Summary of ALICE results from heavy-flavour measurements from pp and Pb-Pb collisions at LHC energies.

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for the ALICE collaboration

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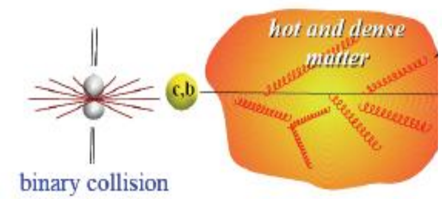
Scope

- Why heavy-flavour?
- ALICE detector and features
- Results:
  - proton-proton (pp) collisions @ $\sqrt{s}$ = 2.76 & 7 TeV
  - Pb-Pb collisions @ $\sqrt{s_{NN}}$ = 2.76 TeV
- Conclusions

Why Heavy Flavour ?

❖ Heavy quarks are produced at the beginning of the collisions with high Q^2.

- pp: pQCD calculations for heavy quark production
- p-A: cold nuclear matter effect (shadowing & gluon saturation).
- Pb-Pb: interaction with hot, dense QCD medium.



❖ Nuclear modification factor,

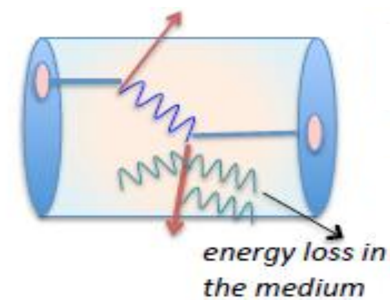
$$R_{AA}(p_t,\eta) = \frac{1}{\langle N_{coll} \rangle} \frac{d^2 N_{PbPb} / dp_t d\eta}{d^2 N_{pp} / dp_t d\eta} \rightarrow R_{AA}^{\pi} < R_{AA}^{D} < R_{AA}^{B}$$

= 1 if no medium / initial state effects.

Energy loss depends on

- colour charge (Casimir factor) $\langle \Delta E \rangle \propto \alpha_s C_R \hat{q} L^2$
- parton mass (“dead cone” effect) $\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$
- medium density & size

Dokshitzer and Kharzeev, PLB 519, 199-206 (2001).



❖ Azimuthal anisotropic flow $$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}\left(1 + 2\upsilon_1 \cos(\varphi - \Psi_1) + 2\upsilon_2 \cos[2(\varphi - \Psi_2)] + \ldots\right)$$

direct flow, elliptic flow,

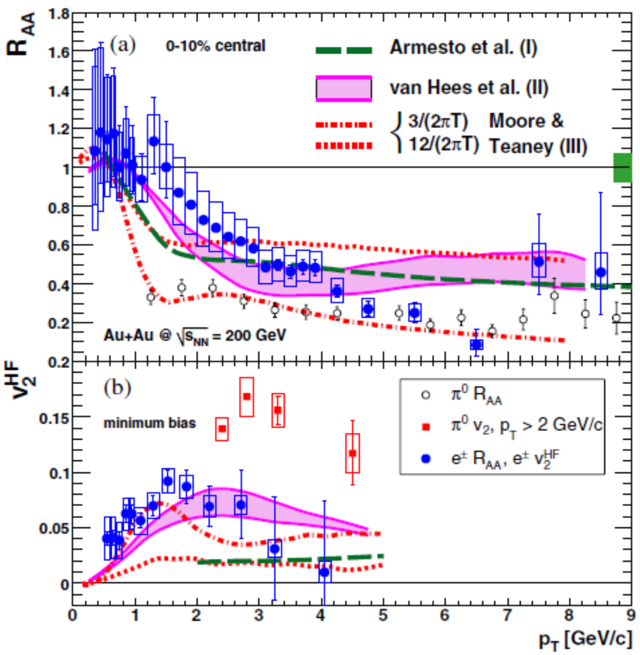
- Sensitive to parton-QCD matter interaction & thermalization ⇒ measurements of transport properties of the medium

→ Clean penetrating probes for QCD medium

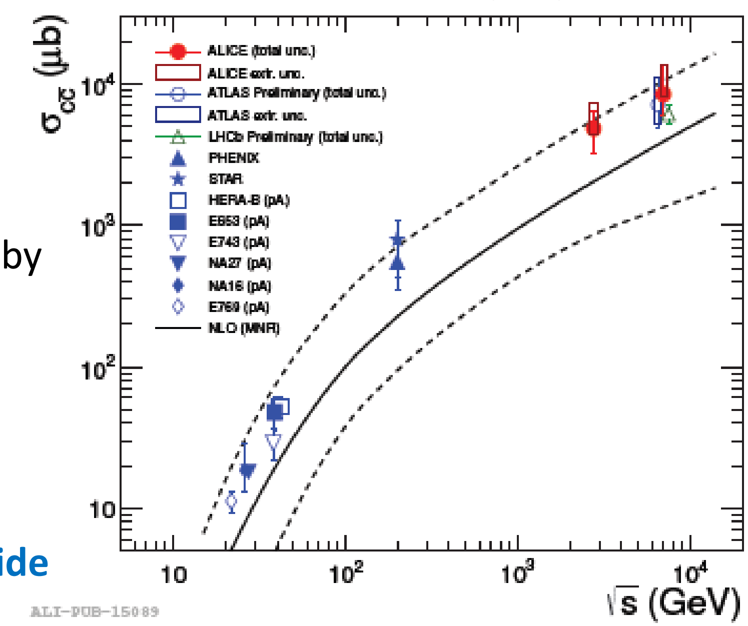
HF production ….

RHIC: A.Adare et al, PHENIX Collaboration, PRL. 98, 172301 (2007).
B. I. Abelev *et al.* STAR Collaboration, PRL. 98, 192301 (2007).

- Large energy loss of HF in the medium
- Substantial elliptic flow, v_2



ALICE Collaboration, JHEP07 (2012) 191



LHC:

- Charm (c) & beauty (b) cross sections are larger by factor 10 (50) at $\sqrt{s_{NN}}$ = 2.76 TeV
- ~60 $c\bar{c}$ expected in central Pb-Pb collisions.

