Open Heavy Flavour and J/ψ production in proton-proton collisions measured with the ALICE experiment at LHC

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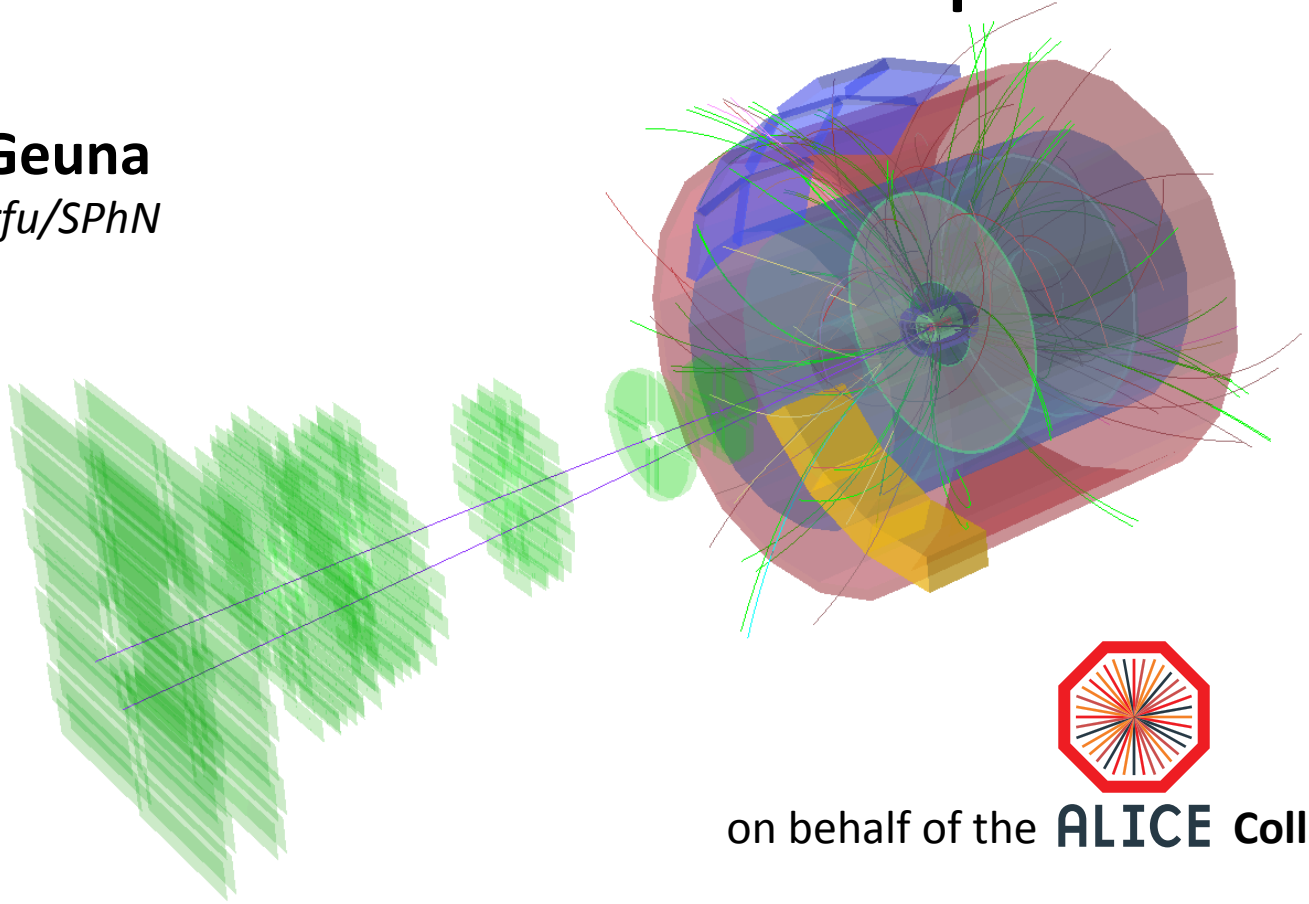


on behalf of the ALICE **Collaboration**

Outline

- Physics motivations
- The ALICE detector
- Open Heavy Flavour production in pp collisions:
  - Charmed meson cross sections
  - Electrons from heavy flavour decays
  - Muons from heavy flavour decays
- J/ψ production in pp collisions :
  - Inclusive J/ψ cross section
  - J/ψ polarization
  - Multiplicity dependence of J/ψ production
  - J/ψ from b-hadron decays
- Conclusions

Physics motivations

Why do we study Open Heavy Flavour and Quarkonium production in pp collisions ?

➡ Testing ground of QCD calculations at the new LHC energy regimes
($\sqrt{s}$ = 2.76 and 7 TeV)

Heavy-Flavour

- Measure production cross section of charm and beauty quarks (down to low p_T)
- Compare to pQCD calculations

Quarkonia

- Study the hadroproduction of quarkonium states
- Challenge for models, but recent progress seen with LHC data

➡ Crucial reference for corresponding measurements in ultra relativistic heavy-ion collisions (Pb-Pb at LHC)

- Heavy Flavours and Quarkonia probe the properties of the strongly interacting medium formed in HI collisions

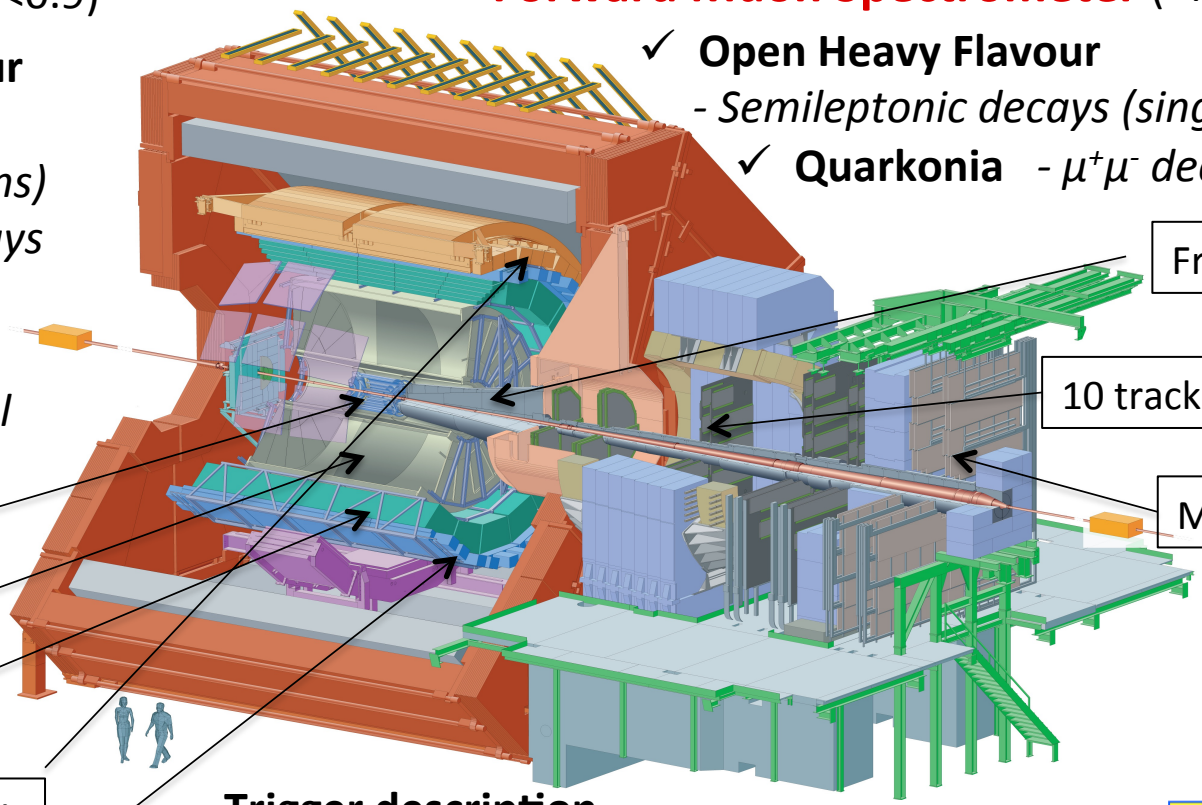
ALICE detector

Central Barrel (|η|<0.9)

- ✓ **Open Heavy Flavour**
  - *Charm hadronic channels (D mesons)*
  - *Semileptonic decays (single electrons)*
- ✓ **Quarkonia**
  - *e^+e^- decay channel*

Forward Muon Spectrometer (-4 < η <-2.5)

- ✓ **Open Heavy Flavour**
  - *Semileptonic decays (single muons)*
- ✓ **Quarkonia** - *$\mu^+\mu^-$ decay channel*



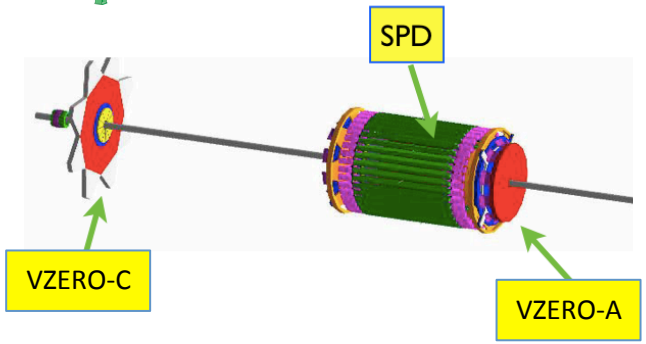
Tracking: ITS, TPC, TRD

PID: TPC, EMCAL, TRD, TOF

Vertexing: ITS

Trigger description

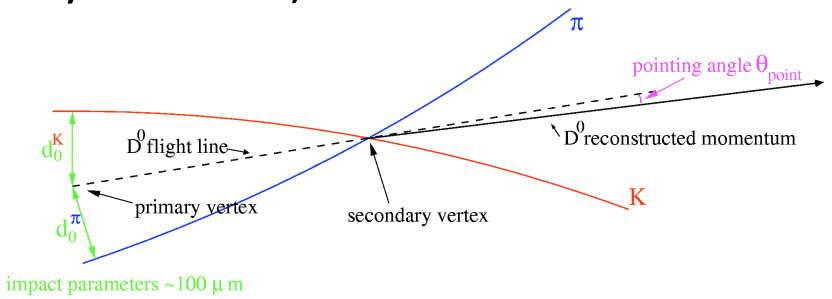
- ***Minimum Bias (MB) trigger***: VZERO-A *or* VZERO-C *or* SPD
- ***Single-Muon trigger***: muon in forward spectrometer in coincidence with MB trigger (p_T^{cut} = 0.5 GeV/c)

