

Joint Institute for Nuclear Research (Dubna)

Reconstruction efficiency in ECAL+3DST+TPC configuration

SAND meeting

Artem Chukanov, Svetlana Vasina

28th of July, 2020

Motivation



Check the energy reconstruction quality and detection efficiency of ν_μ CC interactions in **ECAL+3DST+TPC** configuration

(events were generated in Dubna with the help of GDML file provided by Guang. Edep-sim program was modified to have a smaller steps in Trajectory.Point class, ~ 1 mm to evaluate particles' momenta at the border of detector volumes)

For 3DST calibration and energy reconstruction we applied the same procedure as it was done for the Target Tracker in OPERA experiment

Note

For all detector configurations we consider front ECAL events with the following FV:

$|x| < 169$ cm, $200 < R < 223$ cm, $z < 0$

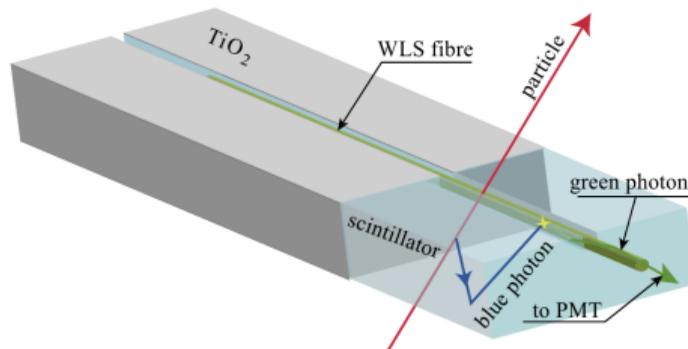
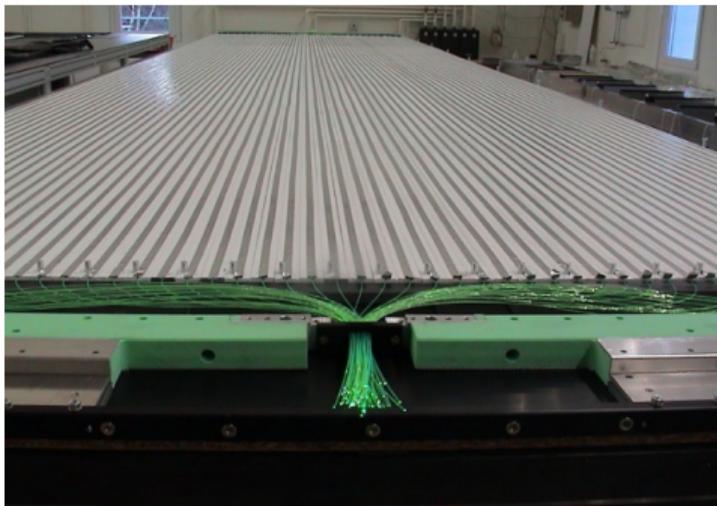
Simulated events number: 1 040 000

All quoted efficiencies are calculated with respect to events generated inside this FV

