Neutrino event reconstruction in LAr + STT + ECal

(Update)

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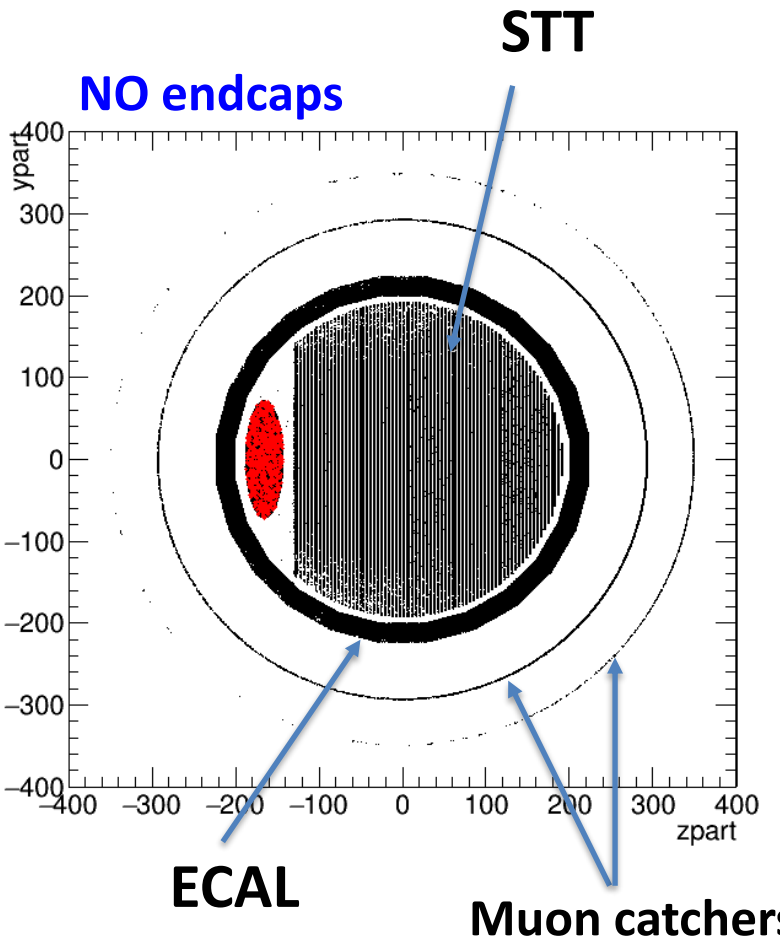
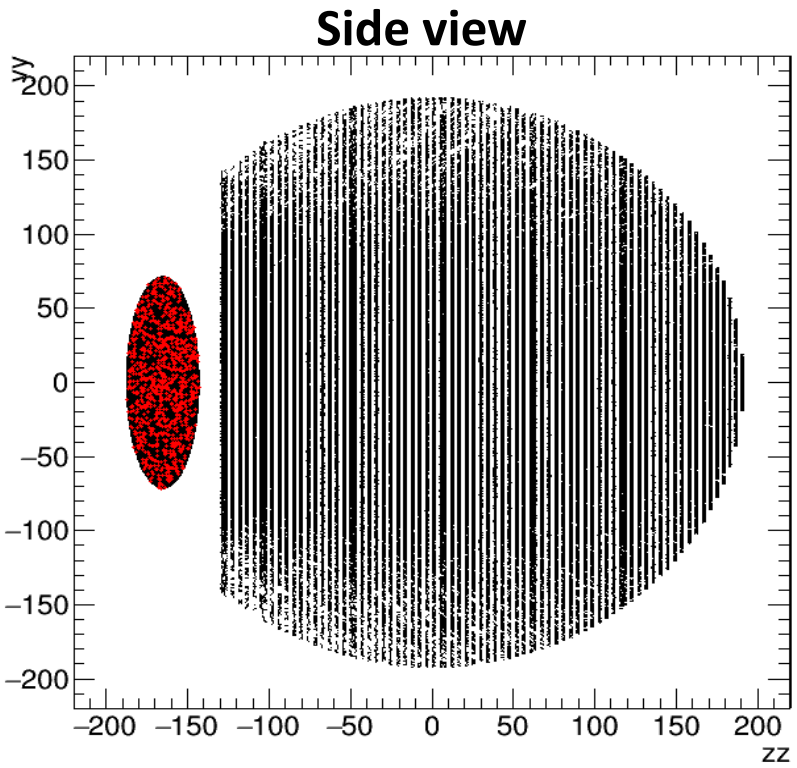
Detector layout (LAr-Target+STT) in FLUKA

- ✓ sample of 10,000 ν_μ-CC interactions in LAr-Target



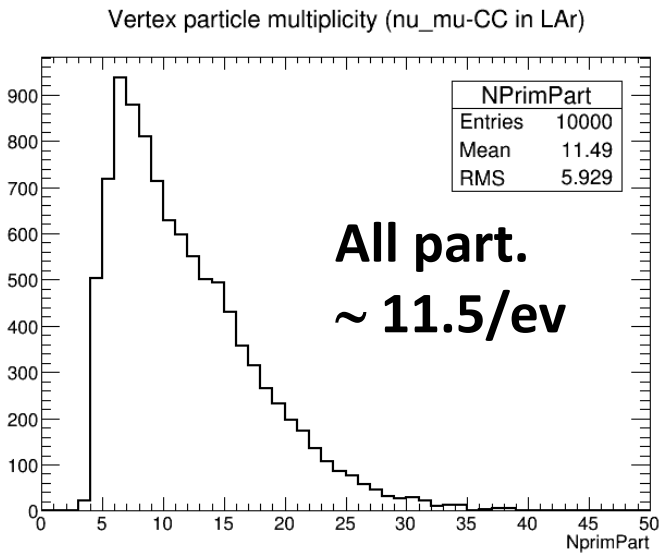


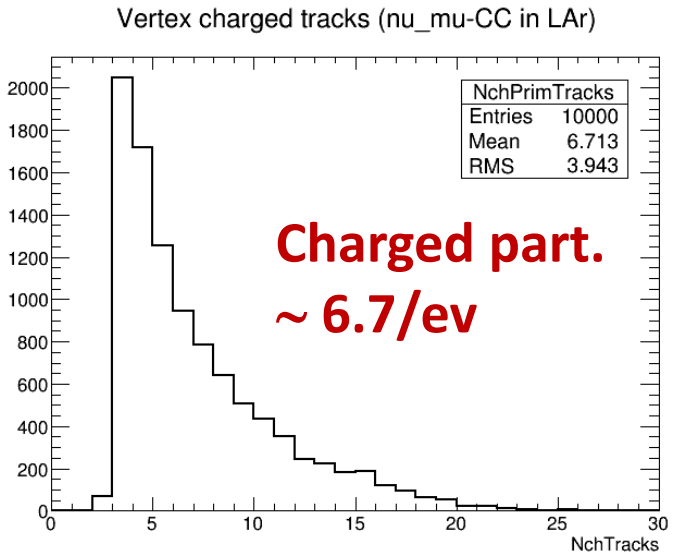
Interaction Vertices in red

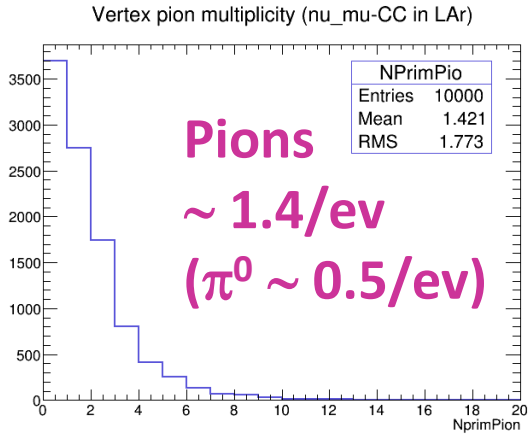
Outline

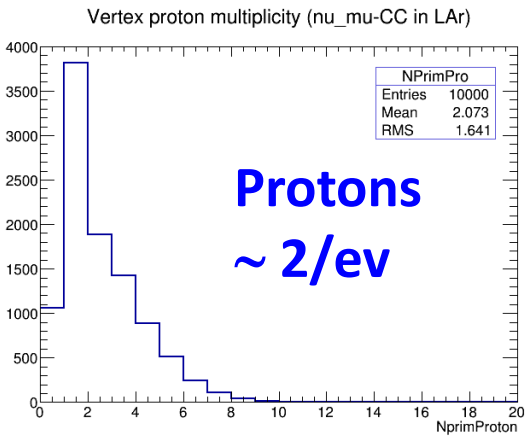
- ✓ **Some event features**
- ✓ **Full event recontruction (preliminary)**
  - ✓ **Track reconstruction**
  - ✓ **Neutrino event estimate (1 track events)**
  - ✓ **Events with more tracks (≤3) …**
  - ✓ **Particle identification …**

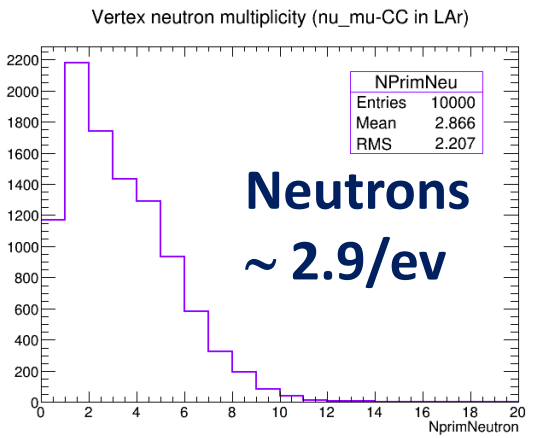
Primary particle multiplicities





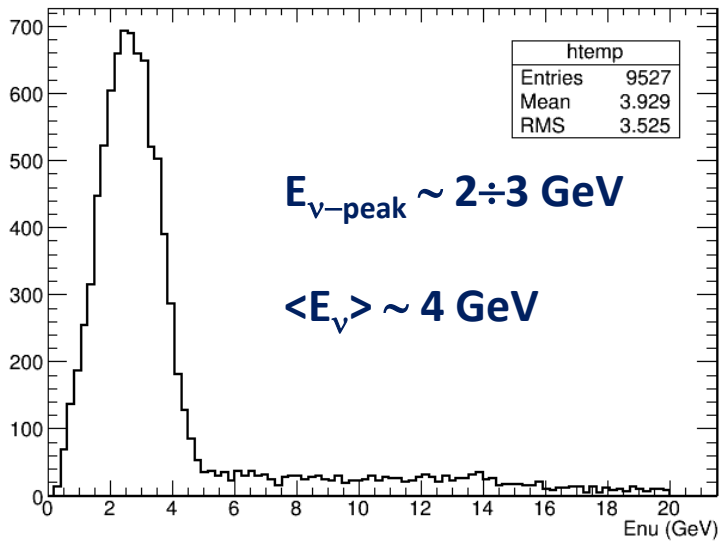


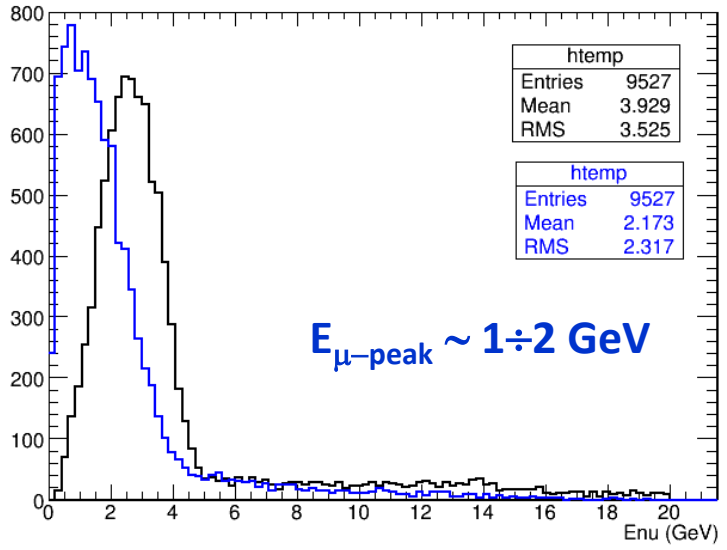




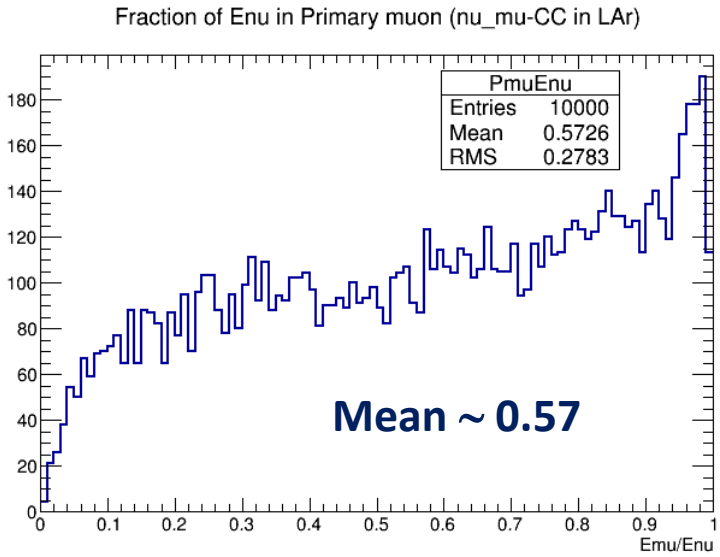
Nuclear fragments ~ 2.6/ev, **Photons ~ 1.4/ev** **+ 1 muon**