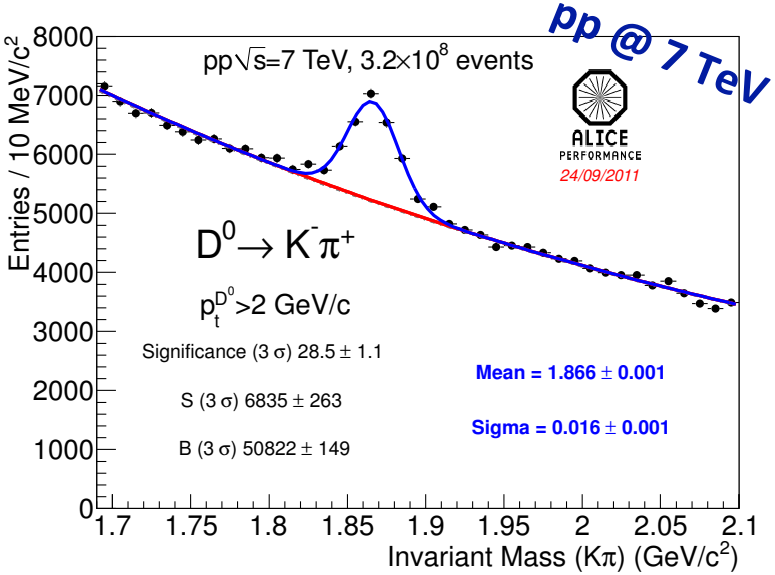


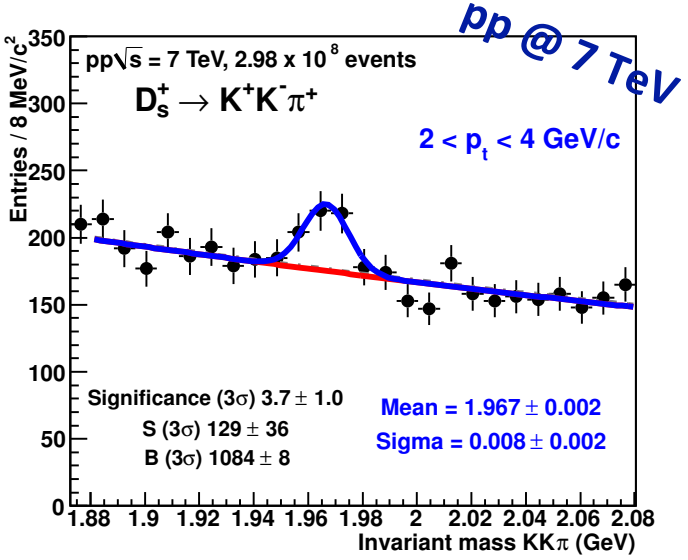
Open Heavy-Flavour: analysis technique (I)

Hadronic channels (|y|<0.5)

- Topological reconstruction (decay channels)
- Tracking: TPC + ITS
- PID: TPC + TOF
- Secondary vertexing: ITS





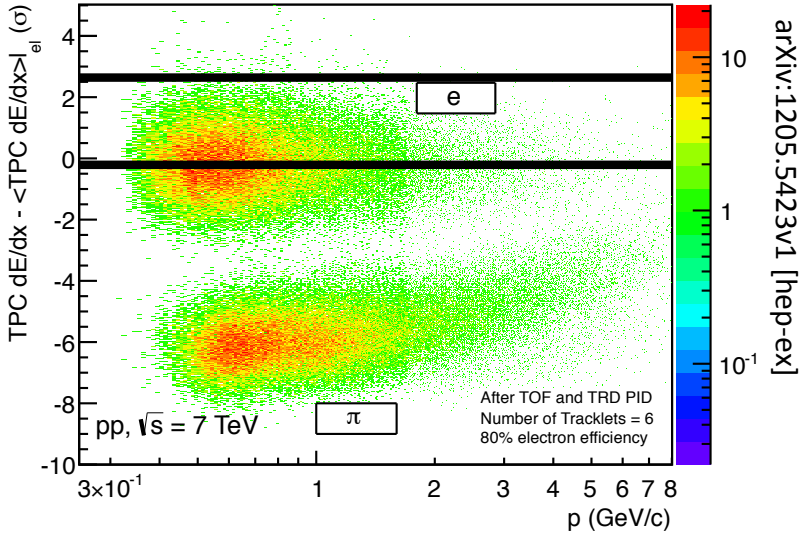


Open Heavy-Flavour: analysis technique (II)

Semileptonic decay channels

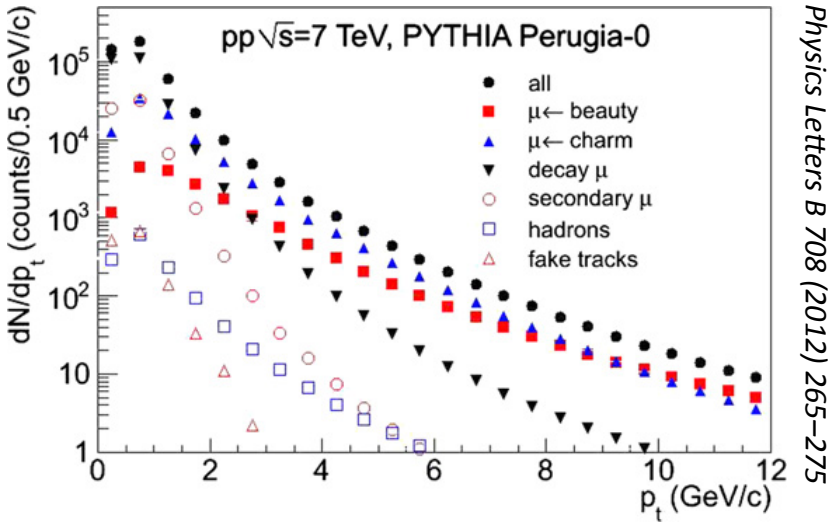
✓ **Single electron channel (|y| < 0.5)**

- PID: TPC + TOF + TRD + EMCAL
- Background estimation: MC cocktail



✓ **Single muon channel (2.5 < y < 4.0)**

- Muon ID: MUON trigger matching
- Background: MC cocktail



D-meson cross section

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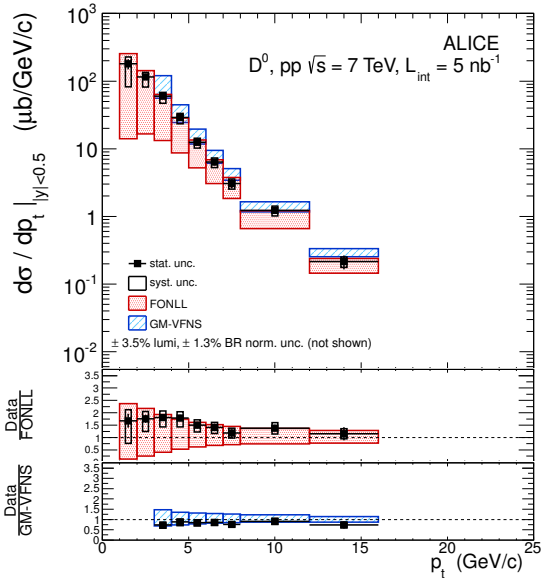
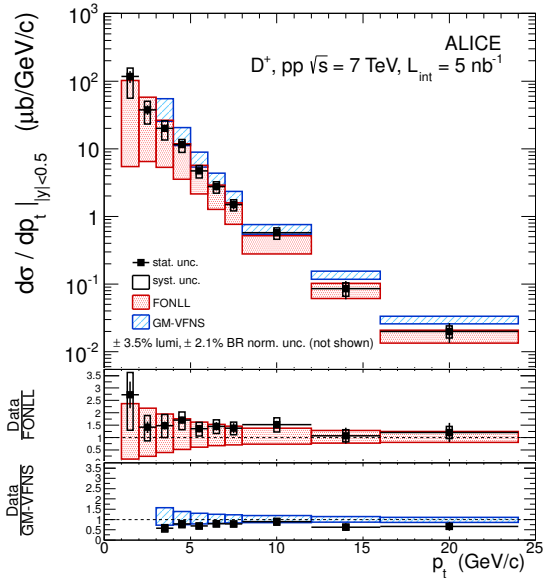




√s = 7 TeV

D^0 D^+ D^{*+}

L_{int} = 5 nb^{-1}

1<p_T<24 (16 for D^0) GeV/c

D_s^+

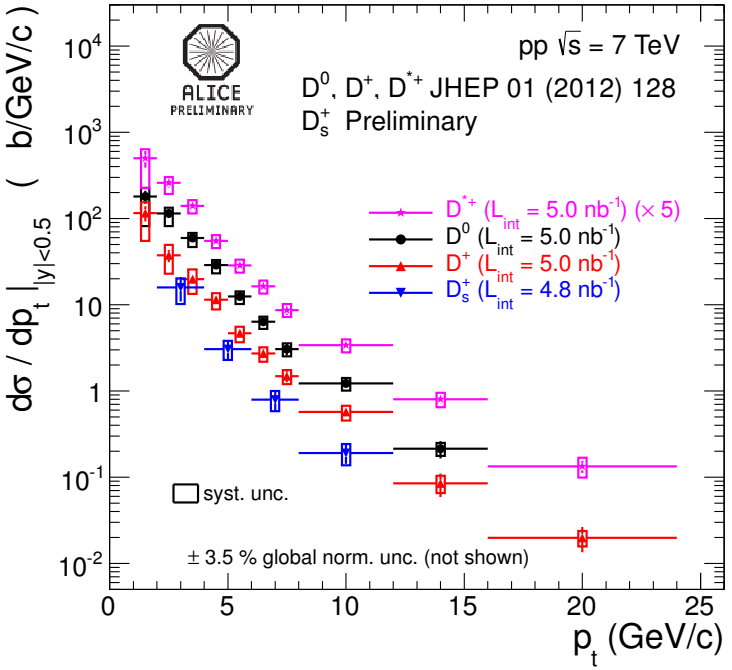
L_{int} = 4.8 nb^{-1}

2<p_T<12 GeV/c

- p_T-differential cross sections of prompt charmed mesons **D^0** , **D^+**, **D^{*+}** and **D_s^+** (|y|<0.5)

