Open charm production in ALICE-FT

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in collaboration with
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Fixed Target at LHC,
Strong 2020 Workshop, Jan 5-7, 2023

Brief Introduction

Motivations:

- Measurements in large Bjorken-x frontier,
- Variable Target System *e.g.* Be, C, Ti, W.
- Intermediate CM Energy:

  $\sqrt{s_{NN}}$= 115 and 72 GeV, with *p* and *Pb* beams.
- Study of Longitudinal expansion of QGP.
- Factorization of CNM effects and more [1].

Setup:

- Channeling proton beam halo with bent crystals [2].
- Compact and retractable solid target system.

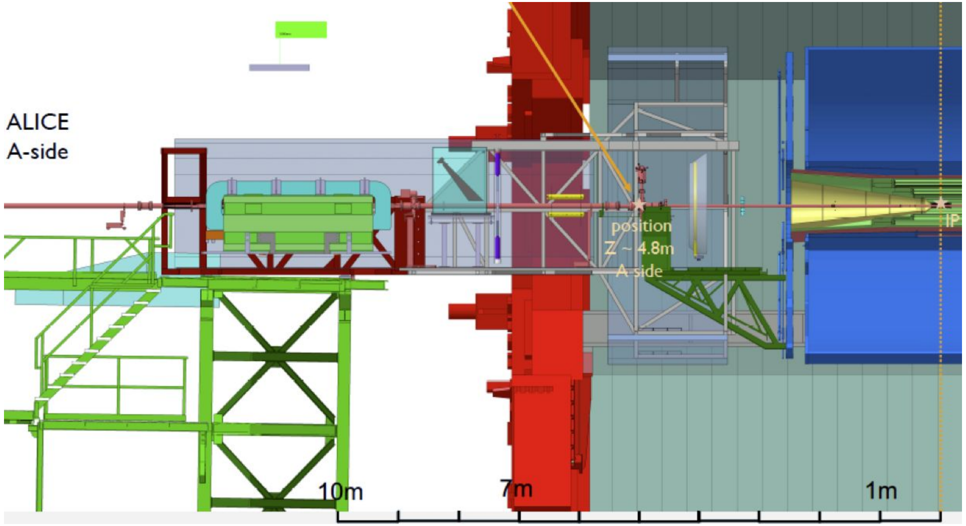


Fig.1: Target position for ALICE Fixed Target Setup

Challenges:

- How does TPC respond to inclined tracks

  (*e.g.* -2.5 < η < - 1.0) ?
- Can we measure Λ, D^0 from FT Events ?

[1] C. Hadjidakis et. al., Physics Reports, **911**, p1-83 (2021), [2] M. Patecki, HB2021 Beam Dynamics Workshop.

Simulation of ALICE TPC

Charged particles:

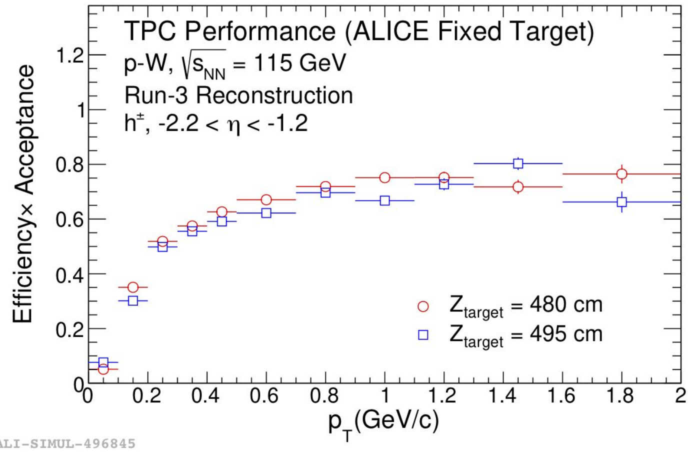
- ★ HIJING is used as p-A event Generator.
- ★ TPC response estimated from O2 Simulation with Run-3 detector setup.
- ★ The Efficiency and p_T Resolution are sufficient for analysis.

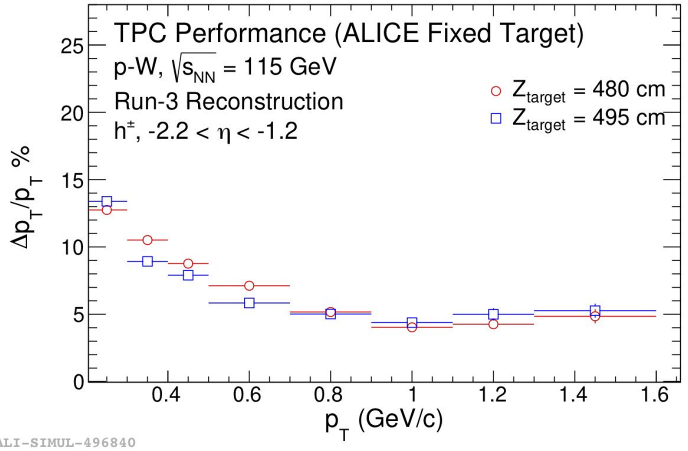
Caveats:

- ➔ There are unmerged track segments
  → To be fixed (later) by TPC experts.
- ➔ The effect of TPC space charge distortions are not taken into account.

Simulation for Λ, D^0 particles:

- ★ We used Fast Decay simulation (with Root's decayer class).
- ★ The efficiency and p_T resolution of charged particles are used as proxy for decay daughters.





For Details: (Upgrade week Sept 19-23, 2022)
https://indico.cern.ch/event/1183733/contributions/5046904/

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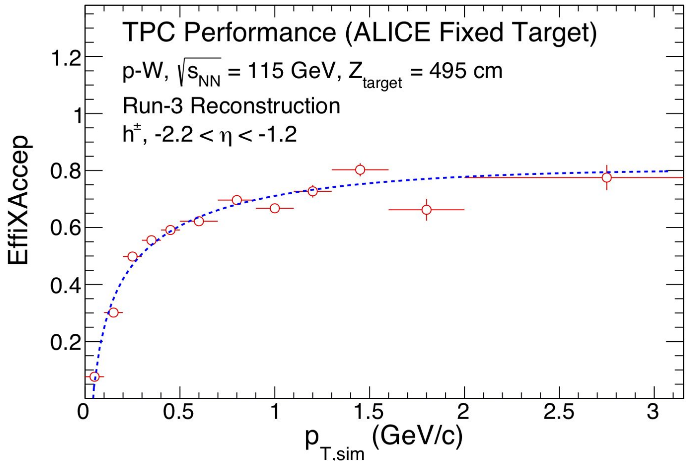
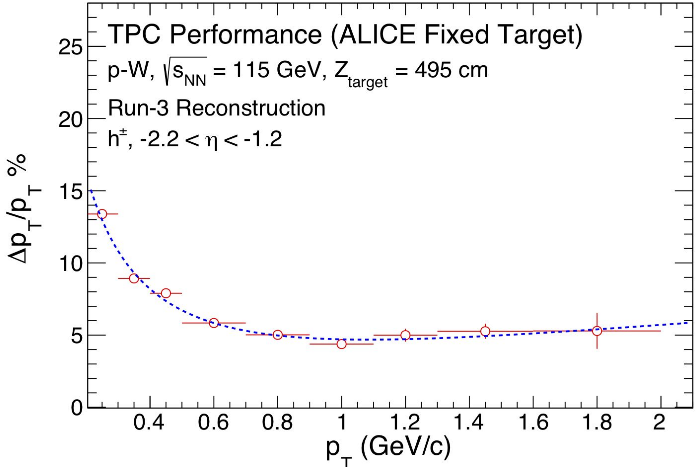




