

# Yield and suppression of electrons from open heavy-flavour decays in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV



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for the **ALICE** Collaboration



- Introduction
- Analysis strategy
- Charm and beauty production in pp collisions at 7 TeV
- Heavy flavour electrons in Pb-Pb collisions at 2.76 TeV
  - Nuclear modification factor
- Summary and outlook



# Heavy Flavour (Charm & Beauty) Production

- **Heavy-flavour quarks (c, b)**

- $m_c \sim 1.3 \text{ GeV}/c^2$ ,  $m_b \sim 4.7 \text{ GeV}/c^2$

- Originate from initial scattering processes

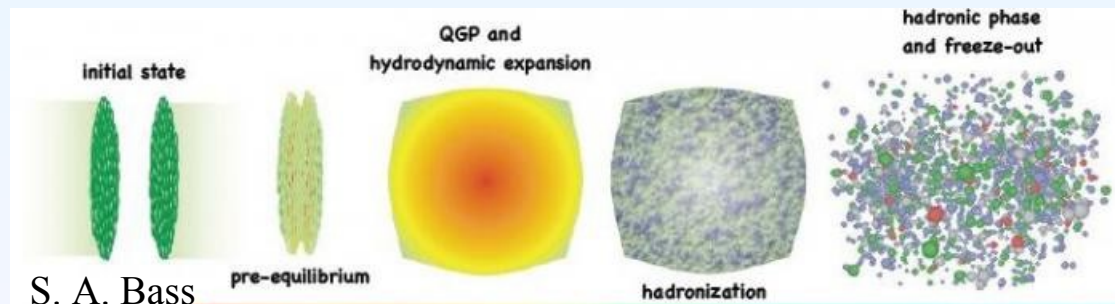
- Produced on a very short time scale ( $\approx 1/(2m_q) \leq 0.1 \text{ fm}/c$ )

→ Sensitive to the full history of the collision

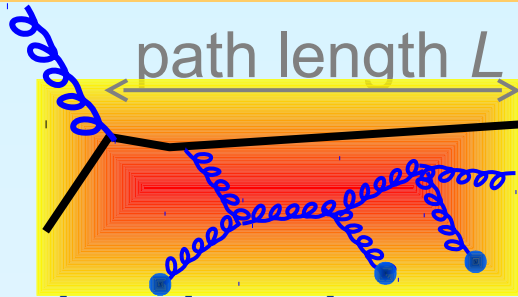
→ Excellent probes to study the de-confined medium produced in nucleus nucleus collisions

- Study flow and energy loss of heavy quark

- Independent way to extract properties of the medium



# Energy Loss in the Medium



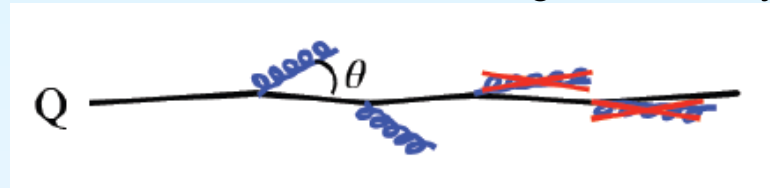
## Color Charge

$C_R = 3$  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:

$$\Delta E_g > \Delta E_{\text{charm}} > \Delta E_{\text{beauty}}$$

$$R_{AA}(\text{light hadrons}) < R_{AA}(D) < R_{AA}(B)$$

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

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

Proton-nucleus collisions: disentangle initial and final state effects

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

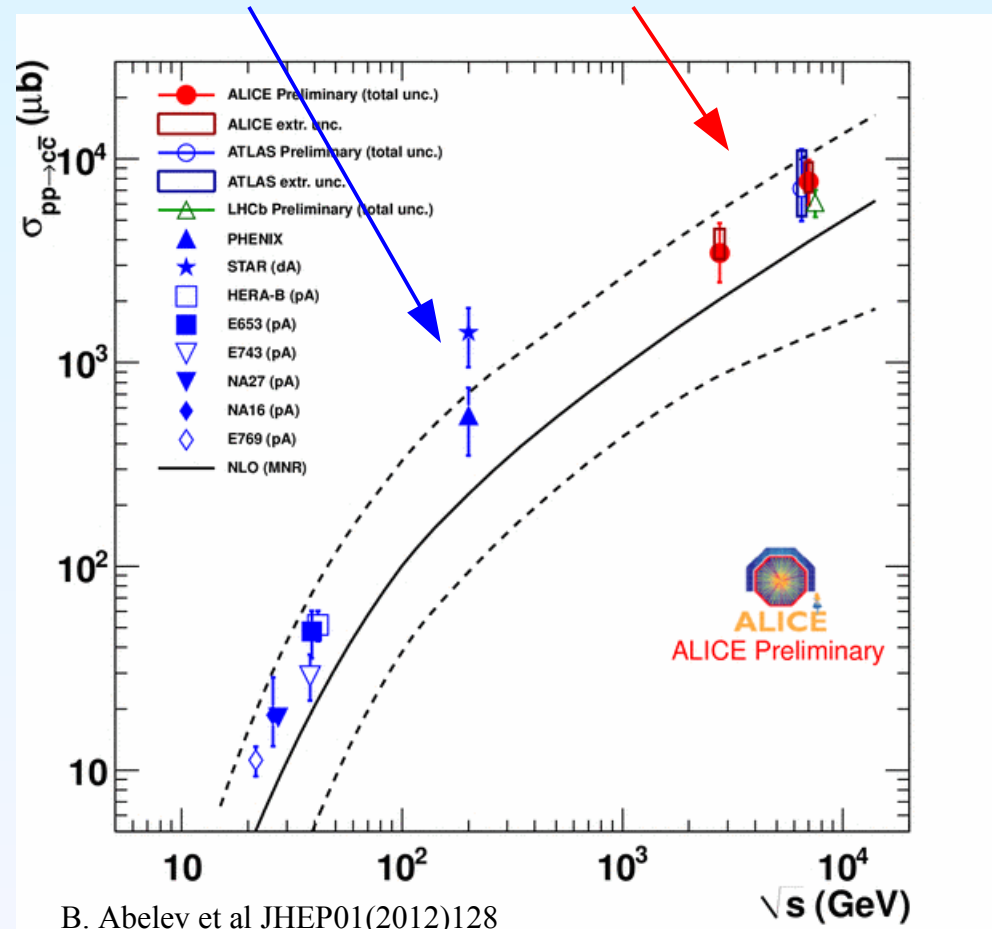
Possible other mechanisms for the interaction with the medium (collisional energy loss, in-medium dissociation, resonance scattering)

# LHC: Heavy Quarks factory



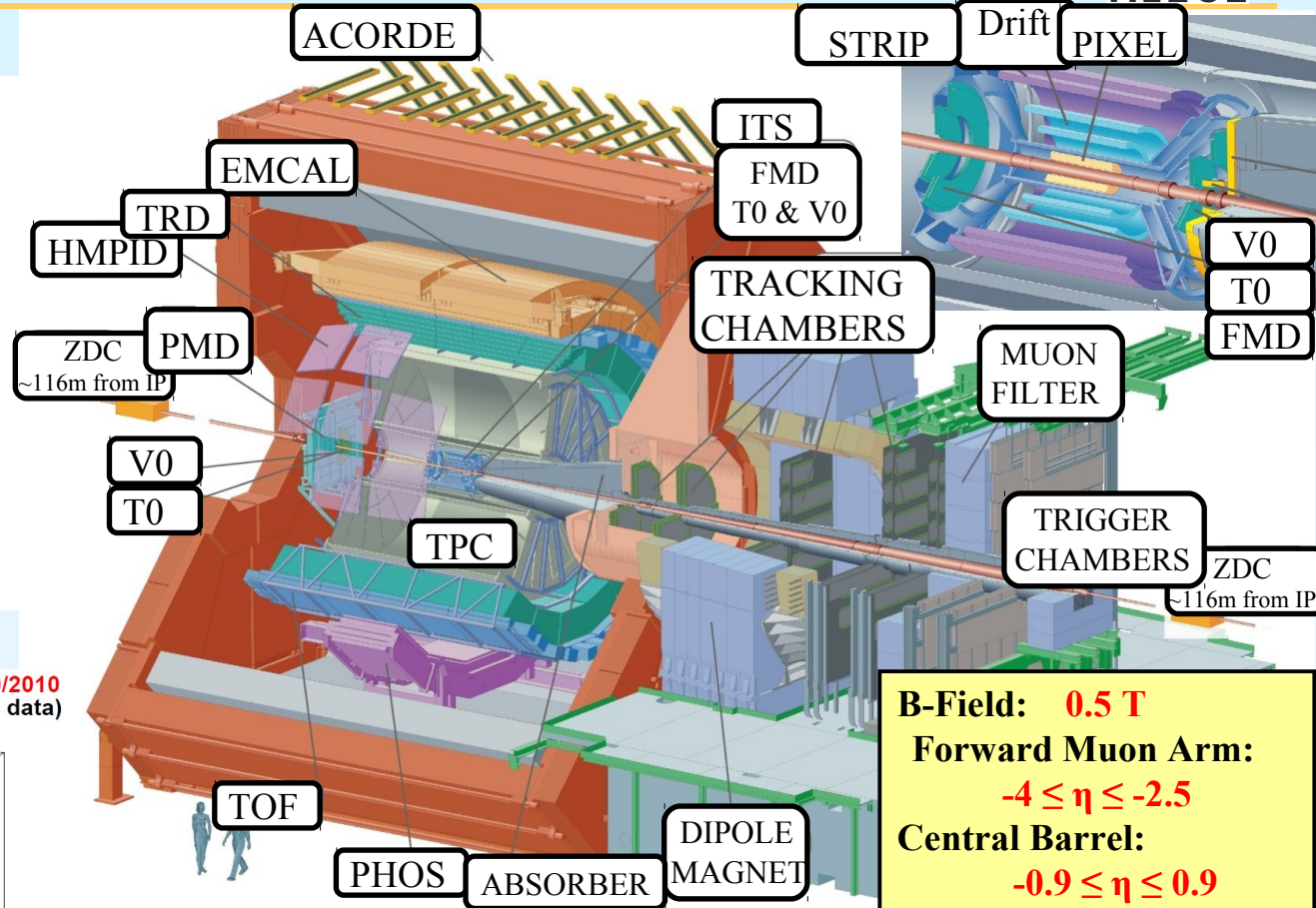
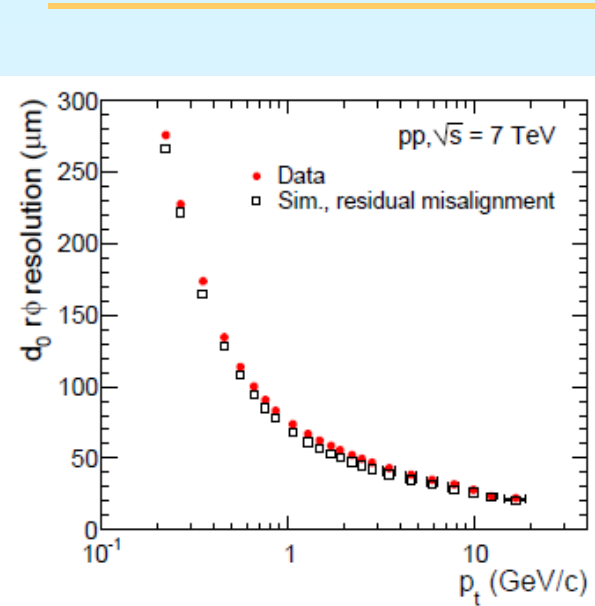
- Heavy quark cross sections much larger than at RHIC energy
- Charm: more than  $\times 5$  from 0.2 (RHIC) to 2.76 TeV (LHC)
- Beauty:  $\times 50-100$  predicted
- Pb-Pb central

