Open charm and J/ψ multiplicity dependence in pp collisions at $\sqrt{s}$ = 7 TeV with ALICE at the LHC

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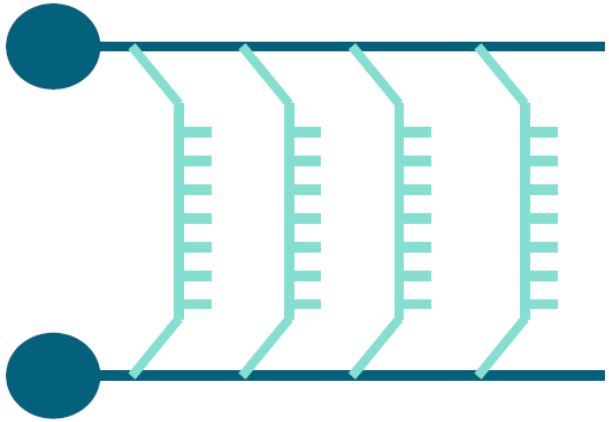
Outline

- Motivation
- The ALICE detector
- Multiplicity dependence of D and J/ψ mesons in pp collisions
- Model comparison
- Conclusions

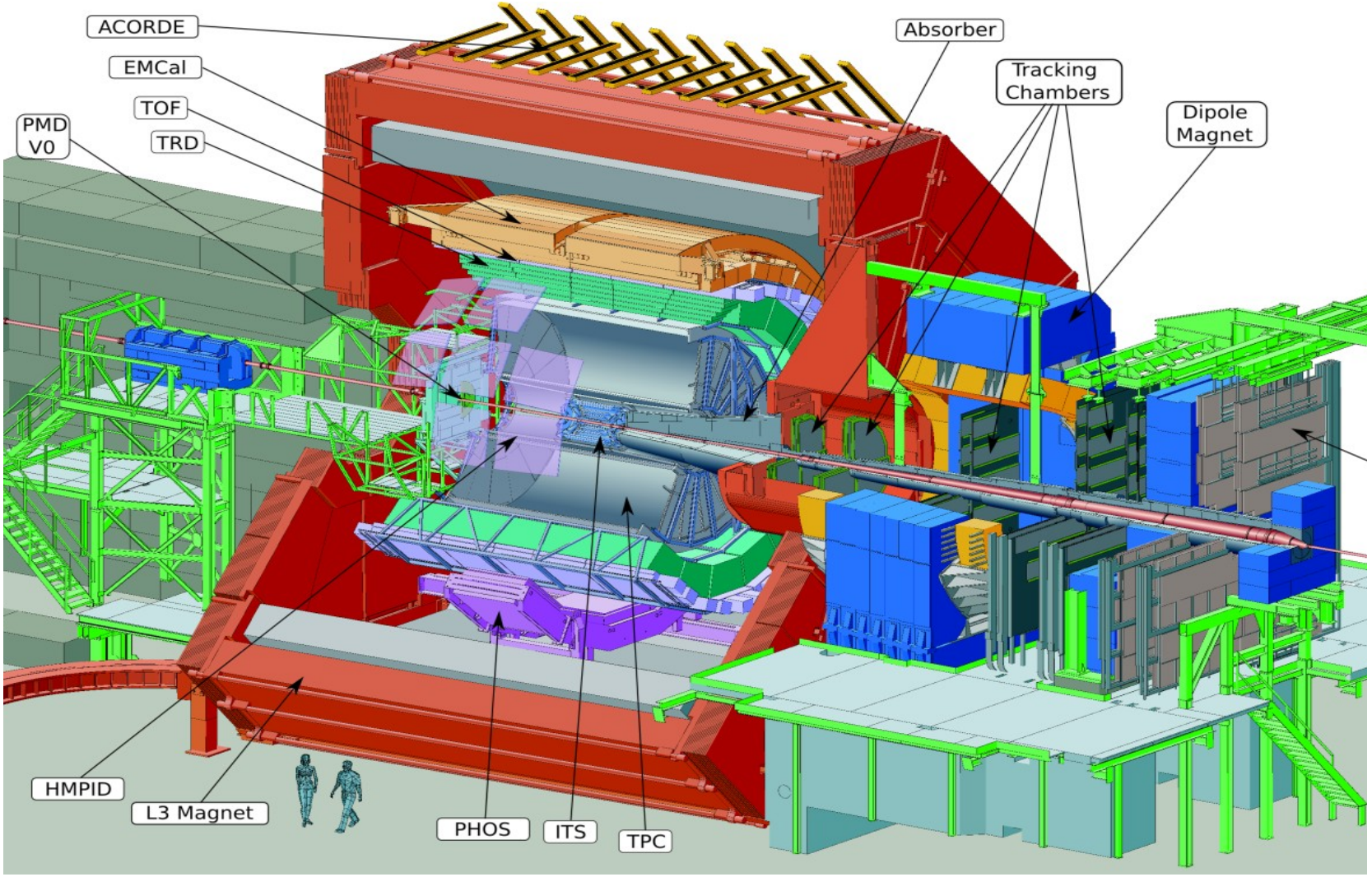
Motivation

- Multiple distinct pairs of partons can collide with each other (Multi-Parton-Interaction) [JHEP 0403, 053 (2004)]
  - The number of elementary interactions is related to the primary charged particles multiplicity
- Charm and beauty quarks are produced in the hard partonic scattering → MPI might affect the hard momentum scales relevant for heavy quark production
  - heavy-flavour particle production vs event multiplicity →explore the range of MPI



- Test interplay between hard component and soft component in pp collisions
- $\langle dN_{ch}/d\eta \rangle$ in high multiplicity pp collisions at LHC ($\sqrt{s}$ = 7 TeV) comparable to that of CuCu interactions at RHIC ($\sqrt{s_{NN}}$ = 200 GeV) PHOBOS, Phys. Rev. C 83, 024913 (2011)
- Hints of collectivity effects in proton-proton collisions K. Werner at al. Phys. Rev. C83:044915, 2011 K. Werner at al. J. Phys. Conf. Ser.316:012012, 2011
- Final state effect on quarkonium production S. Vogel et al. J.Phys.Conf.Ser. 420 (2013) 012034 T. Lang Phys.Rev. C87 (2013) 2, 024907

The ALICE detector



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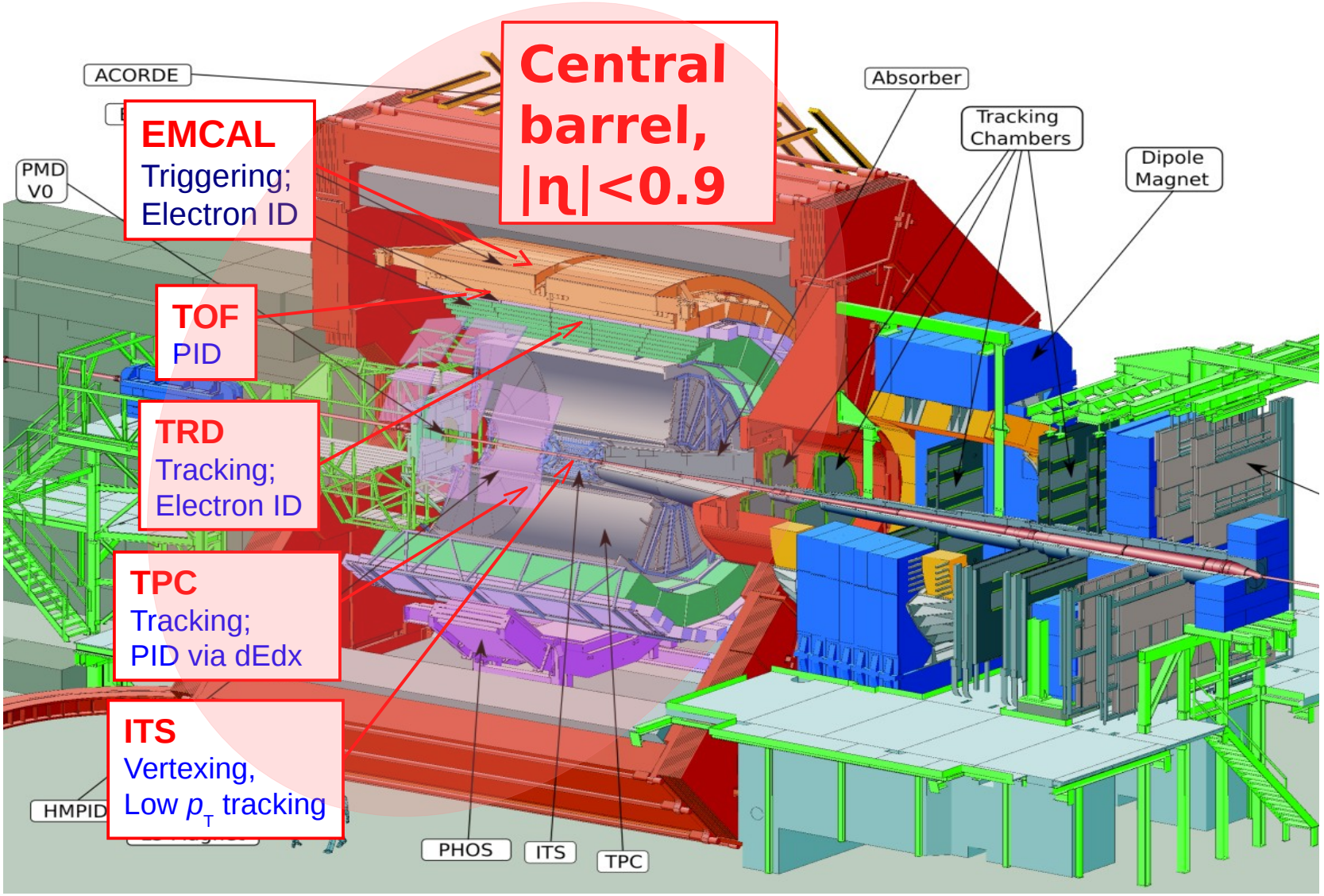

