# Liquid Scintillator Simulations

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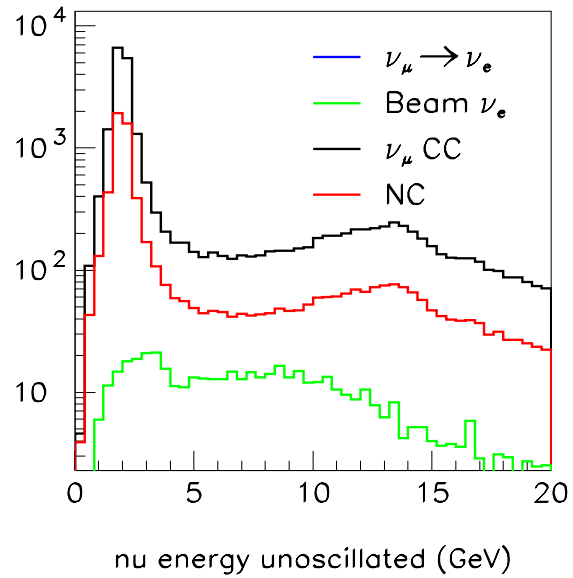
- What has been done
- Where we are on the detector technology comparison
- Job list for the proposal

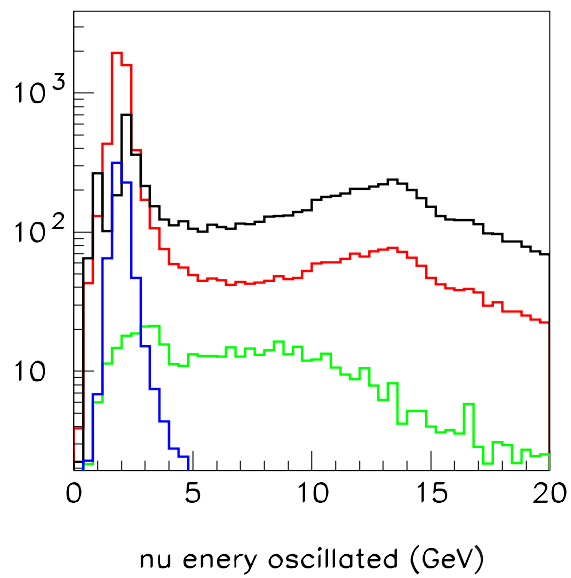
# What has been done

- At the last collaboration meeting results were presented which were heavily biased by the repeated event bug in the generator.
- The analyses were redone and results presented in Off-axis note SIM-24
- Analyses have been done for the proposed Ash River site at 820km and 12km off axis.
- The simulations and analysis methods are as described at the last collaboration meeting and in SIM-24
- Events are found and reconstructed, the track with most hits found using the Hough transform.
- A series of cuts to produce an enhanced sample of $\nu_e$ CC events are made and then a final separation using a likelihood function.

# Events

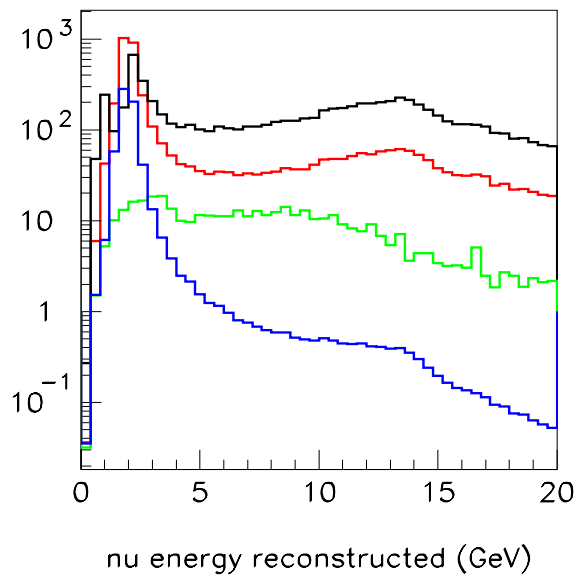
Unoscillated beam events as a function of truth neutrino energy

