Sapore Gravis Workshop
Padova, 9-12 December 2014

Event activity dependence of open heavy flavour and quarkonia in pp and p-Pb collisions at the LHC.

D. Caffarri (CERN)

Padova, 10/12/14

Outlook

- Physics motivations

- Study of particle production vs average multiplicity
  - J/ψ and Υ vs multiplcity in pp collisions
  - D mesons vs multiplicity in pp collisiosn
  - D mesons vs multiplicity in p-Pb collisiosn
  - J/ψ and Υ vs multiplcity in p-Pb collisions

- Study of particle production vs (the best knowledge we have of) centrality
  - D mesons Q_{pPb}
  - J/ψ and $\psi(2S)$ Q_{pPb}

Motivation

- **In pp collisions**:
  - high multiplicity collisions mainly come from Multi Parton Interactions (MPIs)
  - study MPIs at the LHC where they might give a relevant contributions to particle prdocution.

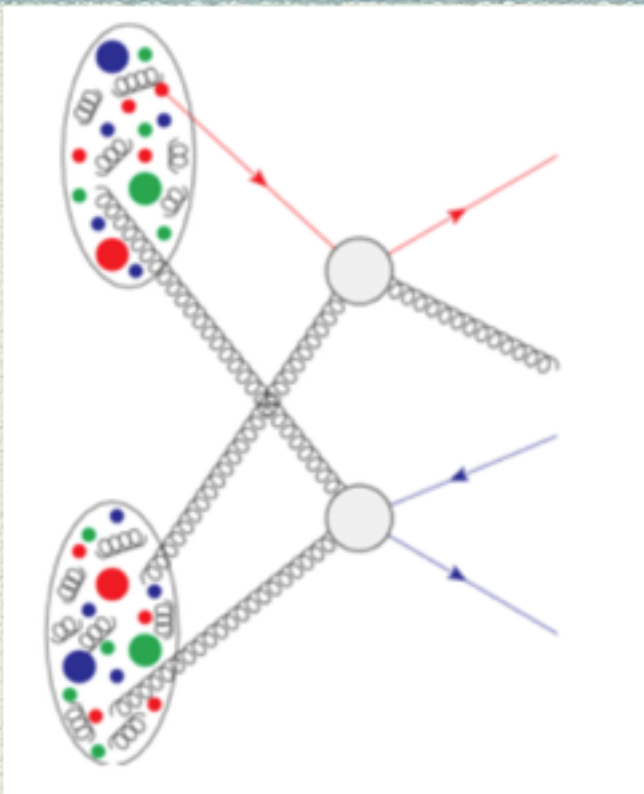
- **In p-Pb collisions**:
  - similarity between high multiplicity pp and p-Pb collisions?
  - study of CNM effects in different multiplicity environment
  - study of the p_T spectra modifications in high/low multiplicity p-Pb collisions vs pp ones.

Motivation

- **Multi-Parton Interactions at the LHC ?**
  - MPIs are expected to play an important role at LHC energies:
    - CMS measurement of jets and underlying events show a better agreement with models including MPIs

      Eur. Phys. J C73 (2013) 2674
    - ALICE measurement of mini-jets shows an increase of MPI contribution with increasing charged particle multiplicity

      JHEP 09 (2013) 049



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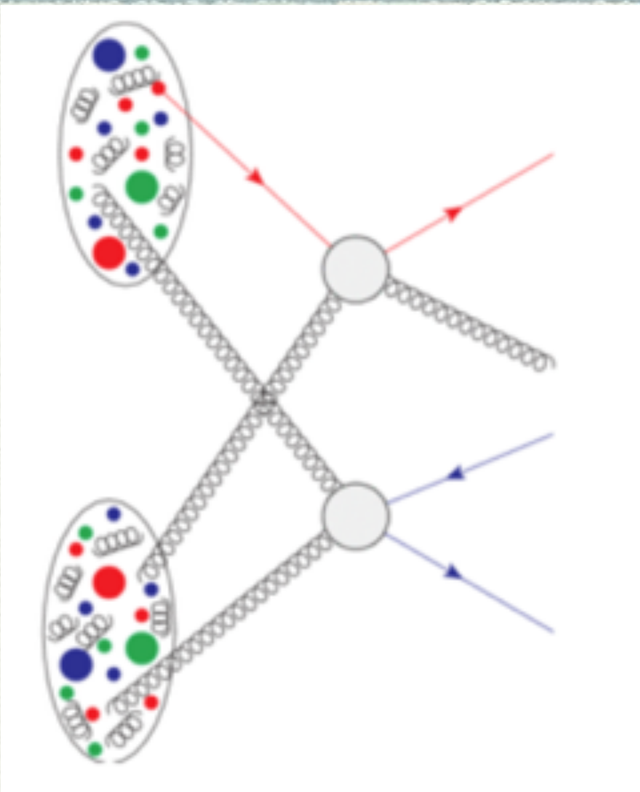
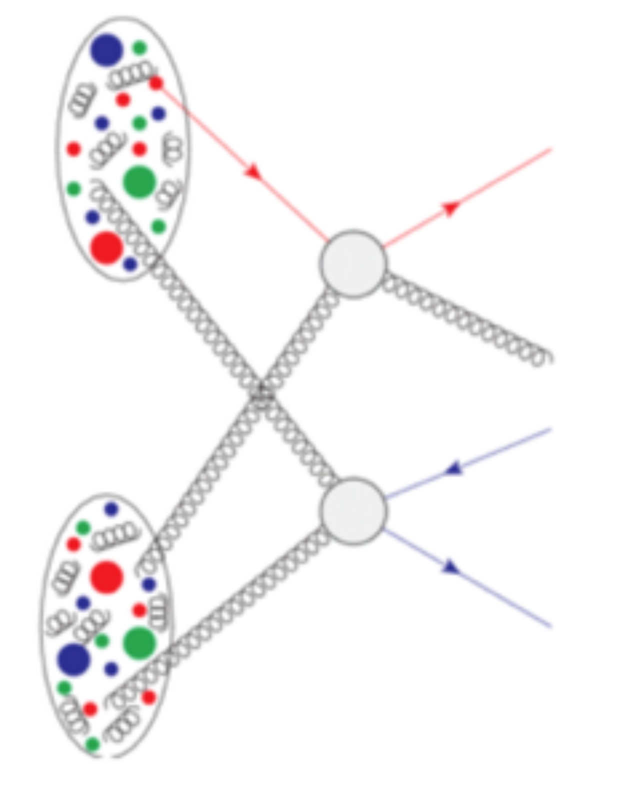


- **MPIs and heavy-flavour ?**
  - NA27 measured that events with charm production have larger charged particle multiplicity (pp collisions, $\sqrt{s} = 28$ GeV) Z. Phys C41:!91
  - LHCb measured double charm production that shows a better agreement with models including double parton scatterin J. High Energy Phys., 06 (2012) 141

Motivation



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- **Sapore Gravis 2013 Sarah Porteboeuf-Houssais's talk:**

https://indico.cern.ch/event/247609/session/6/contribution/66/material/slides/1.pdf

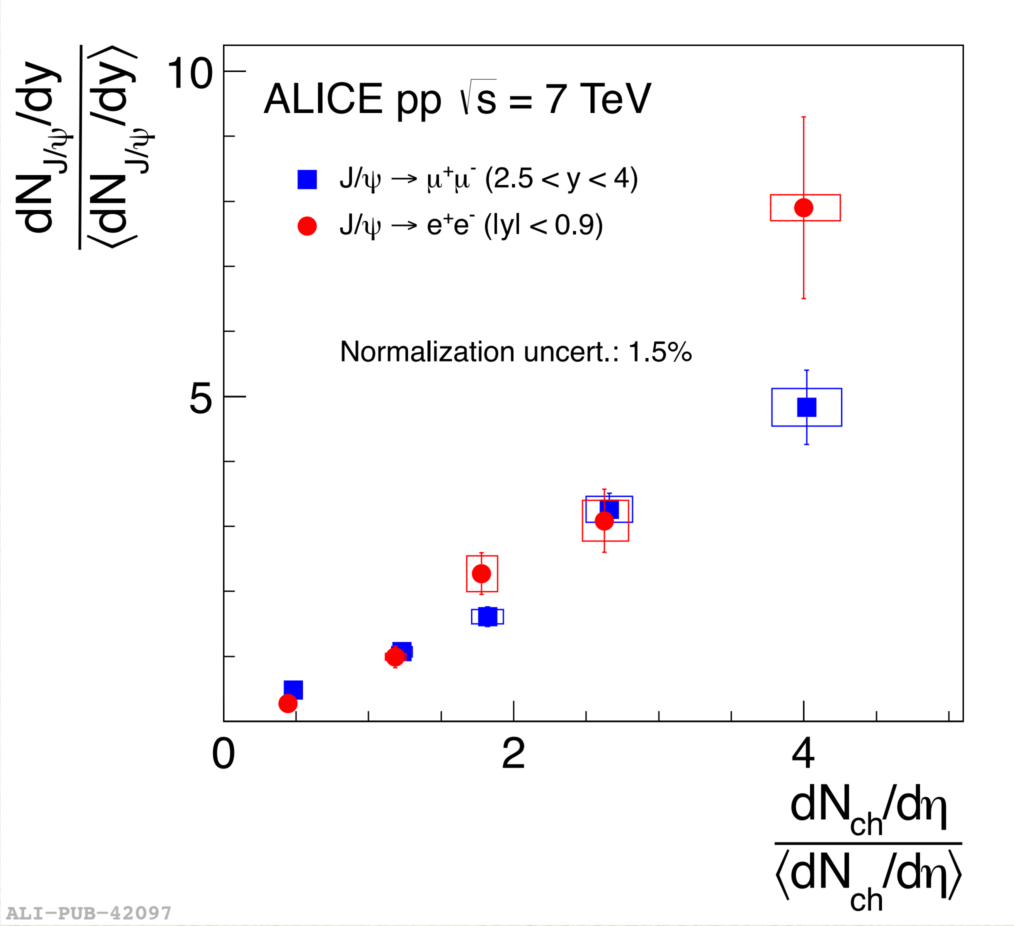
Analyses vs average multiplicity

Observables:

- "y axis": self-normalized yields in multiplicity intervals relative to the multiplicity integrated ones

$$\frac{d^2N/dp_T dy}{< d^2N/dp_T dy >} = \frac{(d^2N/dp_T dy)^{mult}/(\epsilon^{mult} \times N^{mult}_{event})}{(d^2N/dp_T dy)^{tot}/(\epsilon^{tot} \times N^{tot}_{event})}$$

- "x axis": average multiplicity in a given multiplicity bin divided by the total average multiplicity
  - Tracks, "tracklets", energy deposit in forward calorimeters, …



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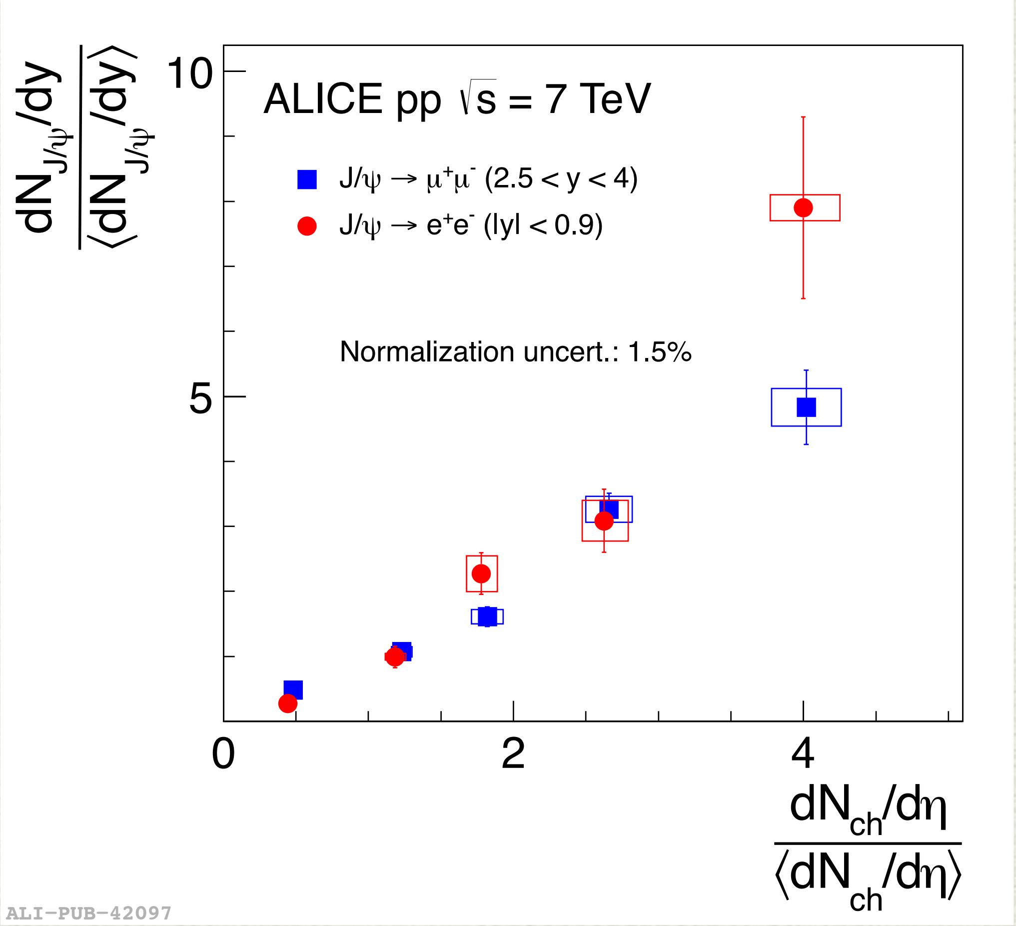
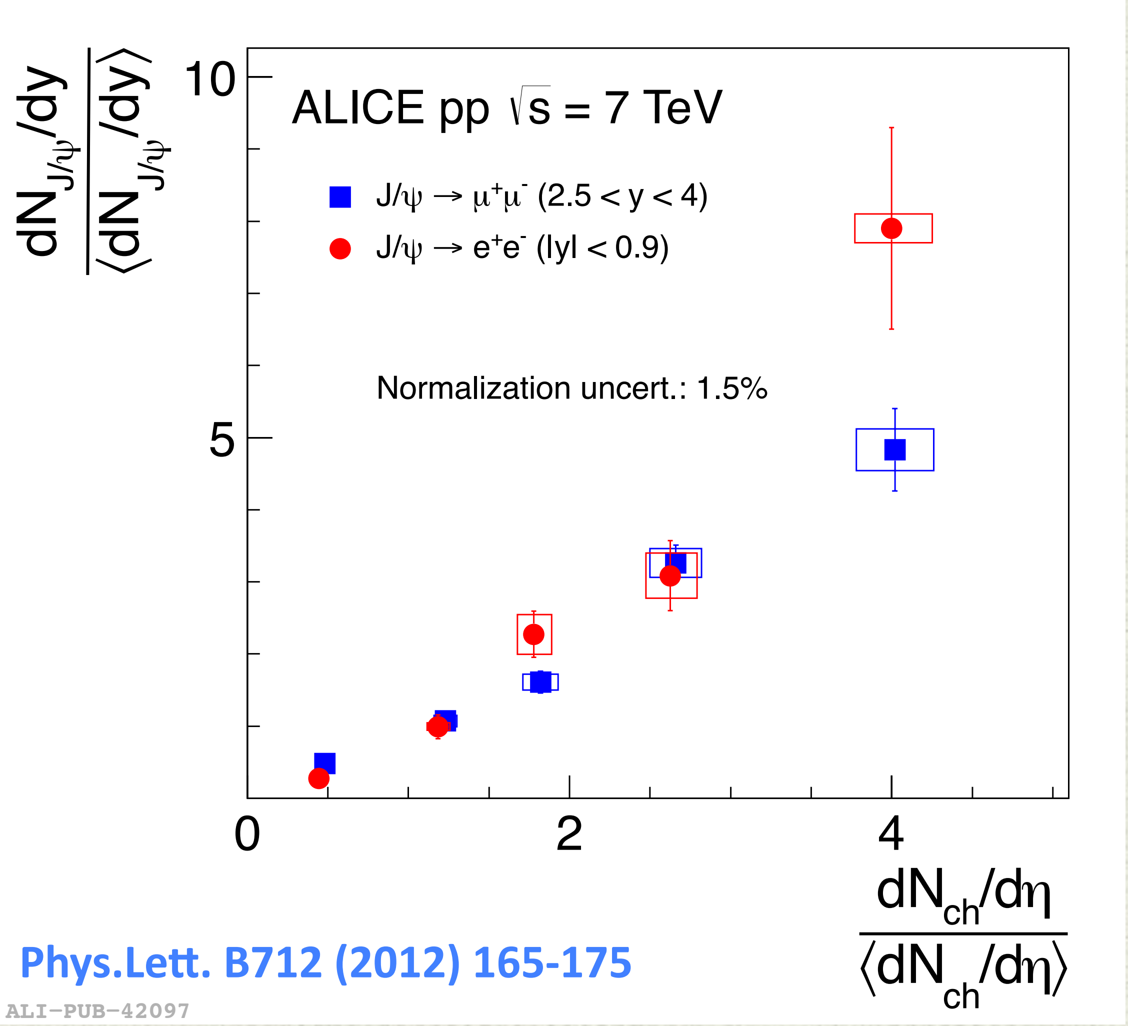


How the rapidity overlap between the measurement and the multiplicity measurement can bias our conclusions?

J/ψ vs mult in pp

J/ψ measured in
- central rapidity region
  - |y| < 0.9
  - $p_T > 0$
- forward rapidity region
  - 2.5 < y < 4
  - $p_T > 0$

Multiplicity measured in |η| < 1



Phys.Lett. B712 (2012) 165-175

Increase of J/ψ yields with charged particle multiplicity:
J/ψ production in pp collisions connected with strong hadronic activity ?
J/ψ production enhanced due to MPI ?

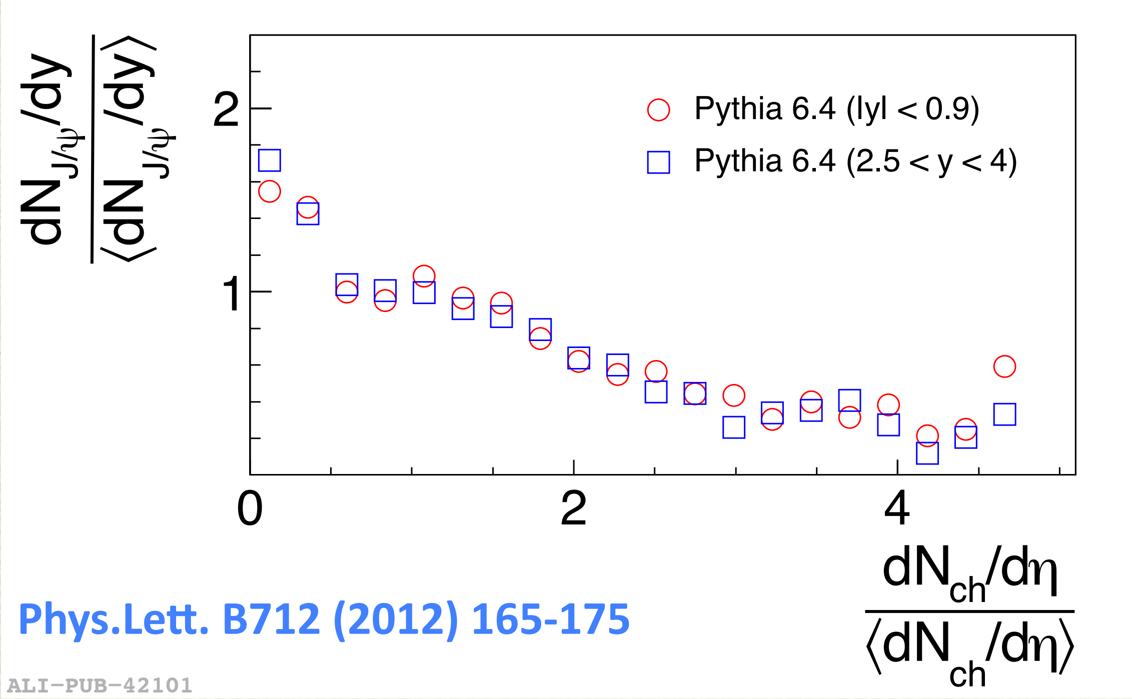
J/ψ vs mult in pp:

PYTHIA 6

J/ψ measured in

- **central rapidity region**
  - $|y| < 0.9$
  - $p_T > 0$
- **forward rapidity region**
  - $2.5 < y < 4$
  - $p_T > 0$

Multiplicity measured in $|\eta| < 1$



Pythia 6.4 with only first hard processes as mechanisms of charm production.
No contributions from MPI nor clusters formation processes.

Clear difference w.r.t PYTHIA 6 with only first hard processes

J/ψ vs mult in pp

J/ψ measured in

- central rapidity region
  - |y| < 0.9
  - $p_T > 0$
- forward rapidity region
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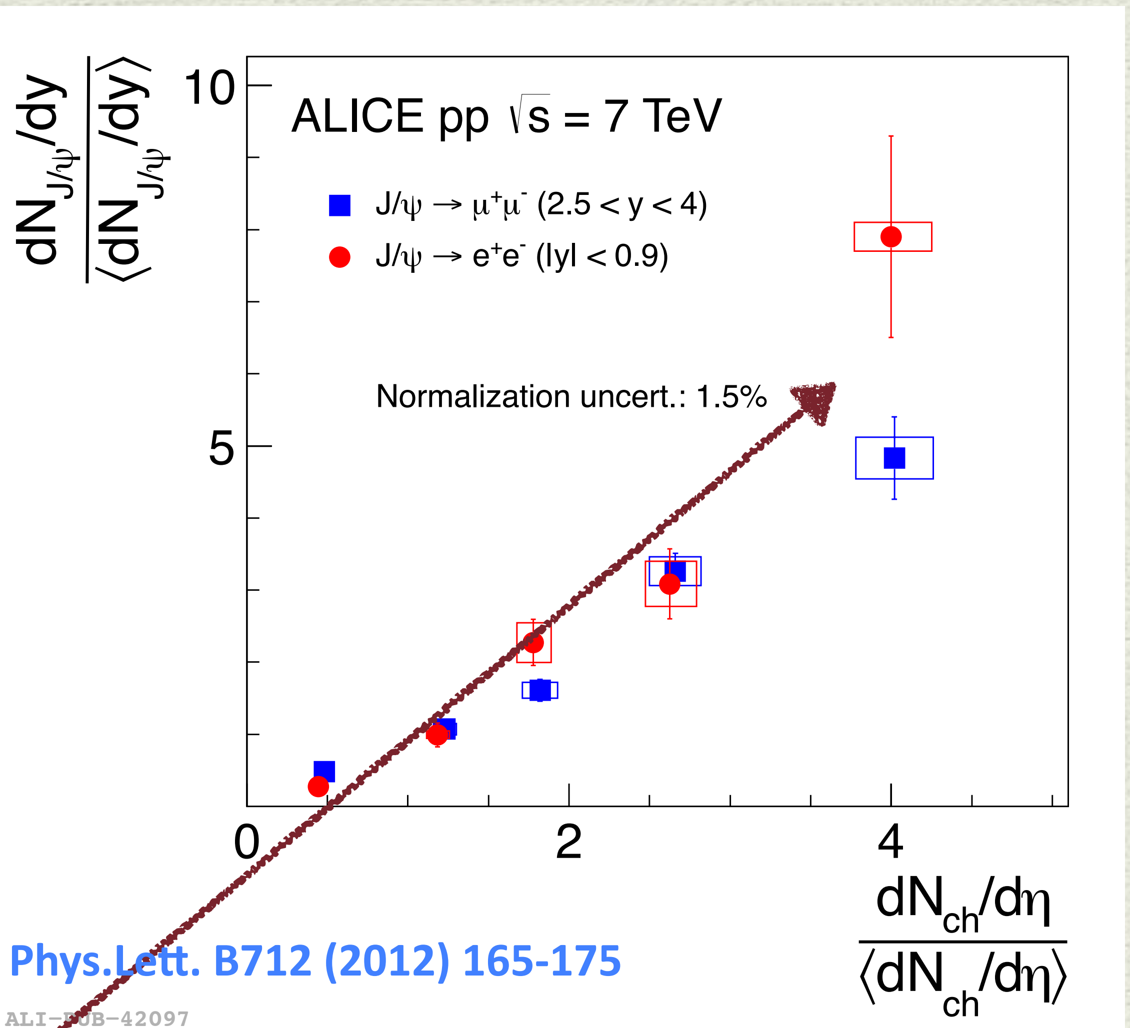

Phys.Lett. B712 (2012) 165-175

1. Do we have a difference in the highest multiplicity bin?

J/ψ vs mult in pp

Ferreiro, Pajares
Phys. Rev. C86 (2012) 034903

J/ψ measured in

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  - $|y| < 0.9$
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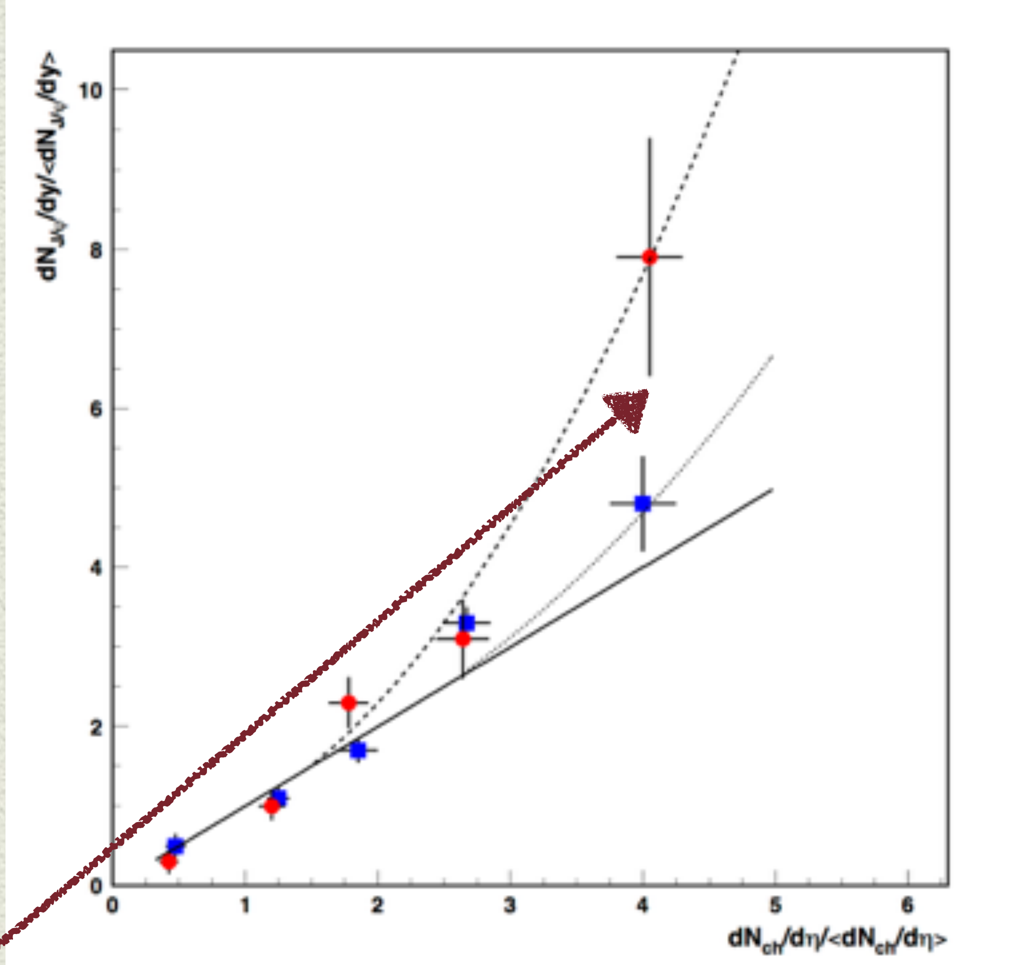

1. Do we have a difference in the highest multiplicity bin?
Trend seems to be reproduced with coherence effect for pp collisions but uncertainties of the measurement are still large.

J/ψ vs mult in pp

J/ψ measured in

- central rapidity region
  - $|y| < 0.9$
  - $p_T > 0$
- forward rapidity region
  - $2.5 < y < 4$
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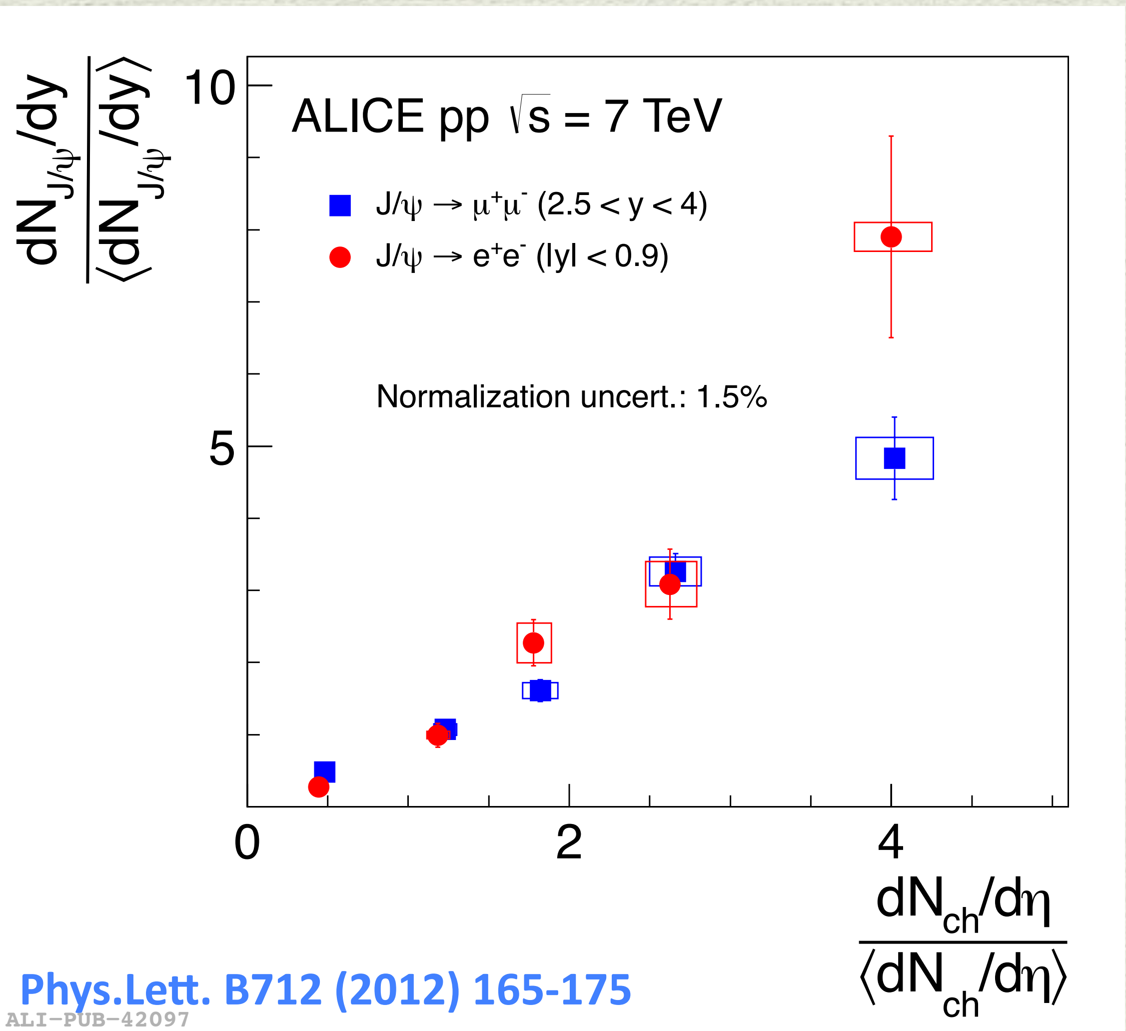
Multiplicity measured in $|\eta| < 1$



Phys.Lett. B712 (2012) 165-175

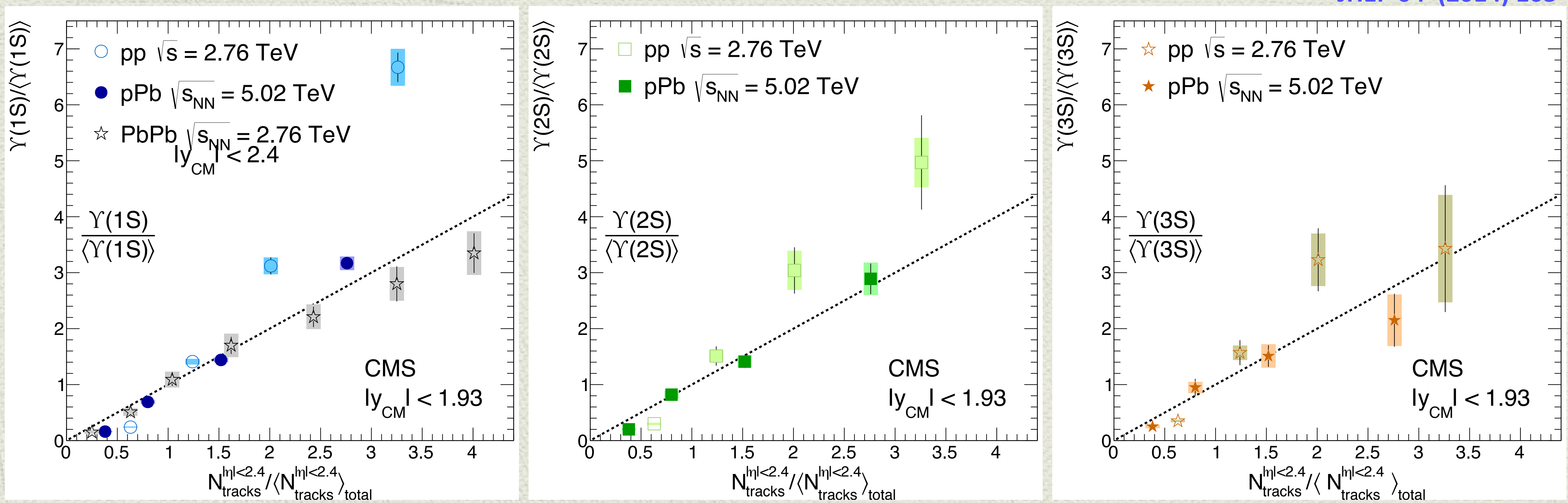
1. Do we have a difference in the highest multiplicity bin?
2. p_T dependence of the measurement? Analysis with higher statistics?
3. “Decoupling” measurement and multiplicity determination (different η) ?