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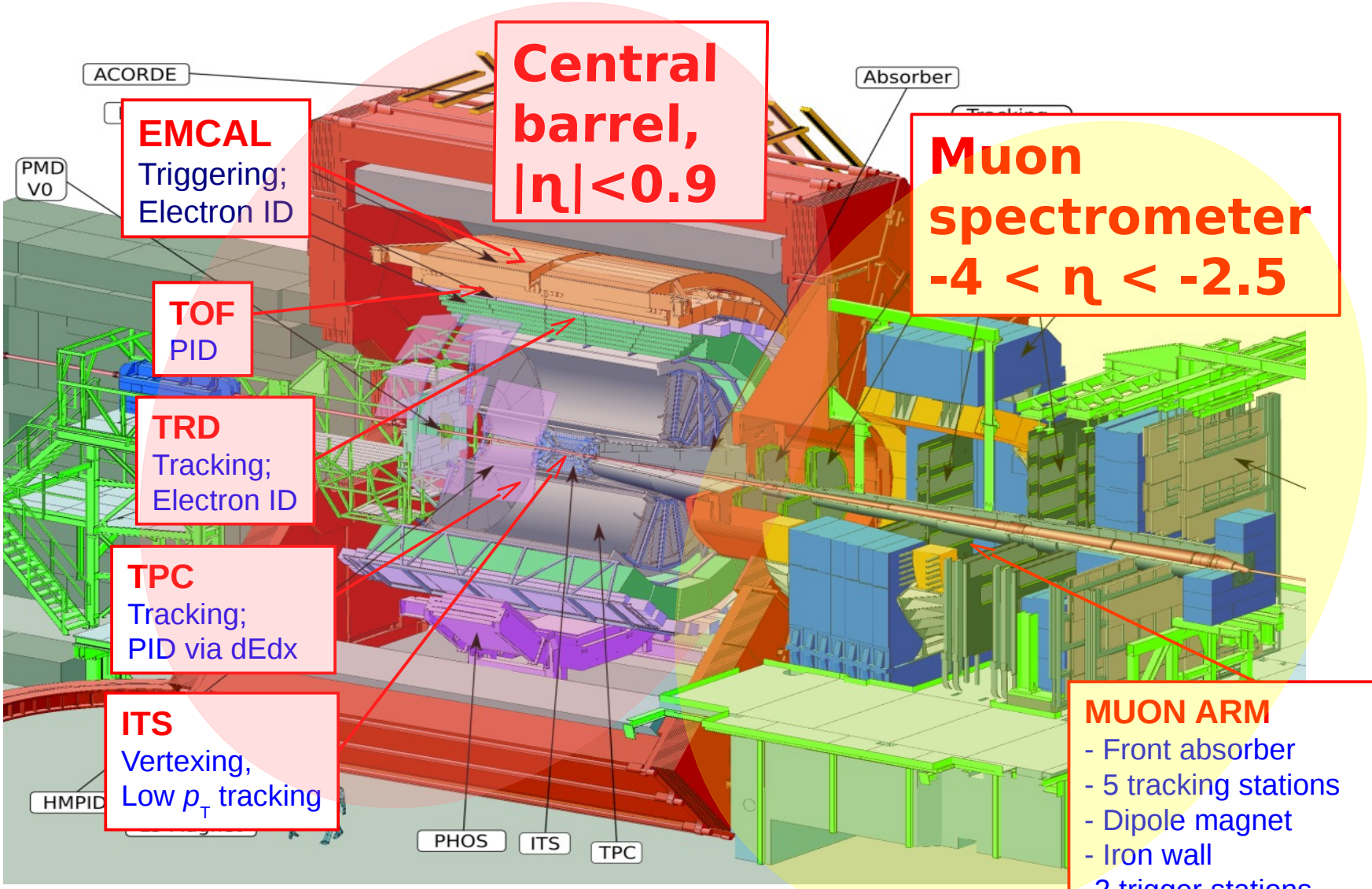


Central barrel, |η|<0.9

EMCAL
Triggering;
Electron ID

TOF
PID

TRD
Tracking;
Electron ID

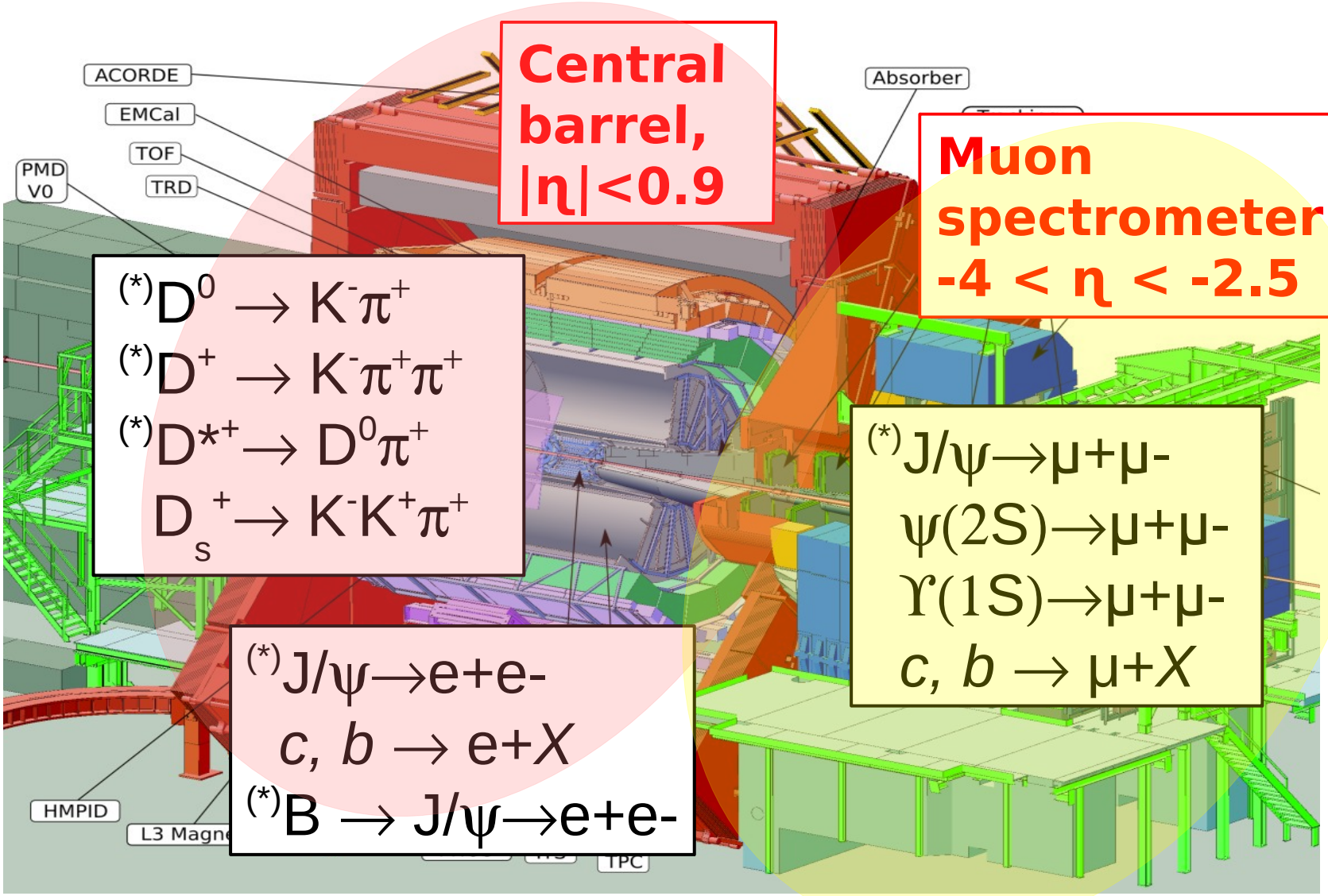
TPC
Tracking;
PID via dEdx

ITS
Vertexing,
Low p_T tracking

Muon spectrometer
-4 < η < -2.5

MUON ARM
- Front absorber
- 5 tracking stations
- Dipole magnet
- Iron wall
-2 trigger stations

The ALICE detector



Central barrel, |η|<0.9

Muon spectrometer -4 < η < -2.5

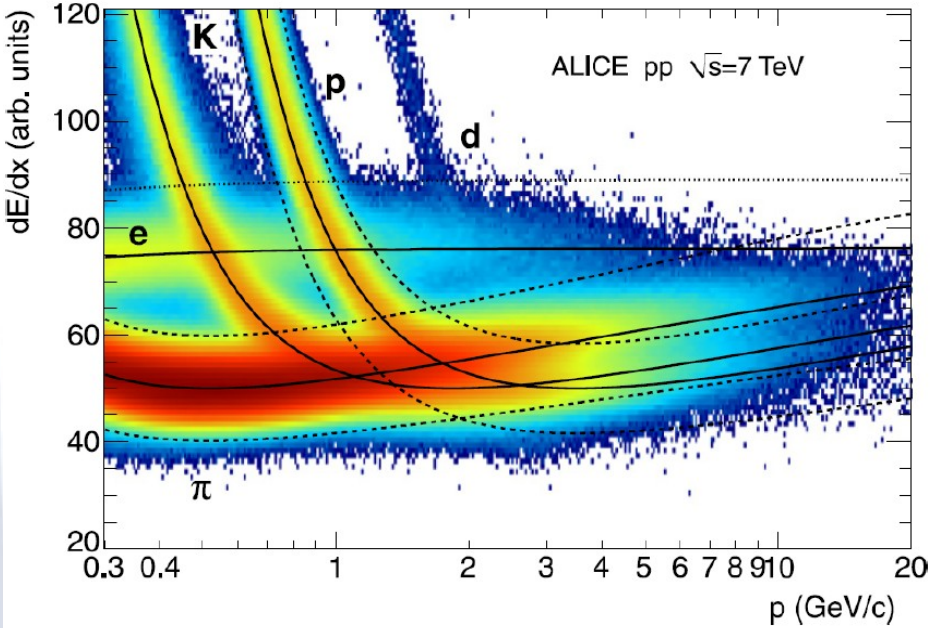
$^{(*)}D^0 \rightarrow K^-\pi^+$
$^{(*)}D^+ \rightarrow K^-\pi^+\pi^+$
$^{(*)}D^{*+} \rightarrow D^0\pi^+$
$D_s^+ \rightarrow K^-K^+\pi^+$

