Heavy Flavour Production in Pb-Pb collisions at LHC with ALICE

Yvonne Pachmayer, University of Heidelberg
for the **ALICE Collaboration**

- **Motivation**
- **Analysis strategy**
- **Nuclear modification factor R_{AA}**
- **Azimuthal anisotropy v_2**
- **Summary and outlook**

BMBF Forschungsschwerpunkt
ALICE Experiment 201

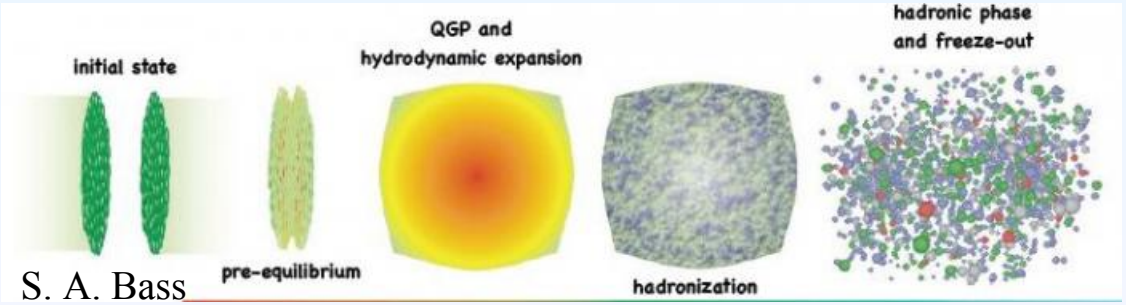
Heavy Flavour (Charm & Beauty) Production

- **Heavy-flavour quarks (c, b)**
  - $m_c \sim 1.3$ GeV/c^2, $m_b \sim 4.7$ GeV/c^2
  - Originate from initial scattering processes
  - Produced on a very short time scale ($\approx 1/(2m_q) \leq 0.1$ fm/c)

    → Sensitive to the full history of the collision

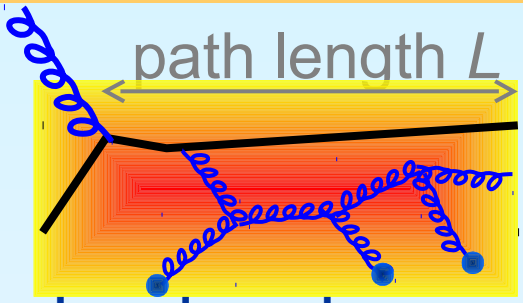
    → Excellent probes to study the de-confined medium produced in nucleus nucleus collisions
    - Study flow and energy loss of heavy quark

      → Independent way to extract properties of the medium



S. A. Bass

Energy Loss in the Medium



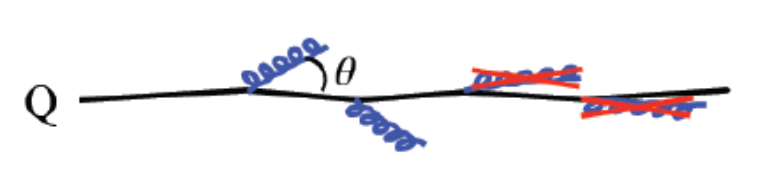
Color Charge
C_R=3 for gluons, C_R=4/3 for quarks

BDMPS approach

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

Transport coefficient related to medium characteristics and gluon density

- **Energy loss depends on**
  - Properties of the medium (gluon densities, size)
  - Properties of the probe (color charge, mass)
- **Dead cone effect**
  - Gluon radiation is suppressed for angles $\theta < M_Q/E_Q$



→ Heavy flavour energy loss should be smaller than the one of light hadrons:
$\Delta E_g > \Delta E_{charm} > \Delta E_{beauty}$
R_{AA} (light hadrons) < R_{AA} (D) < R_{AA} (B)

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \times \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

Dokshitzer and Kharzeev, PLB 519 (2001) 199.
Armesto, Salgado, Wiedemann, PRD 69 (2004) 114003.
Djordjevic, Gyulassy, Horowitz, Wicks, NPA 783 (2007) 493.

Proton-proton collisions: provide important test of pQCD in a new energy domain and heavy ion reference

Possible other mechanisms for the interaction with the medium (collisional energy loss, in-medium dissociation, resonance scattering)

Proton-nucleus collisions: disentangle initial and final state effects

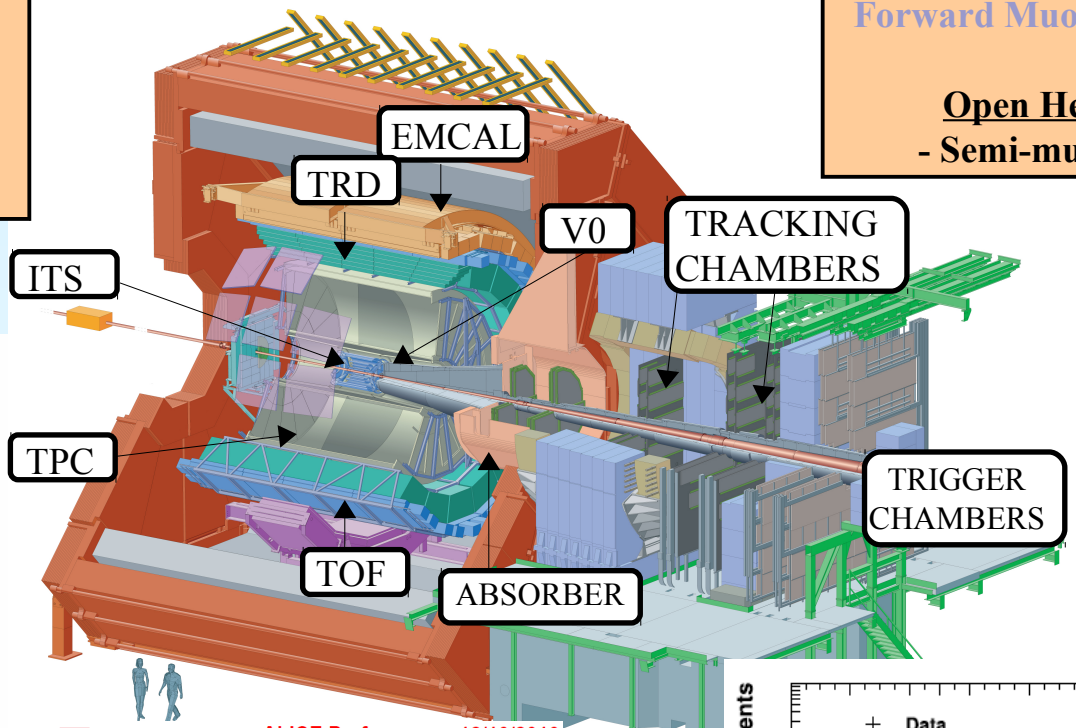
A Large Ion Collider Experiment

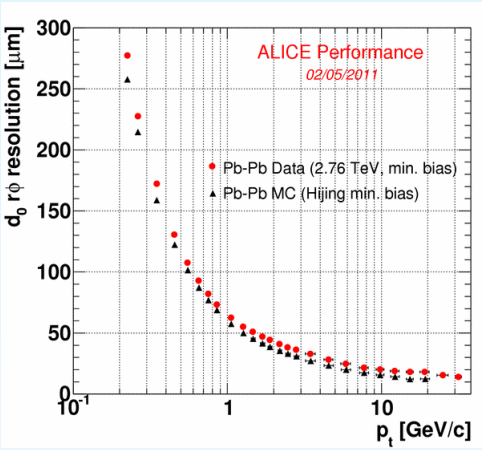
Central Barrel (| η | ≤ 0.9)

