Event reconstruction and background rejection in SAND

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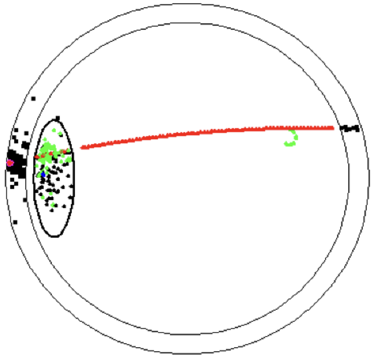


Neutrino events in SAND

- **Interactions in GRAIN (~ 1 ton) useful for:**
  - **monitor of ν spectrum for interactions in Ar**
  - **study of ν-Ar interaction channels**
  - **control samples for ND-LAr calibration**
  - **systematics constraints from nuclear effects, ..**

Full event reconstruction:

- ✓ **Scintillation light in GRAIN (Time, E-deposit, Vertex, tracks, …)**
- ✓ **Tracks in STT (momentum, charge, PID from E-loss, …)**
- ✓ **ECAL (E and Time meas., n detection, PID, bck rejection, ...)**
- ✓ **Background rejection …**

Event Reconstruction in SAND

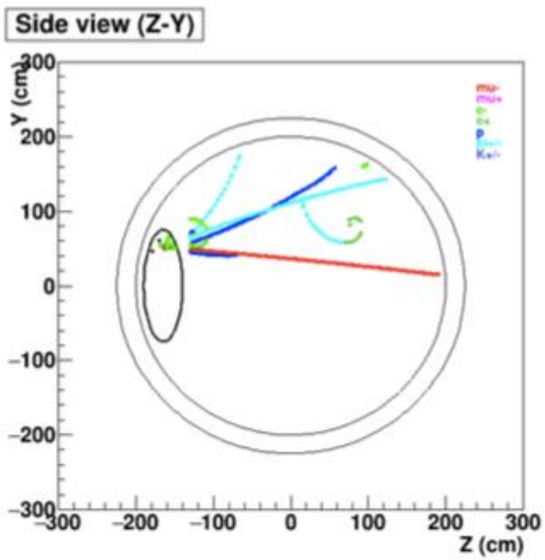
from ν_μ-CC

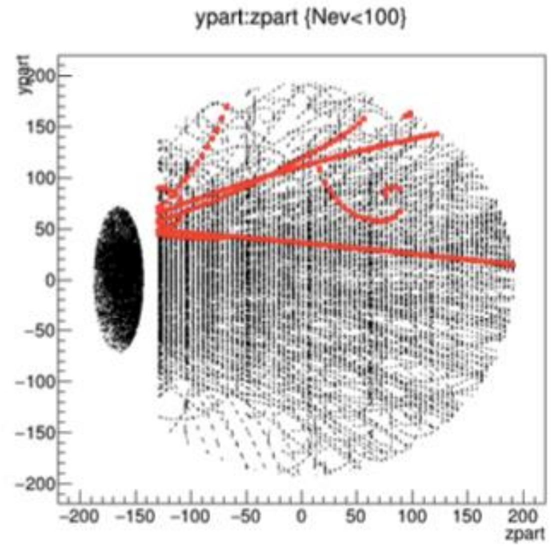
interactions in GRAIN

(~ no MC info used)

Neutrino interactions in GRAIN

From simulated ν_μ - CC interactions in LAr target (FLUKA)





- **GRAIN layout and structure simulated in many details**
- **GRAIN response**: particle hits (position, time, energy deposit)

✓ **Main features of ν interactions:**

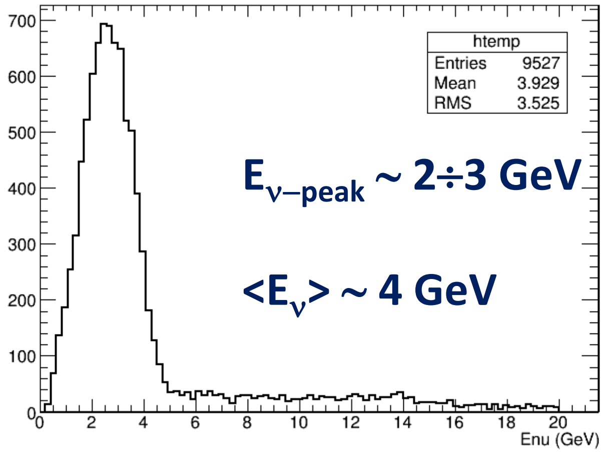
- **Multiplicity and spectrum of generated particles**
- **E_ν fraction deposited in LAr (to be measured from light yield)**
- **Vertex (and tracks) reconstructed in LAr (from times and imaging)**

✓ **Outgoing particles tracked in STT and ECal, for full event reconstruction**

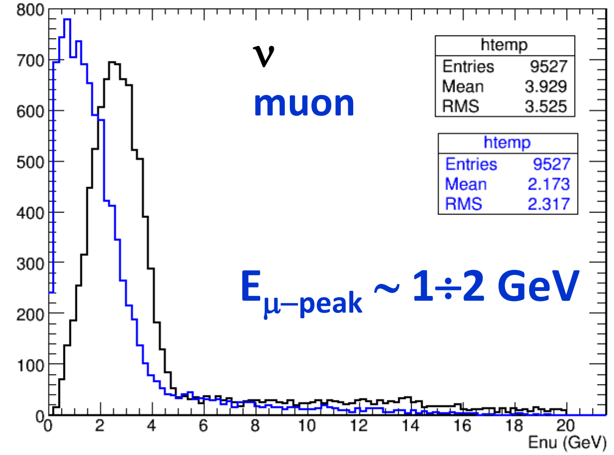
⇒ **Properties of neutrino beam (E_ν, flavors, ..) and ν_μ interactions in LAr**

ν and outgoing particle spectra (ν-Ar in GRAIN)

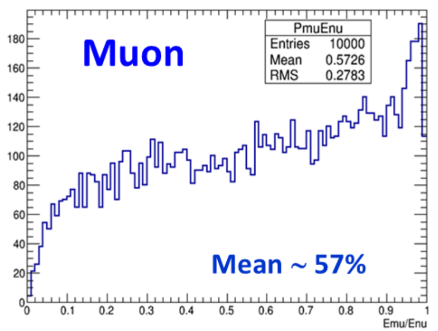
Interacting neutrinos



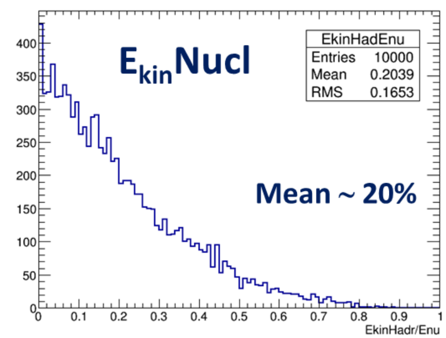
Spectrum of produced muons

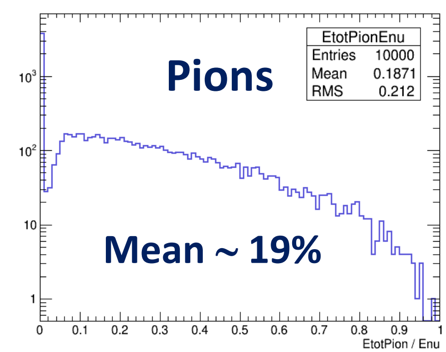


E_ν fraction carried out by produced particles:

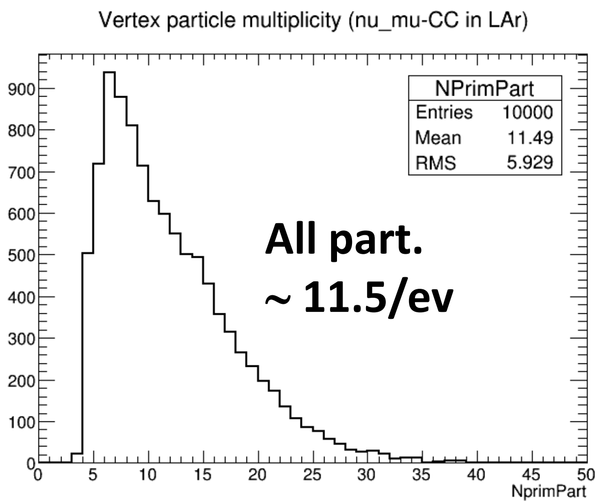


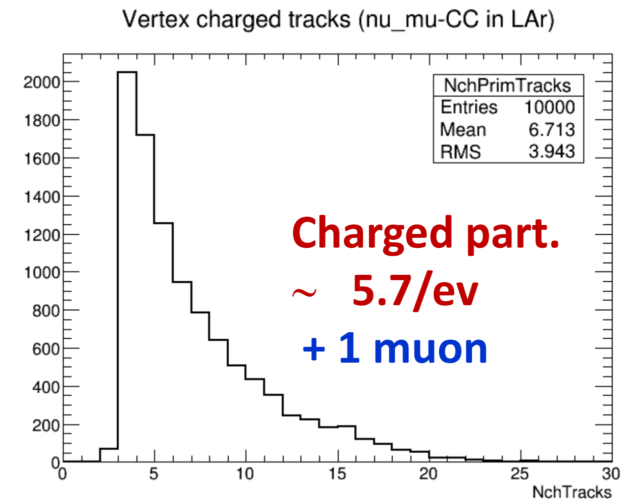
p + n + nucl. frags

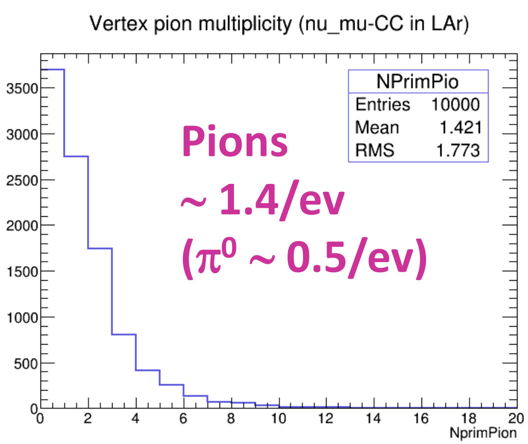


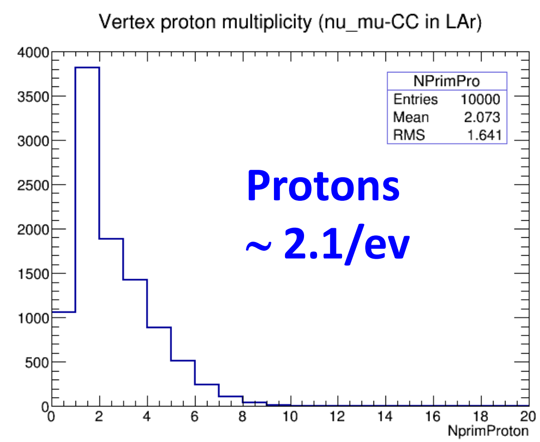


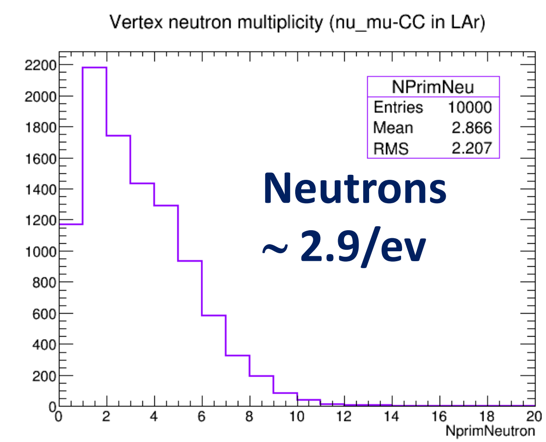
Primary particle multiplicities (ν-Ar in GRAIN)











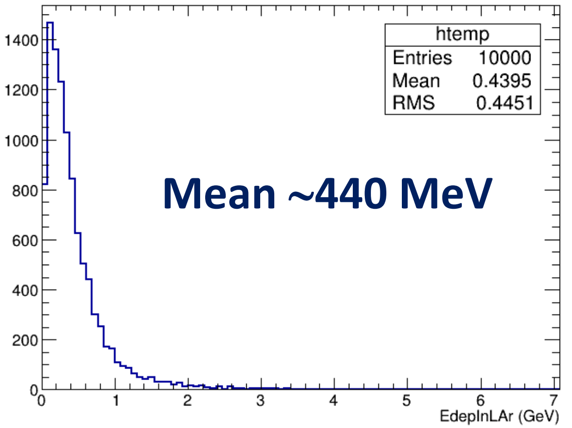
- Nuclear fragments ~ 2.6/ev
- Photons ~ 1.4/ev

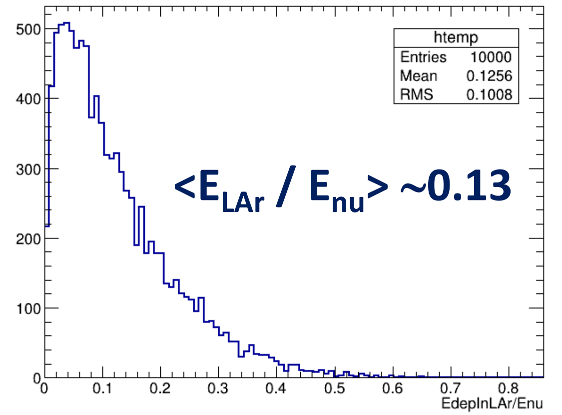
Possible dependence on the generator!

Energy deposited in LAr target

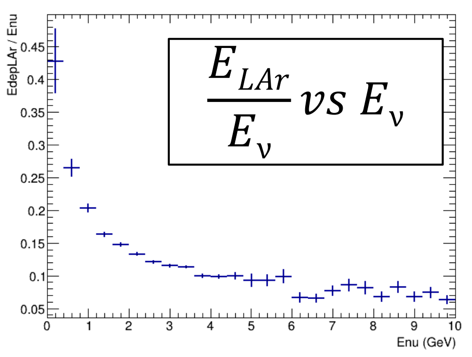
For E_ν reconstruction, the fraction deposited in LAr is not negligible

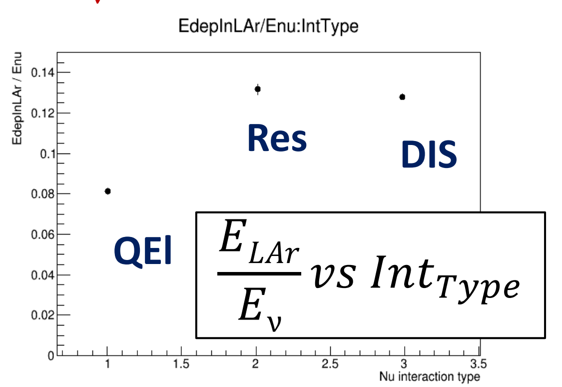
… to be estimated as a calorimetric measure from scintillation light

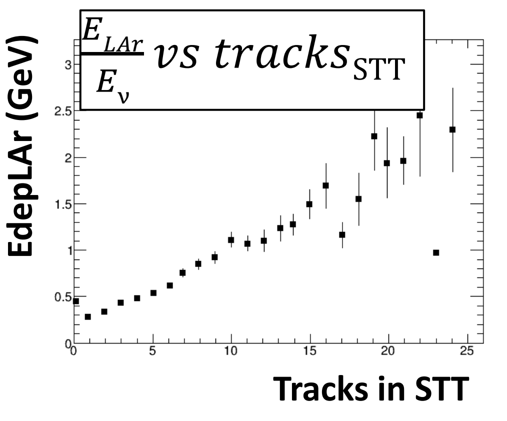




Correlation of $Edep_{LAr}/E_\nu$ with E_ν , CC-Interaction Type, tracks in STT

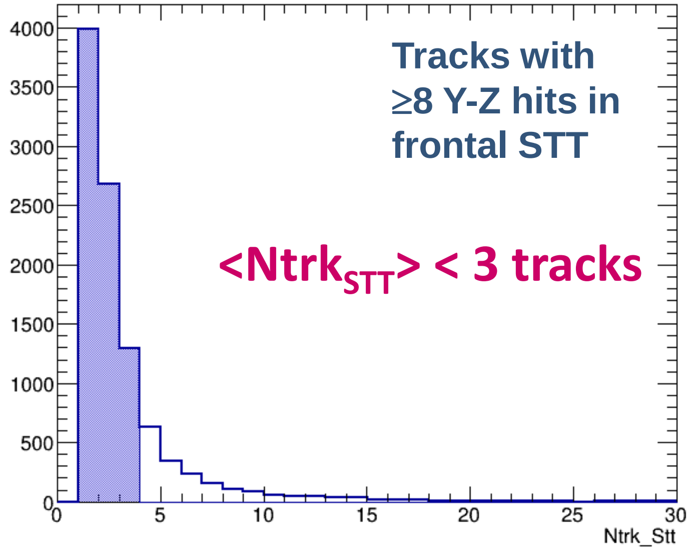






Track multiplicities in STT

Crossing front STT module



Most events with few tracks in STT from interactions in LAr

- ~ **81 % with ≤ 3 tracks**
- ~ **65 % with ≤ 2 tracks**
- ~ **41 % with only 1 track**

Note: secondary tracks can appear due to interactions/decays in STT

- ➢ **Possibility to successfully reconstruct most events by applying global track finding algorithms (as the 'transform method')**
- ➢ **For high track multiplicity events, more sophisticated methods are being implemented in the reconstruction software framework**

Acceptance of STT for particles and events

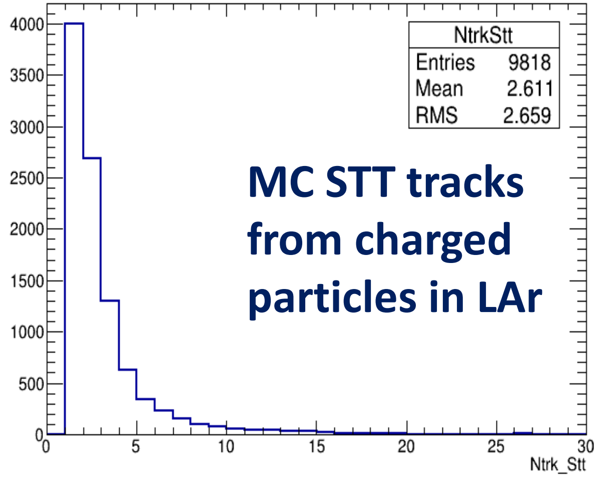
Primary particle	% of Particles		% Events with ≥1 particle tracked in STT
	Tracked in STT	+touching ECAL	
Muon	92 %	90 %	92 %
Proton	17 %	6 %	45 %
Charged pions	46 %	22 %	61 %

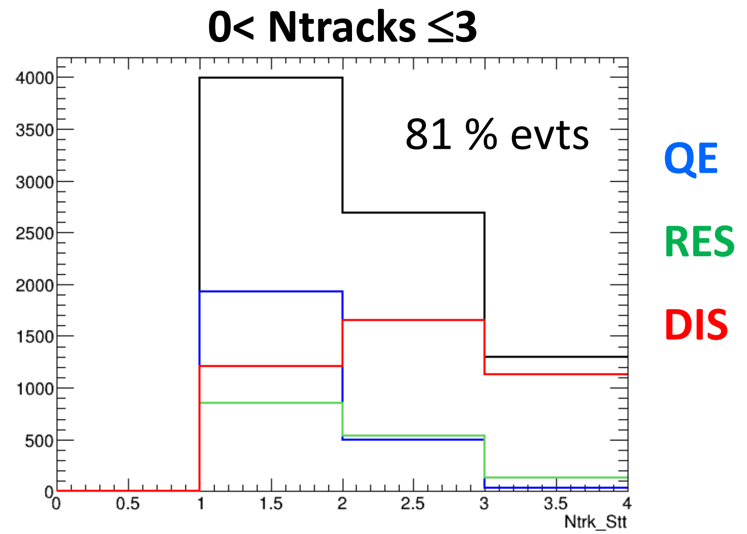
With a cut of Vertex in fiducial volume slices:

	$Zcut_1$	$Zcut_2$	$Zcut_3$
Charged pions	48%	52 %	56%

- **Relevant fraction of primary hadrons absorbed in LAr**
- **A proper fiducial volume cut on vertex in GRAIN can increase the relative acceptance, in particular for π+/π- (useful for some analyses)**

Track multiplicities vs interaction channel



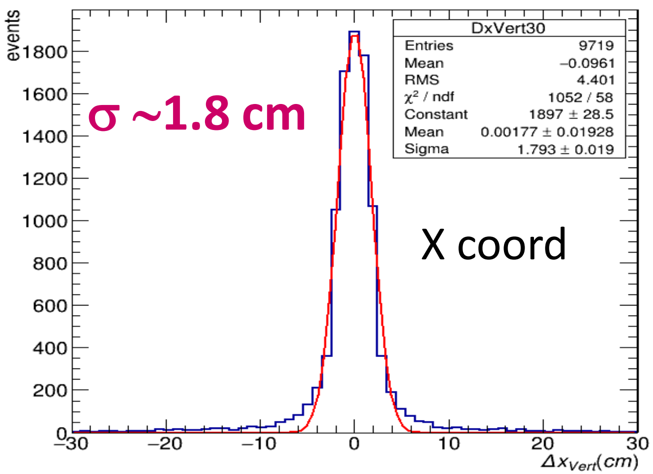


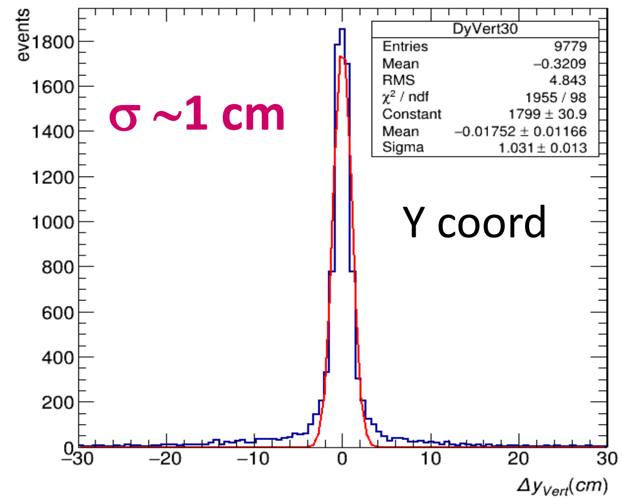
Int-Chan / Track	QE	RES	DIS
>0	25 %	16 %	59 %
>0 and ≤3	31 %	19 %	50 %

