Heavy-flavour Production in proton-proton Collisions with ALICE

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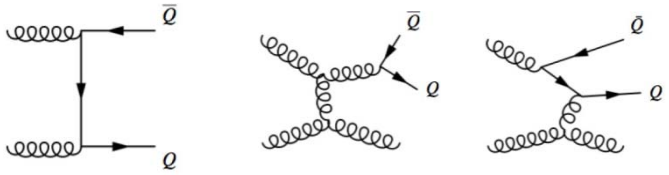
Outline

- **Introduction**
  - ✓ Physics motivations
  - ✓ Detector layout
- **Heavy-flavour Measurements in pp Collisions**
  - ✓ D(B)-meson differential cross sections
  - ✓ D production vs multiplicity
  - ✓ Heavy-flavour decay electrons
  - ✓ Heavy-flavour decay muons
- **Conclusions**

Heavy Flavours: Physics Motivations

- Heavy flavours in pp collisions:
  - Test pQCD calculations in a new energy domain ($3.5x\sqrt{s}_{Tevatron}$)
  - Insight in the production mechanism
  - Copious production of both c & b quarks
  - Reference for pA and AA collisions

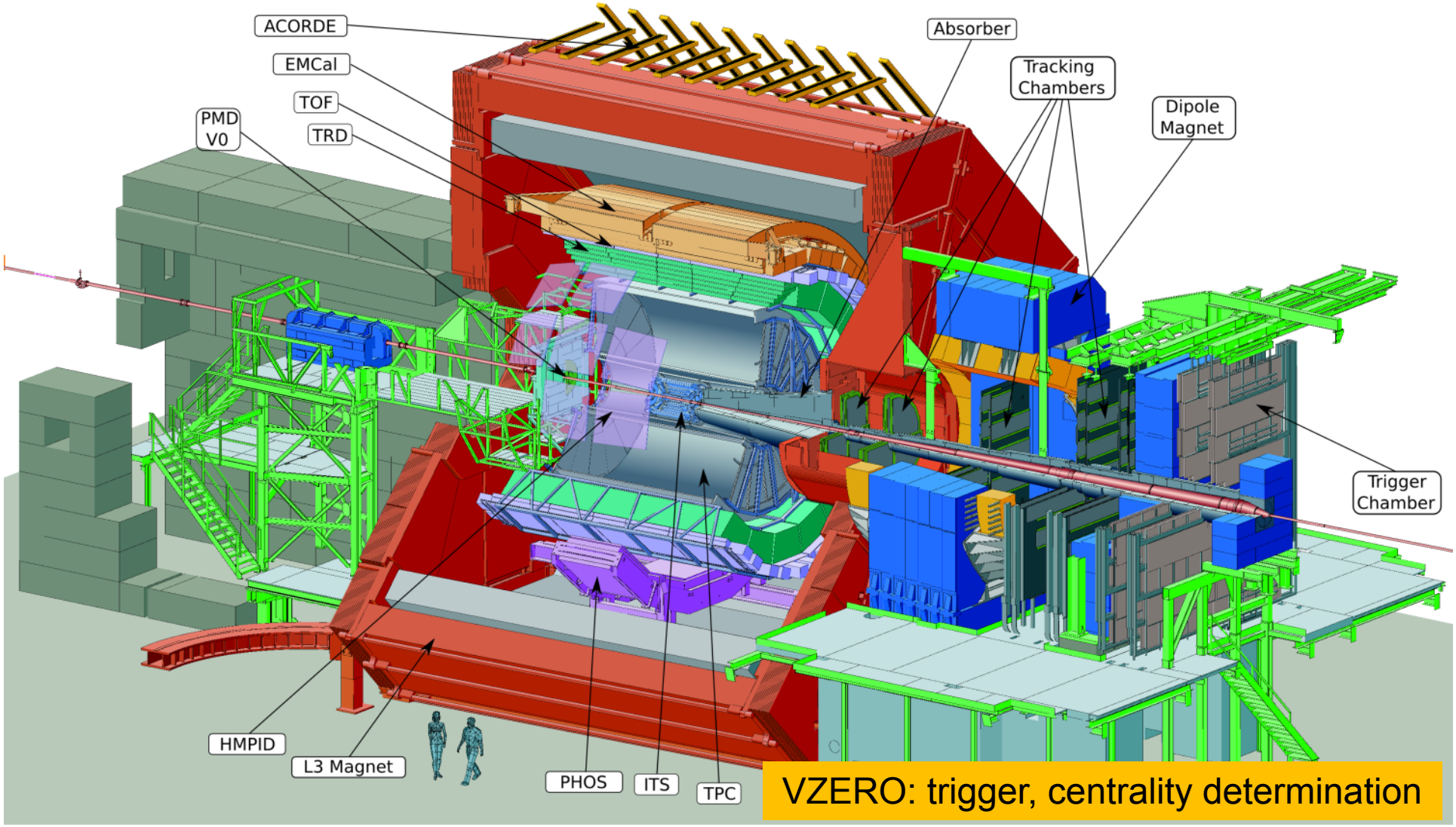


- Heavy flavours in pA collisions: ⟹ p-Pb data started in Jan. 2013
  - Assess initial state effects
    - ✓ Shadowing (PDF modifications in nuclei)
    - ✓ Gluon saturation and Color Glass Condensate

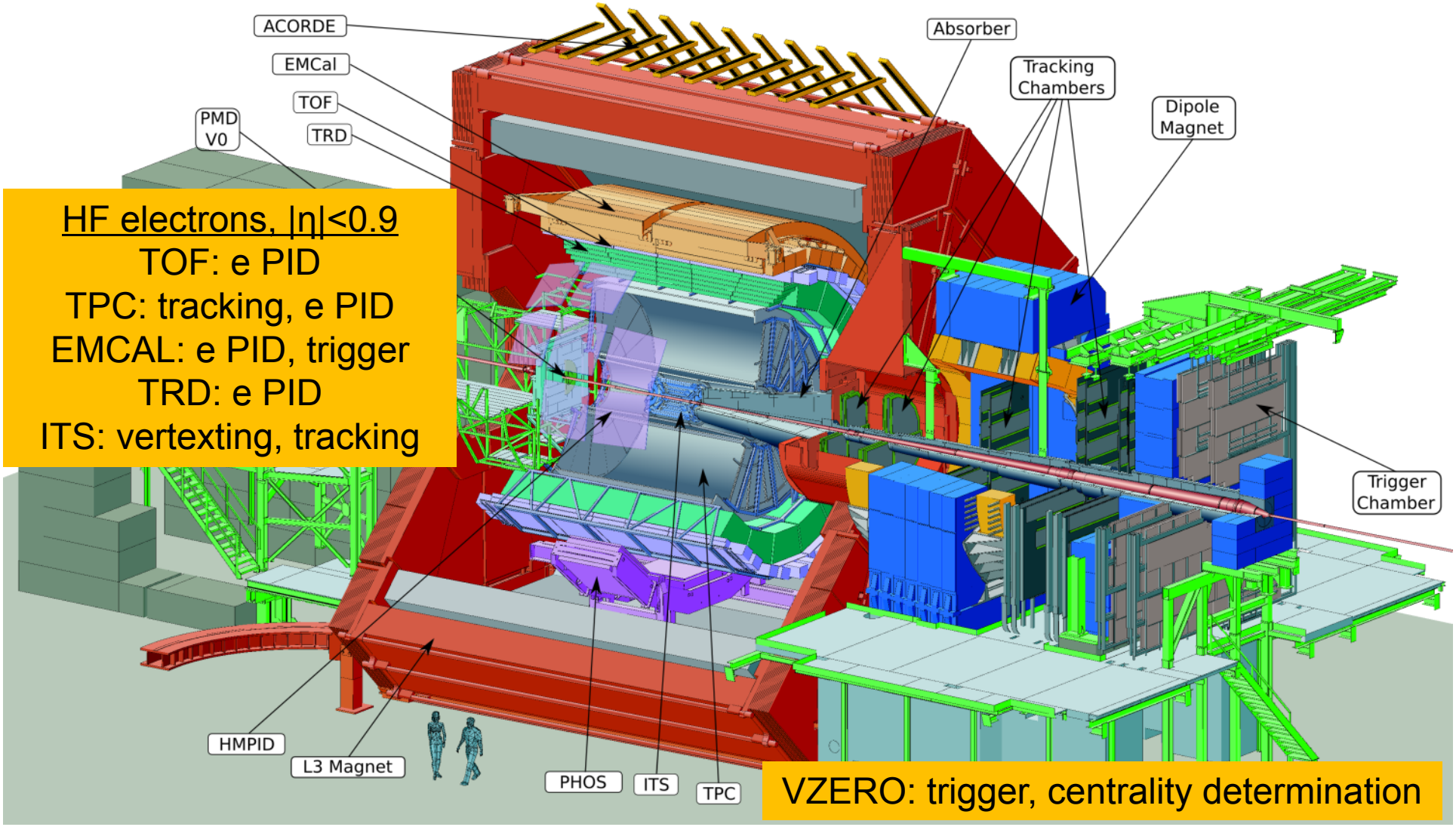
- Heavy flavours in AA collisions: ⟹ Pb-Pb data in 2010 + 2011
  - Energy loss in the QGP (high p_T)
    - ✓ medium density and size ⟹ dN/dp_T, R_{AA}, v_2
    - ✓ color charge (Casimir factor): $\Delta E_{u,d,s} < \Delta E_g$ ⟹ compare to light hadrons
    - ✓ parton mass (dead cone effect): $\Delta E_b < \Delta E_c < \ldots$ ⟹ compare c and b production
  - Thermalisation in the QGP (low p_T)
    - ✓ medium transport properties ⟹ dN/dp_T, R_{AA}, v_2

