Heavy-flavour results in pp collisions at LHC with ALICE

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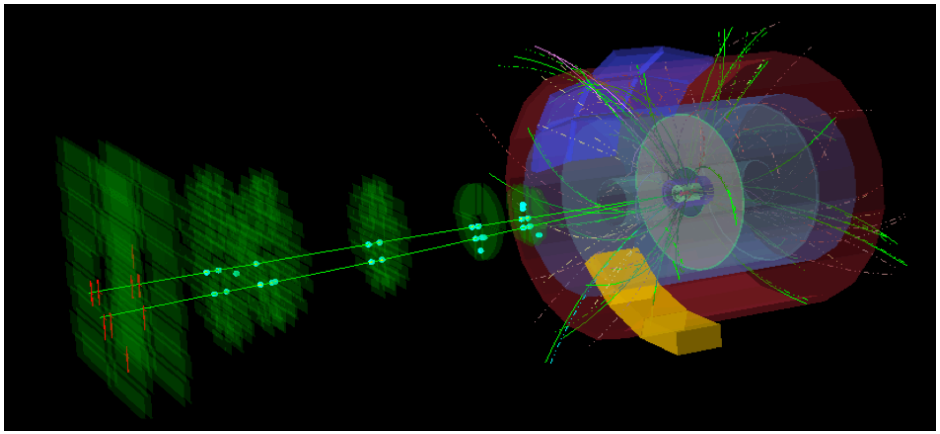
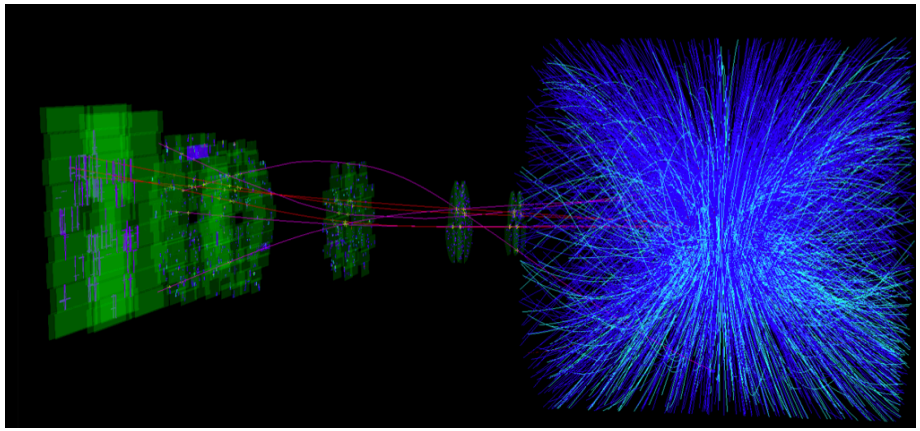
for the ALICE Collaboration

Outline

- ALICE detector highlights for heavy flavour physics
- Physics motivations
- **c → hadrons**: D mesons exclusive decays: D^0, D^+, D_s^+, D^{*+}
- **c,b → electrons**
- **c,b → muons**
- Conclusions

Note: for J/ψ see L. Bianchi talk

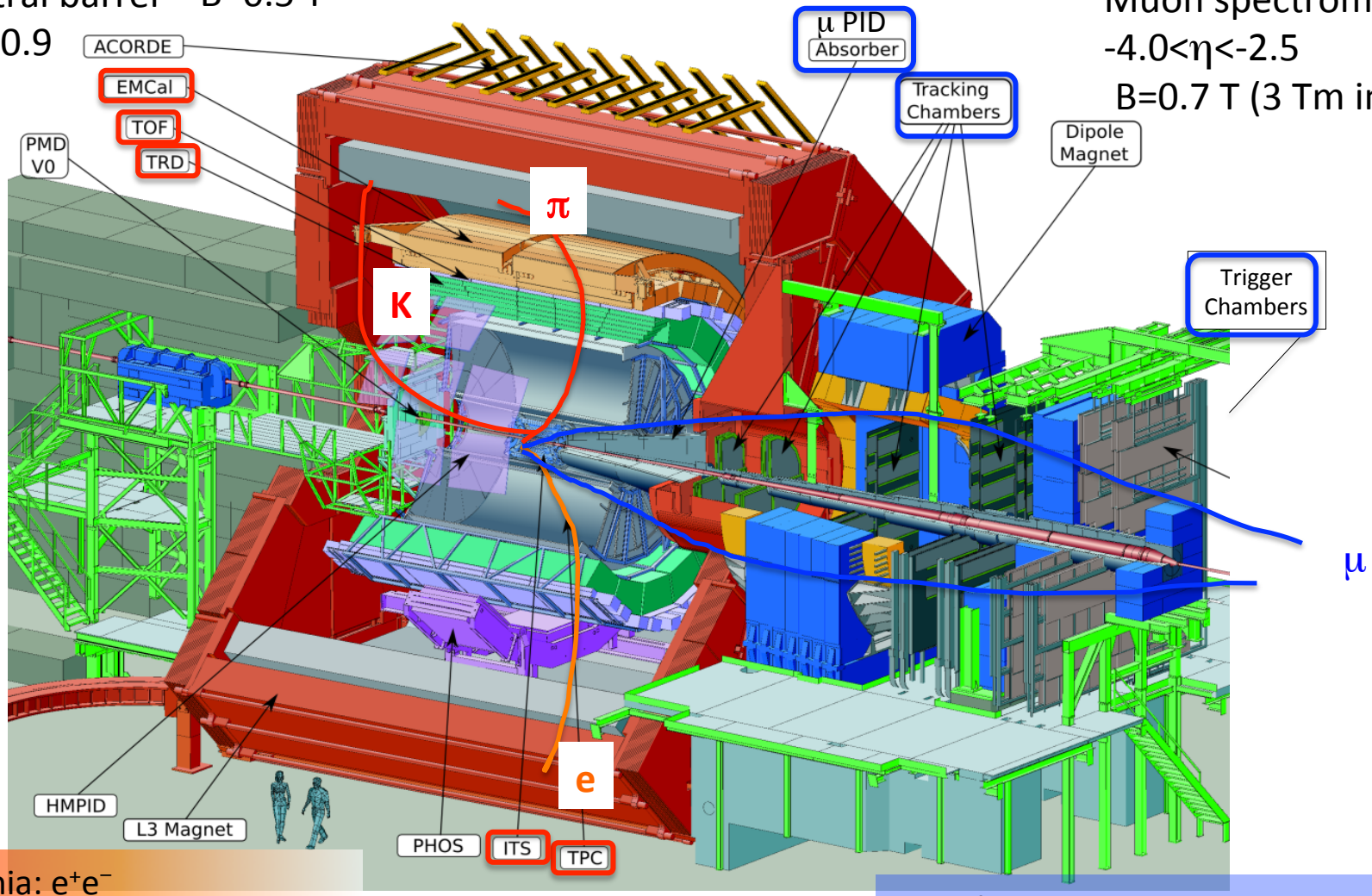




The ALICE detector: some highlights for this talk

Central barrel B=0.5 T
$|\eta|<0.9$

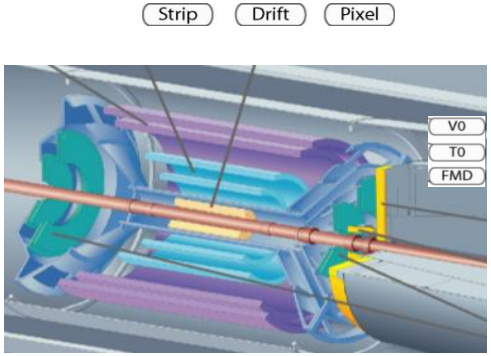
Muon spectrometer:
$-4.0<\eta<-2.5$
B=0.7 T (3 Tm integral)



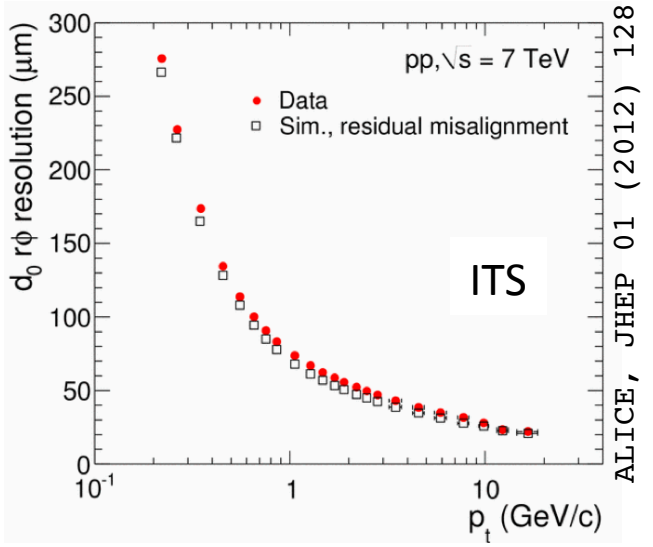
Quarkonia: e^+e^-
Open heavy flavour:
- hadronic decays
- semi-leptonic decays (e)

Quarkonia: $\mu^+\mu^-$
Open heavy flavour:
semi-leptonic decays (μ)

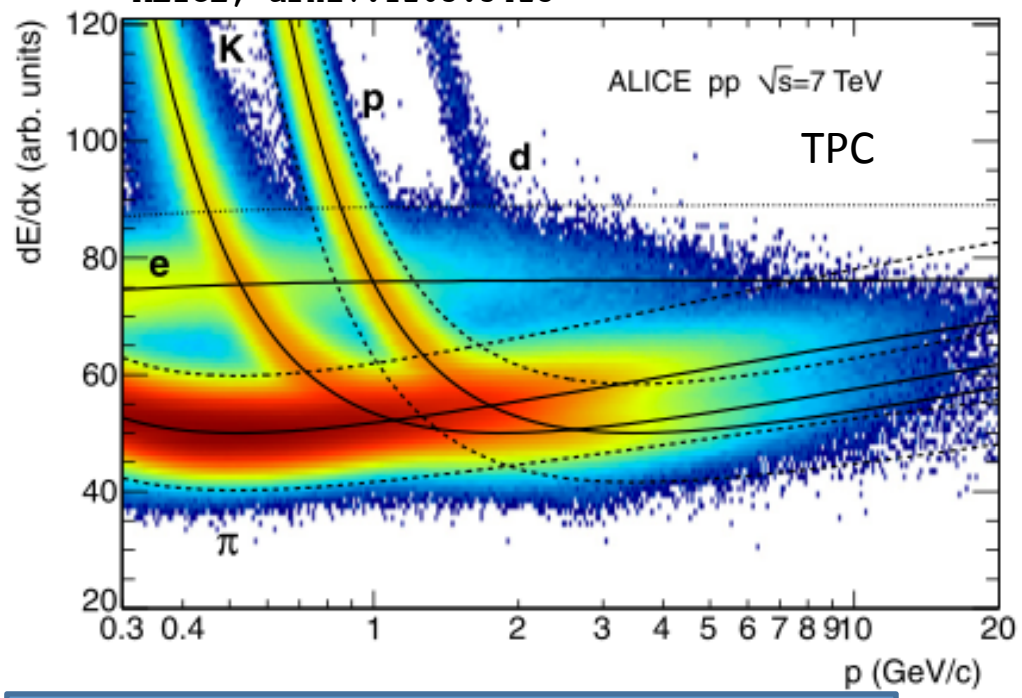
The ALICE detector: some highlights for this talk



