ALICE signals for MPI processes

Sarah Porteboeuf-Houssais
for the ALICE Collaboration

Correlations between partons in nucleons

2nd International spring school of the GDR PH-QCD

30th June – 4th July 2014
LPT - Orsay

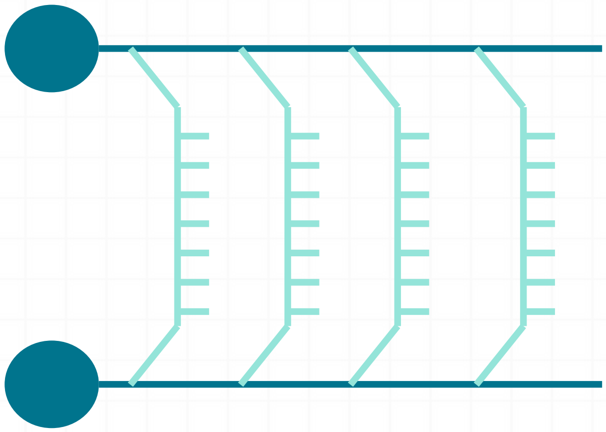
Laboratoire de Physique Corpusculaire de Clermont-Ferrand

OUTLINE

- Multi-Parton interaction study: physics motivation
- The ALICE experiment
- Underlying event measurements
- Multiplicity dependence of two-particle azimuthal correlations
- Charm production as a function of multiplicity

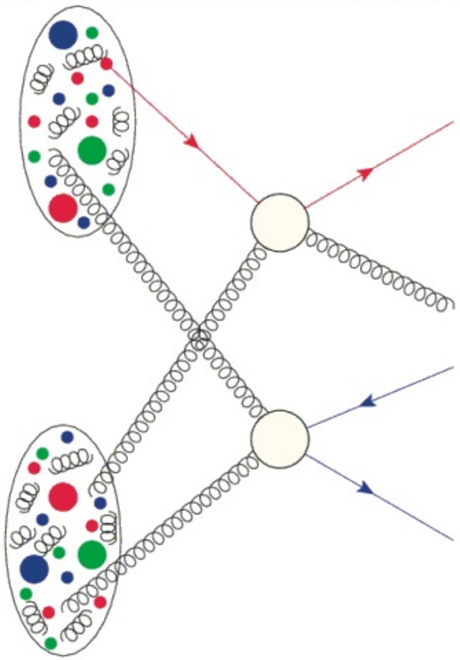
Multiple Parton Interaction (MPI)

✓ A naïve picture



➢ Several interactions, soft and hard, occur in parallel

➢ The number of elementary interactions is connected to the multiplicity



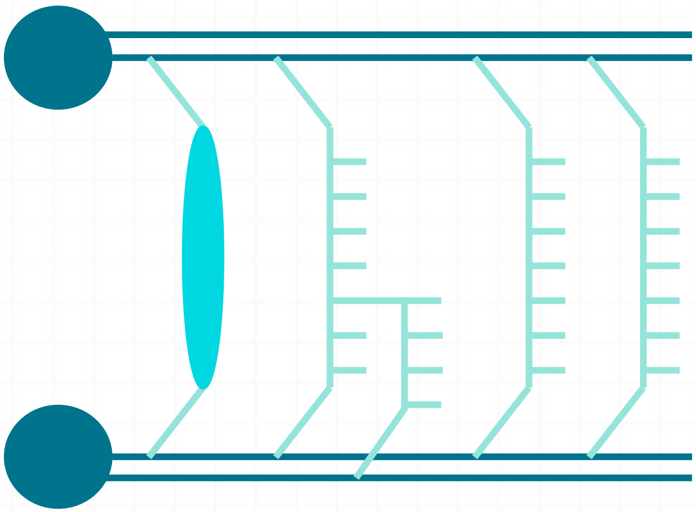
➢ Several hard interactions can occur in a pp collision

➢ In this picture : particle yield from hard processes should increase with multiplicity

sarah@clermont.in2p3.fr

Multiple Parton Interaction (MPI)

✓ <u>A less naïve picture</u>



- Some of the parallel interactions are soft
- Energy and momentum conservation
- Impact parameter dependence
- Re-interaction of partons with others: ladder splitting
- Re-interaction within ladders either in initial state (screening, saturation), or in final state (color reconnections)
- Initial state radiation (ISR) and final state radiation (FSR), hadronic activity around hard processes

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

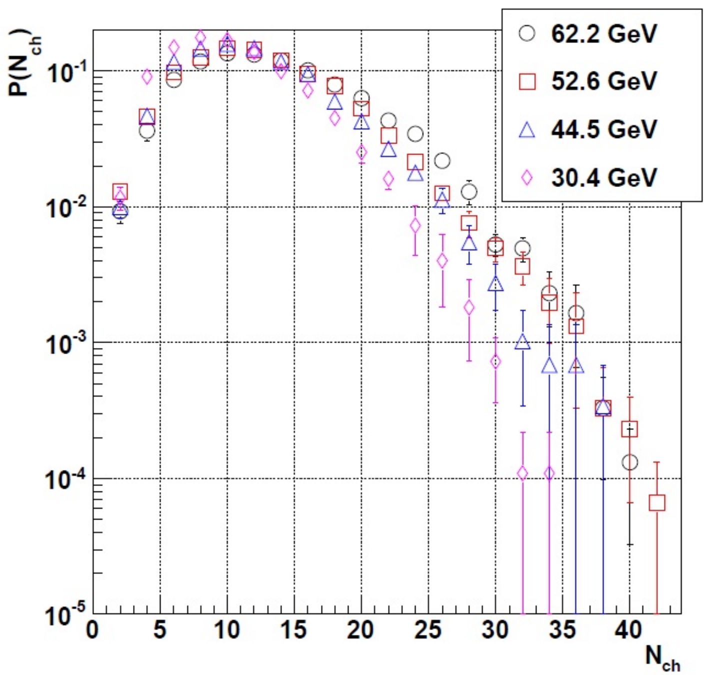
sarah@clermont.in2p3.fr

Needs for MPI

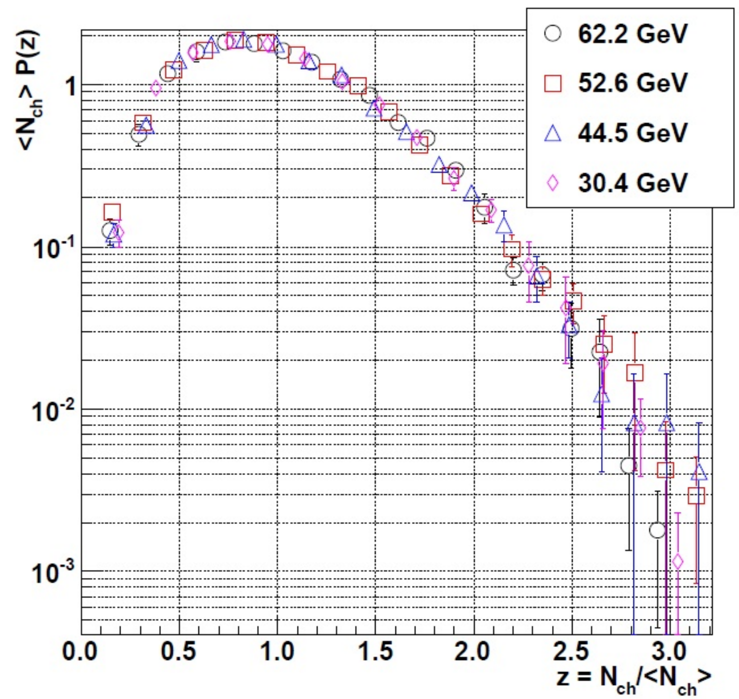
Koba-Nielsen-Oleson (KNO) scaling

Evolution of the charged particle multiplicity distribution in proton-proton collisions $P(N_{ch})$ with $\sqrt{s}$ follows KNO-scaling with

Scaling variable $z = \frac{N_{ch}}{< N_{ch} >}$ and $P(N_{ch}) < N_{ch} >= \Psi(z)$ Energy independent function



Different multiplicity distributions



When self normalized : KNO scaling

NSD events in full phase space measured by the SFM (Split Field Magnet) at ISR energies
Compilation from **J. Phys. G 37 (2010) 083001**

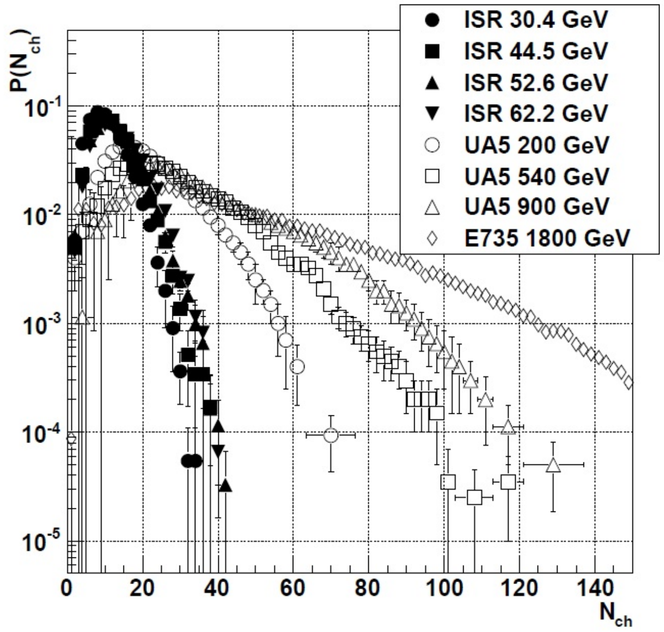
Up to $\sqrt{s}$=200 GeV, it works pretty well!

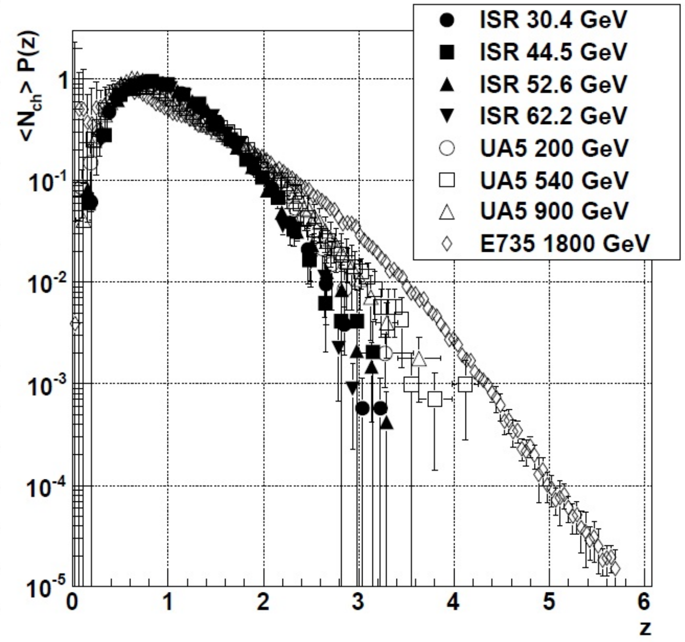
sarah@clermont.in2p3.fr

Needs for MPI

<u>Koba-Nielsen-Oleson (KNO) scaling</u>

At energies greater than $\sqrt{s}$=200 GeV in pp and $p\bar{p}$ collisions,





NSD events in full phase space
Compilation from **J. Phys. G 37 (2010) 083001**

Violation of KNO-scaling ($\sqrt{s}$ > 200 GeV)
Phys. Lett. B 167 (1986) 476

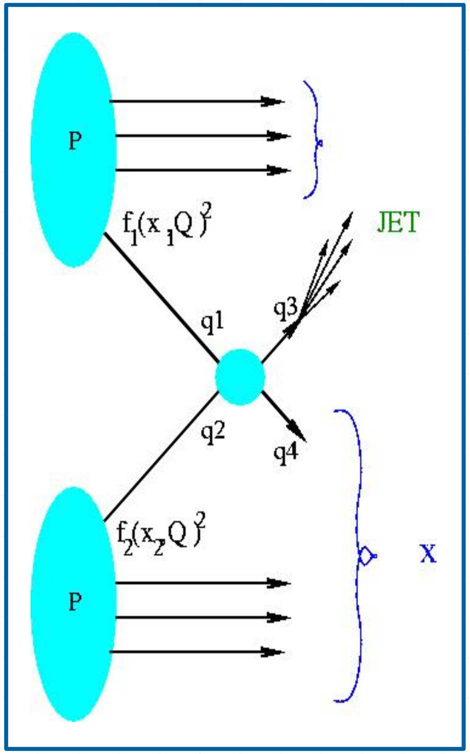
Deviation from KNO-scaling increases with $\sqrt{s}$

Can be interpreted as a consequence of particle production through (soft) MPI

Phys. Rev. D 84 (2011) 034026 Hep-ph/1106.4959 **Phys. Rept. 349 (2001) 301 Hep-ph/0004215** **J. Phys. G 37 (2010) 083001**

Needs for MPI

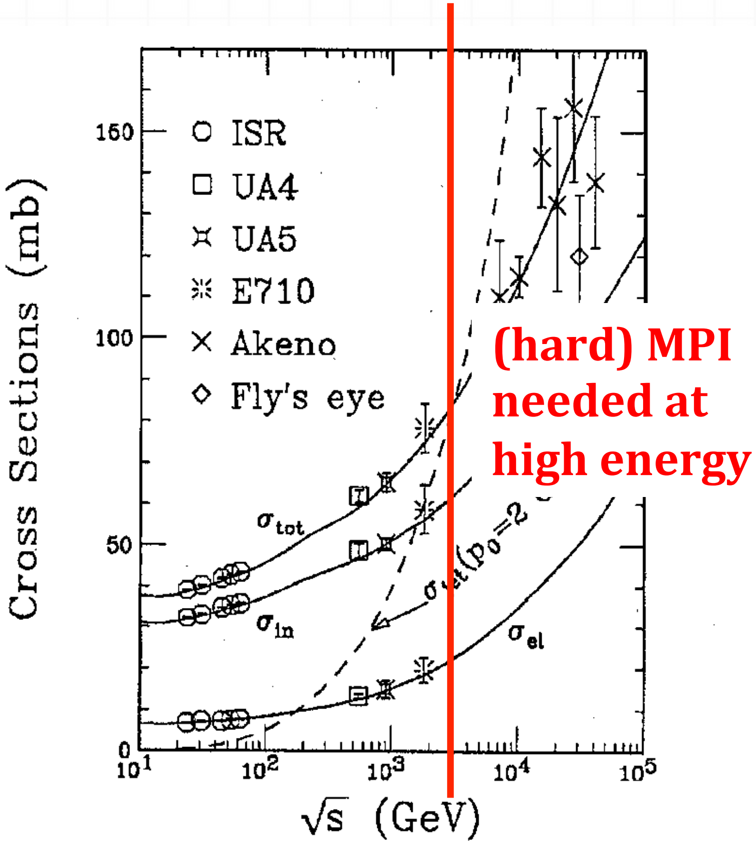
pQCD and inclusive observables



Jet production cross section:
Inclusive cross section: pp -> Jet +X

$$\sigma_{pp \to q3q4} = \iiint dx_1\, dx_2\, d\hat{t} f_1(x_1, Q^2) f_2(x_2, Q^2) \frac{d\hat{\sigma}_{q1q2 \to q3q4}}{d\hat{t}}$$

Limitation at high energy

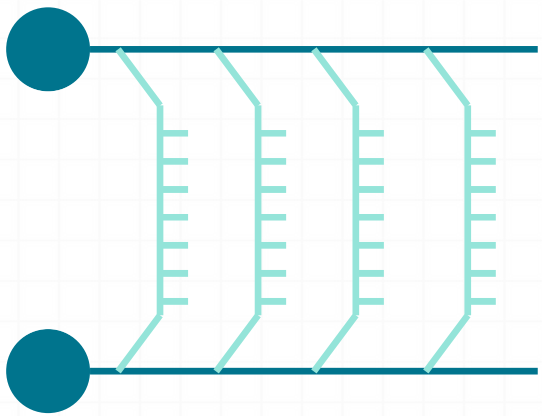


X.N.Wang, M.Gyulassy, Phys. Rev. D45 (1992) 844-856

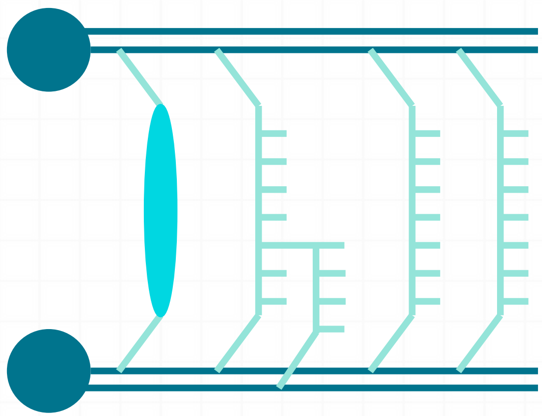
$$< n_{MPI} > = \frac{\sigma_{hard}}{\sigma_{tot}}$$

Needs for MPI

✓ A naïve picture



✓ A less naïve picture



✓ A more complex picture

- ➢ High multiplicity 7 TeV pp events comparable to RHIC Cu-Cu collisions **PHOBOS, Phys. Rev. C 83, 024913 (2011)**

$dN_{ch}^{pp}/d\eta$ up to 70, $dN_{ch}^{Cu\text{-}CU}/d\eta$= 75 in 25-30% at $\sqrt{s}$=200 GeV, $dN_{ch}^{Au\text{-}AU}/d\eta$= 73 in 50-55% at $\sqrt{s}$=200 GeV

- ➢ 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 effects on quarkonium production in pp collisions **S. Vogel et al. J.Phys.Conf.Ser. 420 (2013) 012034/ T. Lang Phys.Rev. C87 (2013) 024907**
- ➢ Quarkonium production mechanism still to be understood, while open charm and beauty production is well described by pQCD

Understanding of elementary interactions in pp collisions is crucial:
Interplay soft-hard, MPI structure, Underlying event (UE)

Where to look for MPI?

We have been knowing since the 90th that MPIs are necessary to describe all features of pp collisions at high energies both for soft and hard production

MPI directly connected with multiplicity

Multiplicity differential studies and exclusive measurements

Seen by others @ LHC

- CMS

Jet and underlying event properties as a function of charged-particle multiplicity in proton-proton collisions at $\sqrt{s}$ = 7 TeV **Eur. Phys. J. C 73 (2013) 2674 hep-ex/1310.4554**

→ Need MPI to describe data, even if actual description not satisfactory (PYTHIA, HERWIG)

ϒ production as a function of multiplicity

- LHCb

Observation of double charm production involving open charm in pp collisions at $\sqrt{s}$ = 7 TeV **JHEP 06 (2012) 141**

Observation of J/ψ-pair production in pp collisions at $\sqrt{s}$=7 TeV **Phys. Lett. B 707 (2012) 52**

→ Double charm and J/Psi production agree better with models including double parton scattering (DPS), 2 explicit hard interactions

Cf. P. Bartalini tomorrow: *Signals of MPI: current status and future experimental challenges?*

sarah@clermont.in2p3.fr

Where to look for MPI with ALICE?

ALICE

- Underlying event measurements

  Underlying Event measurements in pp collisions at √s = 0.9 and 7 TeV with the ALICE experiment at the LHC, **JHEP 07 (2012) 116**

- Multiplicity dependence of two-particle azimuthal correlations

  - *Multiplicity dependence of two-particle azimuthal correlations in pp collisions at the LHC* **JHEP 09 (2013) 049**
  - *Multiplicity dependence of jet-like two-particle correlations in p-Pb collisions at* $\sqrt{s_{NN}}$ *= 5.02 TeV* **arXiv:1406.5463, submitted to PLB**

- Charm production as a function of multiplicity

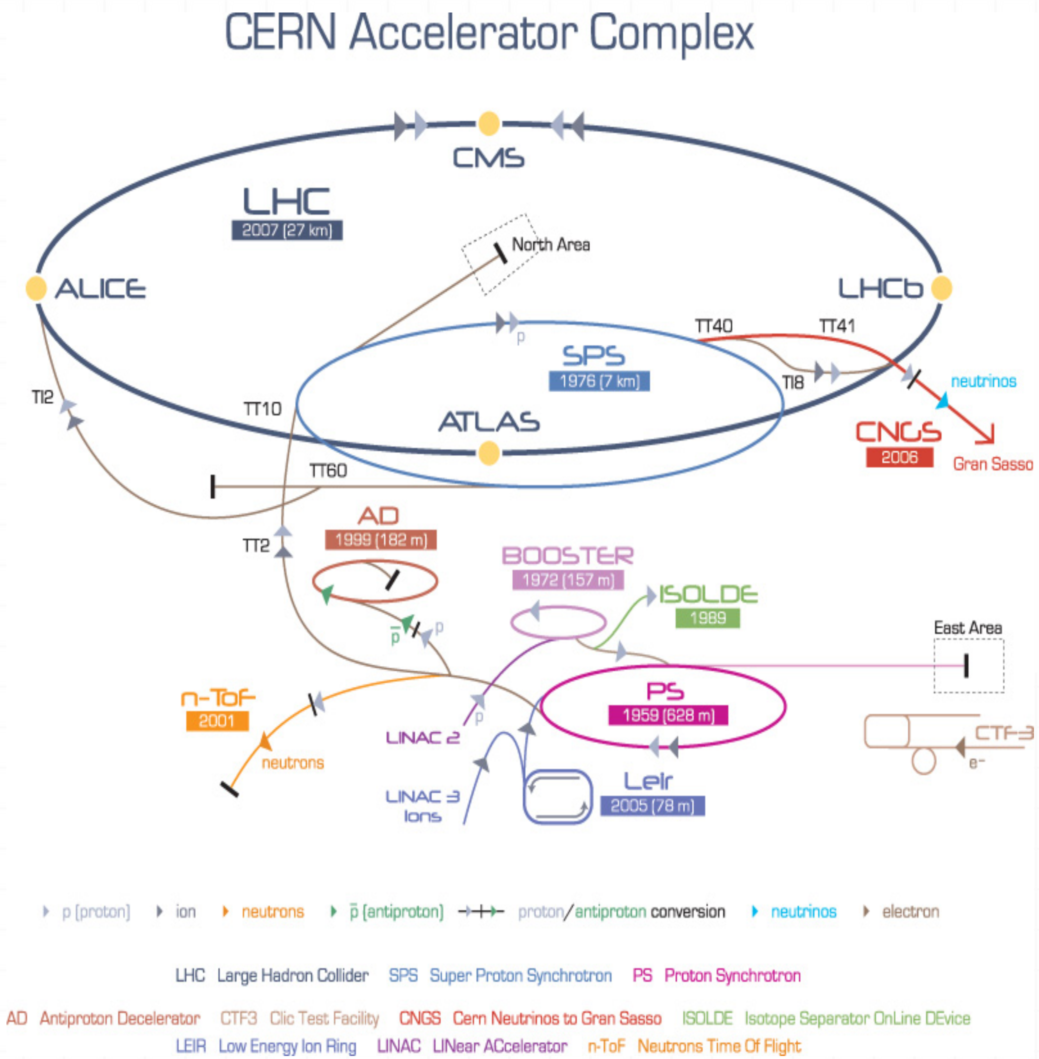
  - J/Ψ production as a function of multiplicity in pp and p-Pb collisions