↳ **X. Zhang's talk**

Heavy Flavours in ALICE



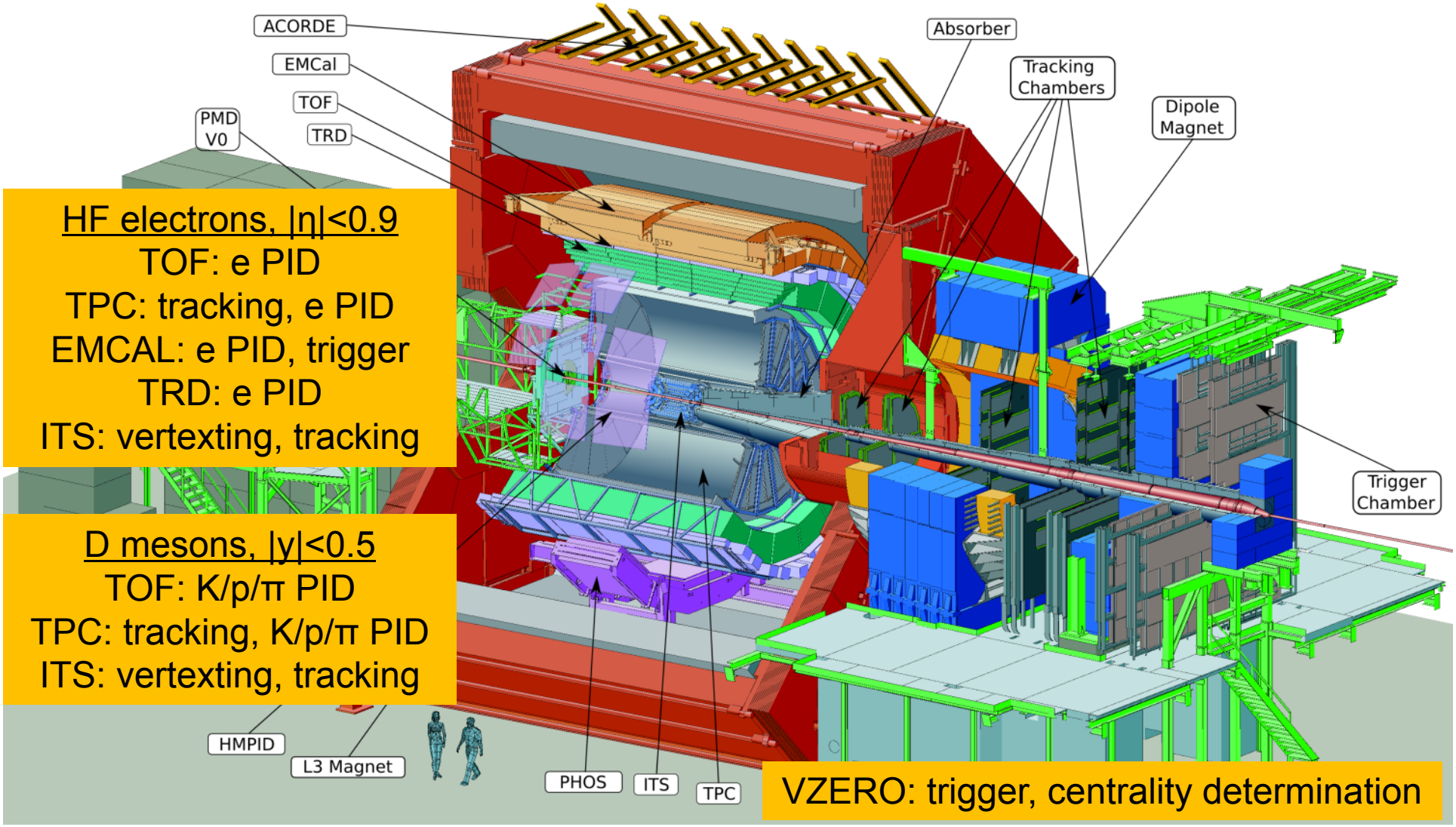
Heavy Flavours in ALICE



HF electrons, |η|<0.9
TOF: e PID
TPC: tracking, e PID
EMCAL: e PID, trigger
TRD: e PID
ITS: vertexting, tracking

VZERO: trigger, centrality determination

Heavy Flavours in ALICE

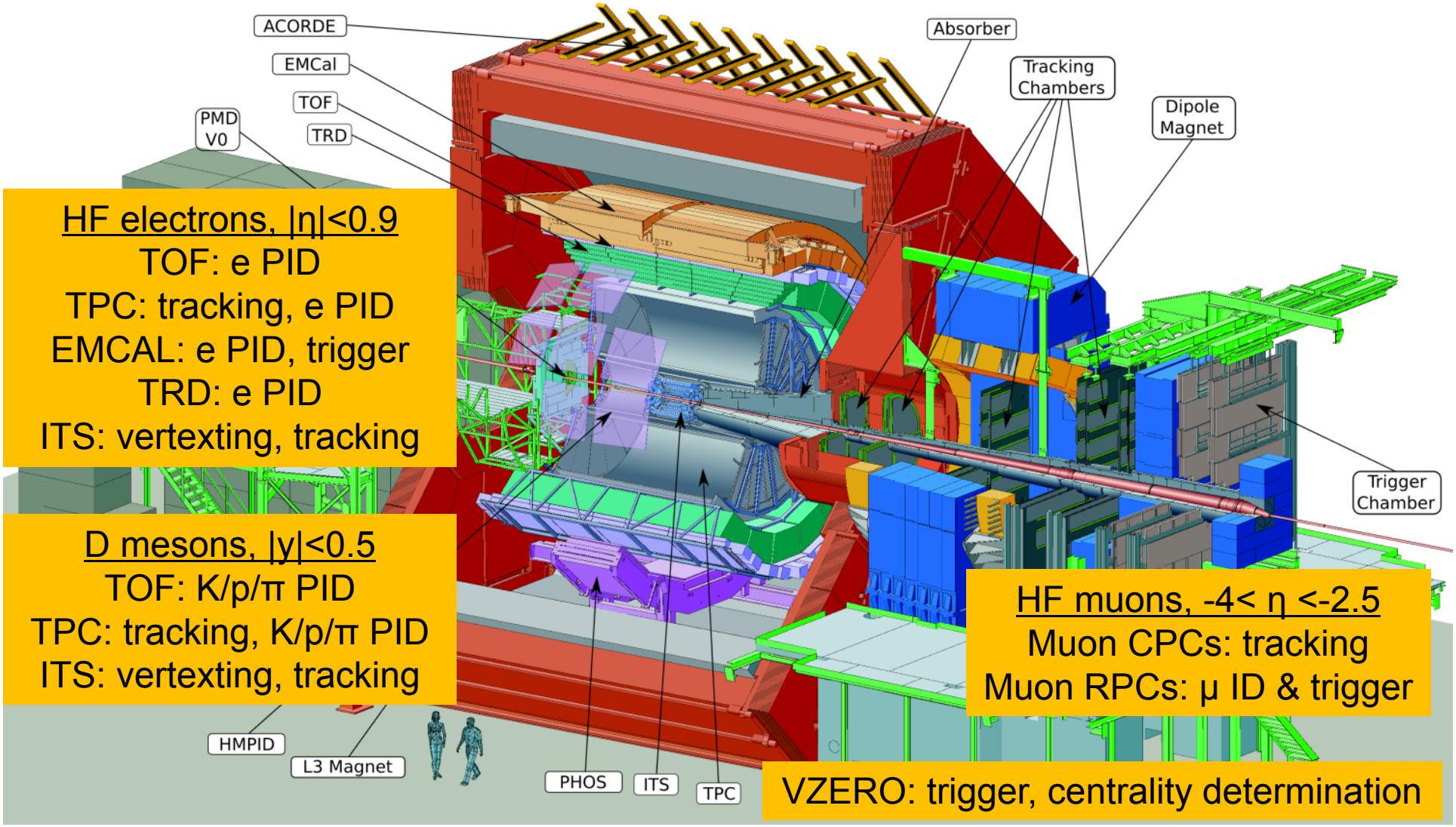


HF electrons, |η|<0.9
TOF: e PID
TPC: tracking, e PID
EMCAL: e PID, trigger
TRD: e PID
ITS: vertexting, tracking

D mesons, |y|<0.5
TOF: K/p/π PID
TPC: tracking, K/p/π PID
ITS: vertexting, tracking

VZERO: trigger, centrality determination

Heavy Flavours in ALICE



HF electrons, |η|<0.9
TOF: e PID
TPC: tracking, e PID
EMCAL: e PID, trigger
TRD: e PID
ITS: vertexting, tracking