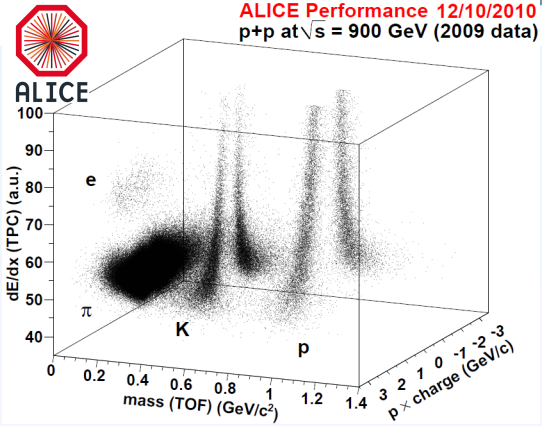
Open Heavy Flavour
- Hadronic decays
- Semi-electronic decays

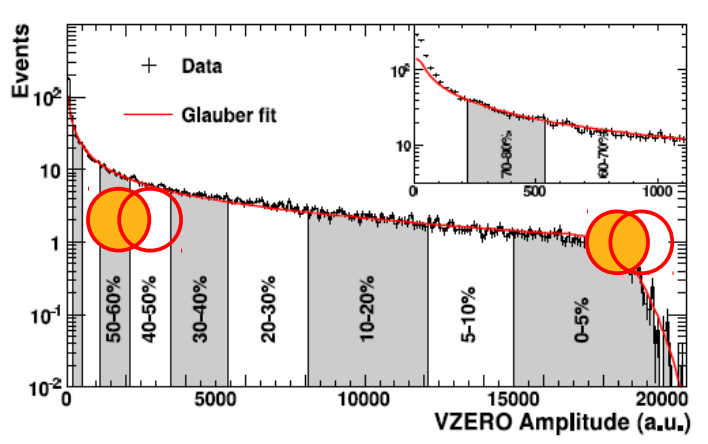
Forward Muon Arm (4 ≤ η ≤ 2.5)

Open Heavy Flavour
- Semi-muonic decays









Phys. Rev. Lett. 106 (2011) 032301

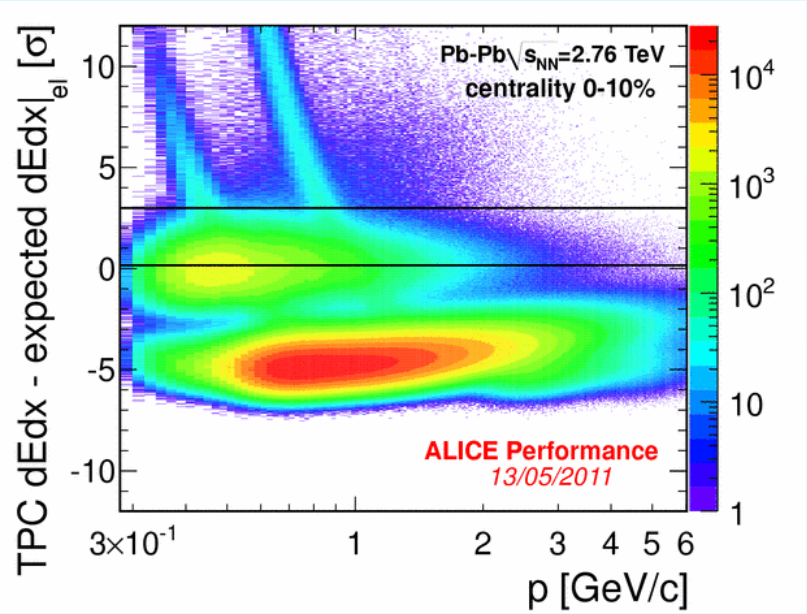
Reconstruction of Electrons from Semi-electronic c/b Decays

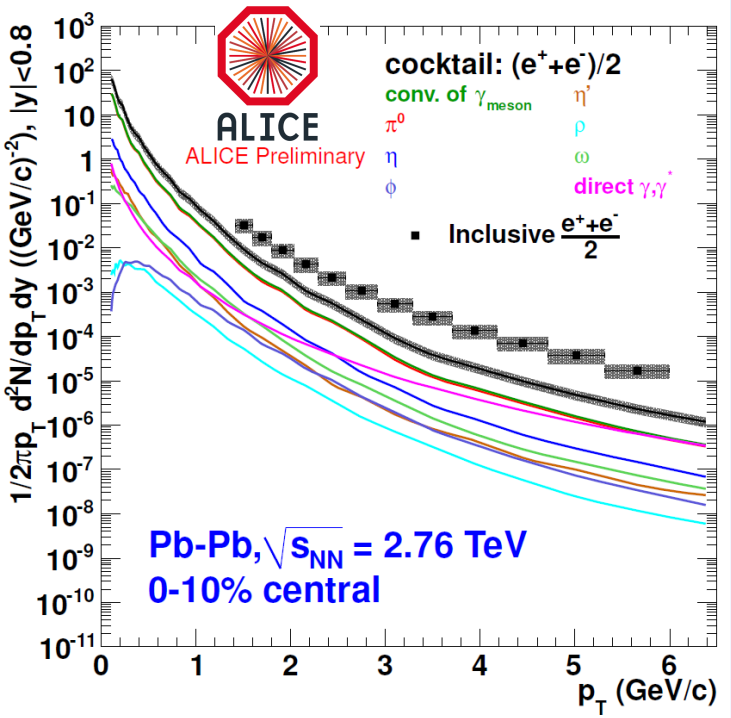
Analysis Strategy

- Electron Identification with Time Of Flight system, Time-Projection Chamber
- Remaining hadron contamination determined via fits of dE/dx in momentum slices
- Requirement of a hit in the innermost layer of the Inner Tracking System (r = 3.9 cm) to reduce bkg from photon conversion
- Subtraction of the background via data-tuned MC cocktail

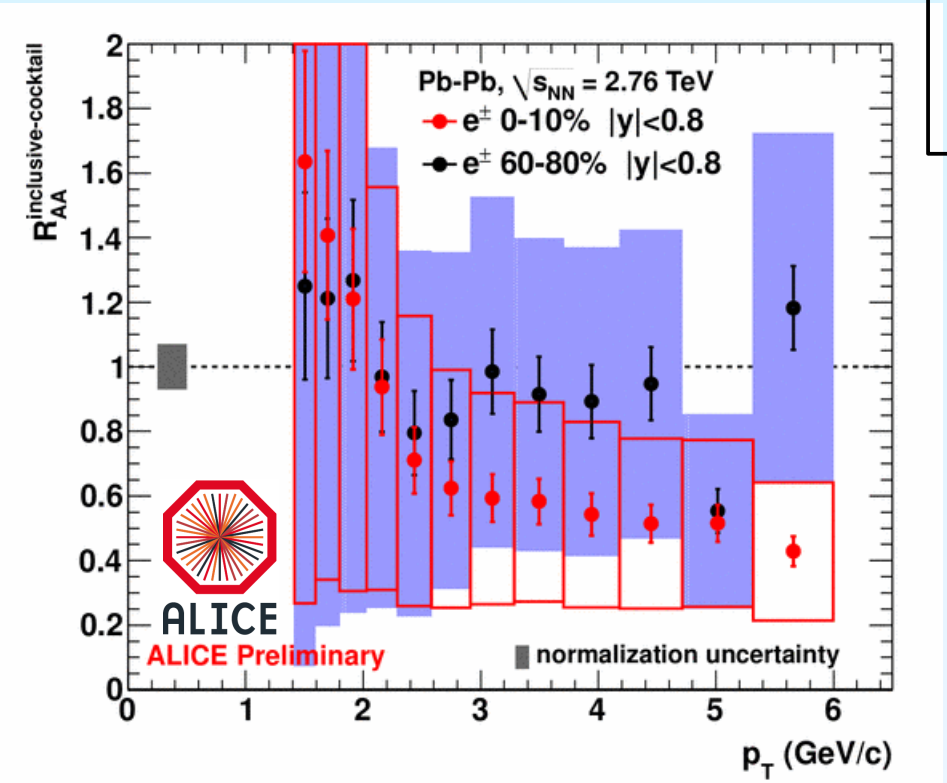
Semi-electronic decays:

c, b → e + anything





Cocktail-subtracted Electron R_{AA}

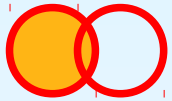


P. Antonioli (4C)

pp reference at 2.76 TeV:
measured 7 TeV spectrum scaled with FONLL
R. Averbeck et al, arXiv:1107.3243