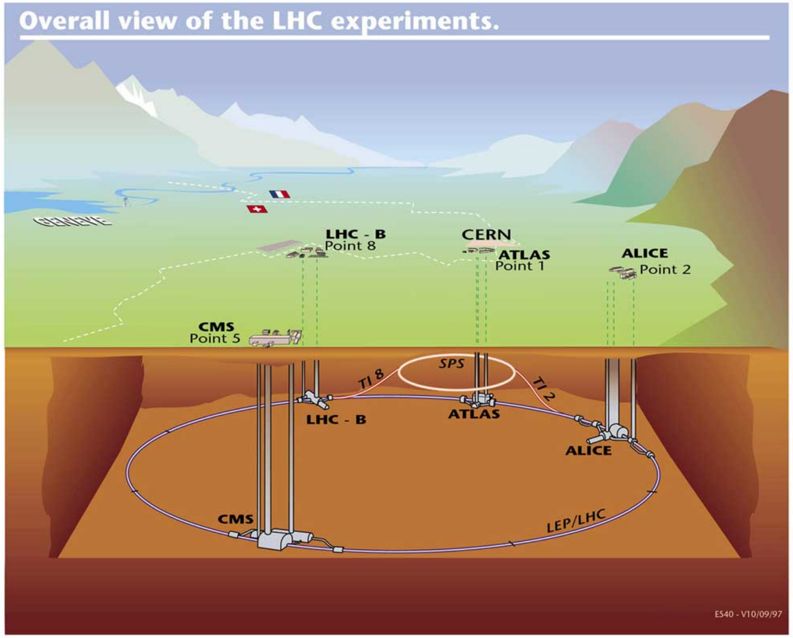
    J/ψ production as a function of charged particle multiplicity in pp collisions at √s = 7 TeV

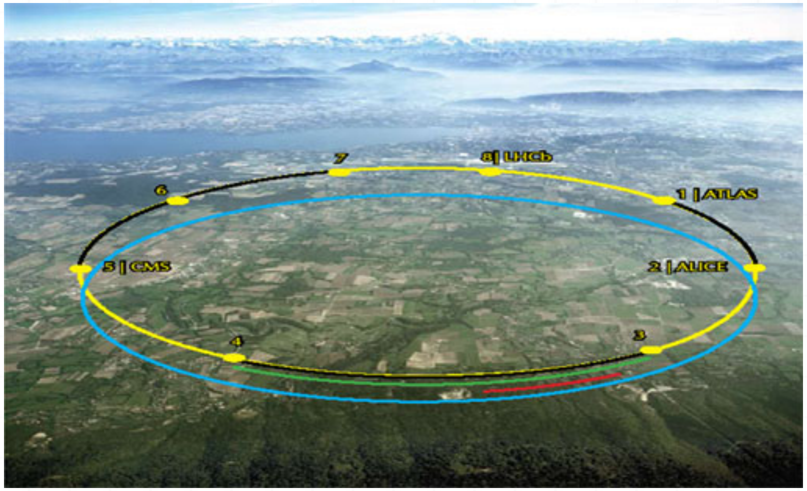
    Phys. Lett. B 712 (2012) 3, 165–175
  - D-meson production as a function of multiplicity in pp and p-Pb, **Paper in preparation**
  - Non-prompt J/Ψ as a function of multiplicity in pp collisions, **Paper in preparation**

No inclusion of $\langle p_T \rangle$ vs. N_{ch}; λ/k0; long range angular correlations (ridge)

The Large Hadron Collider (LHC)

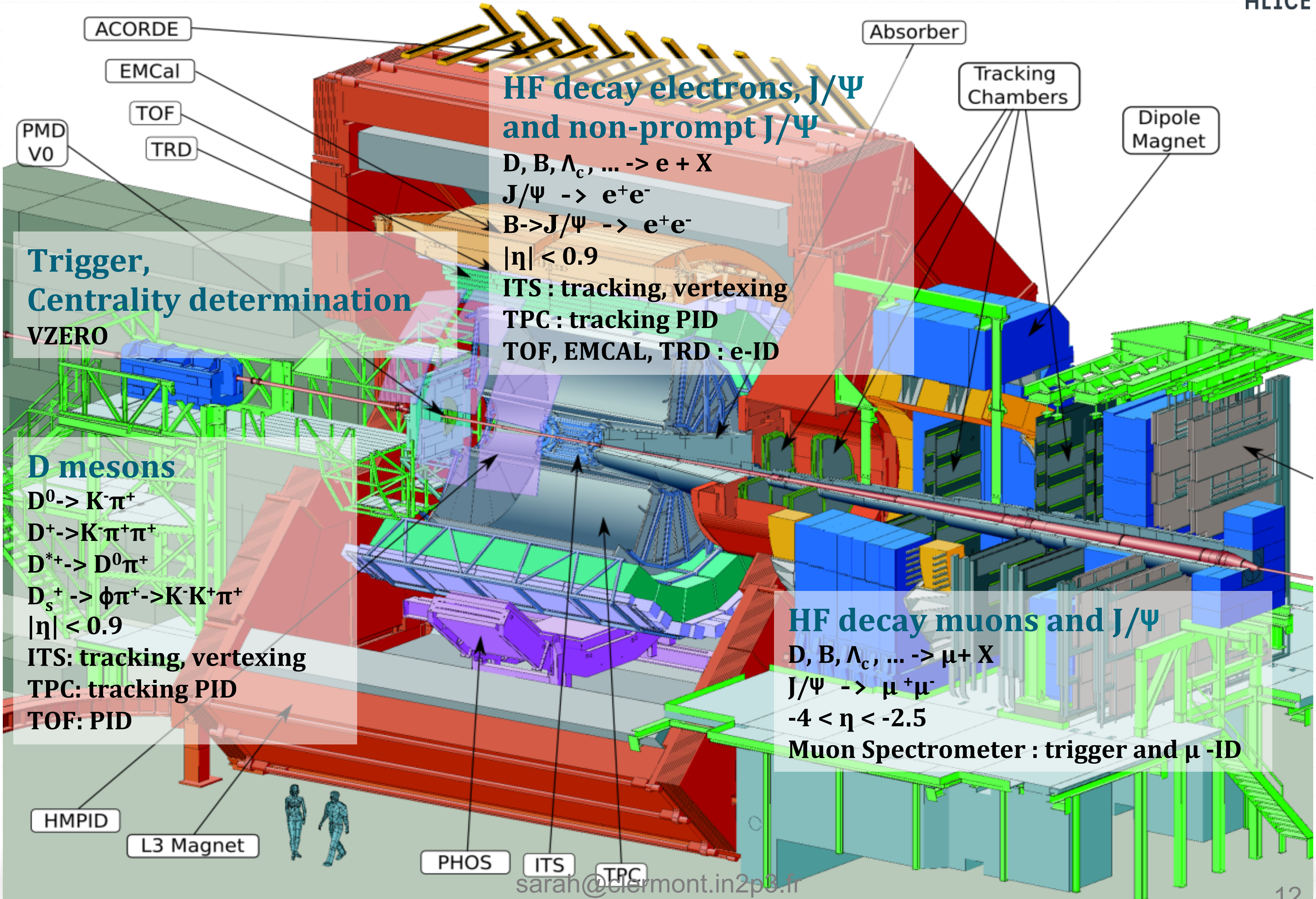






LHC 27 km circumference
50 to 175 m underground

ALICE



HF decay electrons, J/Ψ and non-prompt J/Ψ

D, B, Λ_c, ... -> e + X
J/ψ -> e^+e^-
B->J/ψ -> e^+e^-
$|\eta| < 0.9$
ITS : tracking, vertexing
TPC : tracking PID
TOF, EMCAL, TRD : e-ID

Trigger, Centrality determination

VZERO

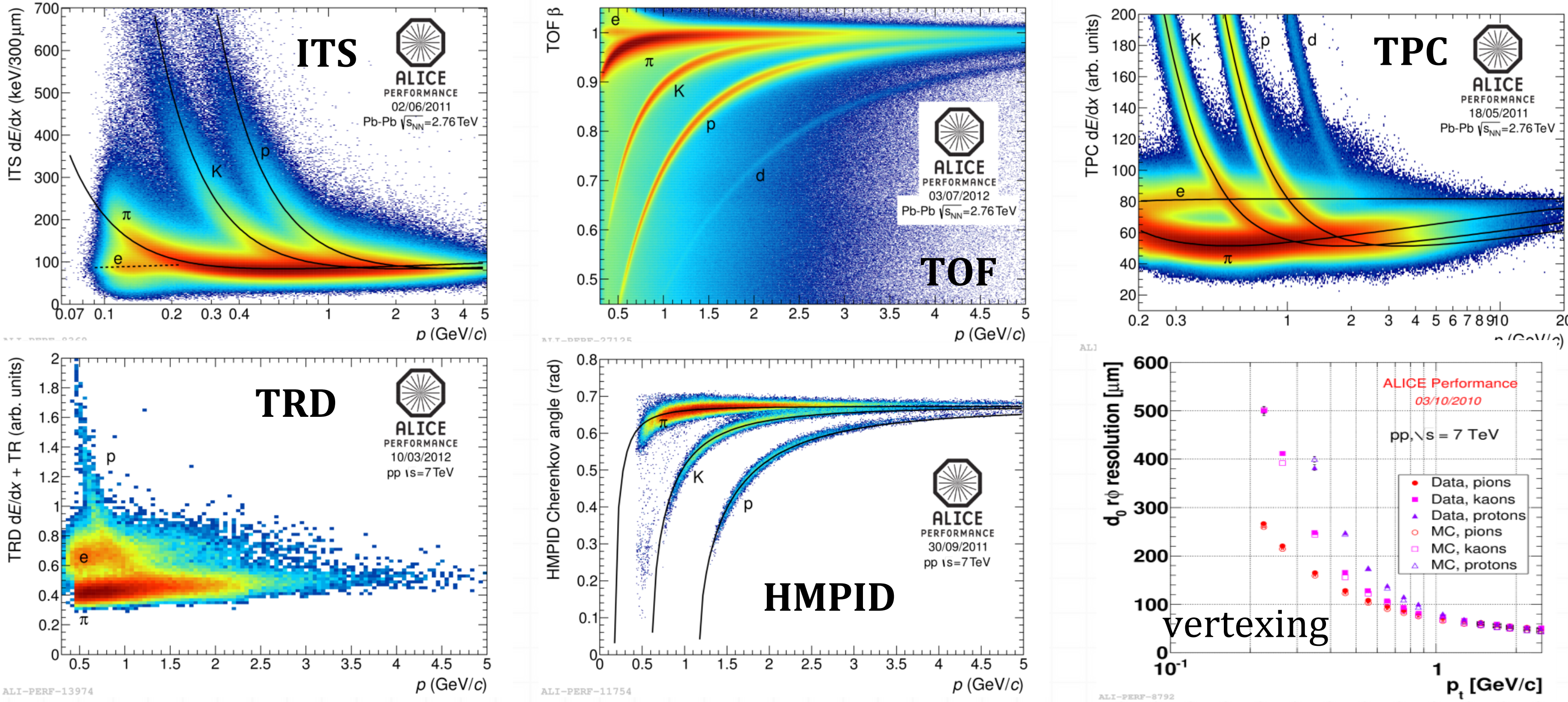
D mesons

$D^0 \to K^-\pi^+$
$D^+ \to K^-\pi^+\pi^+$
$D^{*+} \to D^0\pi^+$
$D_s^+ \to \phi\pi^+ \to K^-K^+\pi^+$
$|\eta| < 0.9$
ITS: tracking, vertexing
TPC: tracking PID
TOF: PID

HF decay muons and J/ψ

D, B, Λ_c, ... -> μ+ X
J/ψ -> $\mu^+\mu^-$
$-4 < \eta < -2.5$
Muon Spectrometer : trigger and μ -ID

ALICE Particle identification



- ✓ extremely low-mass tracker e.g. low material budget
- ✓ particle identification down to $p_{\mathrm{T}} \sim 100$ MeV/c

sarah@clermont.in2p3.fr

Where to look for MPI with ALICE?

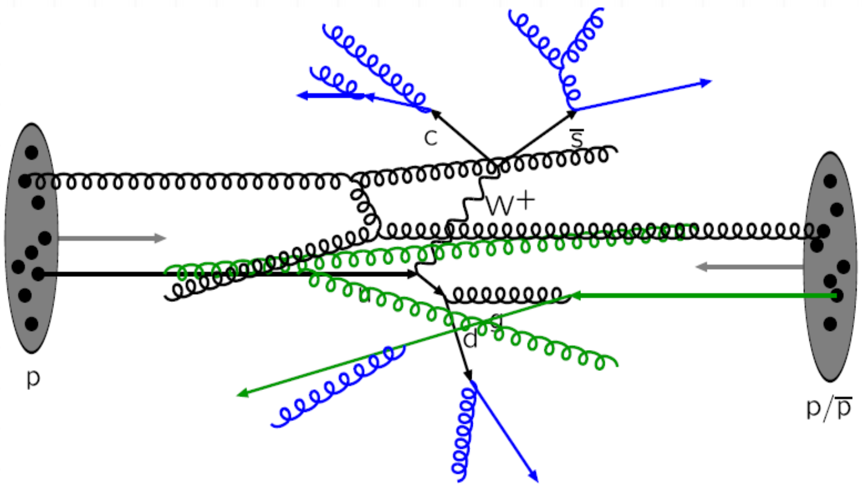
ALICE

- Underlying event measurements

  Underlying Event measurements in pp collisions at $\sqrt{s}$ = 0.9 and 7 TeV with the ALICE experiment at the LHC, **JHEP 07 (2012) 116**

Underlying event measurement

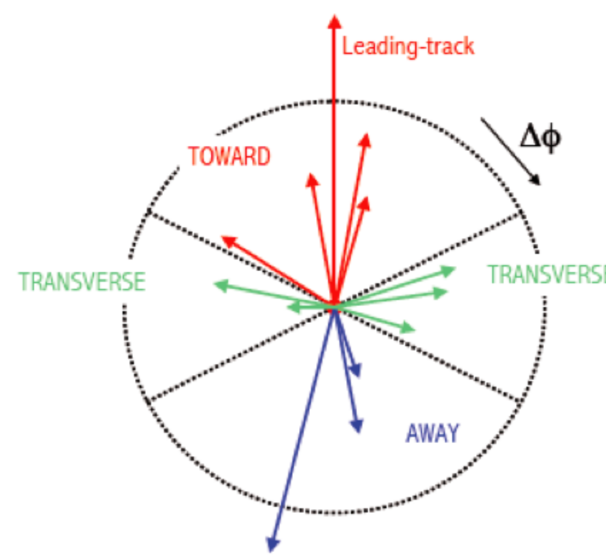
pp collision description “à la” PYTHIA



1 hard scattering on top of underlying event (UE) activity

UE = fragmentation of beam remnants
+ MPI
+ initial and final state radiation (ISR/FSR)

Energy scale given by the leading particle (approximation to the original outgoing parton momentum)



Toward: $|\Delta\varphi|<\pi/3$

Transverse: $\pi/3<|\Delta\varphi|<2\pi/3$

Away: $|\Delta\varphi|>2\pi/3$

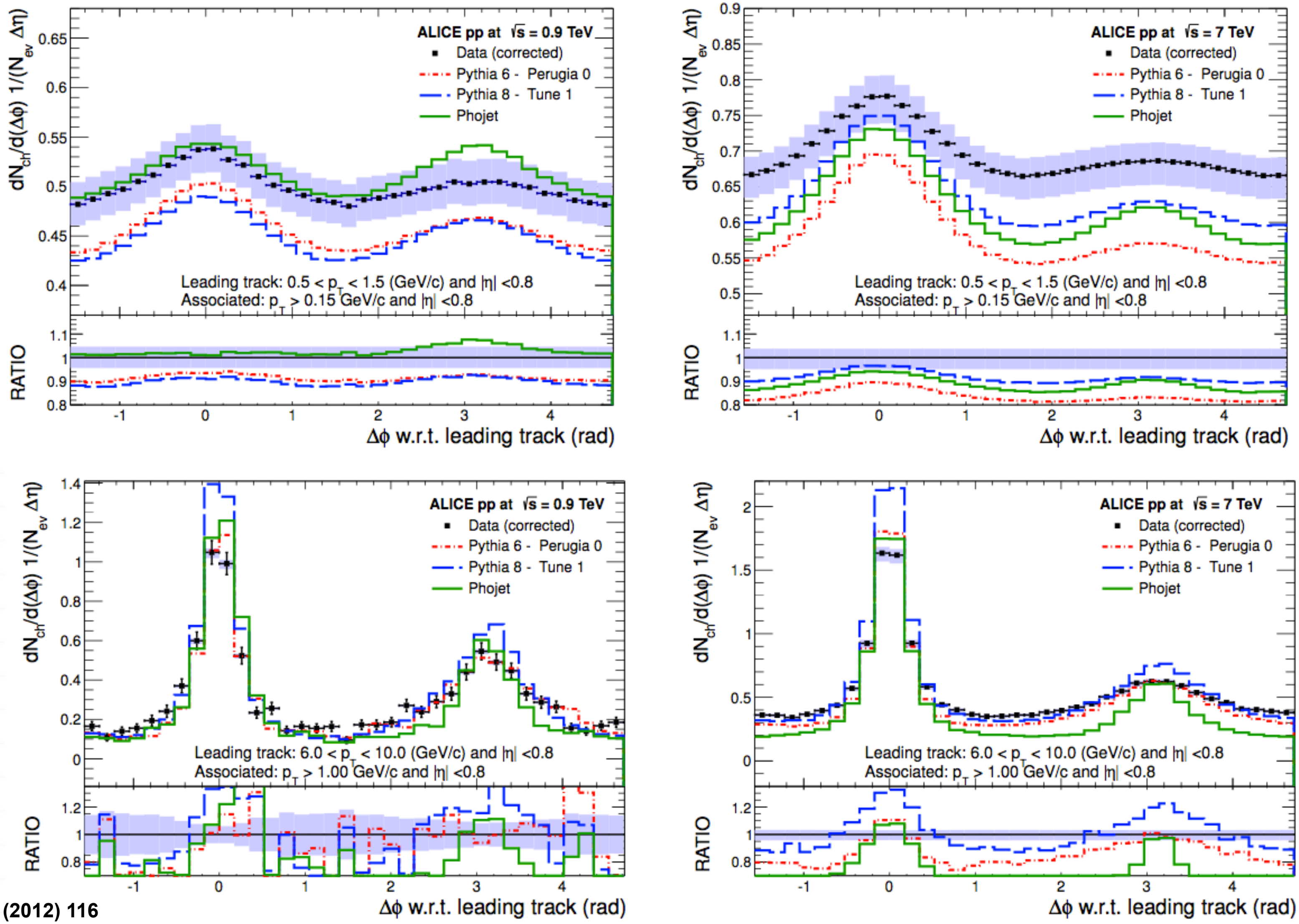
$\sqrt{s}$=0.9 and 7 TeV, p_T threshold: 0.15, 0.5 and 1 GeV/c

Study of charged particle in the three regions gives insight into the UE behavior

Underlying event measurement – Δφ-correlation

Δφ-correlation between tracks and the leading track

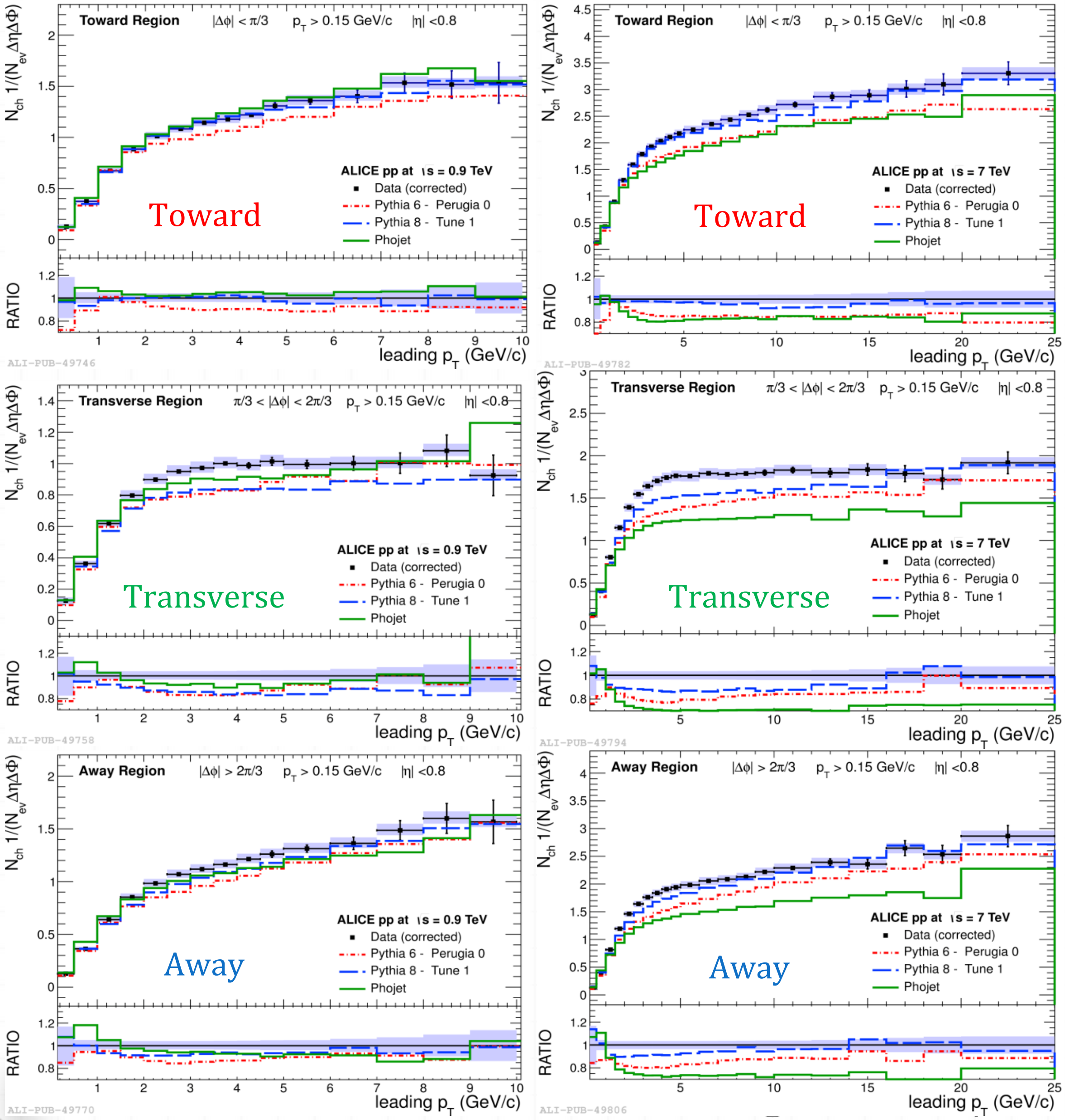
$$\frac{1}{\Delta\eta}\frac{1}{N_{ev}(p_T, LT)}\frac{dN_{ch}}{d\Delta\varphi}$$



JHEP 1207 (2012) 116

Underlying event measurement – Number density

$\sqrt{s}$ = 0.9 TeV $\sqrt{s}$ = 7 TeV



Average charged particle density vs. leading track transverse momentum $p_{\mathrm{T,LT}}$

$$\frac{1}{\Delta\eta\Delta\varphi}\frac{1}{N_{ev}(p_T,LT)}N_{ch}(p_T,LT)$$

- <u>Toward and Away</u>

Monotonic increase with leading p_{T} regions dominated by jet fragmentation, ↑ leading p_{T}: ↑ hadronic activity