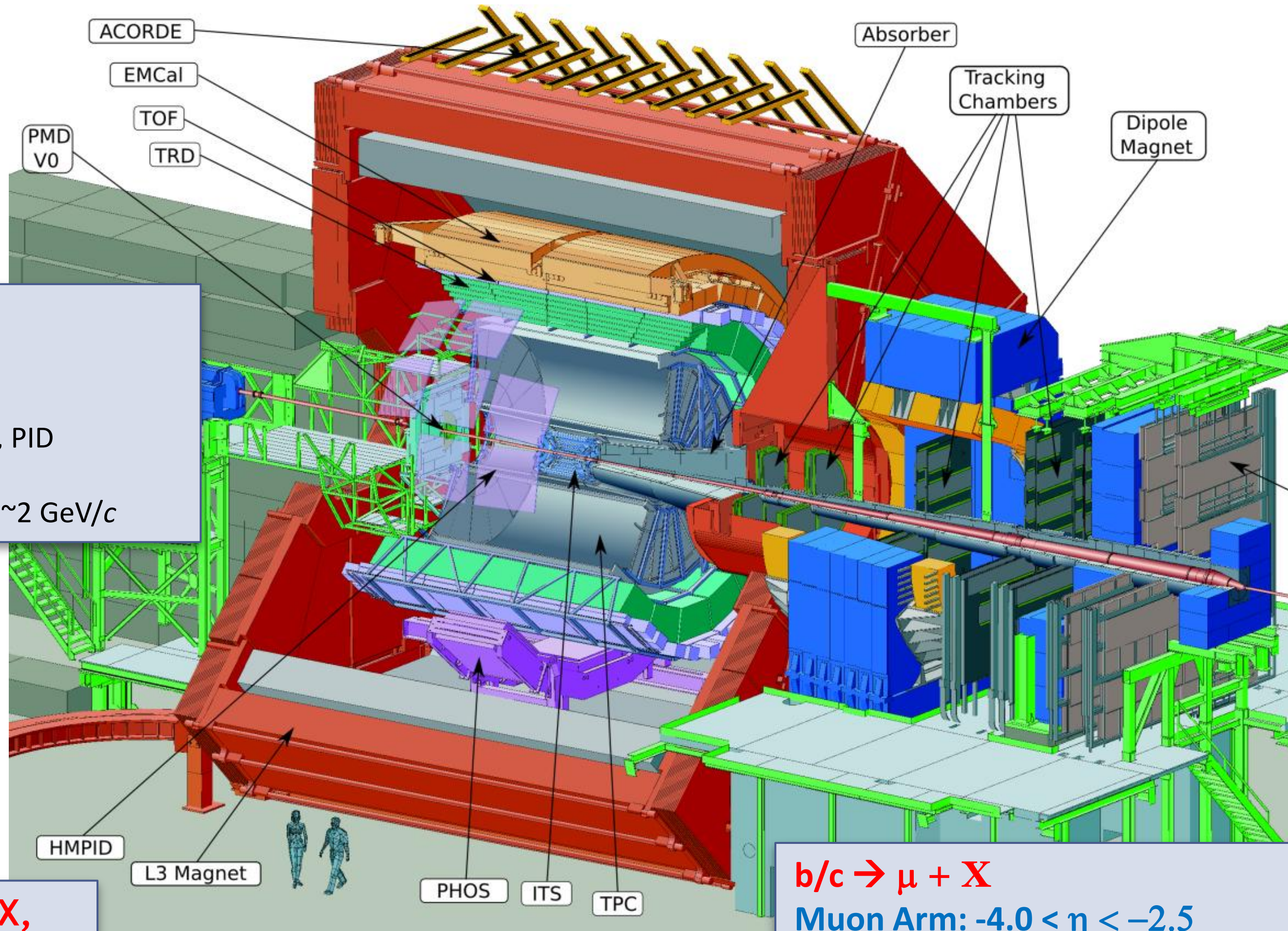
⇒ Large HF production cross sections

ALICE is well suited to measure HF decays in a wide momentum range …

The ALICE detector

B-field: 0.5 T
p_T resolution: 1% @ low p_T – 10% @ 50 GeV/c
Impact parameter resolution : ~ 65 μm @ 1 GeV/c

ALICE



D meson
|y| < 0.5
ITS: Vertexing
TPC: Tracking , PID
TOF: PID
PID : up to p_T ~2 GeV/c

b/c → e + X,
|η| < 0.8
ITS: Vertexing
TPC: Tracking + PID
TRD: PID
TOF: PID
EMCal: PID + Trigger

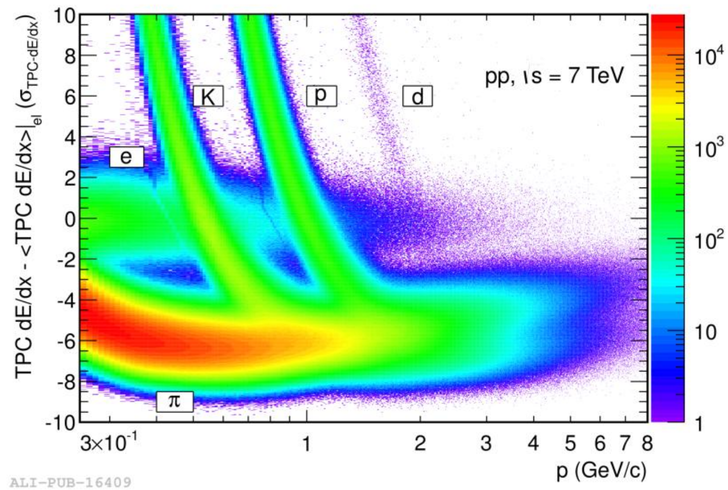
b/c → μ + X
Muon Arm: -4.0 < η < –2.5
10 tracking chambers
4 trigger chambers,
Absorber,
3 Tm dipole magnet
Resolution ($\Delta p/p$) : 1% @ 20 GeV/c,
4% @ 100 GeV/c

HF production in pp collisions

- Test pQCD calculations
- Reference for Pb-Pb

Measurement of HF electrons via b & c hadron decay → HFE

- PID: dE/dx (TPC) + TOF + TRD, (TPC) + EMCal



- Background sources

  Photon conversions

  Dalitz decay of neutral mesons

  (largest)

  Dielectron decays of light vector mesons

  Quarkonia decays

  Direct photons, Drell-Yan processes.

  (Dominant @ high p_T)

- Background subtraction:

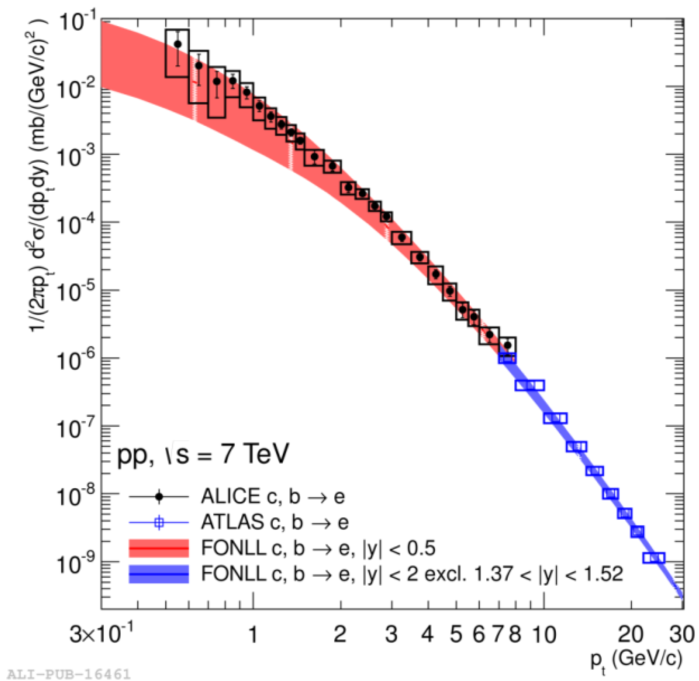
  In pp : Cocktail – MC hadron-decay generator

