Measurement of electrons from heavy flavour decays in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with ALICE

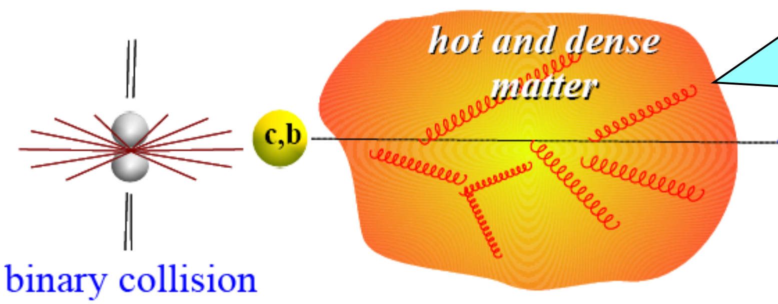
Shingo Sakai for the ALICE collaboration
Lawrence Berkeley National Laboratory

Outline

ALICE

- Introduction
- Electron identification
- pp results
  - Heavy flavour decay electron cross section at $\sqrt{s}$ = 2.76 TeV & 7 TeV
  - Beauty decay electron cross section at $\sqrt{s}$ = 2.76 TeV & 7 TeV
- Pb-Pb results
  - Nuclear modification factor (R_{AA})
  - Azimuthal anisotropy (v_2)
- Summary

Introduction

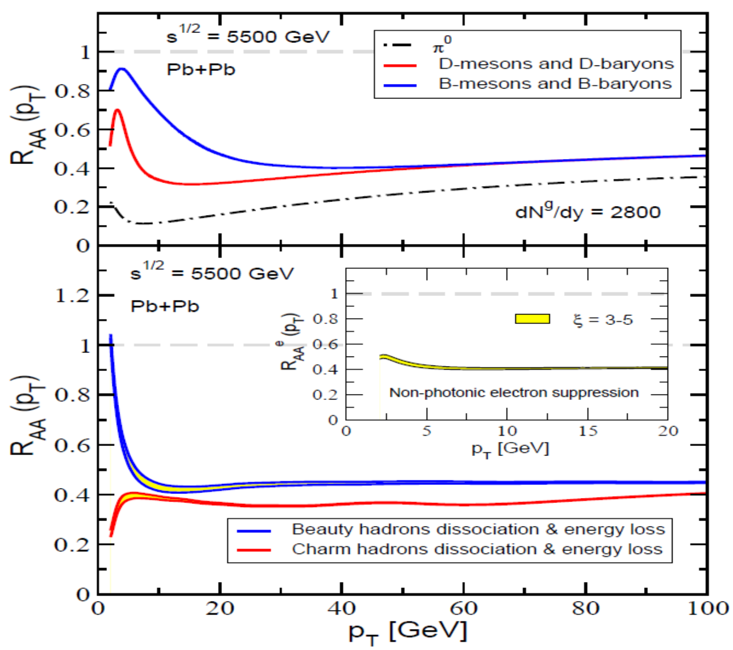


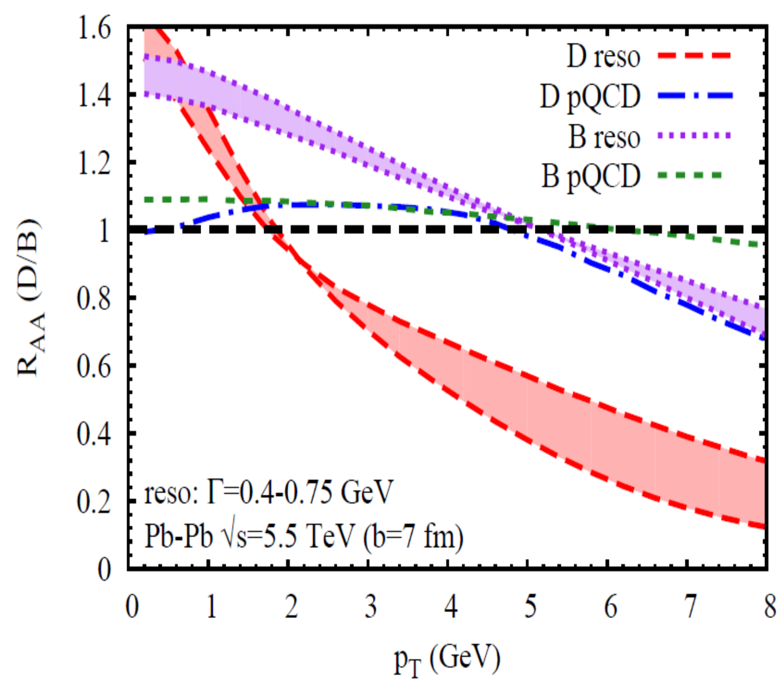
- collective flow
- parton energy loss
  => measurements of transport properties of the medium

- Heavy quarks in heavy-ion collisions
  - Created in the initial parton-parton scatterings
  - Traverse and interact with the hot and dense QCD matter
- Nuclear modification factor (R_{AA})
  - Sensitive to parton energy loss within the QCD matter
  - Sensitive to colour charge and mass dependence
- Azimuthal anisotropy in non-central collisions
  - Sensitive to parton-QCD matter interactions and thermalization

Charm & Beauty Energy Loss

- Theoretical prediction : $R_{AA}^{charm} < R_{AA}^{beauty}$
- See e.g. "Last call for LHC predictions" arXiv:0711.0974
  - Radiative energy loss (dead cone effect): *PLB 632, 81*
  - Collisional dissociation: *PLB 649, 139*
  - Large elastic scattering cross section associated with resonance states of D & B mesons in QGP: *PRC 73, 034913*



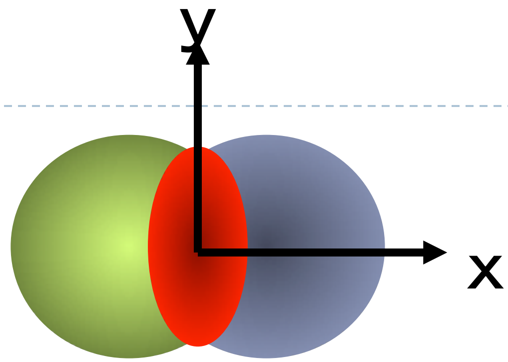


Azimuthal anisotropy

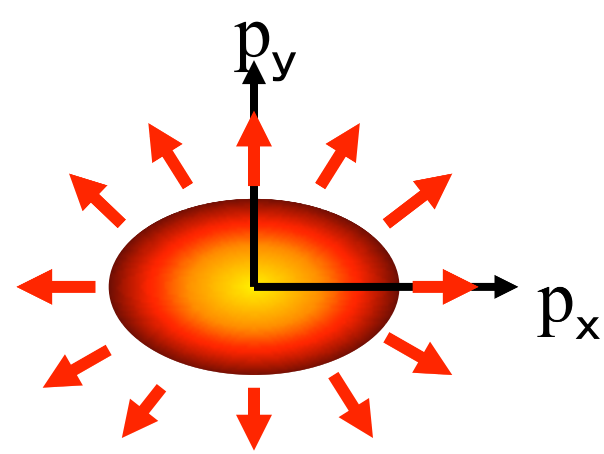
- Elliptic flow

$$dN/d\varphi \propto N_0(1+2v_2\cos(2\varphi))$$

- Transfer initial spatial anisotropy to momentum space anisotropy
  - macroscopic: hydro model => pressure gradient
  - microscopic => scattering in the medium
- Heavy flavour flow
  - indicate strongly coupling & quark level thermalization
- Path-length dependence of energy loss at high p_T



