Recent Results & Chance for my Education
Open Heavy Flavor Hadronization

Jing Wang (CERN)

International Workshop “QCD challenges from pp to AA collisions”
September 4, 2024

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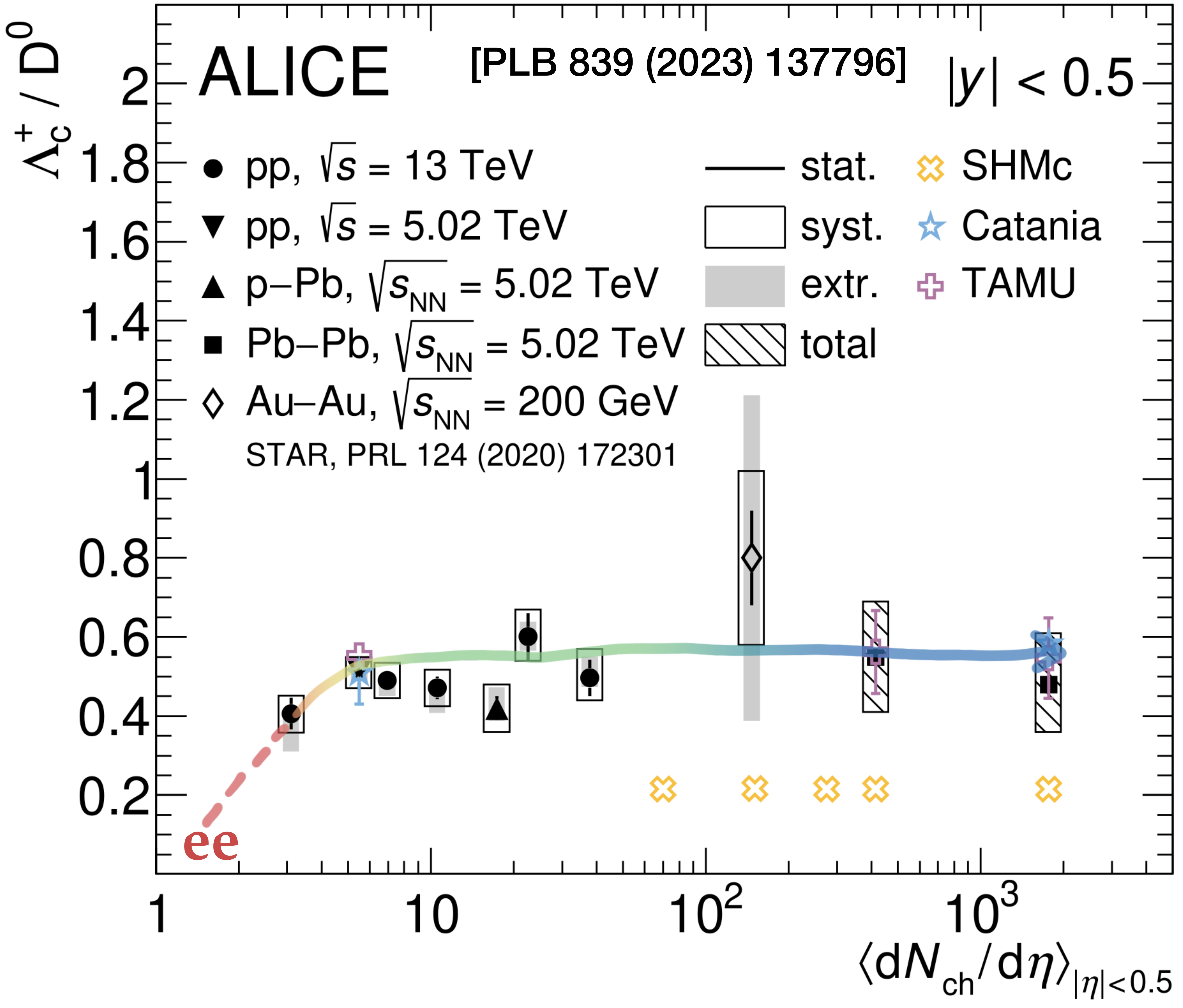
Integrated Λ_c Across Collision Systems

Integrated p_T



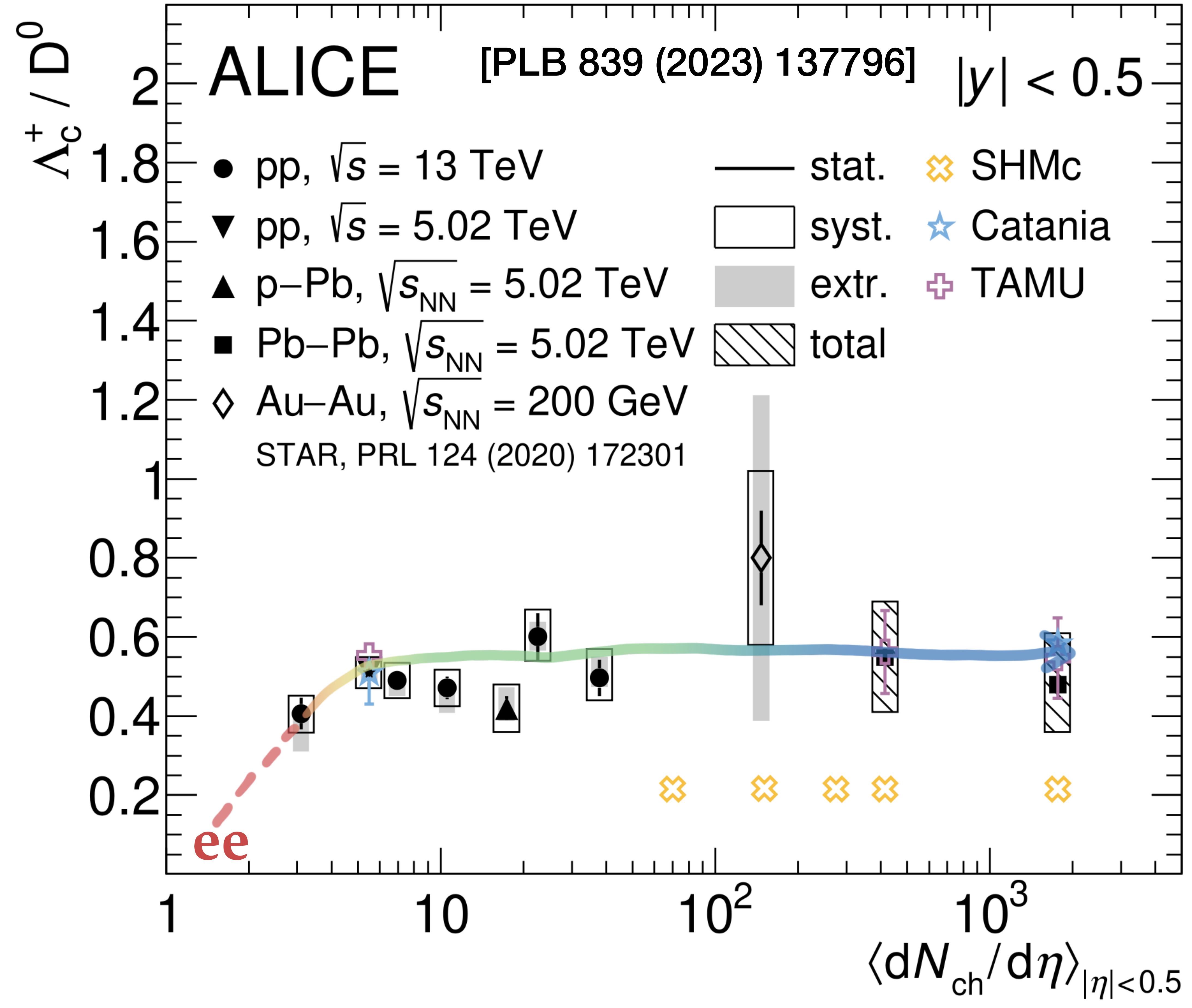
p_T-Integrated yield ratio Λ_c / D^0

- Increases from e^+e^- to low-mult pp
  - ~0.1 → ~0.5
- Saturated from low-mult pp to central PbPb
  - ~0.5

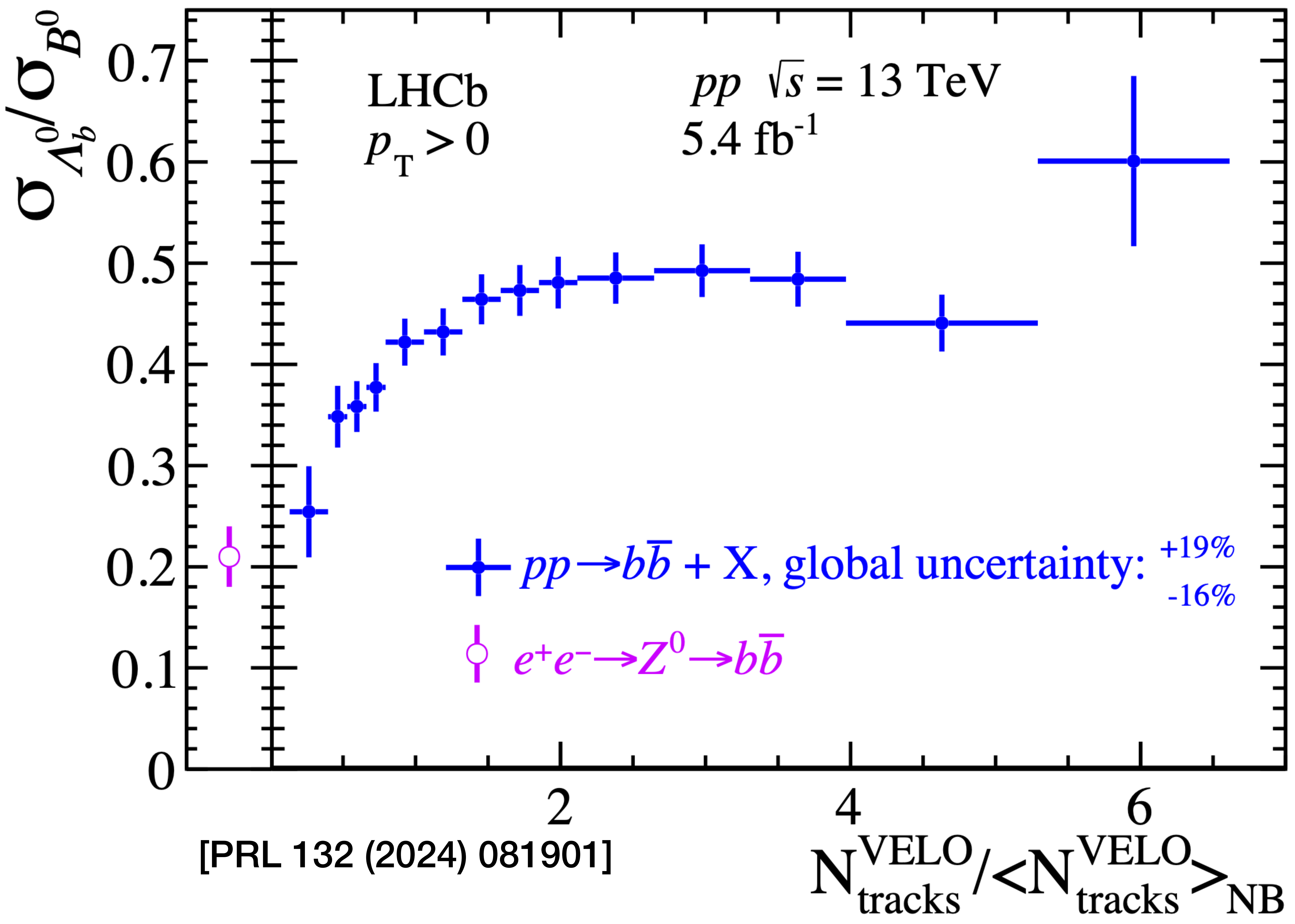
- How each model understand the saturation?

Integrated Baryon Λc vs Λb

Λc / D⁰ Integrated pT



Λb / B⁰ Integrated pT

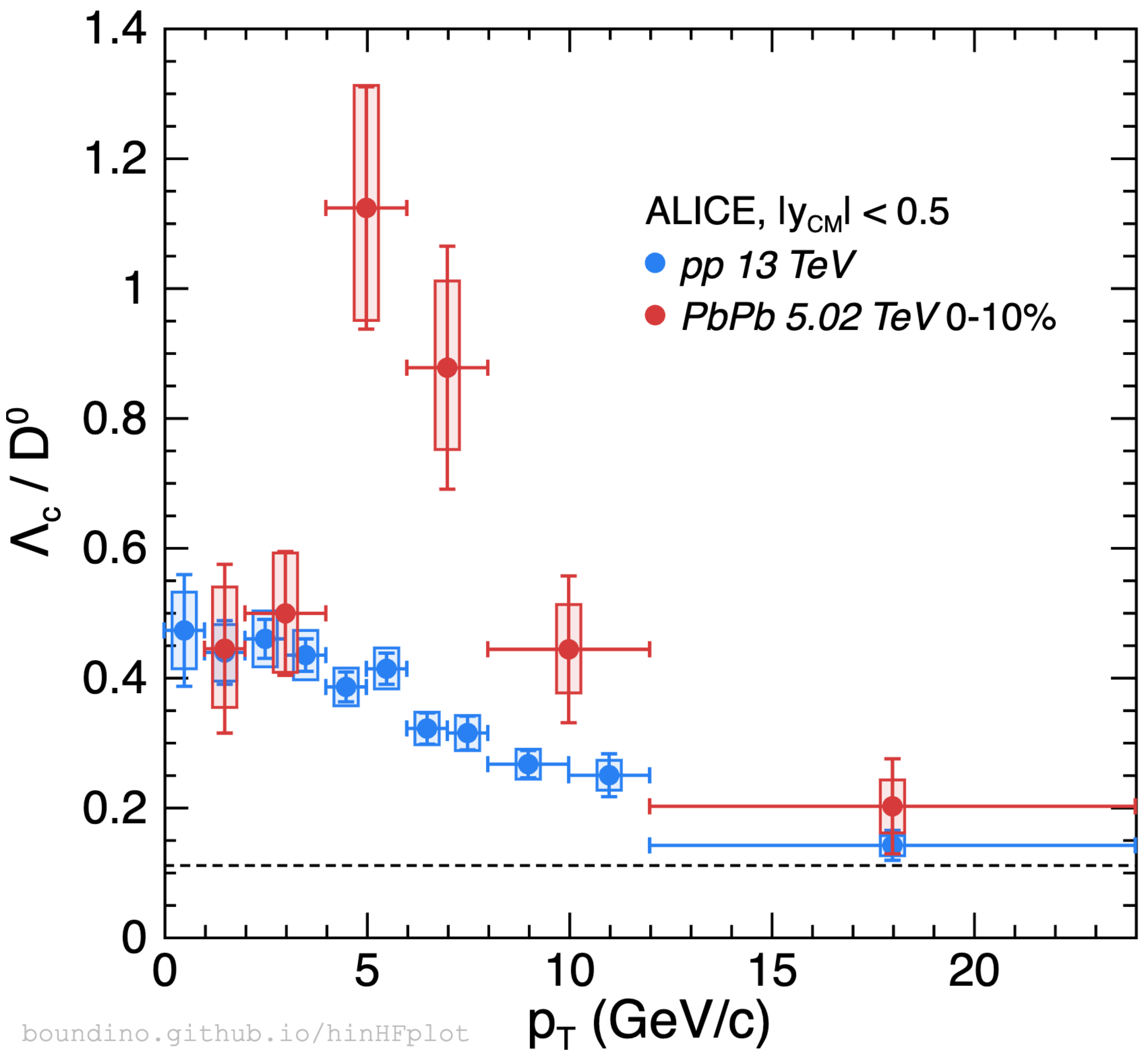


- Similar behavior in beauty sector from ee to high-multiplicity pp

Λ_c p_T Redistribution Across Collision Systems

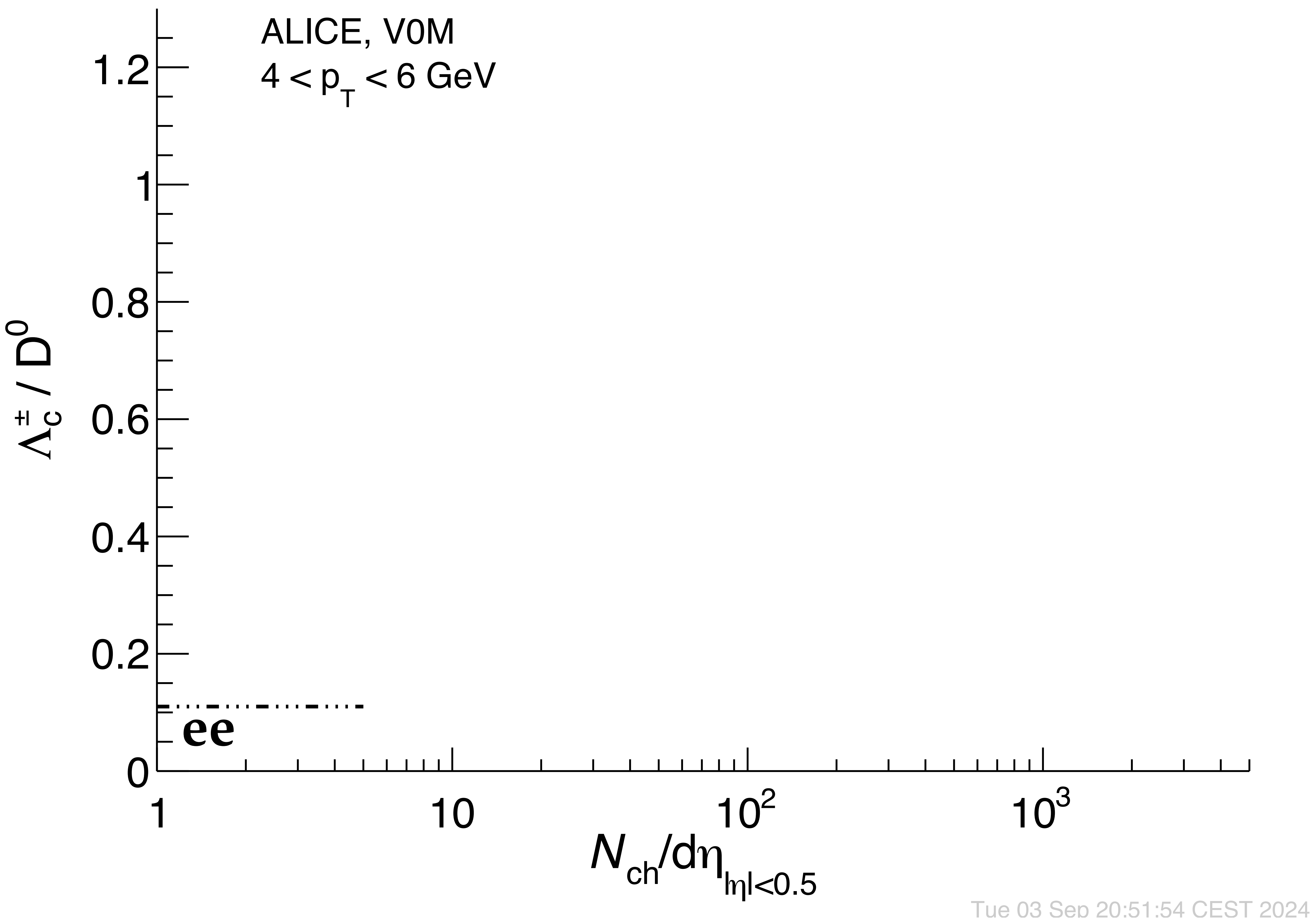
- Although the integrated yield ratio is saturated, p_T dependence is modified

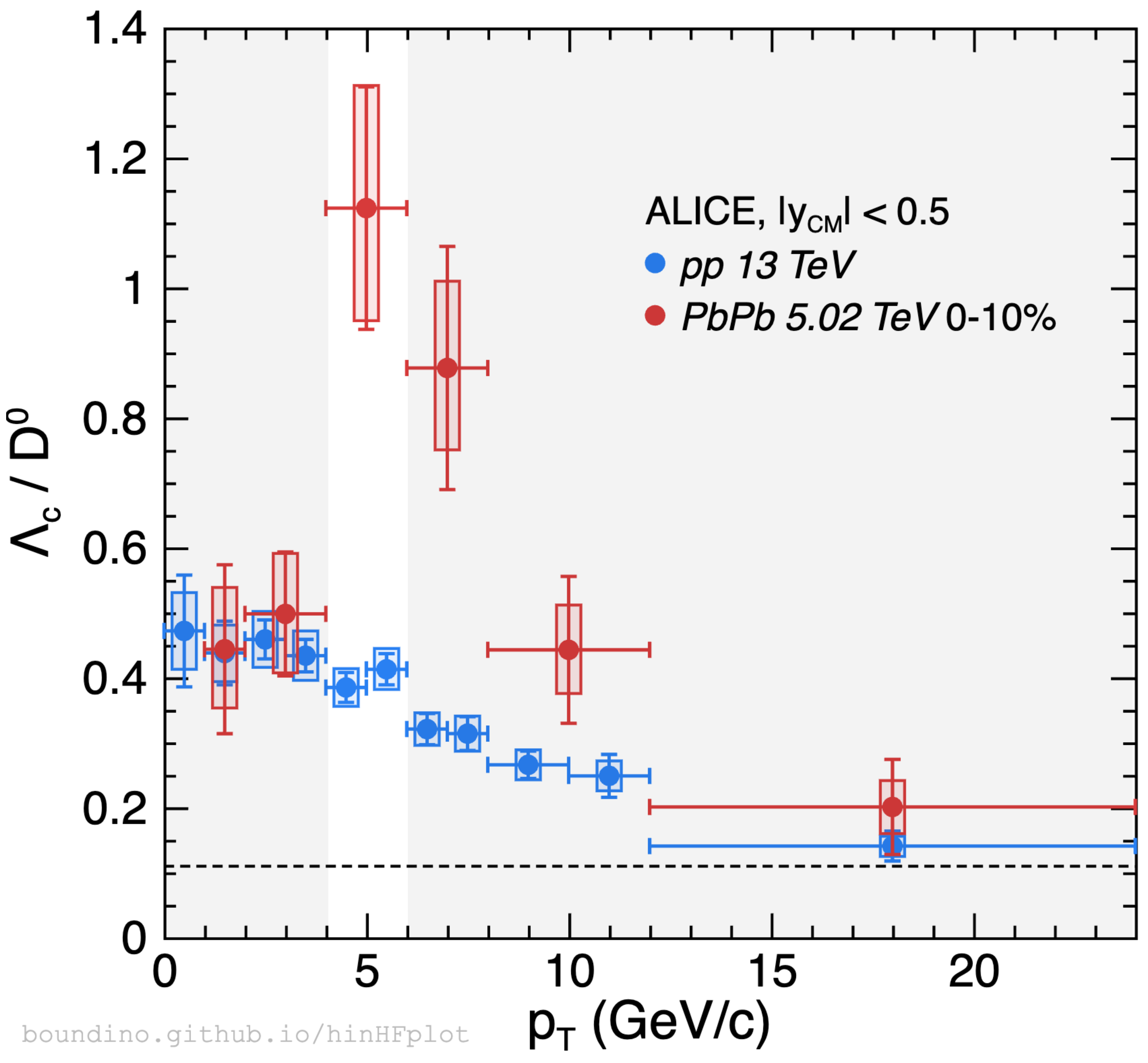
- Is it related to collective flow?



Λ_c p_T Redistribution Across Collision Systems

Intermediate p_T

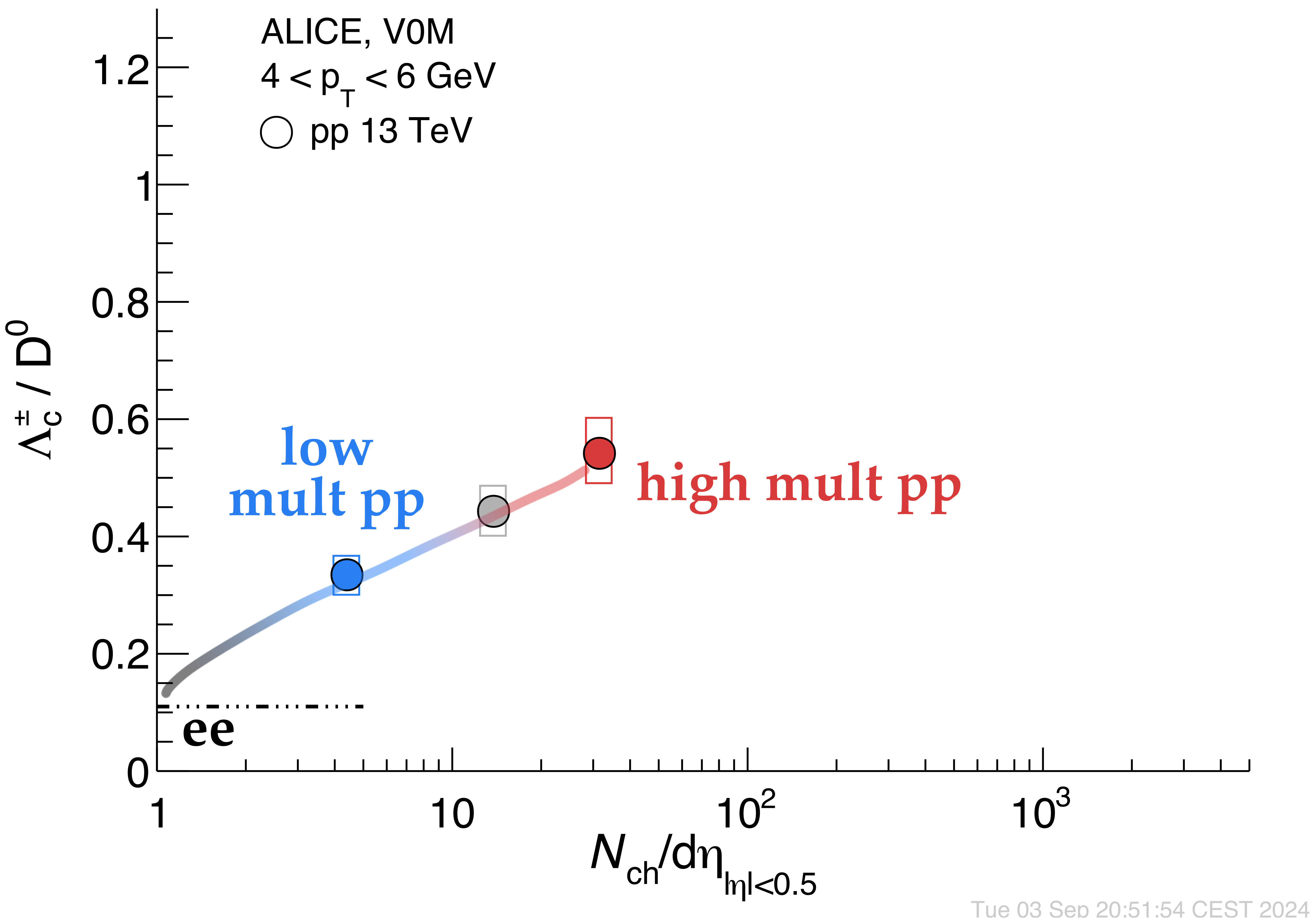




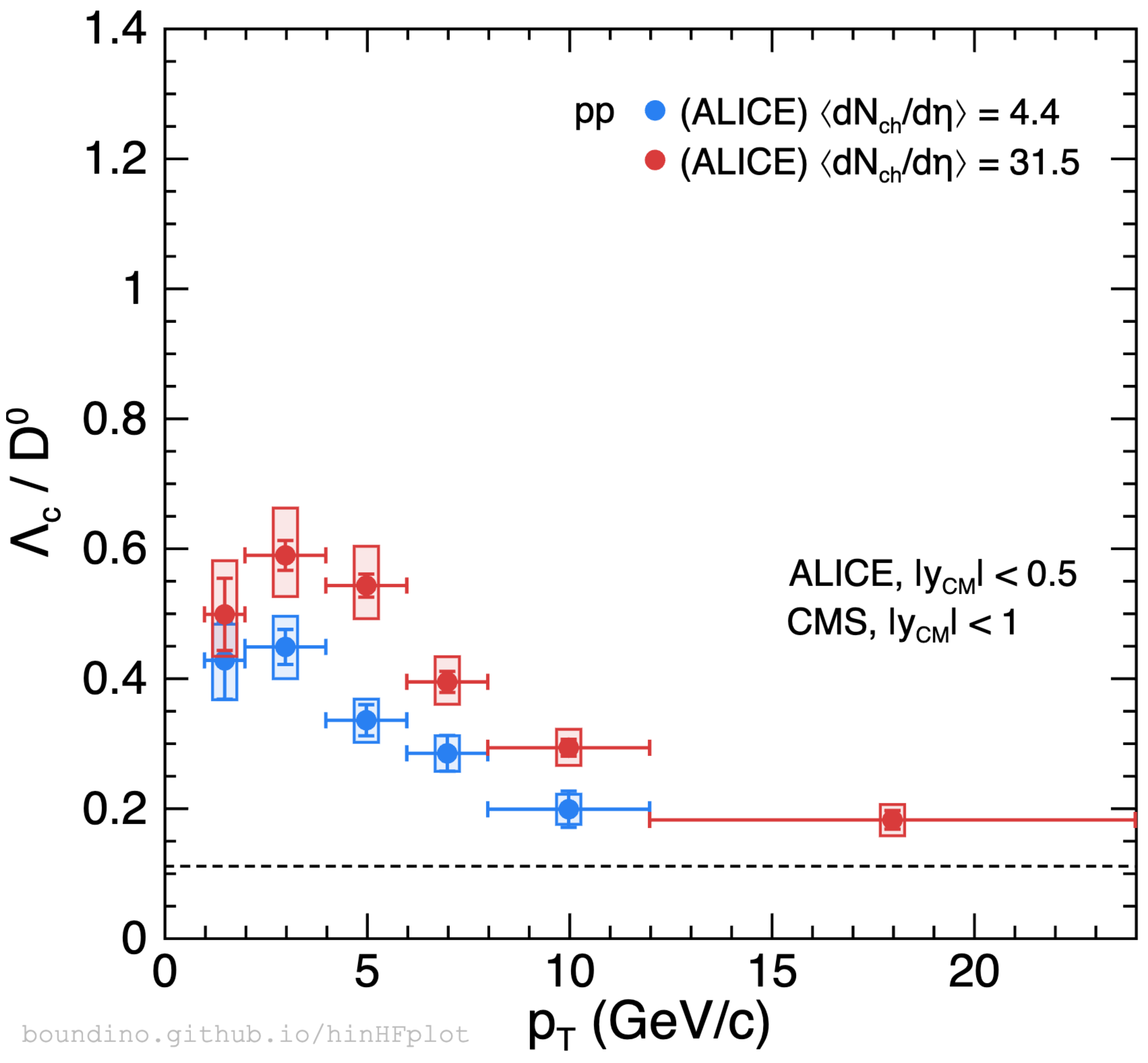
- Scan collision systems for intermediate p_T