D mesons, |y|<0.5
TOF: K/p/π PID
TPC: tracking, K/p/π PID
ITS: vertexting, tracking

HF muons, -4< η <-2.5
Muon CPCs: tracking
Muon RPCs: μ ID & trigger

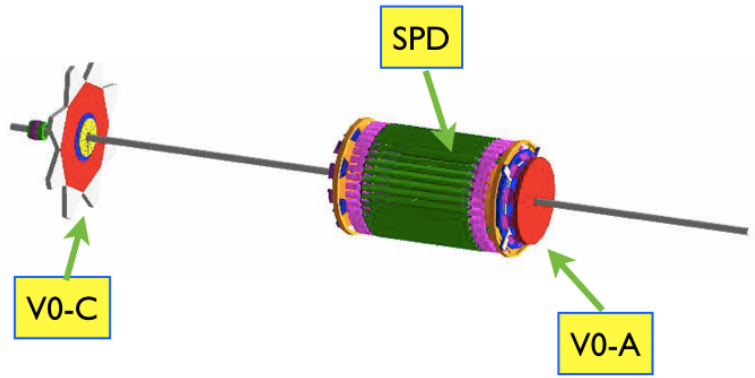
VZERO: trigger, centrality determination

Data Set Used for the Present Analysis

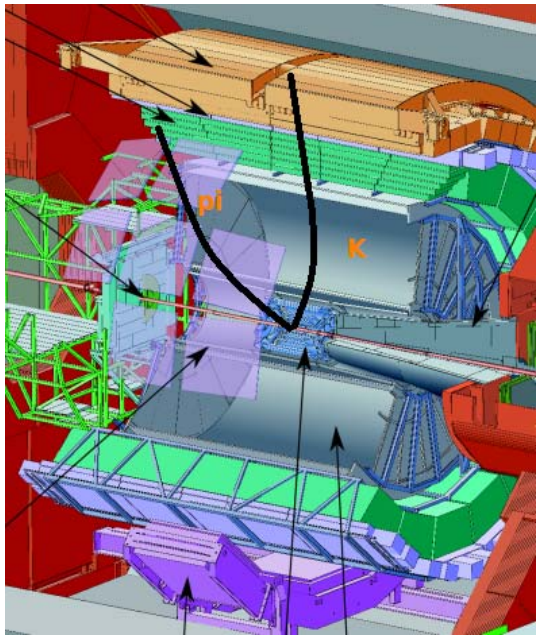
System	pp	pp
Energy (TeV)	7	2.76
Year	2010	2011
L_{int} MB/cent	5/nb	1.5/nb
L_{int} μ	16.5/nb	19/nb

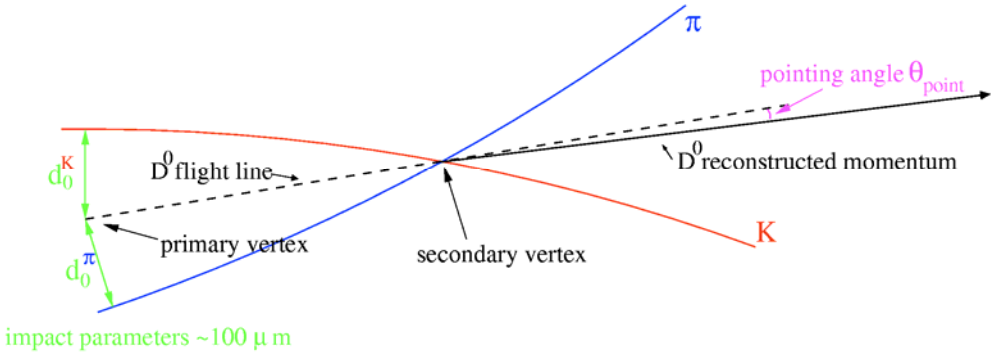
pp

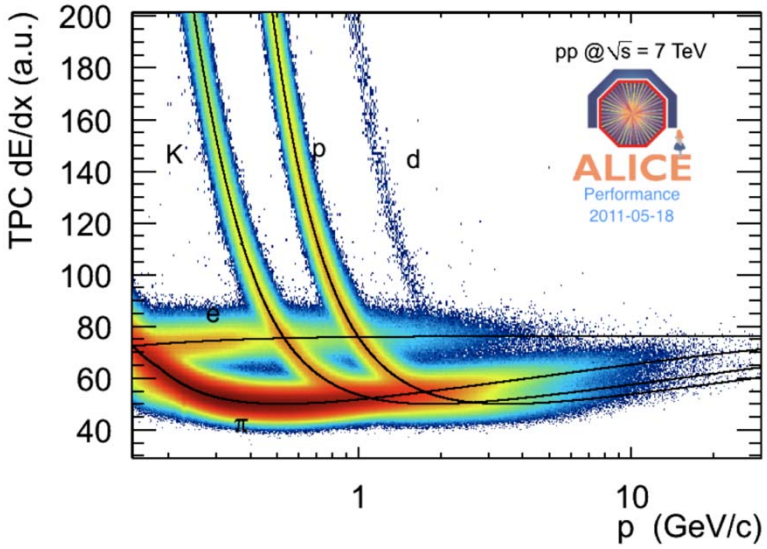
- **Minimum bias (MB): combinations of the following detectors**
  - ✓ **Pixel (SPD) Fast-Or (1 or 2 hits)**
  - ✓ **VZERO scintillators (one or both sides)**
- **Single muon: MB + a muon with p_T > 0.5 GeV/c and -4 < η < -2.5**



D Meson Measurements







- D → hadrons
  - ✓ $D^0 \rightarrow K^- \pi^+$ $c\tau \sim 122.9$ μm
  - ✓ $D^+ \rightarrow K^- \pi^+ \pi^+$ $c\tau \sim 311.8$ μm
  - ✓ $D^{*+} \rightarrow D^0 (\rightarrow K^- \pi^+) \pi^+_{soft}$
  - ✓ $D^+_s \rightarrow \Phi (\rightarrow K^+ K^-) \pi^+$ $c\tau \sim 149.9$ μm

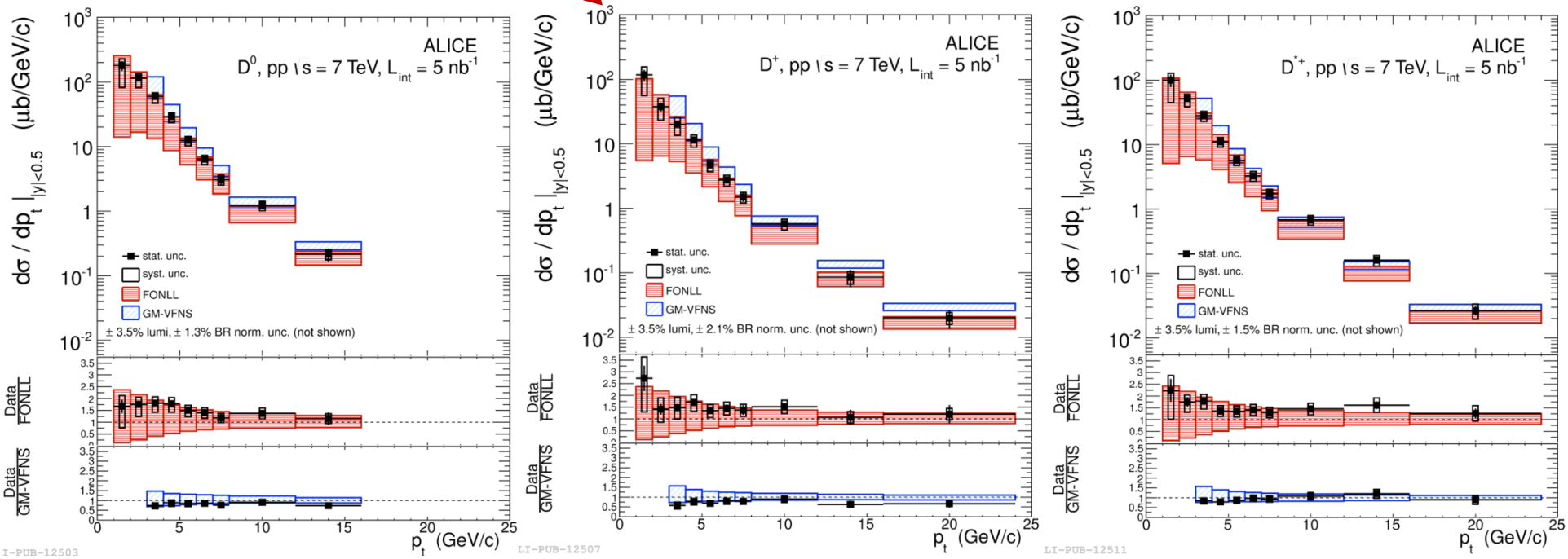
- Topology of the decay resolved via the reconstruction of the secondary vertex. PID to further reduce the combinatorial background

