Open heavy flavour and quarkonium results in pp/p-A/AA collisions in ALICE

Elena Bruna (INFN Torino)

for the ALICE Collaboration

The figures in slides 23, 33, 34 have been updated due to a normalisation problem that was discovered after the conference.
The physics message is unchanged.

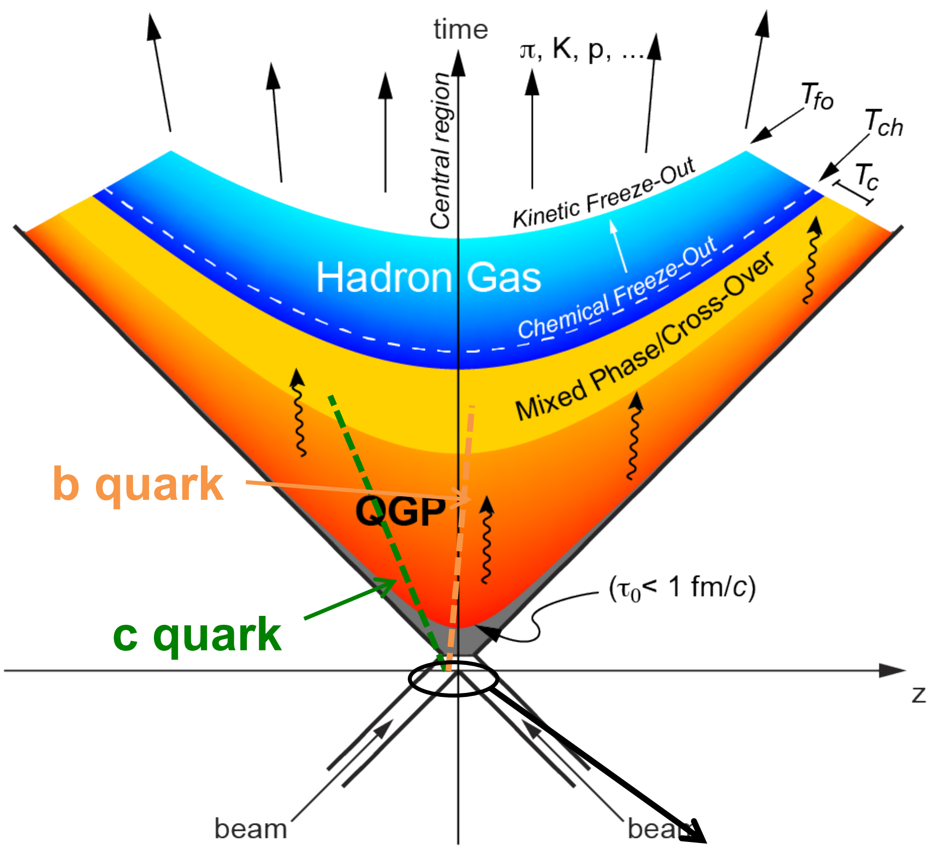
QCD challenges in pp, pA and AA collisions at high energies

ECT* Trento, Feb 27 - March 3 2017

Heavy Flavours: unique probes

- Produced in initial high-Q^2 processes → calculable with pQCD
- Large mass → short formation time → experience medium evolution

  $1/2m_c$ (~0.07 fm/c) < QGP formation time (~0.1-1fm/c) << QGP life time (10 fm/c)
- Expected small rate of thermal production in the QGP ($m_{c,b} >> T$)



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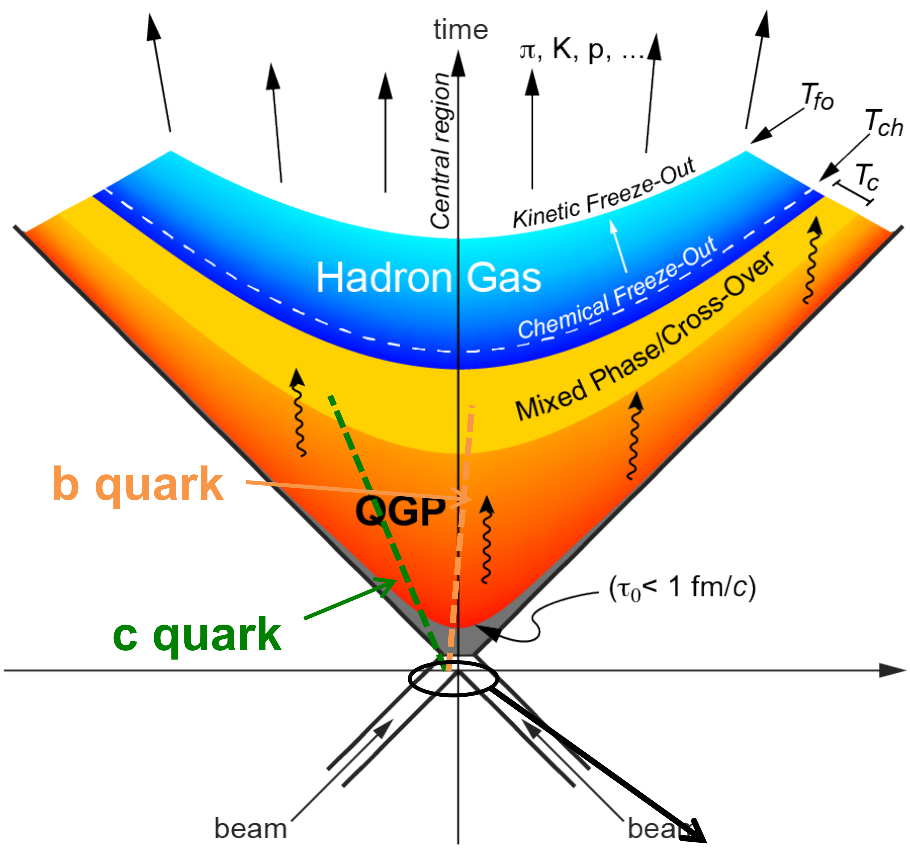


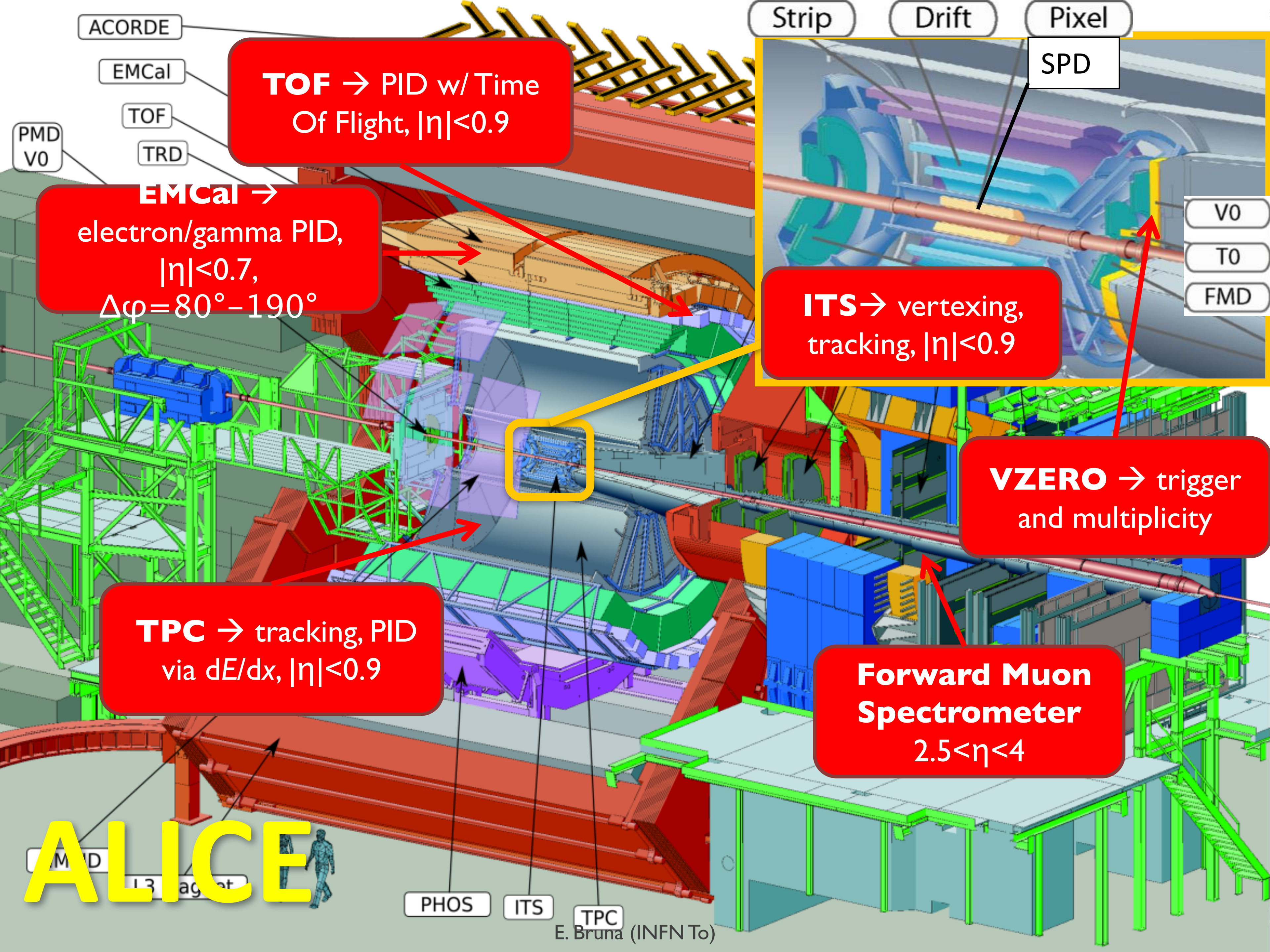
Collision evolution stages probed by heavy quarks:

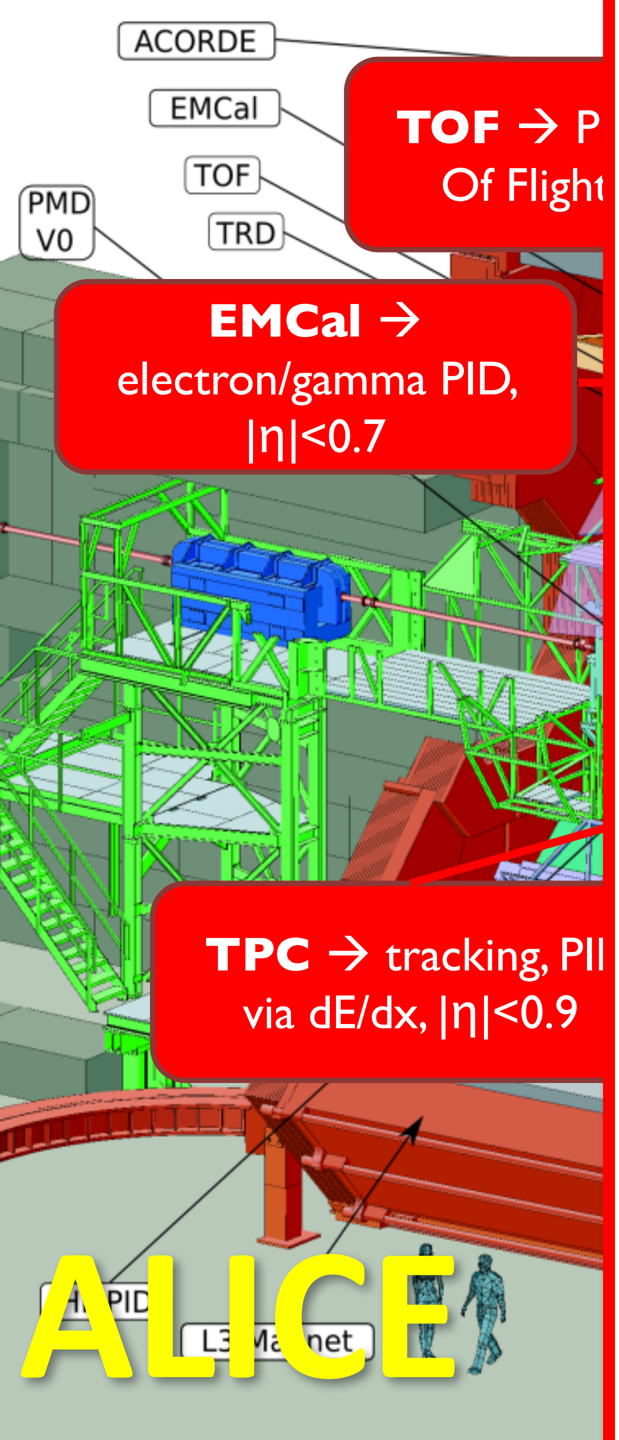
Initial stages:
- test pQCD
- probe nPDF

QGP/partonic phase:
- energy loss: radiative and collisional
- collectivity
- quarkonium melting and (re)generation

Hadronization:
- fragmentation
- recombination

Different collision systems to gain insight in these evolution stages !


ACORDE
EMCal
TOF
PMD
V0
TRD
TOF → PID w/ Time Of Flight, |η|<0.9
EMCal → electron/gamma PID, |η|<0.7, Δφ=80°–190°
Strip
Drift
Pixel
SPD
V0
T0
FMD
ITS→ vertexing, tracking, |η|<0.9
VZERO → trigger and multiplicity
TPC → tracking, PID via dE/dx, |η|<0.9
Forward Muon Spectrometer 2.5<η<4
ALICE
PHOS
ITS
TPC
E. Bruna (INFN To)



pp collisions

$\sqrt{s}$ = 7 TeV: ~3x10^8 events collected in 2010, L_{int}~6 nb^{-1}
$\sqrt{s}$ = 2.76 TeV: ~50x10^6 events collected in 2011, L_{int}~0.9 nb^{-1}
$\sqrt{s}$ = 5 TeV: ~10^8 events collected in 2015, L_{int}~2 nb^{-1}
Min. bias trigger: V0 and SPD
Min. bias + muon trigger (forward)

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

~ **10^8** events collected in 2013, L_{int}~48 μb^{-1}
Min. bias trigger: V0
E_p=4 TeV, E_{Pb}=(208)x1.58 TeV, $\sqrt{s_{NN}}$ = 5.02 TeV
y_{cms}=0.465 (in proton direction)
Min. bias + muon trigger (forward, L_{int}~5 nb^{-1}(p-Pb),
L_{int}~5.8 nb^{-1} (Pb-p))

p-Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

Muon trigger (2016): L_{int}~8.7 nb^{-1} (p-Pb), : L_{int}~12.9 nb^{-1} (Pb-p)

Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

~ **16x10^6** central (0-10%) events in 2011, L_{int}~21 μb^{-1}
~ **18x10^6** semi-central (10-50%) events in 2011, L_{int} ~ 6 μb^{-1}
Min. bias + central trigger: V0
Min. bias + muon trigger (forward, L_{int}~70 μb^{-1})
~ **5x10^6** peripheral (50-80%) in 2010, L_{int}~2 μb^{-1}

Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

~ **150x10^6** events (~**24x10^6** in 30-50%) in 2015
Min. bias: V0
Min. bias + muon trigger (forward, L_{int}~225 μb^{-1})

Heavy flavours with ALICE

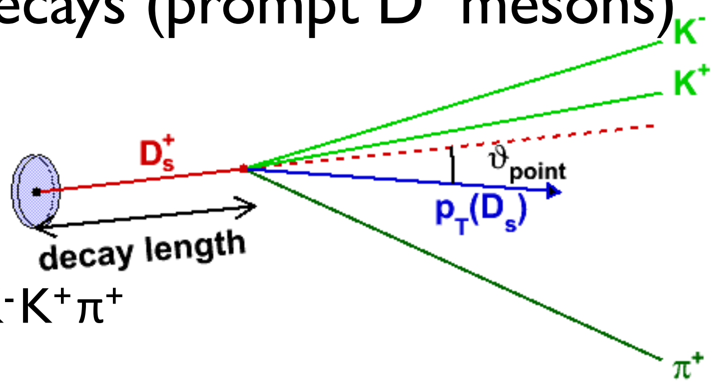
Full reconstruction of D-meson hadronic decays (prompt D mesons)

$D^0 \rightarrow K^-\pi^+$

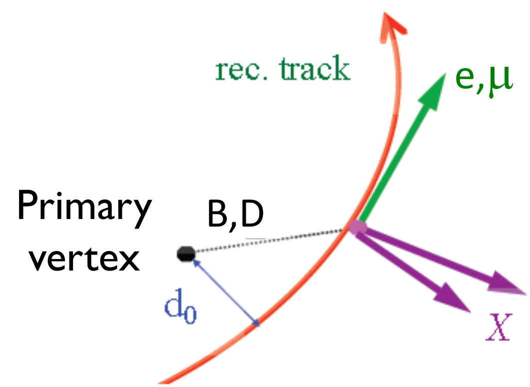
$D^+ \rightarrow K^-\pi^+\pi^+$

$D^{*+} \rightarrow D^0\pi^+$

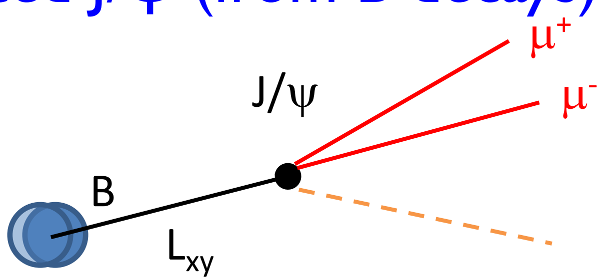
$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^-K^+\pi^+$



Semi-leptonic decays (charm, beauty)



Displaced J/ψ (from B decays)



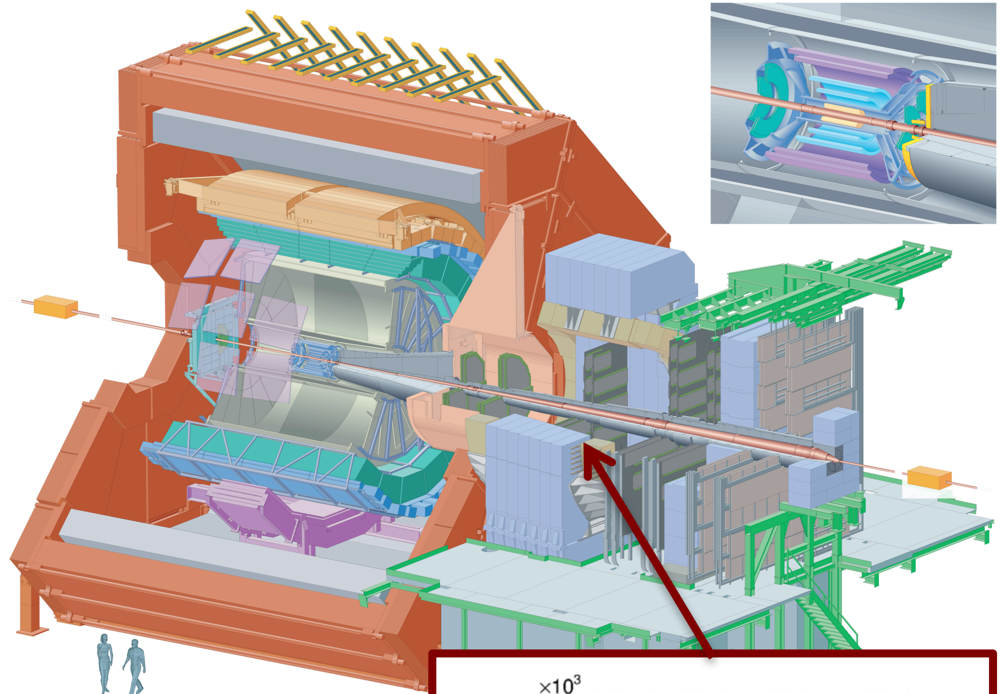
Quarkonia in ALICE

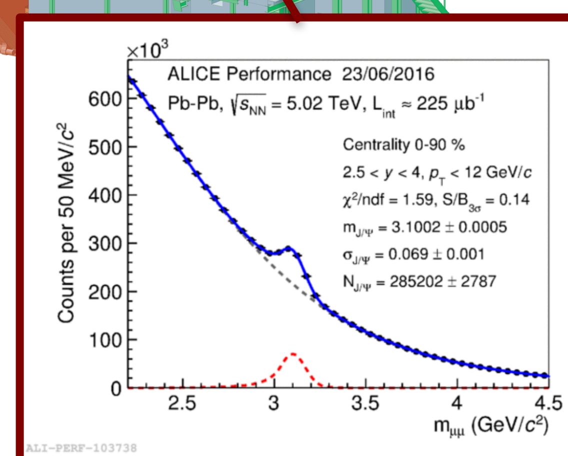
Central barrel:
J/ψ→ e^+e^-, |y|<0.8

Forward muon arm:
J/ψ, ψ(2S), Υ→ $\mu^+\mu^-$, 2.5<y<4

Ultra-peripheral collisions
Forward:
J/ψ, ψ(2S)→ $\mu^+\mu^-$

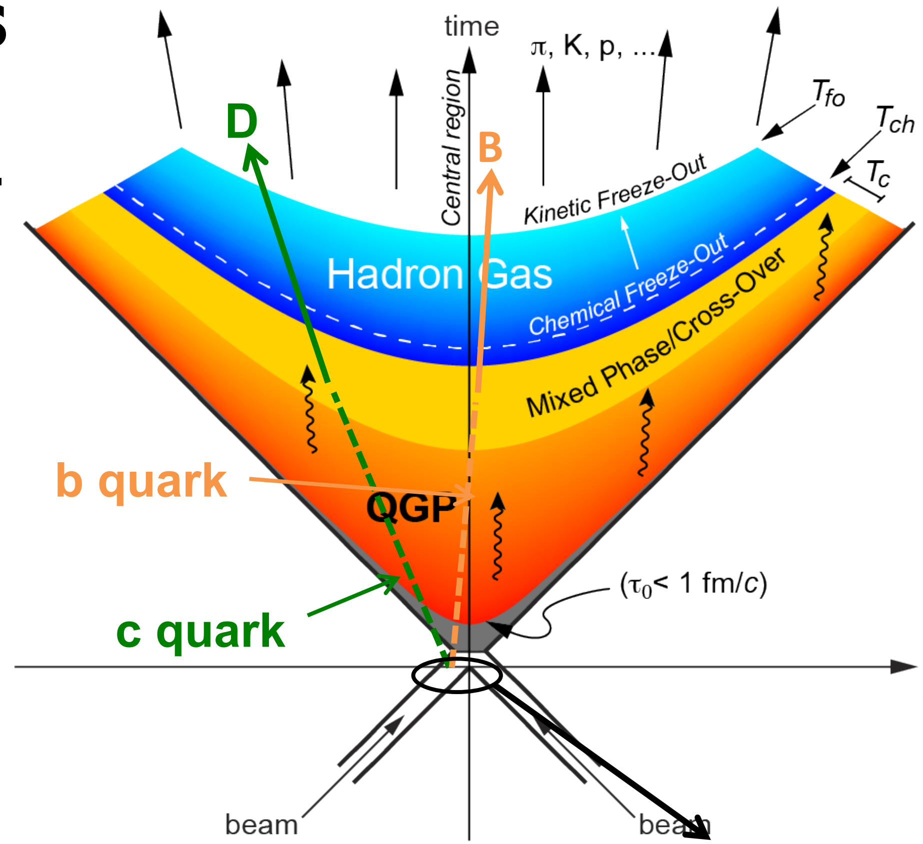
Central:
J/ψ, ψ(2S)→ e^+e^-
J/ψ→ $p\bar{p}$
ψ(2S)→J/ψ ππ
→ **see M. Broz's talk**





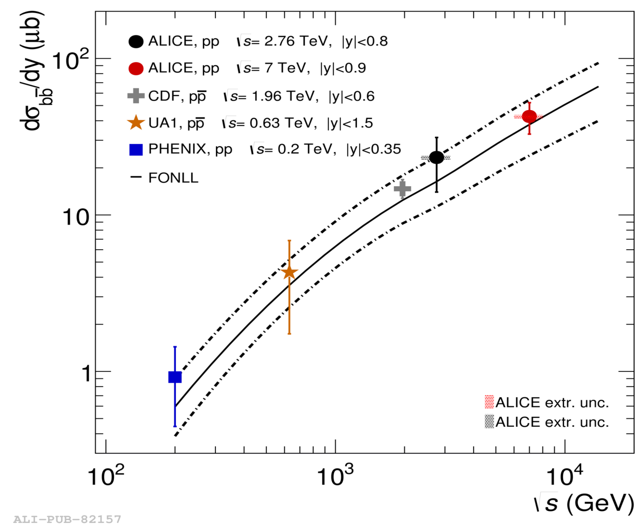
Open heavy flavours

- tomographic probes of the QGP -

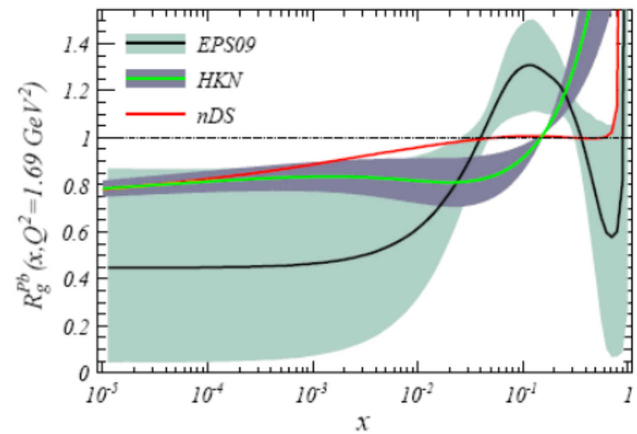


Heavy Flavours in small collision systems

Phys.Lett. B738 (2014) 97

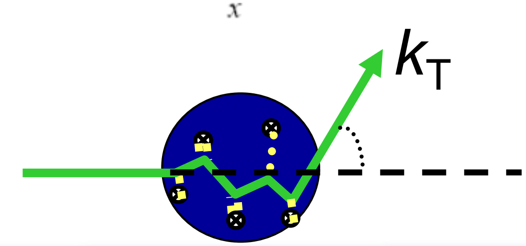


- **pp collisions:**
  - test for pQCD
  - reference for p-A and AA
  - role of Multi Parton Interactions (MPI)
  - study heavy-flavour (HF) production processes and fragmentation



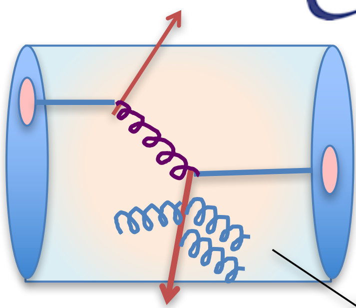
- **p-Pb collisions:**
  - reference for cold nuclear matter (CNM) effects
  - initial/final-state effects
    - nPDF, saturation and more effects

    (k_T broadening, energy loss)
  - role of collision geometry/multiplicity density
  - collective effects in small systems?