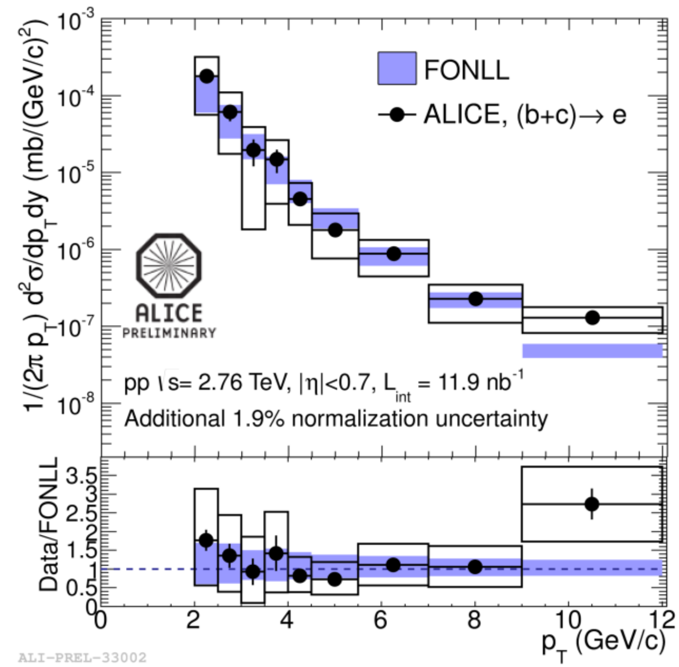
  In Pb-Pb: invariant mass method – removes π^0, Dalitz, photon conversions

- The dN/dp_T of HFE is obtained by subtracting background from inclusive electron spectrum & then normalized to σ(MB).

c → e + X	*BR: 9.6 %*
b → e + X	*BR: 11%*
b -> c → e + X	*BR: 10%*

HFE production in pp collisions @ 2.76 and 7 TeV





ALICE, arXiv : 1205.5423, accepted by PRD

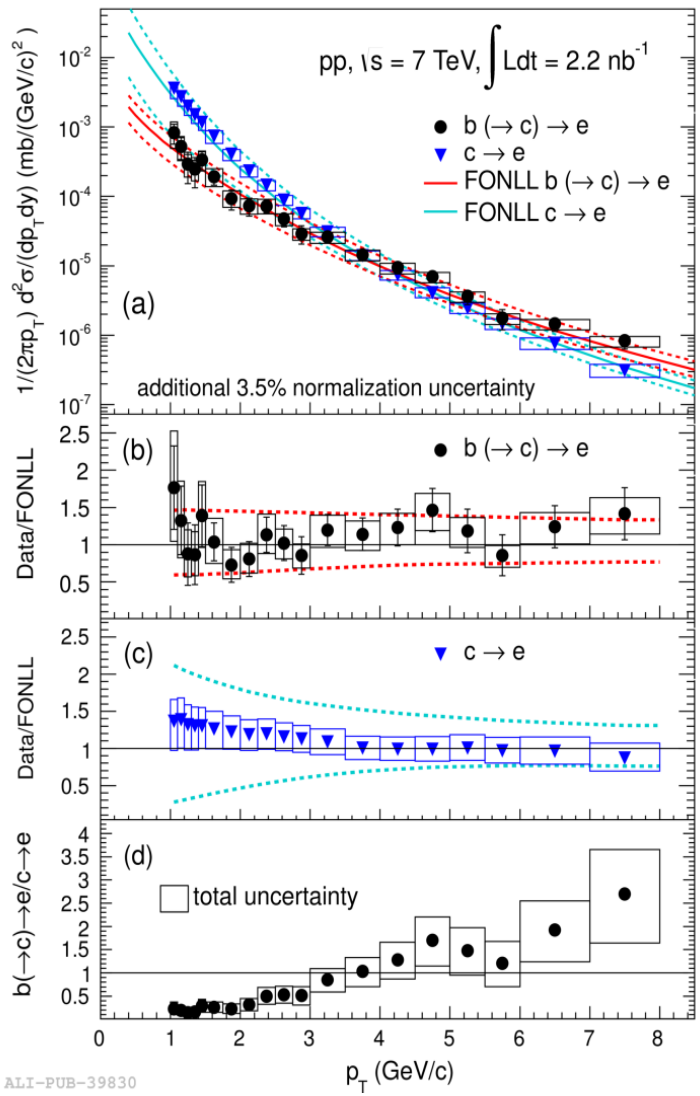
ATLAS, PLB 707 (2012) 438

ALICE data are compared with

• Fixed-Order-Next-to-Leading-Log (FONLL) pQCD calculations. Data are well described by the calculations Cacciari et al., arXiv:1205.6344.

•Complimentary to ATLAS data @ high p_T.

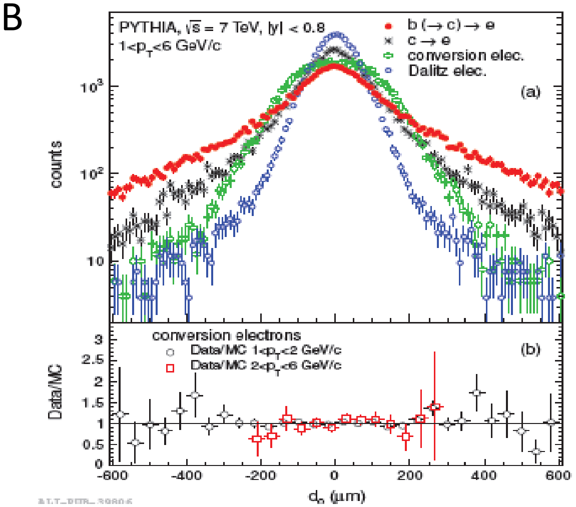
Beauty electrons in |y|< 0.5 in pp collisions @ 7 TeV



•Differential cross sections of HF $e^{\pm}$ from decays of b & c hadrons in $0.5 < p_T < 8$ GeV/*c*

•$e^{\pm}$ selection via p_T dependent impact parameter d_0 cut to enhance S/B

arXiv:1208.1902



•Charm extraction : c → $e^{\pm}$ = HF → $e^{\pm}$ - b → $e^{\pm}$

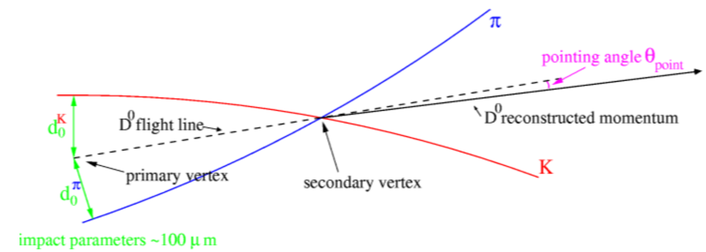
•Beauty takes over from charm @ $p_T > 4$ GeV/*c*.

