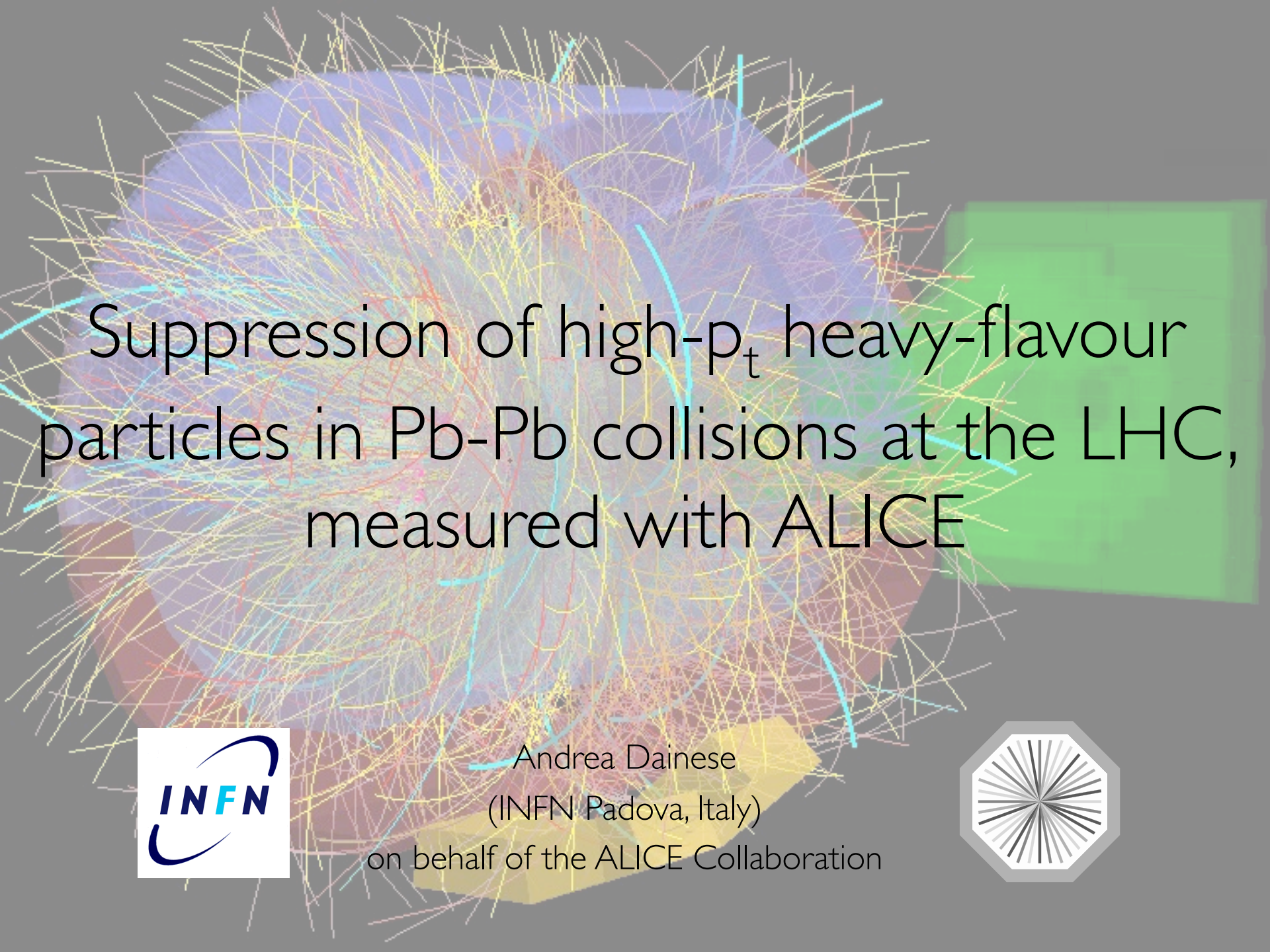


Suppression of high-p_t heavy-flavour particles in Pb-Pb collisions at the LHC, measured with ALICE

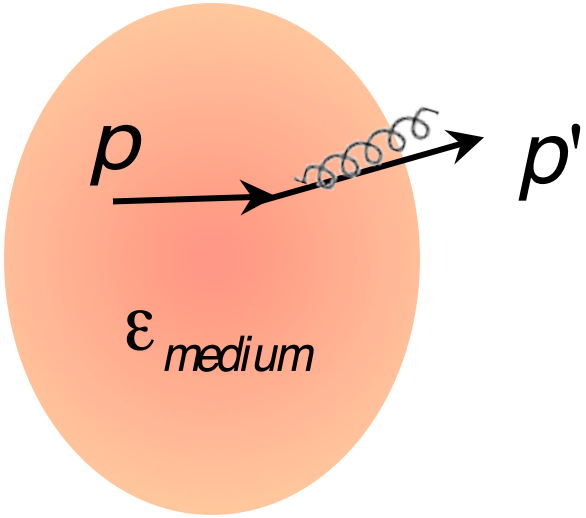
Andrea Dainese
(INFN Padova, Italy)
on behalf of the ALICE Collaboration

Outline of the Talk

- Introduction: heavy quarks as probes of QCD matter at LHC
- Heavy flavour in ALICE
  - D mesons at central rapidity
  - electrons at central rapidity
  - muons at forward rapidity
- Summary

Compare Pb-Pb and pp
→ Nuclear modification

Parton energy loss and the nuclear modification factor



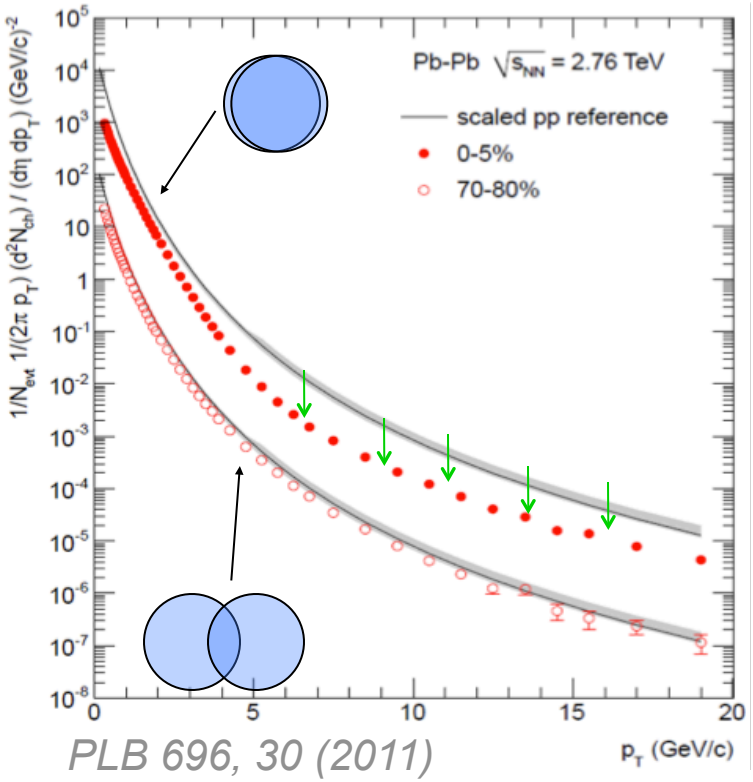
'QCD matter'

Parton Energy Loss by
- medium-induced gluon radiation
- collisions with medium gluons

$$p' = p - \Delta E(\varepsilon_{medium})$$

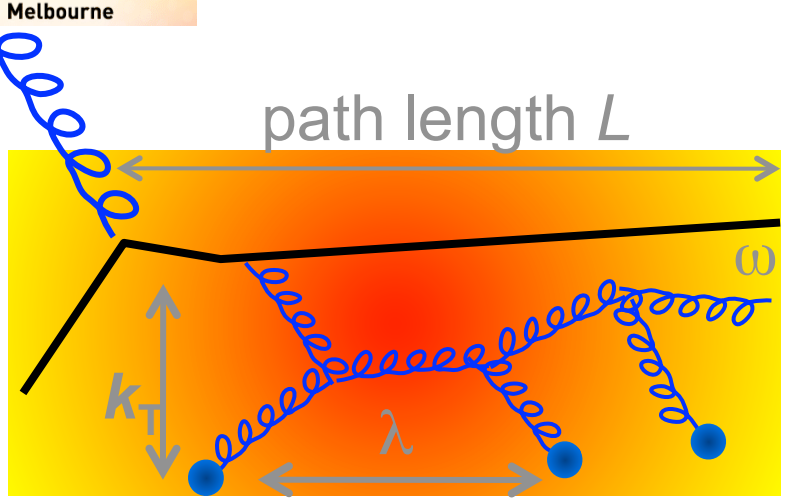
$$dN_{AA}/dp_t < \langle N_{coll} \rangle dN_{pp}/dp_t$$

$$R_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t} < 1$$



PLB 696, 30 (2011)

The parton and the medium



BDMPS-Z formalism

$$\hat{q} = \frac{\langle k_T^2 \rangle}{\lambda} \quad \text{transport coefficient} \quad \propto \varepsilon_{medium}$$

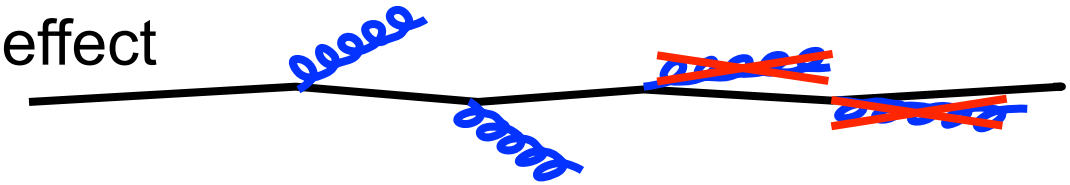
Radiated-gluon energy distrib.:

$$\omega \frac{dI}{d\omega} \propto \alpha_s C_R \sqrt{\frac{\hat{q} L^2}{\omega}}$$

C_R = Casimir coupling factor: 4/3 for q, 3 for g

- In vacuum, gluon radiation suppressed at $\theta < m_Q/E_Q$

  → "dead cone" effect



- *Dead cone implies lower energy loss* (Dokshitzer-Kharzeev, 2001)

Baier, Dokshitzer, Mueller, Peigné, Schiff, NPB 483 (1997) 291.
Zakharov, JTEPL 63 (1996) 952.
Salgado, Wiedemann, PRD 68(2003) 014008.

Dokshitzer, Khoze, Troyan, JPG 17 (1991) 1602.
Dokshitzer and Kharzeev, PLB 519 (2001) 199.