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \times \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

60-80%

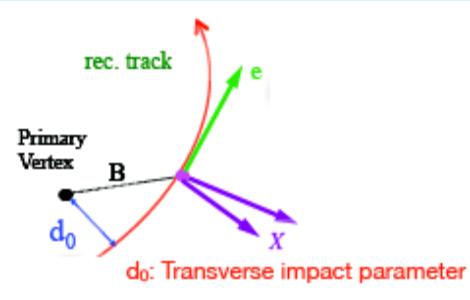


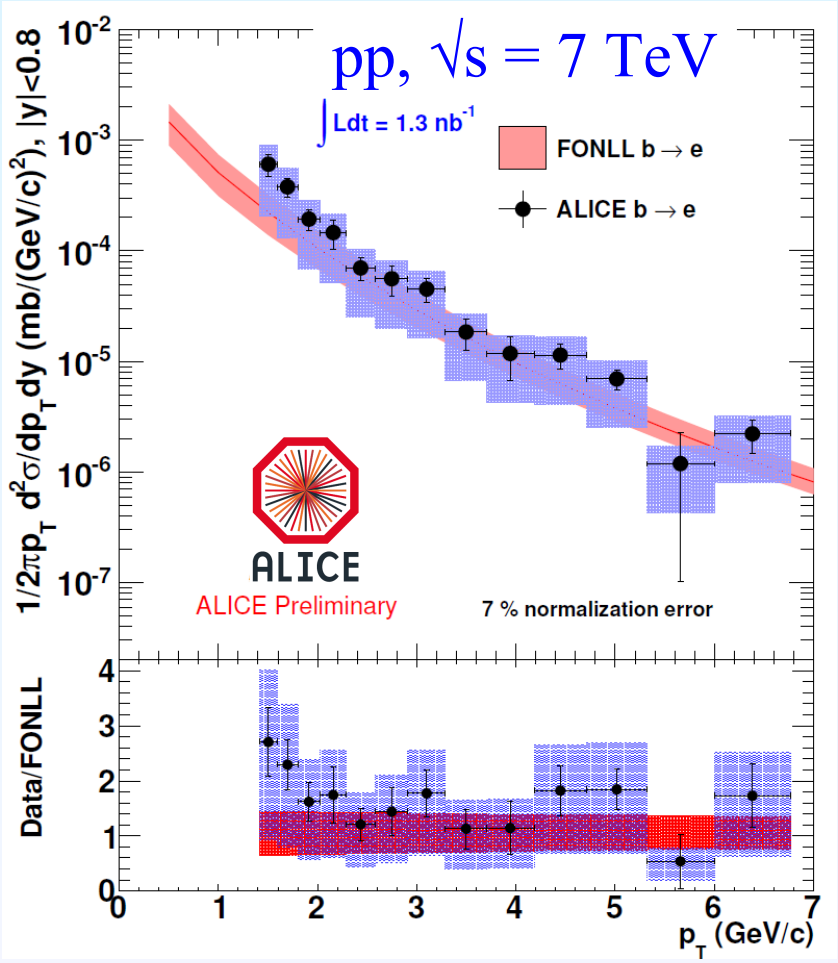
0-10%

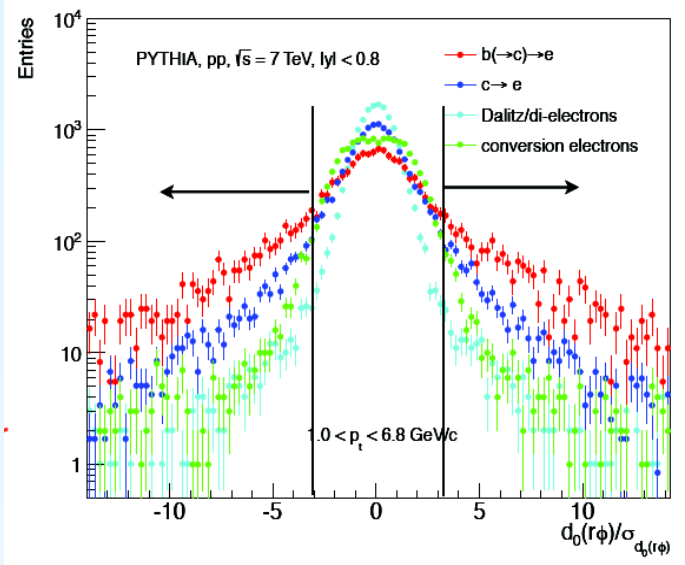
→ p_T region 3.5-6 GeV/c: charm and beauty decays dominate
→ Suppression in central collisions: factor 1.5-4
→ Ongoing:
- Reduction of systematic uncertainty
- High-p_T extension with TRD and EMCAL particle identification

Disentangle Contributions from c and b Decays pp $\sqrt{s}$ = 7 TeV

- Large b mass and $c\tau$ of 500 μm
  → Analysis Strategy: selection of electrons from displaced vertex







→ FONLL in agreement with data
→ Available as reference for Pb-Pb
→ Pb-Pb work in progress

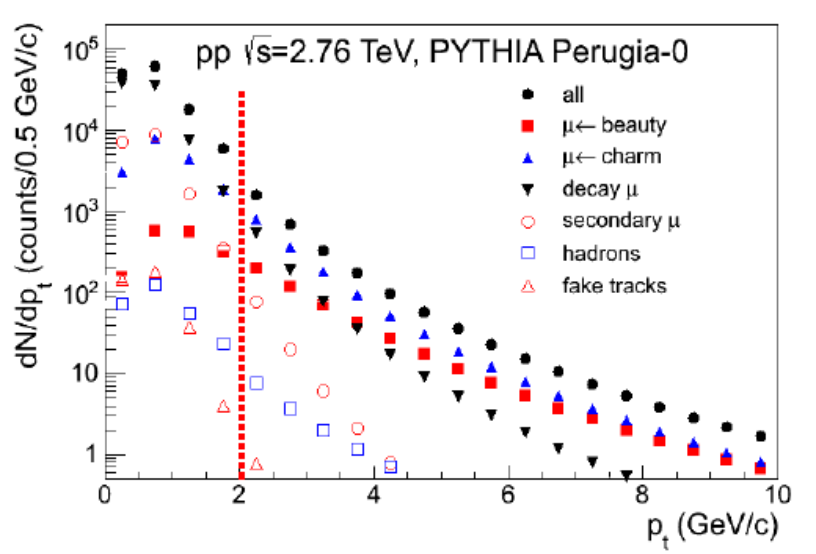
FONLL: Cacciari, Greco, Nason, JHEP05(1998)007 and M. Cacciari private communication