Heavy Flavours in Pb-Pb collisions

- **Energy loss** of heavy-quarks in the medium:
  - modifies phase-space distribution of HQ, and of final-state observables
  - mechanisms: gluon radiation, elastic collisions
  - depends on:
    - Medium density, path-length
    - Colour-charge, parton mass



energy loss in the medium

$$\langle \Delta E \rangle \propto \alpha_s C_R \hat{q} L^2$$

$$\Delta E_g > \Delta E_{u,d} > \Delta E_c > \Delta E_b$$

"dead-cone" effect in radiative energy loss
Dokshitzer and Kharzeev, PLB 519 (2001) 199.

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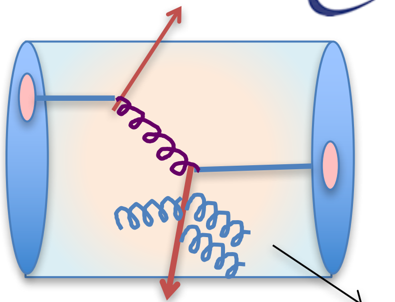

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"dead-cone" effect in radiative energy loss
Dokshitzer and Kharzeev, PLB 519 (2001) 199.

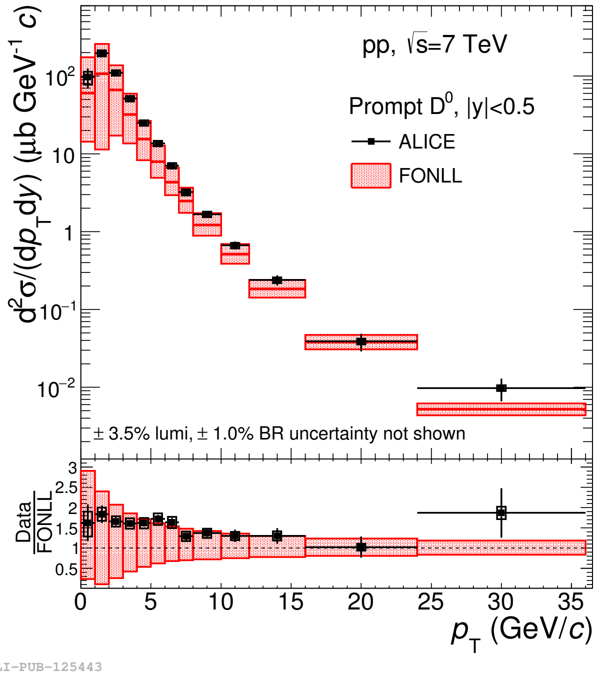
- Do heavy flavours take part into **collective motion** of the system?
  - at low p_T → information on the transport properties of the medium, collectivity and thermalization of HQ

- **Hadronization** mechanism
  - role of coalescence of HQ with low-p_T light quarks in the medium

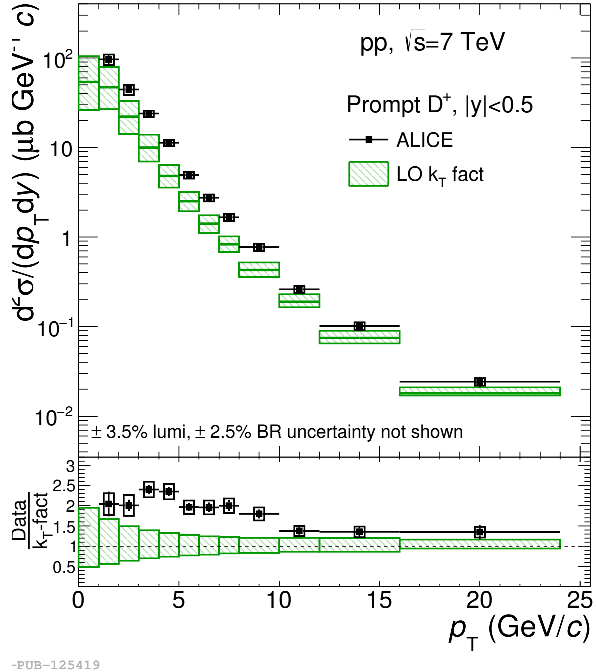
Goal: extract medium properties with heavy-flavour observables

Charm in pp collisions: test for pQCD

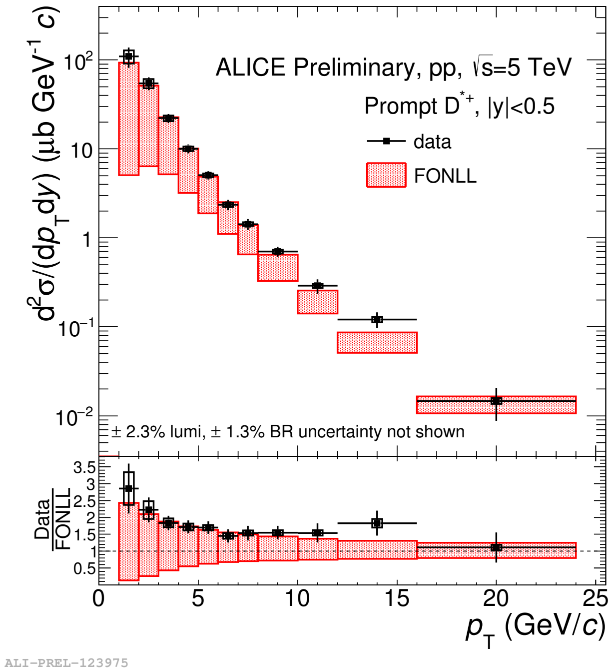
D^0, 7 TeV



D^+, 7 TeV



D^{*+}, 5 TeV



ALICE, arXiv: 1702.00766
Phys. Rev. C 94, 054908 (2016)
JHEP 1201 (2012) 128

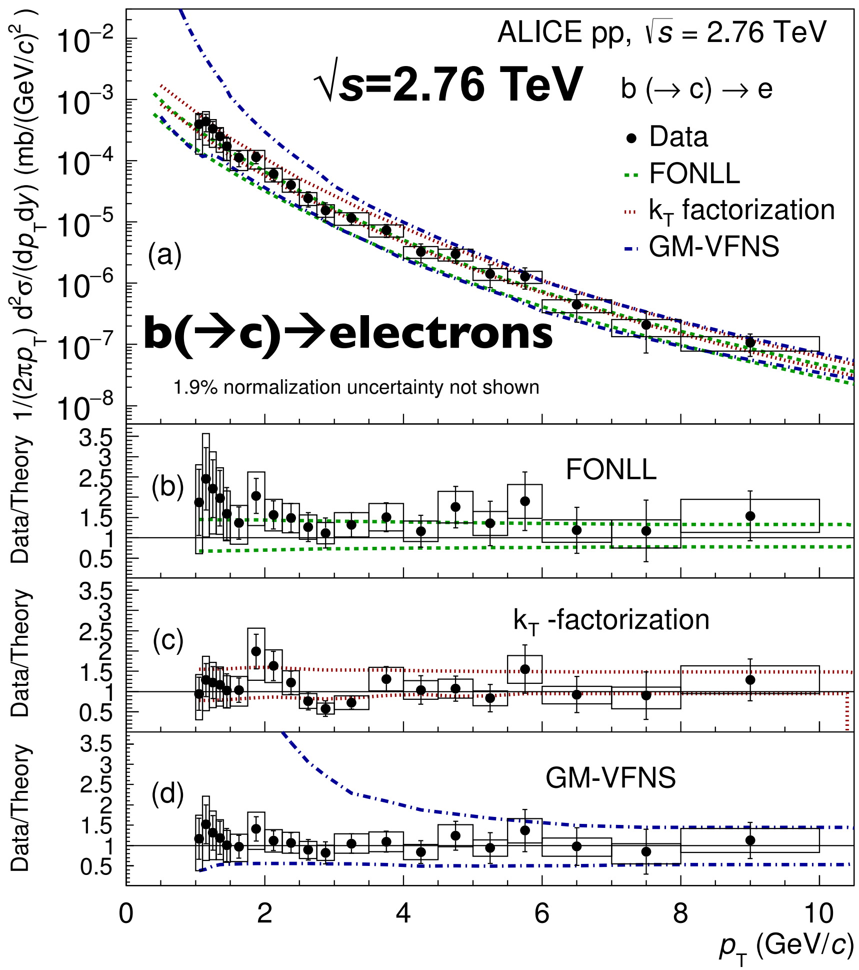
FONLL: JHEP, 1210 (2012) 137
GM-VFNS: Eur.Phys.J., C72(2012)2082
Nucl. Phys. B, 872(2013) 253
LO k_T fact: Phys.Rev., D87 (2013) 094022

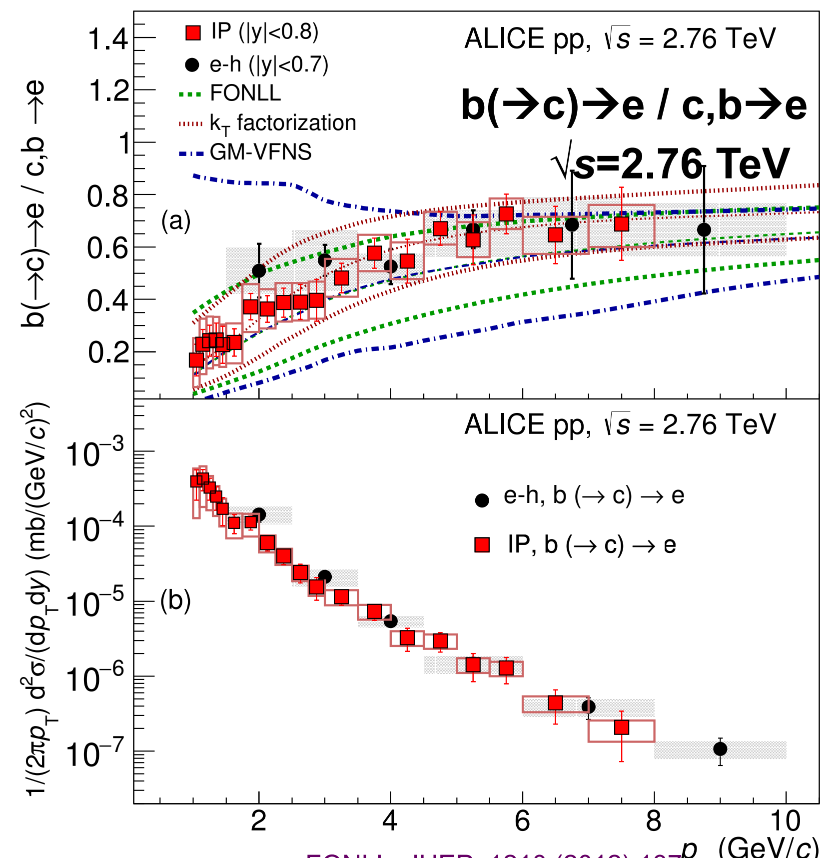
Cross sections at LHC energies well **described by pQCD predictions**.
Charm cross-section on the upper side of the FONLL uncertainty band

pp collisions provide reference for p-A and AA collisions

Leptons from heavy-flavour decays: beauty

Separation between charm and beauty via displaced decay electrons and e-h correlations





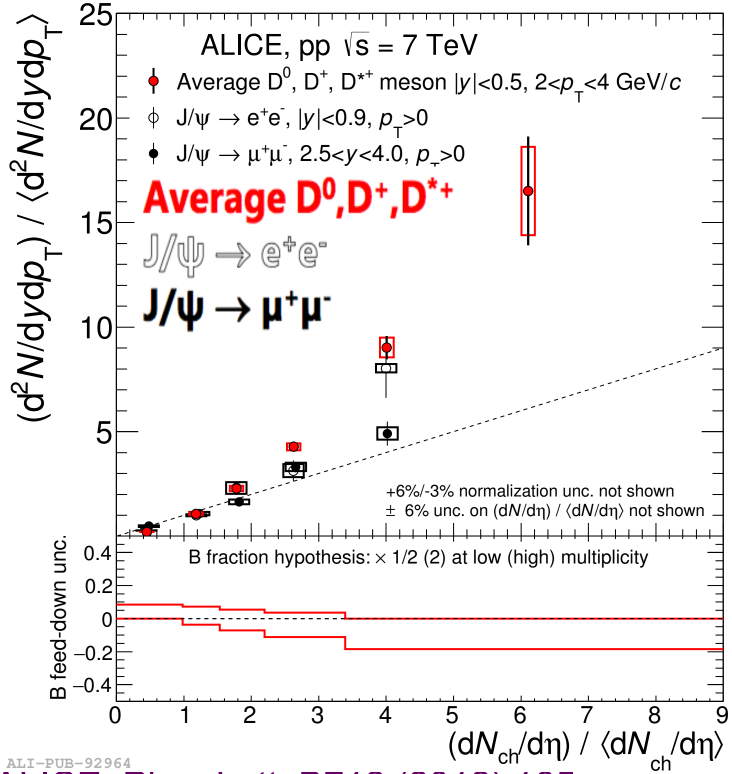
Phys. Rev. D 91, 012001 (2015)
PLB 738 (2014) 97

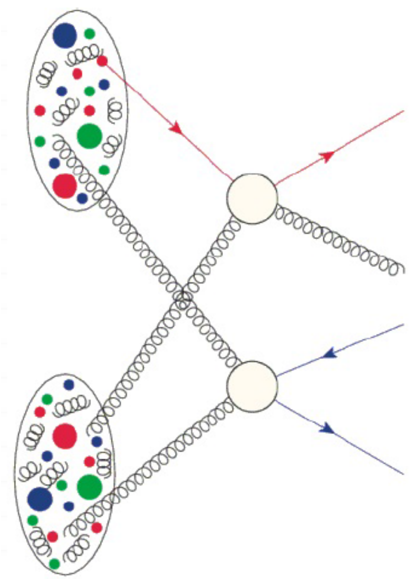
FONLL: JHEP, 1210 (2012) 137.
GM-VFNS:Eur.Phys.J., C72 (2012) 2082.
LO k_T fact: Phys.Rev., D87 (2013) 094022.

Beauty production at 2.76 TeV described by FONLL

HF yields vs event multiplicity in pp

Study the effect of multi-parton interactions (MPI) on the hard heavy-flavour scale





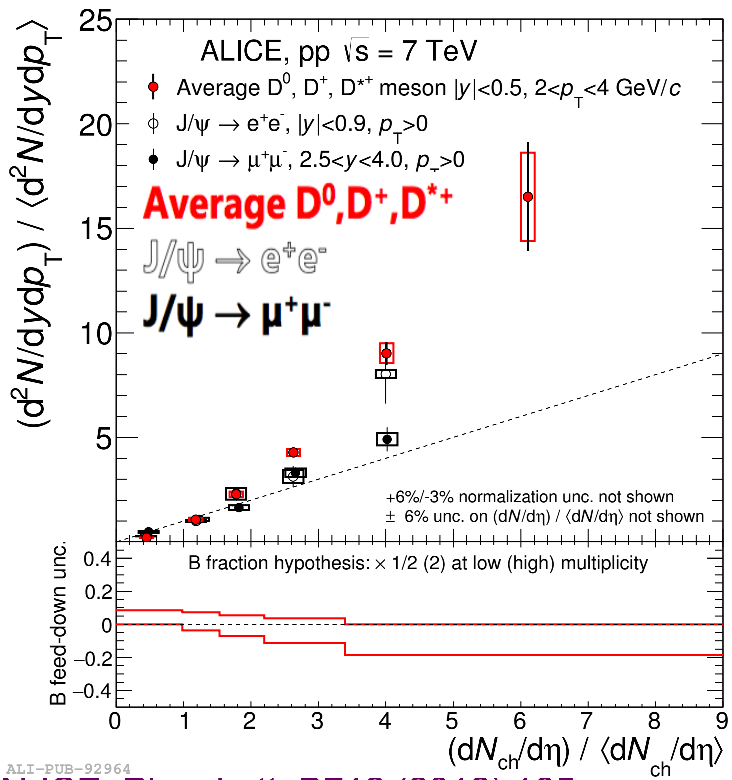
ALICE, Phys.Lett. B712 (2012) 165
JHEP 09 (2015) 148

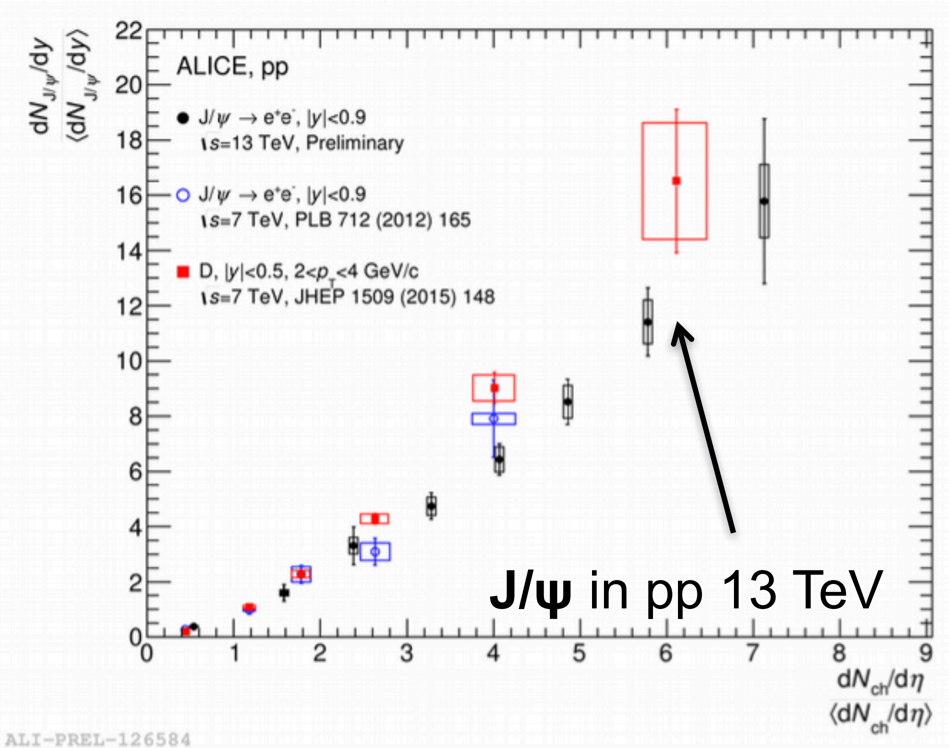
Increasing trend with multiplicity for **D mesons** and **J/ψ** in pp:

- similarity **D** vs **J/ψ** → behaviour related to HQ production process rather than t hadronisation mechanism

HF yields vs event multiplicity in pp

Study the effect of multi-particle interactions (MPI) on the hard heavy-flavour scale



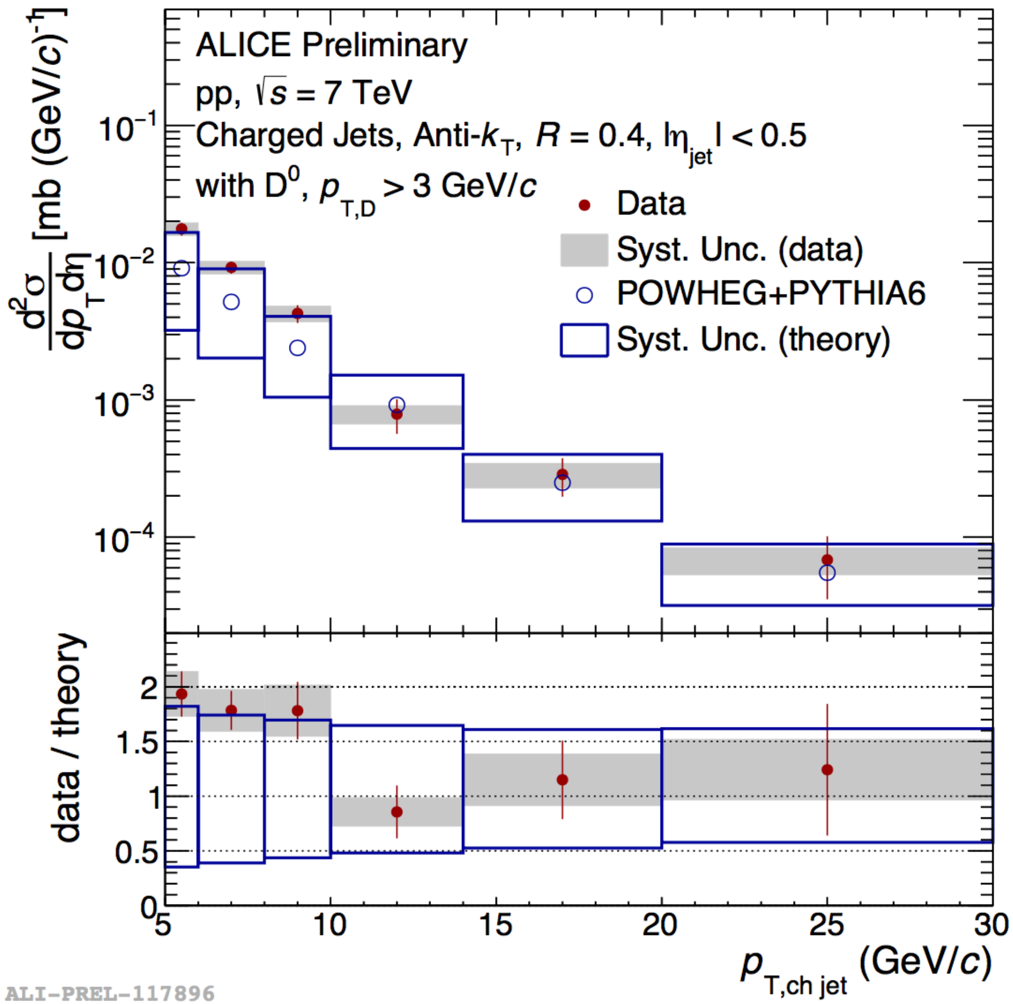


ALICE, Phys.Lett. B712 (2012) 165
JHEP 09 (2015) 148

Increasing trend with multiplicity for **D mesons** and **J/ψ** in pp:

- similar increase in pp $\sqrt{s}$=7 and 13 TeV, multiplicity range for **J/ψ at 13 TeV** extended by ~factor 2
- suggests that MPI are influencing HQ production in high-multiplicity events

Charged jets with D mesons



Anti-k_T jet-finding algorithm, charged constituents, R=0.4

Jets tagged with D^0 reconstructed via their Kπ decay.

