Measurement of charm suppression in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV via D mesons reconstruction in ALICE

High p_T Physics at LHC
Frankfurt 2012

D. Caffarri for the ALICE Collaboration
University of Padova – INFN Sez. di Padova

Outline

- ✧ Parton in-medium energy loss
- ✧ D mesons reconstruction strategy in ALICE
- ✧ D mesons cross section in pp collisions at $\sqrt{s}$ = 7 TeV
- ✧ D mesons yields in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- ✧ Results on D meson suppression in Pb-Pb collisions

Outline

- Parton in-medium energy loss
- D mesons reconstruction strategy in ALICE
- D mesons cross section in pp collisions at $\sqrt{s}$ = 7 TeV
- D mesons yields in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- Results on D meson suppression in Pb-Pb collisions

Parton energy loss

"Hard probes" are produced:

- with hard partonic scatterings
- in a very short time scale

⇓

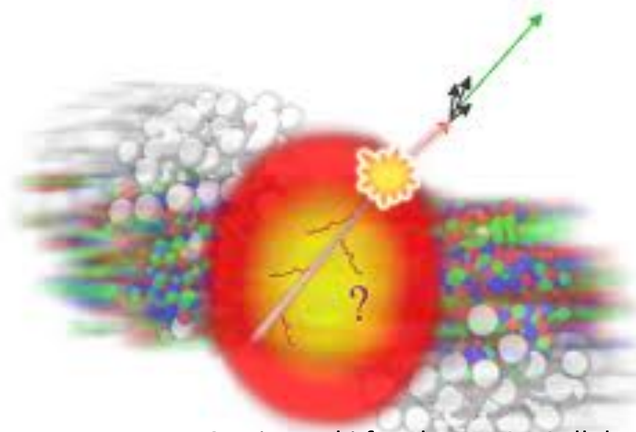
interaction with the medium

⇓

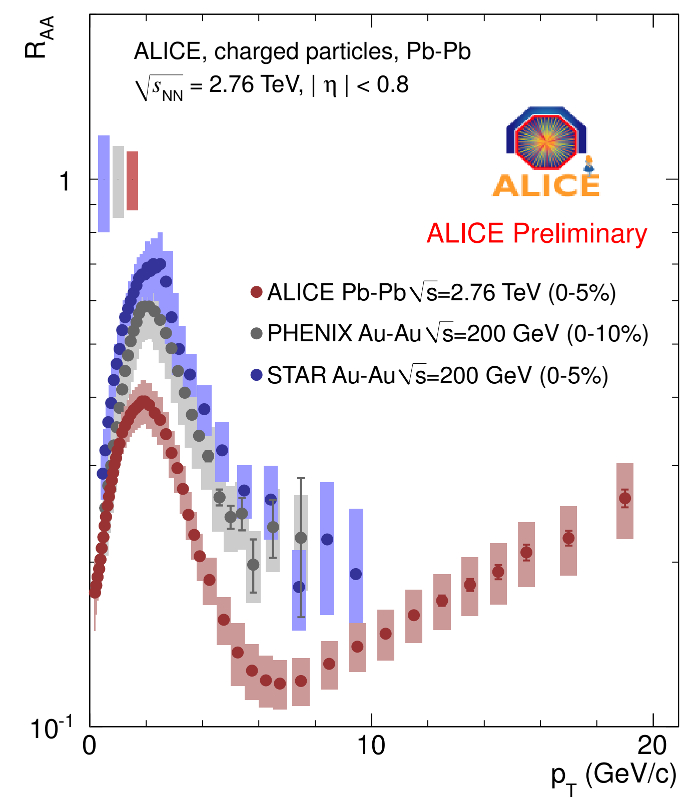
parton energy loss

NUCLEAR MODIFICATION FACTOR

$$R_{AA} = \frac{dN_{AA}/dp_t}{\langle N_{coll} \rangle \times dN_{pp}/dp_t}$$



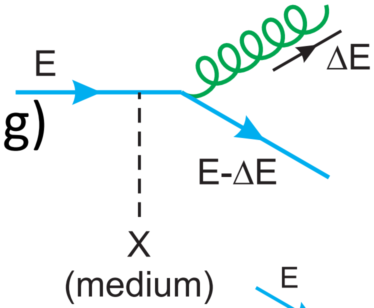
J. Otwinowski for the ALICE Collaboration,
Quark Matter 2011 proceedings arXiv:1110.2985v1



Energy loss mechanisms

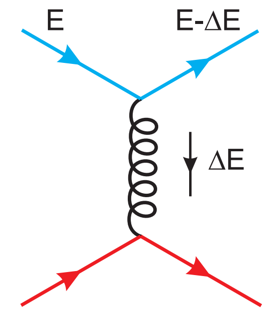
Parton energy loss by:

- medium-induced gluon radiation (inelastic scattering)



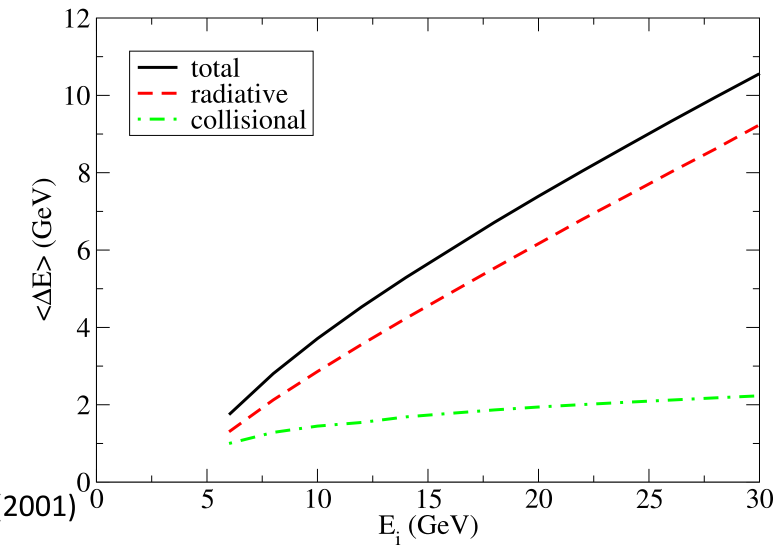
$$\Delta E = \Delta E(\varepsilon, L, C_R, m)$$

- collisions with in-medium partons



The total energy loss:

- dominating contribution radiative energy loss
- small fraction due to elastic collisions



P. Arnold, G.D. Moore and L.G.Yaffe, JHEP 0011, 057, (2001)

Heavy quark energy loss

Gluon radiation of heavy quarks is suppressed due to the introduction of a mass term in the heavy quark propagator.

Dead cone effect

Energy distribution of the radiated gluons

$$\omega \frac{dI_{rad,Q}}{d\omega} = \omega \frac{dI_{rad}}{d\omega} \cdot \left(1 + \frac{\theta_0^2}{\theta^2}\right)^{-2}, \ \theta_0 = \frac{M}{E} = \frac{1}{\gamma}$$

Y.L. Dokshitzer, V.A. Khoze and S.I. Troian, J. Phys. G 17, 1602 (1991);
Y.L. Dokshitzer and D.E. Kharzeev, Phys. Lett. B 519, 199 (2001).

Energy loss **colour charge** dependence

$$\langle \Delta E \rangle \propto C_R$$

$gg \ C_R = 3$

$qg \ C_R = 4/3$

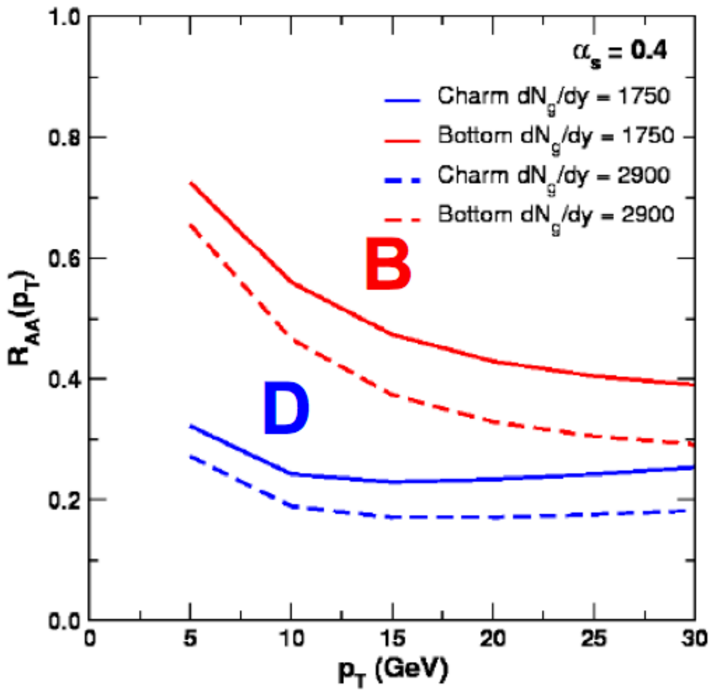
Energy loss **quark mass** dependence

ΔE(light) >ΔE(c) > ΔE(b) → R_{AA} (π) < R_{AA} (D) < R_{AA} (B)

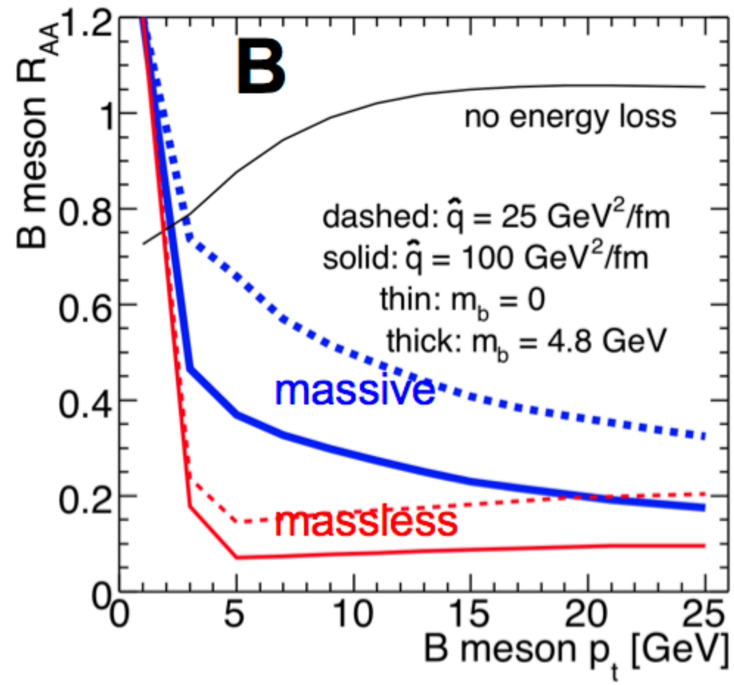
Heavy quarks E. loss: some predictions

Energy loss based predictions (*):
- factor 3-5 suppression for D mesons
- smaller suppression for B mesons

Pb-Pb collisions at √s = 5.5 TeV



Wicks, Gyulassy,
"Last Call for LHC Predictions" workshop, 2007



Armesto, et al. PRD71 (2005) 014003

(*) not up to date predictions.
New predictions at the end...