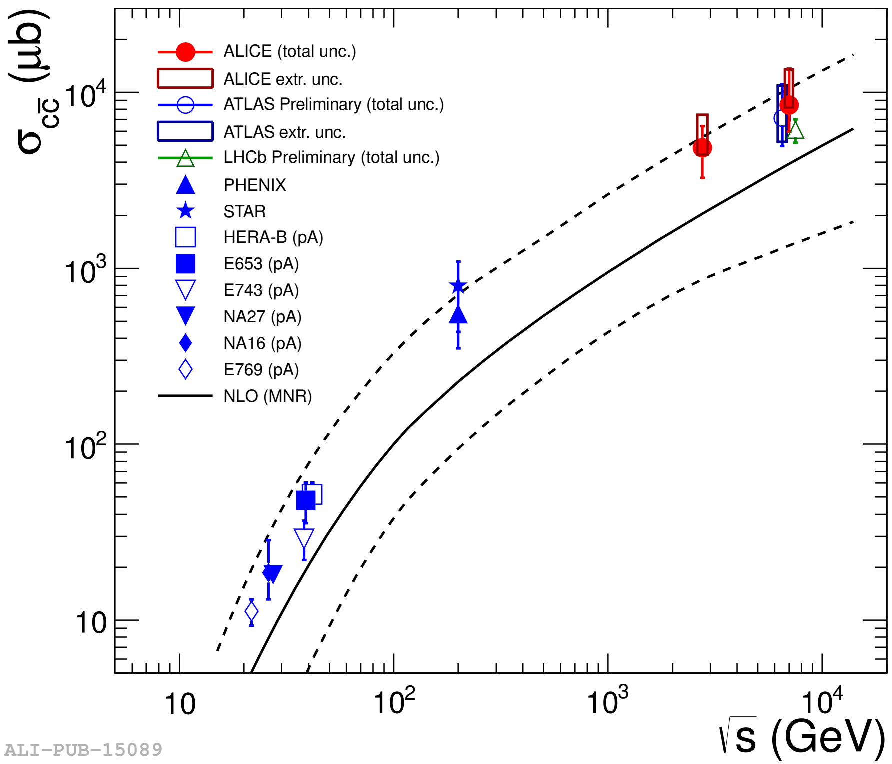
Initial spatial anisotropy



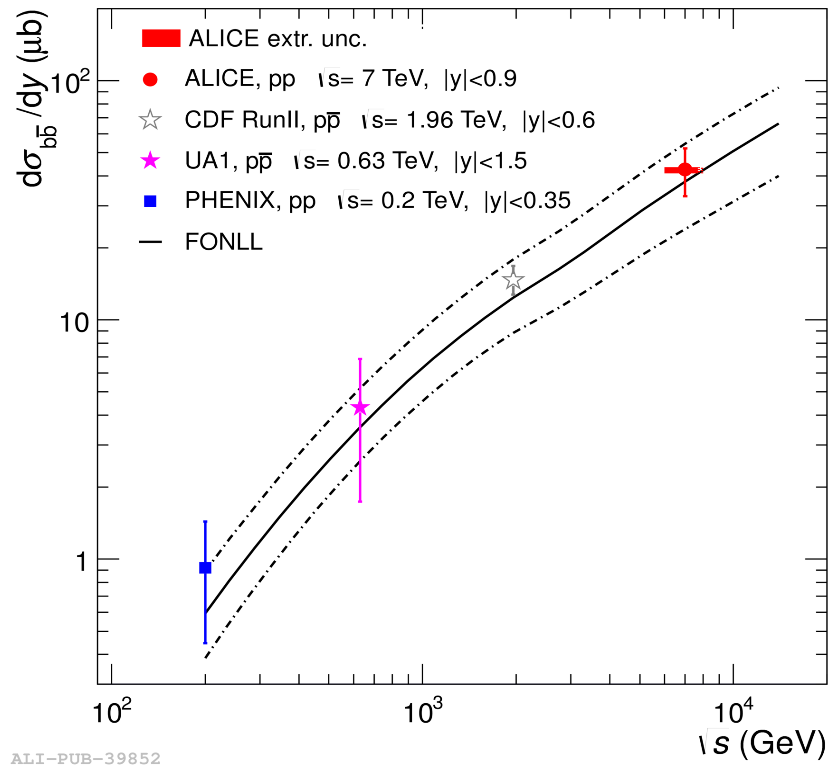
Momentum space anisotropy of particle emission

Heavy flavour production cross section at LHC

JHEP07(2012)191



arXiv: 1208.1902, arXiv: 1205.5880



- Expected in 1 PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
  - Charm (cc) = 60, Bottom (bb) = 2
- Large heavy flavour production cross section

Heavy flavour study via electrons

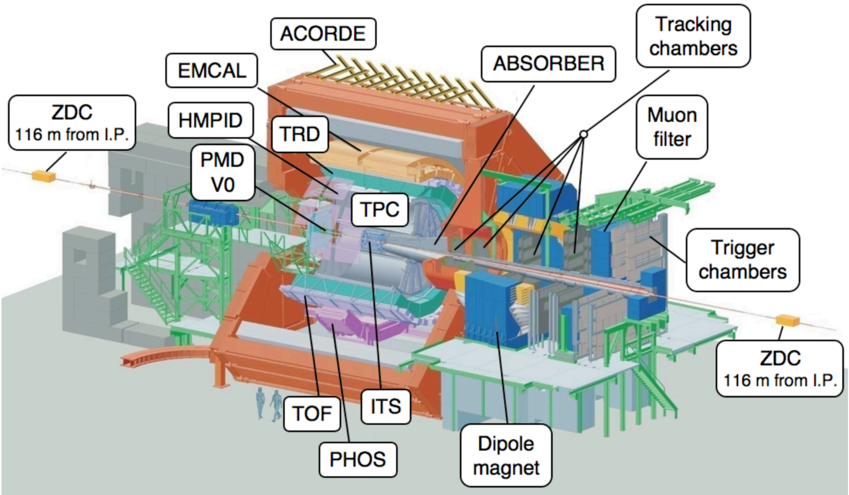
- Signal Electrons:
  - From semileptonic decays of charm & beauty hadrons
- Background Electrons:
  - From photon conversions
  - From Dalitz decays of neutral mesons
  - From quarkonia decays

Branching Ratios:

$c \rightarrow e + X$	$\mathcal{O}$ (9.6%)
$b \rightarrow e + X$	$\mathcal{O}$ (11%)
$b \rightarrow c \rightarrow e + X$	$\mathcal{O}$ (10%)

- Background subtraction
  - Cocktail method
    - Background calculated using measured hadron production cross section
  - Invariant mass method – electrons from 'photonic' sources
    - Reconstruction of electron pairs from the decays of neutral mesons & photon conversions
  - Heavy Flavour decay Electrons (HFE) dN/dp_T obtained via subtraction of the background from the inclusive electron spectrum

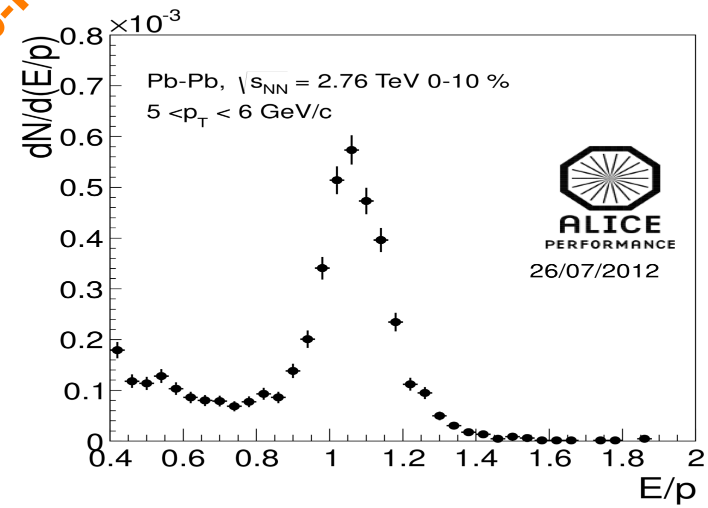
Electron identification in ALICE



- TPC --- measures dE/dx
- TOF --- measures time of flight
- TRD --- measures transition radiation (only in pp collisions now)
- EMCal --- measures energy trigger (single shower)
- ITS --- reconstruct photon conversions charm & beauty separation with impact parameter (done in pp for now)

