Heavy flavour production in pp collisions @ 7 and 2.76 TeV with the ALICE detector

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on behalf of the ALICE collaboration

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Heavy Flavour production at hadron colliders - Berkeley

Outline

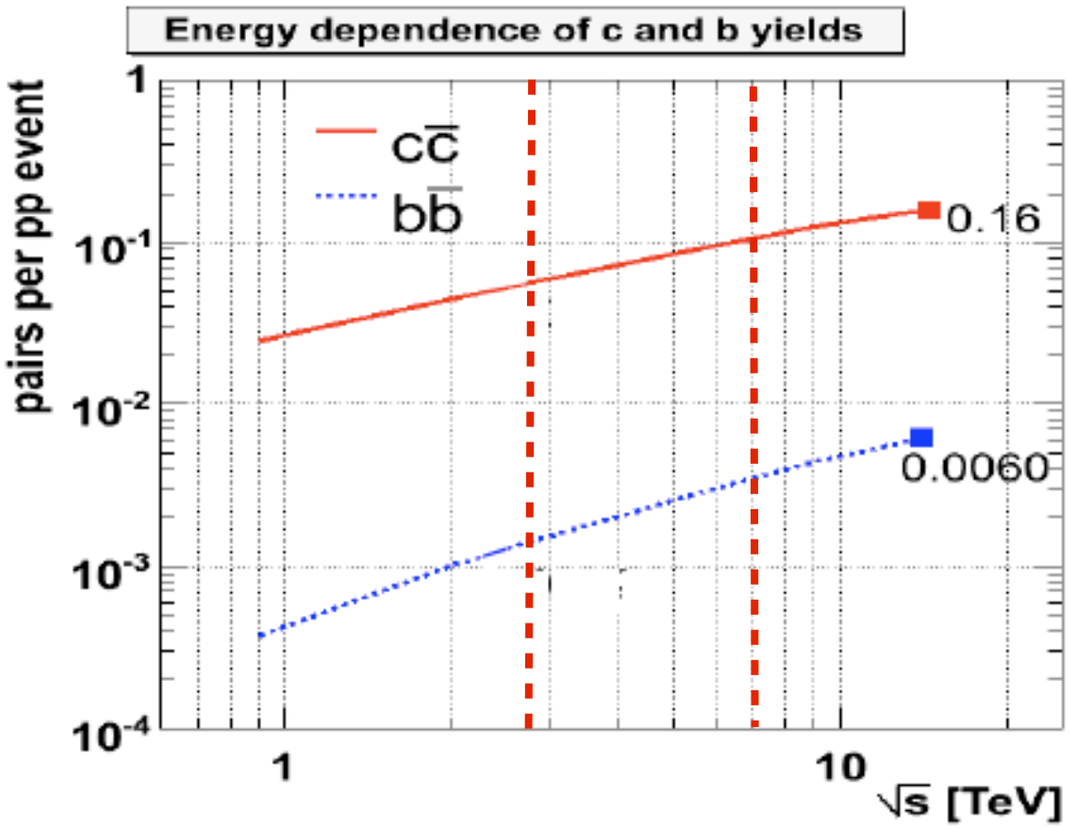
- **Why heavy quarks with ALICE**
- **D mesons production**
  - ✓ D^0, D^{*+}, D^+ and D^+_s production cross sections
  - ✓ D mesons ratios
  - ✓ D production vs multiplicity
- **J/ψ production**
  - ✓ Production cross section at central and forward rapidity
  - ✓ b fraction
  - ✓ Polarization
- **Heavy flavour electrons**
- **Heavy flavour muons**
- **Conclusions**

Why heavy flavours at LHC

- Heavy flavour production provides a pQCD test tool.
  - p-p : test the pQCD predictions, reference for A-A
  - p-A : initial state effects (first LHC run in few days)
  - A-A : probe the high density medium

- Large Hadron Collider.
  - Large cross section, heavy flavour factory
  - NLO production processes become important

- ALICE p_T acceptance:
  - ≥1 GeV/c for charm hadrons.
  - ≥ 0 for quarkonium
  - ≥ 1 GeV/c for b decay electrons

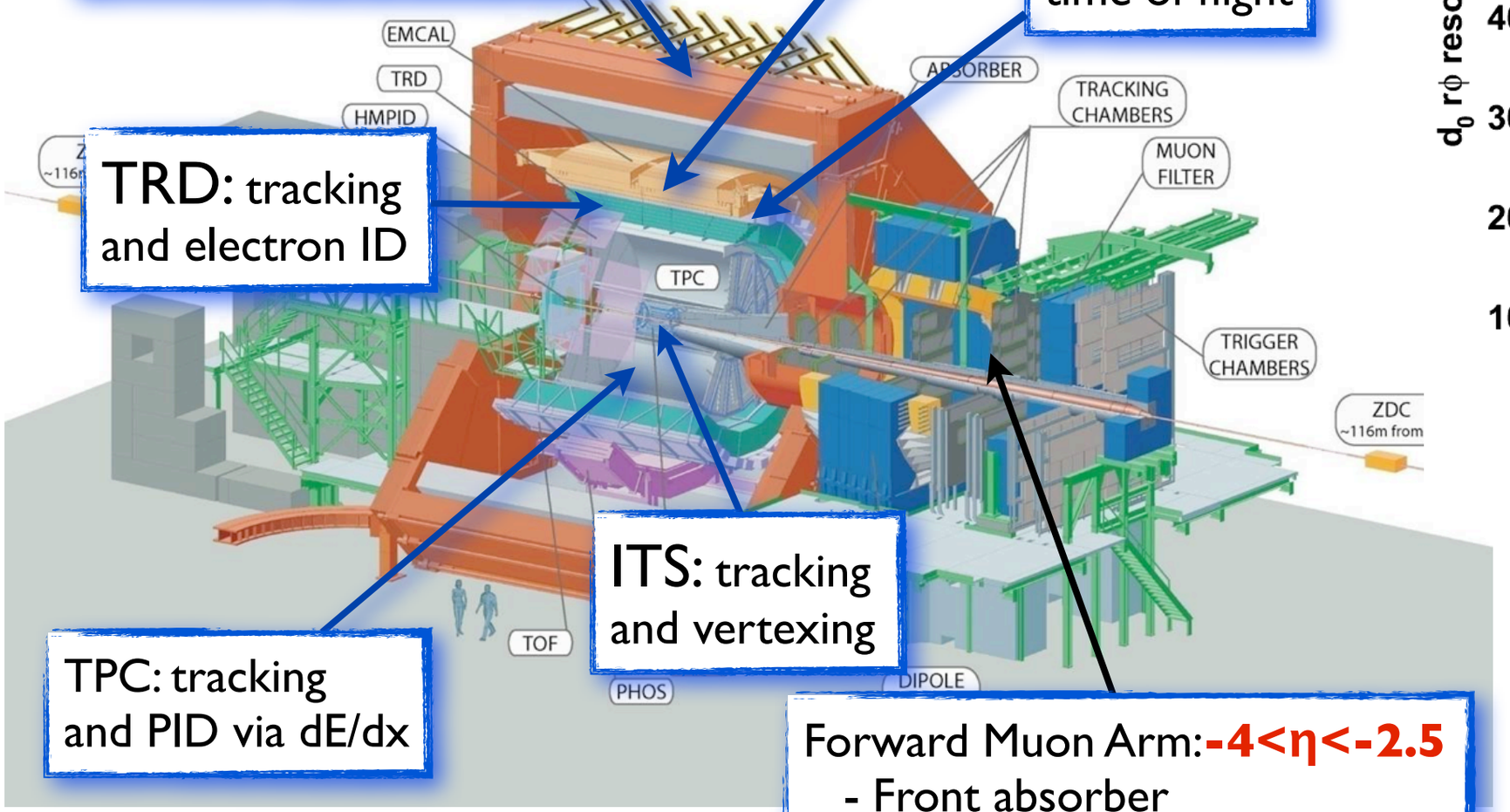


The ALICE experiment

EMCAL: triggering, electron ID

Central barrel: -0.9<η<0.9, Field = 0.5 T

TOF: PID via time of flight



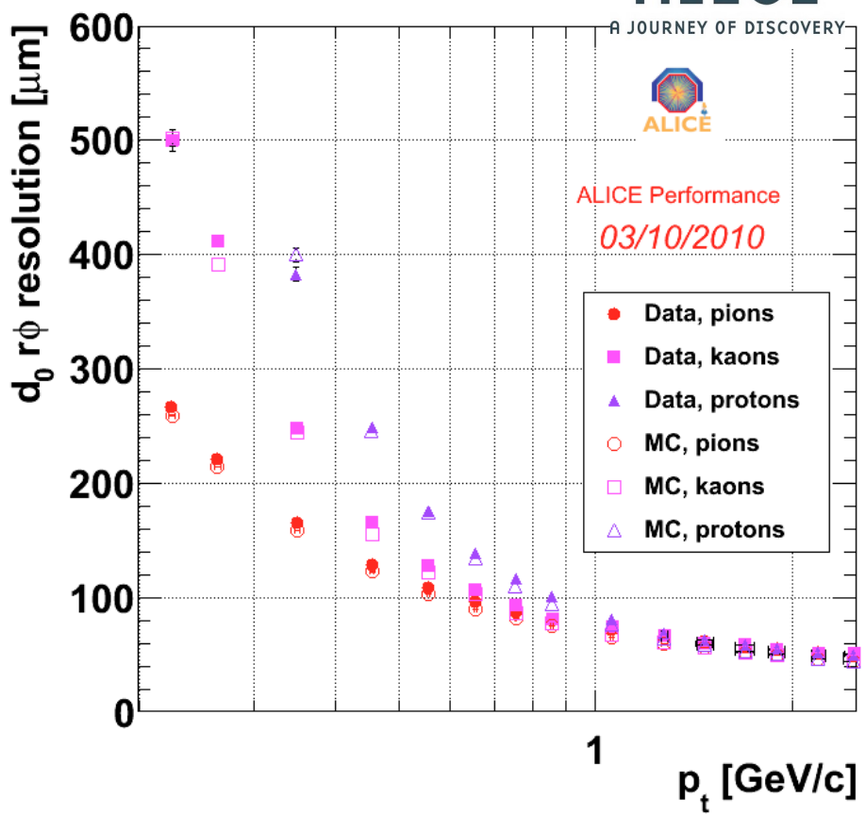
TRD: tracking and electron ID

ITS: tracking and vertexing

TPC: tracking and PID via dE/dx

Forward Muon Arm: **-4<η<-2.5**
- Front absorber
- 5 tracking stations
- Dipole magnet
- Iron wall

-2 trigger stations



☑ Excellent tracking performances with ITS+TPC

☑ PID using ITS+TPC +TOF+TRD+EMCAL

D mesons via hadronic decays

☑ In this talk:

$D^0 \rightarrow K^- \pi^+$

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

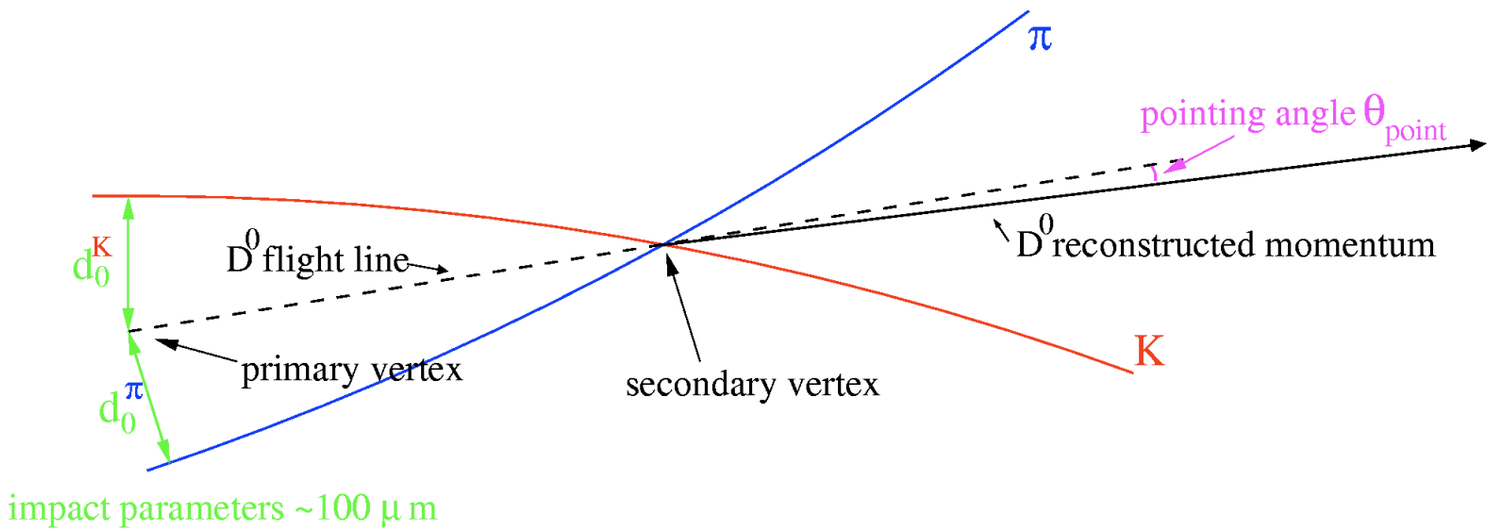
$D^{*+} \rightarrow D^0 \pi^+ \rightarrow K^- \pi^+ \pi^+$

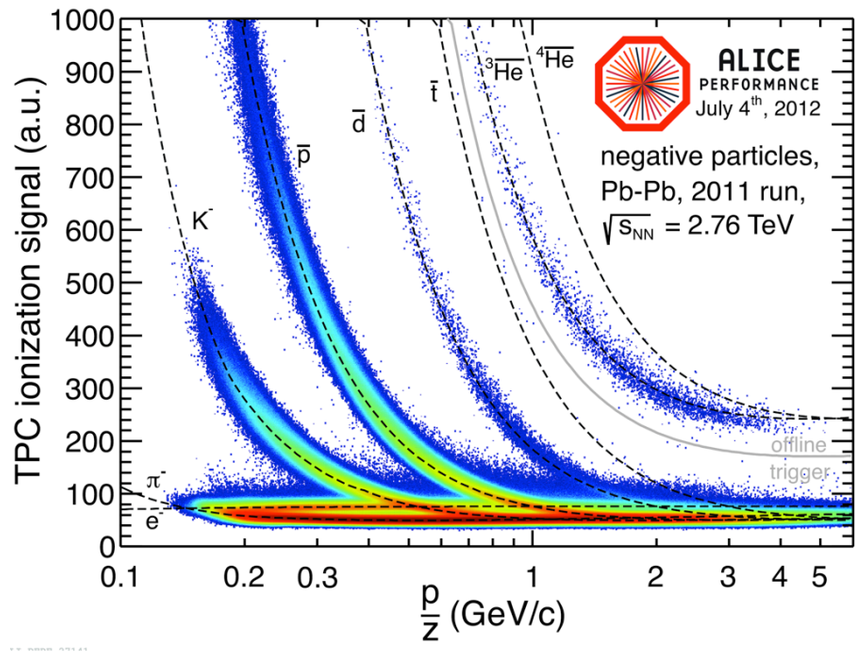
$D^+_s \rightarrow \phi \pi^+ \rightarrow K^+ K^- \pi^+$

Except for D^{*+}, the $c\tau$ of the other D mesons ranges from ~123 to 312 μm

→ Decay vertices displaced by few hundreds of μm from the primary vertex.

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

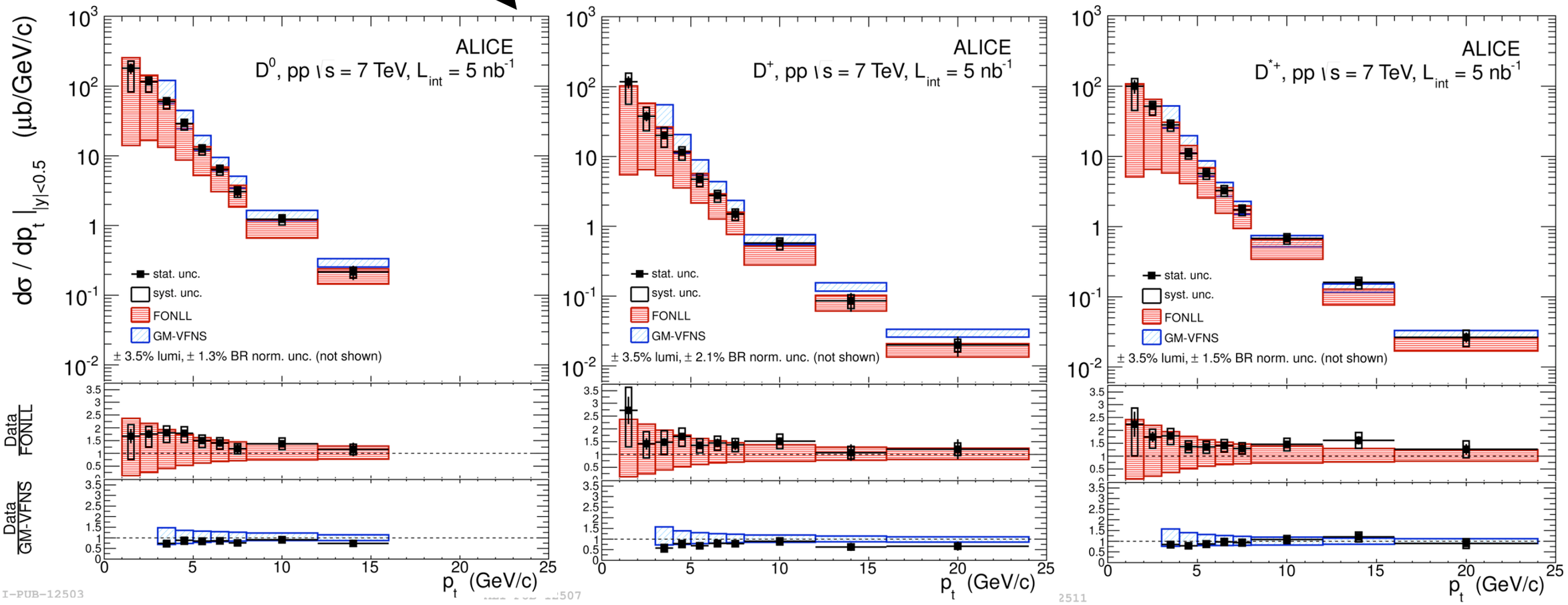




☑ Invariant mass analysis

D meson cross sections in pp @ $\sqrt{s}$ = 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.

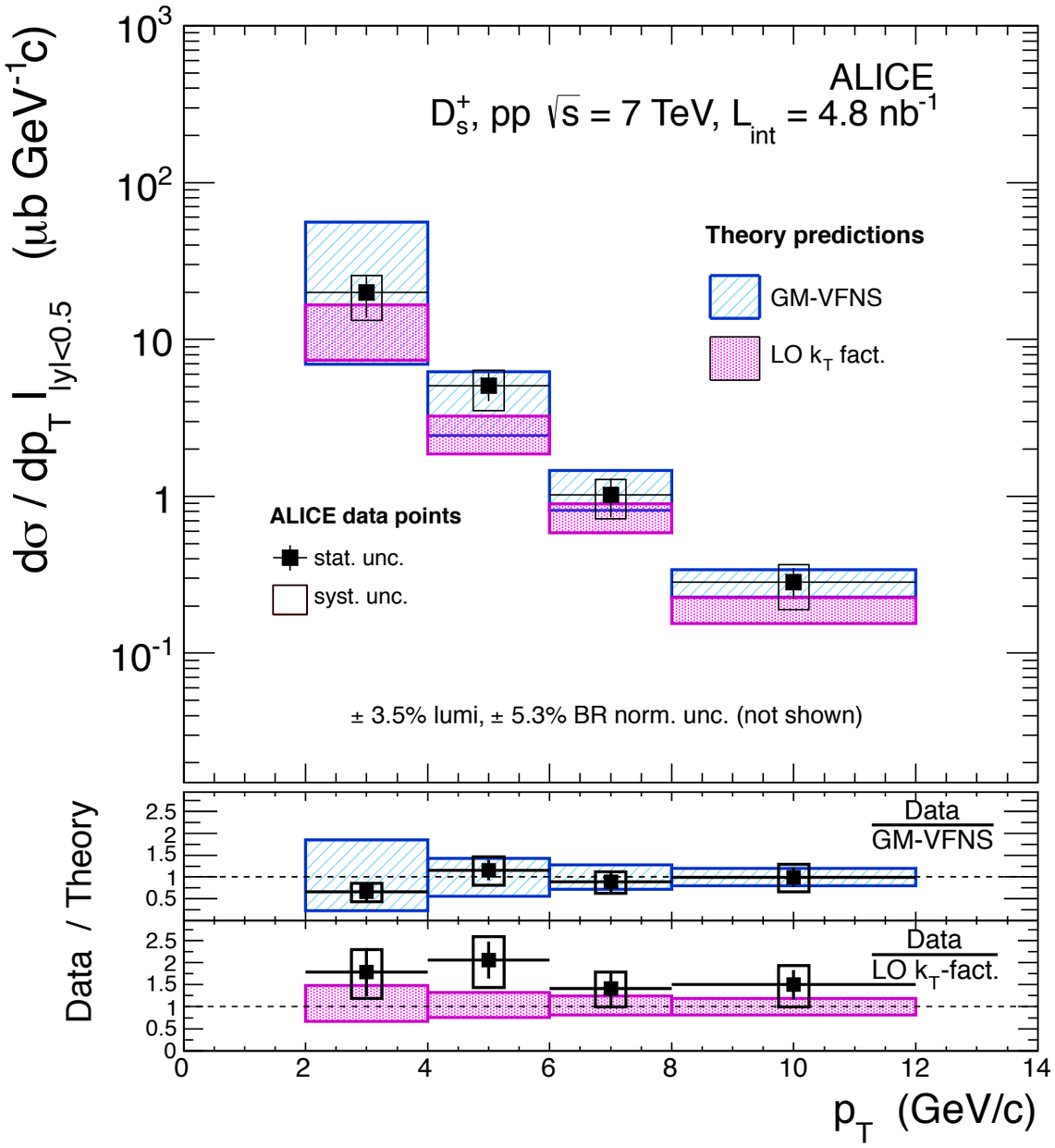
☑ Large p_T coverage [1,24] GeV/c and well described by pQCD predictions.