System $\sqrt{s}_{NN}$ (TeV)	Pb-Pb (0-5%) 2.76 TeV pairs/event c / b
$\sigma_{NN}^{Q\bar{Q}}$ [mb]	2.1 / 0.075
$N_{tot}^{Q\bar{Q}}$	56 / 2
$C_{shadowing}^{EKS98/EPS08}$	0.60 / 0.85

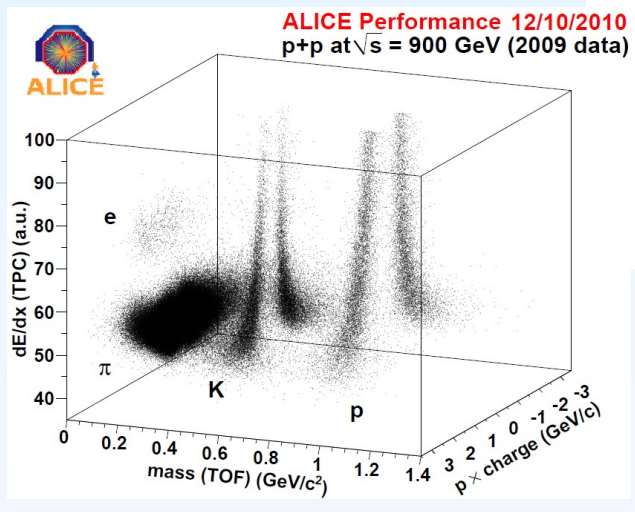


MNR code: Mangano, Nason, Ridolfi, NPB373 (1992) 295. EKS98, EPS08: Eskola et al., EPJC9 (1999) 61; JHEP07 (2008) 102

# A Large Ion Collider Experiment



**B-Field: 0.5 T**  
**Forward Muon Arm:**  
 $-4 \leq \eta \leq -2.5$   
**Central Barrel:**  
 $-0.9 \leq \eta \leq 0.9$



→ Transverse impact parameter resolution  
 $< 75(20) \mu\text{m}$  for  $p_T > 1(20) \text{ GeV/c}$

→ Momentum resolution  $< 2\%$  for  $p < 20 \text{ GeV/c}$

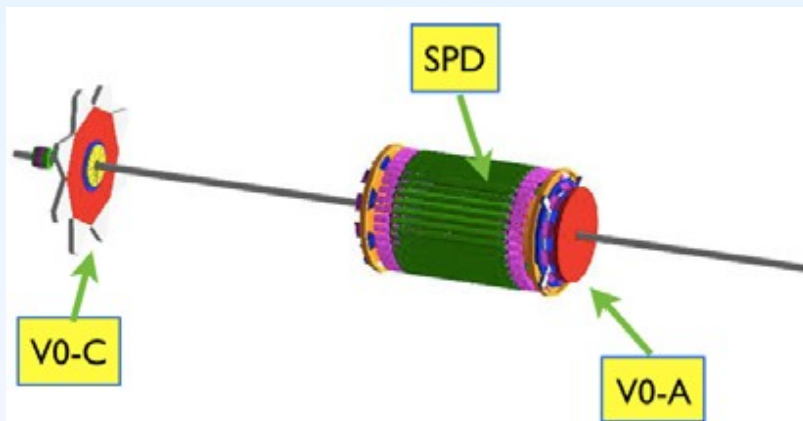
→ Particle identification with various systems

# Data Sets and Trigger Description for the presented results

System	pp (2010)	Pb-Pb (2010)
$\sqrt{s}$ (TeV)	7	2.76
$N_{\text{events}}$	~180 M	17 M

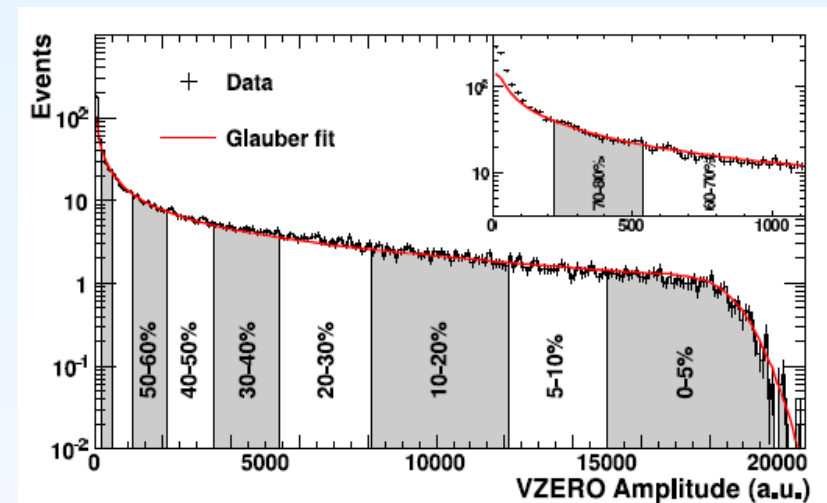
## ■ pp collisions

- minimum bias (MB) trigger:  
V0-A or V0-C or SPD  
(V0: scintillator arrays,  
SPD: silicon pixel detector)



## ■ Pb-Pb collisions

- MB trigger—V0-A and V0-C and SPD
- Collision centrality from Glauber fit to V0 signal



Phys. Rev. Lett. 106 (2011) 032301

# Measuring Heavy Flavours

- **Hadronic decay channels:**  $D^0 \rightarrow K\pi$ ,  $D^* \rightarrow D^0\pi$ ,  $D^{*+} \rightarrow K\pi\pi$

→ D. Caffarri

- **Semi-leptonic channels**

- **$c \rightarrow e + X$**

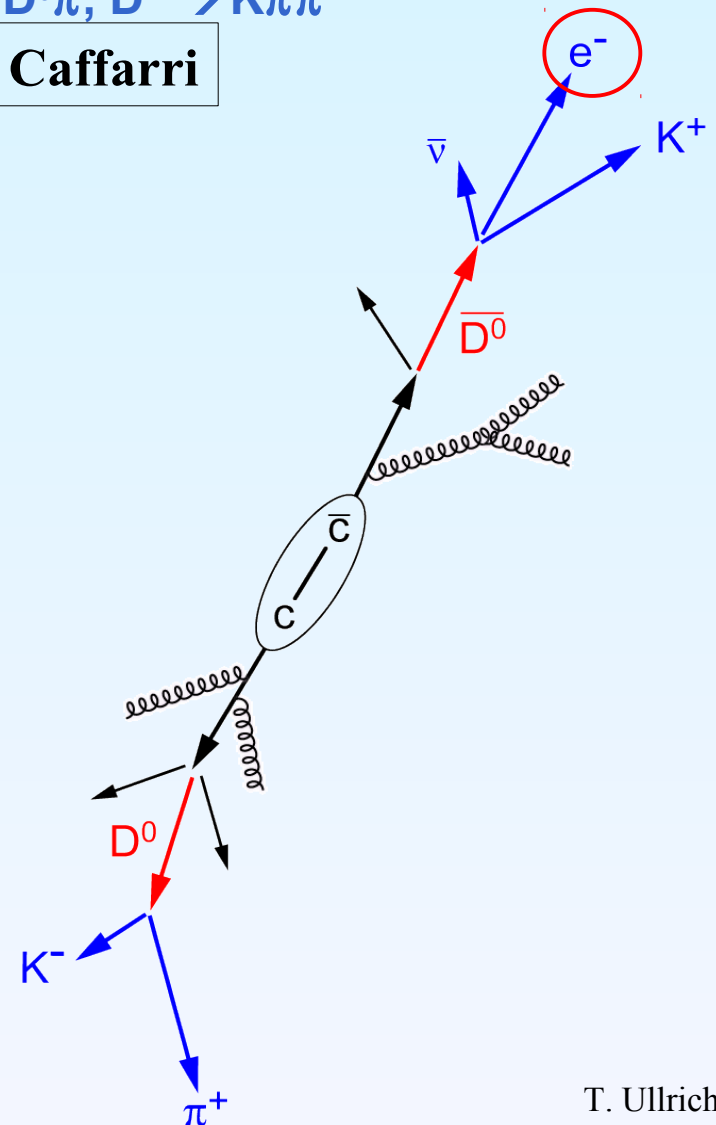
- $D^0 \rightarrow e^+ + X$  (B.R.: 6,49%)
- $D^\pm \rightarrow e^\pm + X$  (B.R.: 16,07%)

- **$b \rightarrow e + X$**

- $B^\pm \rightarrow e^\pm + X$  (B.R.: 10,99%)  
plus:  $B \rightarrow D \rightarrow e^\pm + X$  ( $\sim 10\%$ )

- **Background electrons**

- $\gamma$  conversion in detector material  
( $\pi^0 \rightarrow \gamma\gamma$ ,  $\gamma \rightarrow e^+e^-$ )
- $\pi^0$ ,  $\eta$ ,  $\eta'$  Dalitz decays
- $\rho$ ,  $\omega$ ,  $\phi$  and  $K_{e3}$  decays
- $J/\psi$  and  $Y$  decays
- Drell-Yan and prompt photons



# Electron Identification

## ■ Time of Flight (TOF)

- $\pm 3\sigma$  cut on electron hypothesis
- Suppression of kaons up to  $p = 1.5$  GeV/c and protons up to  $p = 3$  GeV/c