Outline

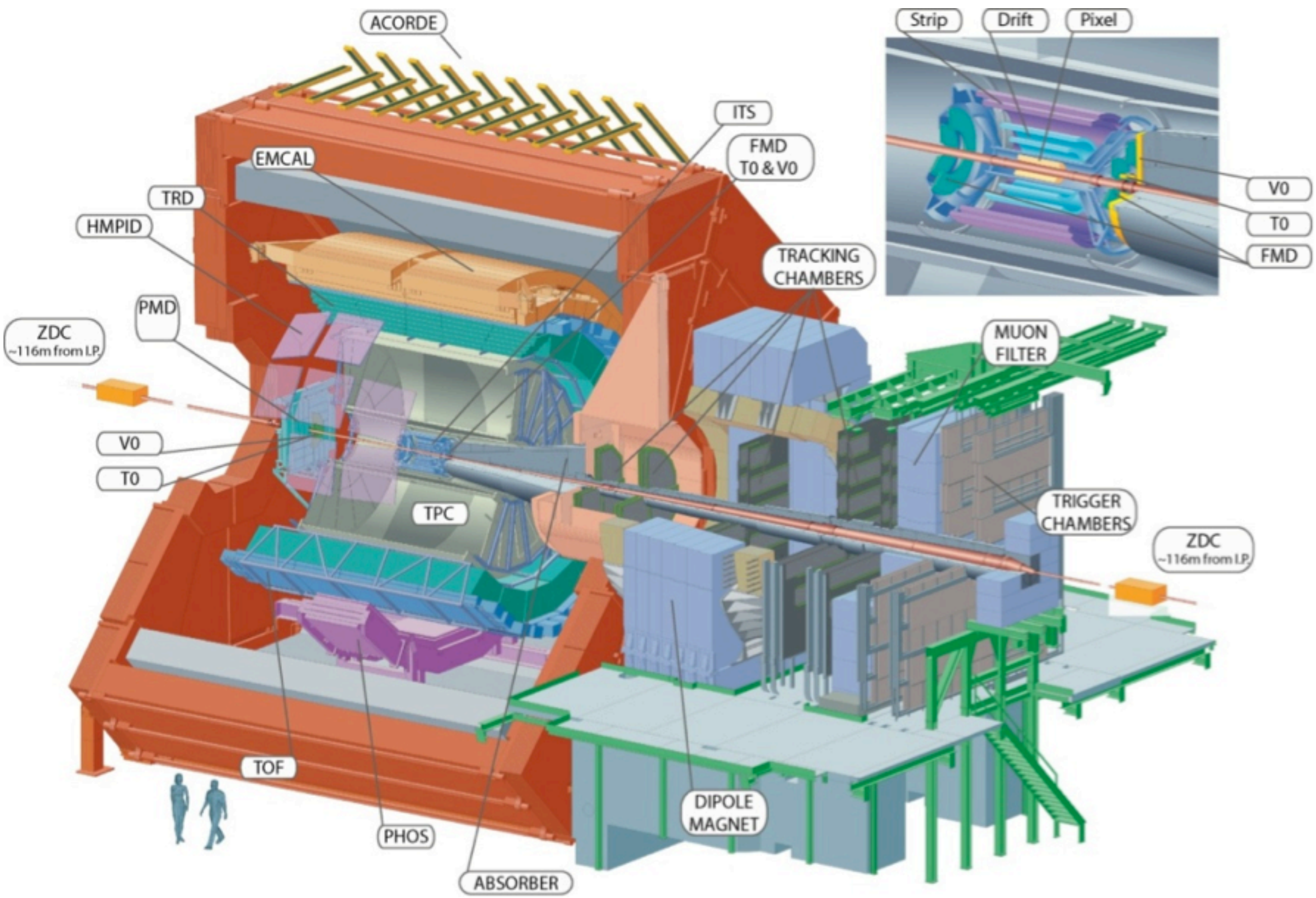
- ✧ Parton in-medium energy loss
- ✧ D mesons reconstruction strategy in ALICE
- ✧ D mesons cross section in pp collisions at $\sqrt{s}$ = 7 TeV
- ✧ D mesons yield in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- ✧ Results on D meson suppression in Pb-Pb collisions

A Large Ion Collider Experiment - ALICE

Trigger:
Silicon Pixel Detector (SPD), V0

Tracking:
Inner Tracking System (ITS), Time Projection Chamber (TPC)

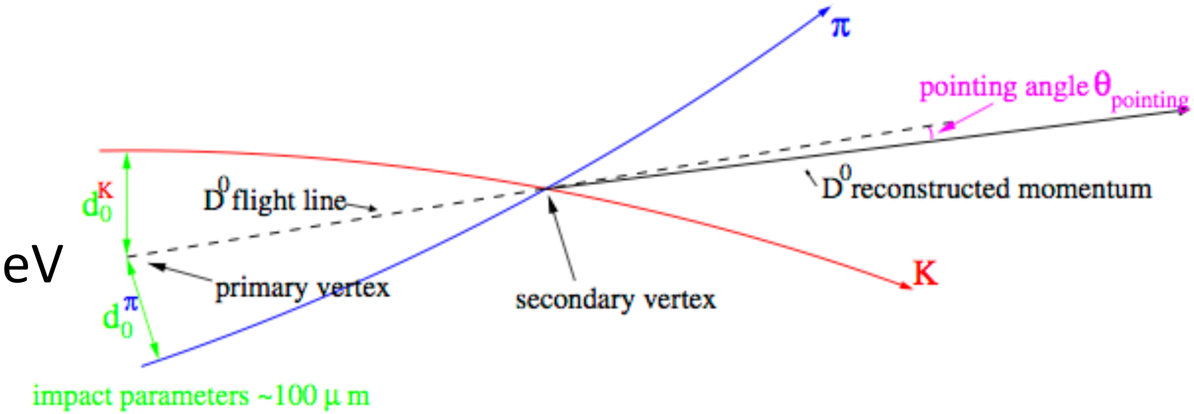
PID:
Time Of Flight (TOF), TPC



D mesons reconstruction strategy

D mesons full hadronic reconstruction.

$D^0 \rightarrow K^-\pi^+$
Mass = 1864.80 ± 0.14 MeV
cτ = 123 μm



$D^+ \rightarrow K^+\pi^-\pi^+$
Mass = 1869.60 ± 0.16 MeV
cτ = 311.8 μm

$D^{*+} \rightarrow D^0 \pi^+$
Mass = 2010.25± 0.14 MeV

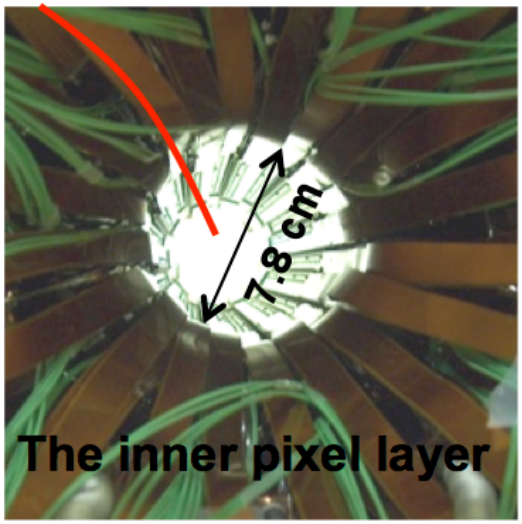
Invariant mass analysis mainly based on:

- secondary vertex reconstruction
- kaon identification

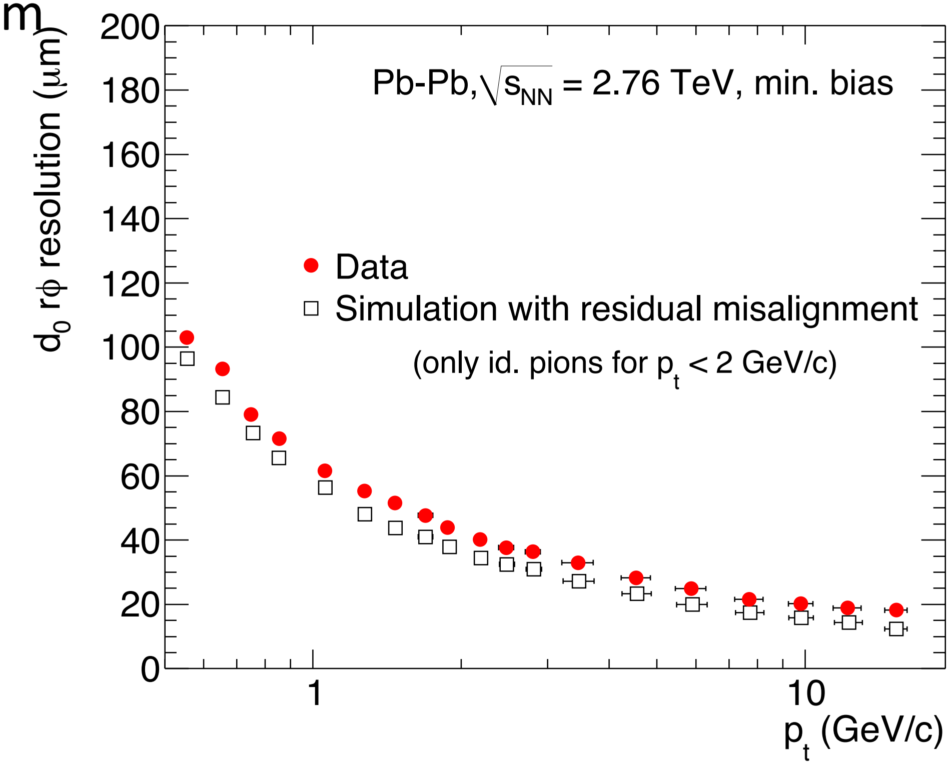
Secondary vertex reconstruction

Displaced vertex topology:

- tracking and vertexing precision crucial for heavy flavour analysis
- Inner Tracking System with 6 Si layers:
  two pixel layers at 3.9 cm and 7 cm



ALICE Collaboration arXiv:1203.2160

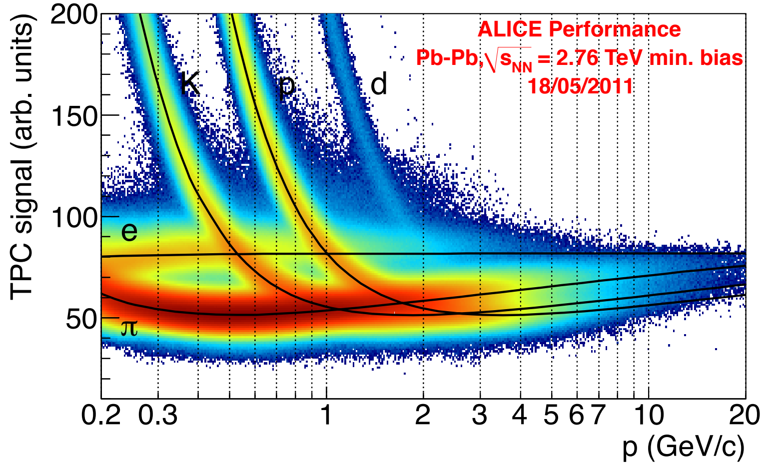


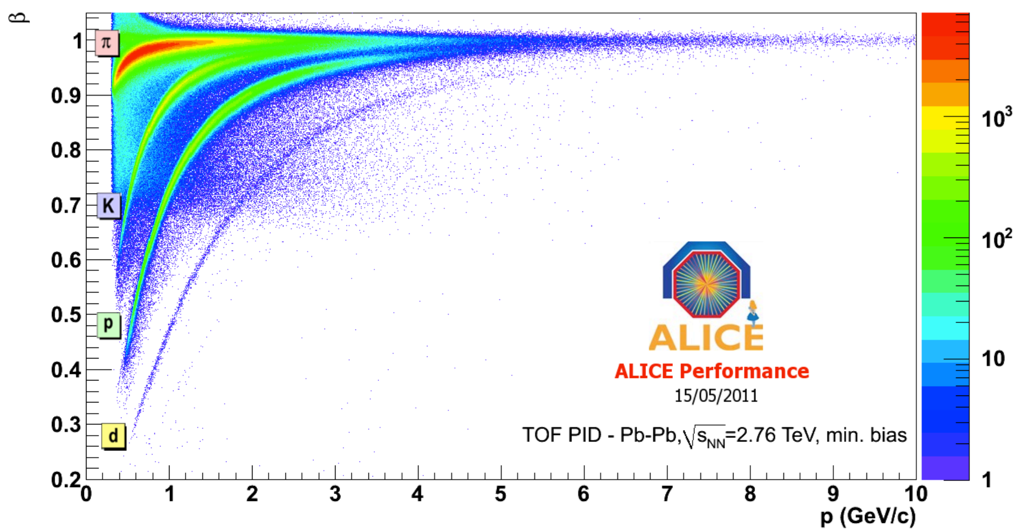
Impact parameter resolution ~ 60μm for p_t = 1 GeV/c

Particle Identification - PID

Conservative PID strategy used to identify the kaon candidates.
Kaons are identified via:

- the energy loss deposit in the TPC (0.6 < p < 0.8 GeV/c 2σ cut)
- the velocity measurement in the TOF (p < 2 GeV/c 3σ cut)





Keep the signal loss as small as possible
Background reduction by a factor 3 for central Pb-Pb collisions.