- Signal extraction: invariant mass analysis

D Meson Differential Cross Section in pp at √s = 7 TeV

D^0, D^+ and D^{*+} cross section at $\sqrt{s}$ = 7 TeV, |y| < 0.5

B. I. Abelev et al. [ALICE Collaboration], JHEP 01 (2012) 128.



✓ **Large p_T coverage [1,24] GeV/c and data described by pQCD predictions (FONLL & GM-VFNS) within uncertainties (seem to lie systematically in the upper part of FONLL and lower part of GM-VFNS)**

FONLL: Cacciari et al., JHEP 9805 (1998) 007
GM-VFNS: Kniehl et al., PRD 79 , 094009 (2009)

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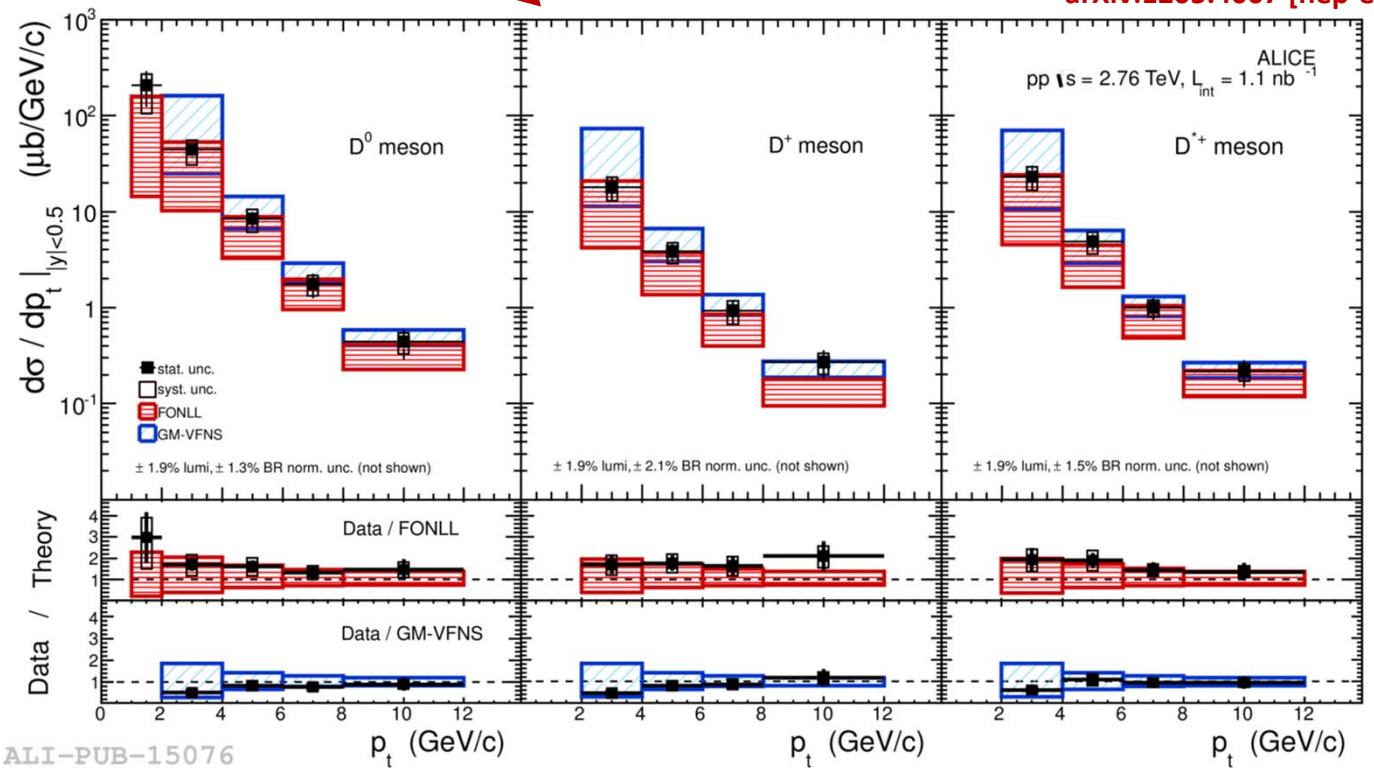
D Meson Differential Cross Section in pp at √s = 2.76TeV

D^0, D^+ and D^{*+} cross section at √s = 2.76 TeV, |y| < 0.5

arXiv:1205.4007 [hep-ex]. JHEP 1207 (2012) 191



✓ **Data described by pQCD predictions (FONLL & GM-VFNS) within uncertainties as in pp collisions at 7 TeV**

FONLL: Cacciari et al., JHEP 9805 (1998) 007
GM-VFNS: Kniehl et al., PRD 79 , 094009 (2009)

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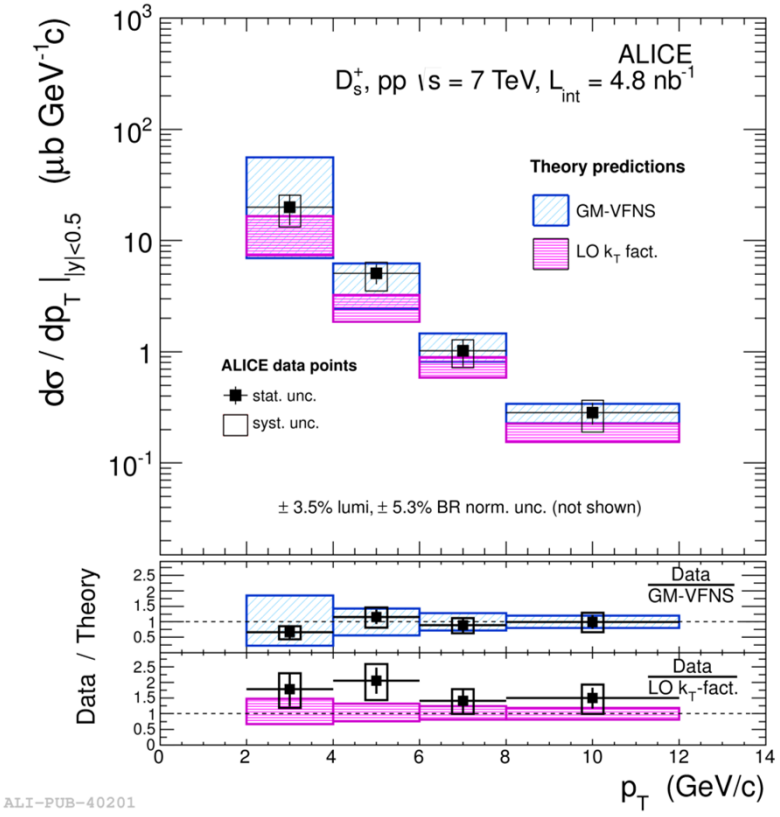
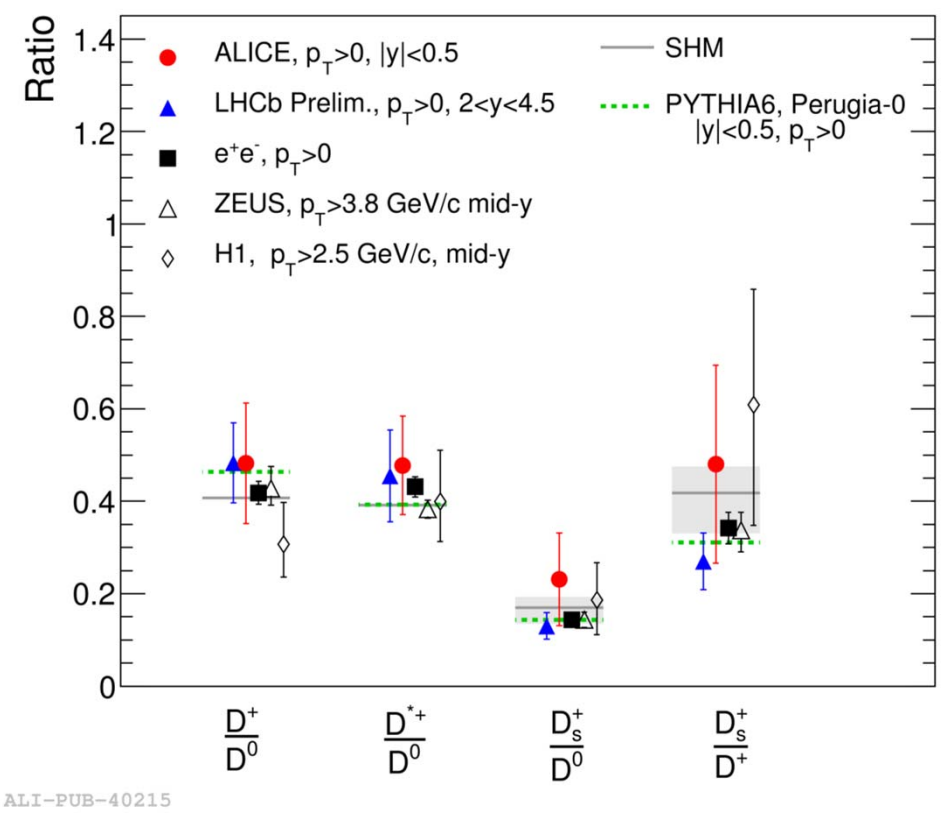
D^+_s Meson Differential Cross Section in pp at $\sqrt{s}$ = 7 TeV





arXiv:1208.1948 [hep-ex]. PLB 718 (2012) 279

- ✓ **D^+_s measured in the p_T range [2,12] GeV/c**
- ✓ **Data described by pQCD predictions within uncertainties**
- ✓ **D ratios are comparable with other experiments**

