Characterising charm jet properties with azimuthal correlations of D mesons and charged particles with ALICE at LHC

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Outline

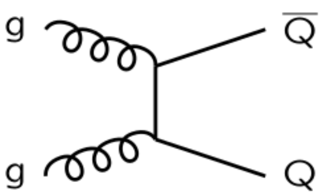
- Physics Motivations
- ALICE Detector
- Analysis Steps
- Extraction of Main Observables
- Results
- Summary and Future Plan

D-hadron azimuthal correlations in pp collisions:

- D-meson correlation in pp collisions can give insight about charm production mechanism

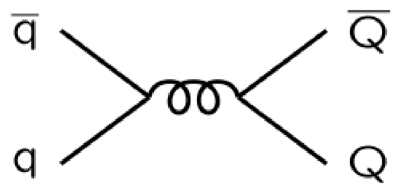
1. Pair Production [Leading Order (LO)] $O(\alpha_s^2)$

Gluon fusion



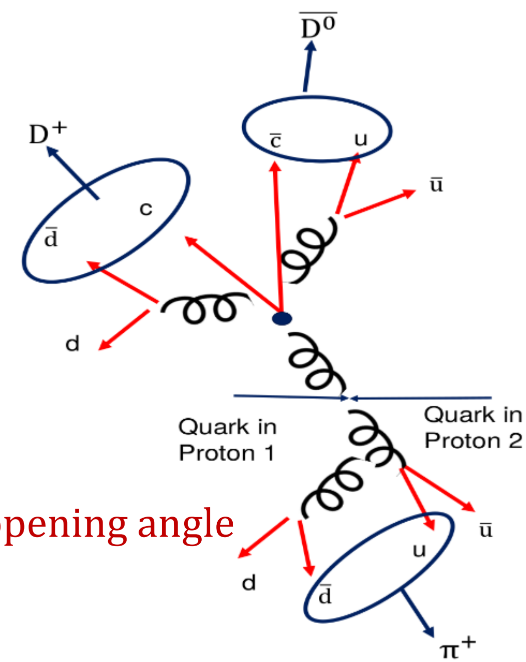
$gg \rightarrow Q\,\bar{Q}$

Quark Annihilation

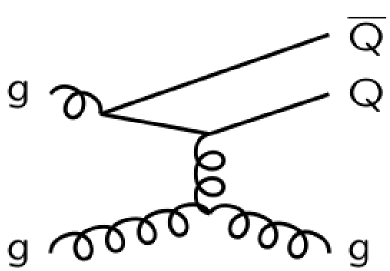


$q\bar{q} \rightarrow Q\,\bar{Q}$

1. Q and $\bar{Q}$ symmetric in p_T back to back
2. Nearly equal near and away-side peak

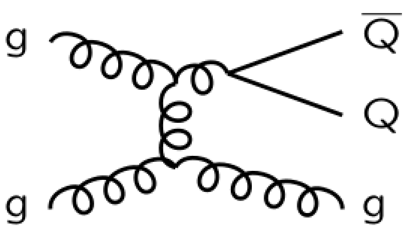


2. Flavour Excitation [Next to Leading Order (NLO)] $O(\alpha_s^3)$

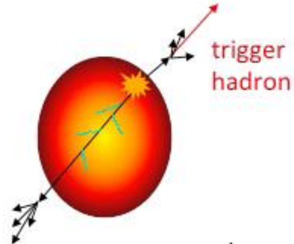


1. Q and $\bar{Q}$ asymmetric in p_T with broad opening angle
2. Away side peak broadening

3. Gluon Splitting [Next to Leading Order (NLO)] $O(\alpha_s^3)$

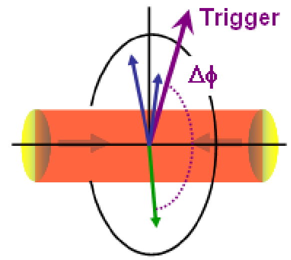


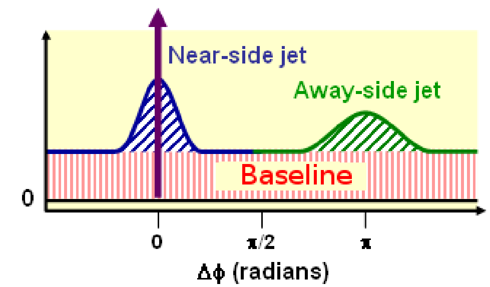
1. Q and $\overline{Q}$ asymmetric in p_T with small opening angle
2. Increasing near side peak



Overall correlation distribution

$$\Delta\eta = \eta_{trig} - \eta_{assoc}$$
$$\Delta\varphi = \varphi_{trig} - \varphi_{assoc}$$

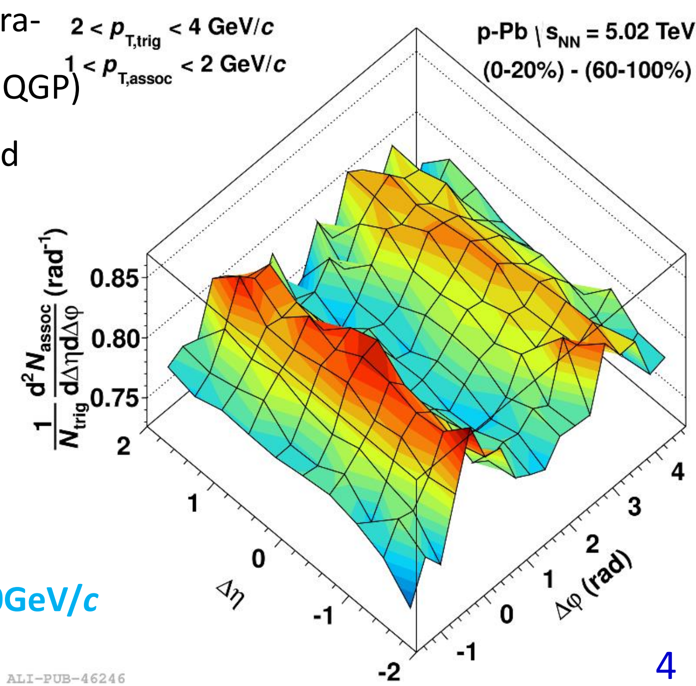




- D-meson correlation in pp collisions also used as the reference for p-Pb and Pb-Pb data

D-hadron azimuthal correlations in p-Pb collisions:

- Heavy quarks produced via hard parton scatterings in the initial stage of ultra-relativistic heavy-ion collisions ⇒ Ideal probes of the Quark-Gluon Plasma (QGP)
- It can Investigate possible **modifications of angular correlations** which could derive from initial-state effects (e.g. CGC) or possible final-state effects
- It can search for long-range **double-ridge** structure in heavy-flavour sector
- It is also a reference to disentangle final-state QGP-induced modifications from cold-nuclear-matter effects



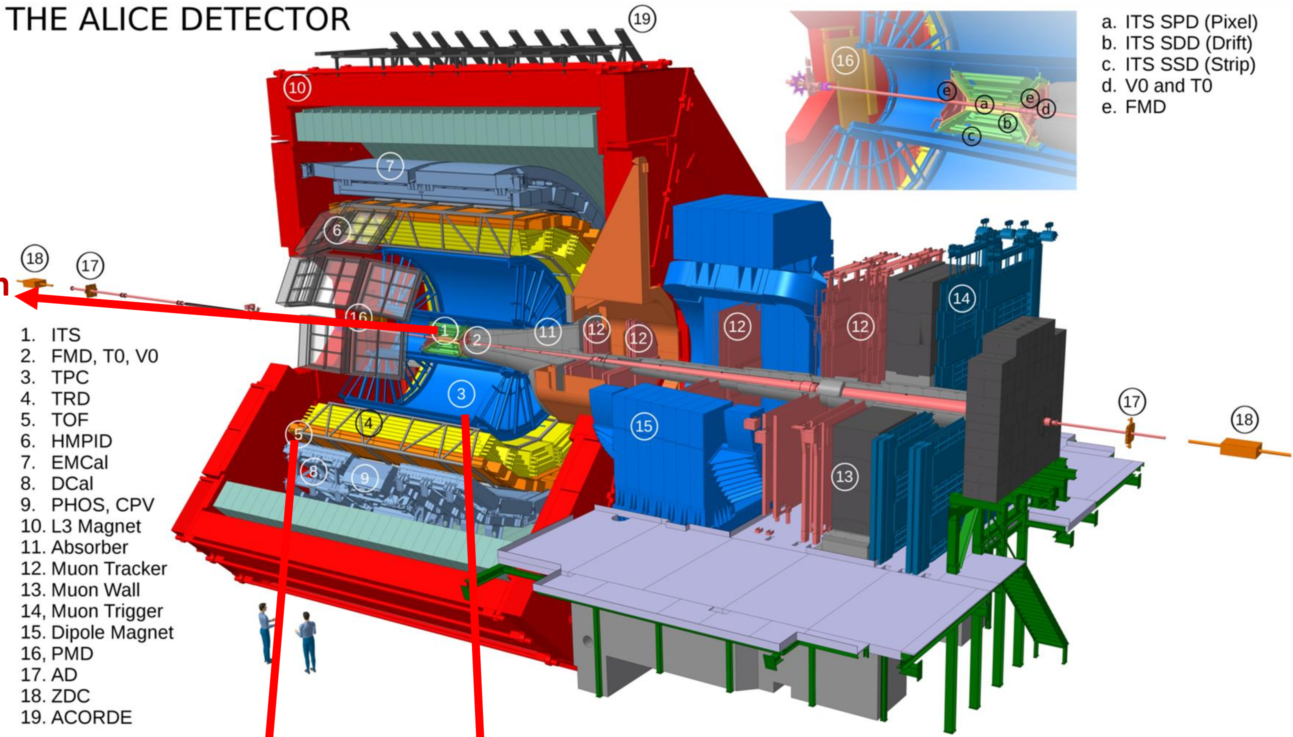
D-meson p_T ranges: **3-5, 5-8, 8-16, and 16-24 GeV/c**

Associated track p_T ranges: **> 0.3, > 1.0, >2.0, >3.0 and 0.3-1.0, 1.0-2.0, 2.0-3.0GeV/c**

❖ Data Sample:

- p-Pb 2016 data with $\sqrt{s_{NN}}$ = 5.02 TeV , Events: 625M
- pp 2017 data with $\sqrt{s}$ = 13 TeV, Events: 373M

ALICE Detector



ITS: Inner Tracking System

TOF: Time Of Flight

TPC: Time Projection Chamber

Branching Ratios

$D^+ \rightarrow K^-\pi^+\pi^+$ (9.13 ± 0.19 %)

$D^0 \rightarrow K^-\pi^+$ (3.88 ± 0.05 %)

$D^{*+} \rightarrow D^0\pi^+$ (67.7 ± 0.50 %)

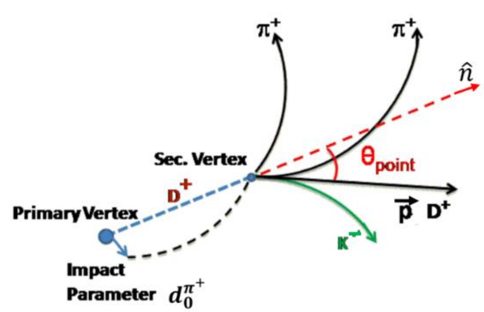
ITS: For tracking and reconstruction of primary, secondary vertices

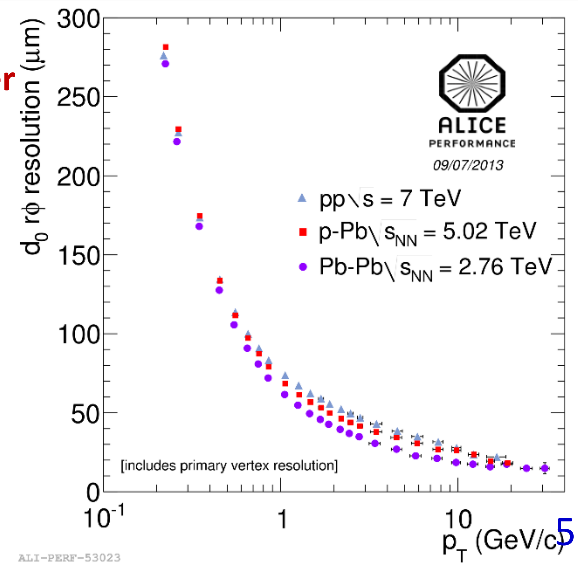
TPC: For tracking and particle identification