M. Cacciari, M. Greco and P. Nason, JHEP 9805 (1998) 007;
M. Cacciari, S. Frixione, N. Houdeau, M. L. Mangano, P. Nason, G. Ridolfi, arXiv:1205.6344

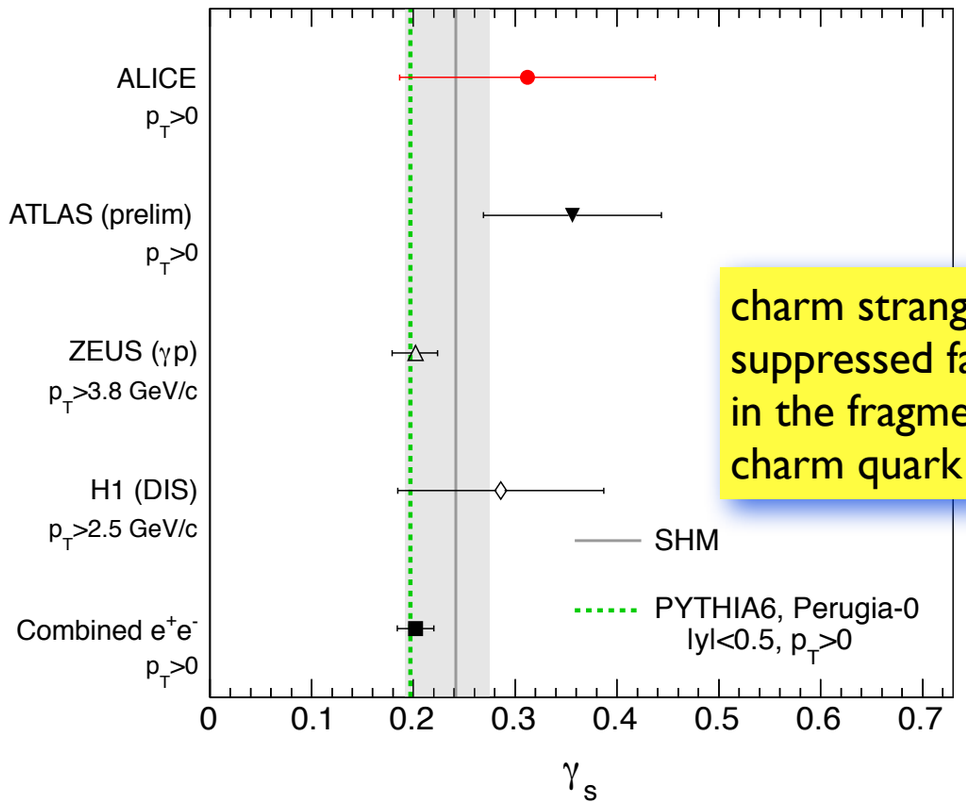
B.A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger, arXiv:1202.0439, DESY-12-013, MZ-TH-12-07, LPSC-12019

D^+_s production cross section

B. I. Abelev et al [ALICE Collaboration]. arXiv:1208.1948 [hep-ex]. PLB 718 (2012) 279.



- D^+_s measured in the p_T range [2,12] GeV/c
- Good agreement with models (LO k_T fact (violet) and GM-VFNS (blue))



charm strange mesons suppressed factor ~3.3 in the fragmentation of charm quark

R. Maciula, M. Luszczak and A. Szczurek, arXiv:1208.6126 [hep-ph].

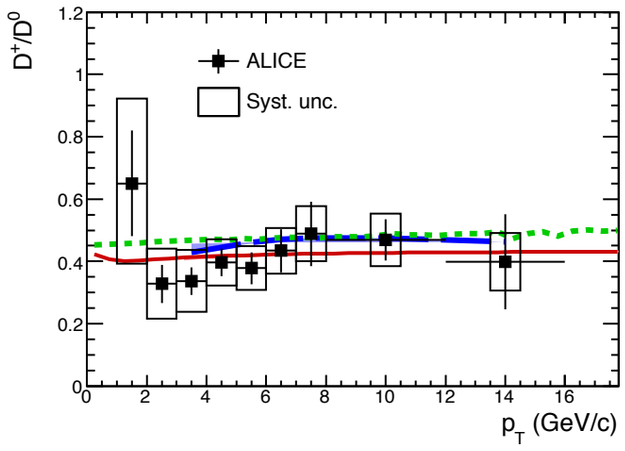
R. Maciula, M. Luszczak and A. Szczurek, private communication

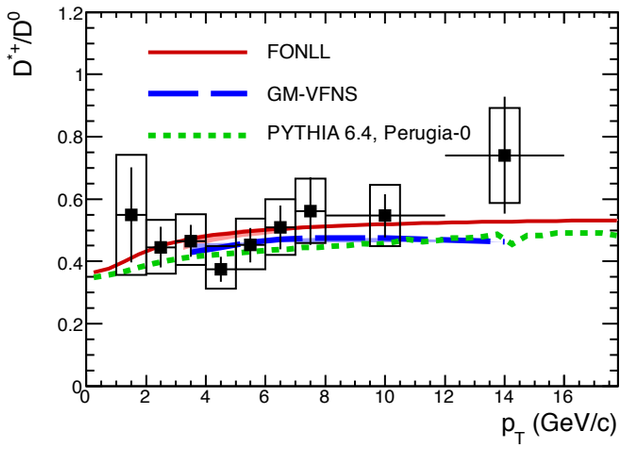
B.A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger, arXiv:1202.0439, DESY-12-013, MZ-TH-12-07, LPSC-12019

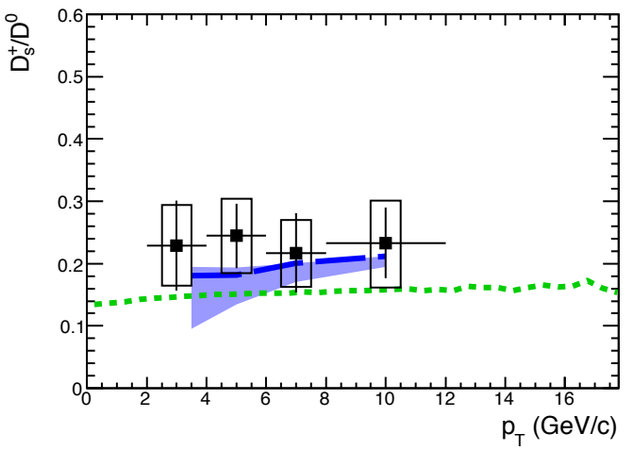
D meson ratios

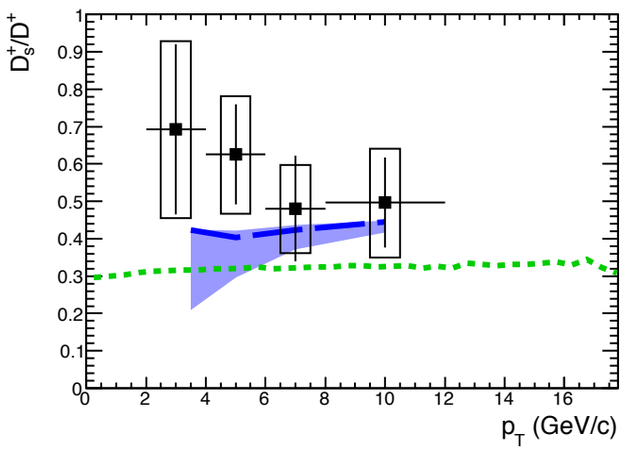
B. I. Abelev et al [ALICE Collaboration]. arXiv:1208.1948 [hep-ex]. PLB 718 (2012) 279.

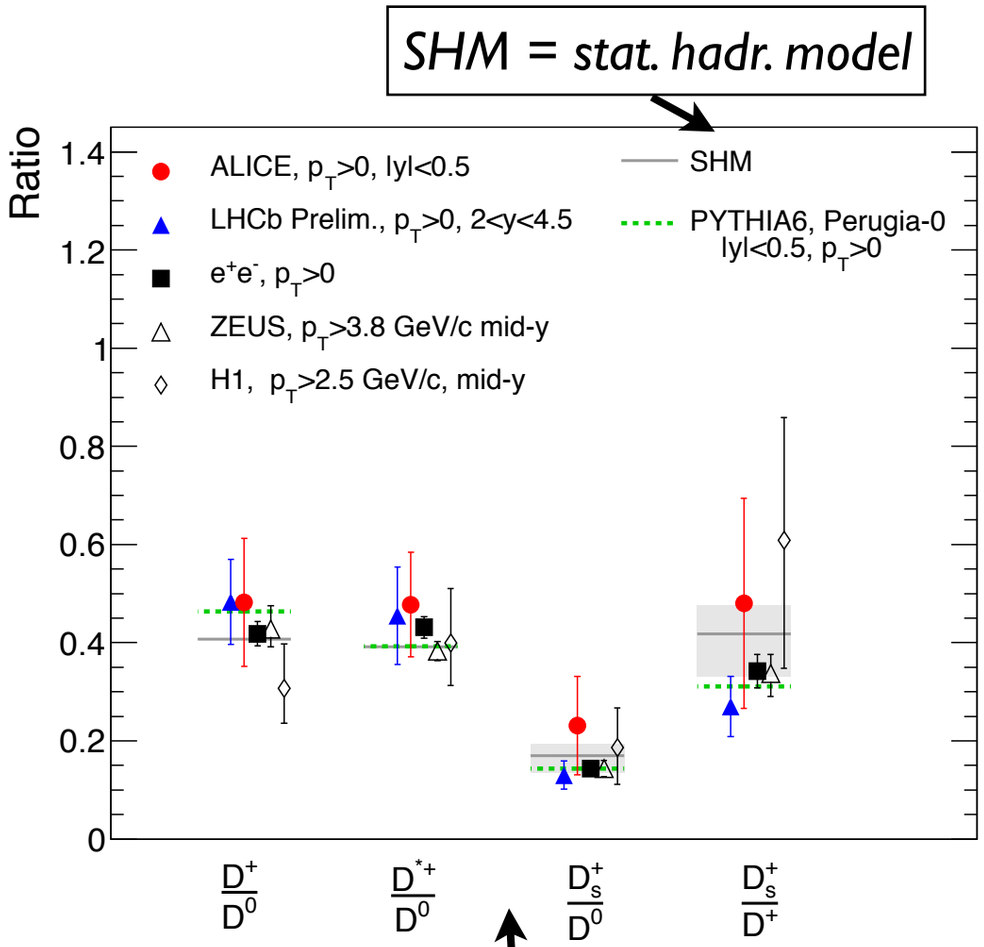
- Model calculations show a good agreement with data. In the case of the $D^+_s/D^0(D^+)$ PYTHIA seems to under-evaluate the p_T-differential ratio.





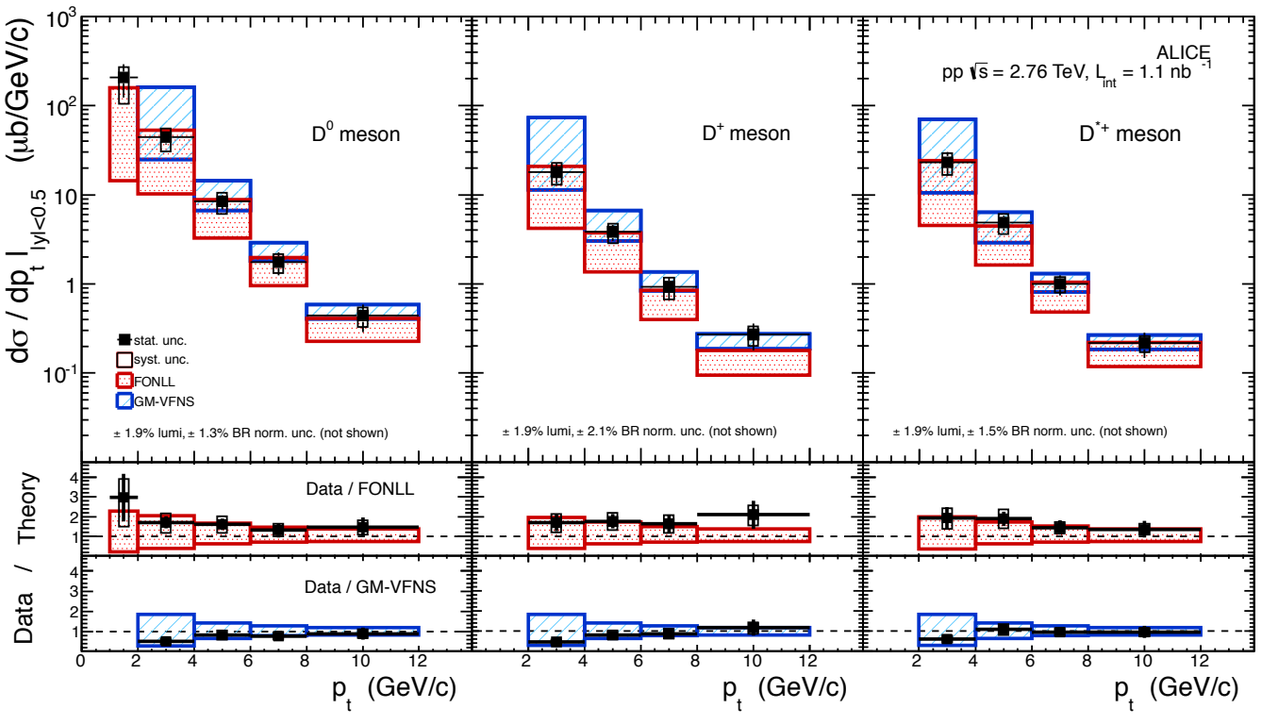




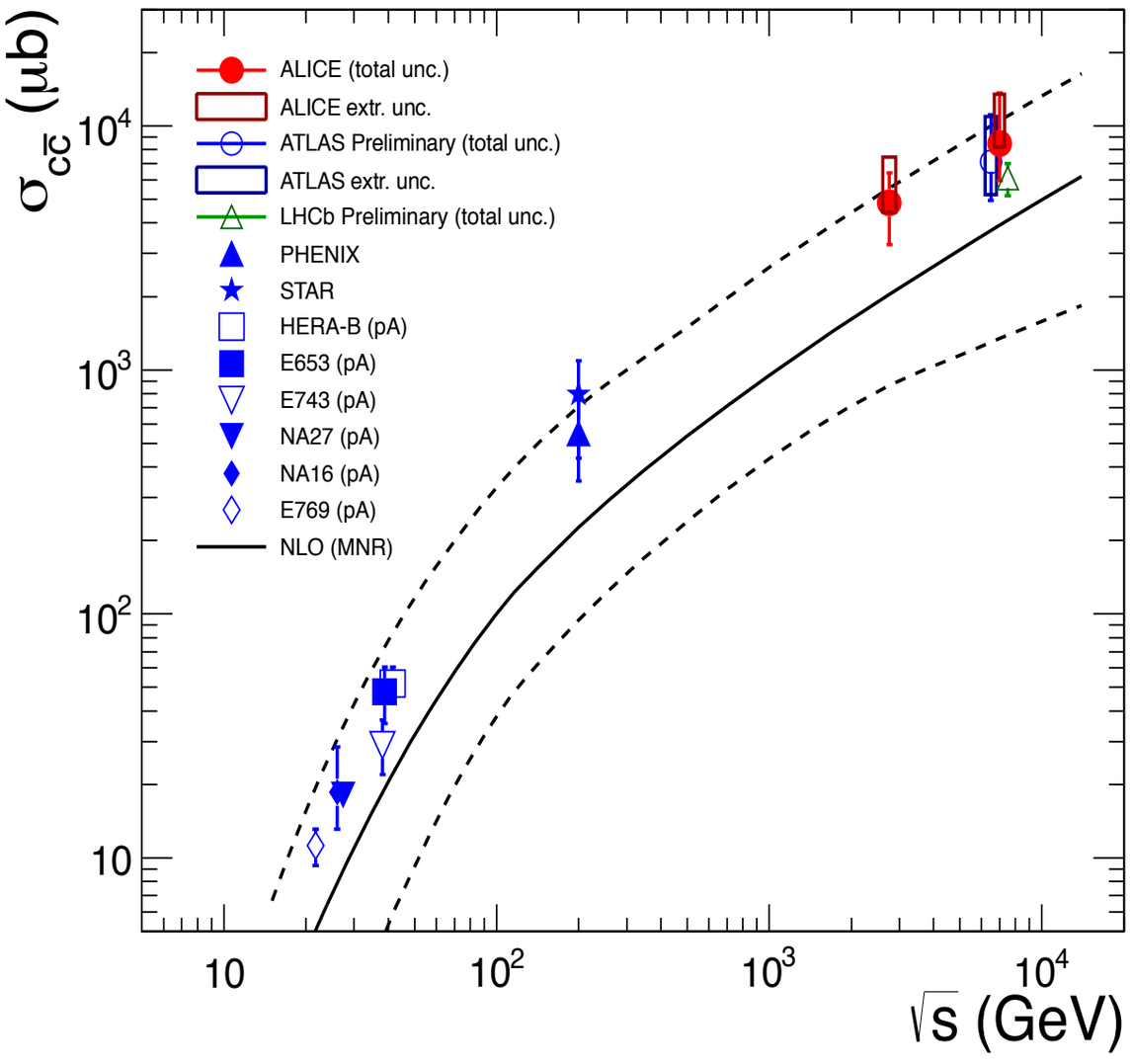


Good agreement between ALICE and LHCb. D ratios comparable in ee, ep and pp

D meson @ 2.76 TeV and total charm cross section



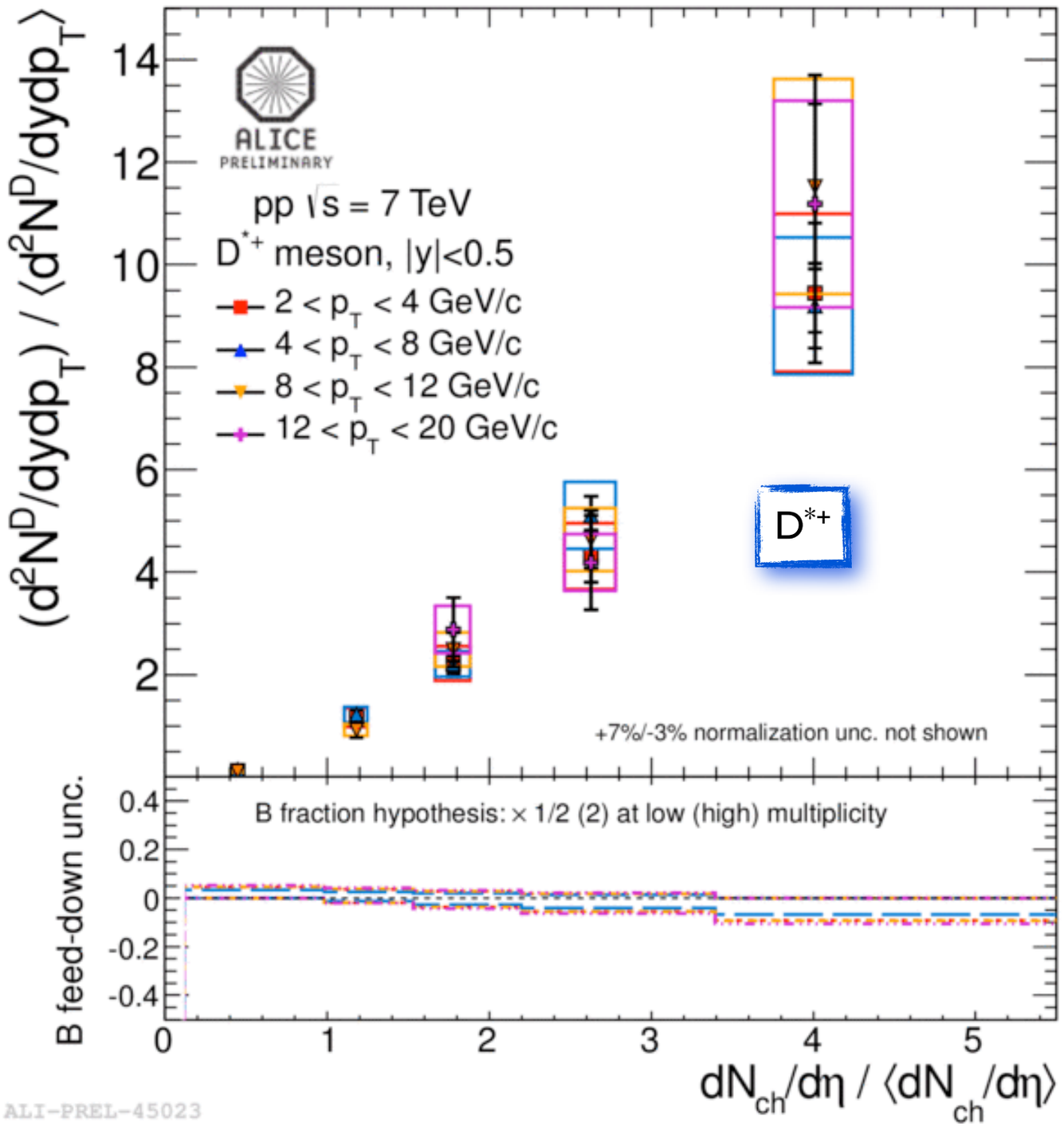
B. I. Abelev et al. arXiv:1205.4007 [hep-ex]. JHEP 1207 (2012) 191.



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

- p_T differential production cross sections of D^0, D^+ and D^{*+} measured @ 2.76 TeV. Good agreement with FONLL and GM-VFNS calculations
- Total nucleon-nucleon (pp) charm production cross section. In case of proton-nucleus collisions the measured cross section have been scaled down by the number of binary nucleon-nucleon collisions. Results are compared with NLO MNR calculation

Production of D mesons vs multiplicity

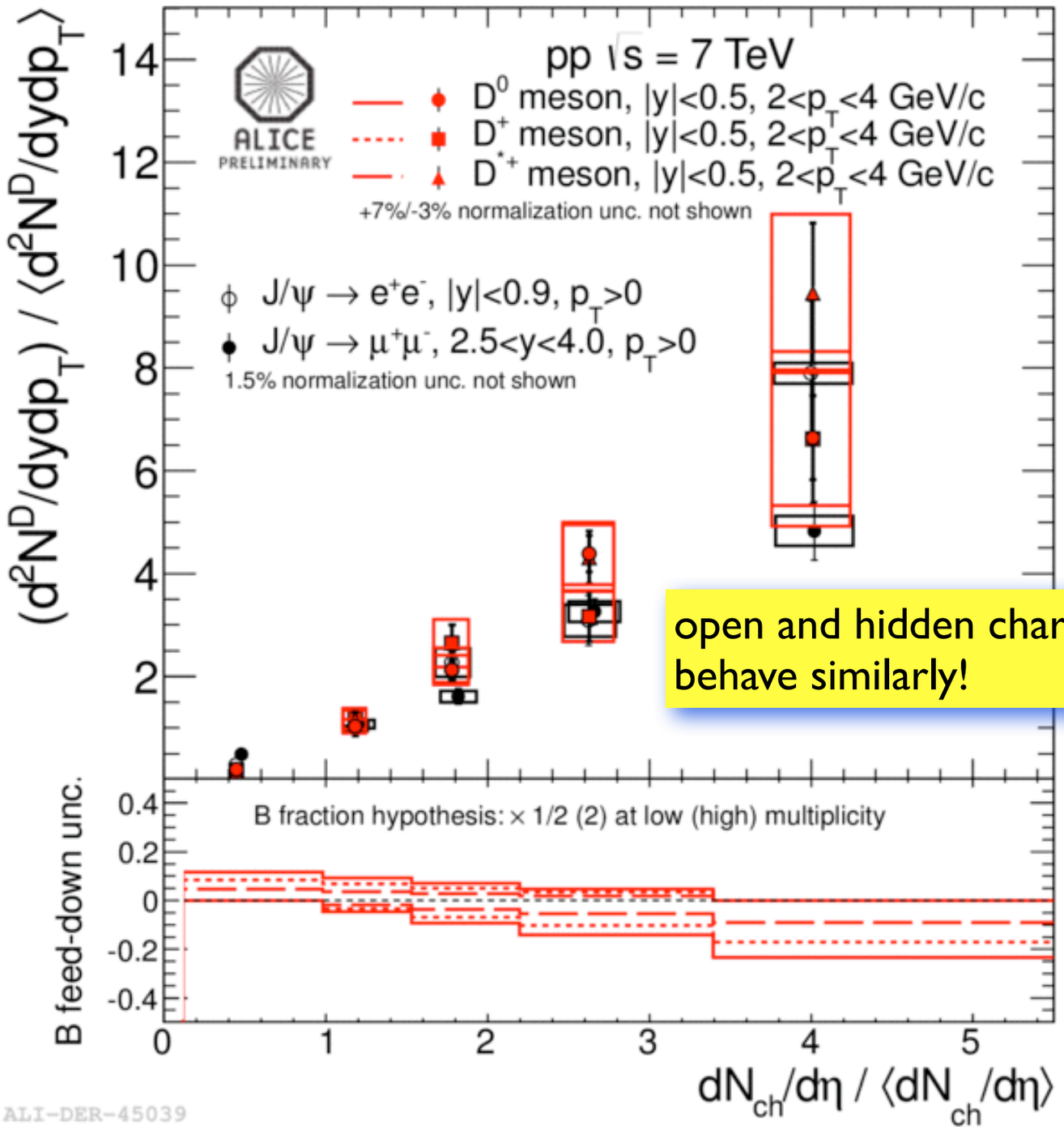


- If, at LHC, there is a substantial contribution of Multi-Parton Interactions on an hard scale then D meson yield may be correlated to the event total charged particle multiplicity

- Different D p_T regions

study the correlation between charm production and event multiplicity as a function of the hardness of the partonic interaction

Comparison with J/ψ



open and hidden charm behave similarly!