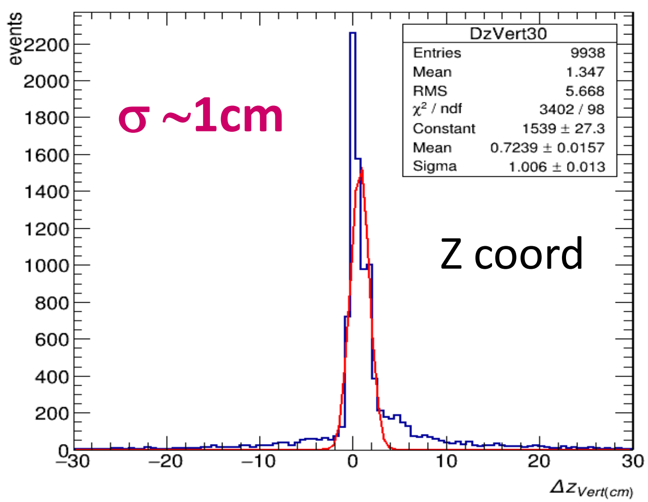
- **Events here reconstructed by a global track finding algorithms**

Vertex reconstruction in GRAIN

Vertex "reconstructed" from hit positions with E_{dep} weights







Basic idea:

tight correlation with scintillation light emission (~40,000 photons/MeV)

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

Track reconstruction (transform method)

Track-finding: global transform method → Vertex needed

- **Use of Vertex position (from MC hits) reconstructed in LAr**
- **"Reconstructed" Vertex used for coordinate transformation:**

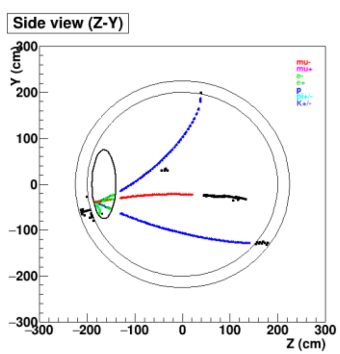
x → u   y → v

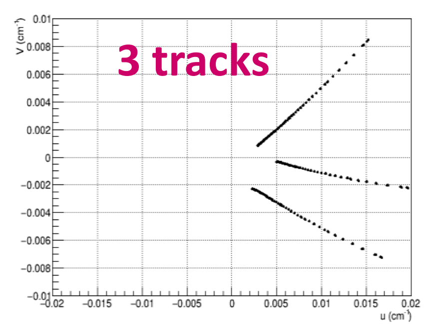
$$u = +(z-z_V) / [(z-z_V)^2 + (y-y_V)^2]$$
$$v = -(y-y_V) / [(z-z_V)^2 + (y-y_V)^2]$$

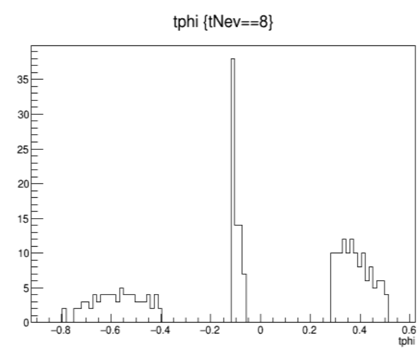
Vertex: (z_V, y_V)

- **Search for peaks in distribution of $\phi = \arctan(v/u)$**
- **Associate digits to tracks (without MC info!) and perform a circular fit**

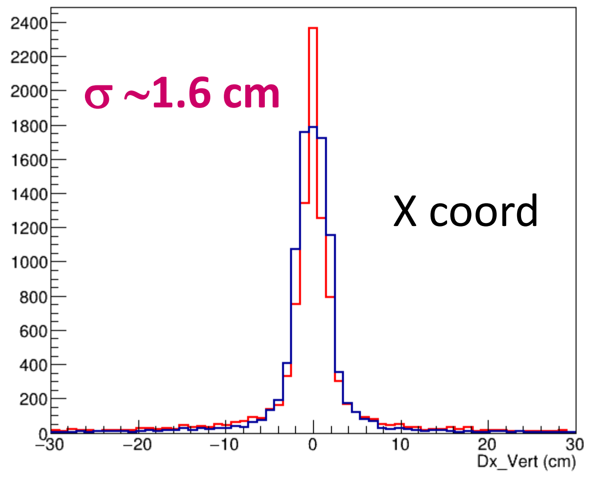
Example:

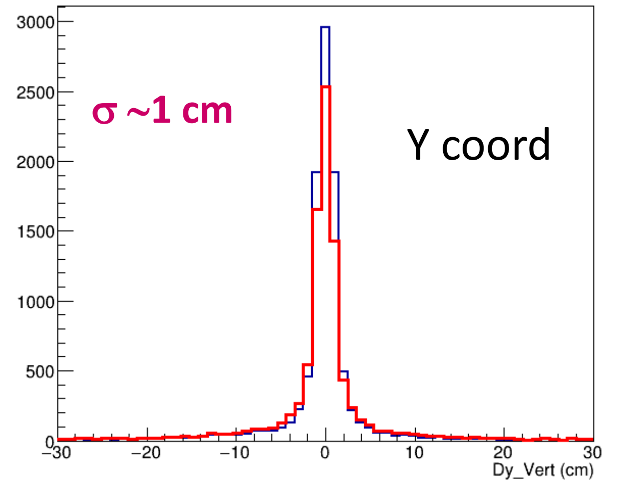




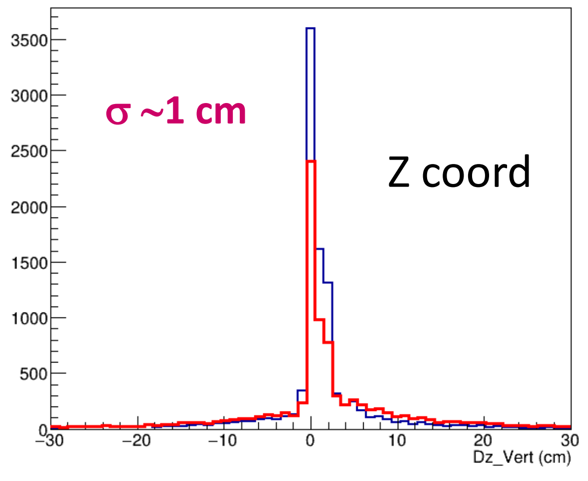


Vertex reconstruction from reco tracks





- LAr hit Edep
- Track crossing



Vertex from the crossing of the two most rigid tracks compared with that from LAr MC-hit distributions

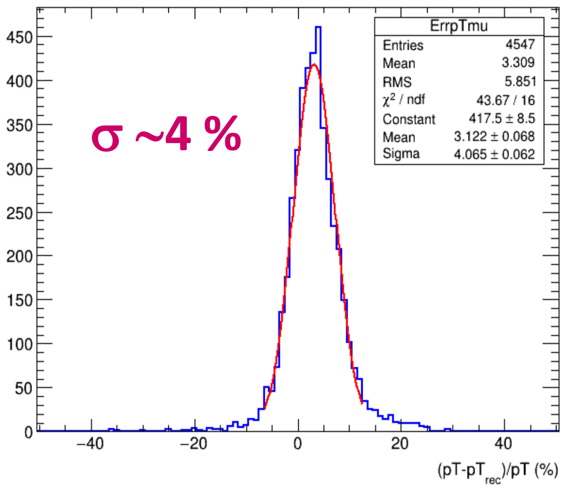
Good agreement (slight improvement on X)

Track-finding procedure could be iterated

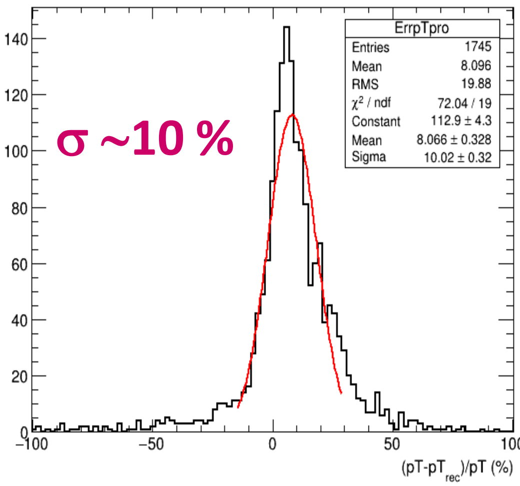
$p_{y\text{-}z}$ reconstruction in STT for μ, p, π+/-

➢ **From circular fit of tracks:**

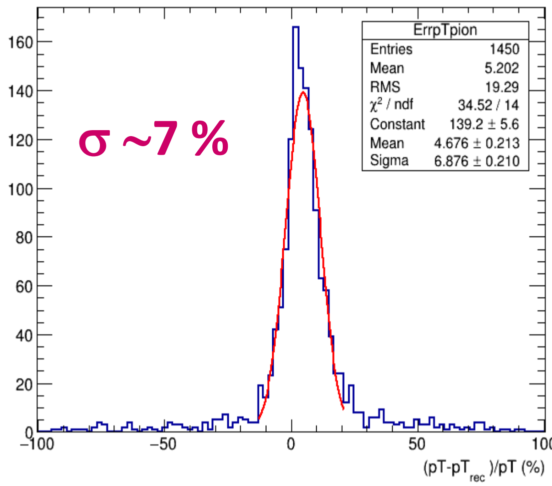
muon



proton



charged pions



✓ **Effect of energy loss, multiple scattering, short tracks, … for proton and pions**

✓ **Charge sign recognition efficiency (from circular fit curvature):**

- **muon: 99.8 %**
- **proton: 98.6 %**
- **pions: 98.5 %**

Misidentification due to very short tracks badly reconstructed

Muon momentum reconstruction in STT

Muon pT from fit by a circle in y-z view

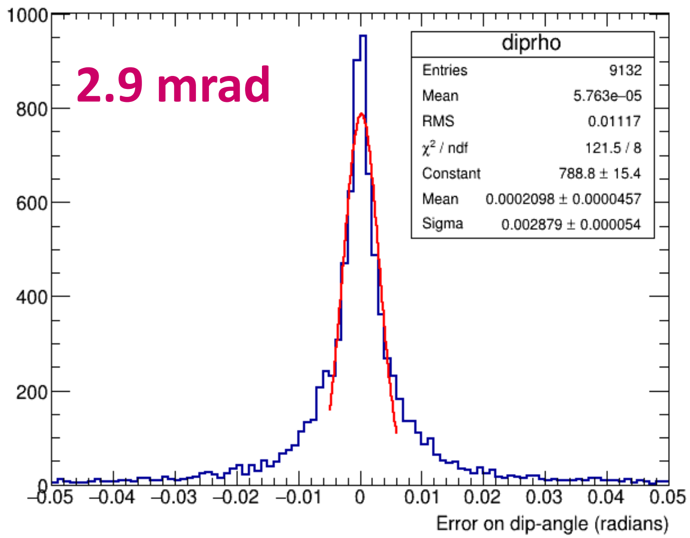
Linear fit in ρ-x view for dip-angle

λ from fit ρ–x

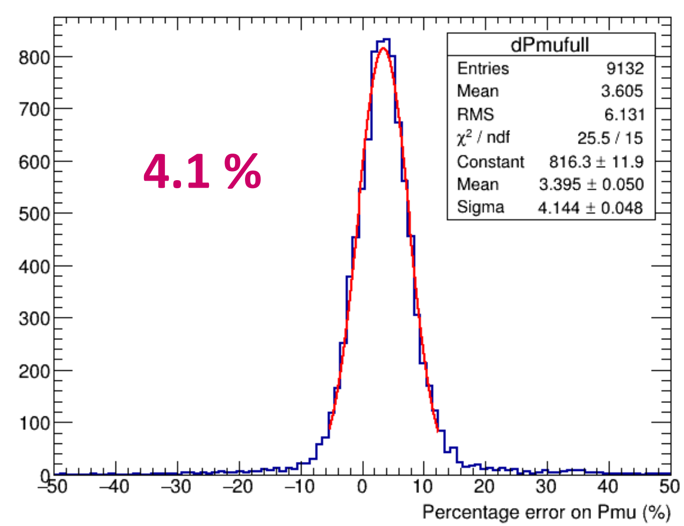
$\rho = z*\cos(\phi) + y*\sin(\phi)$

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

Error on dip-angle λ

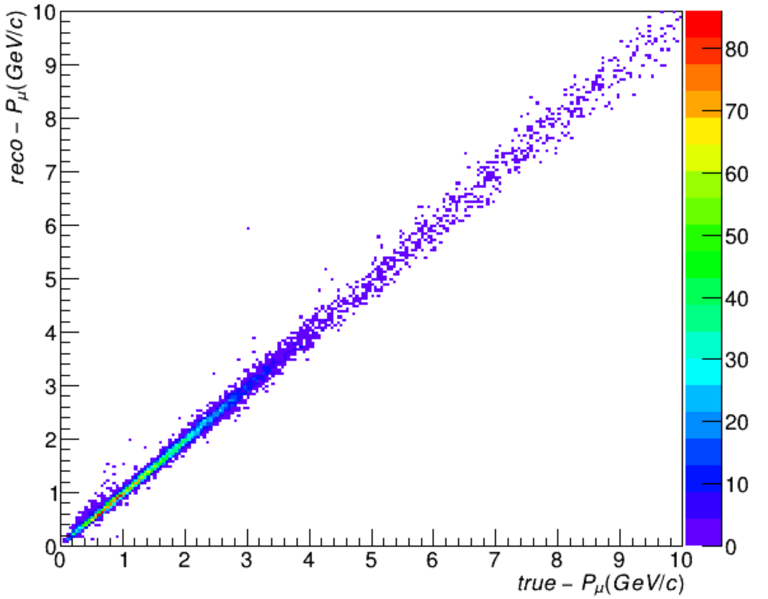


Error on total p: $p=p_{yz}/\cos(\lambda)$



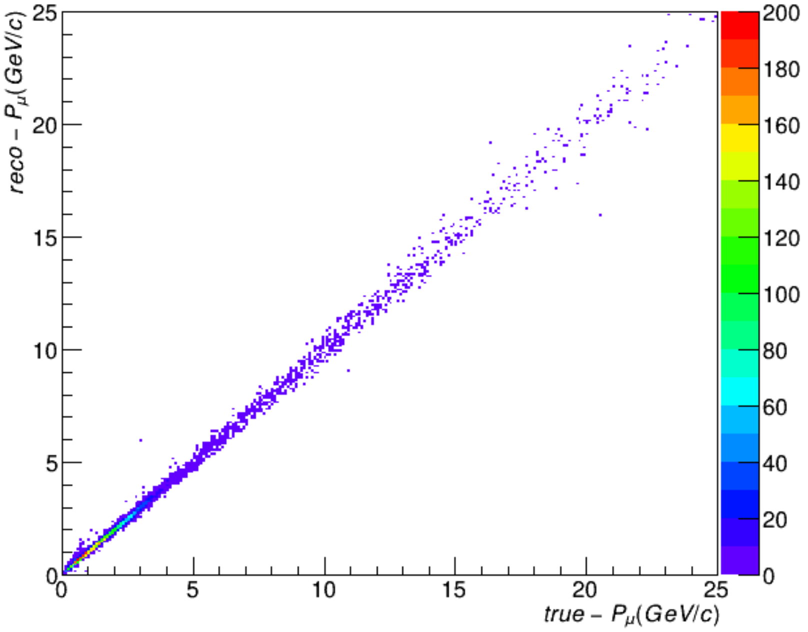
Reco-P_μ vs True-P_μ (muons in GRAIN tracked by STT)

From simple circle fit of tracks in STT



P_μ up to 10 GeV/c

Up to 25 GeV/c



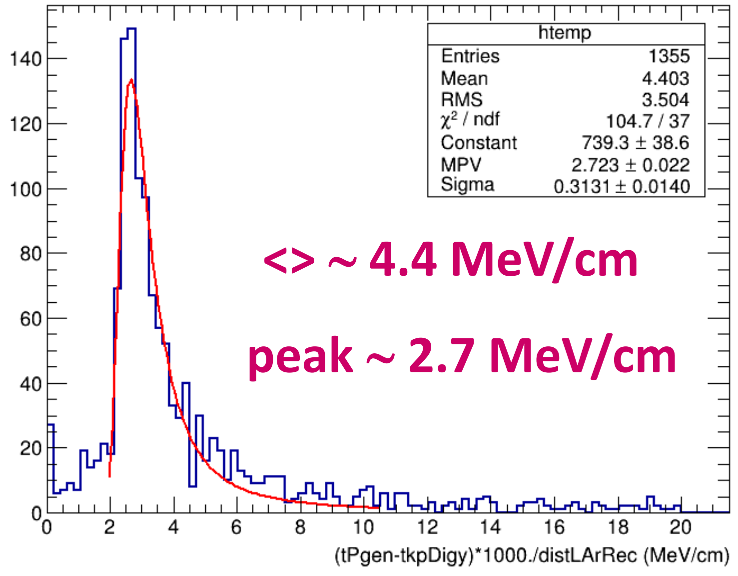
Track energy loss in GRAIN: average

Track energy loss in GRAIN estimated from the reconstructed path-length inside LAr (ΔL) and the measured (MC) specific energy loss (ΔE)

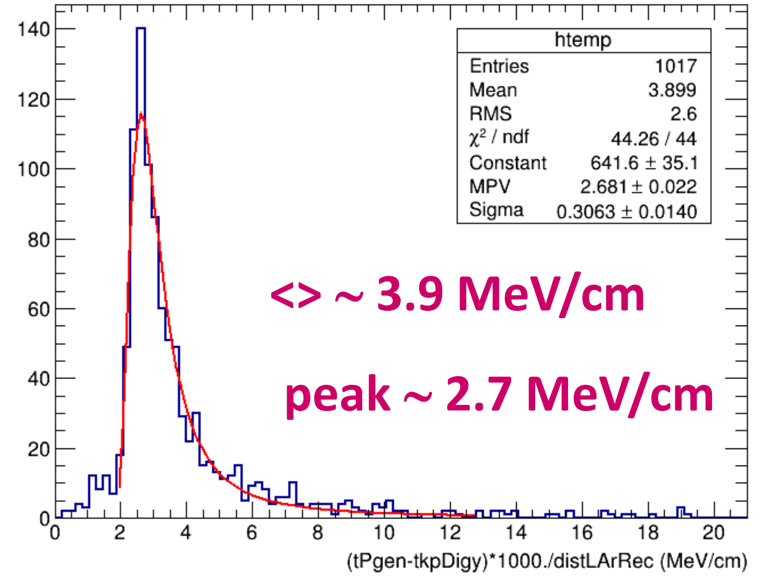
- Path-length: distance btw Vertex and track exit point from GRAIN
- Energy loss in GRAIN: difference between P_{gen} (MC) and P_{track} (reco)

