25th International Workshop on
Deep Inelastic Scatterings
3-7 April 2017, Birmingham

Open heavy-flavour production in pp and p-Pb collisions with the ALICE experiment

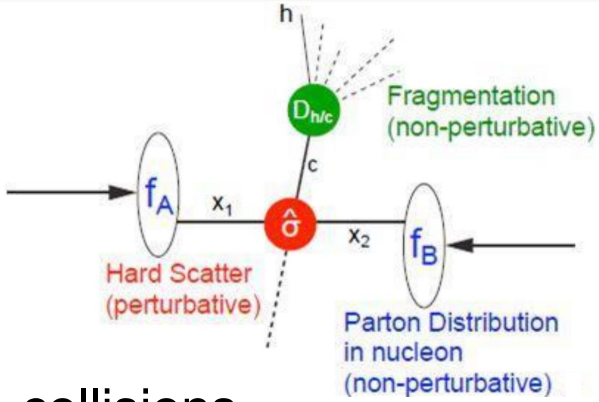
Róbert Vértesi
vertesi.robert@wigner.mta.hu
Wigner RCP, Budapest
for the
ALICE Collaboration

Hungarian Academy of Sciences
Wigner Research Centre for Physics

Heavy-flavour production

pp collisions

- Benchmark of pQCD approaches
  - Heavy quarks: $m_{c,b} >> \Lambda_{QCD}$
  - Momentum transfer is large
  - Genuine hard probes down to low p_T!
- Reference for nuclear modification in pA, AA collisions



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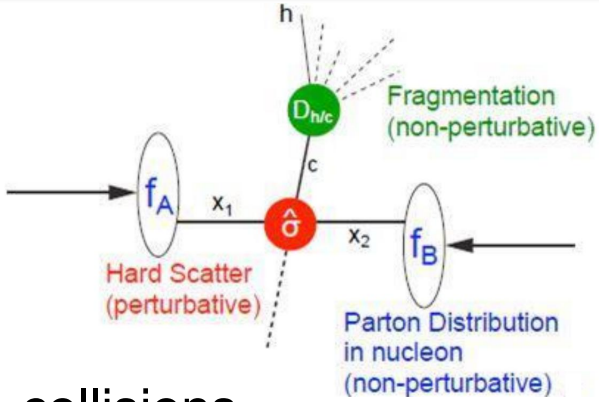


p-Pb collisions

- "Cold" nuclear effects
  - Modification of the free PDF (shadowing)
  - Gluon saturation
  - k_T-broadening
  - Nuclear absorption ...

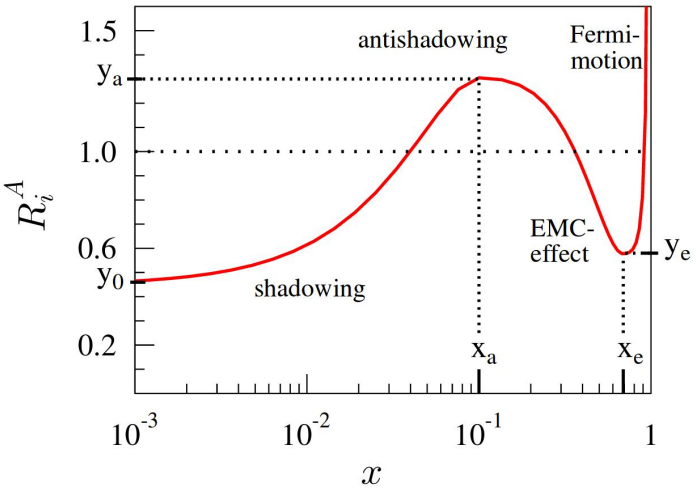
→ Baseline for hot plasma effects in AA coll.

Keep in mind: possible hot effects in pA

- **Observable: Nuclear modification factor**

$$R_{\mathrm{pA}} = \frac{1}{\langle T_{\mathrm{pA}} \rangle} \frac{\mathrm{d}N_{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

Eskola et al., JHEP 0904, 065 (2009)

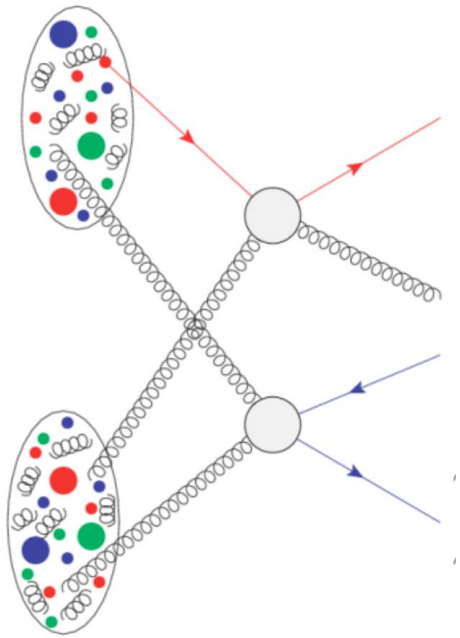


$$f_i^A(x,Q^2) \equiv R_i^A(x,Q^2) f_i^{\mathrm{CTEQ6.1M}}(x,Q^2)$$

More into the details...

HF production vs. event activity

- Interplay between hard and soft processes
- Link between initial and final state
- Origin of observed universality?
- Multiple parton interactions (MPI)?
- Role of collective effects in small collision systems with high multiplicity?



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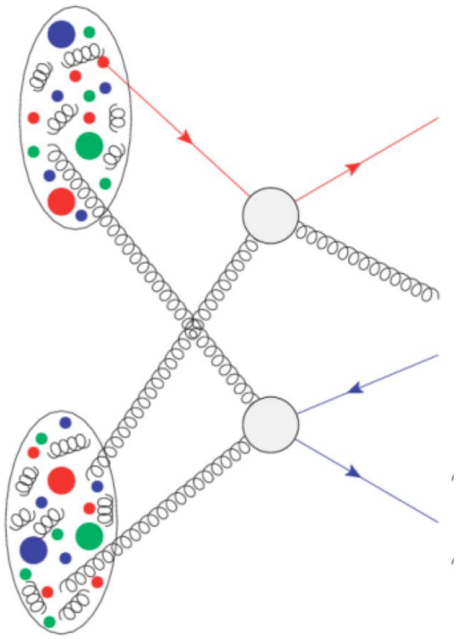
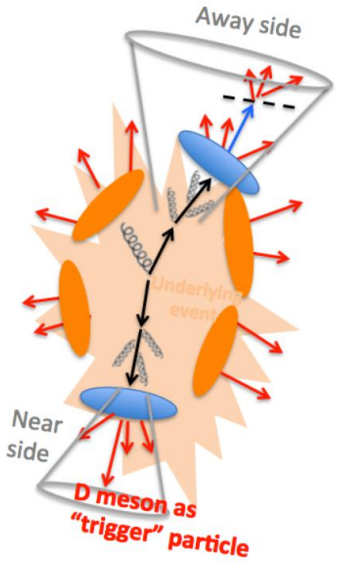


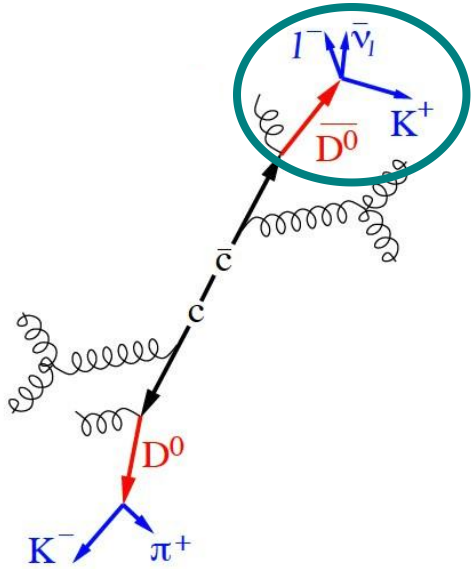
D meson - hadron azimuthal correlations

- Fragmentation of charm vs. light quarks
- Properties of jets with charm content
- Reference for future Pb-Pb measurements
- (Collectivity in p-Pb and high-multiplicity pp collisions)



Experimental access to open HF

- Indirect semi-leptonic decays
  - Typical signature, higher statistics
  - Inclusive measurement
  - A mixture of c, b contributions
    (→ separation by displacement)



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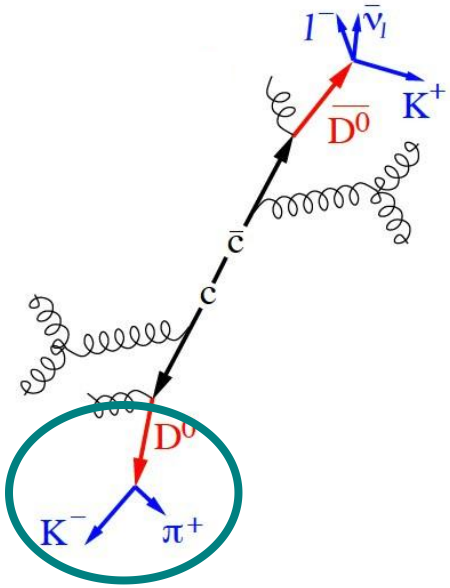

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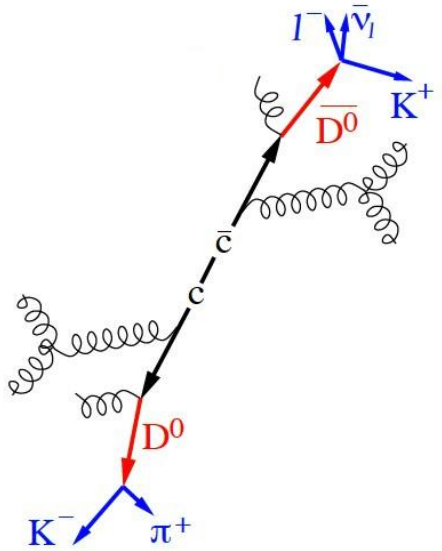
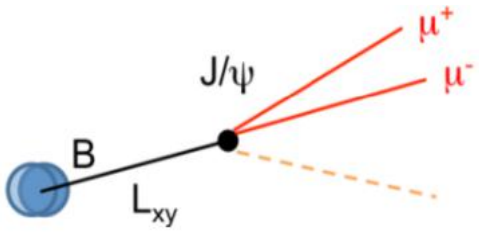
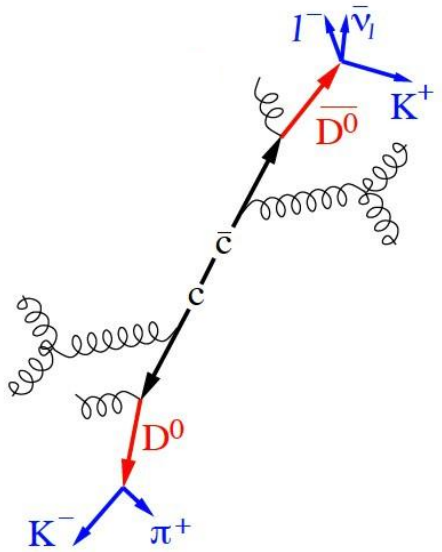
  - Selective to decays of B hadrons
  - Secondary vertex reconstuction needed