- <u>Transverse</u>

Increase interpreted in term of MPI

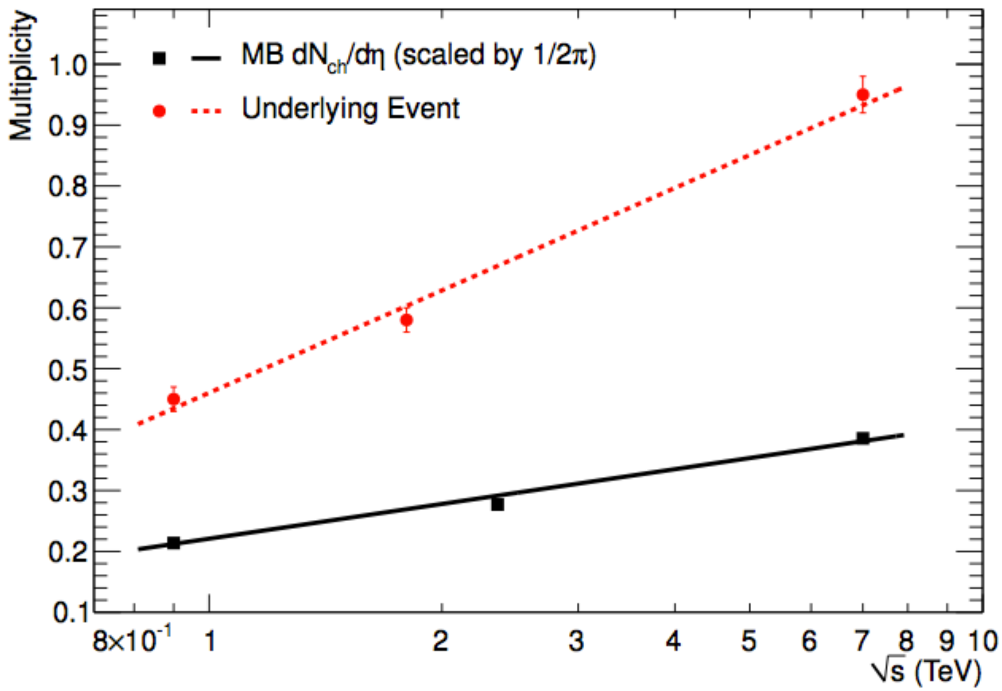
In PYTHIA: higher p_{T} biases towards more central collisions (higher MPI probabilities)

Plateau at ~4 GeV/c : production independent of hard scale

JHEP 1207 (2012) 116

Underlying event measurement – Number density

Comparison of number density in the plateau of the Transverse region (underlying event)
And $dN_{ch}/d\eta$ in minimum bias event

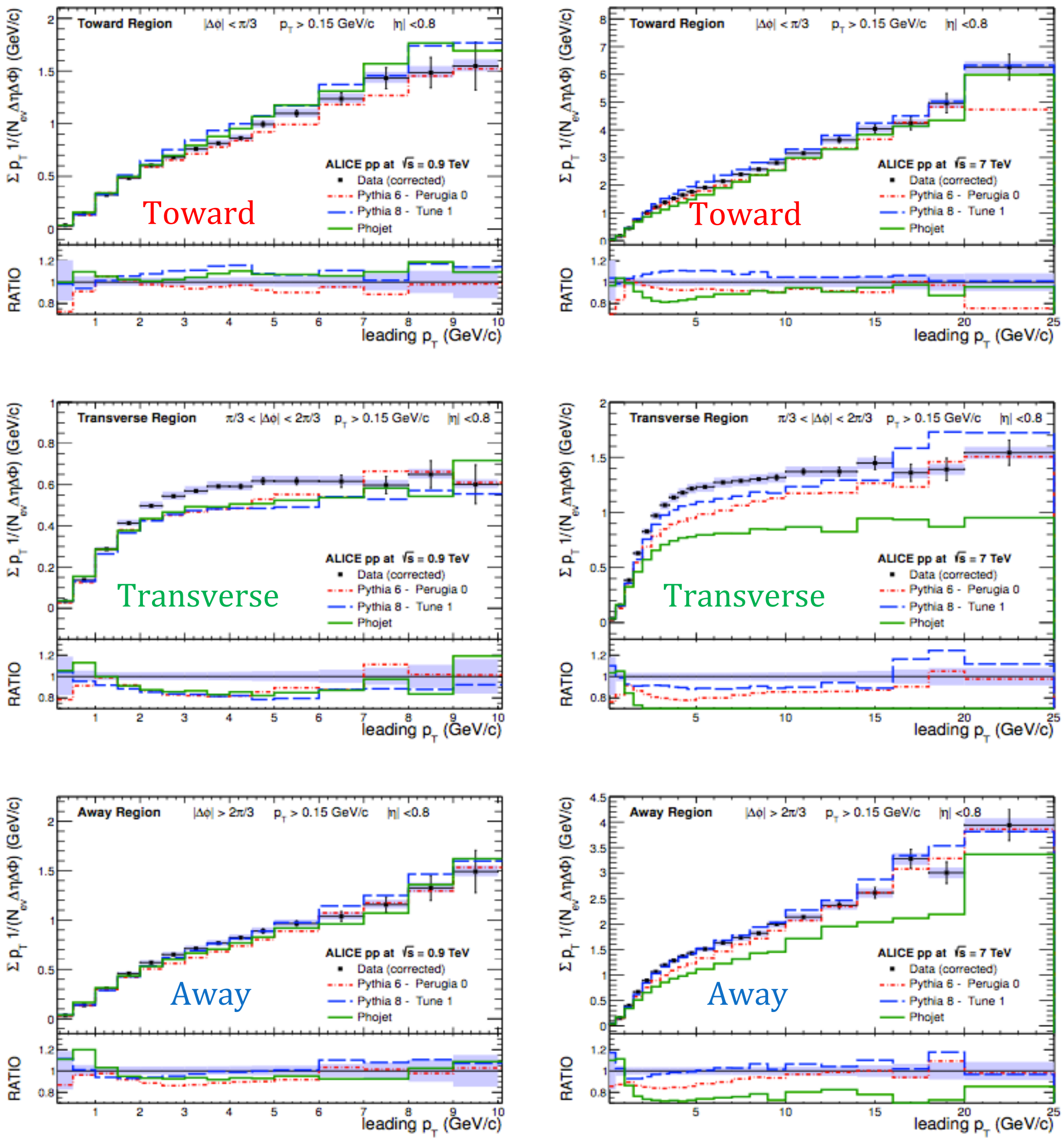


UE number density grows logarithmically and faster than MB $dN_{ch}/d\eta$

JHEP 1207 (2012) 116

Underlying event measurement – Summed p_T

√s = 0.9 TeV   √s = 7 TeV



Average summed p_T density vs. leading track transverse momentum $p_{T,LT}$

$$\frac{1}{\Delta\eta\Delta\varphi}\frac{1}{N_{ev}(p_T,LT)}\sum p_T(p_T,LT)$$

Same behavior and interpretation as for number density

JHEP 1207 (2012) 116

Where to look for MPI with ALICE?

ALICE

- Multiplicity dependence of two-particle azimuthal correlations
  - *Multiplicity dependence of two-particle azimuthal correlations in pp collisions at the LHC*
    JHEP 09 (2013) 049
  - *Multiplicity dependence of jet-like two-particle correlations in p-Pb collisions at* $\sqrt{s_{NN}}$ *= 5.02 TeV*
    arXiv:1406.5463, submitted to PLB

Multiplicity dependence of two-particle azimuthal correlations

Probability distribution of the azimuthal difference: $\Delta\varphi=\varphi_{trig}-\varphi_{assoc}$

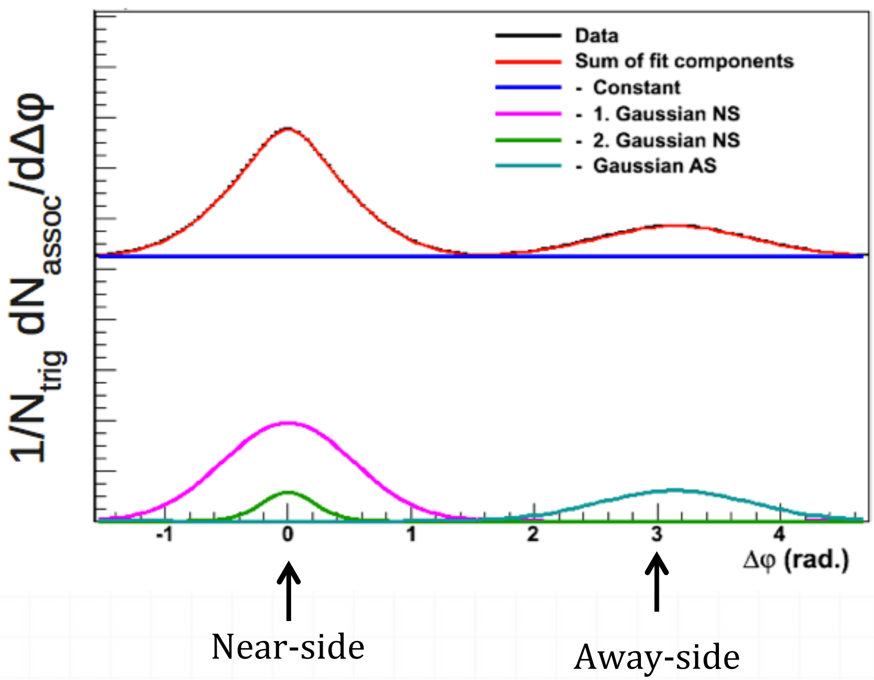
Trigger particles: $p_{T,trig} > p_{T,trig}^{min}$, $|\eta|<0.9$

Associated particles: $p_{T,assoc} > p_{T,assoc}^{min}$, $|\eta|<0.9$

N_{trig}: number of trigger particles

N_{assoc}: number of associated particles

Pair-yield per trigger as a function of Δφ: $$\frac{dN}{d\Delta\varphi} = \frac{1}{N_{trig}}\frac{dN_{assoc}}{d\Delta\varphi}$$



Fit-function to unravel the azimuthal correlation main components

Combinatorial background

Near-side peak: 2 Gaussians

$$f(\Delta\varphi) = C + A_1 \exp\left(-\frac{\Delta\varphi^2}{2\sigma_1^2}\right) + A_2 \exp\left(-\frac{\Delta\varphi^2}{2\sigma_2^2}\right) + A_3 \exp\left(-\frac{(\Delta\varphi-\pi)^2}{2\sigma_3^2}\right)$$

Away-side peak: single Gaussian

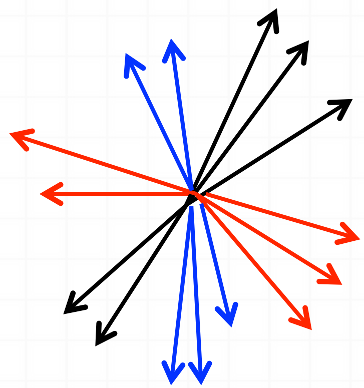
The fitting parameters are used to construct observables

Multiplicity dependence of two-particle azimuthal correlations

ALICE

Observables definition

- ✓ Per-trigger pair yield in the combinatorial background $\langle N_{\text{isotrop}} \rangle = \frac{1}{N_{\text{trigger}}} C$
- ✓ Per-trigger pair yield in the near-side peak $\langle N_{\text{assoc, near-side}} \rangle = \frac{\sqrt{2\pi}}{N_{\text{trigger}}} (A_1\sigma_1 + A_2\sigma_2)$
- ✓ Per-trigger pair yield in the away-side peak $\langle N_{\text{assoc, away-side}} \rangle = \frac{\sqrt{2\pi}}{N_{\text{trigger}}} (A_3\sigma_3)$
- ✓ Average number of trigger particles $\langle N_{\text{trigger}} \rangle = \frac{N_{\text{trigger}}}{N_{\text{events}}}$
- ✓ Average number of uncorrelated seeds $\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trigger}} \rangle}{\langle 1 + N_{\text{assoc, near + away}, p_T > p_{T,\text{trig}}} \rangle}$



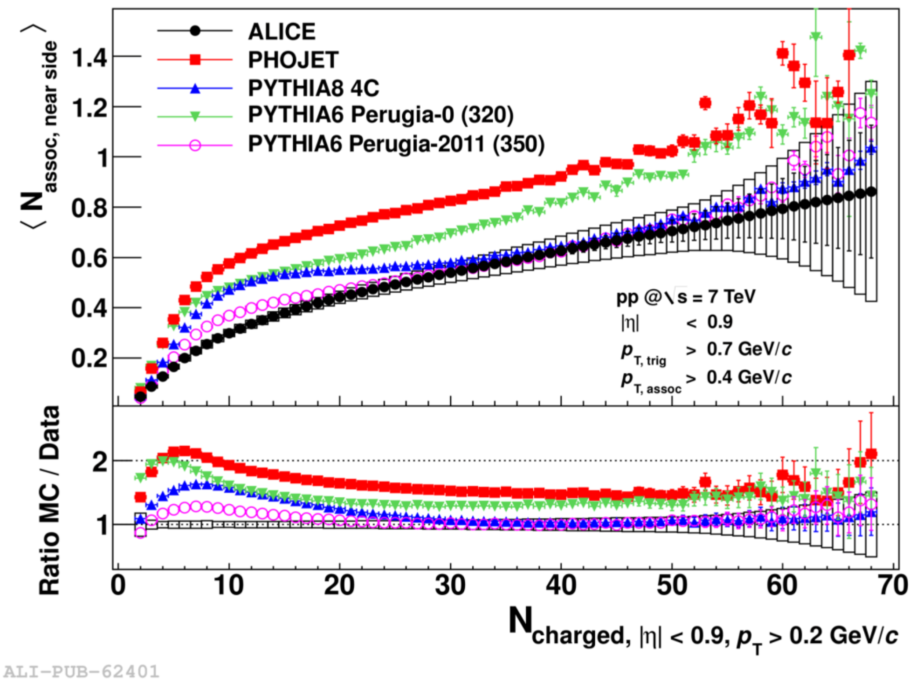
N_{trigger} sensitive to MPI and parton fragmentation

The ratio reduces fragmentation contribution

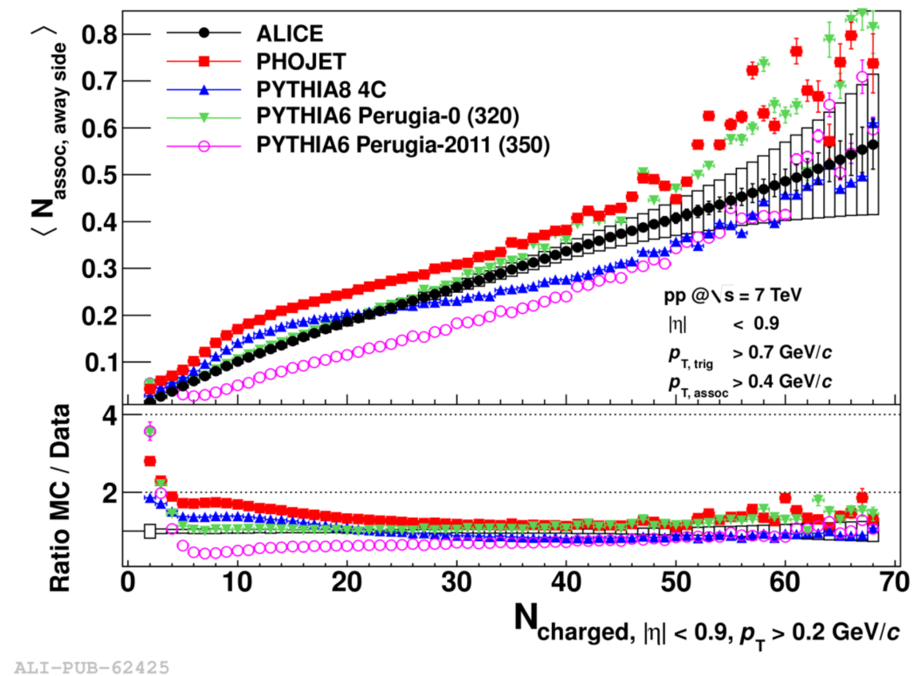
Number of uncorrelated sources of particles
$\Rightarrow$ linked with the number of MPI in the event

Multiplicity dependence of two-particle azimuthal correlations

Per-trigger pair yield in the near-side peak



Per-trigger pair yield in the away-side peak

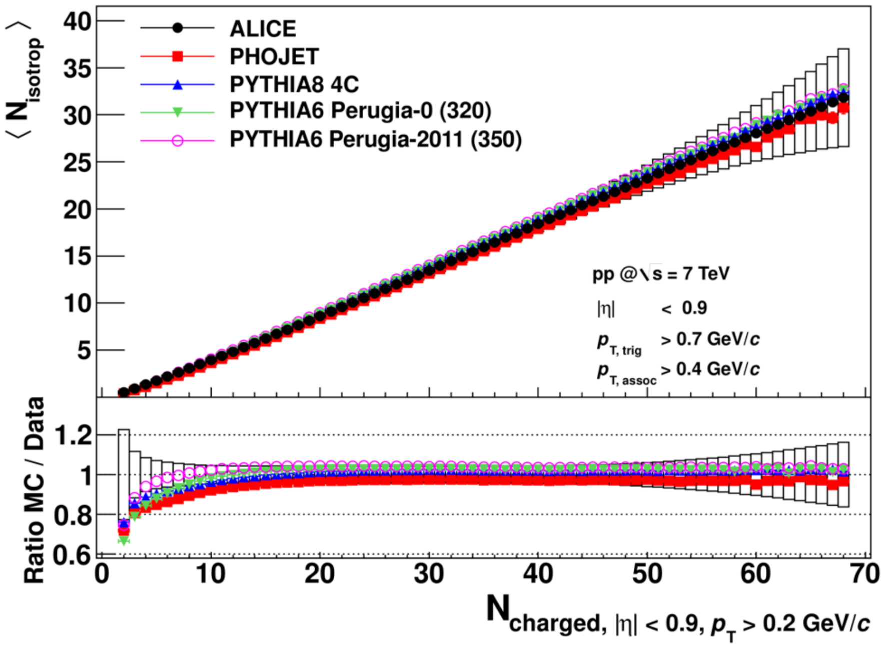


- Near-side pair yield grows as a function of multiplicity
- General trend (increase with multiplicity) present in MC
- Away-side pair yield grows as a function of multiplicity
- None of the MC is able to describe near-side and away-side simultaneously

Multiplicity dependence of two-particle azimuthal correlations

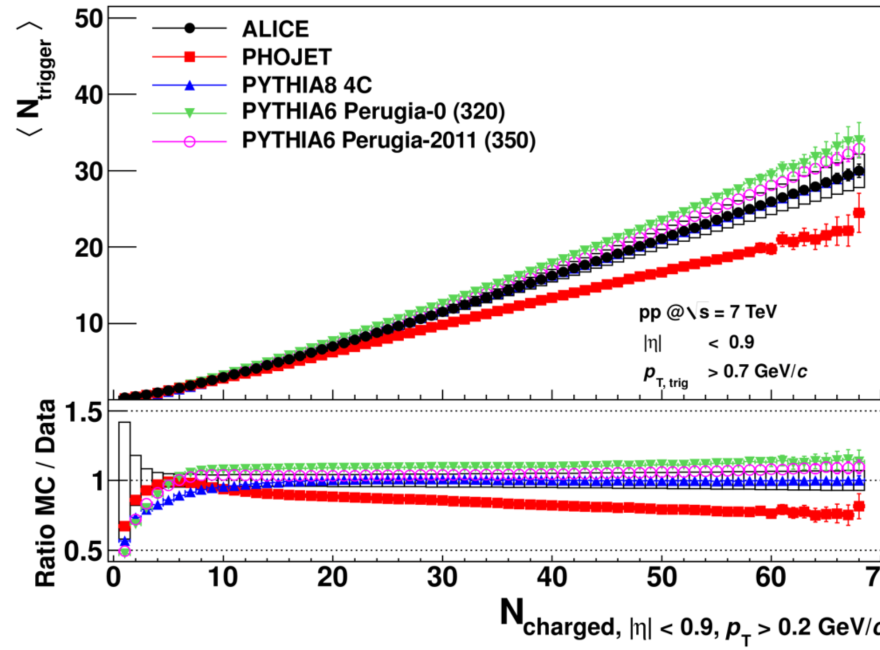
ALICE

Per-trigger pair yield in the combinatorial background



ALI-PUB-62473

Average number of trigger particles



ALI-PUB-62507

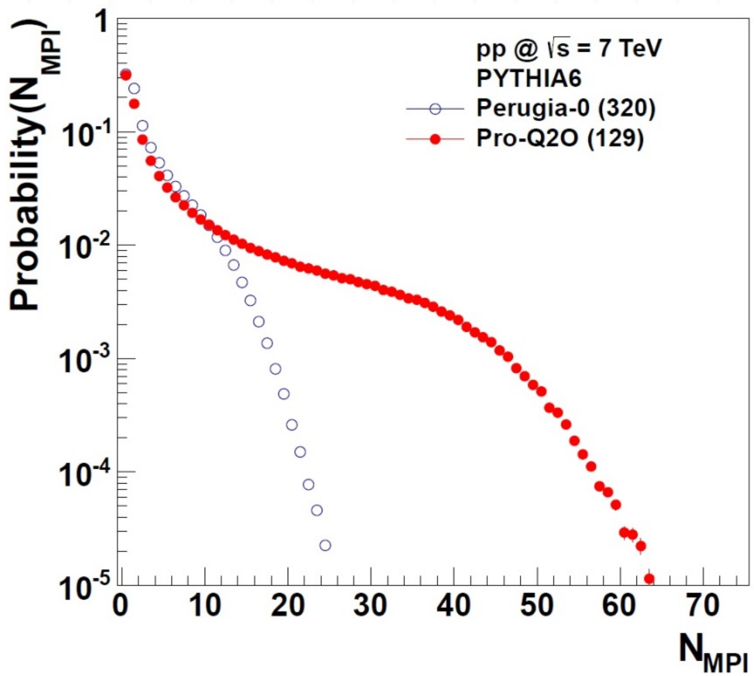
- Linear increase as a function of multiplicity
- Well described by the MC

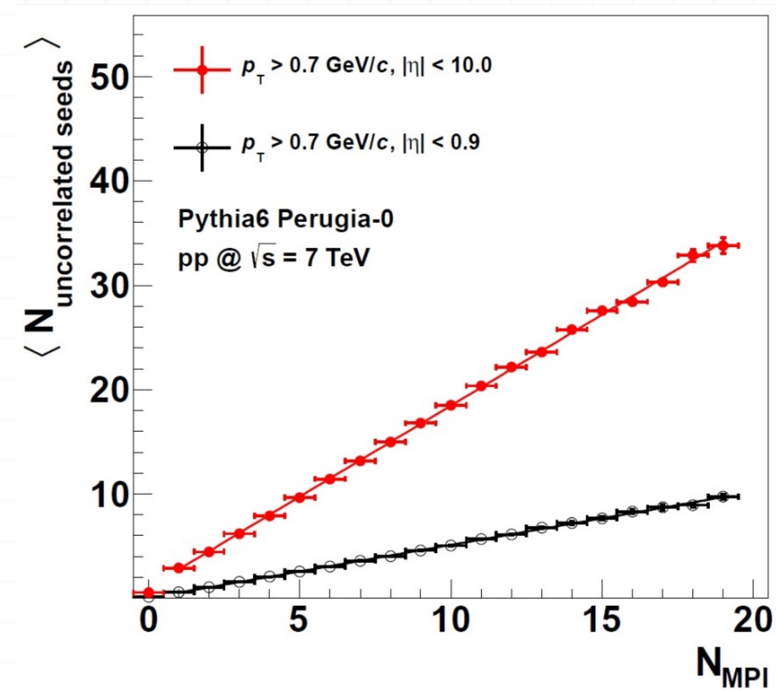
- Deviation from linear increase at high multiplicity
- Both MPI and hadronic activity increase with multiplicity, leading to an increase of particle above a p_T threshold, not reproduced by PHOJET

