Nuclear Modification Factor and Elliptic Flow of Open Heavy Flavours in Pb-Pb Collisions at $\sqrt{s_{NN}}$=2.76 TeV with ALICE

Xiaoming Zhang for the ALICE Collaboration

Institute of Particle Physics, CCNU, Wuhan, China

Laboratoire de Physique Corpusculaire, CNRS/IN2P3, Clermont-Ferrand, France

Lawrence Berkeley National Laboratory, Berkeley, CA, U. S. A.

6th Workshop of the France China Particle Physics Laboratory

March 27-30, 2013, Nanjing, P. R. China

Outline

- Heavy Flavour Physics at the LHC
- Heavy Flavour Measurements with ALICE
- Results and Discussions
- ALICE Upgrade: Muon Forward Tracker
- Conclusion

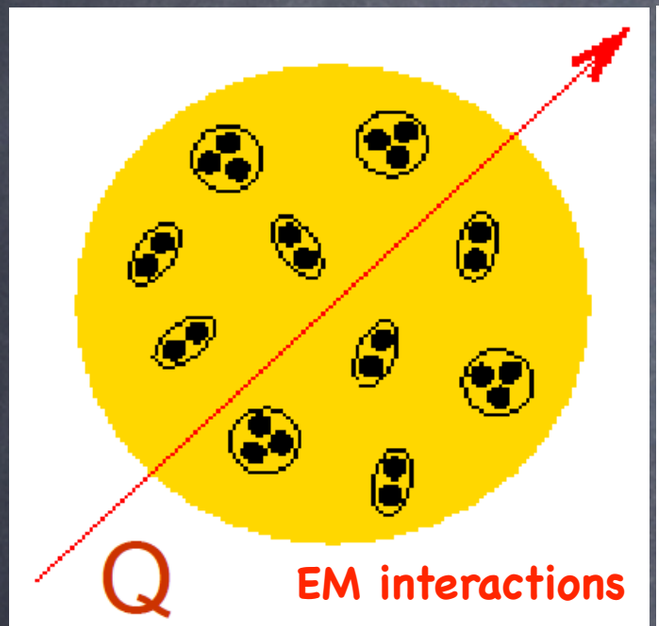
Part I

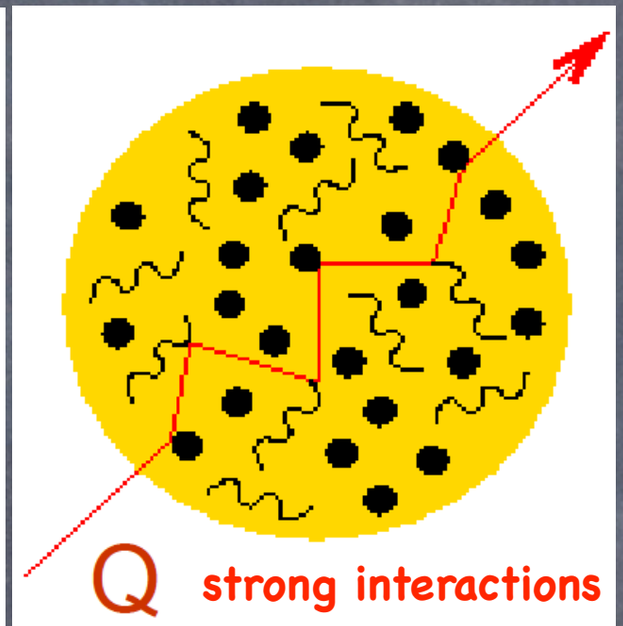
Introduction

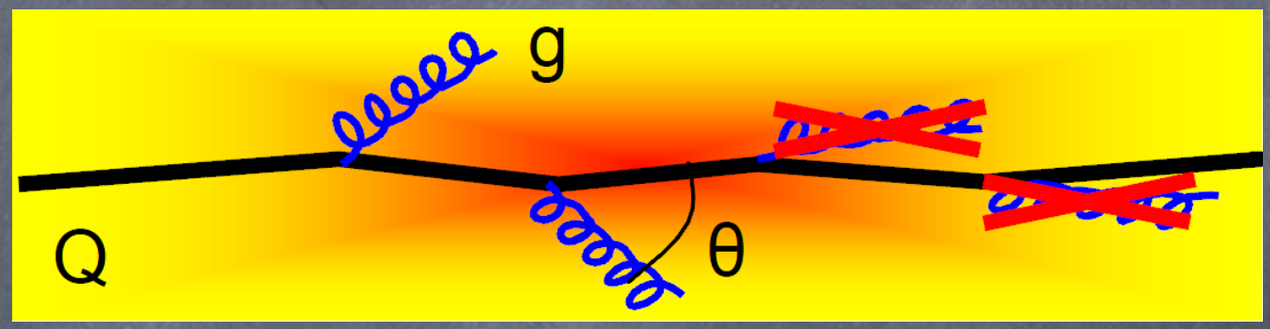
Heavy Flavour Physics at LHC

Heavy flavours in Pb-Pb collisions, tomography of QCD medium:

- nuclear modification factor, $R_{AA}(p_T, \eta)$







Dead cone in heavy quark radiative energy loss: gluon radiation suppressed at $\Theta < m_Q/E_Q$.

Color charge dependence of parton energy loss: gluons loss more energy than quarks in QCD medium.

$$R_{\mathrm{AA}}(p_{\mathrm{t}}) = \frac{1}{< N_{\mathrm{coll}} >} \frac{d\sigma_{\mathrm{AA}}/dp_{\mathrm{t}}}{d\sigma_{\mathrm{pp}}/dp_{\mathrm{t}}}$$

R_{AA}: ratio of particle yields in AA collisions to that in pp collisions scaled by the number of binary collisions.

$$\Delta E_g > \Delta E_{q \approx c} > \Delta E_b$$

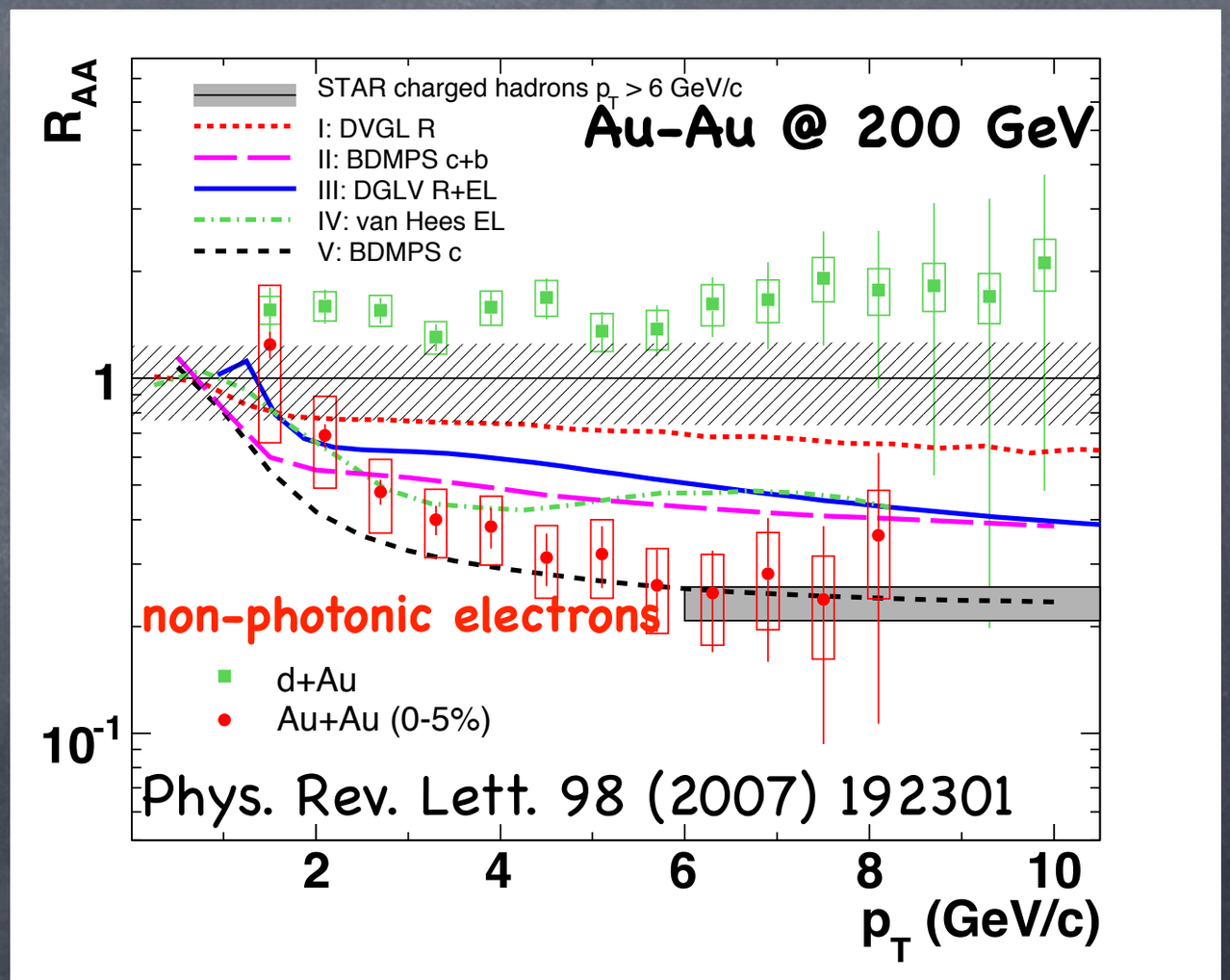
$$R_{AA}^h < R_{AA}^D < R_{AA}^B$$

Heavy Flavour Physics at LHC

Heavy flavours in Pb-Pb collisions, tomography of QCD medium:

- nuclear modification factor, $R_{AA}(p_T, \eta)$

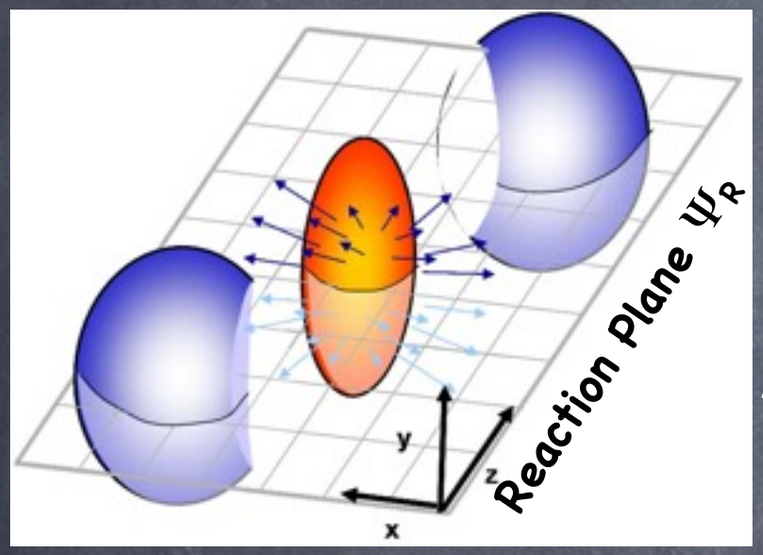
- understand heavy quark in-medium energy loss mechanism:
  - radiative vs. collisional energy loss;
- heavy-to-light ratio:
  - mass and color charge dependence of parton energy loss,
  - distinguish different QGP scenarios.



Heavy Flavour Physics at LHC

Heavy flavours in Pb-Pb collisions, tomography of QCD medium:

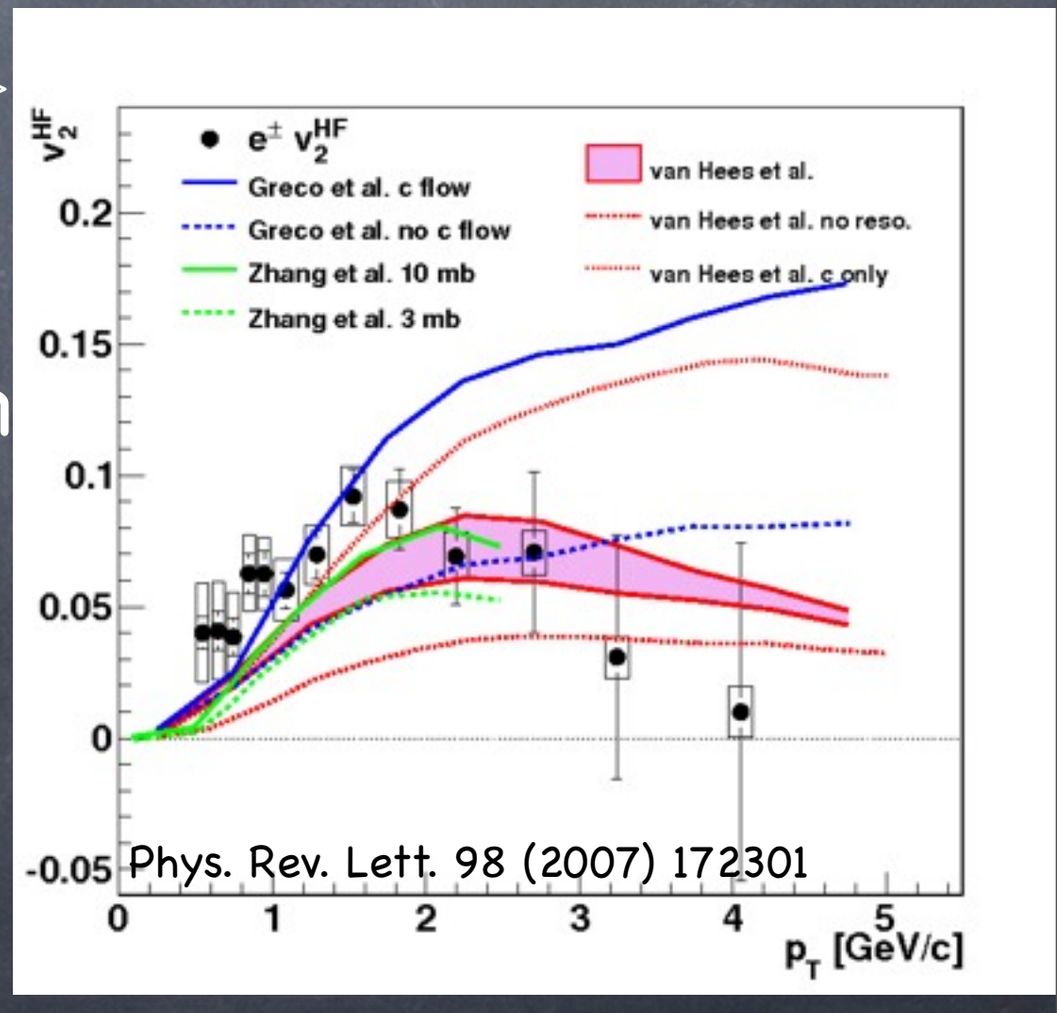
- azimuthal anisotropic flow, $v_n(p_T, \eta)$



$$E\frac{d^3\sigma}{d^3\vec{p}} = \frac{d^2\sigma}{2\pi p_t dp_t dy}[1 + \sum_{n=1}^{\infty} 2v_n \cos n(\phi - \Psi_R)]$$