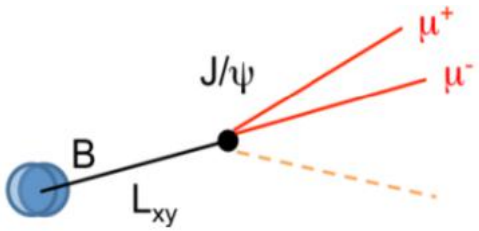


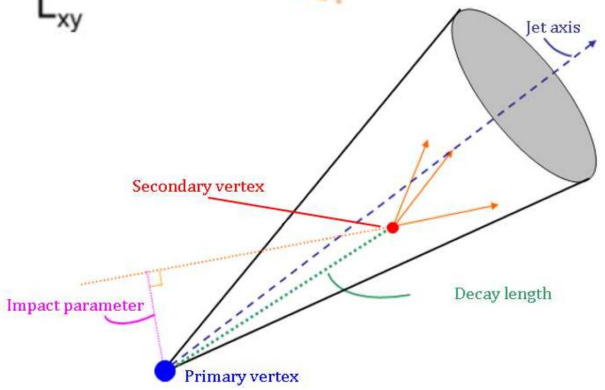


Experimental access to open HF

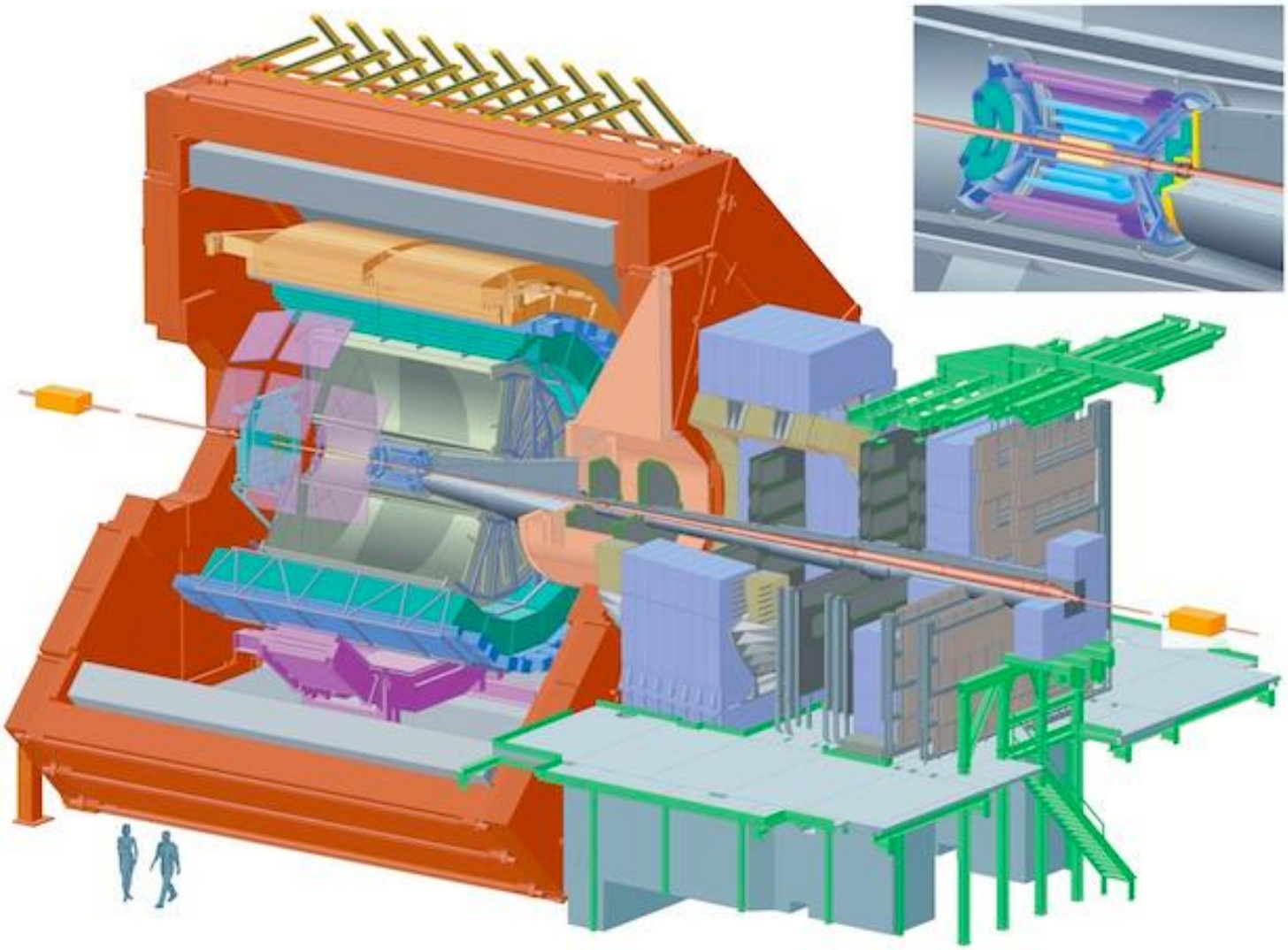
- Indirect semi-leptonic decays
  - Typical signature, higher statistics
  - Inclusive measurement
  - A mixture of c, b contributions (→ separation by displacement)
- Direct reconstruction of hadronic decays
  - Access to kinematics
  - High background (→ secondary vertex)
- Non-prompt J/ψ reconstruction
  - Selective to decays of B hadrons
  - Secondary vertex reconstuction needed
- Full jet reconstruction: D in jets, b-tagging
  - Insight to fragmentation properties
  - Tag via secondary vertex, impact parameter, or via finding a D-meson candidate







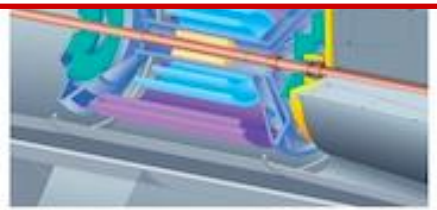
A Large Ion Collider Experiment



A Large Ion Collider Experiment

Central barrel
Acceptance: $|\eta|<0.9$
Magnetic field: $B = 0.5$ T

ITS: charged-particle tracking and ID, vertexing



EMCal: energy, electron ID

TRD: electron identification by transition radiation

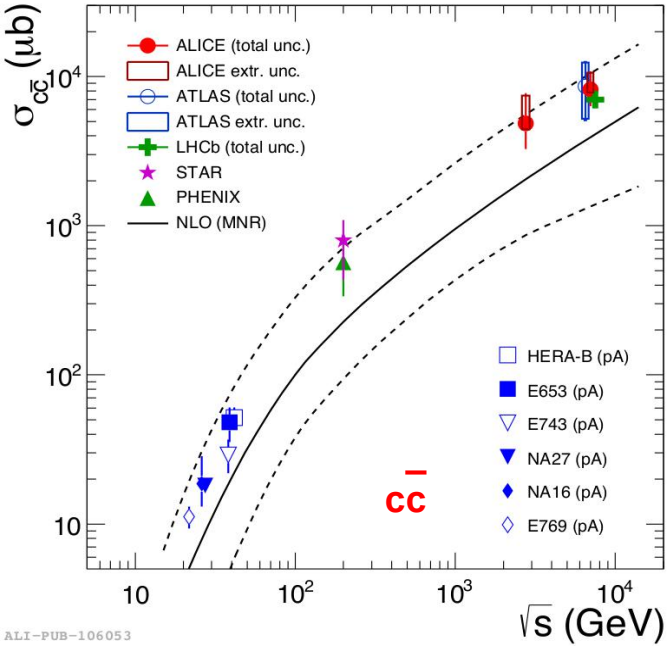
TPC: charged-particle tracking and identification

TOF: charged particle identification by precise time of flight

Muon spectrometer:
Forward: $-4<\eta<-2.5$
muon trigger and tracking

Production in pp: total cross sections

ALICE: PRC 94 (2016) 054908
NLO: NPB 373 (1992) 295

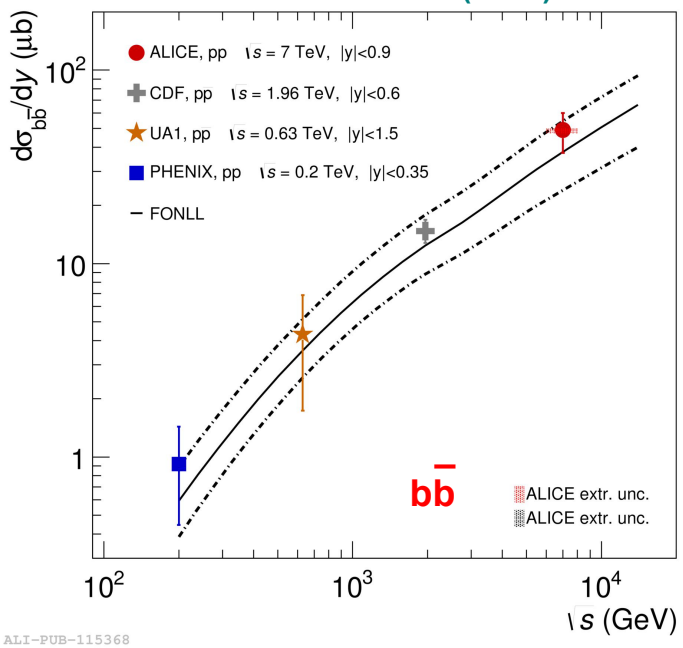


ALICE charm pair production cross section from D⁰ measurements

$$\sigma_{c\bar{c}}(\sqrt{s} = 7 \text{ TeV}) = 8.08^{+2.55}_{-1.04} \text{ mb}$$

arXiv:1702.00766.pdf

ALICE: PLB 738(2014) 97
FONLL: JHEP 1210 (2012) 137



ALICE beauty pair production cross section from heavy-flavour electrons

$$\sigma_{b\bar{b}}(\sqrt{s} = 7 \text{ TeV}) = 383 \pm 120 \ \mu\text{b}$$

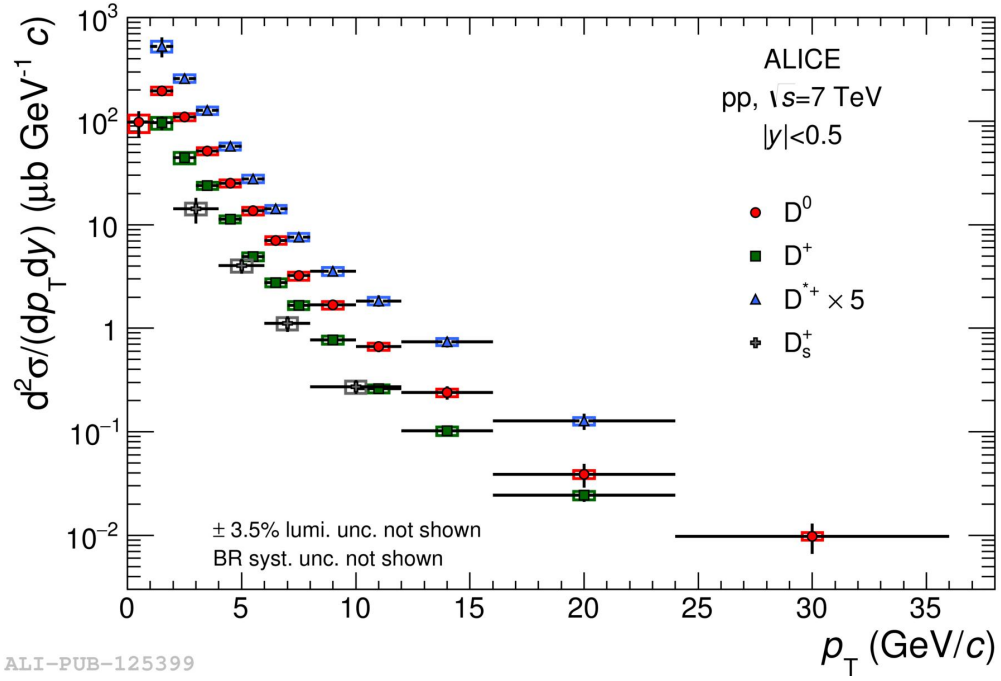
Cross section at several beam energies:

Primary test of models predicting HF production

- ALICE data fit in world data trend
- pQCD gives adequate description (with sizeable uncertanties)

p_T spectrum of D mesons in pp

arXiv:1702.00766



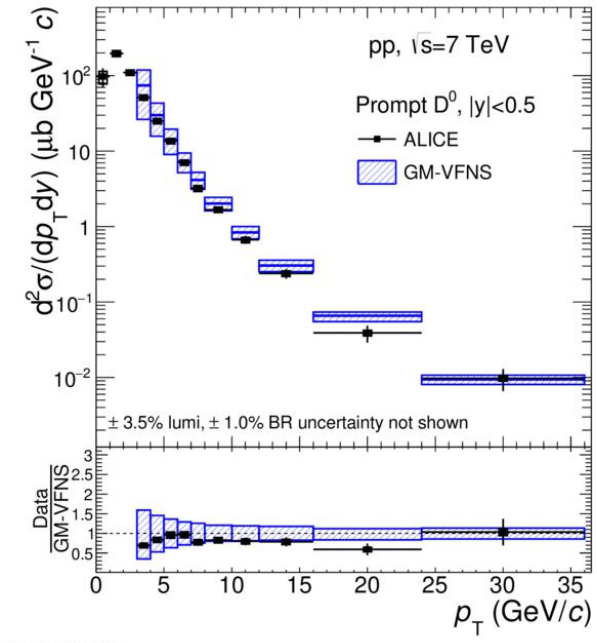
$D^0 \rightarrow K^- \pi^+$	BR ~ 3.9%
$D^{*+} \rightarrow D^0 (\rightarrow K^- \pi^+)\pi^+$	BR ~ 2.6%
$D^+ \rightarrow K^- \pi^+ \pi^+$	BR ~ 9.5%
$D_S^+ \rightarrow \Phi(\rightarrow K^+ K^-)\pi^+$	BR ~ 2.3%

Recent high-precision measurements:
Reference for heavier systems (p-Pb and Pb-Pb)

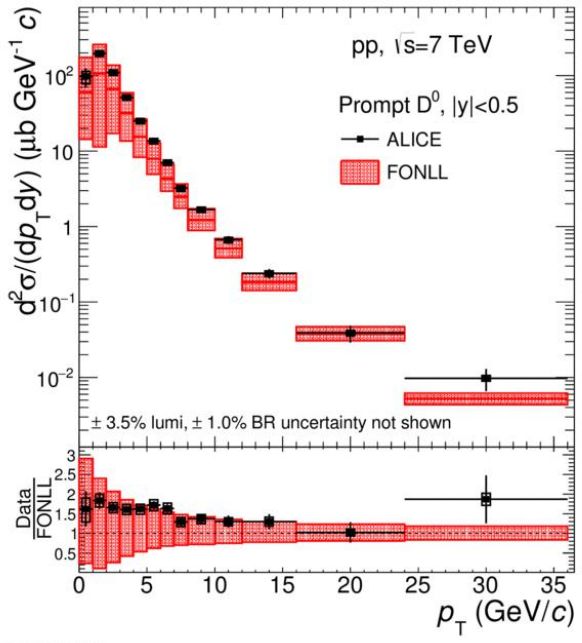
- D^0 at very low p_T (<1 GeV/c): PID only, no vertex reconstruction or topological cuts

p_T spectrum of D^0 vs. models in pp

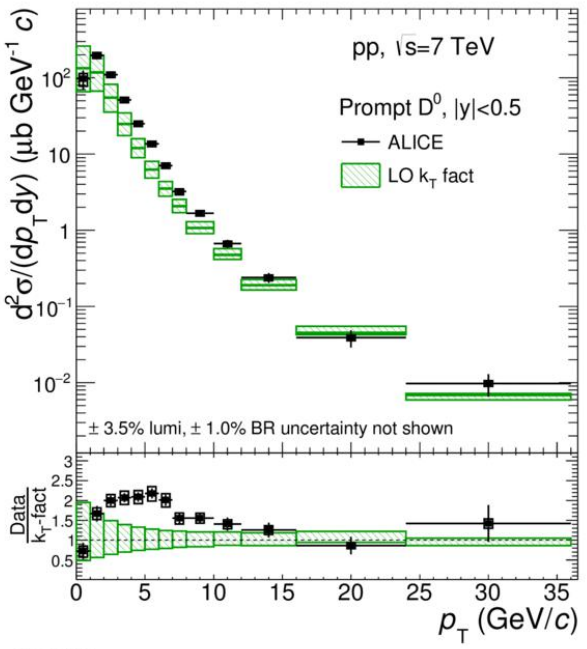
ALICE: arXiv:1702.00766



GM-VFNS: EPJ C72 (2012) 2082



FONLL: JHEP 1210 (2012) 137



LO k_T-fact.: PRD 87 (2013) 094022

Recent high-precision measurements:
Reference for heavier systems (p-Pb and Pb-Pb)

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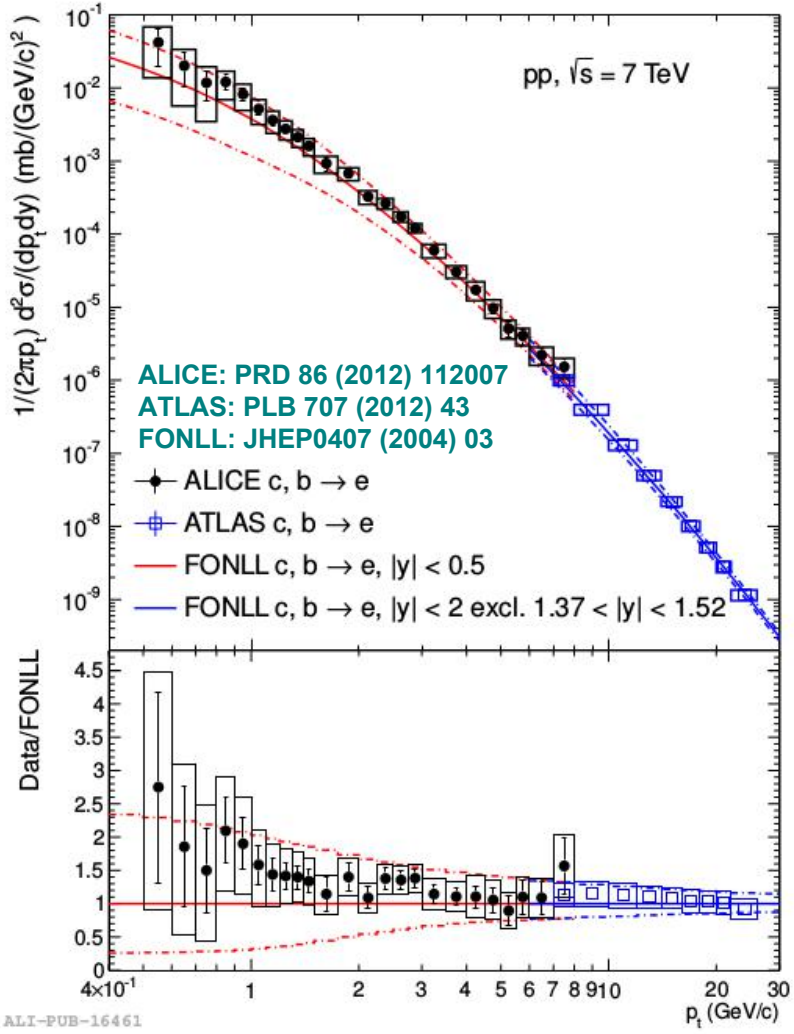
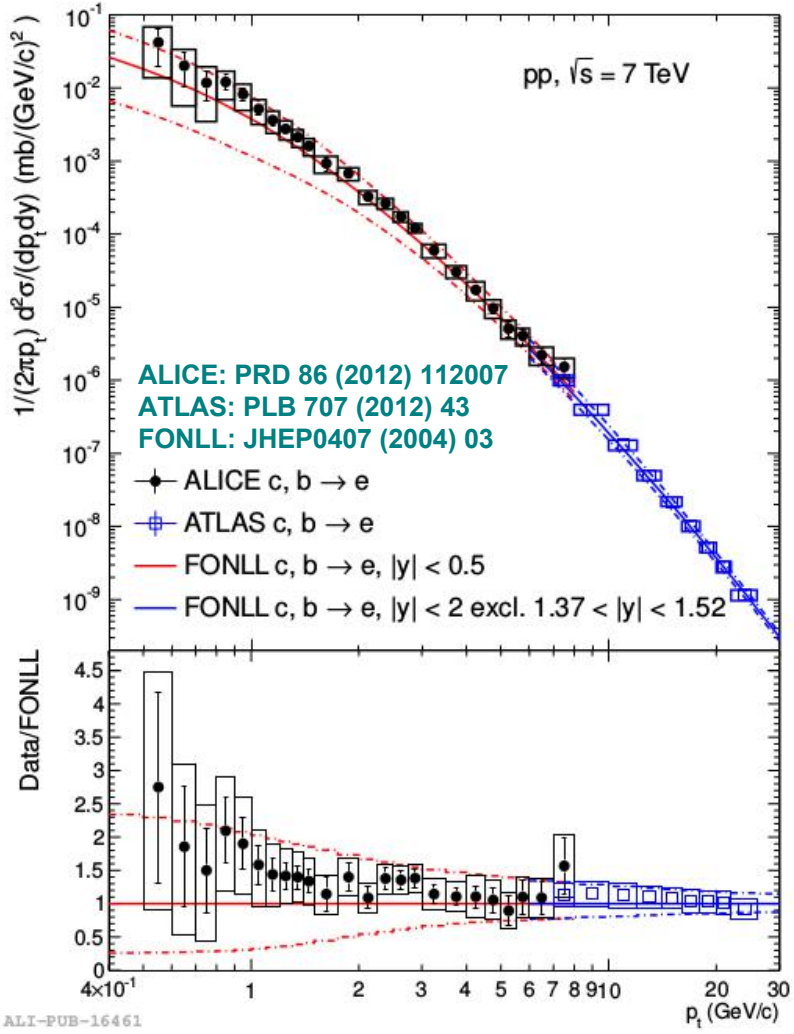
Detailed test of pQCD model predictions

