Charm suppression and azimuthal anisotropy in $\sqrt{s_{NN}}$ = 2.76 TeV Pb-Pb collisions measured with the ALICE detector

Davide Caffarri
Università degli Studi di Padova – INFN Sez. di Padova

Heavy Ion Meeting – 28th March 2013 IPN Orsay

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Outline

✧ Heavy quarks as probes of QCD matter at the LHC

✧ D mesons reconstruction in ALICE
- ✧ reconstruction strategy
- ✧ pp results

✧ Pb-Pb measurements:
- ✧ Heavy flavour suppression at high momentum (R_{AA})
- ✧ Charm azimuthal anisotropy

✧ Comparisons with theoretical models

✧ Summary and outlook

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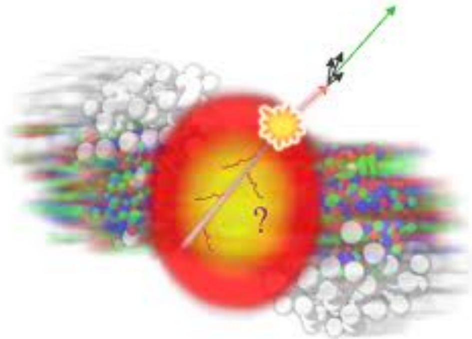
Parton energy loss



"Hard probes" are produced:
- in hard partonic scatterings
- in a very short time scale

⇓

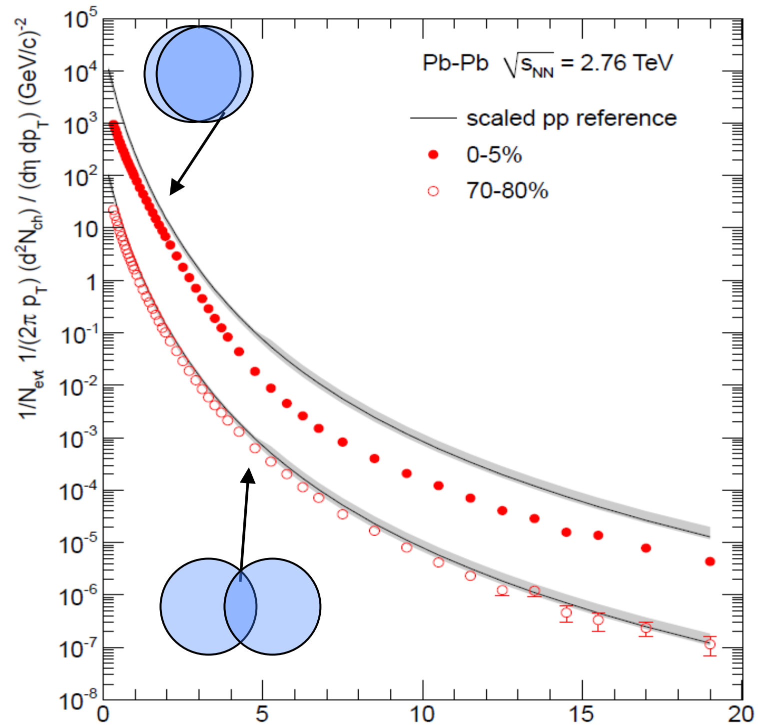
they can interact with the medium formed in heavy ion collisions and lose energy via:
- medium-induced gluon radiation
- elastic collisions with medium gluons

⇓

Parton energy loss effect

$$\boxed{dN_{AA}/dp_t} < \langle N_{coll} \rangle dN_{pp}/dp_t$$

$$R_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$



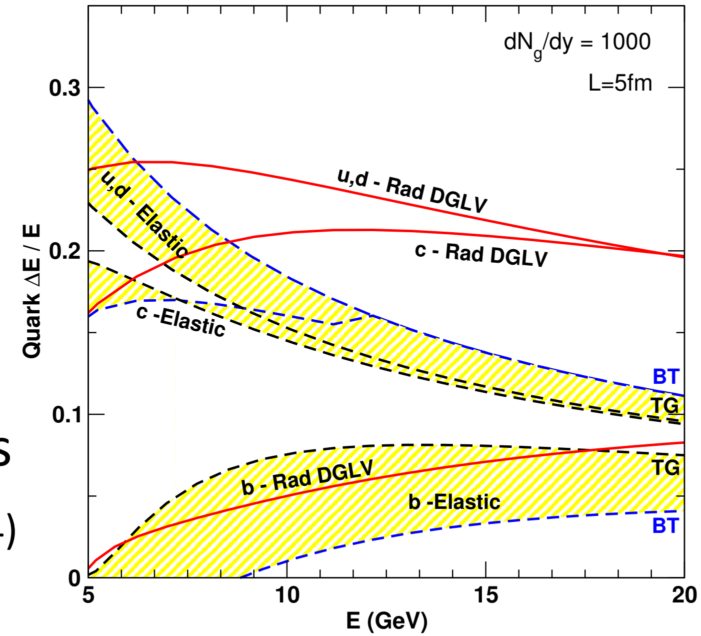
ALICE Coll., PLB 696, 30 (2011)

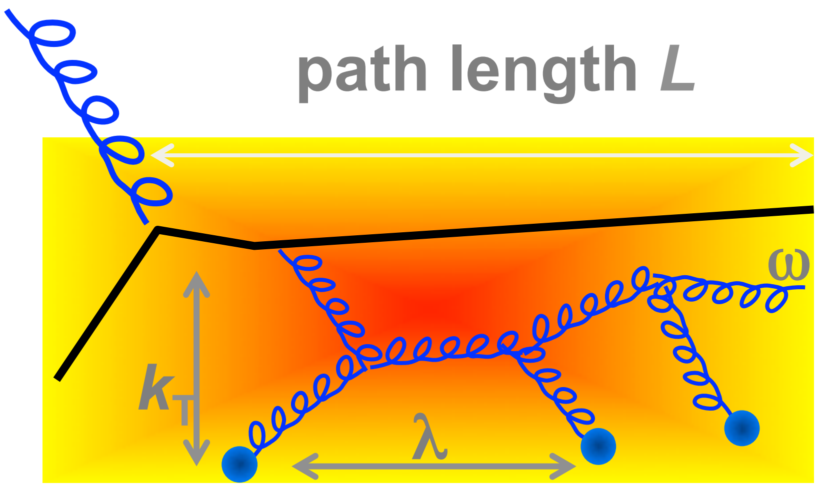
In-medium interaction

The total energy loss:

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

M. Djordjevic, M. Gyulassy, Nucl. Phys. A 733 265 (2004)





$$\hat{q} = \frac{\langle k_T^2 \rangle}{\lambda}$$ transport coefficient

Radiated-gluon energy distribution:

(BDMPS case)

$$\omega \frac{dI}{d\omega} \propto \alpha_s C_R \sqrt{\frac{\hat{q} L^2}{\omega}}$$

C_R = Casimir coupling factor:
4/3 for q, 3 for g

Baier, Dokshitzer, Mueller, Peigné, Schiff, NPB 483 (1997) 291.
Zakharov, JTEPL 63 (1996) 952.
Salgado, Wiedemann, PRD 68(2003) 014008.

Heavy quark energy loss

ALICE

Energy loss **colour charge** dependence $\langle \Delta E \rangle \propto C_R$ $\quad gg\ C_R = 3$, $\quad qg\ C_R = 4/3$

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

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

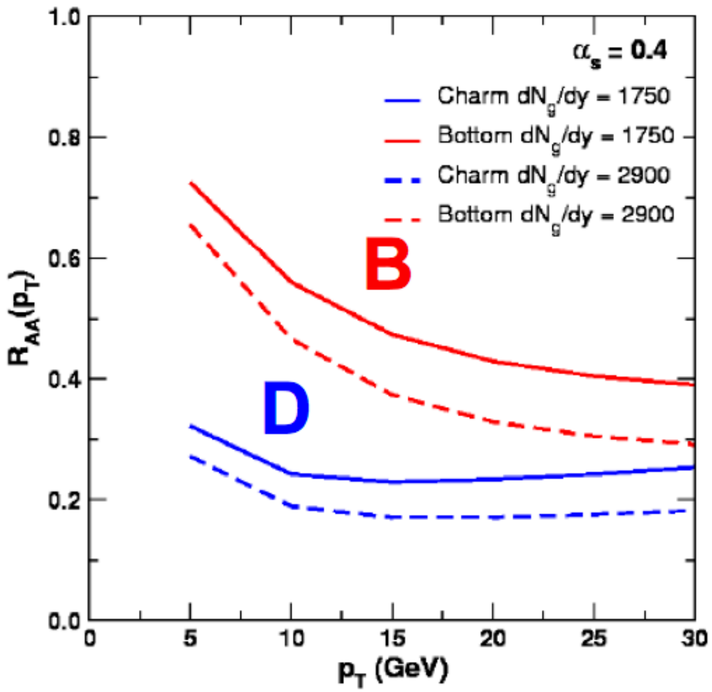
Y.L. Dokshitzer, V.A. Khoze and S.I. Troian, J. Phys. G 17, 1602 (1991);
Y.L. Dokshitzer and D.E. Kharzeev, Phys. Lett. B 519, 199 (2001).

Energy loss **quark mass** dependence

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

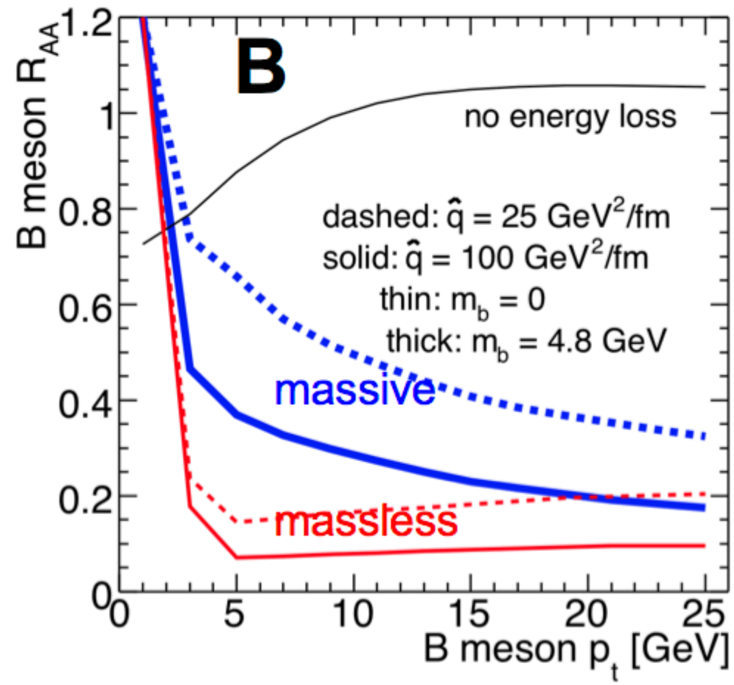
Heavy quarks energy loss: some predictions

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



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

Pb-Pb collisions at √s = 5.5 TeV



Armesto, et al. PRD71 (2005) 014003

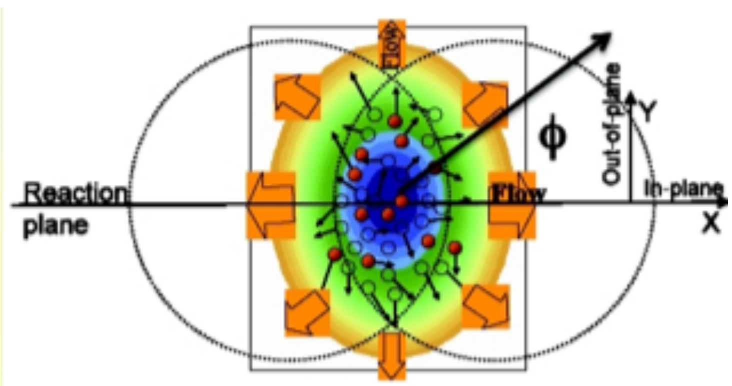
(*) not up to date predictions.
New predictions at the end…

Azimuthal anisotropy: flow and energy loss

✧ Initial spatial anisotropy → momentum anisotropy of particles

✧ The anisotropy is quantified via a Fourier expansion in azimuthal angle (φ) with respect to the reaction plane ($\Psi_{1,2}$)

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



✧ Low p_T v_2 → pressure gradients in medium expansion
→ measure of strength of collectivity (mean free path of outgoing partons)

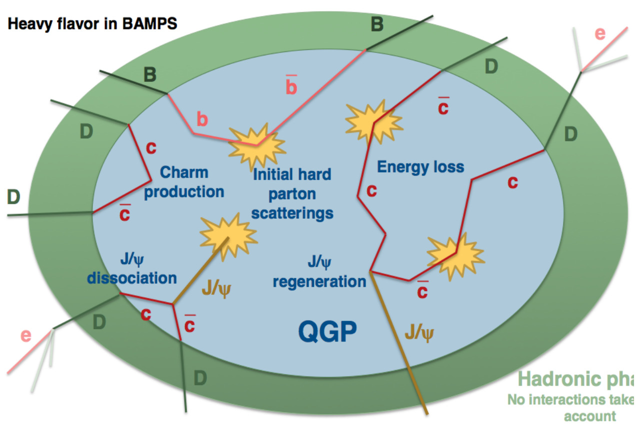
✧ High p_T v_2 → path-length (L) dependent energy loss in an almond-shaped medium
→ asymmetry in momentum space

Heavy flavour v_2

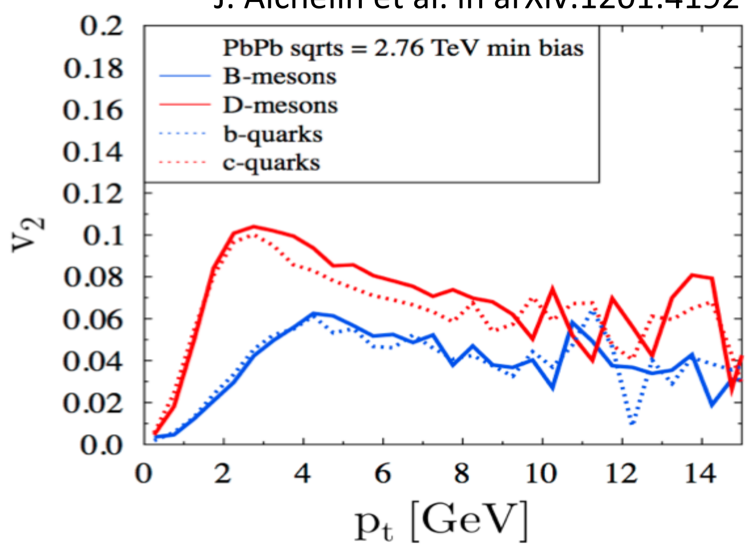
- Due to their large mass, c and b quarks should be less sensitive to the collective expansion
  - → need frequent interaction with large coupling to build their v_2
  - → $v_2^b < v_2^c$

- Uniqueness of heavy quarks: cannot be "destroyed/created" in the medium → transported through the full system evolution

- Charm R_{AA} and v_2 are sensitive to medium transport properties



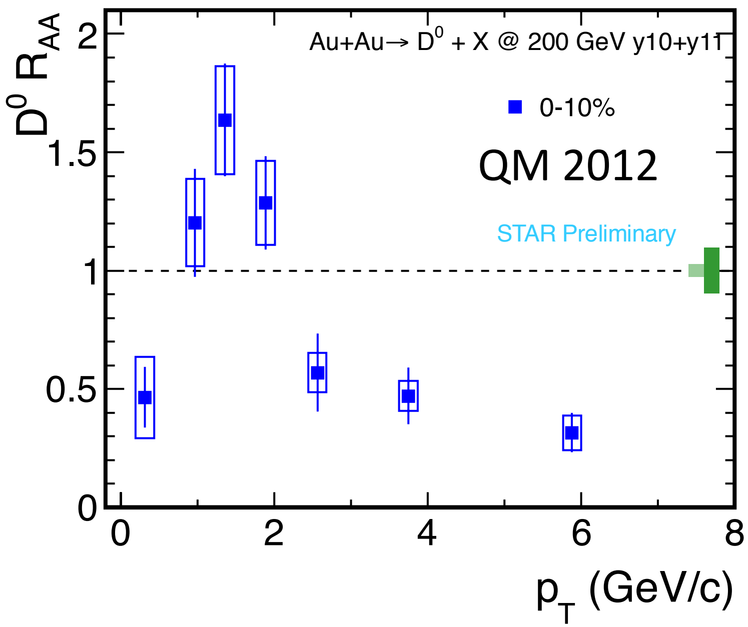
J. Aichelin et al. in arXiv:1201:4192



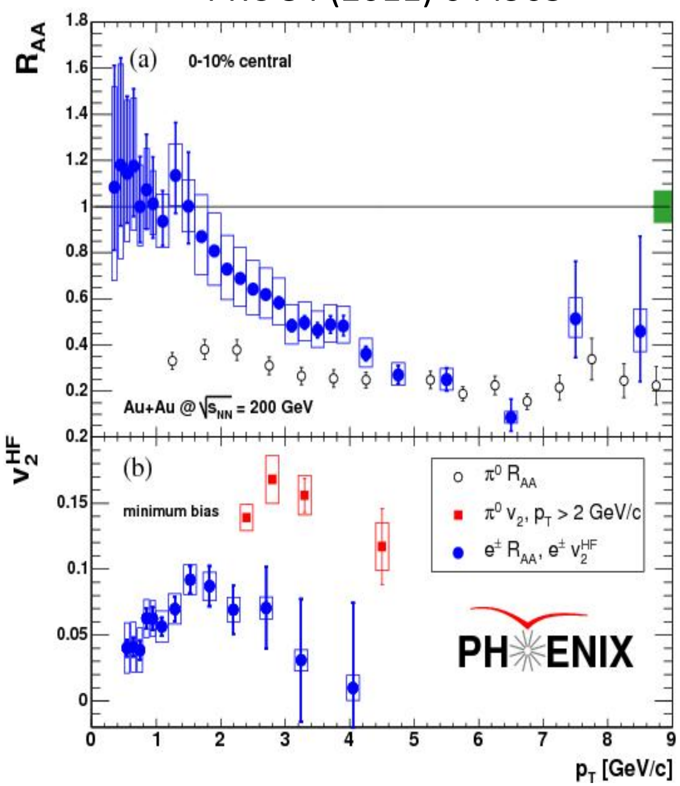
See also J. Uphoff et al., R. Rapp et al., A. Beraudo et al.

Heavy Flavour RHIC results

PHENIX and STAR experiments measured the inclusive spectrum of electrons coming from heavy flavor hadrons decay in Au-Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. → R_{AA}, v_2



PRC 84 (2011) 044905



STAR also measured the exclusive reconstruction of D^0 in the hadronic channel → R_{AA}

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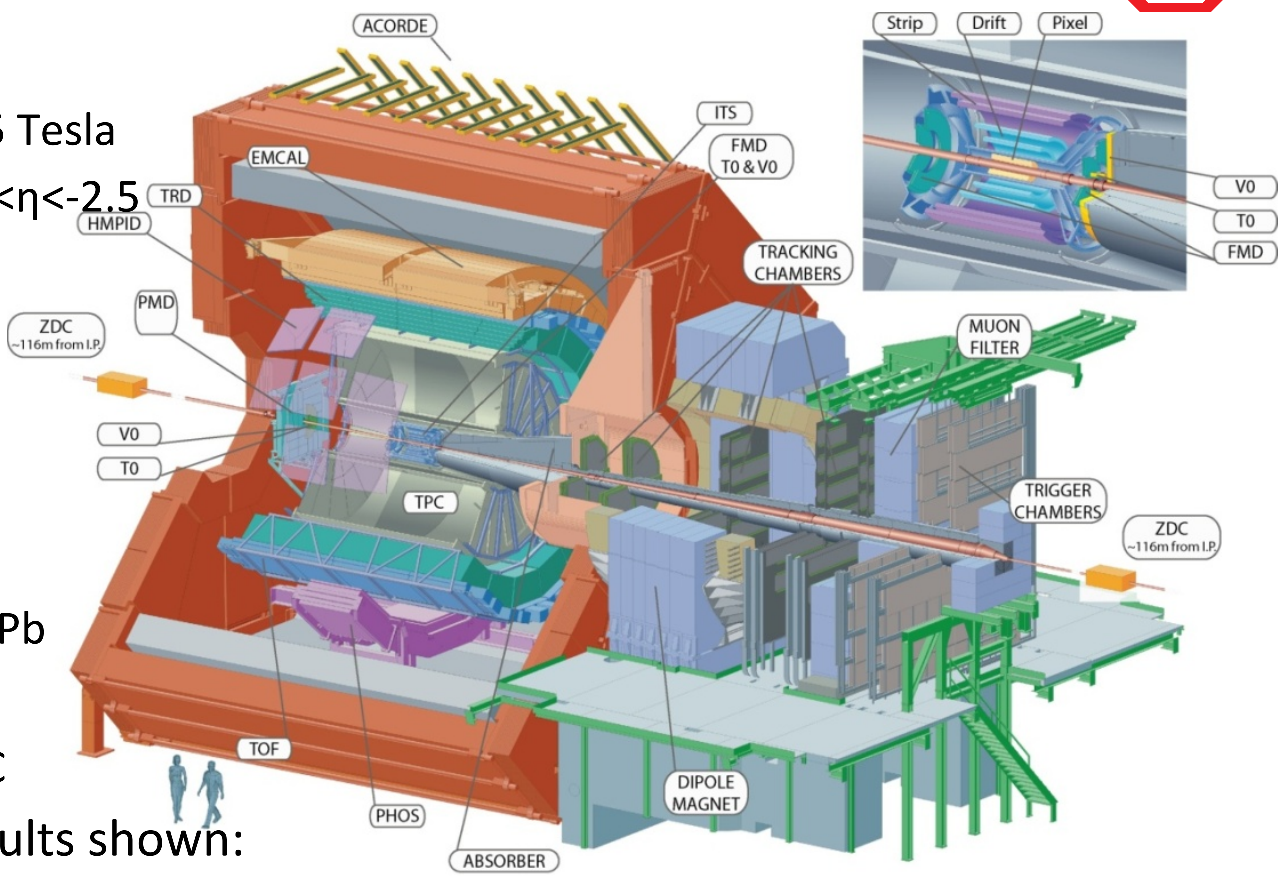
ALICE apparatus and datasets

- Two main parts:
  - barrel ($|\eta|<0.9$), B = 0.5 Tesla
  - muon spectrometer, $-4<\eta<-2.5$
- Crucial for HF:
  - vertexing, tracking
  - hadron and lepton ID
- Triggers:
  - minimum-bias (MB)
    - or centrality, in Pb-Pb
  - single/di muon p_t
  - EMCAL, high-mult., UPC
- Datasets used for the results shown:



system, $\sqrt{s_{NN}}$ (TeV)	pp 7	pp 2.76	Pb-Pb 2.76	Pb-Pb 2.76
year	2010	2011	2010	2011
L_{int} MB/cent	5/nb	1.5/nb	2.5/μb	6.5/μb

ALICE triggers and Pb-Pb centrality

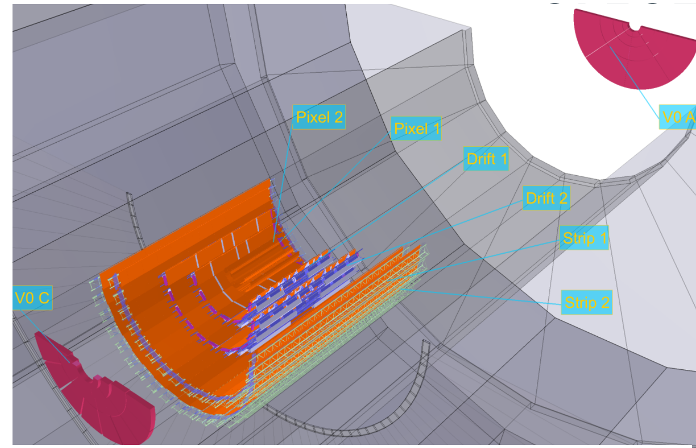
- *Minimum-bias (MB):* combinations of the following detectors

  Pixel Fast-Or (1 or 2 hits)

  VZERO scintillators (one or both sides)

  → pp: 87% of $\sigma_{inelastic}$

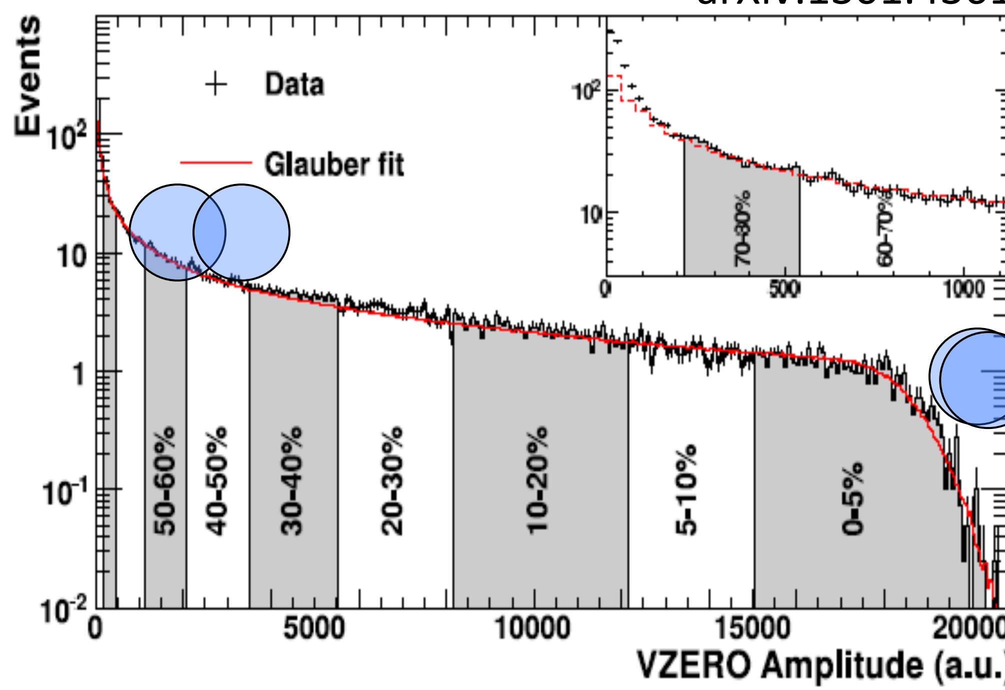
  → Pb-Pb: fully efficient in 0-88% of $\sigma_{hadronic}$
- *Single muon: MB* + a muon with p_T>0.5 GeV/c and $-4<\eta<-2.5$



arXiv:1301.4361

Pb-Pb centrality classes (percentiles of $\sigma_{hadronic}$) from the VZERO signal amplitude, which is well-described by the Glauber-model