⇒ **Energy loss per unitary length, ΔE/ΔL (MeV/cm)**

any particle (≤3 tracks)



muon

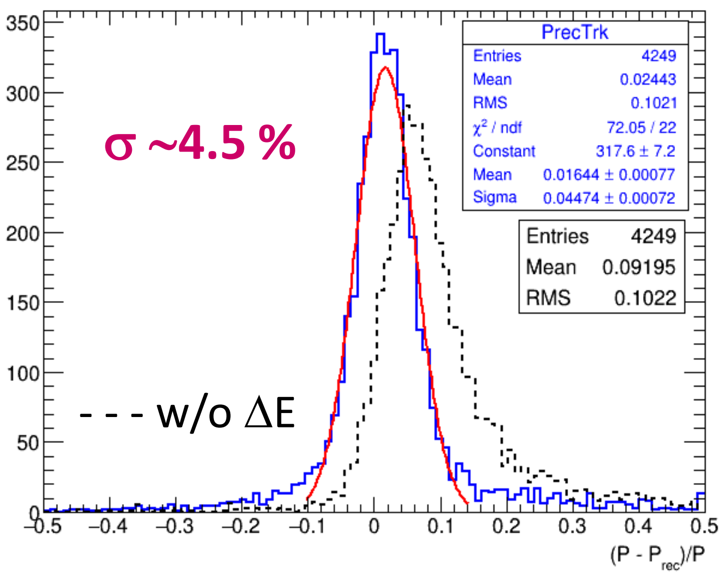


Particle momentum at vertex in GRAIN

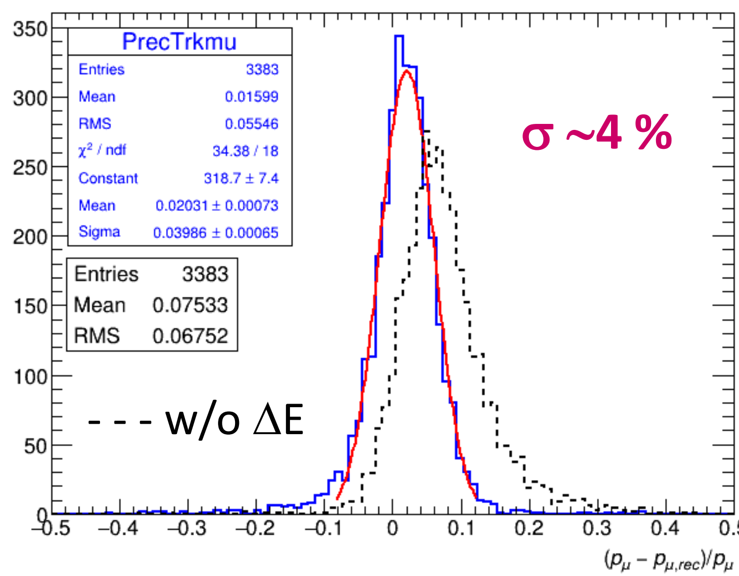
Particle momentum at vertex for each track reconstructed by adding ΔE_i to the measured one in STT, estimated from average Energy loss in GRAIN, $<\Delta E/\Delta L>$:

$$\Delta E_i = Lpath_i * <\Delta E/\Delta L>$$

any particle **($<\Delta E/\Delta L>$ ~4.4 MeV/cm)**



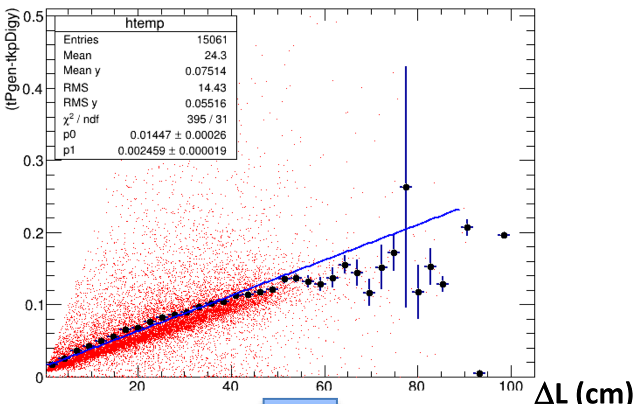
muon **($<\Delta E/\Delta L>$ ~3.9 MeV/cm)**

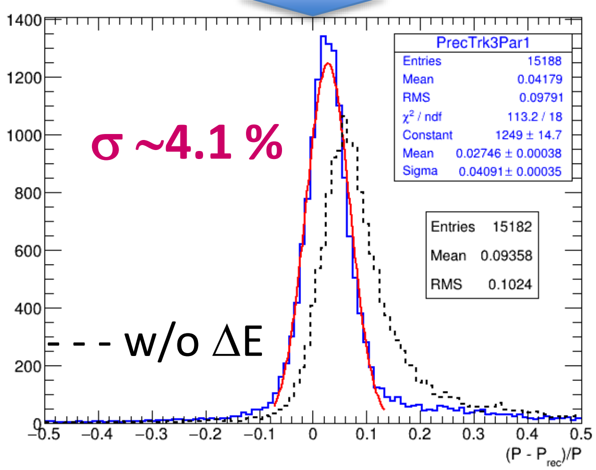


Track energy loss in GRAIN: parametrization

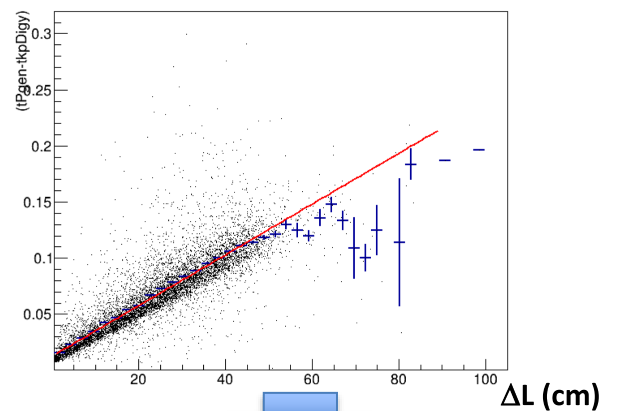
Track energy loss in GRAIN (ΔE) estimated on the basis of the reconstructed path-length inside (ΔL) from a MC based parametrization: $\Delta E = p_1 \times \Delta L + p_0$

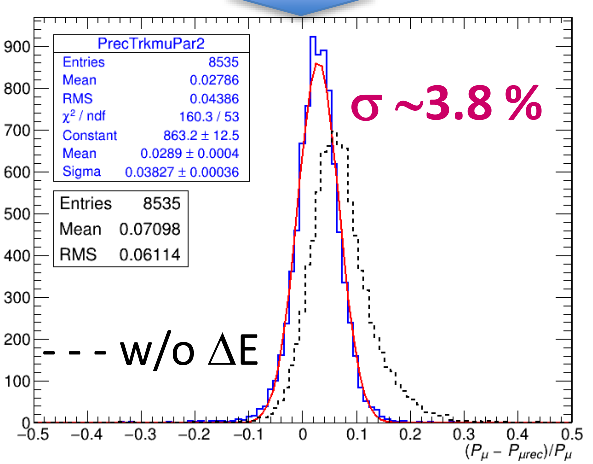
any particle (≤3 tracks)





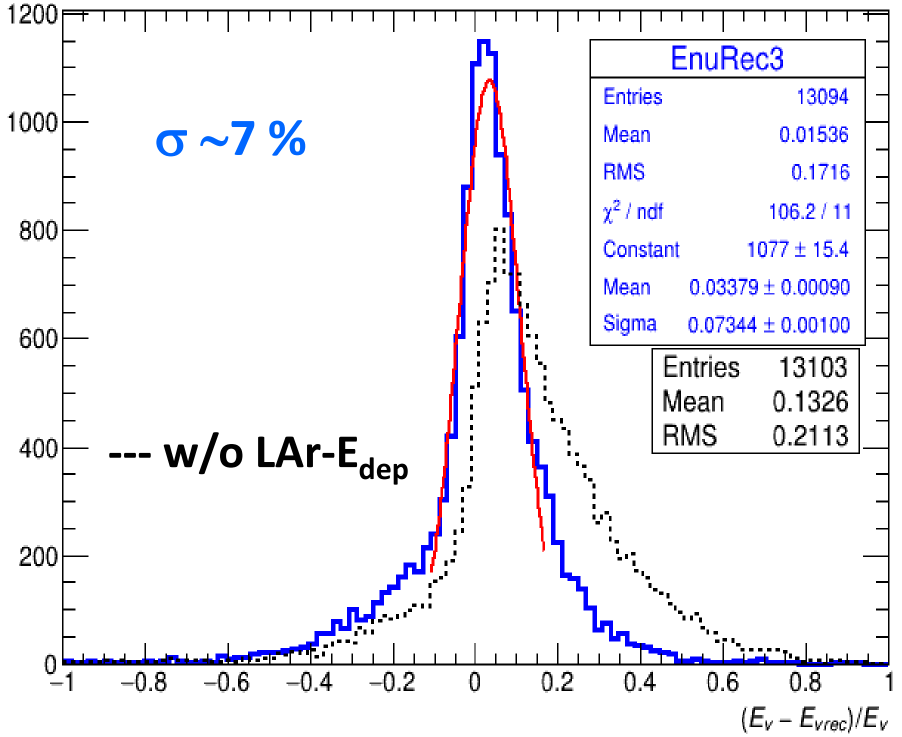
muon





Total ν Energy reconstruction

- Up to 3 tracks reconstructed in both views and matched one by one
- **Momentum of each track reconstructed in STT (sign can identify μ)**
- **Off-track energy clusters in ECal taken into account**



- Edep in LAr ignored (~13 % missing energy)

- Edep in LAr added

Energy deposit in LAr: to be measured through scintillation light collection

✓ Complementary info/cross-check from correlation with tracking and ECAL observables?

External event background

rejection in SAND:

a simple (rough) procedure

Sources of background for SAND detector

Three possible sources of background for SAND:

1) Cosmic radiation
2) Environment radioactivity
3) Beam-related neutrino external interactions

First two negligible thanks to beam spill coincidence

The last one is the most critical

✓ Here some preliminary results on bck evaluation and a possible removal procedure for evts external to GRAIN, based on:

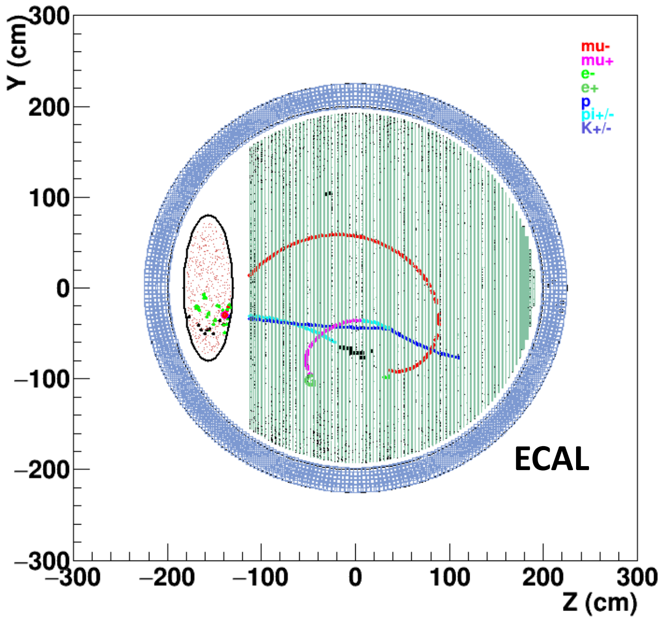
- time information
- energy deposit in LAr
- hits detected in STT and ECAL

Simulation of signal and bck events

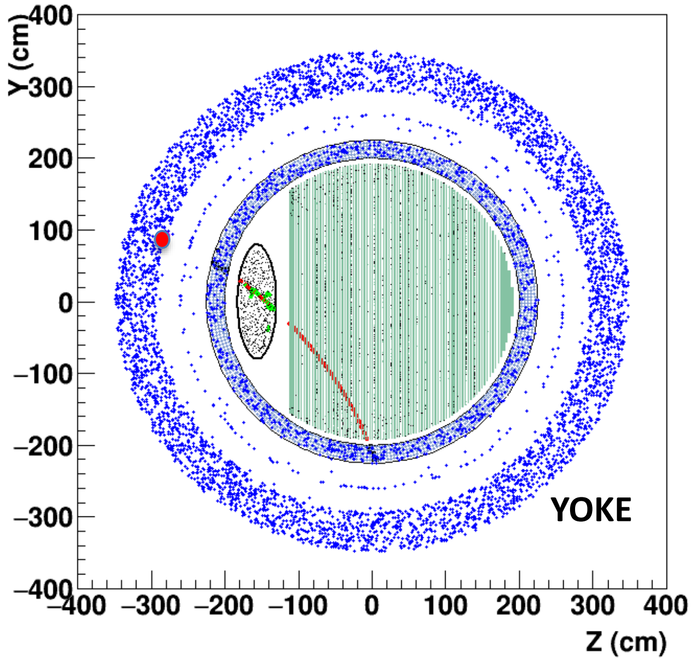
Two samples of ν_μ-CC events simulated by FLUKA code

$2\cdot10^4$ ν_μ-CC interactions in the LAr (signal)

$1.5\cdot10^5$ ν_μ-CC interactions in the Magnet Yoke + ECAL (source of bck)



Interaction Vertexes inside GRAIN



Interaction Vertexes in Magnet-Yoke and ECAL

Nev: ~125,000 in the Yoke, ~25,000 in ECAL)

Summary of expected event rates in SAND

Events from muon-neutrino (CC+NC) interactions per spill (FHC)

	Magnet Yoke		ECAL		Yoke + ECAL		GRAIN	
Total/spill	**69**		**14**		**83**		**0.14**	
CC + (NC)	**51**	(18)	**10**	(4)	**61**	(22)	**0.1**	(0.04)
Evts in **ECAL**	**12** (24%)		**10** (100%)		**22** (36%)			
Evts in **GRAIN**	**2.2** (4,4%)		**2.0** (19%)		**4.2** (6,9%)		**0.1**	
μ's from rock	**~1.7/spill in GRAIN (*)**							

The required rejection power of background from external events relies on the event rates expected for GRAIN

(*) Estimated from the rate on the front ECAL surface, properly scaled to GRAIN

Events detected by GRAIN

The recognition of external interactions is mainly based on time measurements

T_{ECal} : time of the first fired ECAL-cell
T_{GRAIN}: time of the first detected photon

- External interaction:

$$T_{ECal} < T_{GRAIN}$$

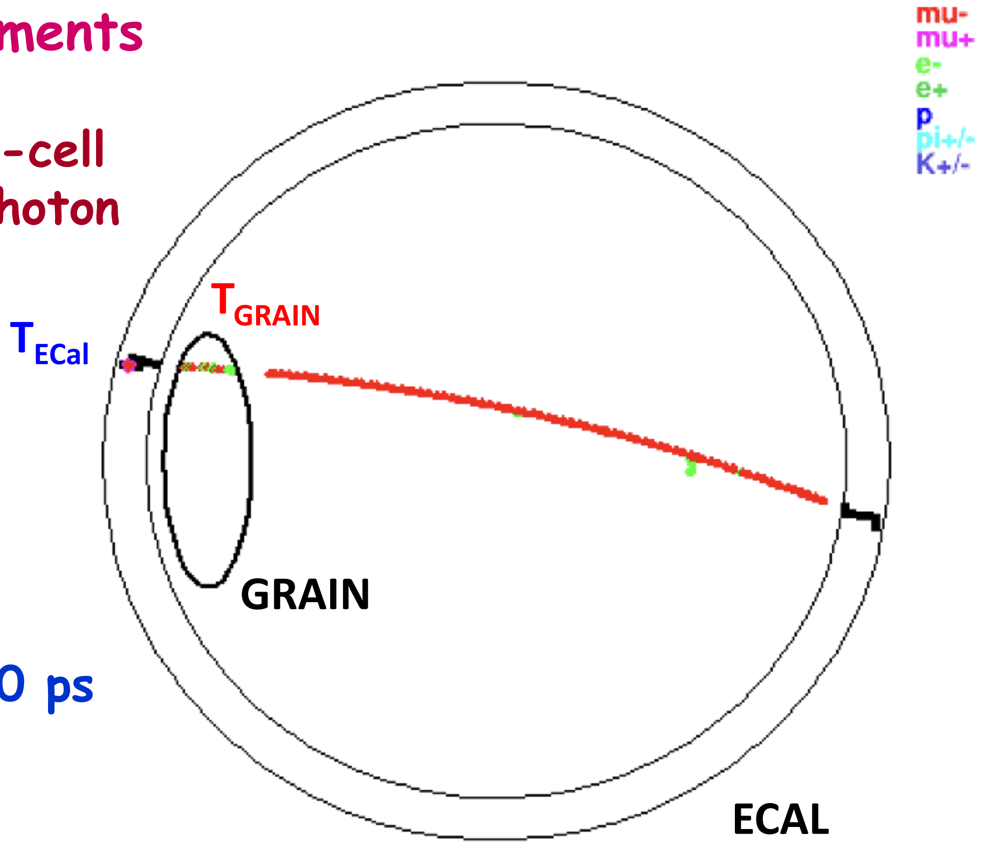
✓ Time resolutions:

ECal $\sigma_t = 54\ ps / \sqrt{E_{GeV}} \oplus 50\ ps$

GRAIN $\sigma_t < 500\ ps$

STT $\sigma_t = 1\ ns$

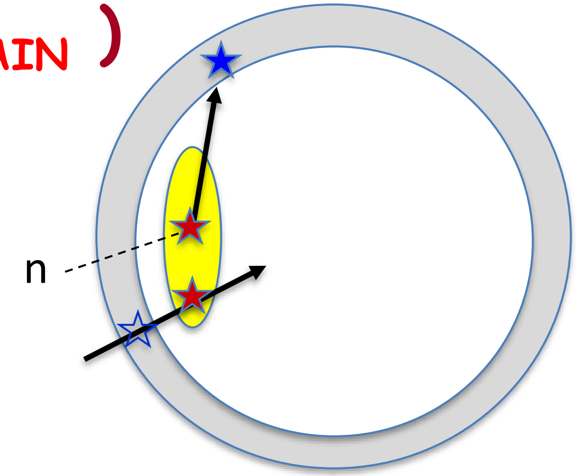
ECal threshold: $E_{th}^{ECal} = 20\ MeV$



Possible failures of the time criteria

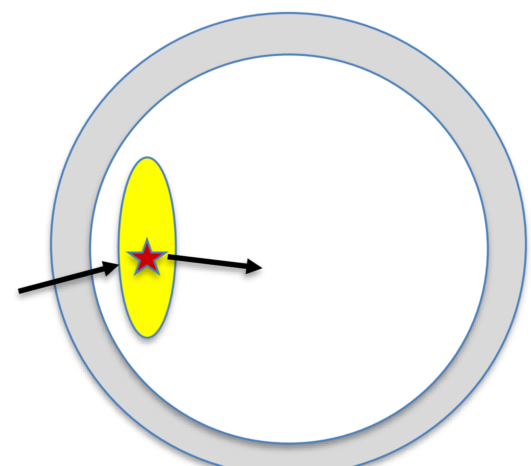
- **Bck 1 → Time reversal (T_{ECal} > T_{GRAIN})**

Time reversal is possible due to limited time resolution or to neutrons giving delayed signals in ECal



- **Bck 2 → T_{ECal} missing**

Deposited energy in ECal cells is below the threshold ($E_{dep} < E_{th}^{ECal}$)



Bck evaluation (Time criteria only)

Time cut: $\Delta T_{1st} = T_{1st}(ECAL) - T_{1st}(GRAIN) > \Delta T_{min}$

- **Internal evts:** η_{INT} = **fraction of events surviving the cut**
- **External evts:**

  η_{EXT1} = **fraction of events surviving ΔT_{1st} cut ($\rightarrow BCK_1$)**

  η_{EXT2} = **fraction of events where T_{ECAL} is missing ($\rightarrow BCK_2$)**

Background estimated from S/N ratio:

$$\left(\frac{S}{N}\right) = \frac{\eta_{INT} \cdot M_{INT}}{(\eta_{EXT1} + \eta_{EXT2}) \cdot M_{EXT}} = \frac{\eta_{INT} \cdot M_{GRAIN}}{\eta_{EXT} \cdot M_{(Yoke+ECAL)}}$$

From time criterium alone

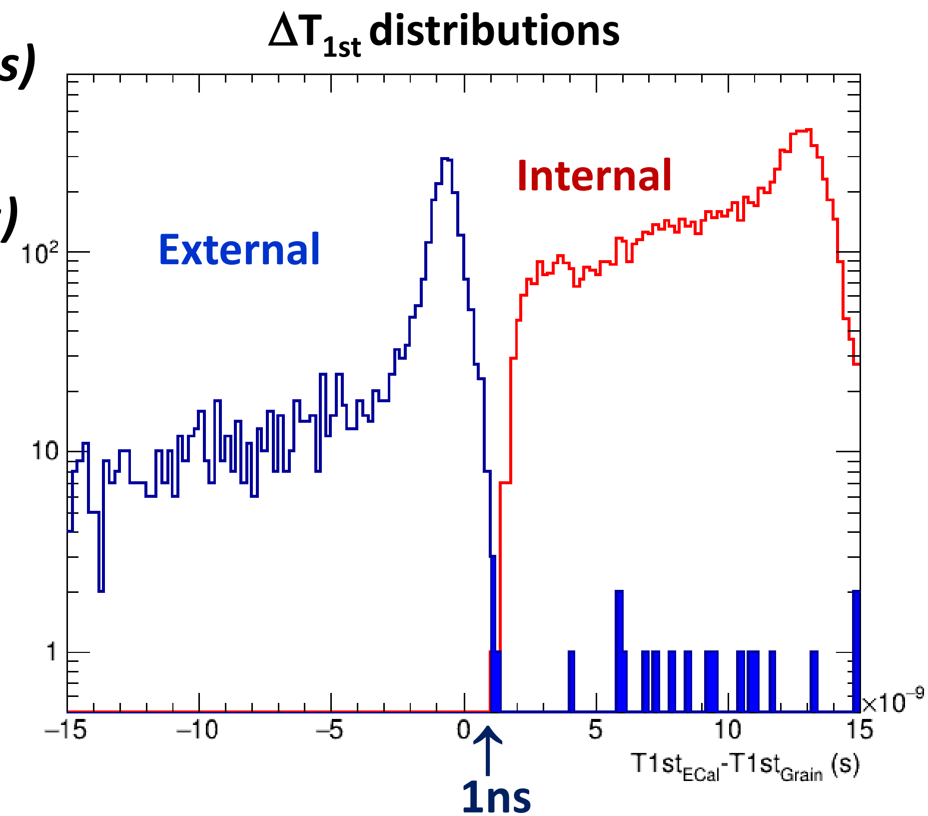
Internal: ν-interactions in LAr *($2\cdot10^4$ evts)*

External: evts from YOKE + ECAL *($1.5\cdot10^5$ evts)*

For: $\Delta T_{1st} > 1ns$

- **Internal evts:** 100% ($\eta_{INT} = 1$)
- **External evts:**

BCK_1: 42 evts/$1.5\cdot10^5$ with $\Delta T_{1st} > 1ns$ ($\eta_{EXT1} = 2.8\cdot10^{-4}$)



BCK_2: 454 evts/$1.5\cdot10^5$ with missing T_{ECAL} ($\eta_{EXT2} = 3.0\cdot10^{-3}$)

$$\left(\frac{S}{N}\right)_{CC} = \frac{\eta_{INT}\cdot M_{INT}}{\eta_{EXT}\cdot M_{EXT}} = \frac{1\times 1\ tons}{3.3\cdot10^{-3}\times 611\ tons} < 1$$

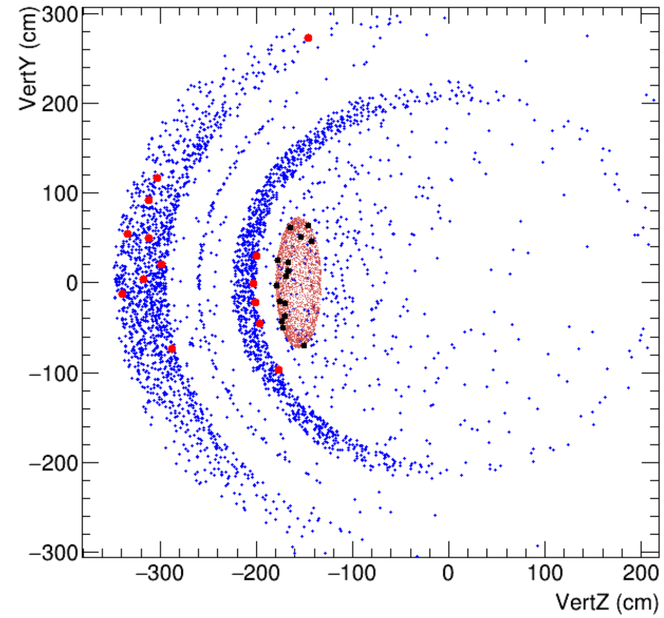
… not enough!