Heavy quark energy loss

q: low ch., ~no mass

u,d,s: m~0, C_R=4/3

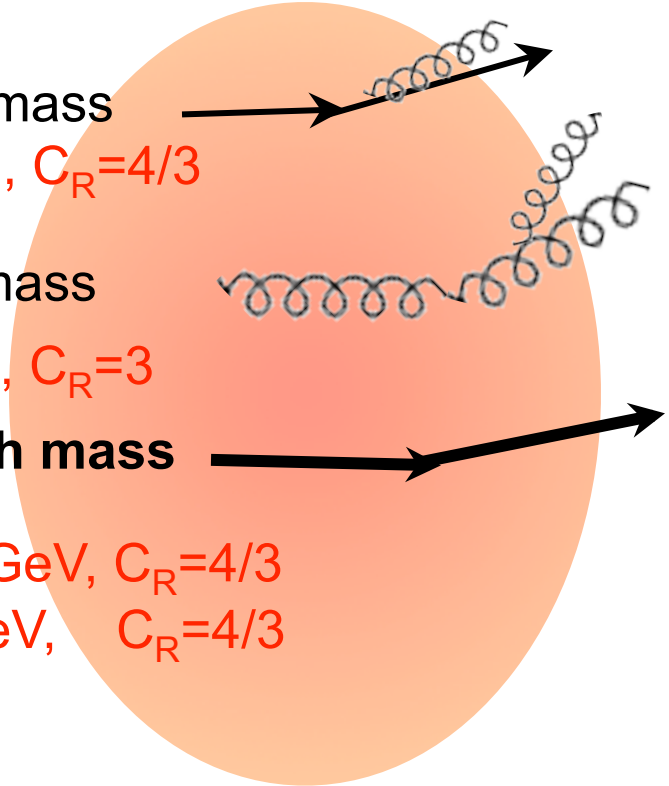
g: high ch., no mass

g: m=0, C_R=4/3

Q: low ch., high mass

c: m~1.5 GeV, C_R=4/3

b: m~5 GeV, C_R=4/3



$$\Delta E(\varepsilon_{medium}; C_R, m, L)$$

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

$$\rightarrow \quad R_{AA}^{\pi} < R_{AA}^{D} < R_{AA}^{B}$$

At RHIC:

- ***Inclusive R_{AA} of e from D and B decay***
- ***No pattern seen***

At LHC:

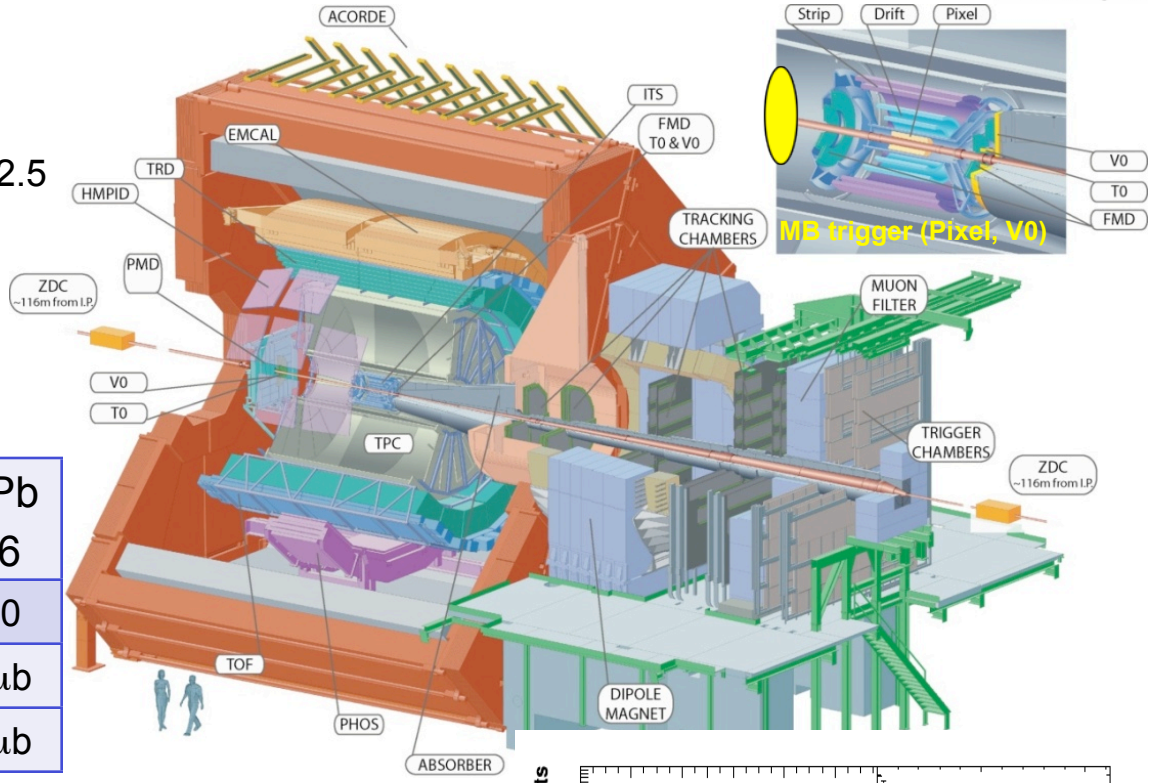
- ***R_{AA} for D and B***
- ***Pattern?***

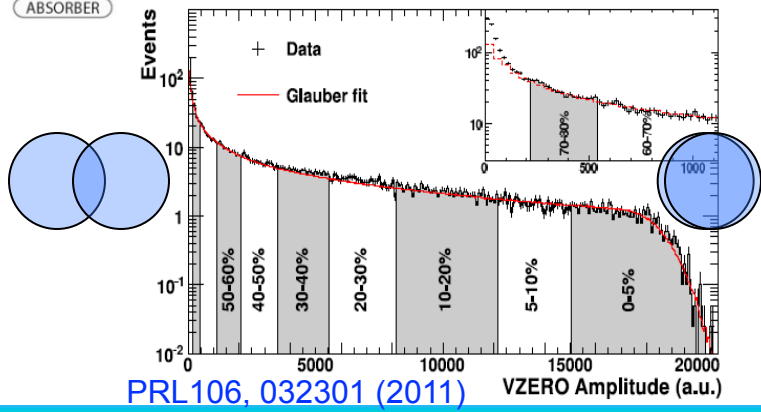
See e.g.:
Dokshitzer and Kharzeev, PLB 519 (2001) 199. Armesto, Salgado, Wiedemann, PRD 69 (2004) 114003.
Djordjevic, Gyulassy, Horowitz, Wicks, NPA 783 (2007) 493.

ALICE apparatus and datasets

- Two main parts:
  - barrel ($|\eta|<0.9$), B = 0.5 Tesla
  - forward muon spectrometer, $-4<\eta<-2.5$
- Crucial for HF:
  - vertexing, tracking
  - hadron and lepton ID
- Datasets used *here*:

system, $\sqrt{s_{NN}}$ (TeV)	pp 7	pp 2.76	Pb-Pb 2.76
year	2010	2011	2010
L_{int} MB/cent	5/nb	1.5/nb	2.5/μb
L_{int} μ	16.5/nb	19/nb	2.5/μb





- Pb-Pb centrality: slices in signal of large-η V0 scintillator arrays

PRL106, 032301 (2011)

ALICE Heavy Flavour detection: D mesons, |y|<0.5

✓ $D^0 \rightarrow K\pi$

$D^+ \rightarrow K\pi\pi$

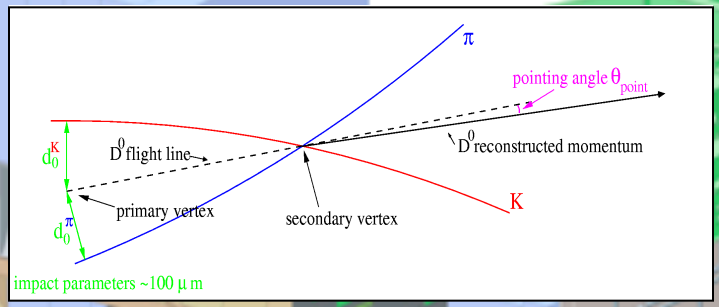
$D^* \rightarrow D^0\pi$

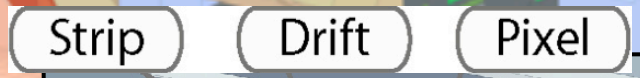
TOF (p/K/π id)

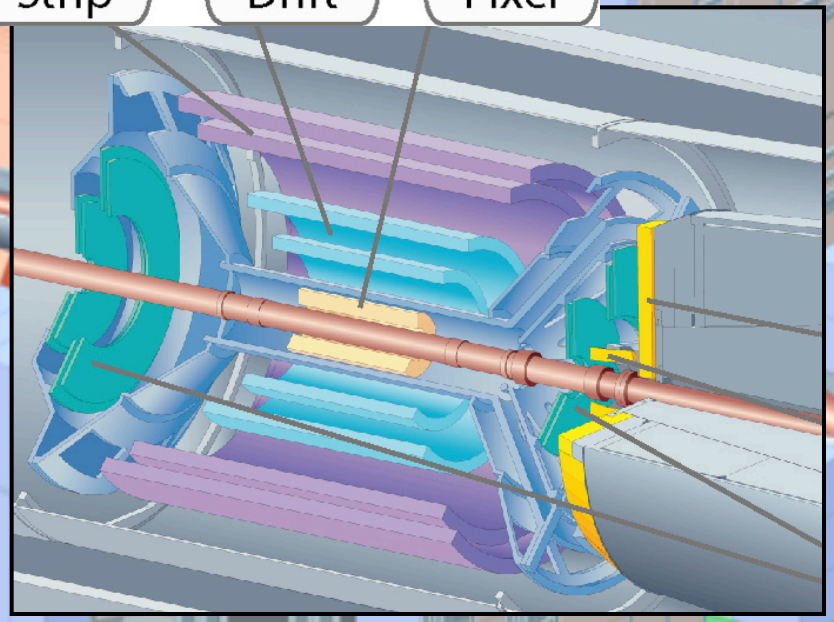
K π

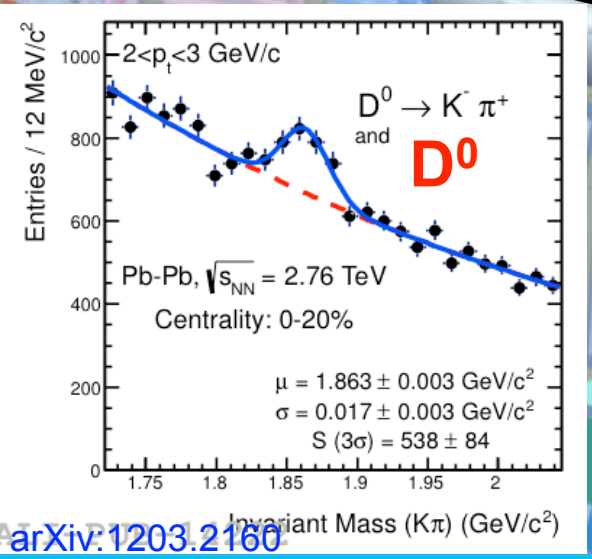
TPC (tracking, p/K/π id)

ITS (tracking & vertexing)