R_{AA} ingredients….

$$R_{AA} = \frac{dN_{AA}/dp_t}{\langle N_{coll} \rangle \times dN_{pp}/dp_t} = \frac{dN_{AA}/dp_t}{\langle T_{AA} \rangle \times d\sigma_{pp}/dp_t}$$

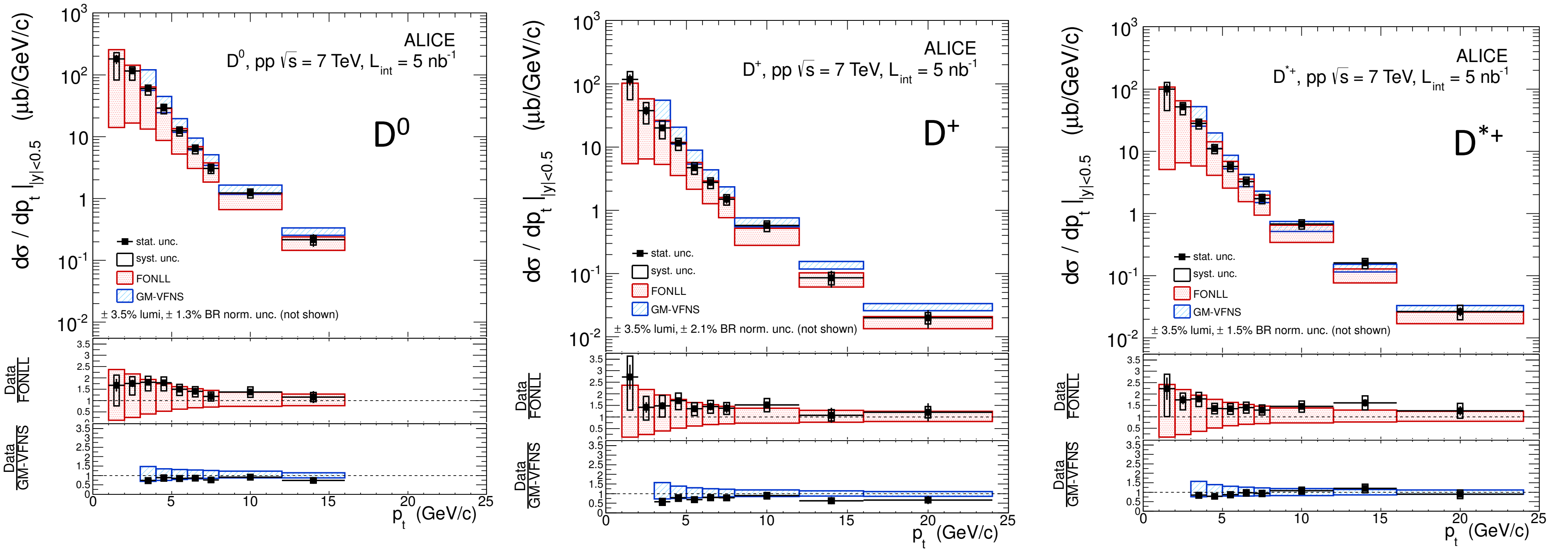
- Glauber fit: measurement of N_{coll} and T_{AA}
- pp reference at √s = 2.76 TeV
- Corrected yields in Pb-Pb collisions

Outline

- Parton in-medium energy loss
- D mesons reconstruction strategy in ALICE
- D mesons cross section in pp collisions at $\sqrt{s}$ = 7 TeV
- D mesons yield in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- Results on D meson suppression in Pb-Pb collisions

D mesons cross section in pp collisions at 7 TeV

[ALICE Collaboration], JHEP 1201, 128 (2012) [arXiv:1111.1553 [hep-ex]].

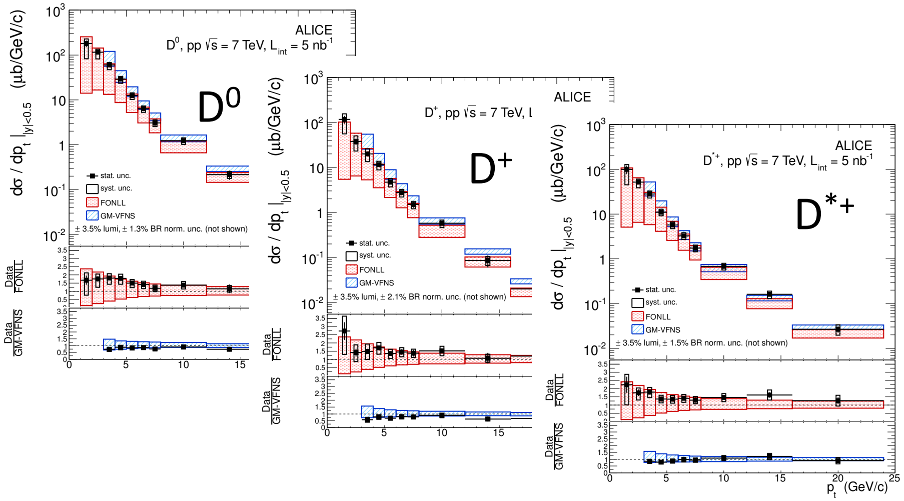


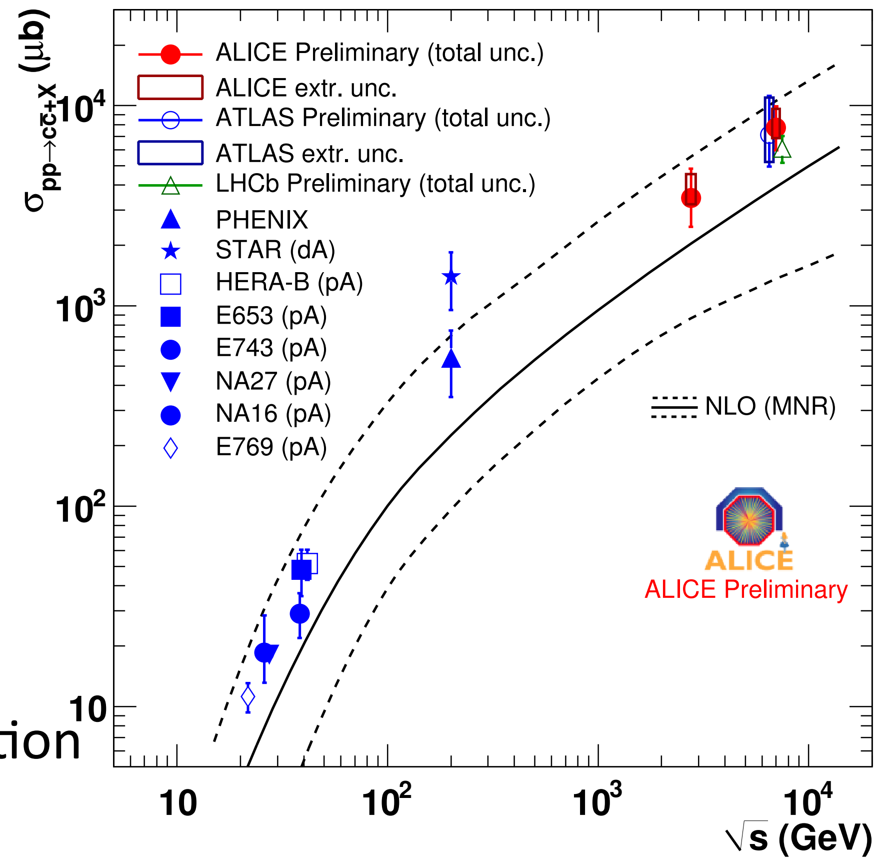
D mesons cross section measured in the range 1 < p_t < 24 GeV/c

pQCD predictions (FONLL and GM-VFNS) compatible with our data

LHC as heavy flavour factory

[ALICE Collaboration], JHEP 1201, 128 (2012) [arXiv:1111.1553 [hep-ex]].





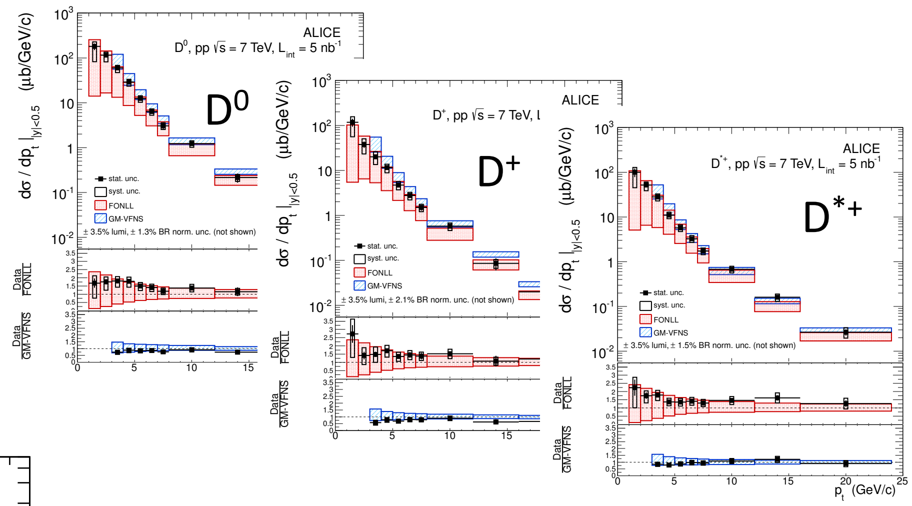
ALICE D mesons measurements
in pp collisions at 2.76 and 7 TeV
used to compute
the total charm production cross section

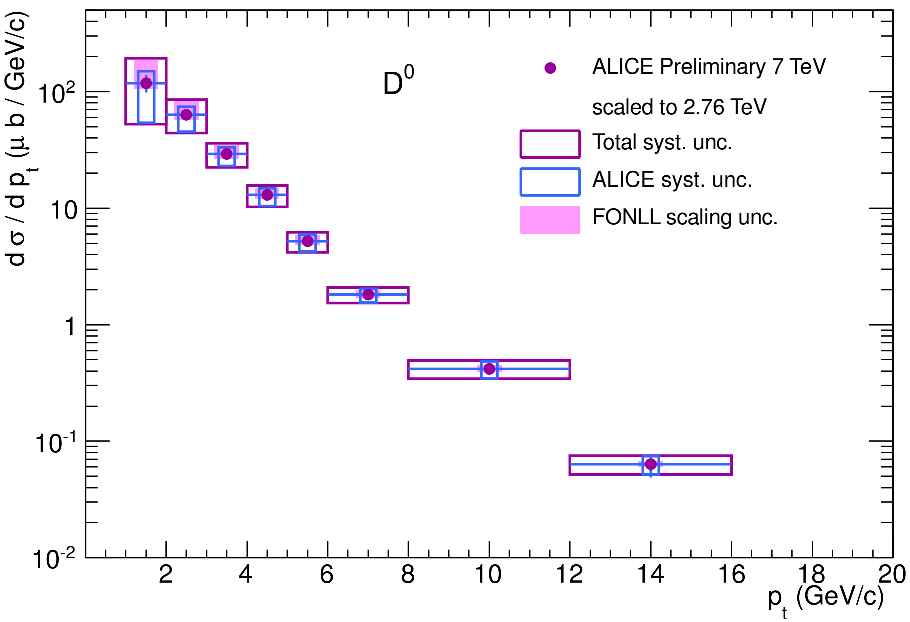
Good agreement with NLO calculation
Increase of a factor ~7 with respect to PHENIX and STAR

pp scaled reference at √s = 2.76 TeV

ALICE pp measurement at
√s = 7 TeV scaled to √s=2.76 TeV
using FONLL predictions.

