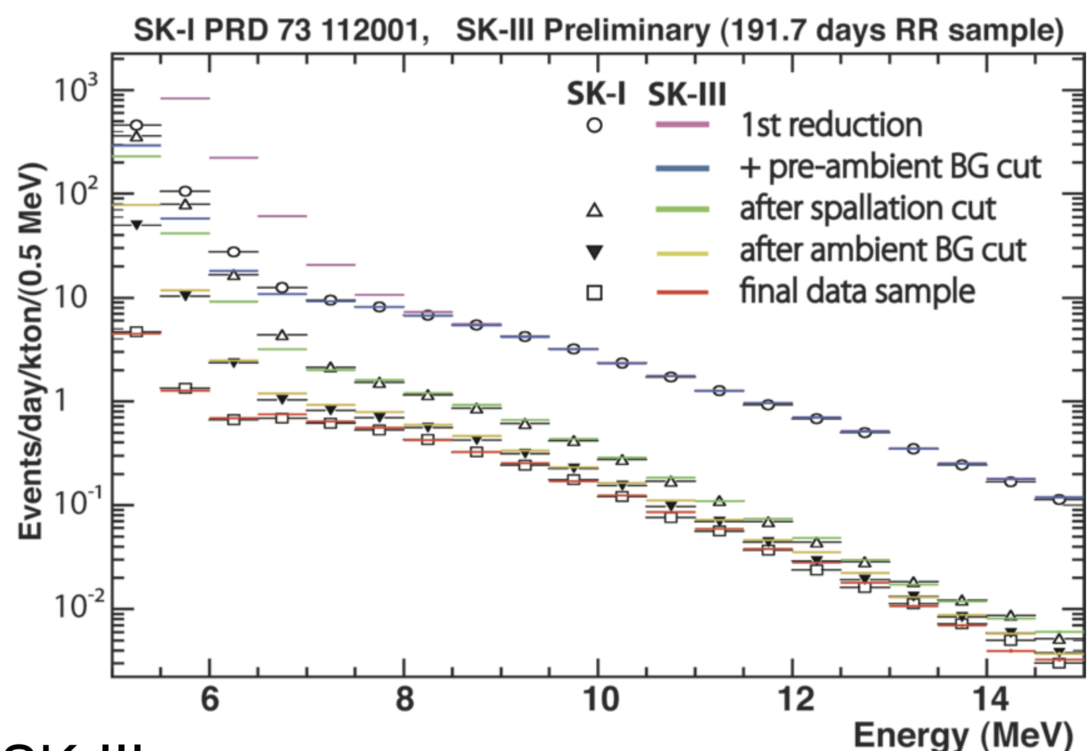
- Measurement goals :
  - Total flux
  - Day night differences
  - Spectrum



- Super-K II 's lower coverage prompted improvement of reconstruction tools
- Now applied to SK-I & SK-III
- Observed rate : ~ 15 ν_e / day above 5 MeV
- **SK-III flux consistent with SK-I & SK-II (flux measurement being prepared)**

