Heavy-Flavour decay leptons in pp, p-Pb and Pb-Pb Collisions with ALICE

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International Conference on the Initial Stages in High-Energy Nuclear Collisions

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Outline

- Motivation
- Measuring heavy flavours (HF) in ALICE
- HF decay leptons in pp, p-Pb, and Pb-Pb collisions
  - Production cross sections
  - Nuclear modification factor in p-Pb and Pb-Pb
  - Elliptic flow in Pb-Pb
- Conclusions

Heavy flavours - motivation

Production

- Heavy quarks (charm and bottom) are primarily produced in the hard scatterings in the initial stages of the collision

Pb-Pb collisions: Probing the QCD matter

- Heavy quarks experience the full evolution of the system, making them excellent probes
- In-medium partonic energy loss - Both mass (dead cone effect) and color charge dependent → $\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$ L. Dokshitzer, D.E. Kharzeev Phys. Lett. B 519 (2001) 199
- Collectivity - in-medium transport properties. Do heavy quarks participate in the collective expansion of the system? Do they thermalize with the medium?

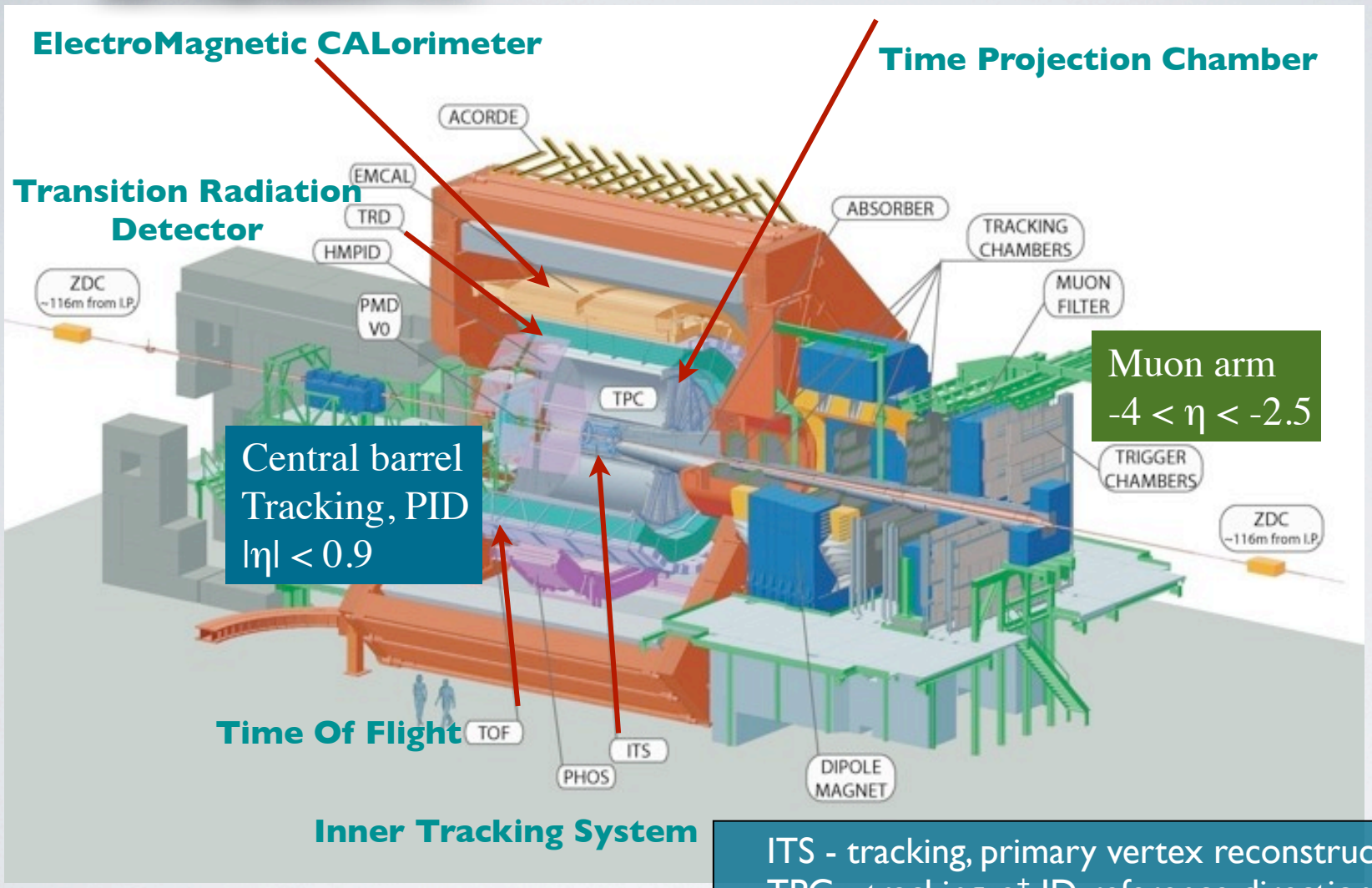
p-p collisions

- Important test of pQCD predictions
- Baseline for effects found in Pb-Pb collisions

p-Pb collisions

- Cold nuclear matter effects
- Modification of parton distributions in nuclei (shadowing/parton saturation)
- k_T-broadening

ALICE



ITS - tracking, primary vertex reconstruction
TPC - tracking, $e^{\pm}$ ID, reference direction for $\mu^{\pm}$ flow
TOF - $e^{\pm}$ ID
TRD - $e^{\pm}$ ID
EMCal - Energy measurement, EMC trigger
V0 - Minimum bias (MB) trigger, centrality and event selection
Muon Spectrometer - $\mu^{\pm}$ tracking, $\mu^{\pm}$ trigger

Open Heavy Flavour Program

Mid rapidity ($|\eta| < 0.9$)

D mesons (D^0, D^+, D^*, D_s) via hadronic decays
- Select on displaced vertices using TPC and ITS
- Particle ID using TPC and TOF
- Invariant mass (M_{inv}) analysis

See talks by A. Festanti and G. M. Innocenti

Single electrons from semi-leptonic D and B decays
- $e^{\pm}$ ID using TRD, EMCal, TPC, and TOF
- Background estimated from MC cocktail or e^+e^- M_{inv} method
- Beauty decay electrons using ITS - exploiting displacement from primary vertex

Forward rapidity ($-2.5 < \eta < -4$)

Single muons from semi-leptonic D and B decays
- Muon spectrometer
- Background primary π, K decays. In pp estimated using MC normalized to measured muon yield at low p_T, in Pb-Pb extrapolated from measured π, K at mid rapidity

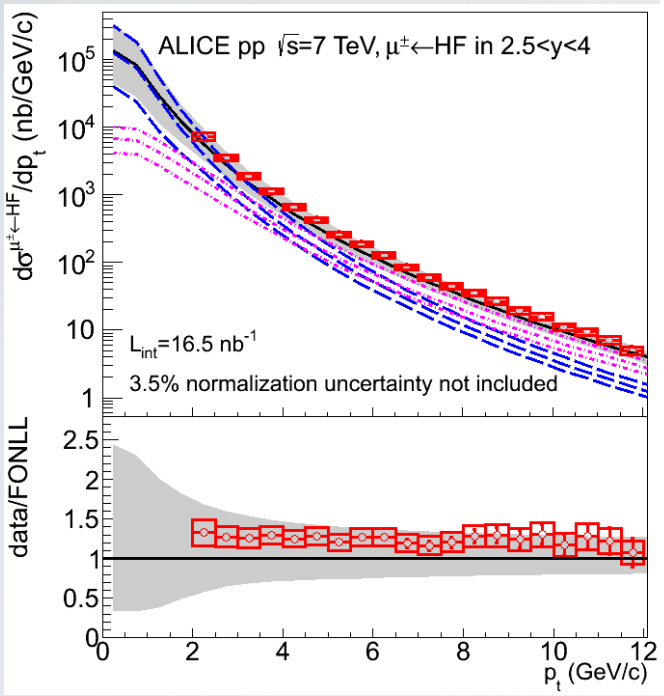
pp collisions

	7 TeV	2.76 Tev
Muons	2010 run, $\mathcal{L}_{int}$ = 16.5 nb^{-1}, MB and μ trigger	2011 run, $\mathcal{L}_{int}$ = 19 nb^{-1}, μ trigger
Electrons	2010 run, $\mathcal{L}_{int}$ = 2.6 nb^{-1} from MB trigger, $\mathcal{L}_{int}$ = 2.1 nb^{-1} from EMCal trigger	2011 run, $\mathcal{L}_{int}$ = 1.1 nb^{-1} from MB trigger, $\mathcal{L}_{int}$ = 14.8 nb^{-1} from EMCal trigger