- ☑ 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

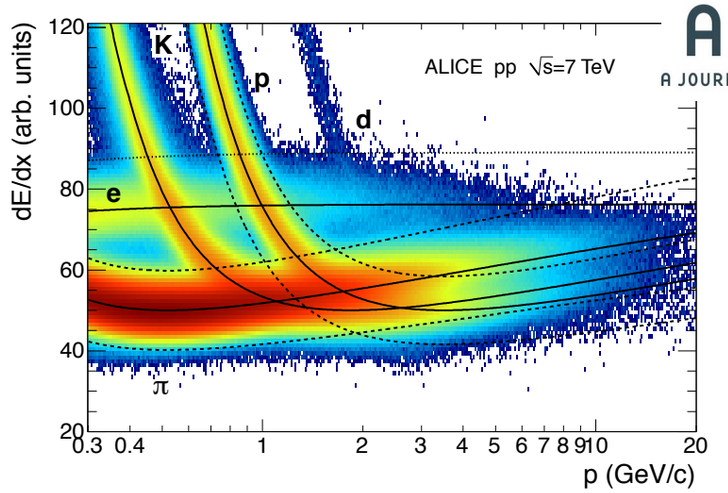
PLB, 712-3 (2012), arXiv:1202.2816

☑ We found a linear increase of the yield with charged particle density, a good consistency of the D^0, D^{*+} and D^+ mesons and no evident p_T dependence (within uncertainties)

J/ψ production

J/ψ in pp @ 7 TeV

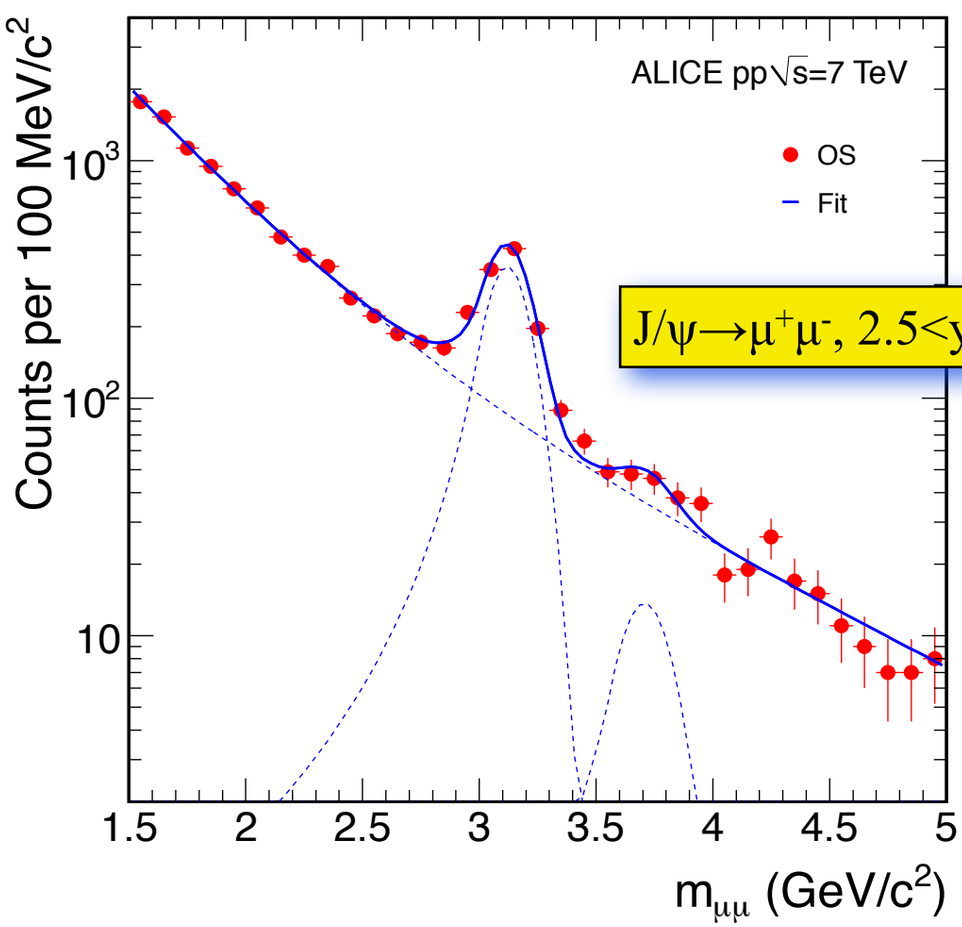
- ☑ Down to $p_T = 0$ at central and forward rapidity
- ☑ Muons identified via muon trigger stations
- ☑ Electrons identified through specific energy loss in the TPC (3σ inclusion cut, 3.5σ and 3σ exclusion cut for pions and protons)



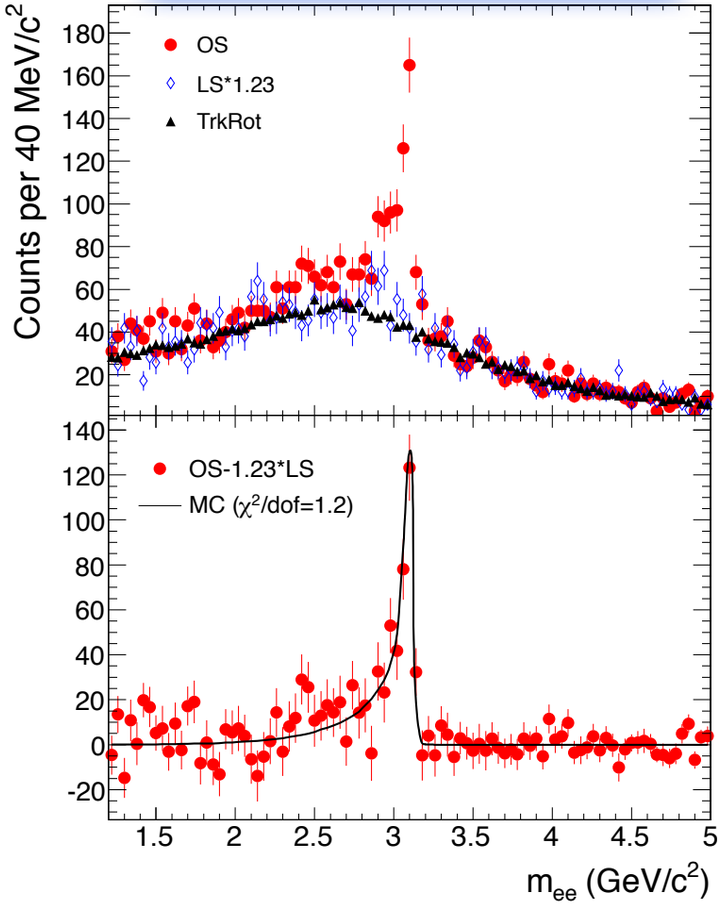
$J/\psi \rightarrow e^+e^-$, $|y|<0.9$, $p_T>0$

2012 *ALICE Coll., Phys.Lett.B 704:442-455,2011*

Erratum, ibid. B718 (2012) 692-698

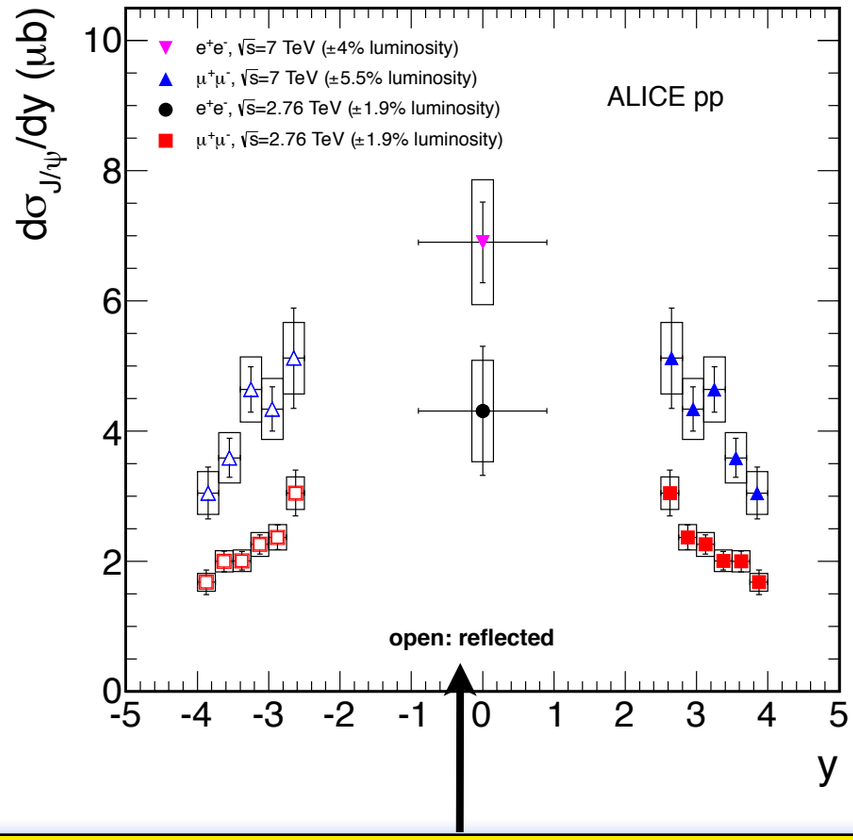


$J/\psi \rightarrow \mu^+\mu^-$, $2.5<y<4$, $p_T>0$



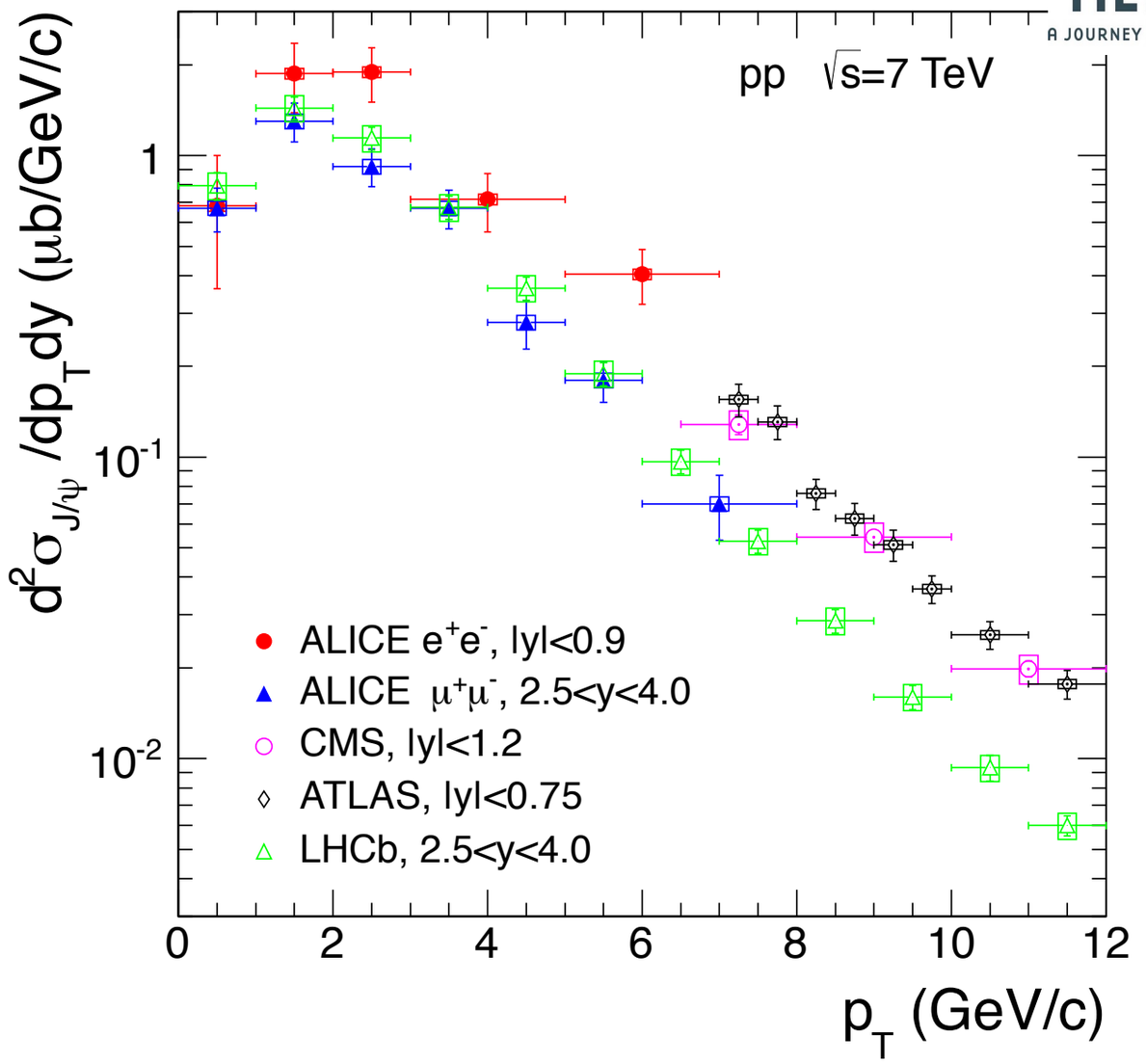
Cross-sections at 7 and 2.76 TeV

arXiv: 1203.3641



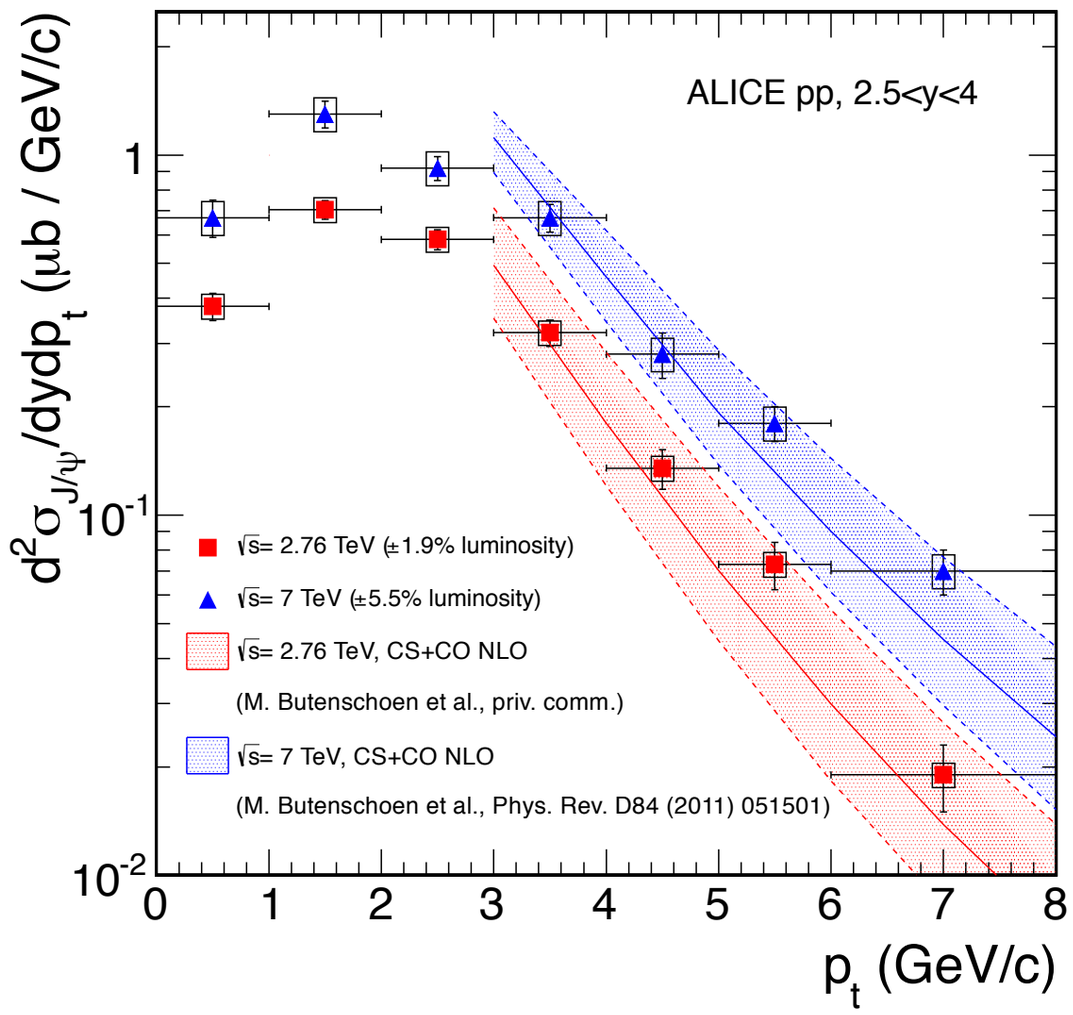
Comparison between 7 and 2.76 TeV

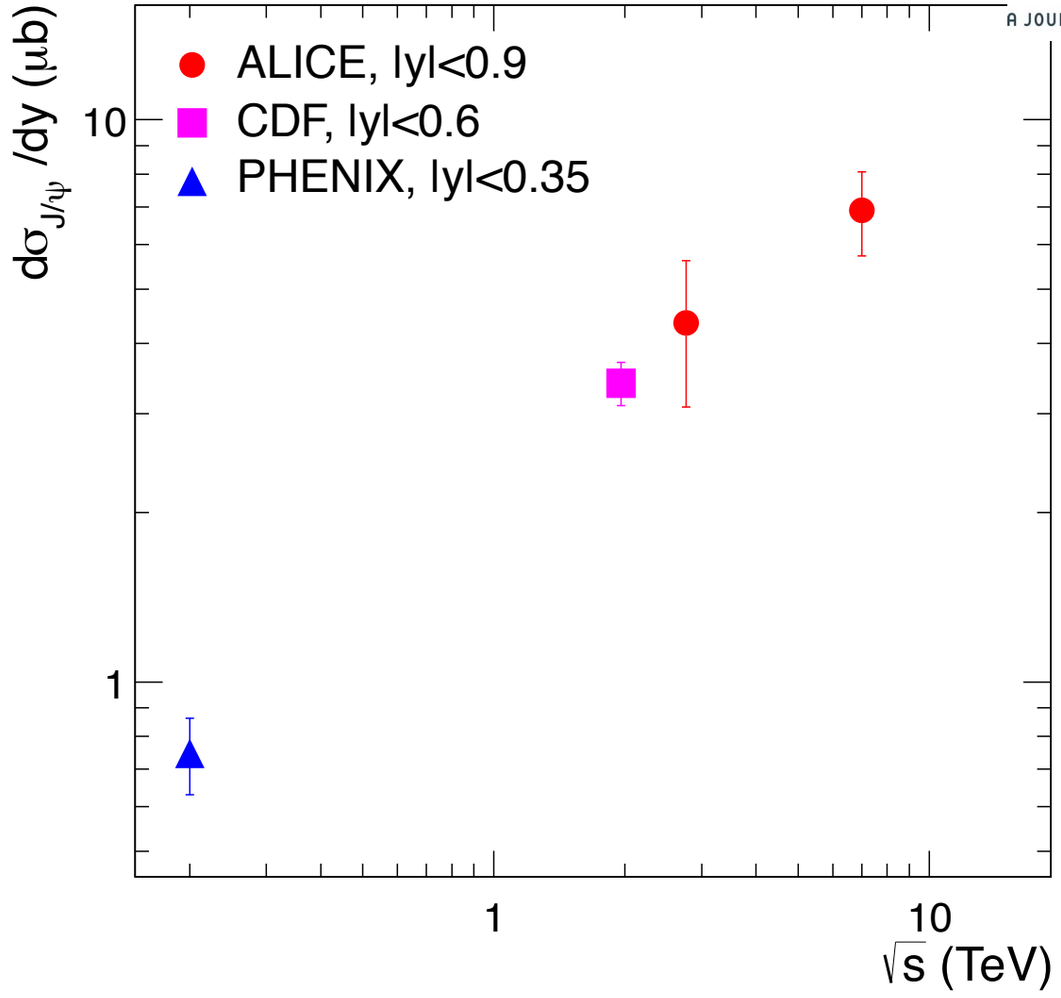
ALICE Coll., Phys.Lett. B 704:442-455,2011



- Comparison at 7 TeV with other experiments show a nice agreement both at forward (LHCb) and central rapidity (ATLAS, CMS)
- In the central rapidity region ALICE is clearly complementary with respect CMS and ATLAS

Comparison with theory and evolution vs √s

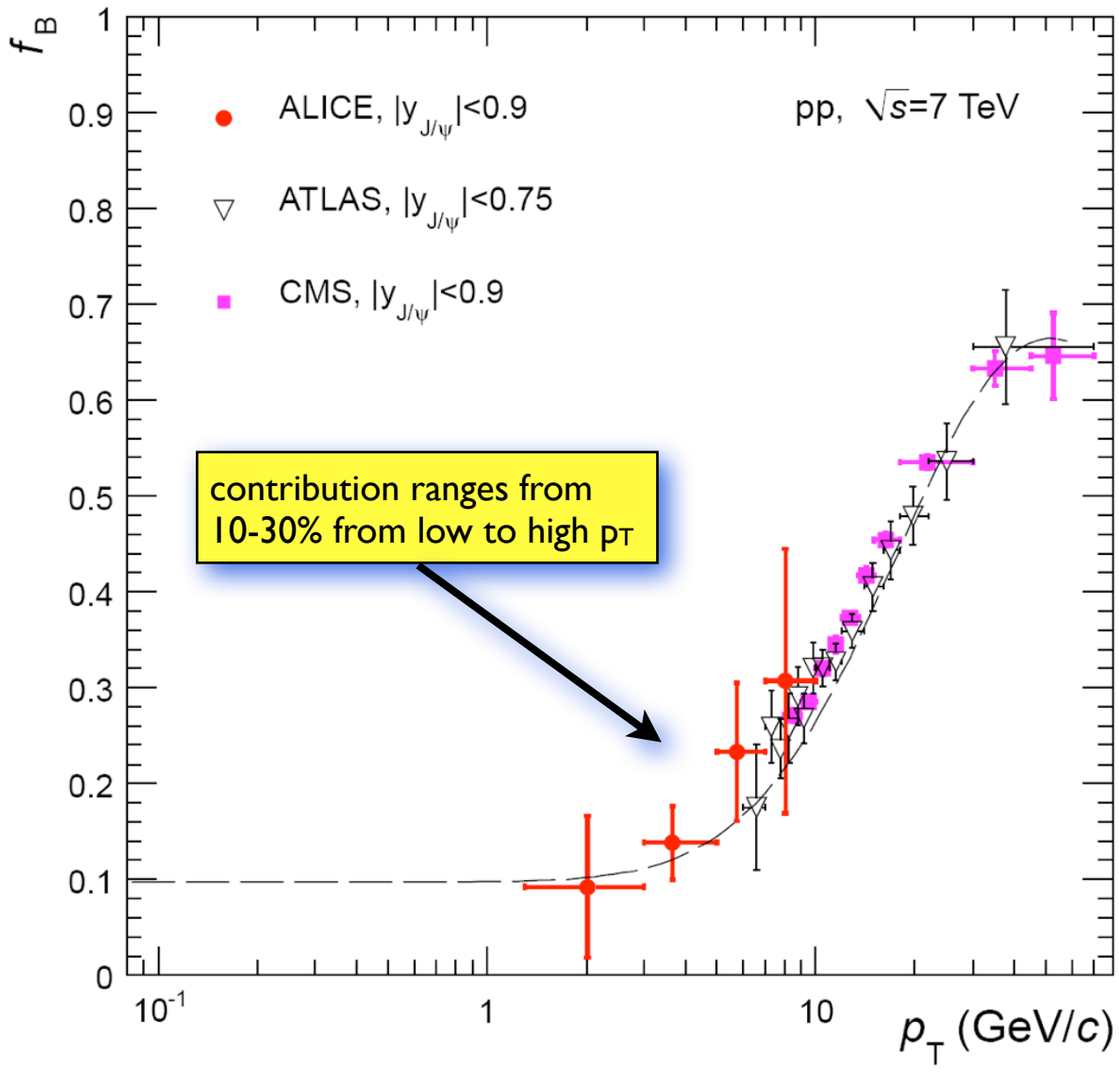




- The double differential production at 7 and 2.76 TeV was compared with a NLO NRQCD calculation performed in the region p_T>3 GeV/c
- Thanks to the unique kinematic of ALICE with respect the other LHC experiments we can compare the p_T integrated mid rapidity cross section with those from lower energy collider experiments

