

ELECTRON NEUTRINOS AS A PROBE OF CHARM PRODUCTION IN THE TARGET



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6th SHiP Collaboration Meeting
CERN
October 7 - October 9, 2015

MOTIVATION

- 1) Electron neutrino detection in the neutrino target can be used to probe charm production yield at the beam dump
- 2) Reconstruction of neutrino energy
- 3) Reconstruction of electron energy
 - performed using ECC brick as a calorimeter
 - standard shower algorithms used in OPERA cannot be applied straightforward in SHiP (1 event/brick VS >200 events/brick)
 - possible overlapping of showers

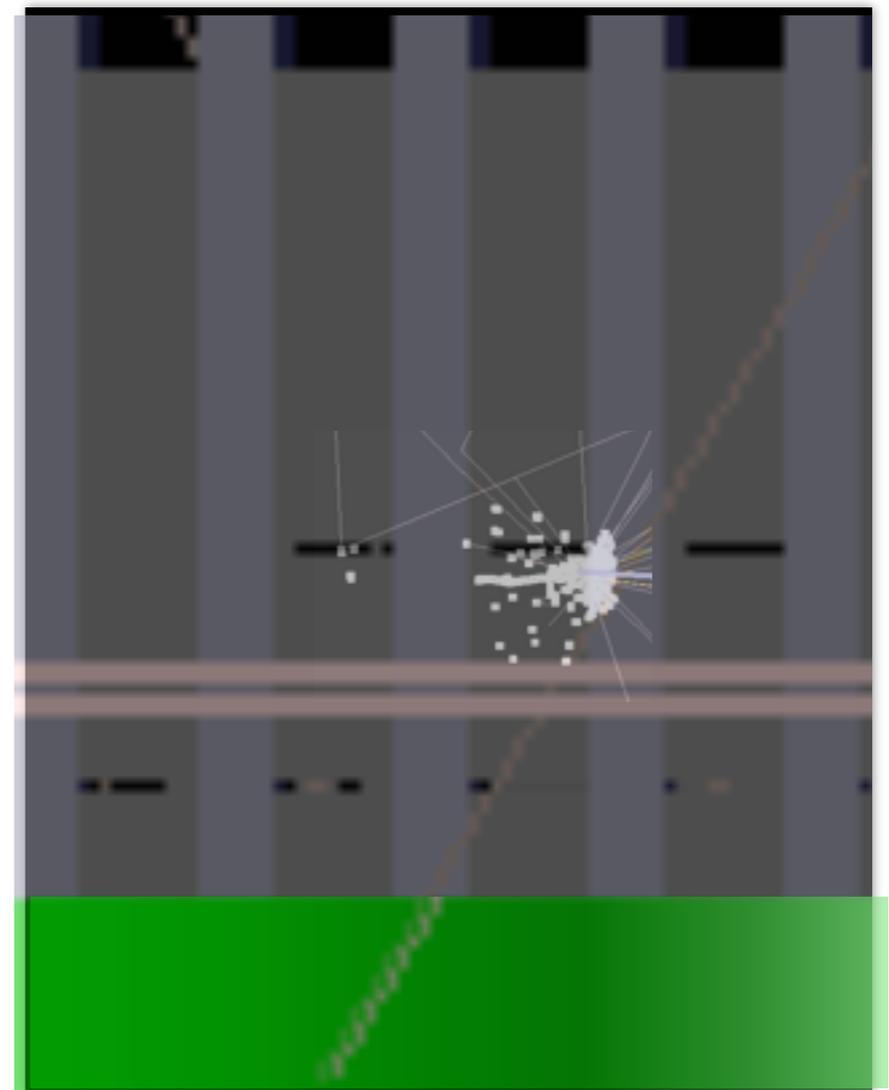
RECONSTRUCTION OF ELECTRON ENERGY

In SHiP, for each brick, we expect to have 232 neutrino interactions on average in 6 months of data taking.

- 144 ν_μ and 59 anti- ν_μ interactions
- 21 ν_e and 8 anti- ν_e interactions

Neutrino interactions with lead generated with NuAge - tuned version with NOMAD neutrino data* (A. Chukanov) - have been used to simulate neutrino interactions in the brick within the FairShip framework.

- 232 interactions (divided as mentioned above among the different flavours) have been simulated for 15 bricks



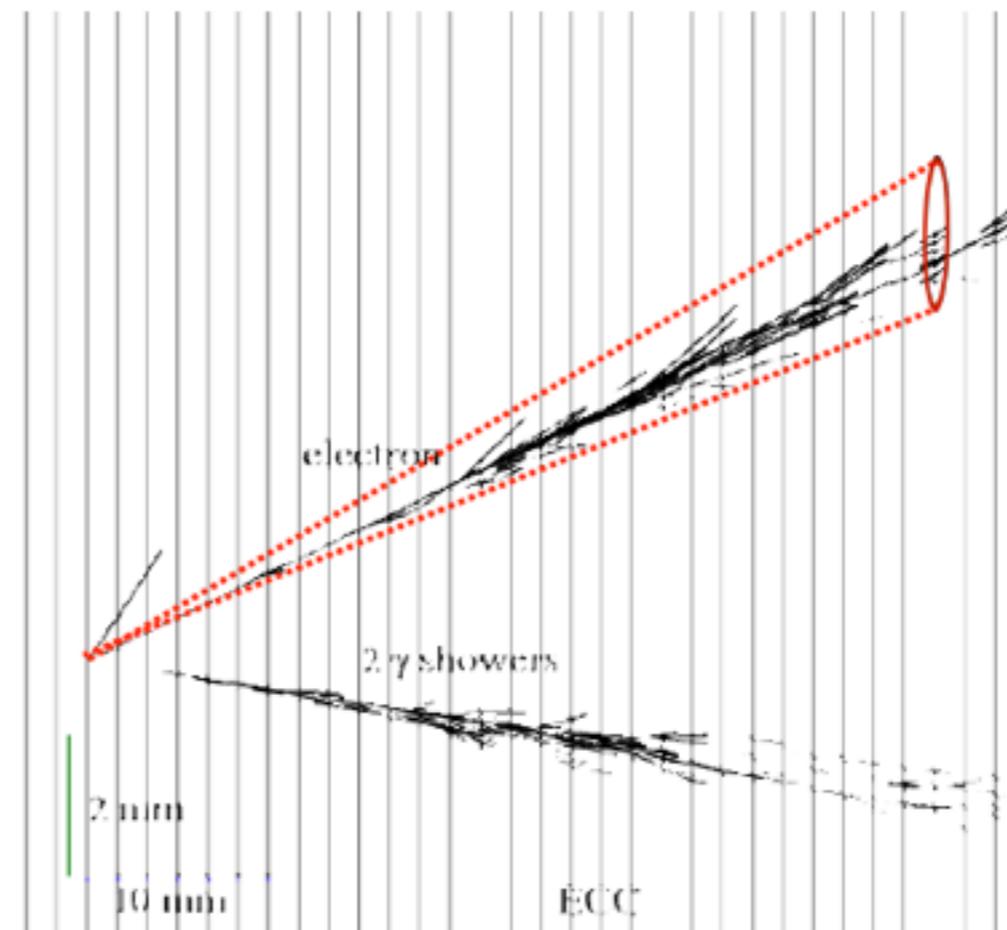
RECONSTRUCTION OF ELECTRON ENERGY

In a OPERA like brick: electron energy can be reconstructed starting from reconstruction of the associated electromagnetic shower.

It is measured taking into account the relationship between the number of tracks belonging to the electron shower and the electron energy.

Main idea

For each ν_e event open a cone around the primary electron track and count the number of BaseTracks (BT) selected in the cone



RECONSTRUCTION OF ELECTRON ENERGY

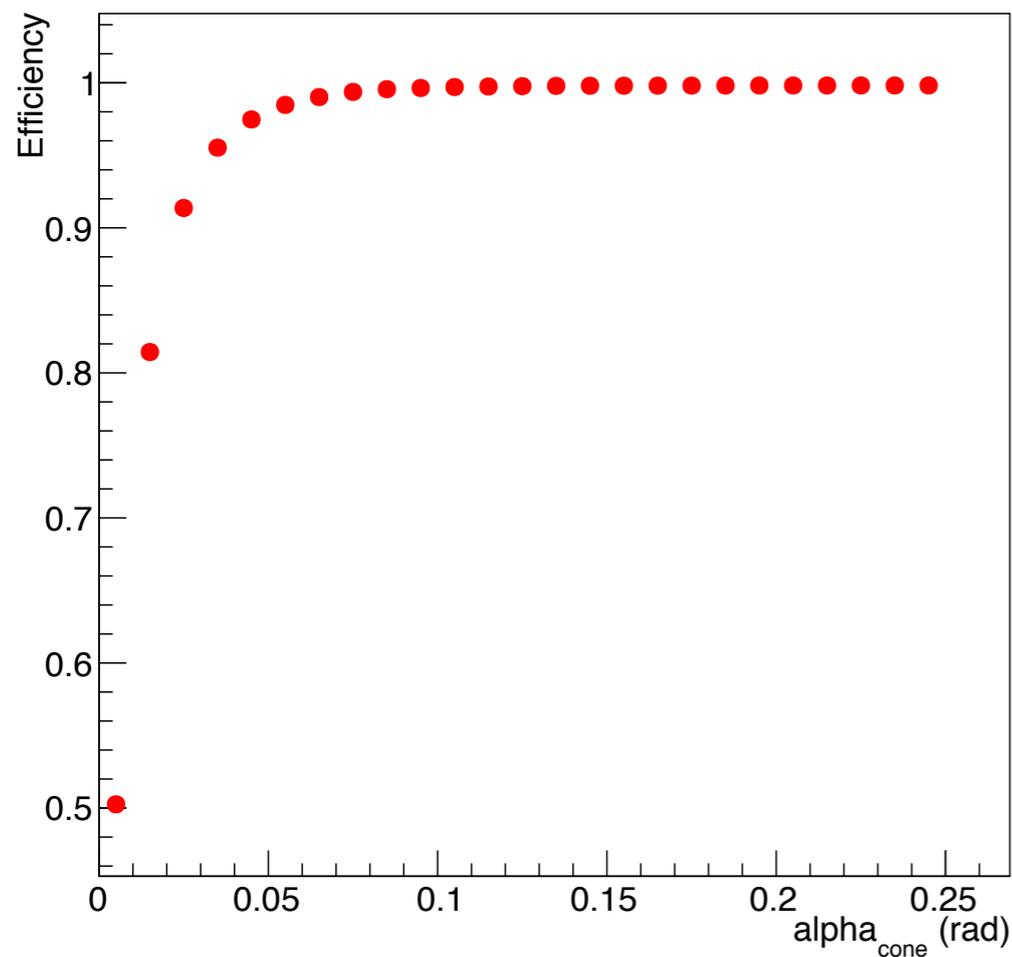
Backgrounds

- Physical
 - It is due to the overlap between the shower produced by any electron in ν_e interactions and showers produced by $\pi^0 \rightarrow \gamma\gamma$ either produced in the same interaction or in any other neutrino interaction in the brick.
 - Passing through muons (100% tagging efficiency assumed)
- Instrumental background
 - Compton electrons in the emulsion films (minor issue with newly produced emulsions)