Multiplicity dependence of two-particle azimuthal correlations

ALICE

Average number of uncorrelated seeds in PYTHIA



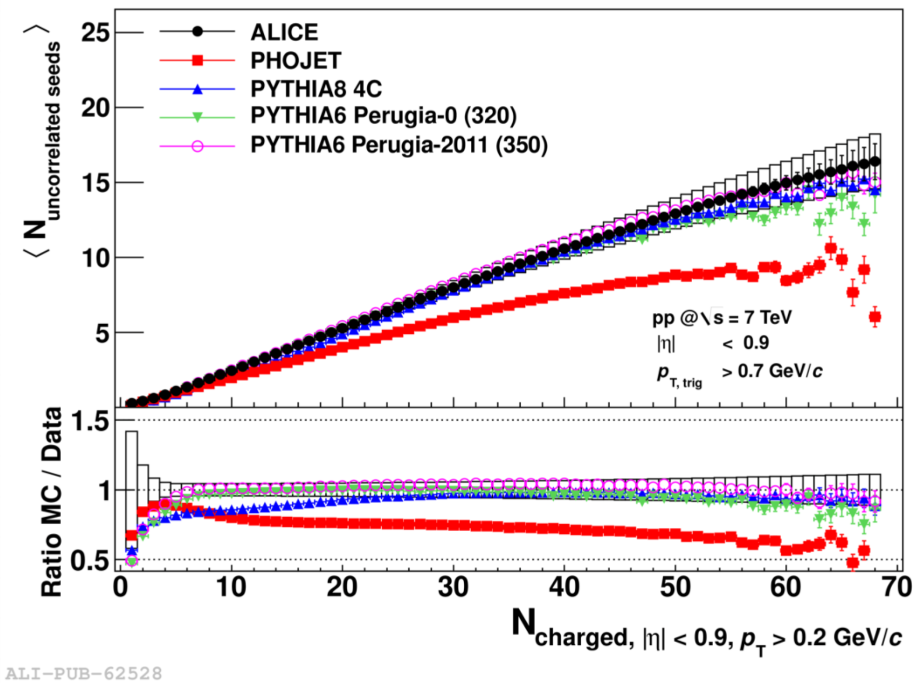


- N_{MPI} = number of hard or semi-hard scatterings in a single pp collision
- Perugia-0 and Pro-Q20: 2 different tunes with a good description of Tevatron data and LHC predictions **Phys. Rev. D 82 (2010) 074018**
- Lead to different probability distributions of N_{MPI}
- $N_{\mathrm{uncorrelated\ seeds}}$ directly proportional to N_{MPI}

JHEP 09 (2013) 049

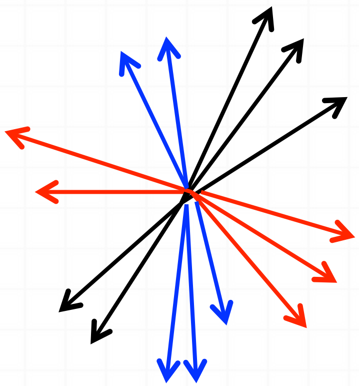
Multiplicity dependence of two-particle azimuthal correlations

Average number of uncorrelated seeds



$$\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trigger}} \rangle}{\langle 1 + N_{\text{assoc, near + away}, \, p_T > p_{T,\,\text{trig}}} \rangle}$$

- Low multiplicity: linear increase
- High multiplicity: increase less than linear

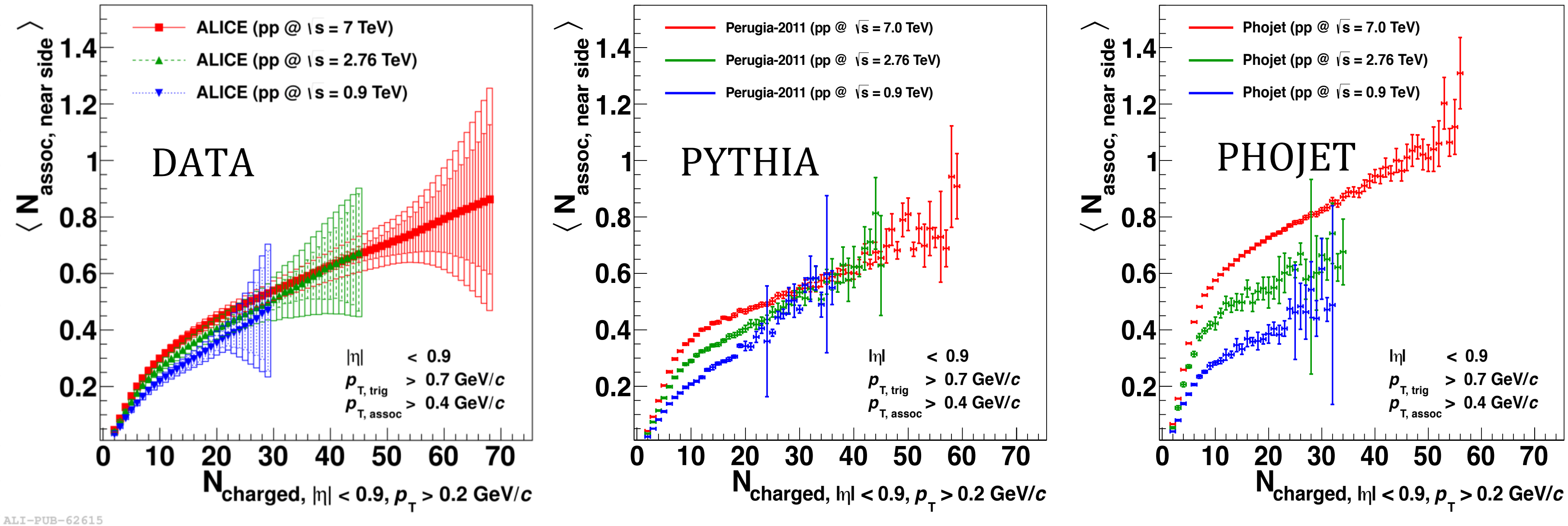


sarah@clermont.in2p3.fr

Multiplicity dependence of two-particle azimuthal correlations

ALICE

Per-trigger pair yield in the near-side peak, evolution with √s



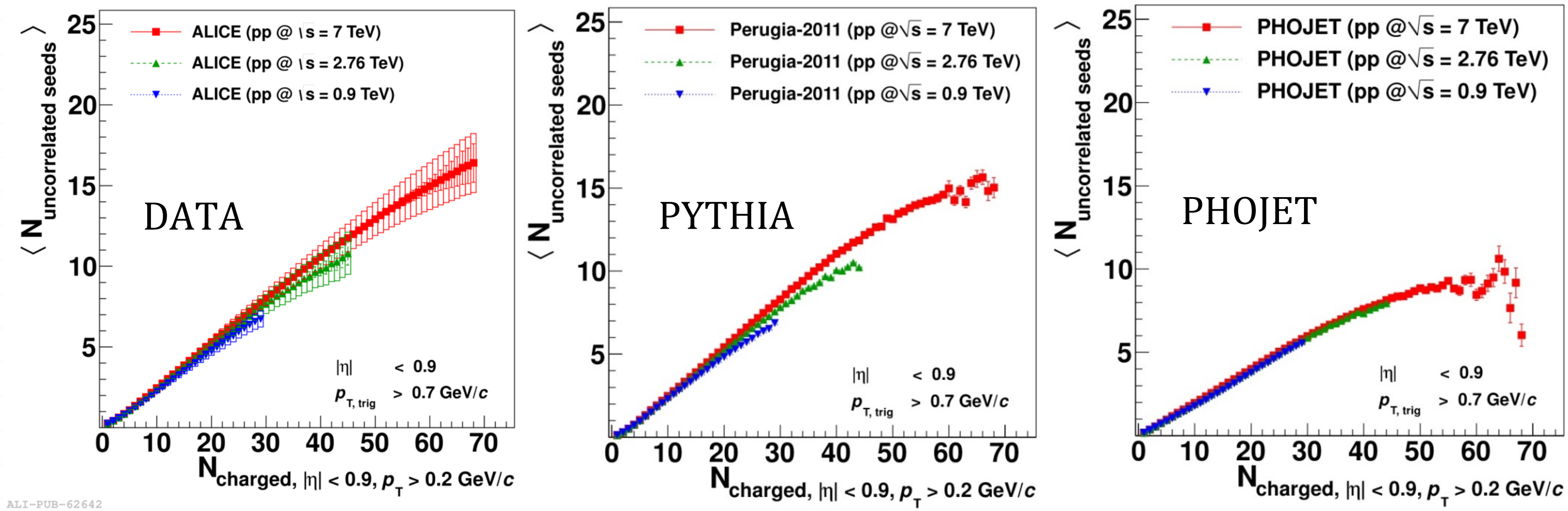
- Near side yield at same multiplicity bin grows with increasing center -of -mass energy
- Splitting between slopes for different √s is larger for PHOJET

sarah@clermont.in2p3.fr

Multiplicity dependence of two-particle azimuthal correlations

ALICE

Average number of uncorrelated seeds, evolution with √s

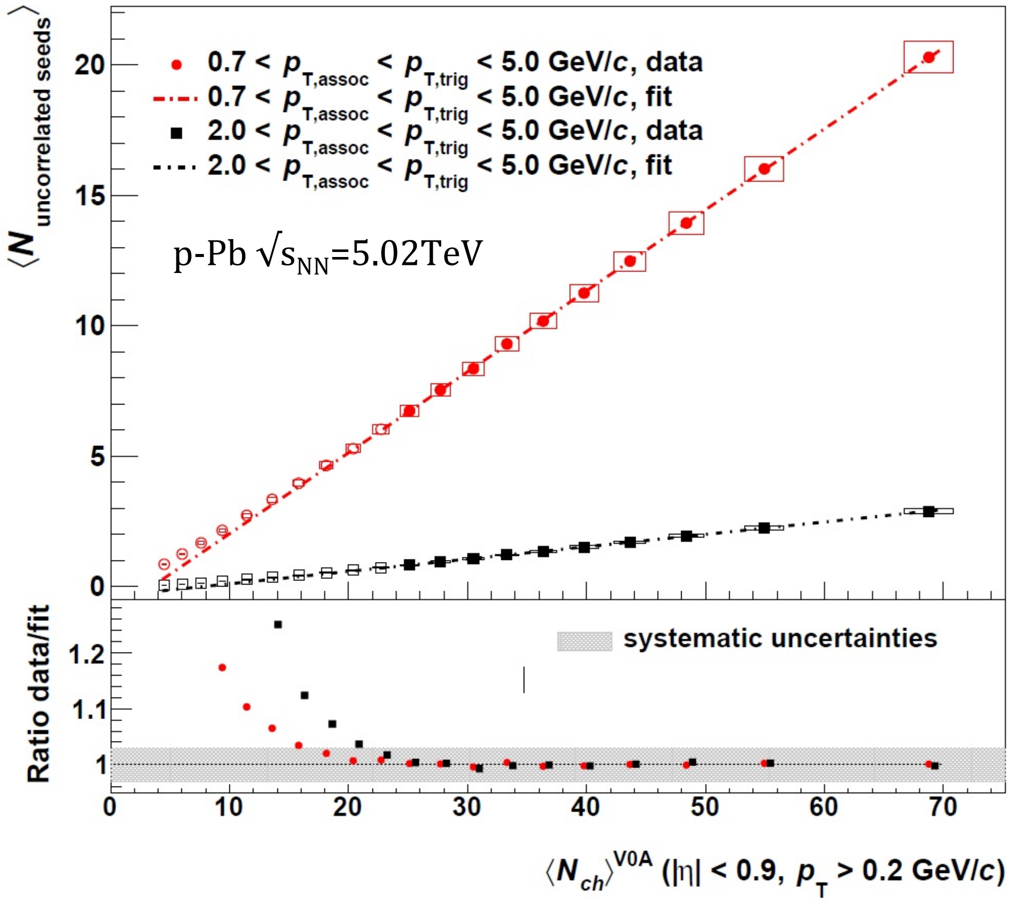


- Only a small √s dependence
- At high multiplicities, the number of uncorrelated seeds saturates.

sarah@clermont.in2p3.fr

Multiplicity dependence of jet-like two-particle correlations in p-Pb collisions

- Long-range angular correlation subtracted (ridge)
- Linear increase (fit in dash-dotted)
- No evidence of a saturation in the number of MPI
- Similar behavior as in pp collisions



arXiv:1406.5463, submitted to PLB

sarah@clermont.in2p3.fr

Where to look for MPI with ALICE?

- Charm production as a function of multiplicity
  - J/Ψ production as a function of multiplicity in pp and p--Pb collisions

    J/ψ production as a function of charged particle multiplicity in pp collisions at $\sqrt{s} = 7$ *TeV*

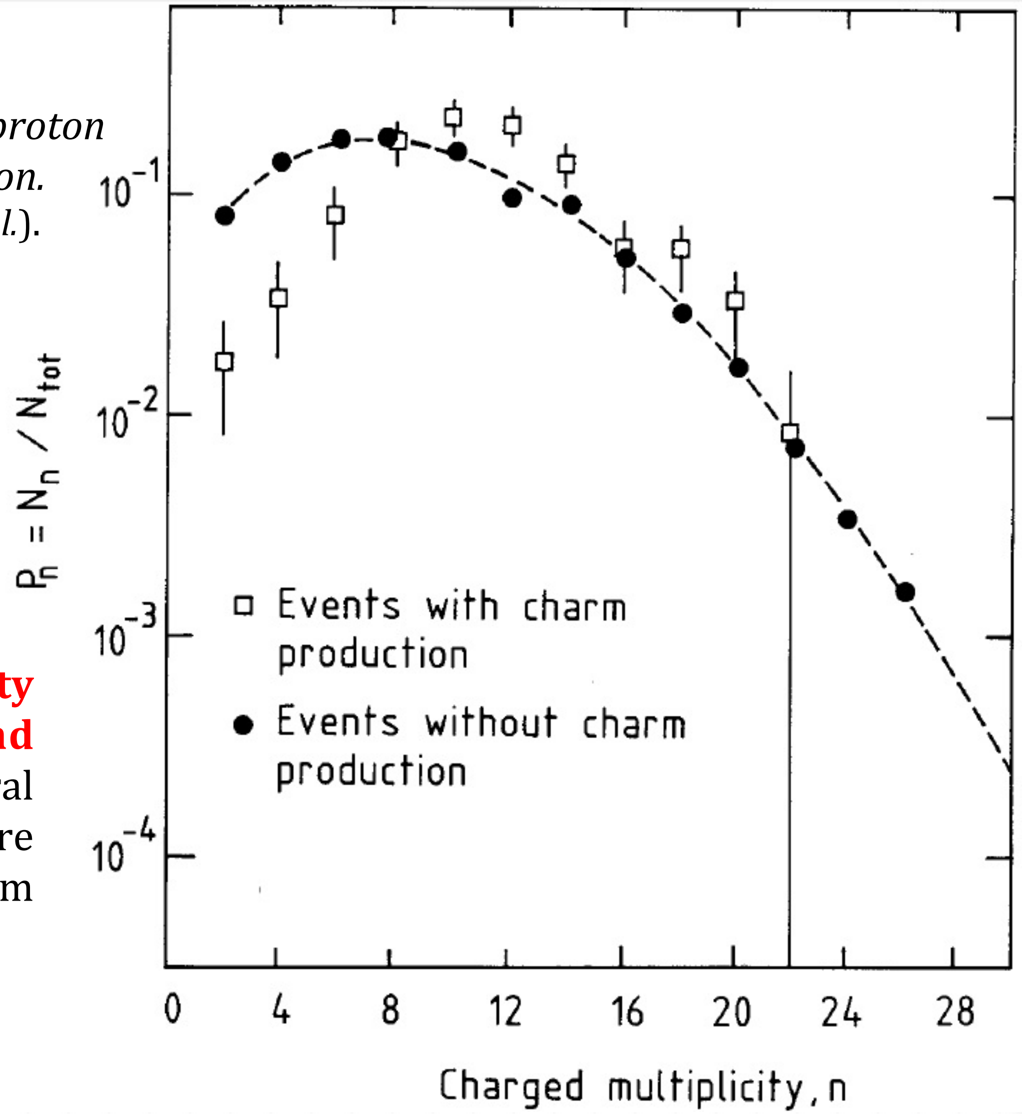
    Phys. Lett. B 712 (2012) 3, 165–175
  - D-meson production as a function of multiplicity in pp and p--Pb
  - Non-prompt J/Ψ as a function of multiplicity in pp collisions

Charm production as a function of multiplicity

ALICE

NA27 publication

Comparative properties of 400-GeV/c proton-proton interactions with and without charm production.
By LEBC-EHS Collaboration (M. Aguilar-Benitez *et al.*).
CERN-EP-88-77, Jun 1988. 16pp.
Z.Phys.C41:191,1988.



Charm production = event with 3,4,5 prongs (signature of charm decay)

“It is clear from fig.1 that the **multiplicity distributions** for interactions **with and without charm are different**. ... It is natural to interpret these differences by the more central nature of collisions leading to charm production.“

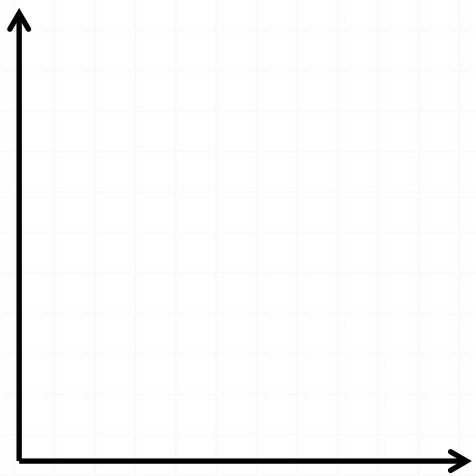
Charm production as a function of multiplicity

➢ <u>The observable</u>

Relative charm production yield as a function of relative charged multiplicity

Charm will be a generic term to refer to quarkonia (J/Ψ) and open charm (D and non-prompt J/Ψ) production

$$\frac{\mathrm{d}N_c / \mathrm{d}y}{< \mathrm{d}N_c / \mathrm{d}y >}$$



$$\frac{\mathrm{d}N_{ch} / \mathrm{d}\eta}{< \mathrm{d}N_{ch} / \mathrm{d}\eta >}$$

Self-normalized quantities, x label: *z* KNO variable

2 advantages :

- ✓ from analysis, various corrections cancel in the ratio
- ✓ for comparison, easier to compare various energies and systems

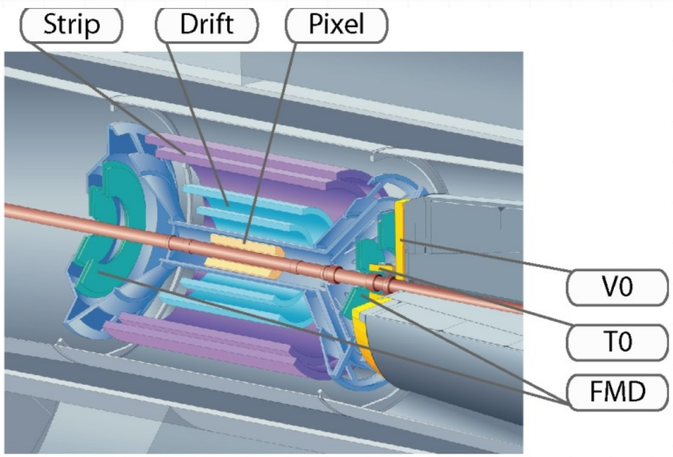
sarah@clermont.in2p3.fr

Charm production as a function of multiplicity

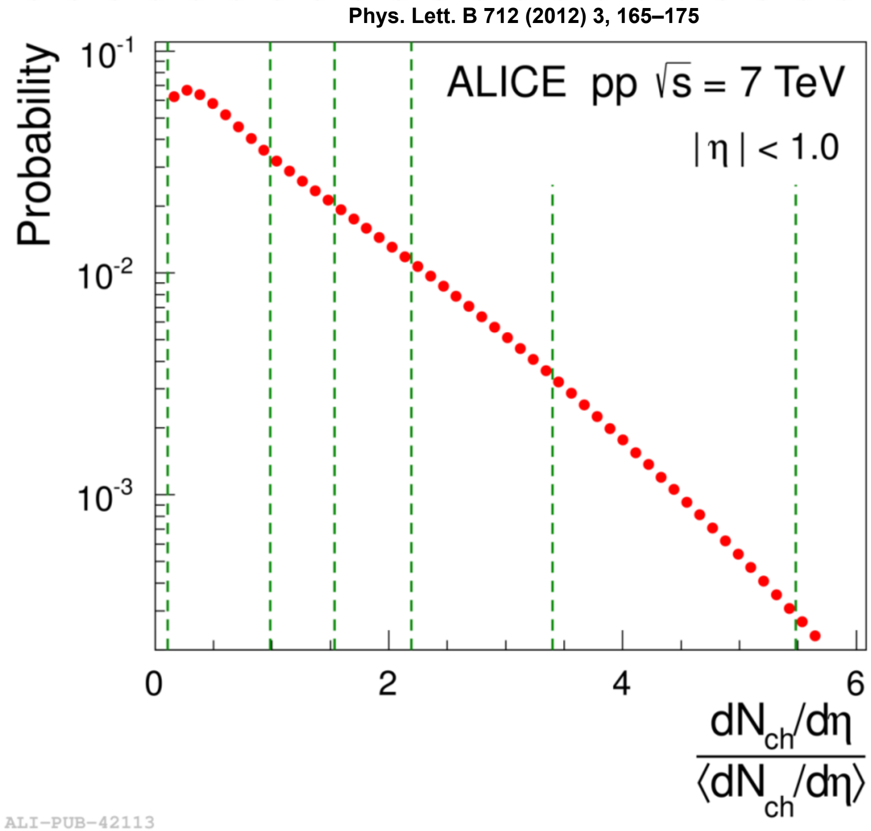
➢ <u>x label</u>

Multiplicity estimator: $N_{\text{tracklets}}$

Tracklets = track segment reconstructed in the SPD pointing to the primary vertex in $|\eta|<1$



$$\frac{dN_{ch}/d\eta}{< dN_{ch}/d\eta >} = \frac{N_{tracklets}}{< N_{tracklets} >}$$



