Heavy Flavor in Heavy-ion collisions
Experimental Overview

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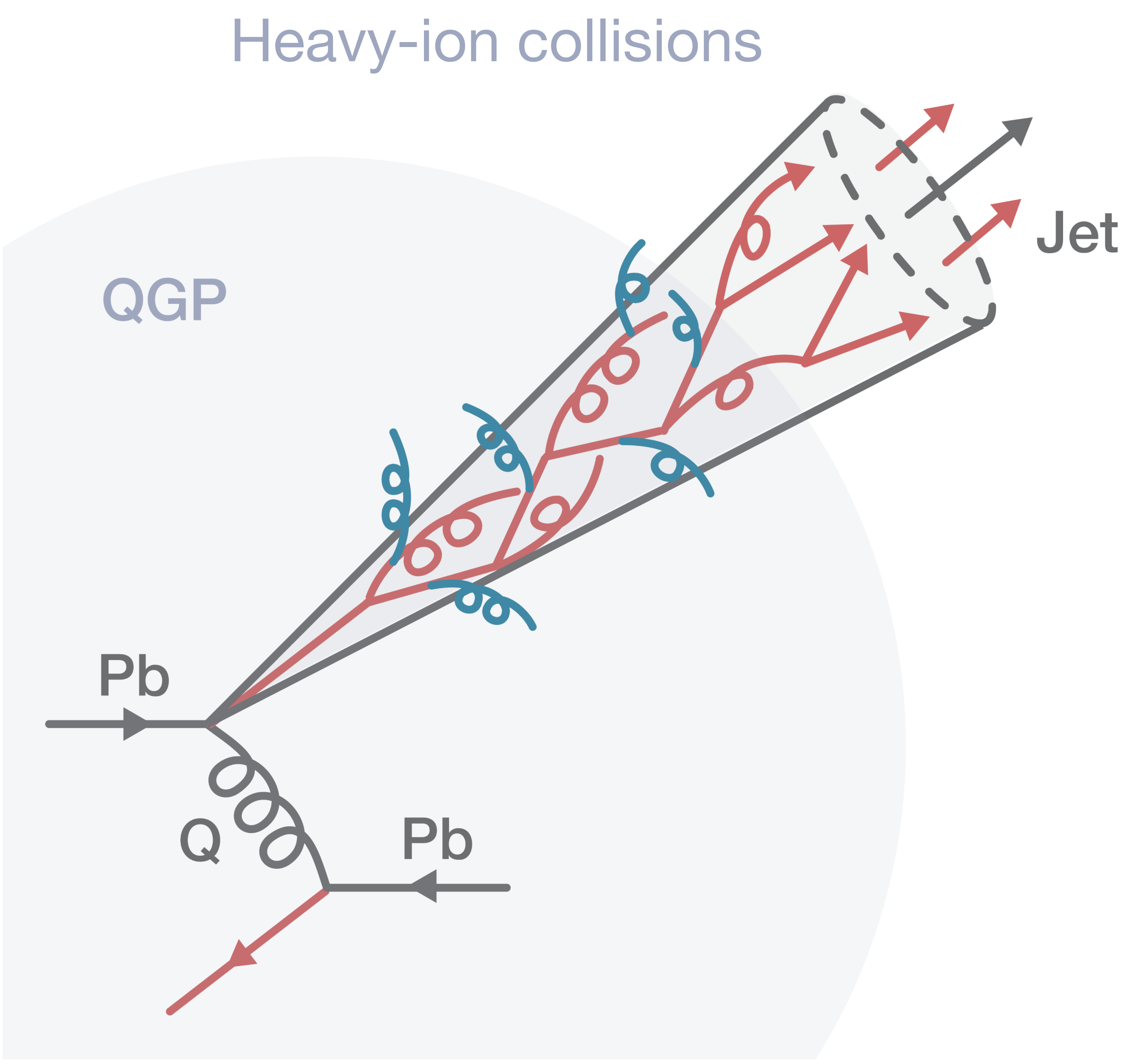
Quark Gluon Plasma After Hydrodynamics

Hard Probes of Quark Gluon Plasma

Hard probes → large Q

- $Q \sim 1/\tau$ creation time
  - Produced early → experience whole evolution
  - Unique access to high temperature stage
- $Q \gg \Lambda_{QCD}$ ~200 MeV
  - Initial production calculable with pQCD
- $Q \gg T_{QGP}$ ~400 MeV for LHC
  - Seldom produced in QGP → Keep identity
- With color charge EM Bosons are also hard probes
  - Strong interaction with QGP