RECONSTRUCTION OF ELECTRON ENERGY

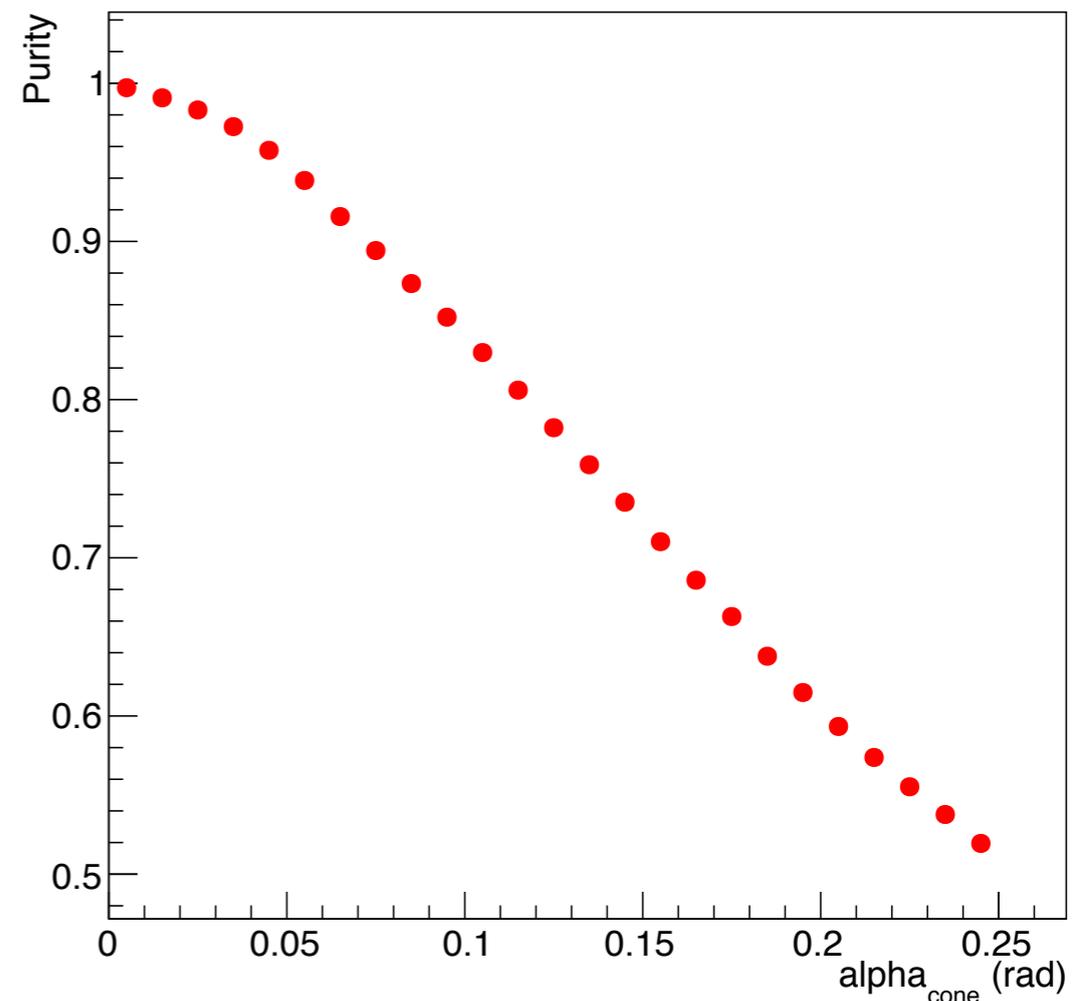
Estimation of cone opening angle

Efficiency



$$\varepsilon = \frac{\text{number of selected shower tracks}}{\text{total number of shower tracks}}$$

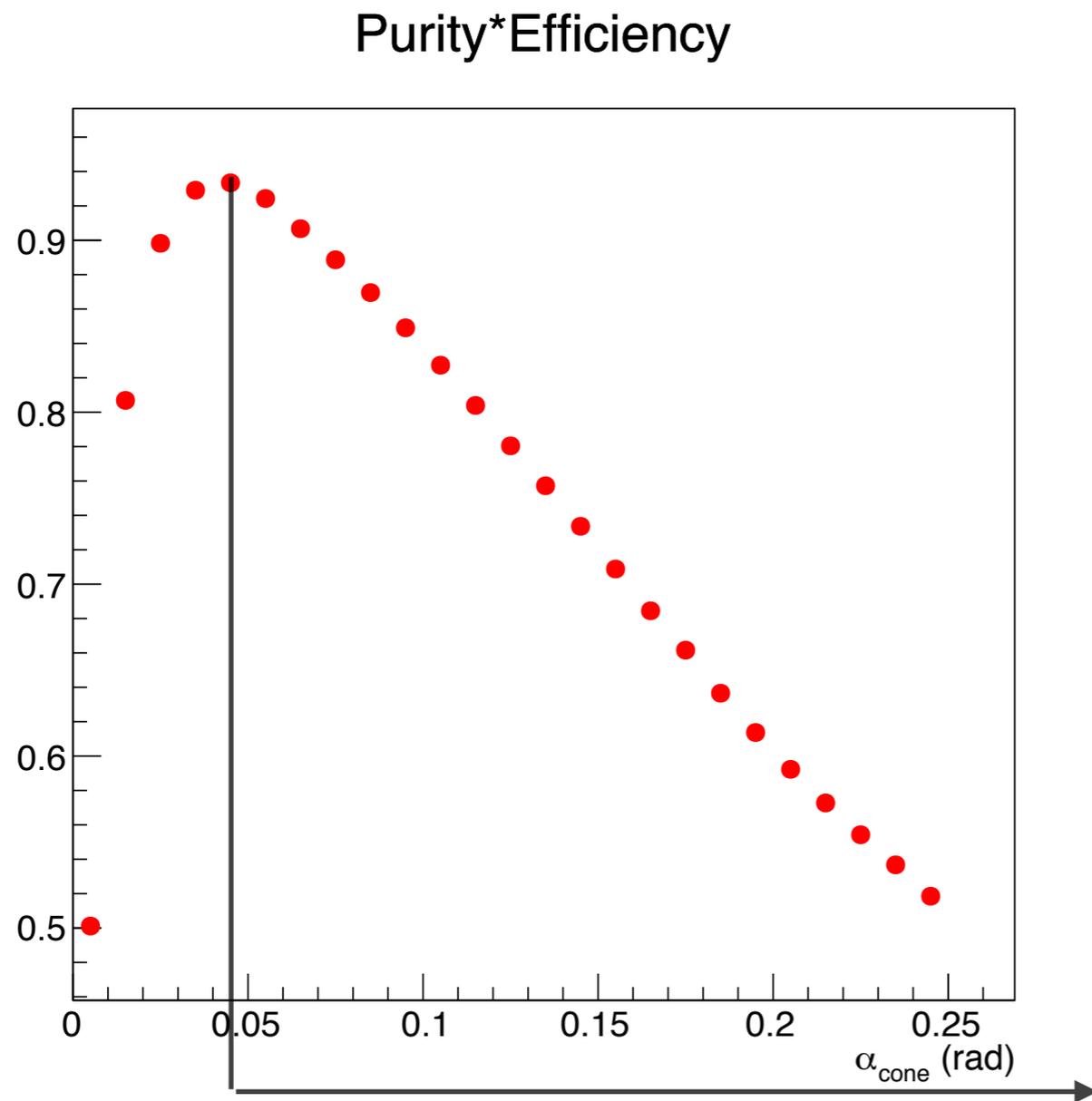
Purity



$$P = \frac{\text{number of selected shower tracks}}{\text{total number of selected tracks}}$$