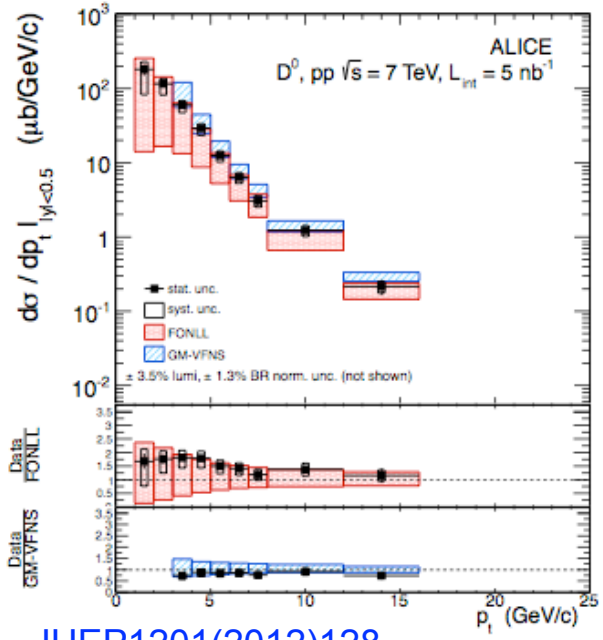


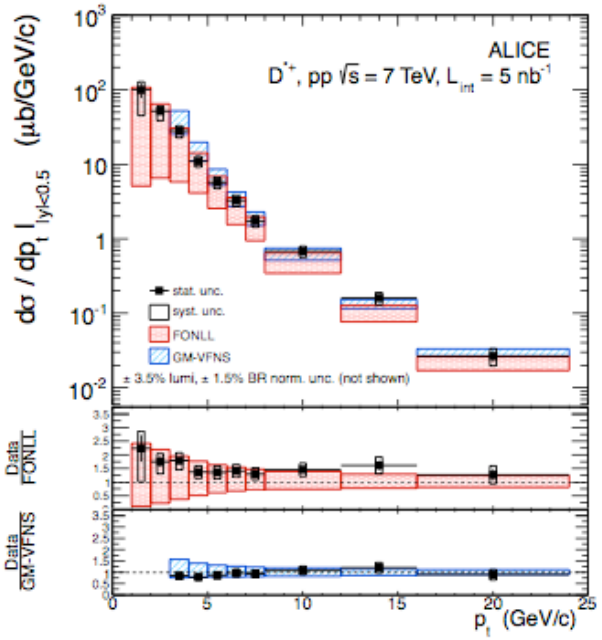




arXiv:1203.2160

D meson cross sections in pp 7 TeV

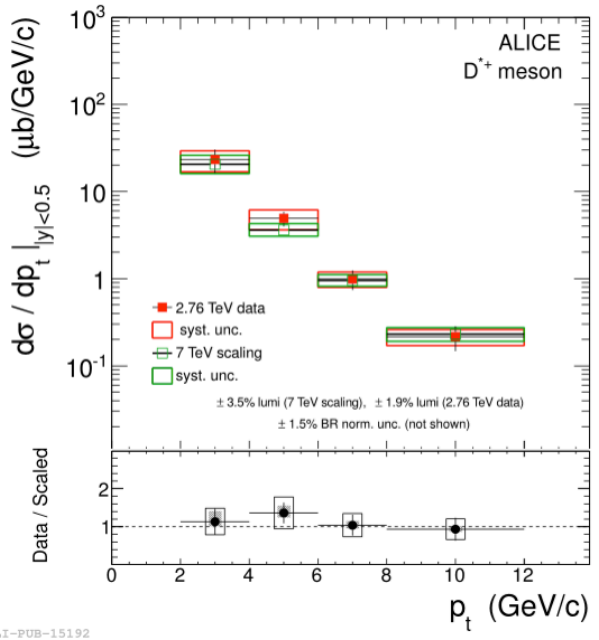




JHEP1201(2012)128

- Used as a reference for Pb-Pb studies (scaled to 2.76 TeV based on FONLL)
- Scaling validated with small dataset at 2.76 TeV

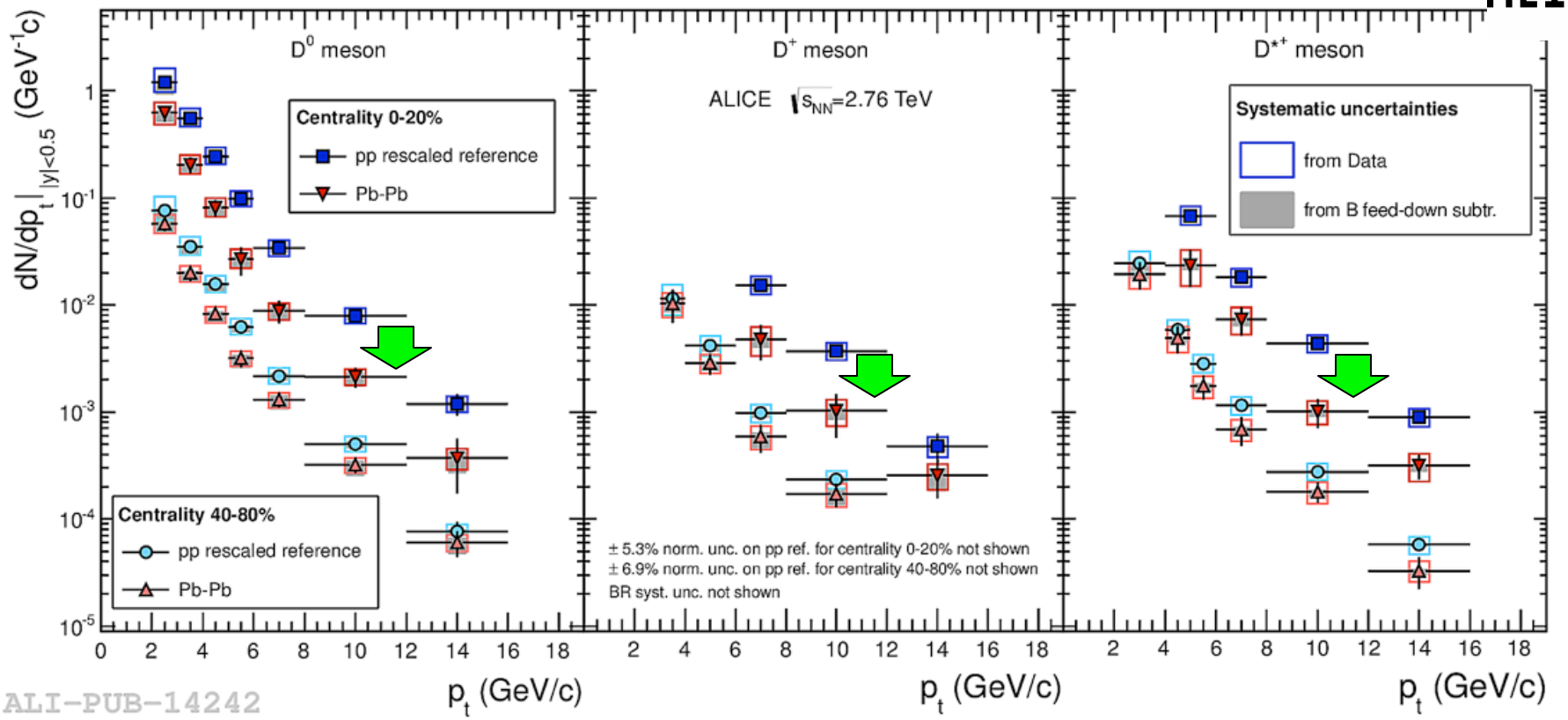
- Well described by perturbative QCD calculations: FONLL and GM-VFNS



JHEP to appear, arXiv:1205.4007

FONLL: Cacciari et al., arXiv:1205.6344
GM-VFNS: Kniehl et al., arXiv:1202.0439

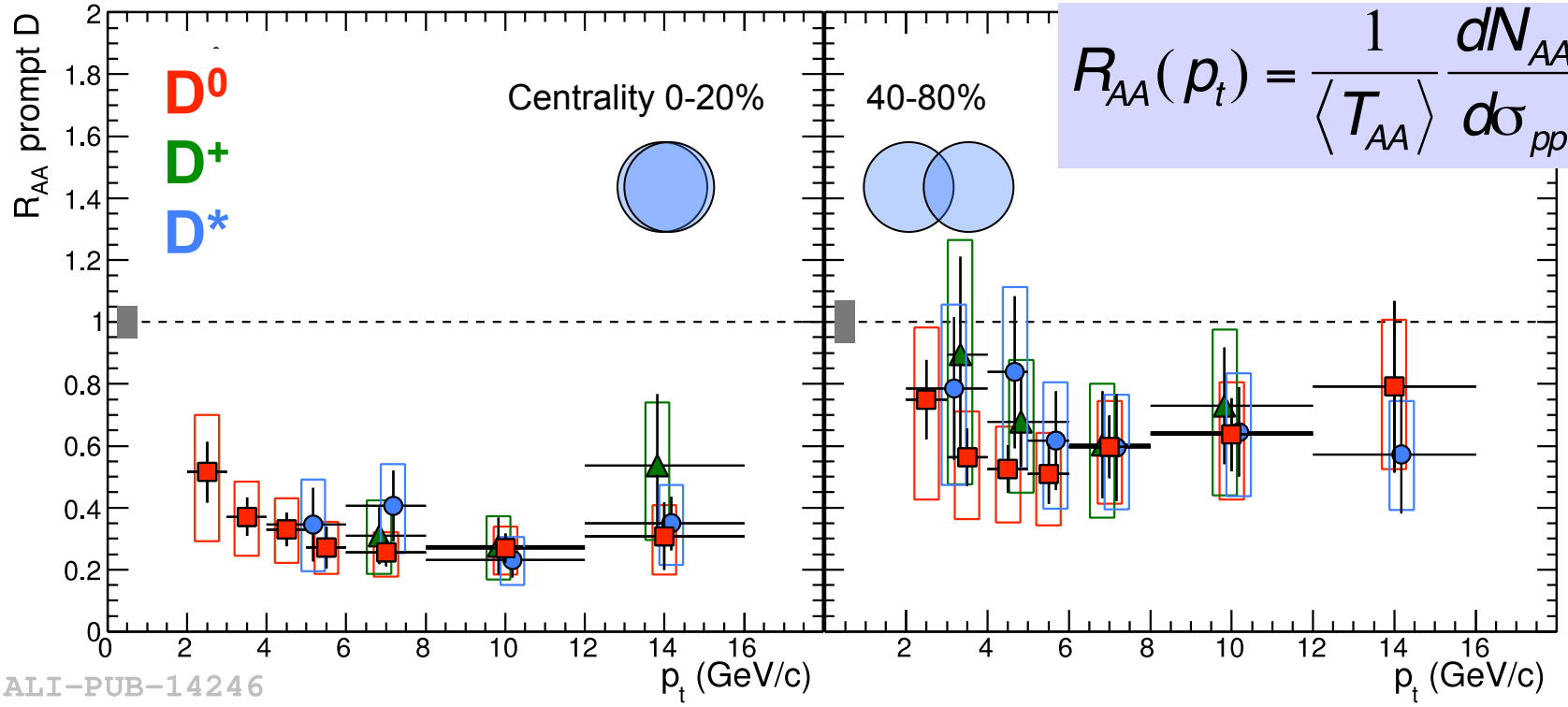
D p_t distributions in Pb-Pb



- Strong suppression ↓ observed in central collisions (0-20%) wrt T_{AA}-scaled pp reference
- Significant suppression also in semiperipheral (40-80%) wrt T_{AA}-scaled pp reference

arXiv:1203.2160

D meson nuclear modification factor



$$R_{AA}(p_t) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_t}{d\sigma_{pp}/dp_t}$$