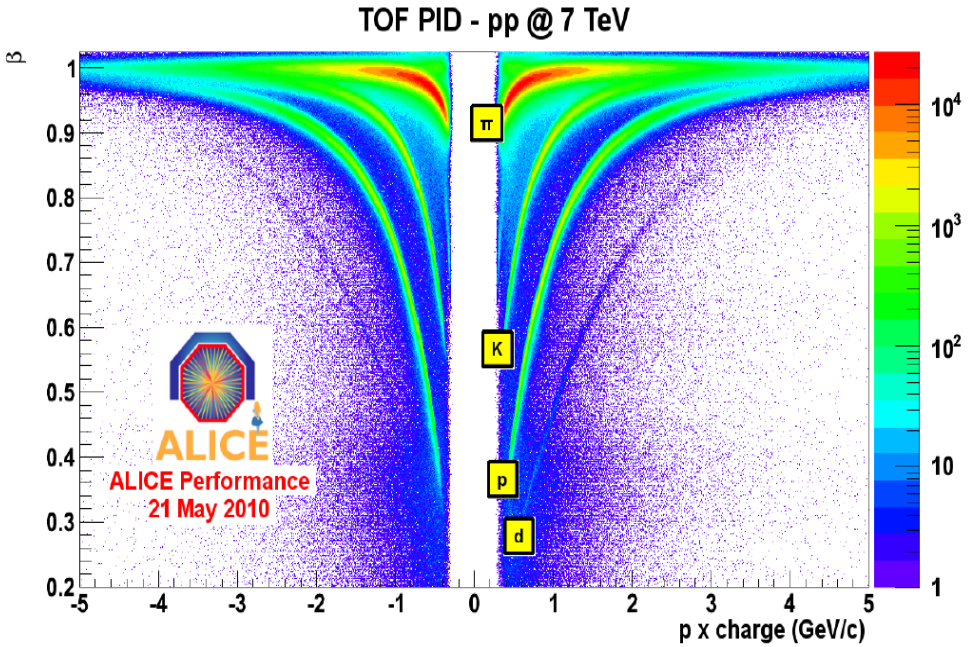
$^{(*)}J/\psi \rightarrow \mu^+\mu^-$
$\psi(2S) \rightarrow \mu^+\mu^-$
$\Upsilon(1S) \rightarrow \mu^+\mu^-$
$c, b \rightarrow \mu + X$

$^{(*)}J/\psi \rightarrow e^+e^-$
$c, b \rightarrow e + X$
$^{(*)}B \rightarrow J/\psi \rightarrow e^+e^-$

$^{(*)}$studied in pp at $\sqrt{s}$ = 7 TeV as a function of the charged particle multiplicity density

The ALICE detector: PID performances



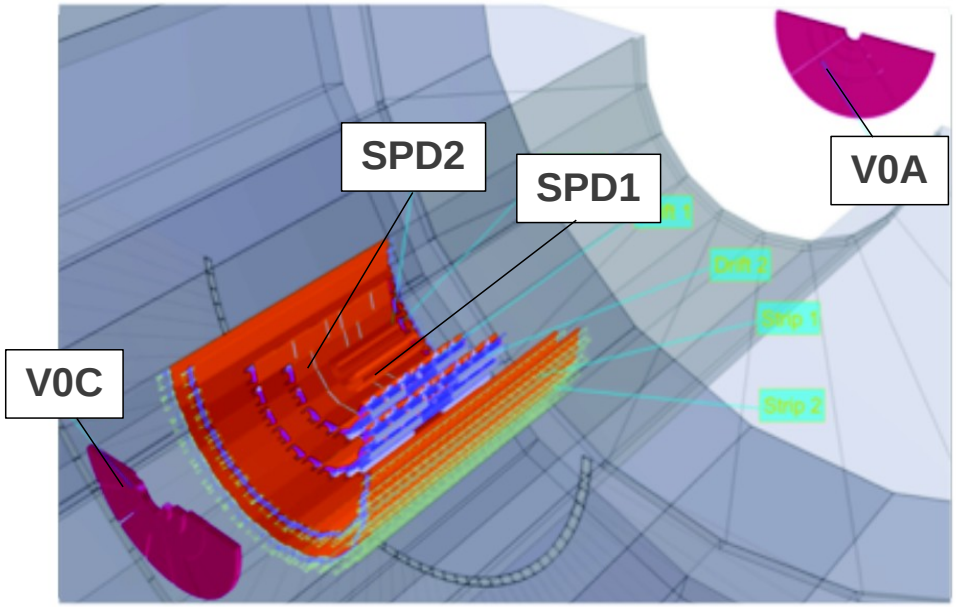


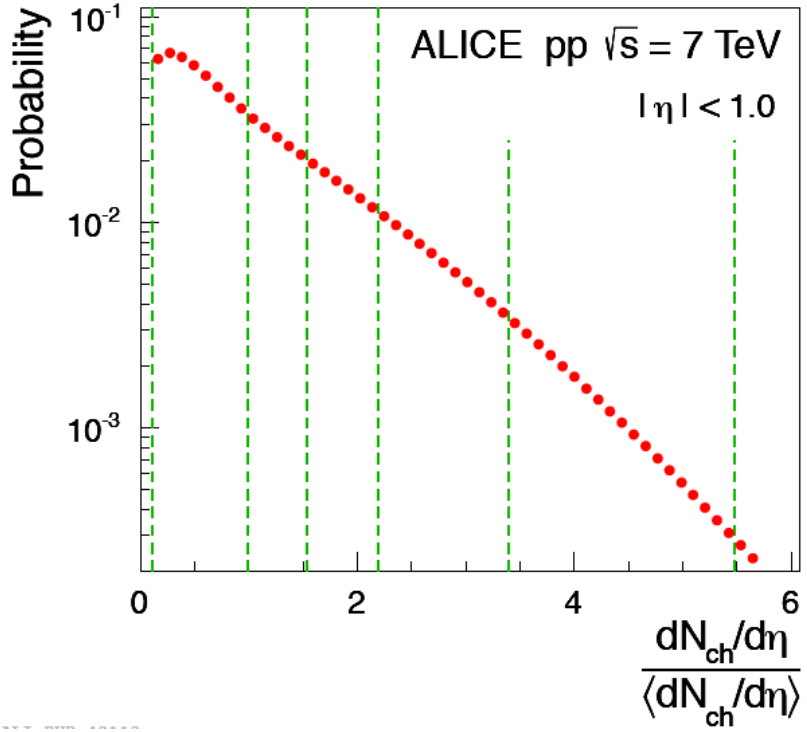
- Particle identification at central rapidity ($|y|<0.9$):
  - crucial for electron identification for both quarkonia and single heavy flavour electron measurements
  - combined PID with TOF and TPC helps to reject background at low p_T
- Muon identification at forward rapidity ($-4<y<-2.5$):
  - Hadron contamination and low pt muons removed by a single track p_T trigger in the muon spectrometer

Multiplicity determination

- Multiplicity estimator: number of reconstructed tracklets in the two innermost layers of Inner Tracking System (ITS) consisting of Silicon Pixel Detectors (SPD)

- analysis performed on a data sample of L_{int} = 5.6 nb^{-1} (2010 pp data collected by Minimum Bias trigger)





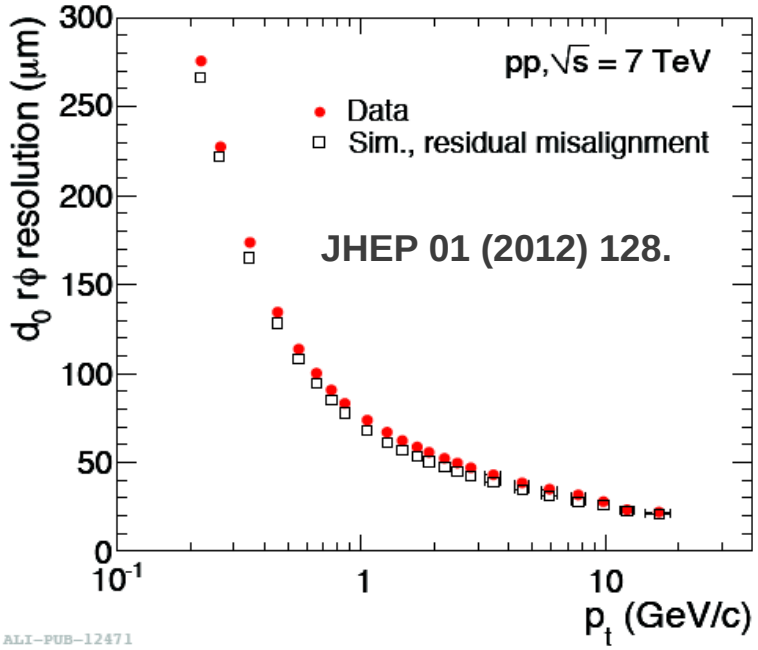
- $N_{tracklets} \propto dN_{ch}/d\eta$

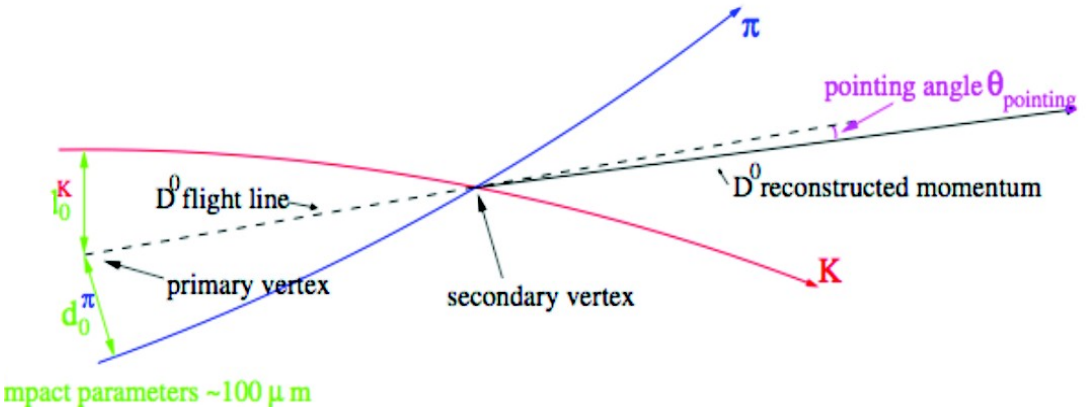
- $\langle dN_{ch}/d\eta \rangle$ = 6.01 ± 0.01(stat.) +0.20-0.12(syst.) for $|\eta|<1.0$

