QCD with ALICE & LHCb

Particle ID, low pile-up, complementary geometries, …

Paolo Bartalini
(Central China Normal University)
on behalf of ALICE and LHCb

What is hot (outline)

- Multiplicity dependent results
  - Particle yields, Correlations, jet and event shapes, …
- Heavy Flavors Production
  - Differential cross sections, Double Parton Scattering, particle ID in jets, Central Exclusive Production, …

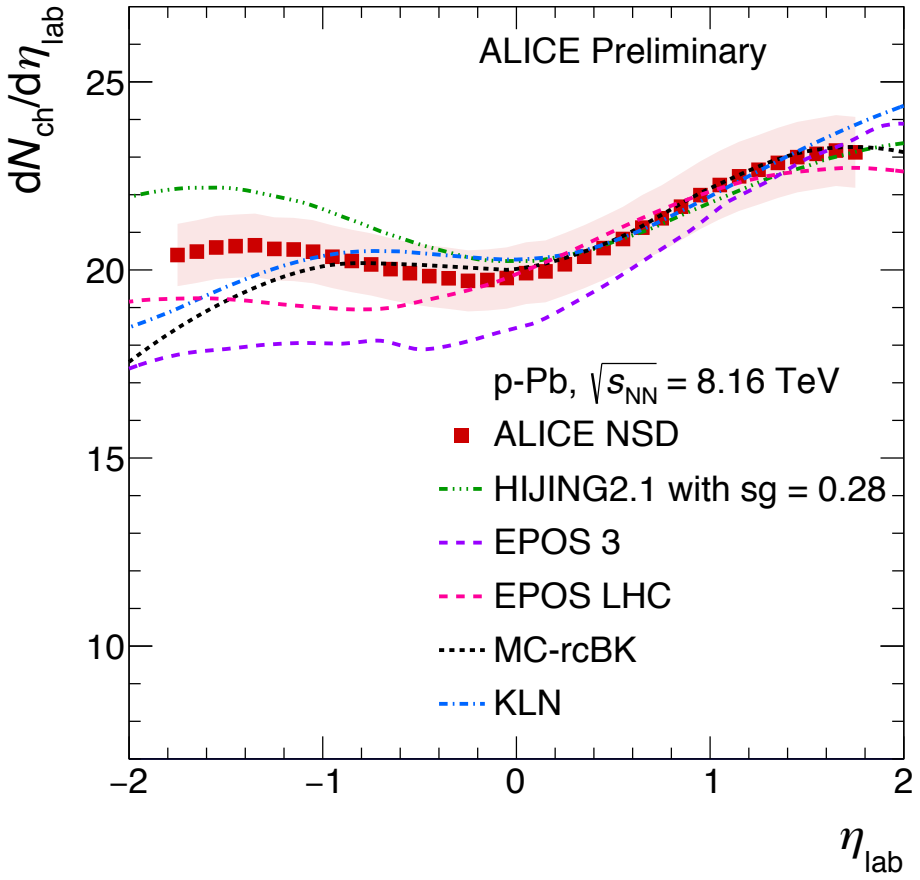
Mostly focusing on pp and p-Pb results

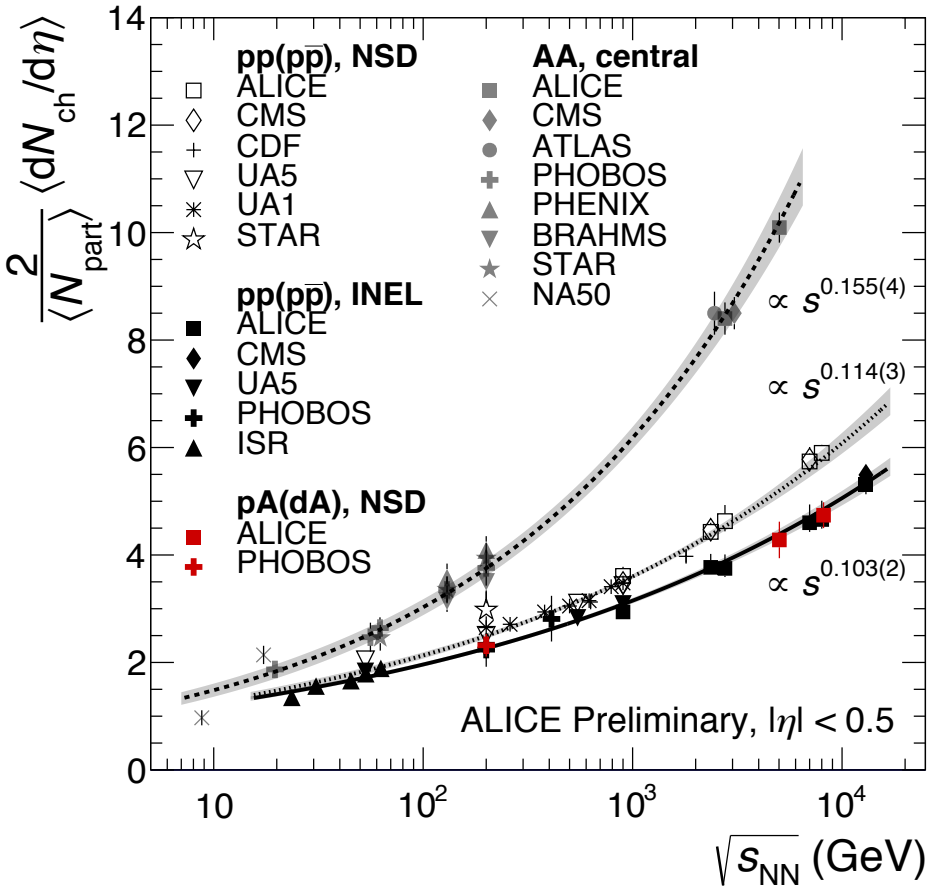
Pseudorapidity (η) and transverse momentum (p_T) distributions of charged particles

- Observables:
  - Differential distributions $\mathbf{d}N_{ch}/\mathbf{d}\eta$, $\mathbf{d}N_{ch}/\mathbf{d}p_T$, …
  - N_{ch} = number of primary charged particles
    - Primary particles are defined as prompt particles produced in the collision, including all decay products, with the exception of those from weak decays of strange particles.
- Detector performance
  - Count charged tracks for $p_T > 50$ MeV/c, reconstruct them for $p_T > 150$ MeV/c

  → Corrections / uncertainties small
- Physics Programme
  - Test of Soft QCD: low x in collinear factorization and alternative descriptions
  - Tuning of the Monte Carlo the models
  - Constrain Multiple Parton Interaction (MPI) rates, correlations
  - Reference pp data to study nuclear effects in nucleus-nucleus and in proton-nucleus collisions
- **Key input to multiplicity-dependent measurements**

$dN_{ch}/d\eta$ measurement in p-Pb at $\sqrt{s_{NN}}$ = 8.16 TeV



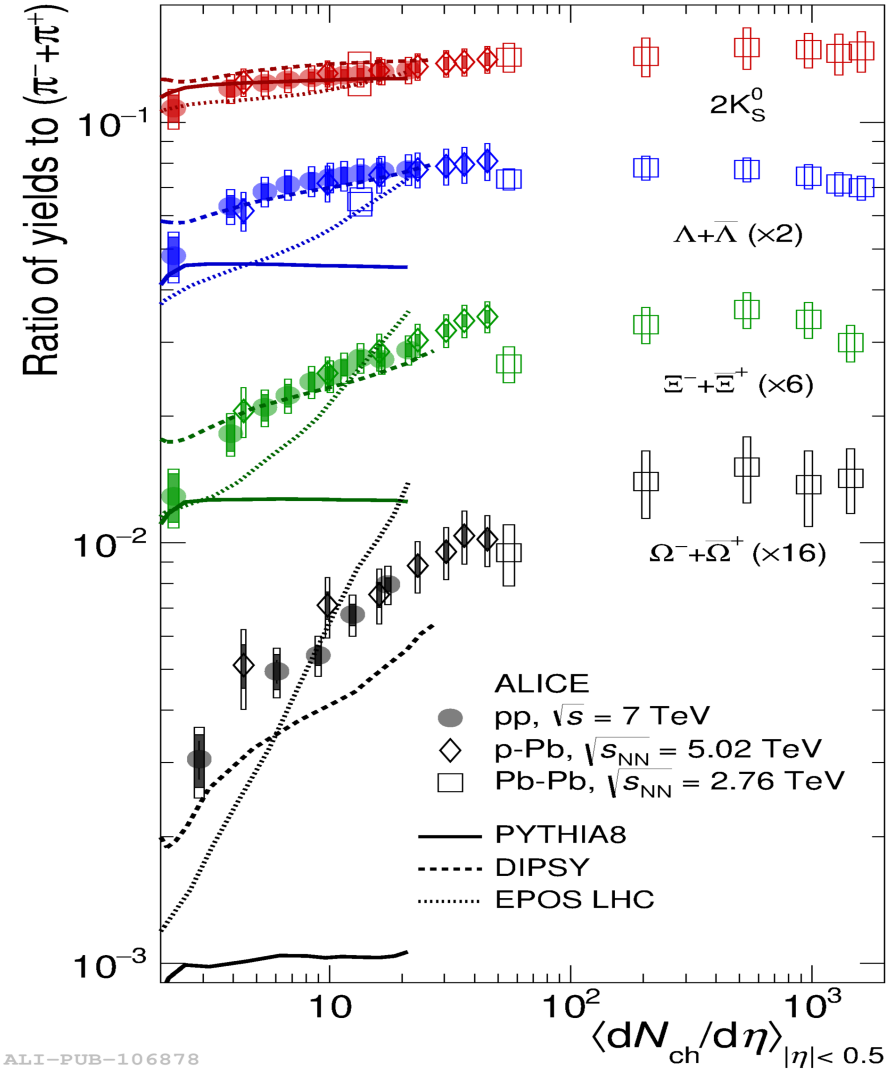


- ✓ MC generators close to data, in particular HIJING
  - ~ 10-15% agreement.
  - Effective tuning effort on Run 1 data
- ✓ Good performance of saturation-based models
- ✓ The NSD pA measurements seem to match the inelastic pp data

$dN_{ch}/d\eta$ measurement in p-Pb at $\sqrt{s_{NN}}$ = 8.16 TeV

- ✓ MC generators close to data, in particular HIJING
  - ~ 10-15% agreement.
  - Effective tuning effort on Run 1 data
- ✓ Good performance of saturation-based models
- ✓ The NSD pA measurements seem to match the inelastic pp data

Study of strangeness production vs charged multiplicity in pp collisions at √s = 7 TeV



- Significant enhancement of strange and multi-strange particle production at High Multiplicity

- Yields in pp and p-Pb interactions are the same (within uncertainties) despite of the differences in the initial state and even match the Pb-Pb ones at higher $\langle dN_{ch}/d\eta \rangle$

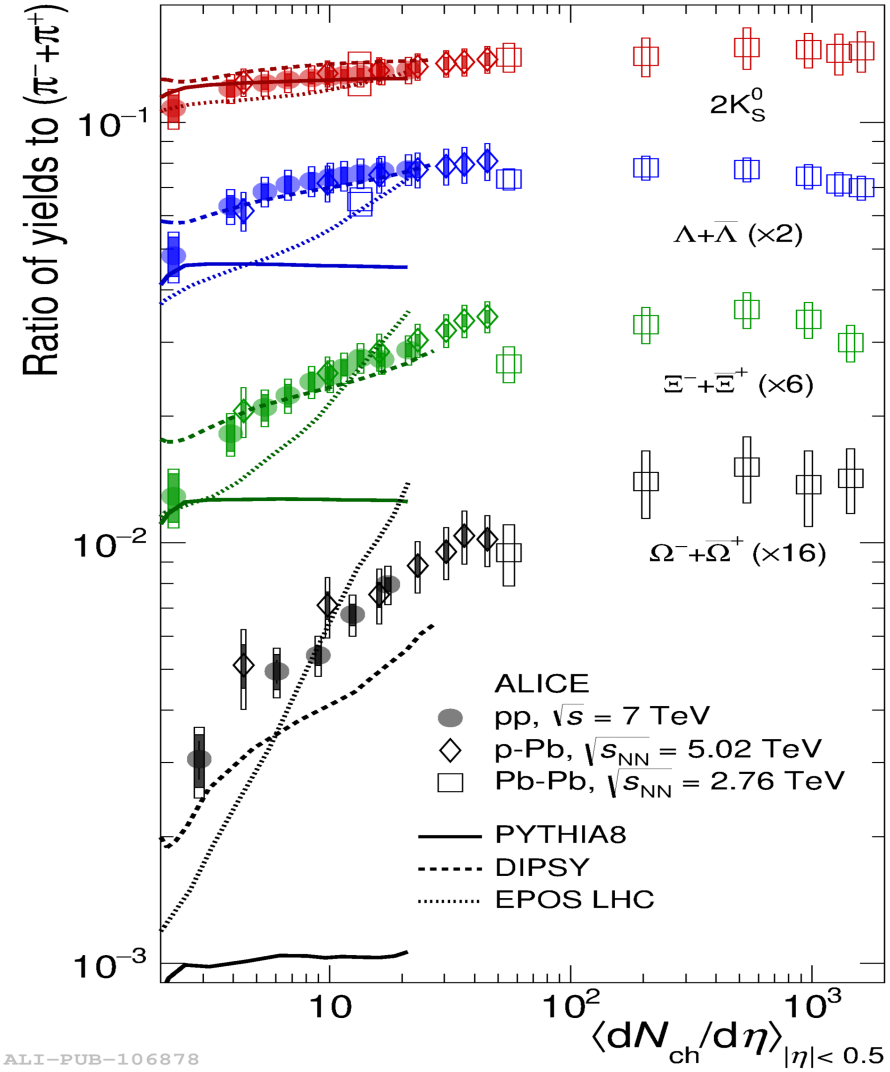
- They basically depend just on the charged multiplicity at mid-rapidity, $\langle dN_{ch}/d\eta \rangle$