- VZERO amplitude used also online for centrality-based triggering



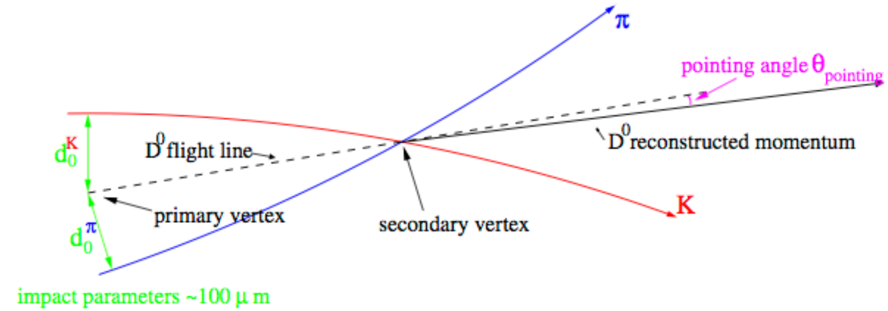
D meson reconstruction

D meson from fully reconstructed hadronic decay channels

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

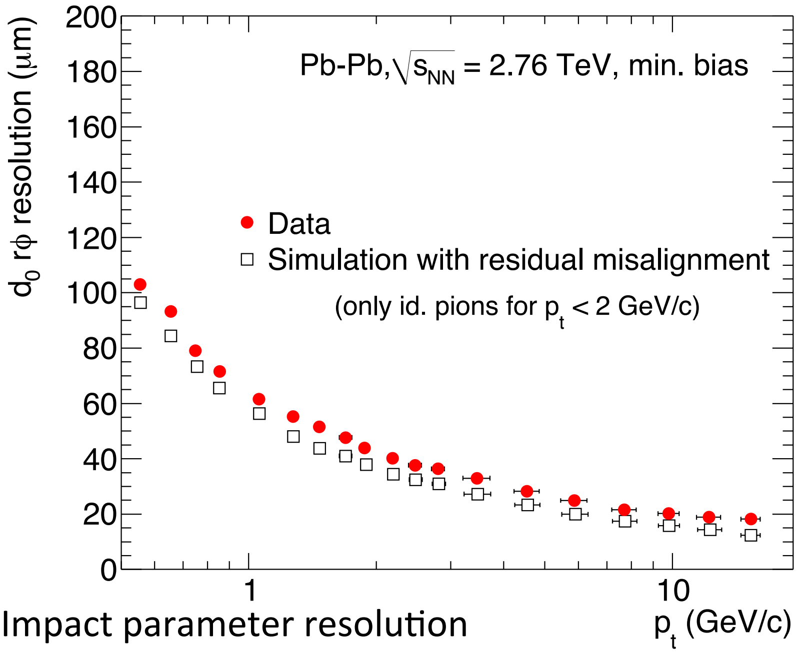
$D^+ \rightarrow K^- \pi^+ \pi^+$

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



Selection mainly based on:

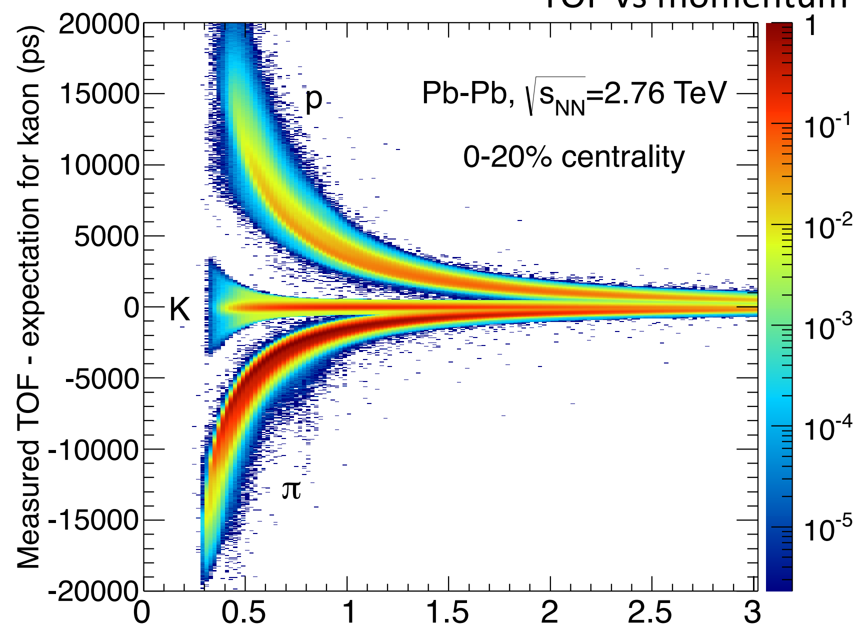
- secondary vertex separation



Impact parameter resolution

- kaon identification

TOF vs momentum

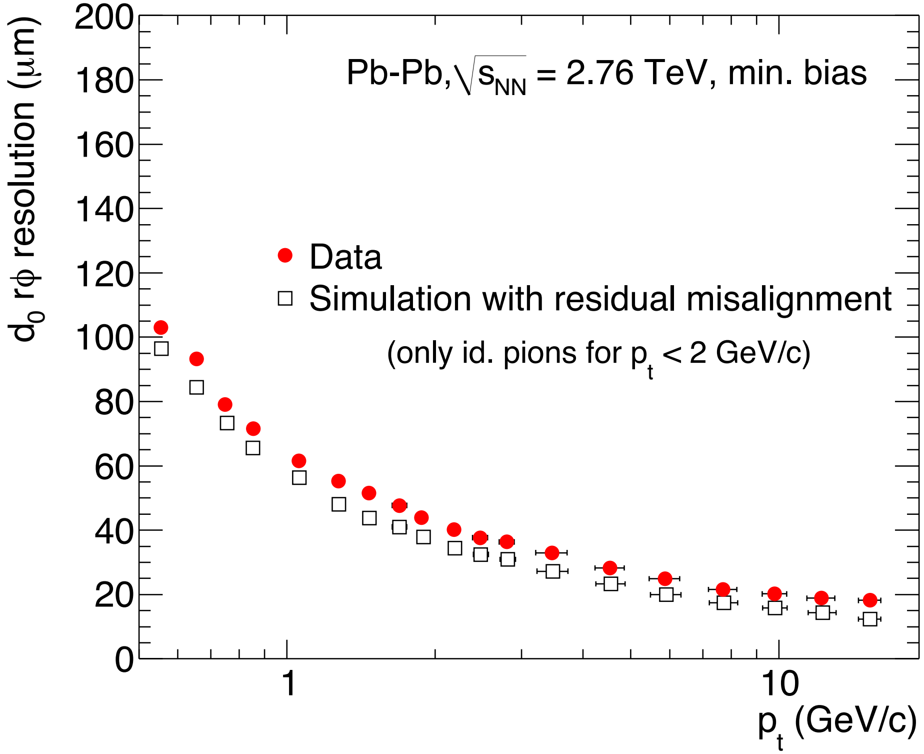


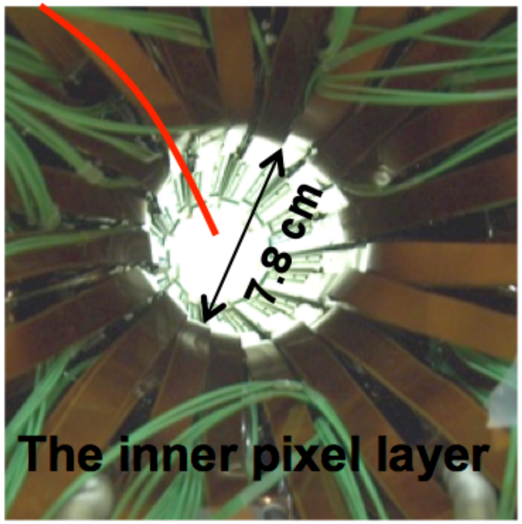
arXiv:1203.2160 [nucl-ex]

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





$$\sigma_{d_0} = \sigma_{track} \oplus \sigma_{primary\ \ vertex}$$

Primary vertex resolution important point for the selection of the secondary vertices

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

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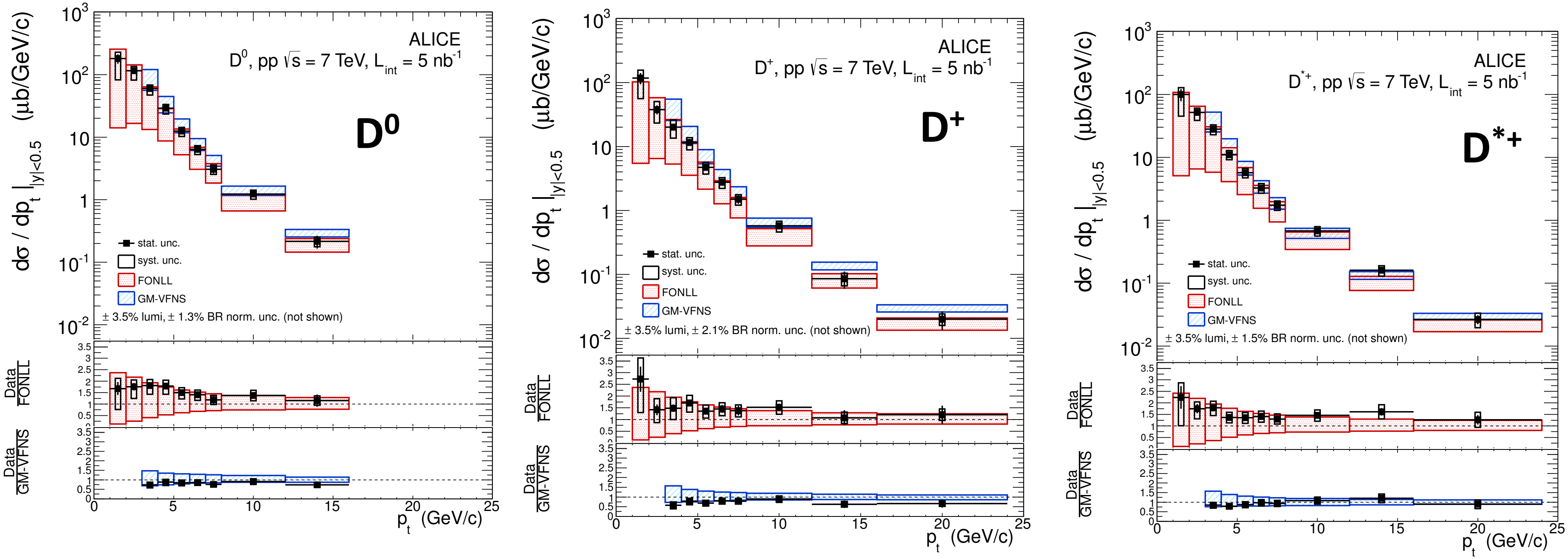
D mesons cross section in pp collisions at 7 TeV

[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

FONLL: Cacciari et al., arXiv:1205.6344

GM-VFNS: Kniehl et al., arXiv:1202.0439

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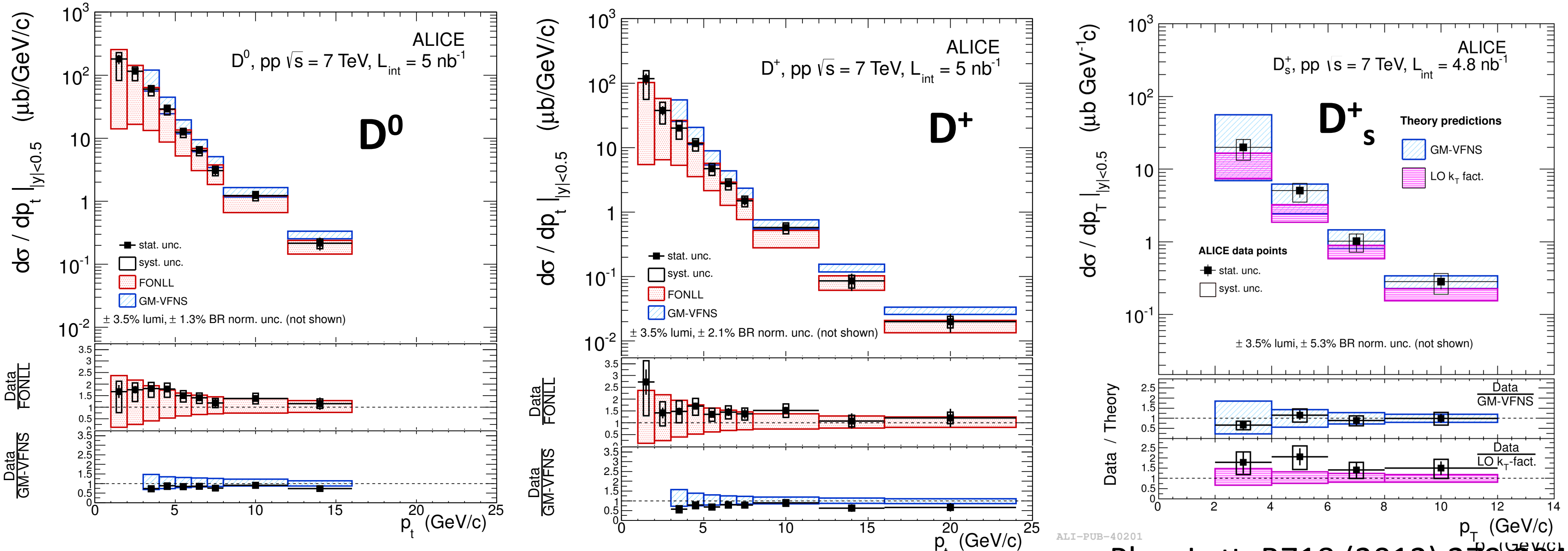


Phys.Lett. B718 (2012) 279-294

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

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

D^+_s mesons cross section measured in the range $2 < p_t < 12$ GeV/c

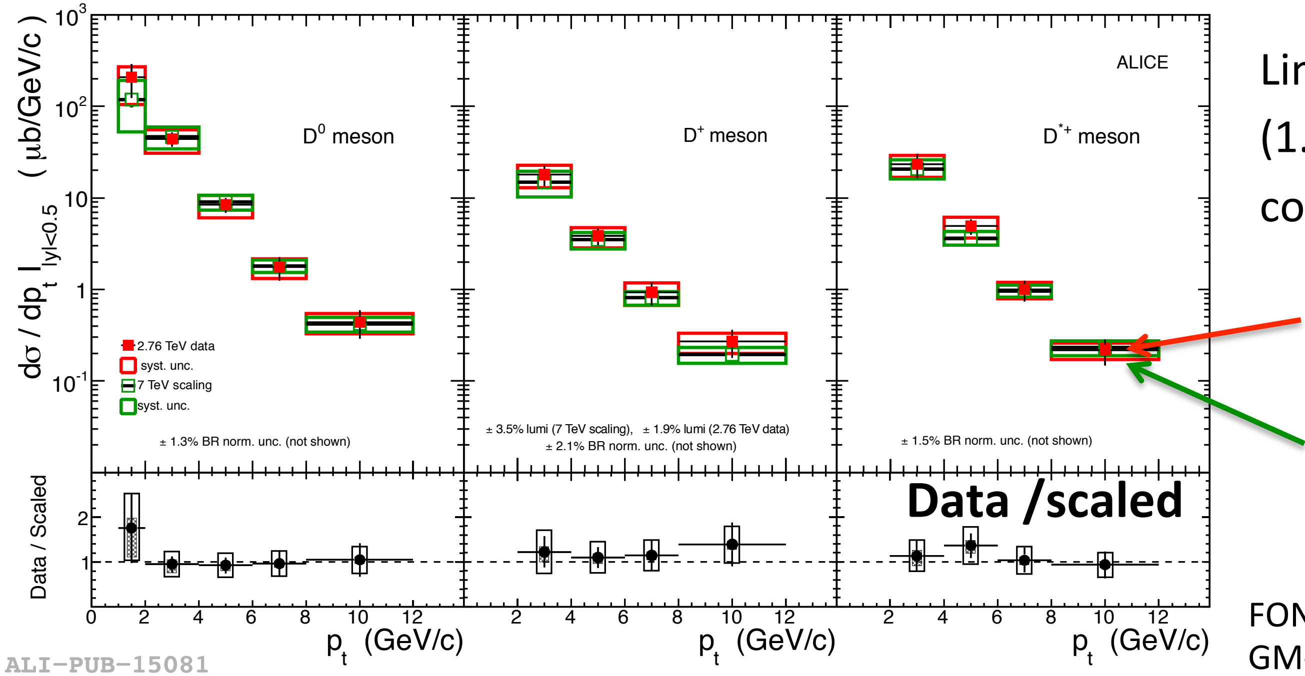
FONLL: Cacciari et al., arXiv:1205.6344

GM-VFNS: Kniehl et al., arXiv:1202.0439

D mesons cross section in pp collisions at 2.76 TeV

JHEP07(2012)191

ALICE



Limited statistics (1.35/nb with MB trigger) collected in 3 days in 2011

FONLL: Cacciari et al., arXiv:1205.6344
GM-VFNS: Kniehl et al., arXiv:1202.0439

Fair description by pQCD within uncertainties (FONLL, GM-VFNS) as for 7 TeV data (not shown here)

ALICE pp measurement at $\sqrt{s}$ = 7 TeV scaled to $\sqrt{s}$=2.76 TeV using FONLL predictions and compared with data.

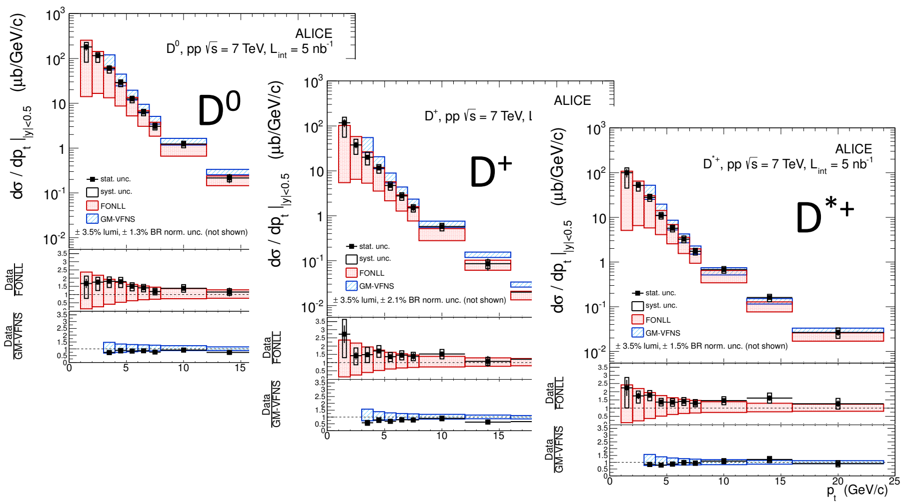
R.Averbeck et al., arXiv:1107.3243

FONLL: Cacciari et al., arXiv:1205.6344
GM-VFNS: Kniehl et al., arXiv:1202.0439

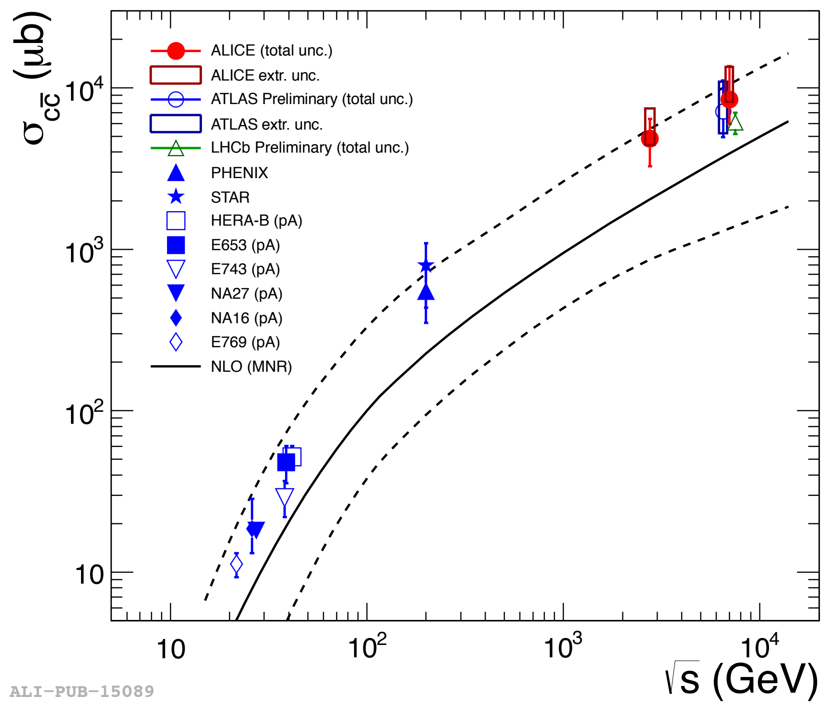
LHC as heavy flavour factory

ALICE

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



JHEP07(2012)191



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 RHIC

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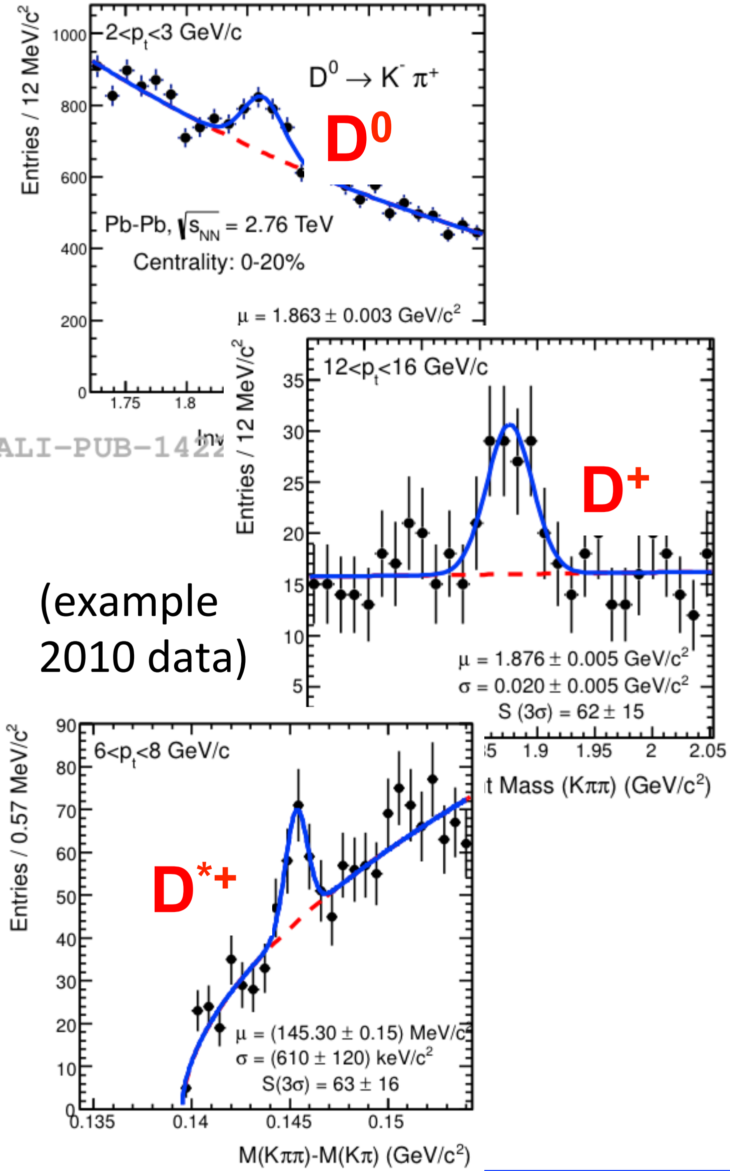
D mesons reconstruction in Pb-Pb collisions

ALICE



(example 2010 data)

2010 : ~3M central collisions (0-20%):

- D^0 : 7 p_t bins in 2-16 GeV/c
- D^+ : 3 p_t bins in 6-16 GeV/c
- D^* : 4 p_t bins in 4-16 GeV/c

2011: ~17M central collisions (0-7.5%)

- D^0 : 9 p_t bins in 1-24 GeV/c
- D^+ : 8 p_t bins in 3-36 GeV/c
- D^* : 8 p_t bins in 3-36 GeV/c

Reconstruction efficiency ~1-10%

- evaluated from MC simulation

Feed-down from B decays ~10-15% after cuts

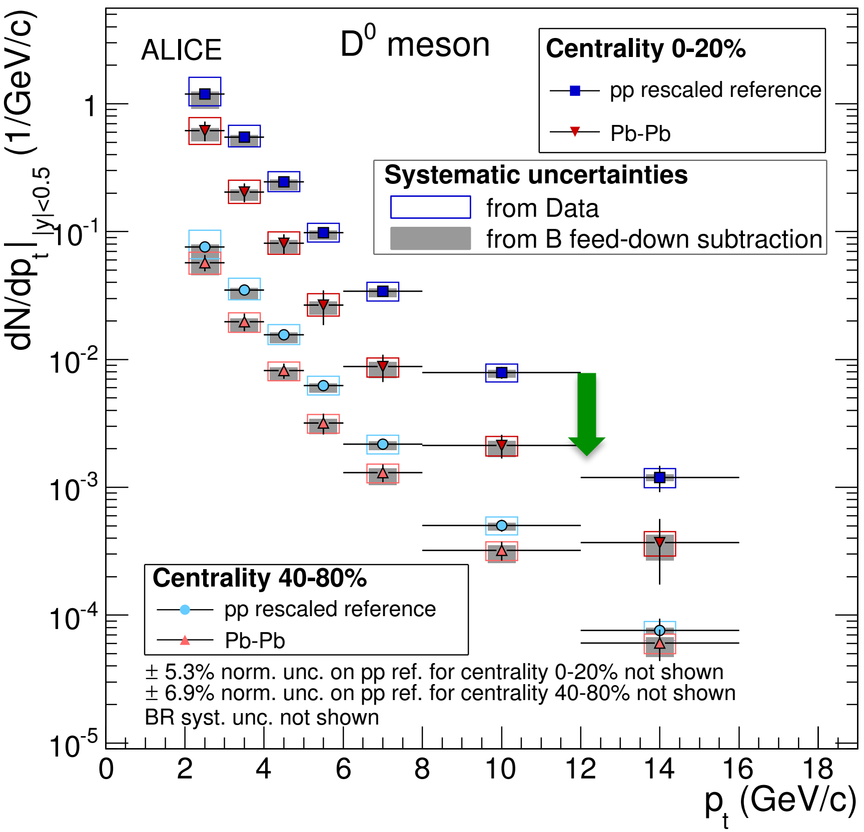
- subtracted based on FONLL with hypothesis on $R_{AA}{}^{B}$

D meson dN/dp_t (2010 data)

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

Pb-Pb yield

Indication of suppression



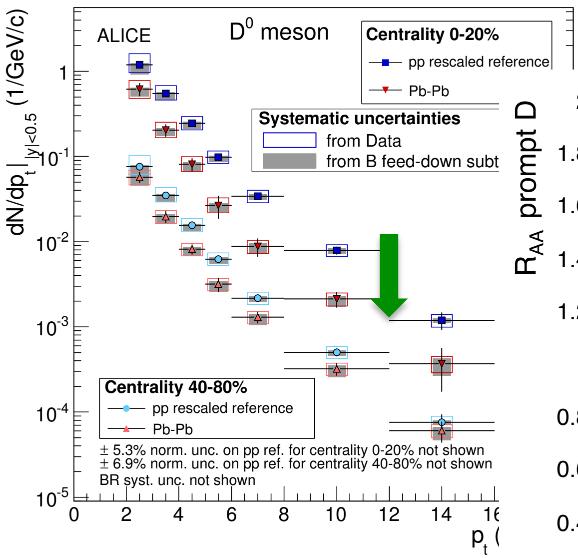
ALICE Collaboration JHEP 1209 (2012) 112

D meson suppression (2010 data)