Λ_c p_T Redistribution Across Collision Systems

Intermediate p_T



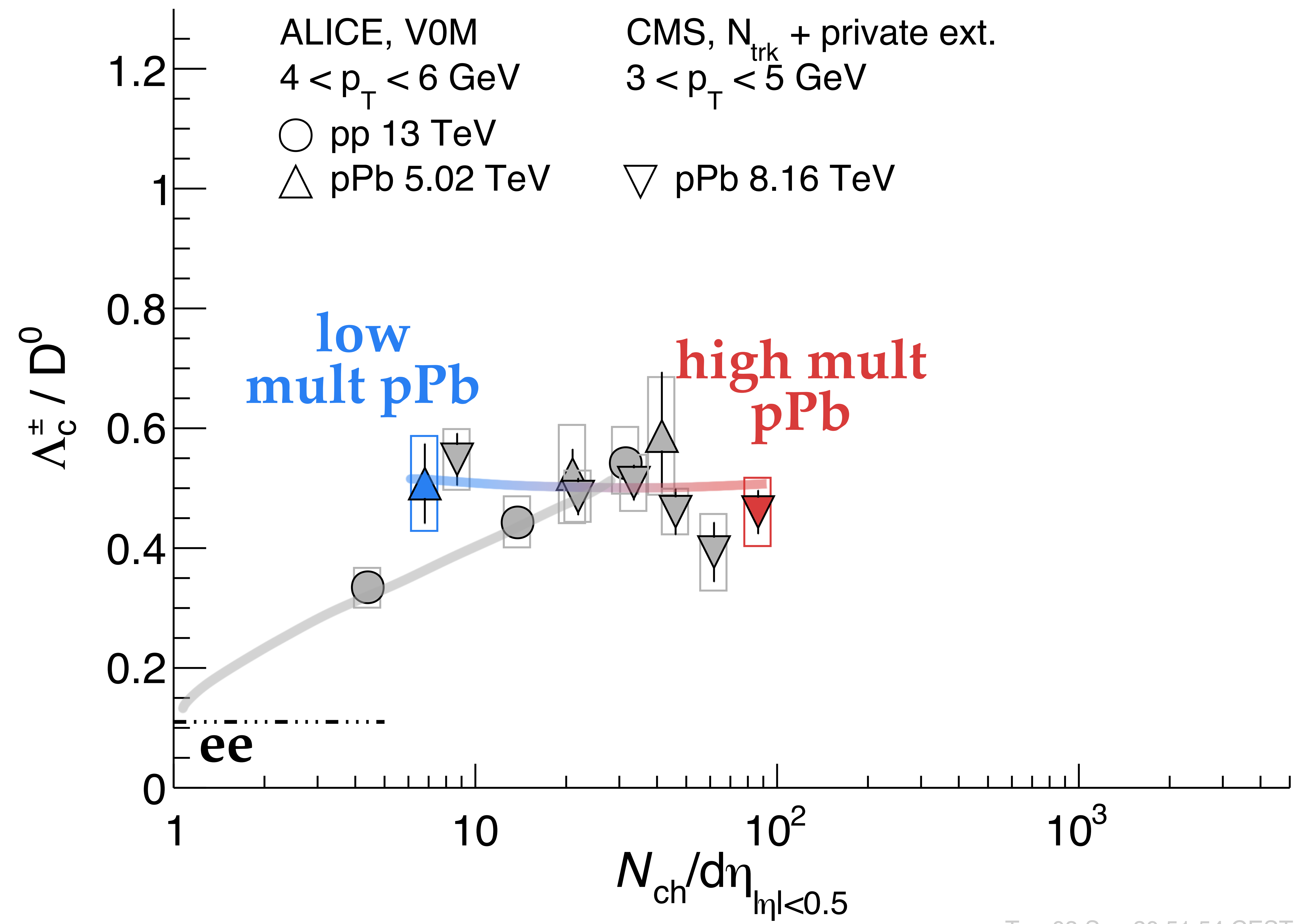
[PLB 829 (2022) 137065]



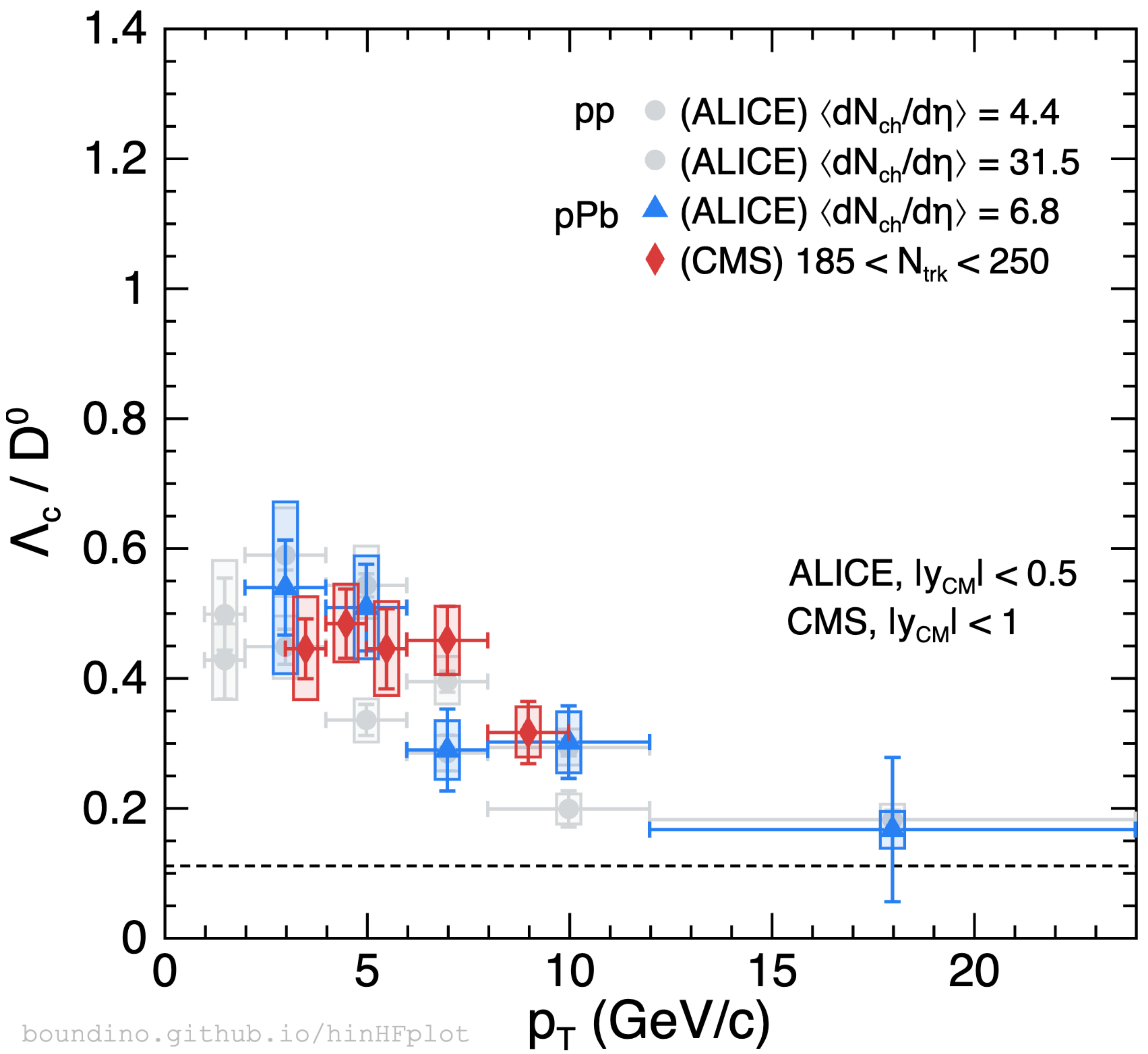
- p_T redistribution already happens in pp vs multiplicity

Λ_c p_T Redistribution Across Collision Systems

Intermediate p_T



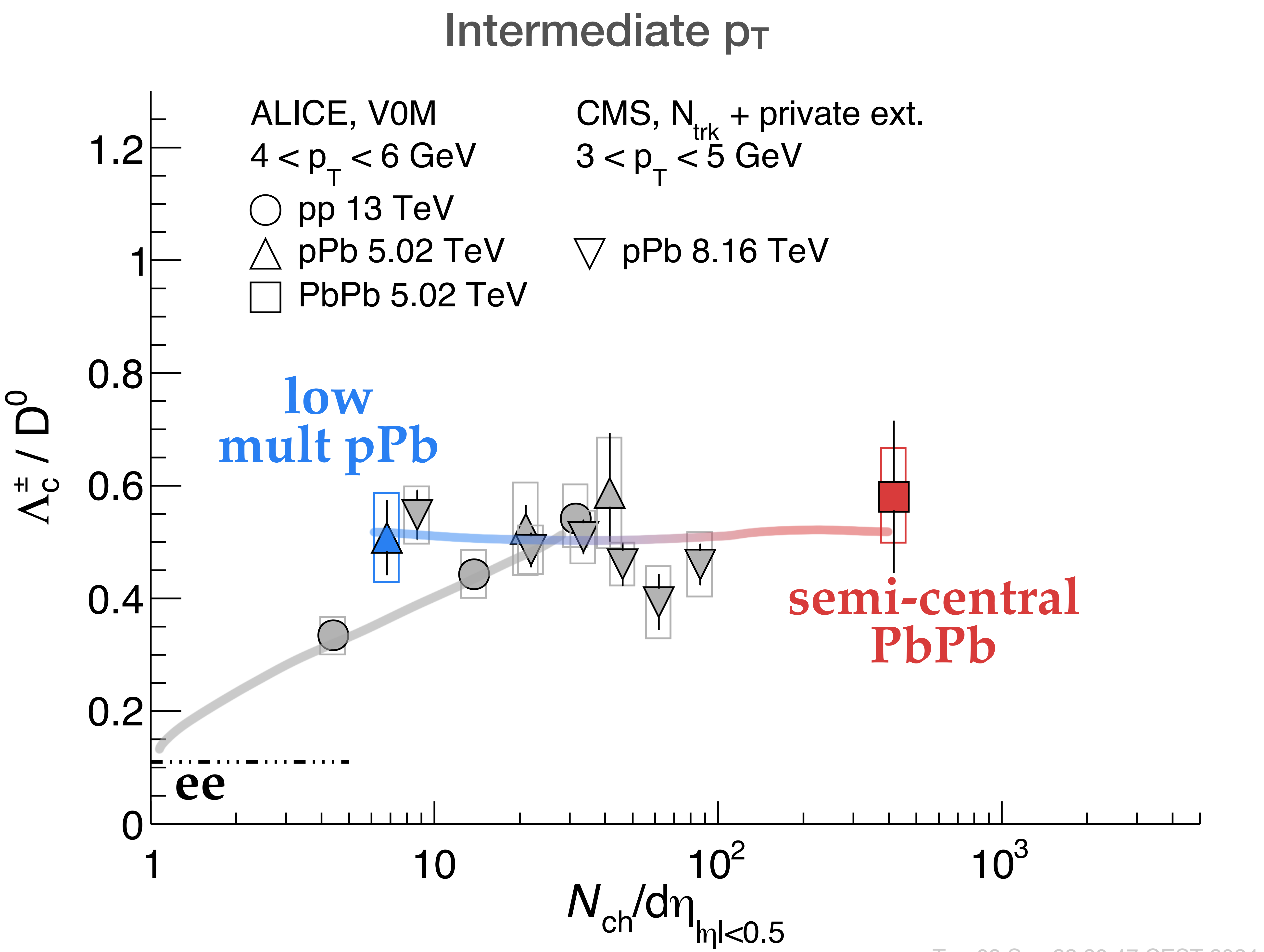
[arXiv:2407.13615]

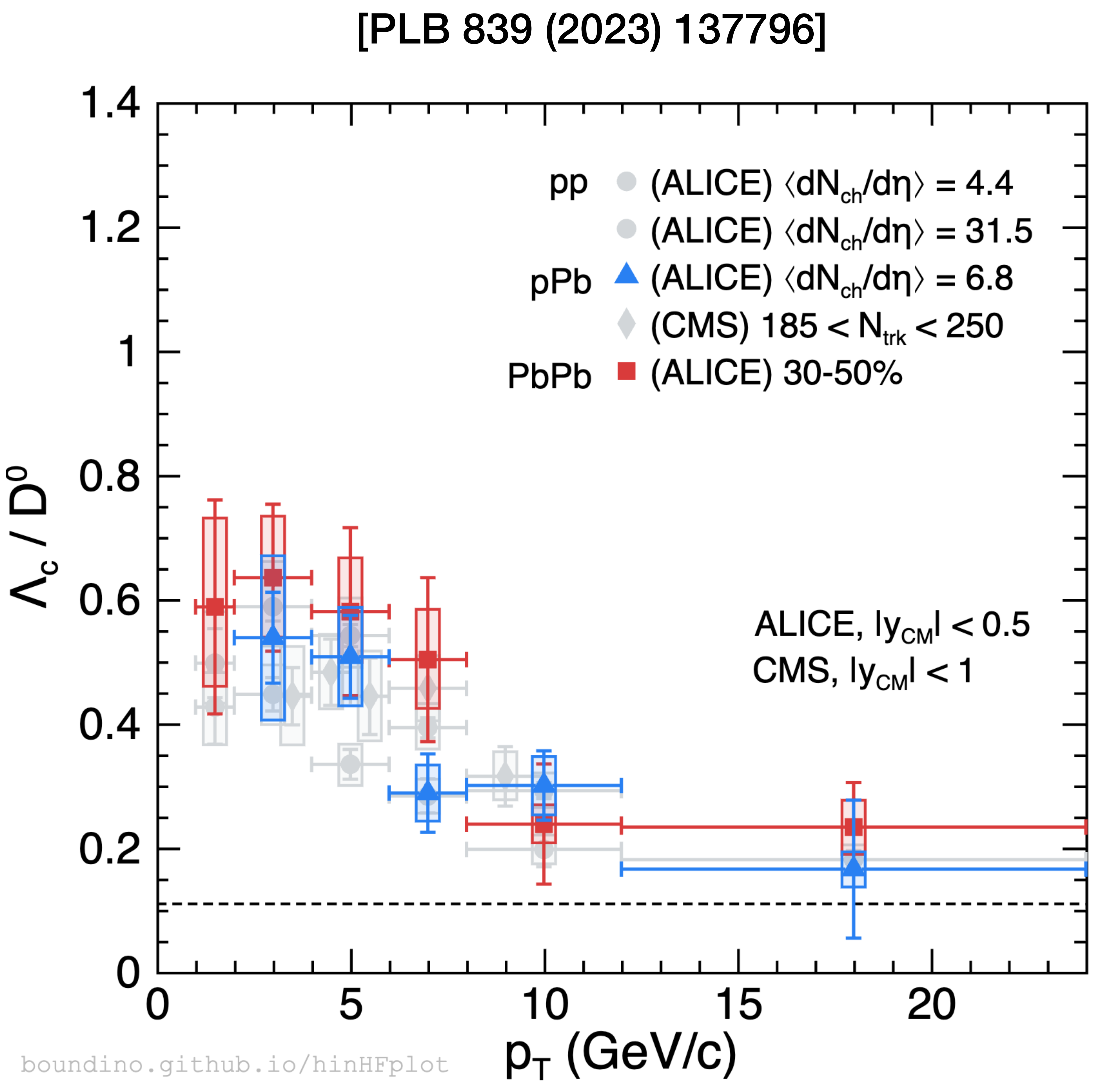


Tue 03 Sep 20:51:54 CEST 2024

- From low-multi pPb to high-multi pPb, not only the integrated yield ratio, but also the p_T distributions do not change much

Λ_c p_T Redistribution Across Collision Systems

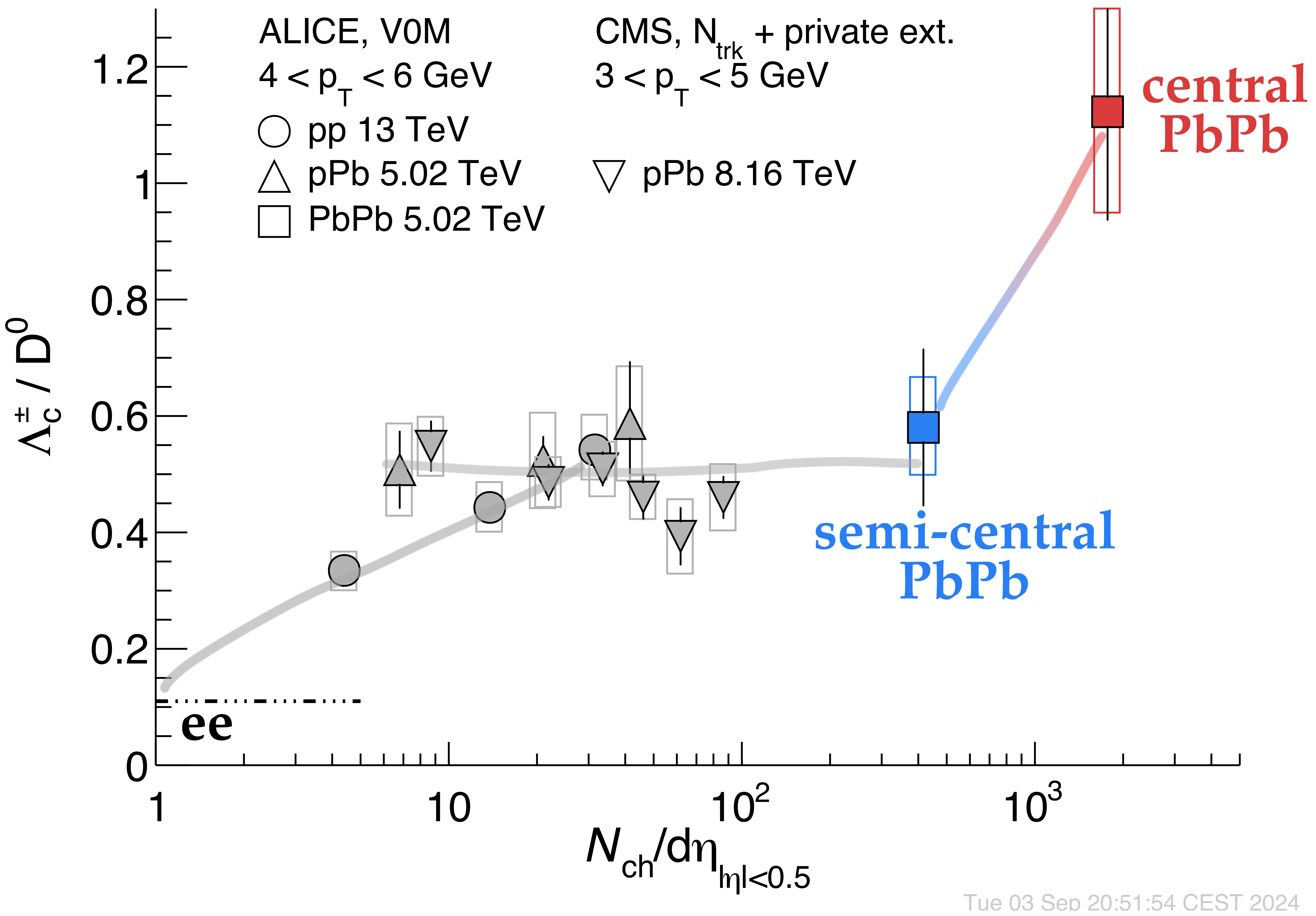




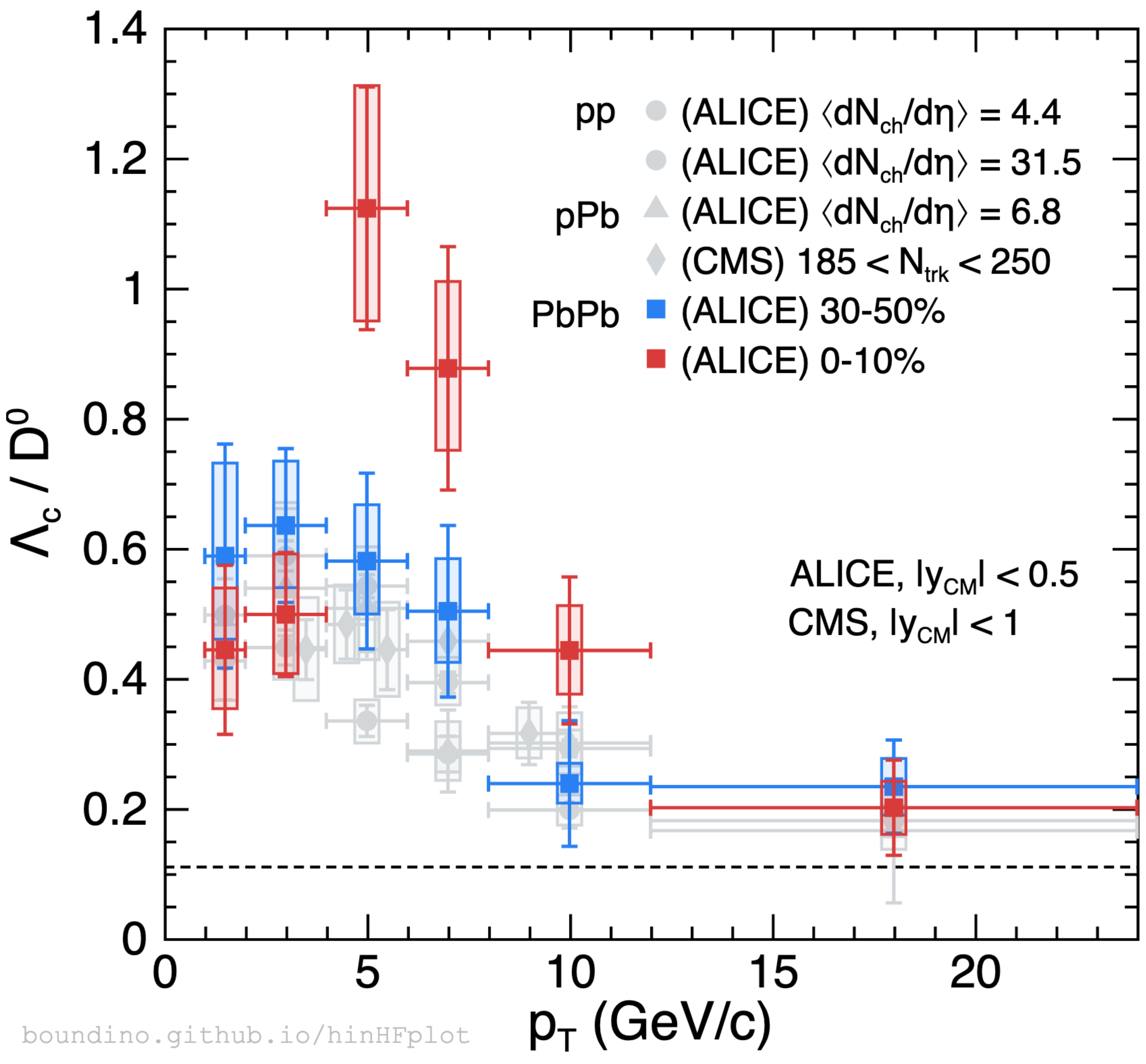
- From low-multi pPb to semi-central PbPb, not only the integrated yield ratio, but also the p_T distributions only change mildly

Λ_c p_T Redistribution Across Collision Systems

Intermediate p_T

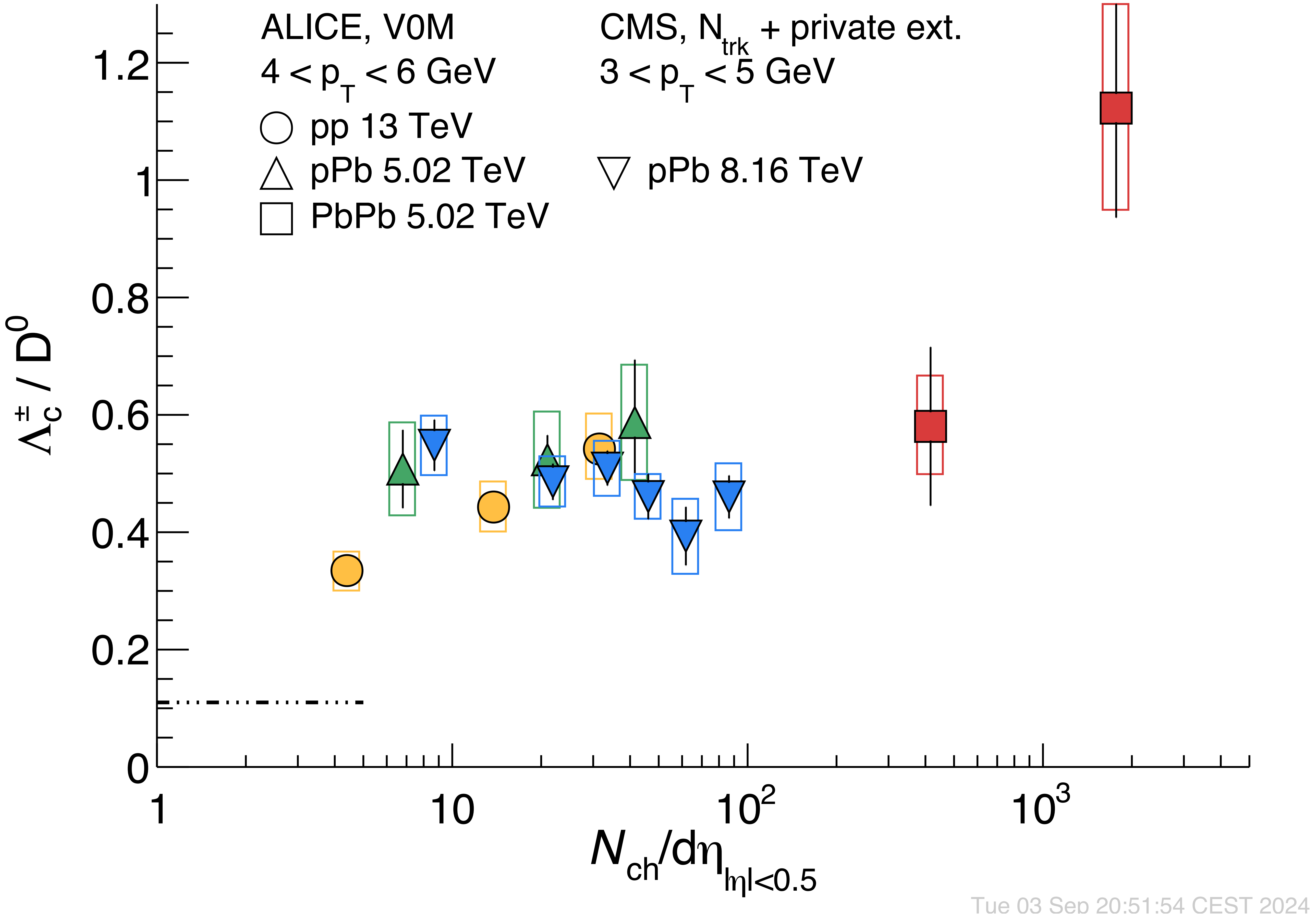


[PLB 839 (2023) 137796]



- The shape changes dramatically from semi-central to central PbPb

Λ_c p_T Redistribution Across Collision Systems

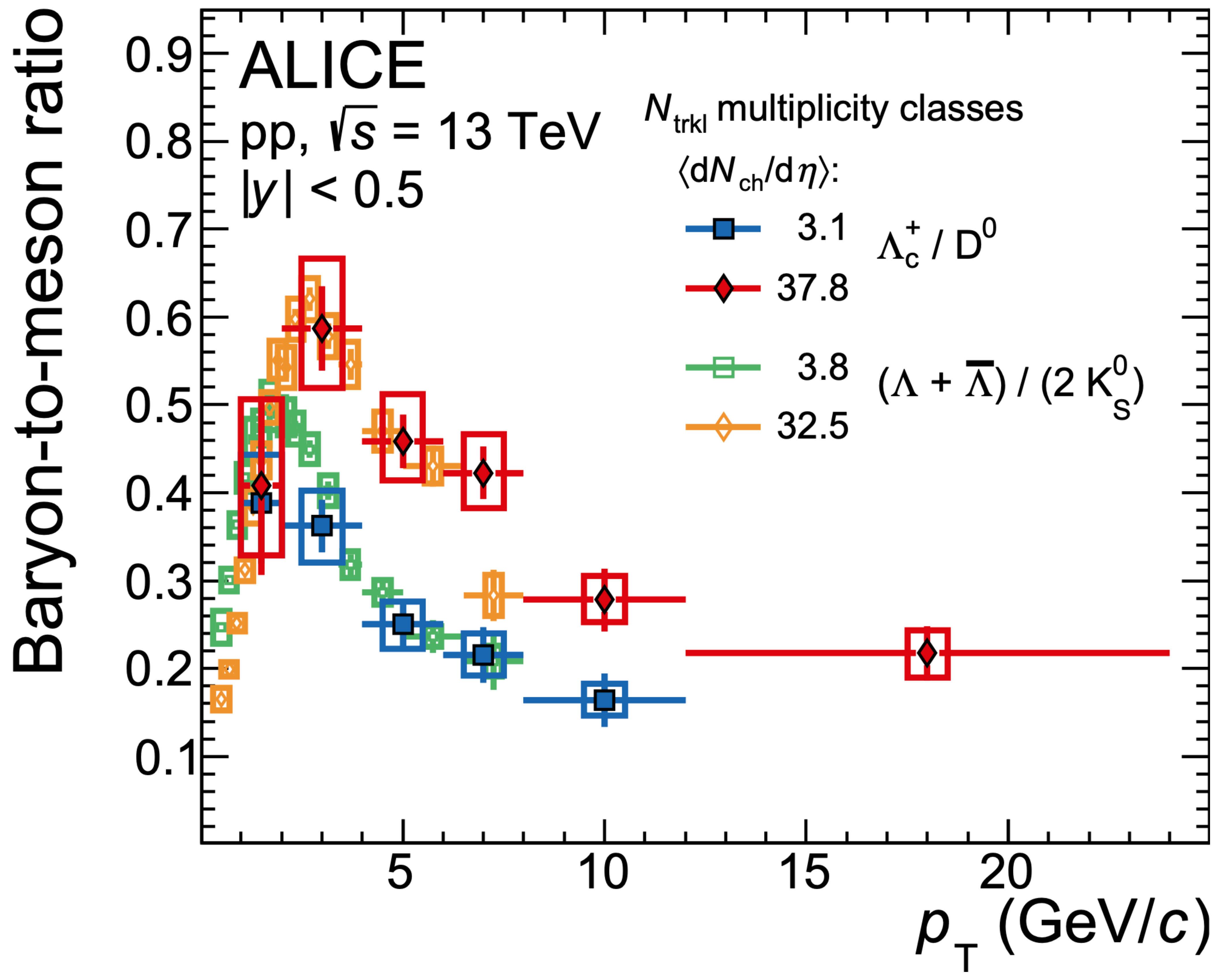


In spite of precision…

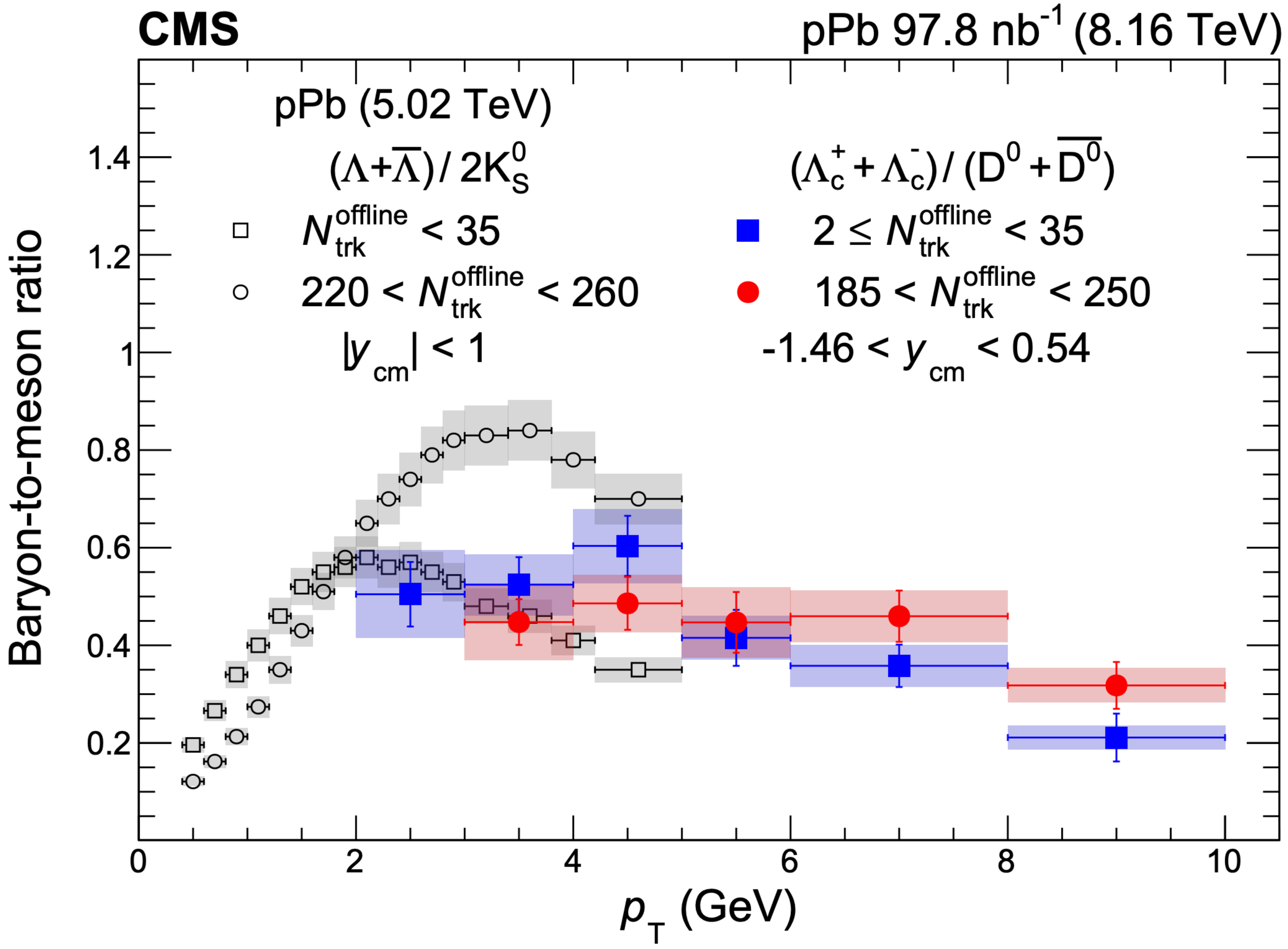
- Is this behavior natural for each mechanism, and how?