## ■ Transition Radiation Detector (TRD)

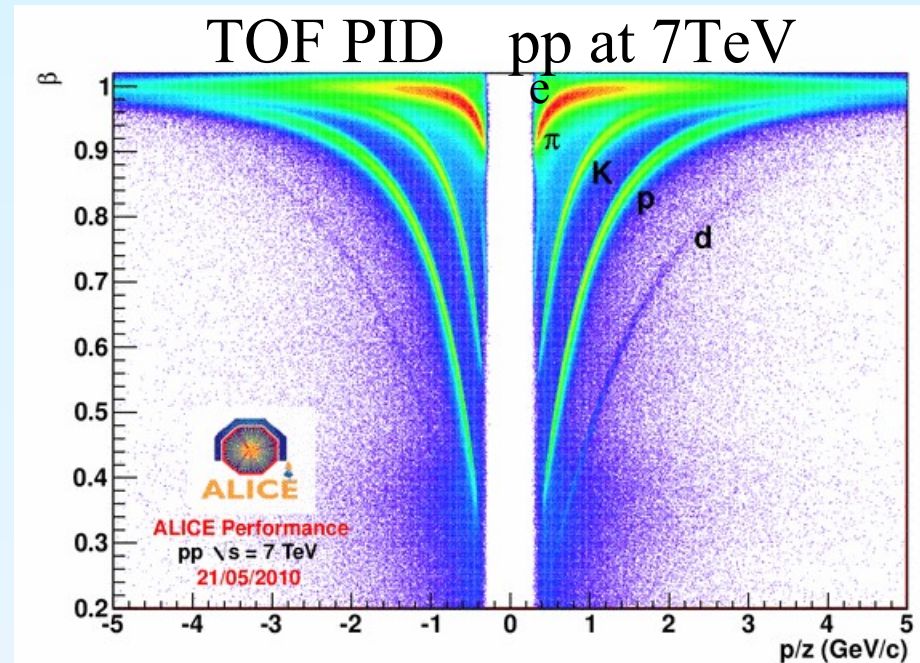
- Electron likelihood cut at 80 % electron efficiency
- Pion rejection

## ■ Time Projection Chamber (TPC)

- Select tracks in the upper half of the electron Bethe-Bloch band ( $0-3\sigma$ )
- Hadron rejection (especially pions  $p < 6$  GeV/c)

## ■ ElectroMagnetic Calorimeter (EMCal)

- TPC-EMCal matching,  $E/p$  cuts
- Hadron rejection



## Detectors used for PID

- pp: TOF+TRD+TPC
- Pb-Pb: TOF+TPC



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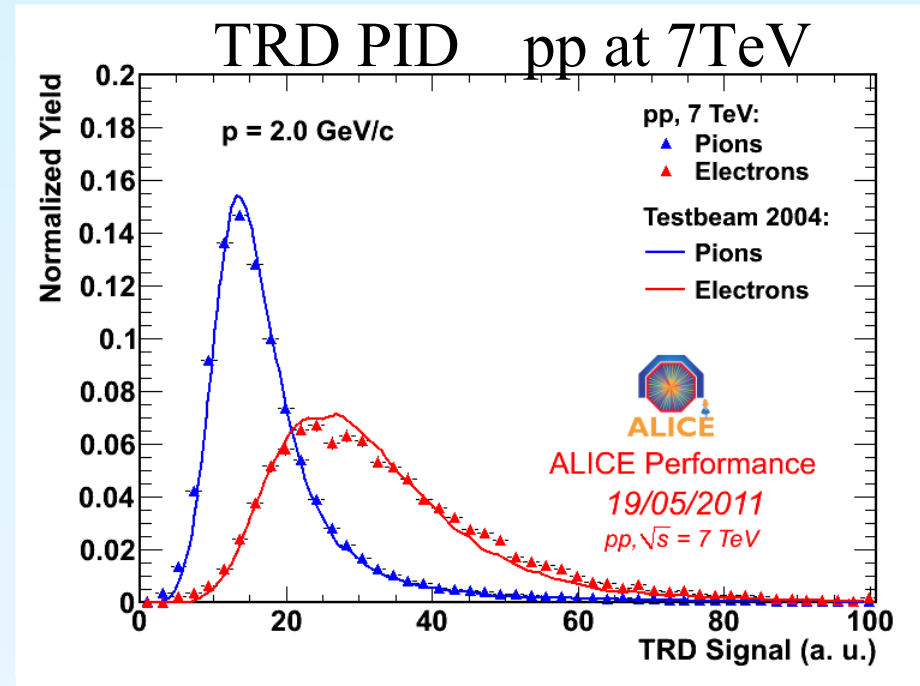
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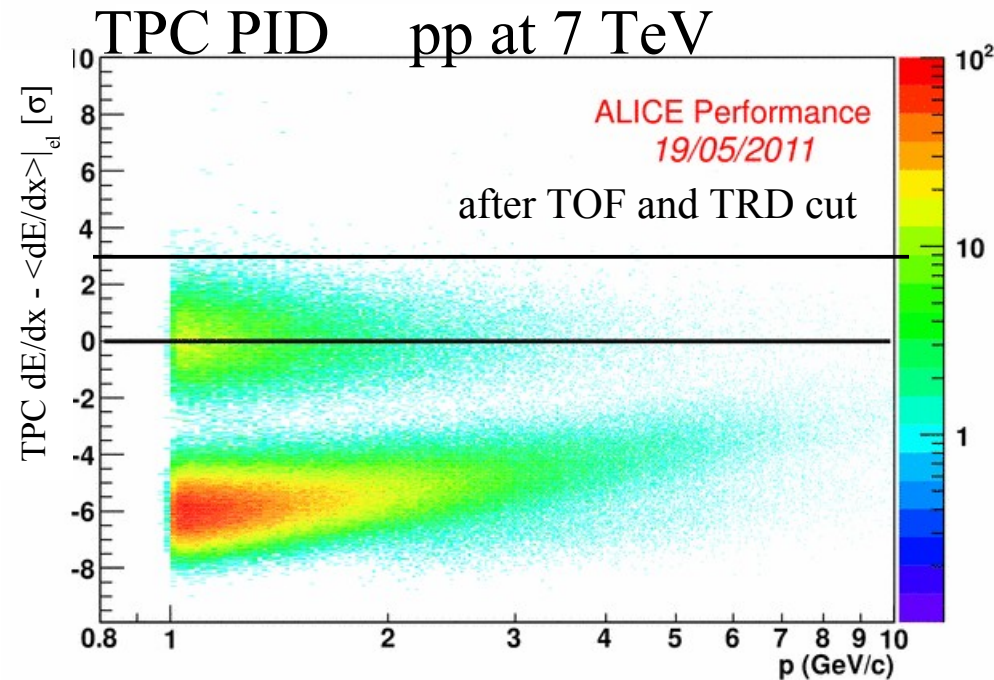
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## Detectors used for PID