- V. Topor Pop, M. Gyulassy, J. Barrette, C. Gale, and A. Warburton, *"Can hyperon/meson ratios in rare high multiplicity pp collisions at Large Hadron Collider energies provide signatures of mini-quark-gluon plasma formation?" Phys.Rev. C86 (2012) 044902*

pp results: *Nature 2017*

p-Pb results: *Phys. Lett. B 758 (2016) 389-401*

Study of strangeness production vs charged multiplicity in pp collisions at √s = 7 TeV



- The description provided by the Monte Carlo Generators is insufficient, however one can rank the models based on their qualitative behavior:

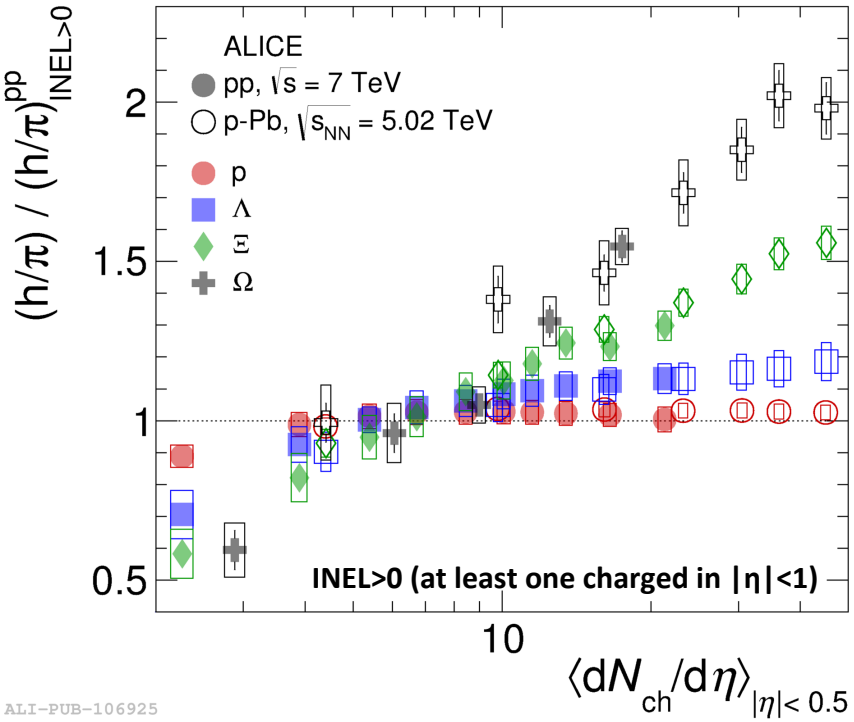
Pythia8 (String fragmentation)
→**too flat**

DIPSY (Rope fragmentation)
→ **closer**

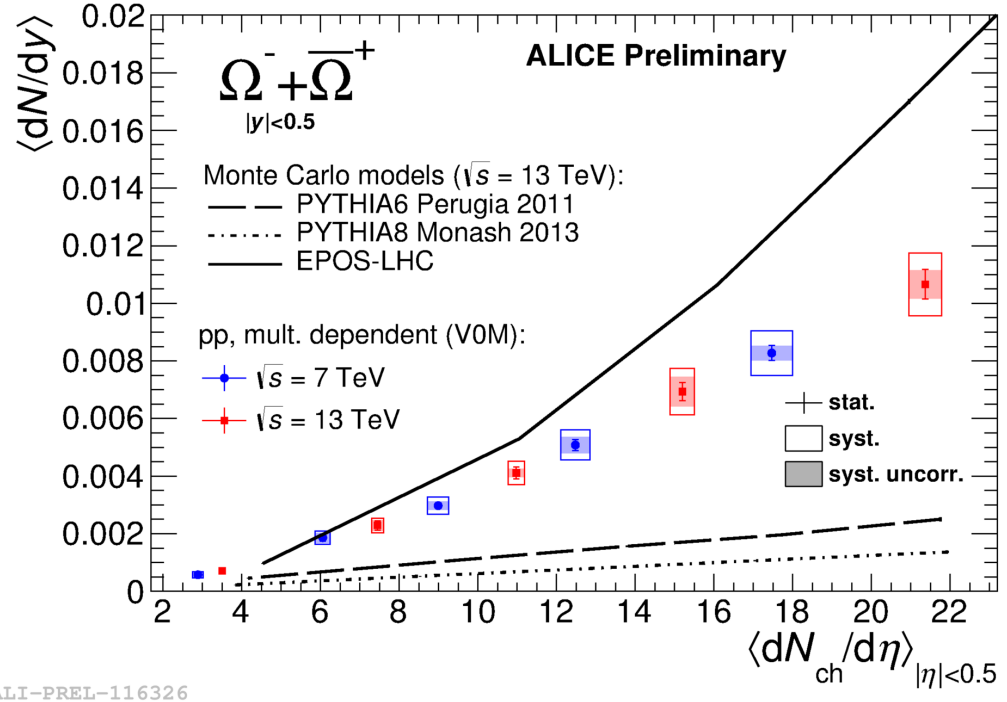
EPOS LHC (Collective hadronization)
→ **too steep**

pp results: *Nature 2017*
p-Pb results: *Phys. Lett. B 758 (2016) 389-401*

Study of strangeness production vs charged multiplicity in pp collisions: dependence on strangeness content and center of mass energy



ALI-PUB-106925



ALI-PREL-116326

- The observed increase is **even more pronounced** for **baryons with higher strangeness content**.

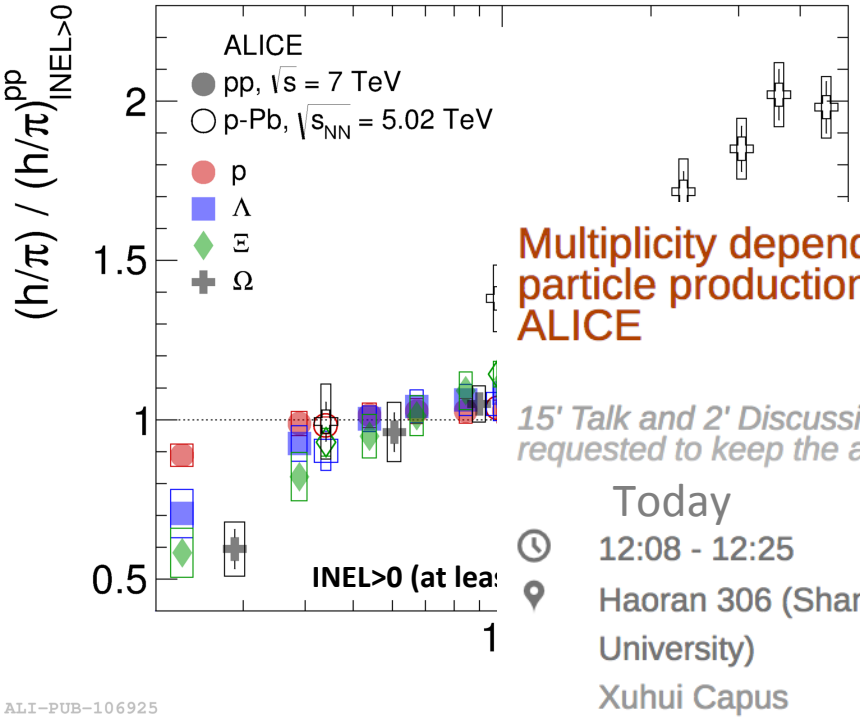
- Measurements at different center of mass energies as a function of multiplicity indicates that the **hadrochemistry is driven by event activity regardless of √s**

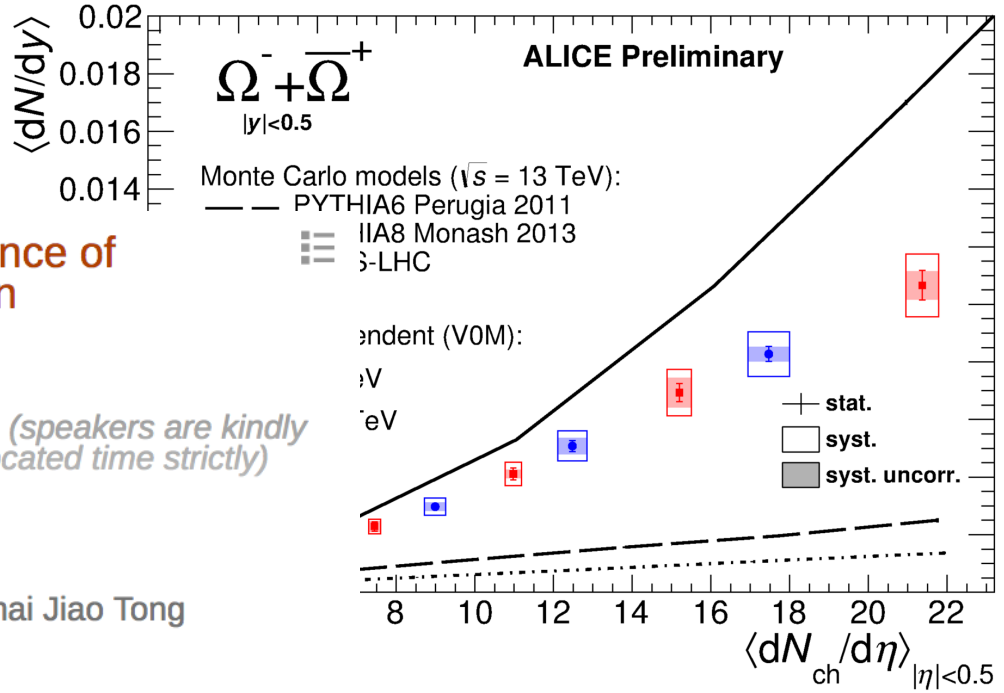
→ Scaling not reproduced by the tested models

pp results: *Nature 2017*

p-Pb results: *Phys. Lett. B 758 (2016) 389-401*

Study of strangeness production vs charged multiplicity in pp collisions: dependence on strangeness content and center of mass energy





Multiplicity dependence of particle production in ALICE

15' Talk and 2' Discussion (speakers are kindly requested to keep the allocated time strictly)

Today
12:08 - 12:25
Haoran 306 (Shanghai Jiao Tong University)
Xuhui Capus

Presenters Giacomo Volpe

- The observed increa ts at different center of mass **pronounced** for **baryo** unction of multiplicity **strangeness content**.

indicates that the **hadrochemistry is driven by event activity regardless of √s**

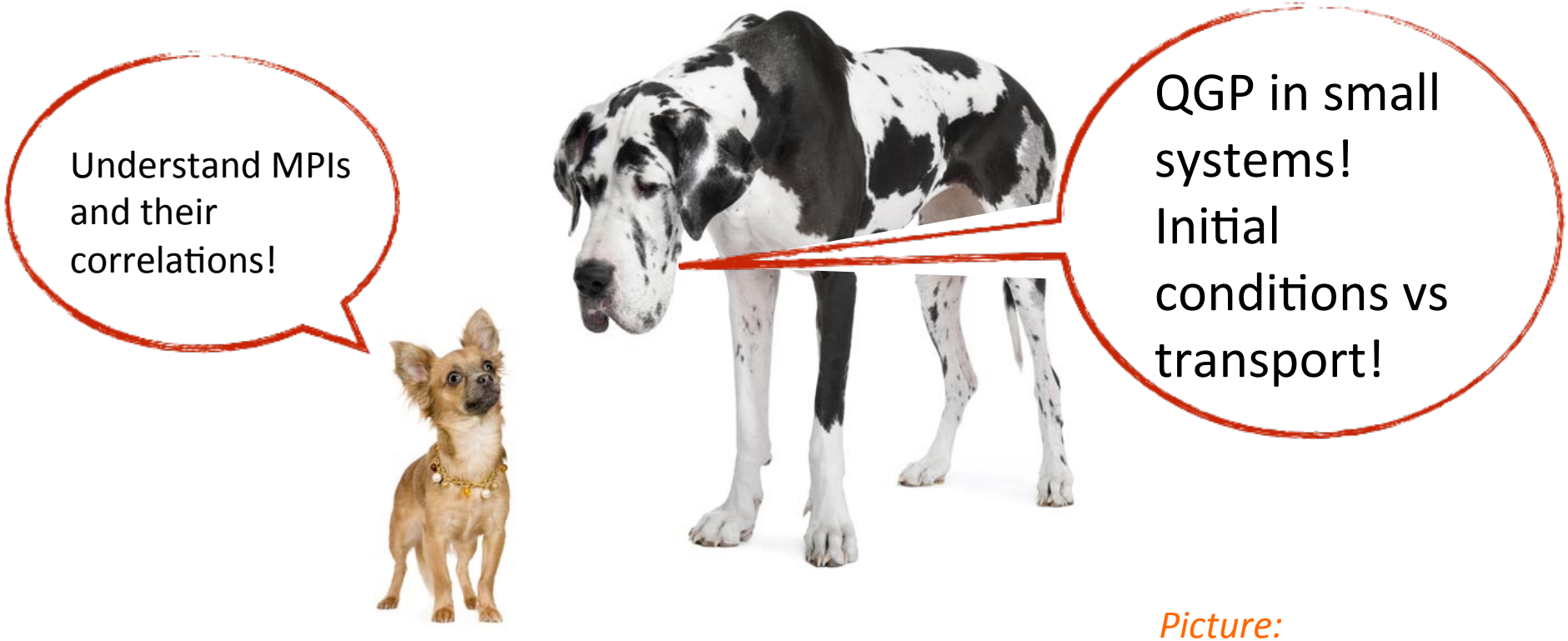
→ Scaling not reproduced by the tested models

pp results: *Nature 2017*

p-Pb results: *Phys. Lett. B 758 (2016) 389-401*

Yet another observation that we **didn't expect**
and we **don't** (fully) **understand** in