Λ_c p_T Redistribution vs Λ/K^0

pp

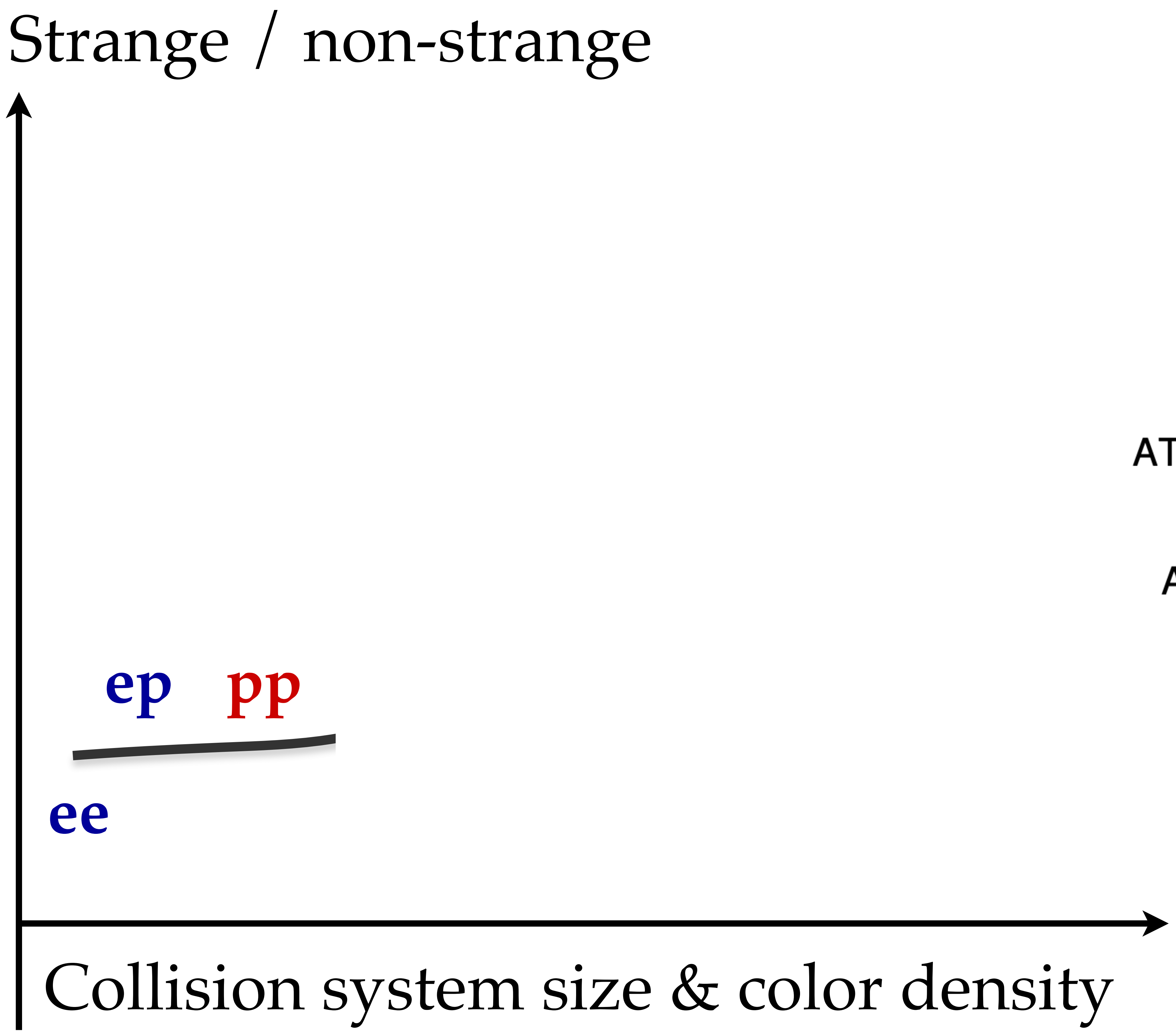


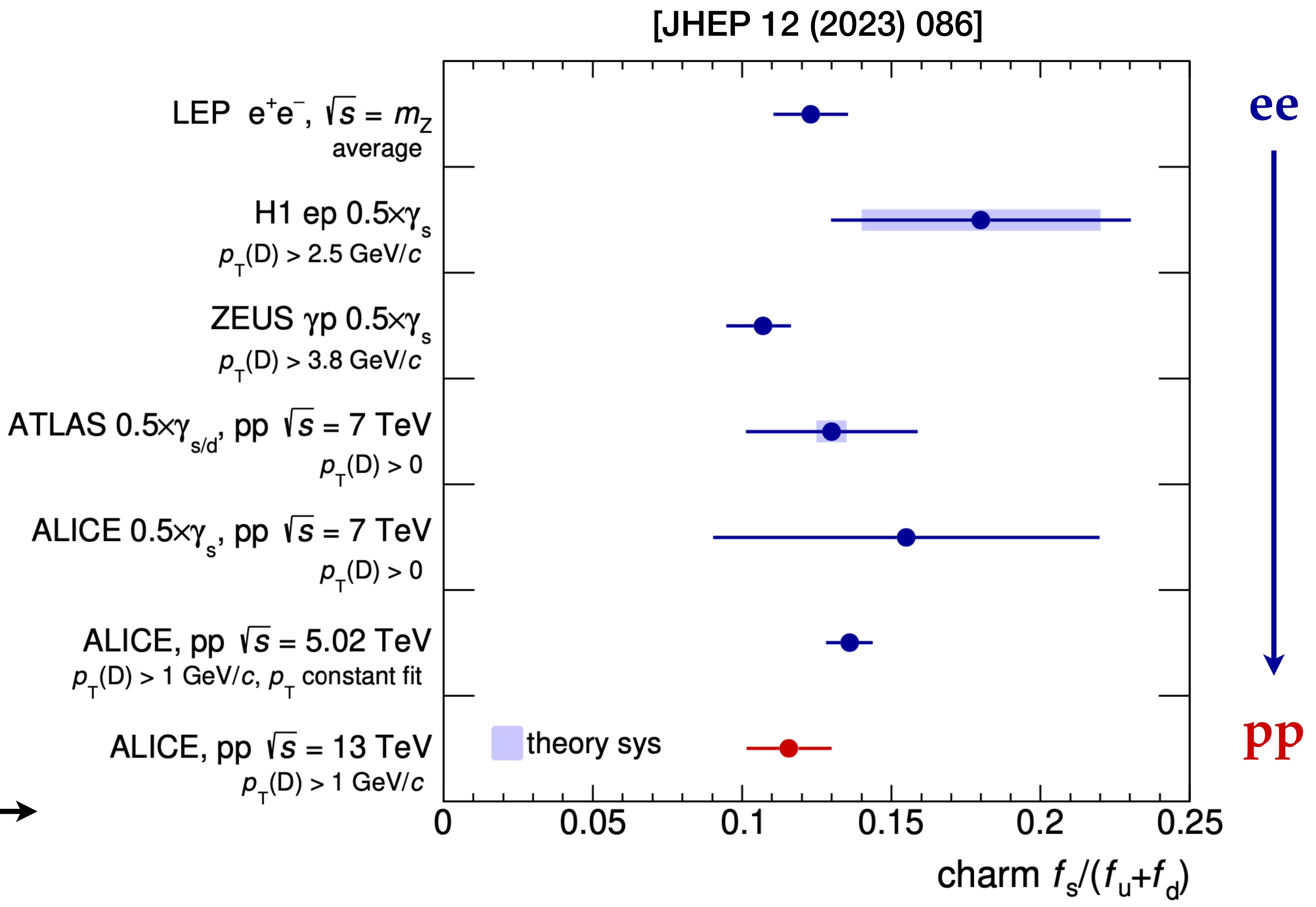
pPb



- Charm and strange are consistent in pp
- Significant difference at higher multiplicity in pPb

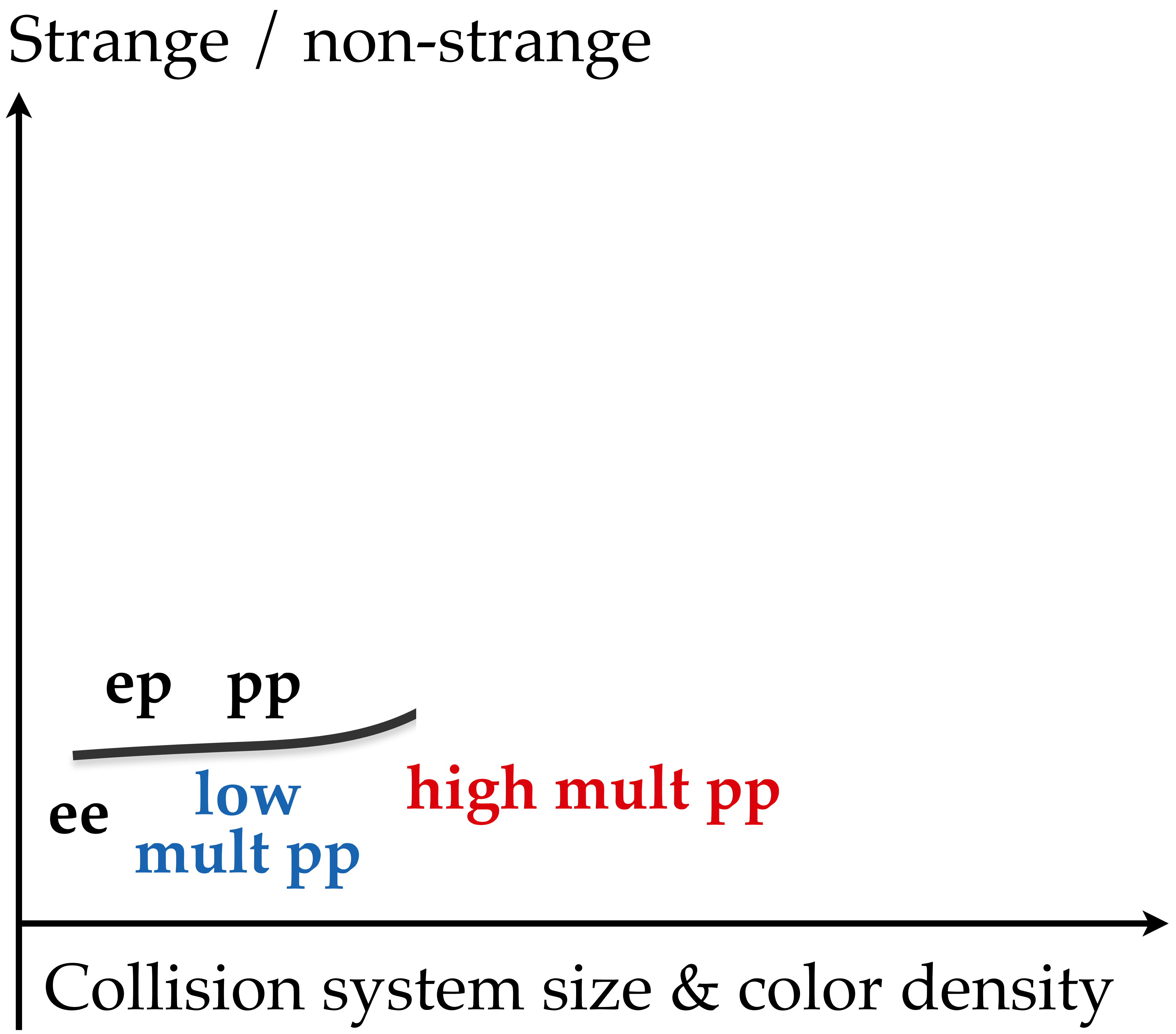
Charm Strangeness Across Collision Systems



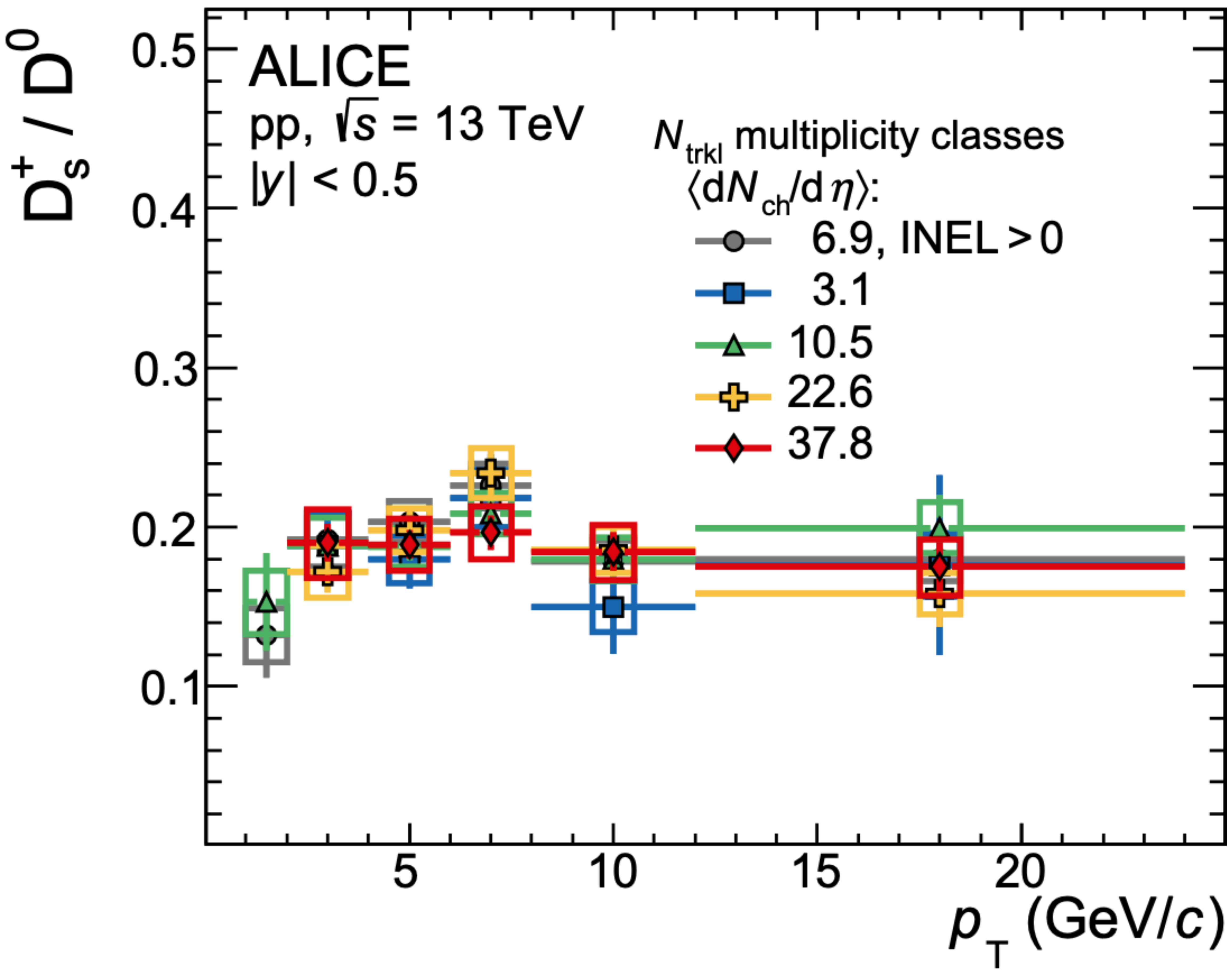


- D_s / D consistent between e^+e^- and pp → Is it contradictory to the significant larger enhancement of Ξ_c compared to Λ_c

Charm Strangeness Across Collision Systems

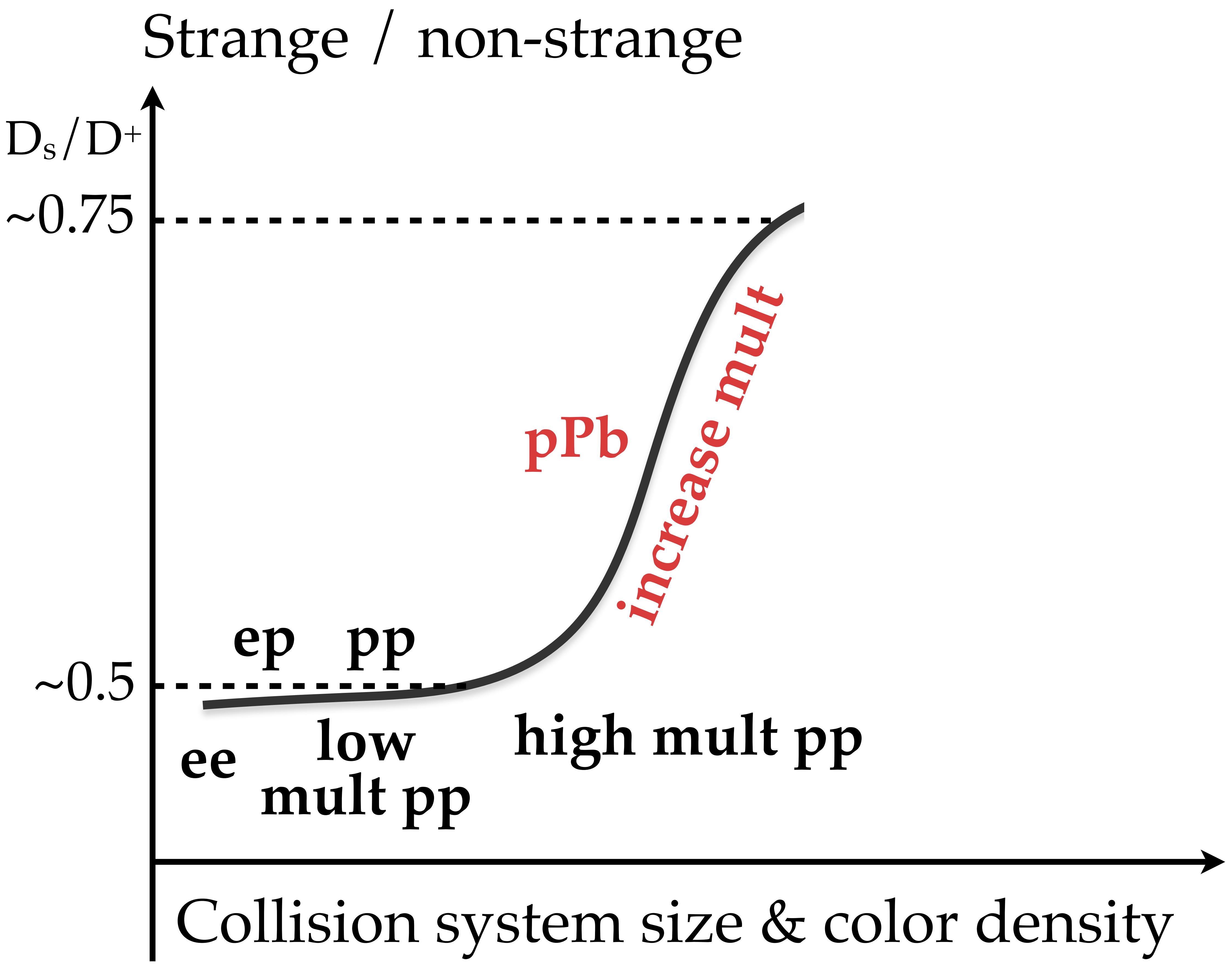


[PLB 829 (2022) 137065]

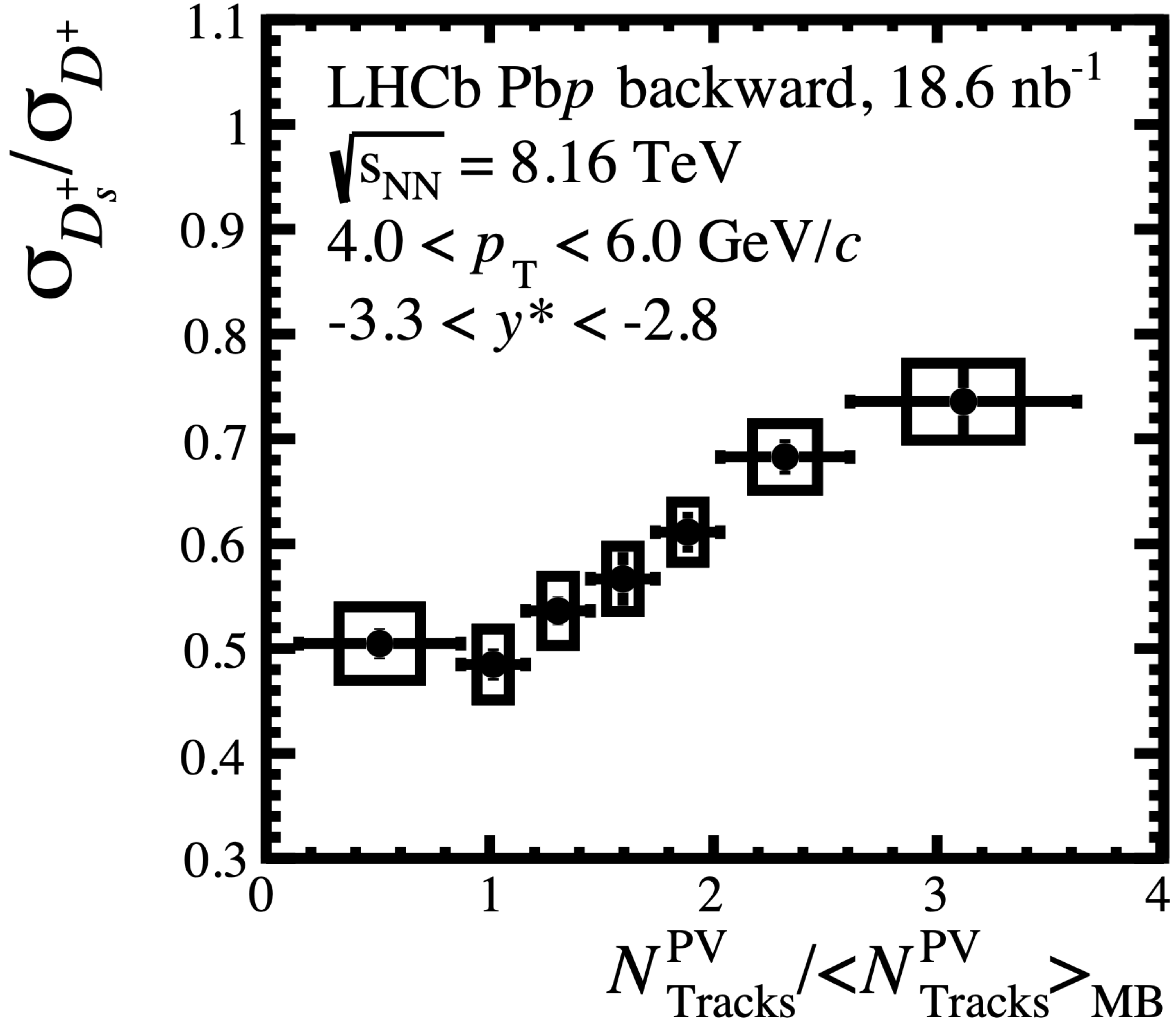


- No significant multiplicity dependence in pp

Charm Strangeness Across Collision Systems

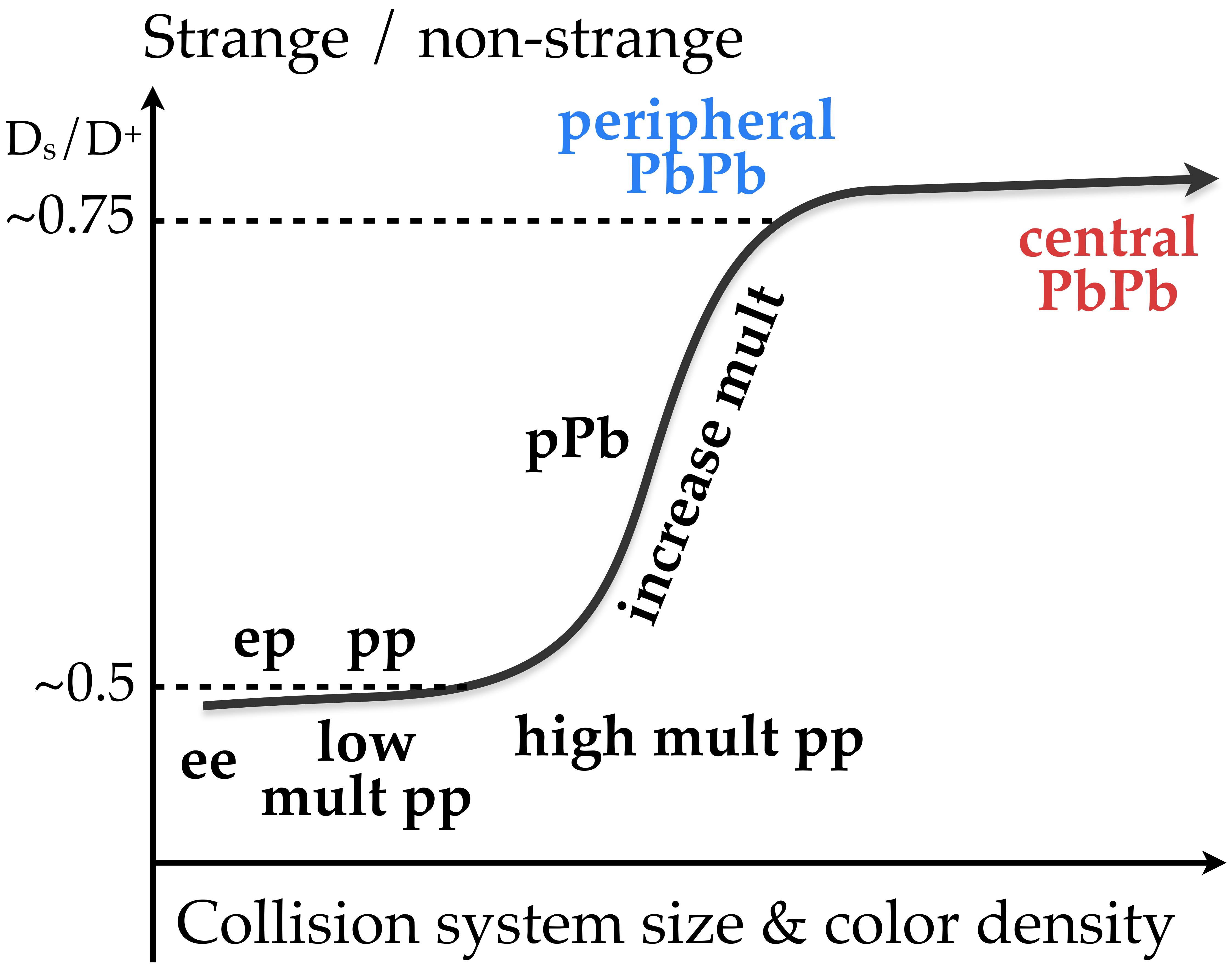


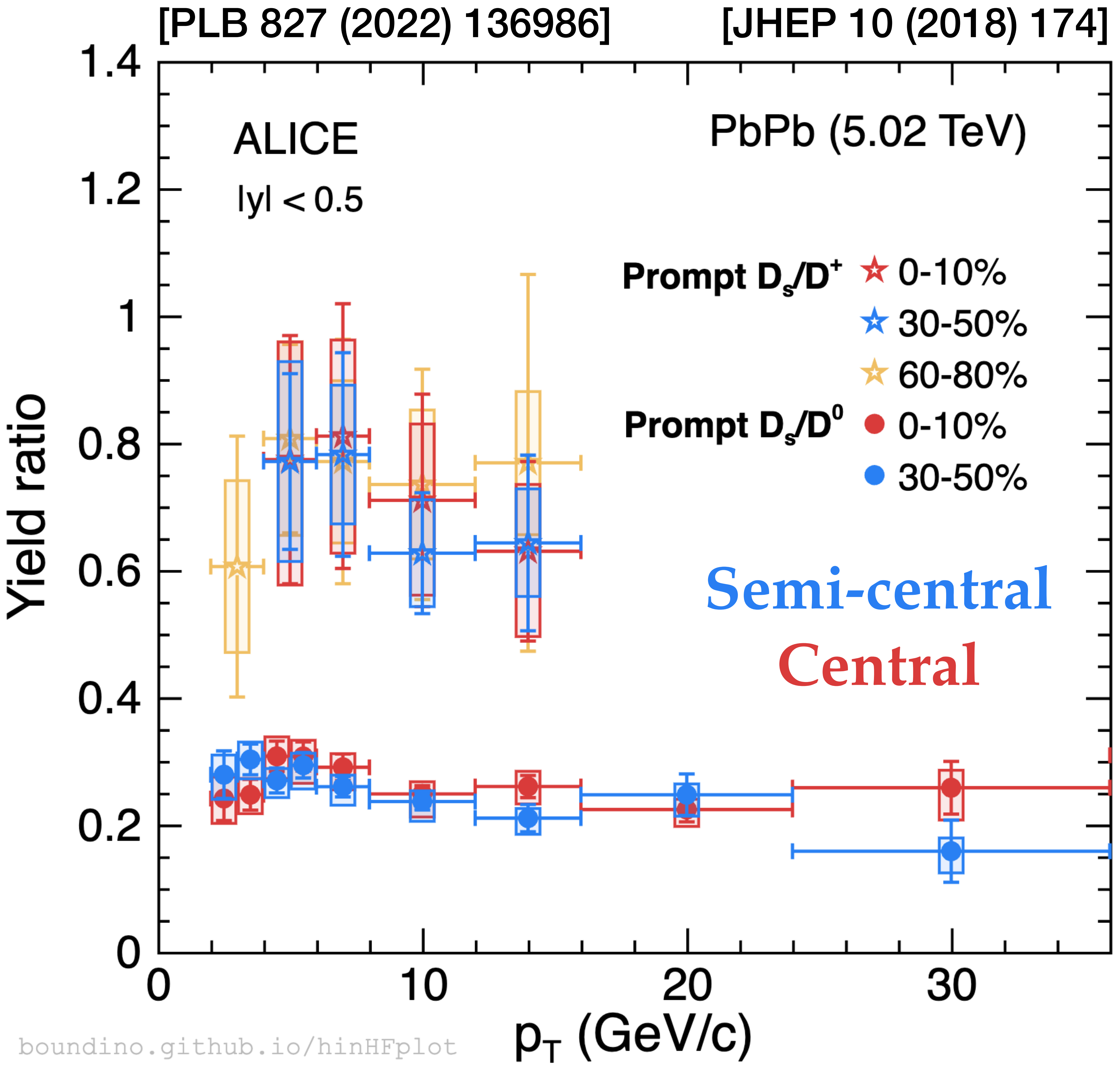
[arXiv:2311.08490]