TOF: For particle identification

We reconstruct all other secondary particles from daughters as shown for D^+

$D^+ \rightarrow K^-\pi^+\pi^+$



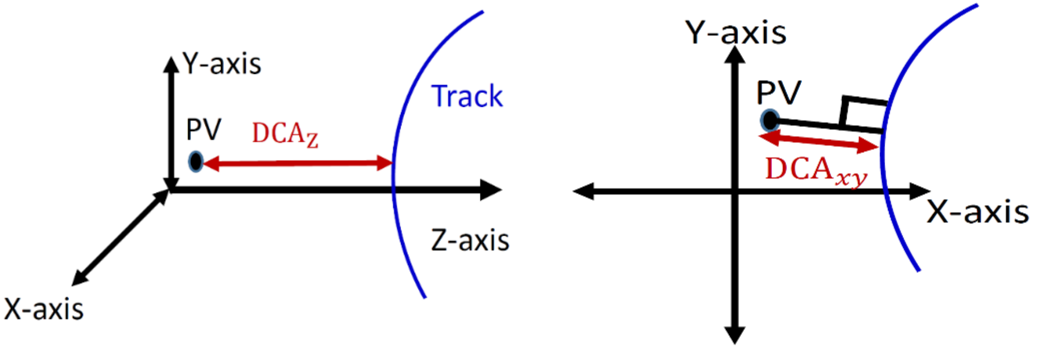


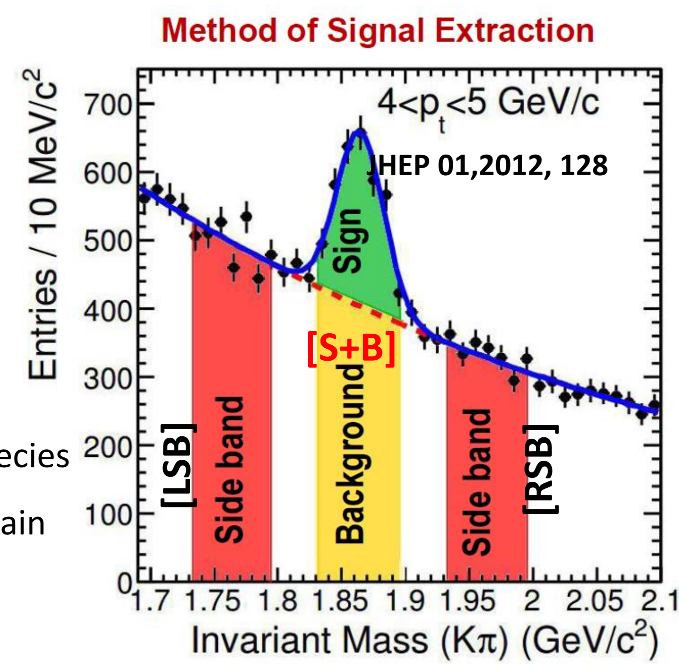
Analysis Steps

- D^+, D^0 and D^* mesons signal extraction from invariant mass plots
- Correlation of D mesons **with primary charged particles** ($\mathbf{e}, \boldsymbol{\mu}, \boldsymbol{\pi}, \mathbf{K}$ **and** $\mathbf{p}$) by removing D-meson daughters
  - **Correlation of D-meson = correlation in [S+B] region – (correlation in [LSB+RSB] region)*SF** $\quad SF = \frac{\text{Background}}{\text{LSB+RSB}}$
- Mixed Event correction for **limited detector acceptance** and inhomogeneities (Mixing with same z-vtx and multiplicity)

$$\frac{d^2N^{MECorr}(\Delta\varphi, \Delta\eta)}{d\varphi\, d\eta} = \frac{\frac{d^2N^{SE}(\Delta\varphi,\Delta\eta)}{d\varphi\, d\eta}}{\frac{d^2N^{ME}(\Delta\varphi,\Delta\eta)}{d\varphi\, d\eta}} \frac{d^2N^{ME}(0,0)}{d\varphi\, d\eta}$$

- Correction for the **contamination of secondary particles** from strange decays and conversion inside detector





- Correction **for D-meson efficiency and associated track efficiency**
- Correction for feed-down of D mesons from B-hadron decays
- **Projection onto $\Delta\varphi$ axis** and the weighted average of the three D-meson species
- Fitting of correlations distributions NS-peak and AS-peak and extraction of main observables **NS yield, NS sigma, AS yield and AS sigma**

Extraction of Main Observables

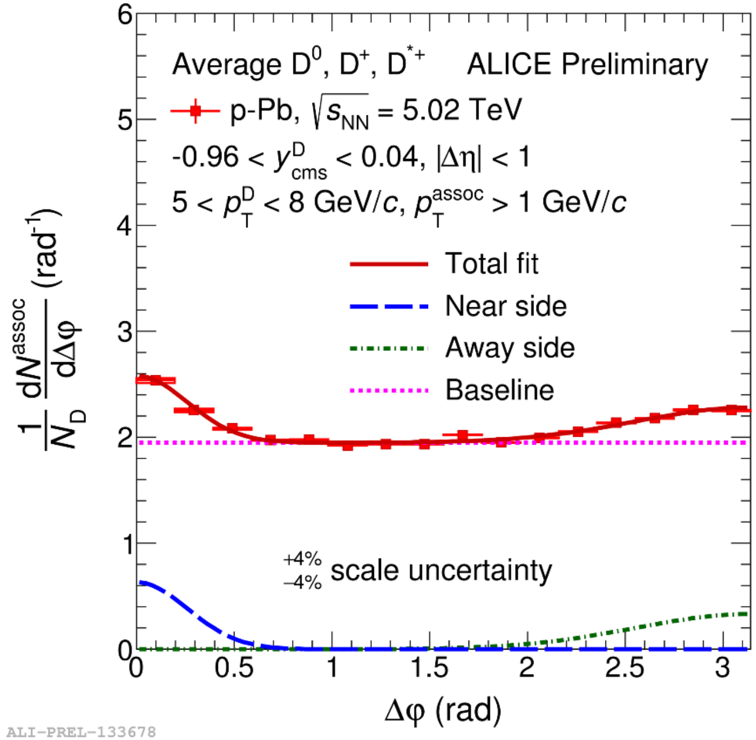
❖ Weighted average of the three D-meson correlation distributions (after reflection over π)

$$\text{Weighted Average } (\mu) = \frac{\sum_i \frac{x_i}{\sigma_i^2}}{\sum_i \frac{1}{\sigma_i^2}} \qquad \text{Error } (\sigma) = \frac{1}{\sum_i \frac{1}{\sigma_i^2}}$$

❖ **Fitting of correlation distribution**

$$f(\Delta\varphi) = c + \frac{Y_{NS}}{\sqrt{2\pi}\,\sigma_{NS}} e^{-\frac{(\Delta\varphi-\mu_{NS})^2}{2\,\sigma_{NS}^2}} + \frac{Y_{AS}}{\sqrt{2\pi}\,\sigma_{AS}} e^{-\frac{(\Delta\varphi-\mu_{AS})^2}{2\,\sigma_{AS}^2}}$$

c: constant for baseline, Near Side (NS) Gaussian fit and Away Side (AS) Gaussian fit



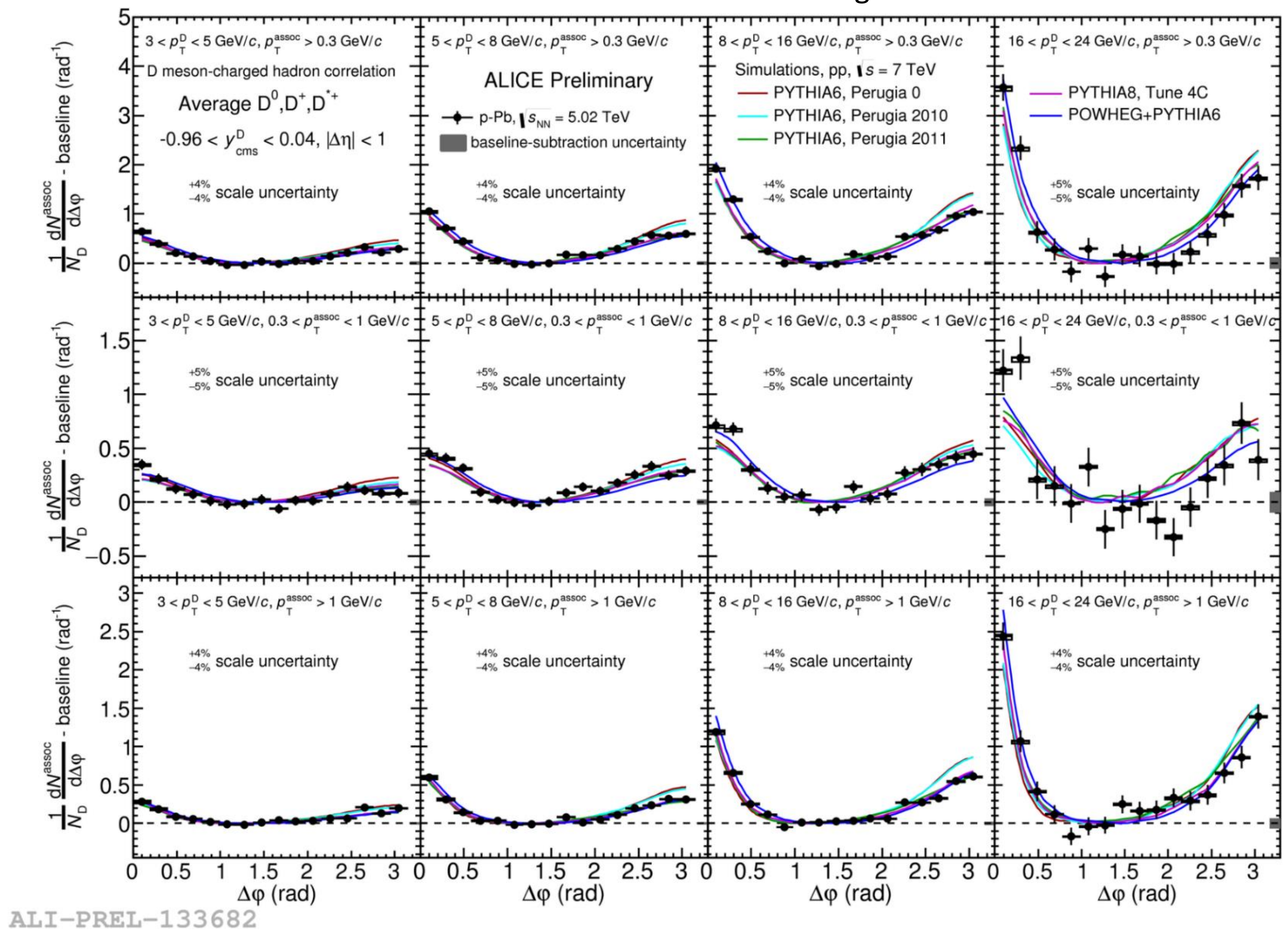
✓ NS, AS peak: If we integrate NS and AS peak over $\Delta\varphi$, gives the number of tracks per D-meson in NS and AS jet

✓ Baseline: If we integrate in over constant region in $\Delta\varphi$, gives the number of underlying track created

In general correlation gives the information how many associated tracks (in different p_T ranges) per D-meson selected in a particular p_T range

Results

- Comparison of data correlation distributions with Monte Carlo (MC) predictions, **p-Pb data $\sqrt{s_{NN}}$ = 5.02 TeV**
- NS and AS correlation distribution shape, and its p_T evolution, show **good agreement with expectations** from Monte Carlo simulations obtained with PYTHIA and POWHEG event generators