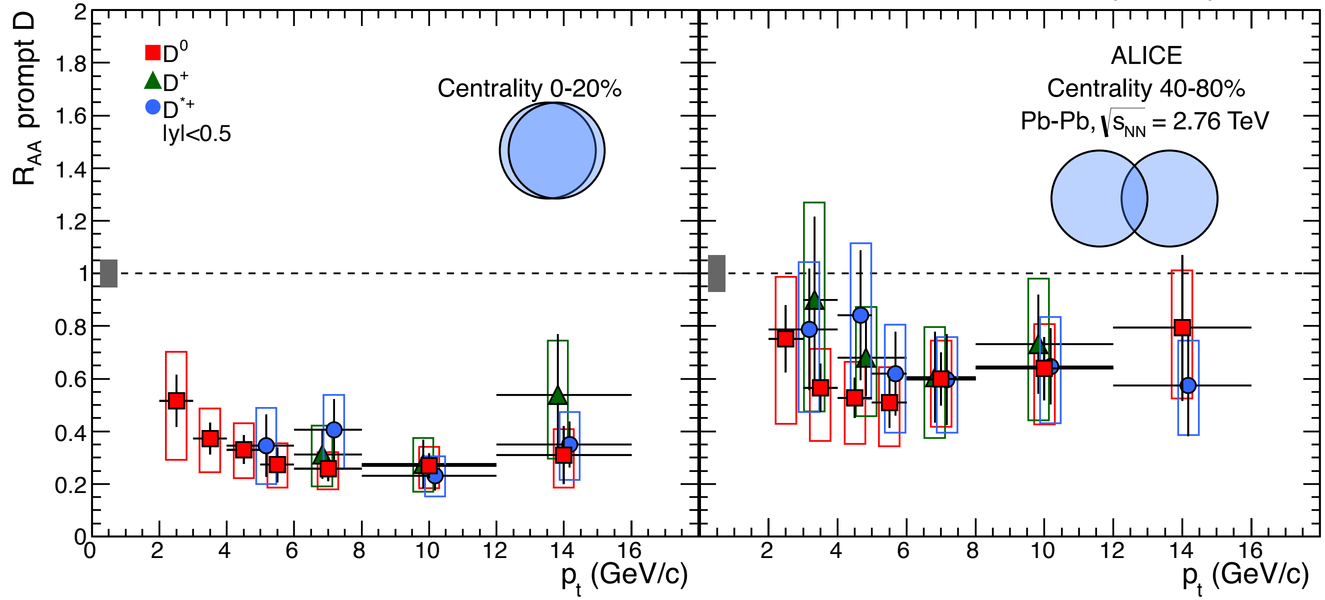
pp scaled reference x $\langle T_{AA} \rangle$

Pb-Pb yield

$$R_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$



ALICE Collaboration JHEP 1209 (2012) 112

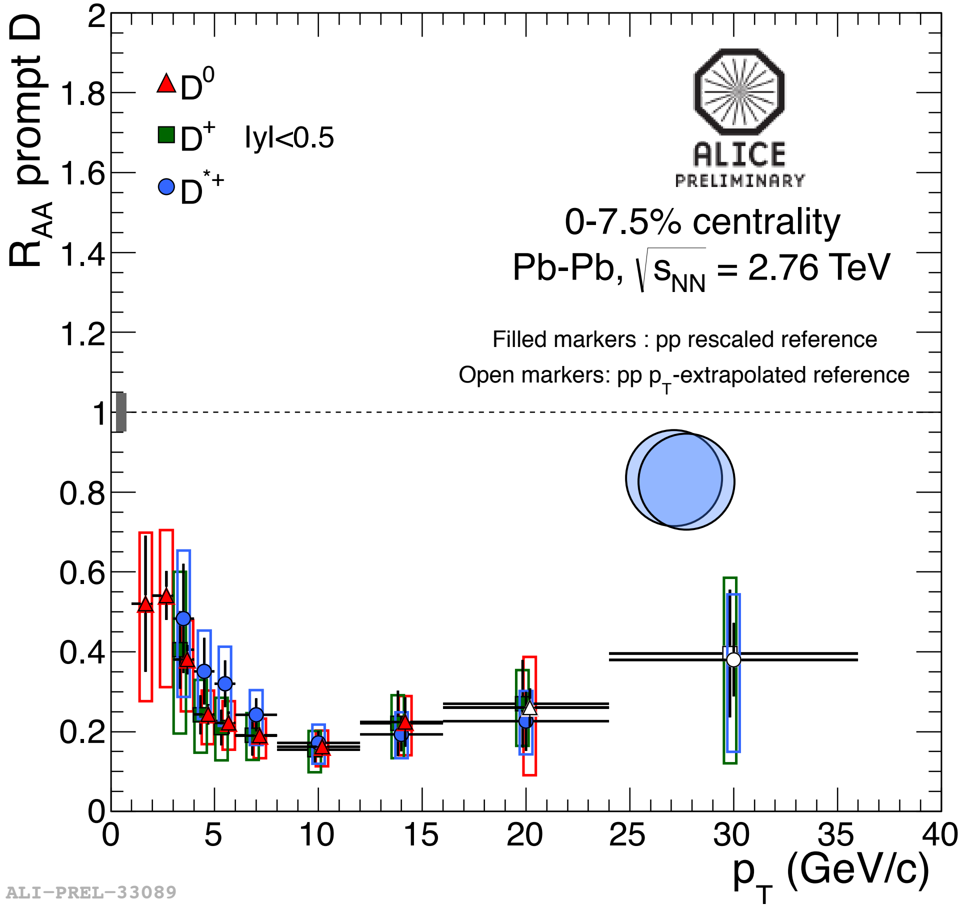


D^0, D^+, D^{*+} R_{AA} measured in the range **2-16 GeV/c with 2010 data**.

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 suppression (2011 data)



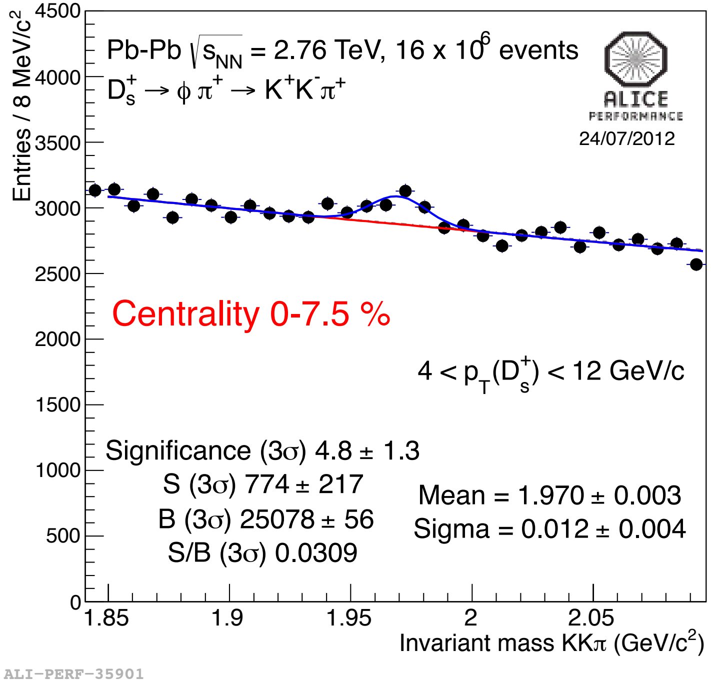
$$R_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$

D^0, D^+, D^{*+} R_{AA} measured in the range **1-36 GeV/c with 2011 data**: Compatible within uncertainties between the three mesons and with 2010 results.

Suppression up to a factor 5 for D^0, D^+, D^{*+} at p_T ~10 GeV/c

D^+_s meson dN/dp_t

$D_S^+ \rightarrow \varphi\pi^+ \rightarrow K^+K^-\pi^+$ BR = (2.28 ±0.12)%
$c\tau\ (D_s^+) = 150\mu m$



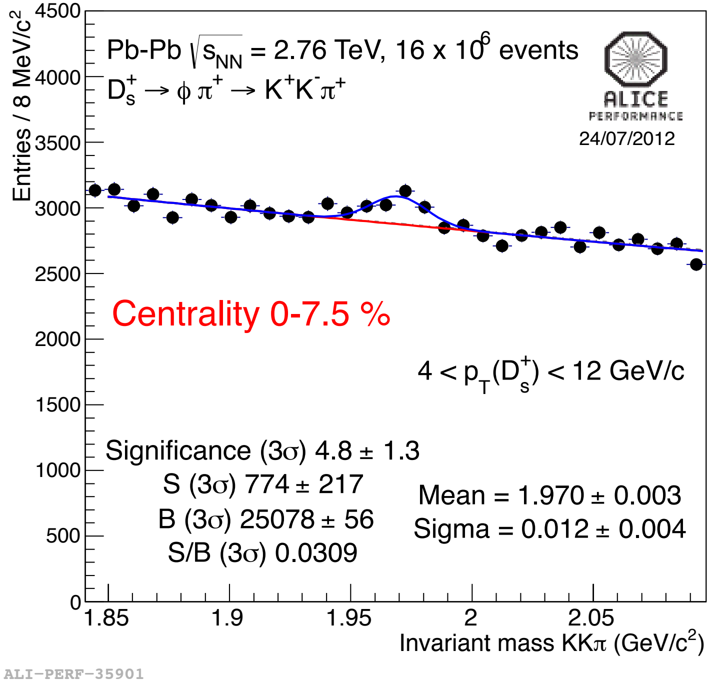
Secondary vertex reconstruction + kaon identification with TPC and TOF.

Analysis in three p_T intervals:
4-6, 6-8, 8-12 GeV/c

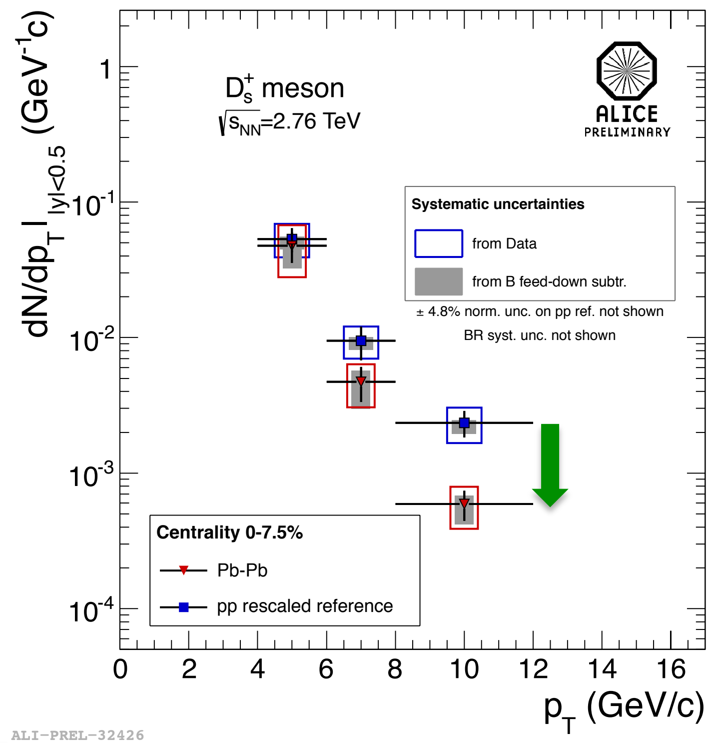
D^+_s meson dN/dp_t

$D_S^+ \rightarrow \varphi\pi^+ \rightarrow K^+K^-\pi^+$ BR = (2.28 ±0.12)%

$c\tau$ (D_s^+) = 150μm



Secondary vertex reconstruction + kaon identification with TPC and TOF.

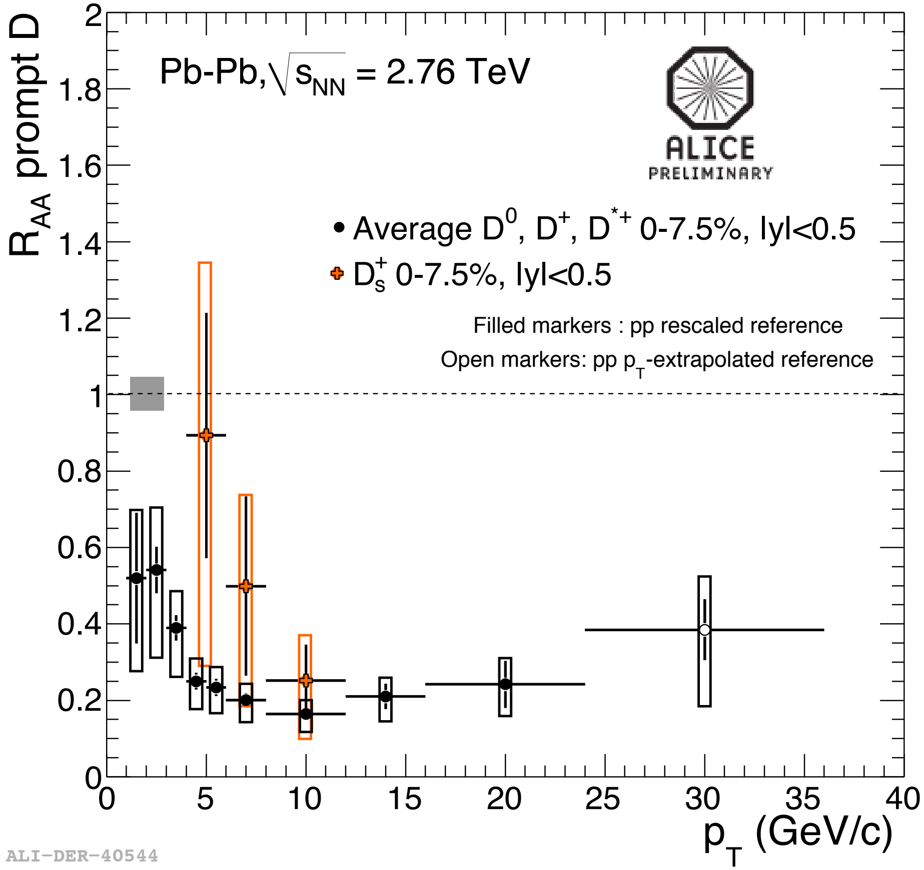


Analysis in three p_T intervals:
4-6, 6-8, 8-12 GeV/c

Indication of suppression at high p_T

D^+_s R_{AA}

D^0, D^+, D^{*+} R_{AA} measured in the range 1-36 GeV/c
D^+_s R_{AA} measured in the range 4-12 GeV/c
with 2011 data in central (0-7.5%) collisions



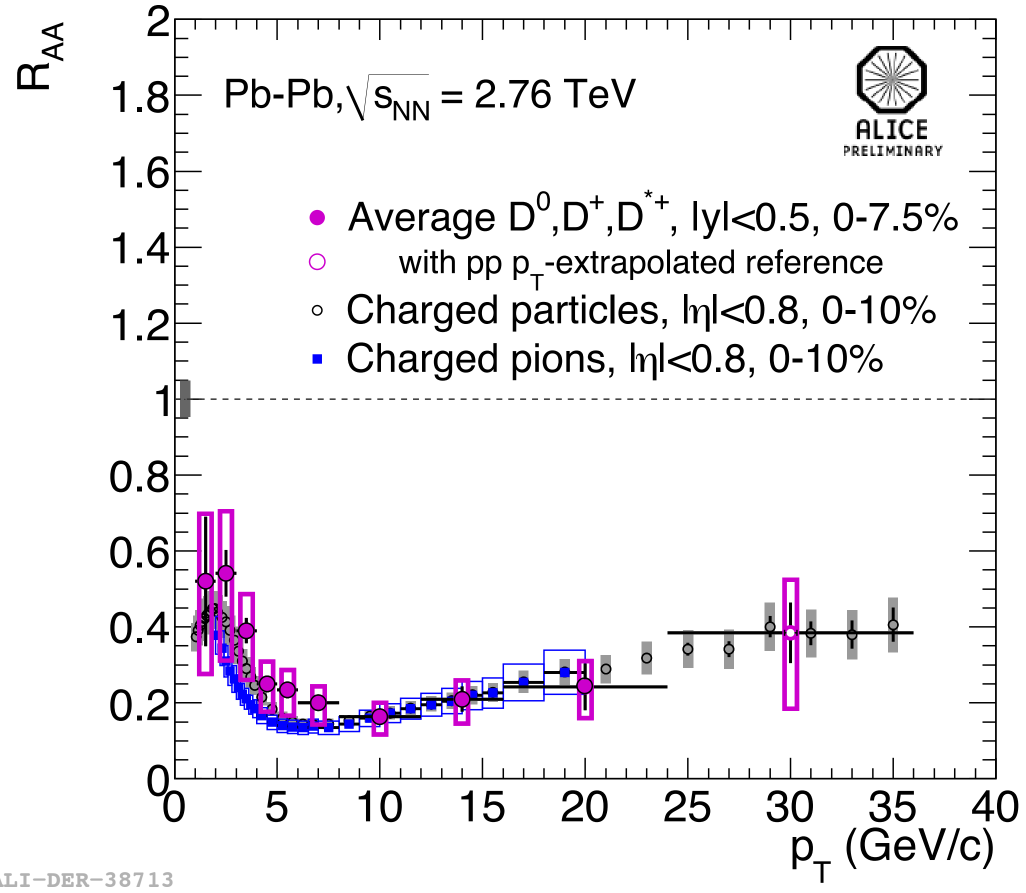
- **First Measurement of D_s^+ R_{AA} in Heavy ion collisions**
- **Strong suppression observed ~3-5 for p_T 8-12 GeV/c**
- **R_{AA} seems to increase at low p_T but current data don't allow for a conclusive comparison.**

Mass effect (I) ?

$R_{AA}(\pi) > R_{AA}(D)$?

✧ D R_{AA} shows a similar trend as charged particles and $\pi^{\pm}$ in 0-10% at high-p_T.

✧ Indication of difference at low-p_T ?? The current systematic and statistical uncertainties don't allow to conclude



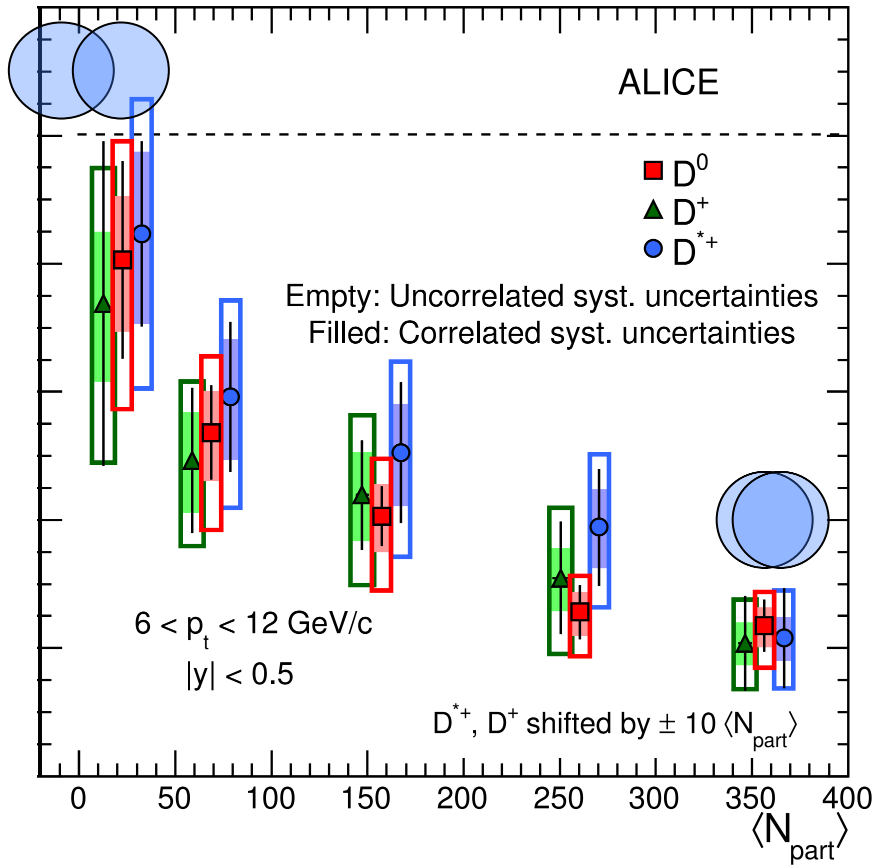
D meson R_{AA} vs. collision centrality

D mesons exclusive reconstruction
$6 < p_T < 12$ GeV/c
$|y| < 0.5$

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

✧ **D mesons suppression shows a clear trend vs centrality.**

ALICE Collaboration arXiv:1203.2160



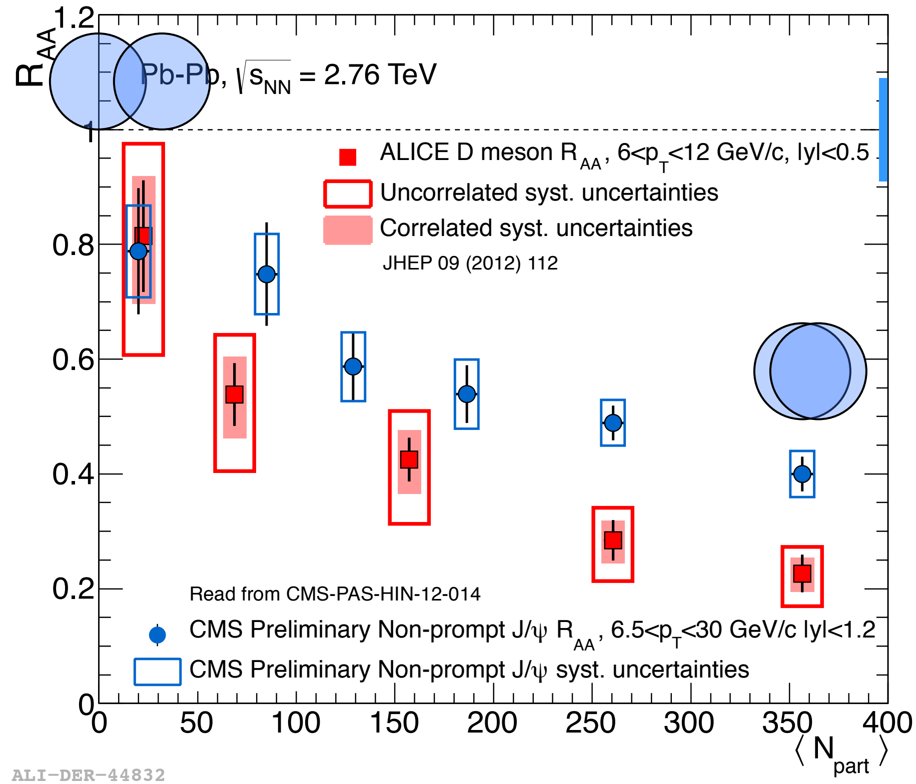
Mass effect (II) ?

$R_{AA}(B) > R_{AA}(D)$?

CMS (CMS-HIN-12-014)
B → J/ψ + *X*
6.5 < p_T (J/ψ) < 30 GeV/c
|y|< 1.2

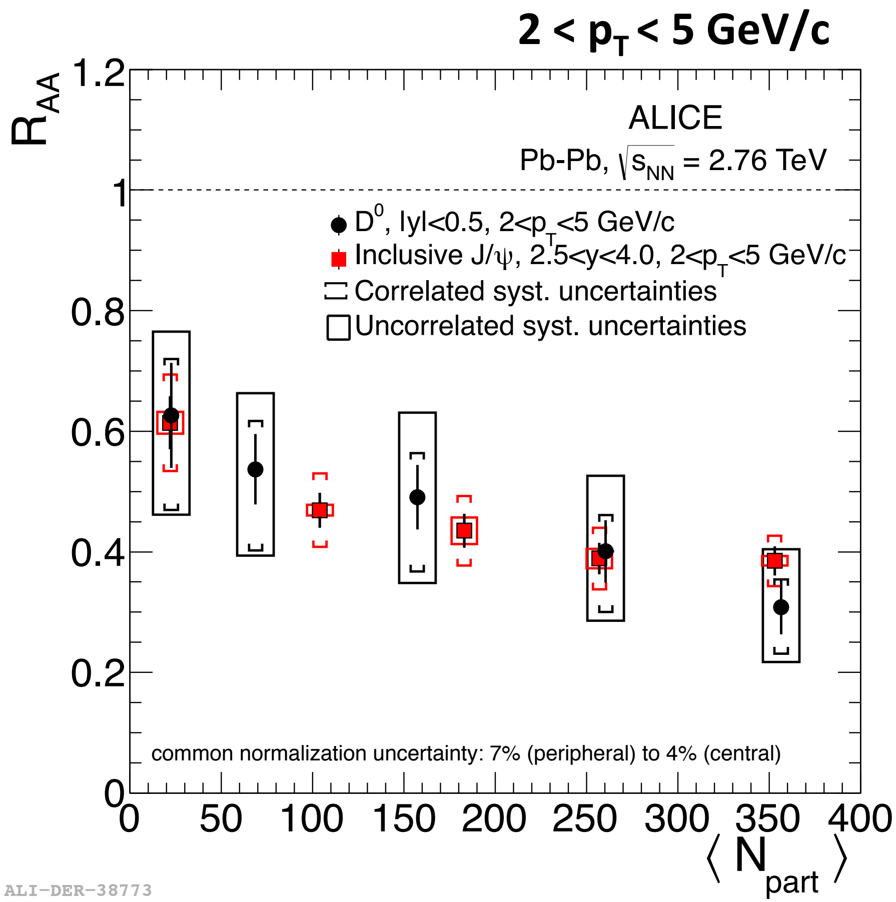
Compared with
D mesons exclusive reconstruction
6 < p_T < 12 GeV/c
|y|< 0.5

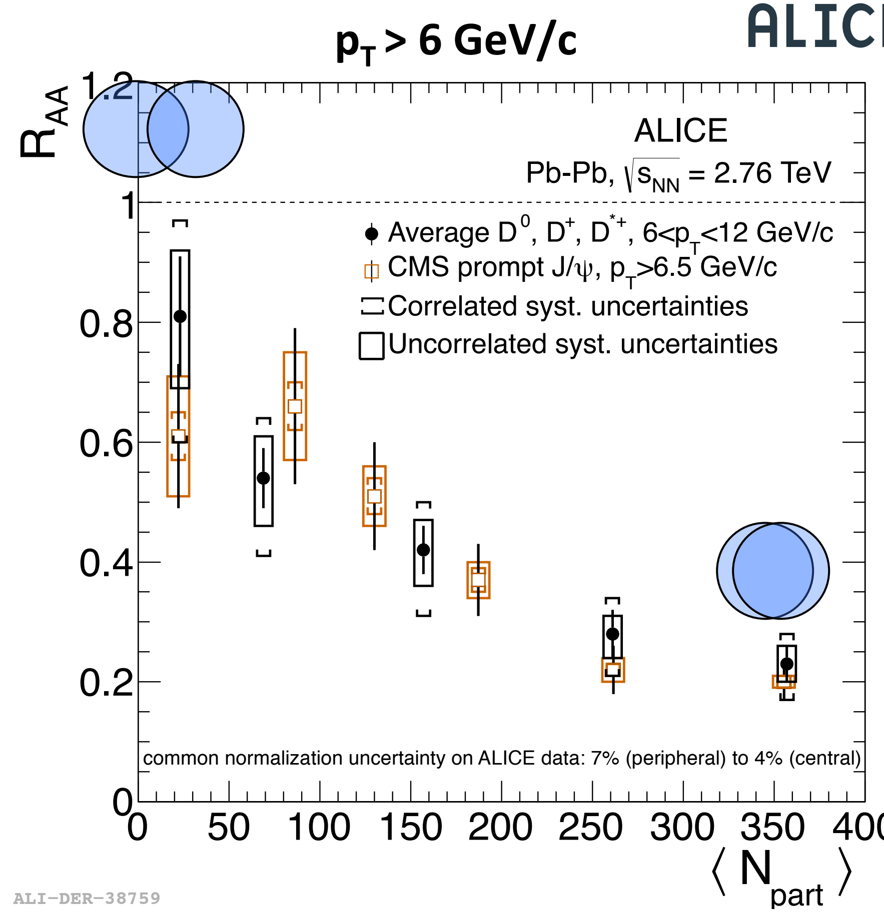
ALICE Collaboration JHEP 1209 (2012) 112



Indication of mass effect?
Different kinematics range for D and B mesons…
Not clear how to conclude.