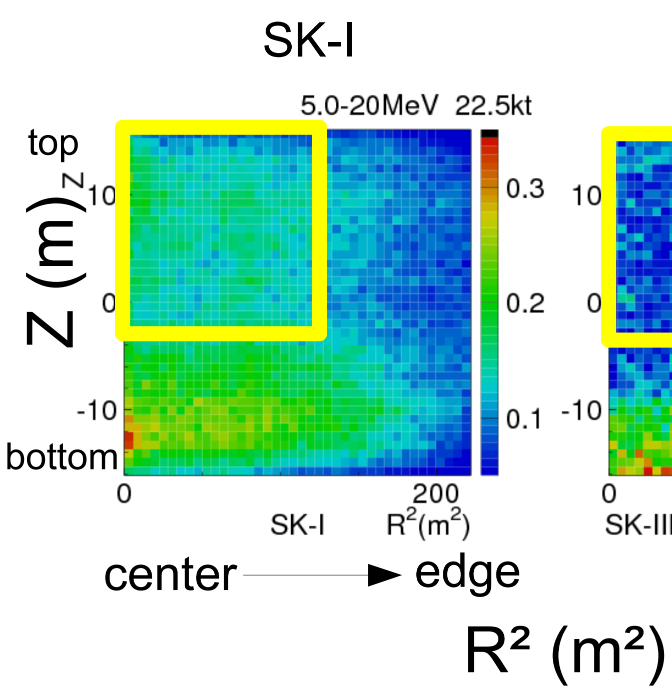
SK-III & SK-I

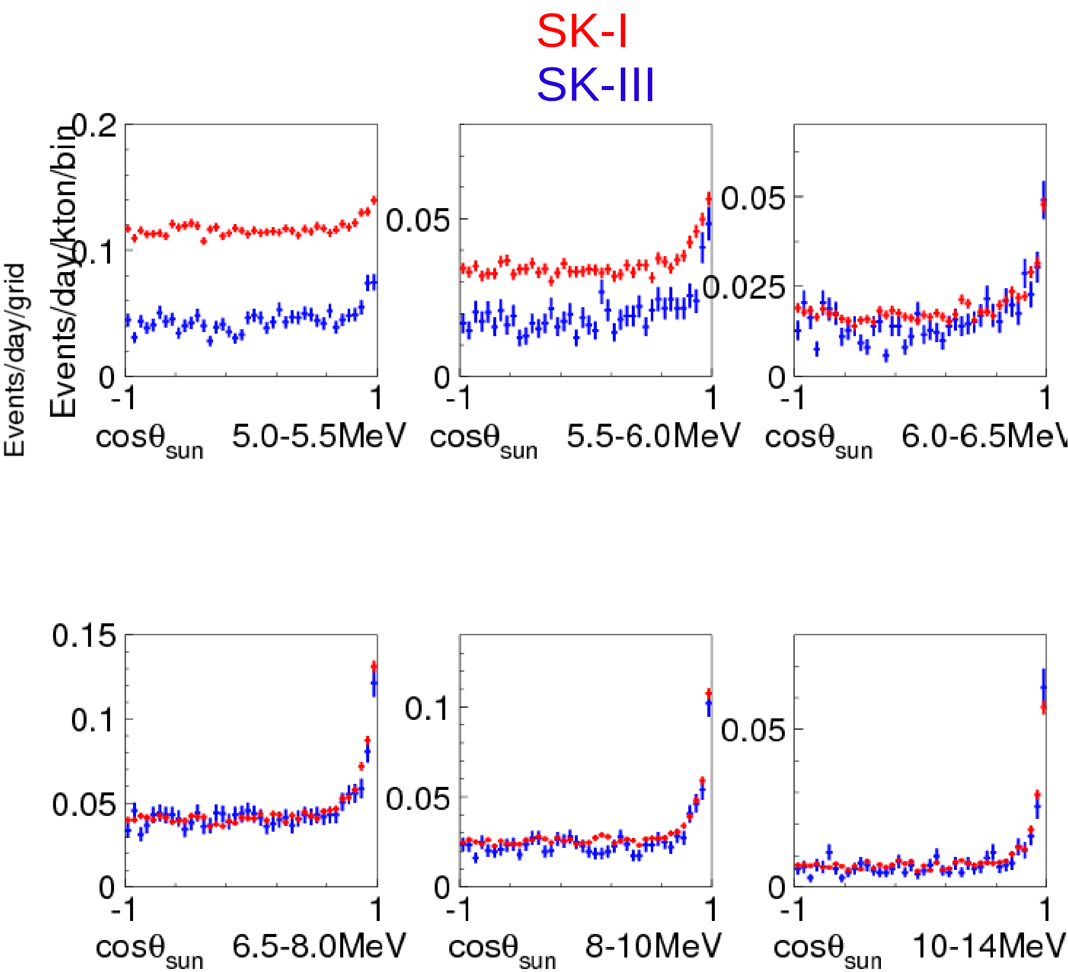
- SK-I “full final” sample
  - Energy > 6.5 MeV
  - Livetime 288.9 days
- SK-III RR (Radon reduced sample)
  - Period from jan 07 to march 08 livetime 191.7 days
  - high radon activity periods rejected
  - 100% trigger efficiency above 5 MeV
- Good agreement between SK-I & SK-III



Improved Backgrounds

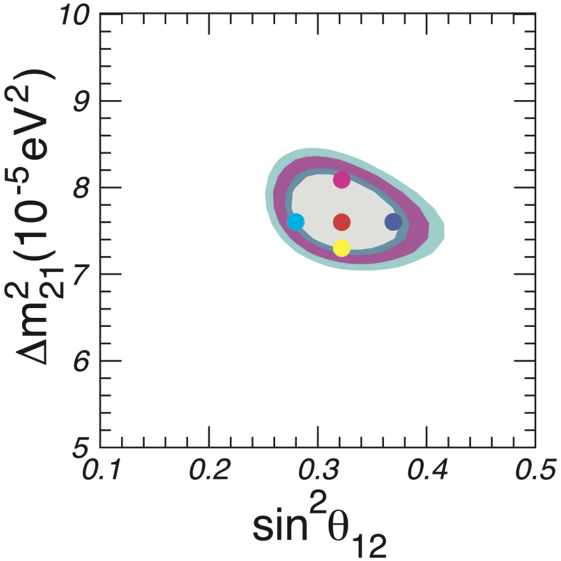
- **Background in SK-III's central region is lower than in SK-I** thanks to improvements in the water system
- Threshold below 5 MeV