- Multiplicity dependence in pPb

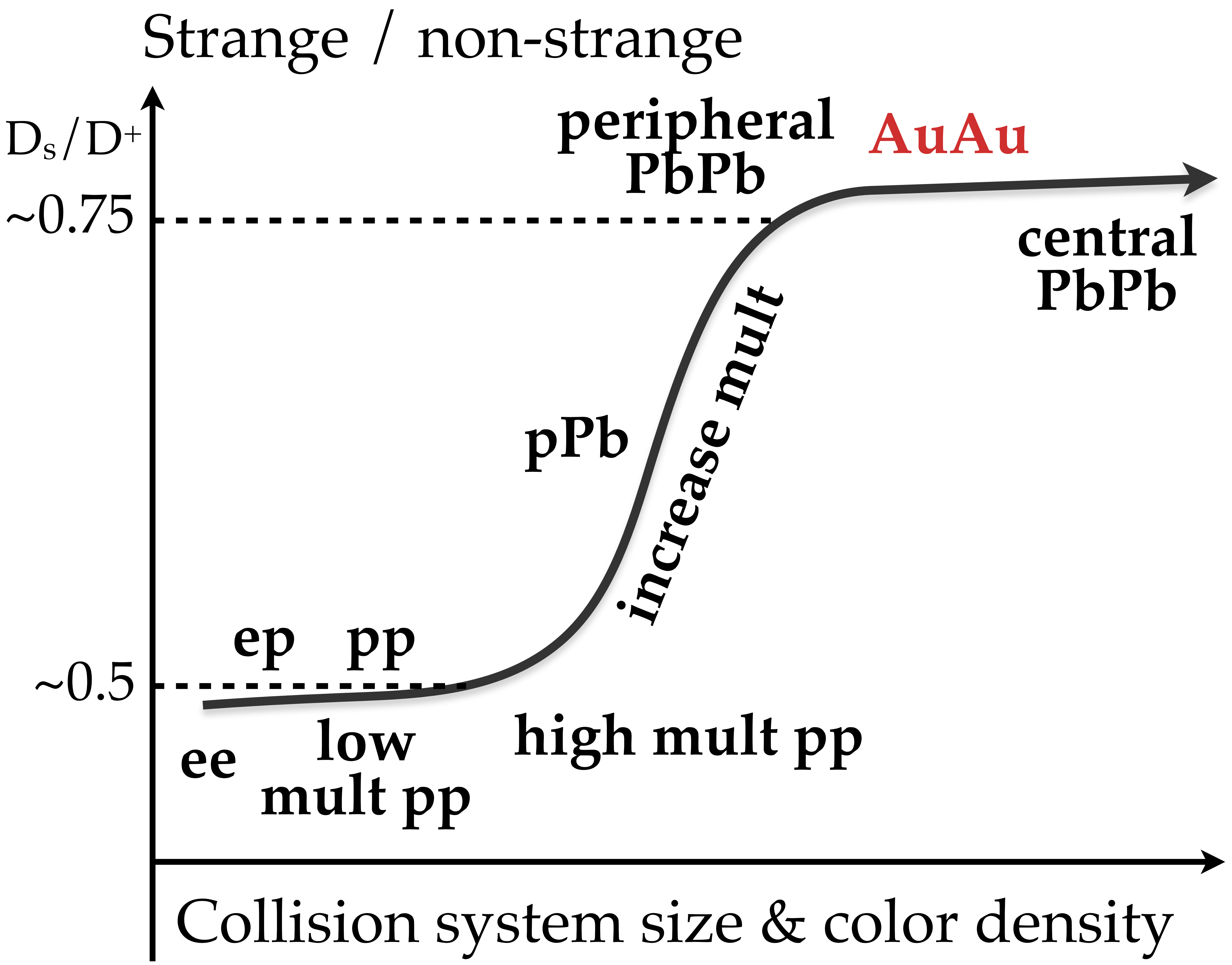
Charm Strangeness Across Collision Systems



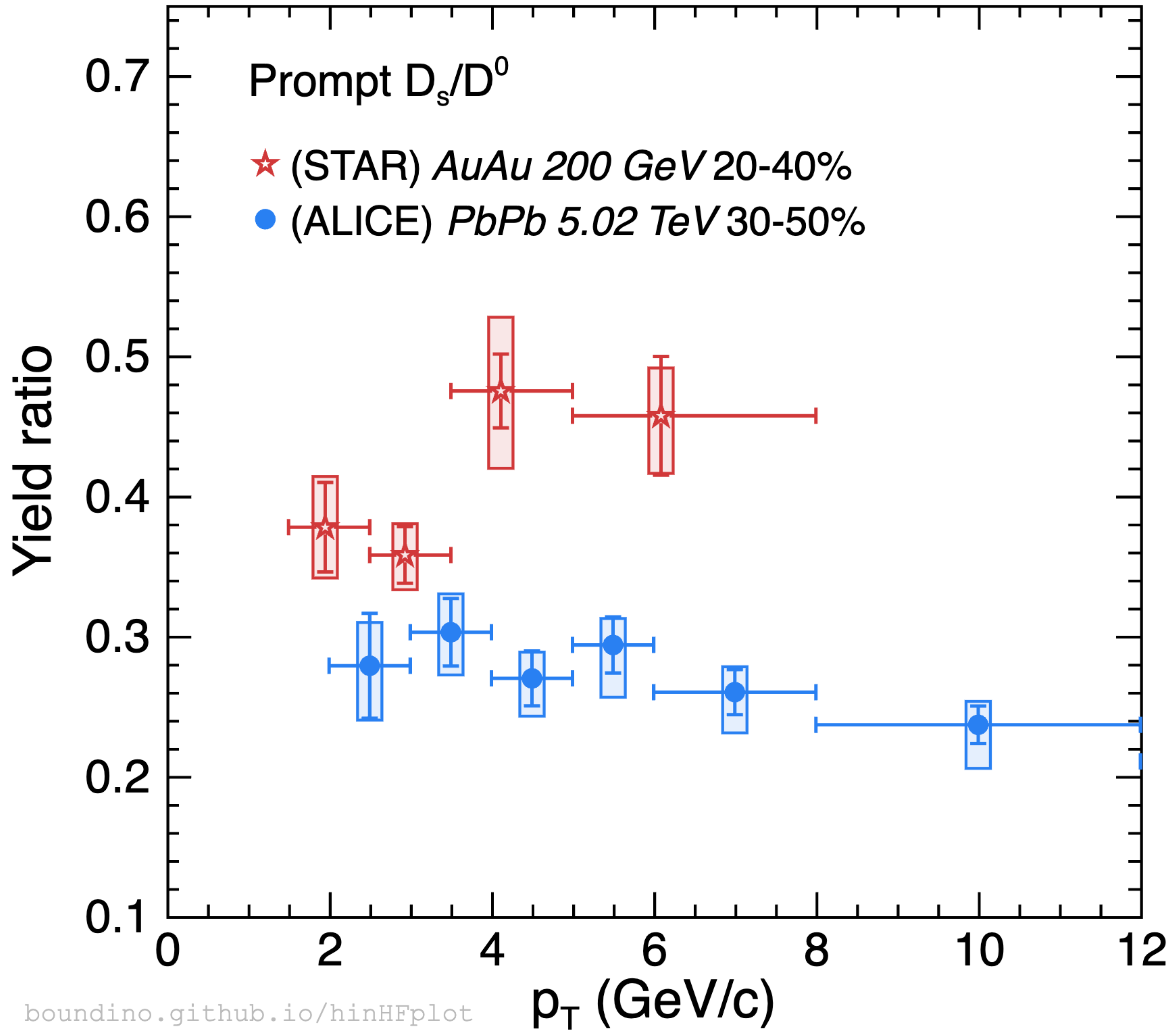


- No significant centrality dependence in PbPb

Charm Strangeness Across Collision Systems

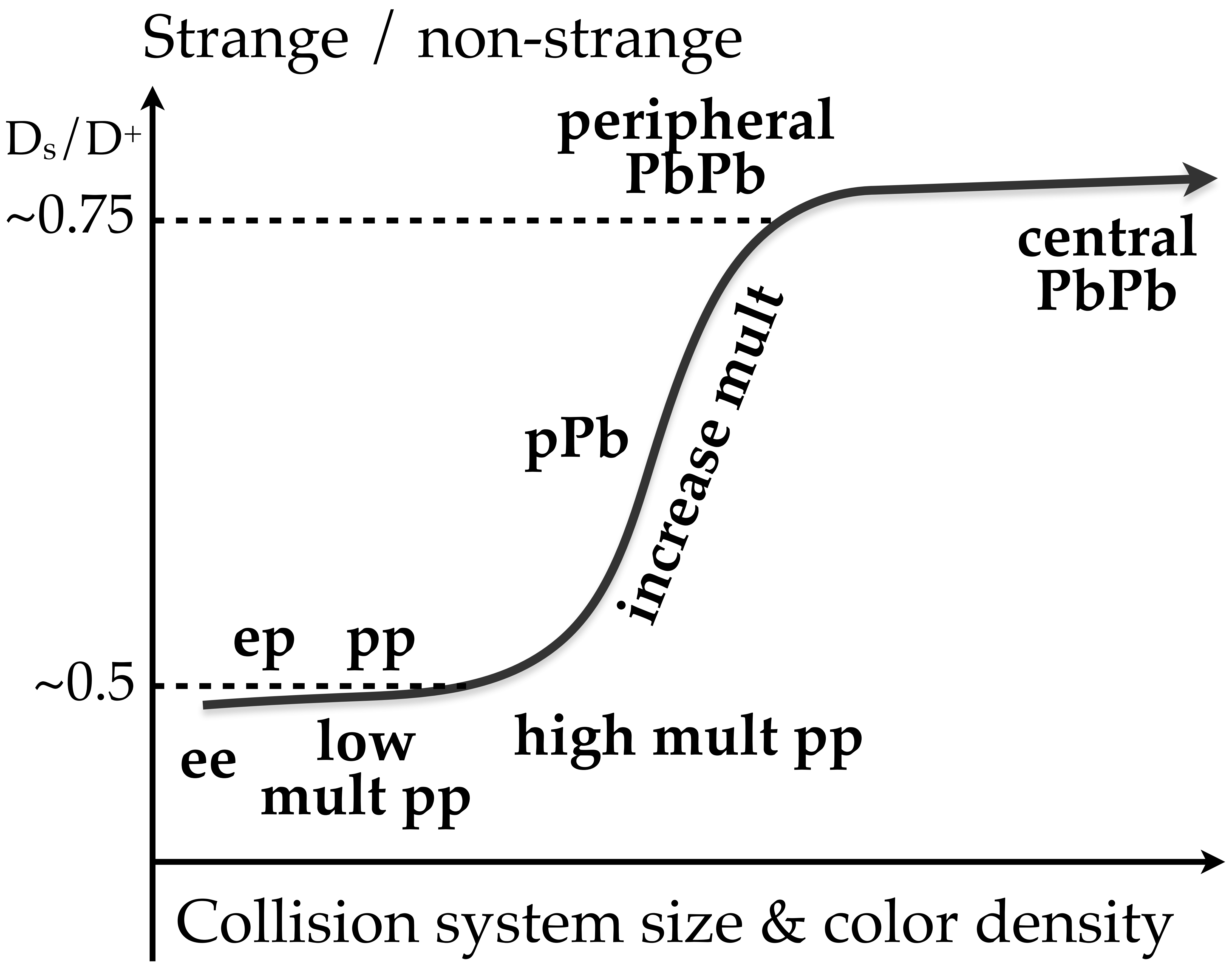


[PRL 127 (2021) 092301]



- I can't see the reason of differences… wait for better measurements?

Charm Strangeness Across Collision Systems

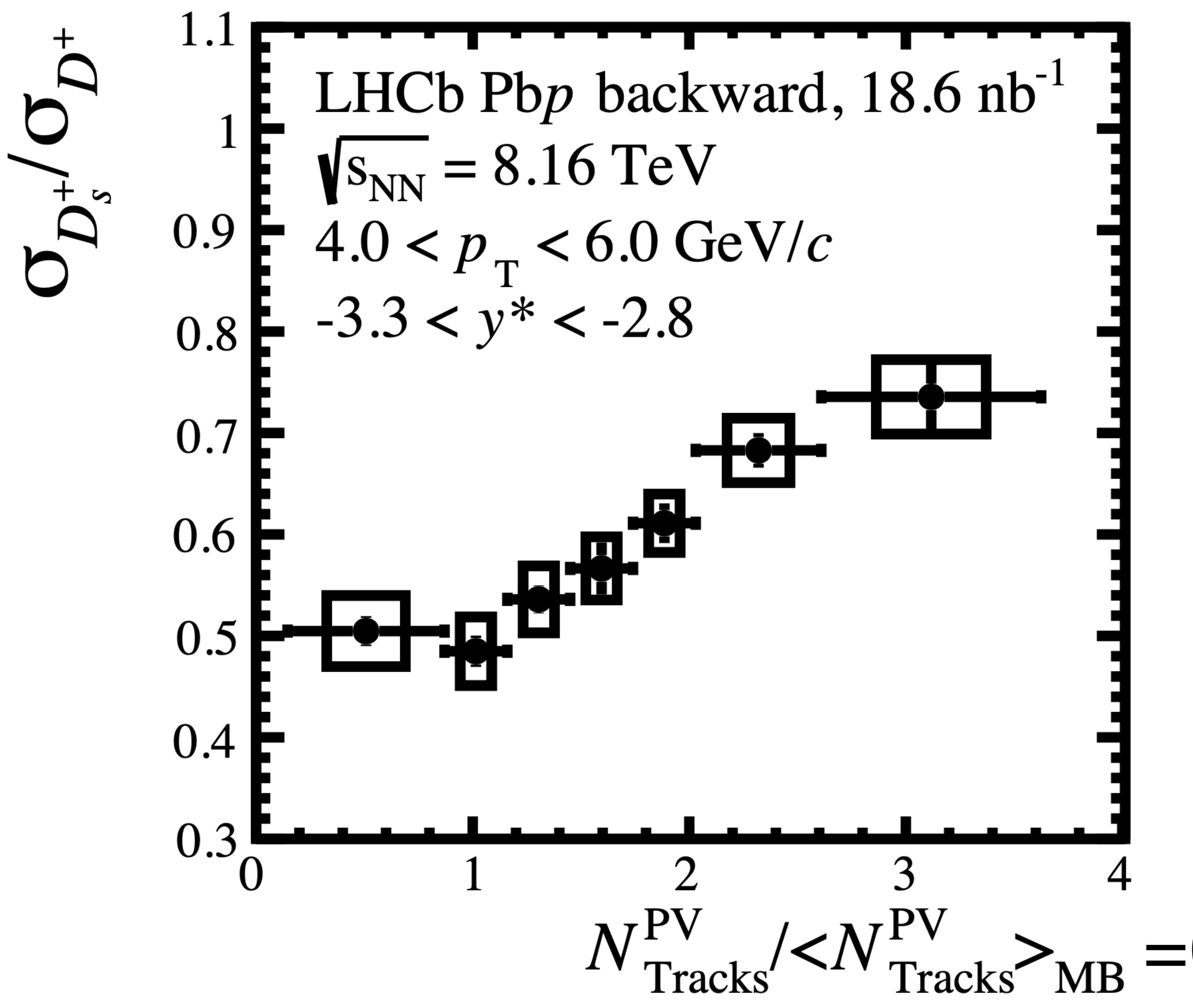


In spite of precision…

- Is this behavior natural for each mechanism, and how?

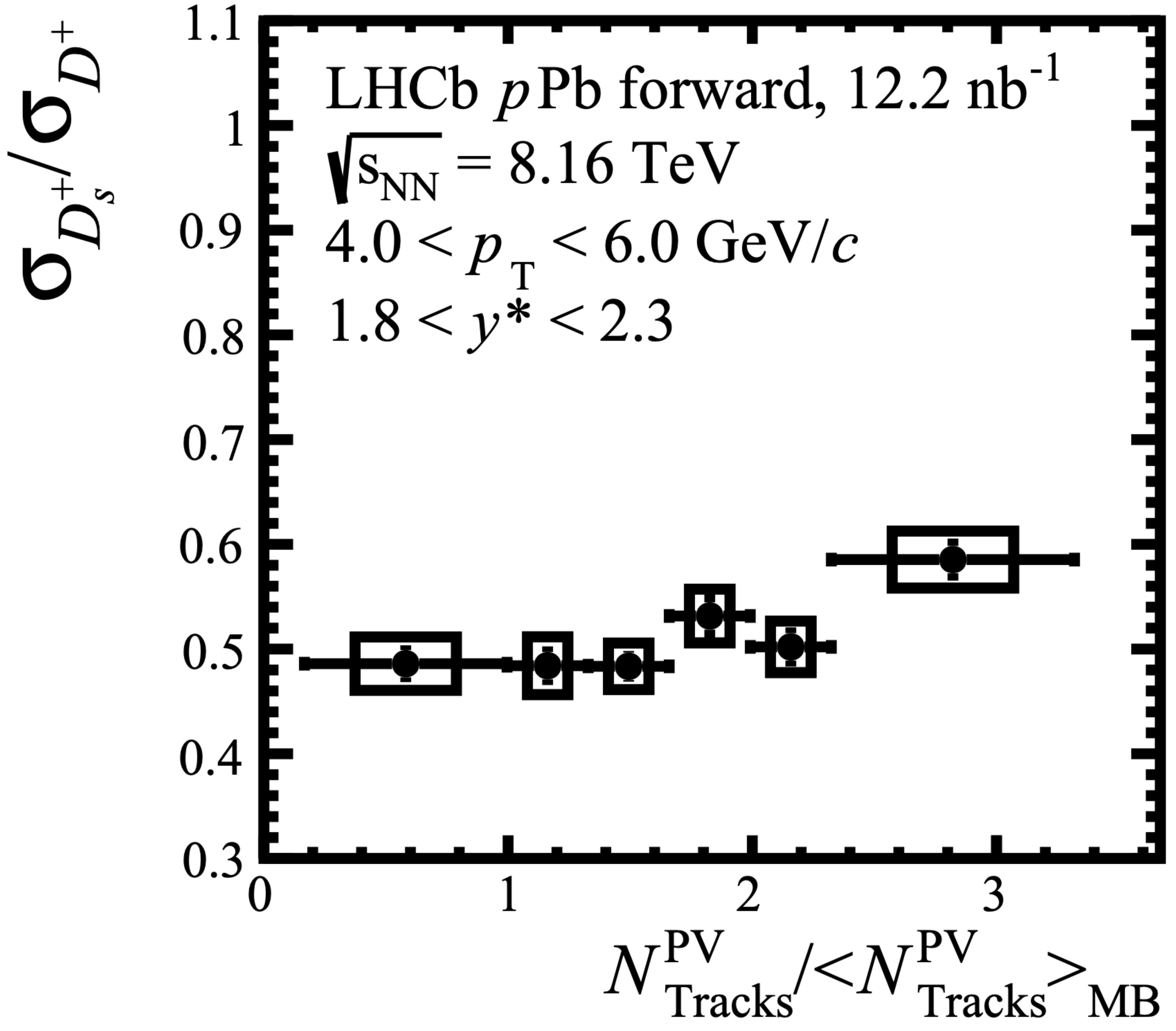
D_s/D^+ in pPb Notes on Multiplicity Dependence

Backward (Pb-going)



=69

Forward (p-going)



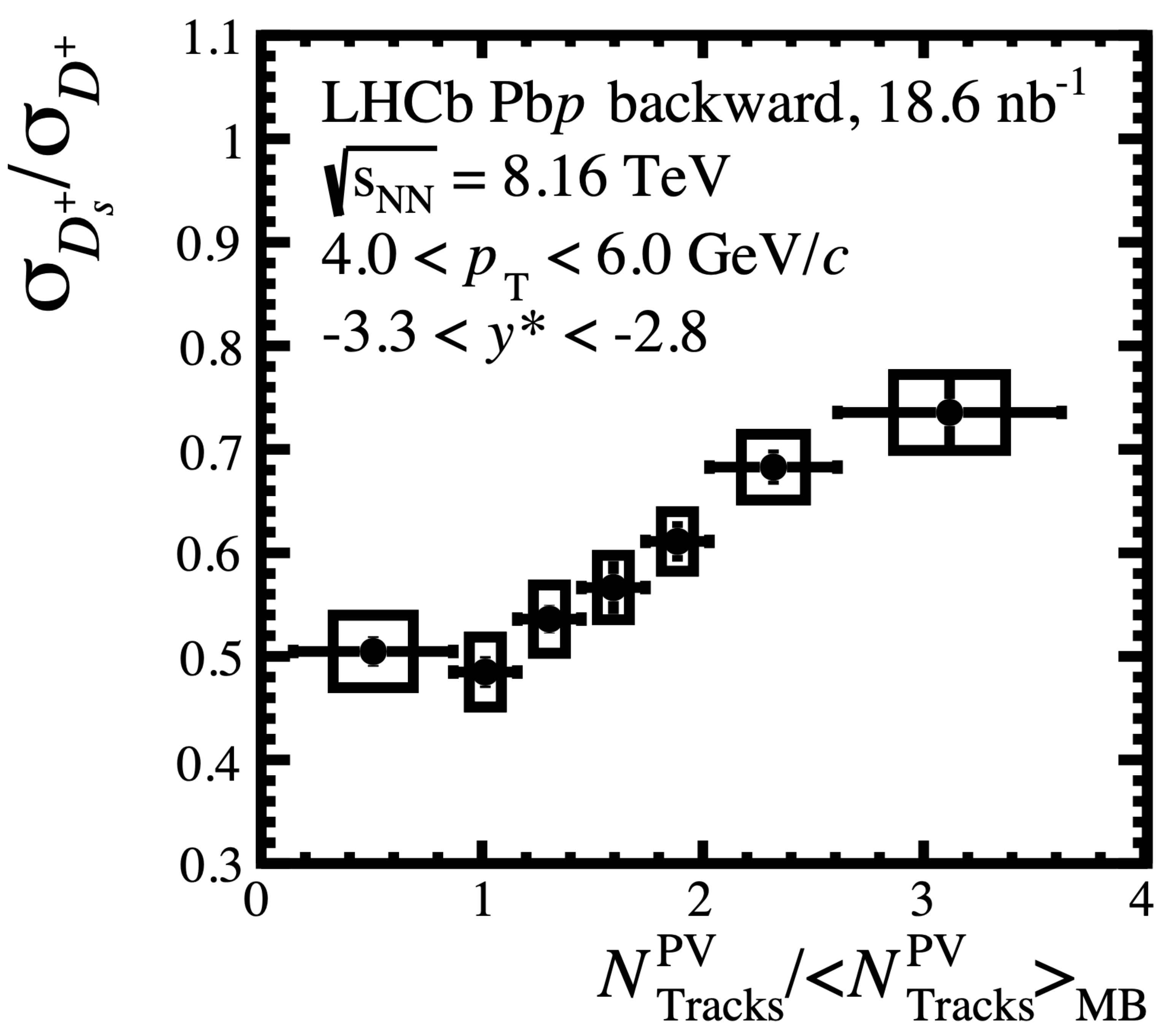
=60

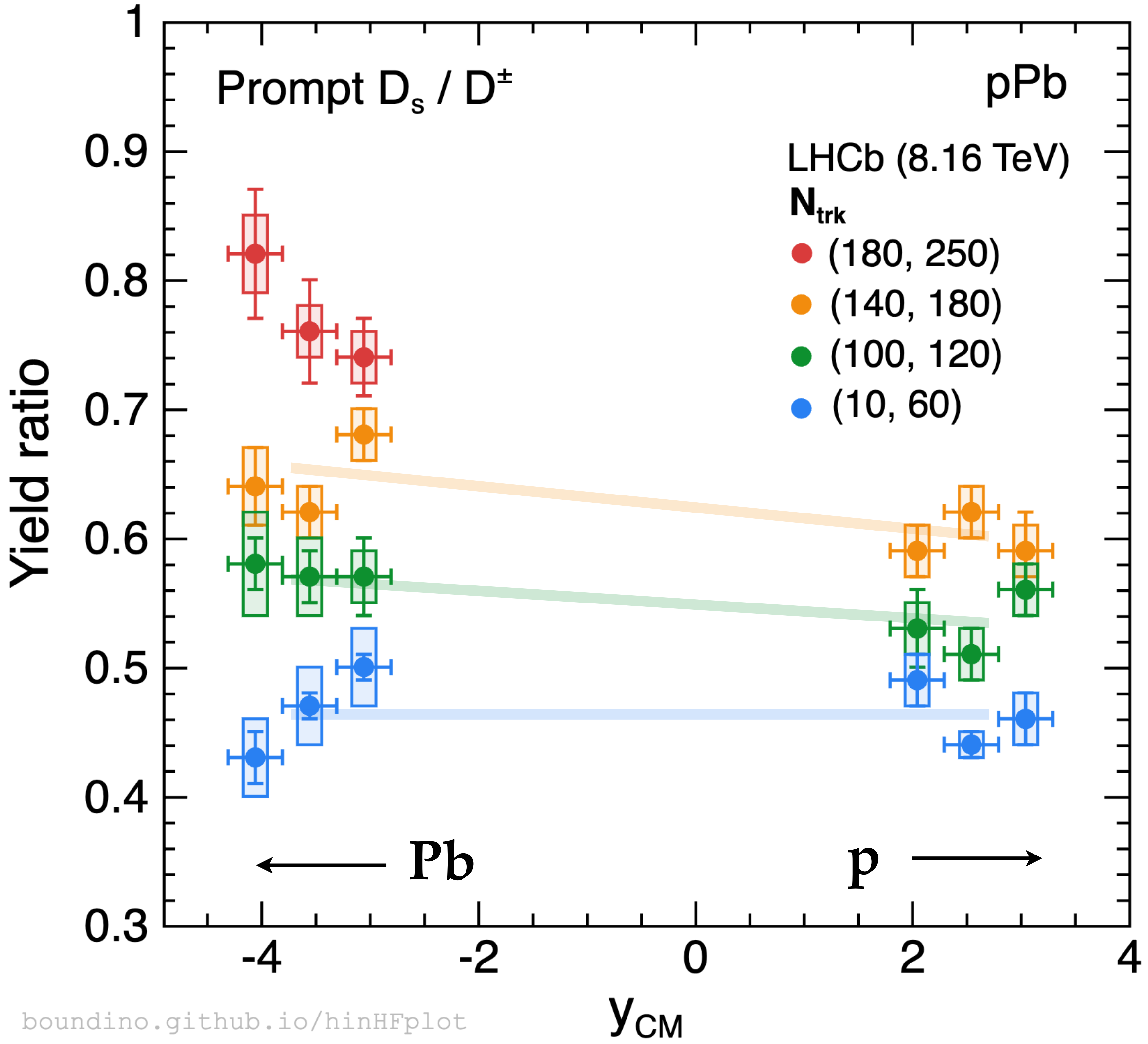
- The dependence seems to disappear at forward rapidity, but the normalization is different in the two directions

D_s/D^+ in pPb Notes on Multiplicity Dependence

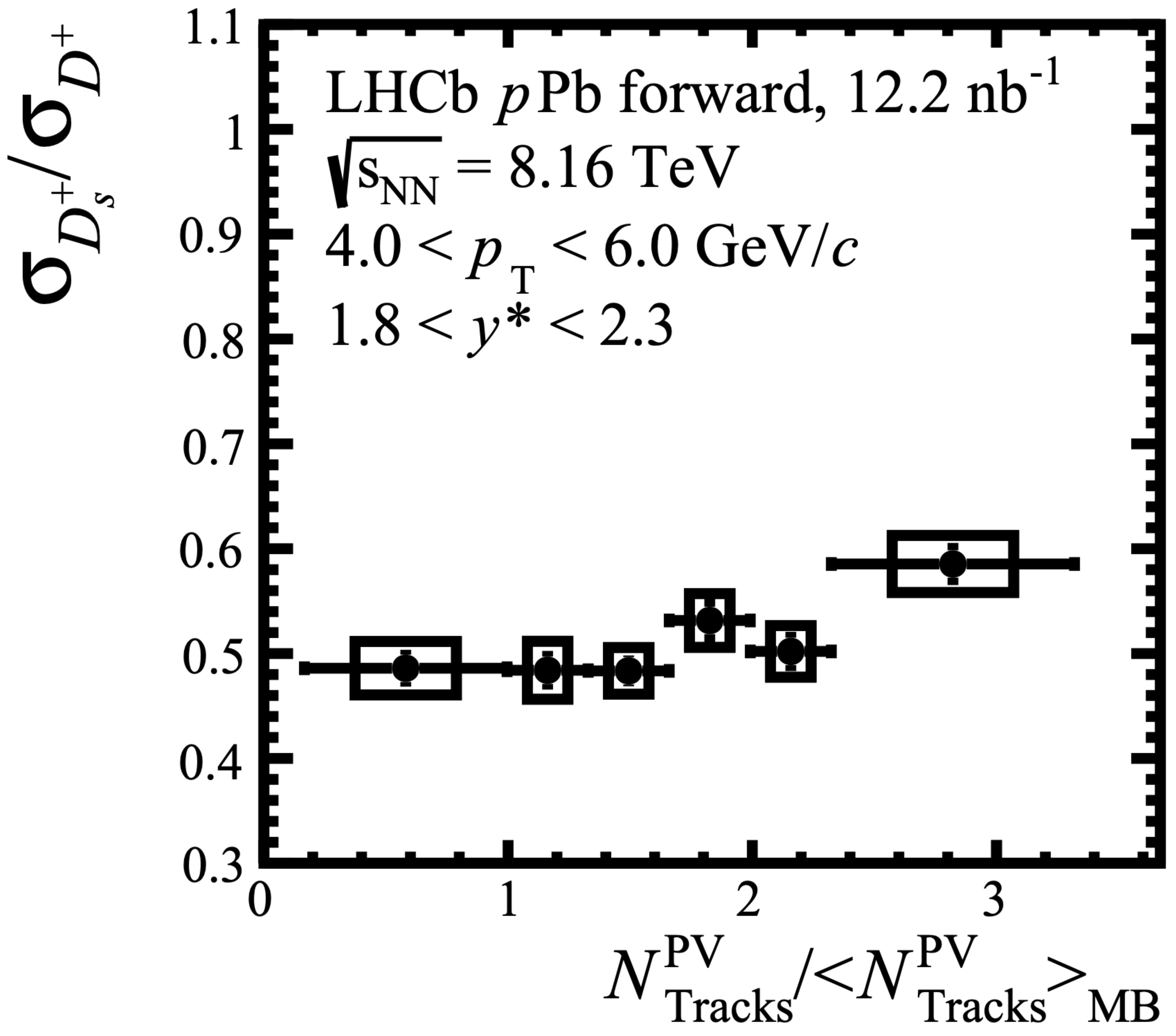
[arXiv:2311.08490]

Backward (Pb-going)