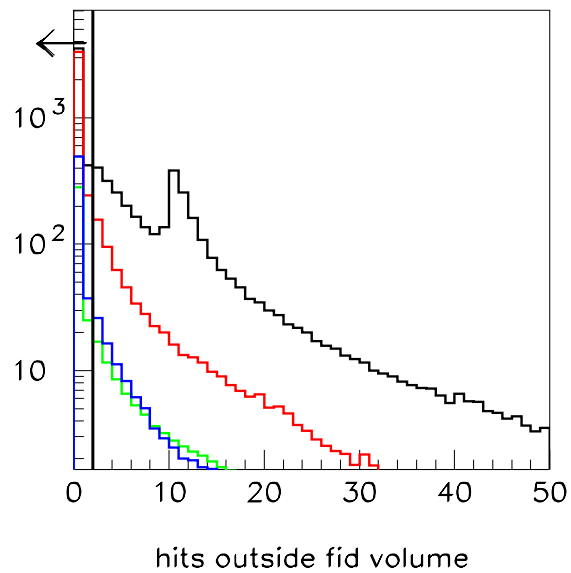



Truth neutrino energy after oscillations

Truth neutrino energy distribution after reconstruction



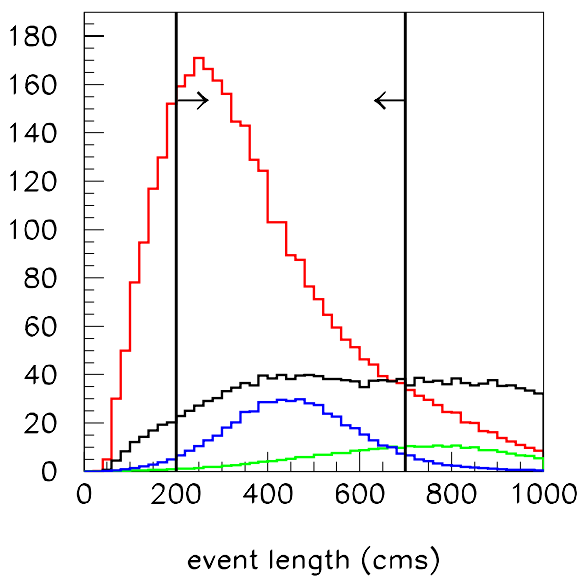



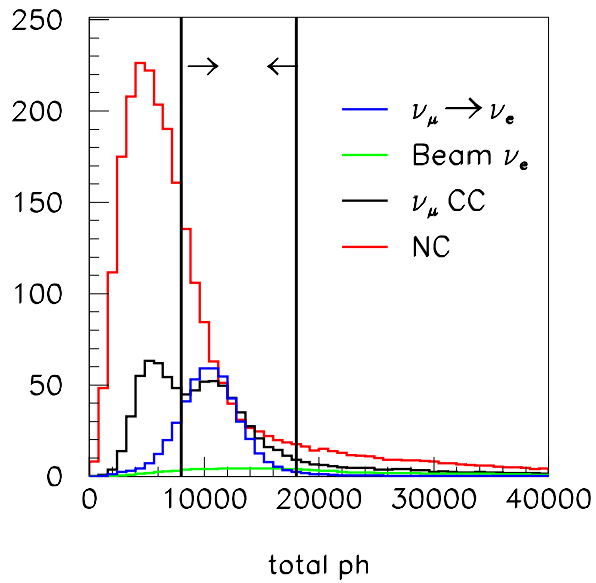

Number of hits outside fiducial volume (50cm lateral, 200cm longitudinal). Events with more than 2 hits outside are rejected. 84% efficiency

# Cuts

Event length

Rejects $\nu_\mu$ CC events



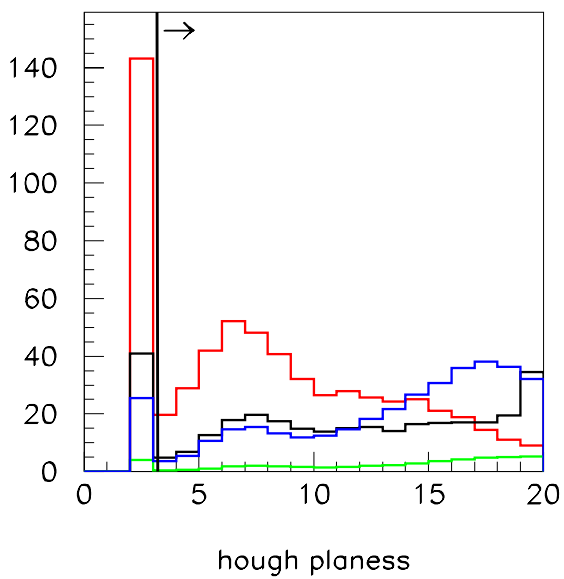



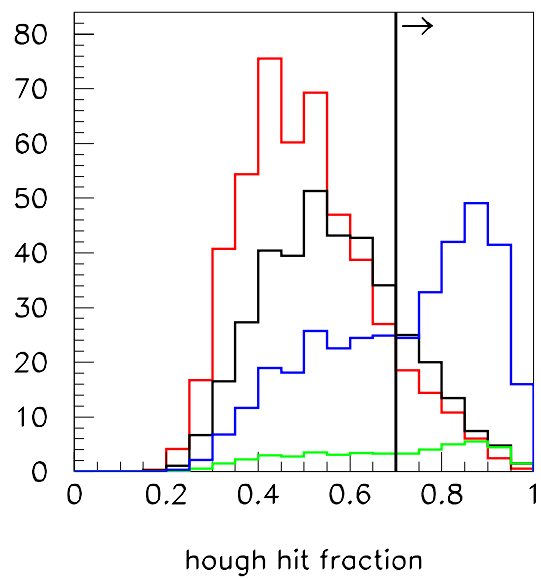

Total pulse height

Rejects high energy $\nu_e$ CC events and low visible energy events

Number of planes in the Hough track.