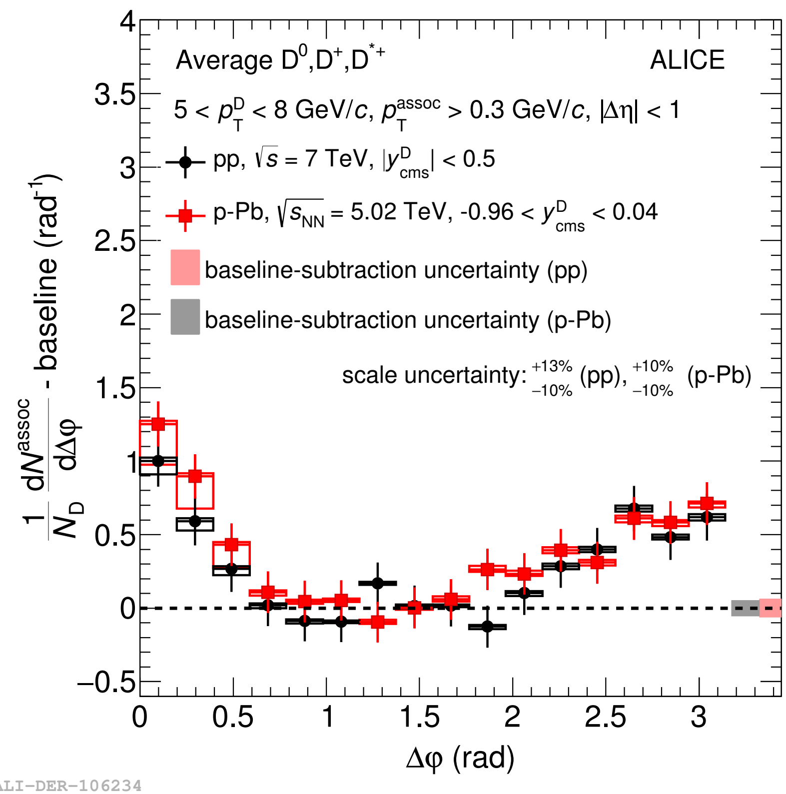
b-decay feed-down subtracted with POWHEG+PYTHIA6 simulations

Corrected to particle level (D-tagging efficiency, unfolding)

Measurement described by POWHEG +PYTHIA6 simulations

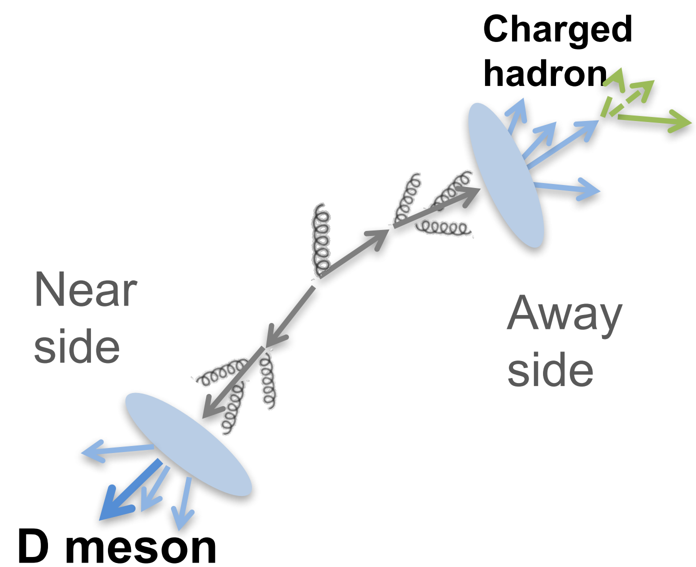
D-h correlations in pp and p-Pb

5<p_T^D<8 GeV/*c*, p_T^{assoc}>0.3 GeV/*c*



ALICE, arXiv:1605.06963

Assess **charm fragmentation and jet properties**, also in presence of the nucleus



Compatibility within uncertainties between **pp collisions at $\sqrt{s}$ = 7 TeV** and **p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV** after baseline subtraction

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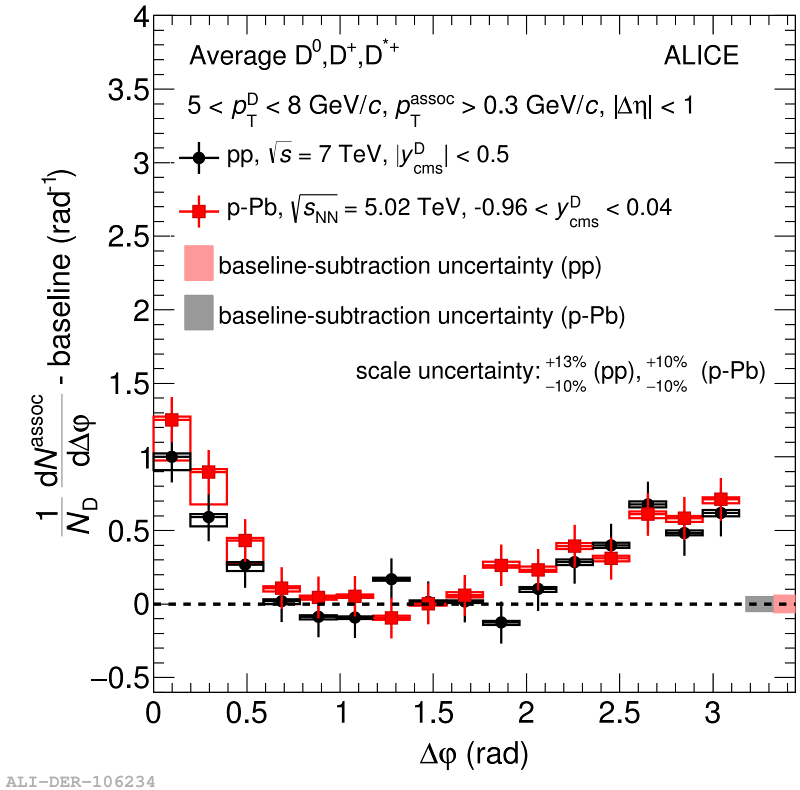
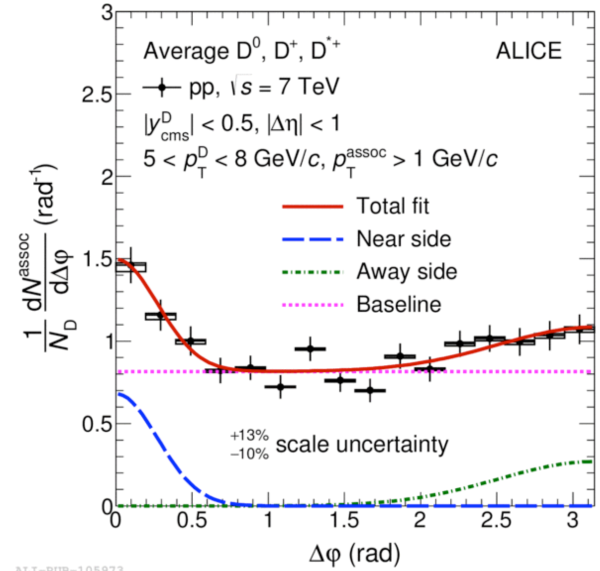


ALICE, arXiv:1605.06963



Quantitative observables extracted from the fit:

- Near-side yield
- Near-side width
- Baseline value

Compatibility within uncertainties between **pp collisions at $\sqrt{s}$ = 7 TeV** and **p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV** after baseline subtraction

D-h correlations in pp and p-Pb

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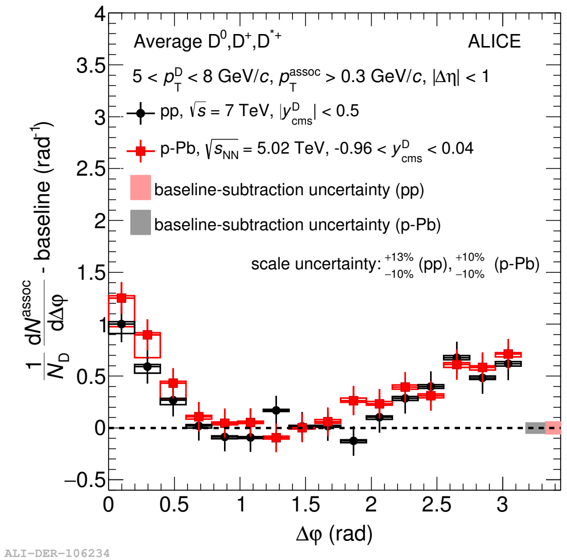
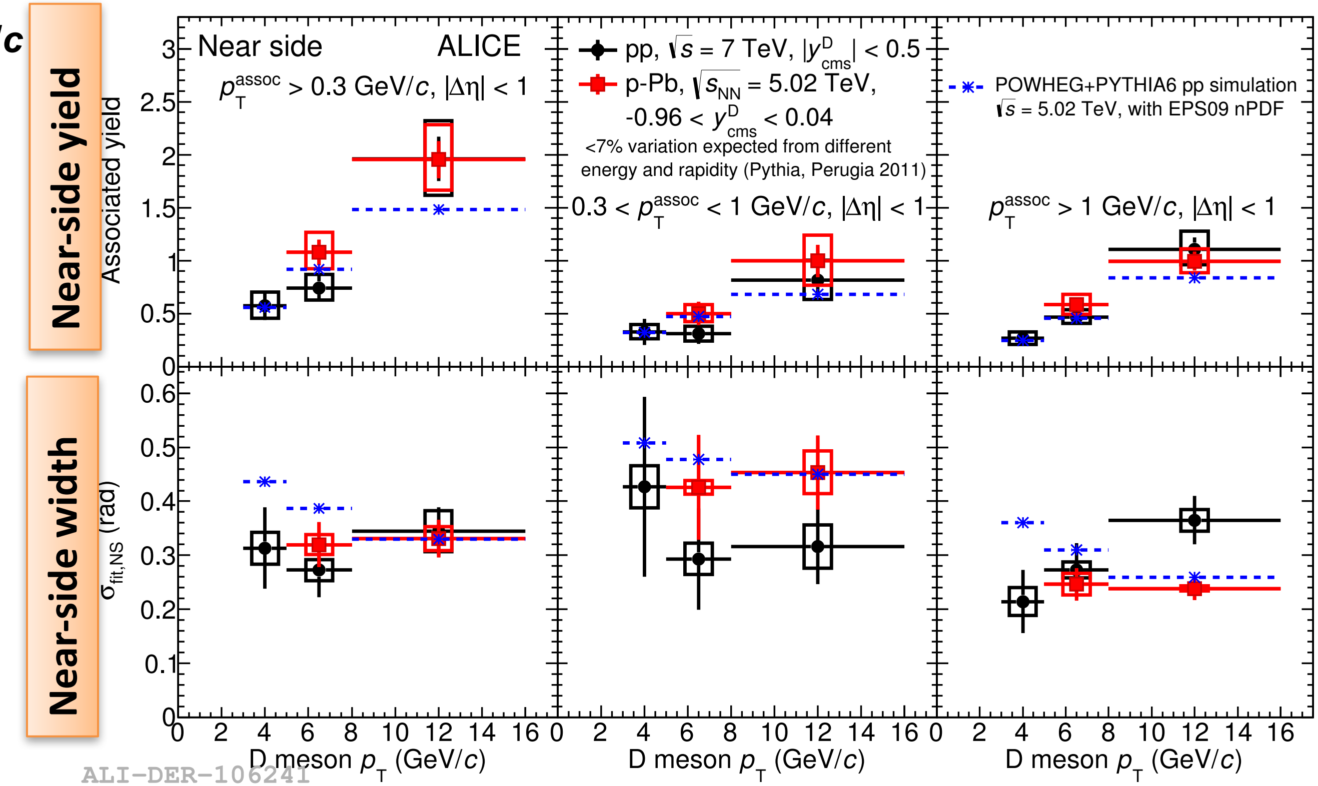


ALICE, arXiv:1605.06963



Compatibility within uncertainties between **pp collisions at √*s* = 7 TeV** and **p-Pb collisions at √s_{NN} = 5.02 TeV** after baseline subtraction

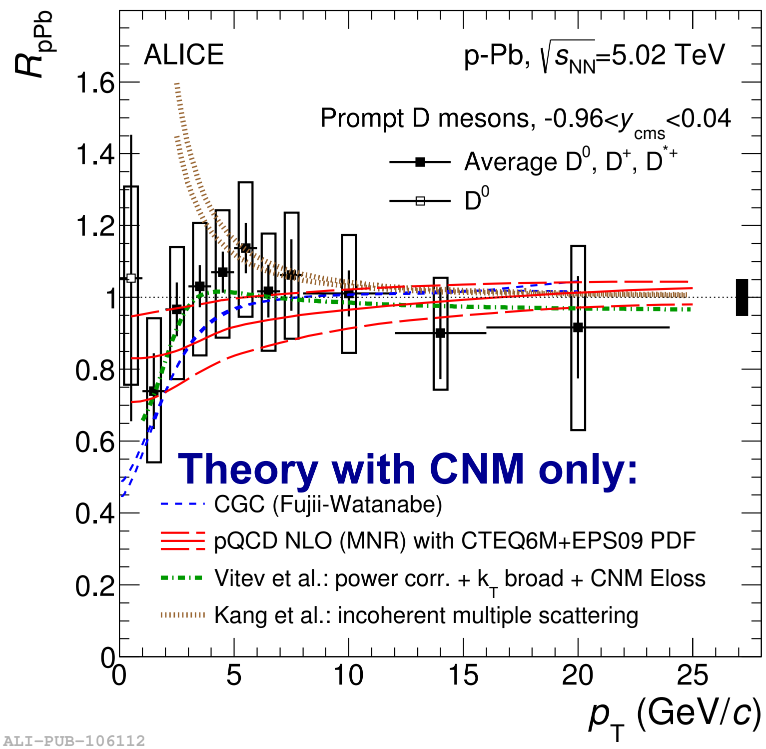
Near-side yields and widths compatible in data and simulations within uncertainties.

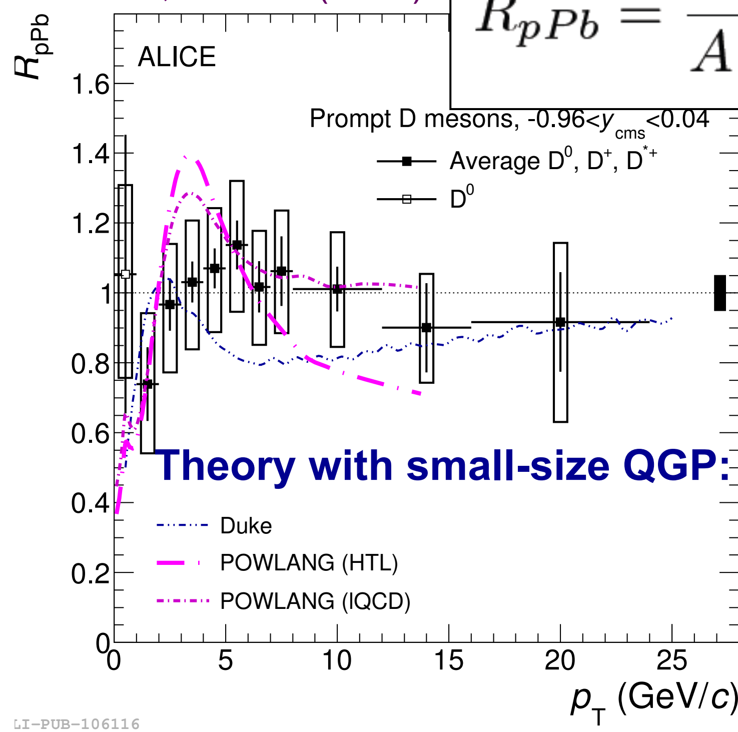
No modifications due to CNM effects in p-Pb seen within uncertainties

p-A: control experiment (and more...)

ALICE, Phys. Rev. C 94, 054908 (2016)

$$R_{pPb} = \frac{(d\sigma/dp_T)_{pPb}}{A \times (d\sigma/dp_T)_{pp}}$$





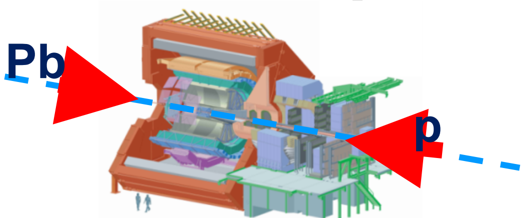
R_{pPb} described within uncertainties by models with:
- initial-state (cold nuclear matter – CNM) effects
- final-state effects due to the presence of hot nuclear medium (high-p_T suppression, radial flow bump at intermediate p_T)

H. Fuji et al., Nucl Phys A920 (2013) 78
M. Mangano et al., Nucl. Phys. B373 (1992) 295
K. J. Eskola et al., JHEP 0904 (2009) 065
Vitev et al., Phys. Rev. C 80 (2009) 05490
Z.-B. Kang et al., Phys. Lett.B740 (2015)23

Y. Xu et al., arXiv:1510.07520
A. Beraudo et al., JHEP 03 (2016) 123

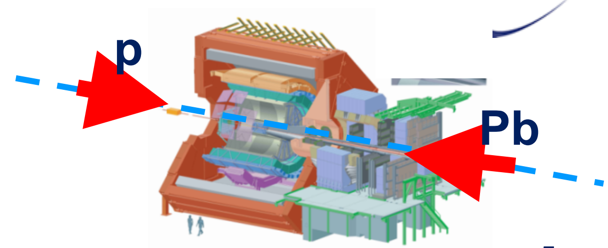
R_{pPb} is compatible with unity within uncertainty, down to p_T=0

HF R_{pPb} at different rapidities



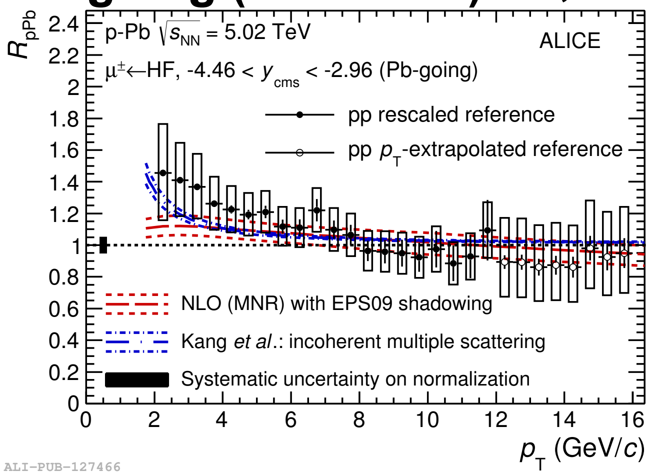
$-4.46<y_{CMS}<-2.96$ $x\sim10^{-2}$

$$R_{pPb} = \frac{(d\sigma/dp_T)_{pPb}}{A \times (d\sigma/dp_T)_{pp}}$$

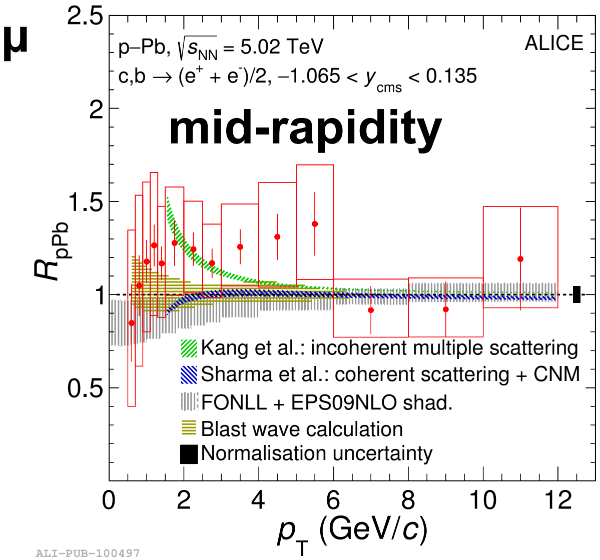


$2.03<y_{CMS}<3.53$ $x\sim10^{-5}$

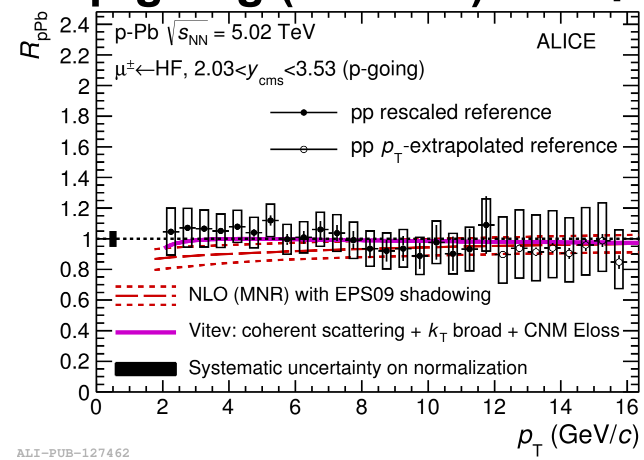
Pb-going (backward) **c,b→μ**



c,b→e



p-going (forward) **c,b→μ**



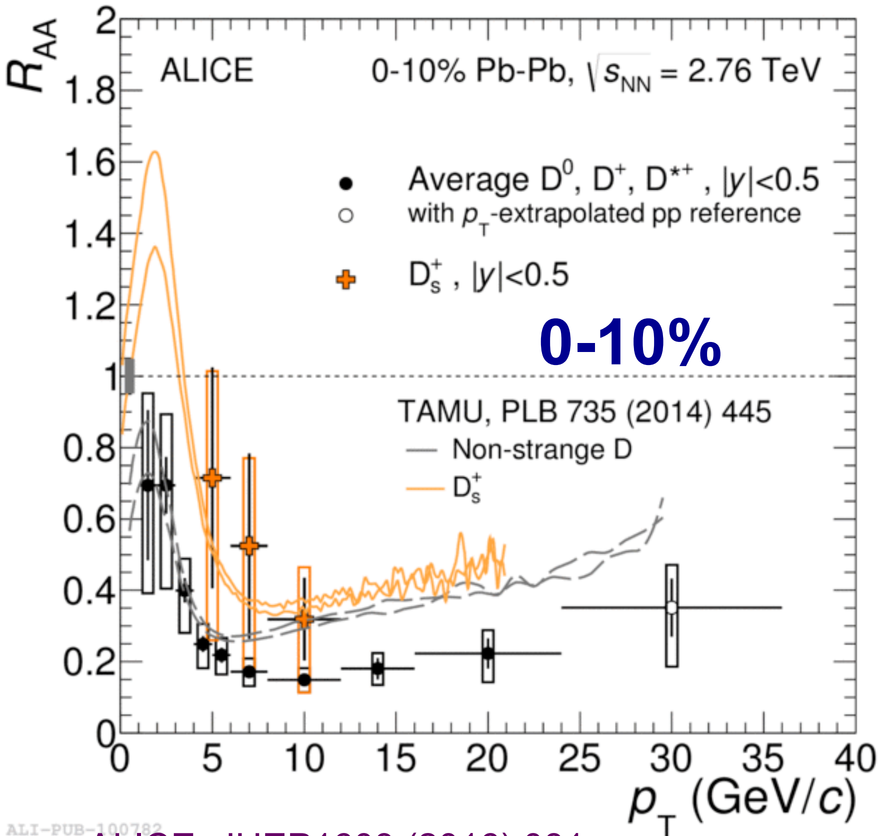
M. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B373 (1992) 295
K. J. Eskola, H. Paukkunen and C. A. Salgado, JHEP 0904 (2009) 065
R. Sharma, I. Vitev et al., PRC 80 (2009) 054902
Z.B. Kang et al., PLB 740 (2015) 23

ALICE: arXiv:1702.01479
Phys. Lett. B 754 (2016) 81

Different x regimes explored in different rapidity ranges → HF probe shadowing/saturation expected to be relevant at low p_T at the LHC

Data described within uncertainties by the models with CNM effects

AA: D-meson R_{AA} at LHC in Run I



ALICE, JHEP1603 (2016) 081
JHEP1603 (2016) 082

$$R_{AA}^{D}(p_T) = \frac{dN_{AA}^{D}/dp_T}{\langle T_{AA}\rangle \times d\sigma_{pp}^{D}/dp_T}$$