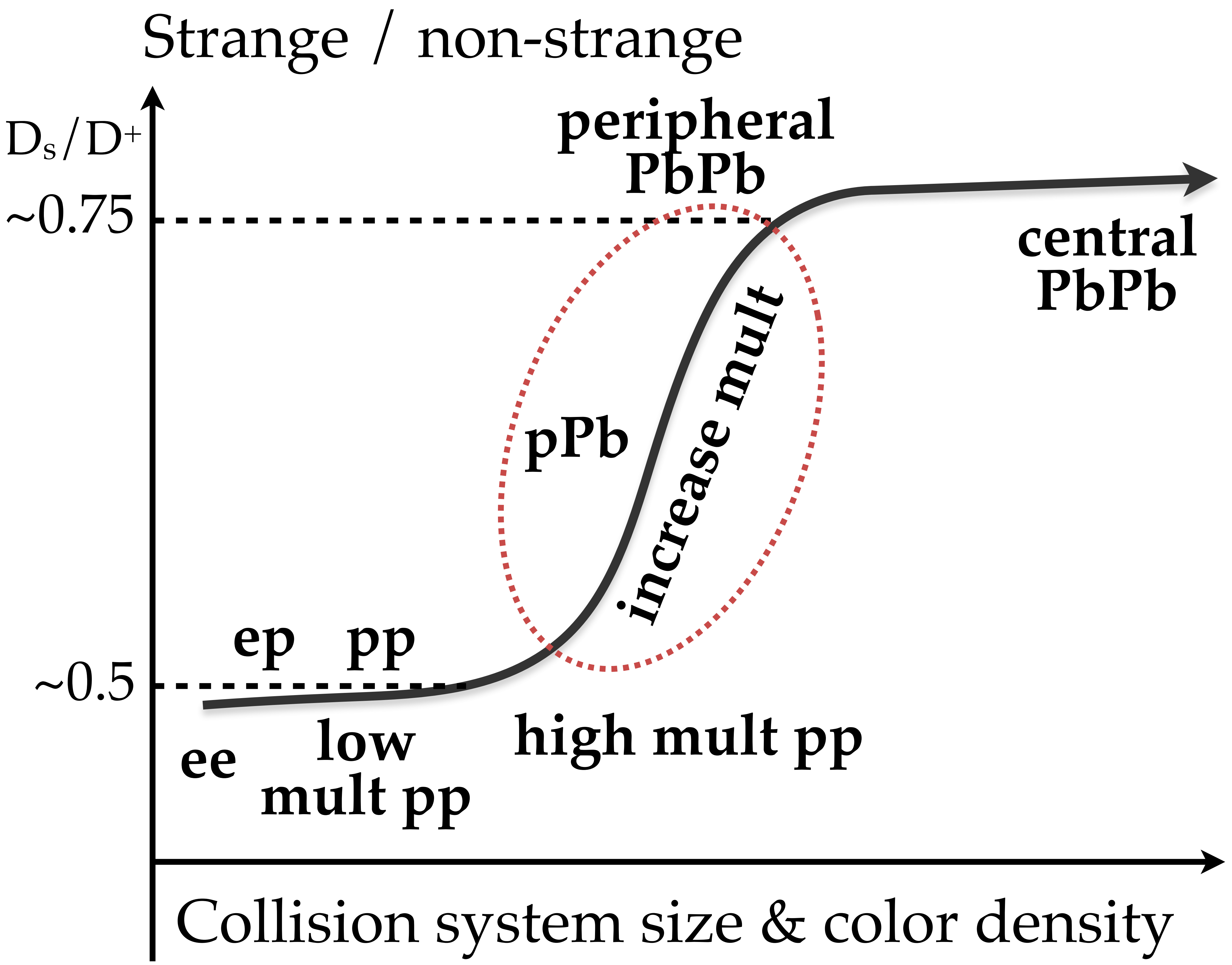


Forward (p-going)

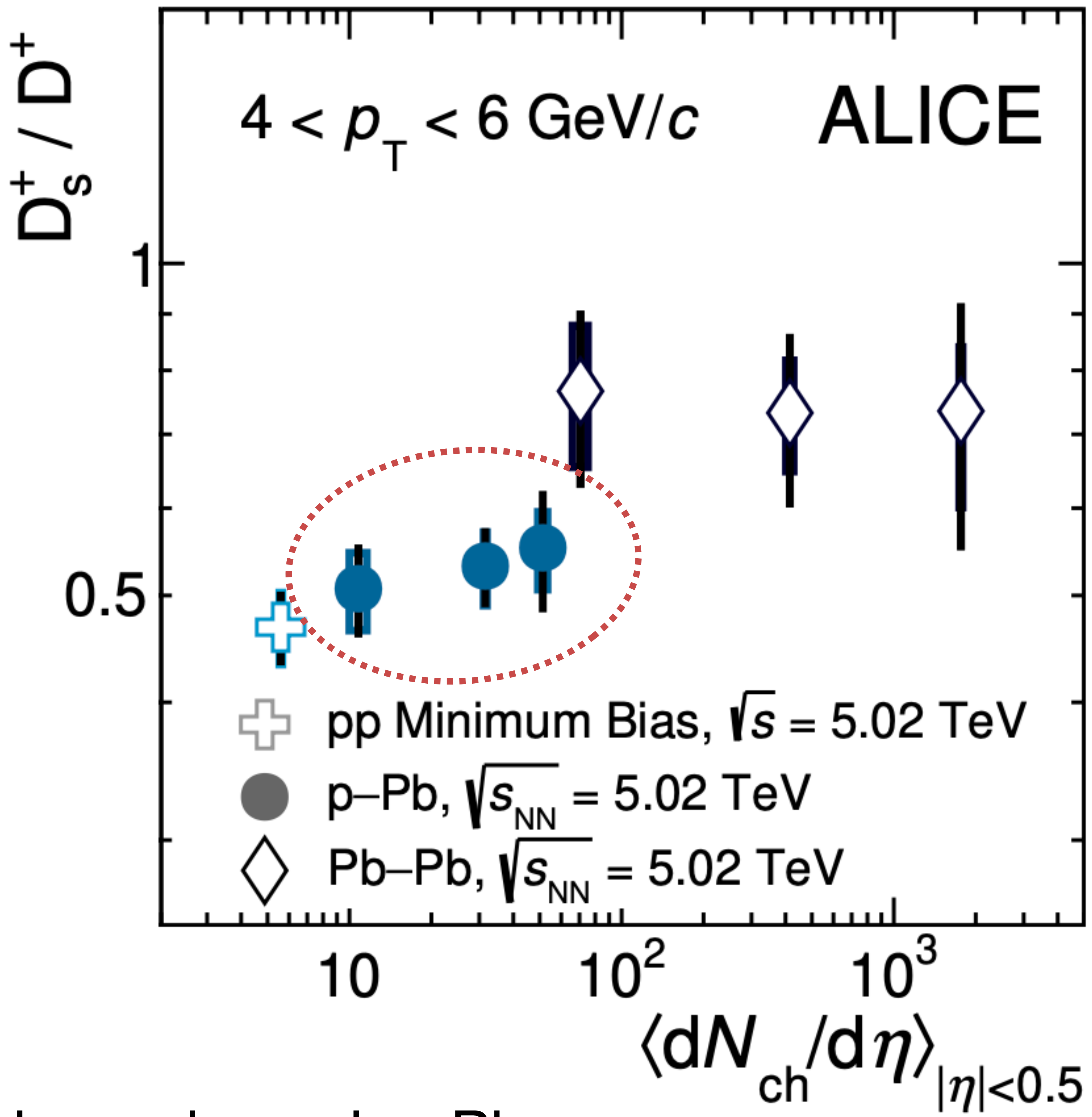


- The highest multiplicities are different between forward and backward
- For the same N_{trk} classes without normalization, the results are similar between forward and backward
- But large |y| seems to have stronger dependence than midrapidity

D_s/D^+ in pPb Notes on Multiplicity Dependence

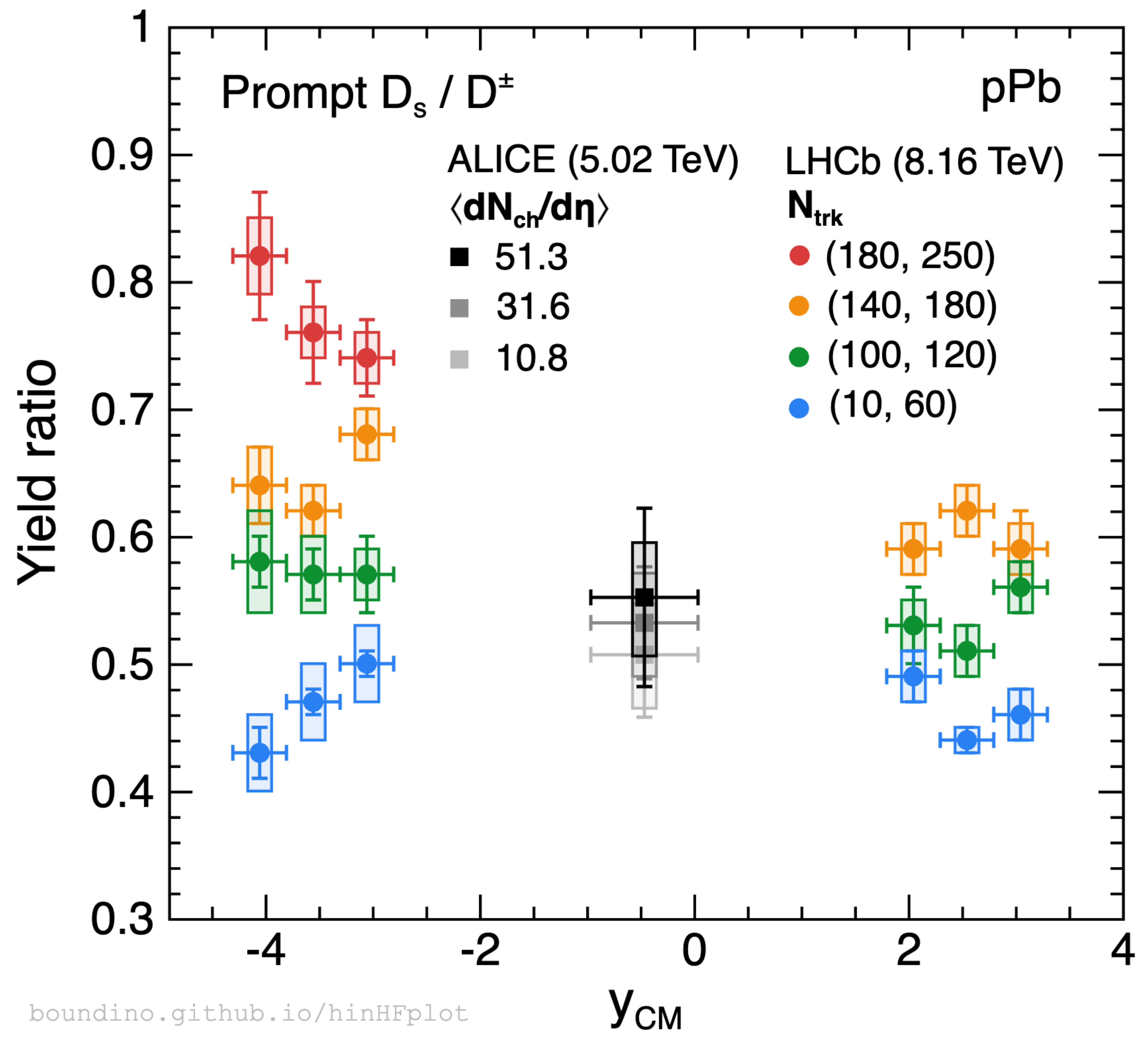


[JHEP 12 (2019) 092]

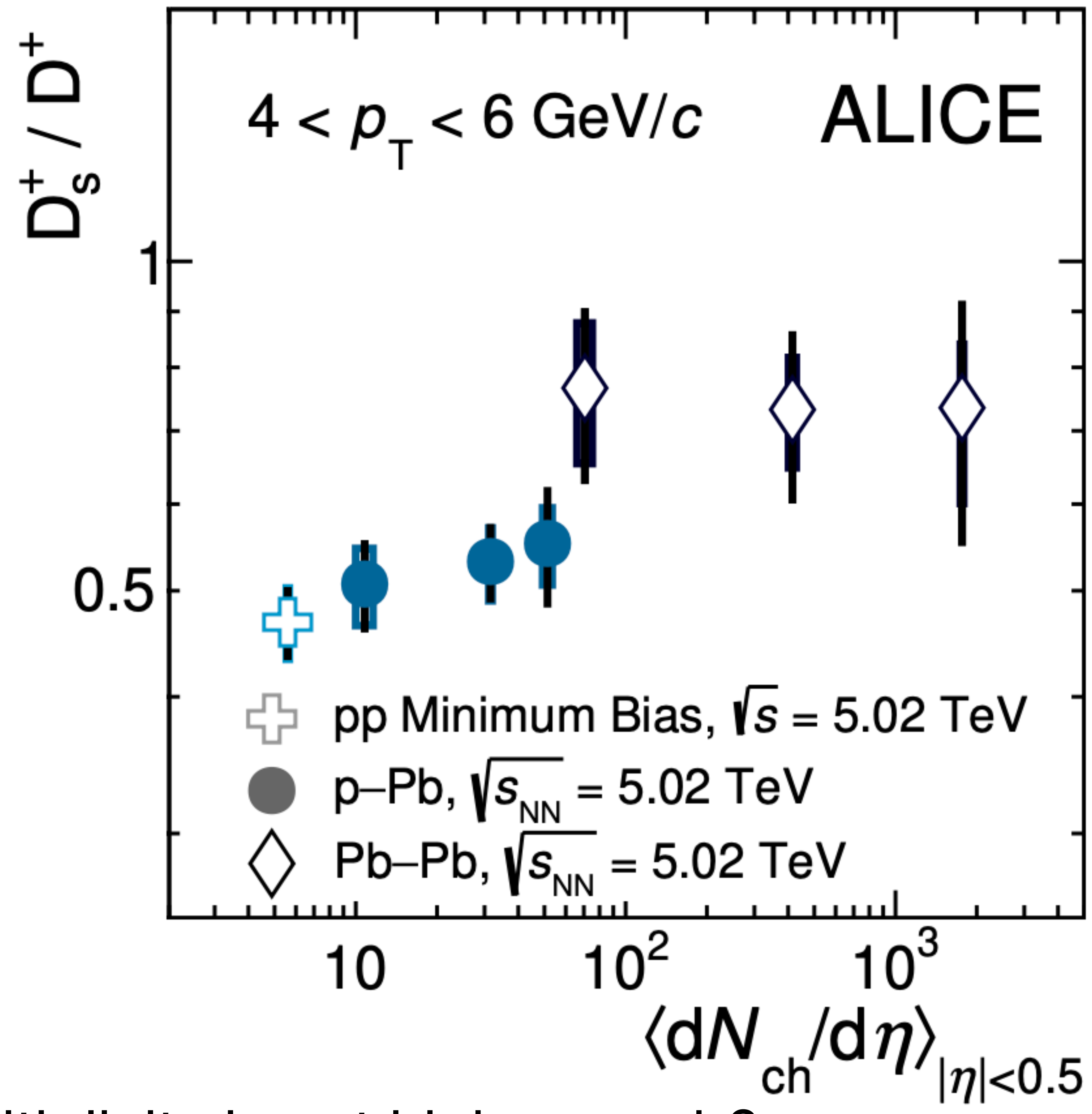


- ALICE sees milder multiplicity dependence in pPb

D_s/D^+ in pPb Notes on Multiplicity Dependence

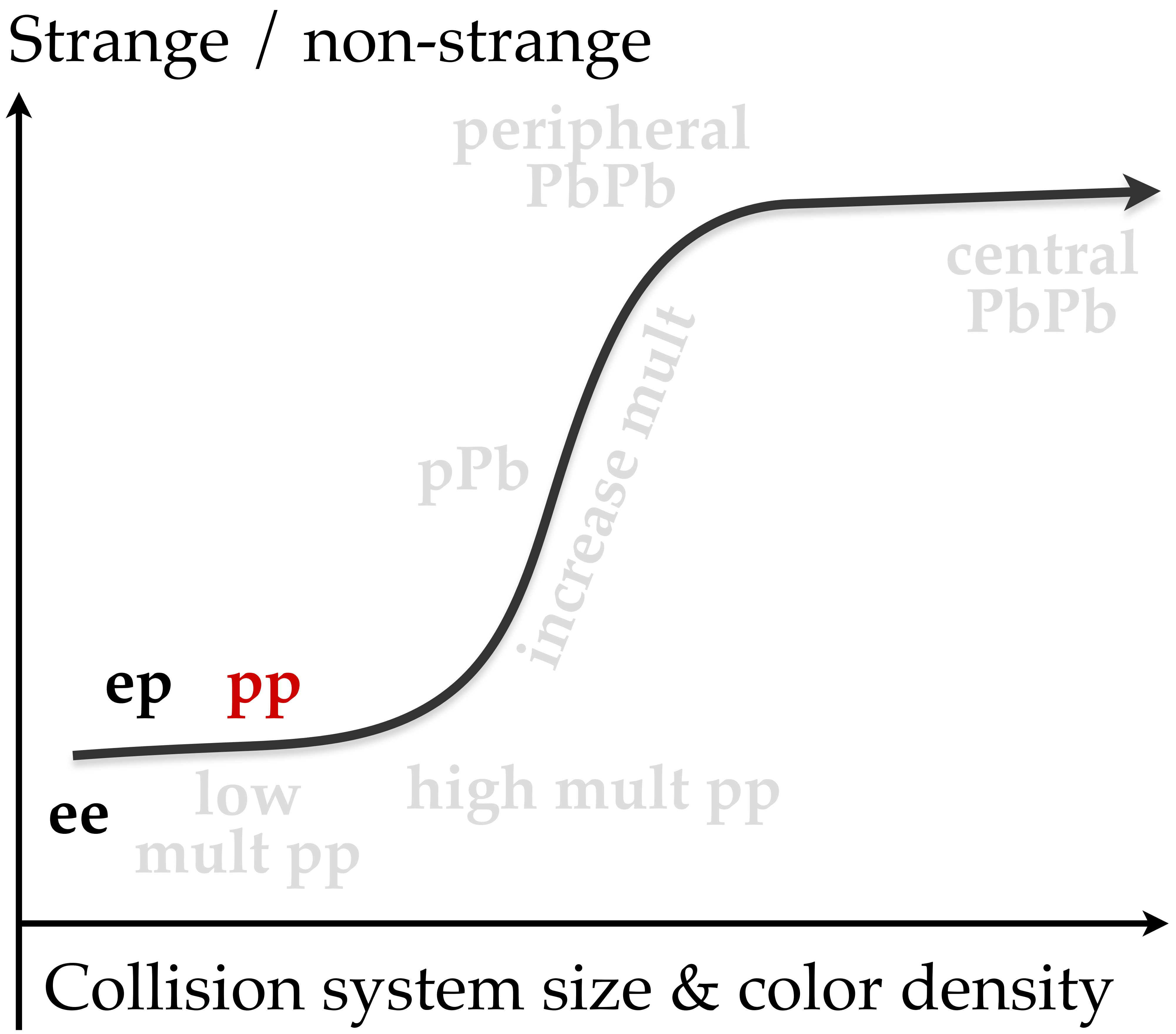


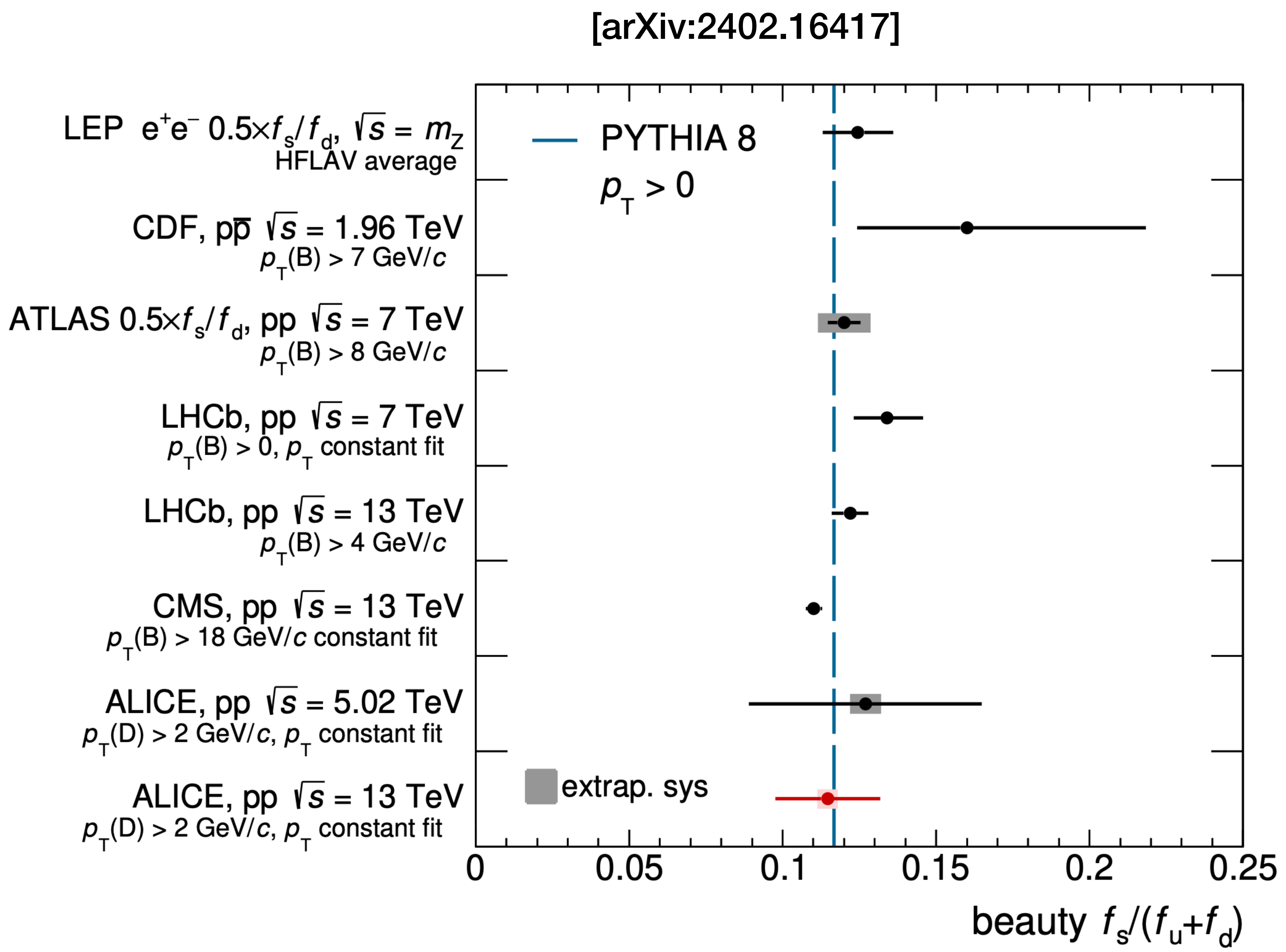
[JHEP 12 (2019) 092]



- Is it possibly because ALICE highest multiplicity is not high enough?
- How to match “similar color density” between ALICE and LHCb

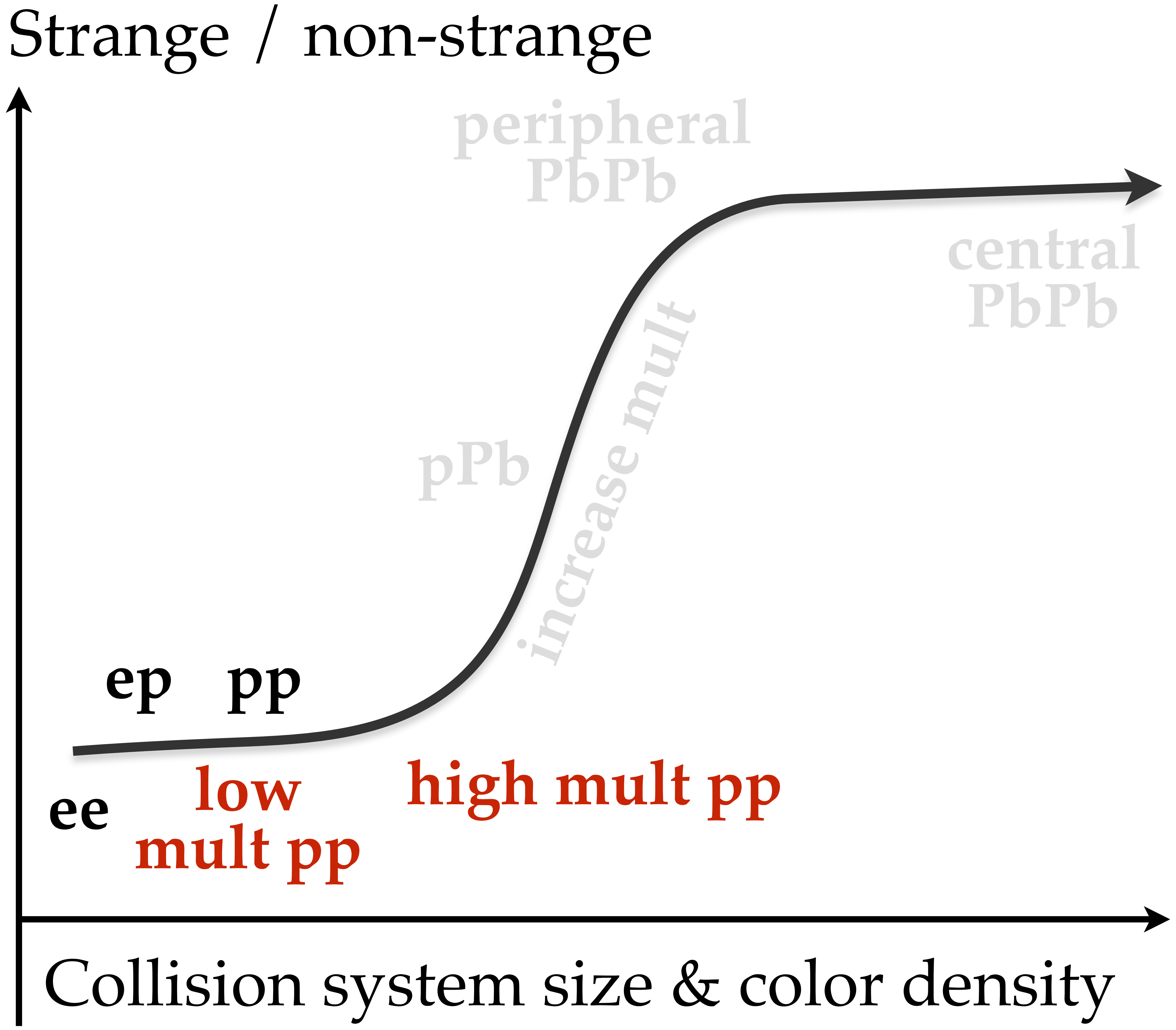
Strangeness Consistent Between D_s & B_s?



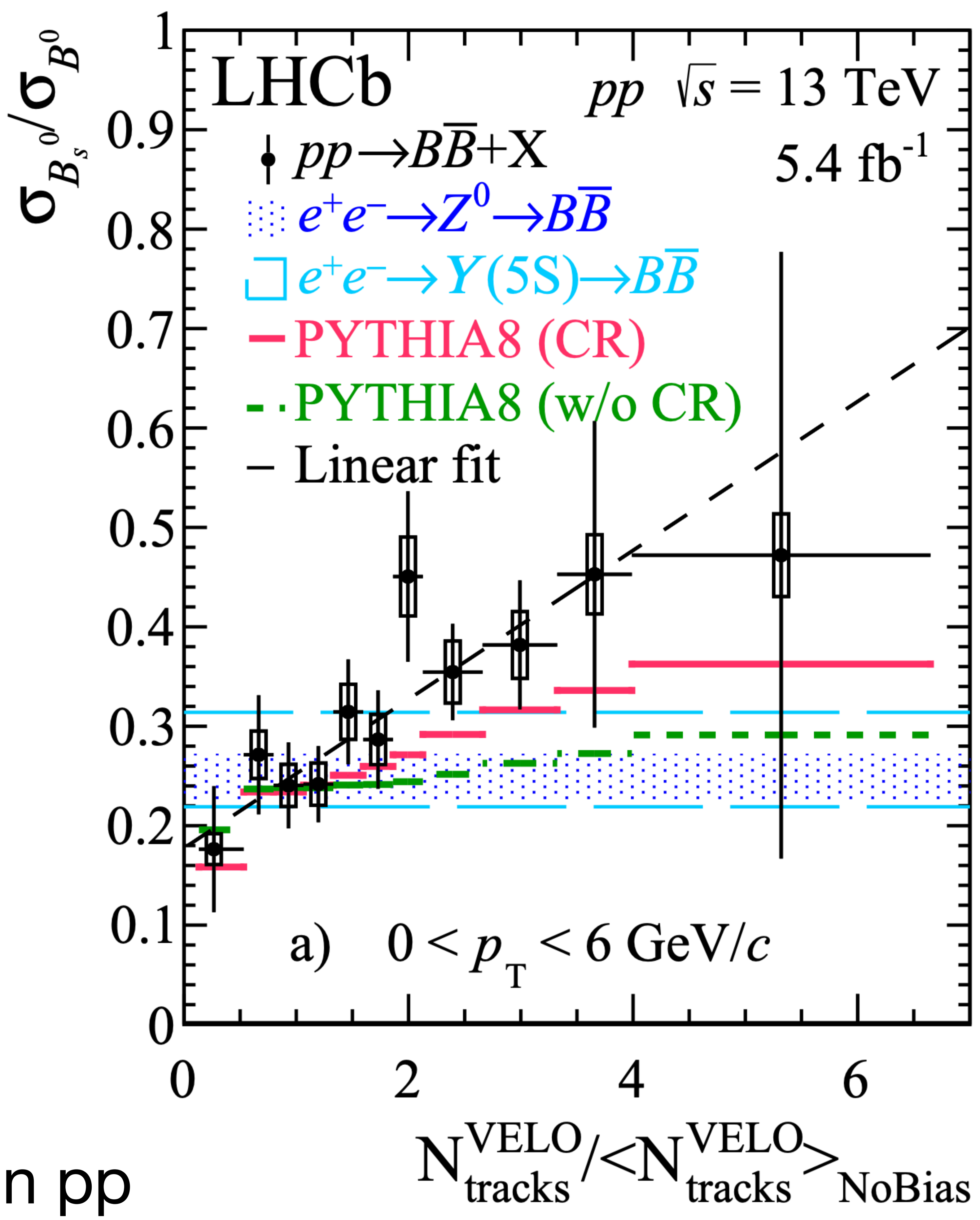


- No modification from ee to pp in beauty sector as well

Strangeness Consistent Between D_s & B_s?