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

Prompt D meson analysis

D meson reconstruction



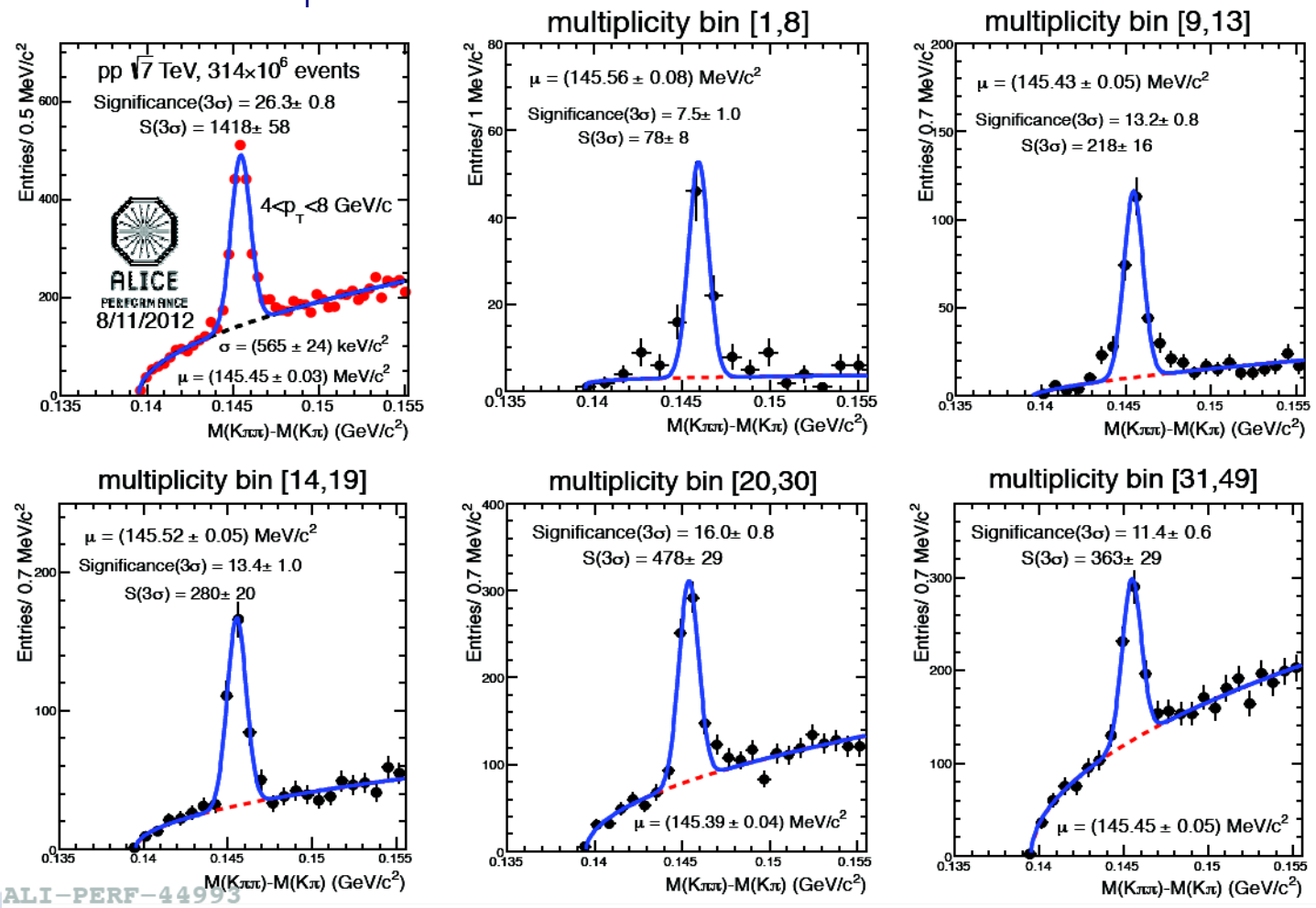


- Particle identification (PID) → based on the combination TPC / TOF detectors
  - TPC allows K/π separation up to ~0.6 GeV/*c*
  - TOF allows K/π separation up to ~2 GeV/*c*

- Candidate's selection → based on full reconstruction of displaced vertex
  - Impact parameter for single track → about 75 μm at p_T= 1 GeV/*c* thanks to the SPD
  - Angle between the D meson flight line and reconstructed particle momentum (θ_{point})

D meson signal as a function of multiplicity

- D^0, D^+, D^{*+} signal studied in both:
  - 5 multiplicity bins
  - 3-5 p_T bins

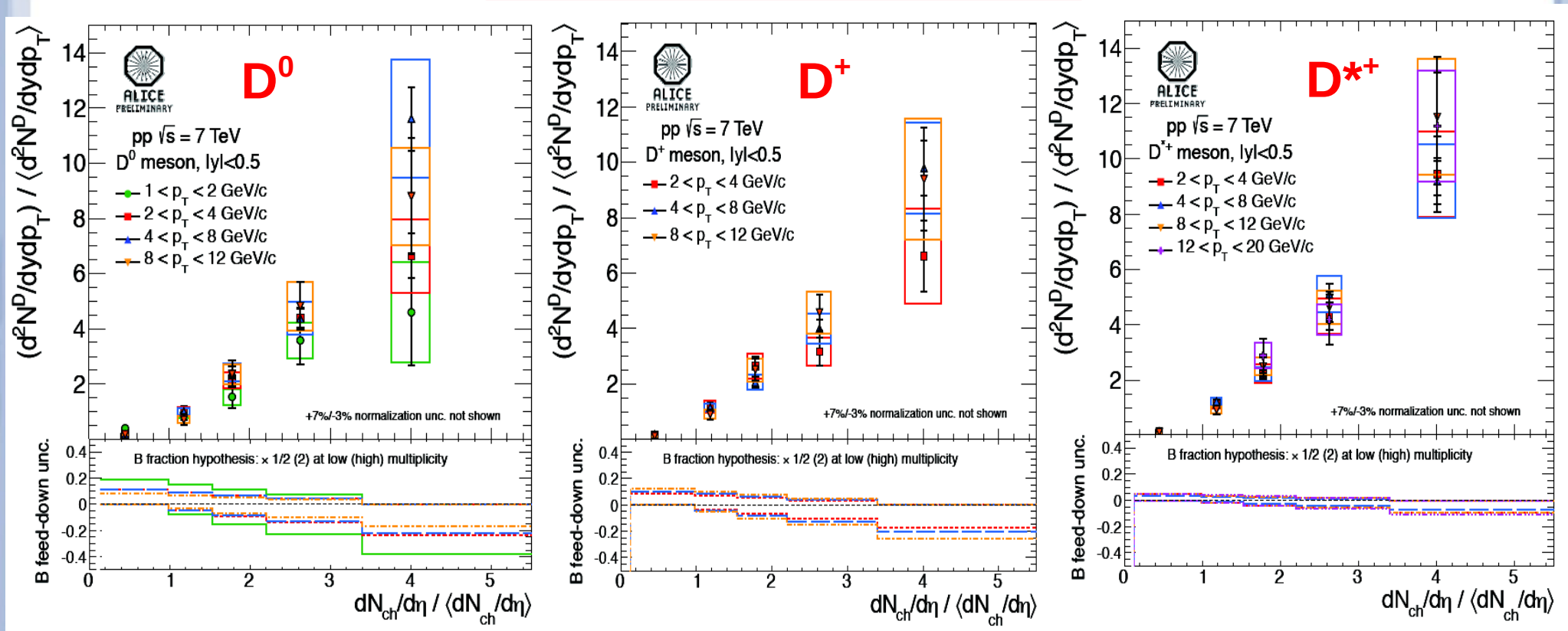


Example D^{*+} spectra in [4,8] GeV/*c* as a function of charged particle multiplicity

ALI-PERF-44993

Prompt D mesons yields vs multiplicity

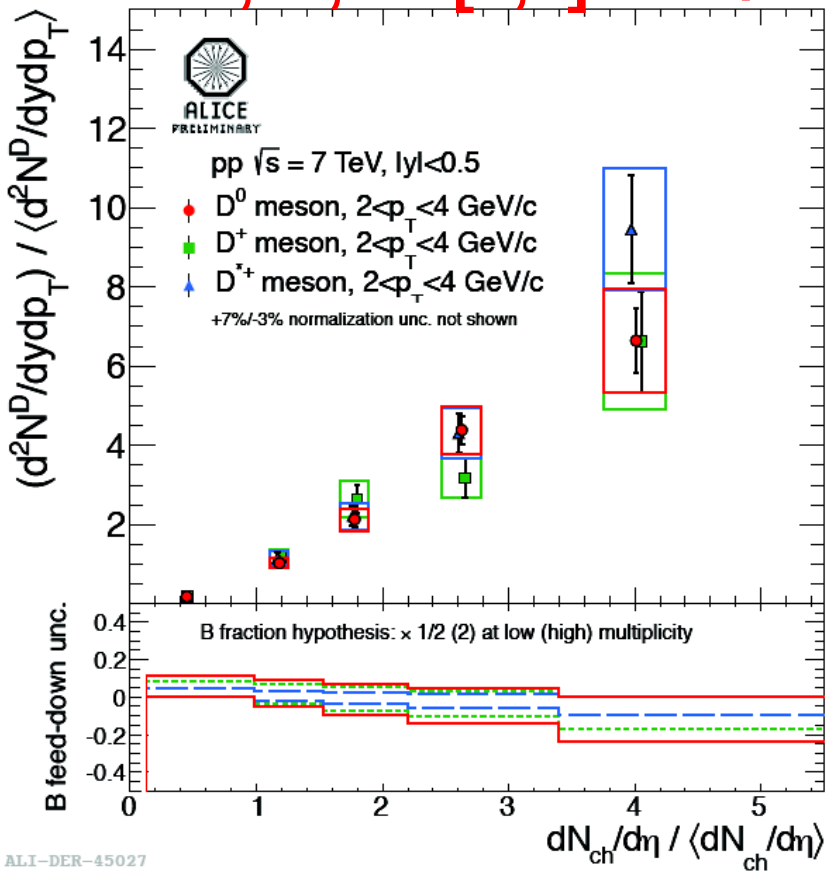
$$\frac{\frac{\mathrm{d}^2N}{\mathrm{d}p_\mathrm{T}\mathrm{d}y}}{\left\langle \frac{\mathrm{d}^2N}{\mathrm{d}p_\mathrm{T}\mathrm{d}y} \right\rangle} = \frac{Y^{\mathrm{mult}}/(\epsilon^{\mathrm{mult}} \times N_{\mathrm{event}}^{\mathrm{mult}})}{Y^{\mathrm{mult\ int}}/(\epsilon^{\mathrm{mult\ int}} \times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



