Quarkonia and open heavy-flavour production in high multiplicity pp collisions

Sarah Porteboeuf-Houssais for the ALICE Collaboration

QGP France, Etretat, 9-12 Septembre 2013

- Physics motivations in the context of MPI
- Overview of experimental results
- PYTHIA 8 comparisons
- What to do next?
- Conclusions

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Motivations

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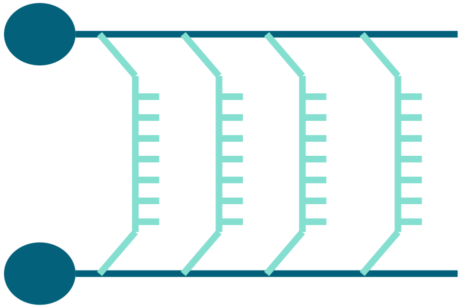
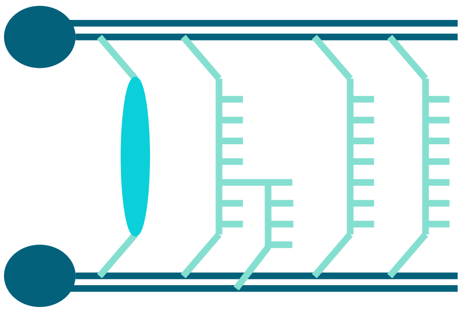
- A naïve picture



- Several hard interactions can occur in a pp collision
- The number of elementary interactions is connected to multiplicity
- In this picture : particle yield from hard processes should increase with multiplicity

=> Studying particle yield as a function of multiplicity is a test for MPI scenario!

- A less naïve picture



- Some of the parallel interactions can be soft
- Re-interaction of partons with others: ladder splitting
- Re-interaction within ladders either in initial state: screening, or in final state (eg. PYTHIA color reconnection scenario)
- ISR/FSR, hadronic activity of a hard process

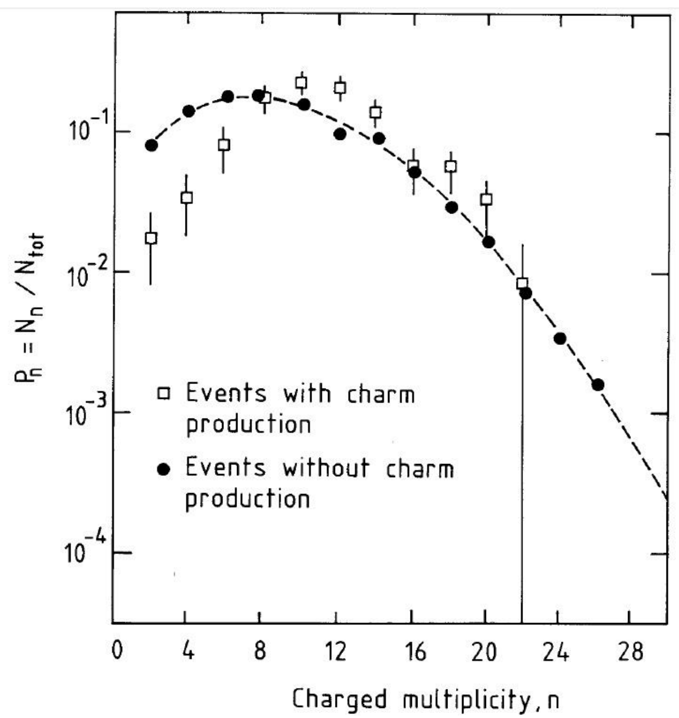
=> Test interaction between hard component and soft component in pp collisions : full collision, color flow, energy sharing.

- A more complex picture
  - High multiplicity 7 TeV pp events comparable to RHIC Cu-Cu collisions PHOBOS, Phys. Rev. C 83, 024913 (2011)
  - Collectivity in pp K. Werner at al. Phys.Rev.C83:044915,2011 / k. Werner at al. J.Phys.Conf.Ser.316:012012,2011
  - Final state effect on quarkonia production S. Vogel et al. J.Phys.Conf.Ser. 420 (2013) 012034/ T. Lang Phys.Rev. C87 (2013) 2, 024907
  - Quarkonia production mechanism still to be understood, while open charm and beauty production is well described by pQCD

Overview of
(mostly ALICE) Experimental Results

Events with Charm with NA27

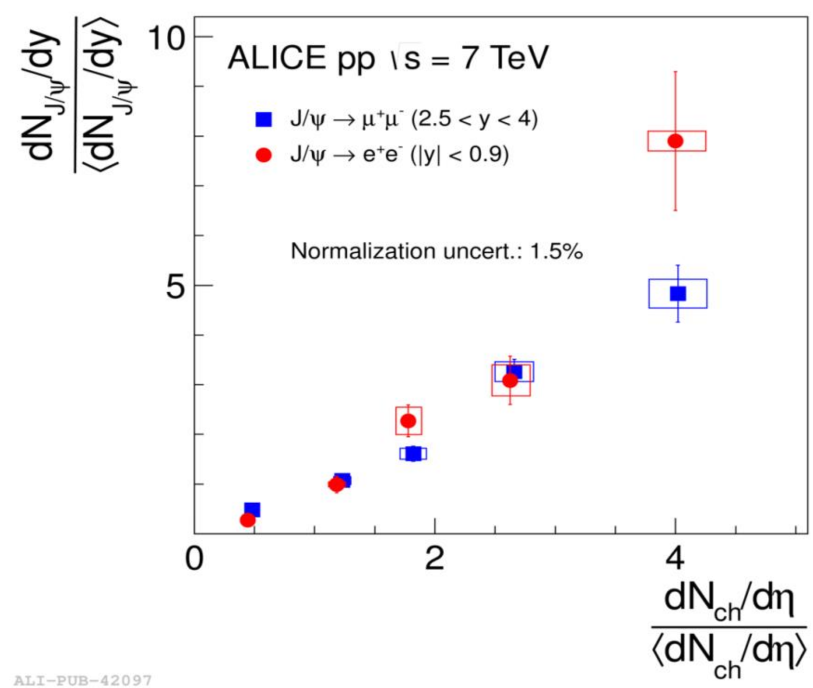
NA27 observed that events with charm have on average a larger charged particle multiplicity in 400 GeV/c pp collisions.



NA27 Z.Phys.C41:191,1988

Inclusive J/ψ with ALICE

ALICE observed a linear increase of the relative inclusive J/ψ yield vs. charged particle density in pp collisions at √s = 7 TeV



ALICE Coll., Phys. Lett. B 712 (2012) 3, 165–175

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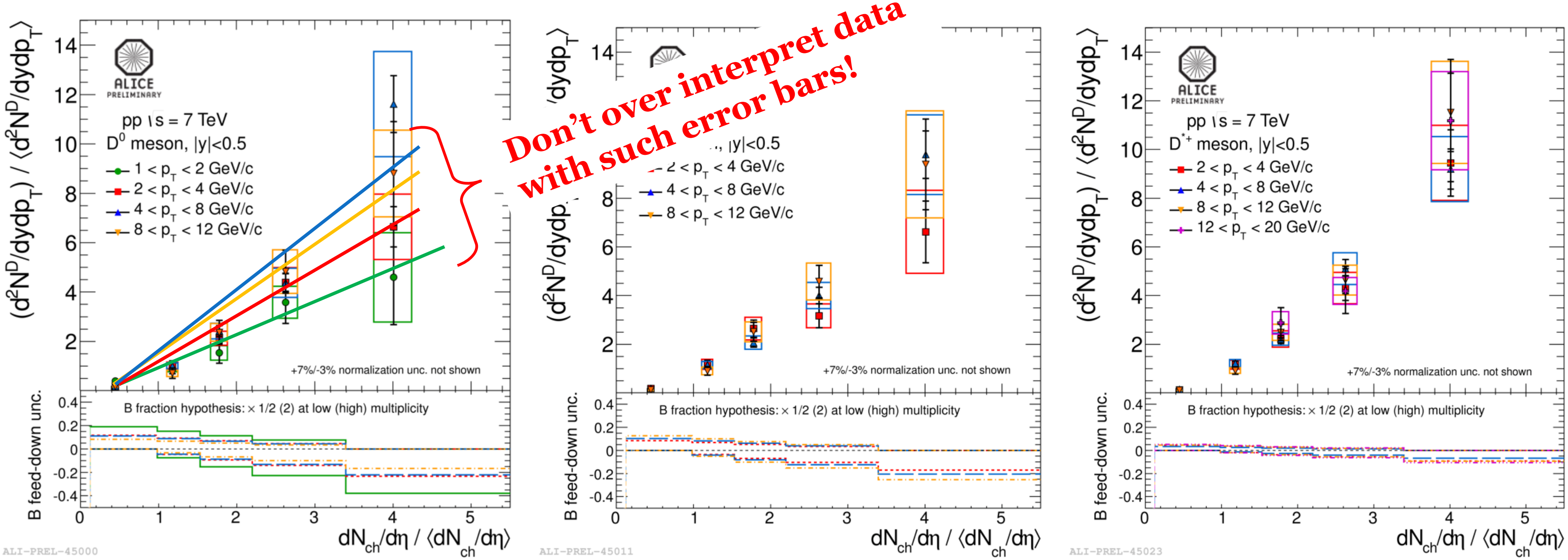
D mesons (D^0, D^+, D^{*+}) in central region ($|y|<0,5$)



Don't over interpret data with such error bars!

Approximately linear increase with charged particle multiplicity within uncertainties

(one could play with fits, but be careful with large error bars)

Similar trend in all p_T bins, the current uncertainties prevent to conclude on a possible p_T dependence

Horizontal size of boxes : systematic uncertainty on $dN/d\eta/\langle dN/d\eta\rangle$
Vertical size of boxes : systematic uncertainties wo feed-down
Bottom panels line: relative feed-down systematic uncertainties

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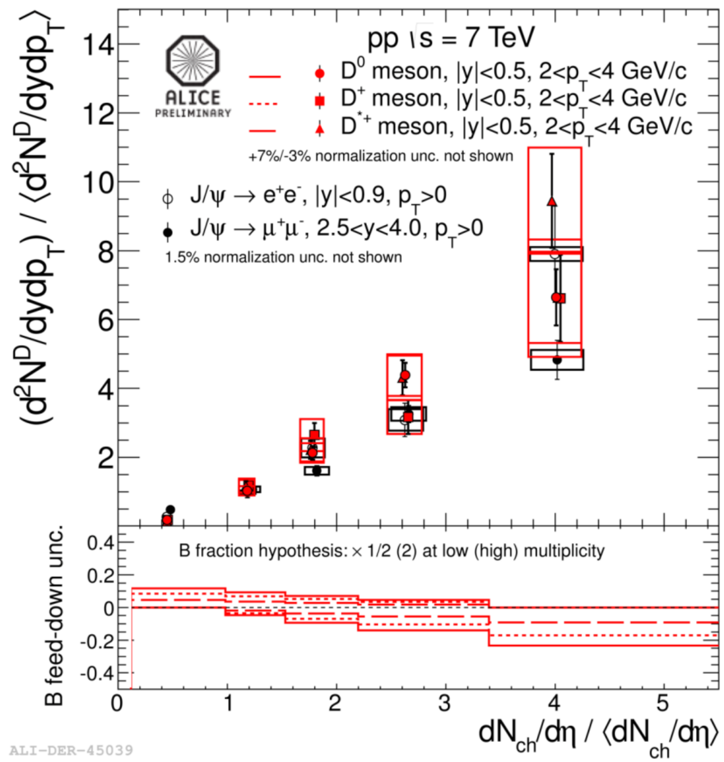
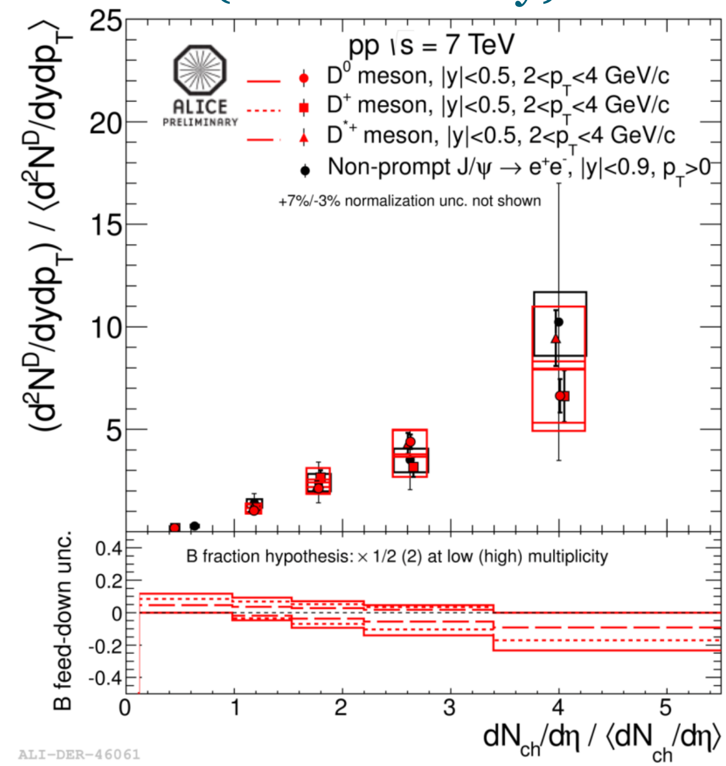
Comparisons of D mesons within the same p_T bin

with inclusive J/Ψ



Prompt D meson ($2<p_T<4$ GeV/c) and inclusive J/ψ ($p_T>0$) yield show a similar increase with charged particle multiplicity.

with non prompt J/Ψ (from B decay)



The results of prompt-D mesons and non-prompt J/ψ present a similar trend within the current statistical and systematic uncertainties.