Υ vs mult in pp

Υ(1S), Υ(2S), Υ(3S) measured in
- central rapidity region
  - $|y| < 1.93$
  - $p_T > 0$

Multiplicity measured in $|\eta| < 2.4$
same rapidity range as the measurement

JHEP 04 (2014) 103



Increasing trend vs charged particle production in particular for Υ(1S)

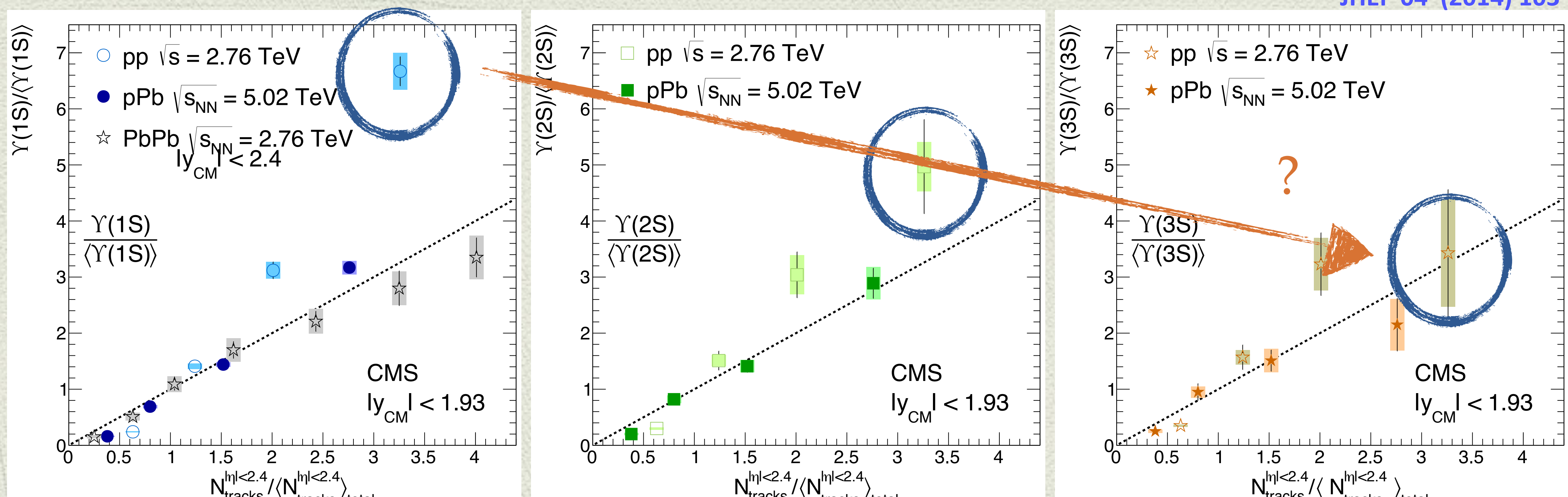
ϒ vs mult in pp

ϒ(1S), ϒ(2S), ϒ(3S) measured in

- central rapidity region
  - |y| < 1.93
  - $p_T > 0$

Multiplicity measured in |η| < 2.4
same rapidity range as the measurement

JHEP 04 (2014) 103



Higher ϒ states less produced in very high-mulitplicity environment than the ground state?

Υ vs mult in p-Pb

JHEP 04 (2014) 103

Υ(1S), Υ(2S), Υ(3S) measured in
- central rapidity region
  - $|y| < 1.93$
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Multiplicity measured in $|\eta| < 2.4$
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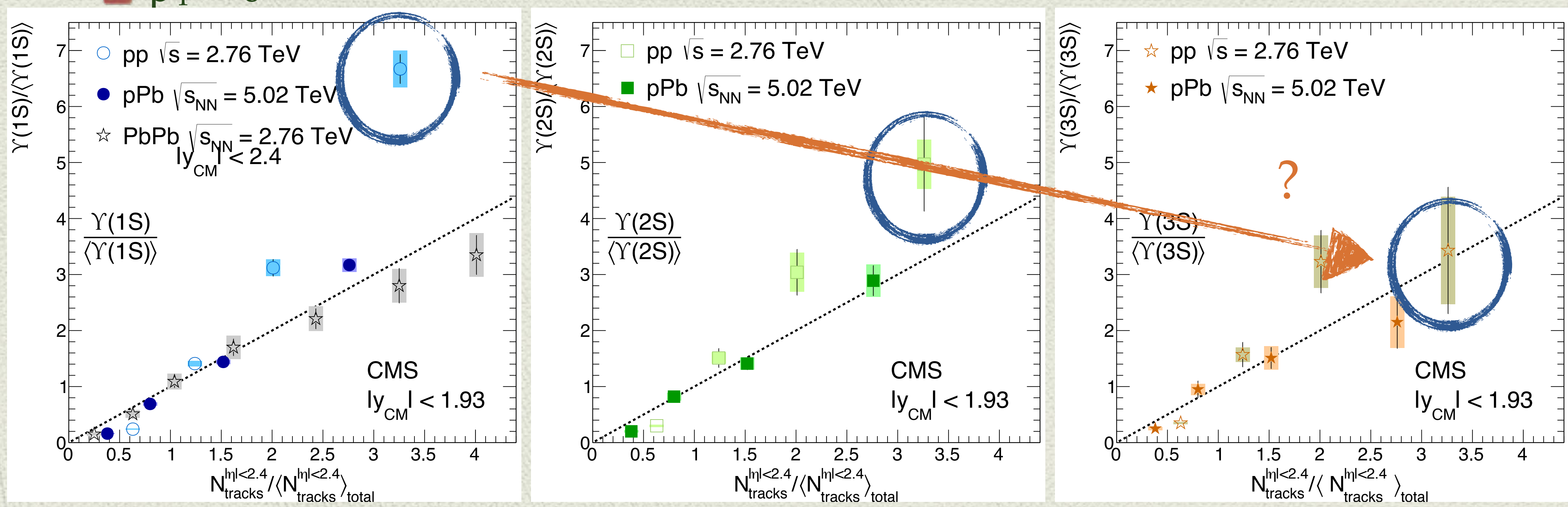


Υ(1S) produced with more particles than the excited states? or excited states are broken in high-multiplicity environment?

ϒ vs mult in pp

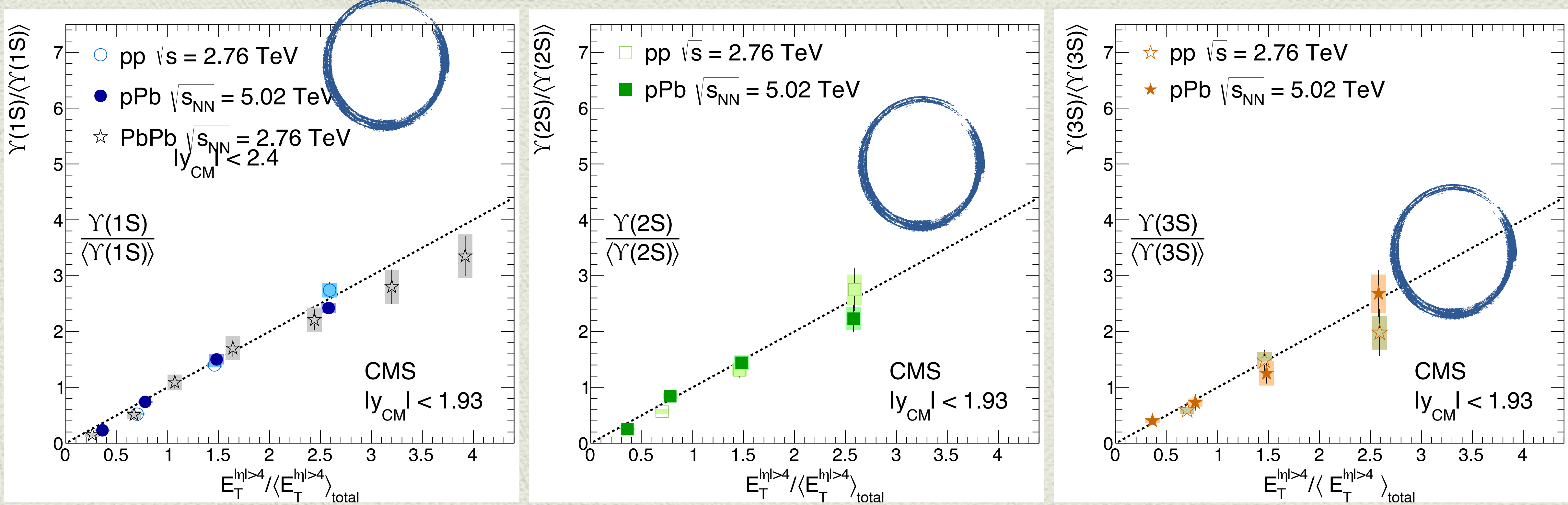
ϒ(1S), ϒ(2S), ϒ(3S) measured in

- central rapidity region
  - | y | < 1.93
  - $p_T > 0$

JHEP 04 (2014) 103

Multiplicity measured in 4 < | η | < 5.2

different rapidity range than the measurement



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Υ(1S), Υ(2S), Υ(3S) measured in

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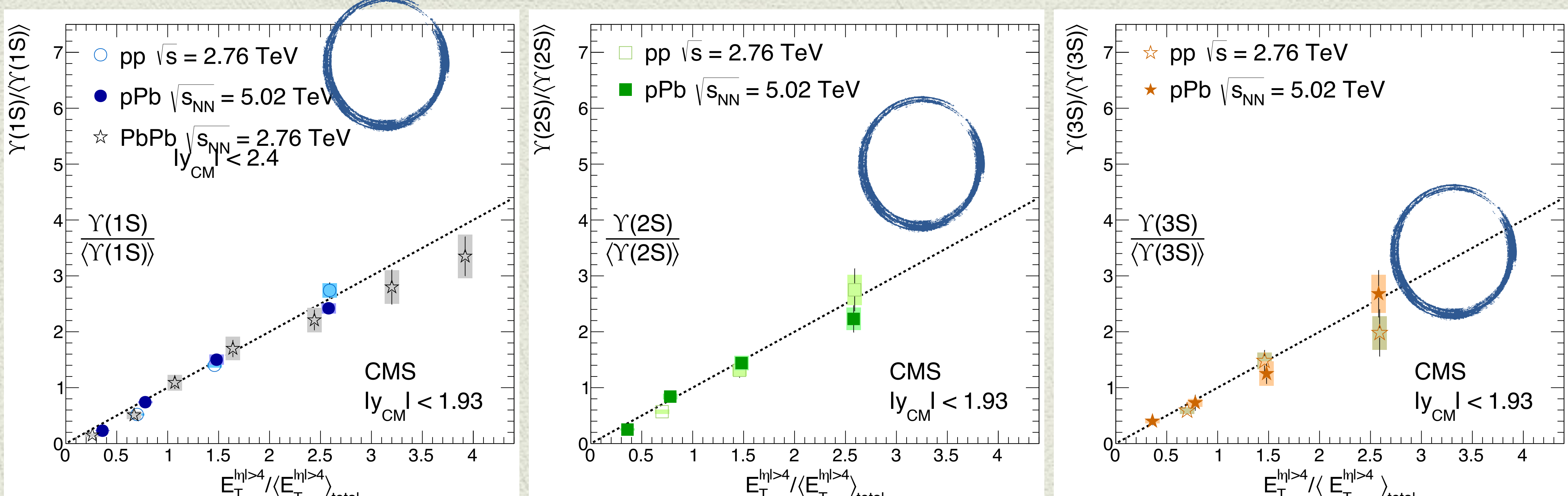
JHEP 04 (2014) 103

Multiplicity measured in 4 < |η| < 5.2

different rapidity range than the measurement



Relative multiplicity at mid or forward rapidity seem to show different trend. Difference due to the different degree of correlation with the region of the measurement ?

J/ψ and Υ vs mult in pp

Phys.Lett. B712 (2012) 165-175

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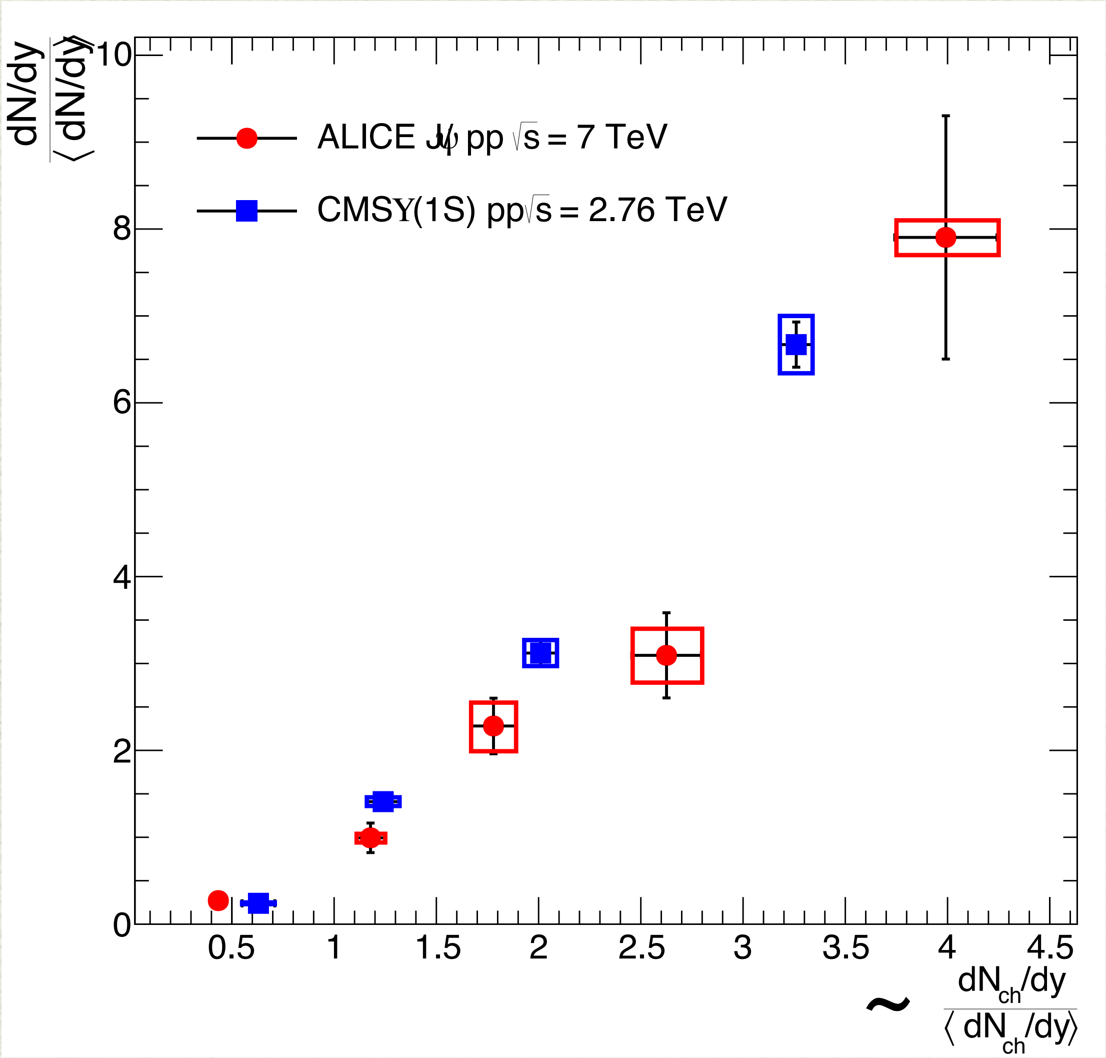
Υ(1S) measured in

- central rapidity region
  - |y| < 1.93
  - $p_T > 0$

J/ψ measured in

- central rapidity region
  - |y| < 0.9
  - $p_T > 0$

For both measurements the multiplicity is measured in the central region



Similar pattern for Υ(1S) and J/ψ in central rapidity production for pp collisions??

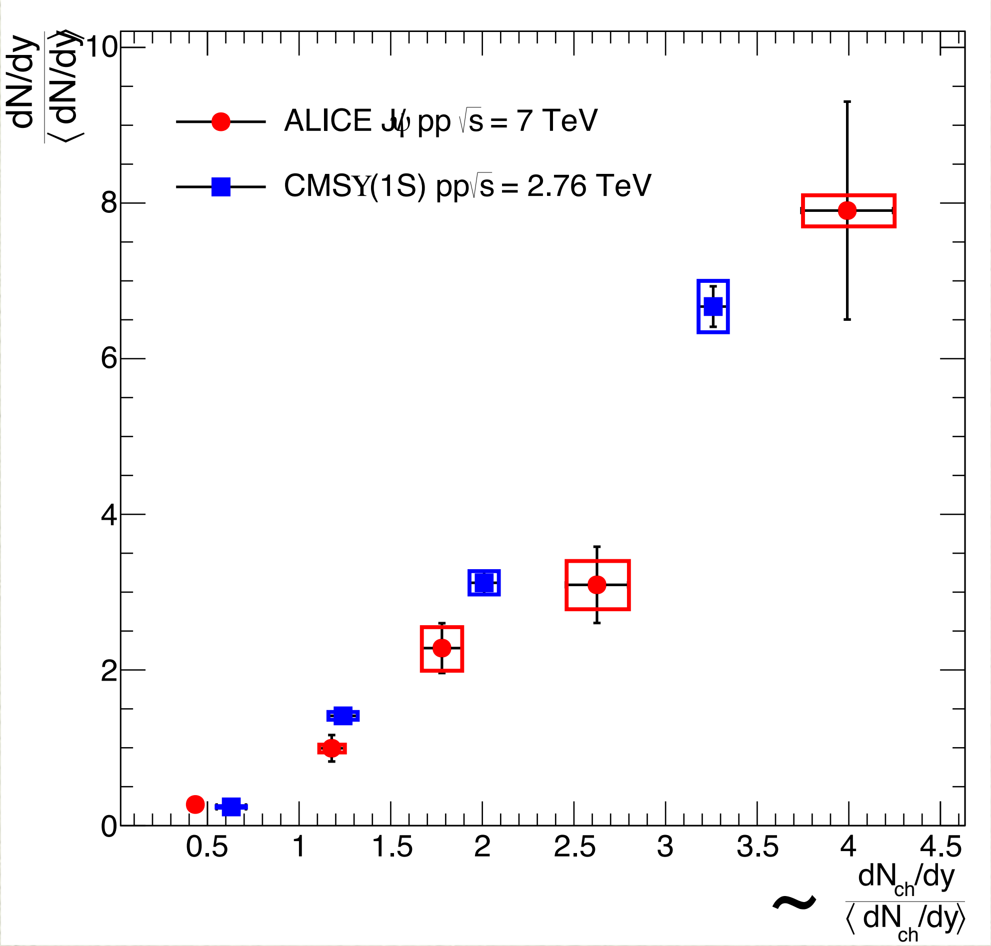
Wrap up(I): quarkonia in pp

- Both J/ψ and ϒ show an increase of the yield vs particle produced in the event.

- For J/ψ the yields seems to increase with a stronger than linear trend, even if uncertainties are still large at high multiplicity

- ϒ show a different trend depending on the η range where the multiplicity is measured

- Similar increase for J/ψ and ϒ when the measurement is done in same "conditions" (central η region for -onia reconstruction and multiplicity measurement) ?

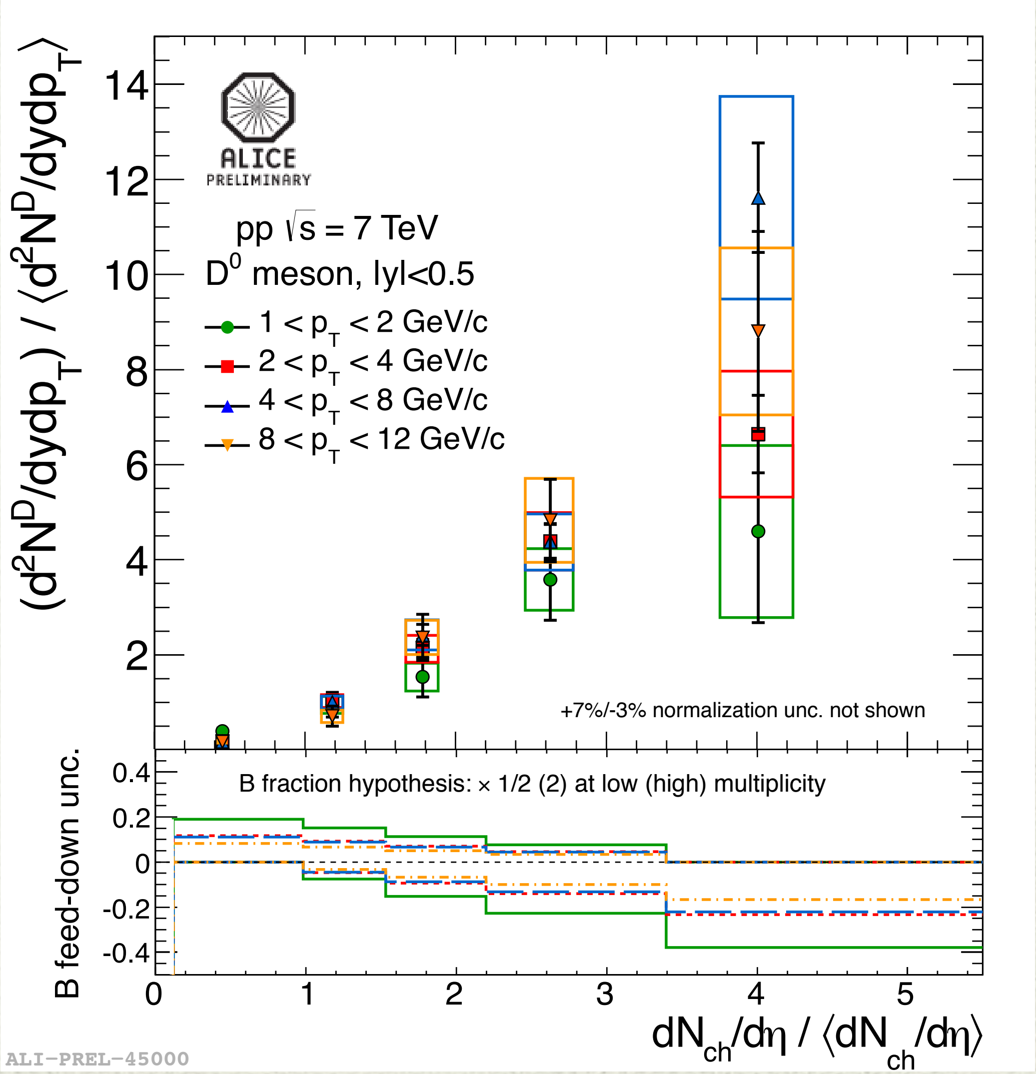


D mesons vs mult in pp

D mesons measured in

- central rapidity region
  - $|y| < 0.9$
  - $1 < p_T < 12$ GeV/c

Multiplicity measured in $|\eta| < 1$



- Self-normalized D-meson yields in different p_T bins are in agreement within uncertainties. **No clear p_T trend observed.**

- Results show an **increase of the yield with charged-particle production**.

Trend of increase. Linear? Polynomial increase?
What do we learn from the trend of the increase?

D mesons and J/ψ

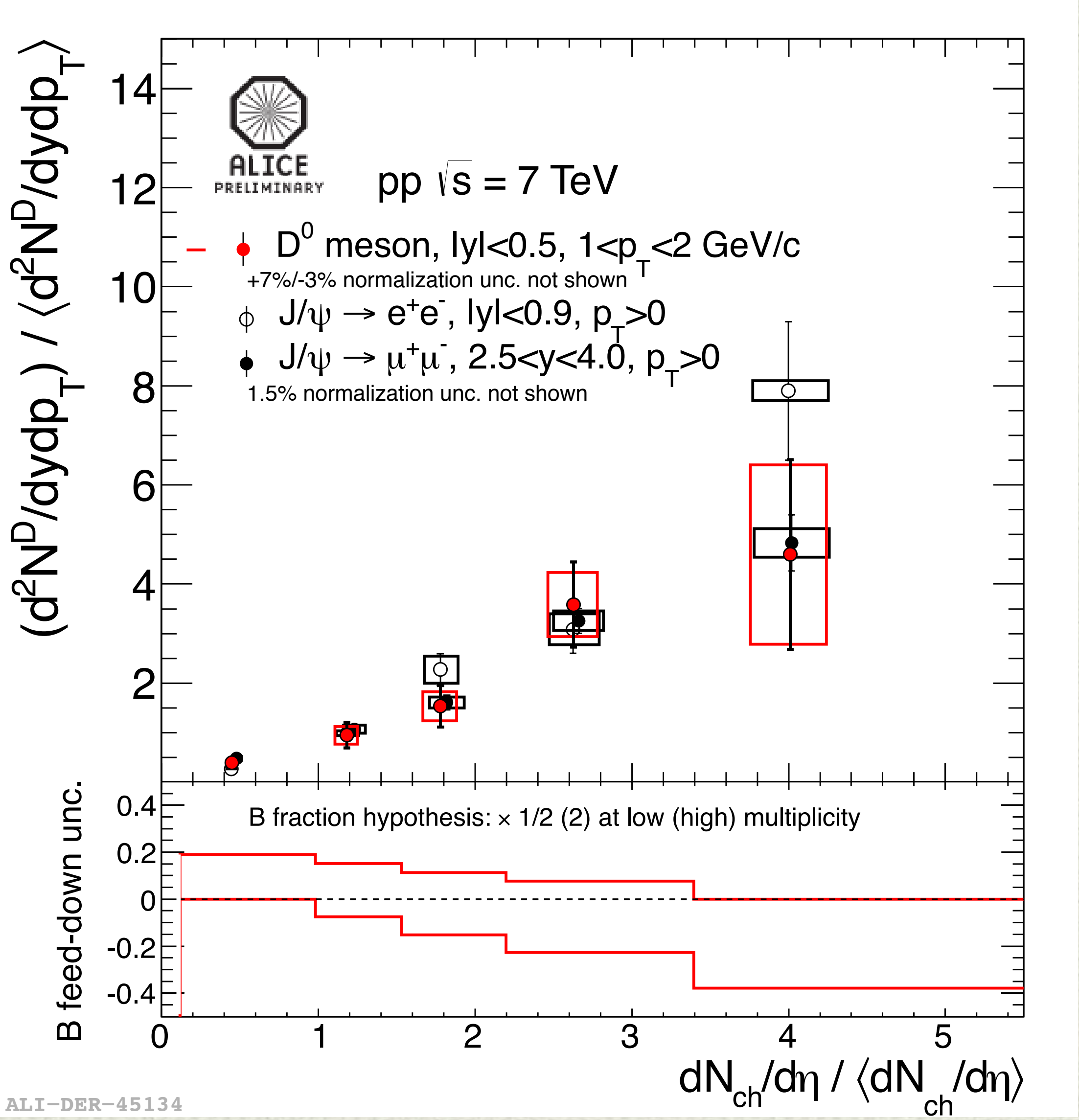
D mesons measured in

- central rapidity region
  - $|y| < 0.9$
  - $1 < p_T < 12$ GeV/c (full range)

J/ψ measured in

- central rapidity region
  - $|y| < 0.9$
  - $p_T > 0$
- **forward rapidity region**
  - **$2.5 < y < 4$**
  - **$p_T > 0$**

Multiplicity measured in $|\eta| < 1$



Increasing trend vs charged particle production for D mesons and J/ψ observed also with a similar magnitude

D mesons and Non-prompt J/ψ

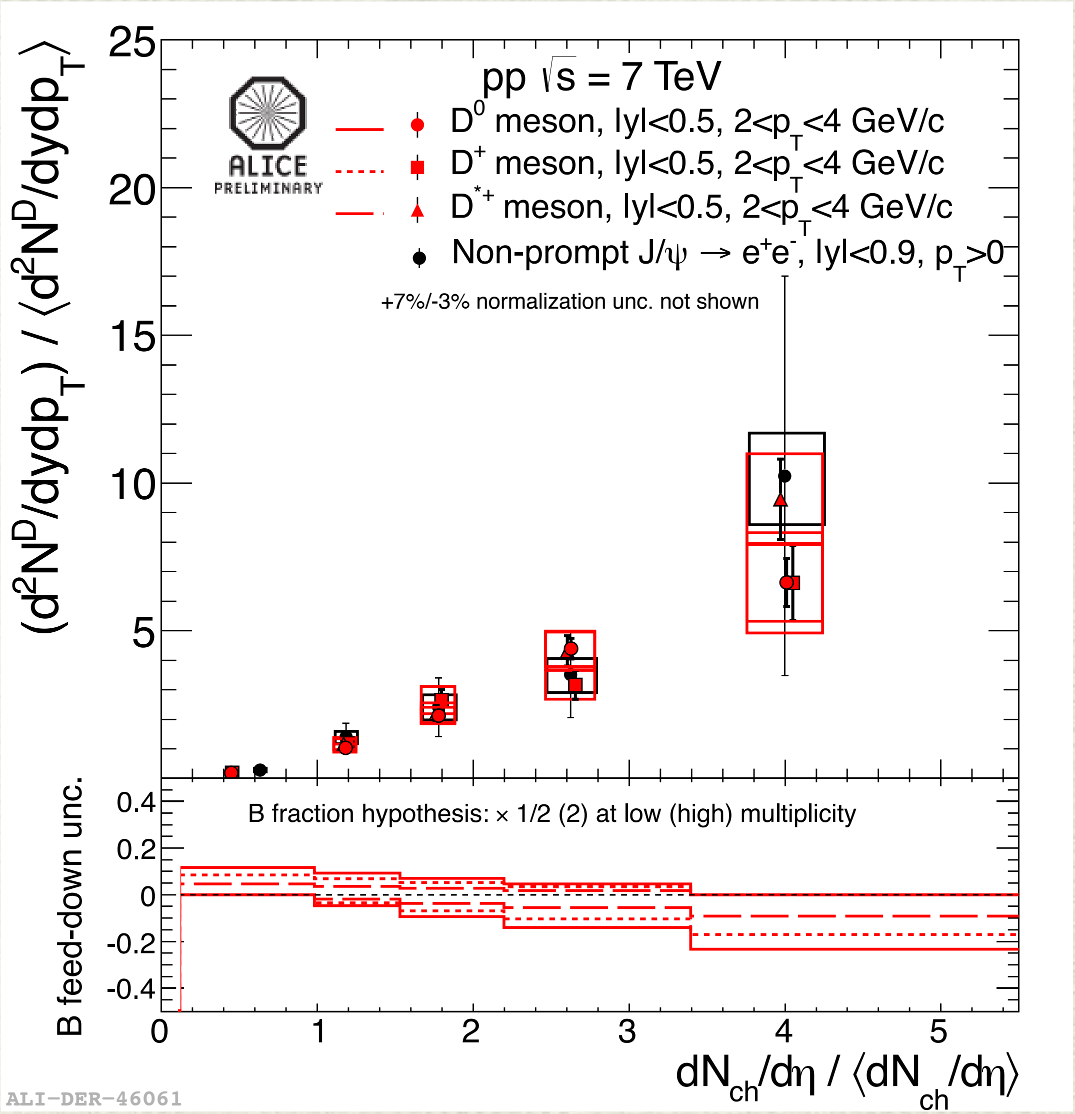
D mesons measured in

- central rapidity region
  - $|y| < 0.9$
  - $1 < p_T < 12$ GeV/c (full range)

Non-prompt J/ψ mesons measured in

- central rapidity region
  - $|y| < 0.9$
  - $p_T > 0$

Multiplicity measured in $|\eta| < 1$



Very similar increase of the yield with charged-particle production for D mesons and non-prompt J/ψ.

What do we learn from the increasing trend?

HF vs mult in pp

PYTHIA 8

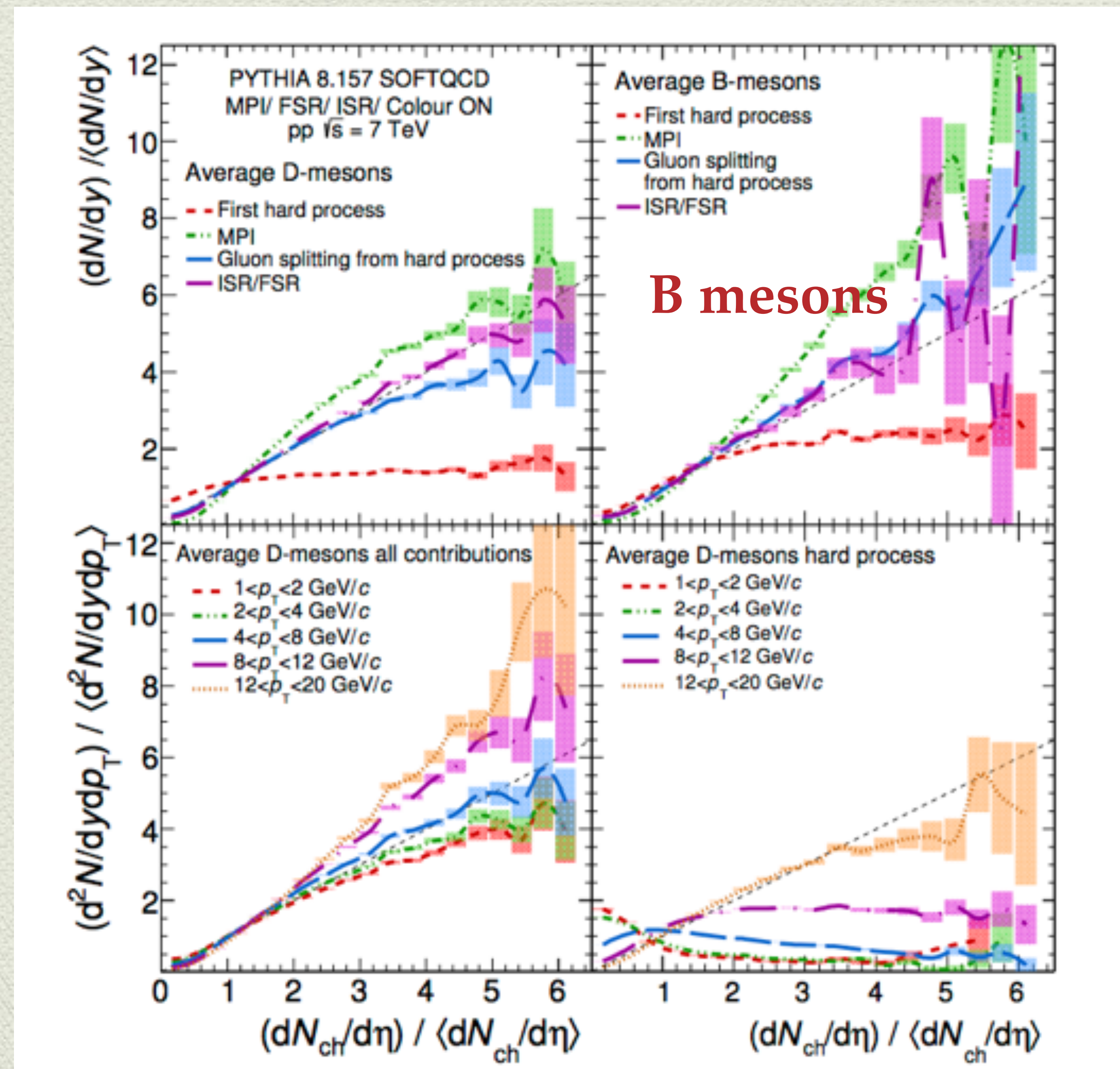
Study done by Sarah Porteboeuf - Houssais

PYTHIA mechanisms of HF production:

1. **First hard process** (gg ➜ $c\bar{c}$, c+u ➜ c+u)
2. **Hard MPI process**
3. **Gluon splitting from hard process** (g ➜ $b\bar{b}$)
4. **Gluon splitting with the gluon coming from ISR/FSR**

	D mesons	B mesons
First Hard	12%	37%
MPI	22%	23%
Gluon Sp	6%	in IRS/FSR
ISR/FSR	60%	40%