•FONLL describes both b → $e^{\pm}$ and c → $e^{\pm}$ differential cross sections also @ low p_T.

Cacciari et al., arXiv:1205.6344.

Prompt D meson hadronic decay reconstruction

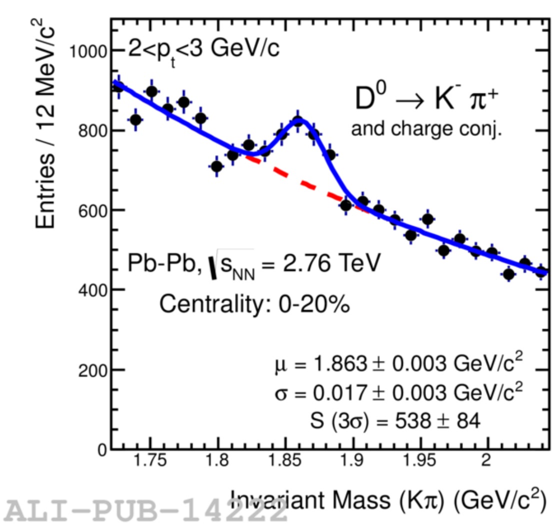
❖ Search for secondary vertices displaced by few hundred μm from primary vertex



ALICE, JHEP9(2012)112

❖ Selection:

- p_T & impact parameter of single tracks,
- PID (π, K) with TPC+TOF
- Pointing angle
- Decay length

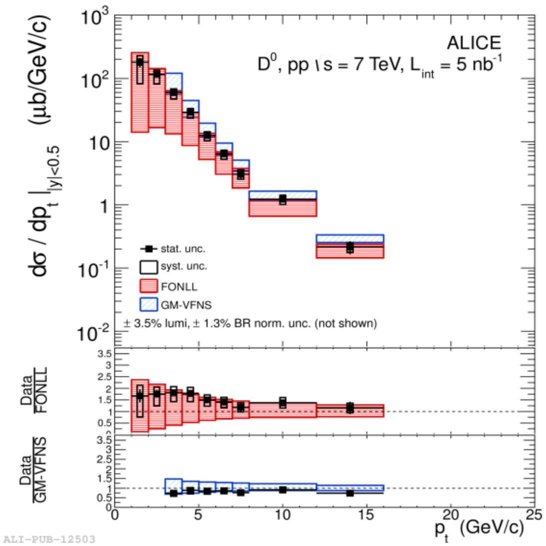


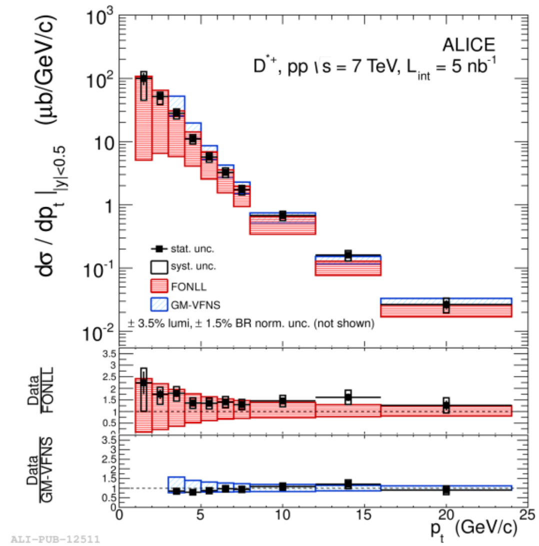
❖ Signal extraction from fits to invariant mass distribution in Pb-Pb.

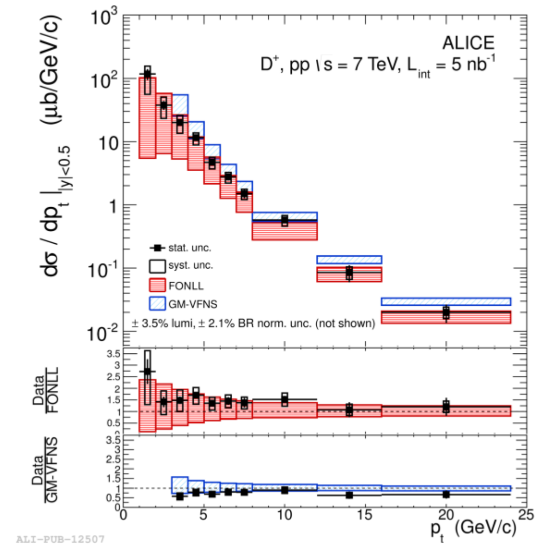
❖ Nnormalized to σ(MB).

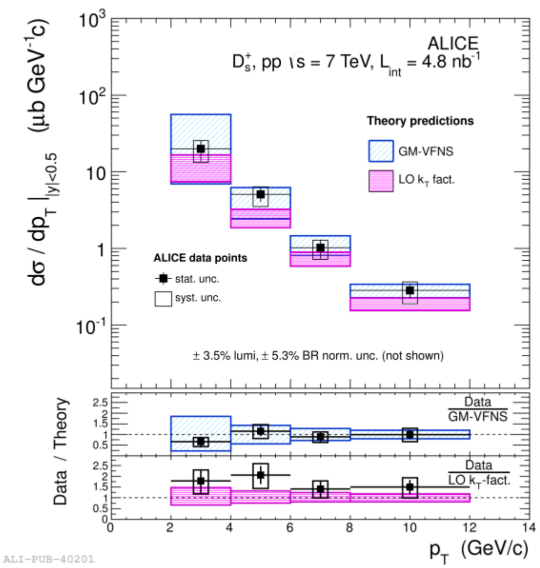
$D^0 \to K^-\pi^+$,	BR: 3.89%
$D^{*+} \to D^0(\to K^-\pi)\pi^+$	BR: 67.7%
$D^+ \to K^-\pi^+\pi^+$	BR: 9.22%
$D_s^+ \to K^+K^-\pi^+$	BR: 5.5%

Prompt charm production at central rapidity in pp collisions @ 7 TeV









- Inclusive p_T distributions for prompt
  - D^0 measured in $1 < p_T < 16$ GeV/c,
  - D^+ & D^{*+} measured in $1 < p_T < 24$ GeV/c