- Suppression for charm with respect to binary scaling is a factor 3-4 above 5 GeV/*c*
- Compatible among the three species
- Less suppression in peripheral collisions

arXiv:1203.2160

ALICE Heavy Flavour detection: electrons, |y|<0.5

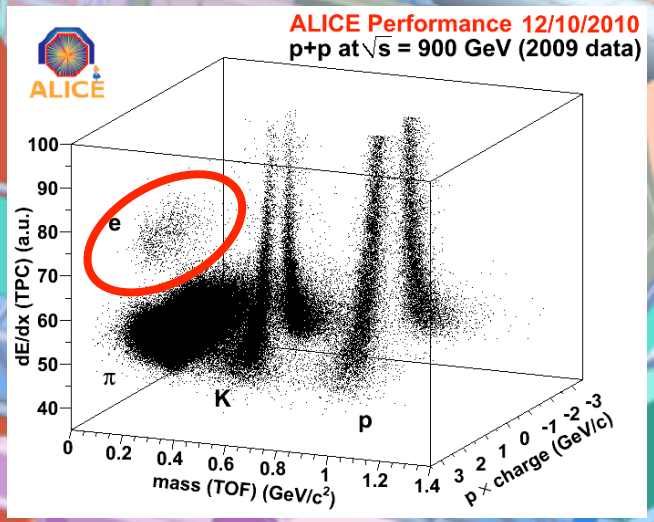
✓ **D,B → e+*X***

TPC/TOF/TRD/EMCAL (e/π id)

TPC (tracking e/π id)

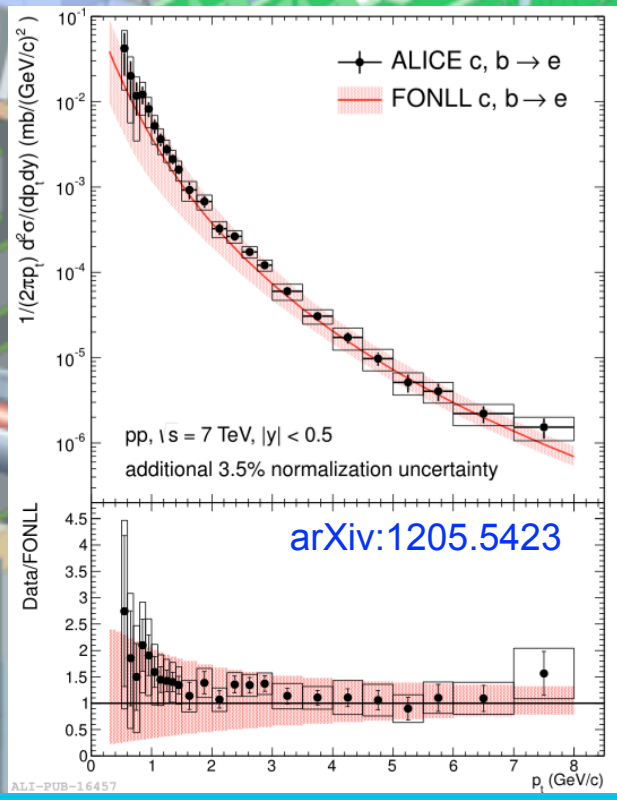
ITS (tracking & vertexing)

e



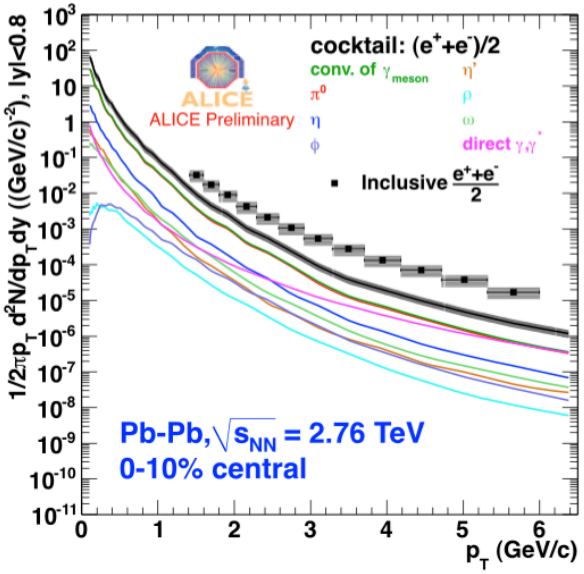
Analysis strategy:

- Inclusive electron spectrum
- Subtract data-tuned cocktail of non-HF backgrounds
- → HF-decay electrons

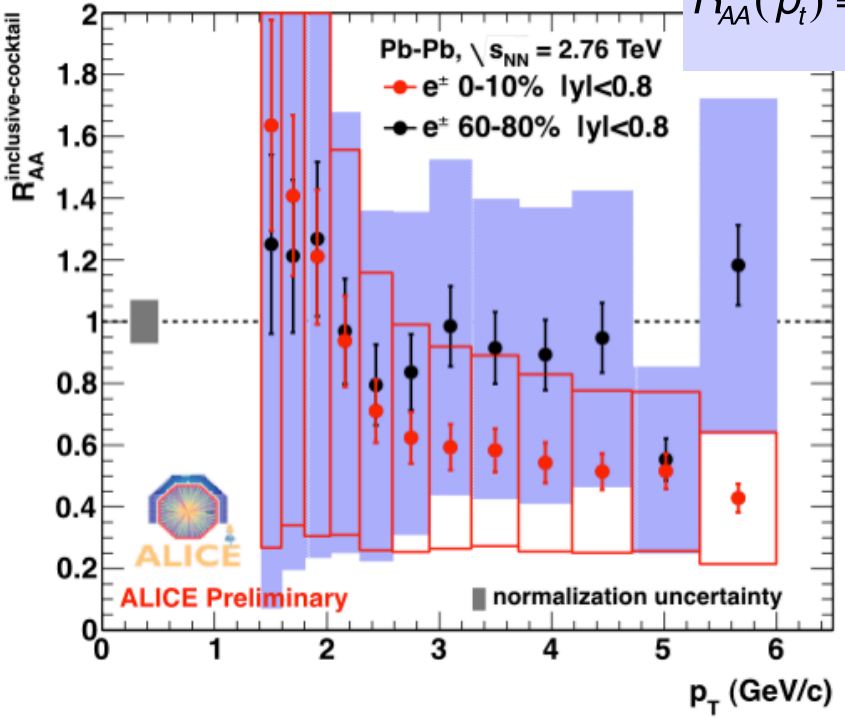


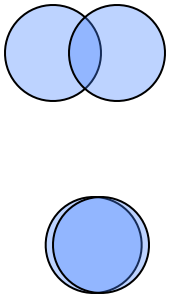
Cocktail-subtracted electron R_{AA}

- Consider (inclusive electrons – cocktail) spectrum
  - low p_t: large systematic uncertainties (mainly from electron ID)
  - above 3-4 GeV/*c*: *dominated by charm and beauty decays*



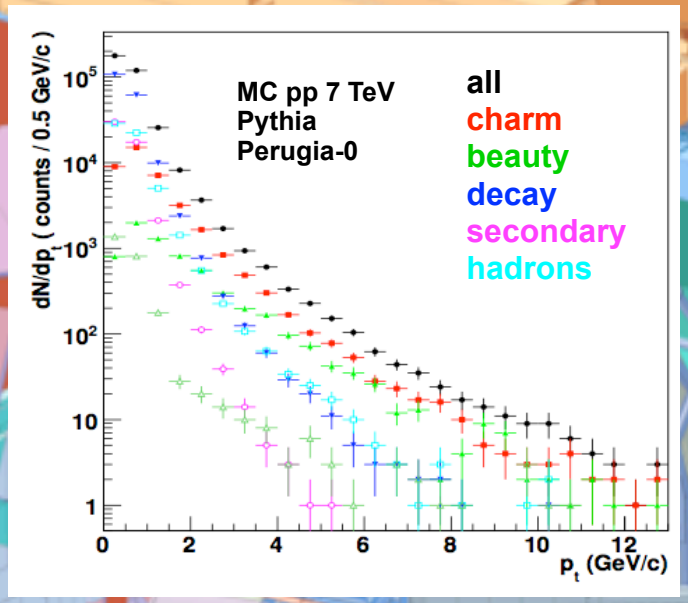
$$R_{AA}(p_t) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_t}{d\sigma_{pp}/dp_t}$$

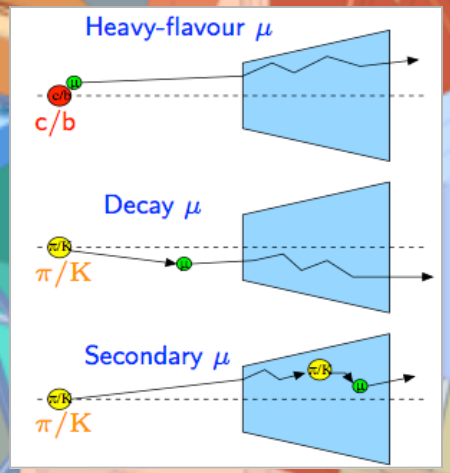




- Suppression in ce

ALICE Heavy Flavour detection: muons, 2.5<y<4





✓ **D,B → μ+*X***

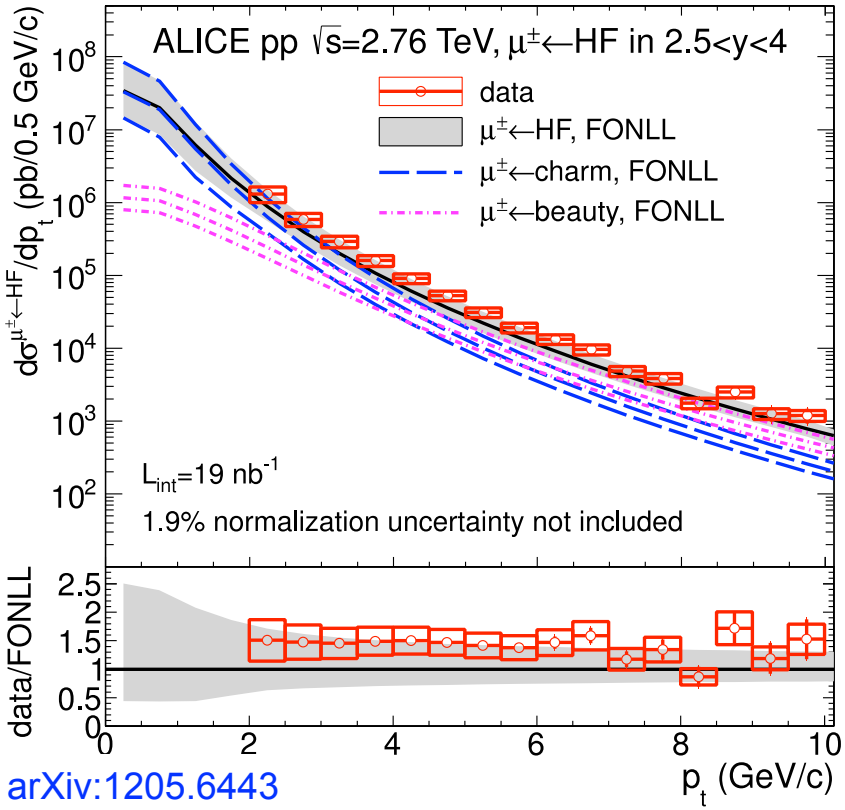
μ

MUON (tracking, μ id)