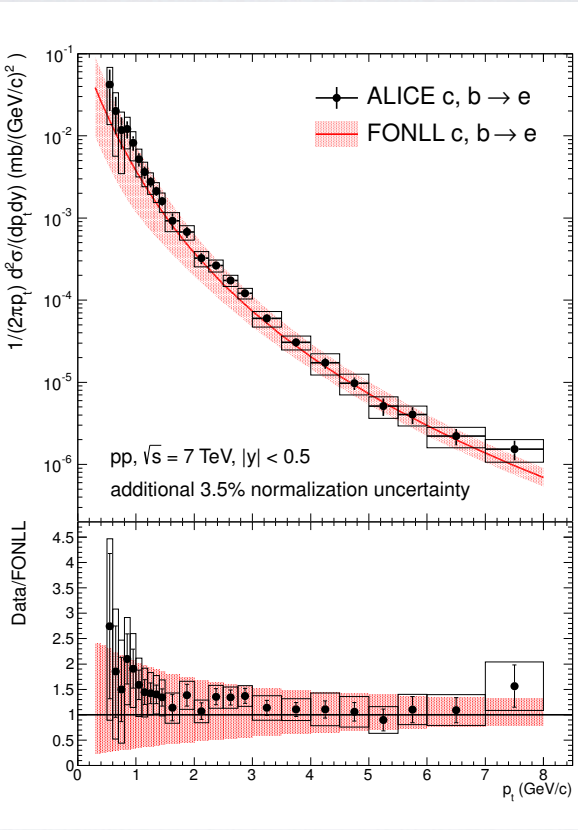
Single HF decay leptons in pp at 7 TeV

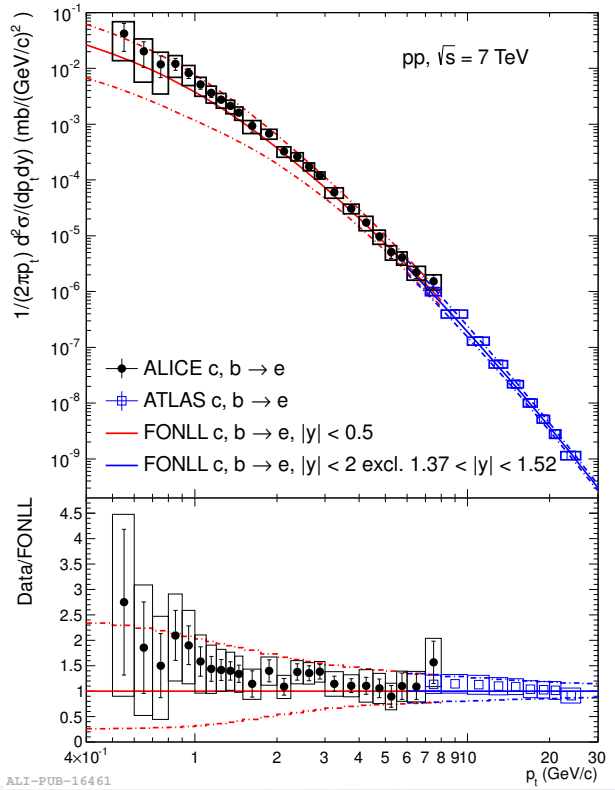
HF decay electrons

HF decay muons



PLB 708 (2012) 265





Phys. Rev. D 86, 112007 (2012)

- Measured production cross section of HF decay muons and electrons
- pQCD predictions (FONLL) describe the data within uncertainties
- Measurements of HF decay electrons in p_T region complementary to ATLAS results

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

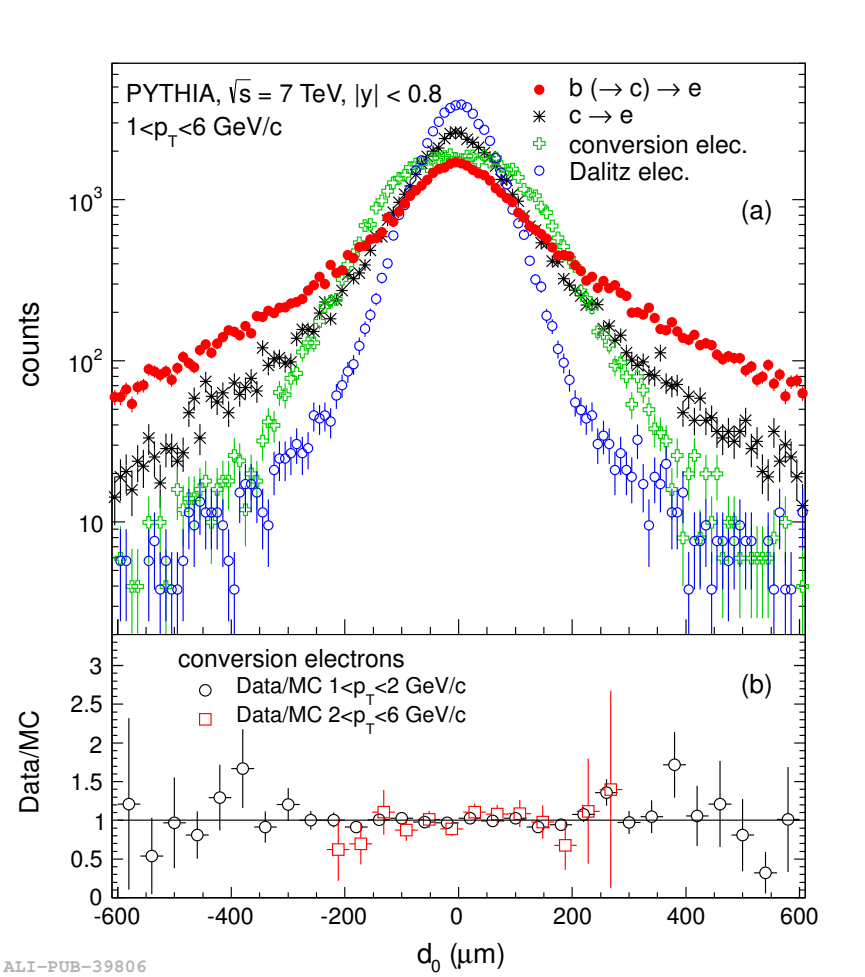
Beauty electrons in pp at 7 TeV

Impact parameter (IP) analysis

- Separate $e^{\pm}$ from B decays
- Exploit relatively long lifetime of B mesons
- Beauty decay $e^{\pm}$ have broader IP (d_0) distribution compared to backgrounds
- Excellent resolution given by the ALICE Inner Tracking System

$\sigma_{d0} < 75$ μm for $p_T > 1$ GeV/c

- Electrons must satisfy p_T dependent condition on d_0
- Background subtraction using simulations