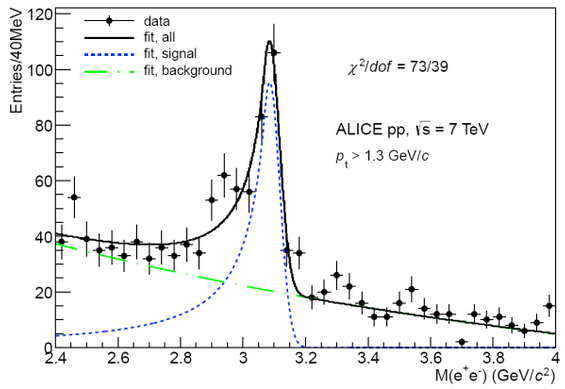
Phys.Lett. B718 (2012) 295-306 Erratum, ibid. B718 (2012) 692-698

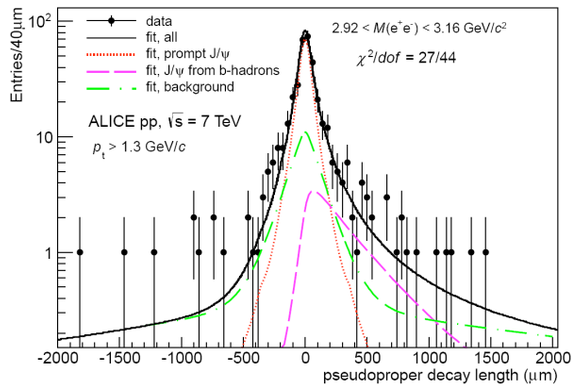
Non prompt J/ψ



- ALICE is able to extract the non-prompt fraction of the inclusive J/ψ cross-section in y<|0.9| via simultaneous log-likelihood fit to the invariant mass and pseudo-proper decay length

$$x = \frac{c \cdot L_{xy} \cdot m_{J/\psi}}{p_t^{J/\psi}}, \qquad L_{xy} = \vec{L} \cdot \vec{p}_t^{J/\psi} / p_t^{J/\psi}$$





JHEP 1211 (2012) 065

- In the p_T integrated region 1.3-10 GeV/c the we get:

$$f_B = 0.149 \pm 0.037\,(\text{stat.})^{+0.018}_{-0.027}\,(\text{syst.})^{+0.025\,(\lambda_{HE}=1)}_{-0.021\,(\lambda_{HE}=-1)}\,(\text{syst.pol.})$$

- The measurement complements CMS and ATLAS measurement extending the p_T reach down to 1.3 GeV/c

J/ψ polarization: method

- Measured through the extraction of the angular distribution of daughter muons in the quarkonium rest frame:

$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta}\cdot(1+\lambda_\theta\cos^2\theta+\lambda_\phi\sin^2\theta\cos 2\phi+\lambda_{\theta\phi}\sin 2\theta\cos\phi)$$

- Due to the low statistics the parameters λ_Φ and λ_θ are not extracted via 2D study but integrating over Φ and $\cos(\theta)$

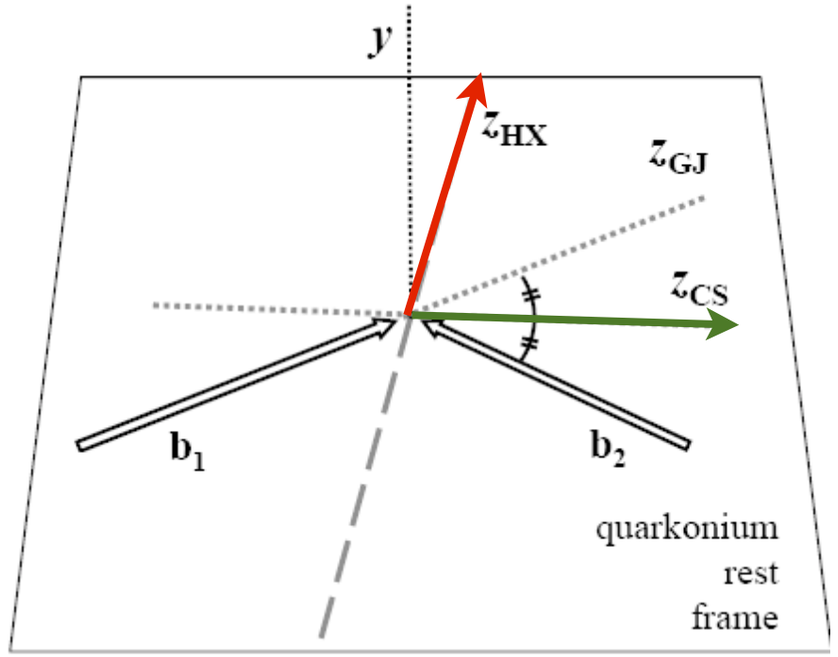
$$W(\cos\theta) \propto \frac{1}{3+\lambda_\theta}\left(1+\lambda_\theta\cos^2\theta\right)$$

$\lambda_\theta = +1 \rightarrow$ transverse polarization

$\lambda_\theta = \ \ 0 \rightarrow$ no polarization

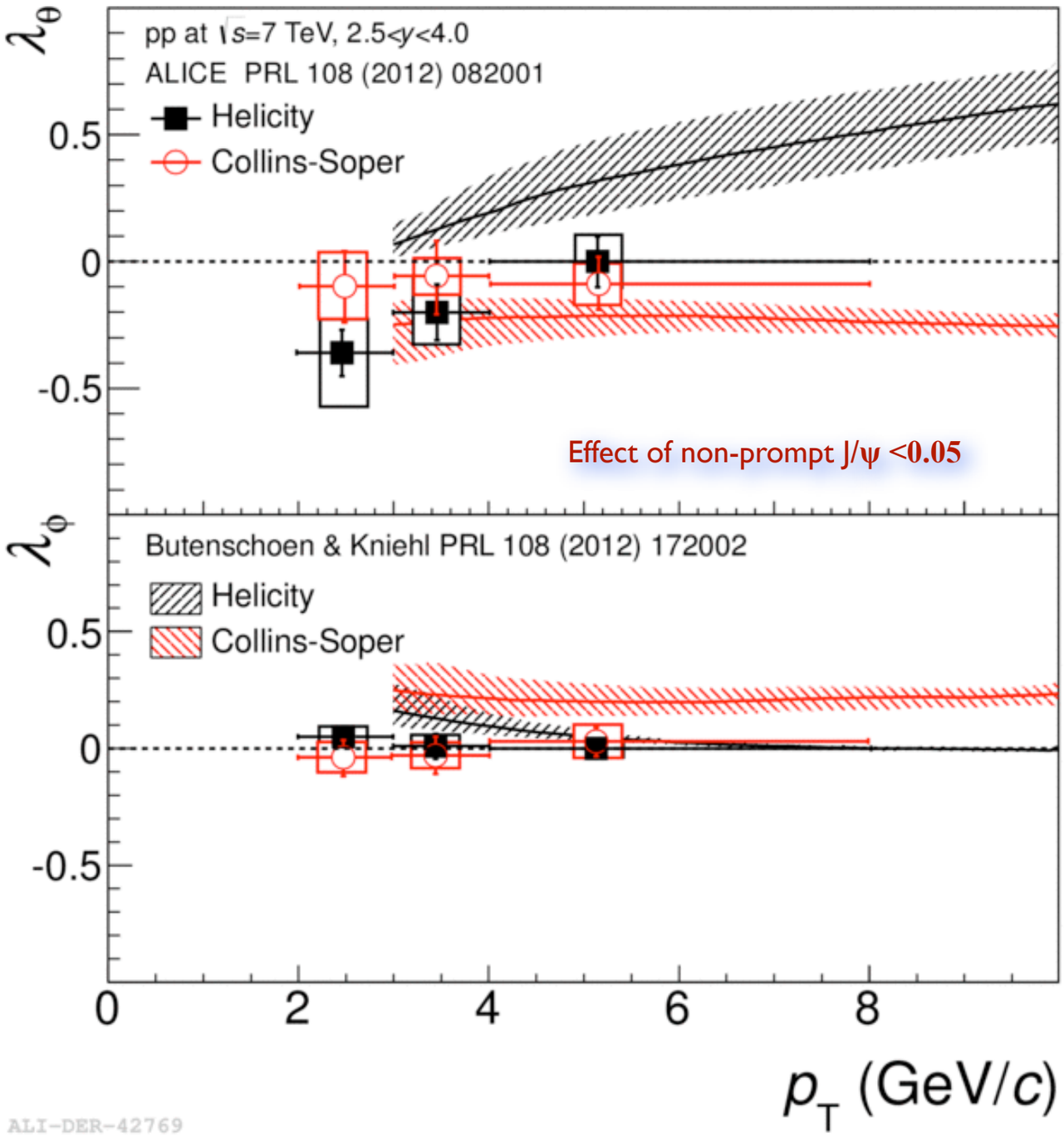
$\lambda_\theta = -1 \rightarrow$ longitudinal polarization

Helicity: J/ψ momentum direction in the collision's rest frame



Collins-Soper: Bisector of the angle between one beam and the opposite ot the other beam in J/ψ rest frame

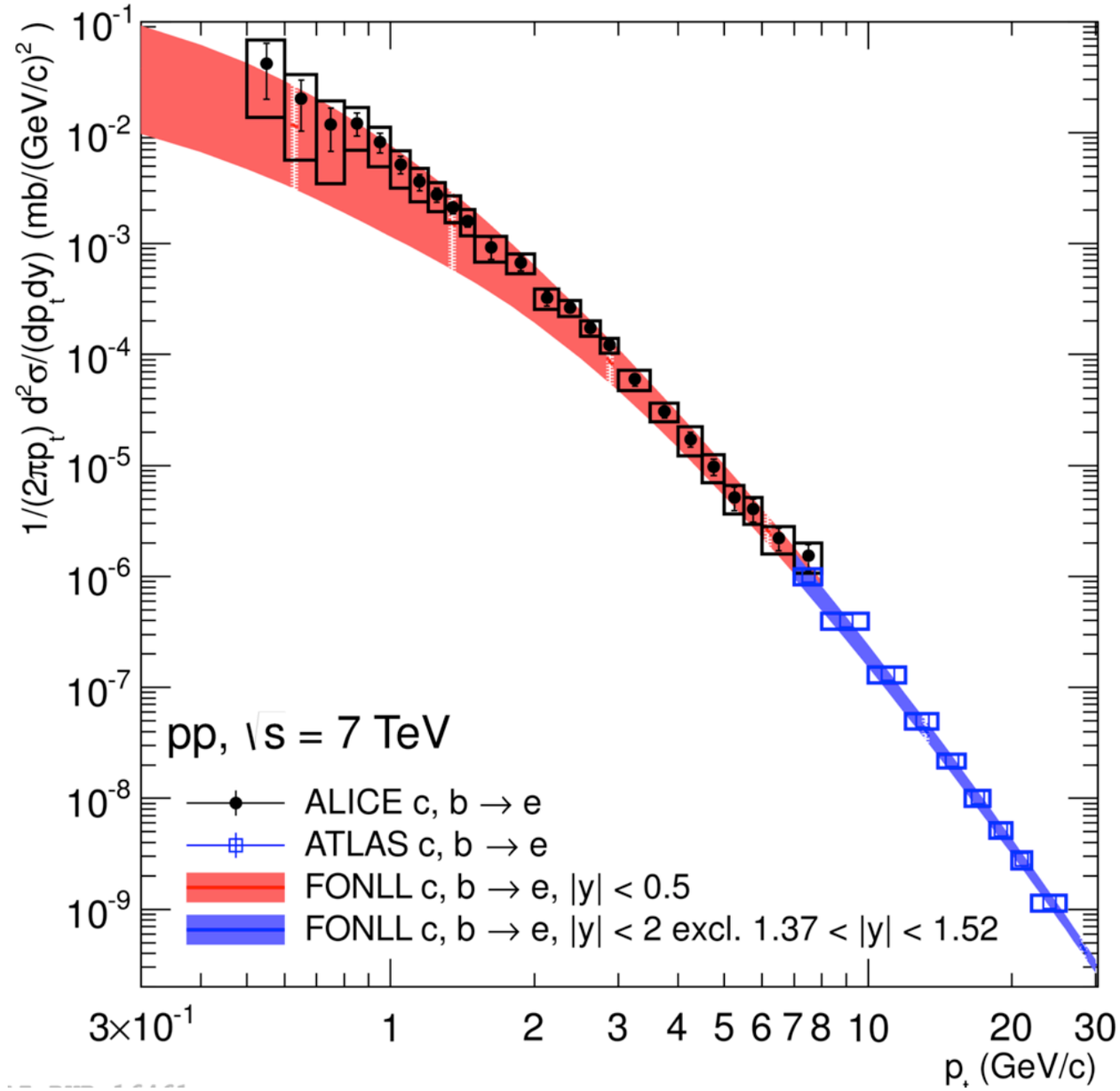
J/ψ polarization: results

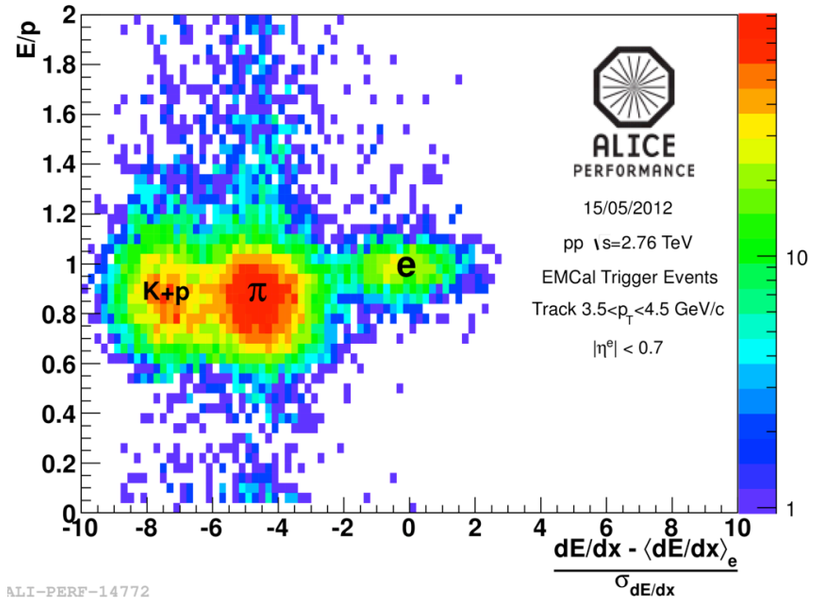


- ☑ No significant polarization observed
- ☑ Hint of a longitudinal polarization at low p_T in the helicity frame (vanishing at high p_T)
- ☑ λ_Φ compatible with 0 in both the reference frames

Heavy flavour decay electrons and muons

Heavy flavour decay electrons @ 7 TeV





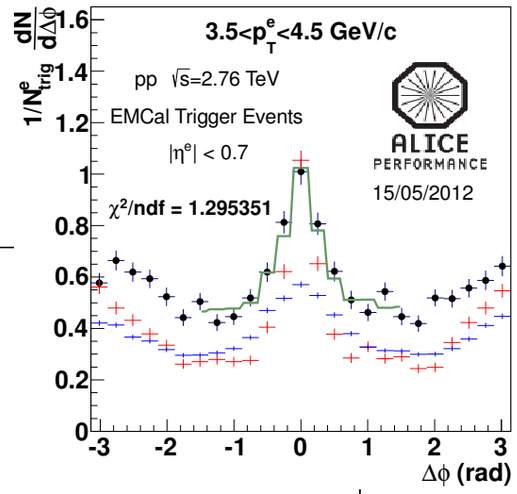
- ☑ High quality tracks in TPC and ITS
- ☑ Electron Identification: TOF+TPC+TRD+EMCAL
- ☑ Cross section of electrons from D and B decays in 0.5-8 GeV/*c*
- ☑ Complementary to ATLAS measurement

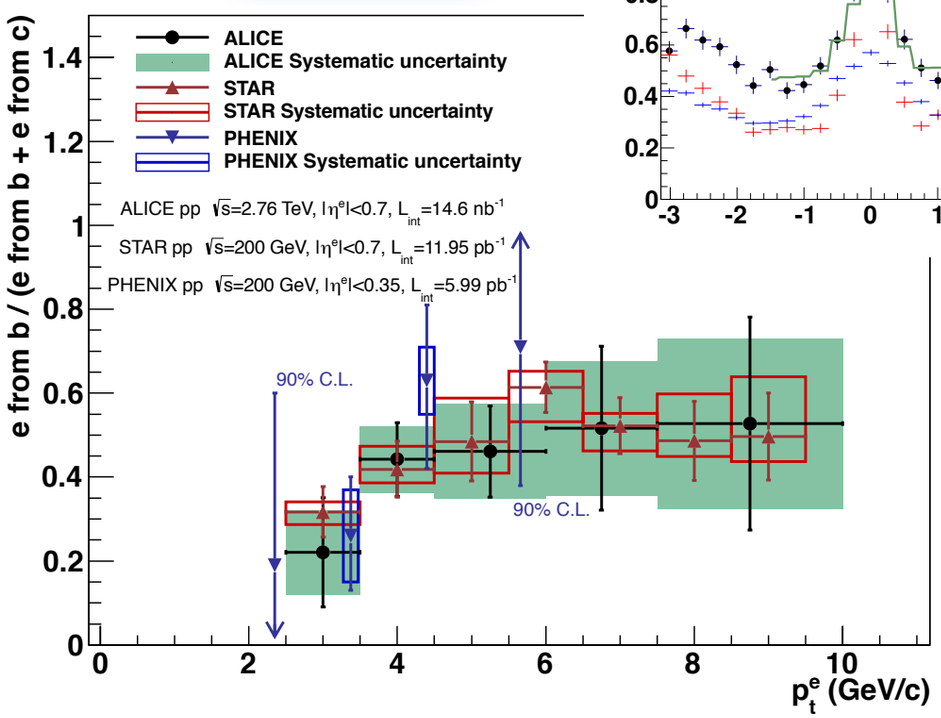
B. I. Abelev et al [ALICE Collaboration] PRD 86 (2012) 112007
ATLAS: PLB707 (2012) 438
FONLL: Cacciari et al., JHEP 1210 (2012) 137

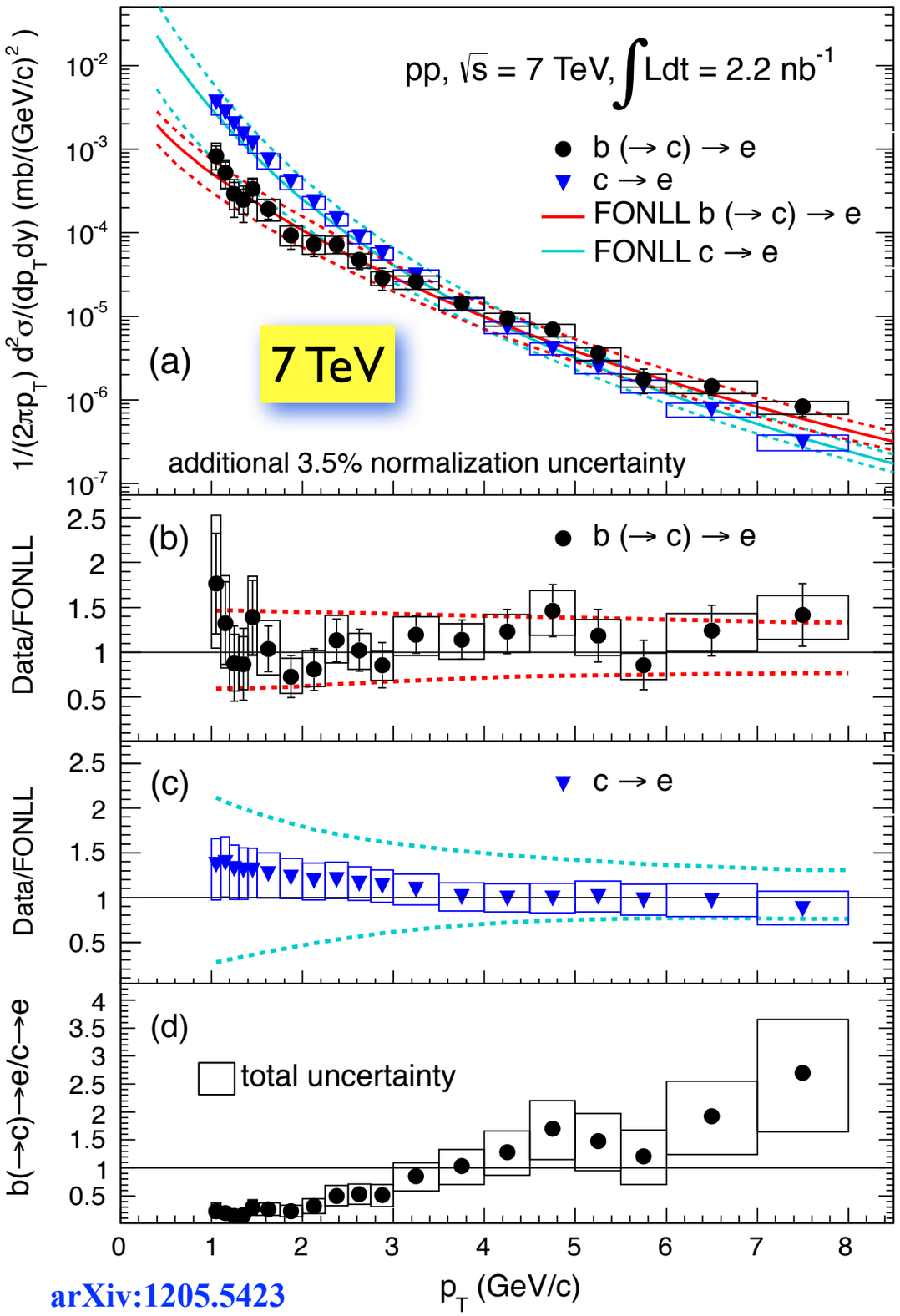
Beauty decay electrons @ 7 and 2.76 TeV

- ☑ Exploit the large displacement of B decay electrons
- ☑ Cut on impact parameter
- ☑ Complementary method based on e-hadron azimuthal correlations.