Residual bck (after ΔT_{min} cut)

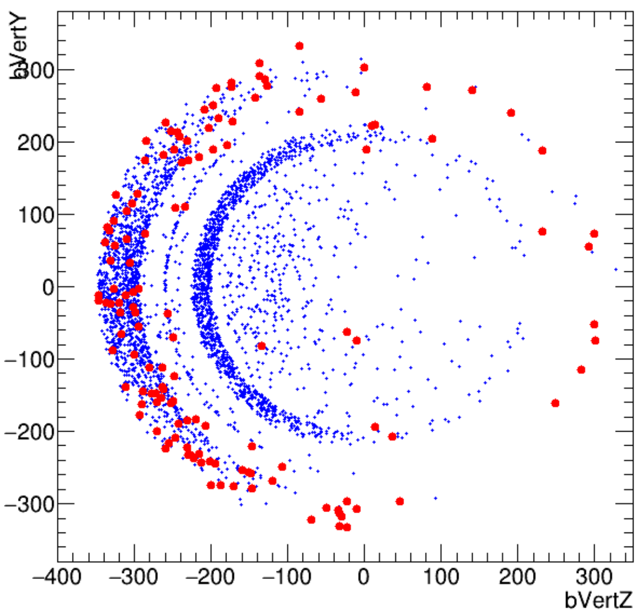
- **Bck 1 → Time reversal (T_{ECal} > T_{GRAIN})**

Mainly coming from ν-interactions in Yoke (and ECal) with 1st hit in LAr due to neutrons and e-'s near the GRAIN front boundary

… cut on fiducial volume in GRAIN ?



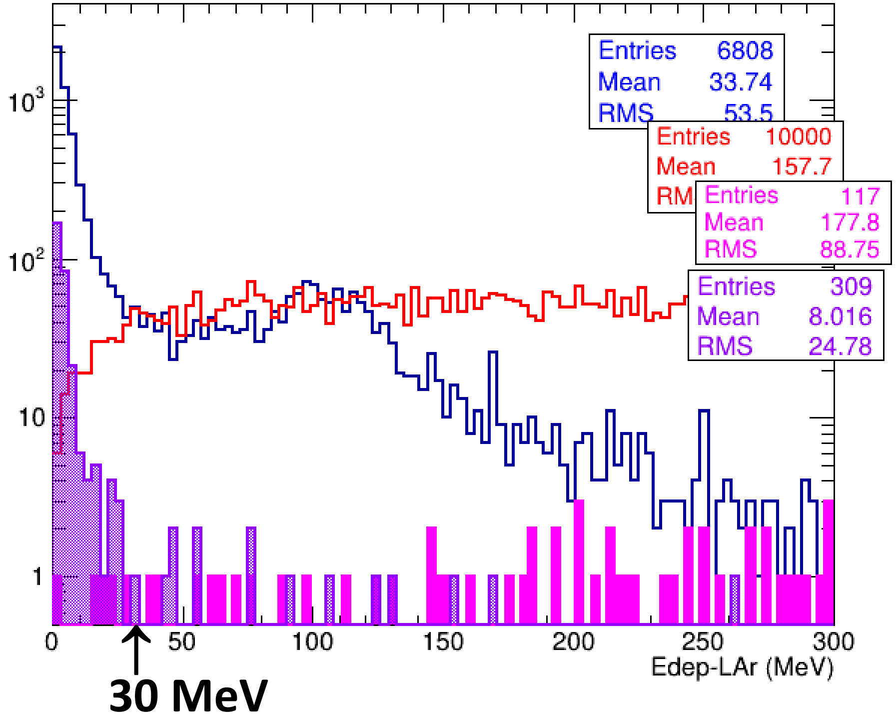
Red dots: event vertexes



- **Bck 2 → T_{ECal} missing**

Mainly coming from ν-interactions in the Magnet Yoke with neutrons interacting in LAr

Cuts to reject bck: Energy deposit in GRAIN



Internal events

External events

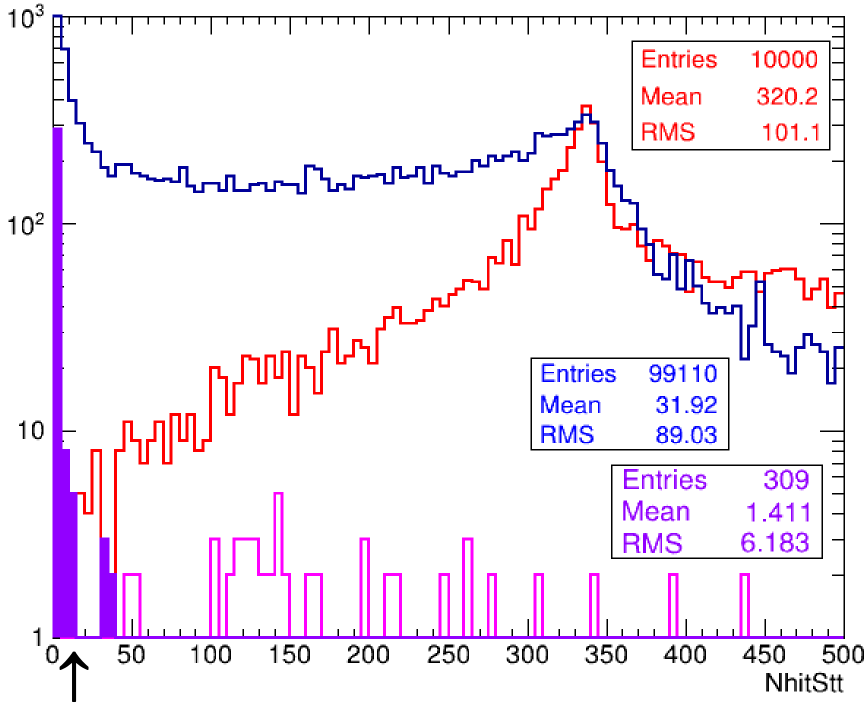
External events with missing T_{ECal}

Internal events with missing T_{ECal}

EdepLAr > 30MeV

- **GRAIN energy cut: EdepLAr > 30 MeV** ← applied to all events!
  - → Internal event efficiency: 97.3%
  - → Bck_1 reduction: ~67% (28 evts surviving out of 42)
  - → Bck_2 reduction: ~4.4% (20 evts surviving out of 454)

Cuts to reject bck: Multiplicity of STT hits



Internal events

External events

External events with missing T_{ECal}

Internal events with missing T_{ECal}

NhitStt ≥ 12

≥6 hits in both views as a minimal requirement for track reconstruction

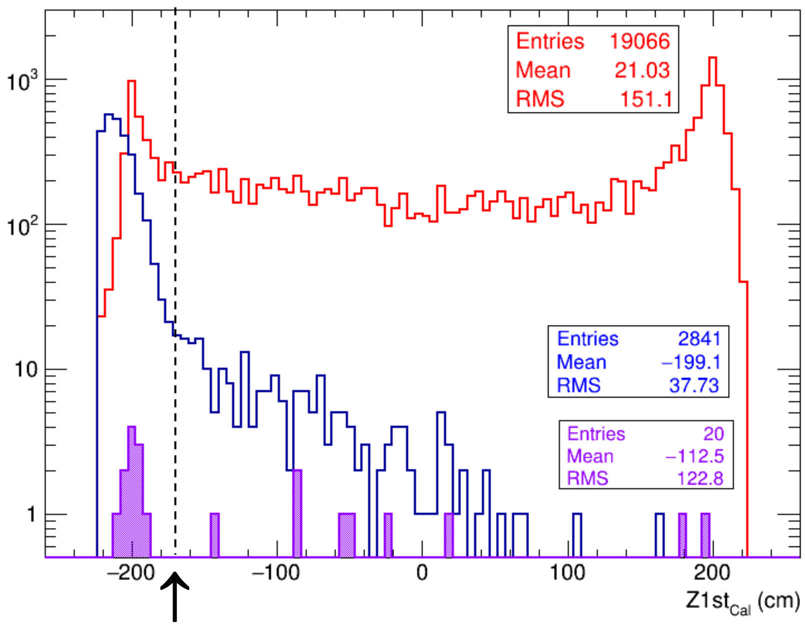
❖ **After the cut on NhitStt:**

→ Internal event efficiency: 96.2%

→ Bck_1 reduction: ~48% (20 evts surviving out of 42)

→ Bck_2 reduction: ~0.7% (3 evt surviving out of 454)

Cuts to reject bck: topology for 1st hit in ECAL



Internal events ($T_{ECal} > T_{GRAIN}$)

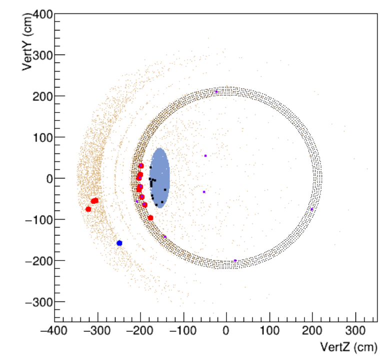
External events (all)

External events with $T_{ECal} > T_{GRAIN}$

1st hit in ECAL from external events mainly in the frontal ECAL modules

Cut: $Z\text{-}1st_{ECAL} > -170$ cm

(use front ECAL as a veto for 1st hit)



- **After $Z\text{-}1st_{ECAL}$ position cut:**
  - → Internal event efficiency: 80.5%
  - → Bck_1 reduction: ~21% (9 evts surviving out of 42)
  - → Bck_2 reduction: ~0.7% (3 evt surviving out of 454)

Bck from external ν_μ-CC events: summary

- **After:** ΔT-info ⊗ EdepLAr-cut ⊗ NhitStt-cut ⊗ Z-1st$_{ECAL}$ cut

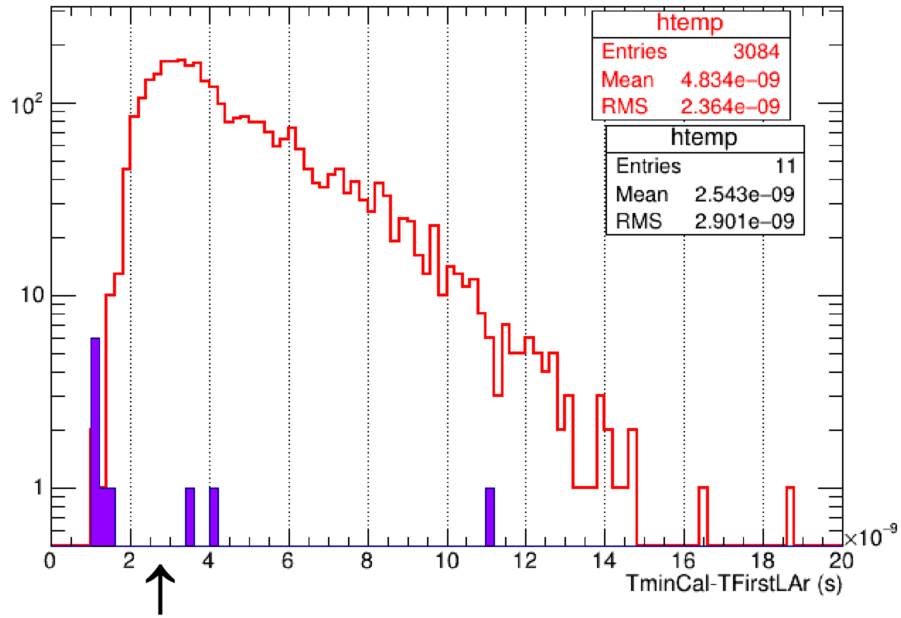
  - **Internal evts:** surviving 80.5% (η_{INT}=0.805)
  - **External evts:** surviving 0.012% (12/1.5·10^5) (η_{EXT}=0.8·10^{-4})

$$\left(\frac{S}{N}\right)_{CC} = \frac{\eta_{INT} \cdot M_{INT}}{\eta_{EXT} \cdot M_{EXT}} = \frac{0.805 \times 1\ ton}{8.0 \cdot 10^{-5} \times 611\ tons} = 16.5 \pm 4.4$$

Bck$_{beam,CC}$ ~ (6.1 ± 1.7) %

(from events in Magnet-Yoke and ECal)

ECAL hit topology: fine tuning



Cut … more event statistics needed

Distribution of (T_{ECal} - T_{GRAIN}) for the sample rejected by the hit topology cut …

Signal events ($T_{ECal} > T_{GRAIN}$)

Bck events with $T_{ECal} > T_{GRAIN}$

- **Tuned cut on (T_{ECal} - T_{GRAIN}) on this event sample: < ~3 ns**

  Surviving Signal > 90 %, Bck residual fraction ~ 10^{-4}

  $\Rightarrow$ S /N ~ 15 $\Rightarrow$ Bck ~ 6.5%

Possible improvements in bck rejection

✓ **Further cuts and criteria can be identified using different variables and methods**

✓ **Use of NN algoriths → work presented by Bing at the DUNE GM in September, for the previous SAND layout** https://indico.fnal.gov/event/46504/contributions/224296/attachments/147485/188992/bkgRej_STT_dunecollab_sep2021_v7.pdf **, based on *GEANT+GENIE* simulation and using:**

- timing information.
- topology information in ECAL.
- teconstruction-level information.

- **Overall 93% efficiency and >99% purity with NN analysis.**
- **Cross check with cut based analysis gives overall 85% efficiency and >99% purity**

Summary

Event reconstruction in SAND

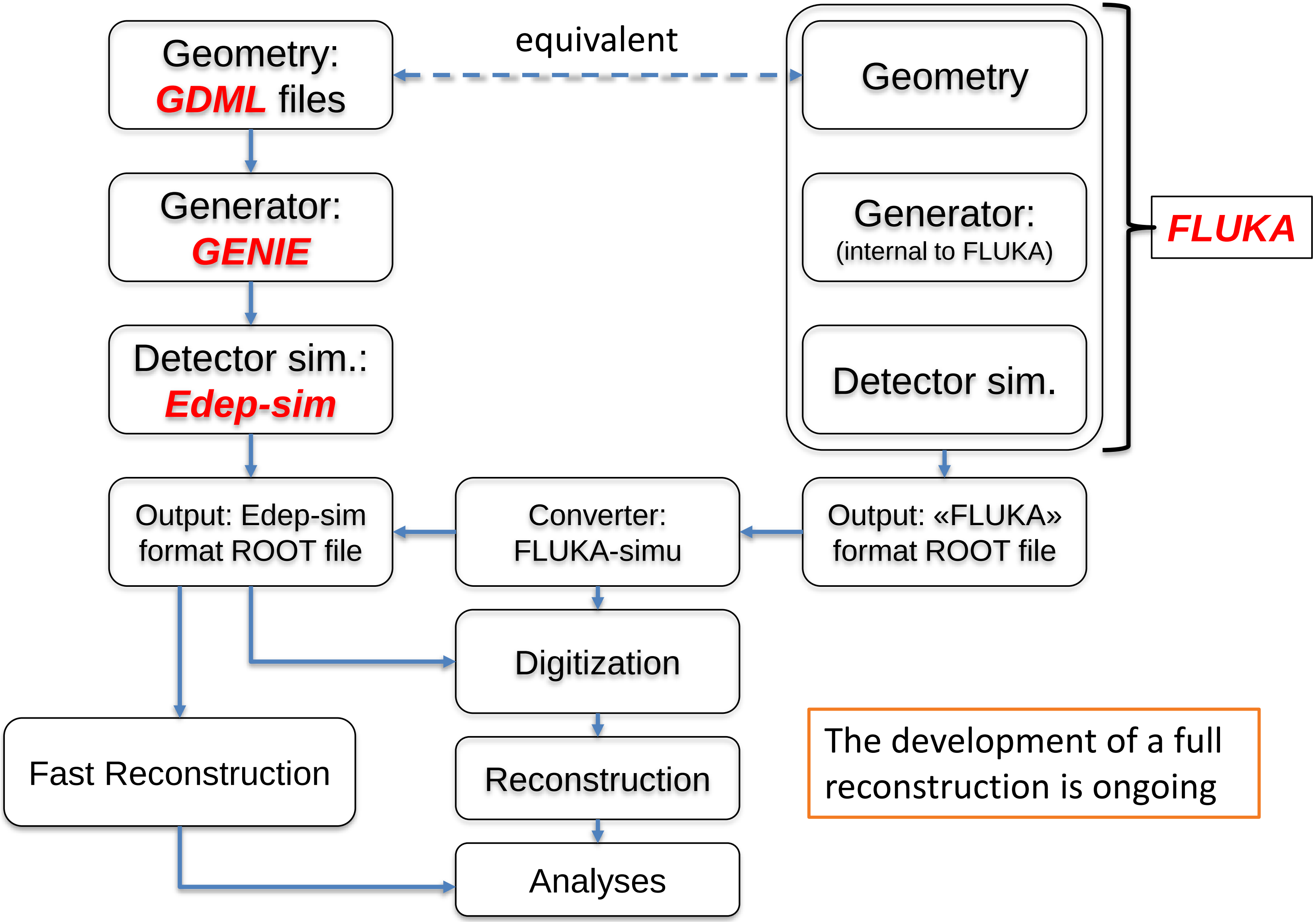
- ✓ Main features of ν events in SAND from a sample of ν_μ interactions in GRAIN simulated with FLUKA
- ✓ Most events contain few tracks in STT (~80% up to 3 tracks) and can be reconstructed by global track finding algorithms.
- ✓ Single particle initial momentum reconstructed by fitting the track in STT and including its energy loss in GRAIN (MC estimate).
  For total E_ν, the total energy deposit in GRAIN must be estimated

Background rejection

- ✓ Implementation of a simple bck rejection procedure based on
  - time information from ECAL and GRAIN
  - simple cuts on energy deposit in LAr and STT hit multiplicity
- ✓ Preliminary results give a final residual background at level of 6%
  Significant improvements are possible using further variables, complementary approaches and different methods (NN algorithms, ..)