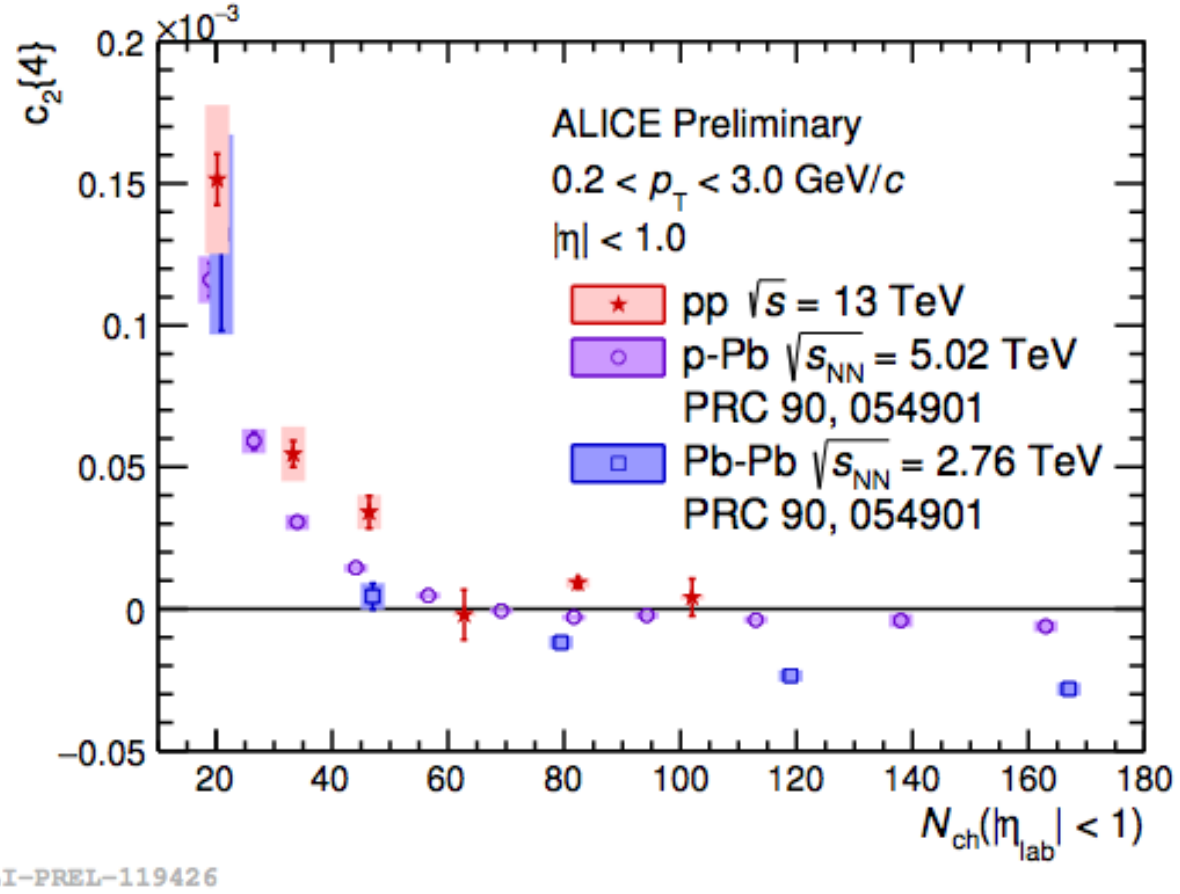
High Multiplicity pp & pA collisions



Picture:
Credit Michele Floris

Interpretations should rely on a rich phenomenology, exploiting also the interplays between different underlying mechanisms

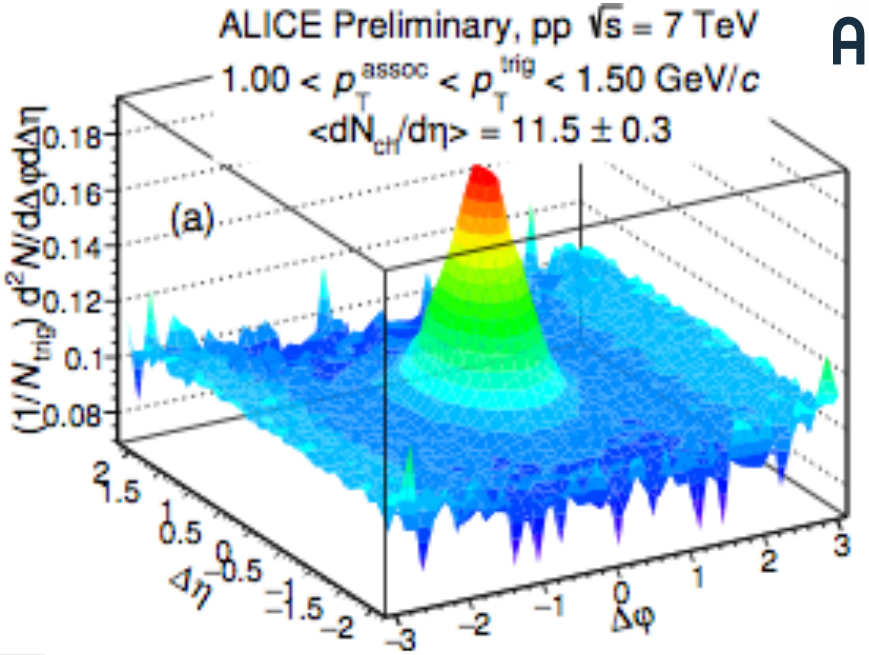
Searches for azimuthal flow in pp collisions at √s = 13 TeV

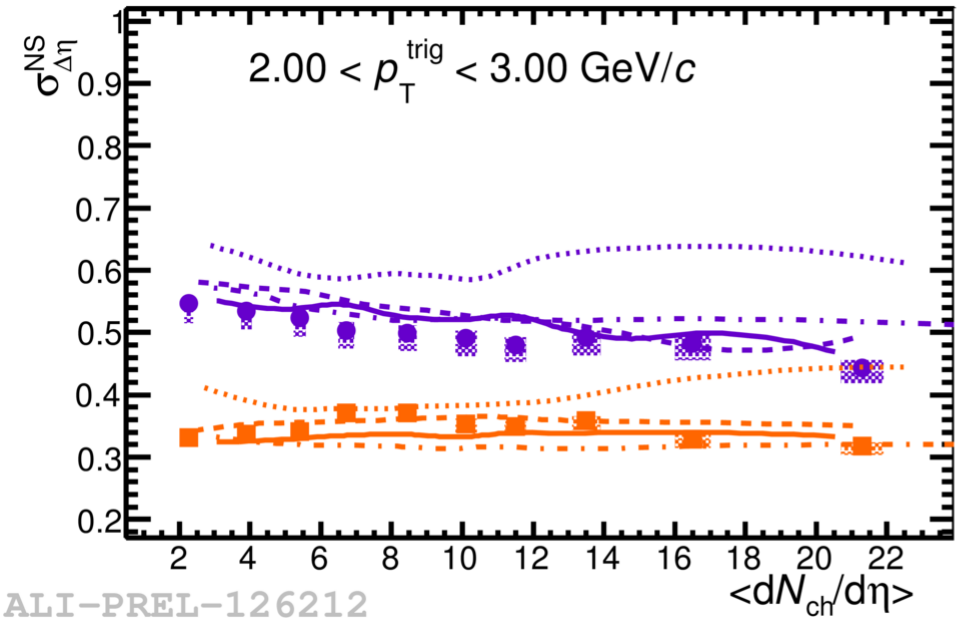


- Negative four-particle cumulant $c_2\{4\}$ indicates collective behaviour *arXiv:1701.03830v1*
  - ✓ No definitive evidence seen in pp by ALICE within uncertainties

Nearside peak in two-particle correlations vs multiplicity in pp at √s = 7 TeV

- Is jet fragmentation altered in high multiplicity pp collisions?
- Jet peak shape shows little to no dependence on multiplicity





ALICE Preliminary, pp √s = 7 TeV

p_T^{assoc} (GeV/c)

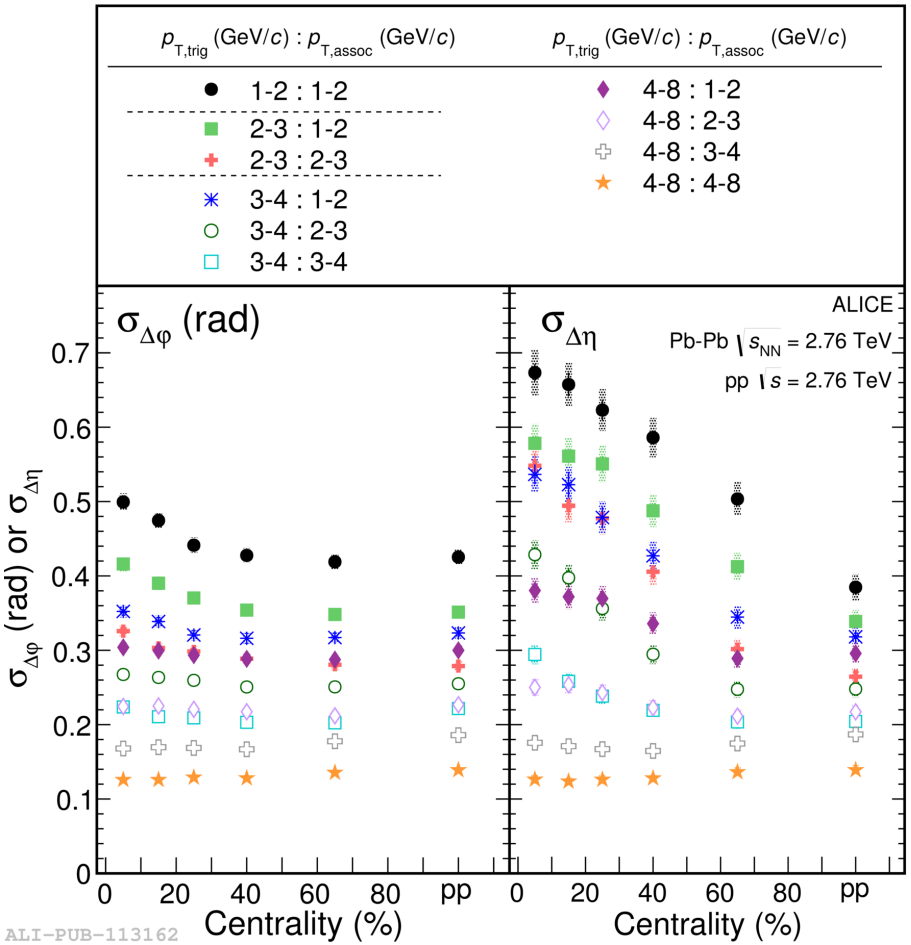
- 0.70 – 1.00 GeV/c
- 1.00 – 1.50 GeV/c
- 1.50 – 2.00 GeV/c
- 2.00 – 3.00 GeV/c
- 3.00 – 8.00 GeV/c

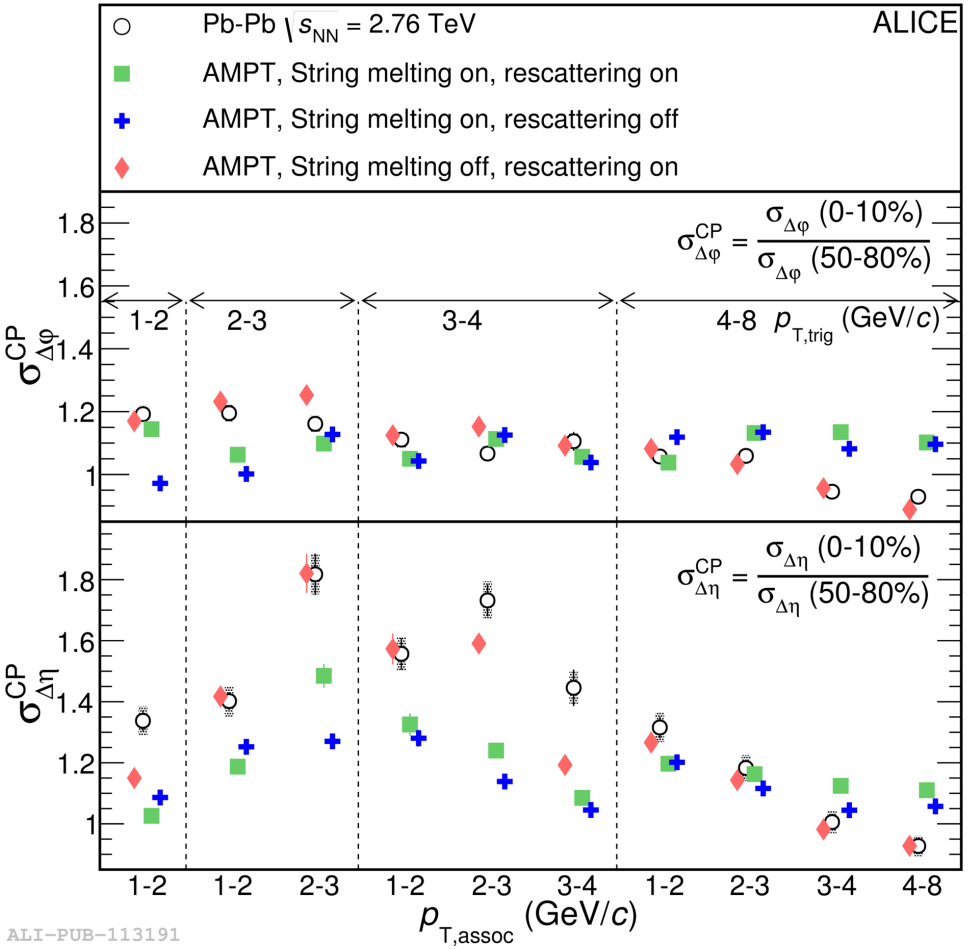
Py6 Perugia2011
Py8 Monash CR
AMPT SM
AMPT no SM