Interesting observations…





Similar trend of D mesons and J/ψ at low and high p_T:

- ✧ $2 < p_T < 5$ GeV/c D (|y|<0.5) vs inclusive J/ψ (ALICE, 2.5<y<4)
- ✧ $p_T > 6$ GeV/c D (|y| < 0.5) vs prompt J/ψ (CMS, |y|<2.4)

Is it a medium effect?

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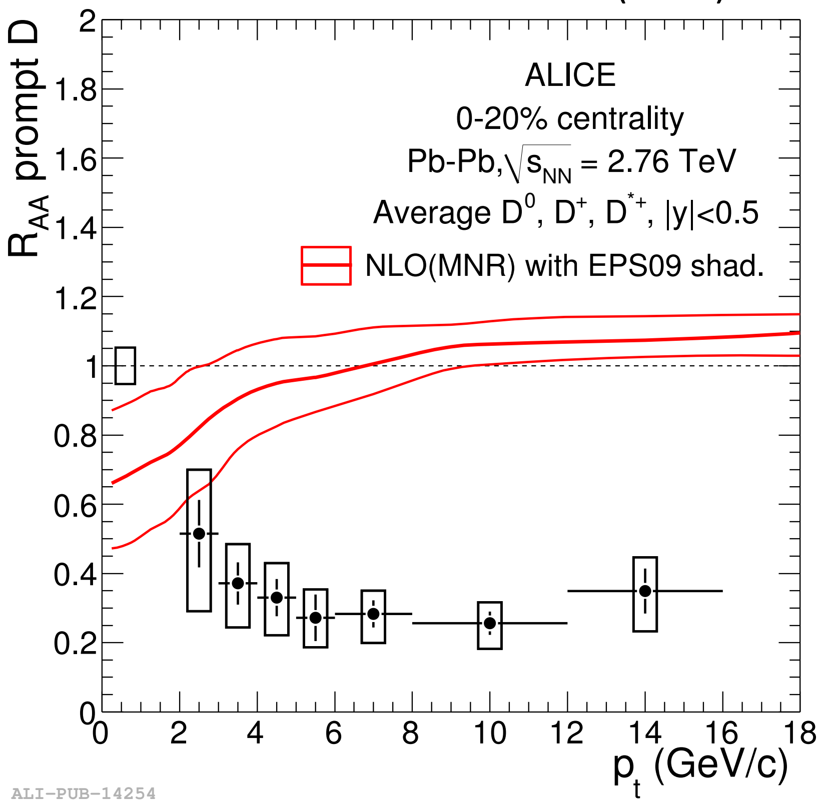


- ✧ High parton density in high-energy nuclei leads to reduction/saturation/ shadowing of the *PDFs* at small *x* (and small Q^2)

- ✧ Small effect expected

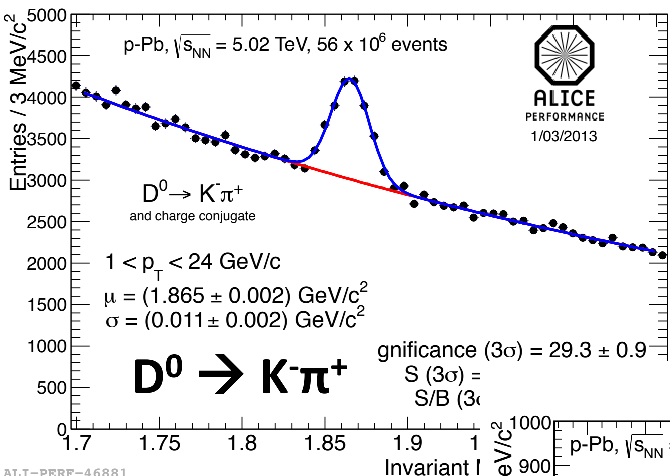
  from PDFs shadowing above 5 GeV/c

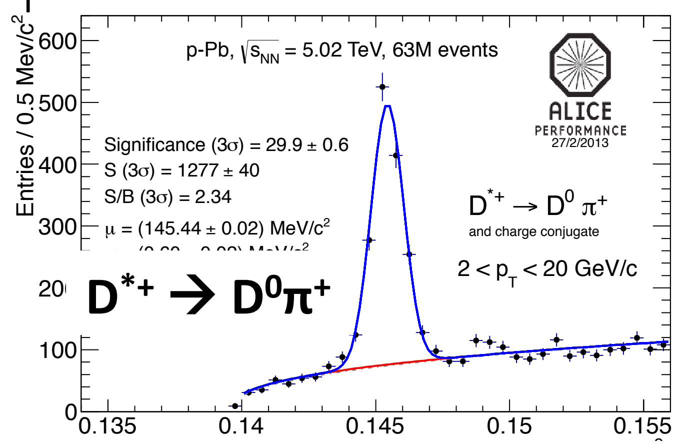
- ✧ Suggests that this is a hot medium effect
- ✧ p-Pb run at LHC crucial to measure initial-state effects

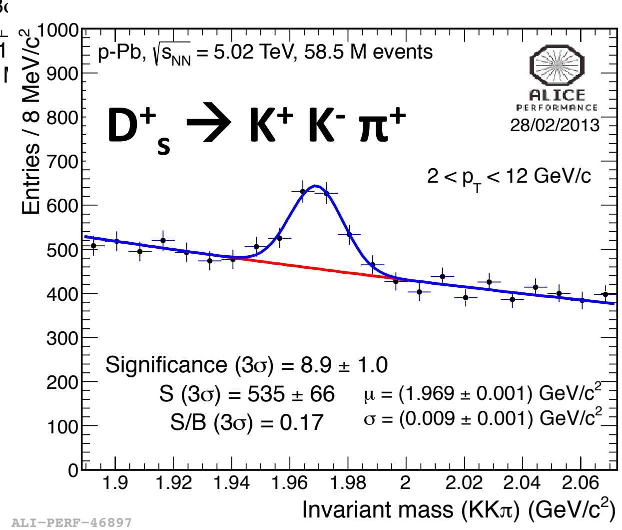
A preview…

D meson in p-Pb to quantify the relevance of initial-state effects, which may be strong at low p_T

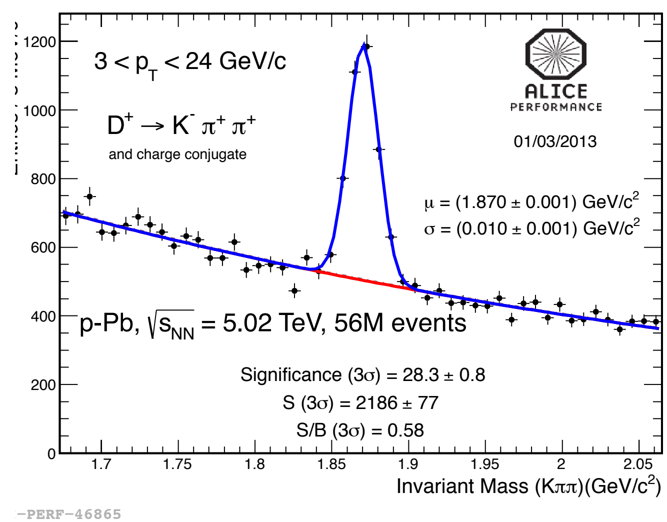
D^0, D^+, D^{*+}, D_S signals with part of 2013 MB statistics.







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



p_T > 1-2 GeV/c for the four D mesons

Outline

✧ Heavy quarks as probes of QCD matter at the LHC

✧ D mesons reconstruction in ALICE
- ✧ reconstruction strategy
- ✧ pp results

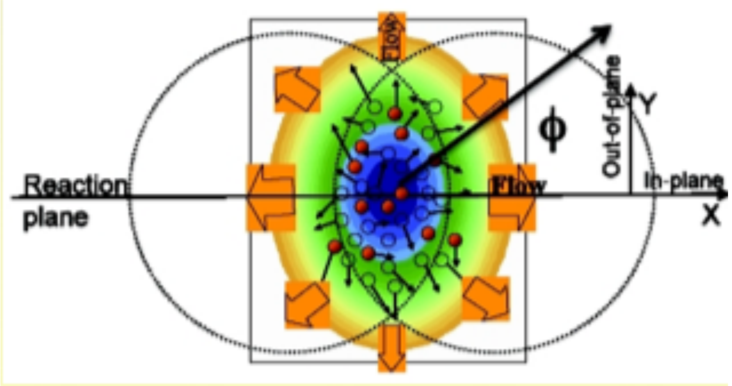
✧ Pb-Pb measurements:
- ✧ Heavy flavour suppression at high momentum (R_{AA})
- ✧ Charm azimuthal anisotropy

✧ Comparison with theoretical models

✧ Summary and outlook.

Event Plane

- Event Plane determination with TPC tracks with $0 < \eta < 0.8$ from the Q_n vector (n=2)

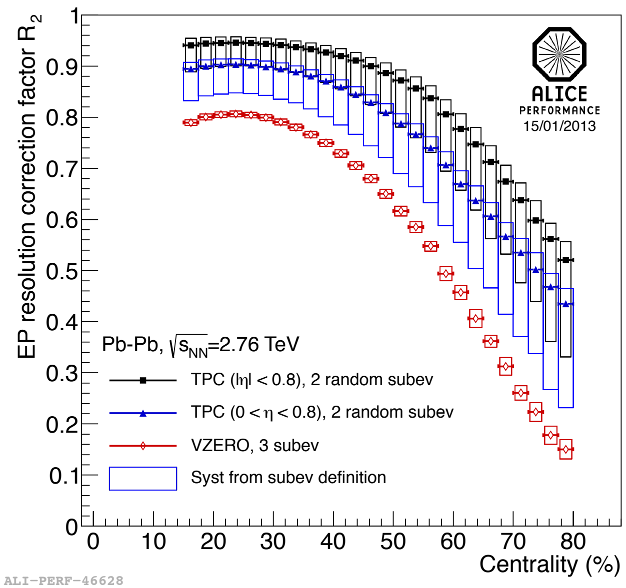


- φ-weights applied to improve the TPC - EP flatness

- Event Plane resolution computed with 2 random sub-events (R_2)*
  Also three sub-events method considered: used to estimate systematic uncertainties

$$R_2 = 0.86 \, ^{+0.03}_{-0.06} \text{ for 30-50\%}$$

obtained as the average of the resolution in finer centrality bins

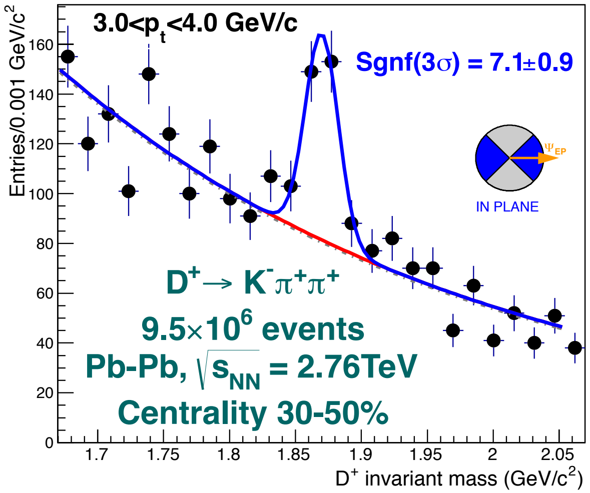


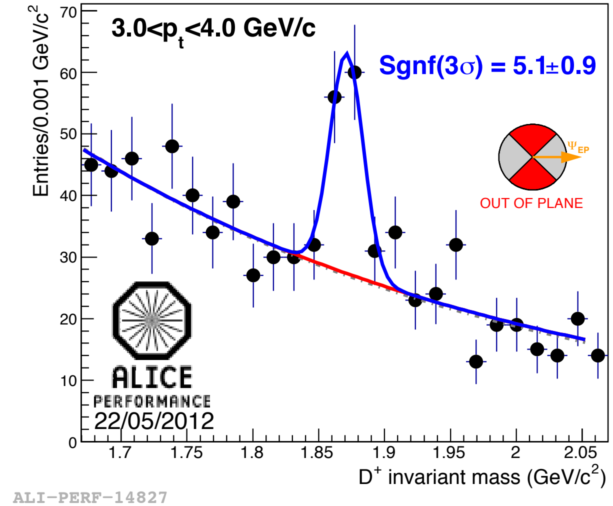
* A. M. Poskanzer, S. A. Voloshin Phys. Rev. C 58 3 (1998)

v_2 from yields In Plane and Out Of Plane

- $|\Delta\varphi| = (\varphi - \Psi_{EP})$
- Definition of the two regions:
  - In Plane: $|\Delta\varphi| < \pi/4$
  - Out Of Plane : $\pi/4 < \Delta\varphi < 3\pi/4$
- Fit the In Plane and Out Of Plane invariant mass distributions to extract the raw yields in the two regions
- v_2 computed from the azimuthal asymmetries after correction for EP resolution

$$v_2 = \frac{1}{R_2}\frac{\pi}{4}\frac{N_{IN} - N_{OUT}}{N_{IN} + N_{OUT}}$$

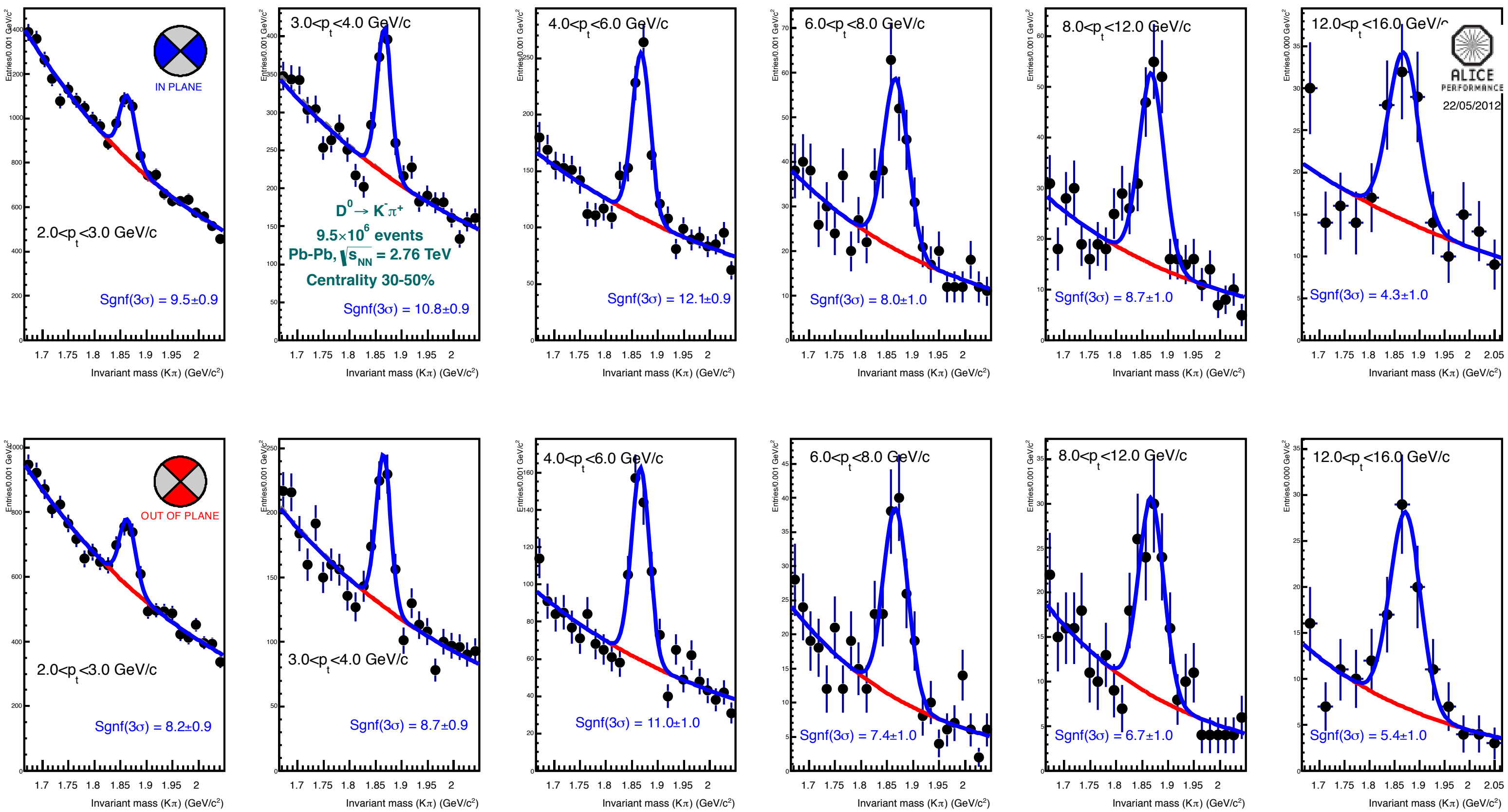




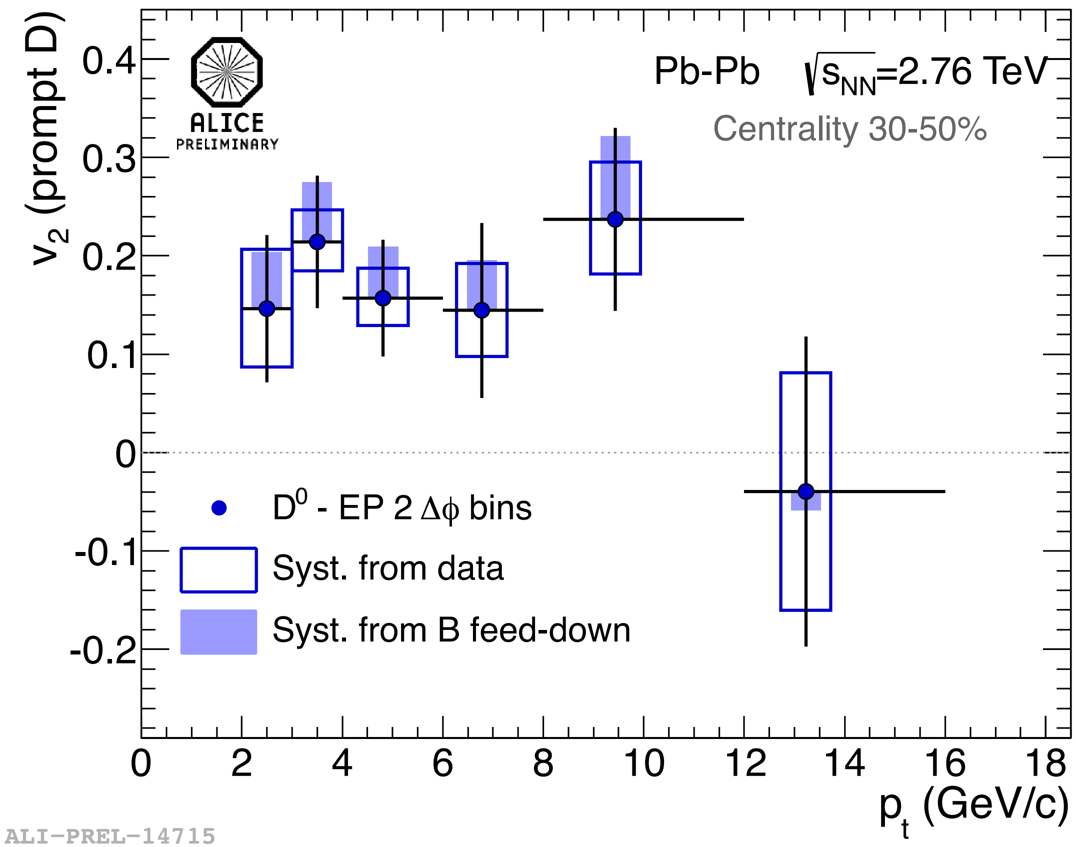
D^0 signal for EP method in 30-50%

- ✧ Signal yield from invariant mass distribution for each p_T bin
- ✧ The gaussian σ of the signal fit is fixed to the value obtained from the mass distributions integrated over Δφ

D^0 30-50%
$2 < p_T < 16$ GeV/*c*

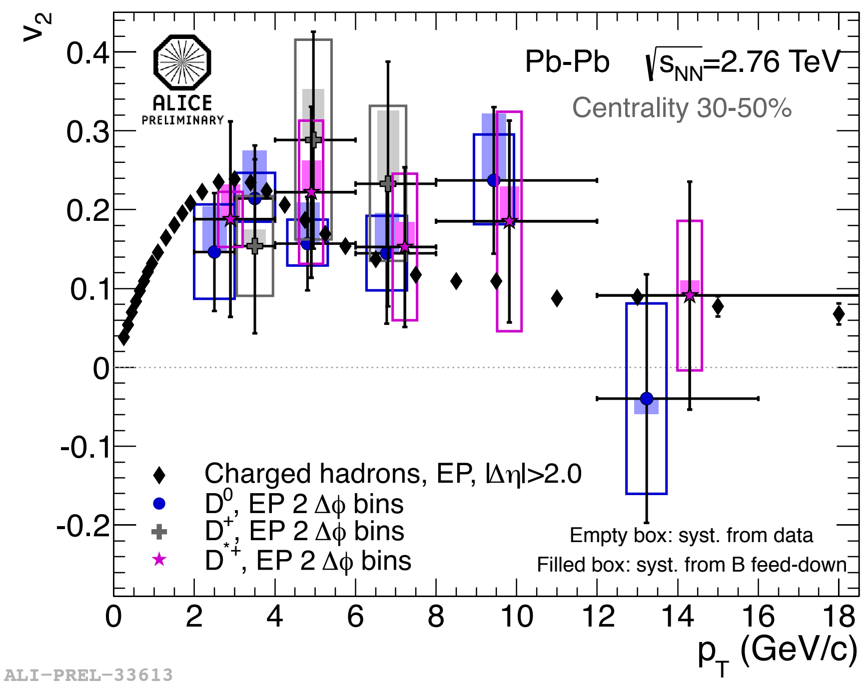


D^0 v_2 in 30-50%

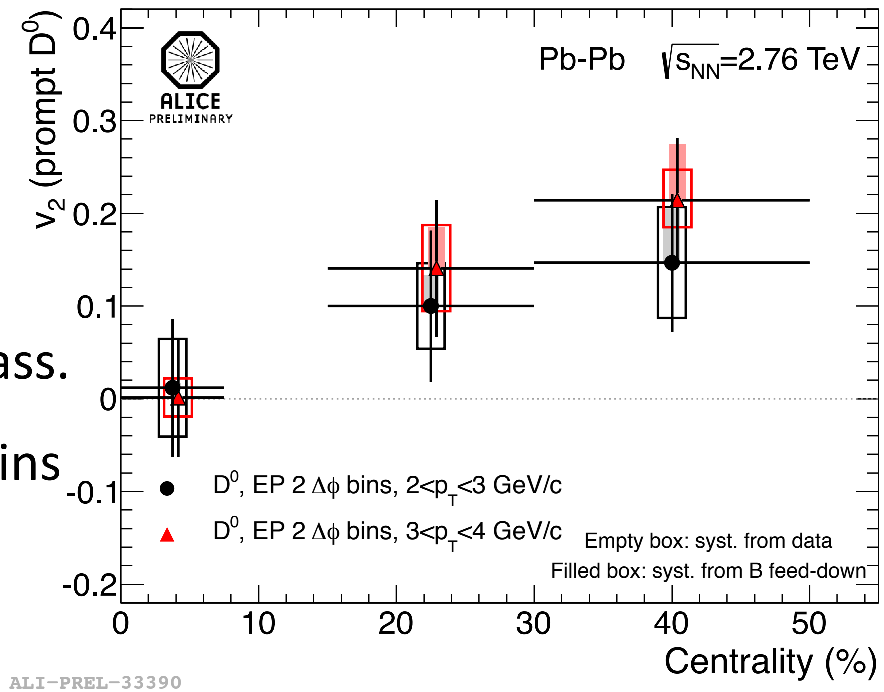


✧ Indication of non-zero D meson v_2 (3 σ effect in $2 < p_T < 6$ GeV/c)

D meson v_2



- ✧ Consistency among the three D meson species
- ✧ D meson v_2 comparable to charged hadron v_2 measured in ALICE in the same centrality class



- ✧ D^0 v_2 is larger in 30-50% centrality class.
- ✧ v_2 centrality dependence in the p_T bins [2-3], [3-4] GeV/*c*, consistent with v_2 larger in semiperipheral than in central events

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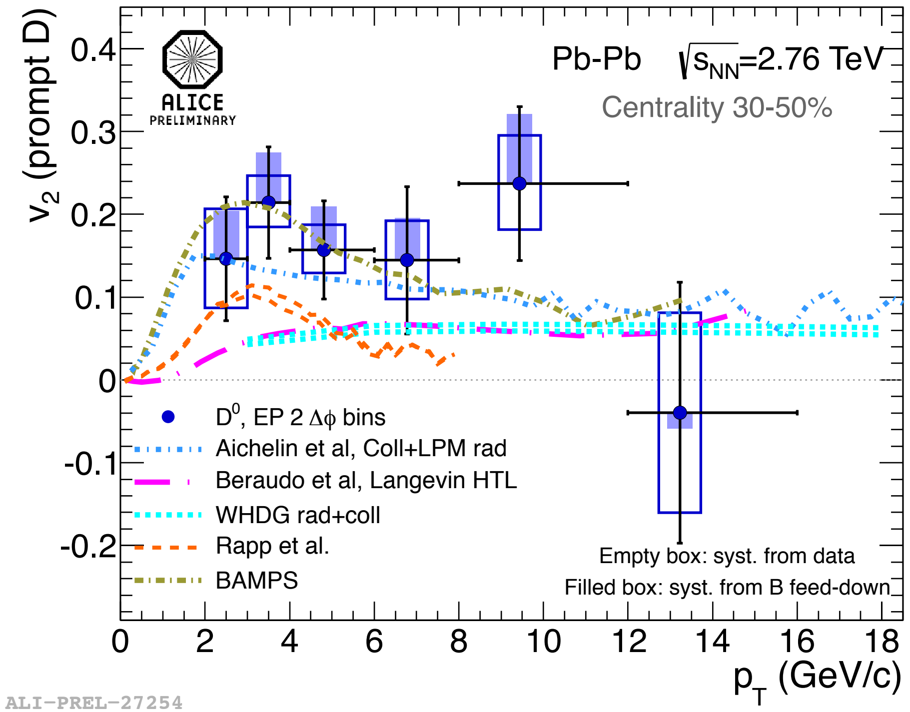
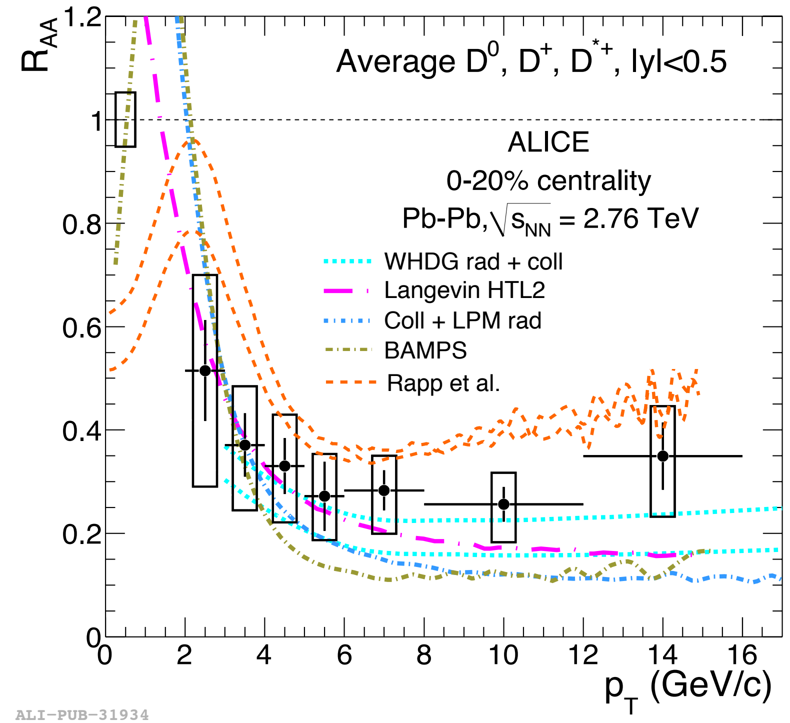
- ✧ Charm azimuthal anisotropy

✧ Comparison with theoretical models

✧ Summary and outlook.