2.76 TeV

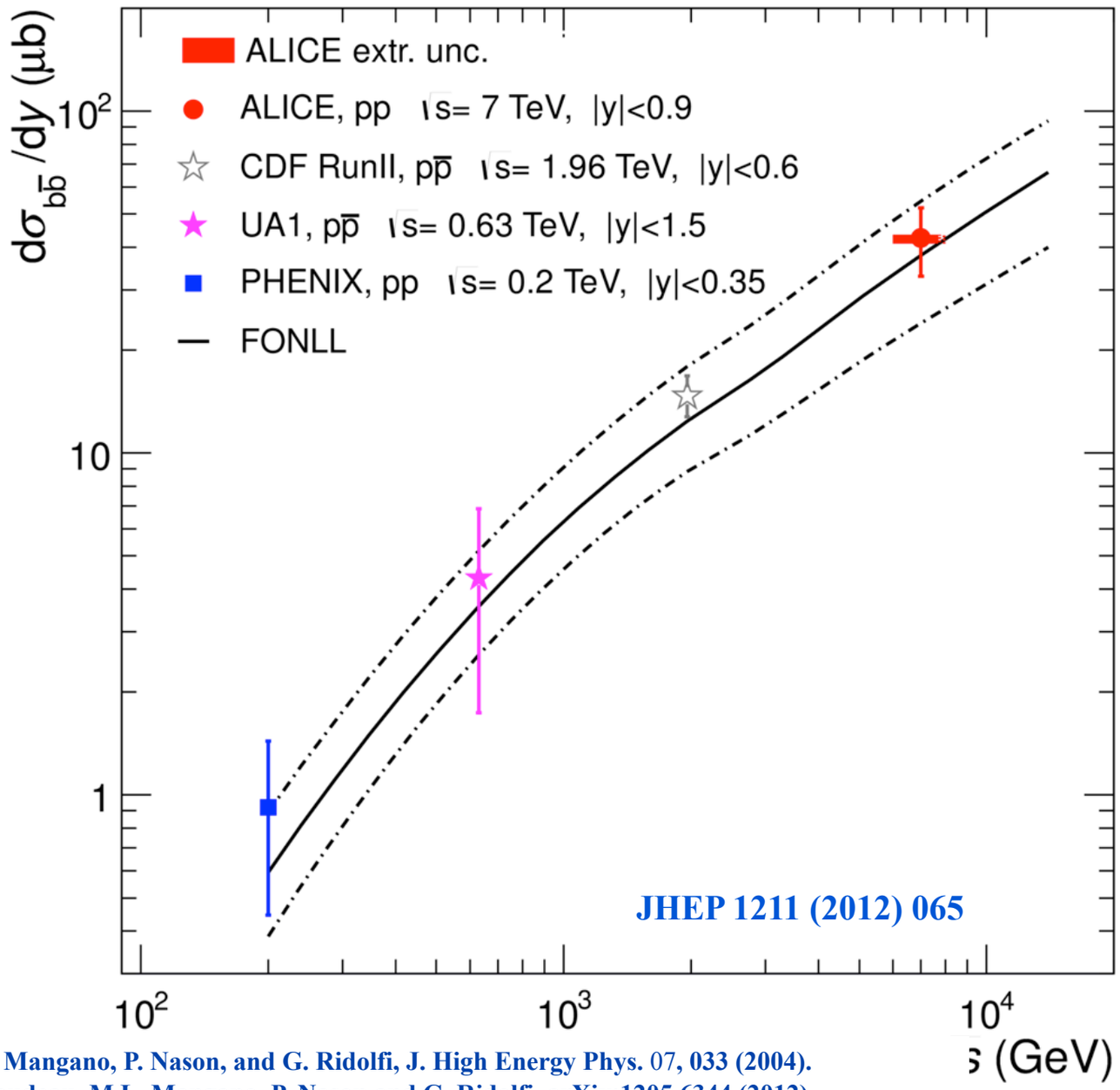






arXiv:1205.5423

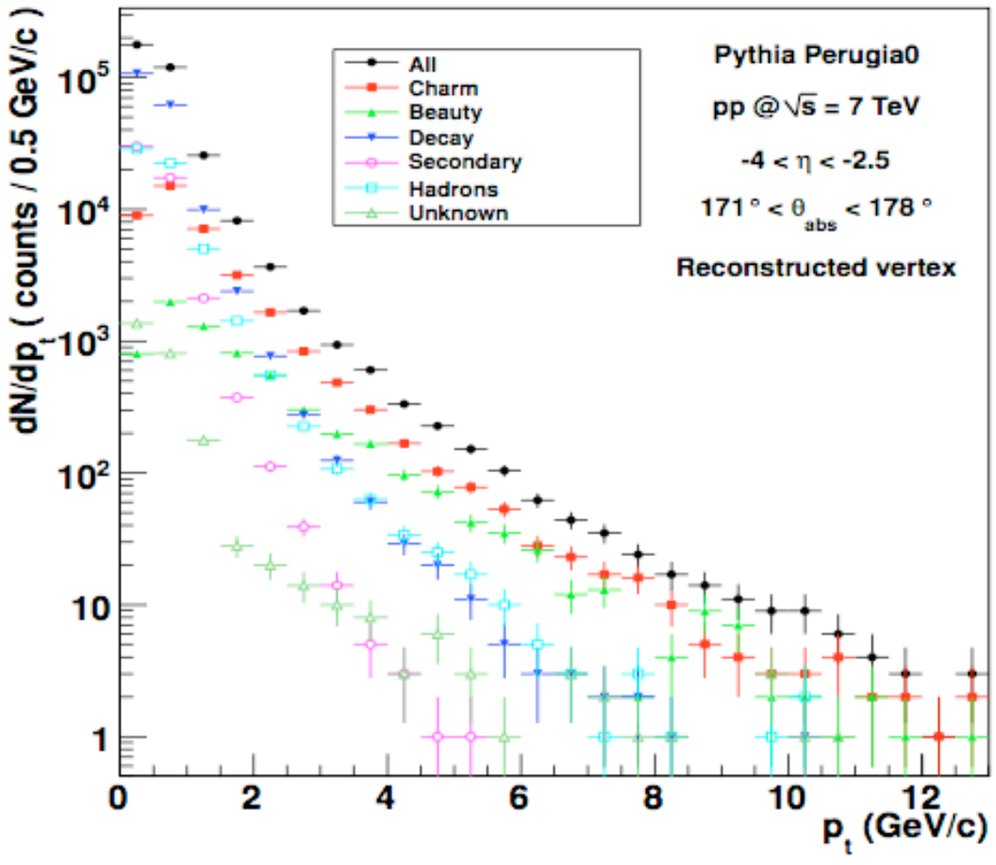
Beauty decay electrons @ 7 TeV



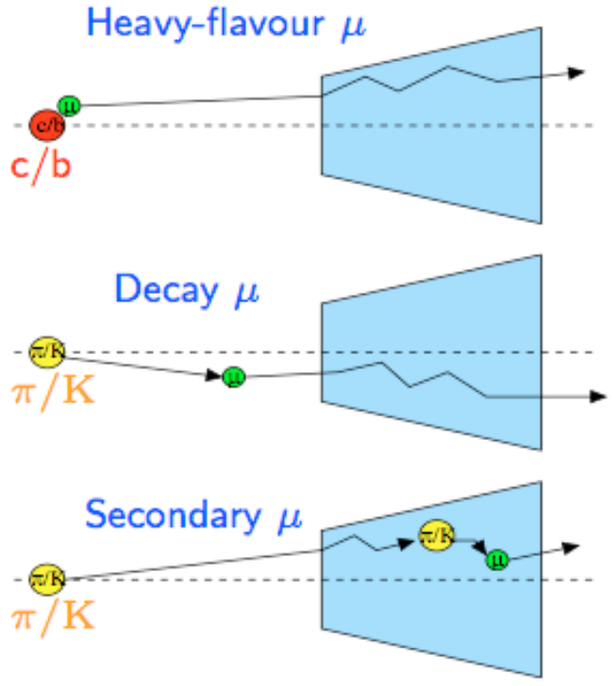
M. Cacciari, S. Frixione, M.L. Mangano, P. Nason, and G. Ridolfi, J. High Energy Phys. 07, 033 (2004).
M. Cacciari, S. Frixione, N. Houdeau, M.L. Mangano, P. Nason and G. Ridolfi, arXiv:1205.6344 (2012).

- Weighted average of displaced J/ψ and heavy flavour beauty electrons compared with other experiments at different center of mass energies. The solid line represent the central value of FONLL

Heavy Flavour muons (-4<η<-2.5)



Muon sources:



☑ Analysis strategy:

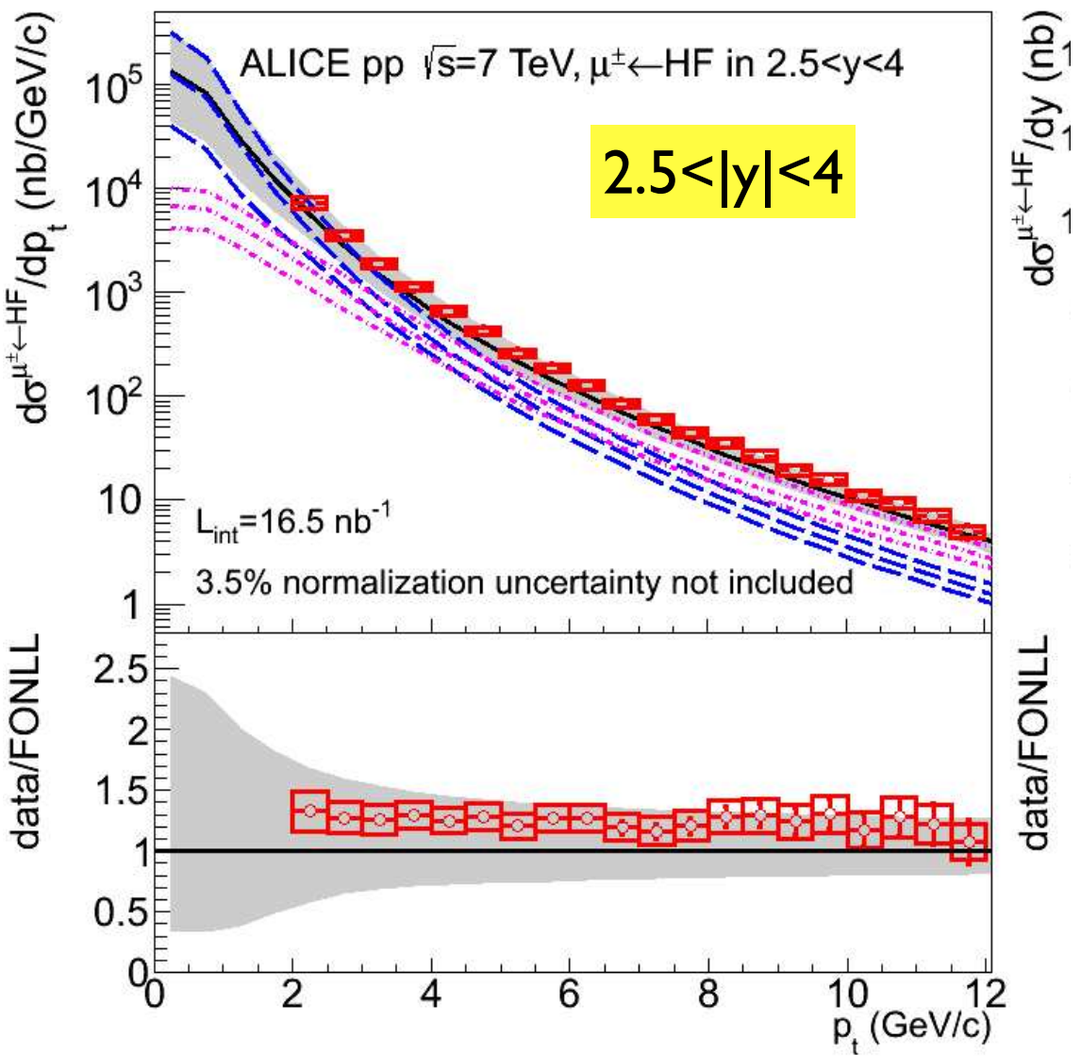
- remove hadrons and low p_T secondary muons by requiring a muon trigger signal
- subtract π/K-decay muons
- what remain are charm and beauty muons

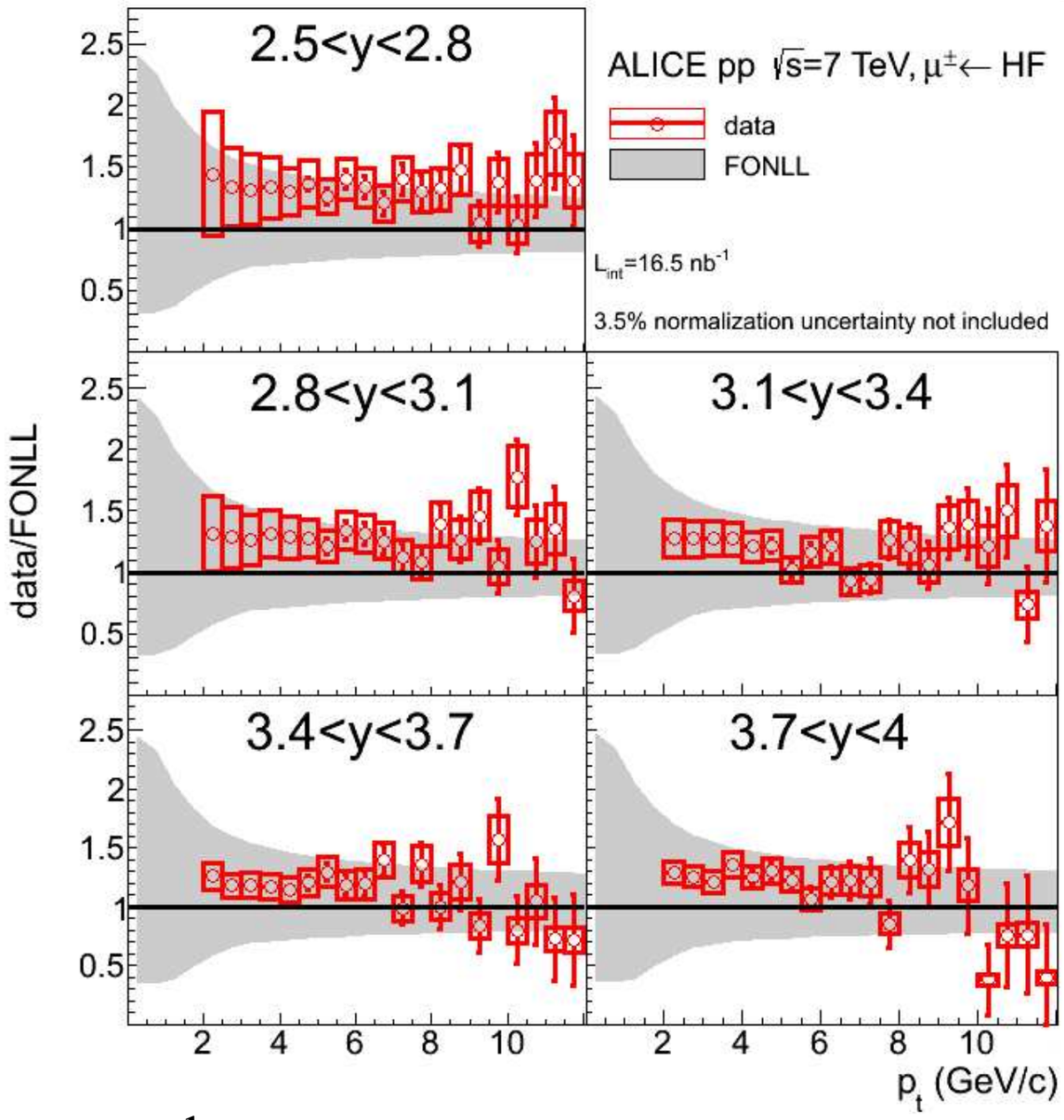
☑ π/K-decay muon subtraction:

- use PYTHIA/PHOJET normalized to inclusive yield below 1 GeV/*c*

Heavy Flavour muons @ 7 TeV

Phys.Lett. B708 (2012) 265-275

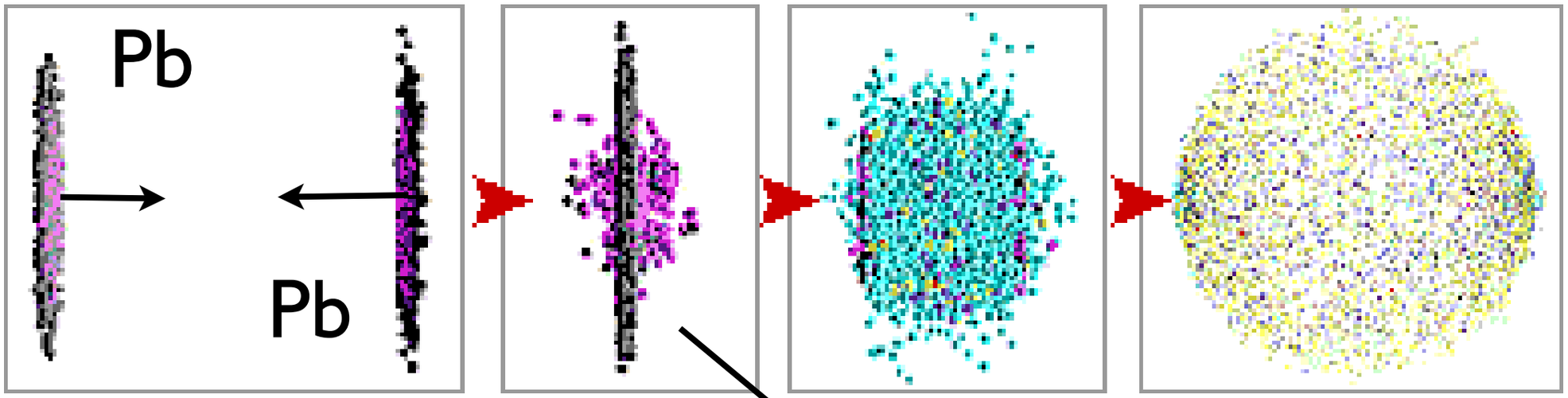


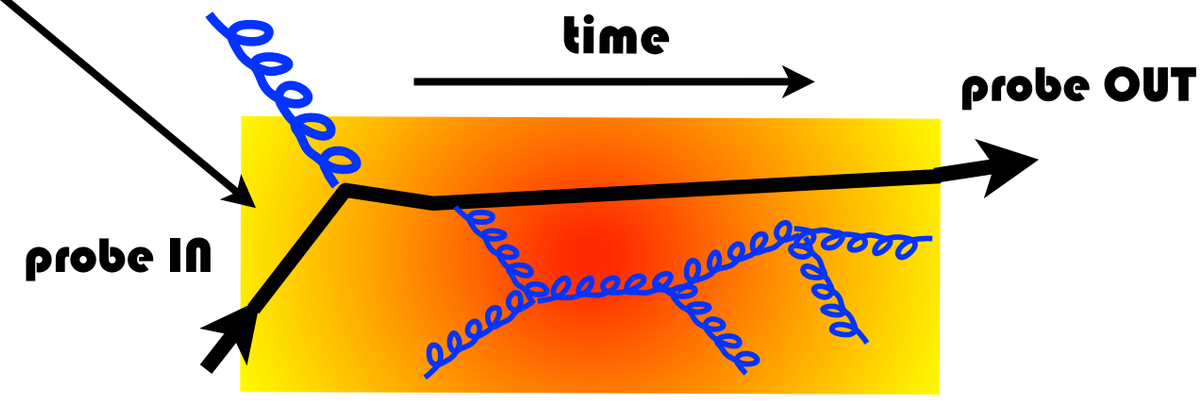


- ☑ FONLL describes the data well, both vs p_T and vs y
- ☑ FONLL indicates beauty dominance above 5 GeV/*c* (central values)
- ☑ Same analysis performed at 2.76 TeV (see backup)

Heavy flavour in pp as reference for Pb-Pb

Heavy flavours in Pb-Pb





- ☑ Heavy quarks produced at the early stage of the collision (*large mass requires high Q^2*)

- ☑ Heavy quarks are expected to lose less energy than light quarks and gluons due to color-charge and dead cone effect → higher penetrating power into QCD medium.

$E_{loss}(light) > E_{loss}(D) > E_{loss}(B)$

Yu. Dokshitzer and D.E. Kharzeev, Phys.Lett. B 519 199–206 (2001). N. Armesto, C. A. Salgado and U. A. Wiedemann. PRD 69 (2004) 114003

M. Djordjevic, M. Gyulassy, Nucl. Phys. A733 (2004) 265.

D sector as example

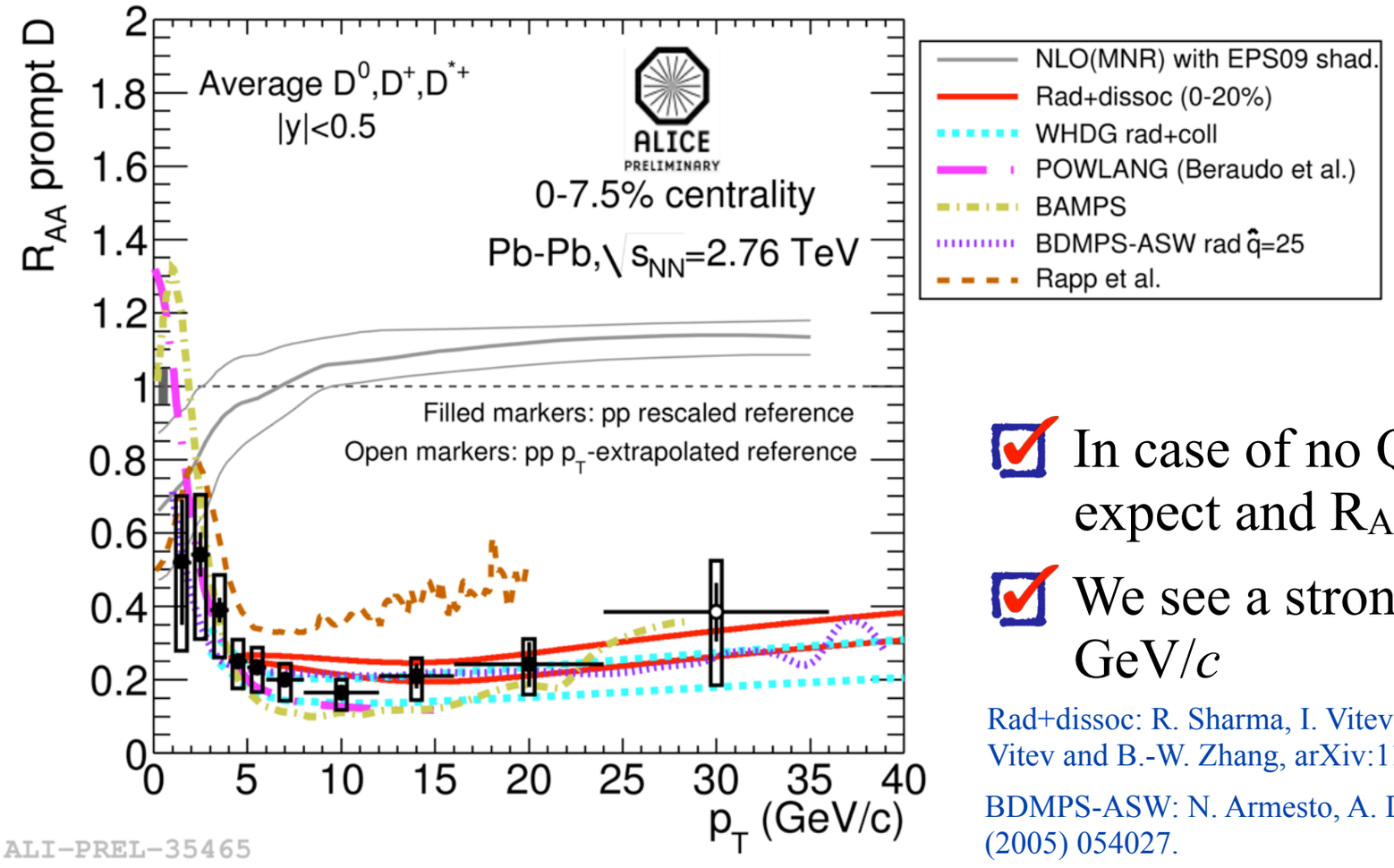
D nuclear modification factor

$$R_{AA}^{D}(p_T) = \frac{dN_{AA}^{D}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}^{D}/dp_T}$$

Pb-Pb yield

Scaling to account for number of binary collisions

pp production cross section



- In case of no QCD medium effects we should expect and $R_{AA} \sim 1$
- We see a strong suppression, factor 5 at p_T =10 GeV/c

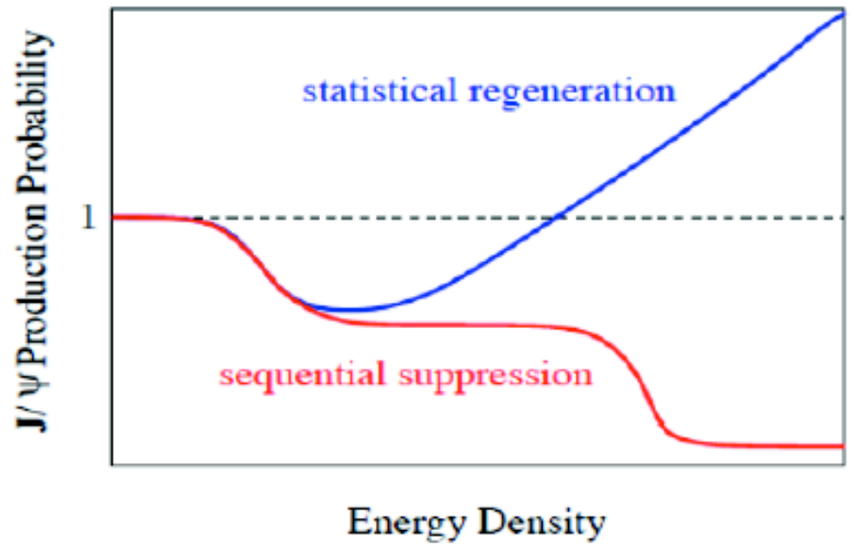
Rad+dissoc: R. Sharma, I. Vitev and B. -W. Zhang, Phys. Rev. C80 (2009) 054902. Y. He, I. Vitev and B.-W. Zhang, arXiv:1105.2566 [hep-ph] (2011).