Neutrino and muon spectra

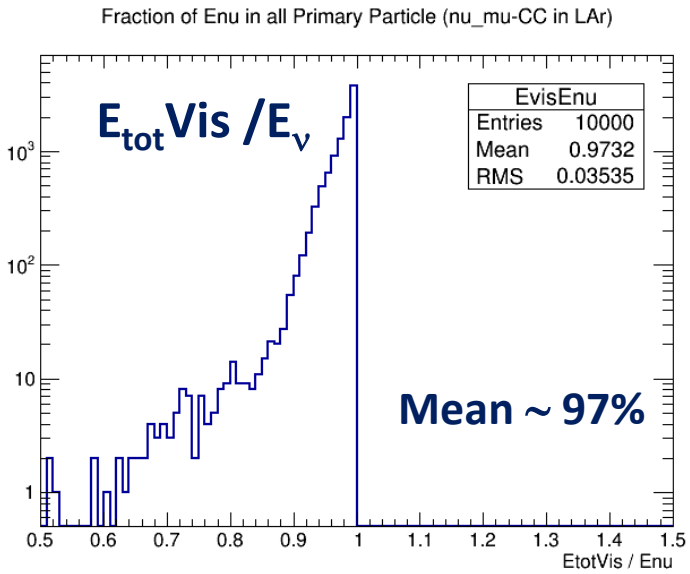




Ratio Pmu/Enu



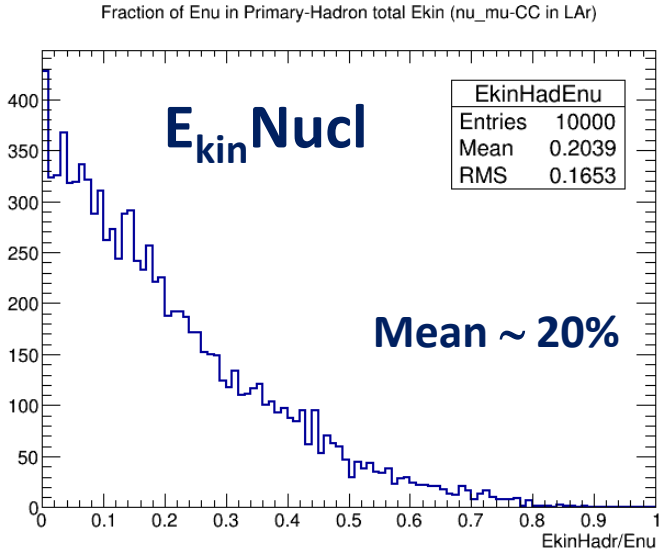
Energy carried out by primary particles

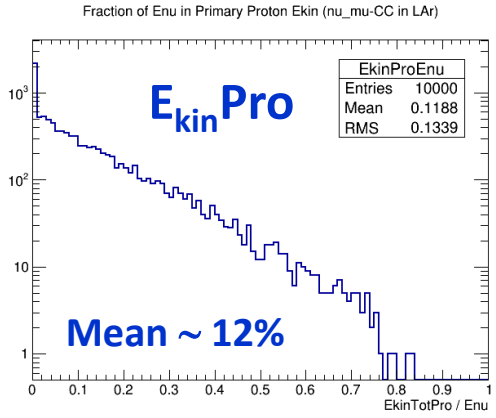


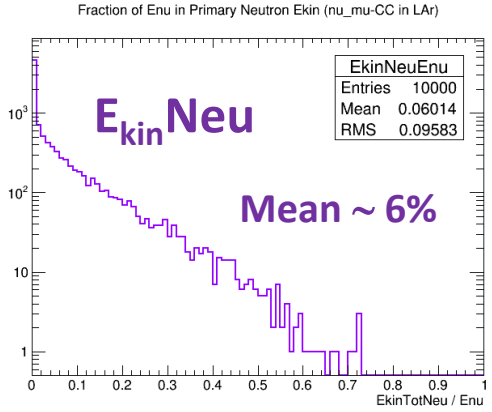
$E_\nu \rightarrow E_{tot}Vis = E_{kin}Nucl + E_{tot}Part$

$E_{kin}Nucl = E_{kin}Pro + E_{kin}Neu + E_{kin}Frag$

$E_{tot}Part = E_{Muon} + E_{Pion} + E_{phot}$

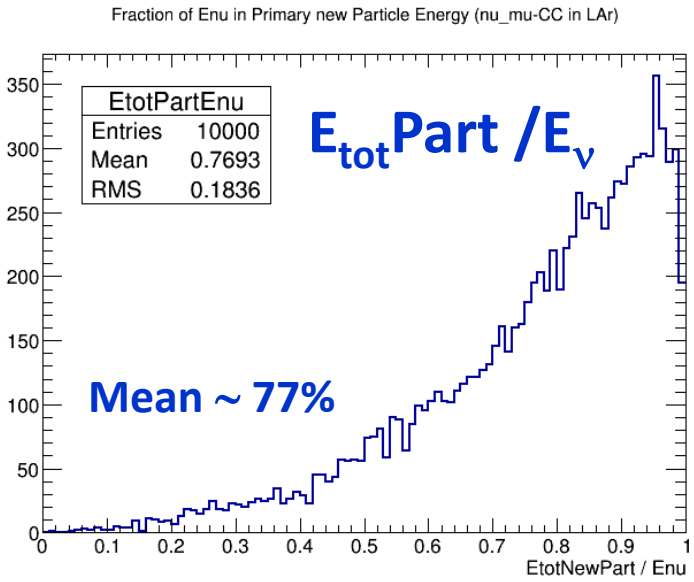


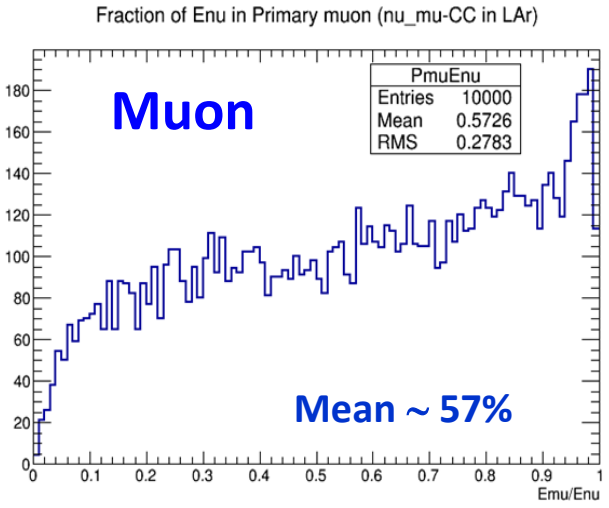


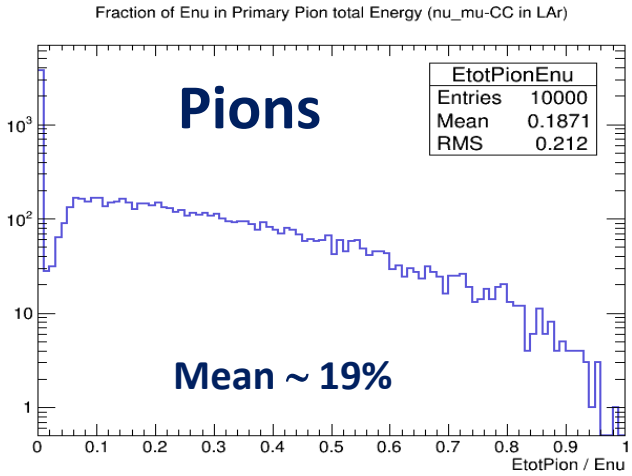


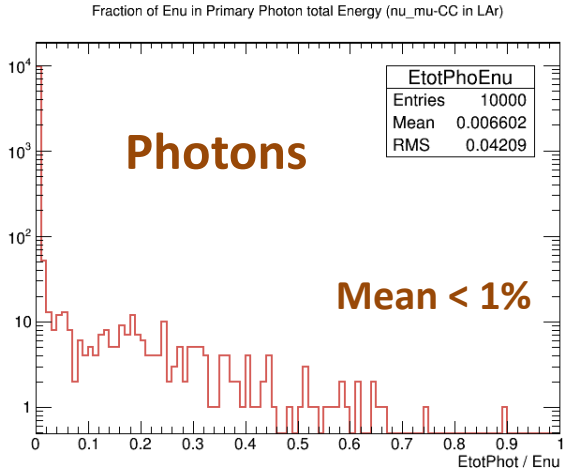
Nuclear fragments: ~2% E_ν

Energy carried out by primary particles

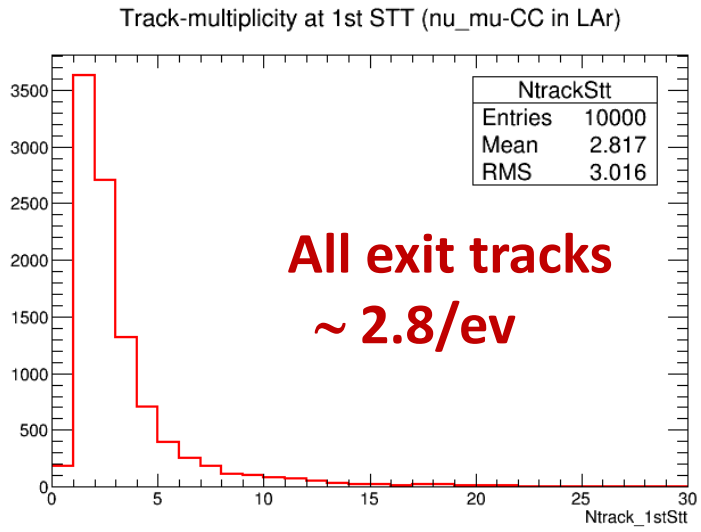






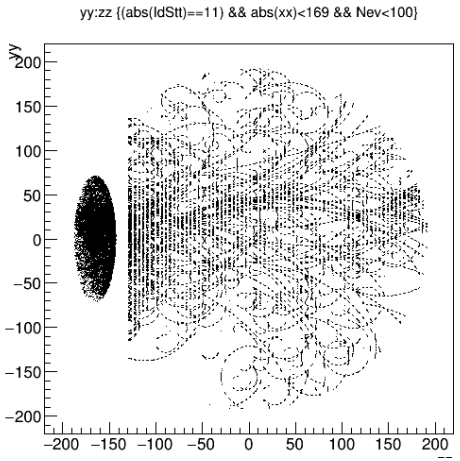


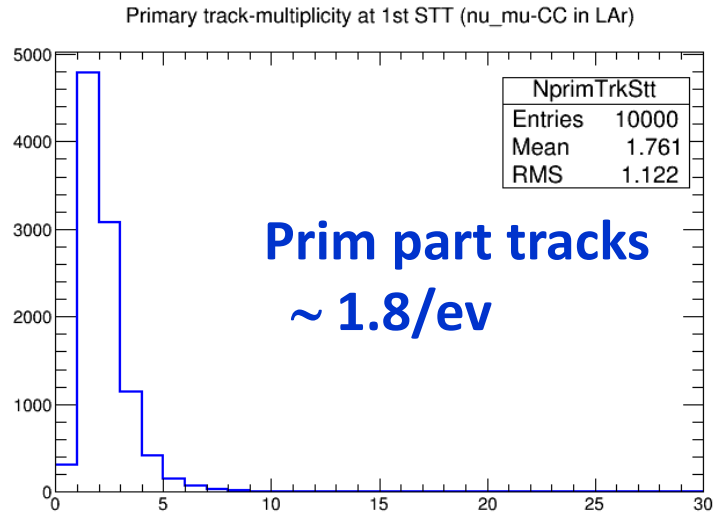
Track multiplicities at 1° ST layer

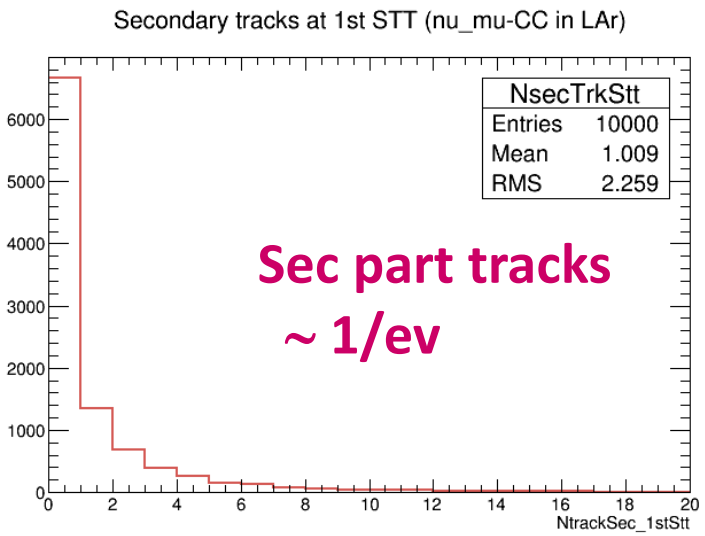


Tracks from Primary and Secondary particles …

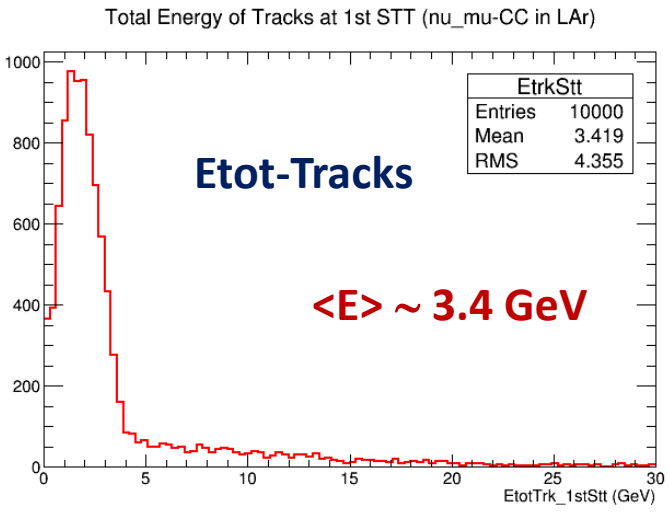
Many secondary electrons (δ rays) in LAr