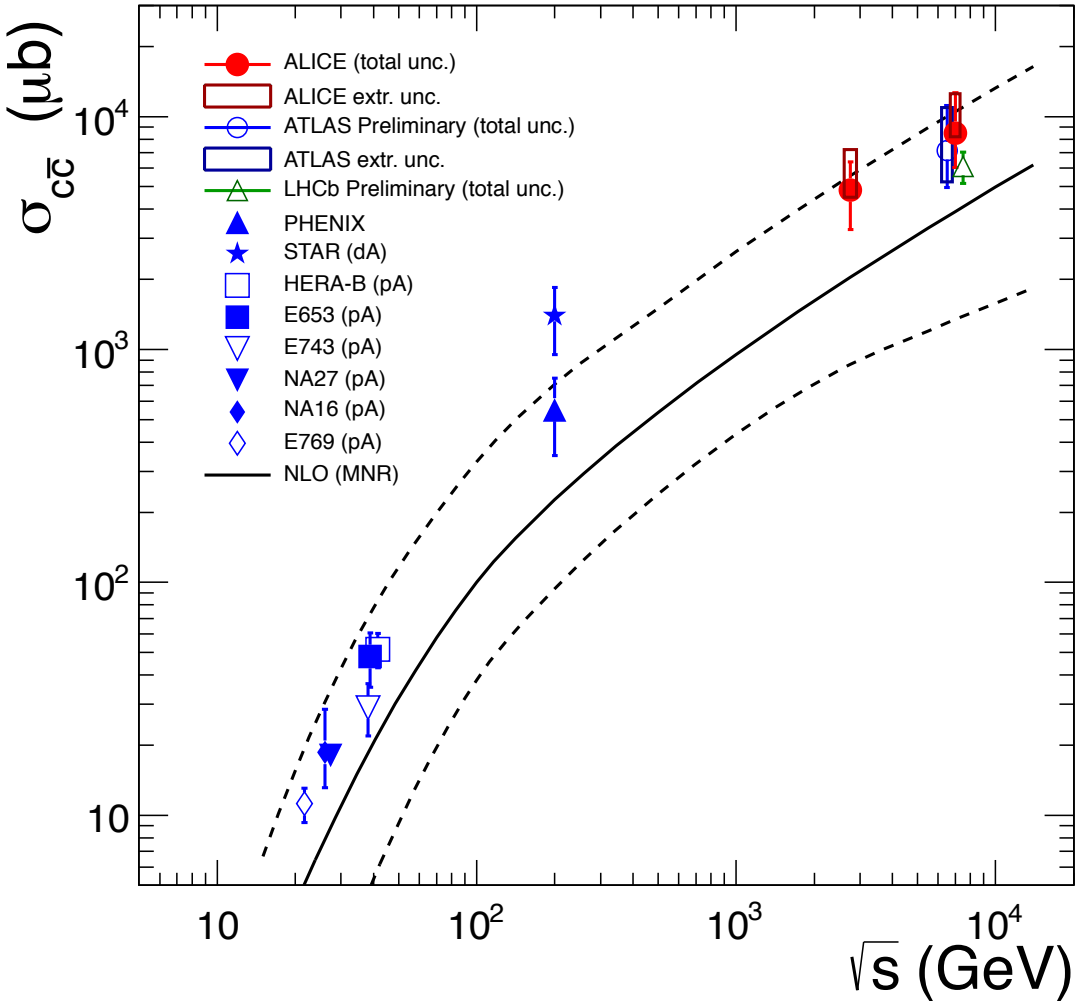
- B-feed down (≈ 10-15 %) subtracted using FONLL calculations

- Data well described by **pQCD predictions** (FONLL and GM-VFNS)



see Gian Michele Innocenti's poster

Total charm cross section



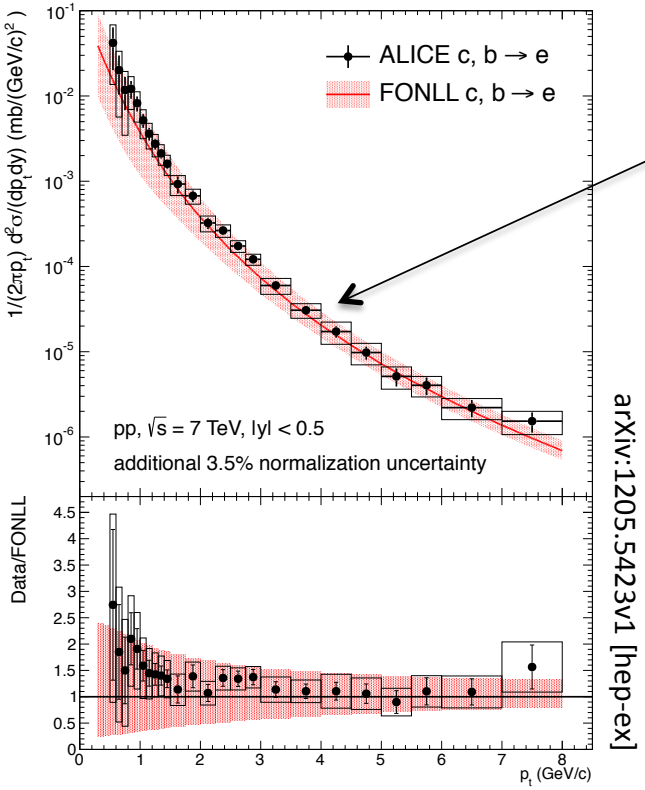
arXiv:1205.4007v1 [hep-ex]

@ √s = 2.76, 7 TeV

- Extrapolation down to $p_T = 0$ and full rapidity using FONLL
- Agreement among the LHC results
- All measurements are in the upper part of the band showing MNR (NLO) calculations

Electrons from Heavy Flavour decays

Differential production cross section of electrons from semileptonic HF decays (|y|<0.5)

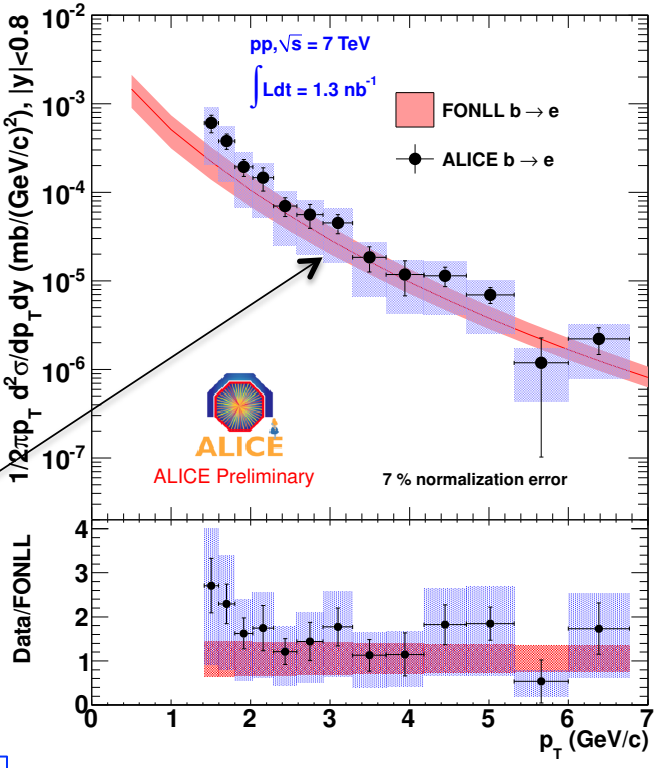


arXiv:1205.5423v1 [hep-ex]

D,B → e+X = Inclusive Electron - cocktail

pp @ 7 TeV

B → e+X from impact parameter analysis



see Min Jung Kweon's talk

D,B → e+X 0.5 < p_T < 8 GeV/c

B -> e+X 1.5 < p_T < 6 GeV/c

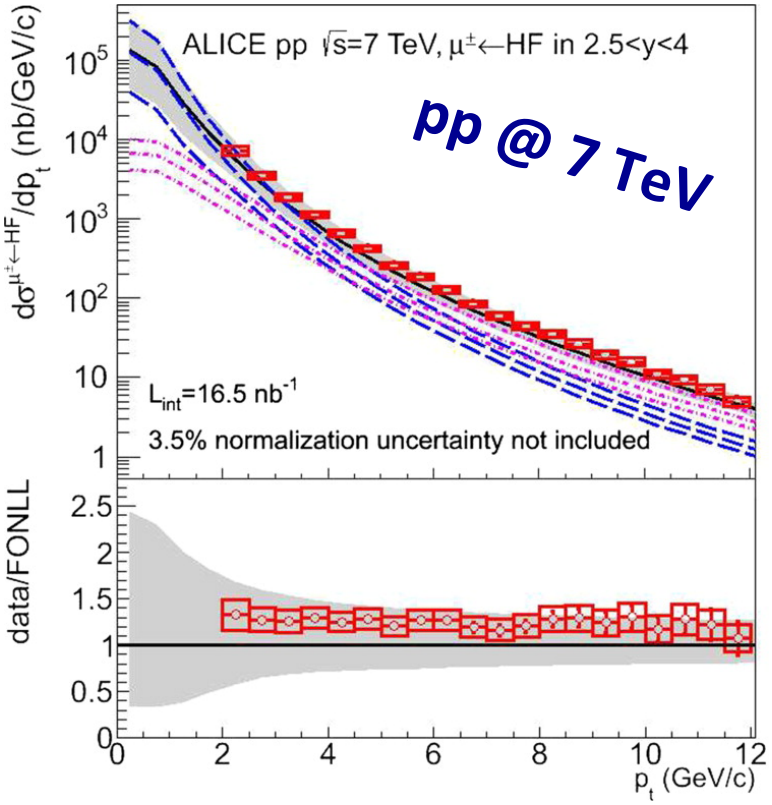
- **Inclusive electron spectrum**: Electron ID TOF-TRD-TPC-EMCAL
- **Subtracted cocktail of electron background** based on measured π^0 spectrum + m_T-scaling + pQCD direct photons + LHC J/ψ and ϒ measurements
  - Well described by **FONLL** b+c → e over the full p_T range

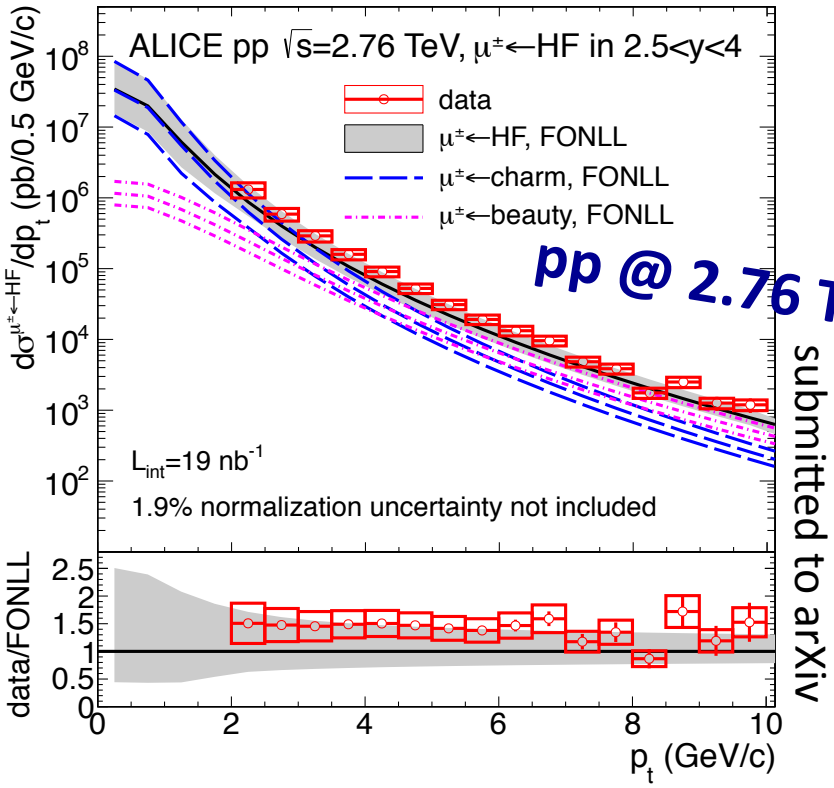
- Measurement of **B → e +X** by electron selection from displaced vertices
- Well described by FONLL b → e calculations