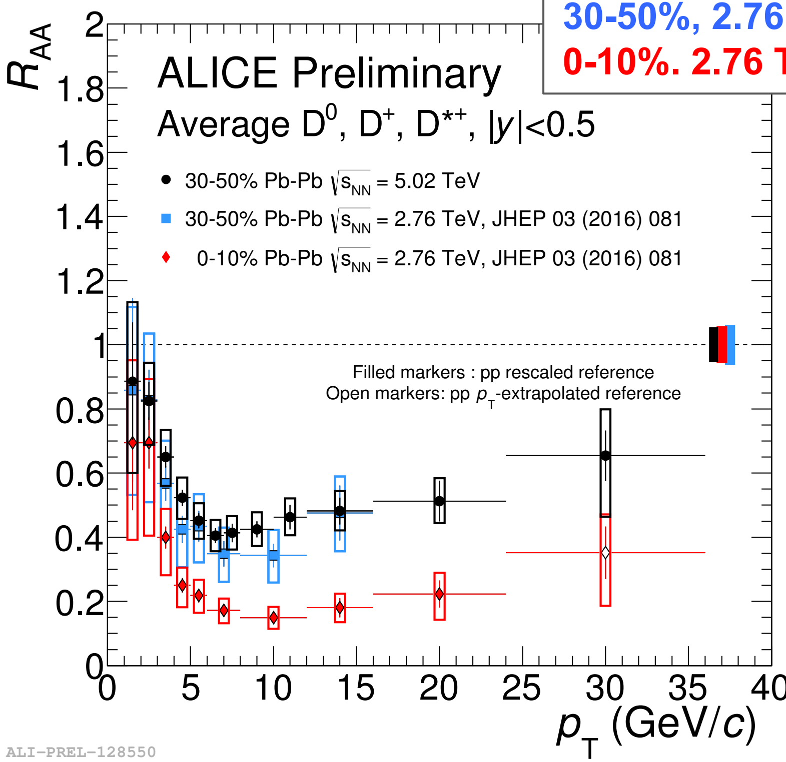
Average D^0,D^+,D^{*+}
D_s

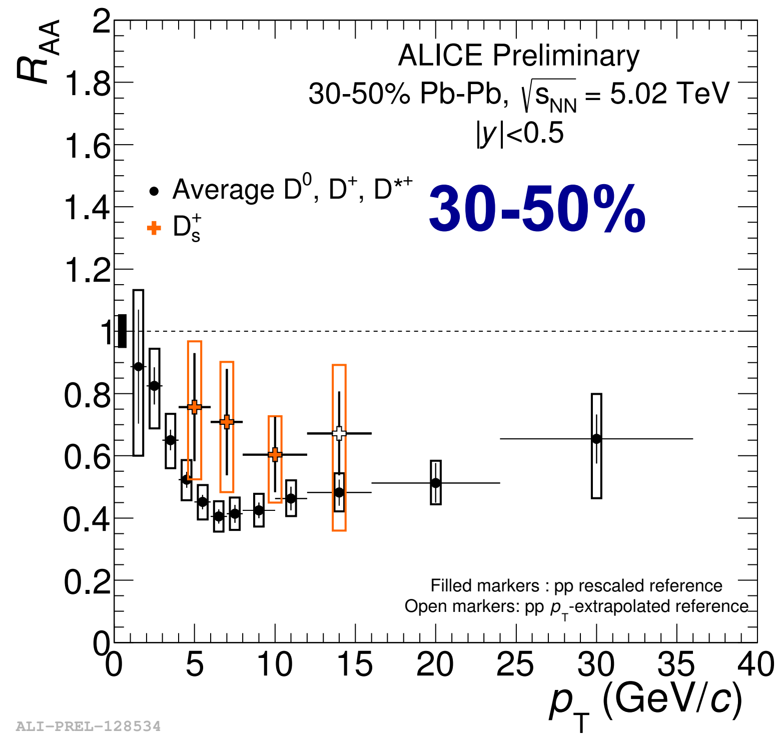
Strong suppression of prompt D-meson yield in central Pb-Pb collisions
- by to a factor of 5 at p_T~10 GeV/c

Hint for less suppression of D_s^+ than non-strange D at intermediate p_T
- expected if recombination plays a role in charm hadronization

AA: D-meson R_{AA} at LHC in Run 2

30-50%, 5.02 TeV
30-50%, 2.76 TeV
0-10%. 2.76 TeV





ALICE, JHEP1603 (2016) 081

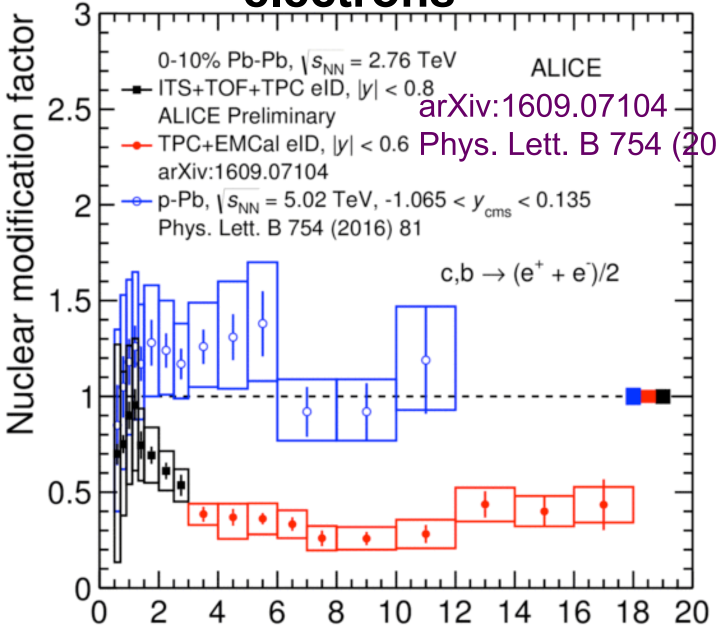
Strong suppression of D^0,D^+,D^{*+} mesons in Pb-Pb at $\sqrt{s_{NN}}$=5.02 TeV

Similar suppression as in Pb-Pb at $\sqrt{s_{NN}}$=2.76 TeV, better precision achieved with Run 2 data

D_s^+ R_{AA} in 30-50% at 5.02 TeV similar to that of non-strange D mesons

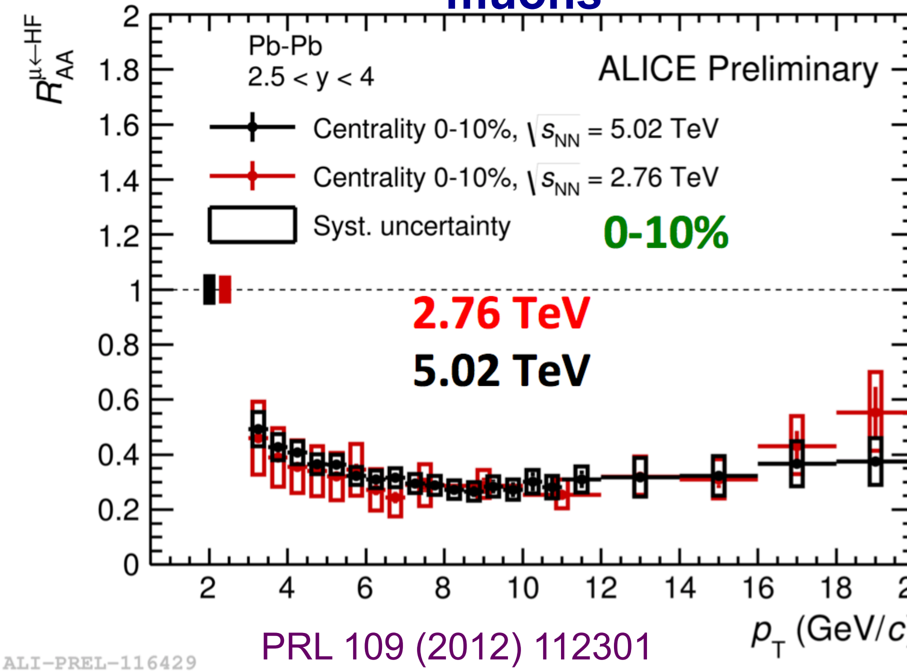
Leptons from HF hadron decays

electrons

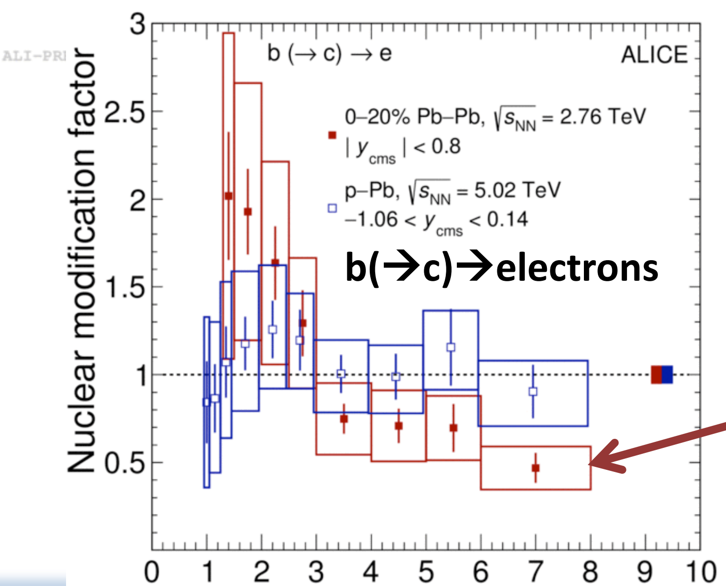


arXiv:1609.07104
Phys. Lett. B 754 (2016) 81

muons



PRL 109 (2012) 112301



arXiv:1609.03898

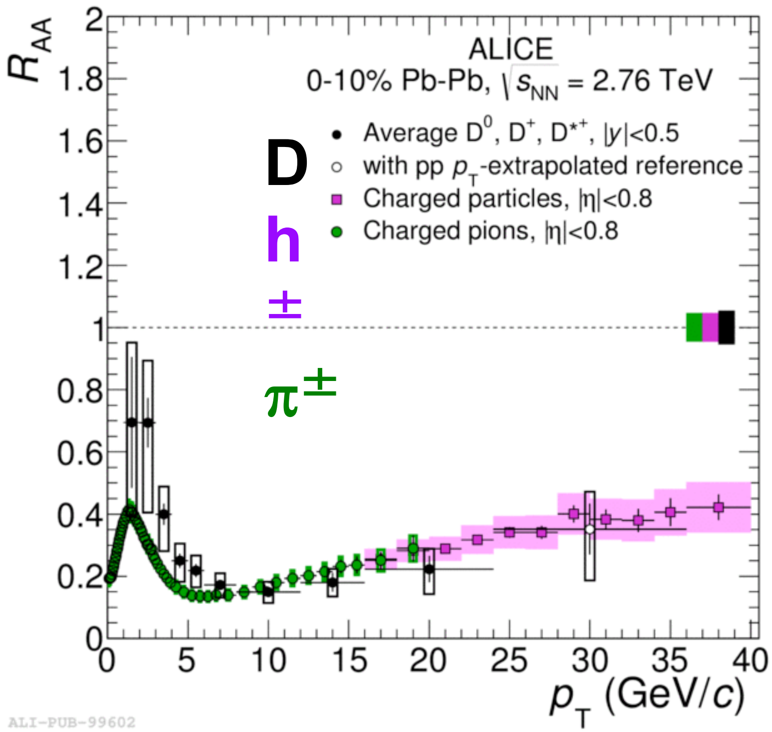
Similar suppression of **electrons and muons from heavy-flavour** hadron decays at the LHC (dominated by beauty at high p_T).

Similar suppression at 2.76 and 5.02 TeV

Electrons from beauty-hadron decays in Pb-Pb collisions.
Hint for suppression for p_T>3 GeV/*c*

R_{AA}: D mesons and charged hadrons

Mass/colour dependence of energy loss?



JHEP1603 (2016) 081

R_{AA}(D)~R_{AA}(π,h±)

What about **ΔE(g)>ΔE(uds)>ΔE(c) ? →R_{AA}(D)>R_{AA}(π,h±)**

→Different quark/gluon spectra

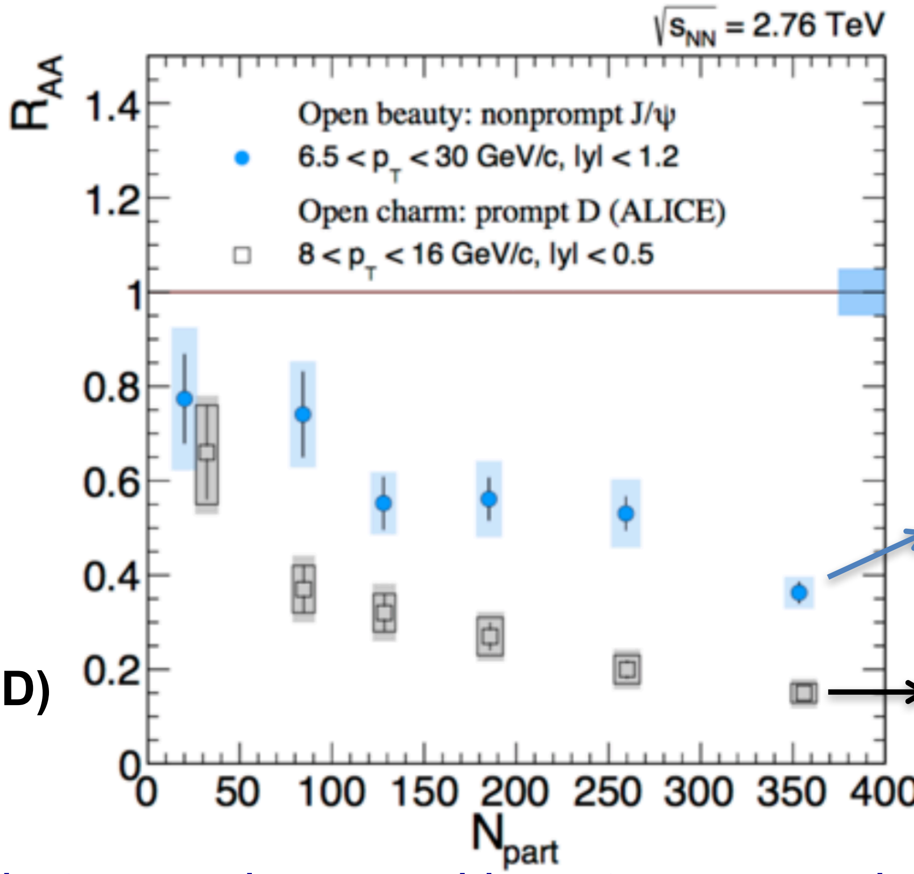
→R_{AA}(π,h±) affected by g/q fragmentation, while R_{AA}(D)~R_{AA}(c) because of harder HQ fragmentation

M.Djordjevic, PRL 112, 042302 (2014)

R_{AA}: D mesons and non-prompt J/ψ

Mass dependence of energy loss?

ALICE, JHEP 1511 (2015) 205
CMS, arXiv:1610.00613



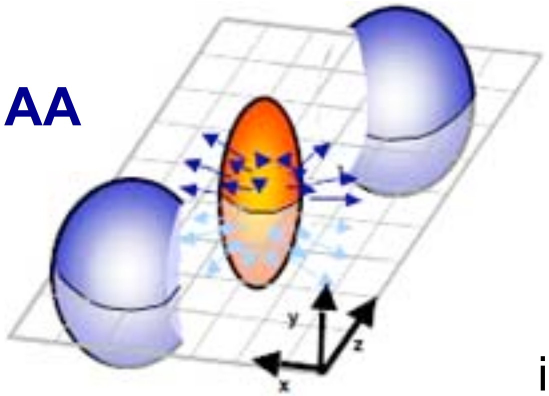
?
$\Delta E(c) > \Delta E(b) \rightarrow R_{AA}(B) > R_{AA}(D)$

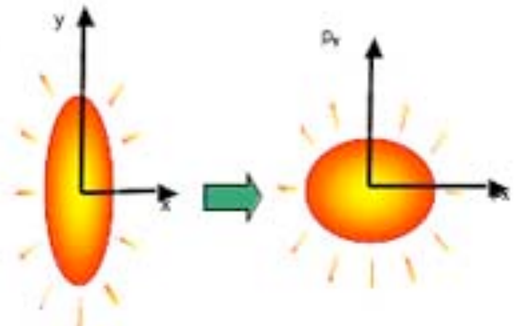
Indication of a difference between charm and beauty suppression in central collisions

In agreement with pQCD in-medium energy loss models predicting mass dependent energy loss

Heavy-flavour azimuthal anisotropy

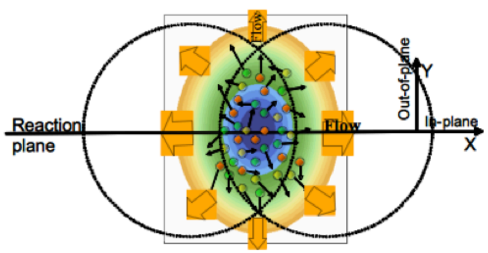
In **non-central AA collisions**:





initial spatial asymmetry → azimuthal anisotropy of final hadrons in momentum space

→non-isotropic azimuthal emission can be parametrized by:



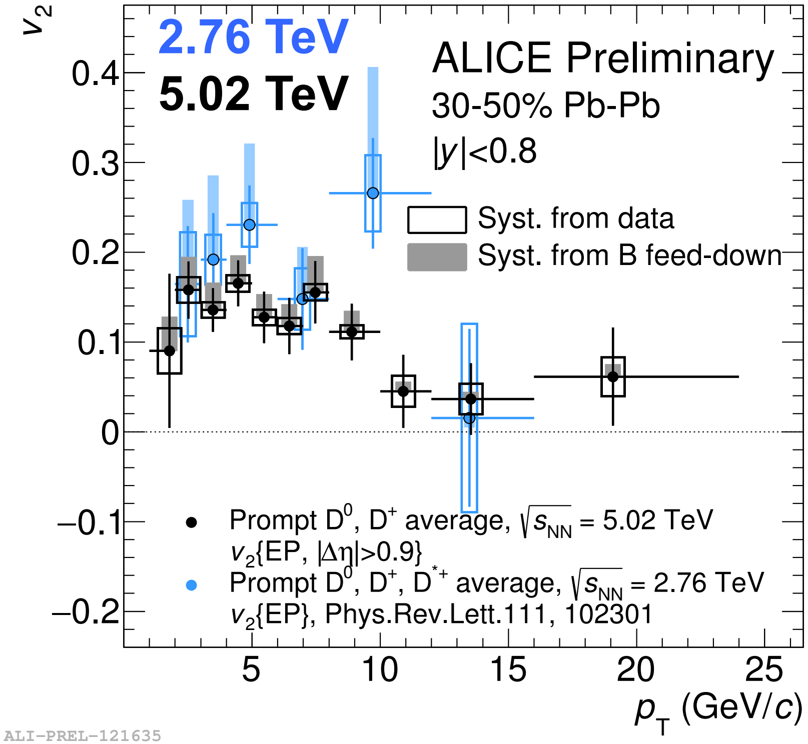
$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}\left(1 + 2v_1\cos(\varphi - \Psi_1) + 2v_2\cos[2(\varphi - \Psi_2)] + \ldots\right)$$

Azimuthal anisotropy originates from:

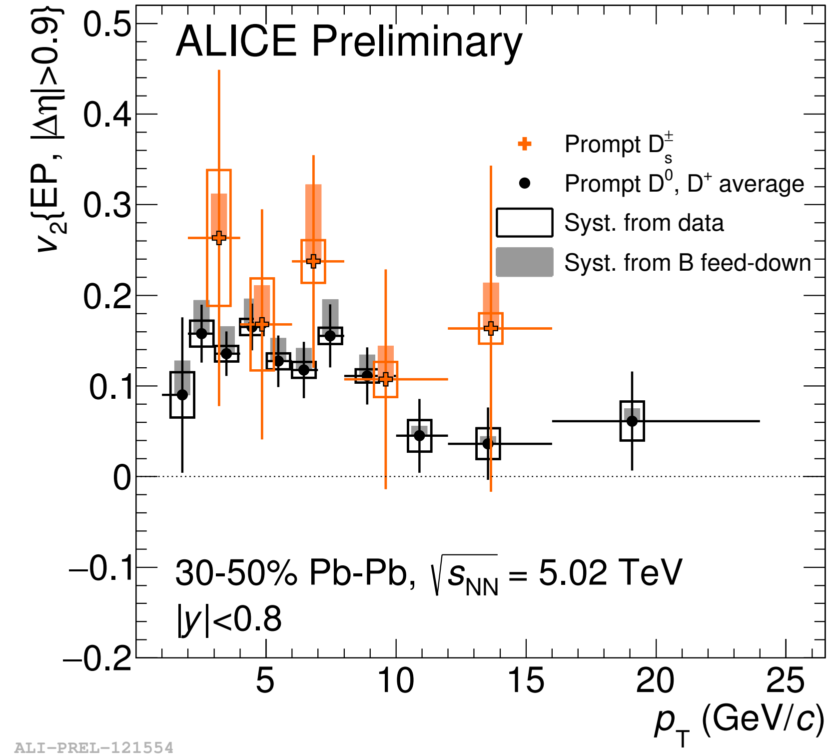
- thermalization/collective motion (low p_{T})
- path-length dependence of energy loss (high p_{T})

Are heavy quarks "flowing" with the medium?

D-meson azimuthal anisotropy



Average D^0,D^+ and D_s

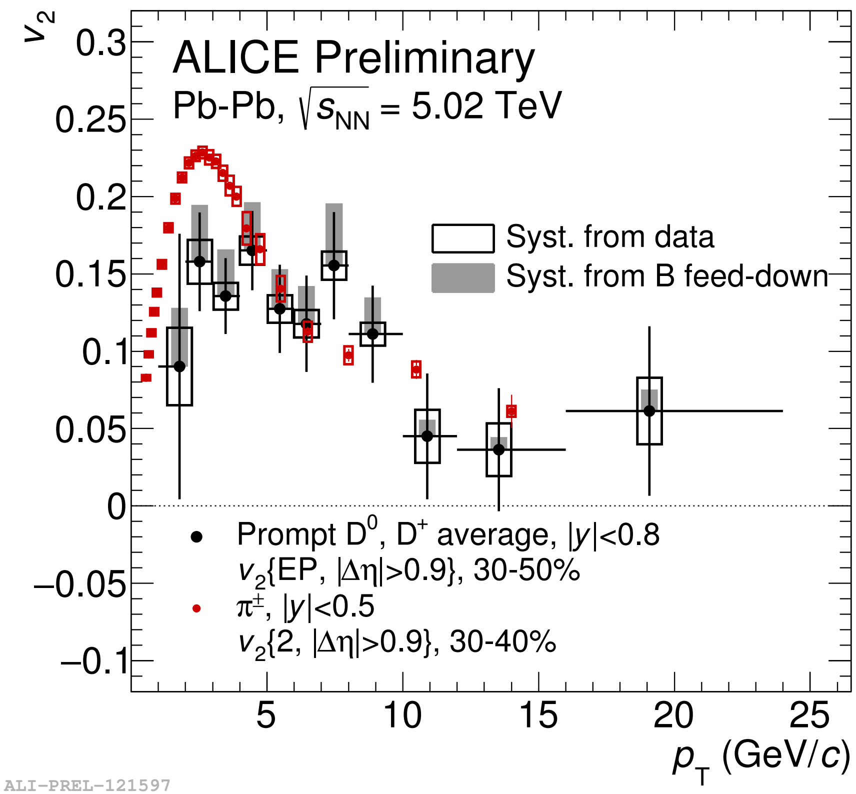


ALICE, PRL 111, 102301 (2013)
ALICE, PRC 90 (2014) 3, 034904

D-meson v_2>0 in 30-50%

- improved precision with Run 2 data
- D_s v_2 measured (first time!)