D mesons



HF vs mult in pp

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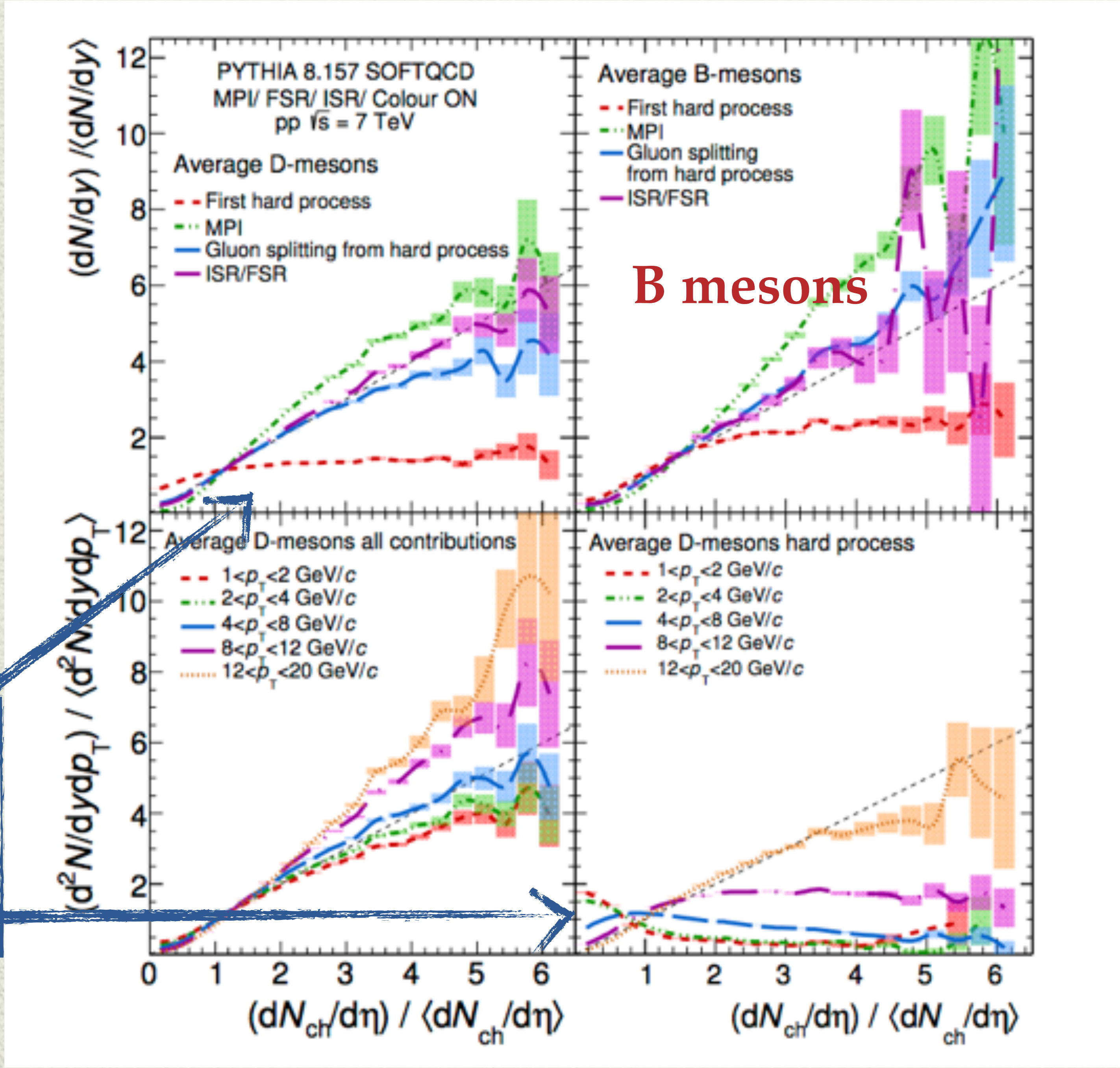
D mesons



In Pythia 8 first hard process independent of multiplicity but dependent on the p_T

HF vs mult in pp

PYTHIA 8

Study done by Sarah Porteboeuf - Houssais

PYTHIA mechanisms of HF production:

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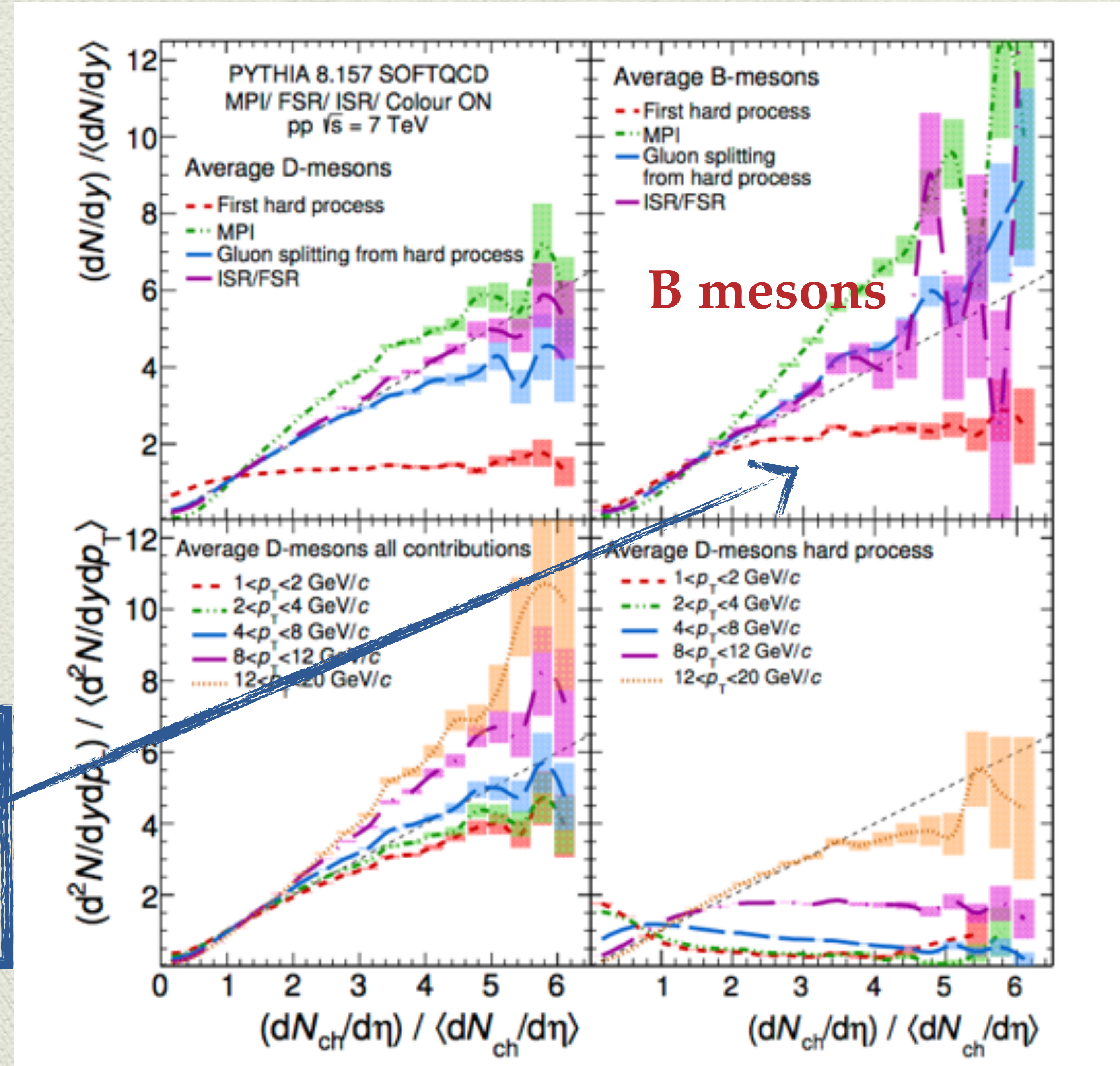
4. **Gluon splitting with the gluon coming from ISR/FSR**

D mesons



B mesons

Similar trend for D and B mesons but different "saturation" threshold

HF vs mult in pp

PYTHIA 8

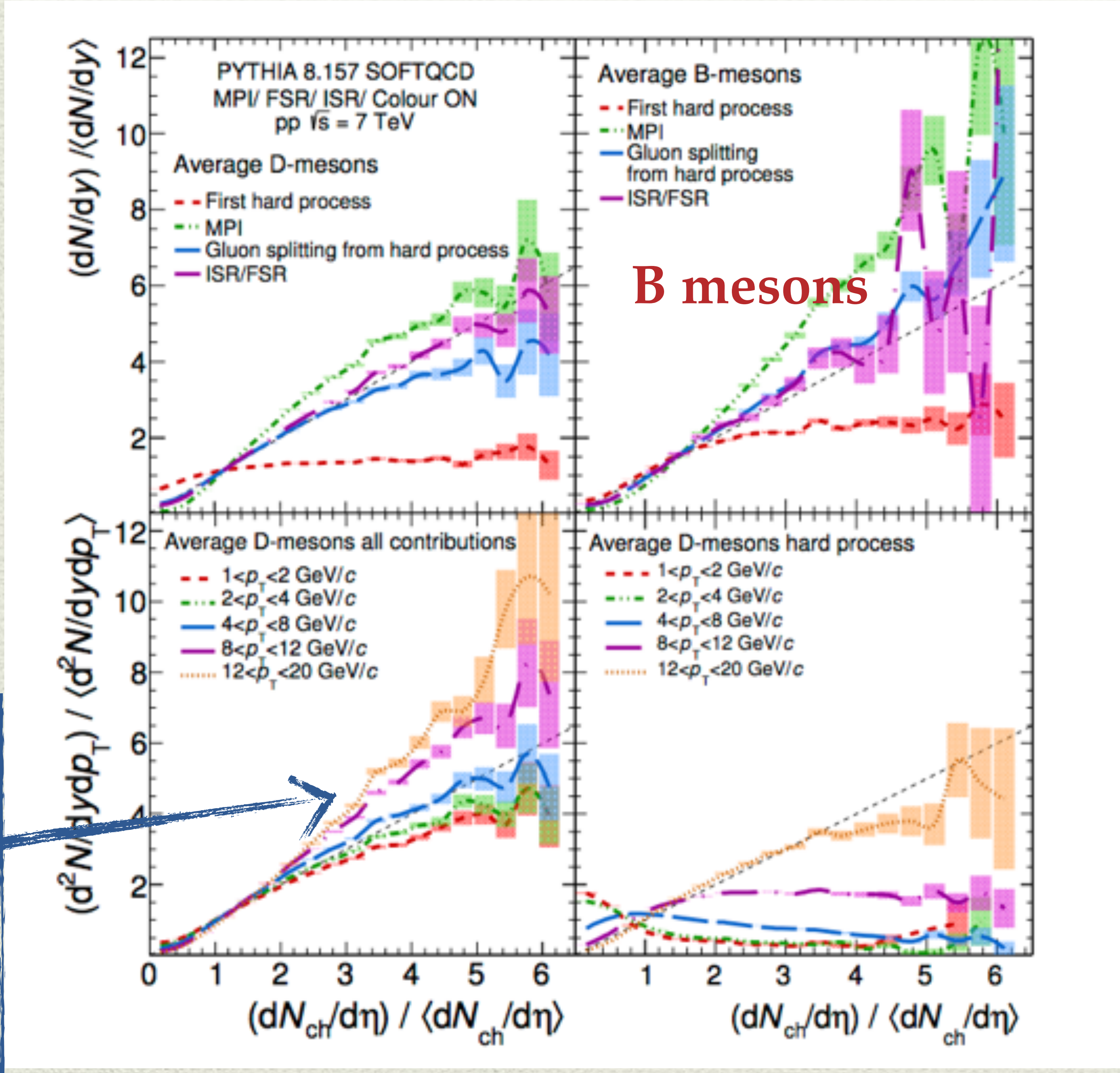
Study done by Sarah Porteboeuf - Houssais

PYTHIA mechanisms of HF production:

1. **First hard process** (gg ➜ $c\bar{c}$, c+u ➜ c+u)
2. **Hard MPI process**
3. **Gluon splitting from hard process** (g ➜ $b\bar{b}$)
4. **Gluon splitting with the gluon coming from ISR/FSR**

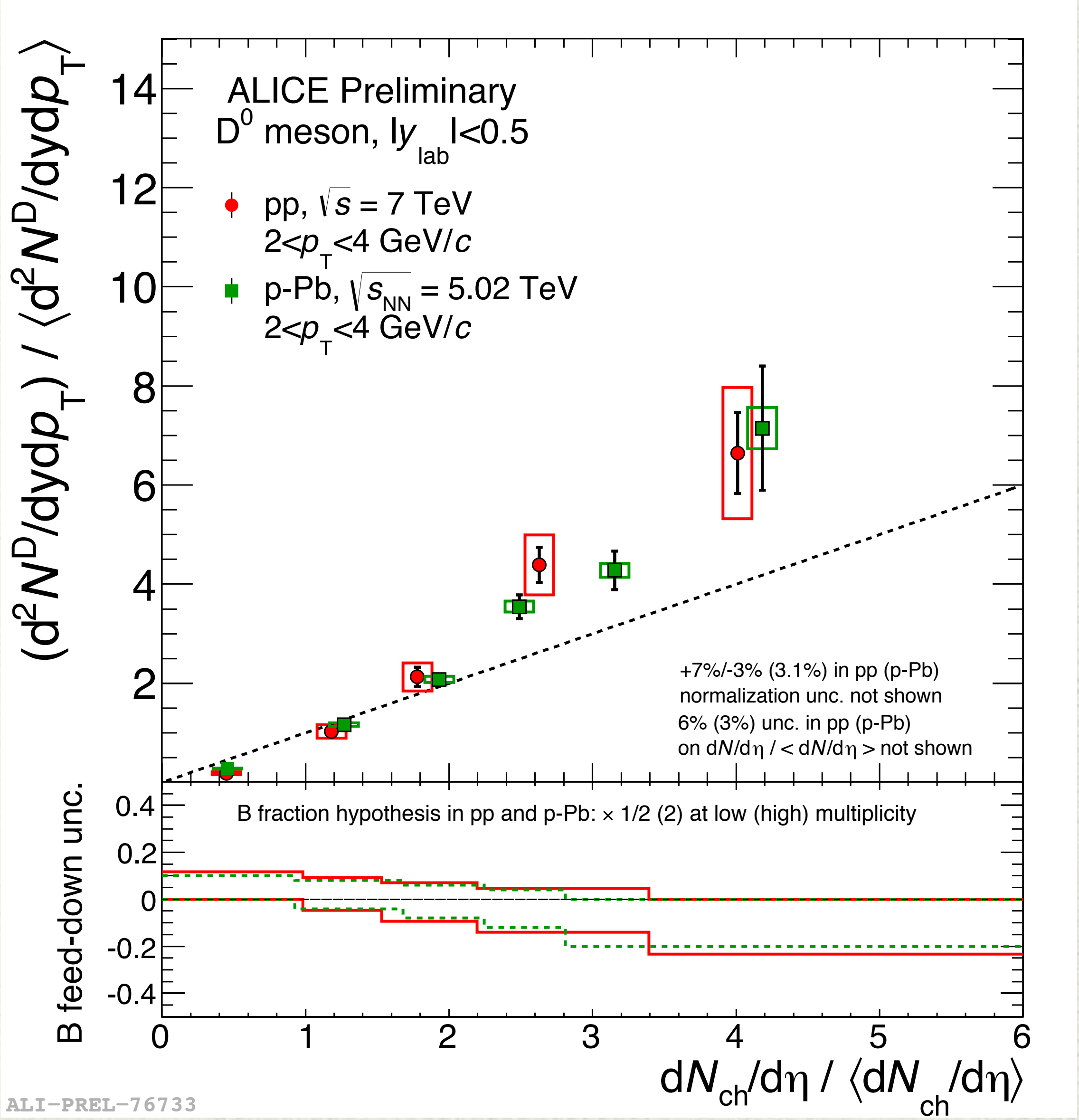
At high multiplicity at p_T ordering is expected for all processes.
For first hard process also at low-multiplicity

D mesons



D mesons vs mult in p-Pb

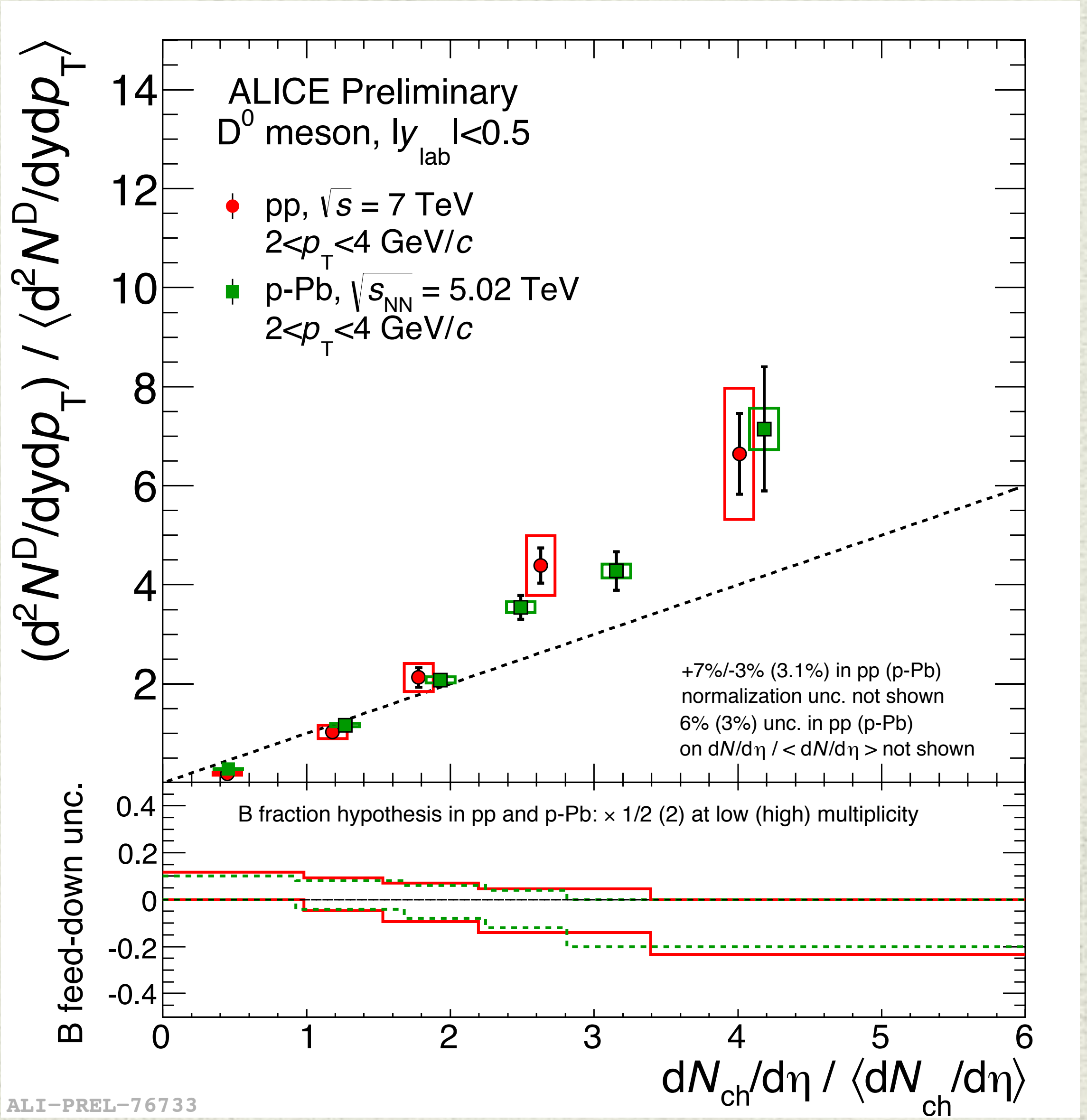
- Similar trend of D-meson production vs multiplicity observed in pp and p-Pb collisions but:
  - **in pp collisions, high multiplicity events come mainly from MPIs,**
  - **in p-Pb collisions, high multiplicity events are originated from collisions with $N_{coll} > 1$**



Similar pattern in pp and pPb suggests that also in pp the underlying physics could be multiple hard collisions

Wrap up (II): D mesons in pp and pPb

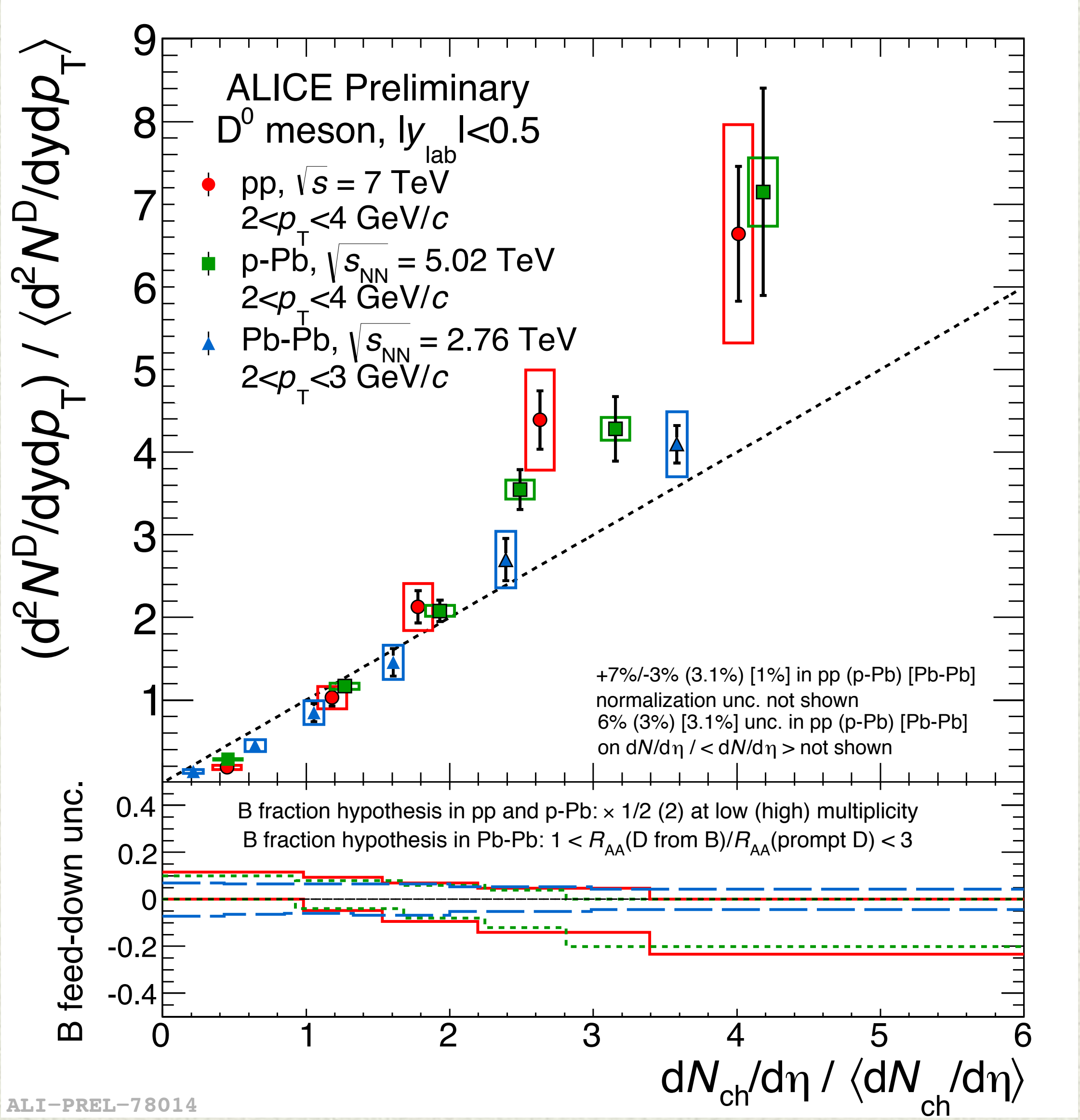
- D mesons show an increase of their yield with the multiplicity produced in the event.
- Similar trend is observed for pp and p-Pb collisions.
- In pp collisions a very similar trend is observed for D mesons, non-prompt J/ψ. Also for inclusive J/ψ the trend is very similar but measurements are in different kinematic regions.
- PYTHIA studies suggest that an increasing trend of the yields cannot be due only to first hard scattering. MPIs or gluon splitting could instead explain this thread. Is this comparable with the results?



D mesons vs mult: pp, p-Pb and Pb-Pb

- The trend seems to be similar also when we compare to Pb-Pb results, but…

  - highest multiplicity bin in Pb-Pb collisions corresponds to 10% of the total cross section, for pp to only 1%.



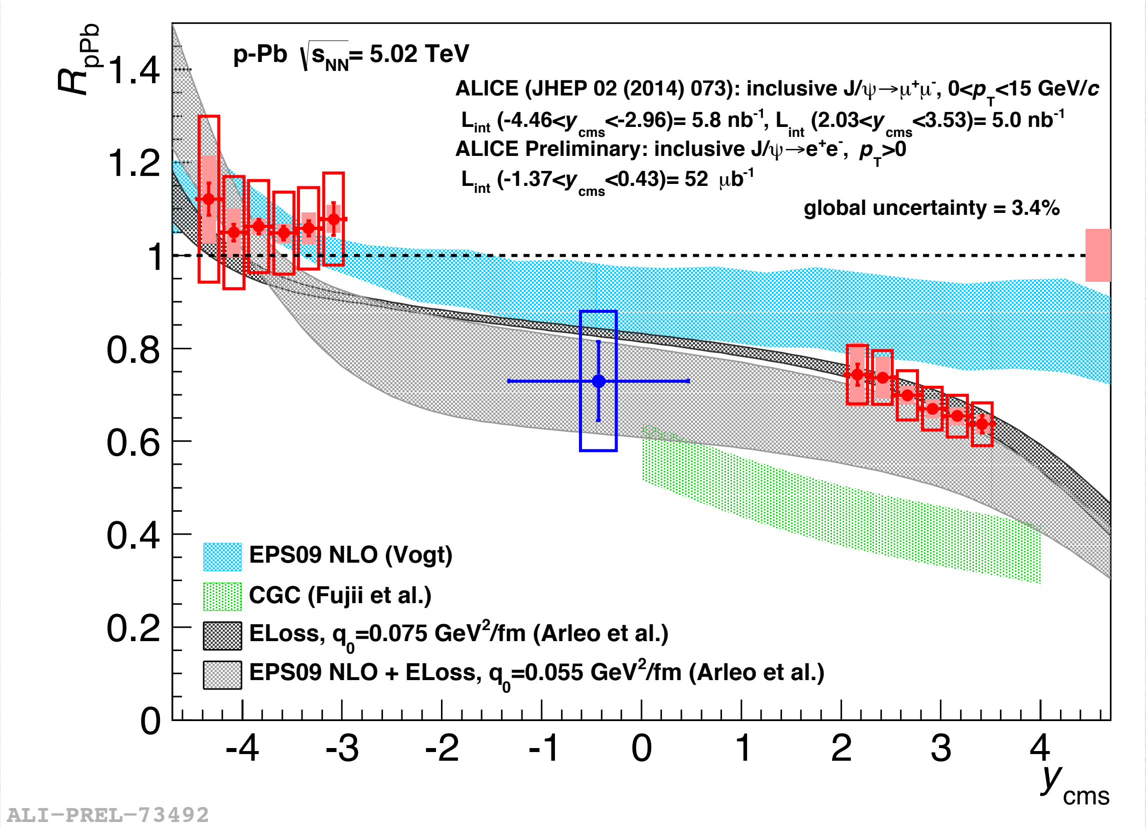
J/ψ in pPb

ALICE

- R_{pPb} multiplicity and momentum integrated:
  - Backward rapidity: small enhancement w.r.t pp collisions.
  - Forward rapidity: ~20% suppression w.r.t pp collisions.
- Results described by the models including shadowing or coherent energy loss.

Talk by Javier Castillo Castellanos

arXiv:!308.6726



J/ψ measured in

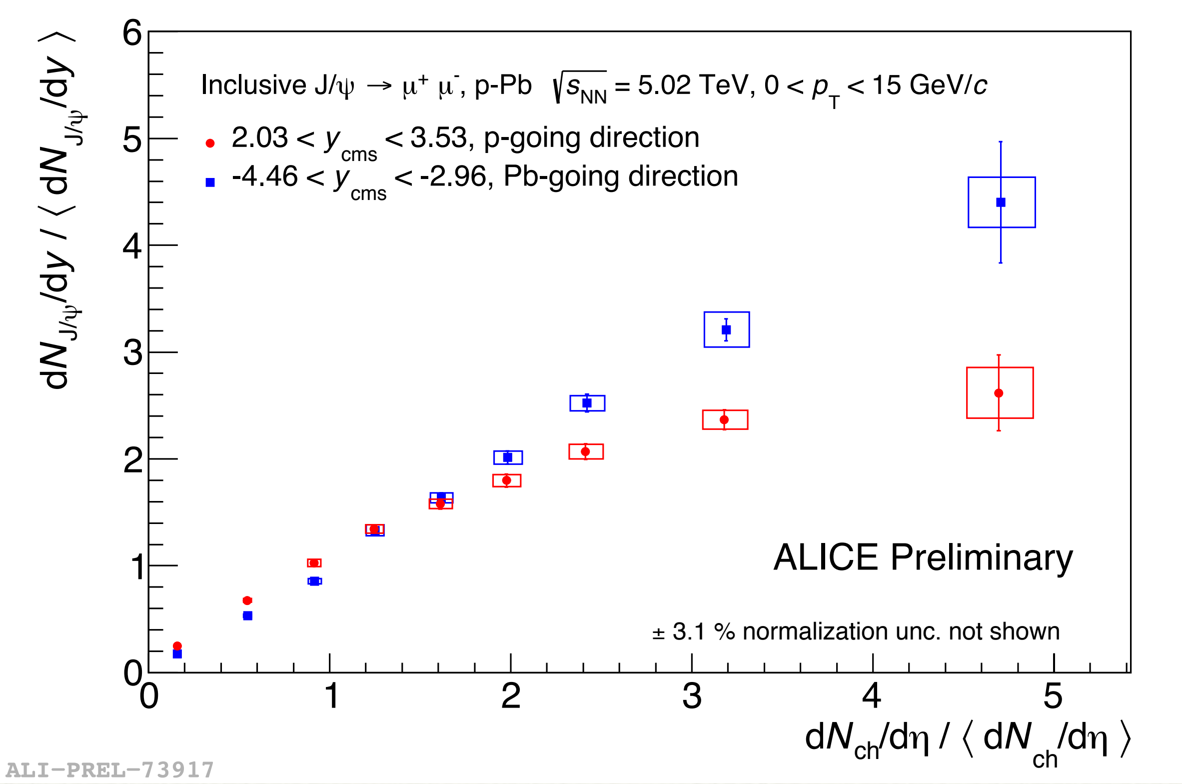
- **forward rapidity region**
  - **2.03 < y_{CMS} < 3.53 (forward)**
  - **-4.46 < y_{CMS} < -2.96 (backward)**
  - **p_T > 0**

J/ψ vs mult in pPb

J/ψ ➜ $\mu^+\mu^-$ measured in

- forward rapidity region
  - 2.03 < y_{CMS} < 3.53 (forward)
  - -4.46 < y_{CMS} < -2.96 (backward)
  - 0 < p_T < 15 GeV/c

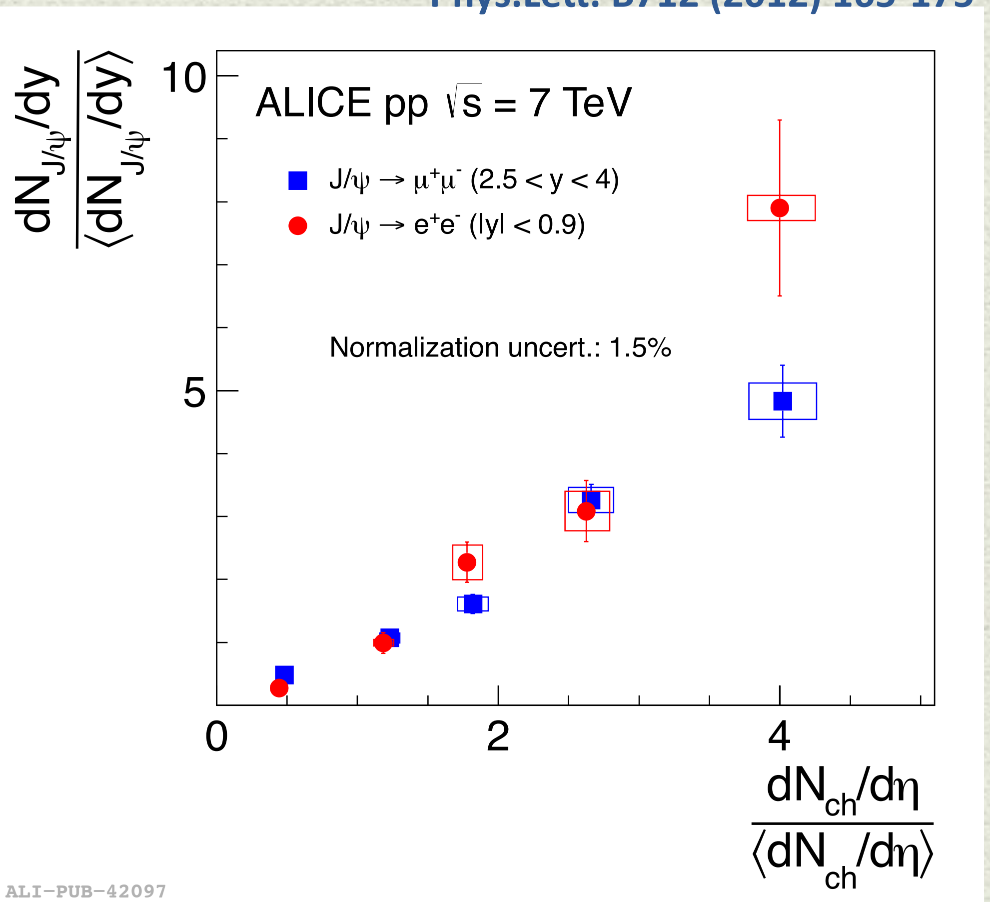
Multiplicity measured in |η| < 1

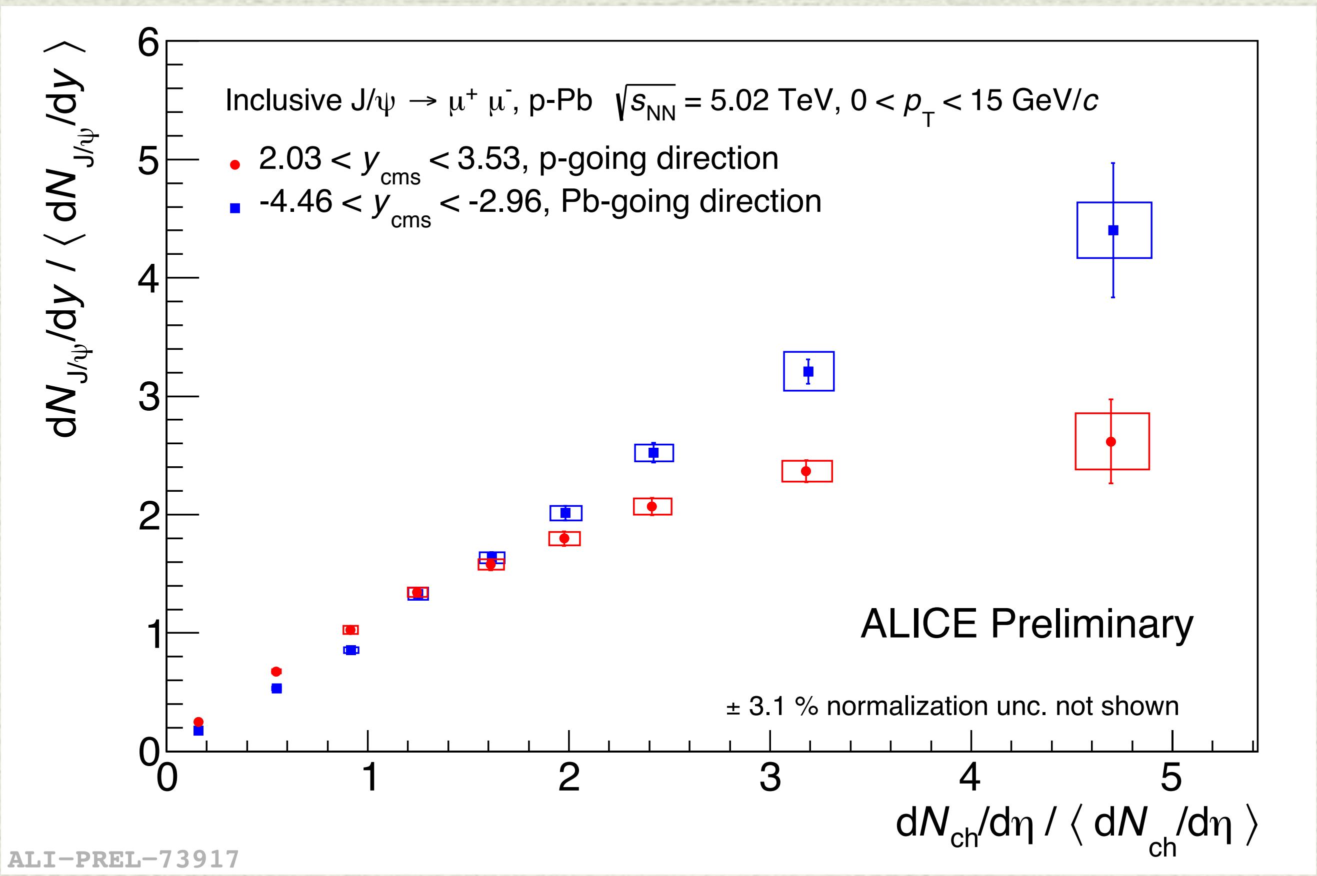


Increasing trend vs charged particle production for J/ψ also in p-Pb collisions.
Different trend in forward and backward region. Due to different Bjorken-x probed? Different CNM effects?