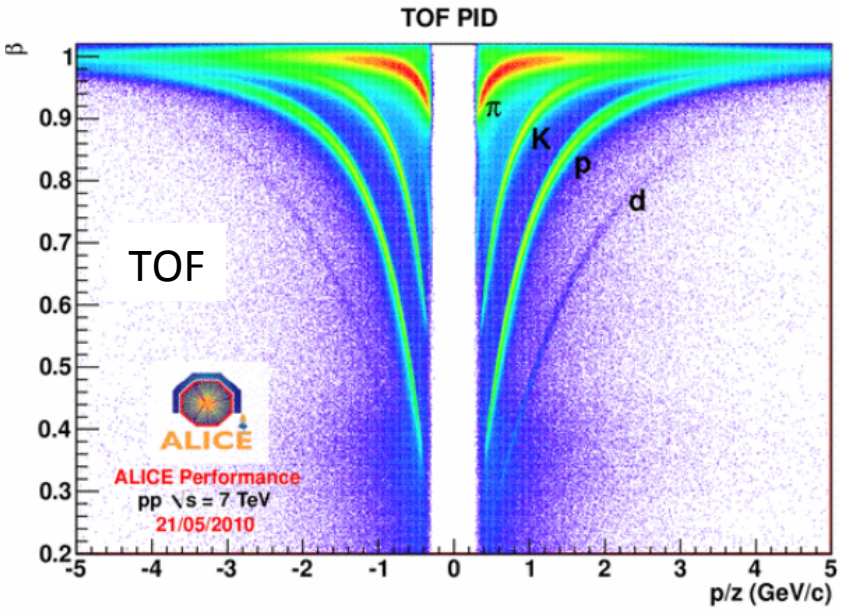
moderate B (0.5 T) + thin material (7.7% X_0 at perpendicular incidence in ITS)
→ **low p_T reach** (80 MeV/c for pions)
three double layers of different silicon technologies
→ **vertex** resolution <100 μm also at low multiplicity



ALICE, arXiv:1205.5423



Extended PID capabilities in the barrel

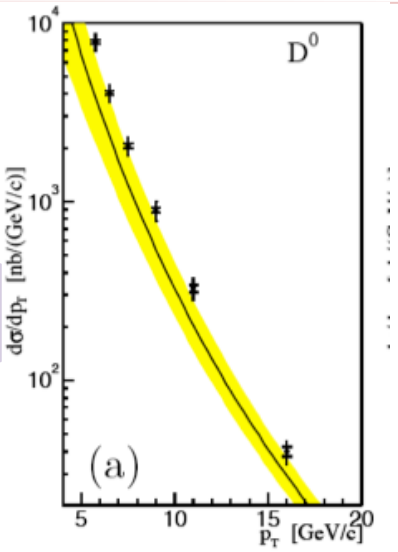


see C. Zampolli talk at this conference about PID in ALICE

Heavy-flavour in pp collisions @ ALICE

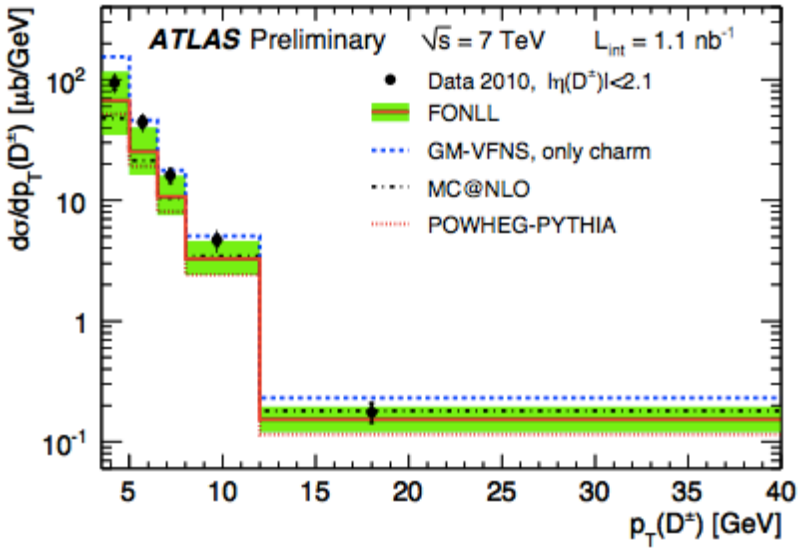
- test pQCD NLO in a new (and increasing) energy regime
- pQCD generally more predictive for beauty than for charm
- ALICE can complement CMS/ATLAS/LHCb data at low p_t
- low p_t allows to explore PDF at low x
- (and... an essential baseline reference for PbPb)

see Y. Pachmayer talk at this conference

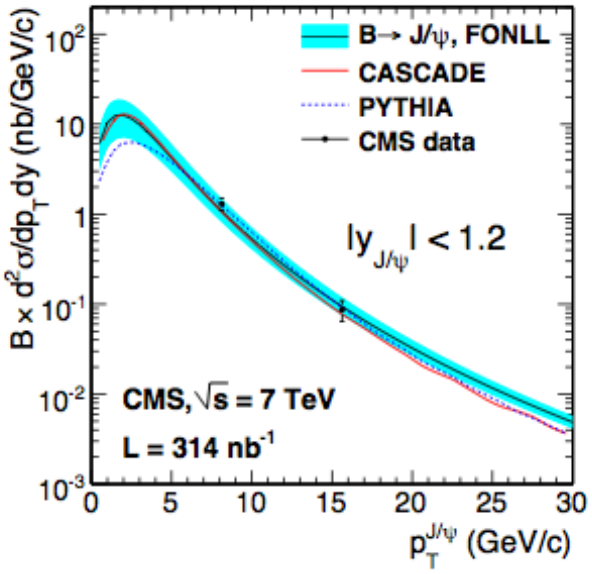


CDF, PRL91 (2003) 241804

ATLAS-PHYS-PUB-2011-102(2011)



CMS, arXiv:1011.4193



See also LHCb D mesons down to p_t=0 at 2<y<4.5

LHCb-CONF-2010-013(2010)

Data compared with Fixed Order Next to Leading Log and Global Mass Variable Flavour Number Scheme computations

(FONLL) M. Cacciari, M. Greco and P. Nason, JHEP 9805 (1998) 7

(GM-VFNS) B. A. Kniehl et al, Eur. Phys. J C41 (2005) 199

Exclusive hadronic decay channels: detection strategy

$D^0 \rightarrow K^- \pi^+$	(B.R. 3.87±0.85%)
$D^+ \rightarrow K^- \pi^+ \pi^+$	(B.R. 9.13±0.19%)
$D^{*+} \rightarrow D^0 \pi^+$	(B.R. 67.7±0.85%)
$D_s^+ \rightarrow \phi\pi^+$	(B.R. 2.32±0.14%)

Identification of secondary vertex (D^0 $c\tau \approx 123$ μm, D^+ $c\tau \approx 312$ μm)

↓

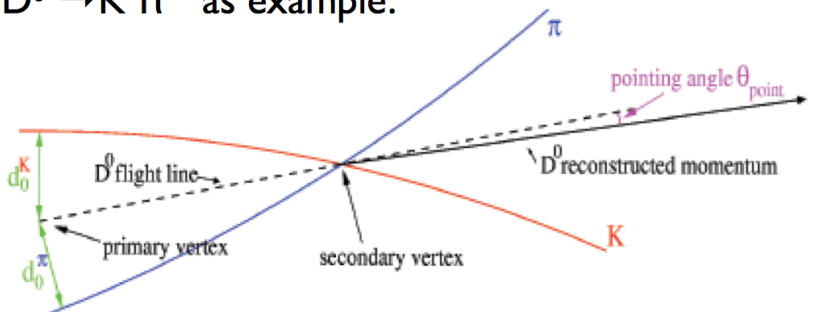
Combinatorial background reduced via secondary vertex and PID

↓

Invariant mass analysis

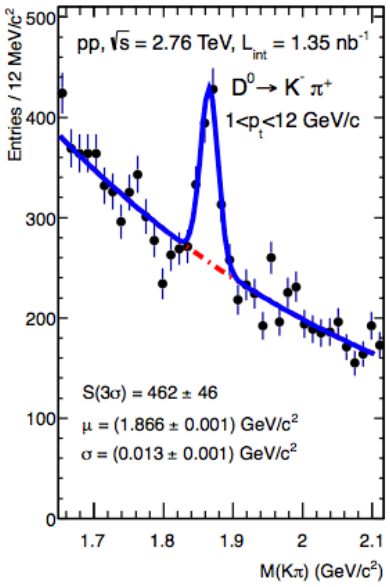
Minimum bias trigger:
1 hit on SPD or two rings of the VO forward scintillator detectors
→ covers 87% of inelastic cross section

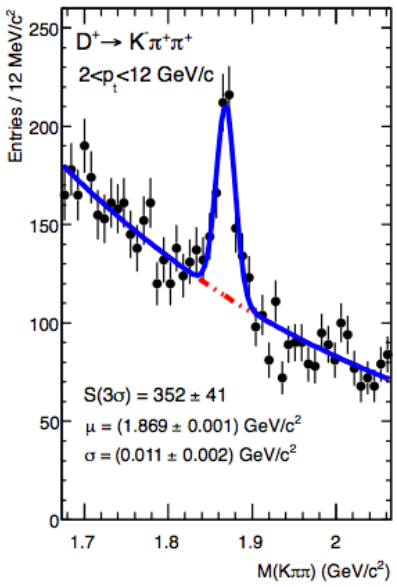
$D^0 \rightarrow K^-\pi^+$ as example.

