Update on muon momentum resolution

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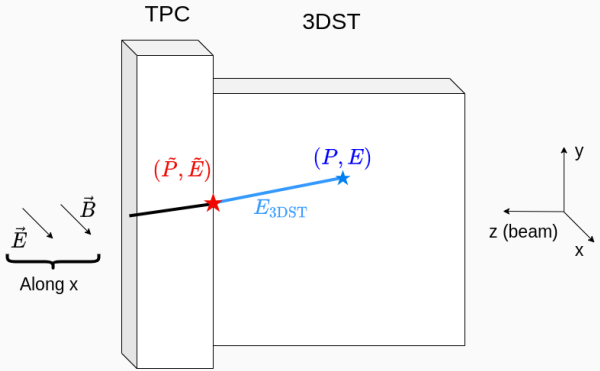
Irfu - CEA Saclay

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 theoretical 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}: $\frac{\sigma_{E_{\text{3DST}}}}{E_{\text{3DST}}} = 2\,\%$
- Change on P_T due to MS in 3DST + materials between 3DST and TPC
- 3DST angular resolution

P_T resolution

P resolution

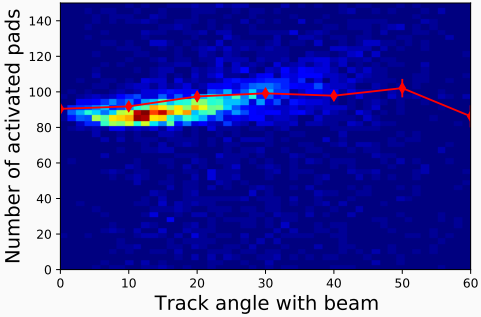
P_T resolution - Inputs from simulation

TPC resolution on P_T is estimated with: $\frac{\sigma_{P_T}}{P_T} = \frac{P_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}.\sigma_{r\phi}$

Inputs

- $B = 0.6$ 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

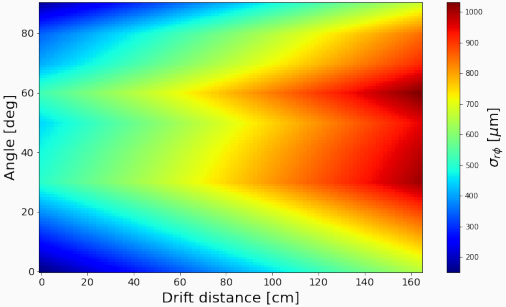


Simulation

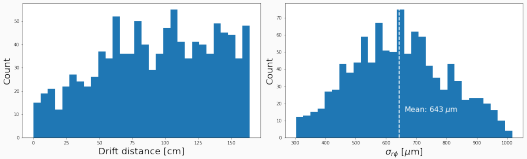
Prototype data are used to estimate $\sigma_{r\phi}$

Resistive Micromegas prototype testing

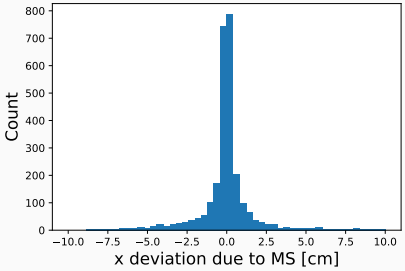
- 2018 test beam at CERN ; 2019 at DESY with magnetic field
- Cosmic data taking at Saclay

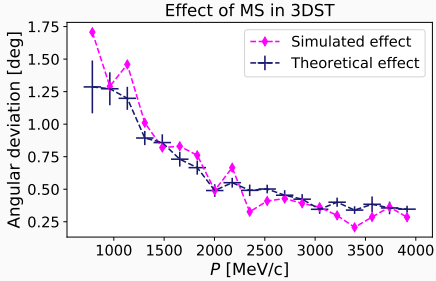


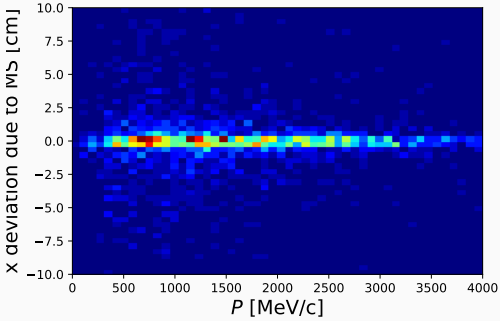
- Dependence of spatial resolution with drift distance and track angle.