D-meson and pion v_2 in Run 2

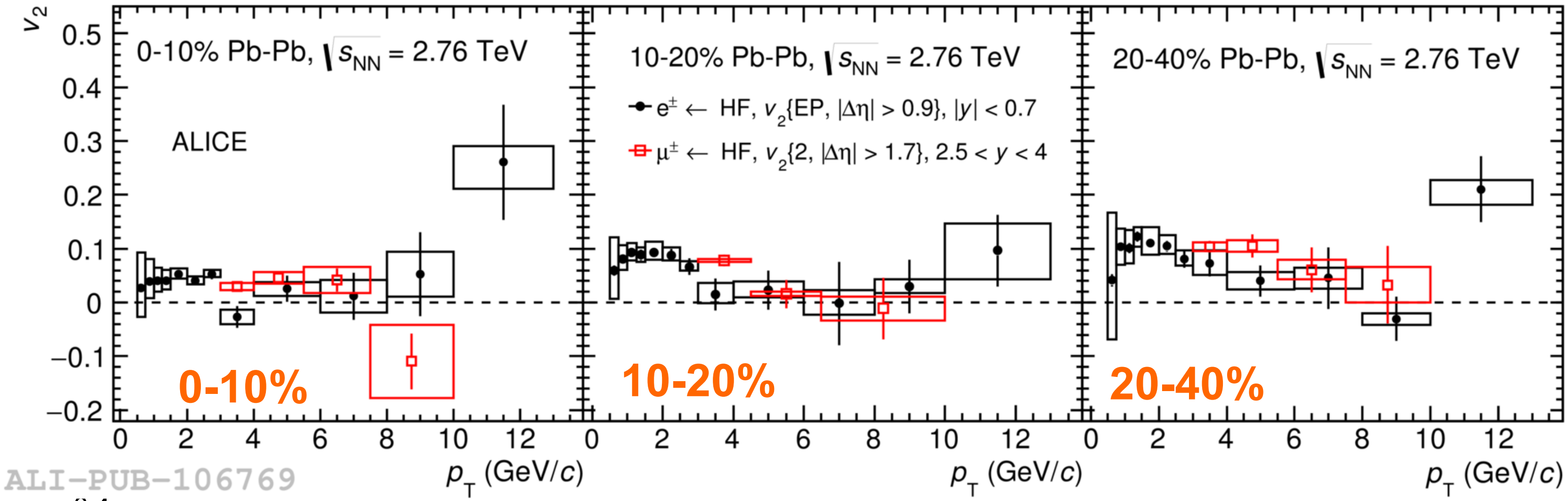


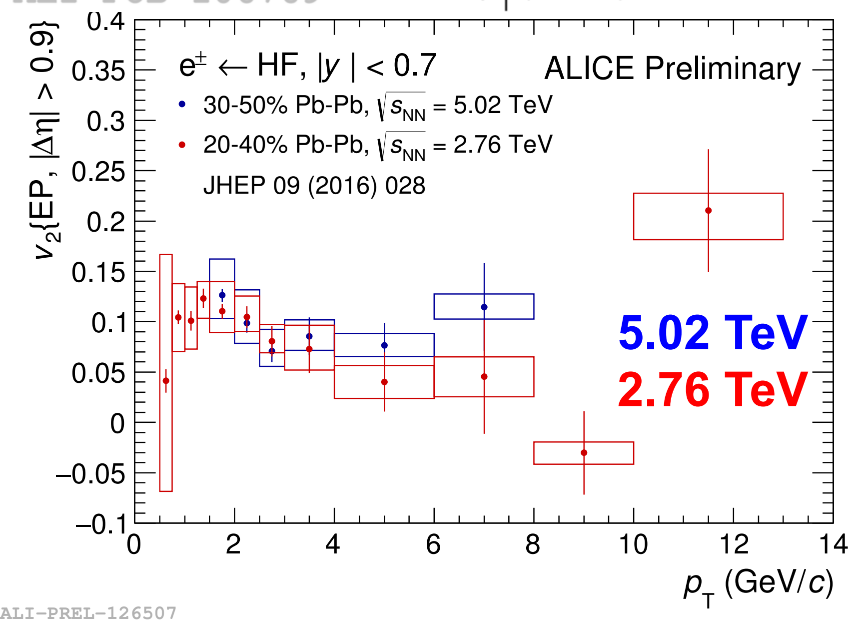
Low p_T: hint of **v_2(charged pions)** slightly higher than **v_2(D)**
High p_T: similar v_2 for D and charged pions

Strong interaction of charm quarks with the medium at LHC

HF lepton azimuthal anisotropy

(c,b)→electrons, muons





ALICE, Phys.Lett. B753 (2016) 41
JHEP 09 (2016) 028

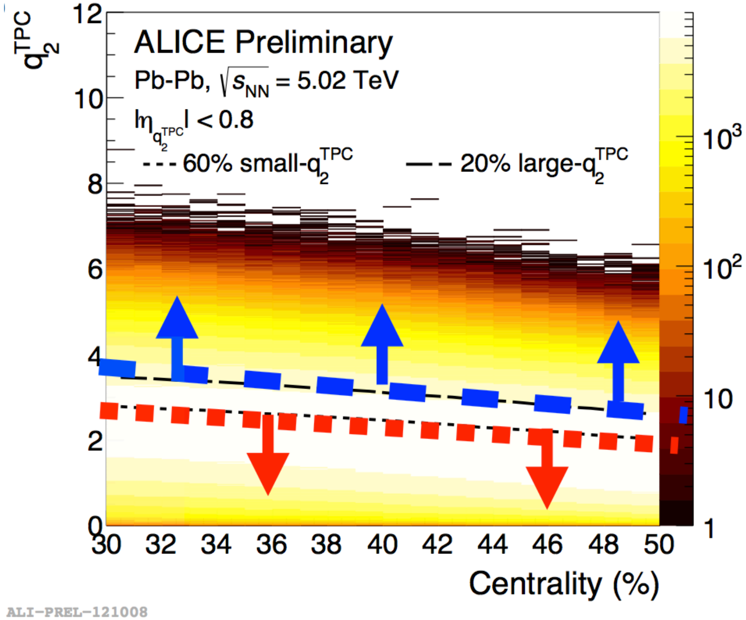
Positive v_2 for e/μ from heavy-flavour decays at LHC energies

v_2 compatible at 2.76 and 5.02 TeV

Event-shape engineering with D's

Idea: measure D v_2 in events with different eccentricity

Is charm affected by event-by-event initial fluctuations?



Divide events on the basis of their q_2:

- 20% of events with **large q_2**
- 60% of events with **small q_2**

$$q_2 = \frac{|Q_2|}{\sqrt{M}}$$

M: multiplicity

$$|Q_2| = \sqrt{Q_{2,x}^2 + Q_{2,y}^2}$$

$$Q_{2,x} = \sum_{i=1}^{M} \cos 2\varphi_i \ , \ Q_{2,y} = \sum_{i=1}^{M} \sin 2\varphi_i$$

Event-shape engineering with D's

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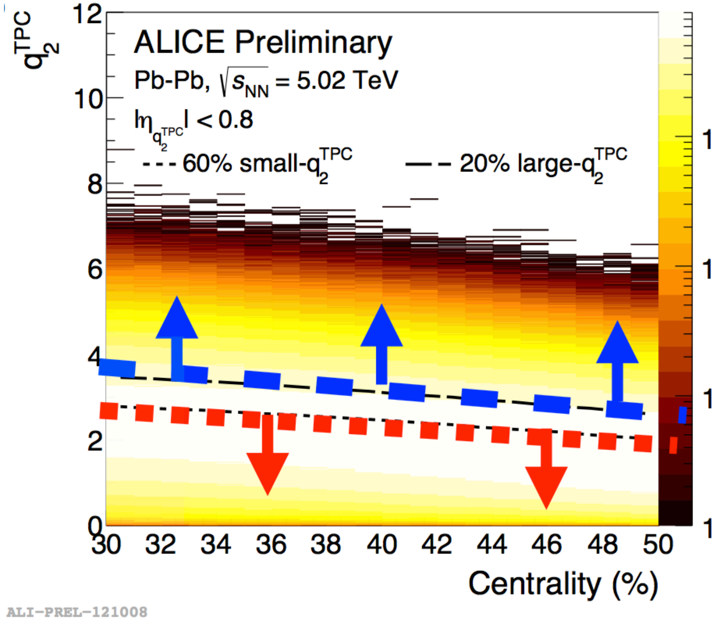

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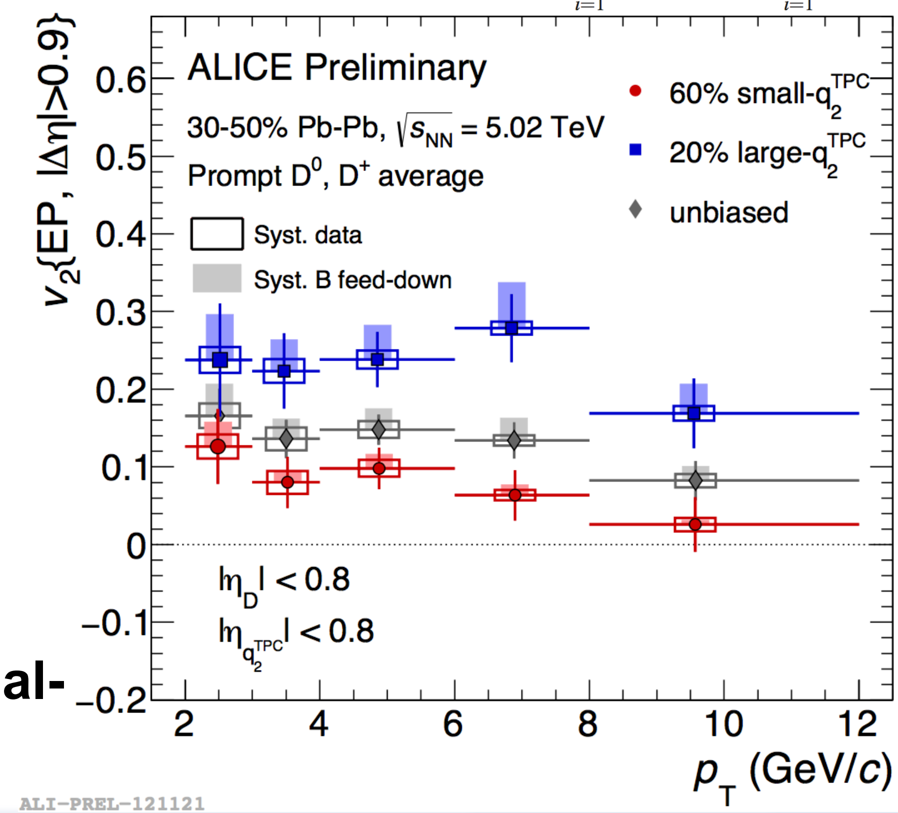
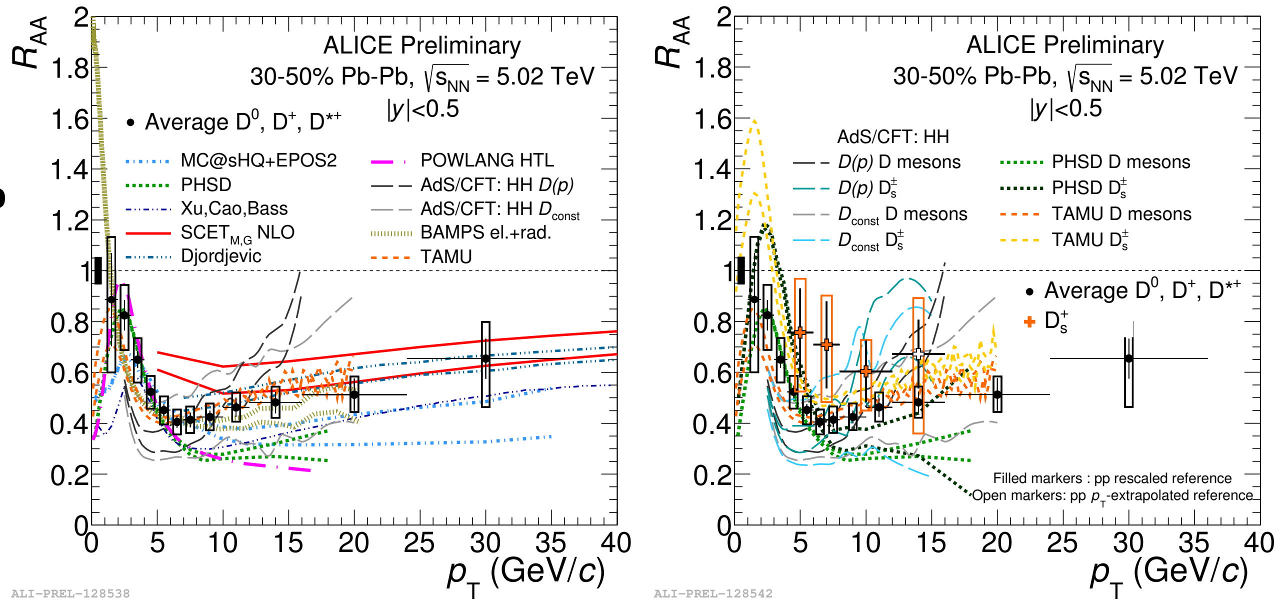


Significant separation of D-meson v_2 in events with **large and small q_2**

Charm sensitive to collectivity of light-hadron bulk, and by **event-by-event initial-state fluctuations**

R_{AA} and v_2: constraints to models

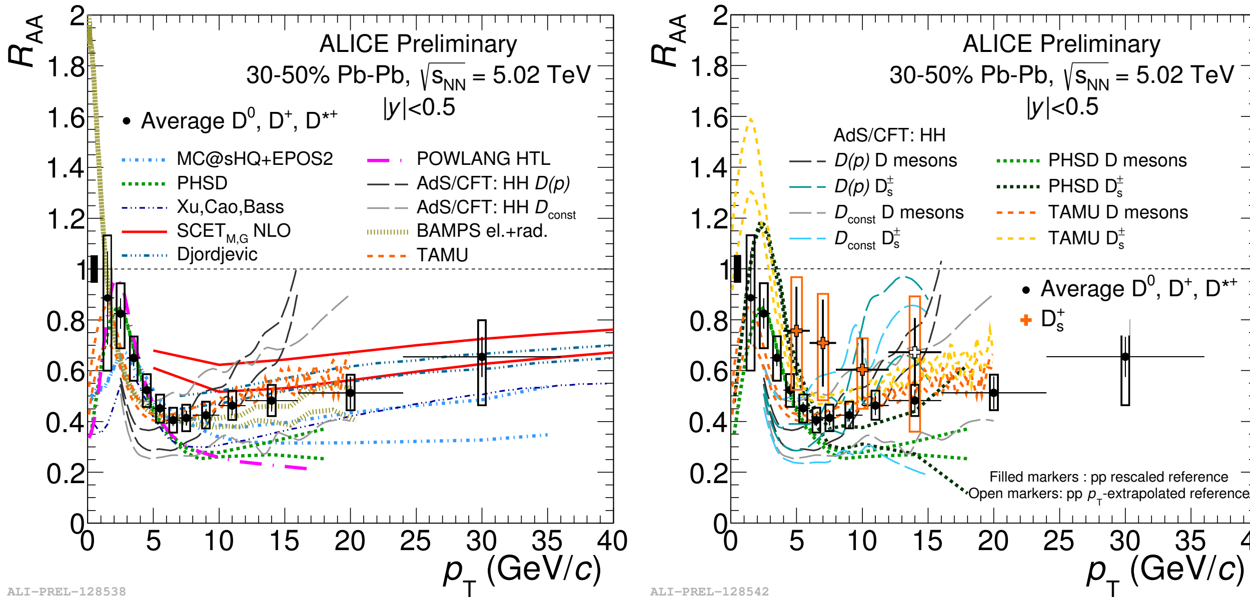
30-50%



- **AdS/CFT:** Ads/CFT correspondence, Langevin Eloss + fluctuations, hydro JHEP 1411 (2014) 017; PR D91 (2015) 8, 085019
- **BAMPS** (Boltzman equation with collisional energy loss –and radiative- in expanding QGP): Fochler et al., J. Phys. G38 (2011) 124152, PRC 84 (2011) 024908
- **Cao, Quin, Bass**(Langevin with coll and rad term and recombination+hydro) arXiv:1605.06447v1
- **Djordjevic** (energy loss due to both radiative and collisional processes in a finite size dynamical QCD medium) Phys. Rev. C 92 (2015) 024918
- **MC@sHQ+EPOS** (coll and rad e.loss in expanding medium based on EPOS model):Aichelin et al., Phys. Rev. C79 (2009) 044906, J. Phys. G37 (2010) 094019
- **PHSD** (Parton-Hadron-String Dynamics transport approach, coalescence): E. Bratkovskaya et al., PRC 93 (2016) 034906
- **POWLANG** (HQ transport with Langevin equation with collisional energy loss and, recombination, viscous hydrodynamic expansion): Alberico et al., Eur.Phys.J C71 (2011) 1666
- **UrQMD** (Langevin equation in UrQMD): T. Lang et al, arXiv:1211.6912 [hep-ph];T. Lang et al., arXiv:1212.0696 [hep-ph].
- **TAMU** (HQ transport with resonant scattering and coalescence+hydro): Rapp, He et al., Phys. Rev. C 86 (2012) 014903
- **Vitev** (in-medium formation and dissociation of D and B, ideal fluid with Bjorken expansion):PLB 639 (2006) 38, PRC 80.5 (2009) 054902
- **WHDG** (pQCD calculation with radiative and collisional energy loss): Horowitz et al., JPhys G38 (2011) 124114

R_{AA} and v_2: constraints to models

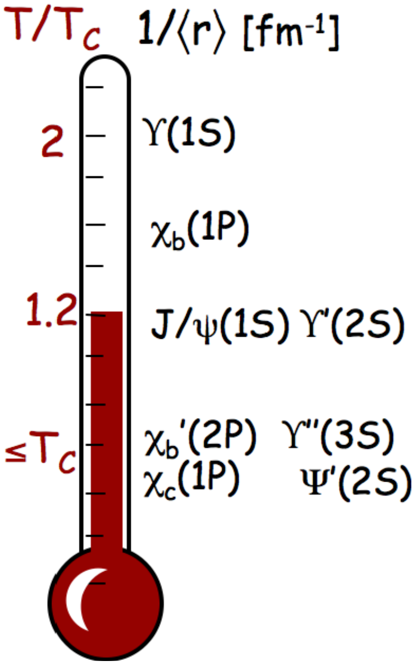
30-50%



R_{AA} and v_2 results start to provide constraints to different in-medium energy loss models, and therefore to medium parameters (transport and diffusion coefficient,…)

Quarkonia

- thermometer of the QGP -

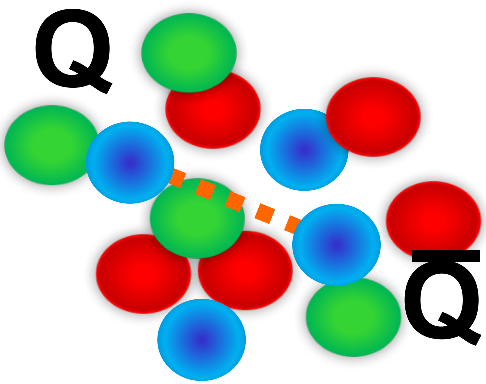


Quarkonia in the QGP

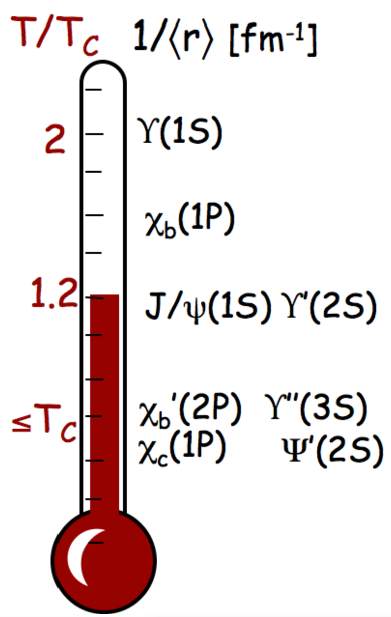
What happens to a $q\bar{q}$ pair in the Quark-Gluon Plasma?

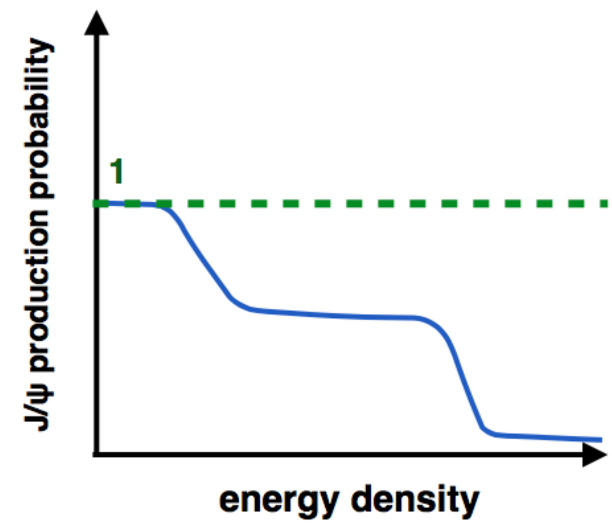
The binding of the $q\bar{q}$ pair is subject to the effects of the colour screening

If resonance radius > screening radius $\lambda_D(T)$
→no resonance can be formed
→suppression of J/ψ as a signature
for the QGP (Matsui, Satz, 1986)



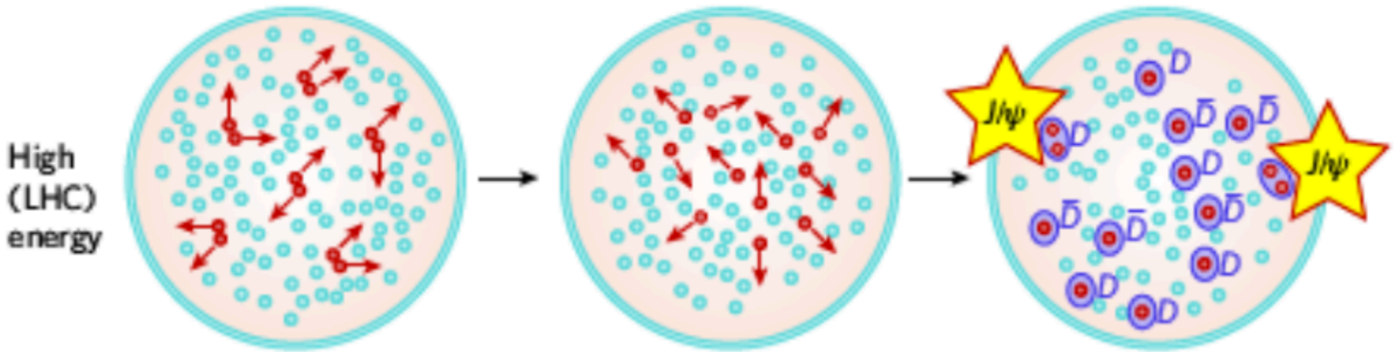
Differences in the binding energies of $q\bar{q}$ states
→ sequential suppression of the states with increasing temperature

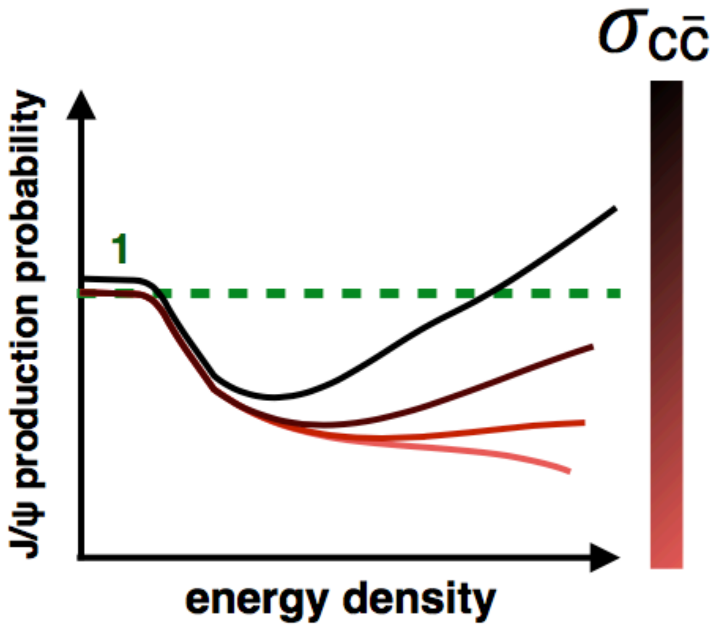




Quarkonia in the QGP: suppression and/or enhancement?