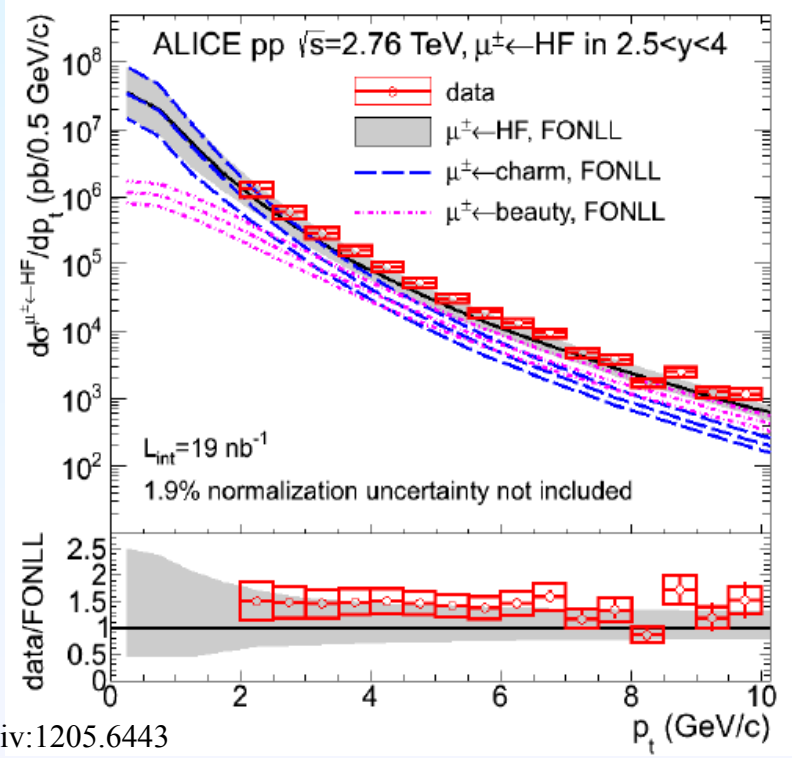
Open Heavy Flavour from Forward Muons 2.5 < y < 4

Semi-muonic decays:

c, b → μ + anything

- **Analysis Strategy**
  - Muon identification with muon arm
  - Removal of hadrons and low p_T secondary muons via requirement of a muon trigger signal, p_T cut-off and DCA cut
  - Subtract muons from pion and kaon decays by subtracting
    - in pp: MC $dNdp_T$ normalized to data at low p_T
    - in PbPb: extrapolated $K^{\pm}$ and $\pi^{\pm}$ spectra, measured at mid-rapidity, to forward rapidities and applying decay kinematics

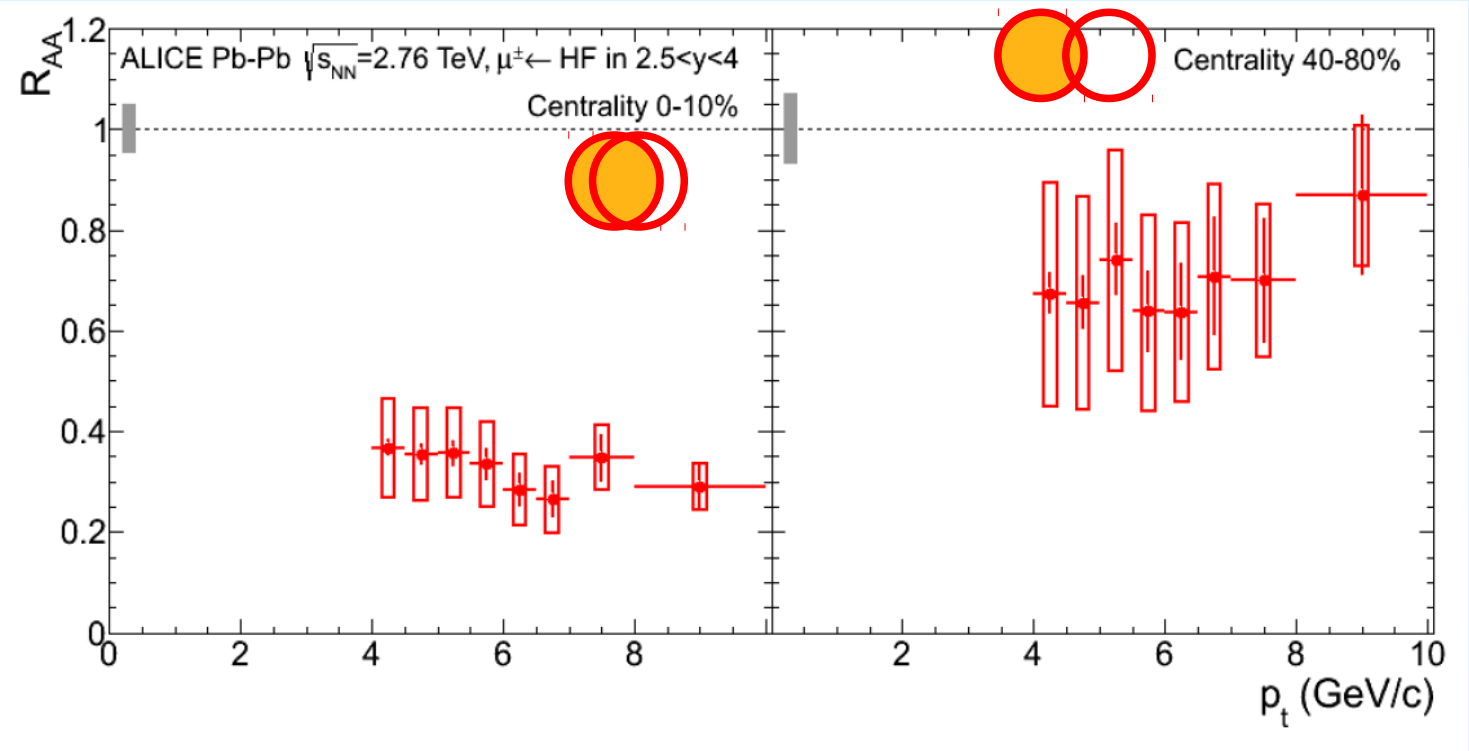




arXiv:1205.6443

Heavy Flavour Decay Muon R_{AA}

arXiv:1205.6443



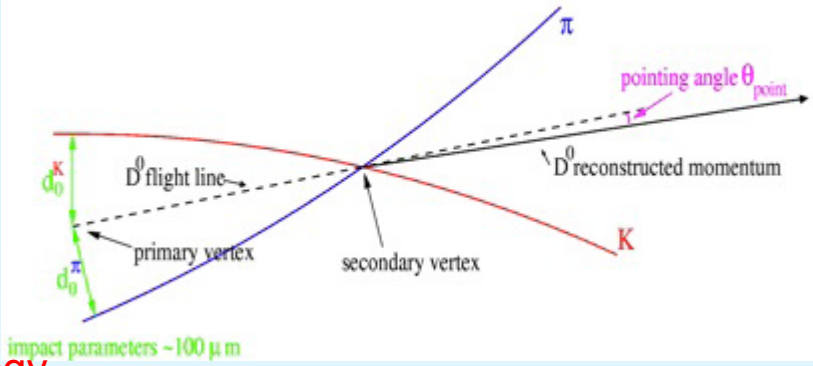
→ Suppression in central collisions:
factor 3, no significant p_t dependence

→ p_T region 6-10 GeV/c: FONLL - beauty decays dominate

D Meson Decay Reconstruction

Hadronic decays:

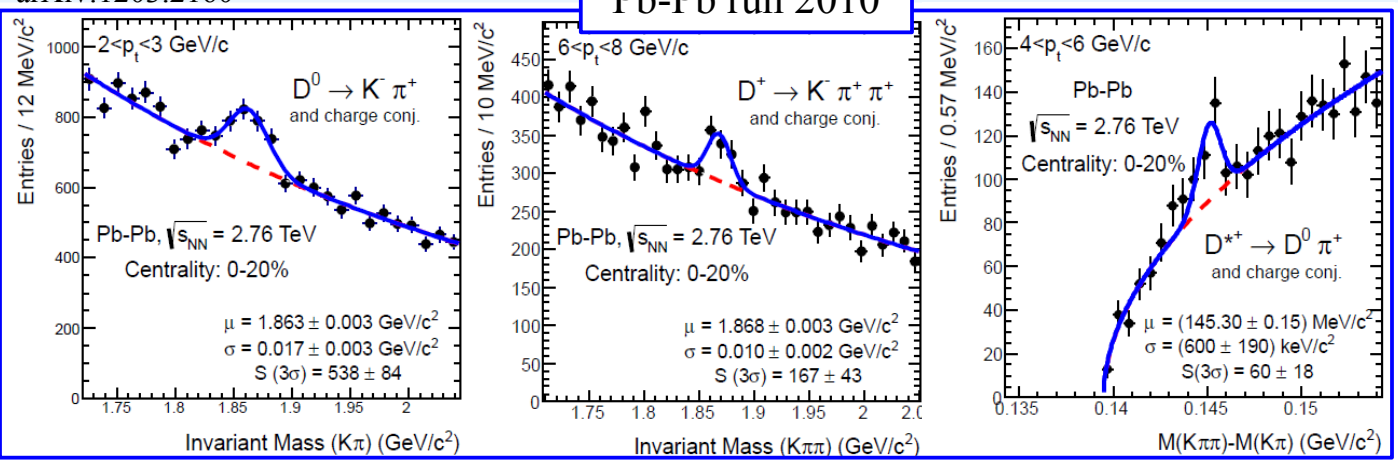
$D^0 \to K^-\pi^+$	$D^+_s \to K^+K^-\pi^+$
$D^+ \to K^-\pi^+\pi^+$	$(\Lambda^+_c \to \pi^+K^-p)$
$D^{*+} \to D^0\pi^+$	$(\Lambda^+_c \to p\bar{K}^0)$
$D^0 \to K^+\pi^-\pi^+\pi^-$	and charge conj.



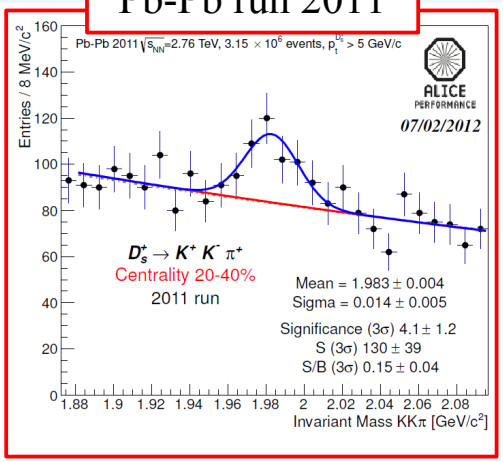
- **Analysis Strategy**
  - Main Selection: displaced-vertices topology
  - Charged Kaon ID in Time-Projection Chamber and Time of Flight system to reduce bkg at low p_T
  - Invariant mass analysis
  - Feed-down from B meson decays corrected with FONLL

arXiv:1203.2160

Pb-Pb run 2010



Pb-Pb run 2011



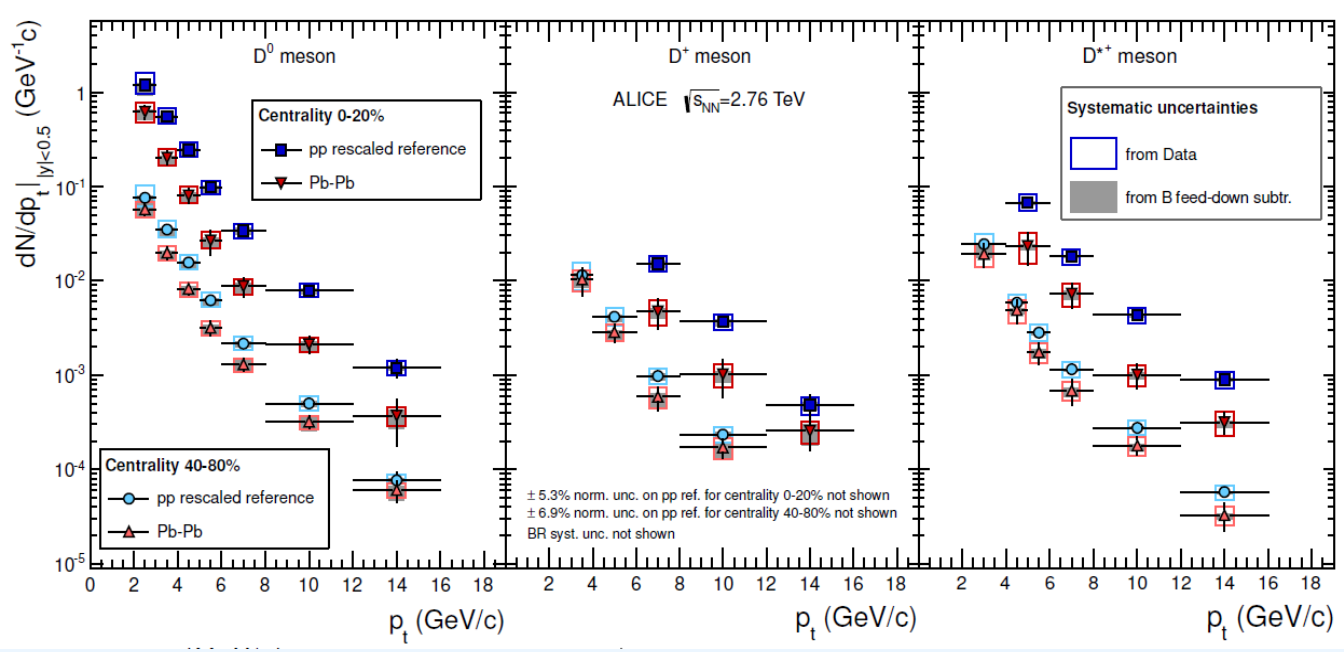
D Meson R_{AA}

- **pp reference at 2.76 TeV: measured 7 TeV spectrum scaled with FONLL**

R. Averbeck et al, arXiv:1107.3243

- Cross-checked against measured result at 2.76 TeV
  (large errors and limited p_t-coverage due to short data taking period)

arXiv:1203.2160, arXiv:1205.4007



pp reference
→ P. Antonioli (4C)

