Neutrino Oscillations with IceCube/DeepCore

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für Bildung
und Forschung

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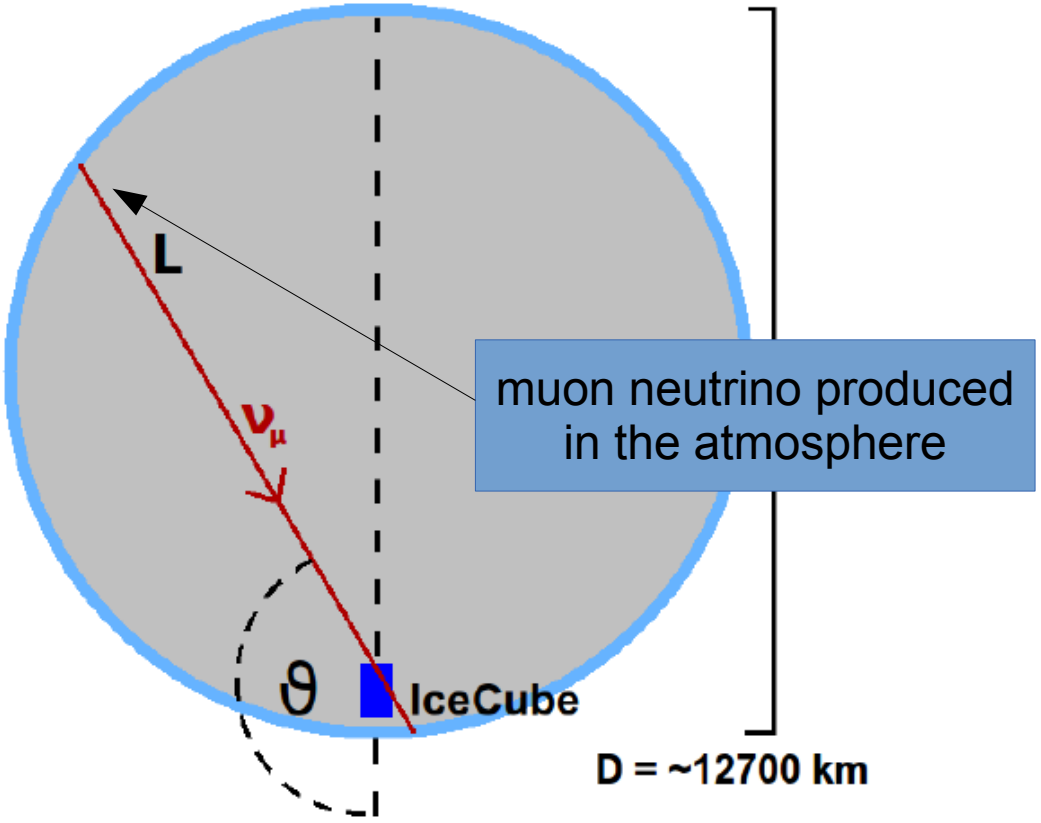
Neutrino Oscillations

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2(2\theta) \cdot \sin^2[1.27 \cdot \Delta m^2(\mathrm{eV}^2) \frac{L(\mathrm{km})}{E_\nu(\mathrm{GeV})}]$$

- probability to measure one neutrino flavor dependent on:
  - traveled distance L
  - energy of the neutrino E
- distance dependent on measured zenith angle



$$L \approx D \cdot \cos(180° - \vartheta)$$

Neutrino Oscillations

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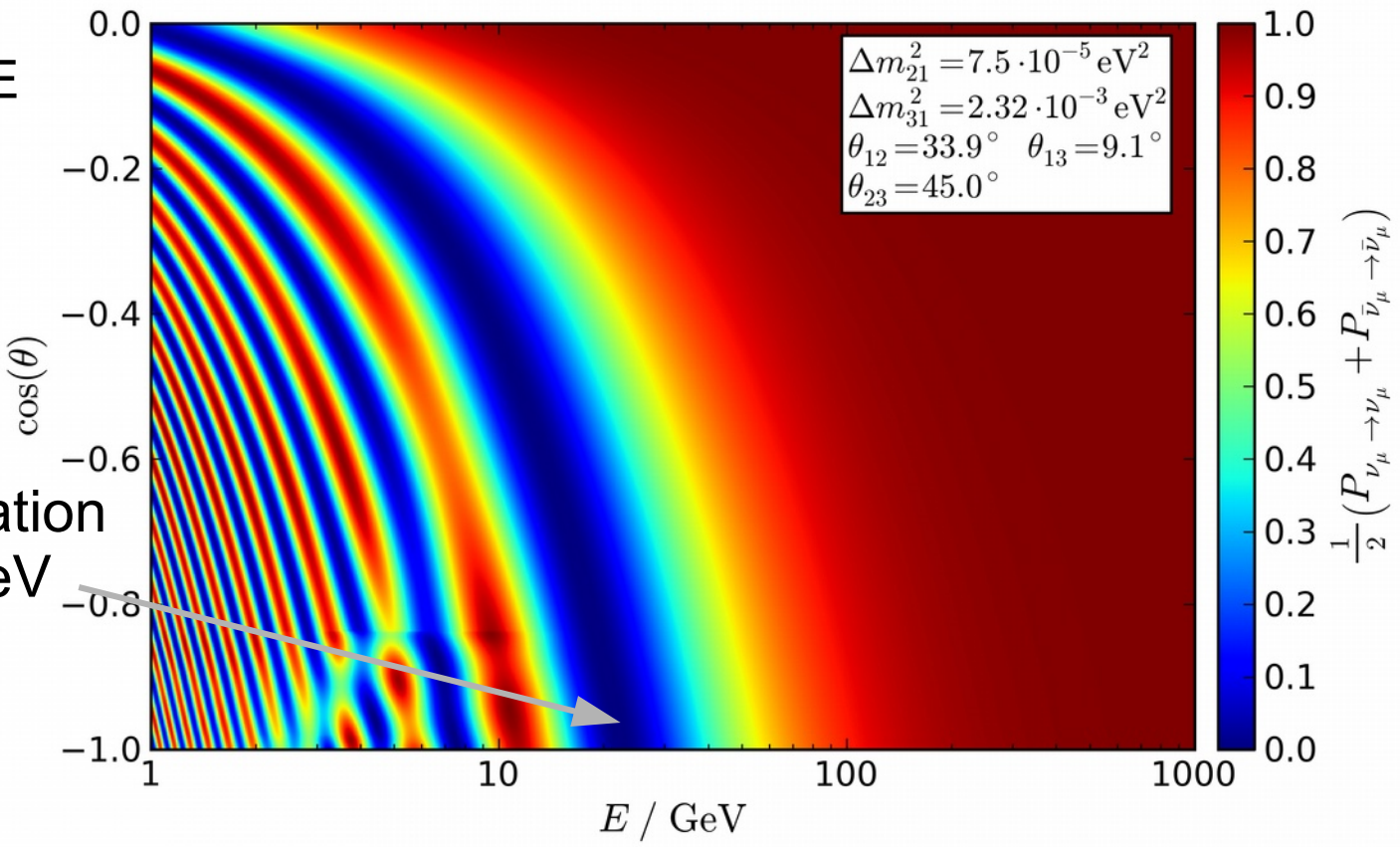
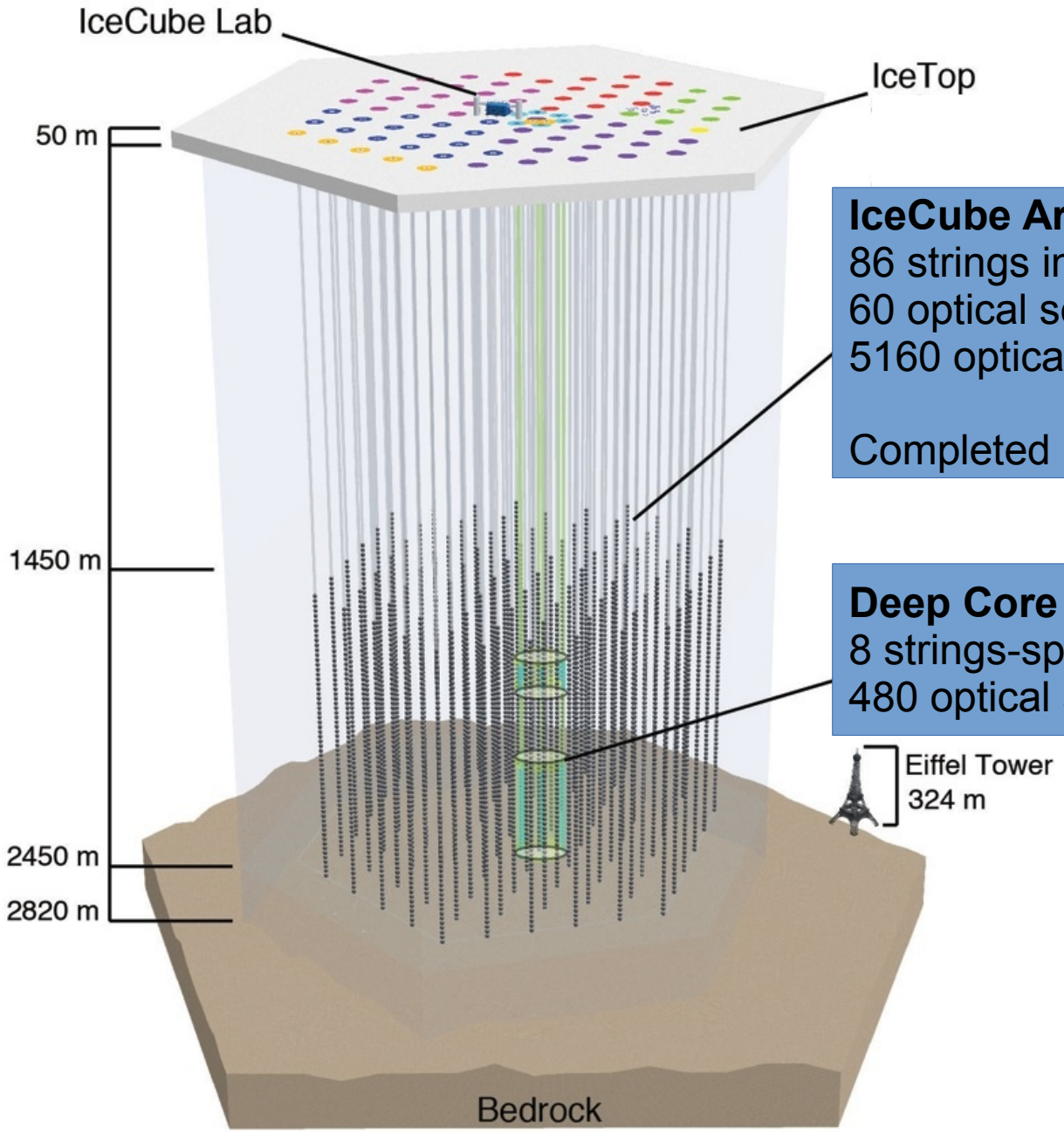
- probability to measure one neutrino flavor dependent on:
  - traveled distance L
  - energy of the neutrino E
- distance dependent on measured zenith angle
- with L = 12700 km (diameter of earth) → the probability of oscillation peaks at approx. 25 GeV