Muons from Heavy Flavour decays

- Background subtraction based on MC dN/dp_T (PYTHIA and PHOJET) normalized to data at low p_T

Physics Letters B 708 (2012) 265–275





submitted to arXiv

- p_T- and y-differential production cross section of muons from HF decay (**2.5 < y < 4**)
- Curves represent FONLL calculations and bands display theoretical systematic uncertainties
- Model calculations provide overall good description up to p_T = 12 (10) GeV/c
- Theoretical charm and beauty components are shown: muon contribution from b decays dominates in the range p_T > 6 GeV/c

see Diego Stocco's talk

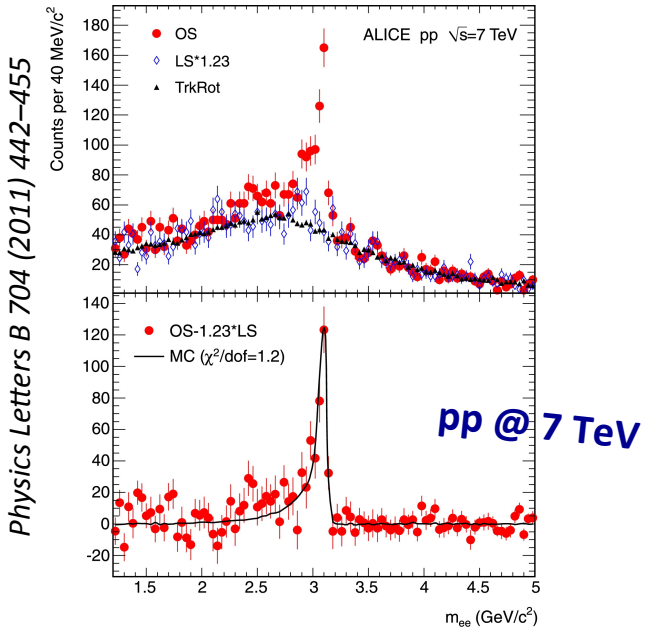
J/ψ: analysis techniques

3 possible sources of J/Ψ

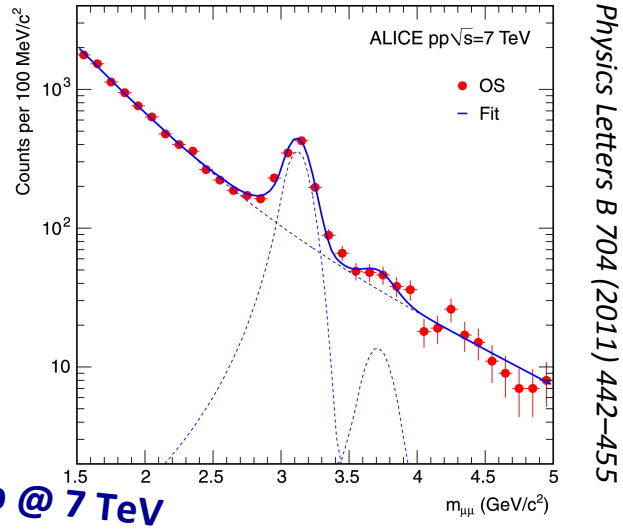
Inclusive J/Ψ
- Prompt J/Ψ
  - Direct production : ~50%
  - Feed down from heavier states (χ_c, Ψ') : ~40%
- J/Ψ from b-hadron decay: ~10% → feasible in the central barrel thanks to good impact parameter resolution

J/Ψ in ALICE

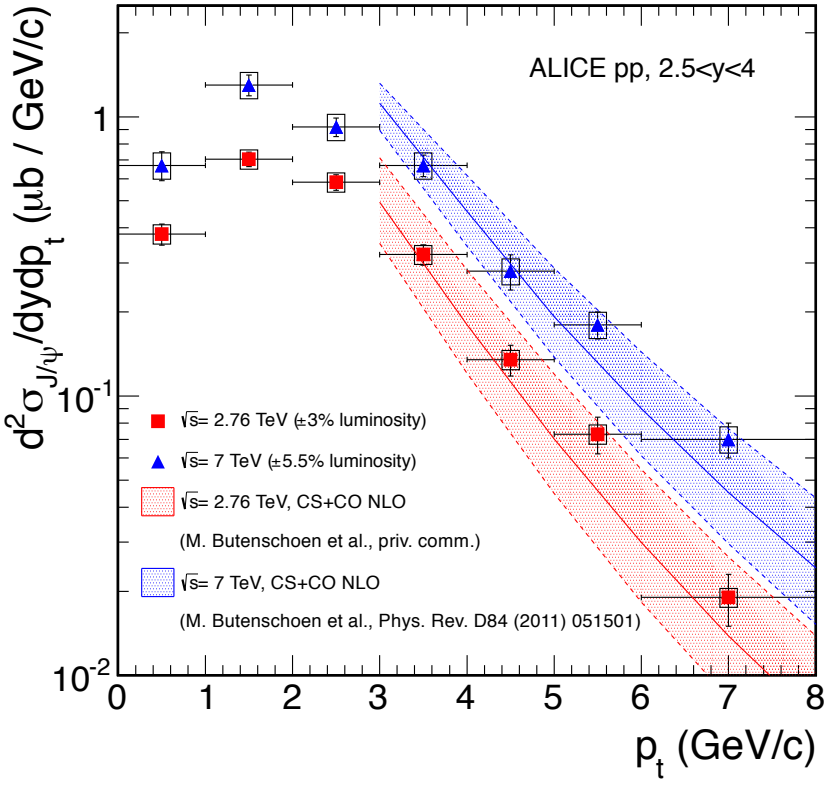
- J/Ψ -> e^+e^- (|y|<0.9)
  - ✓ Tracking: TPC + ITS
  - ✓ PID: TPC + TOF
  - ✓ Secondary vertexing: ITS

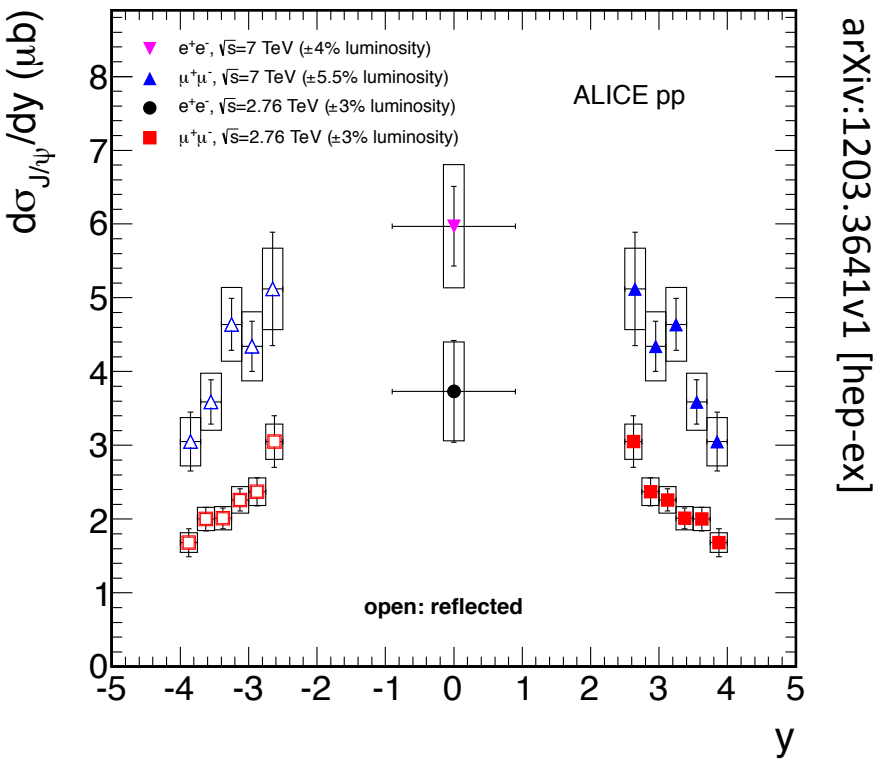


- J/Ψ -> $\mu^+\mu^-$ (2.5<y<4.0)
  - ✓ Tracking: 10 tracking chambers
  - ✓ Muon ID: Front absorber + Muon Trigger
  - ✓ Dedicated Muon trigger



Inclusive J/ψ production cross section





- NRQCD calculations describe well the p_T-differential cross section measured for $p_T > 3$ GeV/c at √s = 2.76, 7 TeV
- y dependence: large rapidity coverage

pp @ √s = 2.76 TeV reference for Pb-Pb

- **Inclusive J/Ψ cross section in pp collisions at √s = 7 TeV**

$$\sigma_{J/\psi}(2.5<y<4) = 6.31 \pm 0.25(stat) \pm 0.76(syst) + 0.95(\lambda_{CS}=+1) - 1.96(\lambda_{CS}=-1)\ \mu b$$
$$\sigma_{J/\psi}(|y|<0.9) = 10.7 \pm 1.0(stat) \pm 1.6(syst) + 1.6(\lambda_{HE}=+1) - 2.3(\lambda_{HE}=-1)\ \mu b$$

Physics Letters B 704 (2011) 442–455

- **Inclusive J/Ψ cross section in pp collisions at √s = 2.76 TeV**

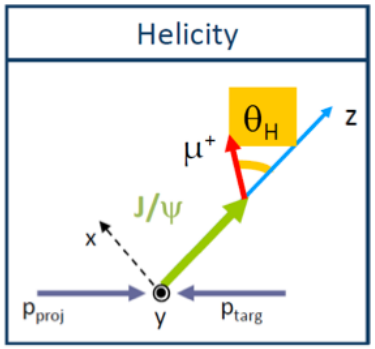
$$\sigma_{J/\psi}(2.5<y<4) = 3.34 \pm 0.13(stat) \pm 0.28(syst) + 0.53(\lambda_{CS}=+1) - 1.07(\lambda_{CS}=-1)\ \mu b$$
$$\sigma_{J/\psi}(|y|<0.9) = 6.71 \pm 1.24(stat) \pm 1.22(syst) + 1.01(\lambda_{HE}=+1) - 1.41(\lambda_{HE}=-1)\ \mu b$$

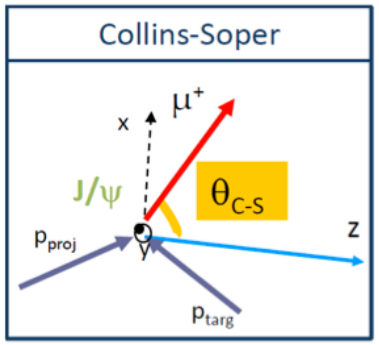
arXiv:1203.3641v1 [hep-ex]