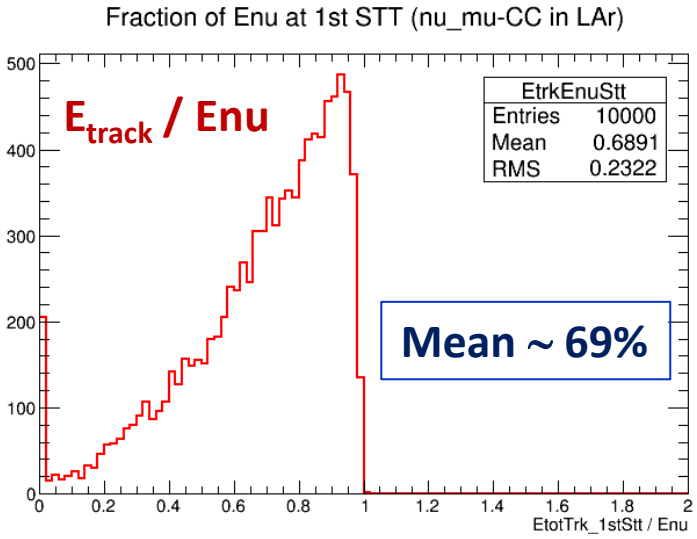


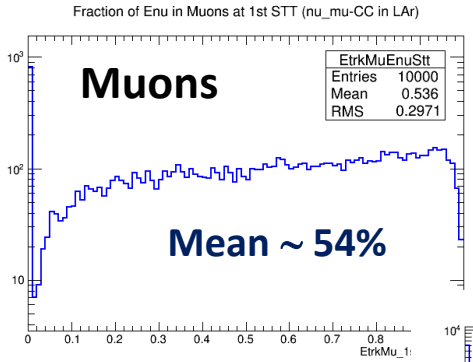


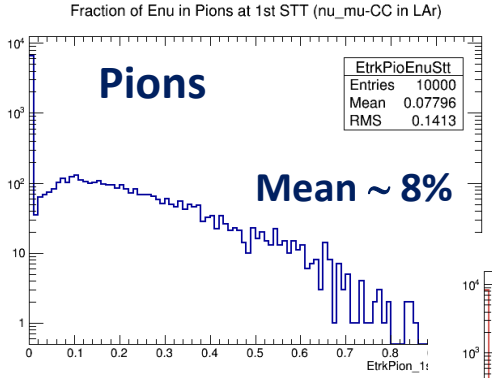


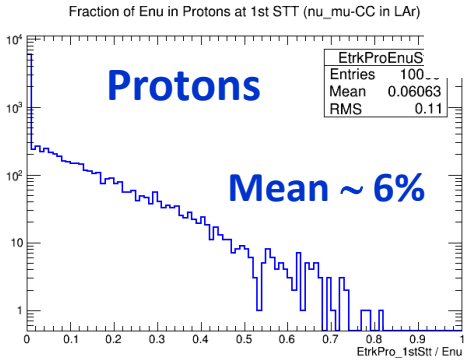
Energy at 1° ST layer

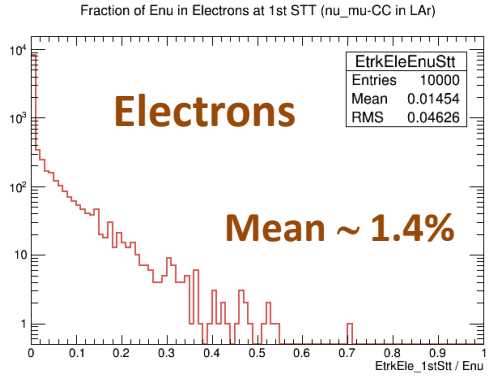






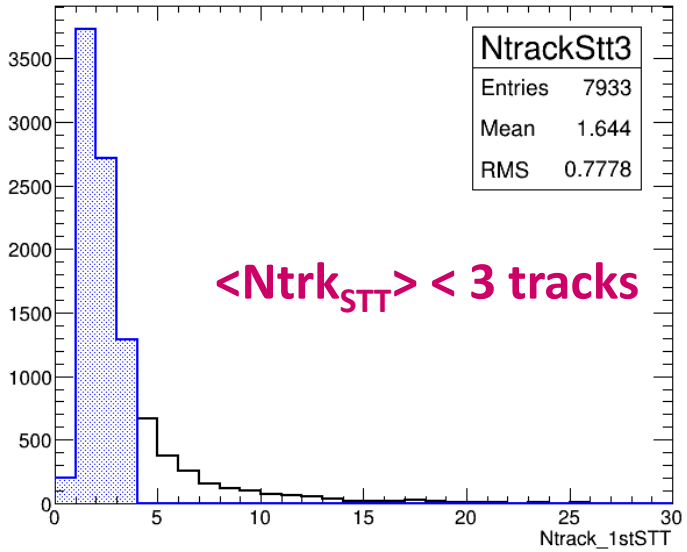






Track multiplicities in STT

At 1° ST layer



Most events with few tracks …

- ~ **79 % up to 3 tracks**
- ~ **65 % up to 2 tracks**
- ~ **37 % only 1 track**

LAr «cleans up» events by absorbing low energy particles and nuclear fragments

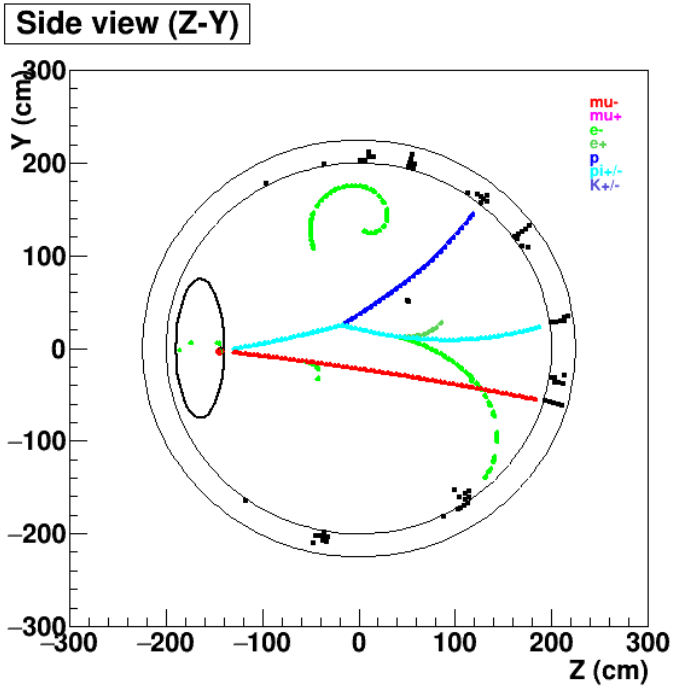
⇒ **Possibility to successfully reconstruct most events by applying global track finding algorithms (<u>with NO MC infos</u>)**

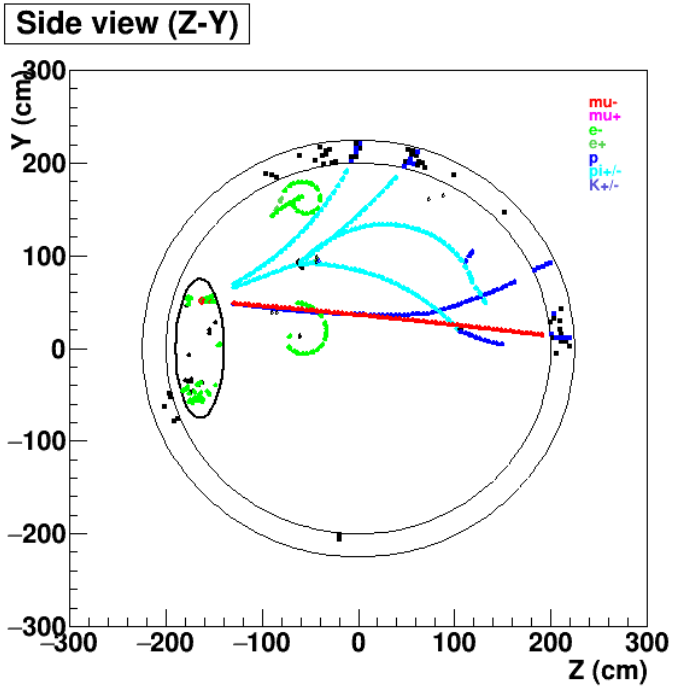
… ν energy fraction deposited in LAr not negligible

Track multiplicities in STT

Track multiplicity at 1st ST layer can underestimate the track multiplicity in STT, due to secondary vertices by interactions, decays, …

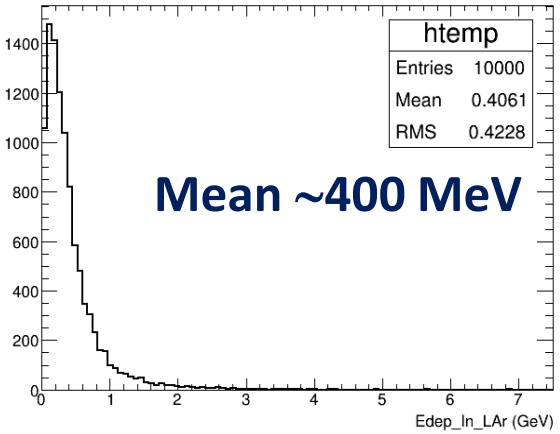
Some examples:

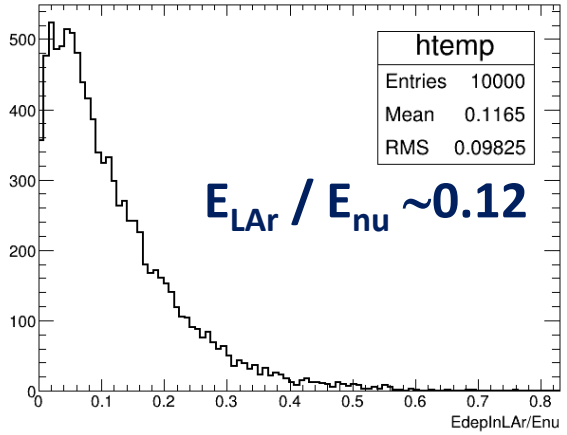




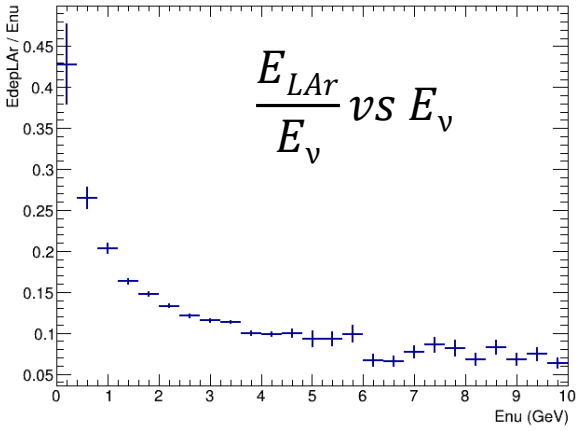
Energy deposited in LAr

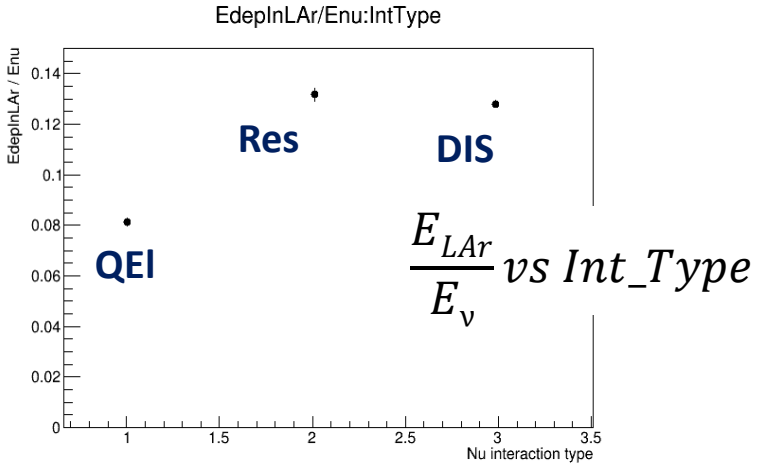
To be estimated as a calorimetric measure





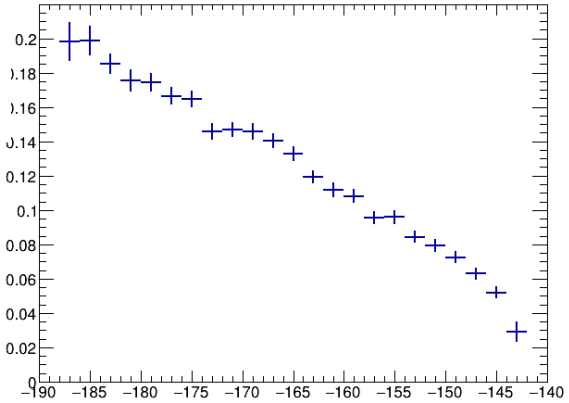
Correlation of $Edep_{LAr}/E_{\nu}$ with ν Energy and CC-Interaction Type