Comparison with models

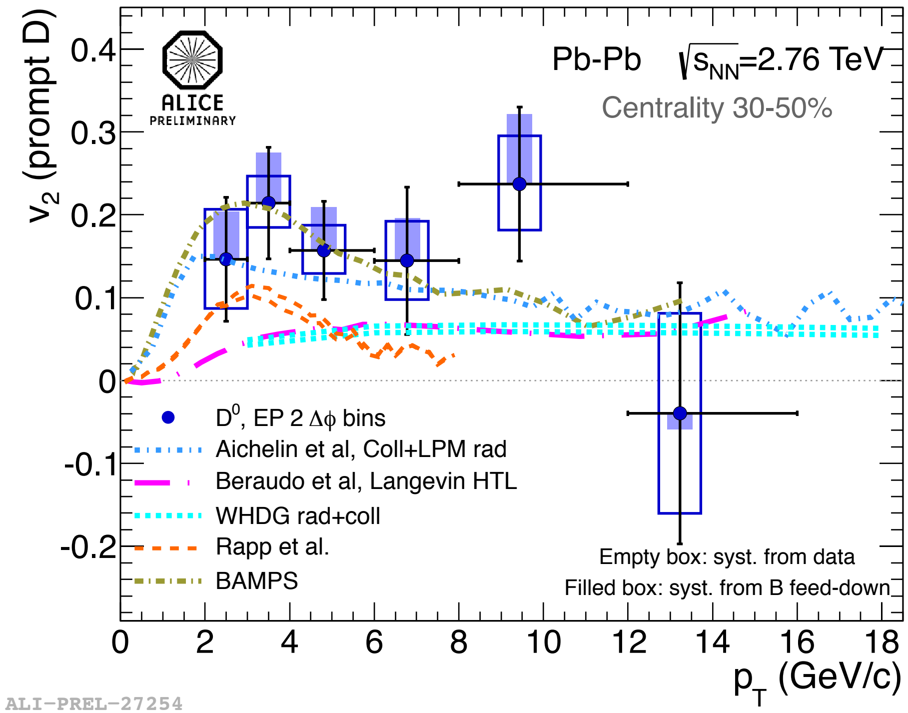


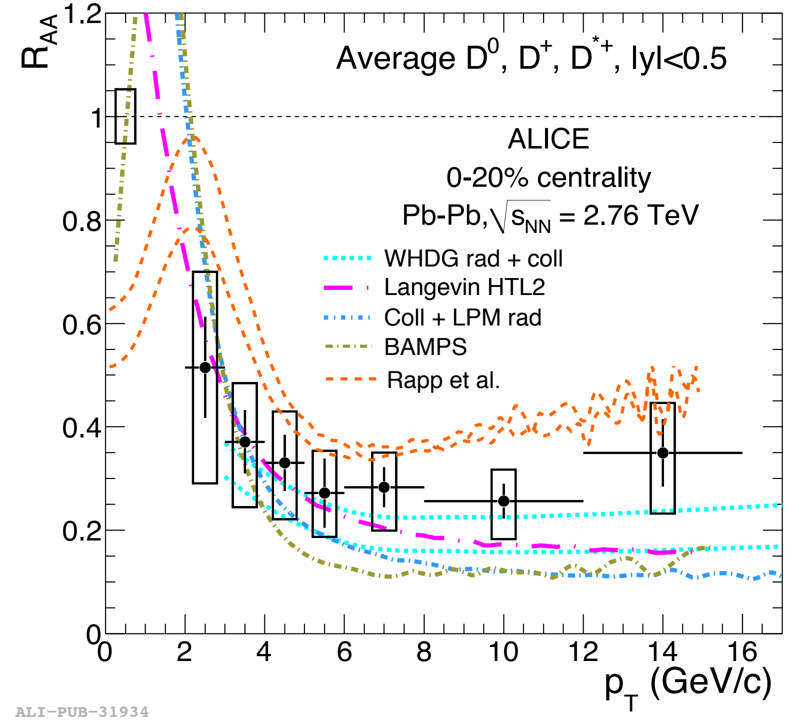


Simultaneous measurement/description of v_2 and R_{AA}
→ understanding of heavy quark transport coefficients of the medium

Comparison with models

arXiv:1203.2160 [nucl-ex]





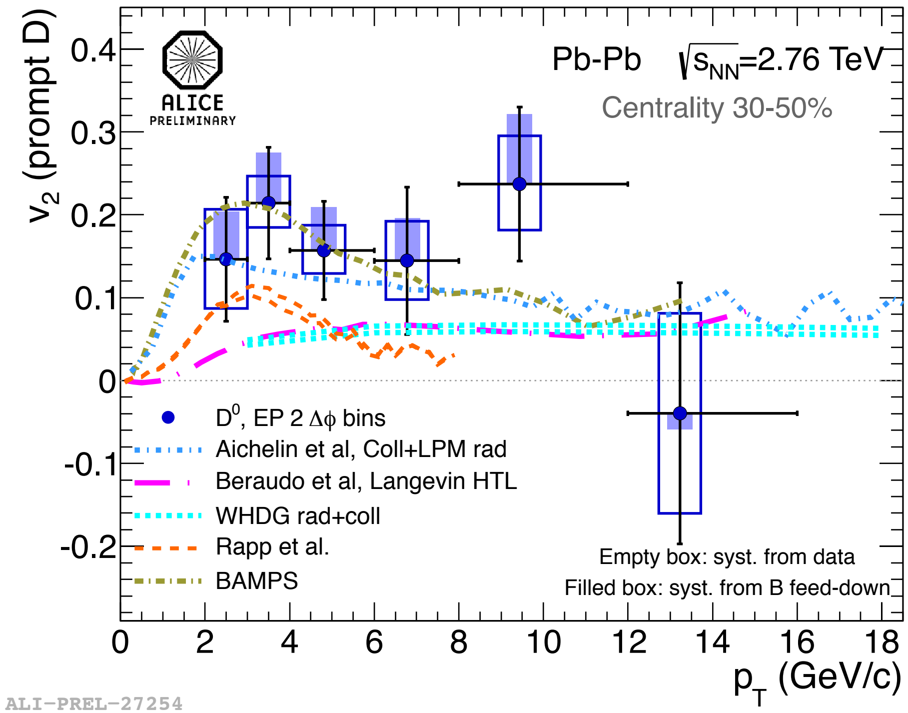
BAMPS[4] and Aichelin et al.[5] can describe v_2 but they seem to underestimate R_{AA}.

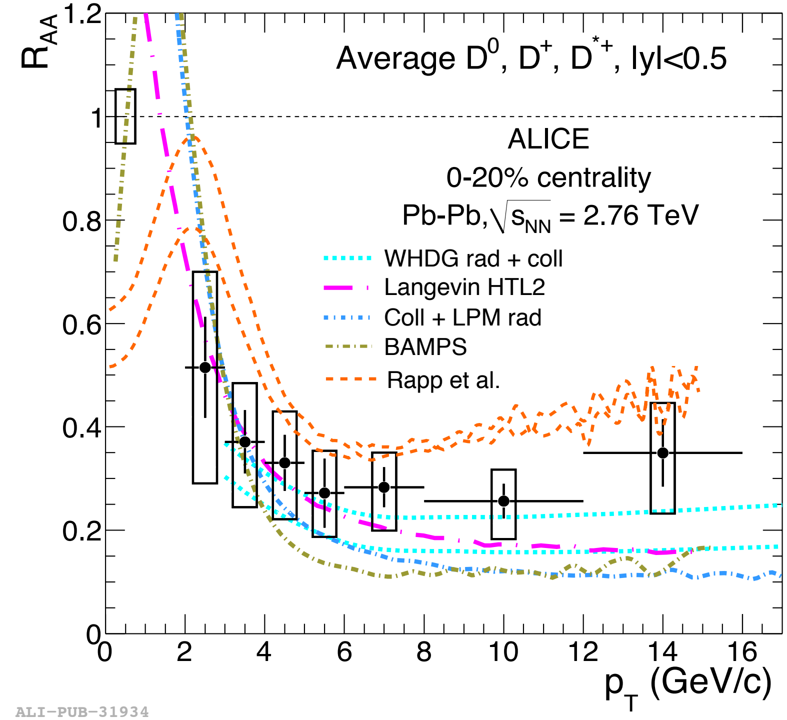
BAMPS[4]: collisional energy loss in expanding medium
Aichelin et al.[5]: collisional + LPM radiative energy loss

[4] Uphoff et al. arXiv: 1112.1559, [5] Aichelin et al. Phys. Rev. C 79 (2009) 044906

Comparison with models

arXiv:1203.2160 [nucl-ex]





WHDG[6] and Beraudo et al.[7] can describe R_{AA} but they seem to underestimate v_2

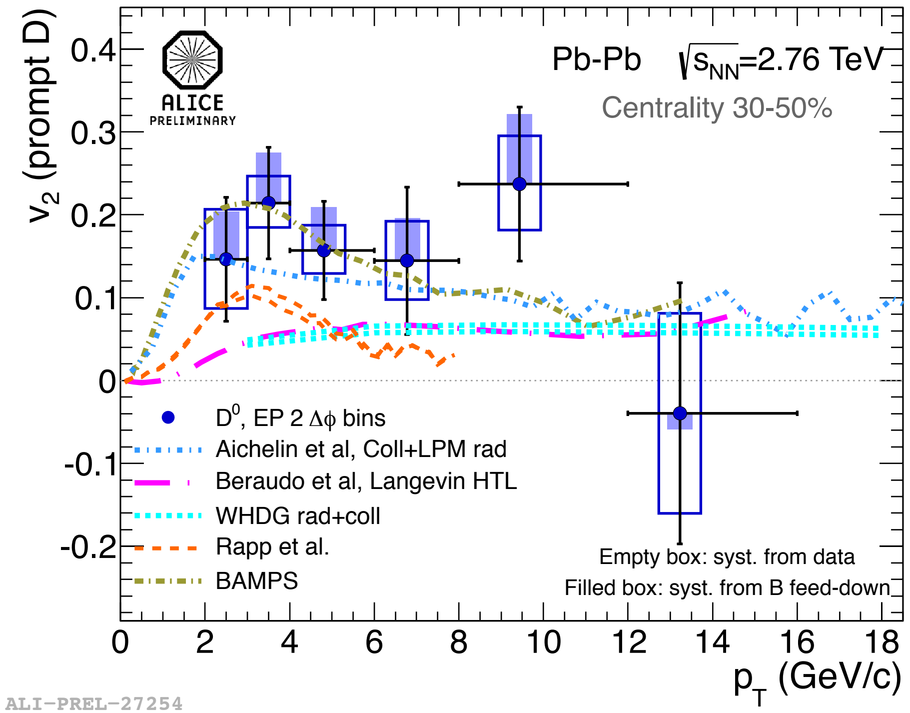
WHDG[6]: collisional + radiative energy loss in anisotropic medium

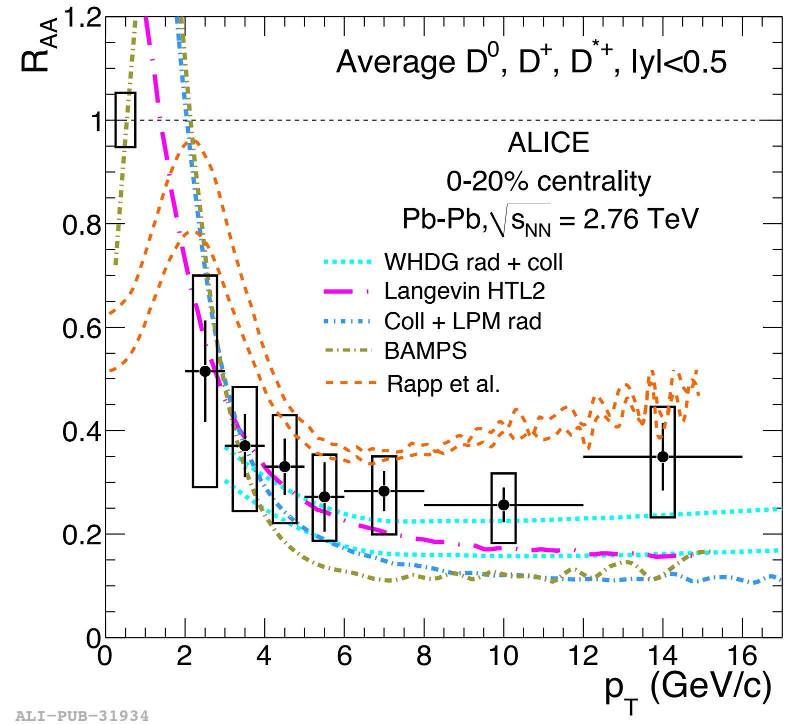
Beraudo et al.[7]: collisional energy loss (Langevin equation)

[6] W. A. Horowitz et al. J. Phys. G38, 124064 (2011), [7] W. M. Alberico et al. Eur. Phyis J. C 71, 1666 (2011)

Comparison with models

arXiv:1203.2160 [nucl-ex]





Rapp et al.[8] seems to underestimate v_2 and it slightly overestimates R_{AA}

Rapp et al.[8]: collisional energy loss via D mesons resonances excitation + hydro evolution

[8] M. He, R. J. Fries and R. Rapp, arXiv:1204.4442[nucl-th]

Conclusions

- ✧ D mesons shows a suppressions in central heavy ion collisions:
  - ✧ factor 5 to p_t ~ 10 GeV/c,
  - ✧ indication of larger suppression for D mesons that for non-prompt J/ψ

- ✧ Non-zero v_2 for D mesons (3σ effect for D^0 in 2-6 GeV/c) in 30-50%:
  - ✧ D mesons "remember" the azimuthal asymmetry of the initial overlap
  - ✧ v_2 comparable with that of the light-flavour hadrons
  - ✧ Cannot conclude on possible difference due to larger c quark mass

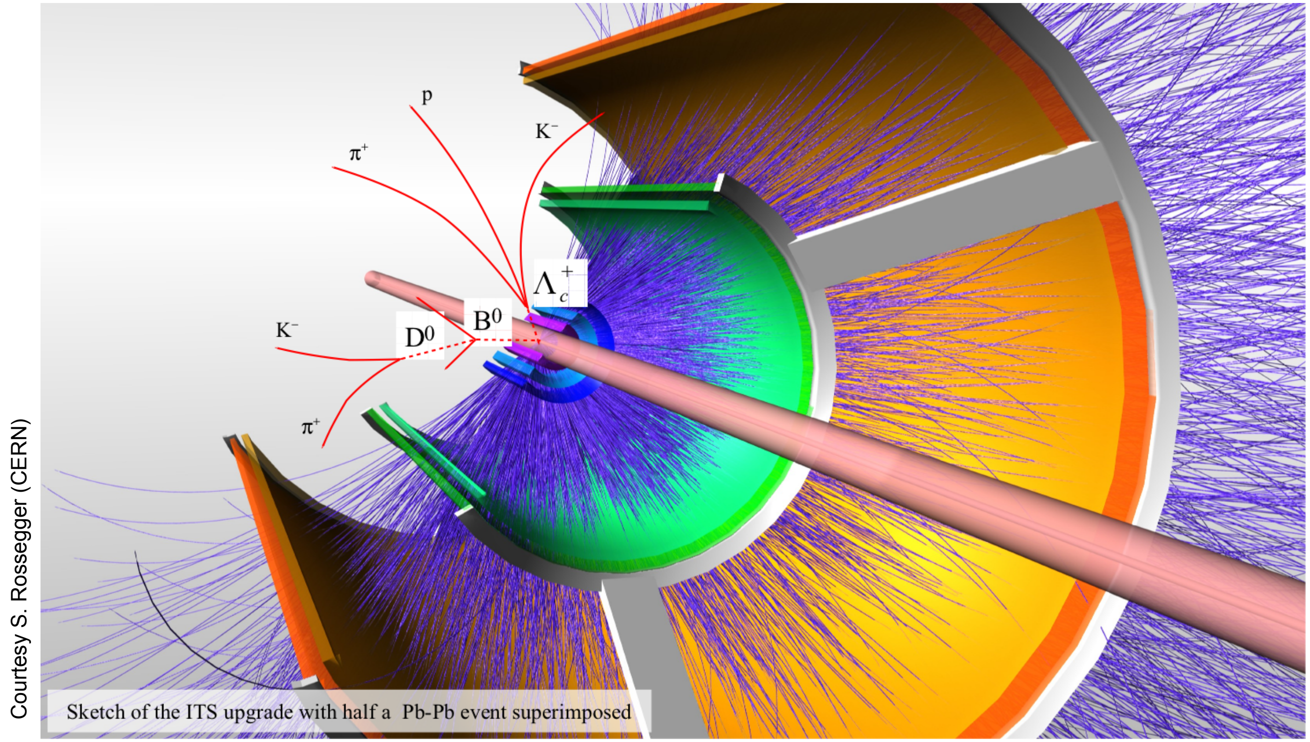
- ✧ Consistent description of charm R_{AA} and v_2 very challenging for models: can bring insight on medium transport properties, also with more precise data from future LHC runs

… and outlook

- Upgrade program endorsed by the LHCC
- Targeted for 2017-2018 LHC shutdown
- Conceptual Design Report CERN-LHCC-2012-013
  Letter of Intent CERN-LHCC-2012-012

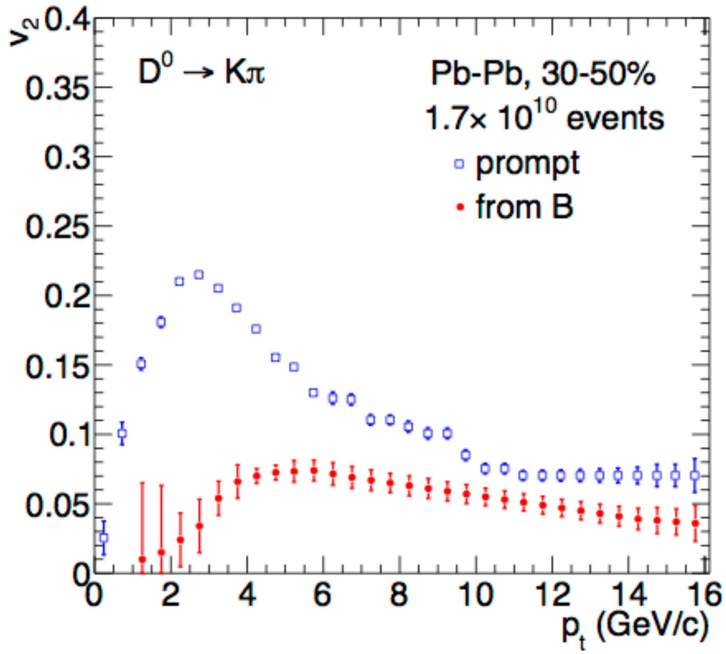
Main points:

- New inner tracker
  → x3 precision
- Major read-out upgrade
  → x100 MB rate



… and outlook

- ✧ Investigate HF in-medium thermalization and hadronization
- ✧ Baryon/meson enhancement and v_2 splitting → most direct indication of light-quark hadronization in a partonic system
  - ✧ Measure this in the HF sector! Does it hold for charm?
  - ✧ Charm baryons: Λ_c

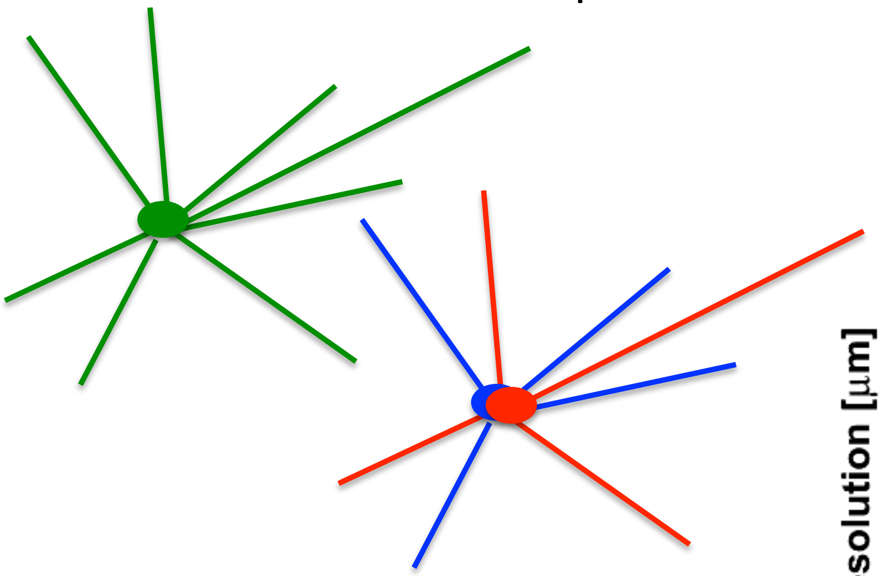


- ✧ Investigate transport coefficients for heavy quarks in the medium
- ✧ Sensitive to medium viscosity
- ✧ Pin down mass dependence

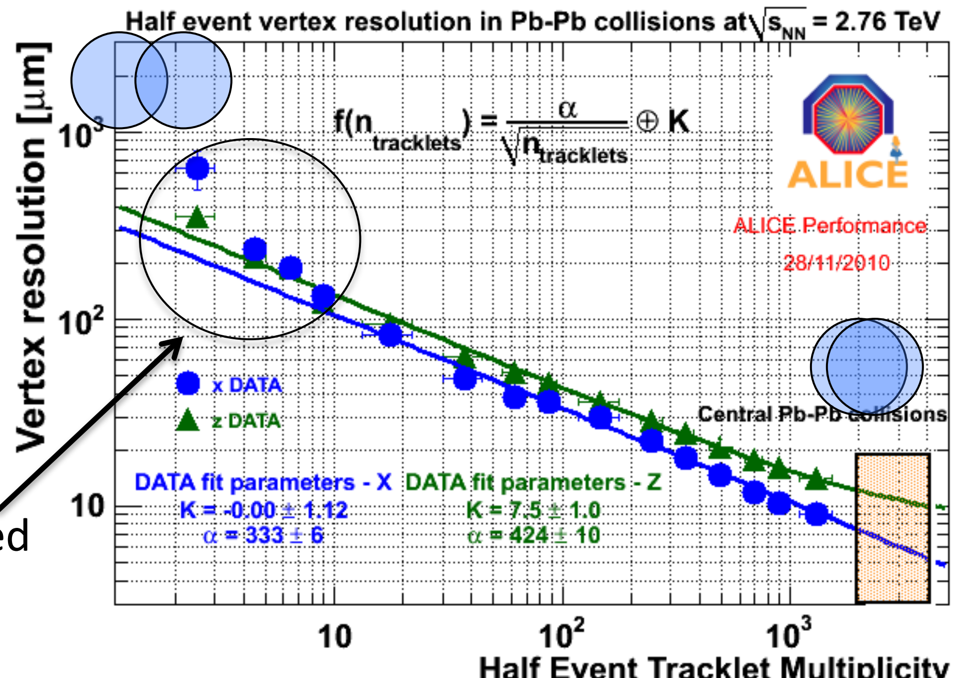
BACK UP

Primary vertex resolution

Half Events Method: 2 sample of random tracks for each event → two reconstructed vertices per event.



Study of the difference between these two vertices as a function of half multiplicity of the event.



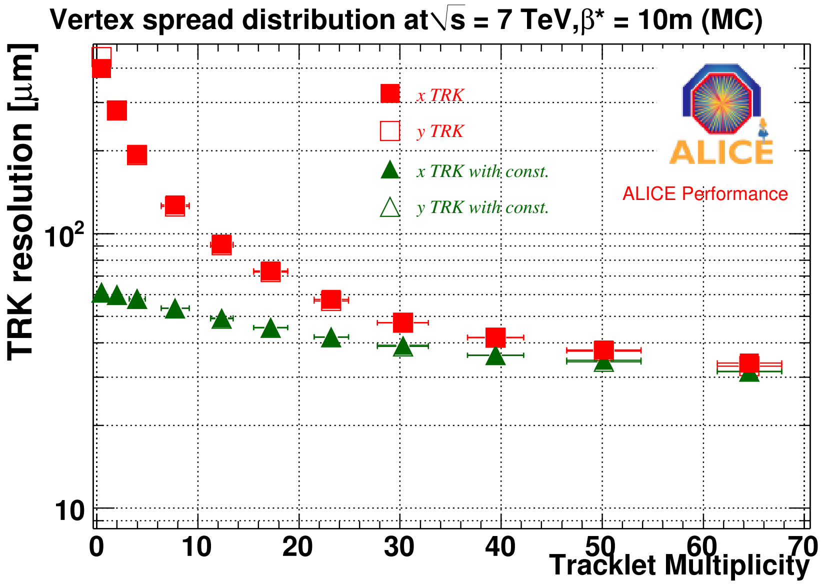
For Pb-Pb central collisions the resolution is smaller than 10 μm.