- Approximately linear increase with charged particle multiplicity
- Similar trend on all p_T bins, the current uncertainties prevents a strong conclusion on a possible p_T dependence

Prompt D mesons yields vs multiplicity

D^0,D^+,D^{*+} [2,4] GeV/*c*



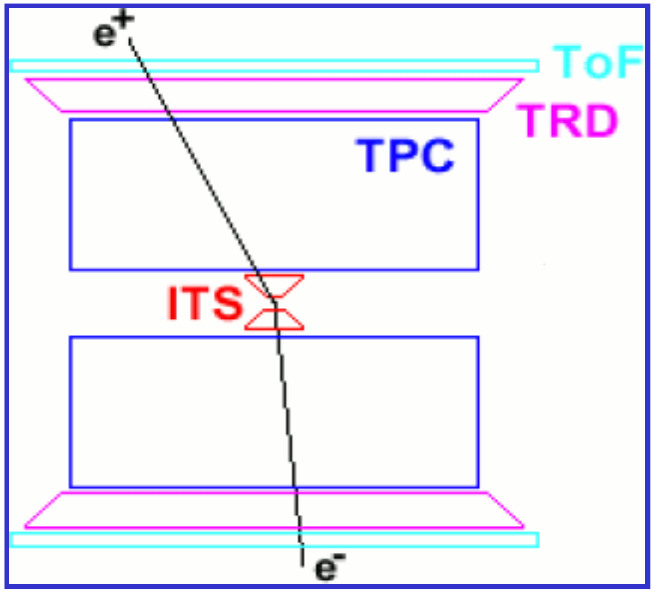
- The results of D^0, D^+ and D^{*+} are consistent within the statistical and systematic uncertainties

- Approximately linear increase with charged particle multiplicity
- Similar trend on all p_T bins, the current uncertainties prevents a strong conclusion on a possible p_T dependence

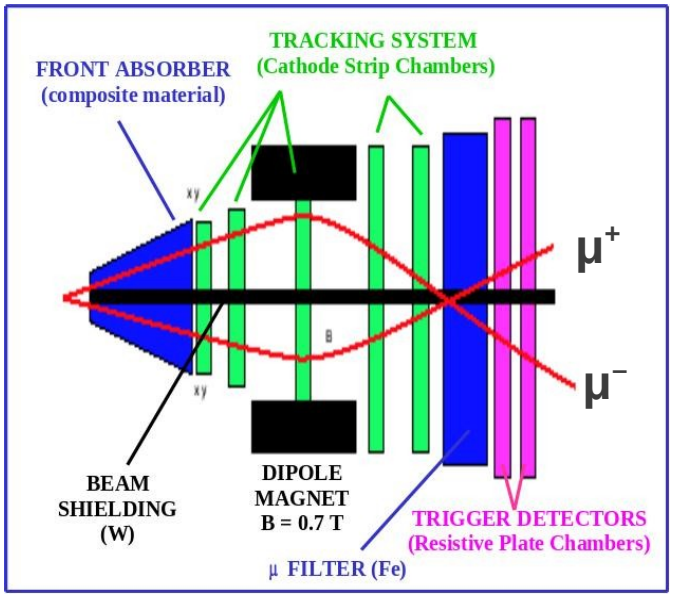
Inclusive and non-prompt J/ψ analysis

J/ψ reconstruction

- ***CENTRAL BARREL (J/ψ → e^+e^-):***
  - tracking with ITS+TPC (+TRD)
  - electron identification:
    - energy loss in TPC
  - Secondary vertex reconstruction with the SPD → allows separation of J/Ψ from B-decays

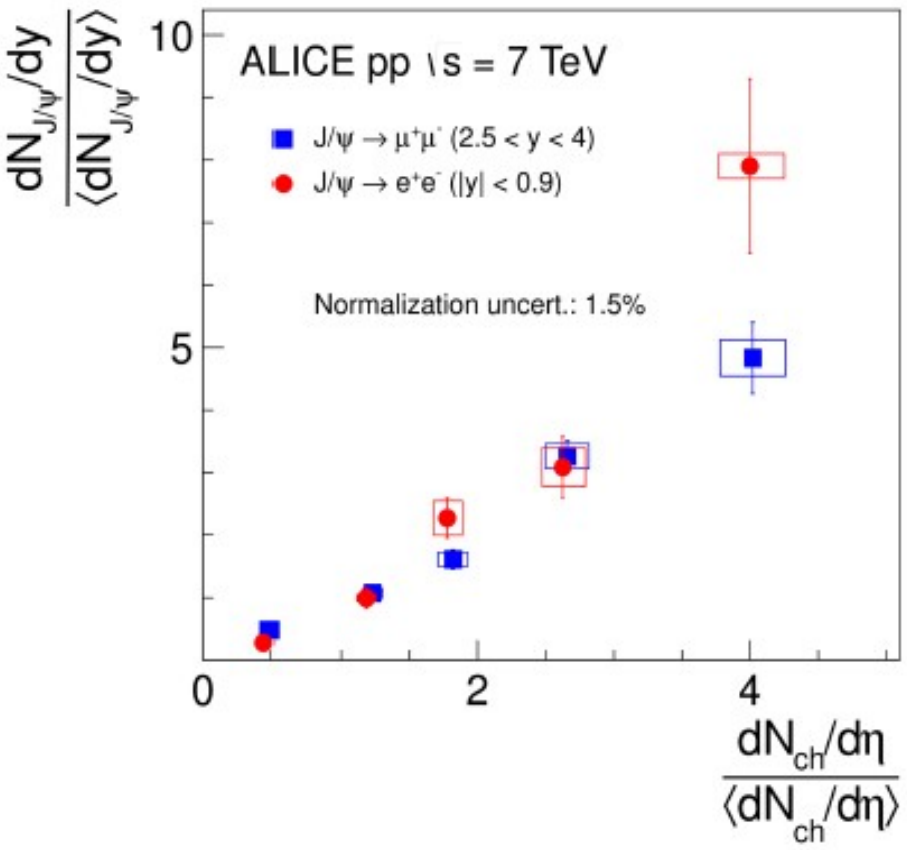


- **MUON SPECTROMETER *(J/ψ → $\mu^+\mu^-$):***
  - Absorbers (to filter out the hadrons)
  - Tracking: 5 stations of Cathode Pad Chambers used;
  - Trigger chambers: RPCs planes used; reduce the background from remaining hadrons and secondary muons produced in the absorber



Inclusive J/ψ yields vs multiplicity

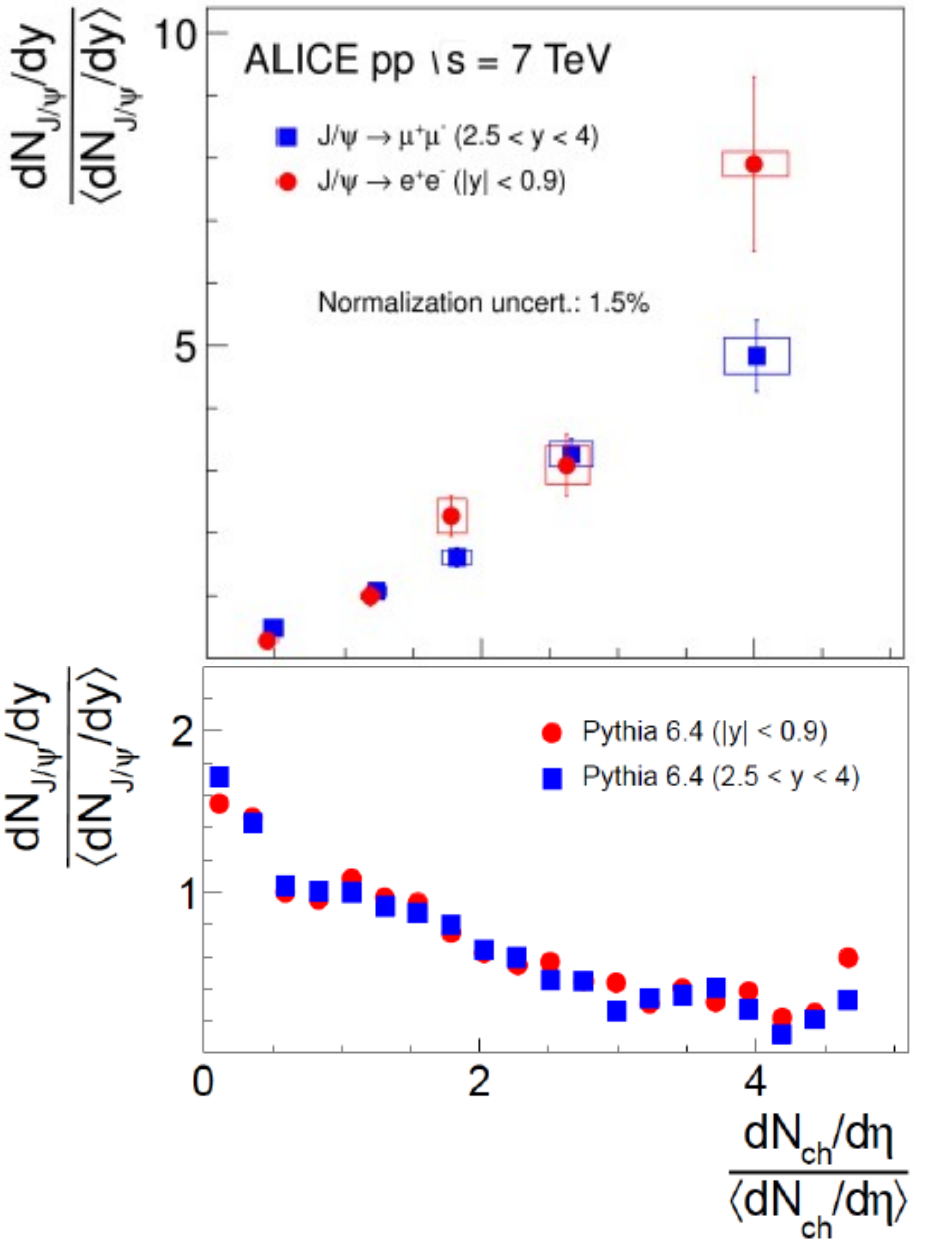
Phys. Lett. B 712, 165 (2012)