With enough $c\bar{c}$ pairs, charmonium can be (re)generated





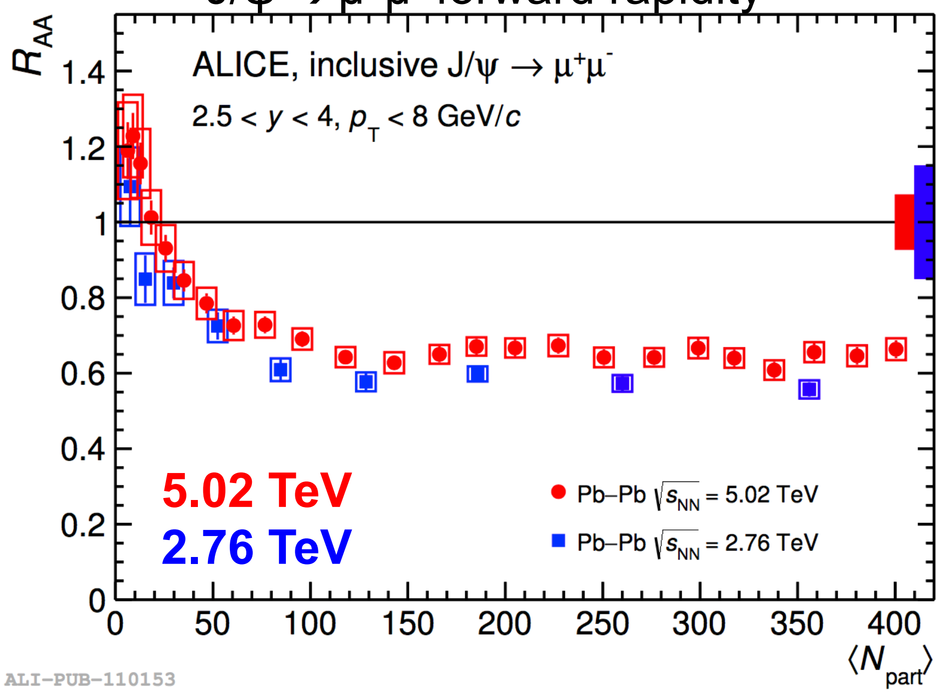
Can lead to charmonium enhancement via (re)combination of $c\bar{c}$ pairs at hadronization or during QGP stage

(predicted differently by various models)

P. Braun-Muzinger and J. Stachel, Phys. Lett. B490(2000) 196,
R. Thews et al, Phys.ReV.C63:054905(2001)

J/ψ R_{AA} vs centrality

J/ψ →$\mu^+\mu^-$ forward rapidity



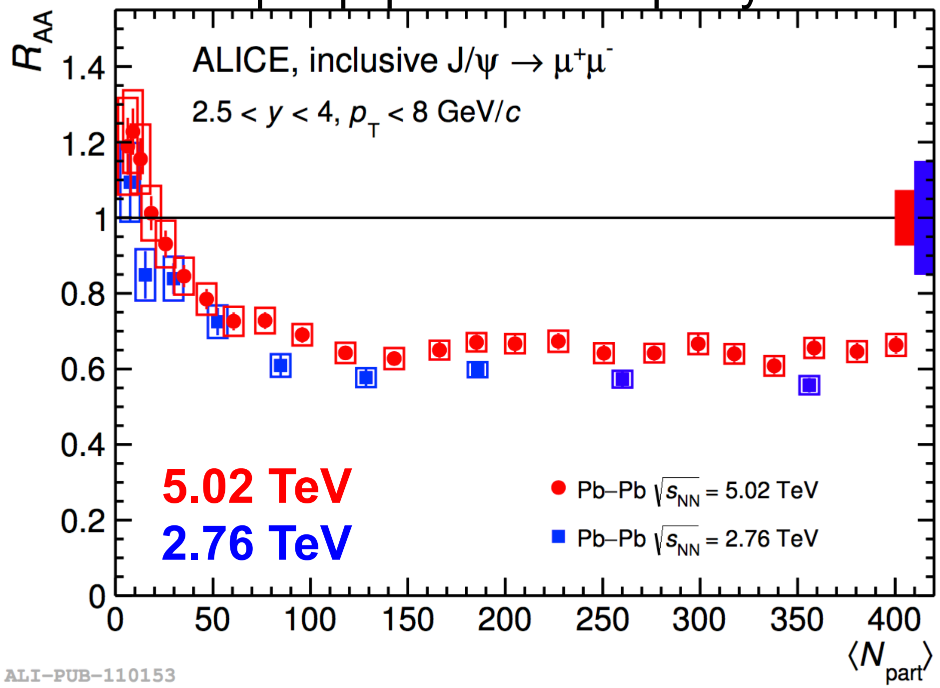
arXiv:1606.08197
PLB 734 (2014) 314-327

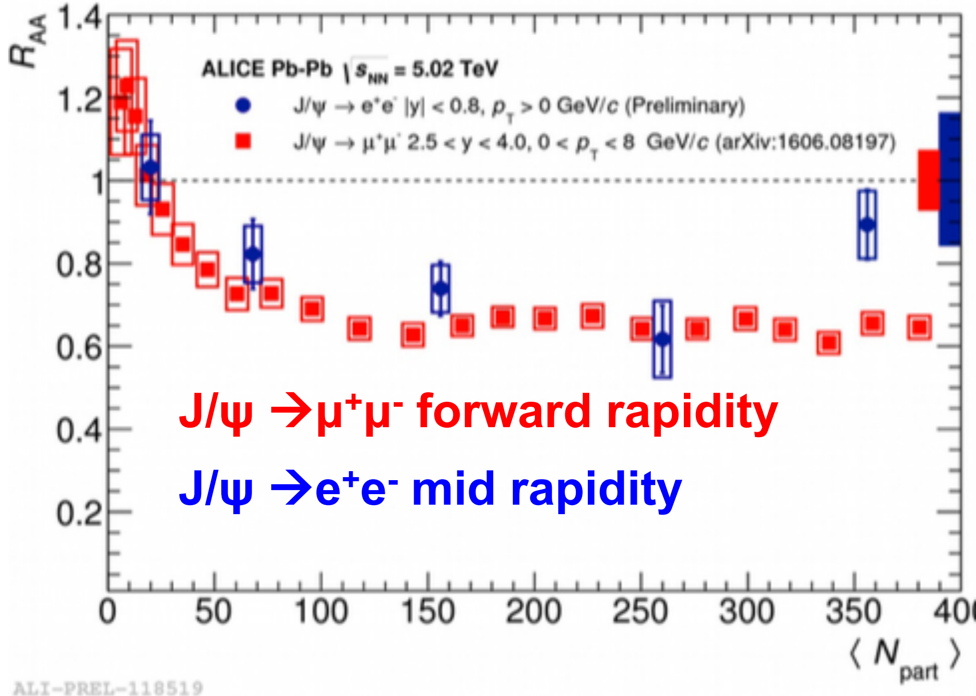
Clear J/ψ suppression and almost no centrality dependence for N_{part}>100 (centrality <50%)

Precision improved w.r.t. $\sqrt{s_{NN}}$=2.76 TeV data

J/ψ R_{AA}

J/ψ →$\mu^+\mu^-$ forward rapidity





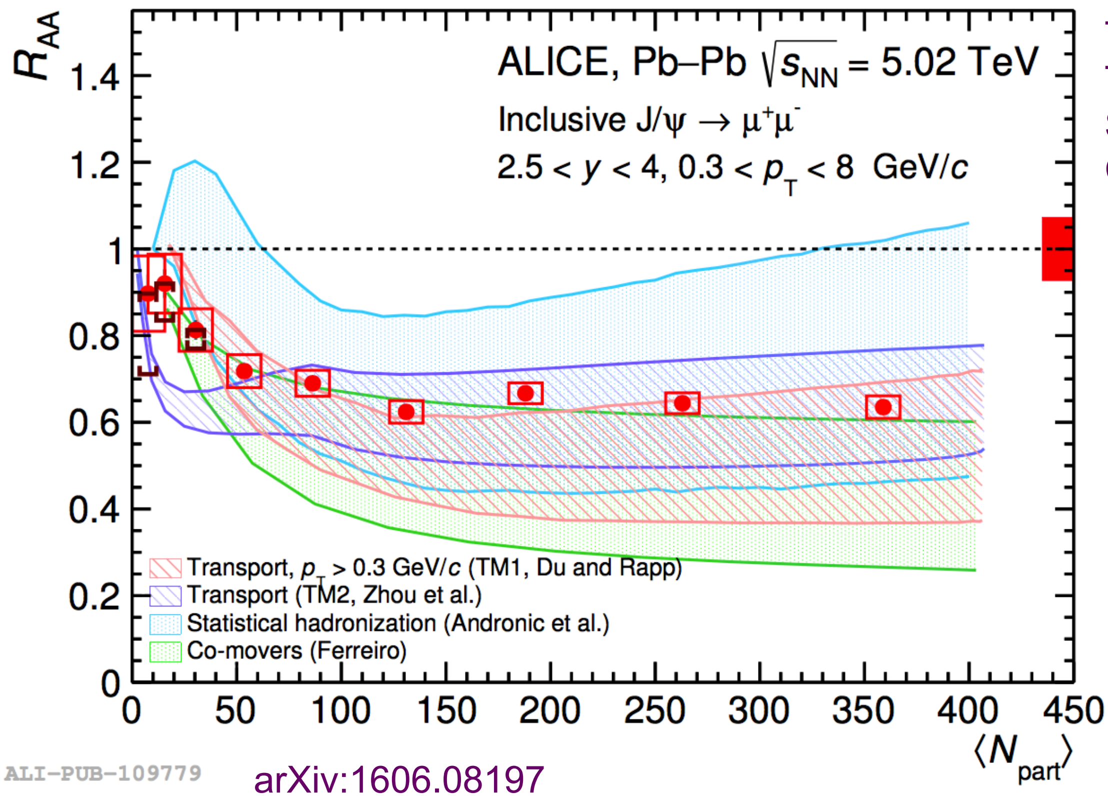
arXiv:1606.08197
PLB 734 (2014) 314-327

Clear J/ψ suppression and almost no centrality dependence for N_{part}>100 (centrality <50%)

Precision improved w.r.t. $\sqrt{s_{NN}}$=2.76 TeV data

Results consistent at mid and forward rapidity

J/ψ R_{AA} and models



arXiv:1606.08197

TM1: Nucl. Phys. A 859 (2011) 114–125
TM2: Phys. Rev. C 89 no. 5, 459 (2014) 054911
Stat. hadr.: Nucl. Phys. A 904-905 (2013) 535c
Comovers: Phys. Lett. B 731 (2014) 57–63

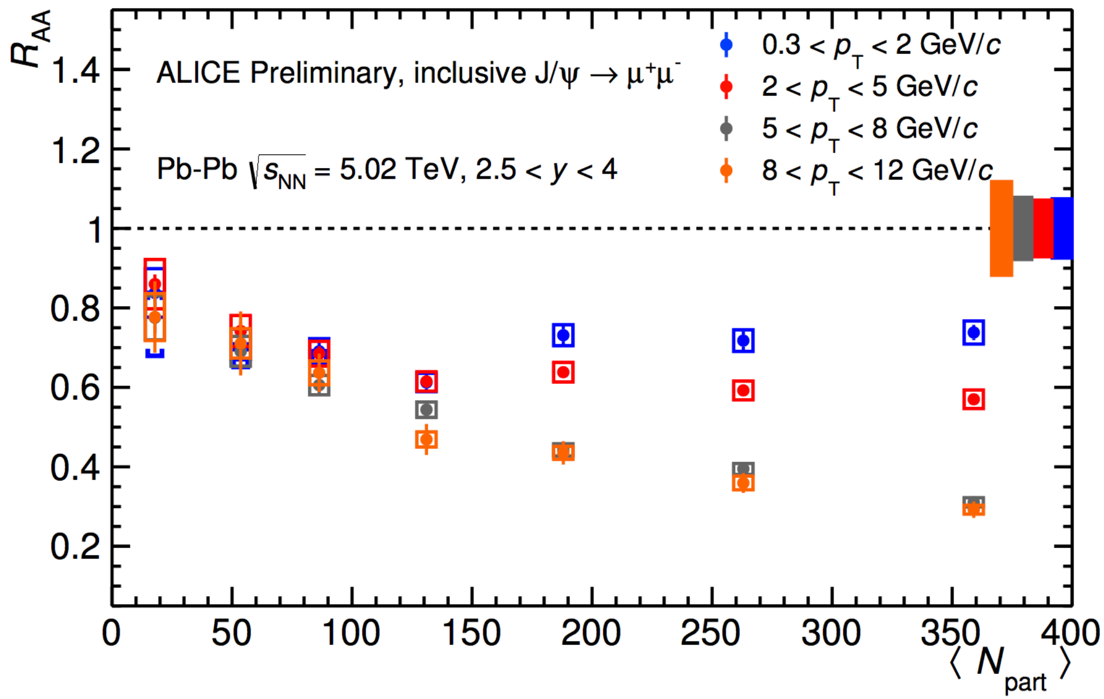
Uncertainties on models:

- charm cross section
- nPDF

Clear J/ψ suppression and almost no centrality dependence for N_{part}>100 (centrality <50%)

Measurement is precise to constrain the models

J/ψ R_{AA} in different p_T ranges

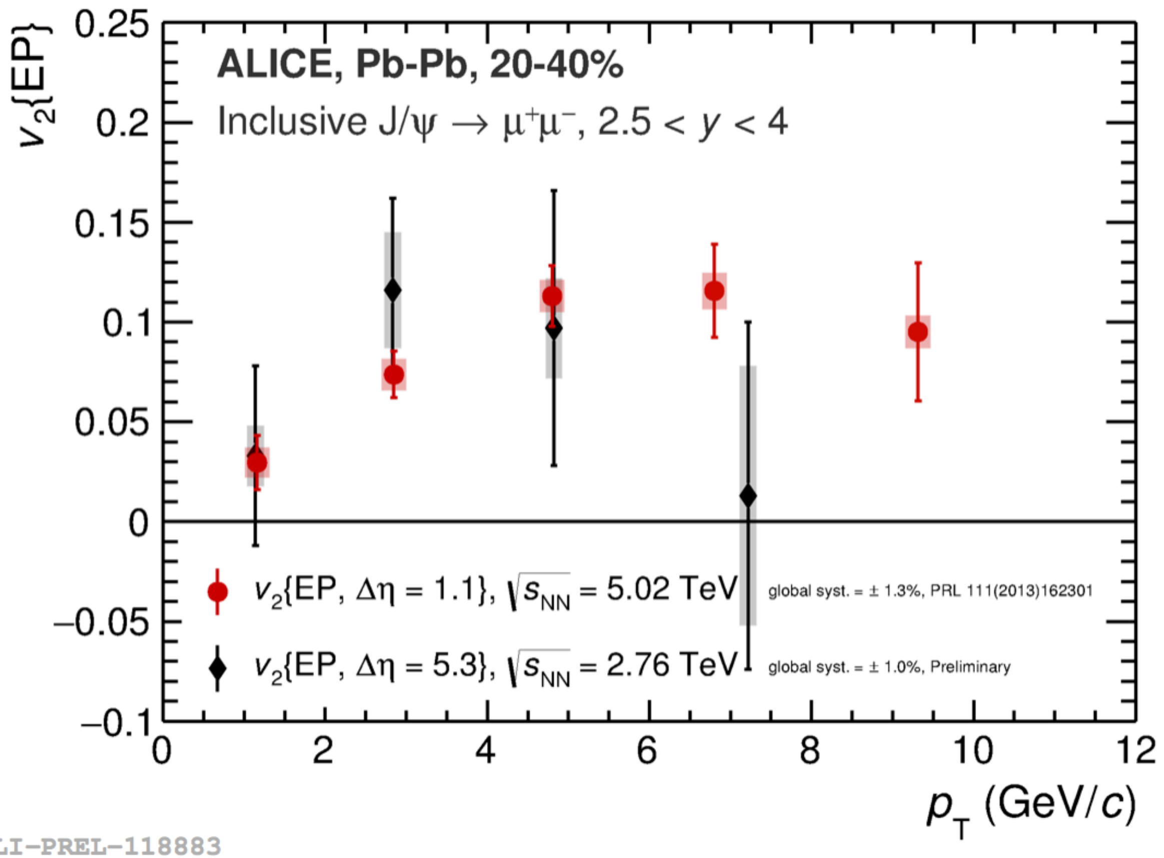


ALI-PREL-117114

If quarkonium formed by (re)combination of $c\bar{c}$ quarks close in momentum
→ it should be at low p_T

Central events: suppression is smaller at **lower p_T**
R_{AA} shows a stronger centrality dependence at **high p_T**

J/ψ elliptic flow



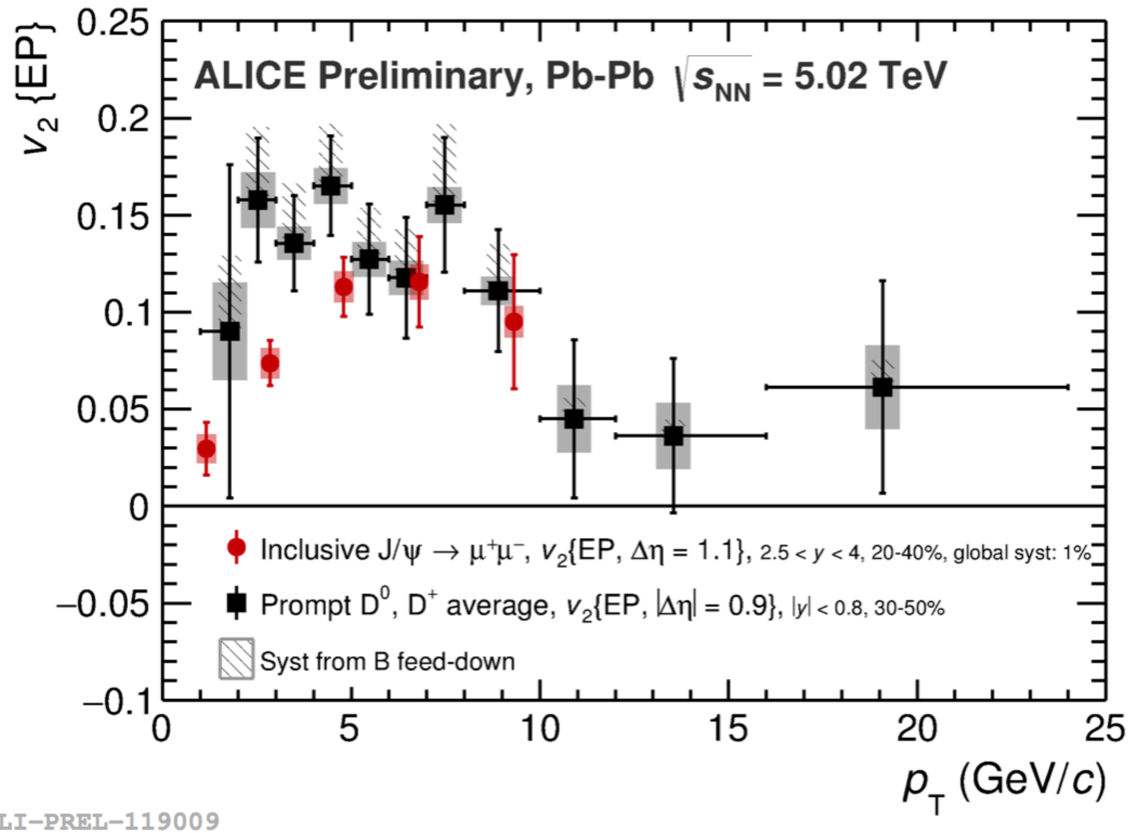
If quarkonium formed by (re)combination of $c\bar{c}$ quarks close in momentum
→ v_2>0

PRL 111 (2013) 162301

Positive v_2 in semi-central collisions (20-40%), 7.6σ significance in 4< p_T < 6 GeV/c at $\sqrt{s_{NN}}$=5.02 TeV

Improved precision w.r.t Run 1 results

J/ψ and D-meson elliptic flow



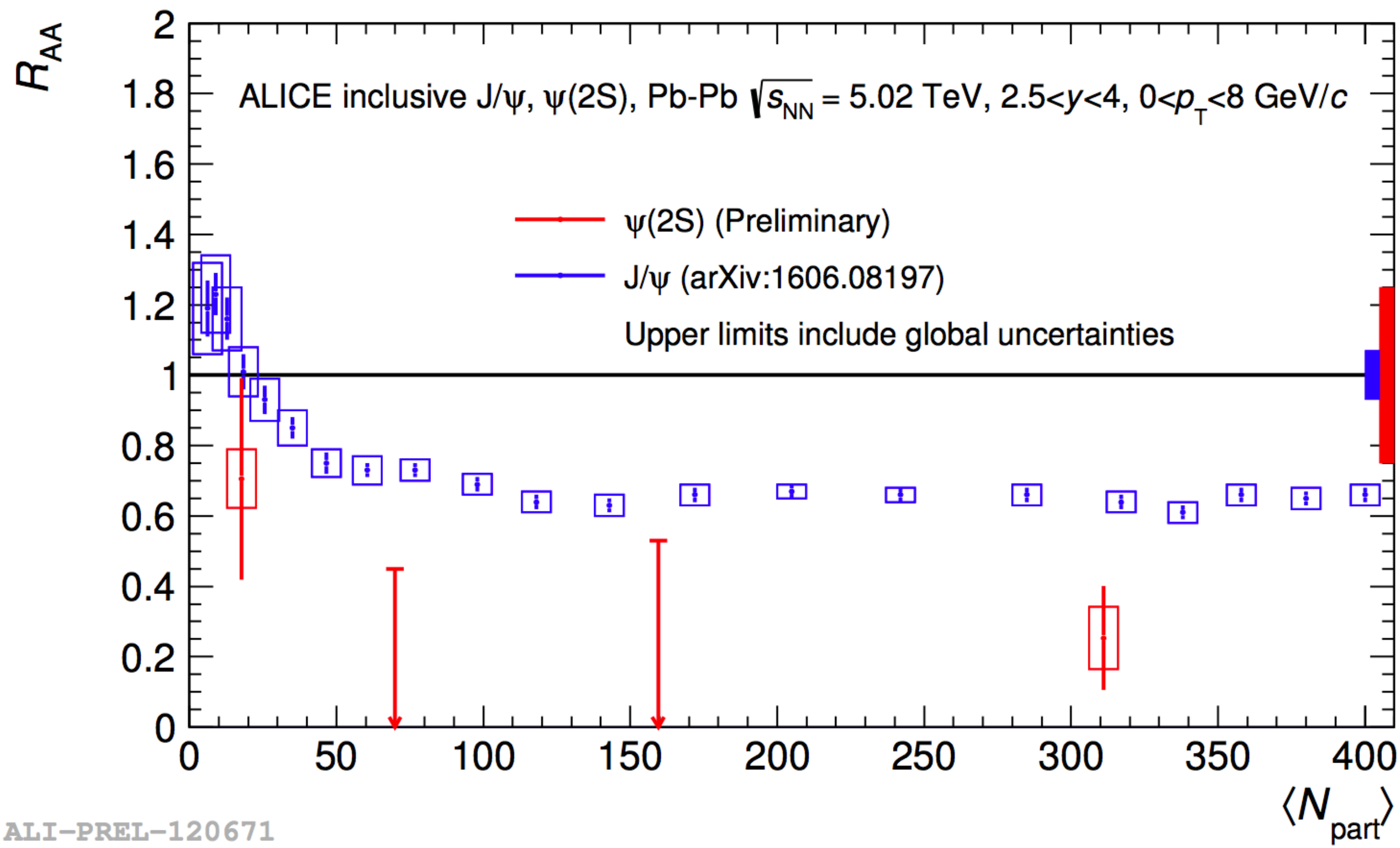
If quarkonium formed by (re)combination of $c\bar{c}$ quarks close in momentum
→ v_2>0

PRL 111 (2013) 162301

Positive v_2 in semi-central collisions (20-40%)

Similar v_2 values for **open** and **hidden** charm

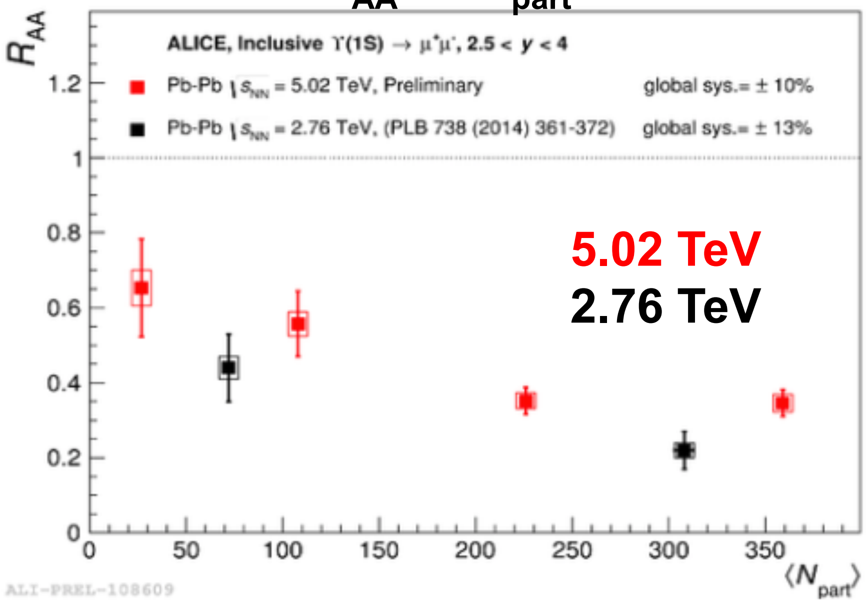
ψ(2S) R_{AA} vs centrality



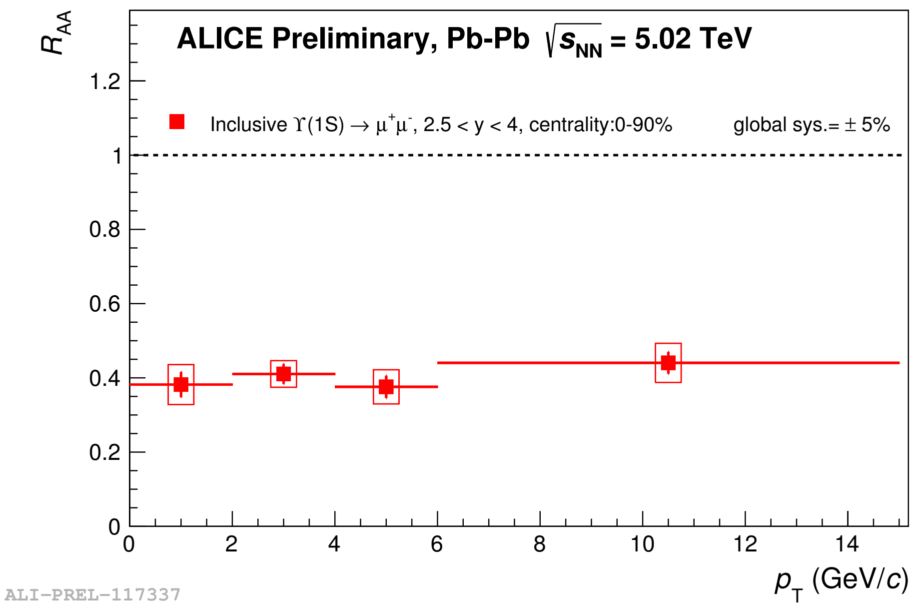
The **ψ(2S)** is more suppressed than the J/ψ in semi-central and central collisions

Bottomonia in ALICE: Υ(1S)