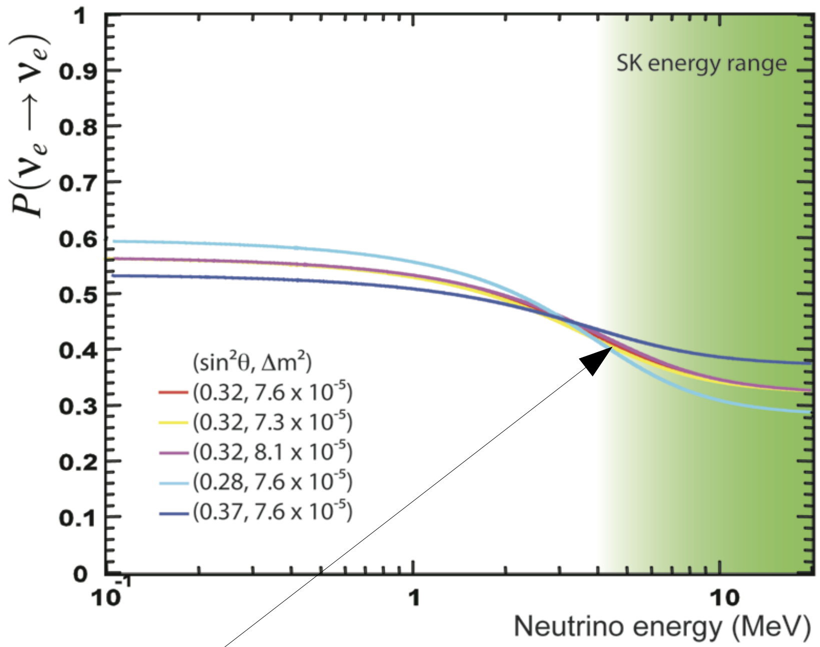




Prospects for SK-IV

hep-ph/040517v6



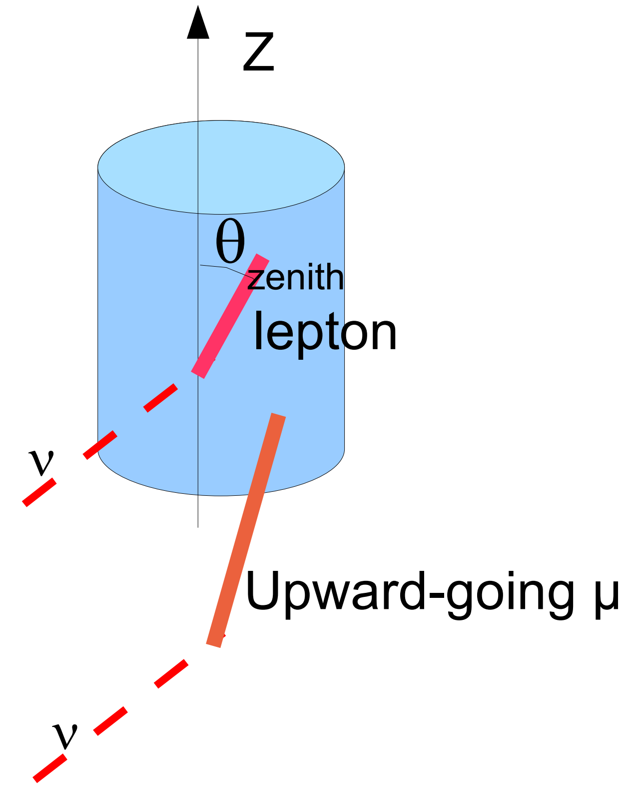


- Test of standard oscillation model
  → look for upturn at low energy
  predicted by LMA solution
- ~ 10 % effect in SK
- Observation requires :
  - Lowering threshold to 4 MeV
  - Reducing energy correlated systematics (to ½ SK-I)
  - Running longer...

Work in progress....

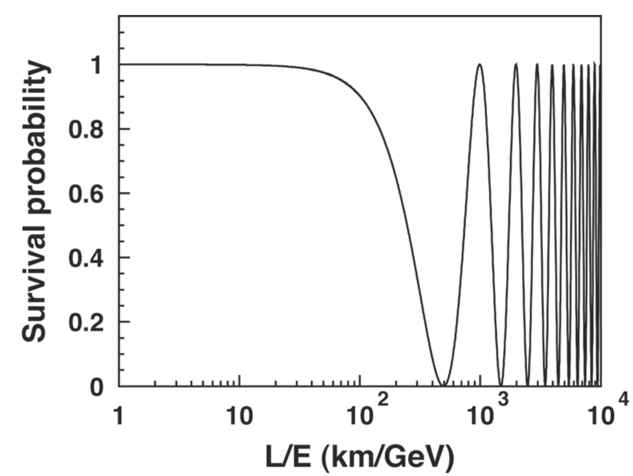
Atmospheric neutrino results

Atmospheric neutrino analyses



- **Zenith angle analysis :**
  - Reconstruct leading lepton track and upward-going muons
  - Angular correlation with incoming neutrino
  - Fit Data & MC zenith angle distributions

- **L/E analysis :**
  - Reconstruct leading lepton track
  - Estimate neutrino flight length L and energy E
  - Look for oscillatory shape in L/E distribution



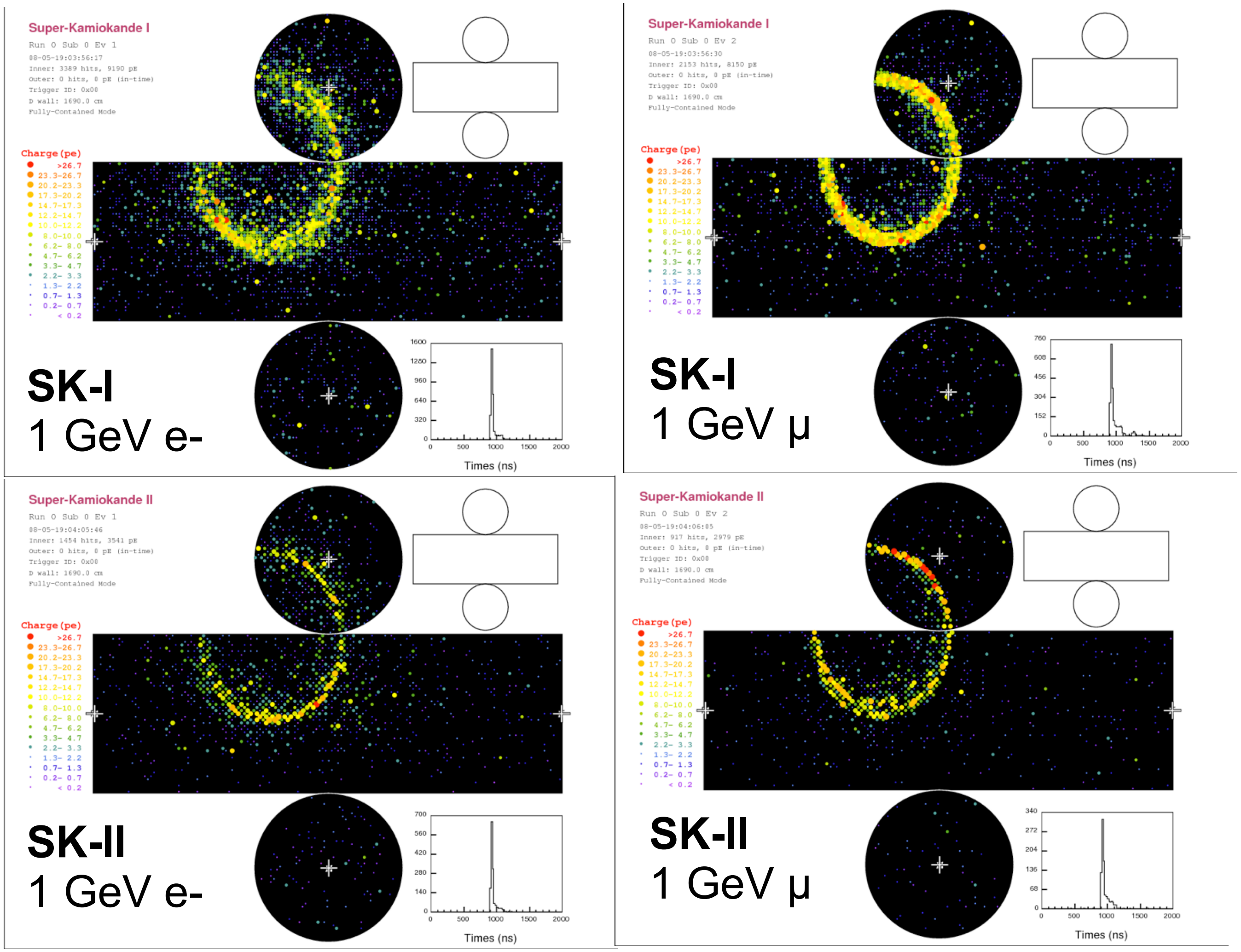
Reconstruction improvements

SK-II only had 20% coverage : careful studies of vertex fitters, ring counting and particle ID algorithms were needed