PLB 721 (2013) 12

Beauty electrons in pp at 7 TeV

Impact parameter (IP) analysis

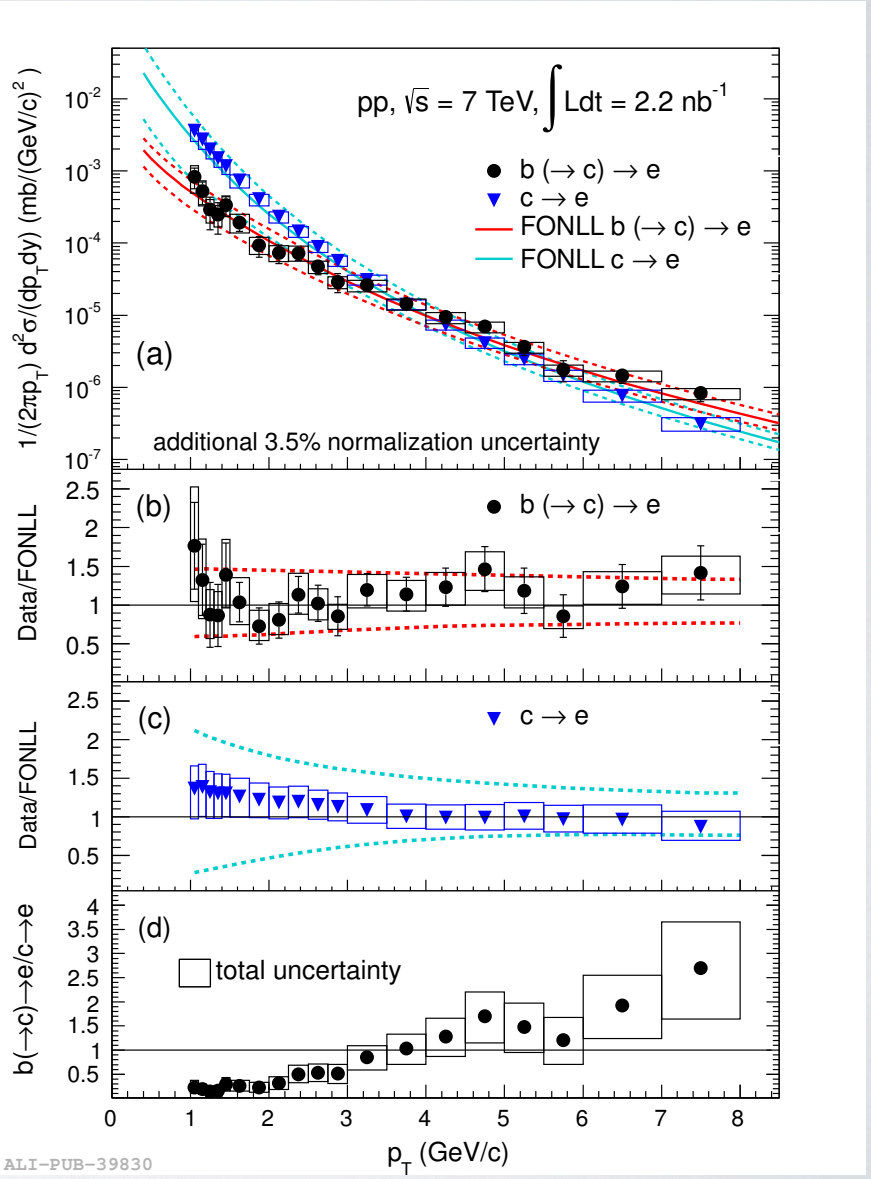
p_T differential production cross section of electrons from beauty hadron decays

- Estimate electrons from charm hadron decays using D mesons measured by ALICE
- Beauty decay electrons start to dominate, relative to charm at p_T of ~ 4 GeV/c
- Compatibility with FONLL calculations

Cacciari et al., JHEP 9805 (1998) 007, JHEP 0103 (2001) 006

- The calculations GM-VFNS and k_T-factorization are also in agreement

Nucl. Phys. B 872 (2013) 253-264, arXiv:1306.6808



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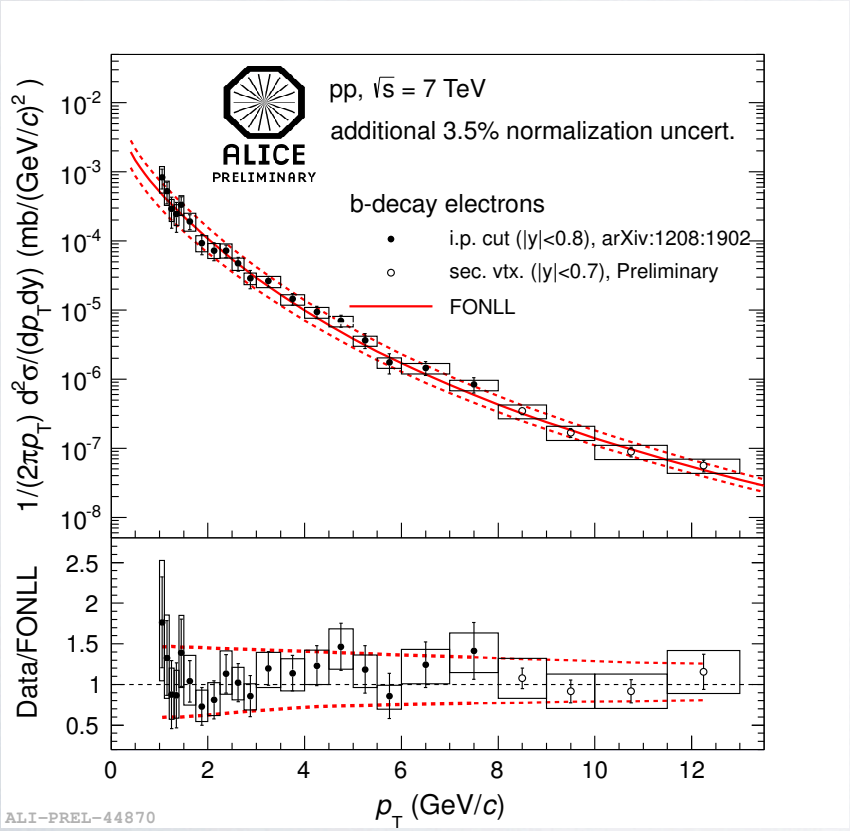
Additional beauty measurements

Alternative methods using EMCal triggered events

Displaced e-h vertices

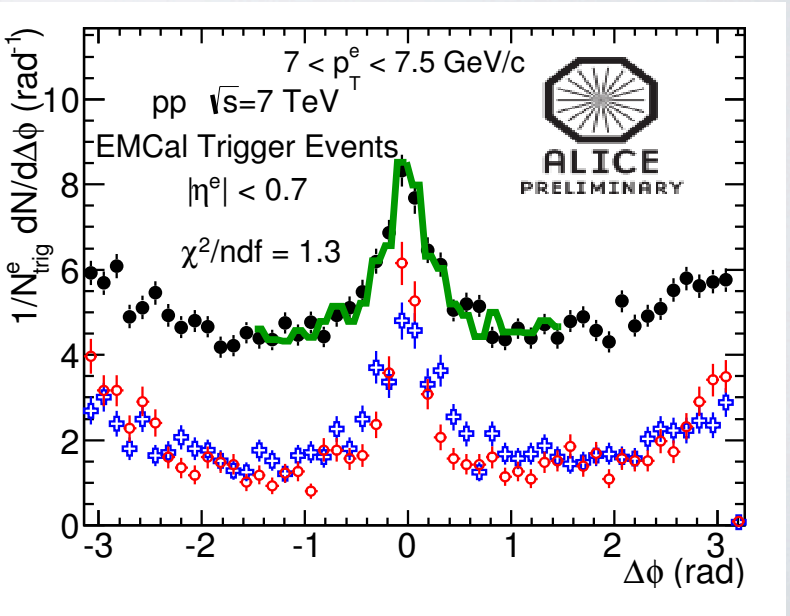
- Reconstruct e-h displaced vertices
- Selection: e-h M_{inv}, distance to primary vertex, and p_T of hadron
- Extends measurement to 13 GeV/c



e-h correlations in Δϕ

- Near-side peak wider for beauty compared to charm hadron decays
- Pythia templates used to estimate relative contribution
- Extends to 18 GeV/c