The IceCube Neutrino Observatory



IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors

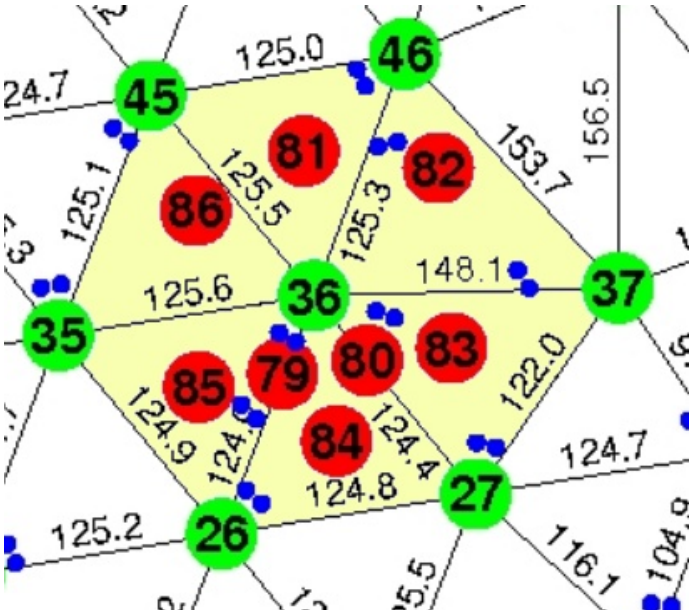
Completed in December 2010

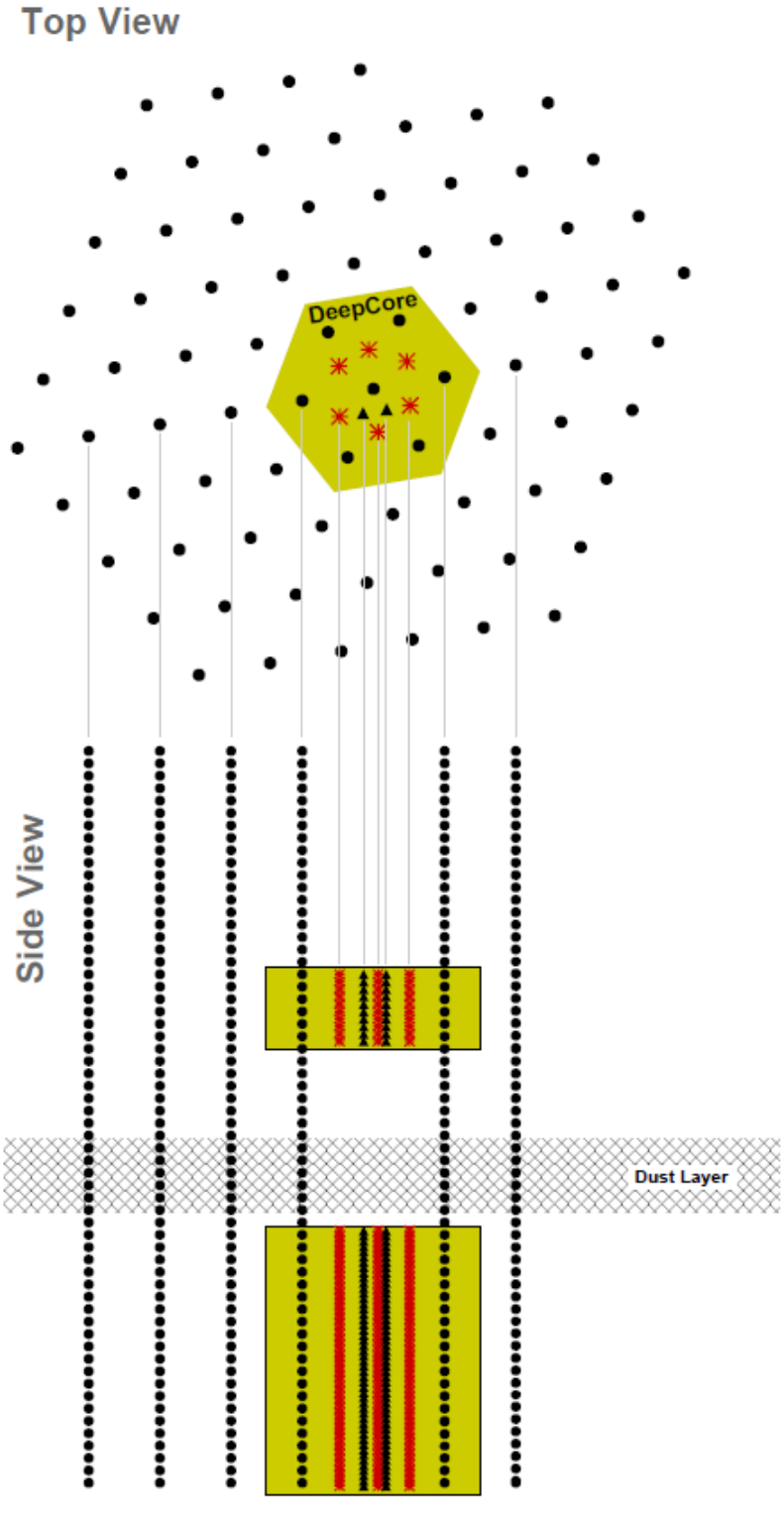
Deep Core
8 strings-spacing optimized for low energies
480 optical sensors

IceCube – DeepCore

- low energy extension in the center of IceCube consisting of 8 extra strings and the 7 center strings
- smaller string spacing and for the new strings smaller DOM spacing
- lowered detection threshold of ~10 GeV