Simulation of Λ and D^0 Efficiencies

Simulation result for Λ particles:

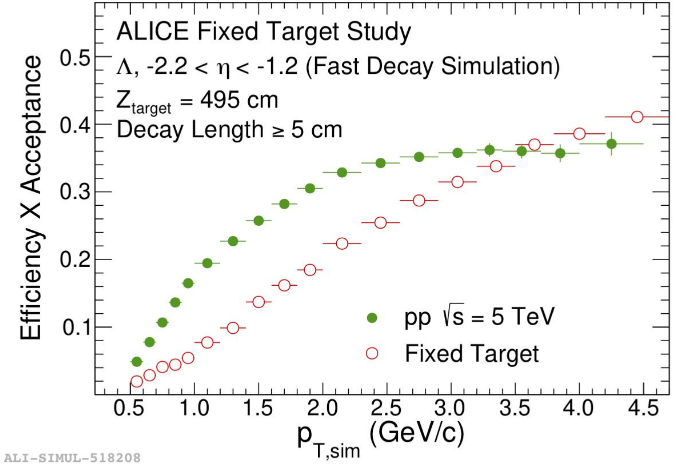
- ★ We applied topological cuts on decay length and invariant mass of Λ.
- ★ No other topological cuts (*e.g.* daughters)
- ★ Efficiency X Acceptance shown for Decay Length ≥ 5cm, and $|M_{inv}| \leq M_{PDG} \pm 10$ MeV.
- ★ Efficiency is lower than collider events ⇒ But sufficient for physics analysis.

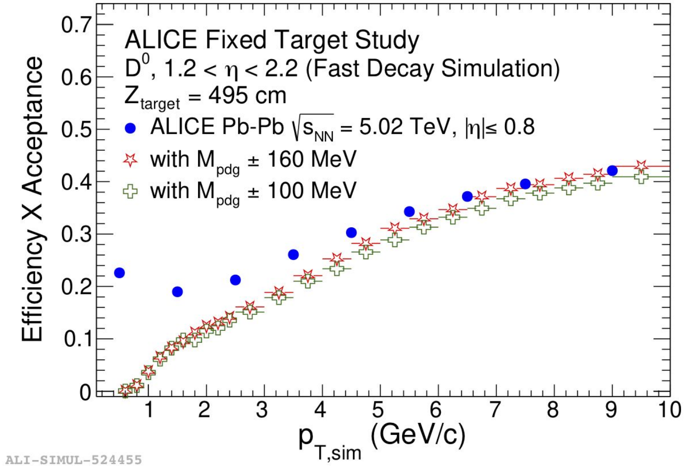
Simulation result for D^0 particles:

- ★ Topological cuts on invariant mass only.
- ★ No other topological cuts (e.g. daughters).
- ★ Efficiency X Acceptance estimated by combinatorial method.
- ★ Efficiency is lower than collider events ⇒ But sufficient for physics analysis for $p_T > 1$ GeV/c.

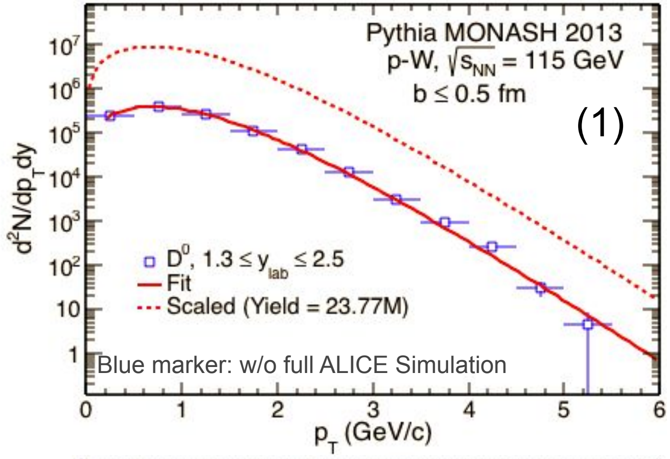
→ Resolution of both particle ≃ 10%, at pT = 1.0 GeV/c.

For Details: (Previous FT Workshop, June 2022)
https://indico.cern.ch/event/1143479/contributions/4828560/





Expected D^0 Yield ($\mathcal{L}_{int}$ = 0.6 pb^{-1}, W target width = 1 cm)



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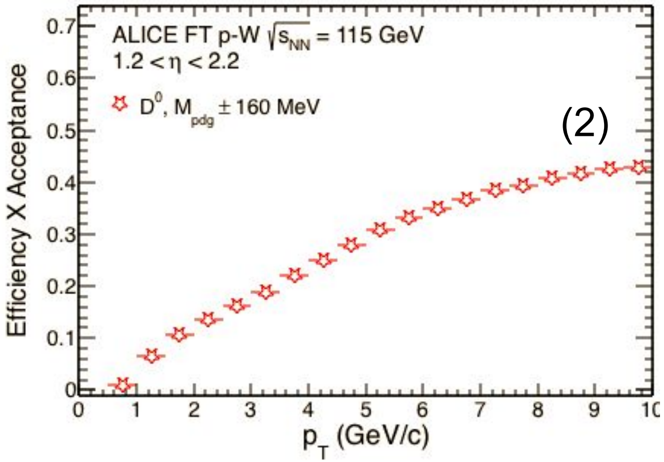

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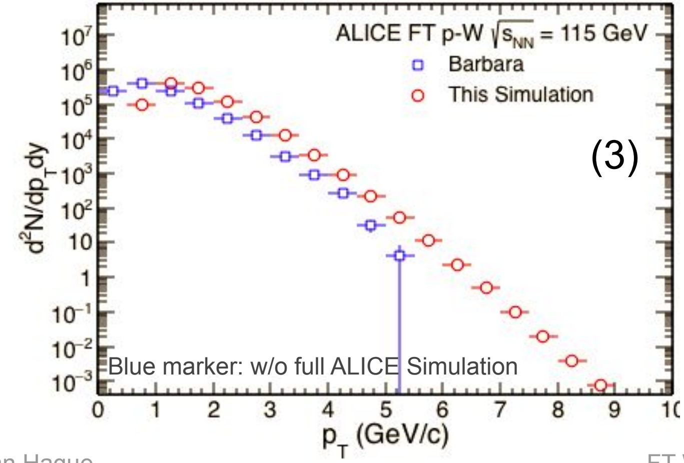
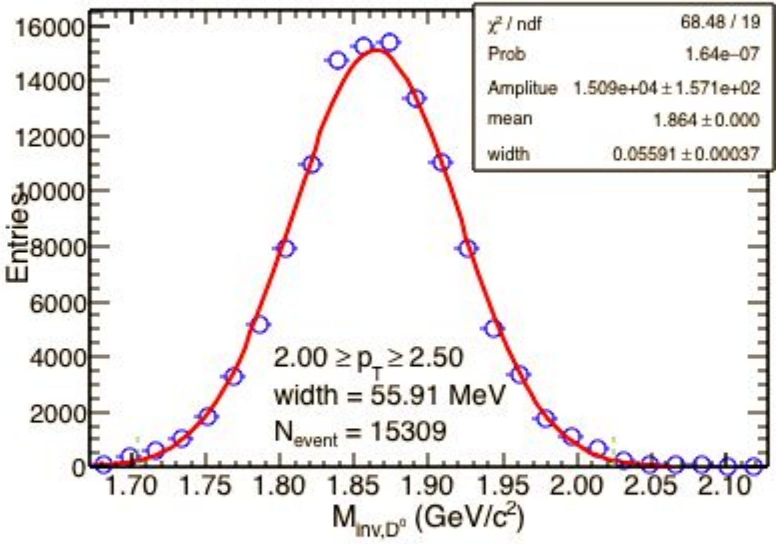