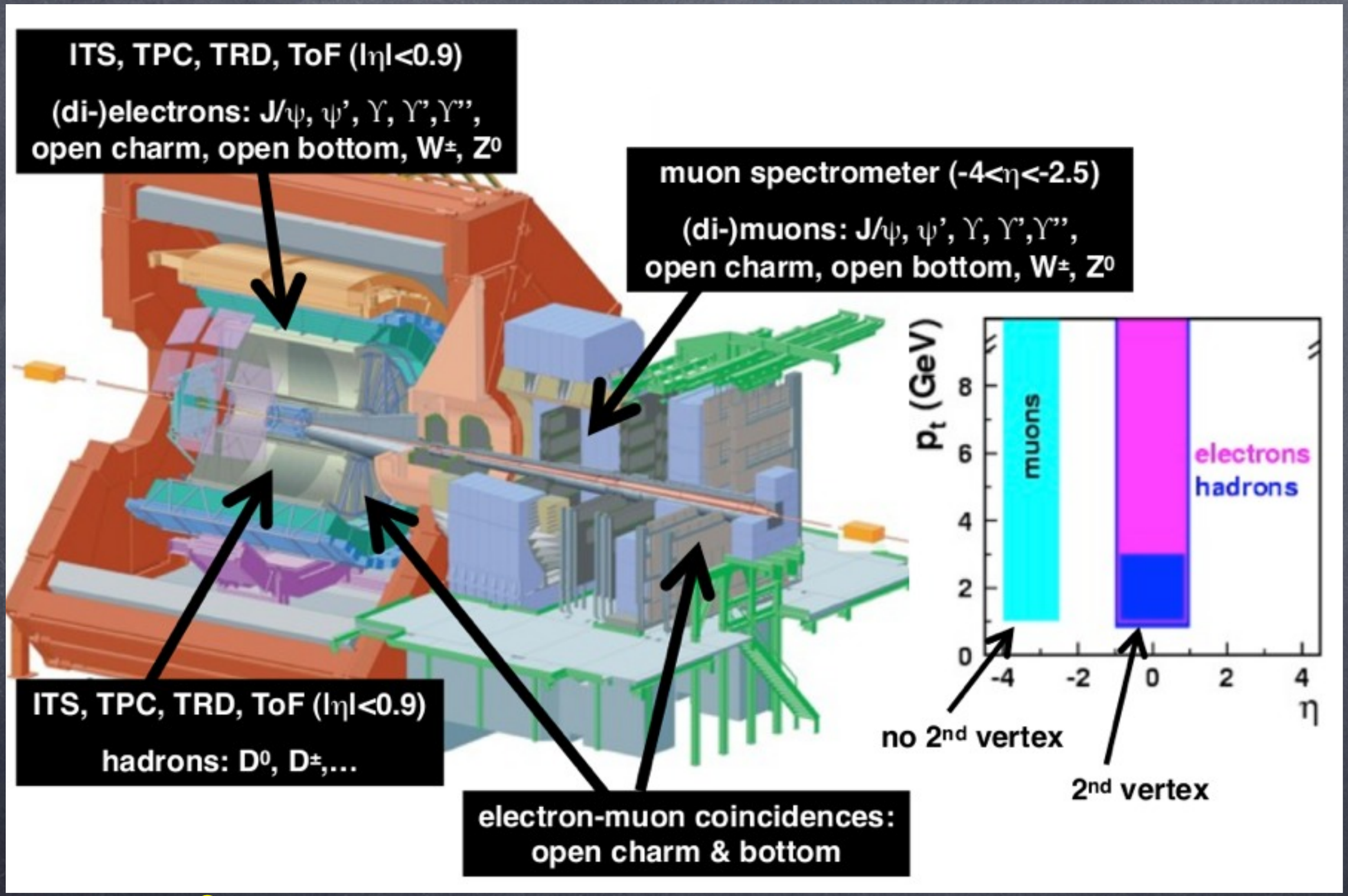
$$v_n = < \cos n(\phi - \Psi_R) >$$

- low p_T region:
  - initial conditions of QCD medium
  - degree of thermalization of heavy quarks in QGP;
- high p_T region:
  - path length dependence of heavy quark energy loss;



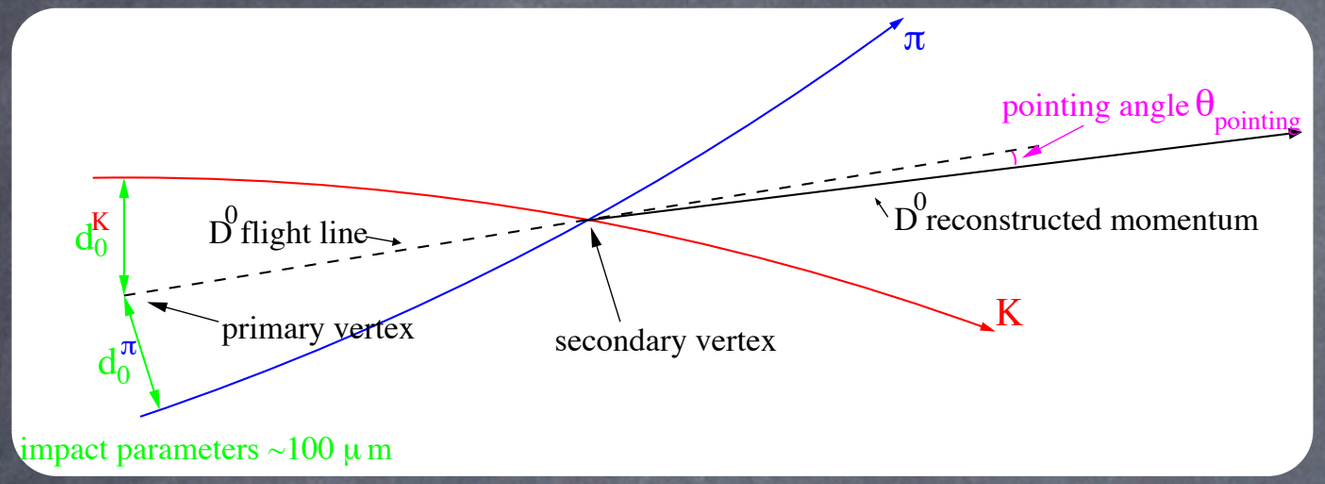
Part II
Heavy-Flavour Measurements with ALICE

Heavy-Flavour Measurements with ALICE



The heavy-flavour physics is investigated in various decay channels and rapidity regions with ALICE.

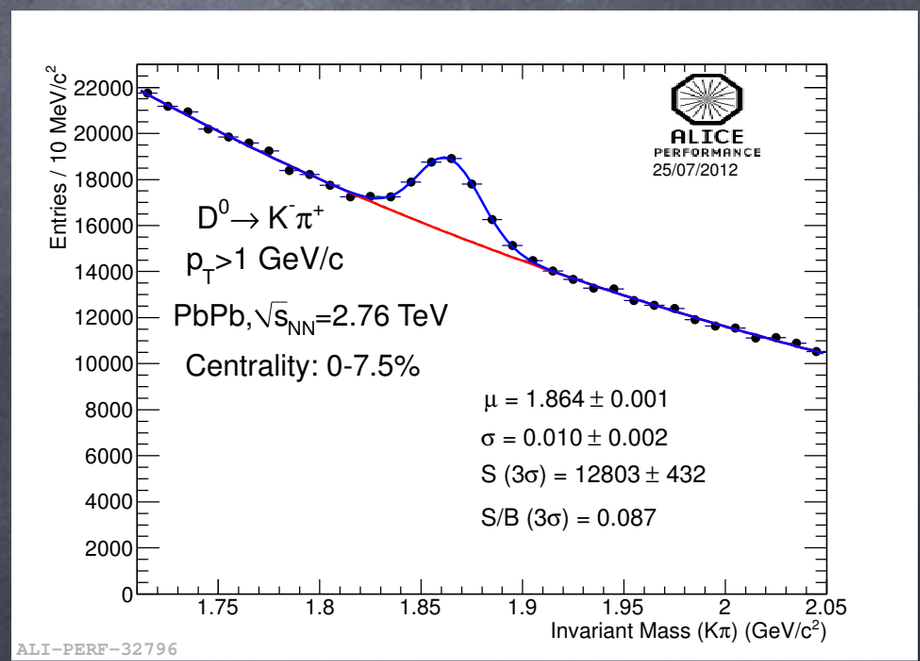
D-meson Measurements ($|\eta|<0.5$)



Tagged channels:

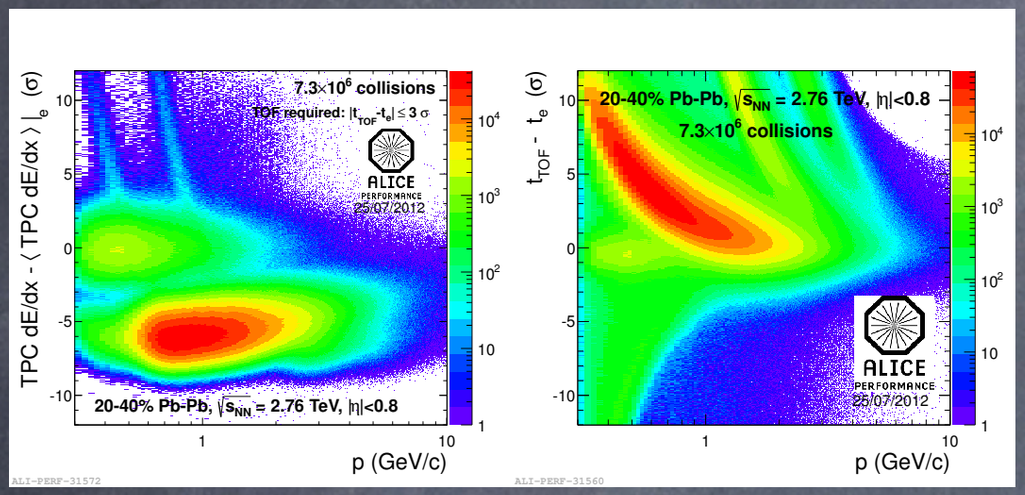
- $D^0 \rightarrow K^-\pi^+$
- $D^{*+} \rightarrow D^0(\rightarrow K^-\pi^+)\pi^+_s$
- $D^+ \rightarrow K^-\pi^+\pi^+$
- $D_s^+ \rightarrow \phi(\rightarrow K^+K^-)\pi^+$

- Strategy: D mesons are reconstructed via the secondary vertices displaced of few hundred micrometers.
- Main selection criteria:
- p_T and impact parameter of single tracks;
- separation between primary and secondary vertices (pointing angle), suppress the combinatorial background;
- PID (π, K and p) using TOF+TPC, reject combinatory background, mainly at low p_T.
- Signal extraction: invariant mass analysis.



Heavy-Flavour Decay Electrons ($|\eta|<0.9$)

Electron PID: TPC (dE/dx)+TOF+TRD+EMcal



Main source of background:

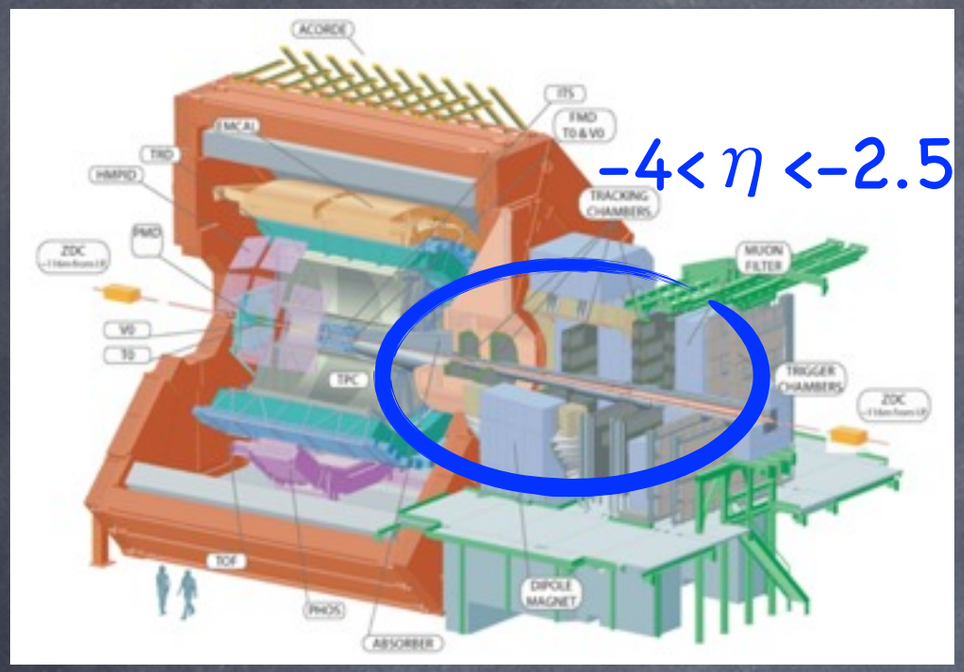
- photon conversions;
- Dalitz decays of neutral mesons;
- quarkonia decays;
- direct photons;
- Drell-Yan processes.

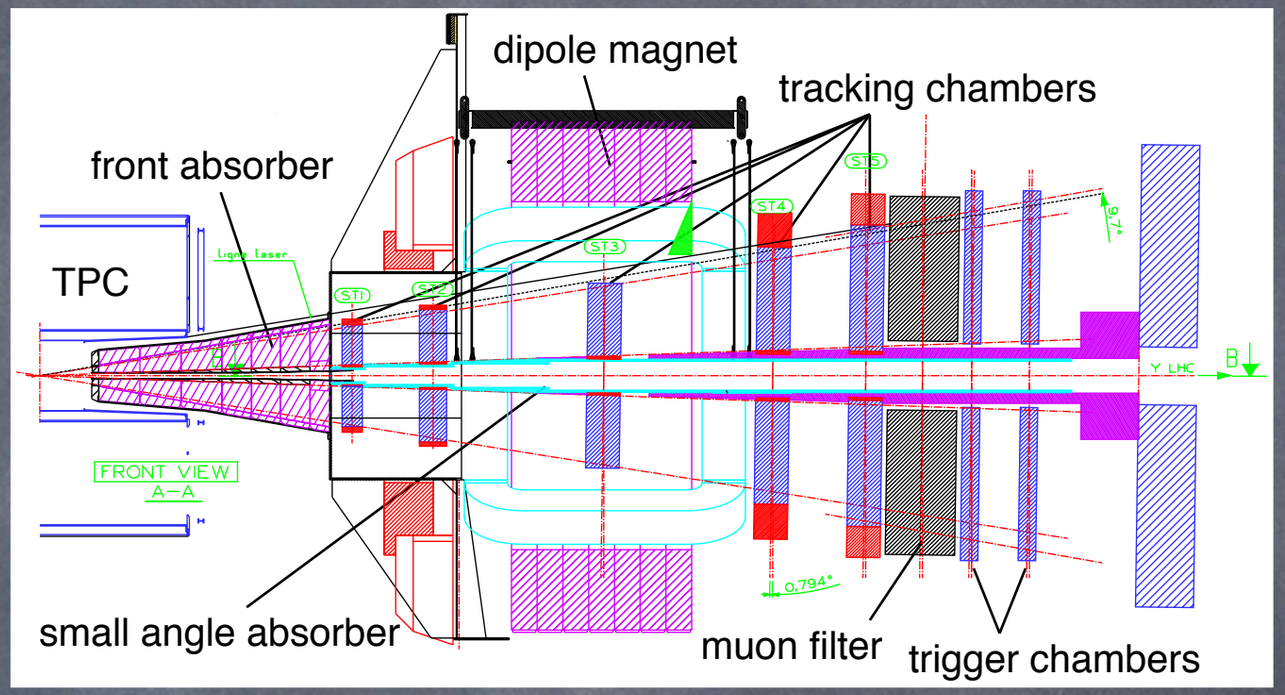
Background subtraction:

- invariant mass method: to remove π^0, Dalitz, photon conversions;
- cocktail: different background sources using Monte Carlo hadron-decay generator.

Heavy-Flavour decay electrons dN/dp_T obtained after subtraction of the background from the inclusive electron spectrum.