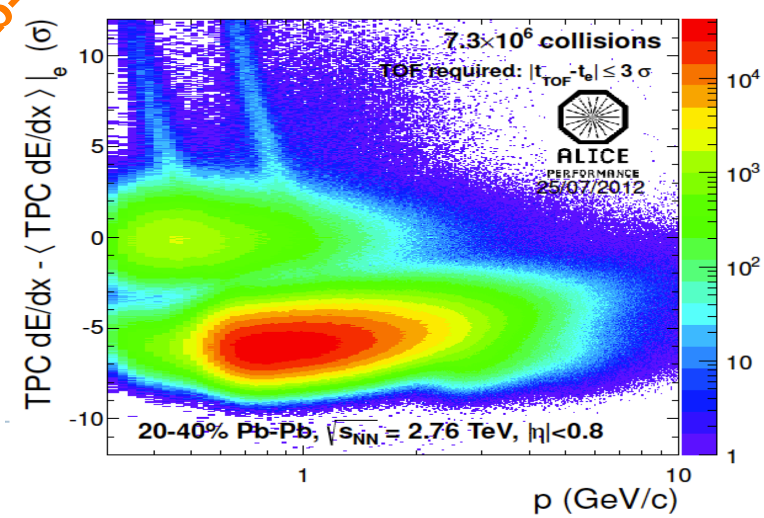
Pb-Pb

TPC + EMCal (dE/dx+E/*p*)

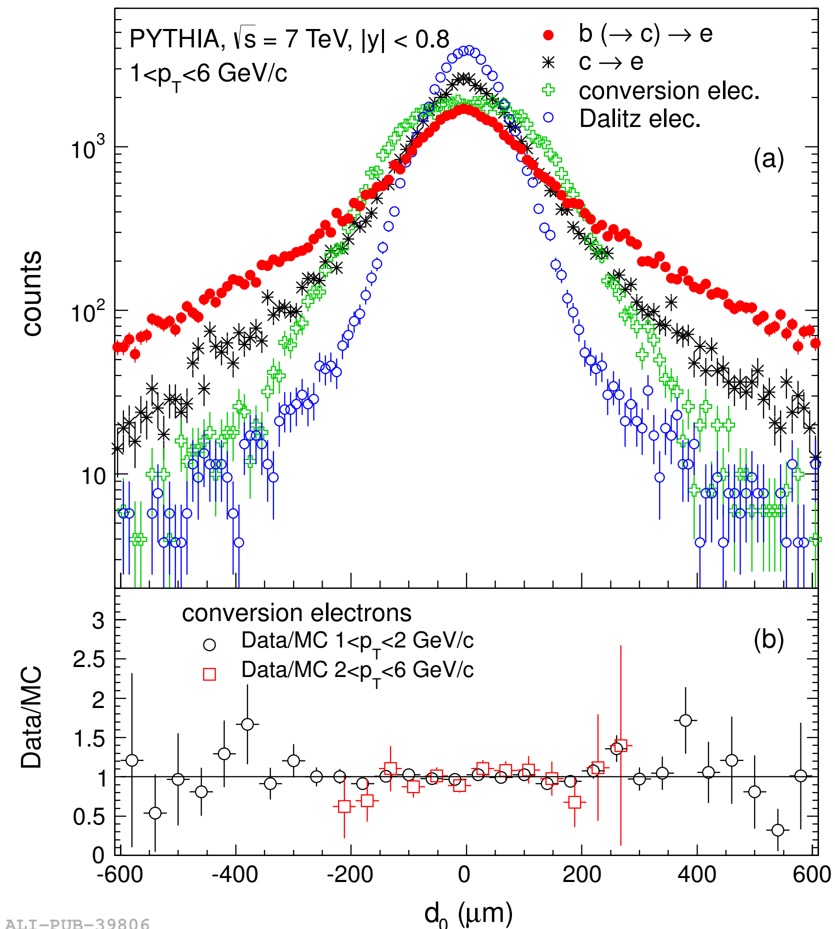


Pb-Pb

TPC +TOF (dE/dx+TOF)



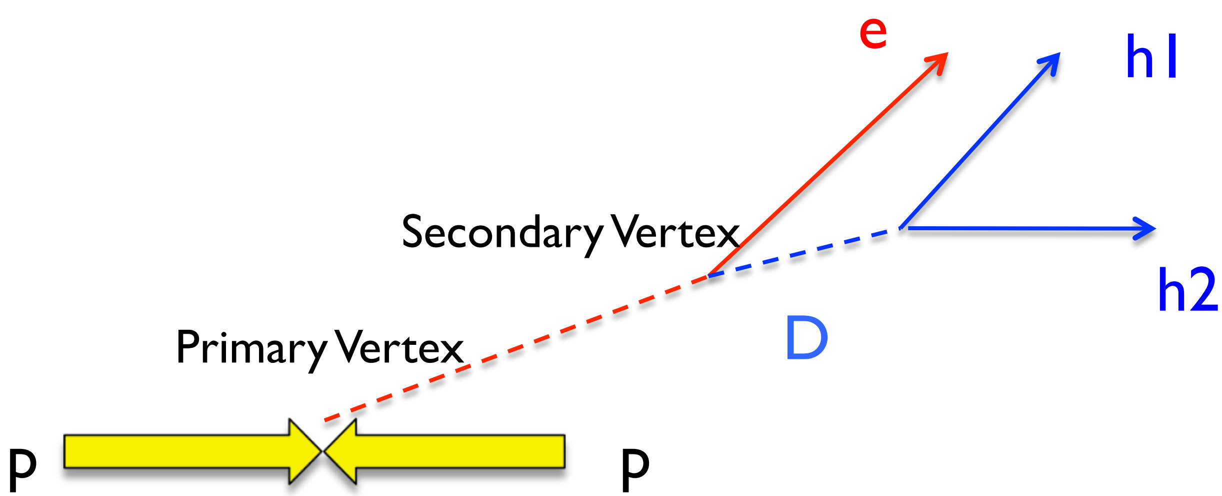
Beauty decay electron separation - Impact parameter method



arXiv: 1208.1902

- Separation based on displacement from primary vertex
  - Preferential selection via their large impact parameter (d_0)
    - $c\tau \sim 500\,\mu$m for B hadron
    - $|d_0|>250\,\mu$m ($p_T \sim 2.5$ GeV/c) (p_T dependent cut)
  - ITS ; impact parameter resolution < 75 μm for $p_T>1$ GeV/c
- Remaining backgrounds estimated based on measured π^0, η & D

Beauty decay electron separation
- b-tag method



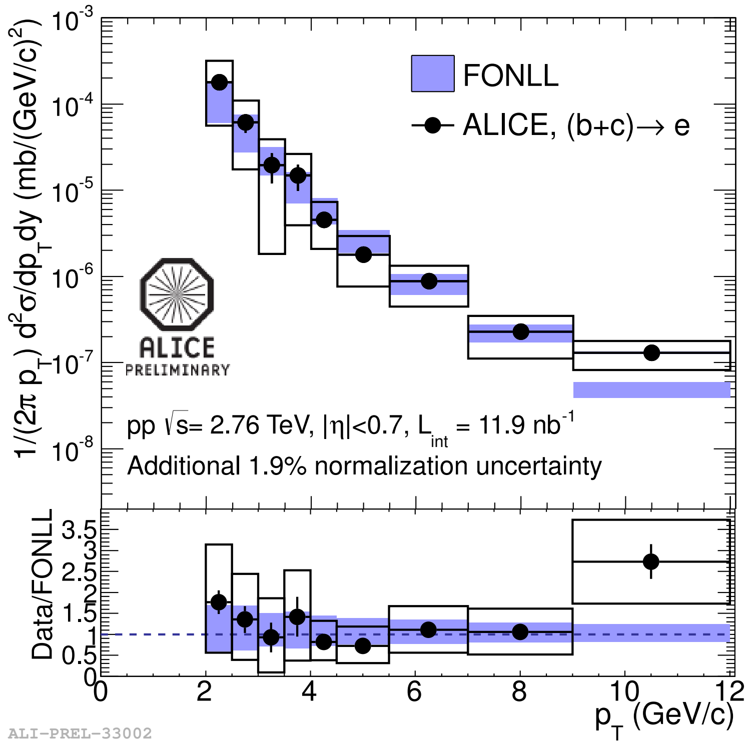
- Pairing electron with associated hadron from B decay
  - Cone radius: hadron should be in a certain cone size
  - Pair DCA: close to electron candidate
  - SignDCA: secondary vertex have a certain sign distance from the primary vertex
  - Invariant mass: B mass > background mass (D, π^0 etc)