R.Averbeck et al., arXiv:1107.3243



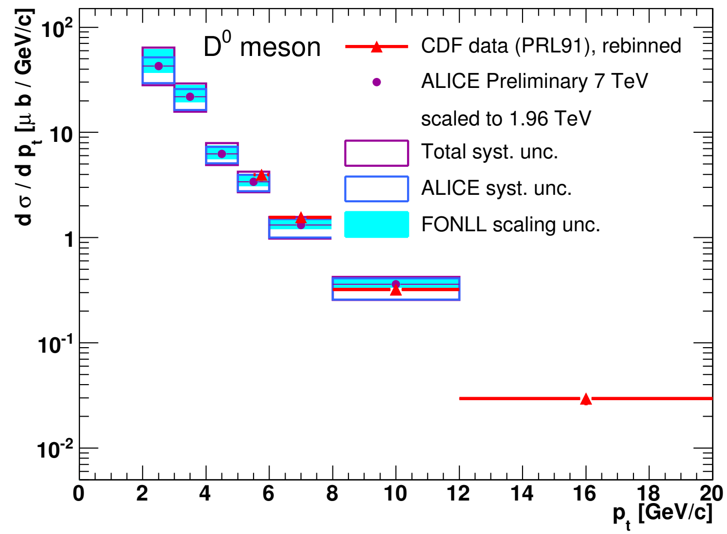


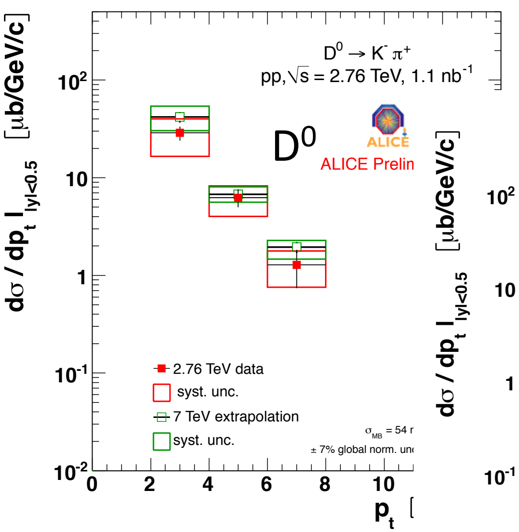
pp scaled reference at √s = 2.76 TeV

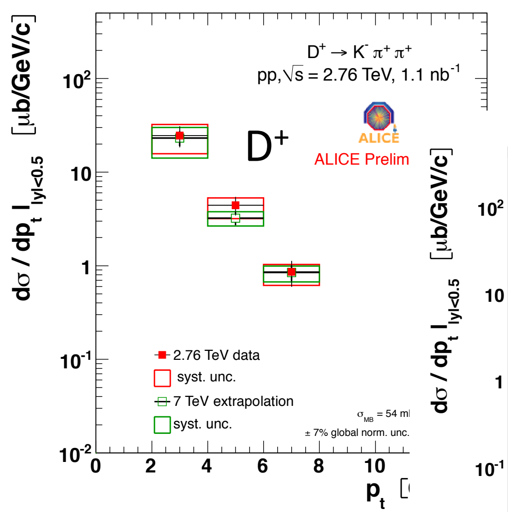
ALICE pp measurement at
√s = 7 TeV scaled to √s=2.76 TeV
using FONLL predictions.
R.Averbeck et al., arXiv:1107.3243

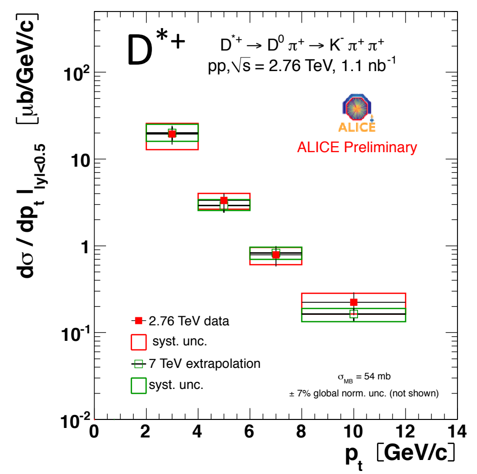
D^0 cross section measurement at √s = 2.76 TeV
(3 days of data taking)

As test the exercise was done scaling at 1.96 TeV and compared to CDF data.





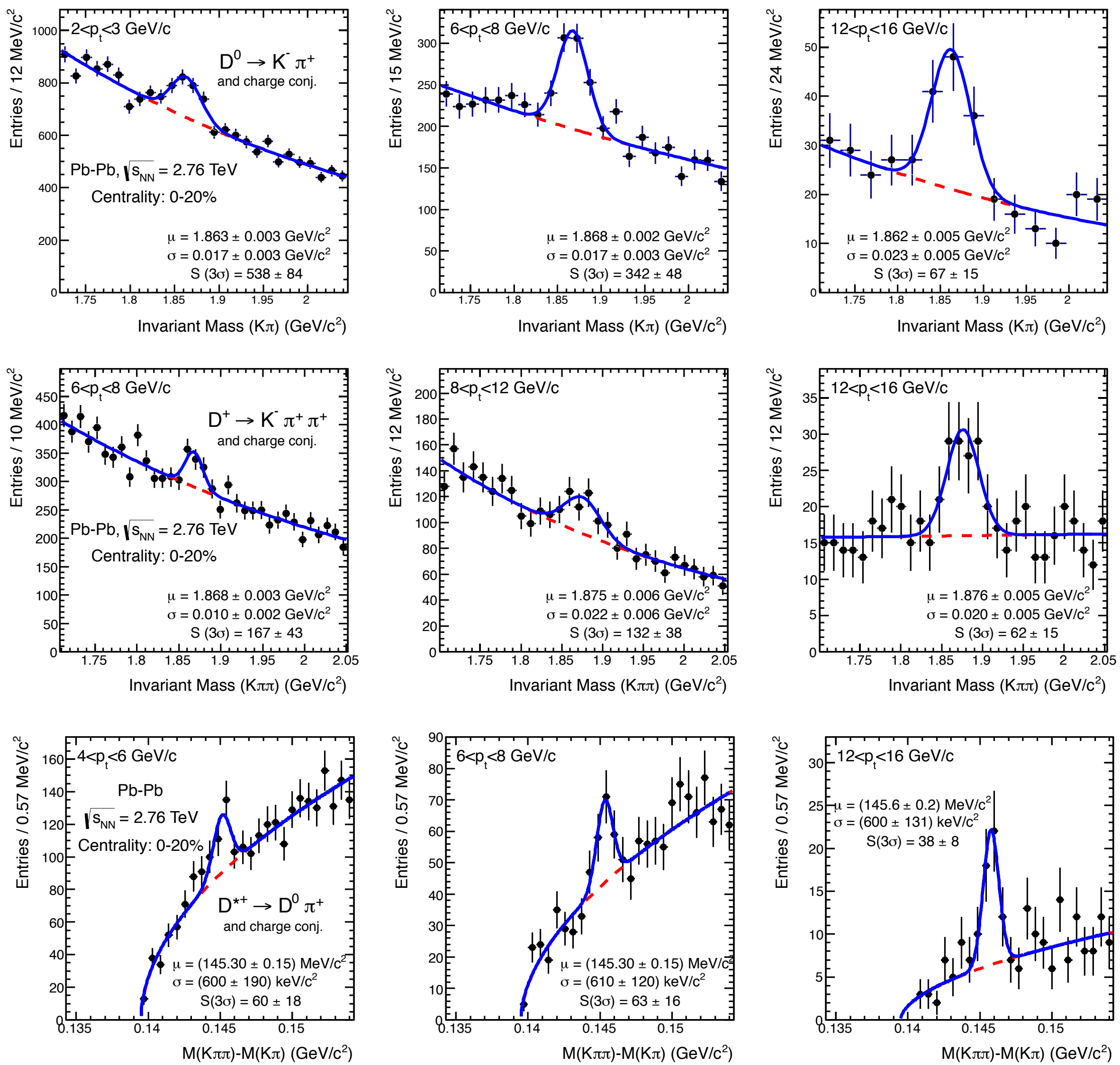




Outline

- Parton in-medium energy loss
- D mesons reconstruction strategy in ALICE
- D mesons cross section in pp collisions at $\sqrt{s}$ = 7 TeV
- D mesons yield in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- Results on D meson suppression in Pb-Pb collisions

Signal extraction: central collisions



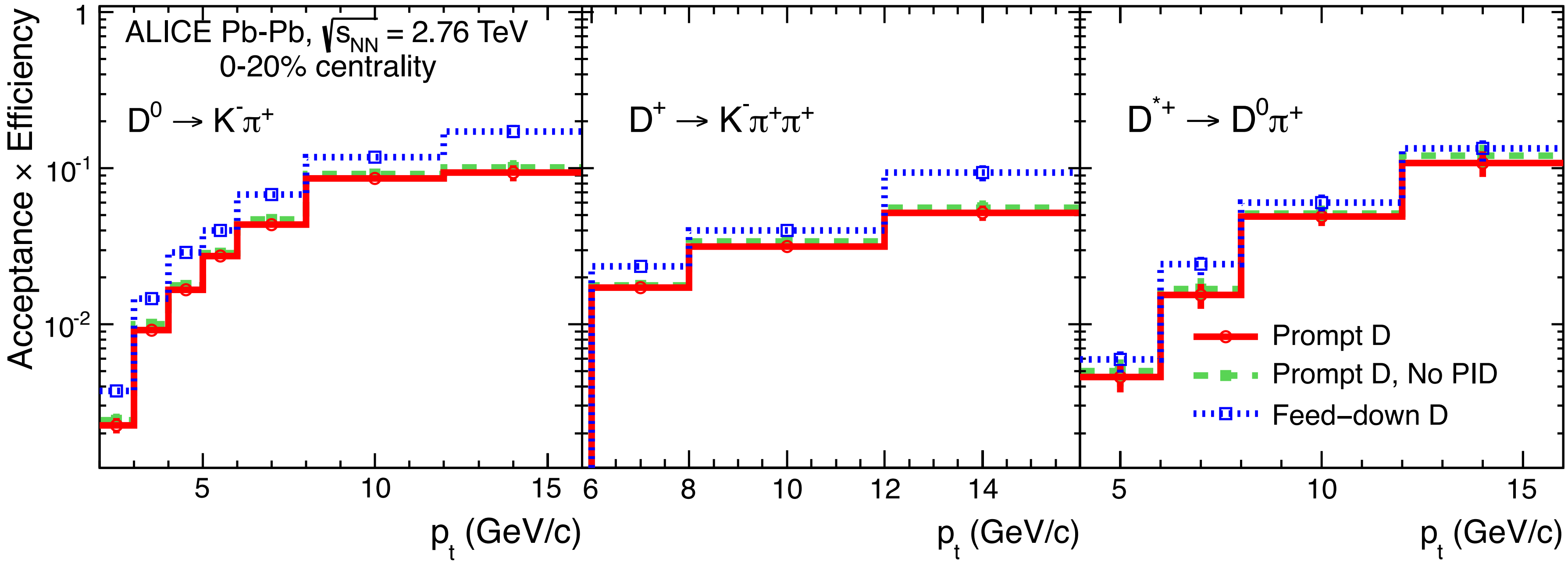
0 - 20% CC
3.1×10^6 events
$2 < p_t < 16$ GeV/c

40-80% CC
6.3×10^6 events
$2 < p_t < 16$ GeV/c

ALICE Collaboration arXiv:1203.2160

Efficiencies

Efficiencies are computed using HIJING PbPb Monte Carlo simulation with embedded PYTHIA cc events



ALICE Collaboration arXiv:1203.2160

Feed down correction and beauty energy loss hypothesis

Beauty feed down:

Monte Carlo method based on FONLL predictions.

Subtraction to the D^0 raw yield the expected secondary raw yields.

Beauty energy loss:

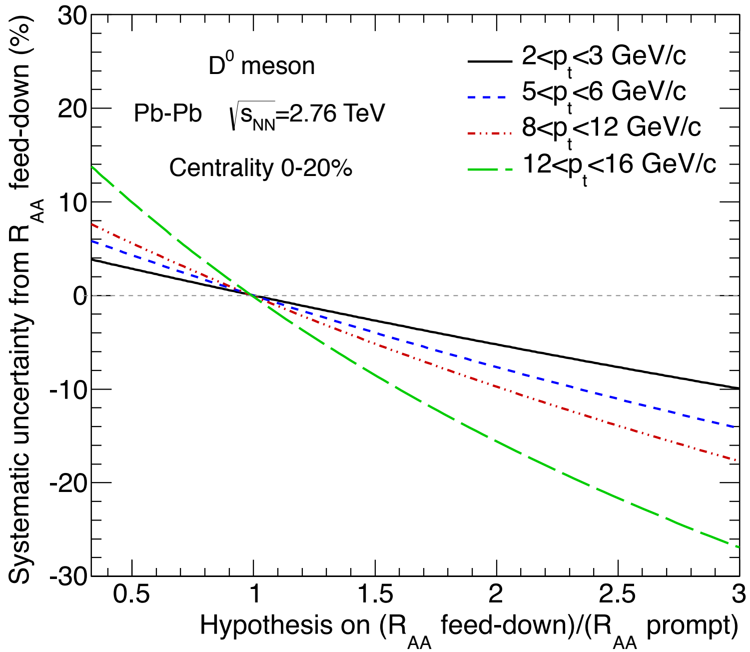
Hypothesis on the energy loss of beauty quarks is adopted.