J/ψ vs mult in pp and pPb

Phys.Lett. B712 (2012) 165-175





J/ψ vs mult in pp and pPb

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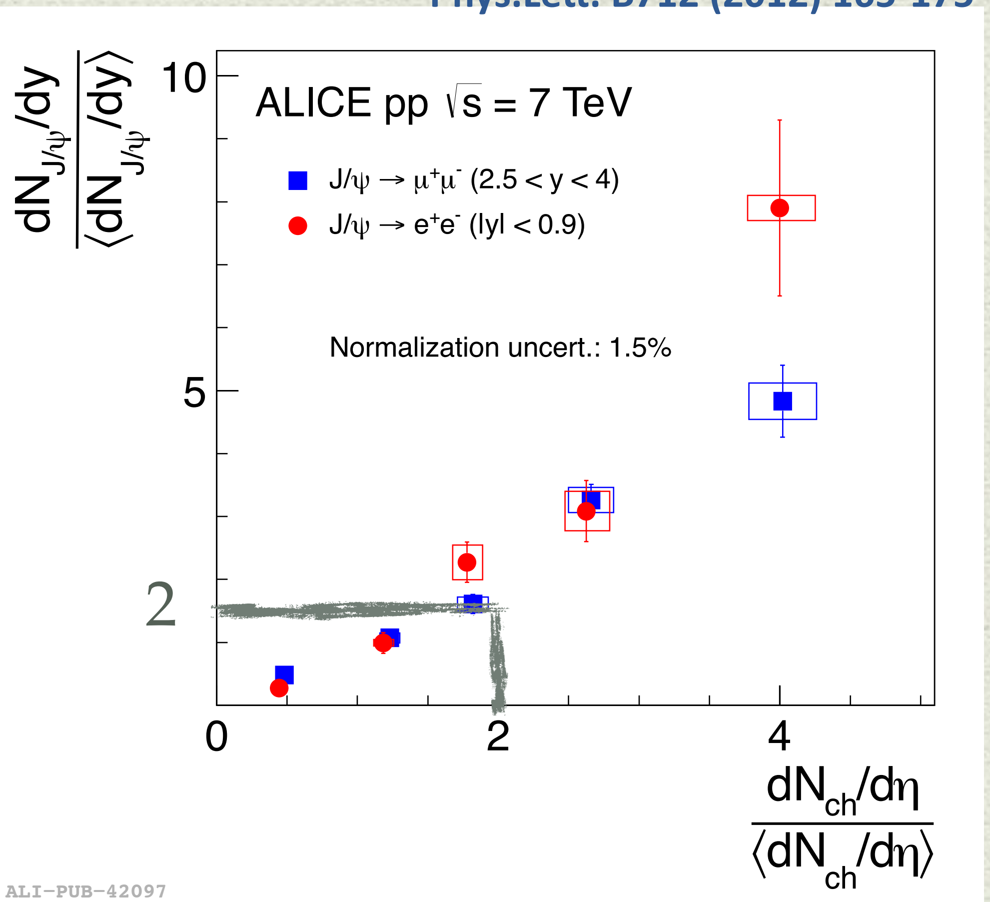
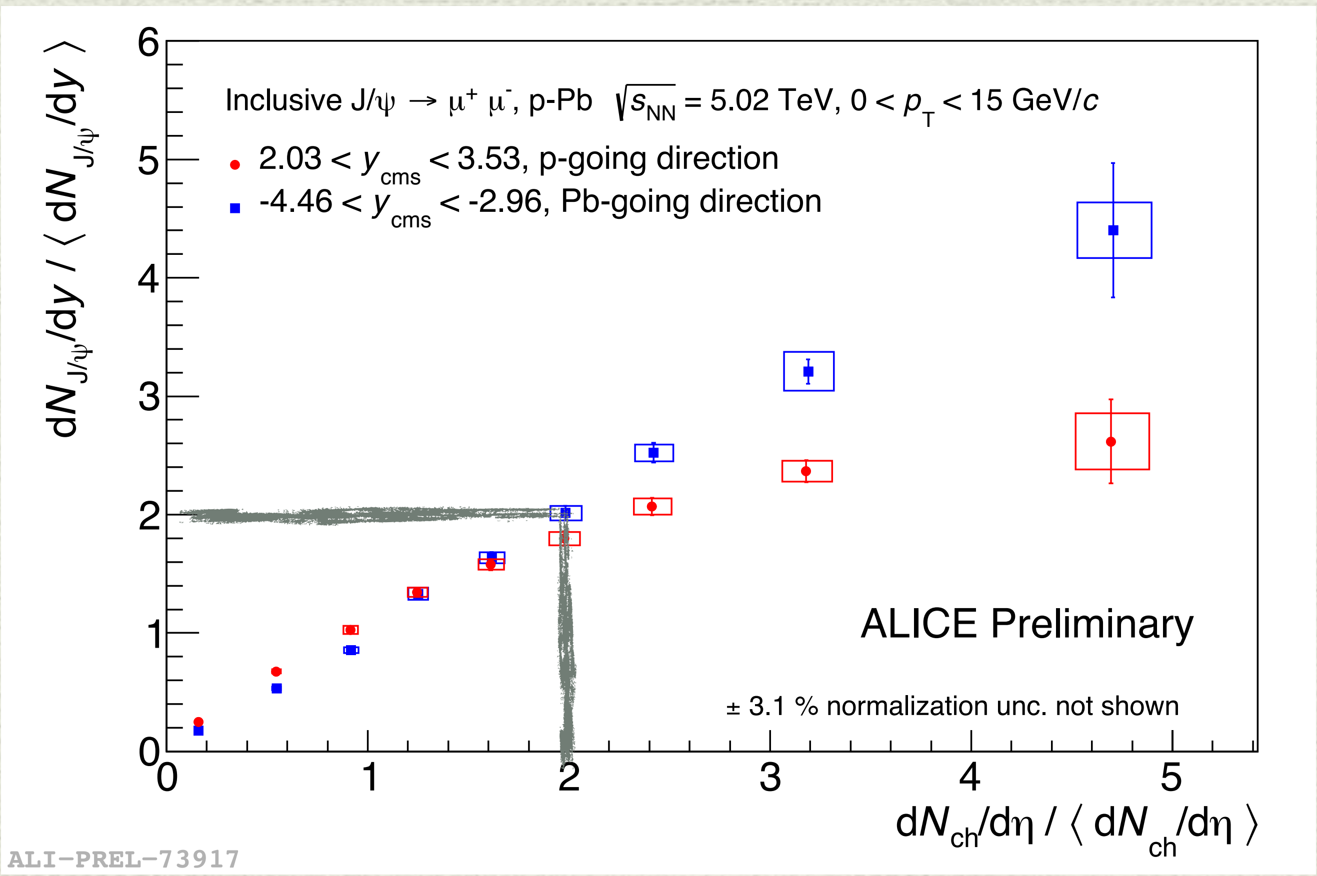
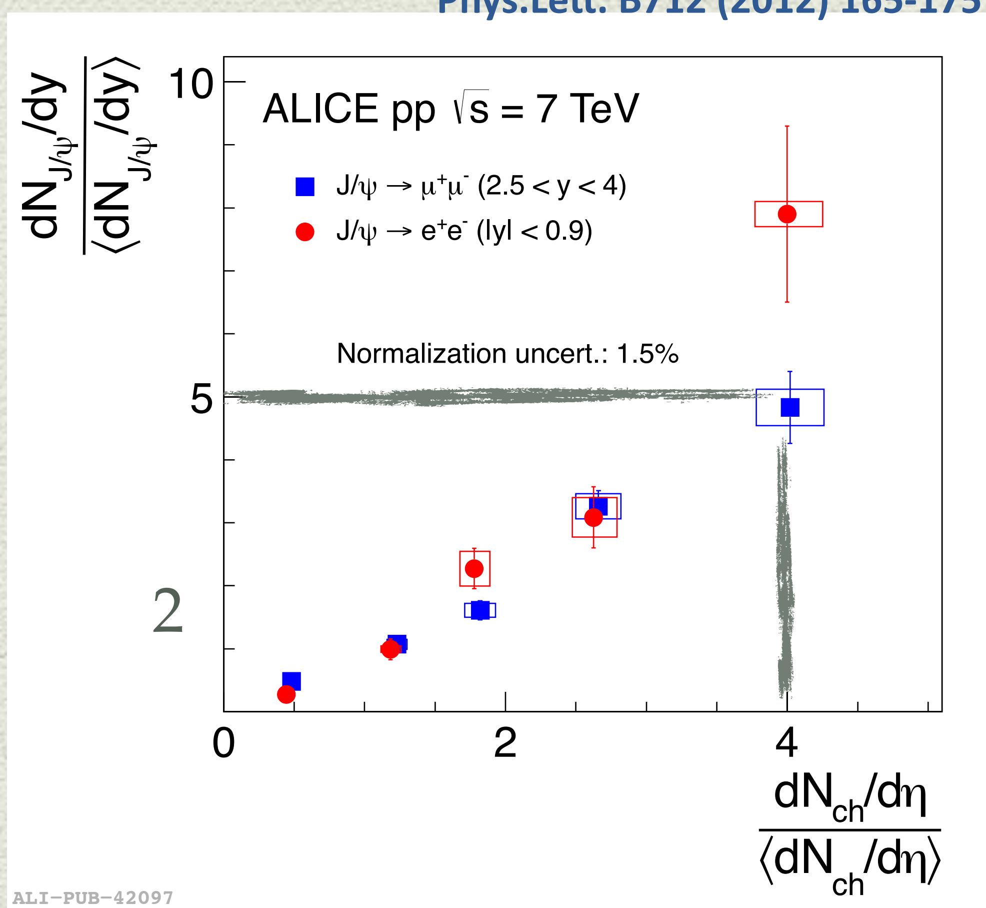


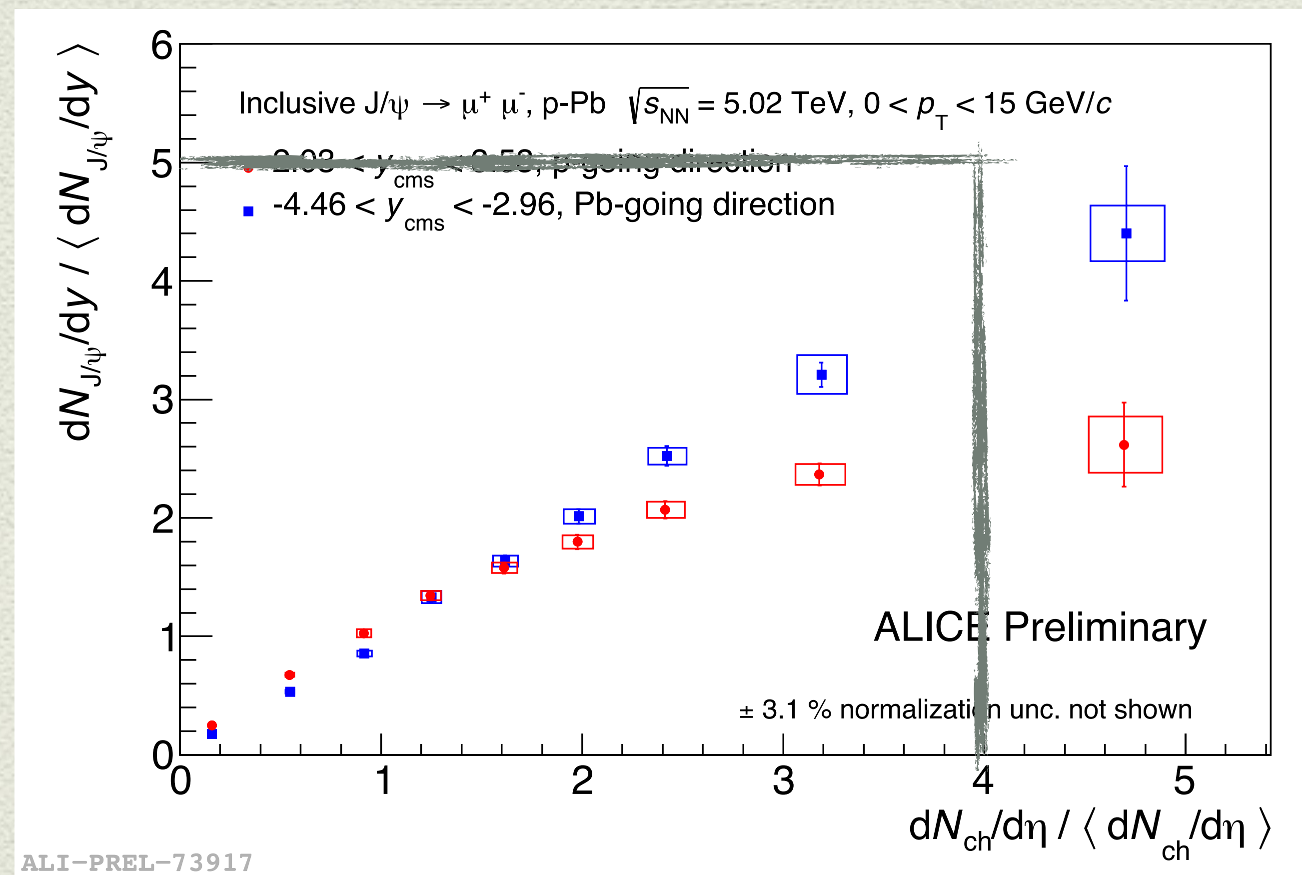


Similar trend observed in pp and pPb for low and intermediate multiplicity events.

J/ψ vs mult in pp and pPb

Phys.Lett. B712 (2012) 165-175

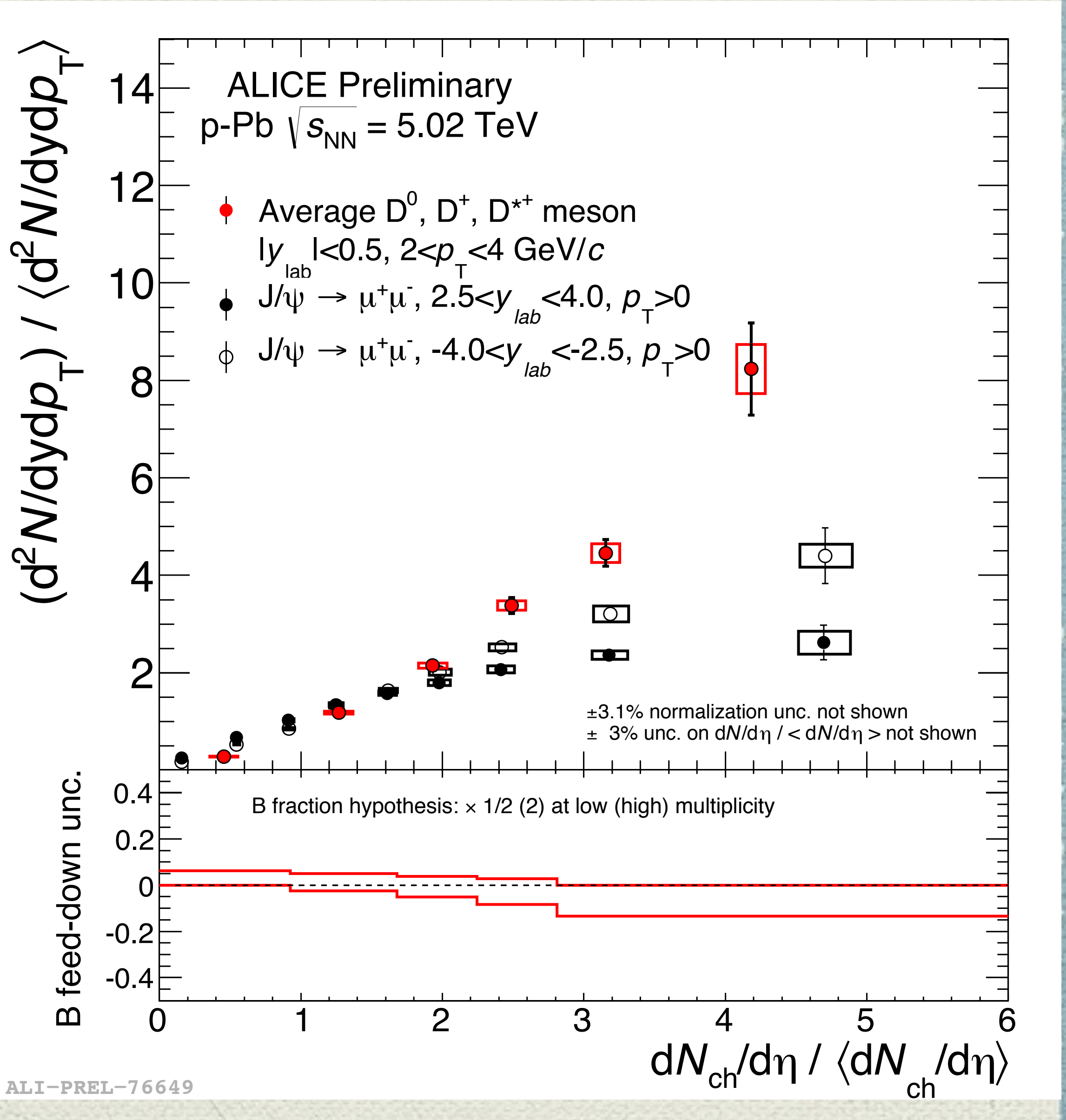




Similar trend observed in pp and pPb for the backward rapidity region
Clear difference (~factor 2) between pp and pPb in the forward region.
CNM?

D mesons and J/ψ vs mult in pPb

- J/ψ production in p-Pb collisions at $\sqrt{s}$ = 5.02 TeV shows
  - an increasing trend vs particles produced
  - different magnitude with respect to D mesons



- But different p_T and y of the measurement ⇒ different CNM effects expected and different $x_{Bjorken}$ probed:
  - Backward: $1.2\times10^{-2} < x_{Bjorken} < 5.3\times10^{-2}$
  - Forward: $1.8\times10^{-5} < x_{Bjorken} < 8.1\times10^{-5}$

Υ in pPb

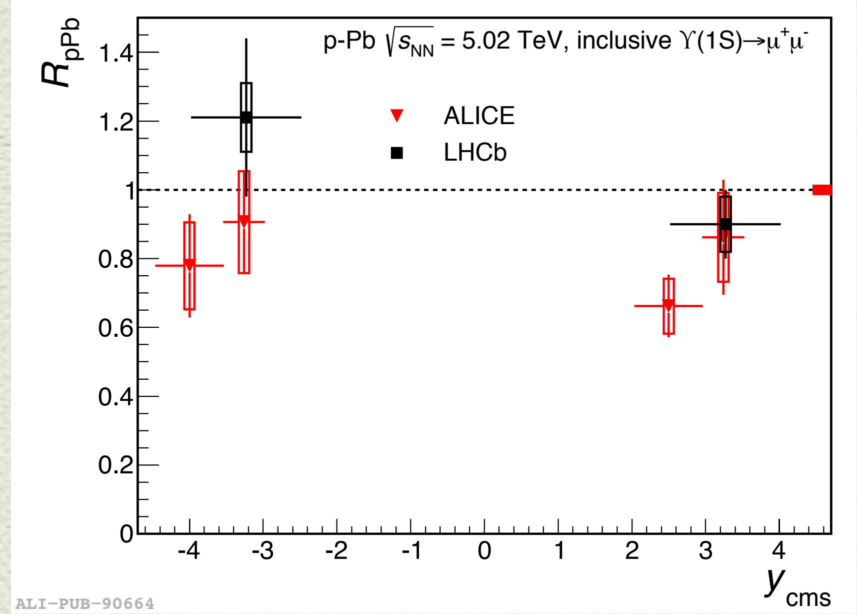
- ALICE and LHCb measured Υ R_{pPb} at forward rapidity in the di-muon channel.

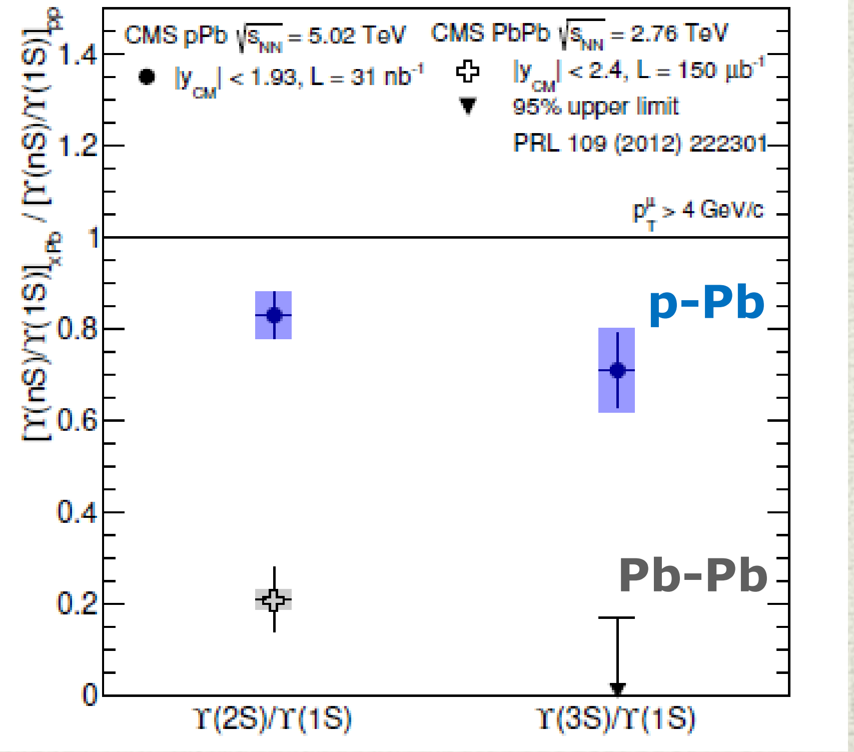
Similar suppression in the two rapidity ranges? Forward more suppressed? Need more data.

- CMS measured the ratios excited / ground state in the central rapidity.

Initial state effects similar for the three Υ states

Talk by Javier Castillo Castellanos





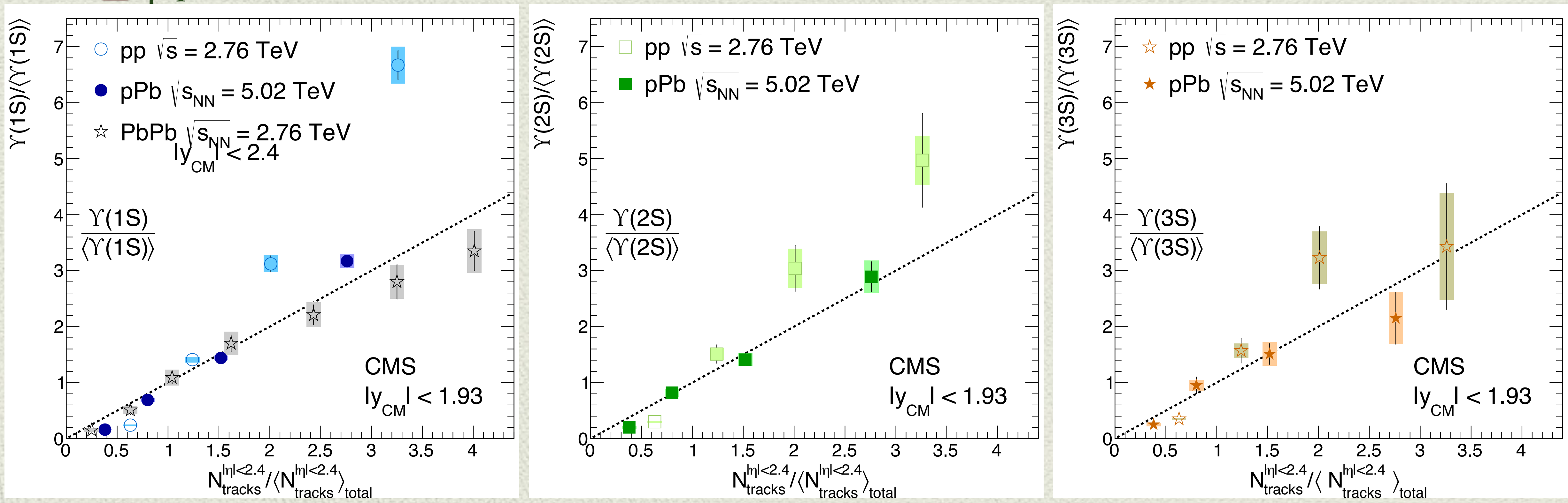
Υ vs mult in p-Pb

JHEP 04 (2014) 103

Υ(1S), Υ(2S), Υ(3S) measured in

- central rapidity region
  - |y| < 1.93
  - $p_T > 0$

Multiplicity measured in |η| < 2.4
same rapidity range as the measurement



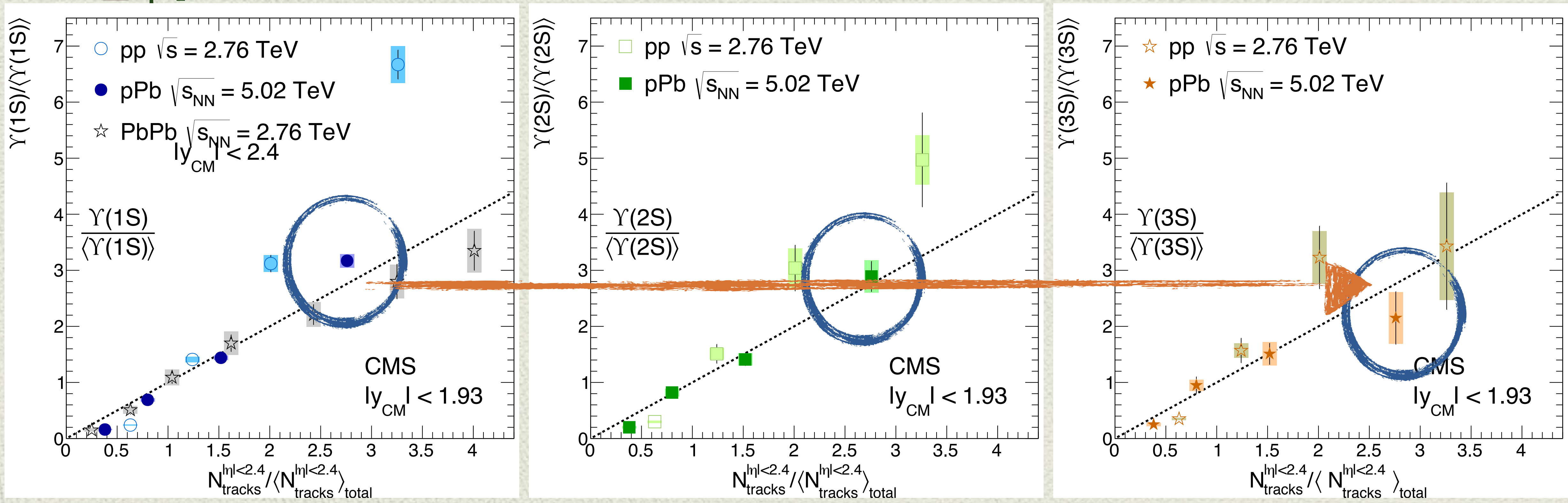
Increase of Υ yields in p-Pb less pronounced than pp collisions.

Υ vs mult in p-Pb

JHEP 04 (2014) 103

Υ(1S), Υ(2S), Υ(3S) measured in
- central rapidity region
  - |y| < 1.93
  - $p_T > 0$

Multiplicity measured in |η| < 2.4
same rapidity range as the measurement



Similar trend in pPb for the three states vs multiplicity.
Different trend w.r.t pp ?

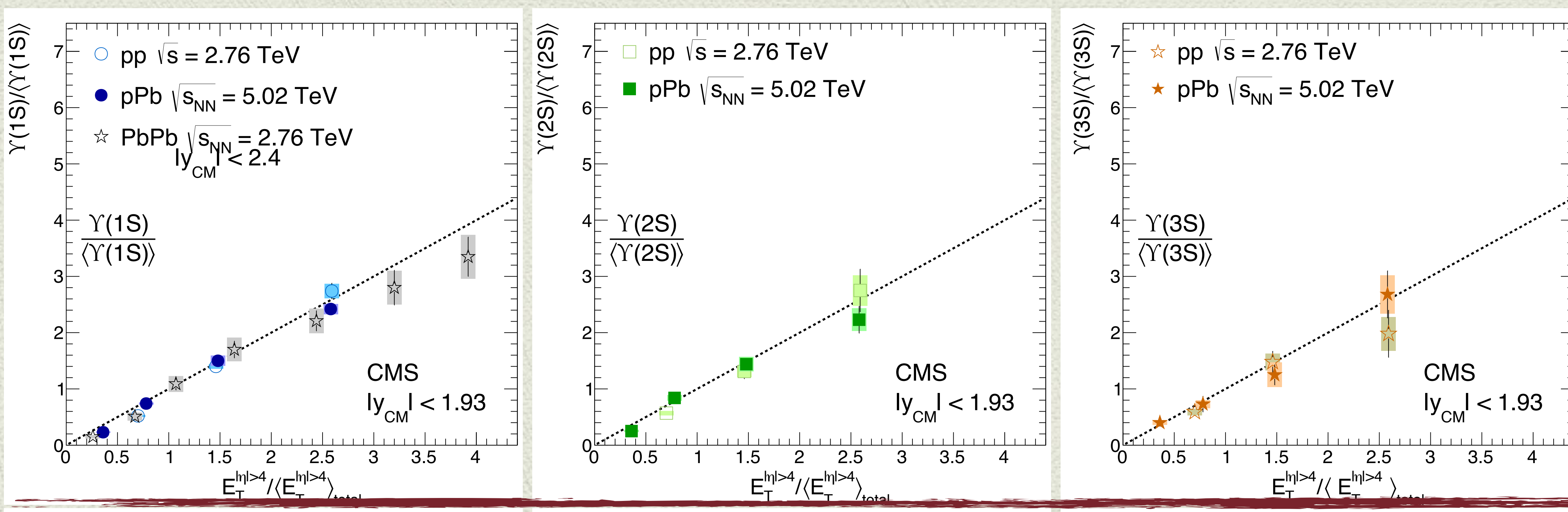
ϒ vs mult in p-Pb

JHEP 04 (2014) 103

ϒ(1S), ϒ(2S), ϒ(3S) measured in

- central rapidity region
  - |y| < 1.93
  - $p_T > 0$

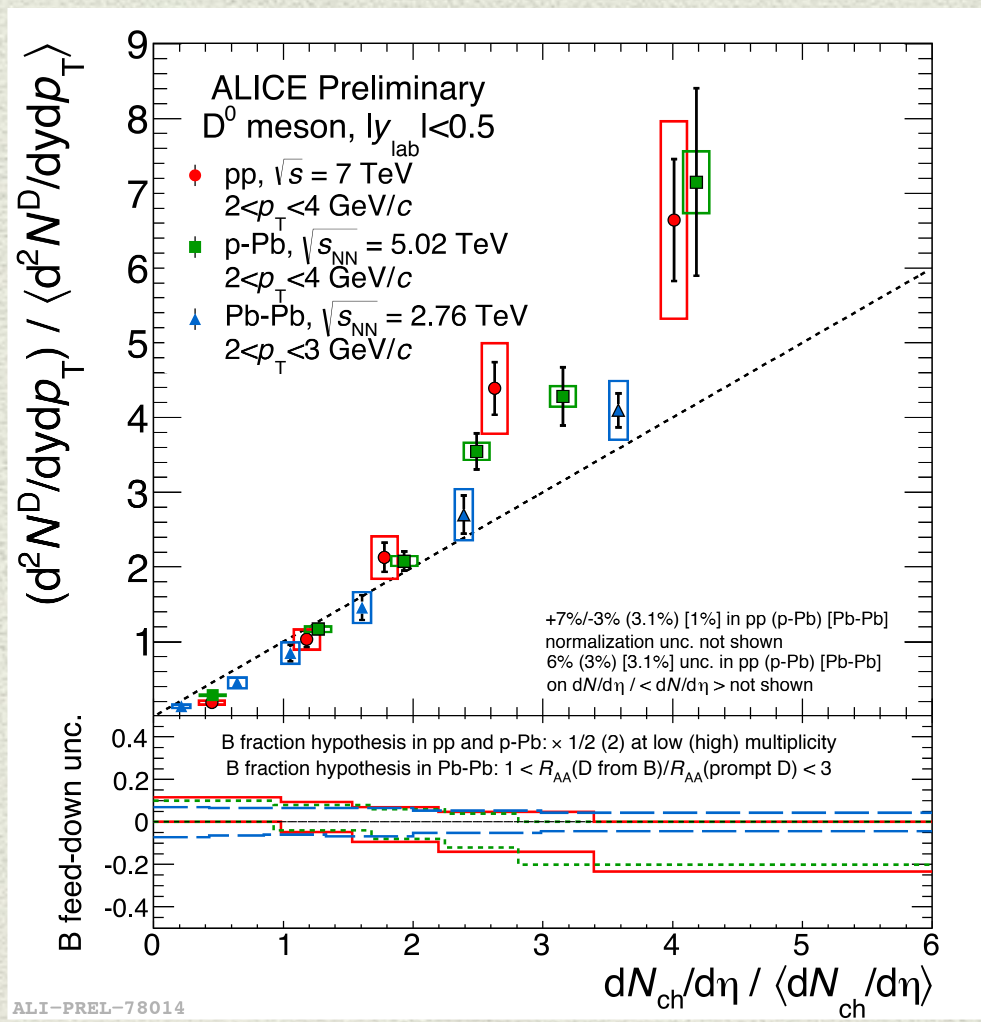
Multiplicity measured in 4 < |η| < 5.2
different rapidity range than the measurement



Using the forward multiplicity estimator ϒ yields seems to increase linearly w.r.t multiplicity.

Comparison of D mesons and ϒ

- ϒ measurement from CMS shows increasing trend in pp and in p-Pb similar to the D meson's one.
- Caveat: different x-axis value. An "absolute" normalisation would be needed in order to compare experiments and theory.