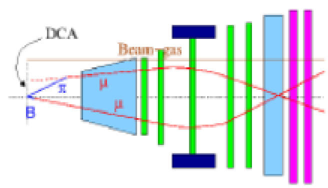
  ALICE, JHEP 1(2012)128

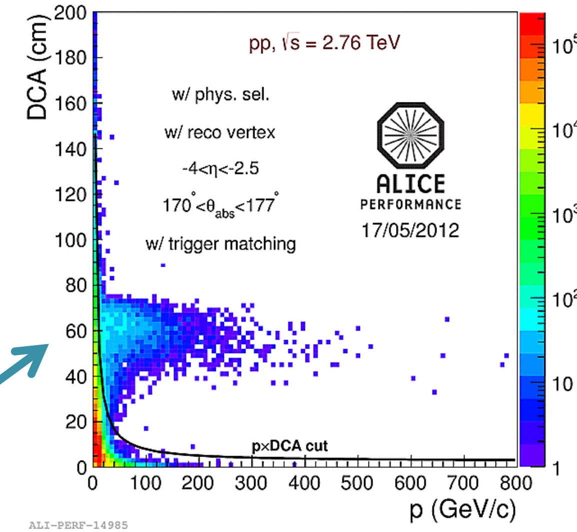
  - D_s^+ measured in $2 < p_T < 12$ GeV/c ALICE, PLB 718 (2012)279
- Data are well described by the pQCD calculations

Cacciari et. al., arXiv:1205.6344,
Kniehl et al., arXiv:1202.0439.
Maciula, et al, arXiv:1208.6126

HF decay muon measurement @ forward rapidity, 2.5 < y < 4.0

- Track selection
  - Muon in the spectrometer acceptance
  - Matched with a tracklet in the trigger system to reject punch-through hadrons
  - p×DCA to reject tracks from beam-gas interaction & fake tracks in PbPb

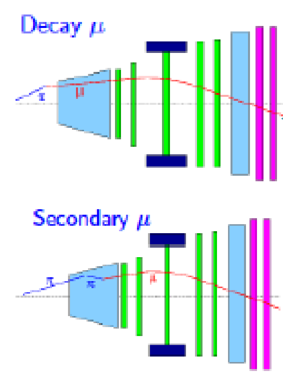


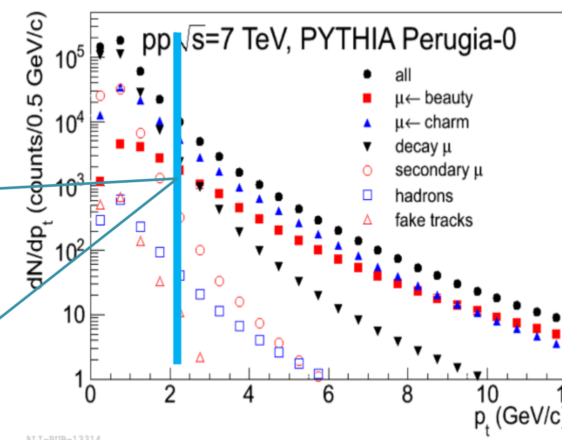


- Background subtraction:
  - π, K decay μ estimated using event generators (PYTHIA, PHOJET)
  - Normalized to data at low p_T.
- Acc × Eff correction

Detector simulation (MC) based on parameterization of p_T & y differential cross sections of B quark from MNR

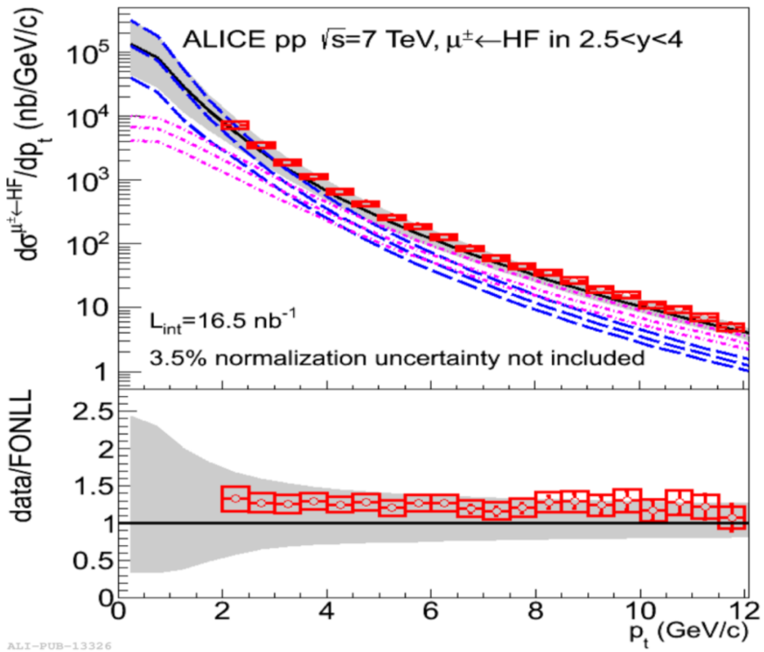
(Mangano, Nason, Ridolfi, Nucl.Phys.B 373 (1992) 295).



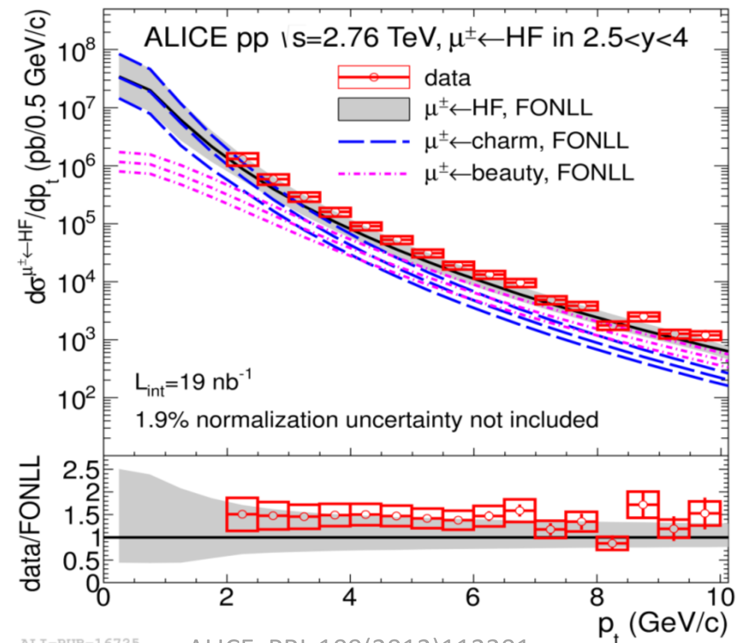


- Normalization to σ(MB)

HF muons @ forward rapidity 2.5 < y < 4.0 in pp collisions at 2.76 TeV & 7 TeV.



ALICE, PLB 708(2012)265



ALICE, PRL 109(2012)112301

- Data are well described by FONLL pQCD calculations within errors Cacciari et. al., arXiv:1205.6344
- Similar conclusions at $\sqrt{s}$ = 2.76 and 7 TeV.