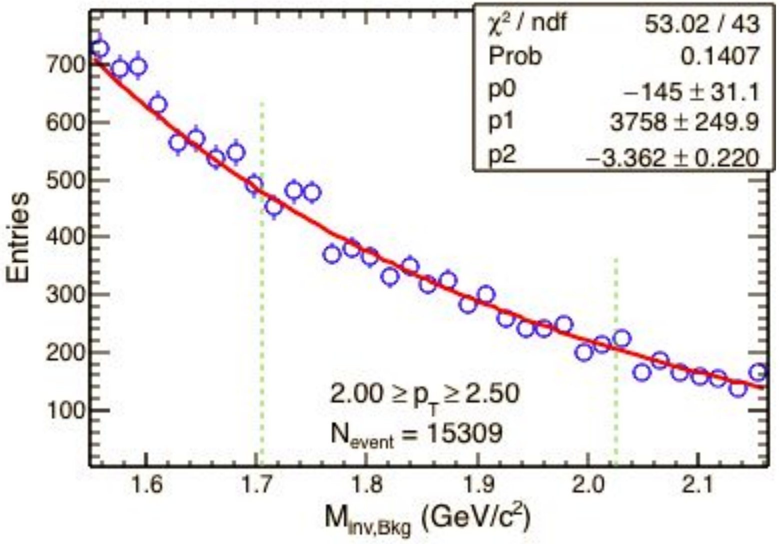
The number of D^0 (w/o efficiency corr.) for 1 year running:
= 0.229E-3 * 184 * 0.542 * 0.0389 * 0.0446 * 0.6E12
= **23.7 X 10^6**

Yield with efficiency:
Pythia (Monash-13) spectra shape (Fig.1) X Efficiency (Fig.2)
= Expected yield in each p_T bin (Fig-3)

Integrated Yield (w/ efficiency): ~ 1 Mil.

D^0 Signal and Combinatorial Background





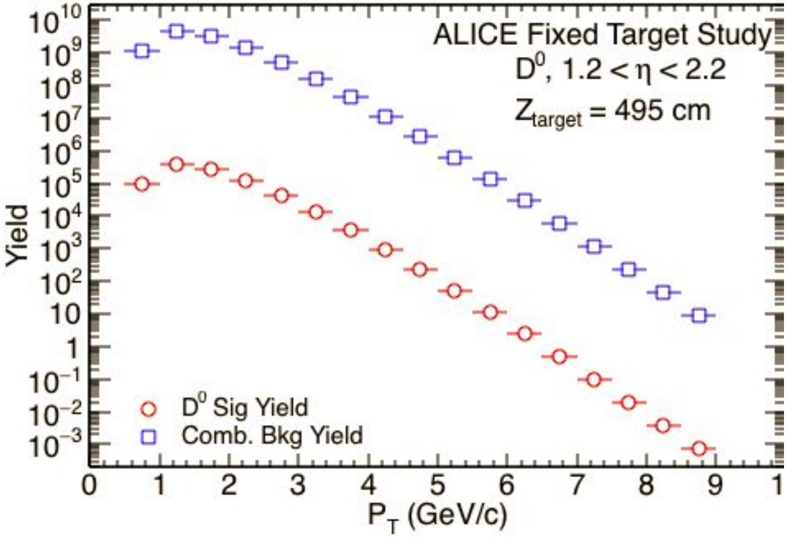
Combinatorial background: **without PID**, *i.e.*, take all +/- pairs.

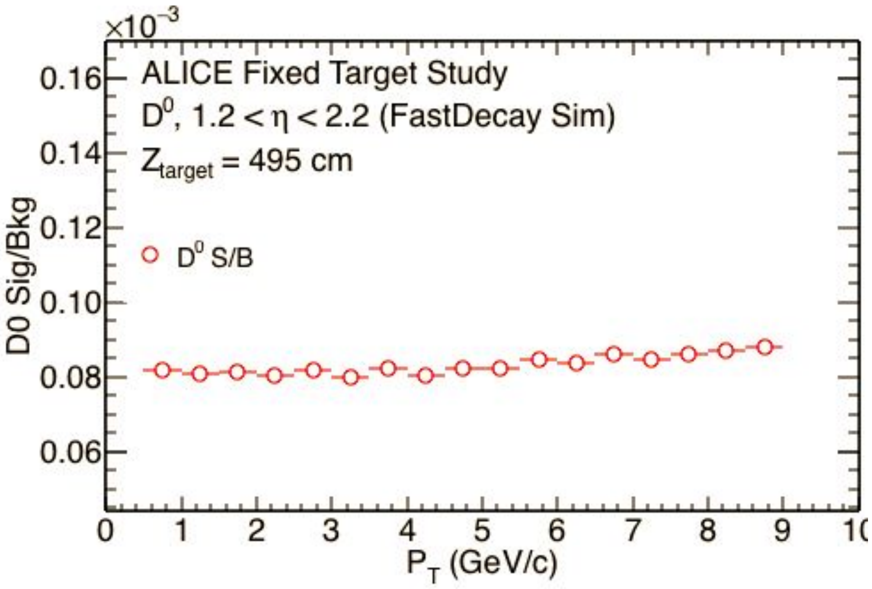
Charged particle multiplicity sampled from **A** **M**ulti **P**hase **T**ransport (AMPT) model.

We generated p-W central events with $\sqrt{s_{NN}}$ = 115 GeV, and tracks selected within $1.2 < \eta < 2.2$.

AMPT Generated particles are also treated for detector effects (efficiency & p_T resolution)

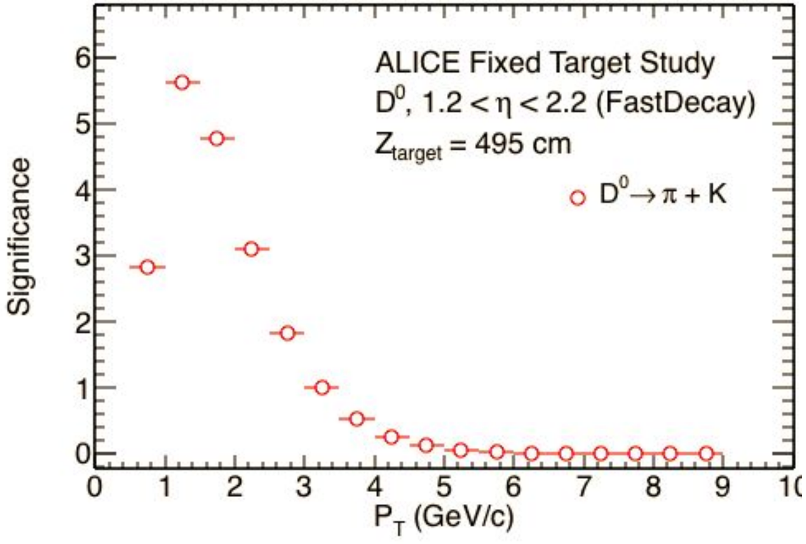
D^0 signal and background yields, S/B ratio