Requires a good track

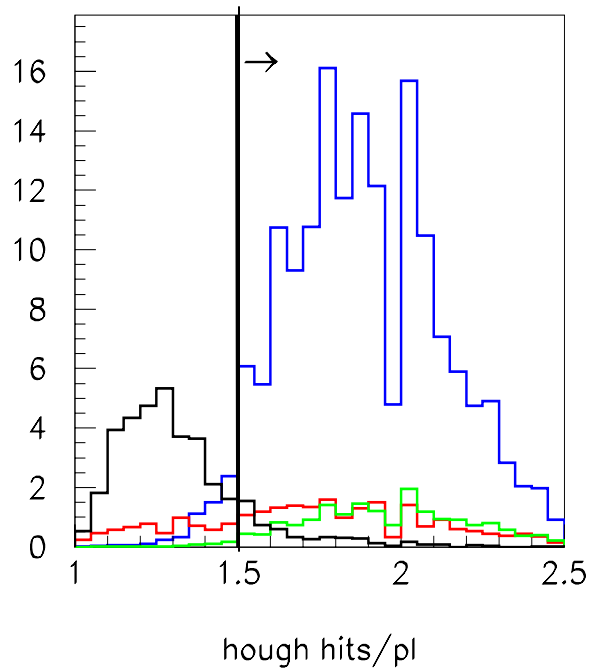


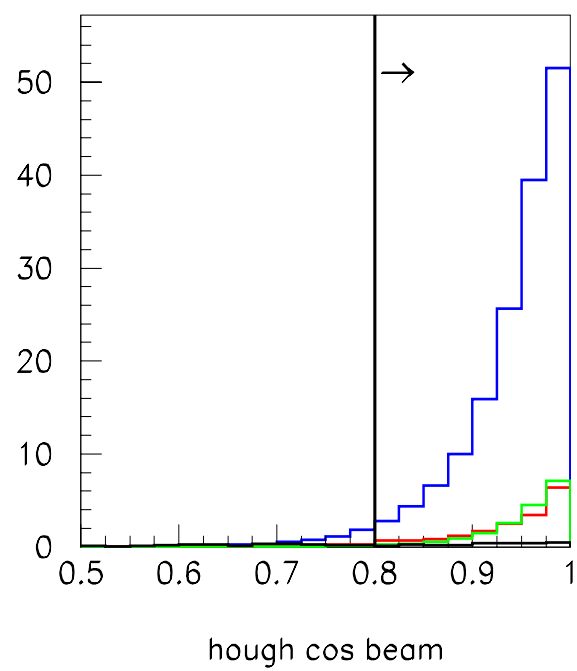




Fraction of hits in the Hough track

Selects low-y or quasi-elastic events

# Cuts

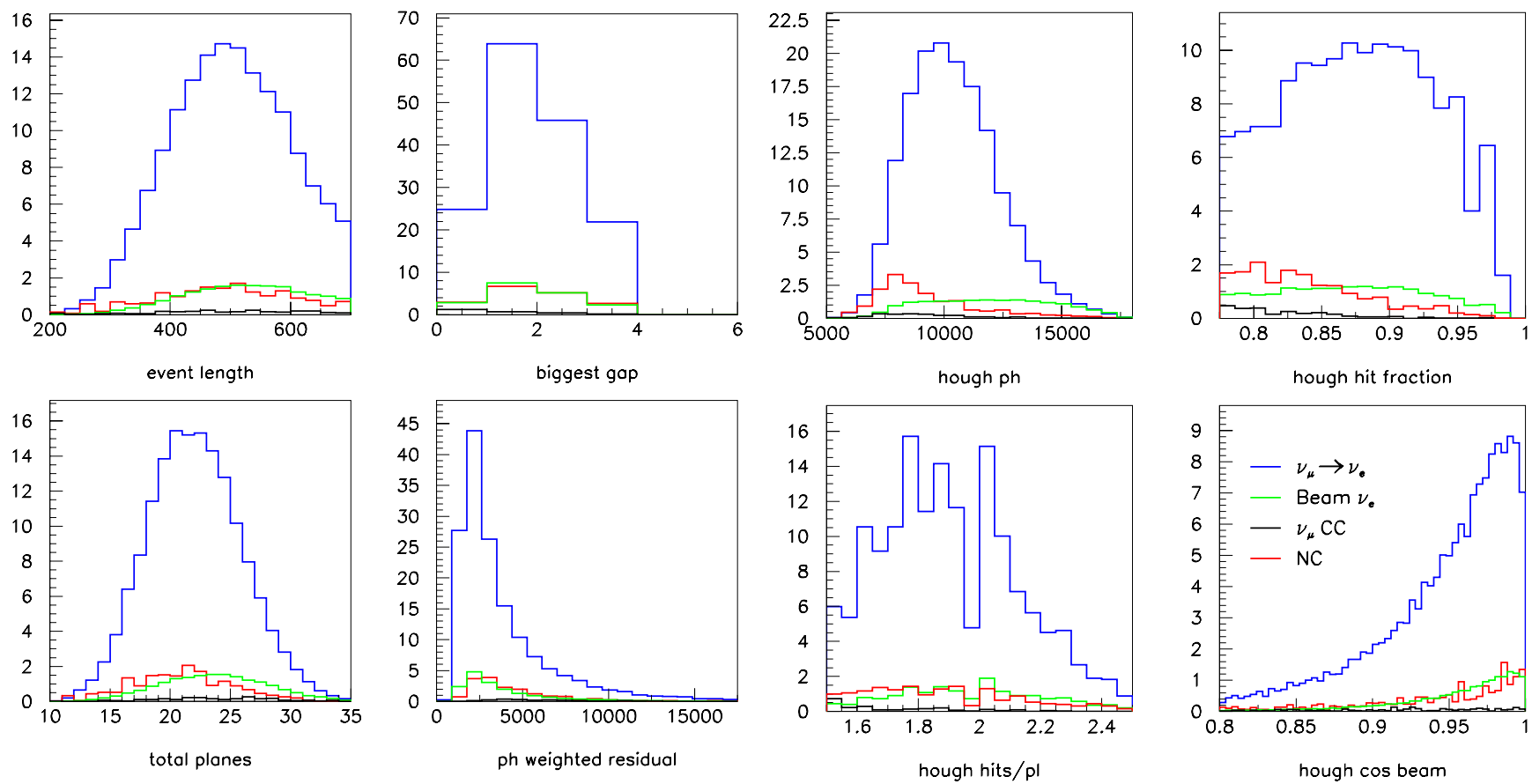


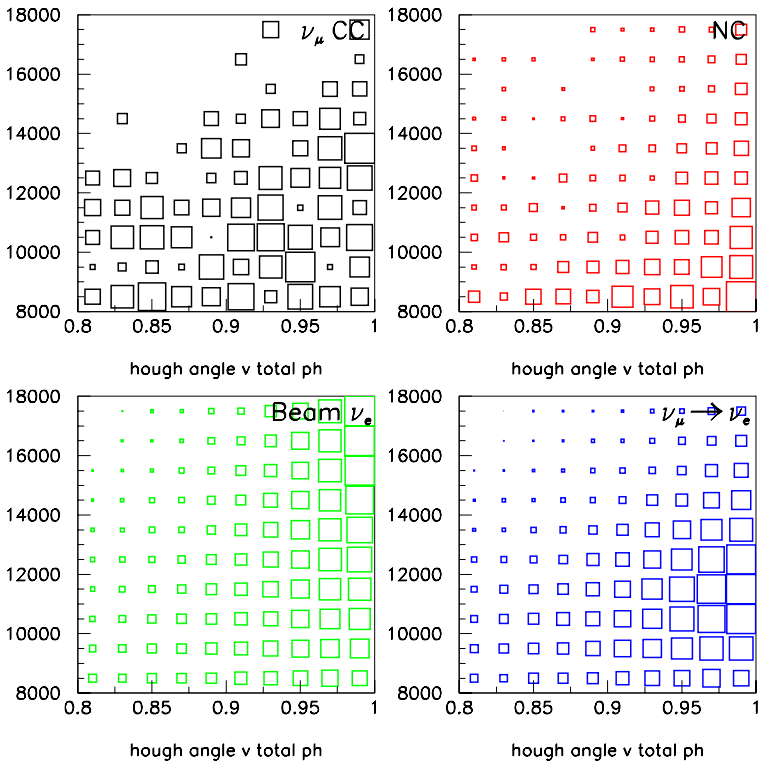

Hits/plane on the Hough track
Selects “fuzzy” electron tracks

Angle of Hough track to beam
Rejects a few mis-reconstructed events

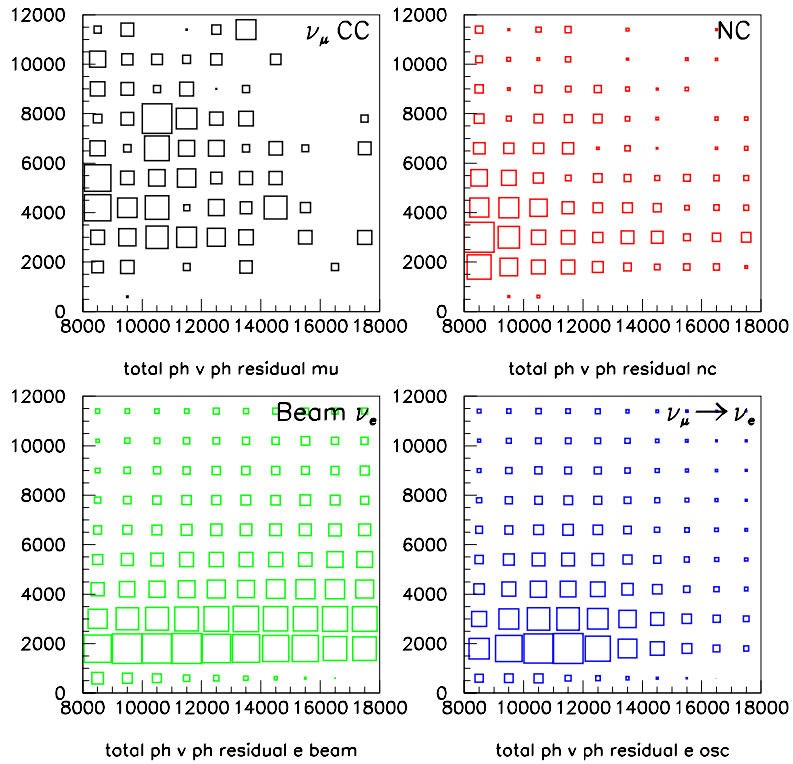
# Likelihood PDFs (sample)