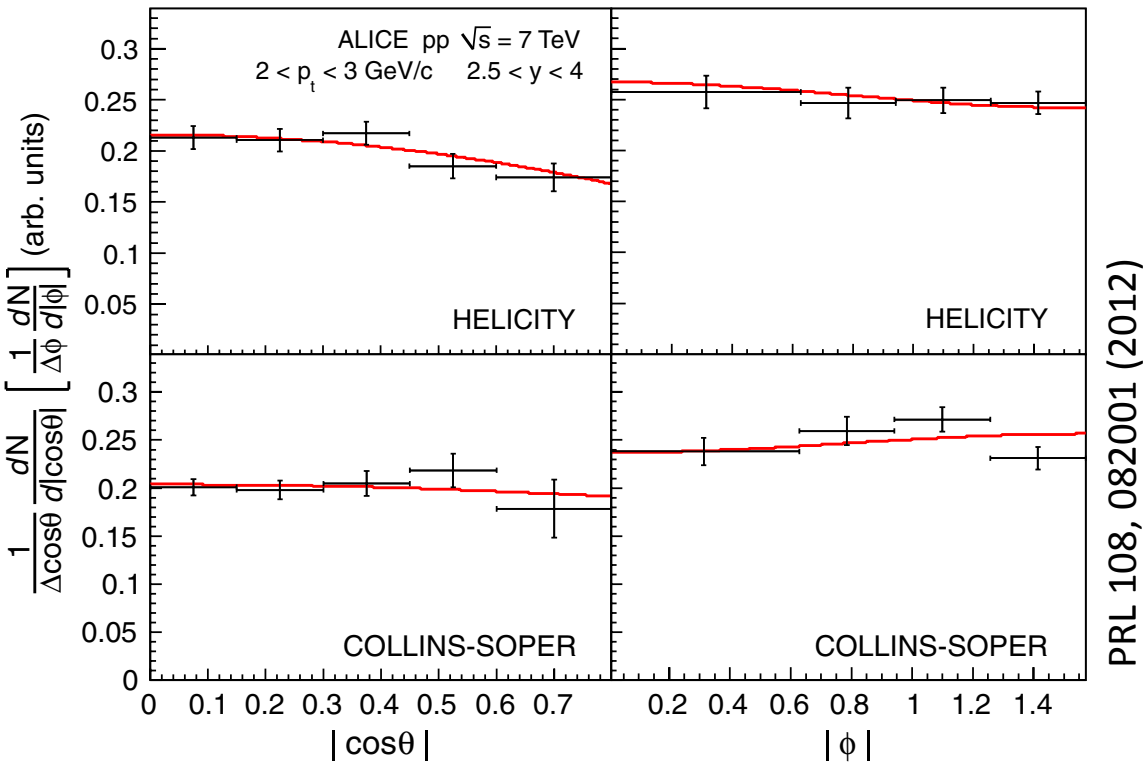
J/ψ polarization

Crucial observable for discriminating among different J/ψ production mechanisms

➡ ALICE measures J/ψ polarization through the **angular analysis of the decay muons** polar (θ) and azimuthal (ϕ) angle distributions analyzed in 2 reference frames (**CS** and **HE**)







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

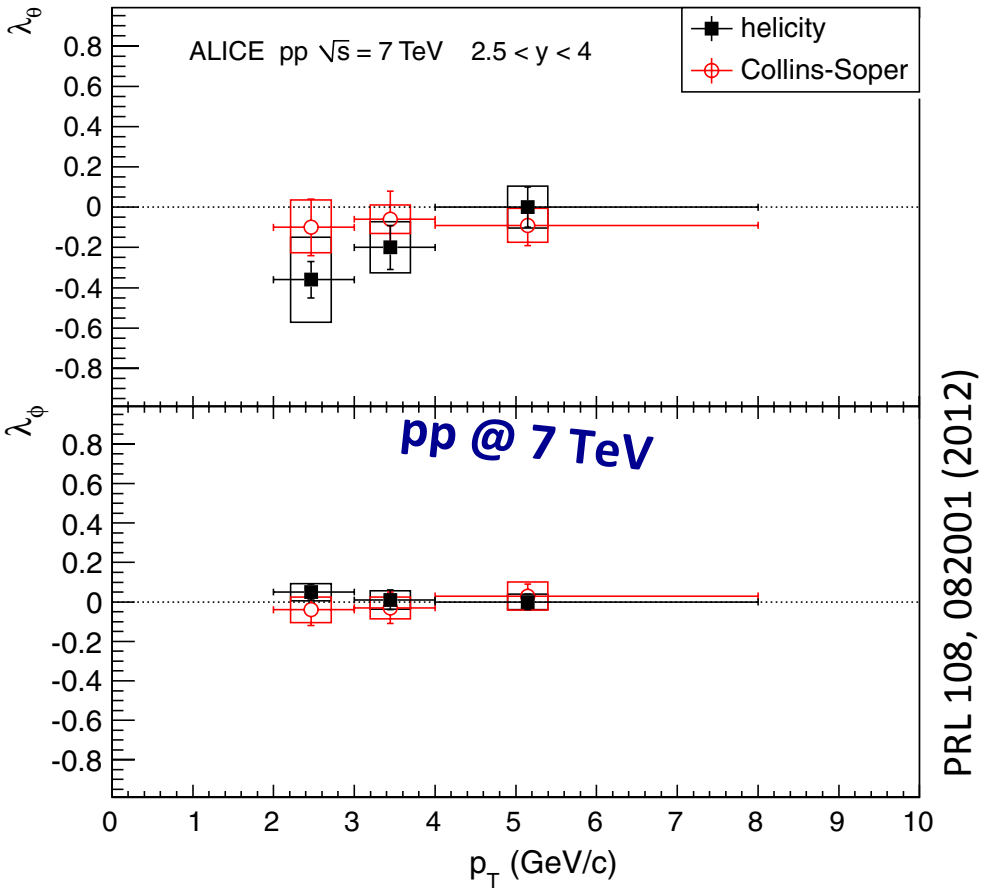
$$W(\phi) \propto 1+\frac{2\lambda_\phi}{3+\lambda_\theta}\cos 2\phi$$

➡ $\lambda_\theta > 0$ transversal polarization

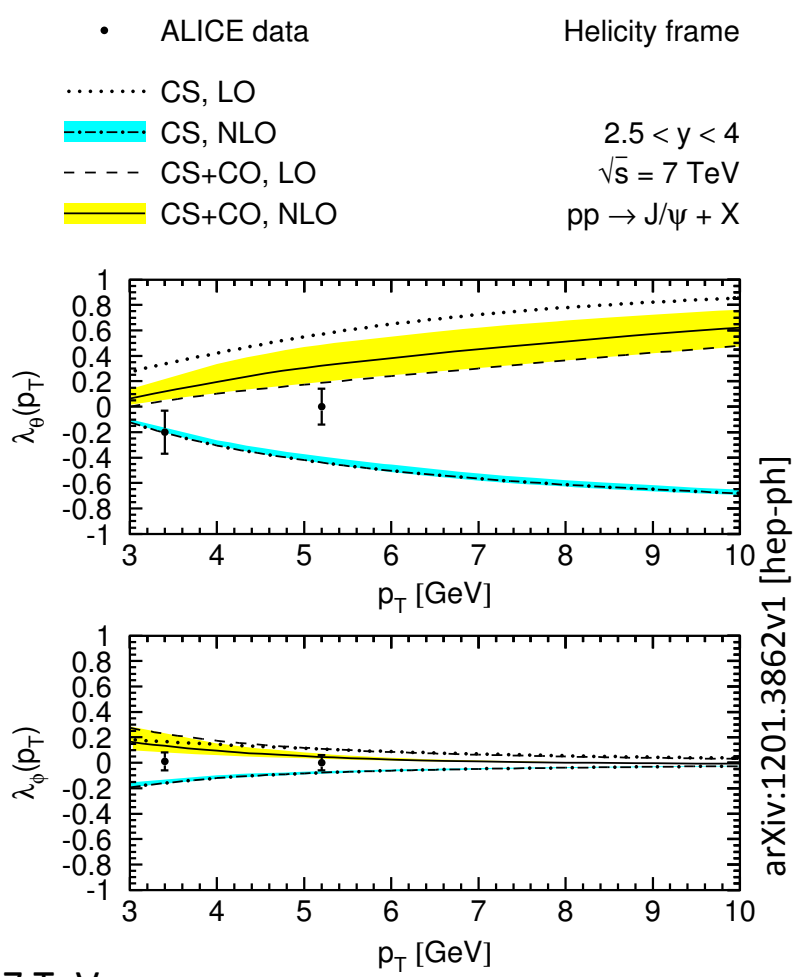
$\lambda_\theta < 0$ longitudinal polarization

First LHC J/ψ polarization results

$L_{int} \approx 100\ nb^{-1}$ $2.5 < y < 4$ $2 < p_T < 8$ GeV/c



PRL 108, 082001 (2012)



arXiv:1201.3862v1 [hep-ph]

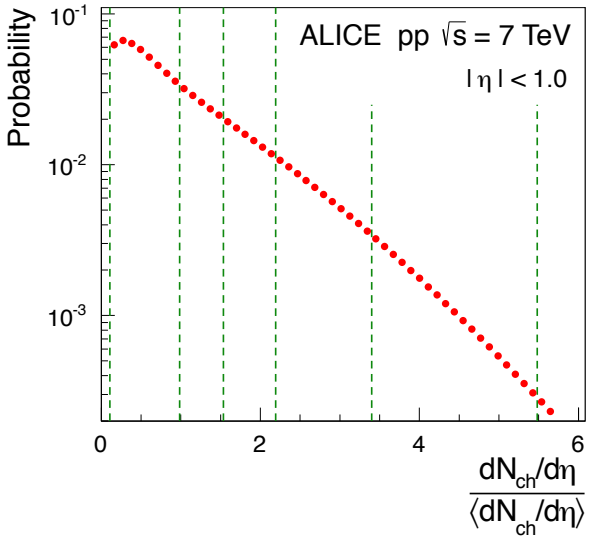
- Almost no polarization for inclusive J/ψ in pp at √s = 7 TeV
- Difference between prompt and inclusive J/ψ polarization was estimated to be, at most, 0.05 (smaller than systematics)
- Higher p_T measurements useful to better understand J/ψ production mechanisms

