Update on TPC resolution

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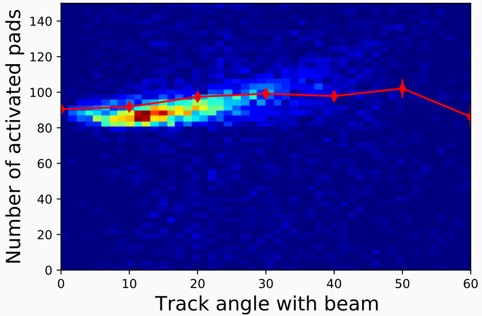
P_T resolution - Inputs from simulation

Resolution is estimated with: $$\frac{\sigma_{p_T}}{p_T} = \frac{p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}.\sigma_{r\phi}$$

Inputs

- $B = 0.6\,\mathrm{T}$
- P_T muon transverse momentum *
- L individual track length *
- N number of leading pads for track *
- $\sigma_{r,\phi}$ resolution taken from prototype data (cosmics and test beam)
- Additional effects (non-uniformities, mis-alignment,...) calibrated by comparing to real neutrino data of T2K

* From track-by-track simulation

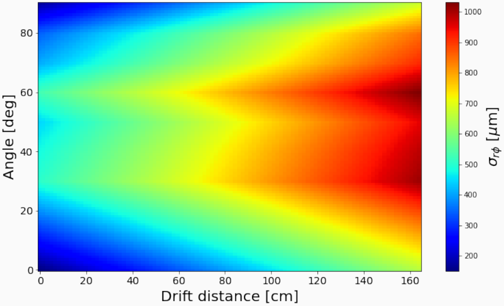


Simulation

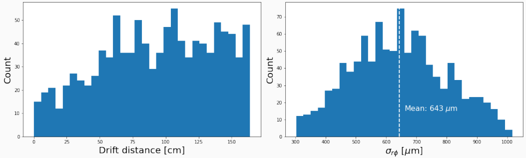
Prototype data are used to estimate $\sigma_{r\phi}$

Resistive Micromegas prototype testing

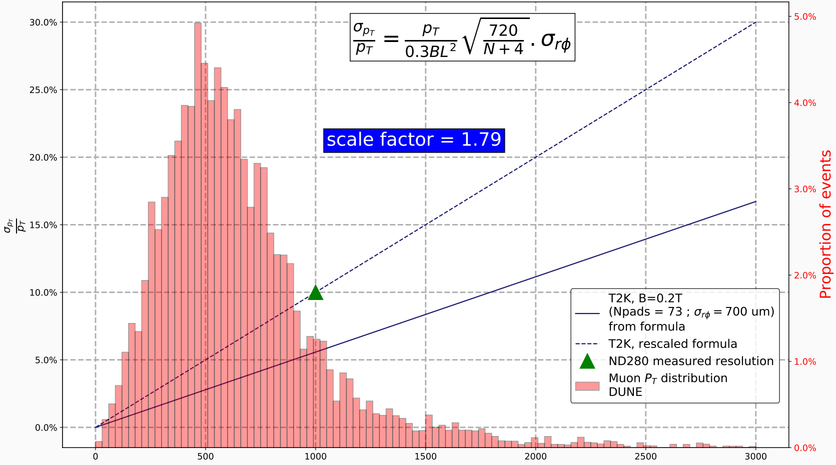
- 2018 test beam at CERN ; 2019 at DESY with magnetic field
- Cosmic data taking at Saclay



- Dependence of spatial resolution with drift distance and track angle.

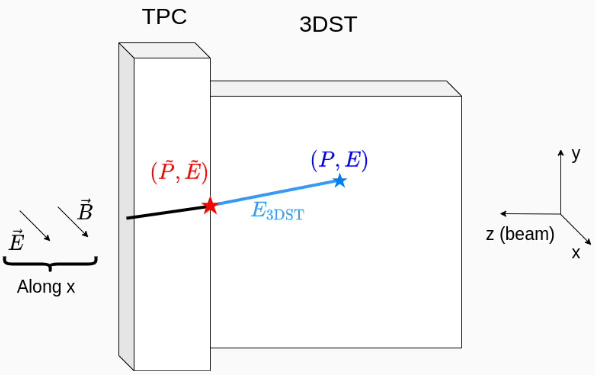


Tuning P_T resolution formula



The formula applied to simulation is a simplification. To take into account all effects in real data (different track angles, effects of diffusion,...) the formula is calibrated with T2K data

Estimating P resolution



- P and E are the initial momentum and energy of the particle
- $\tilde{P}$ and $\tilde{E}$ are the momentum and energy of the particle when entering TPC
- $\tilde{P}_T = \sqrt{\tilde{P_y}^2 + \tilde{P_z}^2}$ measured in the TPC
- E_{3DST} is the energy deposited in the 3DST