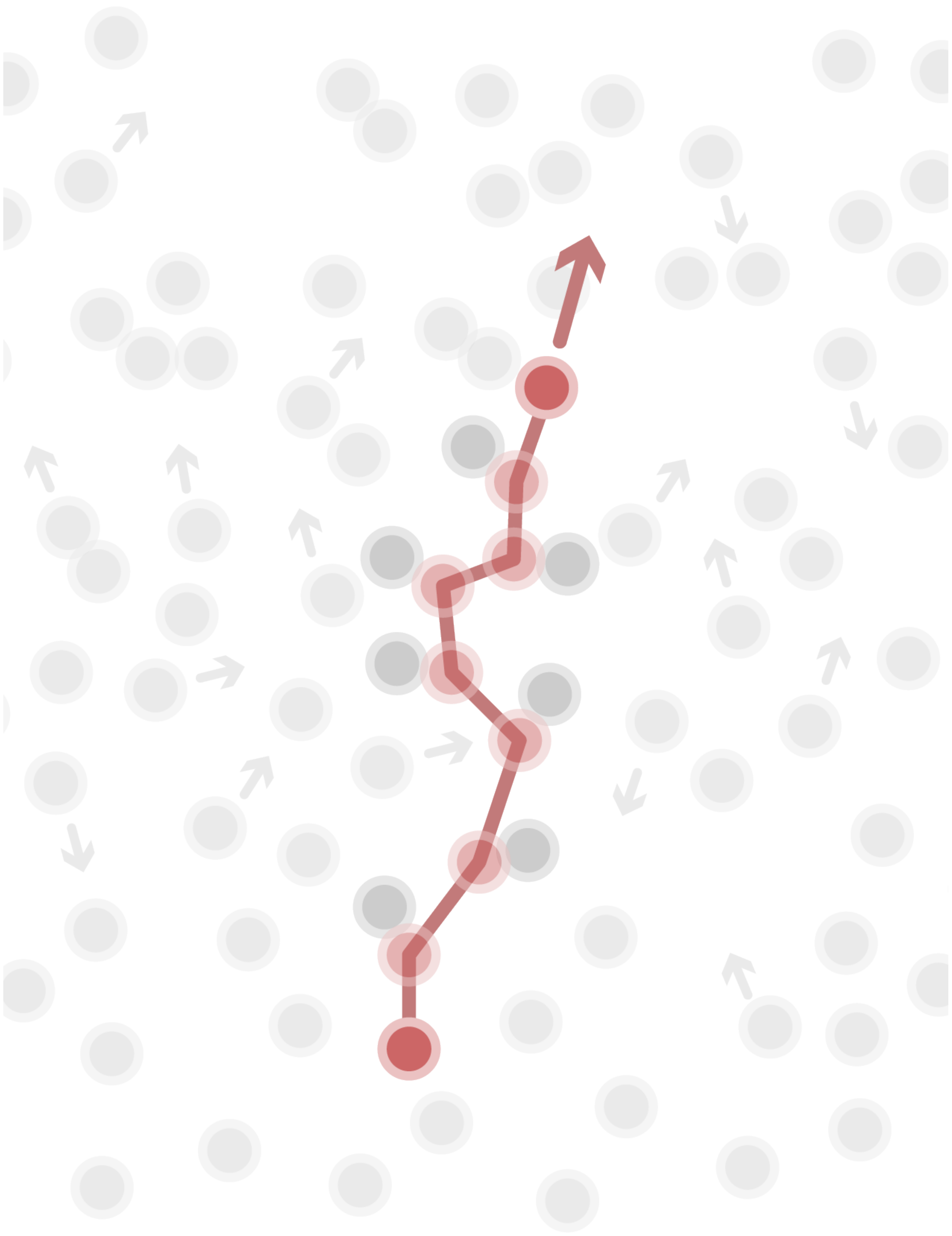


Heavy Flavors vs Jets

Heavy quarks (charm, beauty) → large mass m_Q

- $m_Q \sim 1/\tau$ creation time
  - Produced early → experience whole evolution
  - Unique access to high temperature stage
- $m_Q \gg \Lambda_{QCD}$
  - Initial production calculable with pQCD even at low p_T
  - Different length scale structure by varying p_T
- $m_Q \gg T_{QGP}$
  - Seldom produced in QGP → Keep identity
  - Brownian motion → Diffusion coefficient D_s
- $m_Q \gg m_q$
  - Strong interaction with QGP differently from light quark