- pp: TOF+TRD+TPC
- Pb-Pb: TOF+TPC

# Remaining Hadron Contamination



- Multiple Gaussian fit in momentum slices of the TPC  $dE/dx$  distribution

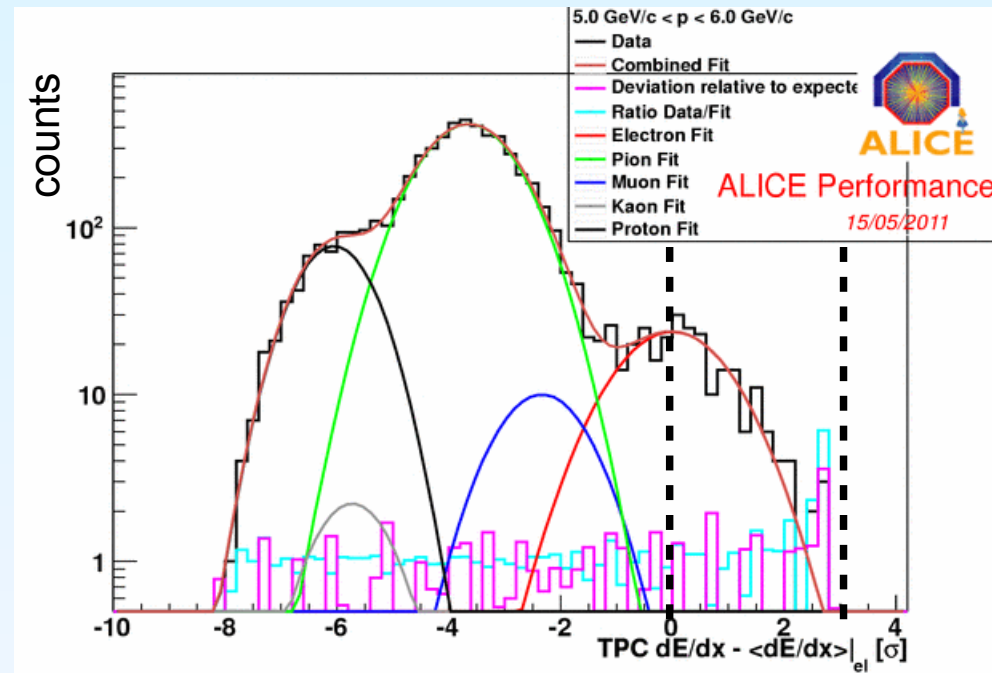
- **Hadron Contamination**

- pp:  $0.5 < p_T < 10$  GeV/c

less than 5% hadron contamination

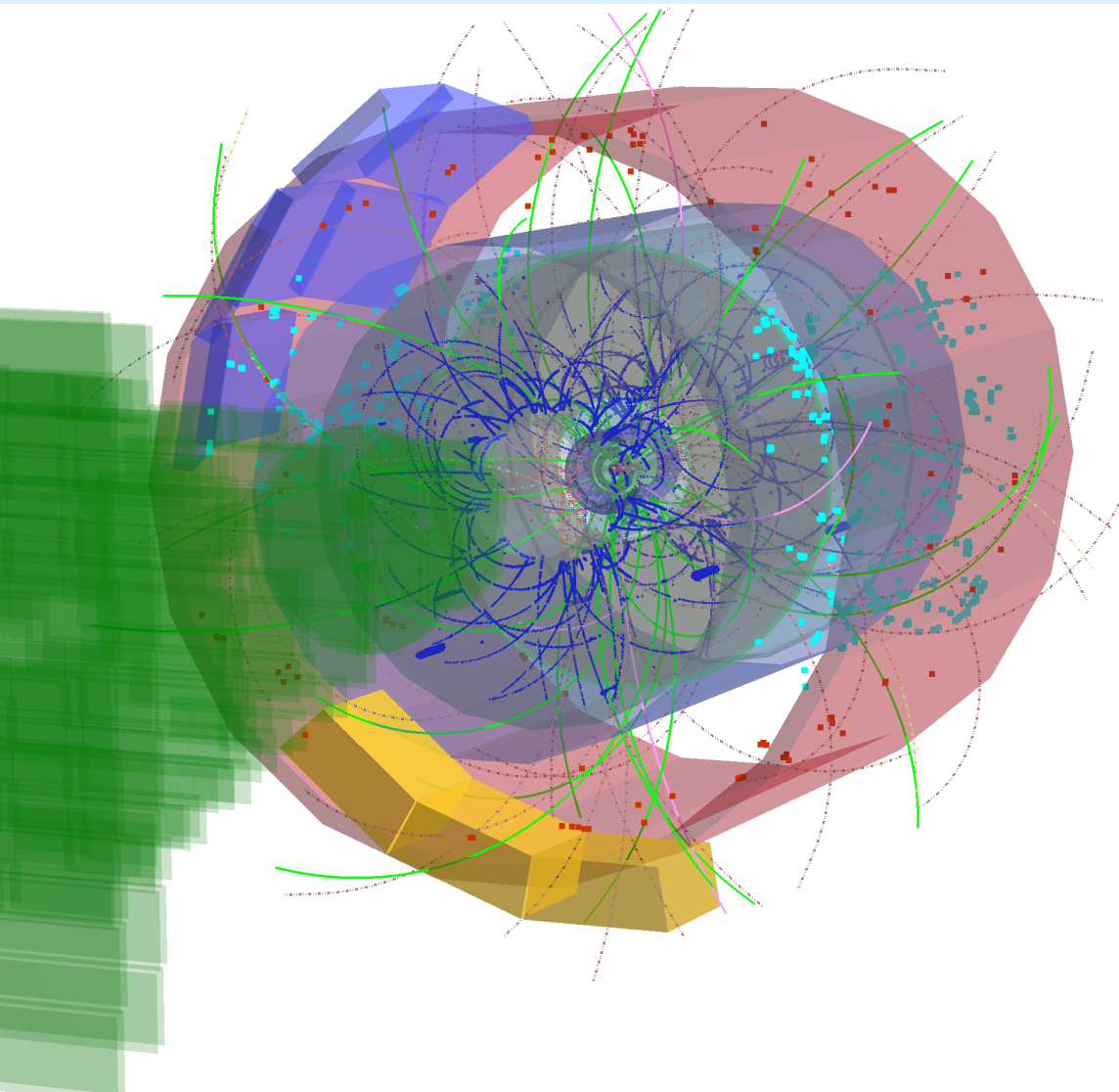
- Pb-Pb:  $1.5 < p_T < 6$  GeV/c

less than 10% hadron contamination



→ **yield is subtracted from the electron spectrum**

# Results in pp at 7 TeV

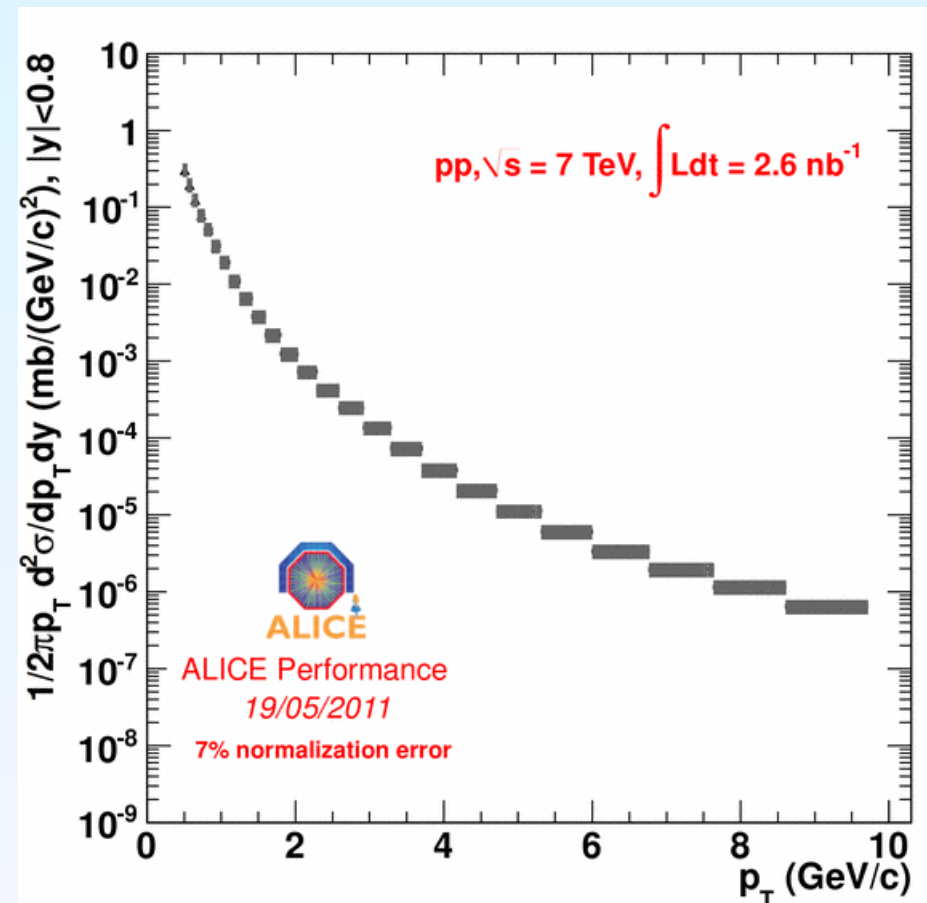
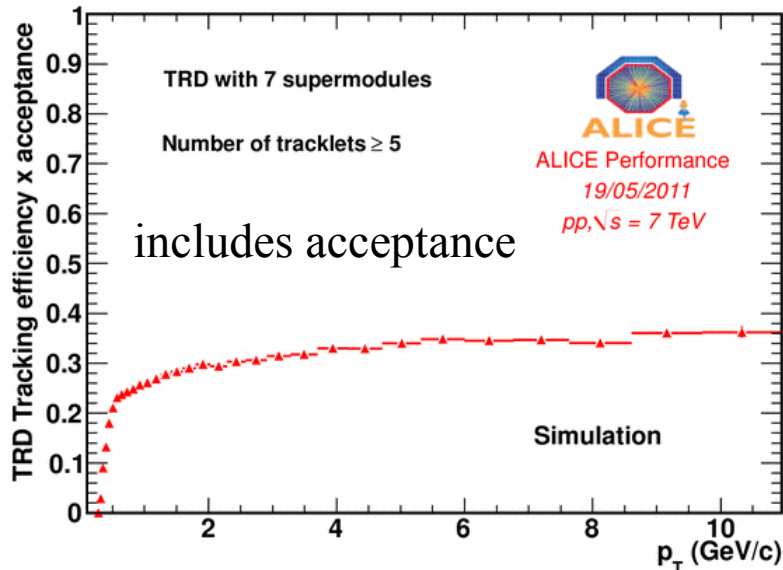


## Minimum Bias Data taken

System $\sqrt{s}$ (TeV)	pp 7
when	2010
$N_{\text{events}}$	$\sim 180$ M

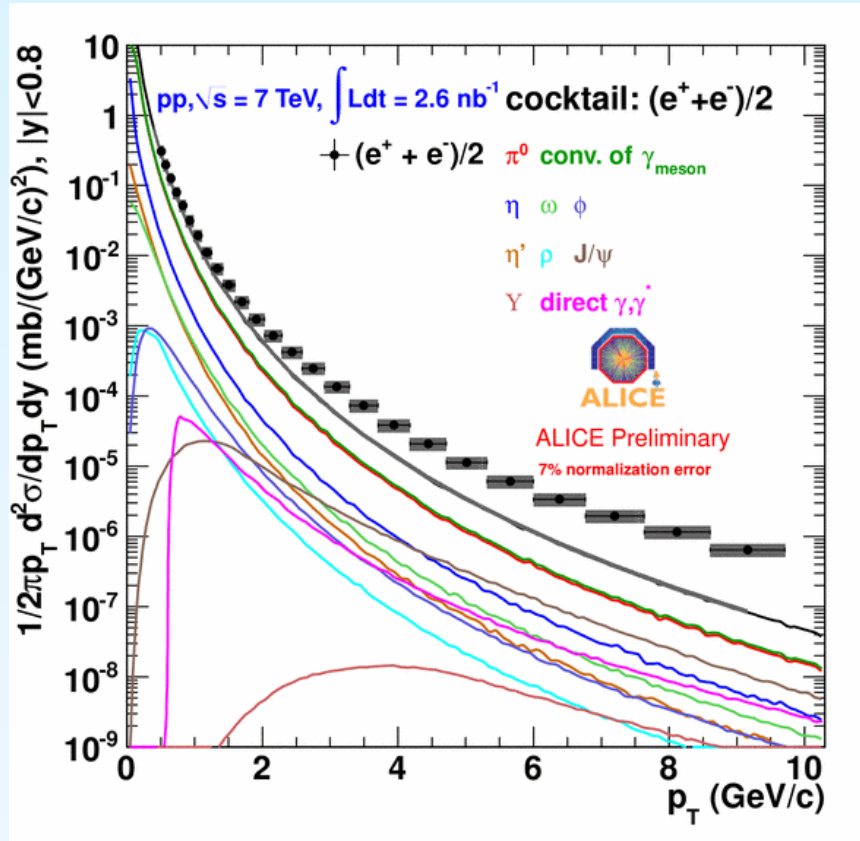
# Inclusive Electron Spectrum

- **Electron identification**
  - TOF+TPC+TRD
  - Remaining hadron contamination subtracted
- **Efficiency and acceptance corrected**
- **Converted to cross-section with VdM results**
- **Systematic uncertainty:  $\pm 20\%$**