Comparison with PYTHIA 8

Why to compare to PYTHIA?

- Several possible physics interpretation:
    - MPI,
    - hadronic activity
    - gluon fluctuation in the proton and proton size effect

- The model used need to provide the soft part and the hard part of the event in the same computation, an inclusive computation is not enough. MC well suited

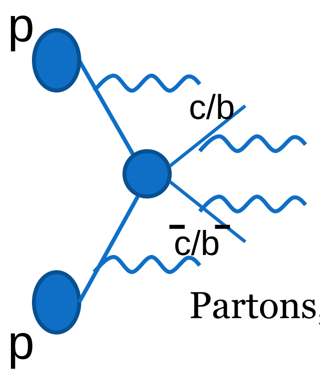
- The hard part should contain heavy quarks: PYTHIA, Cascade.

- Even if we know PYTHIA is not intended for J/Ψ study: a good start and a reference in MC world!

How to produce heavy states in Pythia8 ?

❖ In the 2->2 first hard sub-process: hard production

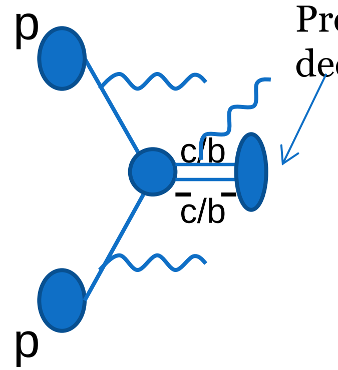
1) Open heavy-flavour production



gg->ccbar
gc->gc

Partons, connected to strings

2) Resonance production



Pre-resonant state (NRQCD):
decay into J/Ψ or ϒ

Can be color singlet
gg->J/Ψ+g

❖ In the 2->2 hard sub-processes of MPI: hard production

Same production mechanisms

Complement the contribution from first hard sub-process

❖ Beam remnant treatment

How to produce heavy states in Pythia8 ?

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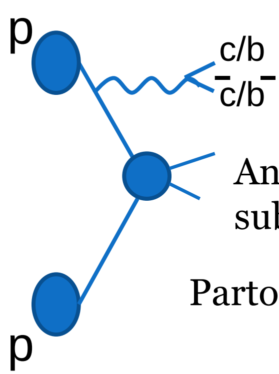
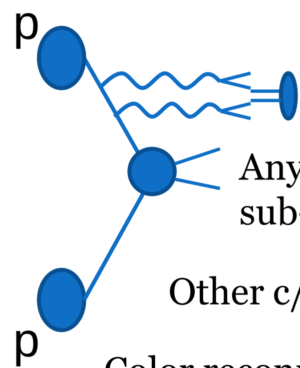
❖ Gluon splitting (g->QQbar, gluons originated from ISR/FSR)



Any hard 2->2
sub-process (gg->gg for example)

Partons, connected to strings



$c\bar{c}$ cluster decay into J/Ψ

Any hard 2->2
sub-process (gg->gg for example)

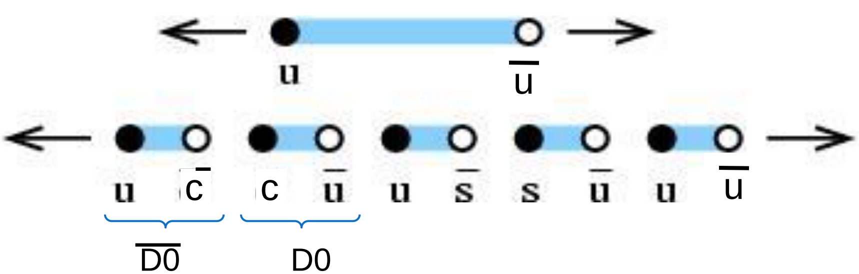
Other c/b connected to strings

Color reconnection make this contribution in PYTHIA6.4

In PYTHIA8 : $c\bar{c}$->J/Ψ, with c and $\bar{c}$ originating from various sources, no explicit cluster state

(N.B Cluster: small peace of string, decay directly into hadrons)

❖ String fragmentation



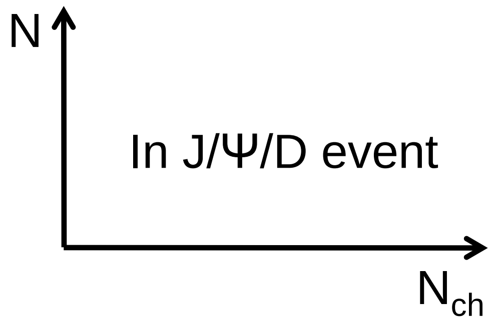
Higher states not available

A MB event can still produce J/Ψ and D mesons via gluon splitting and string fragmentation

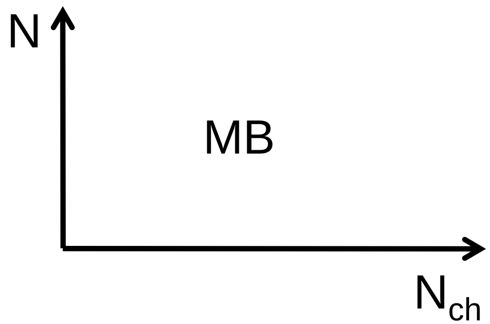
$c\bar{c}$ pair production suppressed as compared to u, d ,s, but available
Is it possible to switch it off?

The strategy

- Count the charged multiplicity in event where a trigger particle is produced (J/Ψ, D)



- Compare with charged multiplicity in MB



- Ratio of the two charged multiplicity distributions and normalize by the mean multiplicity and number of event

! Charged Multiplicity means number of charged particles per pseudo-rapidity unit at mid-rapidity

How to tag the origin of heavy states?

- Start from the particles,
  and reconstruct the mother chain until the origin

  - For example a D meson, origin is a string that contains a c quark,
    Identify this c quark
    Find the initial mother and check its status

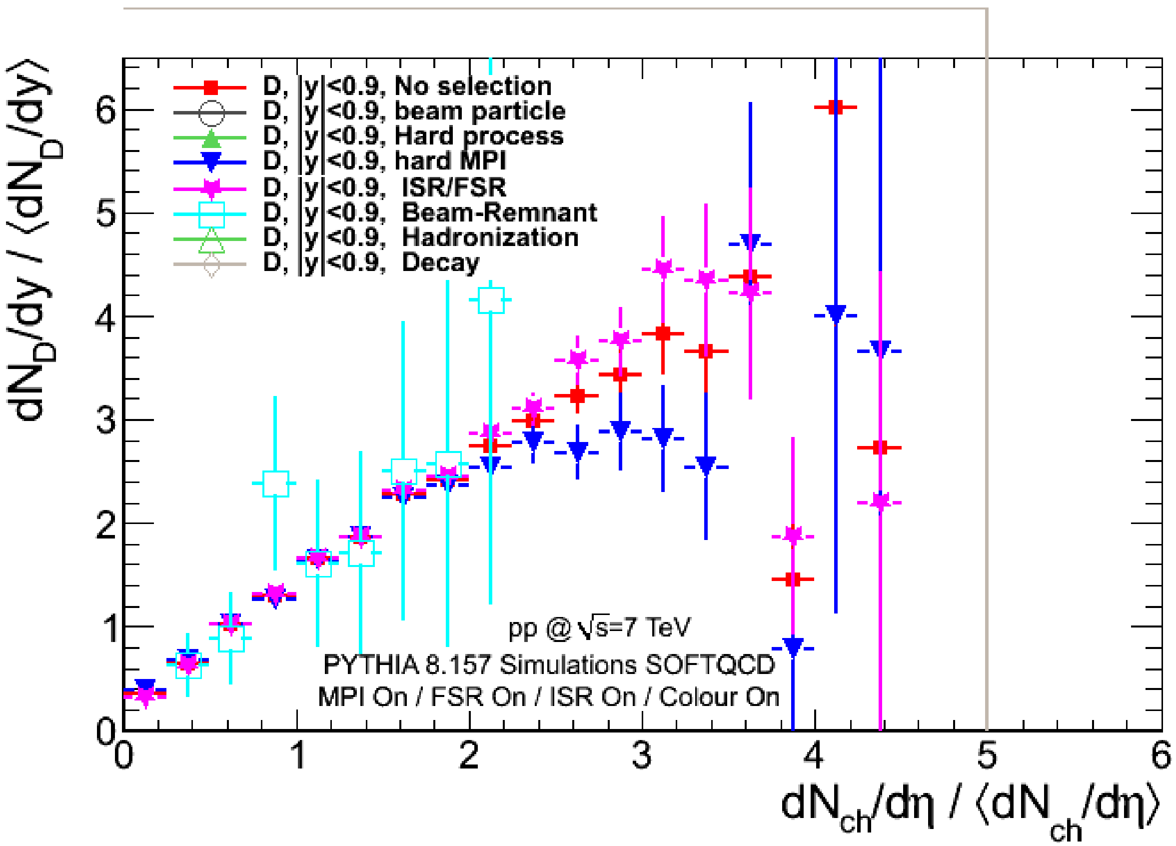
    - A status code is attributed to particles when they are created. In PYTHIA :

code range	explanation
11 – 19	beam particles
21 – 29	particles of the hardest subprocess
31 – 39	particles of subsequent subprocesses in multiple interactions
41 – 49	particles produced by initial-state-showers
51 – 59	particles produced by final-state-showers
61 – 69	particles produced by beam-remnant treatment
71 – 79	partons in preparation of hadronization process
81 – 89	primary hadrons produced by hadronization process
91 – 99	particles produced in decay process, or by Bose-Einstein effects

- Tag this D with the status code of initial mother

1) Basic parameter sets and process selection: Minimum Bias (SOFTQCD), all default in version 8.157

Total (red squares): linear dependence, look like in the data



But NO contribution from the first hard process!