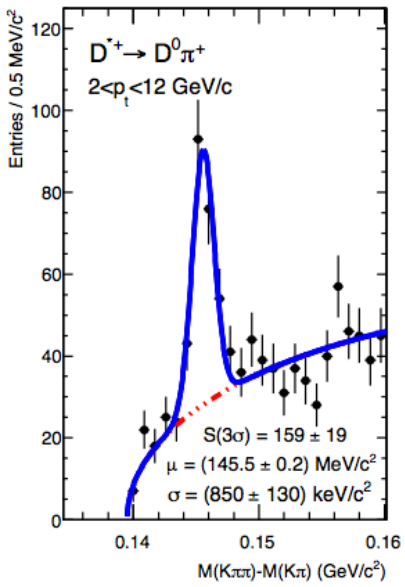


Mass spectra examples at √s=2.76 TeV

ALICE, arXiv:1205.4007

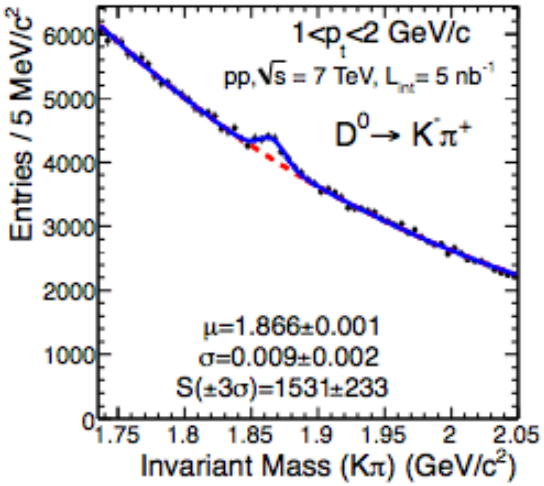




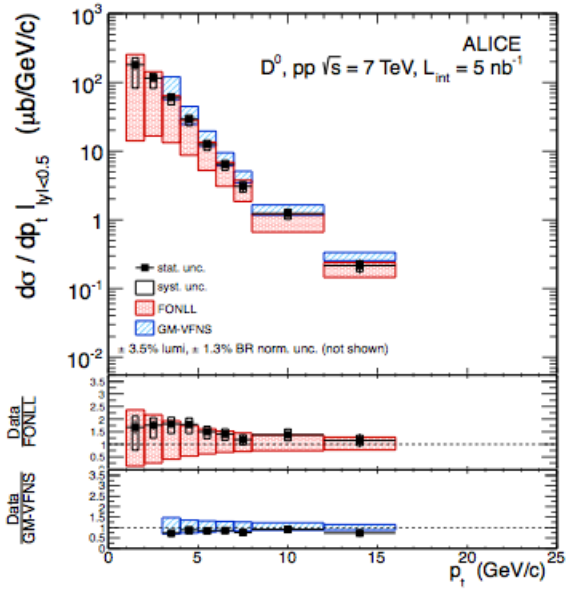


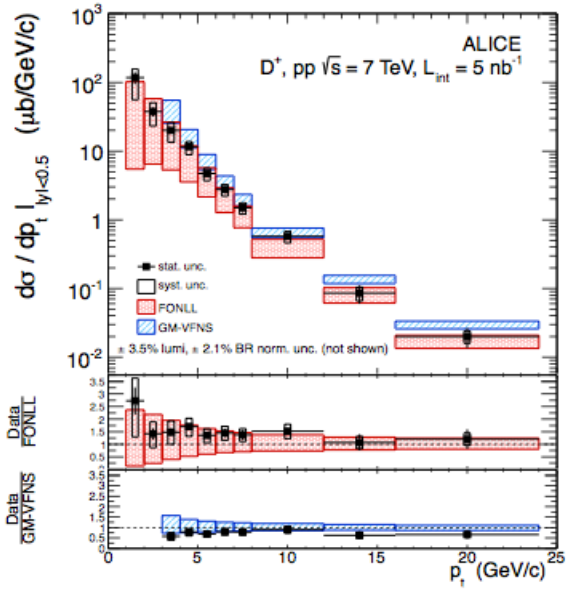
...down to low momentum!

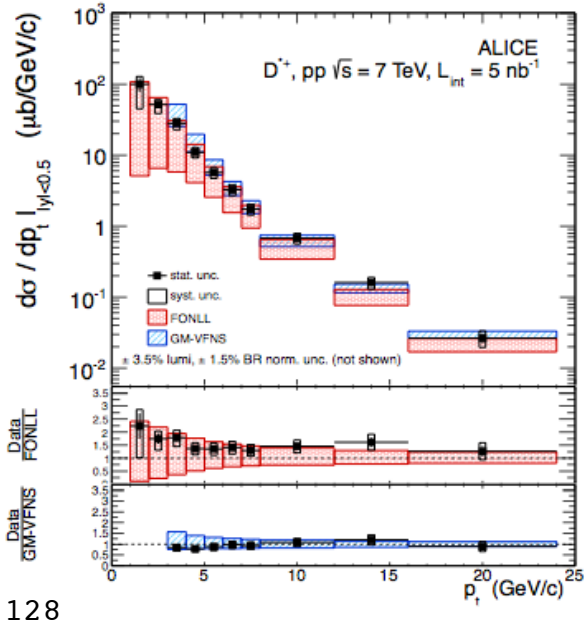
ALICE, JHEP 01 (2012) 128



D meson spectra: results at 7 TeV

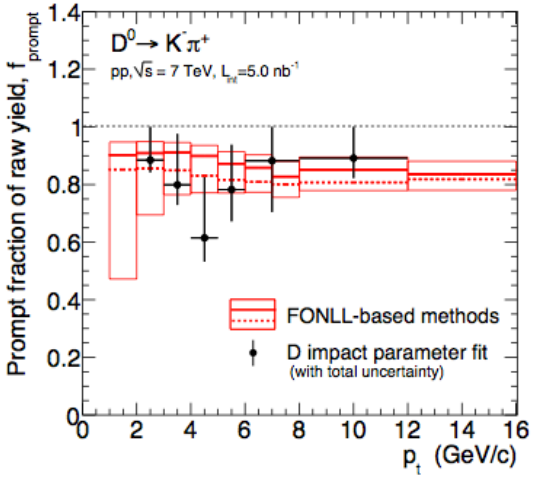


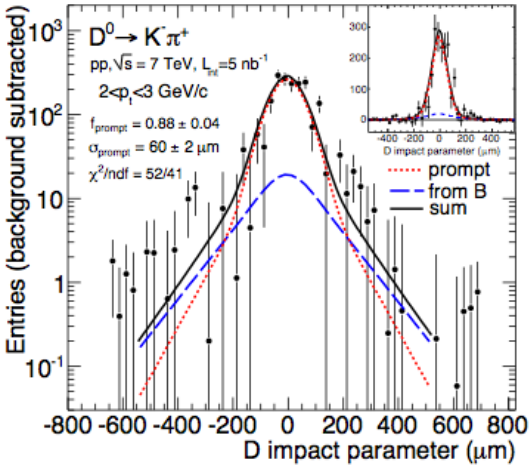




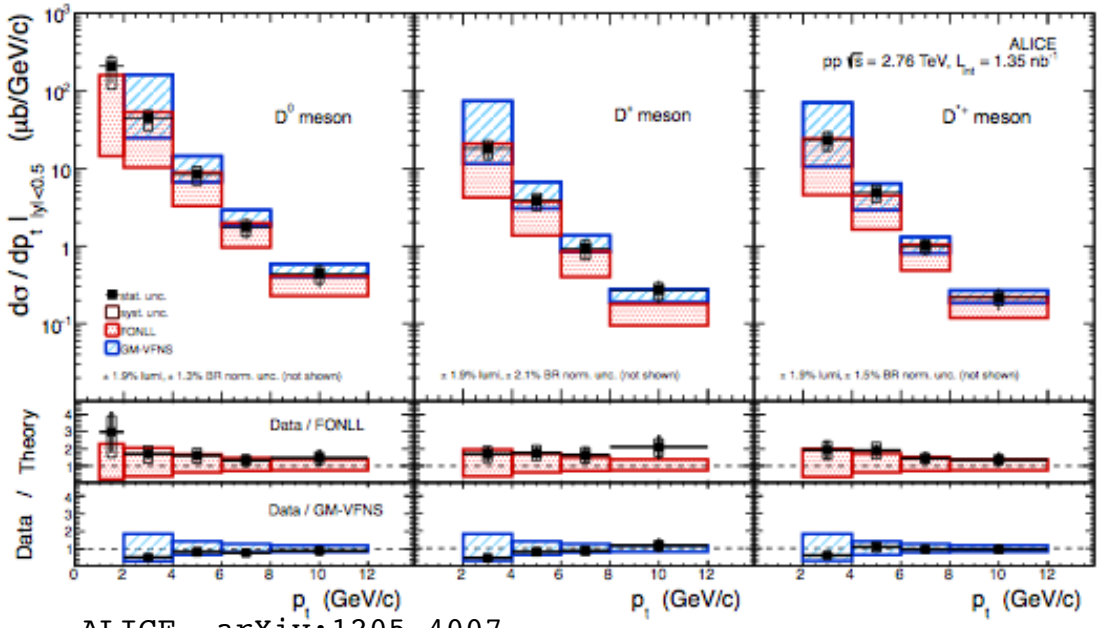
ALICE, JHEP 01 (2012) 128

- ✓ B-feed down evaluated via FONLL and checked with data (impact parameter fit)
- ✓ Both GM-VFNS and FONLL in agreement with data within uncertainties
- ✓ GM-VFNS central values lie systematically above data, FONLL below
- ✓ With reach down to 1 GeV/c → gluon distribution function probed down to x ≈ 10^{-4} (PDF CTEQ6.6 used here)





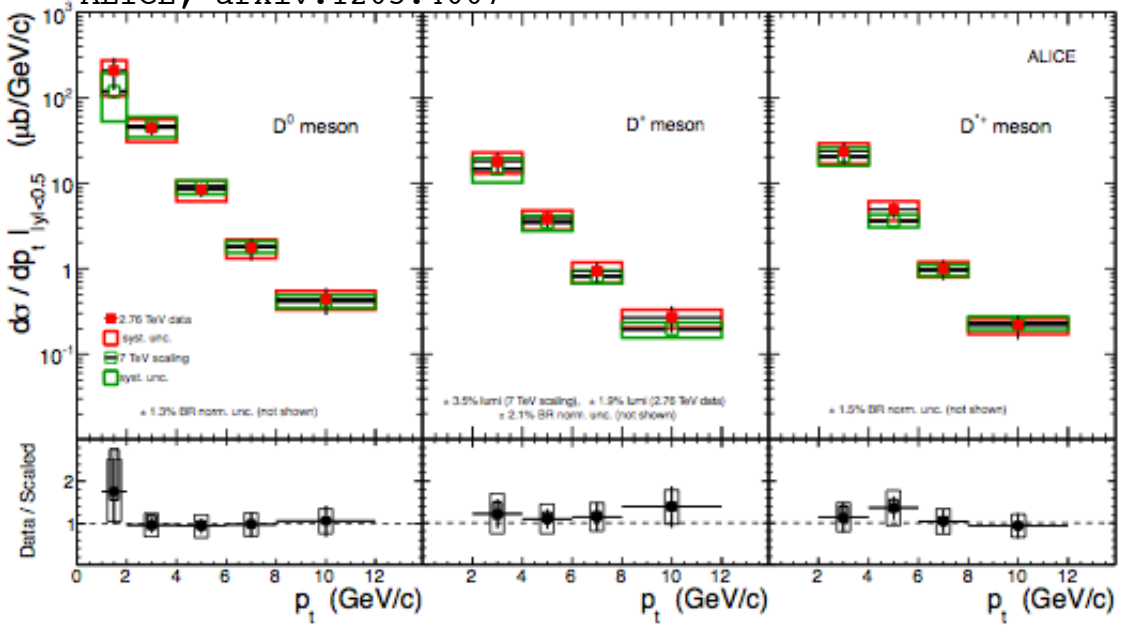
D meson spectra: results at 2.76 TeV



ALICE, arXiv:1205.4007

consistent pattern observed at √s=2.76 (with 27% of int. luminosity at √s=7 TeV)