  → this allows the measurement of oscillations of atmospheric neutrinos



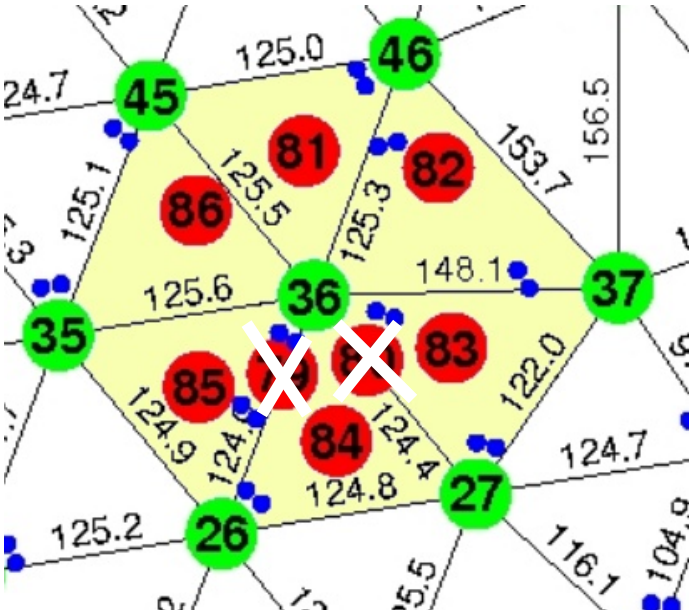


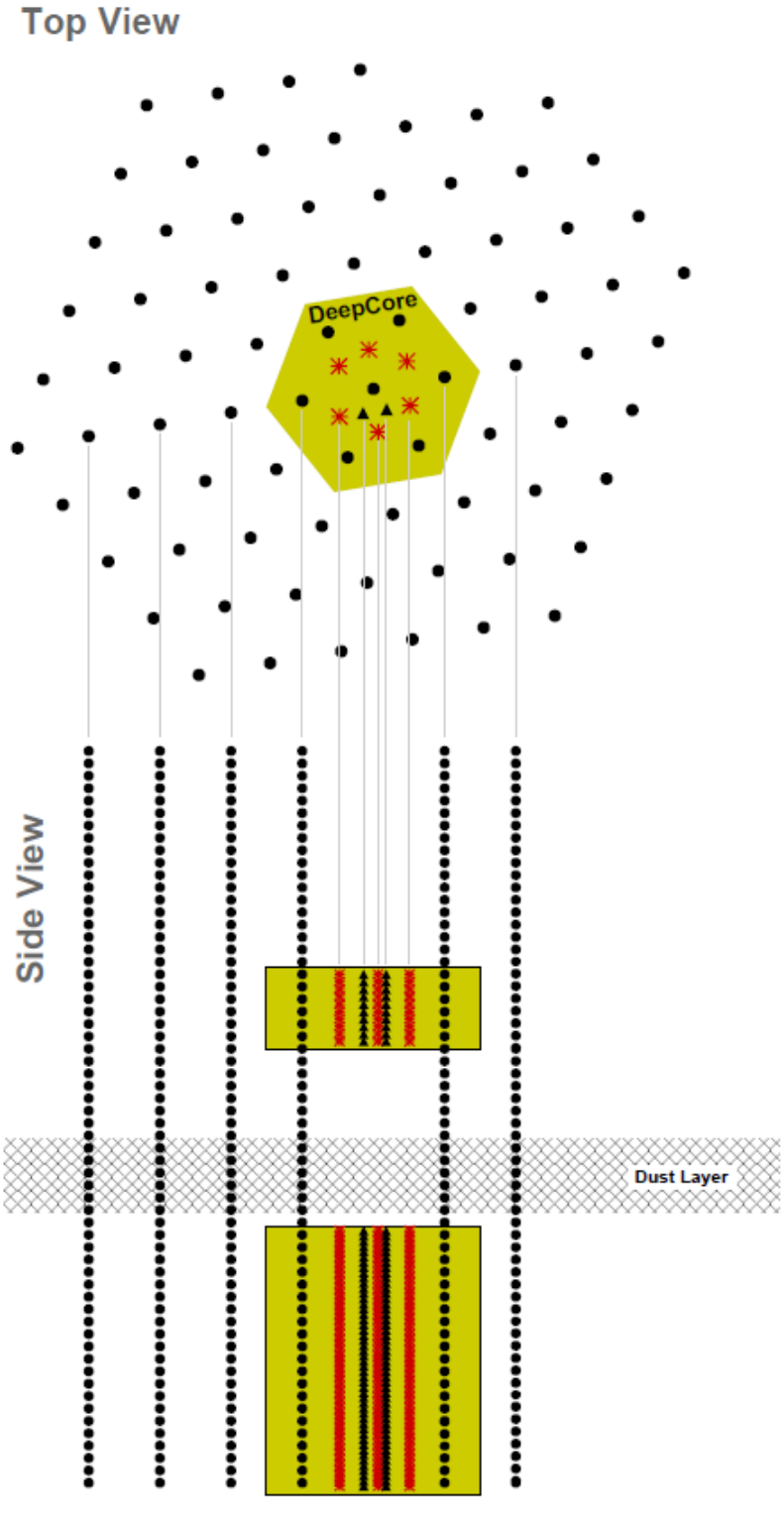
IceCube – DeepCore

- This Analysis:
  Extension of published three year (IC86) result (PRD – arXiv:1410.7227)

- Extension with one previous year
  → detector was not yet completed
  (79 instead of 86 strings)

  Consequences for analysis:
  - different event selection
  - own set of simulations needed
  - has a bit lower statistics



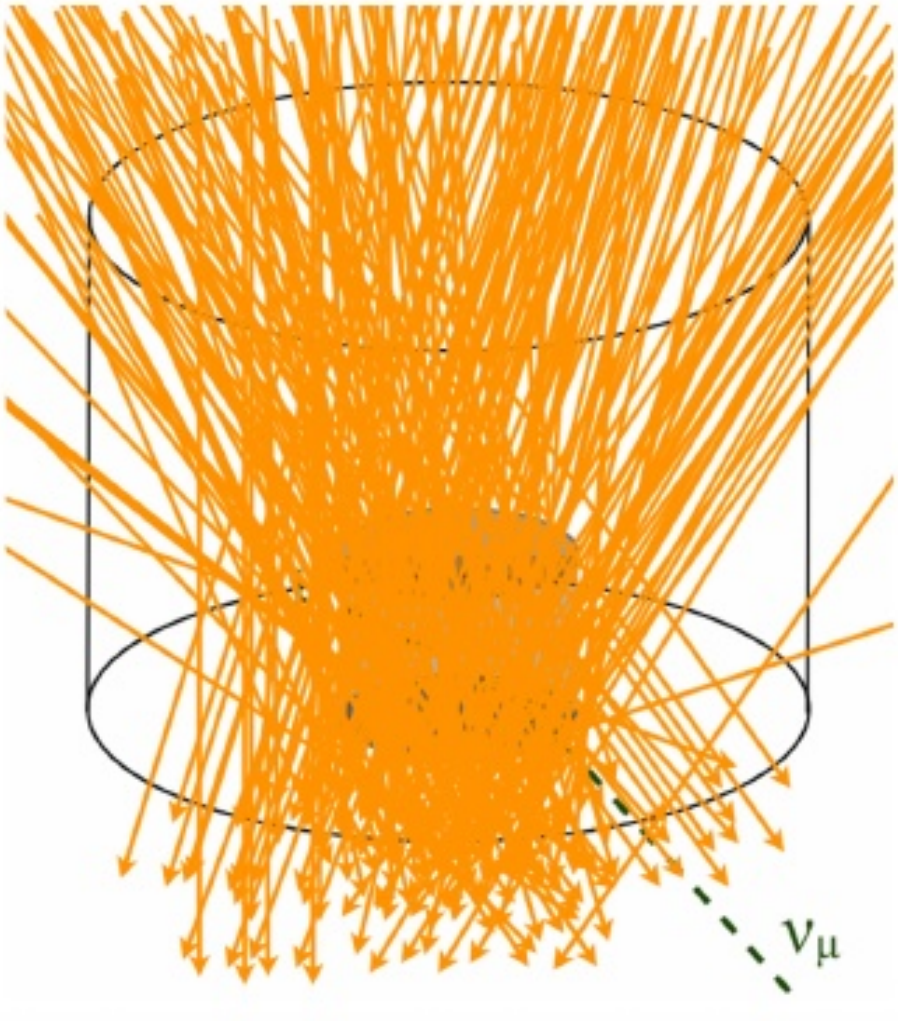


Challenges

- Background of triggered atmospheric muons trigger five orders of magnitude higher than signal