- Data
- MC c → e
- MC b → e
- MC fit



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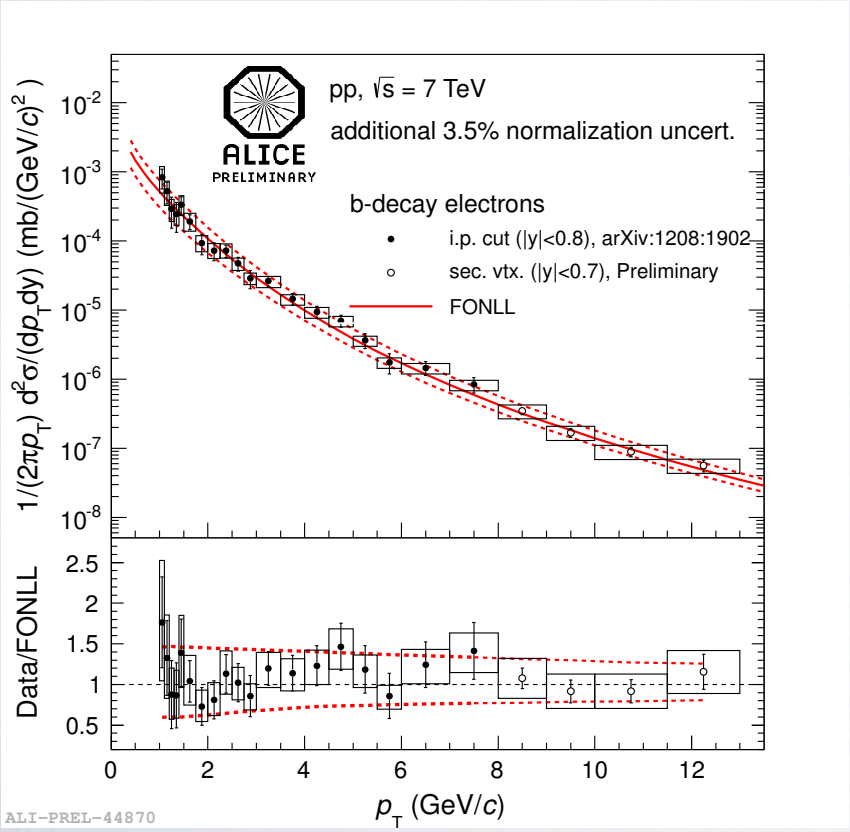

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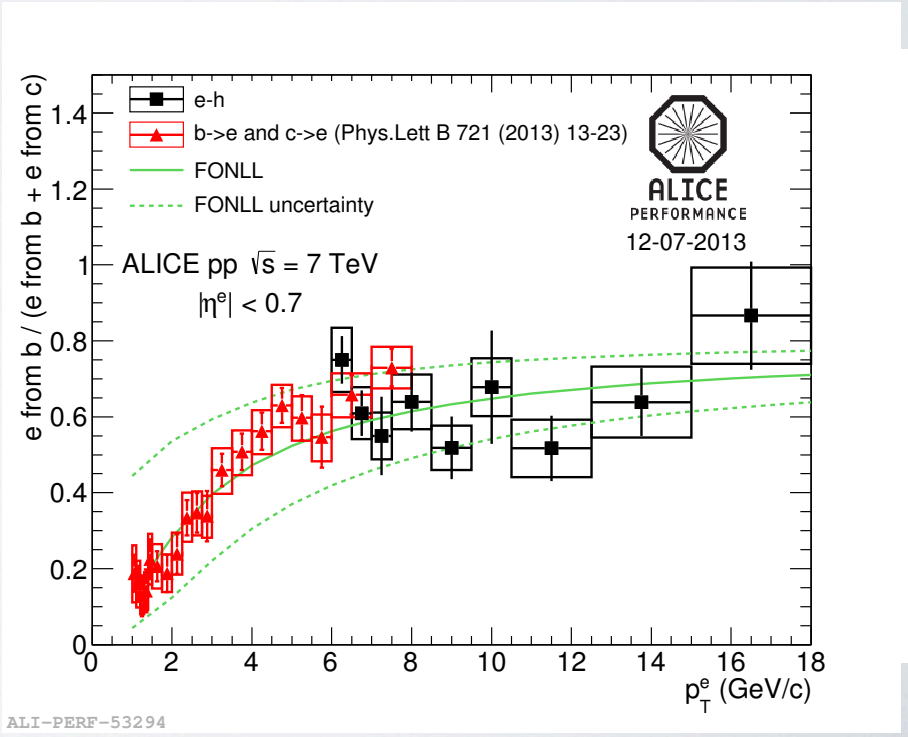
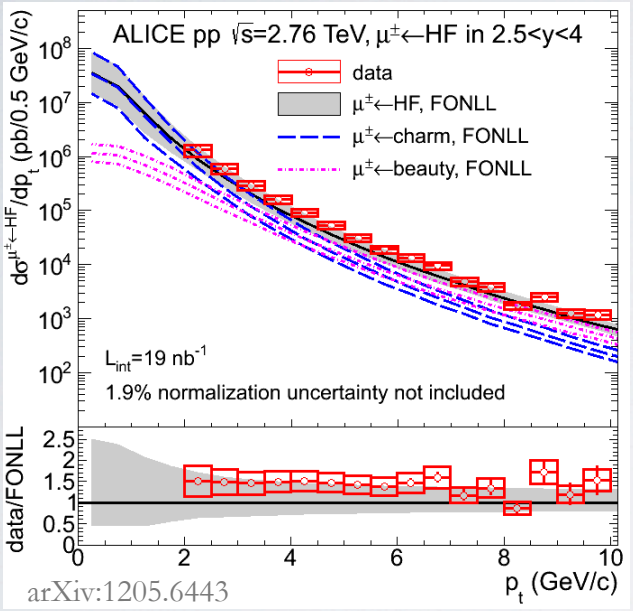