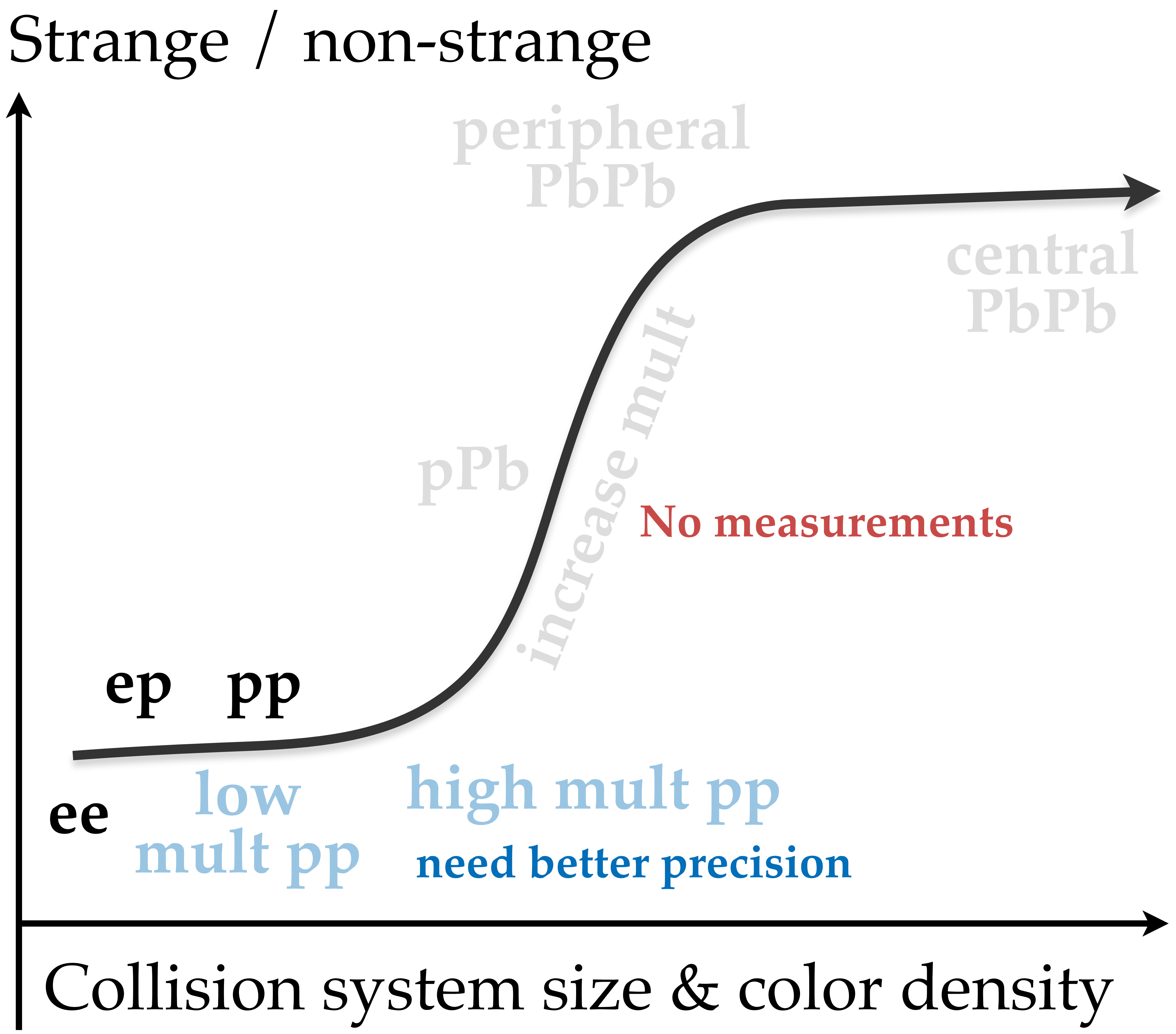


[PRL 131 (2023) 061901]



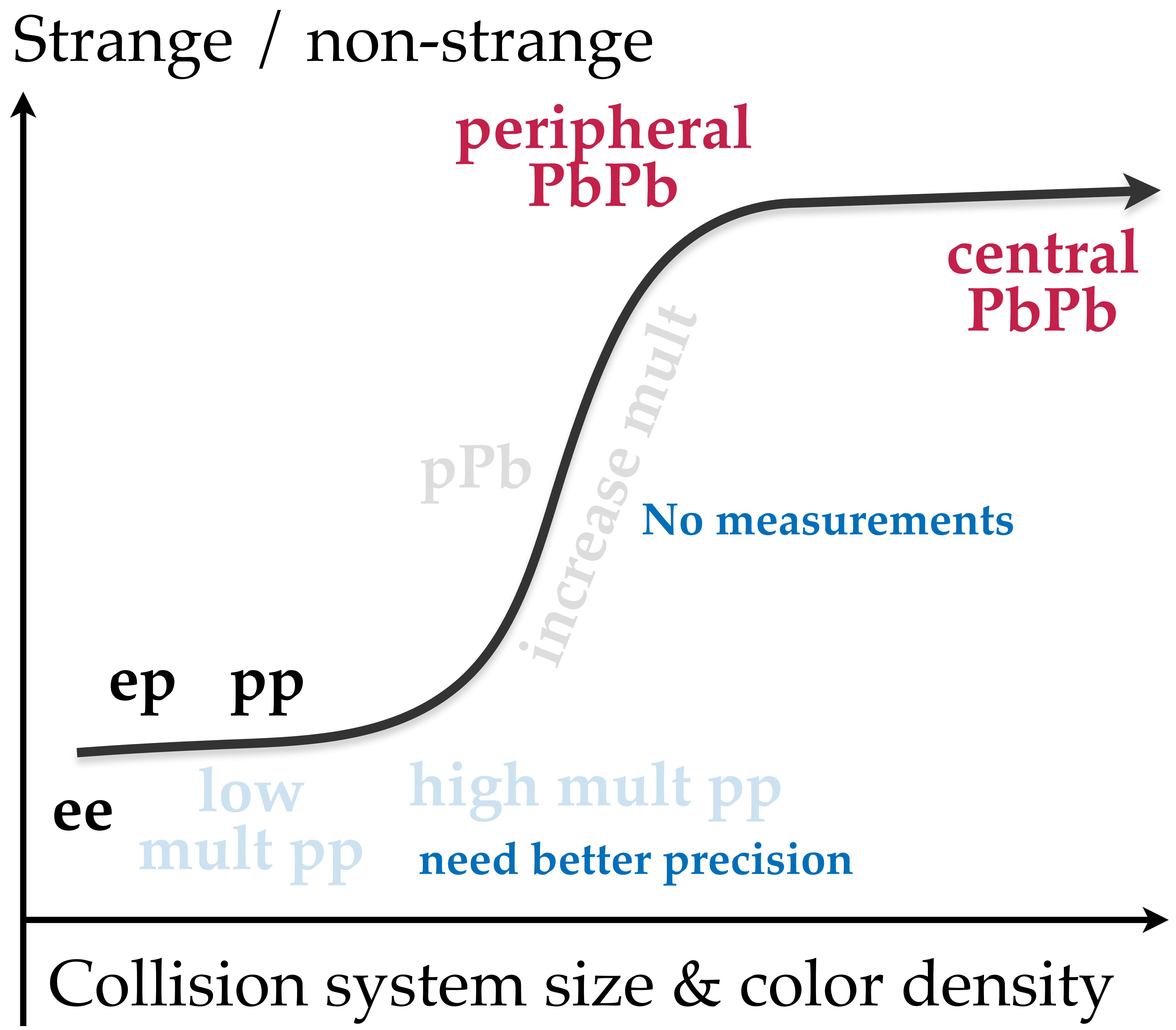
- Different from charm: hint of multiplicity dependence in pp
- Need better precision

Strangeness Consistent Between D_s & B_s?

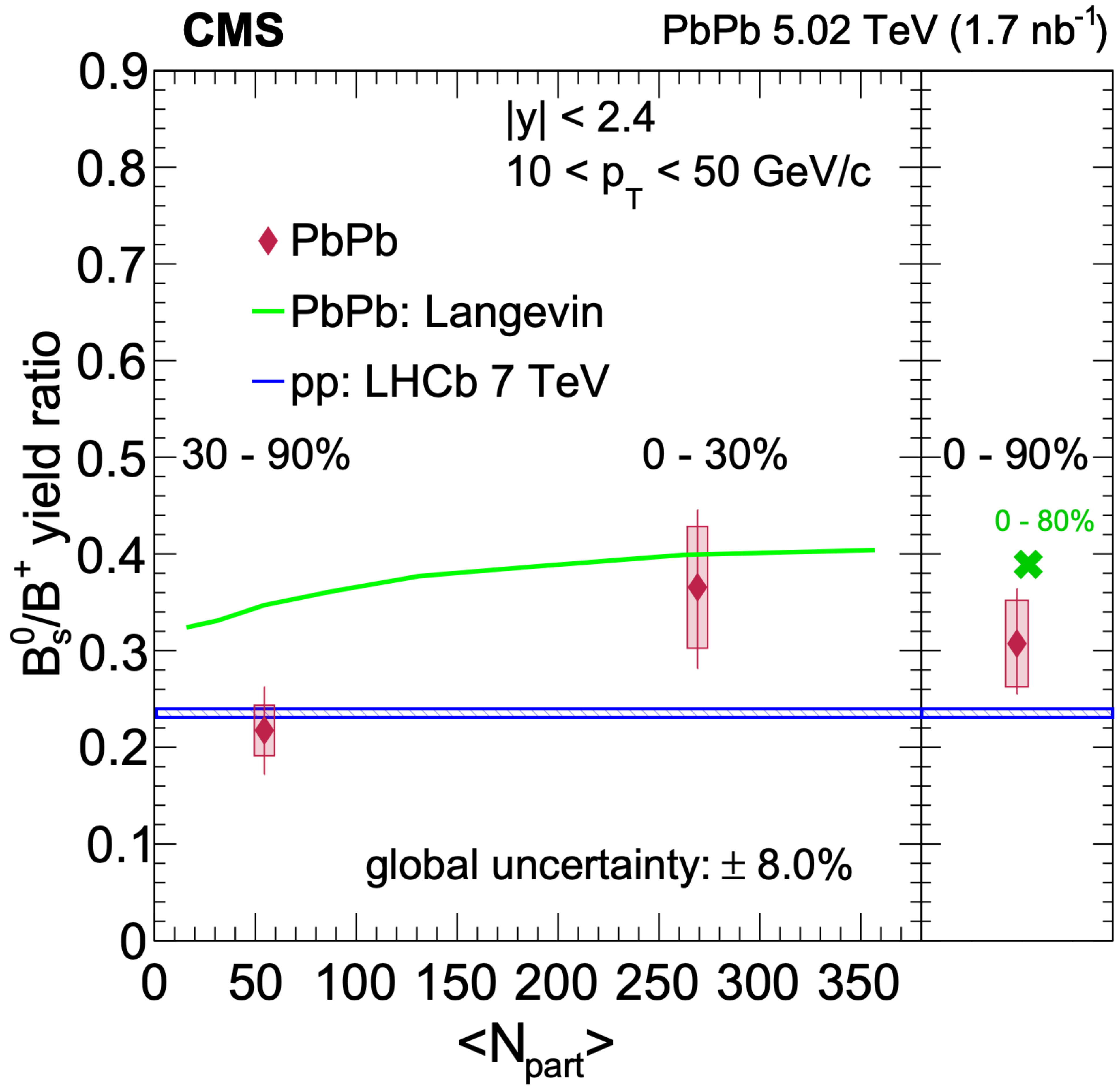


- No B_s measurements in pPb

Strangeness Consistent Between Ds & Bs?

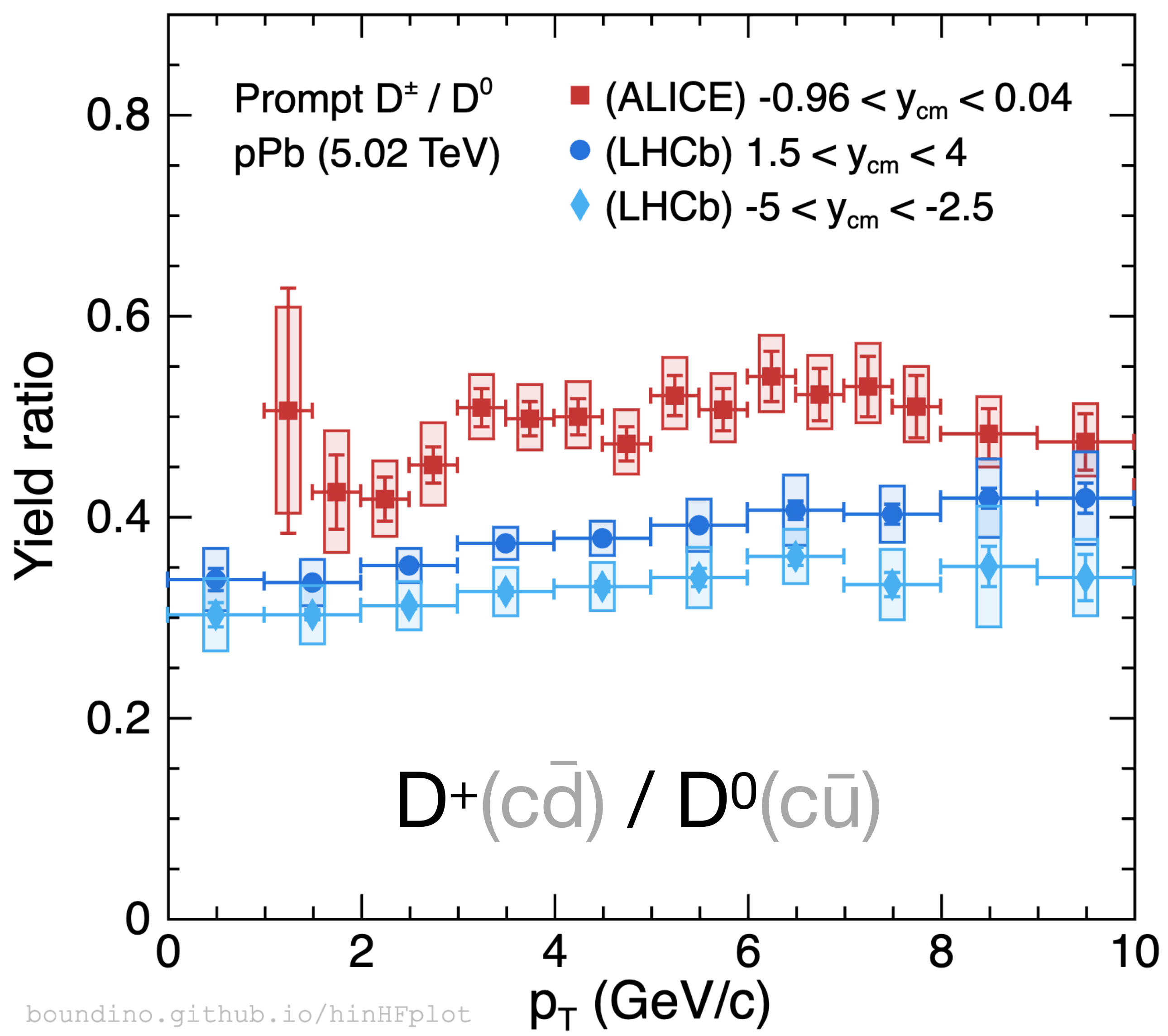


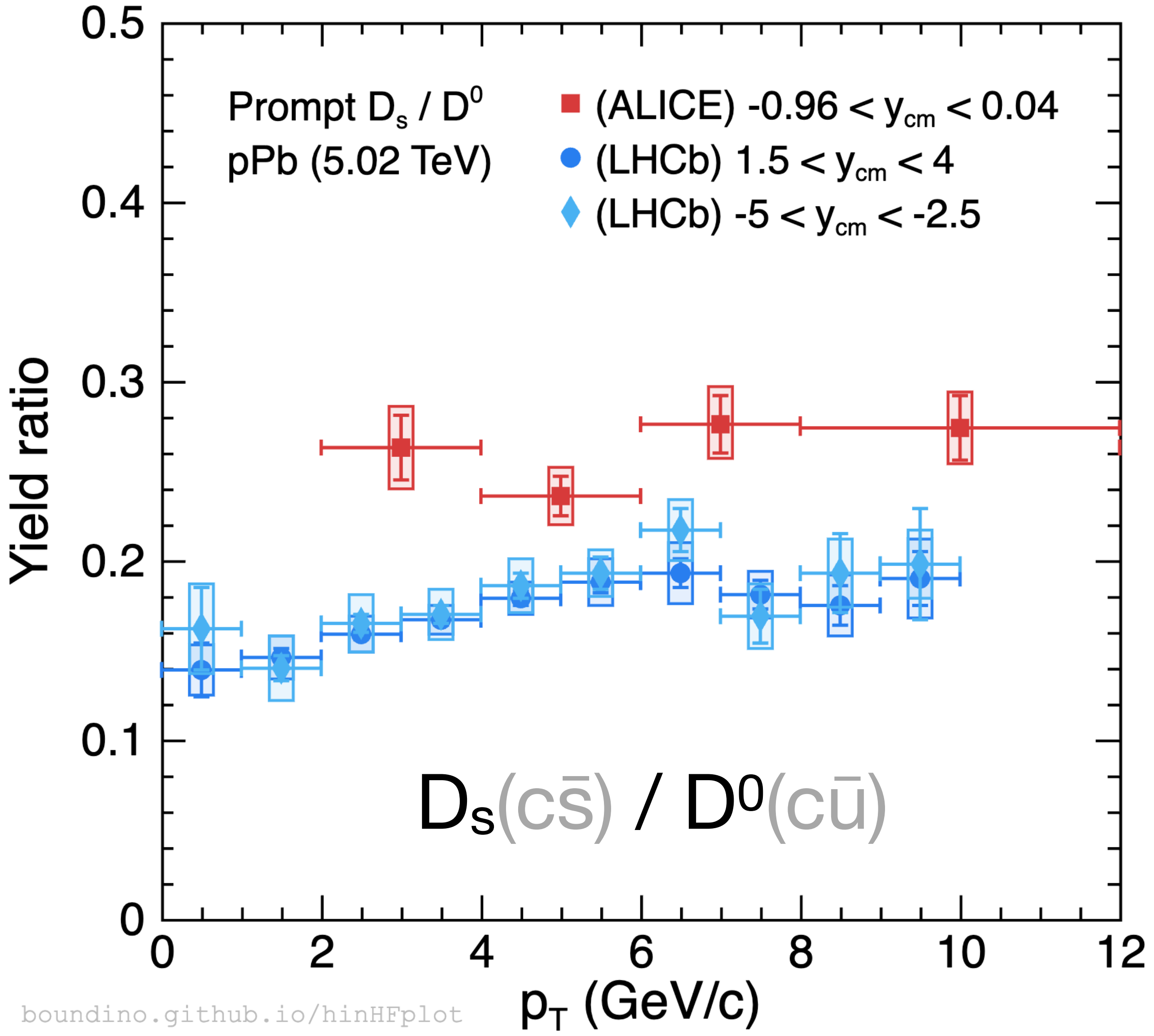
[PLB 829 (2022) 137062]

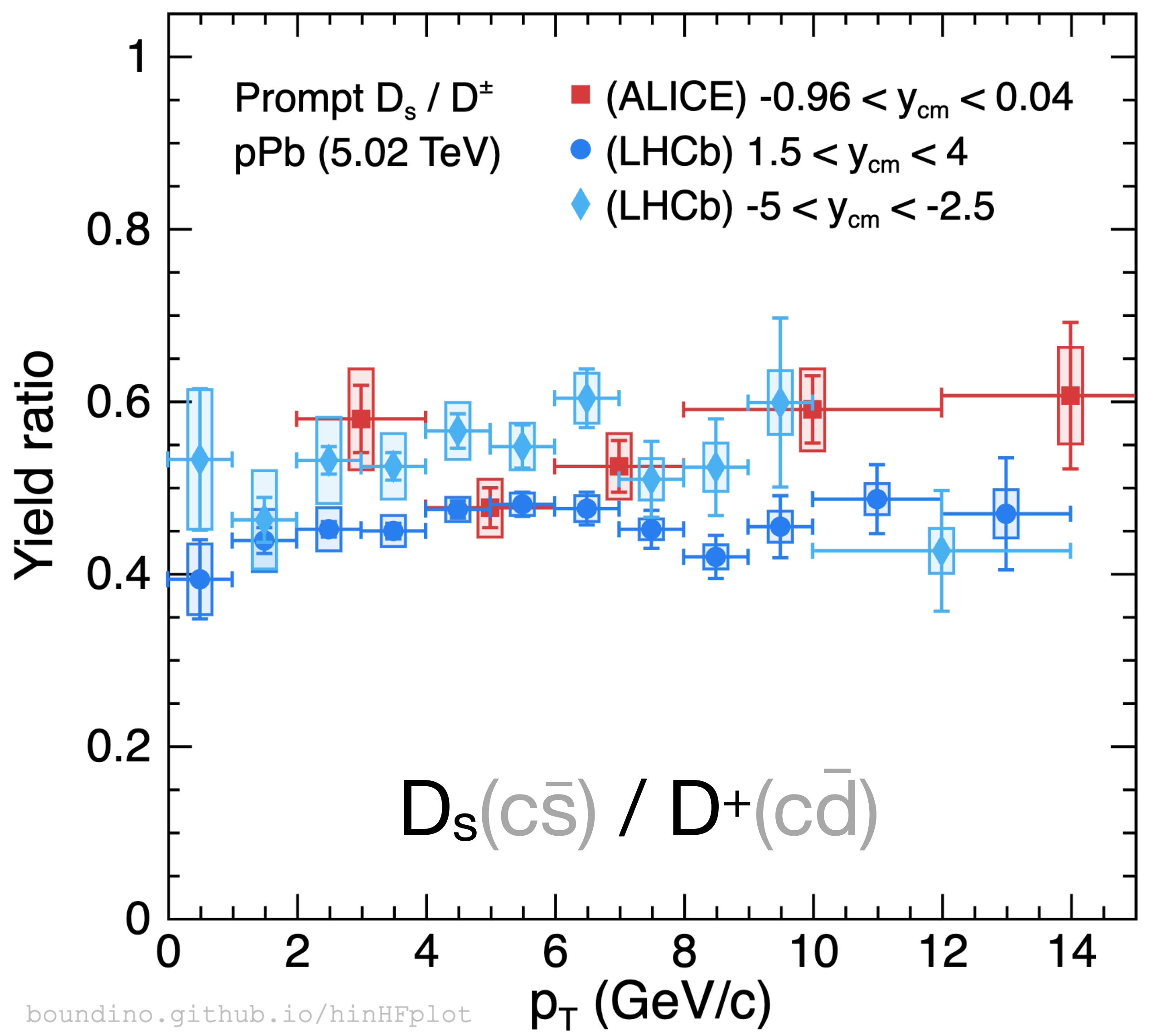


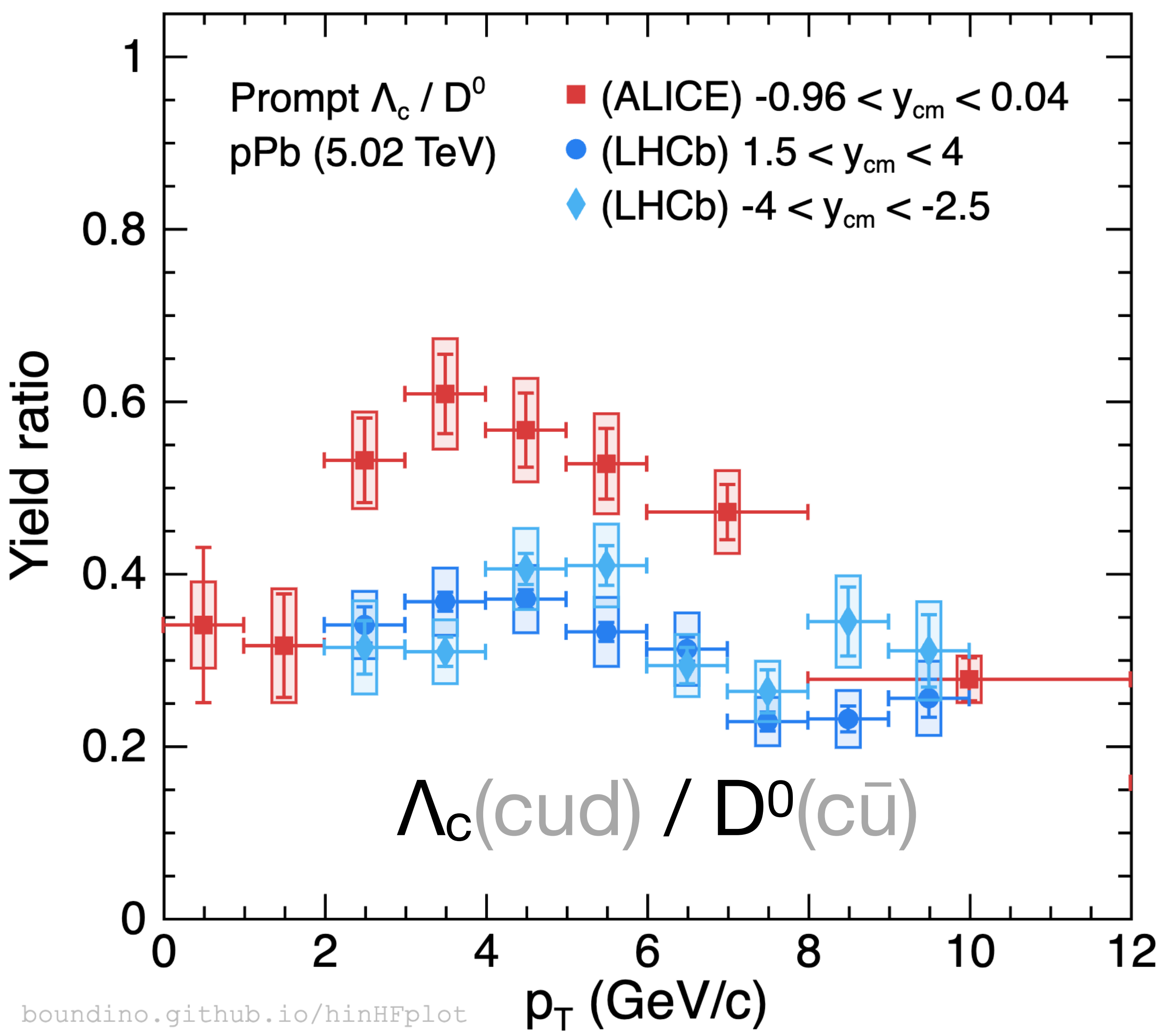
- Different from charm: hint of centrality dependence in PbPb
- Need better precision

