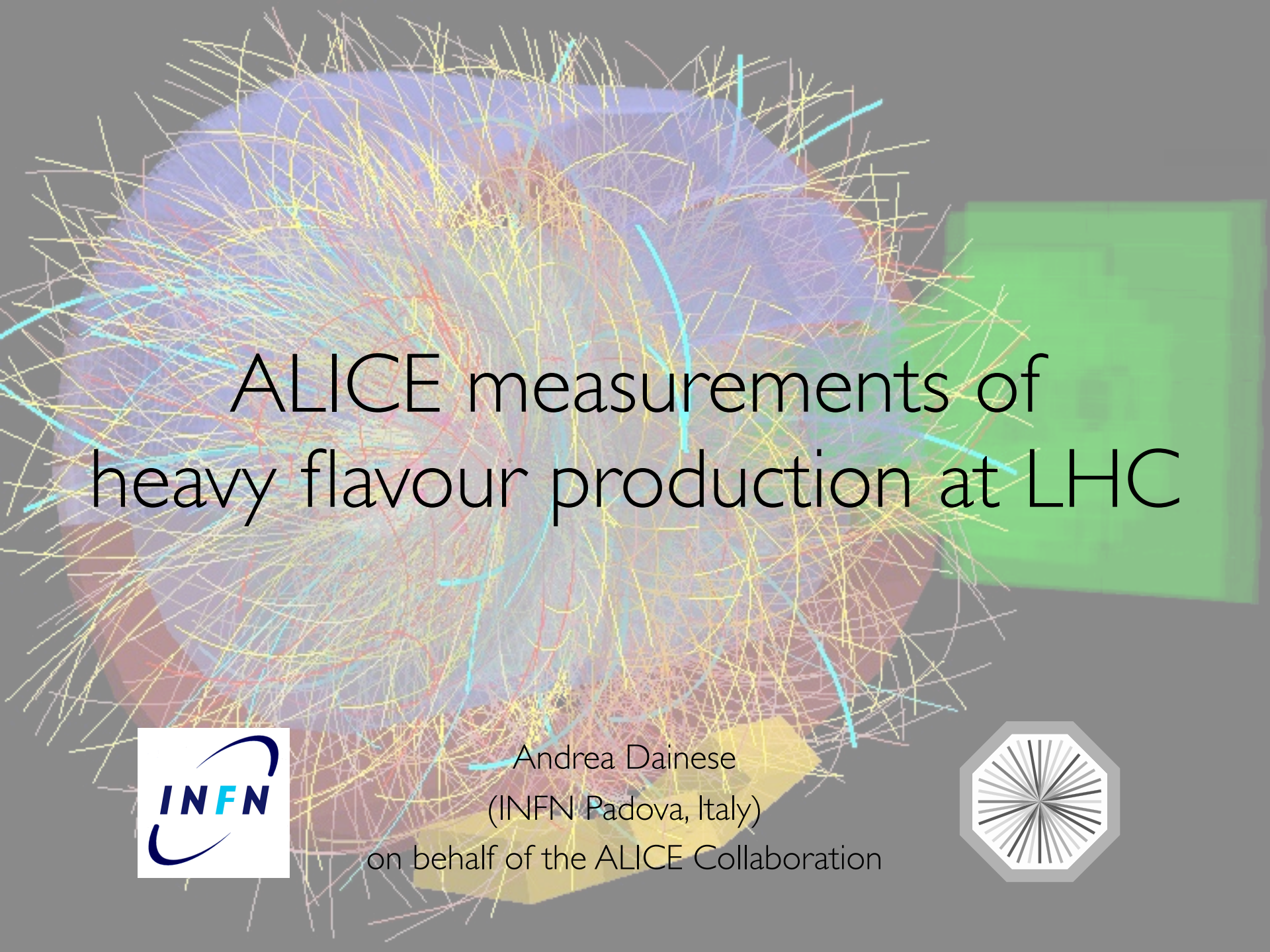

ALICE measurements of heavy flavour production at LHC

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 and pp results
  - D mesons at central rapidity
  - electrons at central rapidity
  - muons at forward rapidity
- Pb-Pb measurements
  - Heavy flavour nuclear suppression at high momentum (R_{AA})
  - Charm azimuthal anisotropy (v_2)
- Outlook & summary

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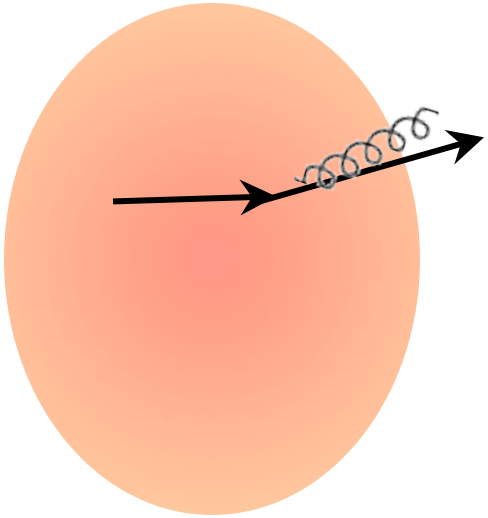
Parton energy loss and the nuclear modification factor



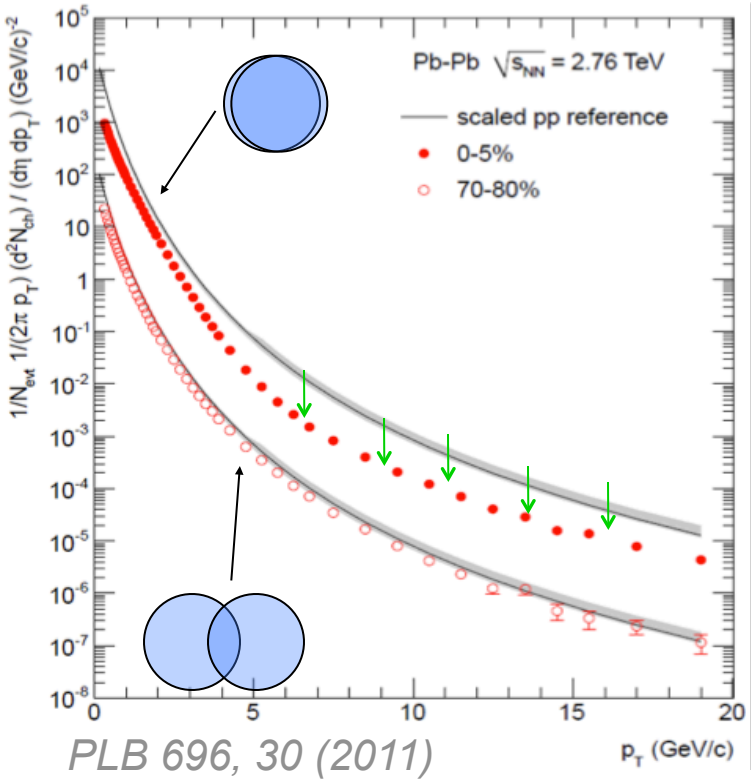
'QCD medium'

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

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

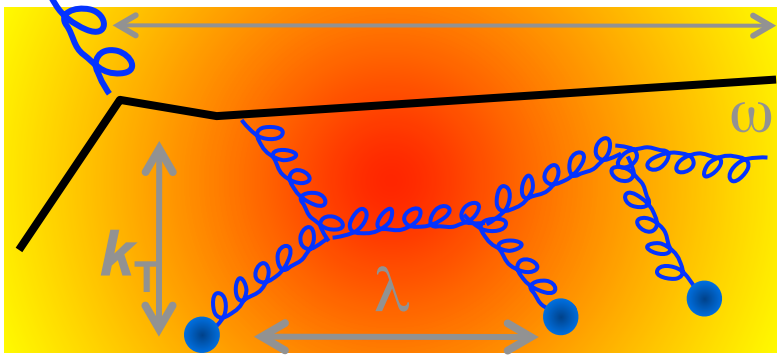
$$dN_{AA}/dp_t < \langle N_{coll} \rangle dN_{pp}/dp_t$$

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



PLB 696, 30 (2011)

The parton and the medium



BDMPS-Z formalism

$$\hat{q} = \frac{\langle k_T^2 \rangle}{\lambda}$$ transport coefficient

Radiated-gluon energy distrib.:

(BDMPS case)

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

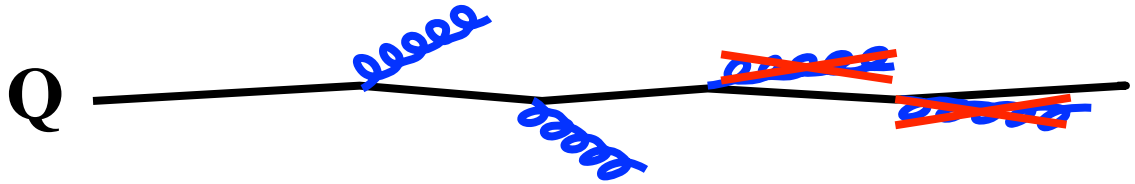
C_R = Casimir coupling factor: 4/3 for q, 3 for g

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

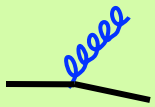
Less gluon radiation for heavy quarks?

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

→ "dead cone" effect



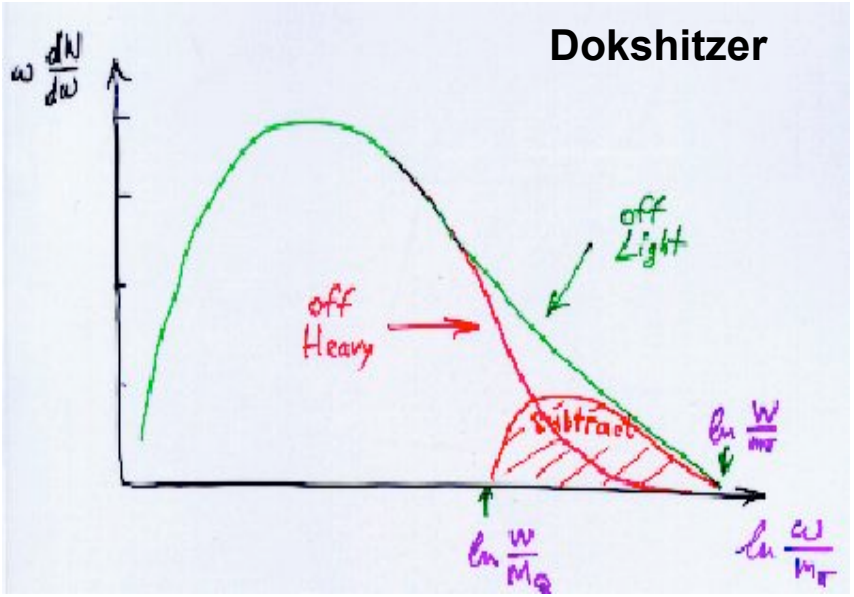
Gluonsstrahlung probability



$$\propto \frac{1}{[\theta^2 + (m_Q/E_Q)^2]^2}$$

- *Dead cone implies lower energy loss* (Dokshitzer-Kharzeev, 2001):
  - energy distribution $\omega dI/d\omega$ of radiated gluons suppressed by angle-dependent factor
  - suppress high-ω tail

$$\omega \left.\frac{dI}{d\omega}\right|_{HEAVY} = \omega \left.\frac{dI}{d\omega}\right|_{LIGHT} \times \left(1 + \left(\frac{m_Q}{E_Q}\frac{1}{\theta^2}\right)^2\right)^{-2}$$



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

Heavy quark energy loss

q: colour triplet

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

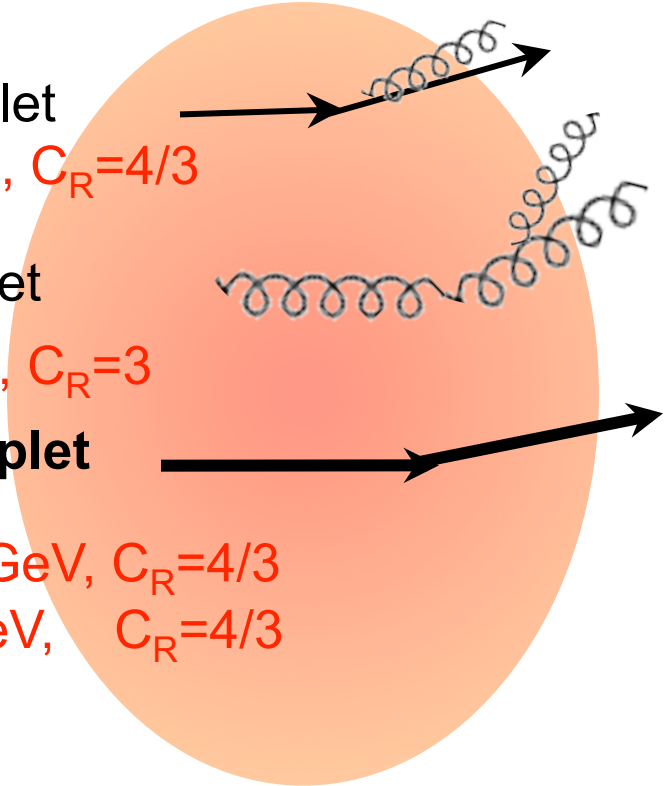
g: colour octet

g: m=0, C_R=3

Q: colour triplet

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

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



'QCD medium'

Parton Energy Loss by

- medium-induced gluon radiation
- collisions with medium gluons

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

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

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

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

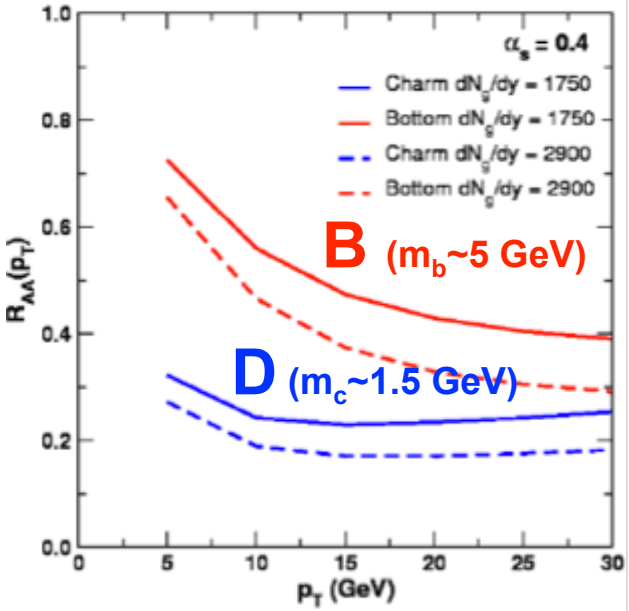
See e.g.:
Dokshitzer and Kharzeev, PLB 519 (2001) 199. Armesto, Salgado, Wiedemann, PRD 69 (2004) 114003.
Djordjevic, Gyulassy, Horowitz, Wicks, NPA 783 (2007) 493.

HQs E loss: some expectations …

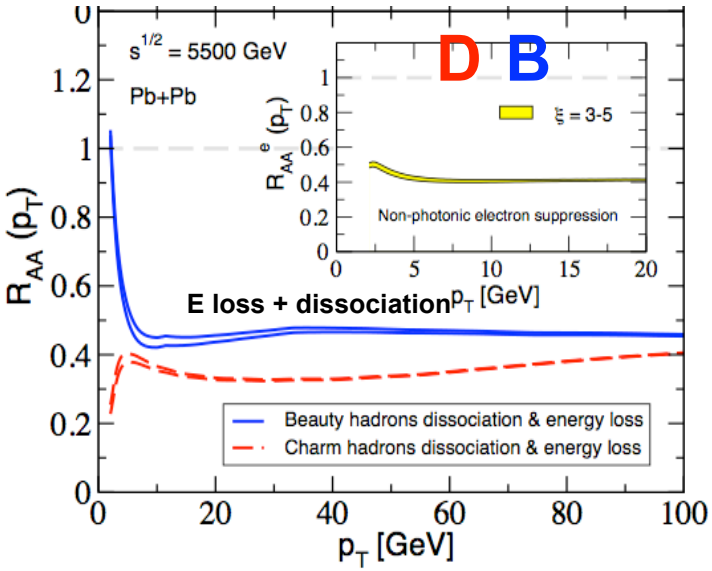
- Energy loss based predictions: factor 3-5 suppression for D mesons
- Significantly smaller suppression for B

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

Radiative E loss



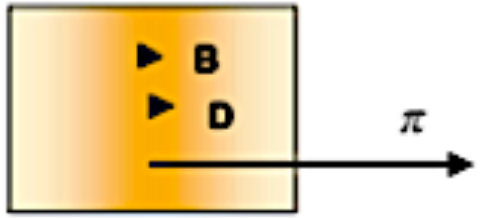
Radiative E loss + dissociation



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

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

π	D	B
25 fm	1.6 fm	0.4 fm

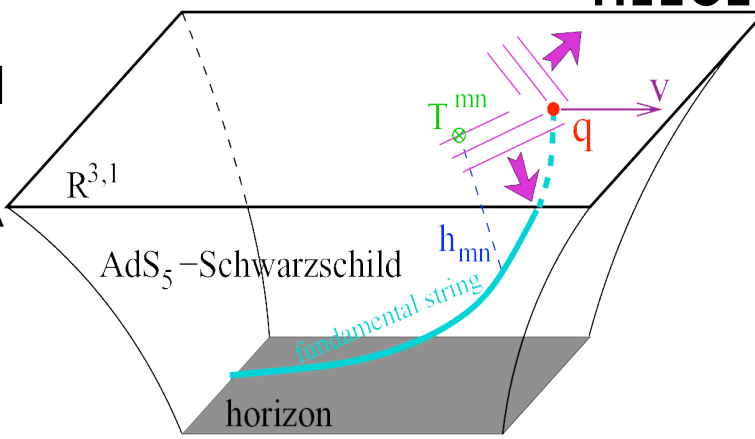


Wicks, Gyulassy, "Last Call for LHC Predictions" workshop, 2007

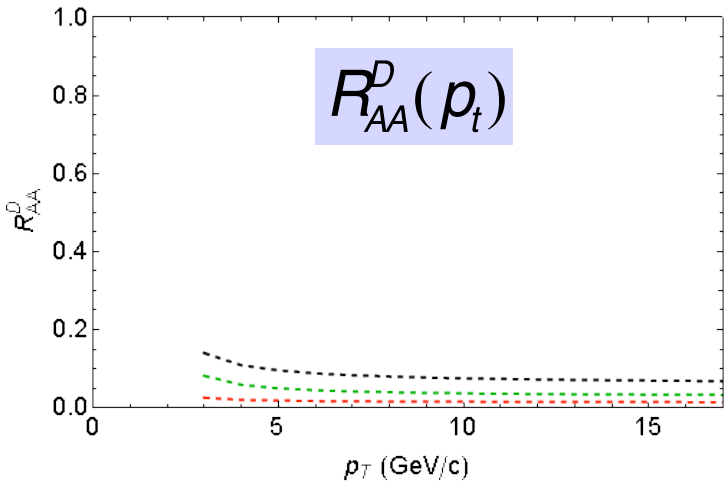
Vitev, et al, PRC80 (2009)

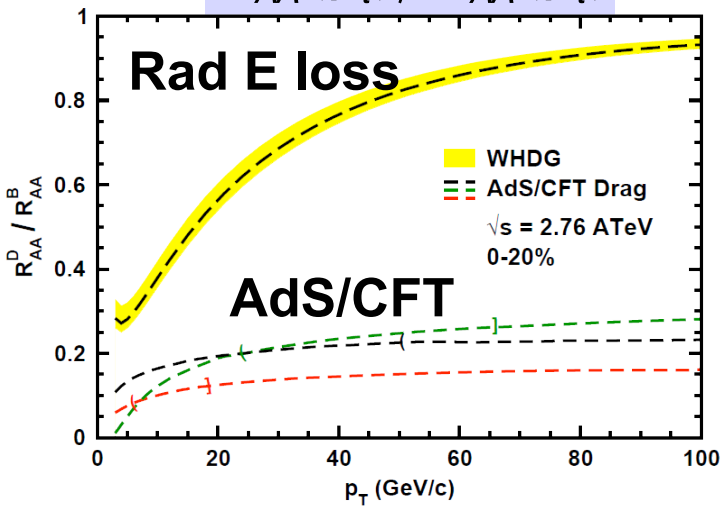
HQs E loss: the AdS/CFT way…?

- Maldacena conjecture: correspondence between super-gravity (Super Yang-Mills) and a Conformal Field Theory w/o gravity (QCD)
- → calculate strongly-coupled QCD in SUGRA
- Model HQ energy loss by embedding a string in AdS space
- Most distinctive prediction:
  - Very strong suppression for charm
  - Small suppression for beauty up to very large p_t



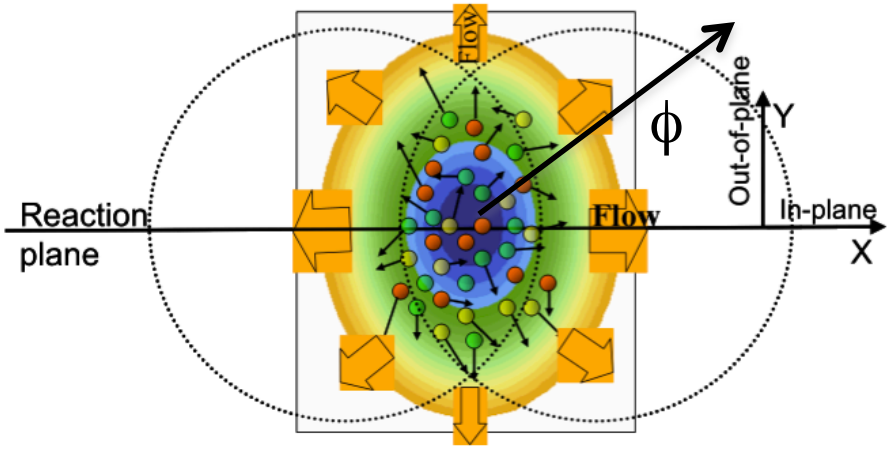
J Friess, Phys Rev D75 (2007)





Horowitz, Gyulassy, PLB666 (2008), Horowitz, arXiv:1108.5876

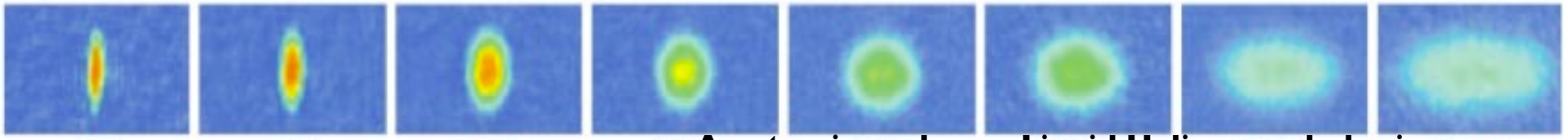
Azimuthal anisotropy: flow and E loss



- System geometry asymmetric in non-central collisions
- Expansion under azimuth-dep. pressure gradient results in azimuth-dep. momentum distributions
- Measured by the elliptic flow parameter $v_2(p_t)$

$$\frac{dN}{Nd\phi} = 1 + 2v_2 \cos\left(2(\phi - \Psi_{RP})\right) + \ldots$$

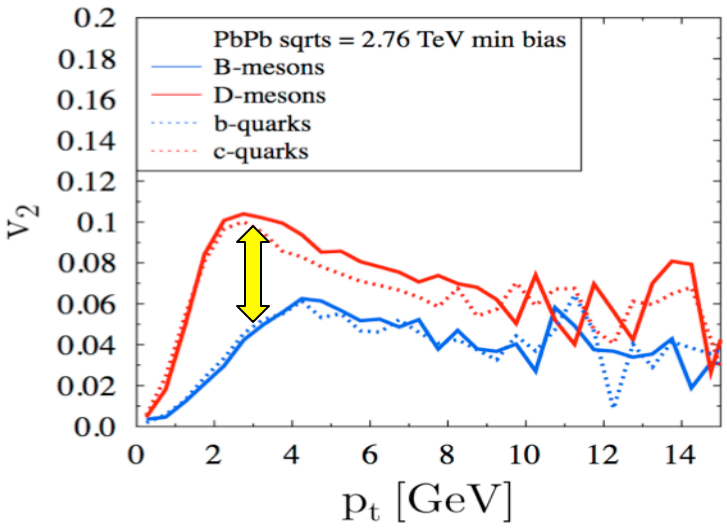
- v_2 of "bulk" (low p_t) provides a measure of strength of collectivity (mean free path of outgoing partons)
- In addition, path-length (L) dependent energy loss in an almond-shaped medium induces an asymmetry in momentum space (high-p_t v_2)

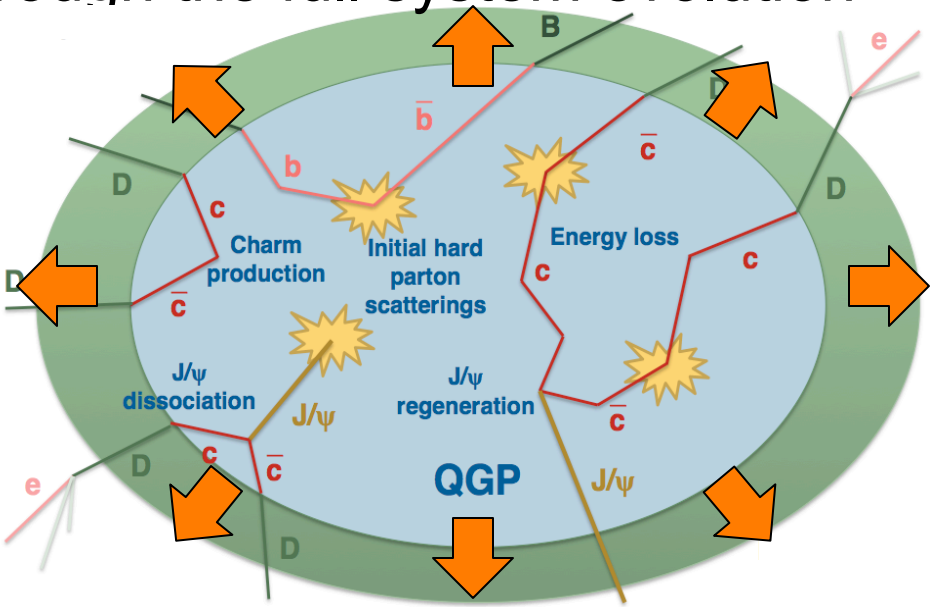


An atomic analogue: Liquid Helium explodes in vacuum

Heavy flavour v_2

- Due to their large mass, c and b quarks should "feel" less the collective expansion
  - → need many interactions with large coupling to build their v_2
  - → $v_2^b < v_2^c$
- Uniqueness of heavy quarks: cannot be "destroyed/created" in the medium → transported through the full system evolution