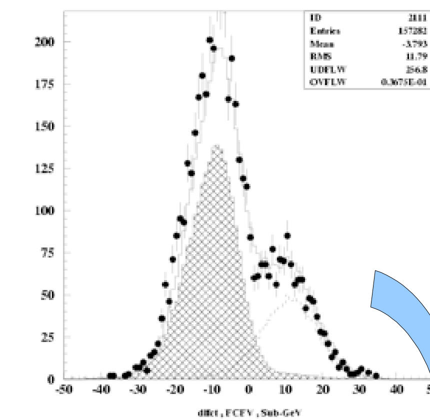
Improvements were applied to SK-III and SK-I

40 %

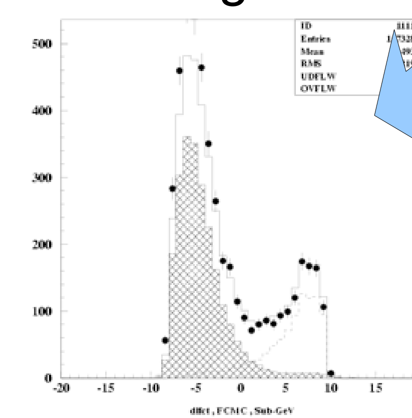
20 %



OLD ring counting



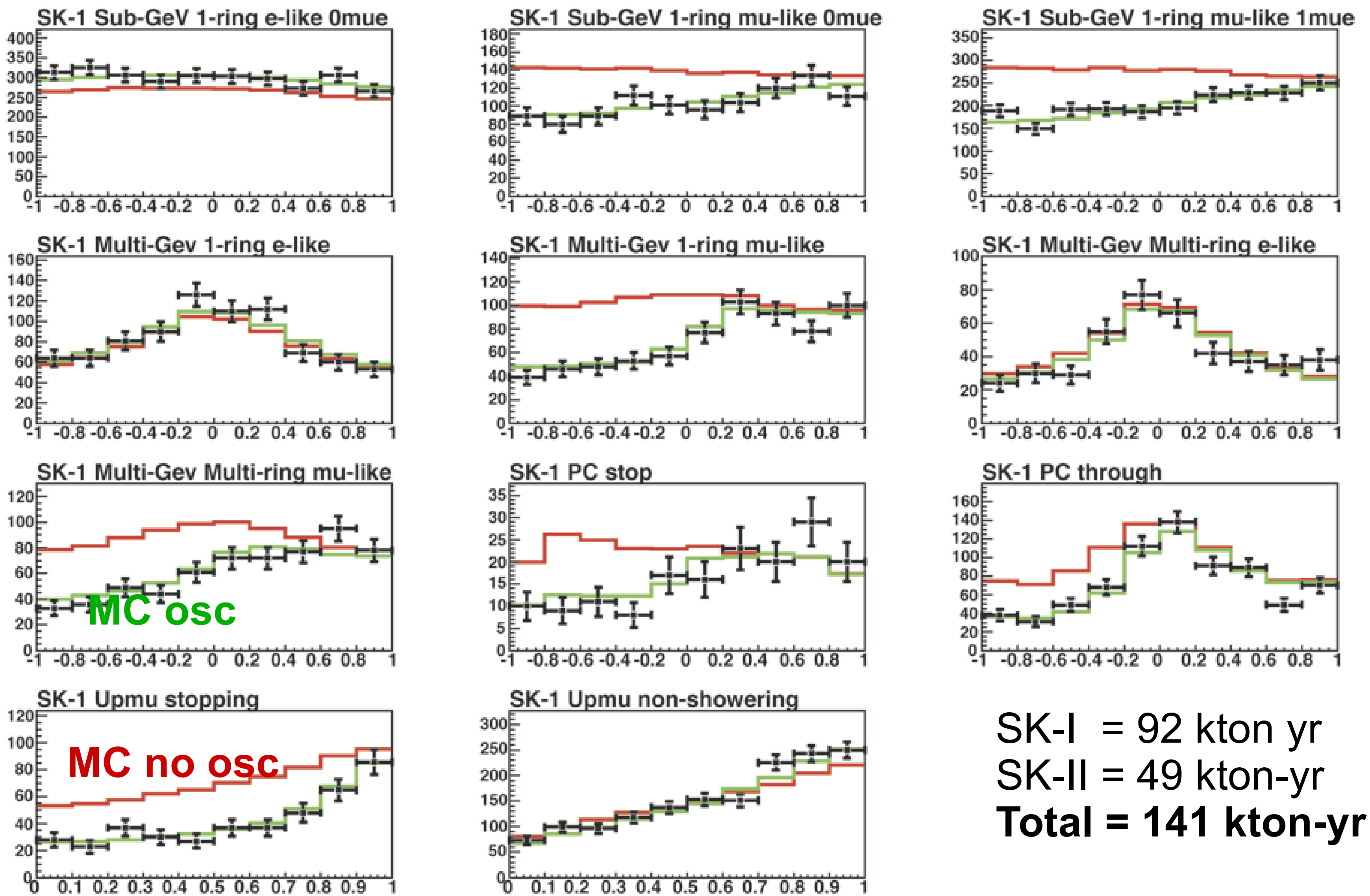
NEW ring counting



Other improvements

- New cosmic ray flux model
  - matches cosmic muon data better (Honda 2006)
- Neutrino cross-section Monte-Carlo improvements:
  - M_A=1.2 GeV/c²
  - Improved single pi resonant production model (added $\Delta \rightarrow N\gamma$, lepton mass effects)
  - Improved of single pi coherent production model (Rein-Sehgal with lepton mass correction)
  - Improved DIS model (GRV98 pdfs with Bodek-Yang correction)
- Detector simulation improvements :
  - Better tuning of scattering & reflections
  - Improved OD tuning
- Higher Monte-Carlo statistics :
  - 500 yrs of SK-I & 500 yrs of SK-II MC generated
- Improved reconstruction :
  - Re-evaluate systematics of the experiment