Brownian motion of heavy quarks in medium

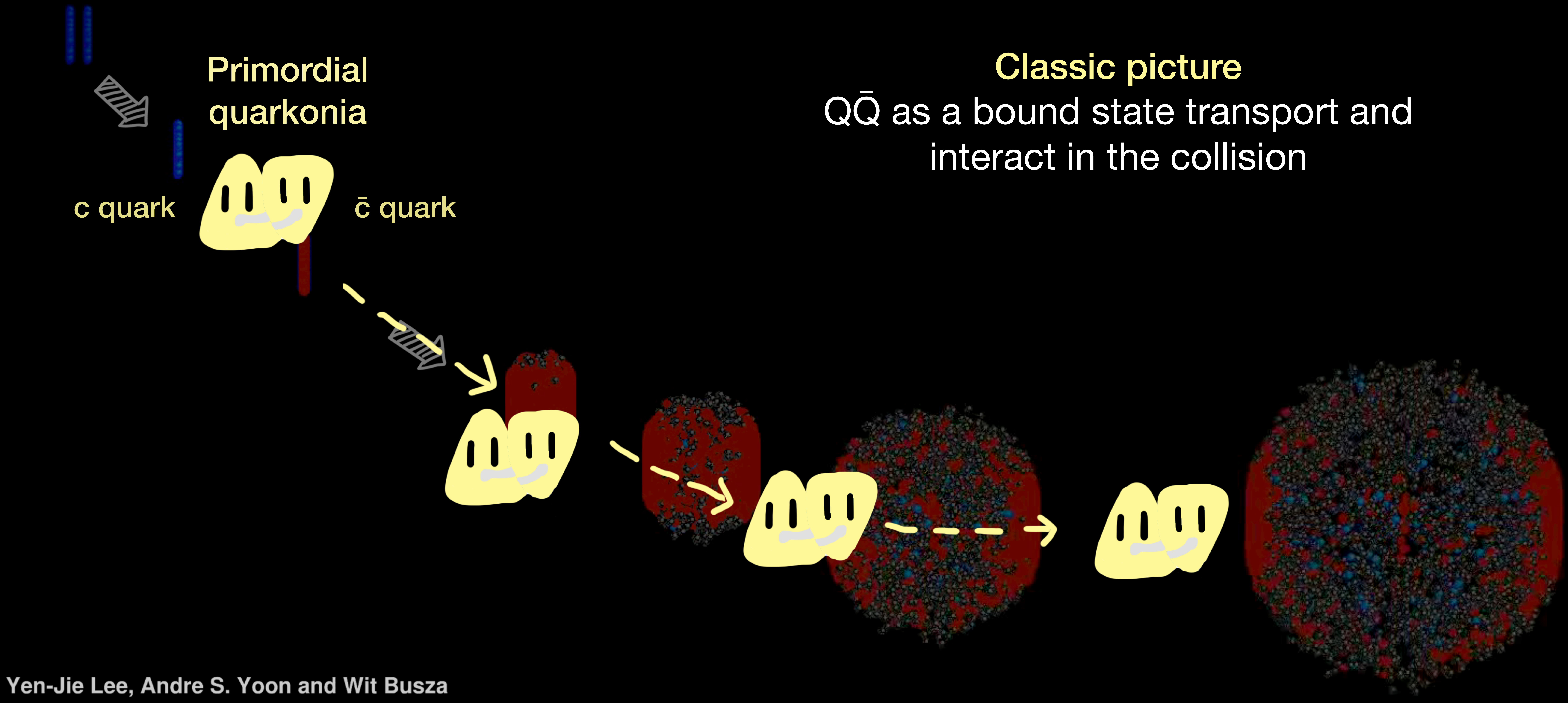


Life of a Heavy Quark in HIC

Life of a Lucky Heavy Quarkonium in HIC

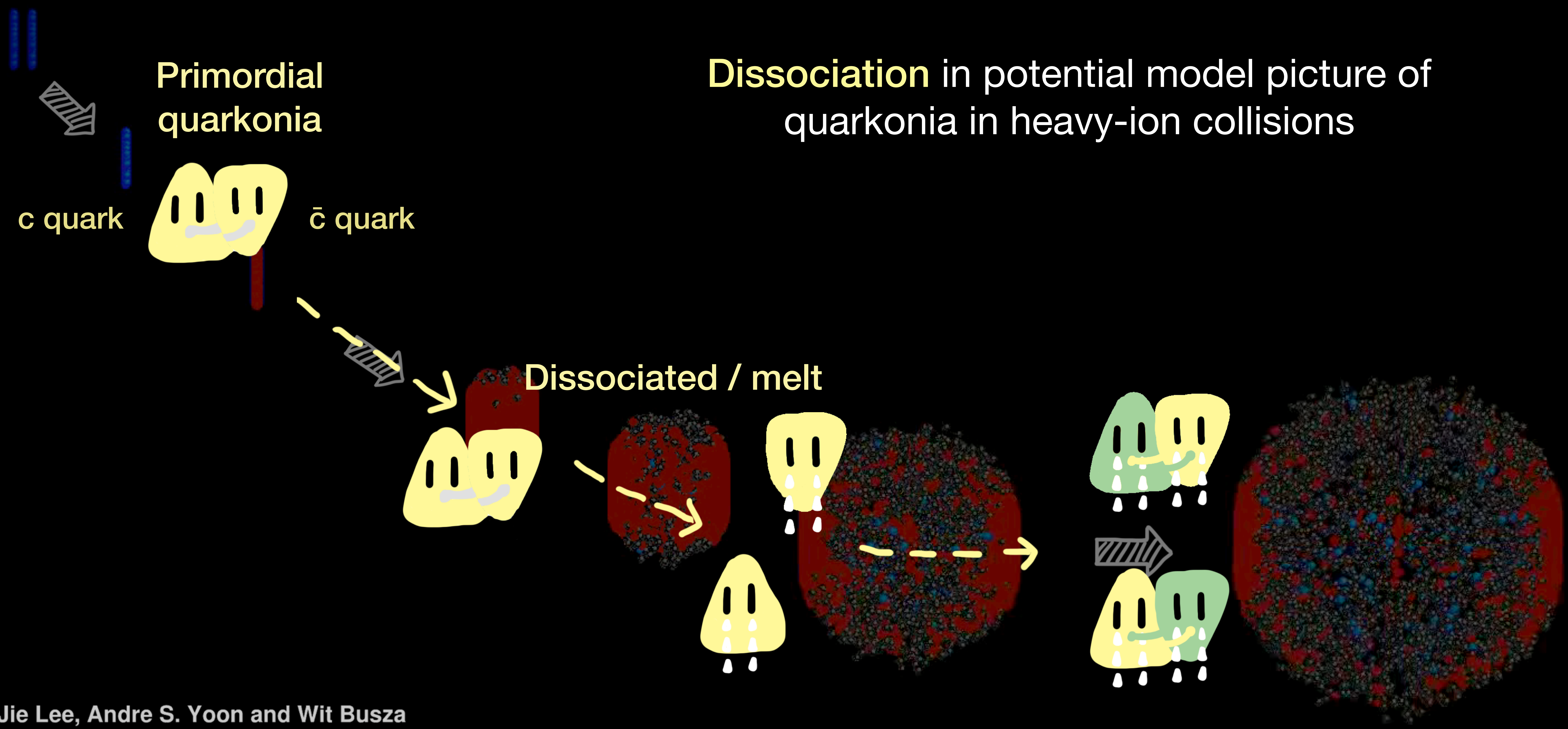
Classic picture

$Q\bar{Q}$ as a bound state transport and interact in the collision



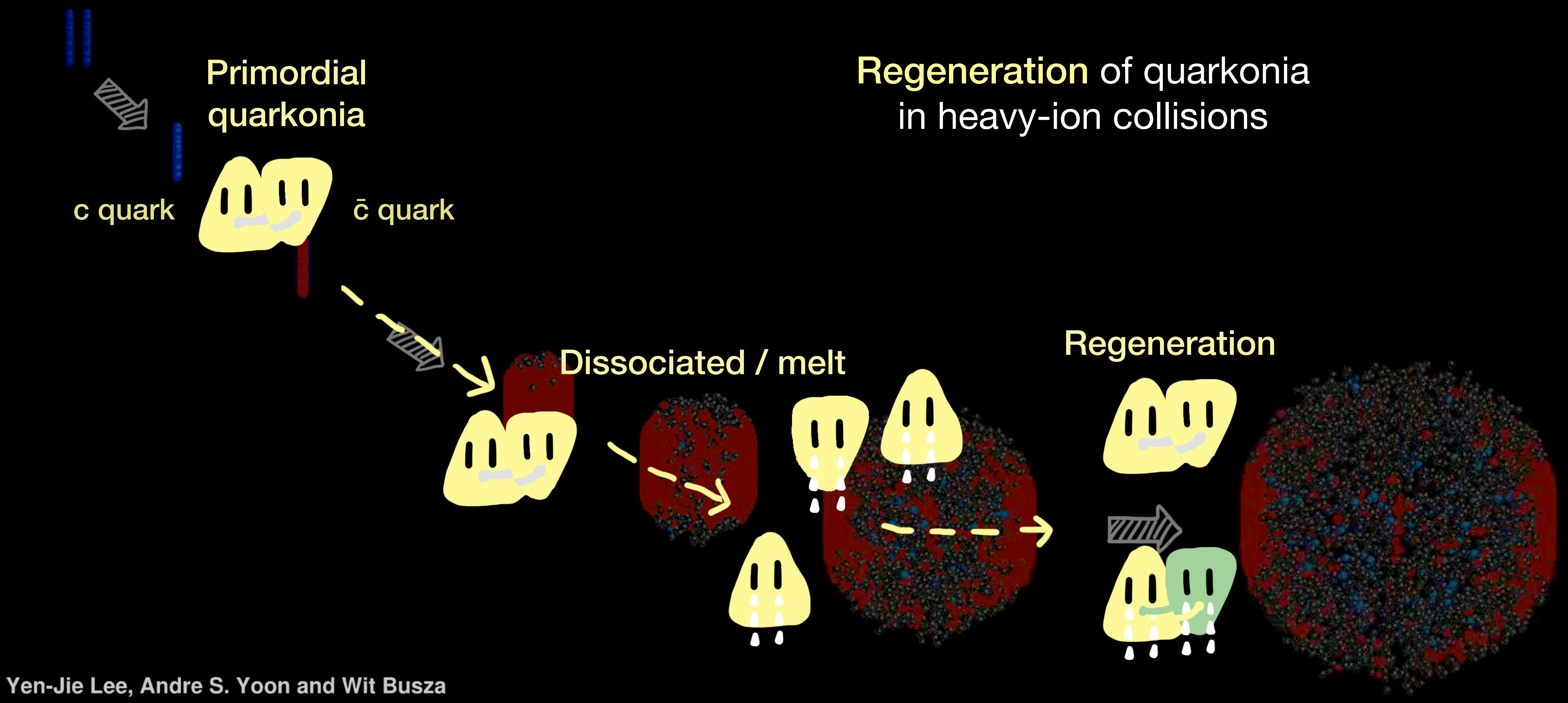
Life of a Weak Unlucky Quarkonium in HIC