2 main contributions:
- Hard from MPI
- Gluon splitting from ISR/FSR

Different behavior for high multiplicities: Need more statistics to conclude

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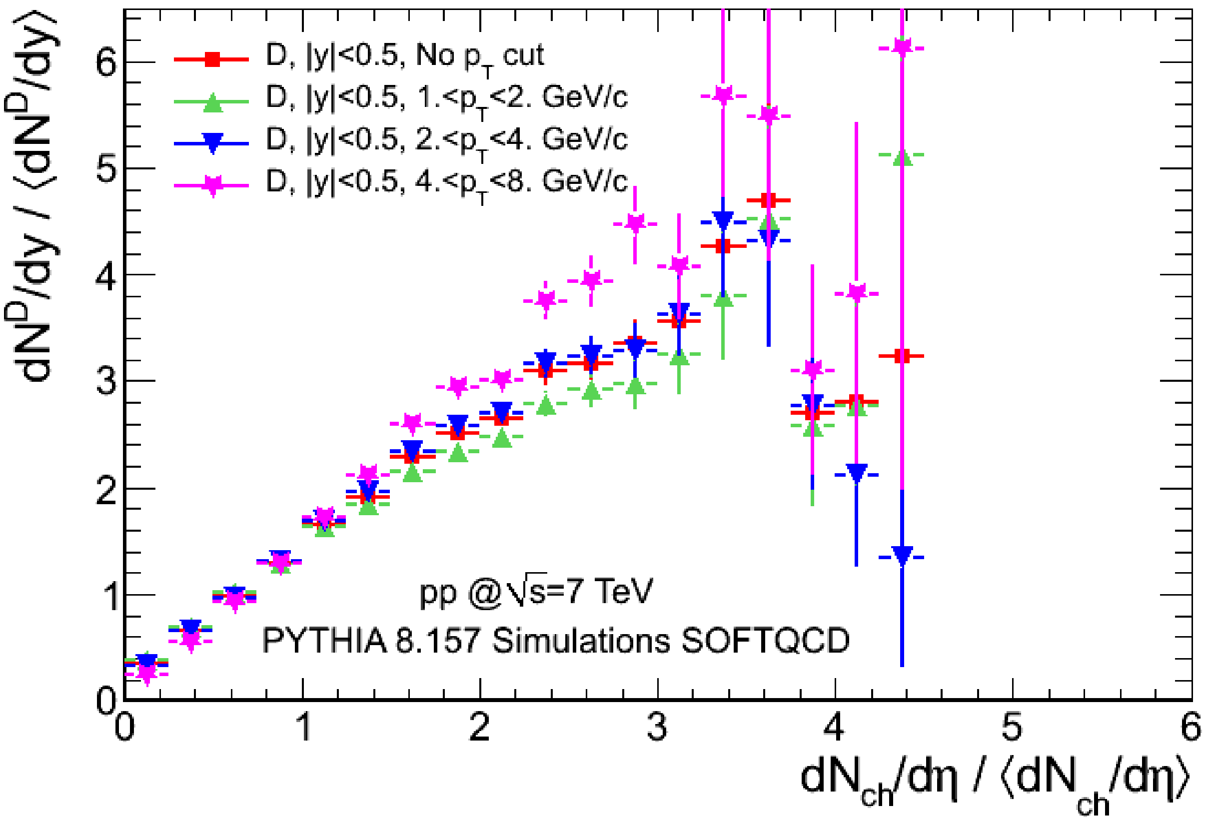
2) A plot with p_T slices



To be done: p_T slices with tagging of origin

Will need higher statistics but could disentangle contributions

An idea to be tested: ISR/FSR should contribute to low p_T

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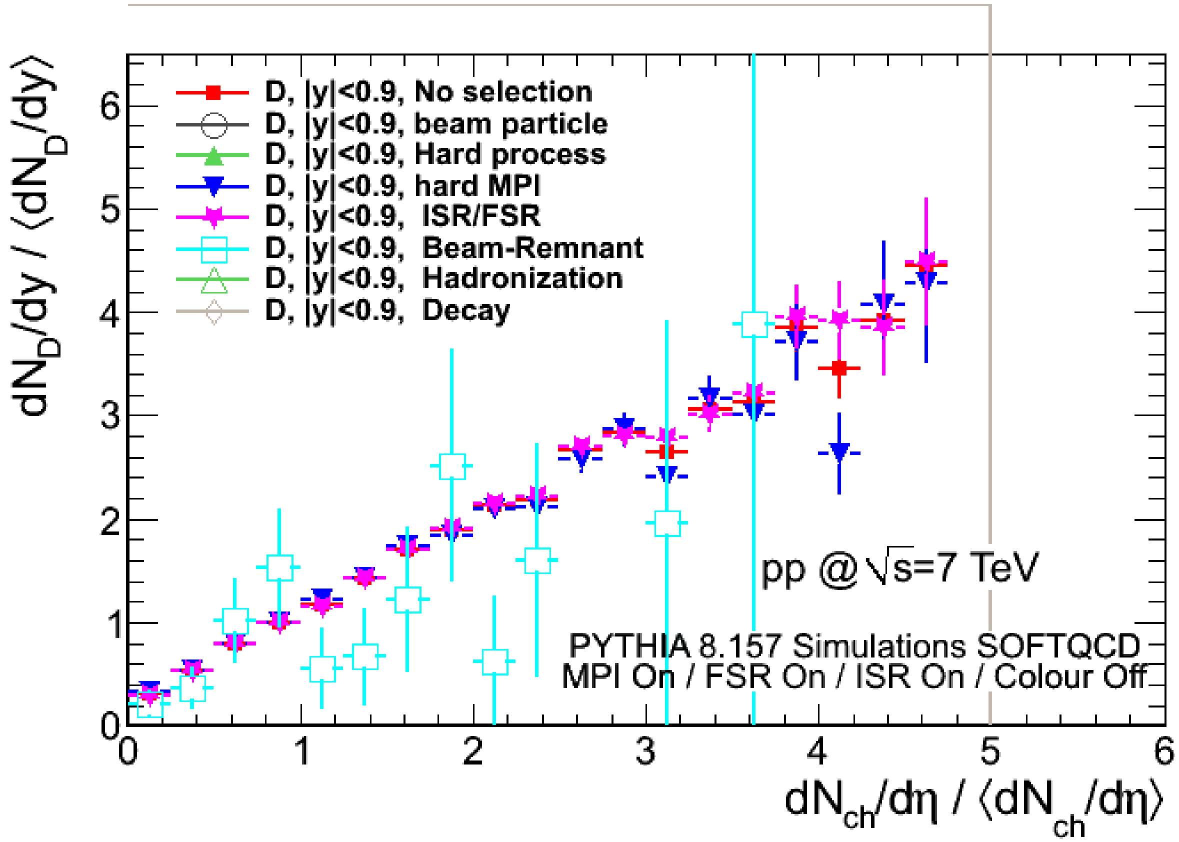
3) Minimum Bias color reconnection off

Motivated by impact of color reconnection scenario in PYTHIA 6 (cluster contribution)
Normalization with MB, color off



NO contribution from the first hard process!

Linear dependence (y=x),
same for ISR/FSR and MPI

Count the number of MPI?

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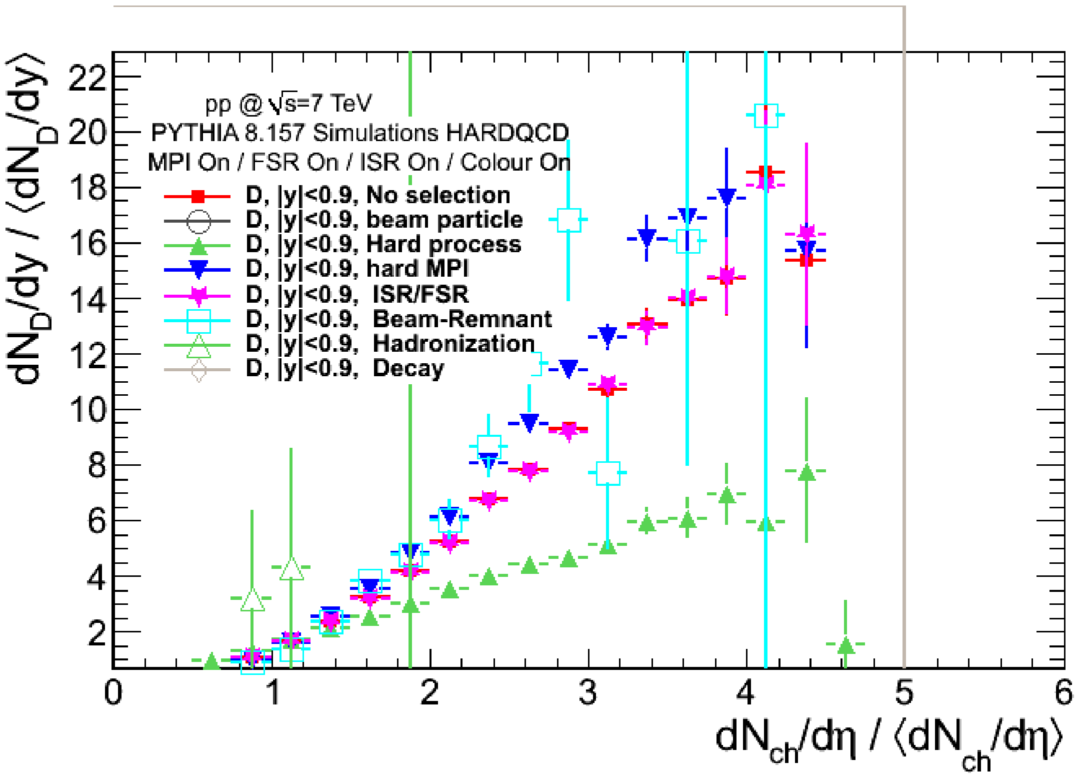
4) HardQCD, p_{Tcut}=10 Gev/c

Motivation: find a process selection with contribution from the first hard process, the first physics contribution (MPI second order)



BINGO !!!!
(full green triangle)

Normalization with MB
(SOFTQCD V 8.157)

<u>Implemented processes:</u>

gg2gg, gg2qqbar, qg2qg, qq2qq, qqbar2gg, qqbar2qqbarNew, gg2ccbar, qqbar2ccbar, gg2bbbar, qqbar2bbbar

! Process selection intended for inclusive hard study only, with a strong phase space cut

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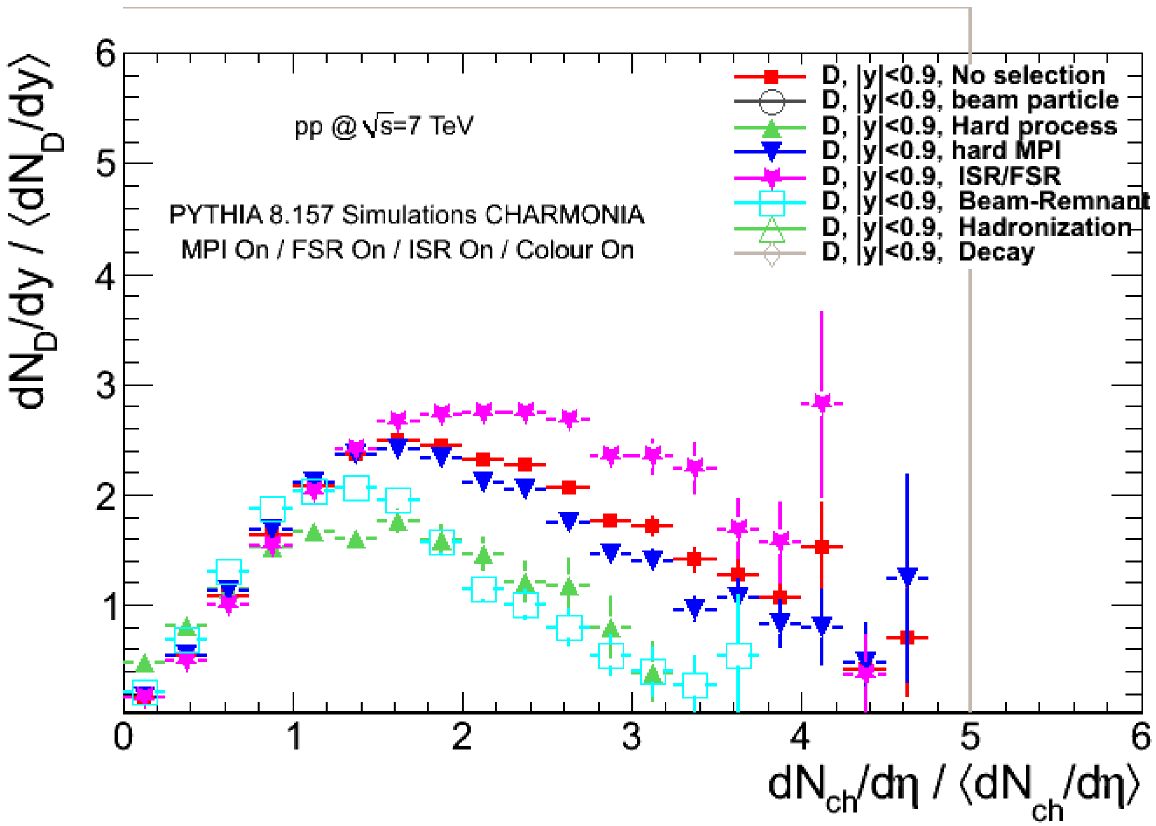
5) Charmonia

Motivation: find a process selection with contribution from the first hard process:
The first physics contribution (MPI second order)



BINGO !!!!
(full green triangle)

Normalization with
MB standard

Different trend than hard,
Maybe a bias due to physics
selection.