J. Aichelin et al. in arXiv:1201:4192 See also J. Uphoff et al., R. Rapp et al., A. Beraudo et al.

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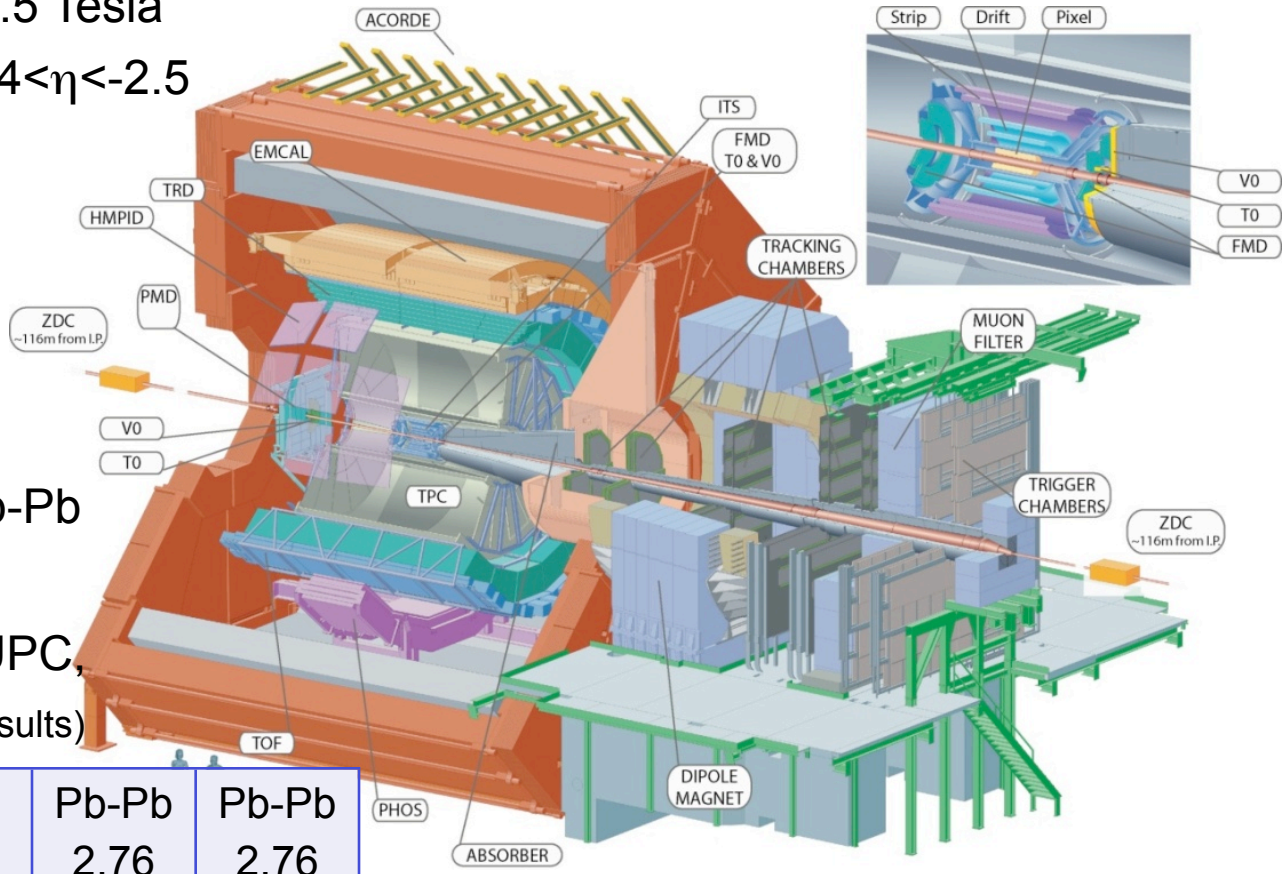
ALICE apparatus and datasets

- Two main parts:
  - barrel ($|\eta|<0.9$), B = 0.5 Tesla
  - muon spectrometer, $-4<\eta<-2.5$
- Crucial for HF:
  - vertexing, tracking
  - hadron and lepton ID
- Triggers:
  - minimum-bias (MB)
    - or centrality, in Pb-Pb
  - single muon p_t
  - EMCAL, high-mult., UPC, dimuon (not for today's results)



system, $\sqrt{s_{NN}}$ (TeV)	pp 7	pp 2.76	Pb-Pb 2.76	Pb-Pb 2.76
year	2010	2011	2010	2011
L_{int} MB/cent	5/nb	1.5/nb	2.5/μb	6.5/μb
L_{int} μ	16.5/nb	19/nb	2.5/μb	--

Datasets used for today's results

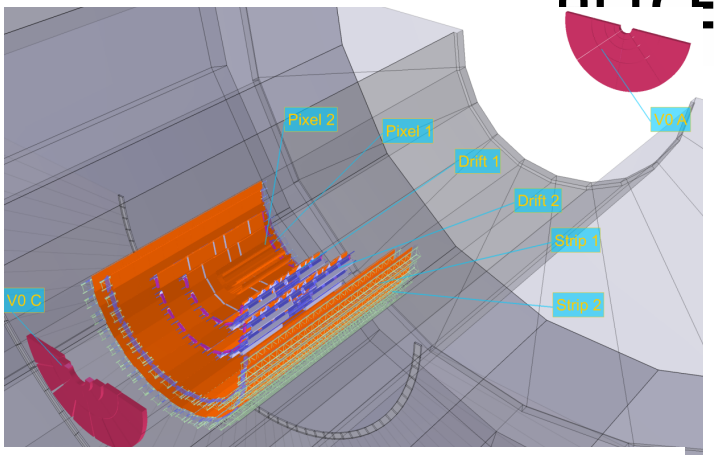
Triggers and Pb-Pb Collision Centrality

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

  Pixel Fast-Or (1 or 2 hits)

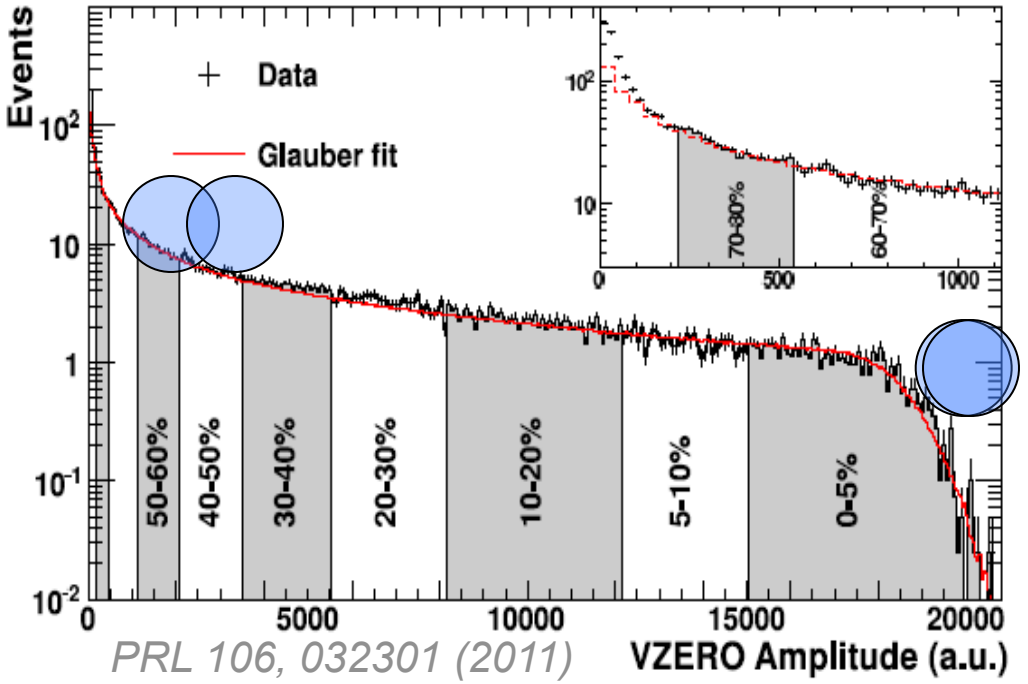
  VZERO scintillators (one or both sides)

- *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)

ALICE Heavy Flavour Detection: D mesons, |y|<0.8

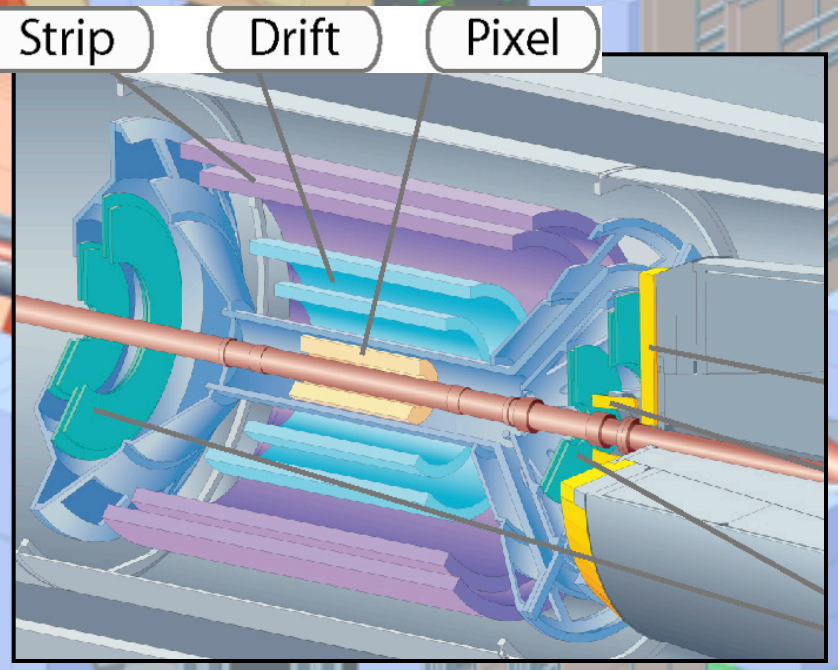
- ✓ $D^0 \rightarrow K\pi(\pi\pi)$
- $D^+ \rightarrow K\pi\pi$
- $D_s \rightarrow KK\pi$
- $D^* \rightarrow D^0\pi$
- $D^0 \rightarrow K\pi\pi\pi$
- $\Lambda_c \rightarrow pK\pi(K^0_S)$

TOF (p/K/π id)

K π

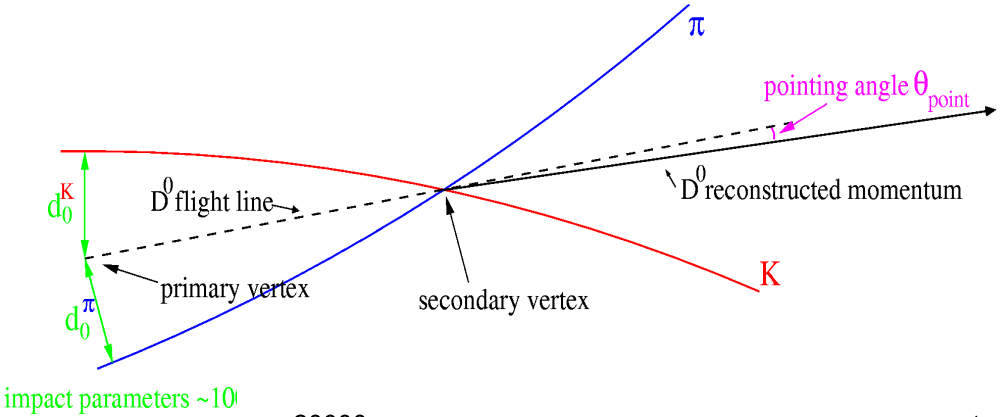
TPC (tracking, p/K/π id)

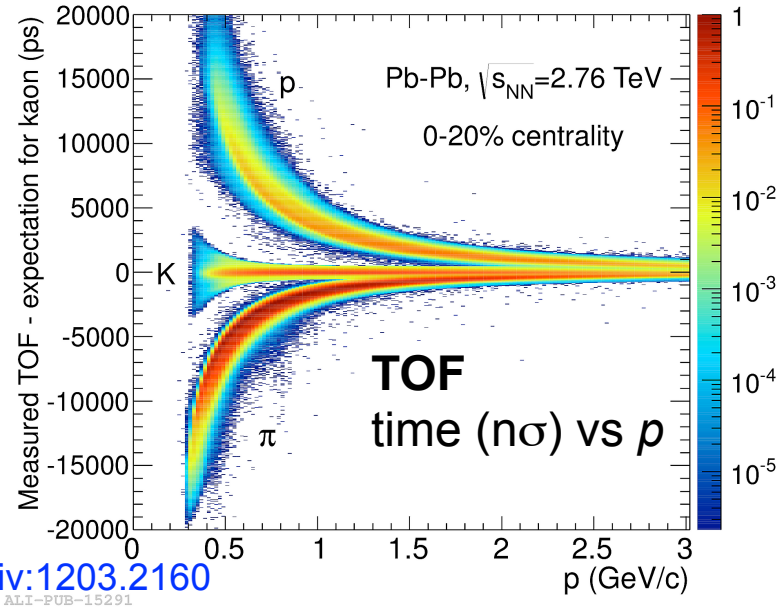
ITS (tracking & vertexing)

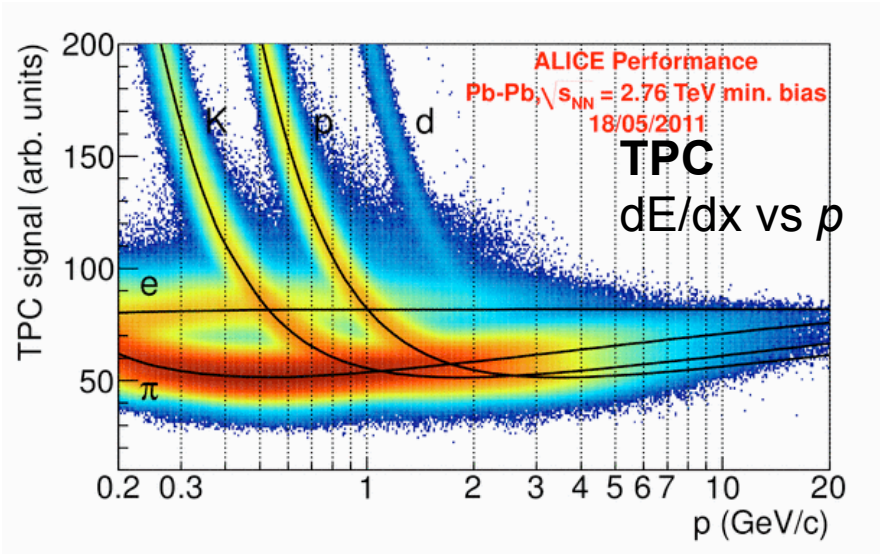


D meson reconstruction in ALICE

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





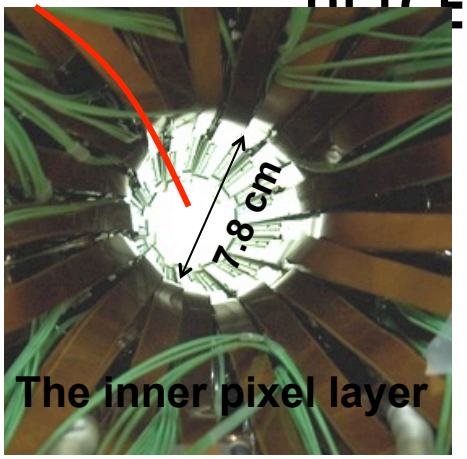


arXiv:1203.2160

ALI-PUB-15291

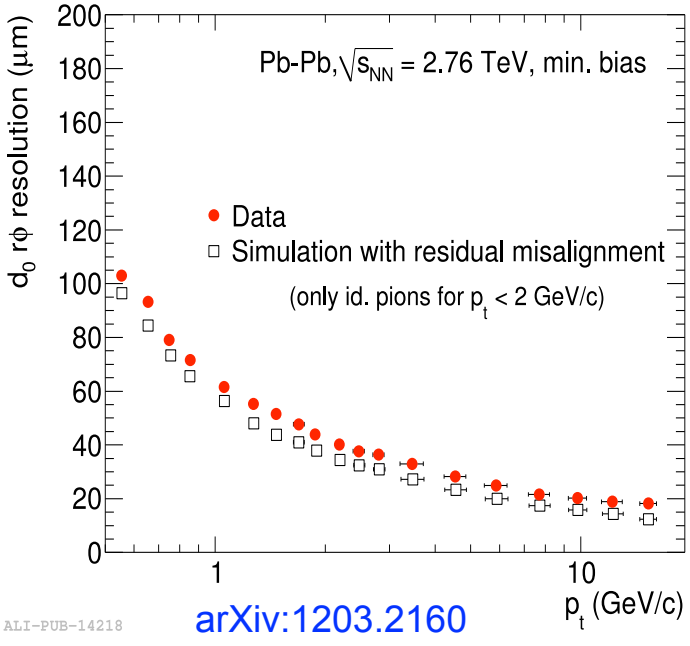
D meson reconstruction in ALICE

- Main selection: displaced-vertex topology
- Tracking and vertexing precision is crucial here
- Inner Tracking System (ITS) with 6 Si layers
  - two pixel layers at 3.9 cm (closest barrel layer at LHC!) and 7 cm
- Excellent track impact parameter resolution:

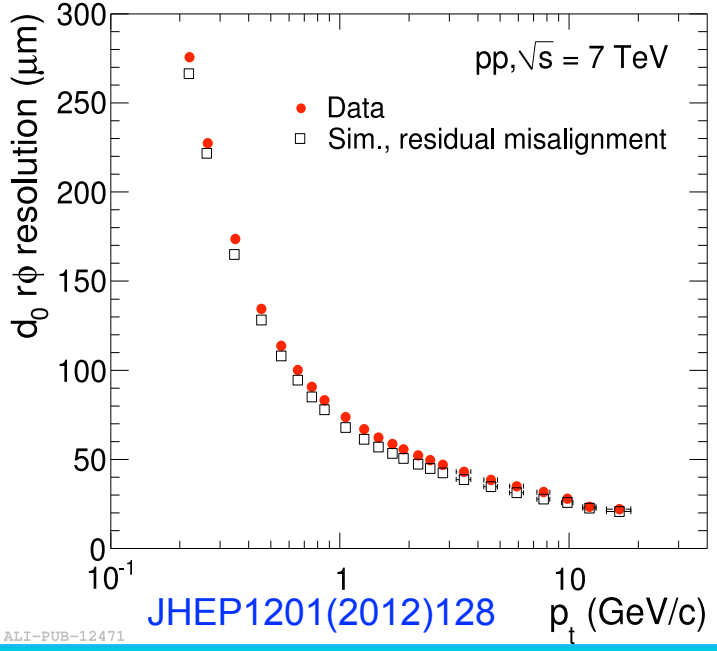


The inner pixel layer

Pb-Pb **pp**



arXiv:1203.2160

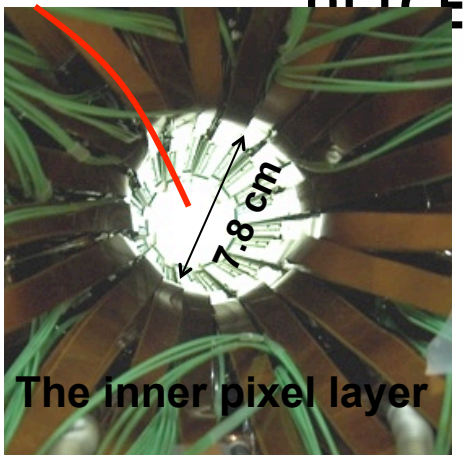


JHEP1201(2012)128

Same tracking precision in pp and Pb-Pb, described within 5 μm in MC,

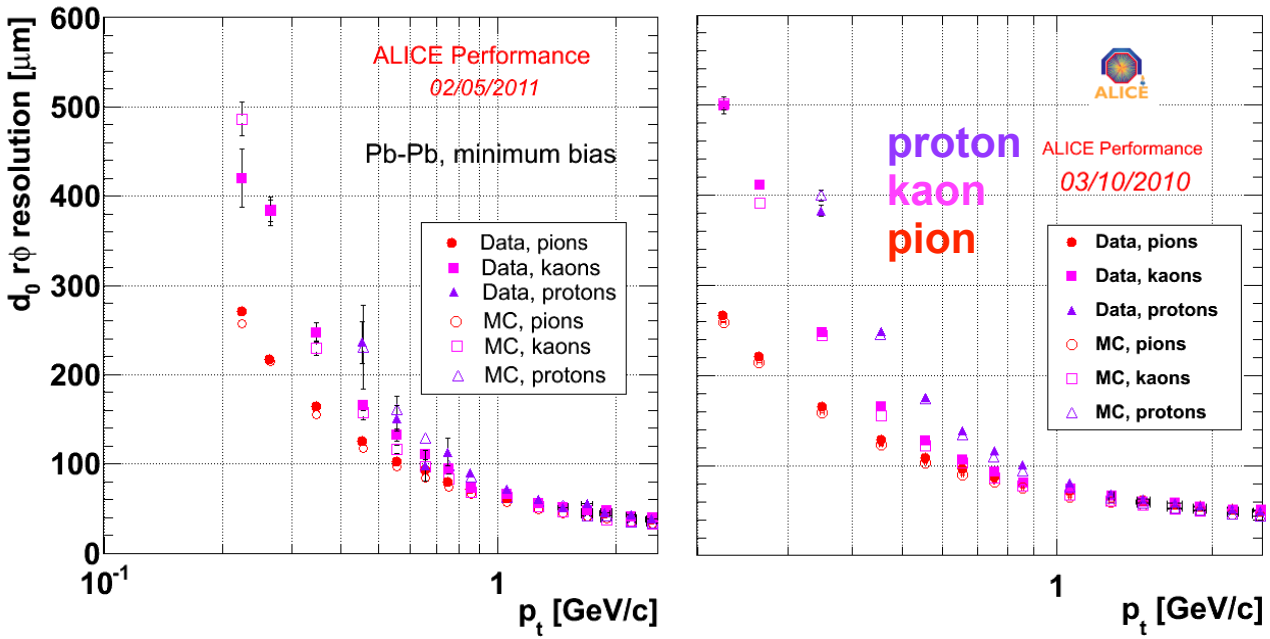
D meson reconstruction in ALICE

- Main selection: displaced-vertex topology
- Tracking and vertexing precision is crucial here
- Inner Tracking System (ITS) with 6 Si layers
  - two pixel layers at 3.9 cm (closest barrel layer at LHC!) and 7 cm
- Excellent track impact parameter resolution:



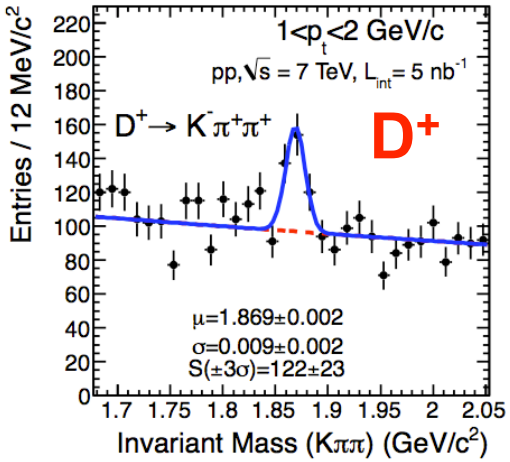
The inner pixel layer

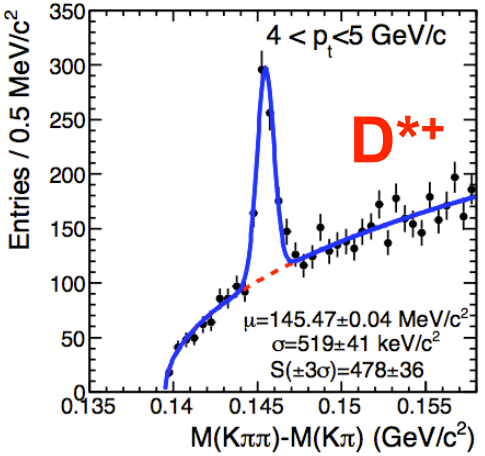
Pb-Pb **pp**

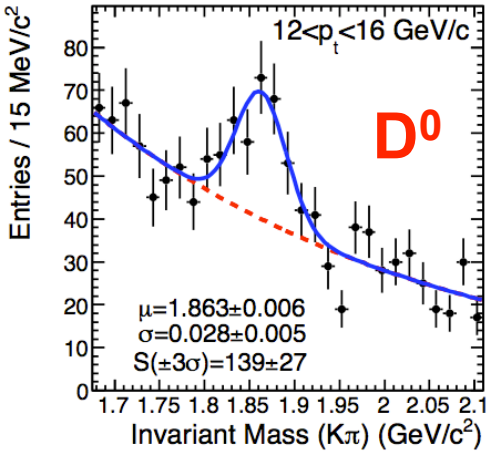


Same tracking precision in pp and Pb-Pb, described within 5 μm in MC, <u>incl. mass dep.</u>