J/ψ production *vs* Multiplicity

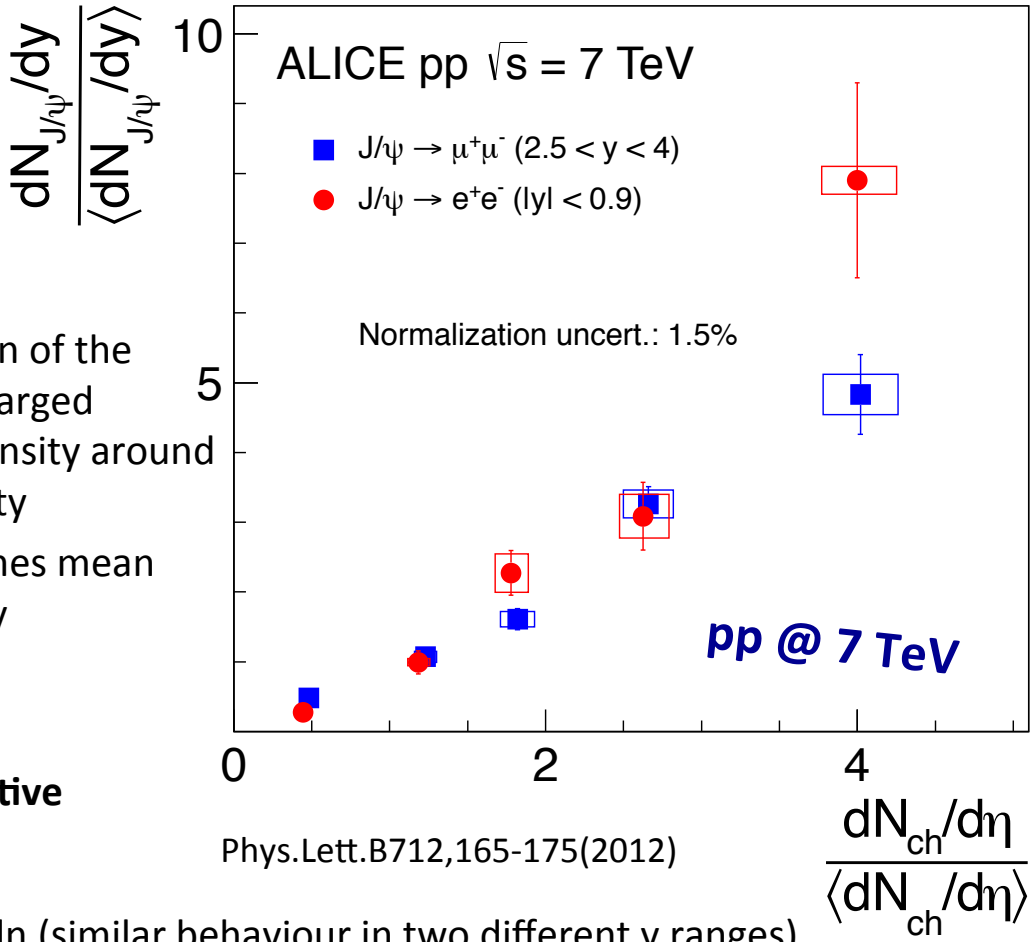
Highest charged particle multiplicity density ($dN_{ch}/d\eta$ ~ 30) reached in our analysis (pp @ √s =7 TeV) is comparable with Cu-Cu collisions (45-55%, semi peripheral collisions) @ $\sqrt{s_{NN}}$ = 200 GeV (RHIC)

similarities between pp @LHC and Cu-Cu @RHIC **?**

✓ Measurement of inclusive J/ψ yield as function of charged particle pseudorapidity density $dN_{ch}/d\eta$



- Distribution of the relative charged particle density around mid-rapidity
- Up to 5 times mean multiplicity



Phys.Lett.B712,165-175(2012)

- **Relative J/ψ yield as a function of the relative charged particle multiplicity**

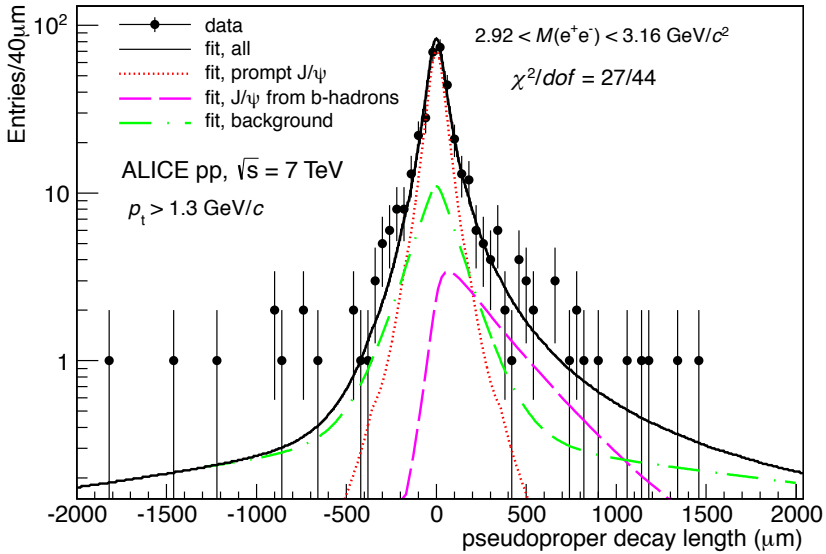
- Approximately linear increase *vs* $dN_{ch}/d\eta$ (similar behaviour in two different y ranges)
- Non-trivial result: for example PYTHIA 6.4 predicts opposite effect

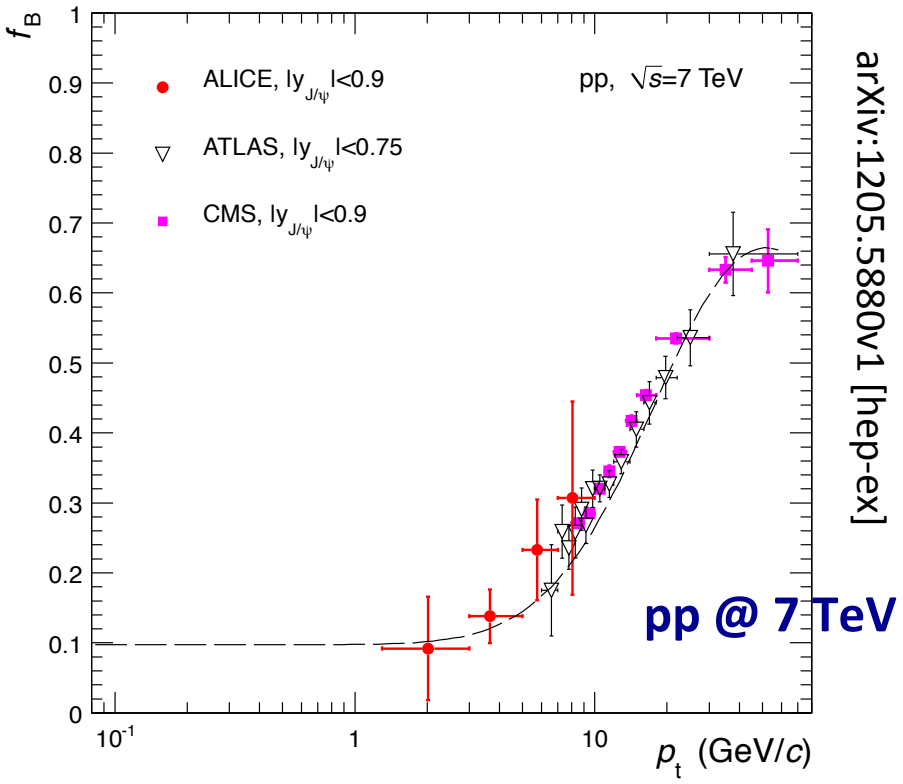
J/ψ from b-hadron decays

Measurement of the fraction, $\mathbf{f_B}$, of the J/ψ coming from b-hadron decays at mid-rapidity and low p_T : unique opportunity at LHC at y =0 !

➡ Feasible in central barrel thanks to good **impact parameter resolution**: $\sigma_{r\phi} < 75$ μm for $p_T > 1$ GeV/c

✓ Contributions from B decays estimated from the pseudo-proper decay length





- Measured region: $\mathbf{p_T > 1.3}$ **GeV/c** $\mathbf{|y| < 0.9}$

$f_B = 0.149 \pm 0.037(\text{stat}) + 0.018 - 0.027\ (\text{syst}) + 0.025 - 0.021\ (\text{syst polar.})$

$\sigma_{J/\psi}$ **(prompt, |y|<0.9,** $\mathbf{p_T}$**>1.3 GeV/c)** $= 7.2 \pm 0.7(\text{stat}) \pm 1.0\ (\text{syst}) + 1.3 - 1.2\ (\text{syst polar.})$ μb

Summary and Conclusions

- Review of the main ALICE results in pp collisions
- Prompt D-mesons, HF electron and muon cross-sections measured in pp collisions at √s = 7 TeV and 2.76 TeV
  - Results well reproduced by pQCD calculations
  - Total charm cross section measurement
- J/ψ production measured at √s = 7 TeV and 2.76 TeV
  - Inclusive J/ψ production cross section
  - First polarization measurement at LHC
  - Substantial increase of J/ψ yield as a function of multiplicity
  - Prompt and non-prompt J/ψ down to low transverse momentum

Thank you for your attention!