ALI-PREL-126212

Nearside peak in two-particle correlations vs multiplicity in Pb-Pb at √s = 2.76 TeV

arXiv:1609.06643, submitted to PRL

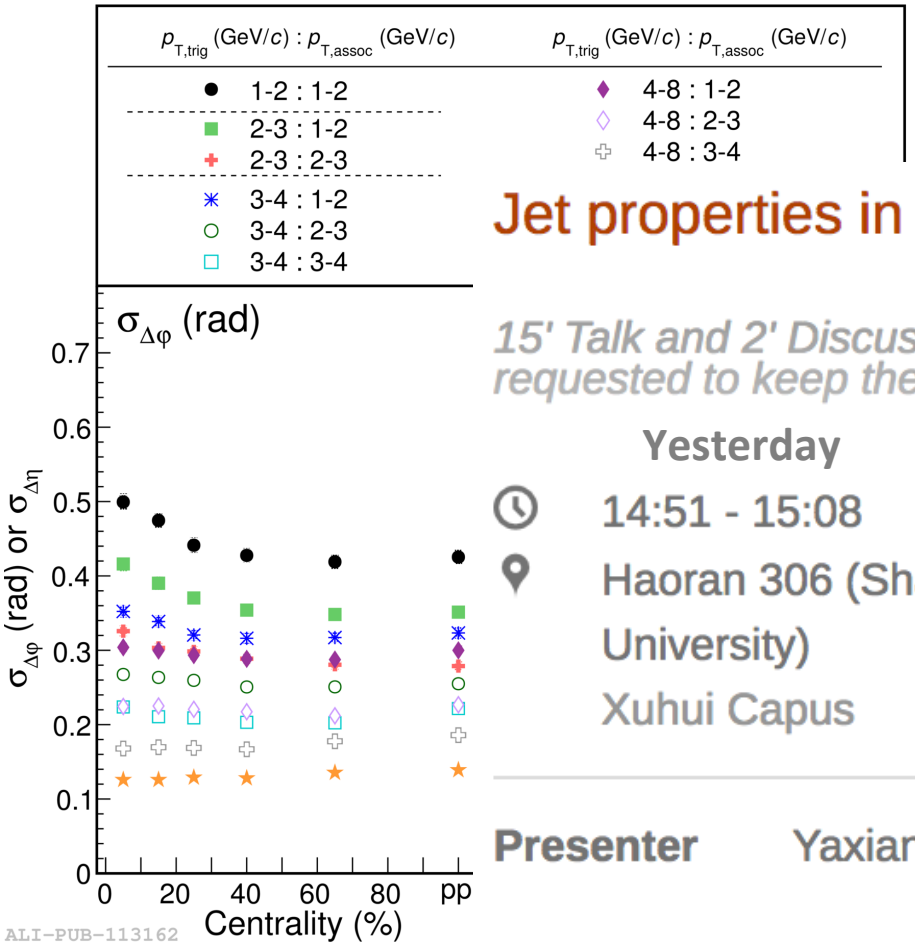


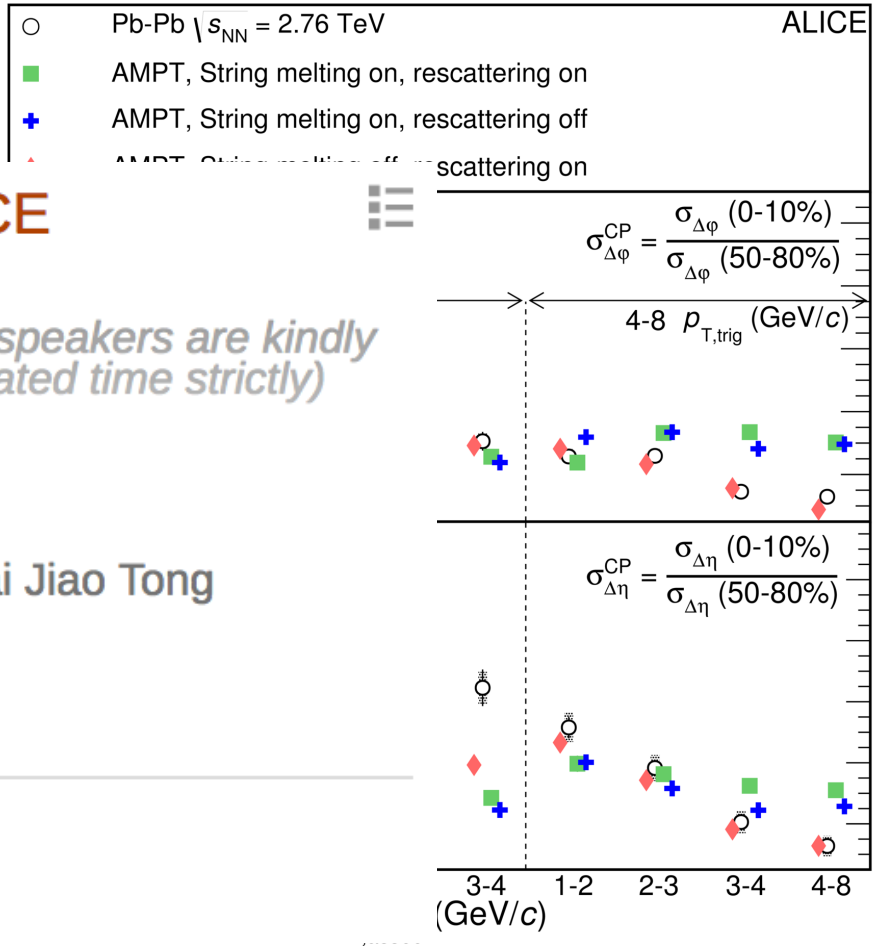


- Ordering of the width according to p_T
- Small broadening in Δφ , significant broadening in Δη
- AMPT description insufficient; best with melting off and re-scattering on

Nearside peak in two-particle correlations vs multiplicity in Pb-Pb at √s = 2.76 TeV

arXiv:1609.06643, submitted to PRL





Jet properties in ALICE

15' Talk and 2' Discussion (speakers are kindly requested to keep the allocated time strictly)

Yesterday

14:51 - 15:08

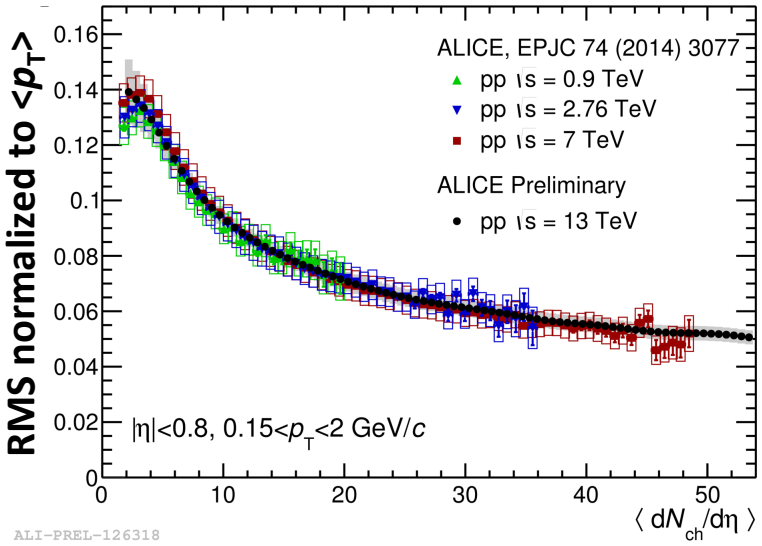
Haoran 306 (Shanghai Jiao Tong University)

Xuhui Capus

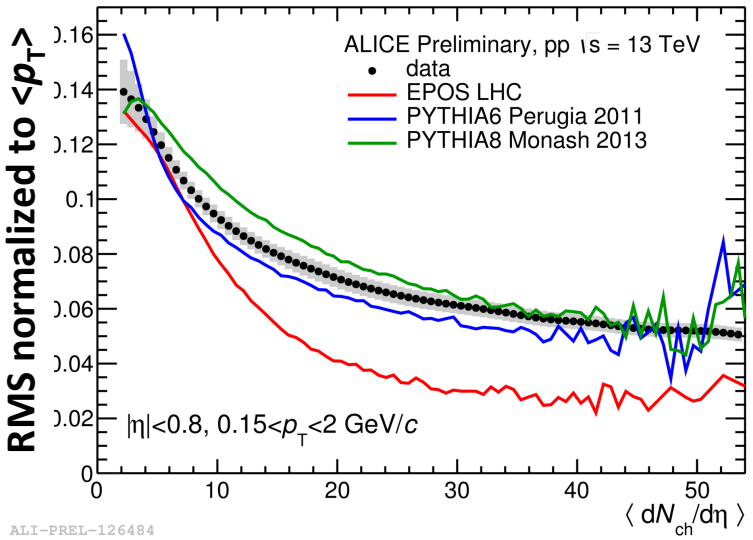
Presenter Yaxian Mao

- Ordering of the width according to p_T
- Small broadening in Δϕ, significant broadening in Δη
- AMPT description insufficient, best with melting off and re-scattering on

Event-by-event $\langle p_T \rangle$ fluctuations in HM pp collisions



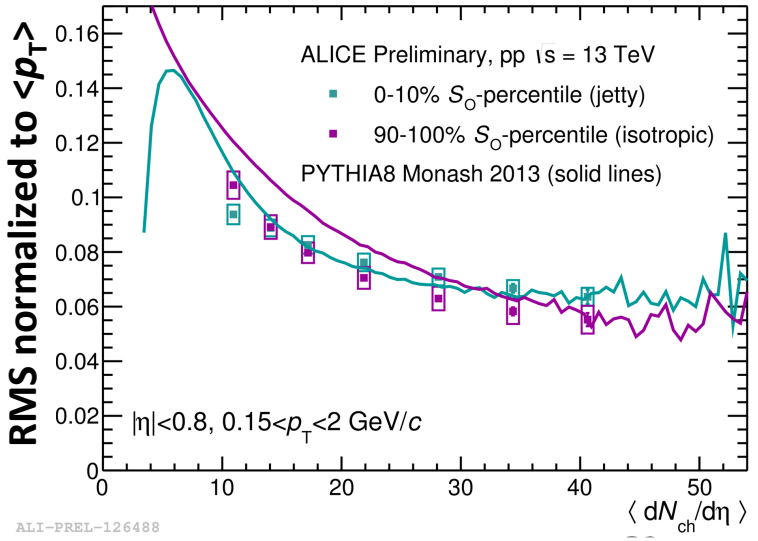
- $\langle p_T \rangle$ fluctuations: yet another multiplicity dependent observable that scales with √s!
  - $\langle p_T \rangle$ itself scales with √s and requires Color Reconnections (CR) in MPI
- Good inclusive description achieved by Pythia, fluctuations underestimated by EPOS LHC
- However, worse description of "spherical" events (We know already that at HM, events look more spherical with respect to the predictions of the QCD models: *Eur.Phys.J. C72 (2012) 2124*)