Dissociation in potential model picture of quarkonia in heavy-ion collisions

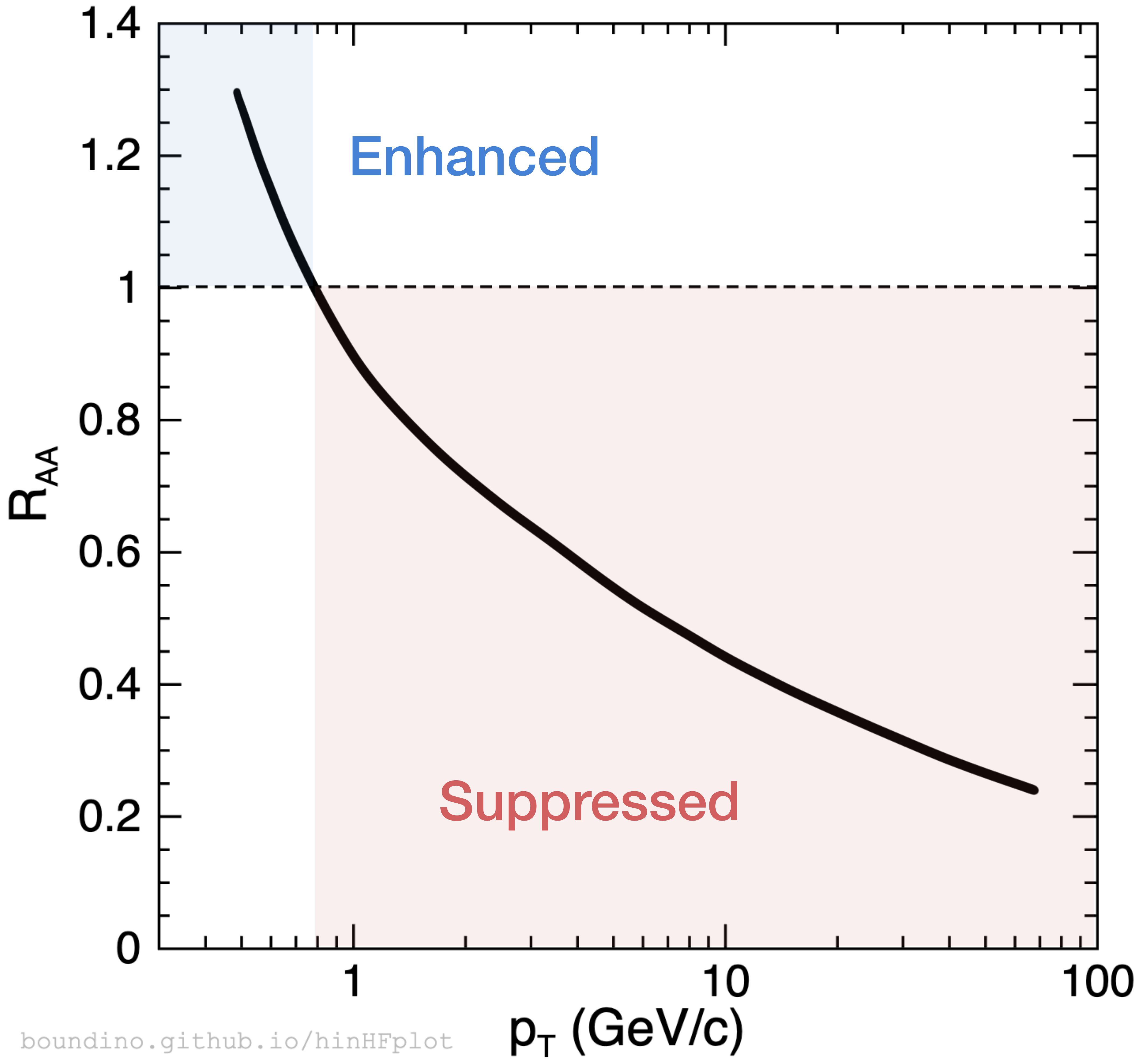


Yen-Jie Lee, Andre S. Yoon and Wit Busza

Life of a Weak Lucky Quarkonium in HIC



Nuclear Modification Factor R_{AA} in AA Collisions



boundino.github.io/hinHFplot

Nuclear modification factor R_{AA}

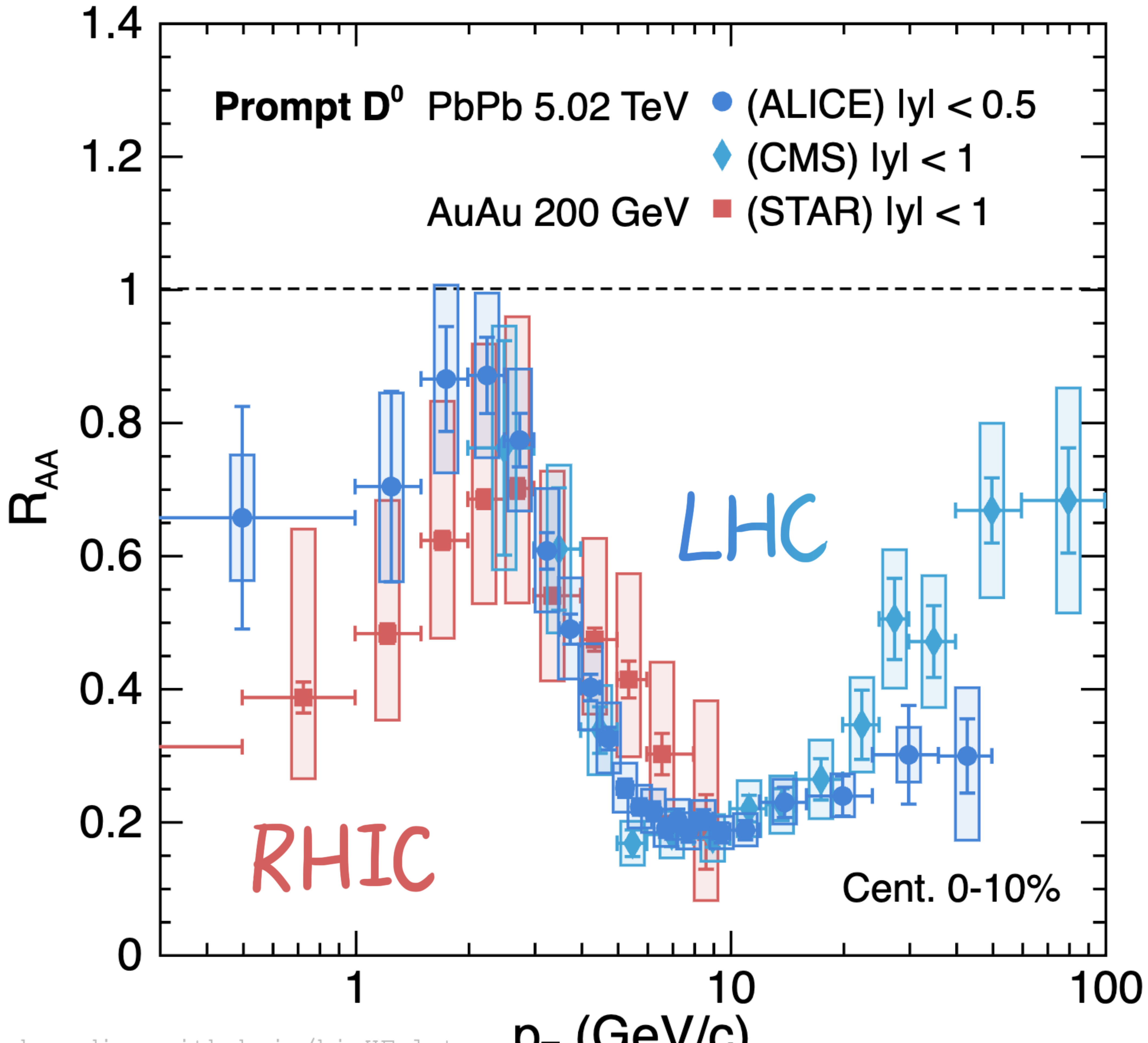
R_{AA} =1: superposition of nucleon-nucleon collisions

