# Reconstruction Methods & Performances in Water

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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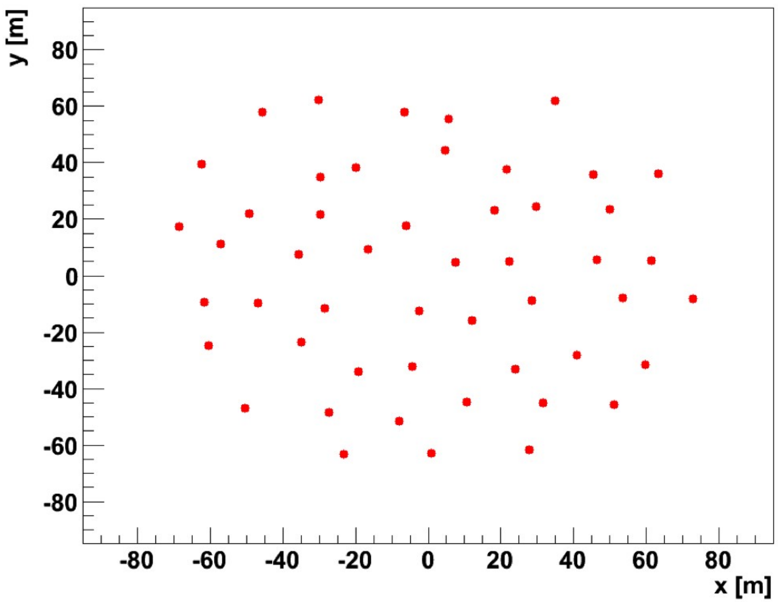
# Outline

- Introduction
- FlavorID
- Track reconstruction:
  - method
  - performance
- Shower reconstruction:
  - method
  - performance

# Introduction

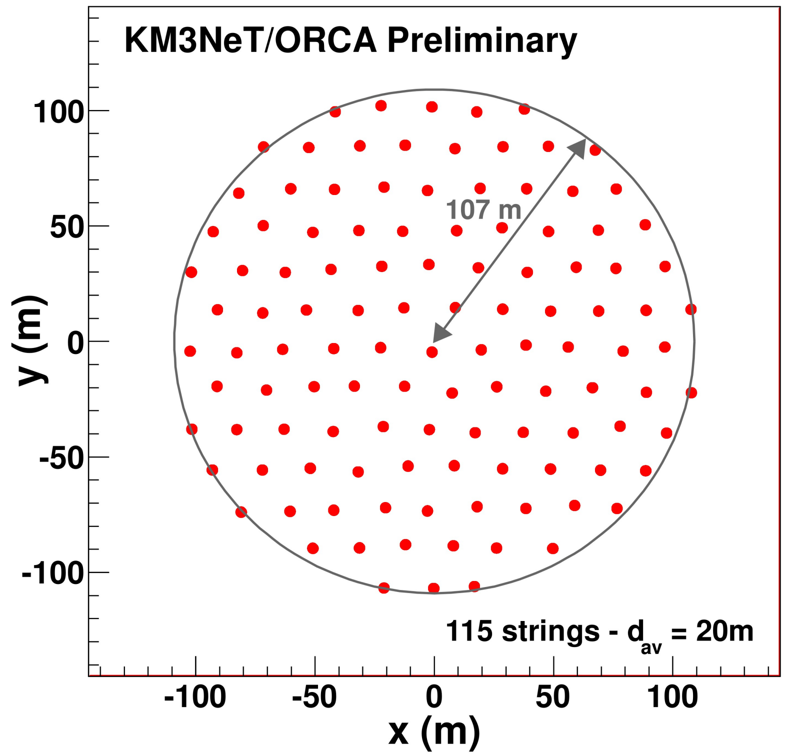
# Detector Layouts

## Reference detector (50strings)




- inst. volume: ~1.8 Mm^3
- height 114m, diameter 140m
- 50 strings, 20m spaced
- 20 DOM/string, 6m spaced

## Proposed detector (115strings)




- inst. volume: ~3.7 Mm^3
- height 102m, diameter 214m
- 115 strings, 20m spaced
- 18 DOM/string, 6m spaced

# MC Simulation

- Neutrino generation
  - GENIE

- Particle propagation & light production:
  - 'km3 + geasim' (Geant3 based)
  - 'KM3Sim' (Geant4 based)

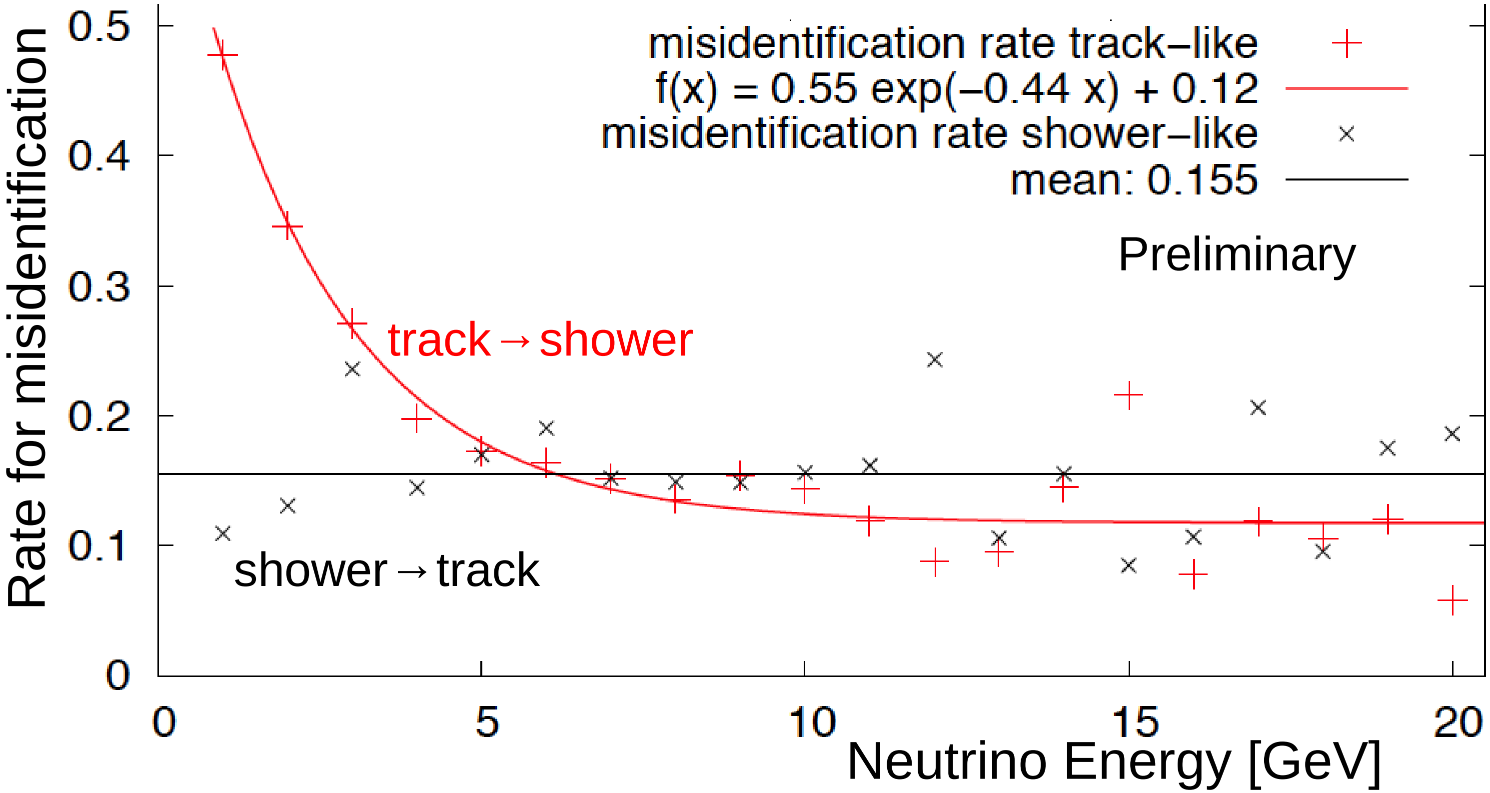
- Optical background from $^{40}$K decay:
  5kHz / PMT and 500Hz in-DOM time-correlated

- All plots are for CC events, weighting: Bartol flux
  - track reco → $\nu_\mu$ CC
  - shower reco → $\nu_e$ CC

# FlavorID

# FlavorID

- For details: see Thomas Heid's talk @ MANTS'13
- Method:
  - Calculate several feature based on track and shower hypothesis
  - Classification via Random Decision Forest
- Performance evaluated on 'premium events' (light nearly fully contained)

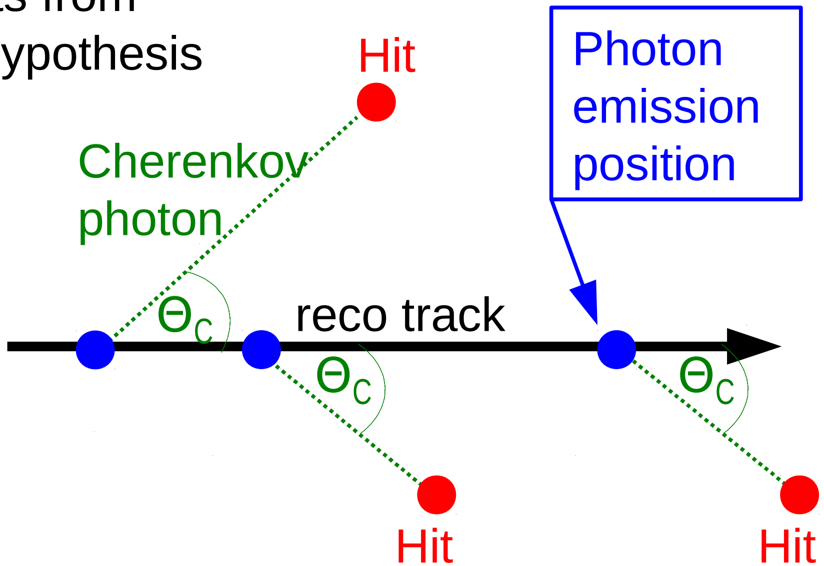


# Track Reconstruction

# Method

- For details: see Agata Trovato's talk @ MANTS'13

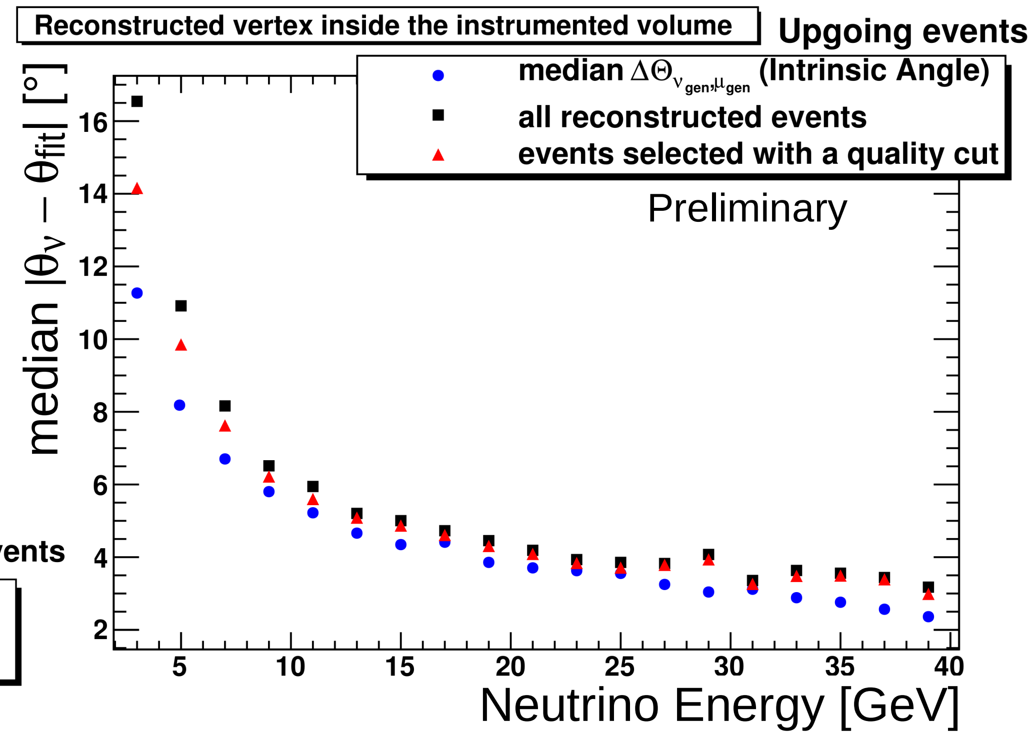
- Procedure:
  - hit selection based on coincidences and causality
  - track fit: maximum likelihood method based on hit time residuals
    similar to AAFit
  - track length estimation:
    1. first / last hit emission point
    2. vertex fit by identifying hits from had. shower and fit vertex hypothesis along reconstructed track