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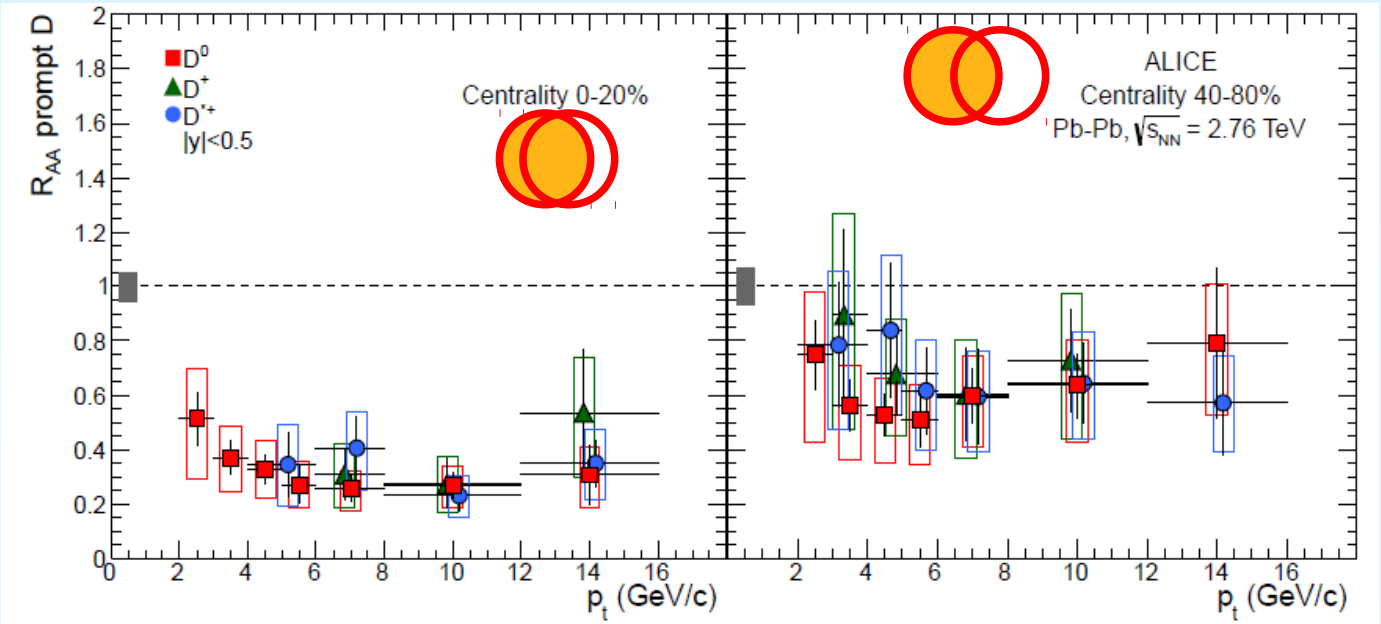


arXiv:1203.2160

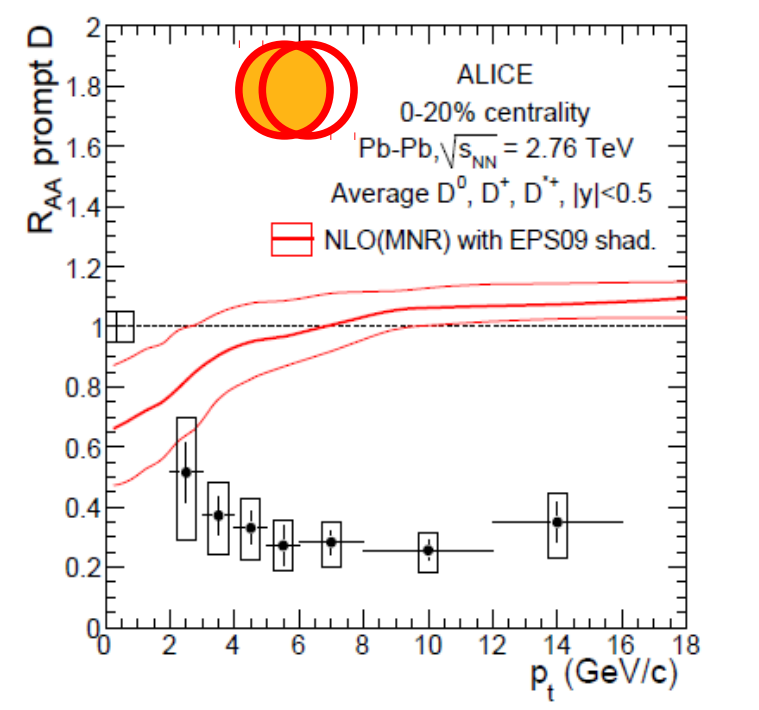
→ Suppression in central collisions: factor 3-4 for p_t > 5 GeV/c

→ Suppression for 40-80% CC: factor 1.5 for p_t > 5 GeV/c

→ Reduce errors with Pb-Pb data from 2011 run:
~factor 6-7 more statistics in 0-7.5% CC

D Meson R_{AA}

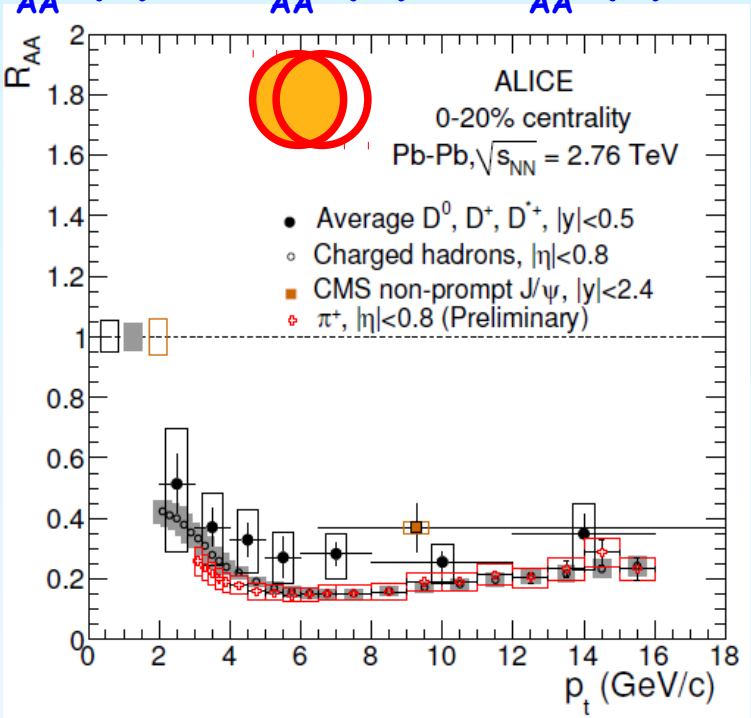
Initial State Effects



- Comparison to NLO + shadowing (EPS09 parametrization)

→ Strong suppression likely to be a final state effect
→ p-Pb measurement end of 2012 will give decisive answer

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

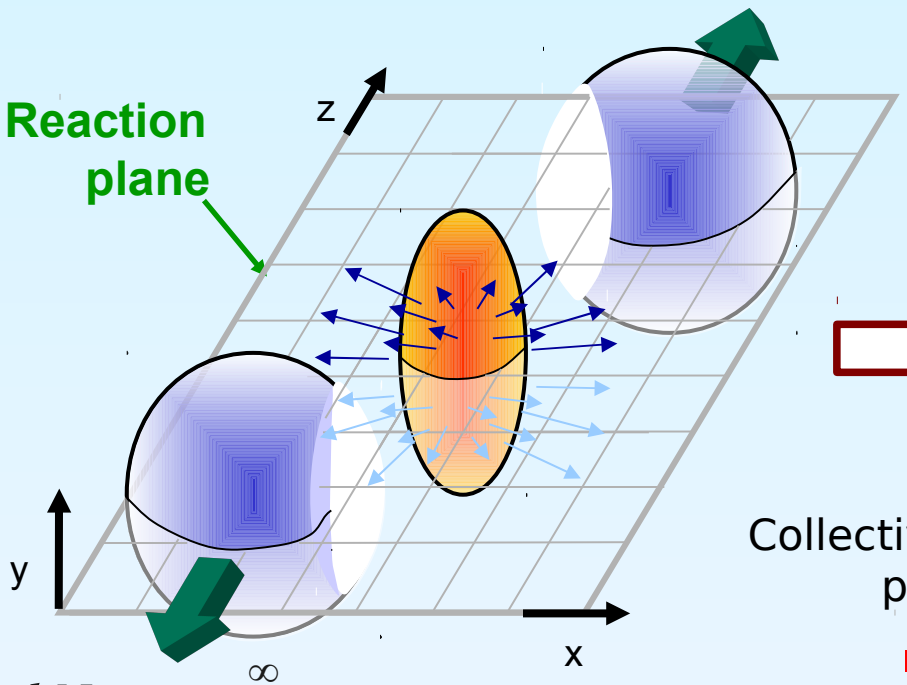


arXiv:1203.2160
arXiv:1201.5069 (CMS)