RECONSTRUCTION OF ELECTRON ENERGY

Estimation of cone opening angle



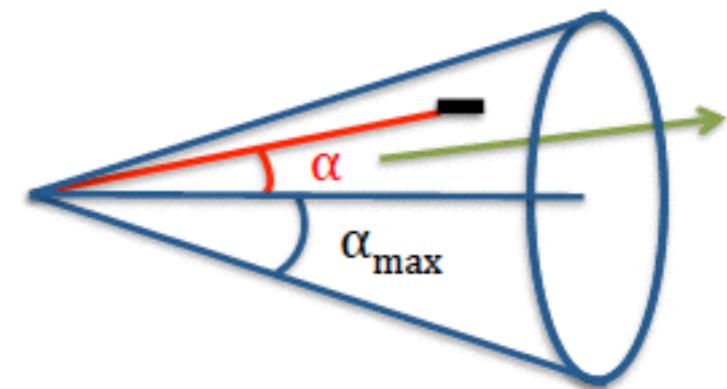
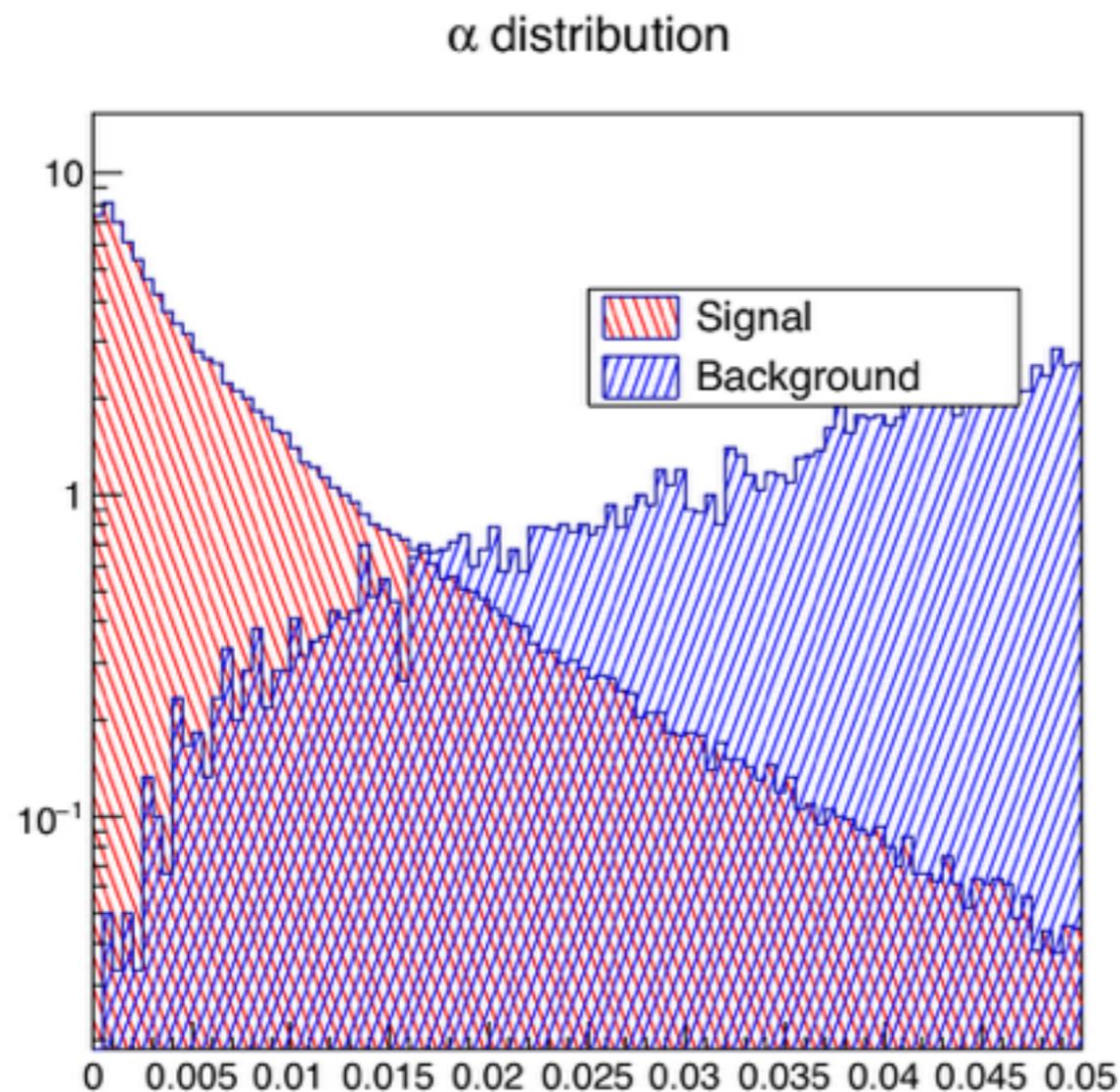
Chosen the opening angle of the cone as the one which maximises the estimator:

purity*efficiency

$$\alpha_{\text{cone}} = 0.045 \text{ rad}$$

RECONSTRUCTION OF ELECTRON ENERGY

Handles to discriminate signal BT from background BT



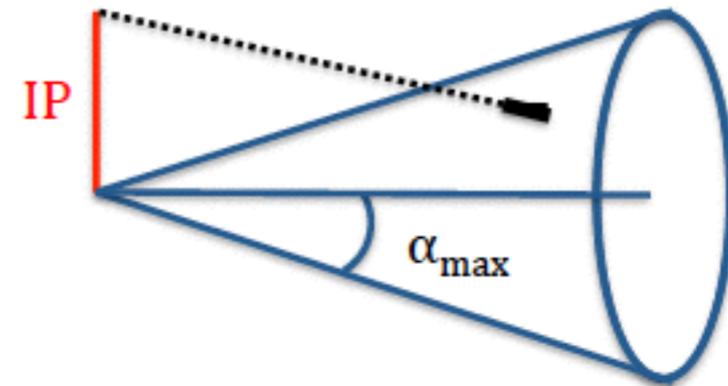
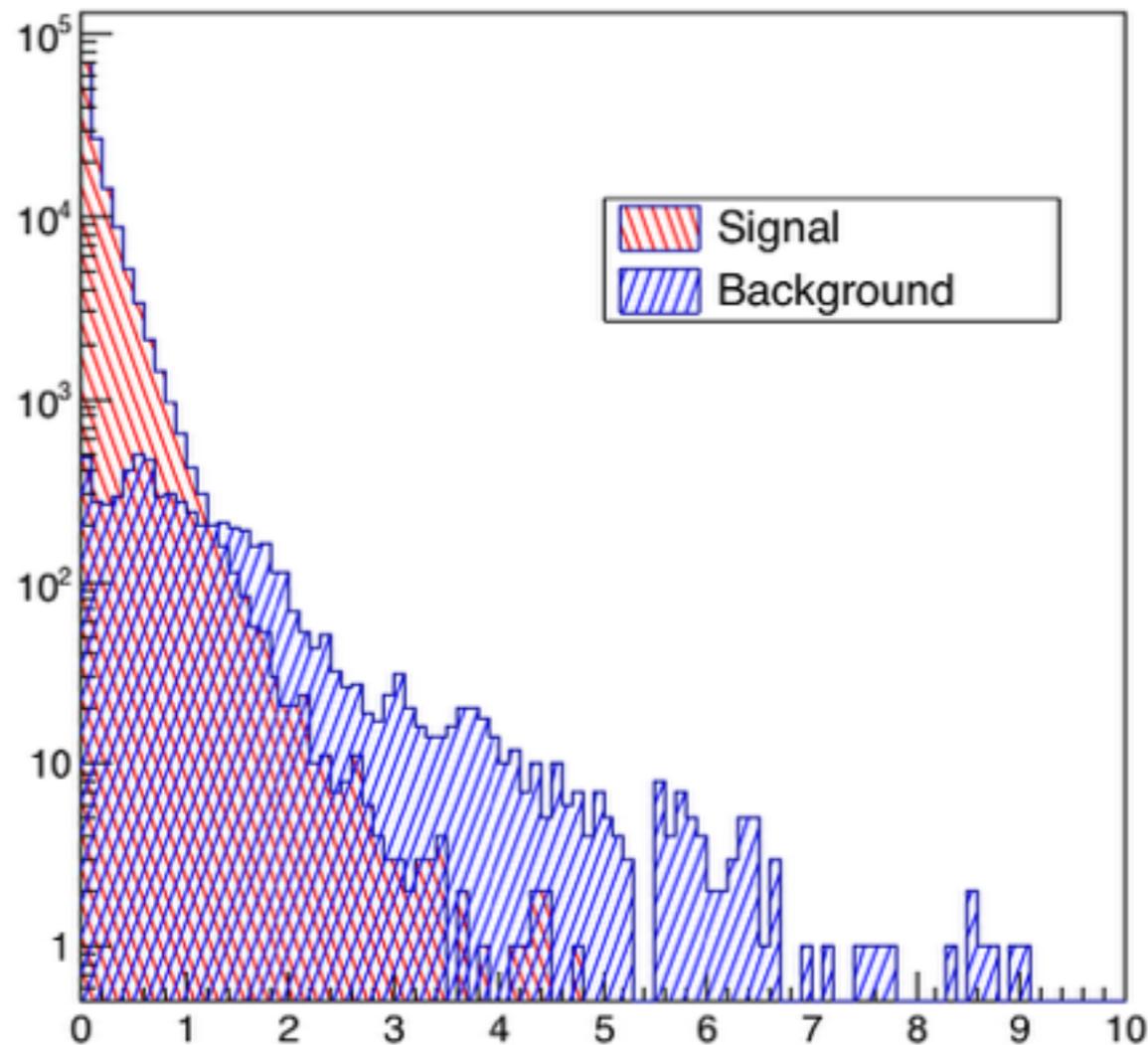
$$\alpha_{\max} = 0.045 \text{ rad}$$

α = angle made by each BT with respect to the axis of the cone computed by connecting the BT with the cone vertex

RECONSTRUCTION OF ELECTRON ENERGY

Handles to discriminate signal BT from background BT

IP distribution



$$\alpha_{\max} = 0.045 \text{ rad}$$

IP = distance between the vertex position and the projection of each BT on the vertex plane

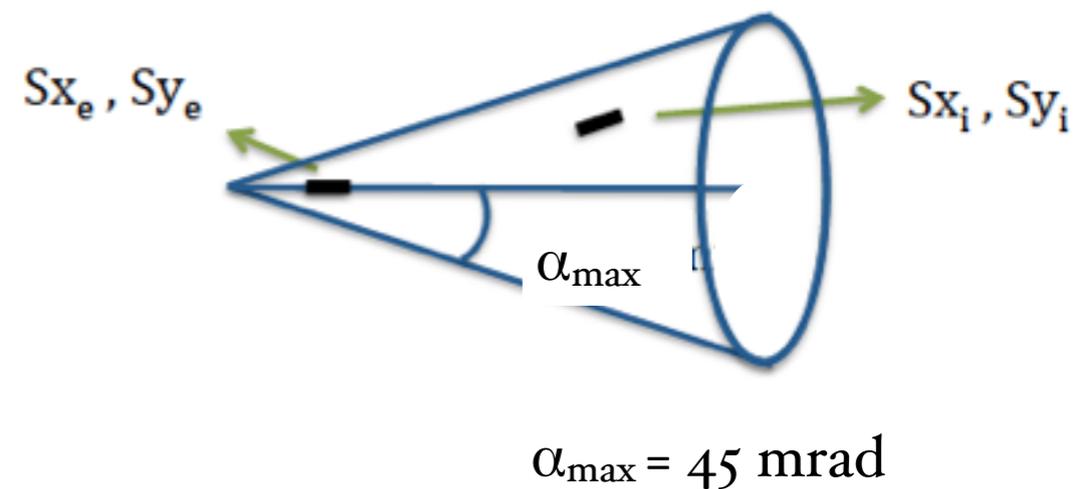
RECONSTRUCTION OF ELECTRON ENERGY

Handles to discriminate signal BT from background BT

Other variables that can be used to perform signal/background discrimination are:

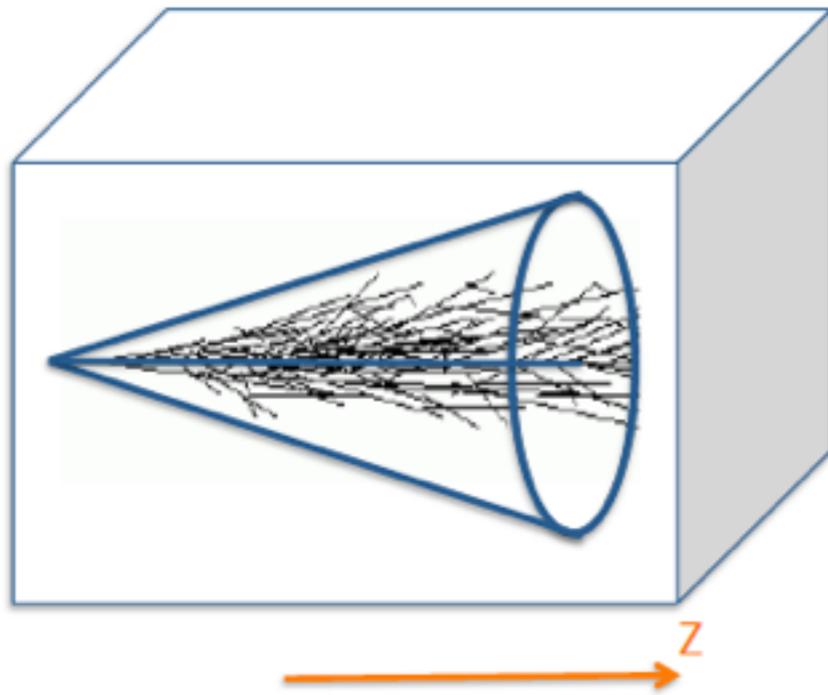
- $\Delta S_X = S_{X_i} - S_{X_e}$
- $\Delta S_Y = S_{Y_i} - S_{Y_e}$

angular difference between the slope of each base-track inside the cone and the slope of the first base-track of electron for both X and Y projection.