Energy deposited in LAr

EdepLAr/Enu

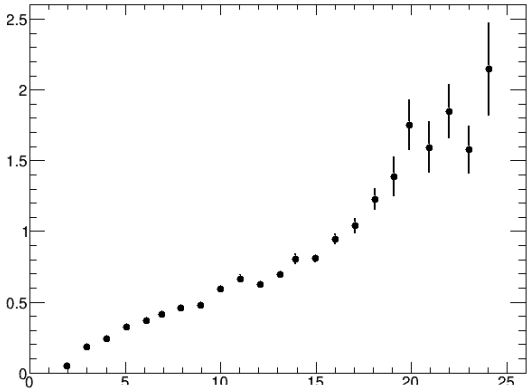


Vertex-Z position

Correlation of $Edep_{LAr}/E_{\nu}$ with Vertex-Z position in LAr-target

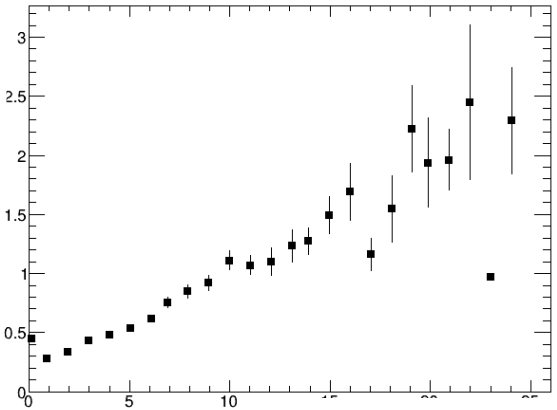
Correlation of $Edep_{LAr}$ with Charged tracks at vertex and tracks in STT

EdepLAr (GeV)



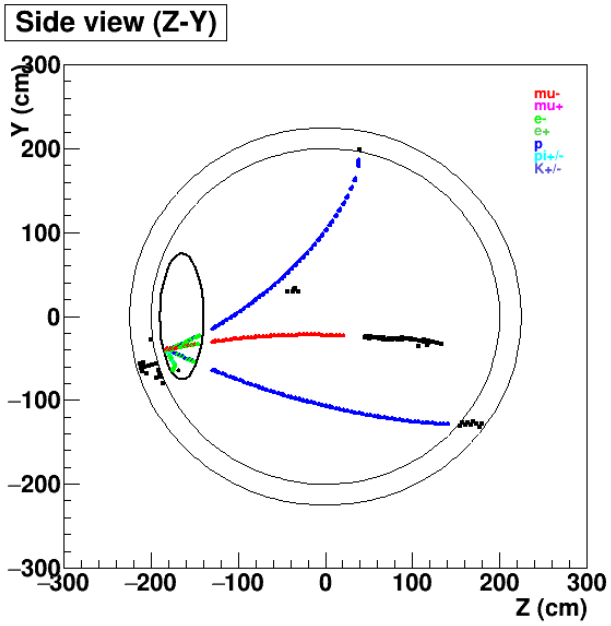
vertex charged Tracks

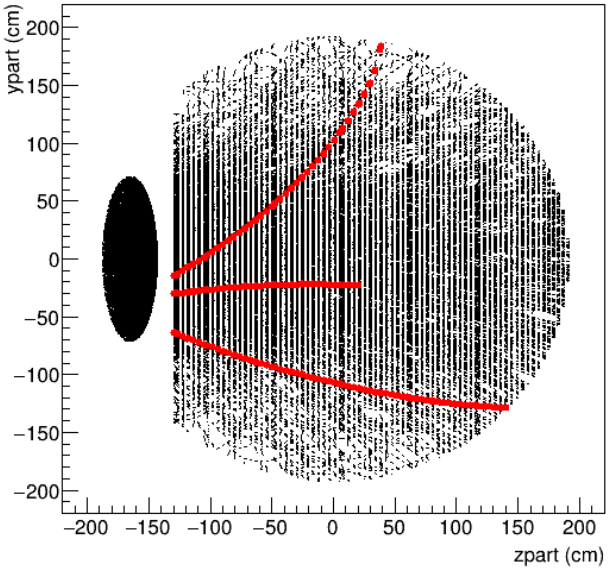
EdepLAr (GeV)



Tracks in STT

Event reconstruction in LAr + ECal + STT





ν_μ - CC interaction in LAr target

- Eν fraction deposited in LAr (evaluated from light yield)
- Vertex reconstructed in LAr (from times and imaging)

✓ External interactions from LAr scint light, ECal signal, time info, topology …

✓ Outgoing particles tracked in STT and ECal

✓ For a few tracks, global transform method expected to work

Event reconstruction strategy

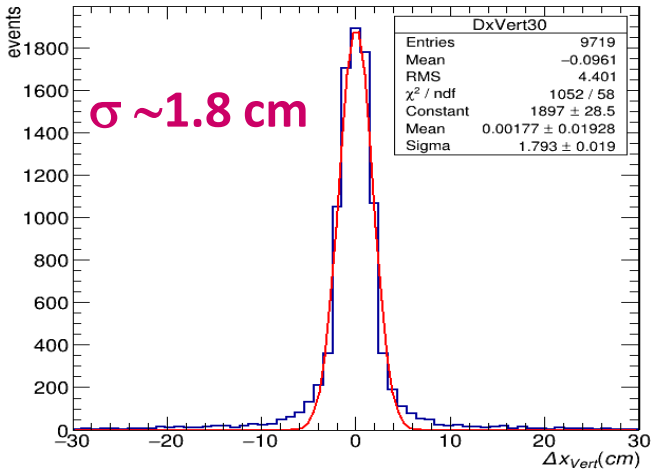
- NOT using MC 'truth'
- Vertex reconstruction (LAr light signals, time, …)
- Track finding (Global transform method) in the tracker
- Linear or circle fits to the tracks
- Vertex reco from crossing of 2 most rigid tracks (Step 1)
- (Possibly, procedure iteration …)

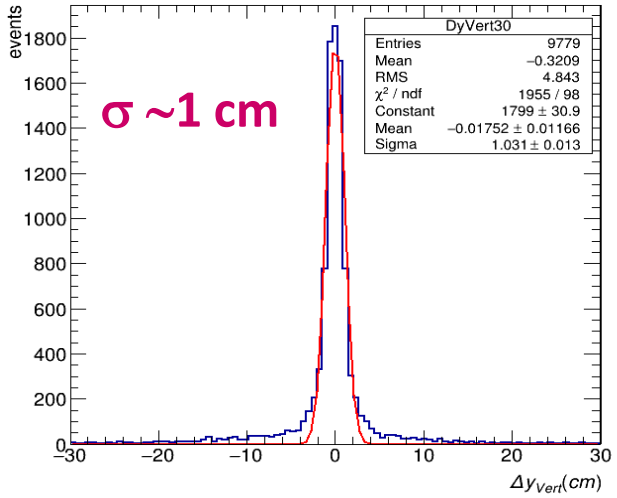
} both X-Z and Y-Z views

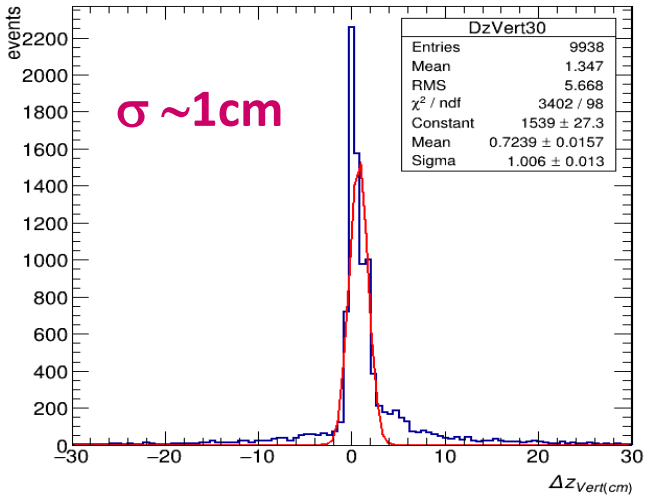
- Matching of tracks in the two views ⇒ track in 3D space ⇐
- Evaluation of $p_\perp$ (from curvature radius) and dip-angle (from x vs ρ linear fit) ⇒ p estimate ⇐
- ECal hits compatible with tracks ⇒ ToF measurement (LAr-Ecal)

+ Track-Eloss in LAr ⇒ β estimate for each track ⇒ PID …

Vertex "reconstruction" in LAr-target from hit positions with edep weights







Basic idea:

tight correlation with scintillation light emission

⇒ Vertex position from light collected by photosensor through lenses or coded masks (precision ~cm)

Track reconstruction (transform method)

Track-finding: global transform method → Vertex needed

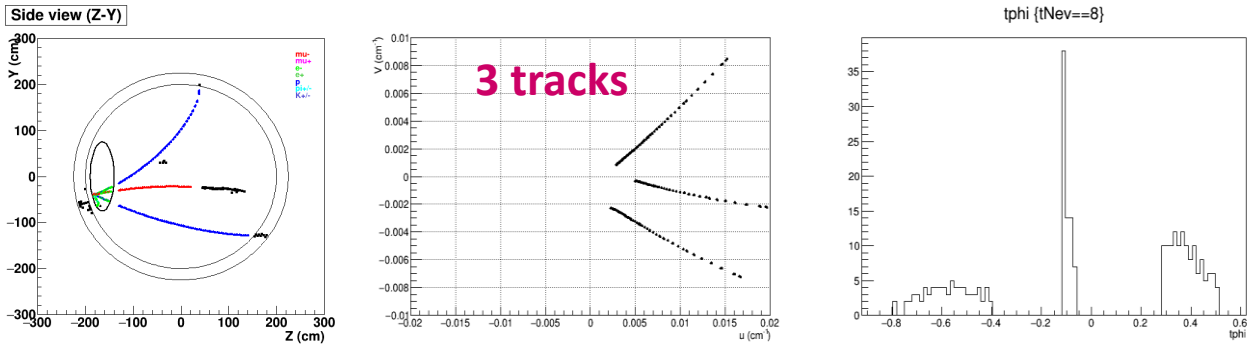
- Use of above Vertex position (from MC hits) reconstructed in LAr
- "Reconstructed" Vertex used for coordinate transformation:
  $x \rightarrow u \qquad y \rightarrow v$

$$u = +(z-z_V) / [(z-z_V)^2 + (y-y_V)^2]$$
$$v = -(y-y_V) / [(z-z_V)^2 + (y-y_V)^2]$$

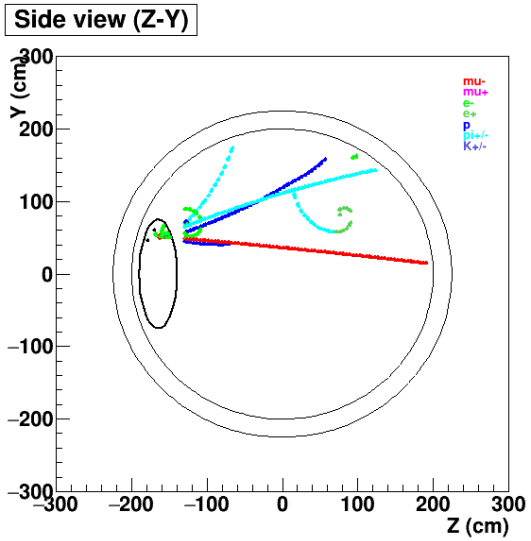
Vertex: (z_V, y_V)

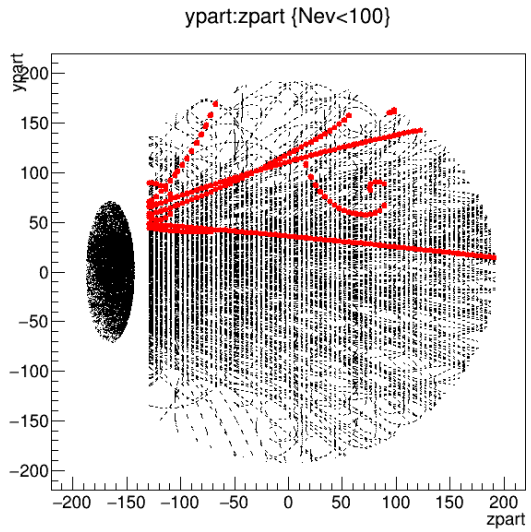
- Search for peaks in distribution of $\phi = \arctan(v/u)$
- Associate digits to tracks and perform the fit (NO MC info used!)