Effect of MS on P_T



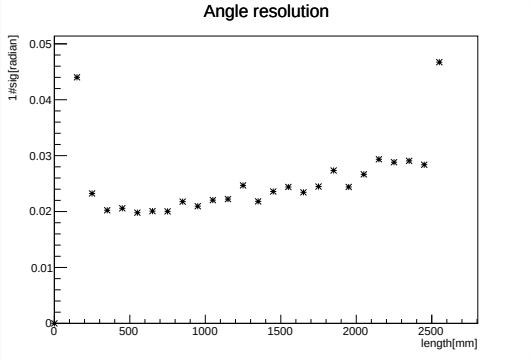


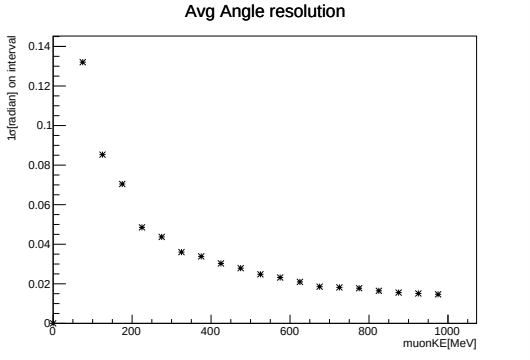


- The effect of MS of P_T is evaluated track by track from the simulation
- Theoretical formula

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta cp} Z \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \ln \frac{x}{X_0}\right)$$

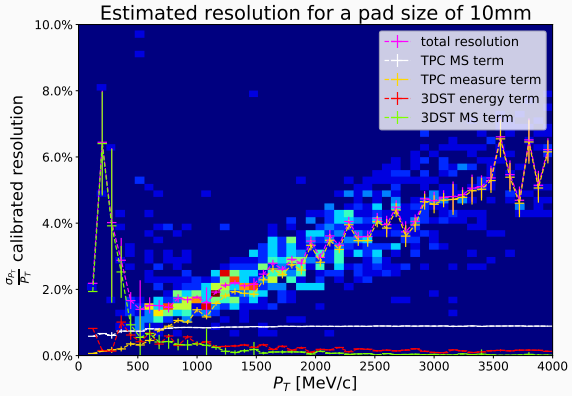
3DST angular resolution (Ki-Young results)

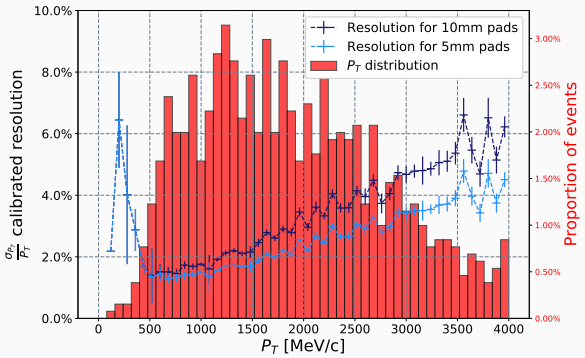




- The resolution on Ψ is computed from simulated tracks reconstruction in 3DST
- The dependance of the resolution depends mainly on the muon energy.