$$R_{AA} = \frac{dN_{AA}/dp_T}{T_{AA} d\sigma_{pp}/dp_T}$$

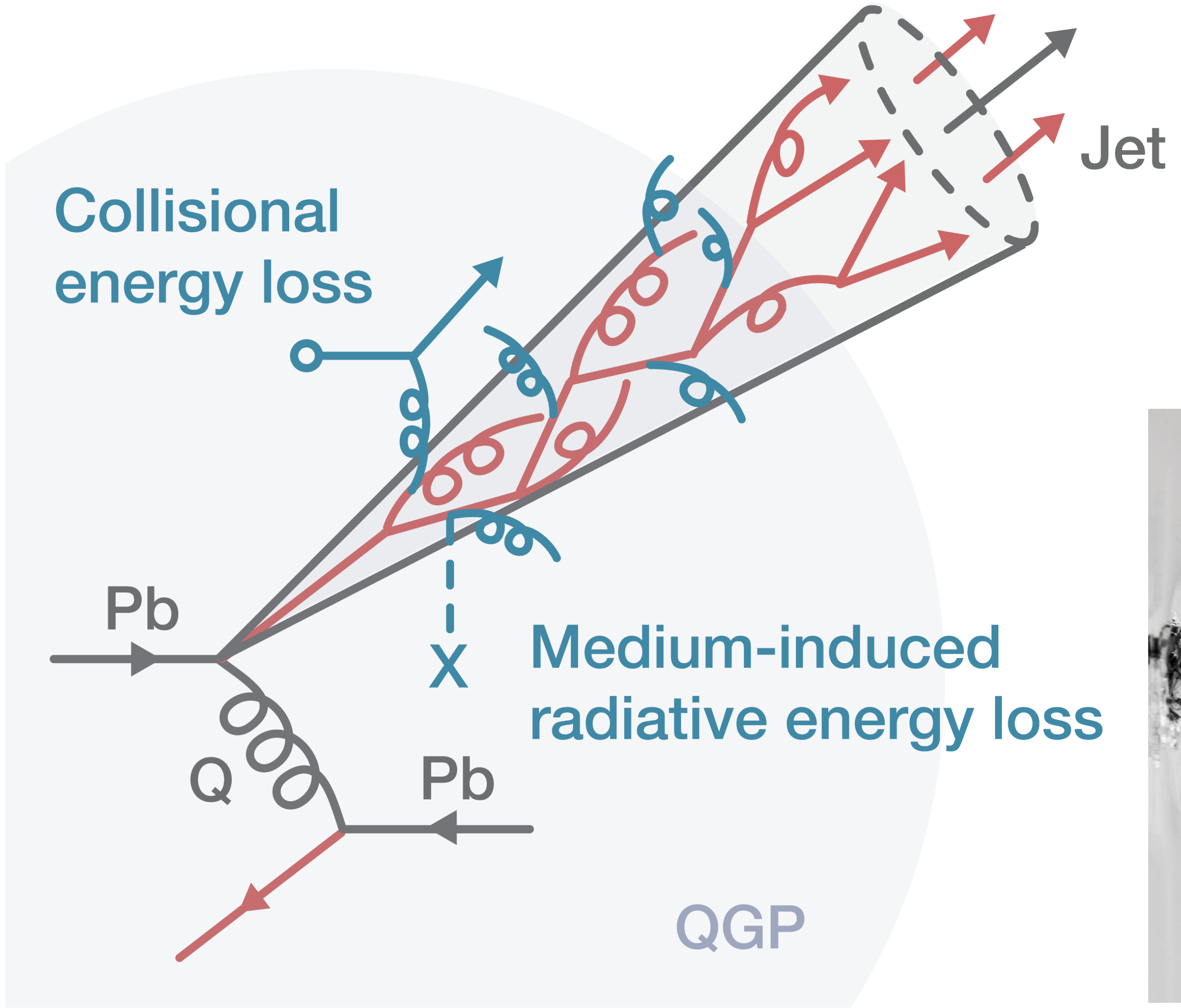
← Heavy-ion

← pp

Nuclear Modification R_{AA} D^0 Mesons



- Prompt D^0 suppression in wide kinematics
  - Charm quark lose energy in QGP via collisions low p_T and radiations high p_T (pQCD picture)