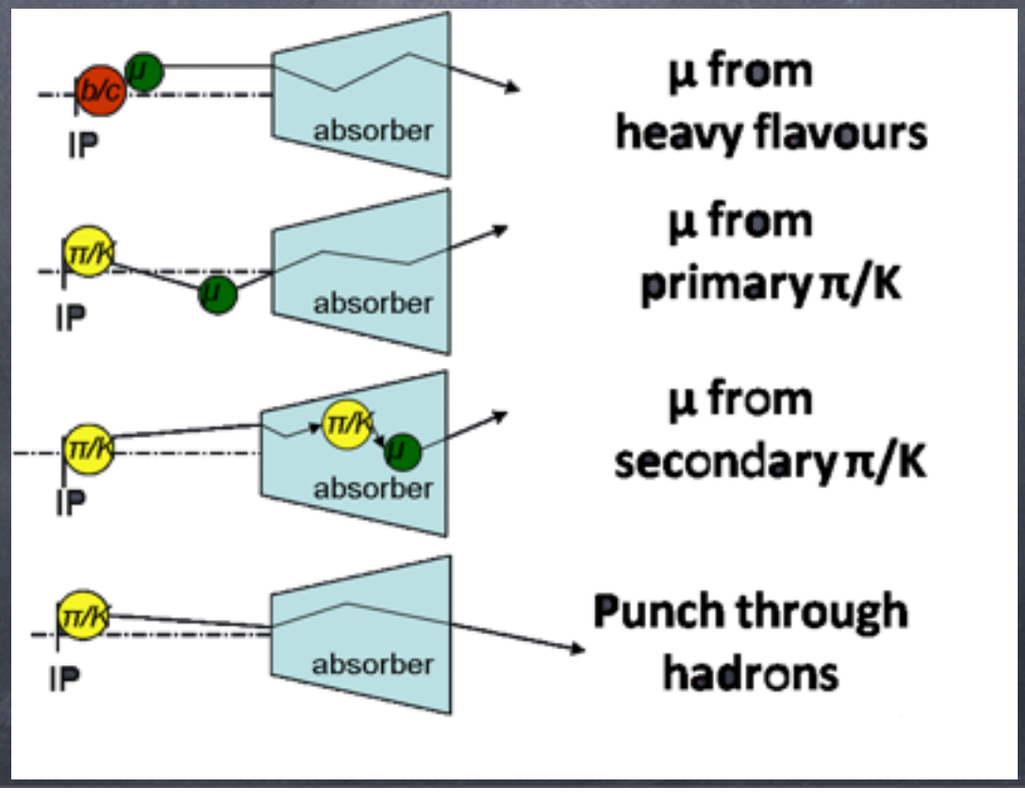
Heavy-Flavour Decay Muons ($2.5<|\eta|<4$)





Track selection:

- $-4<\eta<-2.5$: acceptance of ALICE MUON spectrometer;
- muon trigger matching: reject hadrons that punch through the absorber;
- pointing angle to the vertex: remove beam-gas and particles produced in the absorber.



Decay Muon Subtraction in Pb-Pb Collisons

- Input: K/π spectra in pp collisions and R_{AA} in Pb-Pb collisions at central rapidity measured with ALICE [J. Phy. G, G38 (2011) 124014 & 124080];
- extrapolate K/π spectra in pp collisions to forward rapidity:

$$\frac{d^2N_{\rm pp}^{\rm K/\pi}}{dp_{\rm T}dy} = \frac{d^2N_{\rm pp}^{\rm K/\pi}}{dp_{\rm T}dy}|_{y=0} \times \exp[-\frac{1}{2}(\frac{y}{\sigma_y})^2]$$

with σ_y=3.3 estimated from PYTHIA and PhoJet (error≈15%);

- get K/π spectra in Pb-Pb collisions at forward rapidity via:

$$\frac{d^2N_{\rm AA}^{\rm K/\pi}}{dp_{\rm T}dy} =< T_{\rm AA} > \times R_{\rm AA}^{K/\pi}|_{y=0} \times \frac{d^2\sigma_{\rm pp}^{\rm K/\pi}}{dp_{\rm T}dy}$$

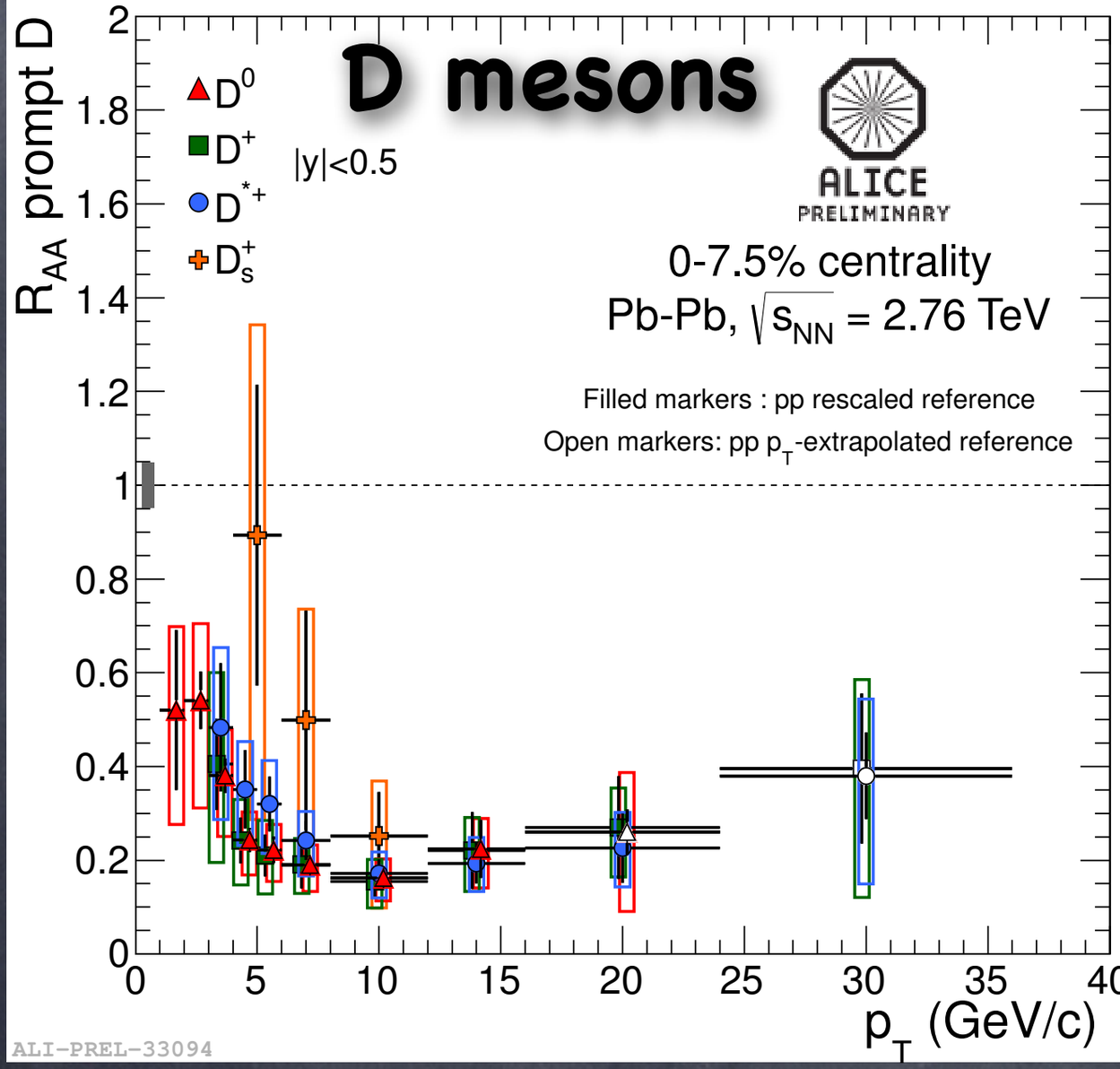
varying K/π R_{AA} between 0 and 200% to estimate the systematic uncertainty on unknown quenching effect at forward rapidity.

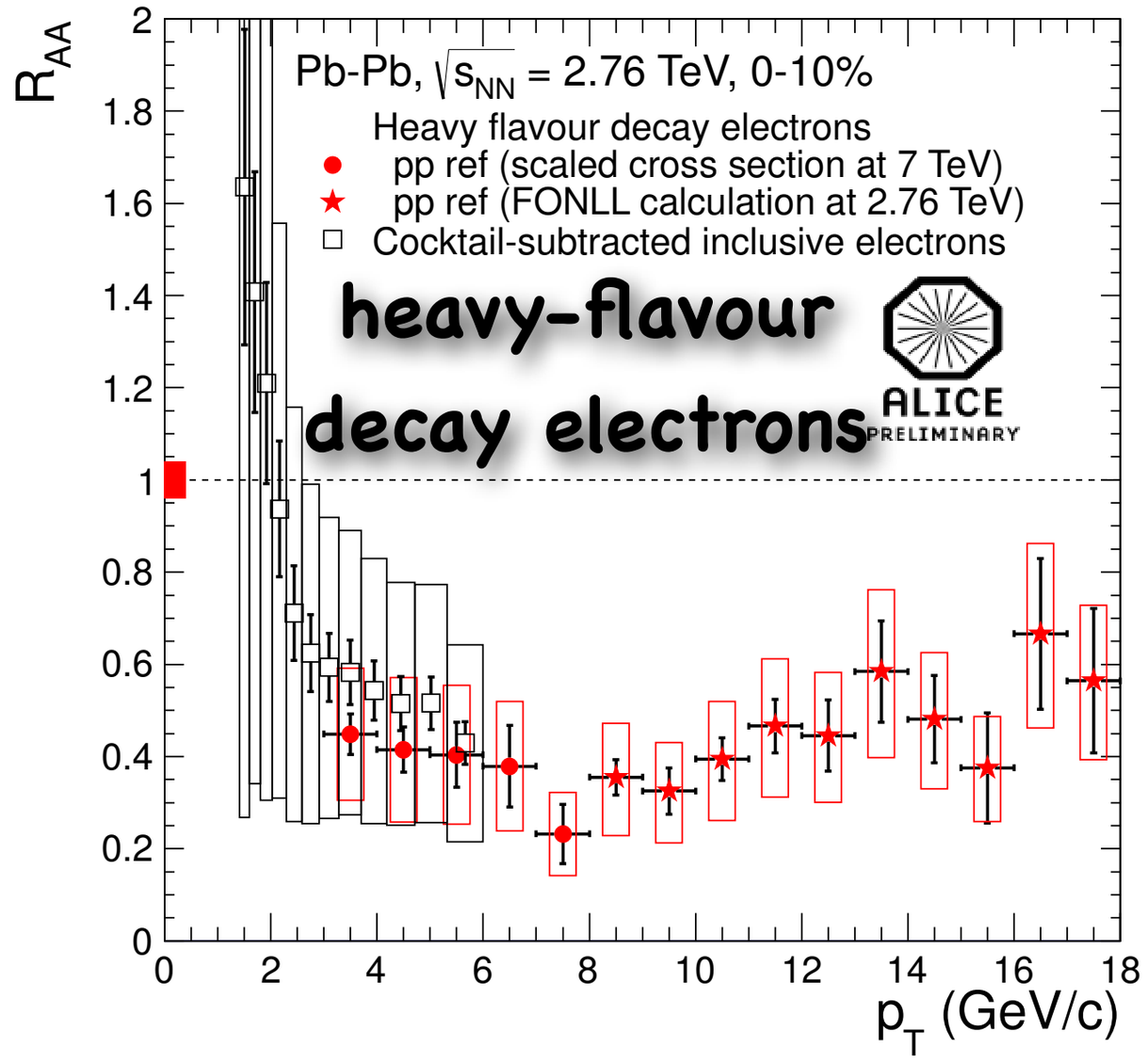
- produce the K/π decay muon background in Monte-Carlo with fast detector simulation.

Part III

Results and Discussions

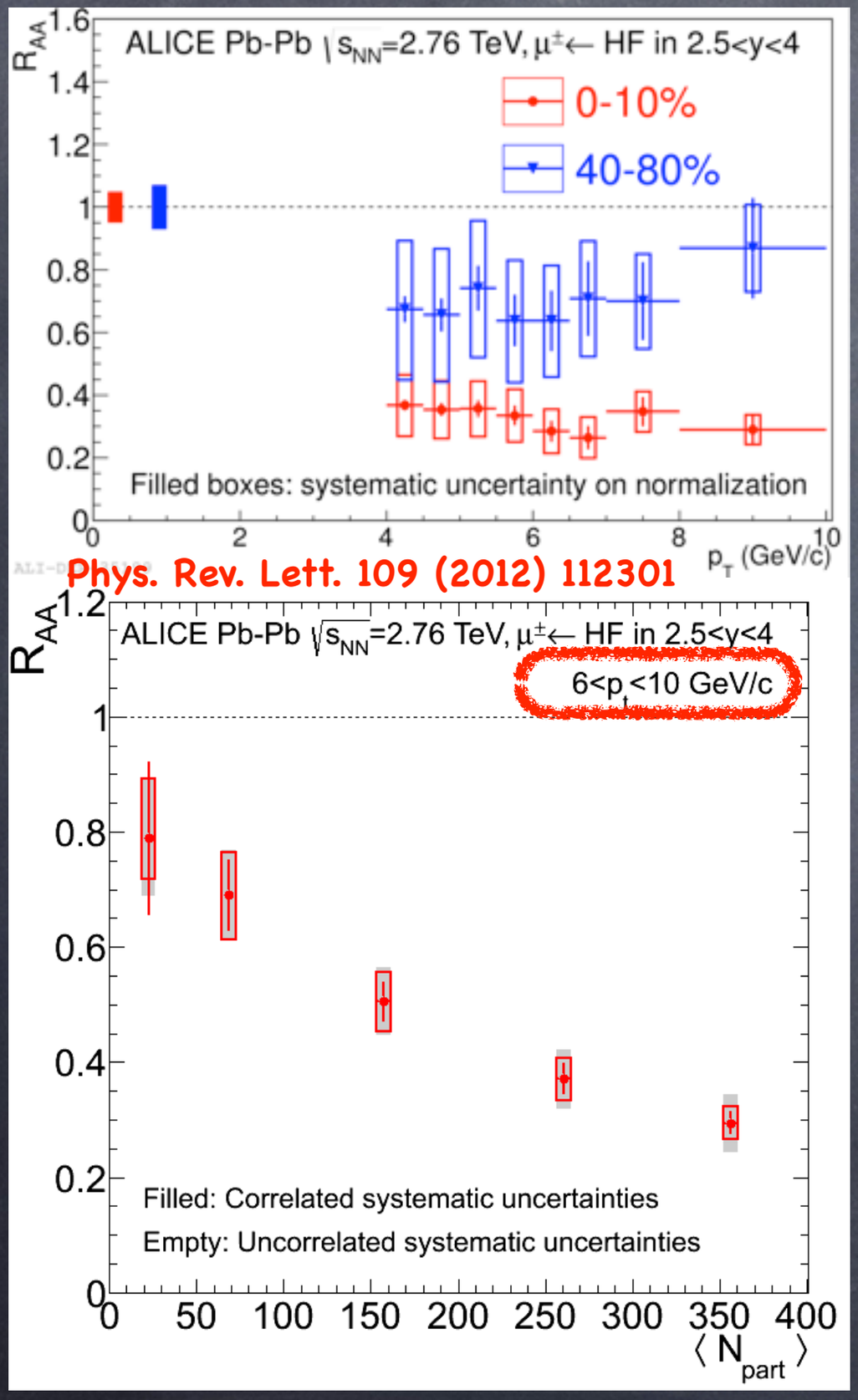
R_{AA} of Heavy Flavours at Mid-rapidity