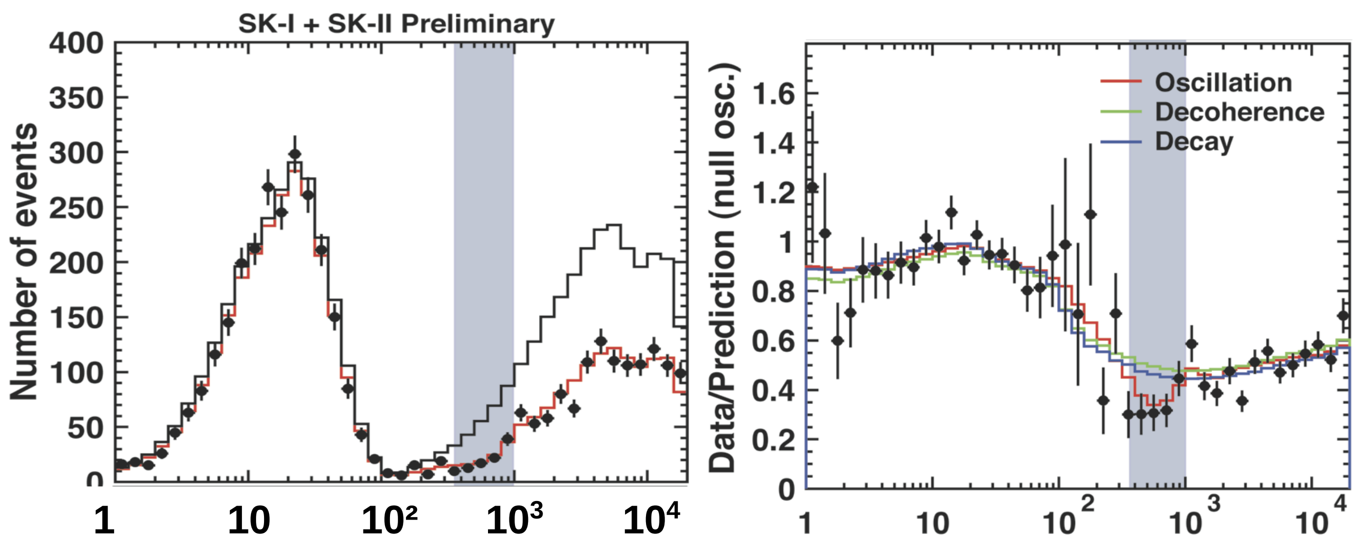
Zenith angle analysis



SK-I = 92 kton yr
SK-II = 49 kton-yr
Total = 141 kton-yr

L/E analysis

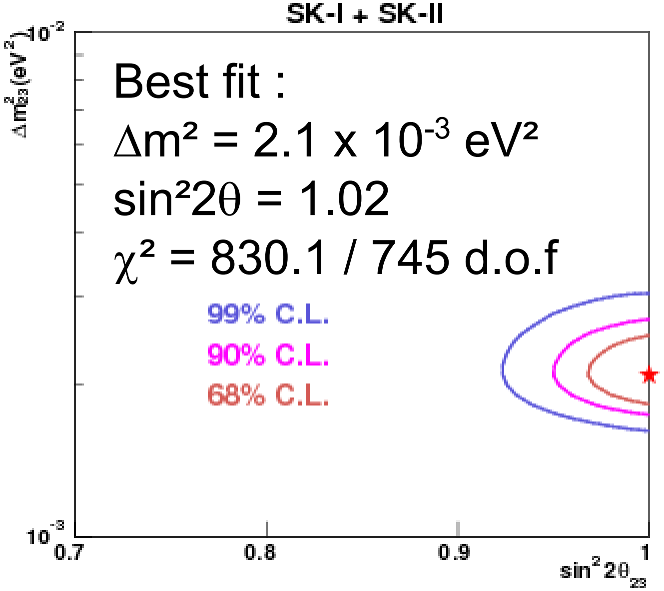
- Select events with good L/E resolution (<70%)
  - Need good pointing accuracy & momentum fitting
  - High energy muons essential for this analysis
    → include partially-contained muons
- Compare (Data/MC no osc) to (MC / MC no osc)
- Oscillatory shape (“dip”) allows to compare different hypotheses for observation :
  - Decoherence model disfavored at 5.0 σ compared to osc.
  - Neutrino decay model disfavored at 4.1 σ compared to osc