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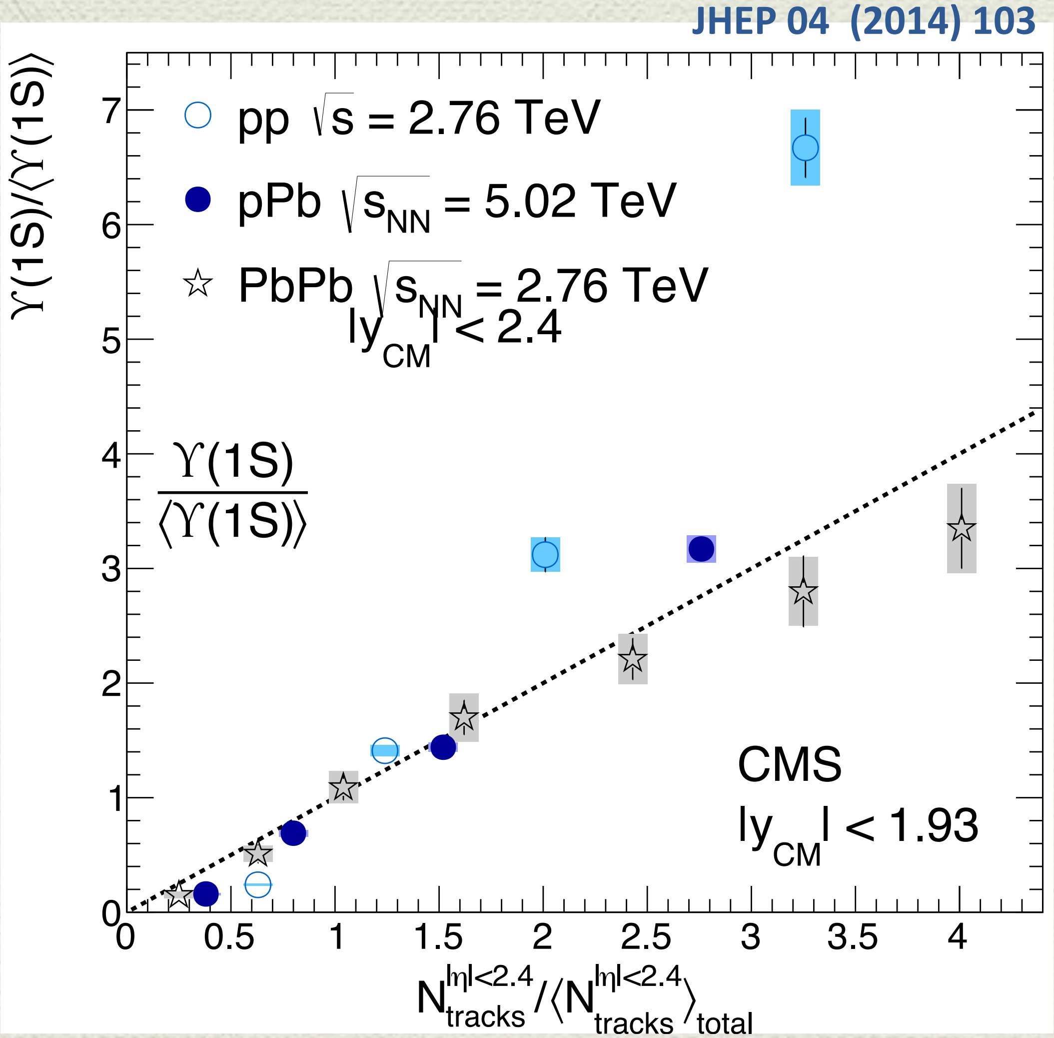
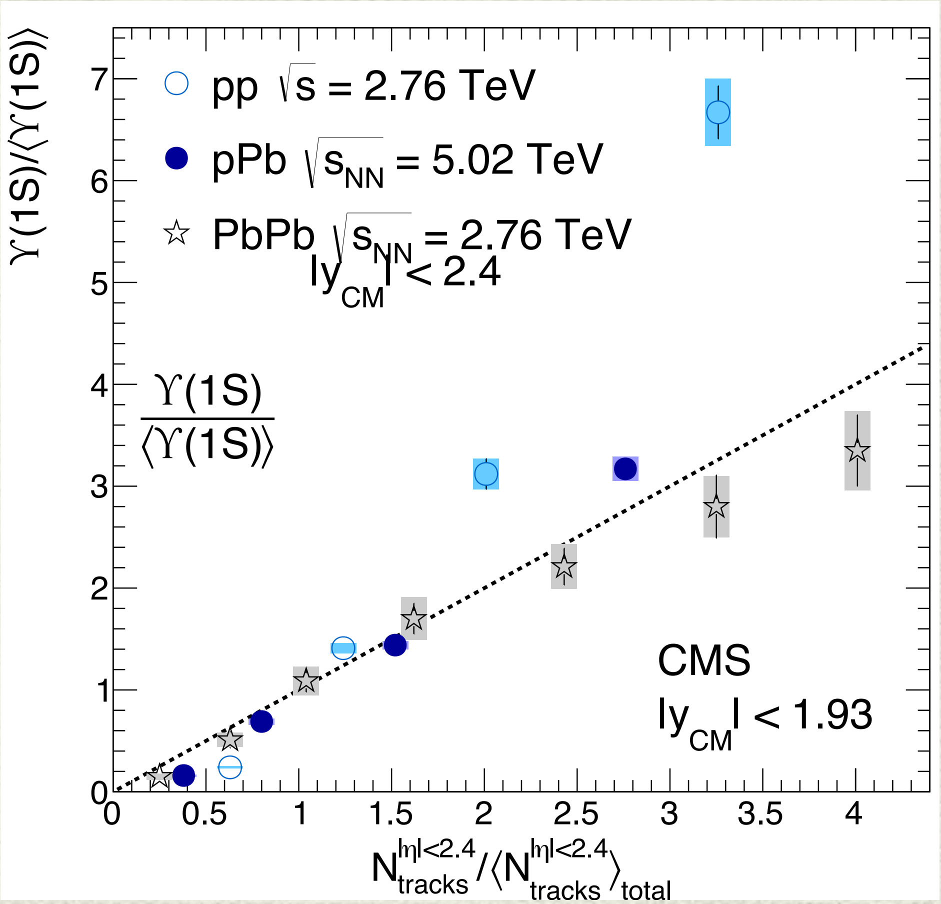


Wrap up (III): quarkonia in pPb

- Different increase of the J/ψ yields for forward and backward region. Different CNM effects?
- J/ψ p-Pb forward measurement shows a smaller increase of the yields than the pp case.
- ϒ show a different trend depending on the η range where the multiplicity is measured but is a real effect or it depend on the multiplicity definiton? Difference between pp and pPb when using the central rapidity multiplicity estimator?

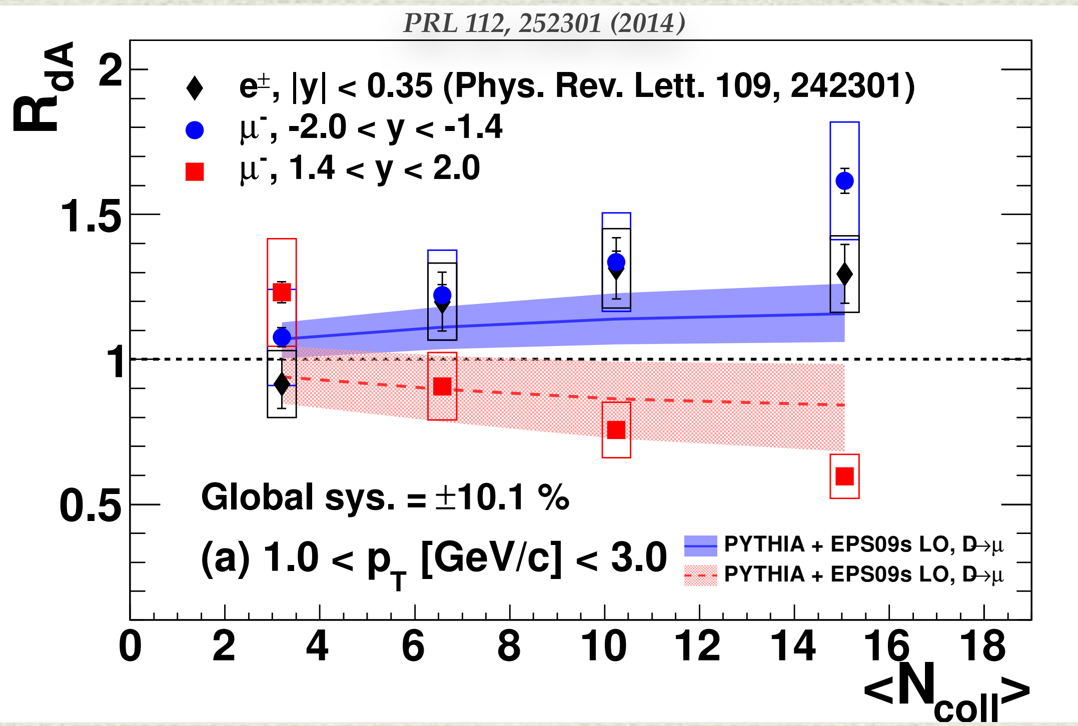
JHEP 04 (2014) 103

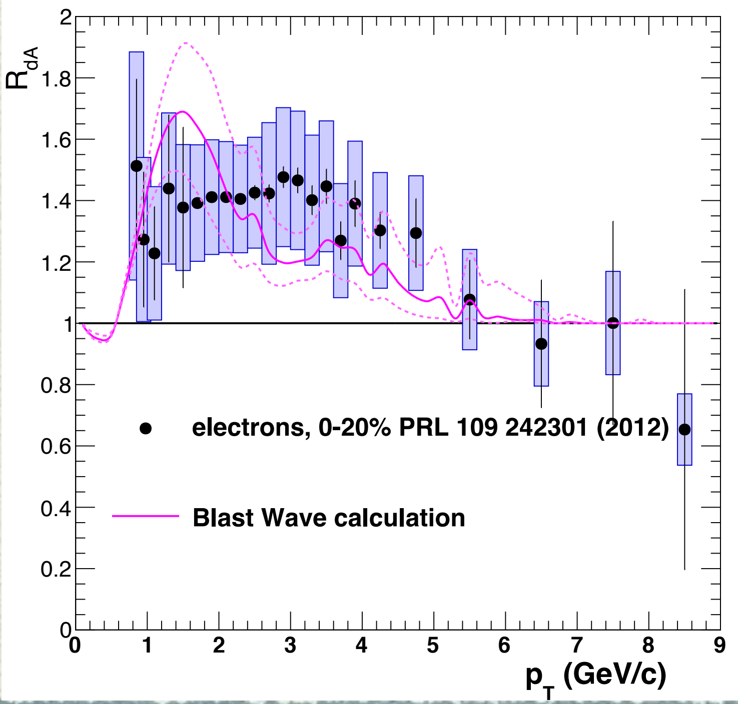


HF R_{dA} vs $\langle N_{coll} \rangle$

PHENIX

- HF leptons measurement by PHENIX in d-Au for $p_T > 2$ GeV/c:
  - HF electrons $|y| < 0.35$
  - HF muons
    - **backward -2.0 < y < -1.4**
    - **forward 1.4 < y < 2.0**
- **Similar trend for HFe and HFμ in backward and central rapidity**
- **Different trend for the forward rapidity. Suppression of HFμ in more central d-Au events.**
- **Possible flow-like effect in small systems?** A. Sickles arxiv:1309.6924





Q_{pPb}

- Goal: Test any **multiplicity dependent modification of the p_T spectra** in p-Pb collisions.

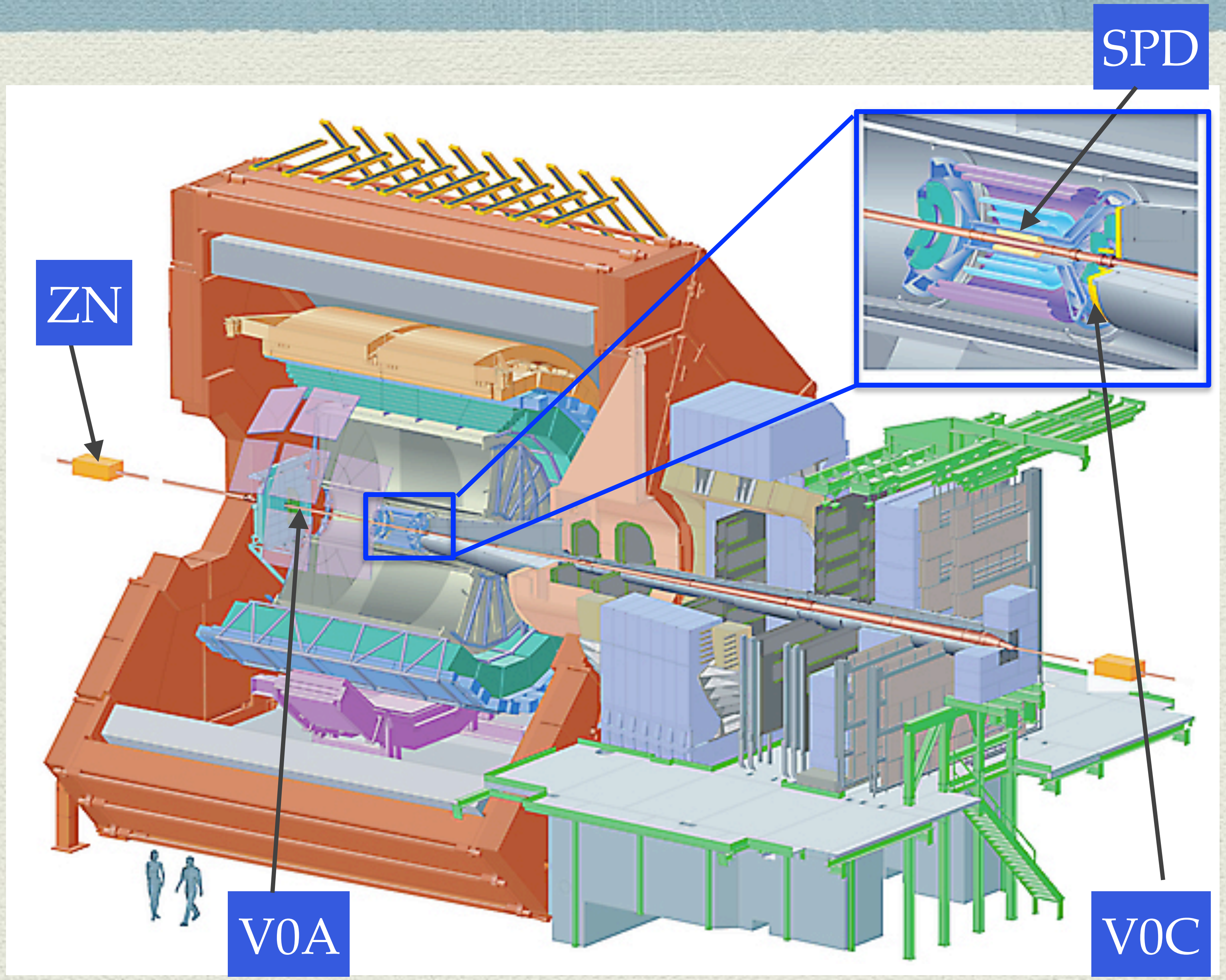
$$Q_{pPb}^{V0A}(p_T) = \frac{dN_{mult}^{pPb}/dp_T}{N_{coll}^{Glauber} dN^{pp}/dp_T}$$

- Strategy: Compare p-Pb and pp yields properly scaled
- But **in p-Pb collisions biases are present in the determination of <N_{coll}>**:
  - multiplicity bias
  - jet veto bias
  - geometrical bias
- The **bias depends on the estimator** used for the multiplicity determination

Multiplicity determination in ALICE

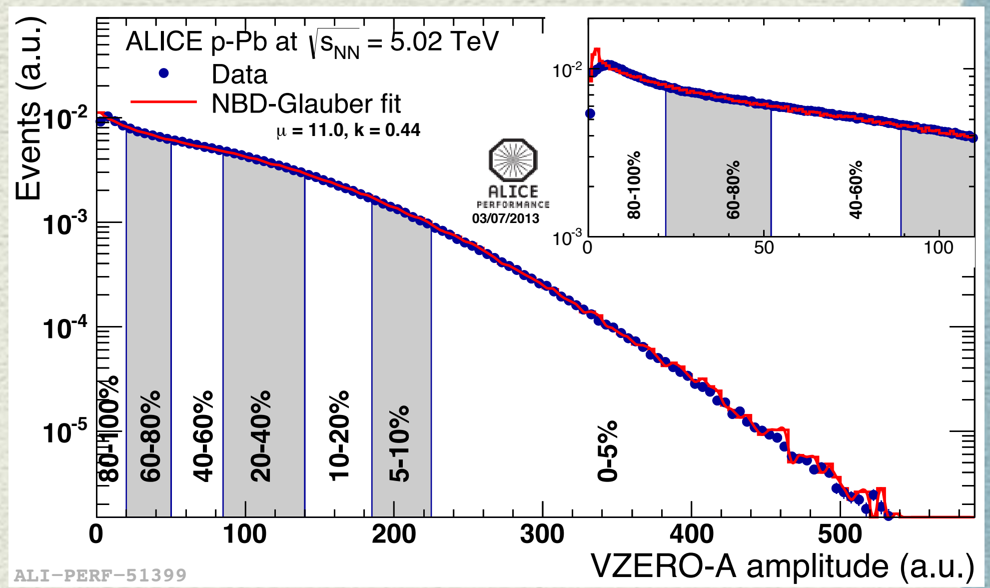
Detectors used for multiplicity measurements:

- **Zero degree Neutral calorimeter (ZN)**: measures the energy deposit in the very forward direction $|\eta| > 8.7$
- **Forward scintillator arrays (VZERO):**
  - $2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$
- **Silicon Pixel Detector (SPD)**: two innermost layers of the ITS
  - $|\eta| < 1$

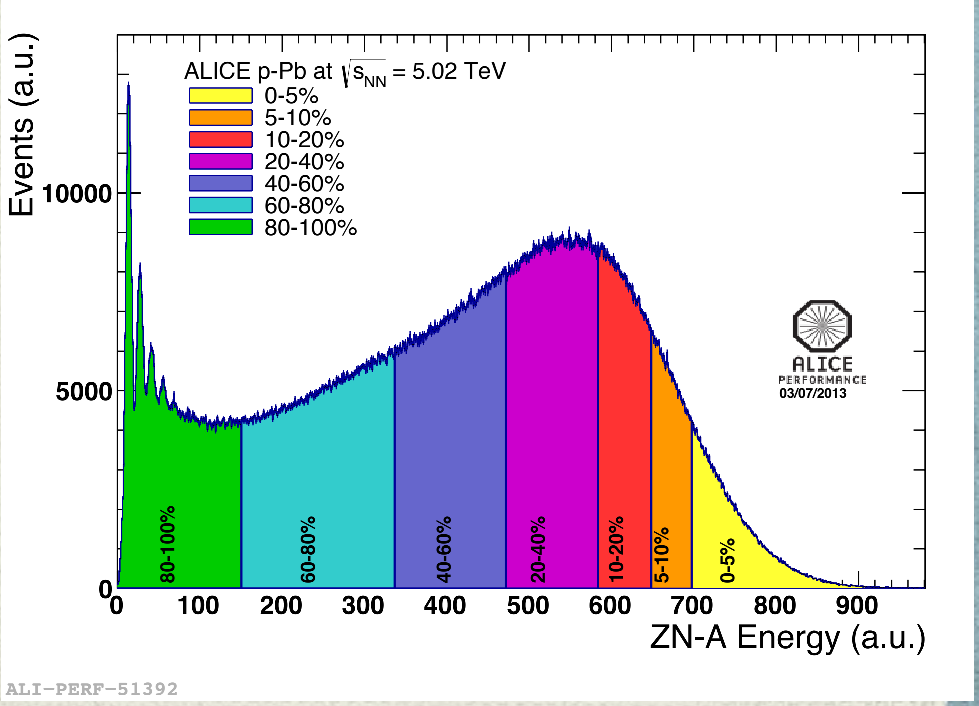


Q_{pPb}: multiplicity estimator definitions

- **V0A**:
  - $< N_{coll}^{Glaub} >$ from Glauber fit to V0A amplitude
  - multiplicity from Negative Binomial Distribution (NBD)

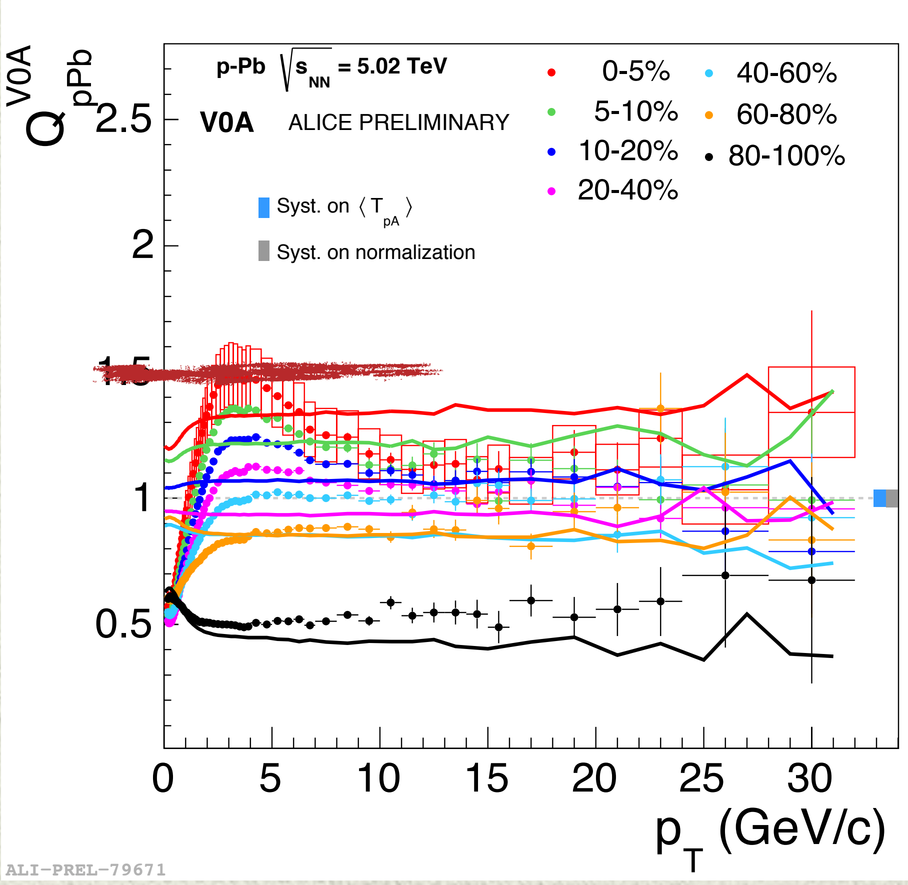


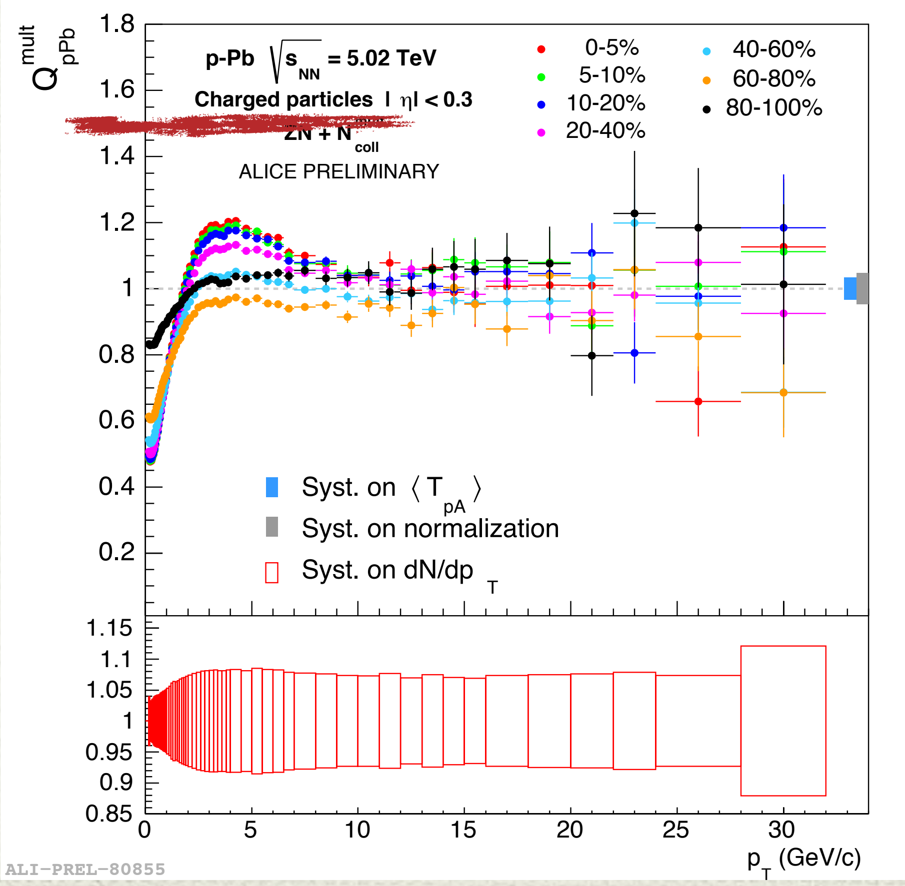
- **ZN:** $< N_{coll}^{mult} >$ obtained with an Hybrid method
  - Slice events in ZN energy (Pb going side)
  - $< N_{part} >$ in ZN energy class obtained by scaling it to the minimum bias multiplicity at mid-rapidity.



D mesons Q_{pPb}

- For V0A estimator, charged hadrons show a hierarchy in the Q_{pPb} going from higher multiplicity to lower multiplicity events. Using the ZNA this difference is reduced.

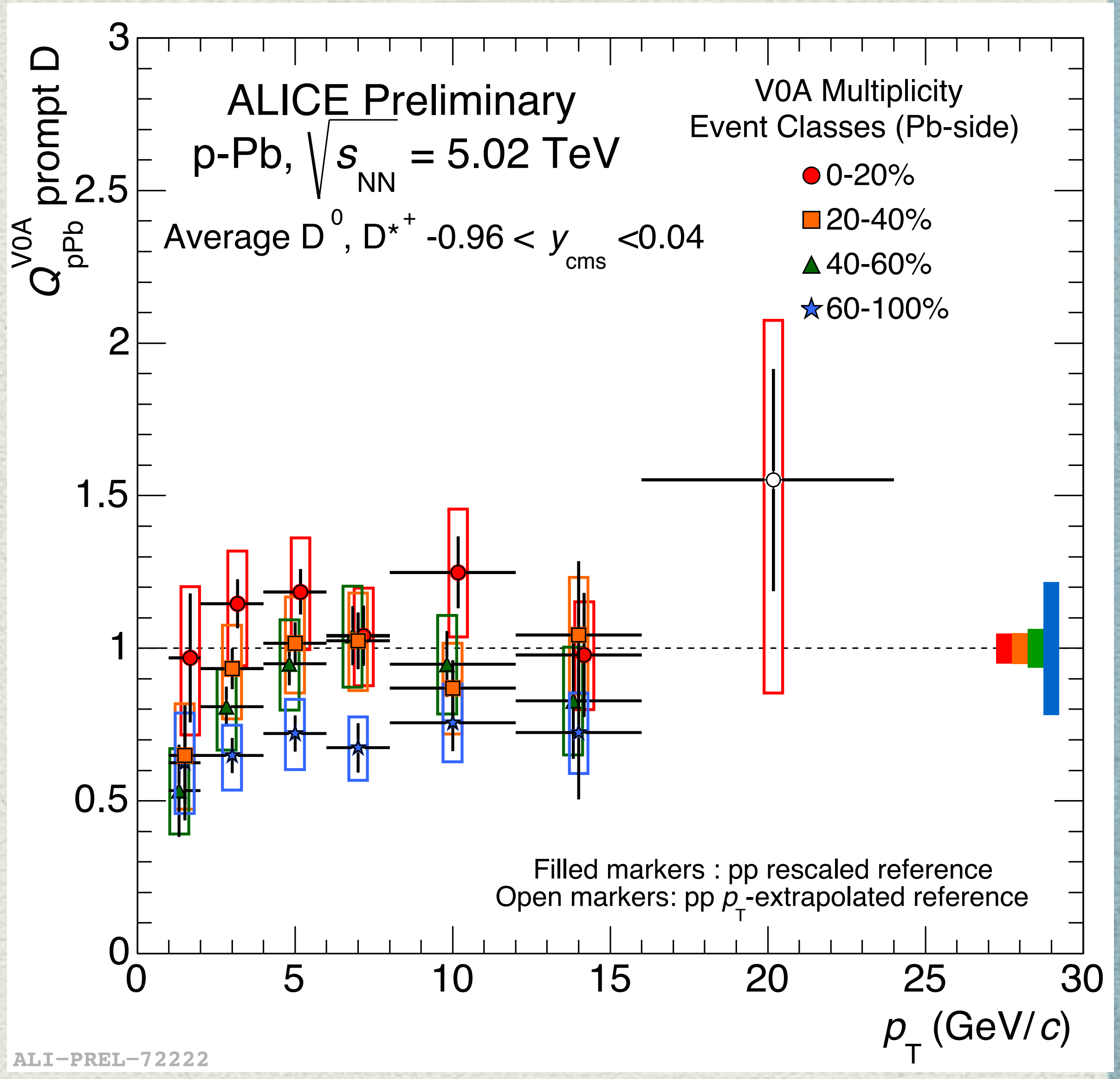




D mesons Q_{pPb}

- For V0A estimator, charged hadrons show a hierarchy in the Q_{pPb} going from higher multiplicity to lower multiplicity events. Using the ZNA this difference is reduced.

- Average D^0 and D^{*+} Q_{pPb} shows a similar residual bias when computed using V0A estimator…

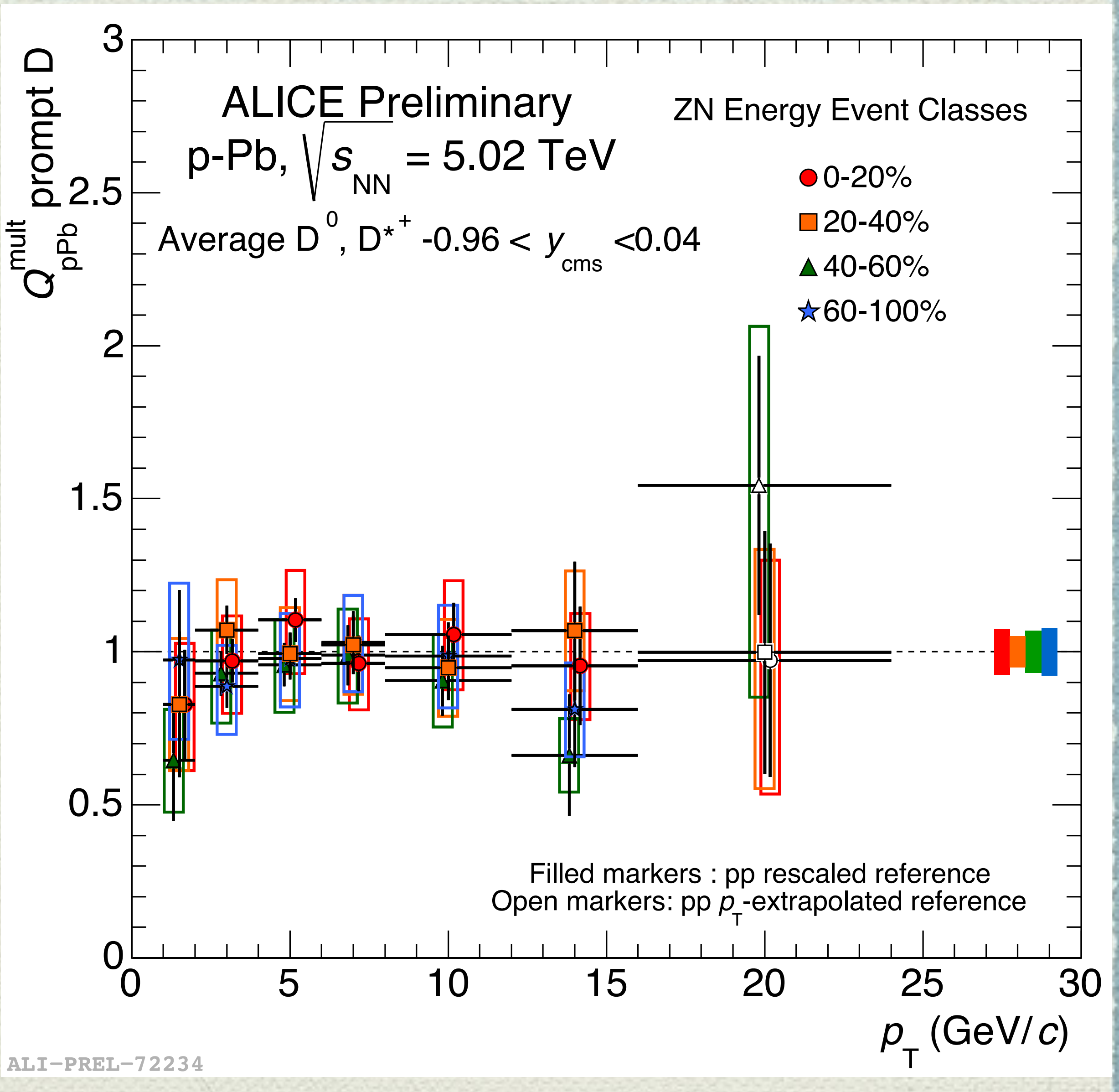


D mesons Q_{pPb}

- For V0A estimator, charged hadrons show a hierarchy in the Q_{pPb} going from higher multiplicity to lower multiplicity events. Using the ZNA this difference is reduced.

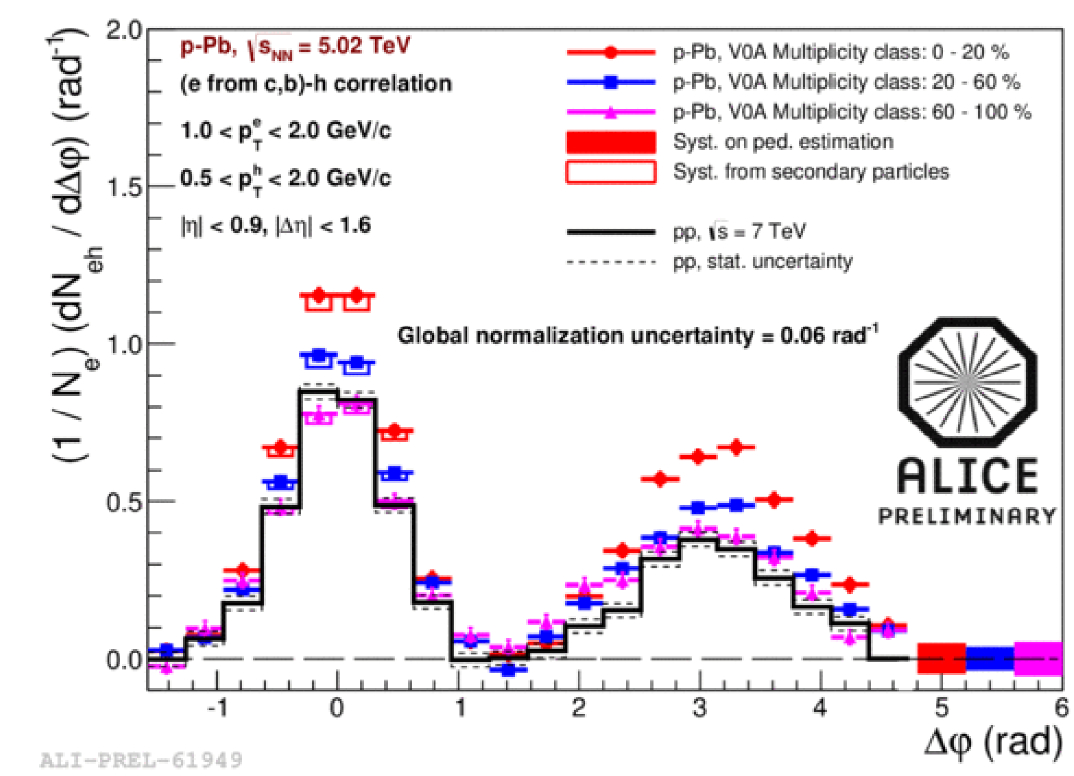
- Average D^0 and D^{*+} Q_{pPb} shows a similar residual bias when computed using V0A estimator…

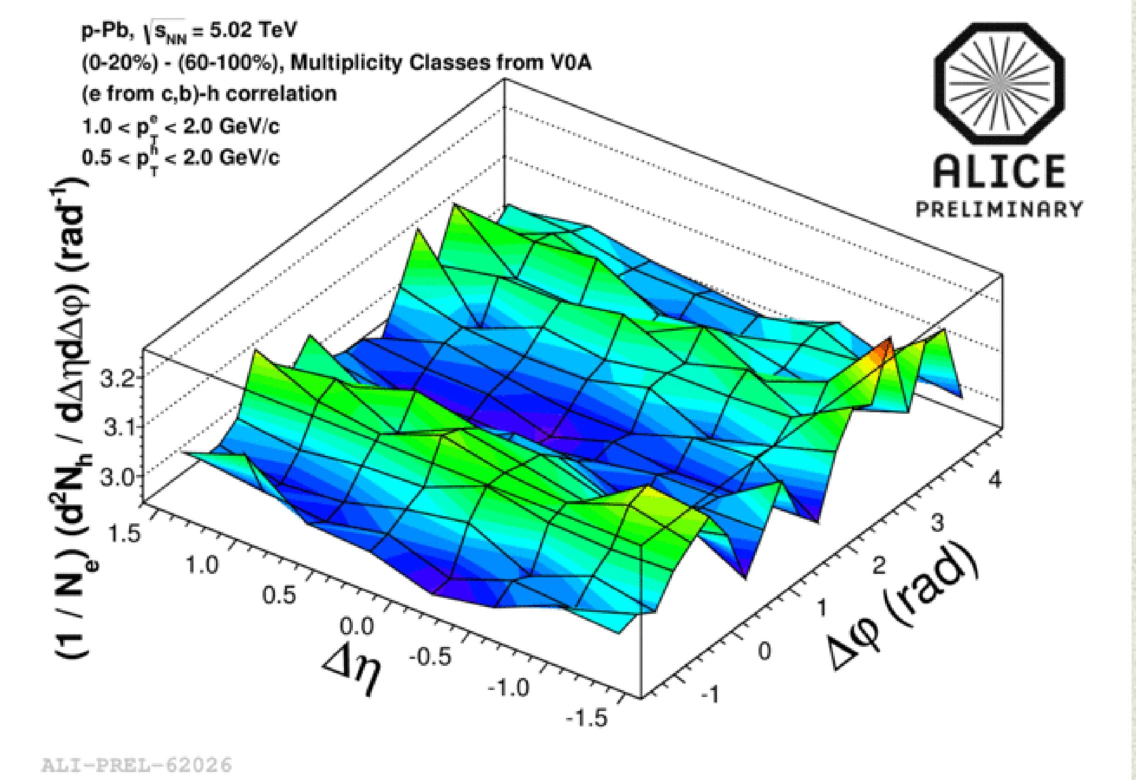
- … that is reduced when using ZN one.