Back-Up

D-meson cross section pp @ 7 TeV

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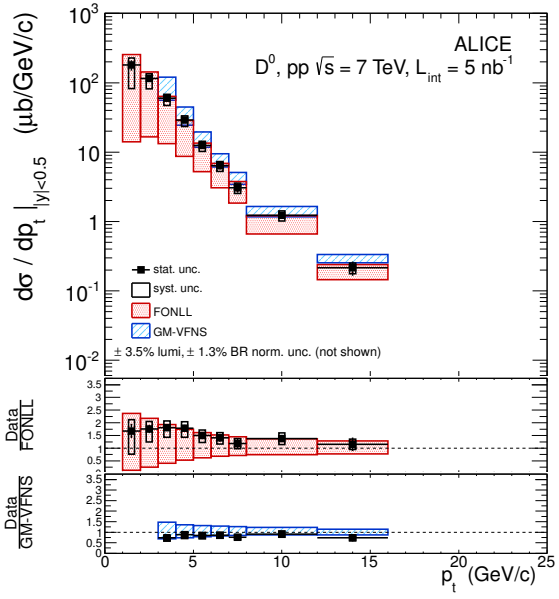
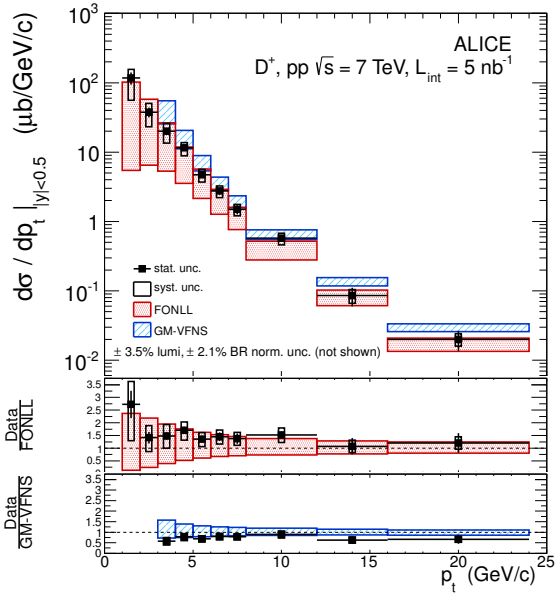
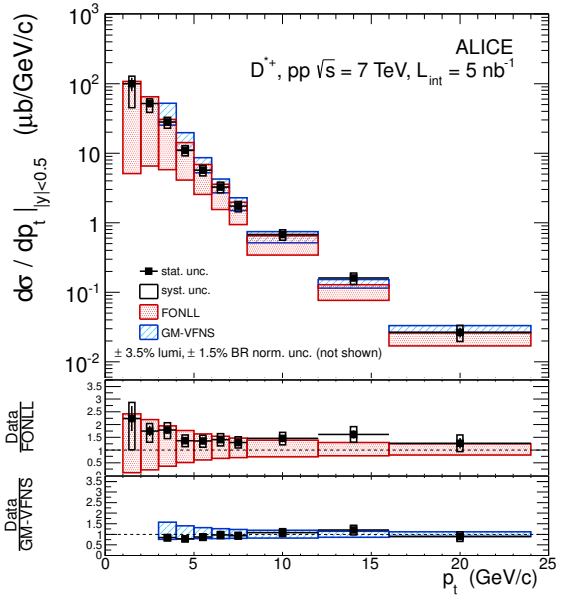
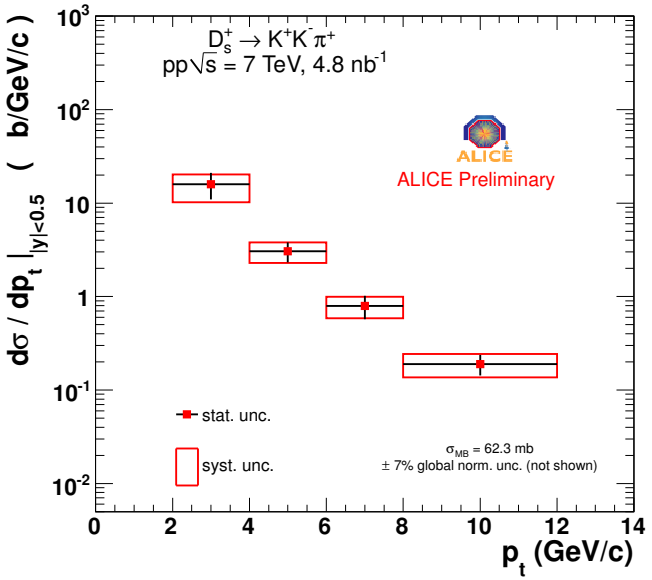








D^0 D^+ D^{*+}

$L_{int} = 5\ nb^{-1}$

$1<p_T<24$ (16 for D^0) GeV/c

D_s^+

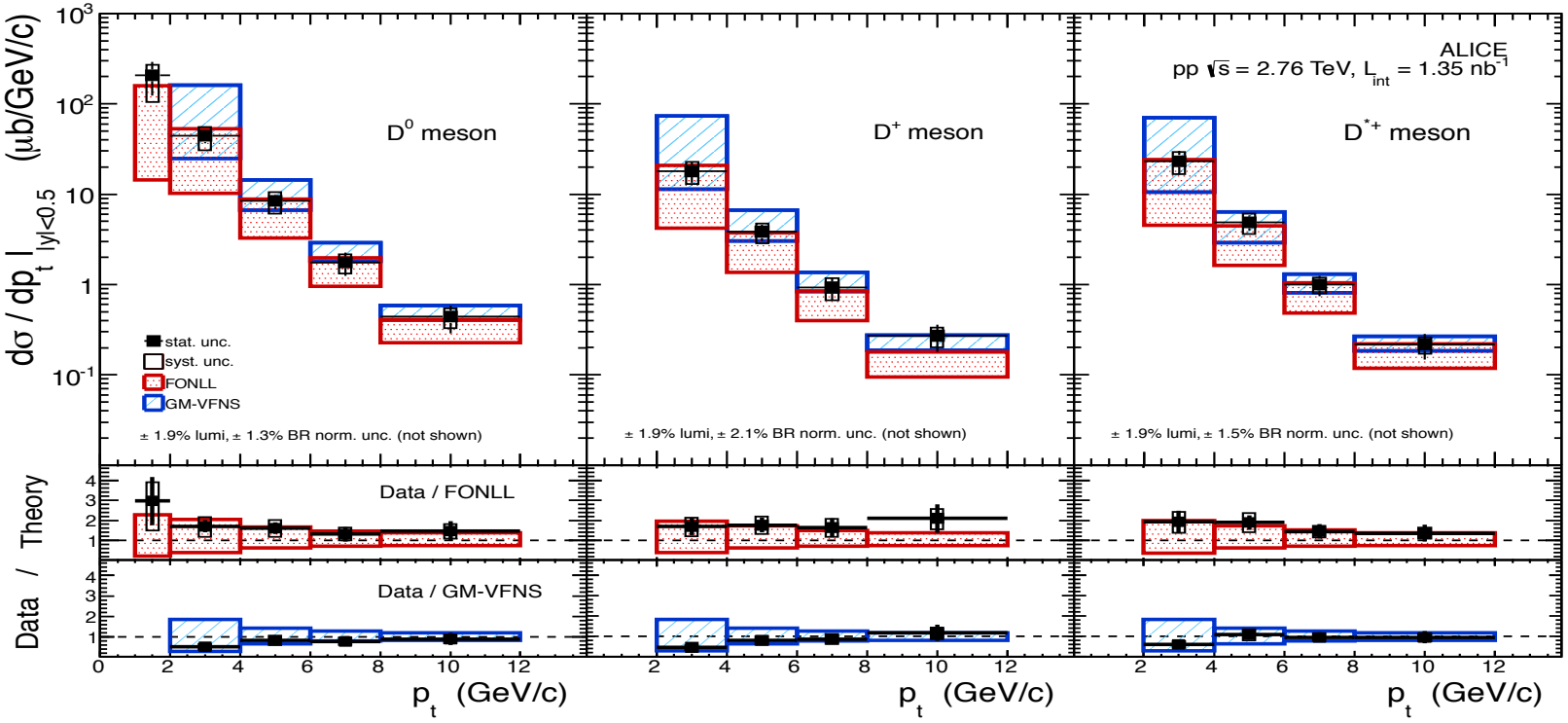
$L_{int} = 4.8\ nb^{-1}$

$2<p_T<12$ GeV/c

- Data well described by pQCD predictions (FONLL and GM-VFNS)

D-meson cross section

pp @ 2.76 TeV



arXiv:1205.4007v1 [hep-ex]

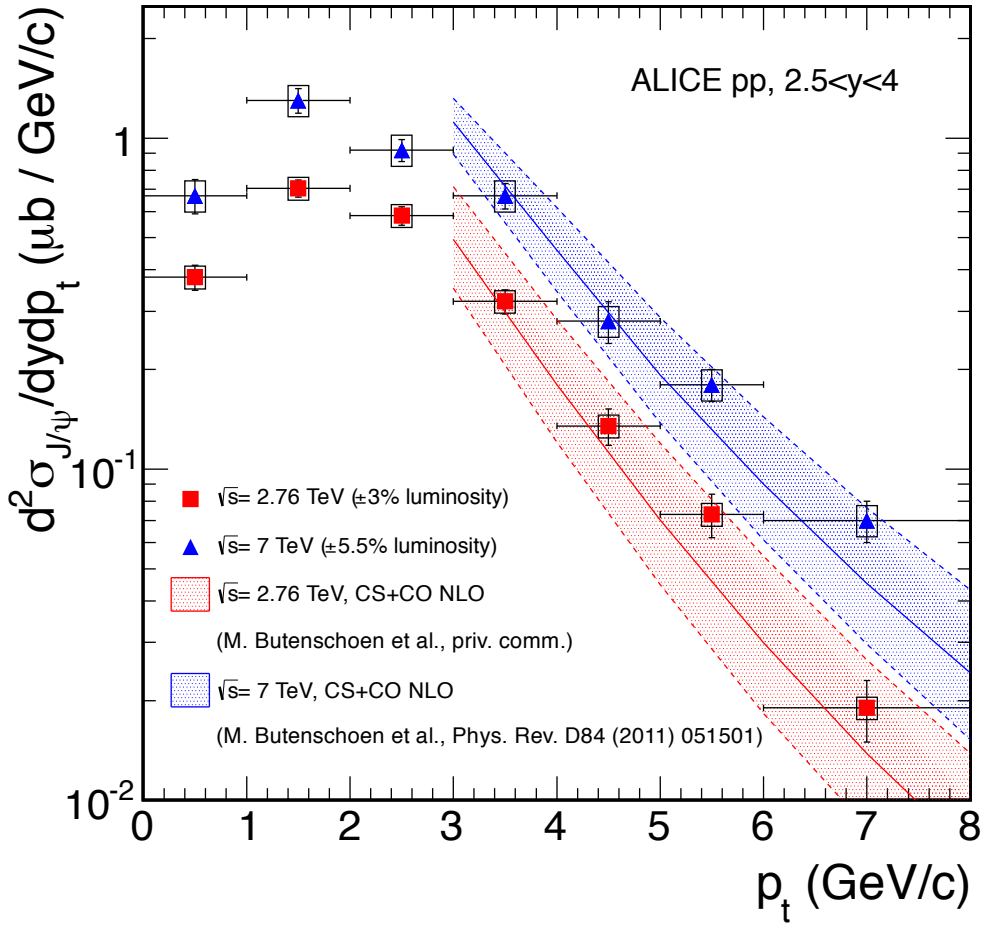
D^0 D^+ D^{*+} **$\sqrt{s}$ = 2.76 TeV**

- L_{int} = 1.35 nb^{-1}
- 2 (1 for D^0) < p_T < 12 GeV/c

- Data well described by pQCD predictions (FONLL and GM-VFNS)

$J/\psi \rightarrow \mu^+\mu^-$: differential p_T distribution

The differential cross section @ $\sqrt{s}$ = 2.76 TeV $d^2\sigma_{J/\psi}/dydp_T$, averaged over the interval $2.5 < y < 4$, for the transverse momentum range $0 < p_T < 8$ GeV/c is presented below



The results are compared with the previously published results @ $\sqrt{s}$ = 7 TeV
(K. Aamodt et al. (ALICE Collaboration), Phys. Lett. **B704** 442 (2011))

The predictions of a NRQCD calculation (*), which includes both colour singlet and colour octet terms at NLO order, are plotted for the two energies in the range $3 < p_T < 8$ GeV/c.

There is a good agreement between the model (NLO NRQCD calculations) and both sets of experimental data

(*) M. Butenschoen and B.A. Kniehl, Phys. Rev. **D84**, 051501 (2011) and priv. comm.