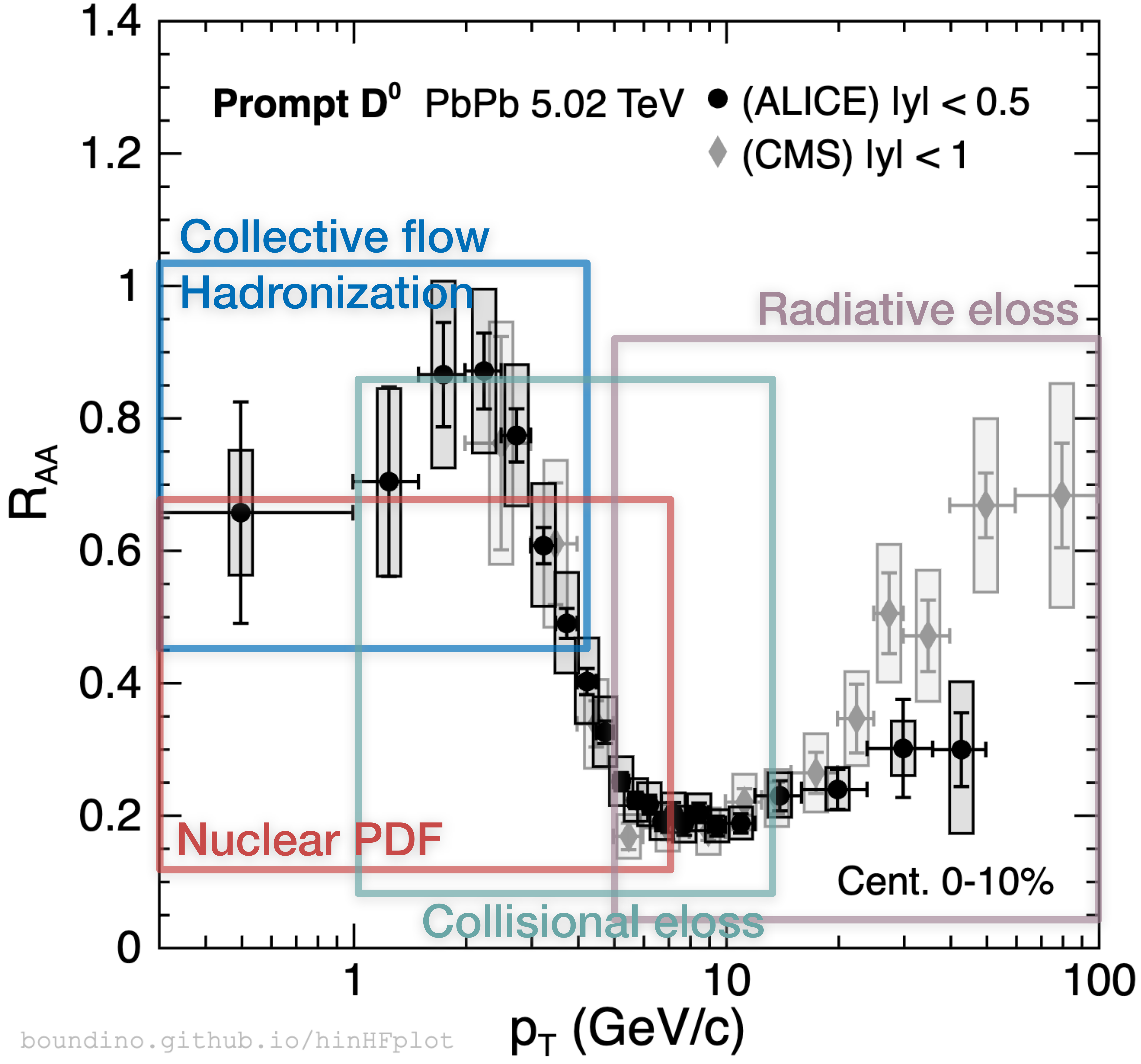


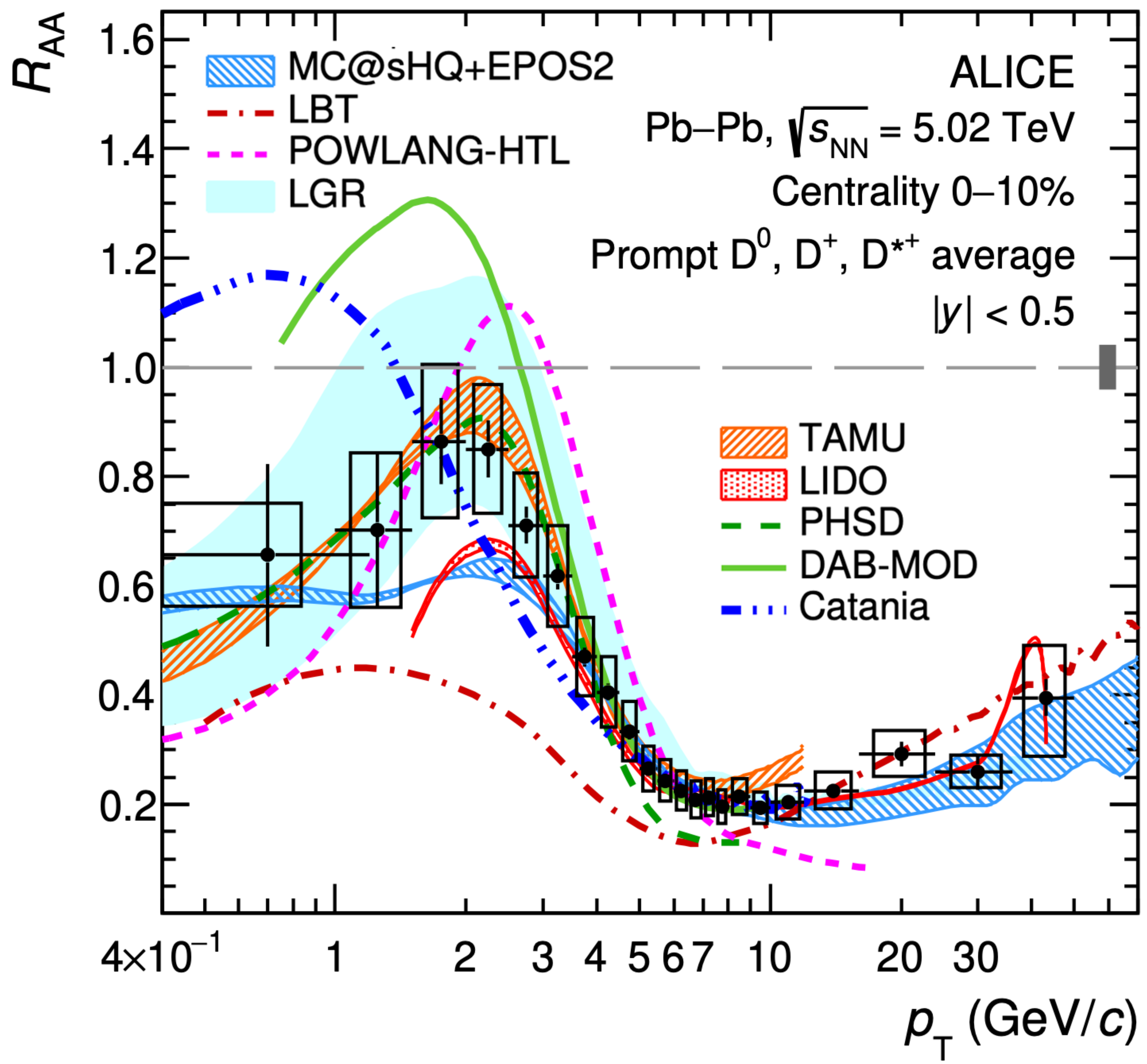
Energy loss of hard parton in QGP in pQCD picture