- Approximately linear increase of J/ψ yield (p_T>0 GeV/c) with charged particle density
- Highest charged particle density bin corresponds to 4 times the minimum bias (MB) density
- Enhancement of J/ψ yield relative to averaged yield in MB events for both rapidity ranges
  - factor of 8 for $|y| < 0.9$
  - factor of 5 for $-4 < y < -2.5$

Inclusive J/ψ yields vs multiplicity

Phys. Lett. B 712, 165 (2012)



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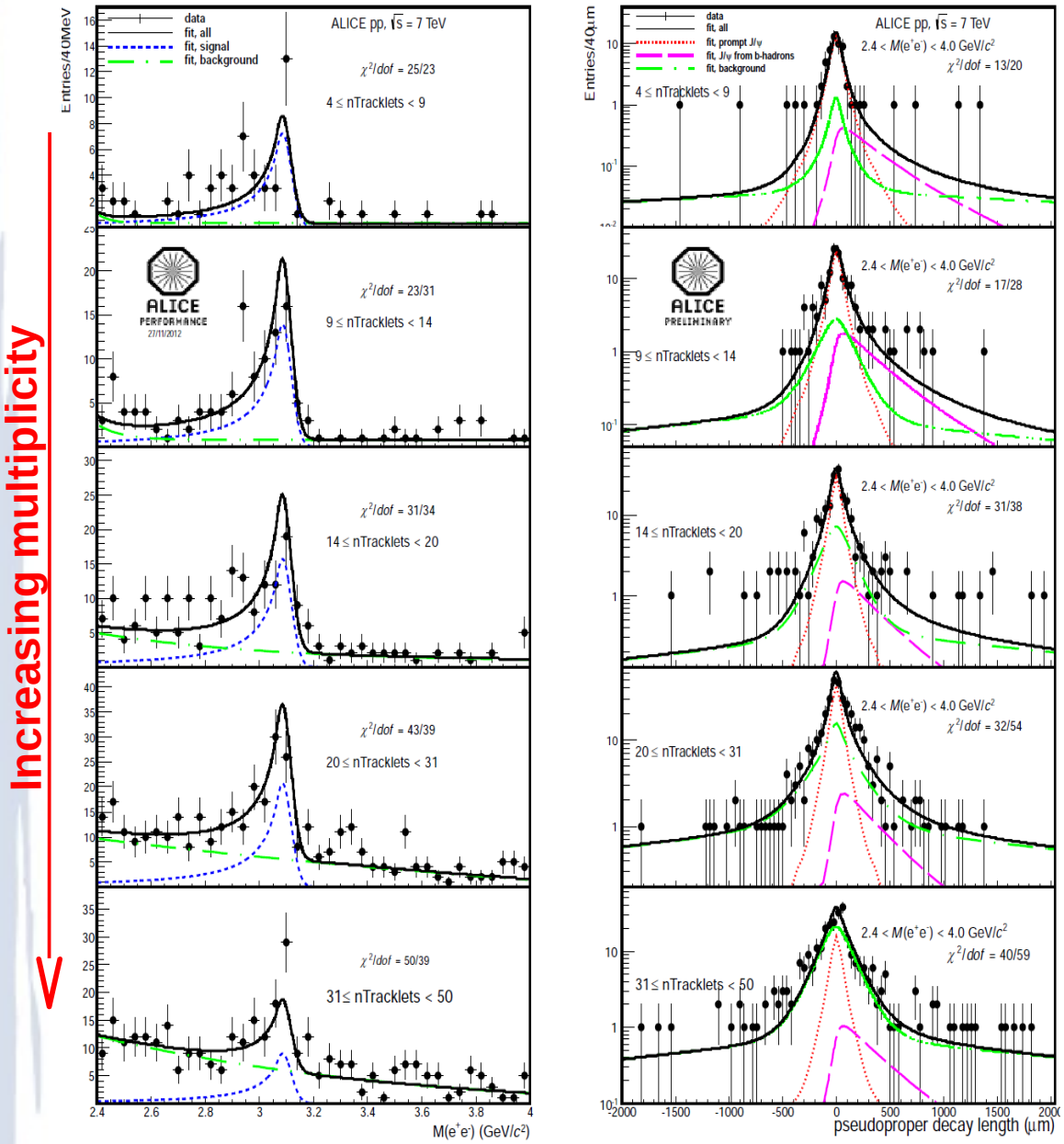
  - factor of 5 for $-4 < y < -2.5$
- Relative yields vs multiplicity not reproduced by Pythia 6.4 simulations

Non-prompt J/ψ analysis (|y|<0.9)



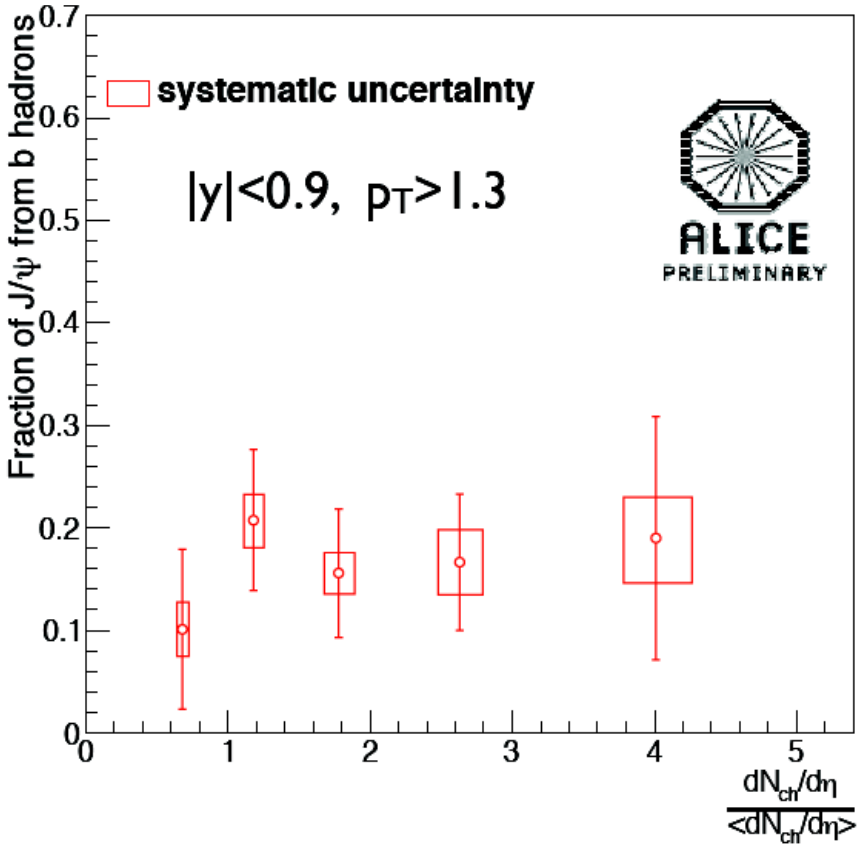
$$f_B = \frac{N_{J/\Psi \leftarrow h_B}}{N_{promptJ/\Psi} + N_{J/\Psi \leftarrow h_B}}$$

- Fraction of non-prompt J/ψ measured using the unbinned 2D log-likelihood fit procedure. Variables used:
  - Invariant mass "m_{ee}"
  - Pseudoproper decay length "x"

$$x = \frac{c \cdot L_{xy} \cdot m_{J/\psi}}{p_t^{J/\psi}}$$

$$L_{xy} = \vec{L} \cdot \vec{p}_t^{J/\psi} / p_t^{J/\psi}$$

Non-prompt J/ψ analysis (|y|<0.9)