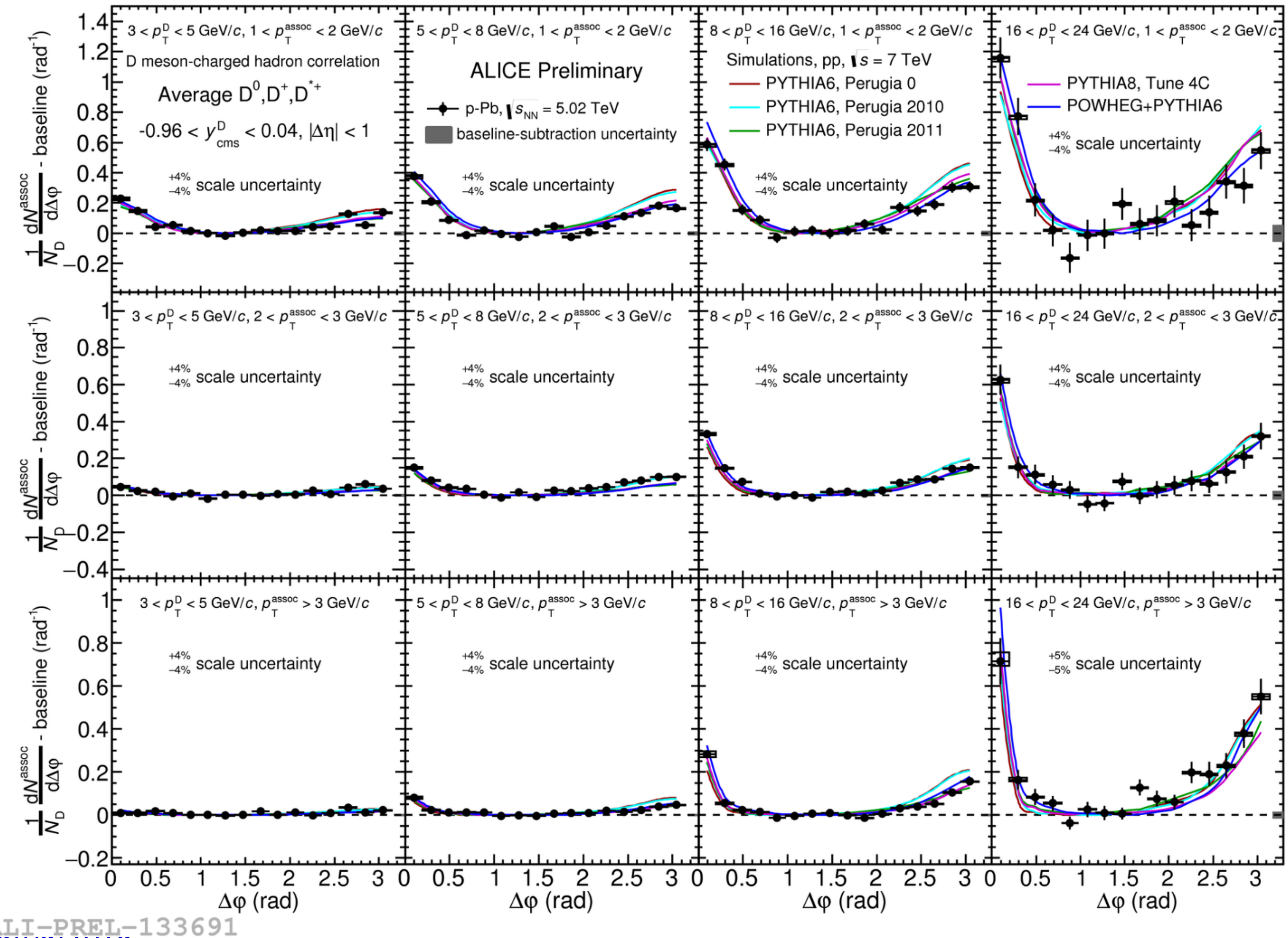
D-meson p_T ranges: **3-5, 5-8, 8-16, and 16-24 GeV/c**

Associated track p_T ranges: **> 0.3, > 1.0 and 0.3-1.0 GeV/c**

POWHEG: Positive Weight Hadron Emission Generator

- Comparison of data correlation distributions with Monte Carlo (MC) predictions,
- NS and AS correlation distribution shape, and its p_T evolution, **show good agreement with expectations** from Monte Carlo simulations obtained with PYTHIA and POWHEG event generators

p-Pb data $\sqrt{s_{NN}}$ = 5.02 TeV



D-meson p_T ranges:

3-5, 5-8, 8-16, and 16-24 GeV/c

Associated track p_T ranges:

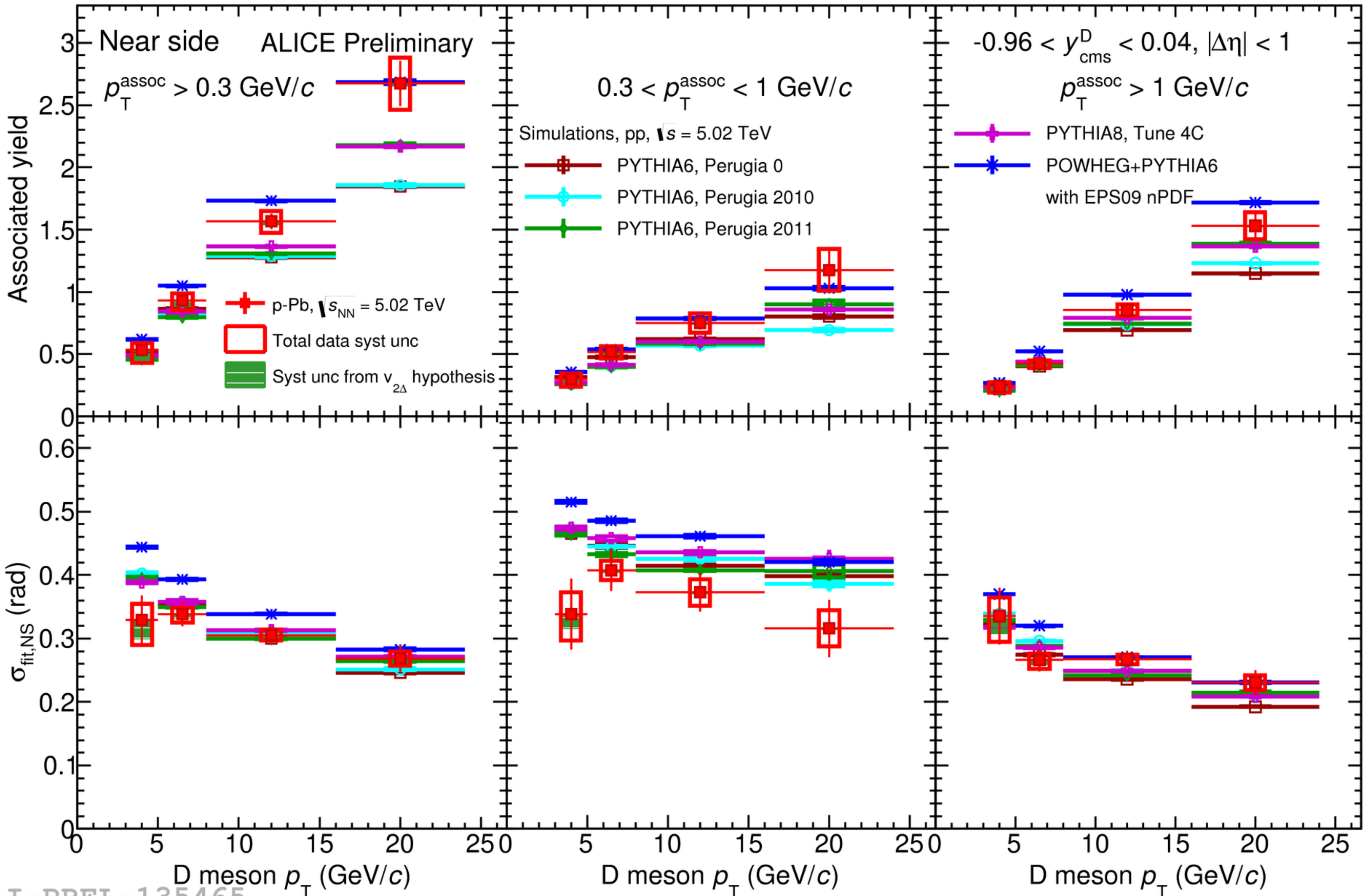
> 3.0 and 1.0-2.0, 2.0-3.0 GeV/c

❖ **Near Side (NS) yield and sigma evolution** with transverse momentum are well described Monte Carlo simulations obtained with PYTHIA and POWHEG event generators

D-meson p_T ranges: 3-5, 5-8, 8-16, and 16-24 GeV/c

p-Pb data $\sqrt{s_{NN}}$ = 5.02 TeV

Lower associated track p_T ranges: > 0.3, > 1.0 and 0.3-1.0 GeV/c



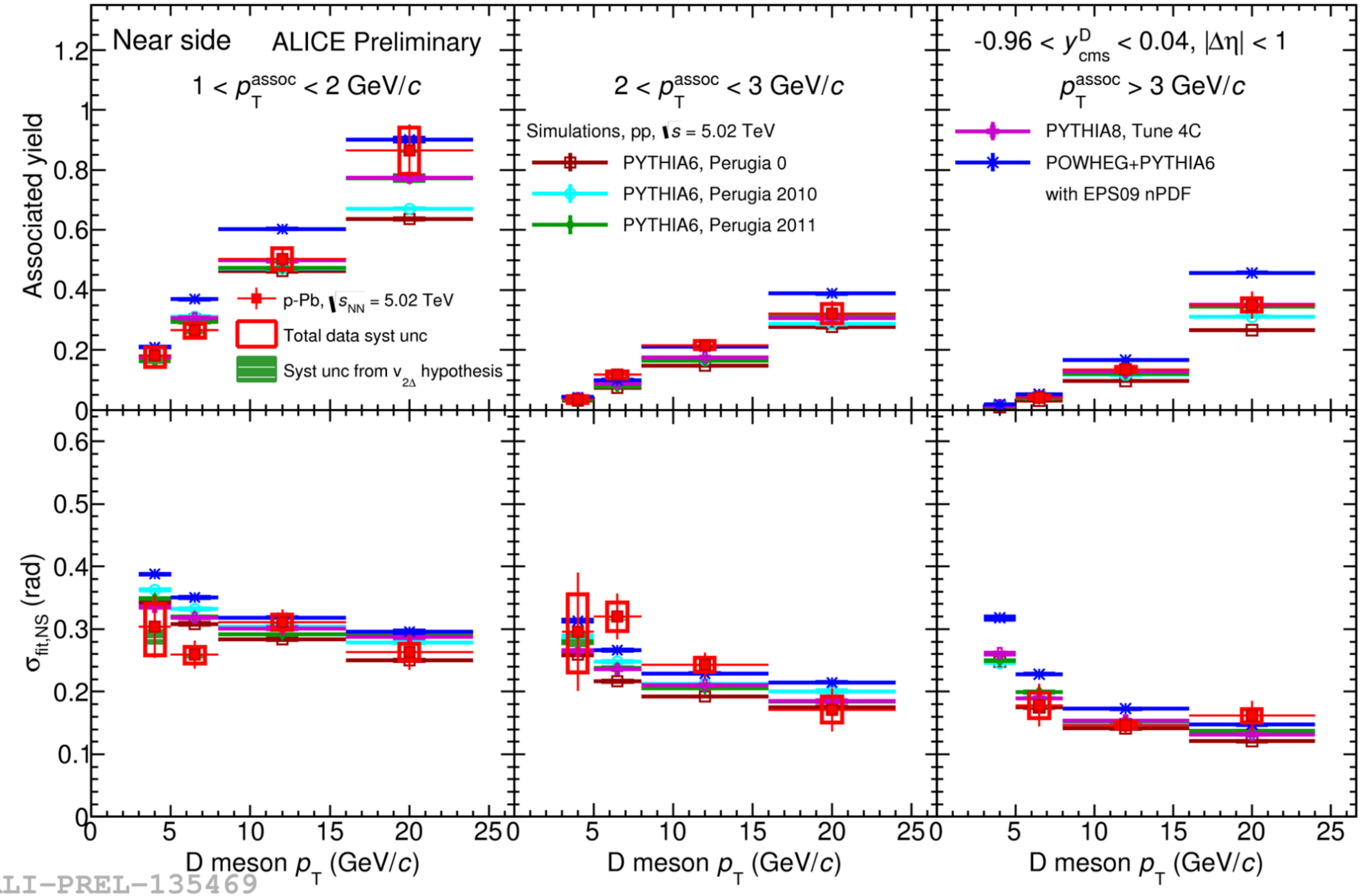
Comparison of NS yield and sigma with MC simulations

❖ **Near Side (NS) yield and sigma evolution** with transverse momentum are well described Monte Carlo simulations obtained with PYTHIA and POWHEG event generators