See

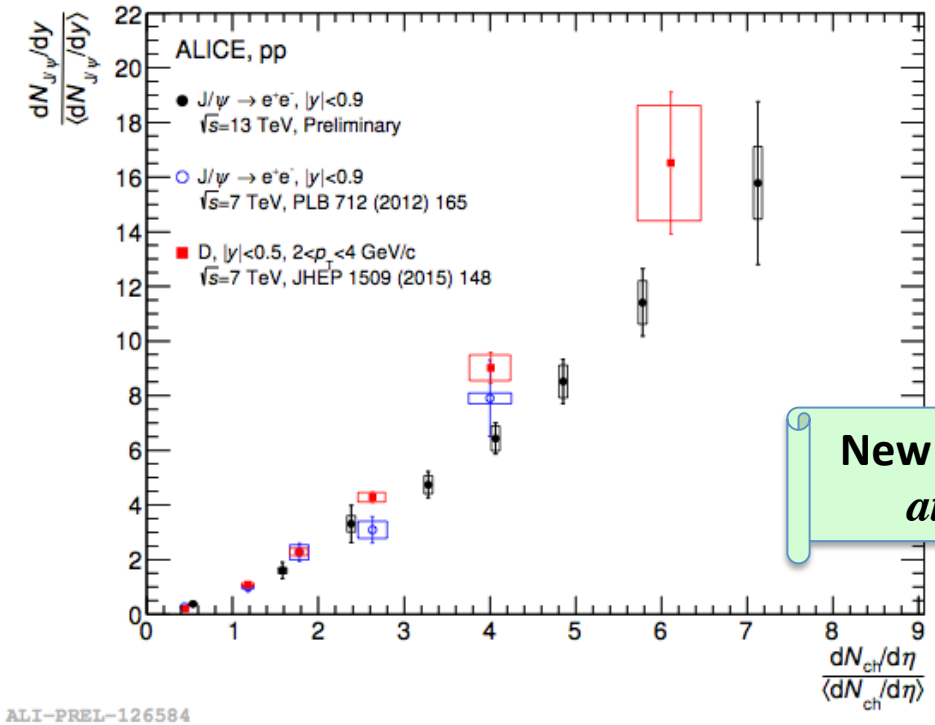
Irais Bautista QM'17

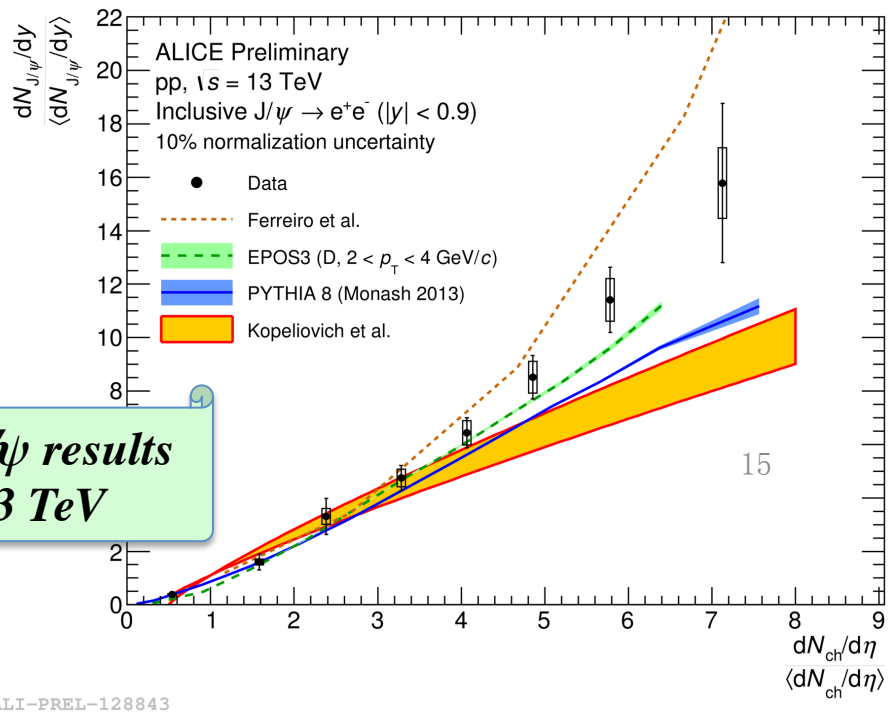
arXiv 1705.02056



J/ψ and Open Charm production vs charged multiplicity in pp

D at 7 TeV, J/ψ at 7 and 13 TeV





New J/ψ results at 13 TeV

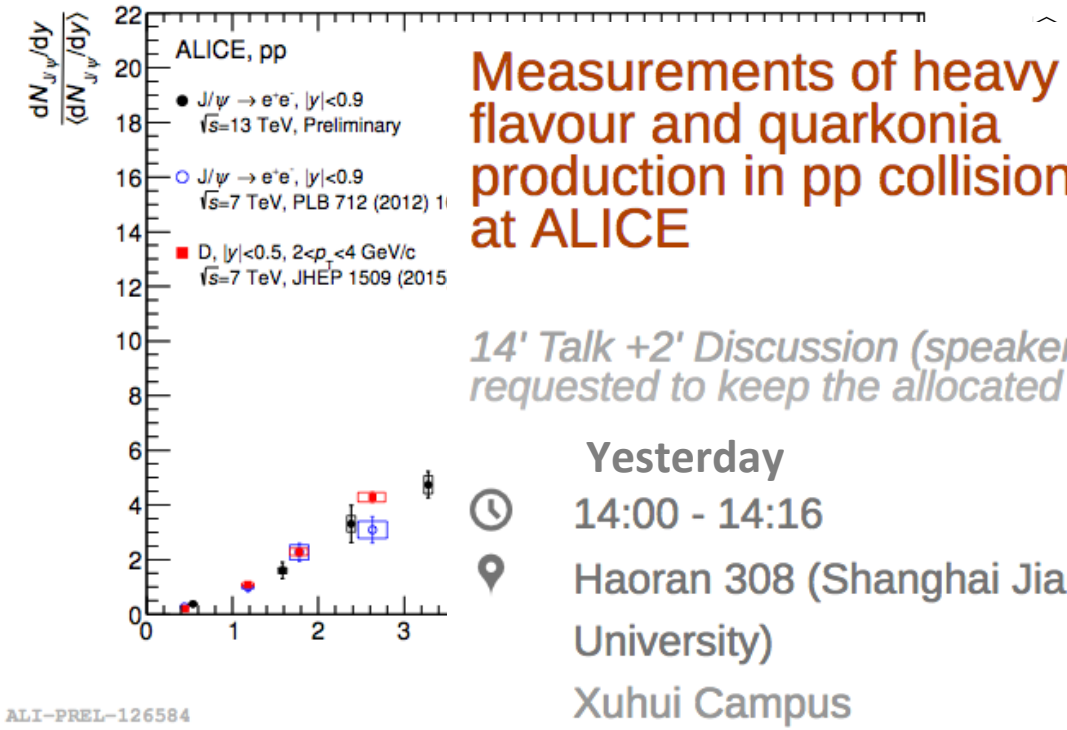
15

Increase of J/ψ and D-mesons yields with multiplicity (stronger than linear)

Models including Multi-Parton Interactions are favored by data

J/ψ and Open Charm production vs charged multiplicity in pp

D at 7 TeV, J/ψ at 7 and 13 TeV



Measurements of heavy flavour and quarkonia production in pp collisions at ALICE

14' Talk +2' Discussion (speakers are kindly requested to keep the allocated time strictly)

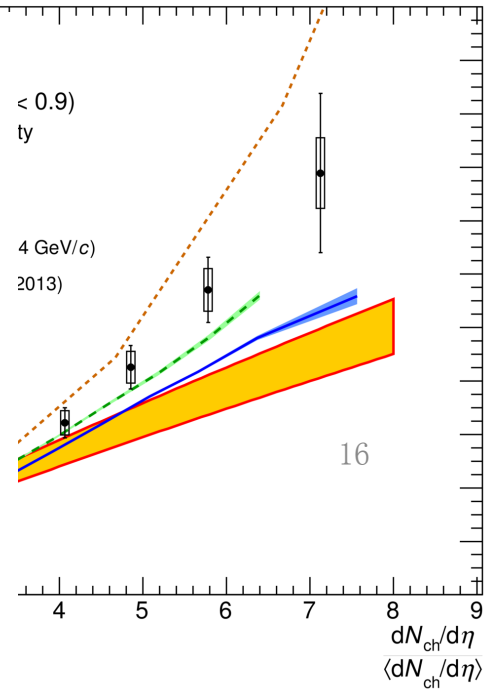
Yesterday

14:00 - 14:16

Haoran 308 (Shanghai Jiao Tong University)

Xuhui Campus

Presenter Antoine Lardeux

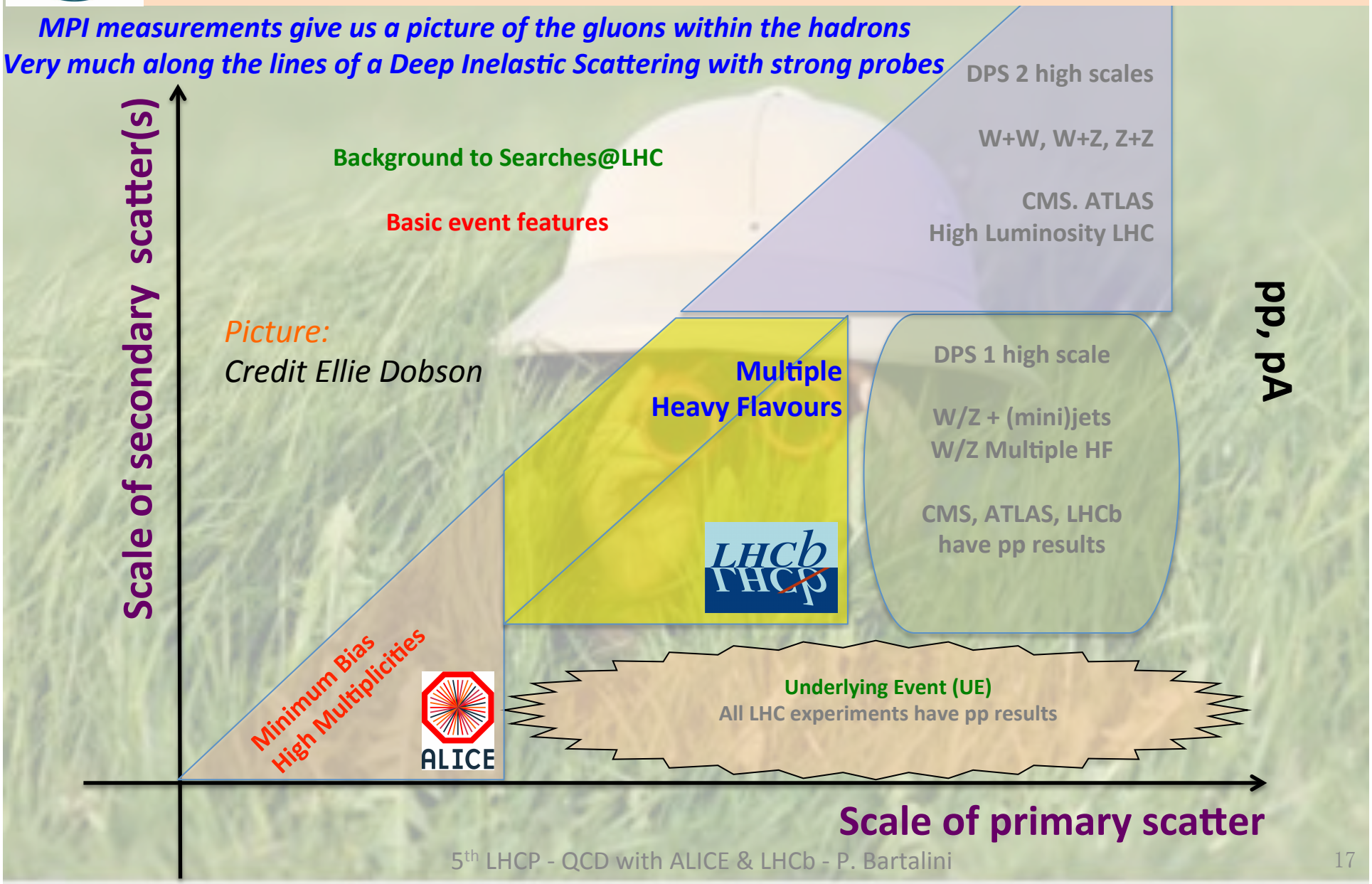


Increase of $J/$ with multiplicity (stronger than linear)

luding Multi-Parton interactions are favored by data

Multiple Parton Interactions (MPI) at the LHC

MPI measurements give us a picture of the gluons within the hadrons
Very much along the lines of a Deep Inelastic Scattering with strong probes

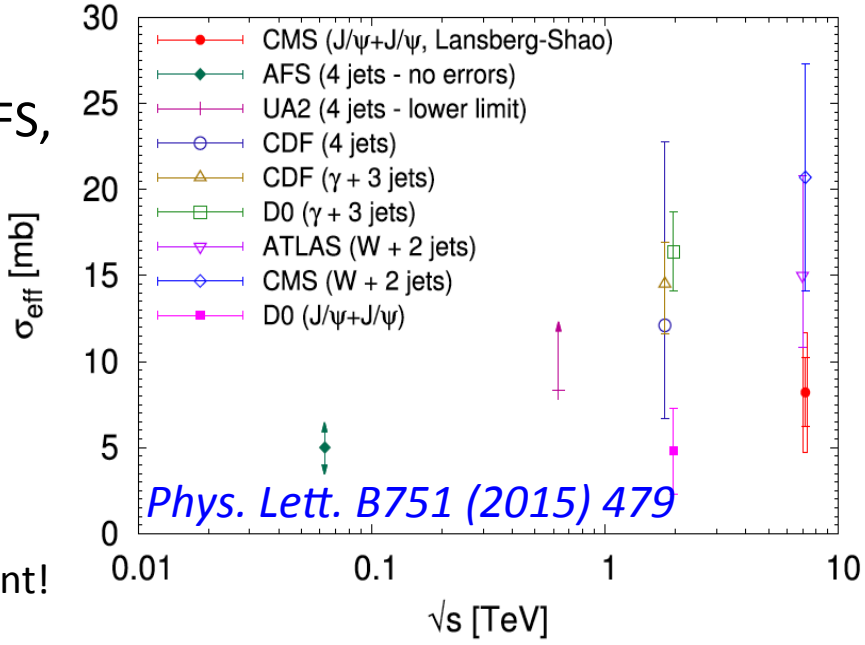


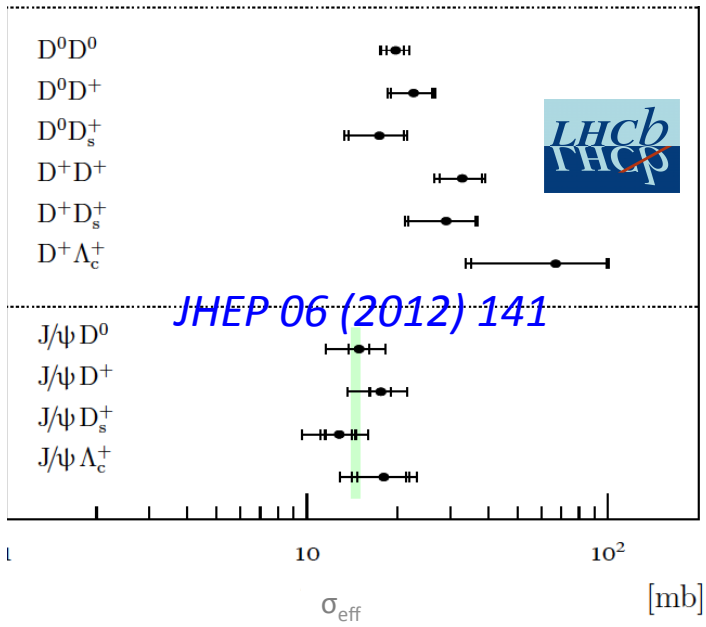
The Double Parton Scattering (DPS) and the effective cross section σ_{eff}

- $\sigma_{DPS}(A+B+X) = m * \sigma(A+X) * \sigma(B+X) / \sigma_{eff}$
  - m = ½ for identical interactions, m = 1 otherwise.
  - Probabilistic interpretation: $P(B|A) = P(B) * (\sigma_{inel}/\sigma_{eff})$.
  - Trivial case of no correlations → $\sigma_{eff} = \sigma_{inel}$ (Probability unchanged)
  - Formalism applies to inclusive processes only.
  - σ_{eff} can be regarded as a hadronic form factor.
  - Huge ongoing TH effort to understand correlations: IP, Flavour, Spin, Color, …
- Under the assumption of purely geometrical correlations:
  - σ_{eff} ≈ geometrical quantity, energy scale and √s independent. [D.Treleani]
  - **TH predictions have large uncertainties**: σ_{eff} = 20÷60 mb.
- Measurements use the relationship in the following way:
  - $\sigma_{eff} = m * \sigma(A+X) * \sigma(B+X) / \sigma_{DPS}(A+B+X)$.
  - Need an accurate Single Parton Scattering (SPS) background.
  - Checking Scale and √s independency is in the EXP TODO list.
  - Statistics often limits the possibility to extract σ_{eff} in a differential way.