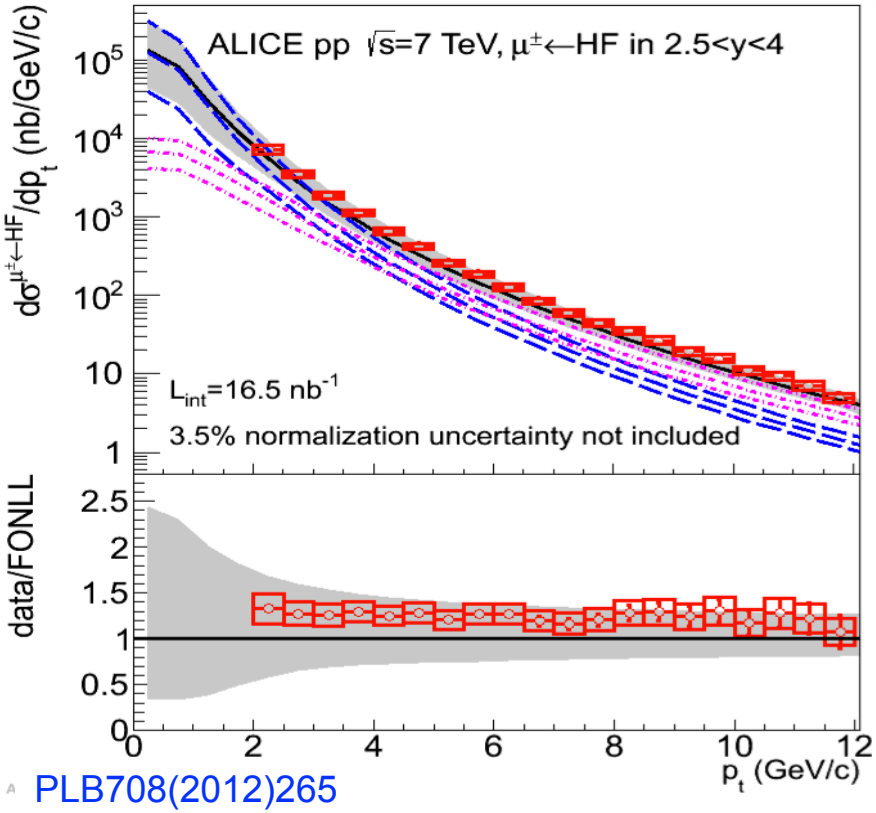
Analysis strategy:

- remove hadrons and low p_t secondary muons by requiring a muon trigger signal
- remove decay muons:
  - pp: MC, normalized to data at low p_t
  - Pb-Pb: from measured π/K yields at central rapidity
- muons from HF (charm and beauty)

HF decay muons: pp 2.76 and 7 TeV, 2.5<y<4



arXiv:1205.6443

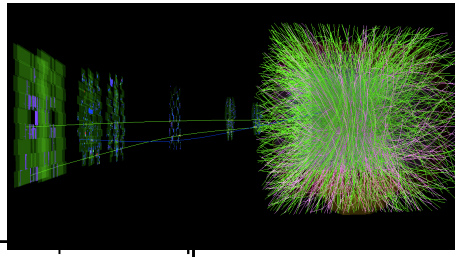


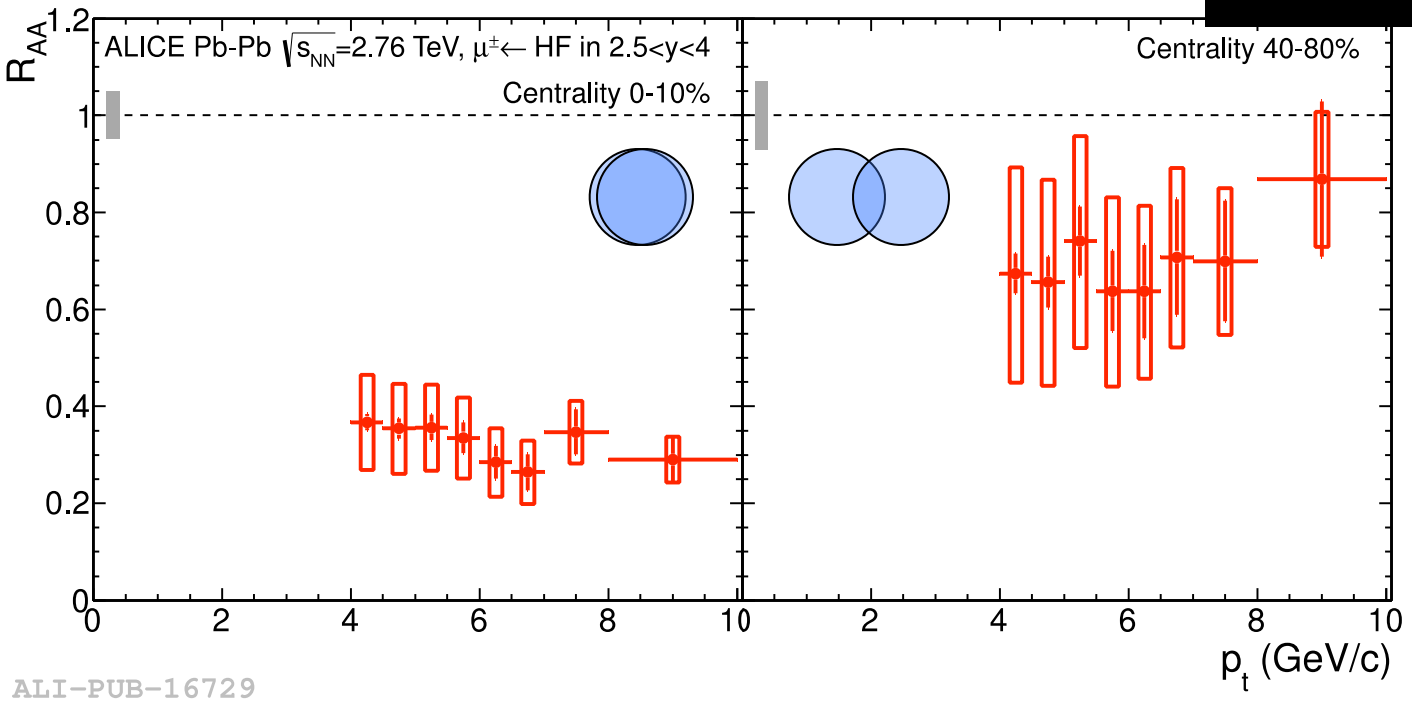
PLB708(2012)265

- High-statistics measurement at both energies (muon trigger)
- FONLL describes the data and indicates beauty dominance above 8 GeV/*c*

HF-decay muon R_{AA} at forward y

$$R_{AA}(p_t) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_t}{d\sigma_{pp}/dp_t}$$

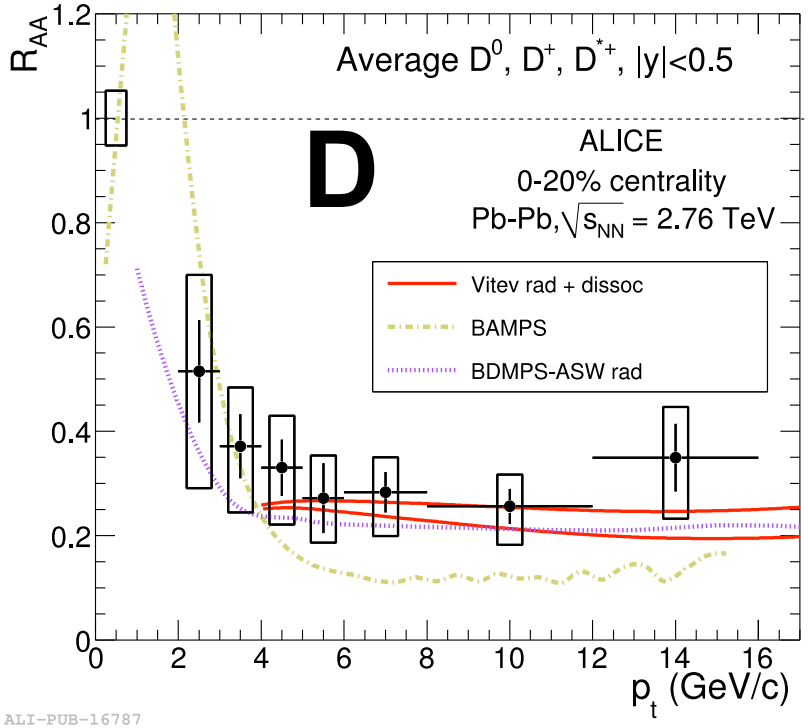


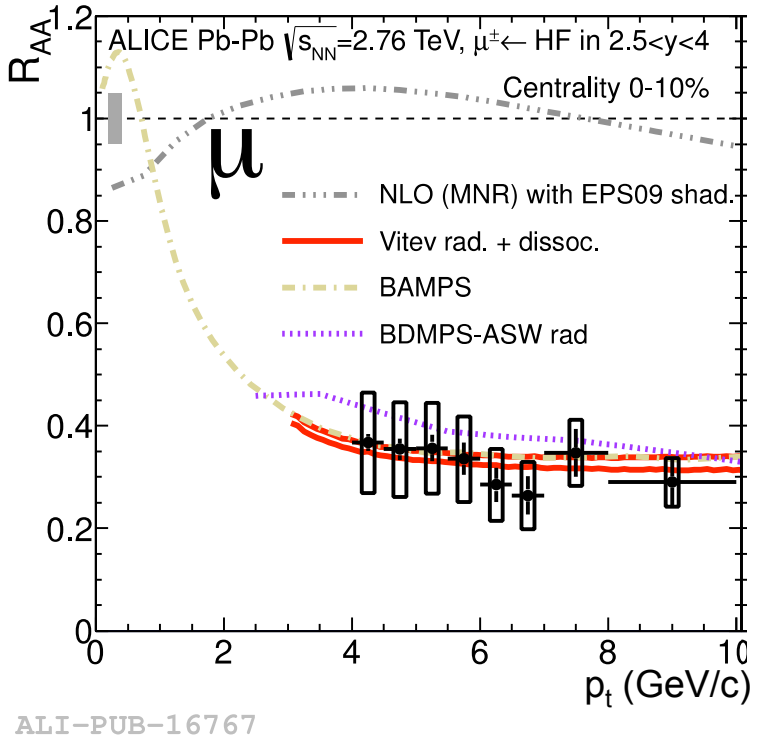


- Suppression by a factor ~3 in central collisions
- No evident p_t dependence

arXiv:1205.6443

Heavy-flavour suppression vs. energy loss calculations





- Models with E-loss (Vitev and BDMPS-ASW) describe both D and μ
- BAMPS model (elastic only) seems to over-suppress charm wrt beauty