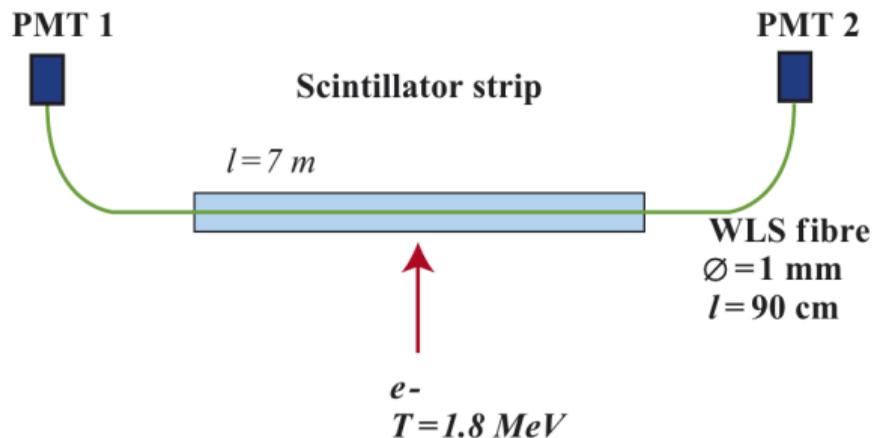
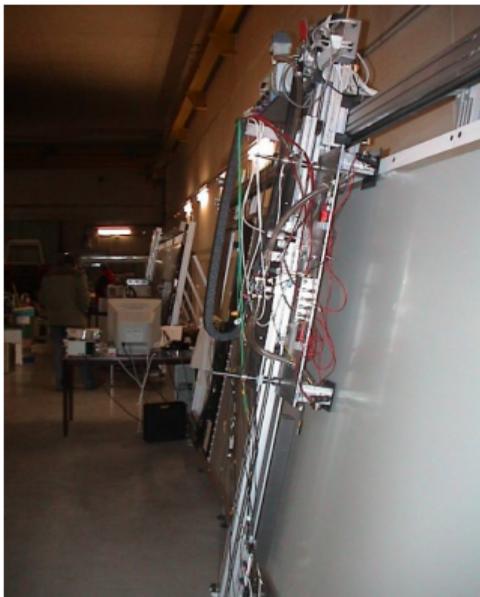
OPERA Target Tracker



OPERA Target Tracker consist from plastic scintillator strips with WLS-fiber inside

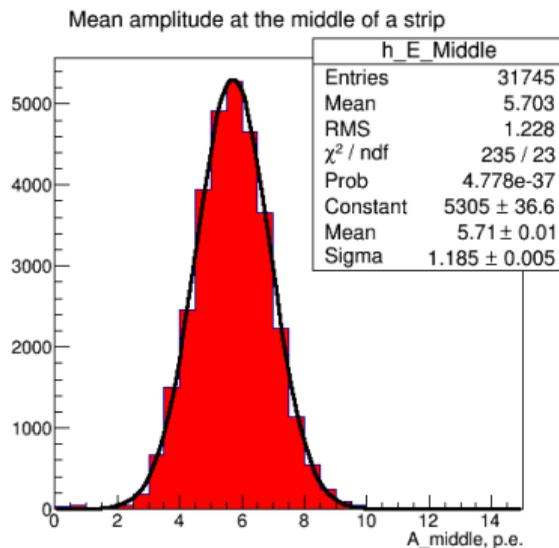
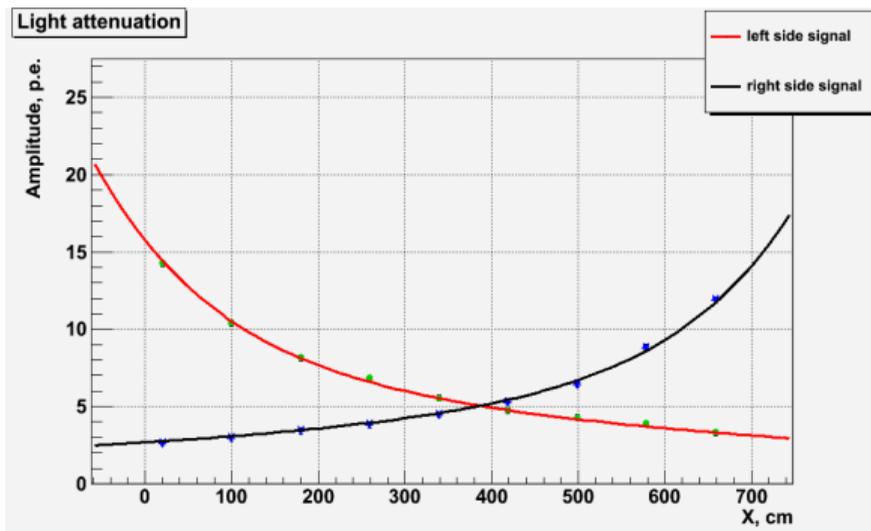


OPERA Target Tracker calibration





Average energy loss of a MIP crossing 1 cm of plastic scintillator is 2.15 MeV.