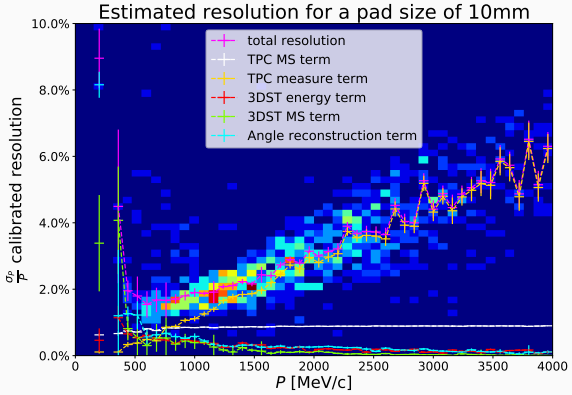
P_T resolution - DOWNSTREAM

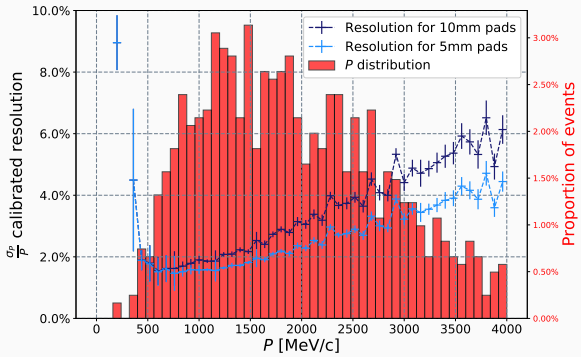




- Only 3DST interactions
- Resolution of around 2 % around 1 GeV
- Peak around 4 % at lower momenta because of MS

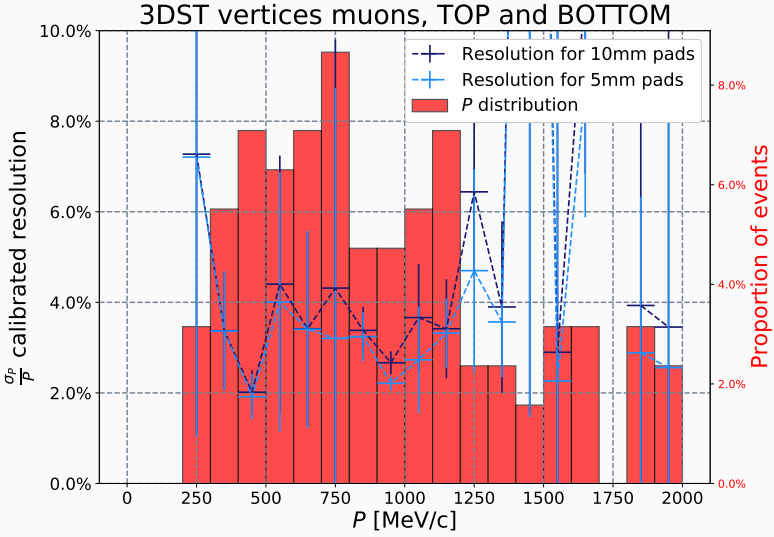
P resolution - DOWNSTREAM



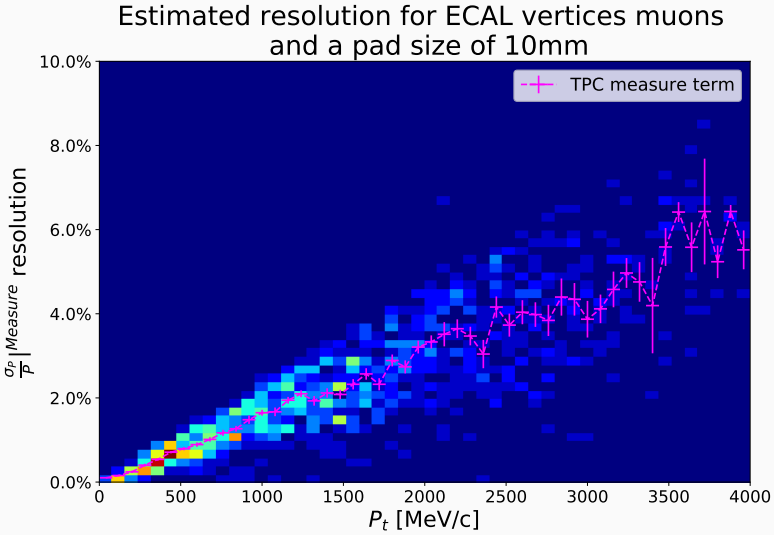


- Only 3DST interactions
- Resolution of around 2 % around 1 GeV
- Peak around 4 % at lower momenta because of MS