Measurement of the effective cross section σ_{eff}

- First results on 4jets already 30 years ago: AFS, UA2: $\sigma_{eff} < 10$ mb.
- Tevatron measurements from the years nineties: $\sigma_{eff} \approx 10 \div 15$ mb.
  - Early measurements: insufficient effort on SPS background modeling!
- LHC (W+2jet, etc.) $\sigma_{eff} \approx 15 \div 20$ mb.
  - Compatible with the Underlying Event measurement!
  - $\langle N_{MPI}\,(UE)\rangle / \langle N_{MPI}\,(MB)\rangle \approx \sigma_{inel} / \sigma_{eff}$
- Trend to quote smaller σ_{eff} values (larger DPS) in final states with *quarkonia*
  - Hint of not understood SPS backgrounds?
- Ambitious DPS measurement program in LHCb
  - Double *J/ψ* at 7 TeV: *Phys. Lett. B707 (2011) 52*
  - Double *J/ψ* at 13 TeV → Next slide!
  - *J/ψ* + open charm and double open charm at 7 TeV: *JHEP 06 (2012) 141 + JHEP 03 (2014) 108*
  - Z+ open charm at 7 TeV: *JHEP04 (2014) 091*
  - ϒ + open charm at 7 and 8 TeV: *JHEP07 (2016) 052*



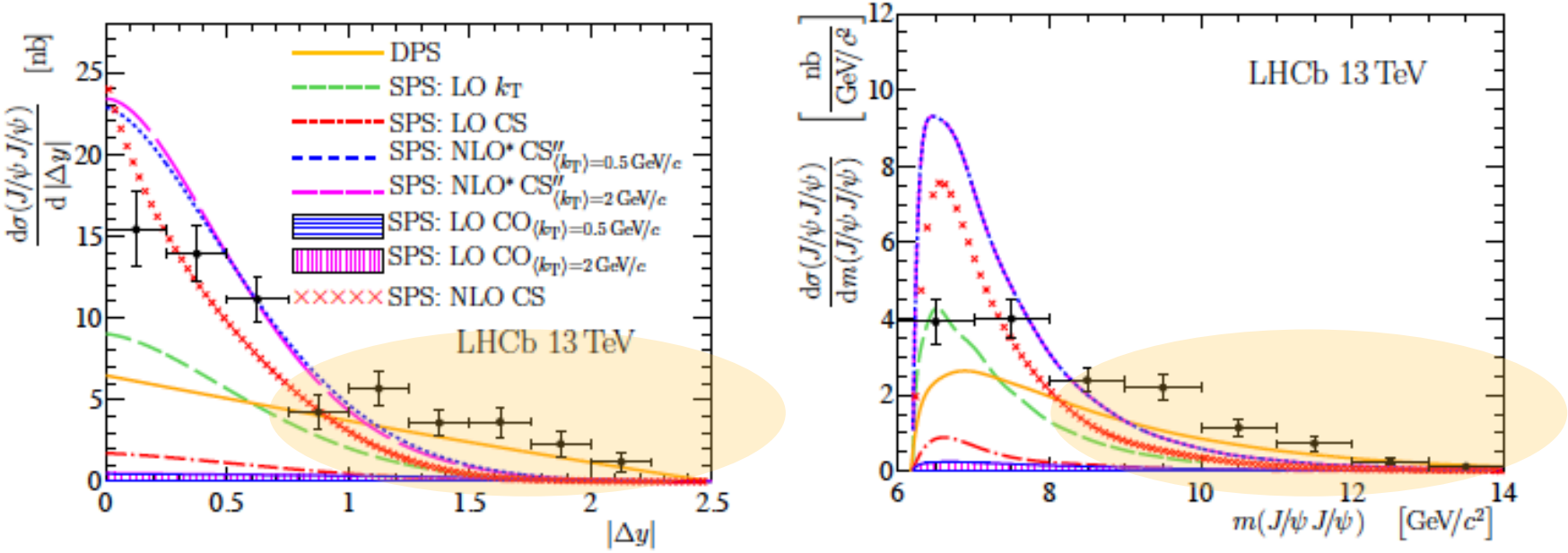


Measurement of the J/ψ pair production cross section in pp collisions at √s = 13 TeV

arXiv:1612.07451

- Cross section measured for J/ψ mesons $p_T < 10$ GeV/c and $2.0 < y < 4.5$
- Large uncertainties on inclusive SPS cross sections from NRQCD
- However differential cross sections show evidence for DPS
- Effective cross section determined using SPS+DPS template fit

→ σ_{eff} values between 10.0 and 12.5 mb are quoted for the considered SPS models



Measurement of the J/ψ pair production cross section in pp collisions at √s = 13 TeV

arXiv:1612.07451

- Cross section measu
- Large uncertainties
- However differentia
- Effective cross sectio

→ σ_{eff} values between

2.0 < y < 4.5

QCD

fit

onsidered SPS models

Measurements of particle production, soft QCD, and double parton scattering with LHCb

15' Talk and 2' Discussion (speakers are kindly requested to keep the allocated time strictly)

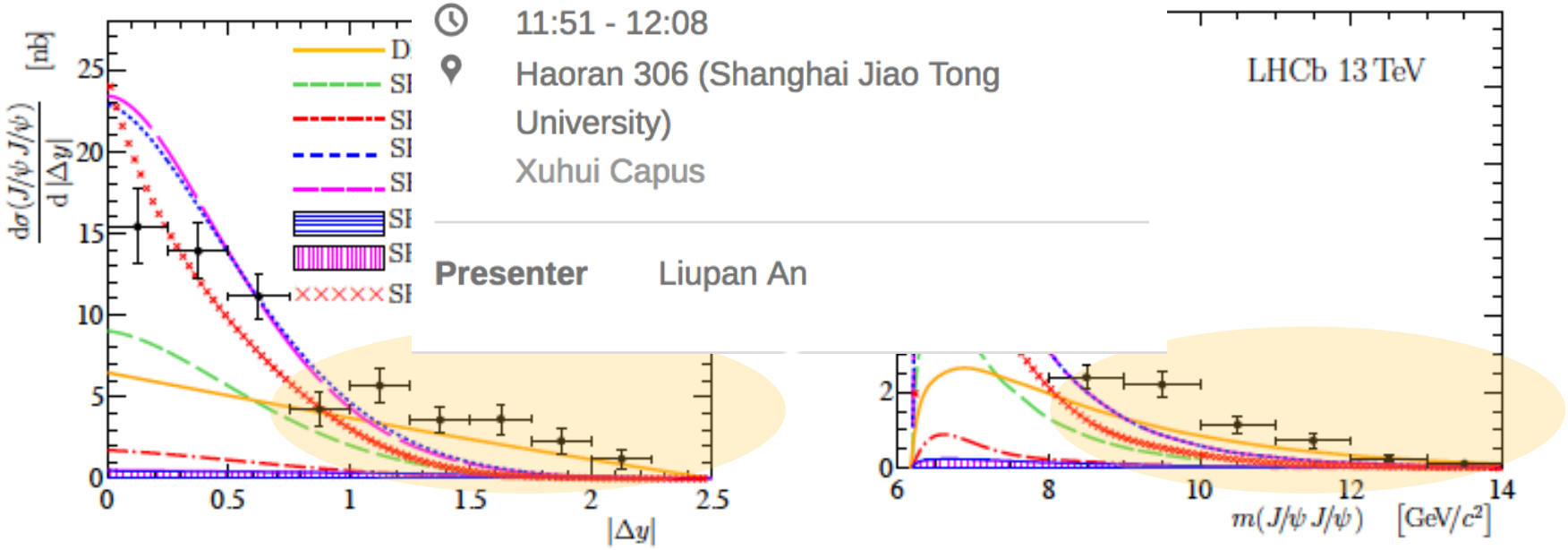
Today

11:51 - 12:08

Haoran 306 (Shanghai Jiao Tong University)

Xuhui Capus

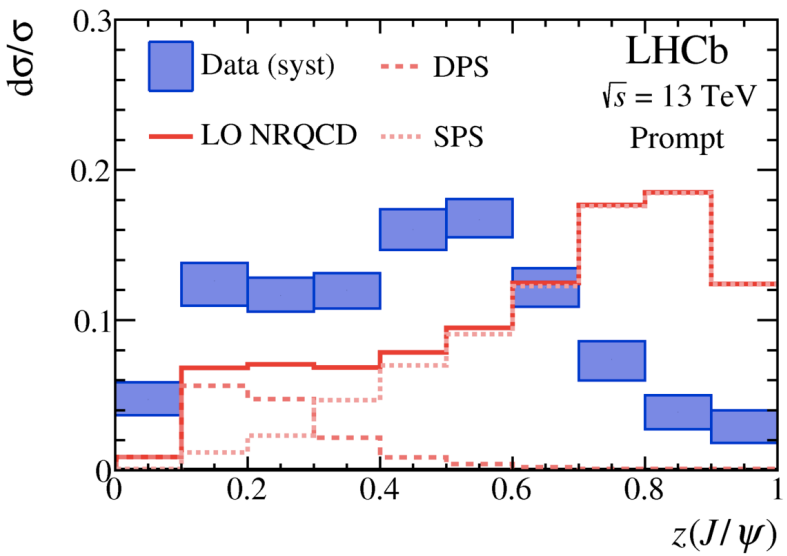
Presenter Liupan An

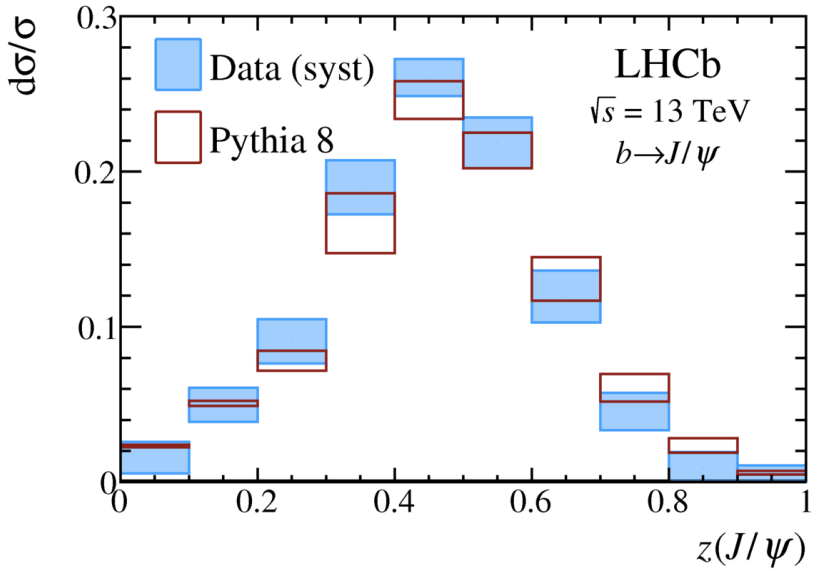


J/ψ production in jets in pp collisions at √s = 13 TeV

Phys. Rev. Lett. 118, 192001 (2017)

- Physics with jets at LHCb covers a wide range of QCD topics: Set important constraints in proton PDFs and probe hard QCD in a unique environment
  - Nice example, brand new analysis: Measurement of the fraction of p_T carried by J/ψ when reconstructed within a jet.
  - Clear difference comparing prompt and J/ψ production from *b*!





J/ψ production in jets in pp collisions at √s = 13 TeV

Phys. Rev. Lett. 118, 192001 (2017)

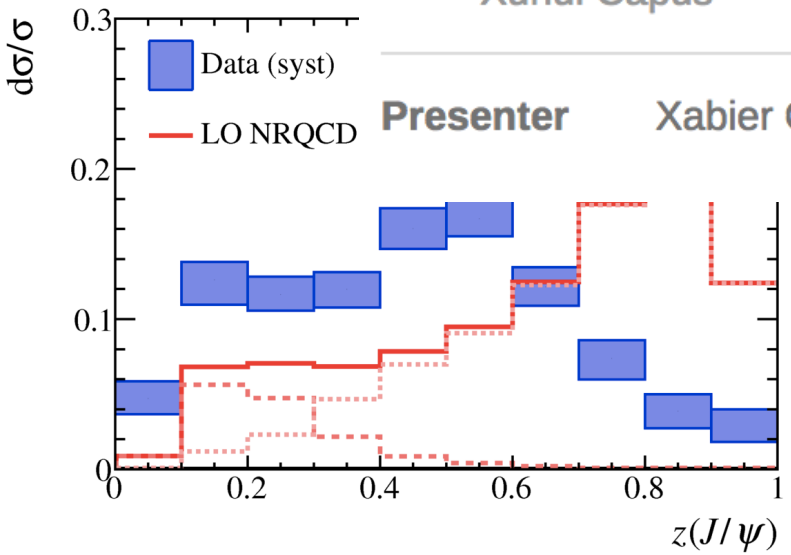
- Physics w … of QCD topics: Set … importan … be hard QCD in a … unique er …
  - Nice exa … of the fraction of p_T … carried b …
  - Clear dif … ction from b!