! Process selection intended for inclusive study only

Conclusions (1)

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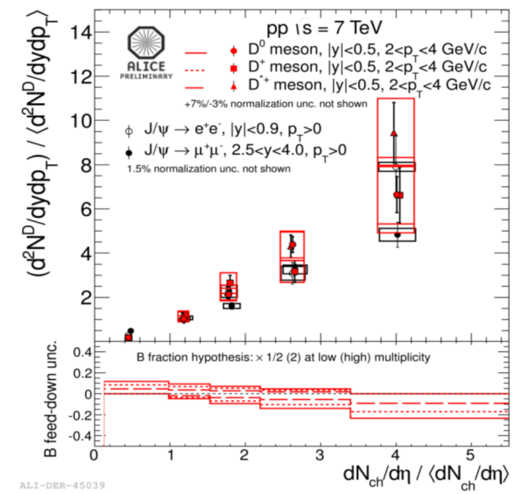
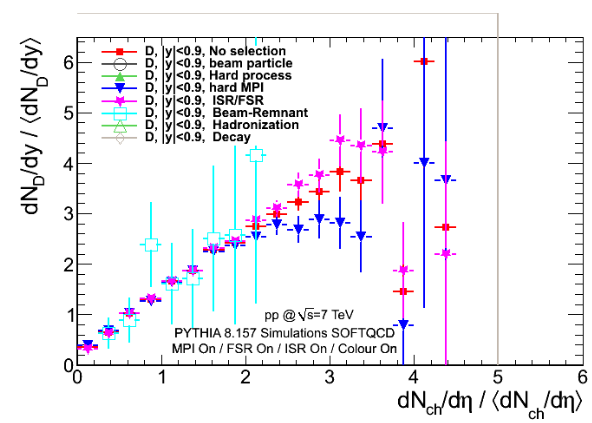
- High multiplicity pp collisions are non trivial interactions!

- Inclusive J/Ψ (central + forward), D mesons with p_T slices and non prompt J/Ψ with the ALICE experiment
  ⇒ present a similar global trend within the current statistical and systematic uncertainties



- PYTHIA 8 Minimum Bias look like data without involving first hard processes, only MPI
  ⇒ Can we really compare?



What to do next?

- Increase statistics
  - inclusive J/Ψ comparable at central/forward region?
  - D in p_T slices: slope dependence in question
  - go higher multiplicities: change of slope to study
  - try to fit (exponential)

- D and non-prompt J/Ψ in the forward region

- Other system than pp

Compare at higher multiplicities the results from various systems (pp, p-Pb, Pb-Pb) and energy.

Recent p-Pb results, hints for collective effect Alice arXiv:1307.3237 / B. Z. Kopeliovich et al. arXiv:1308.3638
=> Maybe an interesting way to look at observables would be as a function of initial energy density, e.g. multiplicity in final state

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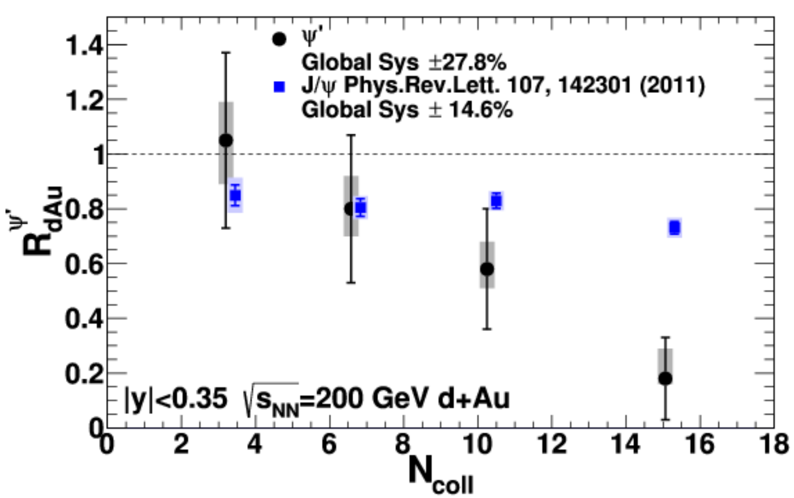
What to do next?

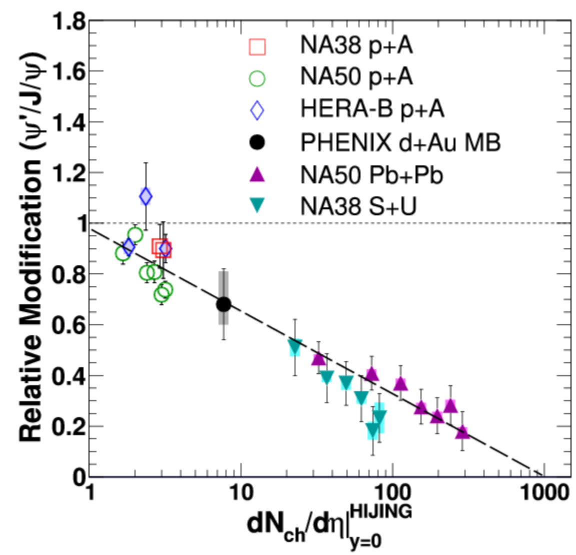
- Other observables: Ψ’, ϒ and other hard probes (isolated photon, jets …)

Universality, hard scale at play
Possible final state effect on quarkonia?

RHIC d-Au 200GeV PHENIX arXiv:1305.5516

R_{dAu} different for J/Ψ and Ψ’





If a final state effect is linked with multiplicity,
should be seen in pp vs. mult at 7 TeV also!!!!!!

What to do next?

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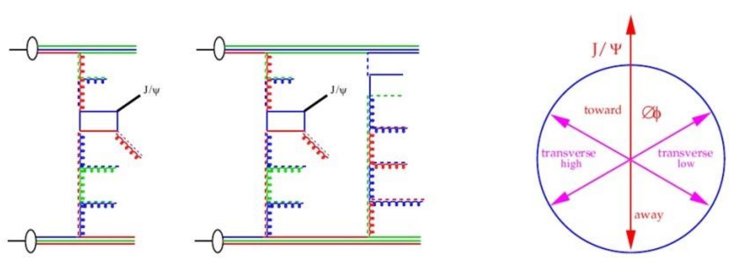
➢ Proposition:
an Underlying Event (UE) event study with quarkonia as trigger particle, "à la Rick Field"

Study meant to understand interplay between jet and UE in pp collisions

III. J/ψ PRODUCTION AND ASSOCIATED JET MULTIPLICITIES

▷ underlying event analysis using gluonic probe [cfr. $Z+$ jets]

▷ perturbative calculation down to $p_\perp$ of order m_ψ



Already discussed by F. Hautmann @MPI2011

▷ See also: J/ψ vs. charged particle multiplicity *[Portebeuf & Granier, arXiv:1012.0719]*

▷ J/ψ pairs as a probe of DPI *[Kom, Kulesza & Stirling, arXiv:1105.4186]*

[LHCb Coll., LHCb-Conf-2011-009]

Conclusions (2)

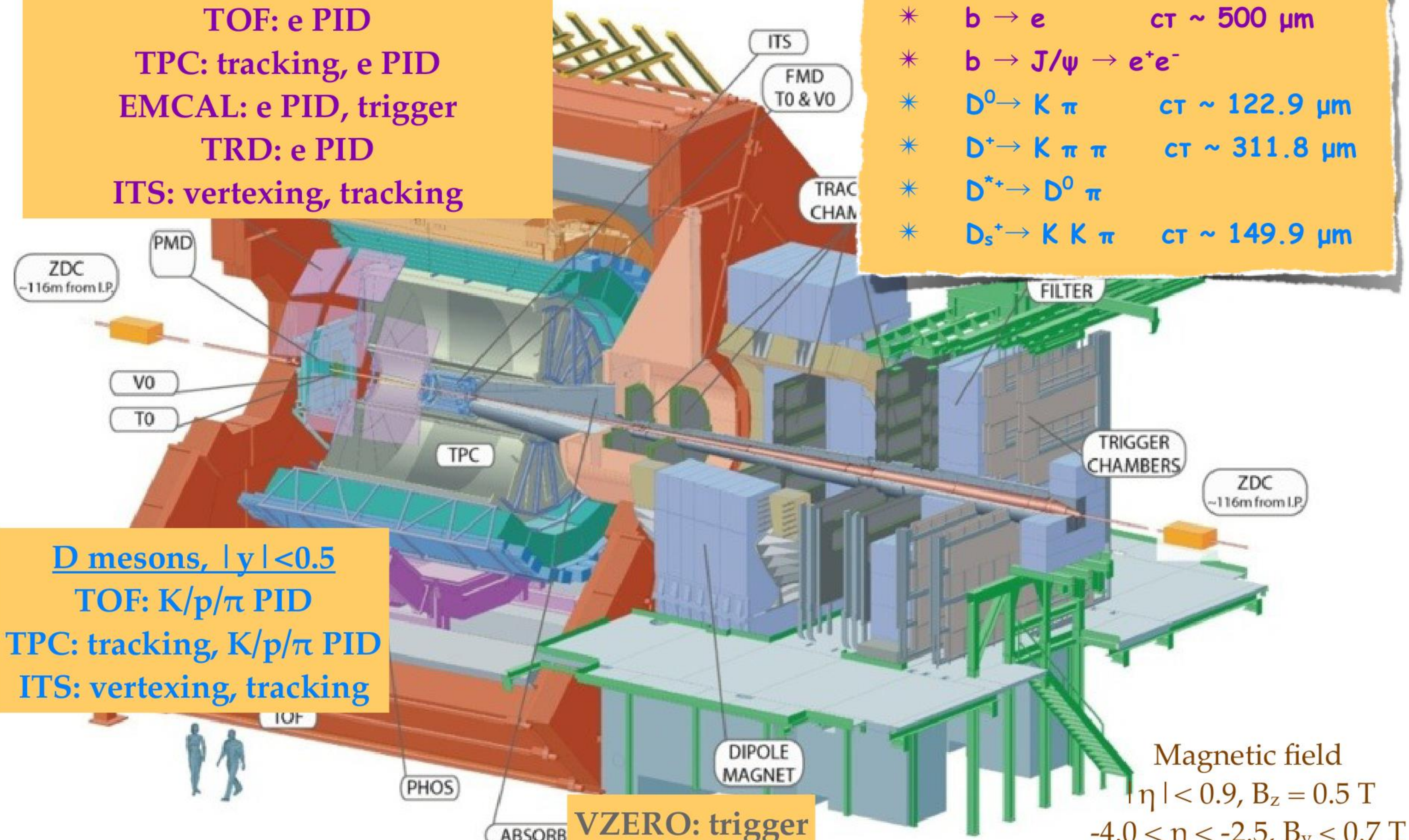
Still many work to be done!

The ALICE Experiment

HF electrons & $J/\psi \rightarrow e^+e$, $|\eta|<0.8$

TOF: e PID
TPC: tracking, e PID
EMCAL: e PID, trigger
TRD: e PID
ITS: vertexing, tracking

- $c, b \rightarrow e$
- $b \rightarrow e$ $c\tau \sim 500\ \mu m$
- $b \rightarrow J/\psi \rightarrow e^+e^-$
- $D^0 \rightarrow K\pi$ $c\tau \sim 122.9\ \mu m$
- $D^+ \rightarrow K\pi\pi$ $c\tau \sim 311.8\ \mu m$
- $D^{*+} \rightarrow D^0\pi$
- $D_s^+ \rightarrow KK\pi$ $c\tau \sim 149.9\ \mu m$



D mesons, $|y|<0.5$

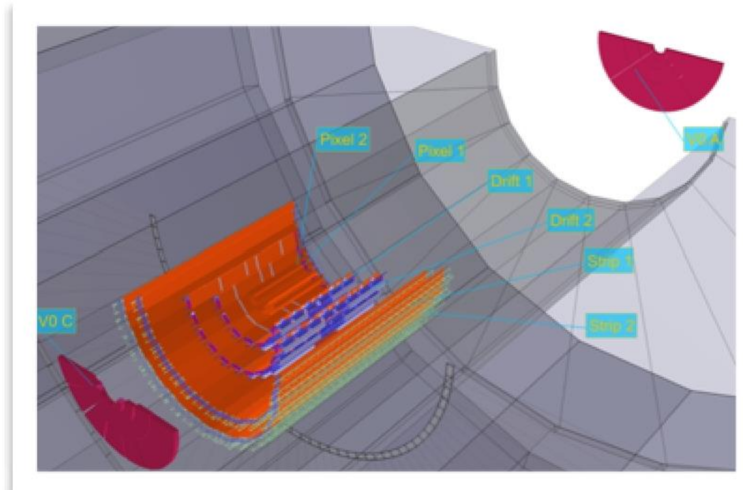
TOF: $K/p/\pi$ PID
TPC: tracking, $K/p/\pi$ PID
ITS: vertexing, tracking

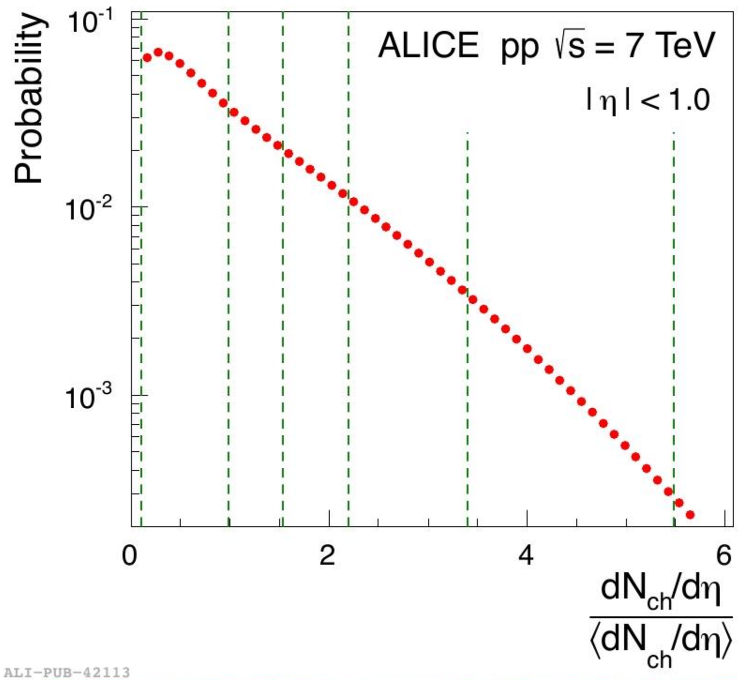
VZERO: trigger

Magnetic field
$|\eta| < 0.9$, $B_z = 0.5$ T
$-4.0 < \eta < -2.5$, $B_y \leq 0.7$ T

Multiplicity determination

- Multiplicity estimator: number of track segments (or *tracklets*) of the **Silicon Pixel Detector** (2 innermost layers of the *Inner Tracking System*).
- 2010 data, with MB trigger: SPD or V0A or V0C.
- The analysis, performed on a data sample of L_{int} = 5 nb^{-1}, required corrections to account for the detector performance variation vs time.