# Likelihood pdfs (sample)



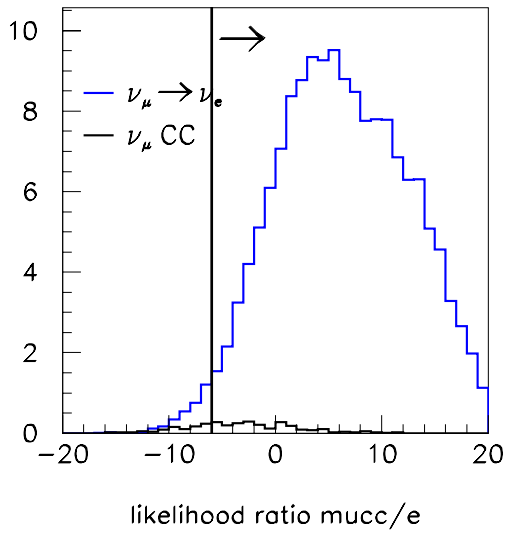

Angle of Hough track to beam versus total pulse height

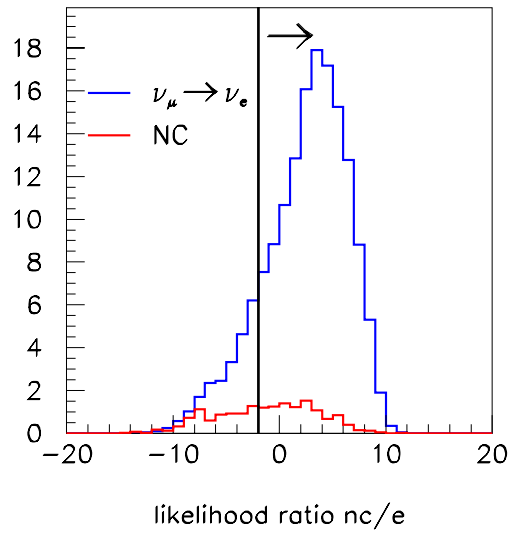



Total pulse height v pulse height weighted residual to fitted line

# Likelihood Ratios

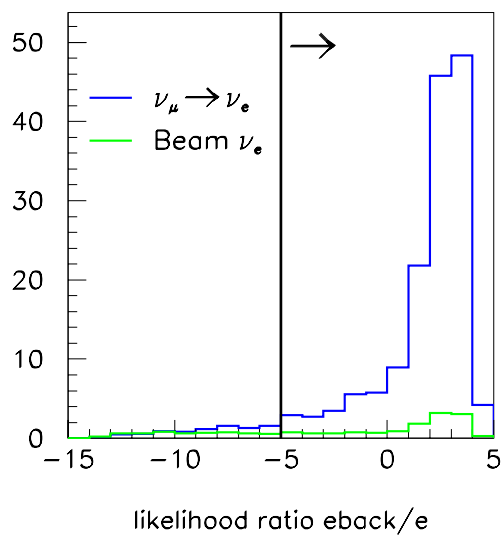
$\nu_e$ oscillated versus $\nu_\mu$ CC




$\nu_e$ oscillated versus NC

$\nu_e$ oscillated versus $\nu_e$ beam



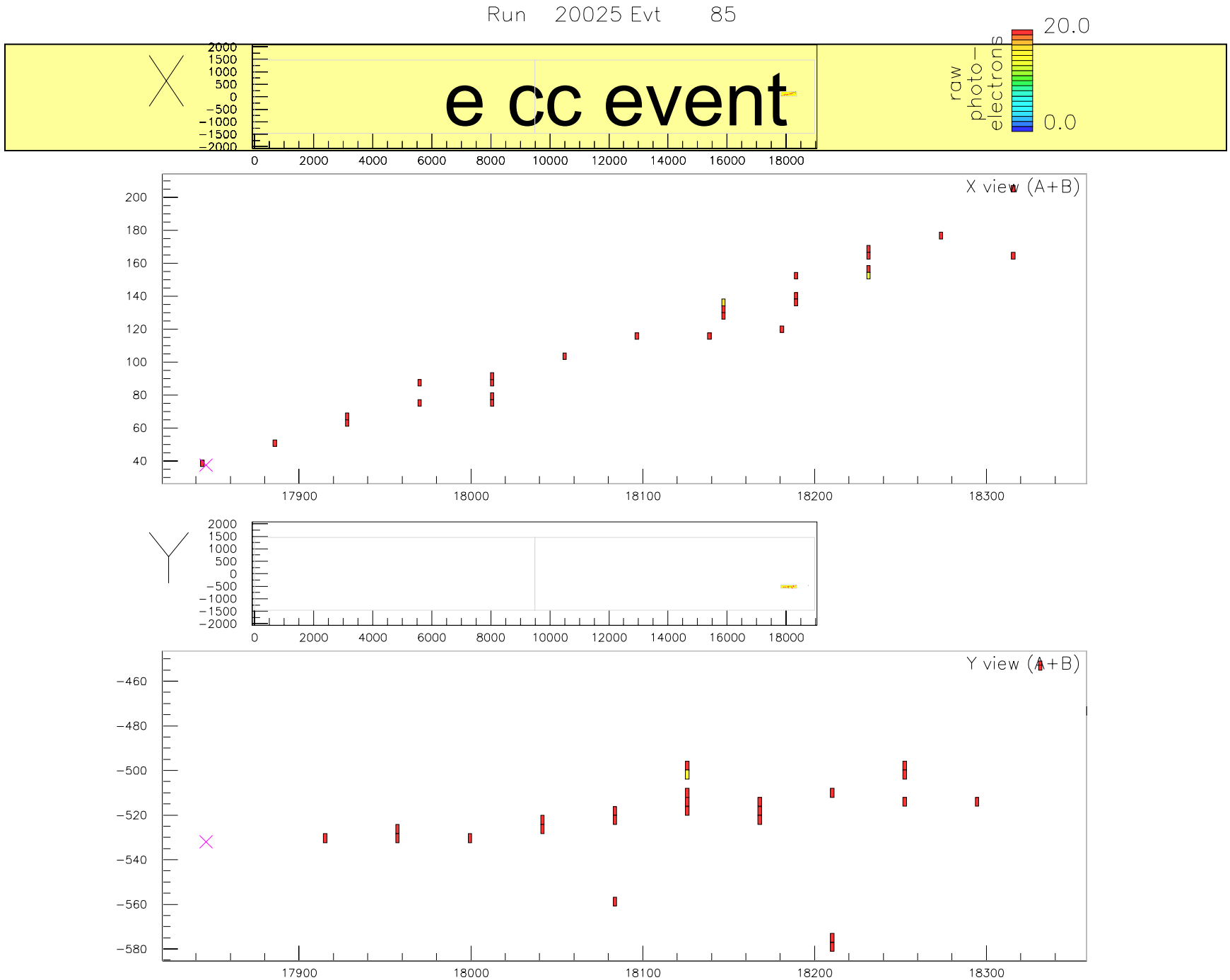

Select as $\nu_e$ events those to the right of the cut line in all three plots

# Numbers

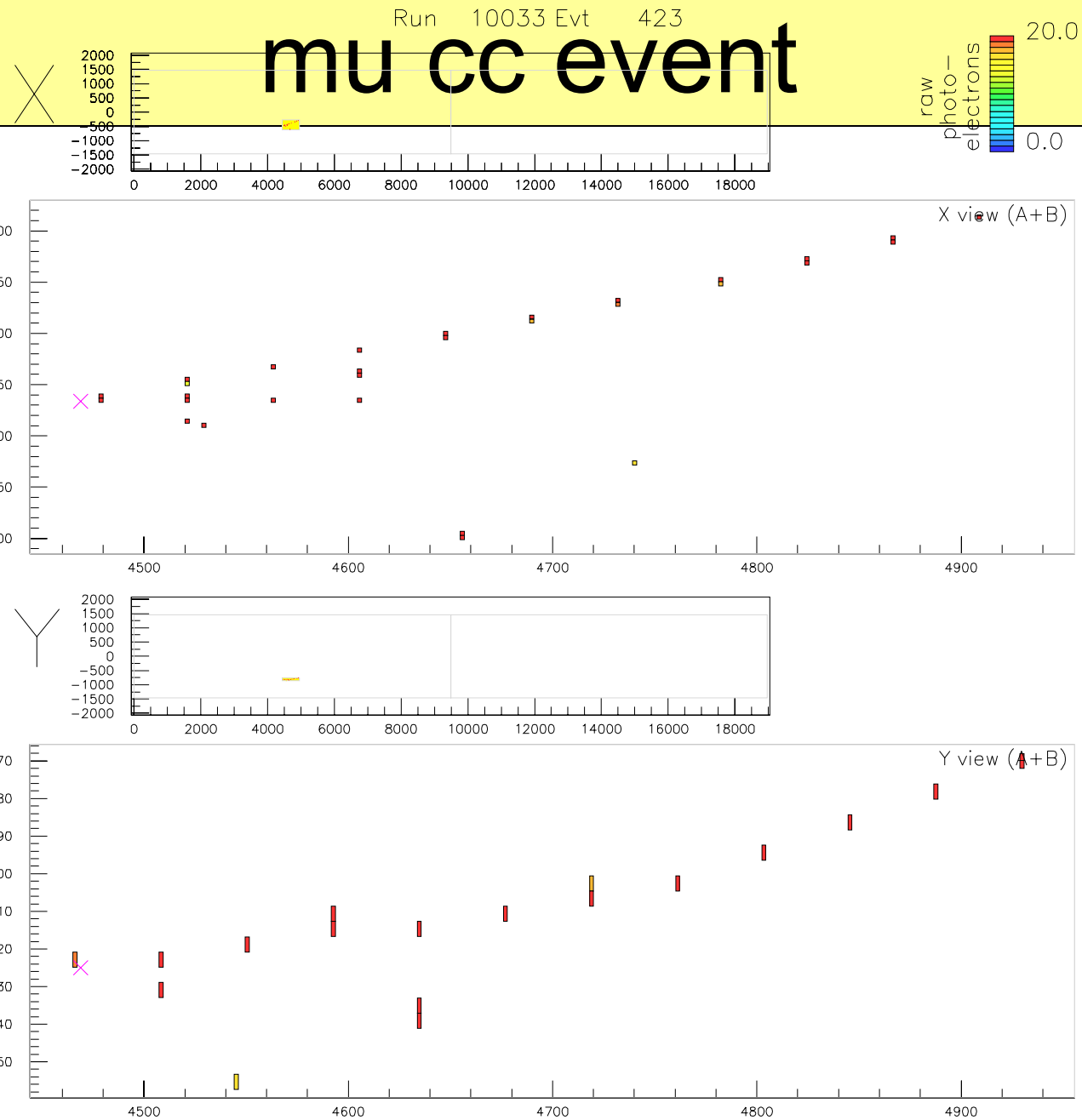
| Cut | $\nu_\mu$ CC | NC | beam $\nu_e$ | $\nu_\mu \rightarrow \nu_e$ signal |
|---|---|---|---|---|
| generated events | 474517 | 461891 | 488439 | |
| beam weighted | 18606 | 5692 | 394 | |
| beam weighted +osc | 6434 | 5692 | 394 | 603 |
| events with good clusters | 6105 | 3530 | 344 | 538 |
| fiducial volume | 3937 | 3216 | 288 | 486 |
| event length | 776 | 2155 | 121 | 417 |
| total ph | 364 | 549 | 46.0 | 334 |
| planes in Hough track | 330 | 425 | 42.2 | 312 |
| Hough fraction | 31.6 | 20.0 | 16.0 | 141 |
| Hough hits/plane | 5.2 | 15.6 | 15.6 | 136 |
| Beam angle | 2.6 | 14.2 | 15.2 | 132 |