LO k_t fact: Maciula, et al, arXiv:1208.6126
GM-VFNS: Kniehl et al., PRD 79 , 094009 (2009)

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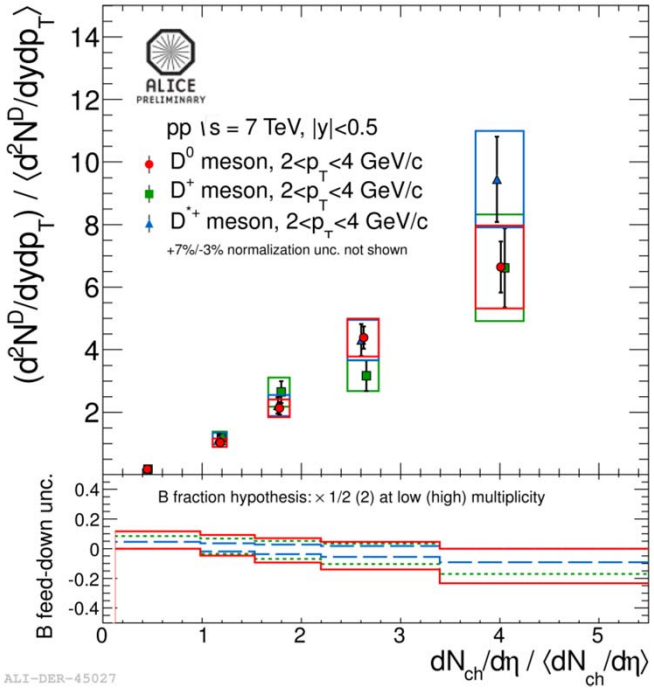
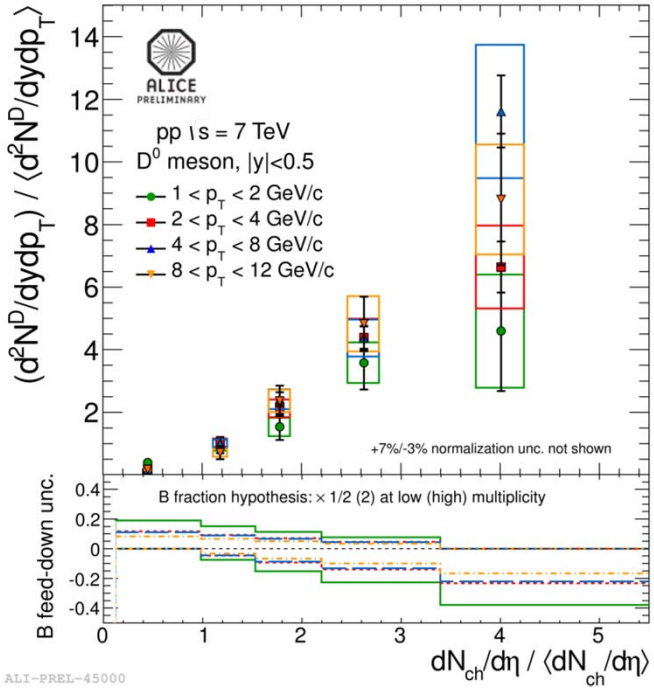
D Meson as a Function of Charged Particle Multiplicity

➢ **If, at LHC, there is a substantial contribution of Multi-Parton Interactions on an hard scale then D meson yield may be correlated to the event total charged particle multiplicity**





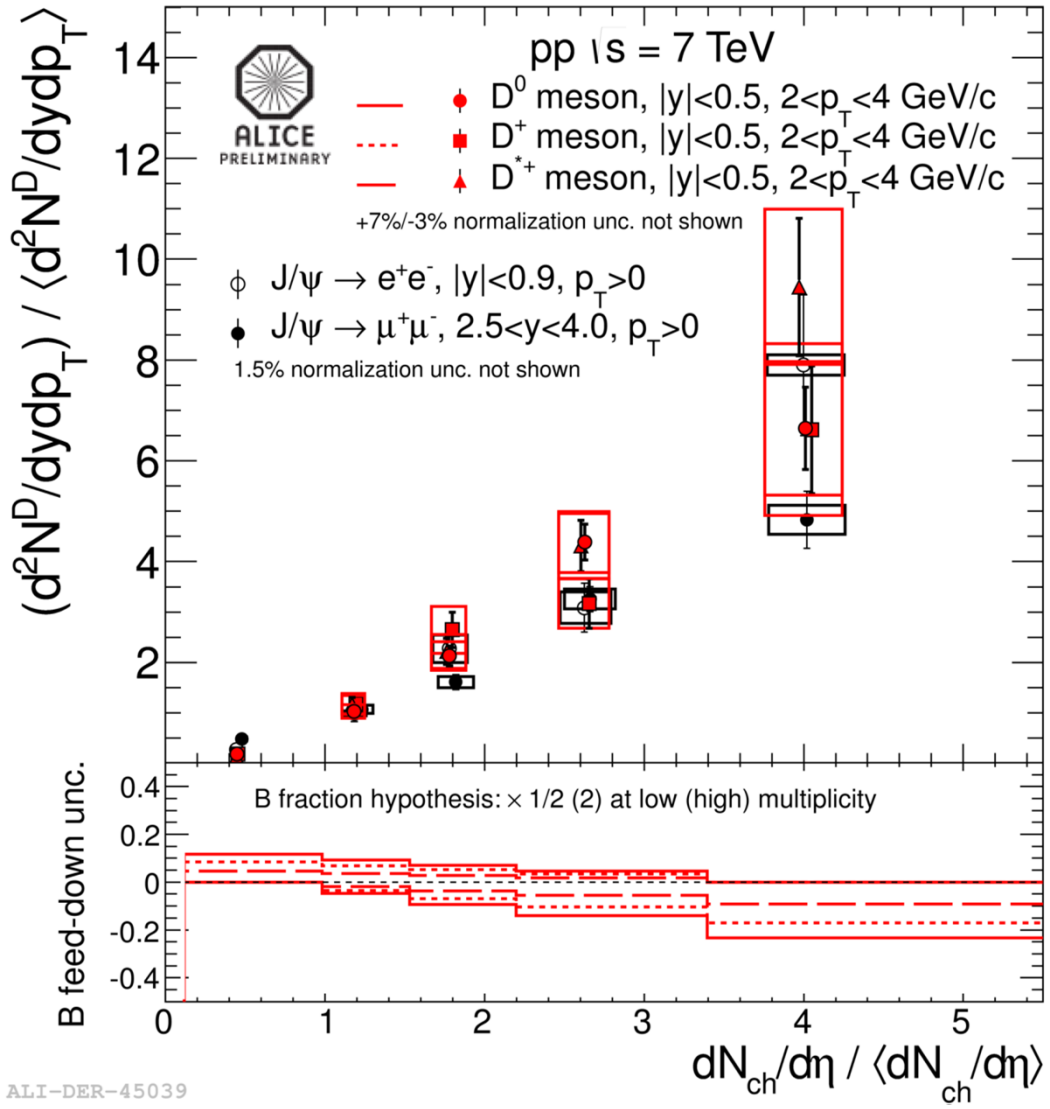
➢ **Relative D-meson yield increases linearly with the relative charged particle multiplicity**

- ✓ **D^0, D^+ and D^{*+} relative yields are consistent within uncertainties**
- ✓ **p_T dependence is not conclusive due to large uncertainties**

➢ **A similar trend and a quantitatively similar enhancement was observed for J/ψ mesons (see next slide)**