# Comparison with Cocktail

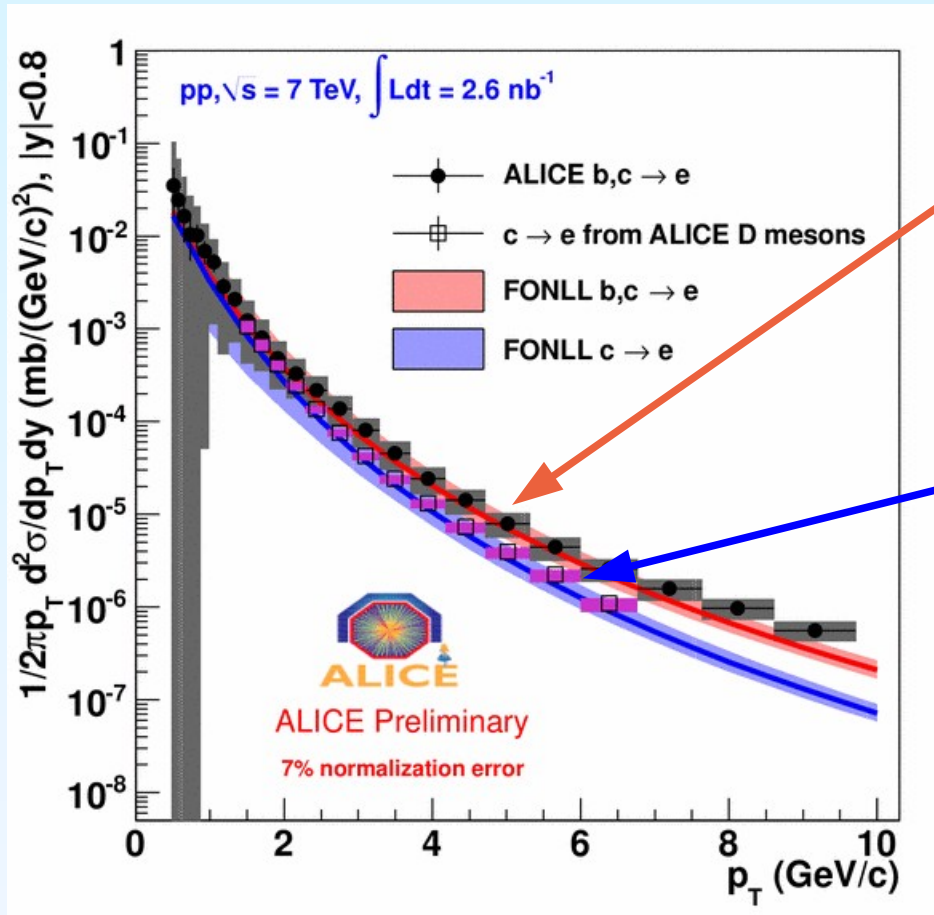
**Method: inclusive – cocktail = electrons from heavy flavour hadron decays (charm and beauty)**



Increasing S/B ratio with increasing momentum

- **Cocktail of known background electrons**
  - $\gamma$  conversion in detector material ( $\pi^0 \rightarrow \gamma\gamma, \gamma \rightarrow e^+e^-$ )
  - $\pi^0, \eta, \eta'$  Dalitz decays
  - $\rho, \omega, \phi$  decays
  - $J/\psi$  and  $Y$  decays
  - QCD photons based on NLO calculations (W. Vogelsang)
- $\pi^0$  input: measurement with ALICE
- Heavier mesons:  $m_T$  scaling
- $J/\psi$  and  $Y$ : measurement with ALICE and CMS
- Ratio Conversions/Dalitz: from known material budget
- Systematic uncertainty:  $\pm 20\%$

# Electrons from Semi-electronic c/b Decays



Inclusive electrons - cocktail  
 =  
 $D, B \rightarrow e + X$

ALICE D meson measurement  
 (hadronic decay)  
 + PYTHIA decay kinematics  
 $\Rightarrow D \rightarrow e + X$

FONLL: M. Cacciari et al JHEP 9805 (1998) 007  
 M. Cacciari et al JHEP 0103 (2001) 006

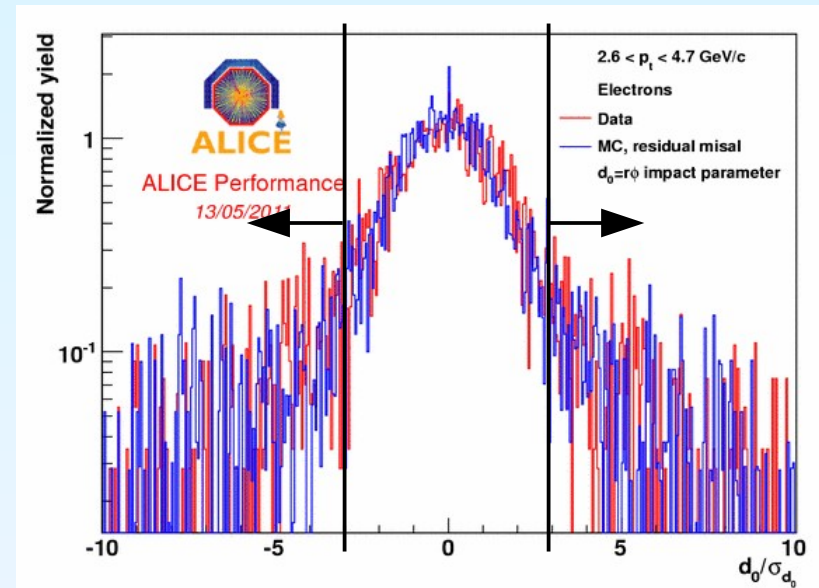
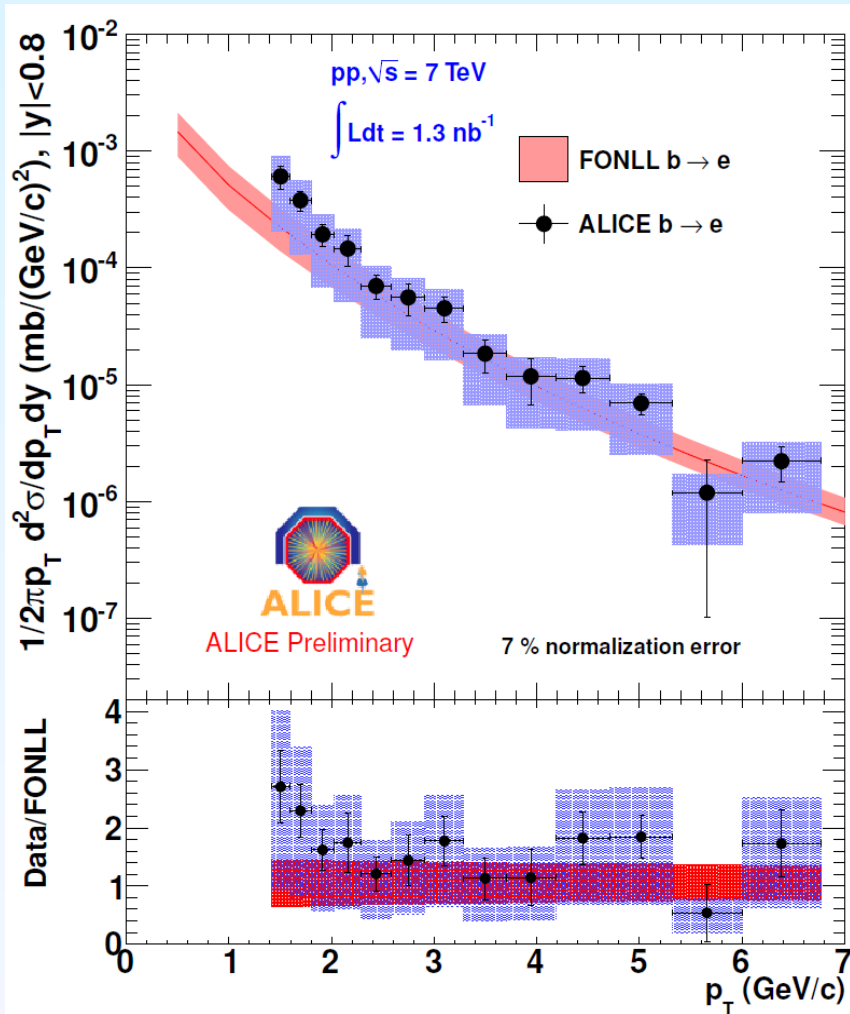
→ FONLL b + c in agreement with data  
 → Consistent with prompt charm measurement from D mesons  
 in the low  $p_T$ -region, where charm dominates

# Beauty Decay Electrons

## $B \rightarrow e + X$

- Large b mass and  $c\tau$  of 500  $\mu\text{m}$

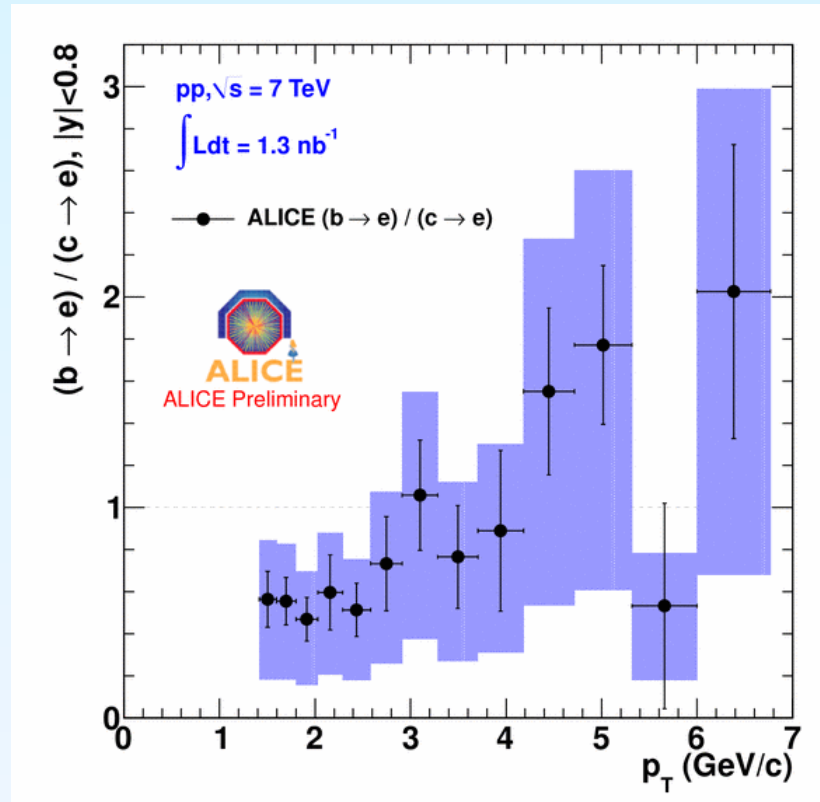
→ Analysis Strategy: selection of electrons from displaced vertex