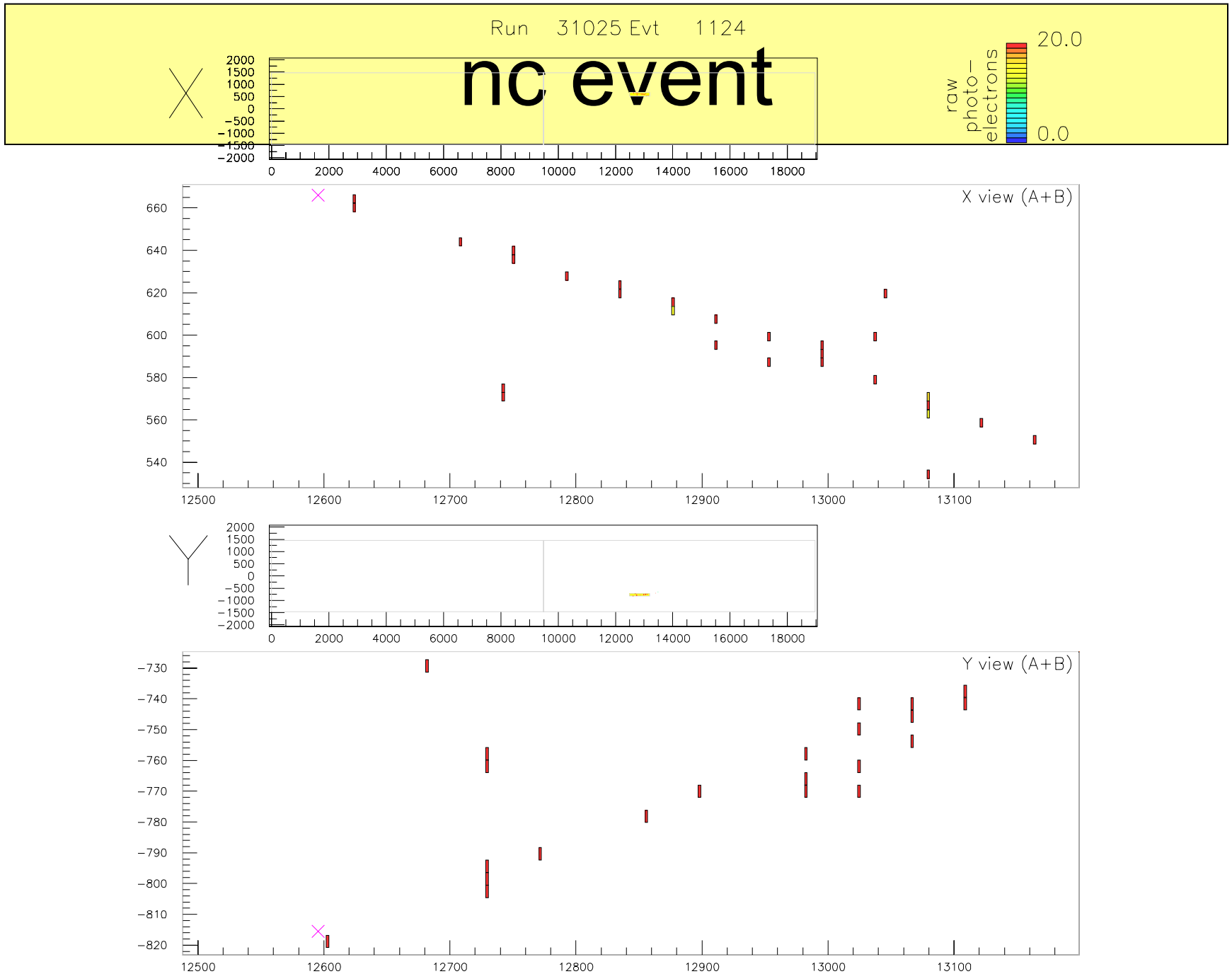
| | | | | |
|---|---|---|---|---|
| Final likelihood cut | 1.1 | 7.5 | 9.1 | 106 |
| Efficiency/rejection | $1.7 \times 10^{-4}$ | $1.3 \times 10^{-3}$ | $2.3 \times 10^{-2}$ | 0.18 |