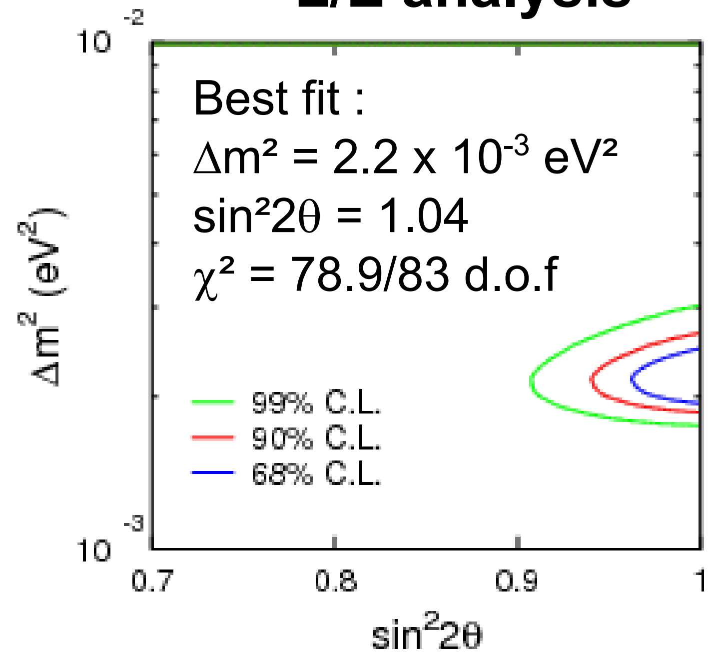
$\log_{10}(L/E)$ $\log_{10}(L/E)$

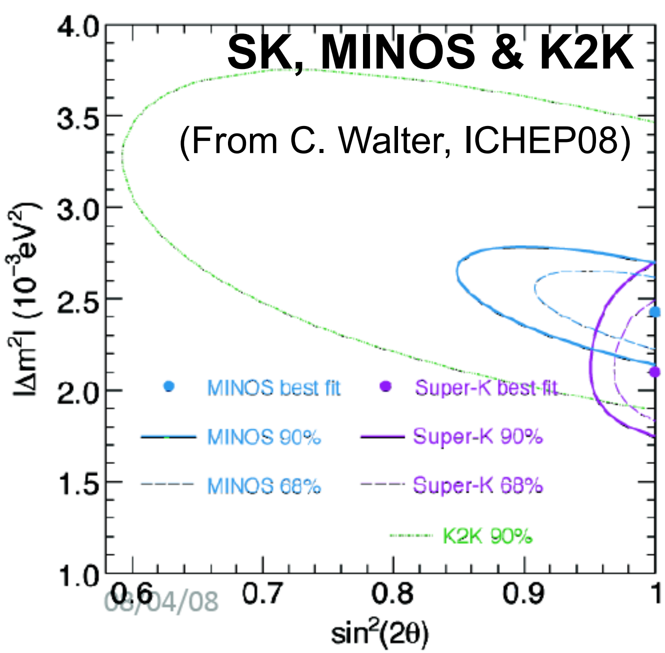
Allowed regions

Zenith angle analysis



L/E analysis

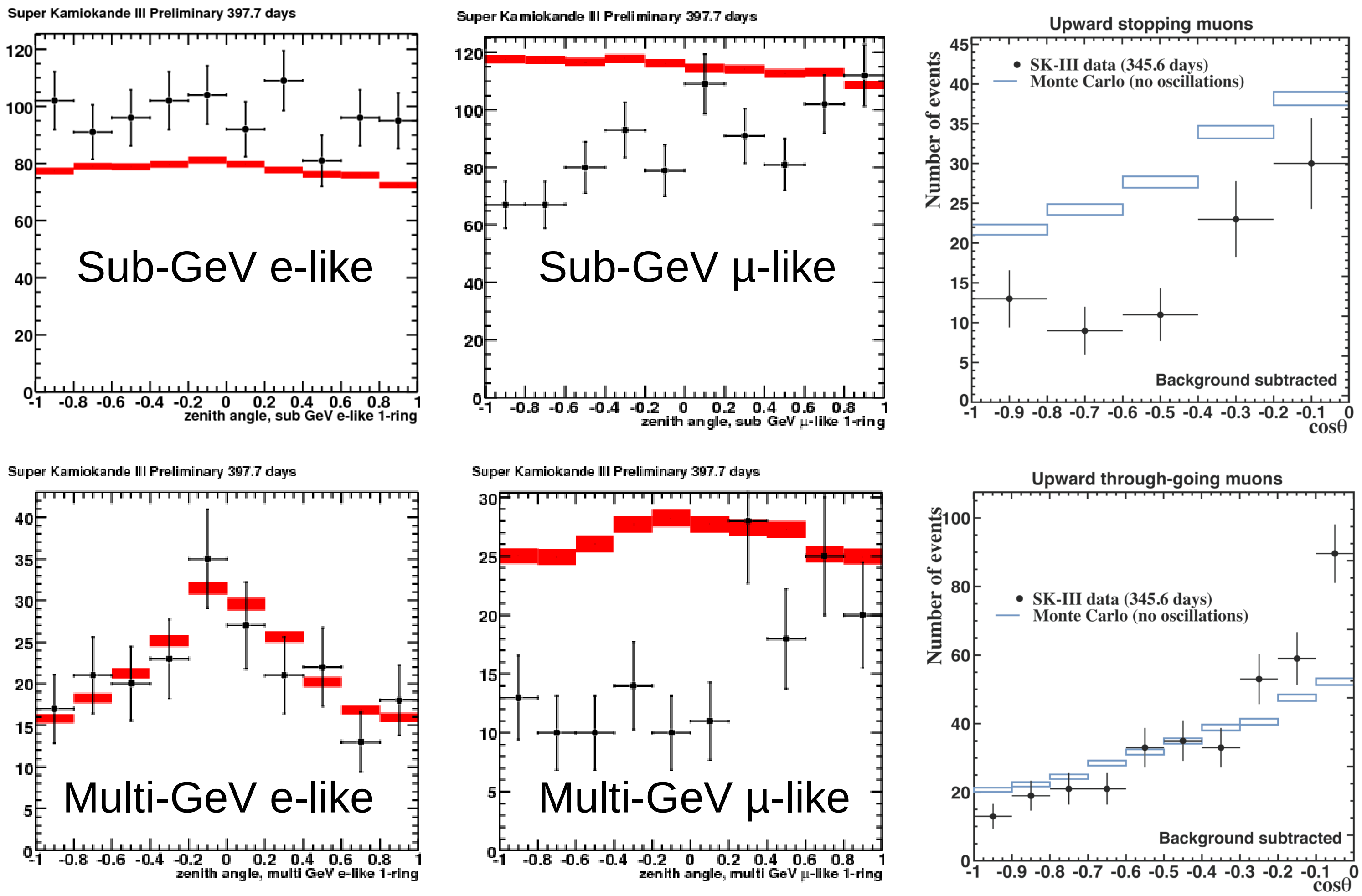




Current best measurement of θ_{23} :

~ 45±4° (10% accuracy)

SK-III preliminary results



No oscillation analysis yet... but clear zenith angle distortion effects.