BACKUP SLIDES

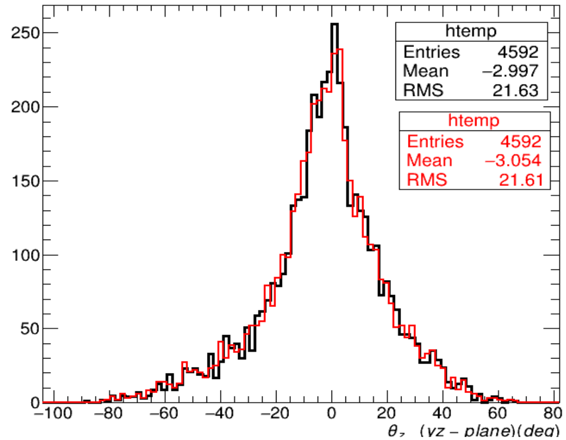
Reconstruction software layout for SAND



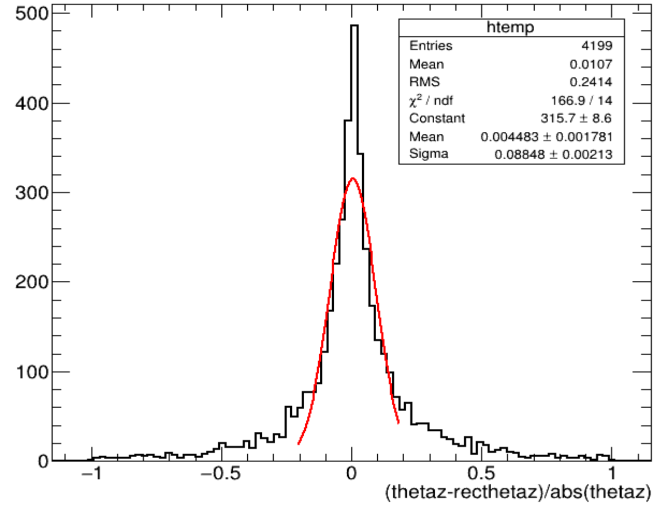
The development of a full reconstruction is ongoing

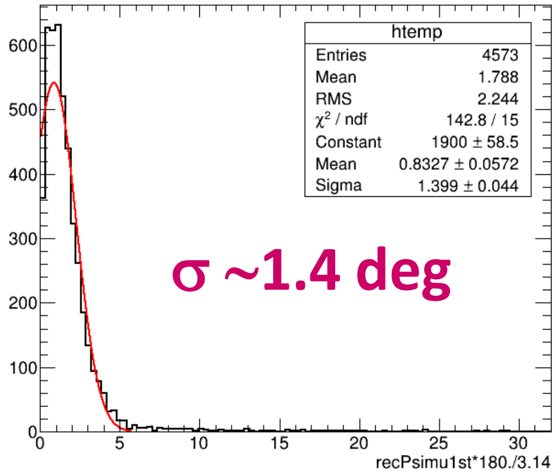
Muons in GRAIN tracked by STT: error on angles

θ_z distribution of μ in bending plane (true and reco)



Error on θ_z of μ in bending plane





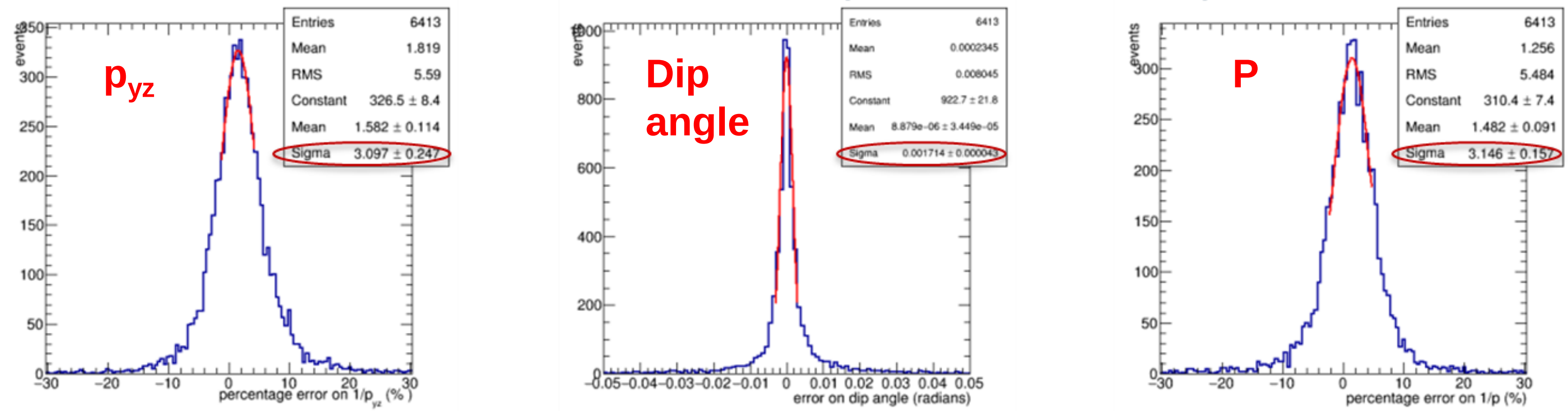
Error on θ_z of μ in space (from first 3 hits)

STT: track reconstruction

- NY> 4 (+ vertex) → target fiducial volume 30 cm from the edges

Muon momentum resolution < 3.4%

from momentum in bending plane + dip angle

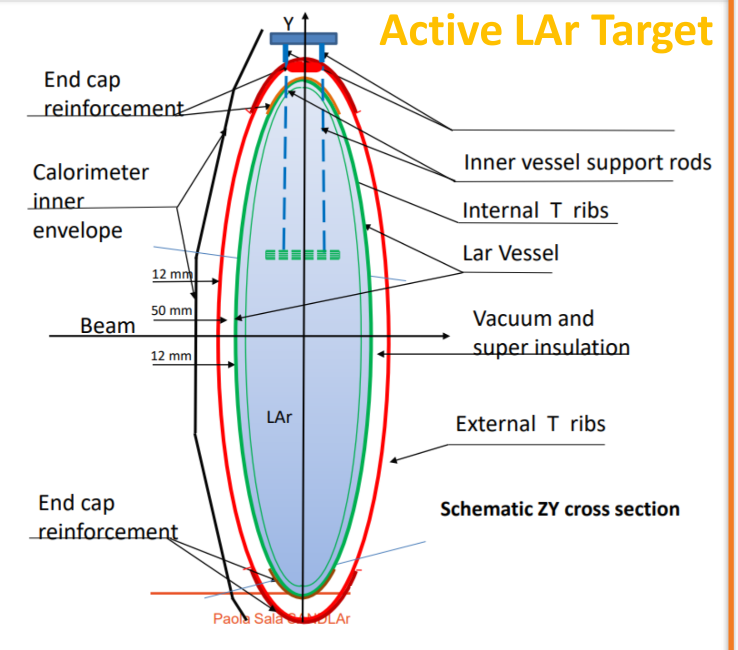


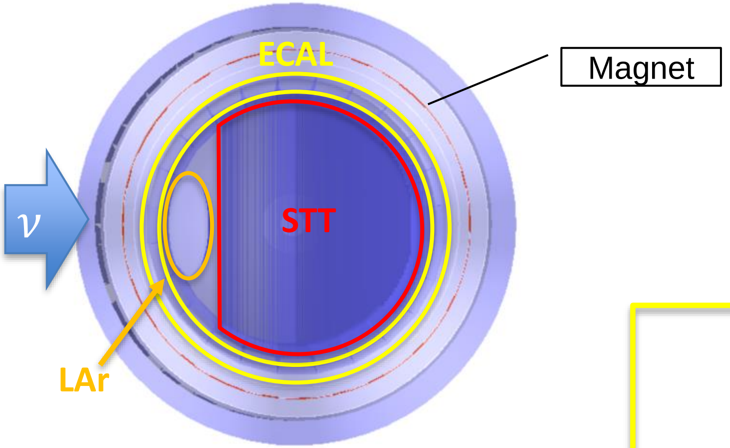
[from circular fit (not Kalman fit)]

Simulation	Target	p_{yz} (%)	dip-angle ($mrad$)	p (%)
FLUKA	LAr meniscus	2.6 ± 0.1	1.67 ± 0.09	2.53 ± 0.08
FLUKA	STT	3.1 ± 0.2	1.71 ± 0.04	3.1 ± 0.2
Geant 4	STT	3.50 ± 0.05	1.1 ± 0.1	3.43 ± 0.05

Wrong sign charge: 0.8% in the full momentum range

GDML geometry (GEANT4): ECAL+GRAIN+STT



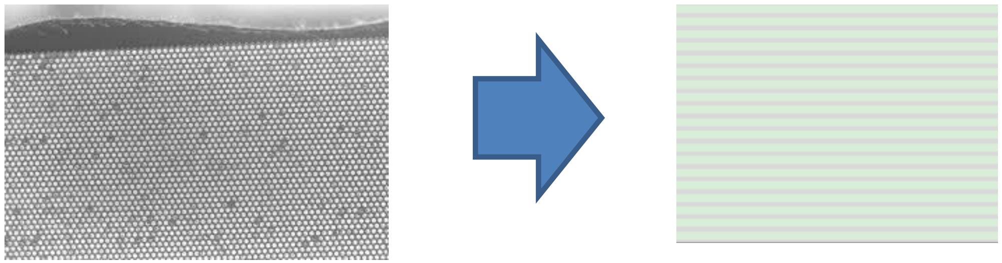


~ 90 STT modules:
- target (CH2 or C)
- radiator (plastic foils)
- XX straw tube plane
- YY straw tube plane

ECAL

24 barrel modules 2 endcaps

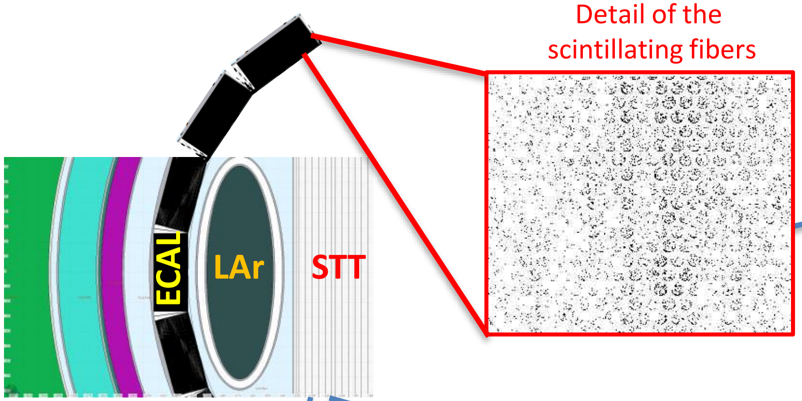
Spaghetti calorimeter approximated as 209 scintillation layers alternated with 209 lead layers

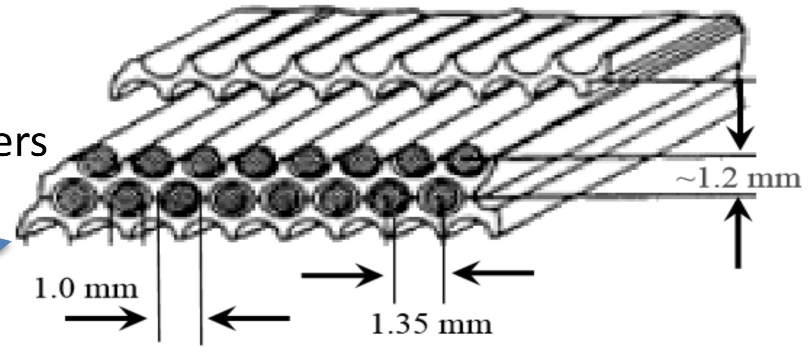


0.7 mm scintillation layer (green)

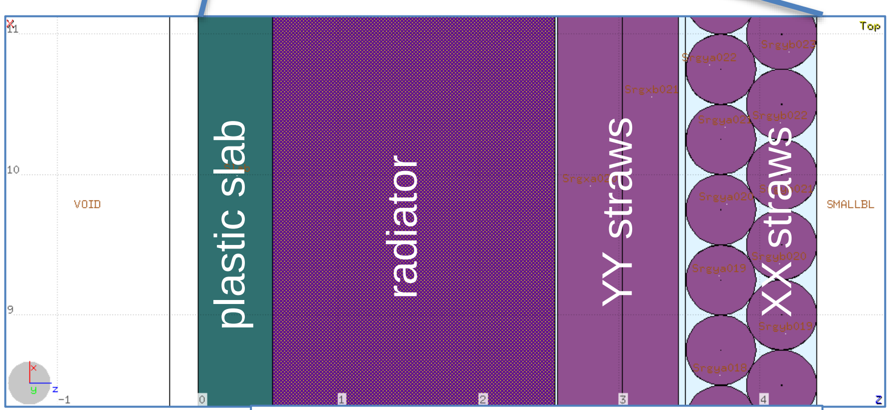
0.4 mm lead layer (gray)

Equivalent FLUKA geometry

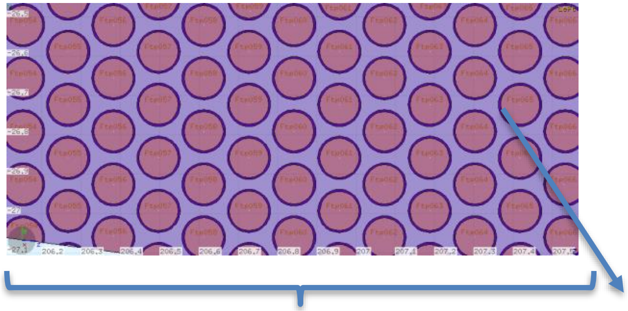




Kloecal fine structure



Detail of a STT module

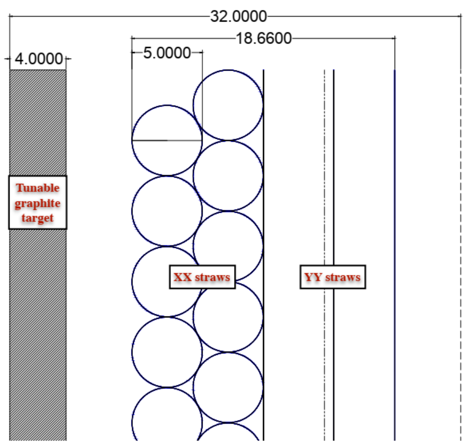


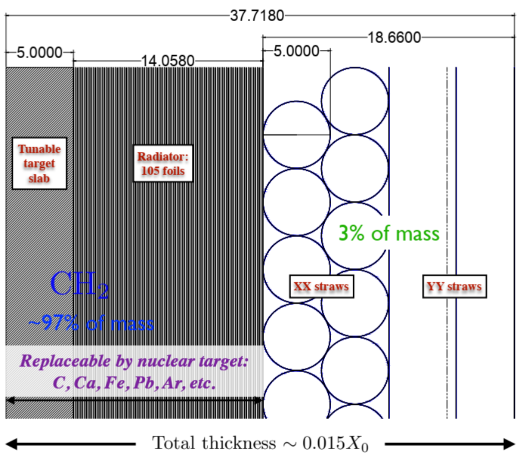
Detail of a ECAL module implemented in FLUKA: fibers, glue, lead

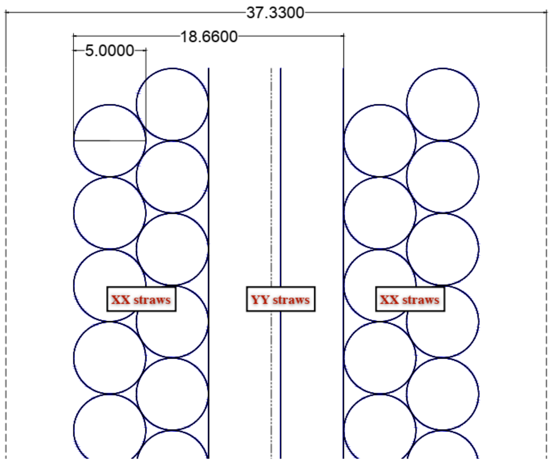
STT: a target + tracker system

- A high precision tracking system including thin (1-2% X_0) targets and TR capability
- A quick remind ⇒ 3 types of modules:

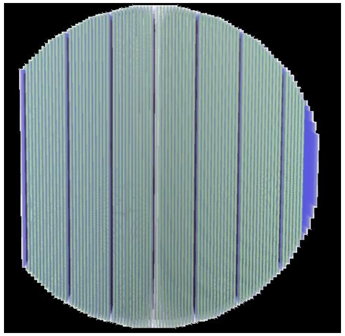
7 Carbon target modules **78 Target + radiator modules** **5 tracker modules: XXYYXX**







- position resolution on single hit: **200 um in y e x**
- time resolution on single hit: **1 ns**
- density: tunable between **0.005 < ρ < 0.18 g/cm³**
- radiation length X_0 ~ **2.6 m,**
- tracking sampling: **0.15% X_0** along z – **0.36%** **X_0** along x,y



Digitization: ECAL

NIM A 482 (2002) 364-386

- Detailed digitization of ECAL response takes into account:
  - Number of photons per deposited energy; scintillation time; attenuation and propagation time along the fibers; response of PMT
- Distinct digitization in FLUKA (geometry information stored in different way, different simulation details, ..), but same output

⇒ **Measured performances are reproduced:**

Time resolution

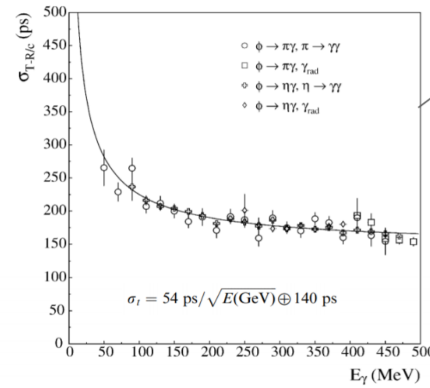
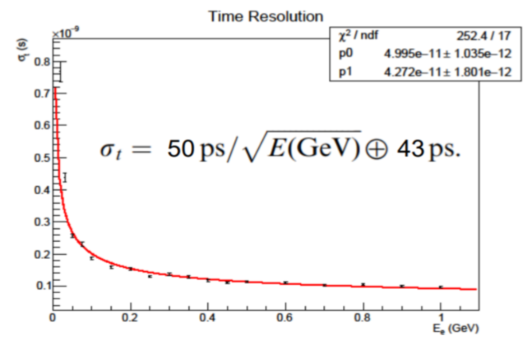


Fig. 32. Time resolution as a function of E_γ for ϕ radiative decays.

Intrinsic resolution:
$\sigma_t = 54$ ps$/\sqrt{E(\mathrm{GeV})} \oplus 50$ ps.



Energy resolution

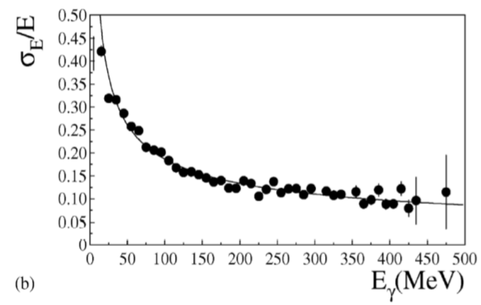
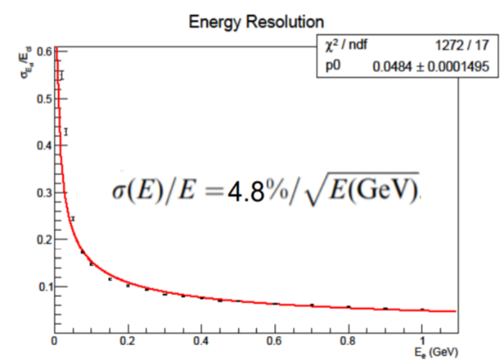
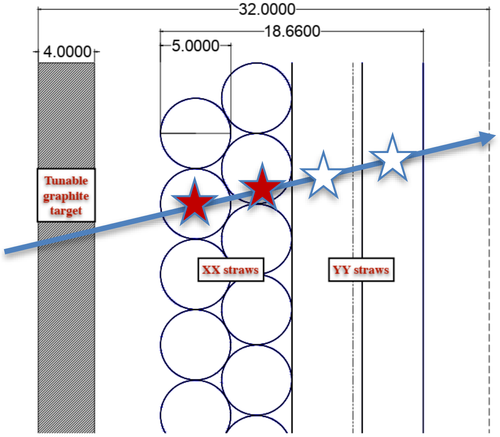


Fig. 20. $(E_{cl} - E_\gamma)/E_\gamma$ (a) and resolution (b) vs. E_γ for $e^+e^-\gamma$ events. The fit gives $\sigma(E)/E = 5.7\%/\sqrt{E(\mathrm{GeV})}$.



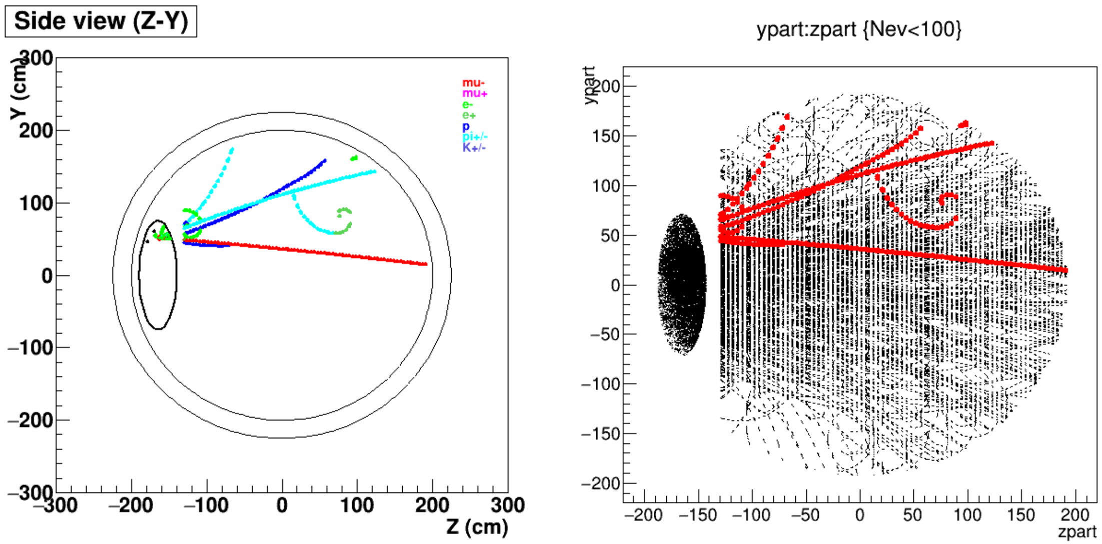
Digitization: STT

- STT space-resolution (0.2 mm for X and Y coordinates, 0.1 mm for Z coordinate) simulated by means of Gaussians
- Energy threshold for STT-hits: 0.1 keV
- For any charged particle in MC-tracks (by GEANT or FLUKA), the hits on STT planes generate the “STT-digits“, one for each STT layer in X-Z and Y-Z views
  - Digit coordinates from the average of hit coordinates
  - Time-resolution on STT digits: 1 ns (Gaussian smearing)

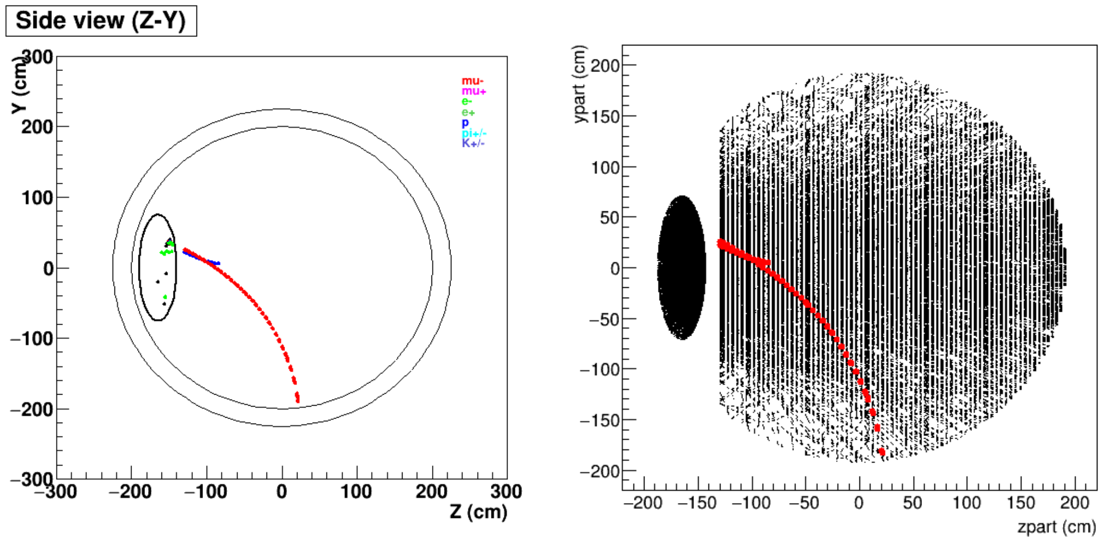


Will be improved soon!