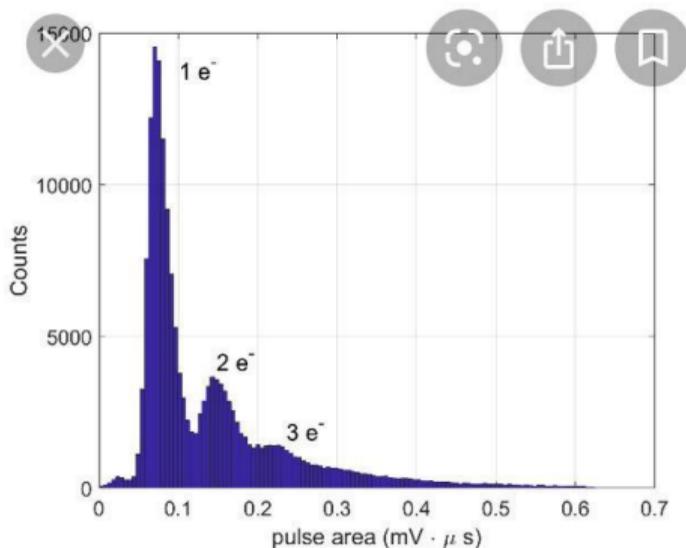
$$A_{left} = A_0(\alpha e^{-\frac{x}{\lambda_s}} + (1 - \alpha)e^{-\frac{x}{\lambda_l}})$$

$$A_{right} = \beta A_0(\alpha e^{-\frac{L-x}{\lambda_s}} + (1 - \alpha)e^{-\frac{L-x}{\lambda_l}})$$

Mean values

- ▶ $A_0 \sim 40$ - number of p.e. for MIP in 0 distance from PMT (taken for 3DST)
- ▶ $\lambda_s \sim 100 \text{ cm}$ - short attenuation length
- ▶ $\lambda_l \sim 700 \text{ cm}$ - long attenuation length
- ▶ $\alpha \sim 0.5$ - ratio between short and long attenuation components
- ▶ β - efficiency ratio between left and right PMTs

SiPM response



Numbers are taken from SiPM calibration by Dubna group for LAr detector

Number of peaks distributed by poisson
Peak width - gaussian distribution with $\sigma \sim 0.1$



Light attenuation: $Exp_1 = A_0(\alpha e^{-\frac{x}{\lambda_s}} + (1 - \alpha)e^{-\frac{x}{\lambda_l}})$

Number of p.e. reached SiPM:

$$A_1 = Exp_1 \cdot E_0 / (2.15 MeV), \quad E_0 - \text{deposited energy in 3DST cube}$$

Number of p.e. in SiPM:

$$N_1 = Poisson(A_1)$$

Signal registered by SiPM:

$$E_1 = \sum_i^{N_1} Gauss(1, \sigma), \quad \sigma \sim 0.1, \quad \text{threshold 1 p.e.}$$



Reconstruction of deposited energy in one PMT:

$$E_1^{rec} = (2.15 \text{ MeV}) \cdot E_1 / Exp1$$

Deposited energy:

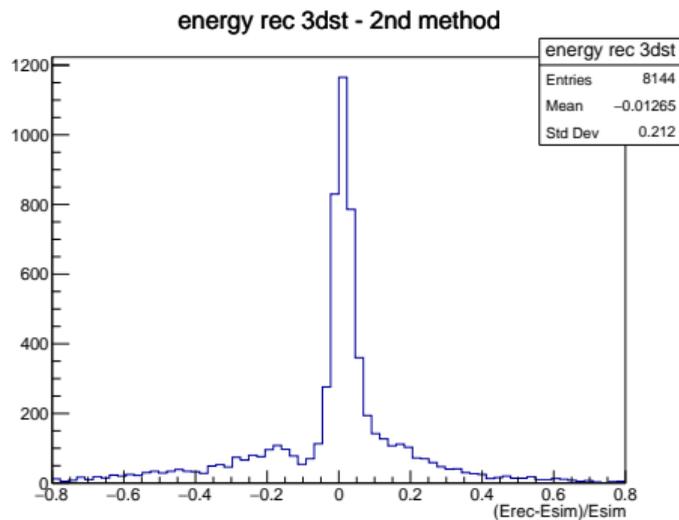
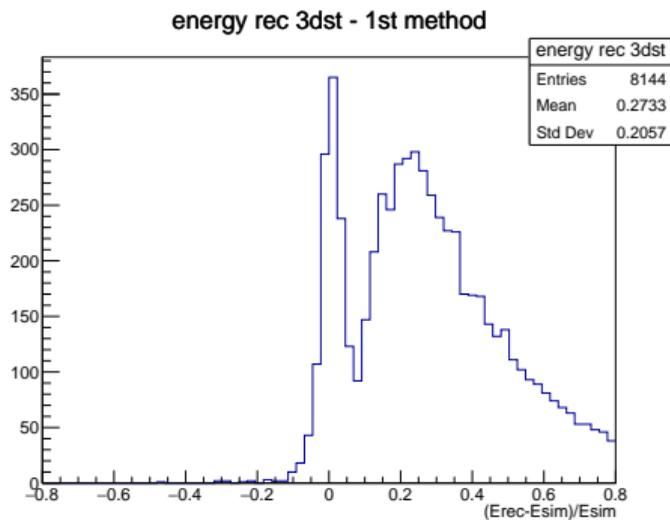
$$E^{rec} = \frac{\sum_{i=1}^3 E_i^{rec}}{3}$$

Note

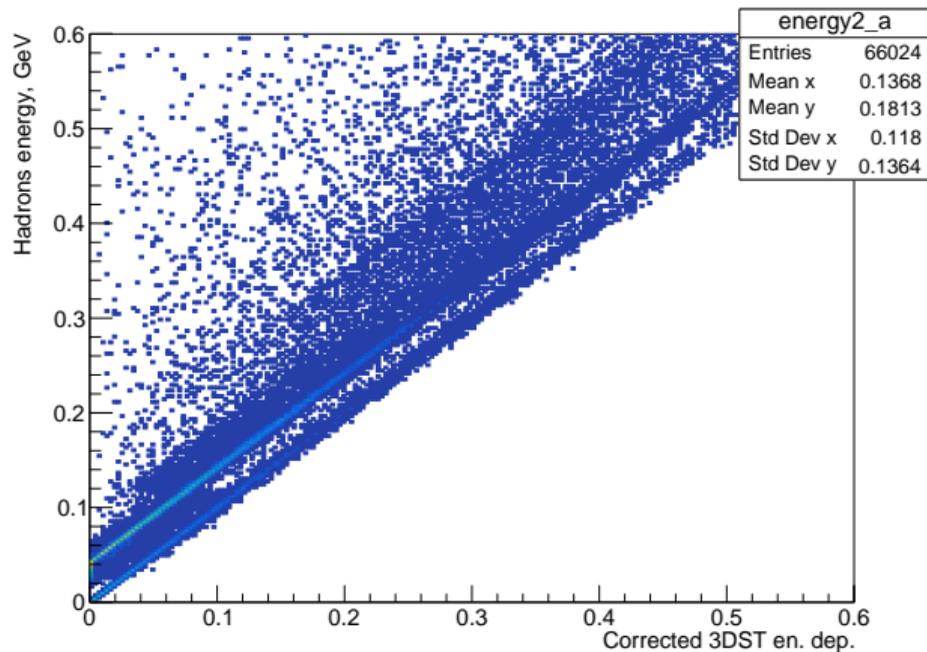
For MC only digitization and deposited energy reconstruction, values of attenuation parameters is not important except of 1 p.e. signal width registered by SiPM ($\sigma \sim 10\%$)