N.B.: lower panel is the estimated uncertainty from B feed-down

Comparison with J/ψ

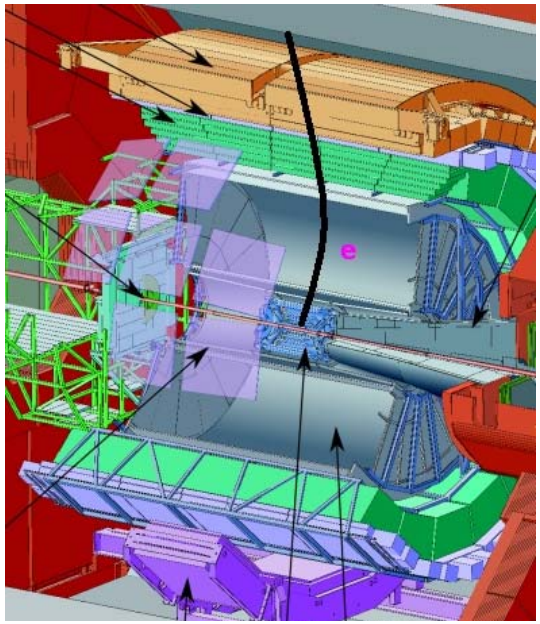


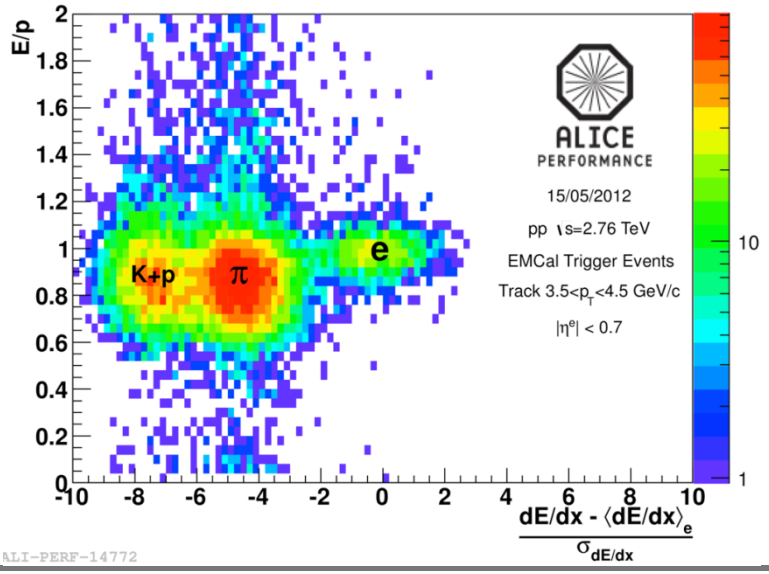
- ✓ D^0, D^+ and D^{*+} meson, $|y| < 0.5$, $2 < p_T < 4$ GeV/c
- ✓ $J/\psi \rightarrow e^+e^-$, $|y| < 0.9$, $p_T > 0$ GeV/c
- ✓ $J/\psi \rightarrow \mu^+\mu^-$, $2.5 < y < 4$, $p_T > 0$ GeV/c

arXiv:1202.2816. PLB 712 (2012) 165

- ➢ **Open and hidden charm behave similarly within uncertainties**

Heavy Flavour Decay Electrons Measurements

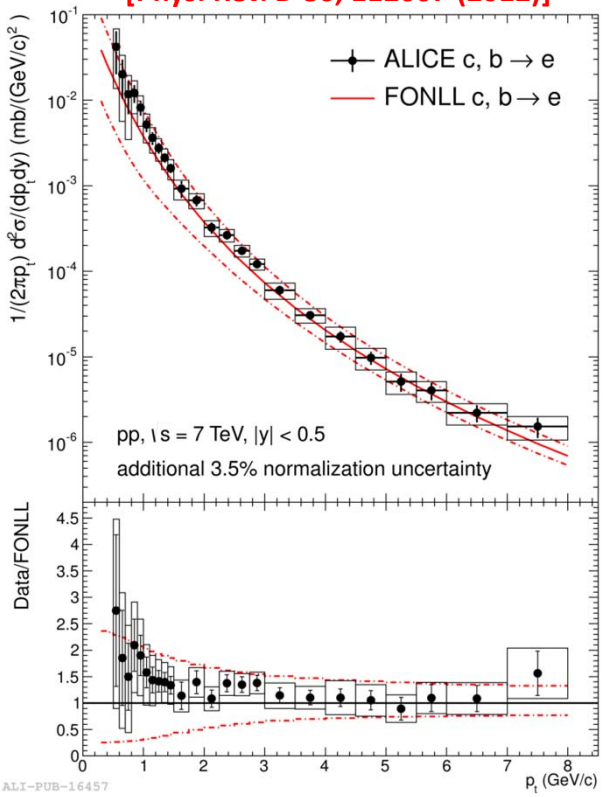


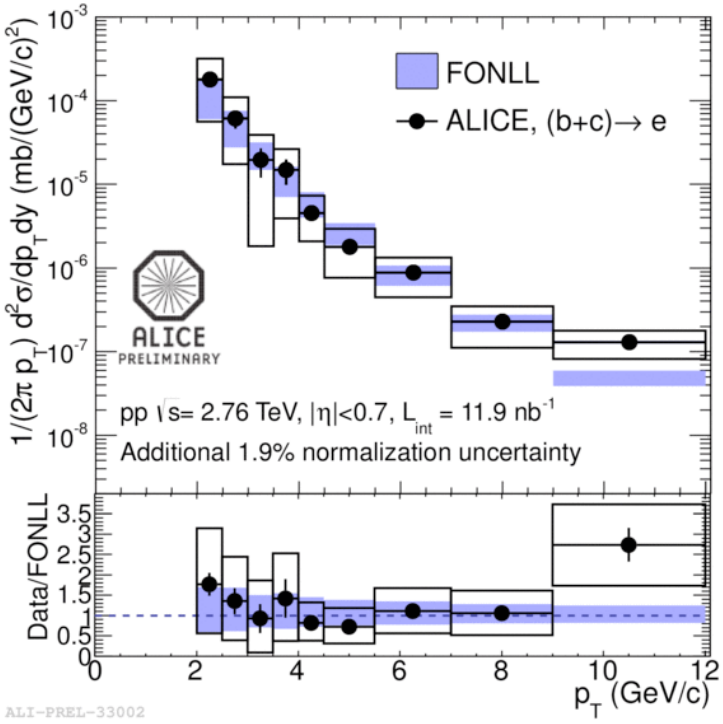


- c/b → electrons
  - ✓ c/b → e + X
  - ✓ b → c → e + X
- Electron identification:
  - ✓ TPC (dE/dx) + TOF + TRD + EMCAL
- Main sources of background:
  - ✓ photon conversions
  - ✓ Dalitz decays of neutral mesons
  - ✓ quarkonia decays
  - ✓ direct photons
  - ✓ Drell-Yan processes
- Background subtraction:
  - ✓ invariant mass method: remove π^0, Dalitz, photon conversions
  - ✓ cocktail: different background sources evaluated using Monte Carlo hadron-decay generator

Heavy Flavour Decay Electrons in pp (I)

[Phys. Rev. D 86, 112007 (2012)]



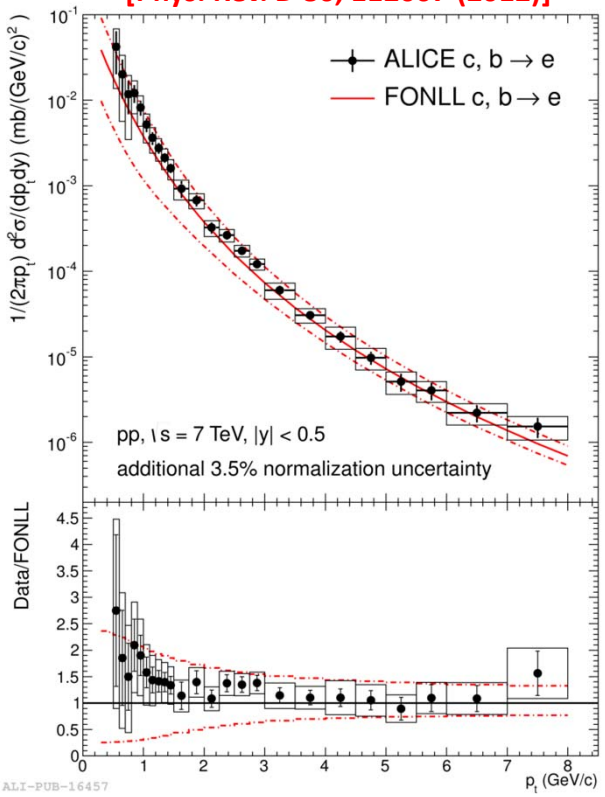


FONLL: Cacciari et al., JHEP 1210 (2012) 137

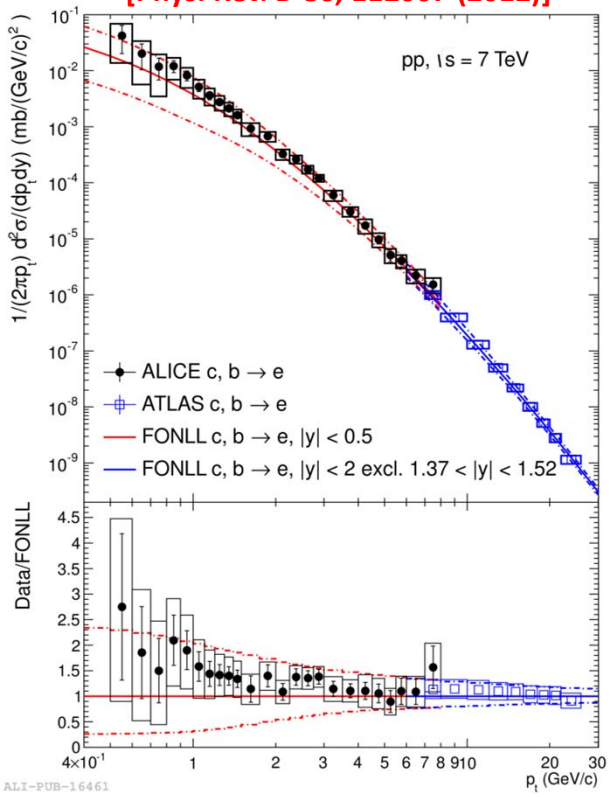
- Electrons from heavy flavours = inclusive electrons - cocktail (based on measured π^0 + m_T scaling)
- Combined 2 PID analysis: TPC-TOF-TRD & TPC-EMCAL
- Good agreement with FONLL (c+b) over the full p_T range