D-meson p_T ranges: 3-5, 5-8, 8-16, and 16-24 GeV/c

p-Pb data $\sqrt{s_{NN}}$ = 5.02 TeV

Associated track p_T ranges: > 3.0 , 1.0-2.0, and 2.0-3.0 GeV/c



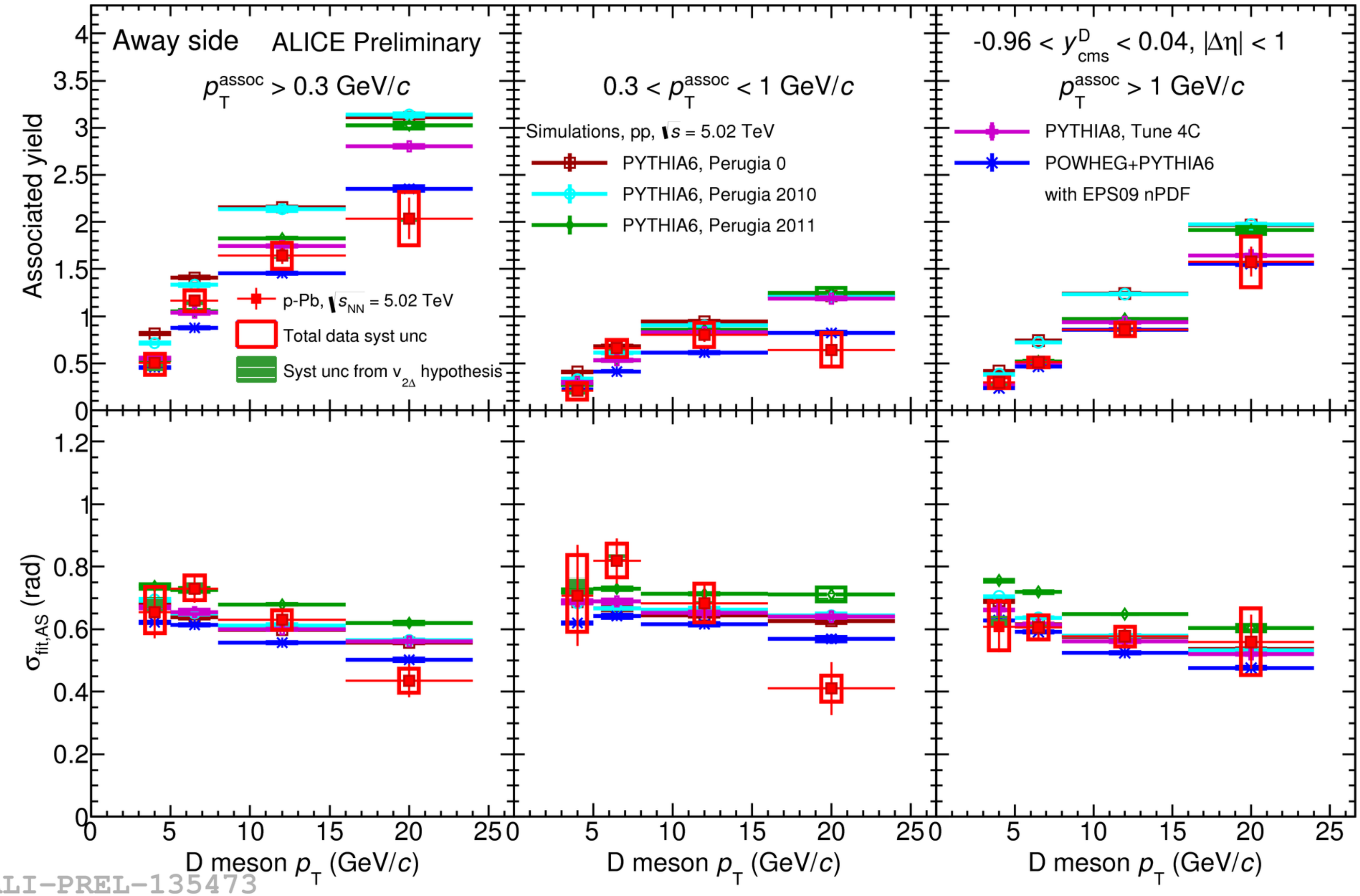
Comparison of NS yield and sigma with MC simulations

❖ **Away Side (AS) yield and sigma evolution** with transverse momentum are well described Monte Carlo simulations obtained with PYTHIA and POWHEG event generators

D-meson p_T ranges: 3-5, 5-8, 8-16, and 16-24 GeV/c

p-Pb data $\sqrt{s_{NN}}$ = 5.02 TeV

Associated track p_T ranges: > 0.3, > 1.0, and 0.3-1.0 GeV/c



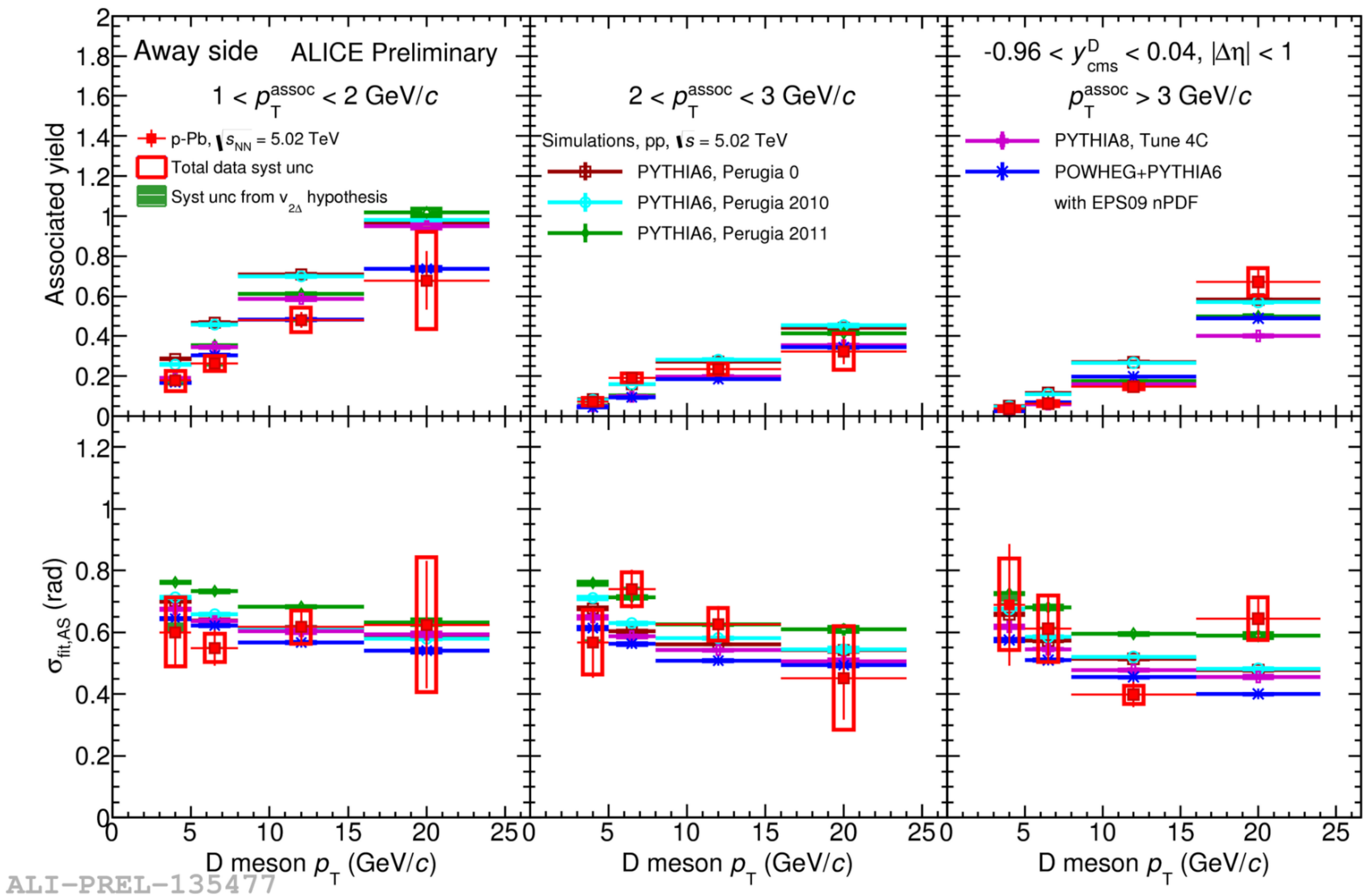
Comparison of AS yield and sigma with MC simulations

❖ **Away Side (AS) yield and sigma evolution** with transverse momentum are well described Monte Carlo simulations obtained with PYTHIA and POWHEG event generators

p-Pb data $\sqrt{s_{NN}}$ = 5.02 TeV

D-meson p_T ranges: 3-5, 5-8, 8-16, and 16-24 GeV/c

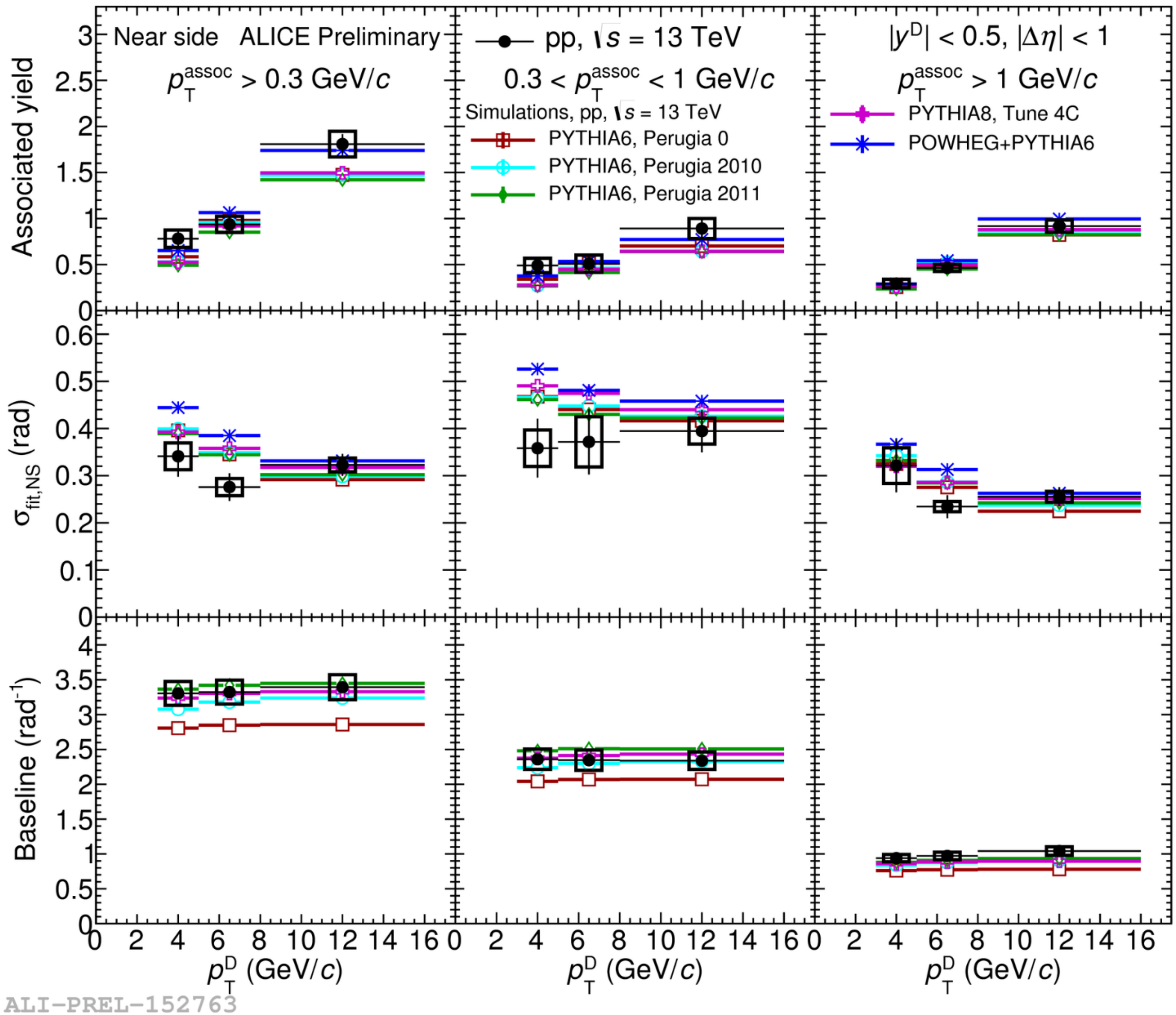
Associated track p_T ranges: > 3.0 , 1.0-2.0, and 2.0-3.0 GeV/c



Comparison of AS yield and sigma with MC simulations

❖ Near Side (NS) yield and sigma evolution with transverse momentum are well described Monte Carlo simulations obtained with PYTHIA and POWHEG event generators