Central value: $R_{AA}^{feed\text{-}down} = R_{AA}^{prompt}$

Hypothesis $0.3 < R_{AA}^{feed\text{-}down} / R_{AA}^{prompt} < 3$

(no correction applied,

a systematic uncertainty added)



ALICE Collaboration arXiv:1203.2160

Systematic uncertainties: 0-20 % CC

	Particle	D^0	
	p_t interval (GeV/c)	2–3	12–16
0–20% centrality	Yield extraction	8%	10%
	Tracking efficiency	10%	10%
	Cut efficiency	13%	10%
	PID efficiency	$^{+15}_{-5}$%	5%
	MC p_t shape	4%	3%
	FONLL feed-down corr.	$^{+2}_{-14}$%	$^{+6}_{-8}$%
	$R_{AA}^{feed-down}/R_{AA}^{prompt}$ (Eq. (3))	$^{+4}_{-10}$%	$^{+14}_{-27}$%
	BR	1.3%	

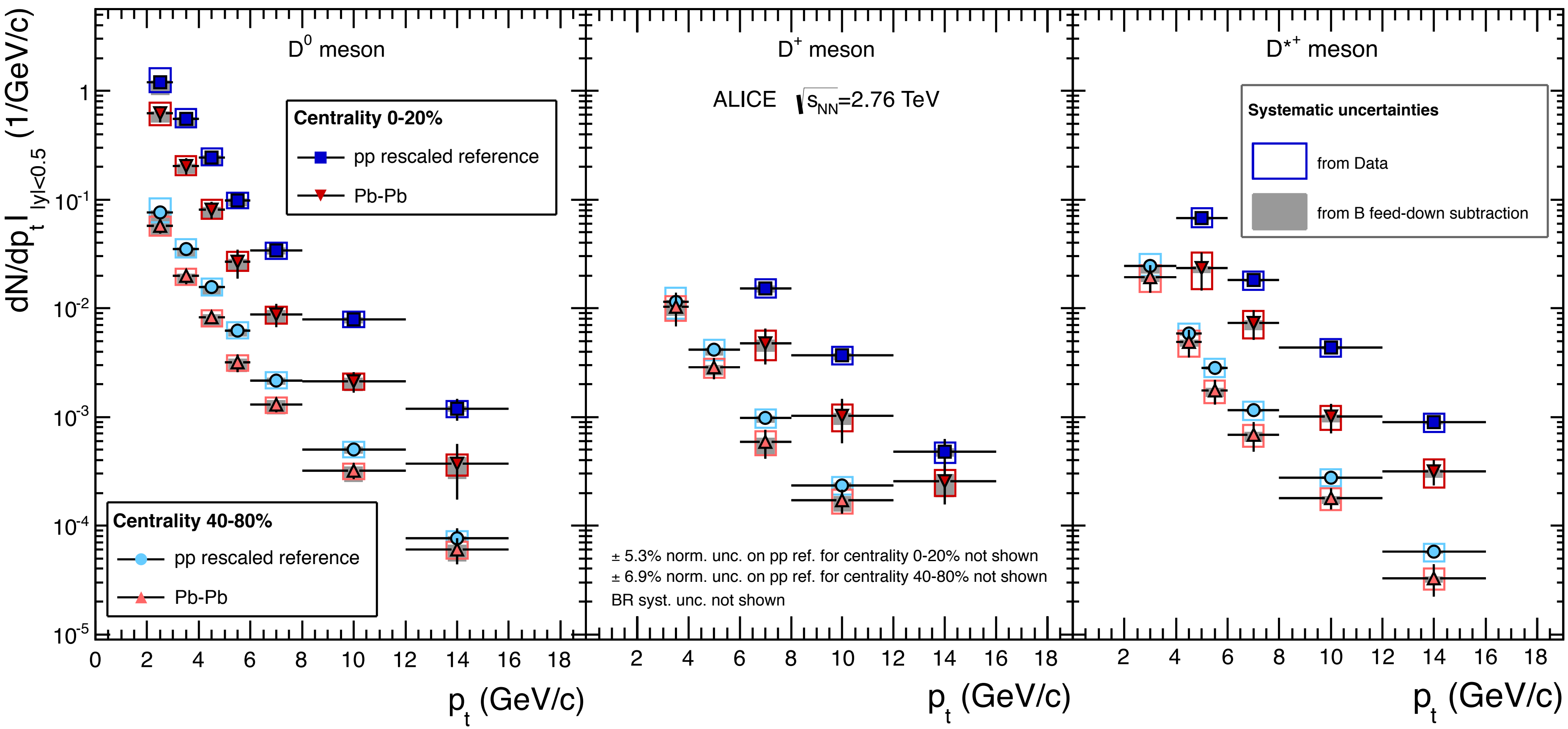
	Particle	D^0	
	p_t interval (GeV/c)	2–3	12–16
0–20% centrality	Data syst. pp and Pb–Pb	$^{+33}_{-41}$%	$^{+28}_{-28}$%
	Data syst. in Pb–Pb	$^{+26}_{-22}$%	$^{+22}_{-22}$%
	Data syst. in pp	17%	17%
	$\sqrt{s}$-scaling of the pp ref.	$^{+10}_{-31}$%	$^{+5}_{-6}$%
	Feed-down subtraction	$^{+15}_{-14}$%	$^{+16}_{-29}$%
	FONLL feed-down corr.	$^{+12}_{-2}$%	$^{+1}_{-2}$%
	$R_{AA}^{feed-down}/R_{AA}^{prompt}$ (Eq. (3))	$^{+4}_{-10}$%	$^{+14}_{-27}$%

ALICE Collaboration arXiv:1203.2160

dN/dp_t

pp scaled reference x $<T_{AA}>$

Pb-Pb yield



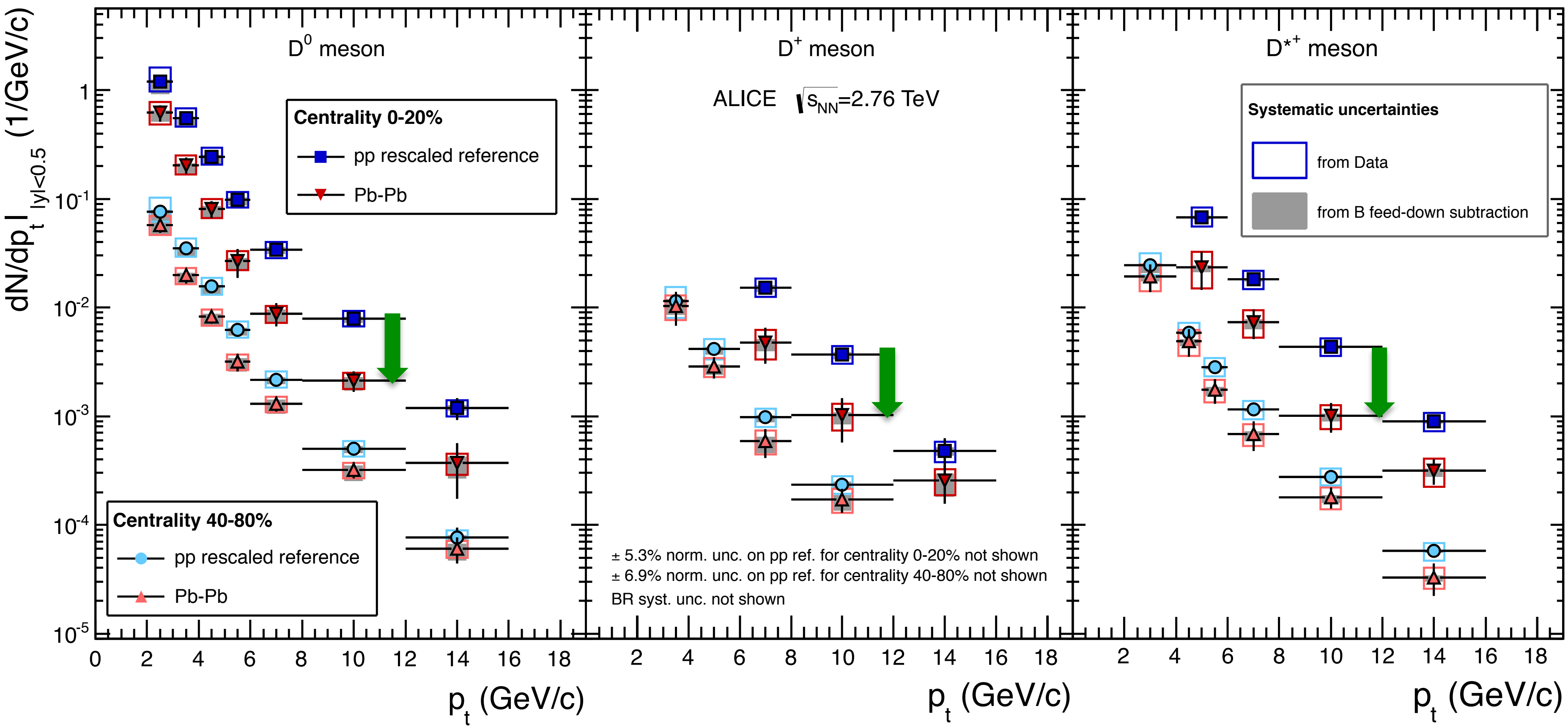
ALICE Collaboration arXiv:1203.2160

dN/dp_t

pp scaled reference x $\langle T_{AA} \rangle$

Pb-Pb yield

Indication of suppression



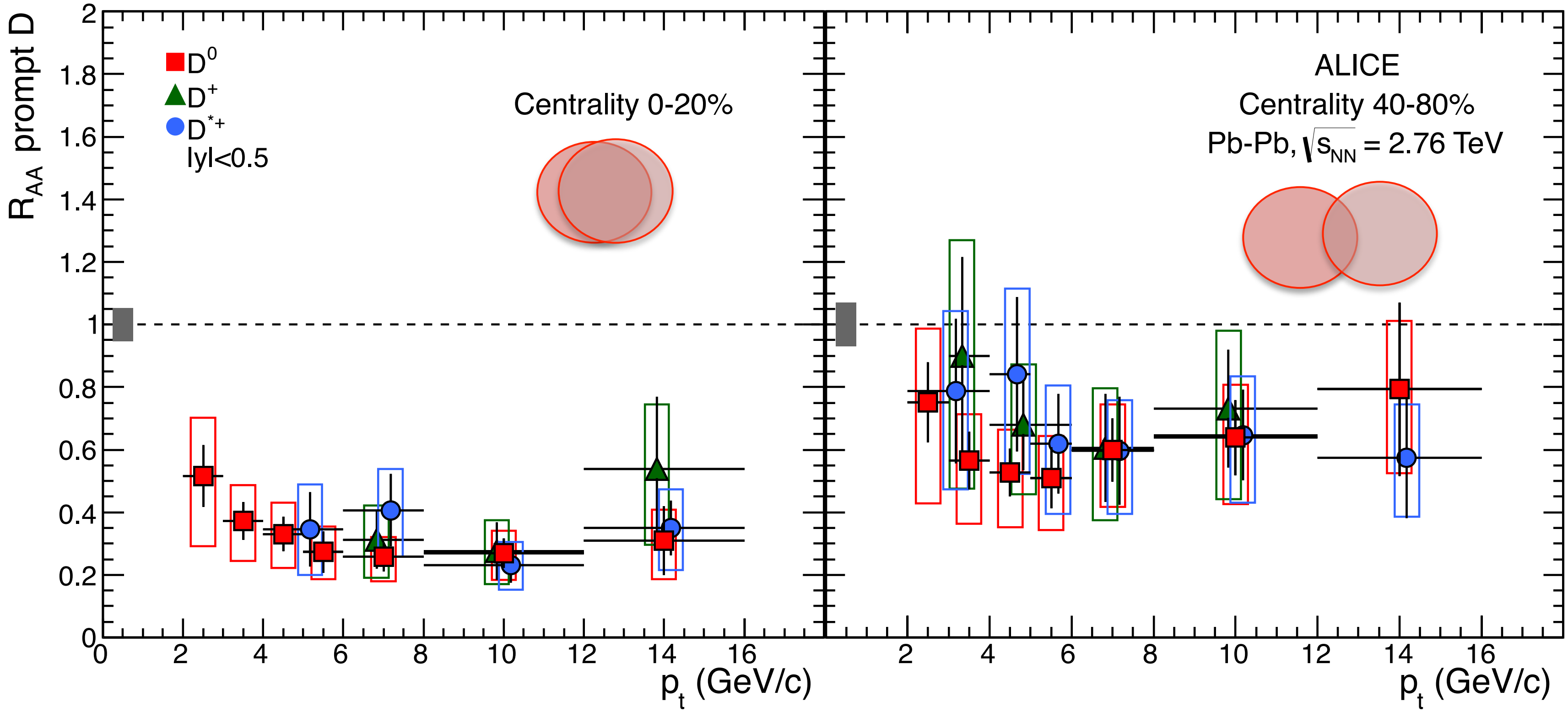
ALICE Collaboration arXiv:1203.2160

Outline

- ✧ Parton in-medium energy loss
- ✧ D mesons reconstruction strategy in ALICE
- ✧ D mesons cross section in pp collisions at $\sqrt{s}$ = 7 TeV
- ✧ D mesons yield in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- ✧ Results on D meson suppression in Pb-Pb collisions