HF production in Pb-Pb collisions @ 2.76 TeV

- ❖ Nuclear Modification Factor, R_{AA}
- ❖ Elliptic flow, v_2

Nuclear modification factor, R_{AA}, in Pb-Pb collisions

- Nuclear Modification factor is defined as follows

$$R_{AA} = \frac{1}{< T_{AA} >} \cdot \frac{dN_{PbPb}/dp_T}{d\sigma_{pp}/dp_T}$$

where,

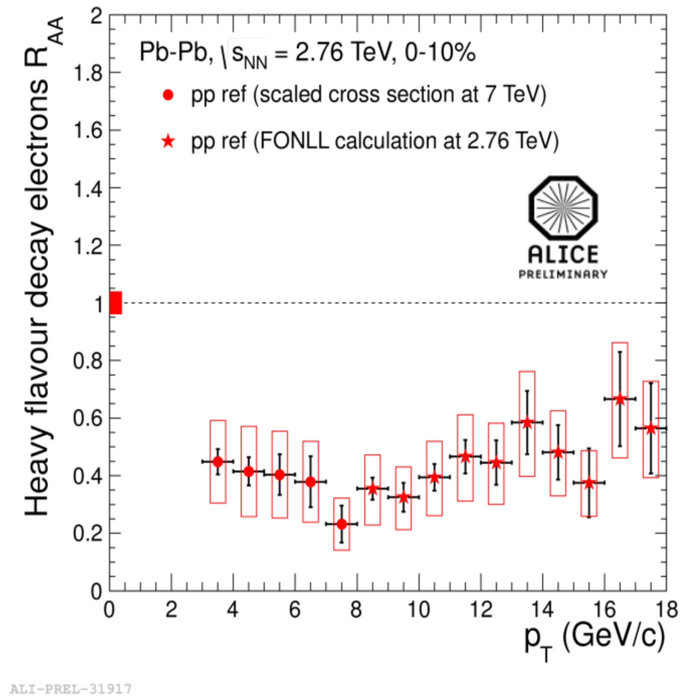
$<T_{AA}>$: Nuclear overlap function average over impact parameter

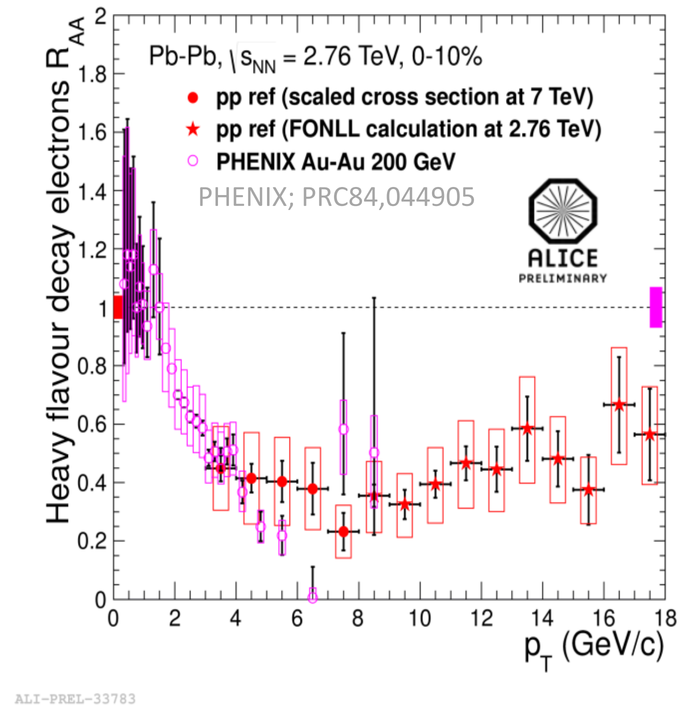
dN_{PbPb}/dp_T: Measured p_T spectrum in Pb-Pb.

$d\sigma_{pp}/dp_T$: Reference p_T spectrum in pp at the same $\sqrt{s}$ as Pb-Pb.

- For the D mesons and HFE the reference p_T differential cross section in pp collision is measured @ $\sqrt{s}$ = 7 TeV and scaled to 2.76 TeV using FONLL calculations.

R_{AA} for HF electrons in Pb-Pb collisions @2.76 TeV



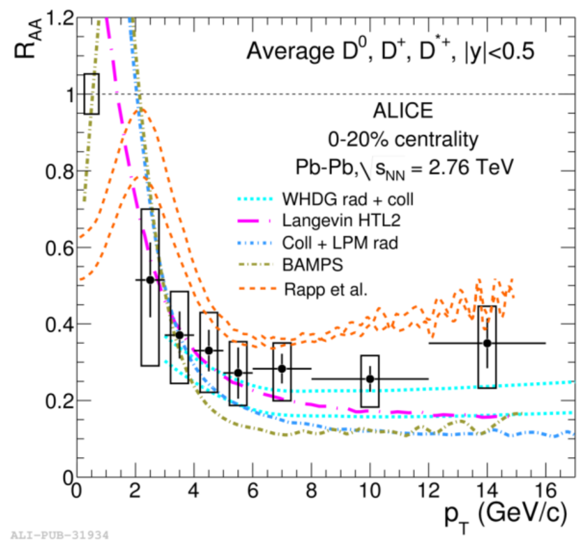


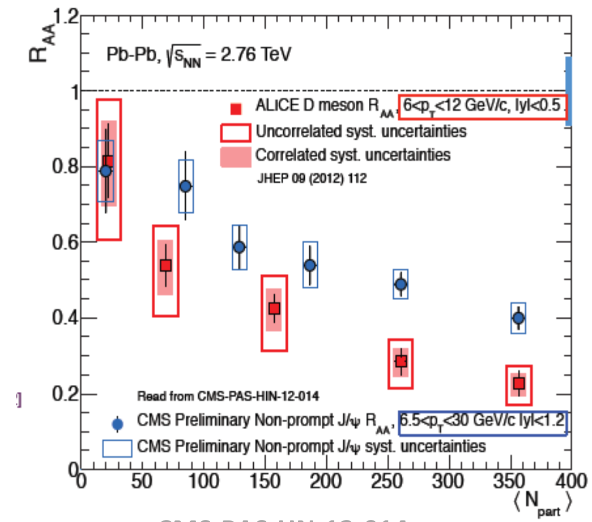
•Suppression of HF decay electrons over a wide p_T range.

•R_{AA} comparable @ ~3 < p_T < ~9 GeV/*c* for RHIC and LHC, taking into account that charm & beauty fractions in this p_T range are different @ RHIC and LHC.