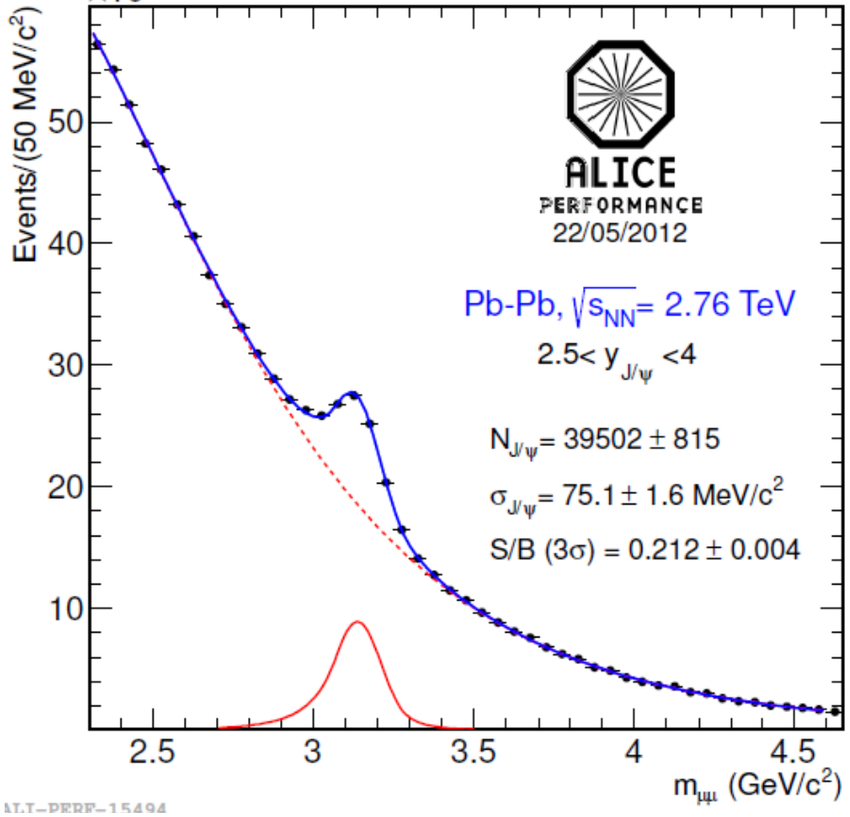
BDMPS-ASW: N. Armesto, A. Dainese, C. A. Salgado and U. A. Wiedemann, Phys. Rev. D71 (2005) 054027.

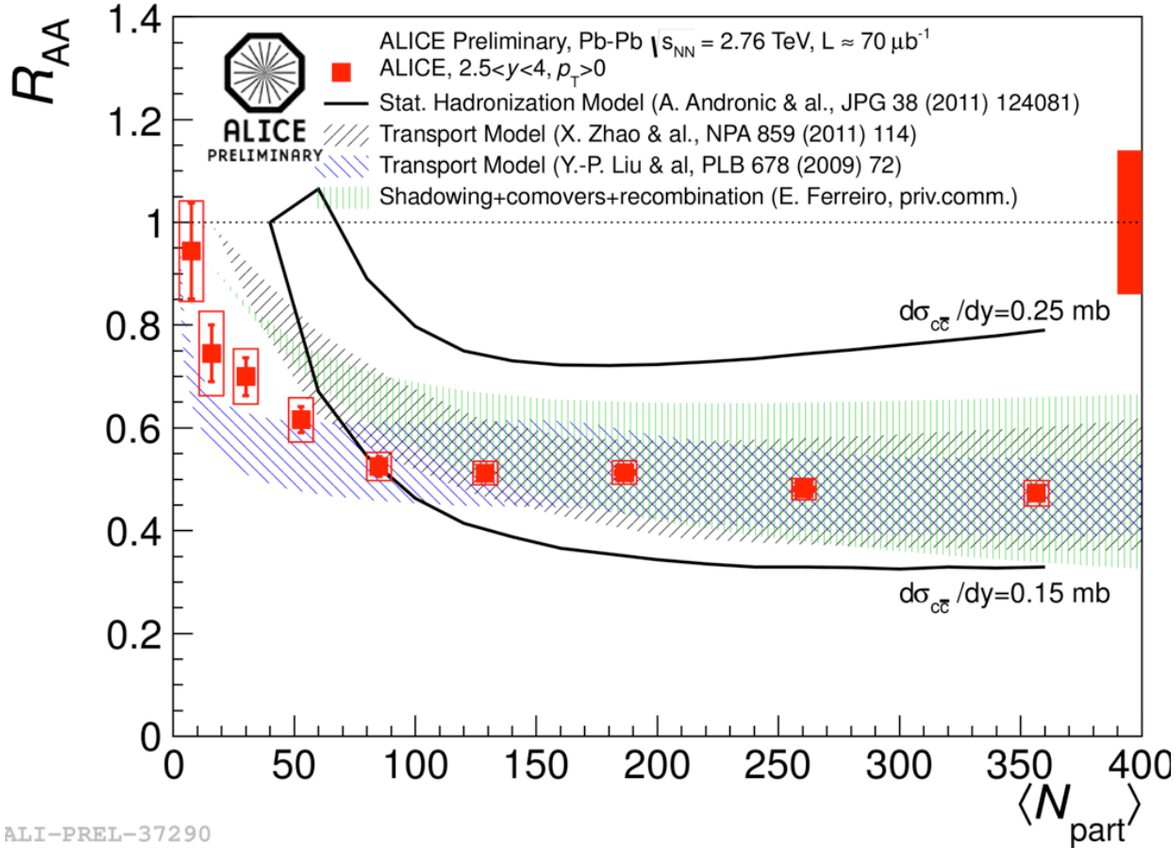
BAMPS: O. Fochler, J. Uphoff, Z. Xu and C. Greiner, J. Phys. G38 (2011) 124152 WHDG rad+coll: W. A. Horowitz and M. Gyulassy, J. Phys. G38 (2011) 124114.

... and J/ψ

- Sequential suppression of the quarkonium states.
  Digal, Petreczky, Satz, PRD 64 (2001) 0940150
- Enhancement via regeneration of quarkonia, due to the large heavy-quark multiplicity
  Andronic, Braun-Munzinger, Redlich, Stachel, PLB 571(2003) 36







Conclusions

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

- D meson production cross section measured down to 1 GeV/c. D meson ratios agrees with LHCb and ee experiments

- J/ψ down to $p_T = 0$ both in central barrel and at forward rapidity

- D mesons and J/ψ production vs charged event multiplicity studied. Agreement between open and hidden charm

- J/ψ polarization investigated. Results are challenging for the models

Backup

Quarkonium production

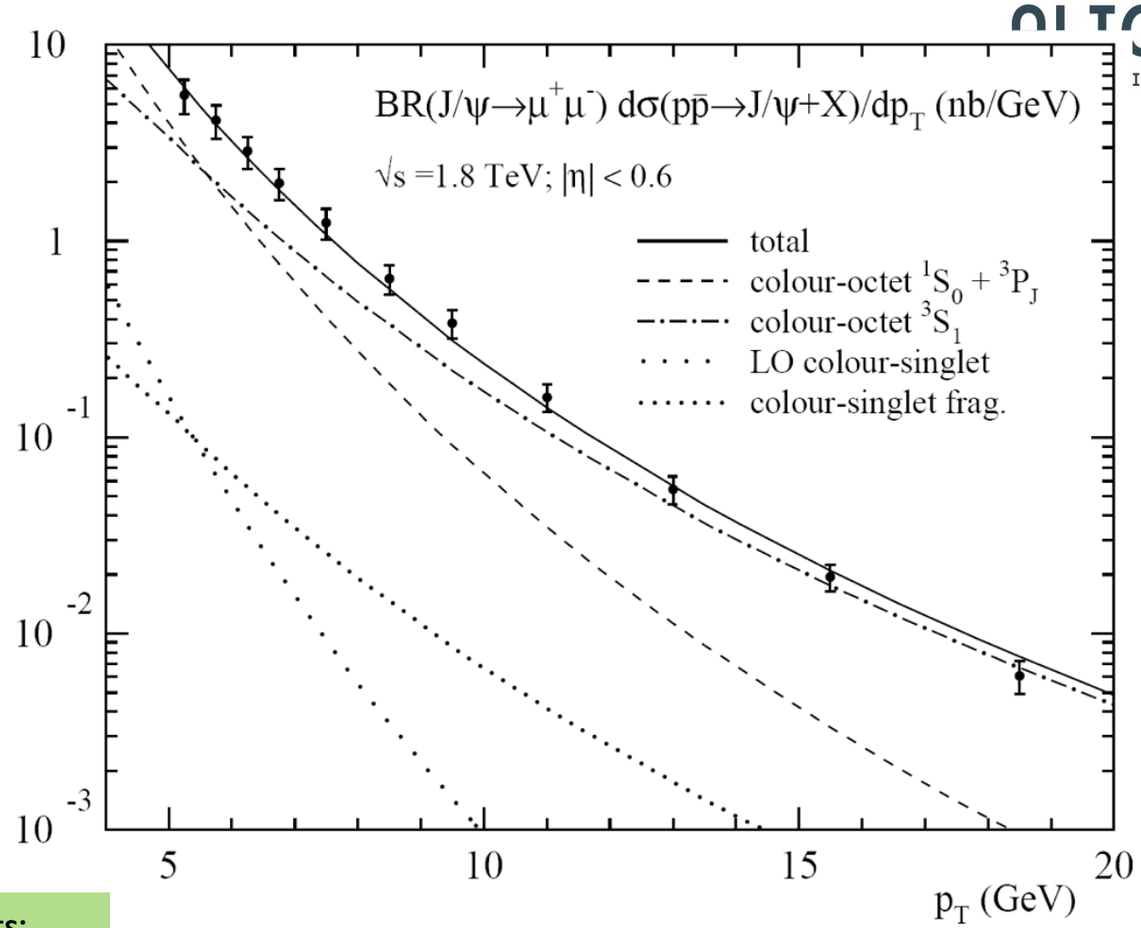
- Quarkonium production:
  - qqbar formation is an hard process
  - binding of the constituents and evolution of the bound state is softer

- Theoretical models assume factorization:

$$\sigma[H] = \sum_i \sigma_n(\Lambda) \langle 0|\mathcal{O}_n^H|0\rangle$$

Short distance coefficients:
- perturbative cross section for the production of a qqbar pair

Long distance matrix elements:
- Non perturbative part embedded
- Assumed to be universal



N. Brambilla*et al.*,arXiv:hep-ph/0412158v2

- In the Color Singlet Model (CSM) the color of the ppbar pair neutralizes in the hard process
- Nonrelativistic QCD (NRQCD): the color can be neutralized also in the long distance part the perturbative cross section can create singlet and octet qqbar systems

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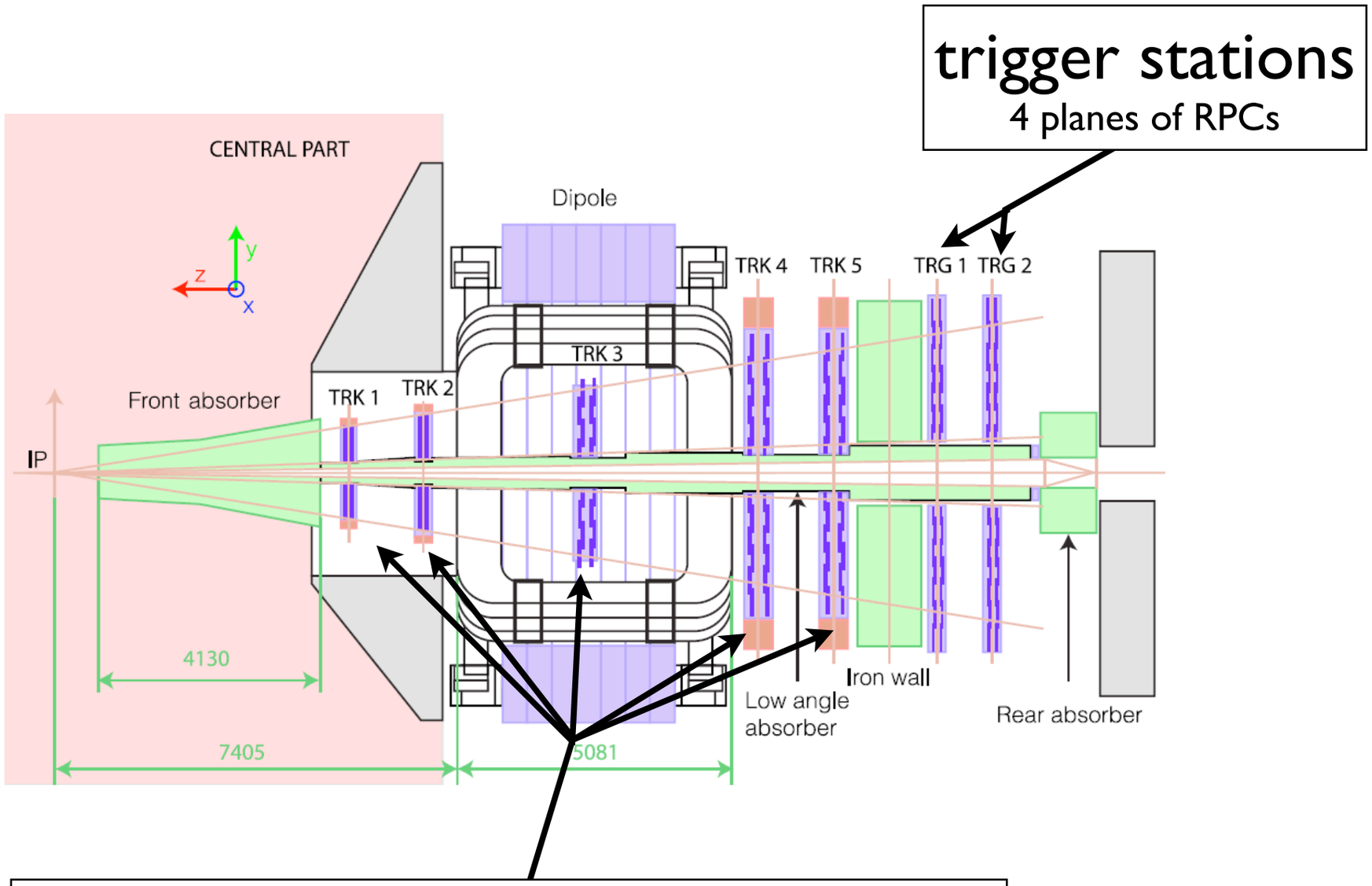
Forward muon spectrometer



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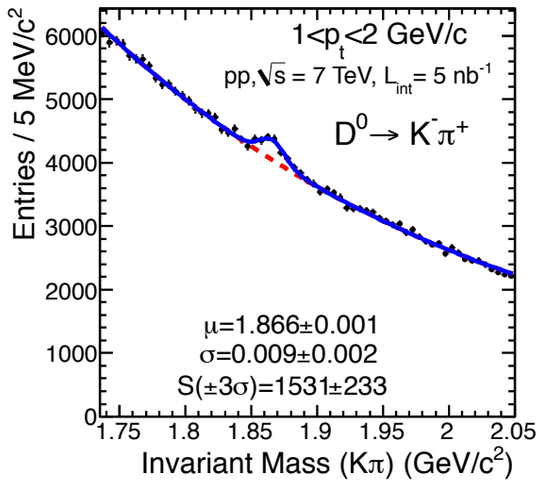
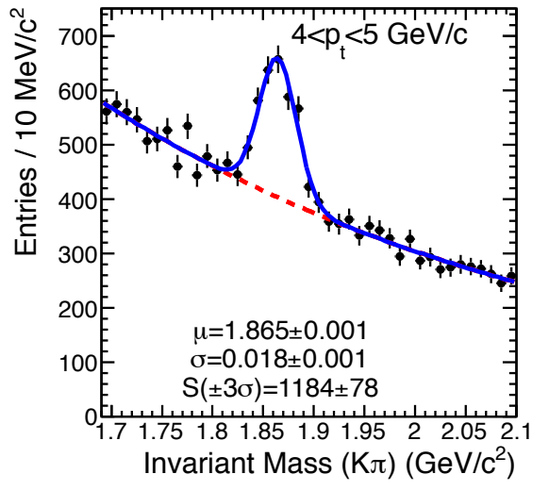
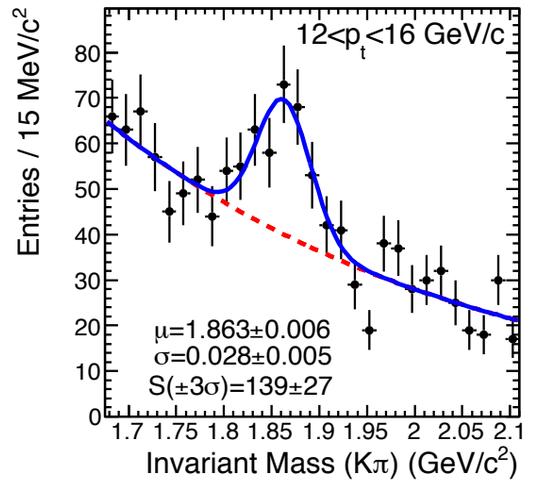
D invariant mass analysis