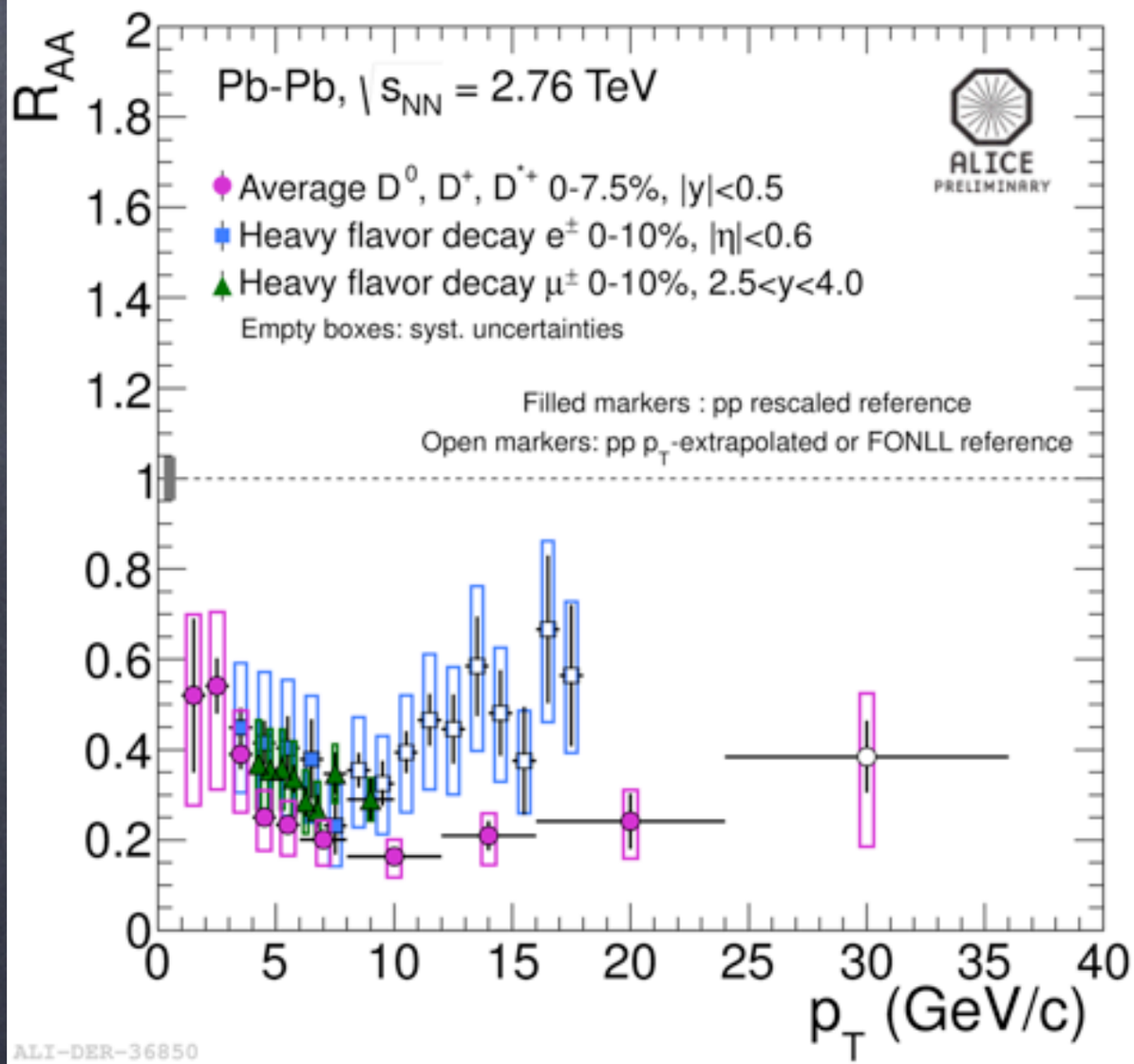
- R_{AA} of D^0, D^+ and D^* agree within uncertainties;
- large uncertainties do not allow us to conclude on the enhancement of strange/non-strange D meson yield that is predicted at low/intermediate p_T if c quarks hadronize by recombination in the medium;
- strong suppression for both D mesons and heavy-flavour decay electrons is observed in central Pb-Pb collisions.

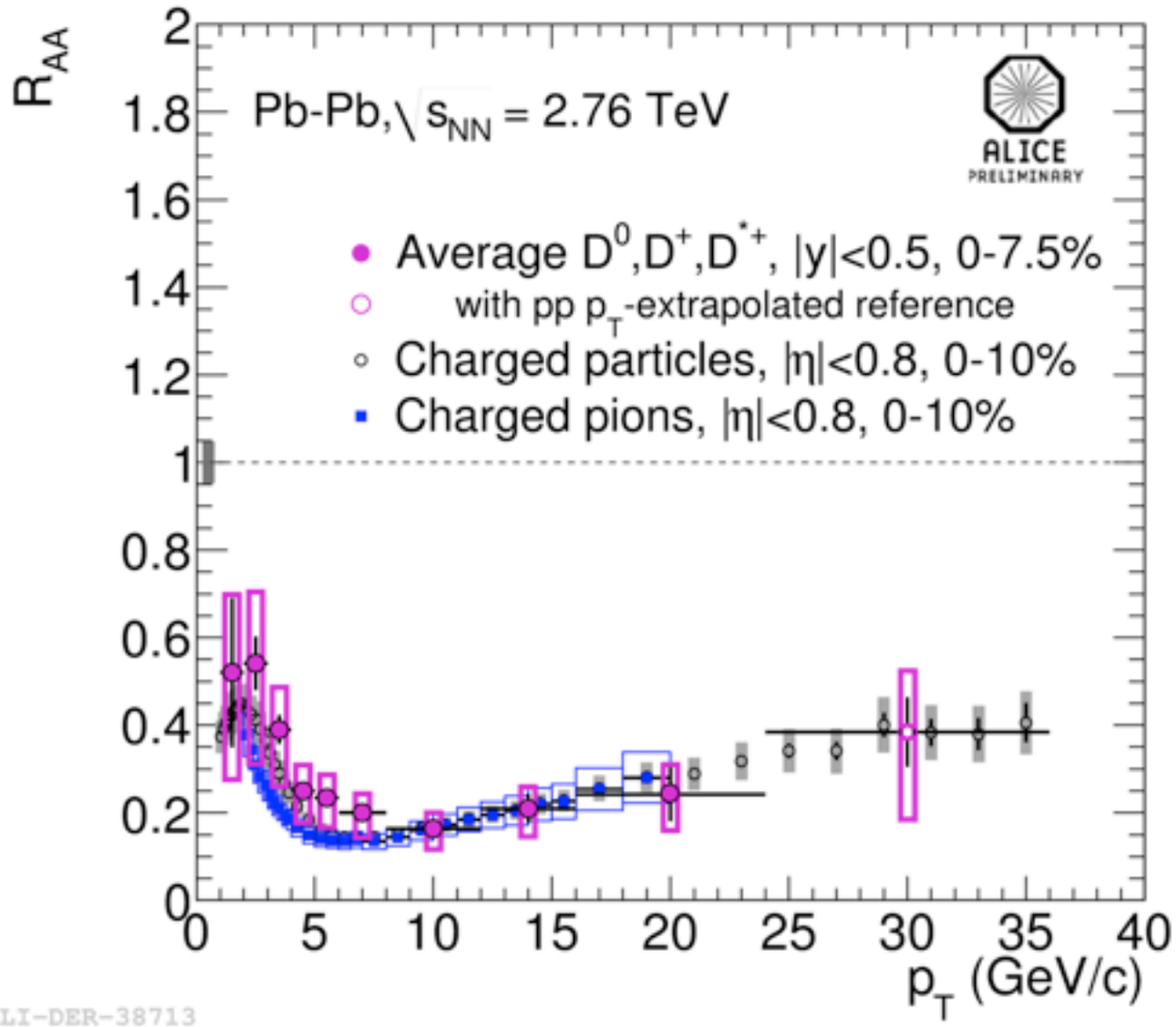
R_{AA} of Heavy-Flavour Muons in Forward Rapidity



- Suppression is observed and is independent of p_T within uncertainties (in the measured p_T interval);
- stronger suppression in central than peripheral collisions, reaching a factor of about 3-4 in the 10% most central collisions;
- in the p_T region (p_T>6 GeV/c), beauty contribution is dominant in pp collisions, according to FONLL calculations.

p_T-differential R_{AA} of Heavy Flavours

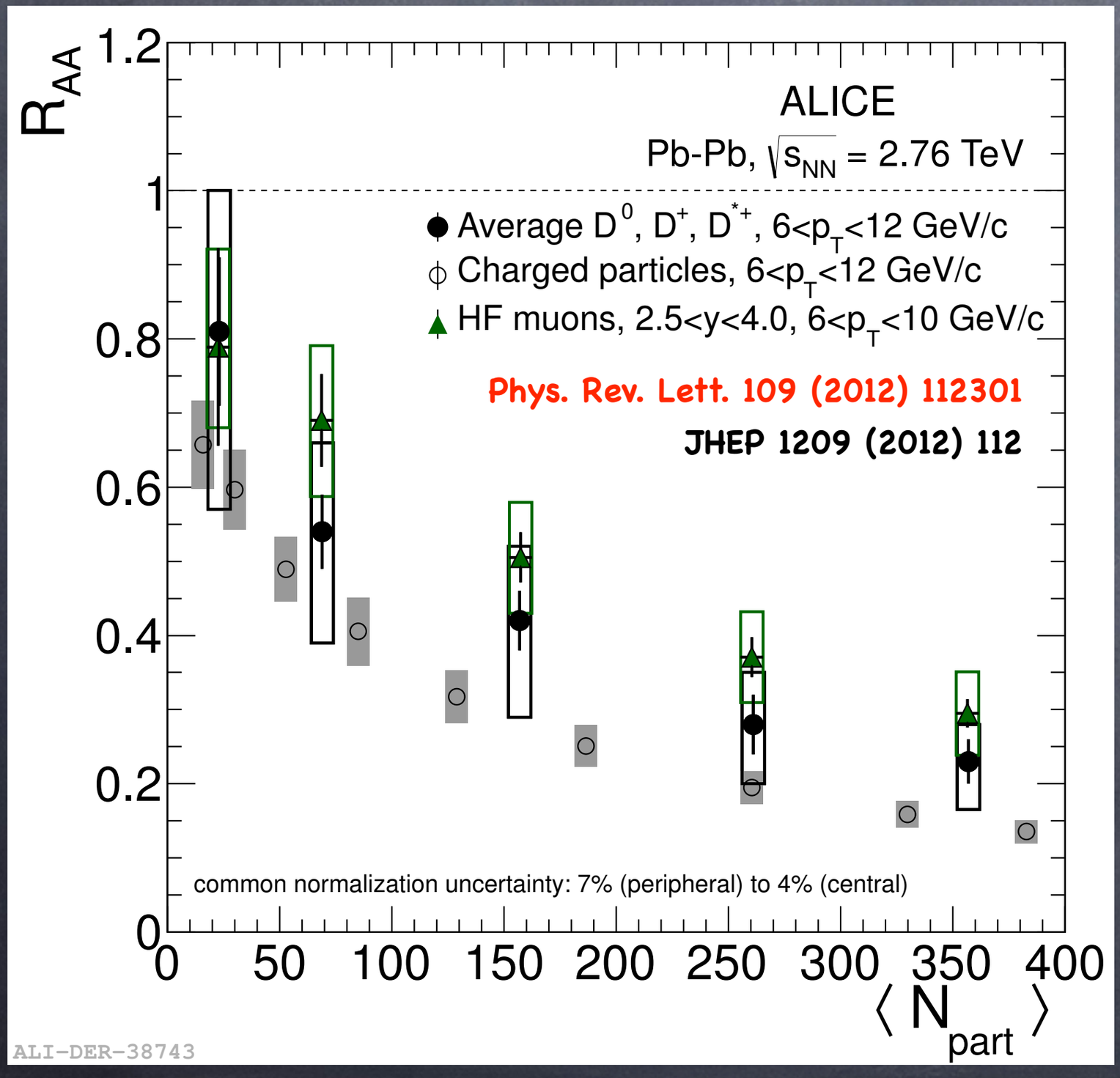




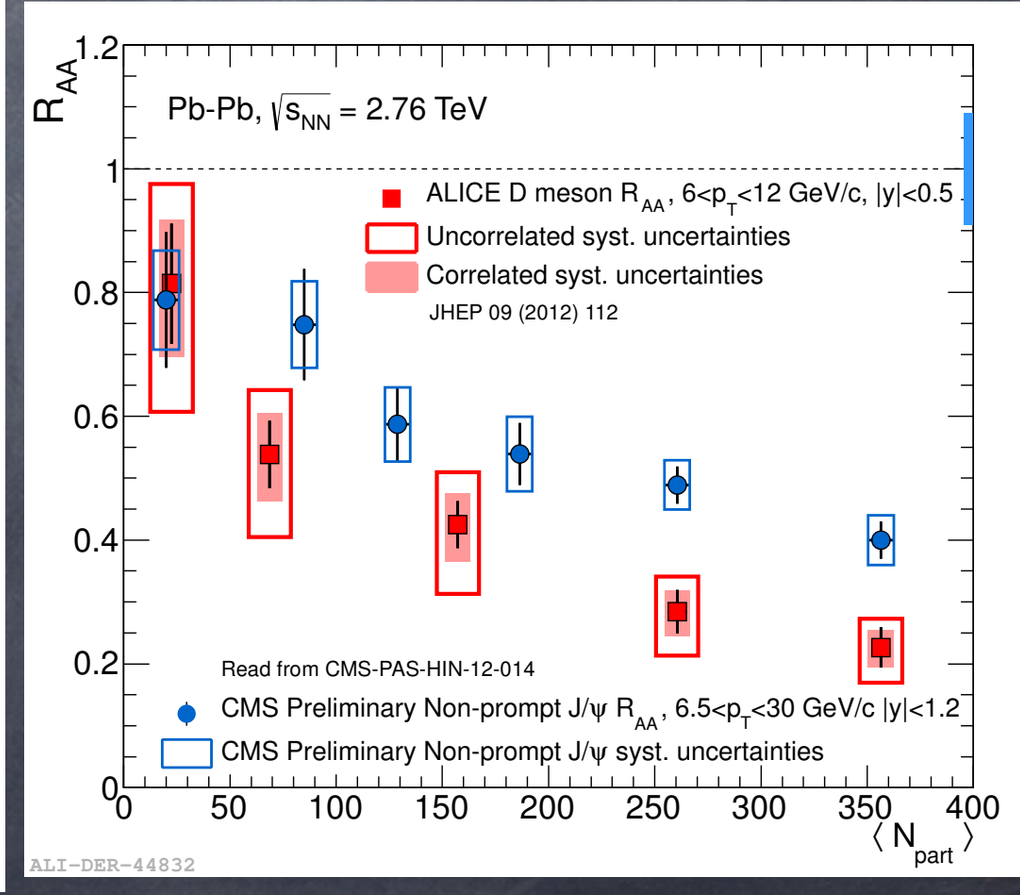
- Similar HF decay e ($|y|$<0.6) and μ (2.5<y<4.0) R_{AA} in 0-10%;
- difficulty: comparison of R_{AA} of D mesons and that of HF decay electrons must consider semi-leptonic decay kinematics ($p_T^e \sim 0.5\ p_T^B$ at high p_T);
- R_{AA} of D mesons shows a similar trend as light hadrons in 0-10%.