D meson cross sections: pp 7 TeV, D^0, D^+, D^*, $|y|<0.5$

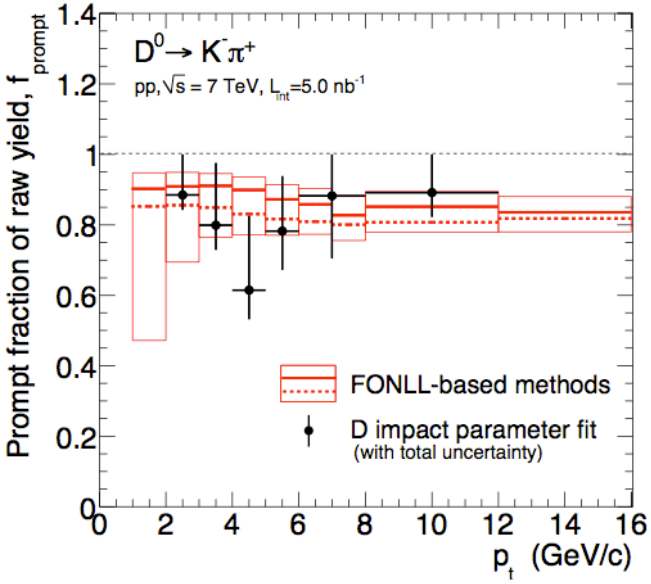


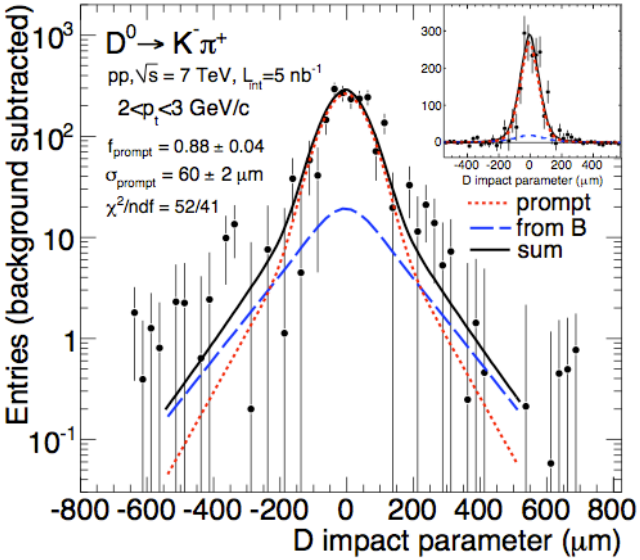




- Signals in 1-24 GeV/c, with 5 nb^{-1}

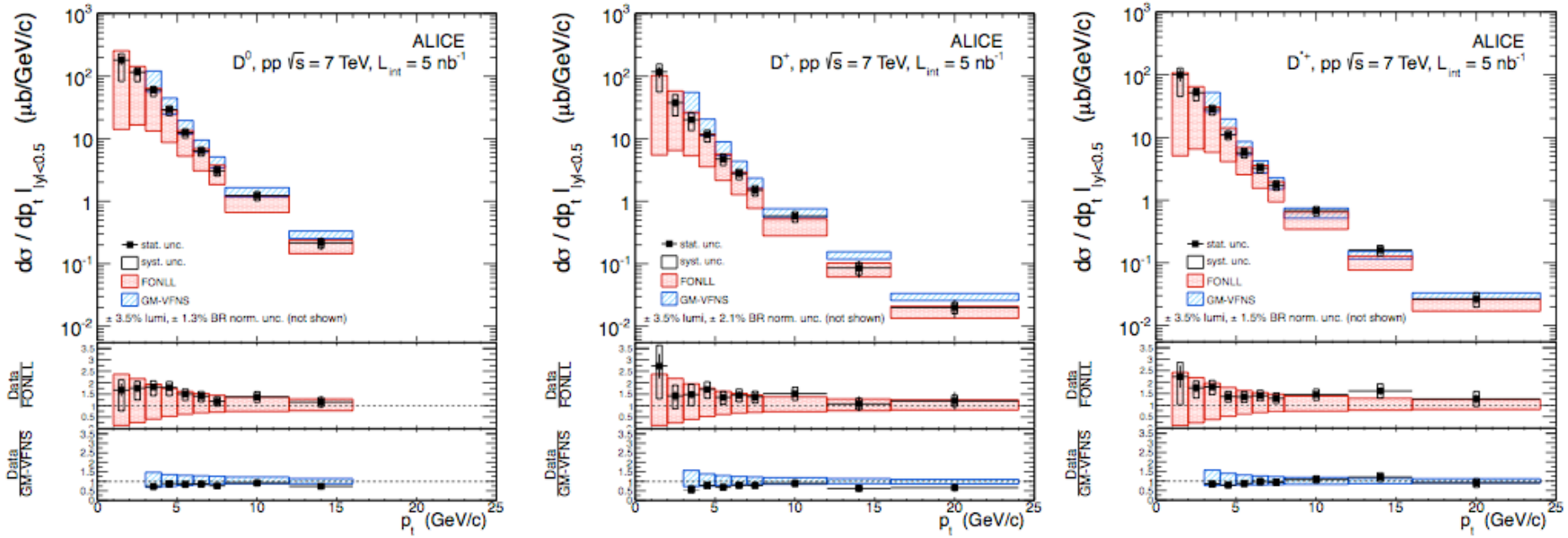
- B→D feed-down subtracted with FONLL
- Cross-checked with D impact parameter fit





JHEP1201(2012)128

D meson cross sections: pp 7 TeV, D^0, D^+, D^*, $|y|<0.5$

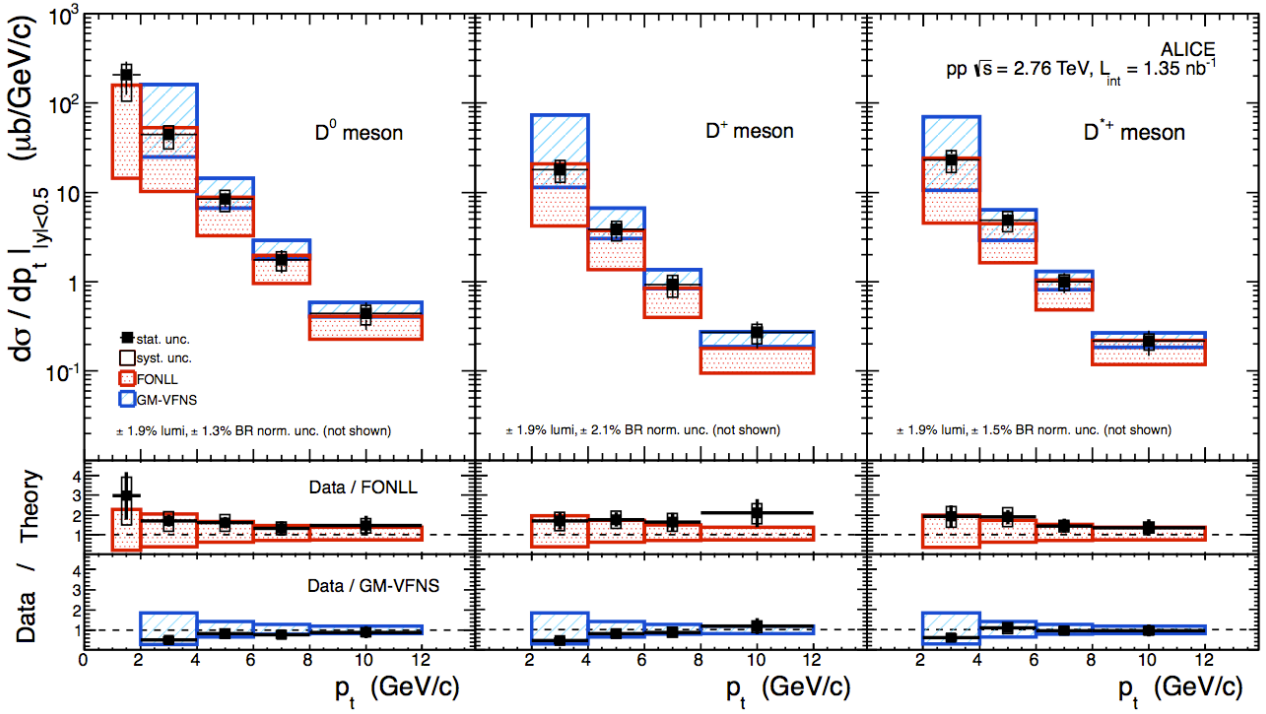


- Compared to perturbative QCD calculations: FONLL and GM-VFNS
- Fair description within uncertainties
  - On upper side of FONLL
  - On lower side of GM-VFNS
- 80% of $d\sigma/dy$ (assuming FONLL p_t shape)

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

JHEP1201(2012)128

D meson cross sections: pp 2.76 TeV, D^0, D^+, D^*, $|y|<0.5$

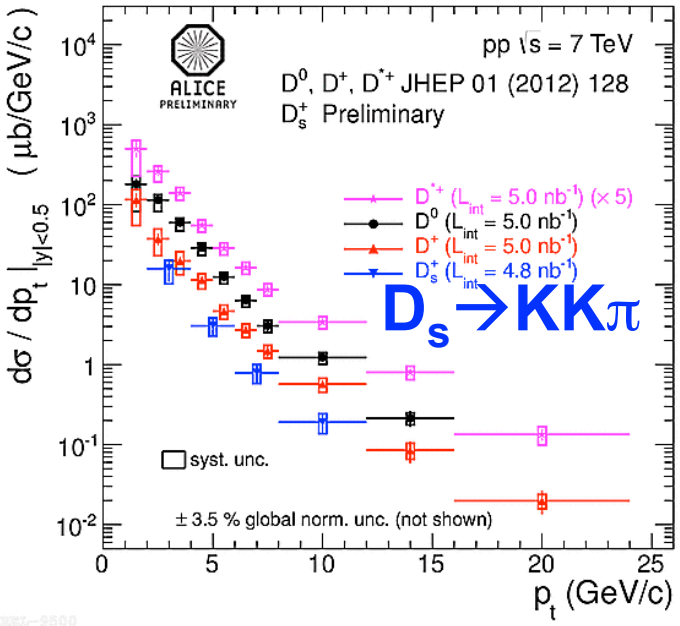


- Limited statistics (1.35/nb with MB trigger)
- Fair description by pQCD within uncertainties
  - On upper side of FONLL
  - On lower side of GM-VFNS

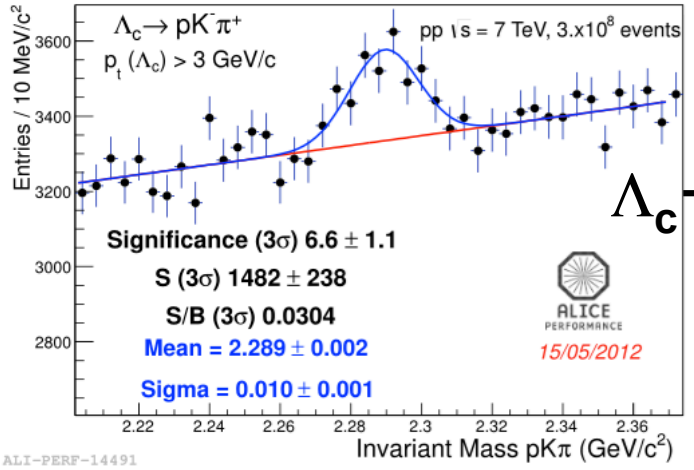
FONLL: Cacciari et al., arXiv:1205.6344
GM-VFNS: Kniehl et al., arXiv:1202.0439

arXiv:1205.4007

More charm in pp: D_s and Λ_c

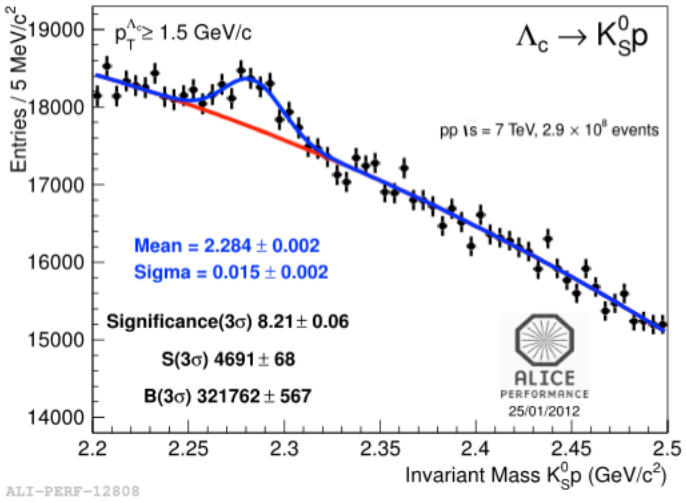


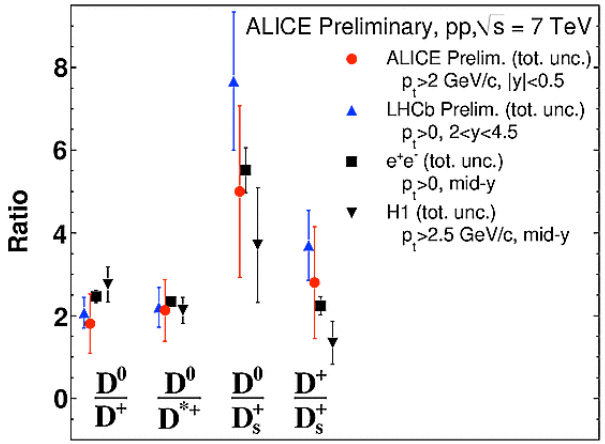
$D_s \rightarrow KK\pi$



$\Lambda_c \rightarrow pK\pi$

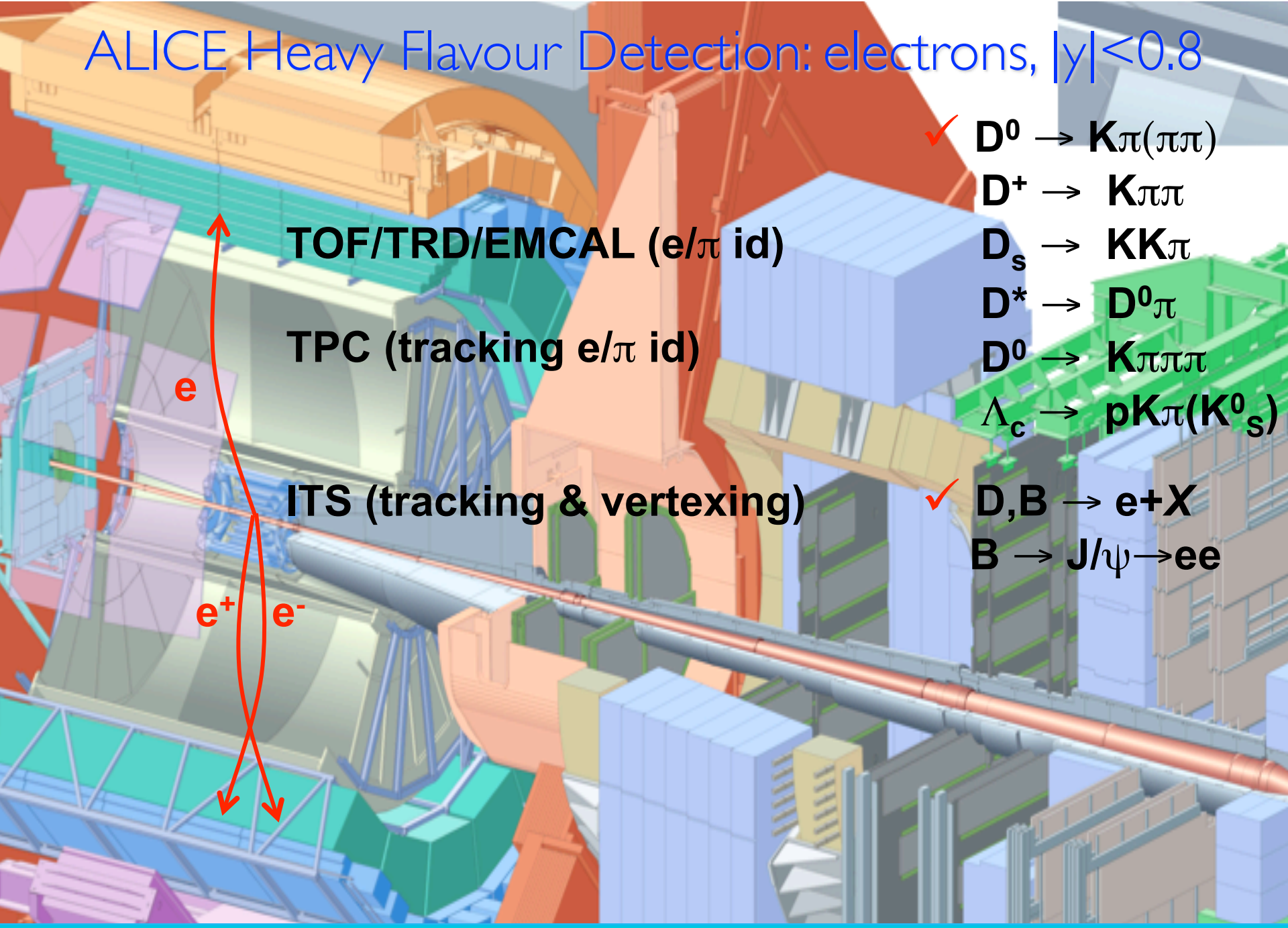
$\Lambda_c \rightarrow pK^0_S$





- ALICE and LHCb agree
- D ratios comparable in ee, ep, pp

ALICE Heavy Flavour Detection: electrons, |y|<0.8

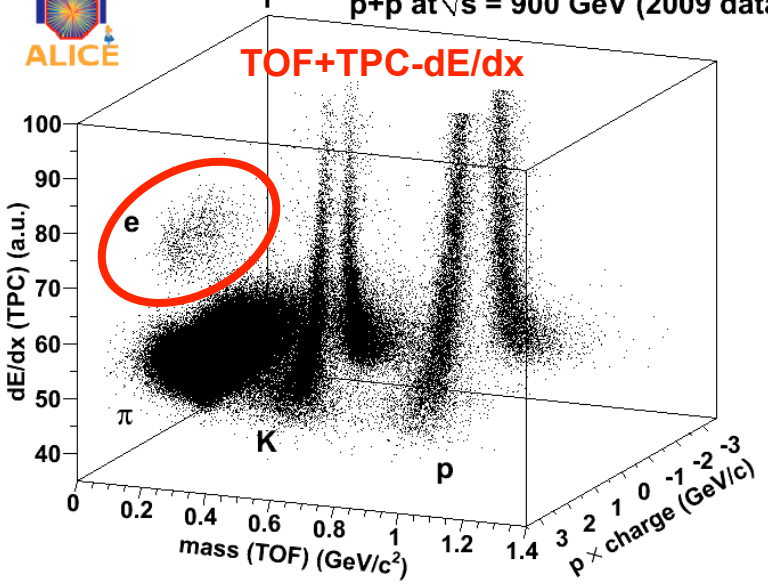


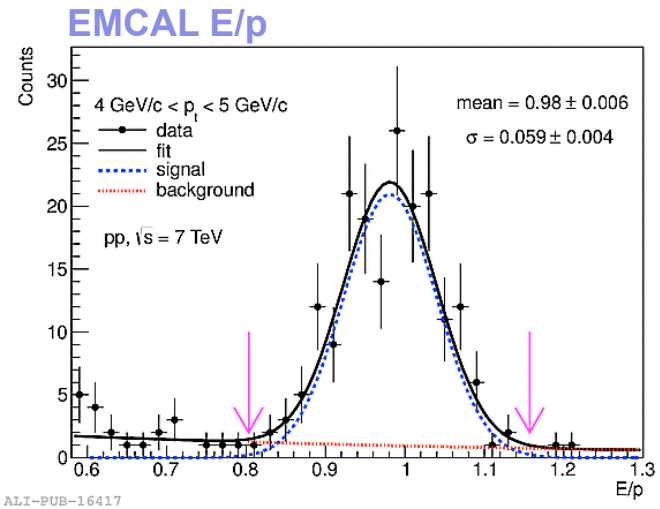
- ✓ $D^0 \rightarrow K\pi(\pi\pi)$
- $D^+ \rightarrow K\pi\pi$
- $D_s \rightarrow KK\pi$
- $D^* \rightarrow D^0\pi$
- $D^0 \rightarrow K\pi\pi\pi$
- $\Lambda_c \rightarrow pK\pi(K^0_S)$
- ✓ $D,B \rightarrow e+X$
- $B \rightarrow J/\psi \rightarrow ee$

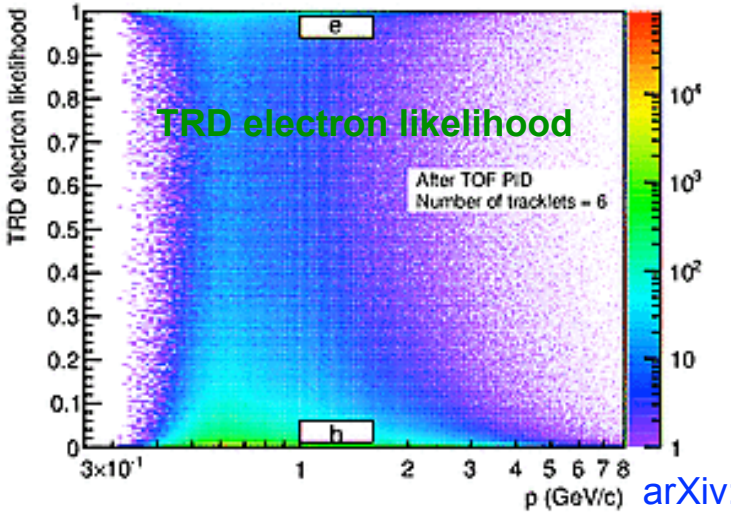
Heavy flavour decay electrons: e-ID

- High quality tracks in TPC and ITS
  - Hit in innermost Si layer to reduce γ–conv. (beam pipe + ~1/3 inner pixel = 0.5% X_0)
- Electron identification:
  - Pb-Pb: TOF + TPC-dE/dx
    - TOF to reject K and p
    - TPC: asymmetric cut around the electron Bethe-Bloch line
  - pp: TOF + TPC-dE/dx + TRD + EMCAL
    hadron contamination measured with a 2-component fit to the TPC dE/dx in *p* slices

example: ALICE Performance 12/10/2010
p+p at $\sqrt{s}$ = 900 GeV (2009 data)

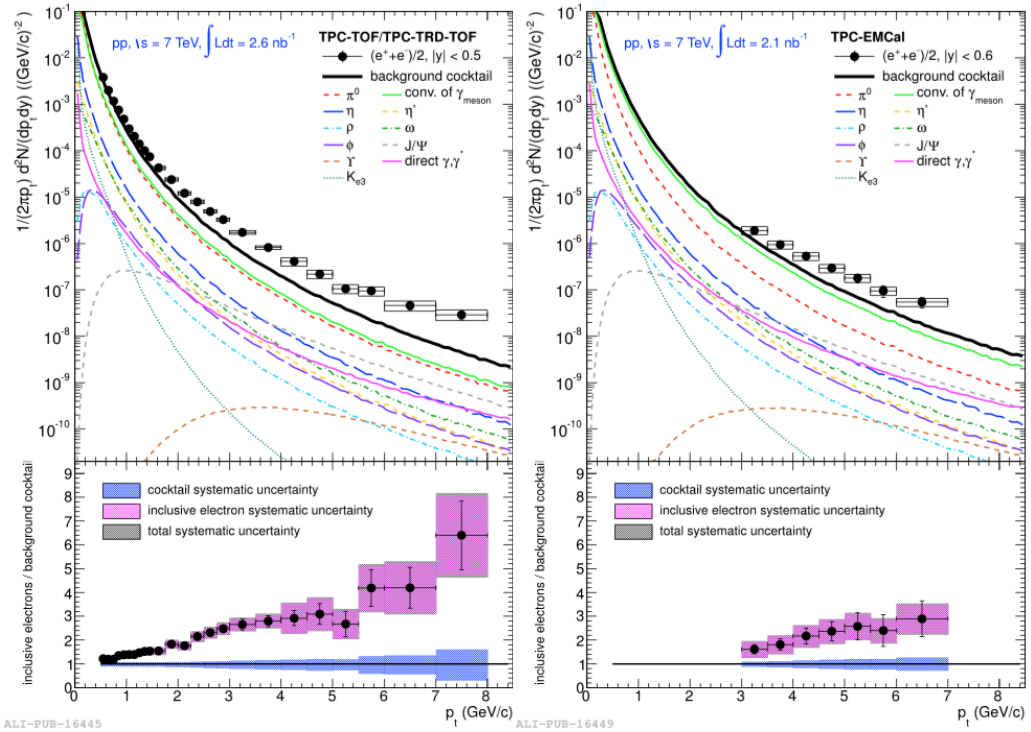


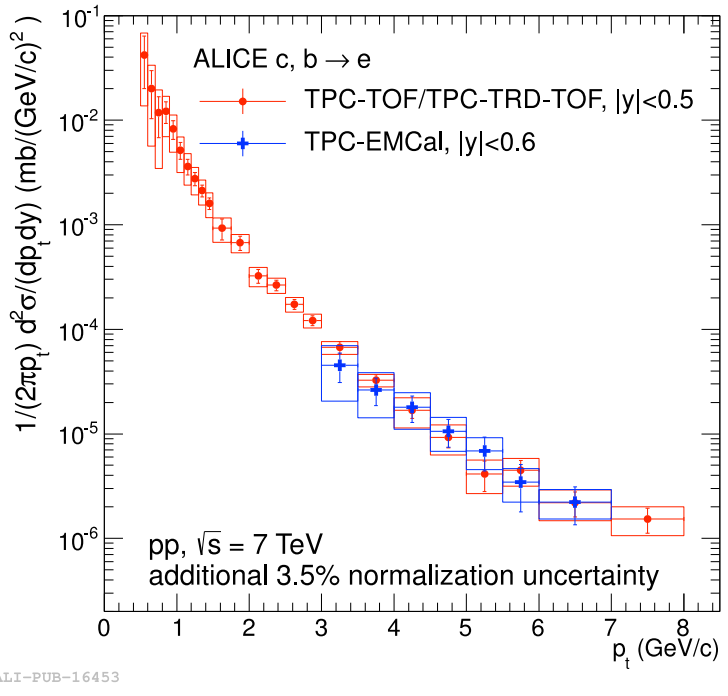




arXiv:1205.5423

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

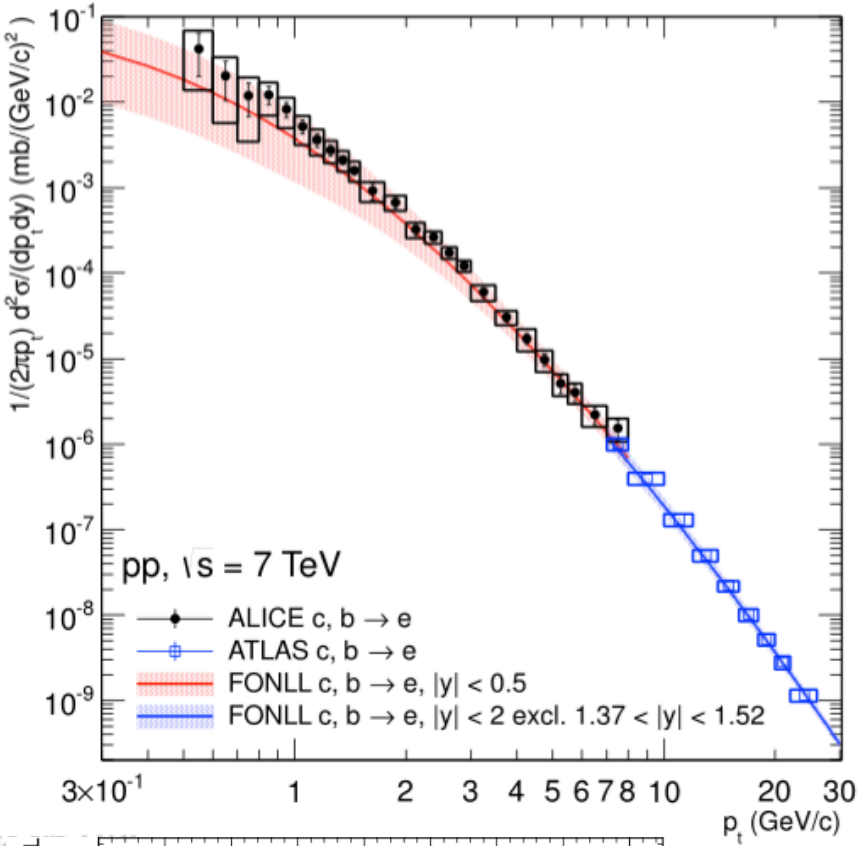


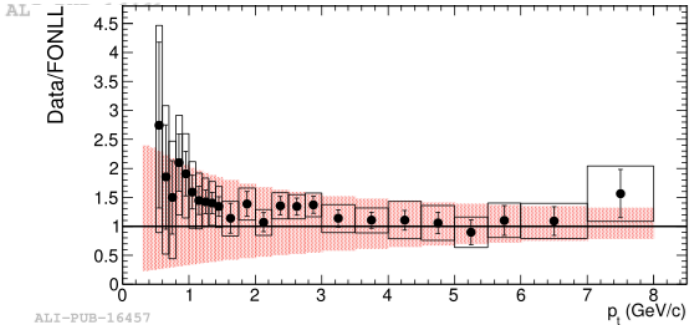


- Inclusive electrons spectrum with two different PID analyses: TPC-TOF-TRD and TPC-EMCAL
- Cocktail of backgrounds
  - "photonic" electrons (from γ "conversions"), based on measured π^0 cross section (m_t scaling for other mesons)
  - quarkonium decays, based on LHC data
  - from direct photons (pQCD)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