- Events get very dim
  → only few DOMs hit

- Cuts that distort the signal have to be avoided
  → use veto information

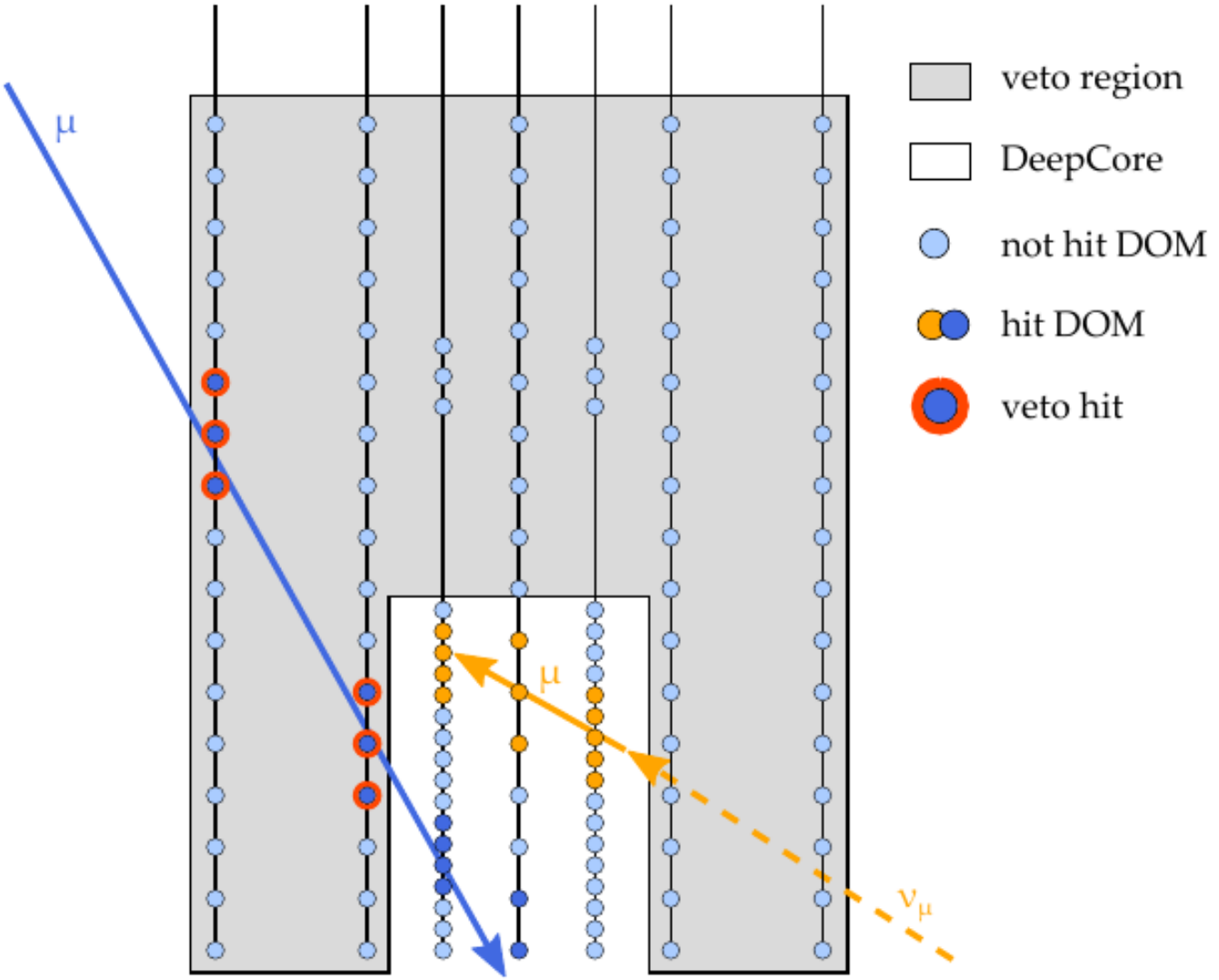


Veto based Event Selection

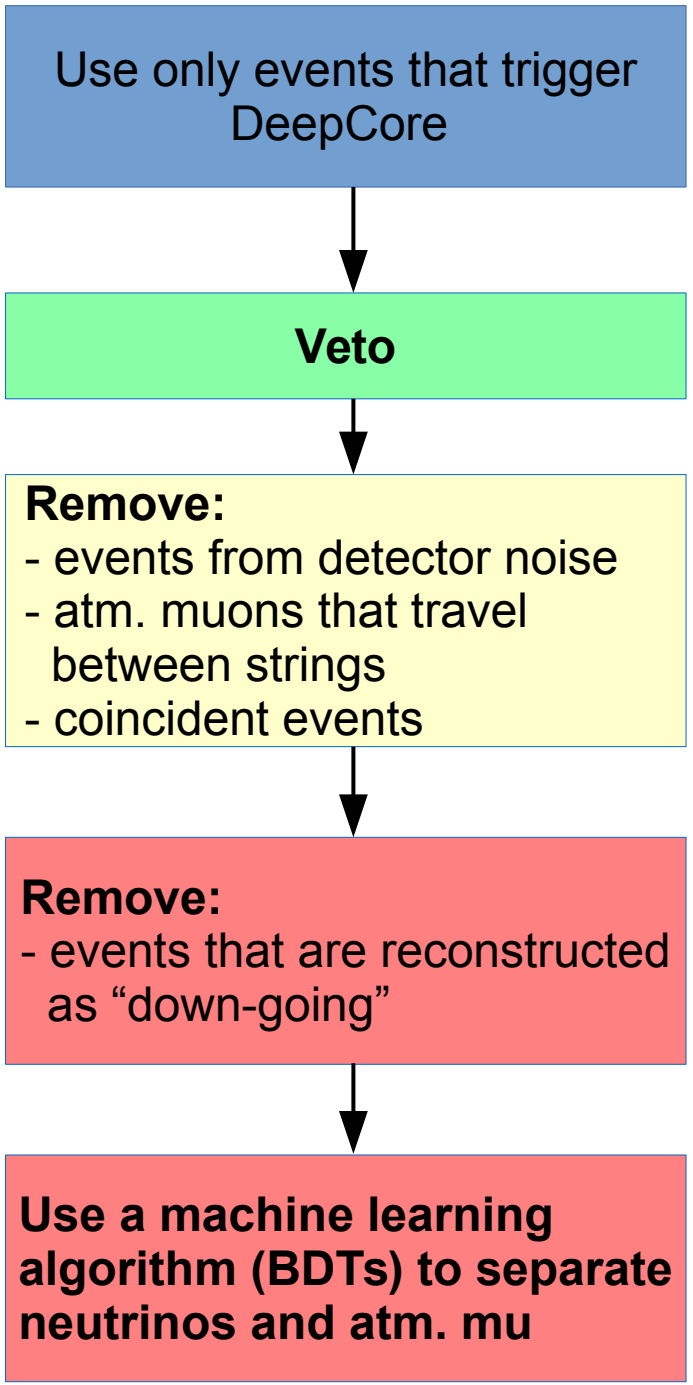
Use the surrounding sparser detector as veto for the dense DeepCore part

Incoming muons will produce hits in the veto before producing hits in DeepCore

Neutrinos can traverse the veto and produce events starting in DeepCore



Event Selection Steps



Event rates (baseline MC, standard oscillations):

Data: 478 mHz Neutrino MC: 3.7 mHz

Data: 151 mHz Neutrino MC: 3.2 mHz

Data: 21.5 mHz Neutrino MC: 2.2 mHz

Data: 0.82 mHz Neutrino MC: 0.81 mHz

Select Events Without Scattered Light

- in the ice muons (from muon neutrinos) are producing Cherenkov light

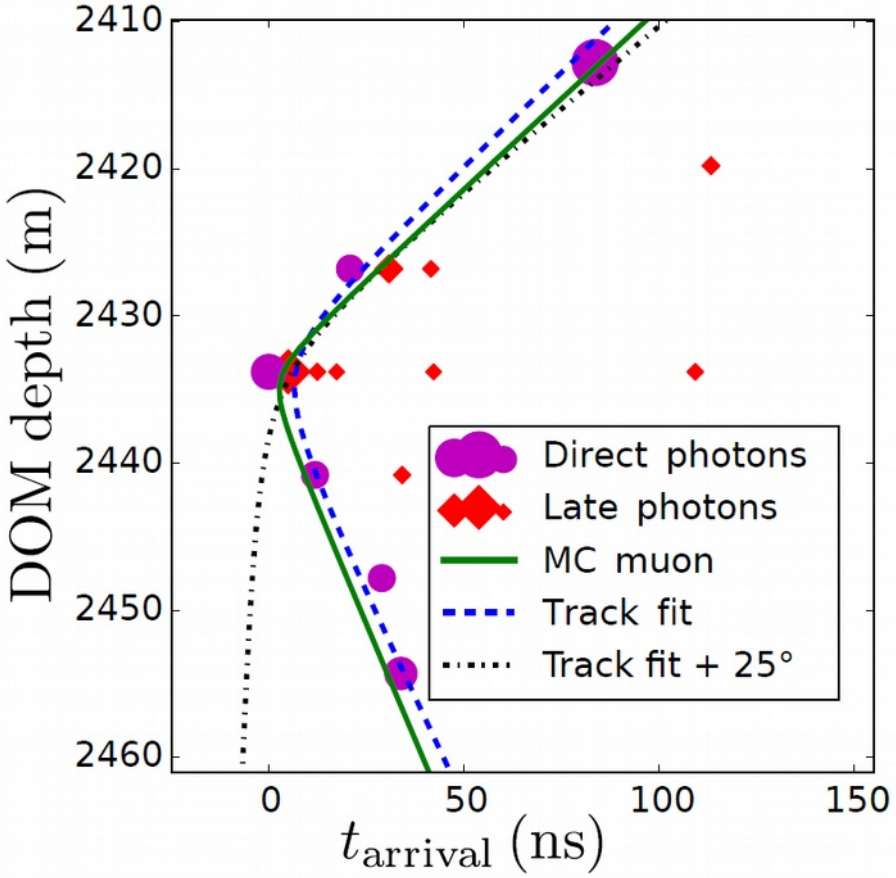
- ideally the Cherenkov cone produces a hyperbolic hit pattern in the detector

Photons scattered in the ice will arrive later at DOMs
→ they will reduce quality of track reconstruction

Look for direct photons:

→ time of hit consistent with photon from Cerenkov hypothesis

remove events with only few direct photons



Resolutions for reconstructions:
Zenith estimator: ~ 10°
Energy estimator: ~ 35%

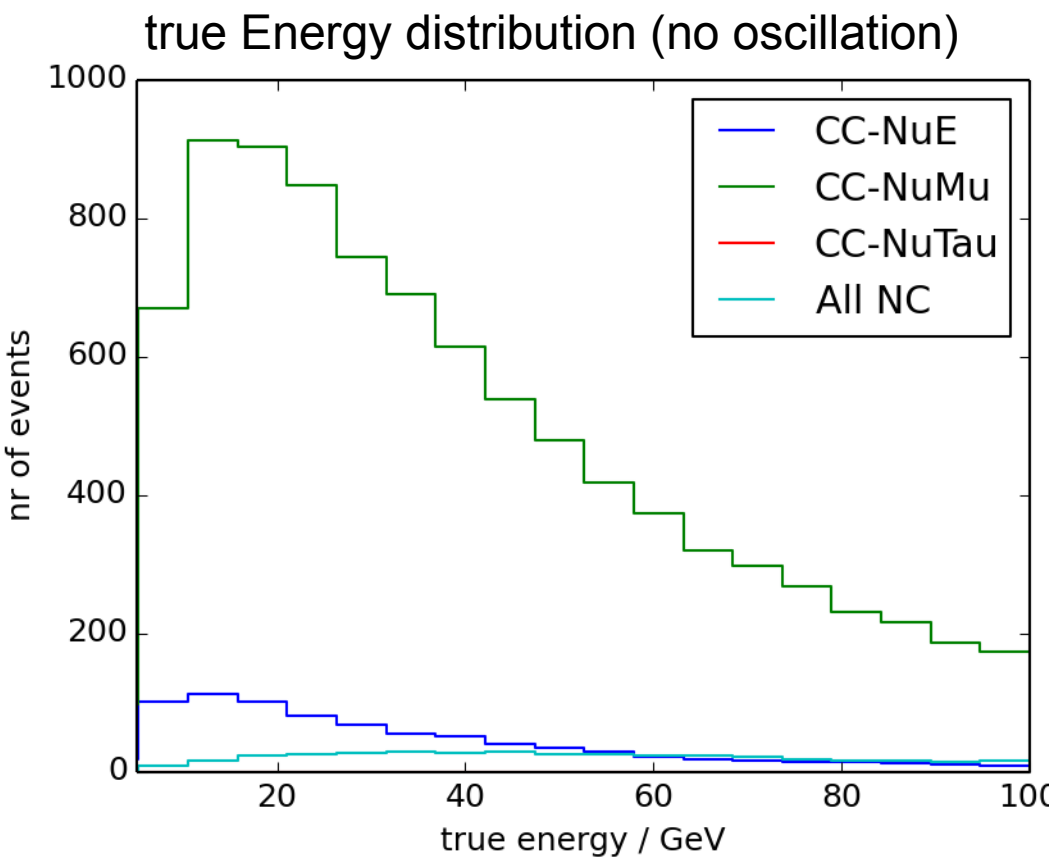
At Final Level – No Oscillations

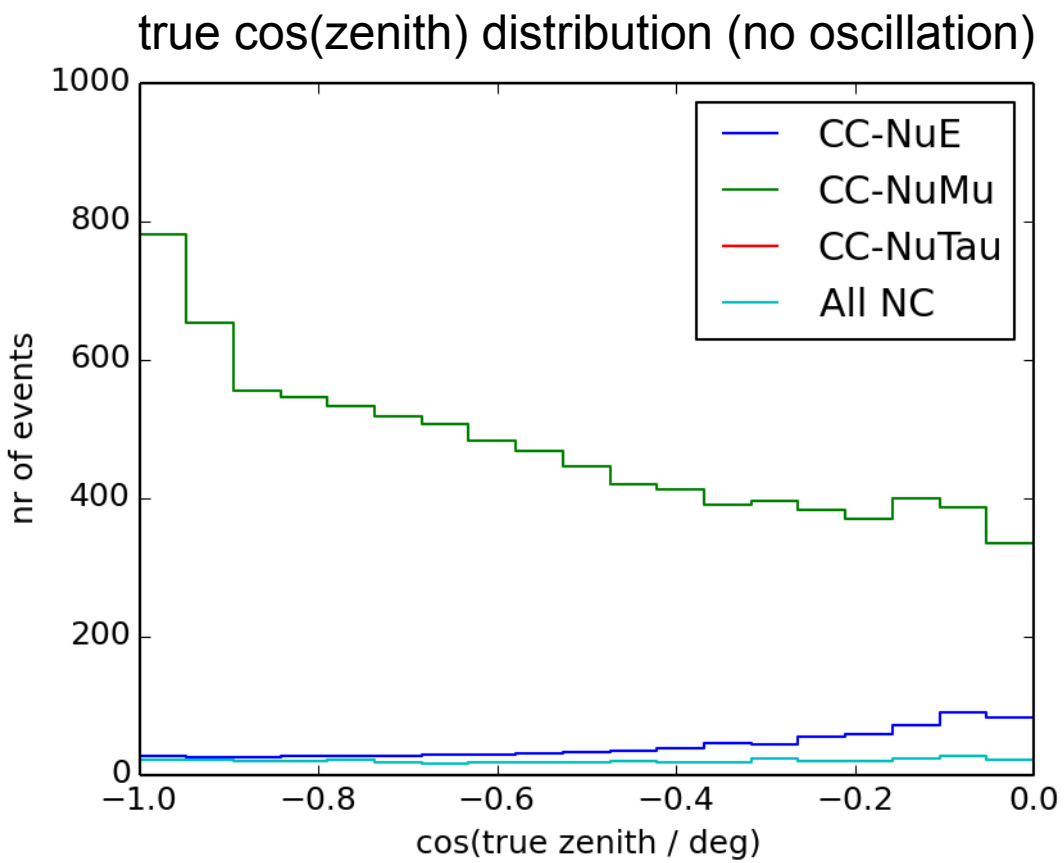
High quality neutrinos dominate the sample

Atm. muons constitute ~5-10% (estimated from data)

Number of events for four years of data: 6346 (IC79: 1172; IC86: 5174)