Heavy Flavour Decay Electrons in pp (II)

[Phys. Rev. D 86, 112007 (2012)]



[Phys. Rev. D 86, 112007 (2012)]



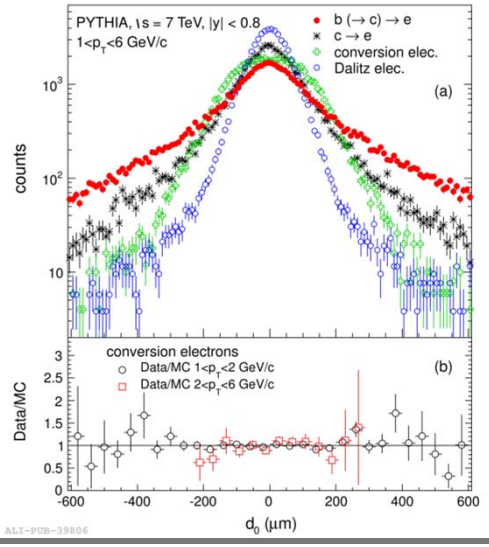
FONLL: Cacciari et al., JHEP 1210 (2012) 137

- Electrons from heavy flavours = inclusive electrons - cocktail (based on measured π^0 + m_T scaling)
- Combined 2 PID analysis: TPC-TOF-TRD & TPC-EMCAL
- Good agreement with FONLL (c+b) over the full p_T range
- Agree with each other in all p_T and complement ATLAS results at low p_T (PLB 707 (2012) 438)

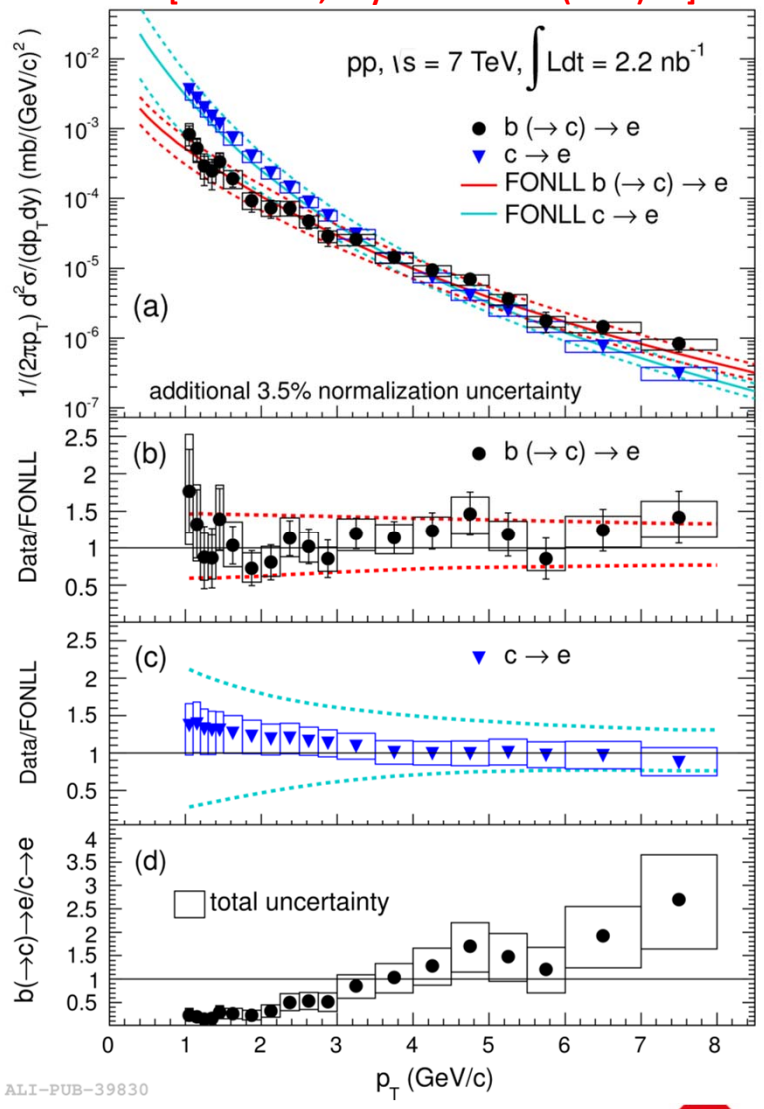
Beauty decay electrons in pp at $\sqrt{s}$ = 7 TeV

- Measurement of B → $e^{\pm}$, |y| < 0.5
  - B hadrons cτ ~ 500 μm
  - ✓ Impact parameter cut (d_0)

    e.g. $|d_0|$ > 250 μm for p_T ~ 2.5 GeV/c
  - Subtraction of remaining background electrons with a cocktail
- Total beauty cross section
- Evaluation of the c → $e^{\pm}$ cross section by subtraction from the inclusive heavy-flavour electrons
- Both charm and beauty differential cross section are in agreement with FONLL pQCD predictions



[ALICE Coll., Phys. Lett. B 721 (2013) 13]



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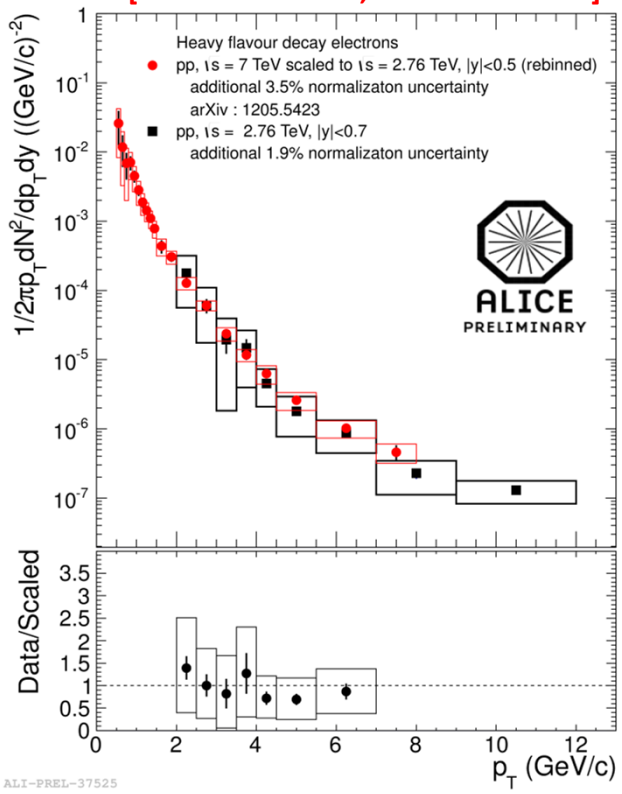
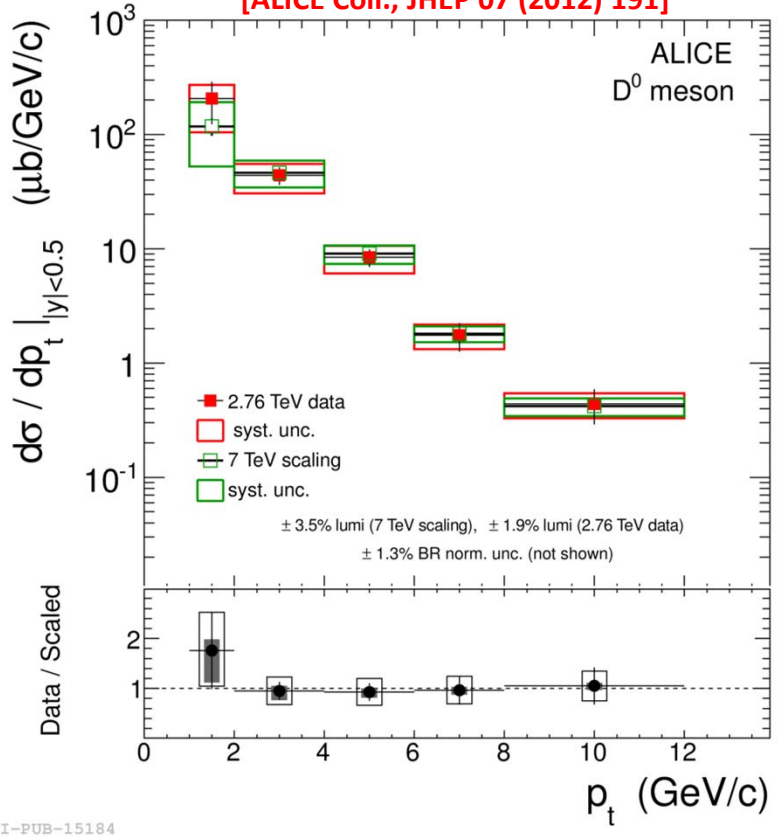
Reference for Pb-Pb Measurement

- ✓ **HF muons: pp data at 2.76 TeV**
- ✓ **HF electrons and D mesons: 7 TeV data scaled to 2.76 TeV**
- ✓ **Scaling: ratio of FONLL cross sections at the two energies**
- ✓ **HF electrons and D mesons data at 2.76 TeV are compatible with 7 TeV data scaled to 2.76 TeV**