R_{AA} vs N_{part}



R_{AA} vs p_T

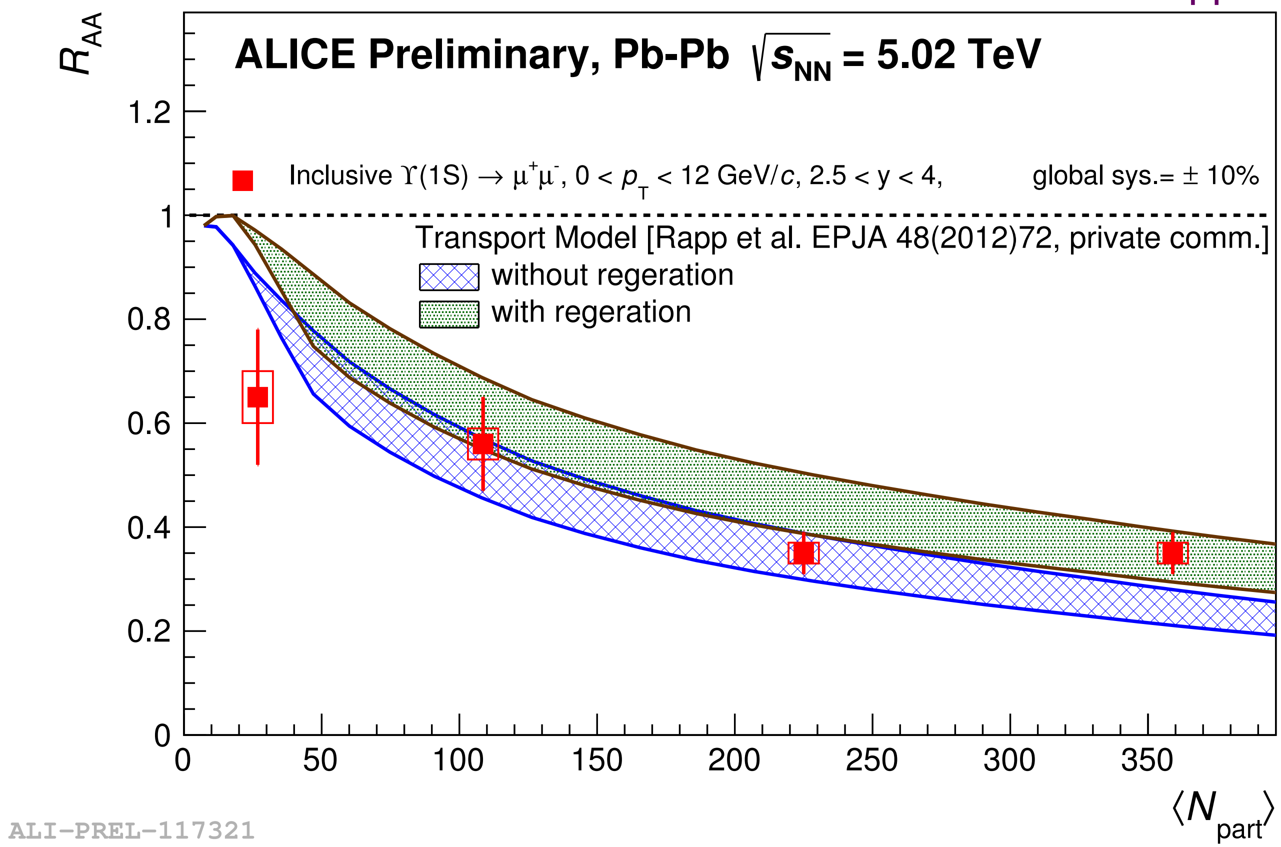


Strong suppression of Y(1S) in central collisions
Suppression increasing with centrality

No evident p_T dependence

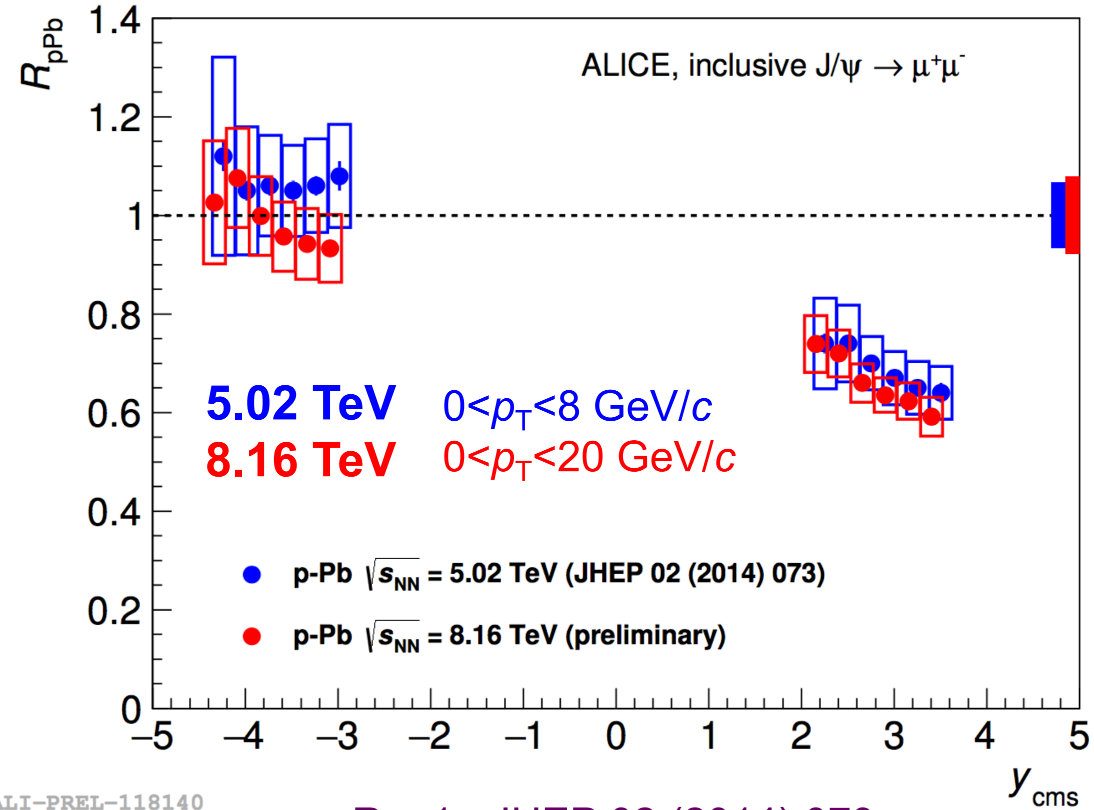
$\Upsilon(1S)$ R_{AA}: model comparison

Rapp et al. EPJA 48 (2012) 72

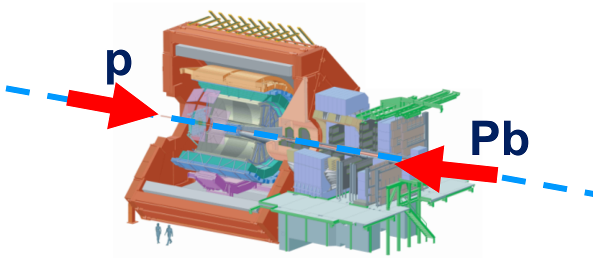


Different models with or without (re)generation component can describe the data within uncertainties

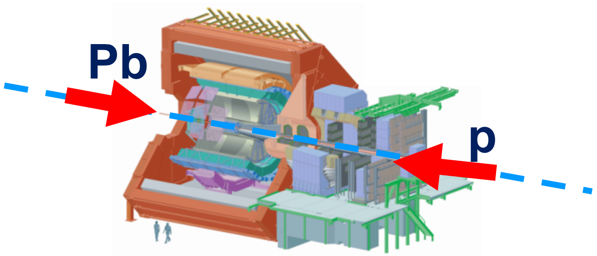
p-Pb: Cold Nuclear Matter effects in quarkonium production



Run1: JHEP 02 (2014) 073



2.03<y_{CMS}<3.53
x~10^{-5}

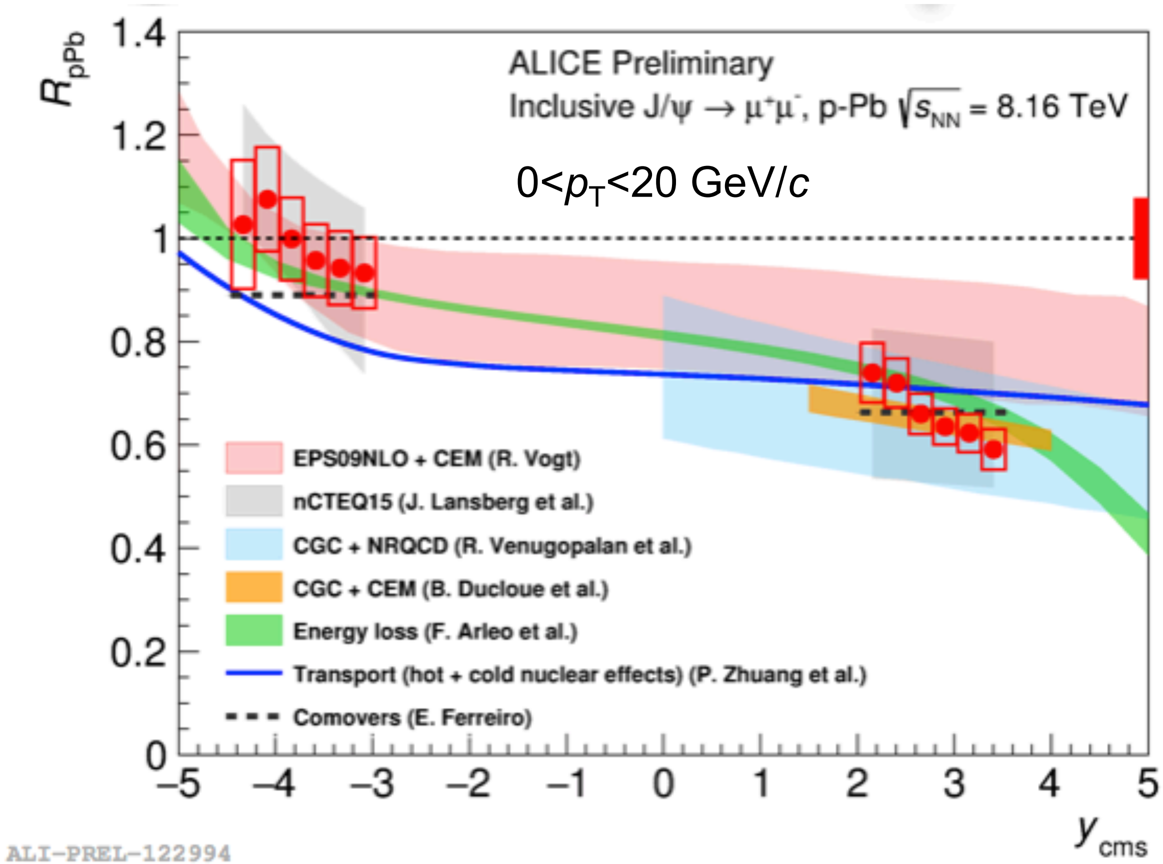


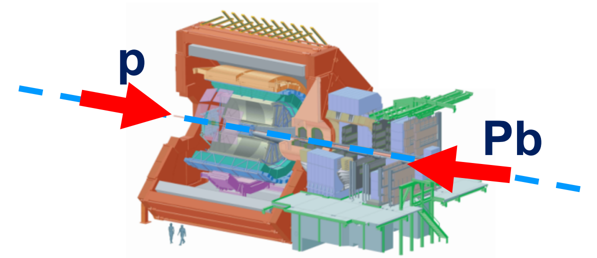
-4.46<y_{CMS}<-2.96
x~10^{-2}

Clear suppression at positive y, and compatible with unity at negative y

R_{pPb} at $\sqrt{s_{NN}}$= 8.16 TeV is similar to the one measured at $\sqrt{s_{NN}}$= 5.02 TeV

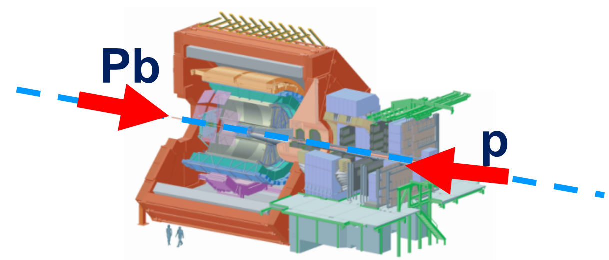
p-Pb: Cold Nuclear Matter effects in quarkonium production





$2.03<y_{CMS}<3.53$

$x \sim 10^{-5}$



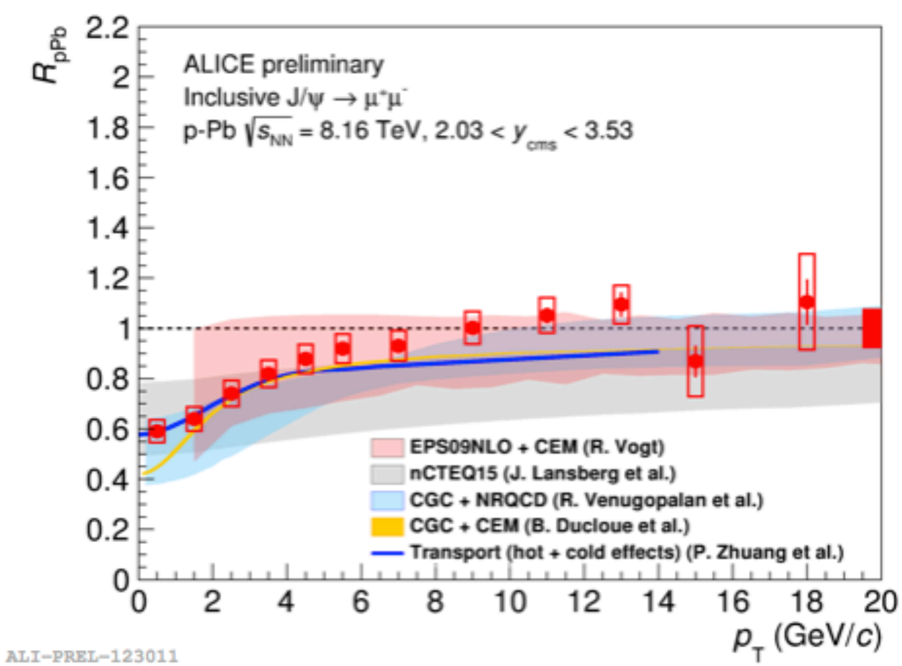
$-4.46<y_{CMS}<-2.96$

$x \sim 10^{-2}$

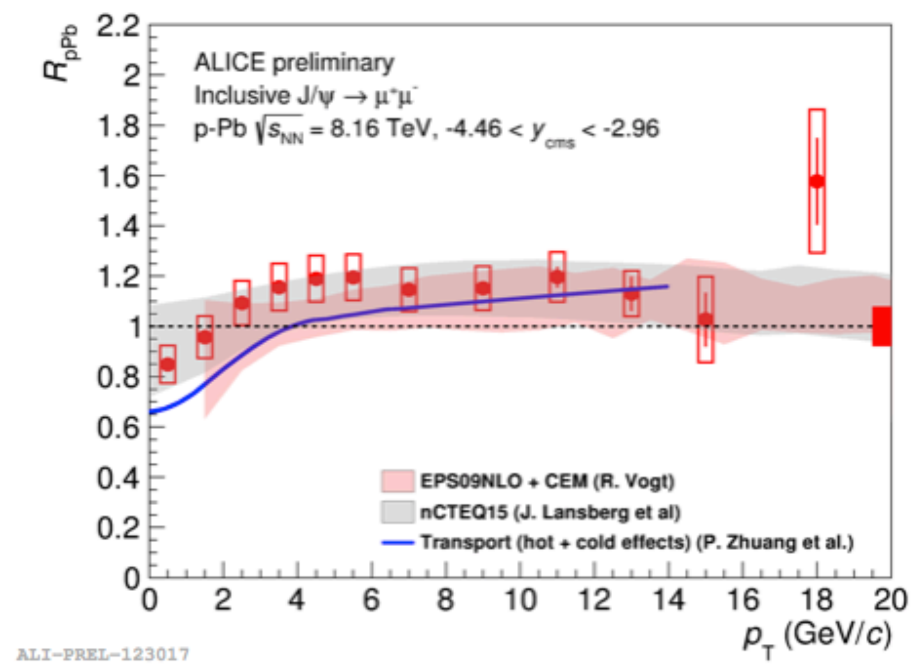
J/ψ production is modified in p-A because of CNM effects at forward rapidity
Reasonable agreement with theoretical predictions (shadowing/e.loss/CGC depend on y)

J/⊖ in p-Pb collisions at 8.02 TeV

p-going (forward)



Pb-going (backward)



The suppression is higher at low p_T for the positive rapidity range

Different models (shadowing, energy loss, CGC) can describe well the data in the two rapidity ranges

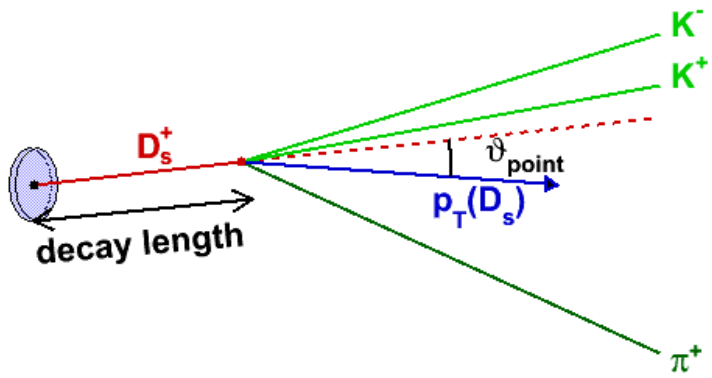
Conclusions

- Large array of heavy-flavour and quarkonium measurements
  - pp provides test pQCD (and more), p(d)-A is the system to study **CNM effects**, but also different *x* regimes and possible collective effects
- Open charm/beauty strongly affected by the medium
  - strong HF **suppression** intermediate/high p_T
  - **mass dependence** of suppression trends in agreement with models
  - **c quarks participate to collective motion (v_2>0 for D and J/⊖)**
- Quarkonia
  - **J/ψ (re)generation** relevant at LHC energies, J/ψ **flows!**
  - ψ(2S) more suppressed than J/ψ
  - strong **suppression of ϒ**
- Next: more precise measurements to sharpen the conclusions
  - **detector and LHC upgrades**
  - Smaller uncertainties, new differential measurements will help to **further constrain theory** (and add information on path-length dependence of energy loss, energy loss mechanisms, thermalization, hadronization, …)

Backup

Measurements of Heavy Flavours in ALICE: D mesons

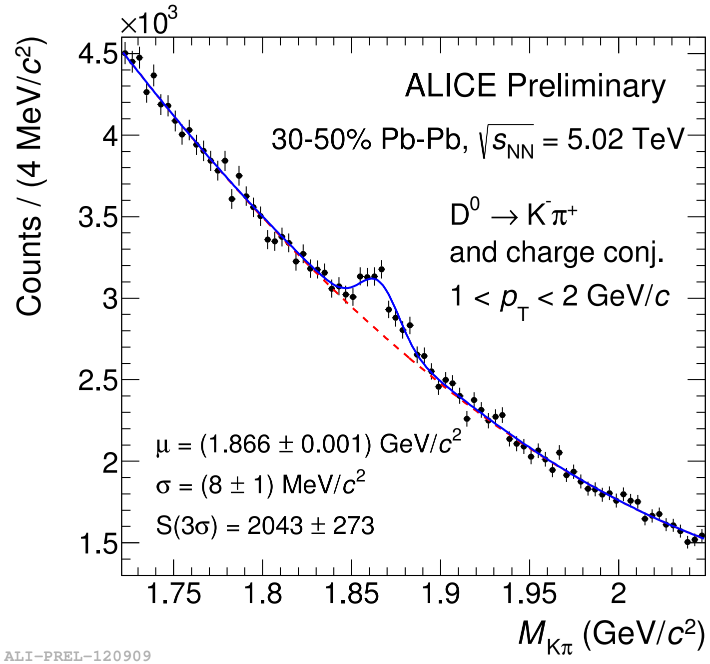
$D^0 \to K^-\pi^+$	BR: 3.88%
$D^{*+} \to D^0(\to K^-\pi^+)\pi^+$	BR: 2.63%
$D^+ \to K^-\pi^+\pi^+$	BR: 9.13%
$D_s^+ \to \phi(\to K^+K^-)\pi^+$	BR: 2.24%



Invariant mass analysis based on displaced secondary vertices, selected with topological cuts and PID

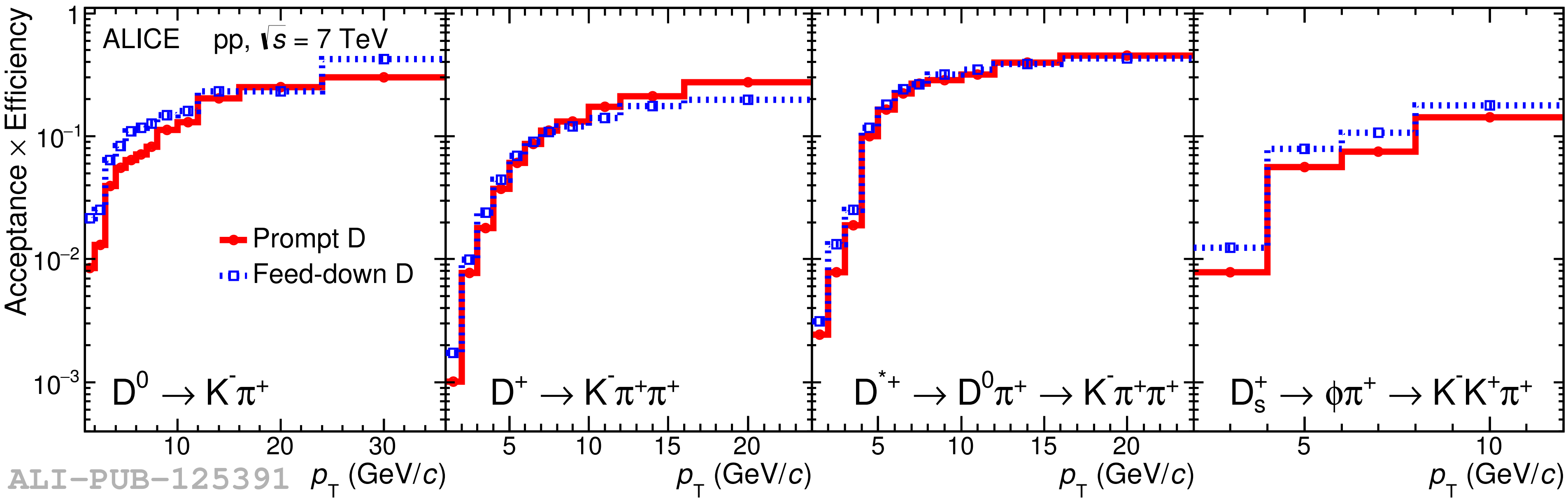
Correction for beauty feed-down (based on FONLL pQCD calculation) to extract results for prompt D mesons