P resolution - TOP & BOTTOM



TPC resolution for ECAL vertices



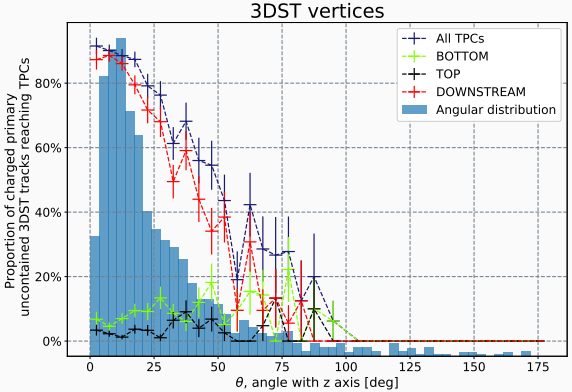
Angular efficiencies

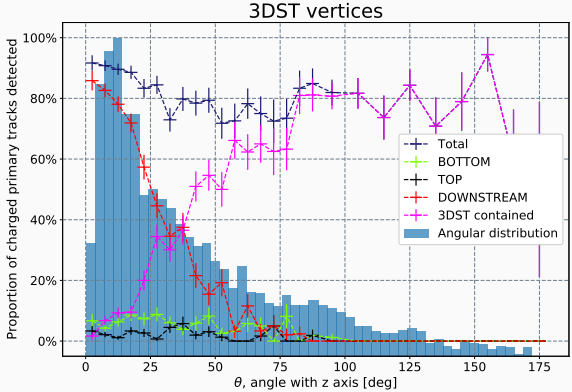
Angular efficiency

For interactions in the detector (ECAL or 3DST) we want to know the proportions of primary tracks that are detected by the subdetectors as function of the angle in order to deduce an overall angular efficiency

- A track is considered as detected by a TPC if the track length in the TPC is $> 20\,\text{cm}$
- The counts for the 3 TPCs are not exclusive (a same particle can be seen by multiple TPCs)
- A track is estimated as contained in the 3DST (or ECAL) if it doesn't exit it.

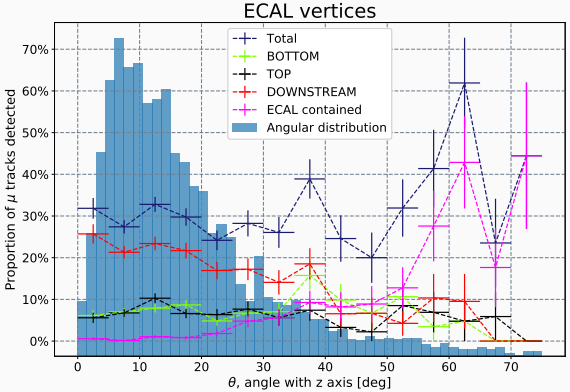
Angular efficiencies - 3DST vertices

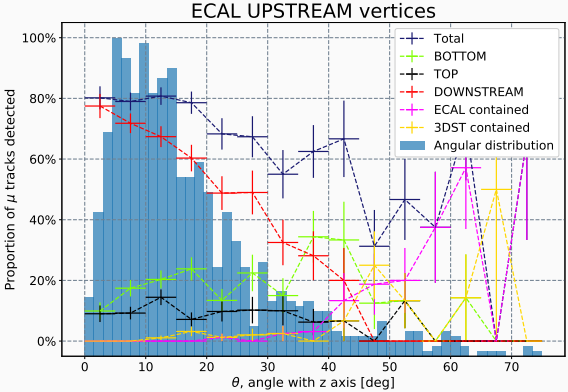




- Only 3DST interactions
- Around 80 % efficiency for all angles
- The impact of TOP and BOTTOM TPCs is relatively low.

Angular efficiencies - ECAL vertices





- Only ECAL interactions. UPSTREAM $\equiv z$ before 3DST
- Around 80 % efficiency for upstream and low angles
- Larger impact of TOP and BOTTOM TPCs

Backup slides

Uncertainties

Computing factors

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

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

This supposes no input from 3DST concerning the momentum.

Uncertainty composition

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

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

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

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

with

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