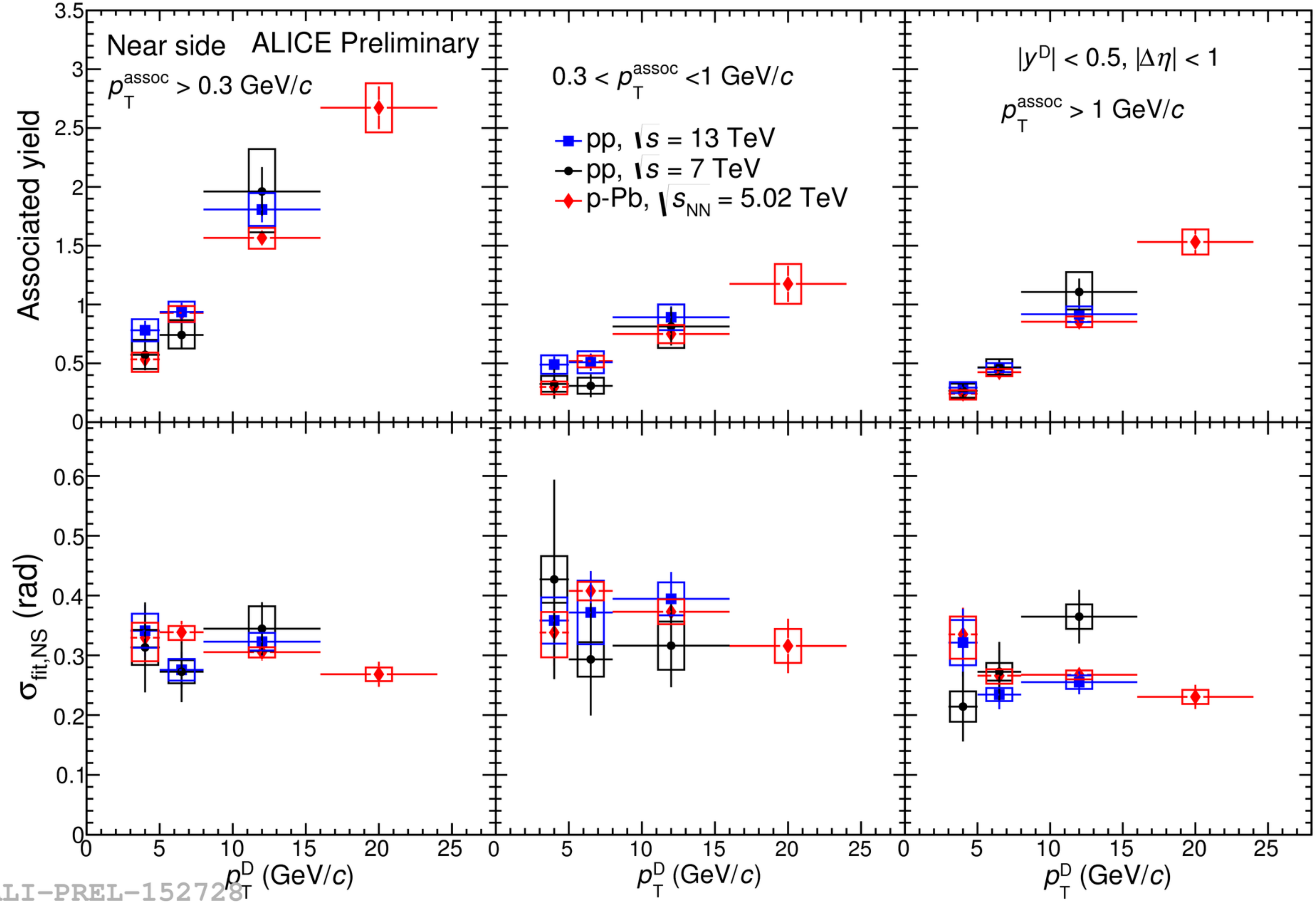
pp data $\sqrt{s}$ = 13 TeV



Comparison of NS yield, sigma and baseline with MC simulations

Comparison between three data sets shows the compatibility with one another

pp data $\sqrt{s}$ = 13 TeV
pp data $\sqrt{s}$ = 7 TeV
p-Pb data $\sqrt{s}$ = 5.02 TeV



Comparison of NS yield and sigma with different data samples

Summary and Future Plan

- In the talk **NS yield, sigma and AS yield, sigma are compared with models** for pp 7 TeV , pp 13 TeV and p-Pb 5 TeV data
- Results show the good compatibility with each other
- Charm jets are well described by the models PYTHIA and POWHEG with in the uncertainties
- **In future we will compare pp 5 TeV to the p-Pb 5 TeV to assess the cold nuclear matter effects**

Thank You !!!

Back Up Slides on wards

Contaminations from secondary and also feed-down always possible

Understanding Decay length

$$\text{decay length } d = v\,\tau$$

$$\text{decay length } d = v\,\gamma\,\tau = c\tau\sqrt{\gamma^2 - 1}$$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- PDG mention $c\tau$ as mean decay length but It will be boosted by gamma factor ($c\tau\sqrt{\gamma^2 - 1}$)

Note: particle life time distribuition is always exponential

$\lambda = 1/\tau$ (Substitute) and x= t

$$\text{Mean } (\mu) = \frac{1}{\lambda} = \text{Sigma } (\sigma)$$

$$p\left(\mu - \frac{\sigma}{2} \leq x \leq \mu + \frac{\sigma}{2}\right) = 0.83$$

83% of the Particles will lie in 1 sigma width around mean

$$f(t) = \frac{1}{\tau} e^{-t}/\tau$$

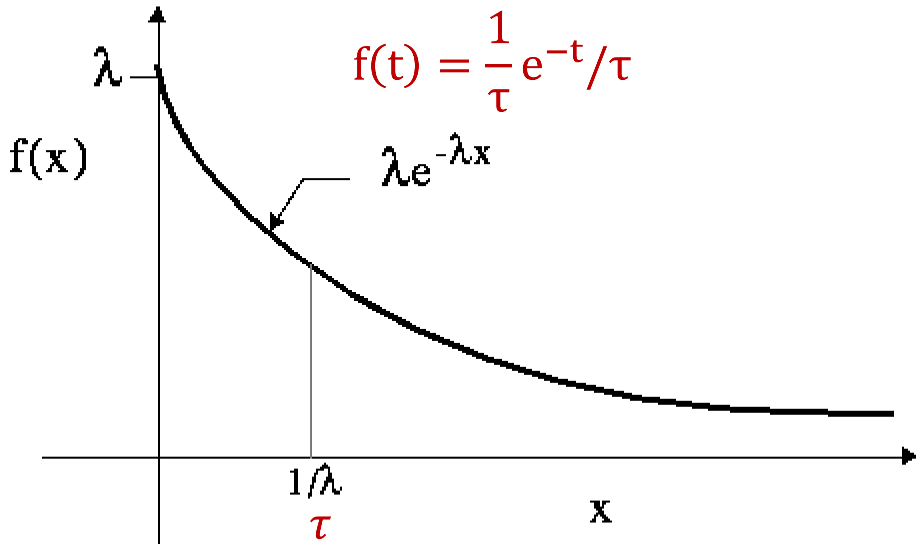


Figure 6. Exponential *pdf*

In general decay length follows exponential distribution with boosting factor ($c\tau\sqrt{\gamma^2 - 1}$)

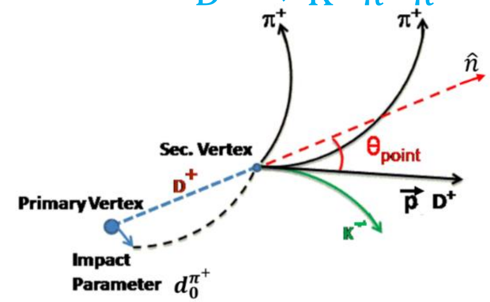
D-meson signal extracted by maximizing the S/B and Significance in invariant mass plots

Understanding Significance and S/B

$$\text{Signal/Background} = \frac{\text{Signal}}{\text{Background}} = \frac{S}{B}$$

$$\text{Significance} = \frac{S}{\sigma\,(S)}$$

$D^+ \to K^-\pi^+\pi^+$



$$N = S + B \qquad\qquad \sigma_N^2 = \sigma_S^2 + \sigma_B^2 = N$$

By assuming Poisson distribution

$\sigma_B^2 = 0$ by some estimator => $\sigma_S = \sqrt{N} = \sqrt{(S+B)}$

$$\text{Significance} = \frac{S}{\sigma(S)} = \frac{S}{\sqrt{(S+B)}}$$

Physically $\frac{\sigma(s)}{s}$ is relative statistical uncertainty in signal so It will be lower as we increase statistics means Significance (inverse of $\frac{\sigma(s)}{s}$) will increase as we increase Statistics

Efficiency Weighted Significance

$$\text{Significance} = \frac{S}{\sigma(S)} = \frac{S}{\sqrt{(S+B)}}\left[= \frac{\frac{S}{\epsilon}}{\sqrt{\frac{(S+B)}{\epsilon}}} = \frac{1}{\sqrt{\epsilon}}\frac{S}{\sqrt{(S+B)}}\right]$$

1. Note: $\epsilon < 1$ so Significance weighted by efficiency will always be higher than unweighted

2. If we want to compare two framework results Significance weighted by ϵ will help

Behavior of Significance:

$$\frac{S}{B} = x \rightarrow B = \frac{S}{x}$$

$$\text{Significance} = \frac{S}{\sqrt{(S+B)}} = \frac{\sqrt{S}}{\sqrt{\left(1+\frac{1}{x}\right)}}$$

Maximum Significance= $\sqrt{S}$ as $x \rightarrow \infty$ means S/B $\rightarrow \infty$

$$\frac{S}{\sqrt{(S+B)}} \leq \frac{S}{\sigma(S)} \leq \sqrt{S} = \sqrt{N}$$

$$\text{Significance} = \frac{S}{\sqrt{N}} = \frac{S}{\sqrt{(S+B)}} = \frac{\sqrt{S}}{\sqrt{\left(1+\frac{1}{x}\right)}}$$

Case1: If x increases (means S/B) and S is almost constant, then Significance will increase.

Case2: If S/B increases but S decreases in same proportion then Significance will be constant.

Case3: If S/B increases and but S is decreases too much then Significance will decrease

Example:

Similar three cases for S/B to decrease also possible

Cut1: N= S+B = 3000 ; S =2000 and B = 1000 [loose cut]

S/B=2 and Significance= 2000/$\sqrt{3000}$ = 36.5

Cut2: N= S+B =300; S=200 and B=100 [Tight Cut]

S/B=2 and Significance = 200/$\sqrt{300}$= 11.5

Cut4: N= S+B =3; S=2 and B=1 [Very Very Tight Cut]

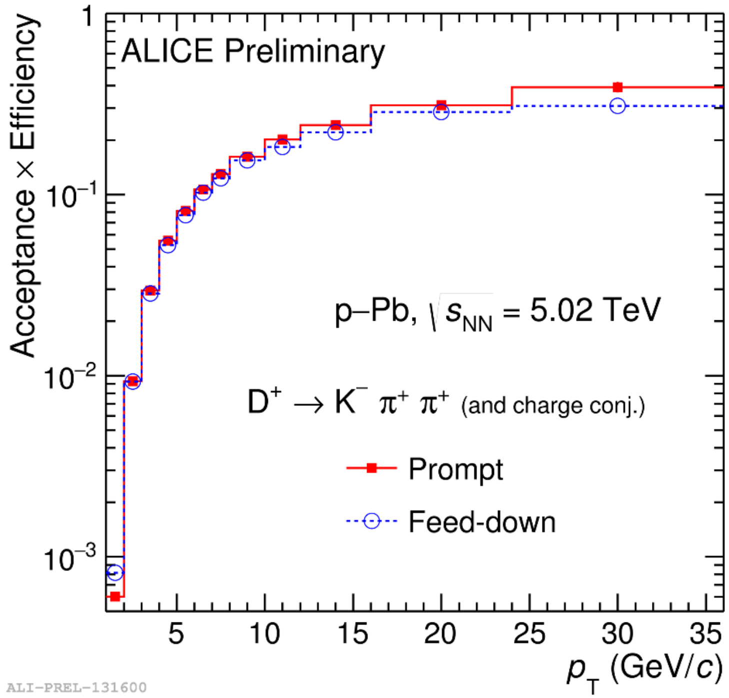
S/B=2 and Significance = 2/$\sqrt{3}$= 1.15

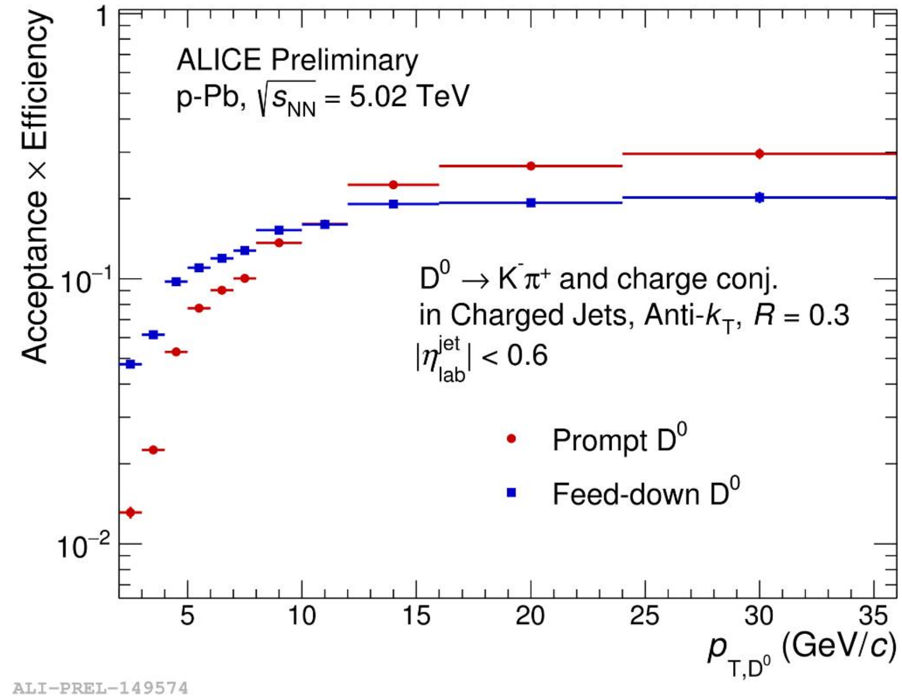
Cut5: N=S+B= 300; S=250 and B=50 [Another Cut]