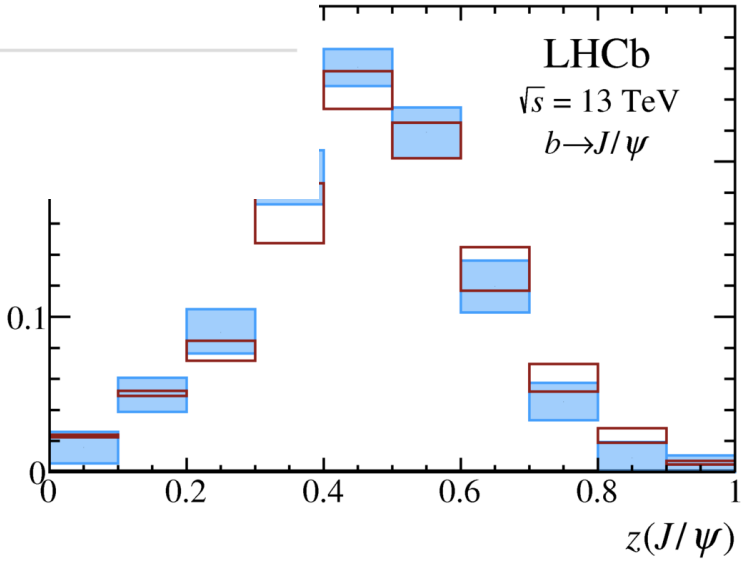
Physics with jets in LHCb

15' Talk and 2' Discussion (speakers are kindly requested to keep the allocated time strictly)

Tomorrow
11:34 - 11:51
Haoran 306 (Shanghai Jiao Tong University)
Xuhui Capus

Presenter Xabier Cid Vidal

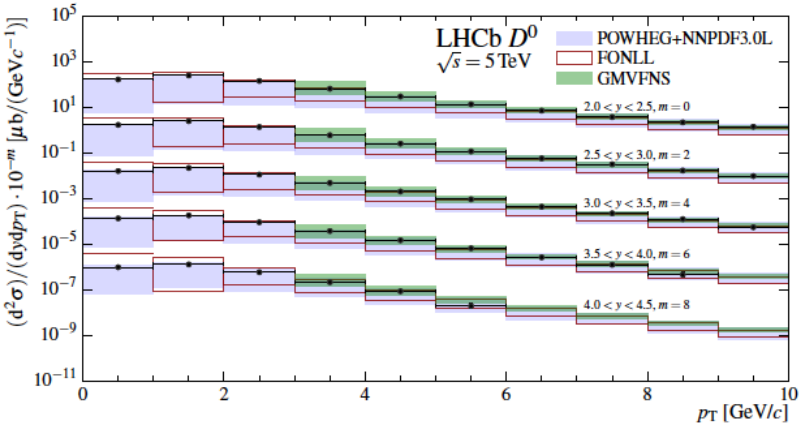


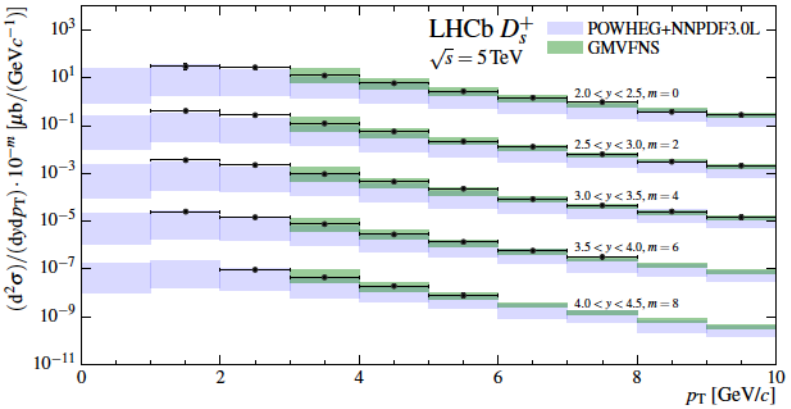


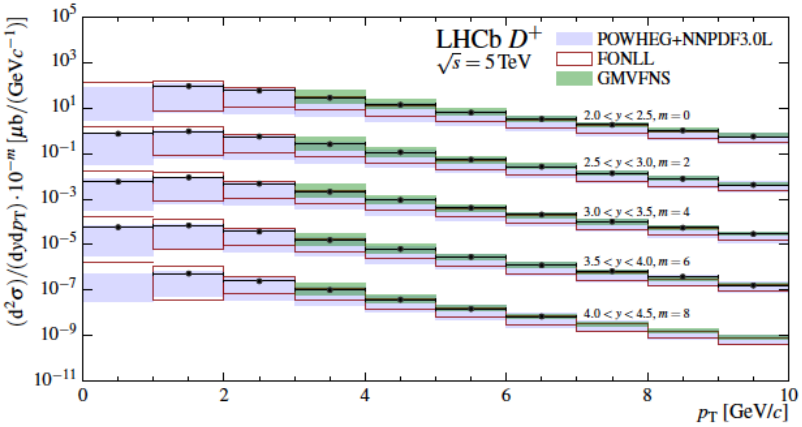
Prompt charm production differential cross sections in pp at √s = 5 TeV

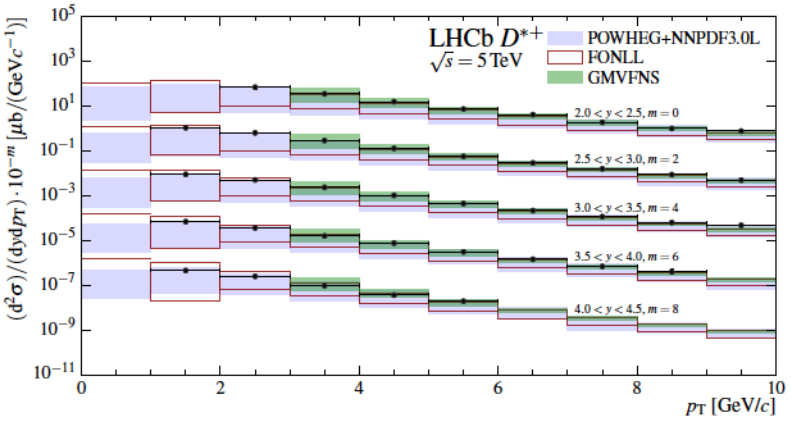
arXiv 1610.02230

(Forward rapidity!)









$0 < p_T < 10$ GeV/c for D_0 and D^+

$1 < p_T < 10$ GeV/c for D_s^+ and D^{*+}

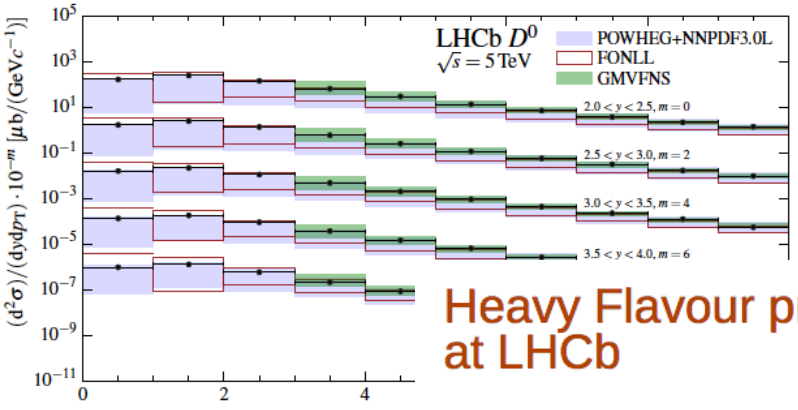
$2.0 < y < 4.5$

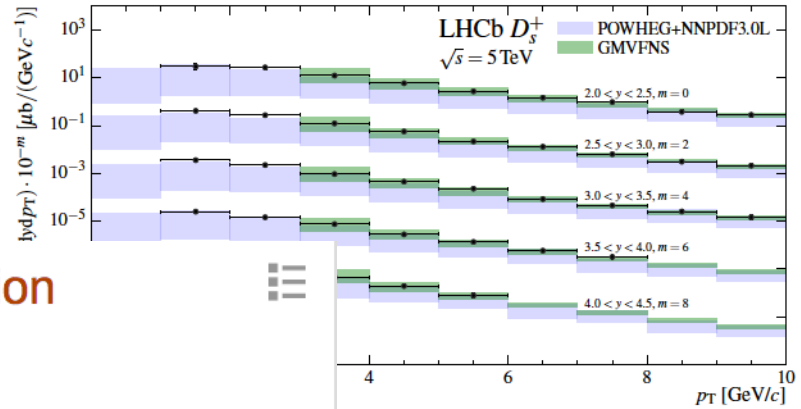
The measured values tend to lie at the upper edge of the predictions

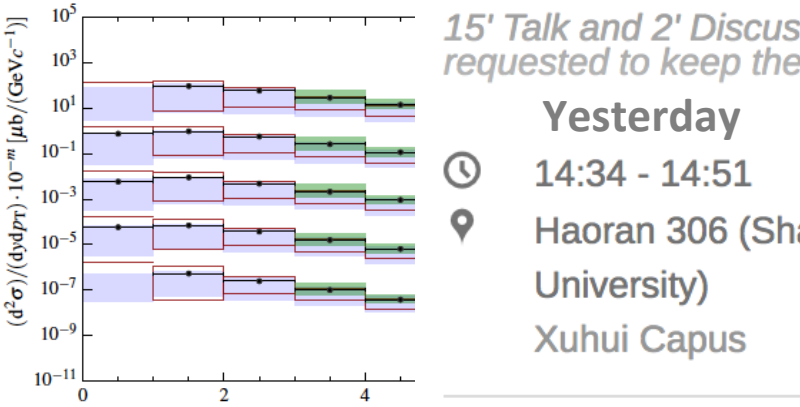
Prompt charm production differential cross sections in pp at √s = 5 TeV

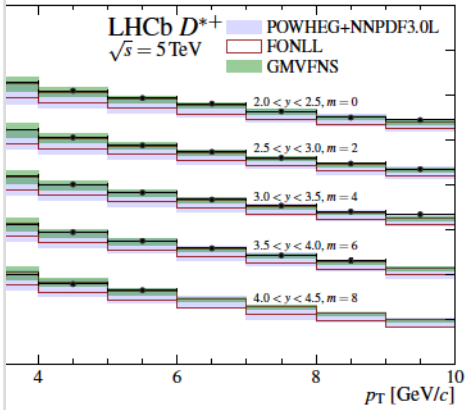
arXiv 1610.02230

(Forward rapidity!)









Heavy Flavour production at LHCb

15' Talk and 2' Discussion (speakers are kindly requested to keep the allocated time strictly)

Yesterday

14:34 - 14:51

Haoran 306 (Shanghai Jiao Tong University)

Xuhui Capus

Presenter Patrick Spradlin

0 < p_T < 10 GeV

GeV/c for D_s^+ and D^{*+}

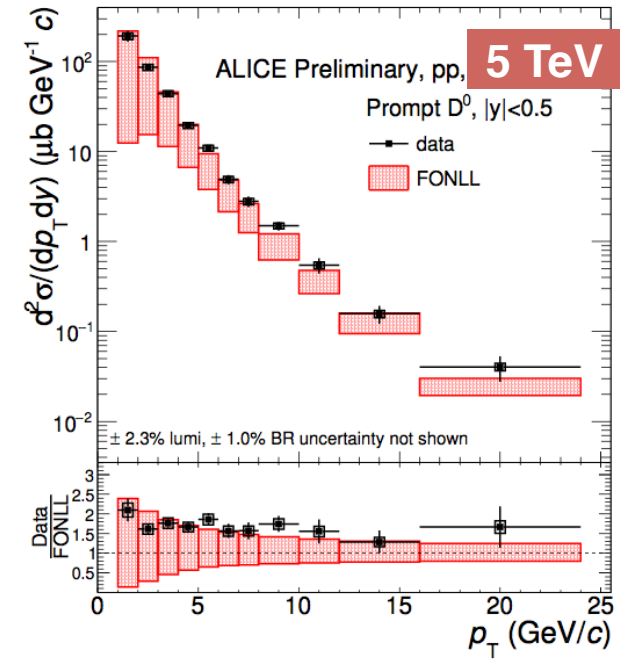
2.0 < y < 4.5

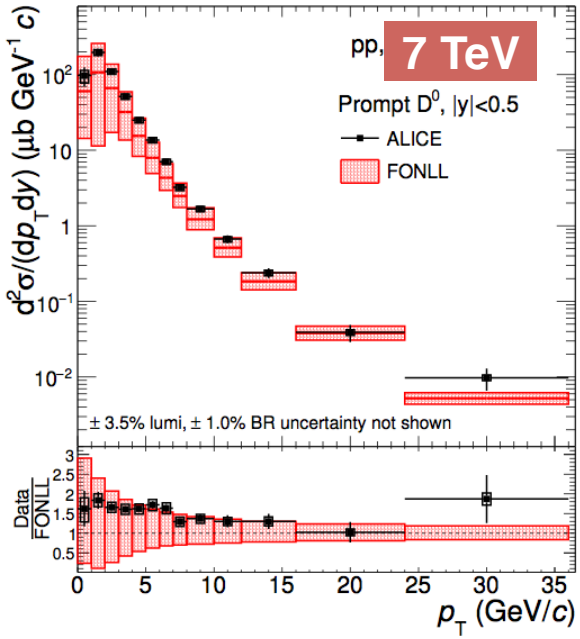
The measured values tend to lie at the upper edge of the predictions