→ FONLL in agreement with data  
 → Available as reference for AA

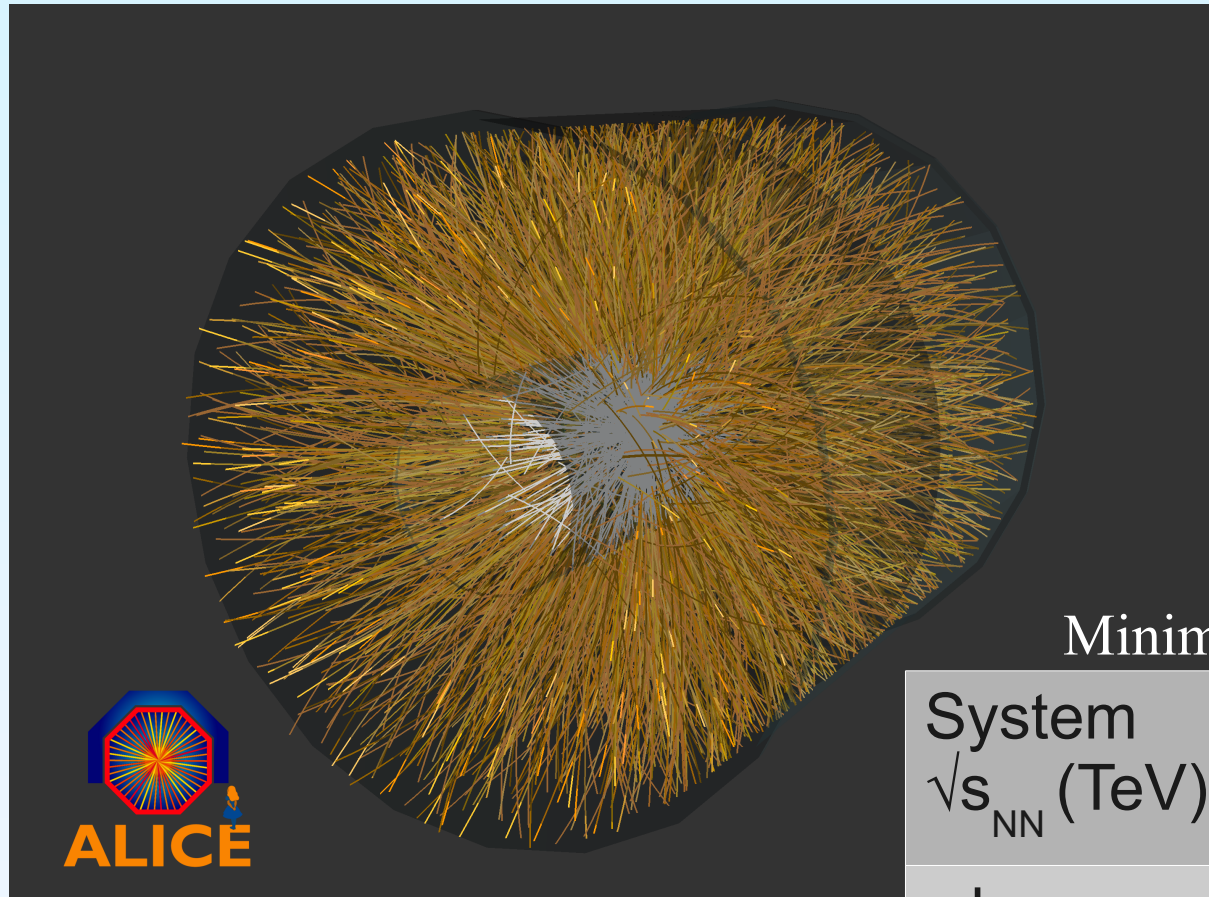


# Electrons from Beauty relative to Electrons from Charm



$\rightarrow$  b/c ratio increases with  $p_T$

# Results in Pb-Pb at 2.76 TeV

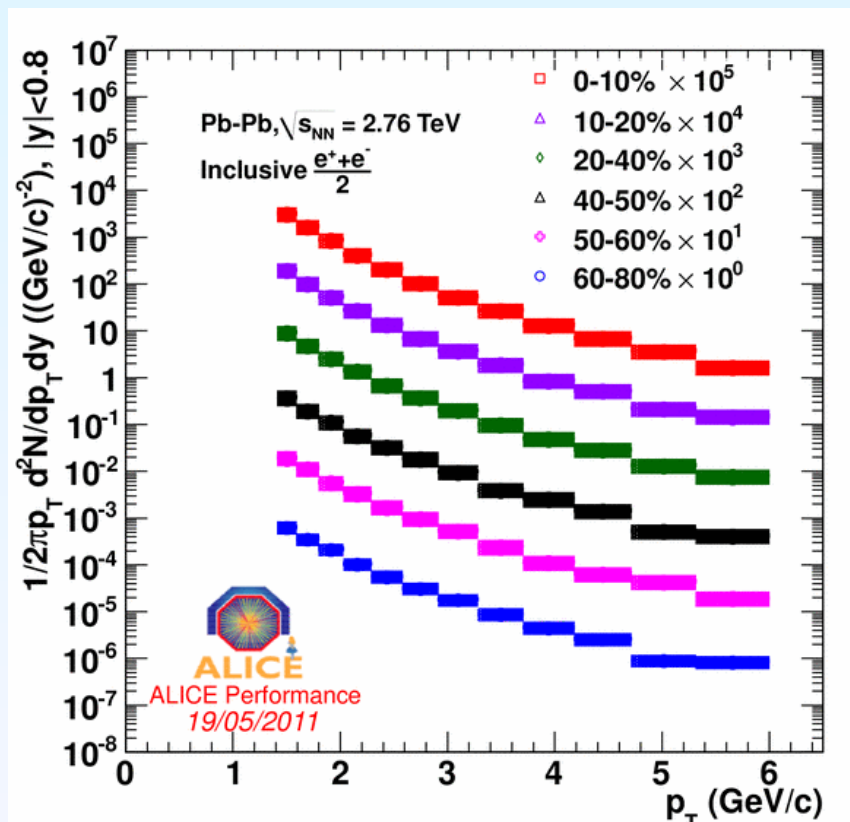


Minimum Bias Data taken

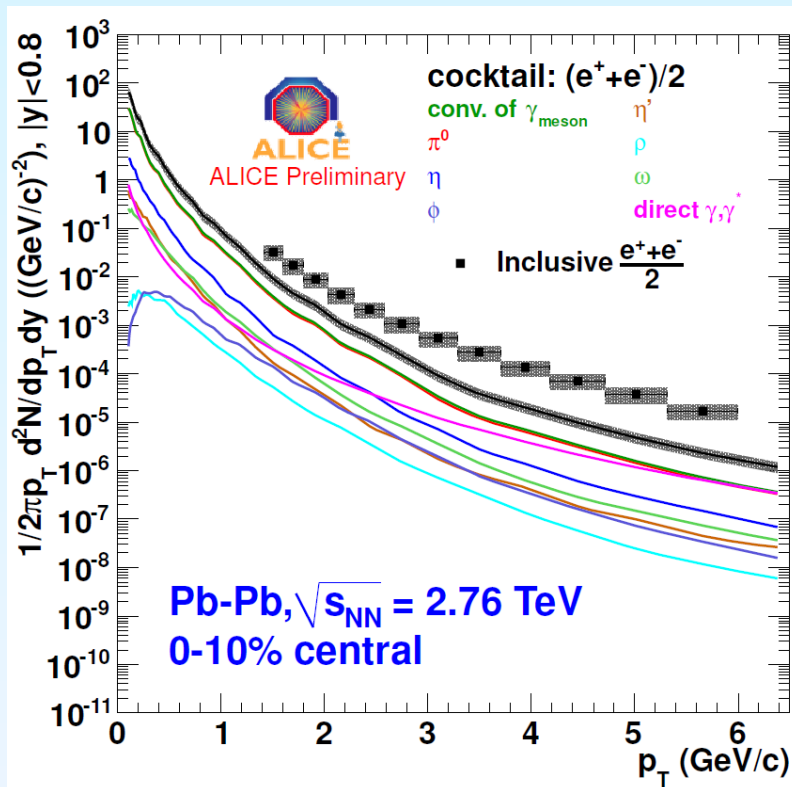
System $\sqrt{s_{NN}}$ (TeV)	Pb-Pb 2.76
when	November 2010
$N_{\text{events}}$	17 M

# Inclusive Electron Spectra

- Analogous analysis scheme as in pp
  - PID: TOF + TPC
  - Centrality dependent
  - Systematic uncertainty:  $\pm 35\%$  (dominated by PID)



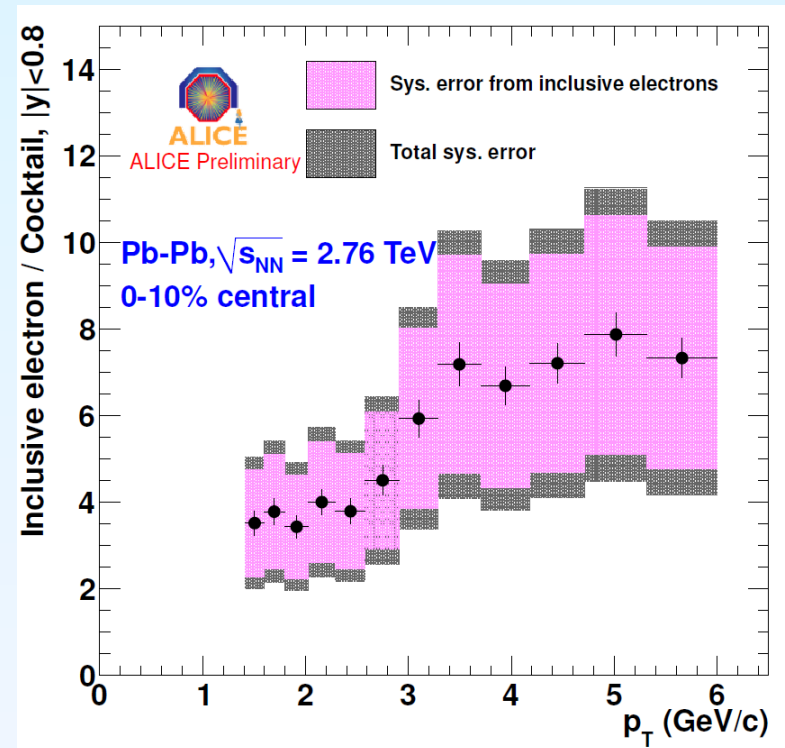
# Comparison with Cocktail



## ■ Cocktail of known background electrons

- Centrality dependent
- $\pi^0$  input: charged pion measurement with ALICE
- Systematic uncertainty:  $\pm 25\%$