The systematic uncertainties on luminosity are shown as boxes, while the error bars represent the quadratic sum of the statistical errors and the other sources of systematic uncertainty

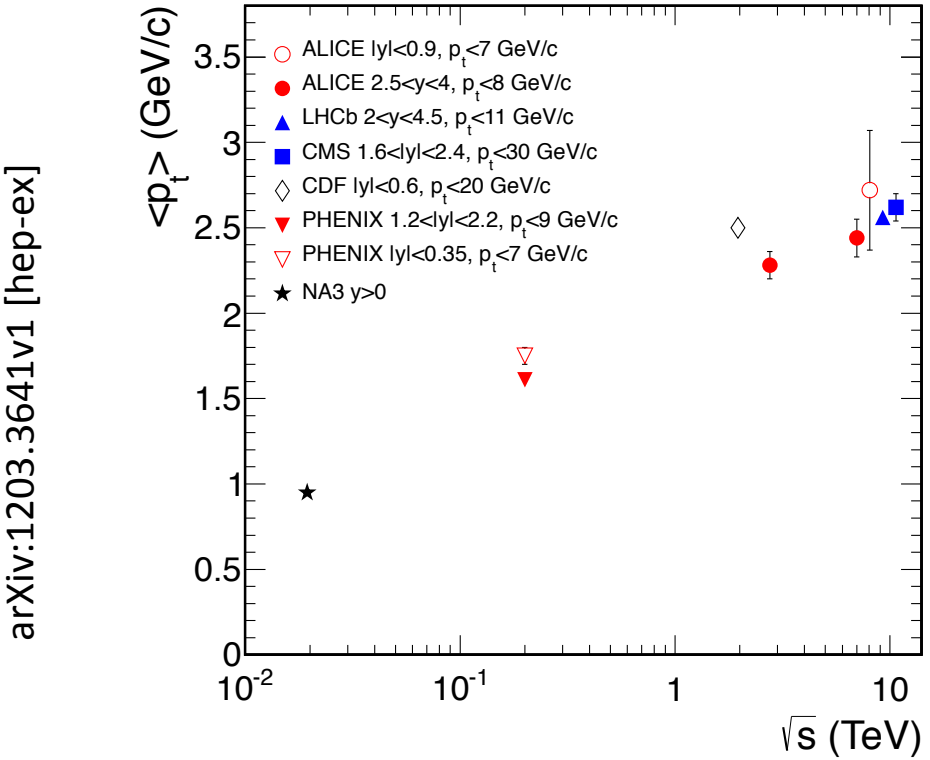
$J/\psi \rightarrow \mu^+\mu^-$: $\langle p_T \rangle$ and $\langle p_T^2 \rangle$

Using the results shown in the previous slide we can compute the $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ for inclusive J/ψ production at forward rapidity y by fitting $d^2\sigma_{J/\psi}/dydp_T$ with the following function:

$$\frac{d^2\sigma}{dp_T dy} = C \frac{p_T}{\left(1 + \left(\frac{p_T}{p_0}\right)^2\right)^x}$$

with C, p_0 and x as free parameters
(this function is widely used in the literature for such a kind of fits)

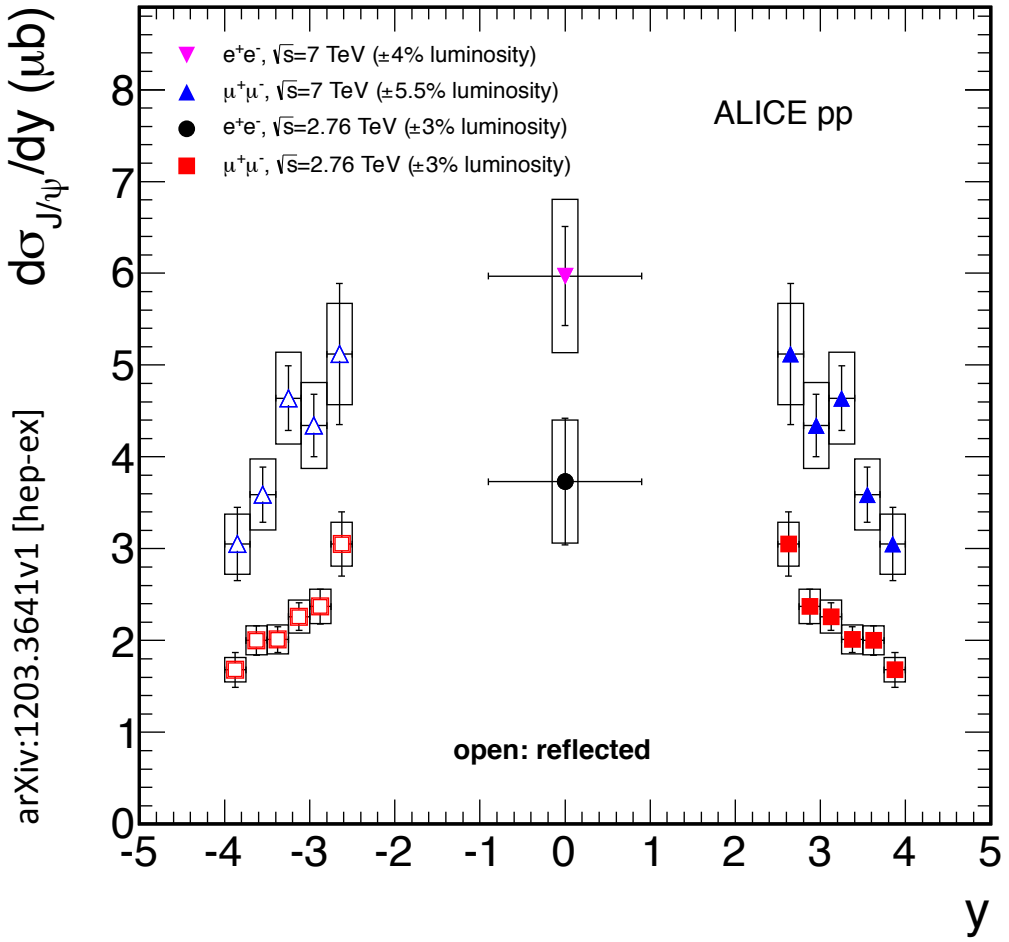
The ALICE results can be compared to results from other experiments



Approximately logarithmic increase with $\sqrt{s}$ continues up to LHC energy

J/ψ→μ⁺μ⁻: differential y distribution

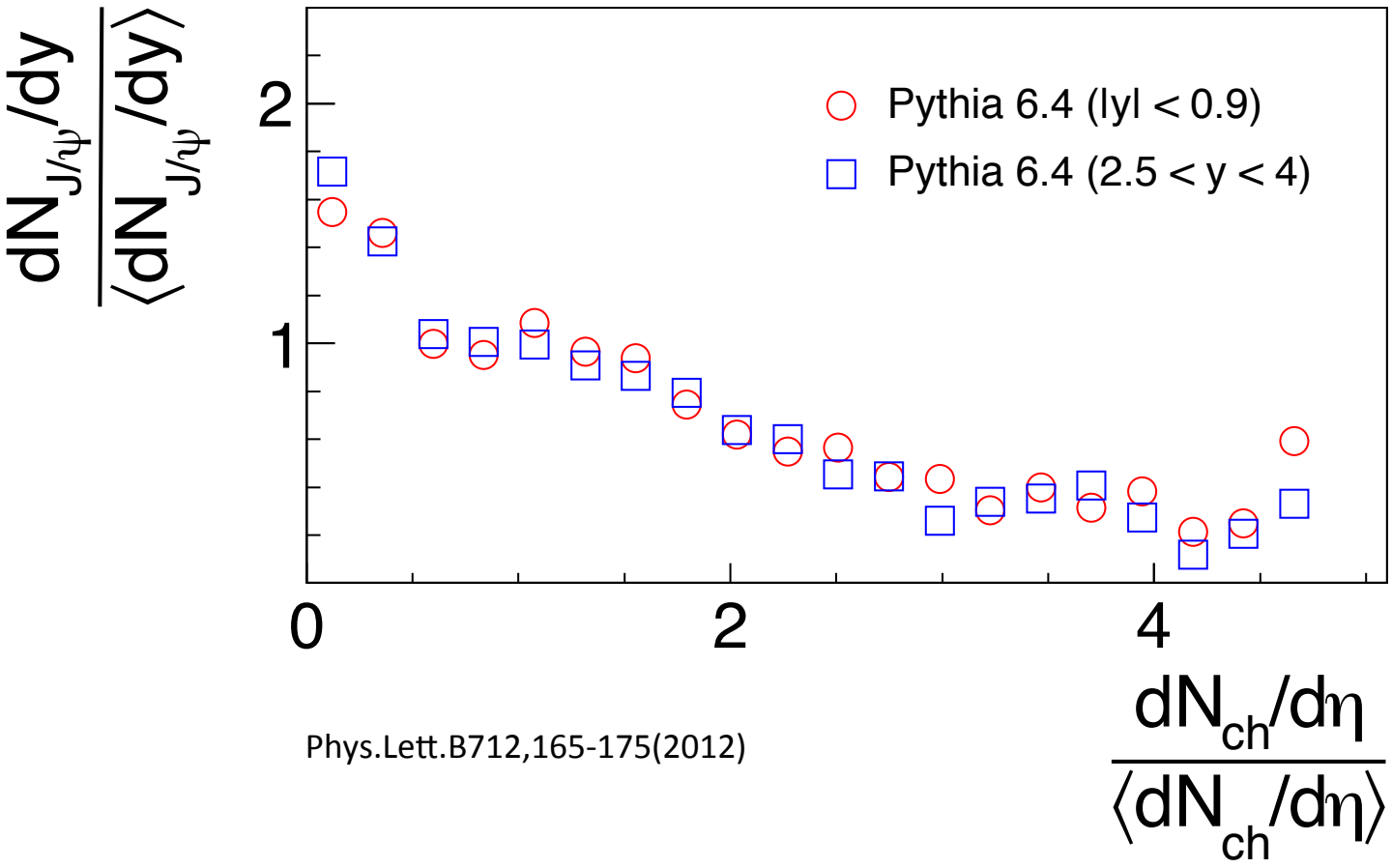
The differential cross section $d\sigma_{J/\psi}/dy$ @ √s = 2.76 TeV is presented below with the previously published results @ √s = 7 TeV (K. Aamodt et al. (ALICE Collaboration), Phys. Lett. **B704** 442 (2011))



J/ψ production cross section measured in the two rapidity ranges covered by the ALICE experiment

The systematic uncertainties on luminosity are shown as boxes, while the error bars represent the quadratic sum of the statistical errors and the other sources of systematic uncertainty

J/ψ production *vs* Multiplicity



Phys.Lett.B712,165-175(2012)

- Approximately linear increase *wrt* $dN_{ch}/d\eta$ (similar behaviour in two different y ranges)
- Non-trivial result: for example **PYTHIA 6.4** predicts opposite effect