D meson R_{AA} vs. p_t

ALICE Collaboration arXiv:1203.2160



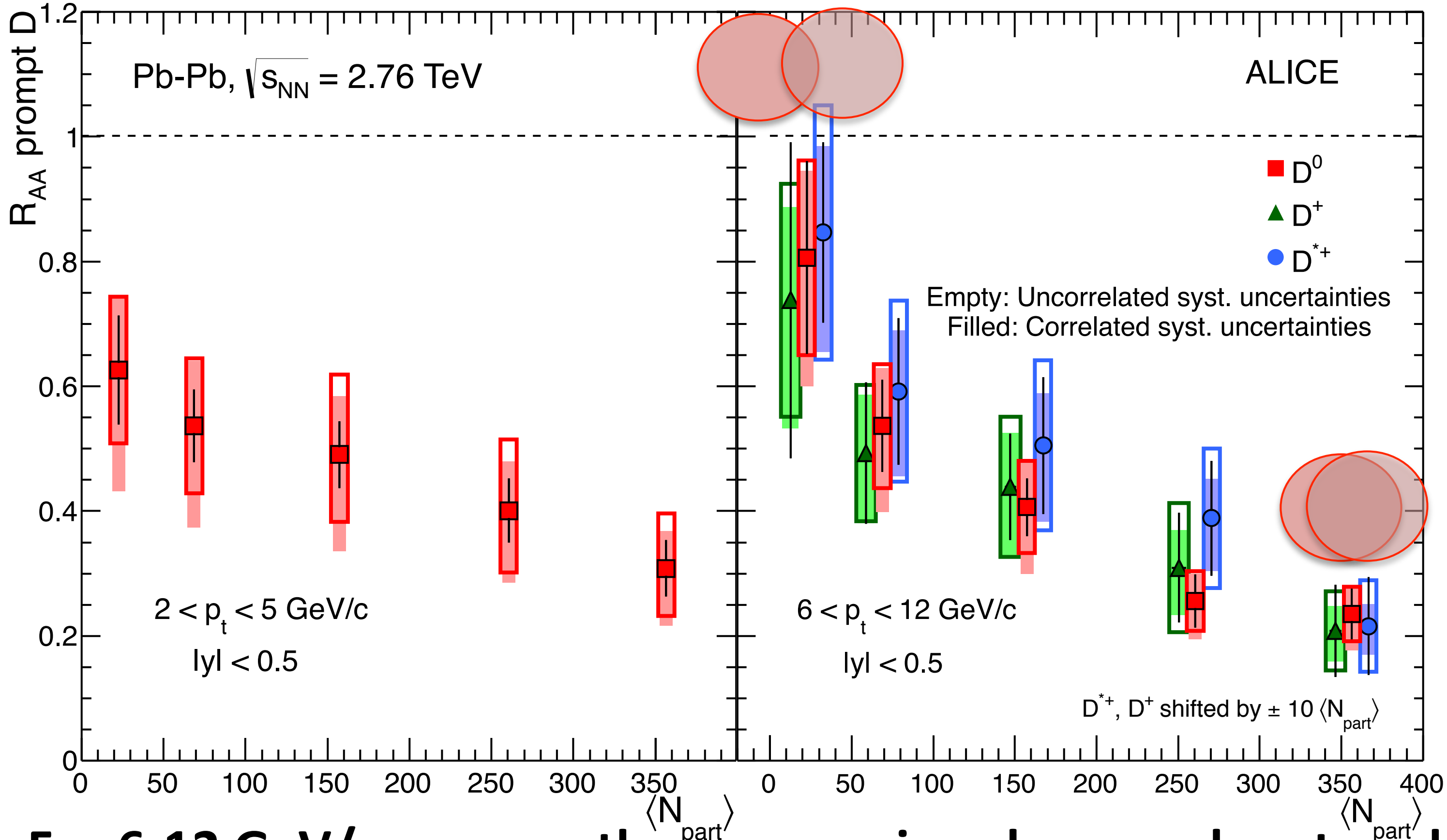
For 0-20% CC suppression is a factor 3-4 for p_t > 5 GeV/c.

For 40-80% CC suppression is about a factor 1.5 for p_t > 5 GeV/c

D meson R_{AA} vs. collision centrality

5 centrality classes: 0-10%, 10-20%, 20-40%, 40-60%, 60-80%.

ALICE Collaboration arXiv:1203.2160



For 6-12 GeV/c p_t range the suppression shows a clear trend with centrality. For lower p_t the dependency is less pronunced.

Initial state effects

Nuclear PDFs ≠ partons PDFs

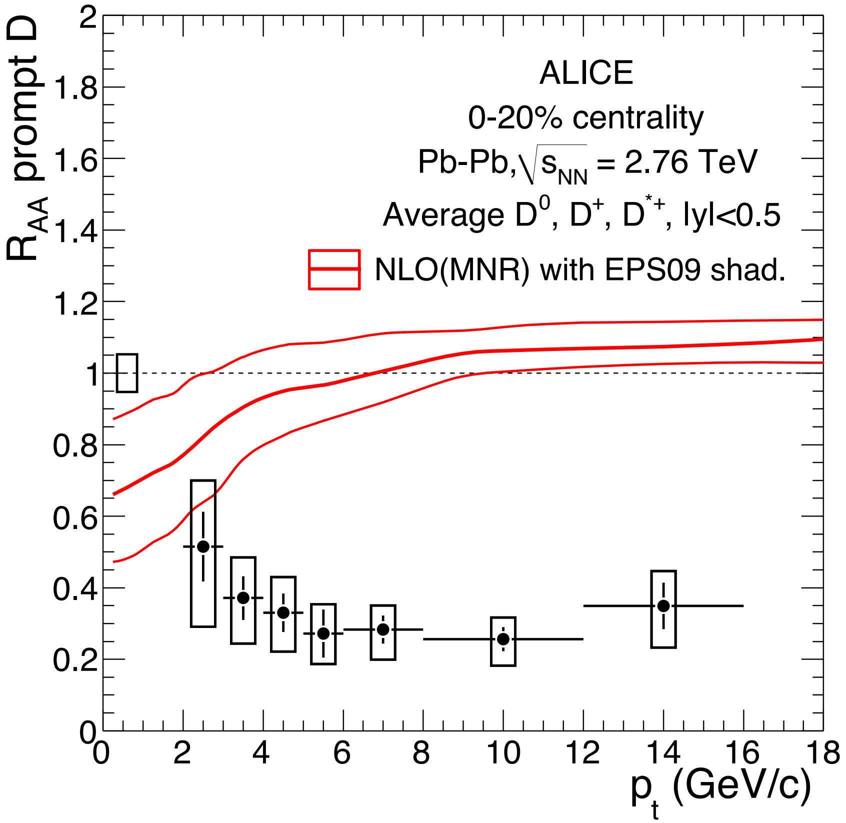
- Small $x^{(*)}$ gluons tend to merge together to reach a larger *x*.
- Initial hard scattering probability reduced at low *x* and Q^2

Shadowing effect computed with pQCD calculation with CTEQ6M PDFs and EPS09 NLO parametrization.

The strong suppression observed is likely to be a final state effect

(*) momentum fraction of the nucleon carried by the parton

ALICE Collaboration arXiv:1203.2160



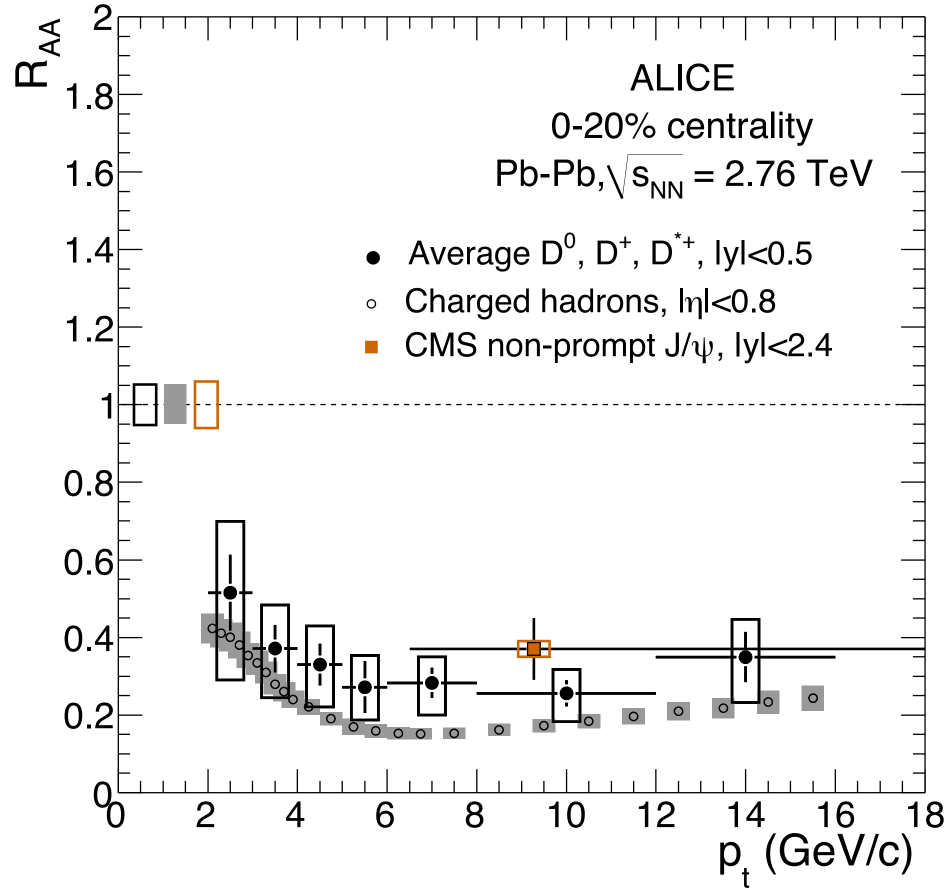
R_{AA} of D mesons averaged using statistical errors as weights.

R_{AA} (π) < R_{AA} (D) < R_{AA} (B) ?

ALICE Collaboration arXiv:1203.2160
CMS Collaboration arXiv:1201.5069

ALICE charged hadrons R_{AA} in the centrality class 0-20% (*).

Displaced J/Ψ from B decays measured by CMS in 0-20%



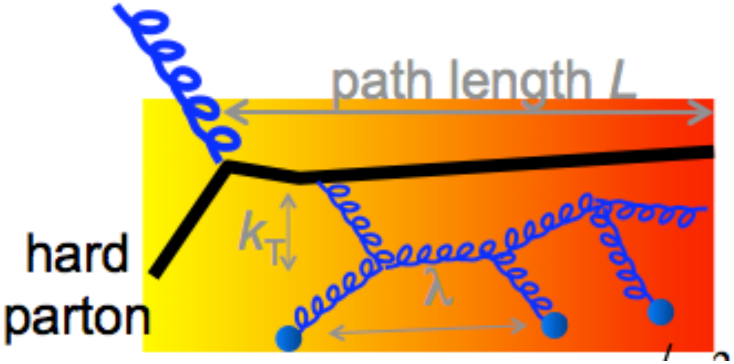
R_{AA} (π) < R_{AA} (D)?
There is an indication of saying yes.
Not conclusive.

R_{AA} (D) < R_{AA} (B)?
Different p_t range, not possible to conclude.

(*) ALICE preliminary results showed that charged pion R_{AA} coincides with charged hadron R_{AA} for p_t > 5 GeV/c

Energy loss models (I)

Path integral approach scattering probability expansion



- pQCD approaches
- Hard parton traversing the medium interacts with various scattering centres.
- Initial parton = lower energy parton + radiated gluon

$$\hat{q} = \frac{\langle k_\perp^2 \rangle}{\lambda}$$

BDMPS – ASW [(1)] multiple-soft bremsstrahlung gluon radiation
DGLV [(2)] starts from a single-hard radiation spectrum
DGLV + collisional energy loss and path length fluctuations → WHDG [(3)]

(1) R. Baier, Y. Dokshitzer, A. Mueller, S. Peigné and D. Shiff, Nucl. Phys. B 483, 291 (1997).
C.A. Salgado and U.A. Weidmann, Phys. Rev. Lett. 89, 092303 (2002).
(2) M. Djordjevic, M. Gyulassy, Nucl. Phys. A 733 265 (2004)
(3) S. Wicks, W. Horowitz, M. Djordjevic and M. Gyulassy, Nucl. Phys. A 784, 426 (2007).