## Pb-Pb 0-10%

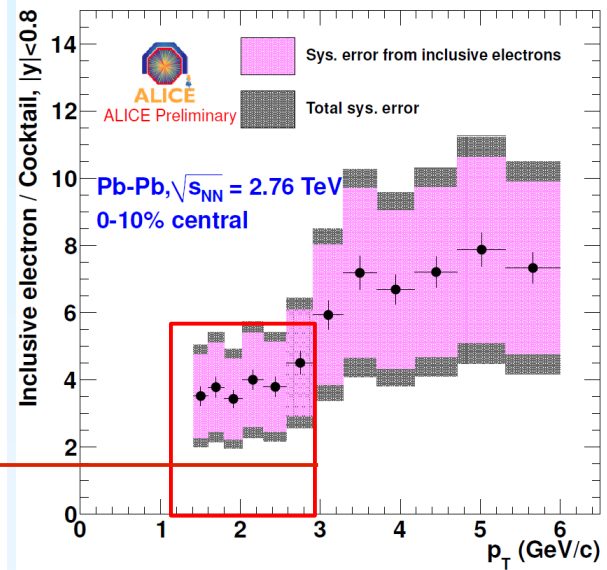
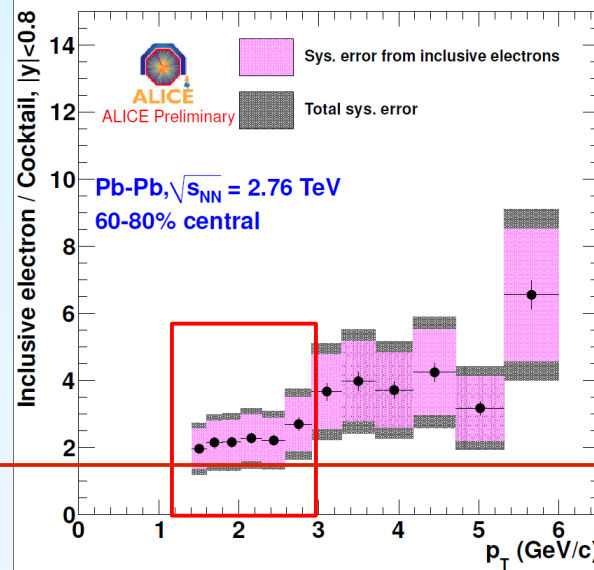
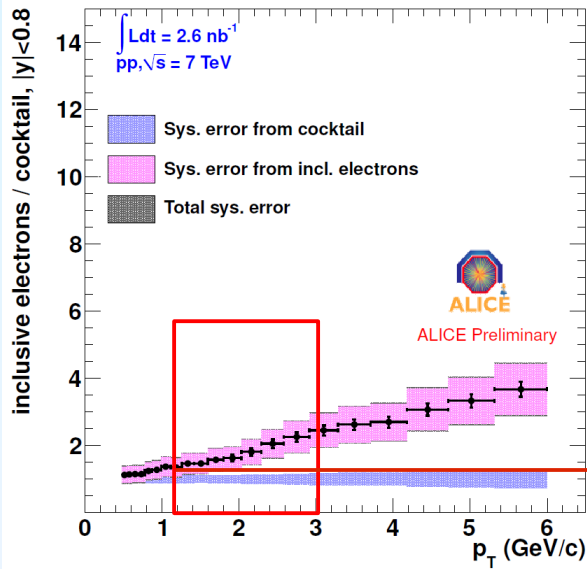
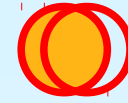
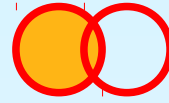


# pp, Pb-Pb peripheral and Pb-Pb central

pp 7 TeV

Pb-Pb 60-80%

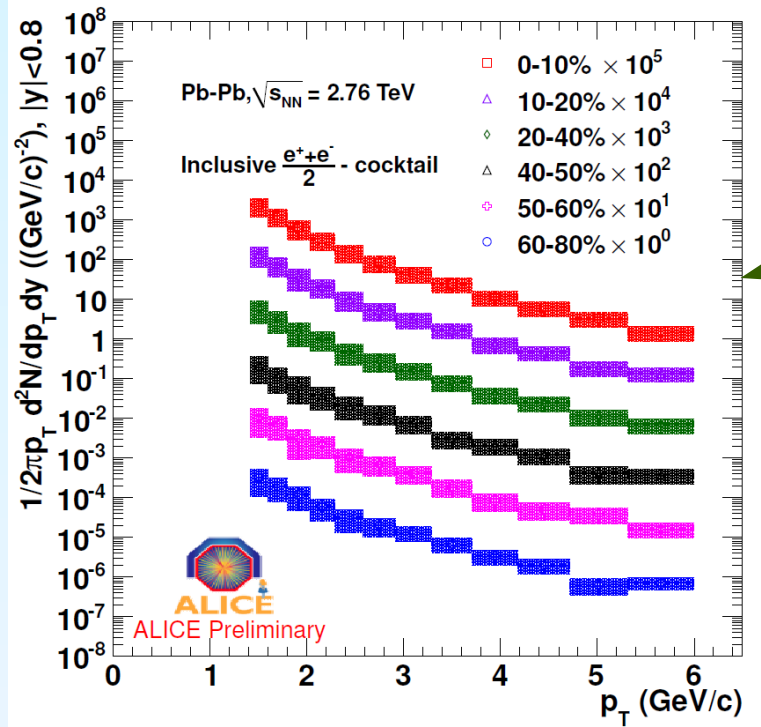
Pb-Pb 0-10%



- Hint of an excess at low  $p_T$  increasing with centrality
- Additional electron source?
  - Thermal charm production ???
  - Thermal Radiation?  
(cfr. PHENIX, PRL104 132301 (2010))

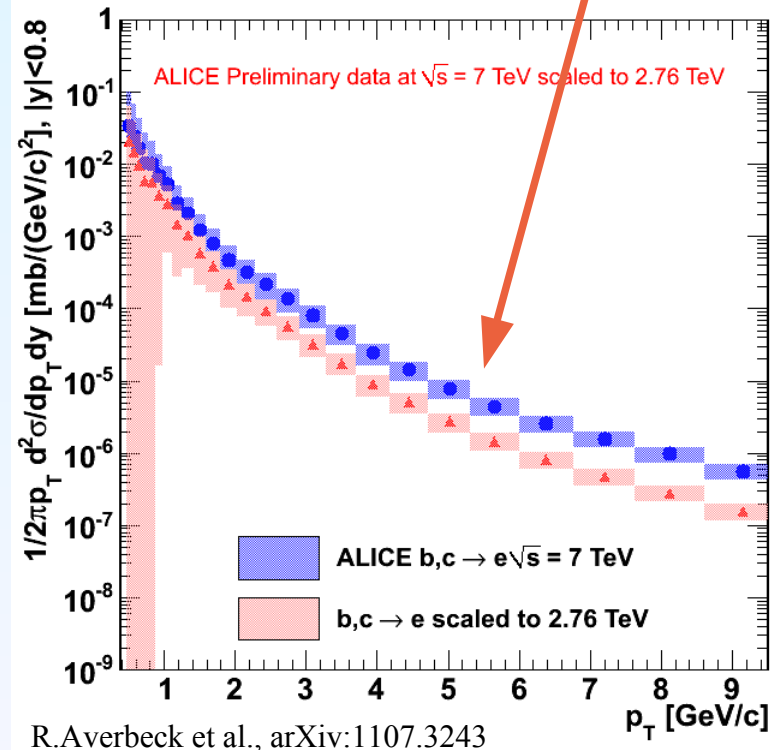
$p_T$  region 3.5-6 GeV/c:  
charm and beauty decays dominate

# Nuclear Modification Factor - the Ingredients -



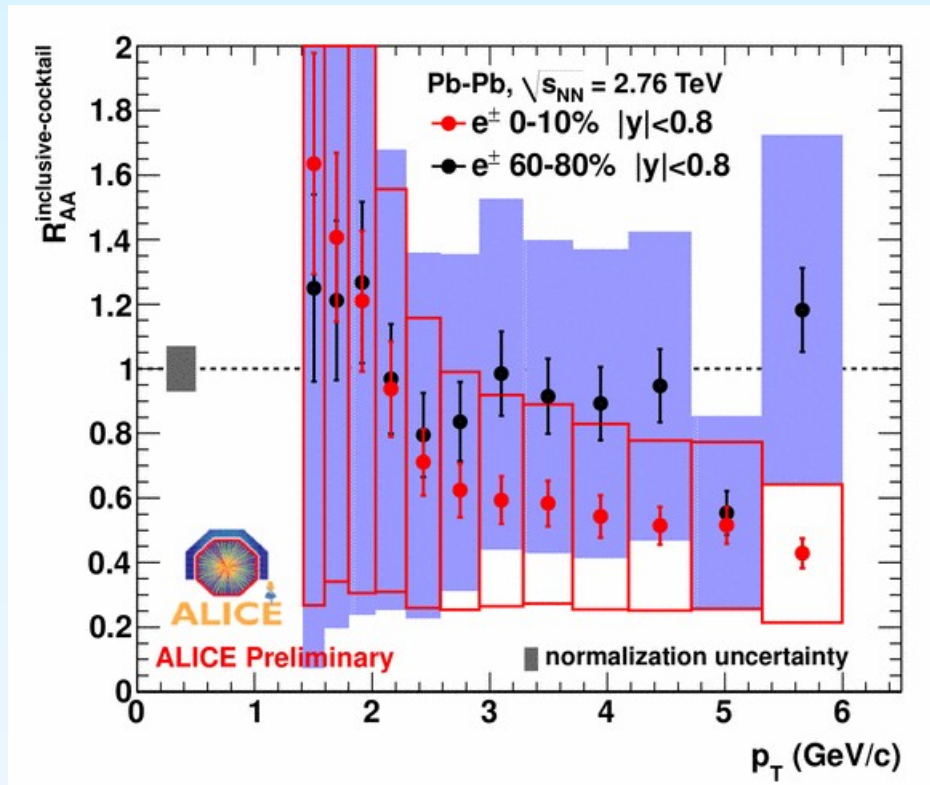
$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \times \frac{dN_{AA} / dp_T}{d\sigma_{pp} / dp_T}$$

calculated based on Glauber Model

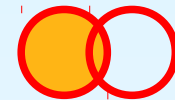


- **pp reference at 2.76 TeV**
  - 7 TeV spectrum scaled with FONLL
  - Same scaling function for electrons from charm and beauty decays
  - Uncertainties:  $\sim 10\%$  at  $p_T > 2$  GeV/c
  - Analysis of pp data at 2.76 TeV in progress  
→ will provide direct reference