pp results

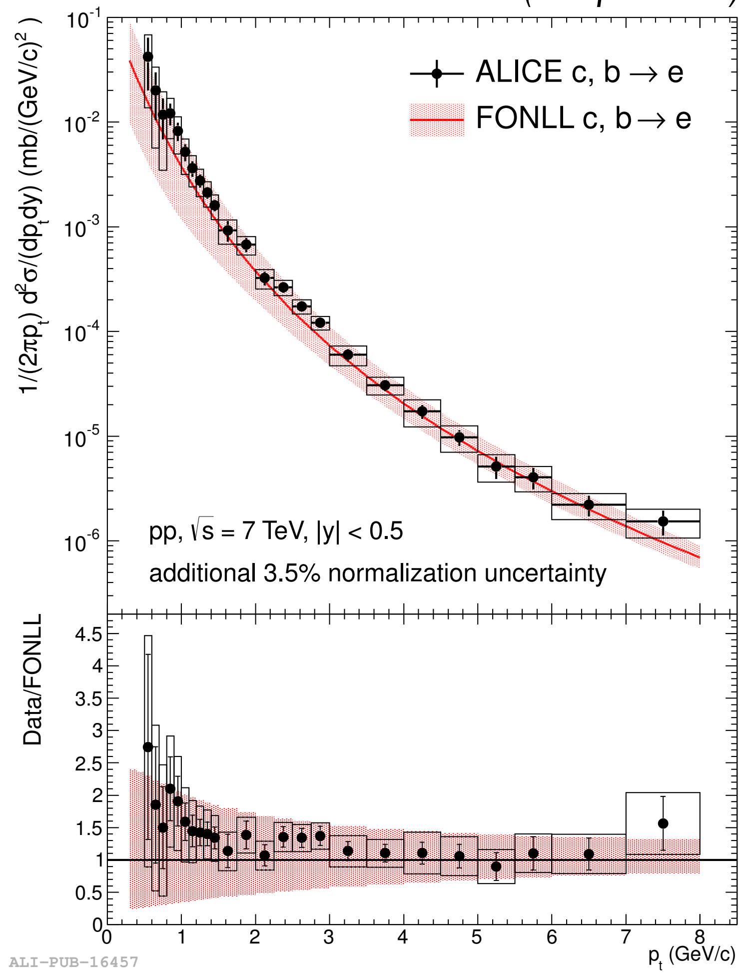
- Heavy flavour decay electron cross section at $\sqrt{s}$ = 2.76 TeV & 7 TeV
  - 7 TeV: L_{int} = 2.6 nb^{-1} (MB),
    - *arXiv: 1205.5423 (accepted PRD)*
  - 2.76 TeV: L_{int} = 0.5 nb^{-1} (MB) , L_{int} = 11.9 nb^{-1} (EMCal trigger)
- Cross section of beauty decay electron at $\sqrt{s}$ = 2.76 TeV & 7 TeV
  - 7 TeV
    - L_{int} = 2.2 nb^{-1} (MB): Impact parameter method
      - *arXiv: 1208.1902 (submitted PLB)*
    - L_{int} = 210 nb^{-1} (EMCal trigger): b-tag method
  - 2.76 TeV: L_{int} = 0.5 nb^{-1} (MB), L_{int} = 11.9 nb^{-1} (EMCal trigger)

* MB : minimum-bias trigger

HFE production cross section in pp collisions at √s = 2.76 and 7 TeV



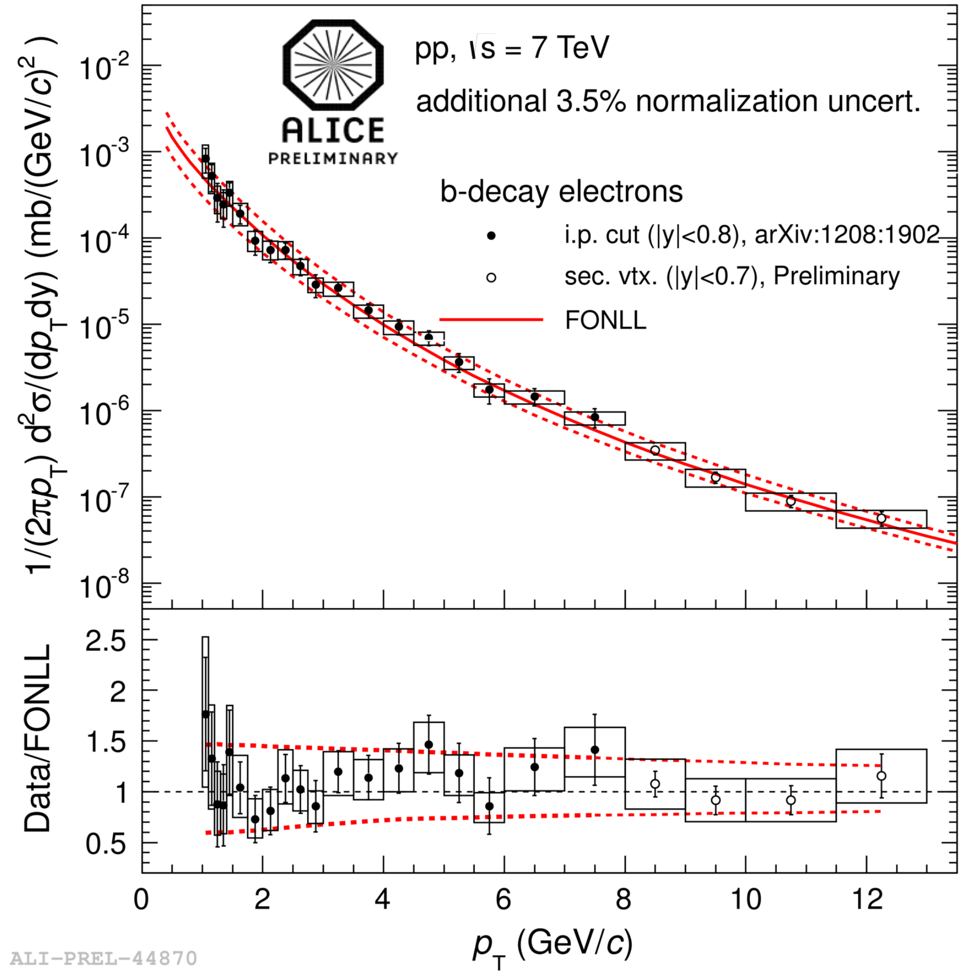
arXiv : 1205.5423 (accepted PRD)