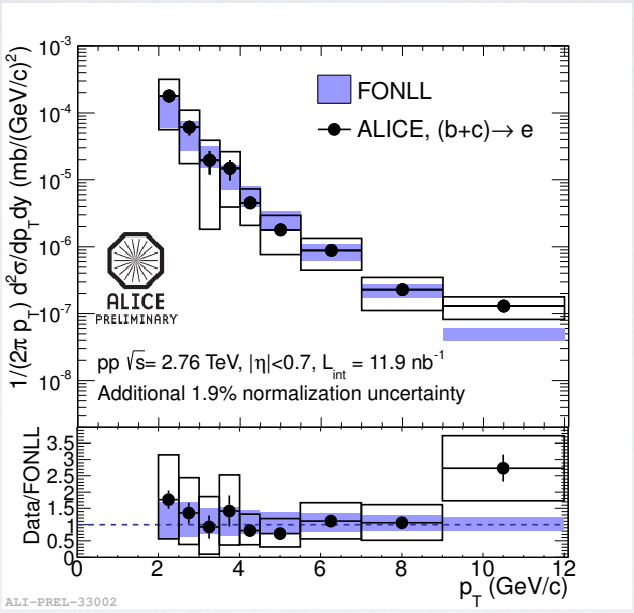
Various results from pp at 2.76 TeV

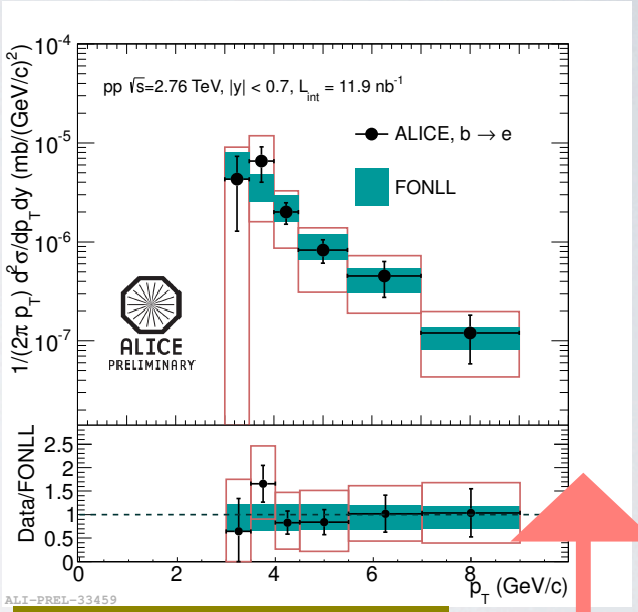
*** reference energy for Pb-Pb**

HF decay muons | **HF decay electrons** | **Beauty decay electrons**

***Used as pp reference for Pb-Pb**



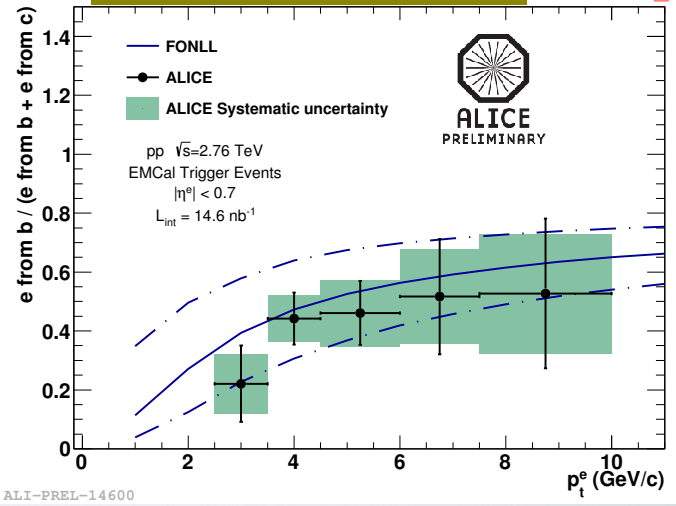




HF decay electrons - pp reference

- Lower uncertainties in 7 TeV sample
- Use FONLL scaled 7 TeV dataset as pp reference for Pb-Pb and p-Pb
  - p_T < 8 GeV/c scaled ALICE results at 7 TeV
  - p_T > 8 GeV/c FONLL extrapolation
- FONLL scaled 7 TeV cross section is consistent with the 2.76 TeV result

Fraction of e from B



Pb-Pb collisions

- **Nuclear modification factor**

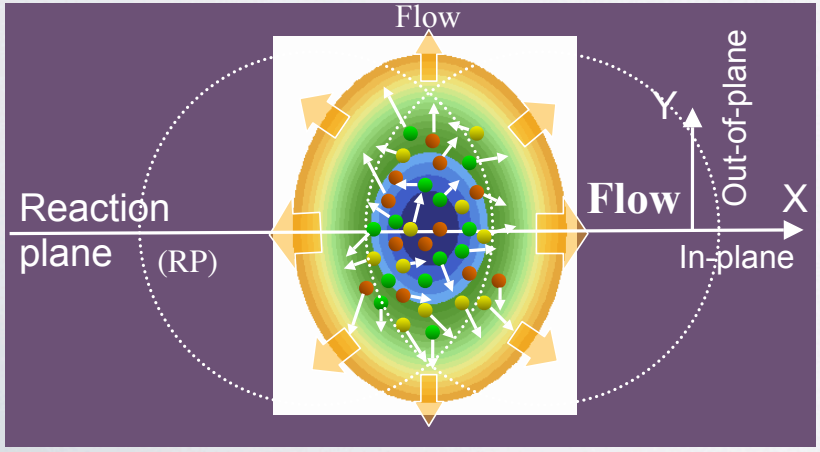
$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{yield\ in\ AA}{yield\ in\ pp} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

* N_{coll} and T_{AA} depend on the centrality of the collision. Estimated using the Glauber model

- **Elliptic flow**- Momentum space azimuthal anisotropy
  - sensitive to collectivity at low p_T and path length dependence of energy loss at high p_T

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2n}{p_T dp_T dy}(1 + 2\sum_{n=1}^{\infty} \nu_n \cos[n(\phi - \Psi_{RP})])$$