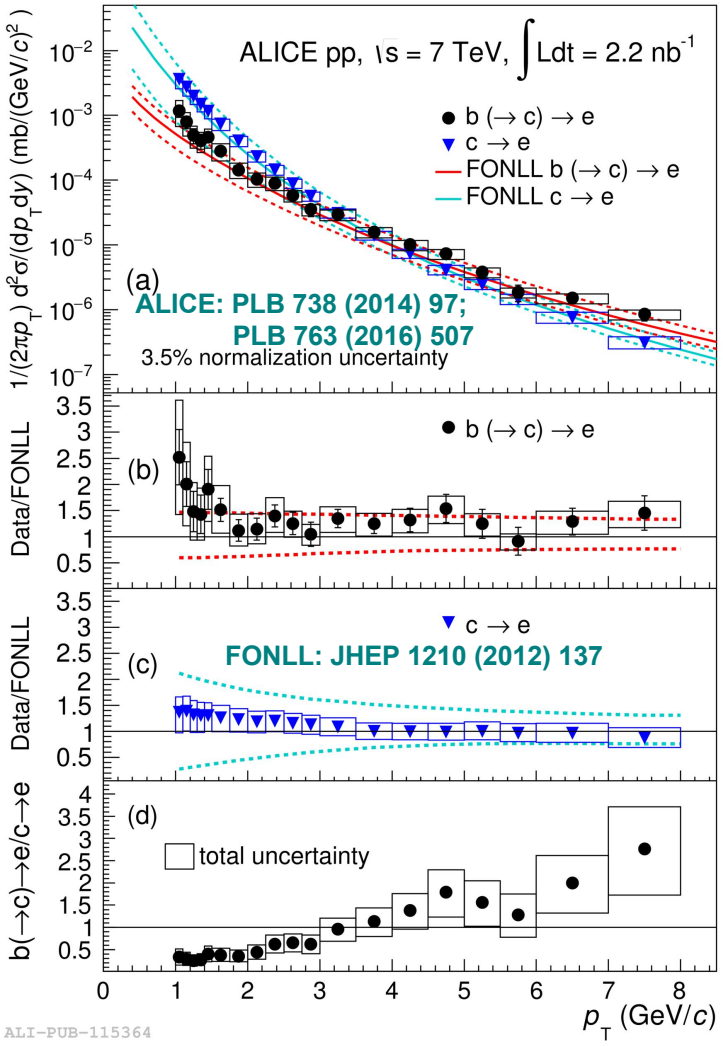
Heavy-flavor electrons in pp



- FONLL pQCD provides good description over a wide p_T range

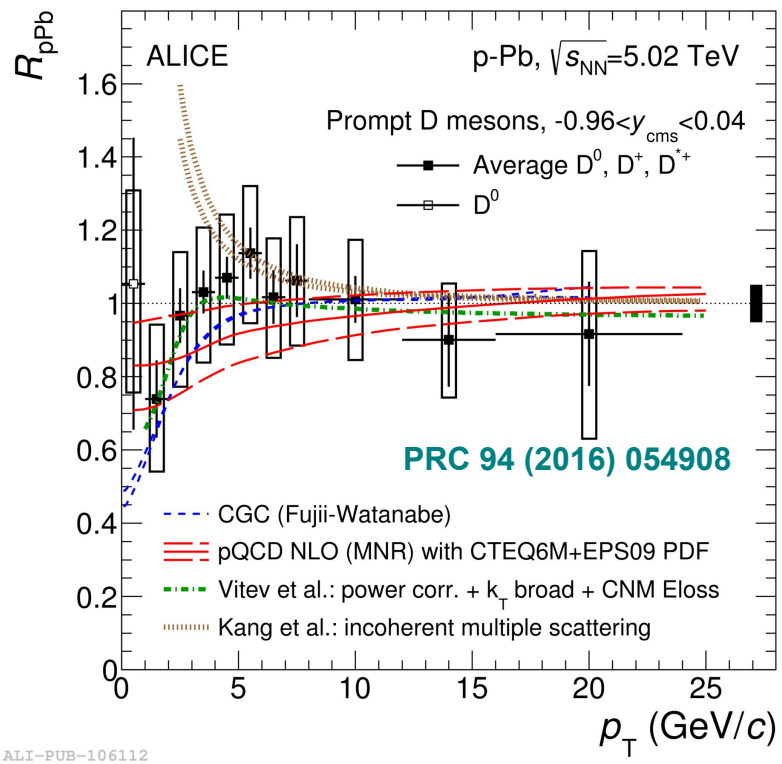
HF electrons: beauty and charm





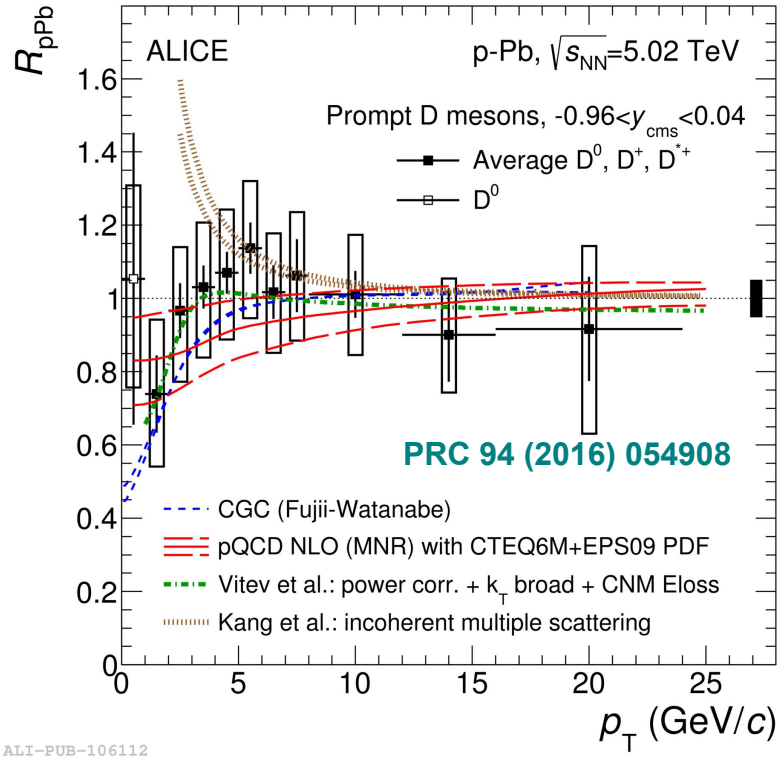
- FONLL pQCD provides good description over a wide p_T range
- Both for beauty and charm

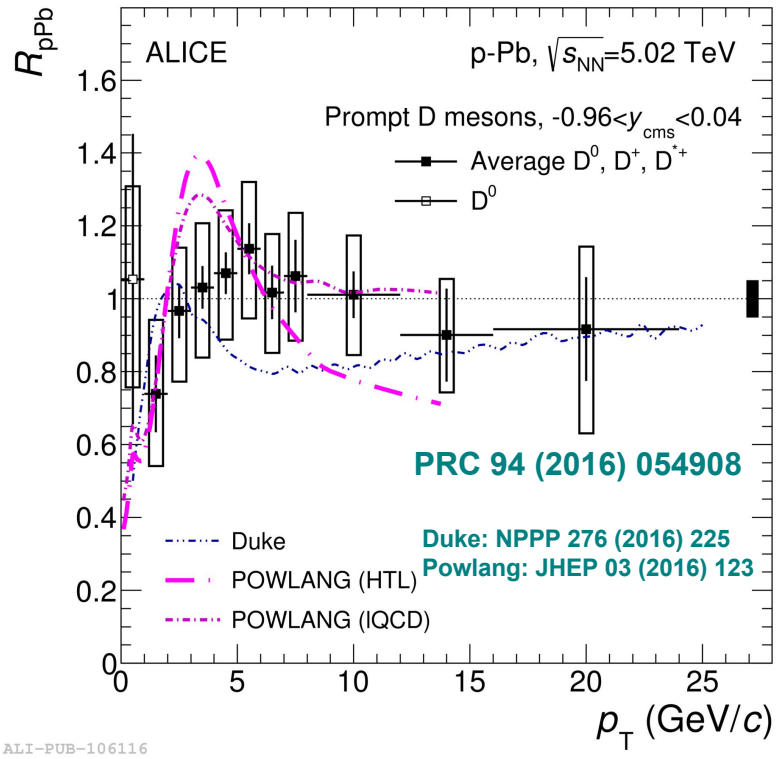
D mesons in p-Pb collisions



- **D-meson production in p-Pb collisions:**
  - **No modification w.r.t. pp collisions within uncertainties**
  - No indication of CNM effects from intermediate to high p_T
  - Data described by several models containing CNM effects

D mesons in p-Pb collisions





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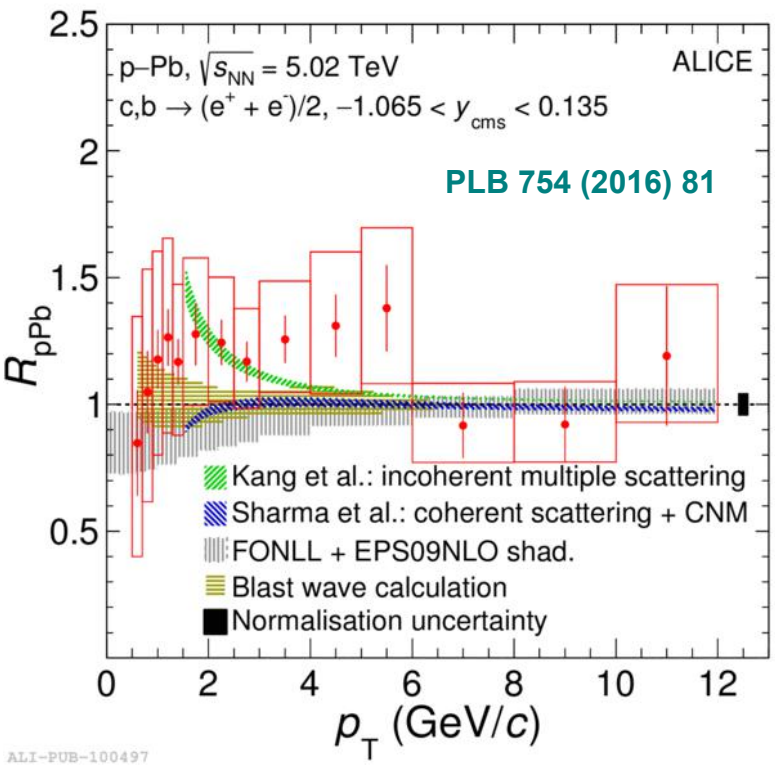
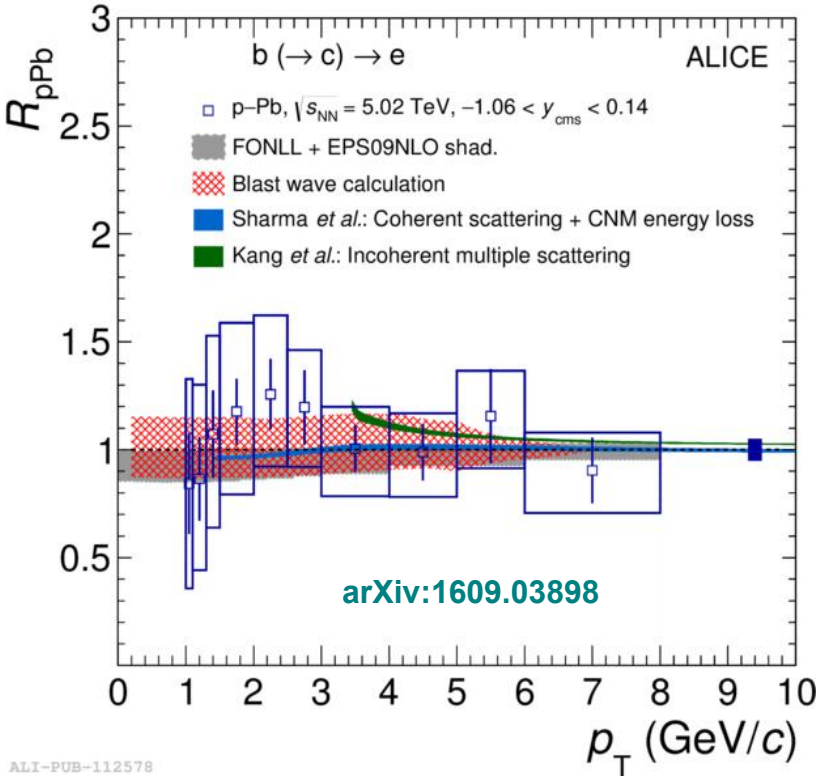
  - Data described by several models containing CNM effects
- Models including small-volume QGP formation also describe data

HF electrons: Charm and Beauty

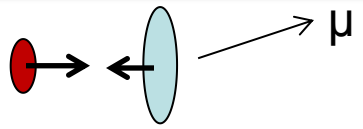




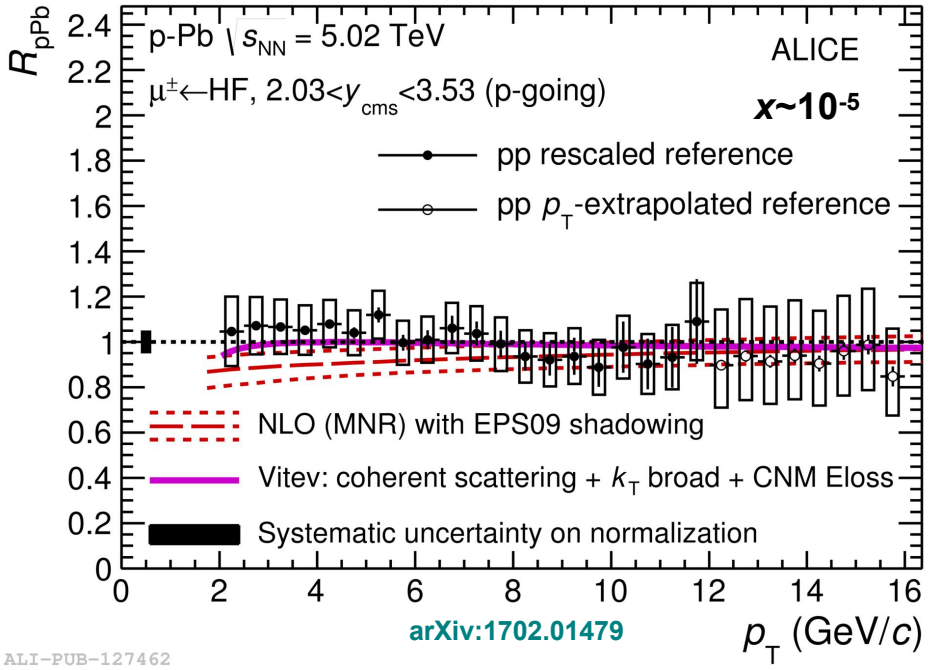
- **HF decay electrons (charm+beauty)** and **separated beauty electrons** both consistent with no modification in p-Pb coll. in the whole p_T range
- Several models describe the data within uncertainties