- ▶ simulate horizontal muons and make ratio between total reconstructed energy deposition and energy lost by muon track (using this method by default)
- ▶ generate ν_{μ} NC event fully contained in 3DST and make dependence between hadrons energy and deposited energy



Deposited energy for fully contained ν_μ NC events in 3DST



Energy resolution in ECAL



For ECAL use same procedure with different parameters (KLOE)

Mean interaction length in ECAL: 0.8λ (0.4λ on average)

Picture description:

we simulated ν_μ NC events in ECAL;

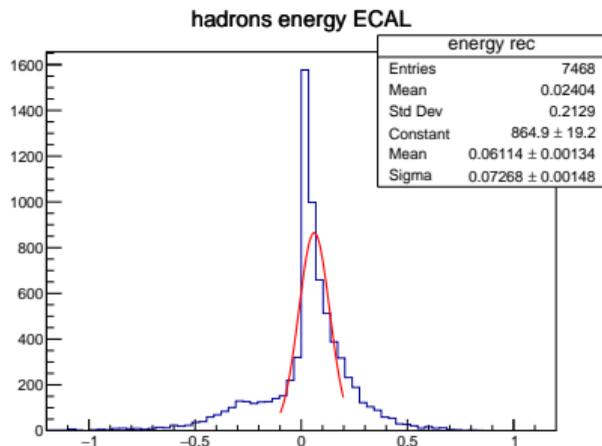
$$E_{true} = E_{had}^{true} - E_{had\ outside\ ECAL}^{true}$$

E_{rec} - reconstructed energy in ECAL

Note

In ECAL+3DST GDML file ECAL is not segmented on active/passive layers (homogeneous active volume) - optimistic case

Energy reconstruction in ECAL
 $(E_{true} - E_{rec})/E_{true}$





For particles that are reached TPC we are measuring momentum in a case of 20 cm traveling inside TPC.

Momentum resolution in TPC: 5% (not using the TPC hits as in the CDR analysis, only average resolution applied)

Neutrino energy: deposited energy in ECAL + deposited energy in 3DST + measured momentum in TPC (with pion or muon masses)



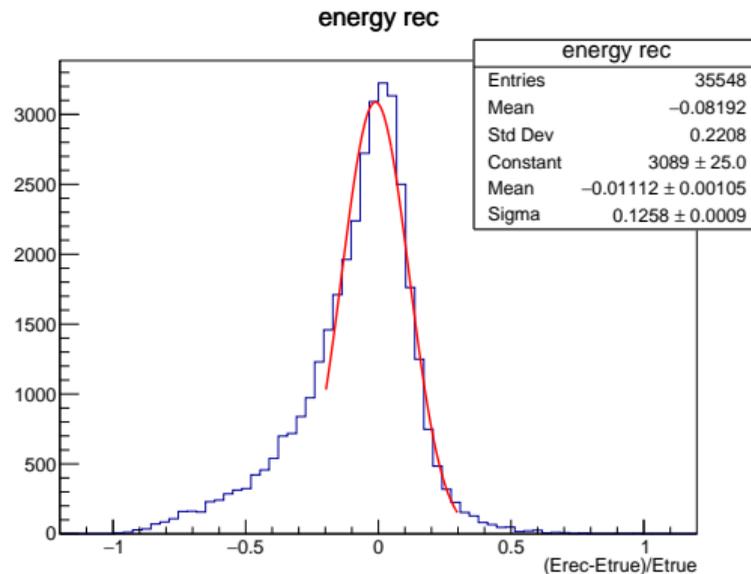
Muon track range cut

3DST > 20 cm or in TPC > 20 cm
(same as in CDR)