Example:

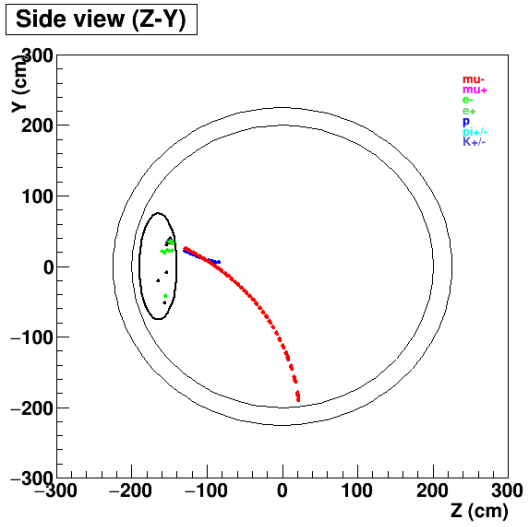


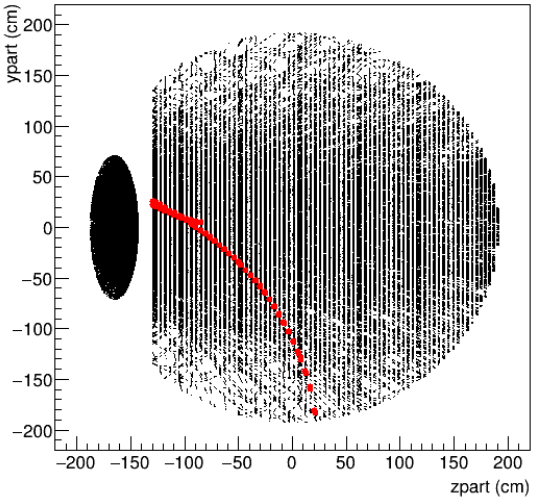
Problematic situations





Many tracks, eventually crossing each other





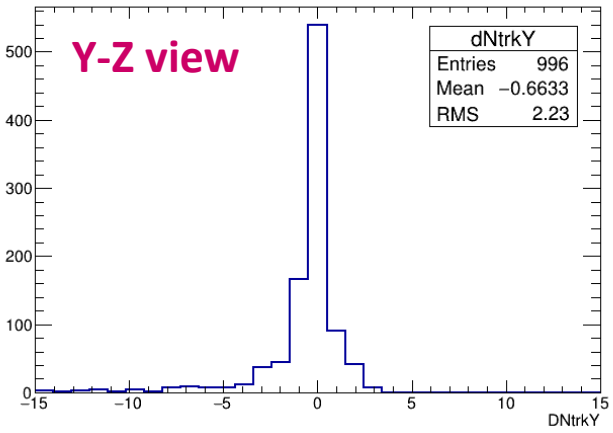
Superimposed tracks, although few

Reconstructed vs real (MC) tracks at 1st STT

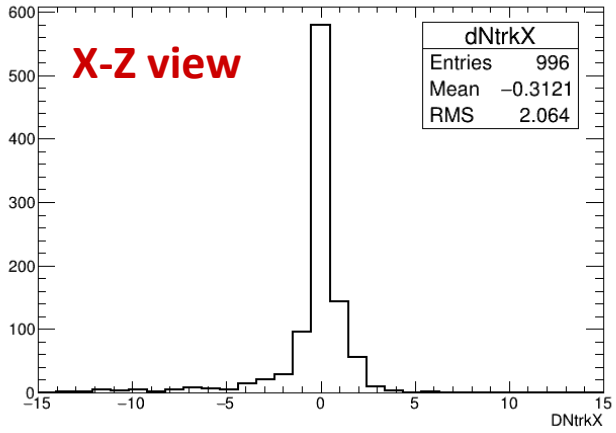
Any track multiplicity

Preliminary

Δ Ntrack

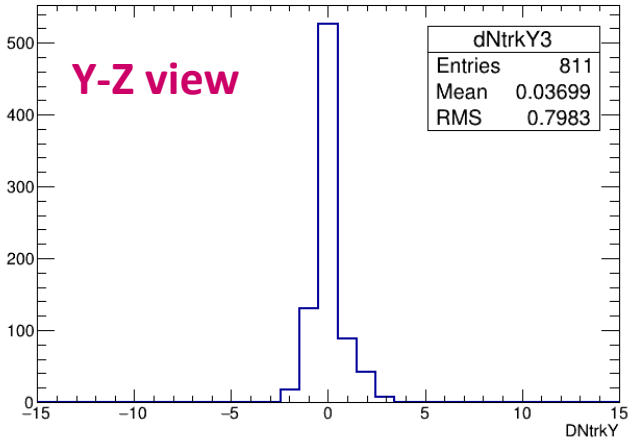


Δ Ntrack

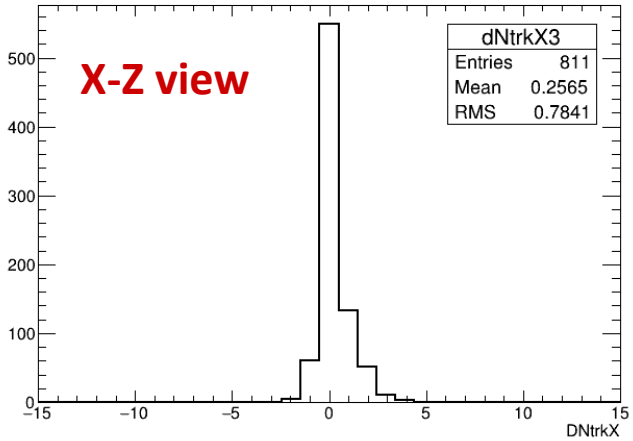


Track multiplicity ≤ 3

Δ Ntrack



Δ Ntrack

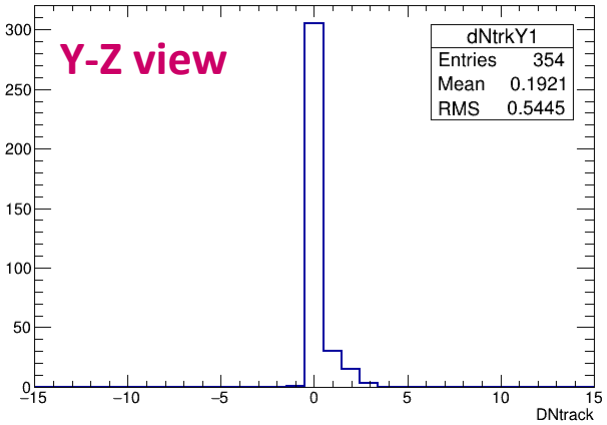


Single track events

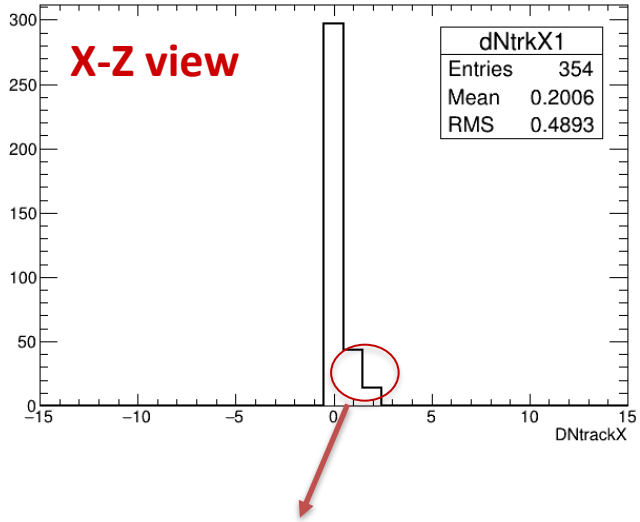
Preliminary

Difference btw Reconstructed and MC (single) track entering STT:

Δ Ntrack

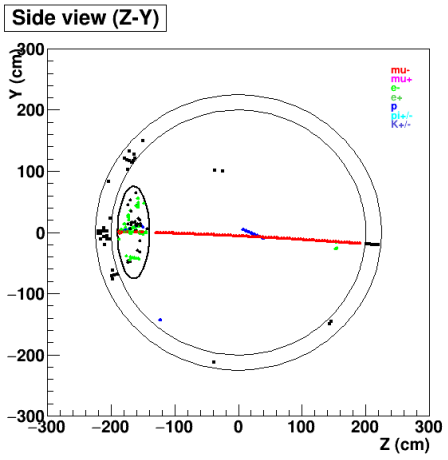


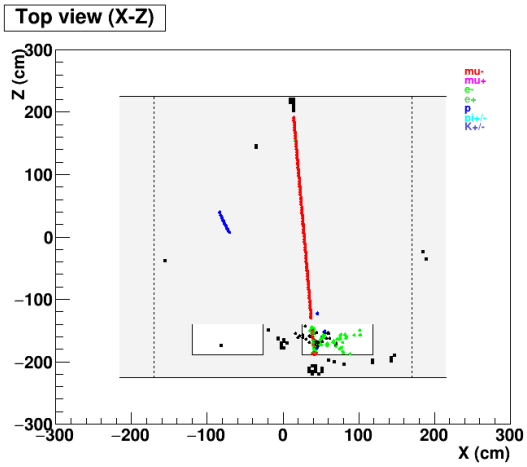
Δ Ntrack



1 track in Y-Z view

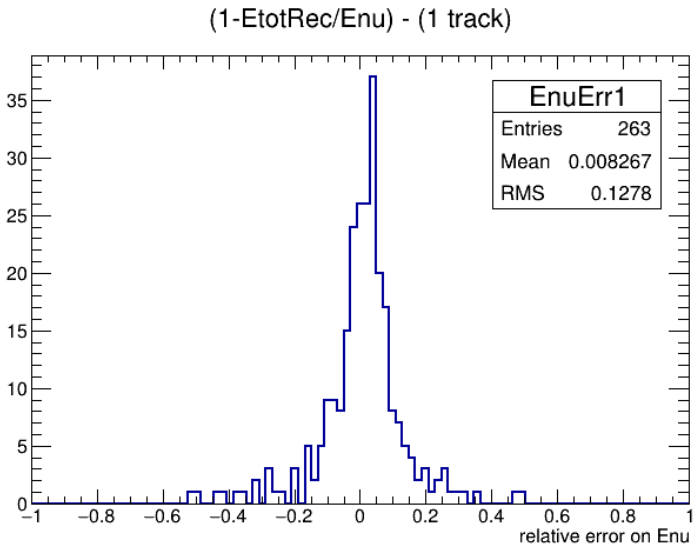
2 tracks in X-Z view

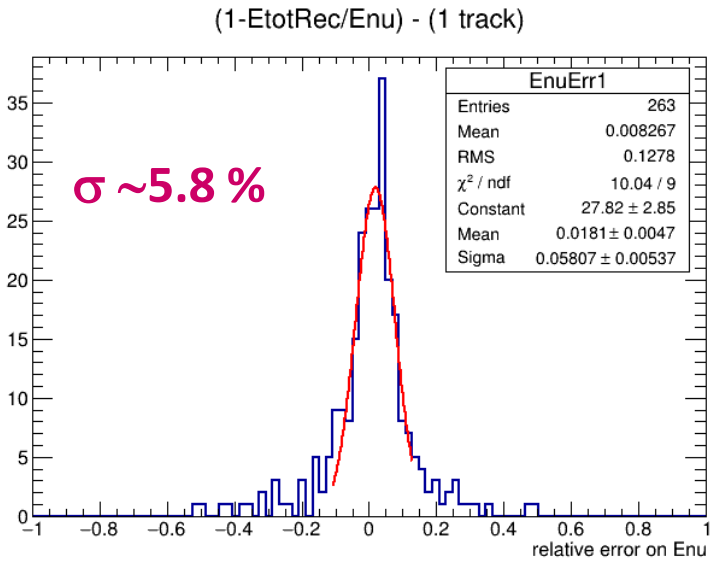




Single track events: ν Energy reconstruction

Preliminary





Track succesfully matched in the 2 views ⇒ track in space (~75%)

Energy deposited in LAr assumed to have been measured

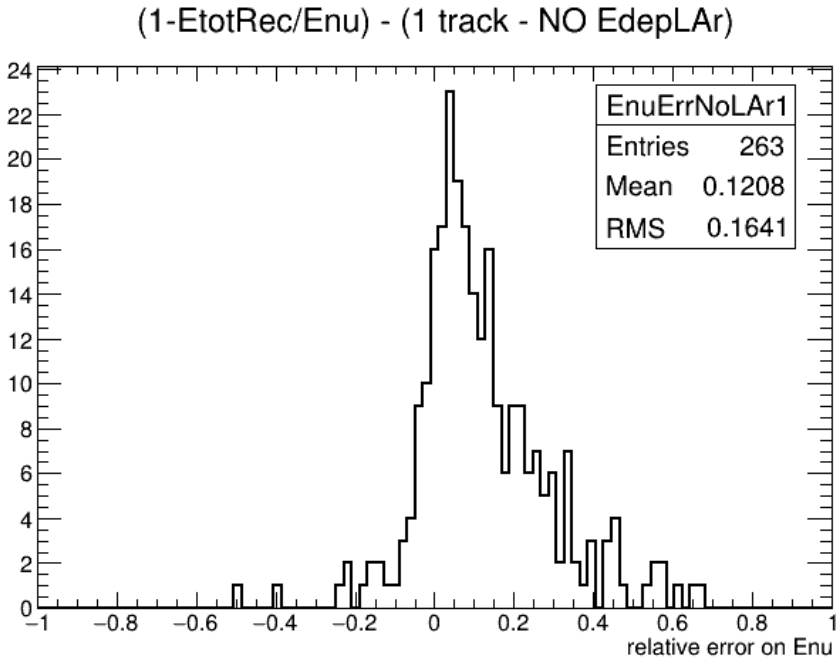
Off-track energy deposited in ECal taken into account

Track ascribed to the muon (true in 95% of events, p in 4%, π± in 1%)

Single track events: ν Energy reconstruction

Preliminary

Ignoring the Energy deposited in LAr …

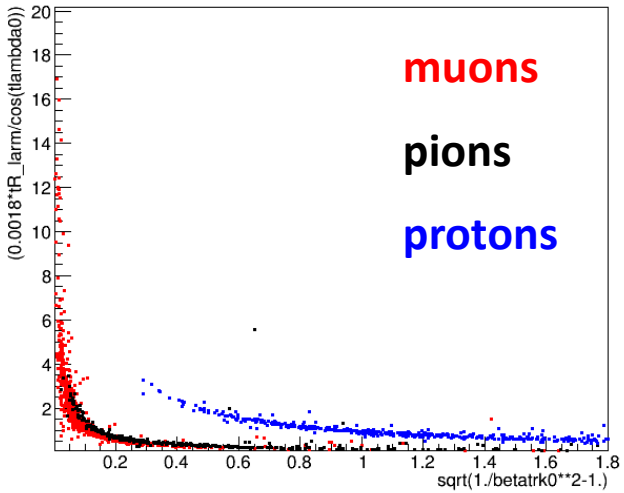


~12 % missing energy (that deposited in LAr)

Off-track energy deposited in ECal taken into account

Identification of charged tracks from β

p vs 1/(β · γ)