Using the ZN estimator no multiplicity dependent modification of D meson production relative to pp collisions, within uncertainties

but... HFe - h correlation





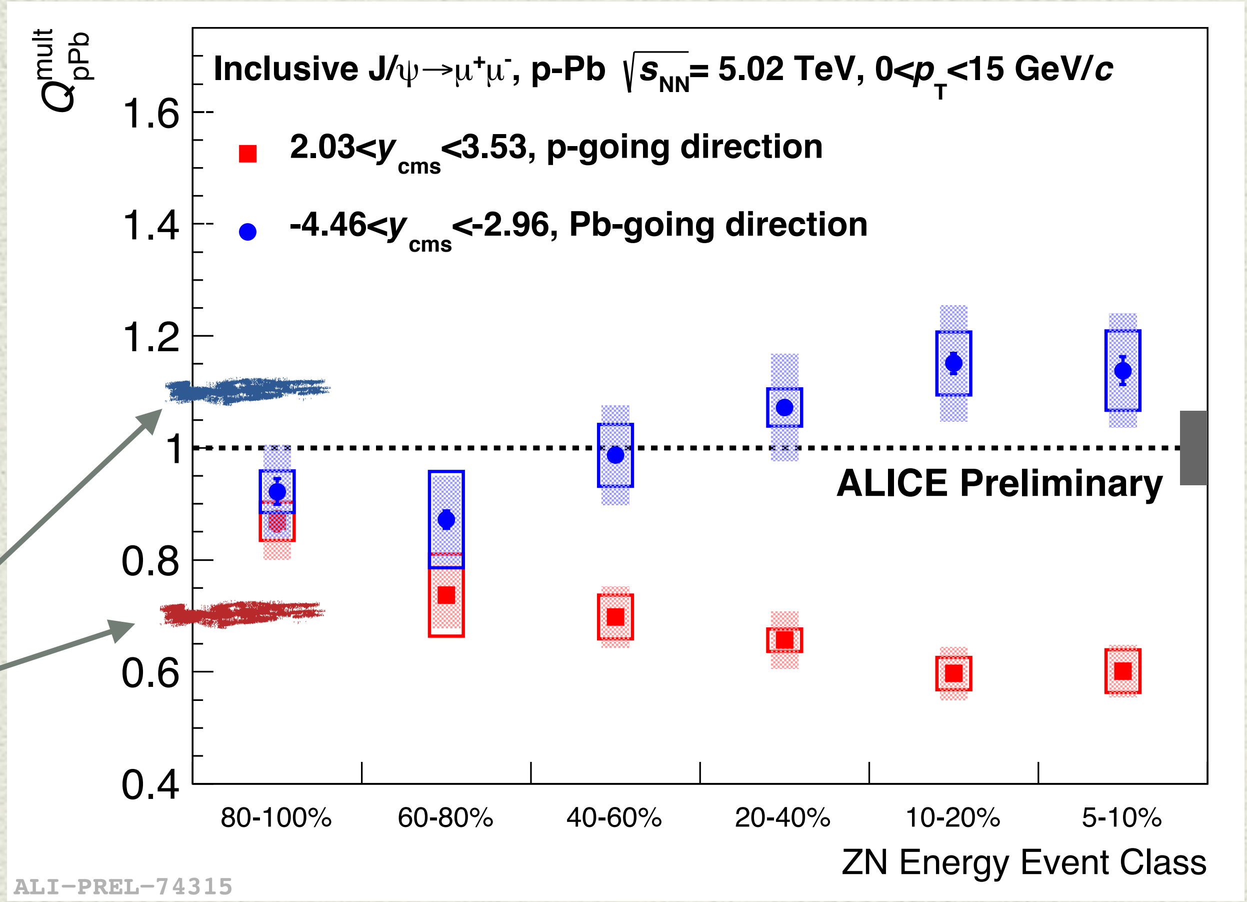
- **Double ridge structure** observed for HFe as for light flavor hadrons in high multiplicity events.
- Measurement done with V0A event multiplicity determination. **"Non-flow" subtracted using lowest multiplicity class**. What happens with ZN estimator?
- A 1 GeV HFe correspond to? How can we compare it with the HFe R_{pPb} at 1? Need further measurements vs event activity.

J/ψ Q_{pPb}

J/ψ ➜ $\mu^+\mu^-$ measured in

- forward rapidity region
  - 2.03 < y_{CMS} < 3.53 (forward)
  - -4.46 < y_{CMS} < -2.96 (backward)

- Focus on the ZN estimator that it is considered to be the less biased.
- Multiplicity integrated values for **backward** and **forward** rapidity



Q_{pPb} consistent with unity at backward rapidity
Decreasing trend from lower to higher multiplicity events for forward rapidity J/ψ

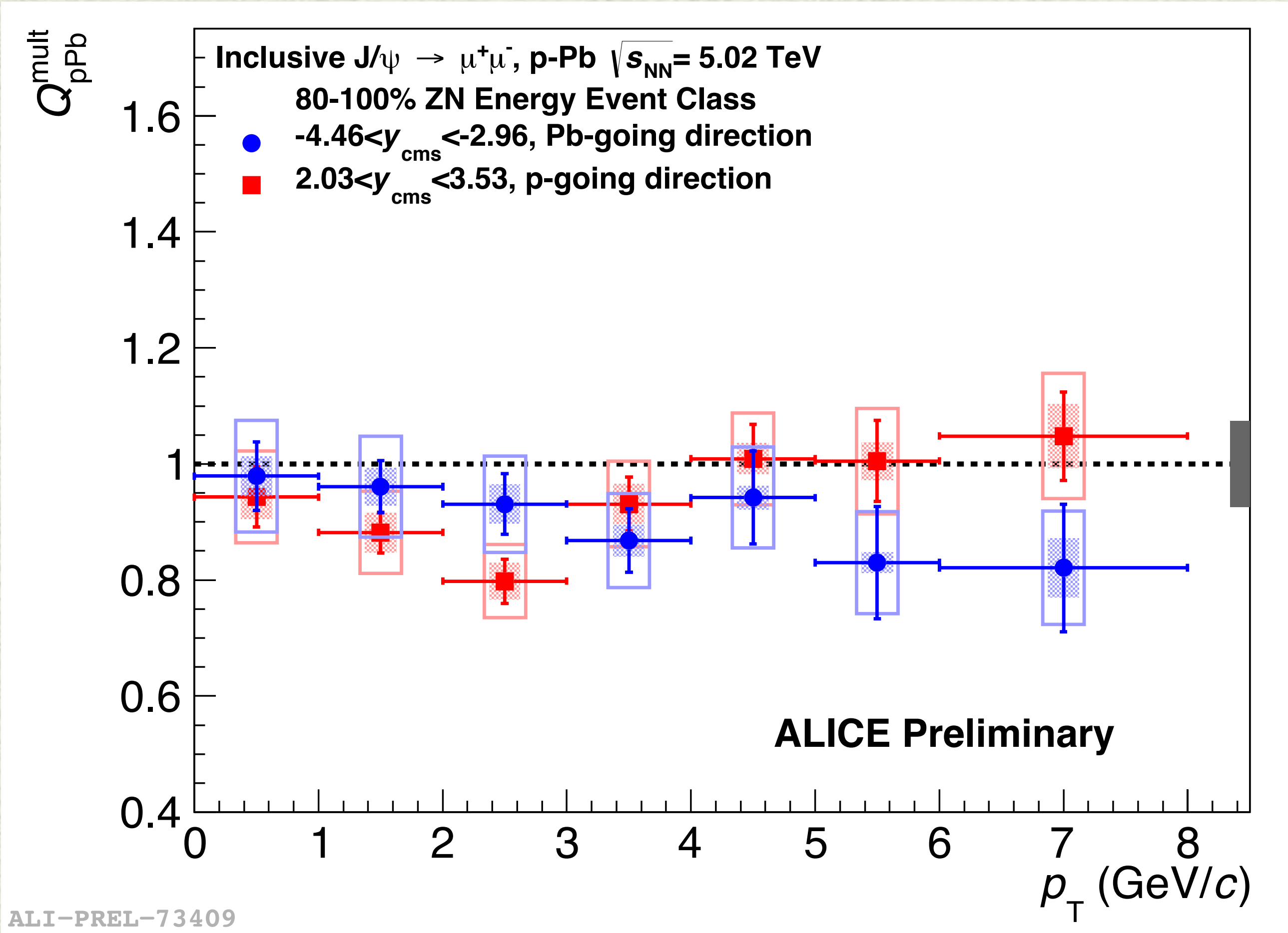
J/ψ Q_{pPb} vs p_T

J/ψ ➜ $\mu^+\mu^-$ measured in

- forward rapidity region
  - 2.03 < y_{CMS} < 3.53 (forward)
  - -4.46 < y_{CMS} < -2.96 (backward)

- Focus on the ZN estimator that it is considered to be the less biased.

Low multiplicity events



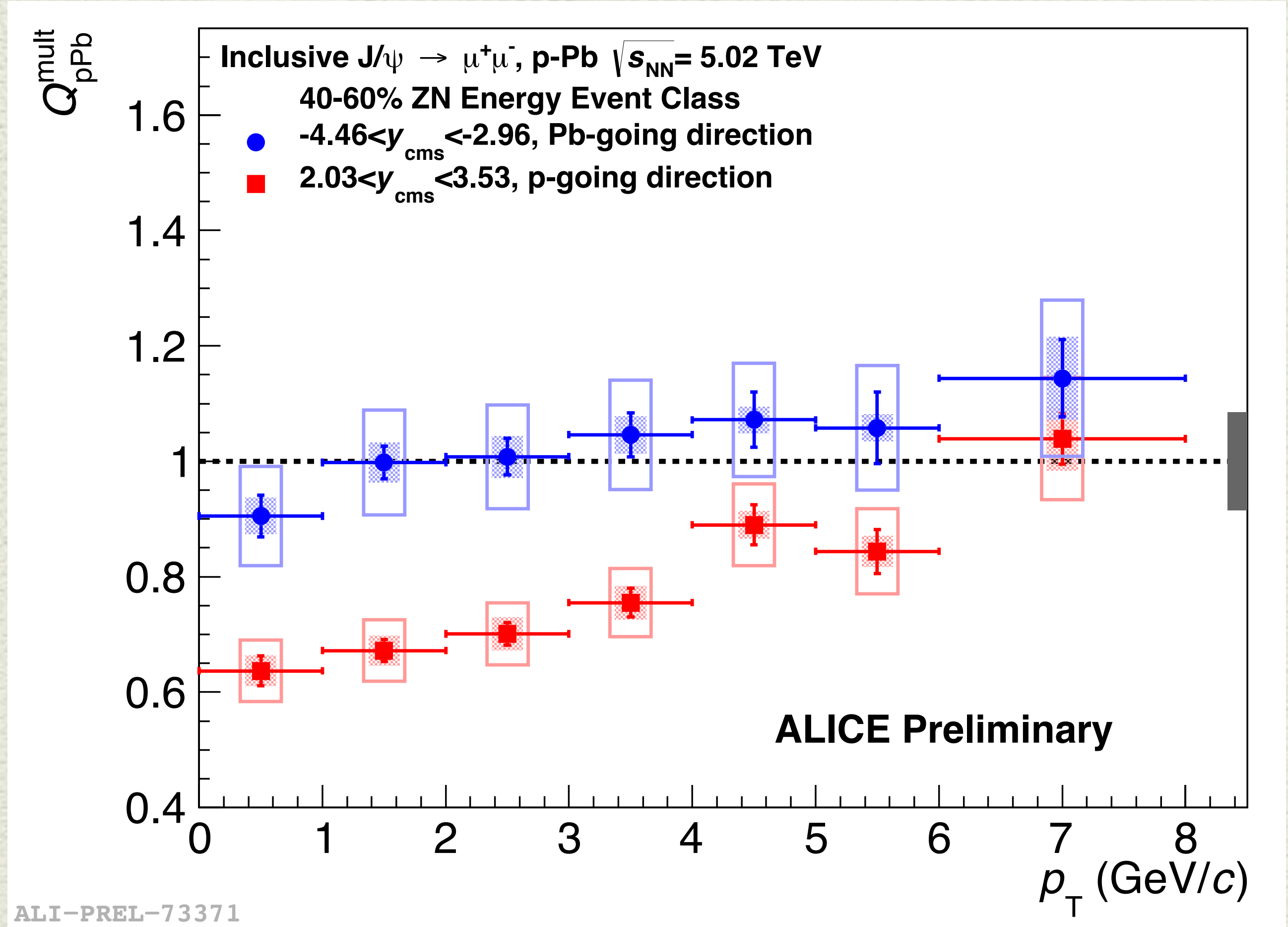
J/ψ Q_{pPb} vs p_T

Middle multiplicity events

J/ψ ➜ $\mu^+\mu^-$ measured in

- forward rapidity region
  - **2.03 < y_{CMS} < 3.53 (forward)**
  - **-4.46 < y_{CMS} < -2.96 (backward)**

- Focus on the ZN estimator that it is considered to be the less biased.

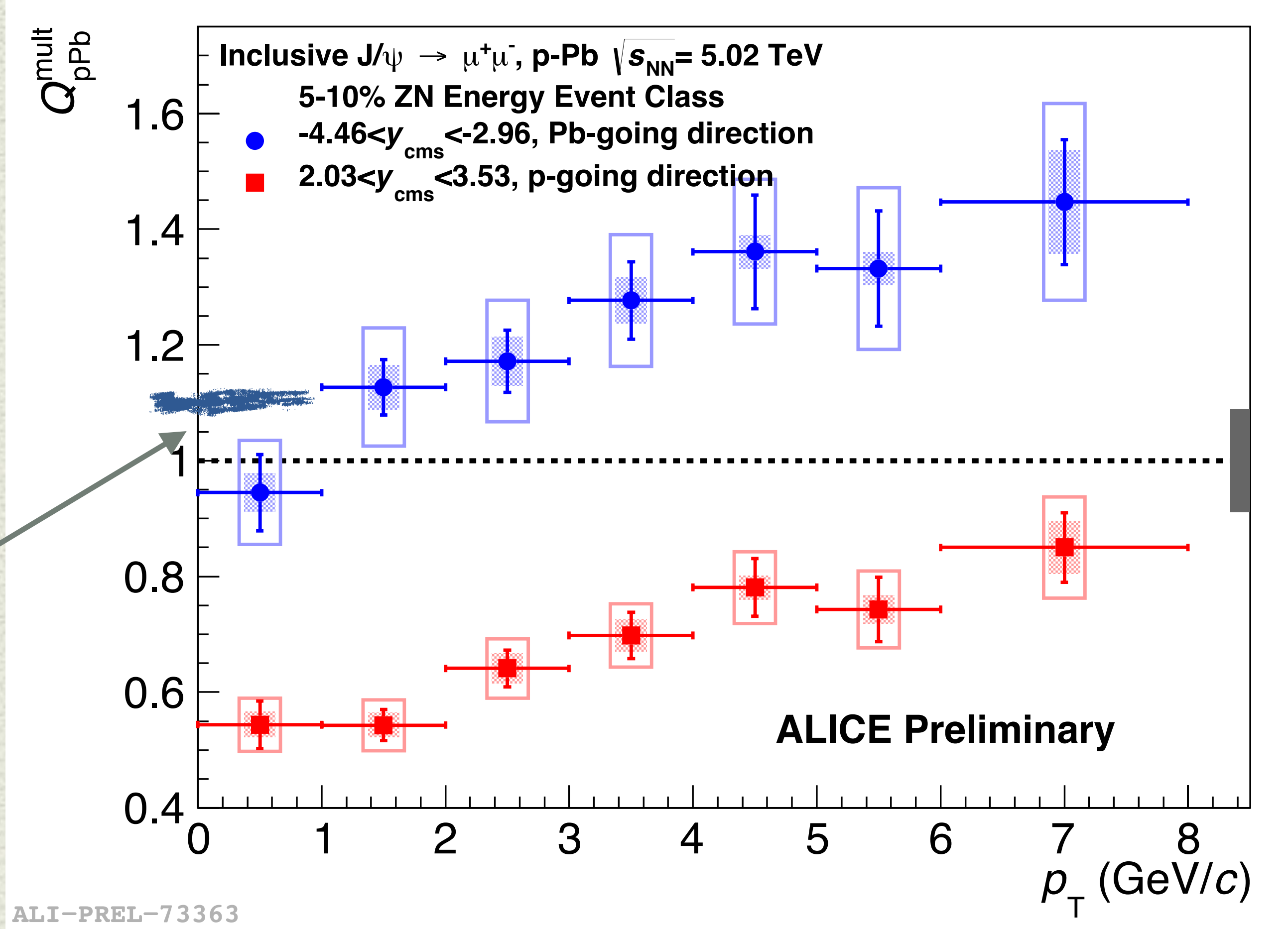


J/ψ Q_{pPb} vs p_T

High multiplicity events

J/ψ ➜ $\mu^+\mu^-$ measured in

- forward rapidity region
  - 2.03 < y_{CMS} < 3.53 (forward)
  - -4.46 < y_{CMS} < -2.96 (backward)



- Focus on the ZN estimator that it is considered to be the less biased.
- p_T integrated values for **backward** rapidity

Backward rapidity J/ψ:

Increase of Q_{pPb} for increased event activity

Clear trend vs p_T: stronger enhancement at high-p_T

J/ψ Q_{pPb} vs p_T

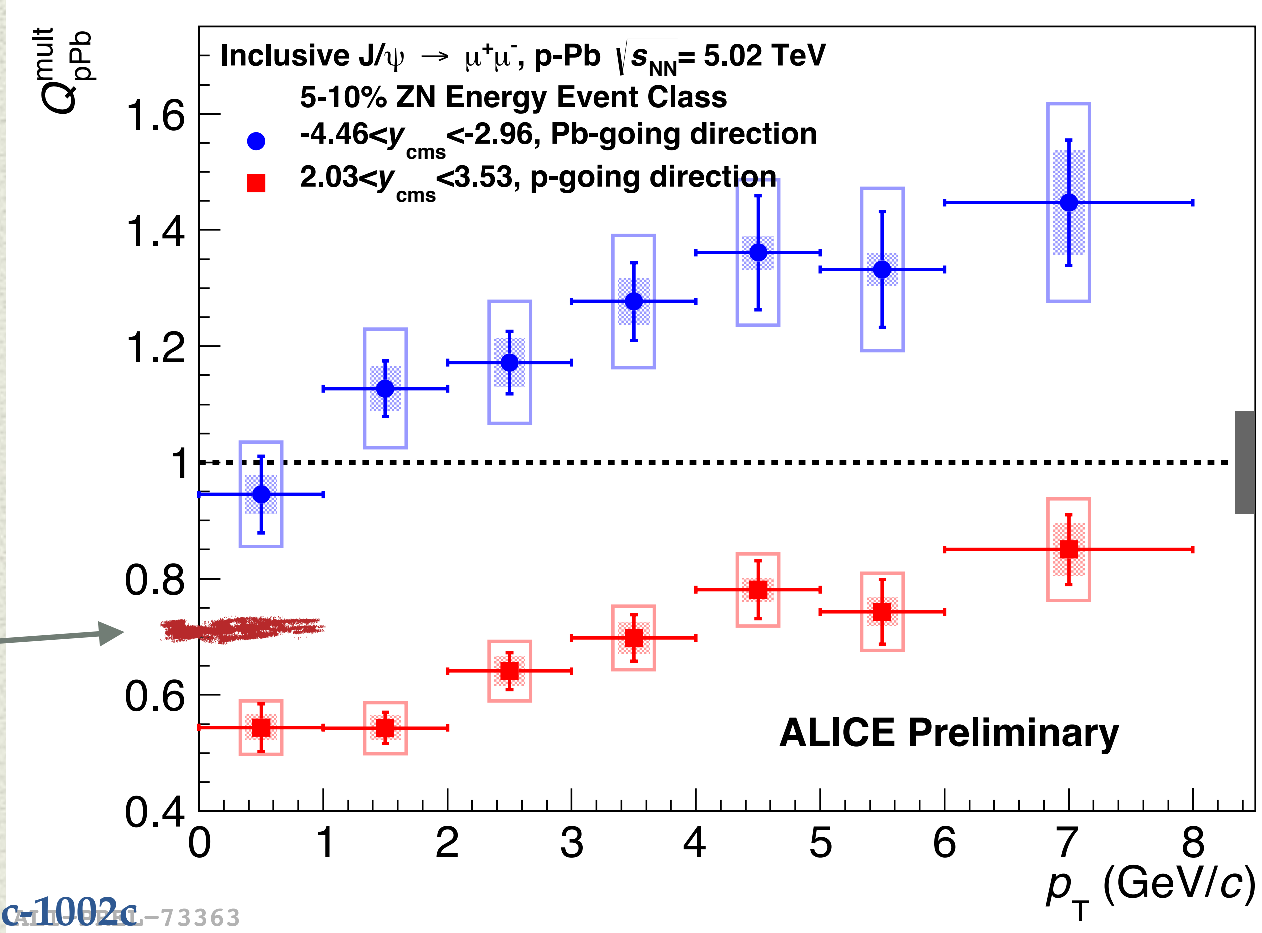
ALICE

J/ψ ➜ $\mu^+\mu^-$ measured in

- forward rapidity region
  - 2.03 < y_{CMS} < 3.53 (forward)
  - -4.46 < y_{CMS} < -2.96 (backward)

- Focus on the ZN estimator that it is considered to be the less biased.
- p_T integrated values for **forward** rapidity
- impact parameter dependent gluon shadowing effect? Nucl.Phys. A904-905 (2013) 999c-1002c

High multiplicity events



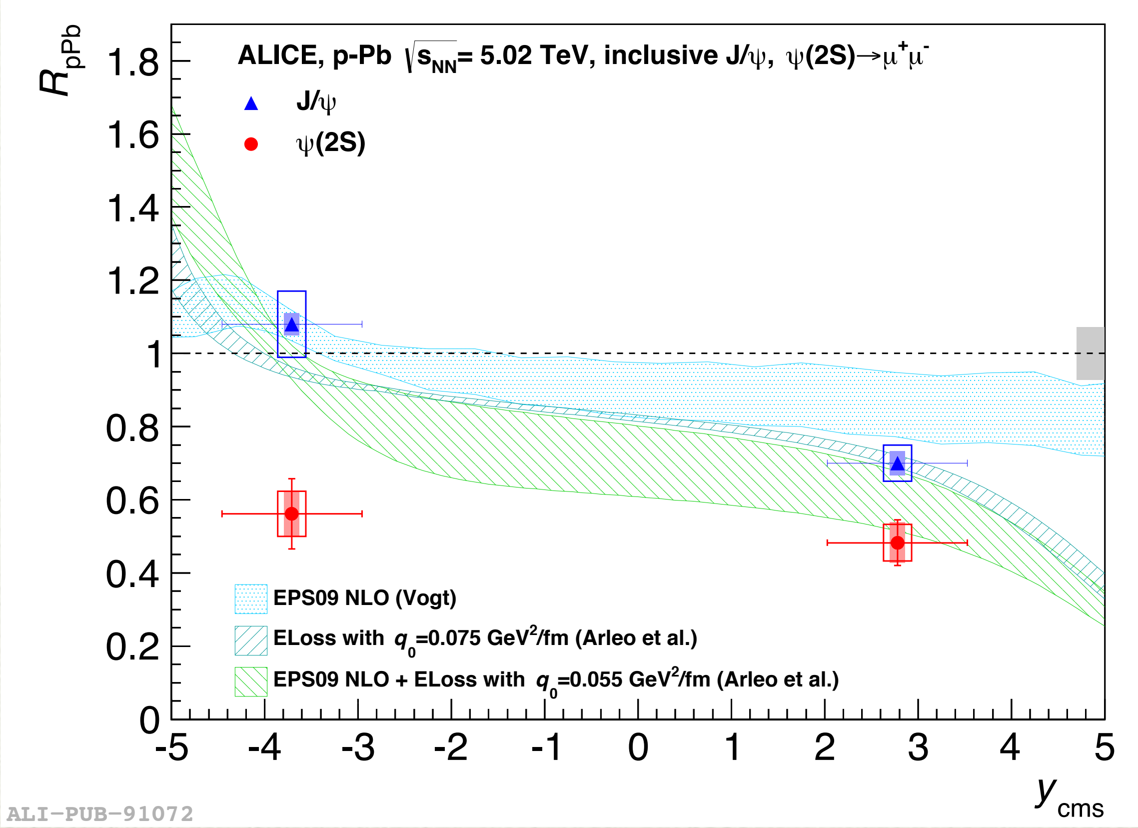
Forward rapidity J/ψ:

Decrease of Q_{pPb} for increased event activity

Clear trend vs p_T: stronger suppression at low-p_T

ψ(2S) in pPb

- R_{pPb} multiplicity and momentum integrated:
  - Both backward and forward rapidity clear suppression observed. Final state effect?



ψ(2S) measured in

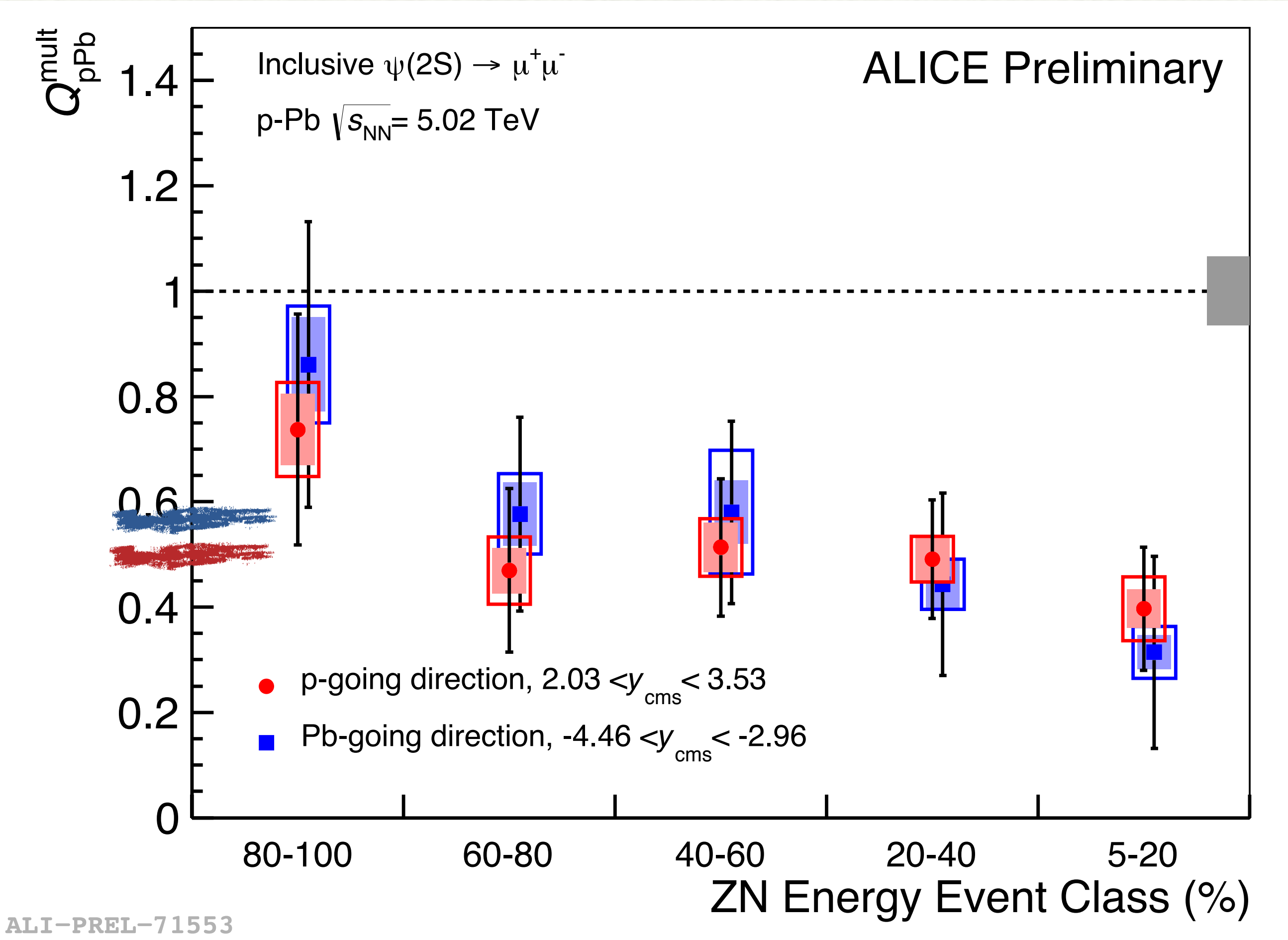
- **forward rapidity region**
  - **$2.03 < y_{CMS} < 3.53$ (forward)**
  - **$-4.46 < y_{CMS} < -2.96$ (backward)**
  - **$p_T > 0$**

ψ(2S) Q_{pPb}

ψ(2S) ➜ $\mu^+\mu^-$ measured in

- forward rapidity region
  - 2.03 < y_{CMS} < 3.53 (forward)
  - -4.46 < y_{CMS} < -2.96 (backward)

- Focus on the ZN estimator that it is considered to be the less biased.
- Multiplicity integrated values for **backward** and **forward** rapidity



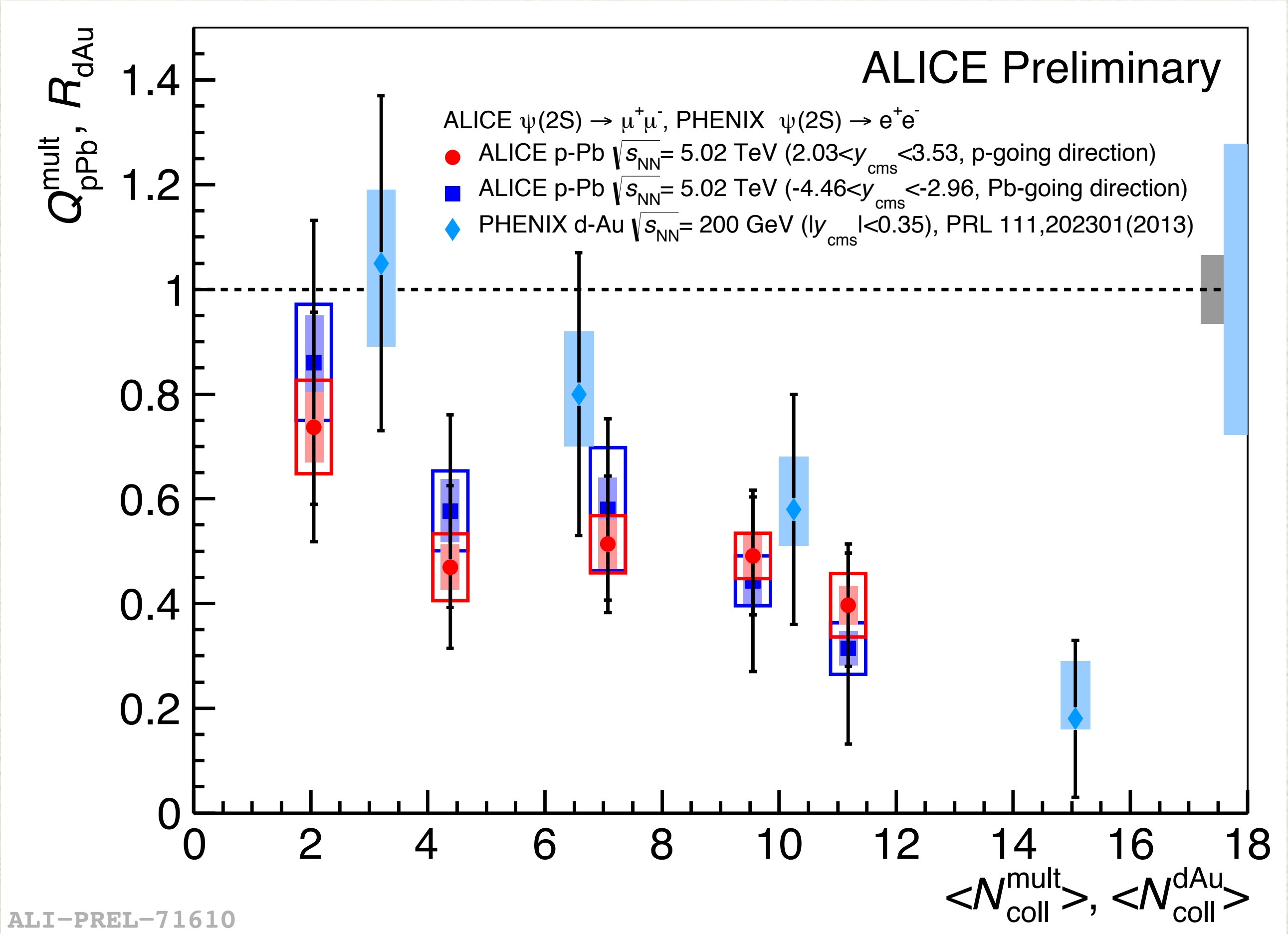
Clear suppression of ψ(2S)
Increasing suppression from low to high multiplicity events
Similar suppression at both backward and forward rapidity

ψ(2S) Q_{pPb}

ψ(2S) ➜ $\mu^+\mu^-$ measured in

- forward rapidity region
  - 2.03 < y_{CMS} < 3.53 (forward)
  - -4.46 < y_{CMS} < -2.96 (backward)

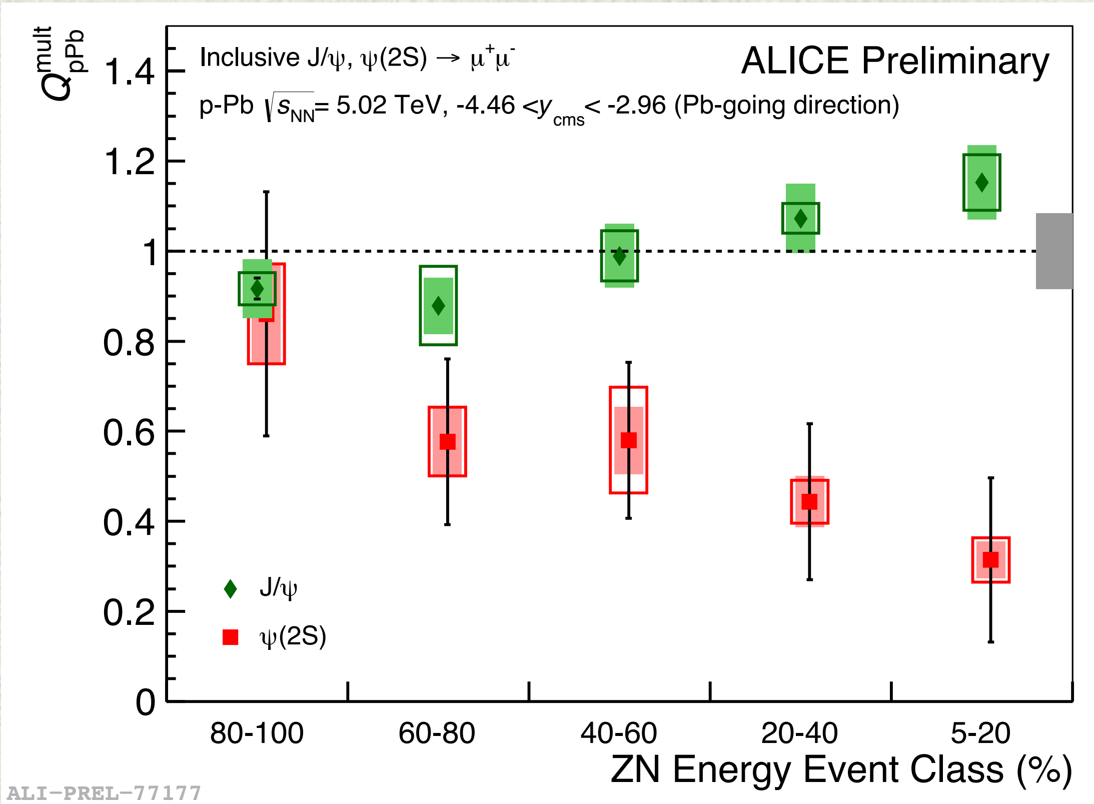
- Focus on the ZN estimator that it is considered to be the less biased.
- Multiplicity integrated values for **backward** and **forward** rapidity



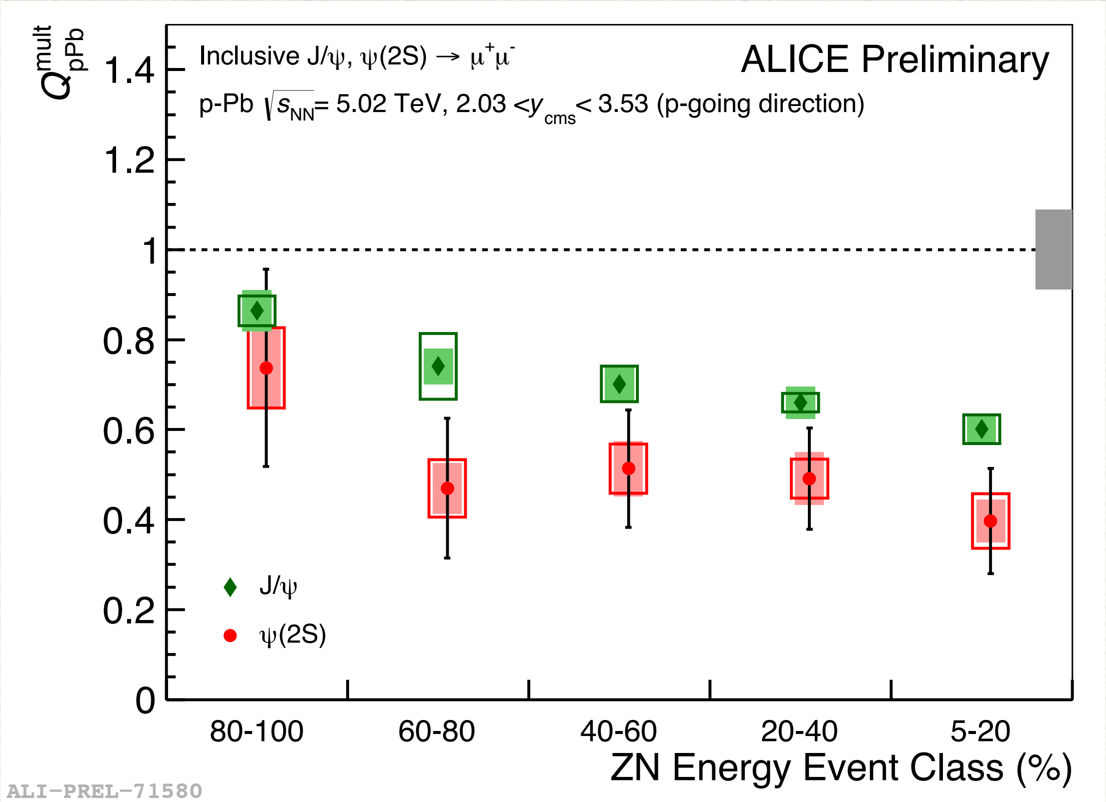
Clear suppression of ψ(2S)
Increasing suppression from low to high multiplicity events
Similar suppression at both backward and forward rapidity
Similar trend observed at RHIC!