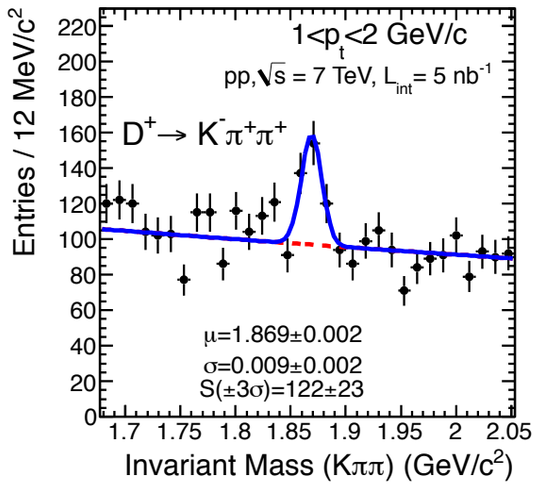
D^0

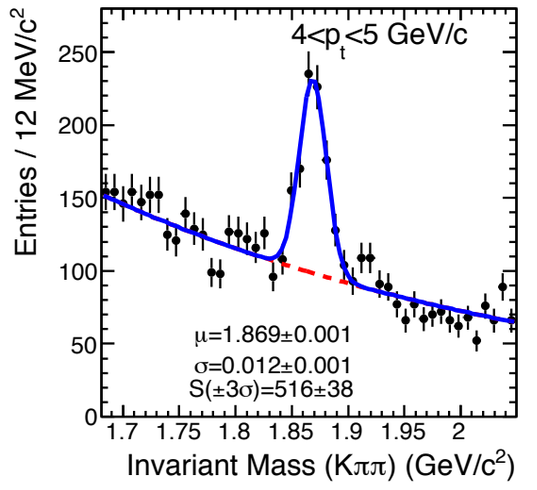


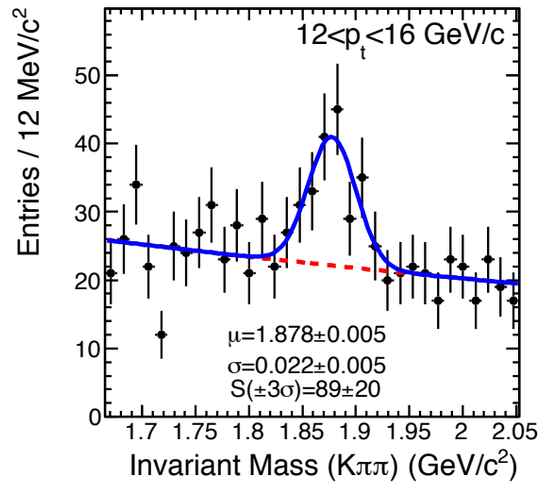




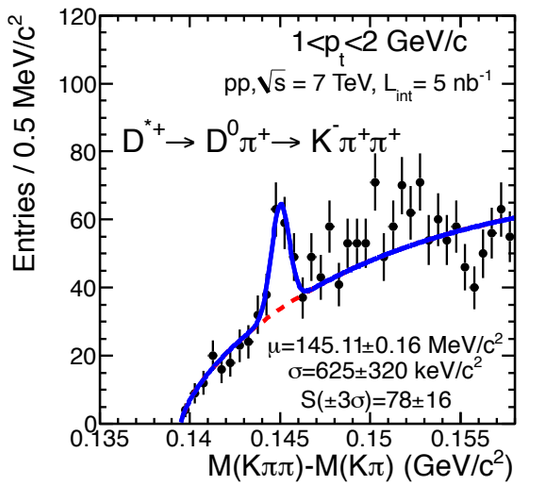
D^+

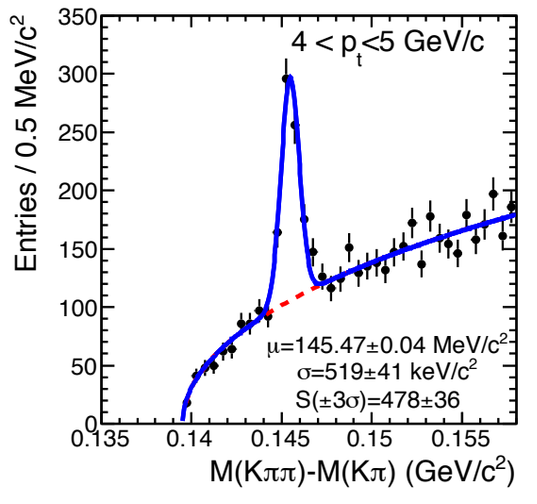


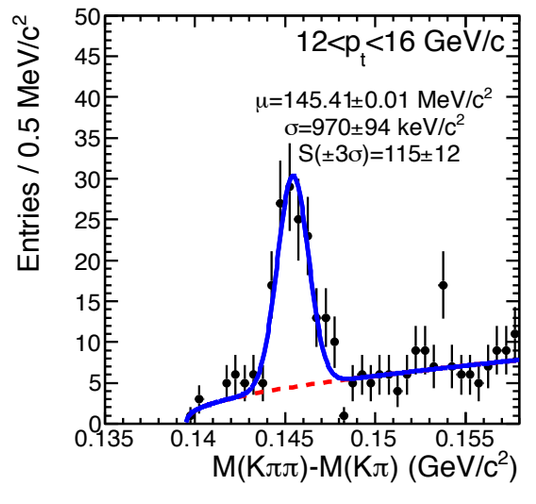




D^{*+}







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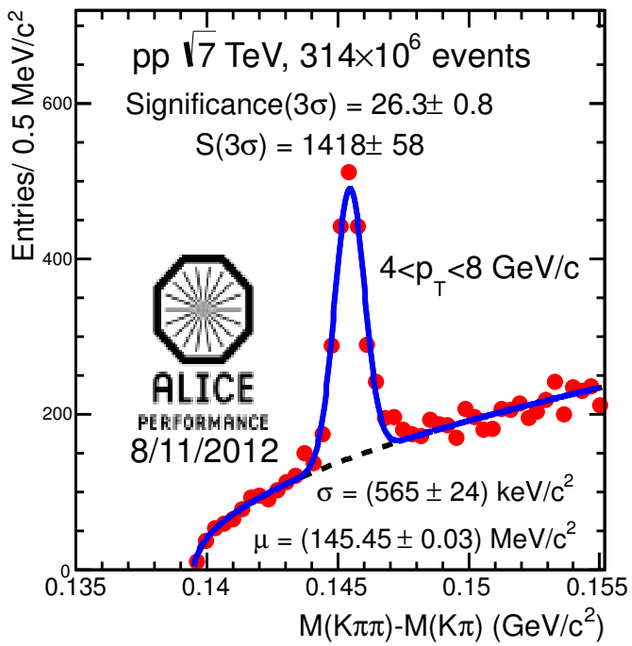
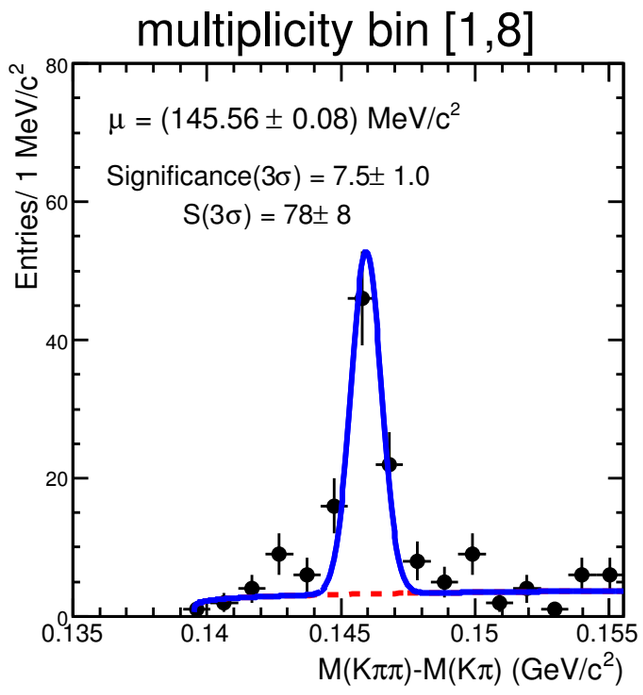
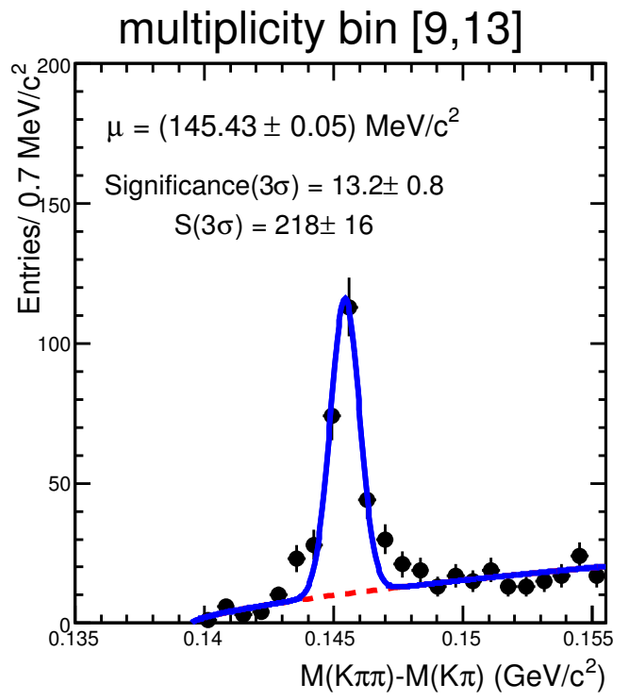
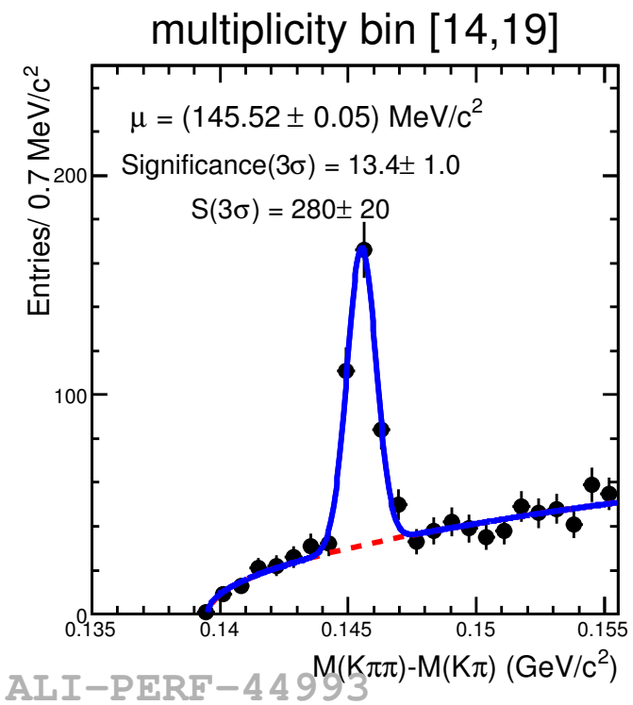
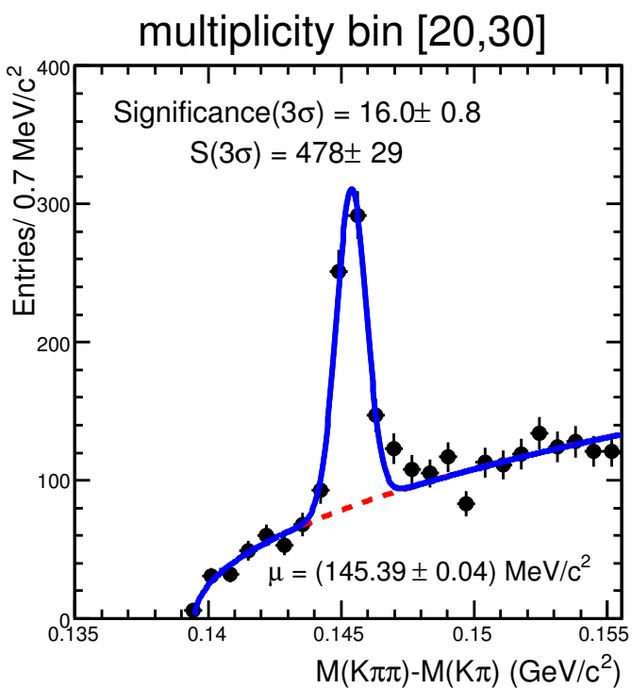
D^{*+} invariant mass analysis vs multiplicity

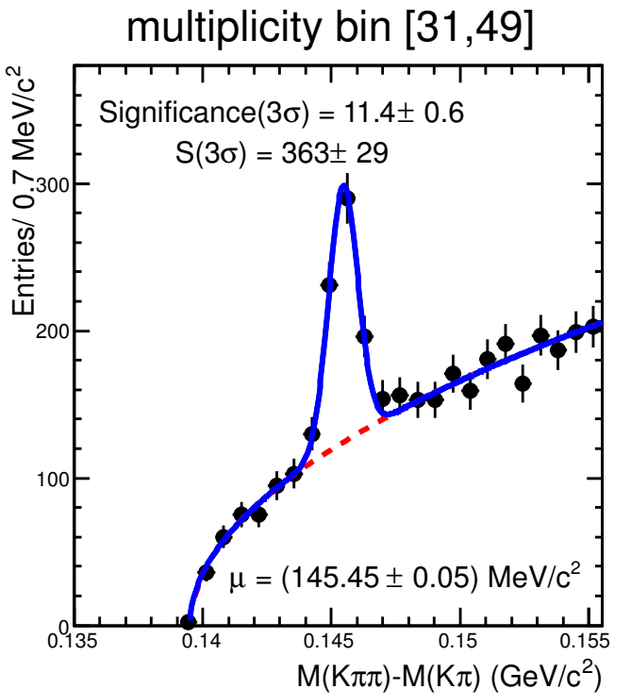












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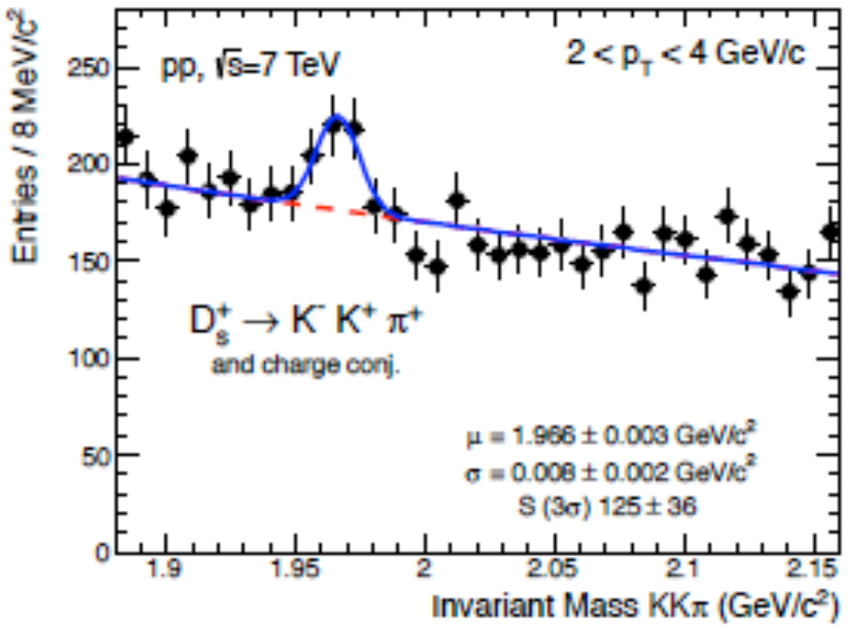
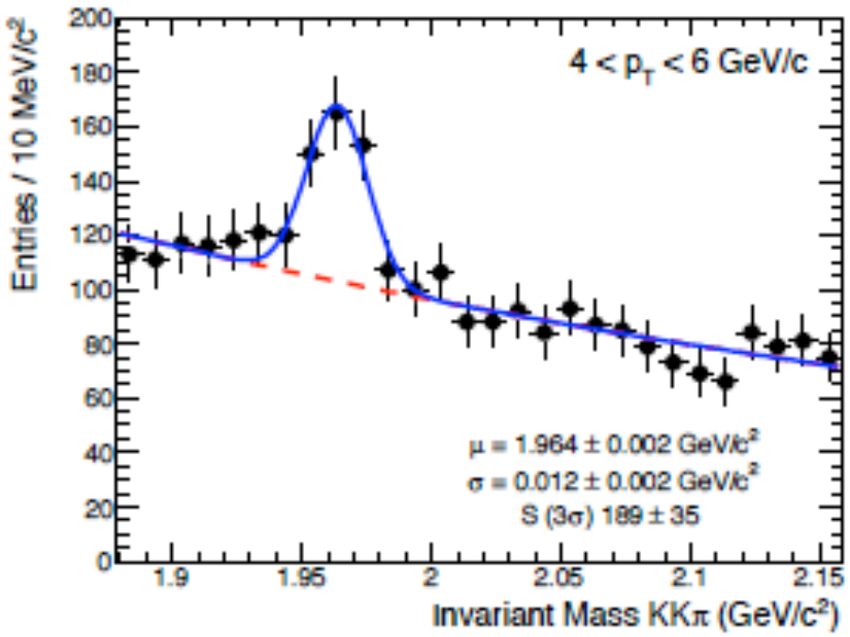
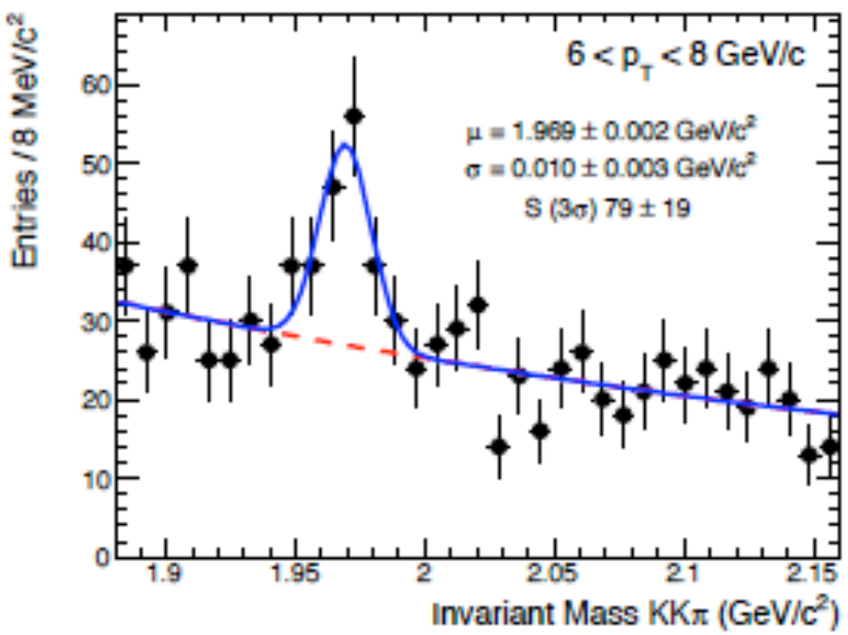
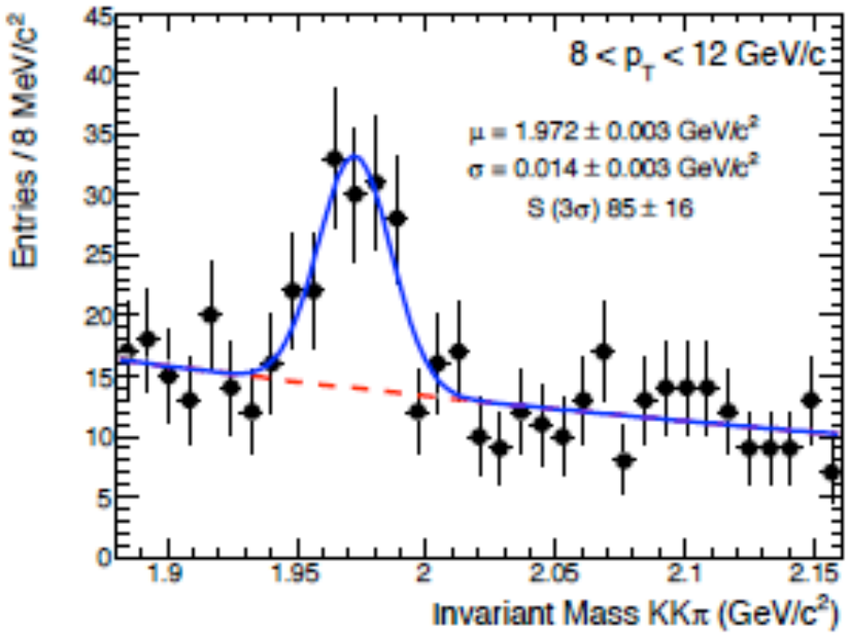
D^+_s invariant mass analysis









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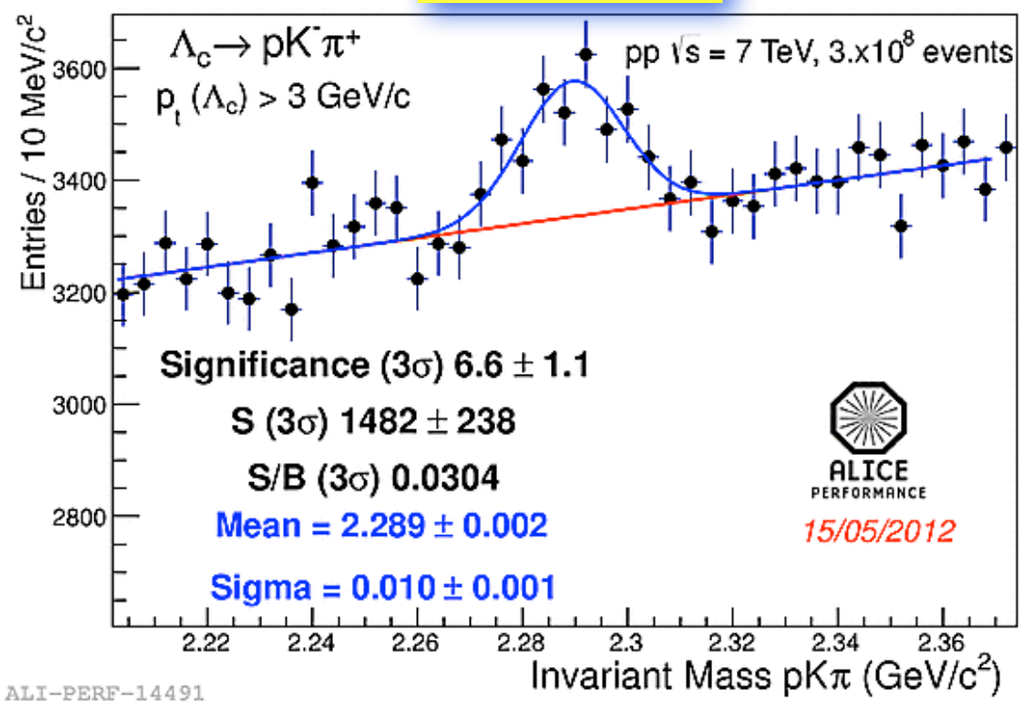
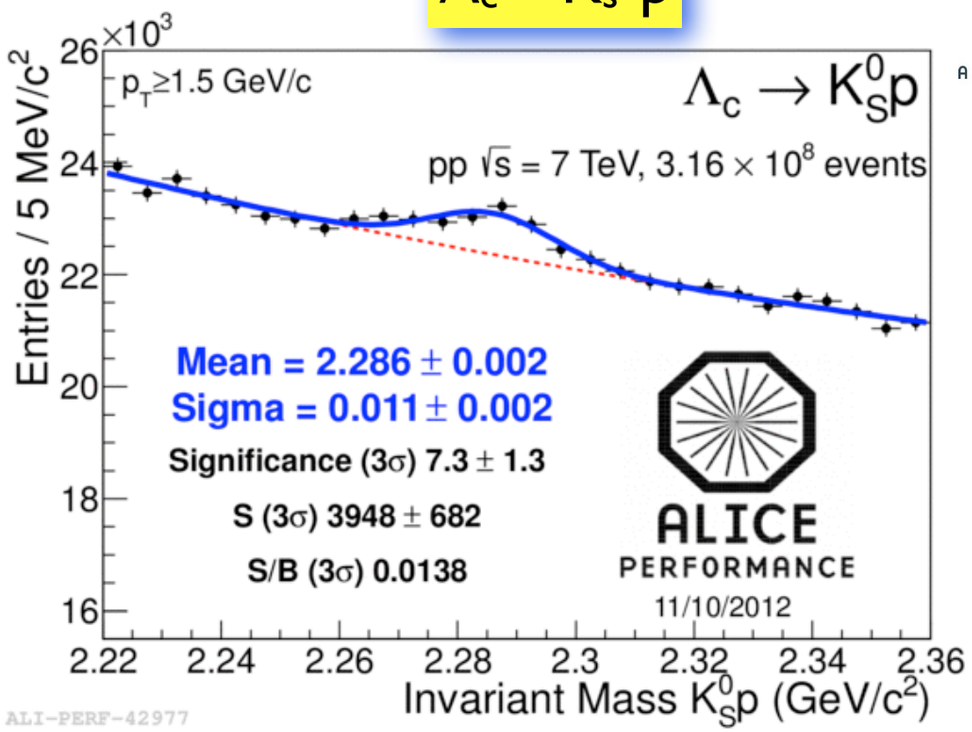
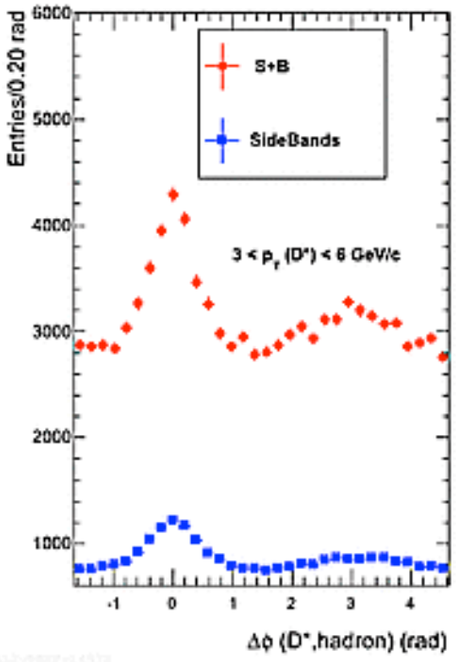
Ongoing ....

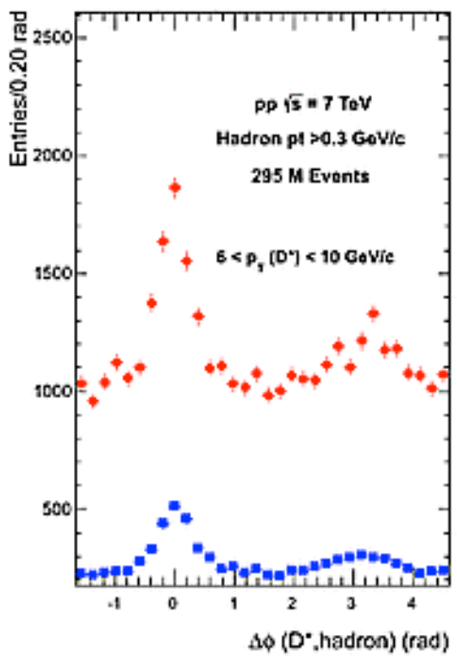
$\Lambda_c \rightarrow pK^-\pi^+$

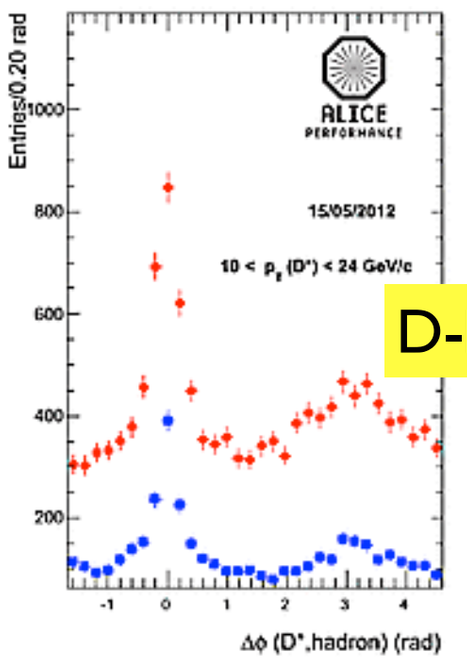


$\Lambda_c \rightarrow K_s^0 p$









D-hadron correlations

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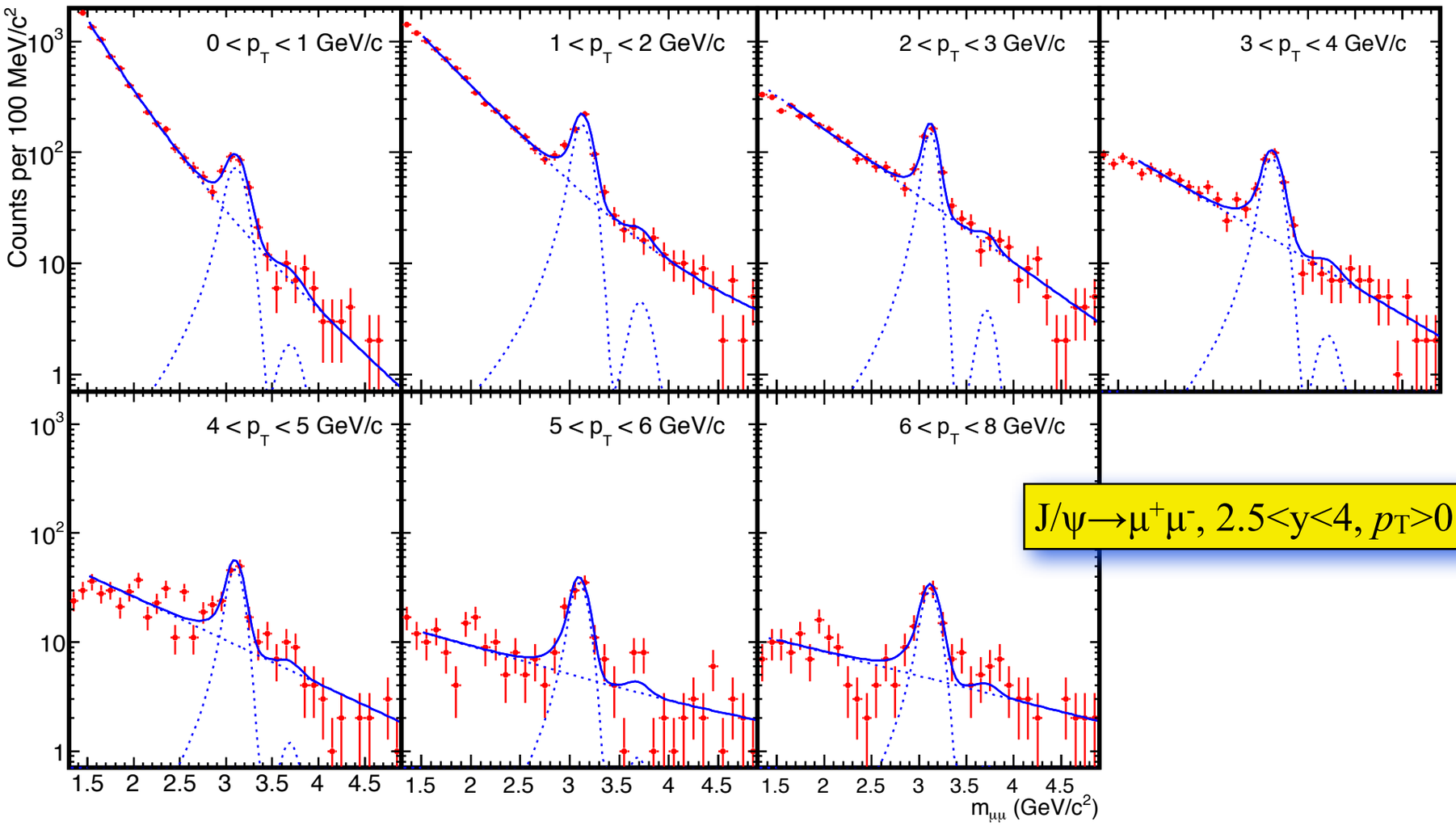
Signal extraction