Heavy-Flavour R_{AA} versus Centrality

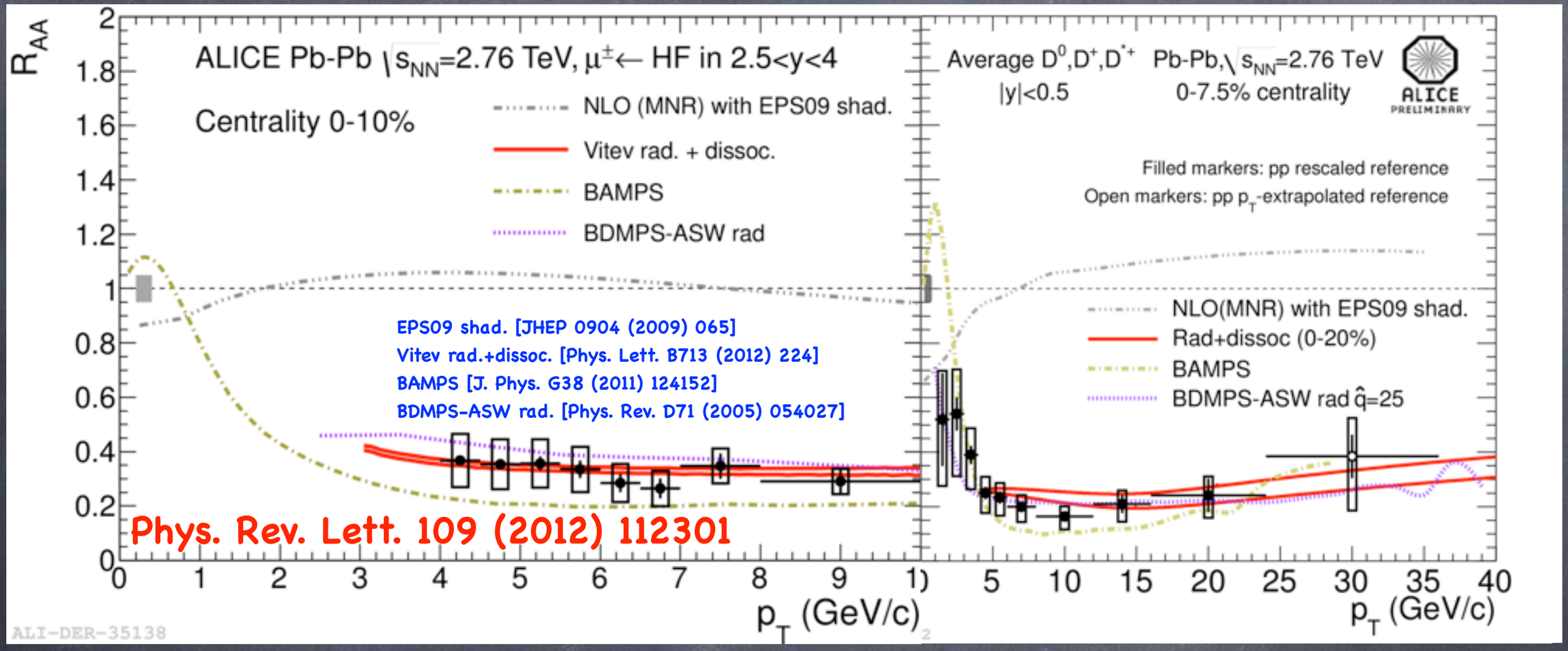
- D meson and HF muon R_{AA} at high-p_T show a similar centrality trend;



- Data not conclusive on R_{AA}(charged hadrons)<R_{AA}(D);
- Non-prompt J/ψ measurement (CMS) indicates R_{AA}(B)>R_{AA}(D).

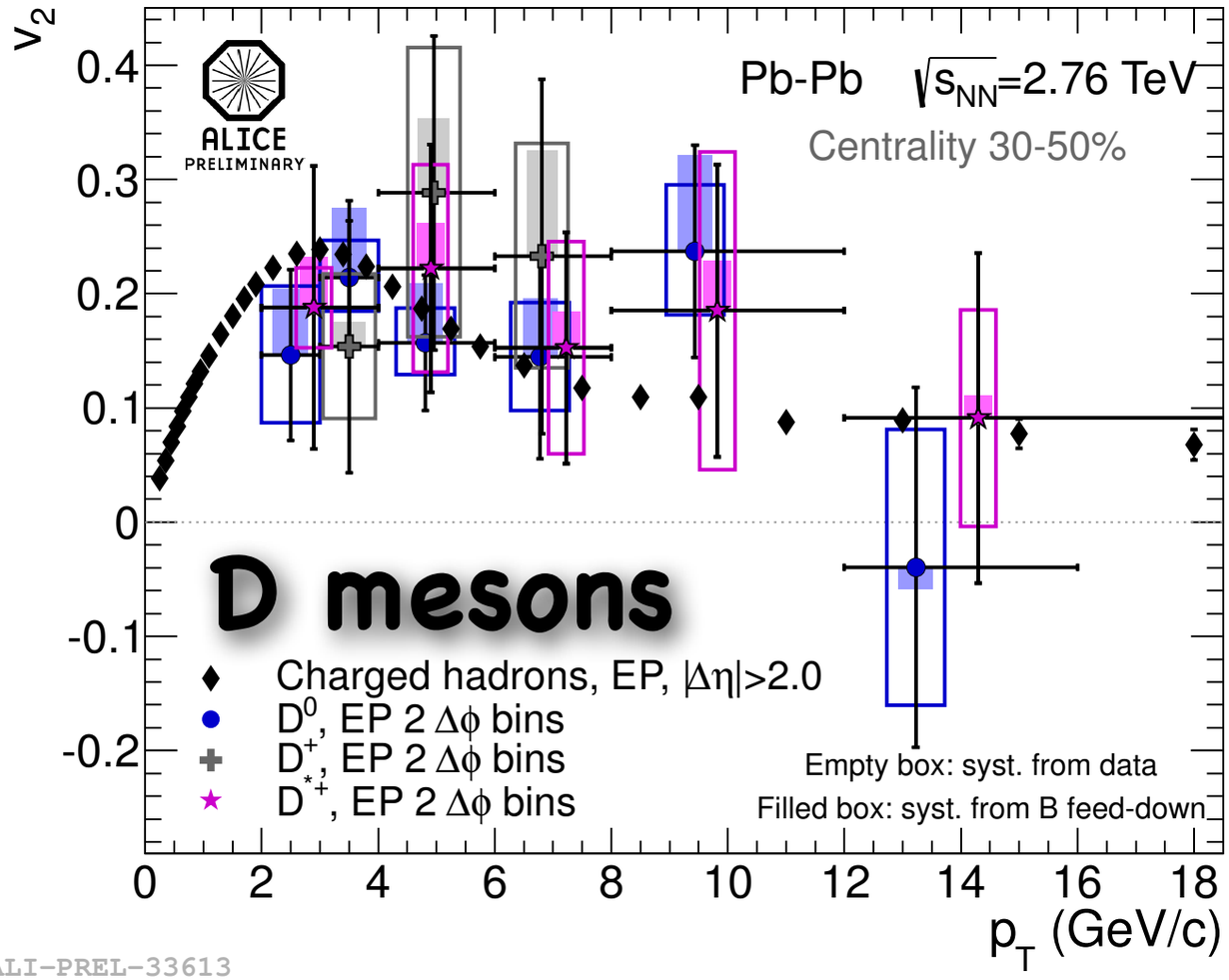


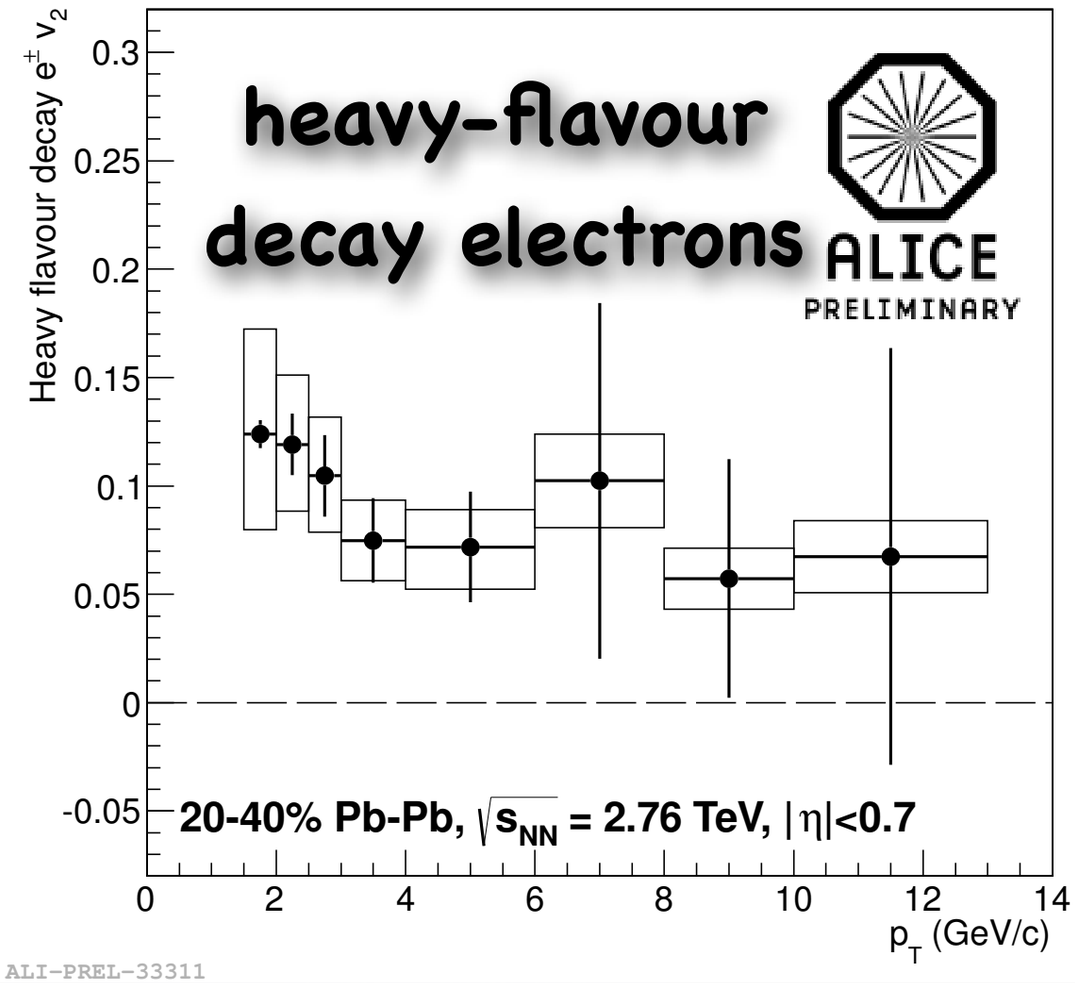
Comparison with Model Predictions



- Model implementing radiative energy loss (BDMPS-ASW) and rad.+dissoc. (Vitev) can describe both muon and D meson data;
- small contribution of shadowing is expected for muons with p_T>4 GeV/c; to be confirmed with p-Pb 2013 data.

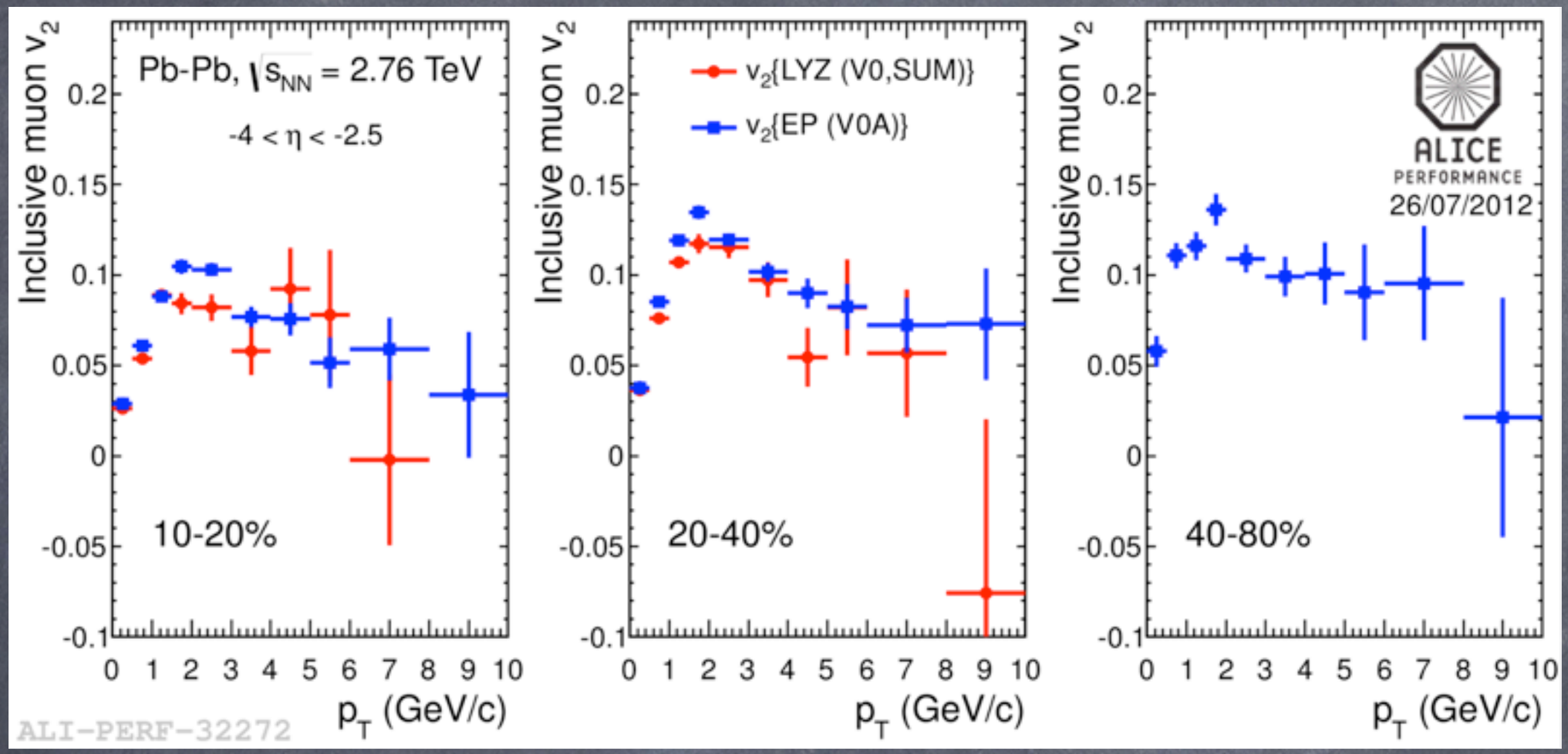
Elliptic Flow of Heavy Flavours in Central Rapidity