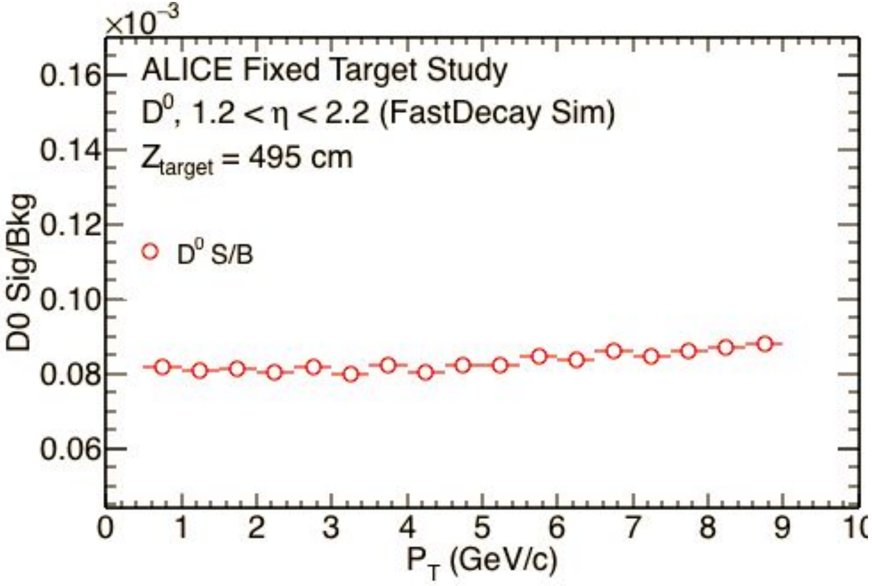




- MB event : D^0 event ratio = **100K : 3.12** (Check backup slide for details).
- This ratio is used as scaling factor for single event combinatorial background.
- The background is scaled up as per expected number of D^0 in each p_T bin.
- Signal / Background ratio is found to be ~ 8×10^{-5}, and almost flat w.r.t p_T.

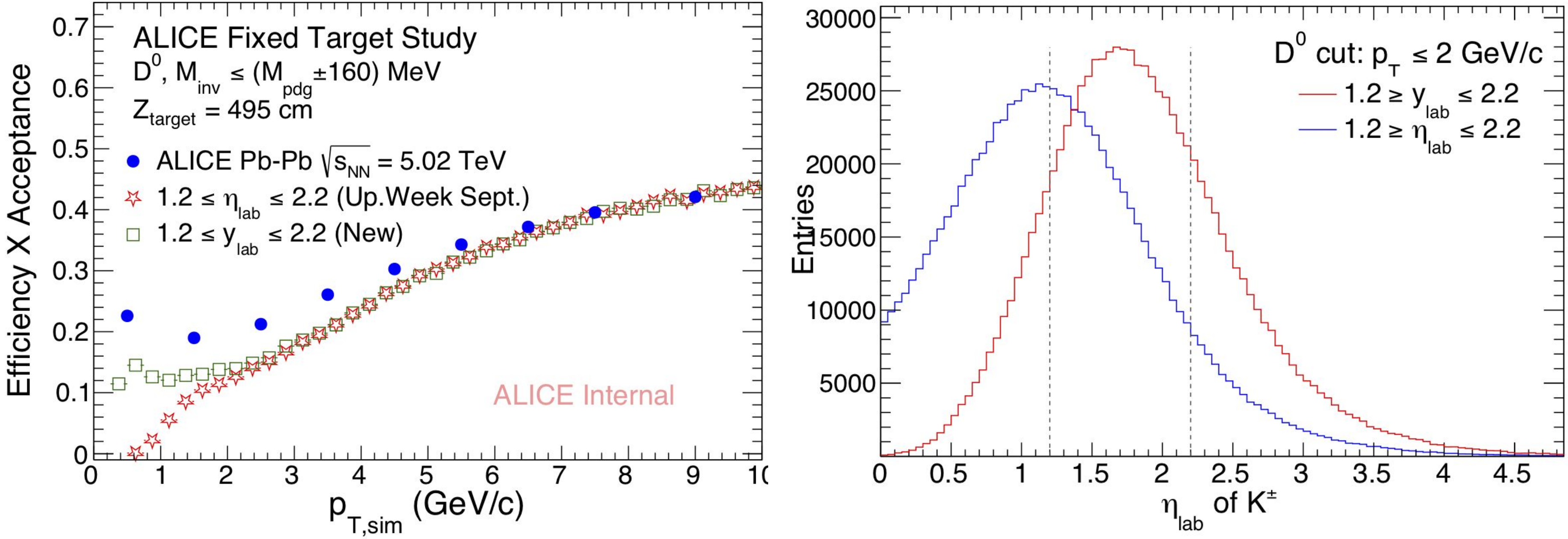
D^0 Significance and S/B ratio





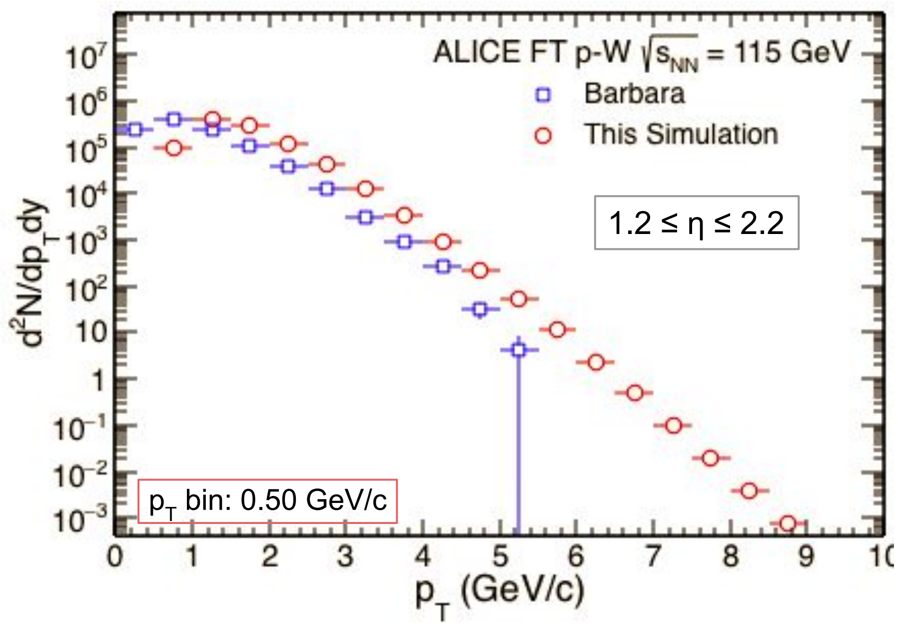
- ➢ Significance defined as = Signal / sqrt{Signal+Background}.
- ➢ D^0 Significance closely follows the shape of the p_T spectra.
- ➢ Significance is maximum around $p_T \approx 1.5$ GeV/c and $< 1\sigma$ for $p_T > 3$ GeV/c.
- ➢ We can extract D^0 yield from the p_T spectra up to 3 GeV/c ⇒ without any vertex tracker.