  → increased precision from Run 2 will be essential

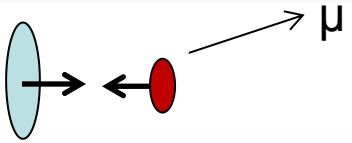
Muons: Forward and backward



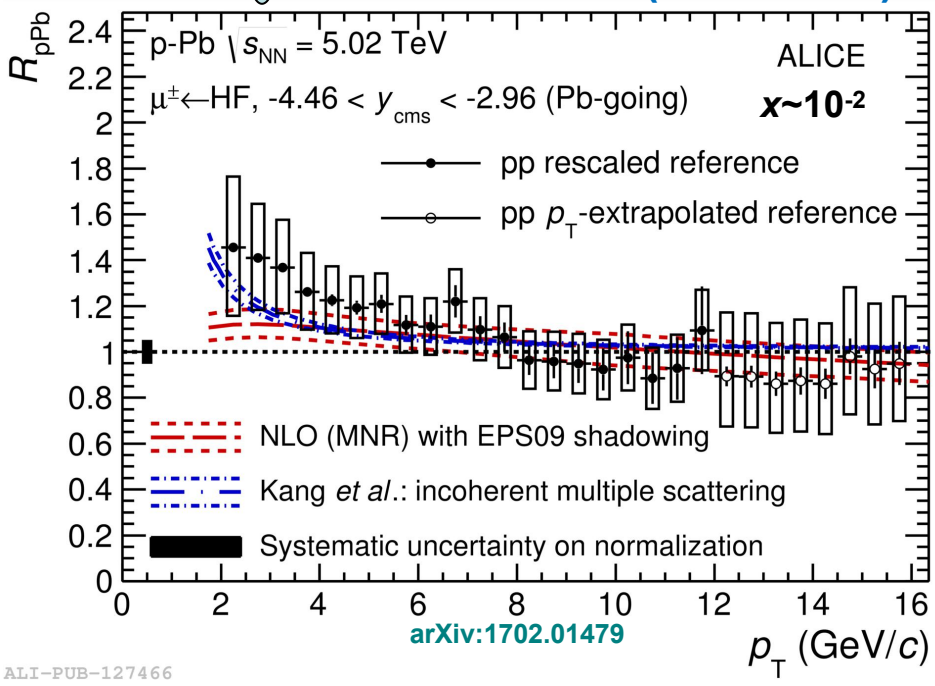
p-going (forward)



ALI-PUB-127462



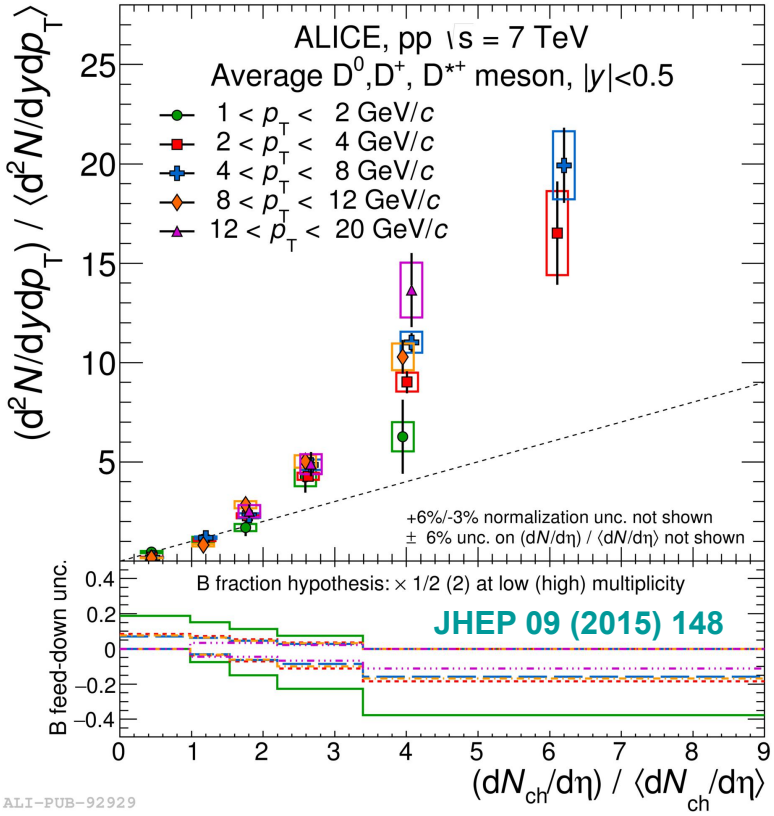
Pb-going (backward)



ALI-PUB-127466

- Heavy-flavour decay muons probe the nPDFs at different *x* values
- Forward production is consistent with no nuclear modification
- **Hint of an enhancement of HF muons at backward rapidity at low p_T**
- Measurements described by models within uncertainties

D meson yields vs. multiplicity (pp)



- Production of **D mesons** increases steeper than linear with multiplicity

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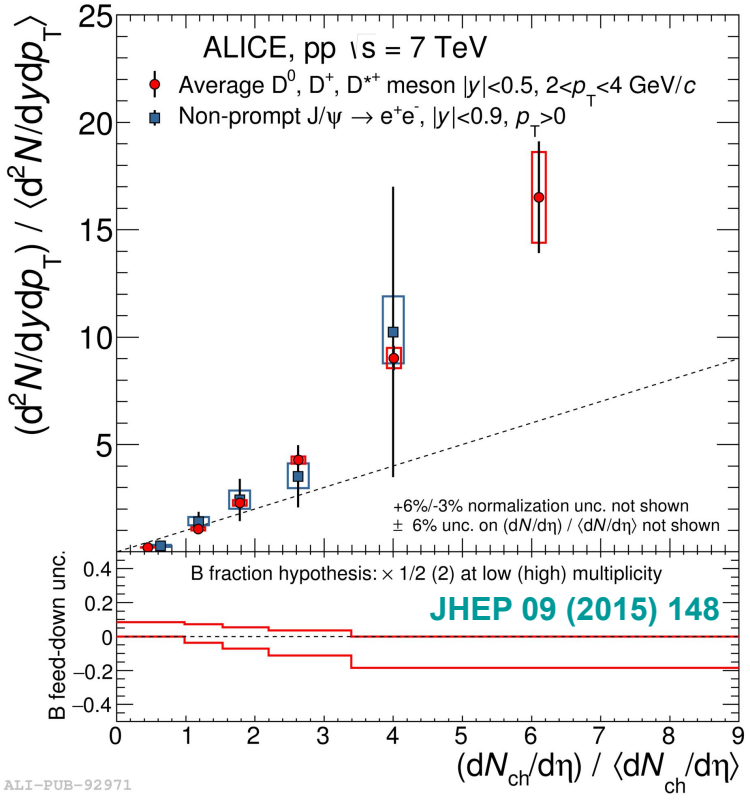
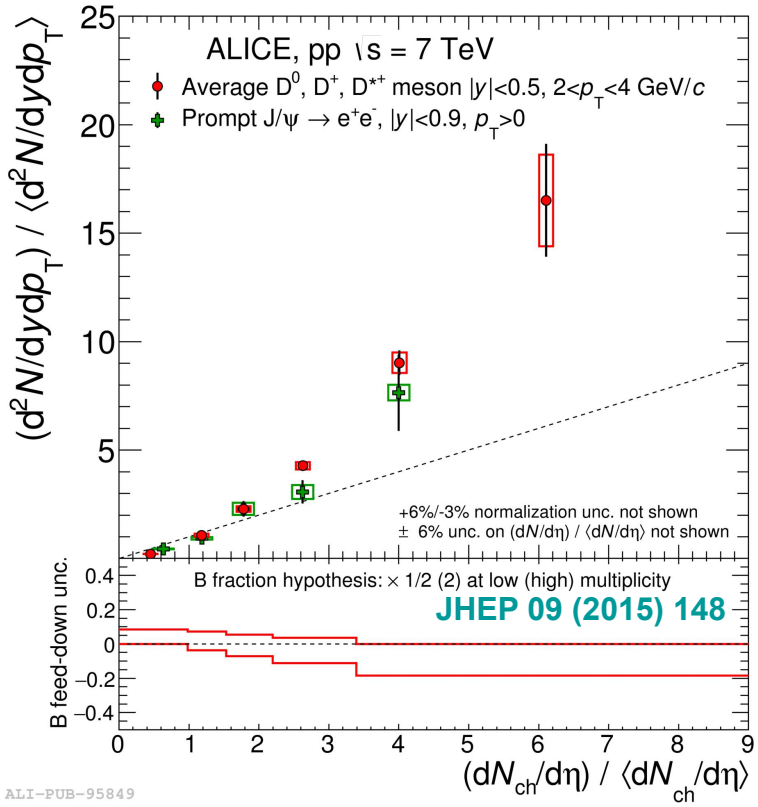


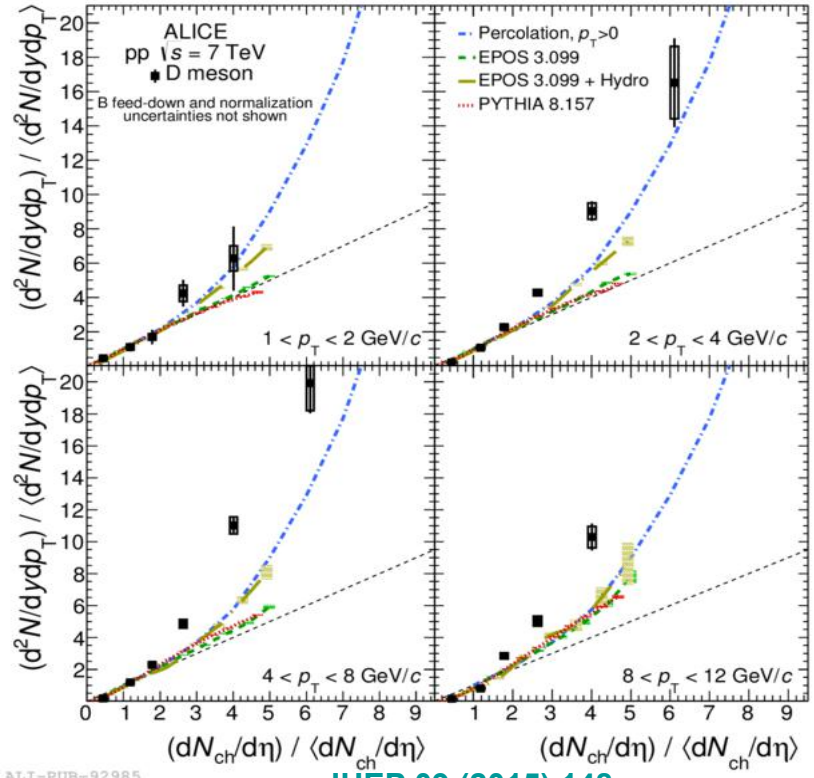


- Production of **D mesons** increases steeper than linear with multiplicity
- Same trend for **non-prompt (B→)J/Ψ** as well as **prompt J/Ψ** yields