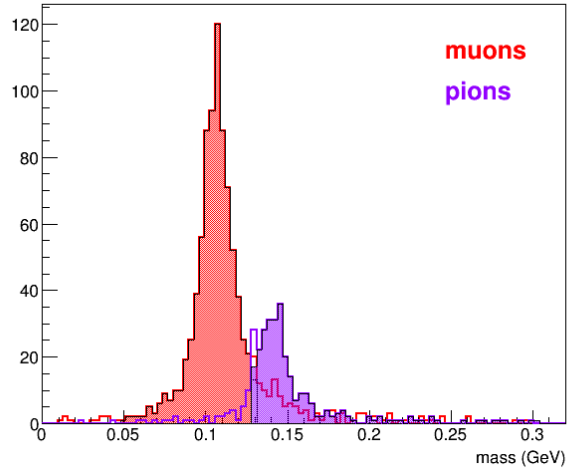


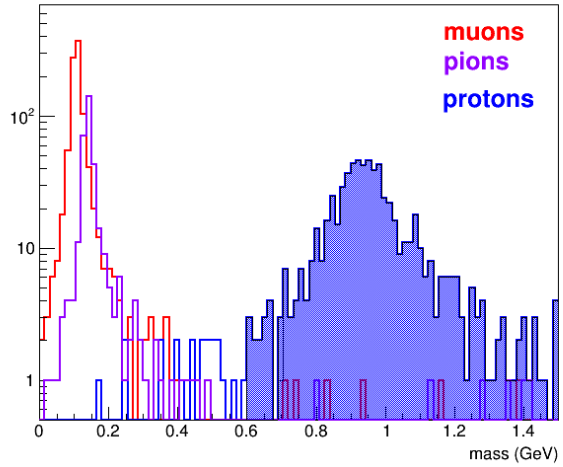
Without taking into account STT and ECal time resolutions

ToF from LAr target and ECal

+

particle energy loss in LAr are needed



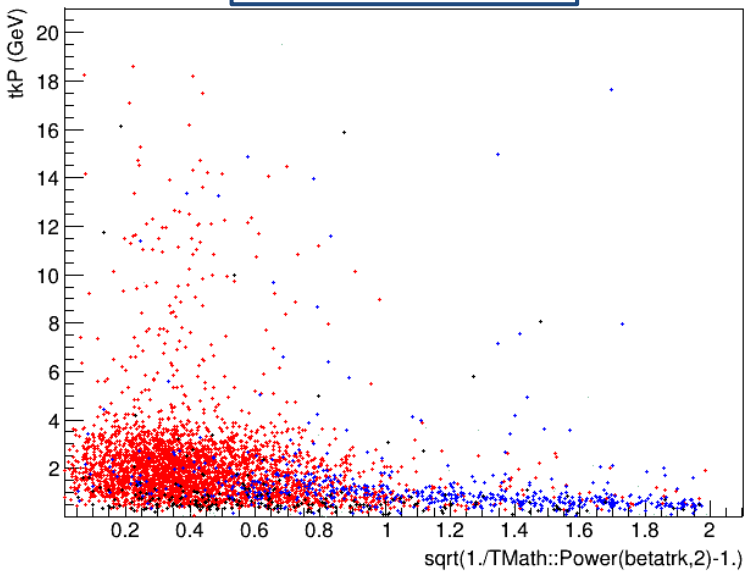


Identification of charged tracks from β

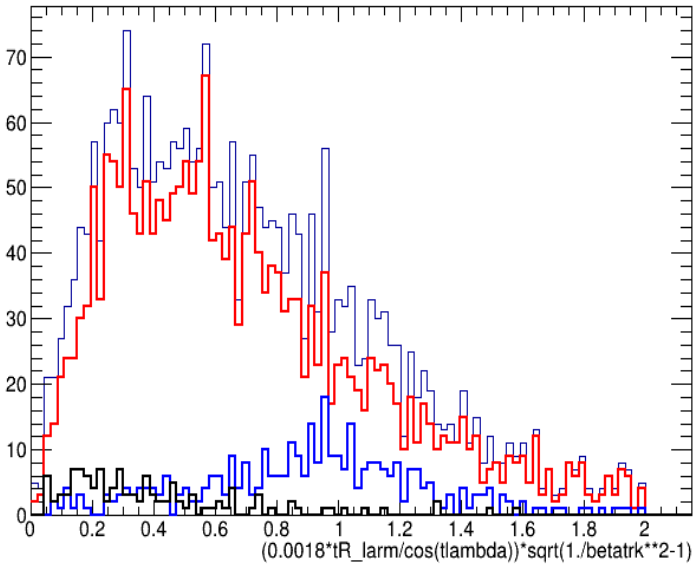
When STT and ECal time resolutions are considered

σ_t (STT) ~ 1 ns

p vs 1/(β · γ)



Mass distribution



NO separation is possible ⇒ ToF from LAr and Ecal (σ_t in LAr ~ 200 ps)

Identification of charged tracks from β

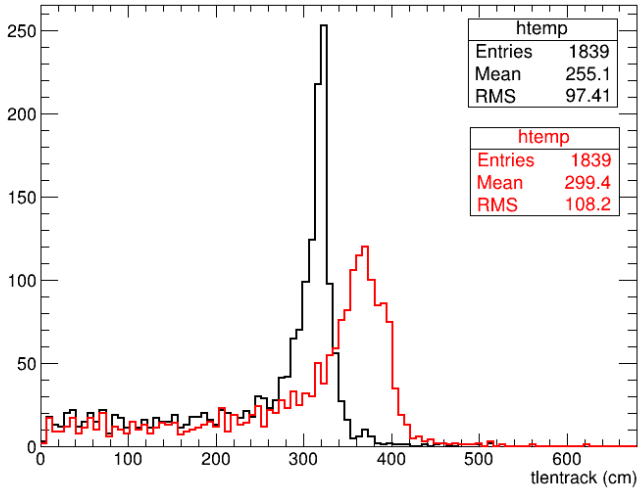
- Track from STT
- β to be determined from LAr and ECal

$\sigma_t^{LAr} = 200ps$

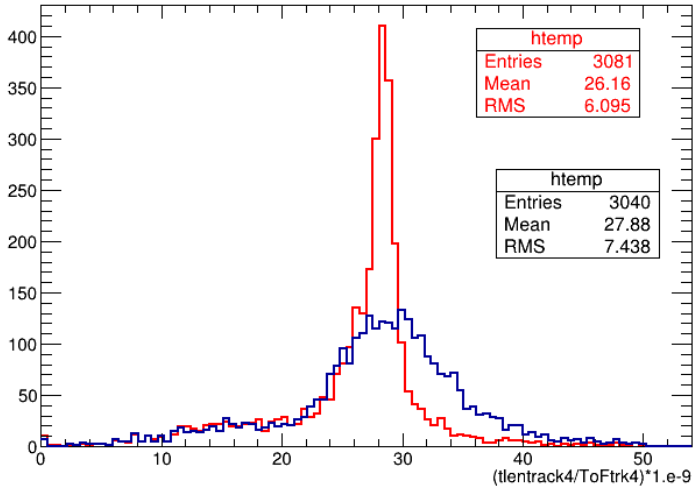
$\sigma_t^{ECal} = 54ps/\sqrt{(E/GeV)} \oplus 50ps$

- ToF from LAr and Ecal
- P_rec at Vertex in LAr (P_{track} from track + E_{loss} in LAr)

Track-length from Vertex to Ecal compared to that from STT+ECal



β values from LAr+ECal compared to STT+Ecal



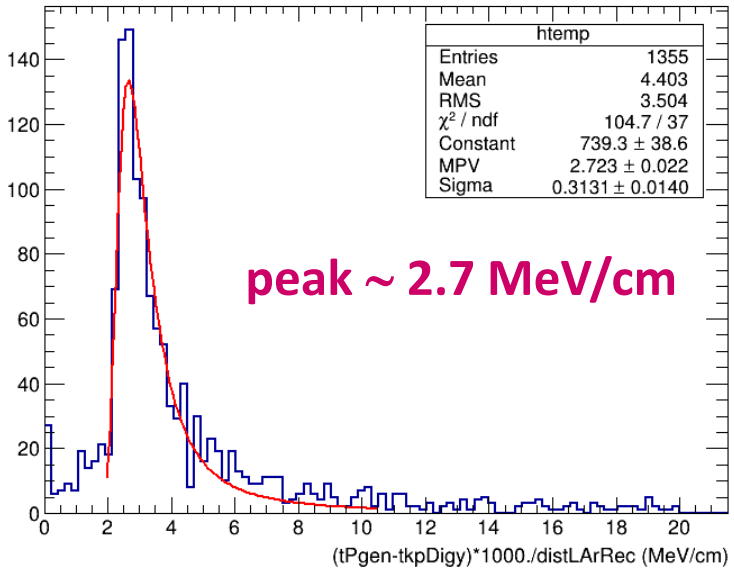
Track energy loss in LAr

From difference between P_{gen} (simu) and P_{track} (reco) and reco Track-length in LAr

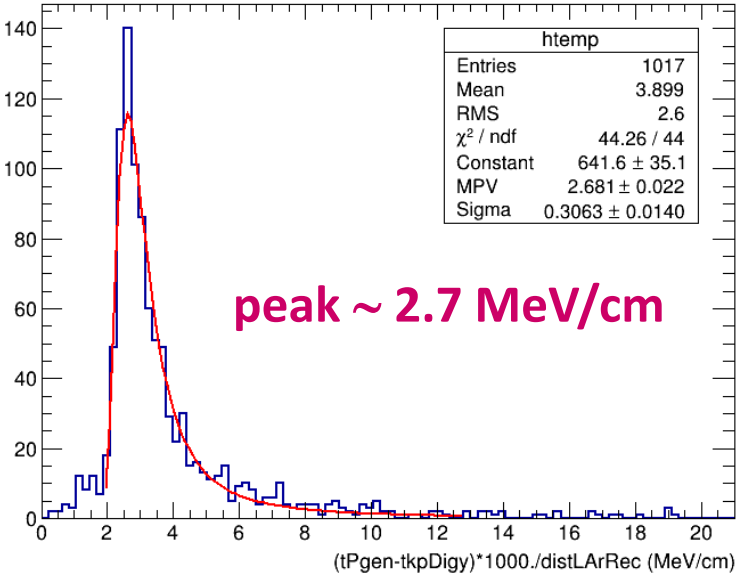
(track-length distance btw reco Vertex and 1° Hit of track in STT)

⇒ Energy loss for unit of length in LAr, dE/dx (MeV/cm):

any particle (≤3 tracks)



muon

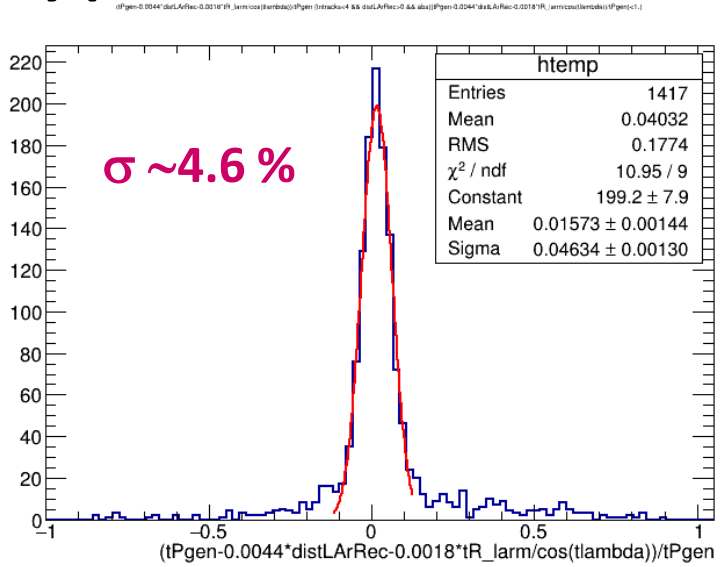


Momentum reconstruction at Vertex

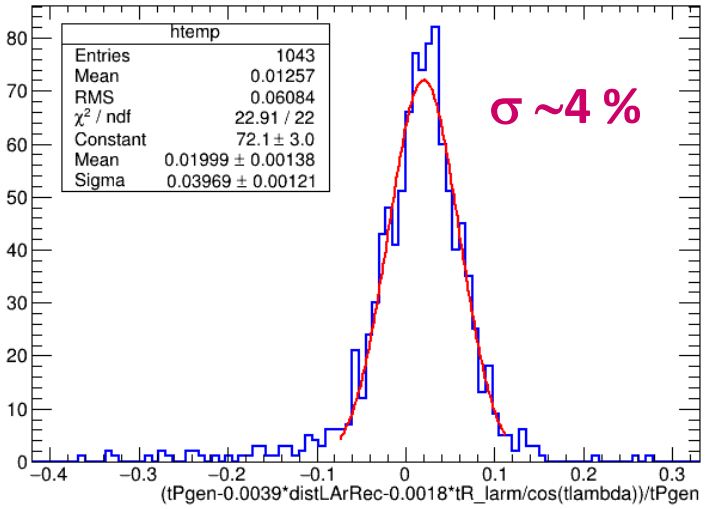
Estimating the track Energy loss in LAr from path-length and previous plots (ΔE = LAr_path*<dE/dx>):

Preliminary

any particle (<dE/dx> = 4.4 MeV/cm)



muon (<dE/dx> = 3.9 MeV/cm)



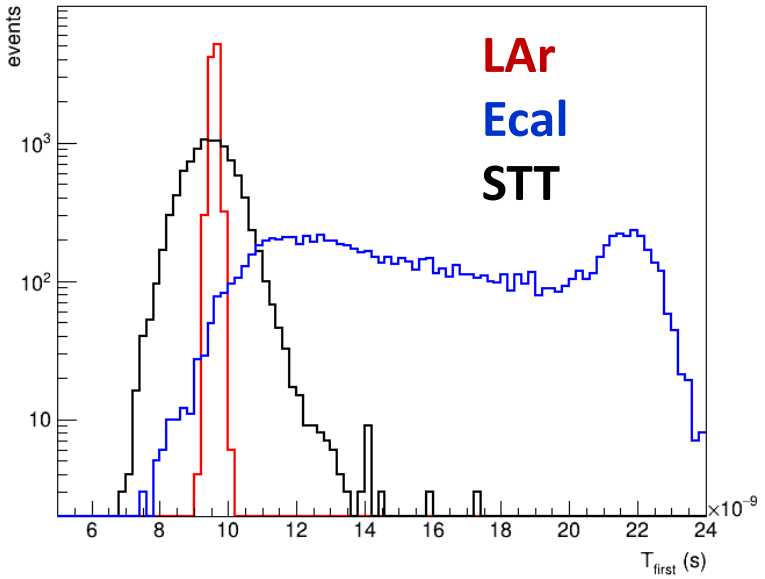
Work in progress

- ✓ **Vertex reconstruction from time and light (Hadamard masks)**
- ✓ **Match of the tracks in the two views of STT and with ECal**
- ✓ **β evaluation for each track (times from ECal and LAr)**
- ✓ **Estimate of Energy deposited by tracks in LAr**
- ✓ **Particle Id**