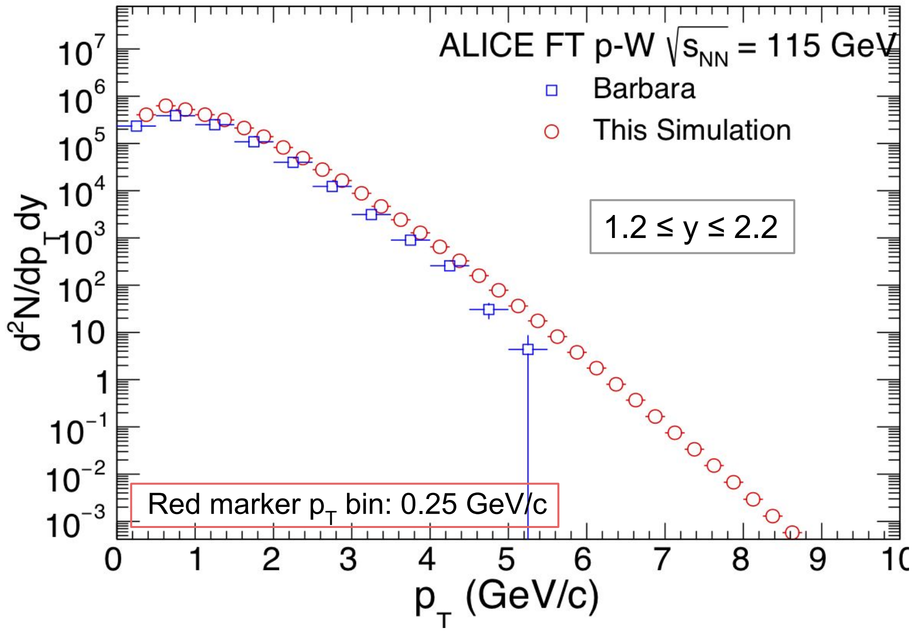
D^0 Efficiency estimation: η vs y cut



- Due to geometry of the FT setup, rapidity cut on D^0 results into better acceptance of daughter tracks.
- Consequently, the tracking efficiency increases for D^0 .
- pT resolution however, remains unchanged.

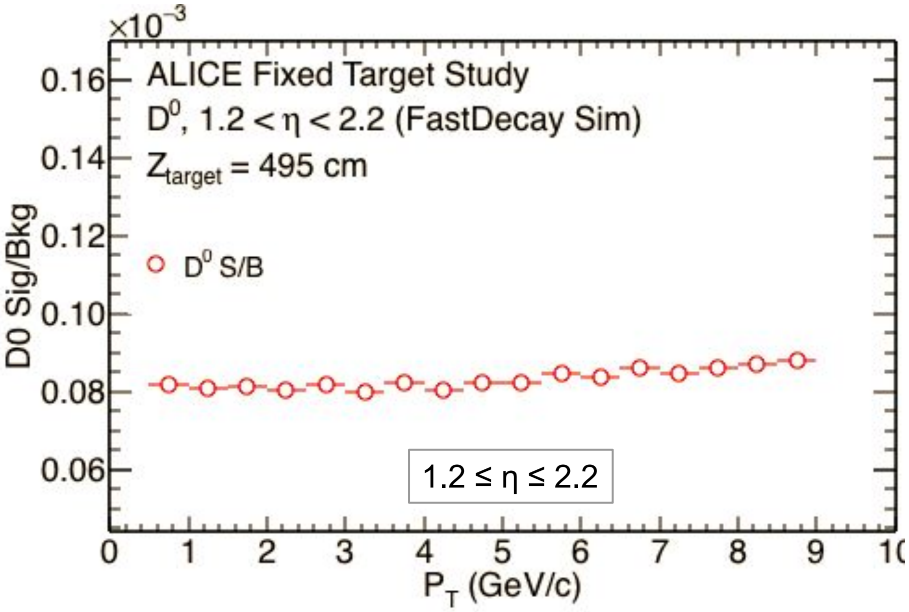
D^0 Expected Yield: η vs y

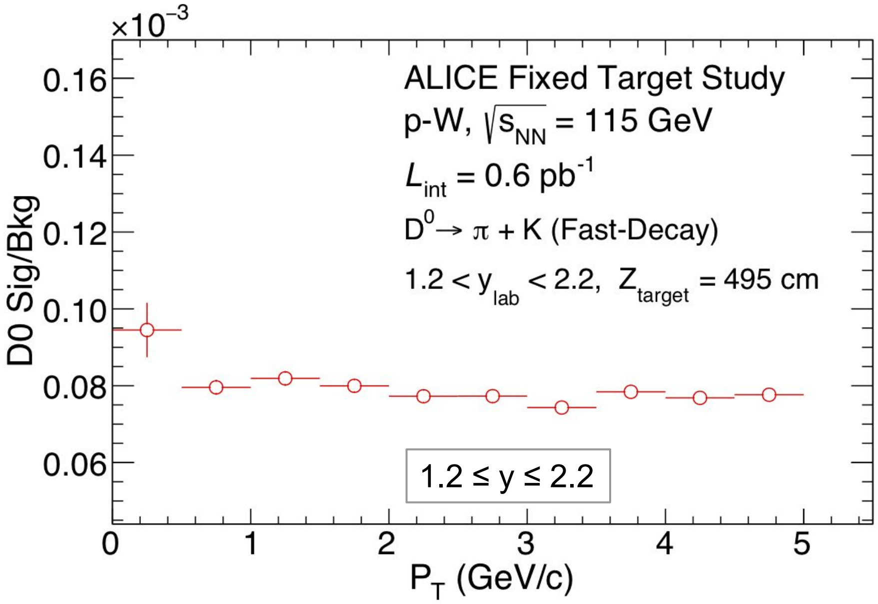




- With rapidity cut, the yield of D^0 improved at lower p_T (< 2.0 GeV/c).
- The S/B and Significance, thus improved at lower p_T