Addtional Effects

- MS in 3DST modifies particle direction
- Energy deposition in 3DST modifies particle energy

Resolution effects taken into account

- Error on sagitta measurement : $\left.\frac{\sigma_{p_T}}{p_T}\right|^{\text{Measure}}$ taken from calibrated formula

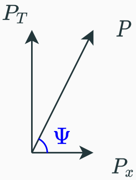
- Multiple scattering in the TPC : $\left.\frac{\sigma_{p_T}}{p_T}\right|^{\text{MS}} = 0.045\frac{1}{B\sqrt{LX_0}} \sim 0.9\,\%$ in our case ($X_0 = 90\,\text{m}$ for CF_4)

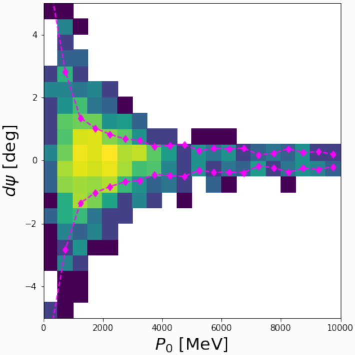
- Error on the measurement of the energy deposit inside 3DST E_{3DST}: $\frac{\sigma_{E_{\text{3DST}}}}{E_{\text{3DST}}} = 2\,\%$

- Error on the track angle due to MS in 3DST

Attempting to take into account MS effect

$$P_x = P\cos\Psi$$
$$P_y = P\sin\Psi\cos\phi$$
$$P_z = P\sin\Psi\cos\phi$$





- $P_T = P\sin\Psi$,
  we can estimate P from P_T and Ψ
- $\tilde{\Psi} = \Psi + \Delta\Psi$,
  $\Delta\Psi$ is the effect of MS in 3DST
- Assuming $\sigma_{\tilde{\Psi}} = \Delta\Psi \rightarrow$ probably inadequate
- Computing $\Delta\Psi$ for each momentum bin and using it as resolution estimation

Uncertainties

Computing factors

$$P = \sqrt{E_{3DST}^2 + 2E_{3DST}\sqrt{m^2 + \tilde{P}^2} + \tilde{P}^2}$$
$$= \sqrt{E_{3DST}^2 + 2E_{3DST}\sqrt{m^2 + \frac{\tilde{P_T}^2}{\sin^2\tilde{\Psi}}} + \frac{\tilde{P_T}^2}{\sin^2\tilde{\Psi}}}$$

$$\frac{\partial P}{\partial E_{3DST}} = \frac{E}{P}$$
$$\frac{\partial P}{\partial \tilde{P_T}} = \frac{\tilde{P}}{P\sin\tilde{\Psi}}\frac{E}{E - E_{3DST}}$$
$$\frac{\partial P}{\partial \tilde{\Psi}} = -\frac{\tilde{P}^2}{P\tan\tilde{\Psi}}\frac{E}{E - E_{3DST}}$$

This supposes no input from 3DST concerning the momentum.

Uncertainty composition

Values measured at the entrance of the TPC are denoted with a tilde $\sim$.

$$\left(\frac{\sigma_P}{P}\right)^2 = \left(\frac{EE_{\mathrm{3DST}}}{P^2}\right)^2 \left(\frac{\sigma_{E_{\mathrm{3DST}}}}{E_{\mathrm{3DST}}}\right)^2$$

3DST energy term

$$+ \left(\frac{\tilde{P}}{P\sin\Psi}\frac{E}{E - E_{\mathrm{3DST}}}\right)^2 \left(\frac{\sigma_{\tilde{P_T}}}{\tilde{P_T}}\right)^2$$

TPC transverse momentum term

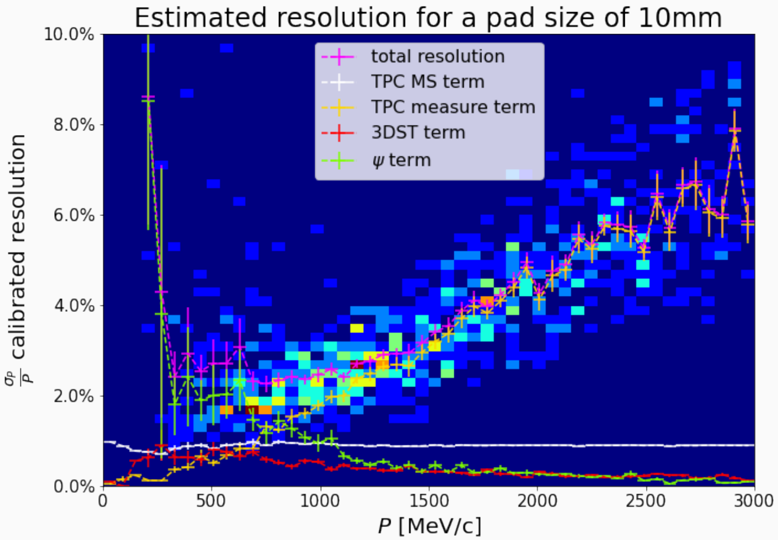
$$+ \left(\frac{\tilde{P}^2}{P^2}\frac{E}{E - E_{\mathrm{3DST}}}\operatorname{cotan}\Psi\right)^2 (\Delta\Psi)^2$$