Figure of Merit = Signal/Background = 25.3±0.4

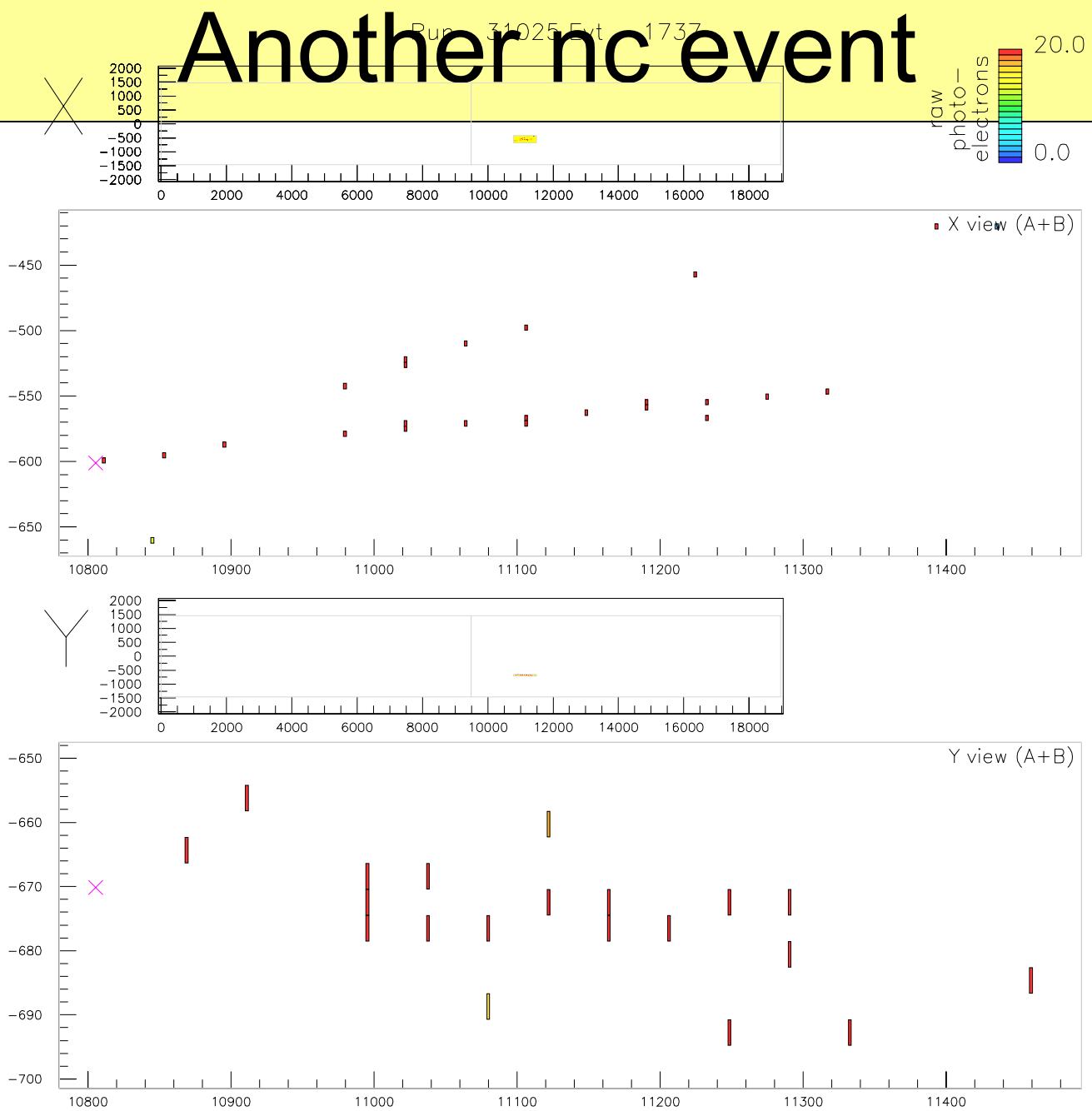

Run 20025 Evt 85
e cc event
raw photo-electrons
20.0
0.0
X view (A+B)
Y view (A+B)

# mu cc event


Run 10033 Evt 423
raw photo-electrons
20.0
0.0
X view (A+B)
Y view (A+B)

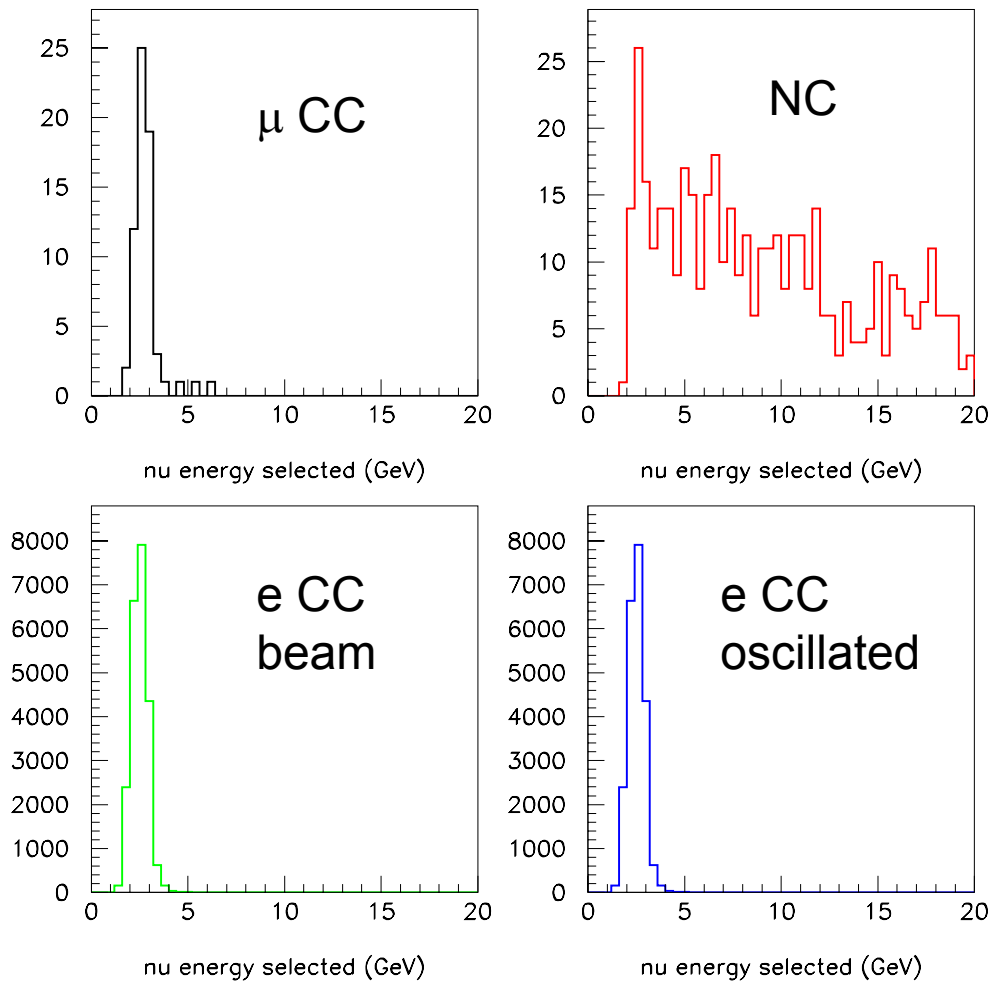

Run 31025 Evt 1124
nc event
raw photo-electrons
20.0
0.0
X view (A+B)
Y view (A+B)