$$\nu_2 = < \cos(2[\phi - \Psi_{RP}]) >$$



Muons

R_{AA}: 2010 run, $\mathcal{L}_{int}$ = 2.7 μb^{-1}, MB trigger

v_2: 2011 run, 8 M semi-central trigger and 8.7 M central trigger events

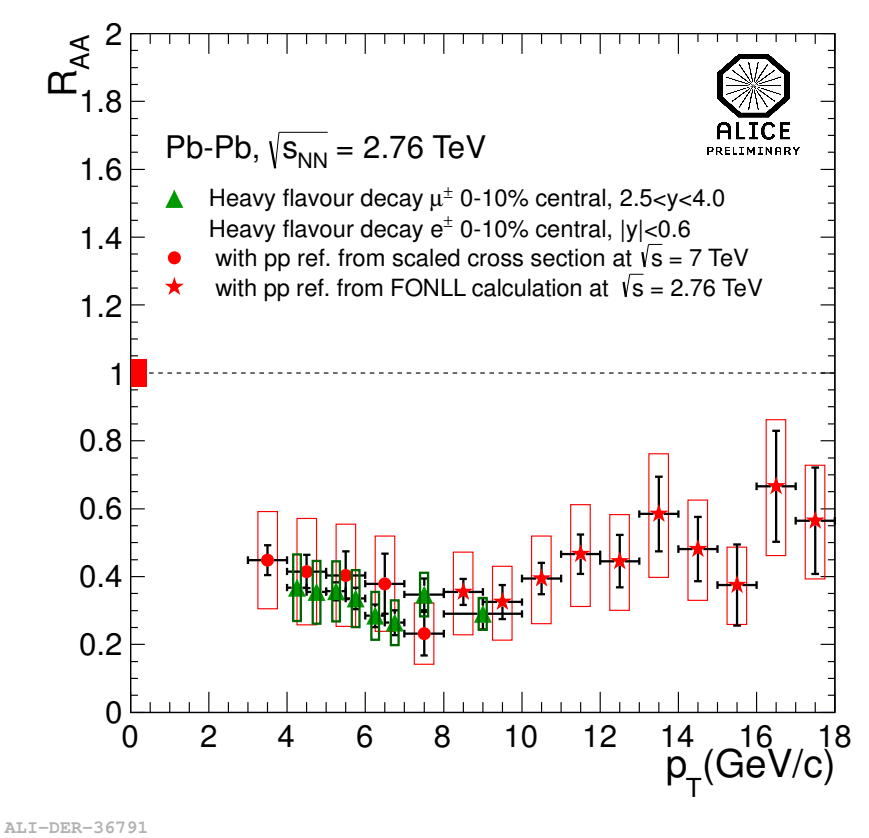
Electrons

R_{AA}: 2011 run, 16.7 M central trigger and 0.67 M EMCal trigger in 0-10%

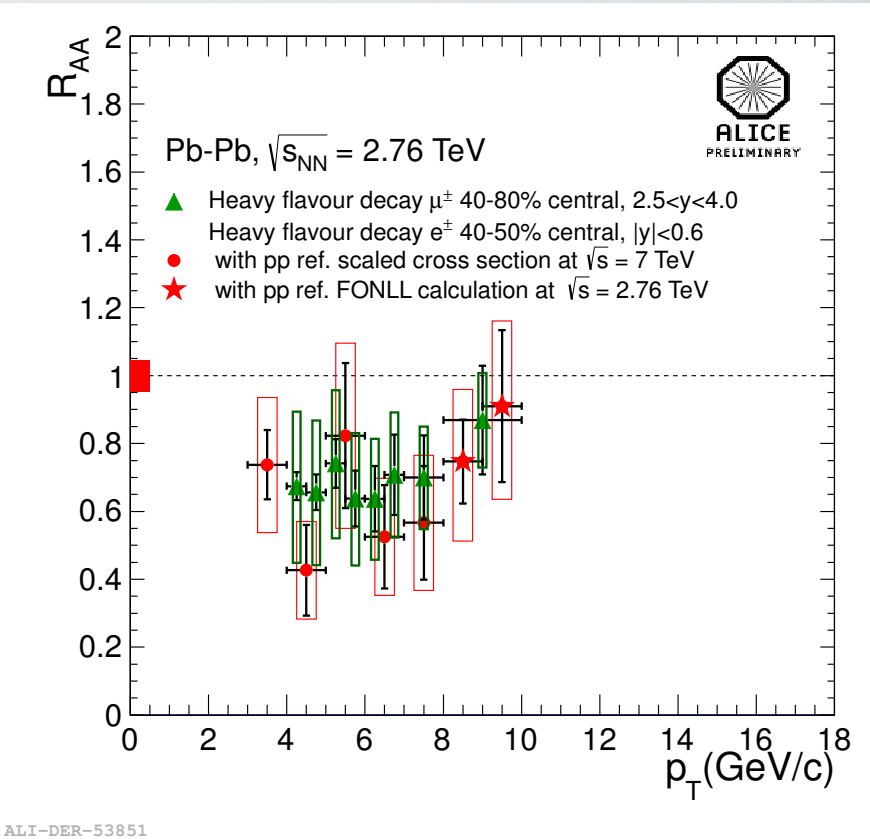
v_2: 2011 run, 7.3 M semi-central trigger and 1.3 M EMCal trigger in 20-40%

R_{AA} of HF decay leptons in Pb-Pb 2.76 TeV

central



peripheral

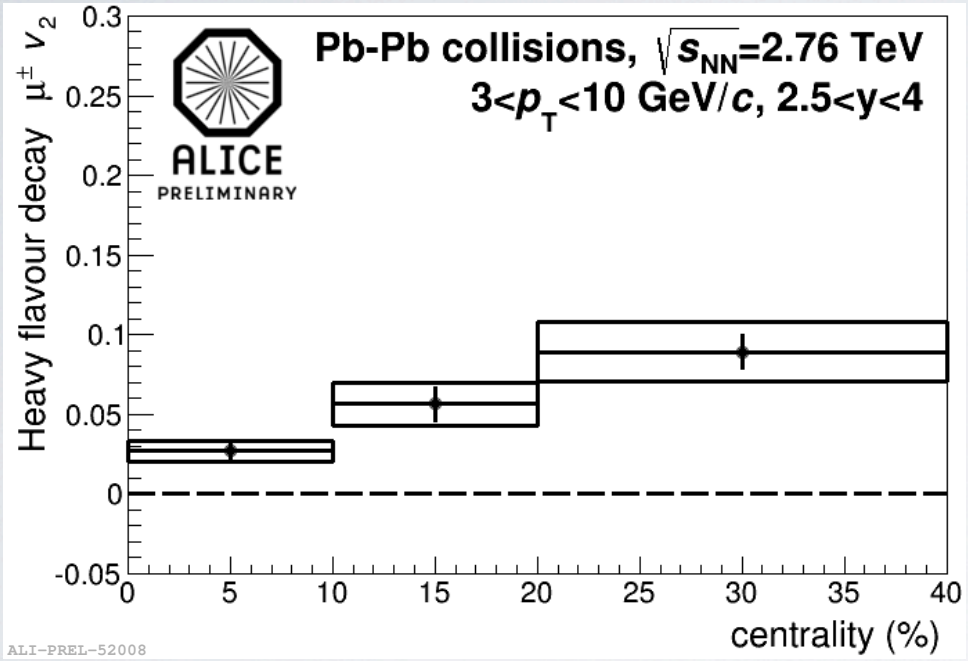


R_{AA} of HF decay **muons** and **electrons** measured in central (0–10%) and peripheral (40–50% for electrons and 40-80% for muons) collisions.

- For p_T ~ 7 GeV/c suppression factor 3-5 for most central collisions
- Suppression of HF decay electrons and HF decay muons comparable
- HF decay electrons suggest rise for higher p_T

v_2 of leptons Pb-Pb at 2.76 TeV

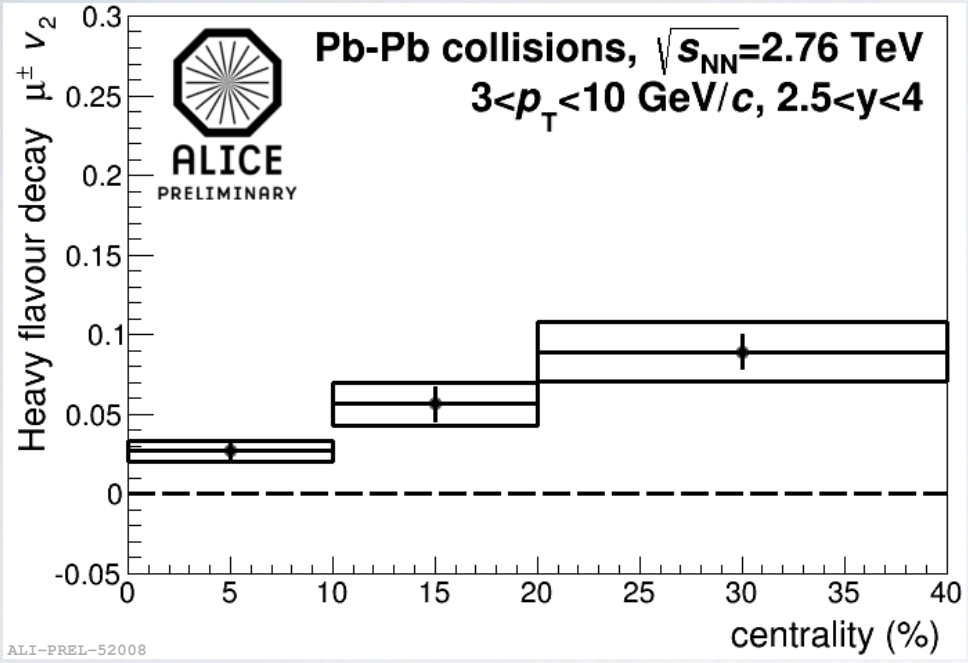
p_T integrated ($3 < p_T < 10$ GeV/c) elliptic flow (v_2) of muons from HF decays measured in $2.5 < y < 4$

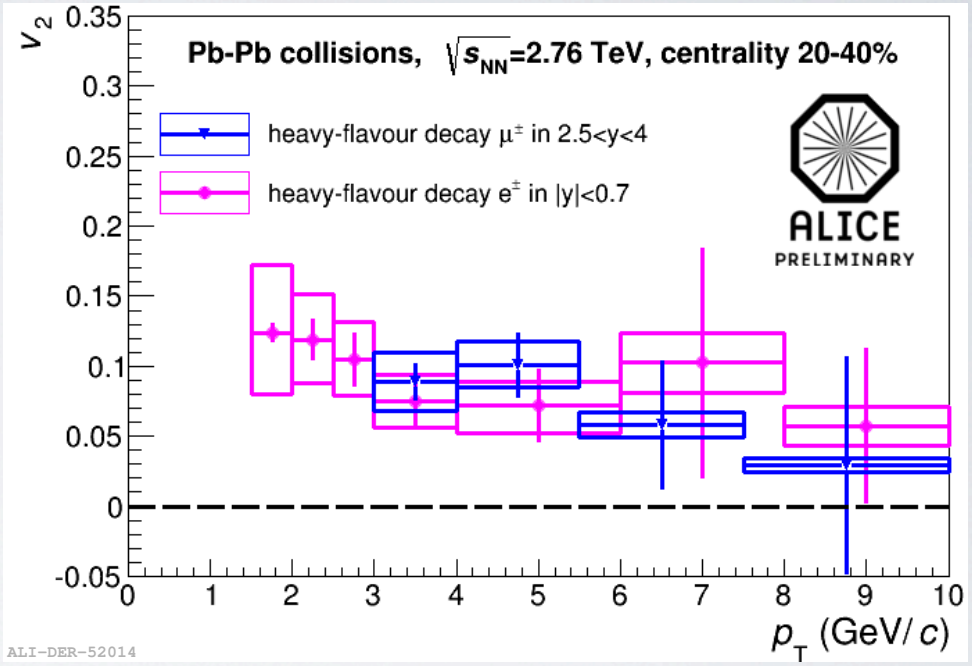


- v_2 increases from central to semi-central collisions
- Non-zero v_2 (3σ effect) in semi-central collisions