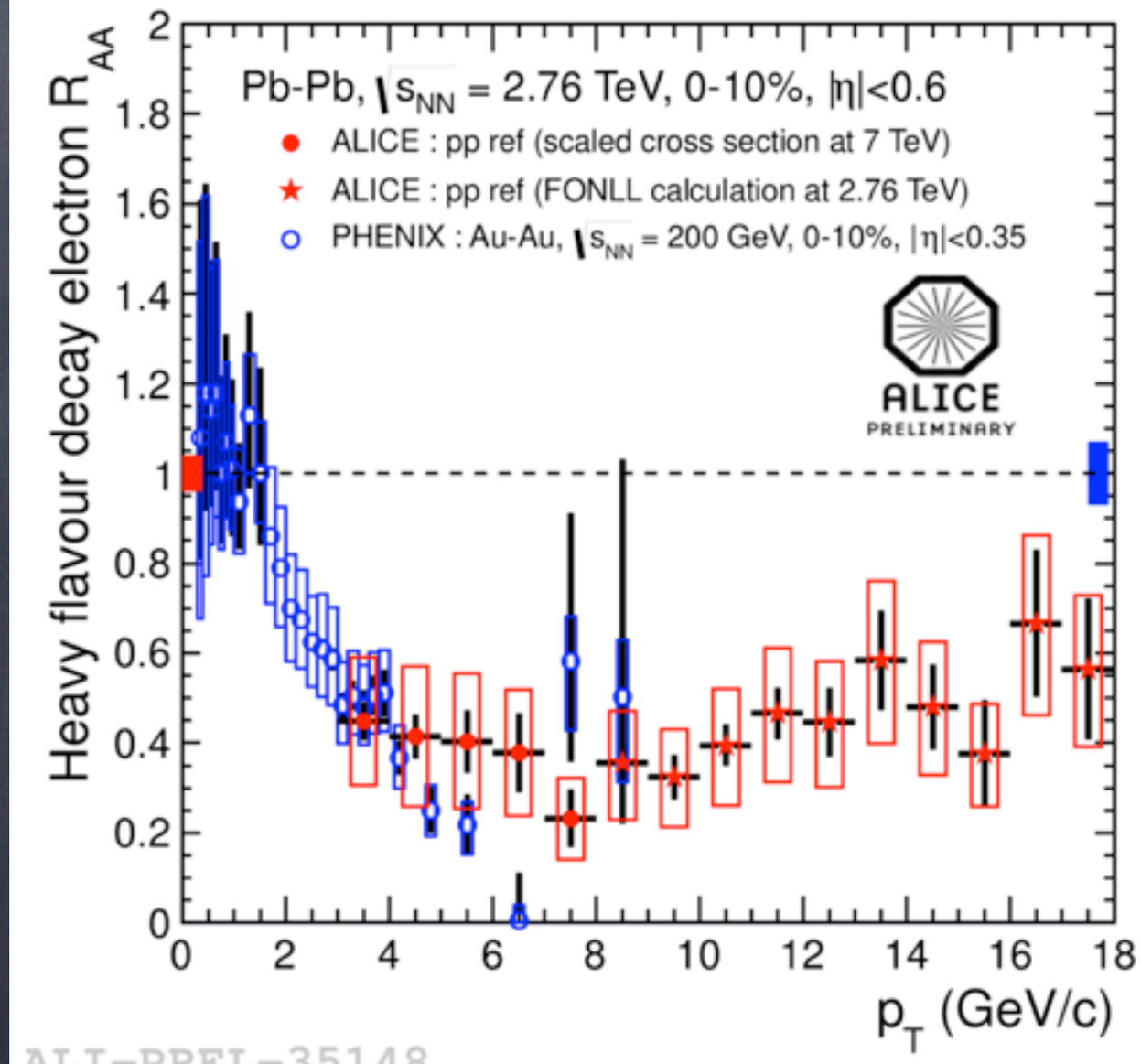
- measured with event plane method;
- consistency among different D mesons;
- non-zero v_2 (3 sigma effect) for D mesons in $2<p_T<6$ GeV/c and heavy flavour electrons in $2<p_T<3$ GeV/c;
- similar v_2 magnitude of D mesons and charged hadrons.

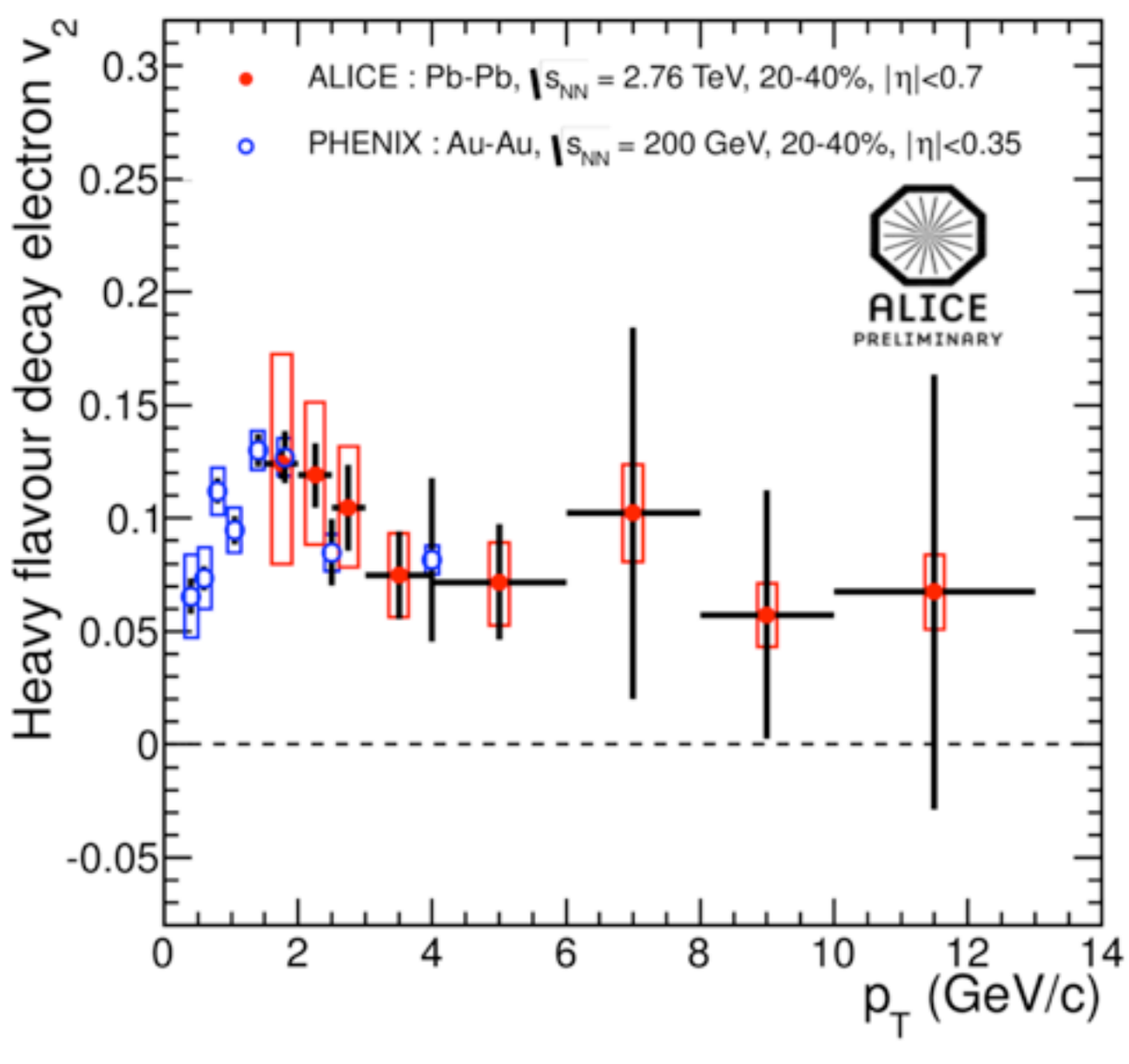
v_2 of Inclusive Muons at Forward Rapidity



- Inclusive muon v_2 is measured up to 10 GeV/c (the background is not subtracted) with Lee-Yan-Zeros (LYZ) and event plane methods;
- results from LYZ are systematically lower than those from EP method: fluctuations or non-flow correlations are suppressed;
- indication for larger v_2 in semi-central than central collisions.

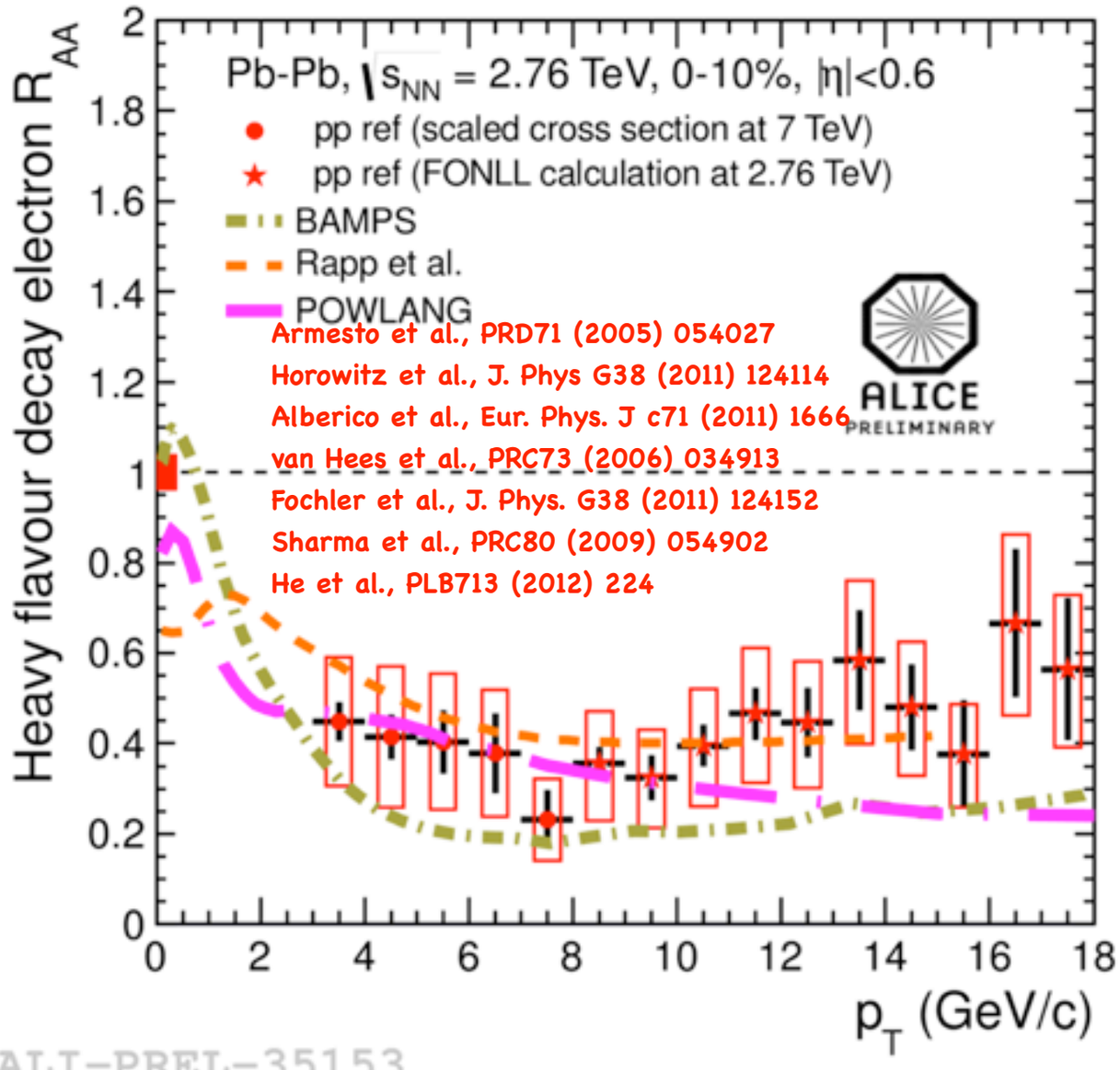
HF Electron R_{AA} and v_2 at RHIC and LHC

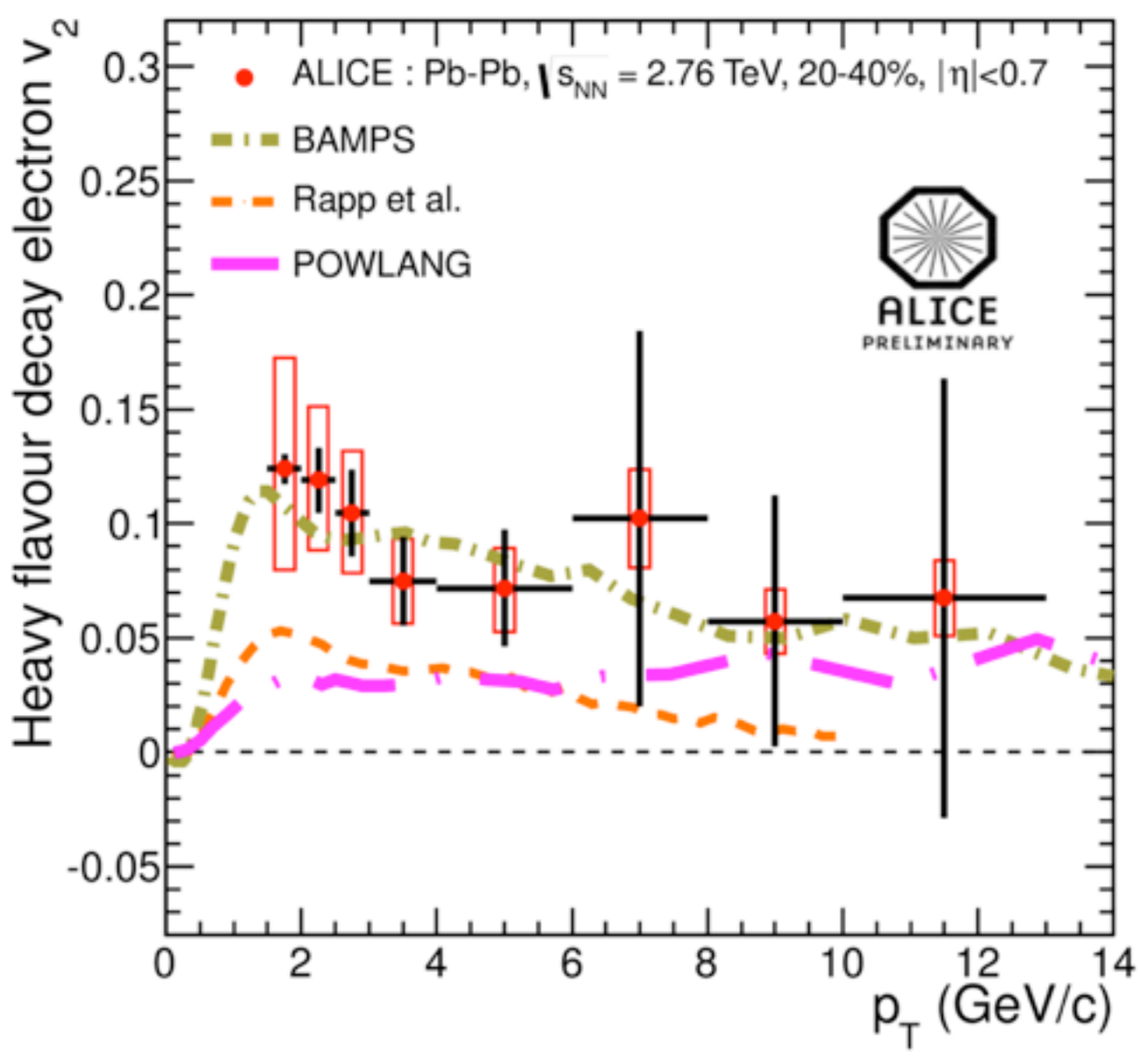




- Similar magnitude of heavy-flavour electron R_{AA} ($3<p_T<9$ GeV/c) and v_2 ($1.5<p_T<4$ GeV/c) at $\sqrt{s_{NN}}$=200 GeV (PHENIX) and $\sqrt{s_{NN}}$=2.76TeV (ALICE),
- Caveat: c/b contribution to the HF electron spectra may differ at RHIC and LHC.