Muon registration efficiency 47.1%

(this number is dominated by pure geometrical acceptance)

Energy resolution 12.6%



Beam monitoring - $\sqrt{\Delta\chi^2(E_\nu)}$



reconstructed events number in front ECAL (ECAL+3DST): 490034 (μ reg. eff. 47.1%),
reconstructed events number in front ECAL (ECAL+STT): 740000 (μ reg. eff. 71.1%)

Proton beam parameter	Variation	ECAL(3DST)		ECAL(STT)		ECAL(3DST) CDR
		true	rec	true	rec	rec
Horn current	+3 kA	8.7	6.5	10.5	7.9	9.2
Water layer thickness	+0.5 mm	3.9	3.3	4.7	3.8	3.2
Decay pipe radius	+0.1 m	5.1	4.1	6.4	5.2	5.3
Proton target density	+2%	4.9	4.3	6.0	5.1	4.4
Beam sigma	+0.1 mm	3.6	3.1	4.4	3.8	2.8
Beam off set X	+0.45 mm	4.1	3.2	5.3	4.1	3.6
Beam theta phi	0.07 mrad θ , 1.57 ϕ	0.7	0.4	0.8	0.4	0.9
Beam theta	0.070 mrad	0.8	0.4	0.9	0.4	0.4
horn 1 X shift	+0.5 mm	3.3	2.4	4.1	2.9	3.7
horn 1 Y shift	+0.5 mm	3.9	2.8	4.8	3.5	2.8
horn 2 X shift	+0.5 mm	0.6	0.3	0.6	0.4	0.7
horn 2 Y shift	+0.5 mm	0.6	0.3	0.7	0.3	0.7

difference in the numbers is a pure geometrical acceptance
same analysis described in CDR



Events number for FV $|x| < 169 \text{ cm}$, $200 < R < 223 \text{ cm}$, $z < 0$:

Simulated events: 1 040 000

Reconstructed events: **490 034**

Events number for FV $|x| < 150 \text{ cm}$, $200 < R < 223 \text{ cm}$, $z < 0$:

Reconstructed events: **443 068**

Events number for FV $|x| < 150 \text{ cm}$, $200 < R < 218.5 \text{ cm}$, $z < 0$ (without outer layer):

Reconstructed events: **361 260**

Reconstructed events (CDR): **660 000**

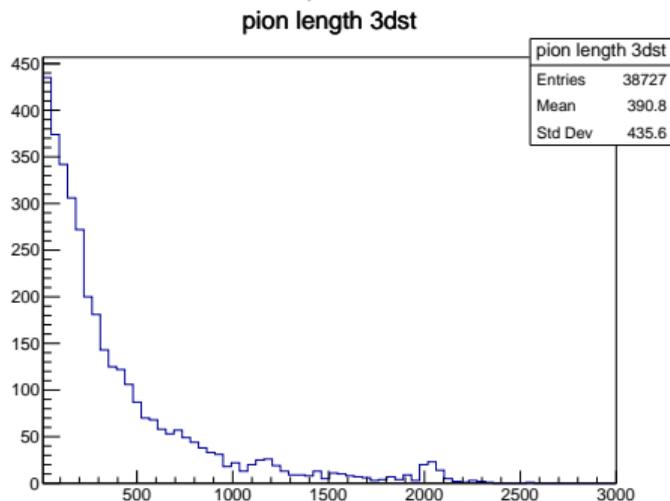


Muon identification:

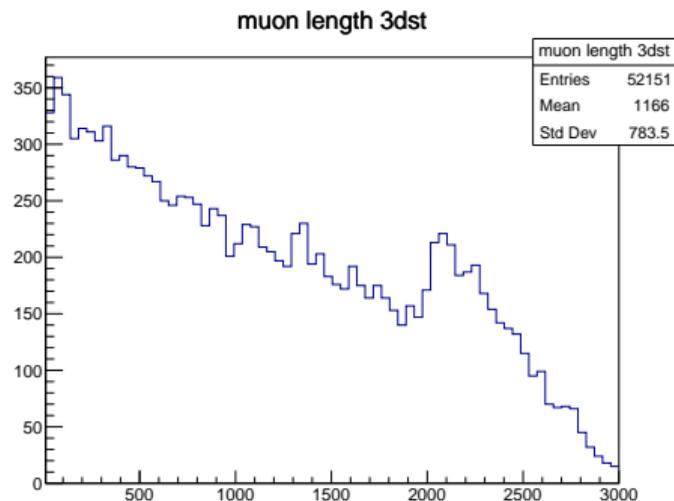
- ▶ detector identification: muon is going out of Yoke at $z > 0$
- ▶ for other muons we are applying range cut
- ▶ excluding muon candidates with inelastic interactions in 3DST (more than 1 charged particles outgoing at the end of track with 100% efficiency of secondary charged track reconstruction)



Pion track length in 3DST
Pions without interactions in 3DST
(200 000 ν_μ NC events)



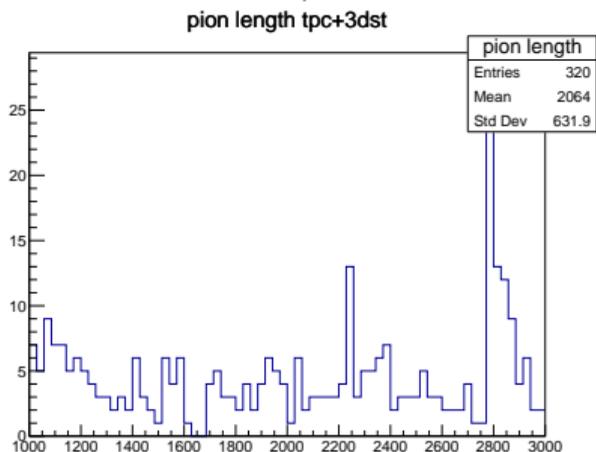
Muon track length in 3DST
(600 000 ν_μ CC events)



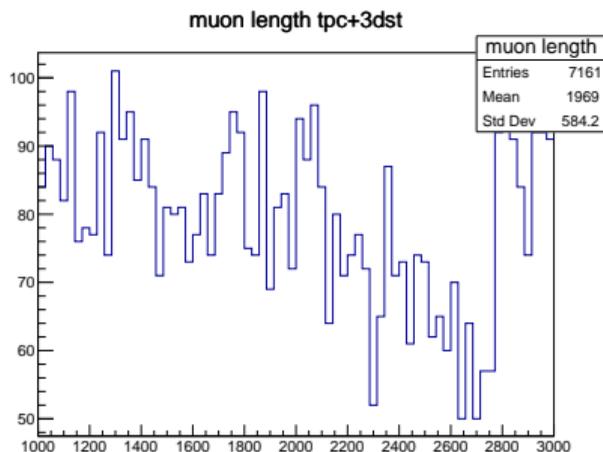
Set range cut for muon track length in 3DST - 100 cm

Used range cut for track length in 3DST 100 cm

Pion track length in 3DST+TPC
Pions without interactions in 3DST
(200 000 ν_μ NC events)