# Cocktail-subtracted Electron $R_{AA}$



60-80%



0-10%

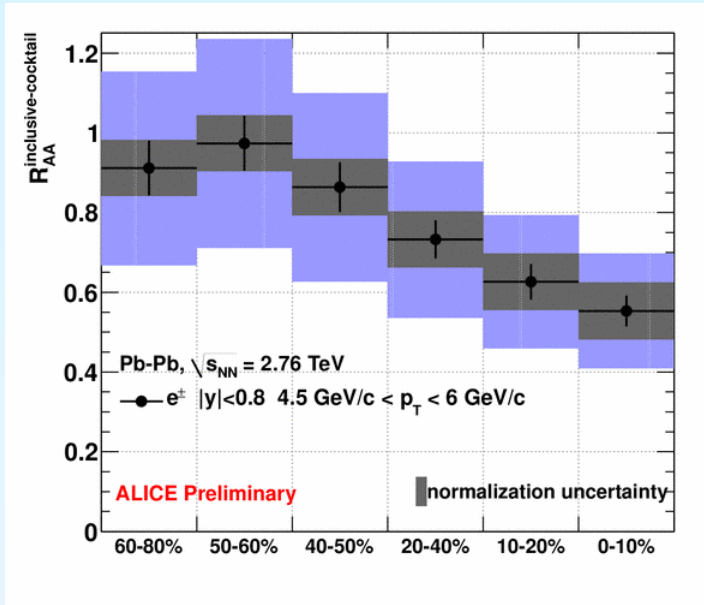


- $p_T$  region 3.5-6 GeV/c: charm and beauty decays dominate
- Suppression in **central** collisions: Factor 1.5-4
- Soon: reduction of systematic uncertainty

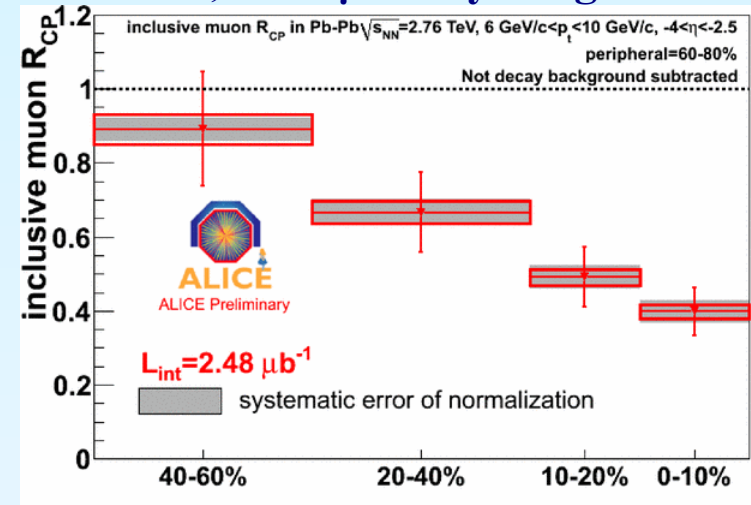
# Open Heavy Flavour Suppression



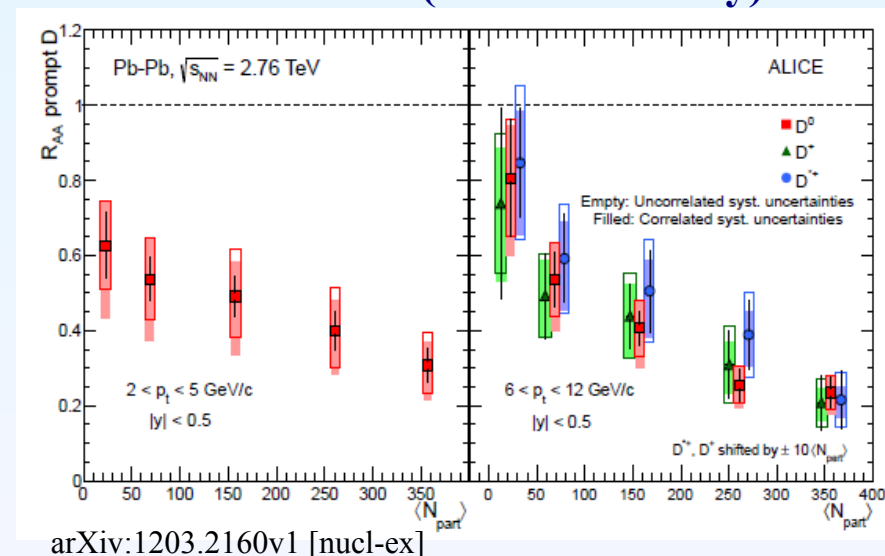
## D, B $\rightarrow$ e + anything



## D, B $\rightarrow$ $\mu$ + anything



## D<sup>0</sup> mesons (hadronic decay)

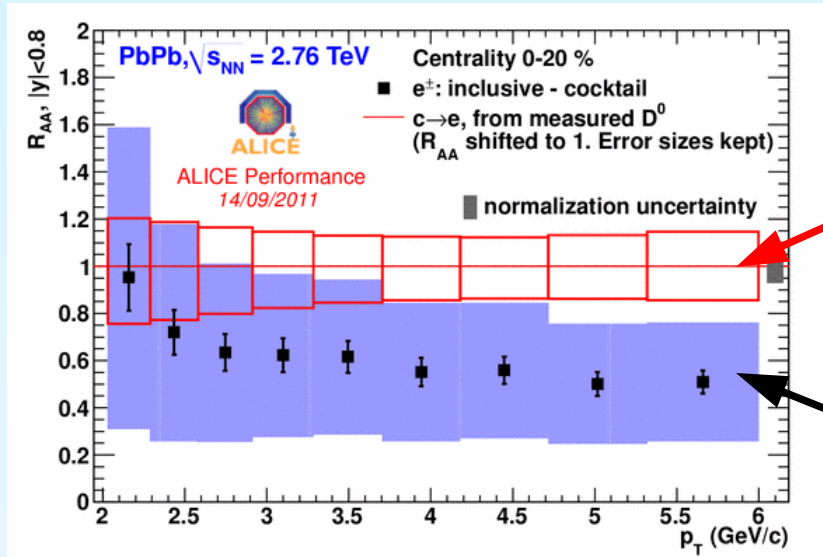


- $\rightarrow$  Suppression increases with centrality
- $\rightarrow$  Consistent centrality dependence
- $\rightarrow$  Mid-rapidity electrons and forward muons similar trend
- $\rightarrow$  D<sup>0</sup>  $R_{AA}$  seems lower (charm versus beauty?)



# Nuclear Modification Factor

$$D \rightarrow e + X$$

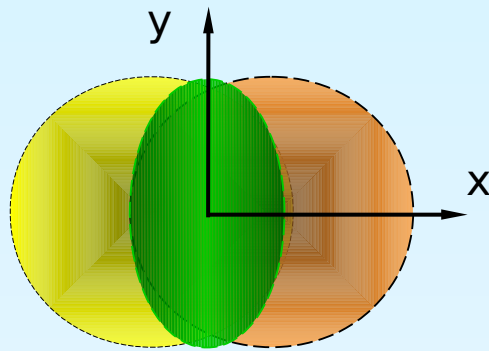


Only systematic uncertainty of  $R_{AA}$  from ALICE D meson measurement (hadronic decay) + PYTHIA decay kinematics  $\Rightarrow D \rightarrow e + X$

$R_{AA}$  for cocktail-subtracted electrons  $D, B \rightarrow e + X$

- Need to reduce large systematic uncertainties
- Possible method to disentangle  $R_{AA}$  for charm and beauty
- Comparison to displaced vertex analysis strategy

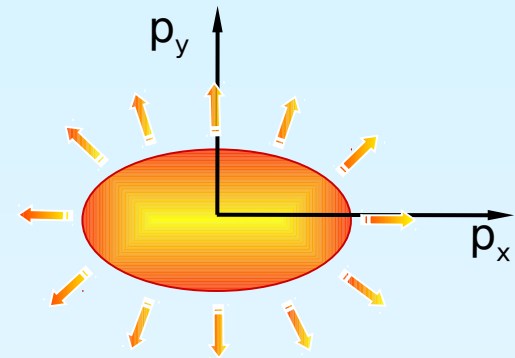
# Outlook: Elliptic flow of electrons from heavy flavour decays



Coordinate space:  
initial asymmetry



Collective interaction  
pressure



Momentum space:  
final asymmetry

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

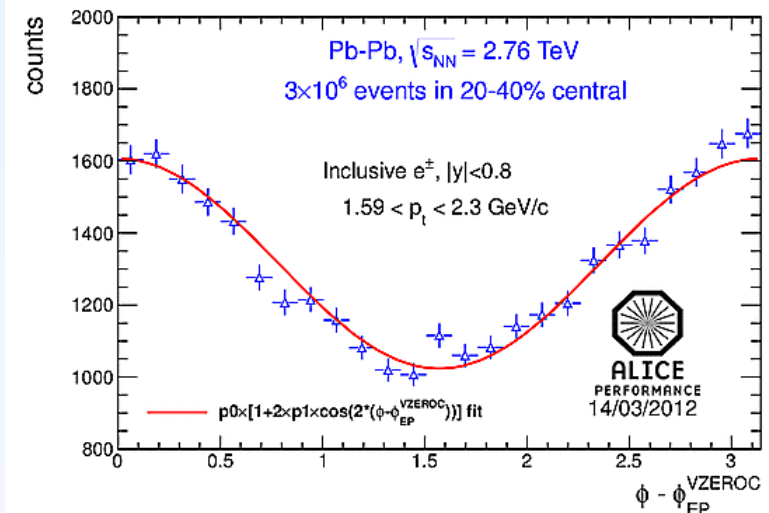
## ■ Flow measurement

- coupling & quark level thermalization
- related to the diffusion coefficient  $D$  and  $\eta/s$   
 $D \propto \eta/(sT)$

## ■ Cocktail subtraction

- Main background source:  $\pi^0 \rightarrow \gamma\gamma, \gamma \rightarrow e^+e^-$

→ Flow of electrons from heavy flavour decays



# Summary and Outlook



- **ALICE has excellent electron identification and vertexing capabilities**
- **Measurement of charm and beauty production via single electrons from heavy meson decays in pp collisions**
  - $D, B \rightarrow e + X$  for  $0.8 < p_T < 10$  GeV/c
  - $B \rightarrow e + X$  for  $1.5 < p_T < 6$  GeV/c
  - FONLL calculations agree within uncertainties
- **Measurement of inclusive electrons in Pb-Pb collisions at 2.76 TeV**
  - Comparison to cocktail of known background sources:  
hint of an excess at low  $p_T$  increasing with centrality
- **Nuclear modification factor in Pb-Pb collisions at 2.76 TeV measured**
  - Data exhibit clear centrality dependence
- **Separation of charm and beauty contribution**
  - Reference for quarkonia studies
- **Flow measurement**
- **Increase of statistics and improvements in systematics will reduce uncertainties**
  - Will benefit from improved luminosity of 2011 Pb-Pb run

# backup

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# Efficiency and Acceptance Corrected Inclusive Electron Spectra



## Efficiency and Acceptance Correction

- Derived from Monte Carlo Simulation
- Cross-checked where possible with data-driven method, where the signal from  $\gamma \rightarrow e^+e^-$  decays is evaluated
- Systematic Error:  $\pm 35\%$**