arXiv:1205.5423

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

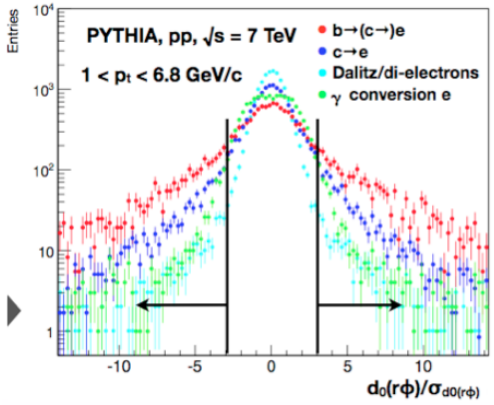




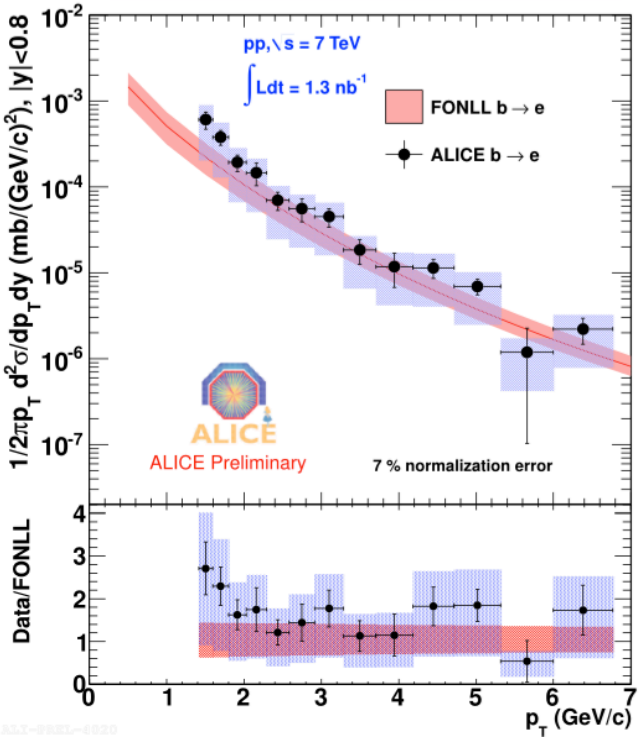
- Cross section of electrons from D and B decays in 0.5-8 GeV/c
- Corresponds to
  - 50% of charm $d\sigma/dy$
  - 90% of beauty $d\sigma/dy$
  - (Assuming FONLL p_t shapes)
- Complementary to ATLAS measurement at central rapidity

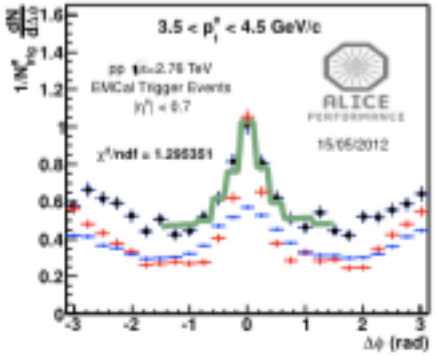
arXiv:1205.5423
ATLAS: PLB707 (2012) 438
FONLL: Cacciari et al., arXiv:1205.6344

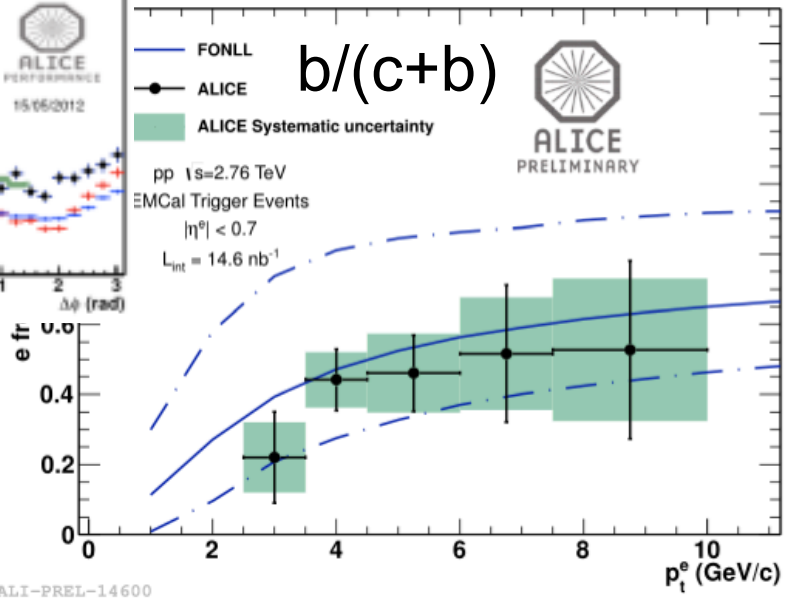
Beauty decay electrons: pp 7 TeV



- Exploit large displacement of B-decay electrons
- Cut on impact parameter
  - Also developing a method based on template fits to impact parameter distribution
- Described by FONLL
- Complementary method based on e-hadron $\Delta\phi$ correlations (exploits different D and B decay kinematics)



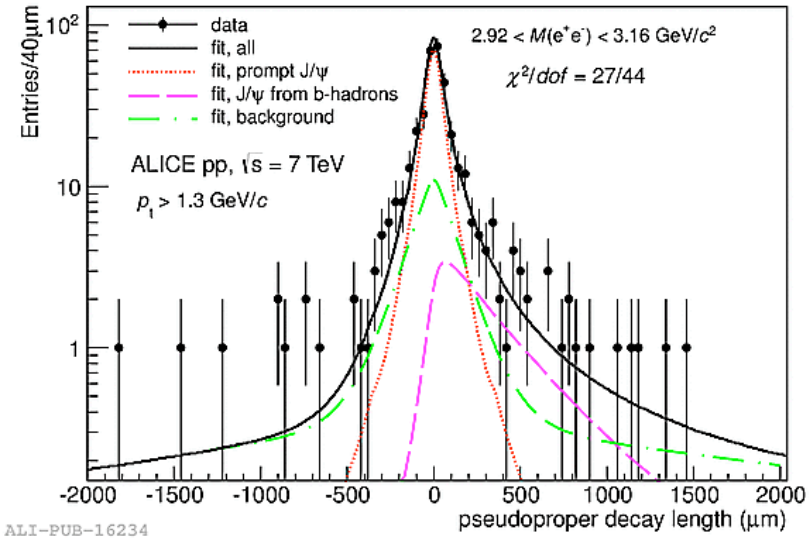


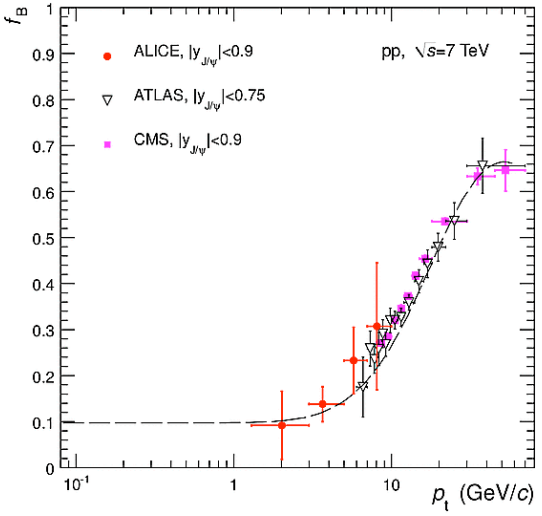


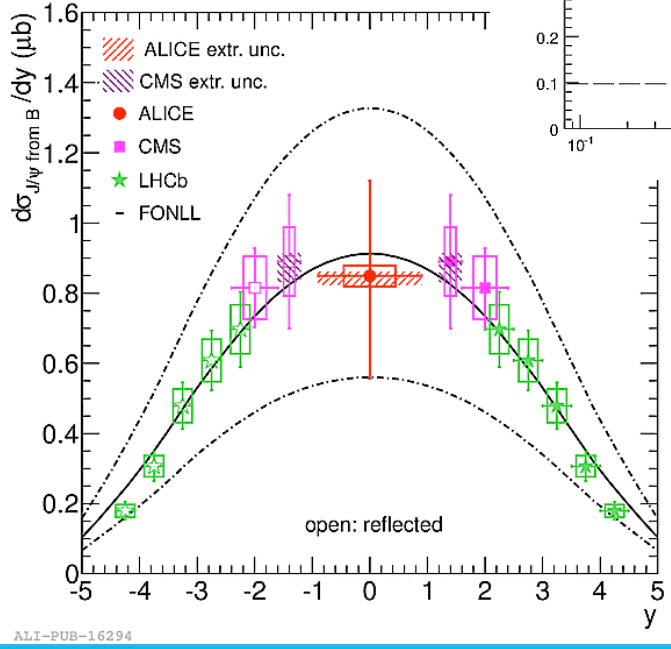
ALI-PREL-14600

Beauty decay J/ψ (→ee): pp 7 TeV

- Simultaneous fit of J/ψ invariant mass and pseudo-proper decay length
- p_t>1.3 GeV/c at central rapidity → unique at LHC
  - Small extrapolation to p_t=0 (with FONLL)
- Statistics limited with MB data (5.6/nb)
  - Ongoing with EMCAL-triggered data

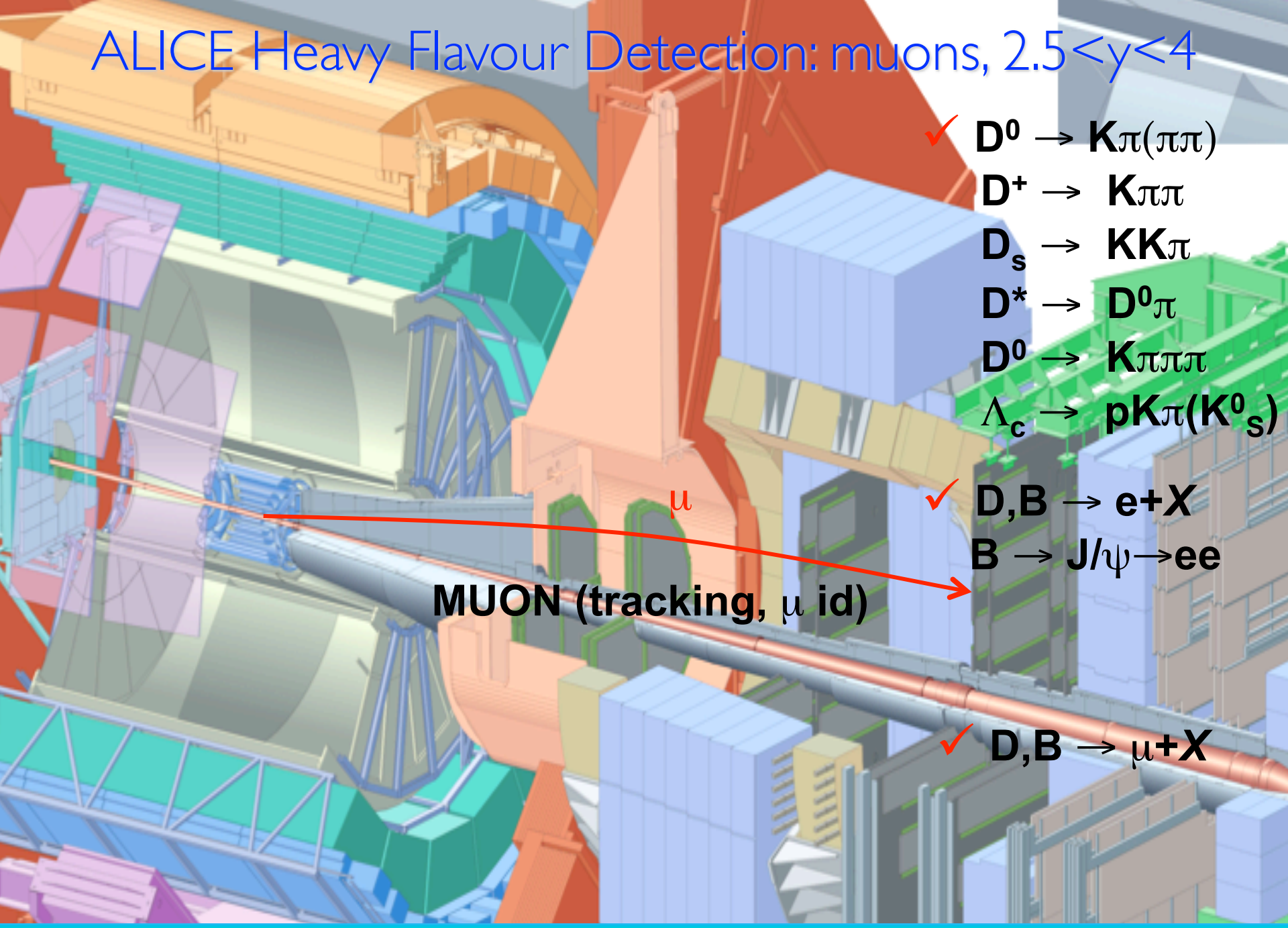






arXiv:1205.5880
FONLL: Cacciari et al., arXiv:1205.6344

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



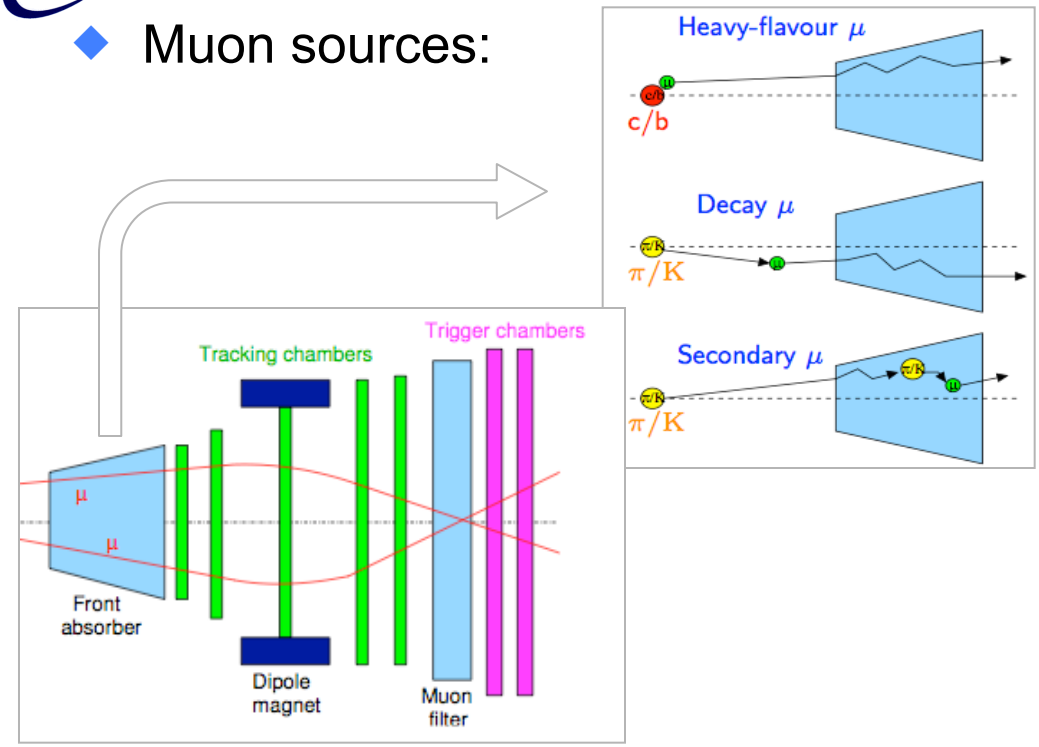
✓ $D^0 \rightarrow K\pi(\pi\pi)$
$D^+ \rightarrow K\pi\pi$
$D_s \rightarrow KK\pi$
$D^* \rightarrow D^0\pi$
$D^0 \rightarrow K\pi\pi\pi$
$\Lambda_c \rightarrow pK\pi(K^0_S)$

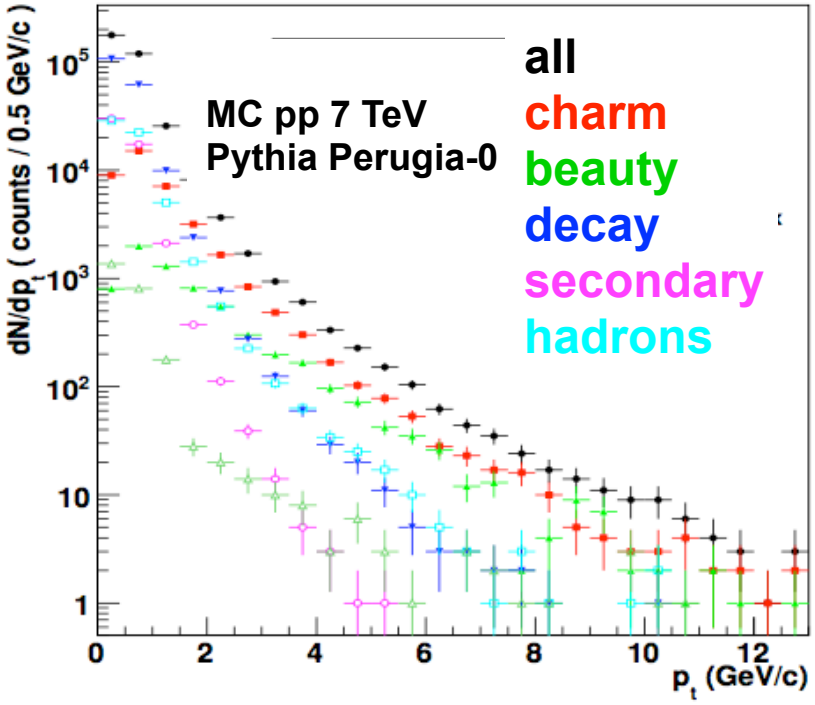
✓ $D,B \rightarrow e+X$
$B \rightarrow J/\psi \rightarrow ee$

✓ $D,B \rightarrow \mu+X$

Heavy flavour from forward single muons

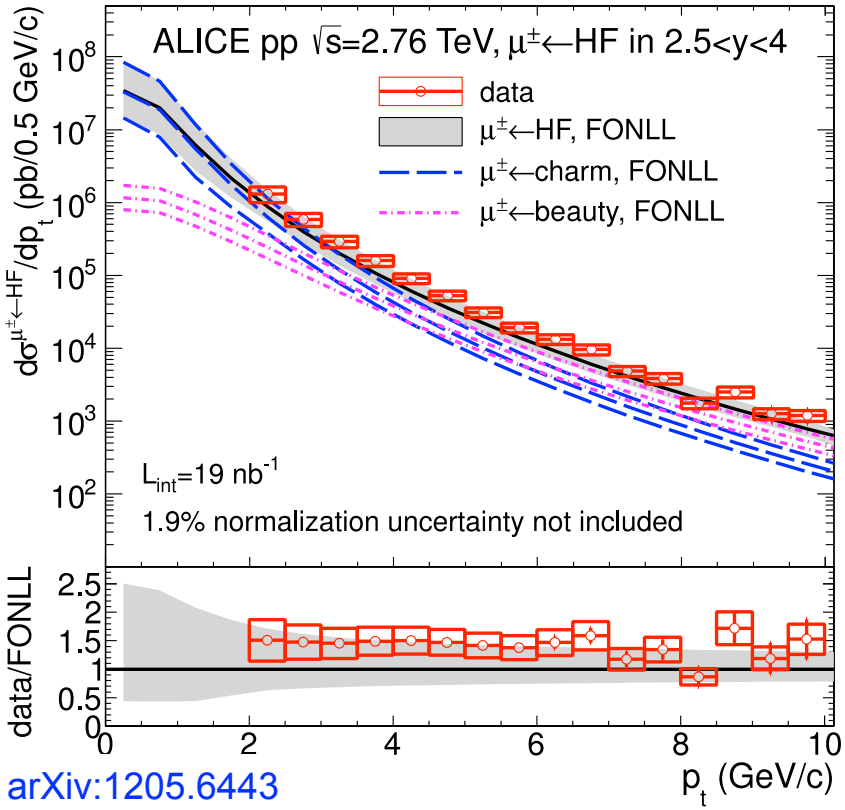
- Muon sources:



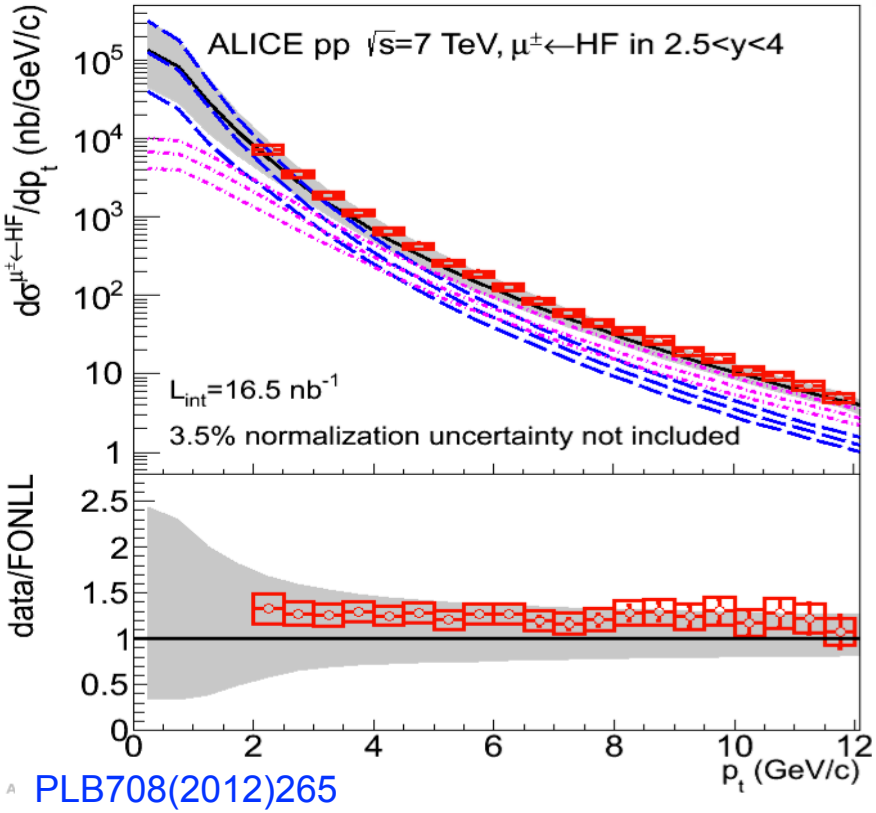


- Analysis strategy:
  - remove hadrons and low p_t secondary muons by requiring a muon trigger signal
  - subtract π/K-decay muons
  - what is left are muons from charm and beauty decays
- π/K-decay muon subtraction:
  - pp: PYTHIA/PHOJET envelope, normalized to inclusive yield below 1 GeV/c
  - Pb-Pb: derived from measured π/K yields at central rapidity

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



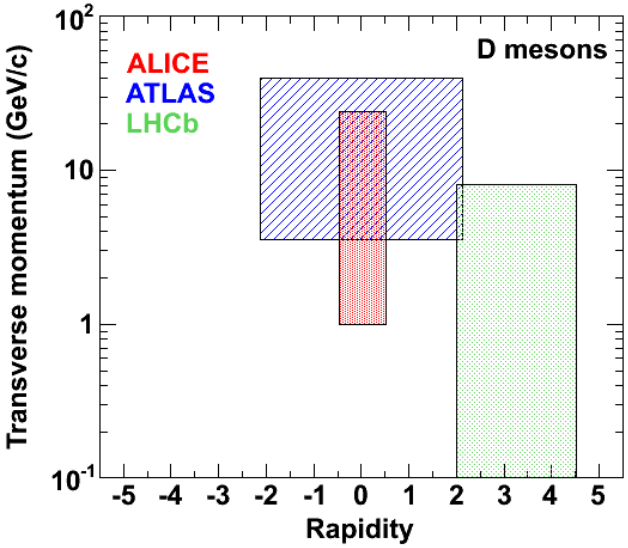
arXiv:1205.6443

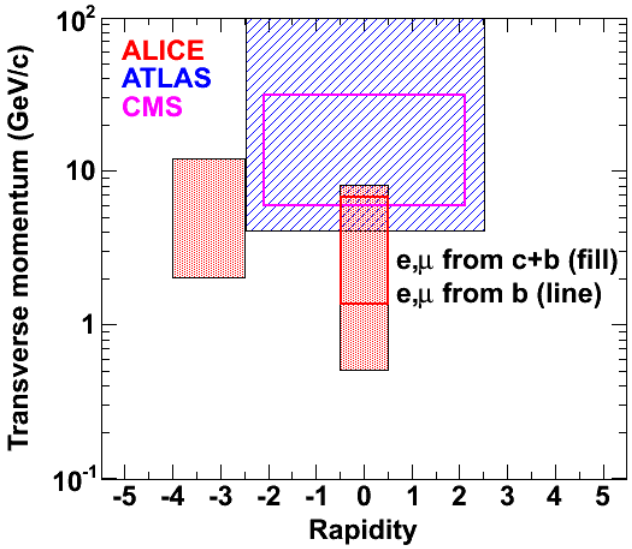


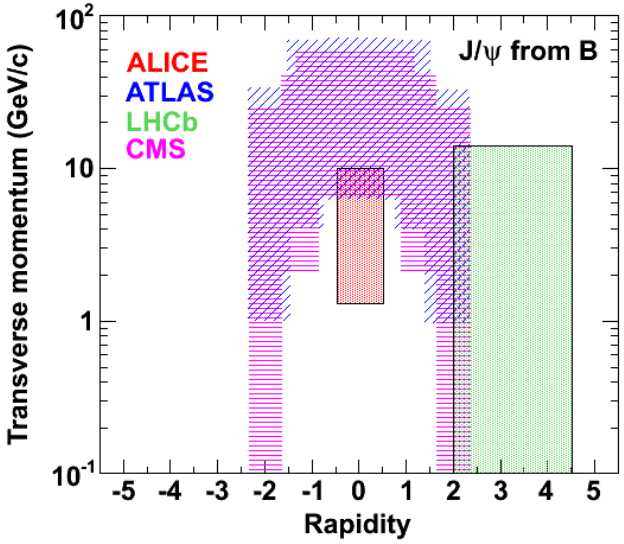
PLB708(2012)265

- High-statistics measurement at both energies (muon trigger)
- FONLL describes the data well, slightly on the low side
- FONLL indicates beauty dominance above 8 GeV/*c*