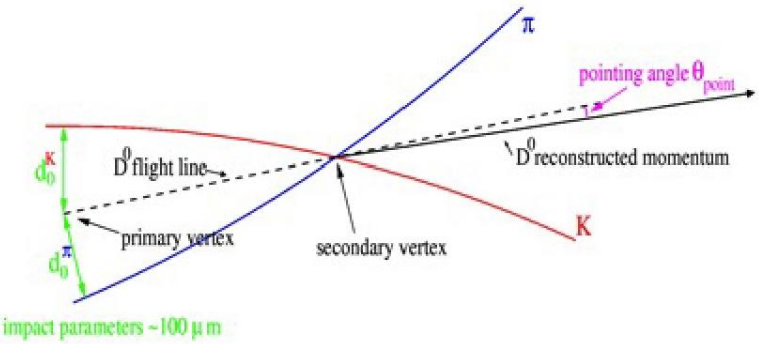
SPD layers of radii of 3.9 cm (1cm from beam vacuum tube) and 7.6 cm. Formed by 9.8×10^{6} pixels of size $50(r\phi) \times 425(z)$ μm^2, with intrinsic spatial resolution of $12(r\phi) \times 100(z)$ μm^2.

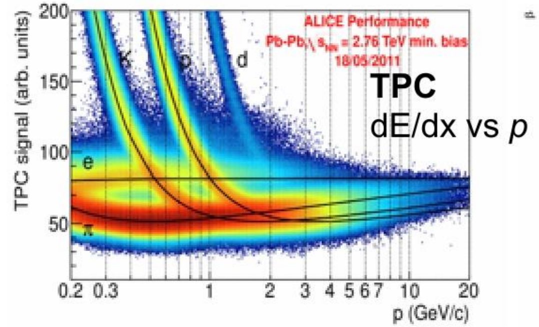
V0 scintillator hodoscopes at $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$

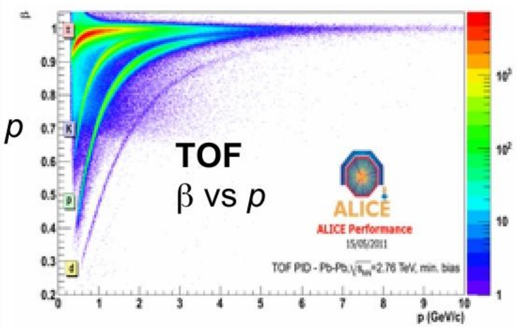
- $N_{tracklets} \propto dN_{ch}/d\eta$
- $\langle dN_{ch}/d\eta \rangle = 6.01 \pm 0.01(\text{stat.})\ ^{+0.20}_{-0.12}(\text{syst.})$ for $|\eta|<1.0$

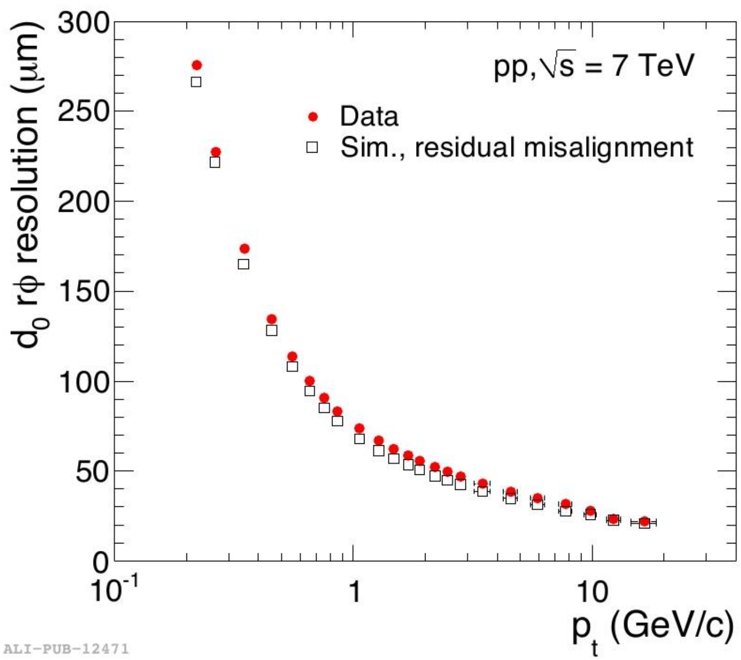
ALICE Coll., Eur. Phys. J. C 68 (2010) 345.
ALICE Coll., Phys. Lett. B 712 (2012) 3, 165–175

D meson reconstruction





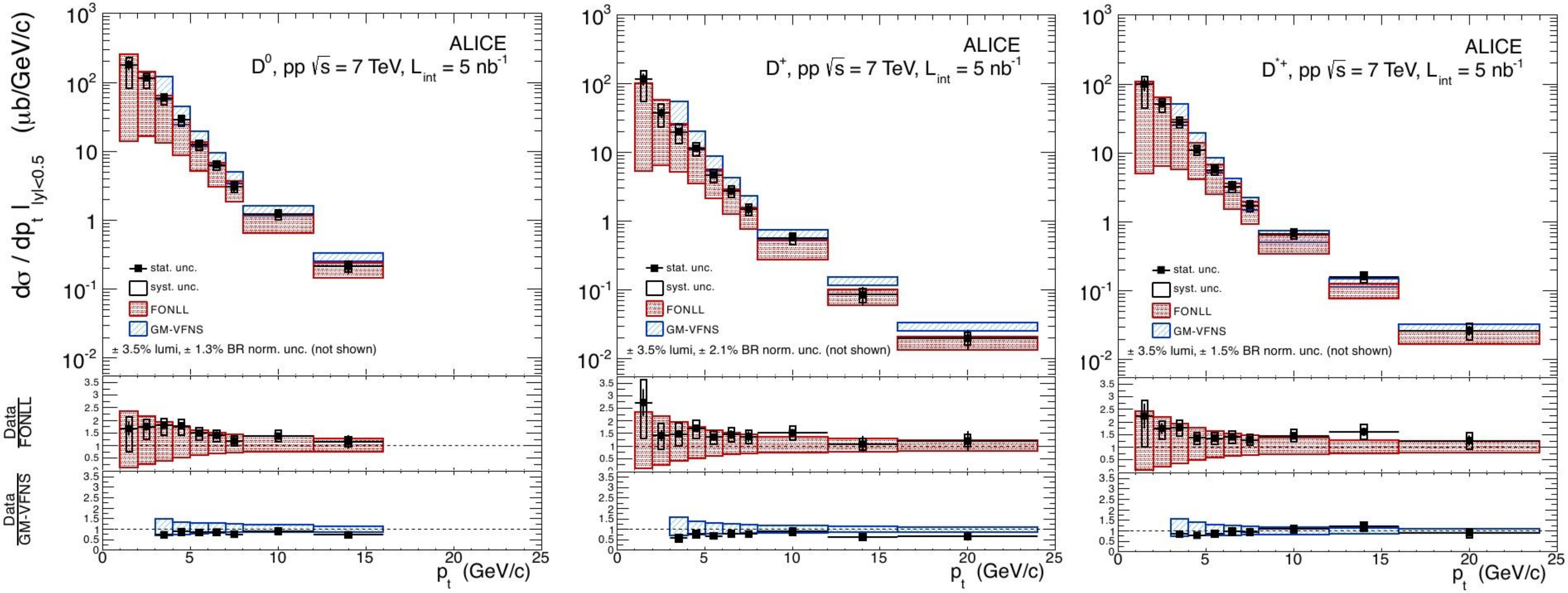




ALI-PUB-12471

- Selection strategy: displaced vertices
- Main geometrical selections:
  - Impact parameter of the tracks,
  - Angle between the meson flight line and the particle momentum.
- Particle identification: K identification thanks to TPC+TOF helps to reject background at low p_T
  - TPC allows K/π separation up to ~0.6 GeV/*c*,
  - TOF allows K/π separation up to ~2 GeV/*c*.

Prompt D^0, D^+, D^{*+} Cross Sections



ALICE Coll., JHEP 01 (2012) 128.
ALICE Coll., JHEP 07 (2012) 191.
ALICE Coll., PLB 718 (2012) 279.

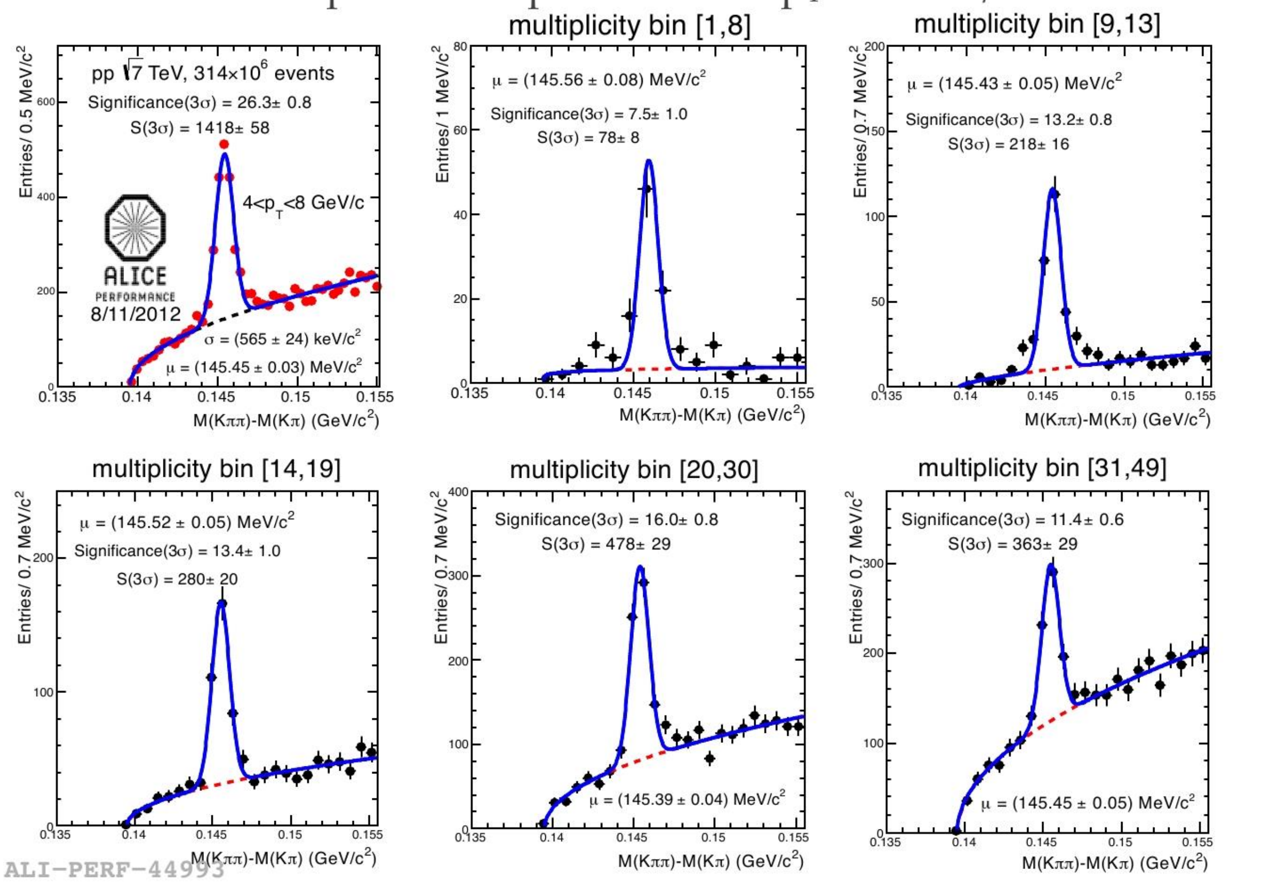
FONLL: Cacciari et al., private comm.
GM-VFNS: Kniehl et al., private comm.