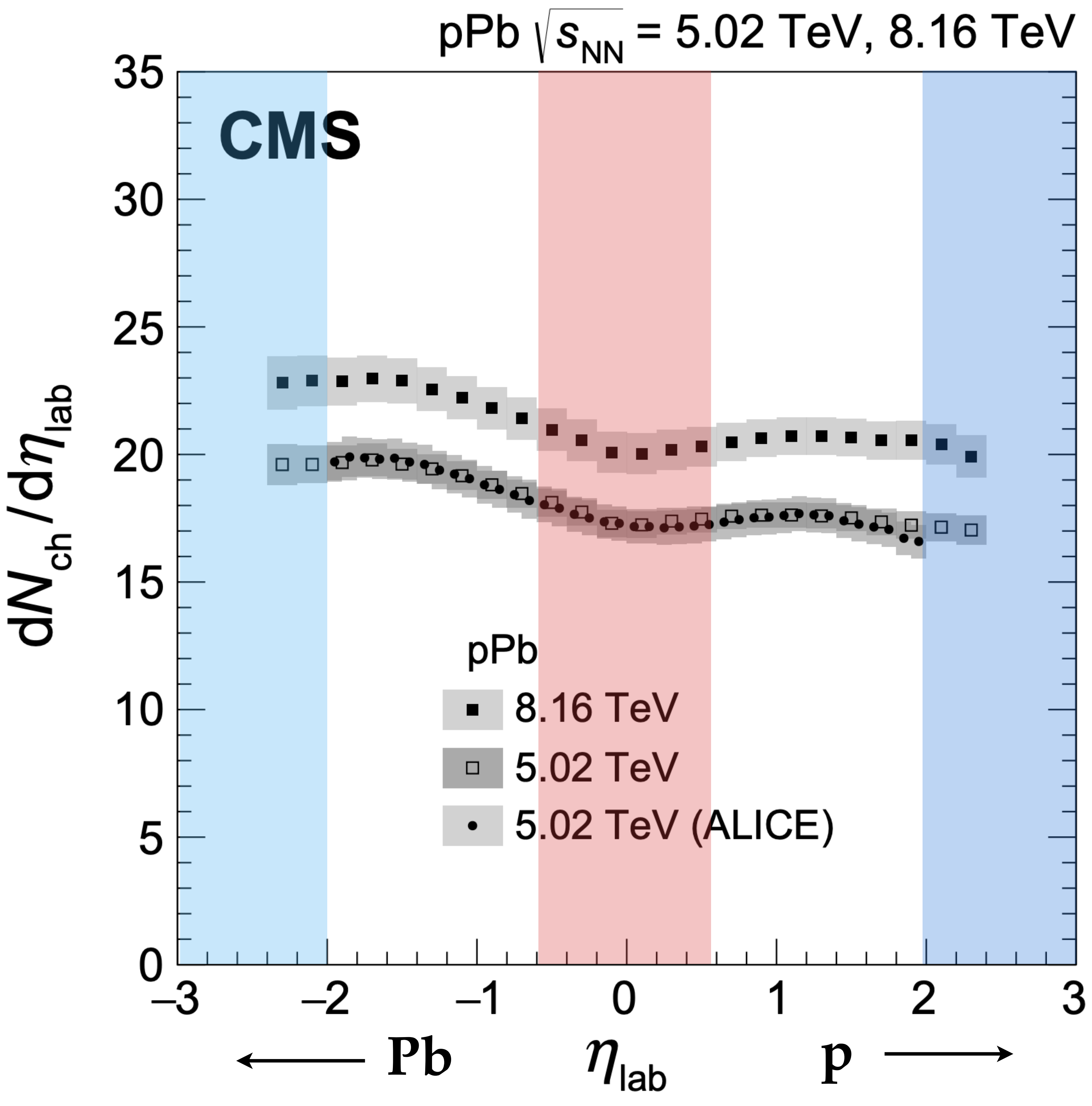
Rapidity Dependence pPb Collisions





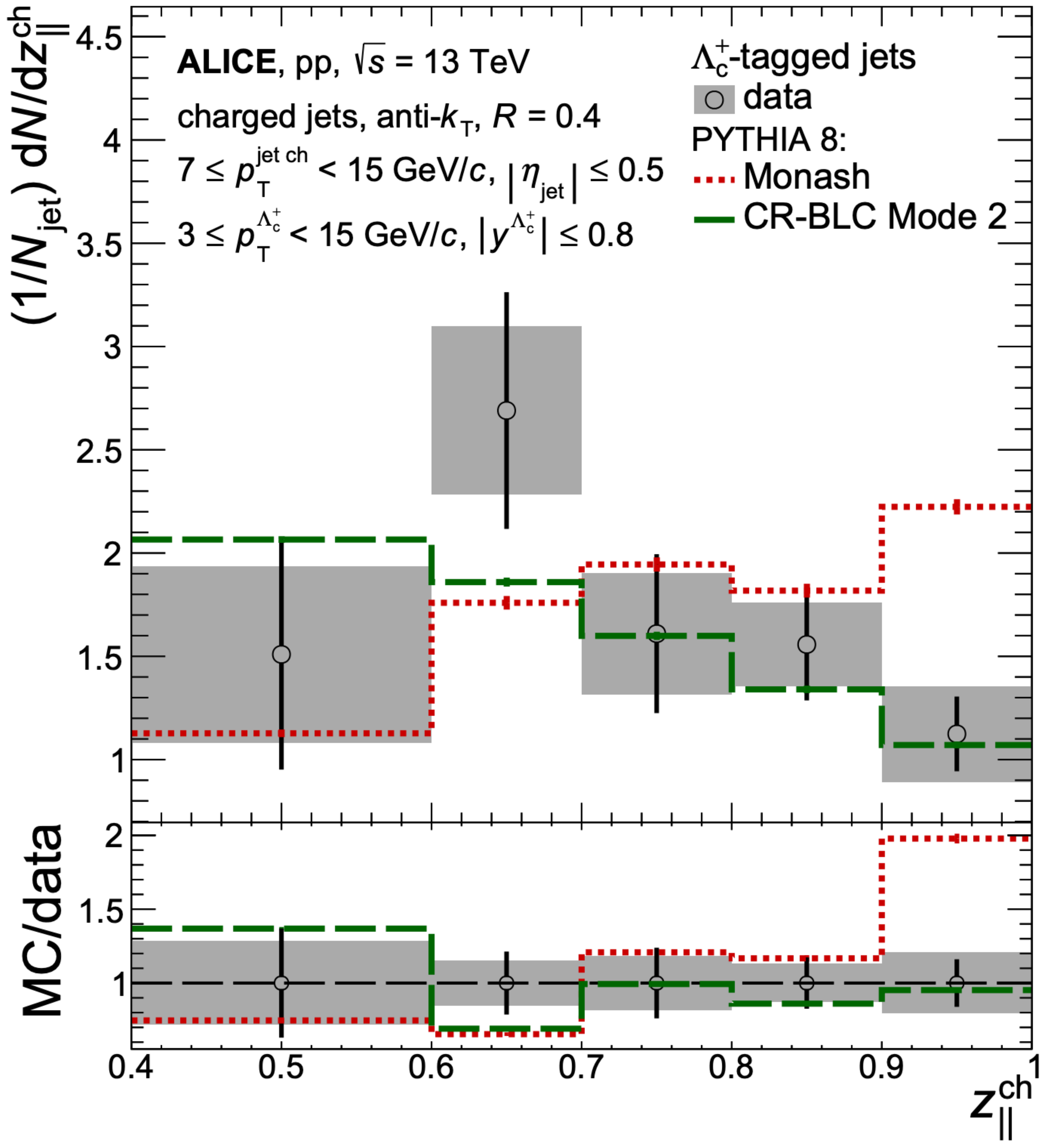


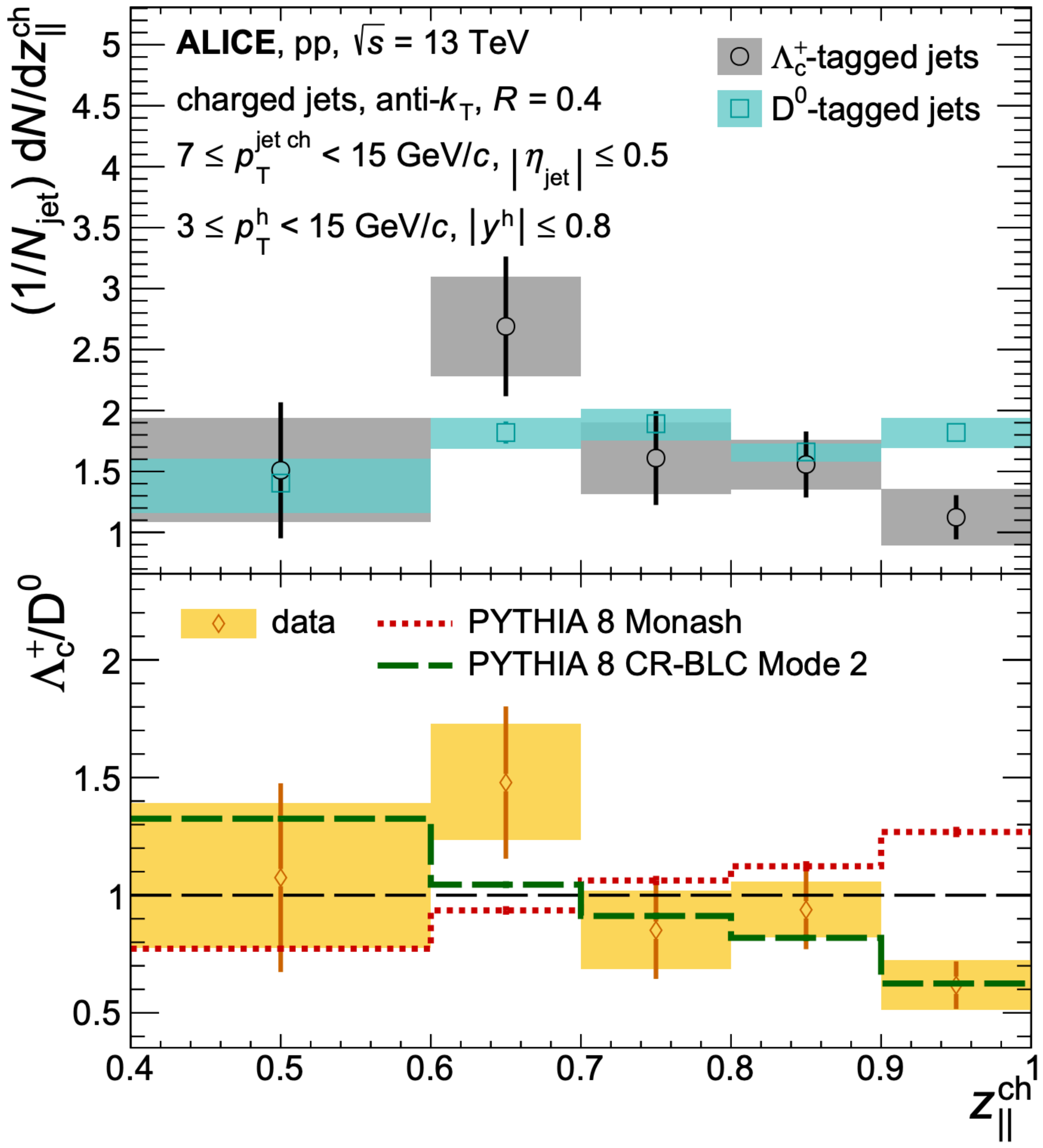




of R_{pPb} and R_{FB} for D^+ versus other D mesons. On average, the multiplicity value at backward rapidity is 1.6 times higher than that at forward rapidity in terms of the backward-forward production ratio of charged particles at the same center-of-mass energy from LHCb [80]. As some contributions of D^+ and D^0 mesons come from the decay of the excited charm resonance, the D^{*+} meson [64, 81], it may be possible to further understand this phenomenon by investigating the production of D^{*+} mesons in high multiplicity pPb events.

Λc Fragmentation Function in Jet What New?





Enjoy More!

🔗 Heavy flavor result playground

https://boundino.github.io/hinHFplot/

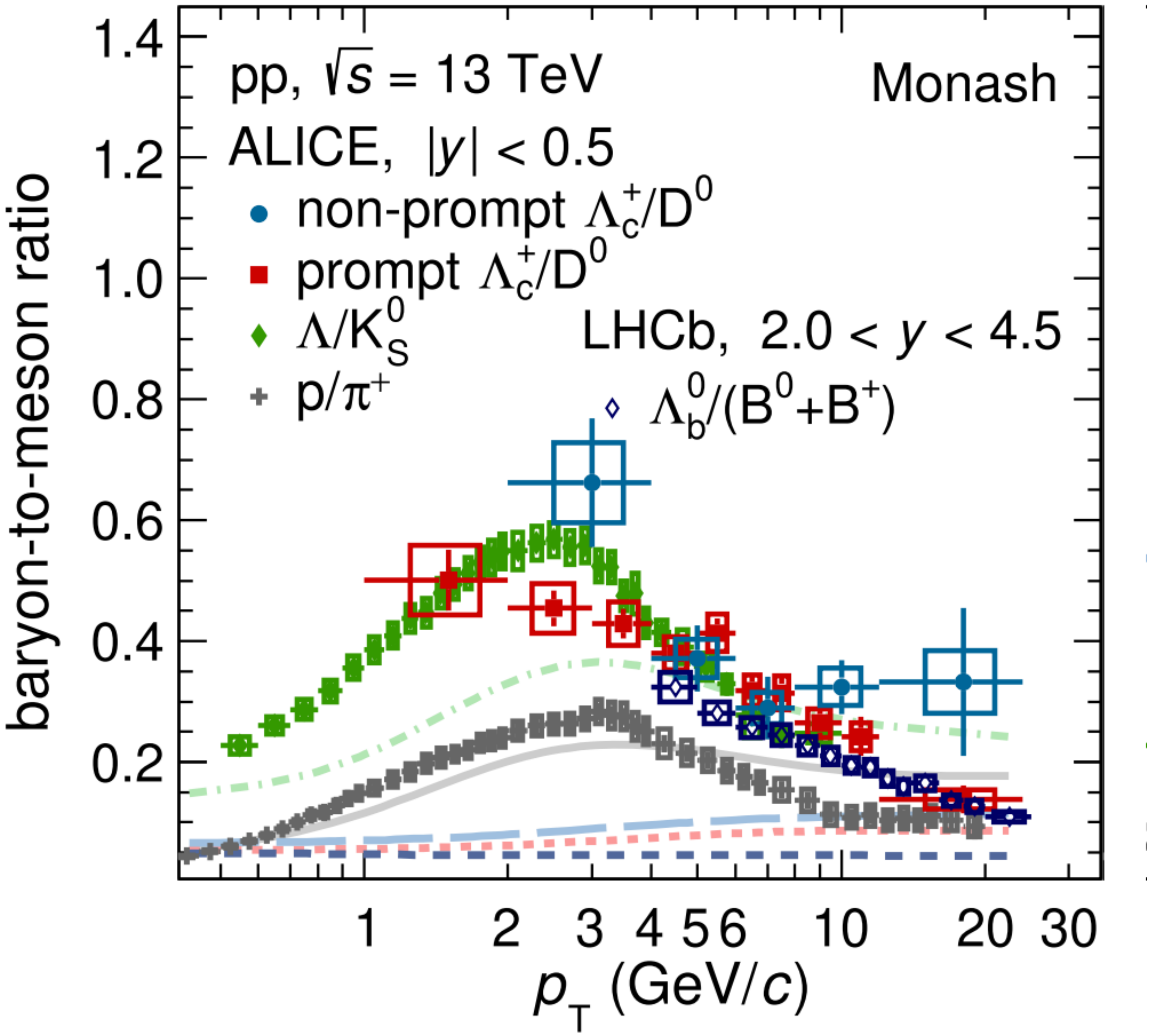
🔗 Heavy flavor in HI publications

Update to 2024 August

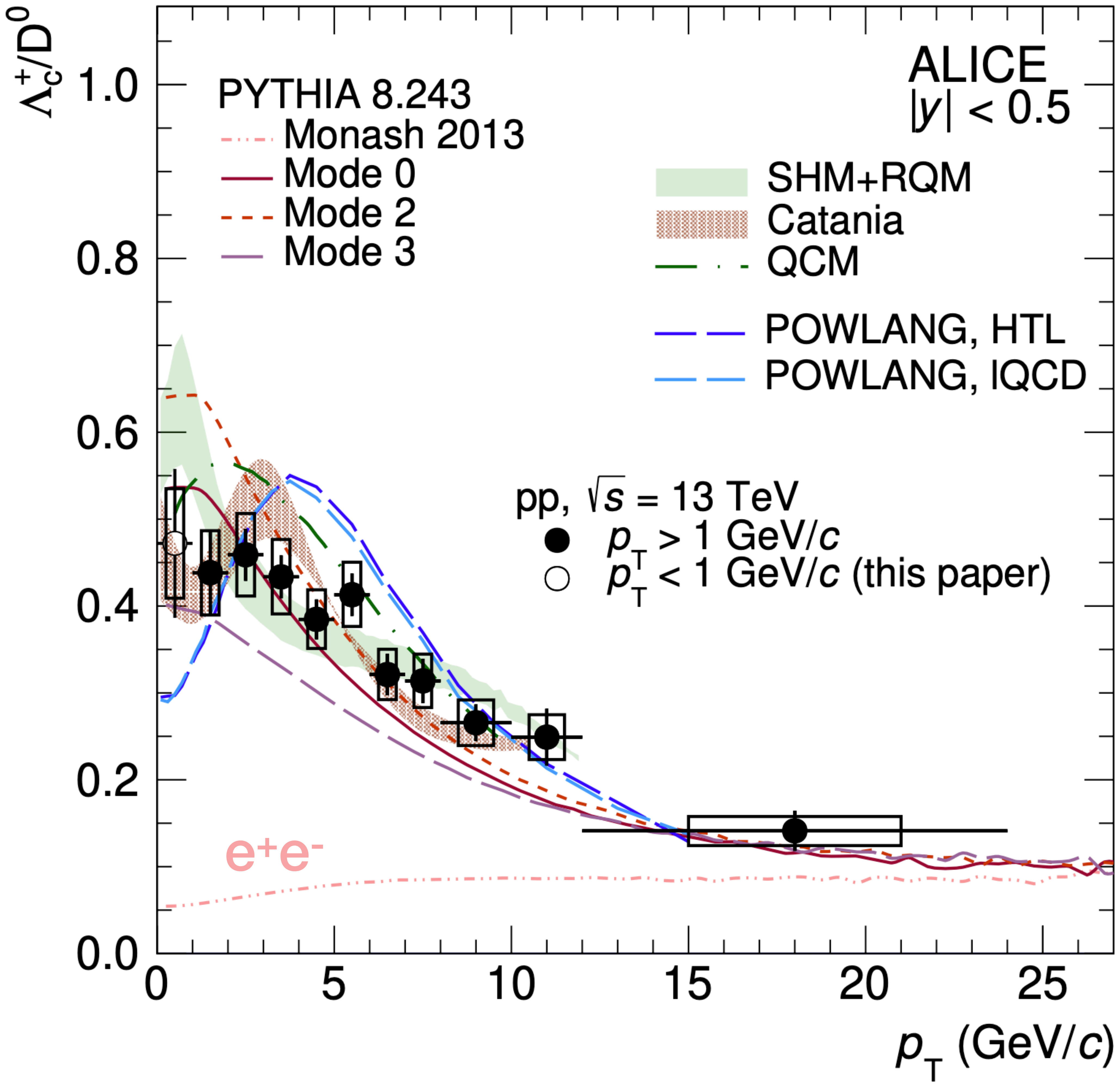

Isabelle
Thanks for your attention!

Λ_c p_T Redistribution vs Λ_b/B

pp



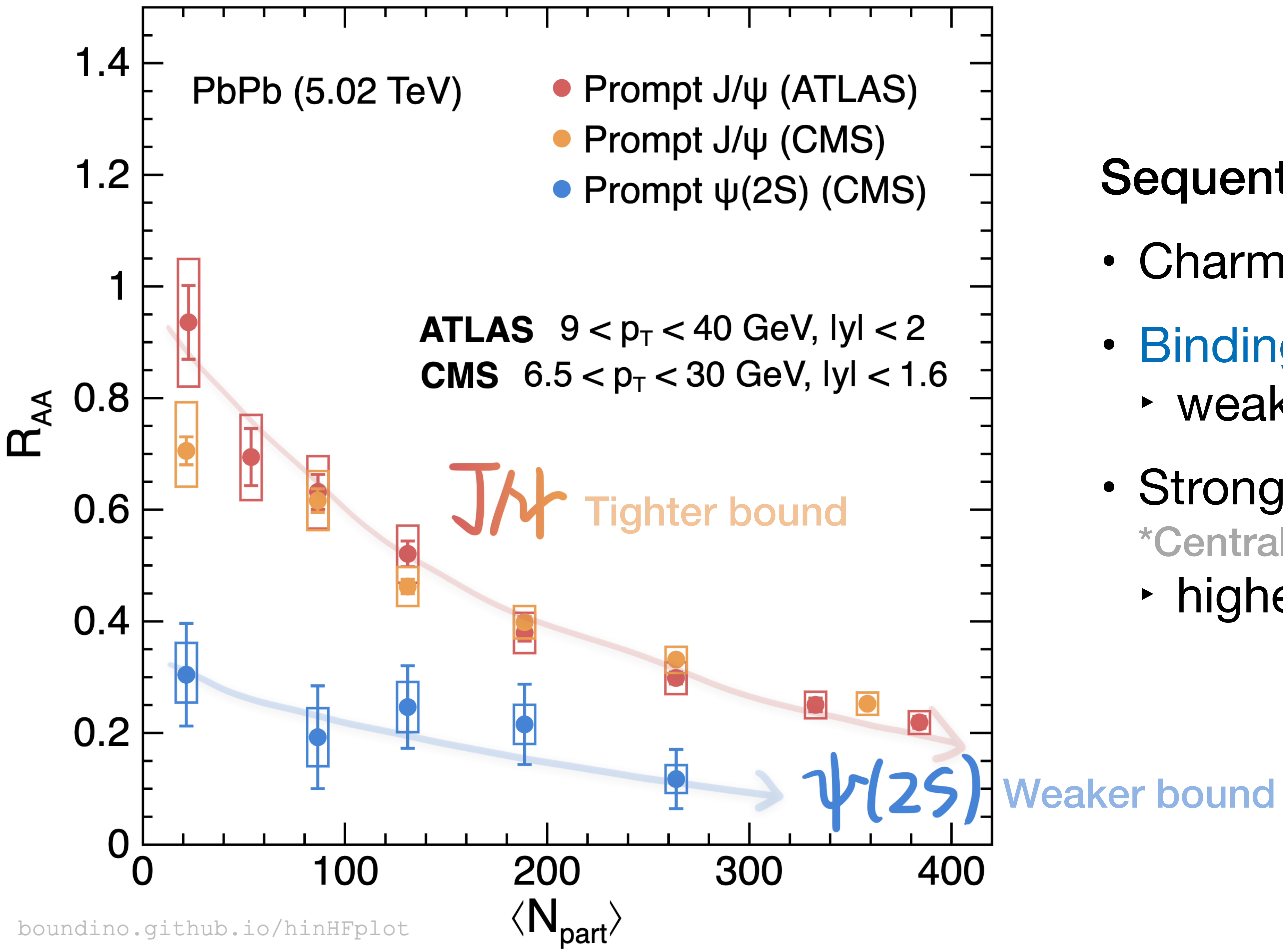
Charm Baryon Λ_c Hadronization in pp



[JHEP 12 (2023) 086]

- Significant larger Λ_c / D^0 observed in pp
  - Stronger enhancement at low p_T compared to e^+e^-
- Theoretical efforts to describe it
  - More excited baryons
  - Color reconnection
  - Coalescence also in pp

Charmonia in QGP Sequential Melting



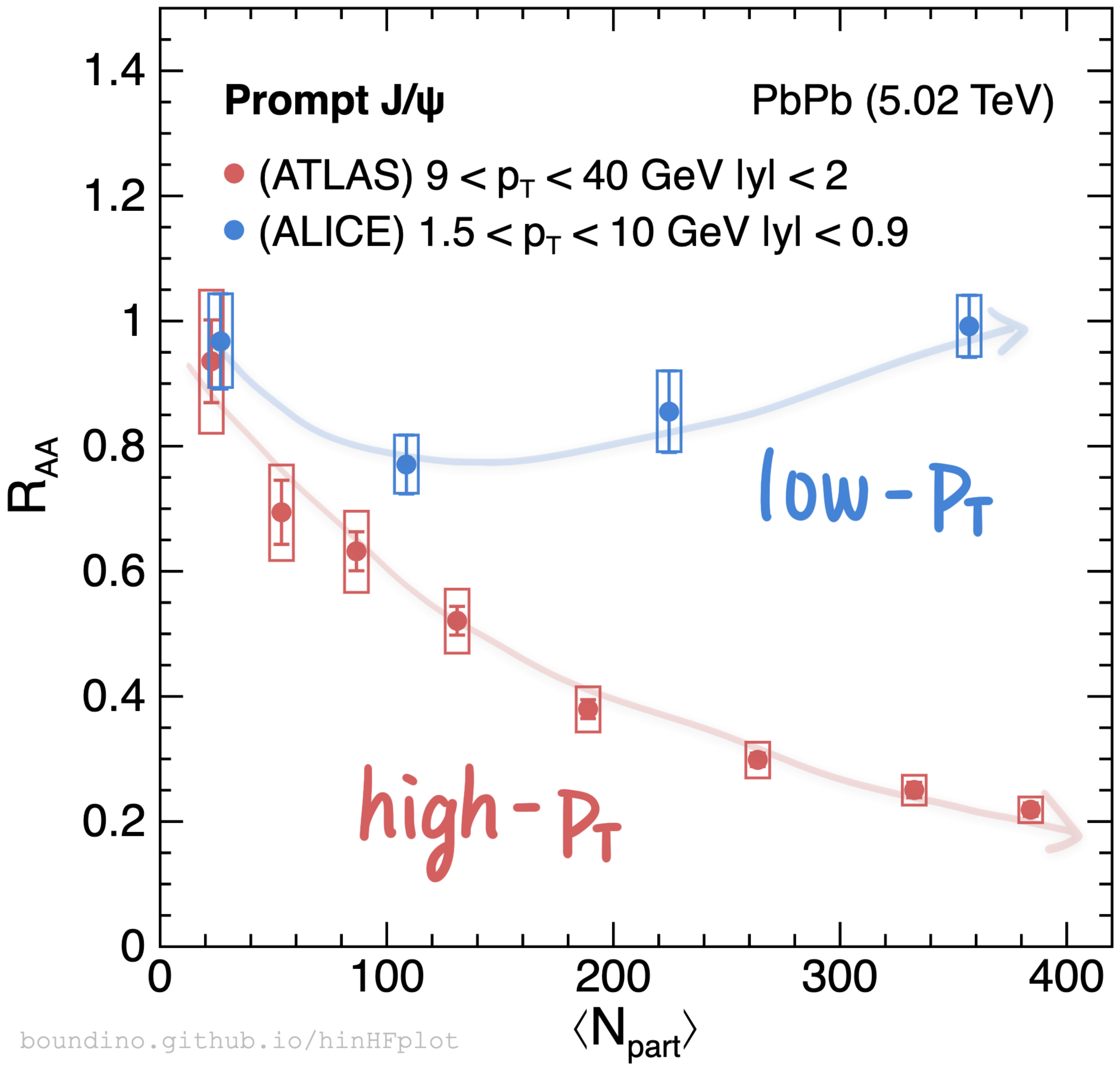
EPJC 78 (2018) 762 EPJC 78 (2018) 509 EPJC 78 (2018) 509

Sequential melting

- Charmonia strongly suppressed in PbPb collisions
- Binding energy hierarchy
  - weaker bound state easier to be dissociated
- Stronger suppression in central events

  *Central: large participant nucleon number N_{part}
  - higher temperature and larger size

Charmonia in QGP Regeneration

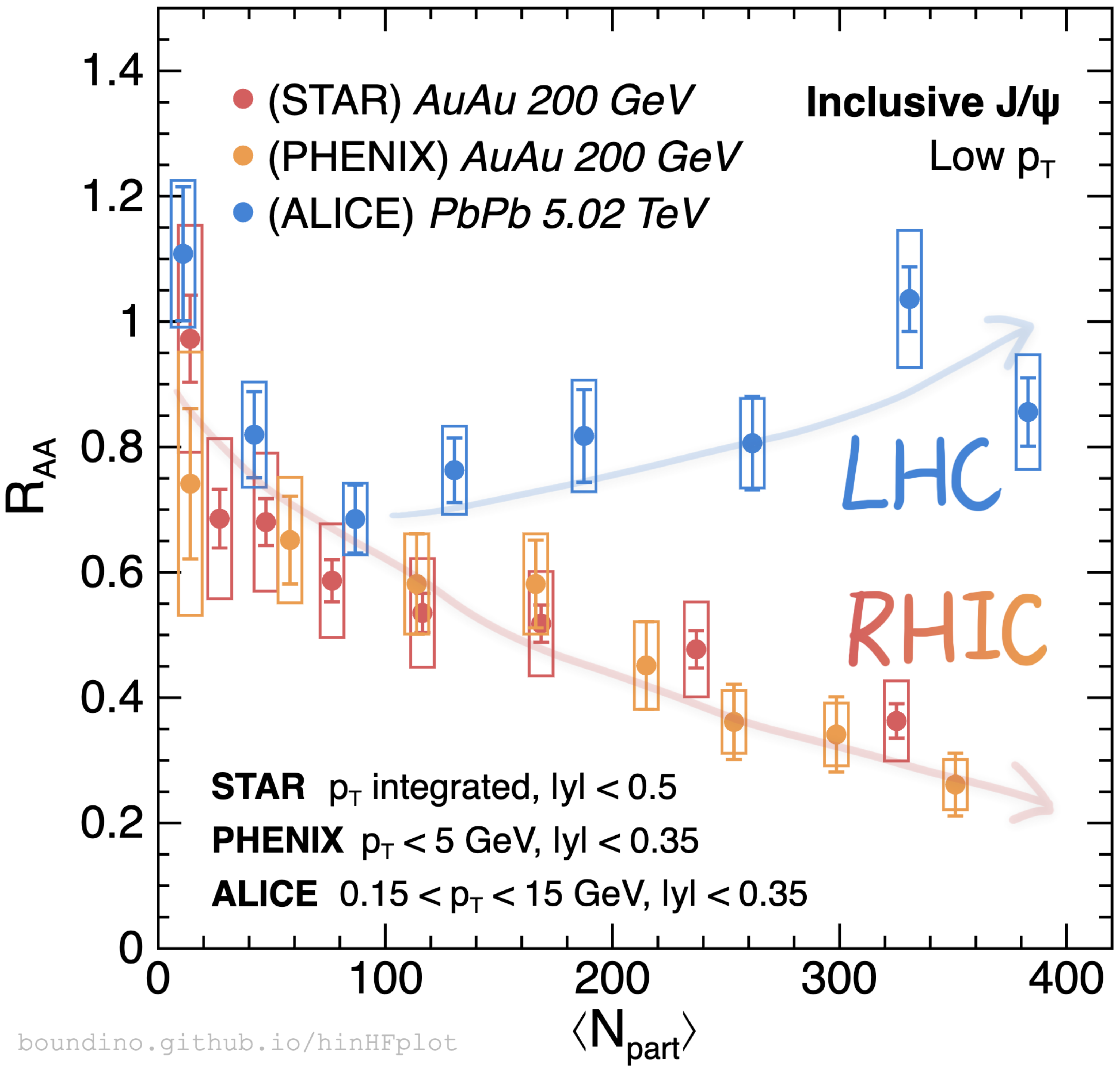


EPJC 78 (2018) 762 JHEP 02 (2024) 066

Significant regeneration

- Uncorrelated $Q\bar{Q}$ in QGP regenerate quarkonia
- Increasing R_{AA} at low p_T towards central events
  - central events have larger $\sigma_{c\bar{c}}$

Charmonia in QGP Regeneration

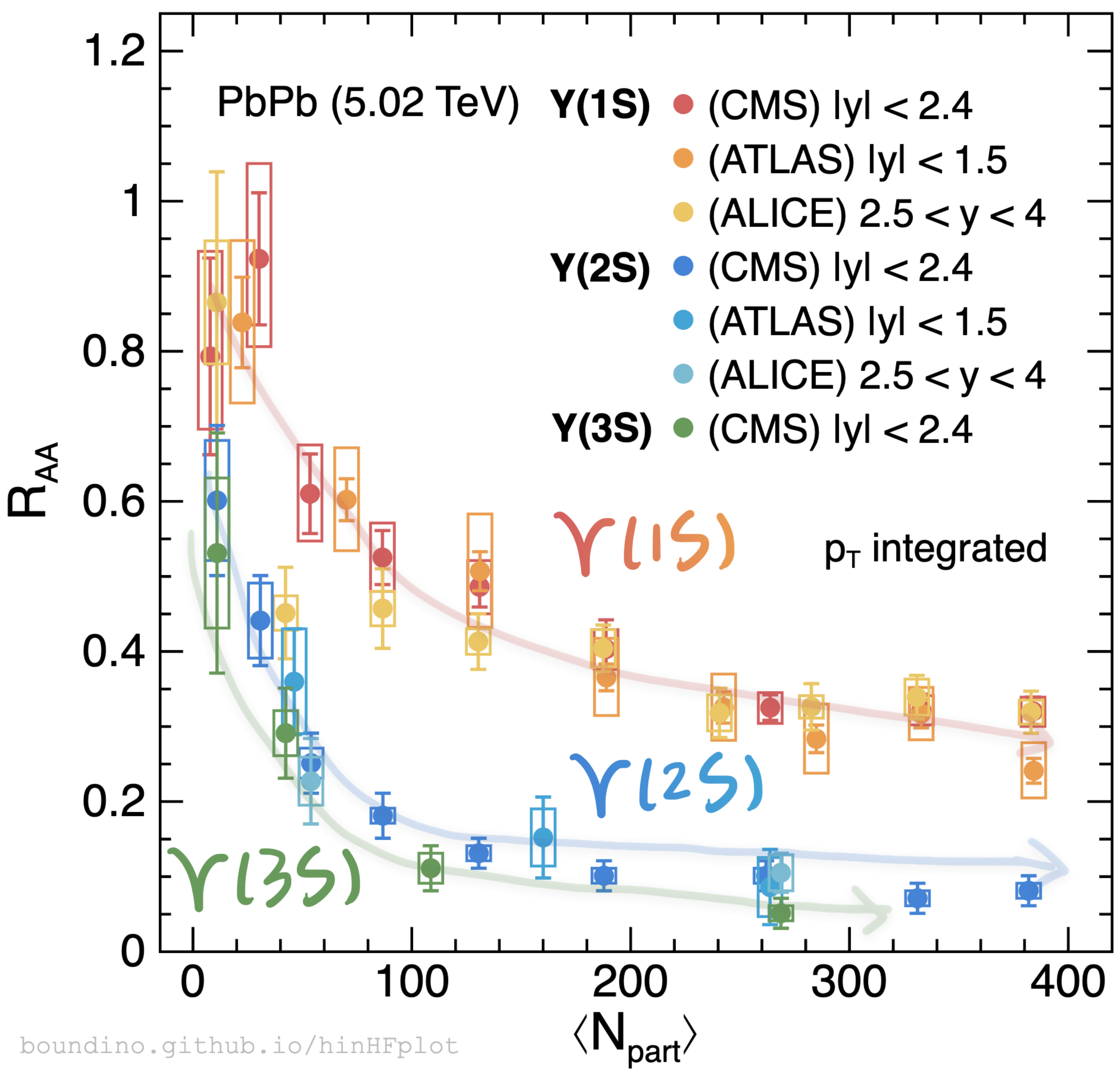


Significant regeneration

- Uncorrelated $Q\bar{Q}$ in QGP regenerate quarkonia
- Increasing R_{AA} at low p_T towards central events
  - central events have larger $\sigma_{c\bar{c}}$
- More significant in LHC than RHIC
  - higher collision energy has larger $\sigma_{c\bar{c}}$