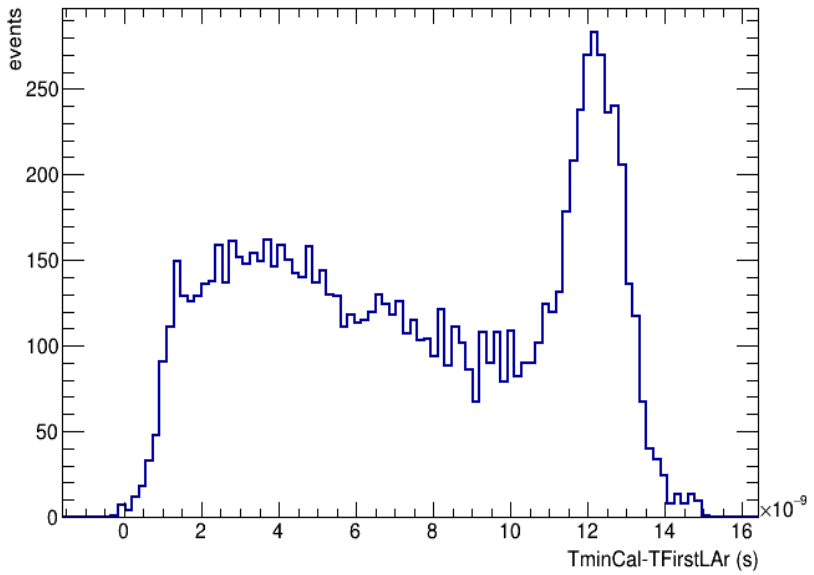
….

Backup

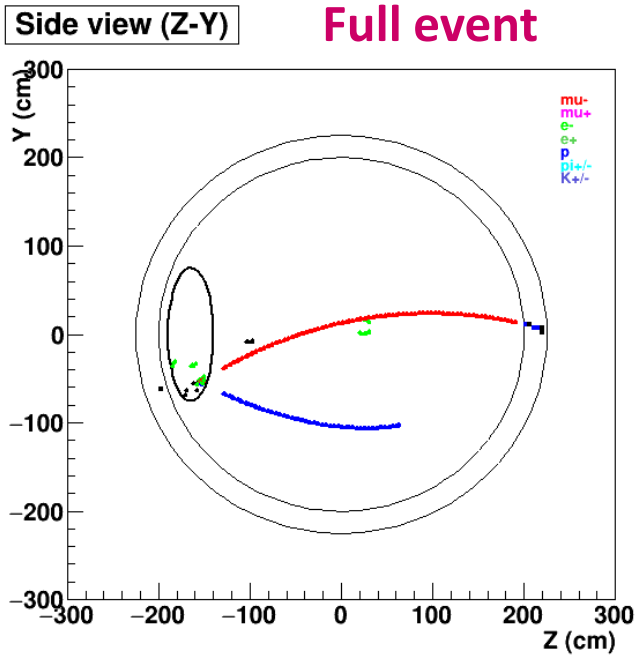
First time in LAr, ECal and STT

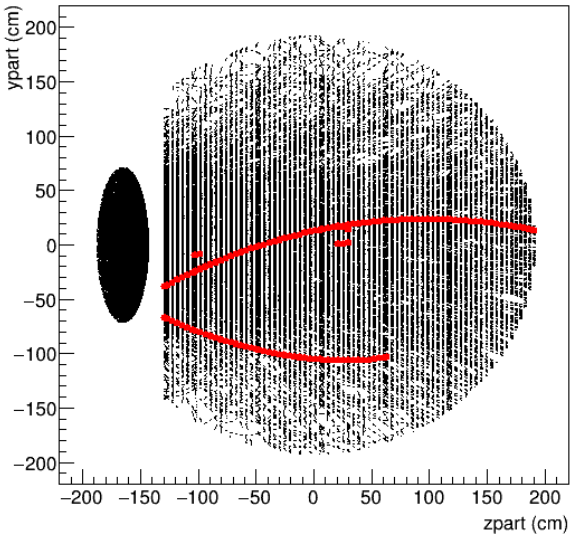


TminCal - TFirstLAr



Full reconstruction of events





Digit:
coordinates = average hit position in the tube

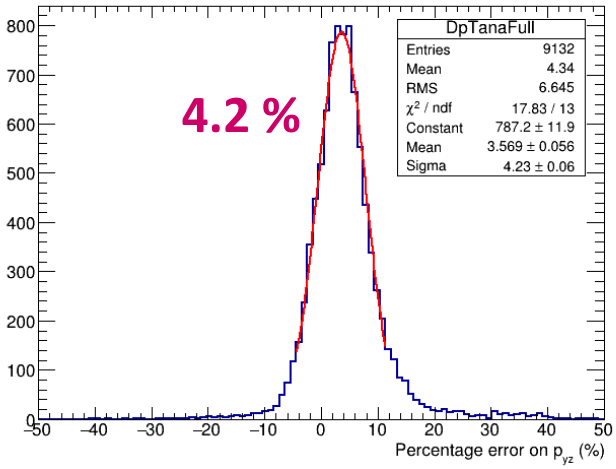
$\sigma_{y,z}$ = 200 μm, σ_t = 1ns

- ✓ ν_μ - CC interaction in LAr target
- ✓ One Digit for each ST layer (154 layers in each view)
- ✓ Track finding and Fit of tracks in the y-z and x-z views, separately

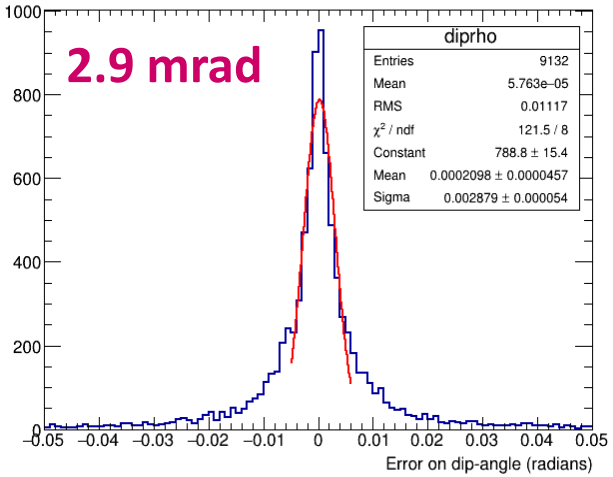
Muon momentum reconstruction in STT

Muon digits identified through MC ⇒ fit by a circle in y-z view (→ pT), linear fit in ρ-x view (→ dip-angle)

Error on p_{yz} tracks



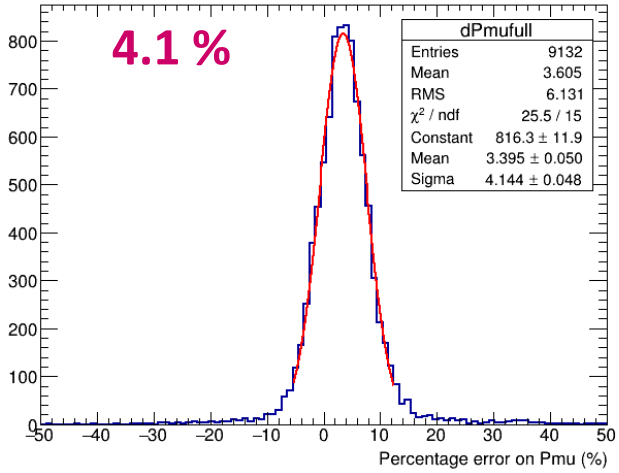
Error on dip-angle



$\rho = z*\cos(\phi) + y*\sin(\phi)$

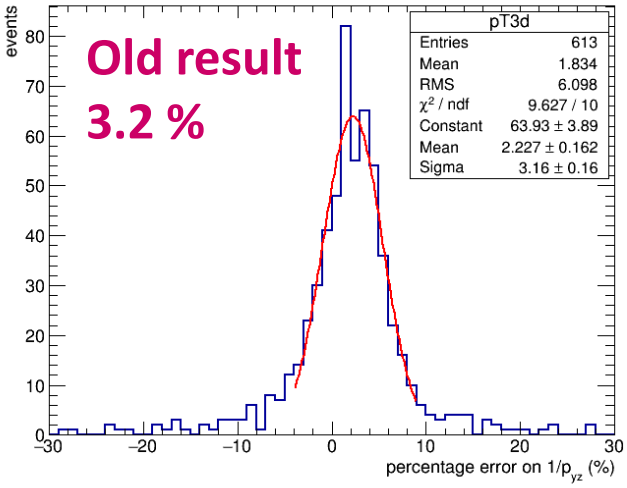
$\phi = \text{atan}(-(z_0-z_C)/(y_0-y_C))$

Error on total p: $p=p_{yz}/\cos(\lambda)$

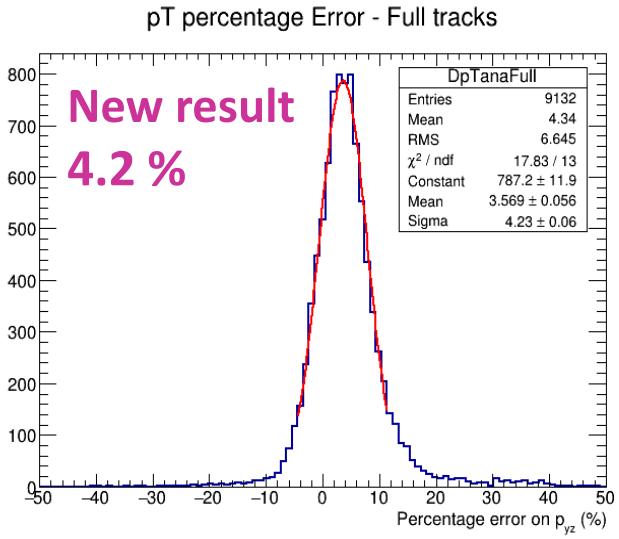


Muon momentum: comparison with old result …

Error on p_{yz}



STT density increased



Main effects: increase of (1) Multiple scattering and (2) energy loss

- **What about fitting only initial portion of track?**
  No improvement is expected, due the track-length (L) dependence …

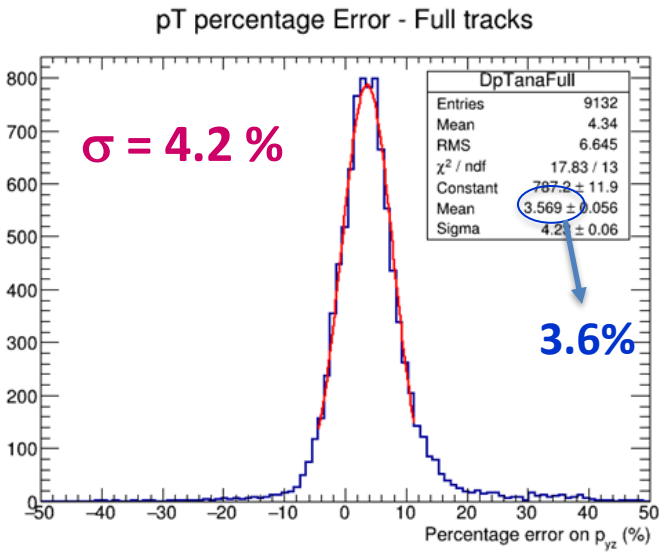
At high energy:

$$\frac{\delta p}{p^2} = \frac{8\delta y}{0.3BL^2}$$

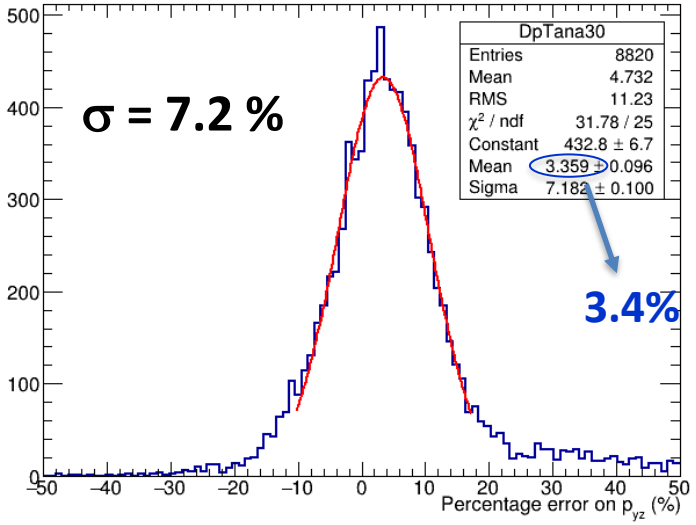
At low energy (where MS dominates):

$$\frac{\delta p}{p} \sim \frac{0.0136}{\beta}\sqrt{\frac{X}{X_0}}\frac{1}{0.3BL}\frac{\sqrt{4A_N}}{N}$$

Full tracks (L ~150 cm)