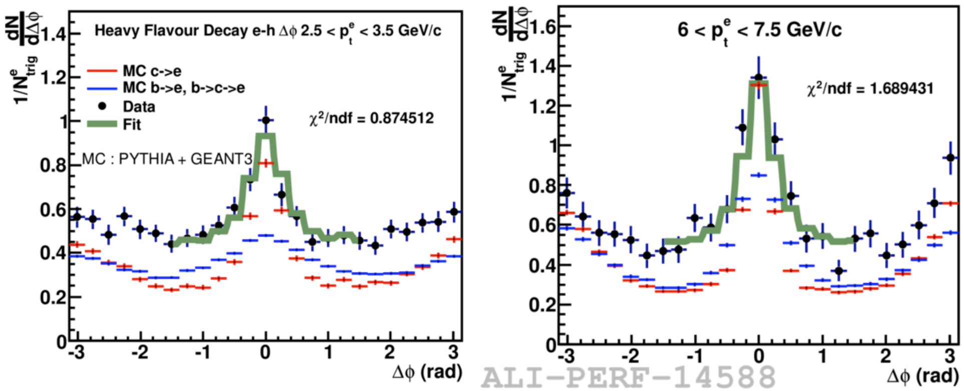
- Well described by FONLL pQCD calculations (M. Cacciari et al. arXiv:1205.6344)
- 7 TeV measurement is scaled to 2.76 TeV and used as R_{AA} reference

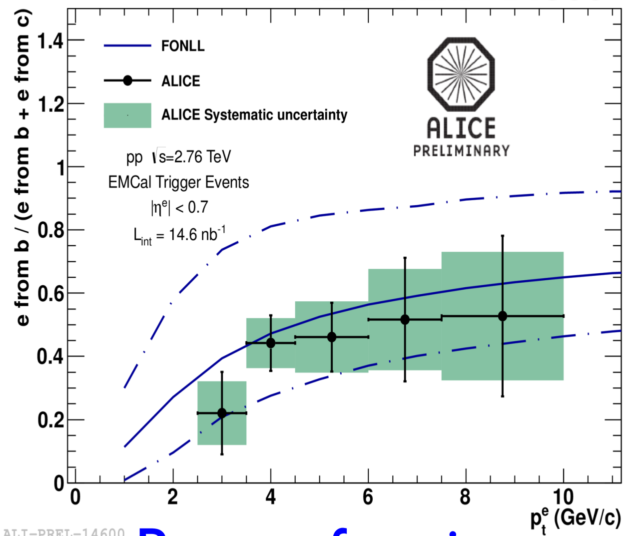
Beauty decay electron cross section in pp collisions at √s = 7 TeV

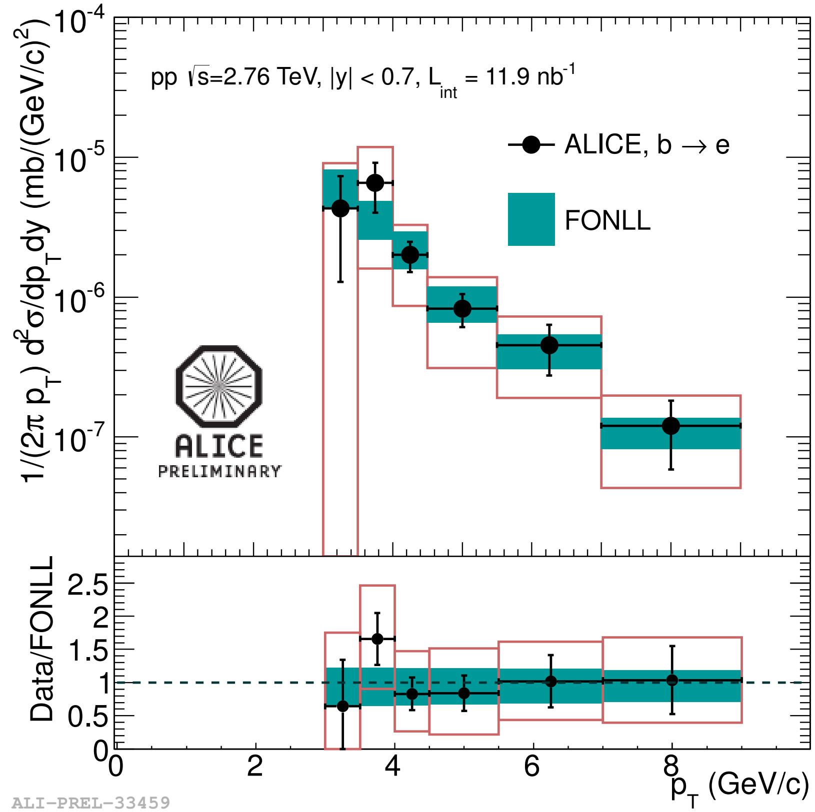
- Beauty decay electron cross section
  - $1 < p_T < 8$ GeV/c
    - Impact parameter
    - arXiv: 1208.1902 (submitted PLB)
  - $8 < p_T < 13$ GeV/c
    - b-tag
- FONLL pQCD calculation agrees well with the measured beauty cross section



B-decay electrons in pp collisions at $\sqrt{s}$ = 2.76 TeV





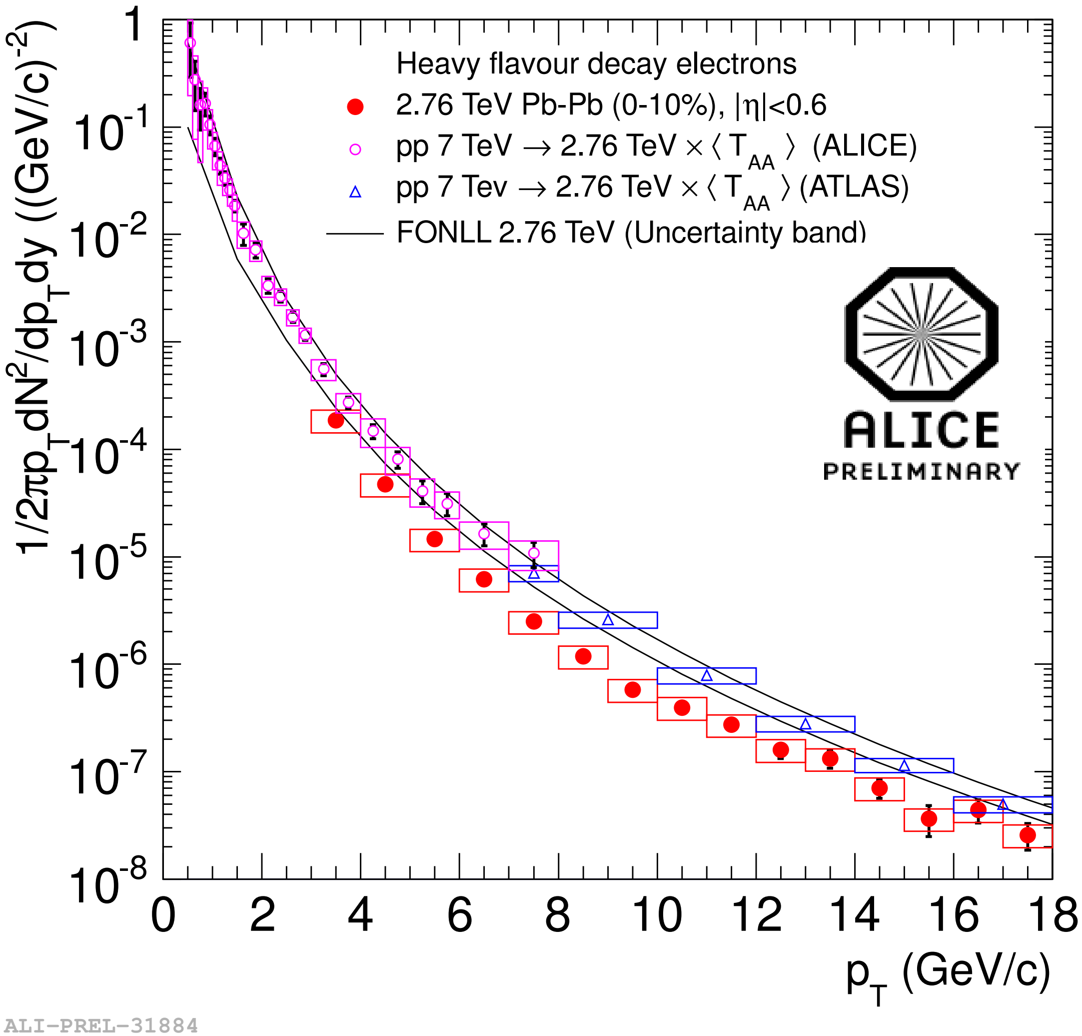


- Beauty fraction measured via azimuthal correlations and comparison to PYTHIA templates
- Measurement consistent with FONLL calculation