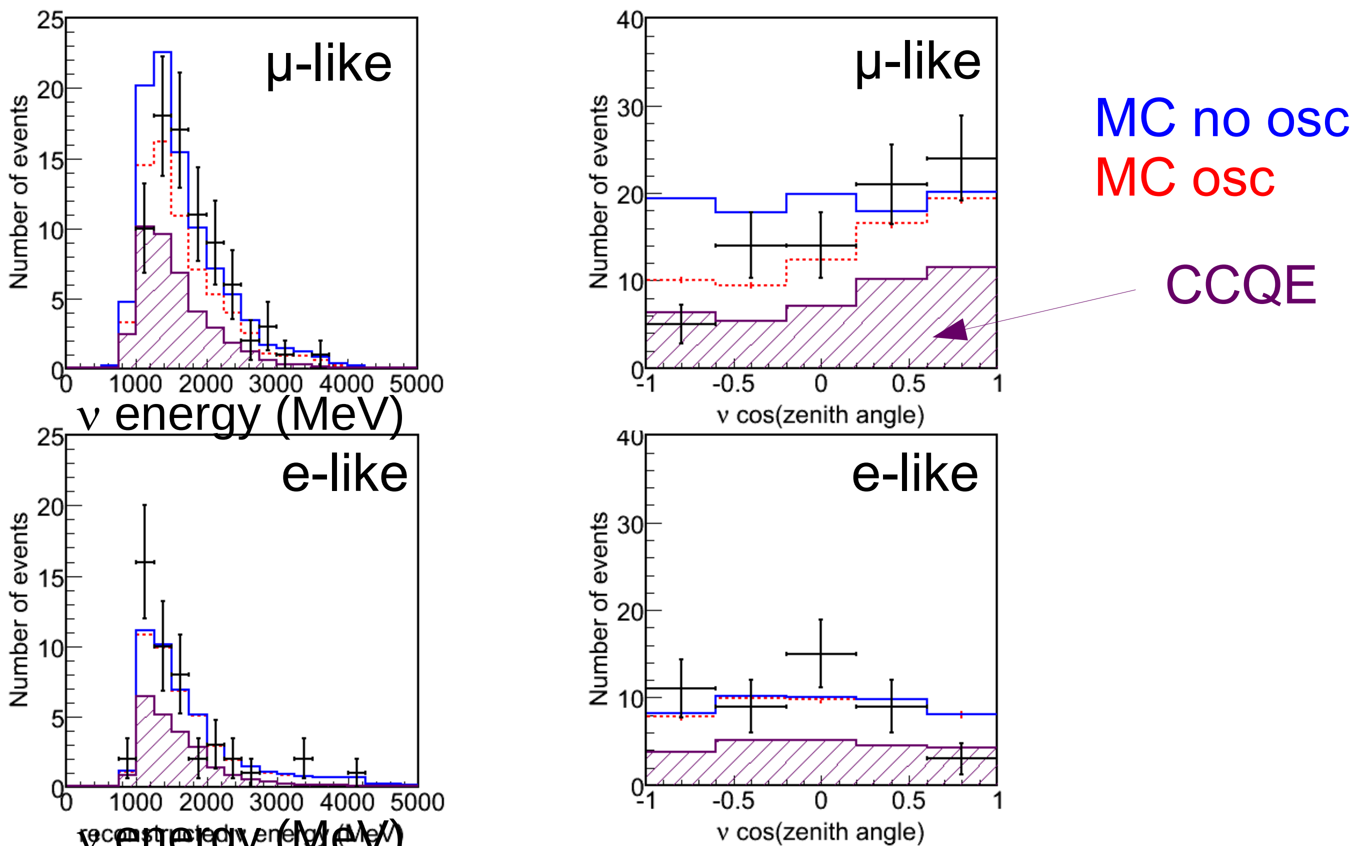
Observation of recoil protons

- Particle ID was extended to identify recoil protons from ν scattering
- Cherenkov threshold in water ~ 1070 MeV/c for protons
- Two main analyses :
  - NC elastic events ν + p → ν + p [not covered today]
  - CCQE events ν + n → lepton + proton
- Goals of recoil proton search in CCQE events :
  - Complete kinematic reconstruction of incoming <u>neutrino</u> energy & zenith angle
  - Selection of a quasi-pure neutrino sample $\nu/\bar{\nu} \sim 9$

PRELIMINARY
SK-I&II data

ν_e&ν_μ energy & zenith angle distributions

Clear zenith angle distortion for μ-like events



Summary

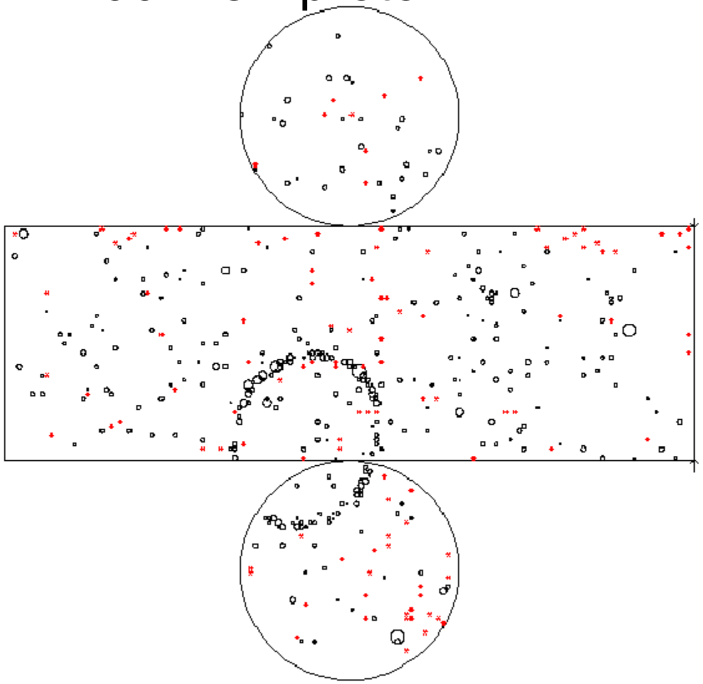
- SK-III has been running for 2 years as of today
  - SK-I+II+III data set : > 25,000 atm ν events
  - Results are compatible with previous observations
  - Reduced background for solar analyses
  - Improved simulation & systematics for analyses
- SK-IV : starting in a few weeks
  - Complete replacement of ID & OD electronics
  - Ready for T2K beam
- Current physics :
  - 23% admixture of sterile neutrinos is allowed
  - θ_{23} measured to ~ 45±4° (10% accuracy)
  - Results on θ_{13} coming soon (current limit $\sin^2\theta_{13} < .14$)
- Future physics goals :
  - See the upturn in solar neutrinos
  - Further constrain atmospheric models & parameters