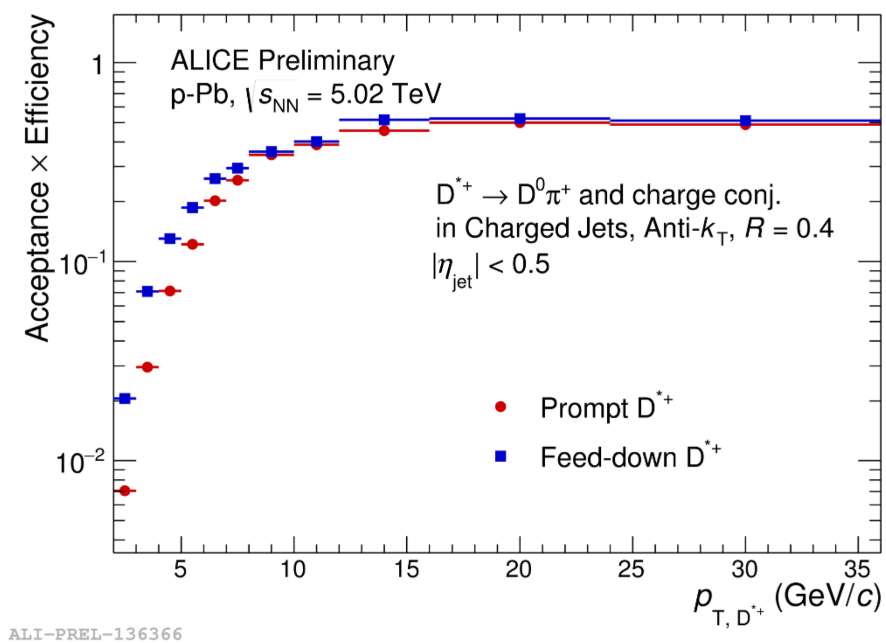
S/B=6 and Significance = 250/$\sqrt{300}$= 14.43

The Best significance we can get $\sqrt{3000}$= 54.8 for cut1 , $\sqrt{300} =$ 17.32 for cut2 and $\sqrt{3}$=1.73 for cut3, For getting large significance we should not reduce stats much

D-meson Efficiency

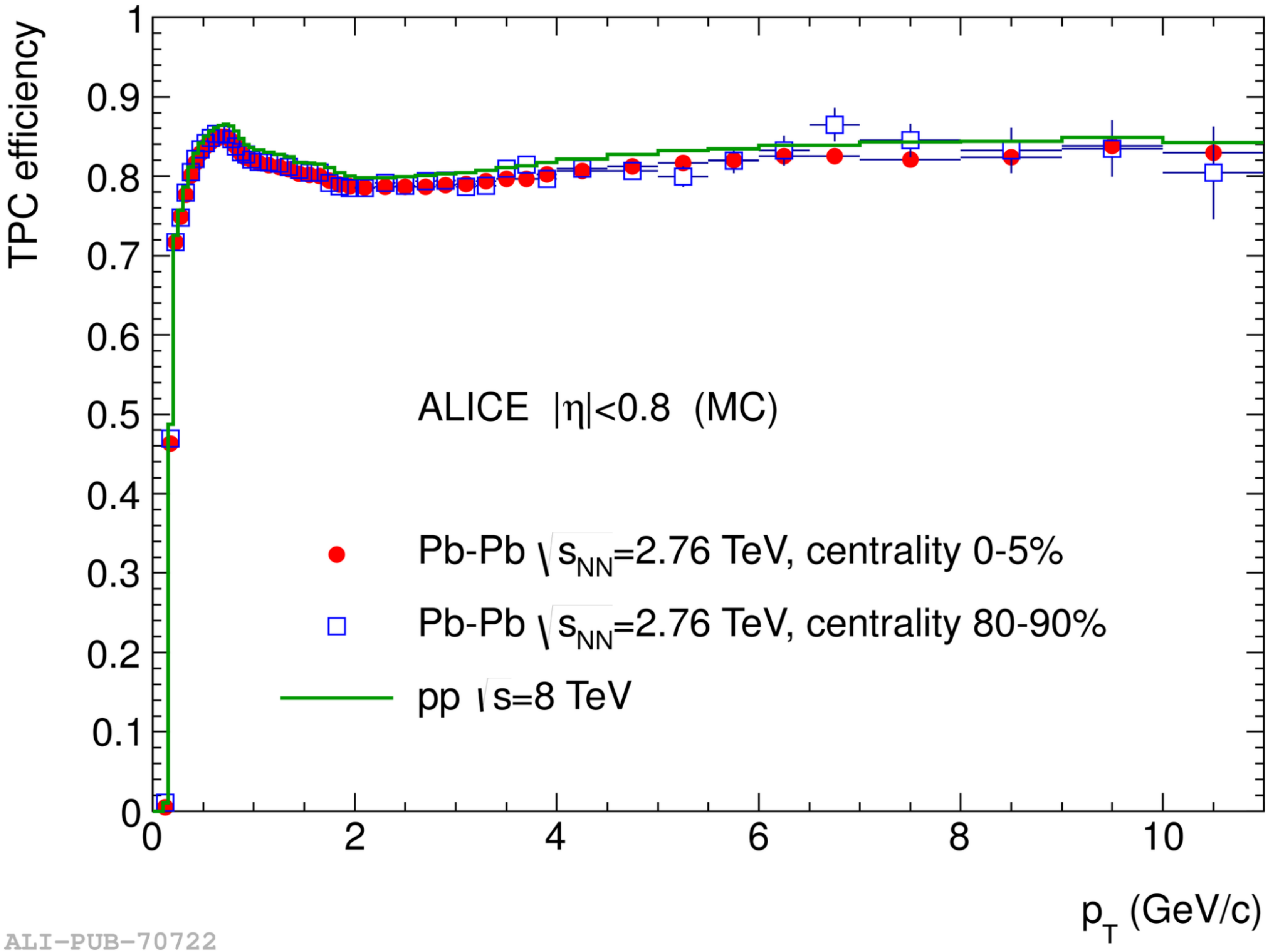






1D Efficiency

Track Efficiency

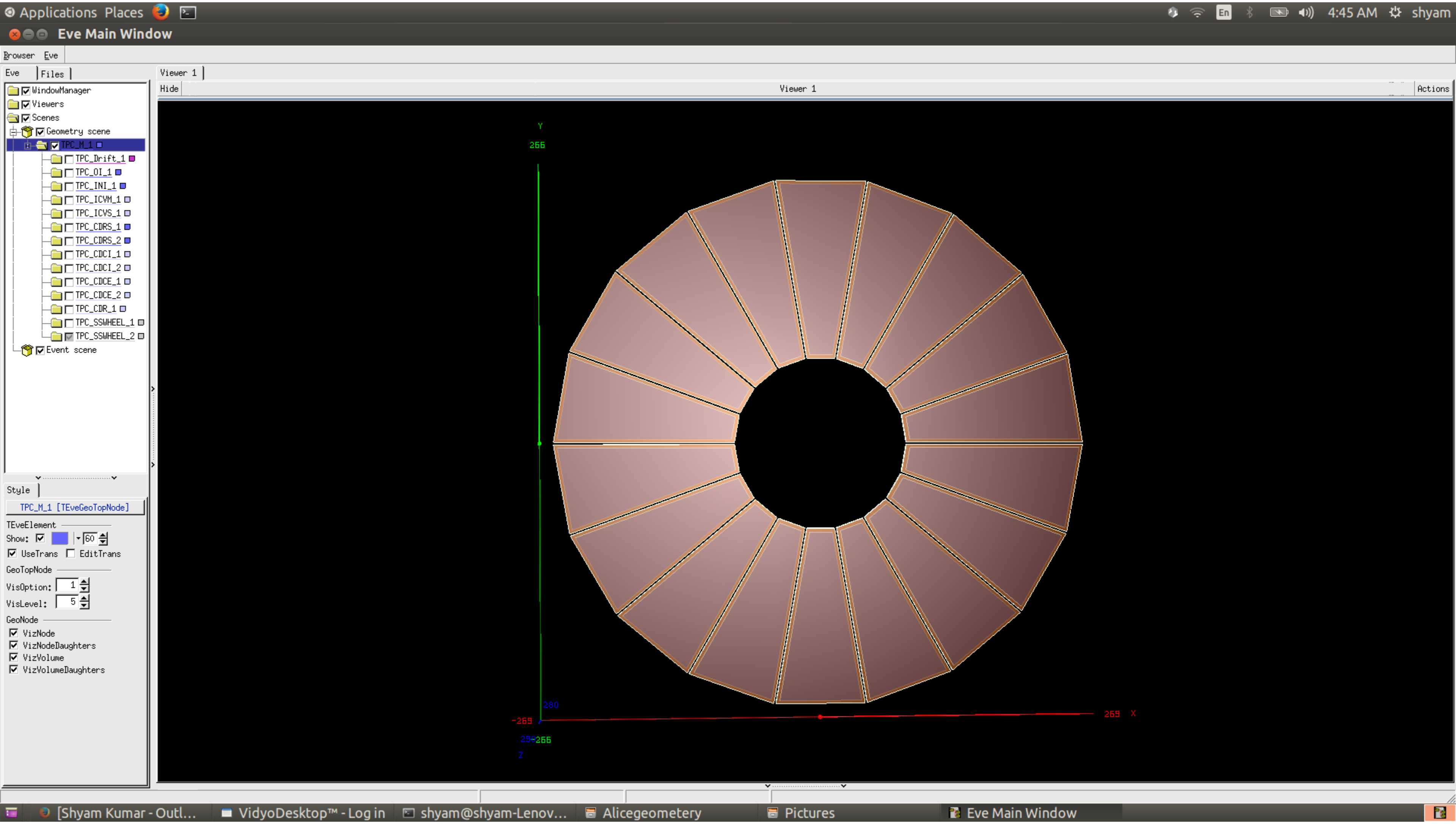


$$P_T\left(\frac{\text{GeV}}{c}\right) = 0.3\ B\ [T]\ R[m]$$

Track Efficiency Explanation

B = 0.5 T

TPC geometry ALICE

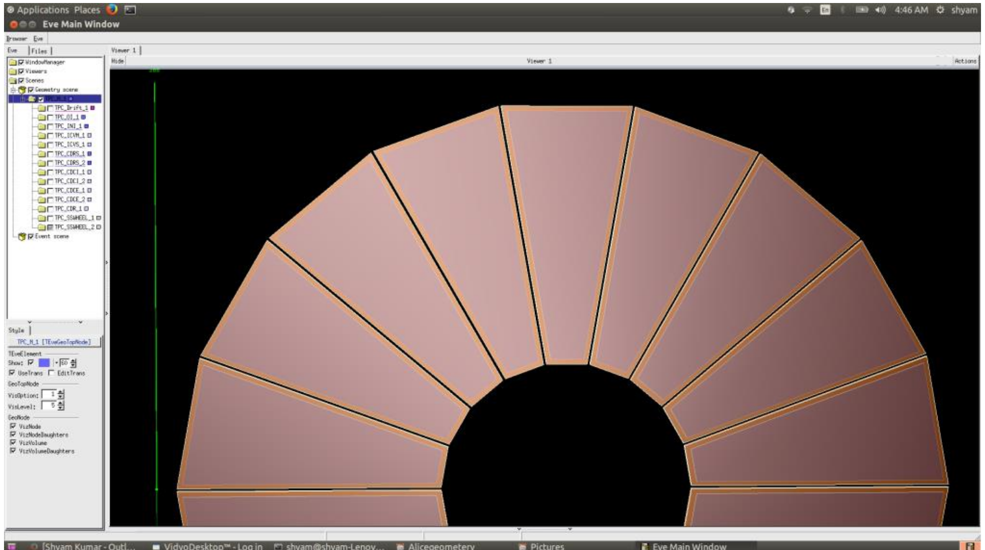


$$R[m] = \frac{P_T}{0.15}$$

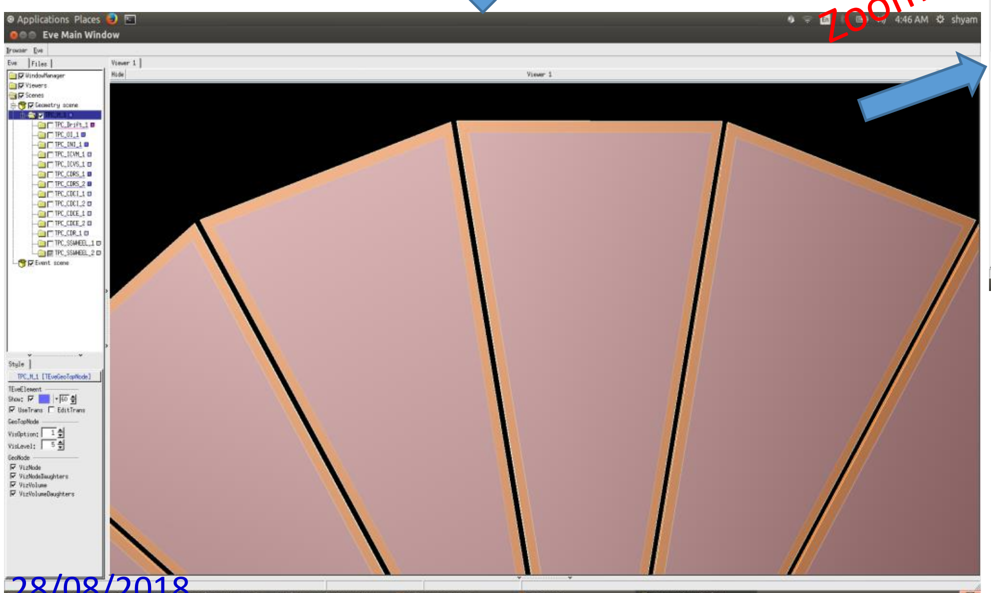
$R \to 0\ as\ P_T \to 0$ and $R \to \infty$ (Straight line) as $P_T \to \infty$