  → No strong flavour dependence

  → Enhancement is likely to be related to $c\bar{c}$, $b\bar{b}$ production processes, is not strongly influenced by hadronisation

Yields vs. multiplicity: models (pp)



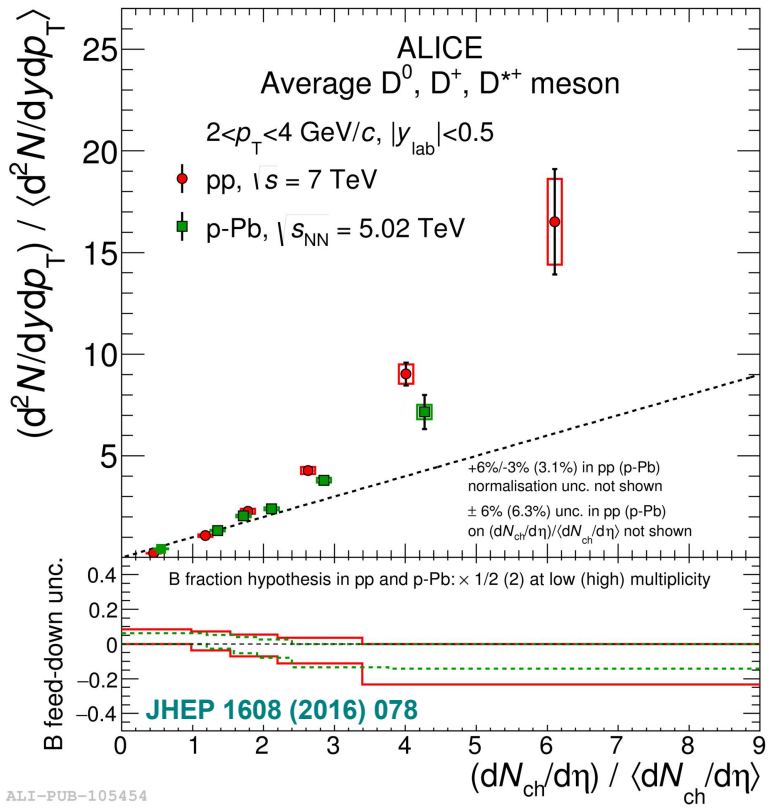
JHEP 09 (2015) 148

- **Percolation model** - PRC 86 (2012) 034903
  - Target-projectile color exchange (scenario similar to MPI)
  - Steeper-than-linear increase
- **EPOS 3.099+Hydro** - PRC 89 (2014) 064903
  - Gribov-Regge formalism
  - MPI linked to multiplicity
  - Steeper-than-linear increase with hydro
- **PYTHIA8** - Comp.Phys.Commun. 178 (2008) 852
  - SoftQCD with color reconnections
  - MPI
  - initial and final state gluon radiation
  - linear increase

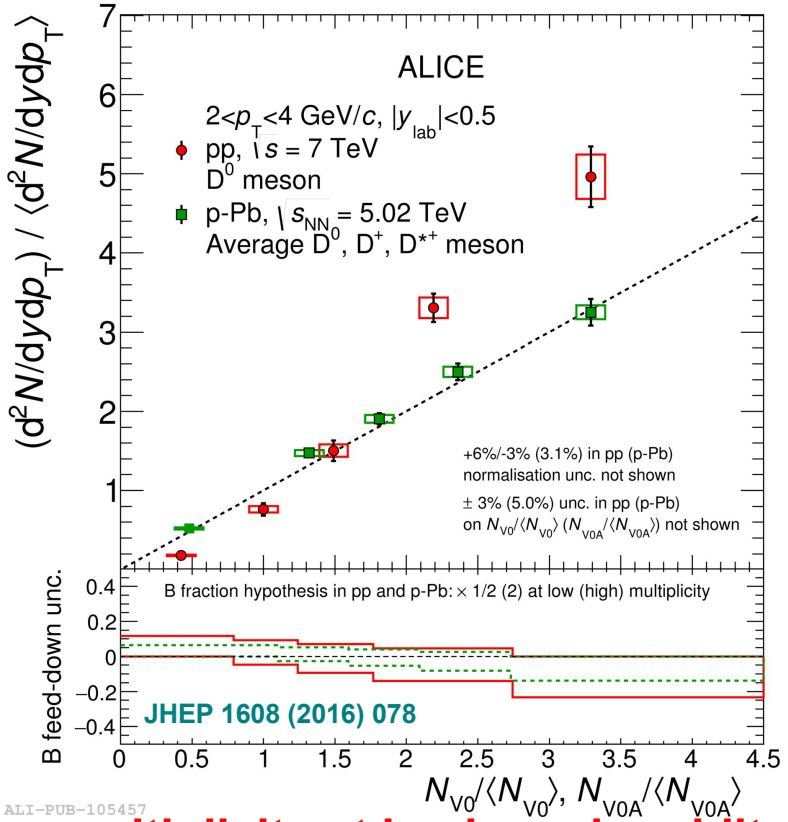
- Production of D mesons increases steeper than linear with multiplicity
- Same trend for non-prompt (B→)J/Ψ as well as prompt J/Ψ yields

- **Models with multiple parton interactions (MPI) also expect stronger-than-linear increase**

D production vs. multiplicity in p-Pb



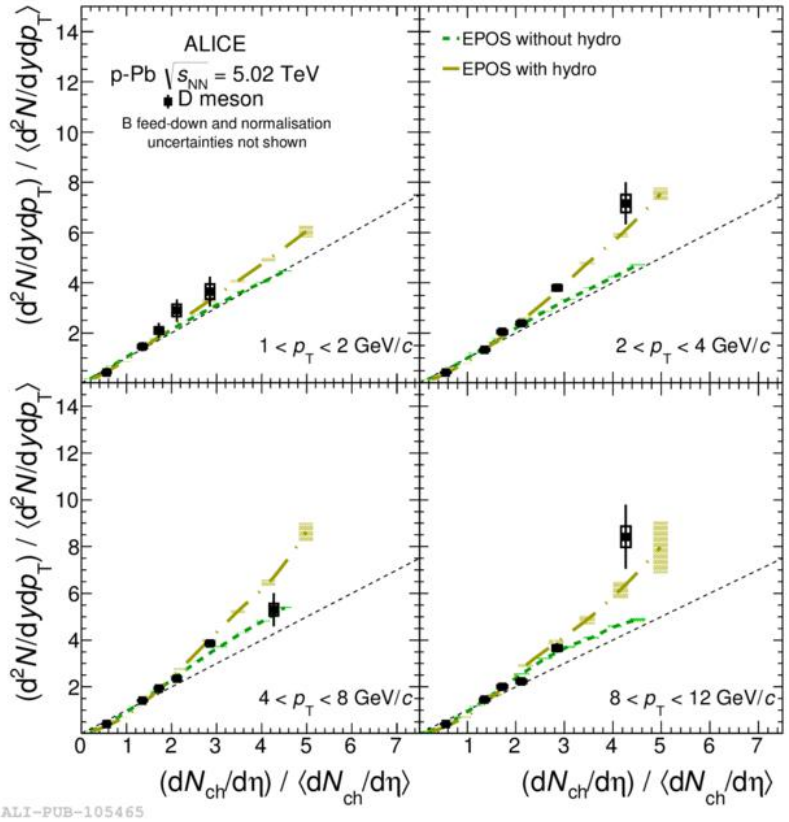
multiplicity at mid-rapidity



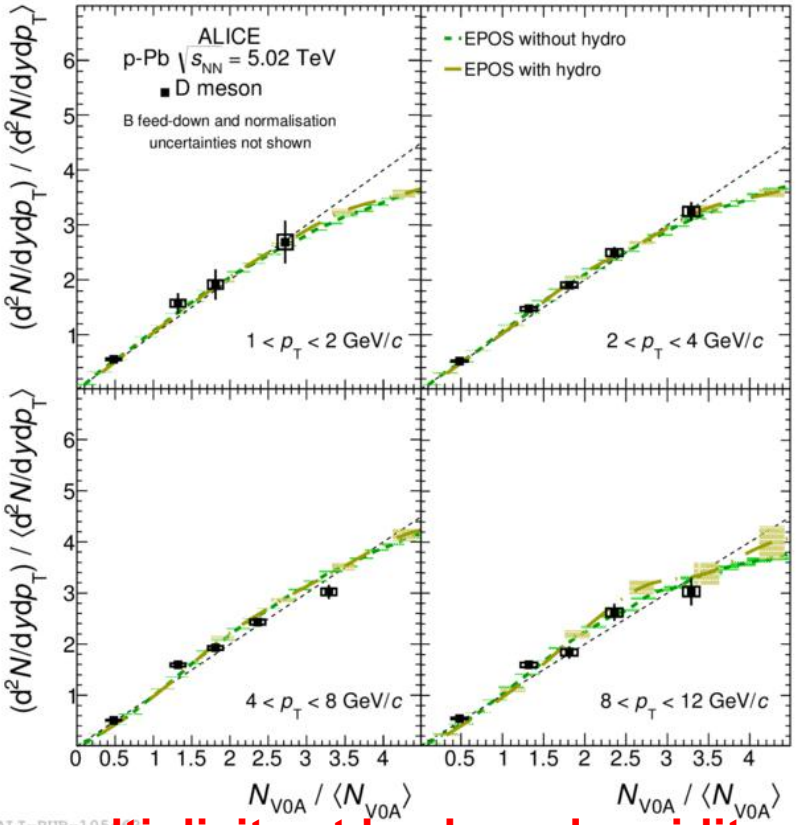
multiplicity at backward rapidity (Pb-going): test auto-correlations

- Multiplicity at mid-rapidity: similar enhancement in p-Pb and pp collisions
- Multiplicity at backward rapidity: linear-like, less rapid increase in p-Pb coll.
  - Contribution of multiple nucleon-nucleon interactions
  - *Note: different pseudo-rapidity range in pp and p-Pb collisions*

Yields vs. multiplicity in p-Pb: models



multiplicity at mid-rapidity



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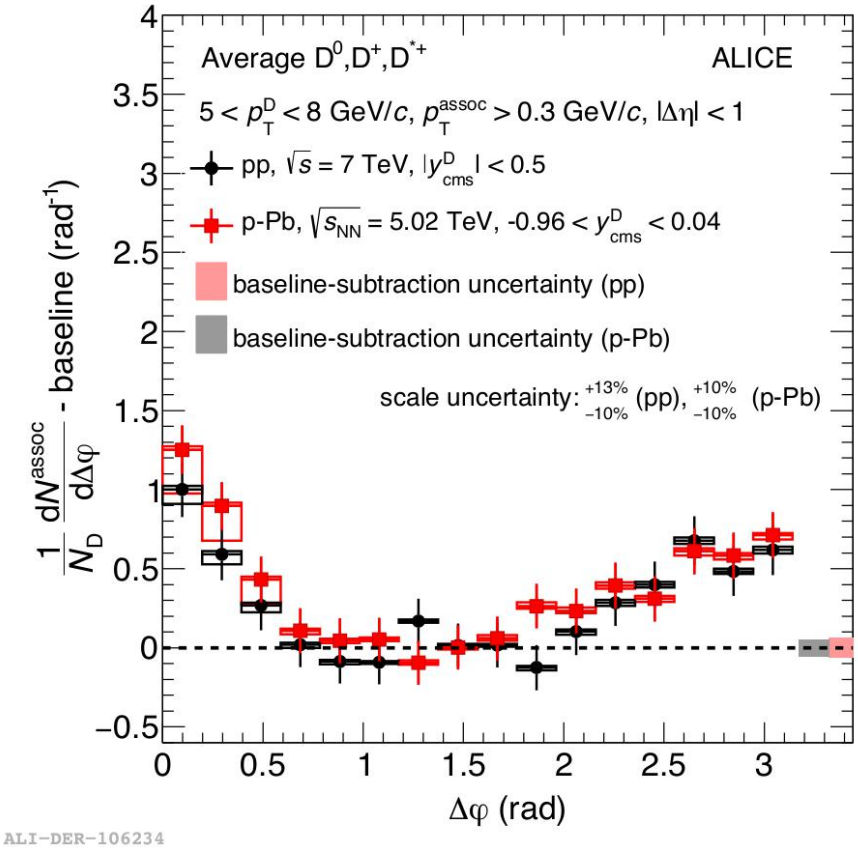
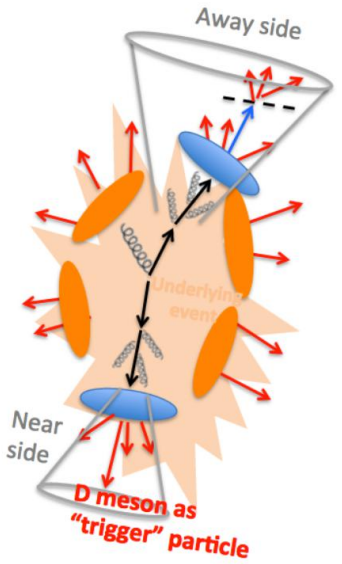
- Multiplicity at mid-rapidity: similar enhancement in p-Pb and pp collisions
- Multiplicity at backward rapidity: linear-like, less rapid increase in p-Pb coll.
- **EPOS with hydro** evolution: qualitatively good description in both cases