2012 *ALICE Coll., Phys.Lett.B 704:442-455,2011*

- Signal extraction:
  - forward rapidity: Crystal Ball + sum of 2 exponential
  - mid-rapidity: events counting after background subtraction in the region 2.92-3.16 GeV/*c*
- Several p_T bins available for both the analyses.In the muon channel, signal extracted in 5 rapidity bins

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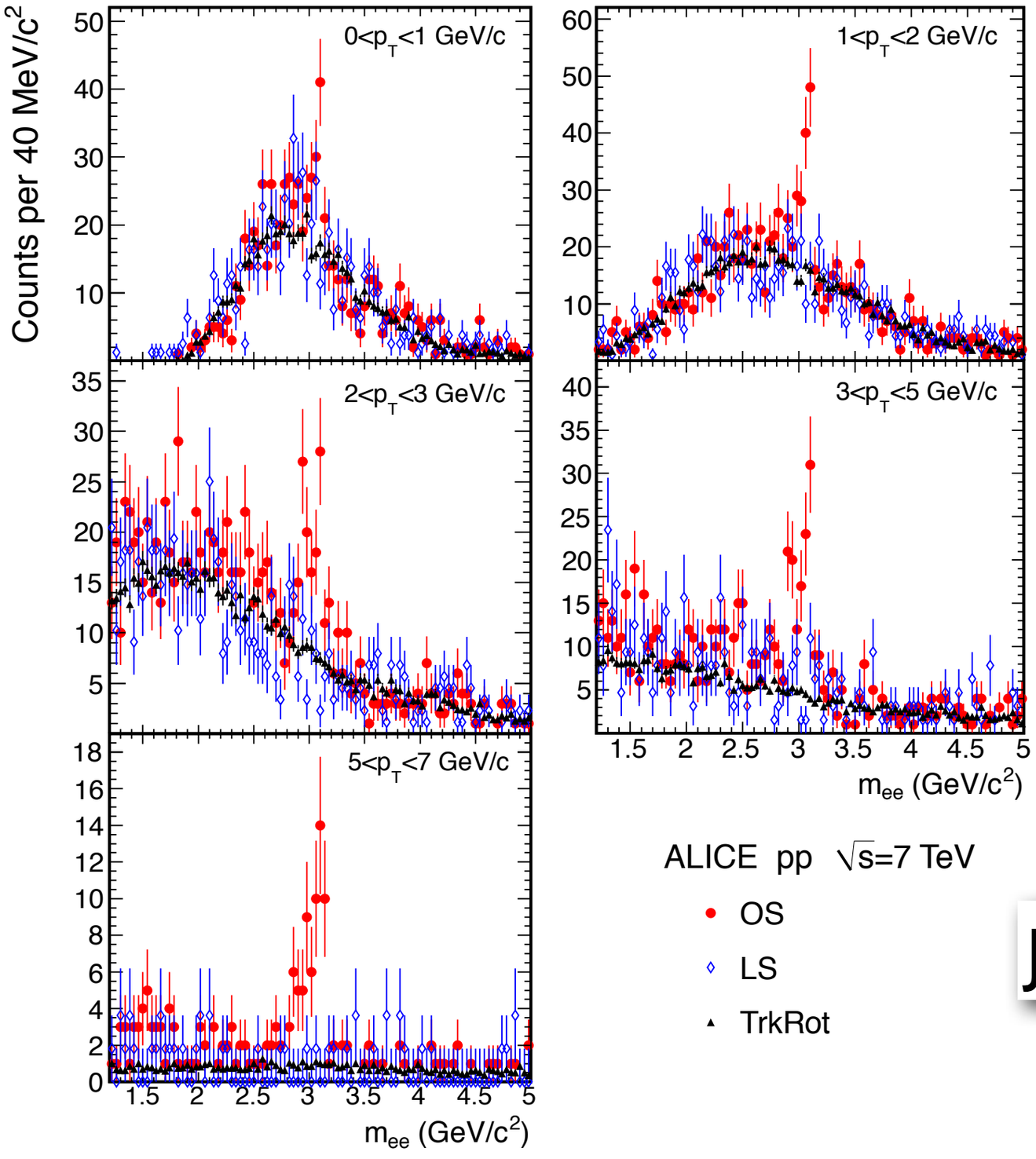
J/ψ at central rapidity



$J/\psi \rightarrow e^+e^-$, $|y|<0.9$

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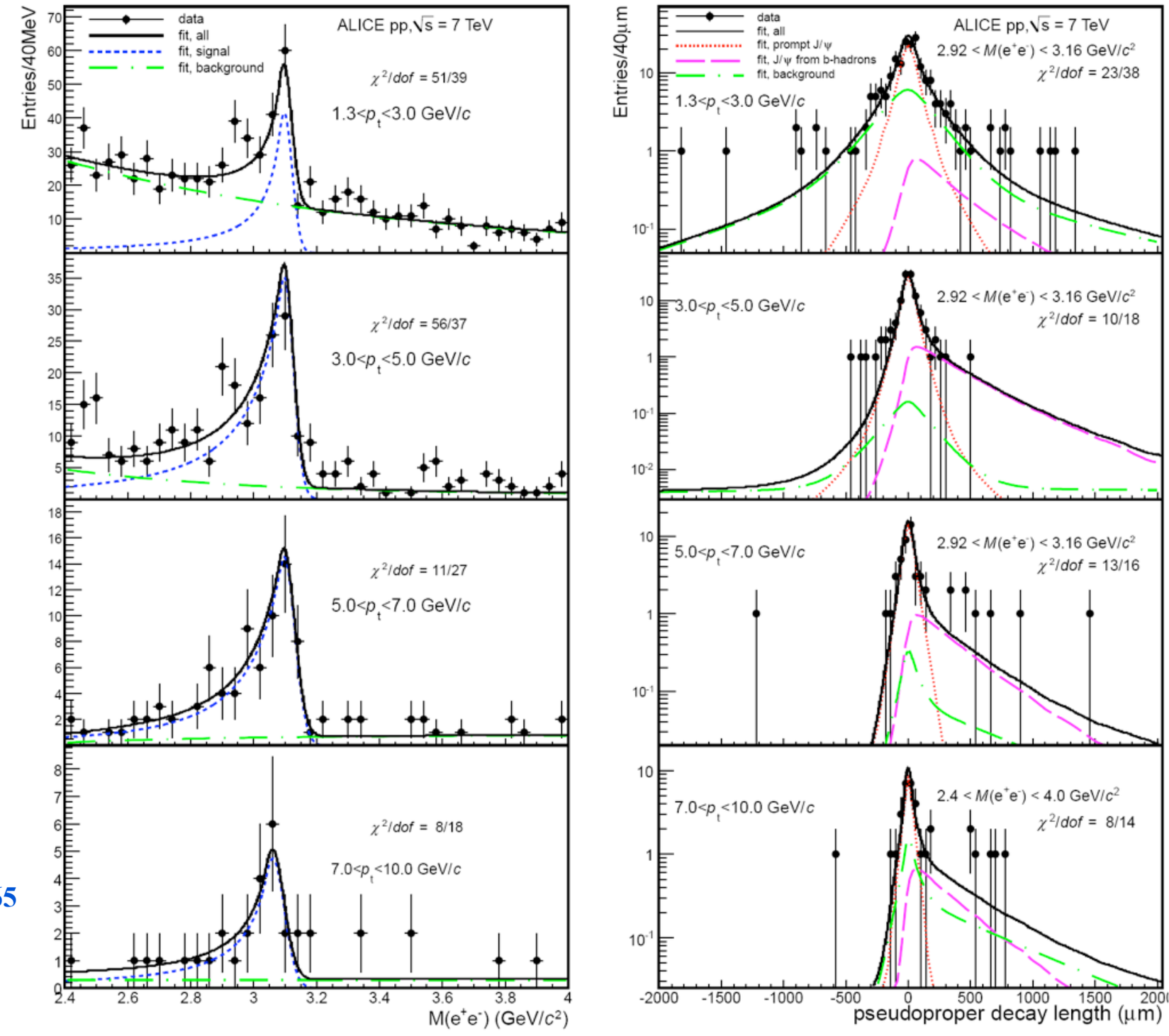
Non prompt J/ψ



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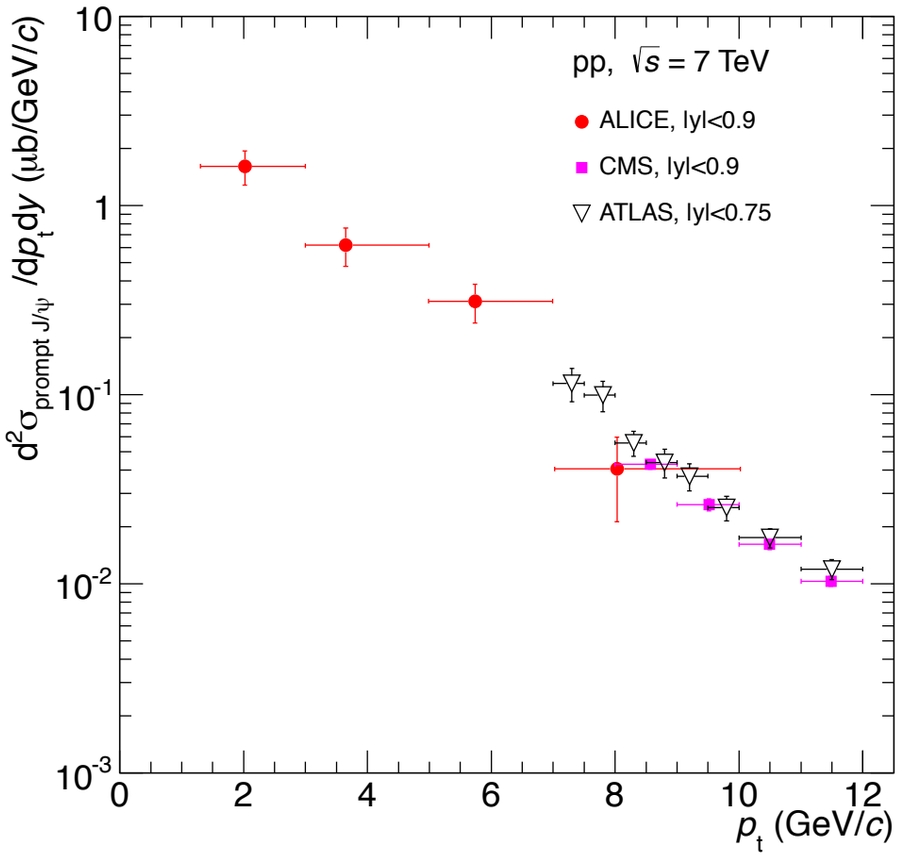
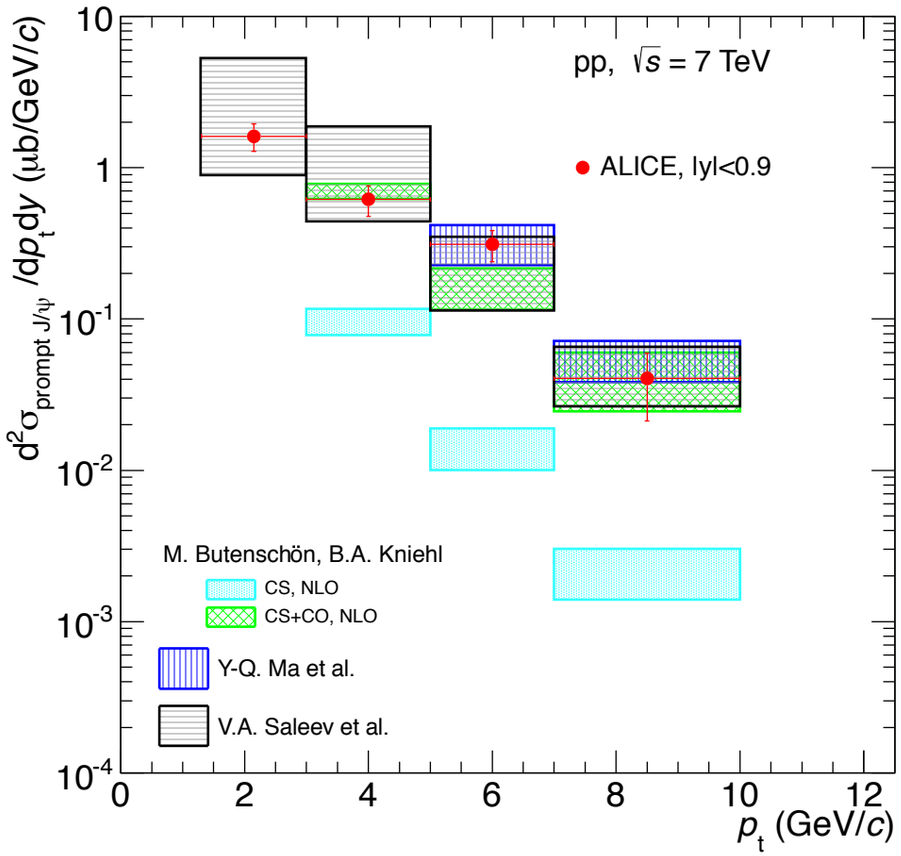
Prompt J/ψ





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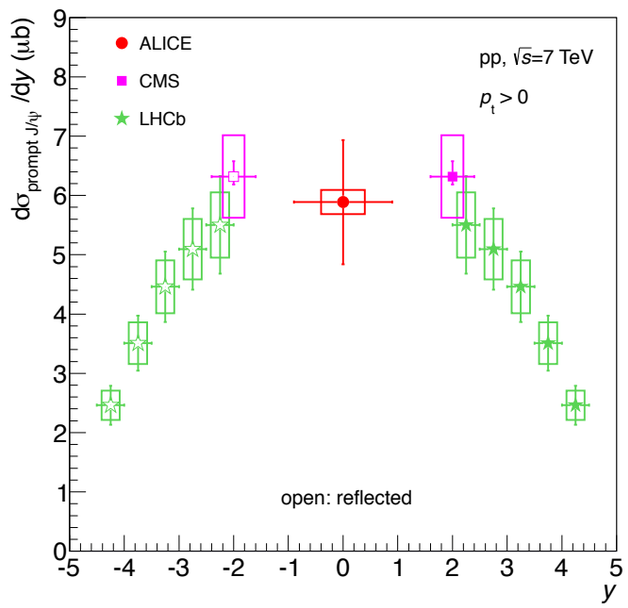
☑ Down to 1.3 GeV/c.



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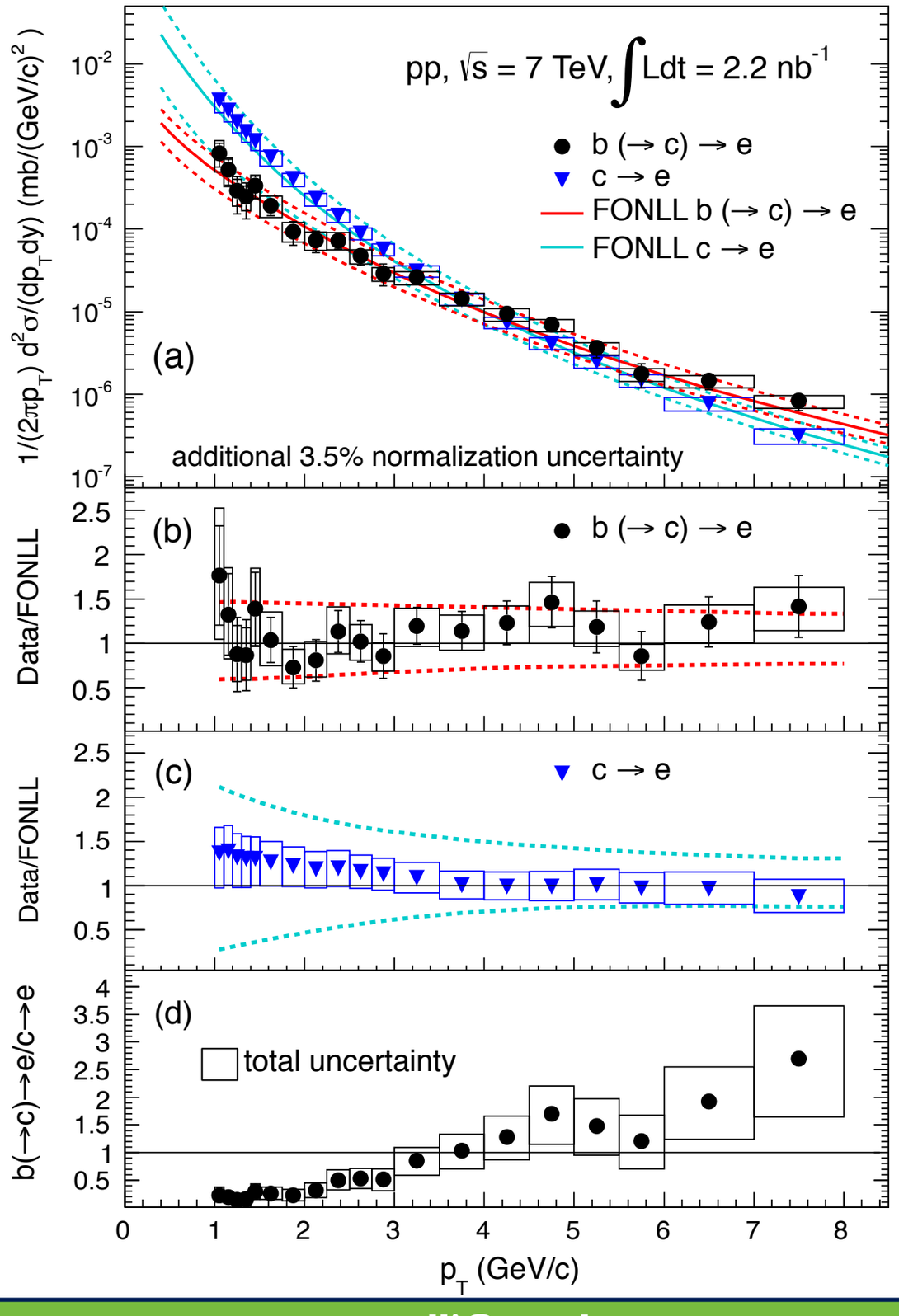
Heavy flavour muons @ 2.76 TeV



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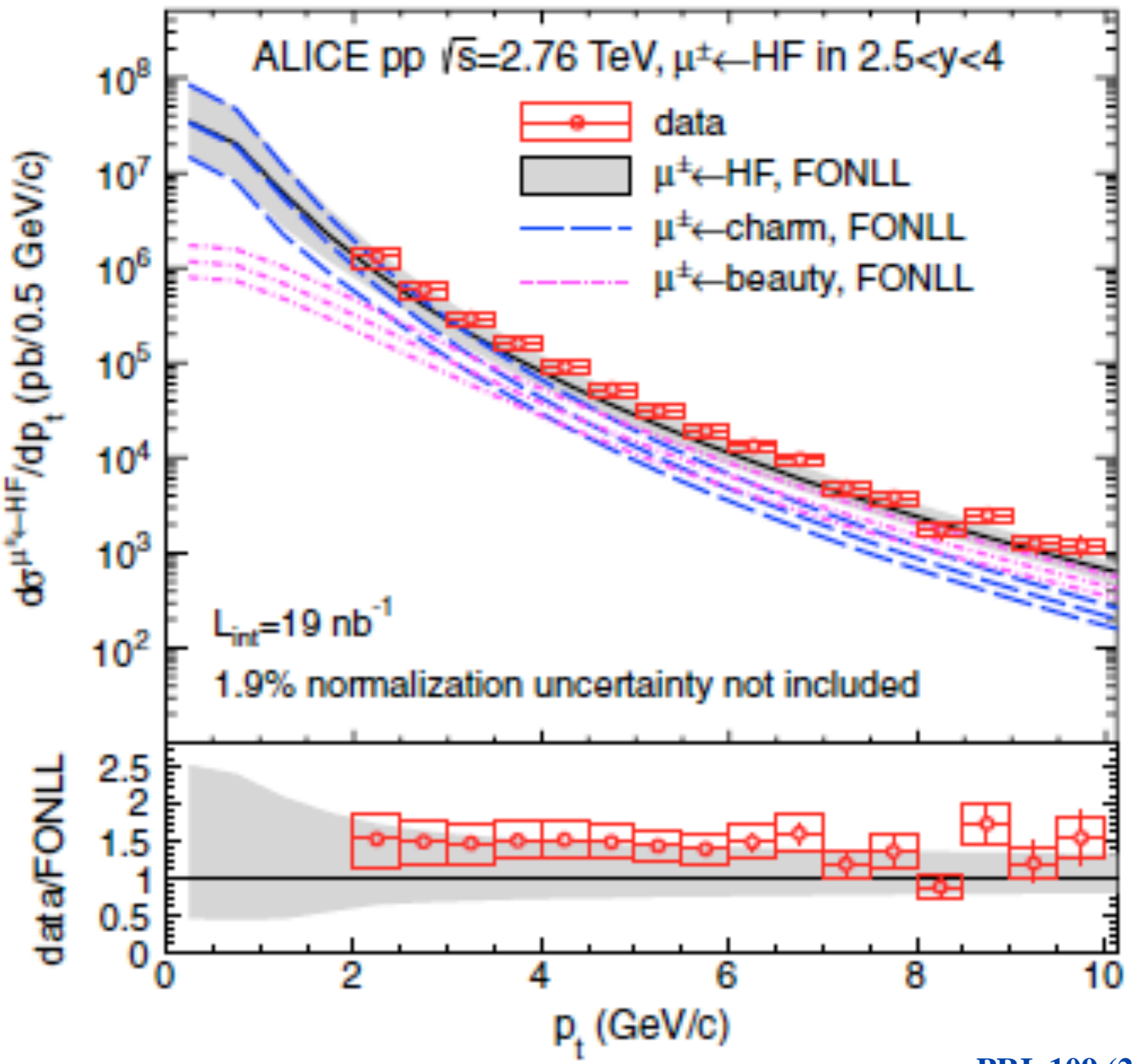
Heavy flavour decay electrons @ 7 TeV



PRL 109 (2012) 112301

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