Average R_{AA} of D mesons in Pb-Pb collisions @ 2.76 TeV

ALICE, JHEP 09(2012)112

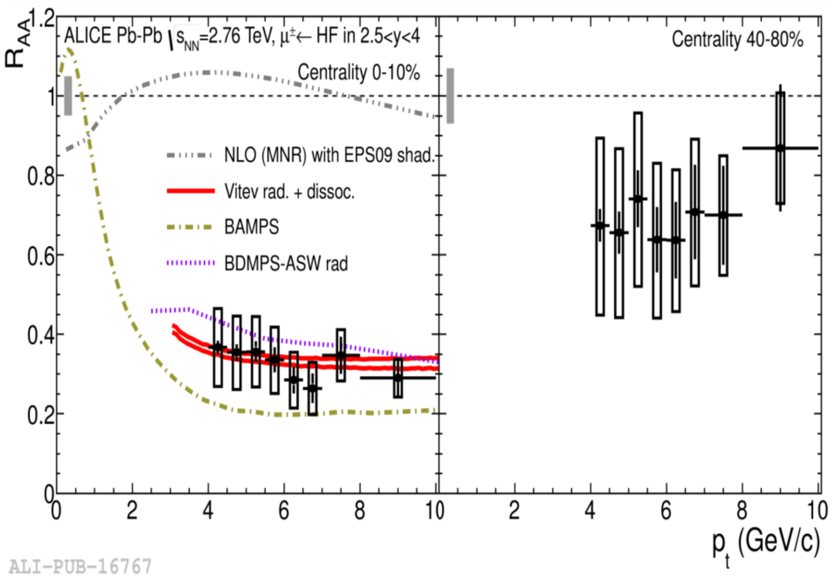


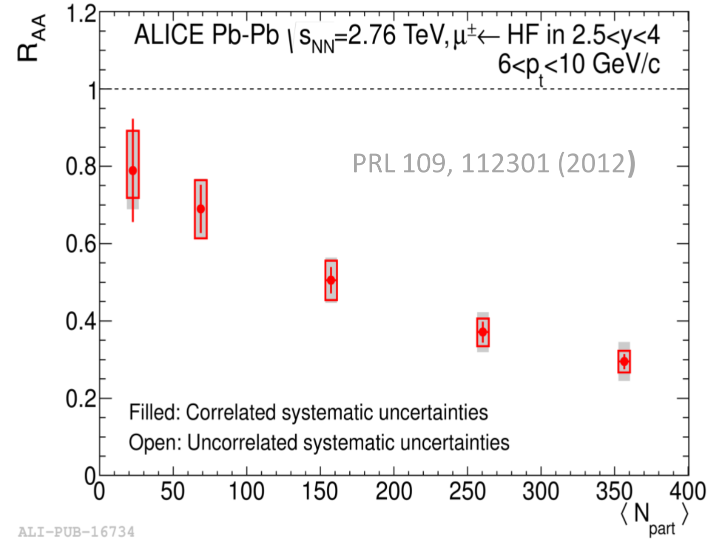


CMS-PAS-HN-12-014

- R_{AA} of D mesons at central rapidity |y| < 0.5 for centrality class 0-20% in Pb-Pb collisions.
  - Suppression by a factor 3 - 4 for p_T > 5 GeV/*c* in the most 20 % central collisions
  - Reduced suppression for peripheral collisions.
- Data are reasonably described by some of the energy loss models $\Rightarrow$ Strong in-medium energy loss for charm quarks.
- Comparison with the non-prompt J/ψ from B decay measured by CMS @ 6.5< p_T <30 GeV/*c* in |y| < 1.2 indicate a different suppression for charm and beauty $\Rightarrow$ not conclusive since rapidity intervals are different & decay kinematics prevent a quantitative comparison.

R_{AA} of HF muons in Pb-Pb collisions at 2.76 TeV





•Stronger suppression in central collisions than in peripheral collisions.

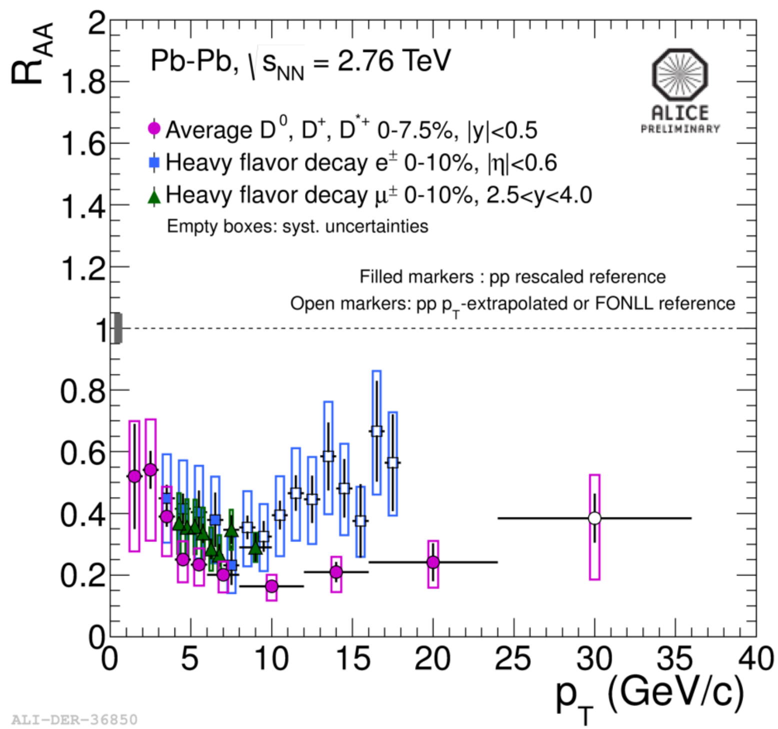
•In the explored p_T range, the suppression is not dependent on p_T.

•In agreement with in-medium energy-loss models (BDMPS-ASW) & (Vitev).

• Small contribution of shadowing is expected for muons with p_T > 4 GeV/c.

To be confirmed with 2013 p-Pb data.

Average D meson in 0-7.5%, HF muon and electron R_{AA} in the 0-10% centrality class in Pb-Pb collisions



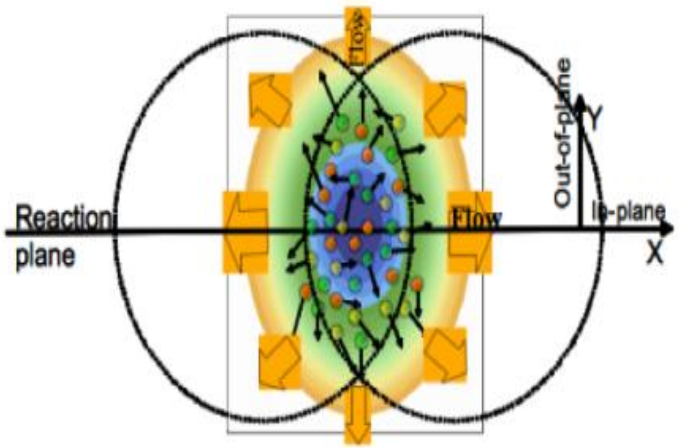
•R_{AA} is compatible for D mesons, HF electrons & muons in $p_T \leq 8$ GeV/*c, w*hen taking into account decay kinematics (electrons & muons carry only a fraction of the p_T of the mother particle).