ALICE and the other LHC experiments





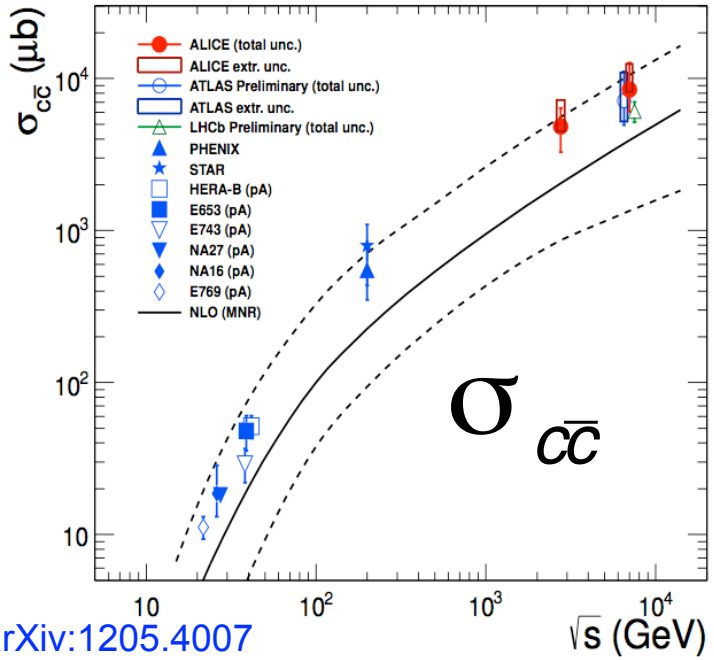


- ✓ Complementary coverages
- ✓ ALICE's special: low-p_t, especially at y=0

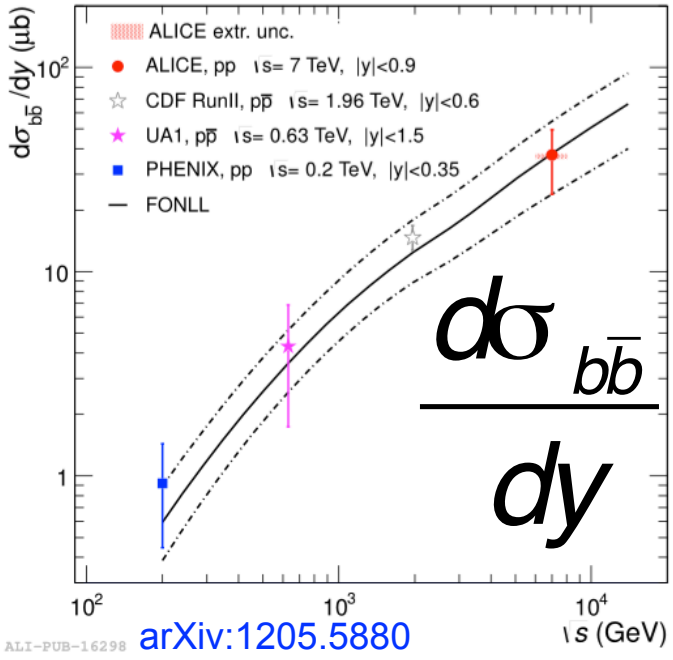
Not shown:
B hadrons (ATLAS, CMS, LHCb)
b-jets (ATLAS, CMS)

Total HQ production cross sections

- D meson and non-prompt J/ψ cross sections at y=0 extrapolated to p_t=0 (and full y, for charm) using FONLL scaling factors



arXiv:1205.4007



arXiv:1205.5880

NLO pQCD: Mangano, Nason, Ridolfi, NPB373 (1992) 295.

ATLAS, ATLAS-PHYS-PUB-2011-012
LHCb, LHCb-CONF-2010-013

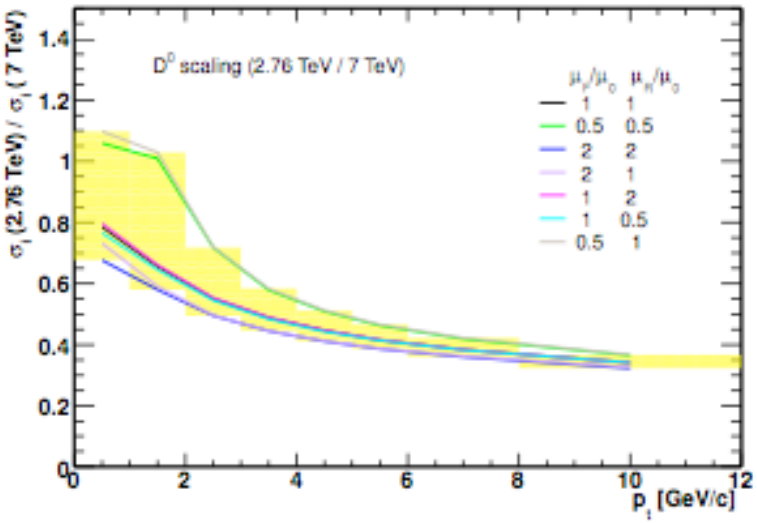
Outline of the Talk

- Introduction: heavy quarks as probes of QCD matter at LHC
- Heavy flavour in ALICE and pp results
  - D mesons at central rapidity
  - electrons at central rapidity
  - muons at forward rapidity
- Pb-Pb measurements
  - Heavy flavour nuclear suppression at high momentum (R_{AA})
  - Charm azimuthal anisotropy (v_2)
- Outlook & summary

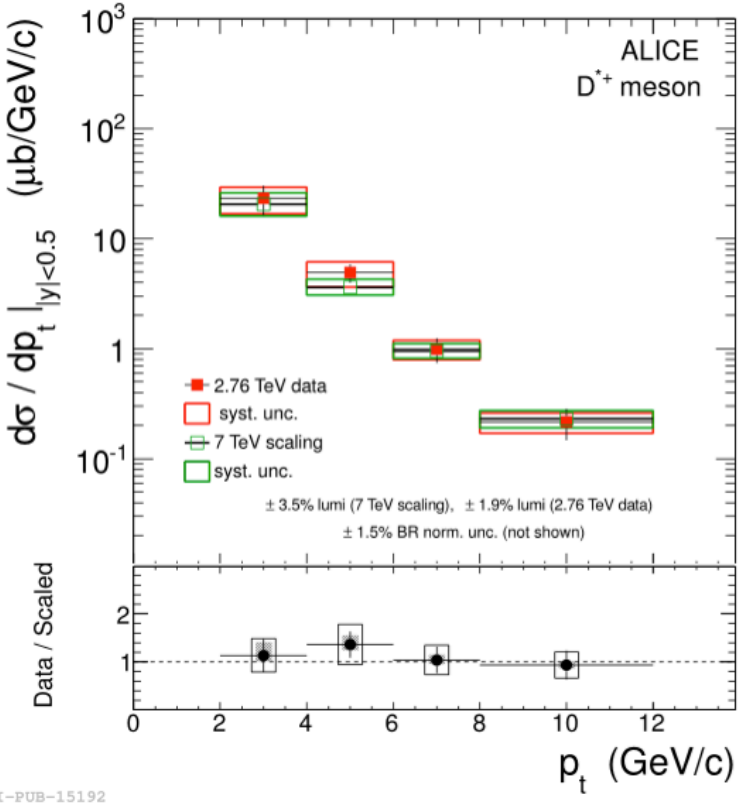
Charm pp reference at 2.76 TeV via pQCD-driven $\sqrt{s}$-scaling

- Scale the 7 TeV cross sections by the 2.76/7 factor from FONLL, with full theoretical uncertainty
  - relative scaling uncertainty: 30% → 5% in the p_t range 2 → 16 GeV/c
- Validated by comparing to measured cross section at 2.76 TeV (fewer p_t bins)

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

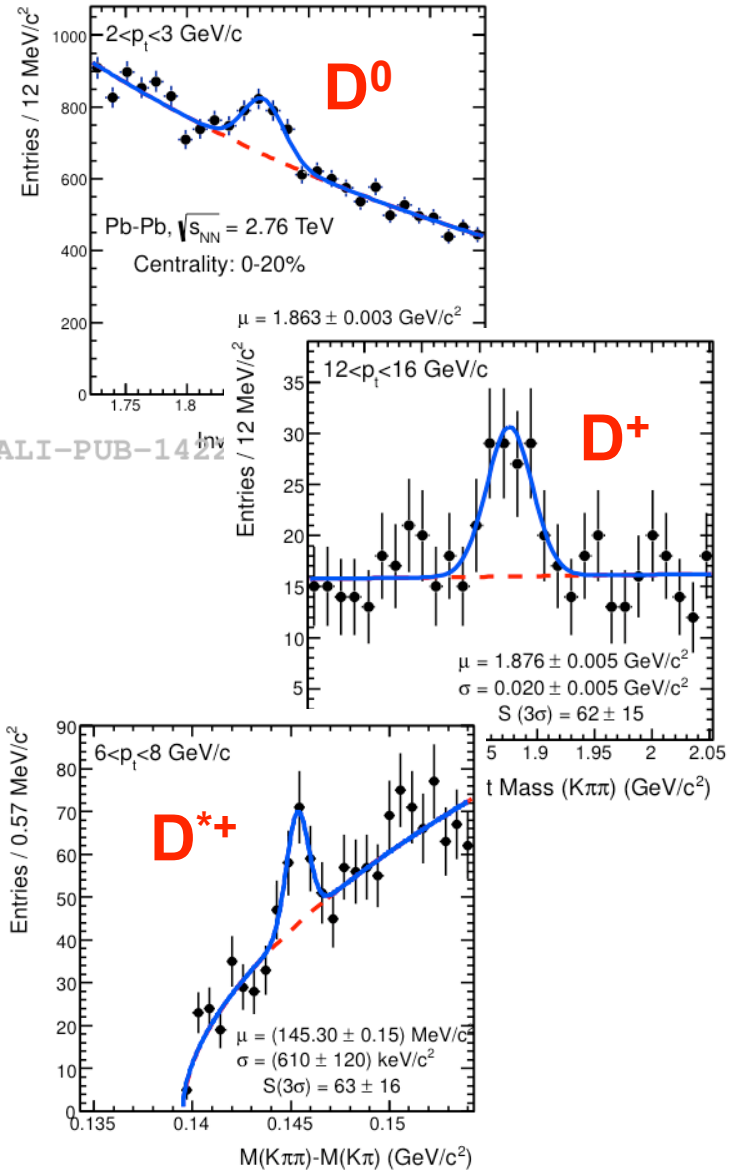


Averbeck et al., arXiv:1107.3243



arXiv:1205.4007

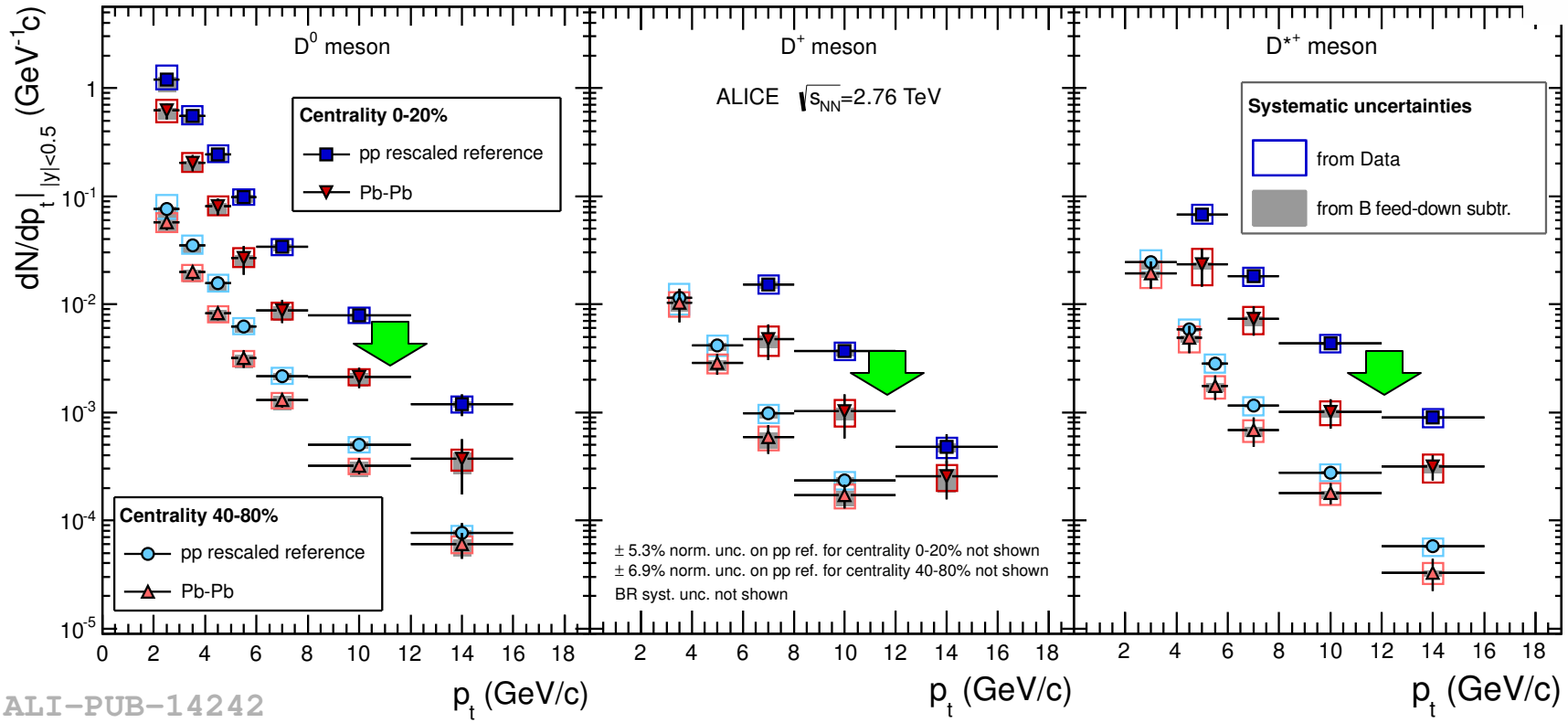
D meson reconstruction in Pb-Pb



- In ~3M central collisions (0-20%):
  - D^0 : 7 p_t bins in 2-16 GeV/c
  - D^+ : 3 p_t bins in 6-16 GeV/c
  - D^* : 4 p_t bins in 4-16 GeV/c
- Reconstruction efficiency ~1-10%
  - evaluated from MC simulation
- Feed-down from B decays ~10-15% after cuts
  - subtracted based on FONLL with hypothesis on R_{AA}^B

arXiv:1203.2160

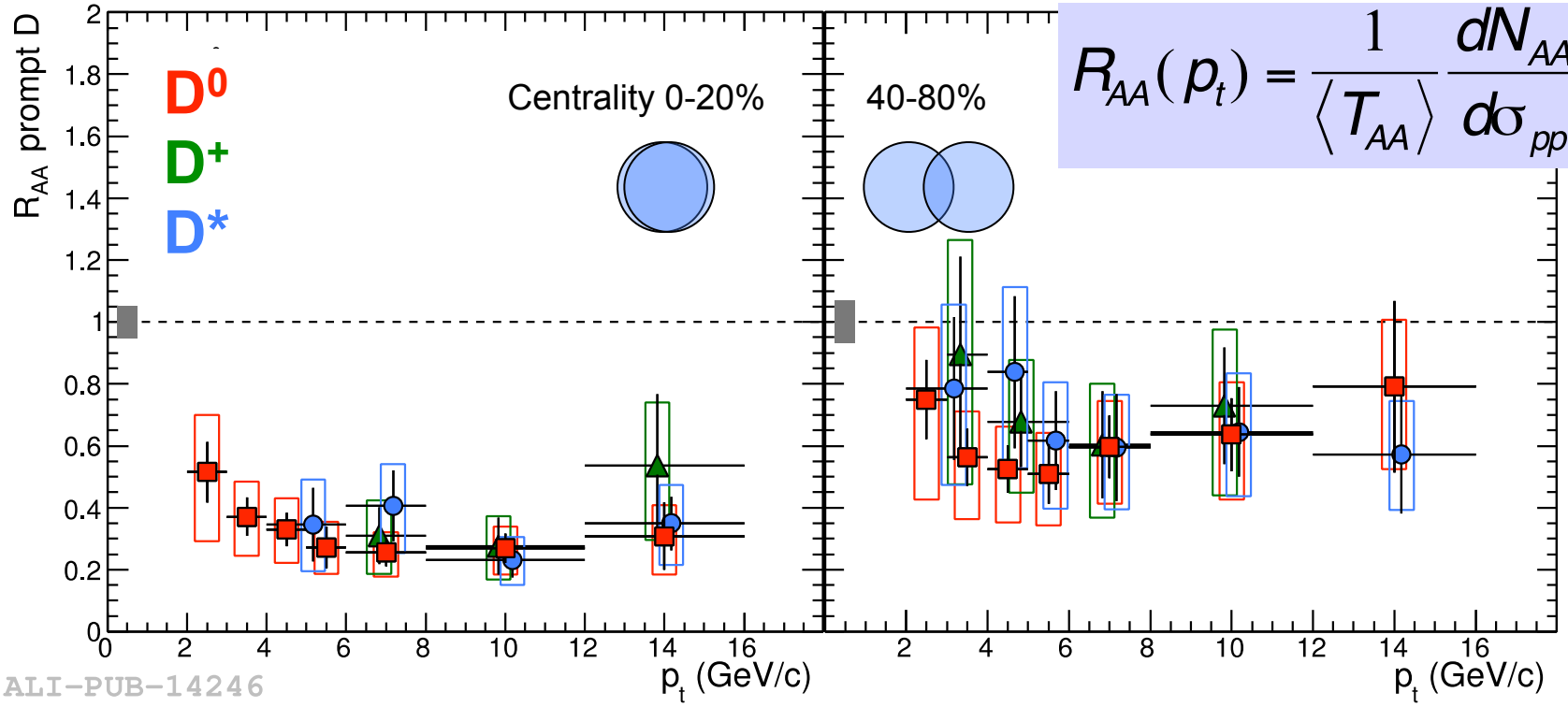
D p_t distributions in Pb-Pb



- 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

The D meson nuclear modification factor



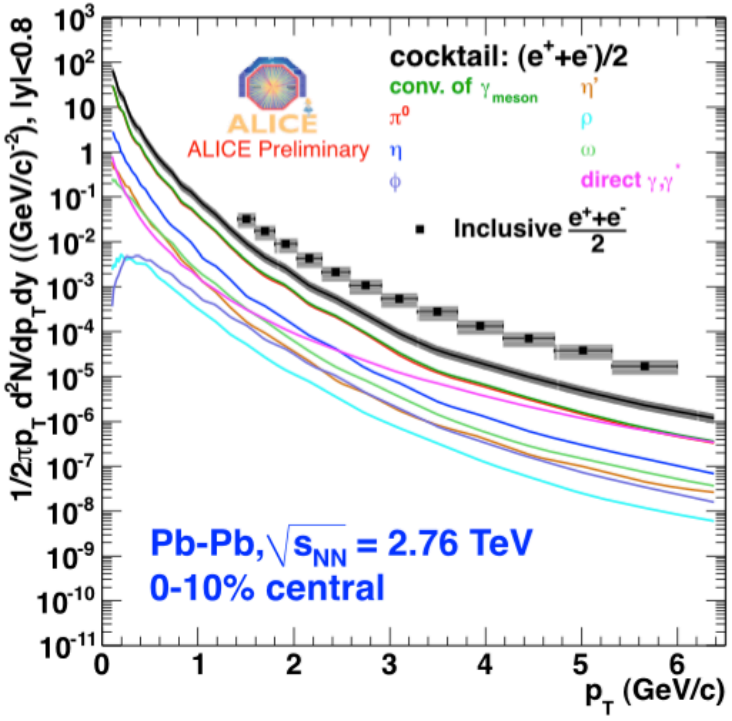
$$R_{AA}(p_t) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_t}{d\sigma_{pp}/dp_t}$$

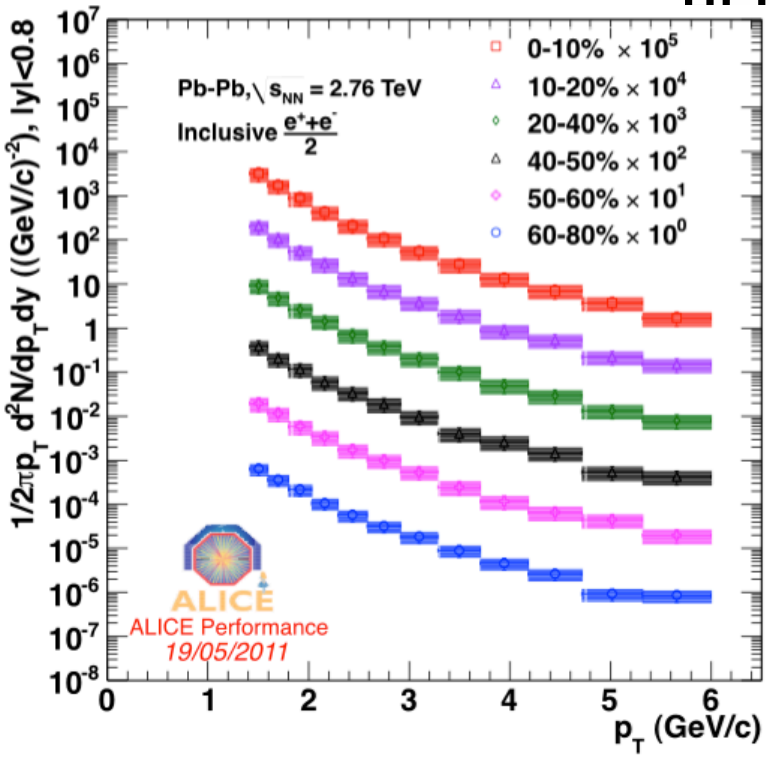
- Suppression for charm with respect to binary scaling is a factor 3-4 above 5 GeV/*c*
- Compatible among the three species
- Less suppression in peripheral collisions

arXiv:1203.2160

Electron p_t spectrum in Pb-Pb

- Inclusive electron p_t spectra in six centrality bins
  - hadron cont. <10% up to 6 GeV/*c*, measured from TPC dE/dx fits

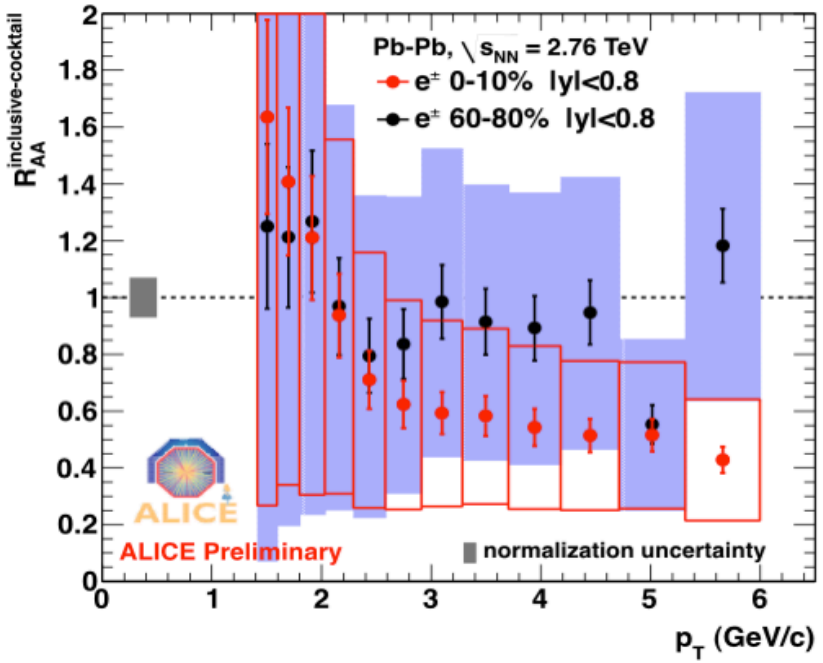




- Background electron cocktail, based on $\pi^{\pm}$ spectra + m_t-scaling + pQCD direct photons
- Subtract cocktail from inclusive spectra