AdS/CFT

Weakly coupled gravity theories → four-dimensional gauge theories
Possible determination of medium viscosity, transport coefficient, heavy quark diffusion coefficient

C. P. Herzog, A. Karch, P. Kovtun, C. Kozcaz and L. G. Yaffe, JHEP 0607, 013(2006)

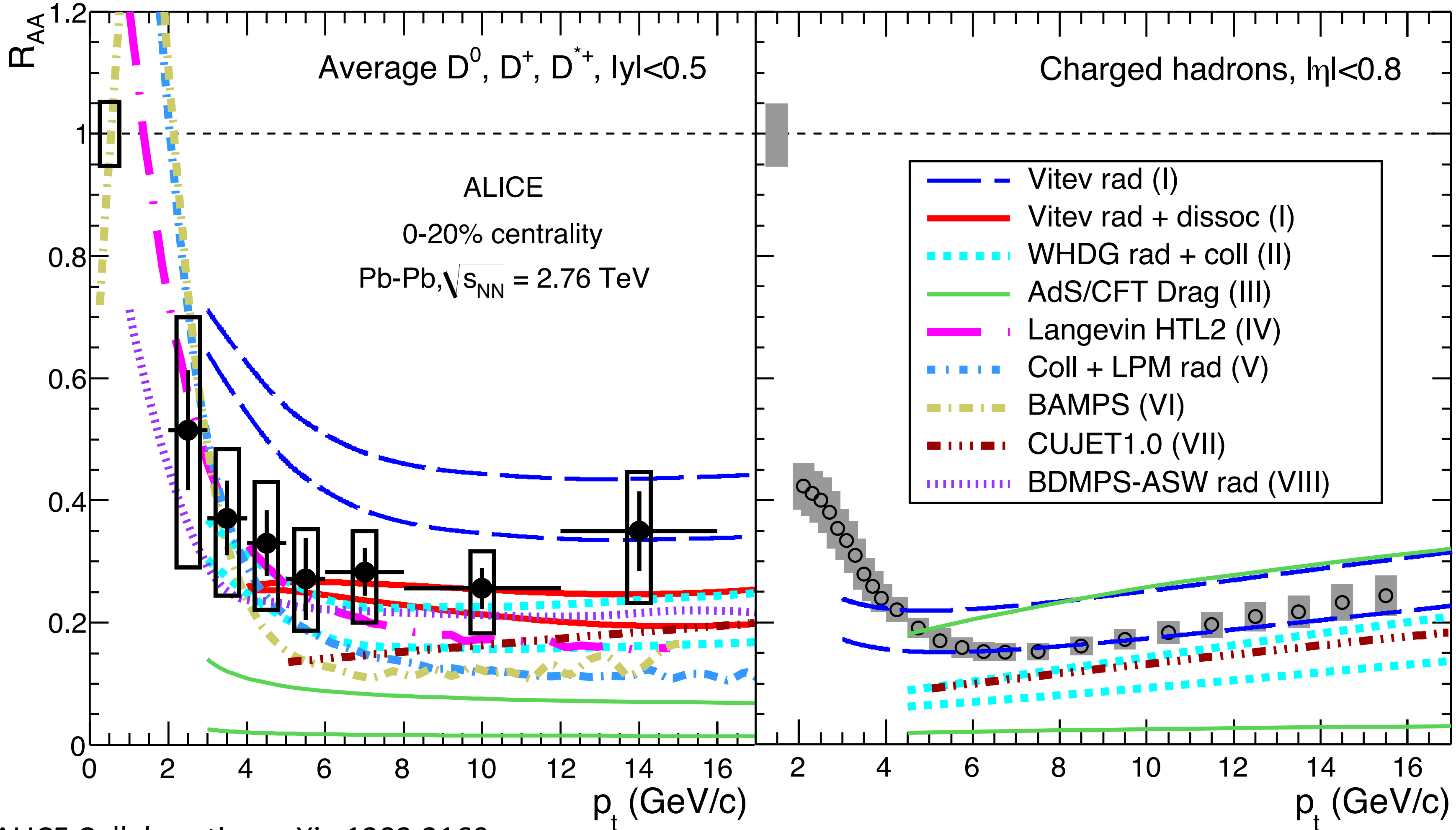
Energy loss models (II)

Transport models

- Interaction of the charm quark with the plasma: drag and diffusion forces that act on the quark
- Charm quark in the QGP → treated with Brownian approximation
- Charm quark density → Boltzmann equation

A. Beraudo, A. De Pace, W.M. Alberico, A. Molinari. arXiv:0902.0741v2 [hep-ph]
J. Uphoff, O. Fochler, Z. Xu and C. Greiner, arXiv:1112.1559 [hep-ph].

Comparison with energy loss models



ALICE Collaboration arXiv:1203.2160

Comparison with energy loss models

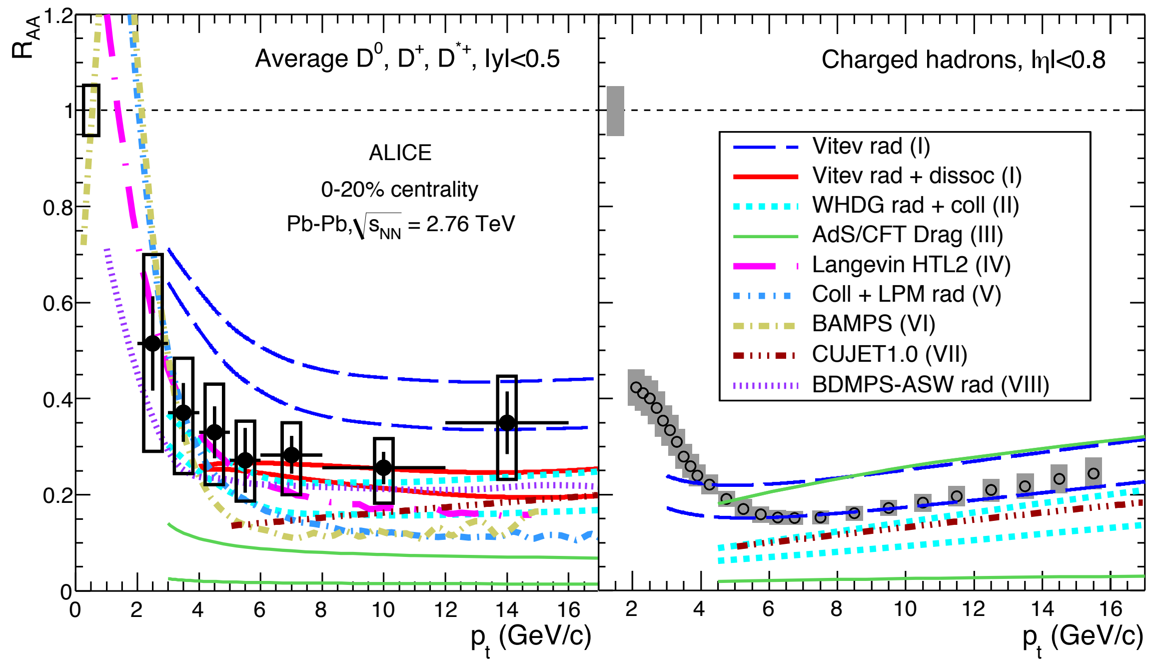
(I) Radiative energy loss with in-medium D meson dissociation

(II) Radiative + collisional energy loss in WHDG

(VII) CUJET1.0

approaches describe reasonably well at the same time charm and light-flavour suppression.

ALICE Collaboration arXiv:1203.2160



(III) AdS/CFT approach seems to underestimate the D mesons R_{AA}

Conclusions…

ALICE

- First measurement of the **direct charm suppression** in central heavy-ion collisions: arXiv:1203.2160

- The D meson Nuclear Modification Factor (R_{AA}) has been studied as a function of p_t and of centrality of the collisions.
  The suppression measured is a factor ~4 for D with p_t > 5 GeV/c
  The effect is decreasing from central to peripheral collisions.

- Comparison with theoretical calculations suggests a final state effect, due to **parton energy loss**.
  A p-Pb run will take place this year to study nuclear shadowing at the LHC.

- The mass hierarchy in the energy loss has been tested and no strong conclusion can be drawn so far.
  There are indications that **$R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$ could be valid**.

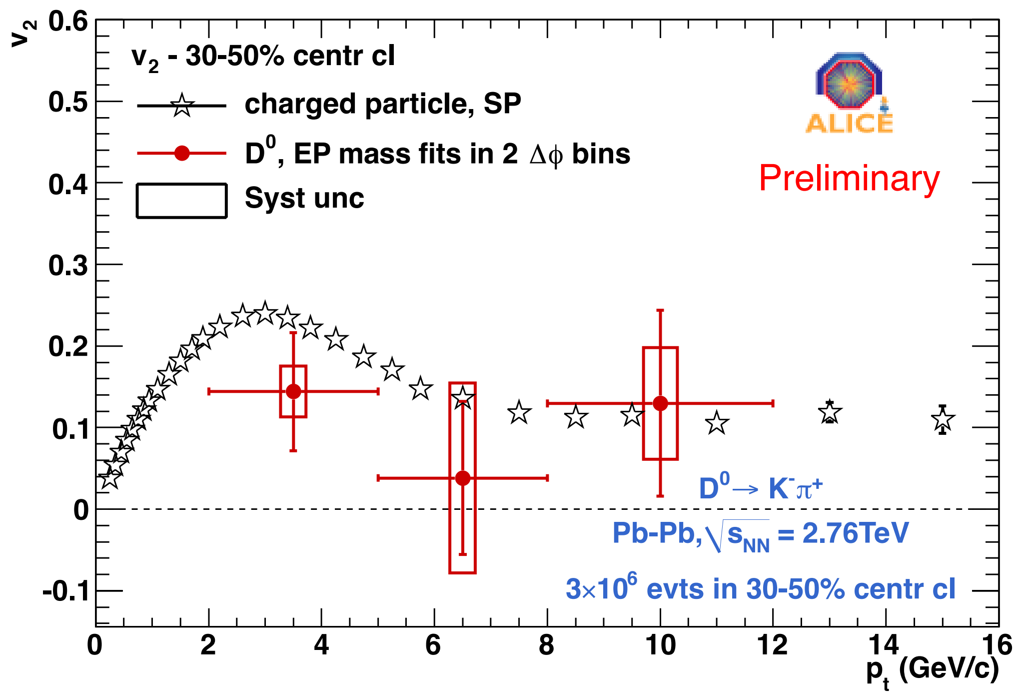
… and outlook

Strong interaction of charm with the medium...
and what about thermalization with the medium?

ALICE first preliminary measurement on charm flow…

The first point suggests a that charm flow is different than zero (1.8σ)

2011 statistics will allow to improve the measurement and to study charm quark thermalization.