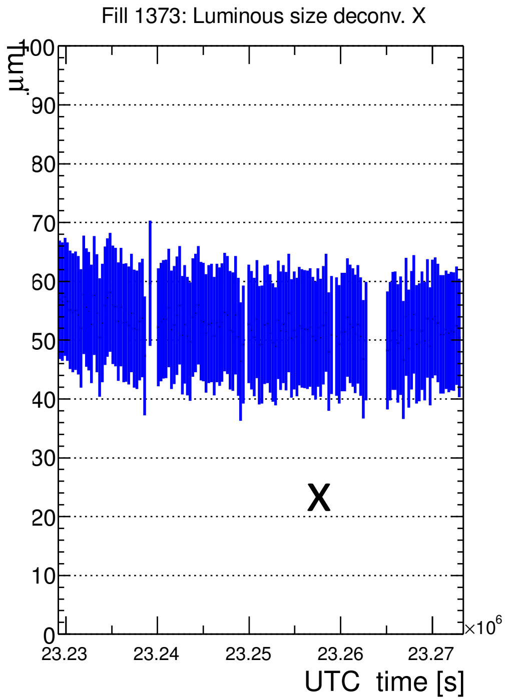
Peripheral and pp collisions need improved resolution on primary vertex:
knowledge of the beam parameters

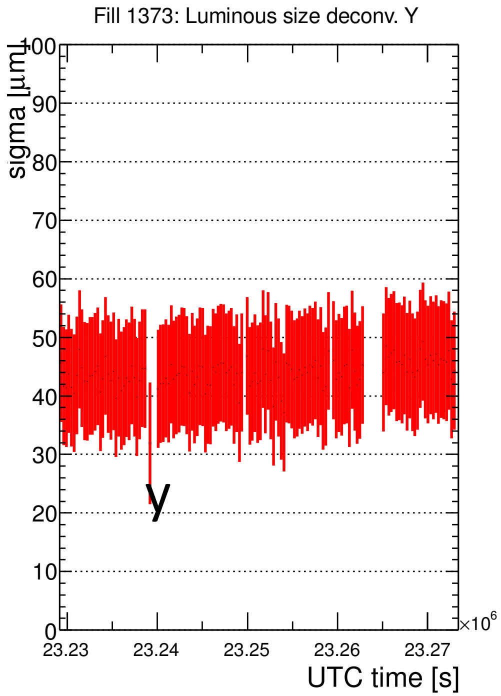
Luminous region determination

Luminous region: convolution of the two particles distributions in the two colliding bunches.
It depends on the optical parameters of the beam (emittance and amplitude function)

For pp collisions primary vertex resolution improved from luminous region determination.

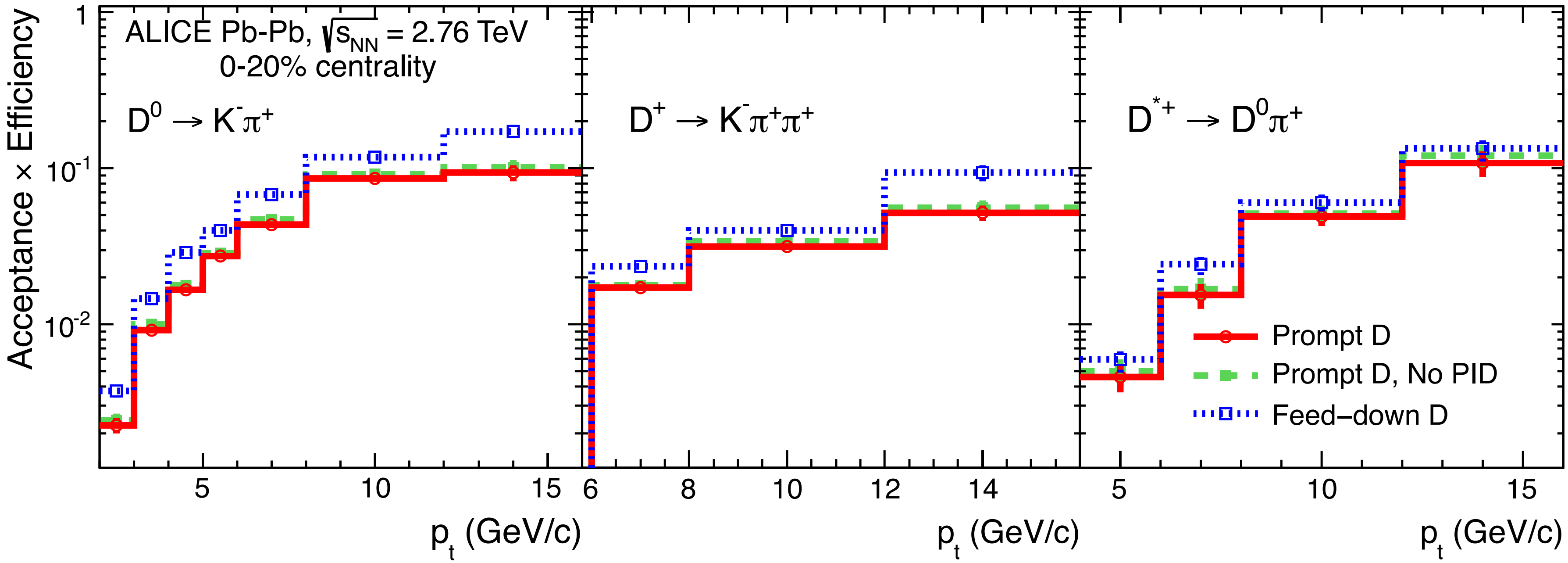






Efficiencies

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



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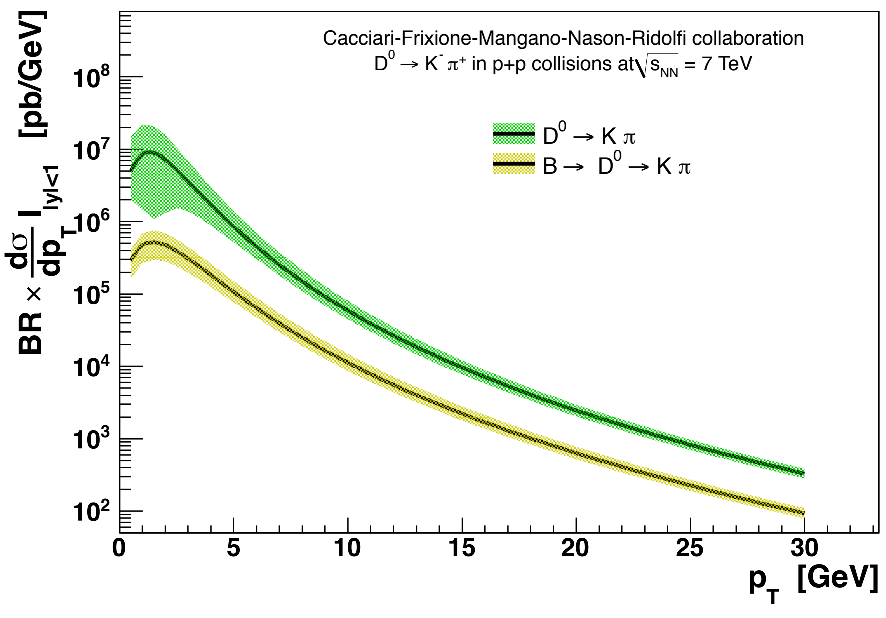
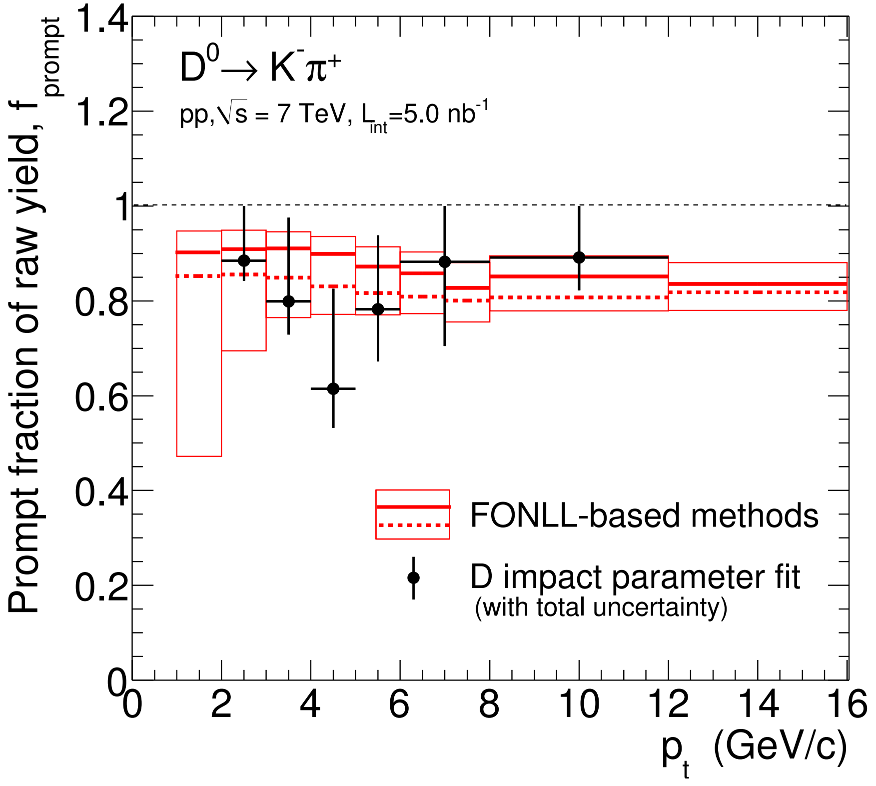
Feed down correction

Beauty feed down:

Monte Carlo method based on FONLL predictions.

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





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:

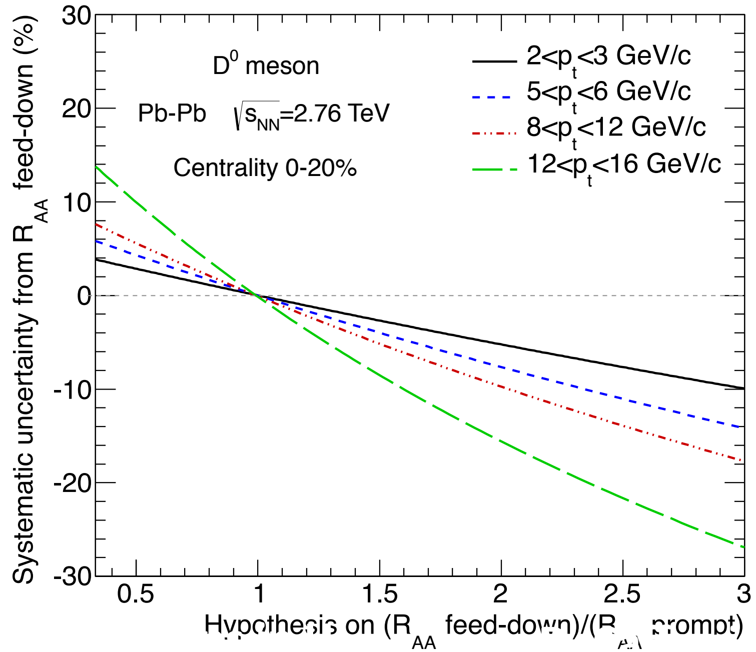
Hypothesis on the energy loss of beauty quarks is adopted.

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)



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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))	$^{+4}_{-10}\%$	$^{+14}_{-27}\%$

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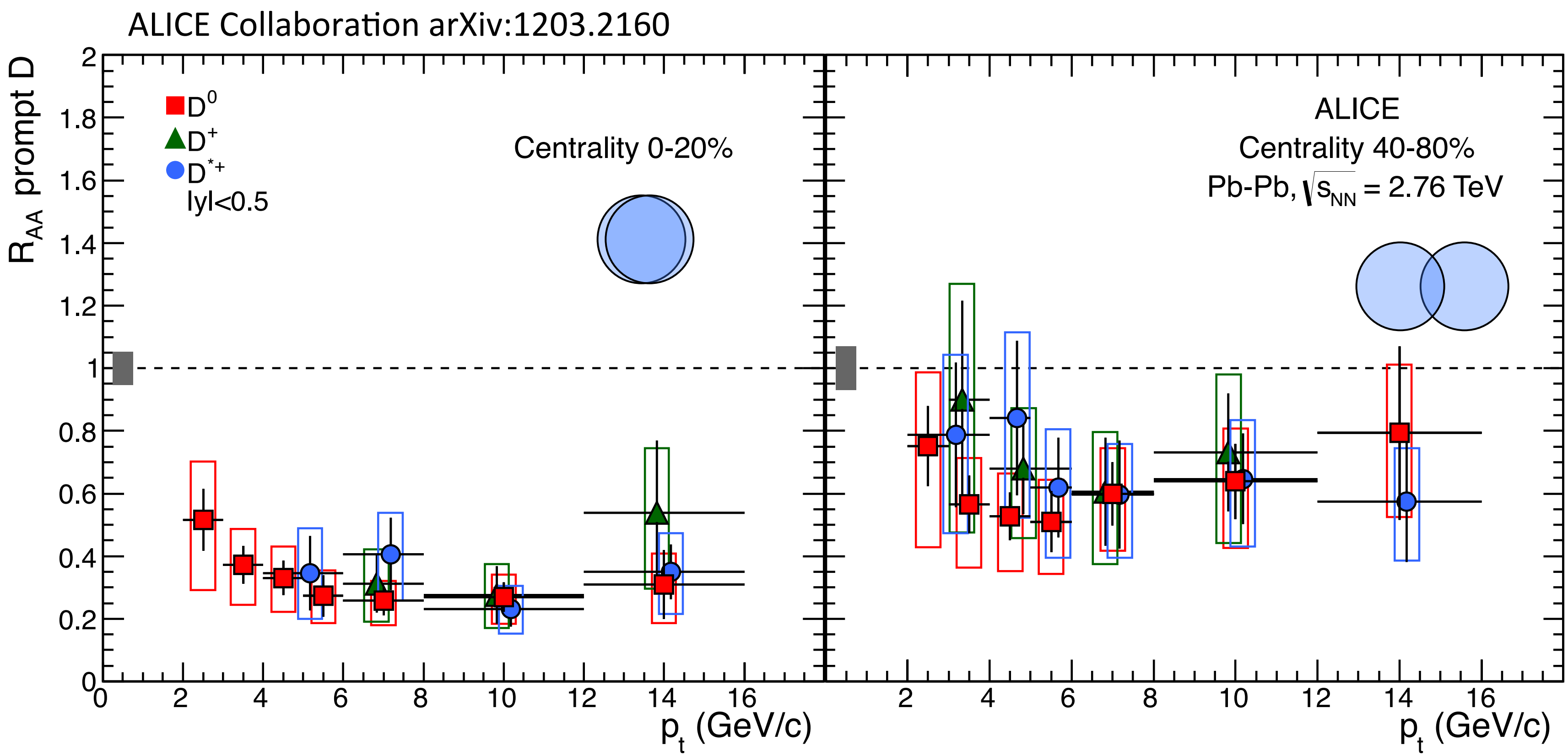
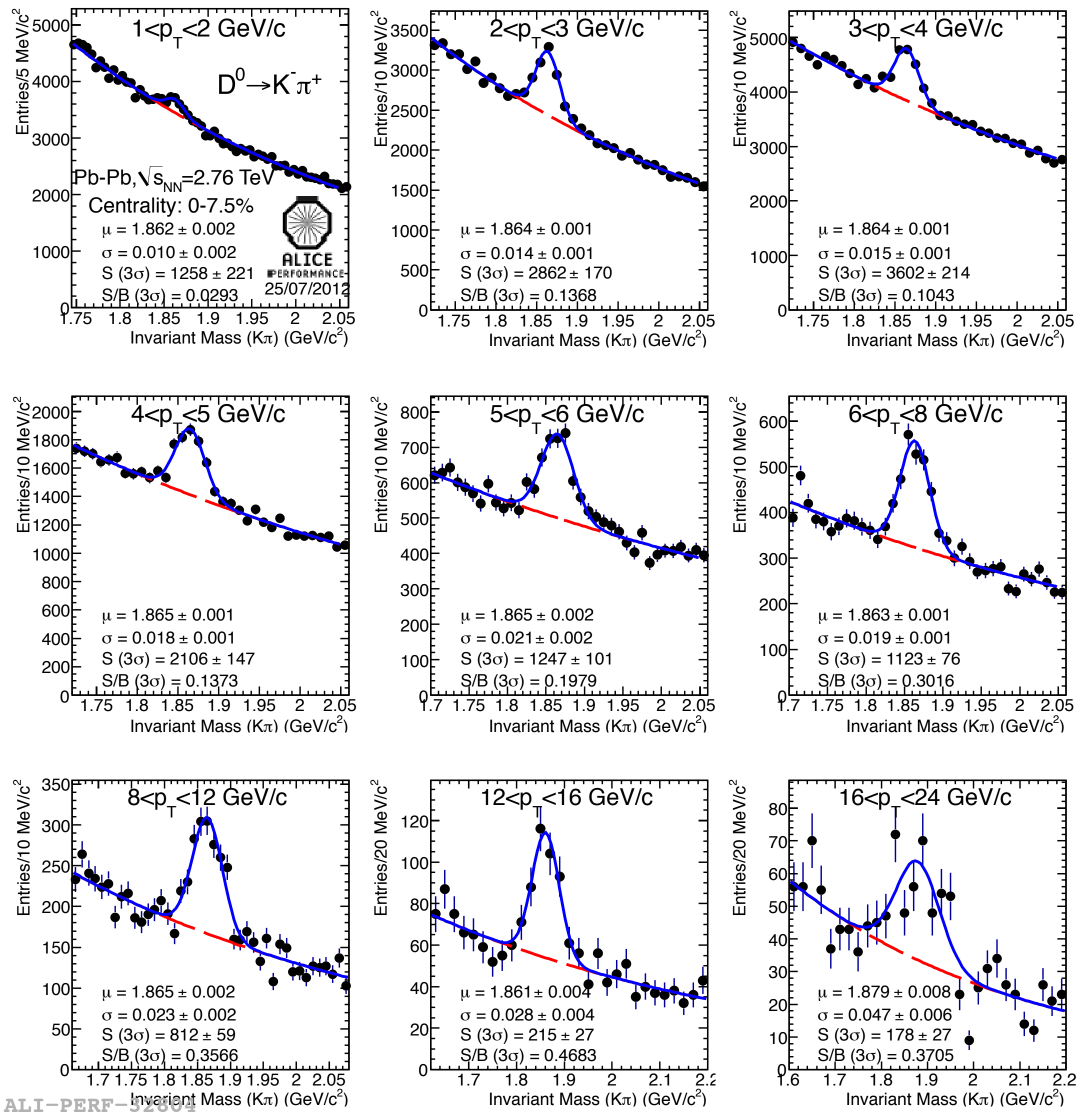
D meson R_{AA} vs. p_t



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

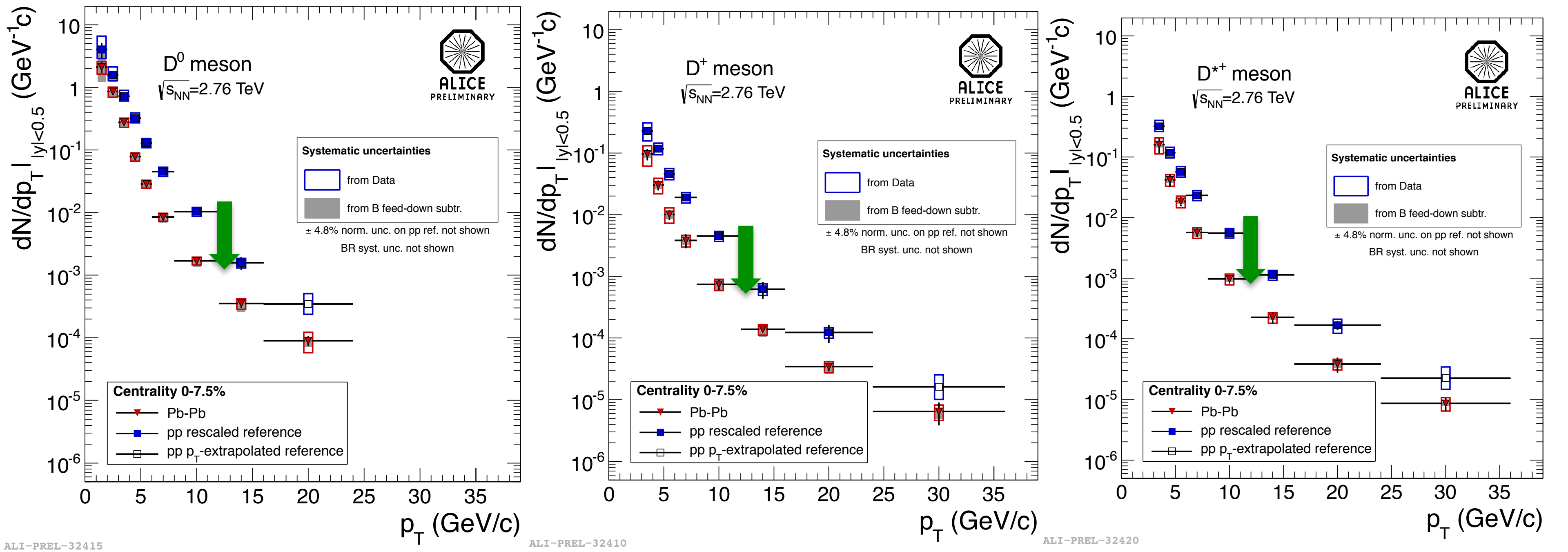
Signal extraction with 2011 Pb-Pb data



In ~17M central collisions **(0-7.5%)**:

- D^0 : 9 p_t bins in 1-24 GeV/c
- D^+ : 8 p_t bins in 3-36 GeV/c
- D* : 8 p_t bins in 3-36 GeV/c

D meson dN/dp_t (2011 data)



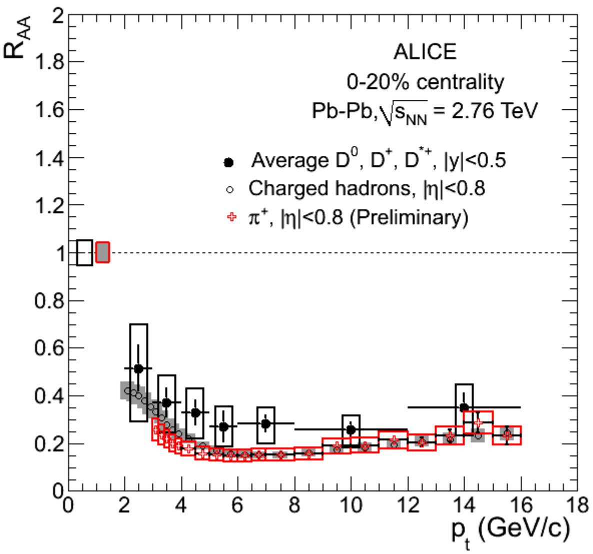
pp scaled reference x <T_{AA}>

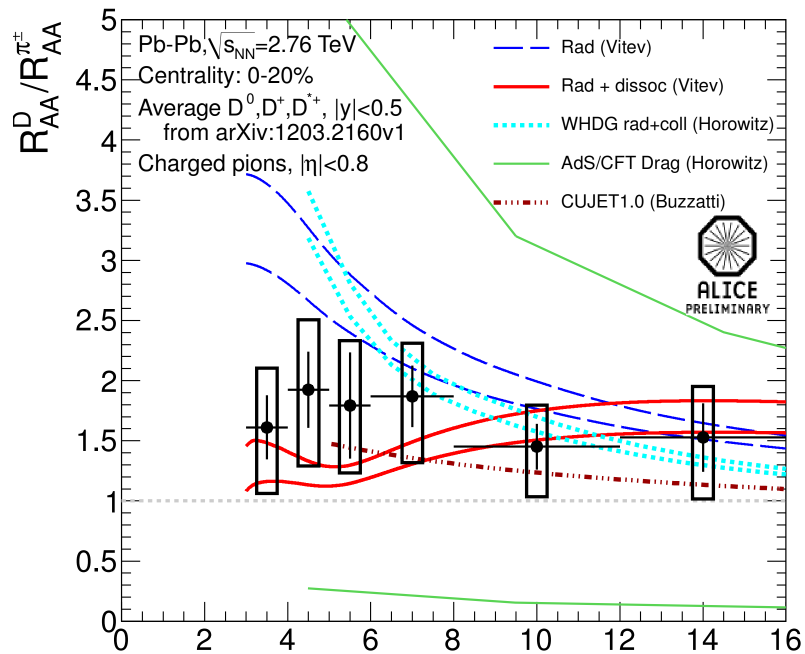
Pb-Pb yield

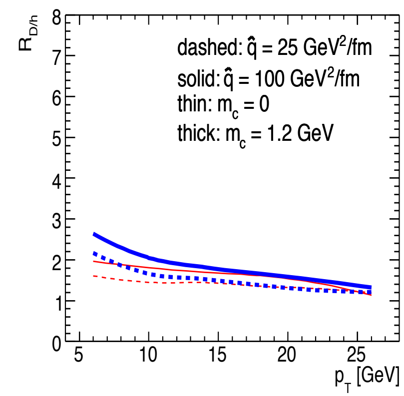
Indication of suppression

Charm and pions

- The suppression of D mesons is comparable to that of pions







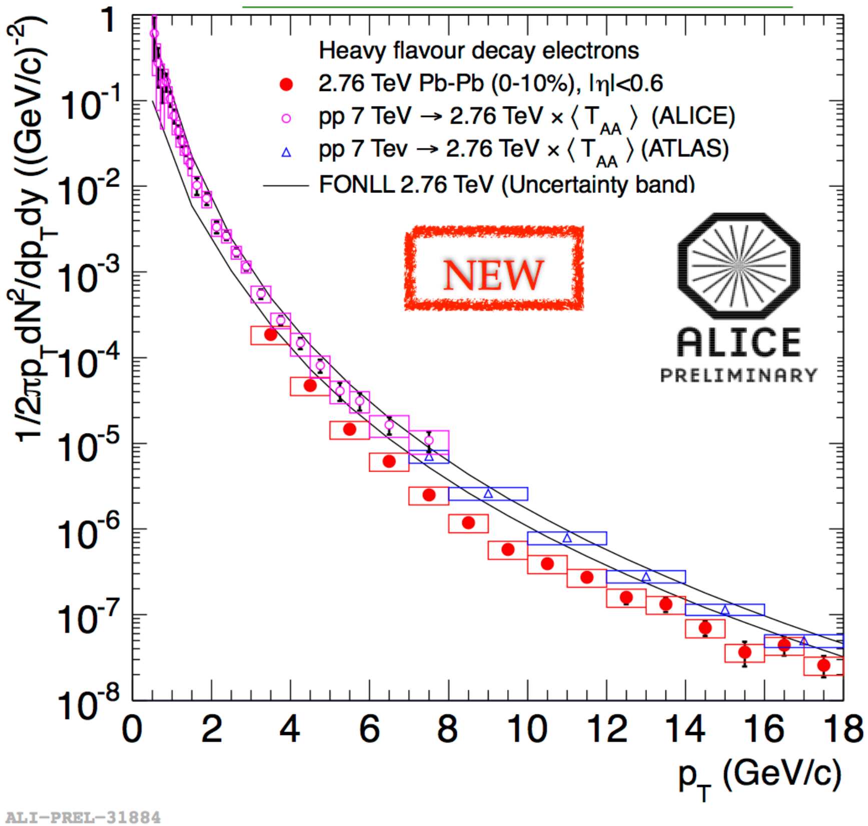
- Heavy-to-light ratio “$R_{D/p}$”: a hint of $R_{AA}{}^{D} > R_{AA}{}^{p}$
- In the model calculations:
  - High-p_t: $R_{D/p} > 1$ due colour charge effects (c-quark vs gluon)
  - Low-p_t: additional increase to mass effects (c-quark mass)

Other HF measurement in ALICE: electrons

✧ HF electrons extracted with the cocktail method:
  background electrons subtracted for the inclusive spectra.