Thank you

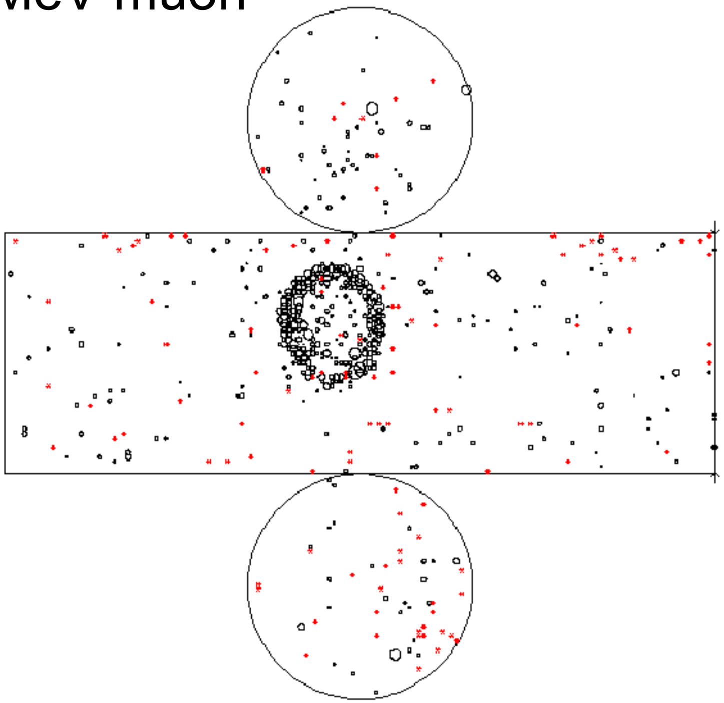
Backup slides

Proton vs muon

~ 1400 MeV proton



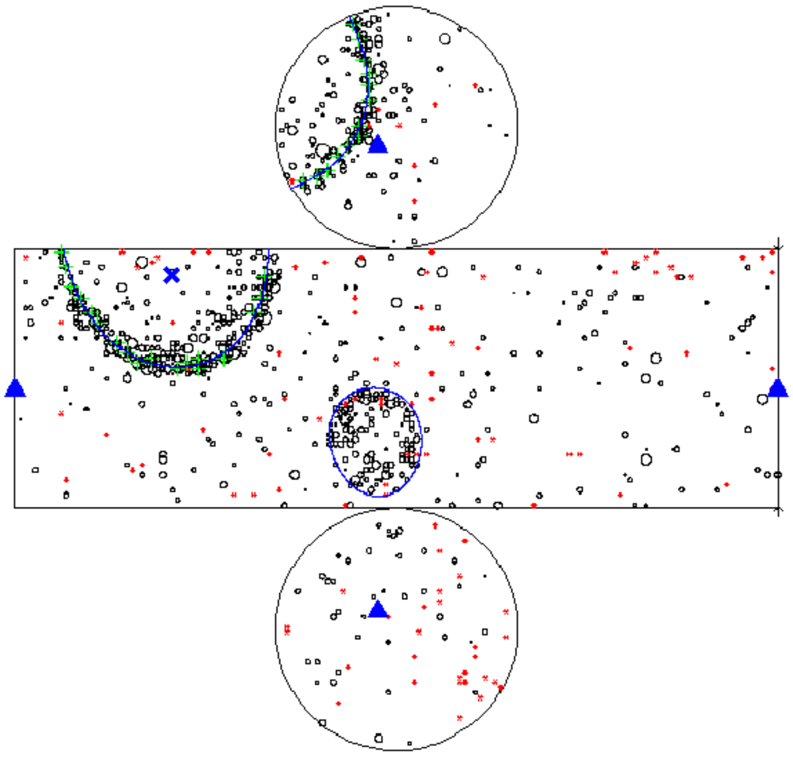
~ 300 MeV muon

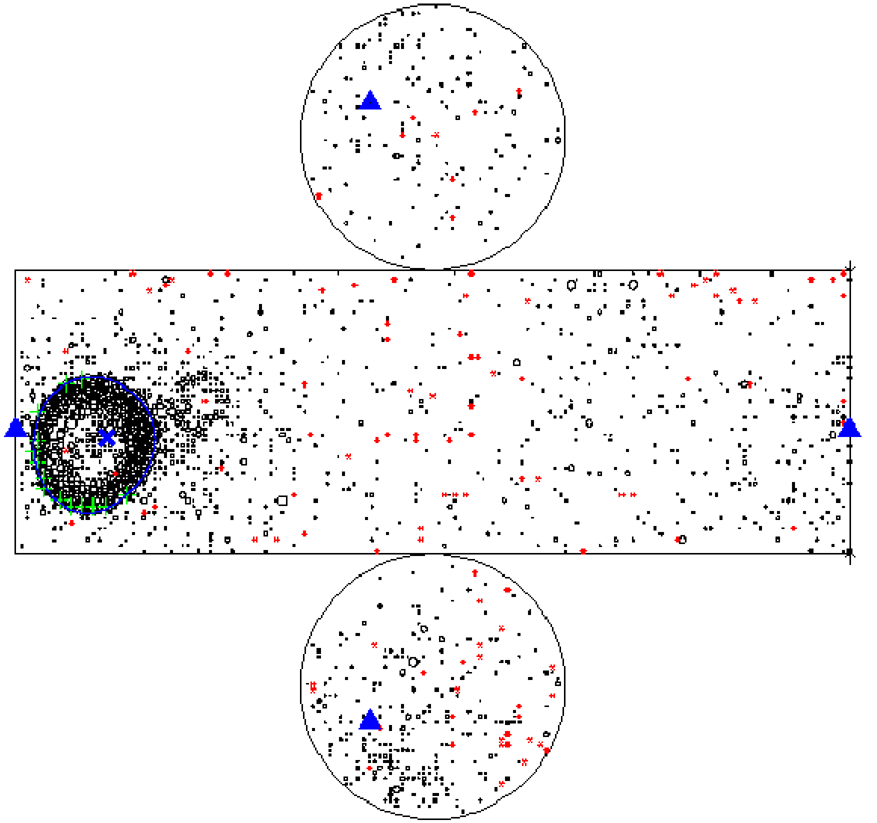


Proton ID relies on :

- smaller opening angle
- “thinness” of the ring
- different light density

CCQE search





CCQE events :

- identified as 2 rings by standard ring finder
- identified as 1 ring but found by dedicated CCQE search algorithm