Pb-Pb results

- HFE R_{AA}
  - Centrality 0-10 %
    - 17 M events (MB) & 0.7 M events (EMCAL trigger)
    - $3 < p_T < 18$ GeV/c , $|\eta| < 0.6$
  - Background estimate : Invariant mass method
- HFE v_2
  - Centrality 20-40 %
    - 3M (2010) + 8.5 M (2011) events (MB) & 1.3 M events (EMCAL trigger)
    - $1.5 < p_T < 13$ GeV/c, $|\eta| < 0.7$
  - Background estimate : Cocktail method
- Centrality & Event Plane determination
  - VZERO ($2.8< \eta <5.1$, $-3.7< \eta <-1.7$) scintillators signal amplitude

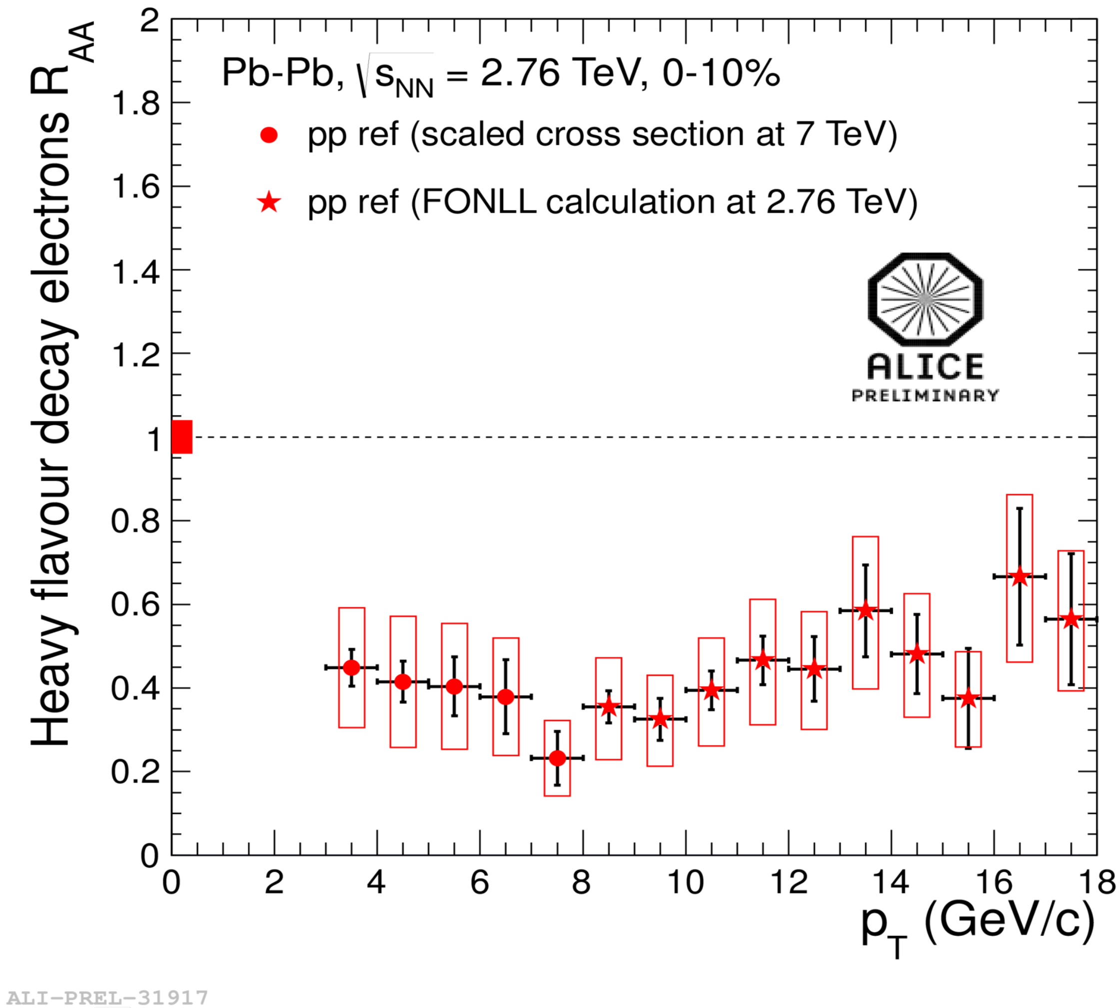
HFE dN/dp_T in 0-10% central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



- HFE dN/dp_T in Pb-Pb and pp references (<T_{AA}> scaled):
  - HFE pp 7 TeV: **ALICE** & **ATLAS** => Scaled to 2.76 TeV (*arXiv 1107.3243*)
  - FONLL calculation : M. Cacciari et al. JHEP 0103 (2001) 006
- Good description of ALICE/ATLAS scaled cross section by FONLL

ATLAS PLB 707:438-45

HFE R_{AA} in 0-10% central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



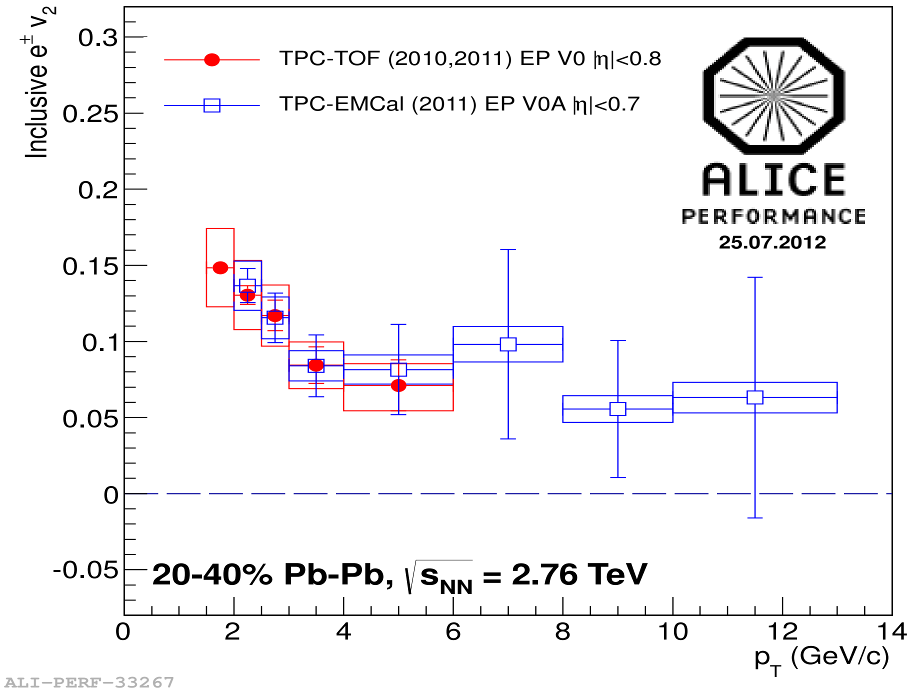
$$R_{AA}(p_T) = \frac{d\,N_{AA}/dp_T}{\langle T_{AA}\rangle \times d\sigma_{pp}/dp_T}$$

T_{AA} : the nuclear thickness function

- pp references used:
  - p_T < 8 GeV/c :
    - ALICE 7 TeV (scaled to 2.76 TeV)
  - p_T > 8 GeV/c :
    - FONLL calculation for 2.76 TeV

- Clear suppression of heavy flavour decay electrons w.r.t. scaled pp references up to p_T = 18 GeV/c