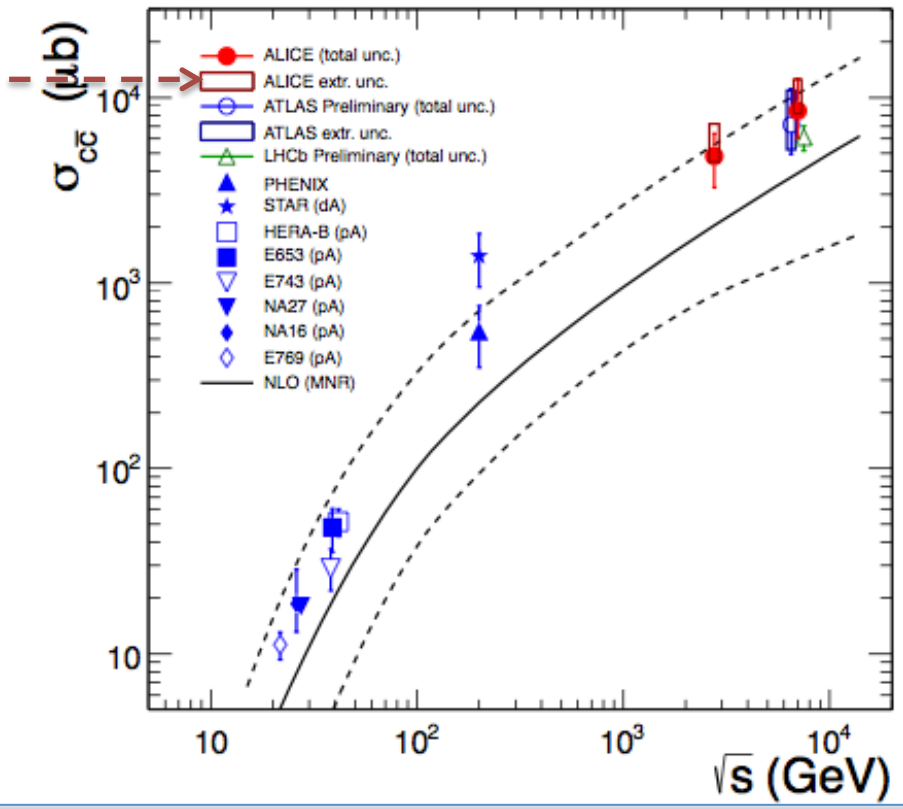
ALICE interest to have reference for PbPb collision



- ✓ comparison with scaling measurement at √s=7 TeV
- ✓ scaling factor (7 → 2.76 TeV) using theor. predictions from FONLL
- ✓ systematic uncertainties in the scaling factor varying perturbative scales μ_F, μ_R and m_c

Total charm cross section

uncertainty due to extrapolation in the full phase-space



ALICE, arXiv:1205.4007
ATLAS, ATLAS-PHYS-PUB-2011-012 (2011)
LHCb, LHCb-CONF-2010-010 (2010)

- fair agreement among LHC experiments
- all points populate upper side of theoretical prediction

NLO MNR: Mangano, Nasone, Ridolfi
Nucl. Phys. B373 (1992) 295
PDF: CTEQ6.6

$0.5<\mu_F/m_c<2$, $0.5<\mu_R/m_c<2$
using constraint $0.5<\mu_F/\mu_R<2$ and $1.3<m_c<1.7$ GeV/c^2

$$\sigma_{c\bar{c}}^{tot}(2.76\ \text{TeV}) = 4.8 \pm 0.8\,(\text{stat.})\,^{+1.0}_{-1.3}\,(\text{syst.}) \pm 0.04\,(\text{BR}) \pm 0.1\,(\text{FF.}) \pm 0.1\,(\text{lum.})\,^{+2.4}_{-0.3}\,(\text{extr.})\ \text{mb},$$
$$\sigma_{c\bar{c}}^{tot}(7\ \text{TeV}) = 8.5 \pm 0.5\,(\text{stat.})\,^{+1.0}_{-2.4}\,(\text{syst.}) \pm 0.1\,(\text{BR}) \pm 0.2\,(\text{FF.}) \pm 0.2\,(\text{lum.})\,^{+4.0}_{-0.3}\,(\text{extr.})\ \text{mb}.$$

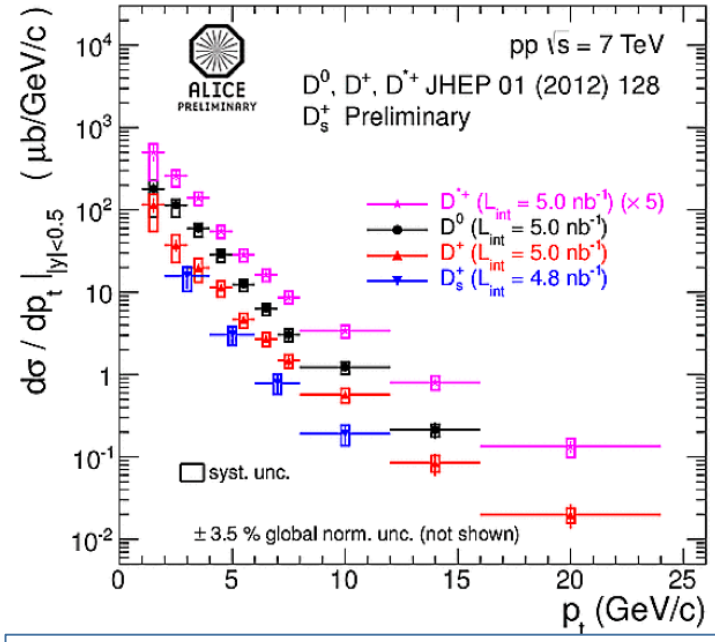
Note also ALICE result on bb at √s=7 TeV production (via J/ψ):

$$\sigma(pp \to b\bar{b} + X) = 244 \pm 64\,(\text{stat.})\,^{+50}_{-59}\,(\text{syst.})\,^{+7}_{-6}\,(\text{extr.})\ \mu\text{b}$$

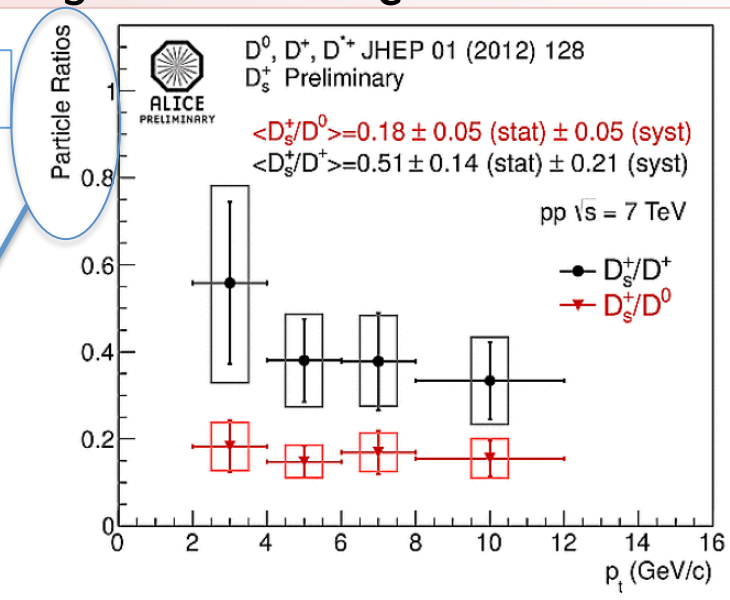
ALICE arXiv:1205.5880

for J/ψ see L. Bianchi talk

And more...: D_s^+ and Λ_c



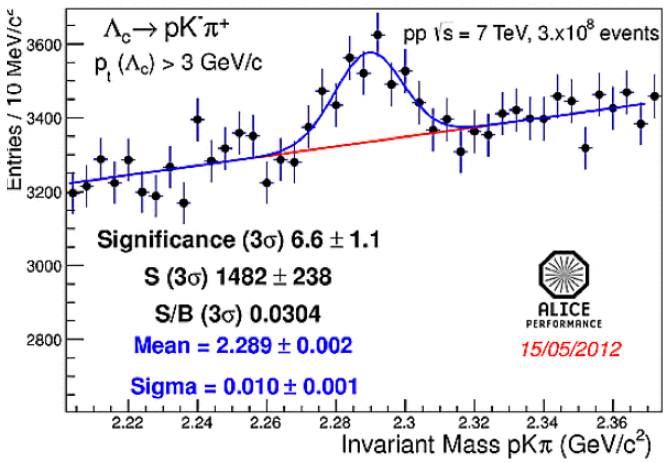
$D_s^+ \rightarrow \phi\pi^+$

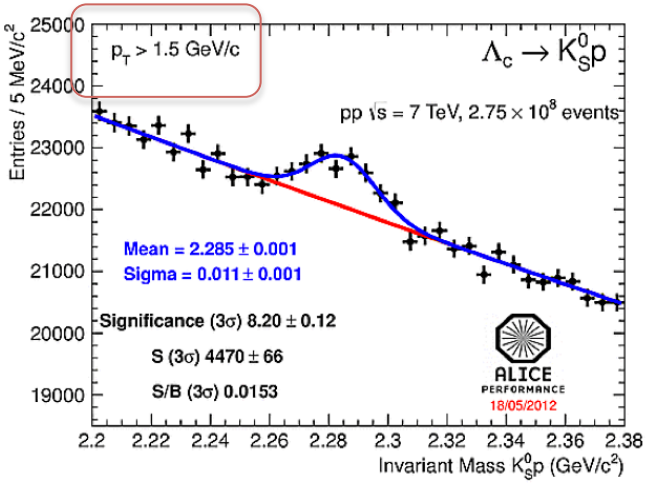


No significant p_T dependence within uncertainties suggests small differences in the shapes of c fragmentaton functions to strange and non strange mesons

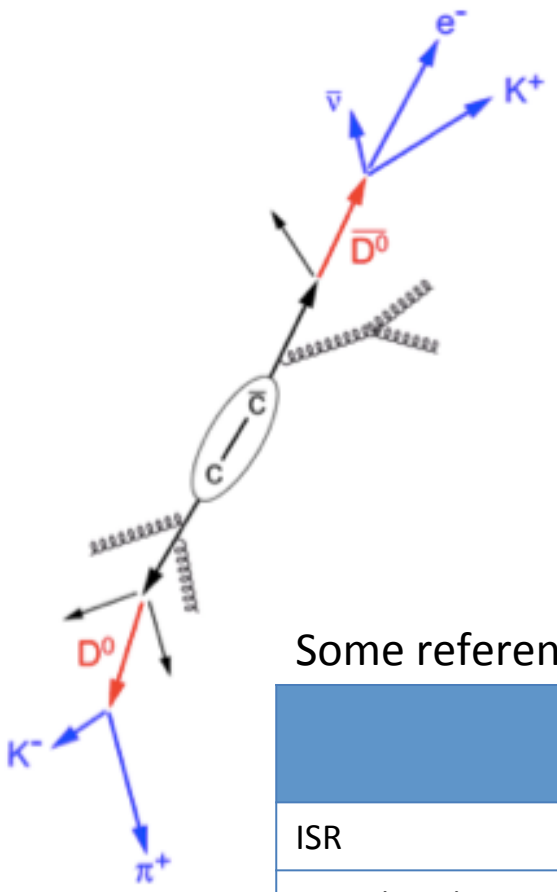
Λ_c in two decay channels:

- challenging, statistically limited
- Λ_c/D very interesting for PbPb program (possible enhancement due to recombination)
- PbPb requires detector upgrade





HF decays: contribution to the inclusive lepton spectra



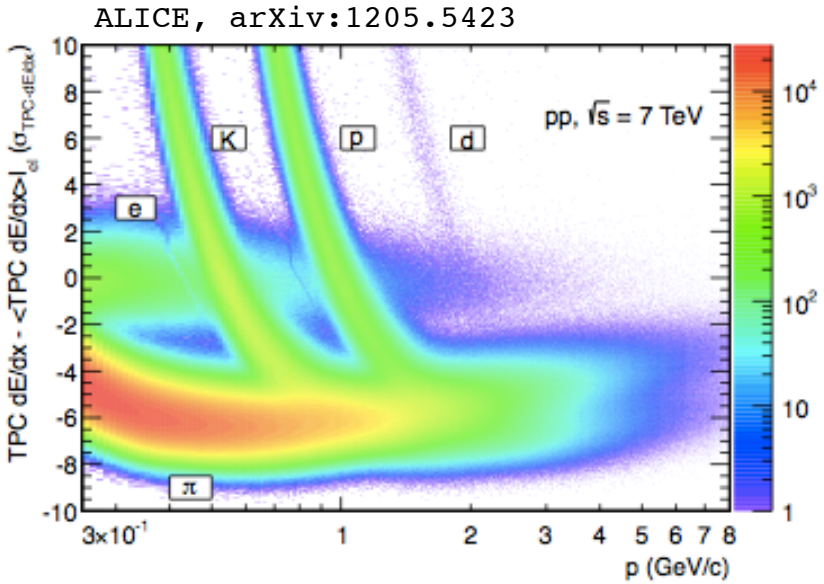
- both charm and beauty have B.R. ≈ 10% to single electrons or muons → a way to measure c and b production
- again a channel where it is possible to explore low p_t region for ALICE
- key reference for PbPb collisions