3DST multiple scattering term

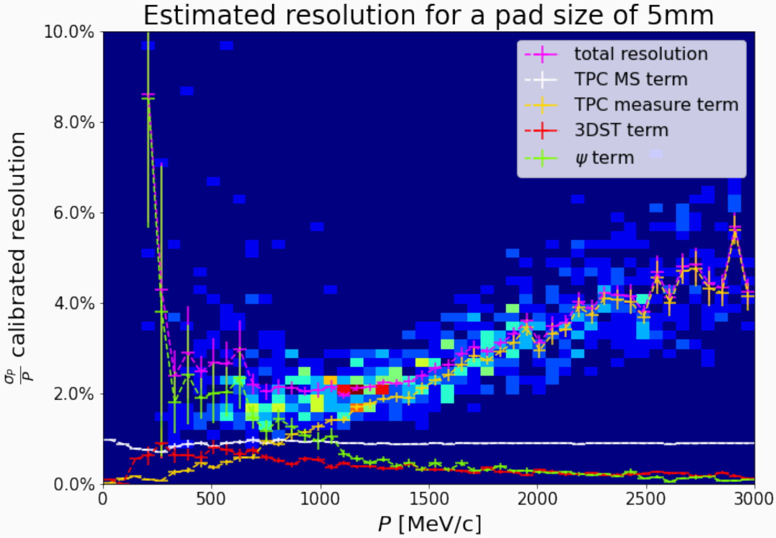
with

$$\left(\frac{\sigma_{\tilde{P_T}}}{\tilde{P_T}}\right)^2 = \left(\frac{\sigma_{\tilde{P_T}}}{\tilde{P_T}}\Bigg|^{\mathrm{Measure}}\right)^2 + \left(\frac{\sigma_{\tilde{P_T}}}{\tilde{P_T}}\Bigg|^{\mathrm{MS}}\right)^2$$

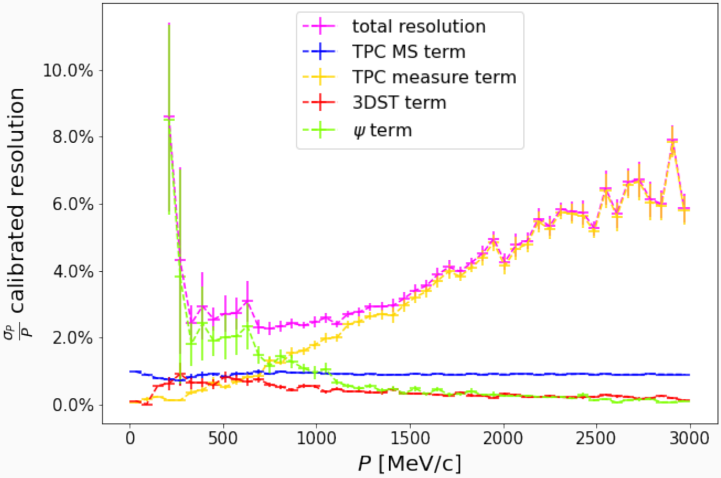
Resolution for 10 mm pads



Resolution for 5 mm pads

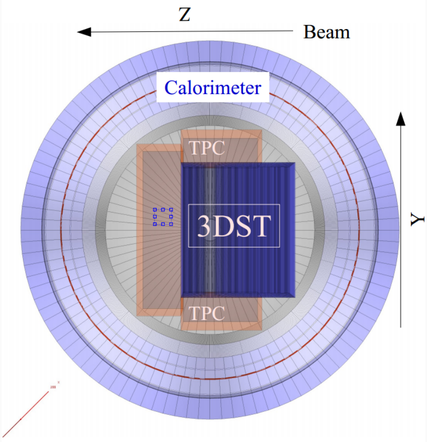


Proportions of the different resolution effects

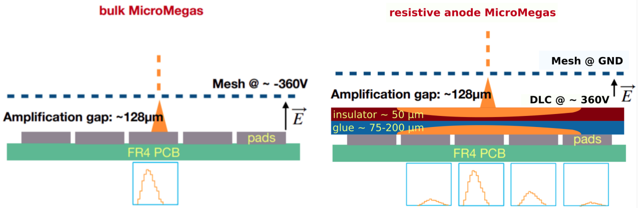


Backup slides

The TPCs in SAND



- 3 TPCs:
  - DOWNSTREAM: (x,y,z) 3.3 m × 3 m × 0.77 m
  - BOTTOM and TOP: (x,y,z) 3.3 m × 0.57 m × 1.41 m
- Cathode in the middle of the TPCs (x direction)
- 2 readout planes for each TPC with resistive MM (developped as R&D for ILC)