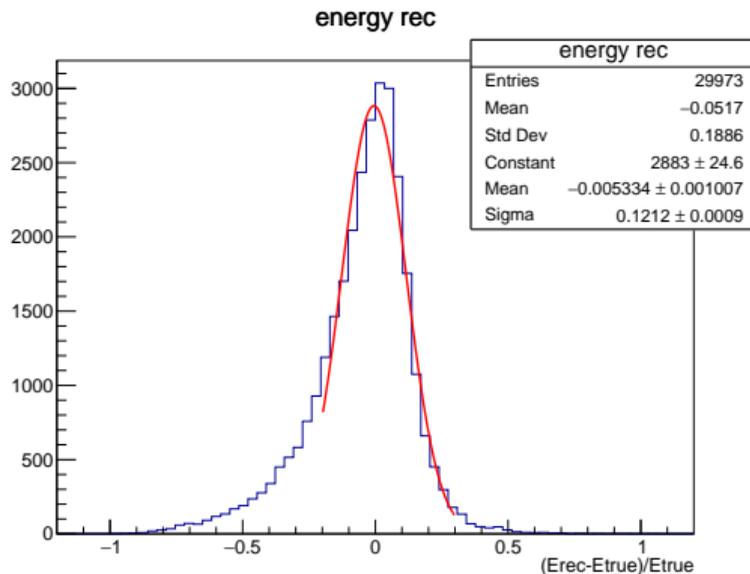
Muon track length in 3DST+TPC
(600 000 ν_μ CC events)



Set range cut for muon track length in 3DST+TPC - 130 cm

- 1) Detector muon identification
muon is going out of Yoke at $z > 0$
- 2) Muon track range cut
 $3DST > 100$ cm and $3DST + TPC > 130$ cm

Muon registration efficiency 41.8%
Energy resolution 12.1%
 ν_μ CC events selection purity 97.2%





1. in ECAL+STT we have a good coordinate resolution \rightarrow good momentum and angles measurement for charged tracks
2. muon track that is crossing STT deposit $\sim 50 \text{ MeV}$ \rightarrow it is possible to reconstruct low energy tracks

For ECAL+STT we can apply kinematical fit for CC/NC separation as it was done for the NOMAD experiment:

Nucl.Phys.B 700 (2004) 51-68, e-Print: [hep-ex/0409037](https://arxiv.org/abs/hep-ex/0409037)

NC/CC separation procedure for SAND in our plans

Beam monitoring - $\sqrt{\Delta\chi^2}(E_\nu)$



reconstructed events number in front ECAL (ECAL+3DST): 434826 (μ reg. eff. 41.8%),
 reconstructed events number in front ECAL (ECAL+STT): 740000 (μ reg. eff. 71.1%)

Proton beam parameter	Variation	ECAL(3DST)		ECAL(STT)		ECAL(3DST) CDR
		true	rec	true	rec	rec
Horn current	+3 kA	8.4	6.3	10.5	7.9	9.2
Water layer thickness	+0.5 mm	3.8	3.2	4.7	3.8	3.2
Decay pipe radius	+0.1 m	4.7	3.8	6.4	5.2	5.3
Proton target density	+2%	4.8	4.2	6.0	5.1	4.4
Beam sigma	+0.1 mm	3.5	3.0	4.4	3.8	2.8
Beam off set X	+0.45 mm	4.0	3.1	5.3	4.1	3.6
Beam theta phi	0.07 mrad θ , 1.57 ϕ	0.7	0.4	0.8	0.4	0.9
Beam theta	0.070 mrad	0.7	0.4	0.9	0.4	0.4
horn 1 X shift	+0.5 mm	3.2	2.3	4.1	2.9	3.7
horn 1 Y shift	+0.5 mm	3.7	2.7	4.8	3.5	2.8
horn 2 X shift	+0.5 mm	0.5	0.3	0.6	0.4	0.7
horn 2 Y shift	+0.5 mm	0.6	0.3	0.7	0.3	0.7



- ▶ preliminary energy reconstruction in 3DST and ECAL has been done
- ▶ we did a preliminary momentum measurement with smearing 5% in TPC
- ▶ muon registration efficiency for front ECAL events - 41.8%
- ▶ neutrino energy resolution of ECAL+3DST+TPC - 12.1%
- ▶ beam monitoring sensitivity for ECAL+3DST is 20-25% less than for the ECAL+STT configuration
- ▶ we need to check ECAL+3DST+TPC with more realistic ECAL simulation
- ▶ improve CC/NC separation for ECAL+STT