Back up slides

Centrality measurement

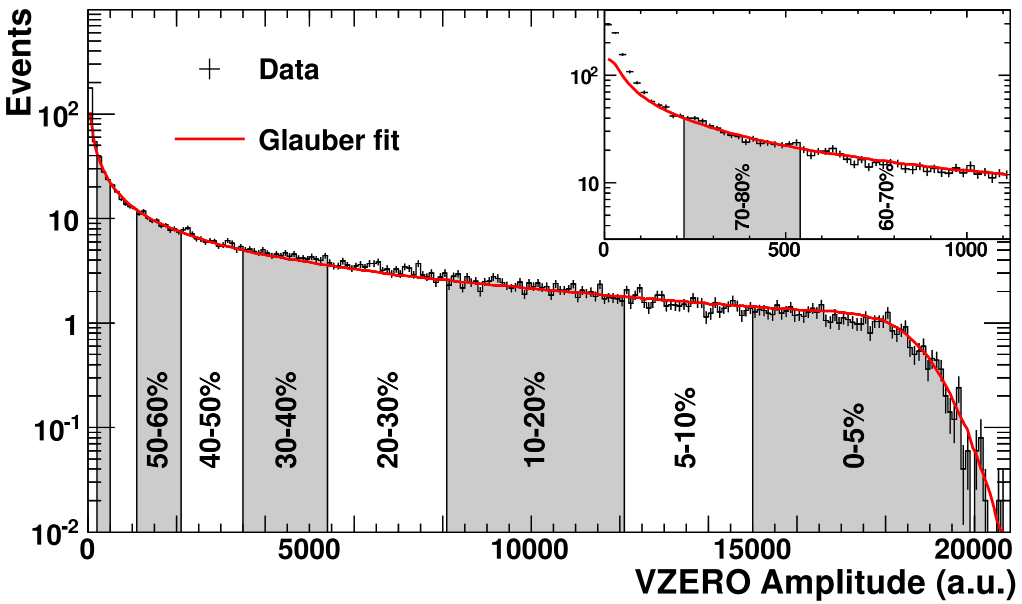
Collision geometry → number of participating nucleons : $N_{part} = 2A - N_{spec}$

Centrality measurement in ALICE:
- use Zero Degree Calorimeter data
- Glauber Fit

⇩

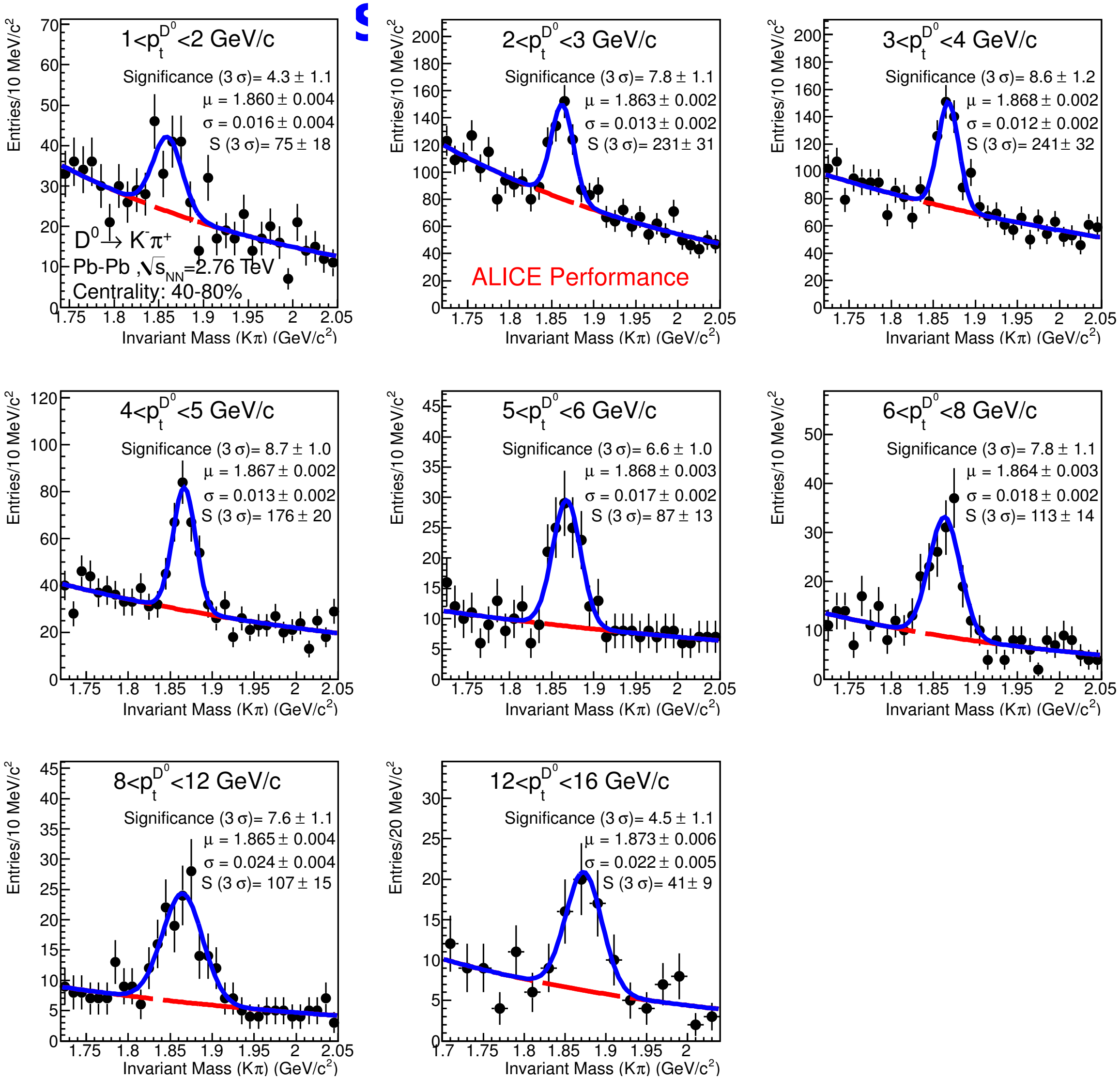
Based on fit on multiplicity distributions of:
- VZERO amplitude
- SPD hits
- TPC tracks

ALICE Collaboration Phys.Rev.Lett. 106 (2011) 032301



Measurement of N_{coll} and T_{AA} → ingredients for the R_{AA}

D^0 Signals in peripheral



40-80% CC

6.3×10^6 events

$2 < p_t < 16$ GeV/c

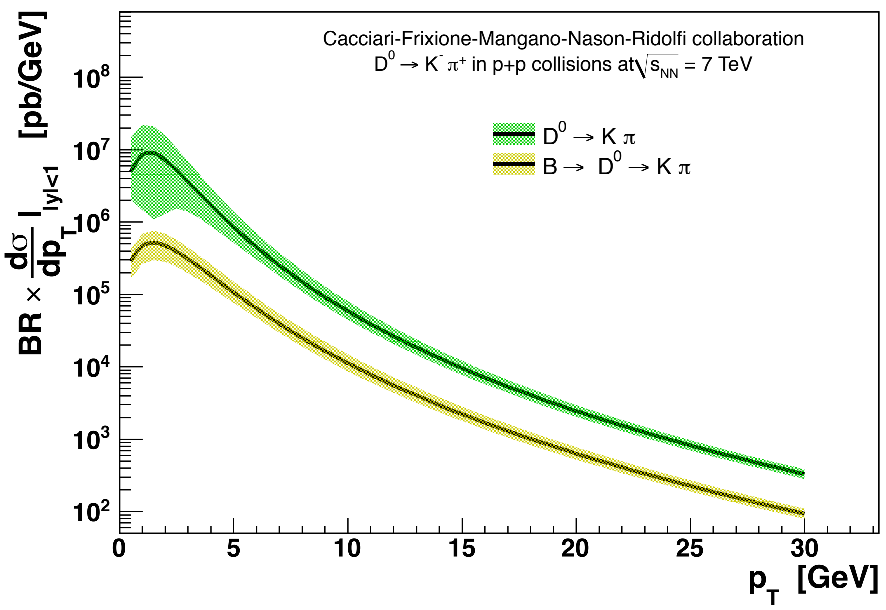
(hint of signal in 1-2)

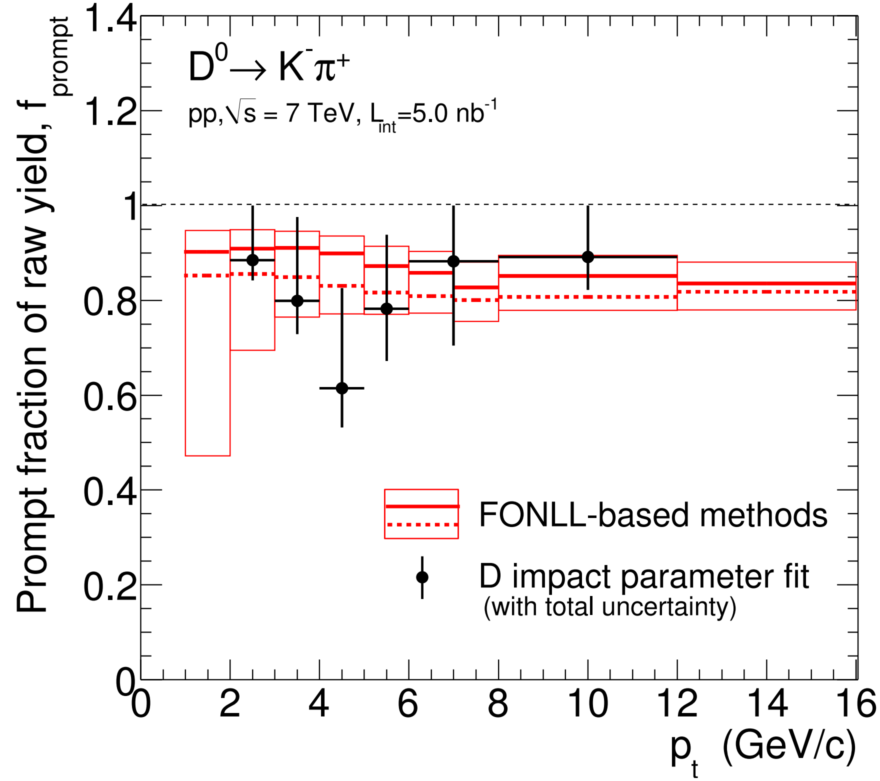
Feed down correction

Beauty feed down:

Monte Carlo method based on FONLL predictions.

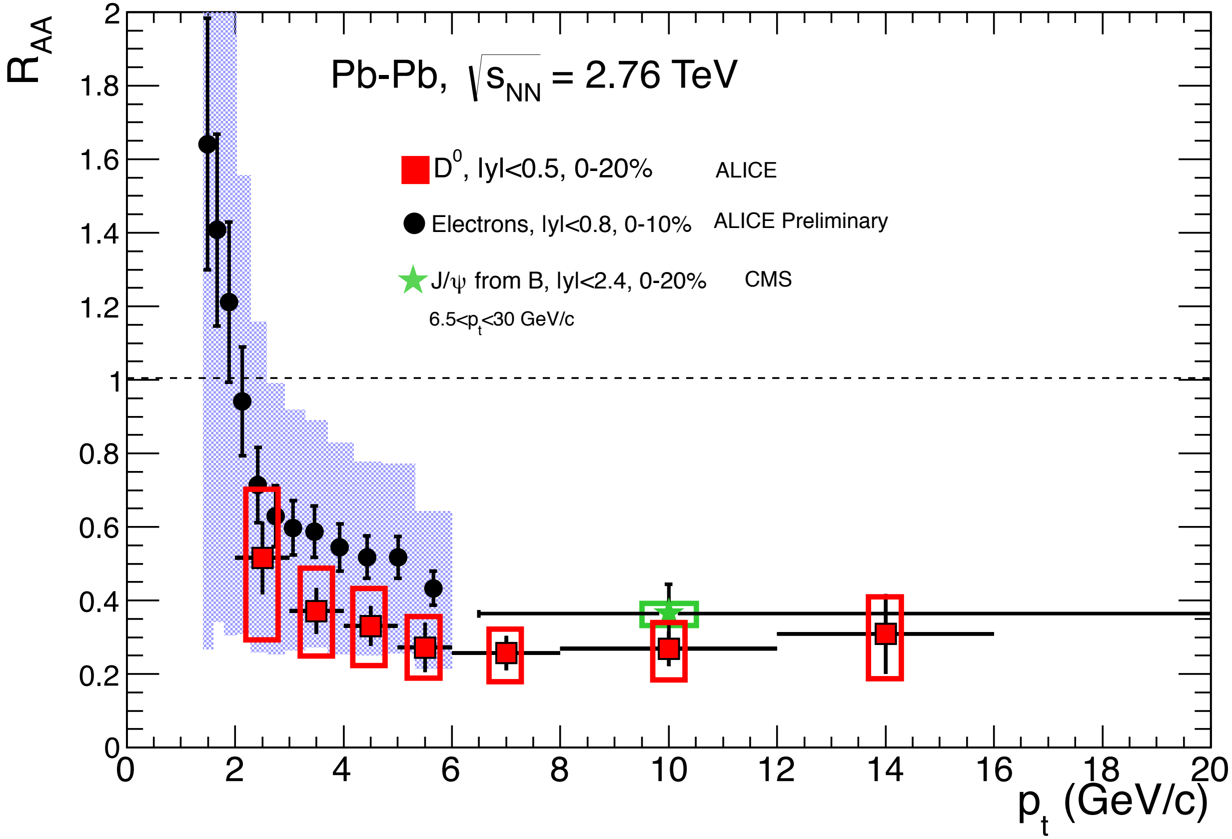
Subtraction to the D^0 raw yield the expected secondary raw yields.





Open heavy flavour comparison

ALICE D^0 and HF electrons measurements
CMS displaced J/Ψ from B decays



Flow measurements