Summary

- Rich set of heavy-flavour production measurements with ALICE
  - ***R_{AA} for D*** ✔
    and B ***At high p_t for now (μ and e)***
- Suppression of high-p_t heavy-flavour production (and charm azimuthal anisotropy → talk by C. Perez)
- Indicate strong medium effect on c and b quarks
- Consistent with expected energy loss mechanisms
  - ***Pattern?*** ***No clear pattern, data not conclusive yet***
- Next step: extended Pb-Pb measurements with 2011 data and measurement of initial-state effects in forthcoming p-Pb run at the LHC

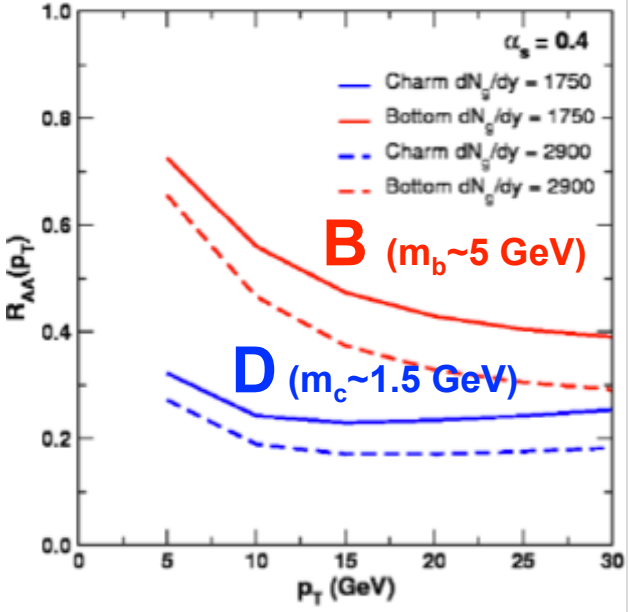
EXTRA SLIDES

HQs E loss: some expectations

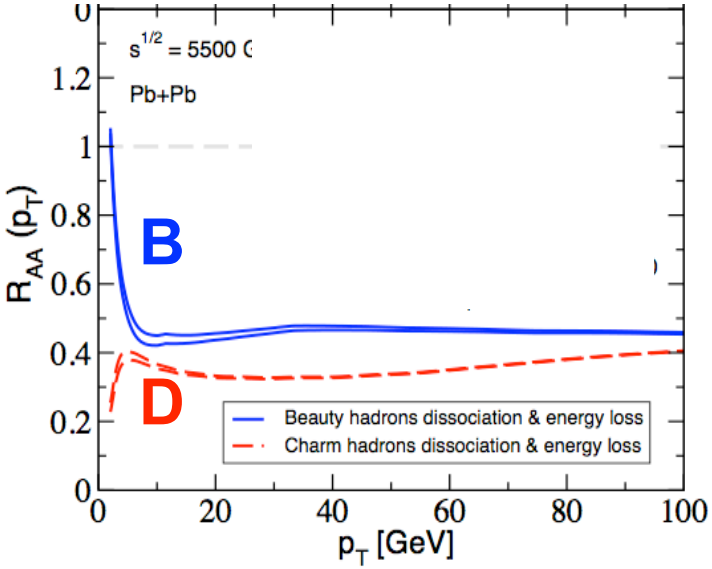
- Energy loss based predictions: factor 3-5 suppression for D mesons
- Significantly smaller suppression for B

$$R_{AA}^{D}(p_t) \text{ and } R_{AA}^{B}(p_t)$$

Radiative E loss



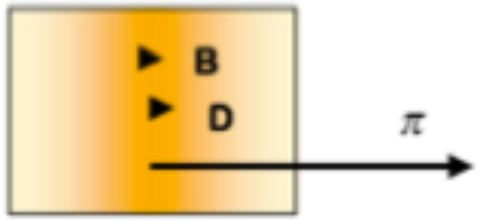
Radiative E loss + dissociation



- Shorter formation time of heavy hadrons → additional R_{AA} suppression due to in-medium dissociation?

$\tau_{form}(p_T = 10\ GeV)$

π	D	B
25 fm	1.6 fm	0.4 fm



Wicks, Gyulassy, "Last Call for LHC Predictions" workshop, 2007

Vitev, et al, PRC80 (2009)

Triggers and Pb-Pb Collision Centrality

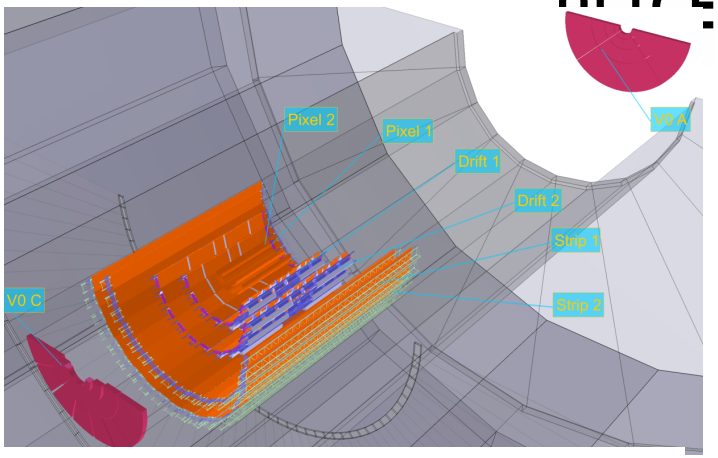
- *Minimum-bias (MB):* combinations of the following detectors

  Pixel Fast-Or (1 or 2 hits)

  VZERO scintillators (one or both sides)

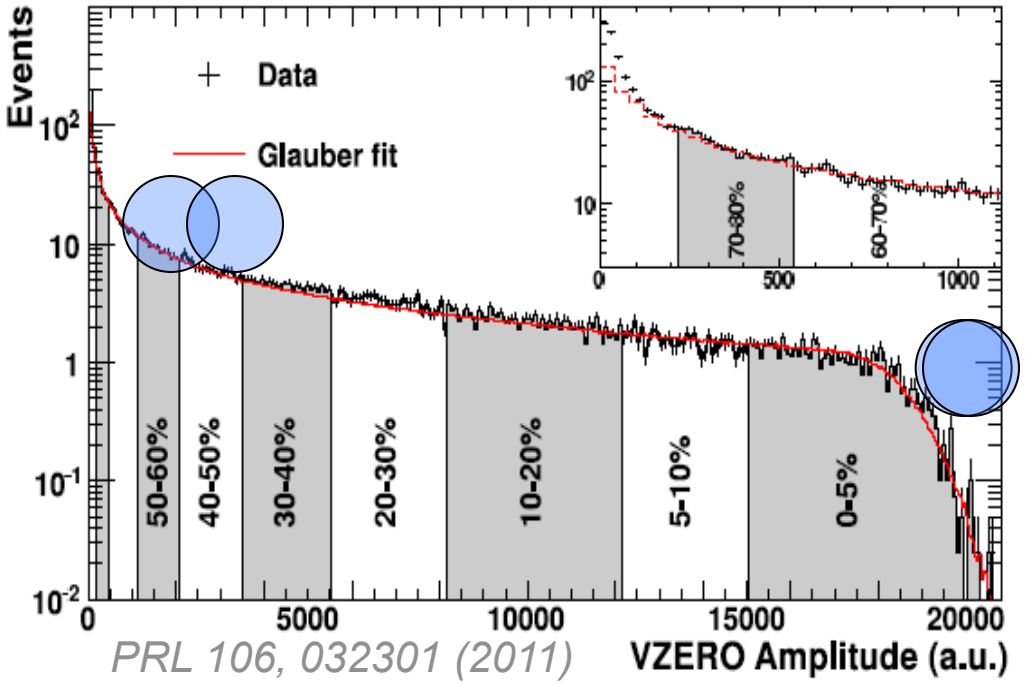
  → pp: 87% of $\sigma_{inelastic}$

  → Pb-Pb: fully efficient in 0-88% of $\sigma_{hadronic}$
- *Single muon: MB* + a muon with p_t>0.5 GeV/c and -4<η<-2.5



Pb-Pb centrality classes (percentiles of $\sigma_{hadronic}$) from the VZERO signal amplitude, which is well-described by the Glauber-model

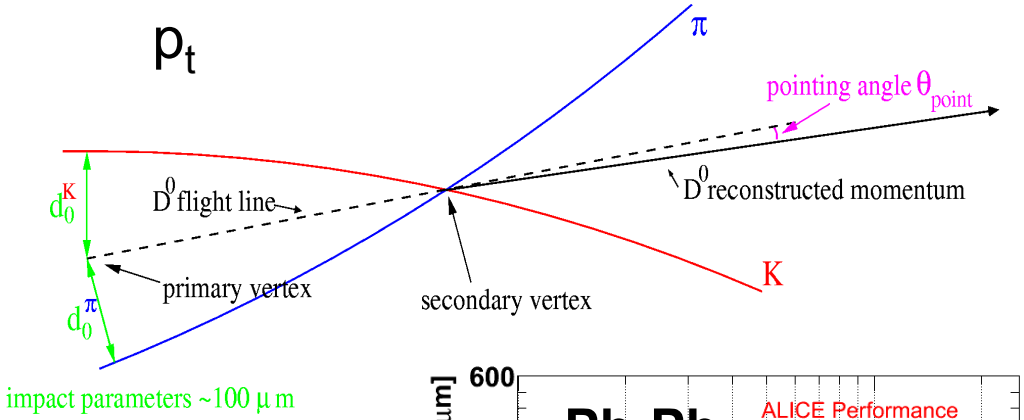
•VZERO amplitude used also online for centrality-based triggering