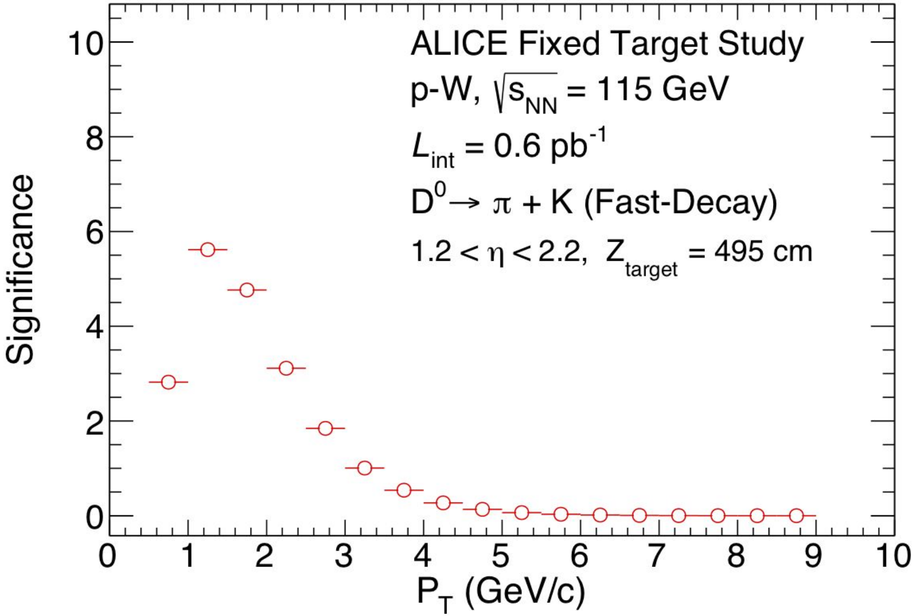
D^0 Signal / Background: η vs y

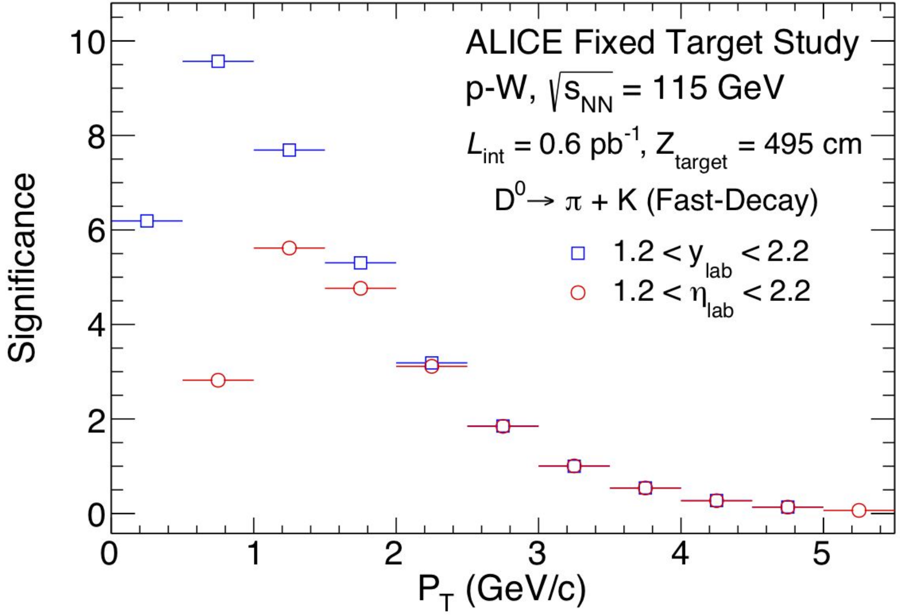




- With rapidity cut, the yield of D^0 improved at lower p_T (< 2.0 GeV/c).
- The S/B improved at lower p_T (first bin).

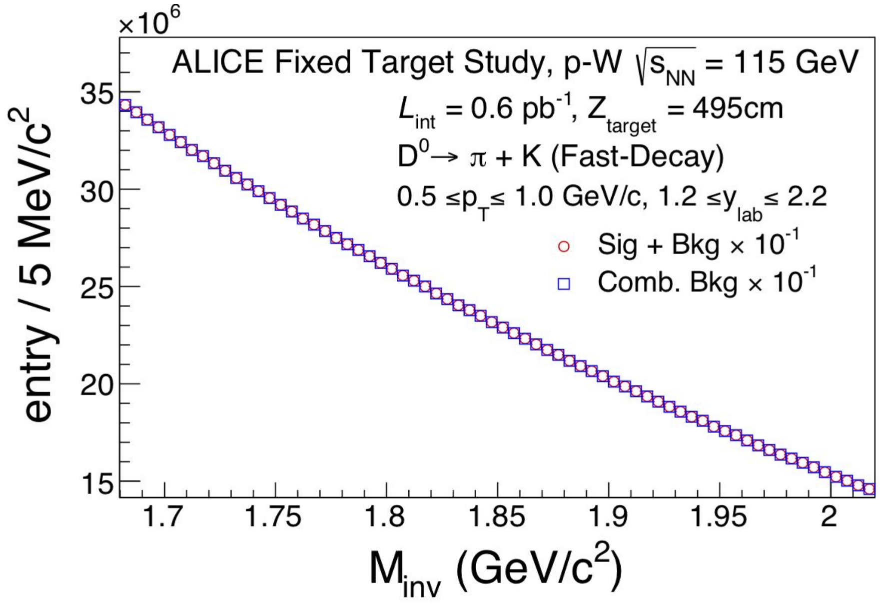
D^0 Significance: η vs y

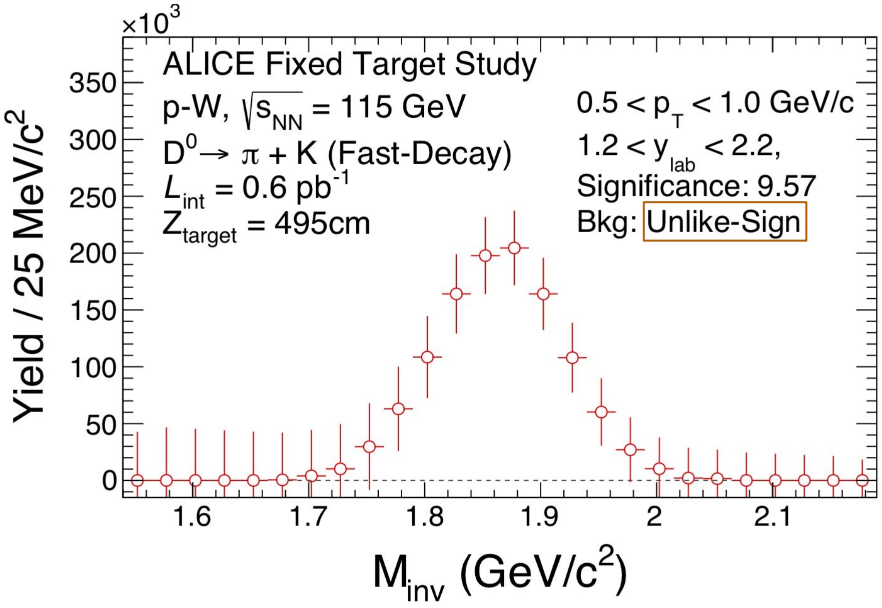




- ➢ With rapidity cut, the yield of D^0 improved at lower p_T (< 2.0 GeV/c).
- ➢ With increase in yield at low p_T , the significance improved (as seen on the right figure).

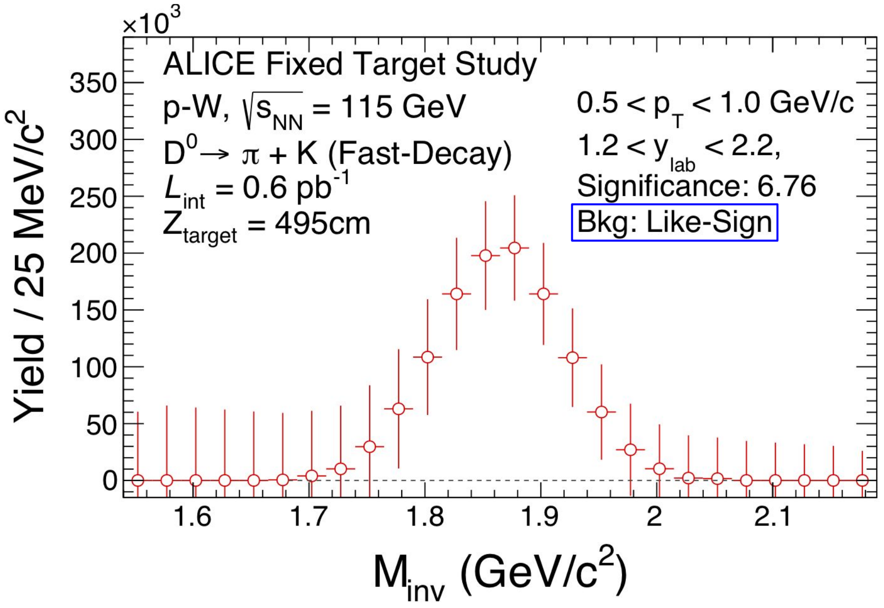
D^0 realistic M_{inv} distributions (for expected yields)