✧ Electron Identification with TPC + EMCAL

✧ Background electrons: π^0 + Dalitz + γ conversion (+ J/ψ cocktail)



Other HF measurement in ALICE: electrons

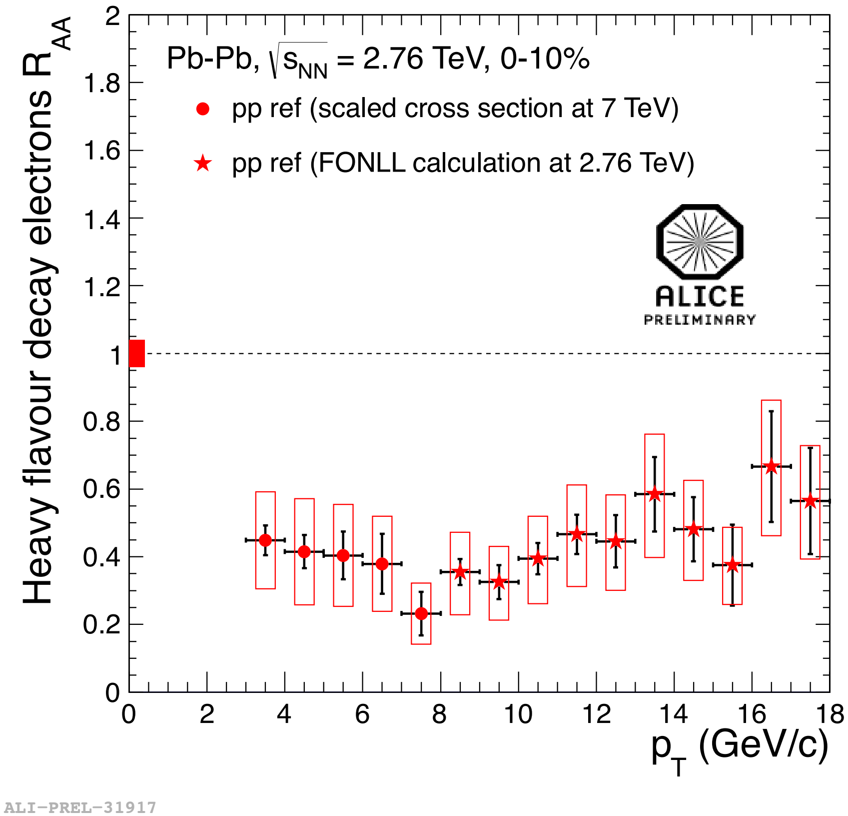
- ✧ HF electrons extracted with the cocktail method:
  background electrons subtracted for the inclusive spectra.

- ✧ Electron Identification with TPC + EMCAL

- ✧ Background electrons: π^0 + Dalitz + γ conversion (+ J/ψ cocktail)

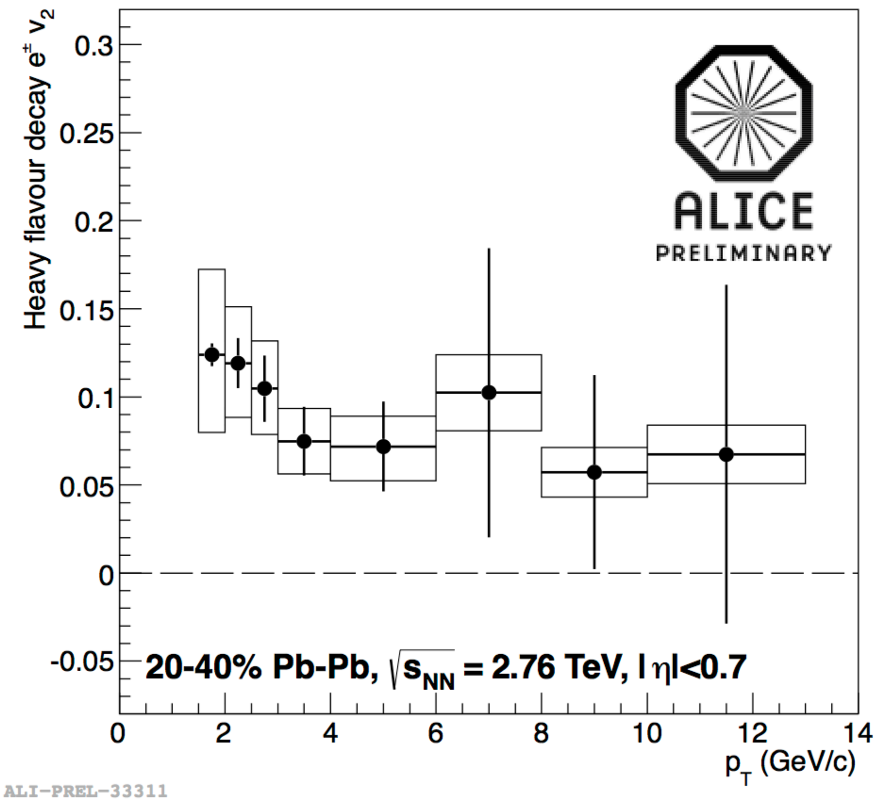
- ✧ **Clear suppression for $3 < p_T < 18$ GeV/c**

- ✧ **Amounts to a factor of 1.5-3 for 3<pT<10 GeV/c**



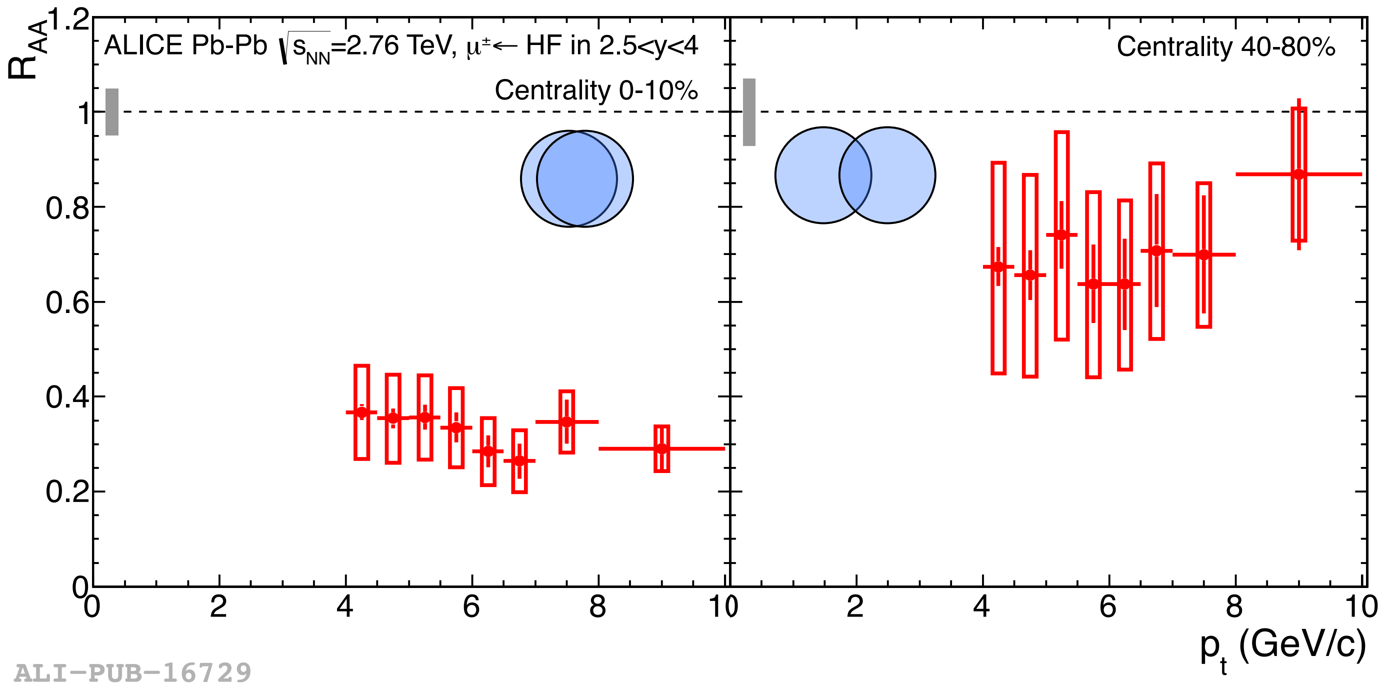
Other HF measurement in ALICE: electrons

- Data Sample 2010+2011 Pb-Pb runs TPC+TOF (MB + centr. tirgger), TPC+EMCAL analyses (EMCAL + centr. trigger)
- HF electrons extracted with the cocktail method: background electrons subtracted for the inclusive spectra.
- Electron Identification with TPC + EMCAL, TPC+TOF
- Background electrons: π^0 + Dalitz + γ conversion (+ J/ψ cocktail) via cocktail with their measured v_2
- **HF electron $v_2 > 0$ at low p_T (>3σ effect in 2-3 GeV/c)**



Other HF measurement in ALICE: muons

- ✧ Muons are reconstructed in the forward spectrometer -4 < y < -2.5
- ✧ Hadrons and low-p_T secondary muons are removed requiring a muon trigger signal.
- ✧ Subraction of π/K decays with PYTHIA and PHOJET in pp, with central rapidity measurement for Pb-Pb



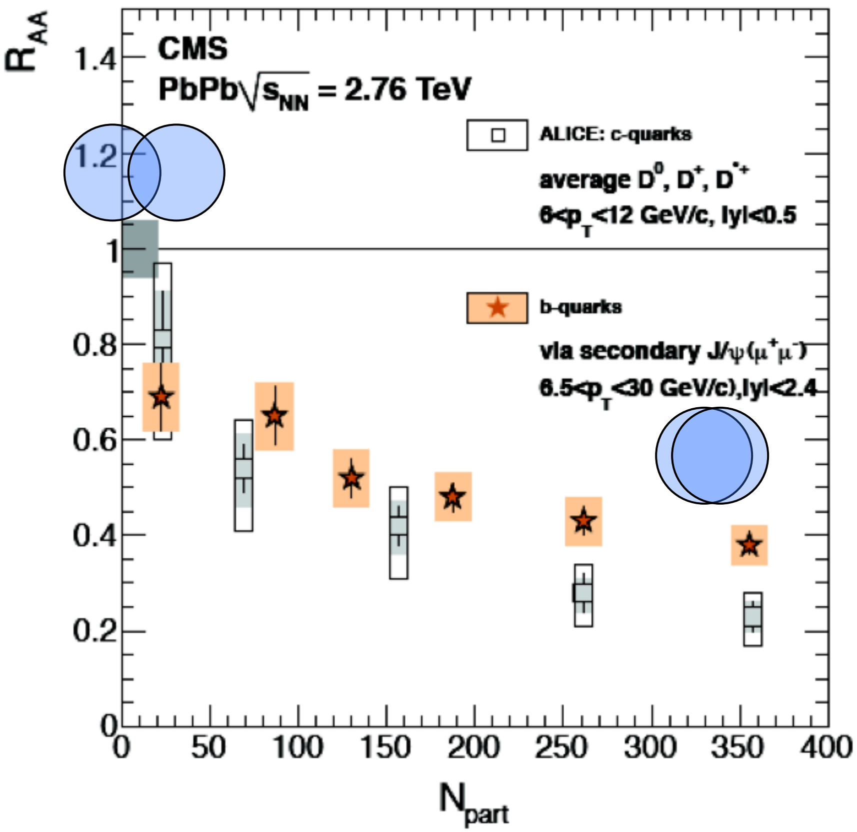
- ✧ **Suppression by a factor of 3 in central collisions**
- ✧ **No evident p_T dependence**

Non prompt J/ψ from CMS

B → J/ψ + *X*
$6.5 < p_T$ (J/ψ) < 30 GeV/c
|y|< 2.4

Compared with
D mesons exclusive reconstruction
$6 < p_T < 12$ GeV/c
|y|< 0.5

Indication of
$R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)$?



Different kinematics range for D and B mesons… not clear how to conclude

D meson v_2: 2 particle Q-Cumulants and Scalar Product methods

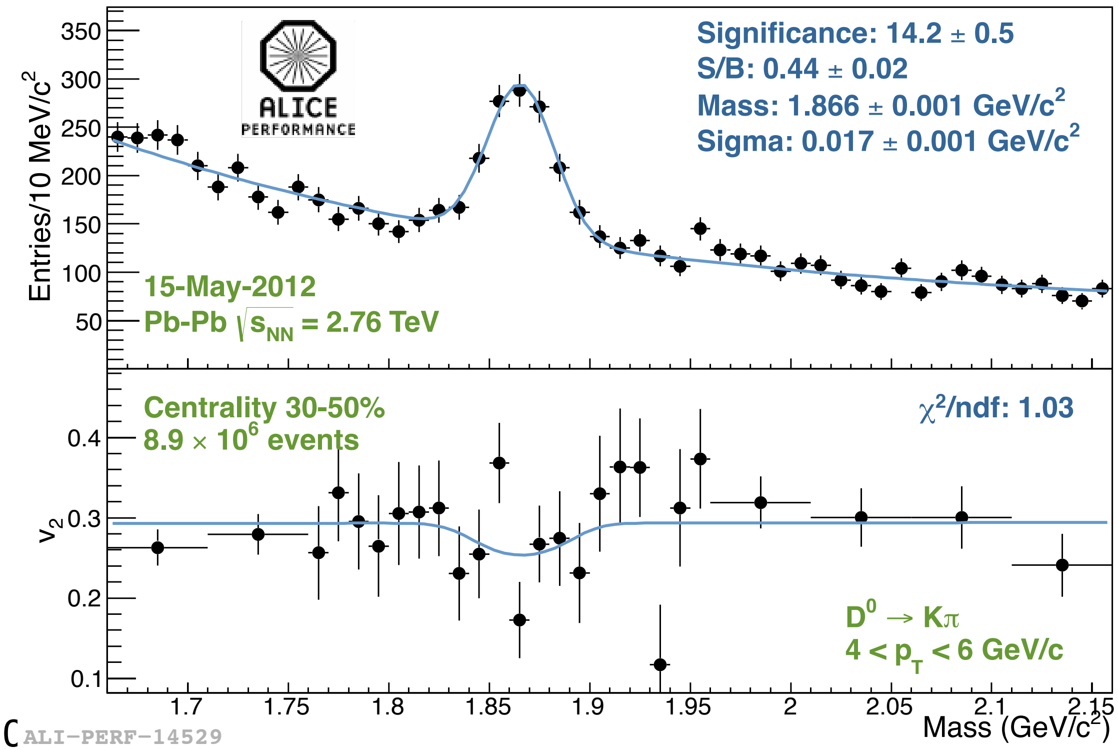
✧ Alternative methods based on 2-particle correlations[2]:
Q-Cumulants and Scalar Product

- sensitive to the same non flow contribution as EP
- no η gap used in the analysis

✧ TPC tracks used as Reference Flow Particles

✧ v_2 obtained from a simultaneous fit of the counts and v_2 vs invariant mass

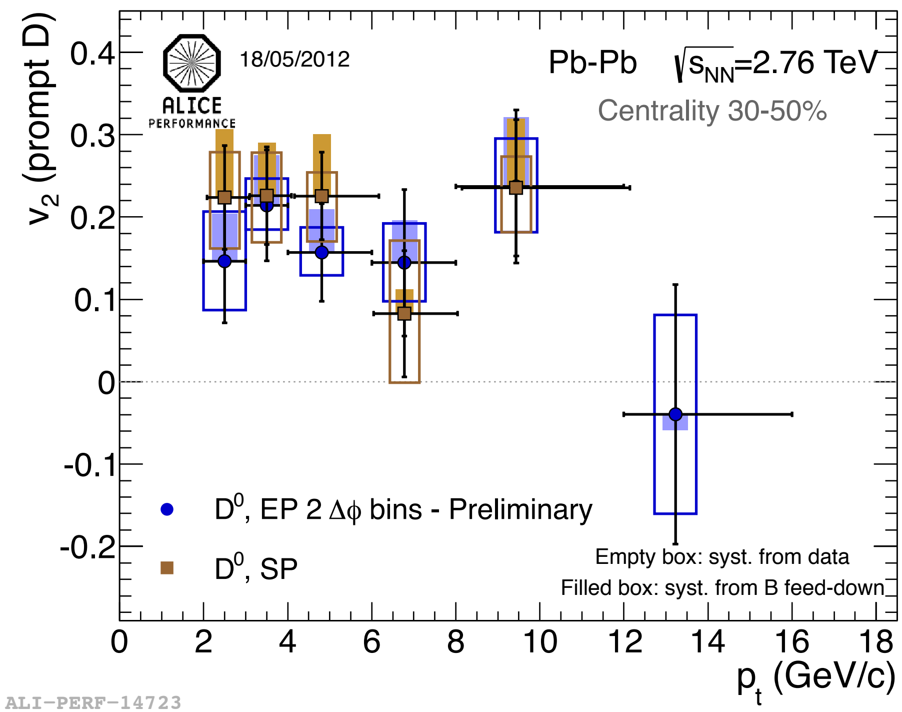
D^0 Q-Cumulants



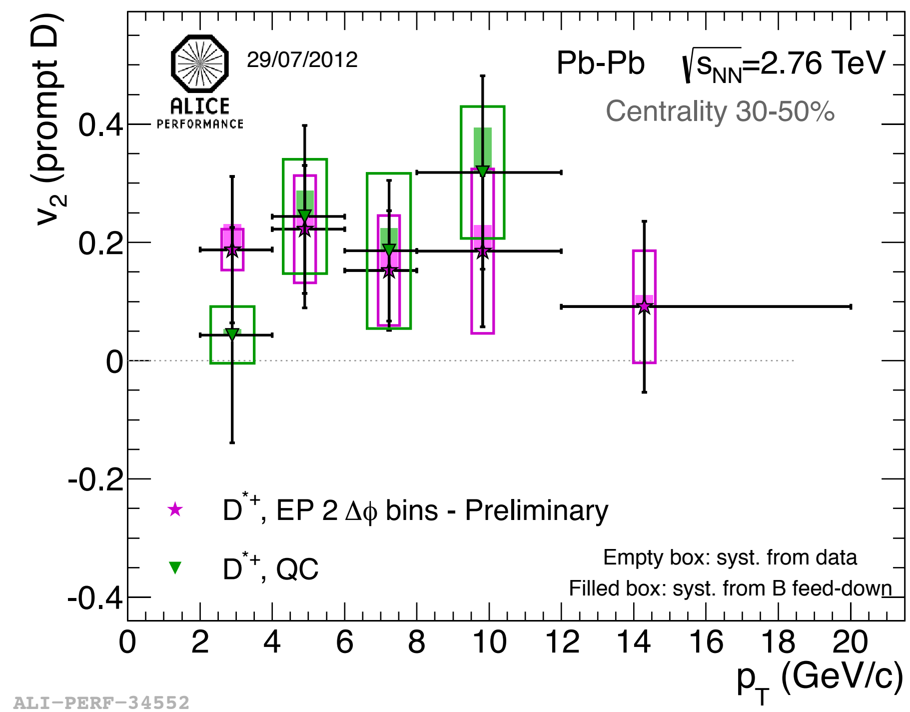
[2] Bilandzic, Snellings, Voloshin, Phys. Rev. C 83 C

D meson v_2 comparison: EP, SC and QC methods

D^0 30-50%
EP, SP methods



D^{*+} 30-50%
EP, QC methods

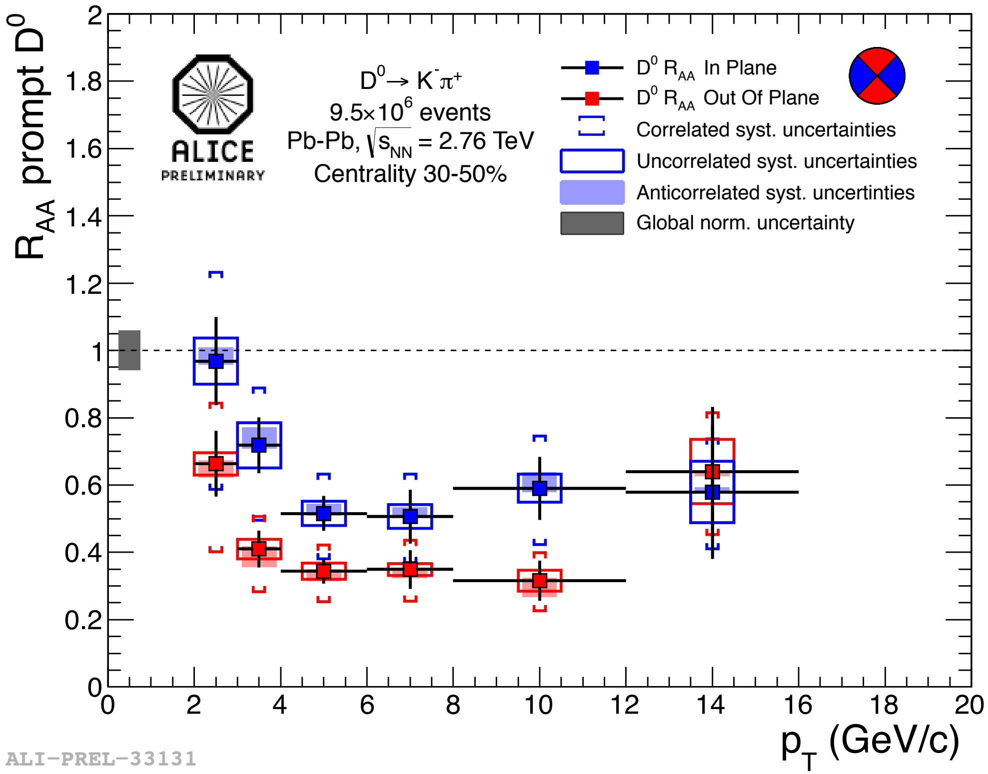


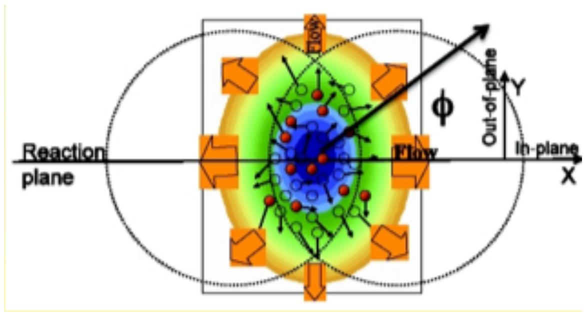
✧ Good agreement between the methods for the different D mesons

D^0 R_{AA} vs EP in 30-50%

- ✧ Raw yield in and out of plane in 30-50%
- ✧ Efficiencies computed from simulations
- ✧ Feed-down subtraction with FONLL calculations
- ✧ Reference: ALICE pp 7 TeV scaled down to 2.76 TeV

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





- ✧ More suppression Out Of Plane with respect to In Plane:
  longer path length at high p_T
  elliptic flow at low p_T

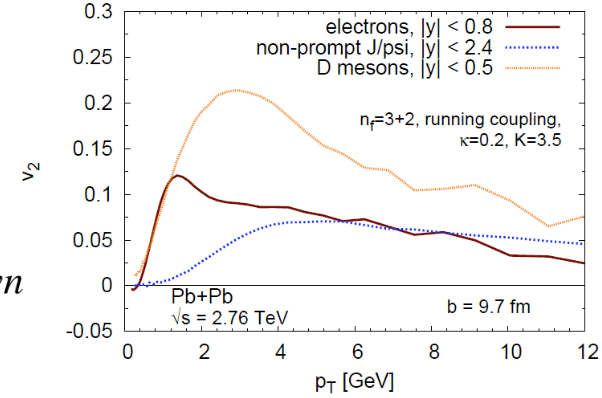
D mesons v_2 Beauty feed down (I)

ALICE

- ALICE sample contains both prompt and feed down D meson. To obtain the v_2^{prompt} of prompt D meson e need to take into account their contribution

- Since v_2 is additive, it is possible to write:

$$v_2^{prompt} = \frac{1}{f_{prompt}} v_2^{inclusive} - \frac{1 - f_{prompt}}{f_{prompt}} v_2^{feed-down}$$



- To subtract the B feed-down contribution, we need an hypothesis on $v_2^{feed\text{-}down.}$ All models predics $v_2^{feed\text{-}down} \leq v_2^{prompt}$.

D mesons v_2 Beauty feed down (II)

- The case $v_2^{\text{feed-down}} = 0$ gives the extreme case and the limit for the (asymmetric) systematic uncertainties:

  $$v_2^{\text{feed-down}} = 0 \rightarrow v_2^{\text{prompt}} = v_2^{\text{inclusive}} / f_{\text{prompt}}$$

- $0.7 < f_{\text{prompt}} < 0.95$ computed with MC efficiencies and FONLL predictions

- f_{prompt} depends also on the relative R_{AA} suppression of feed down and prompt (as in the R_{AA} analysis)

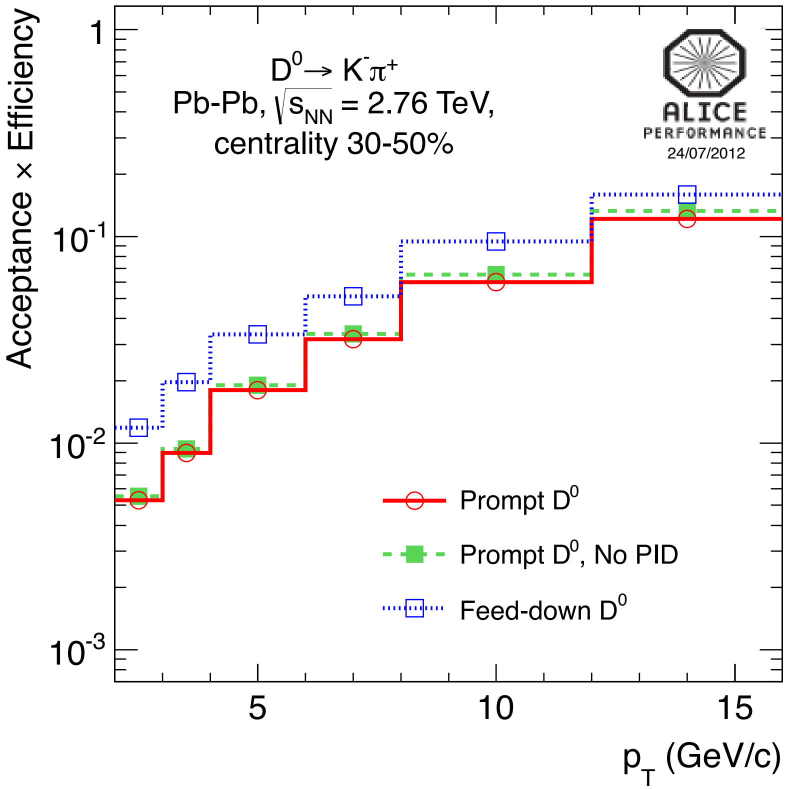
- An asymmetric systematic uncertainties is computed considering the hypothesis:

  $0.5 < R_{AA}^{\text{feed-down}} / R_{AA}^{\text{prompt}} < 2$

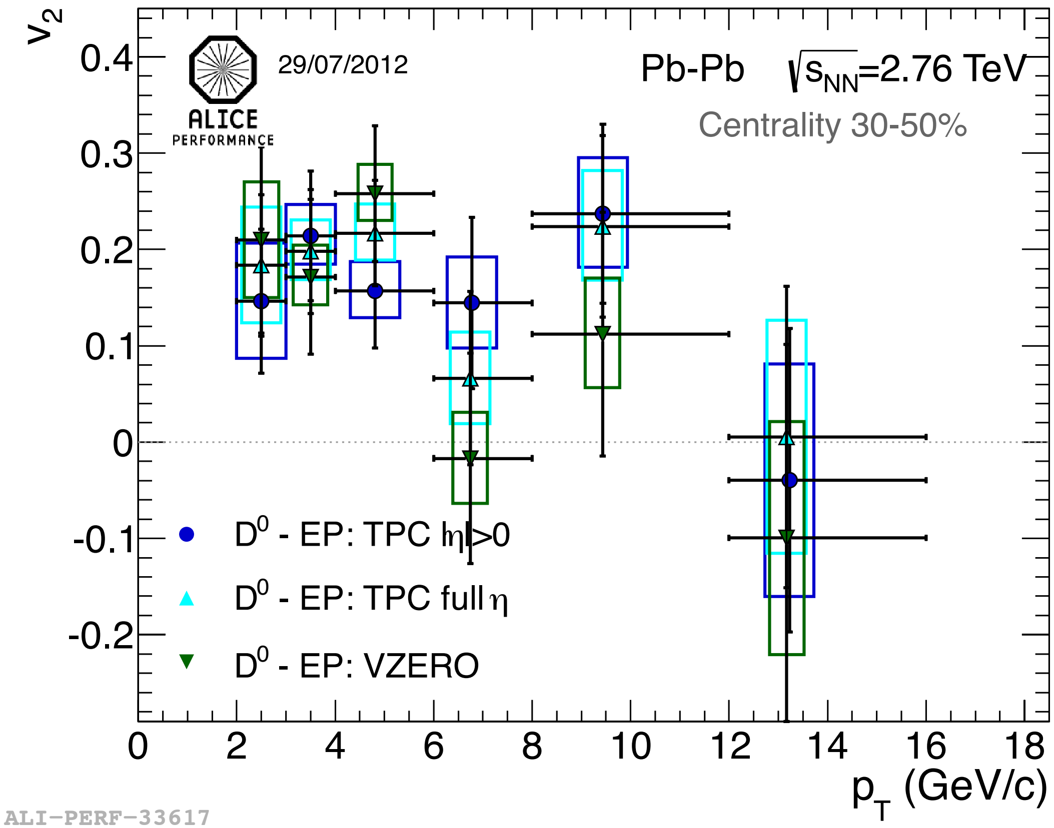
  $0 < v_2^{\text{feed-down}} < v_2^{\text{prompt}}$

Efficiencies

- ✧ Efficiencies computed using HIJING MC with embedded Pythia cc events. 30-50%
- ✧ No centrality dependence observed
- ✧ In Plane - Out Of Plane difference in multiplicity was reproduced with different centrality bins.
  No trend is observed.