Bullet in gelatin block

JHEP 01 (2022) 174 PLB 782 (2018) 474 PRC 99 (2019) 034908

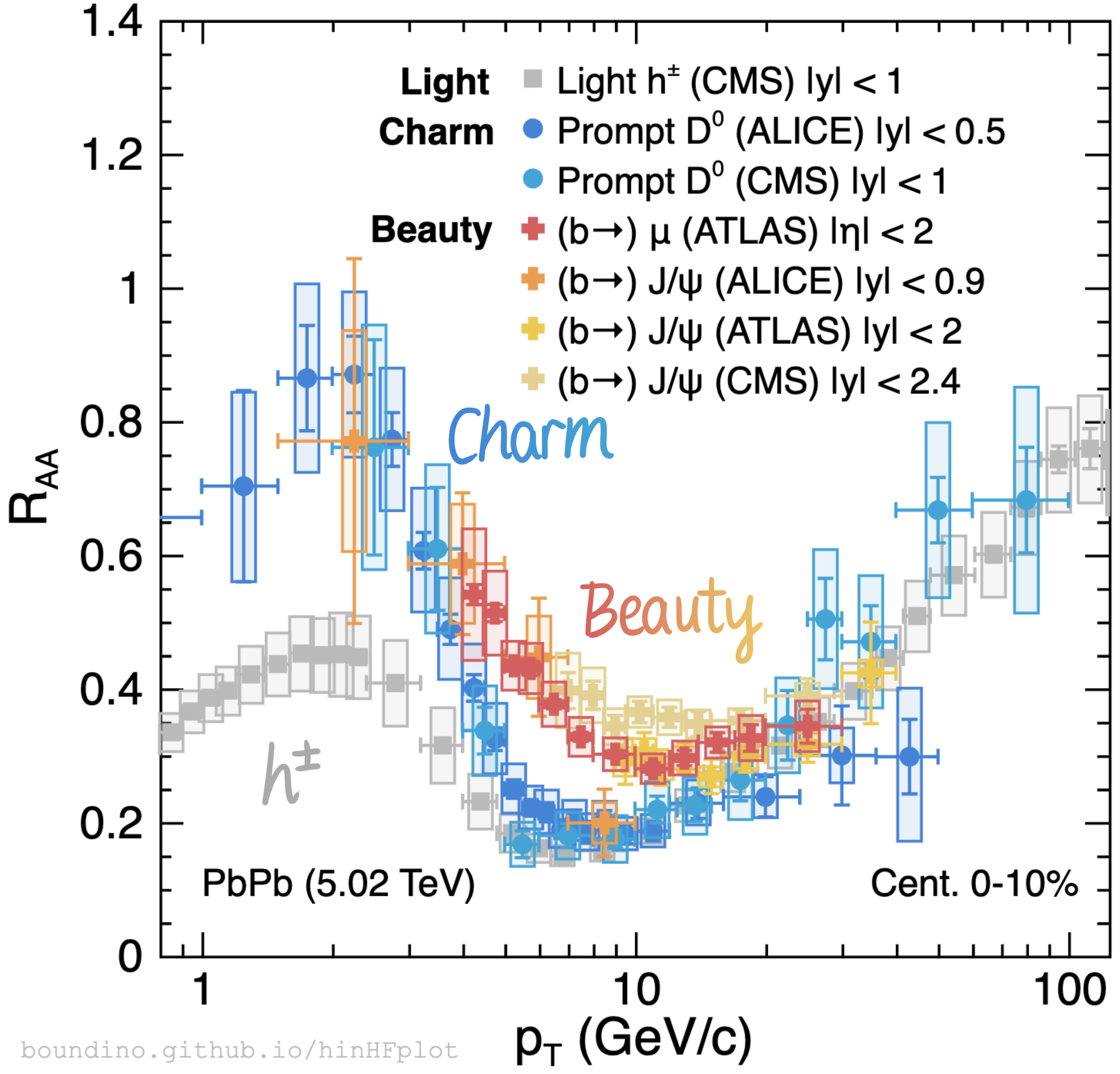
D^0 R_{AA} Understanding the Shape



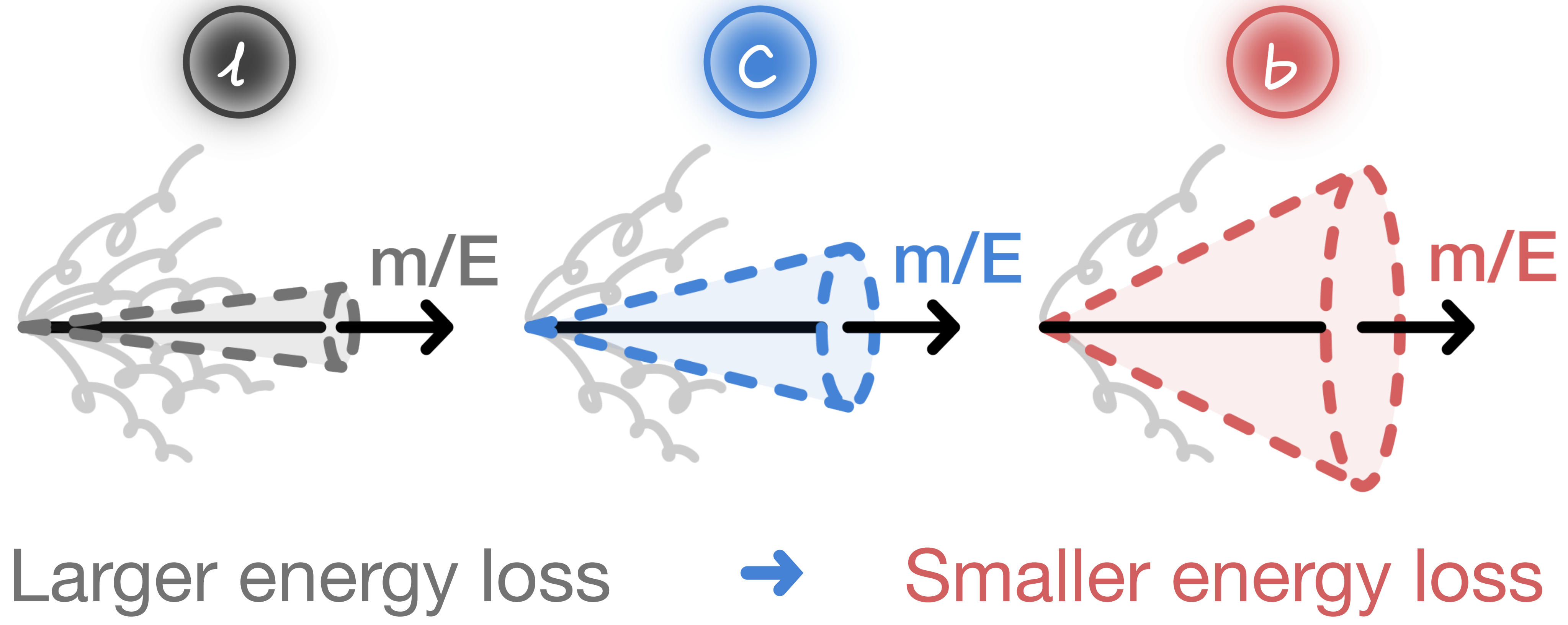


JHEP 01 (2022) 174 PLB 782 (2018) 474

R_{AA} Mass Dependence of Energy Loss

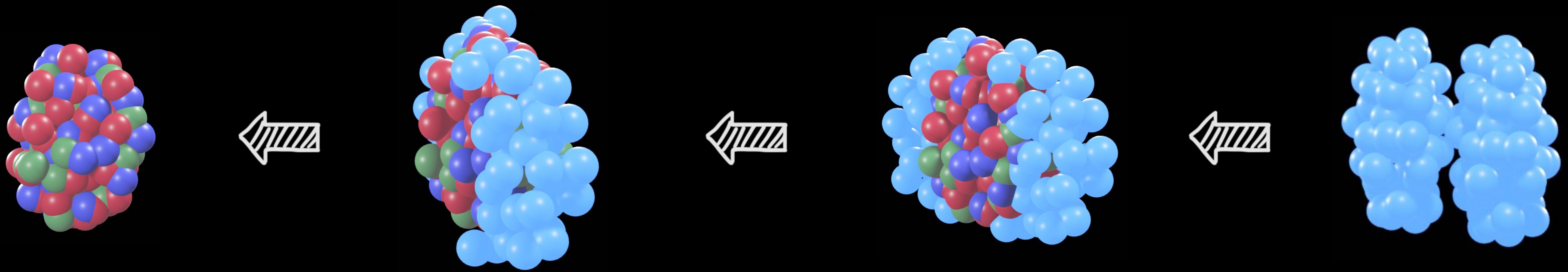


- Flavor dependent energy loss Dead cone effect
  - Radiation is suppressed inside $\theta < m/E$
  - Energy loss $\Delta E_l > \Delta E_c > \Delta E_b$



PLB 829 (2022) 137077 JHEP 02 (2024) 066 EPJC 78 (2018) 762 EPJC 78 (2018) 509

Initial Spatial Anisotropy of Medium



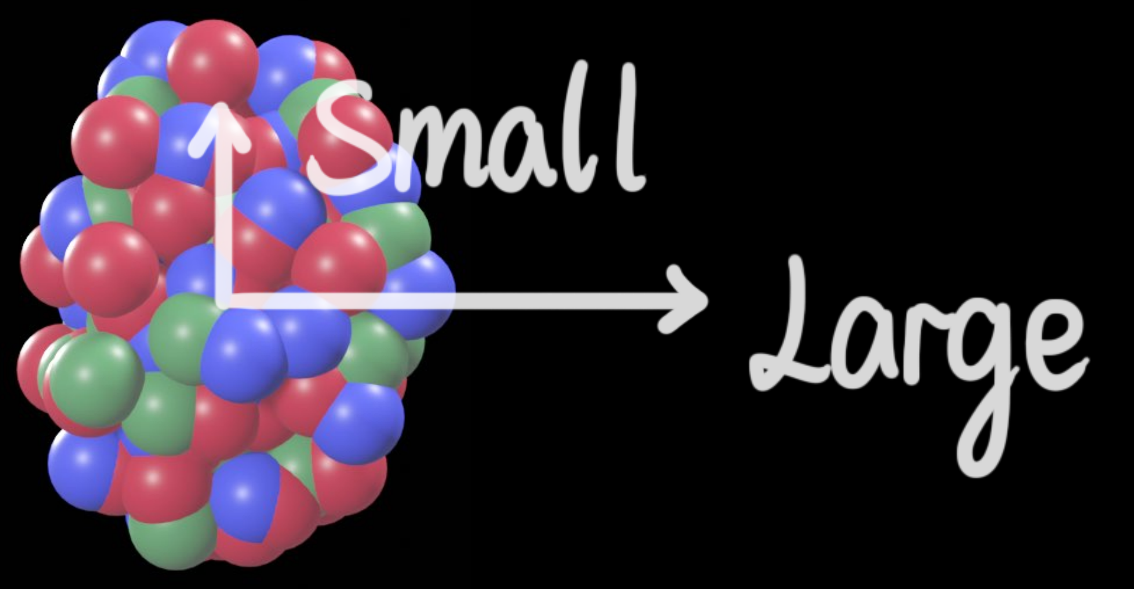
Azimuthal anisotropic Initial shape in peripheral* events