- At $\sqrt{s}$ = 7 TeV, D^0, D^+, D^{*+}: 1 < p_T < 24 GeV/*c*, with 5 nb^{-1}
- At $\sqrt{s}$ = 7 TeV, D_s^+: 2 < p_T < 12 GeV/*c*, with 5 nb^{-1}
- At $\sqrt{s}$ = 2.76 TeV, D^0, D^+, D^{*+}: 1 < p_T < 12 GeV/*c*, with 1.1 nb^{-1}
- **Data well described by pQCD predictions (FONLL and GM-VFNS)**

D meson signal vs. multiplicity in |y|<0.8

- D^0, D^+, D^{*+} signal studied
  - in 5 multiplicity bins, with Number of *tracklets* (1,9,14,10,31,50)
  - and 3-5 p_T bins (1,2,4,8,12,20) GeV/*c*

Example of D^{*+} spectra for $4 < p_T < 8$ GeV/c



Corrections and systematic uncertainties

- The raw yields in a given multiplicity bin (Y^{mult}) are corrected by the reconstruction and analysis acceptance × efficiency (ϵ^{mult}) and divided by the respective values on the multiplicity integrated sample ($^{mult\ int}$).
- This is normalized by the number of events in each multiplicity bin (N_{event}^{mult}) and corrected to that of inelastic collisions ($N_{event}^{inelastic}$)

$$\frac{\frac{\mathrm{d}^2 N}{\mathrm{d}p_\mathrm{T}\mathrm{d}y}}{\left\langle \frac{\mathrm{d}^2 N}{\mathrm{d}p_\mathrm{T}\mathrm{d}y} \right\rangle} = \frac{Y^{\mathrm{mult}}/(\epsilon^{\mathrm{mult}} \times N_{\mathrm{event}}^{\mathrm{mult}})}{Y^{\mathrm{mult\,int}}/(\epsilon^{\mathrm{mult\,int}} \times N_{\mathrm{event}}^{\mathrm{inelastic}})}; \qquad N_{\mathrm{event}}^{\mathrm{inelastic}} = N_{\mathrm{event}}^{\mathrm{multint}}/0.85.$$

- Systematic uncertainties:
  - Relative charged particle multiplicity:
    - Multiplicity bins, $dN_{ch}/d\eta$: 5.4% — ALICE Coll., Phys. Lett. B 712 (2012) 3, 165–175
    - $\langle dN_{ch}/d\eta \rangle$ measurement: $^{+3.3\%}_{-2\%}$ — ALICE Coll., Eur. Phys. J. C 68 (2010) 345.
  - Relative prompt-D meson yields:
    - Yield extraction: vary the signal and background fit function, 5-10%
    - Topological selections: redo the analysis varying the analysis cuts, 5-10%
    - Monte Carlo: description of the signal, N_{ch} and the detector conditions, 10%
    - Feed-down: consider that non-prompt D yields can vary with N_{ch} by 1/2 (2) at low (high) multiplicity, typically 5%
  - Normalization: trigger efficiency correction factor $0.85^{+7\%}_{-3\%}$ — ALICE Coll., arXiv:1208.4968 (2012)

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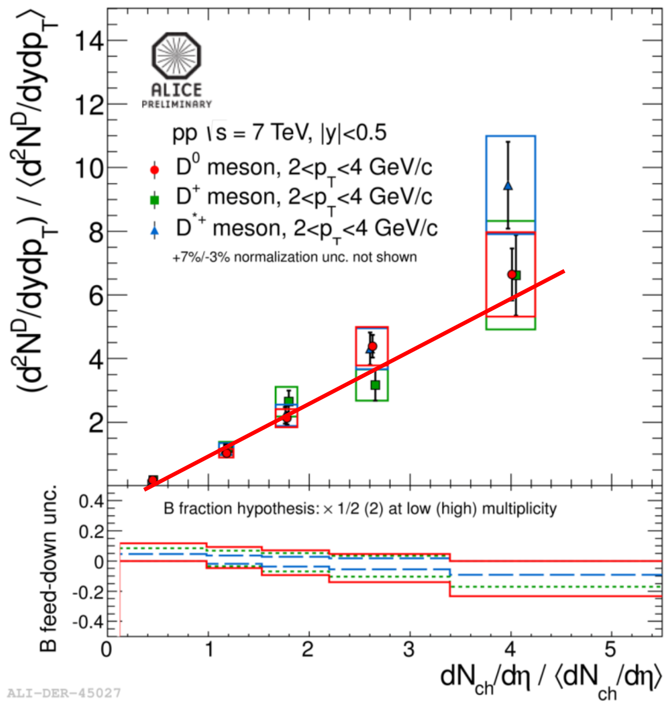
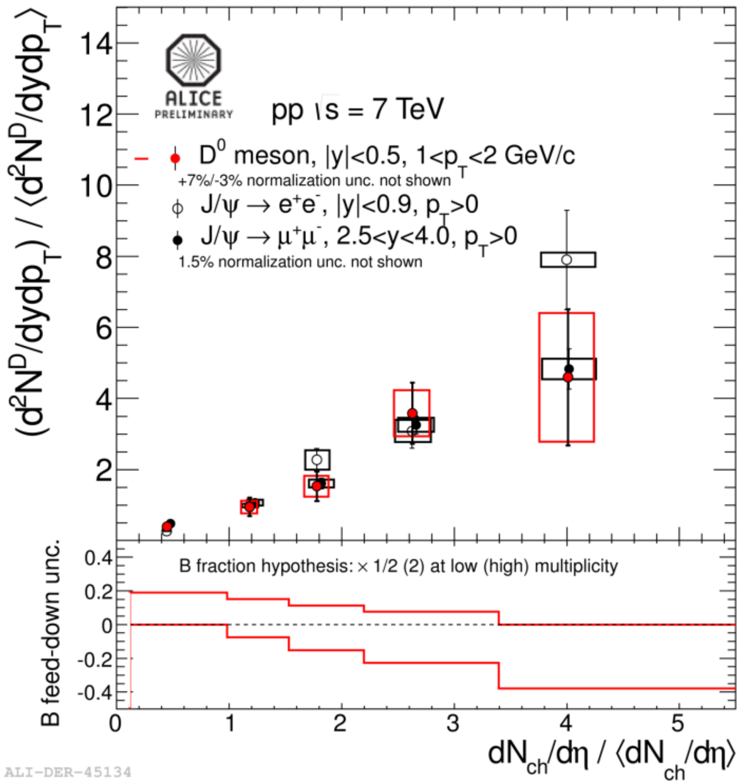
Comparisons of D mesons within the same p_T bin ($2<p_T<4$ GeV/c)

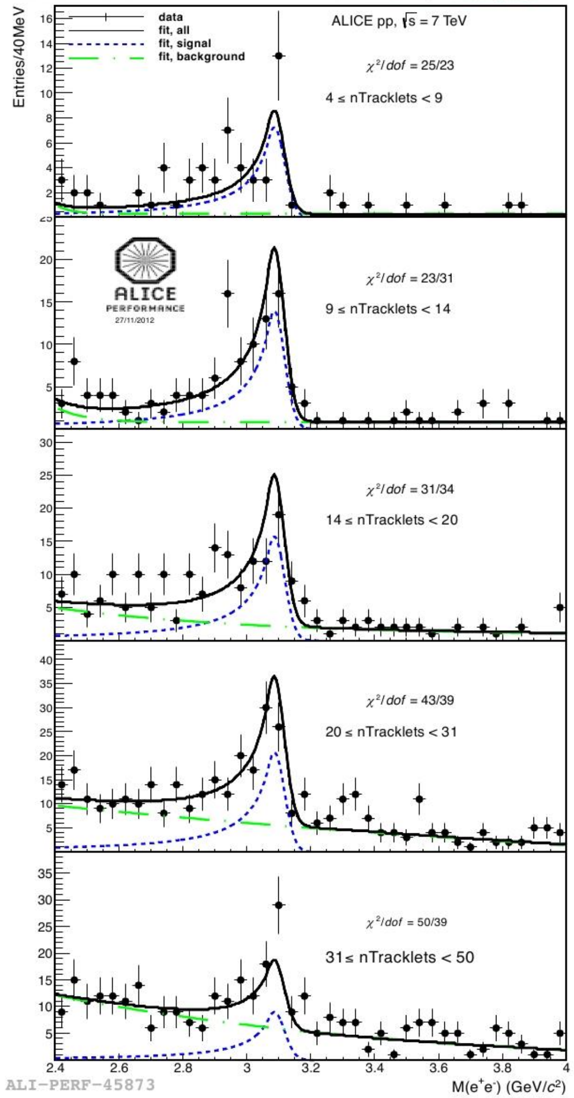




The results of D^0, D^+ and D^{*+} are consistent within the statistical and systematic uncertainties.

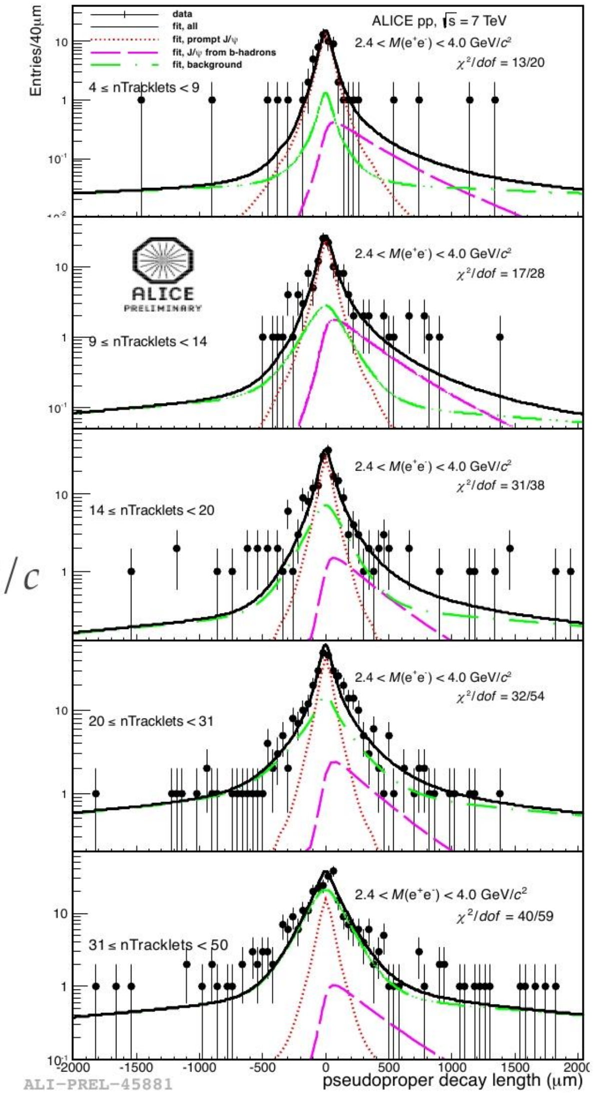
Non-prompt J/ψ determination vs. multiplicity