D^0 v_2: comparison with different EP



Event plane computed using:

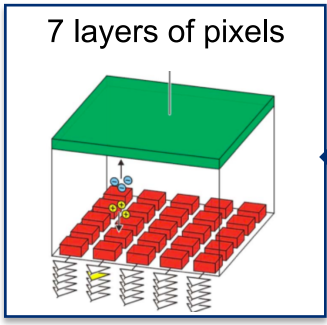
- TPC tracks with $0 < \eta < 0.8$
- TPC tracks with $|\eta| < 0.8$
- VZERO detector ($2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$)

✧ Consistent results for the three Event Plane.
Not sensitive to different nonflow contributions with this uncertainties

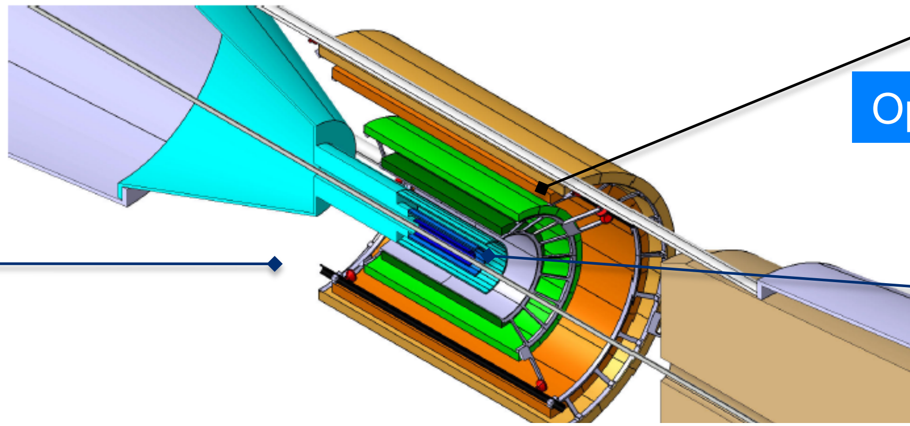
Inner Tracker Upgrade design

Two design options are being studied:

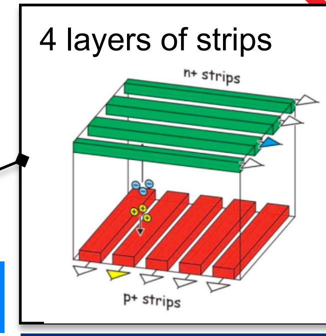
Option A

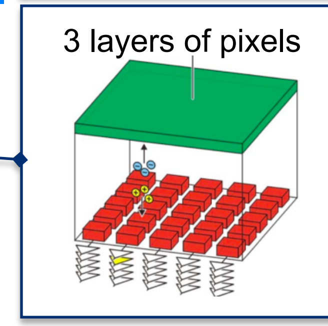


Pixels: O(20 µm x 20 µm)



Option B



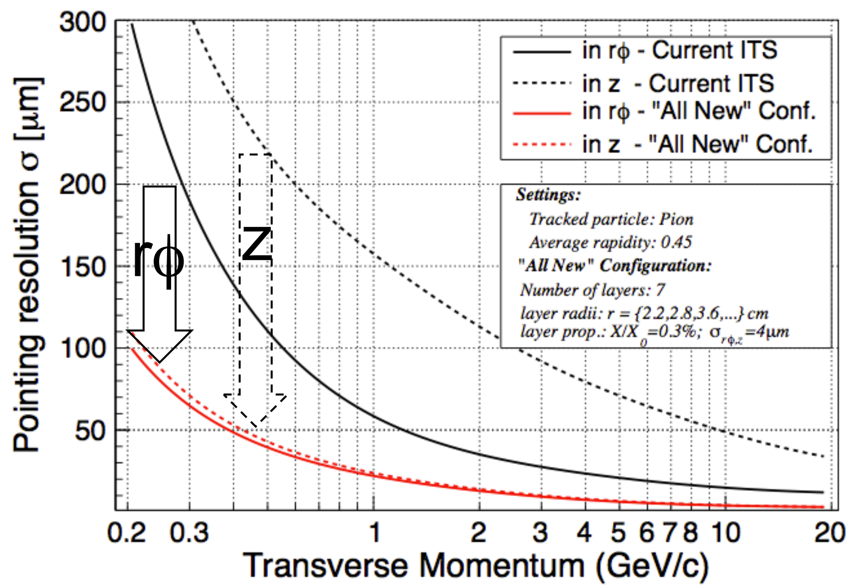


Pixels: O(20 µm x 20 µm)
Strips: 95 µm x 2 cm, double sided

Similar performance (Option A shown):

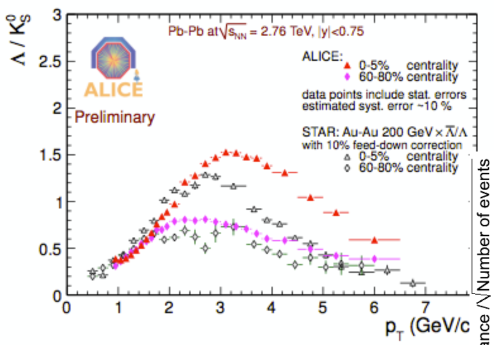
x3 better in rϕ

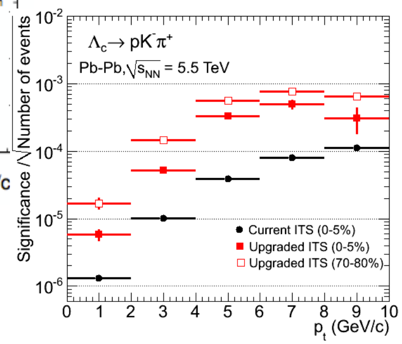
x7 better in z

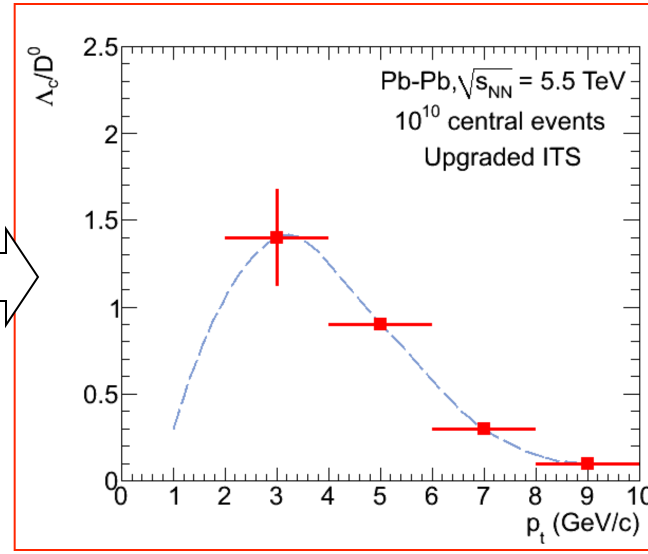


Example of physics performance

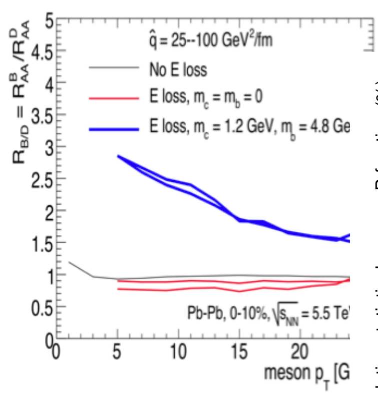
Charm baryon/meson

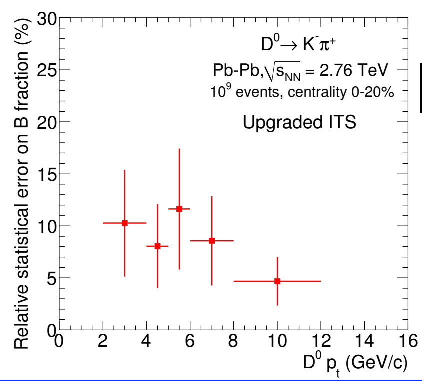


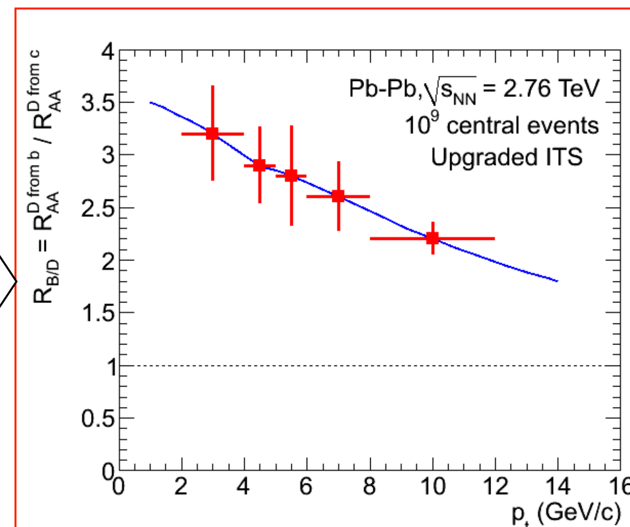




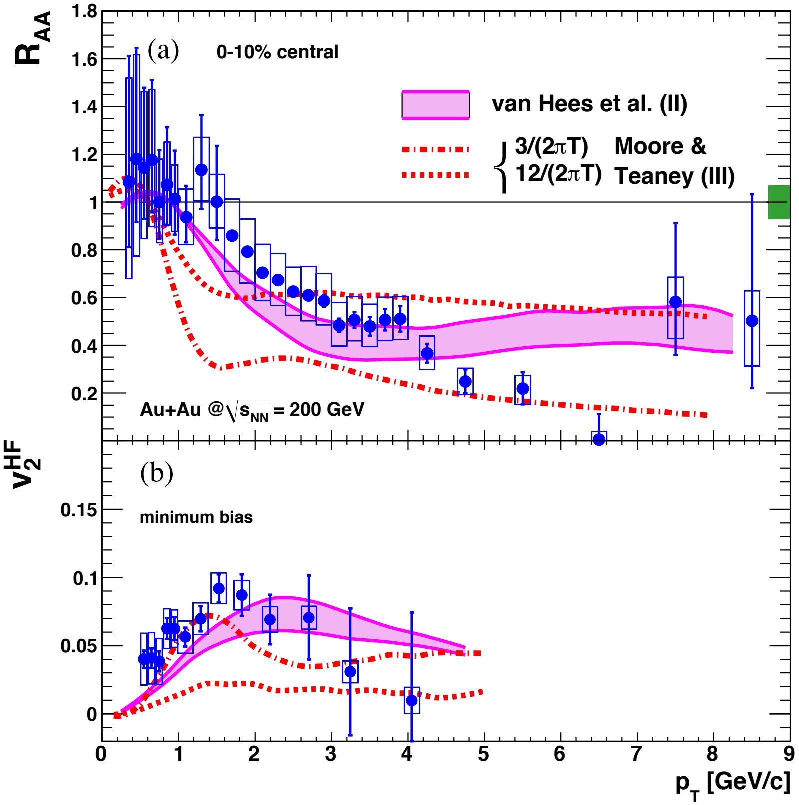
Charm vs beauty suppression

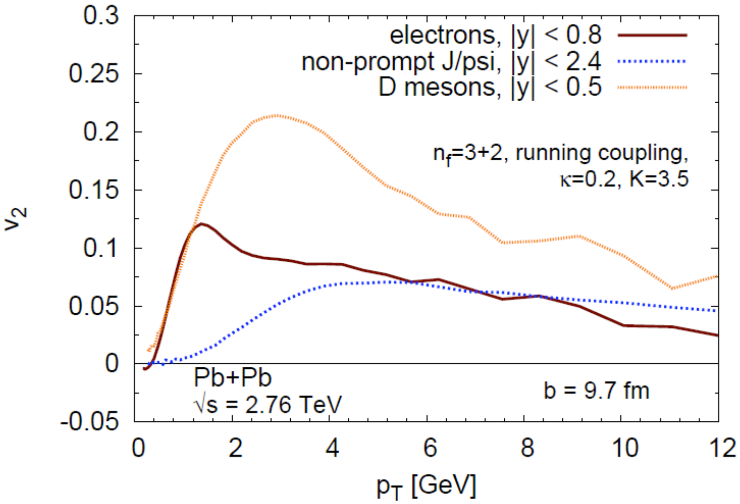






RHIC results and LHC predictions



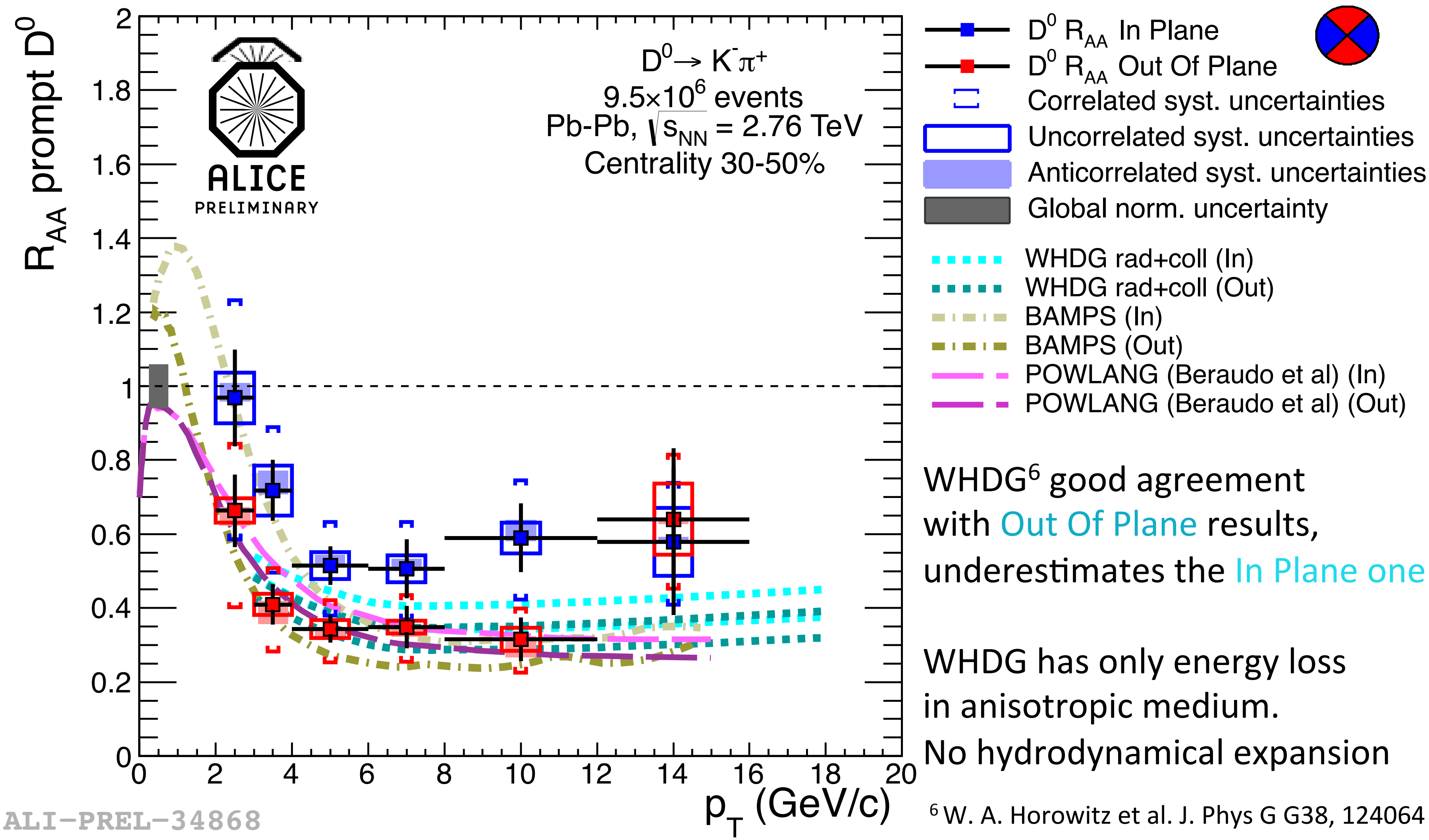


BAMPS

Uphoff et al. arXiv: 1112.1559

- Not all models reproduce R_{AA} and v_2 simultaneously
- we expect $v_2^B < v_2^D$

D^0 R_{AA} vs EP comparison with models

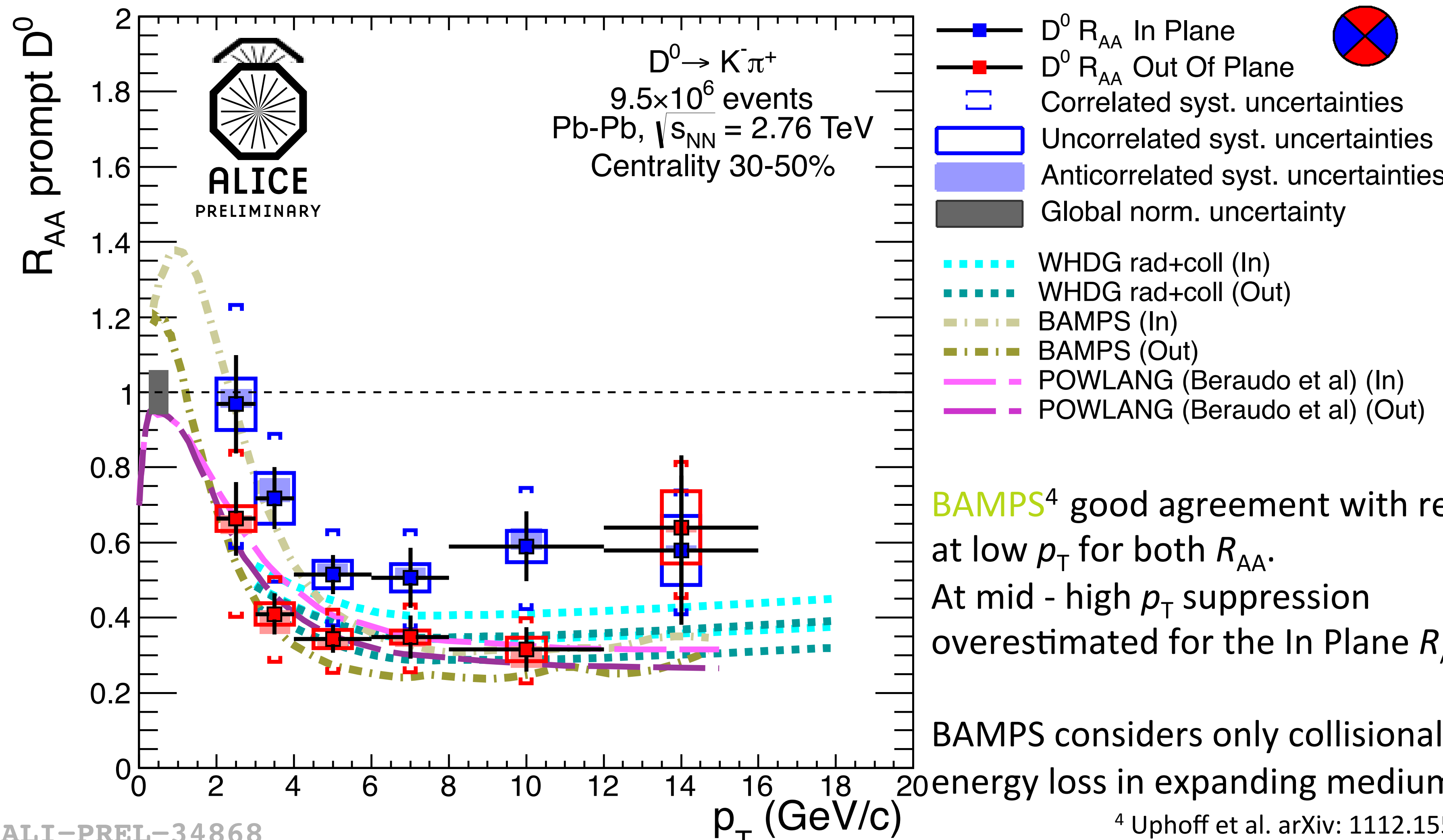


WHDG[6] good agreement with Out Of Plane results, underestimates the In Plane one

WHDG has only energy loss in anisotropic medium.
No hydrodynamical expansion

[6] W. A. Horowitz et al. J. Phys G G38, 124064 (2011)

D^0 R_{AA} vs EP comparison with models



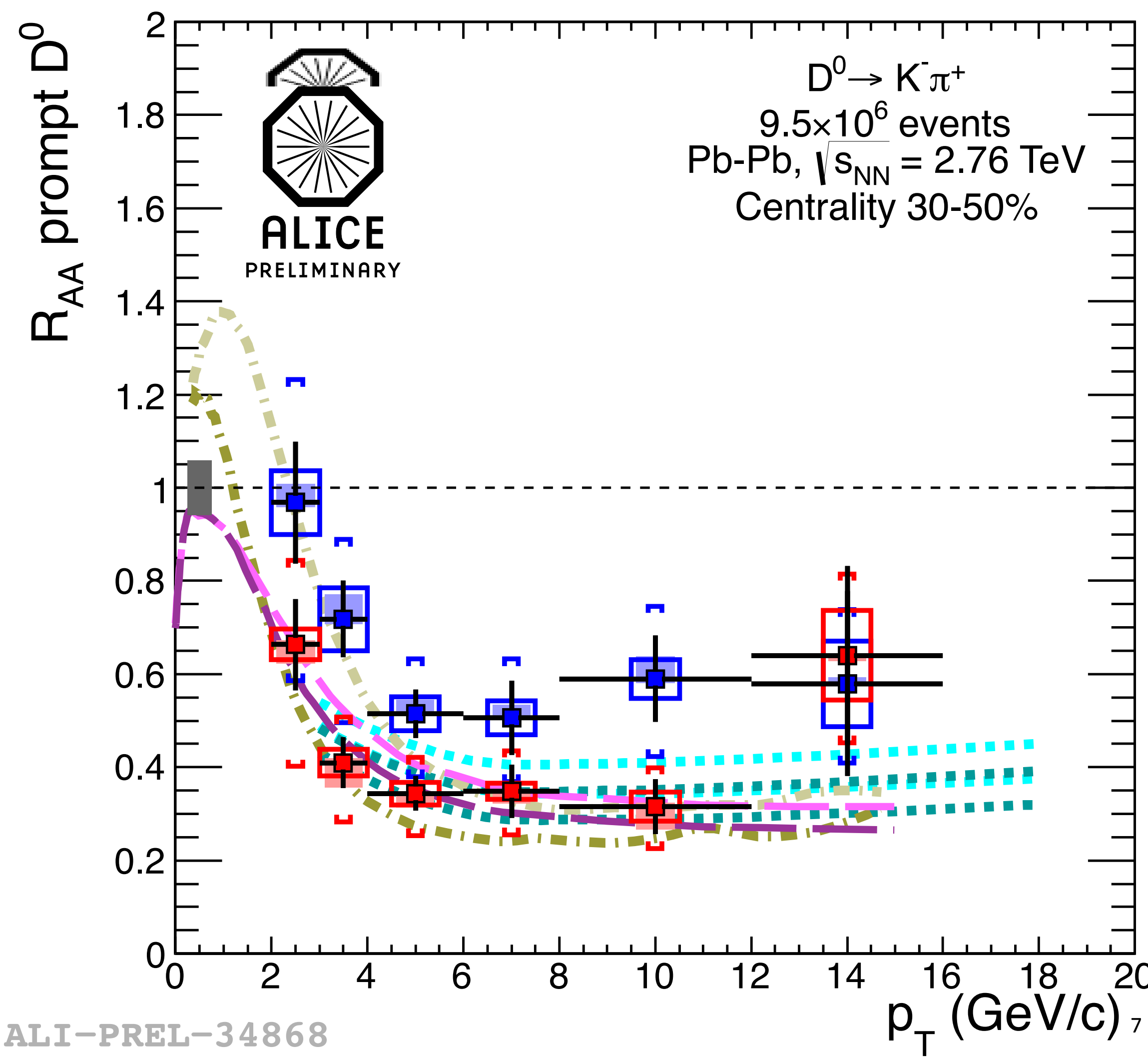
BAMPS[4] good agreement with results at low p_T for both R_{AA}.

At mid - high p_T suppression overestimated for the In Plane R_{AA}.

BAMPS considers only collisional energy loss in expanding medium

[4] Uphoff et al. arXiv: 1112.1559

D^0 R_{AA} vs EP comparison with models



POWLANG[7] good agreement with Out Of Plane R_{AA}, underestimate the In Plane results.

POWLANG[7] considers only collisional energy loss (Langevin equation).

[7] W. M. Alberico et al. Eur. Phys J. C 71, 1666 (2011)

D^0 R_{AA} vs p_T (2011 data)