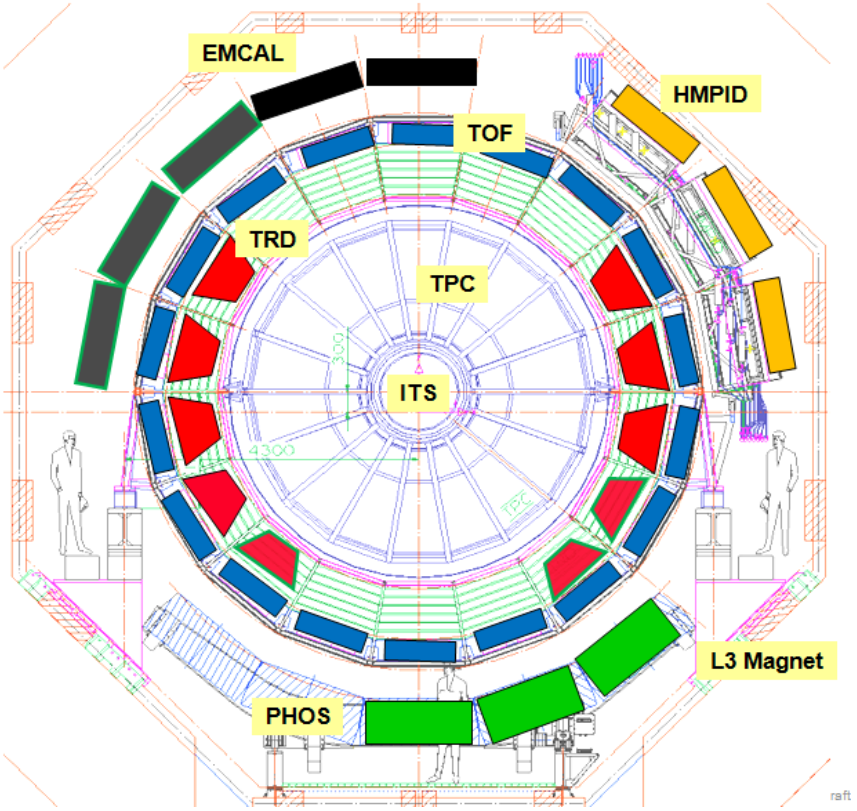
Some references for electron spectra and heavy flavours:

	√s (GeV/c)	p_t range (GeV/c)	
ISR	52.7	1.6-4.7	Phys. Lett. B53 (1974) 212
SppS (UA2)	630	0.5-2.	Phys. Lett. B236 (1990) 488
Tevatron CDF	1960	7-60	Phys. Rev. Lett. 71 (1993) 500
RHIC PHENIX	200	0.3-9	Phys. Rev. C84 (2011) 044905
RHIC STAR	200	3-10	Phys. Rev. D83 (2011) 052006
LHC ATLAS	7000	7-26	Phys. Lett. B707 (2012) 438

Heavy Flavour Electrons: detection strategy

Complement TPC track selection and dE/dx analysis to make e-ID



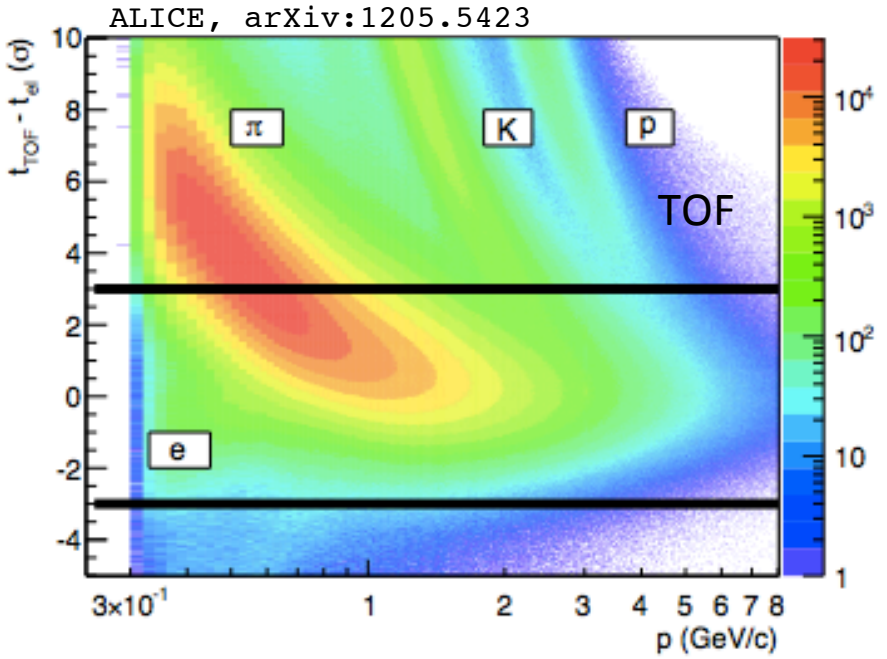


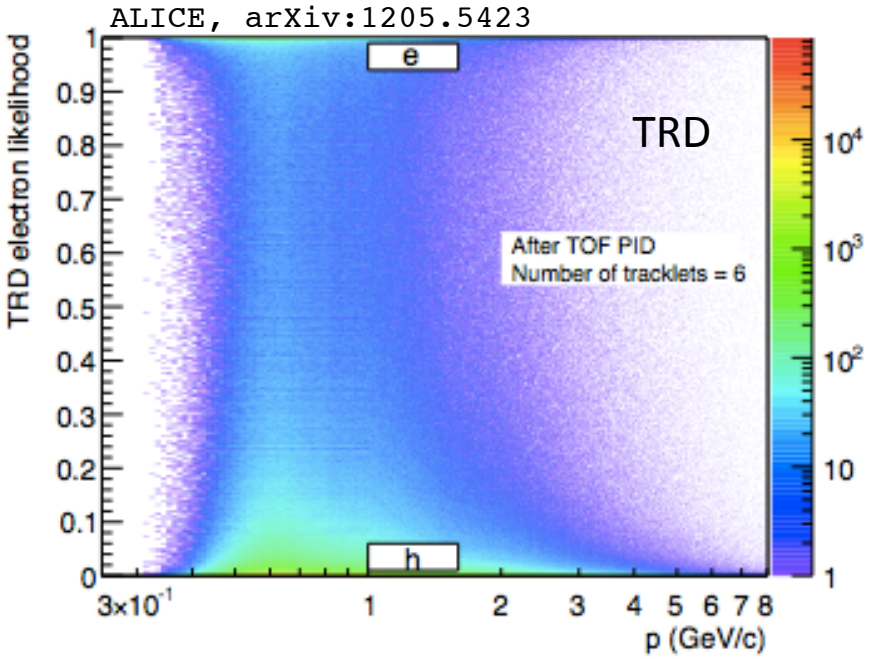
use TPC-TOF(< 4 GeV/c) and TPC-TRD-TOF (> 4 GeV/c)

use TPC+EMCAL

7 TRD modules in 2010 (11 in 2011)
2 EMCAL modules in 2010 (5 in 2011)

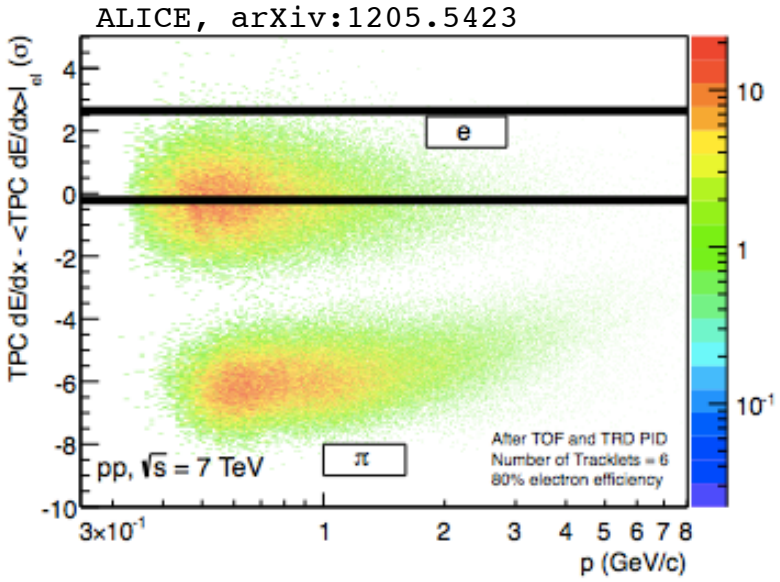
TPC-TRD-TOF analysis





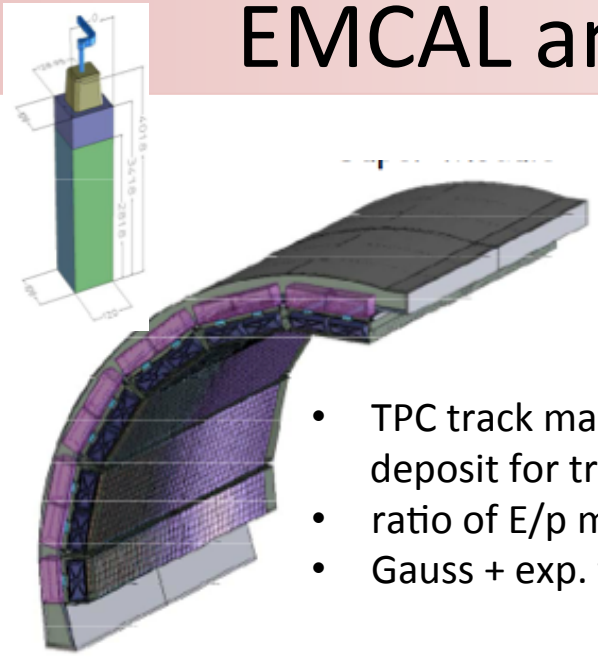
After applying TPC cut:

- ✓ TOF 3σ cut allows pure selection up to p = 4 GeV/c
- ✓ above 4 GeV/c applied TRD cut momentum dependent on electron likelihood (efficiency kept at 80%)



remaining hadron contamination less than 2%

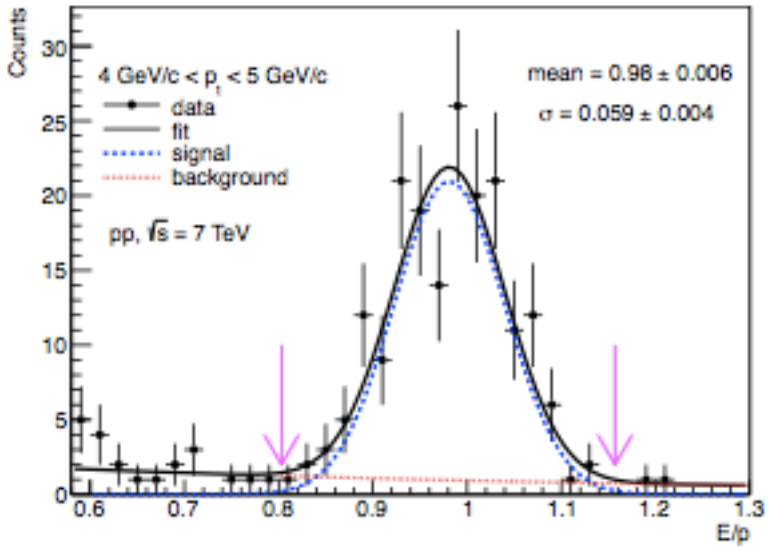
EMCAL analysis and inclusive spectra



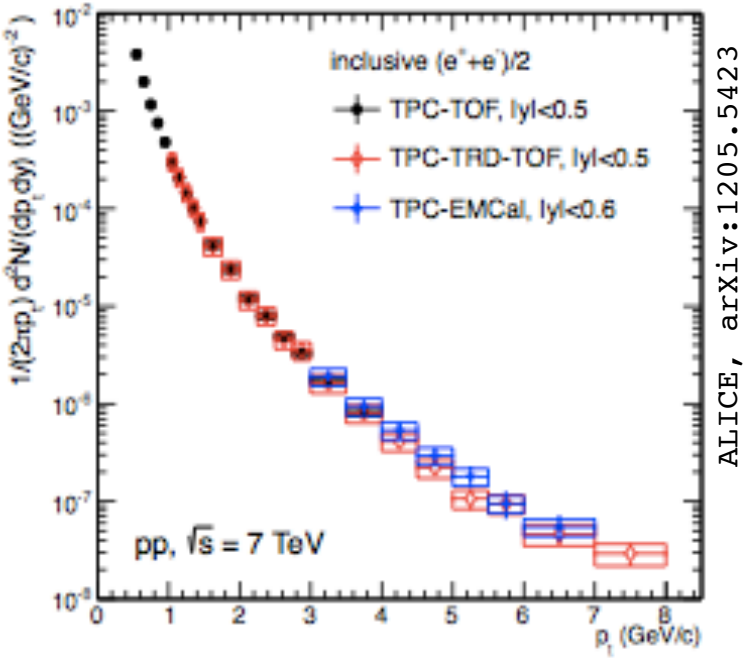
Pb scintillator sampling calorimeter

- TPC track matched with EMCAL energy deposit for tracks with p_t>3 GeV/c
- ratio of E/p measured for these tracks
- Gauss + exp. function fit

ALICE, arXiv:1205.5423

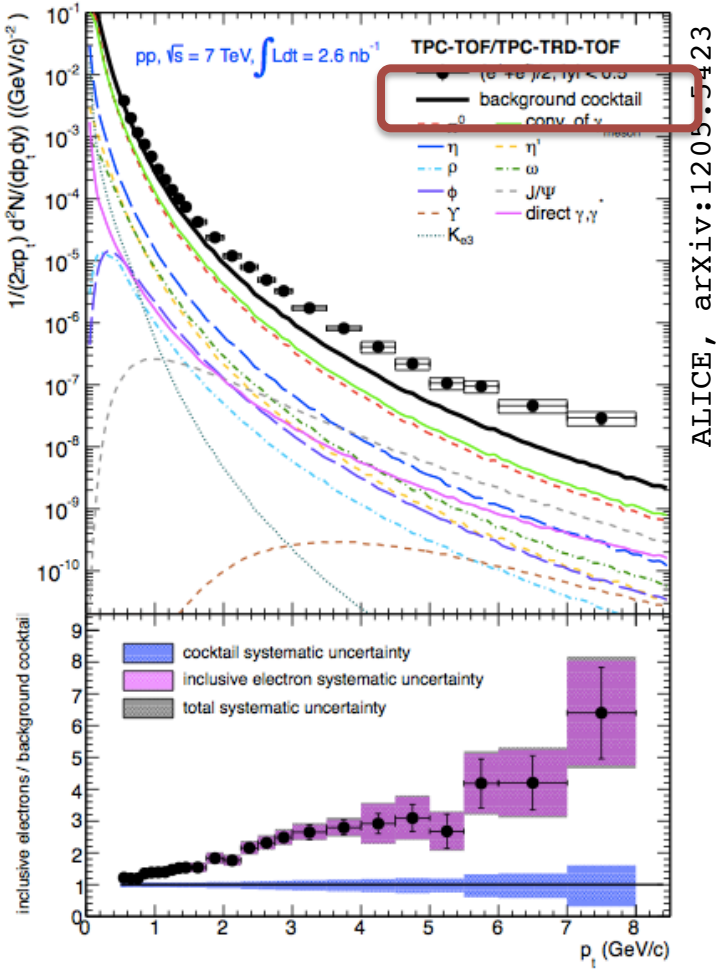


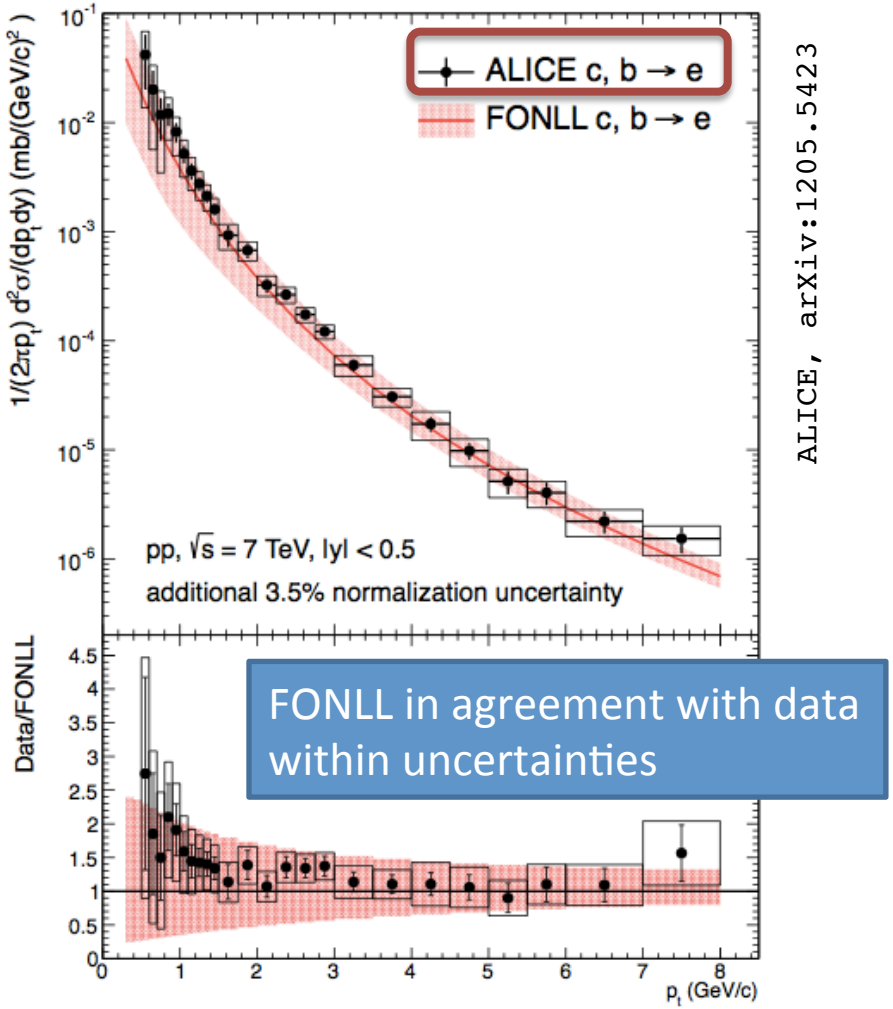
- hadron contamination subtracted statistically
- TPC+TOF and TPC+TRD+TOF analyses agree at 1-4 GeV/c
- note TPC+EMCAL is larger due to different material budget ➔ more photon conversion
- systematic uncertainties studied varying selection cuts (TPC+TOF 8.5%, TPC/TRD/TOF 25%, TPC/EMCAL 20%)



ALICE, arXiv:1205.5423

Background cocktail and electron spectrum





FONLL in agreement with data within uncertainties

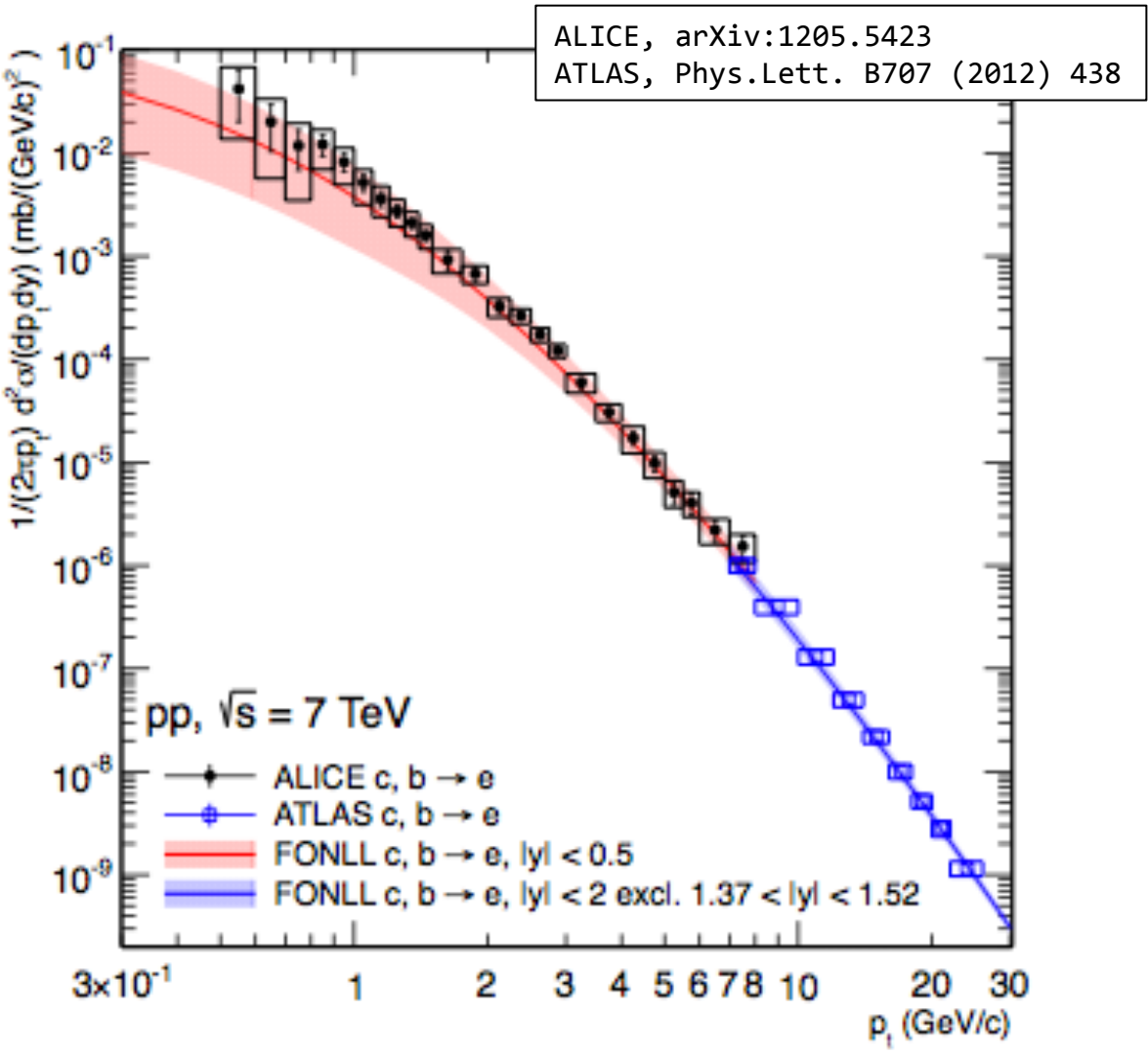
1) Dalitz decays of light neutral mesons + γ conversion → from ALICE data + m_t scaling
2) K→ eπν → negligible due to selection cuts
3) dielectron decays of quarkonia (J/Ψ, Υ) → from ALICE and CMS data
4) e from partonic hard scattering (incl. prompt γ) → NLO pQCD (PDF: CTEQ6M FF: GRV)