Elliptic flow of leptons Pb-Pb at 2.76 TeV

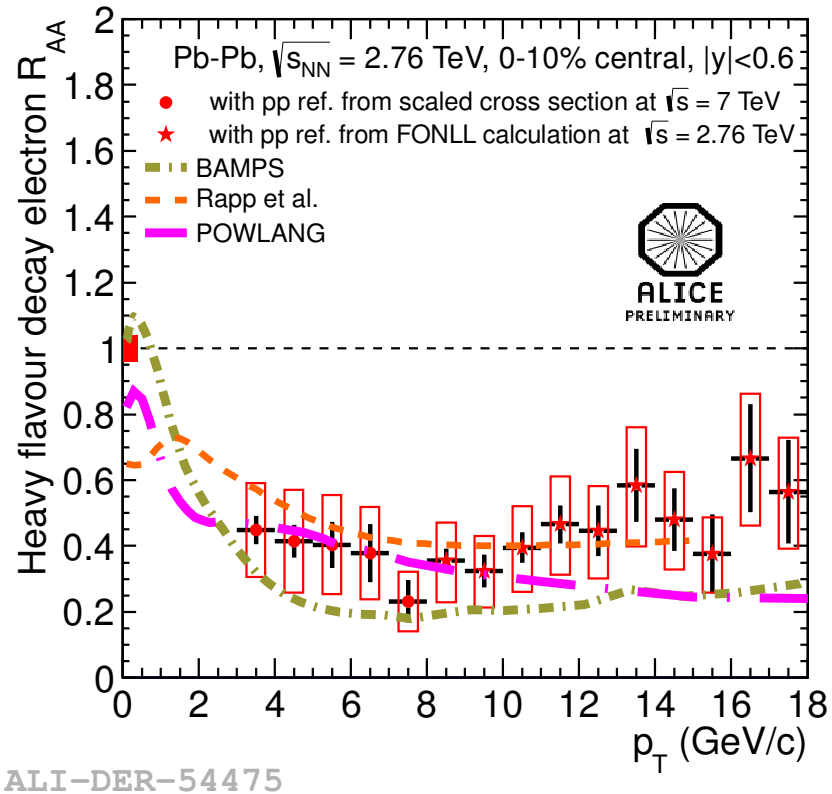
p_T integrated (3 < pT < 10 GeV/c) elliptic flow (v_2) of muons from HF decays measured in 2.5 < y < 4

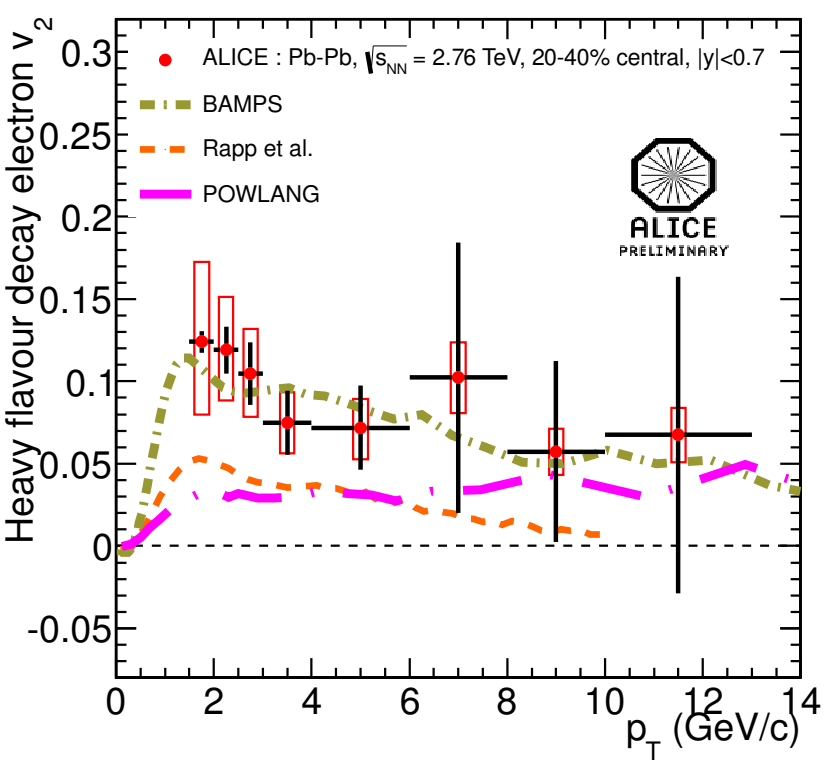




- v_2 increases from central to peripheral collisions
- Non-zero v_2 (3σ effect) in semi-central collisions
- v_2 of HF decay electrons at **mid-rapidity** is compatible with HF decay muons at **forward rapidity** within the experimental uncertainties

Model comparison to HF decay electrons





ALI-DER-54475

Partonic transport models

BAMPS - Radiative and collisional energy loss in a deconfined medium

J. Uphoff et al. arXiv 1205.4945

Rapp et al. - Collisional (elastic) processes via a non-perturbative T-matrix approach

R. Rapp et al. arXiv 1208.0256

POWLANG - Based on Langevin equation with collisional energy loss in a deconfined medium