Azimuthal anisotropy of electrons

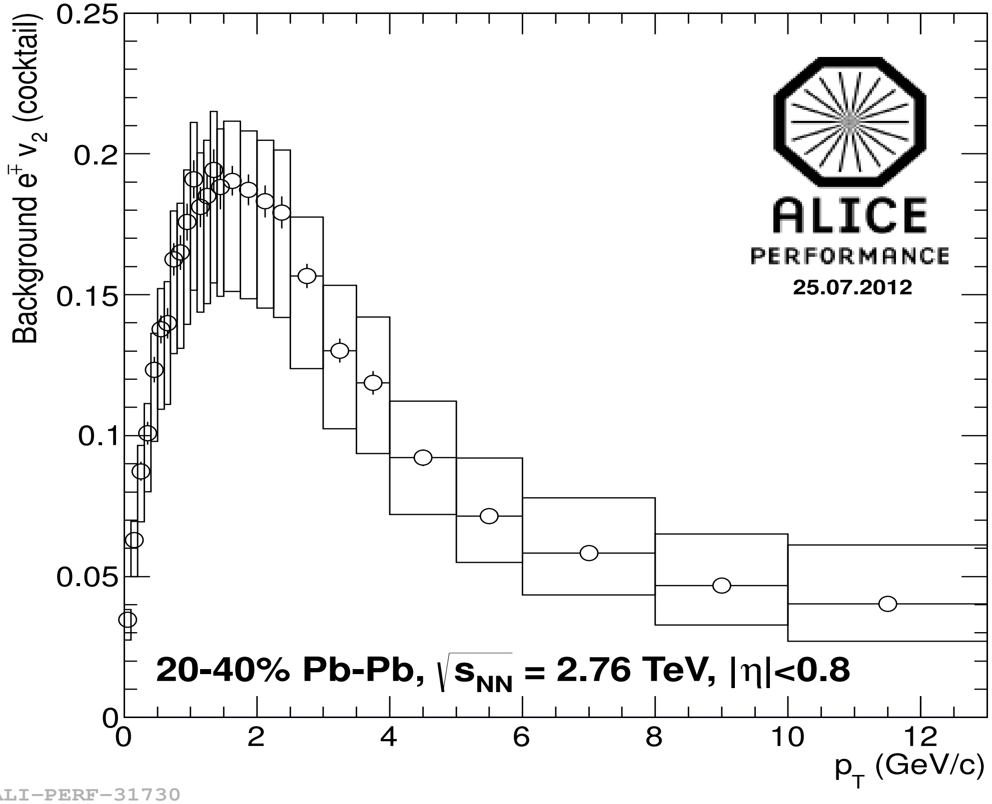


Two complementary analyses :
-TPC+TOF
-TPC+EMCal

- Elliptic flow (v_2) ; $dN/d(\phi-\psi) = N\,(1 + 2v_2^{obs}\cos(2(\phi-\psi_{EP})))$
- Event plane determined with the VZERO detectors ($2.8<\eta<5.1$, $-3.7<\eta<-1.7$)
- HFE v_2 obtained by subtraction of the background electron v_2:

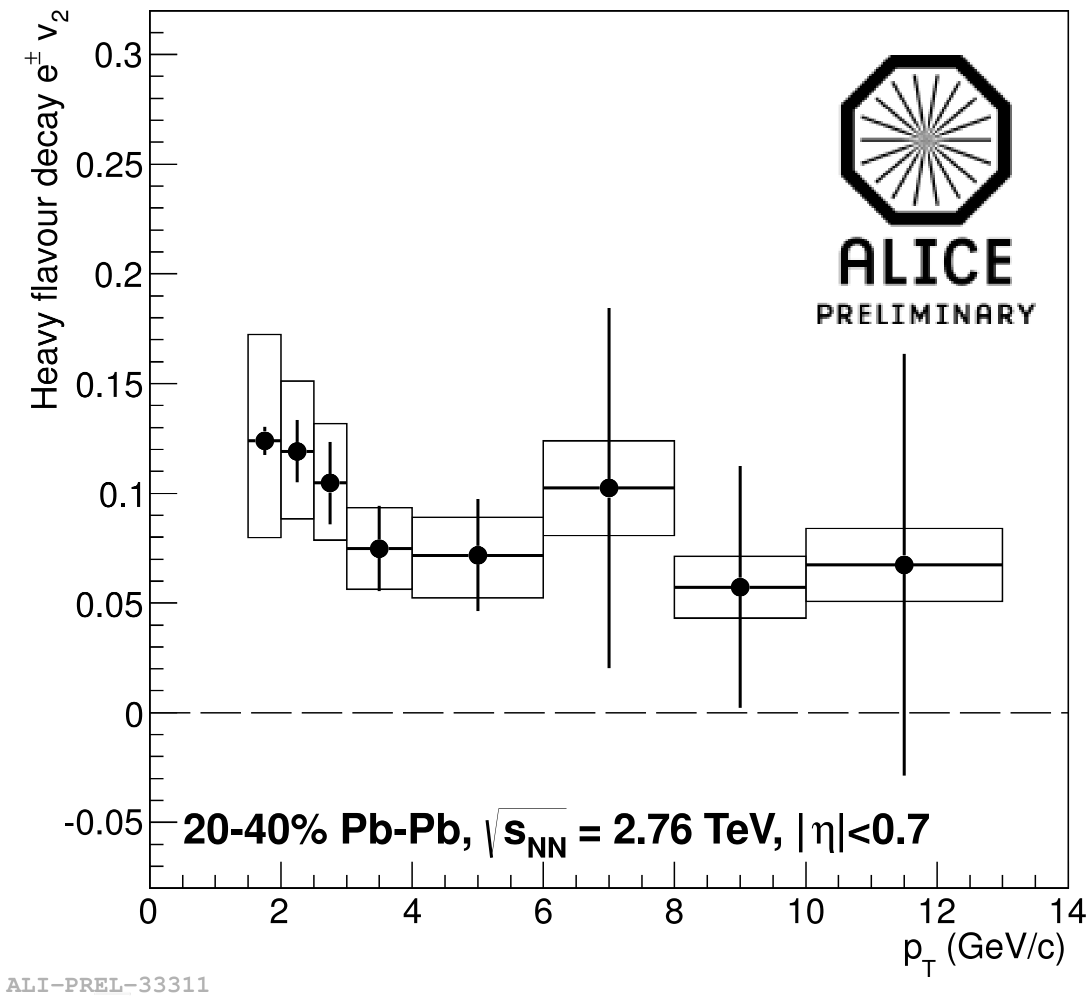
$$v_2^{HFE} = \frac{(1+R)v_2^{inclusive} - v_2^{background}}{R}, \quad R = \frac{N_{HFE}}{N_{background}}$$