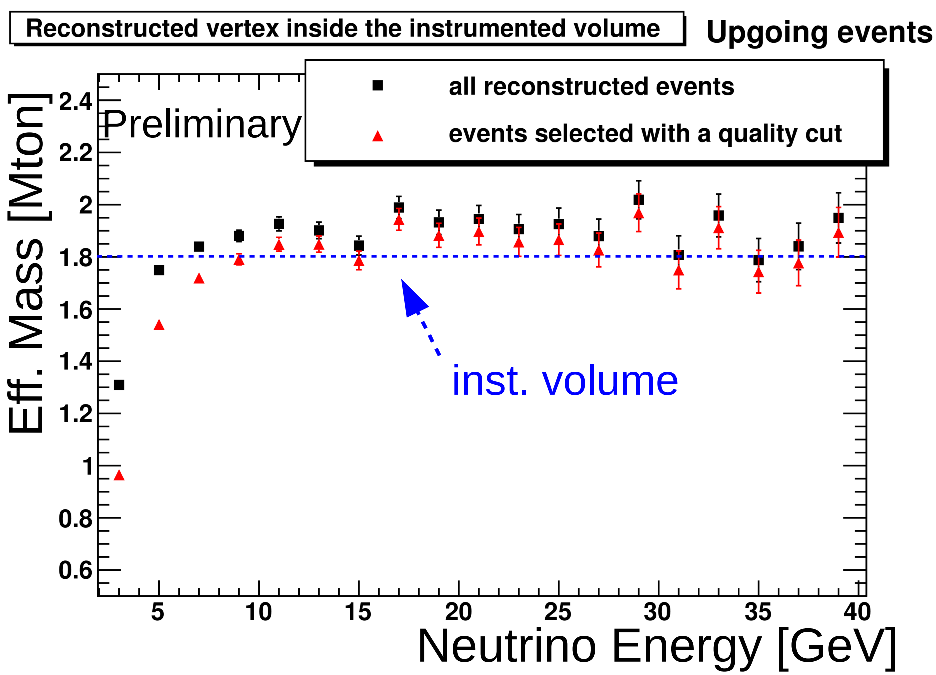


# Performance (I)

- Reference detector
- MC: 'km3 + geasim'

- Reconstructed as up-going & reco vertex inside inst. volume

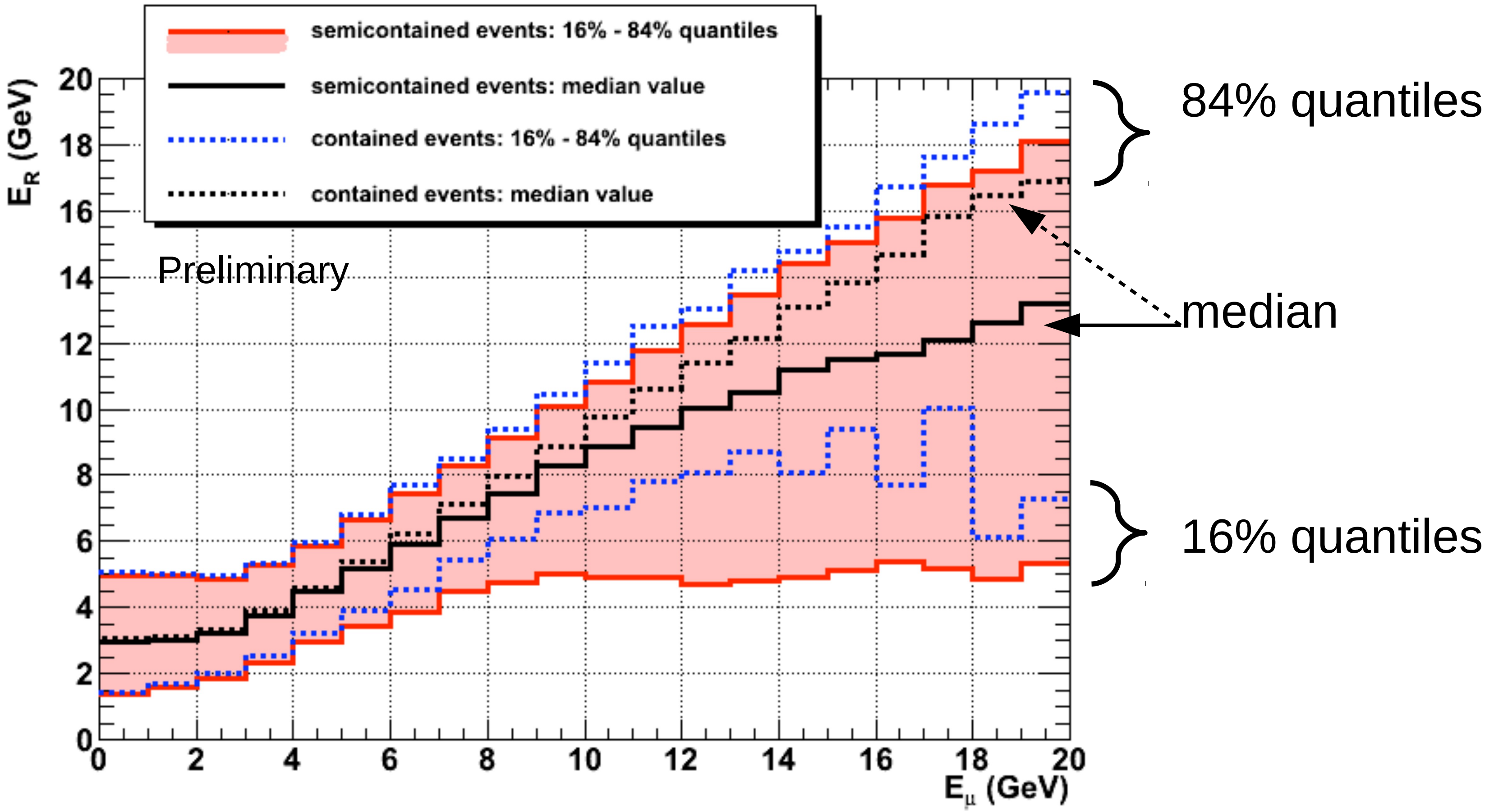



- eff. volume: plateau ~ inst. volume
- angle(reco,nu) slightly worse than intrinsic angle (nu,mu)

# Performance (II)

- Reconstructed as up-going & reco vertex inside inst. volume




- semi-contained: reco vertex inside inst. volume
- contained: estimated endpoint closer to detector centre than vertex

# Outlook

- Pending: adding had. Shower
  'track' reconstruction → 'track + shower' reconstruction

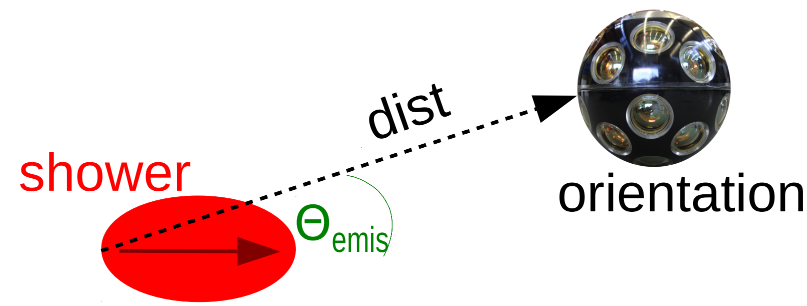
- Studies for proposed detector (115 strings) ongoing

# Shower Reconstruction

# Method

- 1. Vertex fit:
  - maximum likelihood method based on hit time residuals
  - two fits: first robust prefit then more precise fit

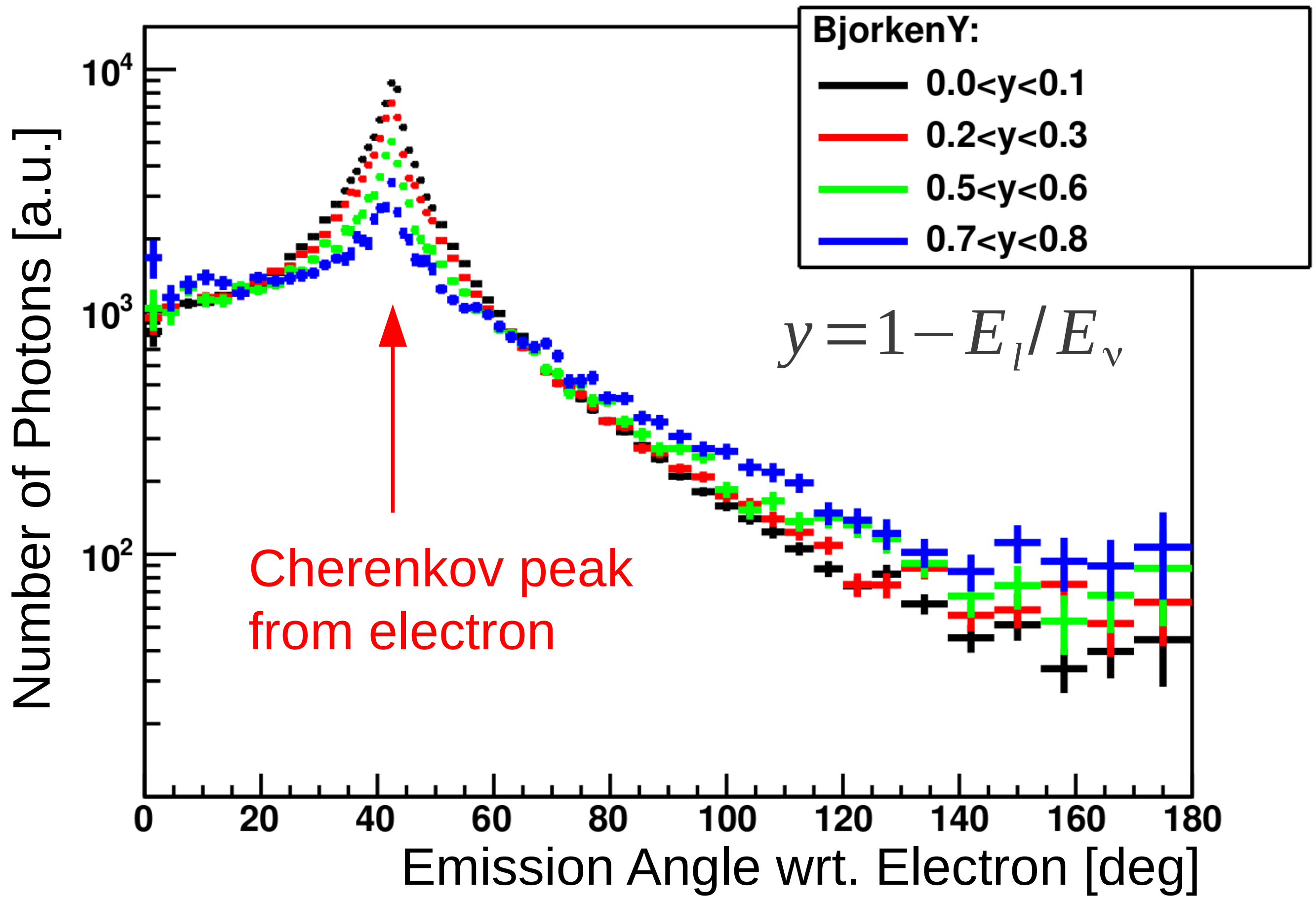
- 2. Energy + Bjorken y + direction fit:
  - PDF for number of expected photons depending on: $E_\nu$ , Bjorken y, emission angle, OM orientation, distance(OM,vertex)




  - maximum likelihood method based probability that hits have been created by certain shower hypothesis ($E_\nu$, Bjorken y, direction)

# Emission Angle Profile

- PDF tables are filled from MC
- Reference direction from electron (mostly dominant particle in shower)




Example bin:

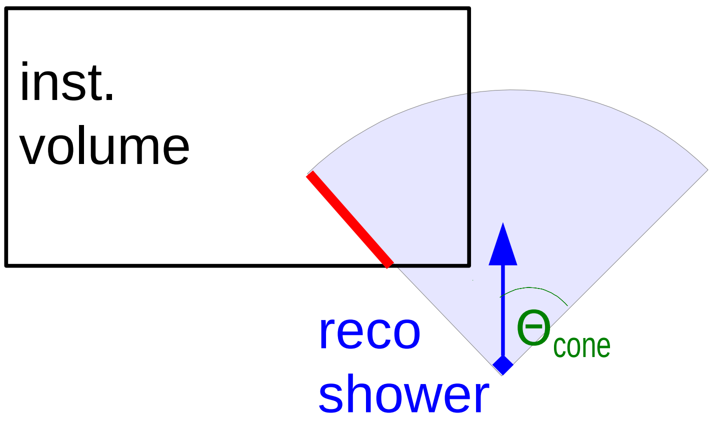
$8 < E_\nu/\text{GeV} < 9$

$40 < \text{dist/m} < 50$

# Event selection

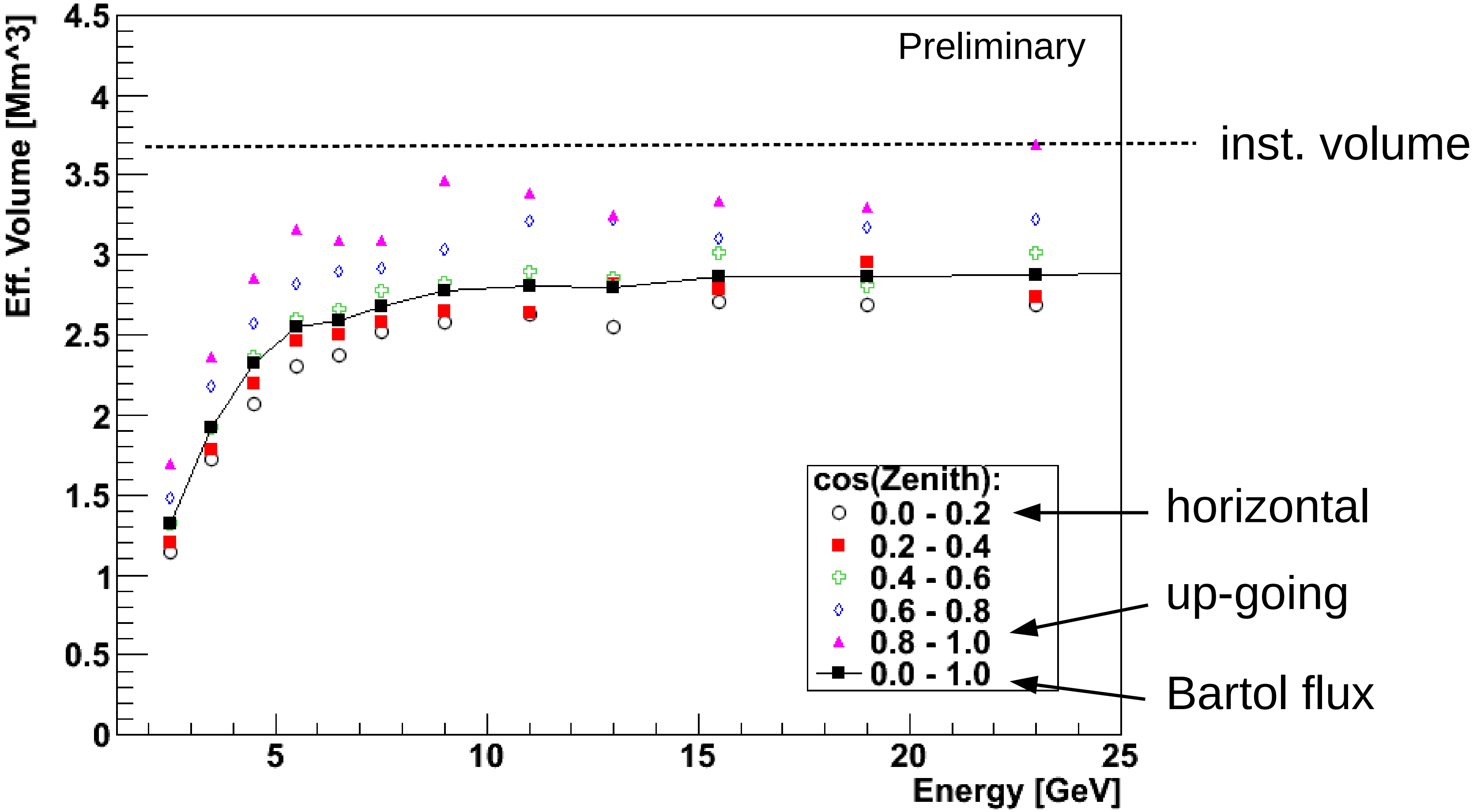
- >= 3 L1-hits (coincidence within 14ns on same OM)
- two vertex fits similar:
  - dist(first_fit, second_fit) < 3m  &  time < 20ns

- 'coverage' cut:
  - idea: require certain minimum of expected light inside inst. volume
  - calculated from reconstructed vertex & direction
    → direction dependent vertex cut



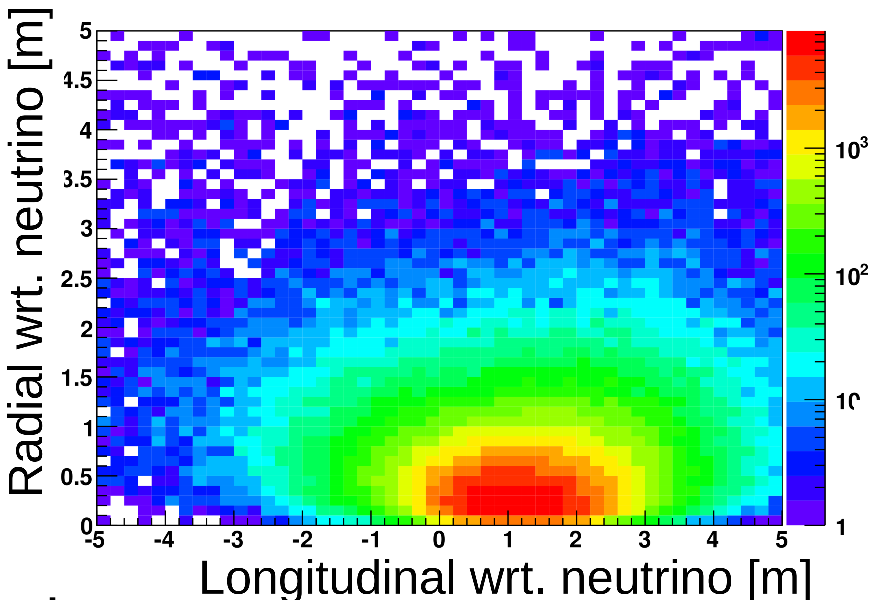
# Effective Volume

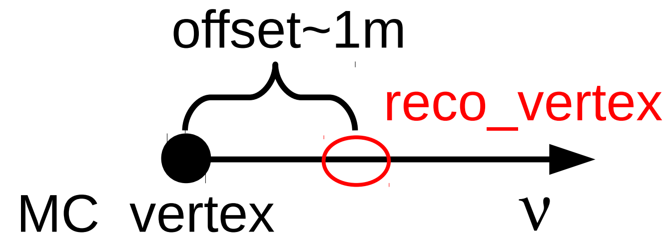
- Proposed detector (115 strings), MC: 'KM3Sim'



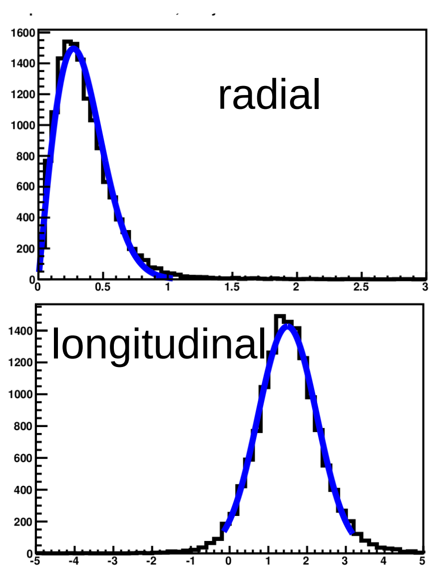

- Plateau: 2.6–3.3 $Mm^3$ (zenith angle dependent), for Bartol flux ~2.8 $Mm^3$
- Turn-on: 90% of plateau reach at ~6 GeV