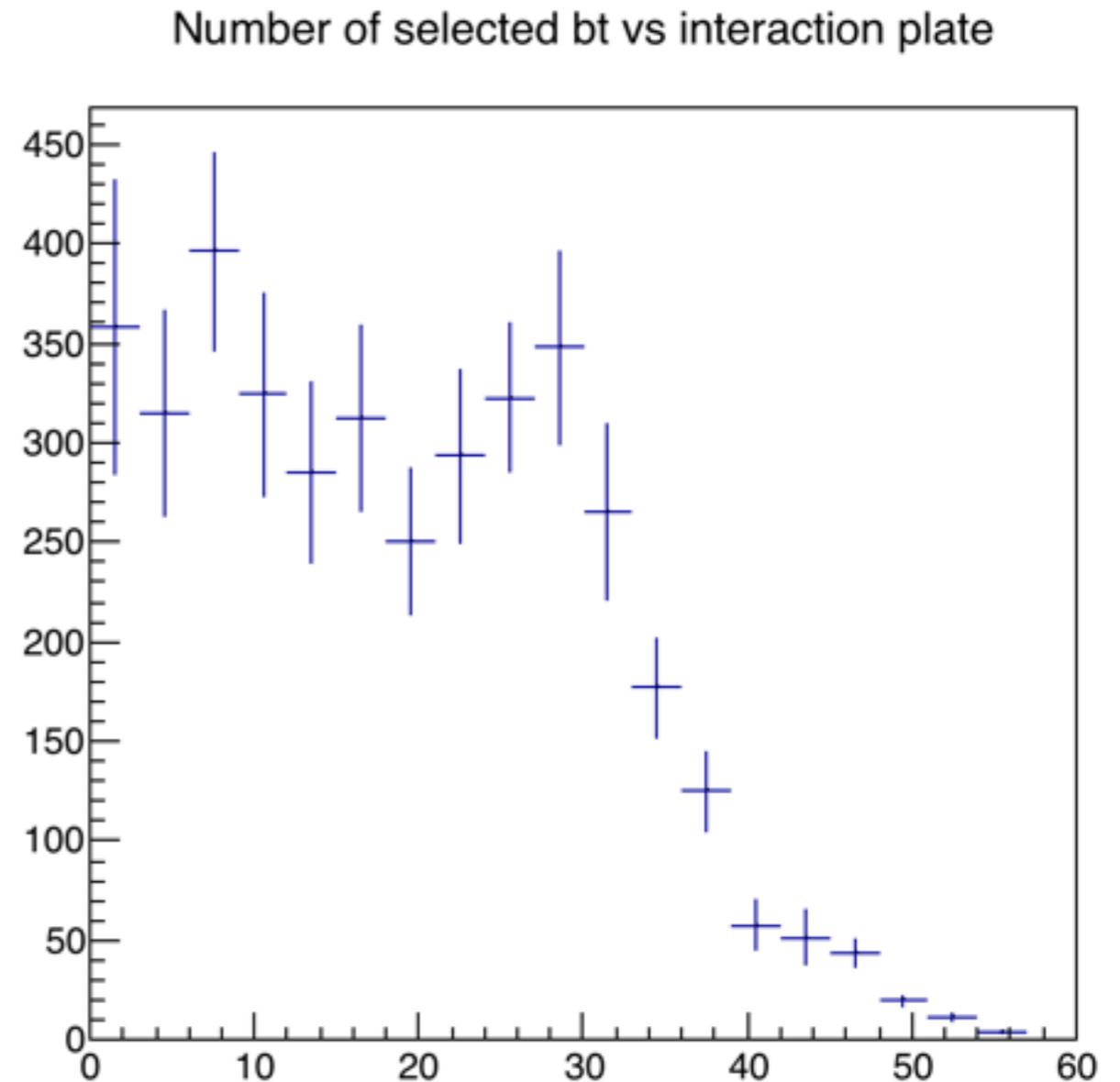
Analysis based on BDT method to determine the best-cut value for variables is foreseen

RECONSTRUCTION OF ELECTRON ENERGY

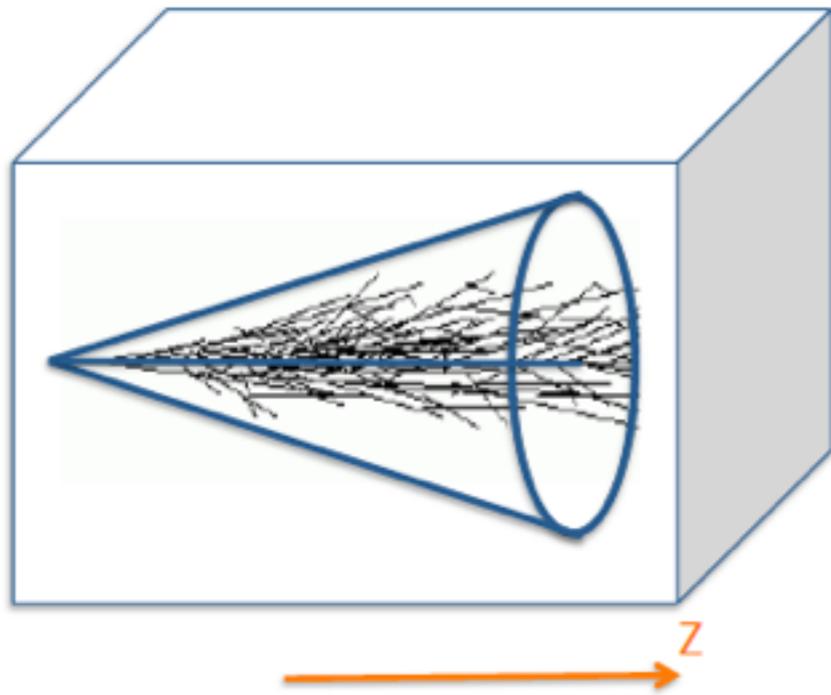


Number of BT produced in an e.m. shower depends not only on electron energy but also on the position of neutrino interaction vertex inside the brick.

The closer the event is to the brick edge less number of BT of the e.m. shower will be contained in the brick.