Oscillation Effect on Simulated Neutrino Data





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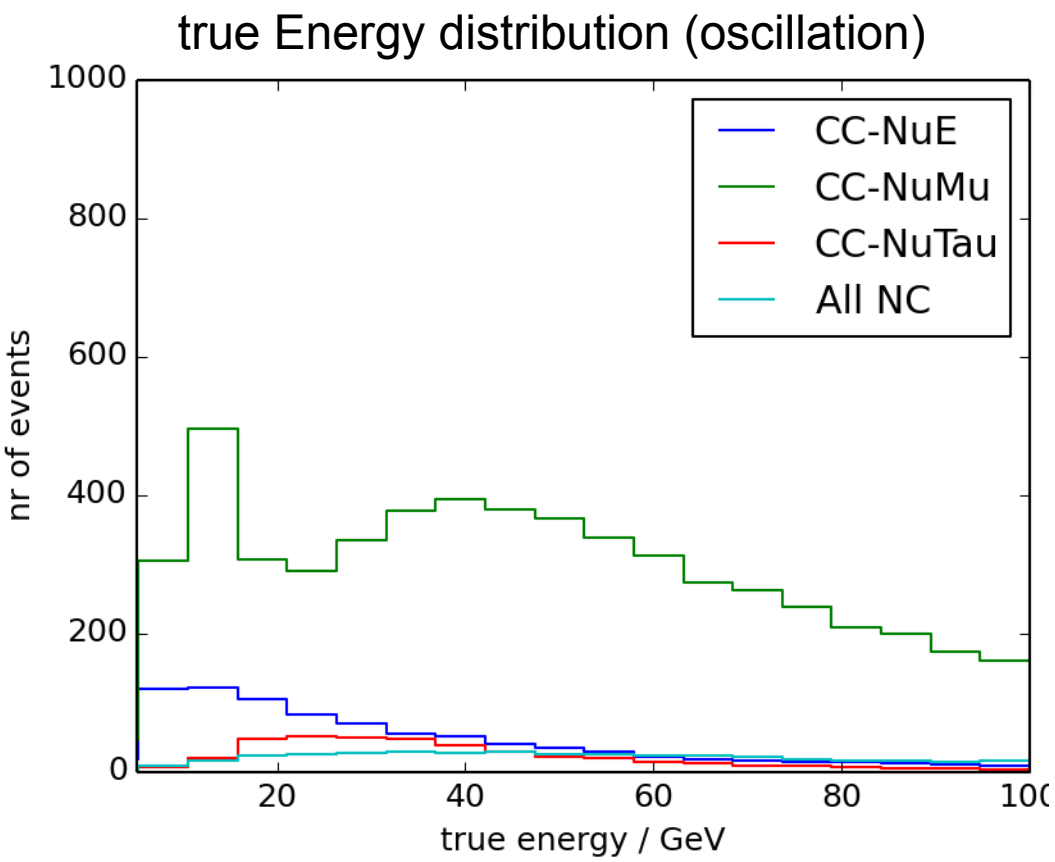
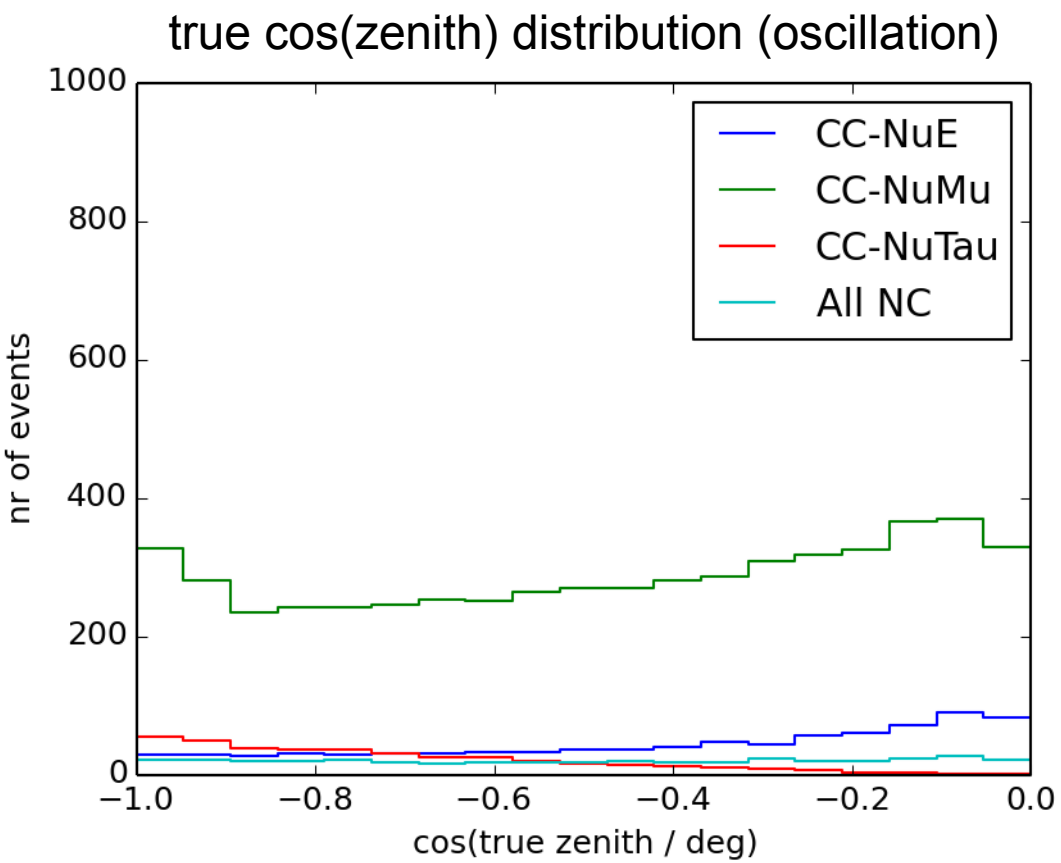
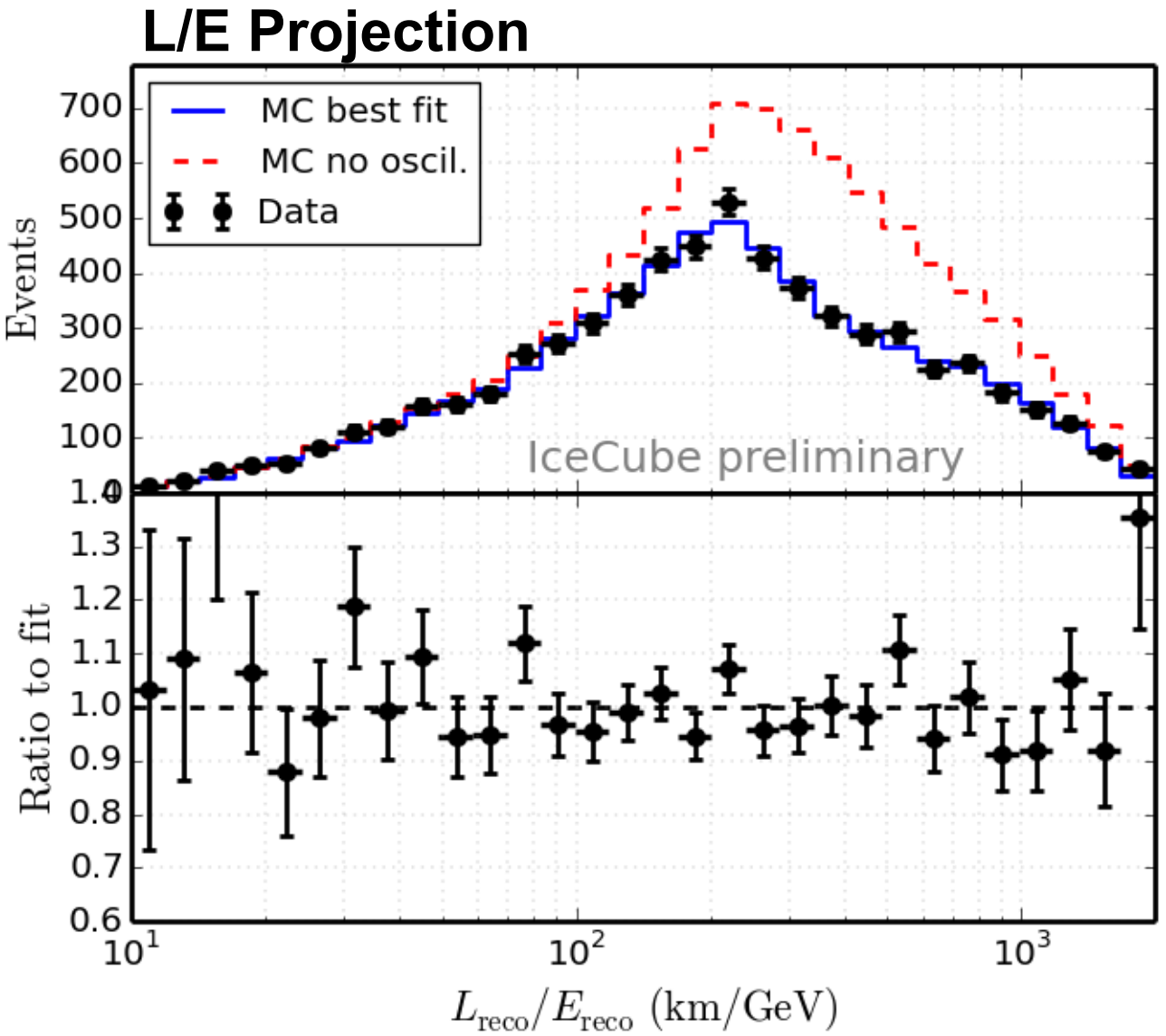




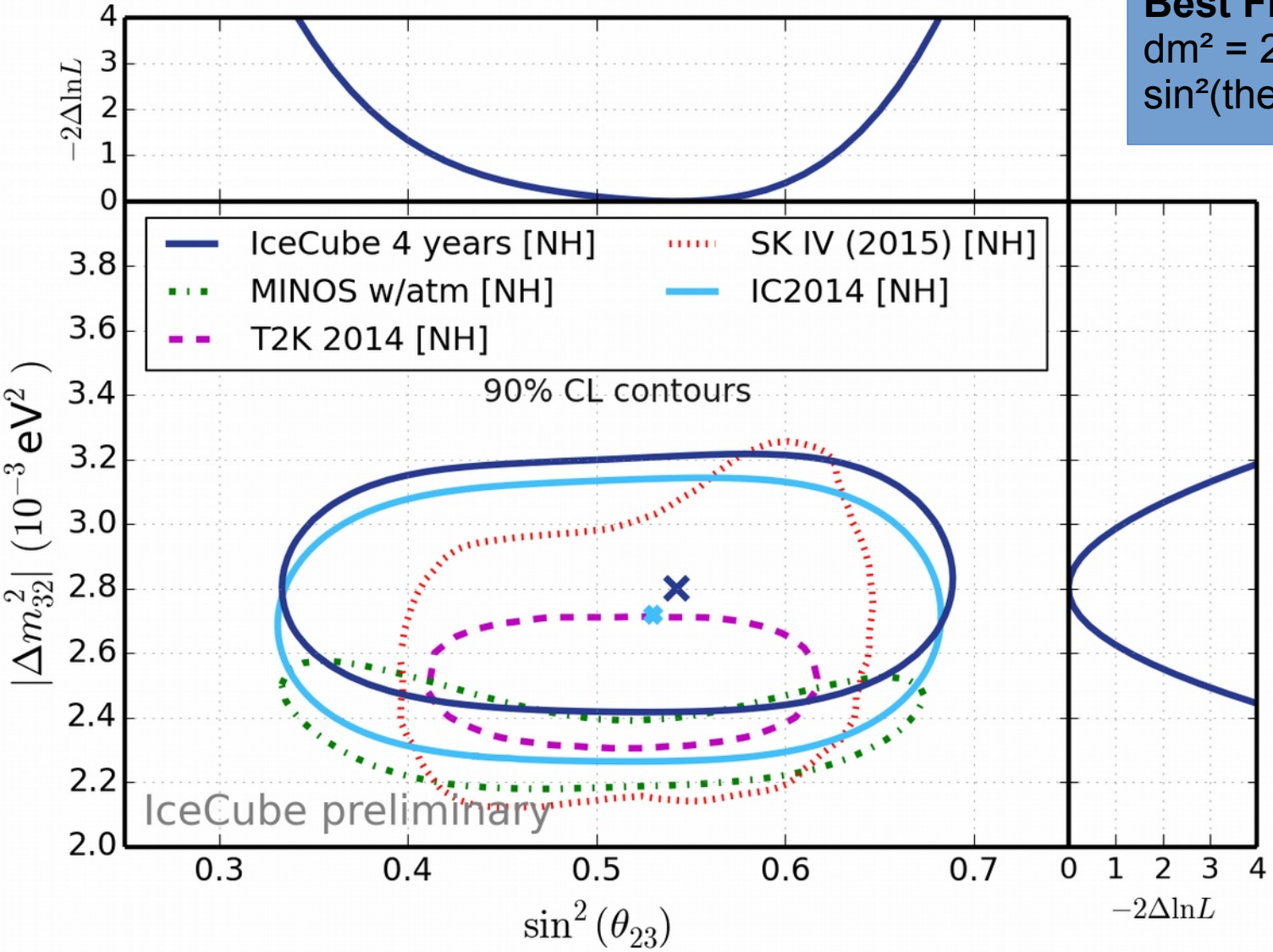
IC79/86 4-year oscillation analysis



- data and simulation for best fit (blue) and without oscillation (red)
- oscillation effect for three flavors and matter effects
- oscillation effect clearly visible
- simulation matches data well
- for actual fit 2D-histograms in reconstructed energy and zenith are used

Result and outlook

IceCube four year oscillation analysis result



Best Fit for four years:
dm^2 = 2.80 (-0.16, +0.20) x 10^{-3} eV^2
$\sin^2$(theta) = 0.54 (-0.13, +0.08)