Problematic situations for transform method



Many tracks, eventually crossing each other

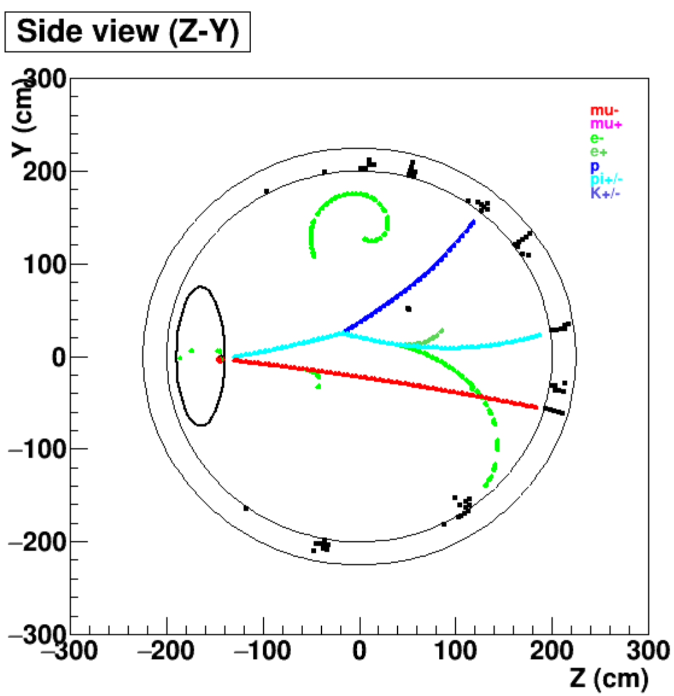


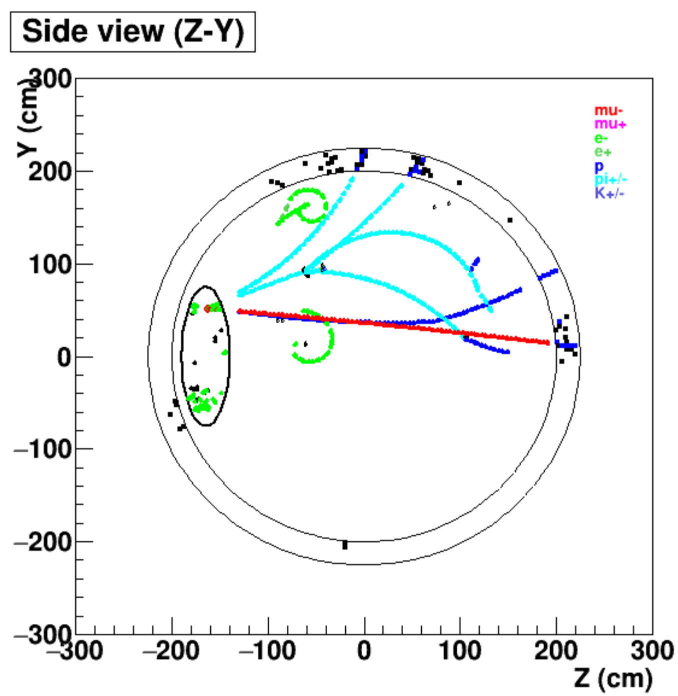
Superimposed tracks, although few

Track multiplicities in STT

The multiplicity of tracks entering STT can underestimate the total track multiplicity in STT, due to secondary vertices by interactions, decays, …

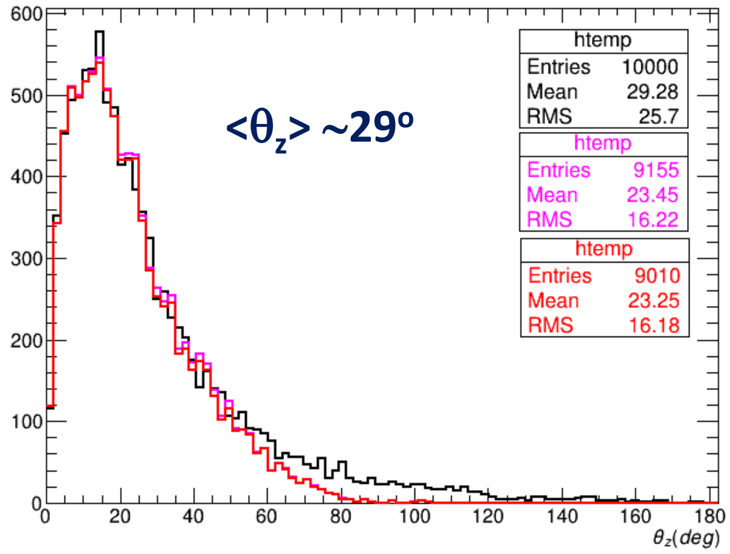
Some examples:



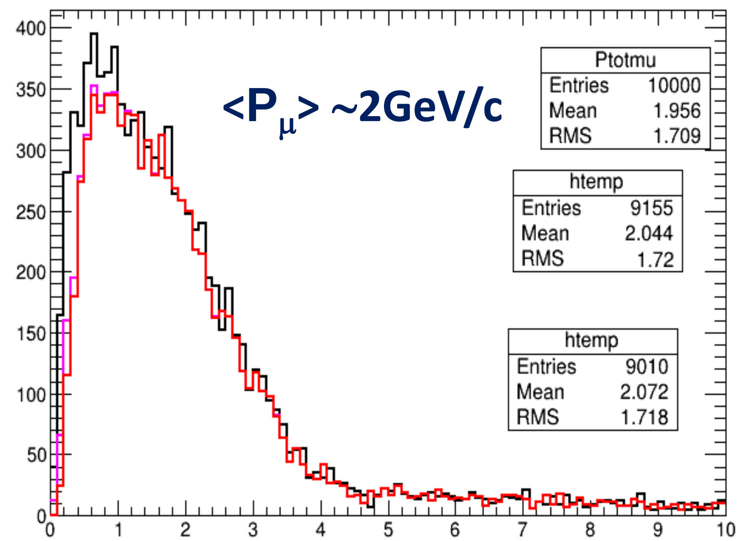


Muon acceptance by STT and ECal

P_μ-angle θ_z w.r.t. beam direction



Muon momentum spectrum

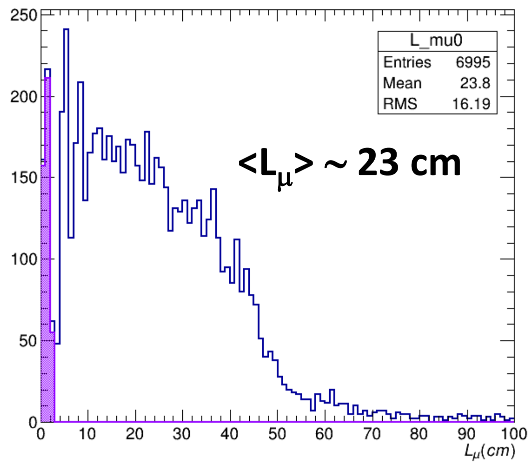


~ 92 % of muons cross the STT front tracking modules

~ 90 % of muons touch ECal after STT

Muon energy loss in GRAIN-LAr

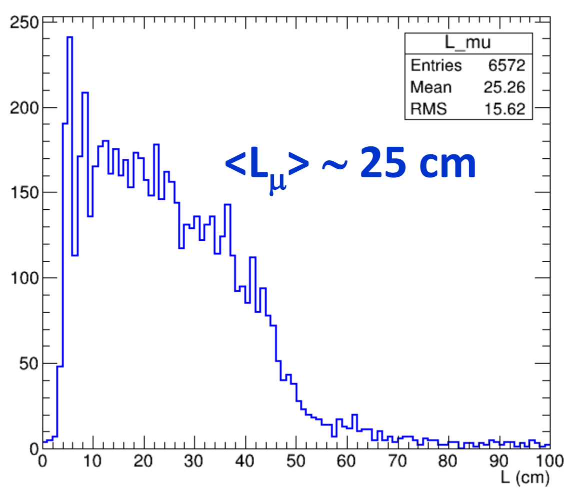
Muon path-length in LAr



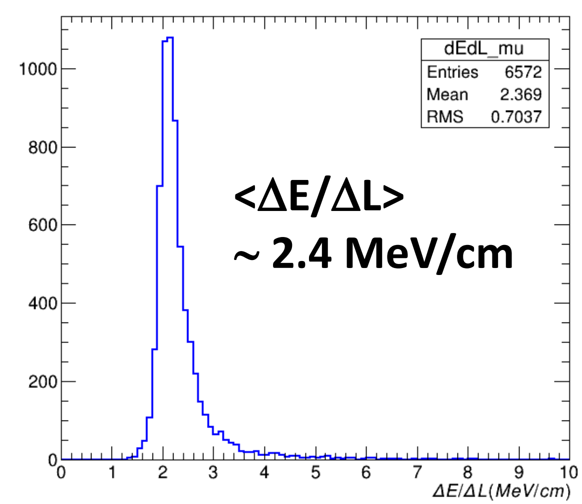
Some muons (~6%) absorbed near the vertex inside LAr

Excluding above events:

Muon path-length in LAr

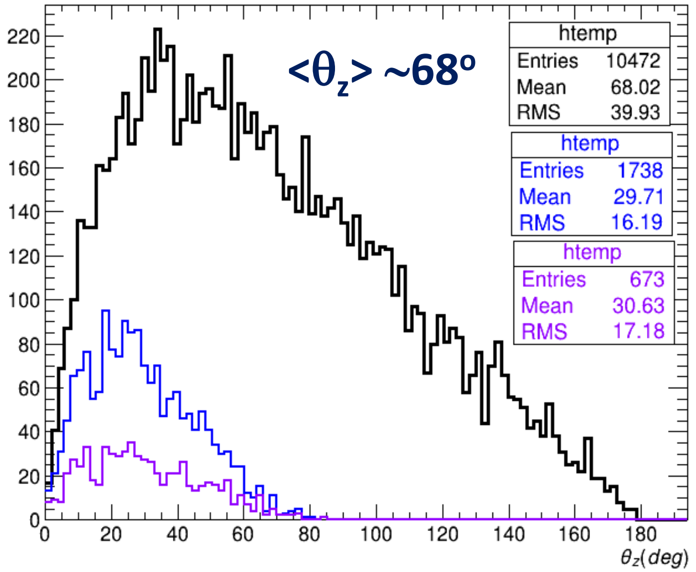


Muon: dE/dL in LAr

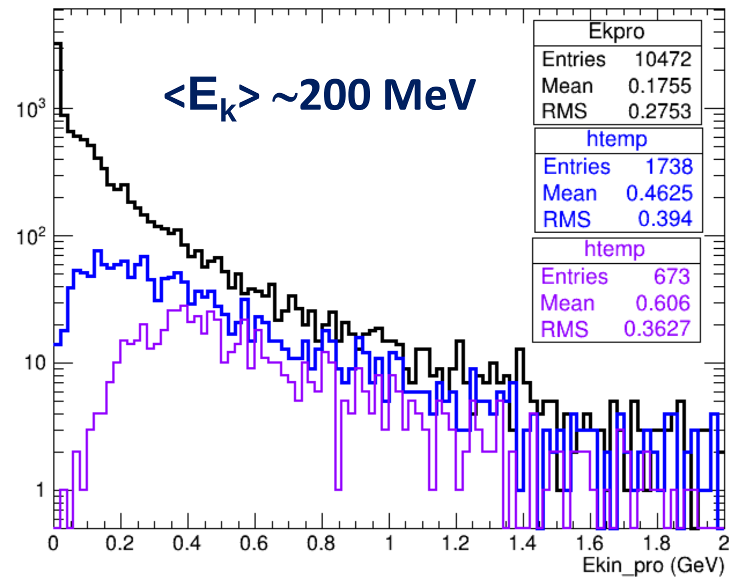


Proton acceptance by STT and ECal

P_p-angle θ_z w.r.t. beam direction



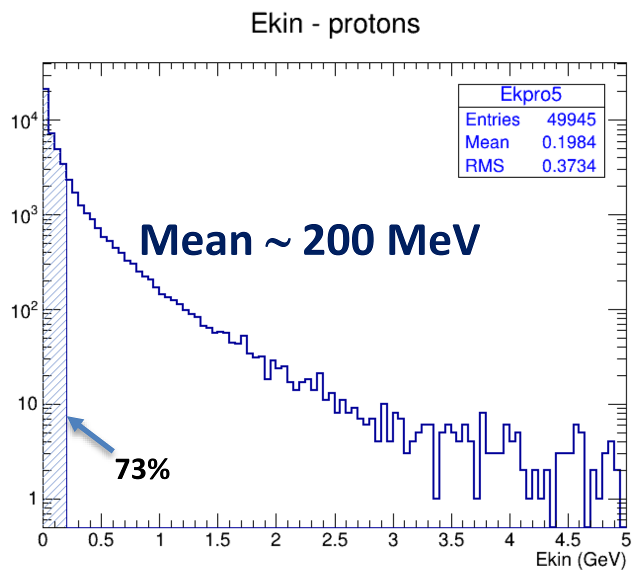
Proton kinetic energy spectrum



~ 17 % of (primary) protons cross the STT front tracking modules

~ 6 % of (primary) protons touch ECal after STT

Proton energy spectrum (ν-Ar in GRAIN)

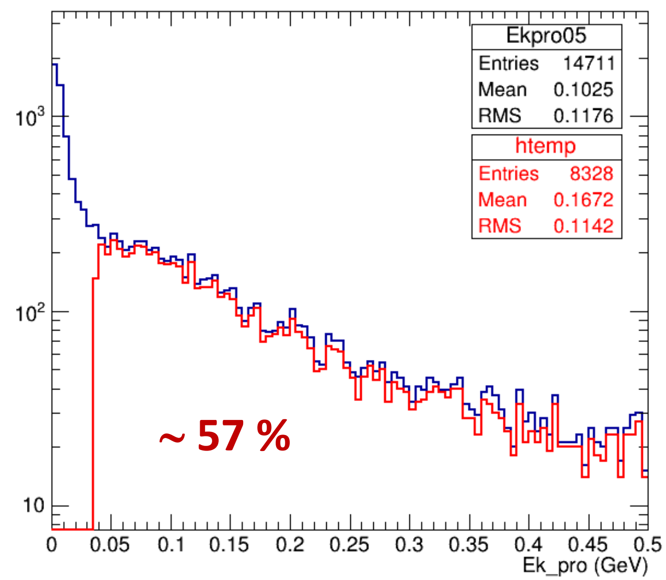


Proton energy spectrum

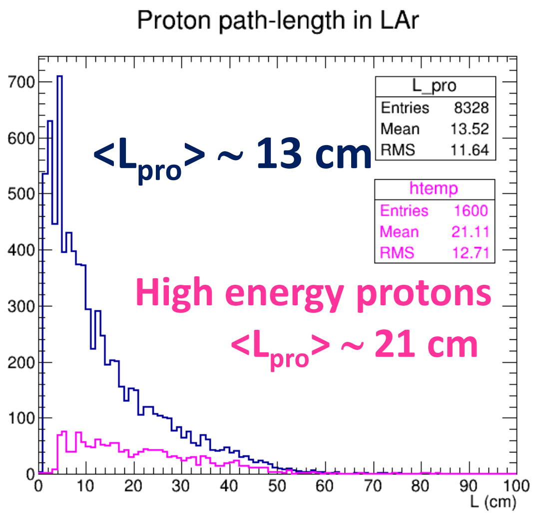
All protons are considered

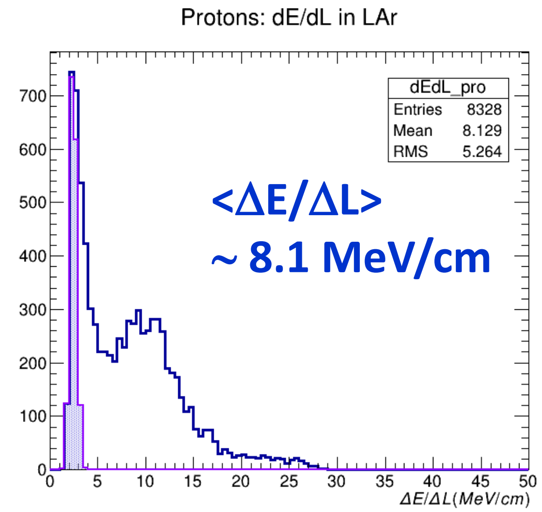
Almost half protons with very low energy immediately absorbed near the vertex (just in 1 step of the simulation)

Excluding such protons:



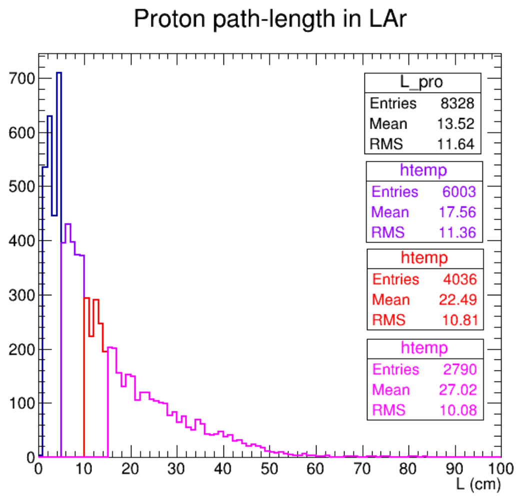
Proton energy loss in GRAIN-LAr





From average values:

E_{thr} ~ 100 MeV for protons to exit LAr



Some cuts on L_{pro}:

>5 cm : 72 %

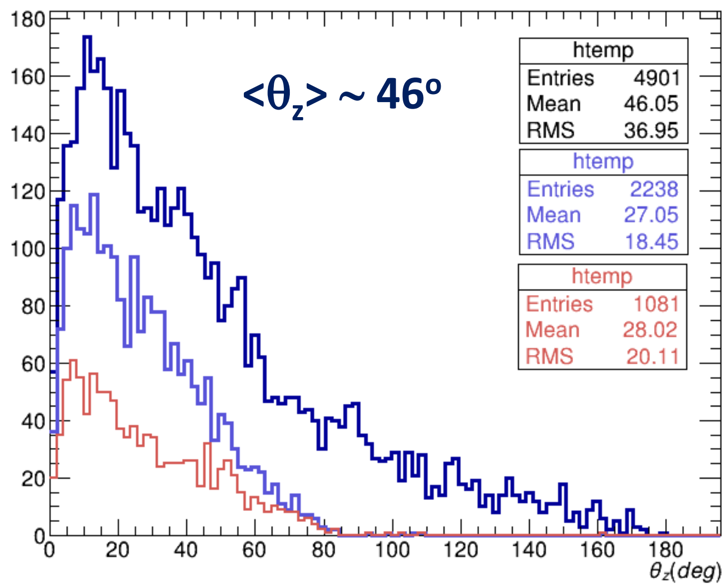
>10 cm: 48 %

>15 cm: 34 %

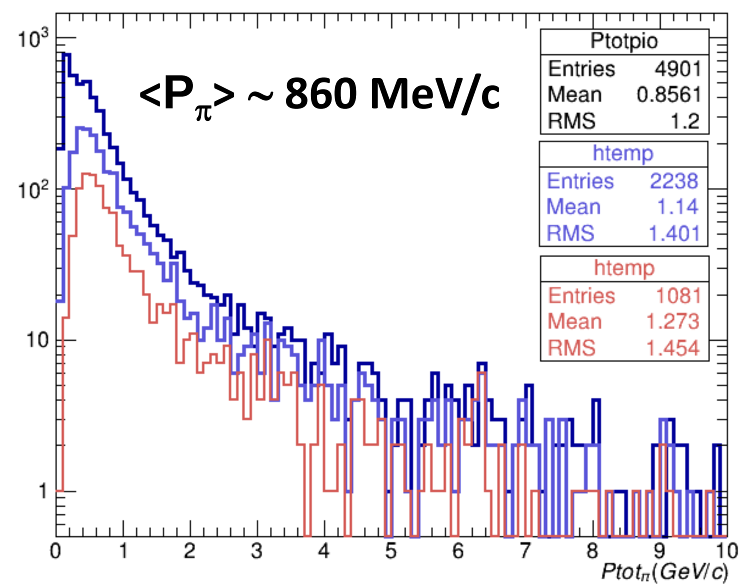
Tracks could be reconstructed in LAr

Acceptance for charged pions by STT and ECal

P_π-angle θ_z w.r.t. beam direction



Charged pion momentum spectrum

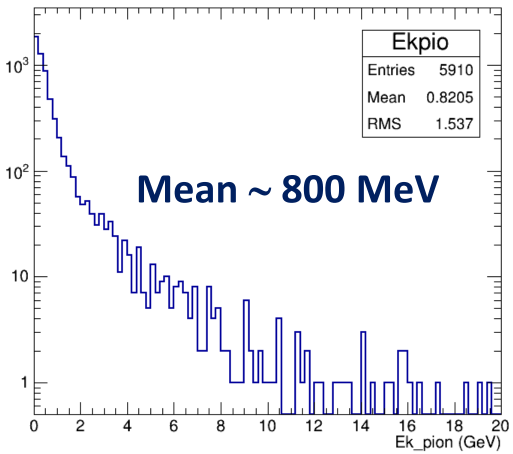


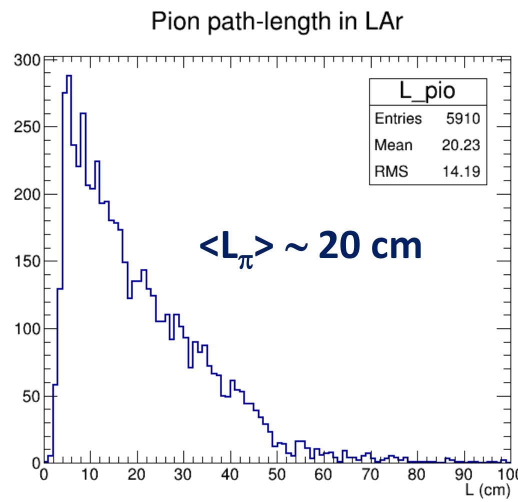
~ 46 % of (primary) pions cross the STT front tracking modules