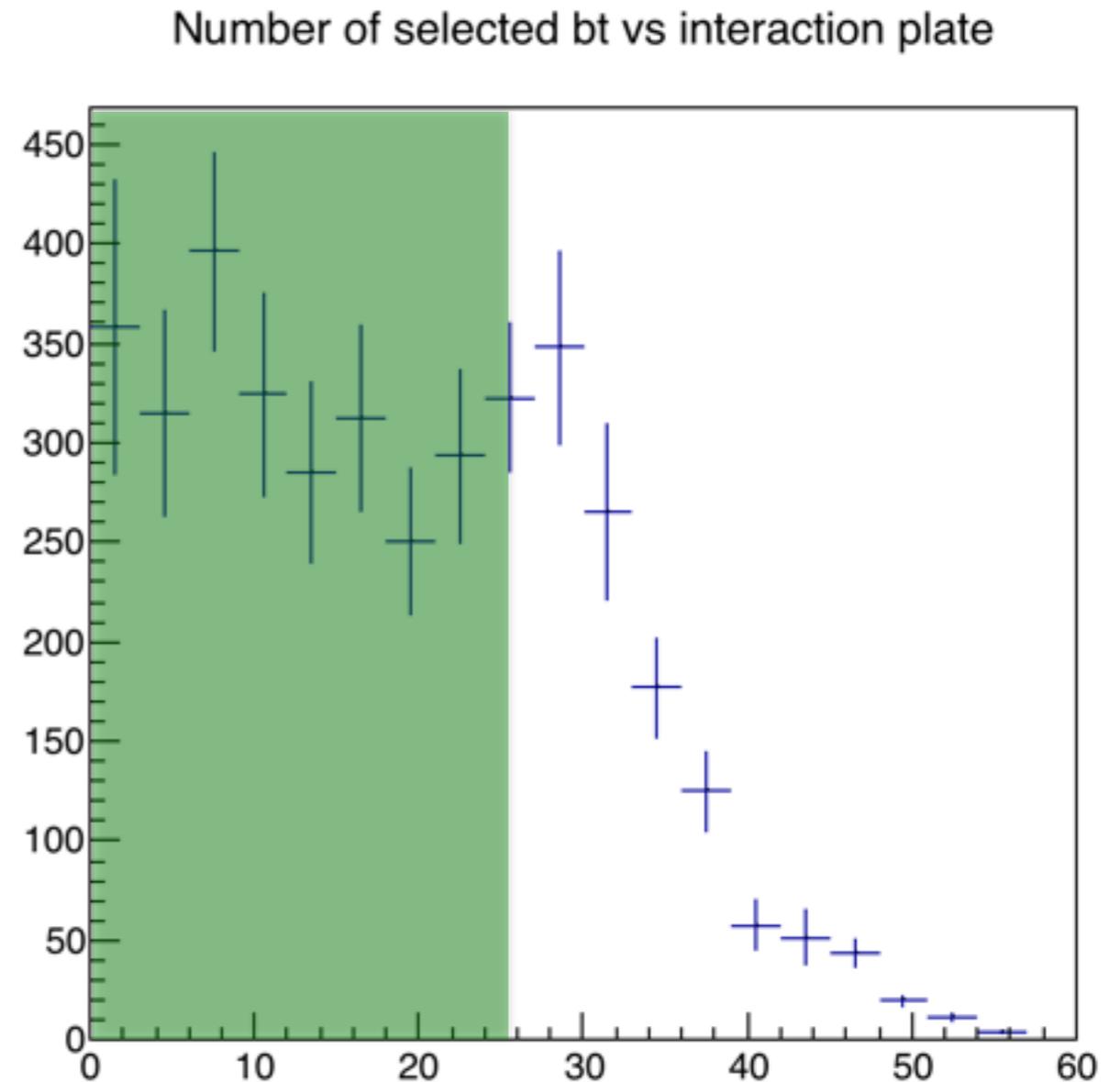


RECONSTRUCTION OF ELECTRON ENERGY



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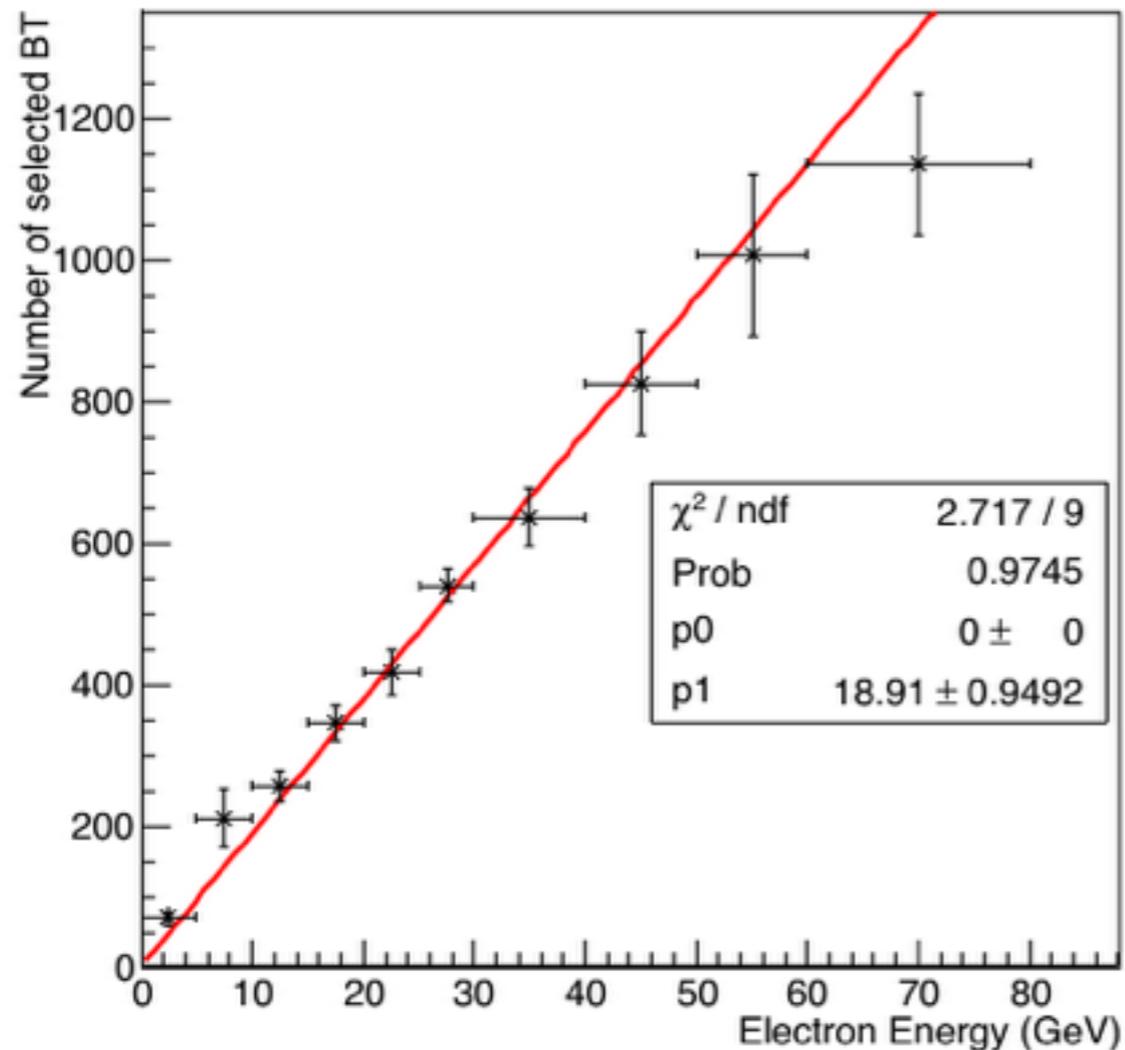
The closer the event is to the brick edge less number of BT of the e.m. shower will be contained in the brick.



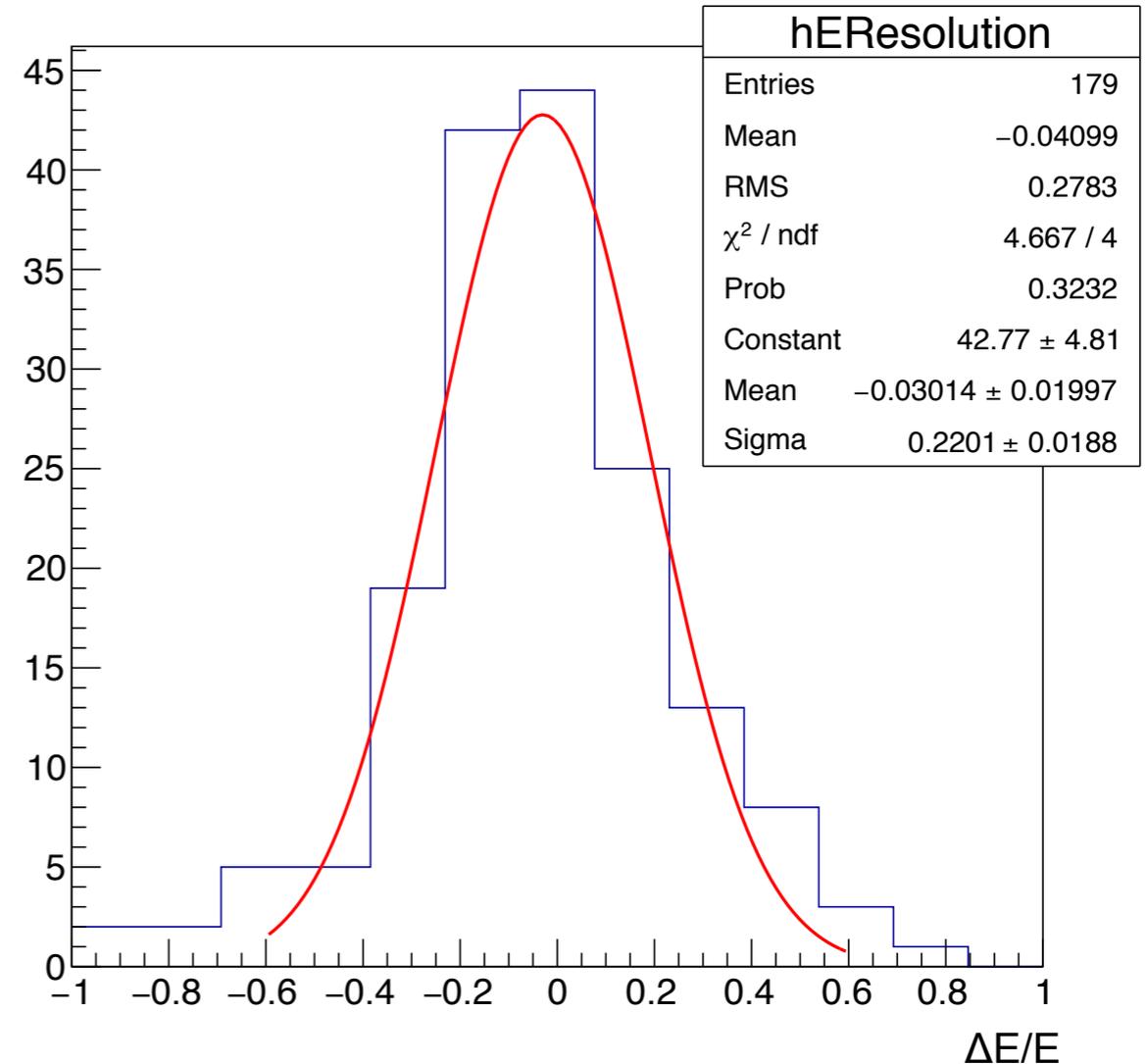
considered only those events with ν_e interaction plate between plate 1 and plate 25

RECONSTRUCTION OF ELECTRON ENERGY

BT selected in the cone VS Electron energy



Reconstructed Energy Resolution



$$\frac{\Delta E}{E} = \frac{E_{True} - E_{Rec}}{E_{True}}$$

Resolution on electron energy of $\approx 22\%$

ELECTRON NEUTRINO ENERGY

Visible tracks in emulsion films

Tracks can be seen in emulsion films if:

- charged
- $p > 0.1 \text{ GeV}/c$
- θ_x and $\theta_y < 1 \text{ rad}$

Definition of primary vertex

A neutrino interaction vertex is said to be identified if in the reconstruction there are :

- 2 visible tracks
- at least 1 of the tracks has $p > 1 \text{ GeV}/c$

ELECTRON NEUTRINO ENERGY

Basic Approach

- Select electron neutrino event satisfying the criteria for vertex identification
- Select in the event only visible charged tracks
 - Sum their MC true energy => Visible energy of the neutrino @ true MC level
- Perform calibration between true MC energy and (true) visible energy
- Estimate resolution on electron neutrino energy