Example for the J/Ψ analysis in pp collisions at $\sqrt{s}$=7 TeV

Charm production as a function of multiplicity

ALICE

- <u>y label</u>

Self-normalized yield in multiplicity intervals relative to multiplicity integrated value

$$\frac{\mathrm{d}N_c/\mathrm{d}y}{<\mathrm{d}N_c/\mathrm{d}y>} = Y^{corr} = \frac{Y^{mult}/(\varepsilon^{mult} \times N^{mult}_{event})}{Y^{tot}/(\varepsilon^{tot} \times N^{tot}_{event} / \varepsilon^{trigger})}$$

c yield/event in a given multiplicity range

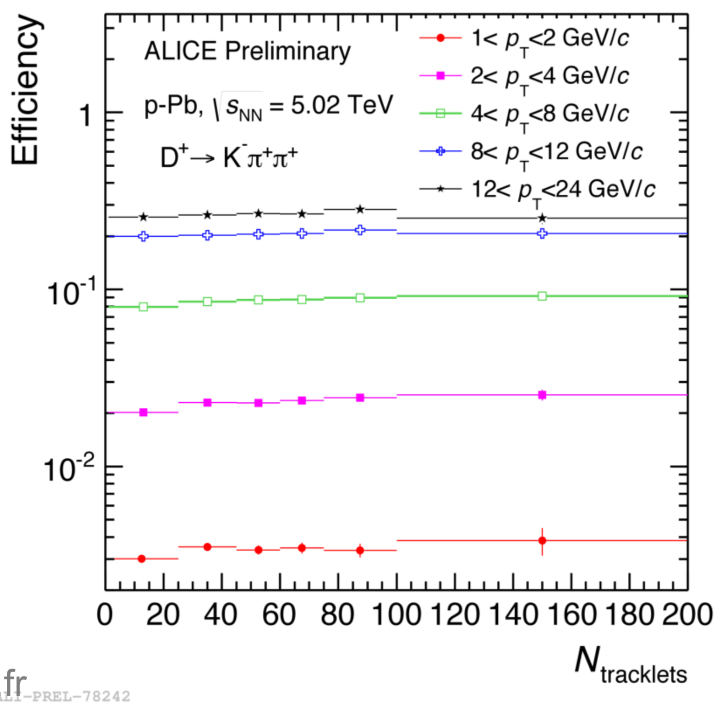
c yield/event integrated in multiplicity

No acceptance correction: cancel in ratio

Trigger efficiency ($\varepsilon^{trigger}$): correct for the fraction of inelastic events not seen by the MB trigger condition

Efficiency correction (ε): example for the D^+, efficiency does not show a strong multiplicity dependence

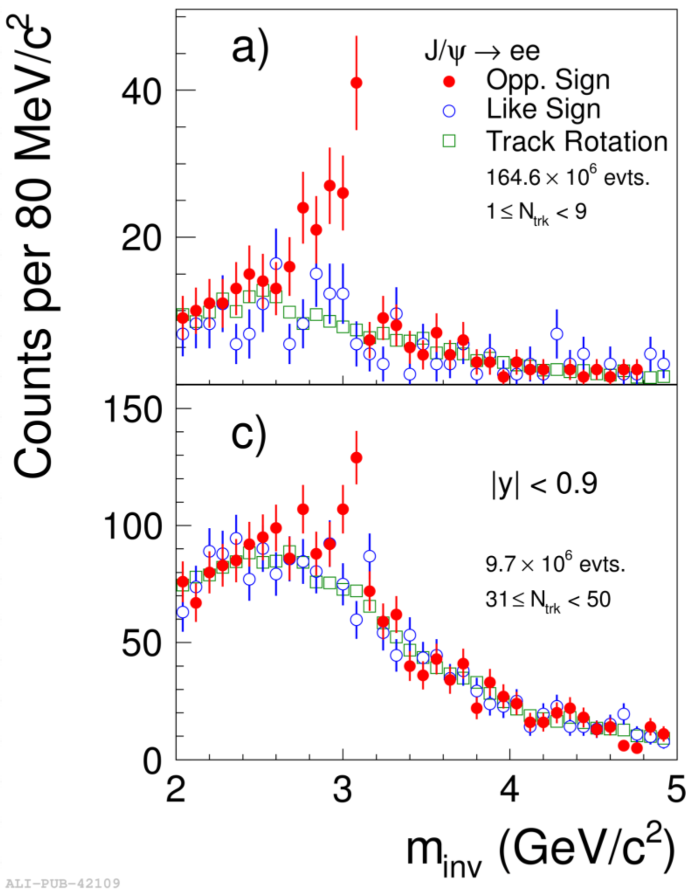
! This generic formula will need adaptation for the various analysis (J/Ψ, D)

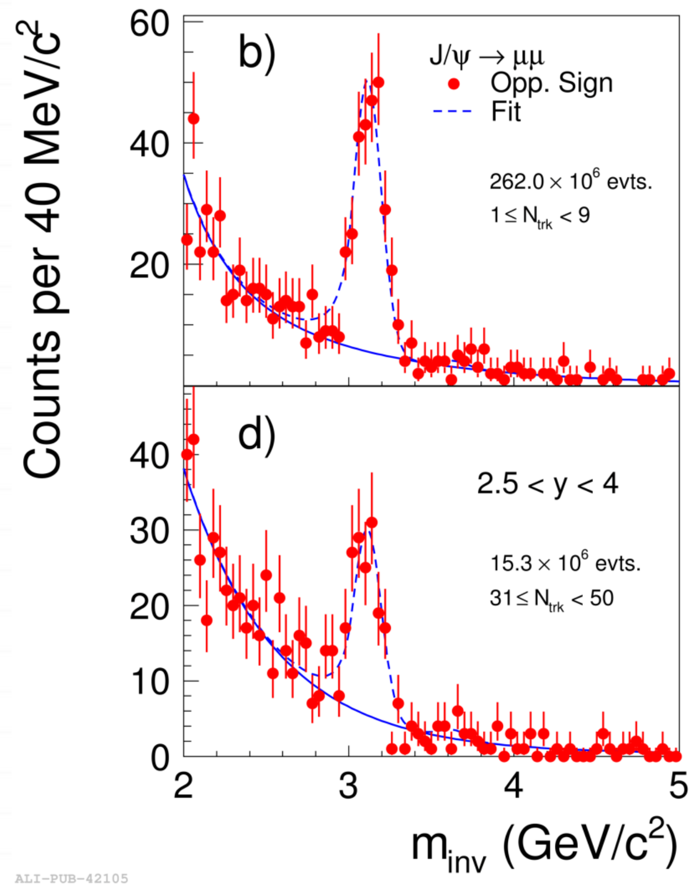


J/Ψ production as a function of multiplicity in pp @ 7 TeV

The electron channel in the central rapidity region (|y| < 0,9)

The muon channel in the forward rapidity region (2,5 < y < 4)





Phys. Lett. B 712 (2012) 3, 165–175

J/Ψ production as a function of multiplicity in pp @ 7 TeV

Approximate linear increase of J/Ψ yield as a function of multiplicity

2 rapidity regions compatible within error bars
(apart from the highest multiplicity bin)

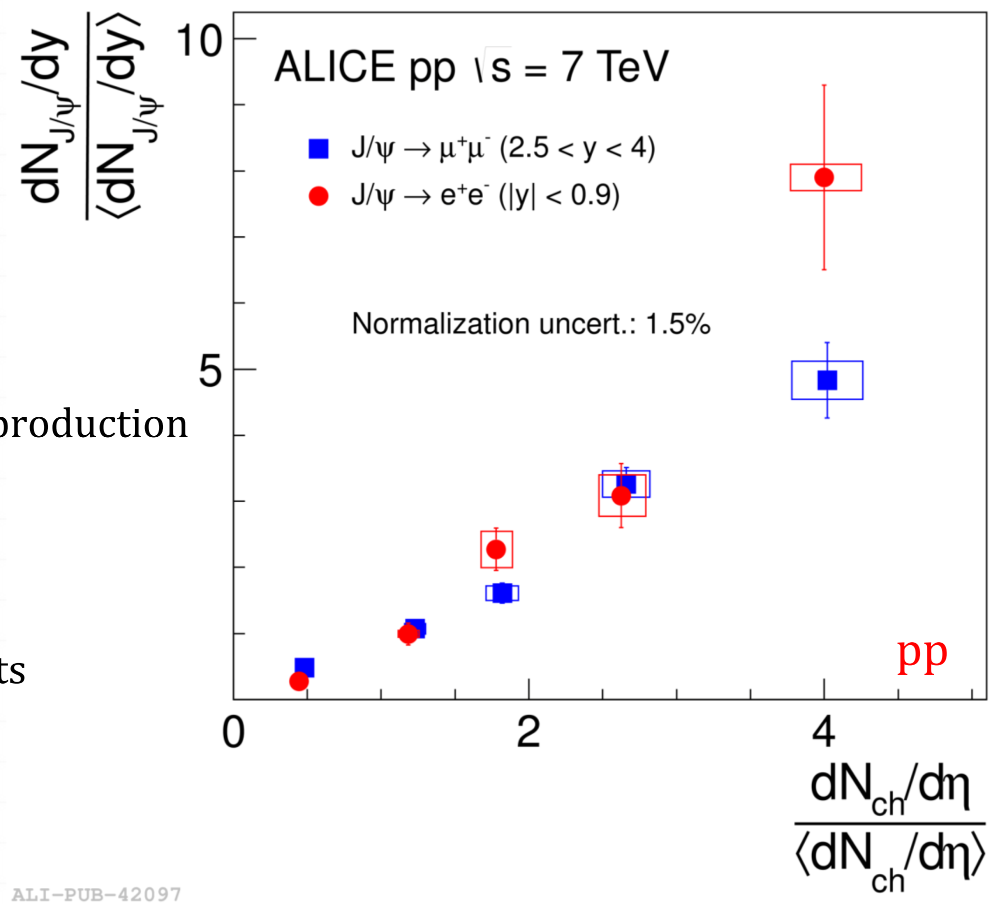
<u>2 possible interpretations:</u>

- Hadronic activity accompanying J/Ψ production
- Multi-parton interaction

<u>But:</u>

Correlation extends over three rapidity units
Correlation extends up to 4 times the mean multiplicity

Phys. Lett. B 712 (2012) 3, 165–175

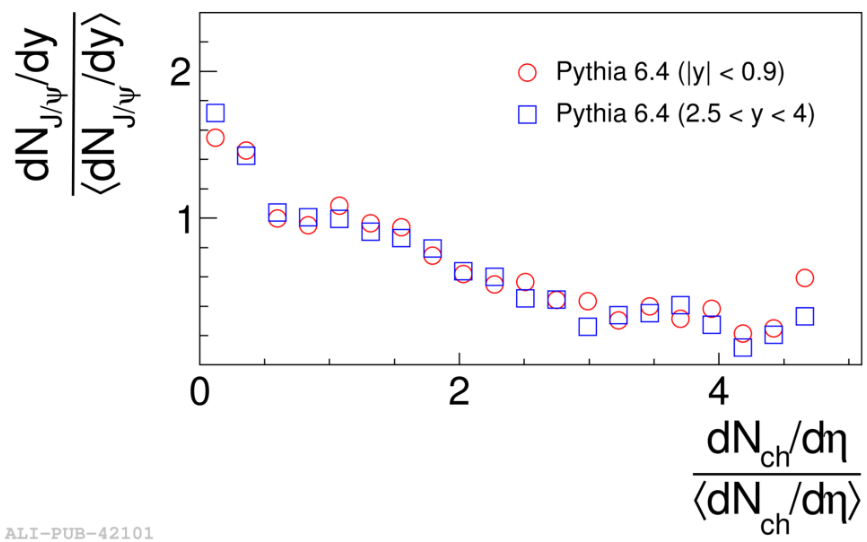


sarah@clermont.in2p3.fr

J/Ψ production as a function of multiplicity in pp @ 7 TeV

ALICE

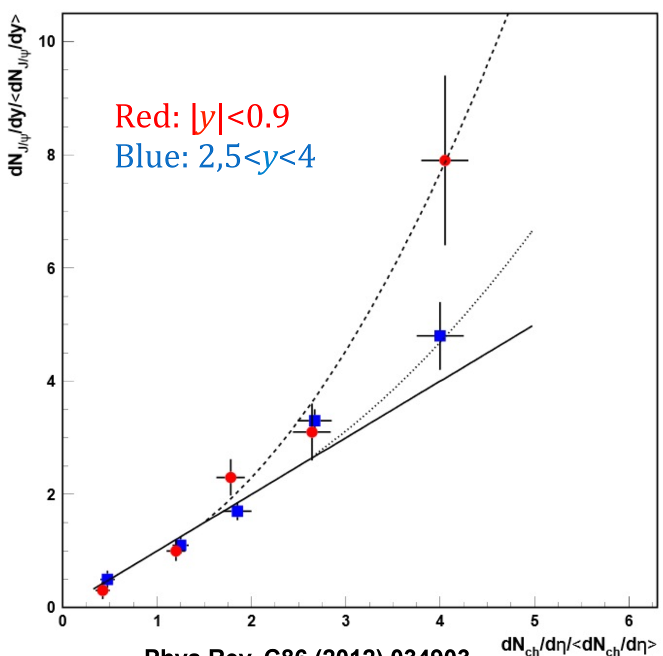
Phys. Lett. B 712 (2012) 3, 165–175



- **Comparison with PYTHIA 6.4**
  - Tune PERUGIA 2011
  - Direct J/Ψ production only

    J/Ψ produced in initial hard interactions

Trend not reproduced by PYTHIA 6.4
MPI without charm in subsequent interactions
MPI ordered in hardness



Phys.Rev. C86 (2012) 034903

- **Comparison with the string percolation model**

Total multiplicity and number of J/Ψ proportional to elementary initial parton-parton interactions (elementary strings)

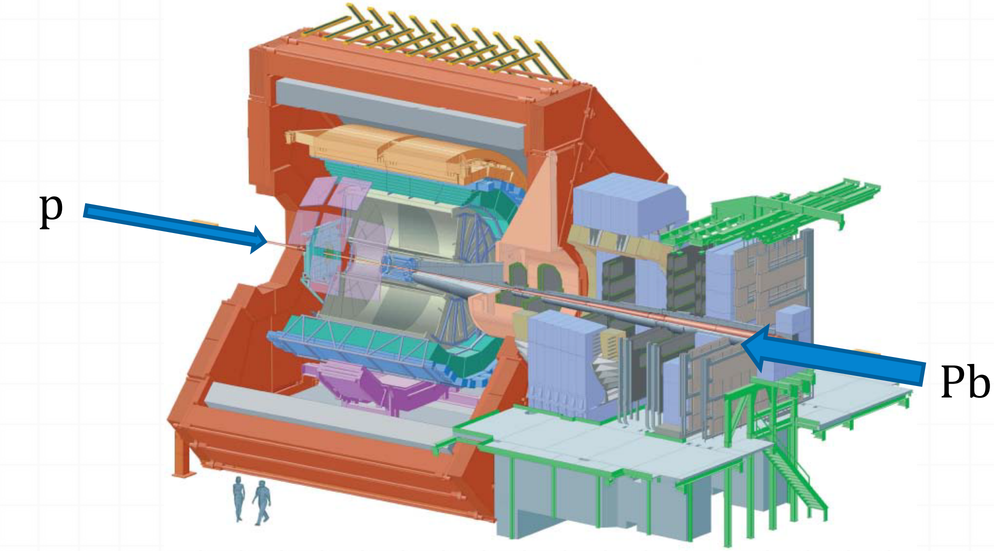
Close to a MPI scenario

Reproduce the trend observed in data
Caveats : post-diction

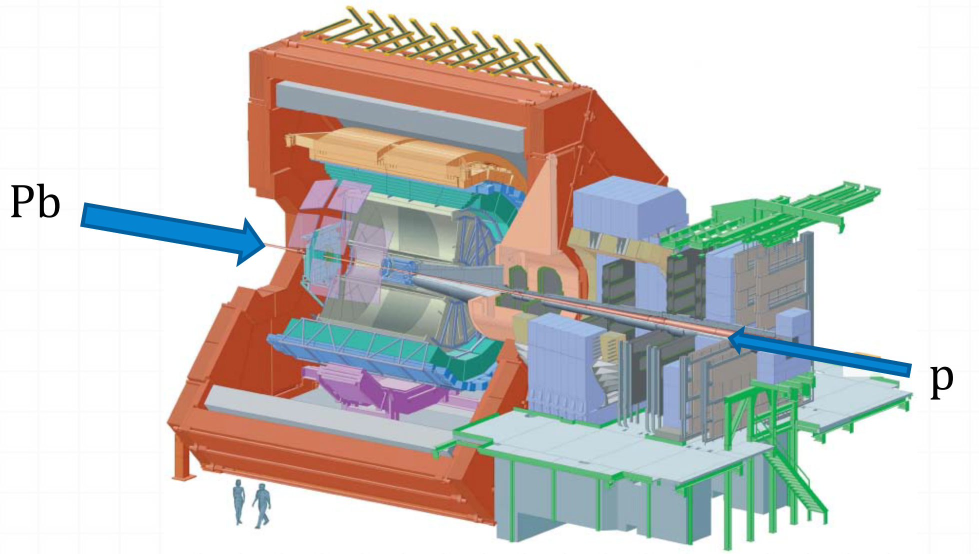
J/Ψ production as a function of multiplicity in p-Pb @ 5,02 TeV

Definition of forward and backward rapidity in p-Pb collisions

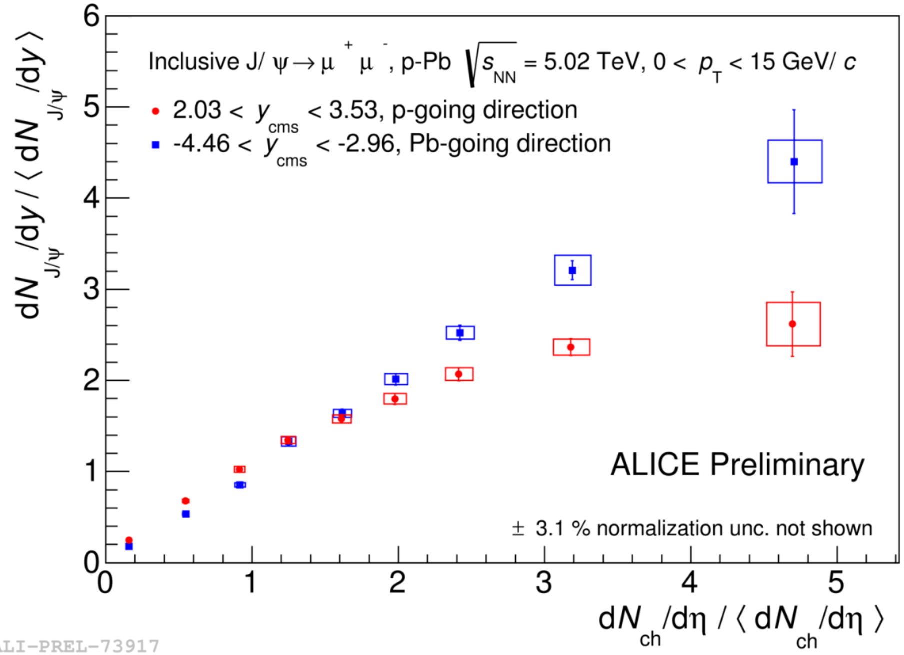
Muon: forward rapidity
p-going direction
$2.03 < y < 3.53$



Muon: backward rapidity
Pb-going direction
$-4.46 < y < -2.96$

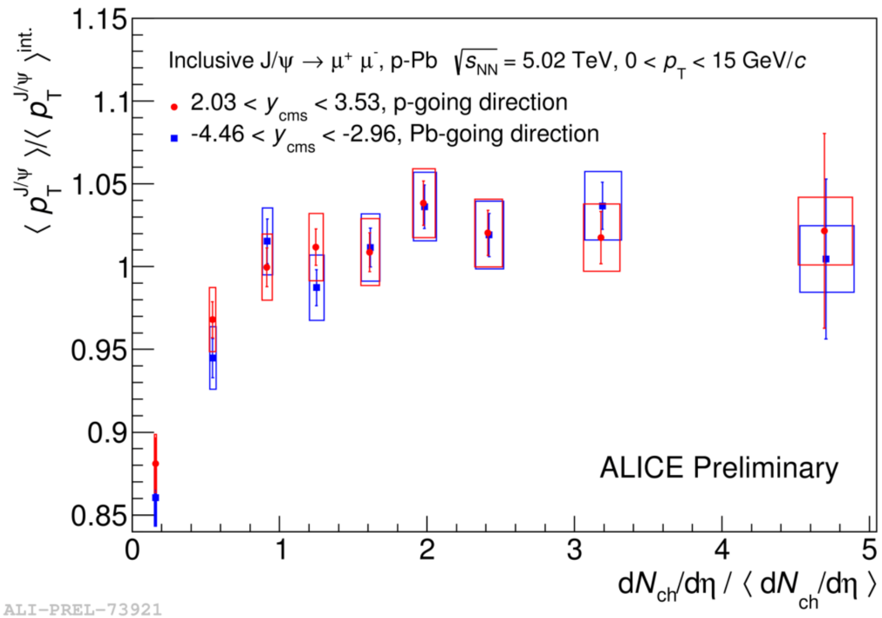


J/Ψ production as a function of multiplicity in p-Pb @ 5,02 TeV



- Strong increase of relative J/Ψ yields at forward and backward rapidity with relative multiplicity
- Similar behavior as in pp collisions
- Deviation at forward rapidity

- Relative J/Ψ $<p_T>$ saturates around $dN_{ch}/d\eta/<dN_{ch}/d\eta>$ ~1,5
- Same behavior observed at forward and backward J/Ψ rapidity