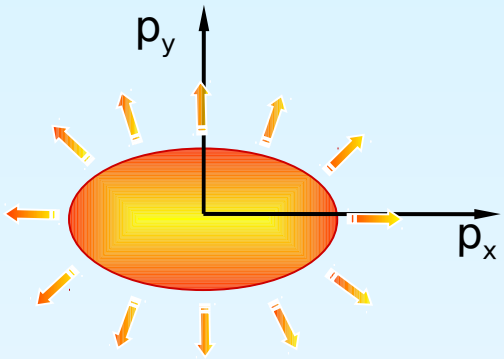
- Preliminary charged π R_{AA} coincides with charged hadron R_{AA} for p_t > 5 GeV/c

→ Hint of R_{AA} (π) < R_{AA} (D)
→ R_{AA} (D) < R_{AA} (B) ? not conclusive - different p_t range
→ Reduce errors (2011 Pb-Pb run)

Collective Effects – Elliptic Flow v_2



Collective interaction pressure



Momentum space: final asymmetry

$$\frac{dN}{d\varphi} \propto 1 + \sum_{n=1}^{\infty} 2v_n(p_T)\cos\left(n\left(\varphi - \Psi_{RP}\right)\right)$$

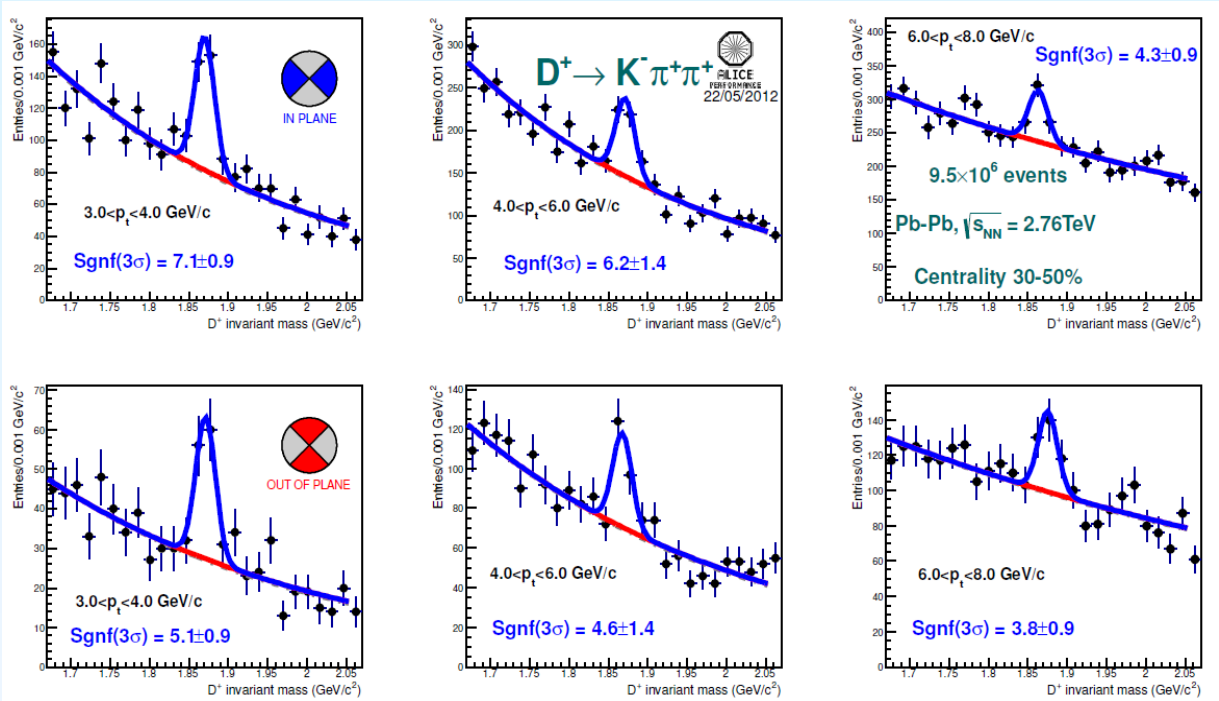
$$v_2 = \left\langle \cos\left(2\left(\varphi - \Psi_{RP}\right)\right)\right\rangle$$

Ψ_{RP} reaction plane angle

φ angle of given particle

- **Anisotropic particle production in-plane and out-of-plane**
- **Evaluation via 2nd Fourier coefficient "v_2"**
- **Charm flow sensitive to**
  - Degree of thermalization of massive quarks in the medium(low p_t)
  - Path length dependence of energy loss (high p_t)

Signal Extraction for D Meson v_2



- **Event plane determination from Q-vector**

$$Q_2 = \begin{pmatrix} \sum_{i-1}^{n} w_i \cos(2\varphi_i) \\ \sum_{i-1}^{n} w_i \cos(2\varphi_i) \end{pmatrix}$$

  - Using tracks in TPC at central rapidity
  - φ_i-weights to improve EP flatness
- **Signal extraction in-plane and out-of-plane**
- **Calculate v_2**

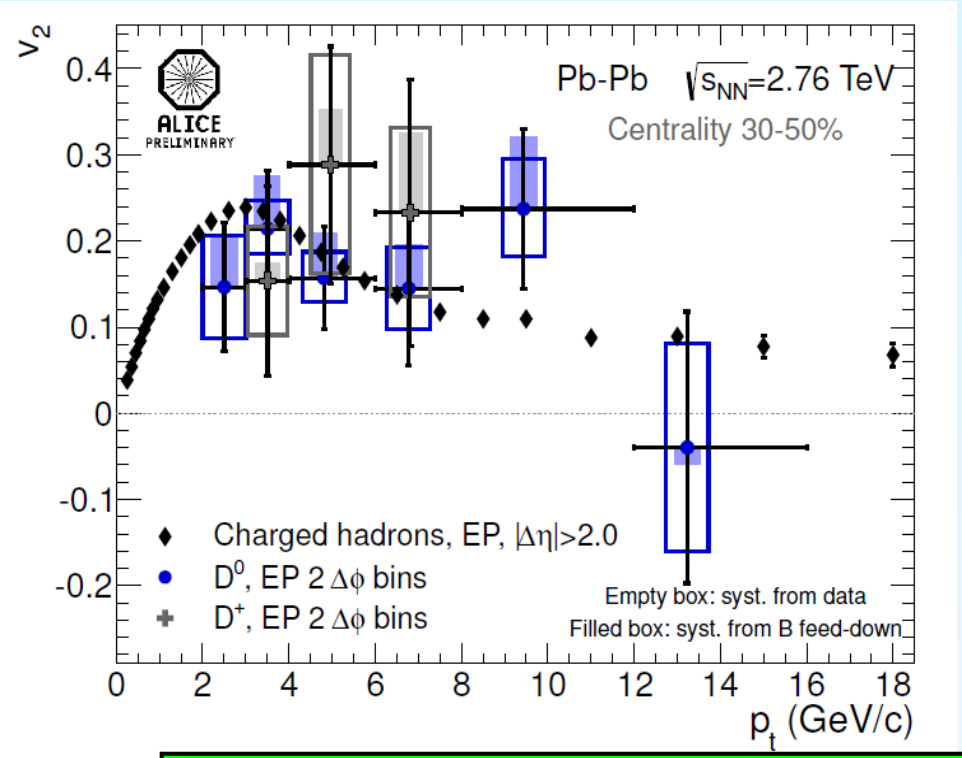
$$v_2 = \frac{\pi}{4} \frac{N_{inp} - N_{outp}}{N_{inp} + N_{outp}}$$