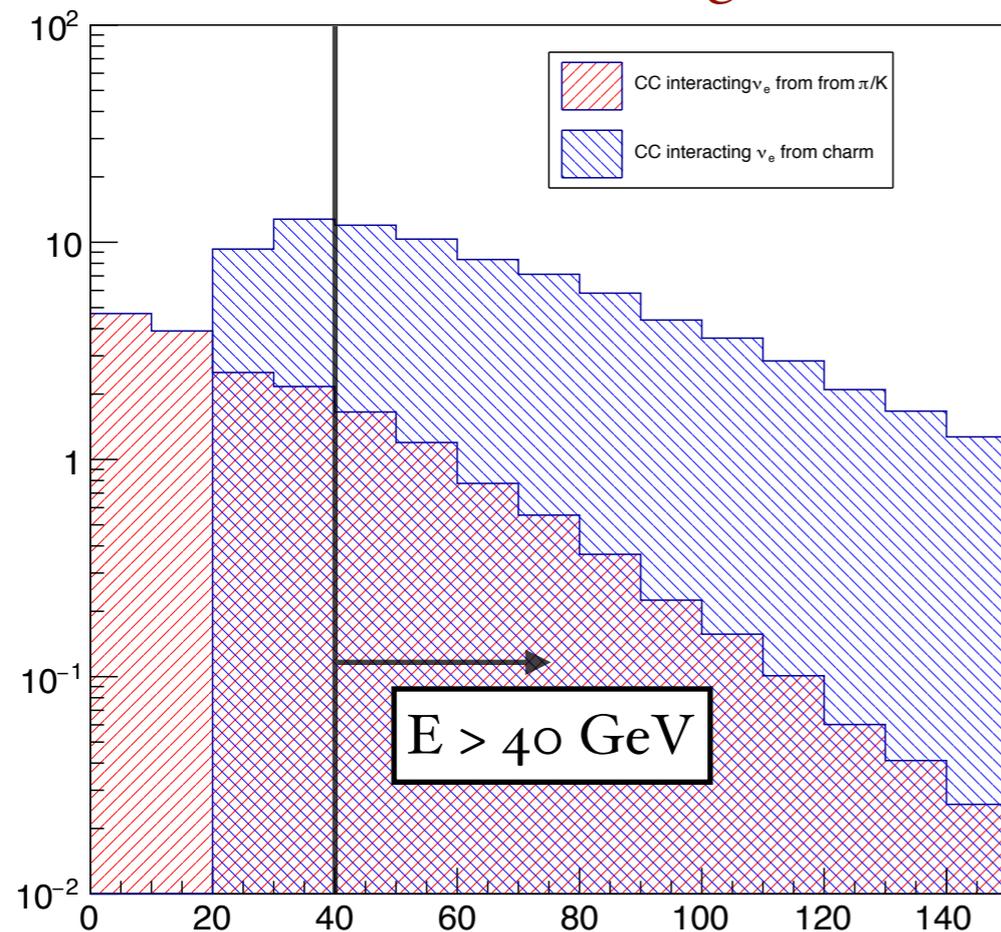
Improvements

- Take into account the experimental resolution on the momenta of the charged hadrons
 - Compact Emulsion Spectrometer to measure momenta
- Sum their energy => Visible energy of the neutrino
- Perform calibration between true MC energy and visible energy
- Estimate resolution on electron neutrino energy

CHARM NORMALISATION FOR HNL STUDIES

Electron neutrinos can be used to probe charm production yield at the beam dump.

$\nu_e + \text{anti-}\nu_e$ CC interacting in
the neutrino target

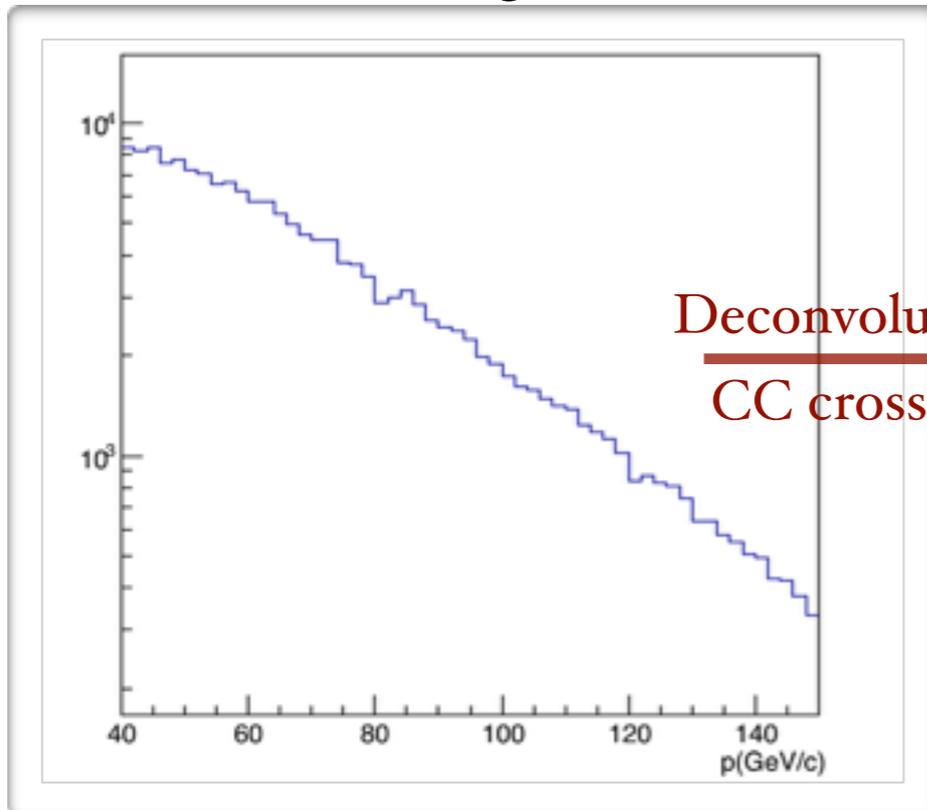


When considering $\nu_e + \text{anti-}\nu_e$ true MC spectrum convoluted with neutrino CC cross-section at an energy above 40 GeV:

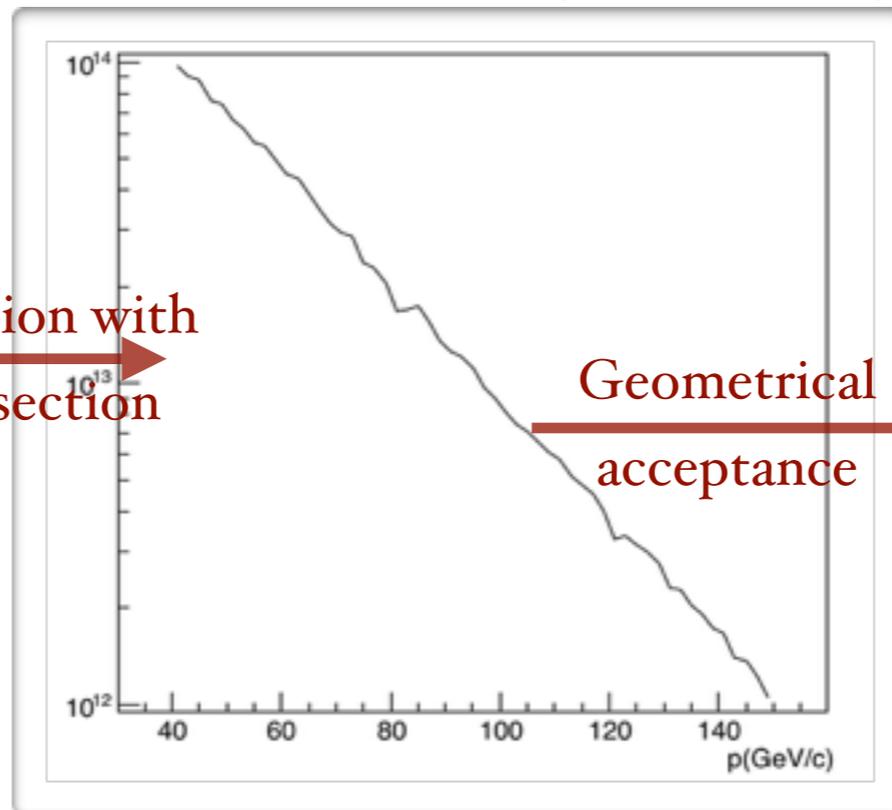
Fraction of neutrinos originating from charmed hadrons $\approx 95\%$

CHARM NORMALISATION FOR HNL STUDIES

1) $\nu_e + \text{anti-}\nu_e$ CC interactions in the neutrino target ($E > 40 \text{ GeV}$)



2) $\nu_e + \text{anti-}\nu_e$ hitting the neutrino detector (from charm)



3) $\nu_e + \text{anti-}\nu_e$ produced at the beam dump (from charm)

$$N_{\nu_e + \bar{\nu}_e}^{bd} (E > 40 \text{ GeV})$$

$$f_{Echarm} = 0.05$$

4) $\nu_e + \text{anti-}\nu_e$ from **charm** produced at the beam dump

$$N_{\nu_e + \bar{\nu}_e}^{bd} = \frac{N_{\nu_e + \bar{\nu}_e}^{bd} (E > 40 \text{ GeV})}{f_{Echarm}}$$

5) Number of charmed hadrons produced at beam dump

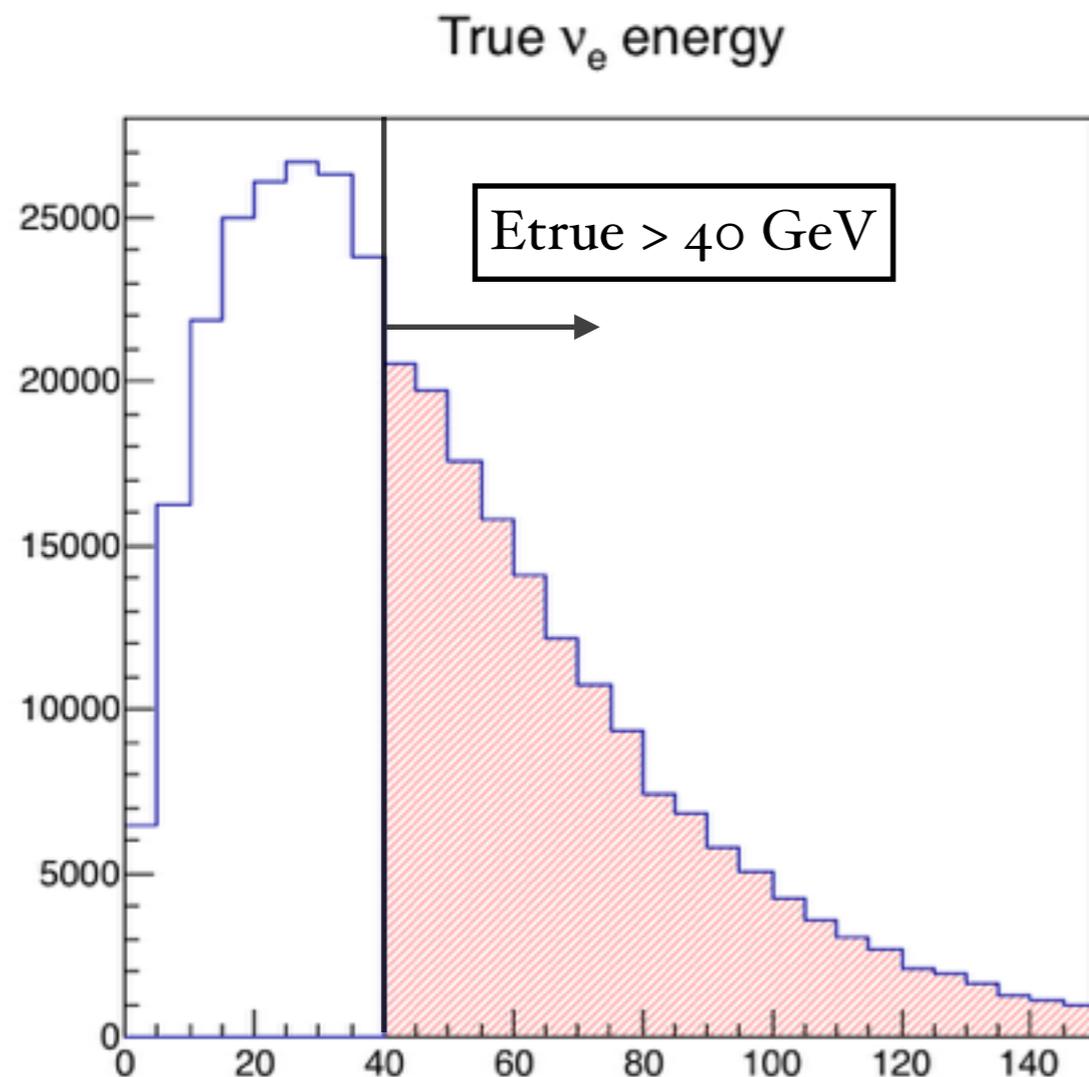
$$N_{\nu_e + \bar{\nu}_e}^{bd} = 2 N_p \frac{\sigma_{cc}}{\sigma_{pN}} \sum_i f_i Br_i$$