# Another nc event



# ν Energy distributions

- ν truth energy distributions for selected events



# Off axis positions

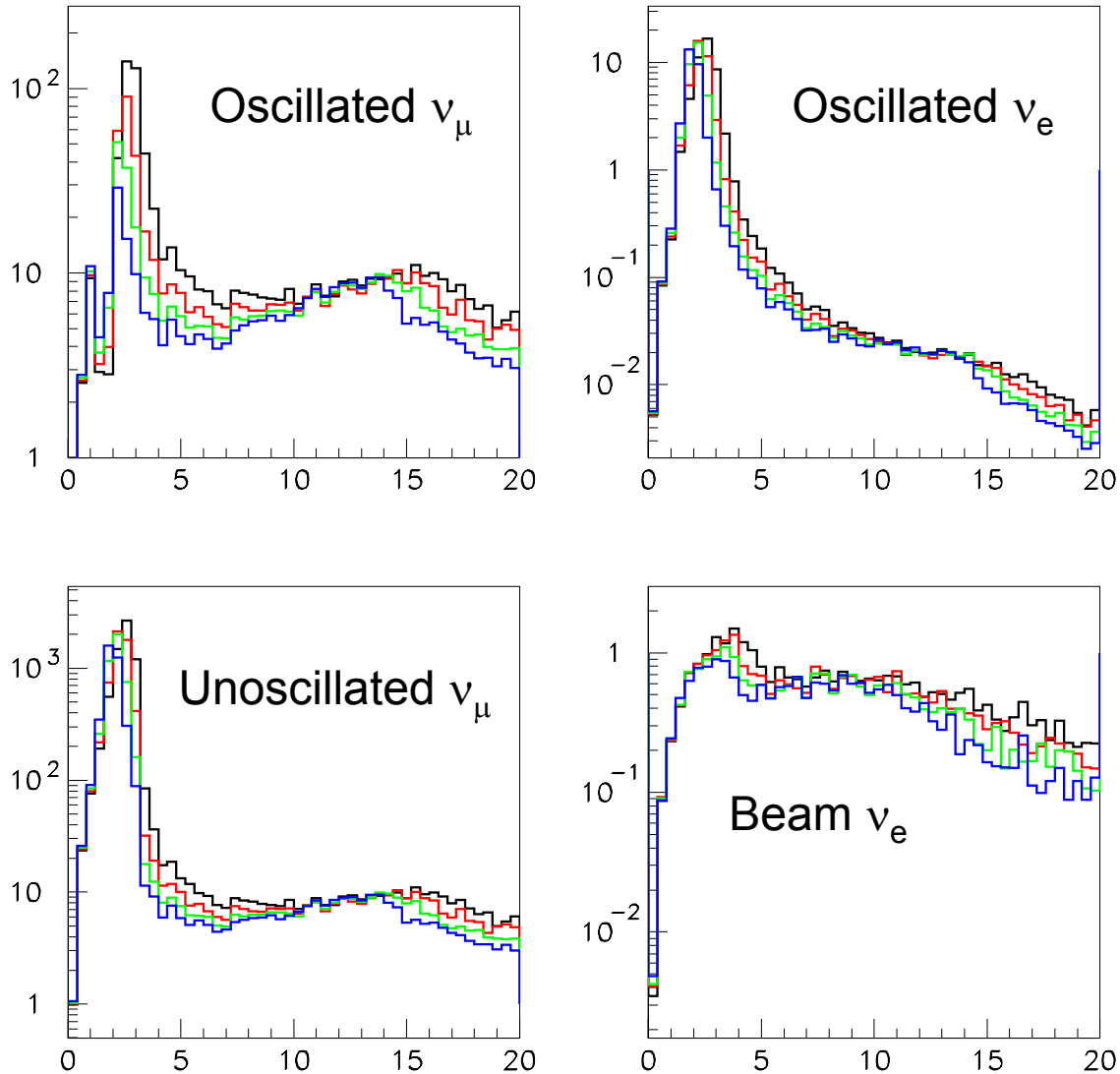
❖Beam spectra generated at 9,10,11,12km off-axis

9 km

10km

11km

12km



# Other Conditions

| Condition | Signal | Back-ground | FOM | FOM2 |
|---|---|---|---|---|
| 820km, 9km offaxis | 169 | 34 | 29.1 | 11.9 |
| 820km, 10km offaxis | 146 | 25 | 28.9 | 11.1 |
| 820km, 11km offaxis | 124 | 20 | 27.8 | 10.3 |
| 820km, 12km offaxis | 102 | 16 | 25.3 | 9.4 |
| 820,12, best for FOM2 | 145 | 34 | 24.6 | 10.8 |
| 820,12, $\sin^2 2\eta_{13}=0.05$ | 51 | 16 | 12.6 | 6.2 |
| 820,12, matter effects | 125 | 16 | 31.1 | 10.5 |

FOM = signal/↙background  FOM2=signal/↙(signal+background)

# Technology Comparisons

- It is hoped by some that we can use the simulations in the choice of technology by assigning a money value to the best FOMs of the different technologies.
- For this to be possible we have to be able to compare like with like. The RPC simulations available until now have been much less detailed than the scintillator.
- Ron Ray is producing better RPC simulations which he will describe next.
- In principle the liquid scintillator with no pulse height measurement and an RPC system with 1D readout in each plane are equivalent up to readout efficiencies and cross-talk effects.
- Liquid scintillator has a plus when a pulse height measurement is made giving information on the number of particles crossing the strip and the RPC has a plus in that it is possible to have 2D readout in a single plane. It is a detailed simulation question which offers more gain.

# Scintillator Job List

- Generate and analyze anti-neutrino events.
- Investigate the optimum conditions for incorporating matter effects and the extraction of the sign of $\Delta m^2$ and $\delta$.
- What size of signal; loose cuts with a lot of background or tight cuts and smaller numbers of events?
- Compare with the RPC analyses