R_{AA} and v_2: Model Comparisons

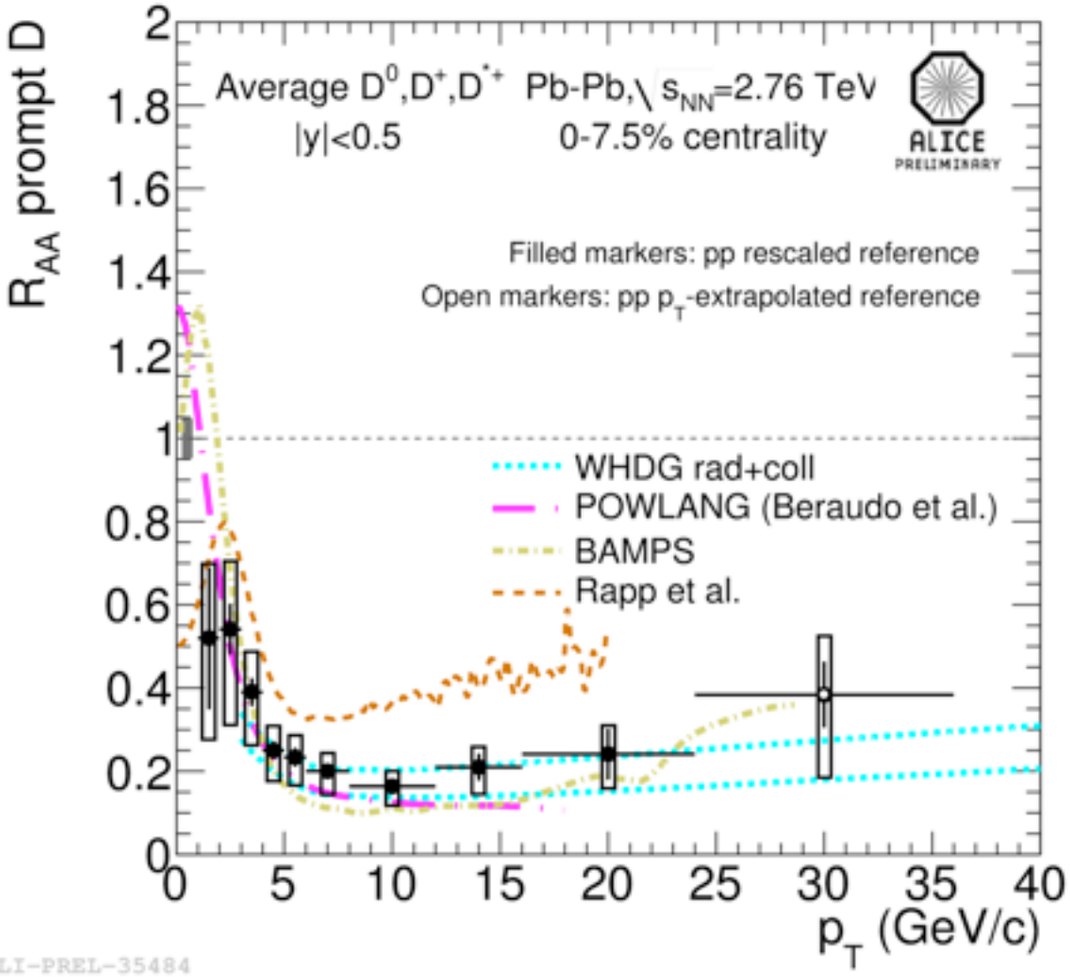


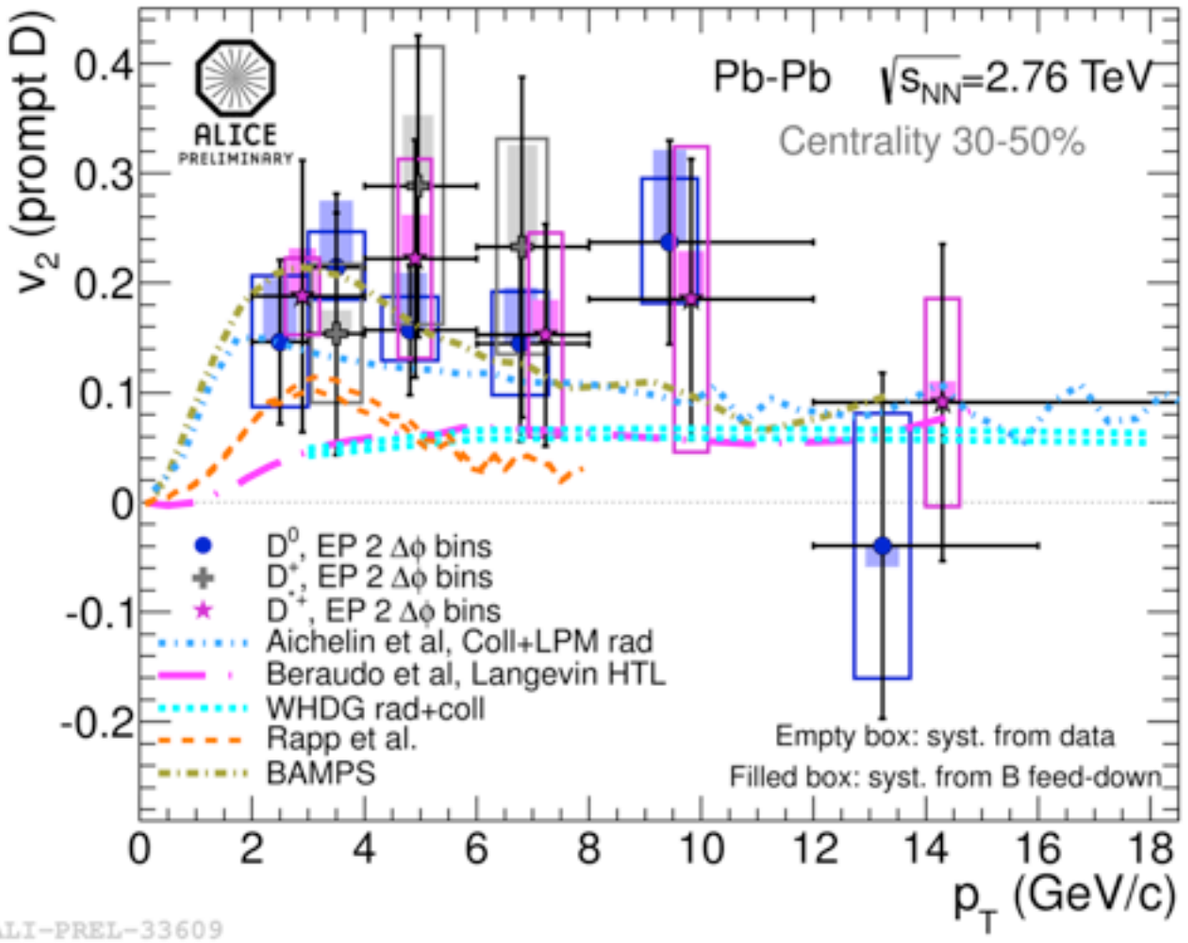


ALI-PREL-35153

The simultaneous description of HF Electron R_{AA} and v_2 is challenging.

R_{AA} and v_2: Model Comparisons





The simultaneous description of D meson R_{AA} and v_2 is challenging.

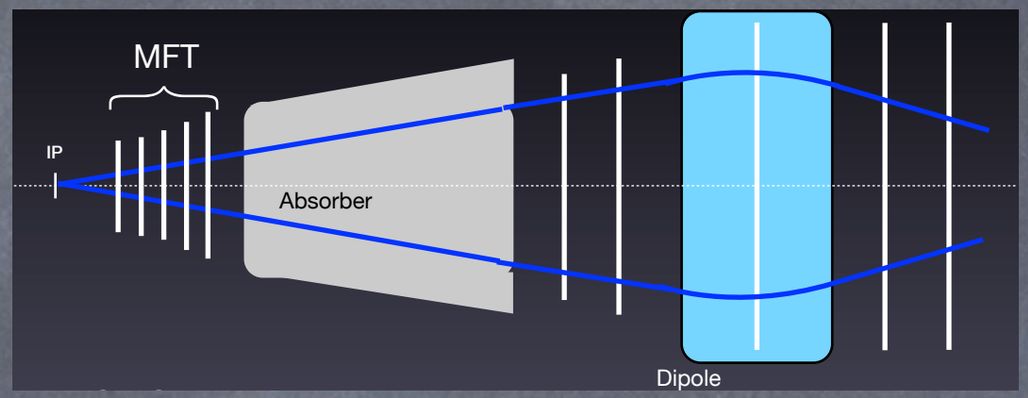
Armesto et al., PRD71 (2005) 054027
Horowitz et al., J. Phys G38 (2011) 124114
Alberico et al., Eur. Phys. J c71 (2011) 1666
van Hees et al., PRC73 (2006) 034913
Fochler et al., J. Phys. G38 (2011) 124152
Sharma et al., PRC80 (2009) 054902
He et al., PLB713 (2012) 224

Part IV
ALICE Upgrade:
Muon Forward Tracker

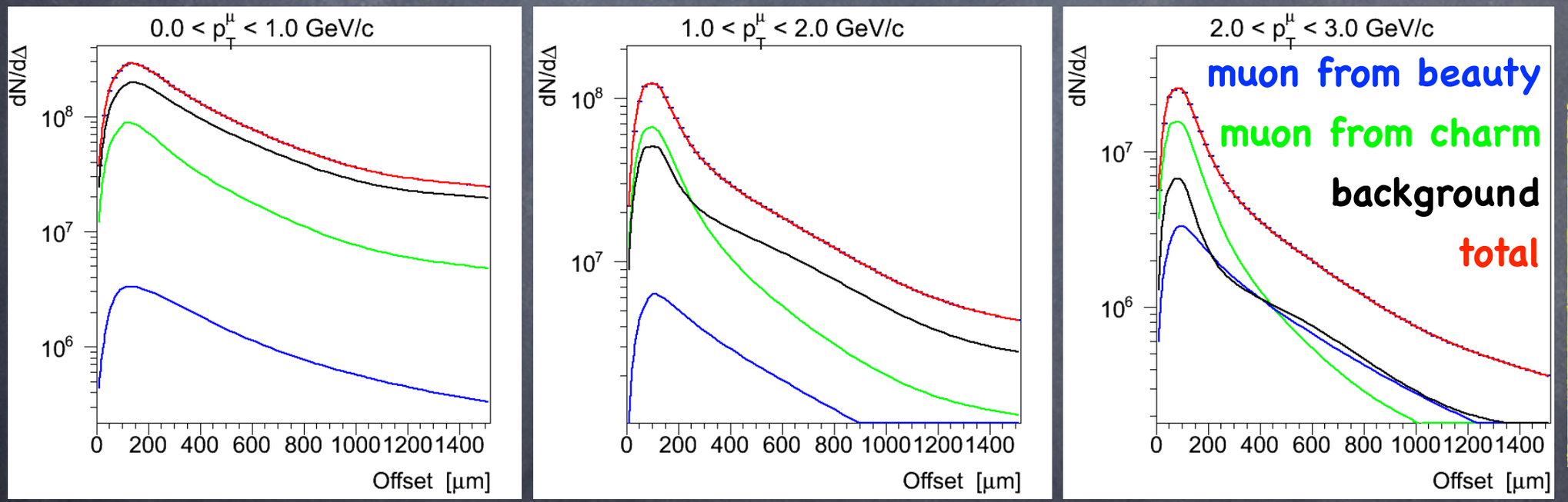
See Antonio's talk for more details on the MFT.

Separate Muons from D- and B-hadron Decays

Challenge of muon spectrometer for single muon analysis: separate muons from D- and B-hadron decays,



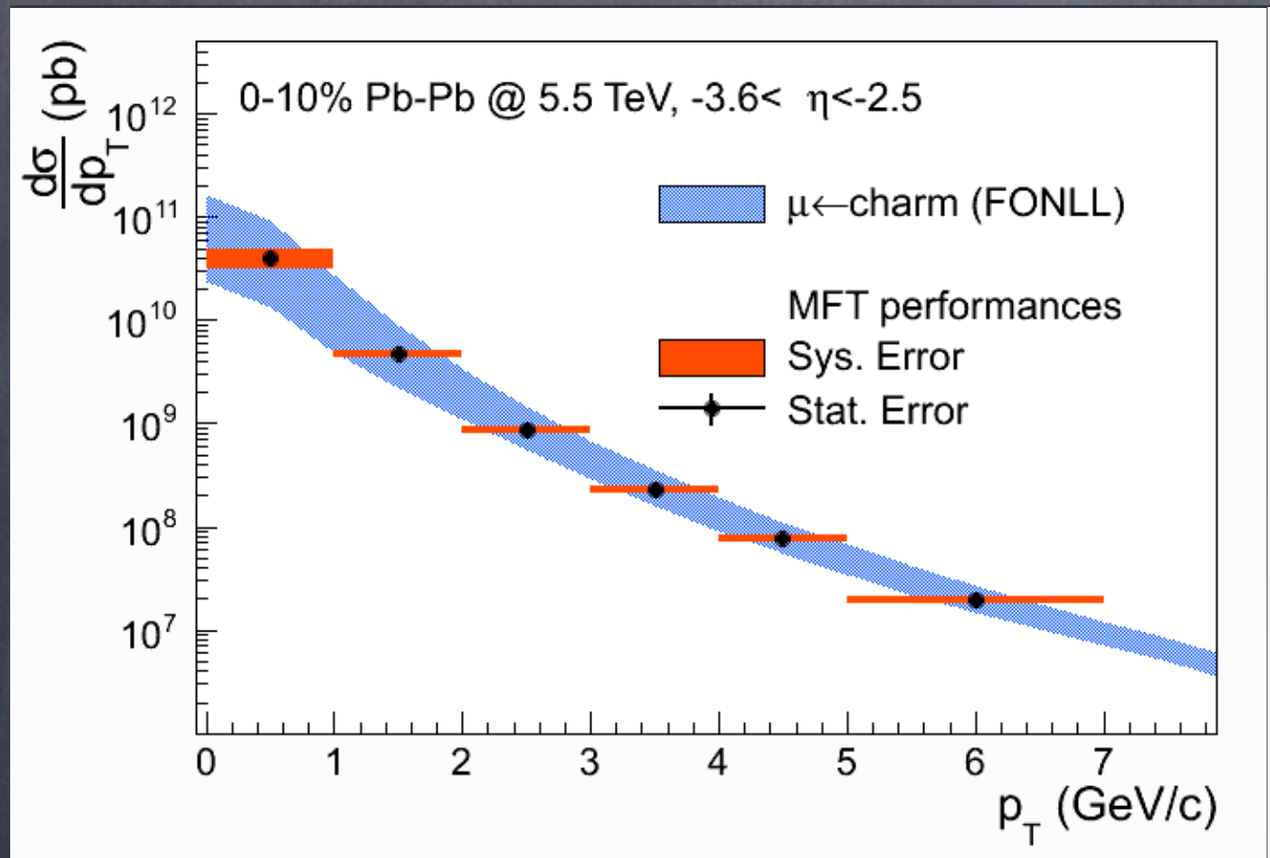
➡testing mass dependence of quark in-medium energy loss and different QGP scenarios.