Increasing $dN_{ch}/d\eta$



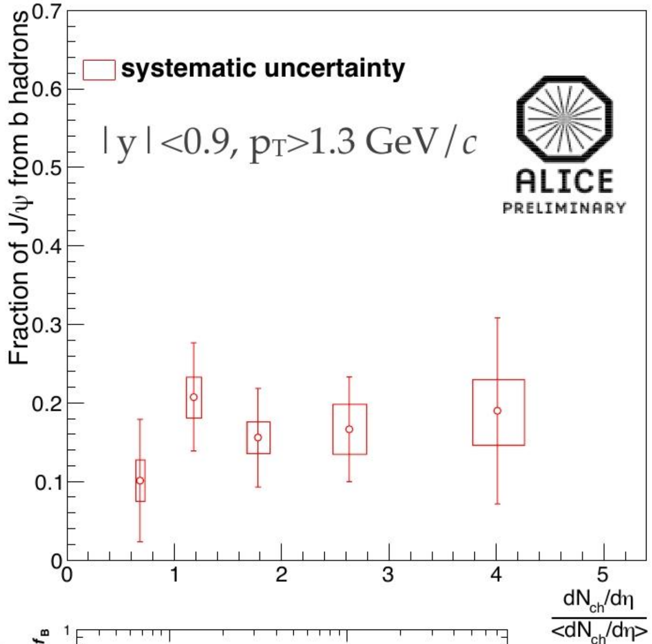
Dielectron unlike sign invariant mass distribution

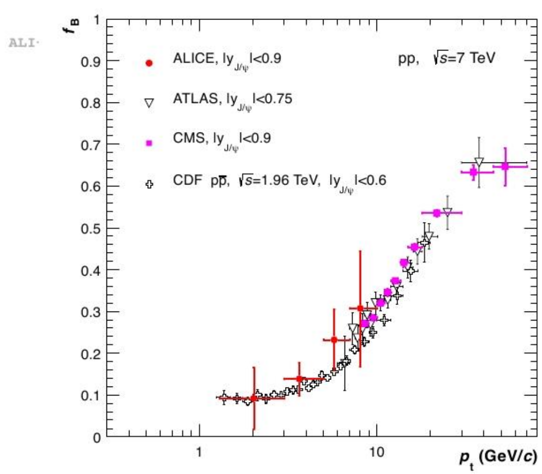
|y|<0.9
p_T>1.3 GeV/c



$$x = L_{xy} \cdot c \cdot m(J/\psi) \,/\, p_{\mathrm{T}}(J/\psi); \qquad L_{xy} = \vec{L} \cdot \vec{p_{\mathrm{T}}}(J/\psi).$$

Non-prompt J/ψ fraction vs. $dN_{ch}/d\eta$





ALI-PUB-44634 ALICE Coll, JHEP 11 (2012) 065.

- **Approximately flat non-prompt J/ψ fraction with charged particle multiplicity**

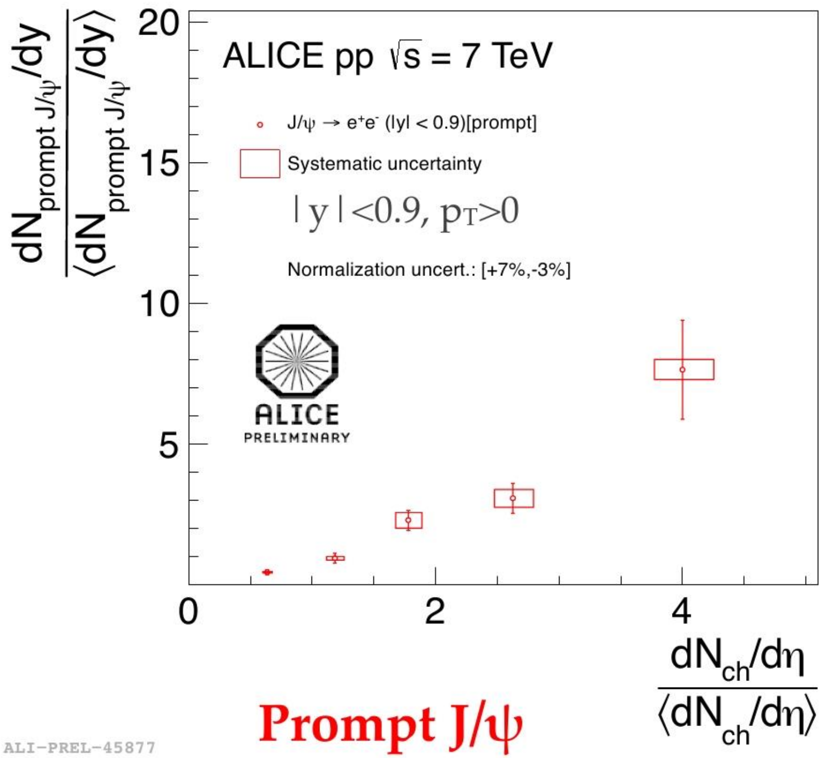
- Prompt and non-prompt yields vs multiplicity can be obtained combining the inclusive yields and the fraction of non-prompt yields vs multiplicity

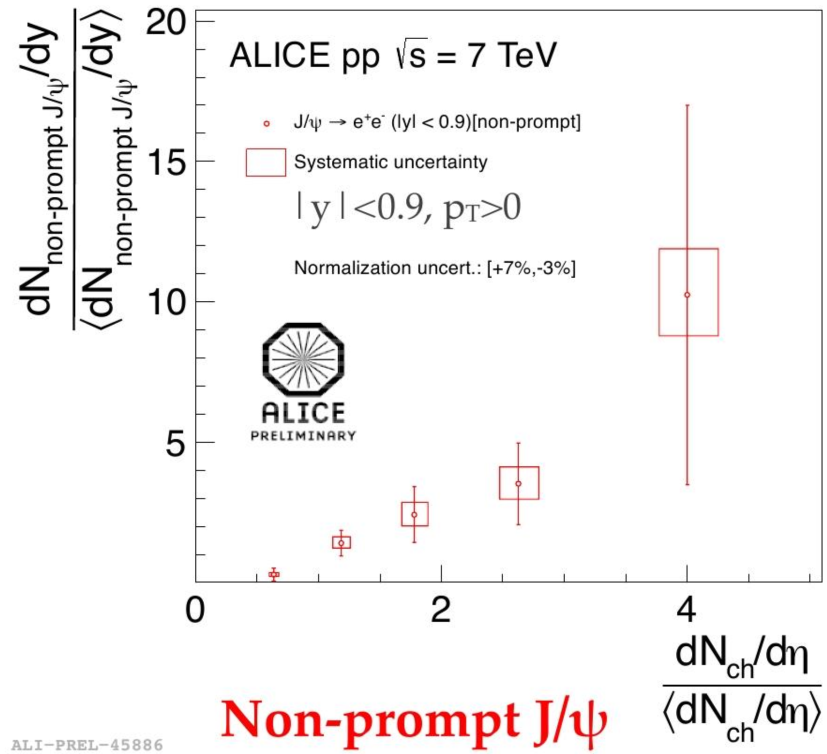
f_B: fraction of J/ψ from B

$$\frac{\frac{dN(J/\psi\ \mathrm{from\ B})}{dy}}{\left\langle\frac{dN(J/\psi\ \mathrm{from\ B})}{dy}\right\rangle} = \frac{\frac{dN(J/\psi)}{dy}}{\left\langle\frac{dN(J/\psi)}{dy}\right\rangle} \times \frac{f_B}{\langle f_B\rangle}$$

$$\frac{\frac{dN(\mathrm{prompt}\ J/\psi)}{dy}}{\left\langle\frac{dN(\mathrm{prompt}\ J/\psi)}{dy}\right\rangle} = \frac{\frac{dN(J/\psi)}{dy}}{\left\langle\frac{dN(J/\psi)}{dy}\right\rangle} \times \frac{1-f_B}{\langle 1-f_B\rangle}$$

Relative prompt and non-prompt J/ψ yields vs. $dN_{ch}/d\eta$





Prompt J/ψ **Non-prompt J/ψ**

- **Approximately linear increase with charged particle multiplicity of both prompt and non-prompt J/ψ**