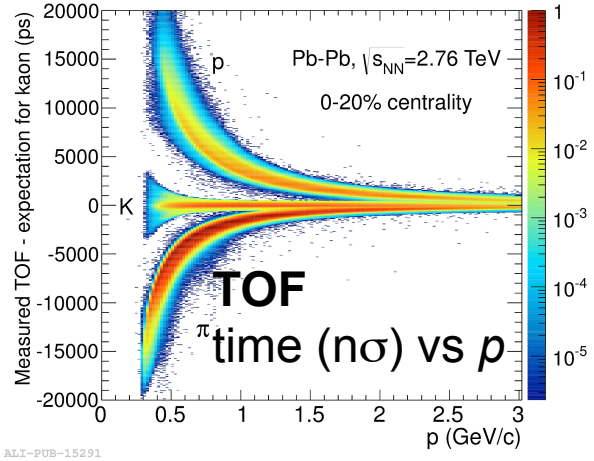


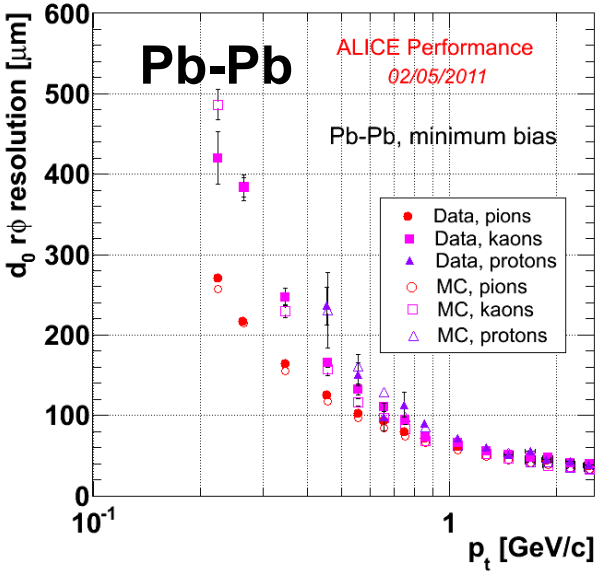
PRL 106, 032301 (2011)

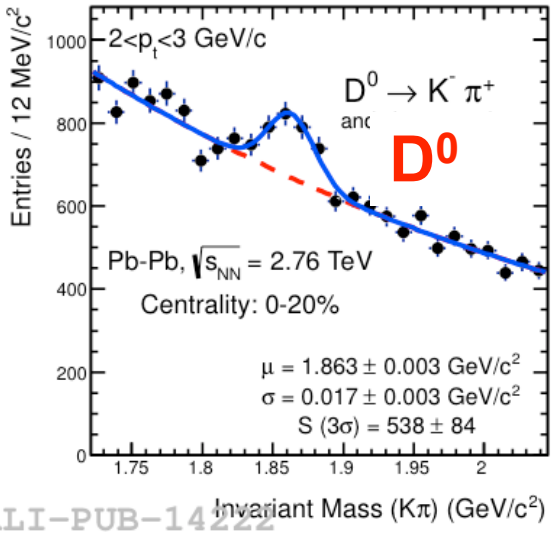
D meson reconstruction in ALICE

- Main selection: displaced-vertex topology
- π/K ID in TPC+TOF helps in rejecting background at low p_t



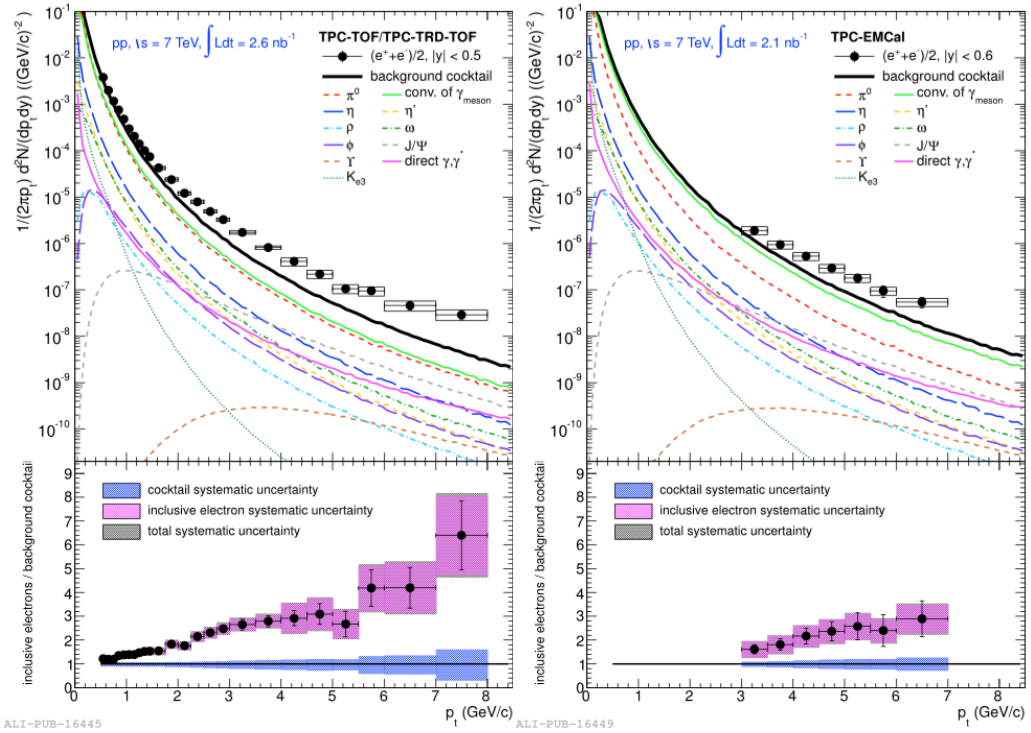


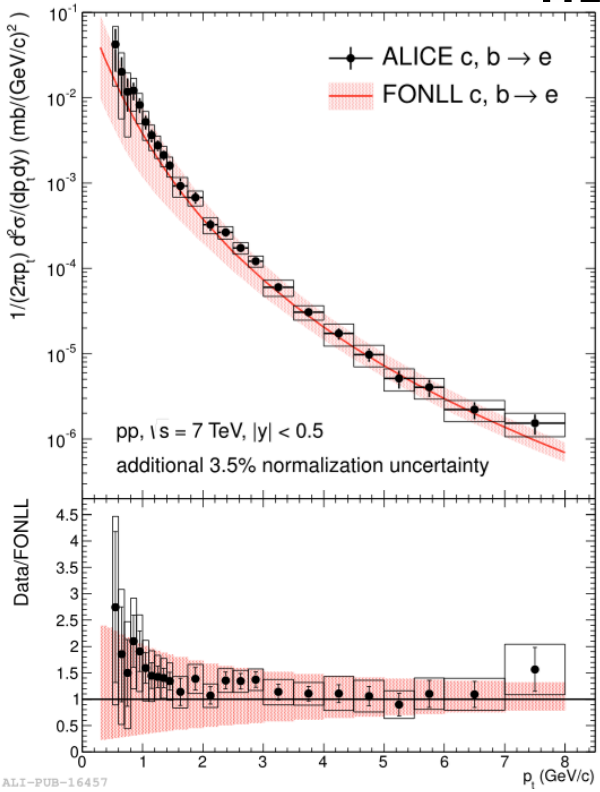




arXiv:1203.216

HF decay electrons: pp 7 TeV, |y|<0.5

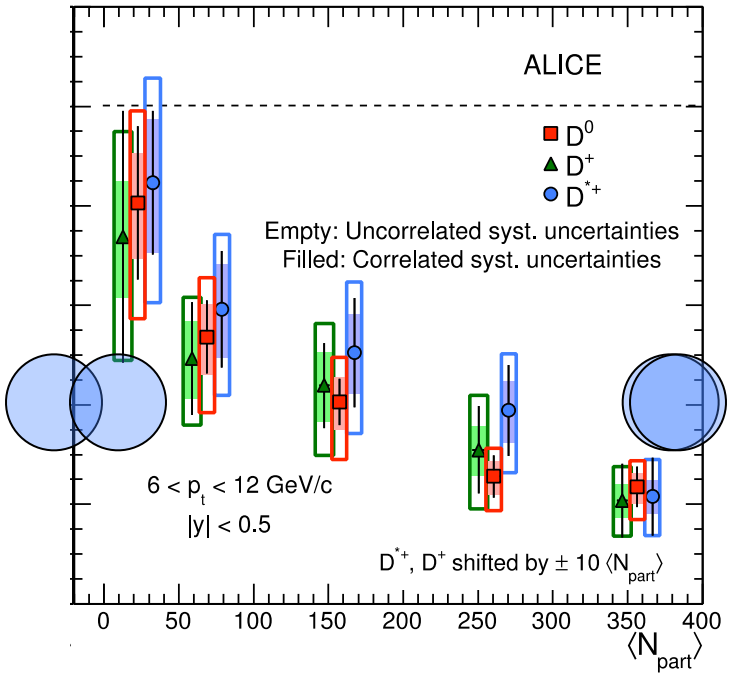


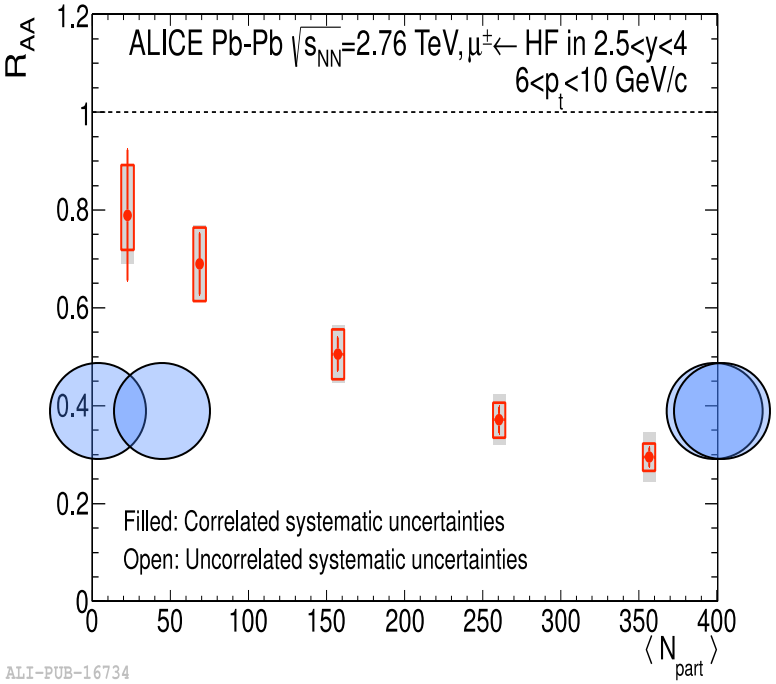


- Inclusive electrons spectrum with two different PID analyses: TPC-TOF-TRD and TPC-EMCAL
- Cocktail of backgrounds
  - "photonic" electrons (from γ "conversions"), based on measured π^0 cross section (m_t scaling for other mesons)
  - quarkonium decays, based on LHC data
  - from direct photons (pQCD)
- Inclusive – Cocktail: electrons from c and b decays → combine the two PID analyses