[R. Averbeck et al, arXiv:1107.3243]



[ALICE Coll., JHEP 07 (2012) 191]



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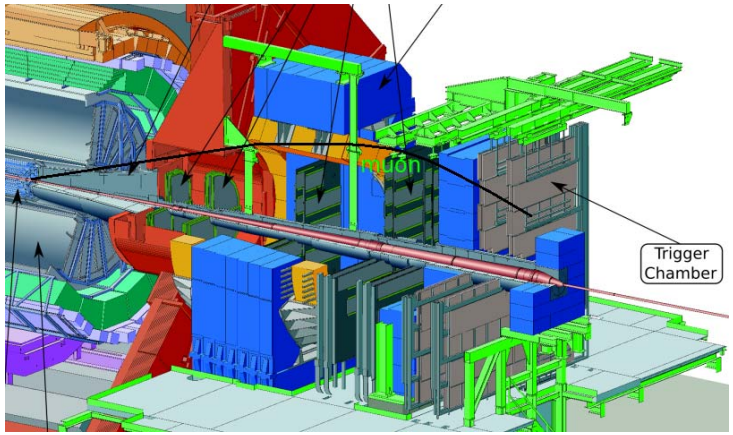
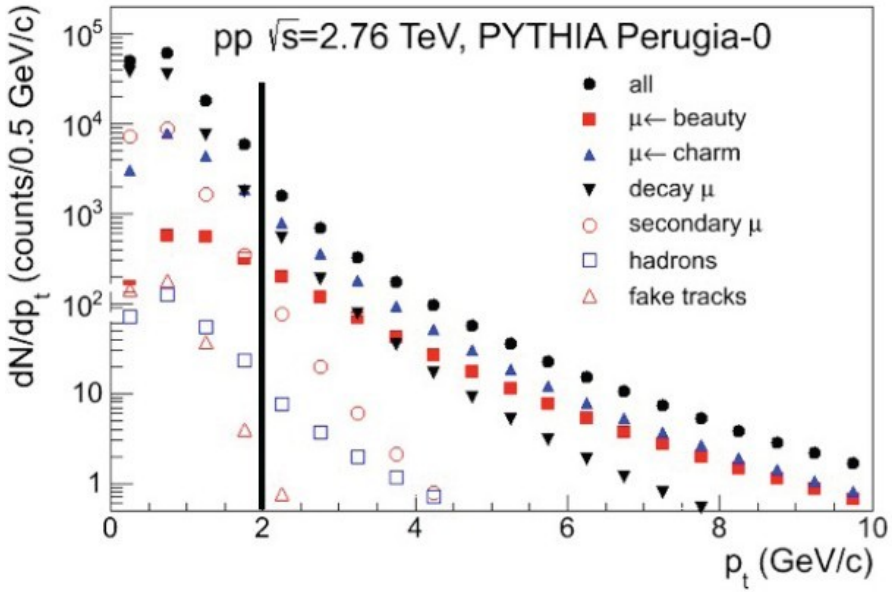
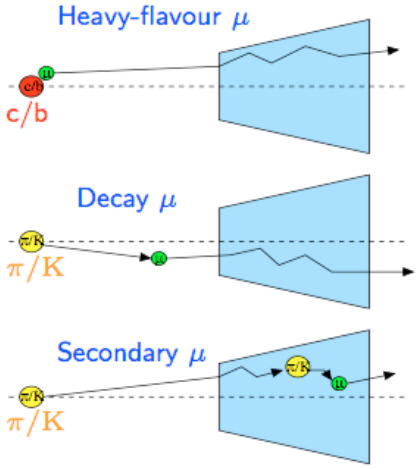
Heavy Flavour Decay Muons Measurements



- c/b → single muons
  - ✓ c/b → μ + X
  - ✓ b → c → μ + X
- Analysis strategy:
  - ✓ remove hadrons and low p_T secondary muons by requiring a muon trigger signal
  - ✓ subtract K/π-decay muons
  - ✓ what remain are charm and beauty muons
- K/π-decay muon subtraction:
  - ✓ use PYTHIA/PHOJET normalized to inclusive yield below 1 GeV/c

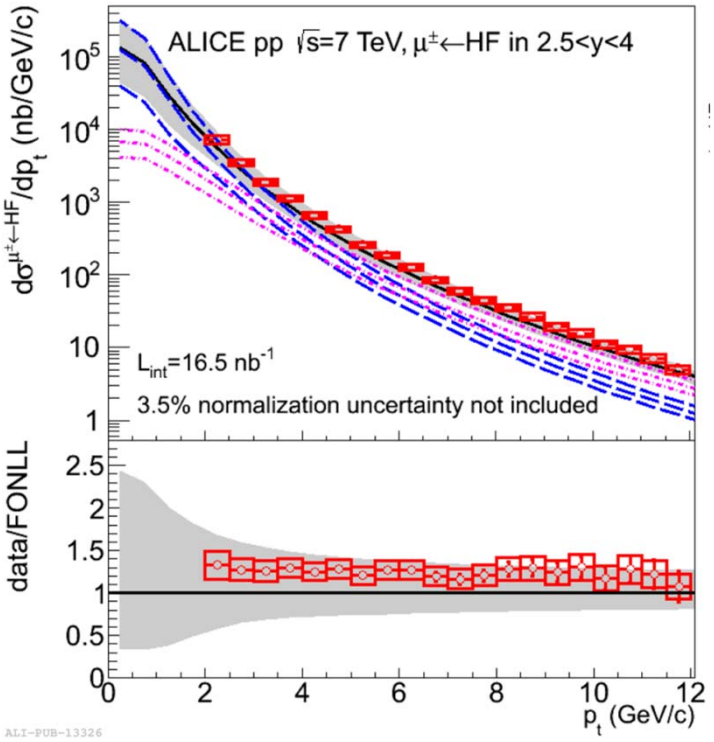




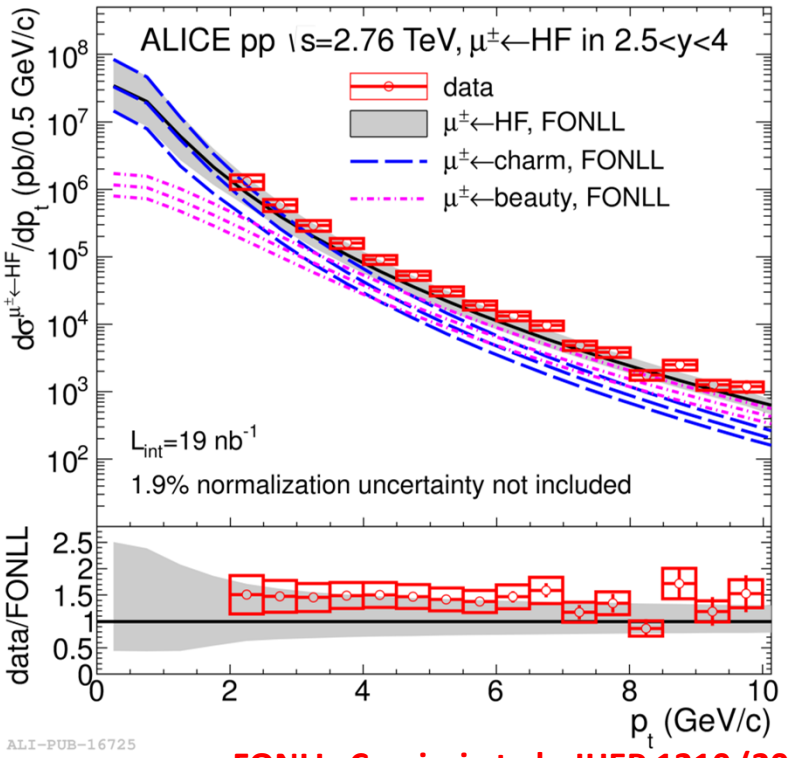
Muon sources

Heavy Flavour Decay Muons in pp

[Phys. Lett. B708 (2012) 265]



[Phys. Rev. Lett. 109 (2012) 112301]



FONLL: Cacciari et al., JHEP 1210 (2012) 137

- ✓ **High-statistics measurement at both energies (muon events)**
- ✓ **Data described by FONLL calculations within uncertainties (lie at the upper limit of FONLL calculations)**
- ✓ **FONLL predicts that muons from beauty decays dominate at $p_T \geq 6$ GeV/c**

Conclusions

- **Primary goal of the ALICE pp studies is to build a solid reference for Pb-Pb analyses and to test pQCD calculations. ALICE can complement the other LHC experiments accessing the low p_T region both for charm and beauty**

- **Good agreement with pQCD calculations for all channels (D(B) mesons, heavy-flavour decay electrons, heavy-flavour decay muons)**

- **D meson differential cross section measured down to 1 GeV/c and D meson ratios agree with results at different energies and in different collision systems**

- **D meson and J/ψ production vs charged event multiplicity studied**
  - ✓ **Agreement between open and hidden charm**
  - ✓ **May indicate that c-cbar production in pp collisions is connected with a strong hadronic activity or that multi-parton interactions also affect the hard momentum scales**

- **HF electrons and D mesons data at 2.76 TeV are compatible with 7 TeV data scaled to 2.76 TeV**