Note: here non-prompt J/ψ yields are a measurement of the B hadron yields

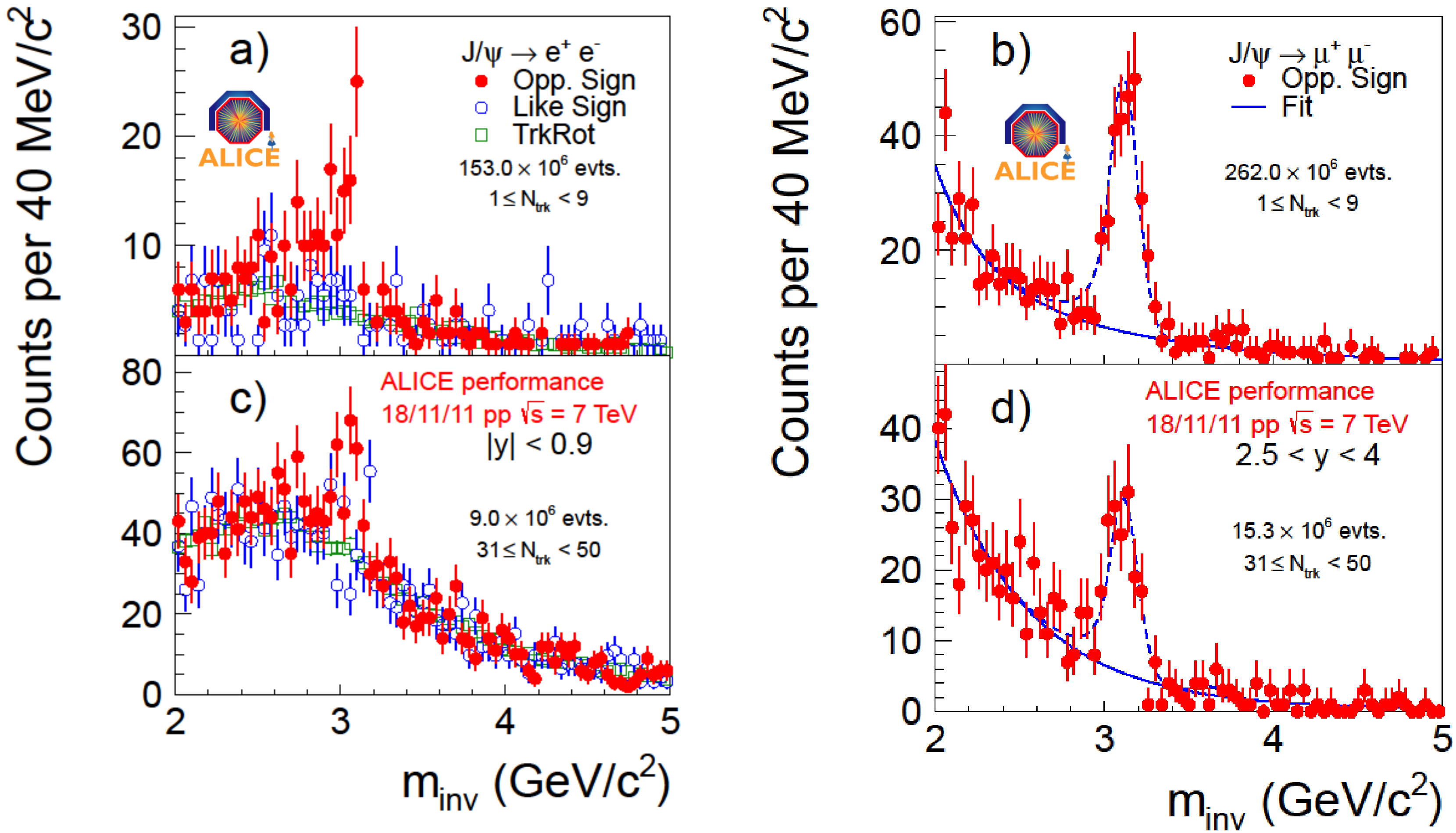
J/ψ signal in 7 TeV pp data

With the central barrel

L=4.5 nb−1

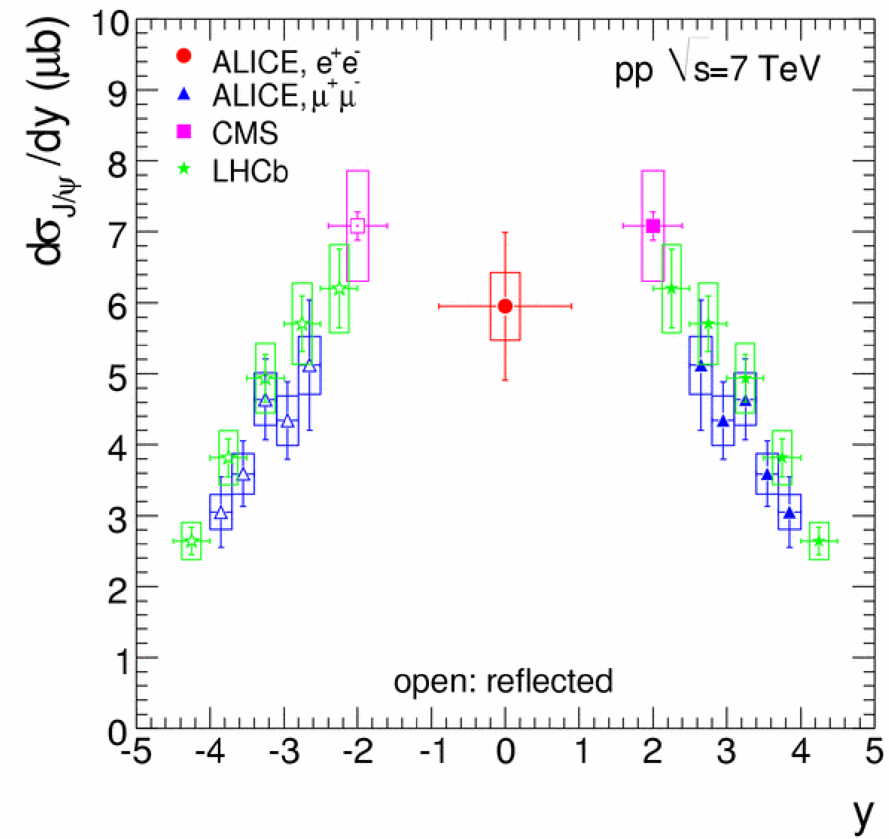
With the Muon spectrometer

L=7.7 nb−1

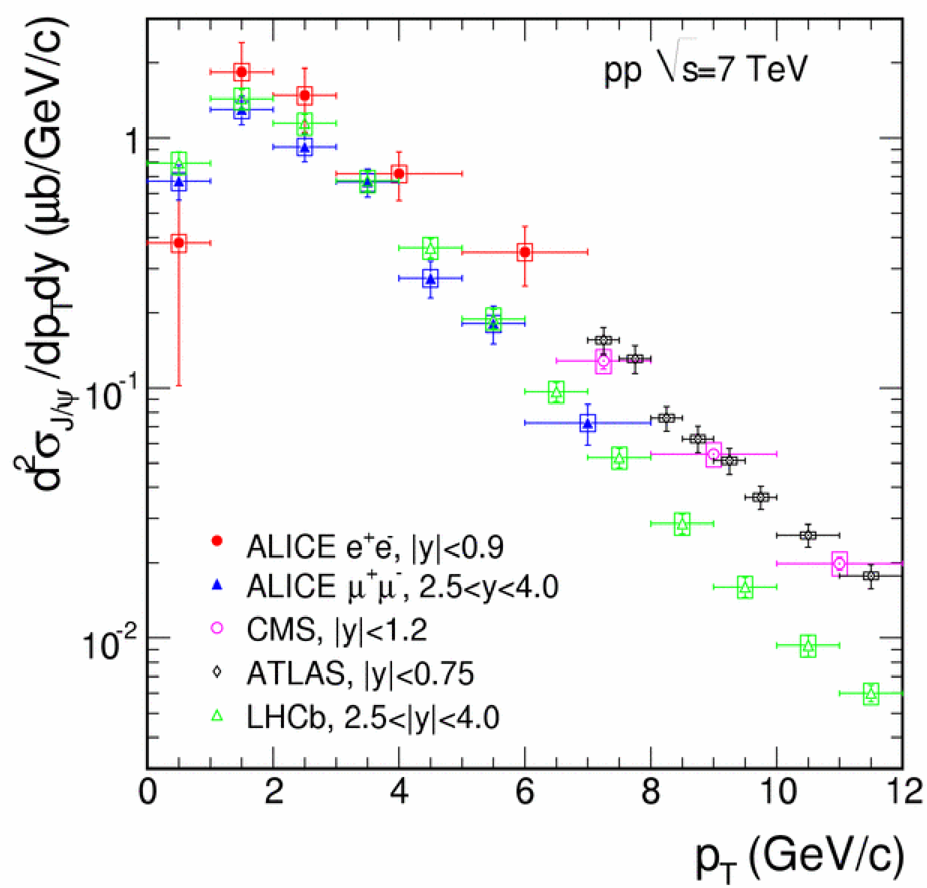


J/ψ signal in 7 TeV pp data

K. Aamodt et al., Phys. Lett B704(2011), 442-455, arXiv/1105.0380



ALI-PUB-139

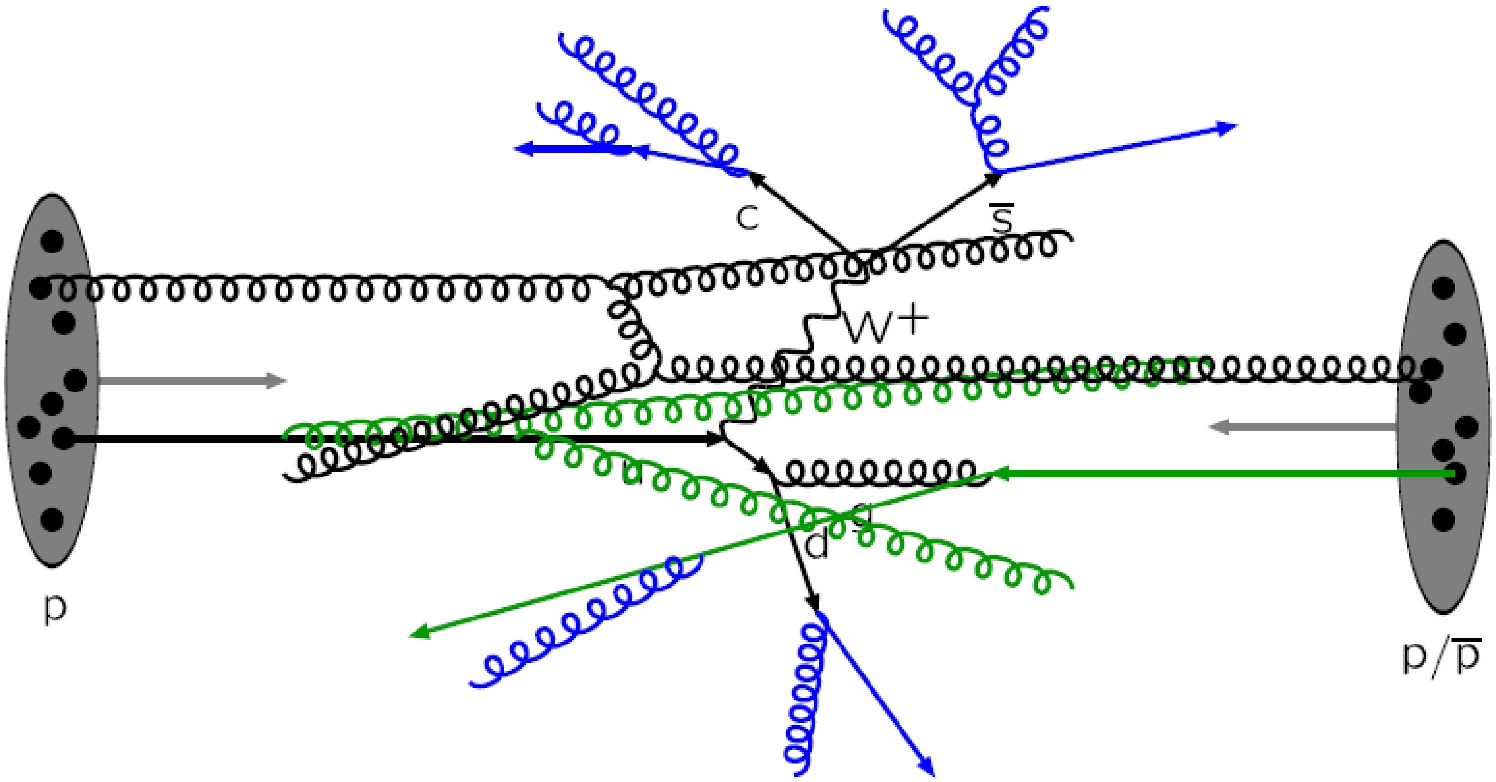


ALI-PUB-136

- Inclusive J/y production in the rapidity ranges |y| < 0.9 and 2.5 < y < 4, through the decays J/y →e+e− and J/y →μ+μ−.
- Lint = 5.6 nb−1 (for the J/y → e+e−channel) and Lint = 15.6 nb−1 (for J/y → μ+μ−)
- pT-integrated cross sections : σ_{J/y} (|y| < 0.9) = 10.7 ± 1.0 (stat.) ± 1.6 (syst.)+ 1.6 (λ_HE = 1) − 2.3 (λ_HE = −1) mb
  σ_{ J/y }(2.5 < y < 4) = 6.31 ± 0.25 (stat.) ± 0.76 (syst.)+ 0.95 (λ_CS = 1) − 1.96 (λ_CS = −1) mb.

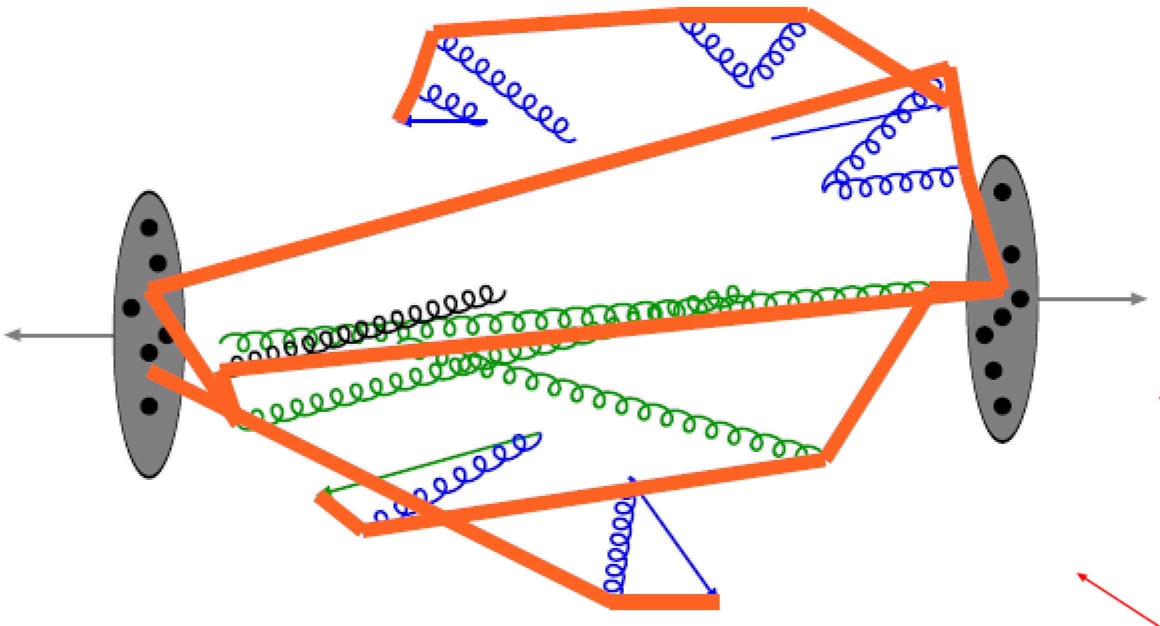
PYTHIA comparison : first attempt

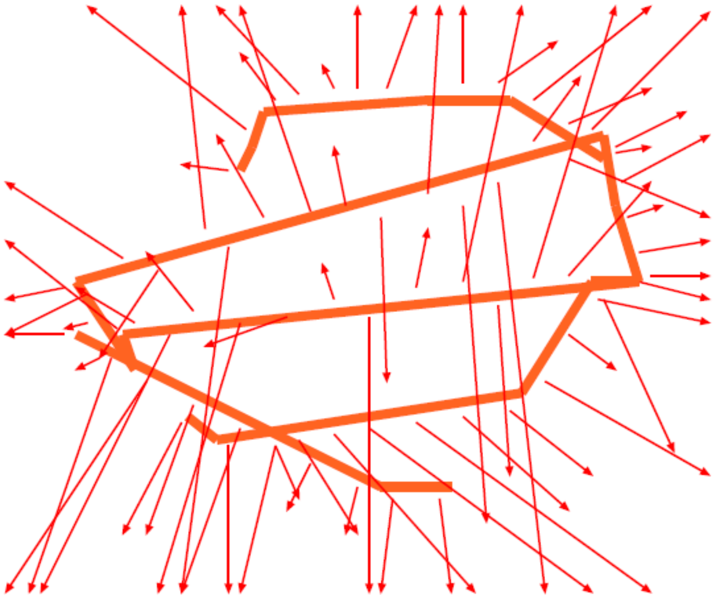
PYTHIA 6.4 Physics



PYTHIA comparison : first attempt

PYTHIA 6.4 Physics





PYTHIA comparison : first attempt
PYTHIA 6.4 J/ψ