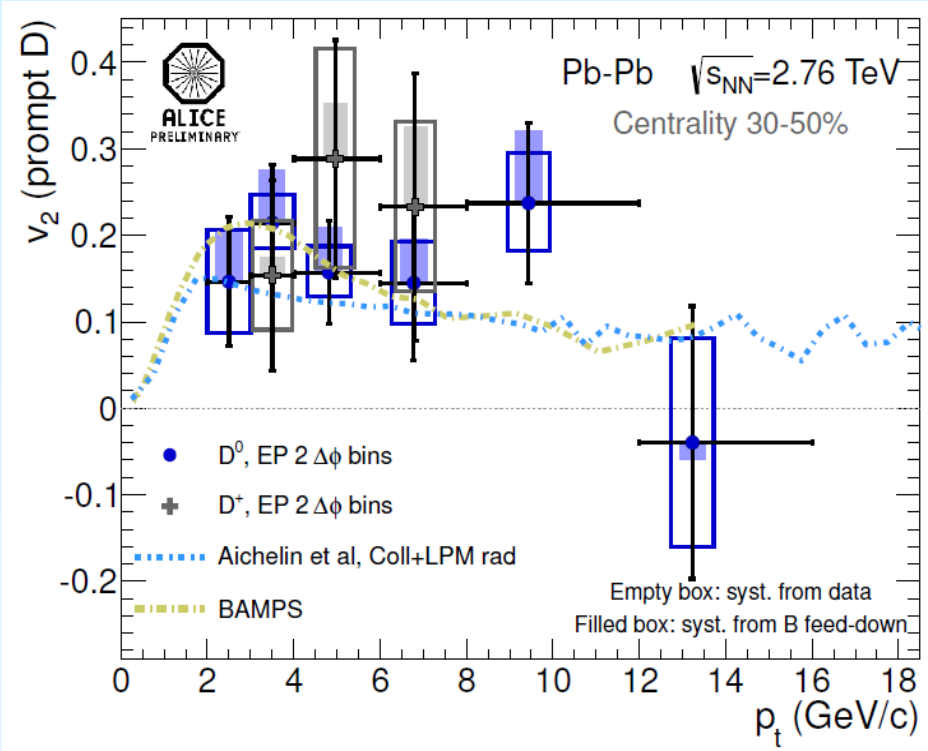
- **Correct for EP resolution**

D^0 and D^+ Meson v_2

in 30-50% Collision Centrality

arXiv:1205.4945 (BAMPS), arXiv:1201.4192 (Aichelin et al.)





- → Indication of non zero v_2
- → 3σ effect in 2-6 GeV/c for D^0
- → D meson v_2 comparable with v_2 of charged hadrons measured with ALICE in the same rapidity region
- → Models based on charm transport in the medium predict a non-zero v_2 of up to 0.15-0.20

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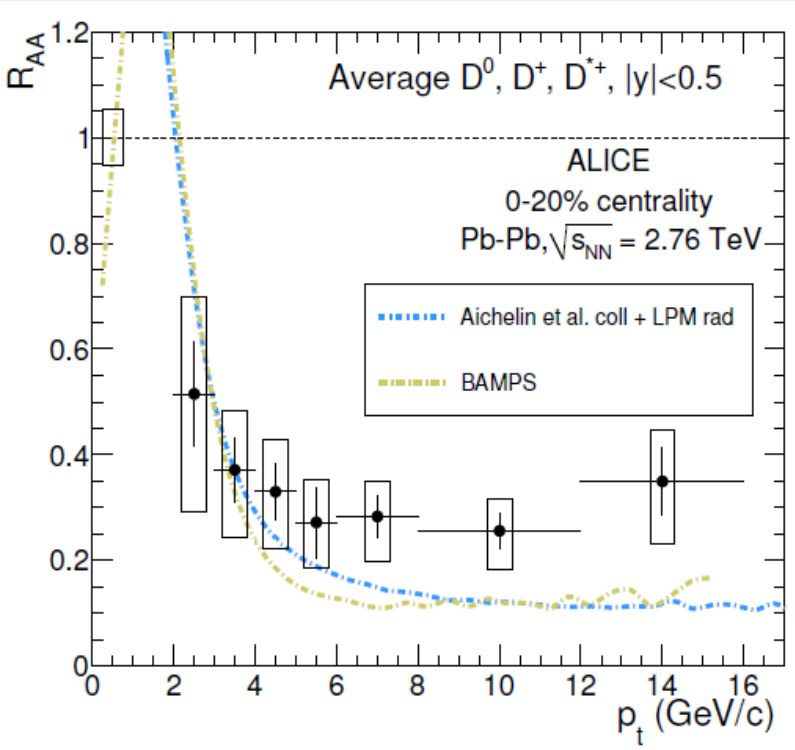

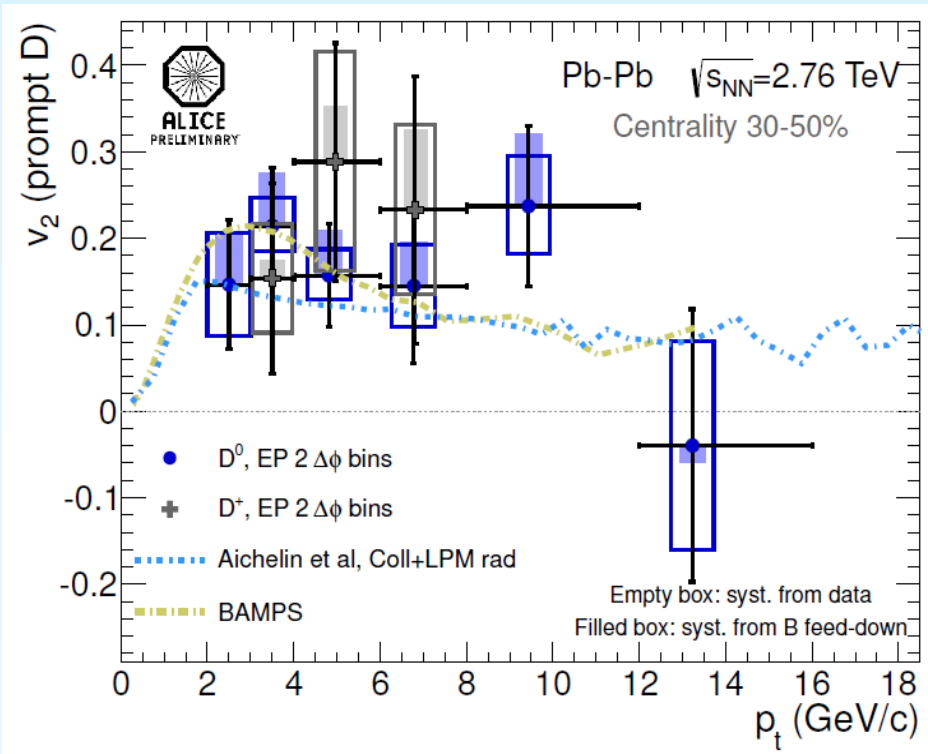

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- → 3σ effect in 2-6 GeV/c for D^0
- → D meson v_2 comparable with v_2 of charged hadrons measured with ALICE in the same rapidity region
- → Models based on charm transport in the medium predict a non-zero v_2 of up to 0.15-0.20, but do not describe well the R_{AA}

Summary and Outlook

- **ALICE has excellent particle identification and vertexing capabilities**
  $\longrightarrow$ Rich harvest of heavy flavour results
  - Nuclear modification factors R_{AA}
    - Measured in several channels, which all show a strong suppression in central collisions
    - Comparison with theoretical models suggests final state effect
    - Possible hint of lower suppression for D than for pions
  - D meson azimuthal anisotropy
    - Indication of non zero v_2
    - Comparable with charged hadron v_2

- **Outlook**
  - Separate charm and beauty contribution
  - Reduction of systematic uncertainties and increase of p_t reach
  - Disentangle initial and final state effects (p-Pb run end of 2012)