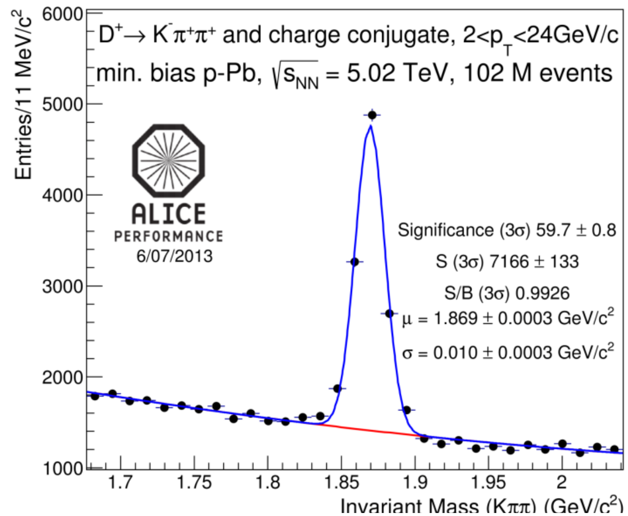


sarah@clermont.in2p3.fr

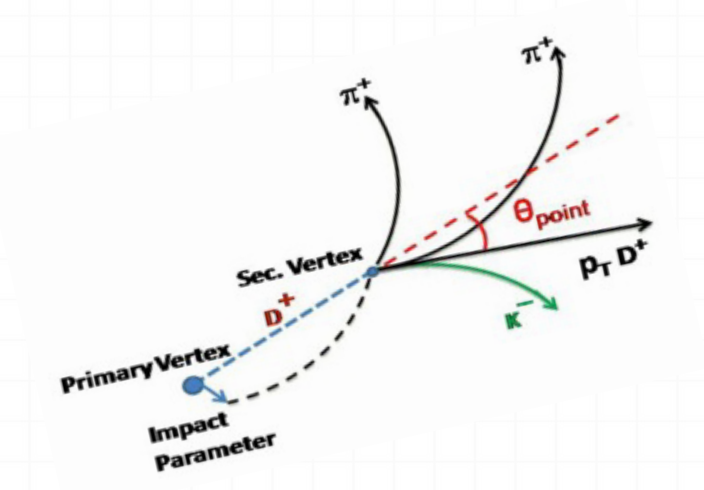
D-meson reconstruction

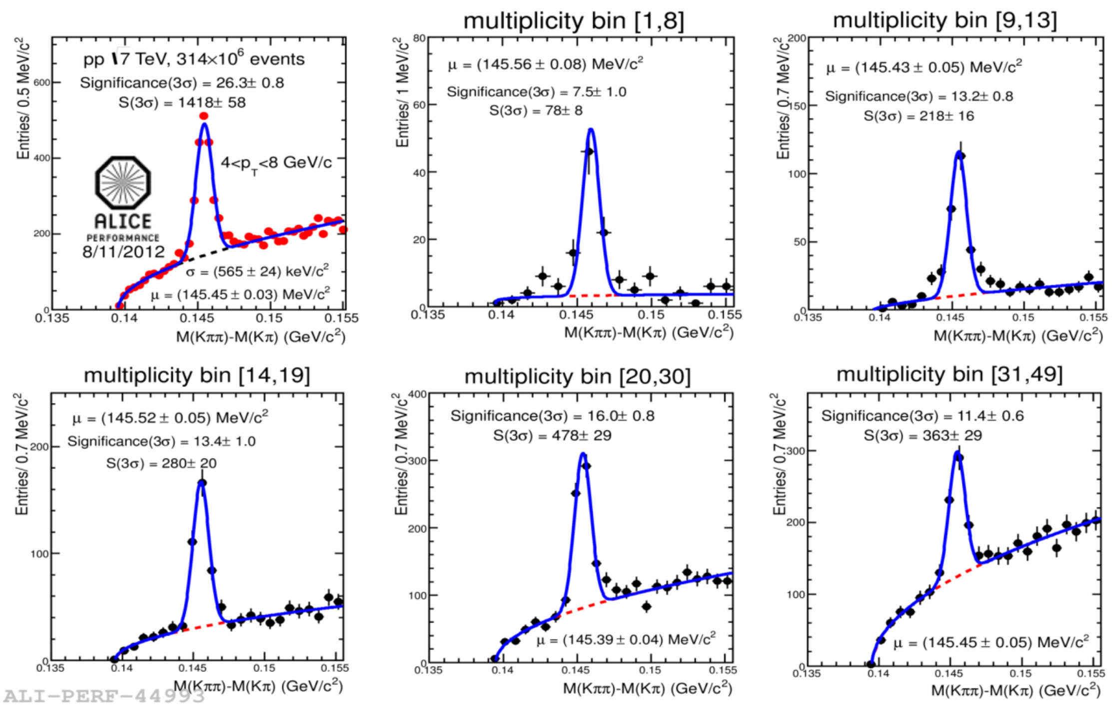
D-mesons reconstructed in ALICE central Barrel

- $D^0 \rightarrow K^- \pi^+$ (BR 3.88%, $c\tau$=123 μm)
- $D^+ \rightarrow K^- \pi^+ \pi^+$ (BR 9.13%, $c\tau$=312 μm)
- $D^{*+} \rightarrow D^0 \pi^+$ (BR 67.7%, strong decay)



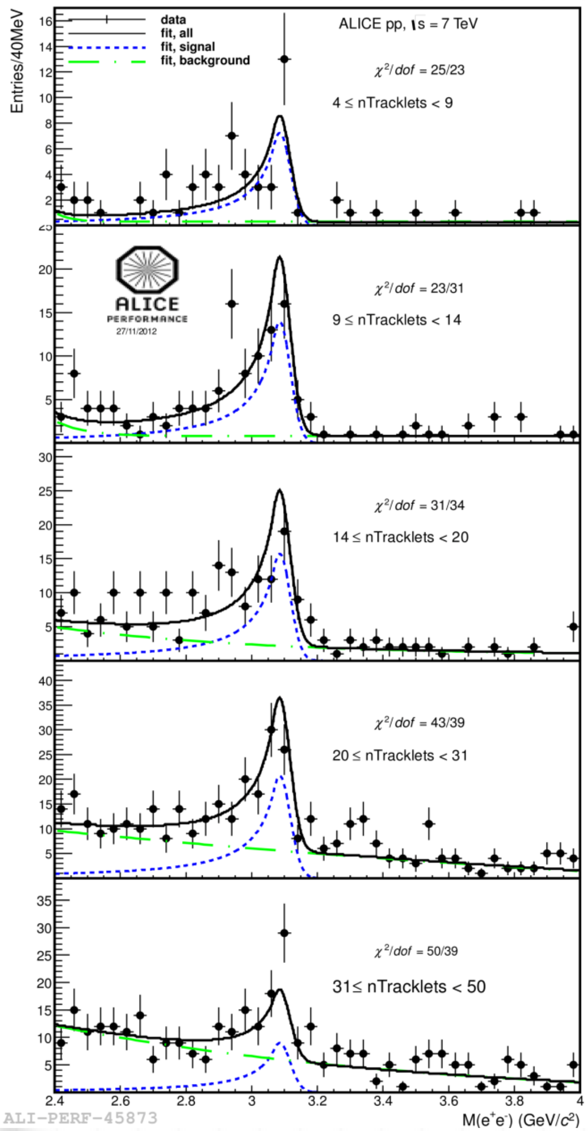
Selection based on decay vertex and PID

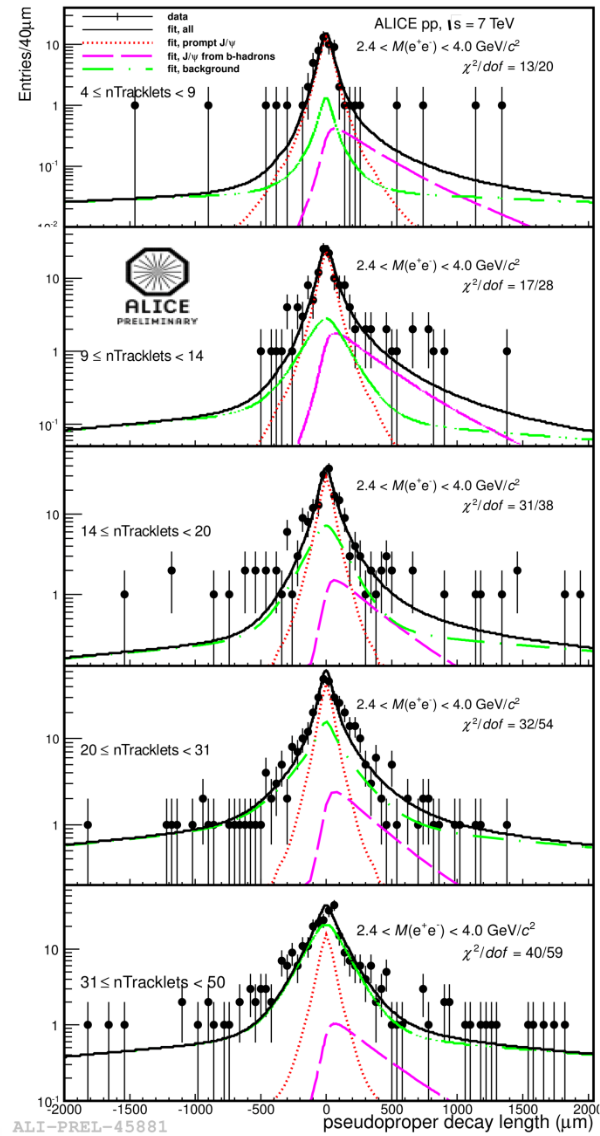




Non-prompt J/Ψ

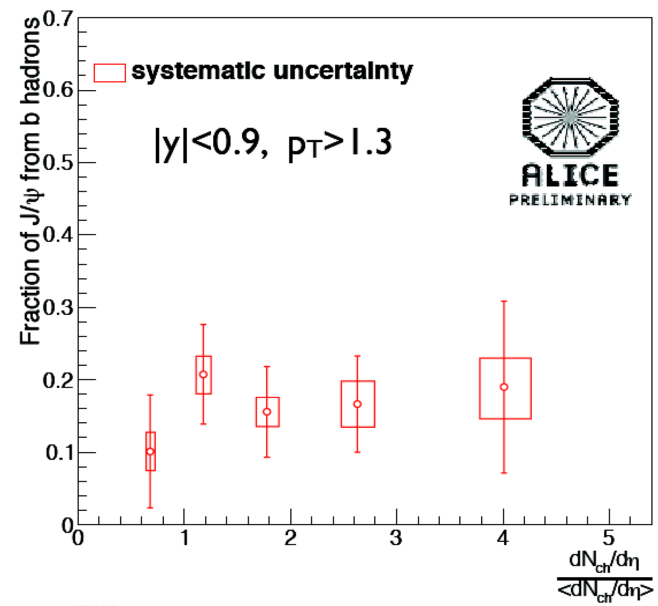
Secondary vertex reconstruction with the SPD
→ allows separation of J/Ψ from B-decays



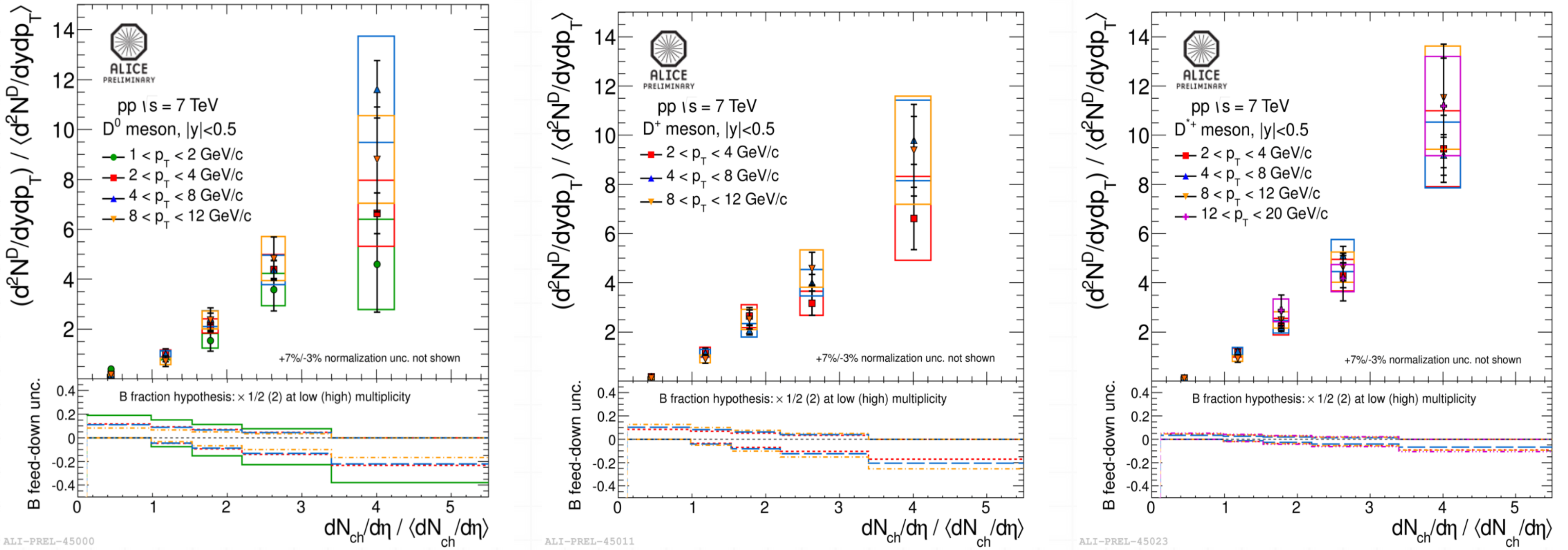


$$f_B = \frac{N_{J/\Psi \leftarrow h_B}}{N_{prompt J/\Psi} + N_{J/\Psi \leftarrow h_B}}$$

Fraction of non-prompt J/ψ measured using the unbinned 2D log-likelihood fit procedure.



D-mesons (D^0, D^+, D^{*+}) in pp collisions at $\sqrt{s}$ = 7 TeV in central rapidity region ($|y|$<0,5)



Approximately linear increase with charged particle multiplicity within uncertainties

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

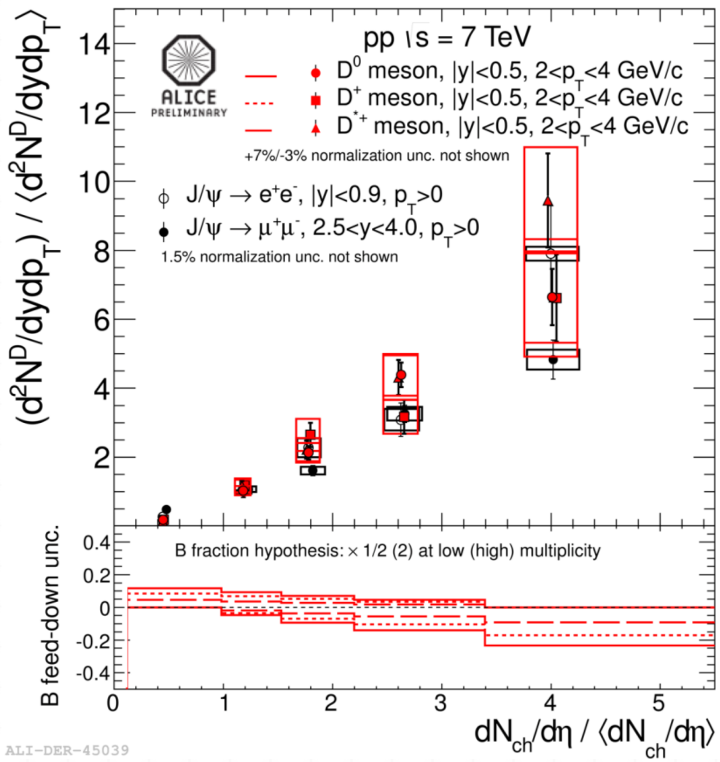
Vertical size of boxes : systematic uncertainties wo feed-down

Horizontal size of boxes : systematic uncertainty on $dN/d\eta/\langle dN/d\eta \rangle$

Bottom panels line: relative feed-down systematic uncertainties

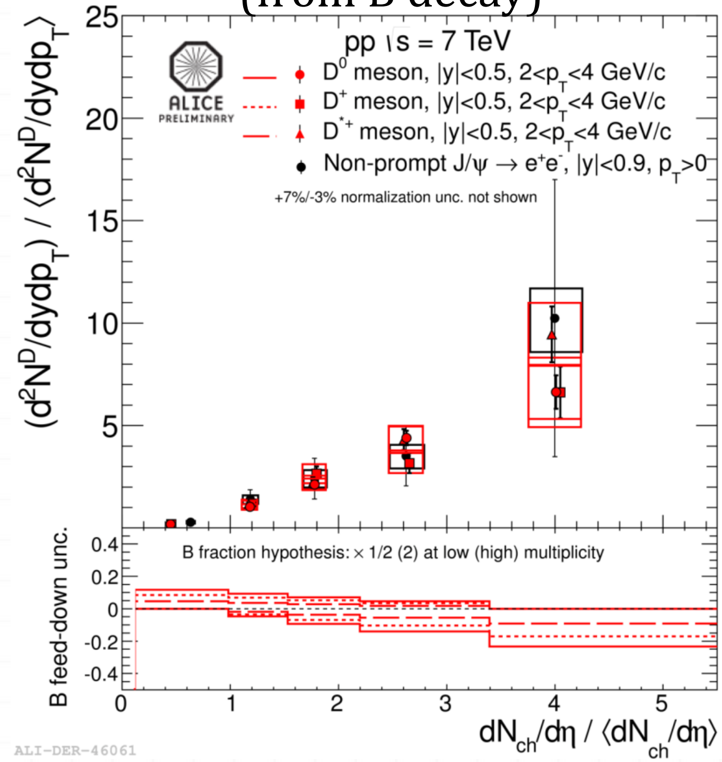
D-mesons (D^0, D^+, D^{*+}) in pp collisions at $\sqrt{s}$ = 7 TeV in central rapidity region ($|y|<0{,}5$)

➢ Comparison 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.

➢ Comparison with non prompt J/Ψ (from B decay)



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

D-mesons in pp collisions at $\sqrt{s}$ = 7 TeV

ALICE

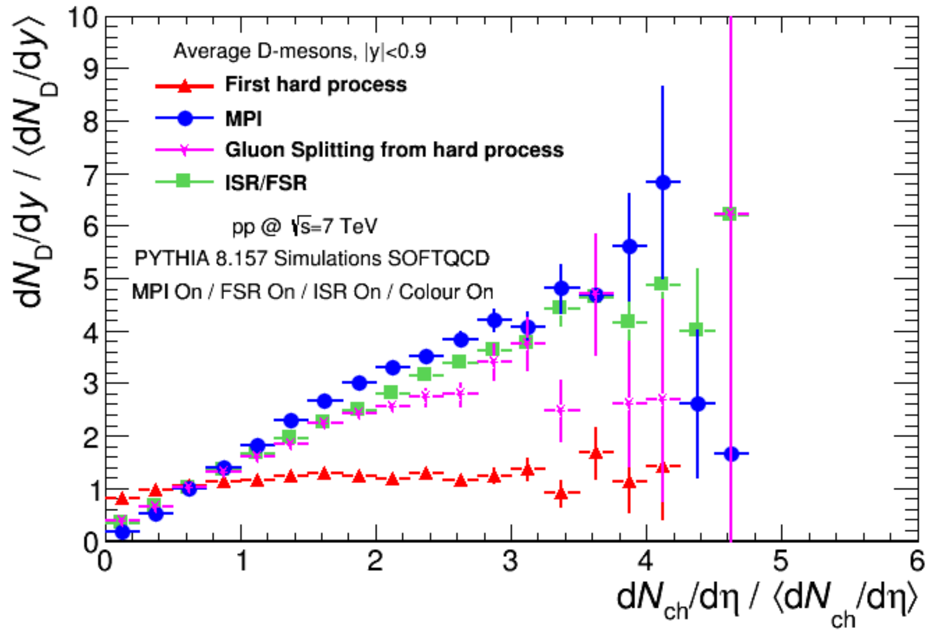
➢ Comparison with PYTHIA 8

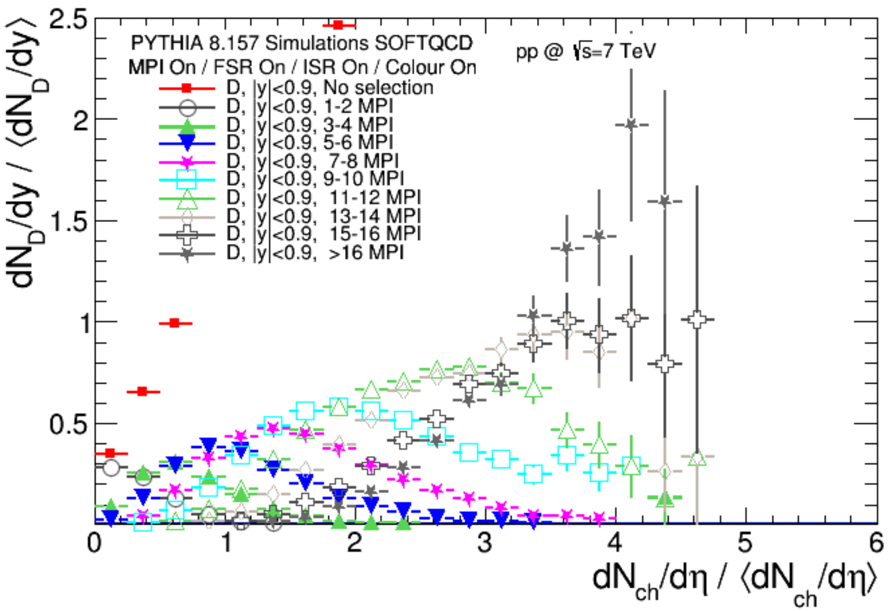
Improvement of MPI scenario
(charm in subsequent MPI)

Various contributions to the total D-meson production

- First hard process: flat
- MPI, ISR/FSR, gluon splitting increase trend with increasing multiplicity

In question: relative amount of each contributions
Major contribution (~60%) from ISR/FSR





Slices with the total number of MPI in the event, grouped by 2

Red (no selection) is the sum of all contribution

Each slices has almost the same weight in the total contribution

Zoom on the different contribution

What we expect from MPI: addition of MPI built the multiplicity

nont.in2p3.fr

D-mesons in pp collisions at $\sqrt{s}$ = 7 TeV

- Comparison with EPOS

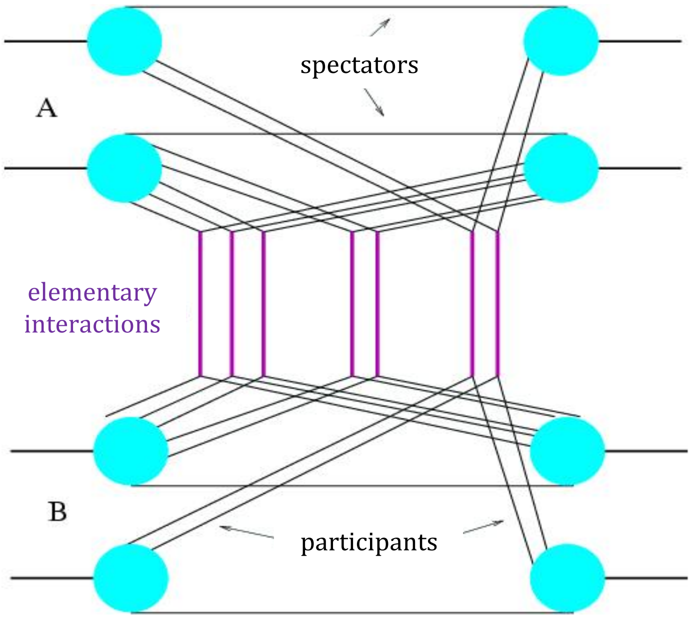
Initial conditions:
marriage of pQCD+ Gribov-Regge Theory + Energy sharing

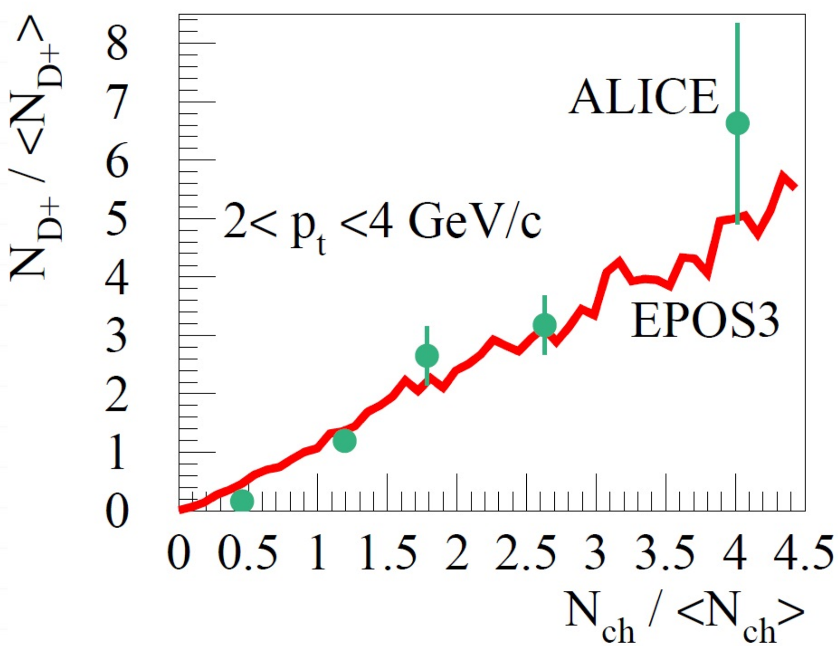
Same framework for pp p-A and A-A collisions
Saturation scale