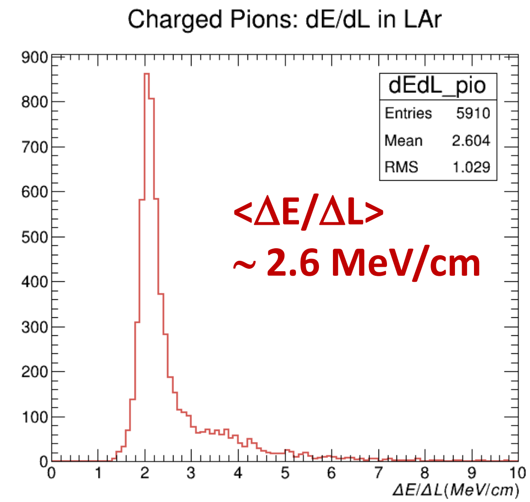
~ 22 % of (primary) pions touch ECal after STT

Charged pion energy loss in GRAIN-LAr

Pion energy spectrum

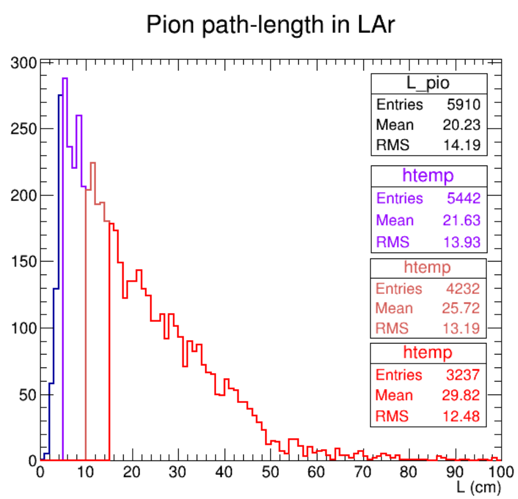






From average values:

E_{thr} ~ 50 MeV for charged pions to exit LAr



Some cuts on L_π:

>5 cm : 92 %

>10 cm: 72 %

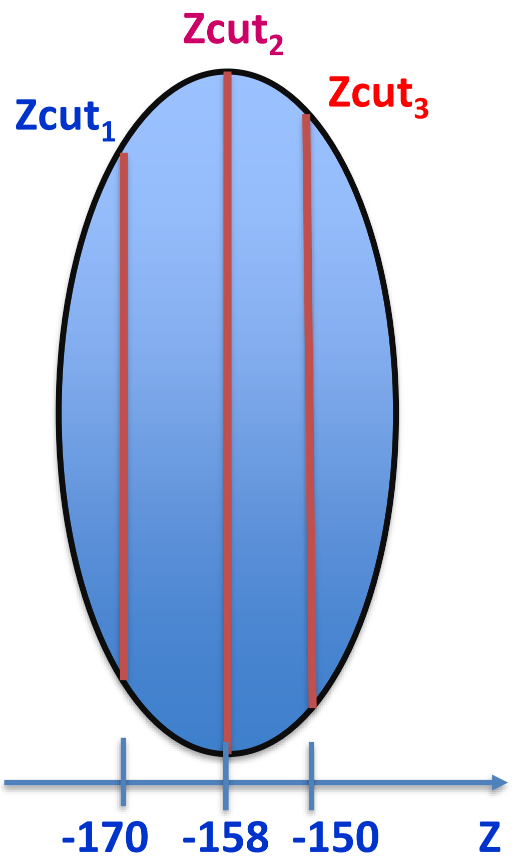
>15 cm: 55 %

Tracks could be reconstructed in LAr

Fiducial volume cut on vertex in GRAIN-LAr

Z range of Vertex in GRAIN-LAr: from -180cm to -138cm

Cut on Vertex along beam direction: Z > Zcut



$Zcut_1$ = -170 cm

- ~ 48 % of (primary) pions cross the STT front tracking modules
- ~ 23 % of (primary) pions touch ECal after STT

$Zcut_2$ = -158 cm

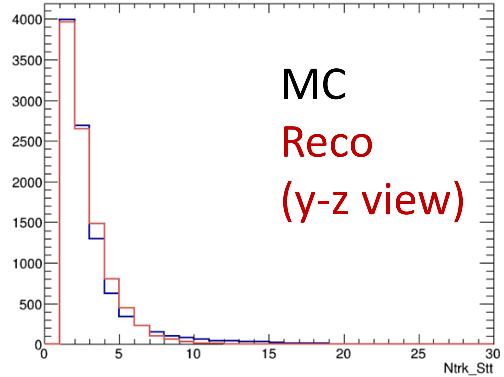
- ~ 52 % of (primary) pions cross the STT front tracking modules
- ~ 26 % of (primary) pions touch ECal after STT

$Zcut_3$ = -150 cm

- ~ 56 % of (primary) pions cross the STT front tracking modules
- ~ 27 % of (primary) pions touch ECal after STT