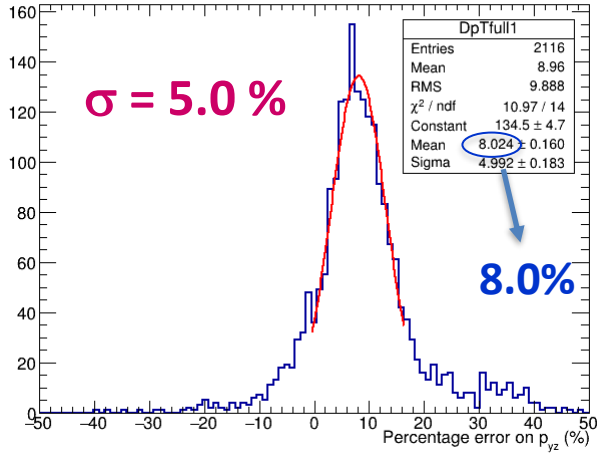


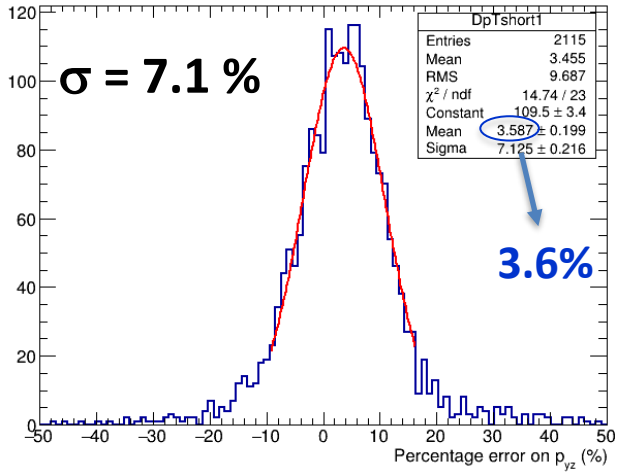
Short tracks (L ~60 cm)



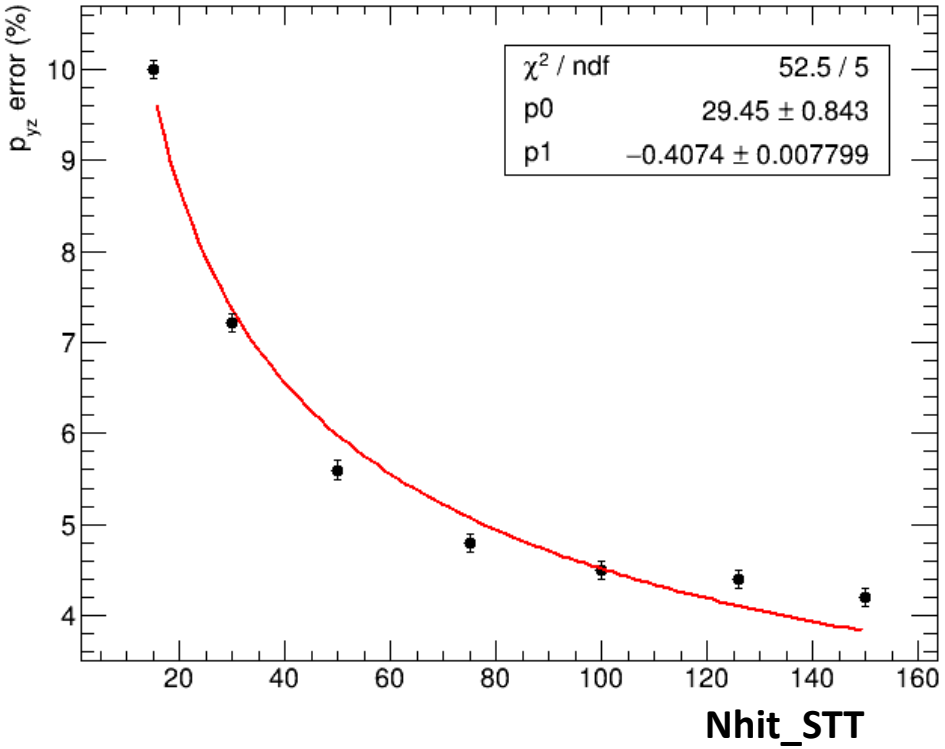
Peak offset related to energy loss

Pmu < 1 GeV/c





Error on Muon pT: dependence on Track-Length



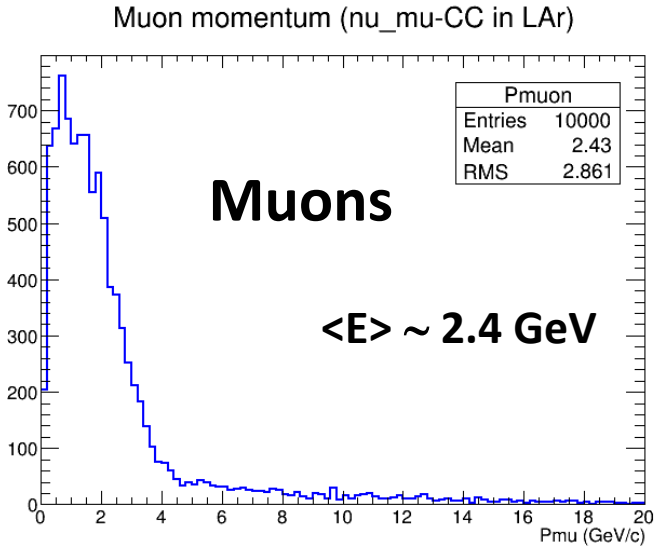
Fit function:

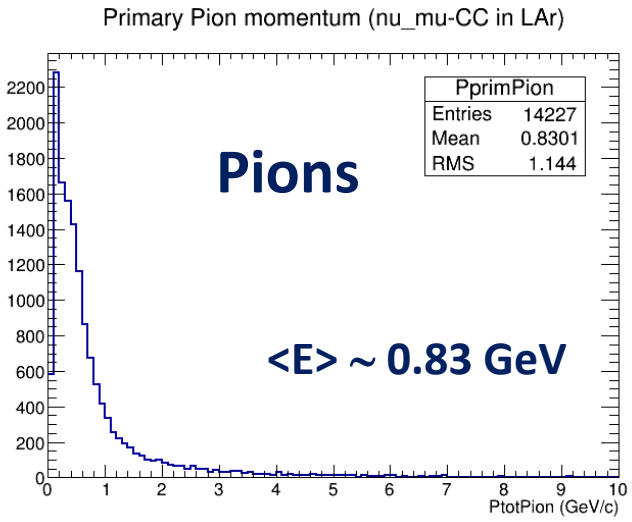
$p0 * N_{hit}^{\ p1}$

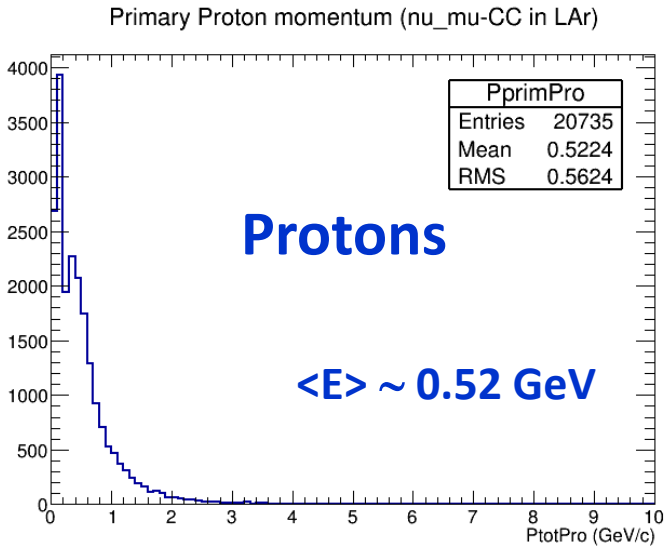
Length: $L(cm) \sim 2*Nhit_STT$

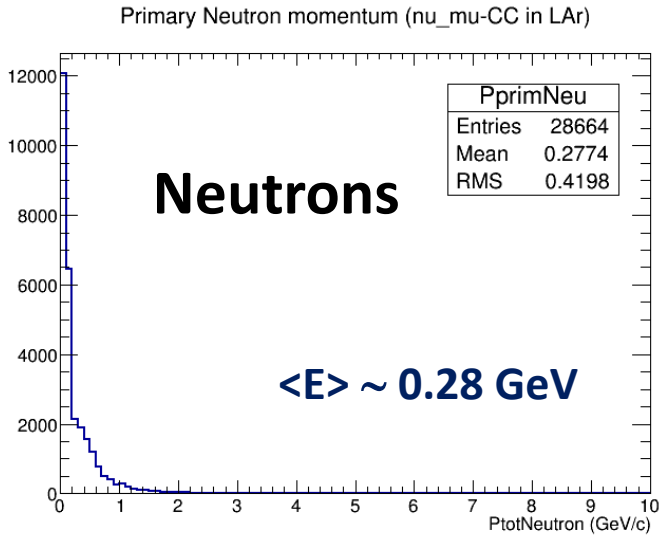
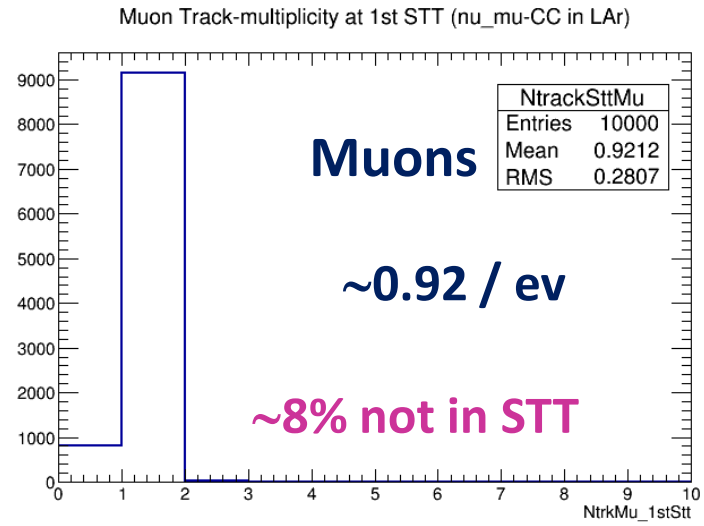
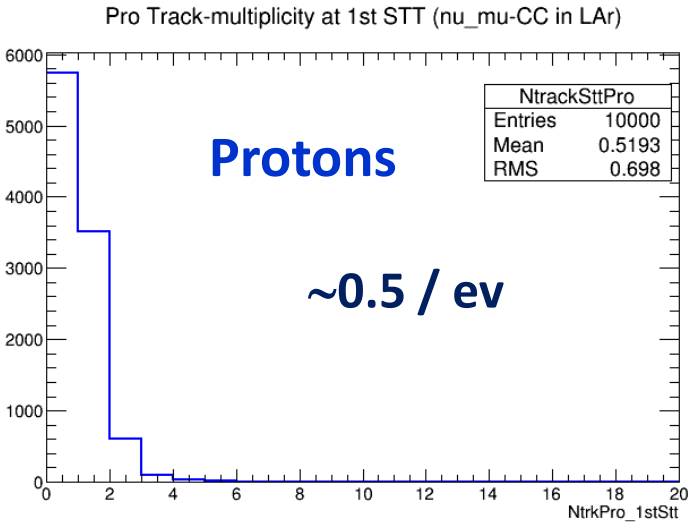
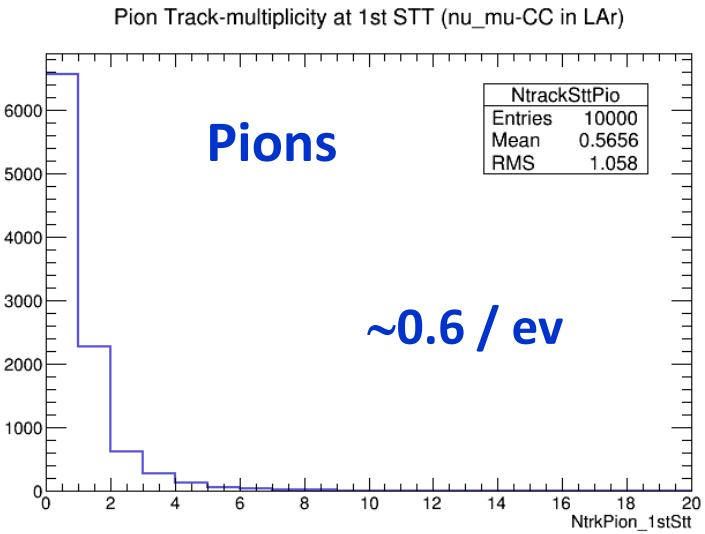
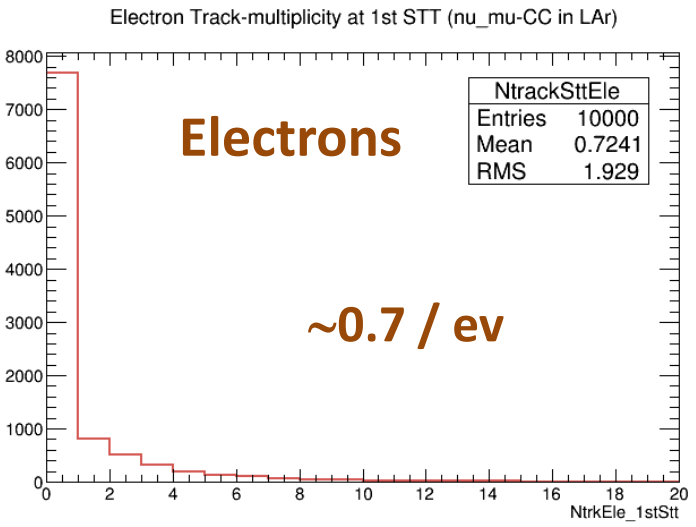
Dependence of δpT on L : $\delta pT/pT \propto 1/\sqrt{L}$

Primary particle spectra









Track-type multiplicities at 1° ST layer