In EPOS Gribov-Regge multiple scattering gives naturally

$$N_{hard} \propto N_{charged} \propto N_{elementary\ interactions}$$

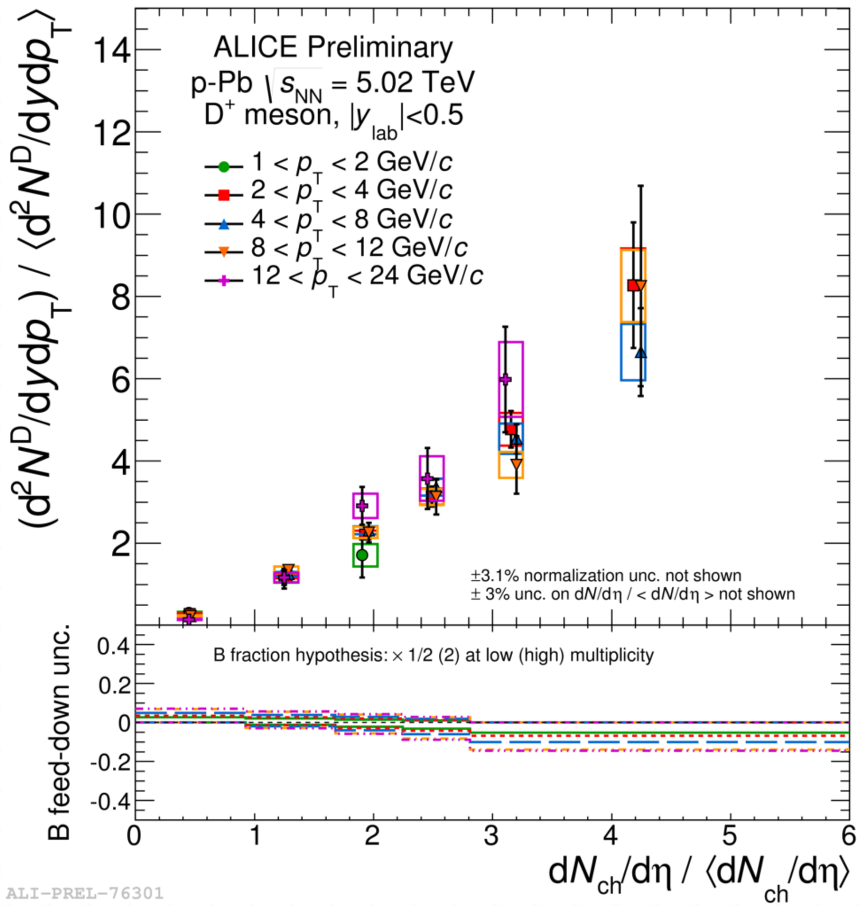
N_{hard} = multiplicity of particles produced in hard processes

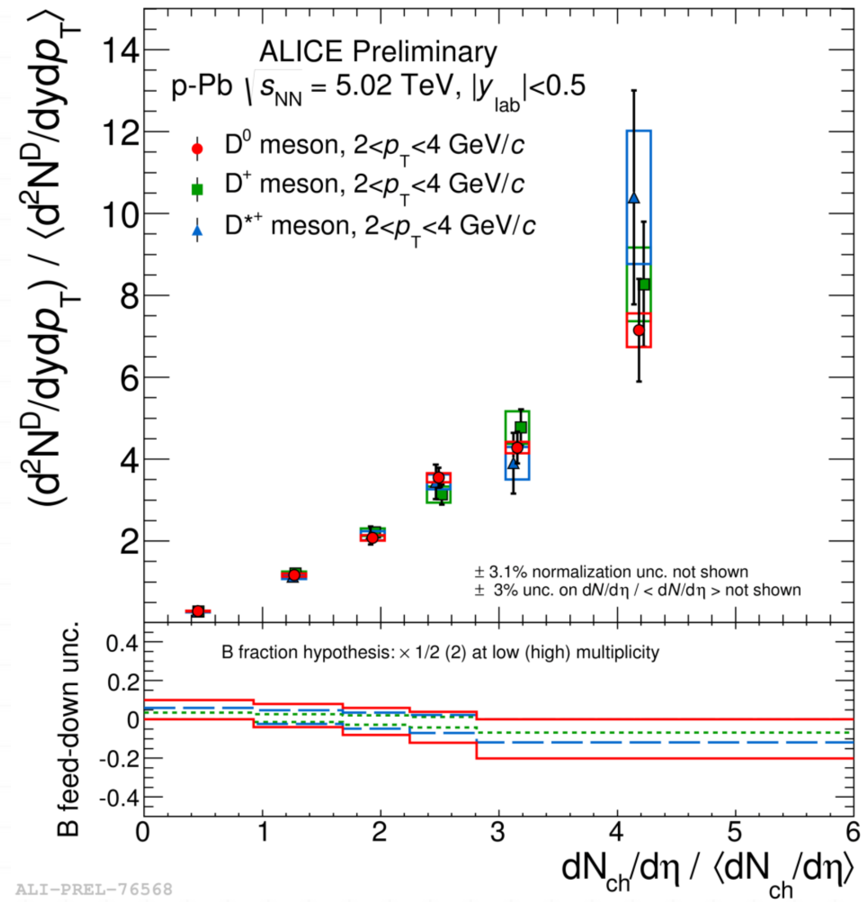




EPOS 3 prediction for D^+ in red
Quark matter 2014

D-mesons (D^0, D^+, D^{*+}) in p-Pb collisions at $\sqrt{s}$ = 5,02 TeV in central rapidity region ($|y_{lab}|$<0,5)

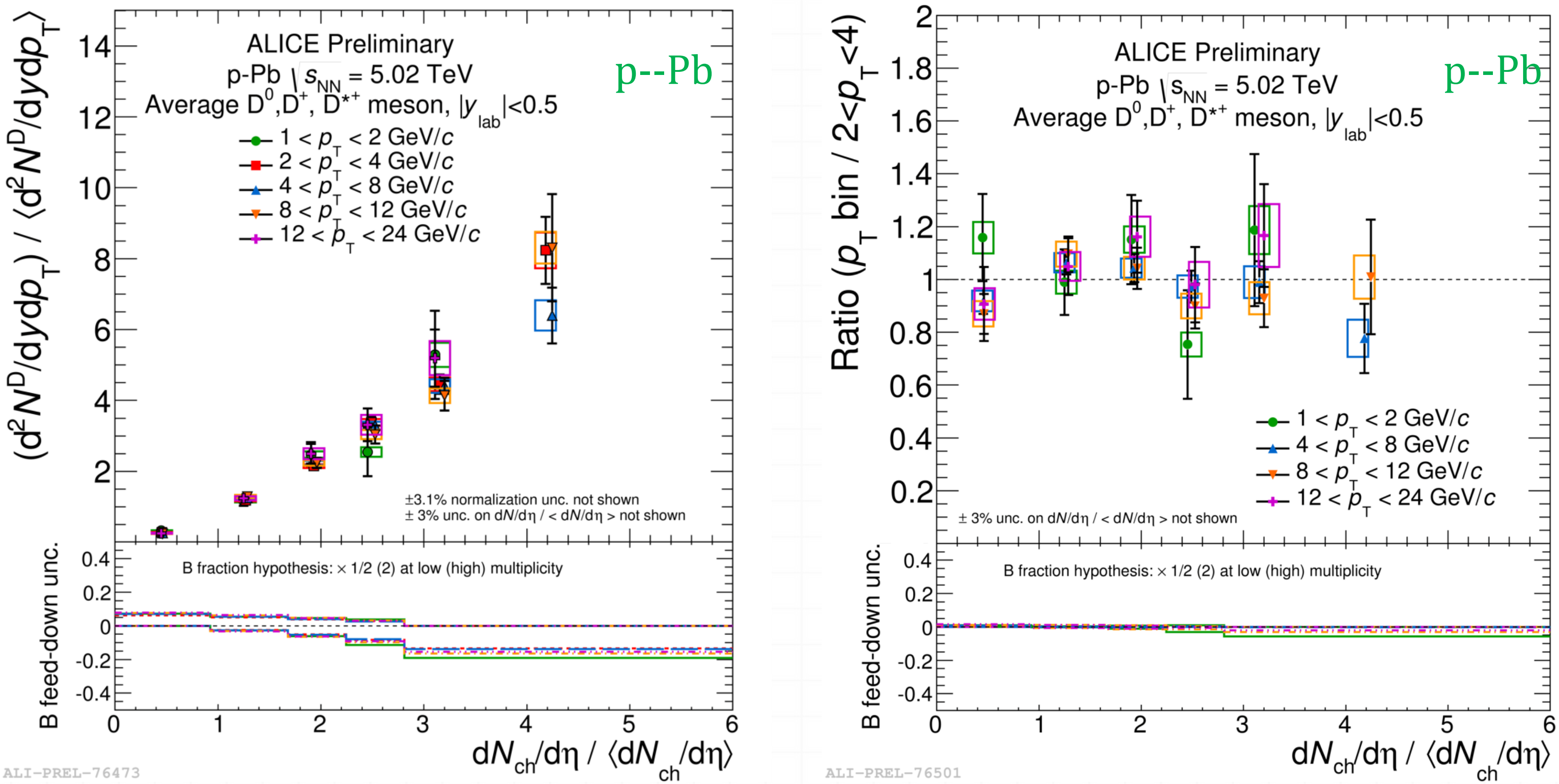




- D^+-meson yields show an increase with charged-particle multiplicity compatible within p_T bins
- D^0, D^+ and D^{*+}-meson yields show an increase with charged-particle multiplicity
- D^0, D^+ and D^{*+}-meson yields are consistent with each other within uncertainties

sarah@clermont.in2p3.fr

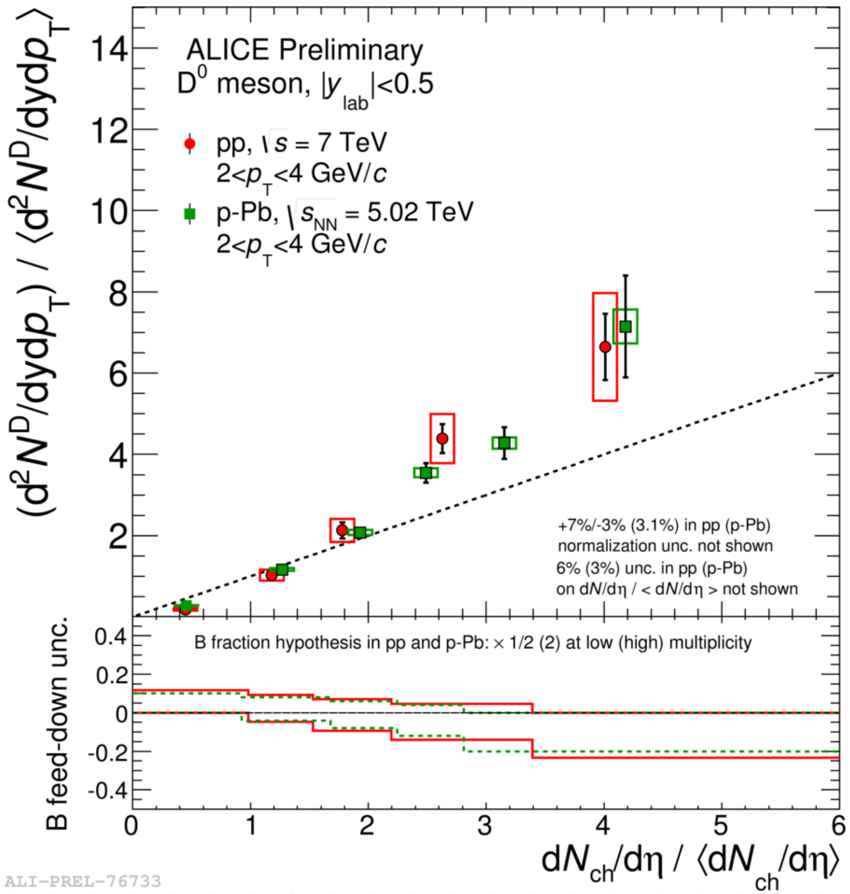
D-mesons (D^0, D^+, D^{*+}) in p-Pb collisions at $\sqrt{s}$ = 5,02 TeV in central rapidity region ($|y_{lab}|<0,5$)

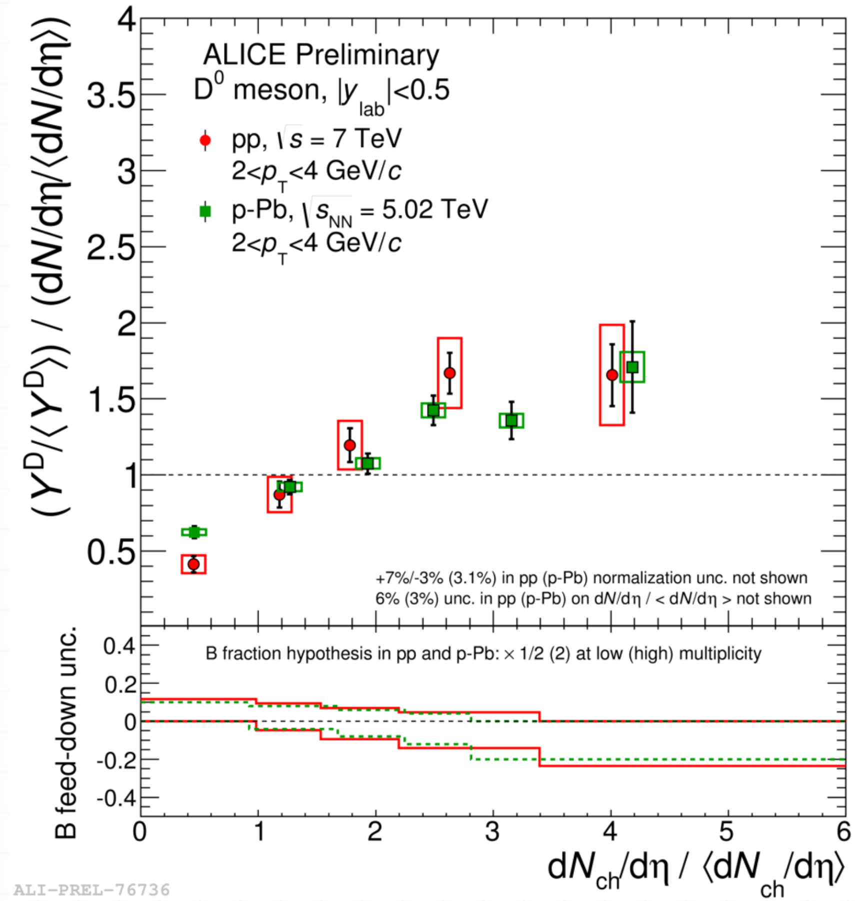


- Average D-meson yields show an increase with charged-particle multiplicity
- Results in different p_T bin are in agreement within uncertainties

sarah@clermont.in2p3.fr

Comparing D-mesons in pp and p-Pb collisions





- pp and p--Pb collisions present similar trends
- Highest multiplicity events in pp collisions mainly due to MPI's
- Highest multiplicity events in p--Pb collisions also originates from higher number of binary collisions

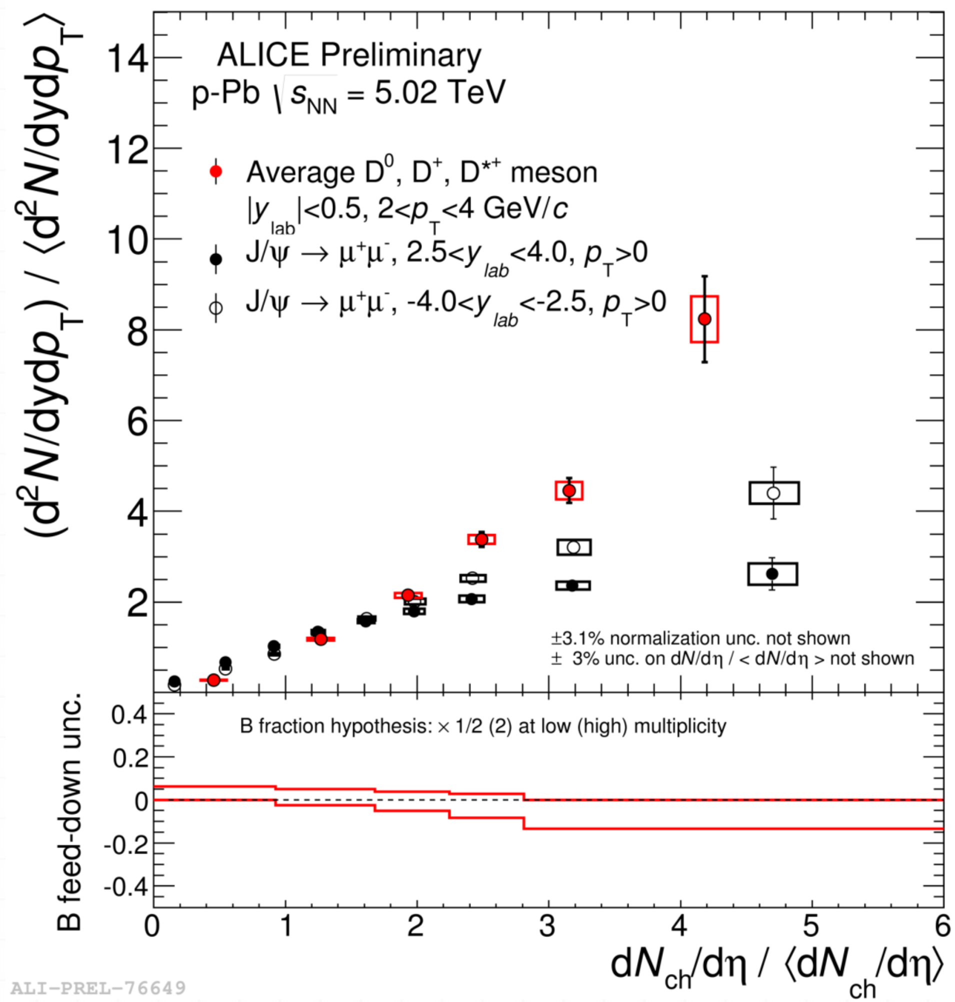
Comparing D-mesons and J/Ψ in p-Pb collisions

- In p--Pb collisions D and J/Ψ show an increasing trend with multiplicity
- Deviation at highest multiplicity

But:

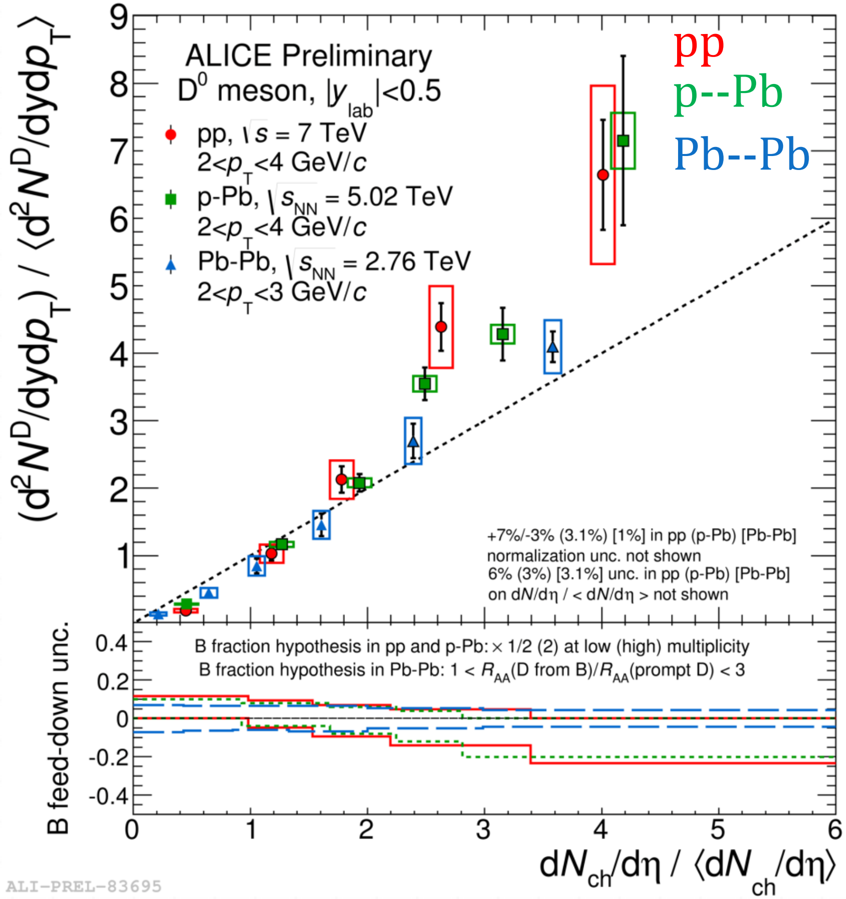
D-mesons and J/Ψ are measured in different p_T and rapidity regions