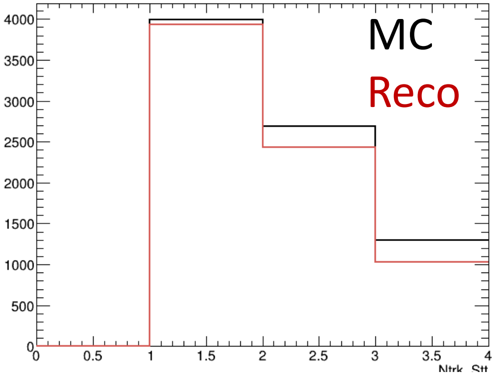
Reconstructed vs MC tracks in STT

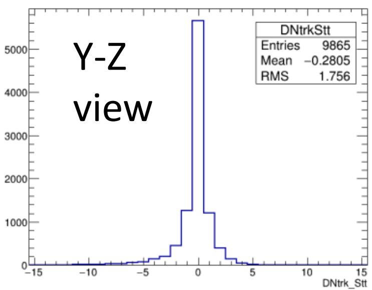
Ntracks > 0

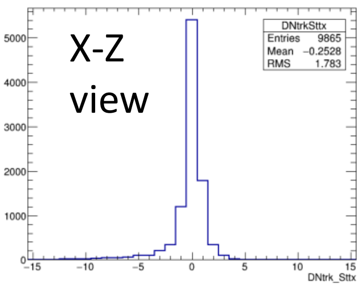


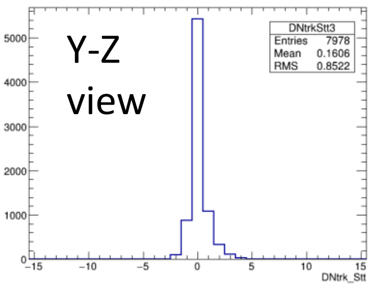
Track multiplicity distribution

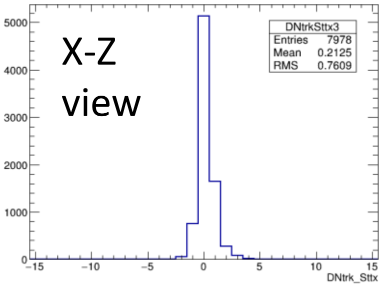
0 < Ntracks ≤ 3

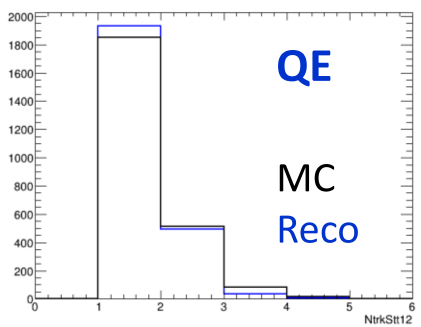


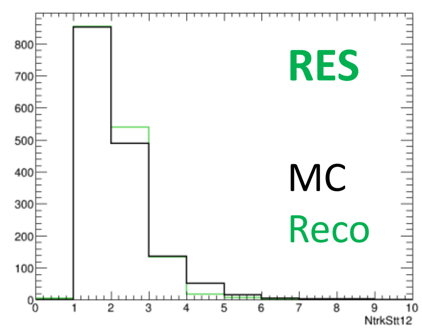


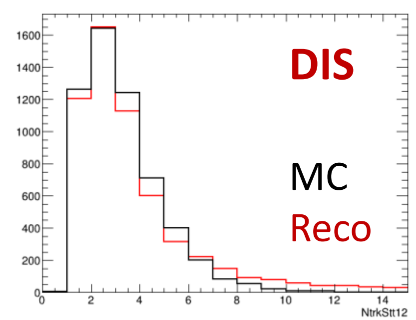






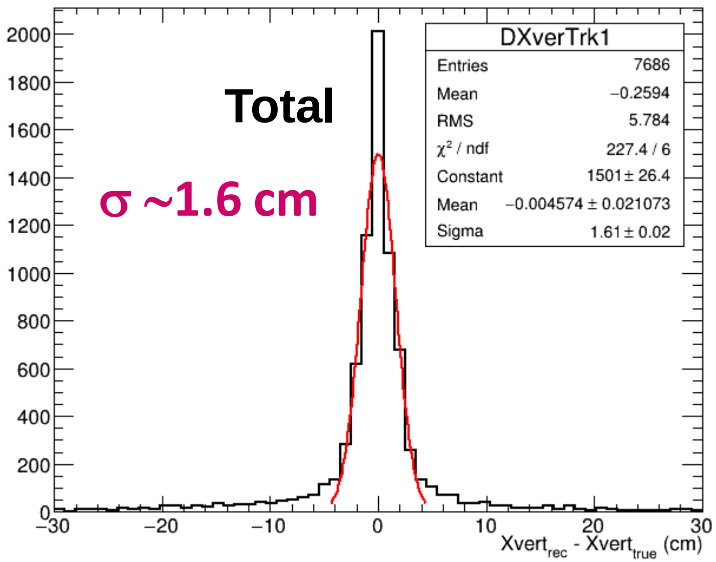


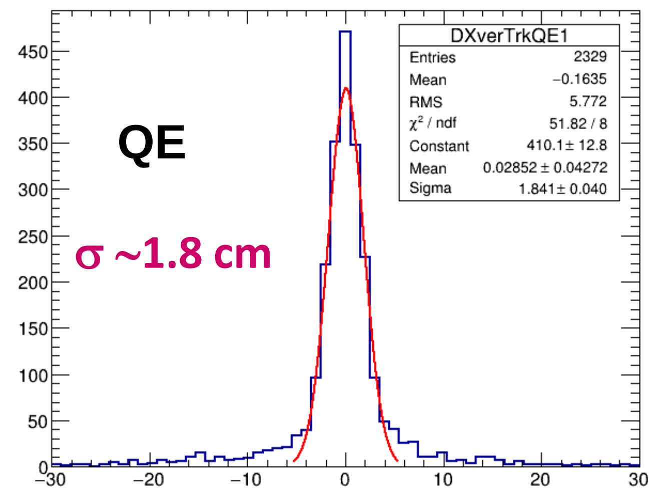


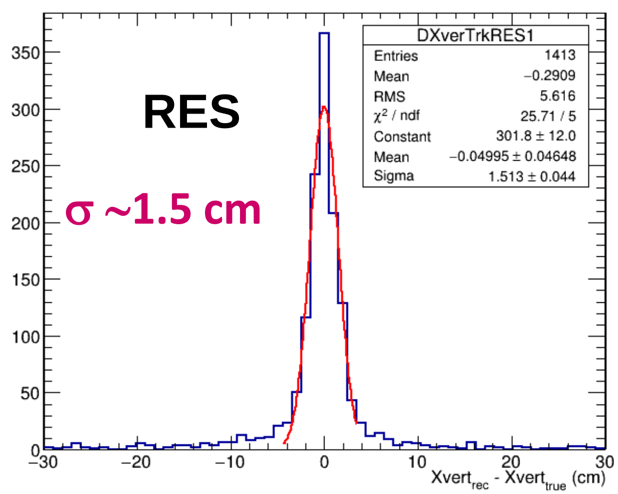


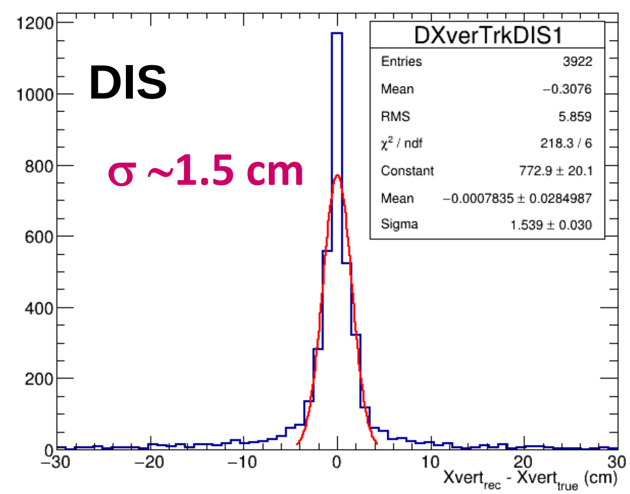
Vertex reconstruction from reco tracks

Reconstruction of X coordinate



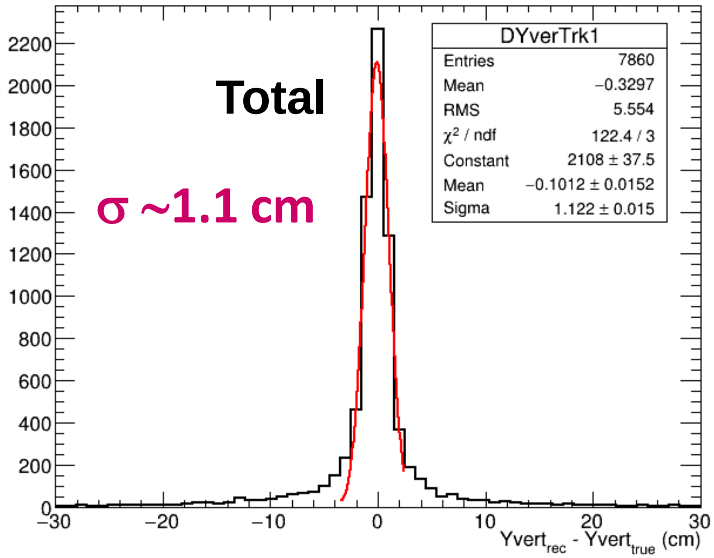


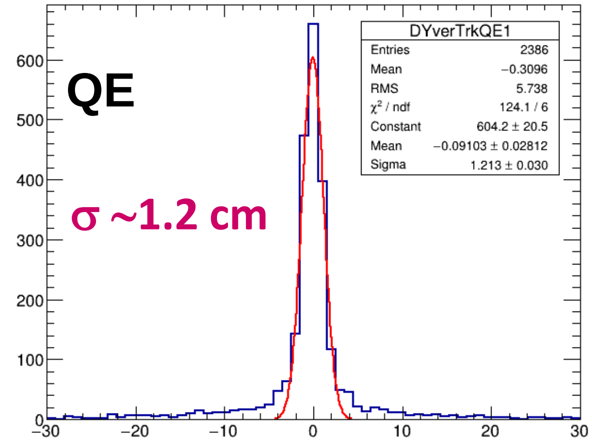


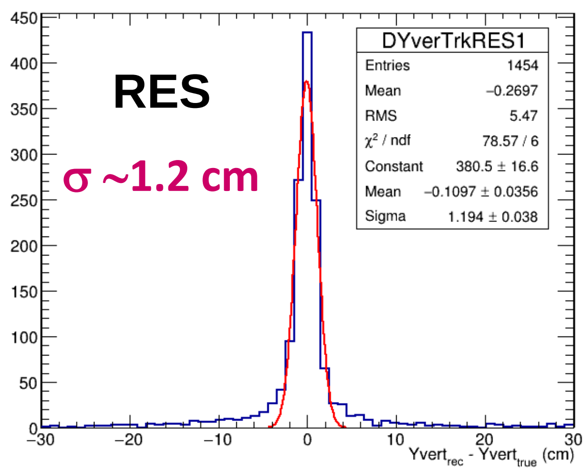


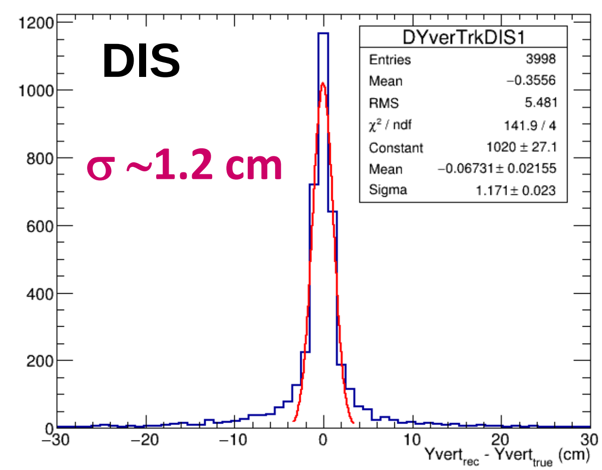
Vertex reconstruction from reco tracks

Reconstruction of Y coordinate



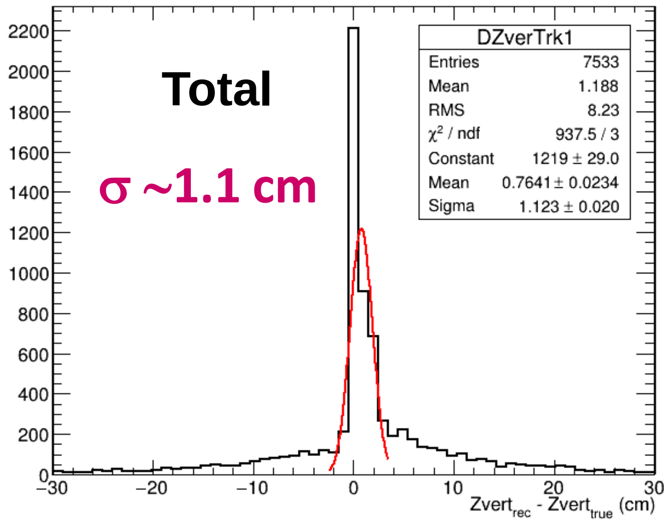


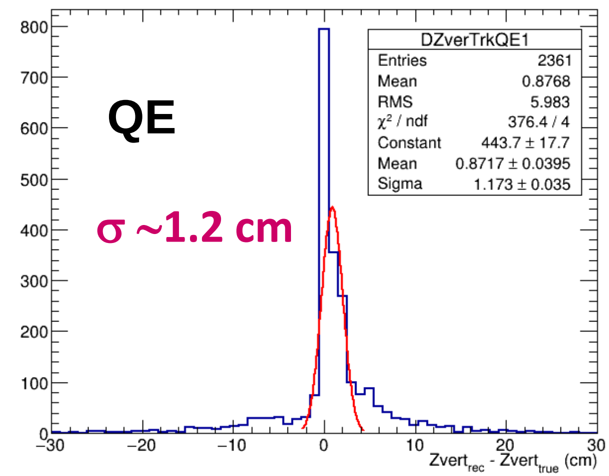


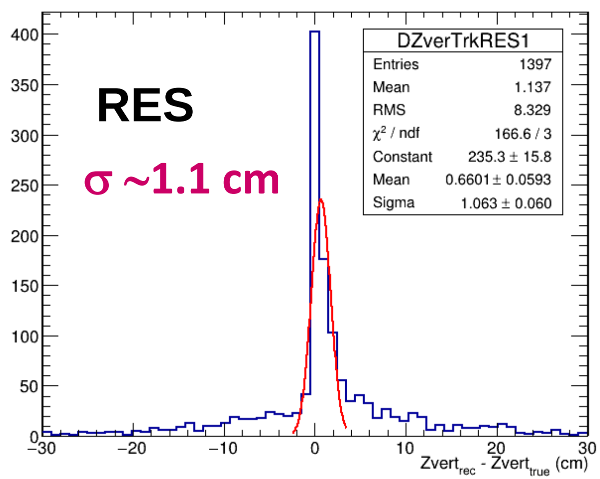


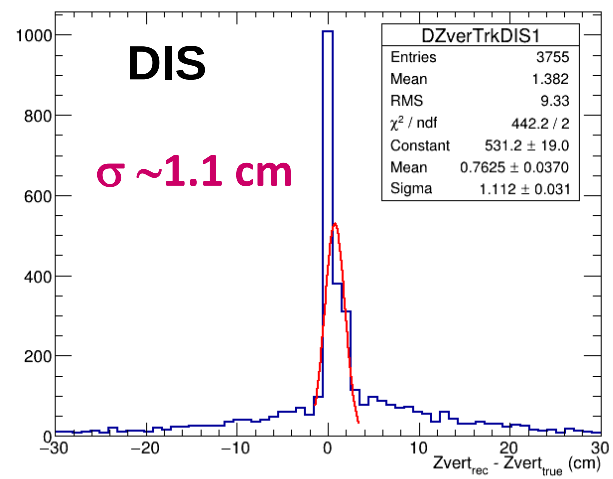
Vertex reconstruction from reco tracks

Reconstruction of Z coordinate

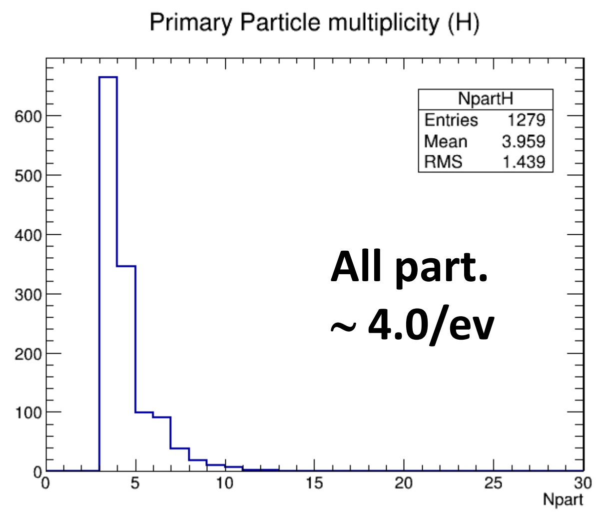


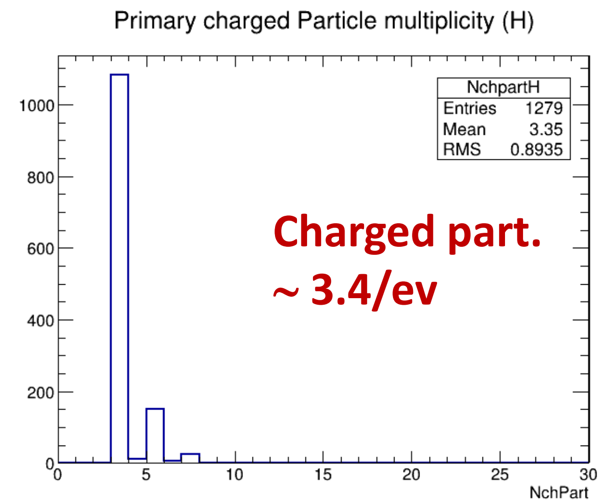


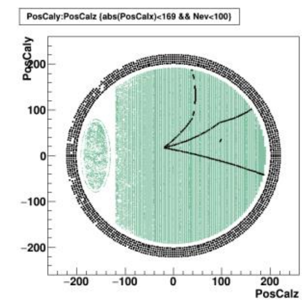




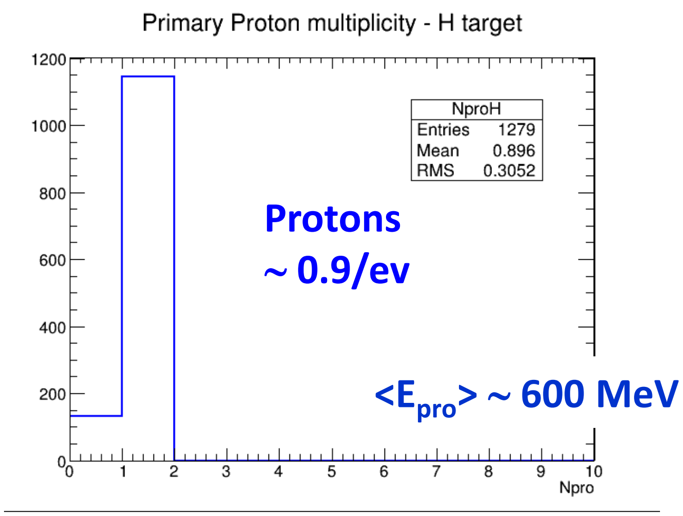
ν_μ interactions on H in STT

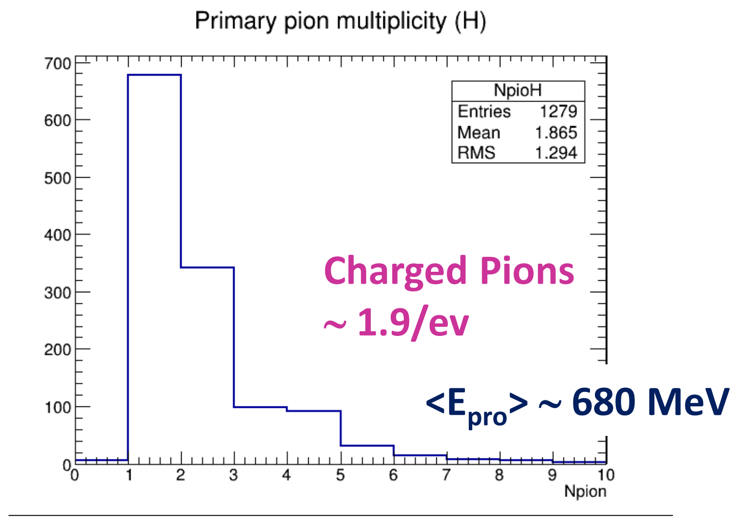




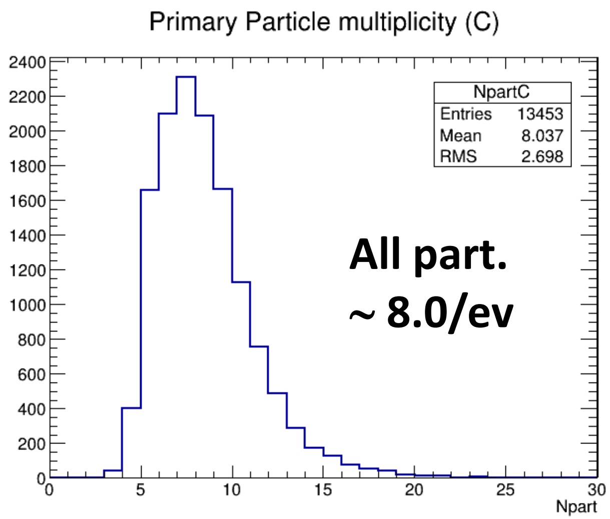


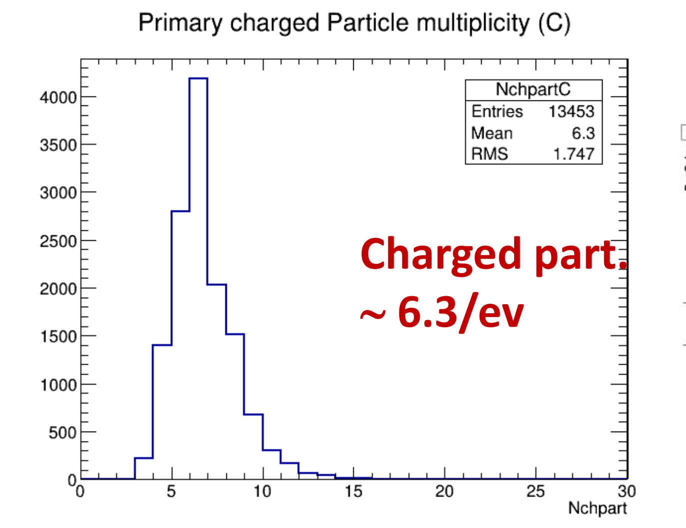
RES interaction on H (~ 40% events on H)

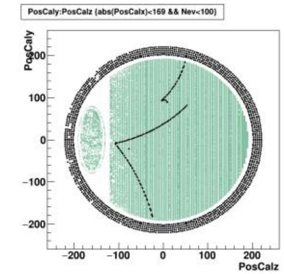




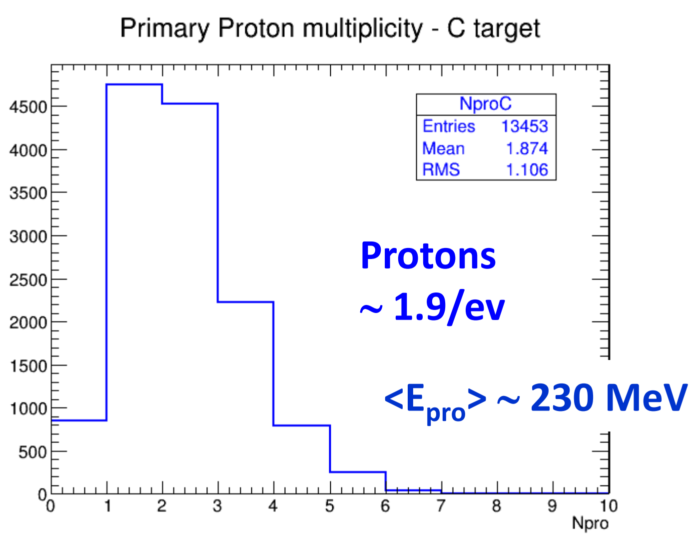
ν_μ interactions on C in STT

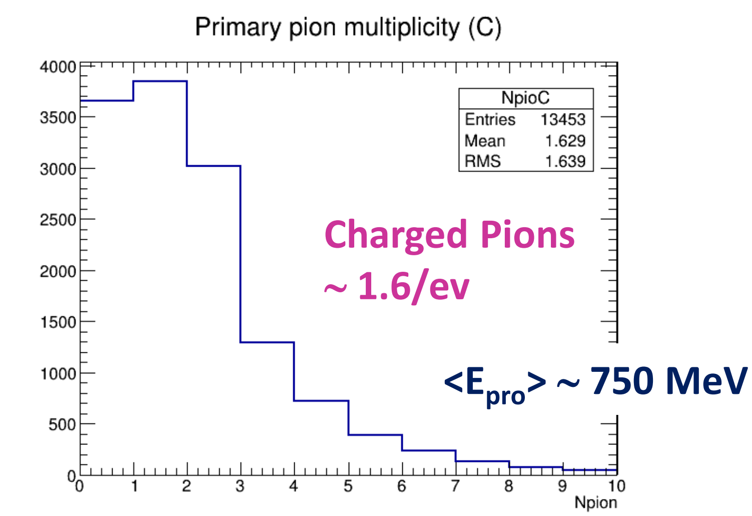






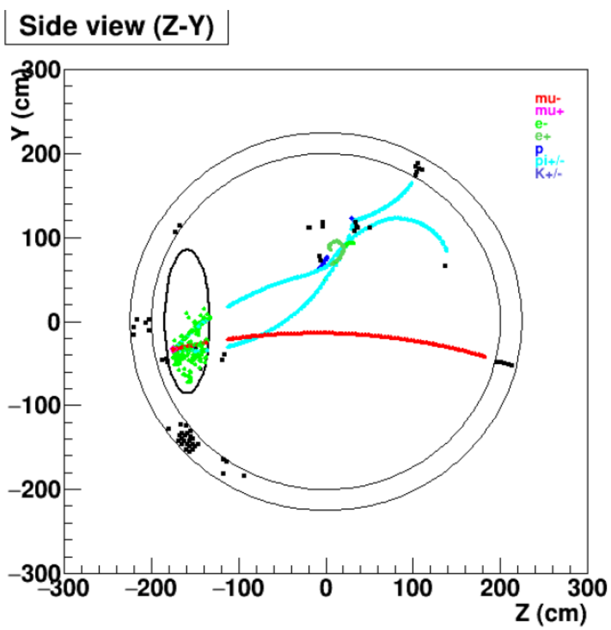
DIS interaction on C
(~ 40% events on C)

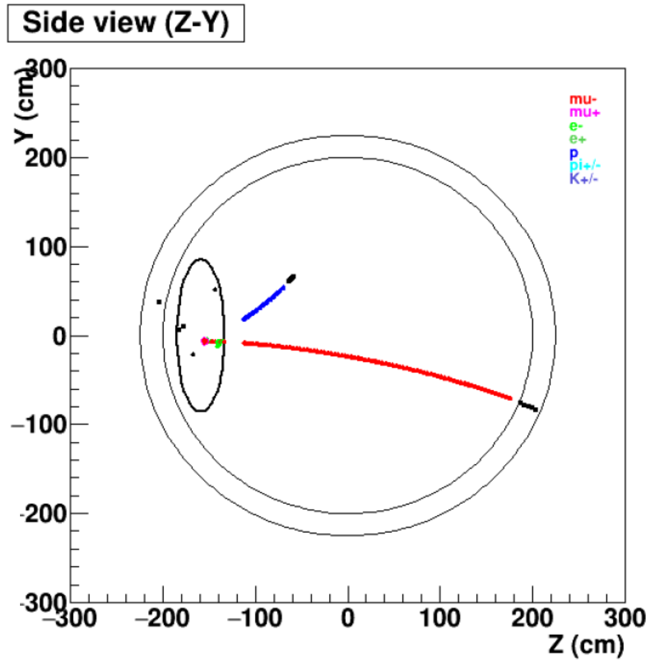


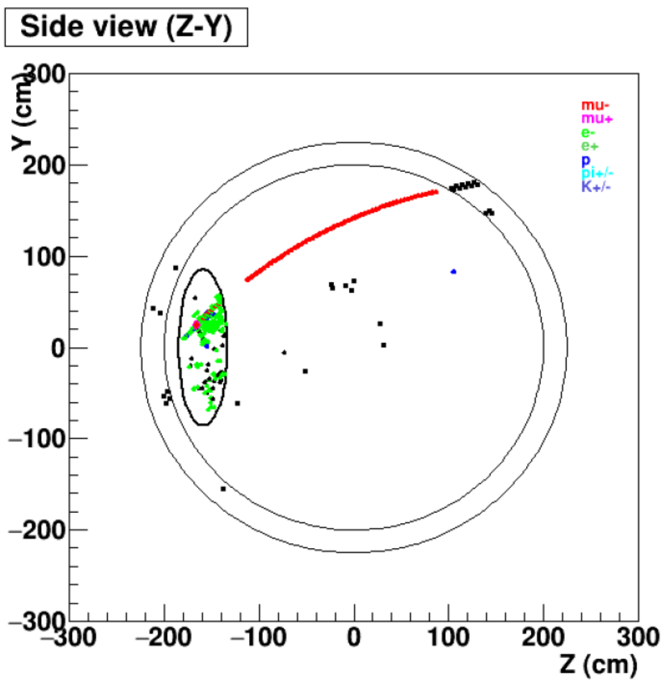


Display of some events

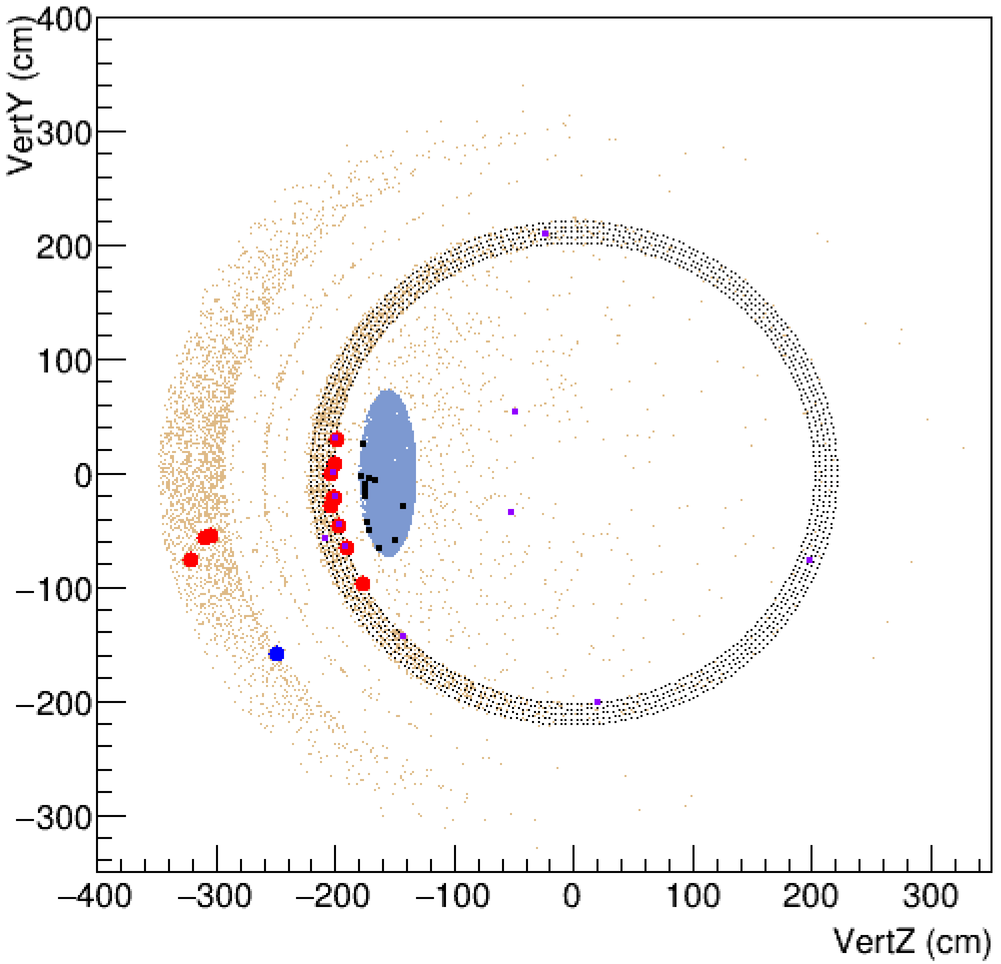
ν_μ CC interactions in GRAIN LAr







Residual bck events: vertex distribution



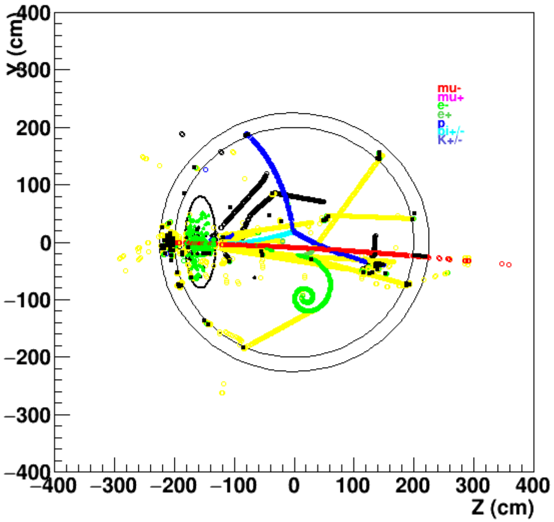
Vertex of bck_1 events

Vertex of bck_2 event

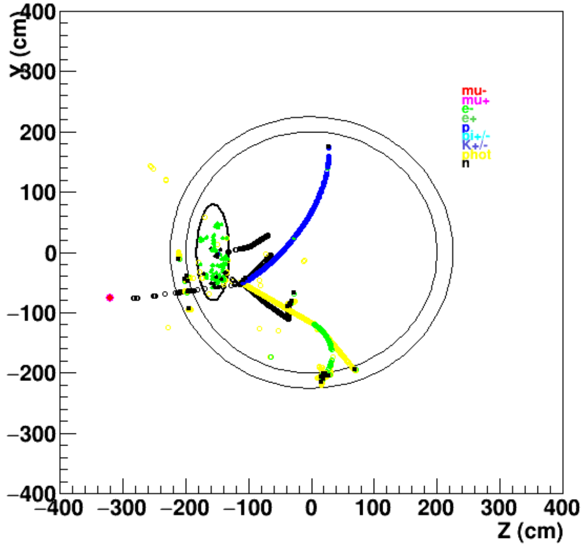
1st hit in GRAIN

1st hit in ECAL

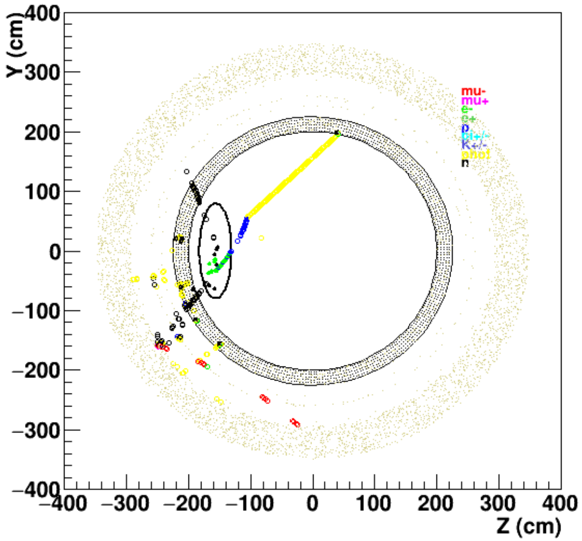
Display of bck events



Bck of type 1 with vertex in ECAL



Bck of type 1 with vertex in the Yoke



Bck of type 2 with vertex in the Yoke