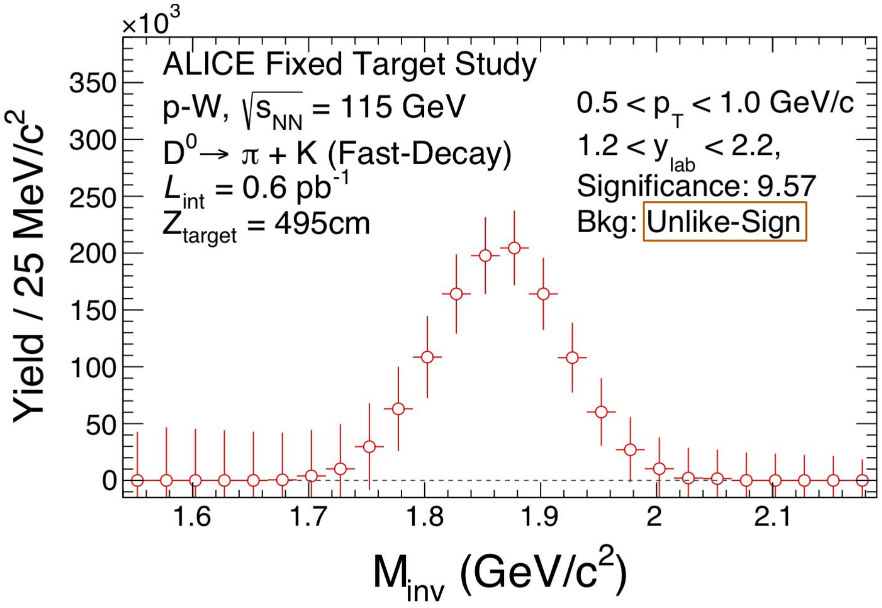




- Figure on the left: M_{inv} distribution for events with D^0, and unlike-sign (mixed event) background.
- Figure on the right: M_{inv} distribution of D^0, after subtraction of two histograms on the left figure.
- Uncertainties on the mixed event bkg are assumed to be 0 (infinitive statistics).

D^0 realistic M_{inv} distributions (for expected yields)





- Figure on the left: M_{inv} distribution for D^0 signal, with like-sign (same-event) background method.
- Figure on the right: M_{inv} distribution for D^0 signal, with unlike-sign (mixed-event) background method.

Summary & Outlook

Summary:

1. D^0 Expected yield as function of p_T improved with y_{lab} cut.
2. The D^0 significance improved (upto ~10σ) with rapidity cut.
3. Physics analysis with D^0 in ALICE FT is possible without any additional tracker.

Outlook:

1. Study PID dependence of TPC response for FT tracks.
2. Study the trigger mechanism for FT events with forward detectors.

Acknowledgements:

Ruben Shahoyan, David Rohr, Marco Van Leeuwen, Jochen Klein, Marcin Patecki.

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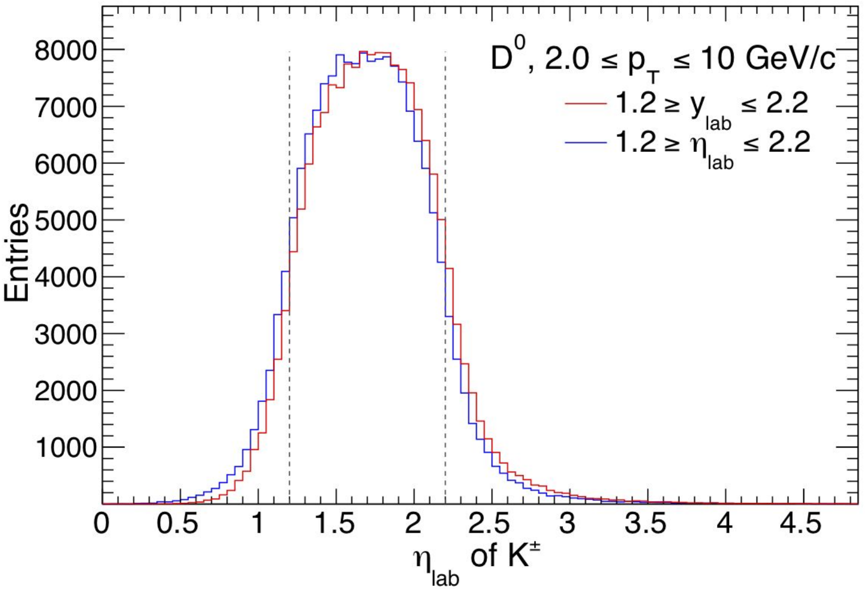
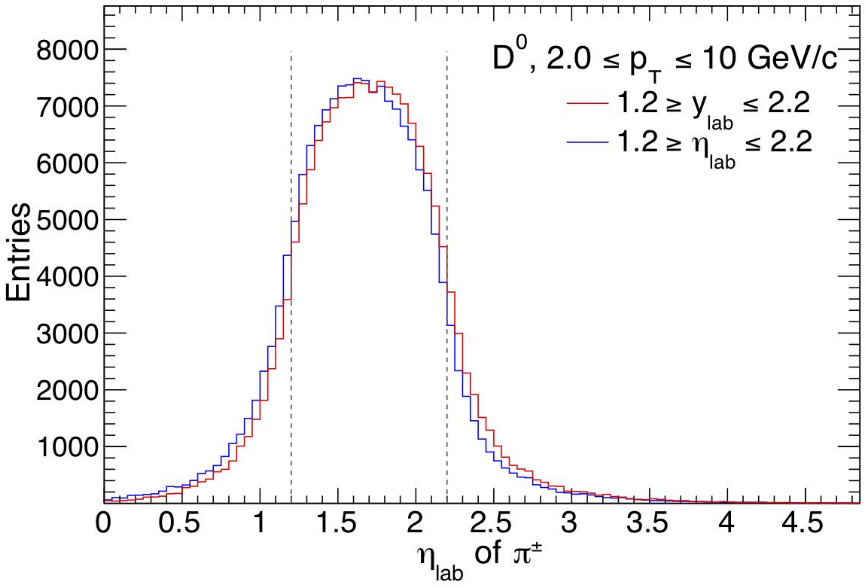
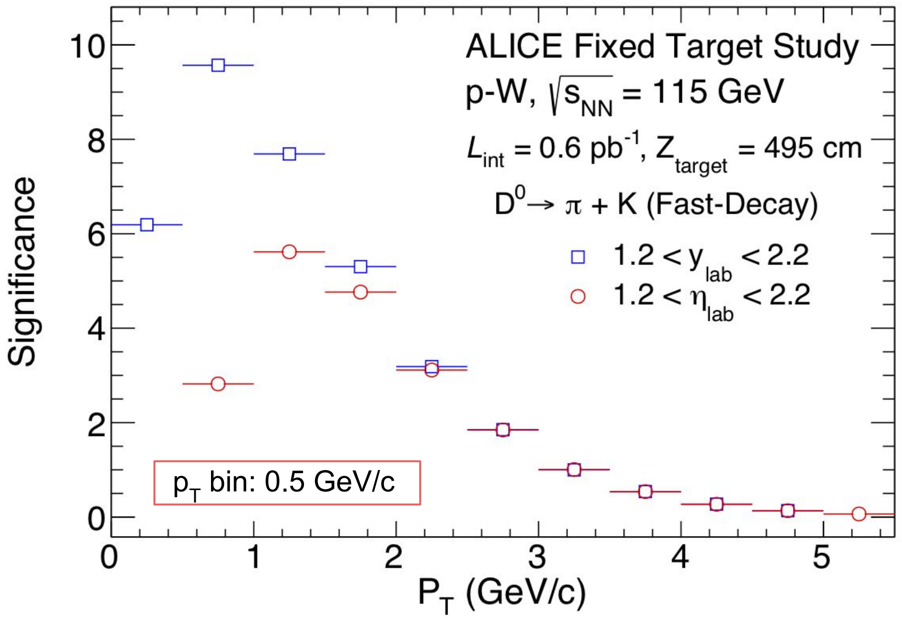
Thanks for your attention!