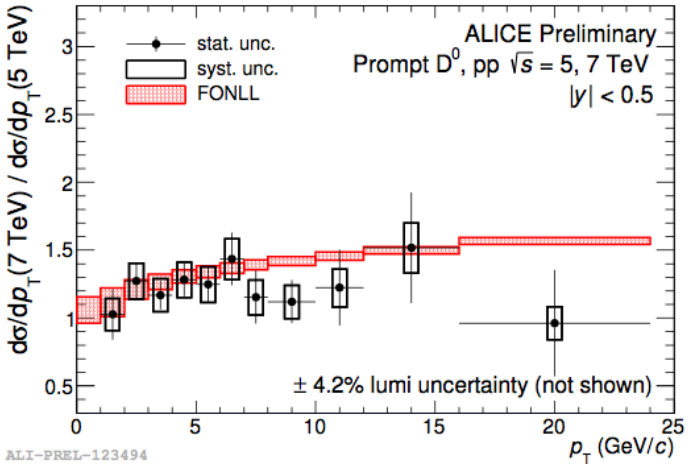
Prompt charm production differential cross sections in pp at √s = 5 and 7 TeV

(Central rapidity!)

arXiv:1702.00766







Ratio compatible with pQCD-based model

New D^0 cross section measurement at 5 TeV

Measurement down to zero p_T at 7 TeV

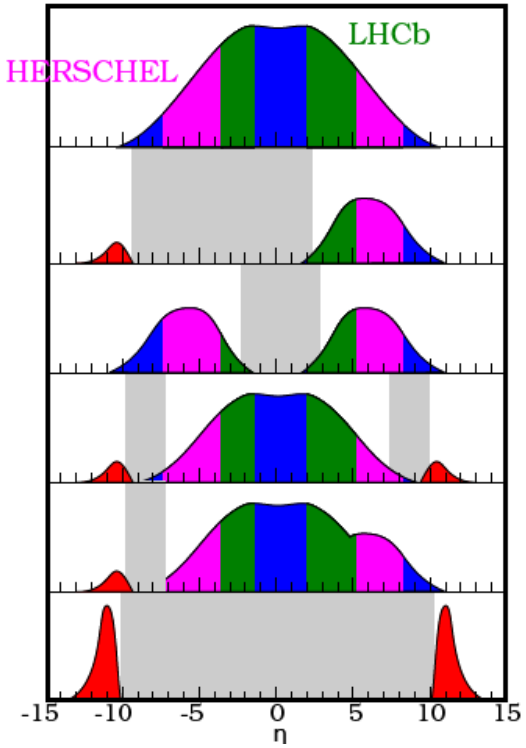
The measured values tend to lie at the upper edge of the FONLL predictions

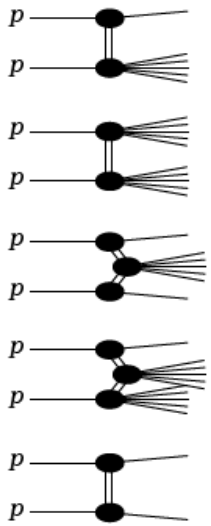
Central Exclusive Production of J/ψ & $\psi(2S)$

LHCb CONF 2016_007

New data at $\sqrt{s}$ = 13 TeV allows to explore up to $W = \sqrt{s_{\gamma p}} \approx 2$ TeV

RUN II upgrade HERSCHEL (High Rapidity Shower Counter) helps to reject inelastic Backgrounds





inelastic

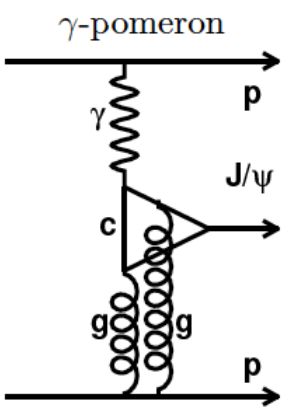
single diffraction

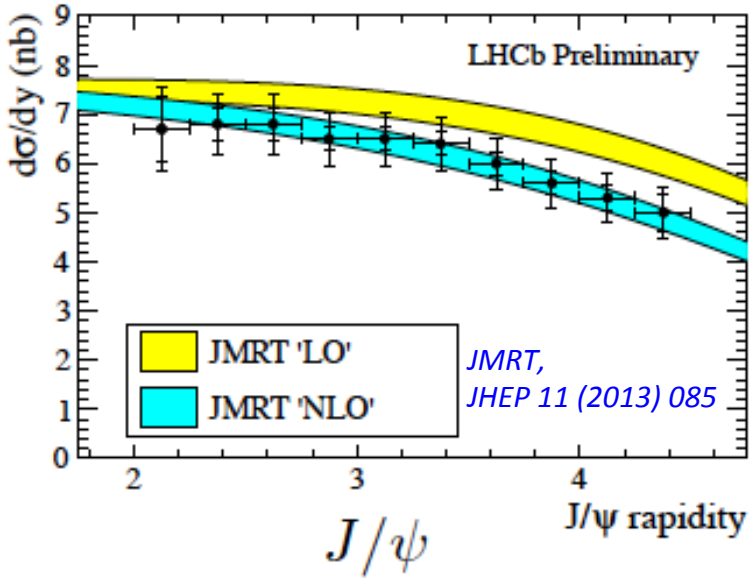
double diffraction

CEP elastic

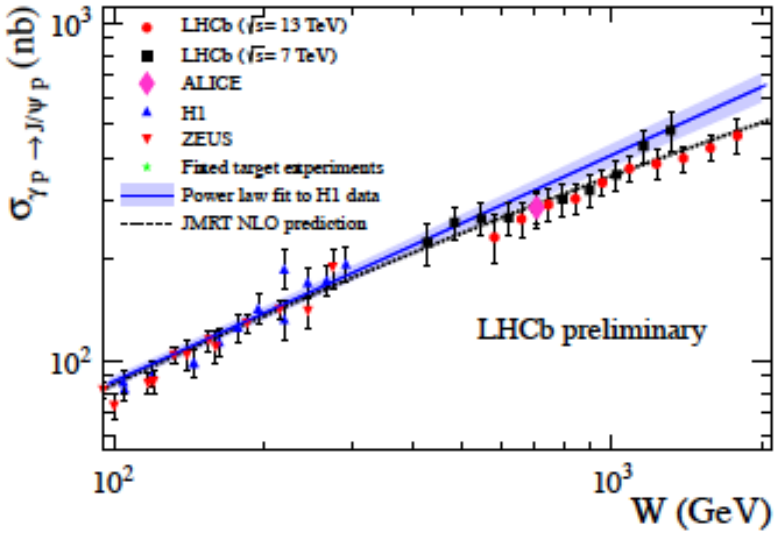
CEP inelastic

elastic





JMRT, JHEP 11 (2013) 085



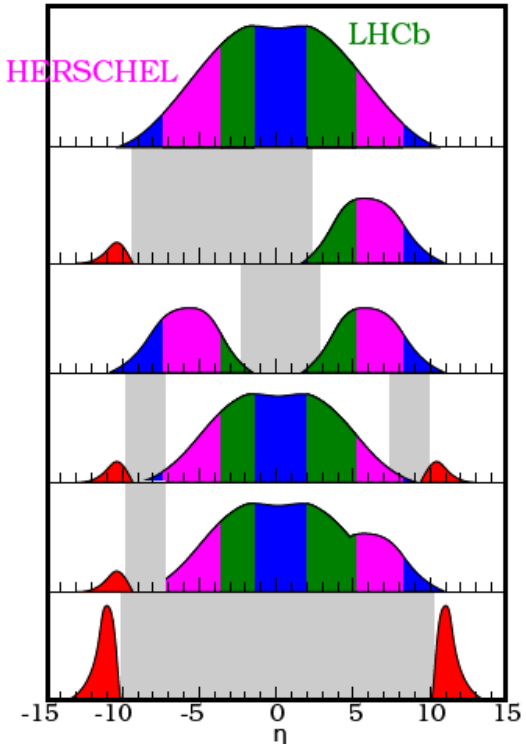
More info on J.P Ilten MPI'2016

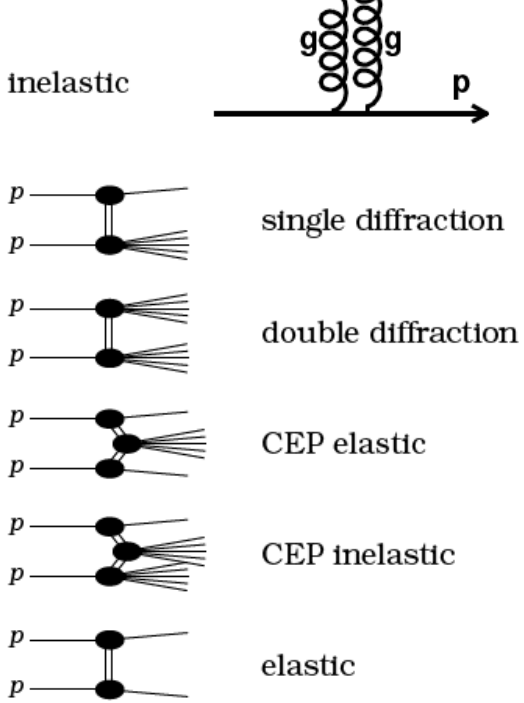
Central Exclusive Production of J/ψ & $\psi(2S)$

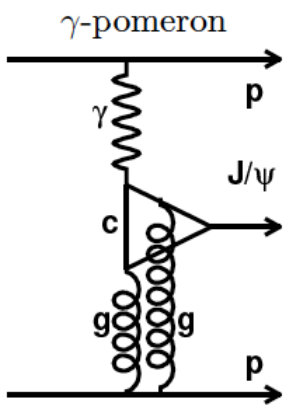
LHCb CONF 2016_007

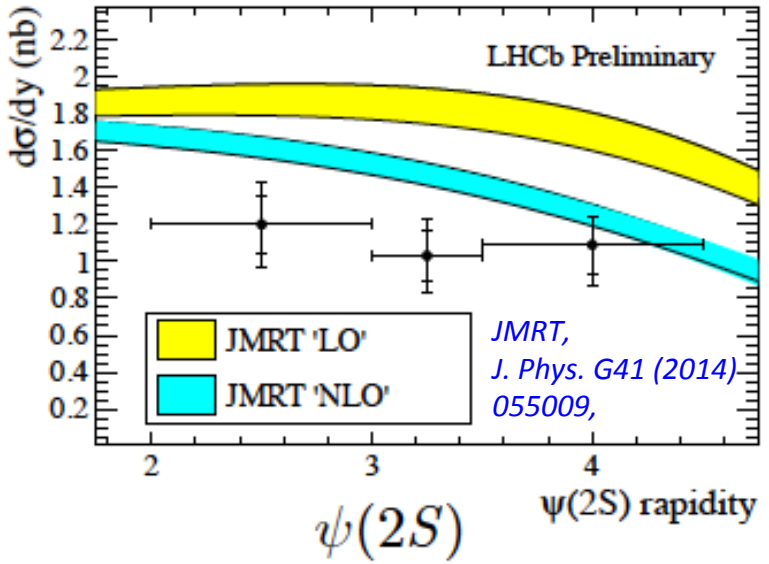
New data at $\sqrt{s}$ = 13 TeV allows to explore up to W = $\sqrt{s_{\gamma p}} \approx$ 2 TeV

RUN II upgrade HERSCHEL (High Rapidity Shower Counter) helps to reject inelastic Backgrounds

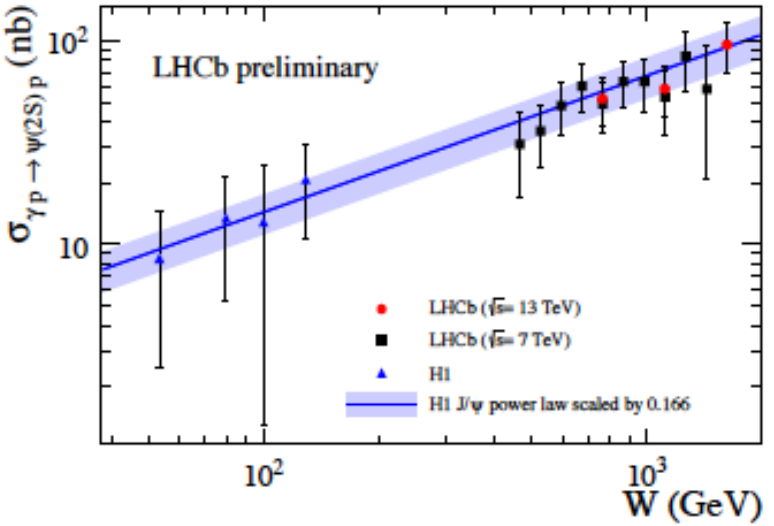








JMRT, J. Phys. G41 (2014) 055009,



More info on J.P Ilten MPI'2016

Conclusions

- Rich set of new QCD results from LHC RUN I & II
- ALICE highlights in the High Multiplicity final states of small systems
  - interpretation of the results still controversial: MPI, QGP, CGC, interplays
- LHCb highlights in the measurement of HF production x-sections
  - Status of the art measurements of the high p_T MPI rates