J/ψ and ψ(2S) Q_{pPb}

Backward rapidity



Forward rapidity

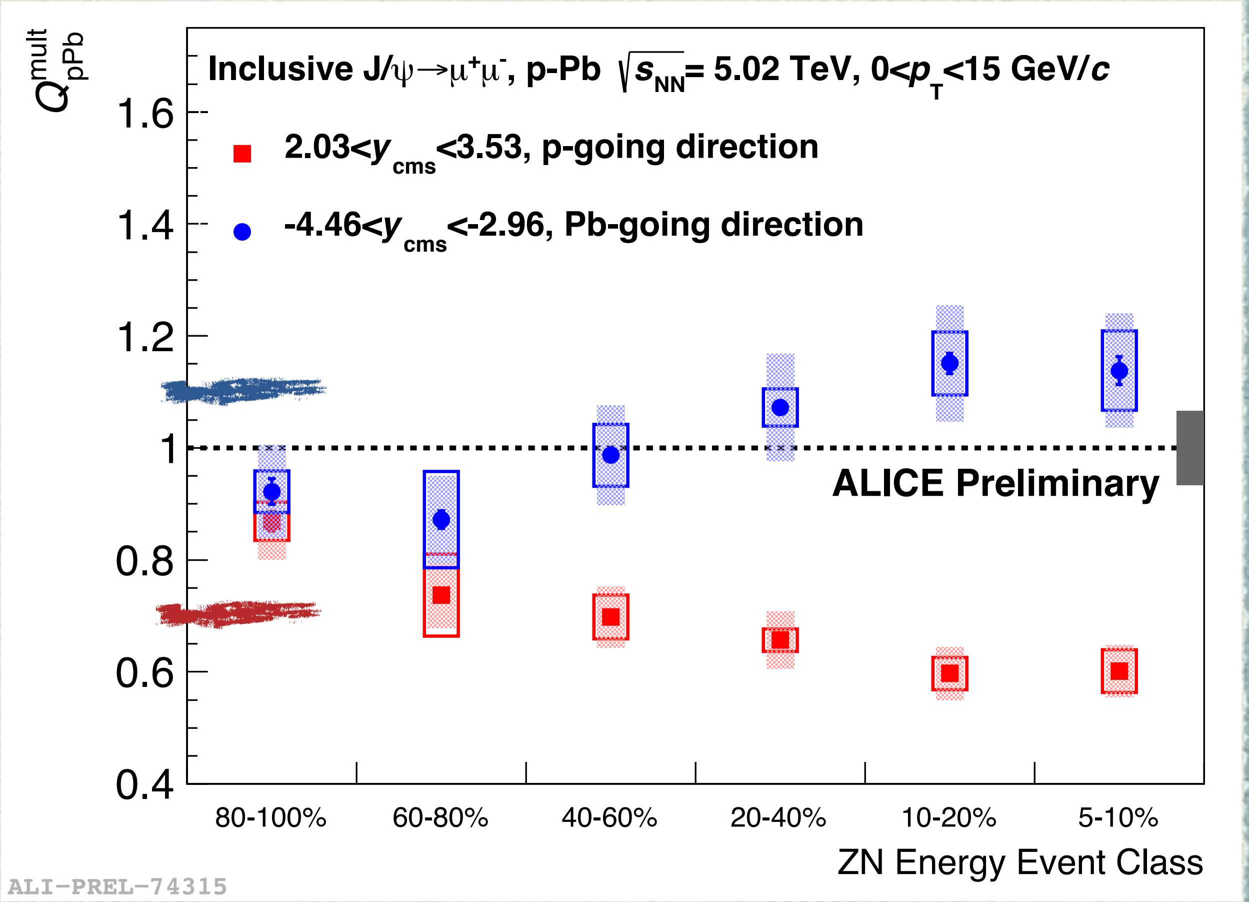


Forward rapidity: J/ψ and ψ(2S) show a similar decreasing trend vs event activity
Backward rapidity: J/ψ and ψ(2S) clear different behavior, ψ(2S) is more suppressed in high multiplicity events.

Wrap up (IV): Q_{pPb}

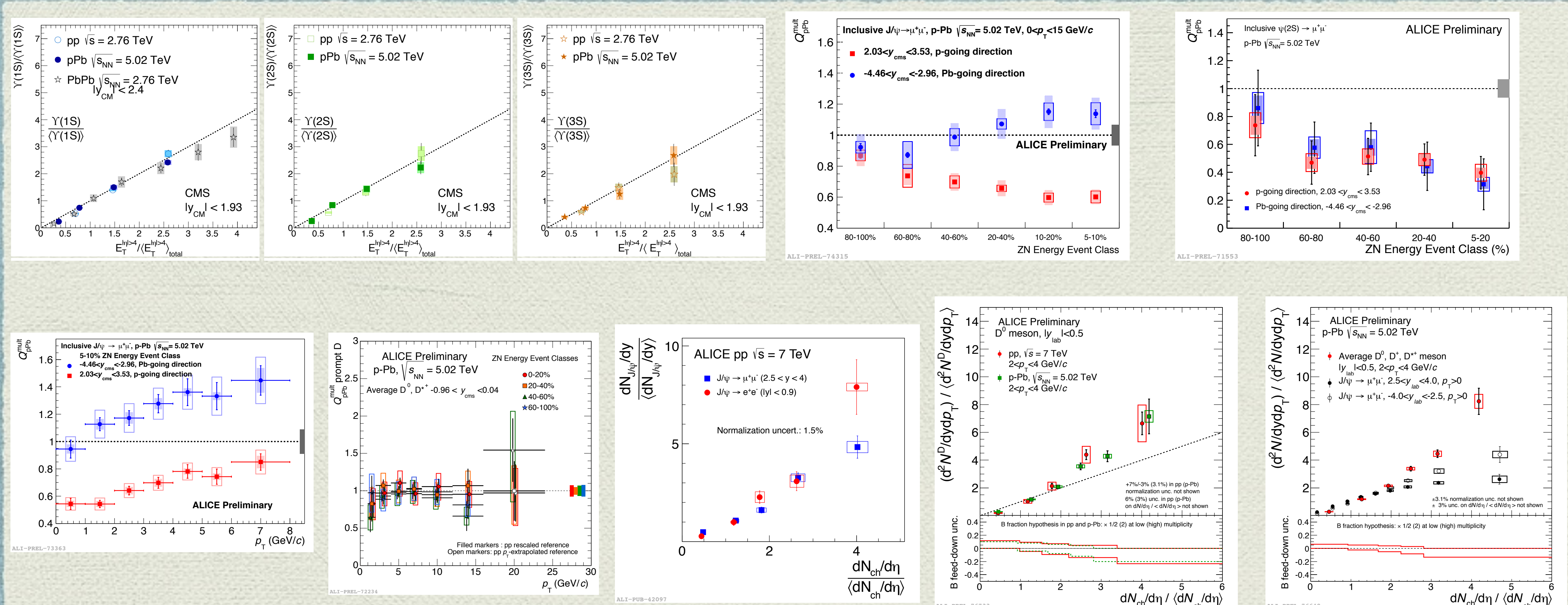
- D mesons: no multiplicity dependent modification of the spectra is observed within uncertainties.

- J/ψ Q_{pPb}:
  - **Backward rapidity**: Increase of Q_{pPb} for increased event activity; stronger enhancement at high-p_T
  - **Forward rapidity**: Decrease of Q_{pPb} for increased event activity; stronger suppression at low-pT



- ψ(2S) Q_{pPb}:
  Increasing suppression from low to high multiplicity events
  Similar suppression at both rapidities

Conclusions?



- **Measurements performed differentially in multiplicity can try to bring insight on the production mechanisms of heavy flavor hadrons.**
- **Important to understand any bias on the physics measurements that the "centrality" determination in p-Pb might cause.**

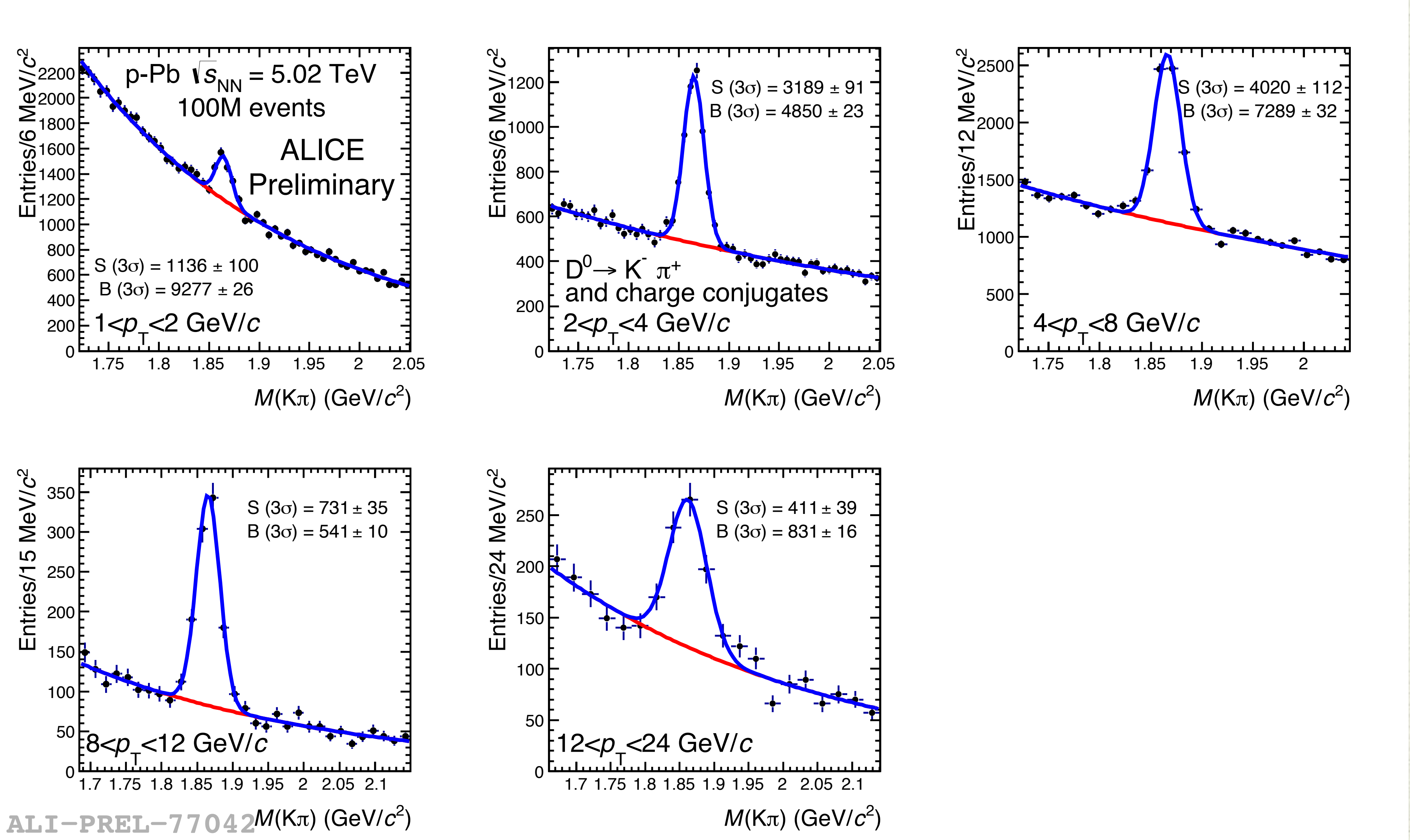
Thanks for the attention!!!
Thanks to the organizers for the possibility to give this talk!!!
Thanks to R. Arnaldi, L. Benhabib, Z. Conesa del Valle, A. Dainese, F. Prino for the help with the preparation of this talk.

Back Up

D vs multiplicity: Integrated raw yields

$$\frac{d^2N^D/dydp_T}{< d^2N^D/dydp_T >} = \frac{(d^2N^D/dydp_T)^{mult}/(\epsilon^{mult} \times N^{mult}_{event})}{(d^2N^D/dydp_T)^{tot}/(\epsilon^{tot} \times N^{tot}_{event})}$$

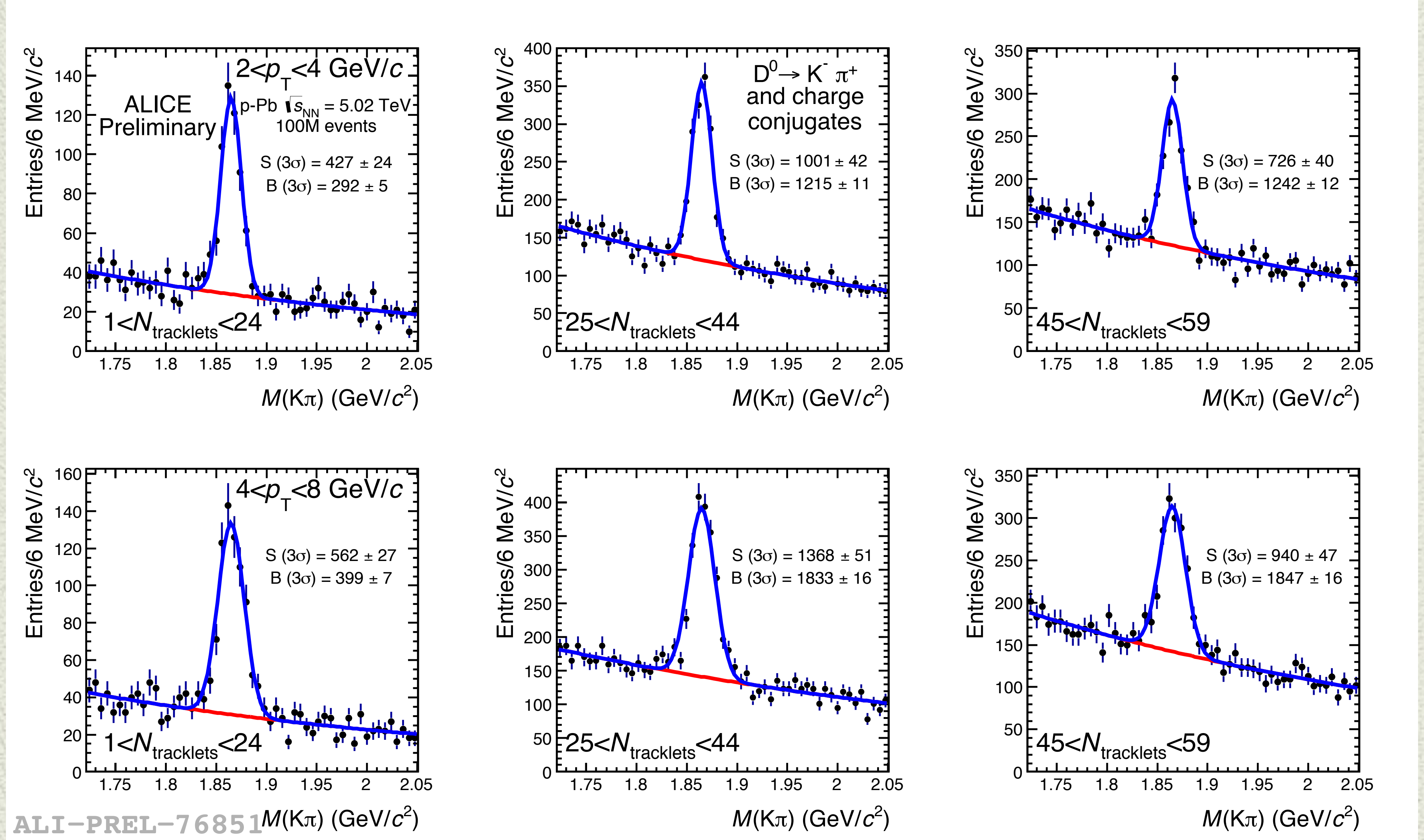
Multiplicity integrated yields in 5 p_T intervals



D vs multiplicity: multiplicity differential raw yields

$$\frac{d^2N^D/dydp_T}{< d^2N^D/dydp_T >} = \frac{(d^2N^D/dydp_T)^{mult}/(\epsilon^{mult} \times N^{mult}_{event})}{(d^2N^D/dydp_T)^{tot}/(\epsilon^{tot} \times N^{tot}_{event})}$$

Multiplicity differential yields in p_T intervals

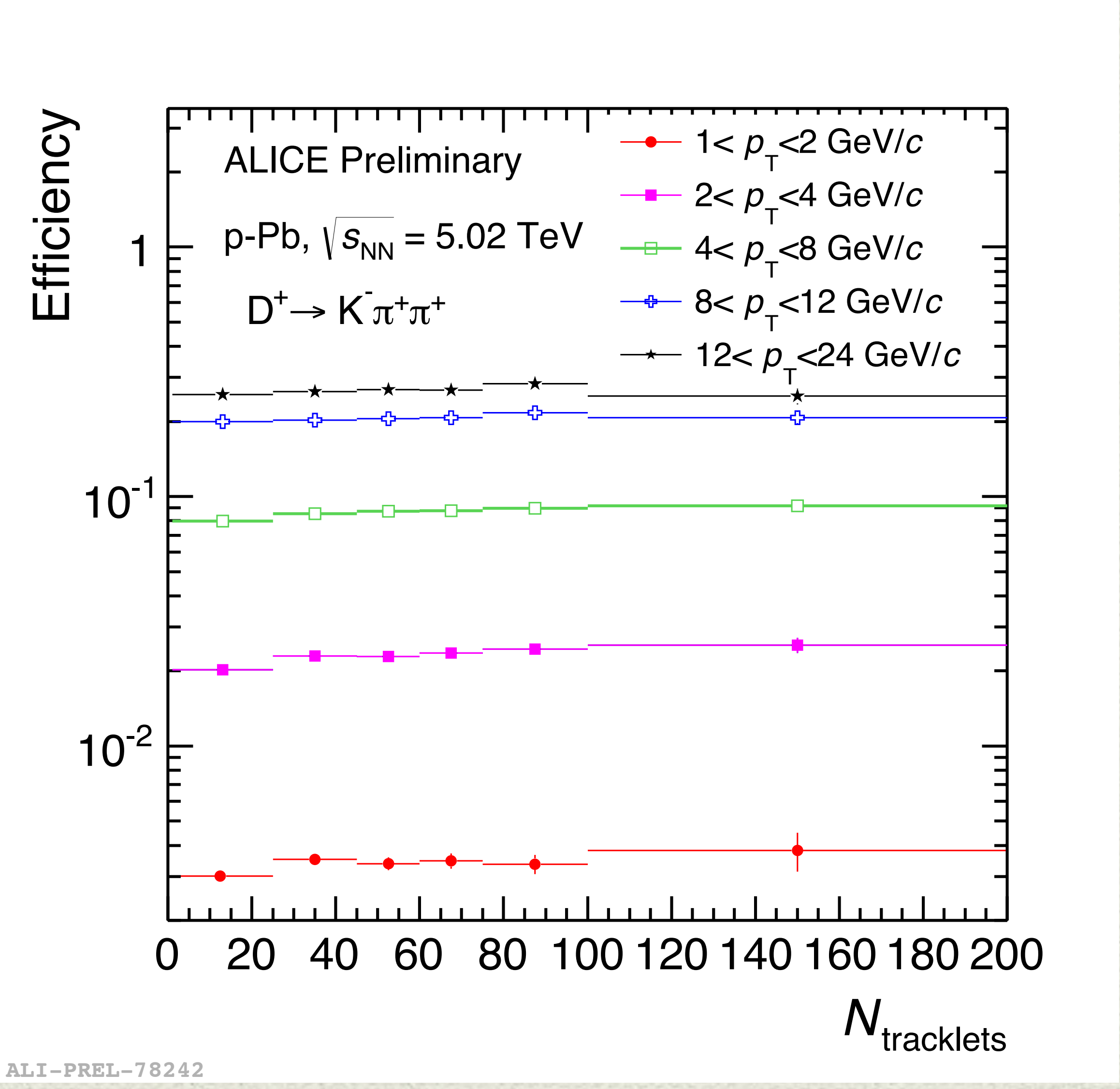


D vs multiplicity: Efficiencies

$$\frac{d^2N^D/dydp_T}{< d^2N^D/dydp_T >} = \frac{(d^2N^D/dydp_T)^{mult}/(\epsilon^{mult} \times N^{mult}_{event})}{(d^2N^D/dydp_T)^{tot}/(\epsilon^{tot} \times N^{tot}_{event})}$$

Efficiencies does not show a strong multiplicity dependence

Efficiencies increase with increasing p_T



D vs multiplicity: Feed down subtraction

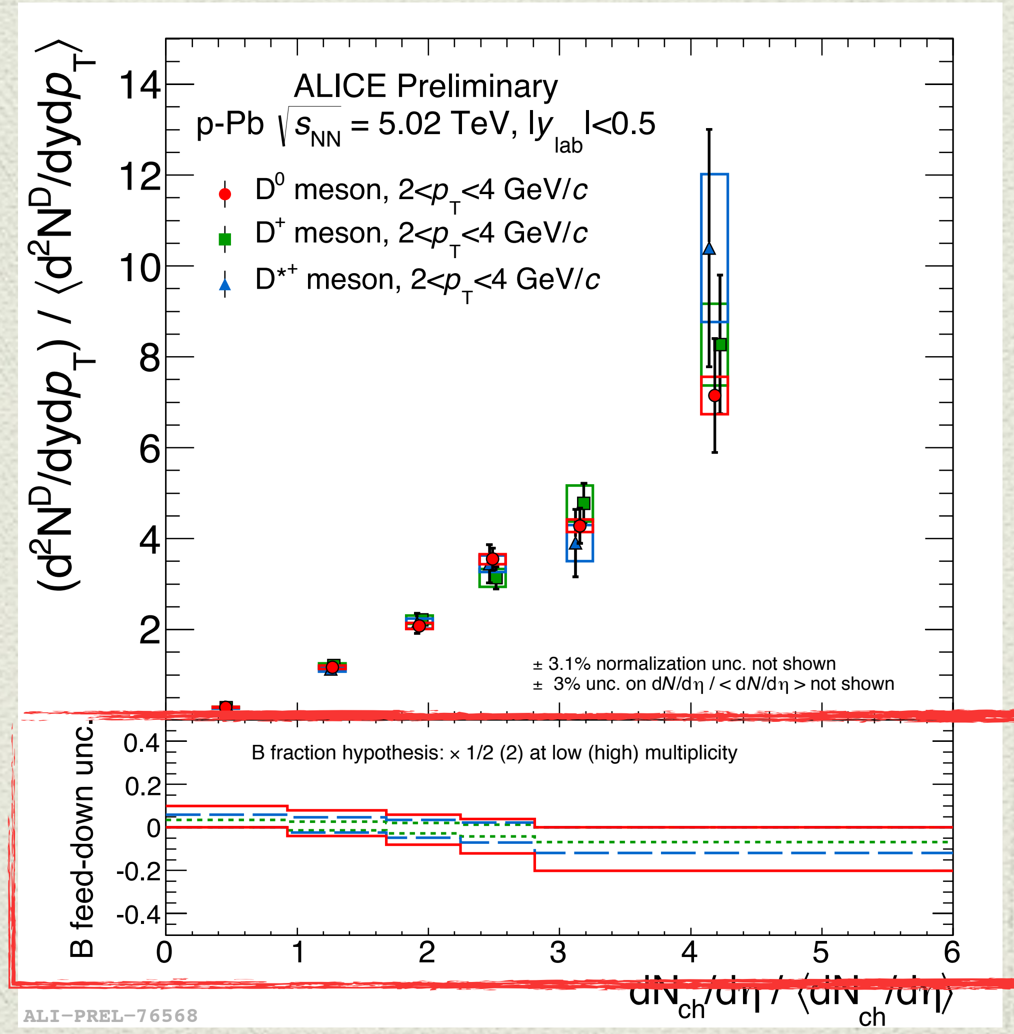
Assumption: the fraction of prompt D mesons f_{prompt} does not depend on multiplicity

$$\frac{d^2N^D/dydp_T}{< d^2N^D/dydp_T >} = \frac{(d^2N^D/dydp_T)^{mult}/(\epsilon^{mult} \times N^{mult}_{event}) * \cancel{f_{\text{prompt}}}}{(d^2N^D/dydp_T)^{tot}/(\epsilon^{tot} \times N^{tot}_{event}) * \cancel{f_{\text{prompt}}}}$$

Systematic uncertainties assigned due to beauty feed down fraction:

variation of beauty contribution vs multiplicity up to a factor of 2

maxiumum 20% at high p_T



D vs multiplicity: systematic uncertainties

Yield extraction systematic uncertainties

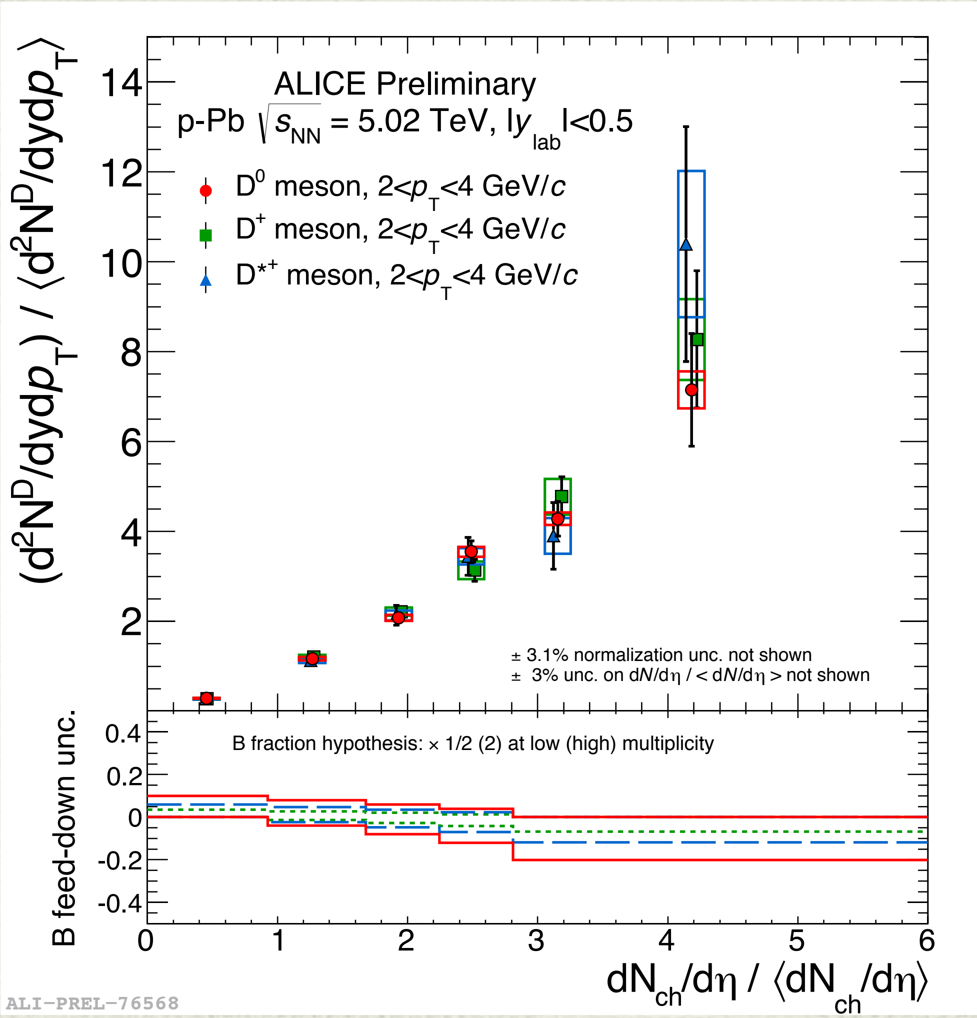
p_T (GeV/c)	Multiplicity bin					
	1-24	25-44	45-59	60-74	75-99	100-199
1-2	4%	3%	3%	5%	6%	-
2-4	3%	3%	3%	3%	3%	5%
4-8	3%	3%	3%	3%	3%	5%
8-12	4%	3%	3%	3%	4%	5%
12-24	6%	3%	3%	5%	5%	-

D vs multiplicity in pp collisions

Studied observable: self-normalized yields in multiplicity intervals relative to the multiplicity integrated ones

$$\frac{d^2N^D/dydp_T}{< d^2N^D/dydp_T >} = \frac{(d^2N^D/dydp_T)^{mult}/(\epsilon^{mult} \times N^{mult}_{event})}{(d^2N^D/dydp_T)^{tot}/(\epsilon^{tot} \times N^{tot}_{event})}$$

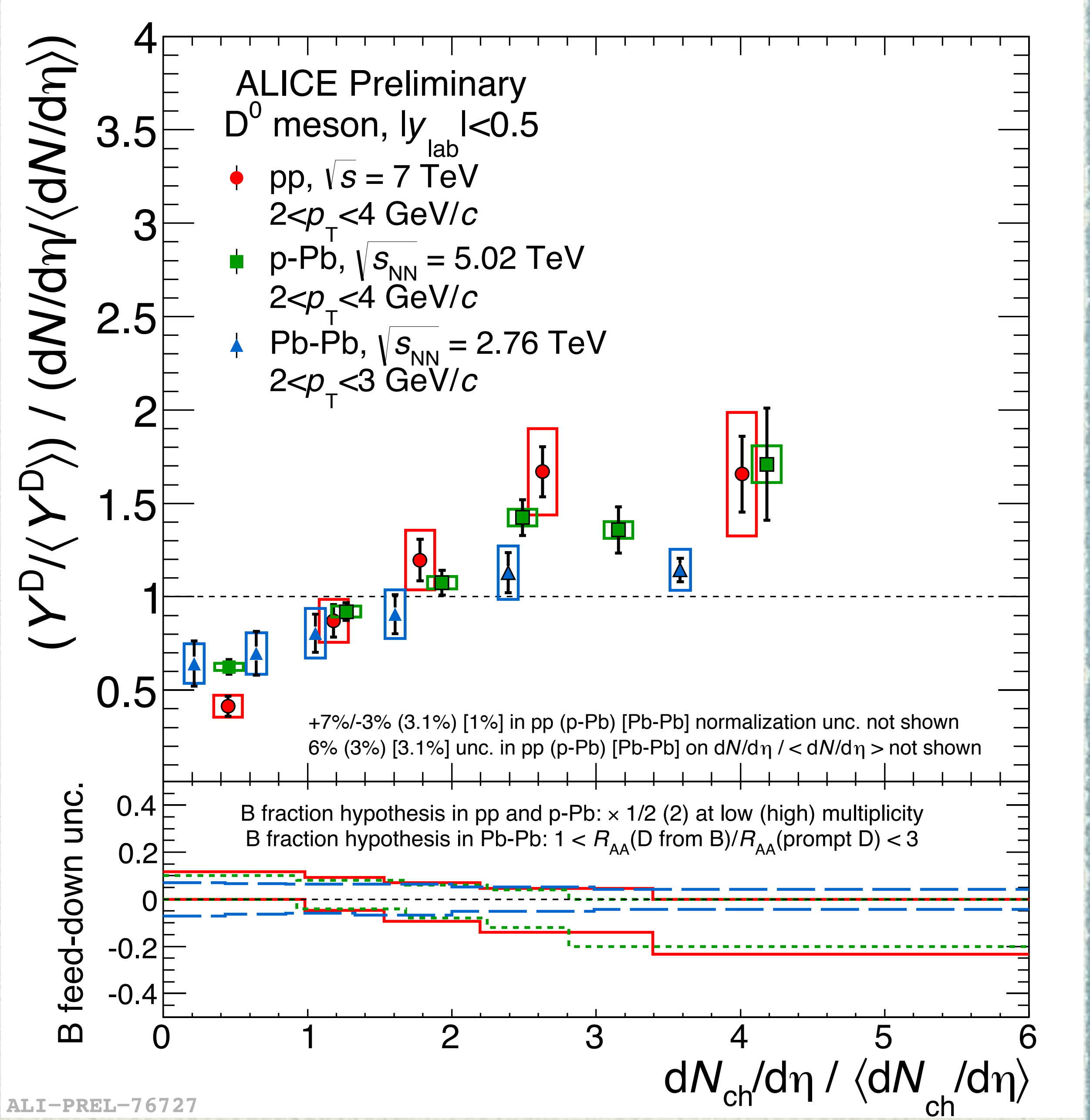
- D^0, D^+ and D^{*+} **measurements are in agreement** within uncertainties.
- Self-normalized D meson yields in different p_T bins are in agreement within uncertainties. **No clear p_T trend observed.**
- Results show an **increase of the yield with charged-particle production**.