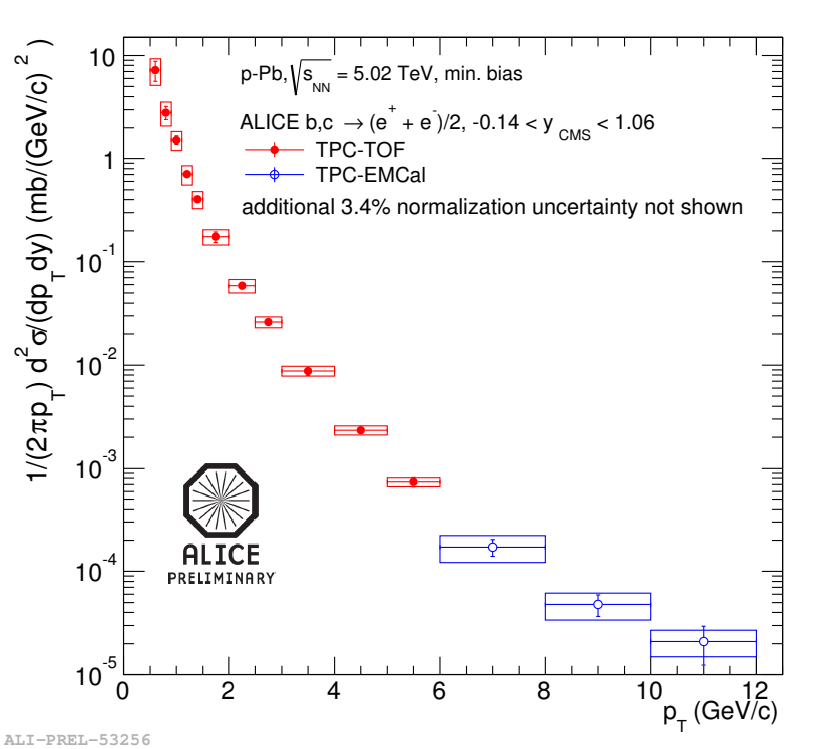
A.Beraudo et al J.Phys.G G38 124144

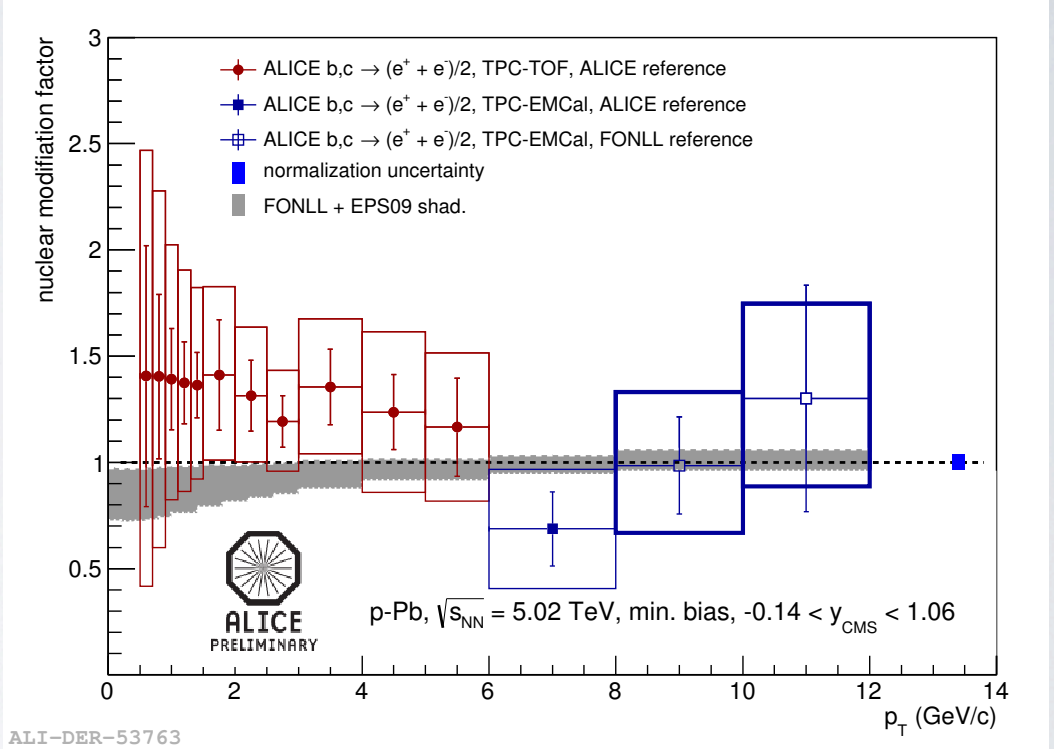
Difficult for models to describe both observables simultaneously

p-Pb collisions

$R_{p\text{-}Pb}$ electrons in p-Pb at 5.02 TeV

Electrons	2013 run, 105 M MB trigger events





- Results using 2 different eID strategies are consistent
- Data described by FONLL+EPS09 parametrization of shadowing, within the uncertainties K. J. Eskola, H. Paukkunen and C.A. Salgado JHEP 0904 (2009) 065
- Data hint at small cold nuclear matter effects, as observed for light flavour hadrons

Conclusions

Open heavy flavours at ALICE measured via semi-leptonic decay channels

Nuclear modification factor:

- In Pb-Pb HF decay leptons show a strong suppression in central collisions for $p_T > 3$ GeV/c
- Moves toward unity in peripheral collisions
- In p-Pb, results are consistent with small cold nuclear matter effects and EPS09 shadowing describes the measured $R_{p\text{-}Pb}$ within uncertainties

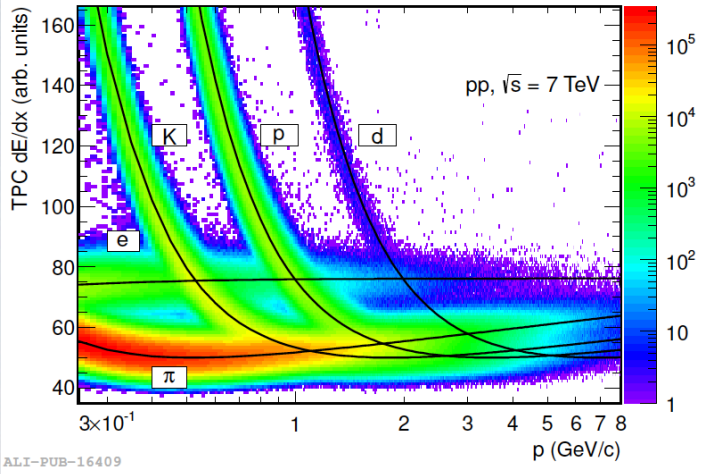
Elliptic flow:

- Indication of non-zero v_2 in semi-central collisions
- Comparable v_2 of muons in forward rapidity and electrons in the mid rapidity range

Backup

Electron ID in ALICE

Phys. Rev. D 86, 112007

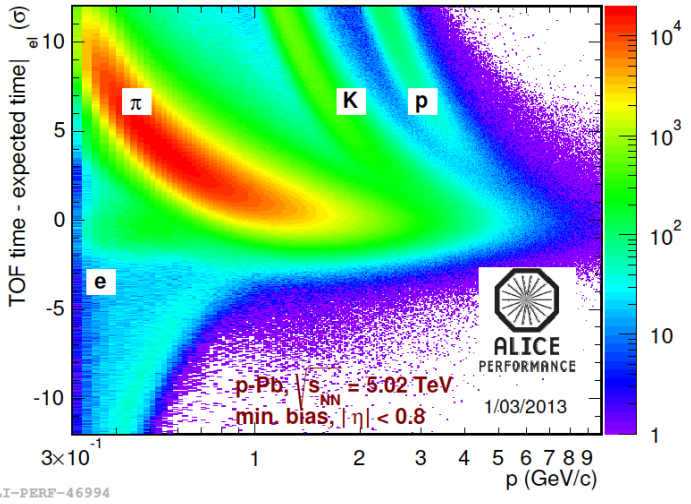


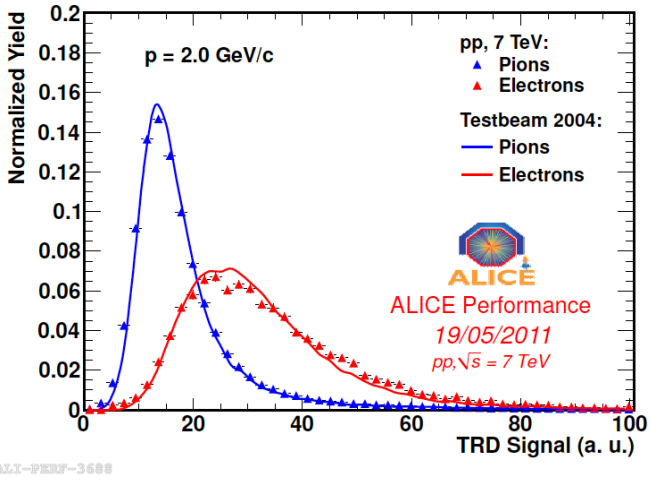
TPC

dE/dx

TOF

time of flight



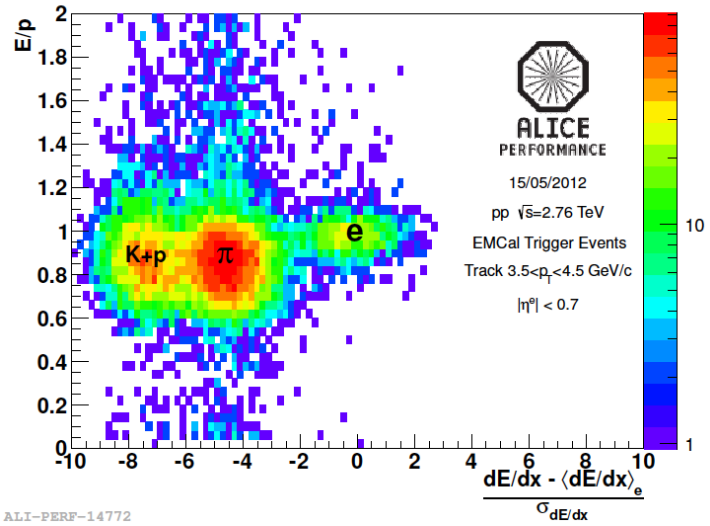


TRD

dE/dx + transition radiation

EMCal

E/p



HF decay muon R_{AA} w/ model comparisons