with $i = D^\pm, D^0, \bar{D}^0, D_s^\pm, \Lambda_c, \bar{\Lambda}_c$

CHARM NORMALISATION FOR HNL STUDIES

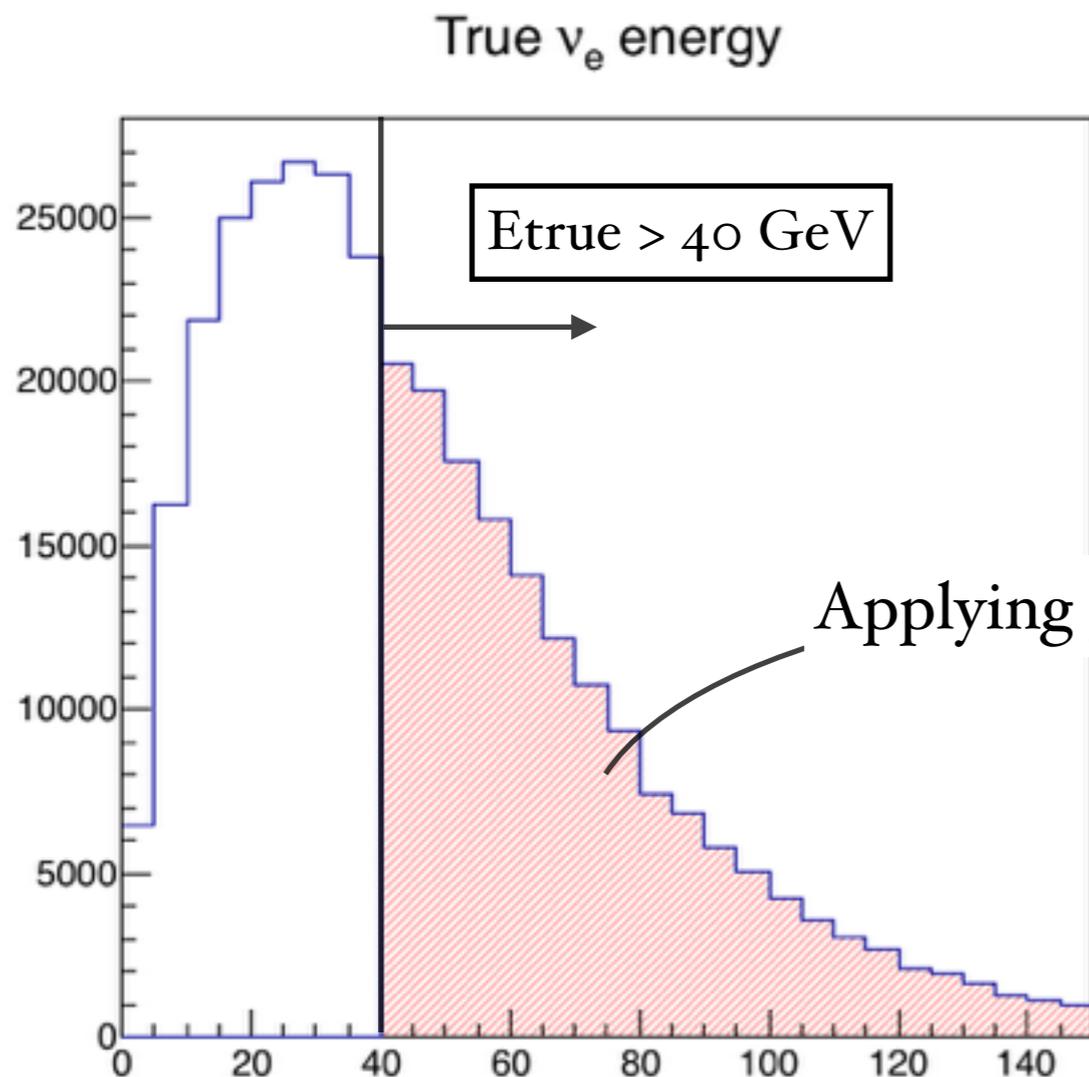
However, in true life we don't have the MC true energy of the neutrinos, but we have to estimate it.

Seen results on electron energy resolution we can assume that we have a 30% resolution on the neutrino energy.

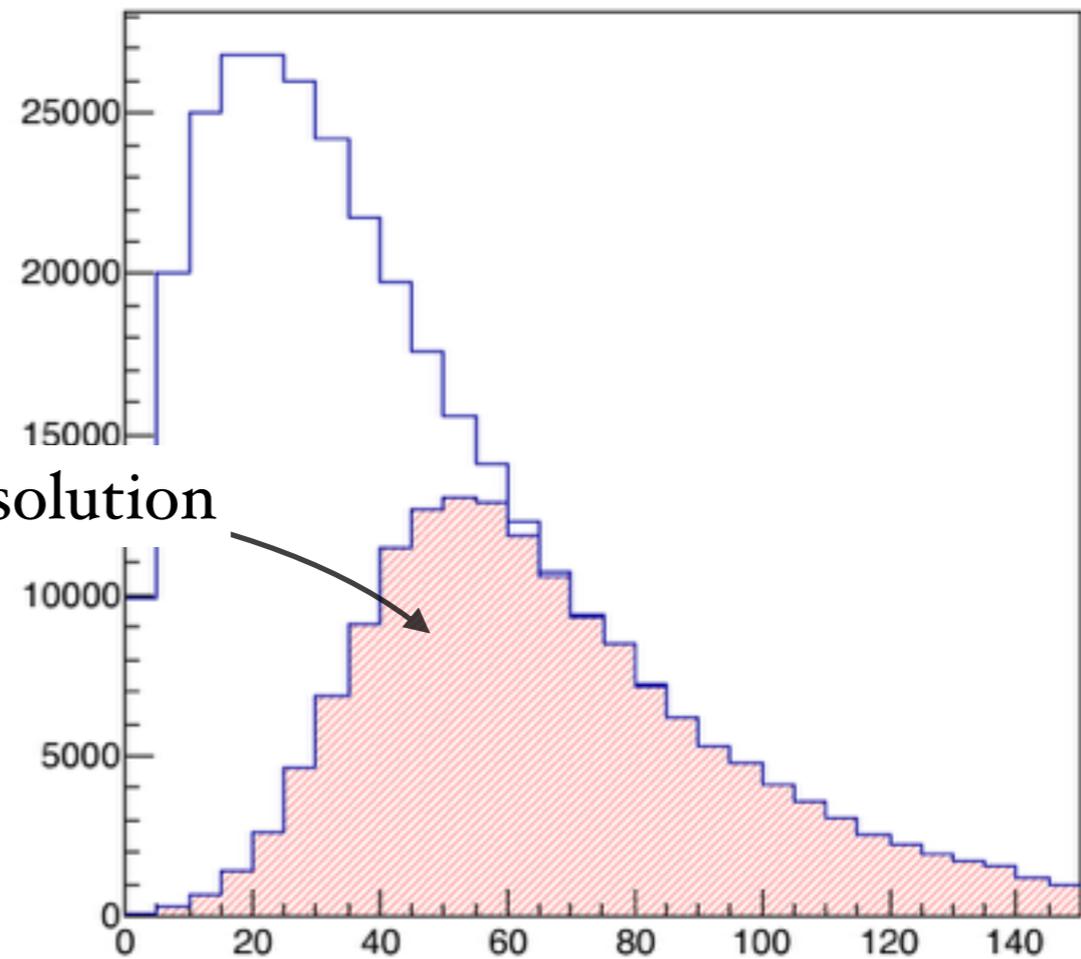


CHARM NORMALISATION FOR HNL STUDIES

When applying a resolution of 30% on the estimation of neutrino energy, we get the following spectrum of $\nu_e + \text{anti-}\nu_e$ CC interacting in the neutrino target and a corresponding migration of events with $E_{\text{true}} > 40$ GeV in events with E_{rec} both over and under 40 GeV.