Background electron v_2 – cocktail method



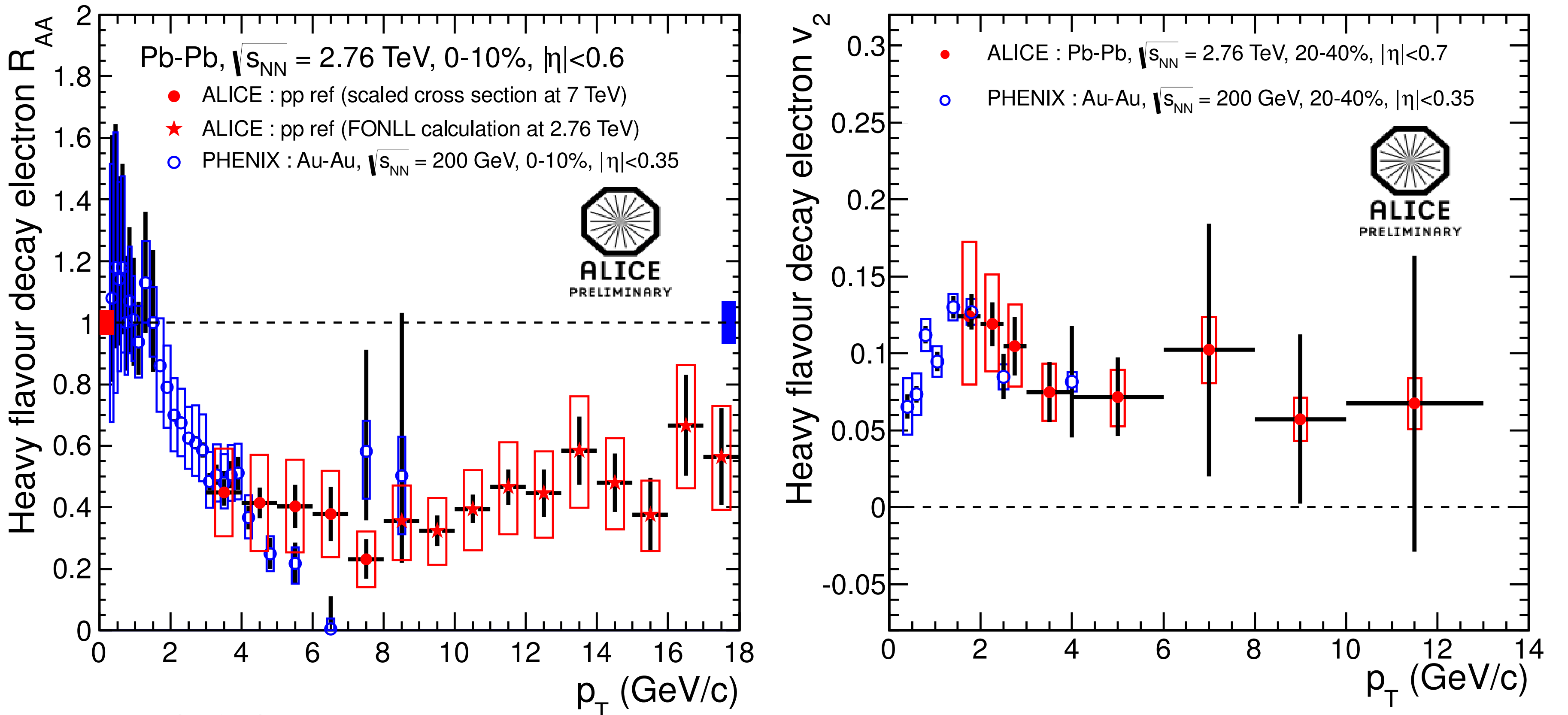
- Background v_2 : decay electrons from neutral meson & converted photons;
  - calculated from parent v_2 and p_T spectrum
  - Assume : $\pi^0 = \pi^+$, m_T scaling for η , direct γ $v_2 = 0$

Heavy flavour decay electron v_2



- Heavy flavour decay electron v_2 after subtracting background electron v_2
- Combined result from TOF+TPC & TPC+EMCal measurements
- HFE v_2 > 0 observed in 20-40 % centrality class
  - > 3 σ in 2 < p_T < 3 GeV/c

Comparison with 200 GeV Au-Au collisions at RHIC (PHENIX |y|<0.35)

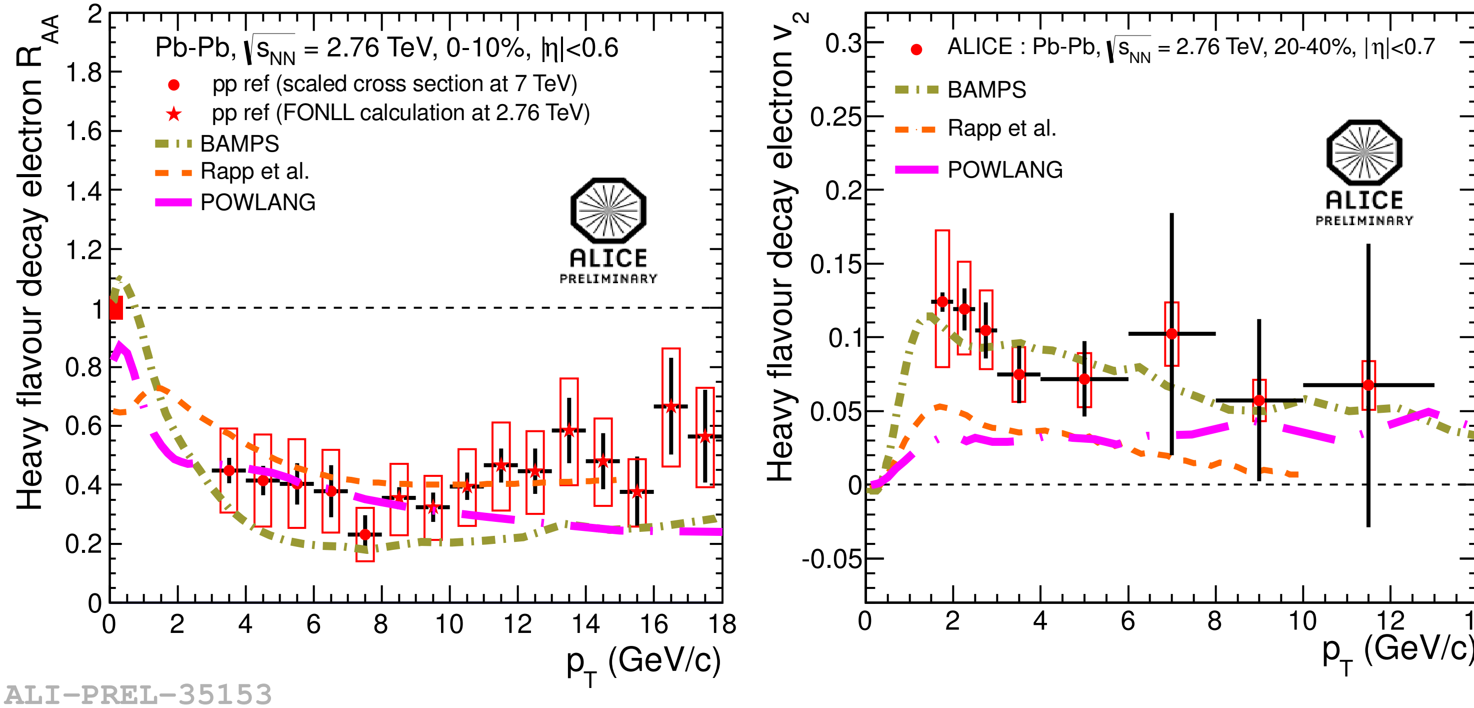


ALI-PREL-35148

- Magnitude of R_{AA} ($3<p_T<9$ GeV/c) and v_2 ($1.5<p_T<4$ GeV/c) comparable at the two energies

PHENIX; PRC84, 044905

Comparison with models



- BAMPS[1] model : HQ transport with collisional energy loss in expanding QGP
  - Seems to underpredict HFE R_{AA} , consistent with HFE v_2
- Rapp[2] : heavy quarks transport with in-medium resonance scattering and coalescence
  - Consistent with HFE R_{AA}, seems to underestimate HFE v_2
- POWLANG[3] : Heavy quark transport (Langevin eq.) with collisional energy loss
  - Seems to underpredict HFE R_{AA} and to underestimate HFE v_2 at high p_T

(1) J. Uphoff et al. arXiv 1205.4945 (2)R. Rapp et al. arXiv 1208.0256 (3)A. Beraudo et al J.Phys.G G38 124144

Summary

- Heavy flavour decay electrons & B decay electrons production cross sections are well described by FONLL pQCD calculations (pp 2.76 TeV & 7 TeV)
- Strong suppression of the HFE yield up to 18 GeV/*c* in 0-10% most central events ($R_{AA} \sim 0.4$)
  - Clear indication for substantial energy loss of heavy quarks in the hot and dense medium
- Non-zero HFE v_2 observed in 20-40% central events:
  - Suggests strong re-interactions within the medium
- p-Pb run in January to measure initial state effects