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*



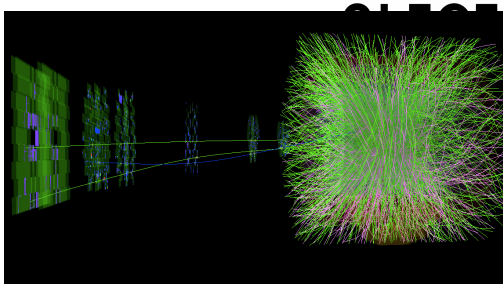
60-80%

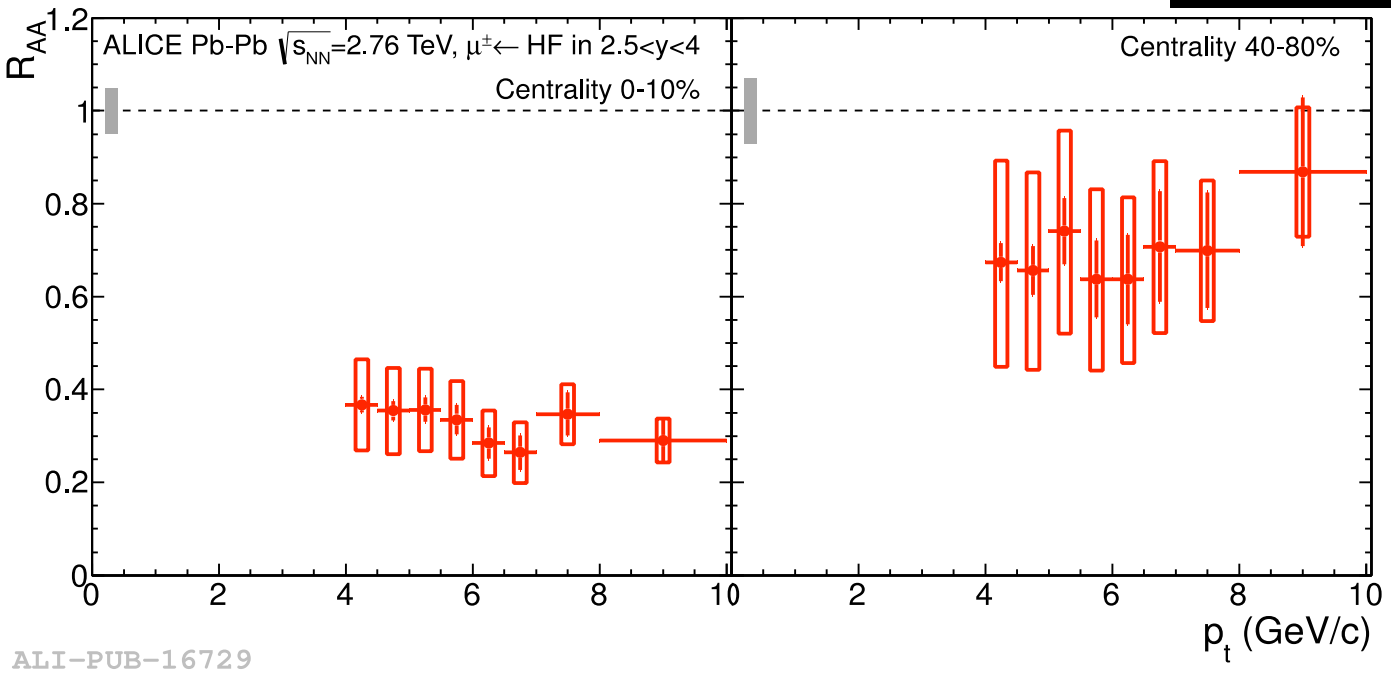
0-10%

- Suppression in central collisions: factor 1.5-4

HF-decay muon R_{AA} at forward rapidity

- Subtraction π/K-decay muons based on ALICE measurements at y=0 (π and K dN/p_t and R_{AA})
  - consider systematic uncertainty from y-extrapolation

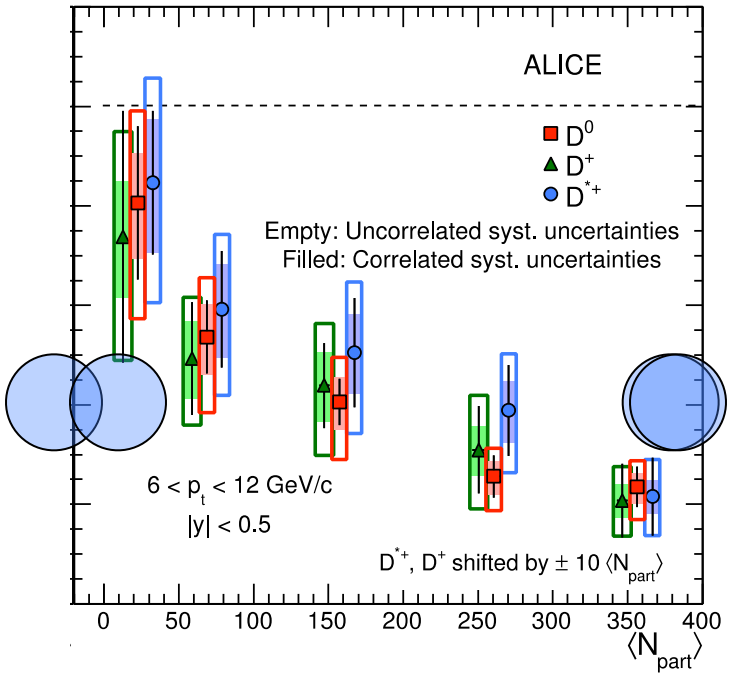


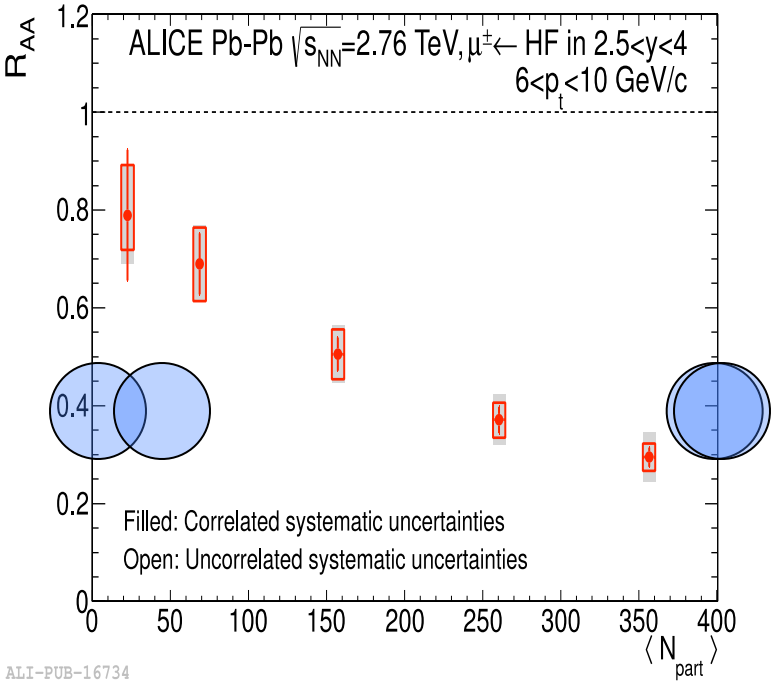


- Suppression by a factor ~3 in central collisions
- No evident p_t dependence

arXiv:1205.6443

Centrality dependence of suppression



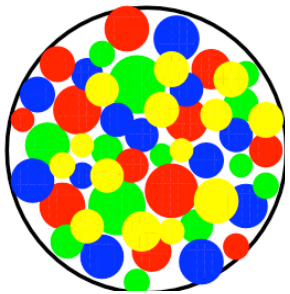


- Large suppression in central collisions (x3-4)
  - Less suppression towards peripheral collisions

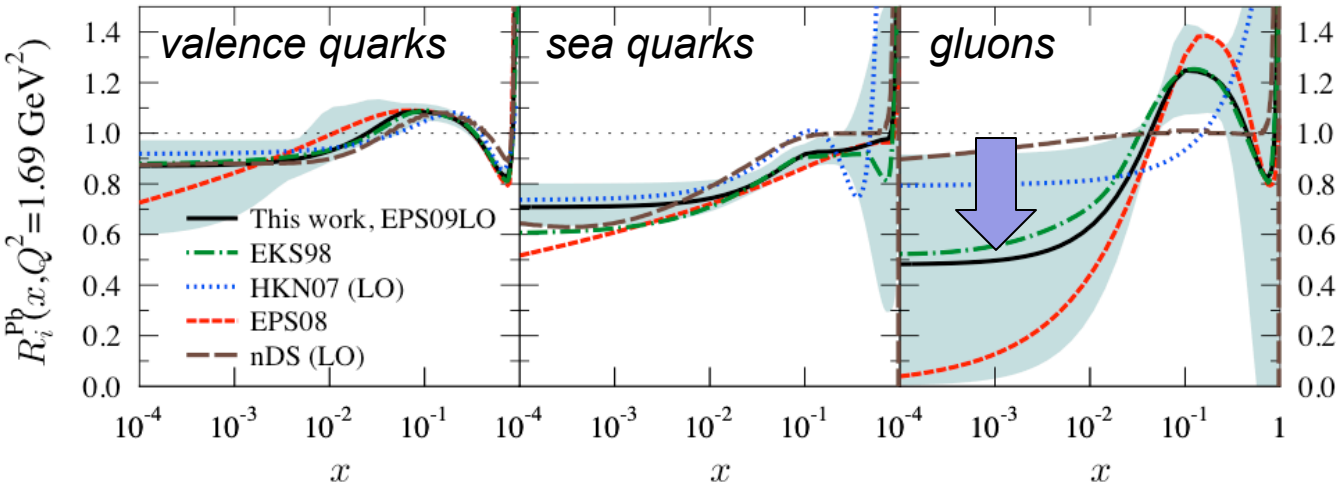
Is it a QCD medium effect?

- The observed suppression can have a contribution from initial-state effects, not related to the hot QCD medium
- High parton density in high-energy nuclei leads to reduction/ saturation/shadowing of the *PDFs* at small x (and small Q^2)

$$\frac{dN^D_{PbPb}}{dp_T} = PDF(x_1)PDF(x_2) \otimes \frac{d\hat{\sigma}^c}{dp_T} \otimes P(\Delta E) \otimes D_{c\to D}(z)$$

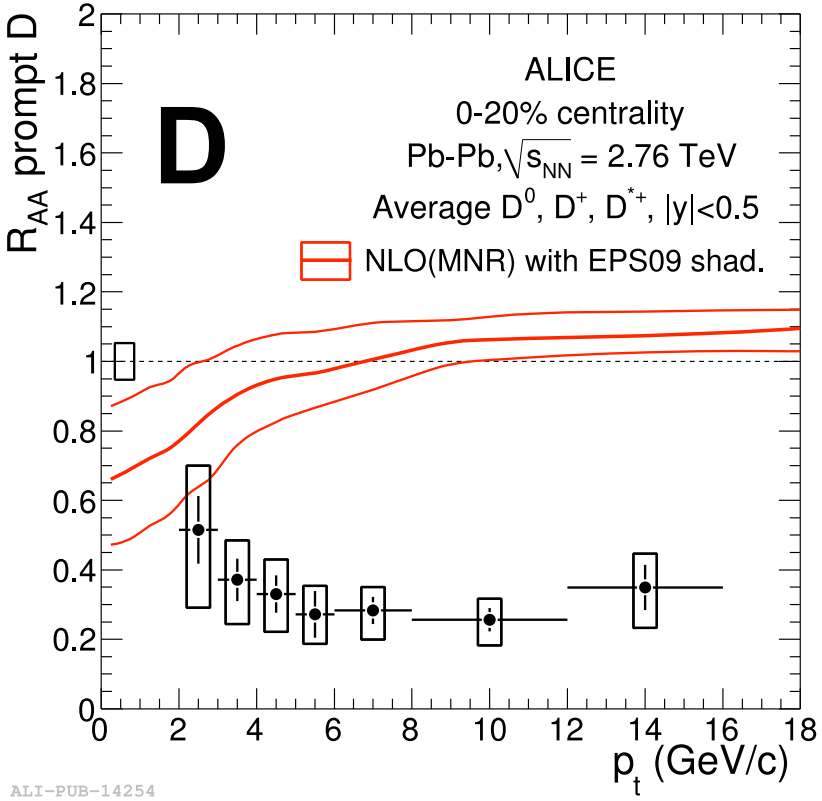


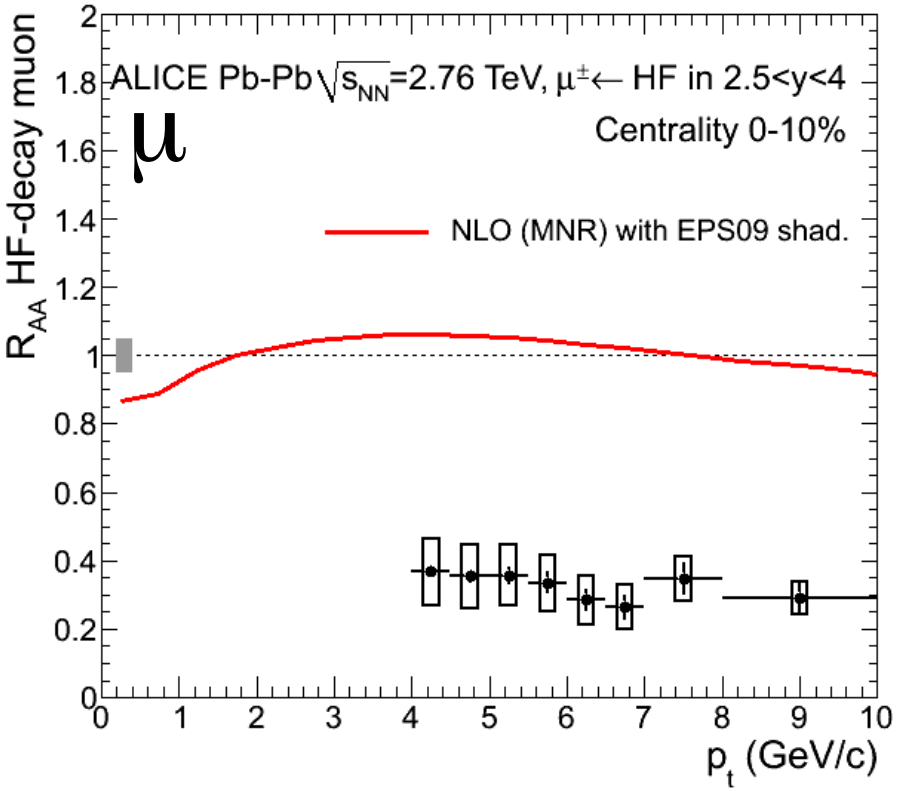
Nuclear modification of PDFs



see e.g. Eskola et al. JHEP0904(2009)065

Is it a QCD medium effect?

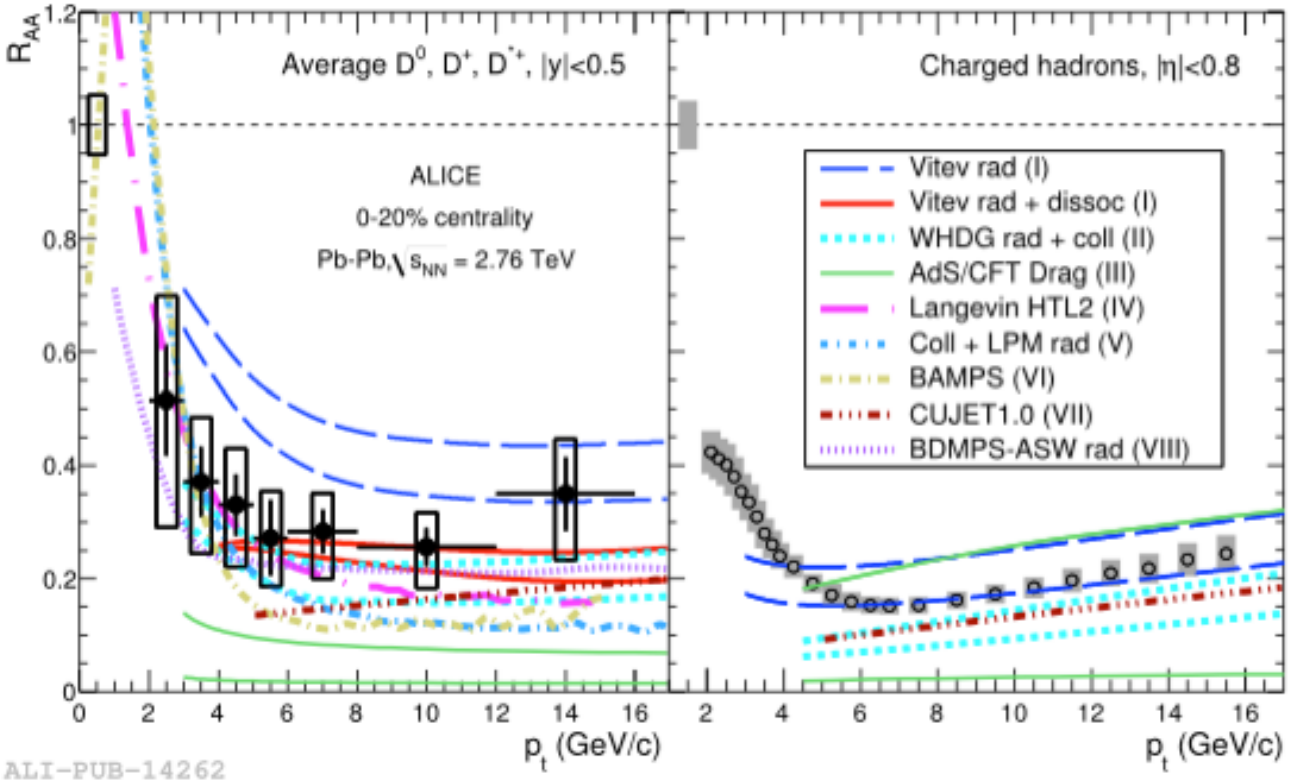




- Small effect expected from PDFs shadowing above 5 GeV/c
- Suggests that this is a hot medium effect
- p-Pb run at LHC crucial to measure initial-state effects

Comparisons: E-loss models

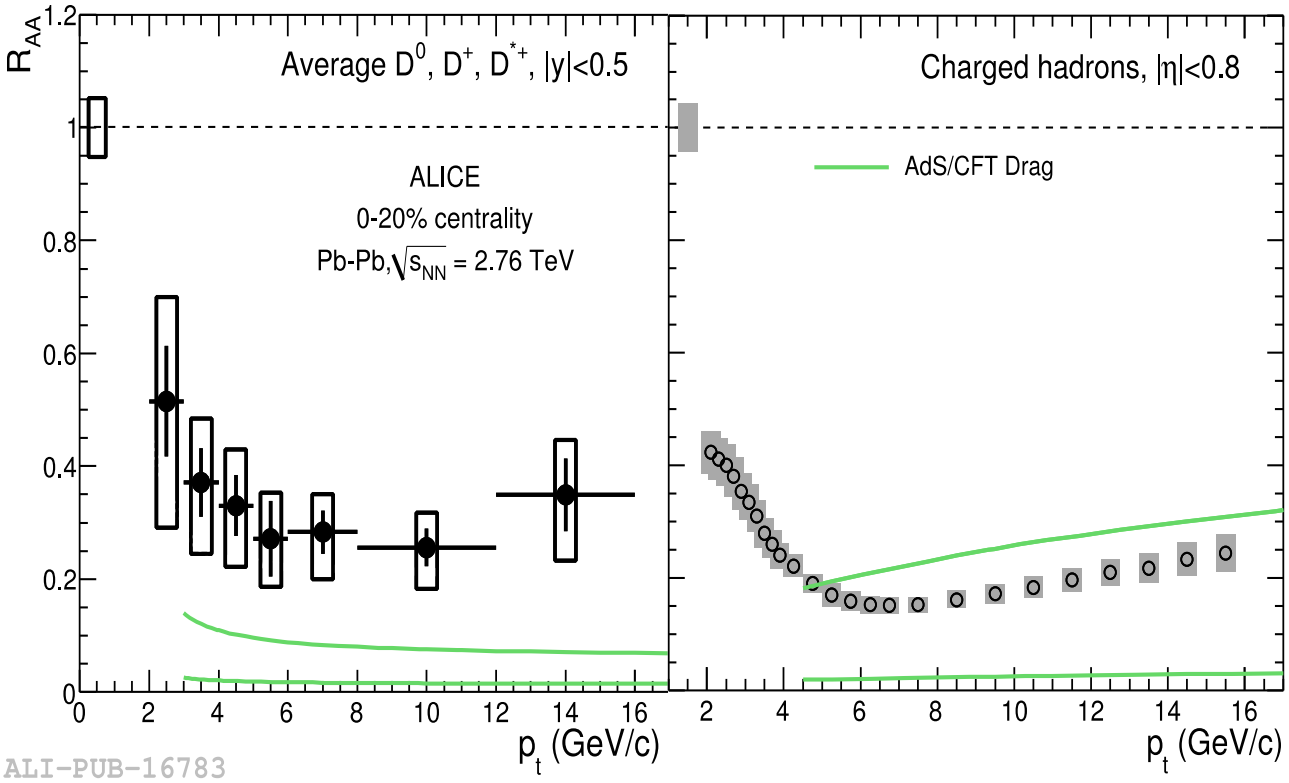
- Several models based on E-loss and heavy-quark transport describe qualitatively the measured charm R_{AA}



- 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

Comparisons: E-loss models

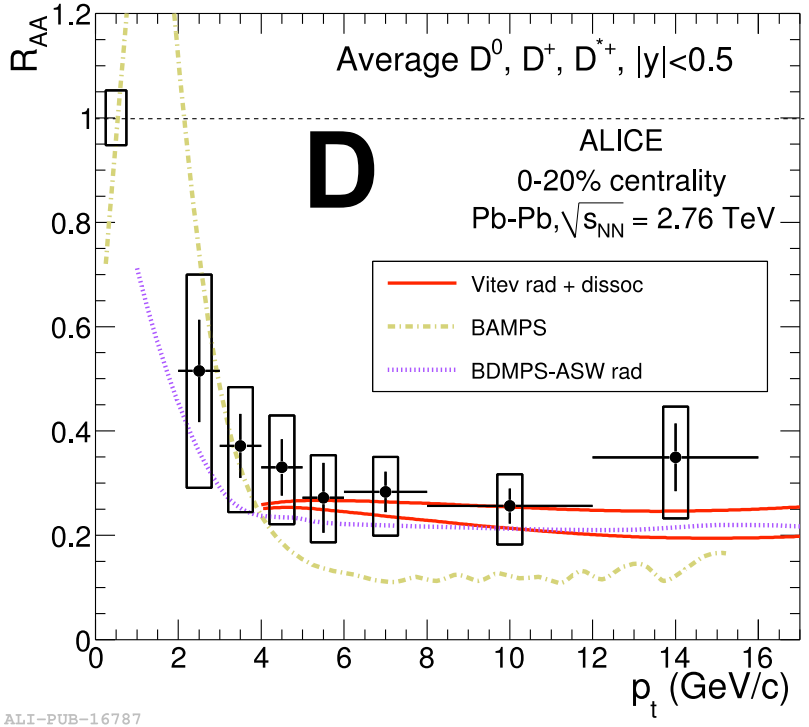
- Several models based on E-loss and heavy-quark transport describe qualitatively the measured charm R_{AA}

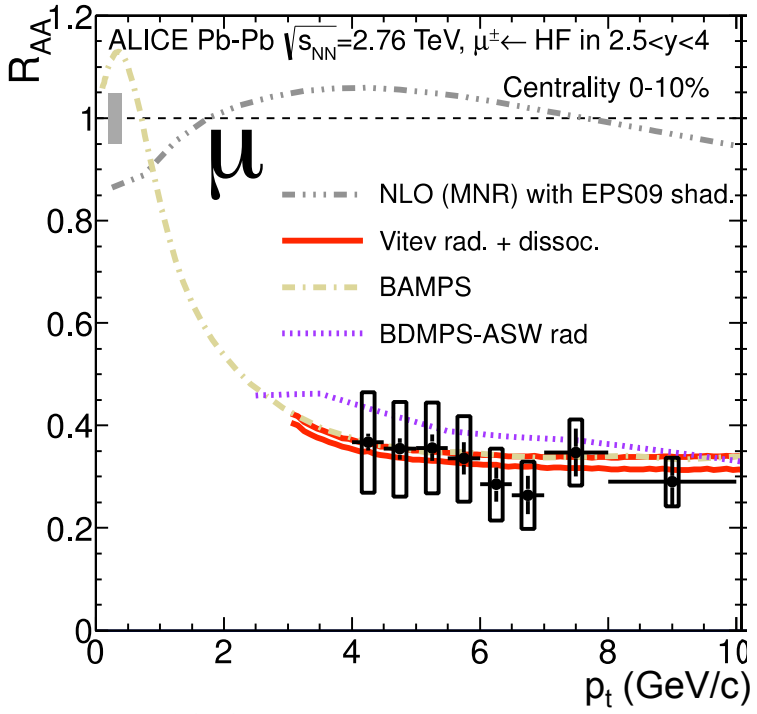


- Models with E-loss (radiative, rad. + coll.) generally close to both D and charged RAA
  - Vitev rad + D dissoc
  - WHDG and CUJET1.0 rad + coll
- Model based on AdS/CFT Drag over-suppresses charm

Comparisons: D and muons

- Do we understand consistently D mesons (charm at y~0) and muons (charm+beauty at y~3) ?
- "Compare" them through model 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

Outline of the Talk

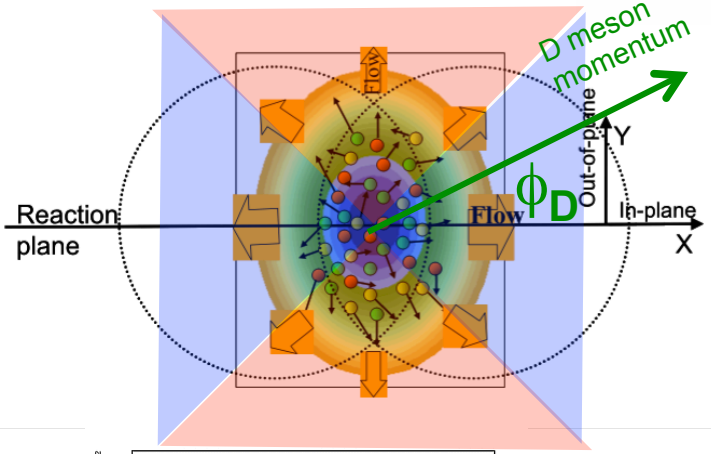
- Introduction: heavy quarks as probes of QCD matter at LHC
- Heavy flavour in ALICE and pp results
  - D mesons at central rapidity
  - electrons at central rapidity
  - muons at forward rapidity
- Pb-Pb measurements
  - Heavy flavour nuclear suppression at high momentum (R_{AA})
  - Charm azimuthal anisotropy (v_2)
- Outlook & summary