Track Efficiency

TPC geometry ALICE



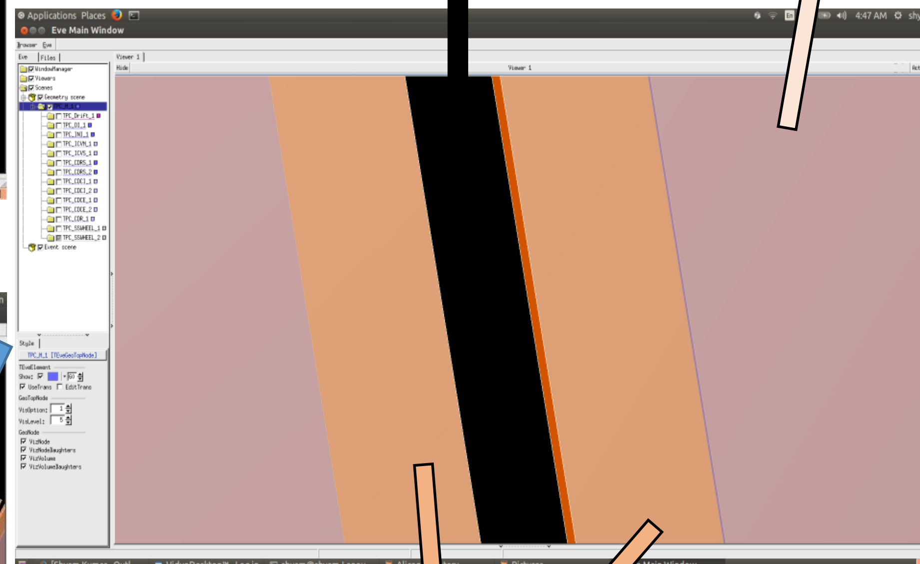
Zoom



Zoom

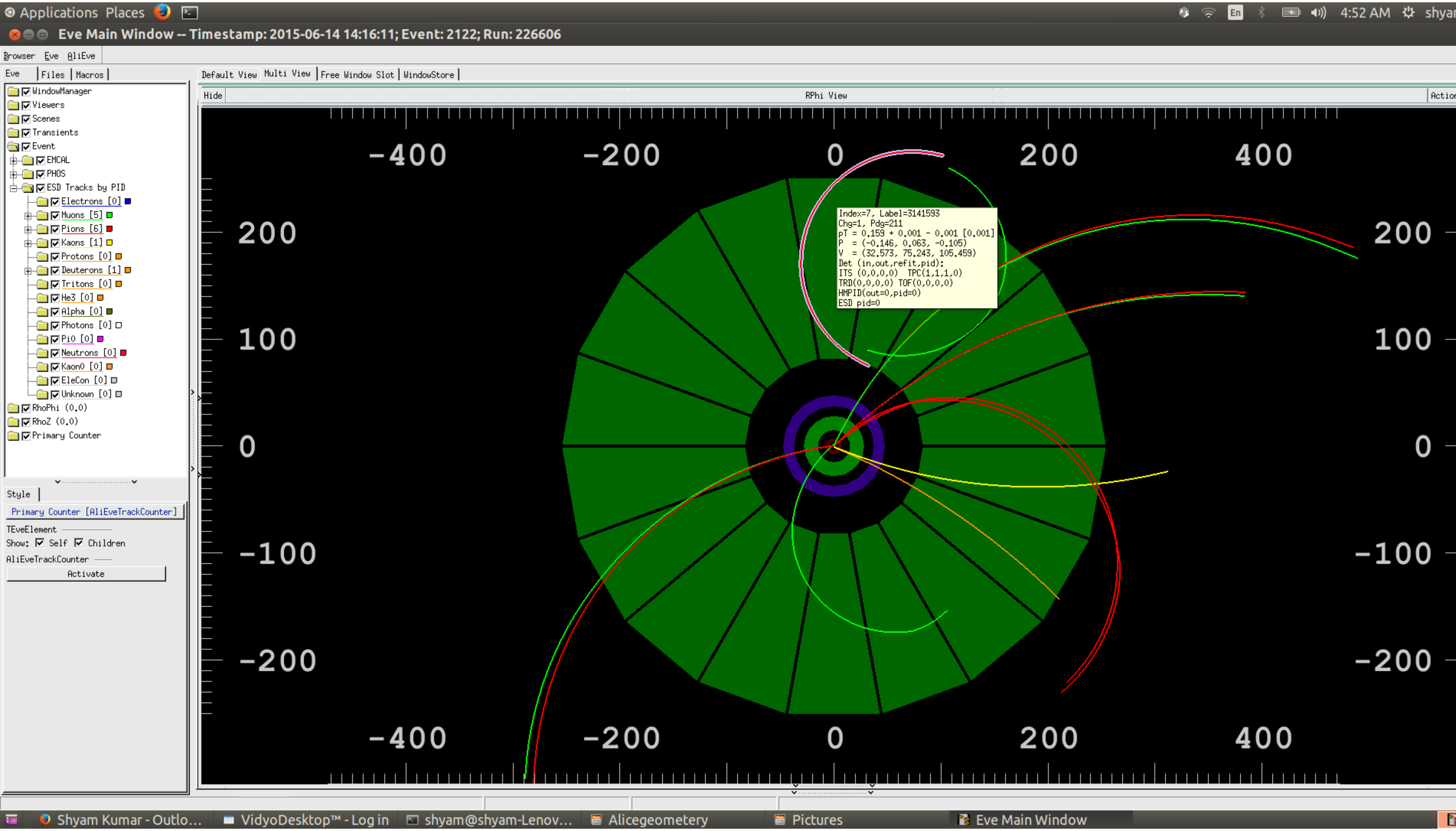
Read out Chambers
(Dead region)

Active region



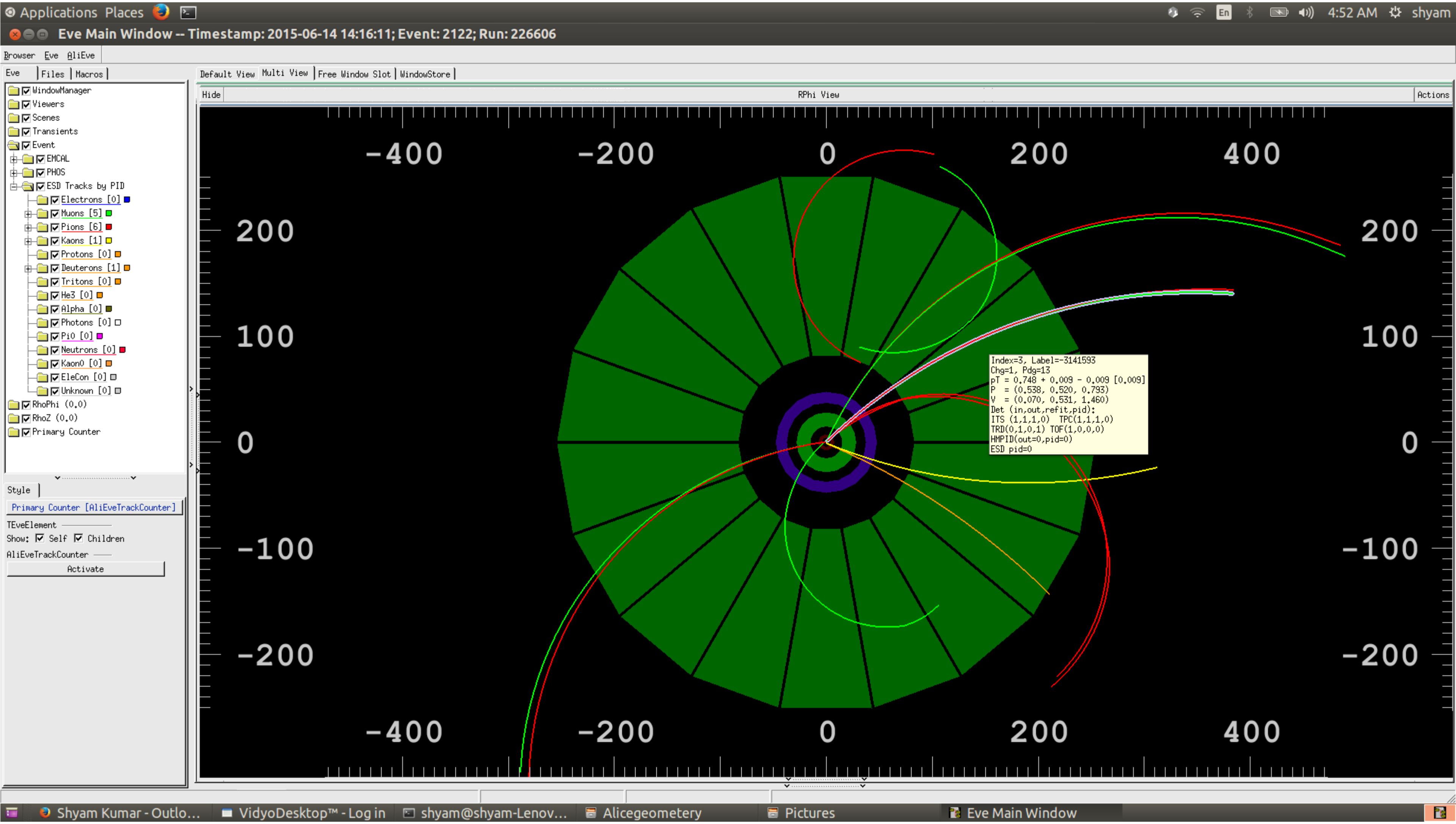
(Dead region)
~1.5 cm from both sectors so is ~ 3cm

$P_T = 0.159$ GeV/c [Highlight track]