Comparison of pp, p-Pb and Pb-Pb collisions

- The trend seems to be similar also when we compare Pb-Pb results, but…

highest multiplicity bin in Pb-Pb collisions corresponds to 10% of the total cross section, for pp to only 1%.



QpPb: Hybrid method some details

Assumption 1 : ZN insensitive to dynamical biases

➜ slice events in ZN

Assumption 2:

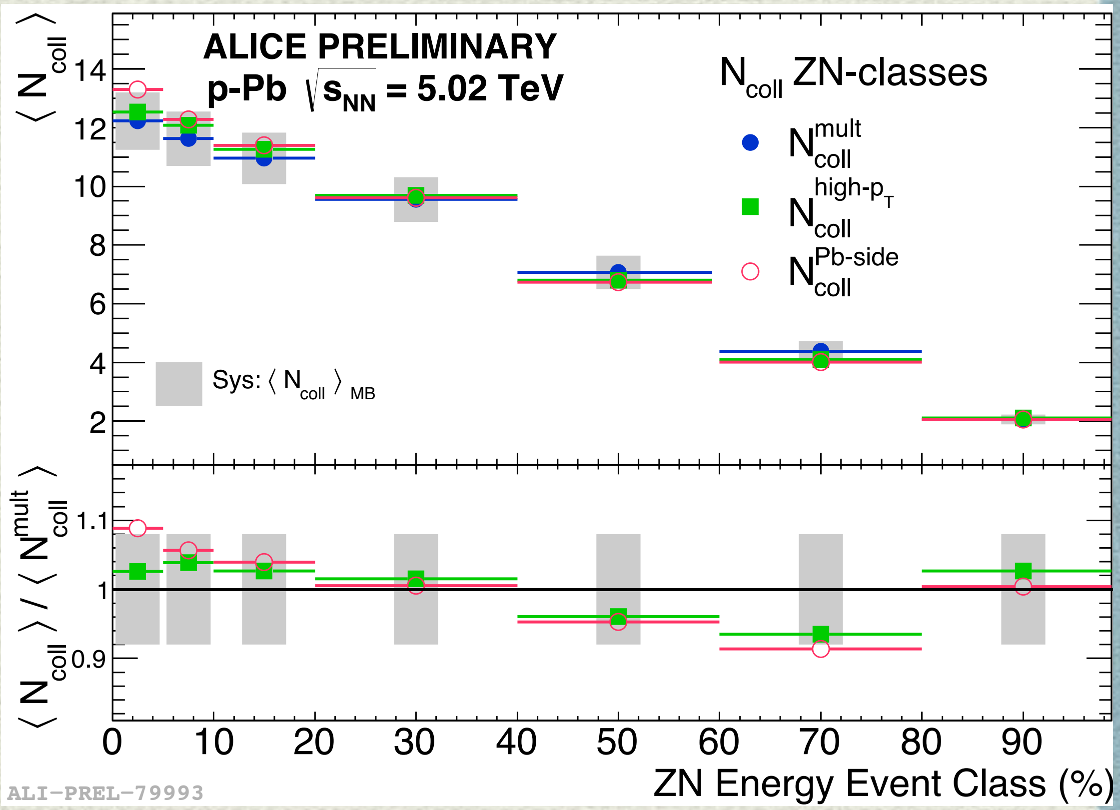
a. **mid-rapidity dN/dη scales with N_{part}**
b. **Pb-side dN/dη scales with N_{part} (= N_{coll} for p-Pb collisions)**
c. **Yields at high-pT scales with N_{coll}**

$$\langle N_{part}\rangle_i^{mult} = \langle N_{part}\rangle_{MB} \cdot \frac{\langle S\rangle_i}{\langle S\rangle_{MB}}$$

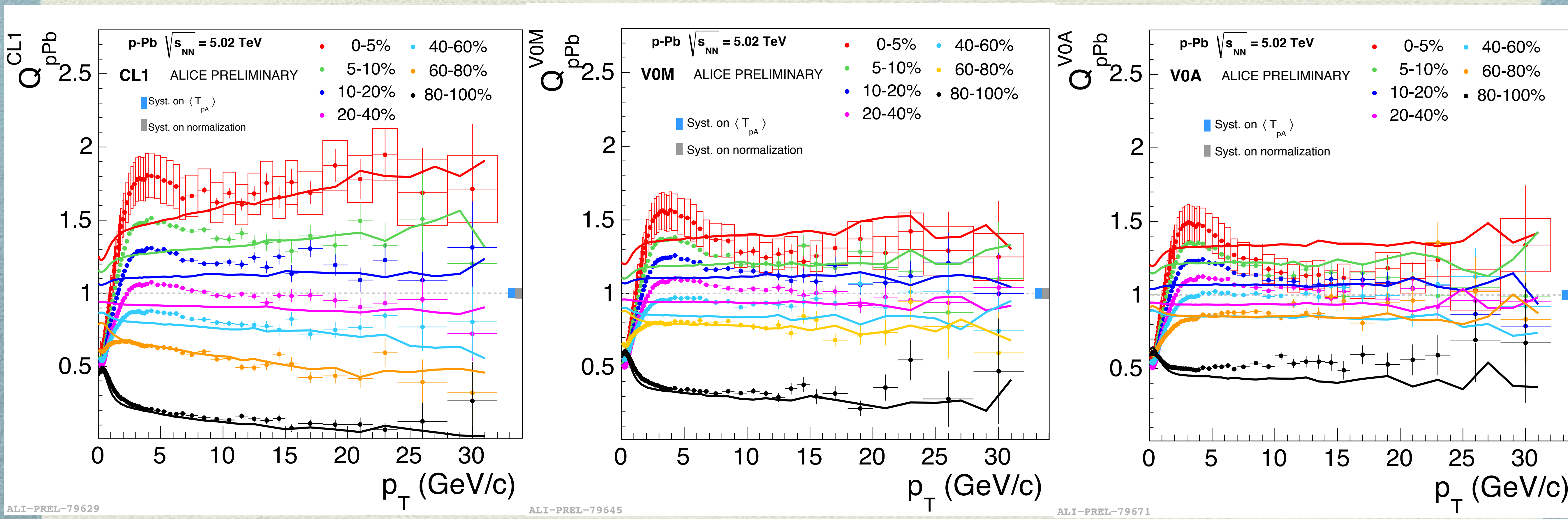
$$\langle N_{coll}\rangle_i^{mult} = \langle N_{part}\rangle_i^{mult} - 1$$

$$\langle N_{coll}\rangle_i^{Pb-side} = \langle N_{coll}\rangle_{MB} \cdot \frac{\langle S\rangle_i}{\langle S\rangle_{MB}}$$

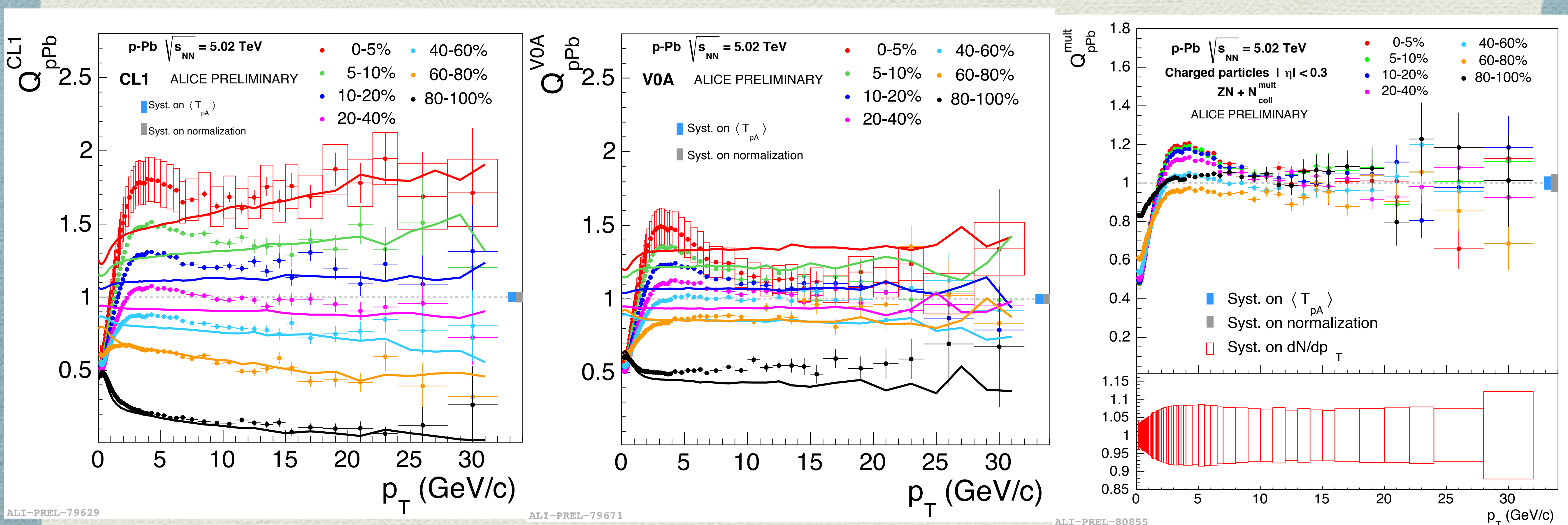
$$\langle N_{coll}\rangle_i^{high-p_T} = \langle N_{coll}\rangle_{MB} \cdot \frac{\langle S\rangle_i}{\langle S\rangle_{MB}}$$



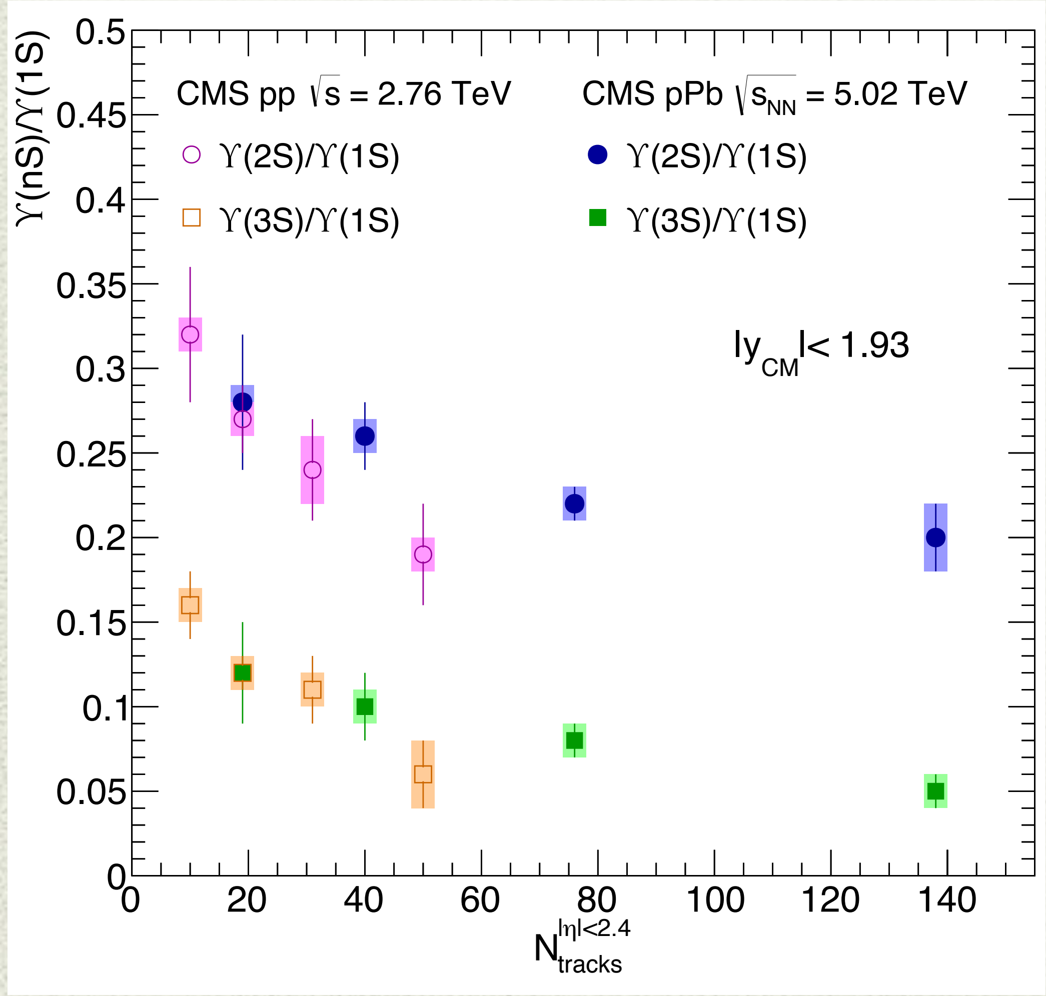
QpPb: other estimators



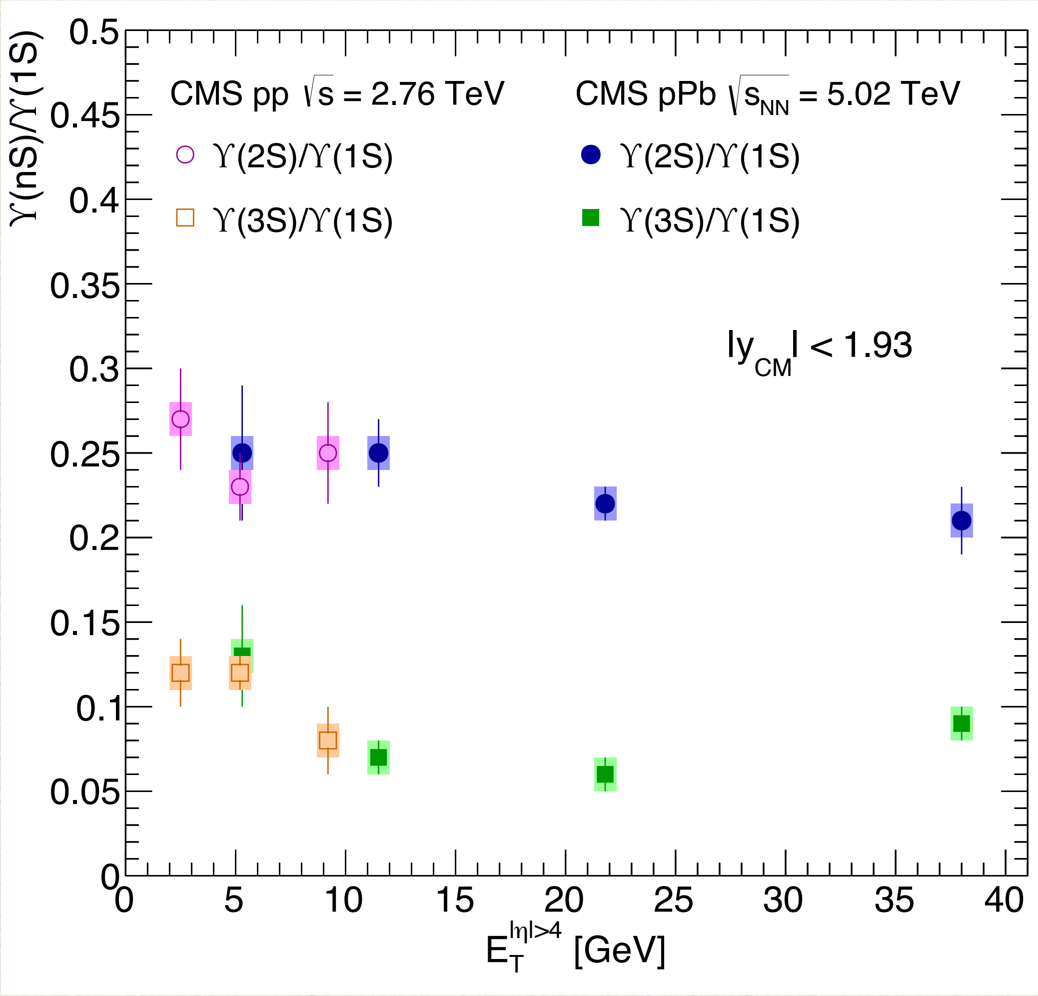
QpPb: other estimators



Υ vs mult

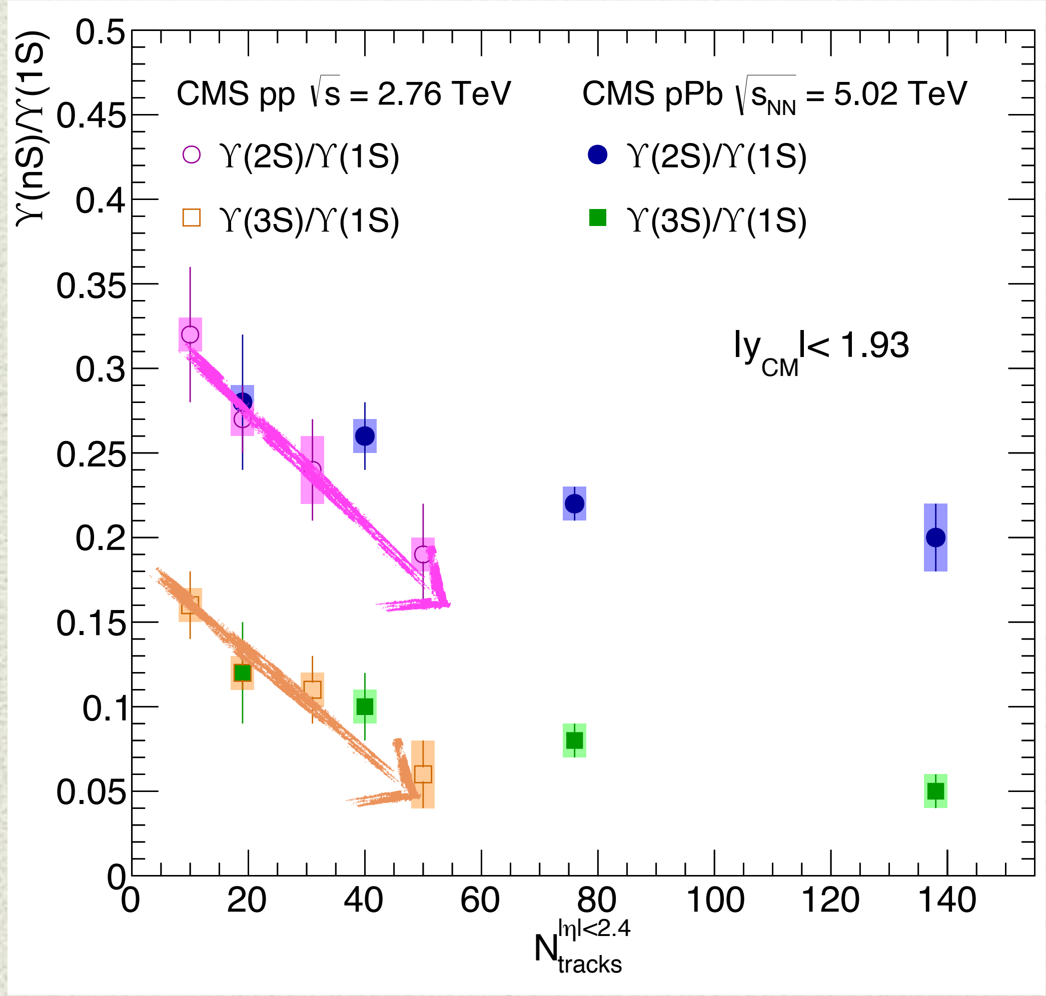


Υ(nS)/Υ(1S)
CMS pp √s = 2.76 TeV
CMS pPb √s_NN = 5.02 TeV
Υ(2S)/Υ(1S)
Υ(3S)/Υ(1S)
Υ(2S)/Υ(1S)
Υ(3S)/Υ(1S)
|y_CM|< 1.93
N_tracks^|η|<2.4

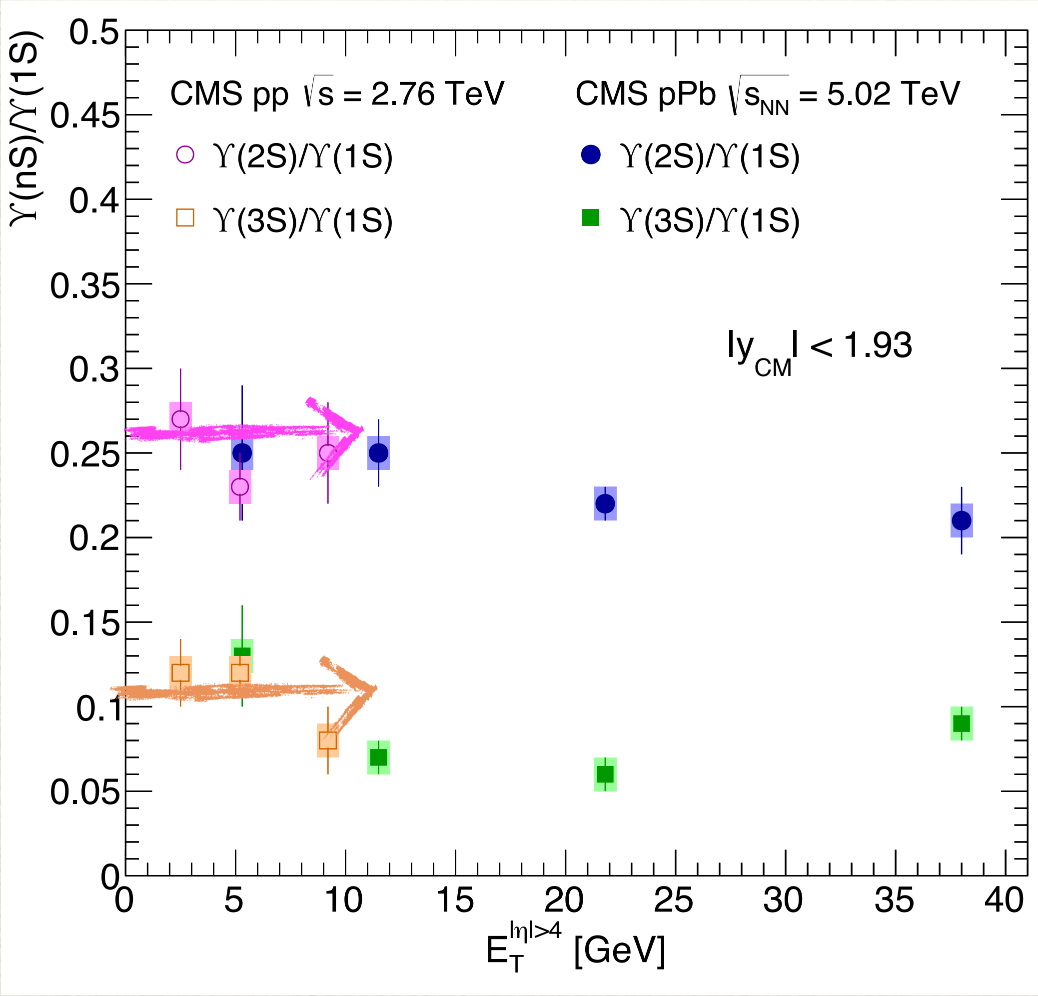


Υ(nS)/Υ(1S)
CMS pp √s = 2.76 TeV
CMS pPb √s_NN = 5.02 TeV
Υ(2S)/Υ(1S)
Υ(3S)/Υ(1S)
Υ(2S)/Υ(1S)
Υ(3S)/Υ(1S)
|y_CM| < 1.93
E_T^|η|>4 [GeV]

Υ vs mult

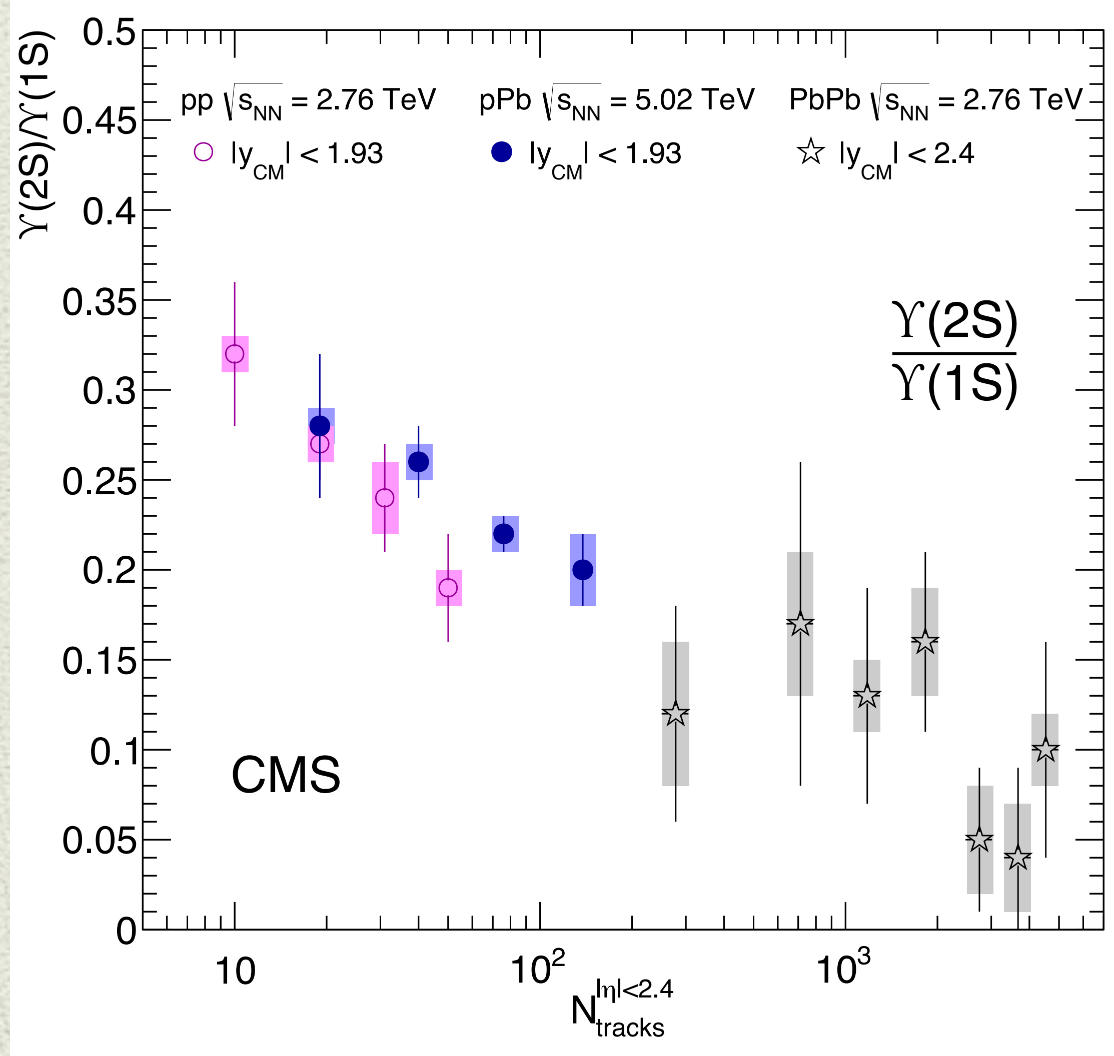


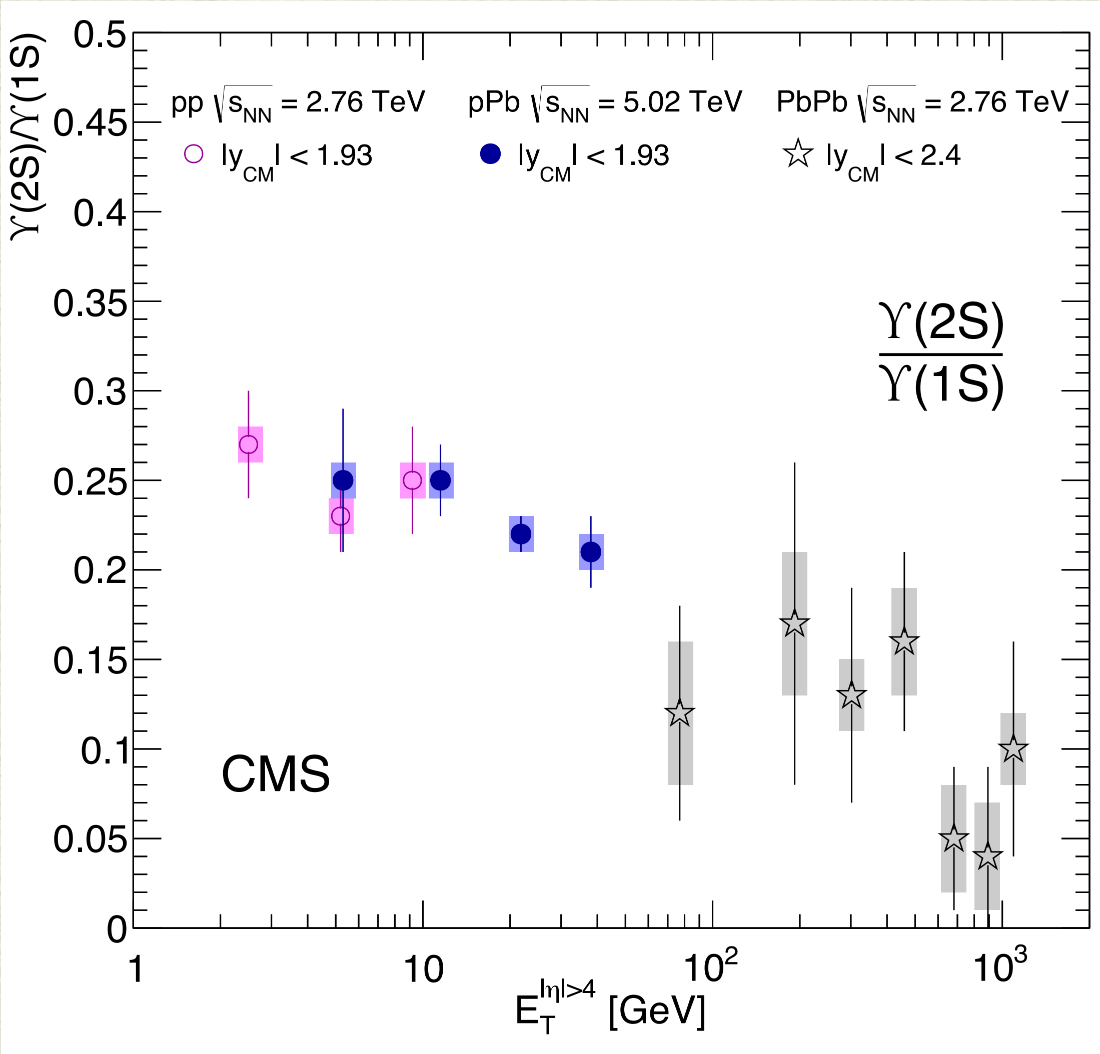
Υ(nS)/Υ(1S)
CMS pp √s = 2.76 TeV
CMS pPb √s_NN = 5.02 TeV
Υ(2S)/Υ(1S)
Υ(3S)/Υ(1S)
Υ(2S)/Υ(1S)
Υ(3S)/Υ(1S)
|y_CM|< 1.93
N_tracks^|η|<2.4



Υ(nS)/Υ(1S)
CMS pp √s = 2.76 TeV
CMS pPb √s_NN = 5.02 TeV
Υ(2S)/Υ(1S)
Υ(3S)/Υ(1S)
Υ(2S)/Υ(1S)
Υ(3S)/Υ(1S)
|y_CM| < 1.93
E_T^|η|>4 [GeV]

ϒ vs mult


ϒ(2S)/ϒ(1S)
pp √sNN = 2.76 TeV
pPb √sNN = 5.02 TeV
PbPb √sNN = 2.76 TeV
|yCM| < 1.93
|yCM| < 1.93
|yCM| < 2.4
ϒ(2S)/ϒ(1S)
CMS
N tracks |η|<2.4


ϒ(2S)/ϒ(1S)
pp √sNN = 2.76 TeV
pPb √sNN = 5.02 TeV
PbPb √sNN = 2.76 TeV
|yCM| < 1.93
|yCM| < 1.93
|yCM| < 2.4
ϒ(2S)/ϒ(1S)
CMS
E T |η|>4 [GeV]

ψ(2S) in pPb

Can the stronger suppression of the weakly bound ψ(2S) be due to break-up of the fully formed resonance in CNM?

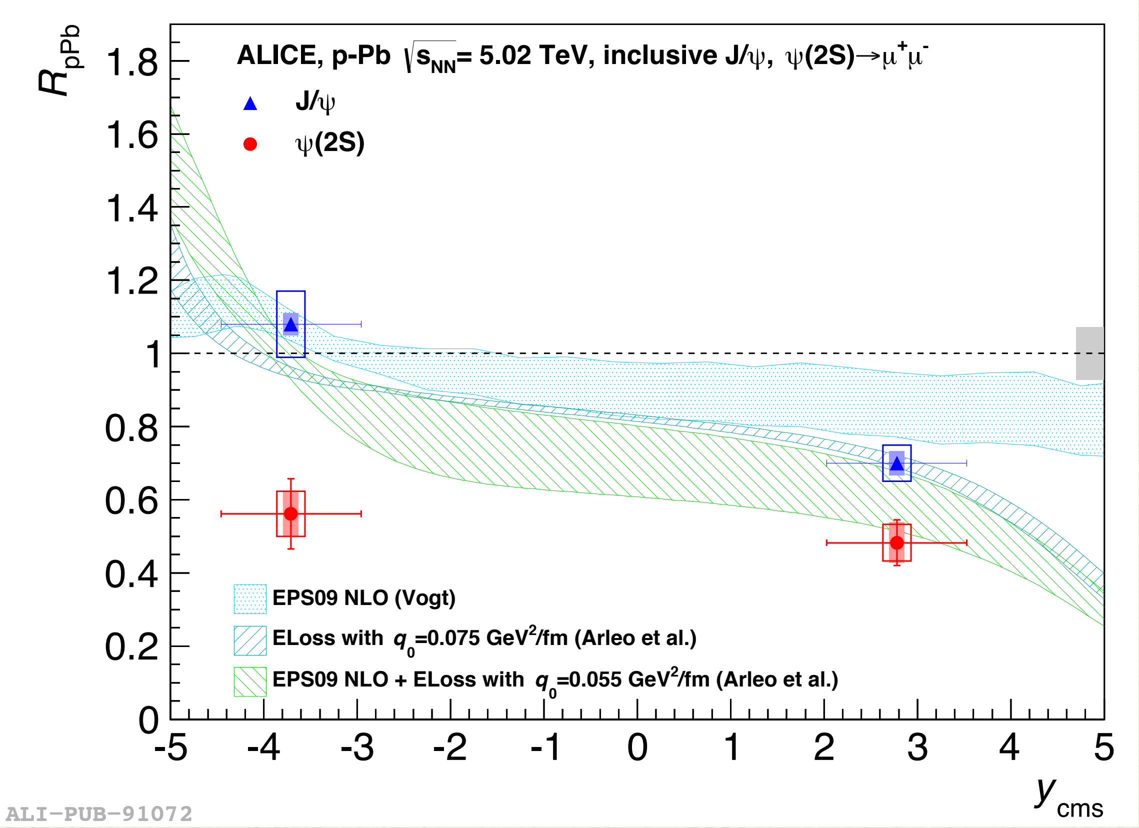
Possible if formation time (τ_f ~0.05-0.15fm/c) < crossing time (τ_c)

forward-y: τ_c~10^{-4} fm/c

backward-y: τ_c~$7x10^{-2}$ fm/c

➜ break-up effects excluded at forward-y

➜ at backward-y, since $\tau_f \sim \tau_c$, break-up in CNM can hardly explain the very strong difference between J/ψ and ψ(2S) suppressions



ψ(2S) measured in

- **forward rapidity region**
  - **2.03 < y_{CMS} < 3.53 (forward)**
  - **-4.46 < y_{CMS} < -2.96 (backward)**
  - **p_T > 0**