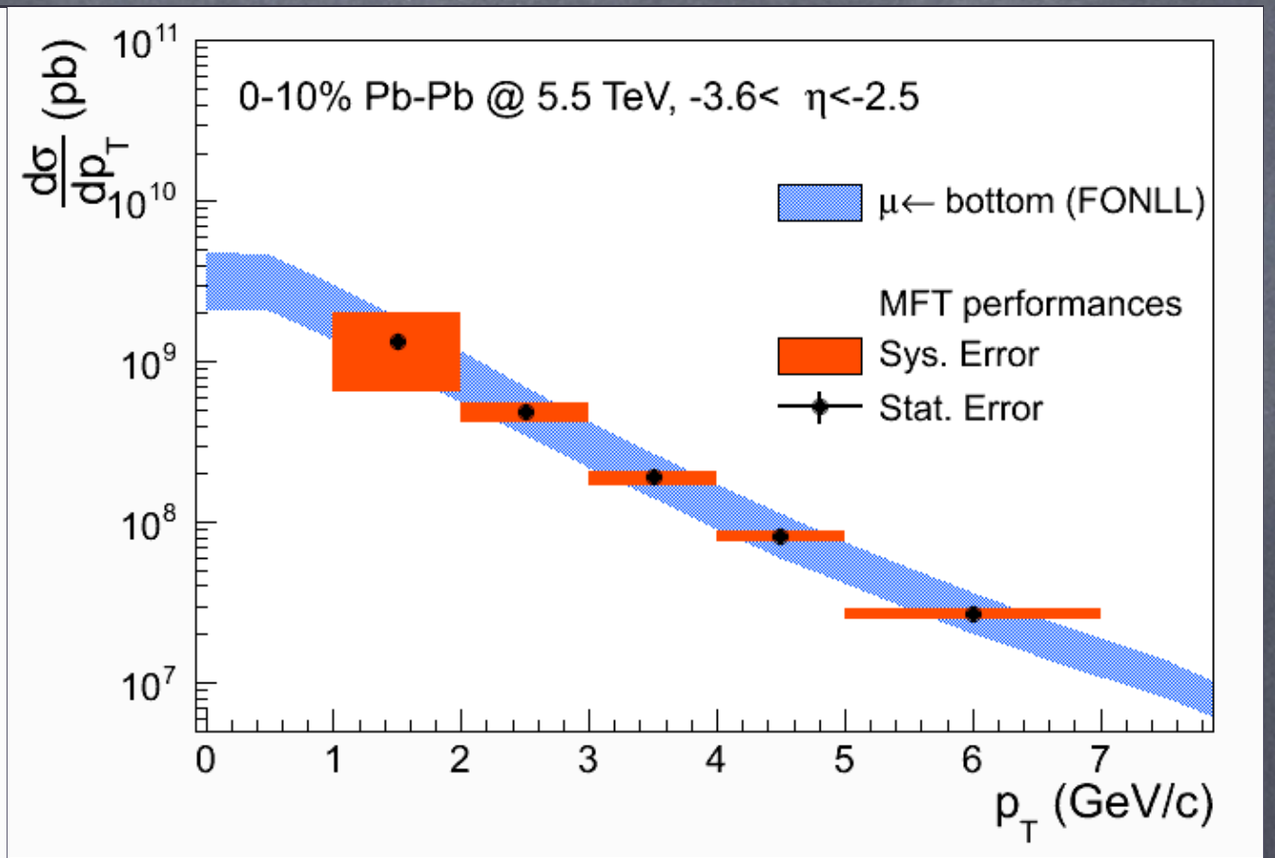


offset: transverse distance between the primary vertex and the muon track.

Distinguish charm and beauty components and background in inclusive muon spectra via the combined fit on the offset distribution which is related to the decay length of different particle species.

Performance Results





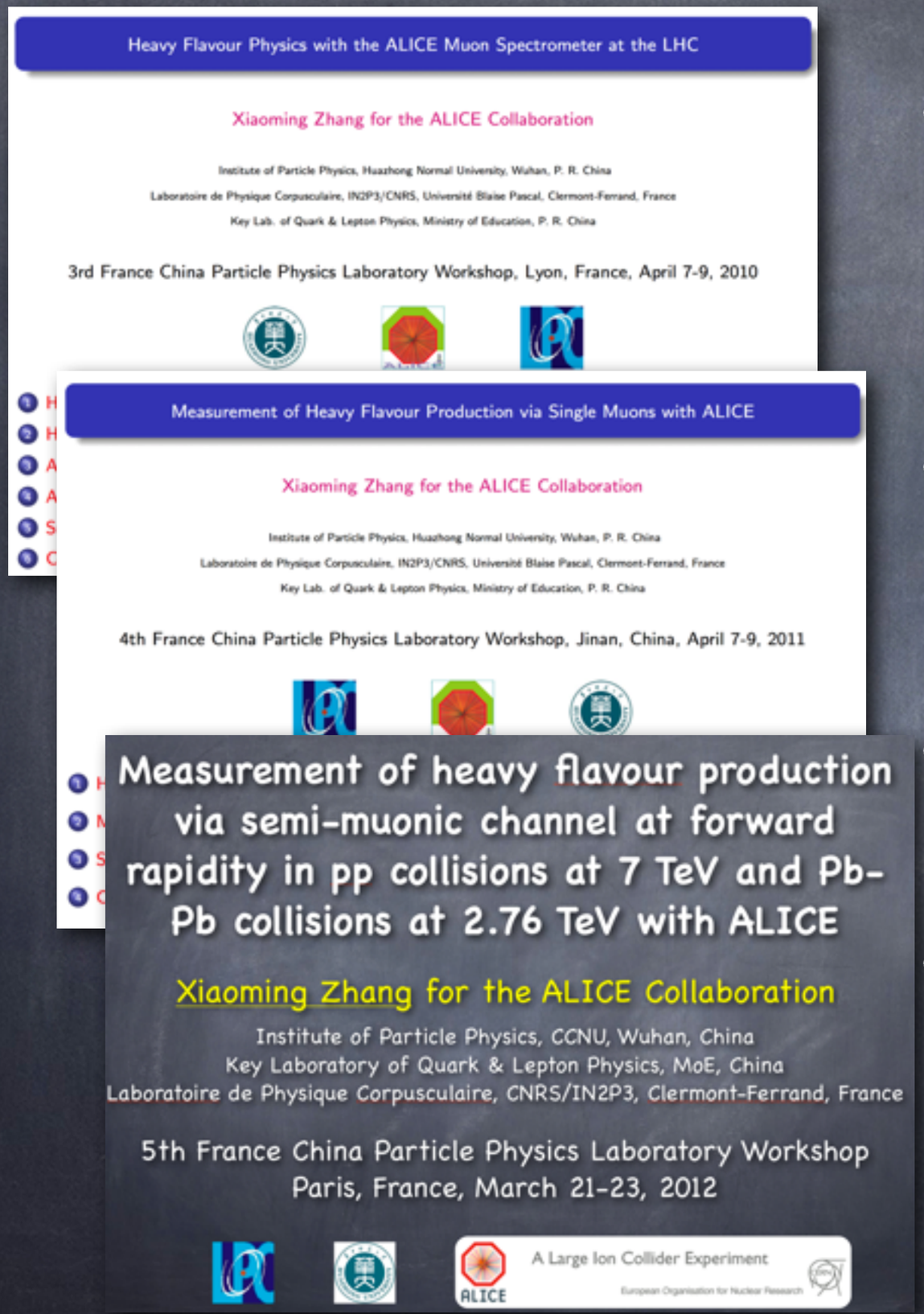
- D decay muons and B decay muons are well separated down to p_T=0 (D decay muon) and 1 GeV/c (B decay muon);
- well controlled systematic uncertainties (<10%).

Conclusion

- Heavy-flavour production has been measured with ALICE in the semi-muonic channel at forward rapidity and semi-electronic and hadronic (D mesons) channels at central rapidity in Pb-Pb collisions;
- a strong suppression is observed in all cases;
- results of muons from heavy-flavour decays at forward rapidity are similar to that of heavy-flavour electrons and D mesons at central rapidity;
- non-zero v_2 of D mesons and heavy-flavour decay electrons are observed in mid-rapidity region;
- challenge for models to describe simultaneously the R_{AA} and v_2 of D mesons and heavy-flavour electrons;
- the MFT should allow to unravel the charm and beauty components down to very low p_T, and, the upgrade of ALIE Inner Tracker System (ITS) in mid-rapidity region will allow to separate D and B hadrons with data driven approaches as well as to improve dramatically the precision of the D meson measurements, to measure the Λ_c baryon.

Thanks!

My FCPPL Activities



- Joint PhD (Sep. 2009 - Jun. 2012) between:
  - CCNU, Wuhan, China & LPC, Clermont-Ferrand, France,
  - grant from France Embassy in Beijing.
- Supervisors:
  - Daicui Zhou (China),
  - Philippe Crochet & Nicole Bastid (France).
- Working in the MUON group of the ALICE Collaboration,
  - since September 2008 (master II).
- PhD defense at 23 May 2012, Wuhan.

Thanks for the support from FCPPL!

Backup

Heavy Flavour Physics at LHC

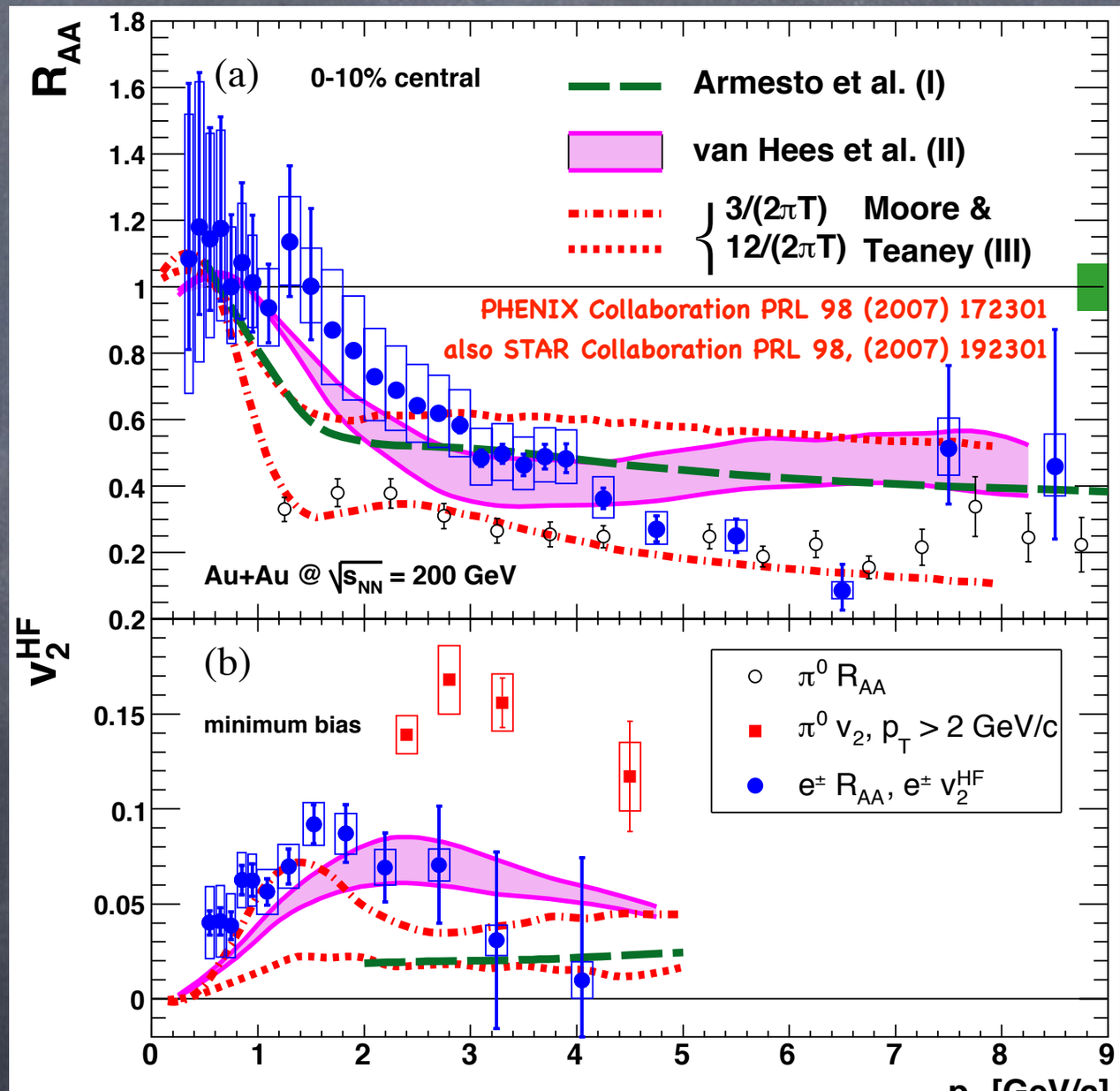
Heavy Flavours in AA collisions:

- tomography of QCD medium,
  - mass and color charge dependence of parton energy loss,
    R_{AA}(light hadron)<R_{AA}(D)<R_{AA}(B)
    [Phys. Rev. D69 (2004) 114003, Phys. Rev. D71 (2005) 054027],
  - Distinguish different QGP scenarios [J. Phys. G, G38 (2011) 124114];
- azimuthal anisotropic flow, $v_n(p_t, \eta)$,
  - low p_T region: initial conditions of QCD medium, degree of thermalization of heavy quarks in QGP,
  - high p_T region: path length dependence of heavy flavour energy loss.

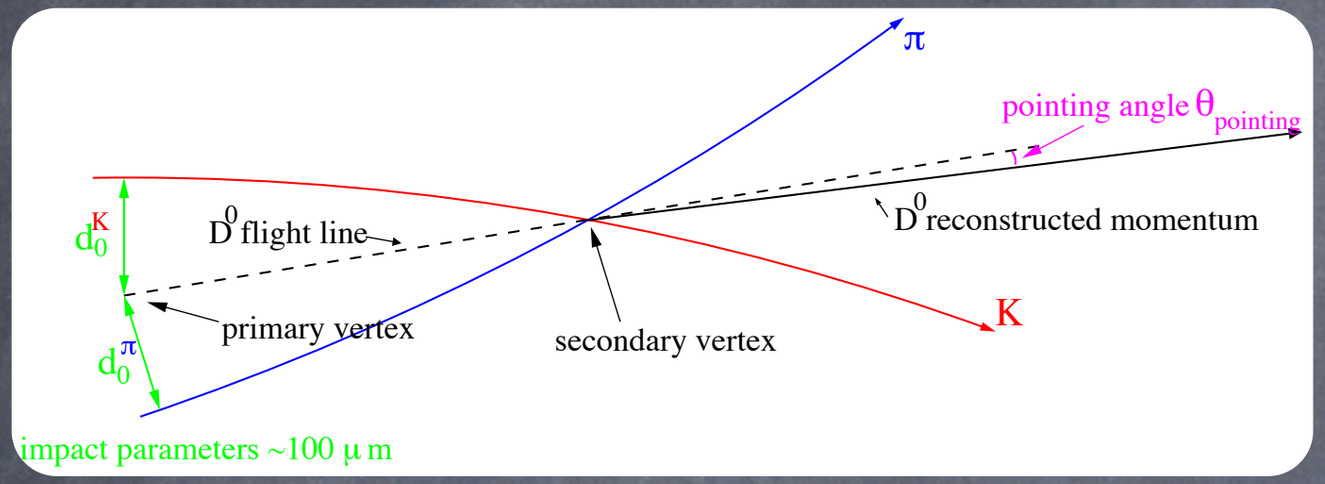
Heavy Flavour in pA collisions:

- investigate cold nuclear effects,
  - initial state radiations,
  - (anti-)shadowing, k_T broadening,
  - color glass condensate.

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



D-meson Measurements ($|\eta|<0.5$)



- Strategy: D mesons are reconstructed via the secondary vertices displaced of few hundred micrometers.

Tagged channels:
- $D^0 \rightarrow K^-\pi^+$
- $D^{*+} \rightarrow D^0(\rightarrow K^-\pi^+)\pi^+_s$
- $D^+ \rightarrow K^-\pi^+\pi^+$
- $D_s^+ \rightarrow \phi(\rightarrow K^+K^-)\pi^+$

- Main selection criteria:
- p_T and impact parameter of single tracks;
- topological selection (pointing angle), suppress the combinatorial background;
- PID (π, K and p) using TOF+TPC, reject low p_T background.
- Signal extraction: invariant mass analysis.