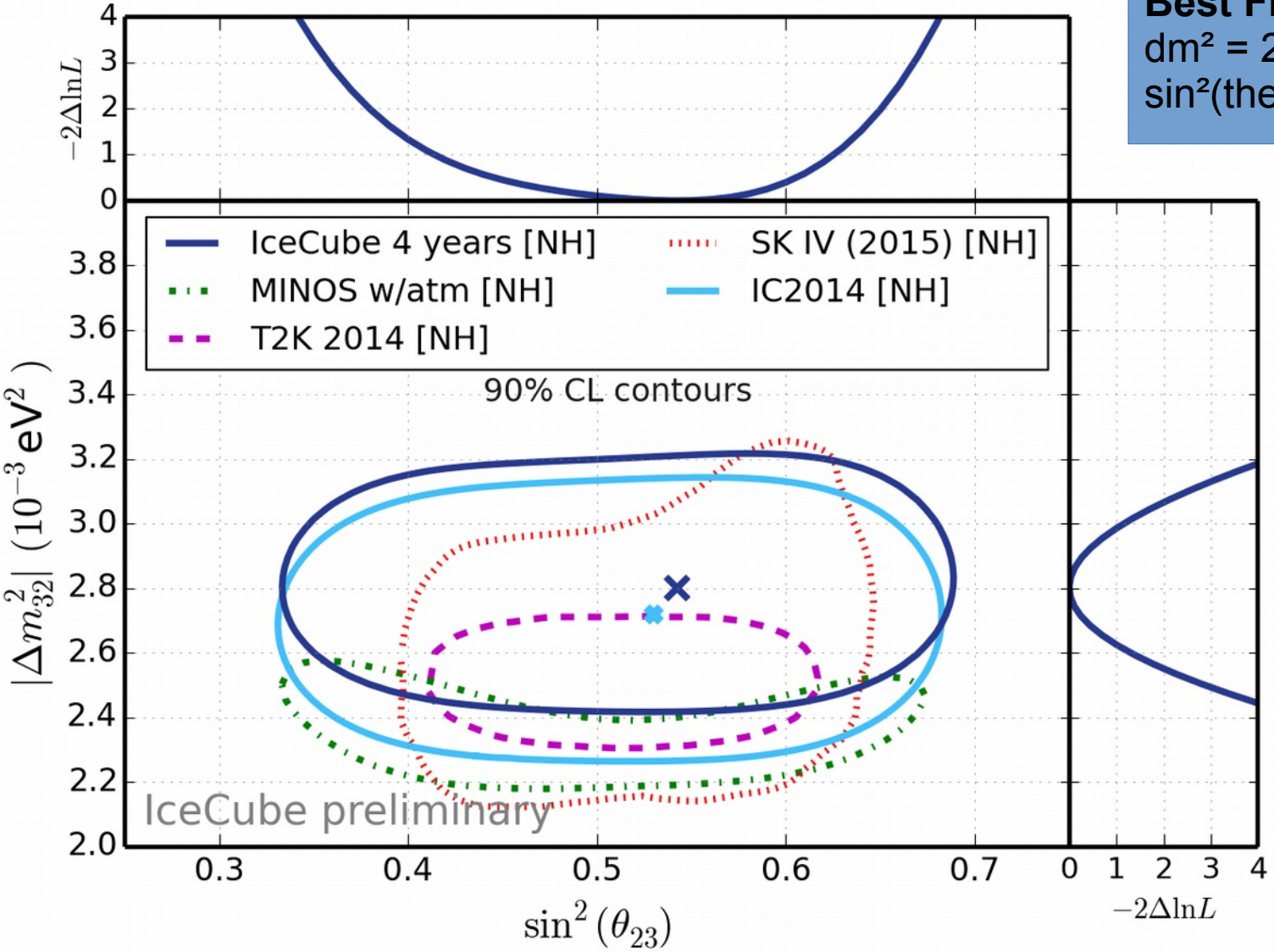
Published result with 3-years (IC2014):

dm^2:
2.72 (-0.19, +0.20) x 10^{-3} eV^2

$\sin^2$(theta):
0.53 (-0.12, +0.09)

Result and outlook

IceCube four year oscillation analysis result



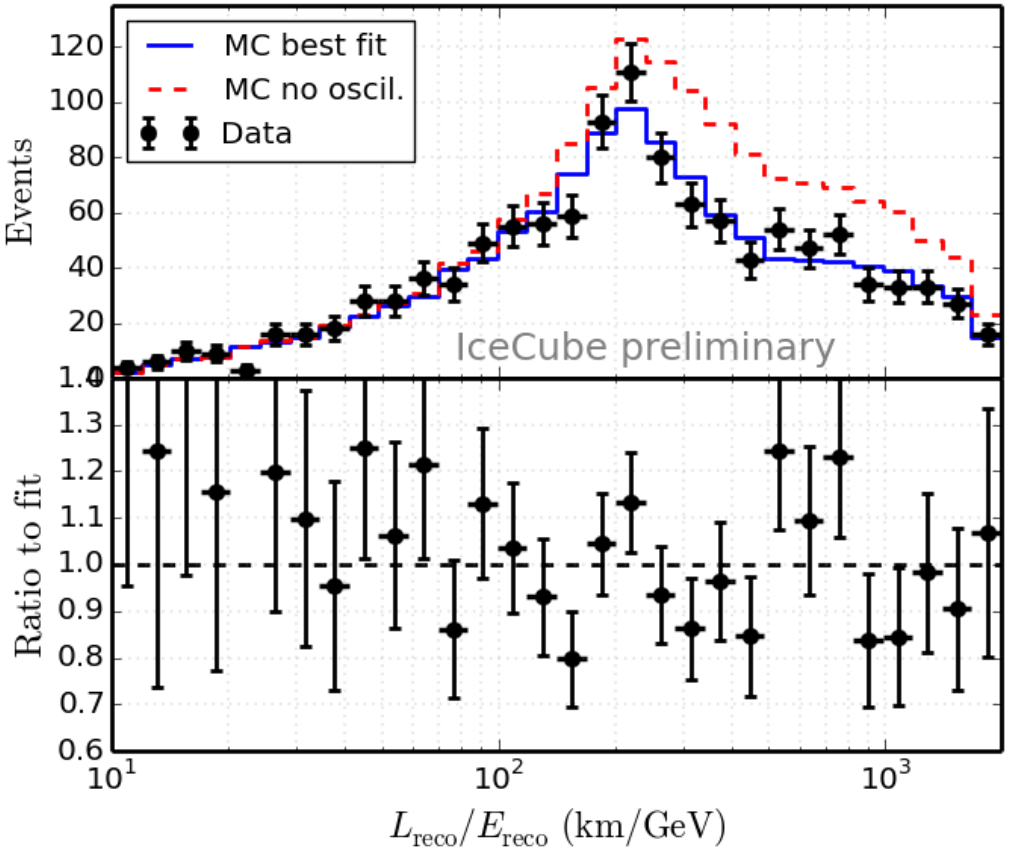
Best Fit for four years:
$dm^2 = 2.80\ (-0.16, +0.20) \times 10^{-3}\ eV^2$
$\sin^2(\theta) = 0.54\ (-0.13, +0.08)$

- extra year of data raises sensitivity
- new reconstructions methods are on the way
- the next year is ready to be included
- the future will see analyzes that highly raise the statistics (~50000 events)

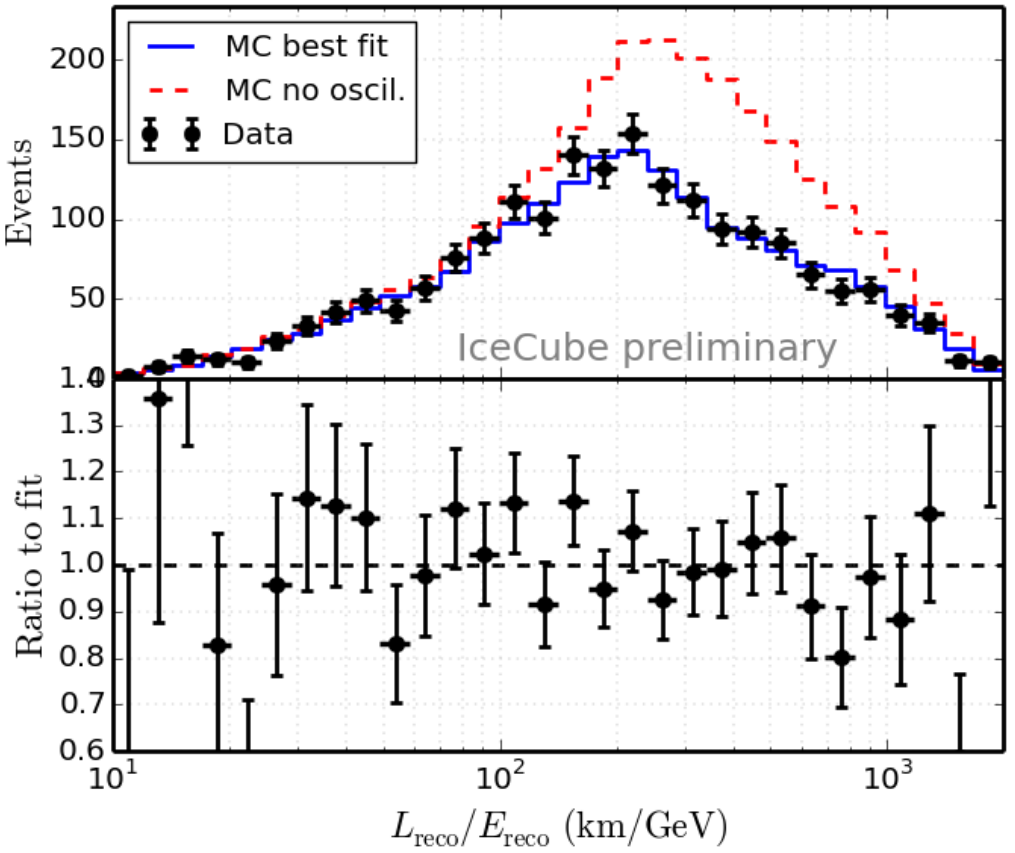
Backup

L/E distributions at best fit for 4-years

IC79 (one year)