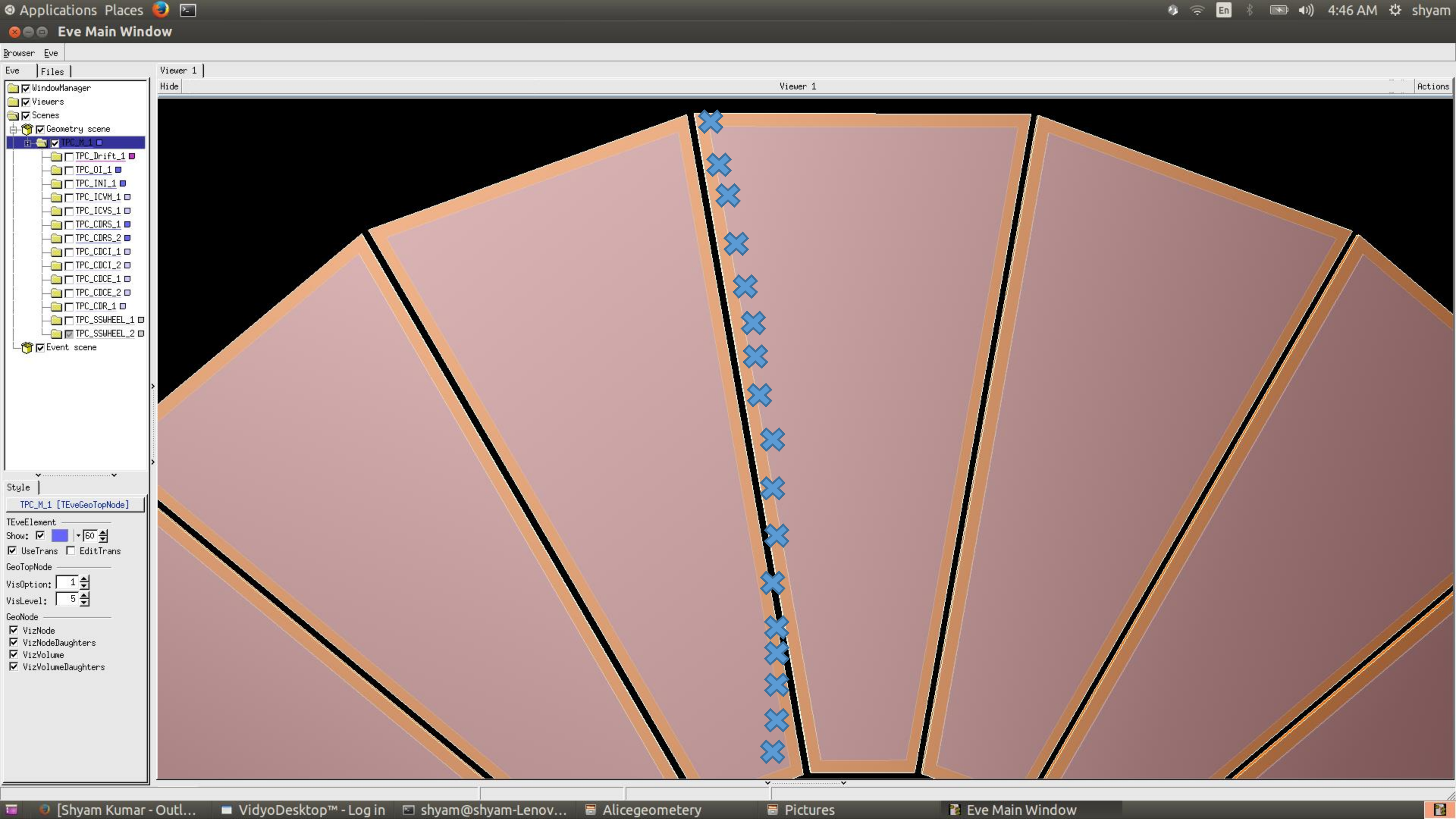


At Low Pt Radius of curvature is small means bending is more so dead space traversed is very small so we always get sufficient hit to reconstruct them (Always efficiency will be high)

$P_T = 0.748$ GeV/c [High lighted track]



Very high Pt track will almost straight so they will either lie in completely in active region or dead region so It is just geometric efficiency which is constant so efficiency is constant at very high Pt

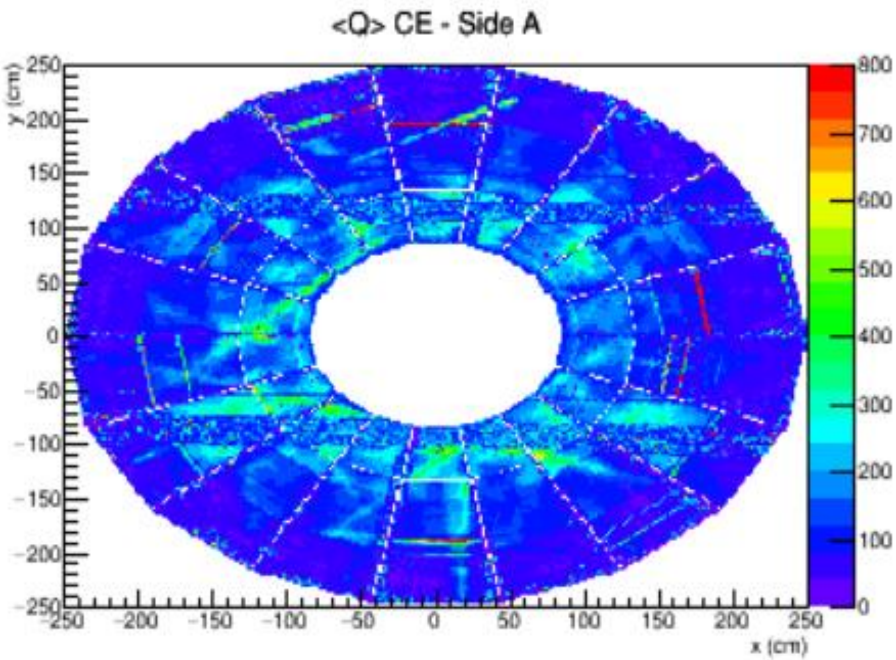


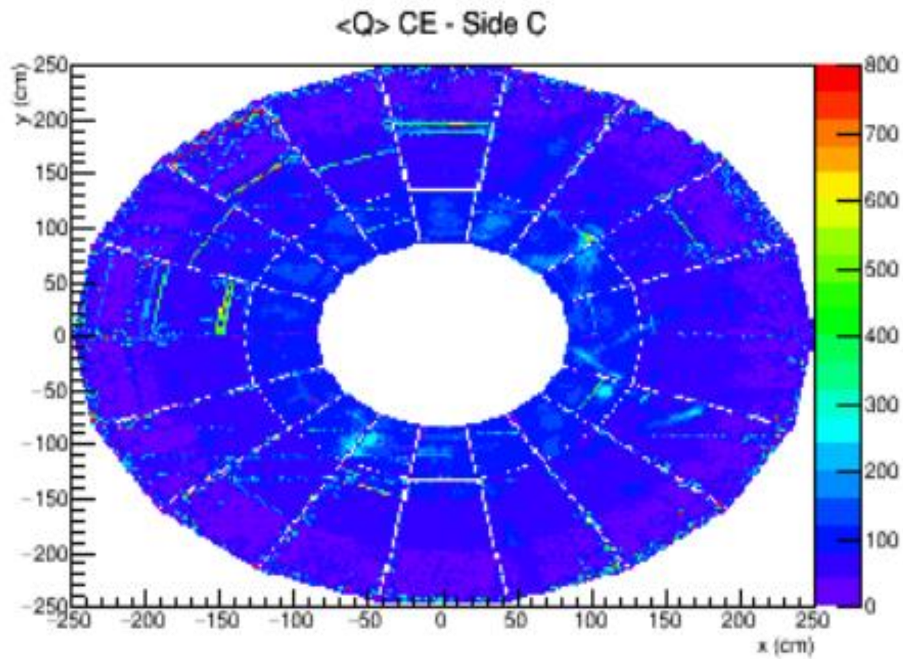
There will a range of Pt where tracks just hits some hits in active region then completely goes to dead region this corresponds to dip in the efficiency plot this is the intermediate case of low Pt and high Pt

Thanks to Ruben Shahoyan

DQM Plot for TPC

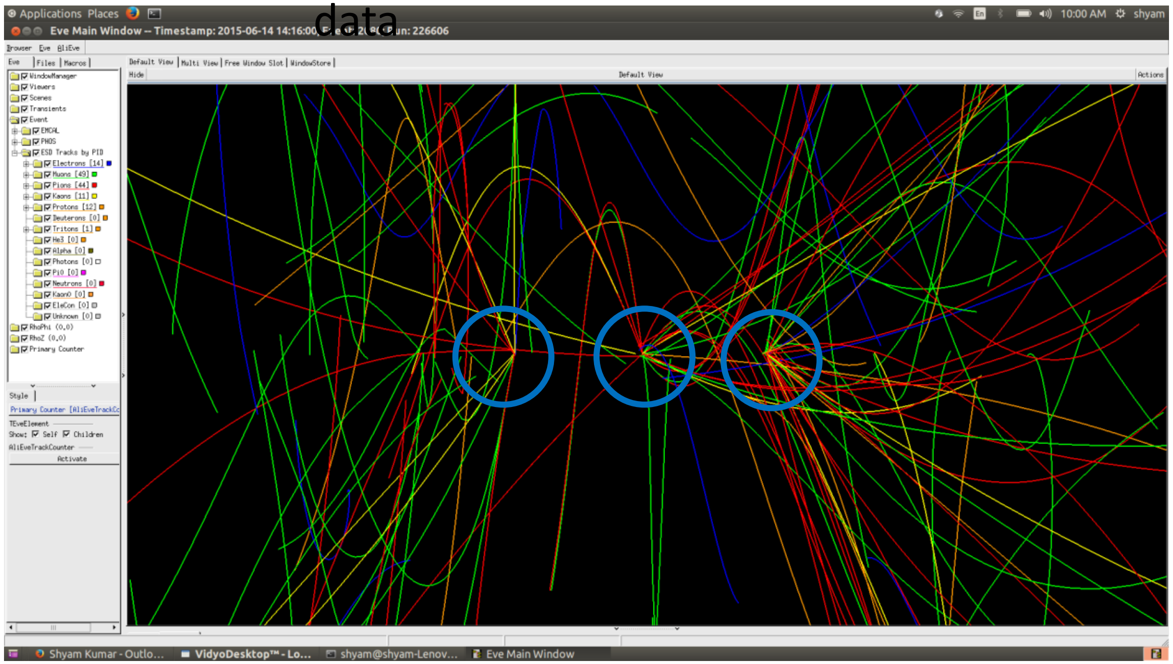
		278167	12/09/2017 10:58:35	4.7 h	204	20	17	PHYSICS_1			60 321 689	3 530.68	PHYSICS	C	BeamDump	No	
		278166	12/09/2017 09:14:02	1.7 h	204	20	17	PHYSICS_1			21 690 819	3 565.22	PHYSICS	C	Operator_Request	No	
		278165	12/09/2017 07:38:58	1.5 h	204	20	17	PHYSICS_1			20 257 196	3 620.59	PHYSICS	C	Operator_Request	No	
		278164	12/09/2017 05:13:16	2.4 h	204	20	17	PHYSICS_1			31 272 463	3 616.15	PHYSICS	C	Operator_Request	No	
		278163	12/09/2017 04:05:36	1 h	203	20	16	PHYSICS_1			13 434 130	3 424.45	PHYSICS	C	Operator_Request	No	
		278162	12/09/2017 03:57:24	5.1 m	194	20	15	PHYSICS_1			1 200 799	3 280.87	PHYSICS	C	Operator_Request	Yes	
		278161	12/09/2017 03:52:40	0.5 m	195	20	16	PHYSICS_1			106 824	1 148.64	PHYSICS	C	Subsystem_failure:DCS	Yes	
		278160	12/09/2017 03:39:24	3.2 m	204	20	17	PHYSICS_1			714 210	2 811.85	PHYSICS	C	Operator_Request	Yes	



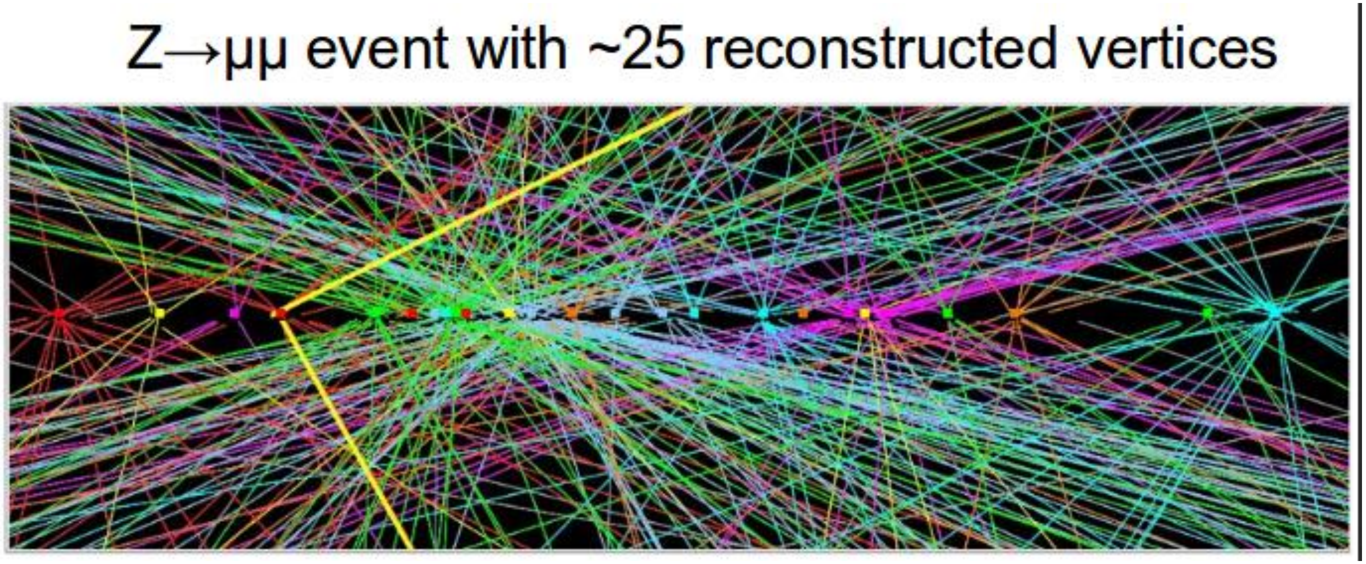


3 vertices in single collision

Event Pile Up (In Bunch) LHC15f_pass1 data



ALICE



ATLAS