Heavy flavour electrons

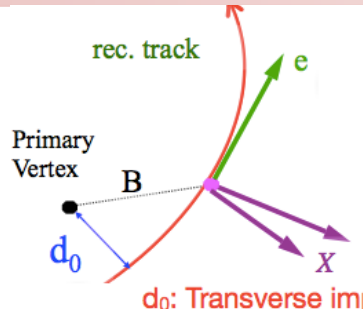
FONLL sys. unc. estimated varying parameters as per ccbar cross-section (plus $4.5<m_b<5.0$ GeV/c^2)

Within uncertainties FONLL agree with data, note how theor. uncertainties grow at low p_t

nice complementarity: ALICE takes most of the total σ, ATLAS extends up to 26 GeV/c!

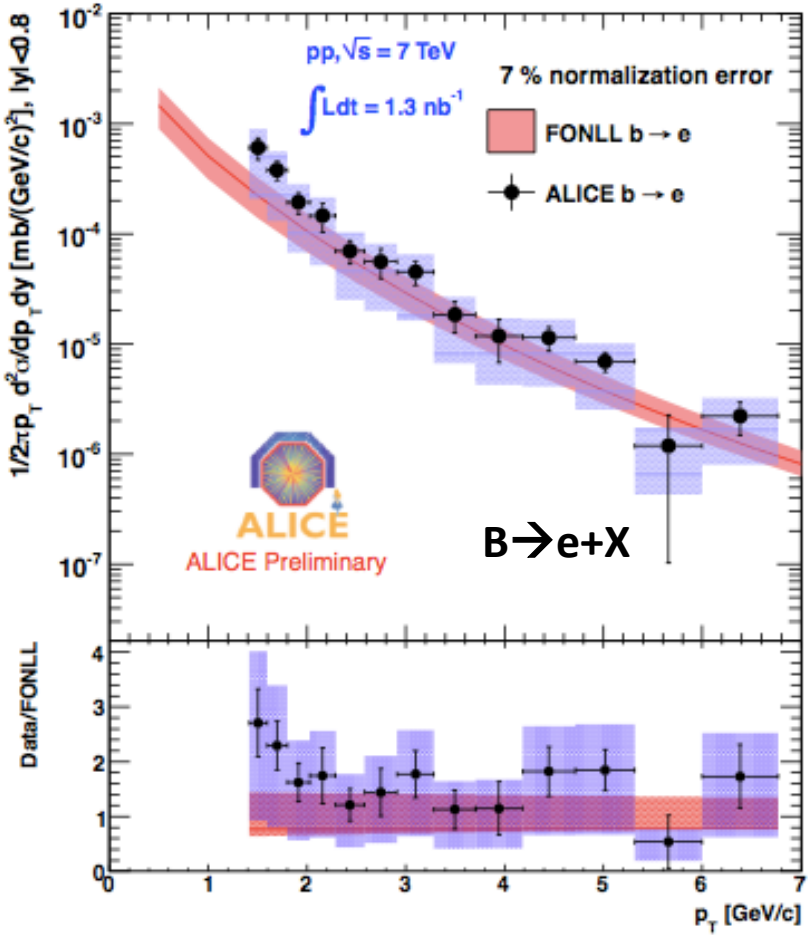


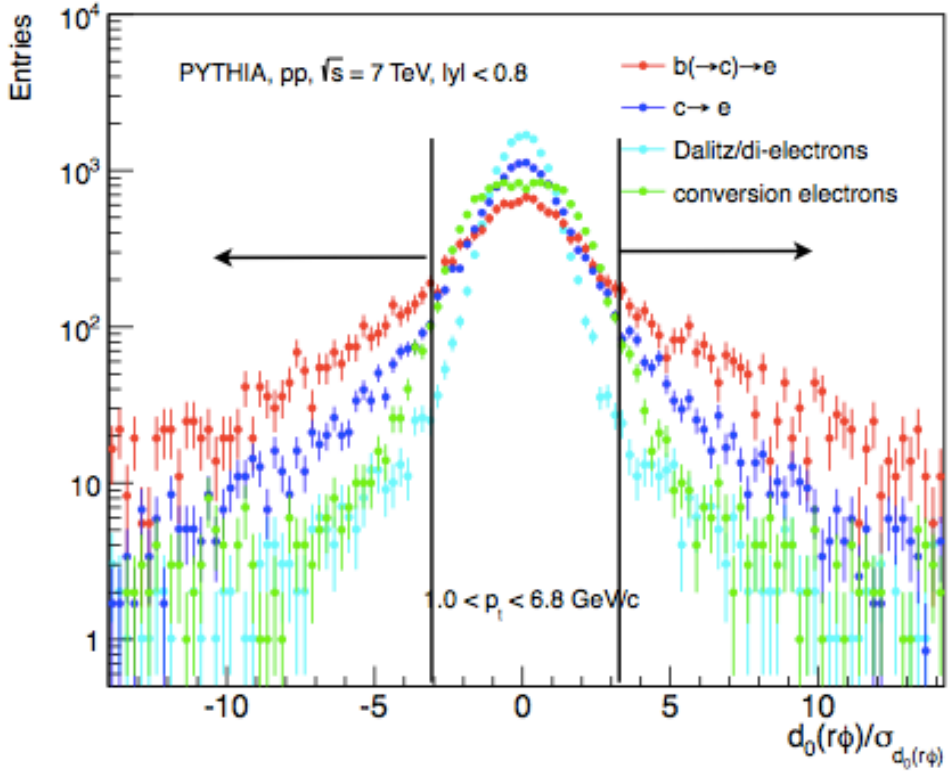
Identify the b contribution: impact parameter



d_0: Transverse impact parameter

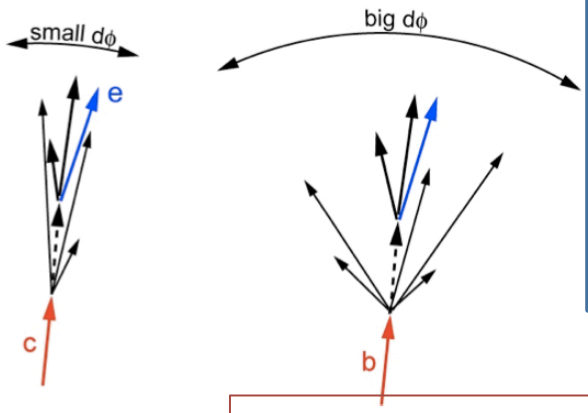
Impact parameter analysis to extract $\sigma(B \rightarrow e+X)$ exploiting $(c\tau)_B \approx 500\ \mu m$





analysis in progress:
→better understanding of MC vs data of the impact parameter distribution
→reducing syst.uncertainty at low p_t

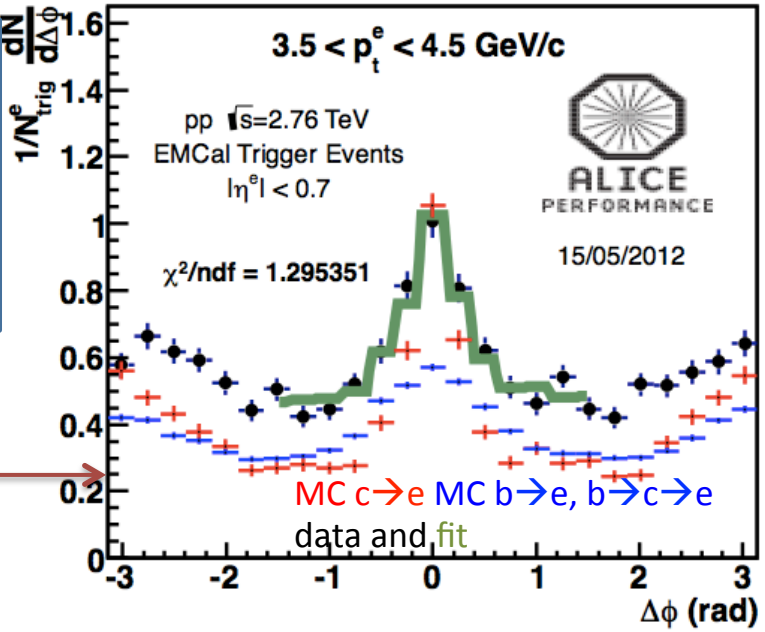
Identify the b contribution: e-h azimuthal correlations

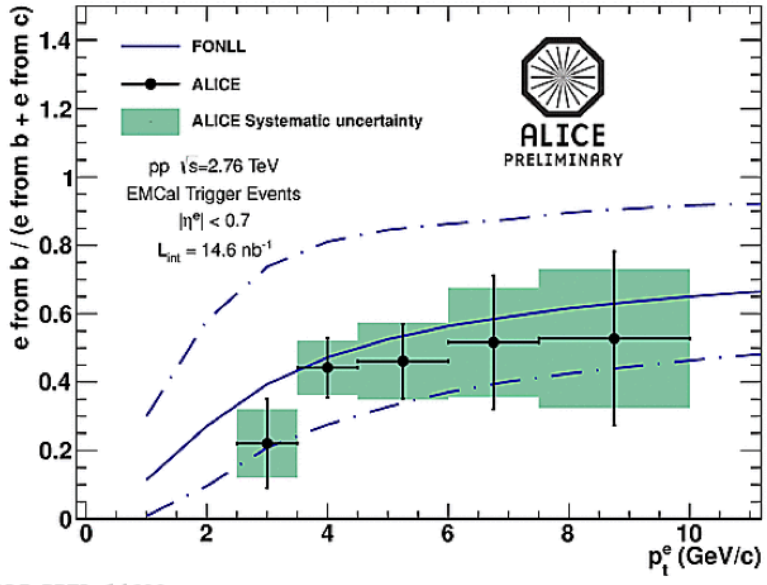


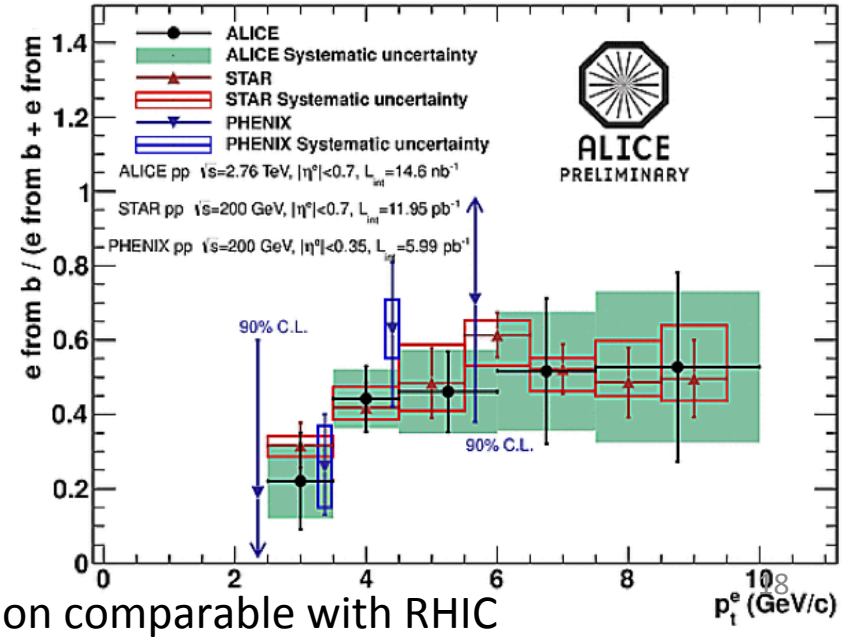
HF-decay electron / hadron correlation show broader distribution for beauty due to its larger mass