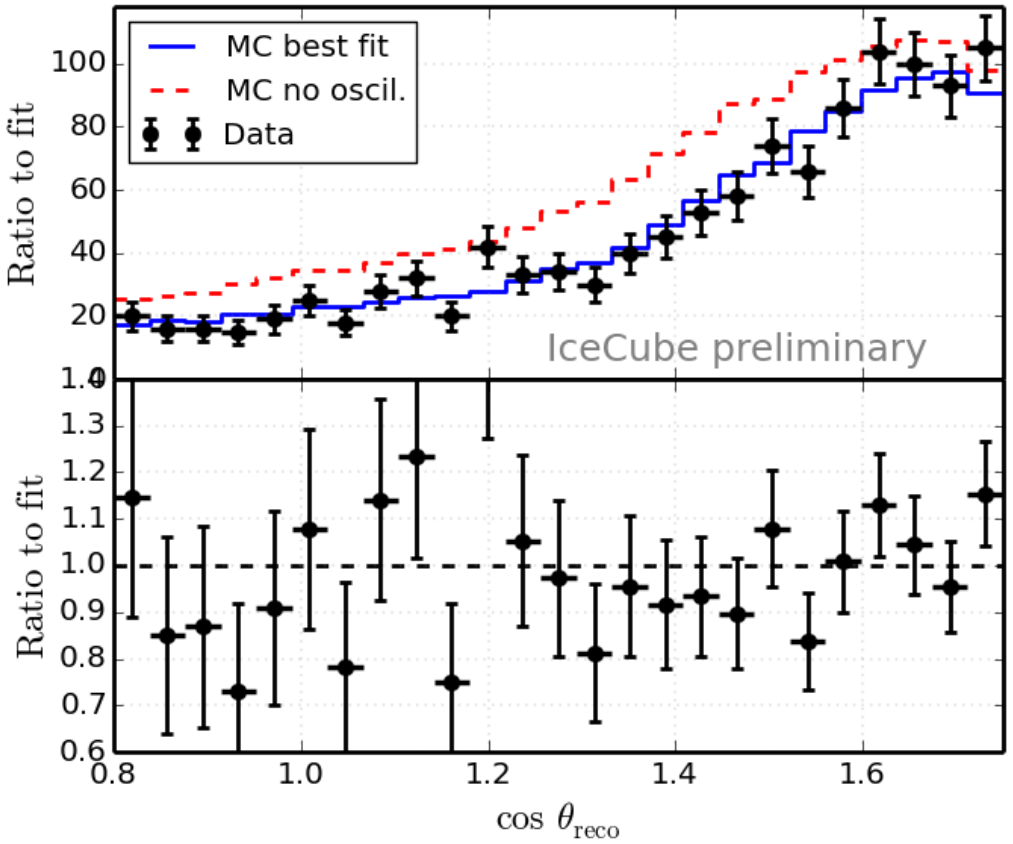


IC86 (one year)

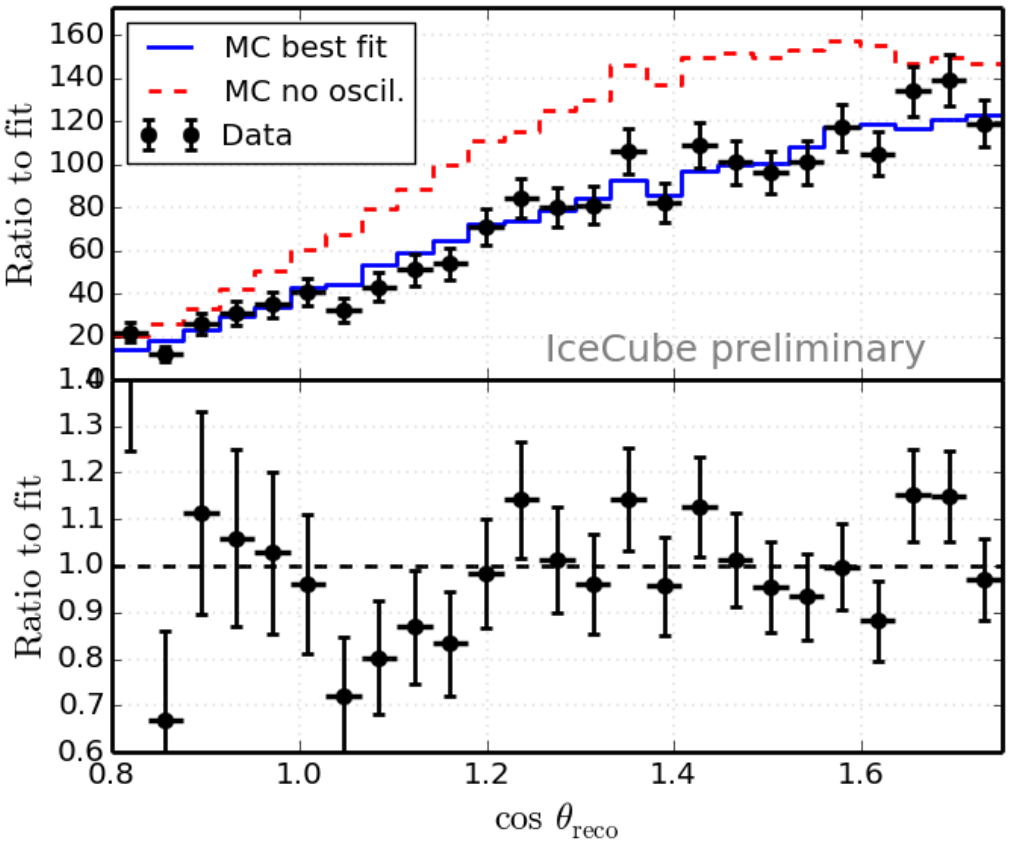


Energy distribution at best fit for 4-years

IC79 (one year)

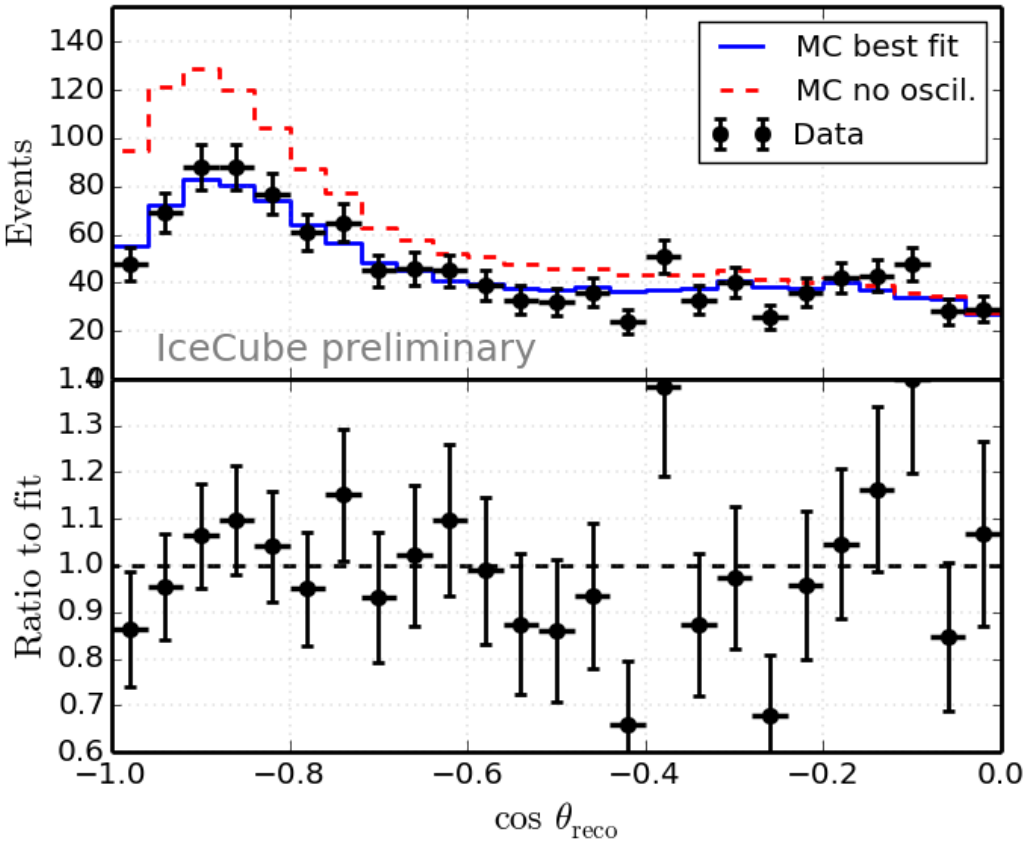


IC86 (one year)



Zenith distribution at best fit for 4-years

IC79 (one year)



IC86 (one year)