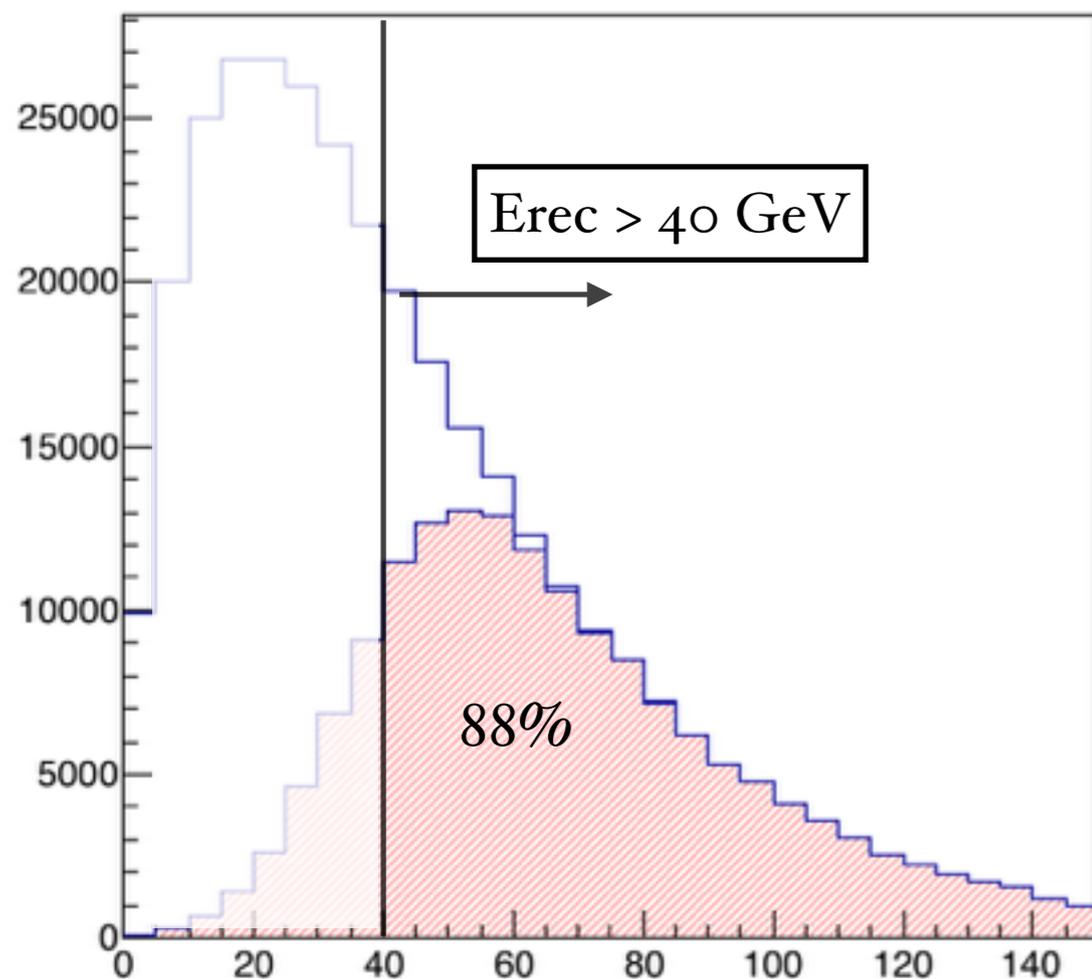
Reconstructed spectrum of $\nu_e + \text{anti-}\nu_e$
CC interacting in the neutrino target



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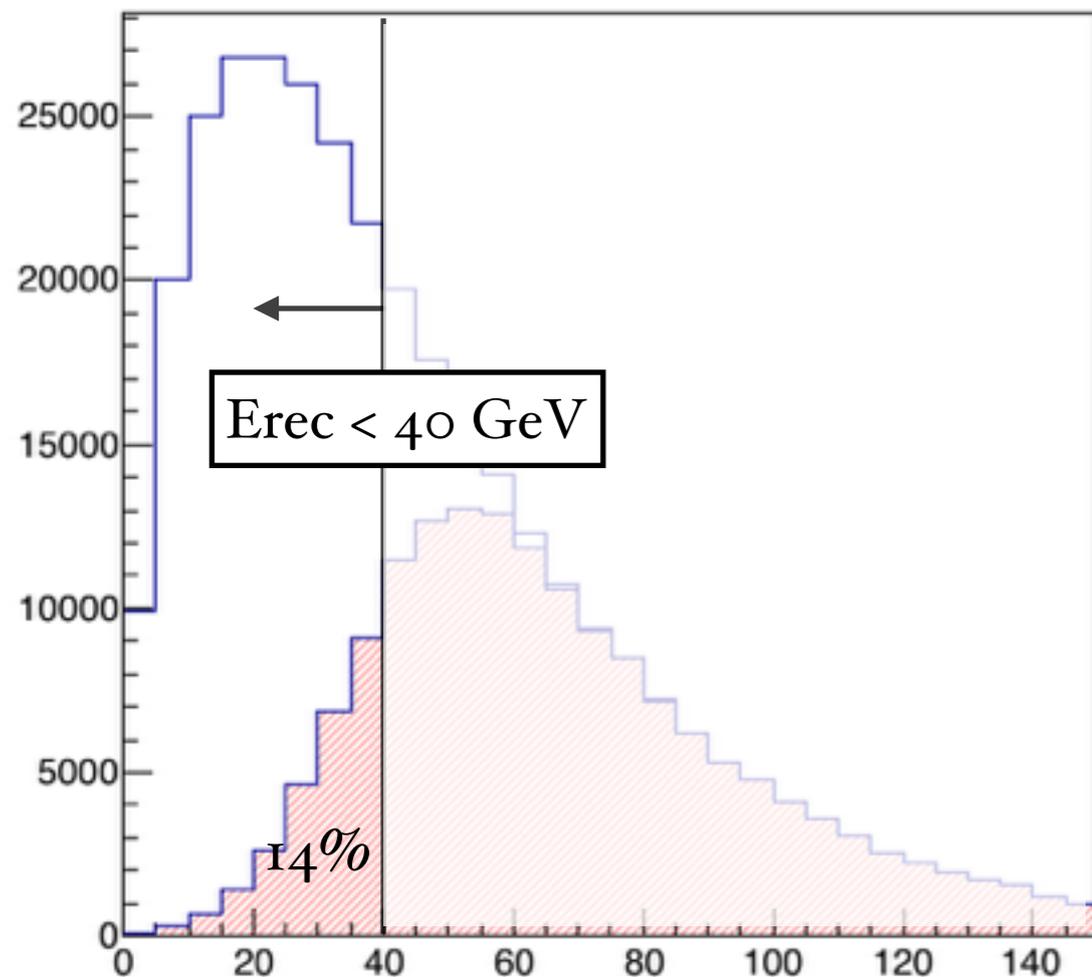


	$E_{\text{rec}} < 40$ GeV	$E_{\text{rec}} > 40$ GeV
$E_{\text{true}} < 40$ GeV	86%	12%
$E_{\text{true}} > 40$ GeV	14%	88%

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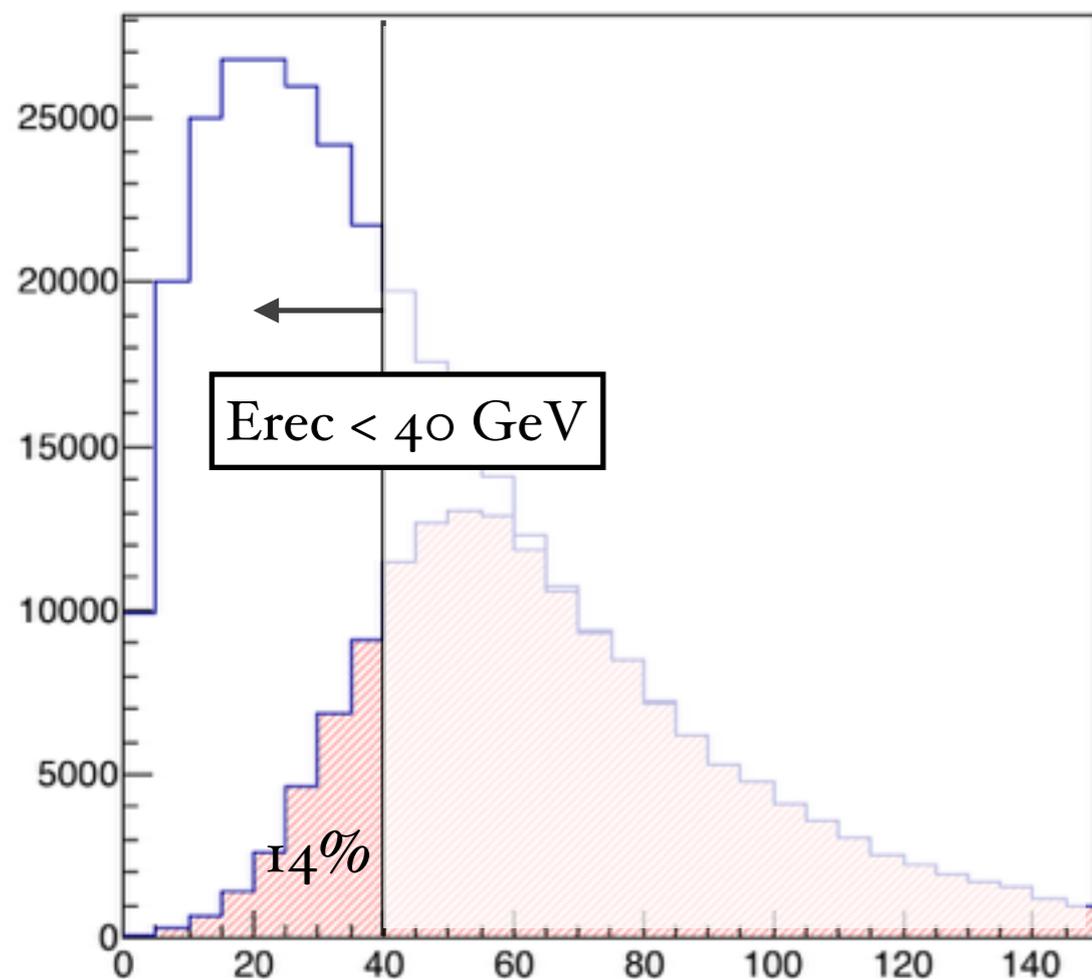


	E_{rec} < 40 GeV	E_{rec} > 40 GeV
E_{true} < 40 GeV	86%	12%
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Reconstructed spectrum of $\nu_e + \text{anti-}\nu_e$ CC interacting in the neutrino target



	$E_{\text{rec}} < 40 \text{ GeV}$	$E_{\text{rec}} > 40 \text{ GeV}$
$E_{\text{true}} < 40 \text{ GeV}$	86%	12%
$E_{\text{true}} > 40 \text{ GeV}$	14%	88%

The number of events which really have an $E_{\text{true}} > 40$ GeV is 5% more of the events with a reconstructed energy of $E_{\text{rec}} > 40$ GeV

CHARM NORMALISATION FOR HNL STUDIES

A 30% resolution in energy gives a 5% of error on the number of events selected for the estimation of charm normalisation.

Next steps

- Perform a shape analysis to retrieve true energy spectrum above 40 GeV from the reconstructed one
- Apply deconvolution with cross section
- Perform all the steps shown in slide 17 to retrieve info on the number of charmed hadrons produced at beam dump

CONCLUSIONS

- Estimation of the electron energy resolution: 22%
- Same algorithm for shower energy reconstruction useful for estimation of the energy of π^0
- Resolution on neutrino energy assumed to be 30%
- Overall error of 5% on the estimation of the number of events used to probe the charm production yield