Δφ fit with MC (PYTHIA+GEANT) template to extract b contribution

$$\Delta\phi_{e-h}^{HF} = const + r_B \Delta\phi_{e-h}^{B} + (1 - r_B)\Delta\phi_{e-h}^{D},$$



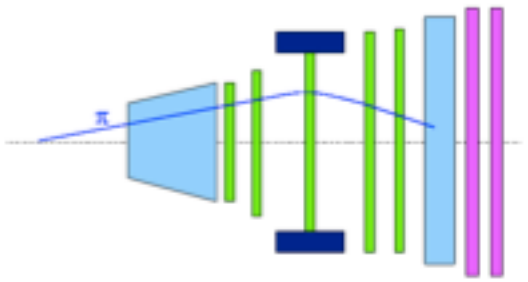




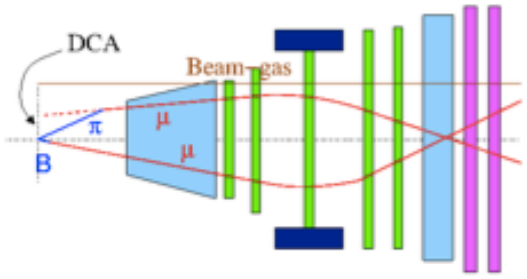
b-fraction comparable with RHIC

Heavy flavour decay muons at forward rapidity

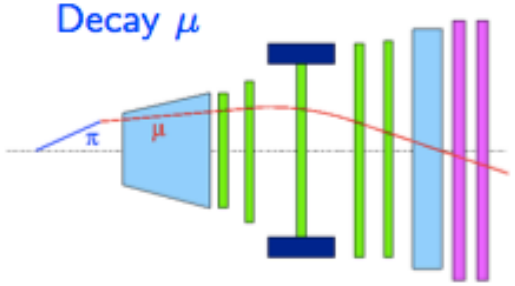
Hadron punch through



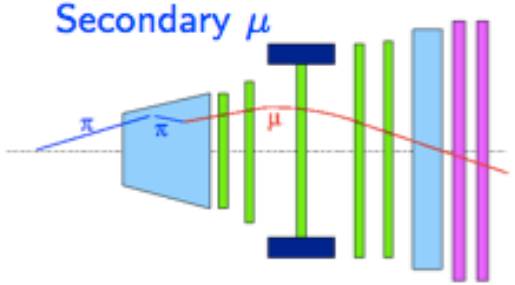
Beam gas interactions



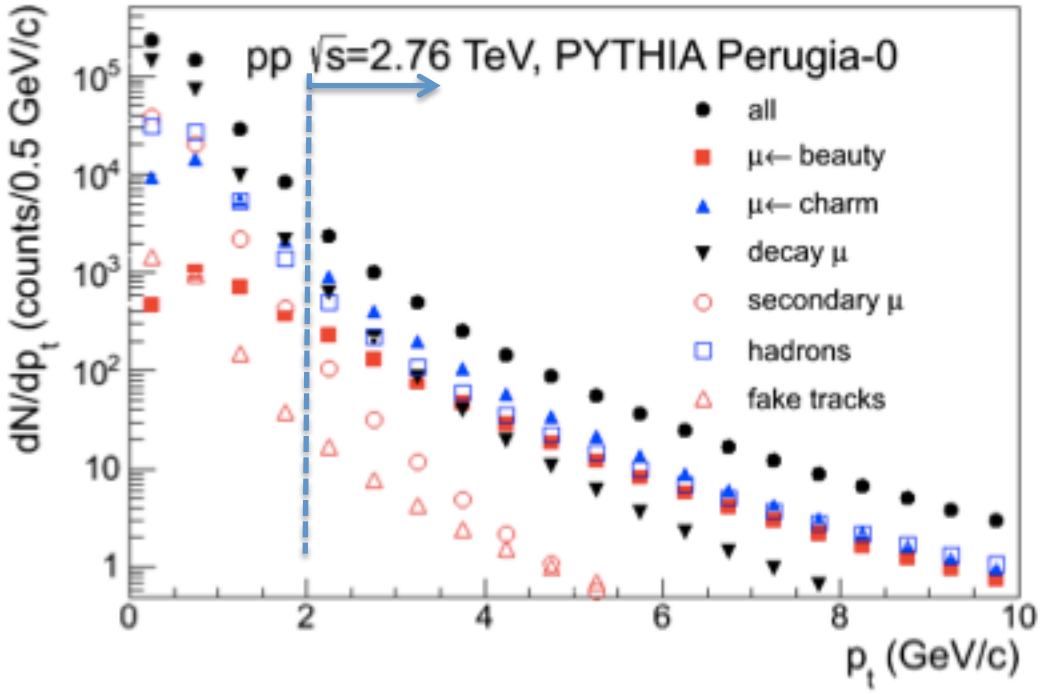
Decay μ



Secondary μ

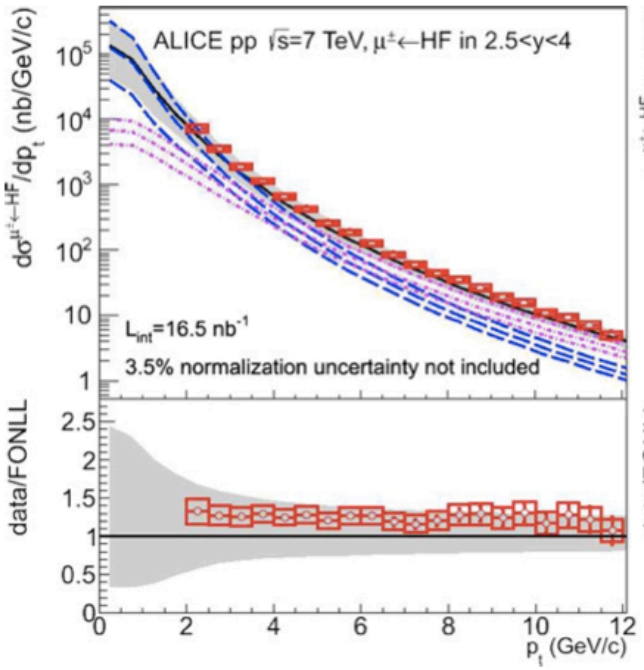


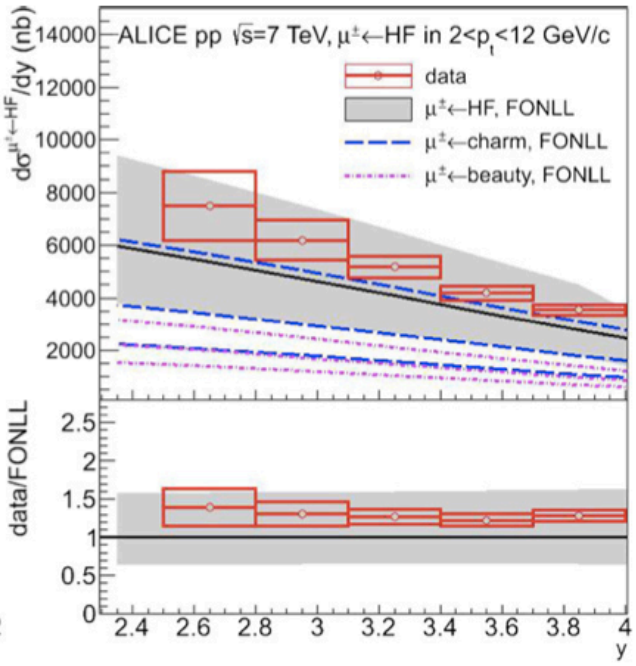
ALICE μ spectrometer $2.5<\eta<4$



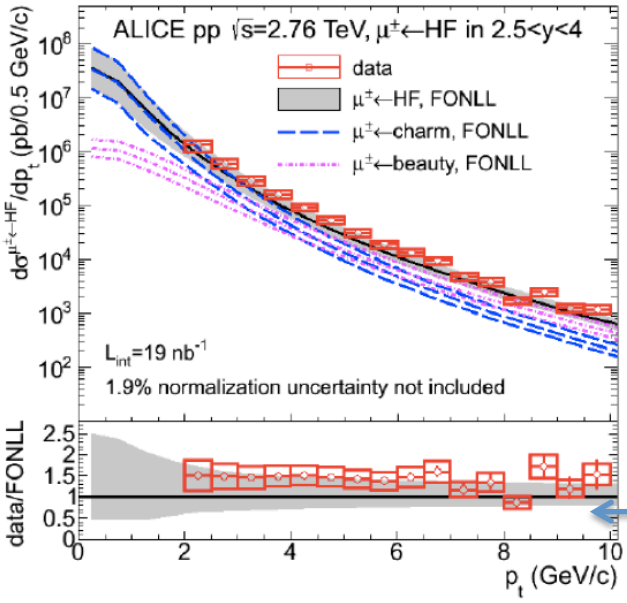
- p_t > 2 GeV/c to reduce background
- decay μ dominant background,
- Background subtracted using MC (PYTHIA and PHOJET): main contribution to systematics: 13% (model) + 5-20% (transport)

Heavy-flavour decay muons at 7 and 2.76 TeV





ALICE,
Phys. Lett. B708 (2012)265



ALICE, arXiv:1205.6443

HF(c,b)→ muons

- data described by FONLL, consistently with results from CMS and ATLAS at mid-rapidity
- b contribution expected to be dominant at p_t>6 GeV/c
- "excess" of data with respect to FONLL central values: on average 1.3 (consistent with ALICE D mesons measurement) but well within uncertainties
- useful recent check at √s=2.76 TeV

Outlook & conclusions

- wide range of results obtained by ALICE in pp for heavy flavours at √s=7 and 2.76 TeV
- within uncertainties FONLL and GM-VFNS describe well data
- low p_T reach (down to 1-2 GeV/c) and PID capabilities allow ALICE to complement HF results of other experiments at LHC

- reference baseline for PbPb studies achieved

see Y. Pachmayer talk at this conference

- J/ψ in pp at ALICE (including polarization)

see L. Bianchi talk at this conference

- heavy flavours in pPb collisions: will allow study of initial state effects and PDF nuclear modification

making good plans for 2012 pPb beams: see ALICE talks at.. PLHC2013 ☺