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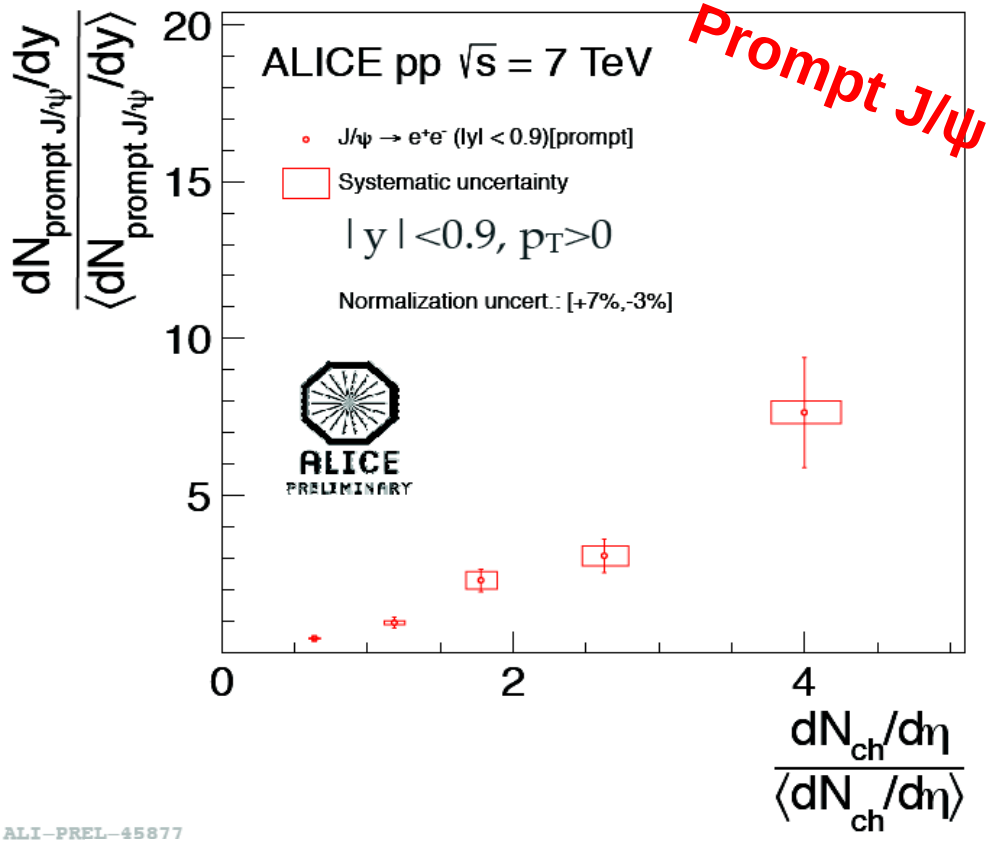
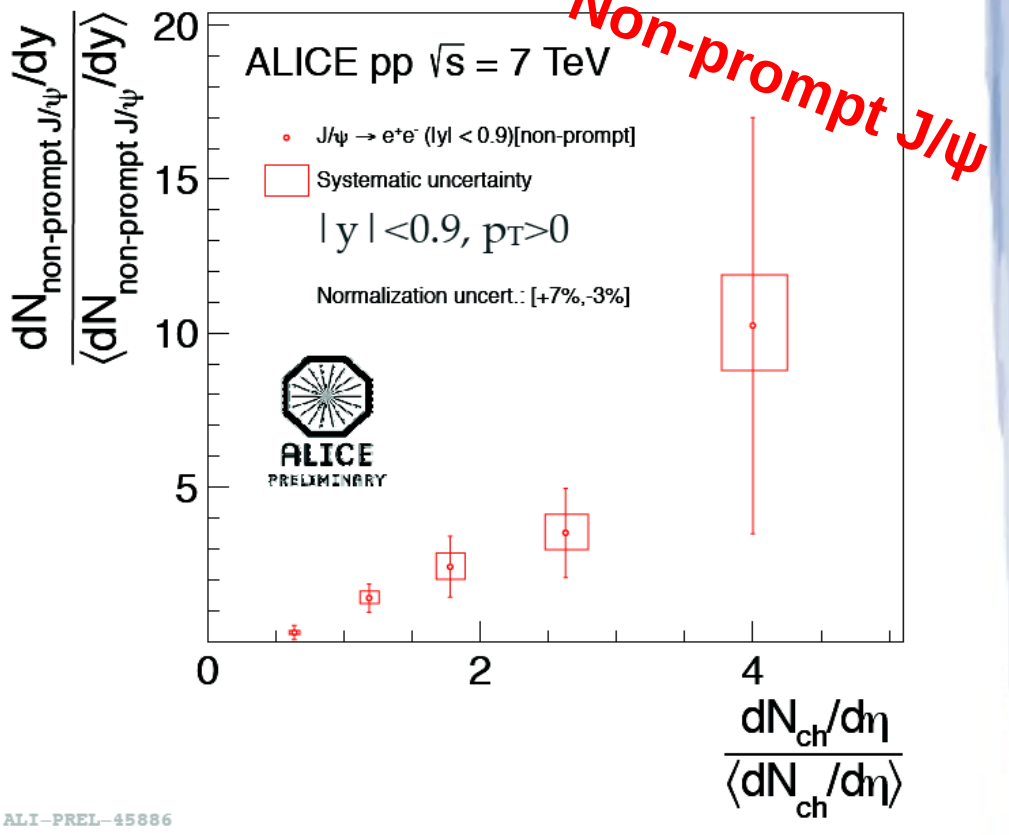
$$L_{xy} = \vec{L} \cdot \vec{p}_t^{J/\psi} / p_t^{J/\psi}$$

- **Approximately flat non-prompt J/ψ fraction as a function of charged particle multiplicity**

Prompt and non-prompt J/ψ yields





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

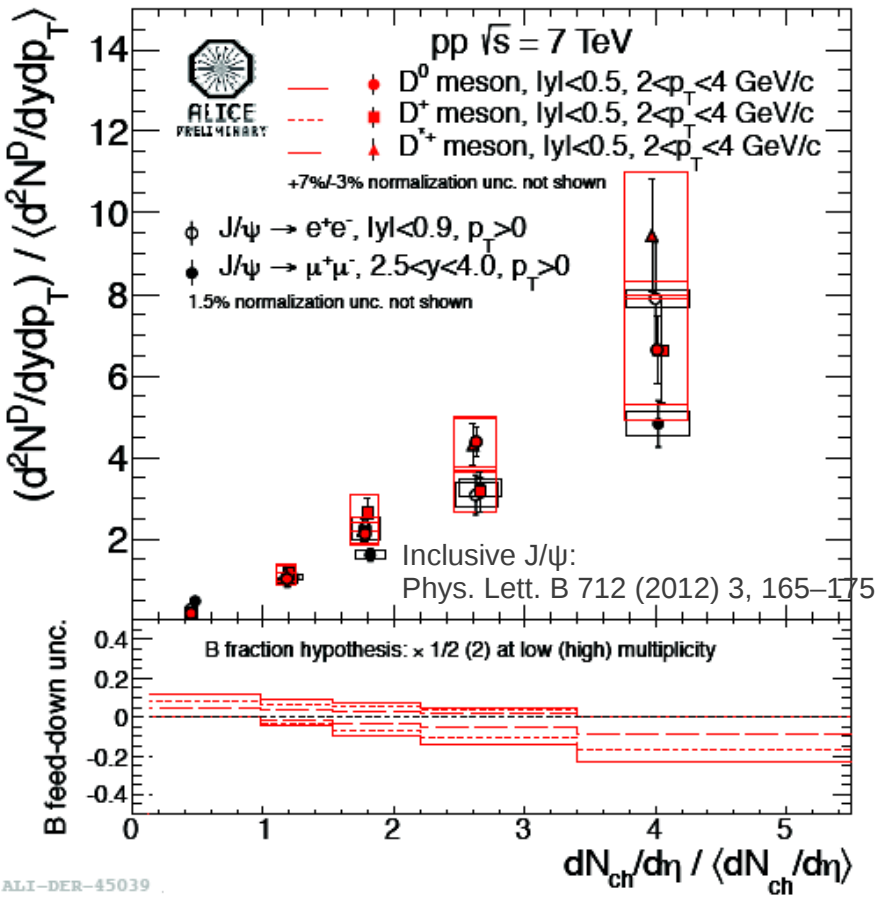
$$\frac{\frac{dN(J/\psi \text{ from B})}{dy}}{\left\langle \frac{dN(J/\psi \text{ from B})}{dy} \right\rangle} = \frac{\frac{dN(J/\psi)}{dy}}{\left\langle \frac{dN(J/\psi)}{dy} \right\rangle} \times \frac{f_B}{\langle f_B \rangle}$$

- Approximately linear increase with charged particle multiplicity of both prompt and non-prompt J/ψ yields
  - the non-prompt J/ψ yields reflect the beauty hadron yields