FONLL: JHEP, 1210 (2012) 137

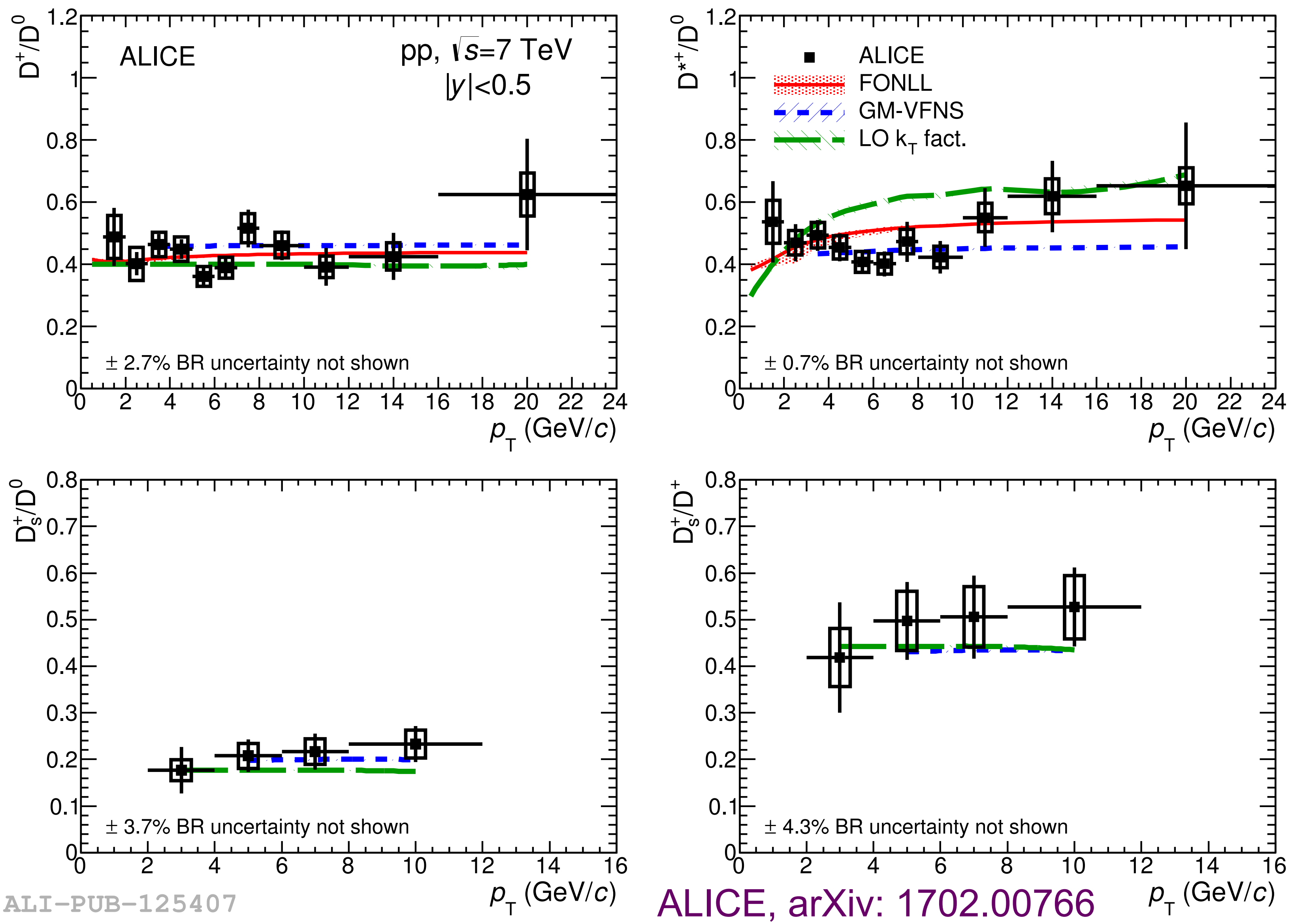


D-meson efficiencies in pp 7 TeV

ALICE, arXiv: 1702.00766



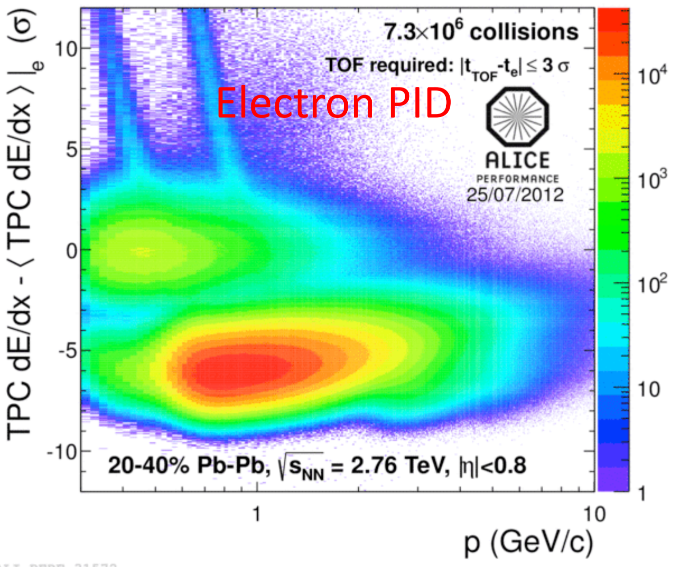
D-meson ratios in pp 7 TeV



ALICE, arXiv: 1702.00766

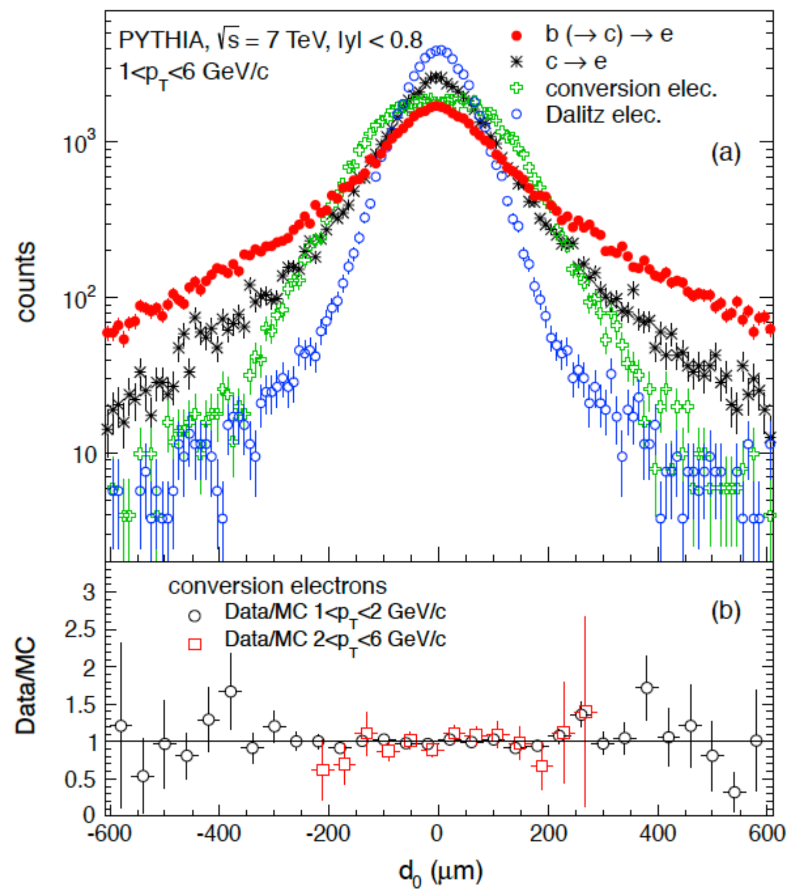
Measurements of Heavy Flavours in ALICE: electrons

Electrons: mid-rapidity



Beauty-decay electrons: extra cut on impact parameter, separation via e-h correlations

Phys.Lett. B721 (2013) 13-23



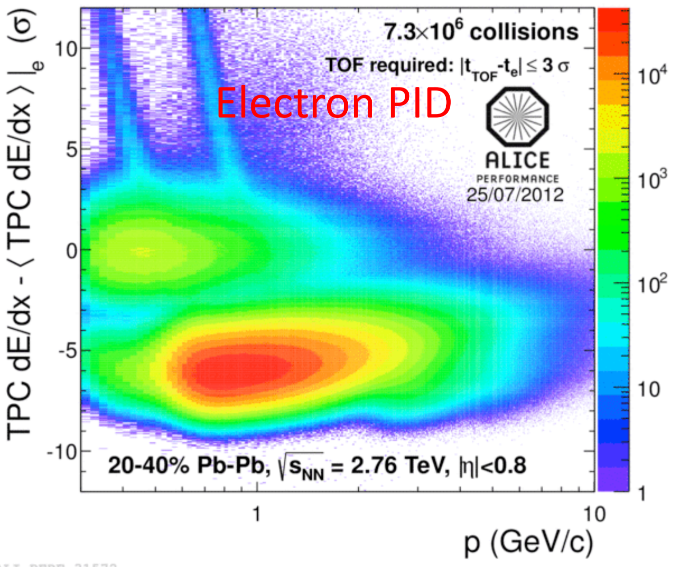
Background (mainly π^0/η Dalitz decays, photon conversions) subtracted with:

→ Invariant mass of low-mass e^+e^- pairs

→ Cocktail of different background sources with MC hadron-decay generator

Measurements of Heavy Flavours in ALICE: electrons/muons from c and b

Electrons: mid-rapidity



Background (mainly π^0/η Dalitz decays, photon conversions) subtracted with:

→ Invariant mass of low-mass e^+e^- pairs

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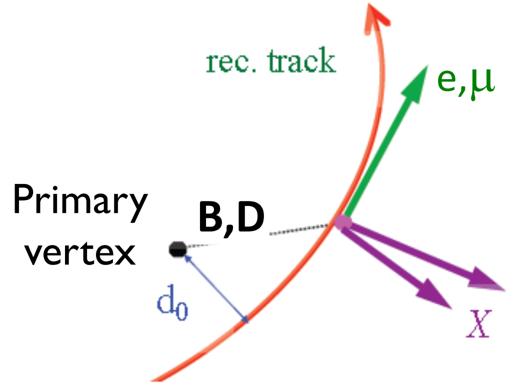
Beauty-decay electrons: extra cut on impact parameter, separation via e-h correlations

Muons: forward rapidity



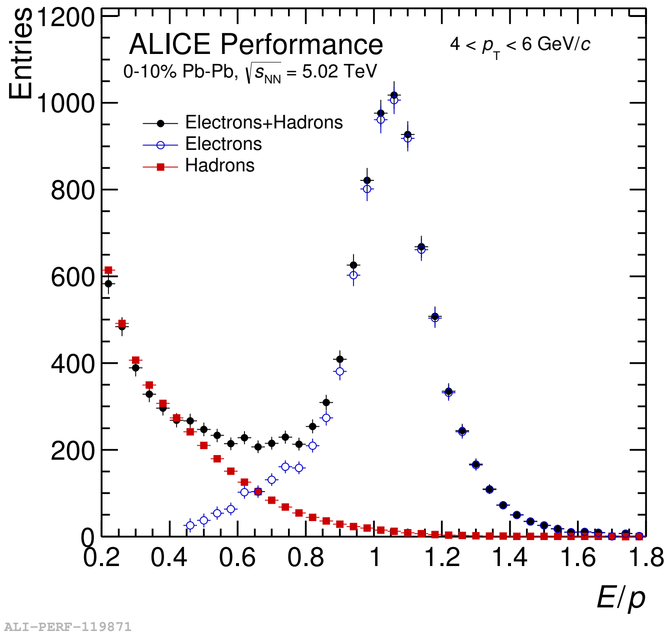
Geometrical cuts, track matching with trigger (from muon chambers)

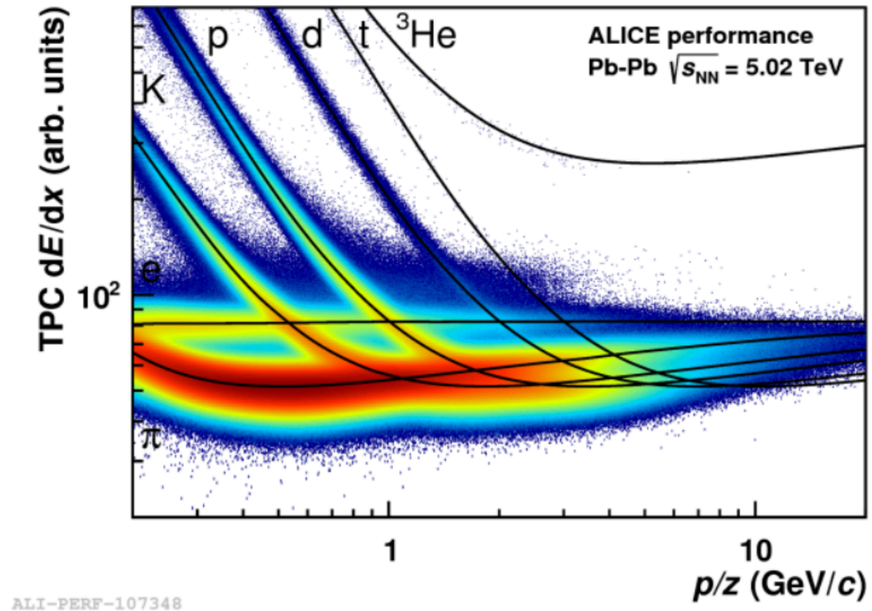
Impact parameter cut to reject part of beam-gas interactions and decays

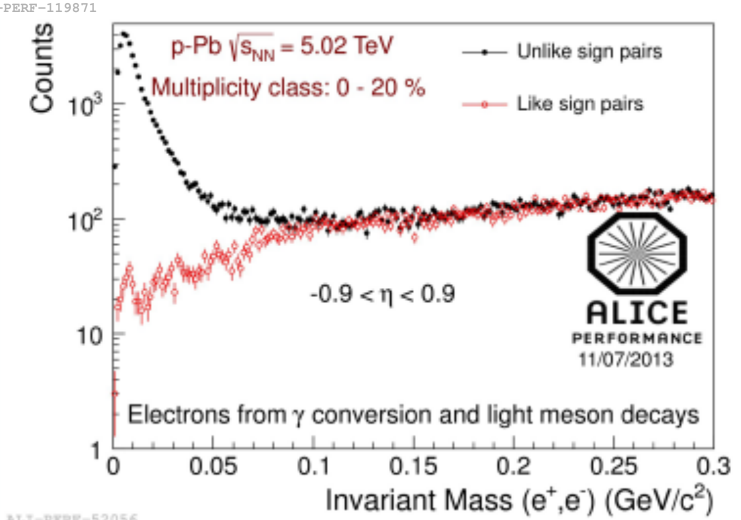
Remaining background (π,K→μ) subtracted with MC (pp) and data-tuned MC cocktail (p-Pb, Pb-Pb)

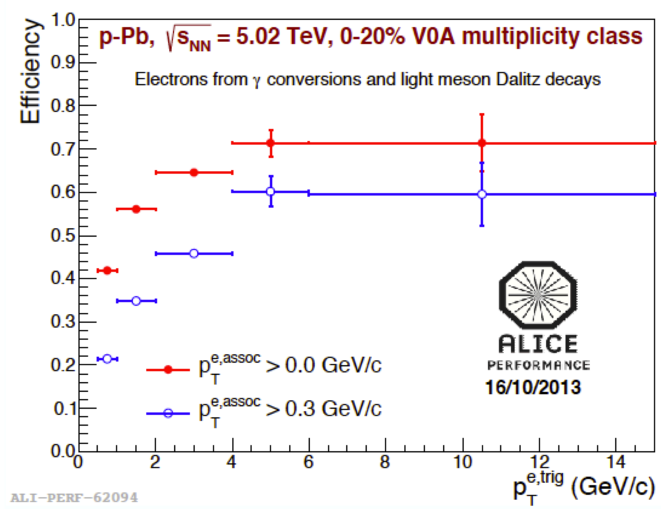
Low p_T cut to reject π, K decays > 2 (4) GeV/c in pp, p-Pb (Pb-Pb)

Electron identification



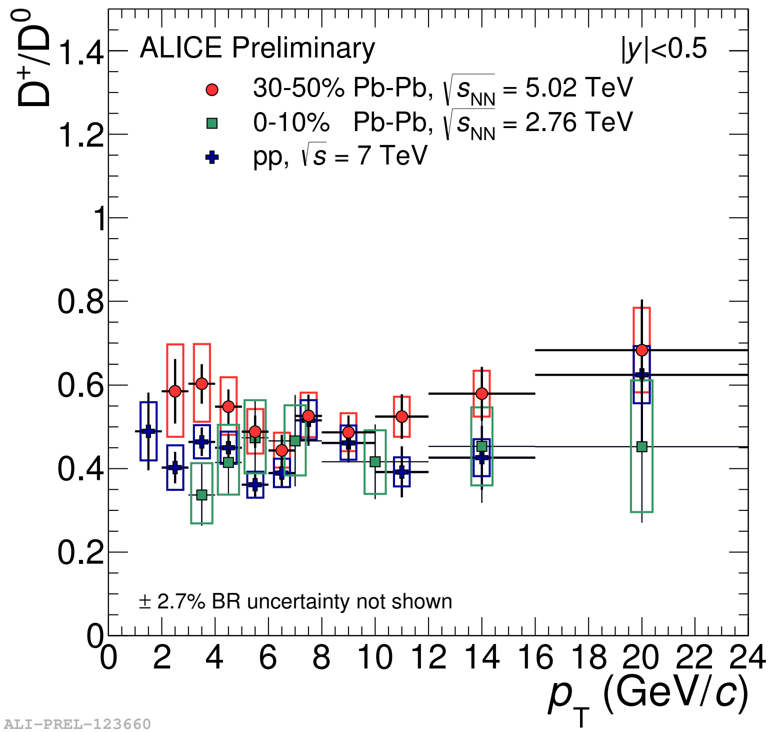




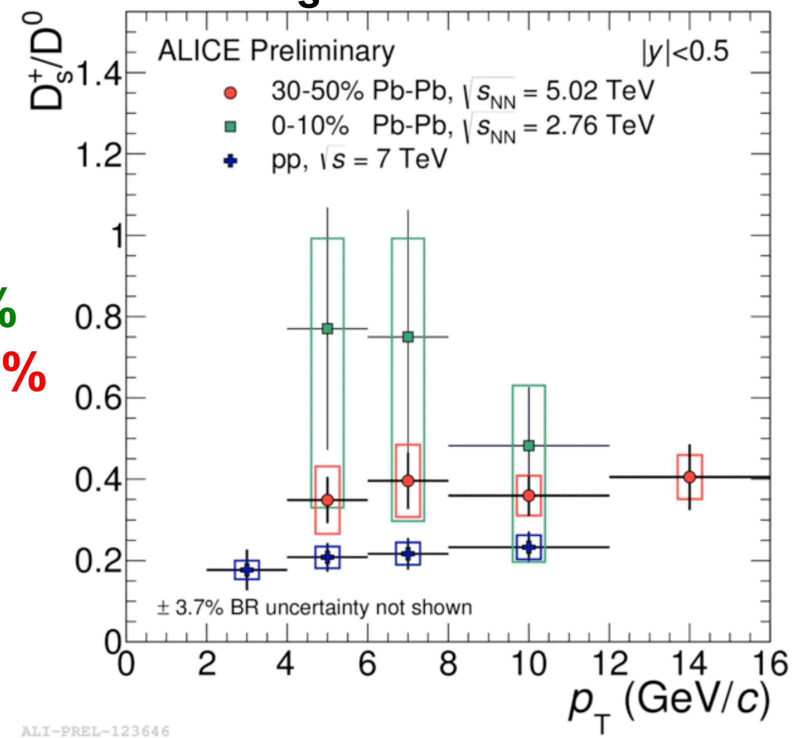


Charm meson ratios

D^+/D^0



D_s/D^0

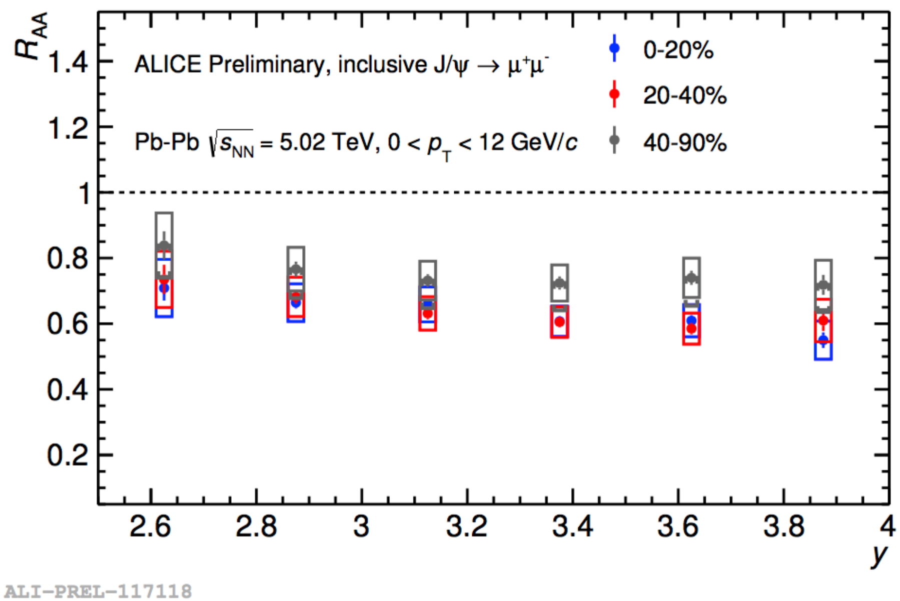


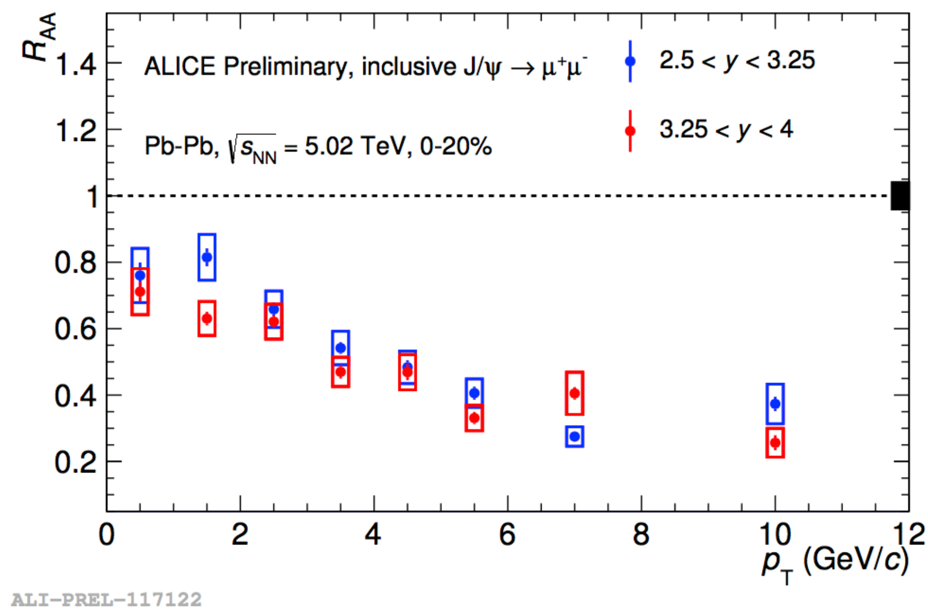
PbPb 0-10%
PbPb 30-50%
pp

D^+/D^0 ratio: compatibility between different collision systems
D_s/D^0 ratio: increasing trend from **pp** to **semi-central** to **central** Pb-Pb.

J/ψ rapidity dependence

- Rapidity dependence of the R_{AA} is studied in three centrality ranges

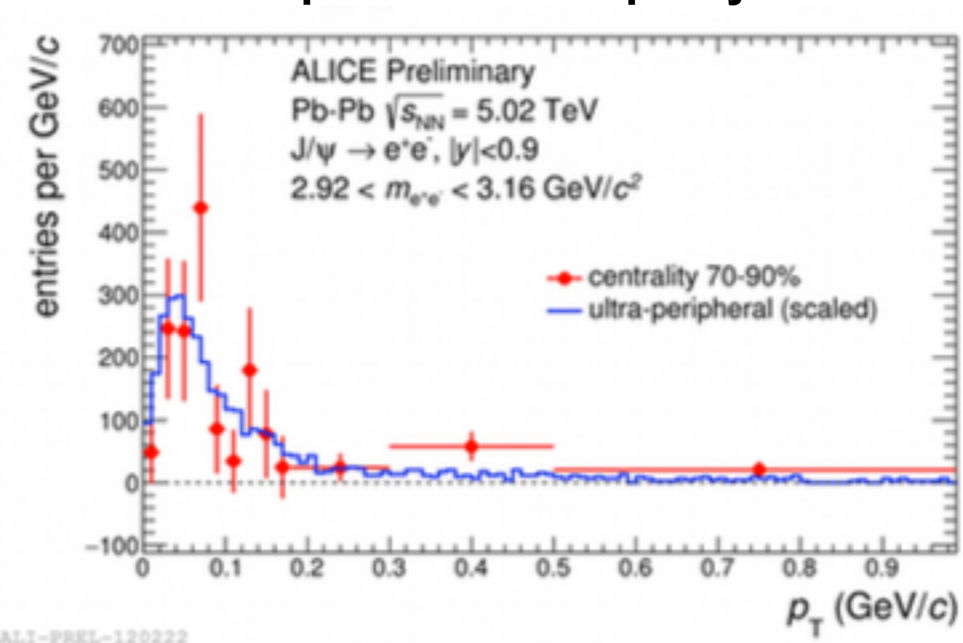




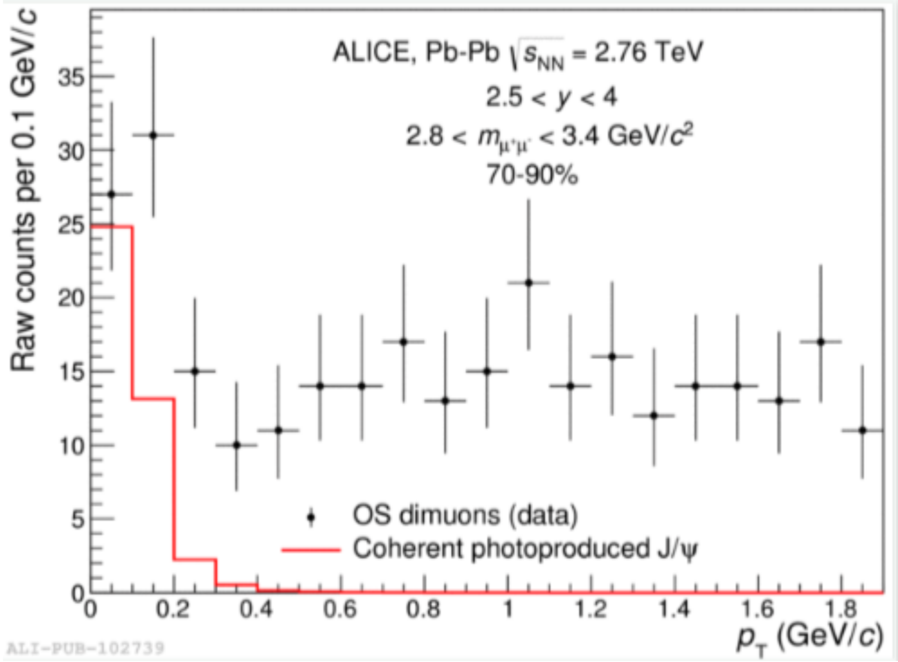
- A negligible rapidity dependence of the R_{AA} in different centrality and p_T ranges
- Would be interesting to have comparison with model calculations !

Low-p_T J/ψ excess

J/ψ → e^+e^- mid rapidity



J/ψ → $\mu^+\mu^-$ forward rapidity



In agreement with measurements in ultra-peripheral collisions → mostly coherent photoproduction origin