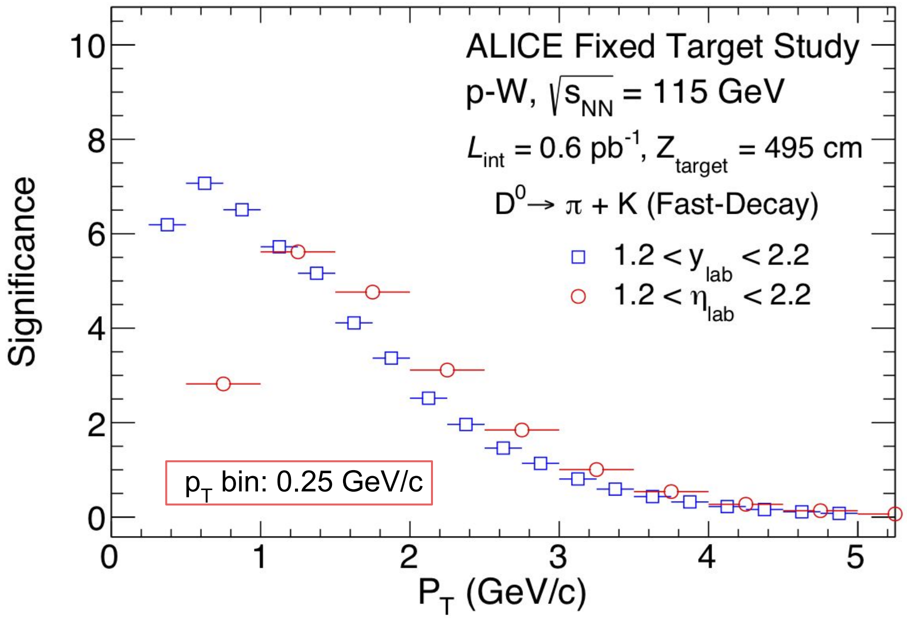
Back-up: Daughter Acceptance: high p_T D^0



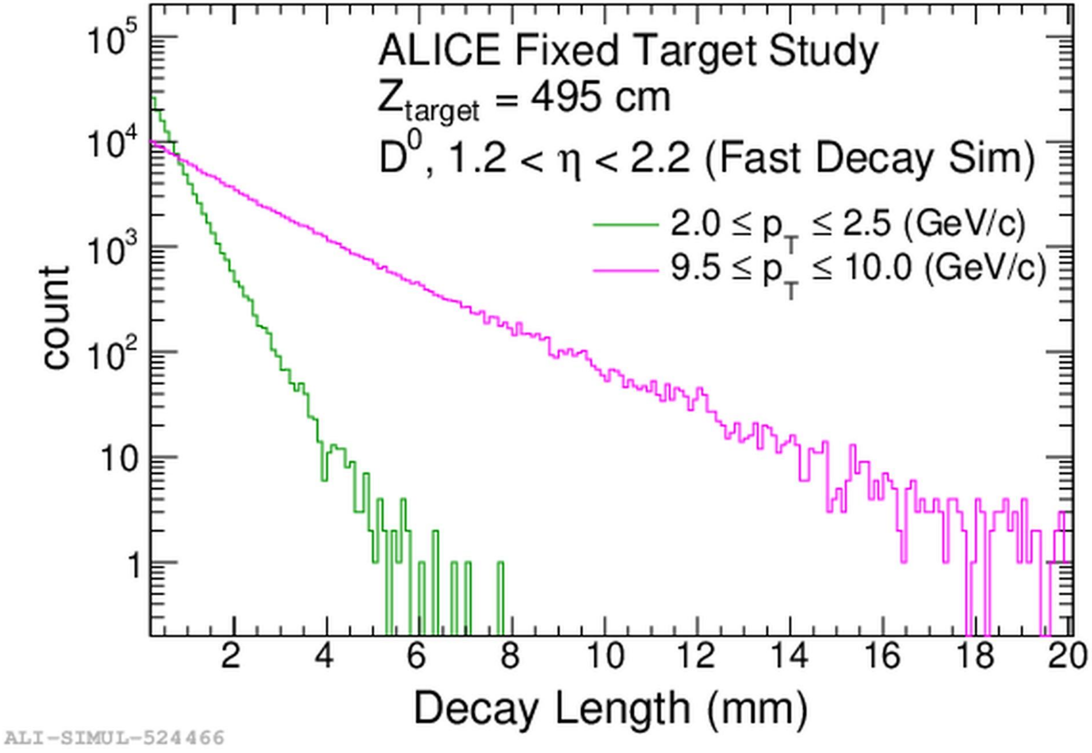


D^0 Significance: with fine p_T bins





D^0 Decay length



Event ratio estimation D^0 vs MB (part-1)

Estimation of D^0 production rate in p-W events at $\sqrt{s_{NN}}$ = 115 GeV.

We have a cross section of charm production in pp collisions from HELA-Conia σ^{cc} : 0.229 mb.

Charm production cross section for p-W events = A* σ^{cc} where (A = mass number for W).

Inelastic cross section of pp collisions at $\sqrt{s_{NN}} = \sigma_{inel}$ = 39 mb.

Inelastic cross section of p-W collisions: $\sigma_{inel} * A^{2/3}$

D0 production ratio from open charms : 0.542

Therefore, the ratio of events with D^0 to the number of MB events in p-W collisions:

$$\frac{N_{D0}}{N_{MB}} = 0.542 * \frac{\sigma^{cc} A}{\sigma_{inel} A^{2/3}} = 0.542 * \frac{\sigma^{cc} A^{1/3}}{\sigma_{inel}}$$

Event ratio estimation D^0 vs MB (part-2)

Therefore using known values of cross sections & A, we get,

N_{D0}/N_{MB} = 0.542*0.229*$(184)^{1/3}$ / 39 = 0.018086 = **18** D^0 Events per 1000 MB Events.

Now, we only consider the D0 → K + pi channel, for which the branching ratio is 3.89%. Therefore, we need to take into account this factor as well.

The revised ratio of D^0 events to MB event for the $D^0 \rightarrow$ K + pi channel is,

N_{D0}/N_{MB} = 0.018086*0.0389 = 0.0007035 = **70** $D^0 \rightarrow$ K+pi events per 100K MB Events.

Finally, the rapidity acceptance factor for FT setup = 4.46%

Therefore, N_{D0} ($1.2 < y < 2.2$) / N_{MB} = 70*0.0446 / 100K = **3.12 / 100K**