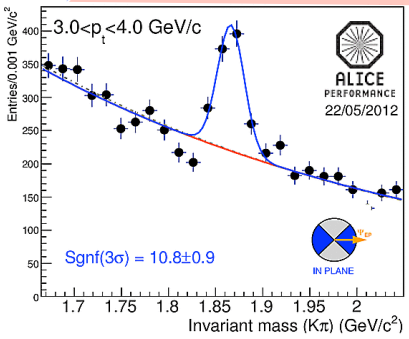
D azimuthal anisotropy - methods

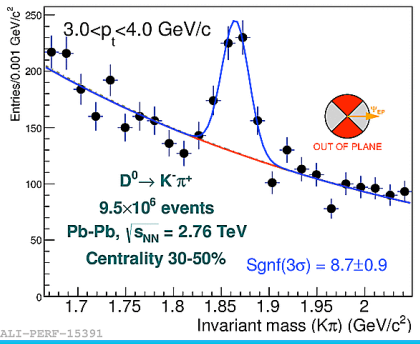
- Analysis in semi-central events (15-30% and 30-50%), 2011 Pb-Pb run
- Reaction plane direction (Ψ_{RP}) estimated from azimuthal distribution of all tracks (Event Plane method)
- V2 from comparison of D yields in two regions of $\Delta\phi = \phi_D - \Psi_{RP}$

$$v_2 = \frac{\pi}{4} \frac{N_{IN} - N_{OUT}}{N_{IN} + N_{OUT}}$$

- Other methods give consistent results
  - For the experts: Scalar Product, 2-particle Q-Cumulants

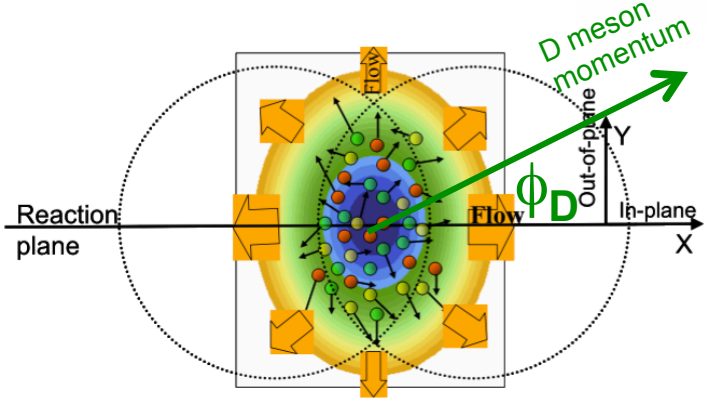


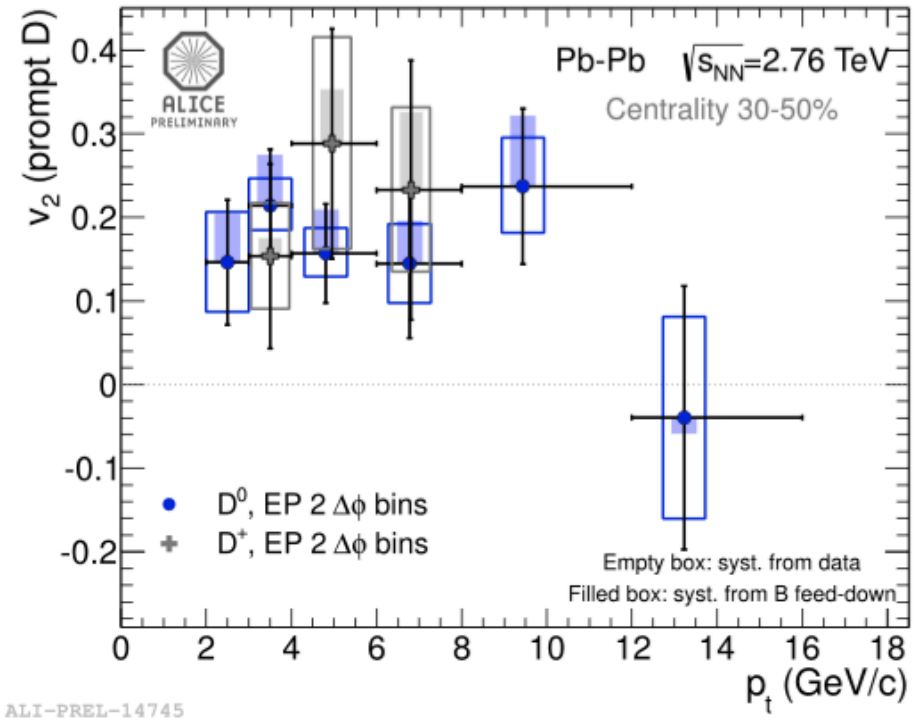


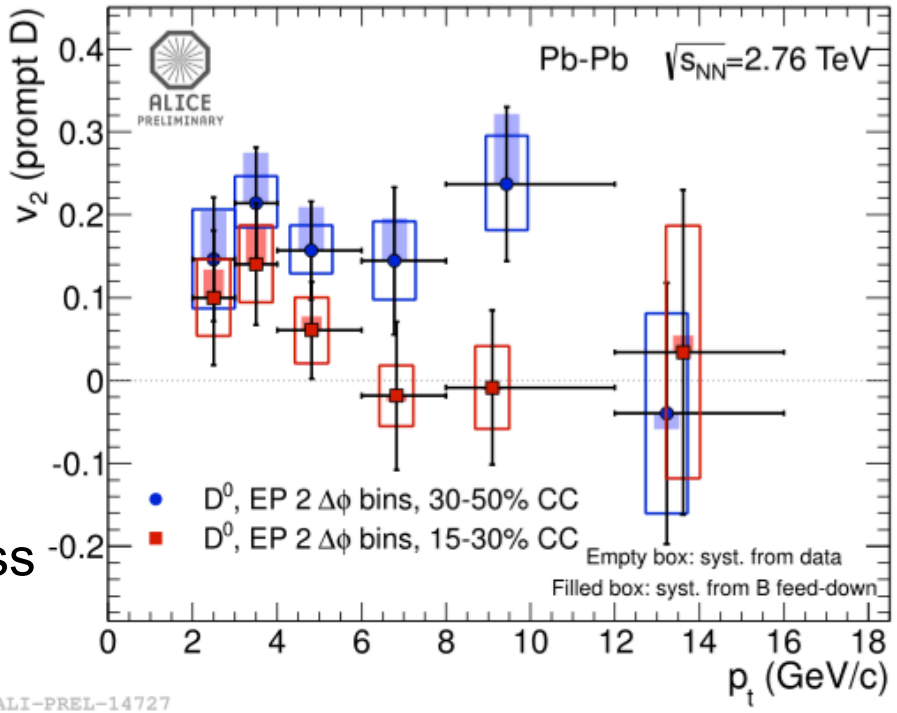


D^0 and D^+ azimuthal anisotropy

- Indication for non-zero v_2 (3σ effect for D^0 in 2-6 GeV/c) in 30-50%



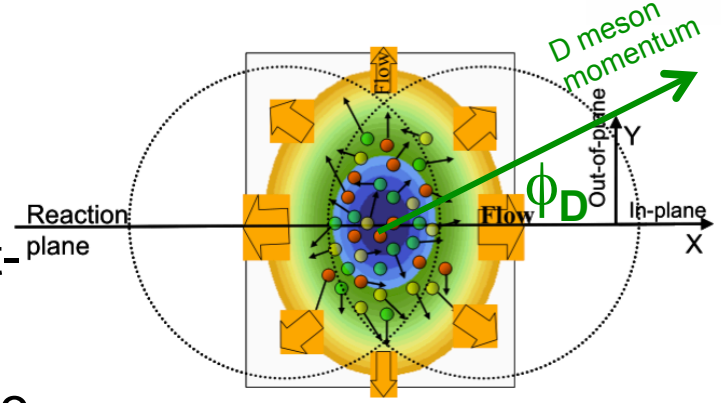


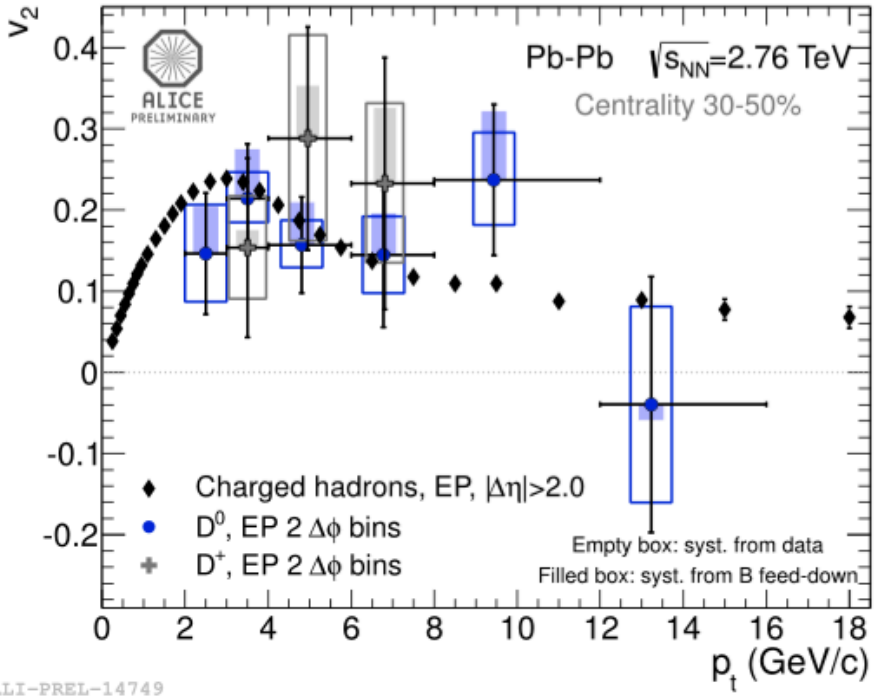


- In more central events (15-30%, less initial asymmetry), v_2 seems to be smaller, as expected

D v_2 vs. bulk of particles

- Observed $v_2 > 0$ suggests that D mesons "remember" the azimuthal asymmetry of the initial overlap
- v_2 qualitative comparable with that of the light-flavour hadrons
- Cannot conclude on possible difference due to larger c quark mass

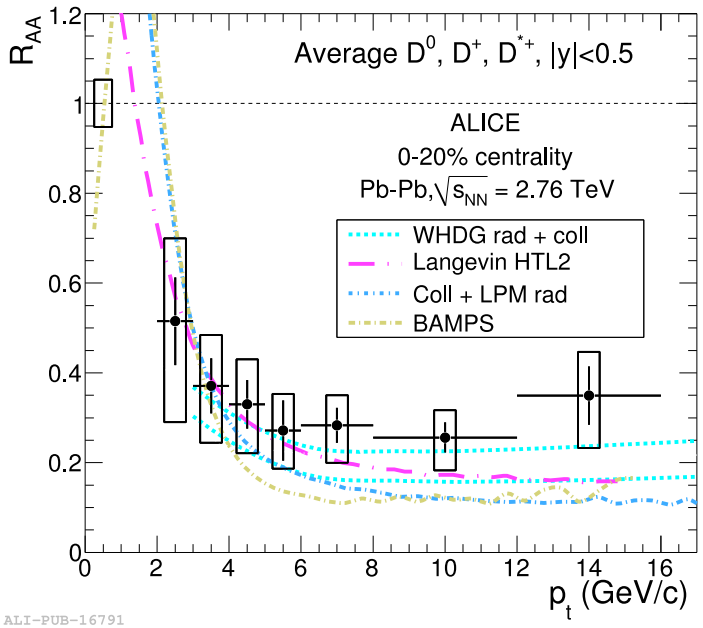


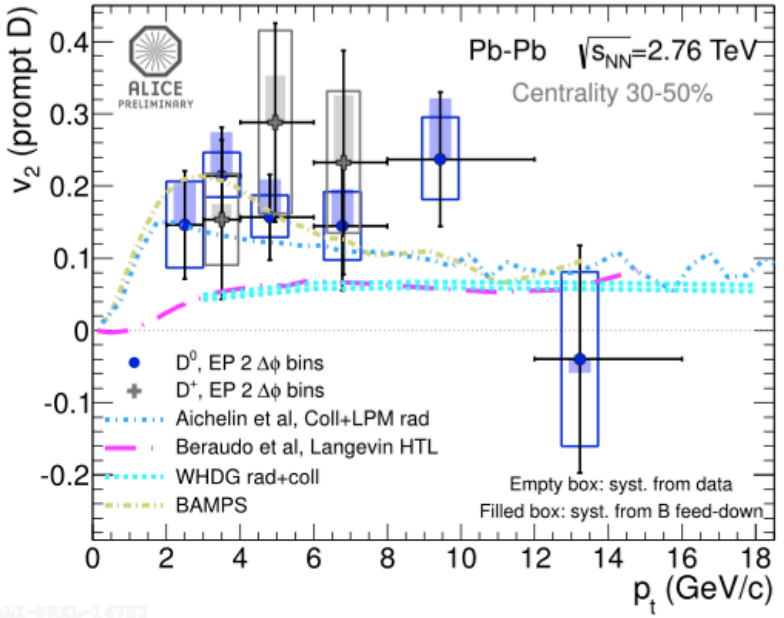


D R_{AA} and v_2 vs. models

- Comparison with both observables possible for some of the models
- In particular, the models that implement heavy quark transport in the medium do track the c quarks through the entire evolution of the system

  → uniqueness of heavy quark probes (initial production, flavour conservation)





→ Rad + coll E loss (WHDG) with static partonic scattering centers tends to underestimate v_2

→ Transport (BAMPS, Aichelin) in collectively-expanding partonic system give v_2 closer to data, but too much R_{AA} suppression

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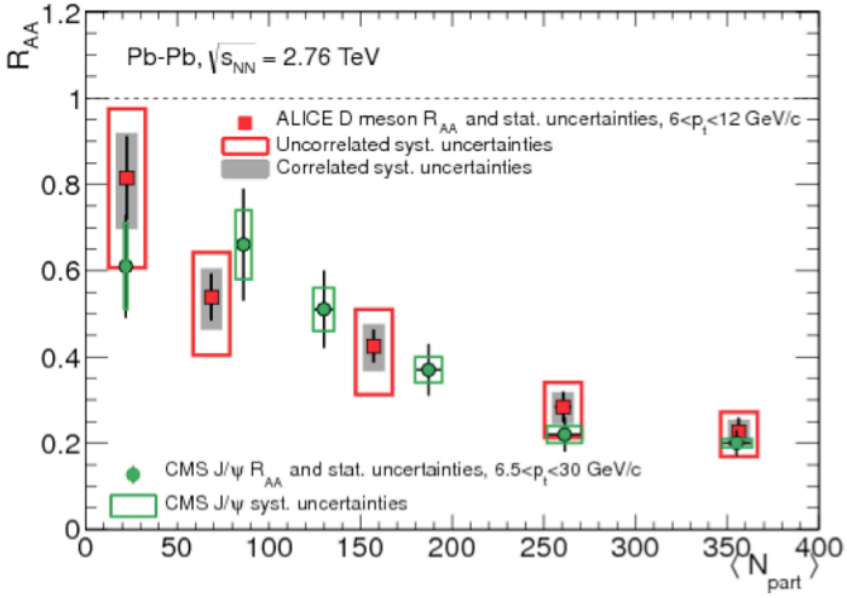
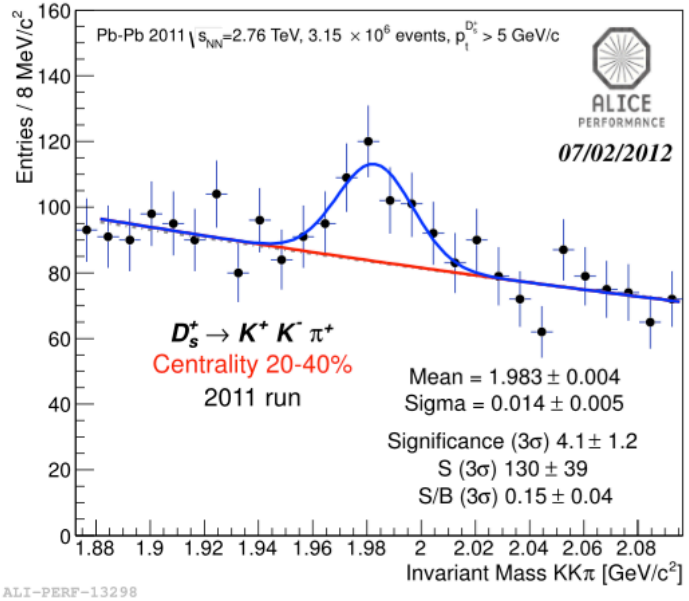
Outlook: ongoing with Pb-Pb 2011

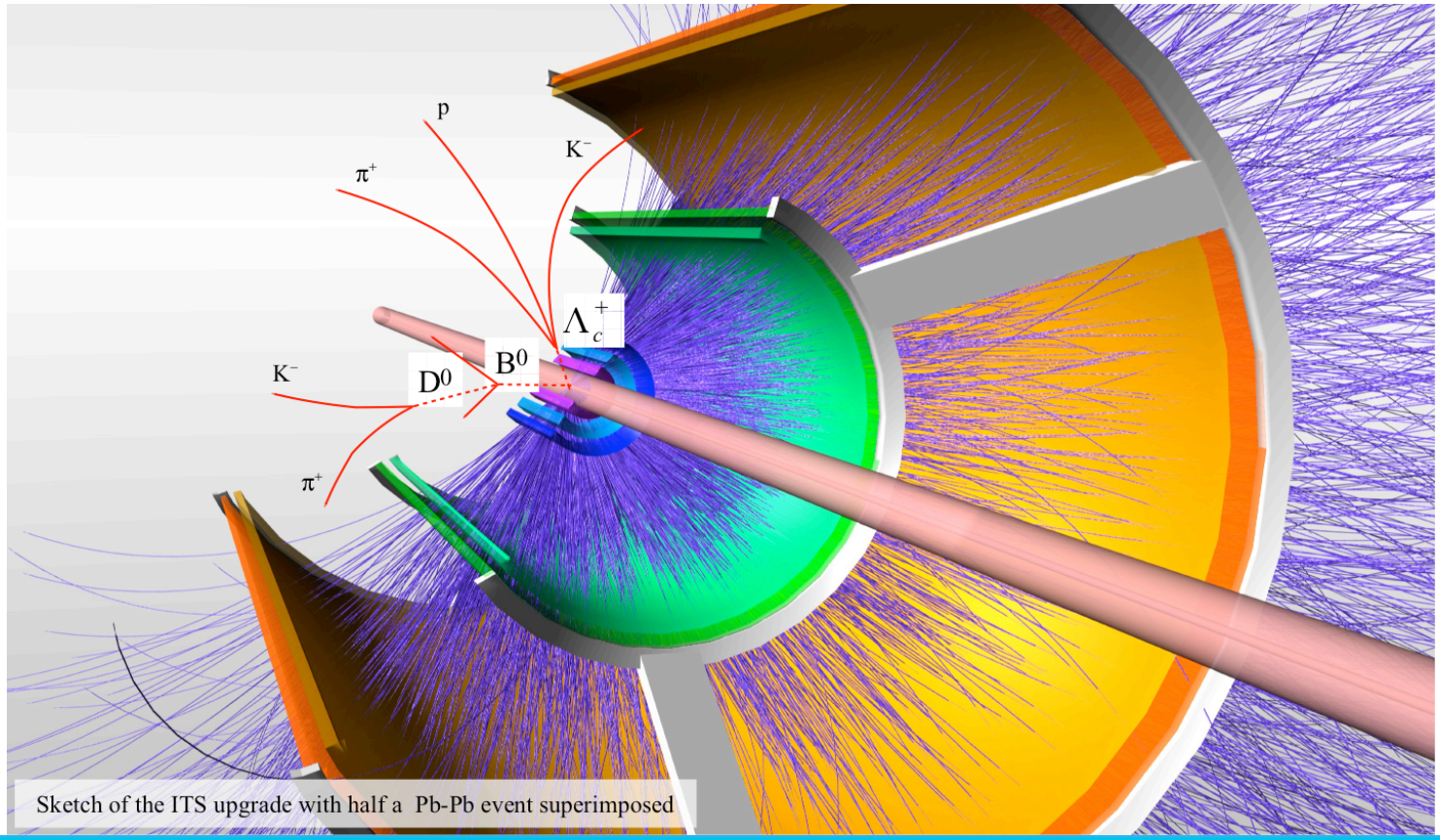
- Separation of b-decay electrons in Pb-Pb
- Flow with electrons and muons
- Extension of D production measurement to low and high p_t
  - Total charm cross section in Pb-Pb → comparison with J/ψ
- D_s production in Pb-Pb → D_s/D enhancement if c quarks hadronize by recombination in a (s-rich) medium





Furthermore ahead … upgrading the Inner Tracking System

- Upgrade Concept recently approved by Collaboration
- Targeted for 2017-2018 LHC shutdown
- Conceptual Design Report CERN-LHCC-2012-005



Courtesy S. Rossegger (CERN)

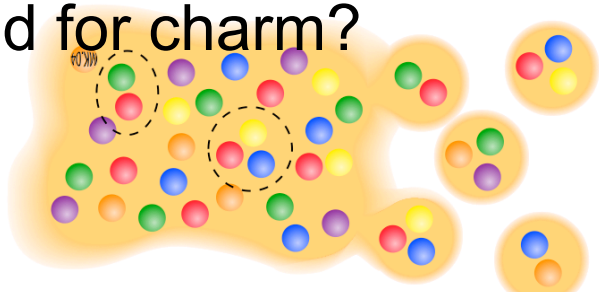
Sketch of the ITS upgrade with half a Pb-Pb event superimposed

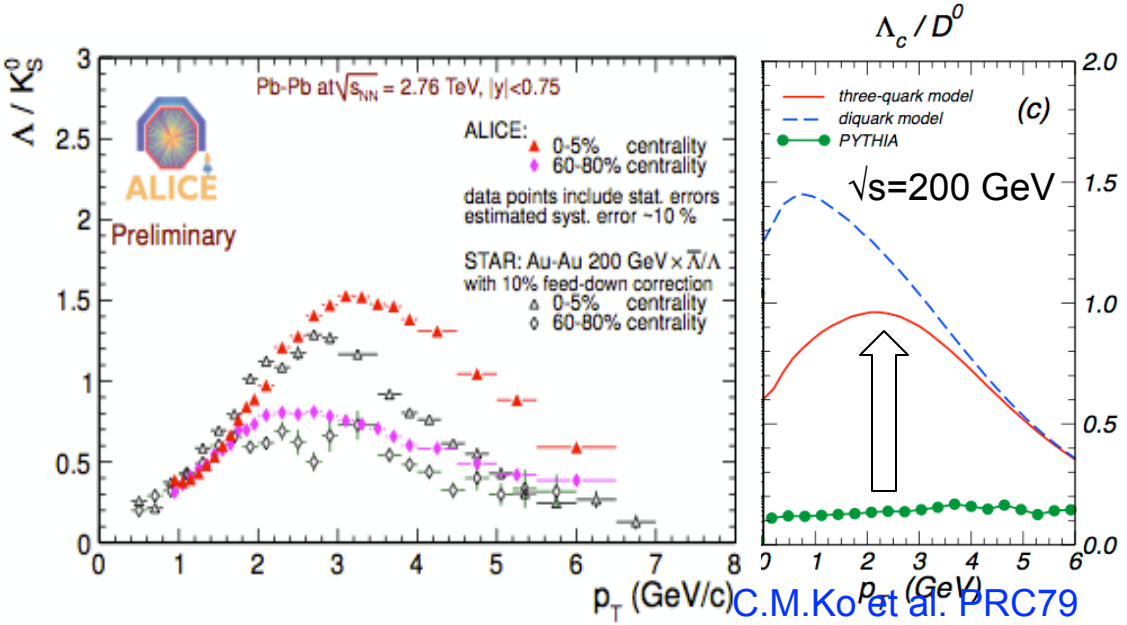
Inner Tracking System Upgrade: HF physics goals in a nutshell (1)

- Investigate HF in-medium thermalization and hadronization
- Baryon/meson enhancement and v_2 splitting → most direct indication of light-quark hadronization in a partonic system

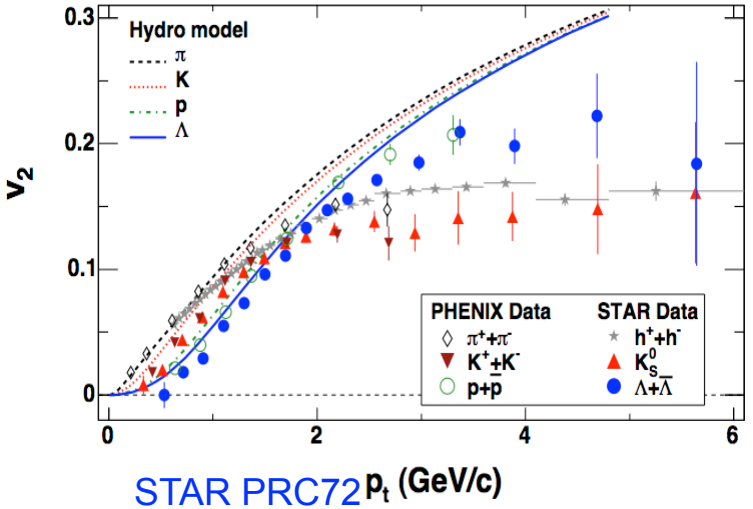
→ Measure this in the HF sector! Does it hold for charm?