D-h azimuthal correlations

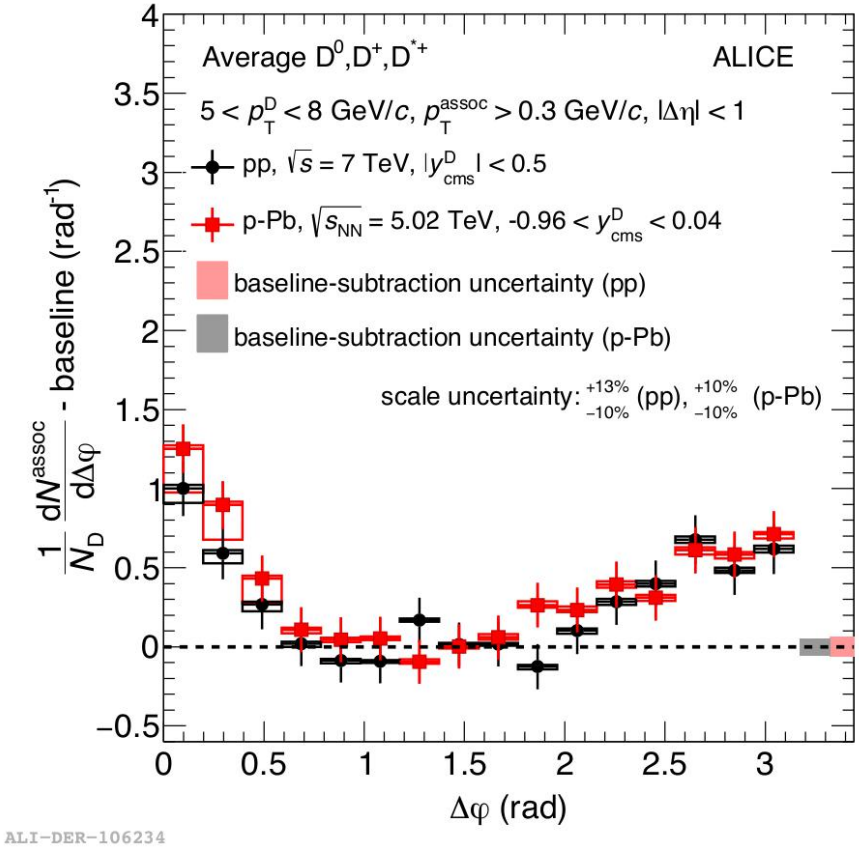


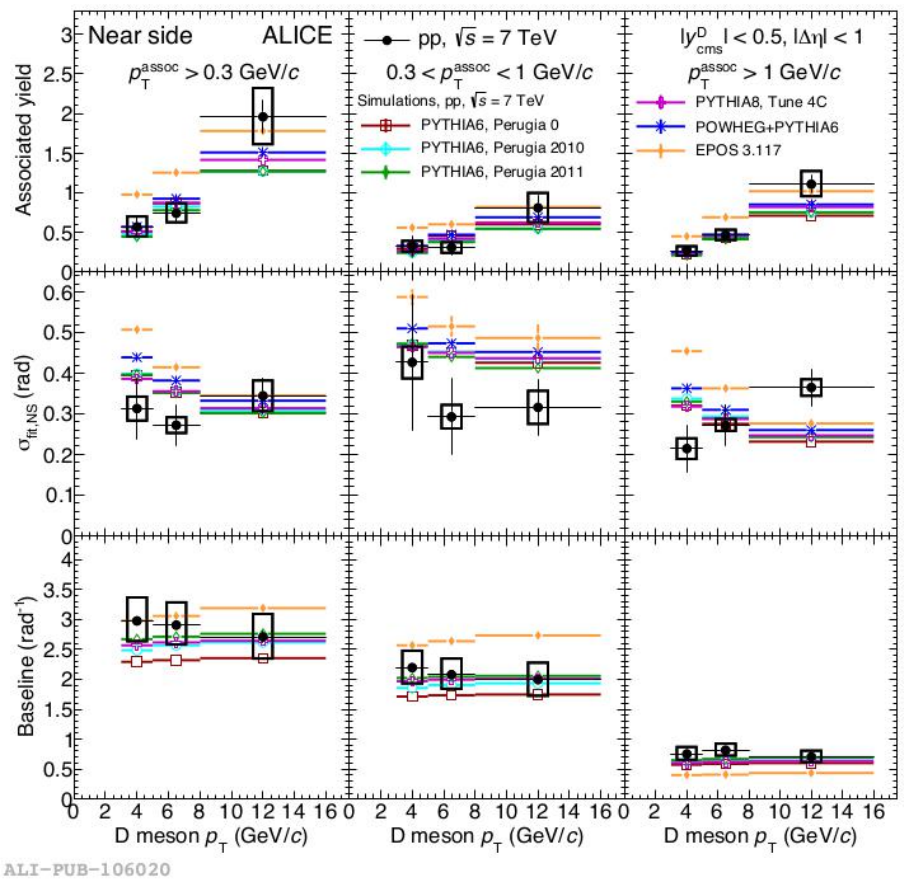


Charged hadron – D-meson correlations in azimuthal angle

- No significant difference between correlations in **p-Pb** and **pp** collisions after baseline subtraction

D-h azimuthal correlations





Charged hadron — D-meson correlations in azimuthal angle

- No significant difference between correlations in **p-Pb** and **pp** collisions after baseline subtraction
- Near side peak fit parameters (yield, width, baseline) typically described by simulations (PYTHIA8, POWHEG+PY6, EPOS3.117) within uncertainties

Summary and outlook

pp collisions, $\sqrt{s}$=7 TeV: adequate understanding with pQCD models

p-Pb collisions, $\sqrt{s_{NN}}$=5.02 TeV: **Nuclear modification is moderate**

- Hint of nuclear modification of HF muons in the backward direction
- Whether matter in p-Pb collisons is entirely cold still remains a question

HF production vs. multiplicity: Steeper-than-linear increase

- Qualitatively expected by models with MPI and hydrodinamical effects

D-h correlations

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- Data reproduced by models within uncertainties

LHC in Run 2: a real heavy-flavour factory!

pp collisions with higher luminosity at $\sqrt{s}$=5 to 13 TeV

p-Pb: Already 6x Run 1 stats at $\sqrt{s_{NN}}$=5.02 TeV, new data at $\sqrt{s_{NN}}$=8.16 TeV

- Higher precision: smaller uncertainities, greater model selectivity
- New measurements: HF fragmentation with b- and D jets

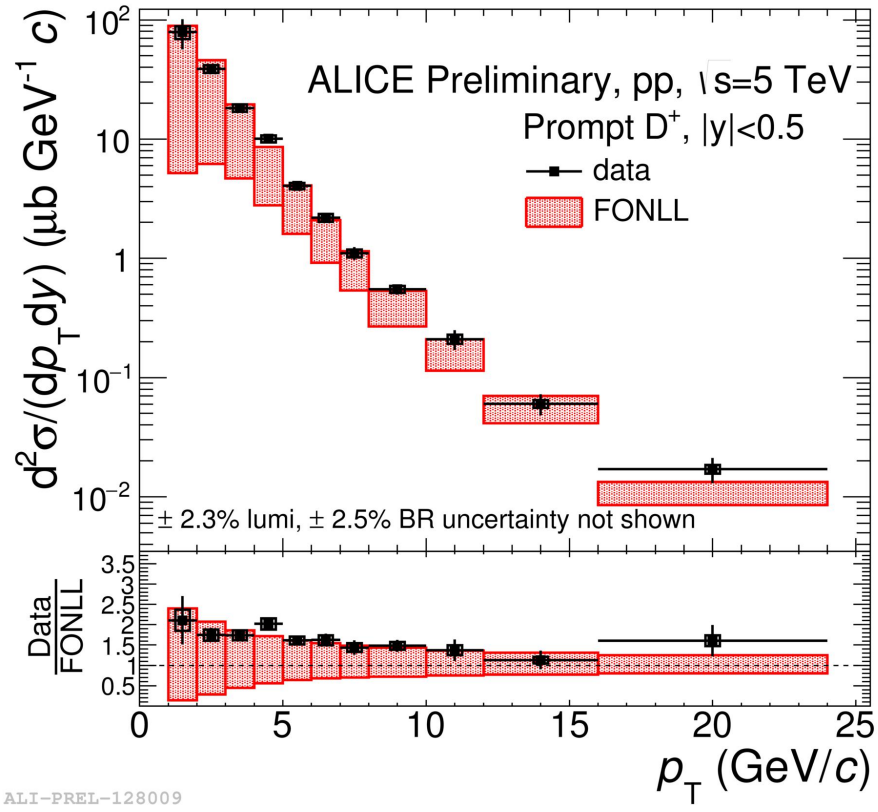
Run 3 upgrades: ITS, TPC, readout, Muon Forward Tracker

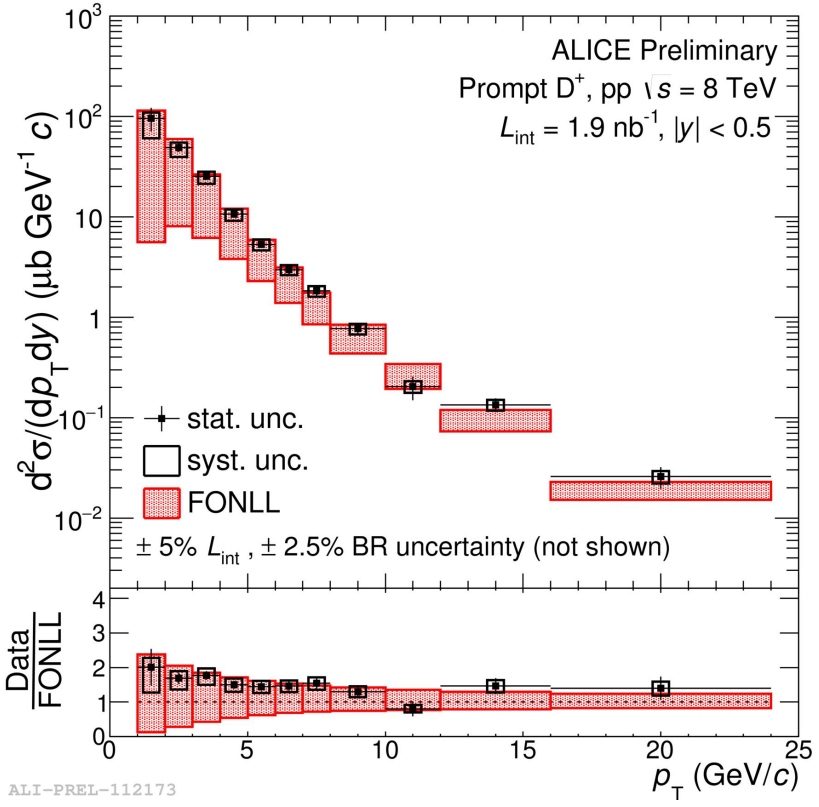
- Goal: ~100x statistics gain w.r.t. Run 1 + Run 2.