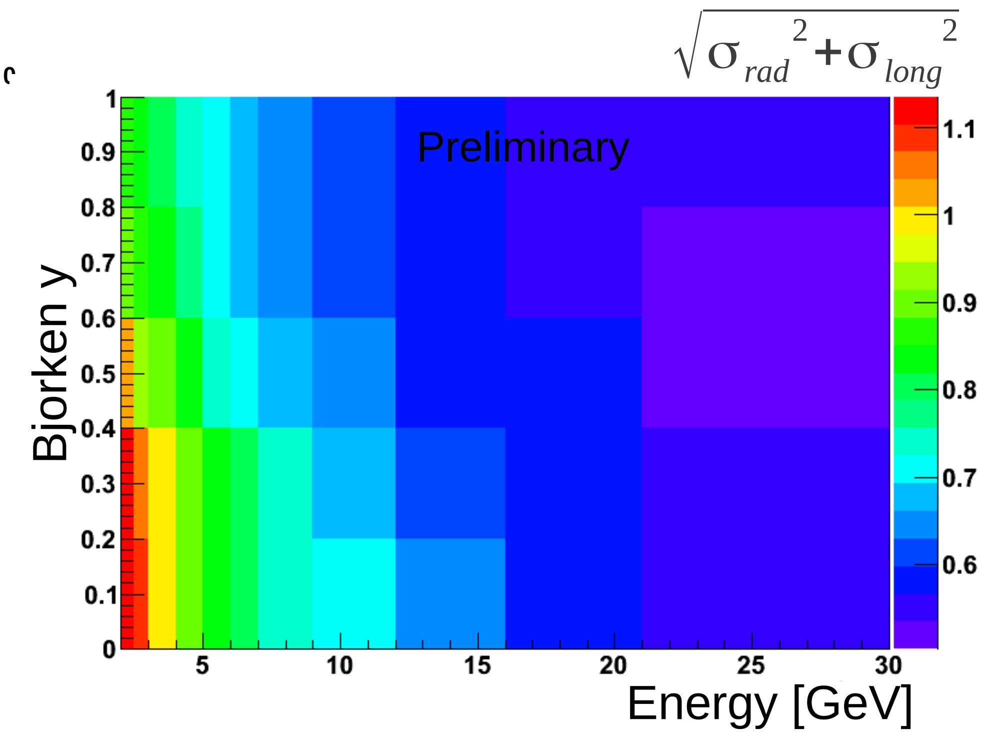
# Vertex Resolution



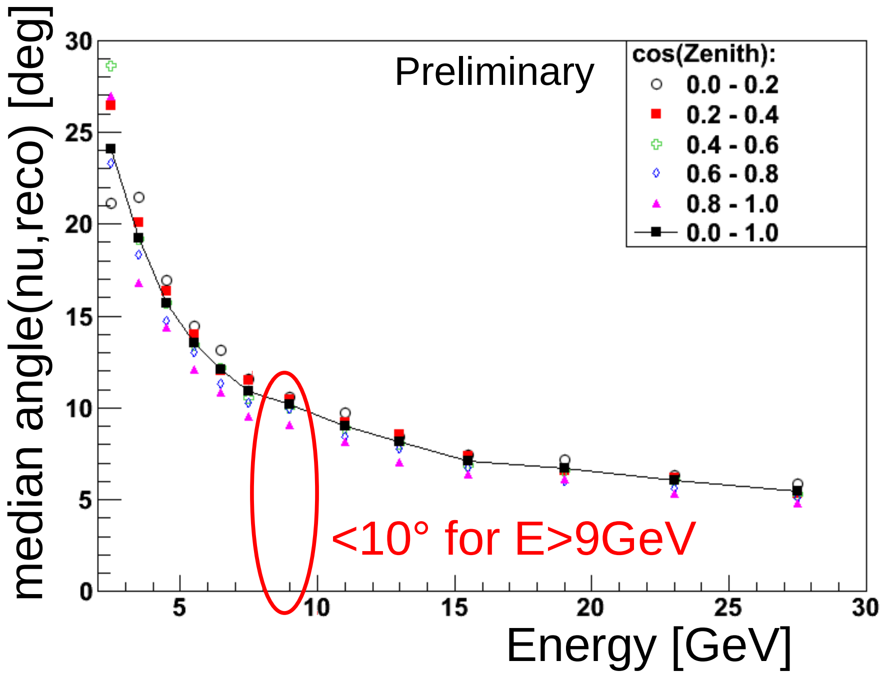

Fit in
(E,y) bins



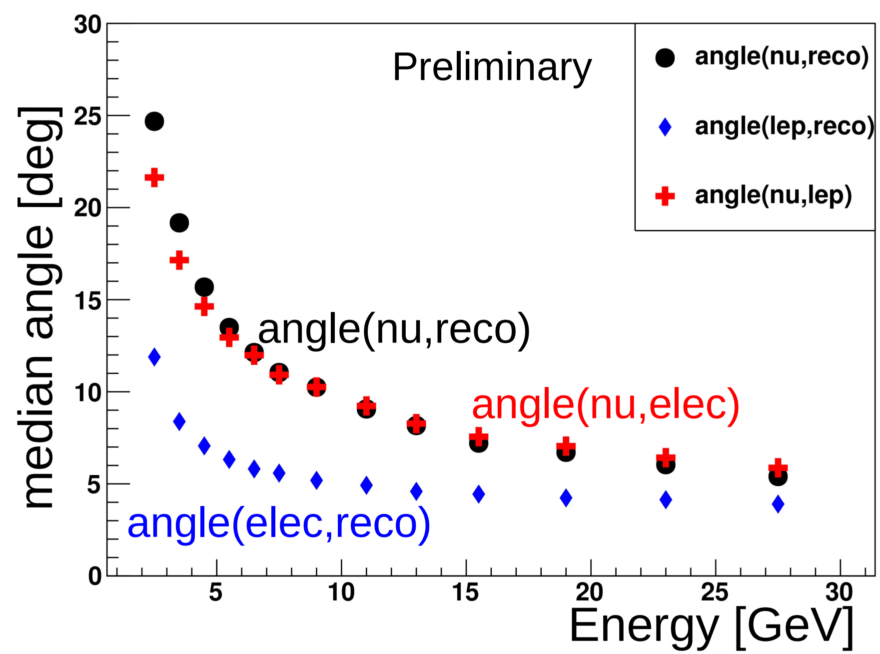




- Vertex resolution 0.5-1 m (longitudinal error dominates)

# Direction Resolution




- Reconstruction finds the electron in nue CC events




- Up-going better than horizontal

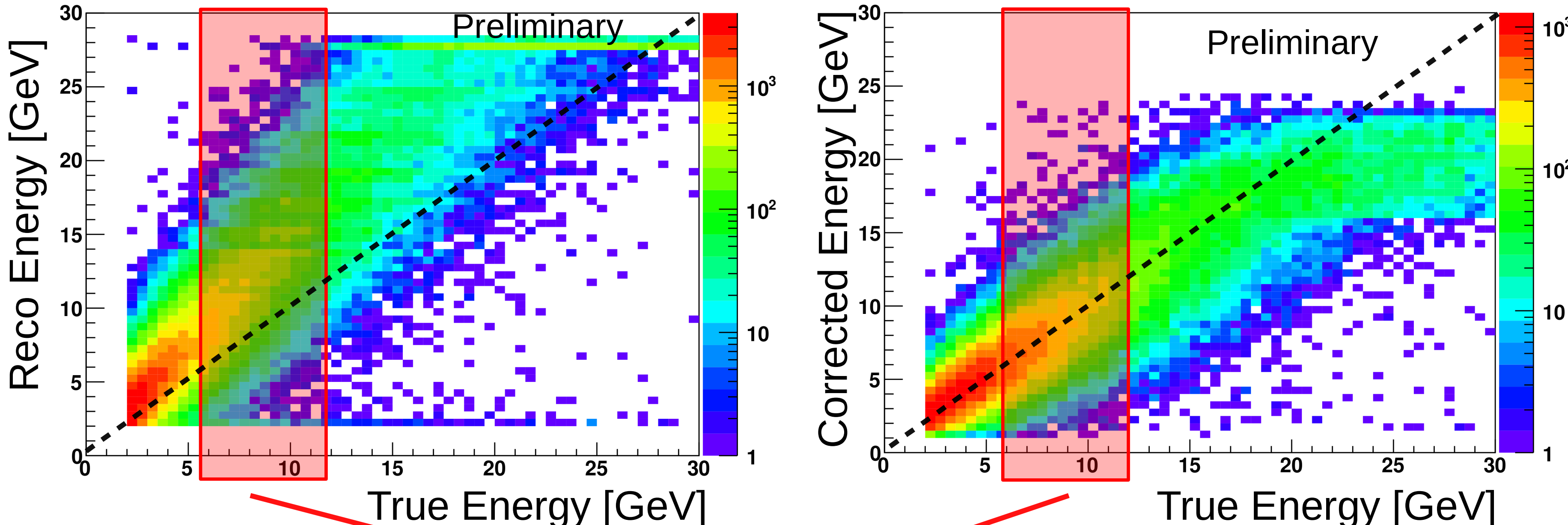
- Reason: multiPMT (19 ↓, 12 ↑)

# Energy Reconstruction

- Problem 1: PDF tables have been produced from MC with $2<E_\nu<30$

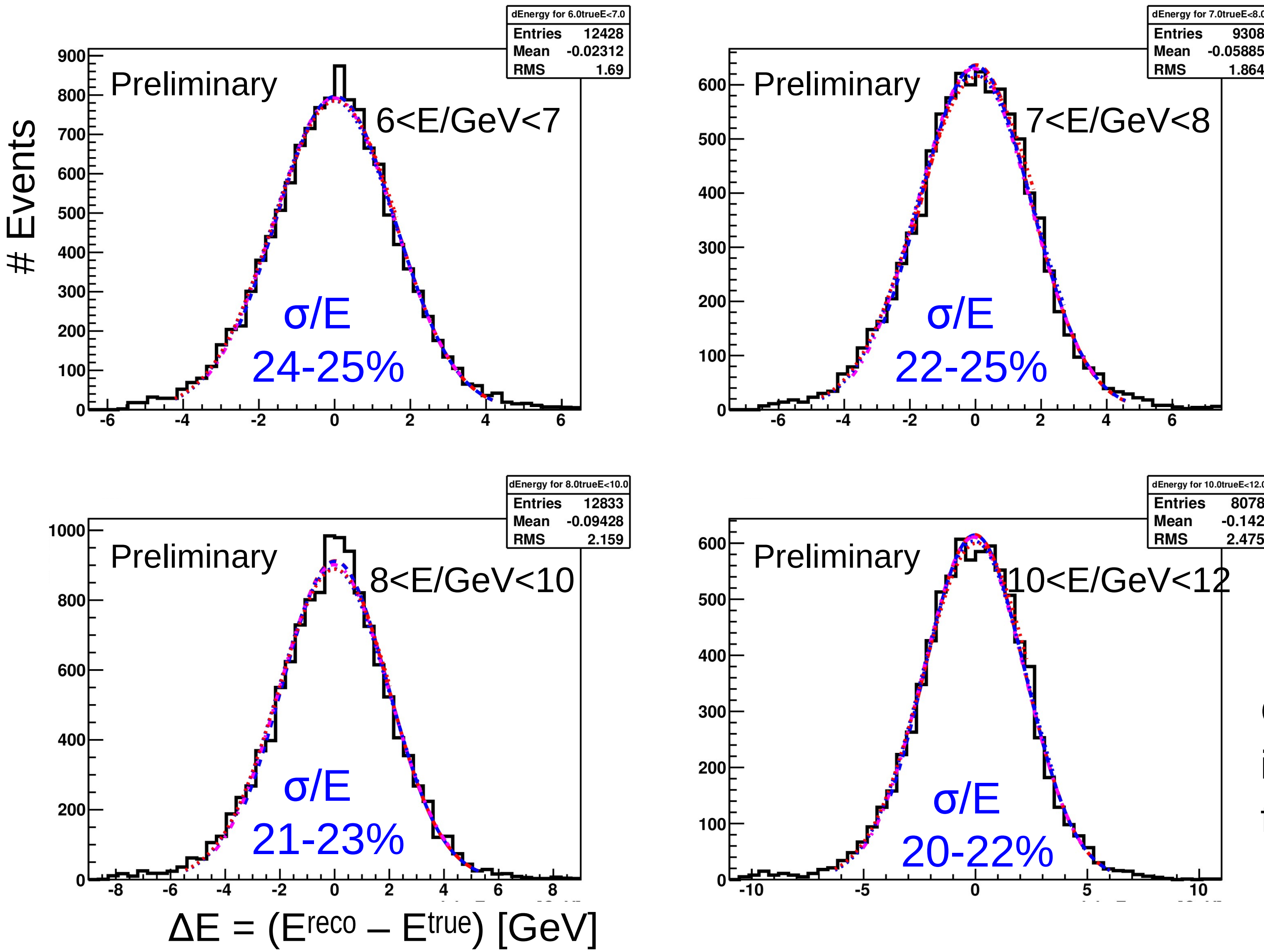
  → reco energy in [2,30] GeV
- Problem 2: $E_{reco} / E_{true} \sim 1.5–2$
- Work-around: do energy correction

  corrected energy = function( reco E, reco y, reco zenith )