→ Charm baryons: Λ_c





C.M.Ko et al. PRC79



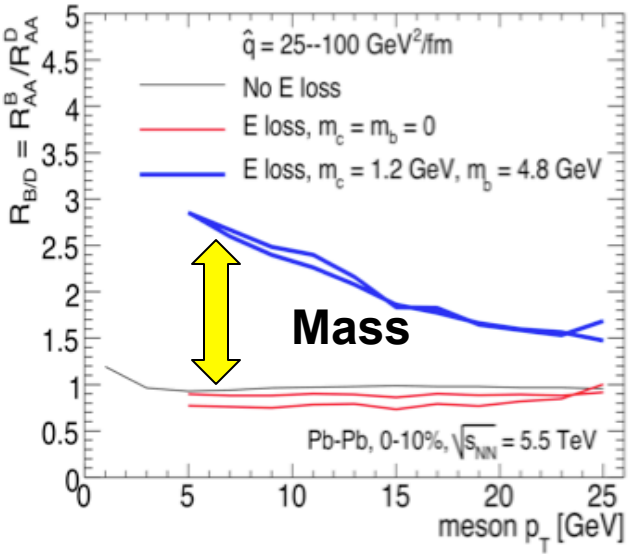
STAR PRC72

Inner Tracking System Upgrade: HF physics goals in a nutshell (2)

- Investigate transport coefficients for heavy quarks in the medium
- Sensitive to medium viscosity
- Pin down mass dependence

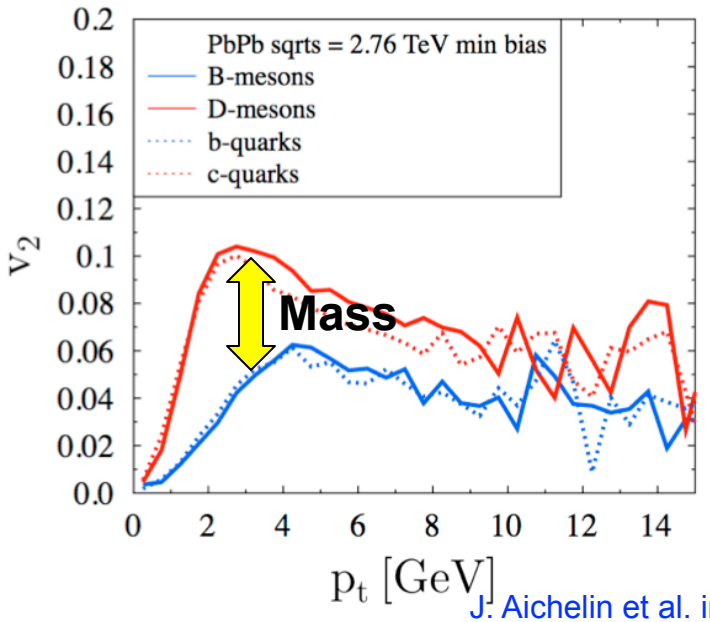
➡ Measure precisely R_{AA} and v_2 of D and B in a wide p_t range

B/D R_{AA}



Armesto et al., PRD71 (2005)

D and B v_2



J. Aichelin et al. in arXiv:1201:4192

Inner Tracker Upgrade requirements

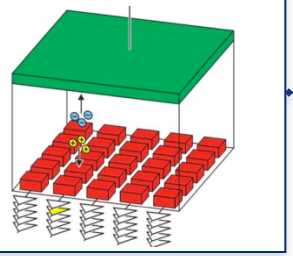
- Largely improved spatial resolution (x3), especially at low p_t
  - Closer (3.9 cm → 2.2 cm)
  - Thinner (1% → 0.3% of X_0 / layer)
  - Smaller pixels (50x425 μm^2 → 20x20 μm^2 cell size)
  - → Strengthen ALICE uniqueness at low p_t
- Fast readout
  - Cope with possible LHC Pb-Pb luminosity upgrade after LS2 (~$6 \times 10^{27} cm^{-2} s^{-1}$)
  - Upgraded ALICE records data at 50 kHz
  - Integrate 10/nb after LS2 (~10^{10} central Pb-Pb events)
- PID capabilities being considered (ALICE's special)

Inner Tracker Upgrade design

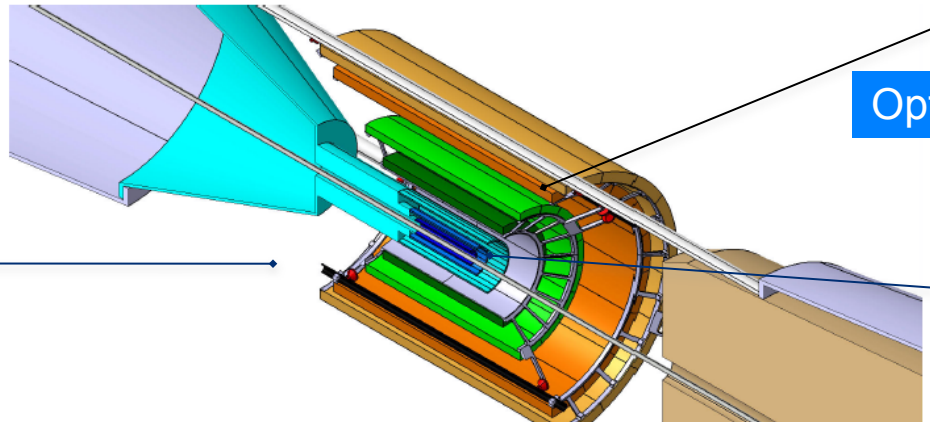
Two design options are being studied:

Option A

7 layers of pixels

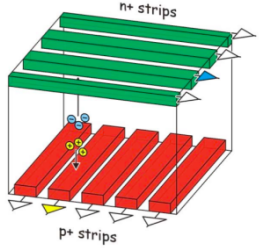


Pixels: O(20 μm x 20 μm)

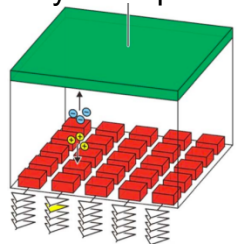


Option B

4 layers of strips

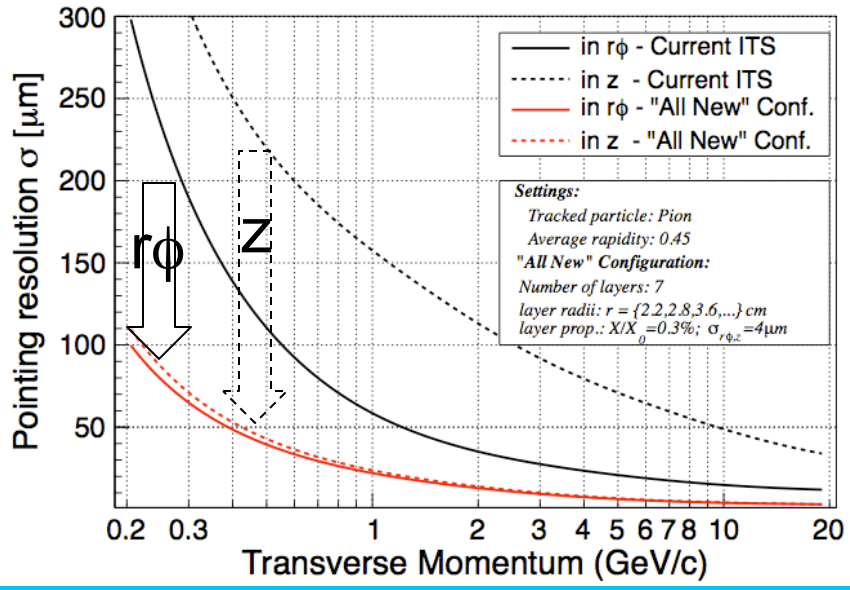


3 layers of pixels



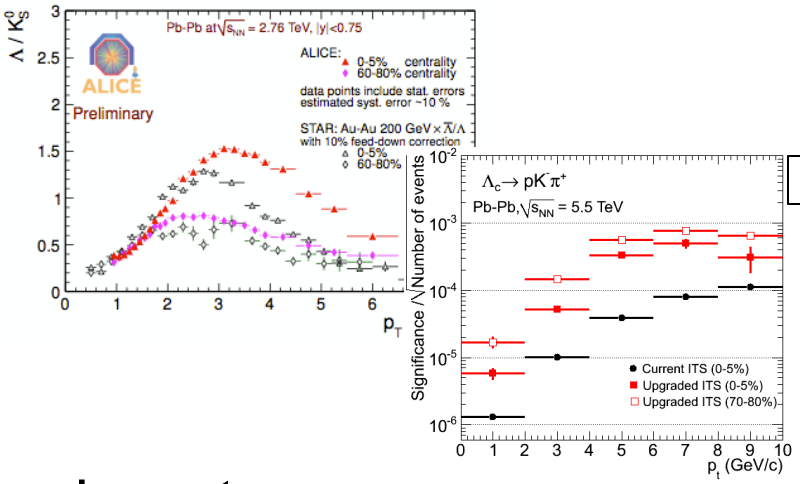
Pixels: O(20 μm x 20 μm)
Strips: 95 μm x 2 cm, double sided

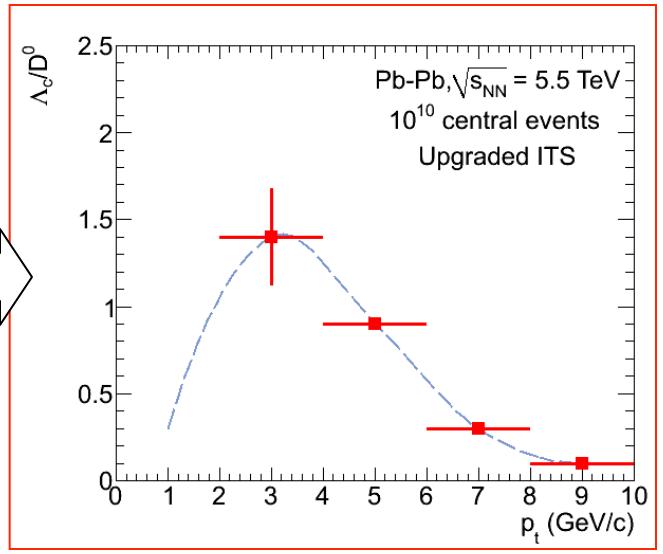
Similar performance (Option A shown):
- x3 better in rϕ
- x7 better in z



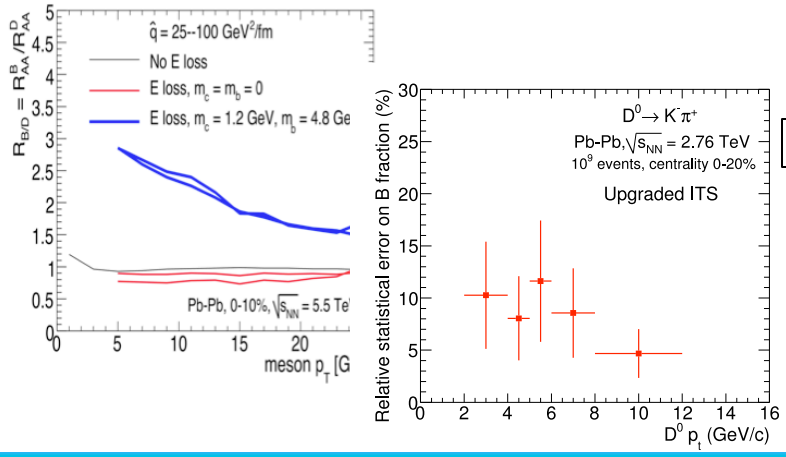
Example physics performance

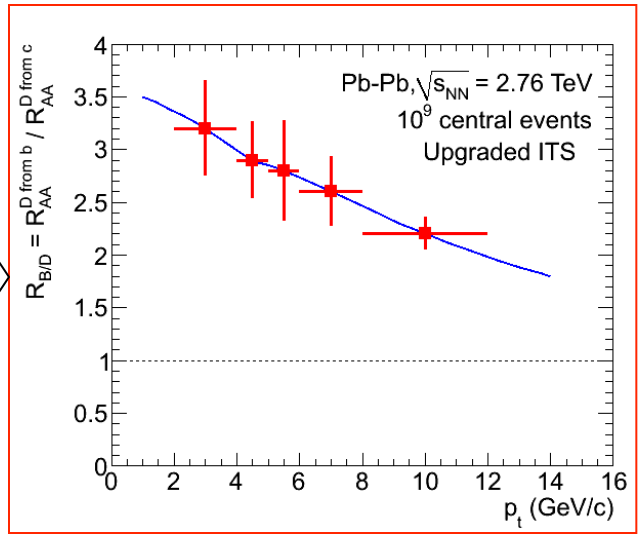
Charm baryon/meson





Charm vs beauty suppression





ITS Upgrade CDR, CERN-LHCC-2012-005

Summary

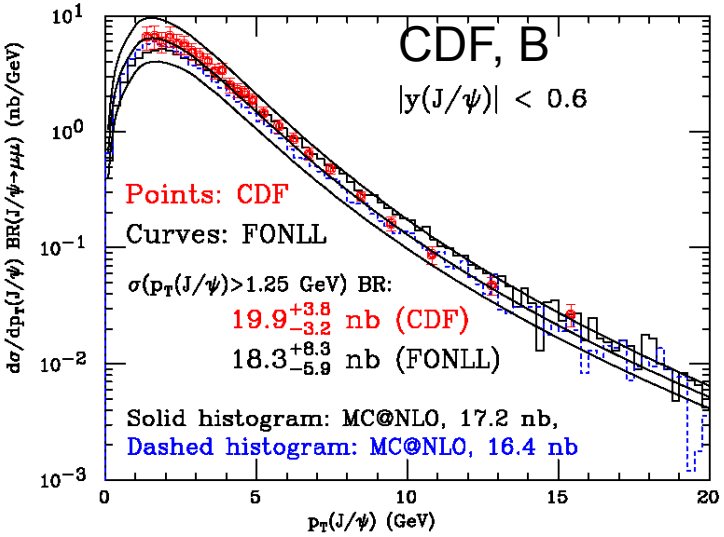
- Heavy-flavour production measurements in pp and Pb-Pb
- pp reference data also provide important complementary information wrt other experiments
- Suppression of high-p_t heavy-flavour production and charm azimuthal anisotropy
- Indicate strong medium effect on c and b quarks
- Consistent with expected energy loss mechanisms

- Much more being prepared for the (near and far) future

Thanks to all ALICE Collaborators,
in particular the Heavy Flavour wg

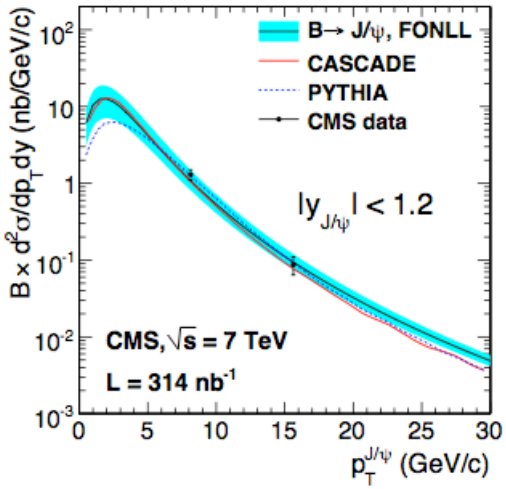
EXTRA SLIDES

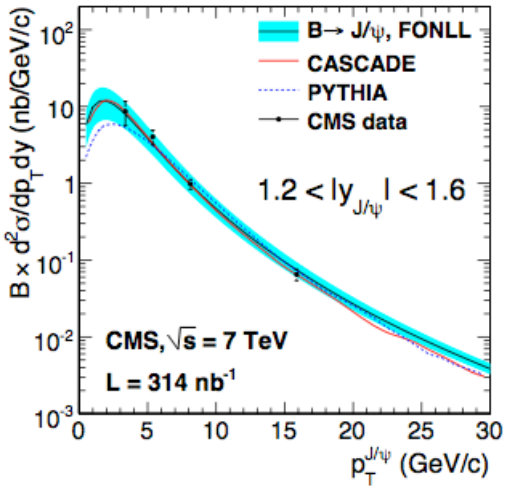
FONLL vs. data, beauty production 2-7 TeV

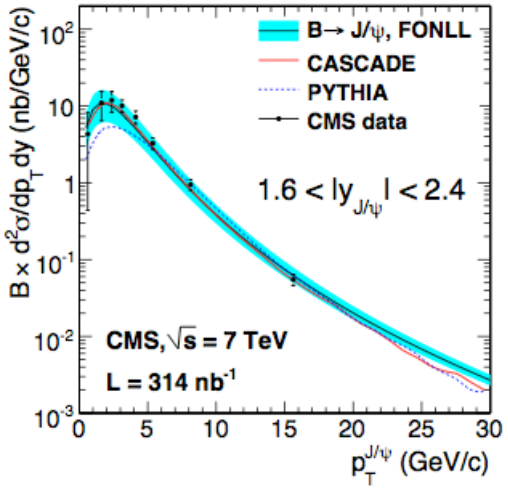


FONLL, MC@NLO:
Cacciari, Frixione, Mangano, Nason and Ridolfi, JHEP0407 (2004) 033

CMS, arXiv:1011.4193





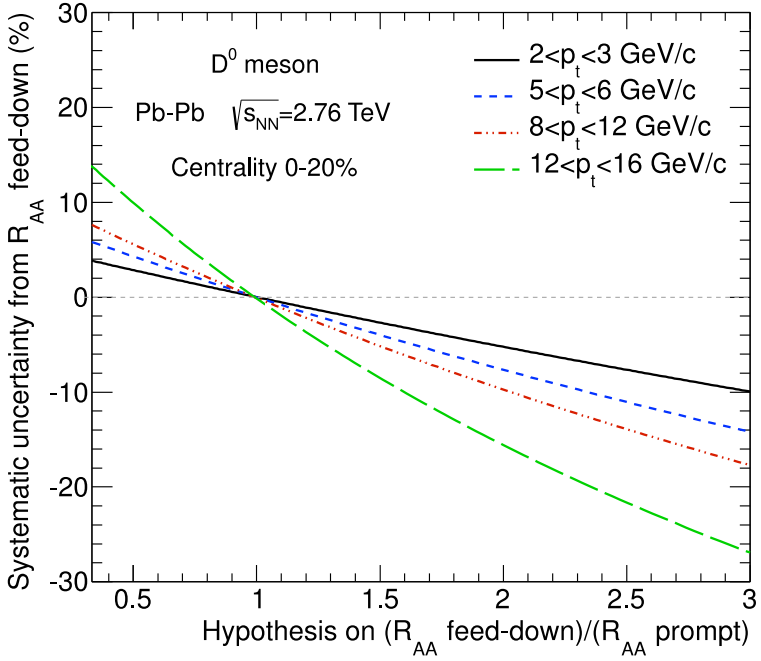


B feed-down: effect on R_{AA}^{D}

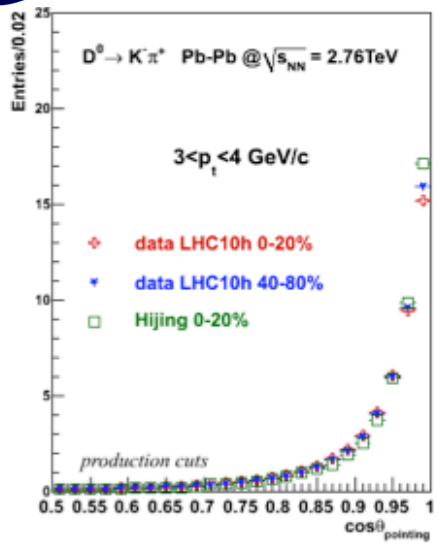
- Correction for B→D:

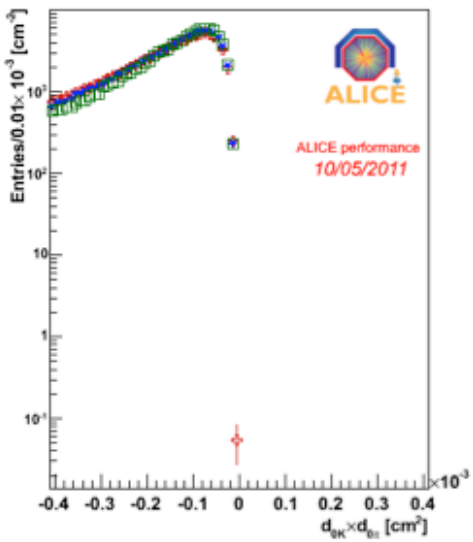
$$-\langle T_{AA} \rangle \times \varepsilon^{MC}_{DfromB} \times \frac{d\sigma^{FONLL}_{DfromB}}{dp_t} \times R^{B}_{AA}$$

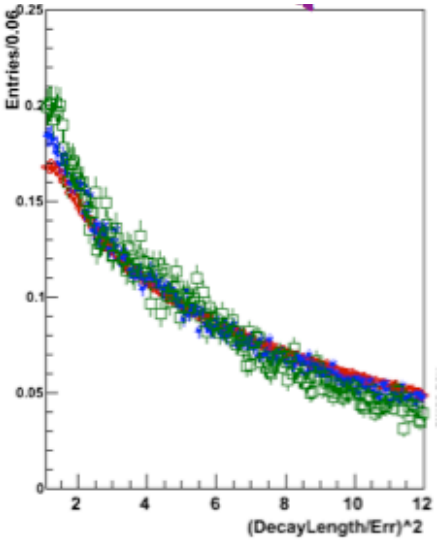
  - from FONLL, using ALICE efficiencies for these D's: ~10-15%
    - systematic uncertainty from FONLL, partly cancels in R_{AA}^{D}
  - + need to make hypothesis on R_{AA}^{B}
    - conservative: $1/3 < R_{AA}^{D}/R_{AA}^{B} < 3$ → systematic uncert. on R_{AA}^{D}

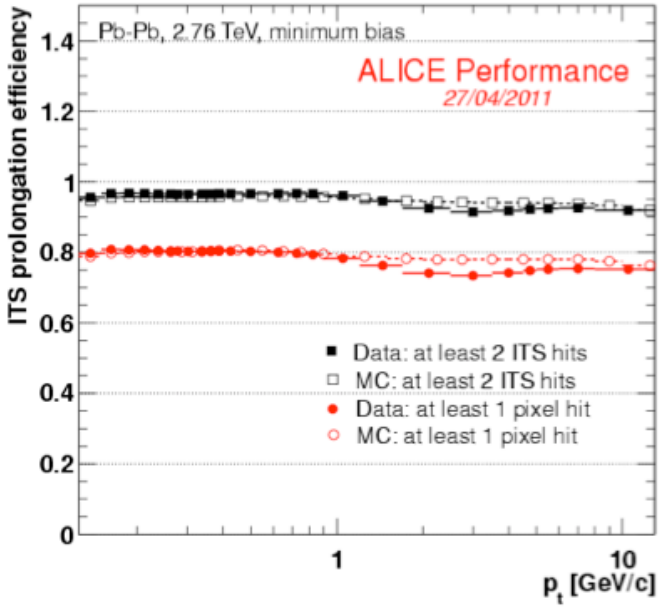


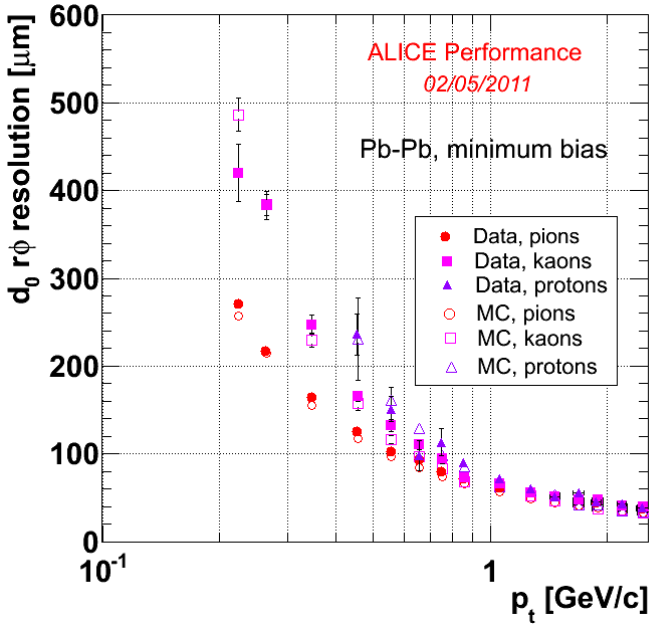
D mesons Pb-Pb: data vs MC





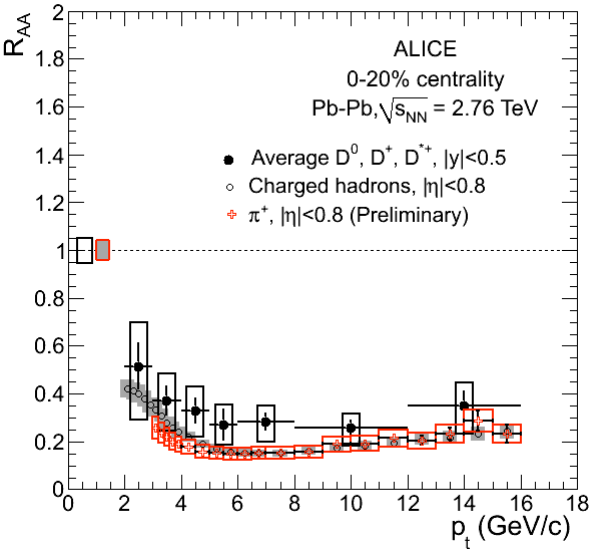


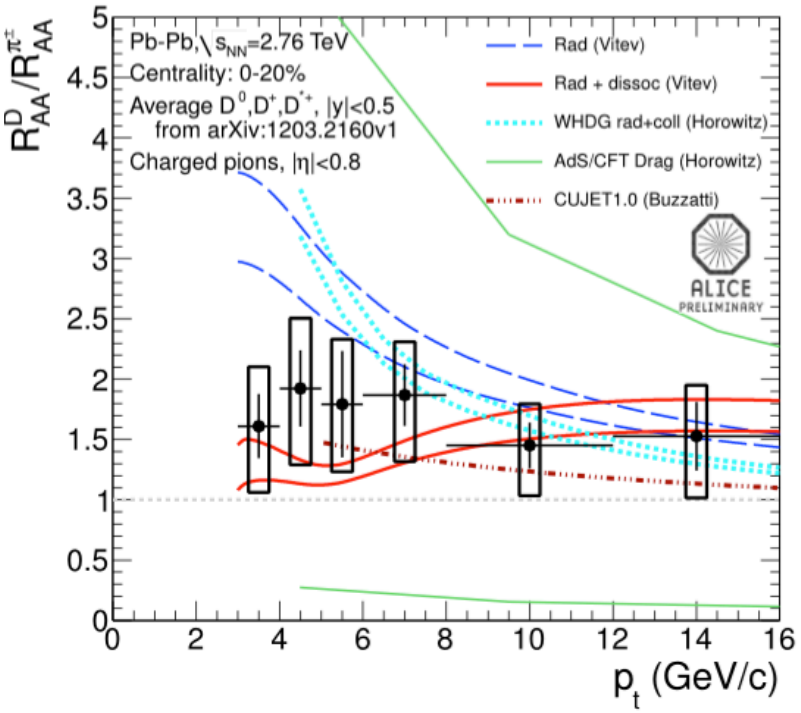


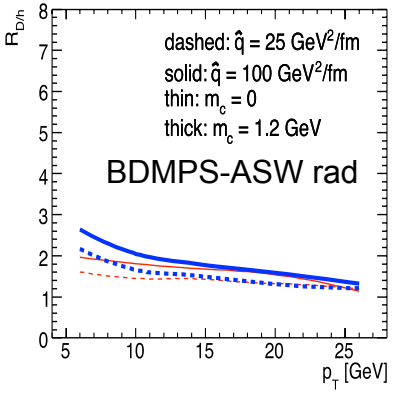


Comparisons: charm and pions

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







- 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)