Thank you!
Slides
Longboats
Backup

Run 2 D^+ in 5-TeV and 8-TeV pp

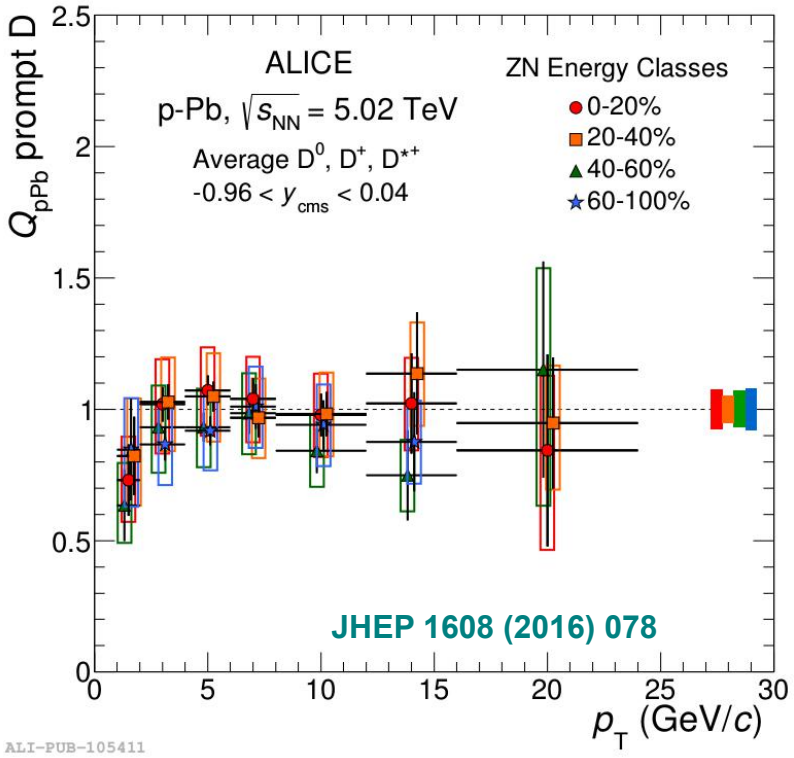
New Run-2 5-TeV and 8-TeV dataset!





- Higher luminosity (~6x at 5 TeV)
- Wider coverage of the √s scale
- Higher precision, better reference

D mesons in p-Pb collisions



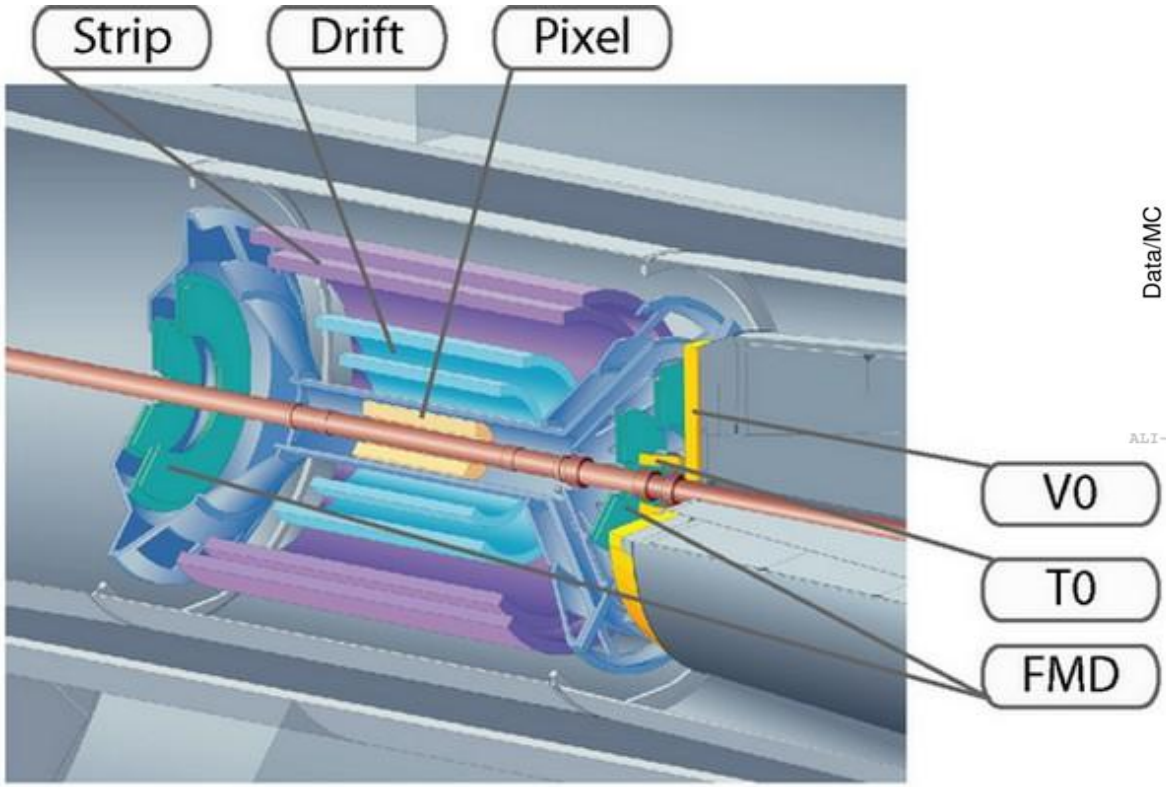
- Q_{pPb} : centrality-dependent nuclear modification factor (~R_{pPb})
- Centrality estimation based on zero-degree neutron calorimeter

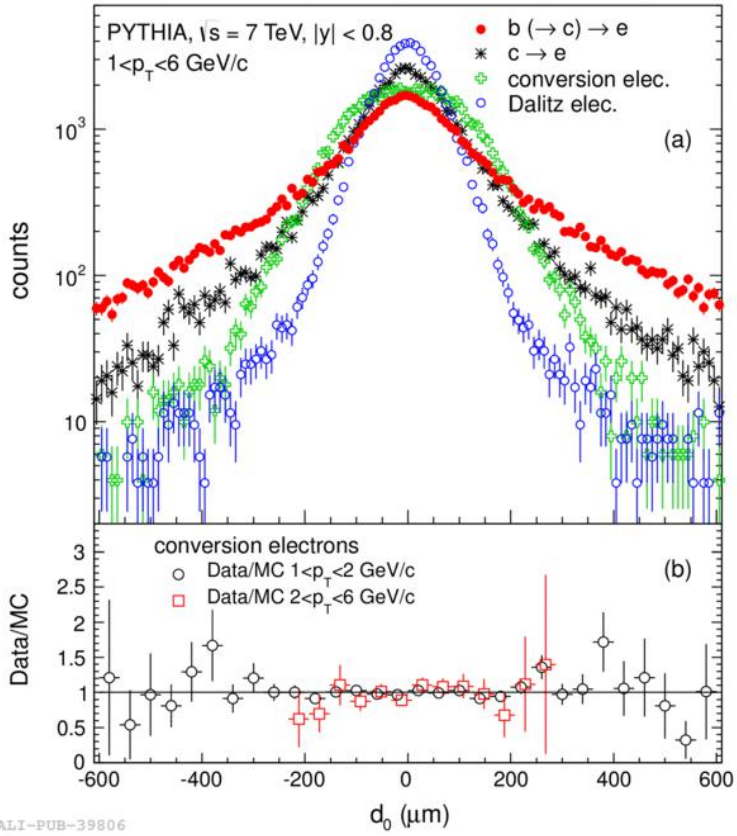
- No multiplicity dependent modification of D-meson production relative to pp collisions within uncertainties

Inner Tracking System

- Semiconducting technology
- Resolves secondary vertex

heavy quark lifetimes: $c\tau(D) \sim 100\text{-}300\ \mu m$
$c\tau(B) \sim 400\text{-}500\ \mu m$
Secondary vertex resolution: $<100\ \mu m$





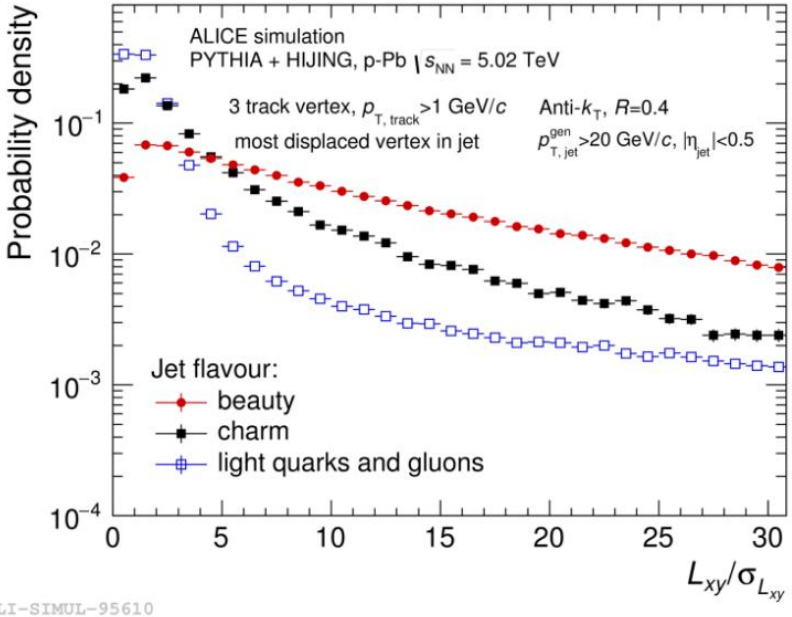
PLB 721 (2013) 13

Physics reach after LS2 (2019-20)

Observable	Current, 0.1 nb^{-1}		Upgrade, 10 nb^{-1}	
	$p_{\mathrm{T}}^{\mathrm{min}}$ (GeV/c)	statistical uncertainty	$p_{\mathrm{T}}^{\mathrm{min}}$ (GeV/c)	statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 %	0	0.3 %
$\mathrm{D_s}$ meson R_{AA}	4	15 %	< 2	3 %
D meson from B R_{AA}	3	30 %	2	1 %
J/ψ from B R_{AA}	1.5	15 % (p_{T}-int.)	1	5 %
B^+ yield	not accessible		3	10 %
Λ_{c} R_{AA}	not accessible		2	15 %
$\Lambda_{\mathrm{c}}/\mathrm{D}^0$ ratio	not accessible		2	15 %
Λ_{b} yield	not accessible		7	20 %
D meson v_2 ($v_2 = 0.2$)	1	10 %	0	0.2 %
$\mathrm{D_s}$ meson v_2 ($v_2 = 0.2$)	not accessible		< 2	8 %
D from B v_2 ($v_2 = 0.05$)	not accessible		2	8 %
J/ψ from B v_2 ($v_2 = 0.05$)	not accessible		1	60 %
Λ_{c} v_2 ($v_2 = 0.15$)	not accessible		3	20 %
Dielectrons				
Temperature (intermediate mass)	not accessible			10 %
Elliptic flow ($v_2 = 0.1$) [4]	not accessible			10 %
Low-mass spectral function [4]	not accessible		0.3	20 %
Hypernuclei				
${}^{3}_{\Lambda}\mathrm{H}$ yield	2	18 %	2	1.7 %

ALICE ITS upgrade TDR

b-jet tagging performance



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