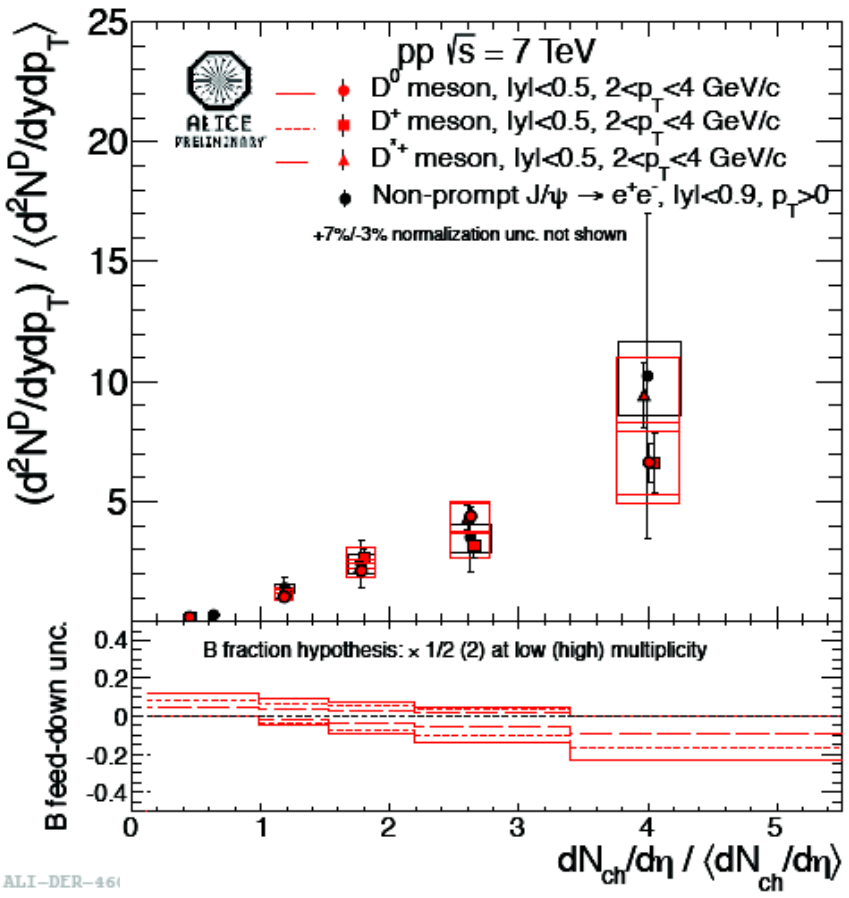
Comparison of results

Comparison of prompt D mesons and J/ψ yields vs multiplicity

D-mesons – inclusive J/ψ

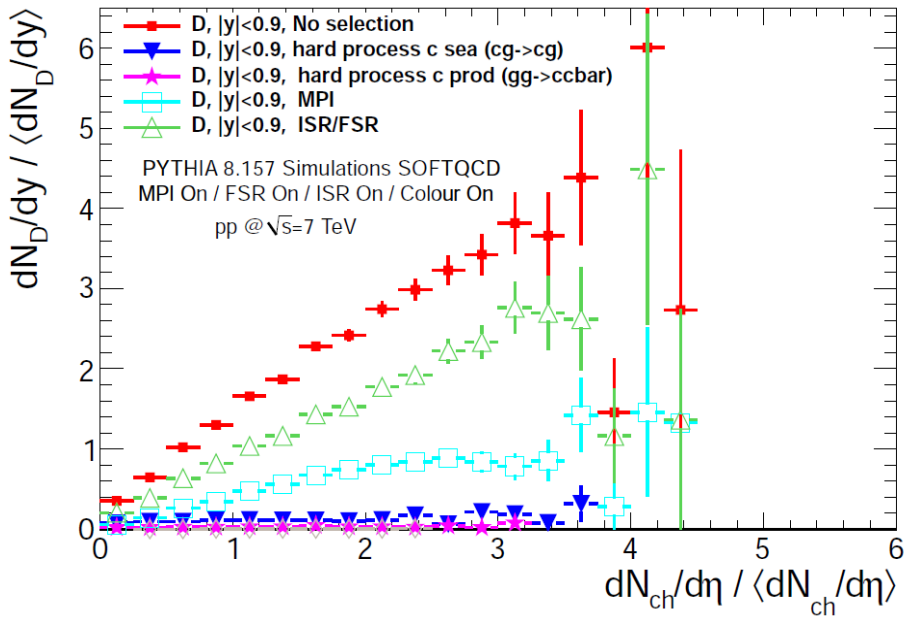


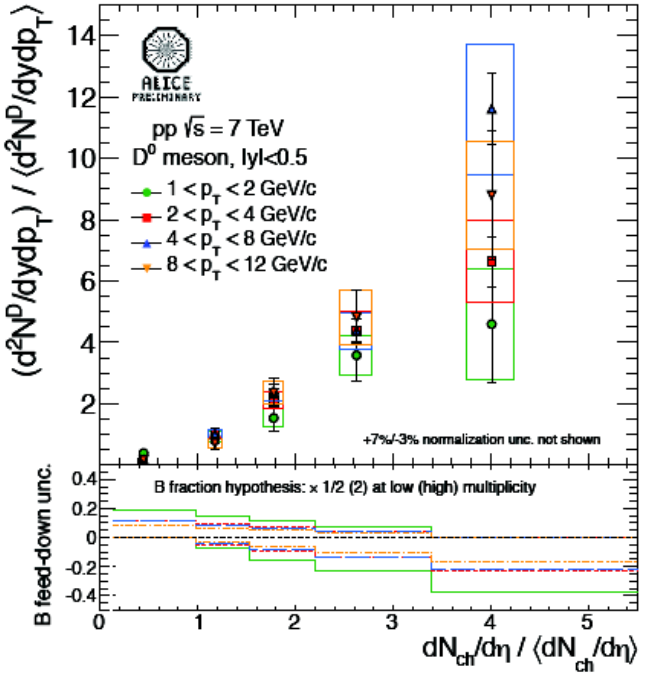
D-mesons – non-prompt J/ψ



- Prompt D meson (2<p_T<4 GeV/c) and J/ψ (p_T>0) yields (both inclusive and non-prompt) show a similar increase with charged particle multiplicity within the current statistical and systematic uncertainties

Comparison with selected PYTHIA 8 results





- PYTHIA8 → improvements w.r.t. PYTHIA 6: the MPI scenario involves heavy quarks in MPI 2 → 2 hard sub-processes
- SoftQCD:minbias tune (all parameters set by default)
  - **Total D meson yield production** originate from: **gluon splitting from ISR/FSR**, **MPI**, first hard processes (**sea interaction**, **gluon fusion**)
- The total D meson yield production in PYTHIA 8 (similar for all D mesons) shows a linear increase with charged particle multiplicity → similar as observed on data
- Interesting to note that first hard contributions follow a flat behaviour as a function of charged particle multiplicity → MPI could be one possible interpretation of the observed increase of yields

Conclusions

- Prompt D meson yields measured in $|y|<0.5$ as a function of charged particle multiplicity density:
  - Linear increase similar for all D mesons species
  - No p_T dependence observed with the present statistic and systematic uncertainties
- Inclusive J/ψ yields measured at central ($|y|<0.9$) and forward rapidity ($-4<y<-2.5$) region → similar increase observed in the two rapidity windows
  - Non-prompt J/ψ fraction and beauty hadron yields also measured at mid rapidity as a function of dN_{ch}/dn
- Prompt-D meson, prompt and non-prompt J/ψ yields show a similar increase with charged particle multiplicity
- PYTHIA 8 (SoftQCD minbias tune): total D meson yield production shows a linear increase with charged particle multiplicity
  - Flat behaviour of contributions from first hard processes → hint of MPI as a possible reason of observed behaviour

Back-up

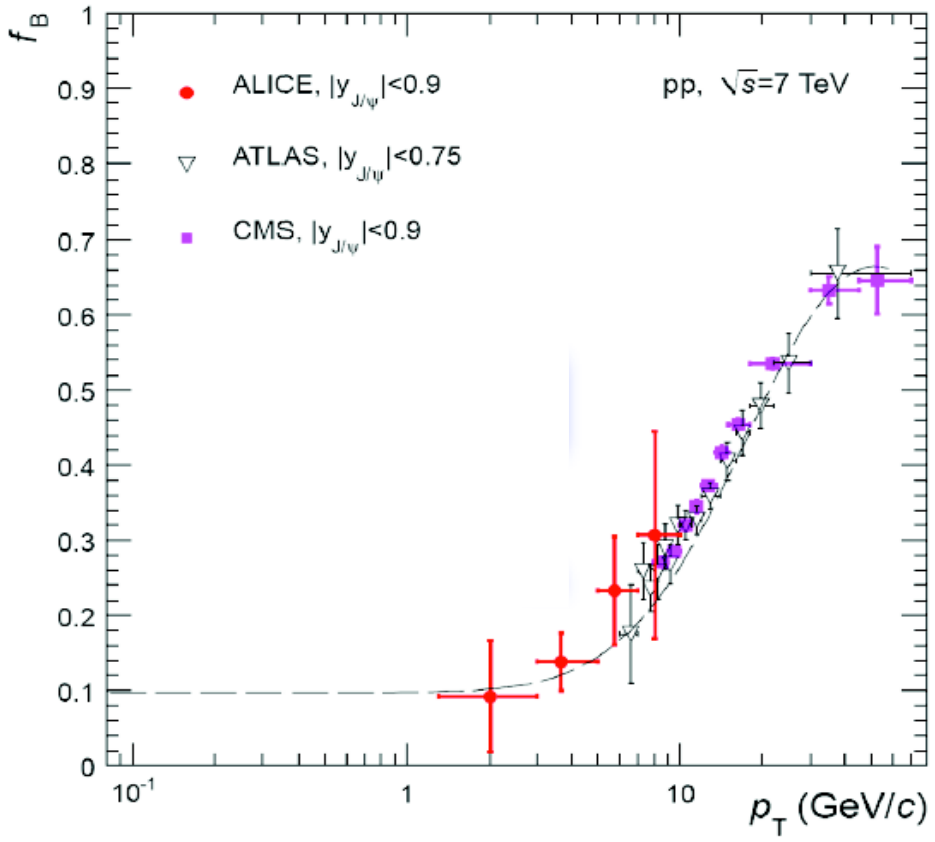
Corrected yields and systematics

- 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 ($\epsilon^{mult\ int}$).
- This is normalized by the number of events in each multiplicity bin (N_{event}^{mult}) and corrected to that of inelastic collisions ($N_{event}^{inelastic}$)

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

- 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)

f_B vs p_T (pp at $\sqrt{s}$ =7 TeV)



$$f_B^{model}(p_T) = \frac{\frac{d\sigma^{FONLL}_{J/\psi \leftarrow h_B}}{dy dp_T}}{\frac{d\sigma^{phenom.}_{J/\psi}}{dy dp_T}}$$

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

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

Beauty feed-down correction for D mesons

- The fraction f_{prompt} of D mesons coming from c quark hadronization, i.e. the correction factor that accounts for the feed-down from B meson decays, was evaluated using the B production cross section from the FONLL pQCD and the B → D decay kinematics from the EvtGen package

$$f_{\mathrm{prompt}} = 1 - \left(N^{\mathrm{D}^{\pm}\ \mathrm{from\ B\ raw}} / N^{\mathrm{D}^{\pm}\ \mathrm{raw}}\right)$$

$$N^{\mathrm{D}^{\pm}\ \mathrm{from\ B\ raw}}\Big|_{|y|<y_{\mathrm{fid}}} = 2\,\frac{\mathrm{d}\sigma^{\mathrm{D}^{+}\ \mathrm{from\ B}}_{\mathrm{FONLL}}}{\mathrm{d}p_{\mathrm{t}}}\Bigg|_{|y|<0.5} \cdot \Delta y\,\Delta p_{\mathrm{t}} \cdot (\mathrm{Acc}\times\epsilon)_{\mathrm{feed\text{-}down}} \cdot \mathrm{BR} \cdot L_{\mathrm{int}}$$

- Central values computed assuming $f_{prompt}(mult) = f_{prompt}(MB)$ → they cancel out in the ratio used to compute relative D mesons multiplicities
  - Systematic: fraction of non-prompt D mesons ($1-f_{prompt}(mult)$) can vary with N_{ch} by 1/2 (2) at low (high) multiplicity