- Energy resolutions are only trustable in medium energy range 6-12 GeV

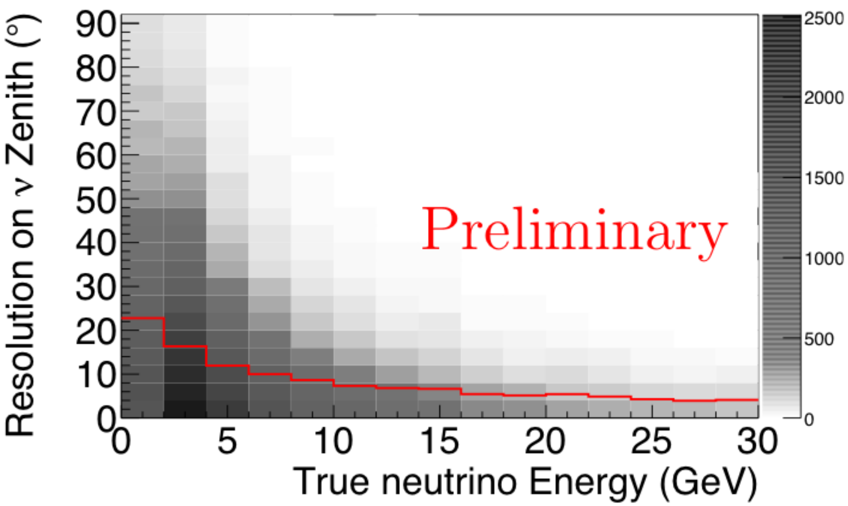
# Energy Resolution

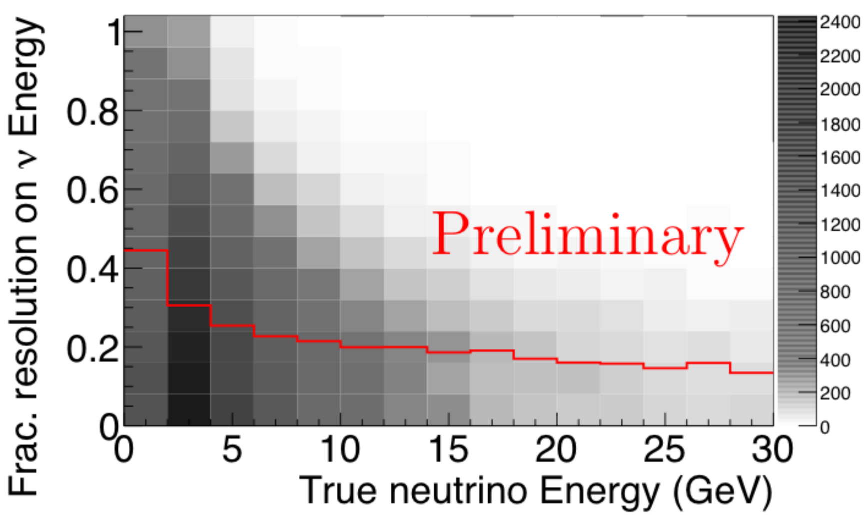



Gaussian fits in different fit ranges

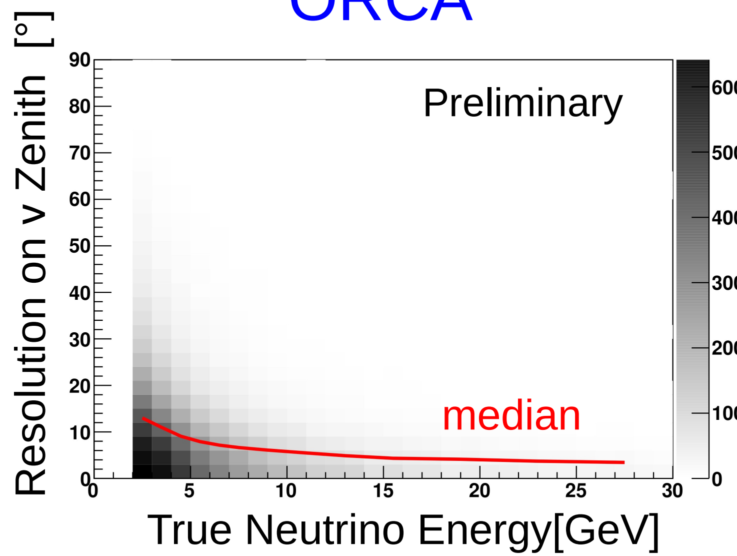
# Comparison with PINGU LoI

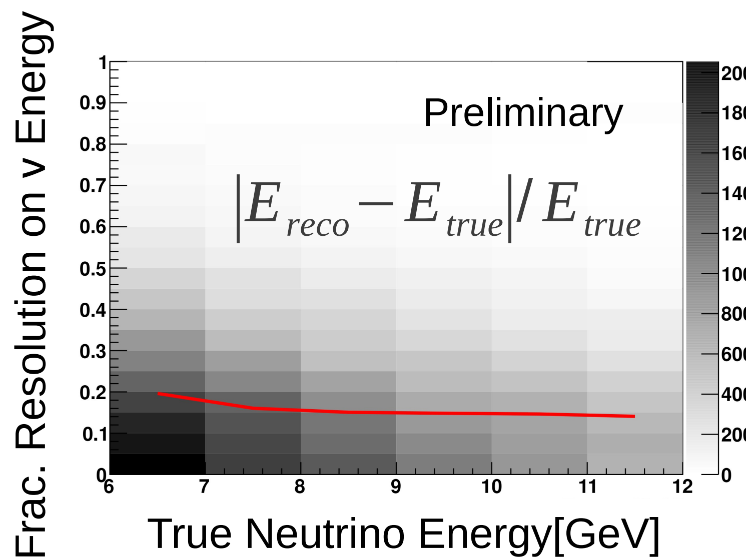
## PINGU (LoI, 2014)




## ORCA

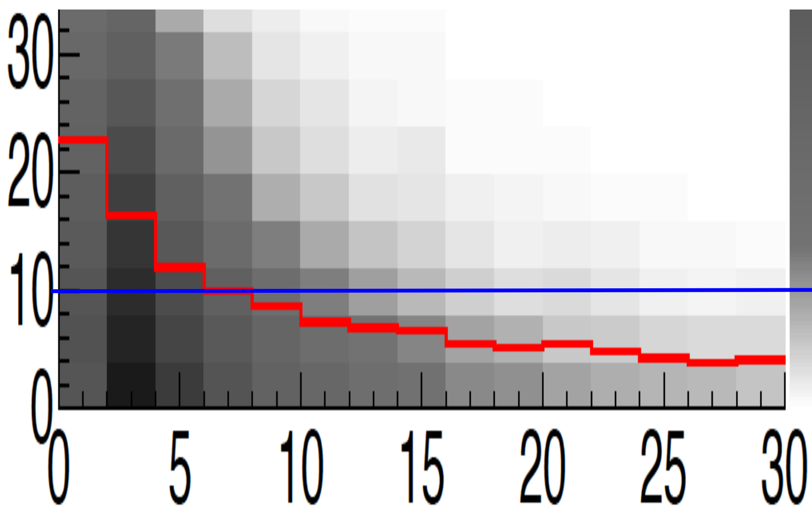


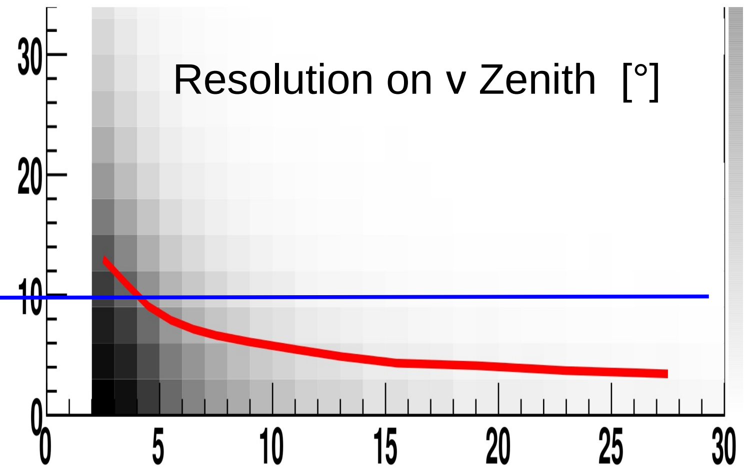



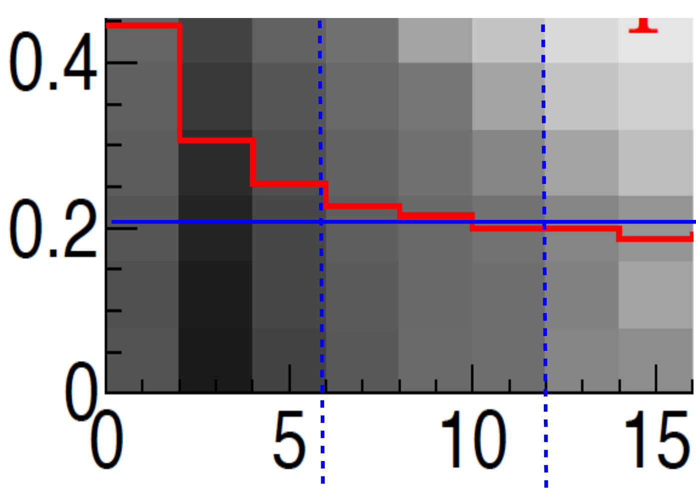
# Comparison with PINGU LoI

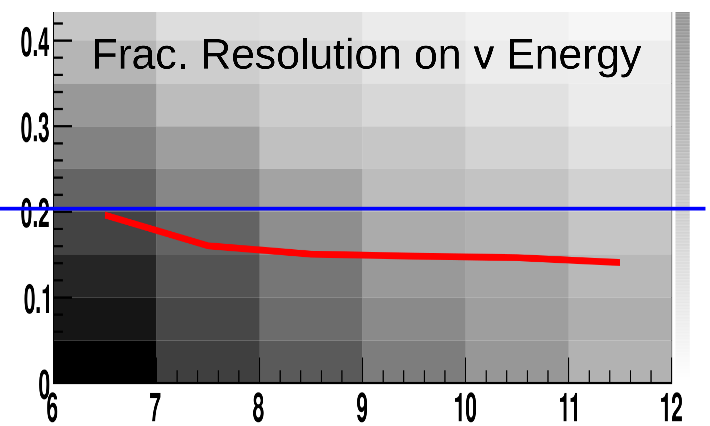
## PINGU (LoI, 2014)

## ORCA

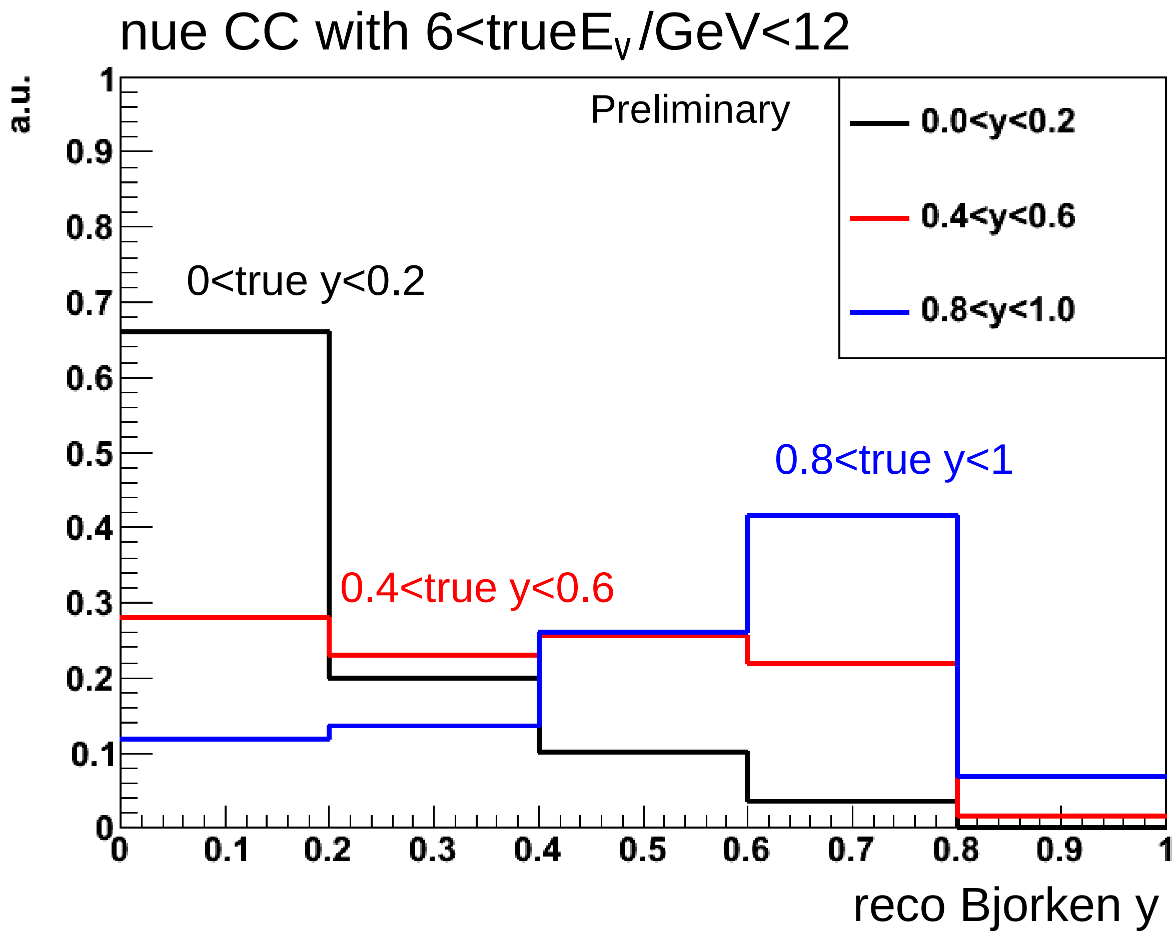






# Bjorken y Sensitivity

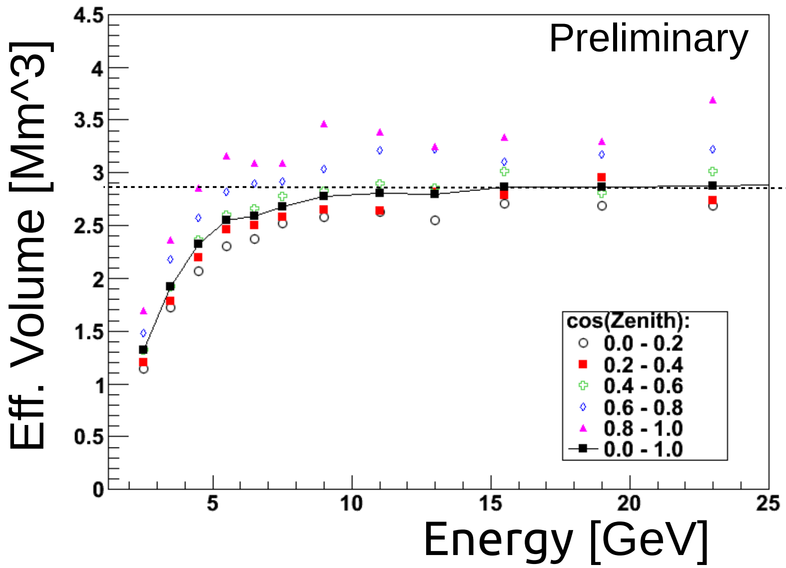



- Sensitivity to Bjorken y in nue CC events

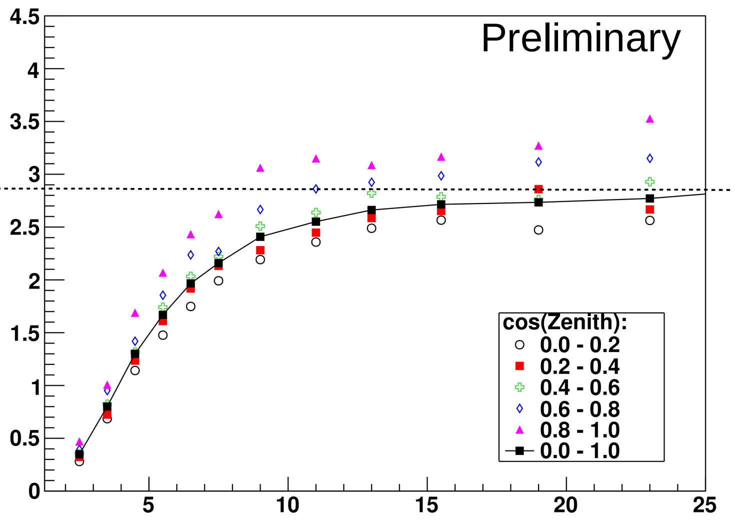
# Comparison 6m vs. 12m spacing

- What happens for a less dense detector?
  - masking every second OM on each string in proposed detector
  - → same inst. volume, but 9 instead of 18 OM/string