PLB 797 (2019) 134917 PRL 98 (2007) 232301 PLB 849 (2024) 138451

Bottomonia in QGP

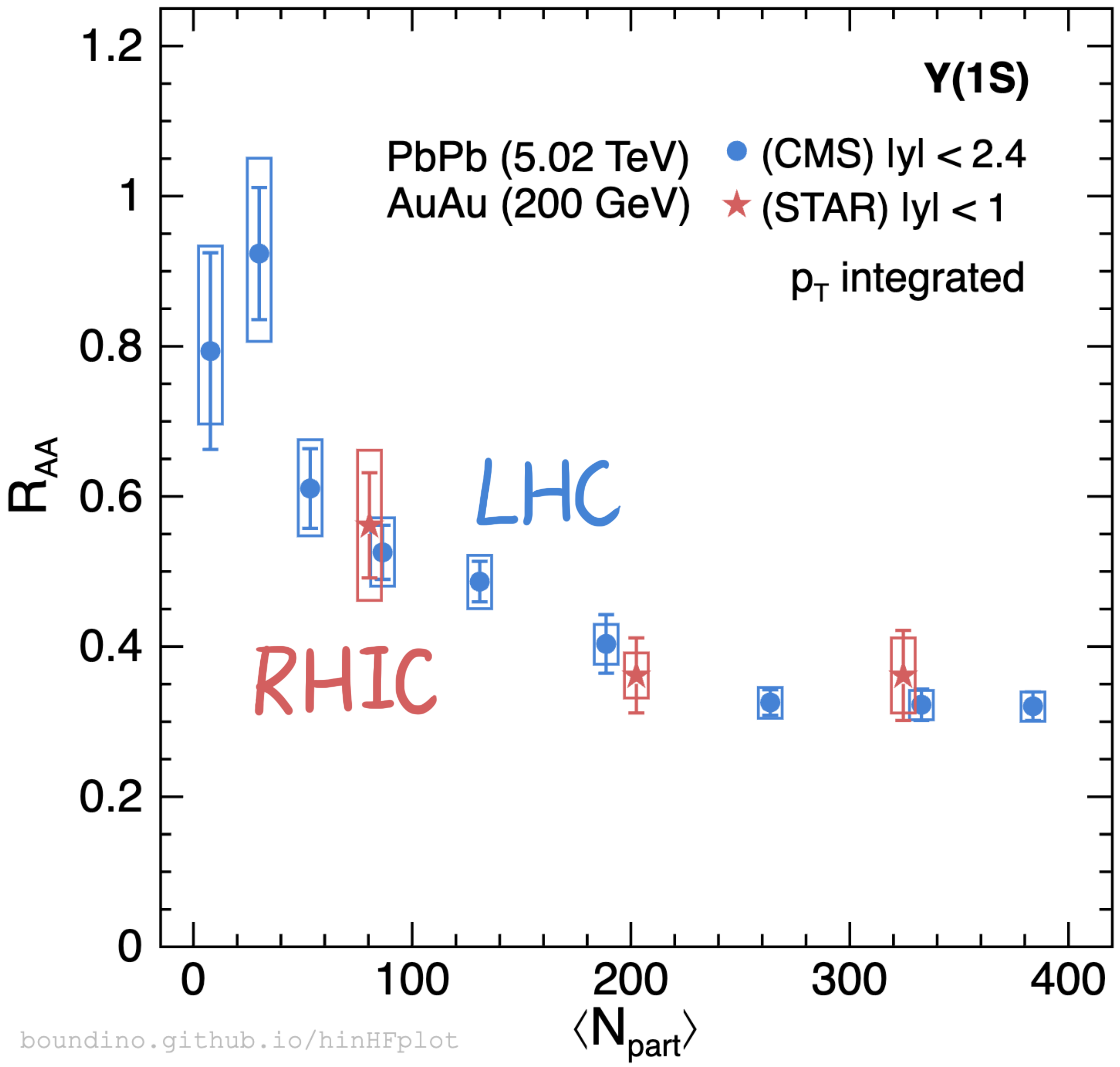


Sequential melting

- Bottomonia strongly suppressed in PbPb collisions
- Binding energy hierarchy
  - weaker bound state easier to be dissociated
- Weak (if any) uncorrelated recombination expected for Υ(nS)
  - smaller $\sigma_{b\bar{b}}$ than $\sigma_{c\bar{c}}$

arXiv:2303.17026 PRC 107 (2023) 054912 PLB 822 (2021) 136579

Heavy Quarkonium Production Challenge

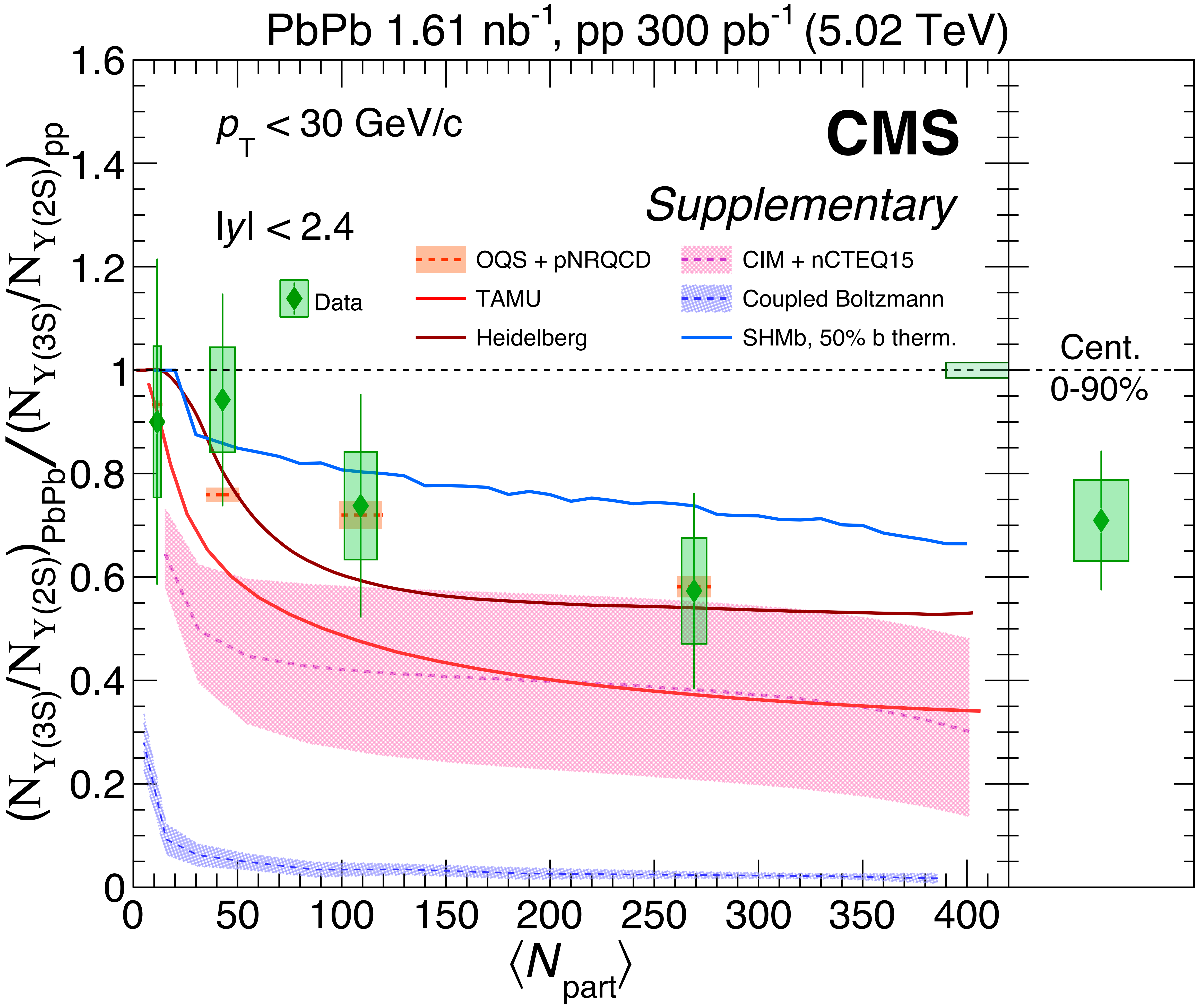


PLB 790 (2019) 270 PRL 130 (2023) 112301

Happy with dissociation + regeneration picture?

- Why is Υ(1S) suppression degree so similar in LHC and RHIC?
  - even if they have different initial temperatures
- Why does Υ(1S) not continue decreasing in most central events?
  - models with regeneration still don't describe it
- Feed-down contribution not well constrained

Heavy Quarkonium Production Challenge

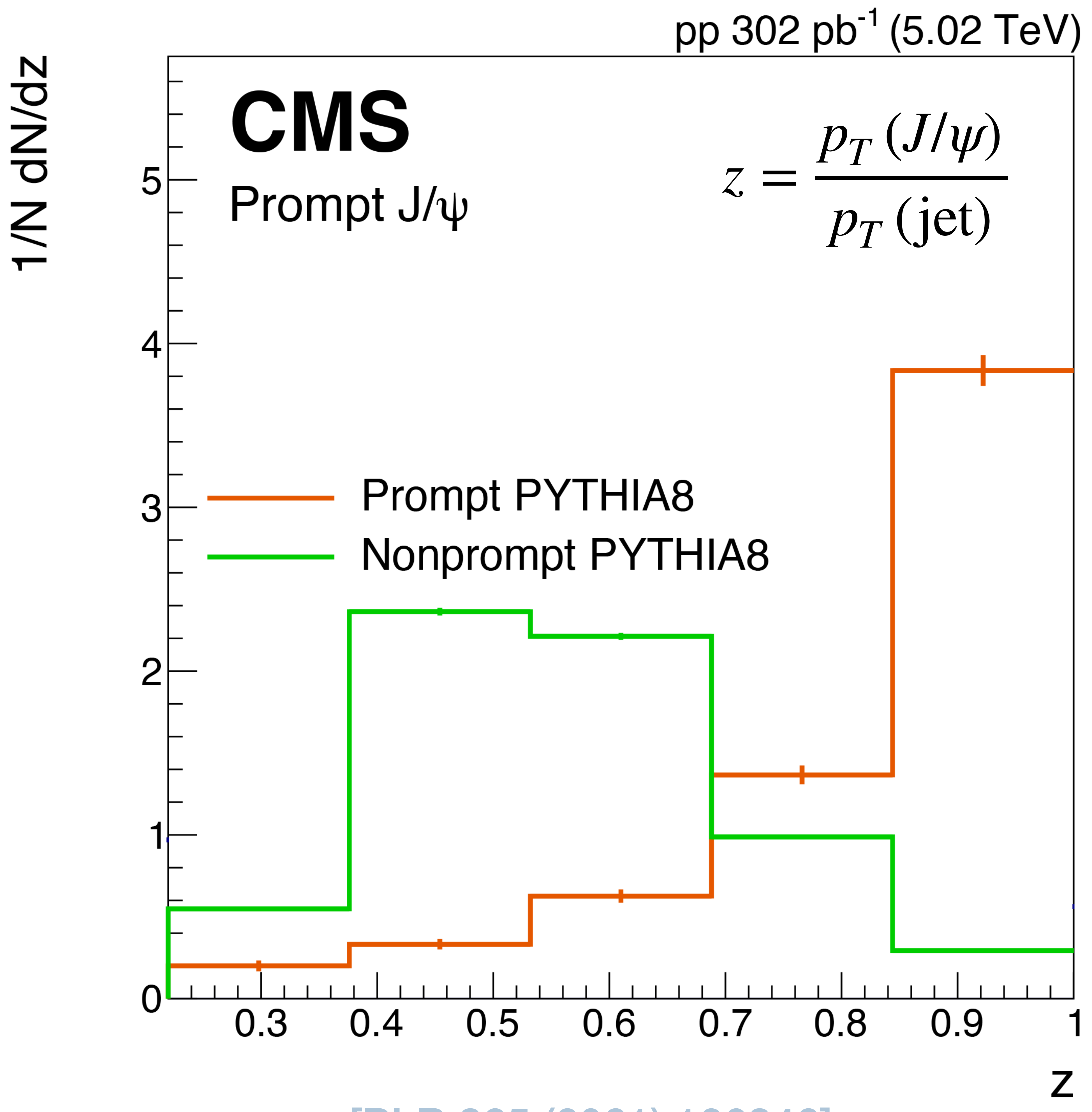


[2303.17026]

More excited states Y(3S) observation

- Challenging for theoretical models
  - Particle ratio cancels nPDF effect
- Crucial to constrain feed-down contribution

Revisit J/ψ Really Primordial?



[PLB 825 (2021) 136842]

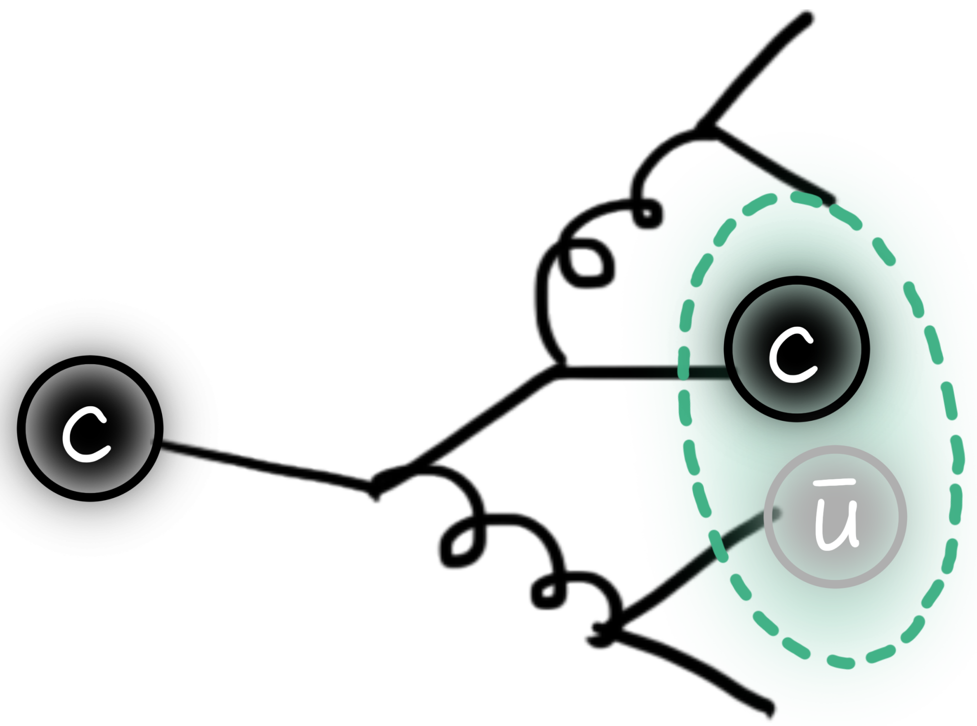
Early bound state picture

- Few surrounding jet activities

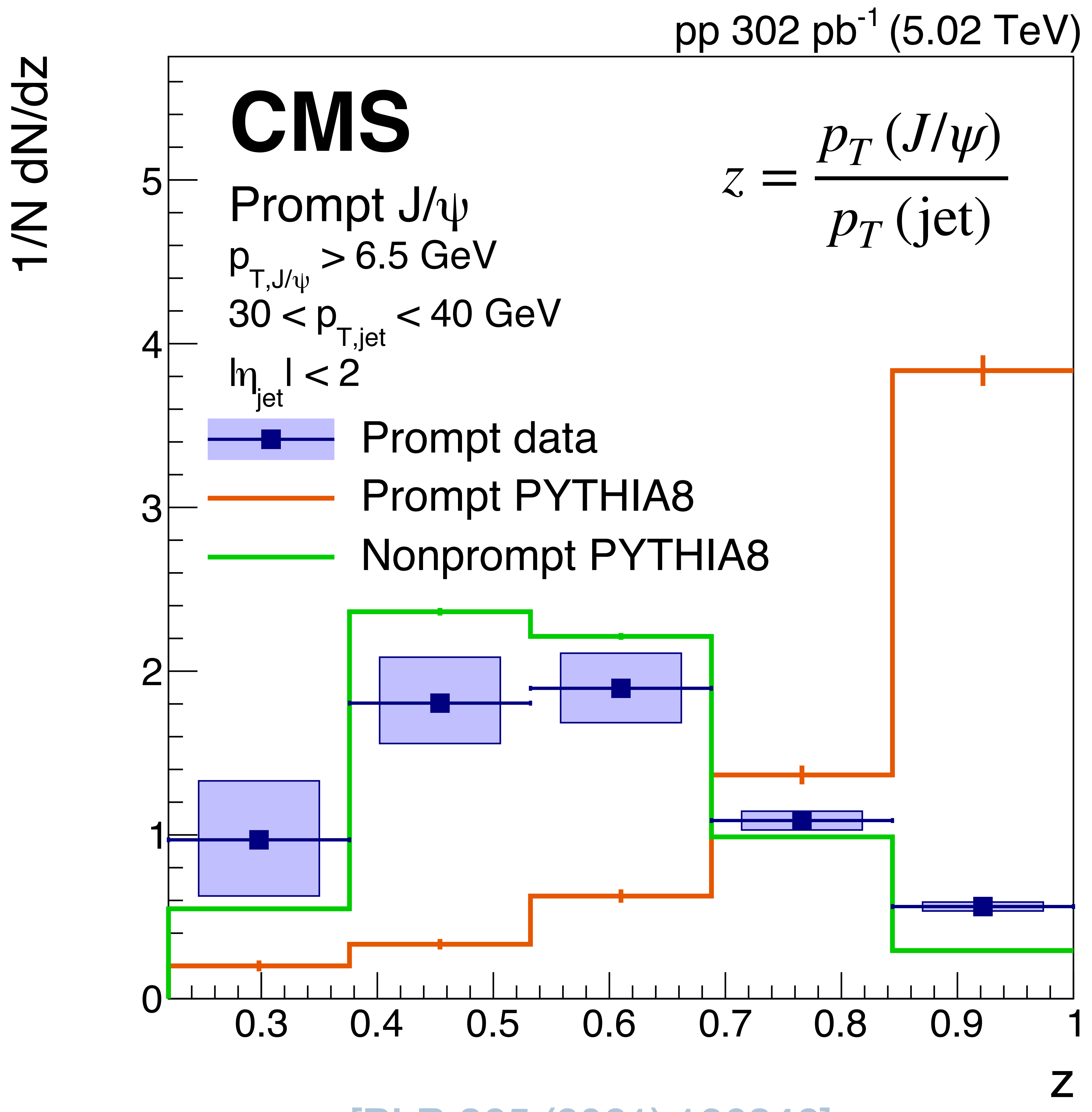
Late jet fragmentation picture

How open heavy flavors are formed

- J/ψ only carries partial transverse momentum in the jet shower



J/ψ Production Potential Jet Fragmentation

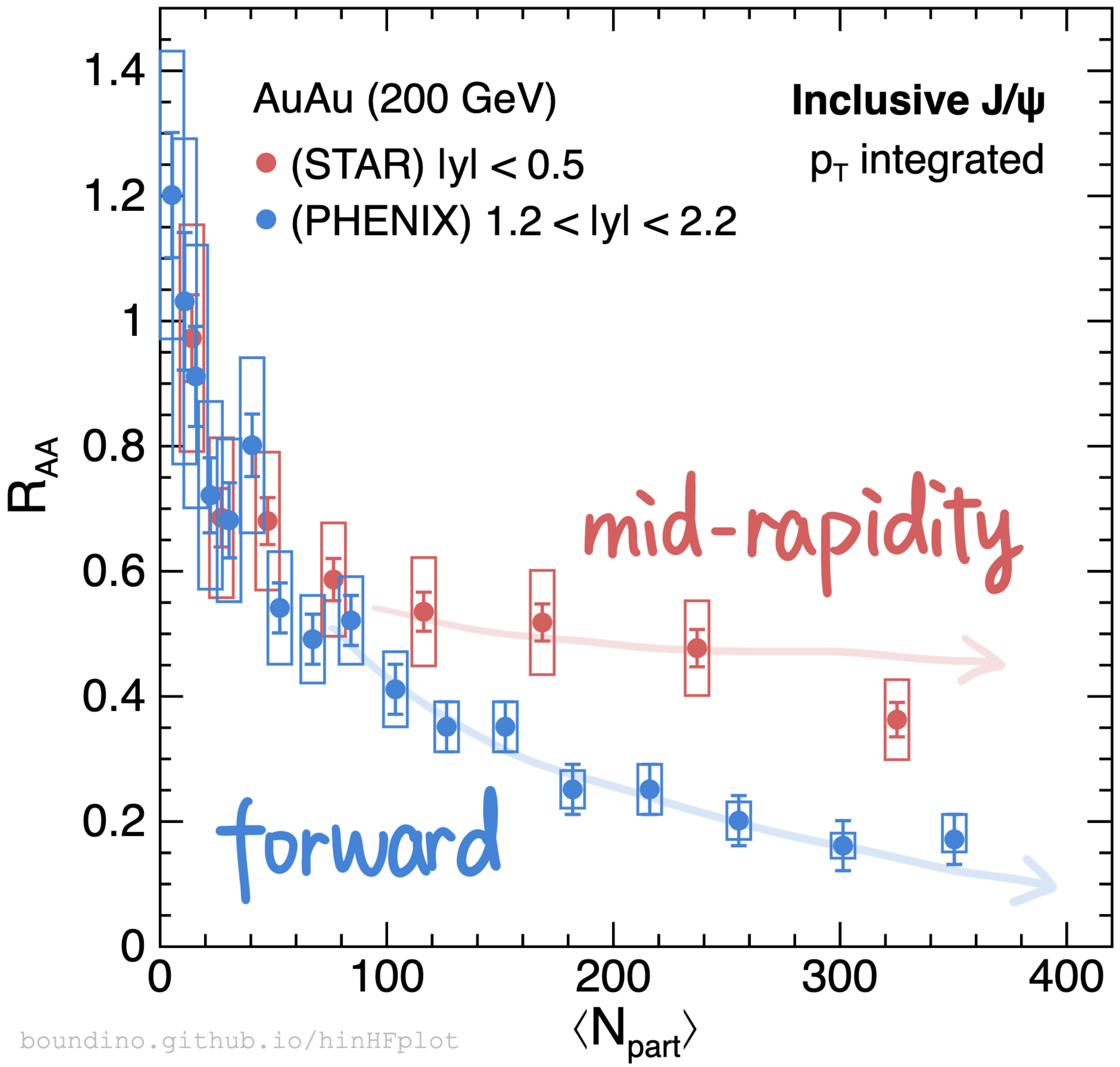


[PLB 825 (2021) 136842]

Early bound state picture
Late jet fragmentation picture

- J/ψ have more surrounding jet activities than (model) expected in pp
  - Similar to open heavy flavors
  - Parton energy loss may also play an important role in J/ψ suppression in HIC

Charmonia in QGP Other Effects



- Stronger suppression at forward rapidity than mid-rapidity
  - similar observable in both LHC and RHIC

Cold nuclear matter effects

*Not saying rapidity dependence is due to CNM

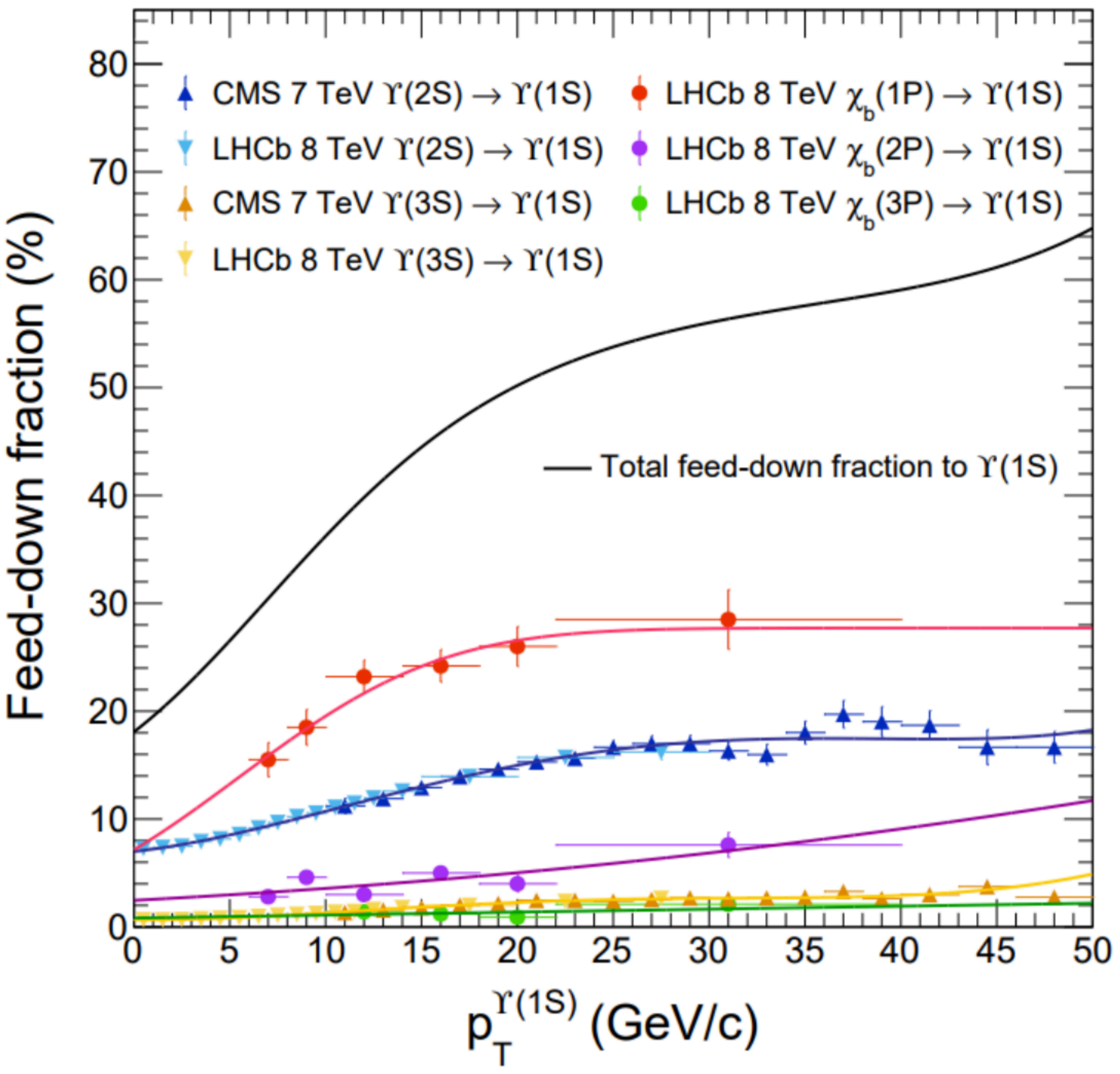
- Comover breakup, nuclear absorption
- Nuclear PDF
- Initial coherent energy loss

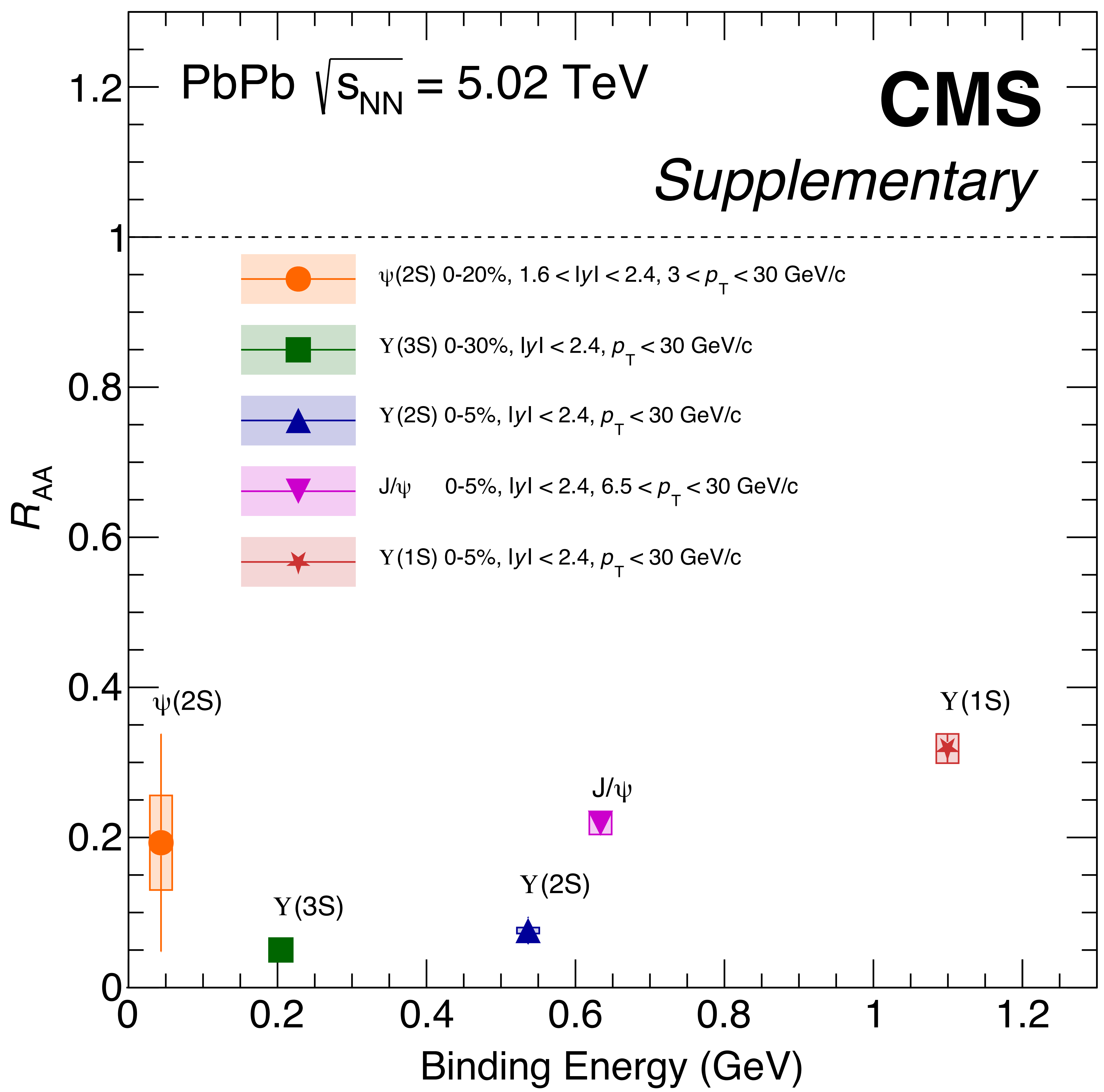
Luminosity Projection Conservative

Quantity	pp	O–O	Ar–Ar	Ca–Ca	Kr–Kr	In–In	Xe–Xe	Pb–Pb
$\sqrt{s_{NN}}$ (TeV)	14.00	7.00	6.30	7.00	6.46	5.97	5.86	5.52
L_{AA} ($cm^{-2}s^{-1}$)	3.0×10^{32}	1.5×10^{30}	3.2×10^{29}	2.8×10^{29}	8.5×10^{28}	5.0×10^{28}	3.3×10^{28}	1.2×10^{28}
$\langle L_{AA} \rangle$ ($cm^{-2}s^{-1}$)	3.0×10^{32}	9.5×10^{29}	2.0×10^{29}	1.9×10^{29}	5.0×10^{28}	2.3×10^{28}	1.6×10^{28}	3.3×10^{27}
$\mathscr{L}_{AA}^{month}$ (nb^{-1})	5.1×10^{5}	1.6×10^{3}	3.4×10^{2}	3.1×10^{2}	8.4×10^{1}	3.9×10^{1}	2.6×10^{1}	5.6
$\mathscr{L}_{NN}^{month}$ (pb^{-1})	505	409	550	500	510	512	434	242
R_{max} (kHz)	24 000	2169	821	734	344	260	187	93
μ	1.2	0.21	0.08	0.07	0.03	0.03	0.02	0.01
$dN_{ch}/d\eta$ (MB)	7	70	151	152	275	400	434	682
	at $R = 0.5$ cm							
R_{hit} (MHz/cm^2)	94	85	69	62	53	58	46	35
NIEL (1 MeV n_{eq}/cm^2)	1.8×10^{14}	1.0×10^{14}	8.6×10^{13}	7.9×10^{13}	6.0×10^{13}	3.3×10^{13}	4.1×10^{13}	1.9×10^{13}
TID (Rad)	5.8×10^{6}	3.2×10^{6}	2.8×10^{6}	2.5×10^{6}	1.9×10^{6}	1.1×10^{6}	1.3×10^{6}	6.1×10^{5}
	at $R = 100$ cm							
R_{hit} (kHz/cm^2)	2.4	2.1	1.7	1.6	1.3	1.0	1.1	0.9
NIEL (1 MeV n_{eq}/cm^2)	4.9×10^{9}	2.5×10^{9}	2.1×10^{9}	2.0×10^{9}	1.5×10^{9}	8.3×10^{8}	1.0×10^{9}	4.7×10^{8}
TID (Rad)	1.4×10^{2}	8.0×10^{1}	6.9×10^{1}	6.3×10^{1}	4.8×10^{1}	2.7×10^{1}	3.3×10^{1}	1.5×10^{1}

Table 1: Projected LHC performance: For various collision systems, we list the peak luminosity L_{AA}, the average luminosity $\langle L_{AA} \rangle$, the luminosity integrated per month of operation $\mathscr{L}_{AA}^{month}$, also rescaled to the nucleon–nucleon luminosity $\mathscr{L}_{NN}^{month}$ (multiplying by A^2). Furthermore, we list the maximum interaction rate R_{max}, the minimum bias (MB) charged particle pseudorapidity density $dN/d\eta$, and the interaction probability μ per bunch crossing. For the radii 0.5 cm and 1 m, we also list the particle fluence, the non-ionising energy loss, and the total ionising dose per operational month (assuming a running efficiency of 65%).

Feed-Down, Binding Energy





Beam Schedule Long Term