Azimuthal anisotropic flow in Pb-Pb collisions

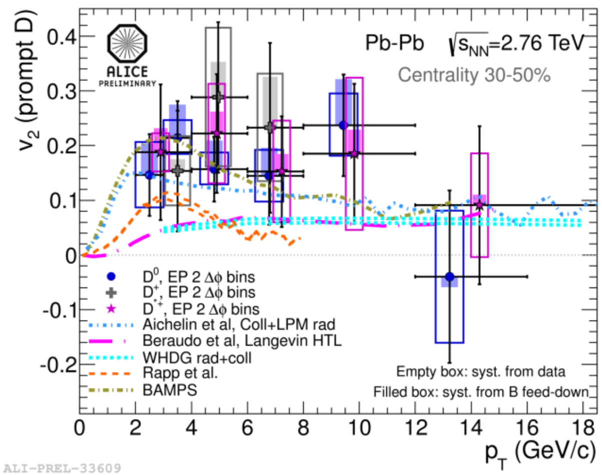
•Non- isotropic emission w. r. t. the reaction plane can be a sign of path-length dependence of energy loss (high-p_T) and/or thermalization / collective motion (low p_T)

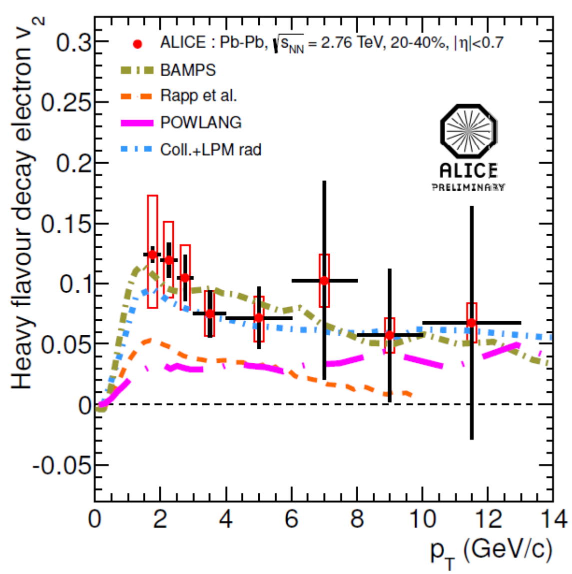
$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}\left(1 + 2v_1\cos(\varphi - \Psi_1) + 2v_2\cos[2(\varphi - \Psi_2)] + \dots\right)$$

where
N – number of particles emitted in the collision
φ - azimuthal angle
ψ- reaction plane angle
v_1 – direct flow
v_2 - elliptic flow



Elliptic flow in Pb-Pb collisions @ 2.76 TeV





- Non-zero v_2 observed for HF electrons and D mesons.
- Consistency between D^0, D^+ & D^{*+} meson trends.
- v_2 of both D mesons HF electrons are reasonably described by some of the models.

Conclusions

ALICE has measured D mesons, electrons and muons from HF decays in pp and Pb-Pb collisions @ $\sqrt{s}$ = 7 TeV and 2.76 TeV, respectively.

- In pp collisions: D mesons, HF electrons and muons are well reproduced by pQCD models.
- In Pb-Pb collisions:

  - Strong suppression for HF electrons, muons and D mesons in central Pb-Pb collisions relative to pp (R_{AA}).

  - Charm mesons (D^0, D^+ and D^{*+}) show a consistent (similar) trend.

  - Indications of non-zero v_2 for D mesons (2 - 6 GeV/c) and HF electrons (2 – 3 GeV/c) in semi-peripheral Pb-Pb collisions.

  - Model predictions describe both the R_{AA} and v_2 for the D mesons and HF electrons reasonably well.

- In p-Pb:

  - Will provide an important constraint of initial state effects of heavy quark production at LHC energies.

  - Runs will take place in early 2013.

Thank you

Backup slides

Production cross section for D meson calculated as

$$\left.\frac{\mathrm{d}\sigma^{D^+}}{\mathrm{d}p_T}\right|_{|y|<0.5} = \frac{1}{2}\frac{1}{\Delta y \Delta p_T}\frac{f_{\mathrm{prompt}}(p_T)\cdot N^{\mathrm{D}^{\pm}\mathrm{raw}}(p_T)\big|_{|y|<y_{fid}}}{(Acc\times\varepsilon)_{\mathrm{prompt}}(p_T)\cdot \mathrm{BR}\cdot L_{\mathrm{int}}}$$

where

$N^{D\pm raw}(p_T)$ → measured inclusive raw yield obtained from invariant mass analysis in each p_T interval (of width Δp_T).

f_{prompt} → prompt fraction of the raw yield

$(Acc \times \varepsilon)_{prompt}$ → acceptance x efficiency of prompt mesons, where

ε → accounts for vertex reco, track reco & selection & for D meson candidate selection with 2nd vertex and PID cuts

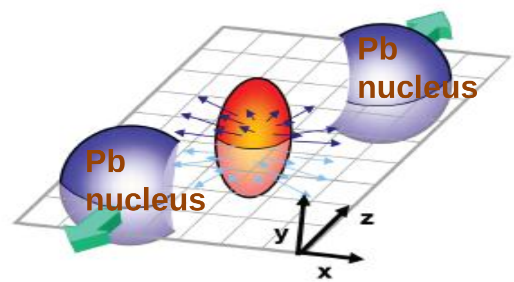
Δy (= $2y_{fid}$) → width of the fiducial rapidity coverage,

BR → decay branching ratio

½ → accounts for the fact that measured yield include particle / antiparticle while σ are given for particles only

$L_{int} = N_{pp,MB} / \sigma_{pp,MB}$ → integrated luminosity, where $N_{pp,MB}$ and $\sigma_{pp,MB}$ are the number and cross section of the pp interaction passing the MB trigger condition.

Elliptic flow in Pb-Pb collisions



The elliptic flow is defined as:

$$\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}} = N\left[1 + 2\sum_{n=1}^{\infty} v_n cc\right]$$

Background subtraction, e.g. for HF electrons

$$v_2^{\mathrm{HFE}} = \frac{(1 + R_{\mathrm{SB}})v_2^{\mathrm{incl}} - v_2^{\mathrm{back}}}{R_{\mathrm{SB}}}$$

$$v_2^{\mathrm{back}} = \sum_i R_i \, v_2^i$$

where

v_2^{incl} : v_2 of inclusive electrons

v_2^{back} : v_2 of background electrons

v_2^{HFE} : v_2 of HF electrons

R_{SB} : signal-to-background ratio

v_2^i : electrons v_2 of source i

R_i : contribution of source i