**6m spacing**

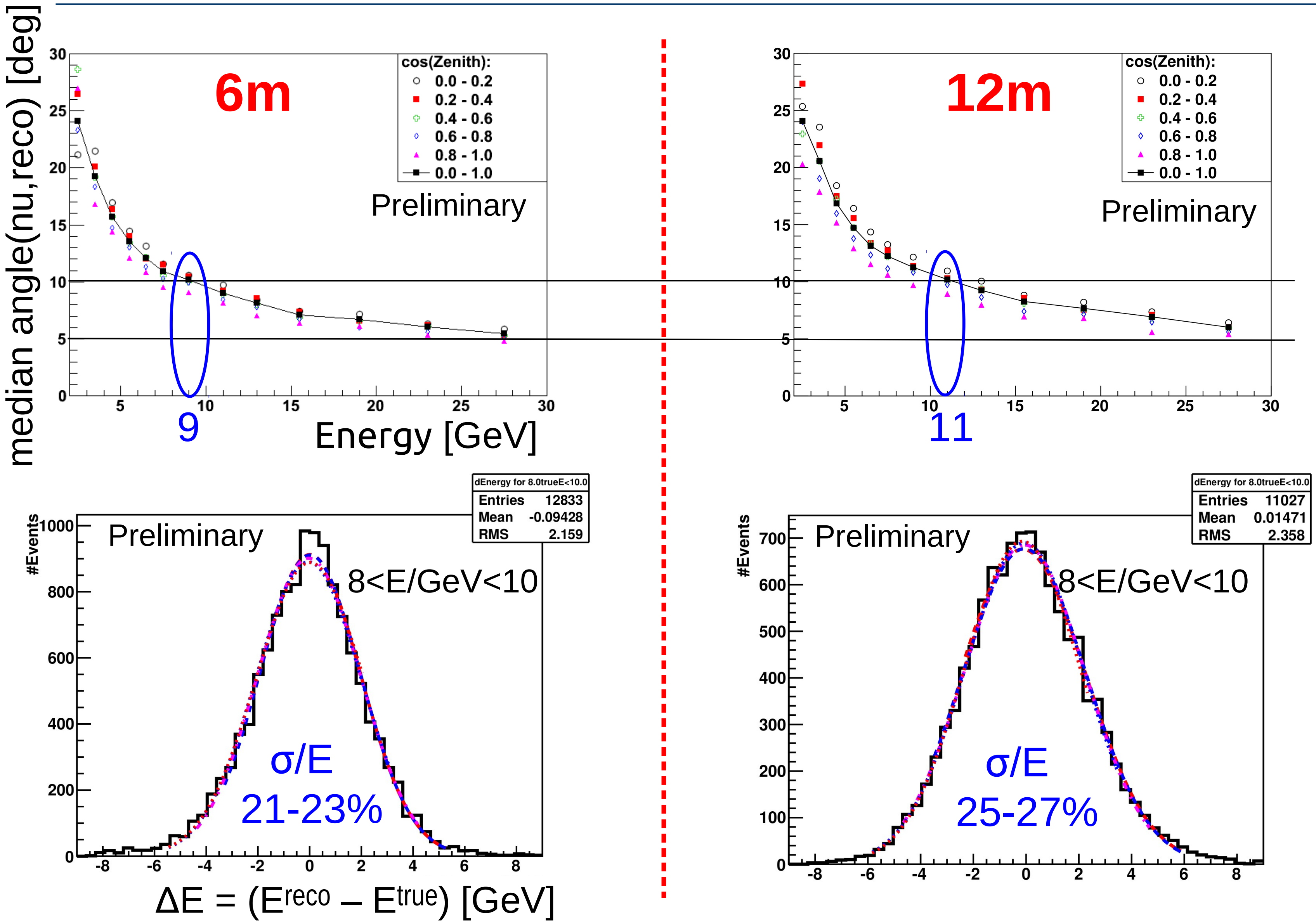



**12m spacing**




- Effective volume: similar plateau value, less steep turn-on

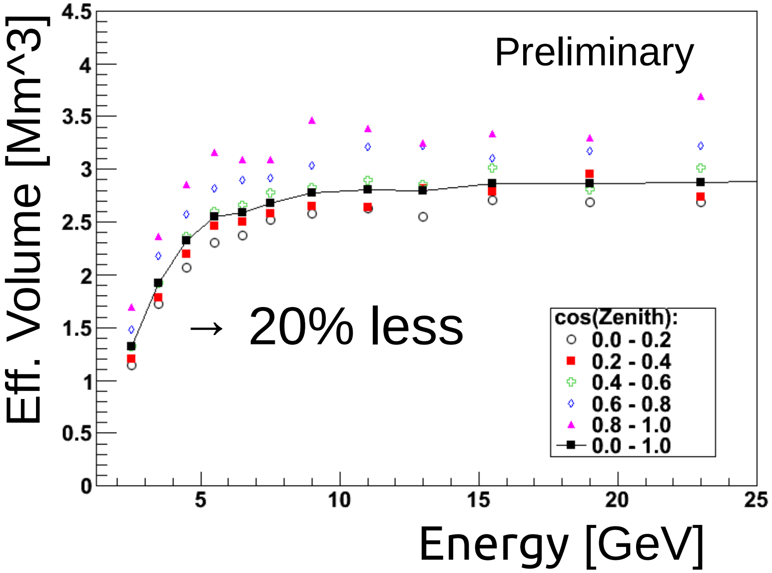
# Comparison 6m vs. 12m spacing



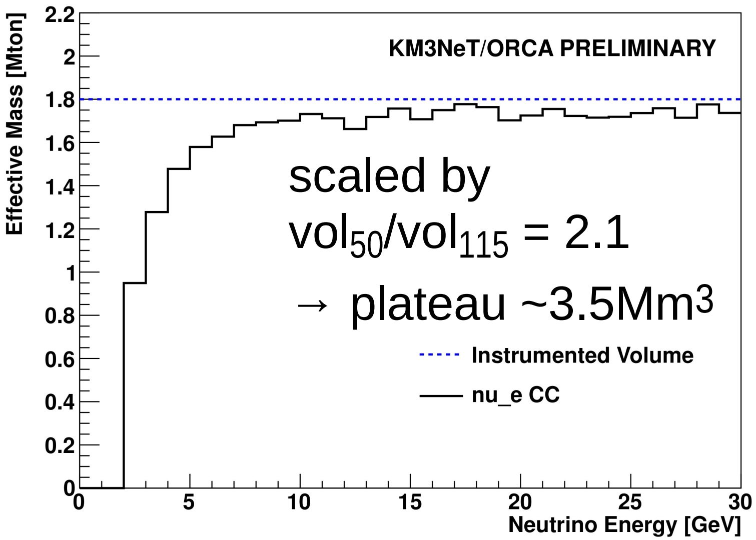
# Comparison with the Past (I)

- Official sensitivity study used:
  - reference detector
  - resolutions from 'premium events' (→ optimistic assumptions)
  - effective volume of 50 string detector scaled to 115 string detector

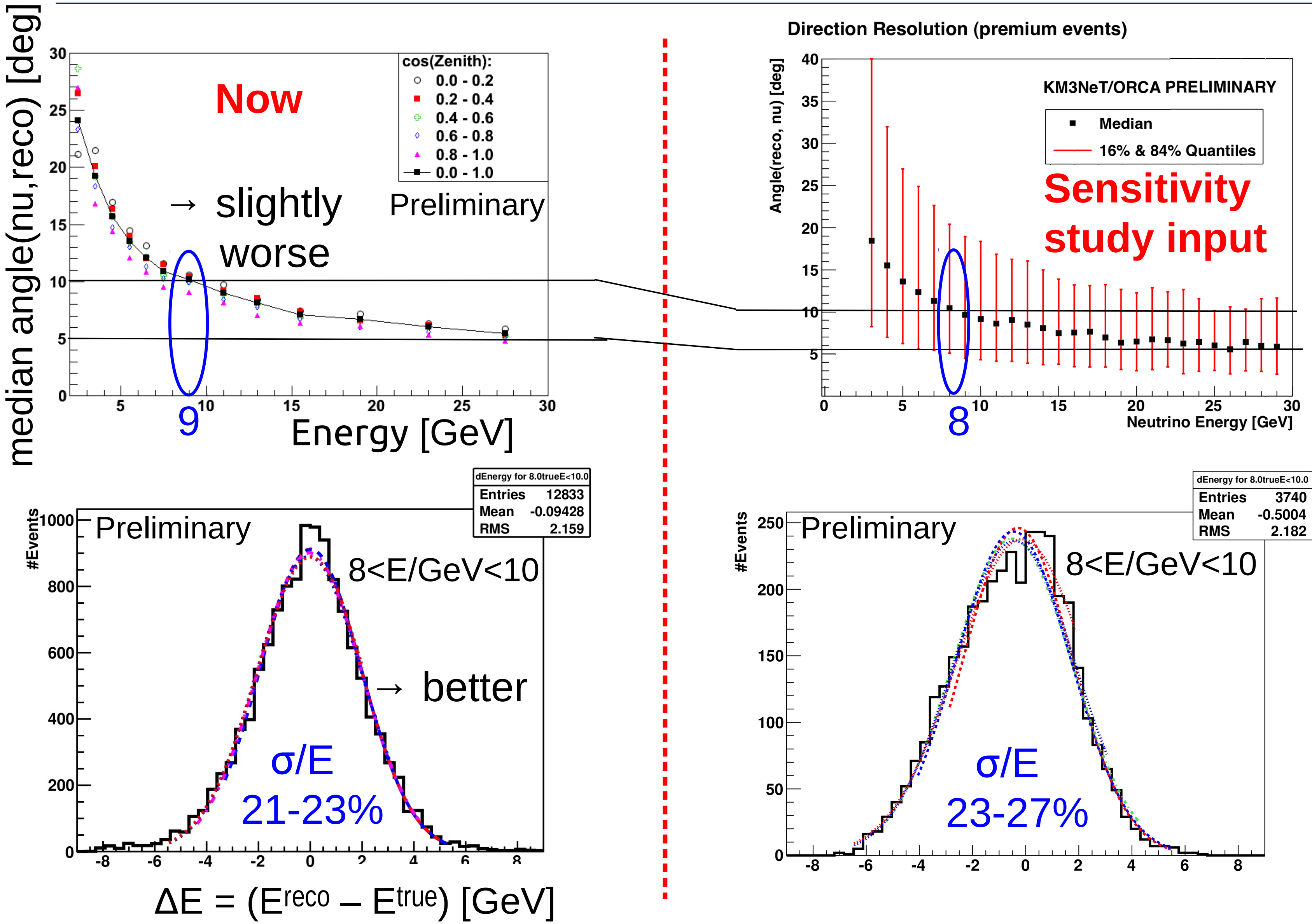
**Now**




**Sensitivity study input**



# Comparison with the Past (II)

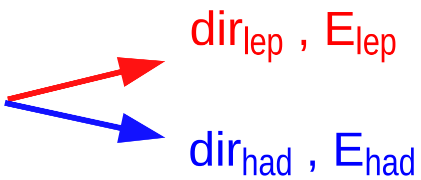


# Summary

- Track reconstruction & FlavorID same performance as MANTS'13
- Focused on shower reconstruction in proposed detector:
  - effective volume: plateau of 2.8Mm$^3$ reached at ~6GeV
  - energy resolution: Gaussian with $\sigma/E$=21-23% @ 9GeV
  - angular resolution: median <10° for E>9GeV

    → resolutions better than PINGU LoI
  - ORCA can see the electron in nue CC event