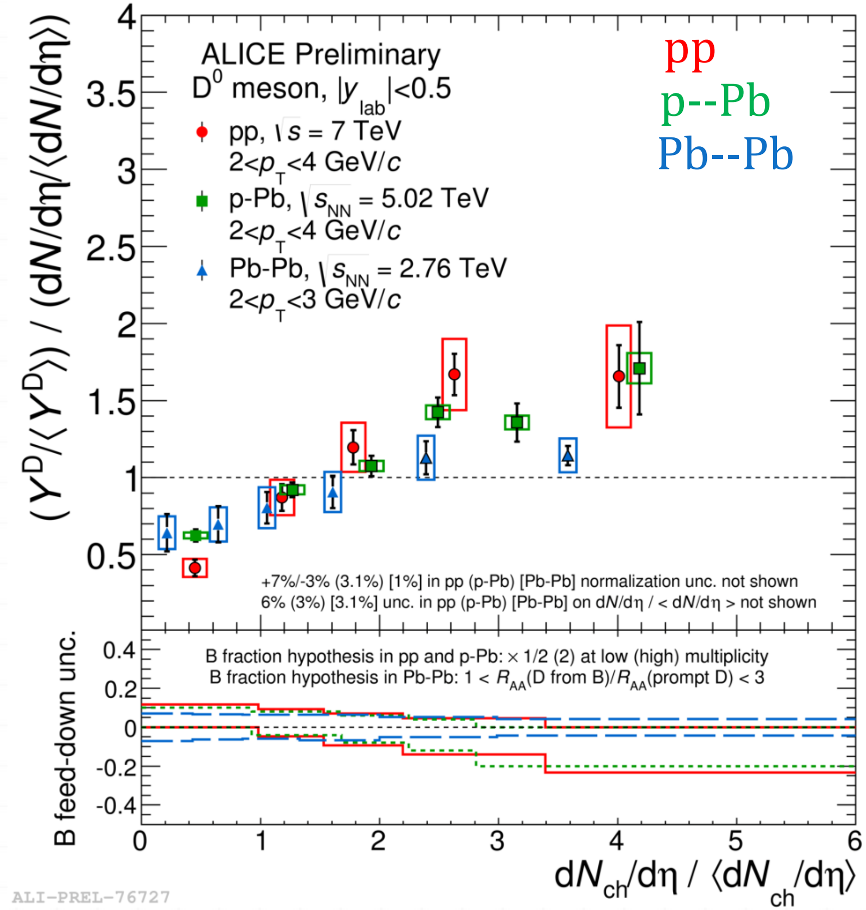
Leading to different cold nuclear matter (CNM) effects and different Bjorken-x probed values



sarah@clermont.in2p3.fr

Comparing D-mesons in pp, p-Pb and Pb-Pb collisions

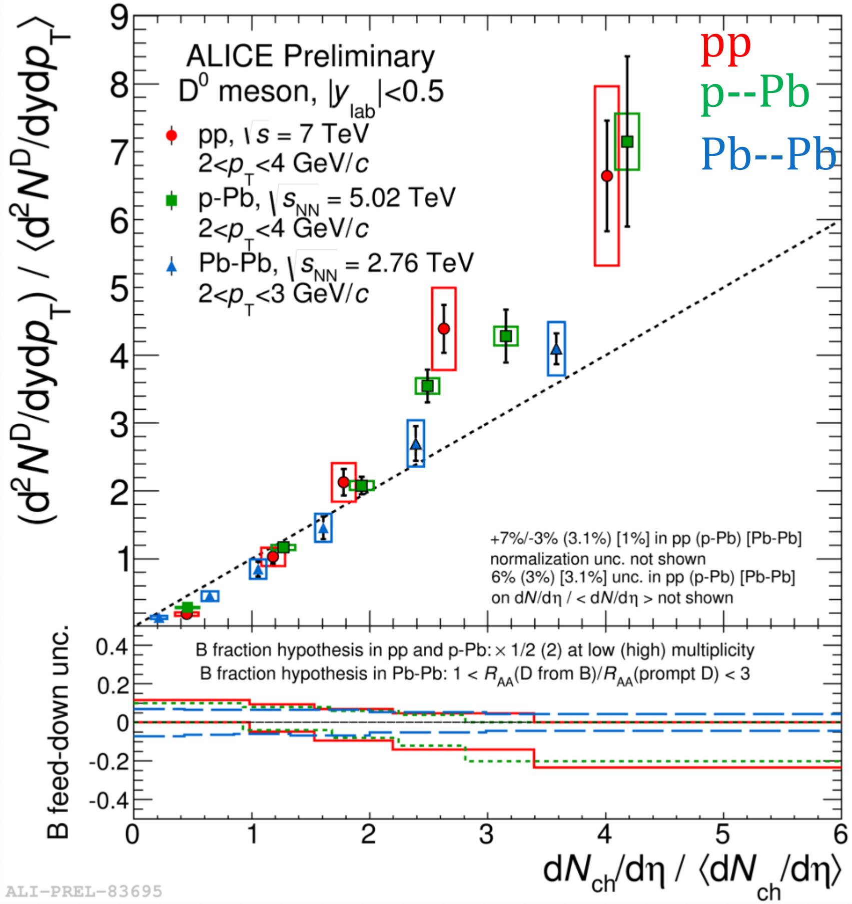


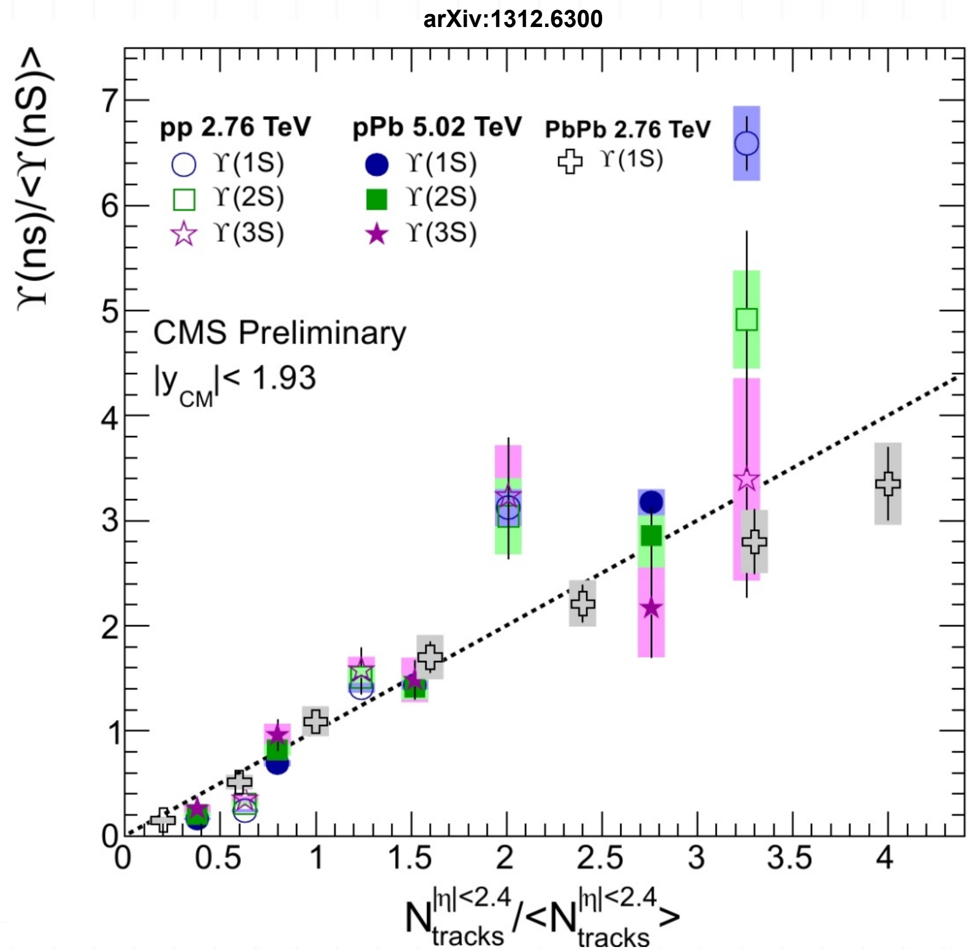


- At low multiplicity, similar trend in the three systems
- In Pb--Pb collisions, reflects evolution of N_{coll} with centrality

sarah@clermont.in2p3.fr

Comparing with ϒ in pp, p-Pb and Pb-Pb collisions





- ϒ measurement from CMS (**JHEP 04 (2014) 103**) shows increasing trend in pp, p-Pb and Pb-Pb collisions
- Increase up to 8 for average D-mesons and J/Ψ in central rapidity region, comparable to the magnitude of ϒ(1s) measured by CMS

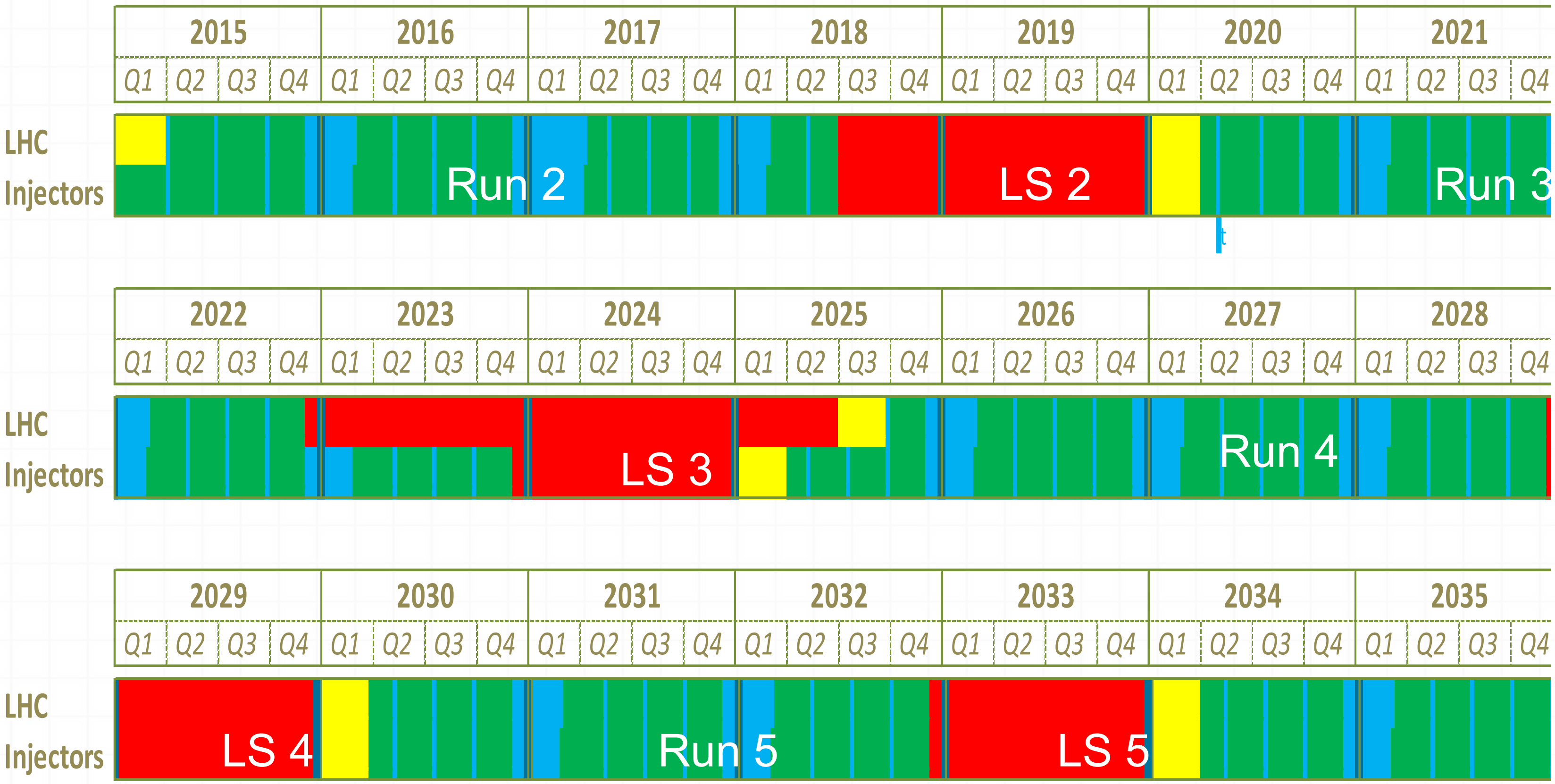
sarah@clermont.in2p3.fr

ALICE

LHC schedule after LS1

approved by CERN management, LHC experiments spokespersons and technical coordinators Monday 2nd December 2013

LS2	starting in 2018 (July)	=> 18 months + 3months BC (Beam Commissioning)
LS3	LHC: starting in 2023	=> 30 months + 3 BC
	injectors: in 2024	=> 13 months + 3 BC



sarah@clermont.in2p3.fr

ALICE running conditions during RUN II (2015-2017)

Year	System	E [TeV]	Lumi [$cm^{-2}s^{-1}$]	Rate [kHz]	Level	Weeks	Trigger
2015	p-p	13	$1\text{-}2 \cdot 10^{29}$	10-20	YES	24	MB
	Pb-Pb	5.1	10^{27}	8	YES	4	
2016	p-p	13	$0.5\text{-}1 \cdot 10^{31}$	500	YES	24	RARE
	Pb-Pb	5.1	10^{27}	8	YES	4	
2017	p-p	13	$0.5\text{-}1 \cdot 10^{31}$	500	YES	24	RARE
	p-Pb	8.2(?)	$0.5\text{-}1 \cdot 10^{28}$	10-20	YES	2	MB
	p-Pb	8.2(?)	10^{29}	200	YES	2	RARE

Values to be compared to:

- $\mathcal{L} = 4.6\ 10^{26}\ cm^{-2}s^{-1}$ in Pb-Pb collisions 2011 (2.76 TeV)
- $\mathcal{L} = 2\ 10^{31}\ cm^{-2}s^{-1}$ in pp collisions 2012 (8 TeV)
- $\mathcal{L} = 10^{29}\ cm^{-2}s^{-1}$ in p-Pb/Pb-p collisions 2013 (5.02 TeV)

Looking at the future

How to improve our understanding of proton-proton collisions and multi-parton interactions?

➢ More exclusive measurements and higher multiplicities

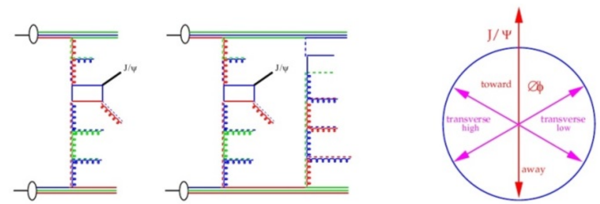
- ❑ More particles vs. mult (Ψ', isolated γ and jets)
- ❑ p_T differential study (started with D-mesons)
- ❑ Higher multiplicities and energies in pp (RUN 2 @ 13 TeV)
- ❑ Higher multiplicities and energies in heavier systems (p--Pb and Pb--Pb) (RUN 2 ~ 8 and 5 TeV)
- ❑ More on correlations and hadronic activity around heavy-flavor

- ❑ Underlying Event (UE) event study with charm as trigger particle, "à la Rick Field"

Already discussed by F. Hautmann @MPI2011

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



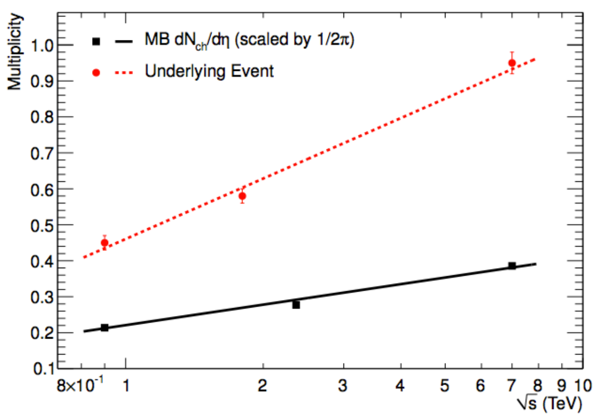
▷ See also: J/ψ vs. charged particle multiplicity [Portebeuf & Granier, arXiv:1012.0719]
▷ J/ψ pairs as a probe of DPI [Kom, Kulesza & Stirling, arXiv:1105.4186] [LHCb Coll., LHCb-Conf-2011-009]

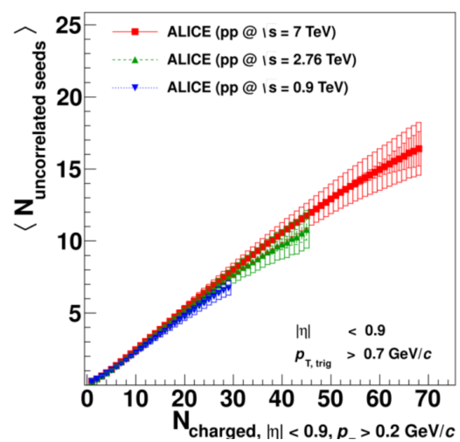
All ideas are welcome!

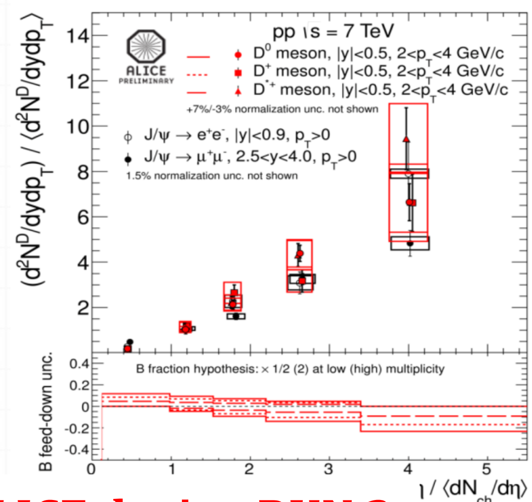
sarah@clermont.in2p3.fr

Conclusions

- ✓ LHC made us enter a new era for the understanding of proton-proton collisions and multi-parton interactions
- ✓ The ALICE experiment allows us to study MPI (3 related published papers and several analysis ongoing)
- ✓ Underlying event measurements
  - ➢ Toward and Away region dominated by jet fragmentation (number density and summed p_T)
  - ➢ Transverse region dominated by UE activity, low-pT increase due to MPI, saturation independent of hard scale
- ✓ Multiplicity dependence of two-particle azimuthal correlations
  - ➢ $\langle N_{\text{uncorrelated seeds}} \rangle$ can probe number of MPI
  - ➢ PYTHIA Perugia 2011 gives the best description of ALICE results
  - ➢ At high multiplicities deviation from linear scaling
  - ➢ Similar behavior of $\langle N_{\text{uncorrelated seeds}} \rangle$ in p-Pb collisions (no deviation from linear)
- ✓ Charm production as a function of multiplicity
  - ➢ J/Ψ, D-mesons and non-prompt J/Ψ self-normalized yield show an increasing trend with increasing charged-particle multiplicity
  - ➢ Suggest presence of MPIs at high multiplicities
  - ➢ Trends compatible in pp and p-Pb collisions



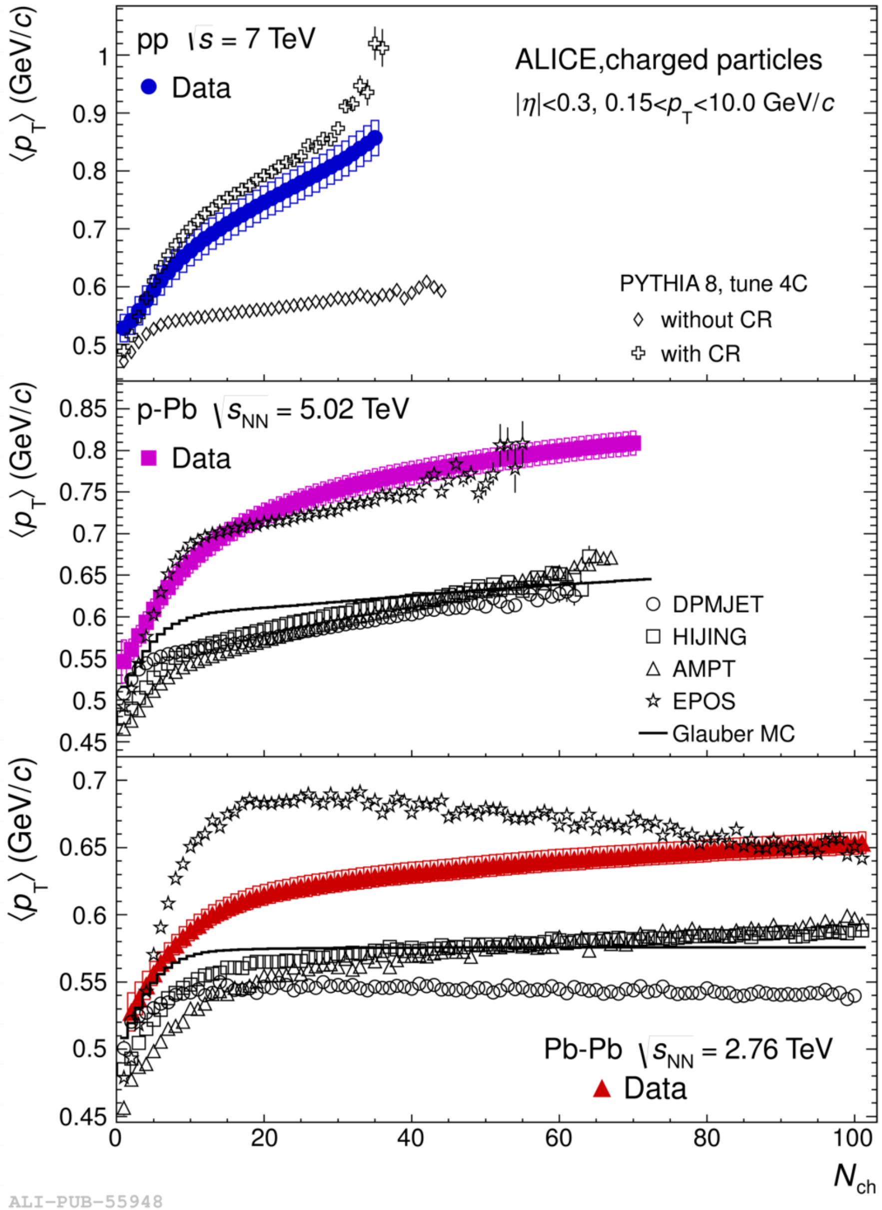




A bright future for the understanding of MPI with ALICE during RUN 2

Back-Up

$<p_{T}>$ vs. N_{ch}



Phys. Lett. B 727 (2013) 371

sarah@clermont.in2p3.fr

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

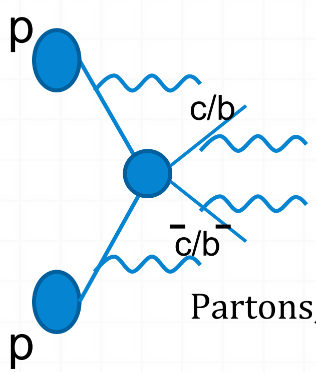
- The hard part should contain heavy quarks: PYTHIA, Cascade.

- 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

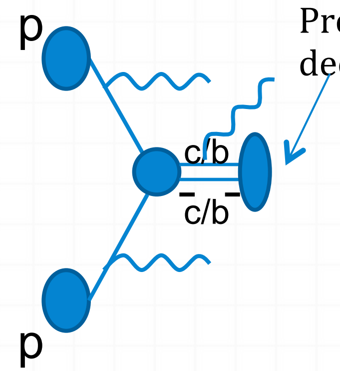
1) Open heavy-flavour production



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

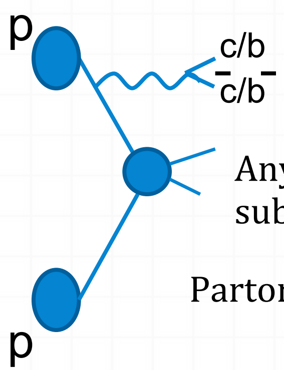
Same production mechanisms

Complement the contribution from first hard sub-process

❖ Beam remnant treatment

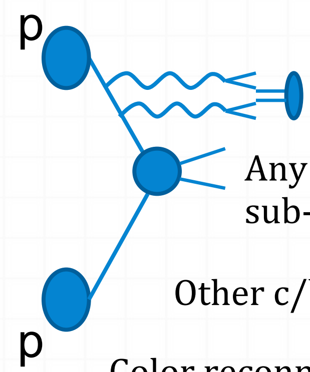
How to produce heavy states in Pythia8 ?

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



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

Partons, connected to strings



cc̄ cluster decay into J/Ψ

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

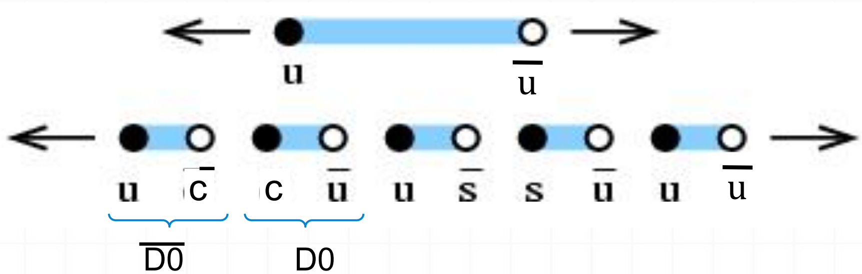
Other c/b connected to strings

Color reconnection make this contribution in PYTHIA6.4

In PYTHIA8 : cc̄->J/Ψ, with c and c̄ originating from various sources, no explicit cluster state

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

❖ String fragmentation



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

cc̄ pair production suppressed as compared to u, d ,s, but available

Higher states not available