Charge spreading between multiple pads allows improved resolution with large pads (smaller number of channels)

Simulation

Event generation

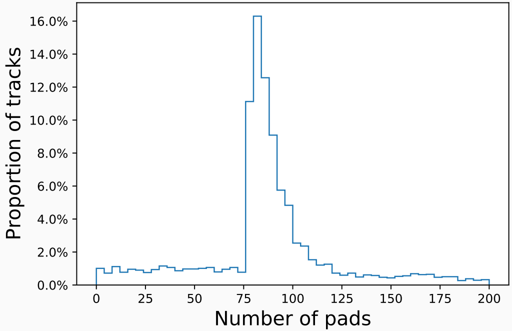
- Events are generated with GENIE.
- Energy deposits in all the active areas of the detector are computed by GEANT.

TPC simulation

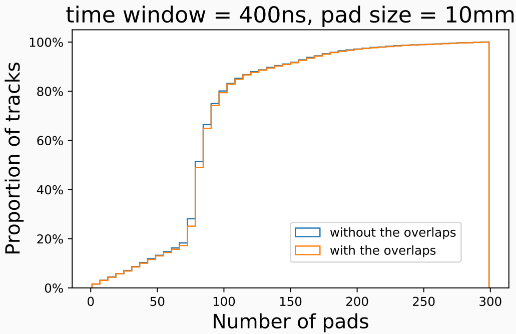
1. Events are given a vertex time according to the beam time profile.
2. Energy deposition segments of charged particles are projected onto ERAMs
3. Drift effects taken into account: drift time, longitudinal spread, transverse spread
4. Fixed charge spreading applied on pads -> fixed multiplicity per hit
5. Each pad hit is stored
6. Computing overlaps for each pad in a given time window (proxy for charge spreading time + shaping time).

Available implementation of TPC model in ERepSim.

Impact of the overlaps on the number of pads



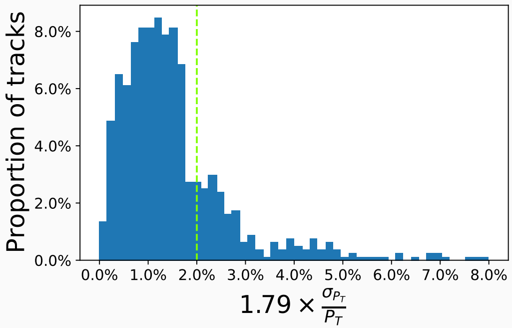
Distribution of the number of leading pads for muon tracks in DOWNSTREAM TPC

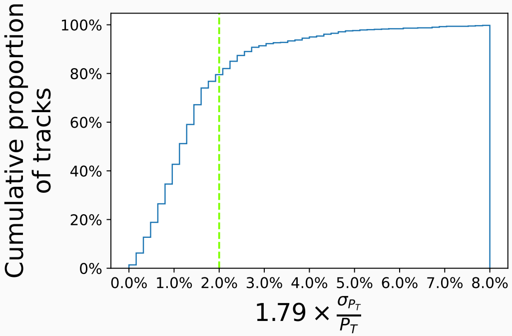


Cumulative distributions of the number of leading pads for muon tracks in DOWNSTREAM TPC with and without overlapping pads

The impact of the overlaps on the number of available pads for the reconstruction is very minimal!

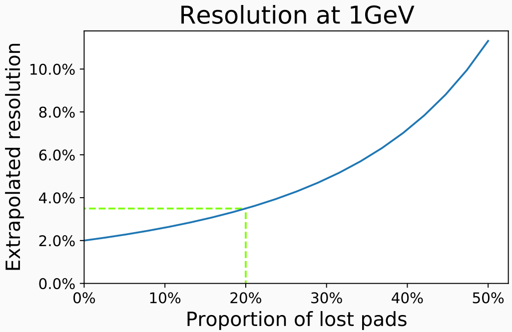
P_t resolution





Around 90 % of the tracks have an estimated resolution better than 2 % on P_t.

Impact of the overlaps on resolution



Very conservative worst case scenario: overlapping hits are lost leading pads

$$\sigma \sim \frac{1}{\left(100 - \%_{\text{overlap}}\right)^{5/2}} \sigma_0$$

Even for the tracks with 20 % of overlapping hits (1 ‰ of events), the resolution at 1 GeV stays below 4 % in the worst case scenario.

Resolution for 10 mm pads without T2K rescaling