    → Bjorken y sensitivity
- Detector optimisation study is ongoing
- Outlook:
  - 2 particle fit: electron / muon + had. shower

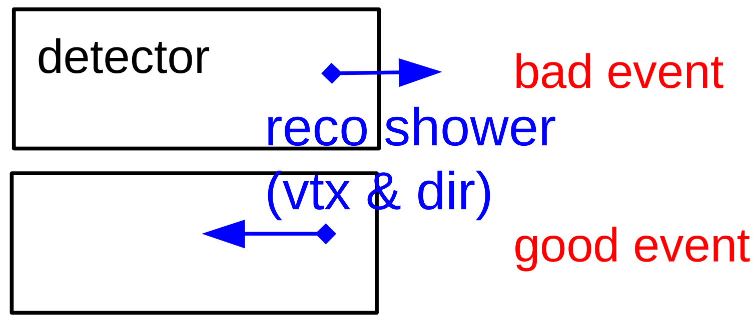


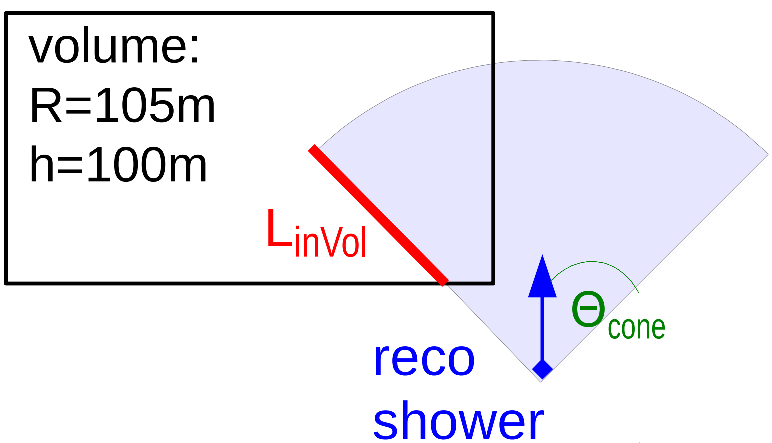
# BACKUP

# Coverage Cut

- Idea: require certain minimum of expected light inside inst. volume
- better than simple vertex cut, because allowed region of reconstructed vertices depends on reconstructed direction

  example: same reco vertex,
  but different reco direction

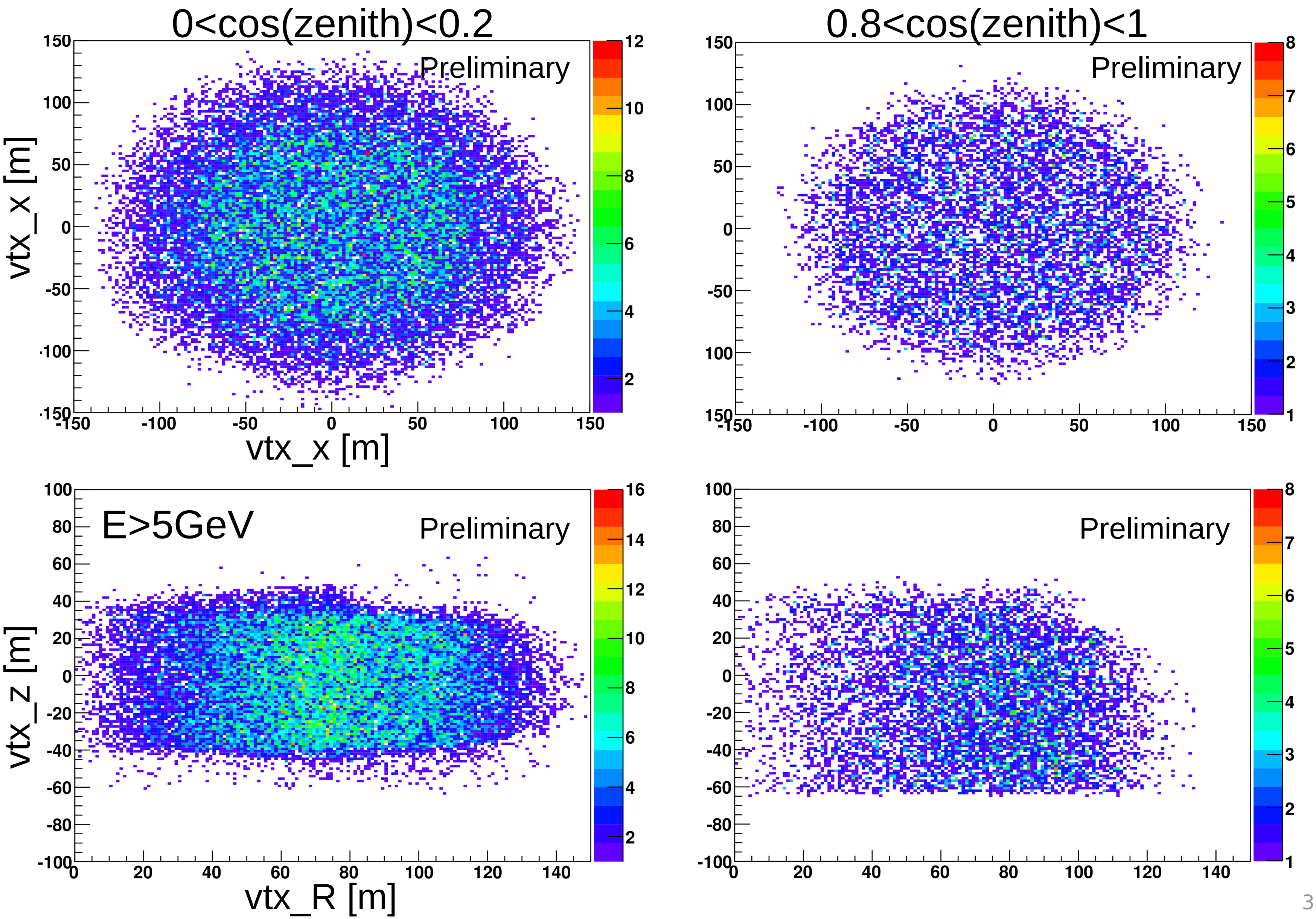


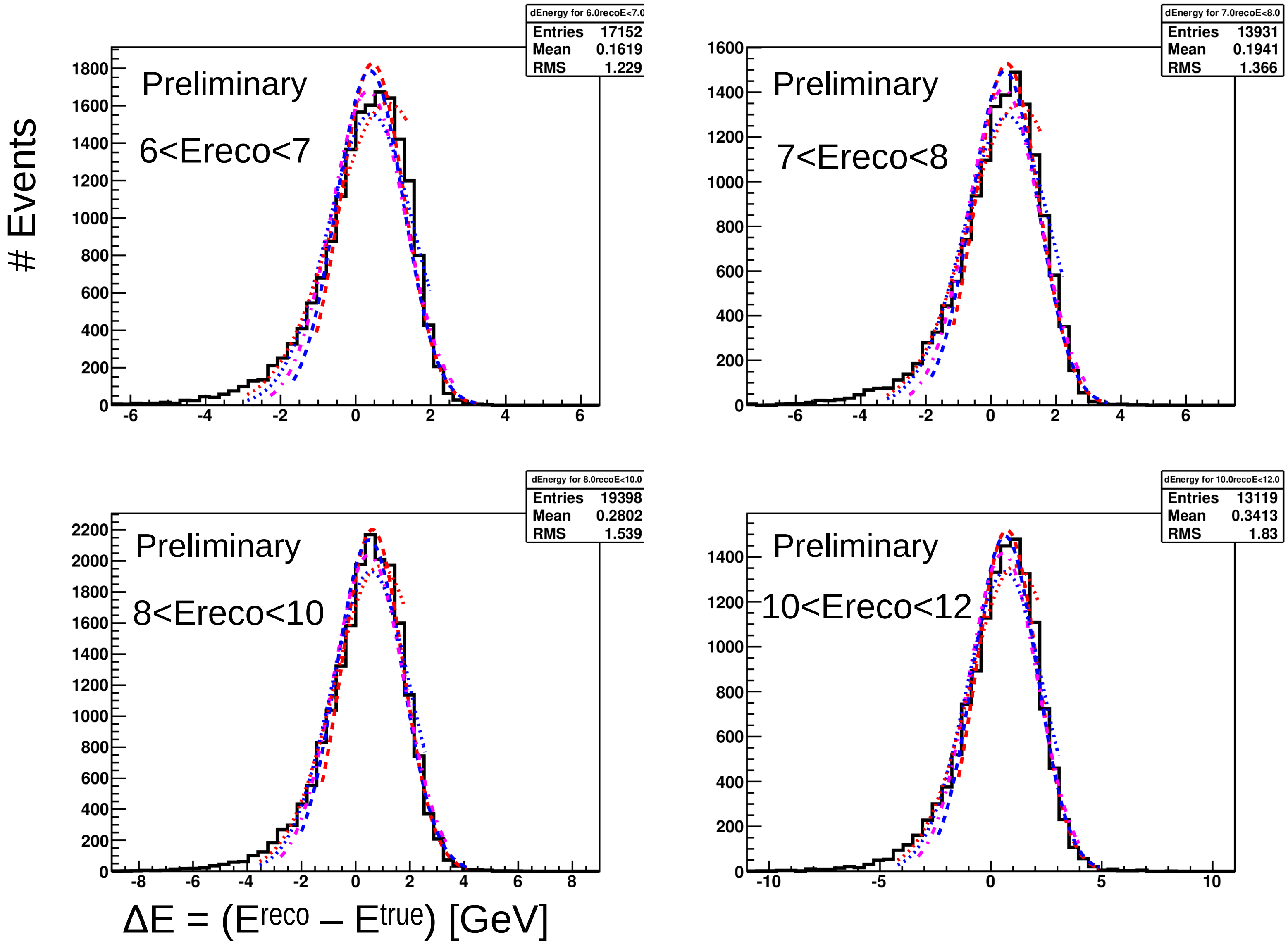

- calculate fraction of directions on cone around reconstructed shower with certain 'containment' in inst. volume
- 'containment' condition:
  - $L_{inVol}$ > 20m within [10m, 70m]
  - attenuation → <70m, 'not too close' → >10m
- Require:

  Θ=45deg → f>0.75
  Θ=60deg → f>0.6
  Θ=75deg → f>0.5

# Selected Reco Vertex Positions

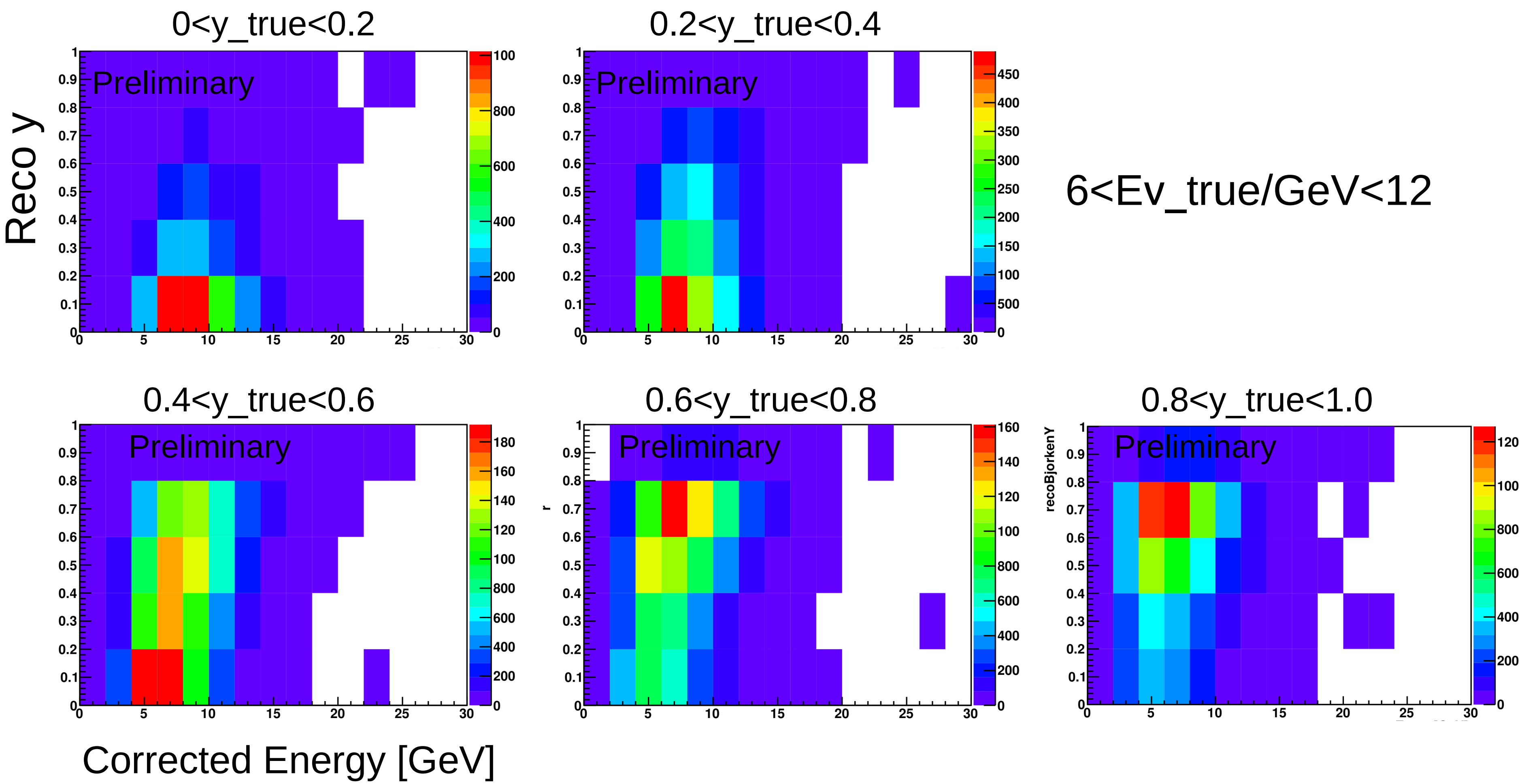


# Energy Resolution in Ereco Bins



# Correlation: y – reco Ecorr

- Correlation: reco y ↔ recoEcorr

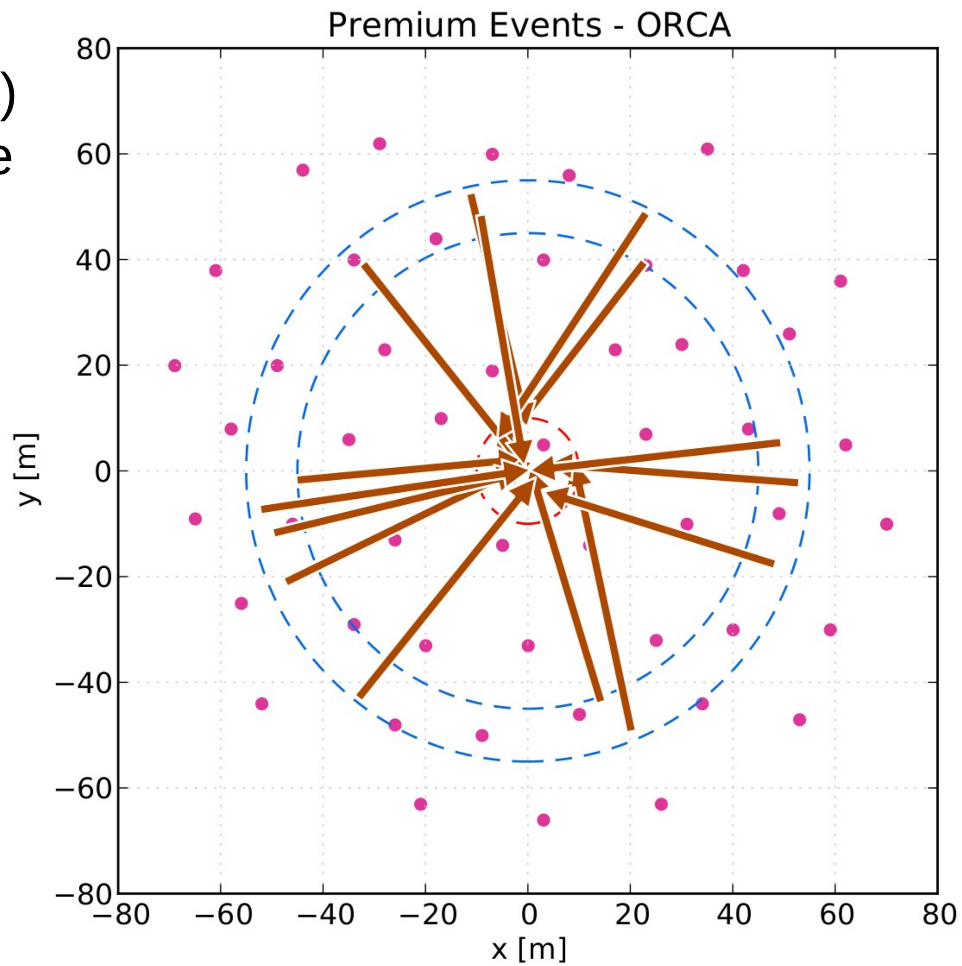


# Premium Events

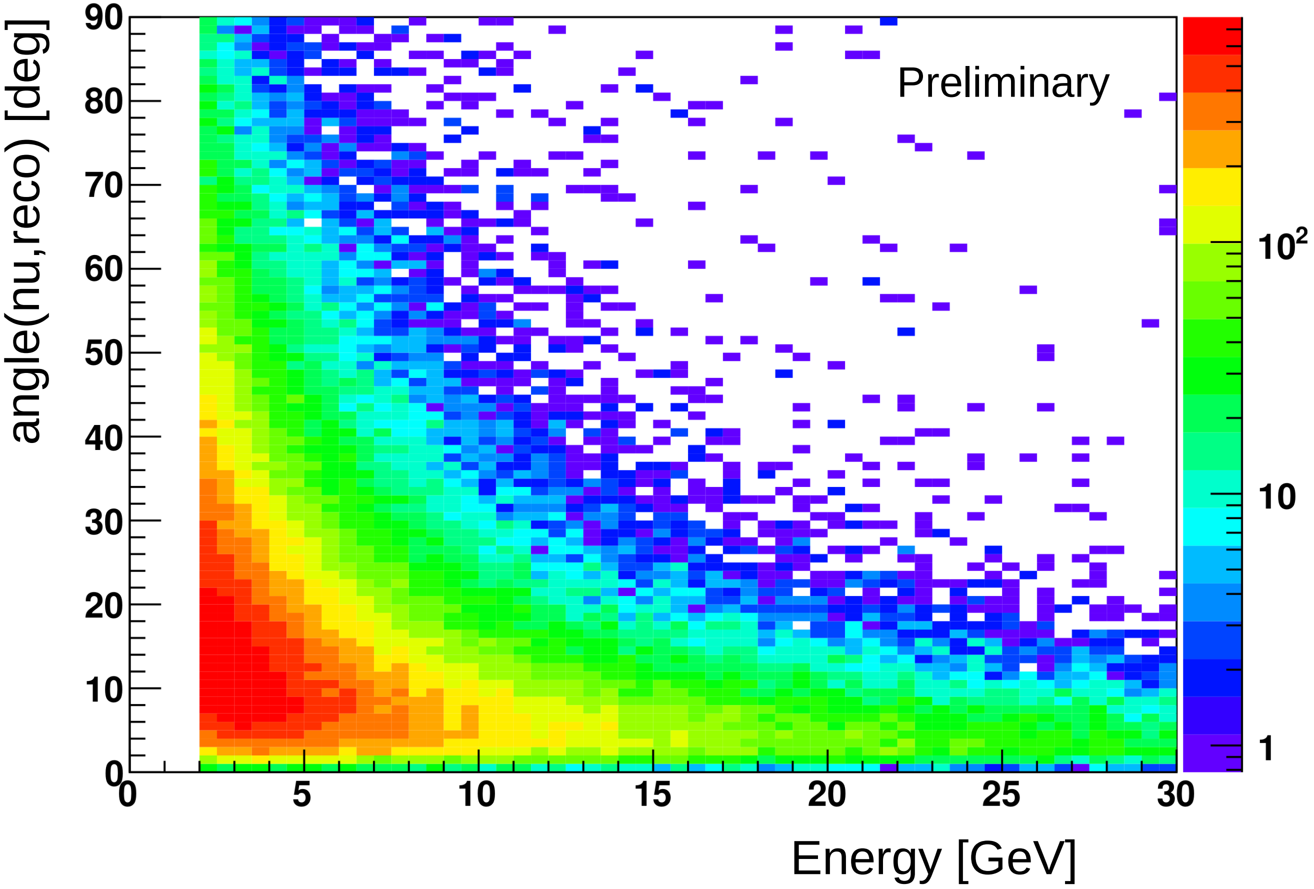
- Idea:

  produce events where (nearly) all produced light is detectable → inside inst. volume

- Reference ORCA detector

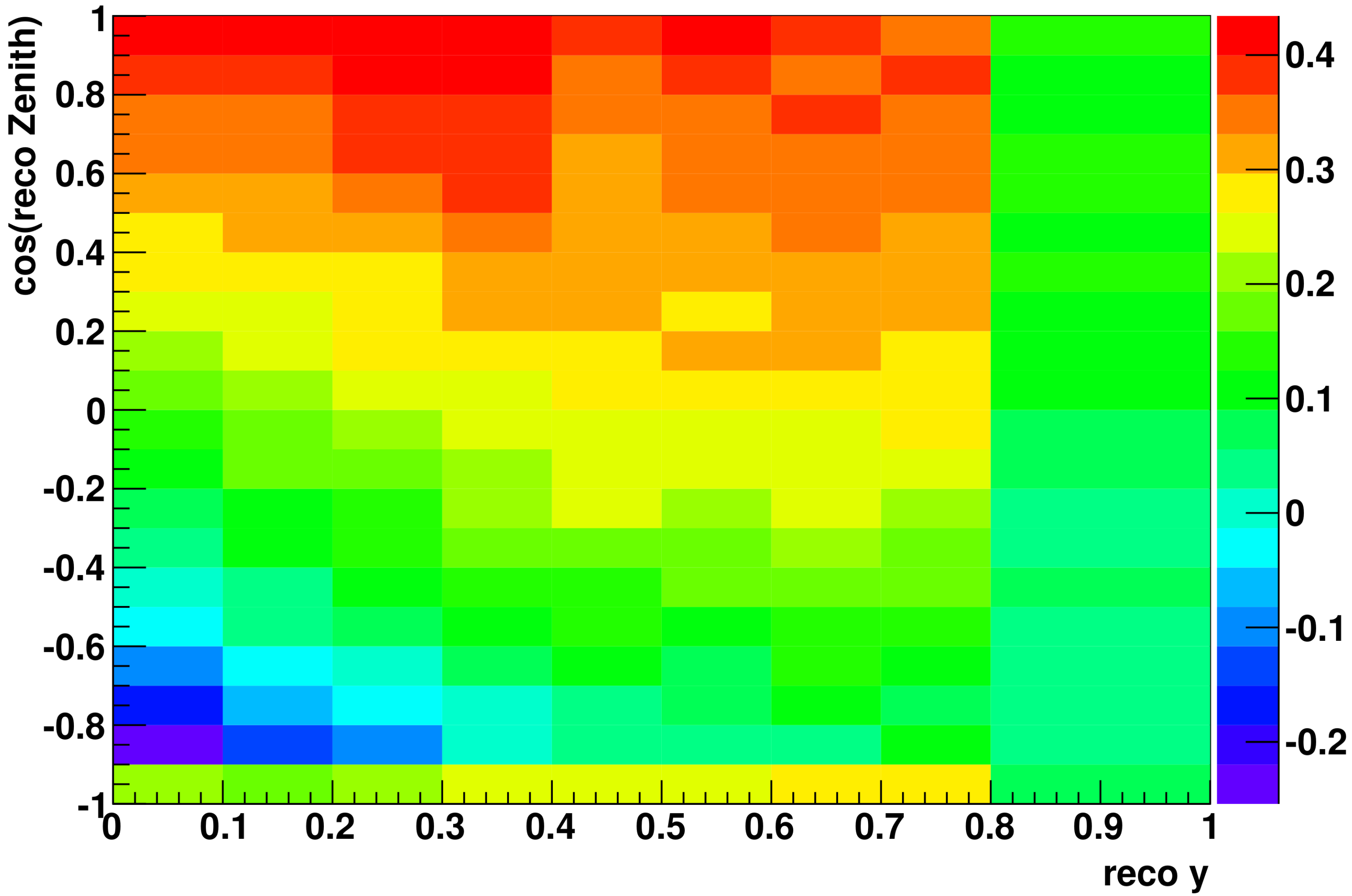


# Direction Resolution



# Shower Energy Correction Map

$$\left(E_{reco} - E_{true}\right) / E_{reco}$$



# Muon Neutrino Energy Resolution