arXiv:1205.5423

Centrality dependence of suppression

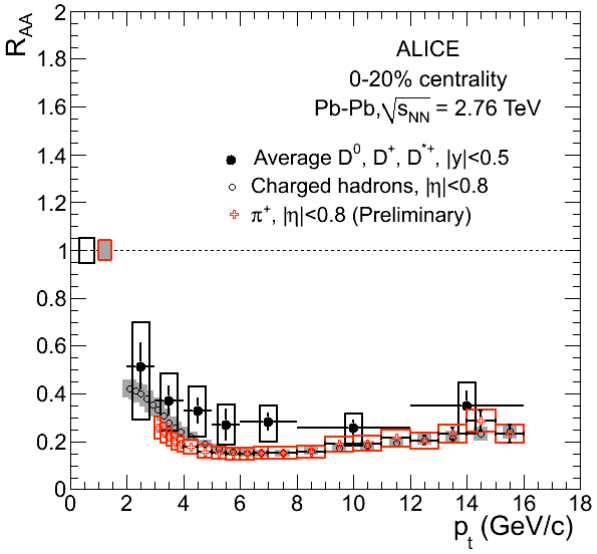


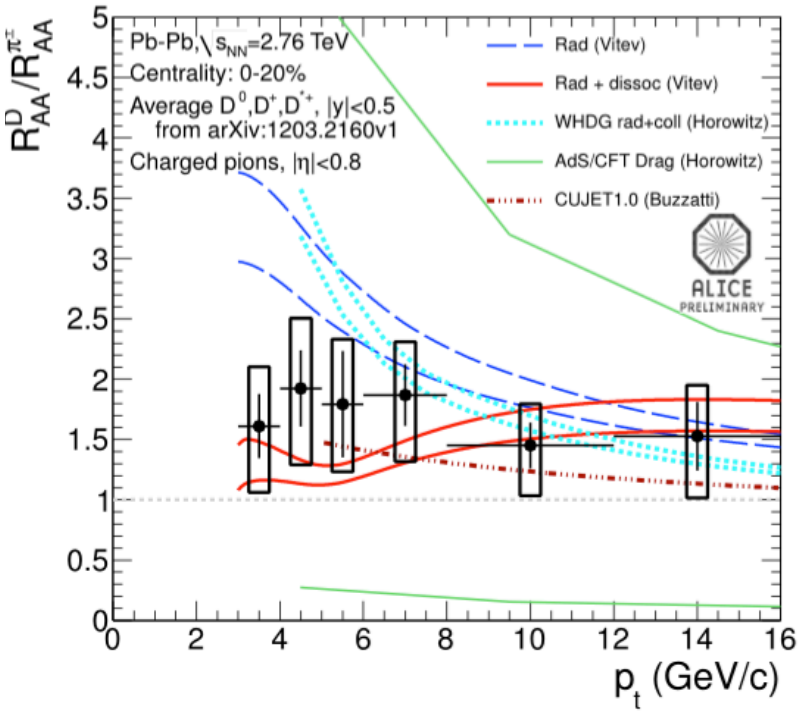


- Large suppression in central collisions (x3-4)
  - Less suppression towards peripheral collisions

Comparisons: charm and pions

- The suppression of D mesons is comparable to that of pions



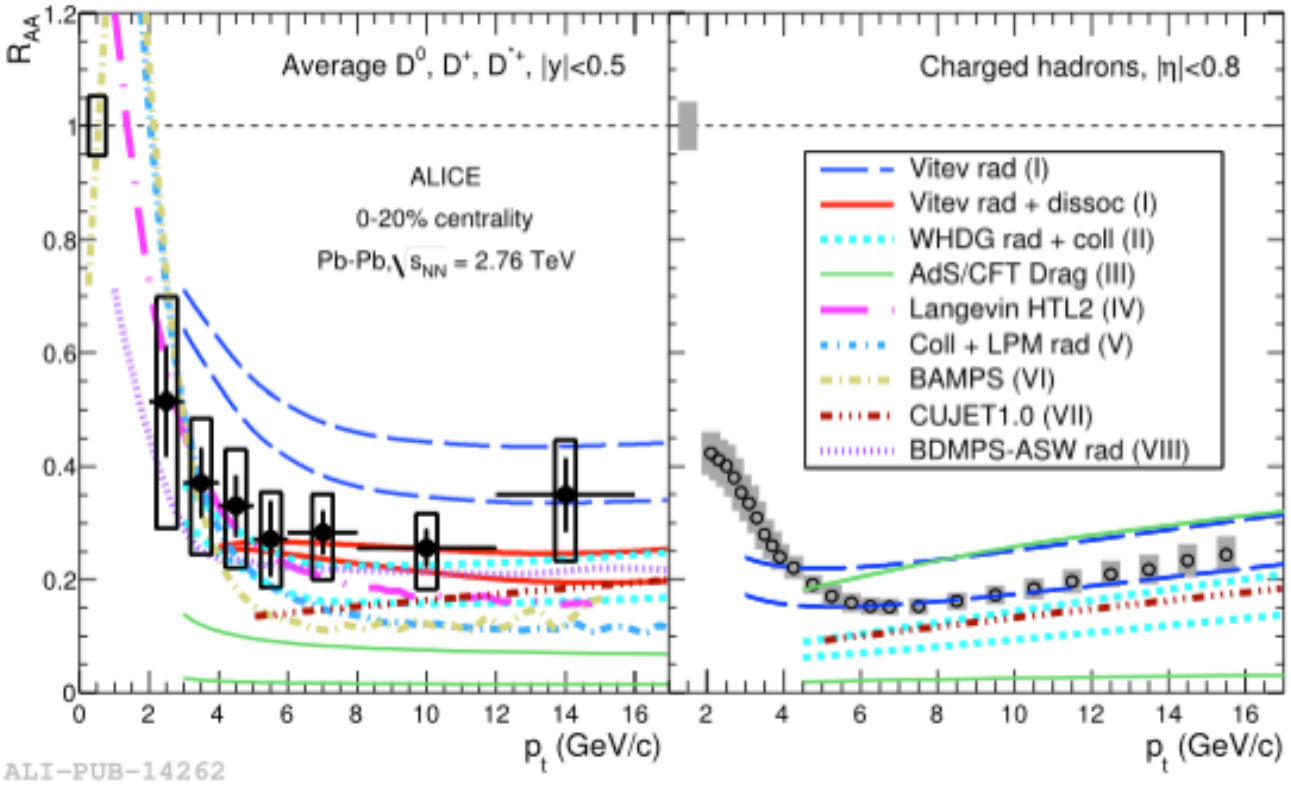


ALI-PREL-14698

- Heavy-to-light ratio "$R_{D/\pi}$": a hint of $R_{AA}^D > R_{AA}^\pi$
- In the model calculations:
  - High-p_t: $R_{D/\pi} > 1$ due colour charge effects (c-quark vs gluon)
  - Low-p_t: additional increase to mass effects (c-quark mass)

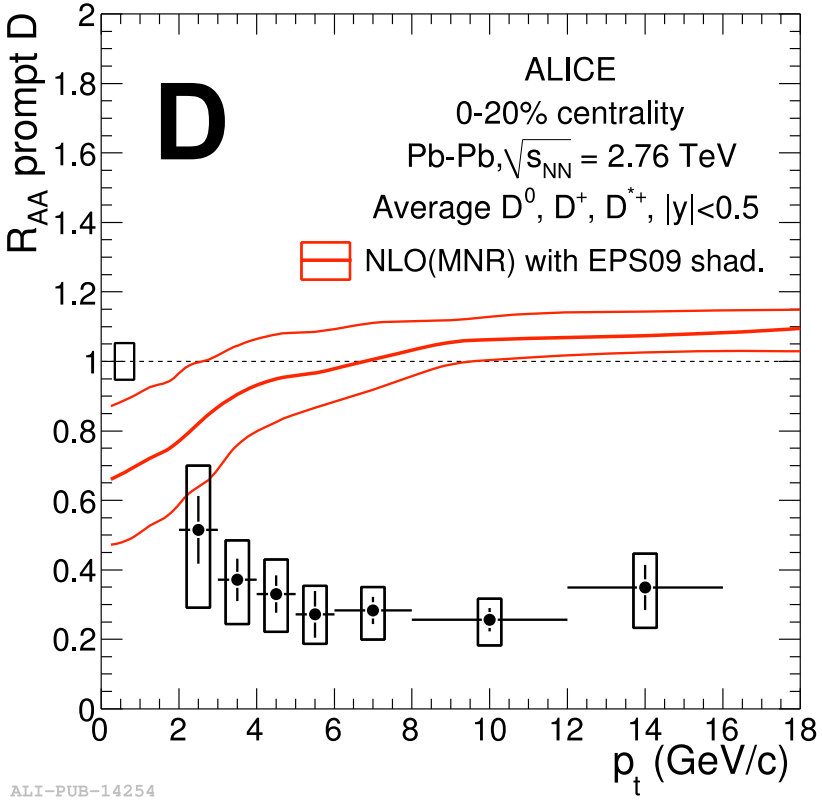
Comparisons: E-loss models

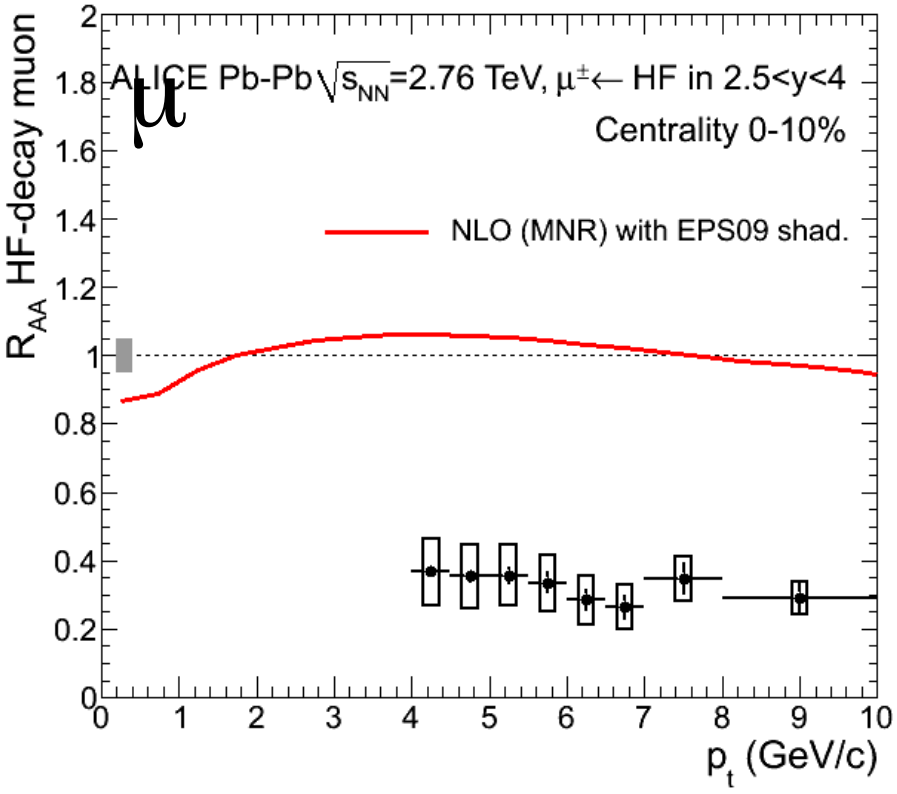
- Several models based on E-loss and heavy-quark transport describe qualitatively the measured charm R_{AA}



- Models with E-loss (radiative, rad. + coll.) generally close to both D and charged RAA
  - Vitev rad + D dissoc
  - WHDG and CUJET1.0 rad + coll
- Model based on AdS/CFT Drag over-suppresses charm

Is it a QCD medium effect?





- Small effect expected from PDFs shadowing above 5 GeV/c
- Suggests that this is a hot medium effect
- p-Pb run at LHC crucial to measure initial-state effects