*Peripheral: relatively large impact parameter

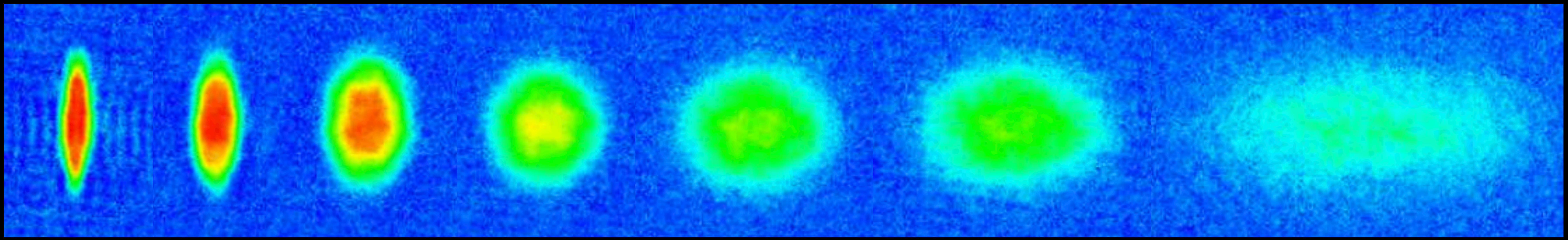
Animation

Collective Flow

Pressure gradient



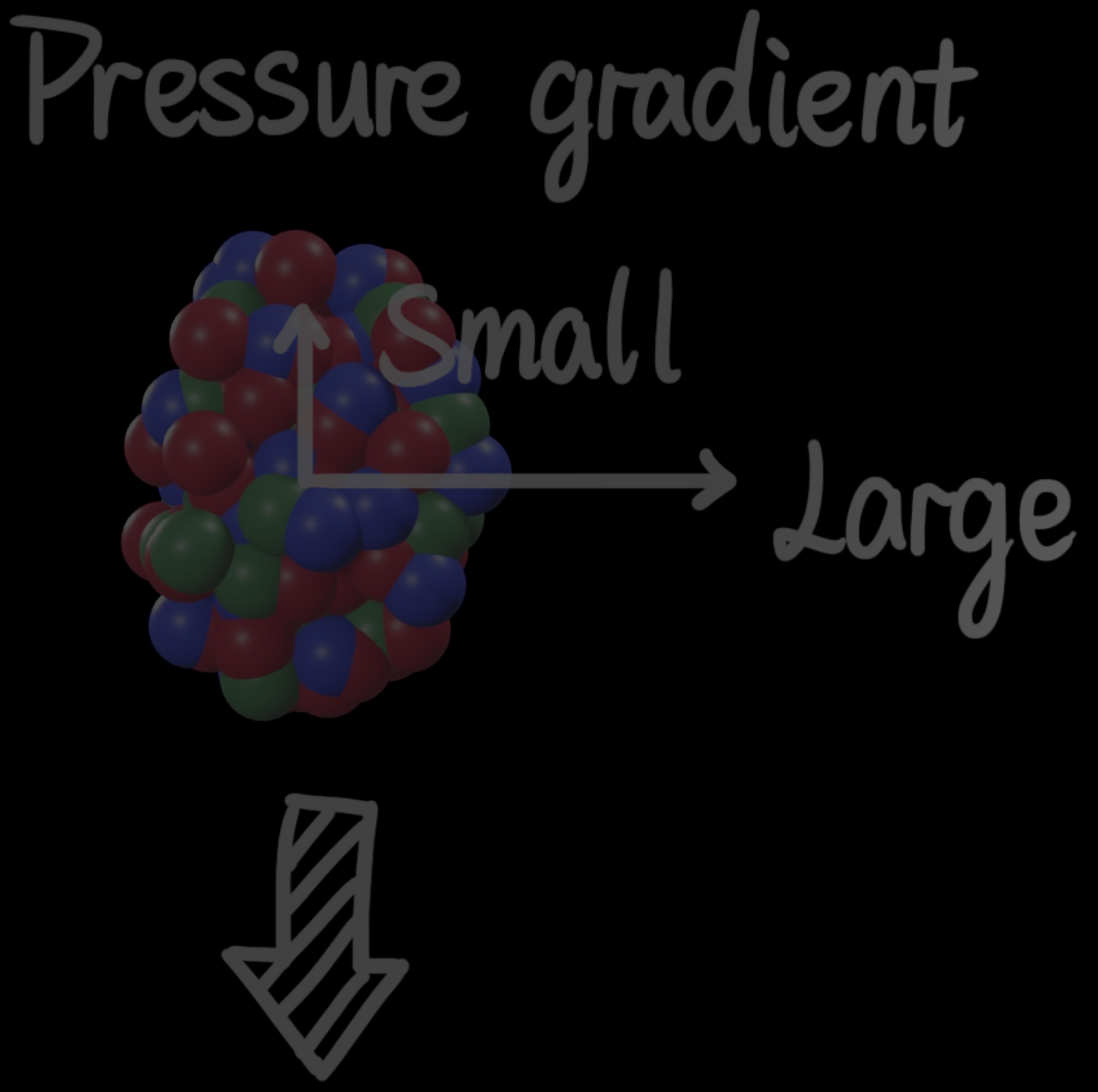
→ Time



Pressure driven expansion

Science 298 (2002) 2179

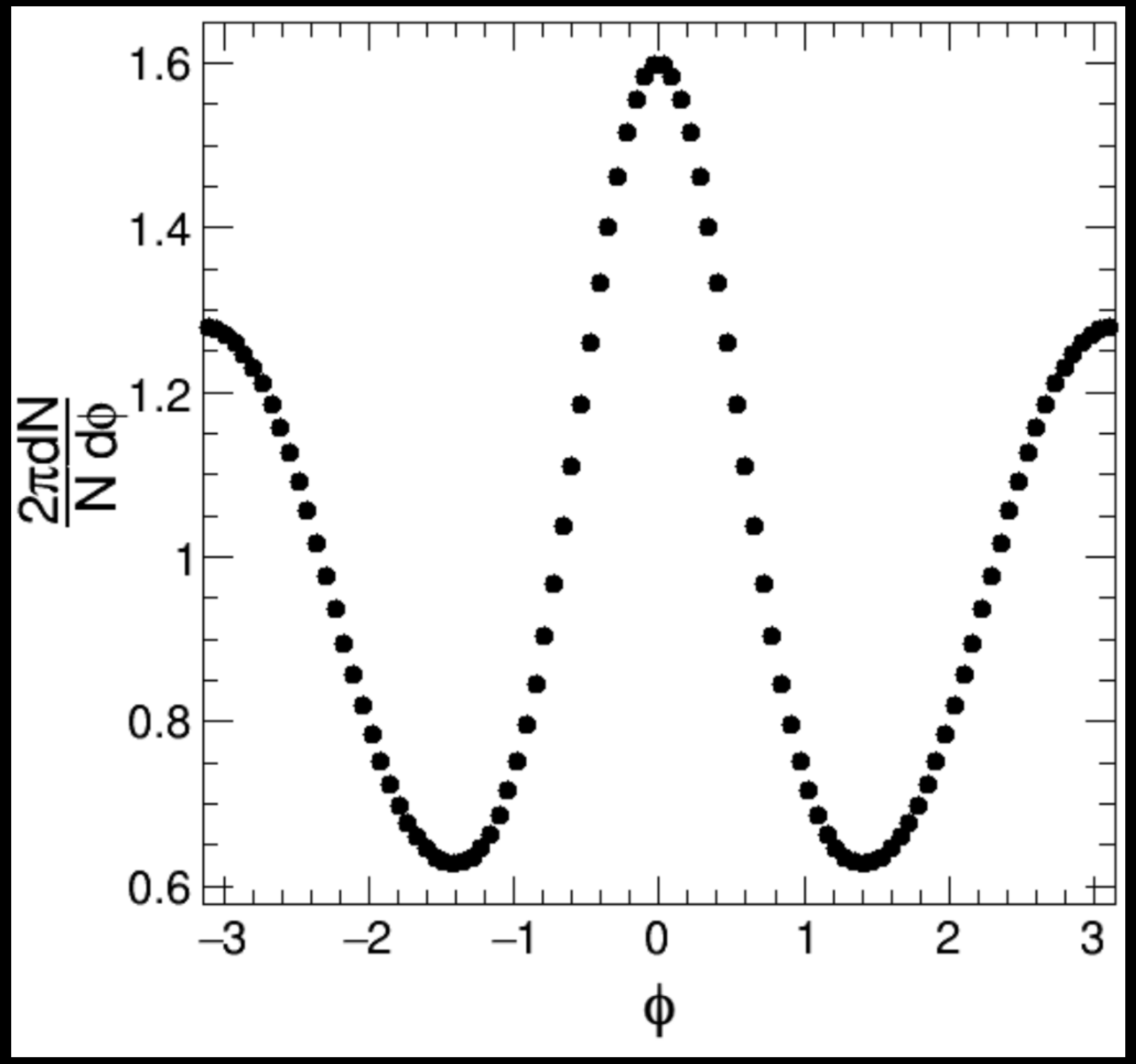
Collective Flow

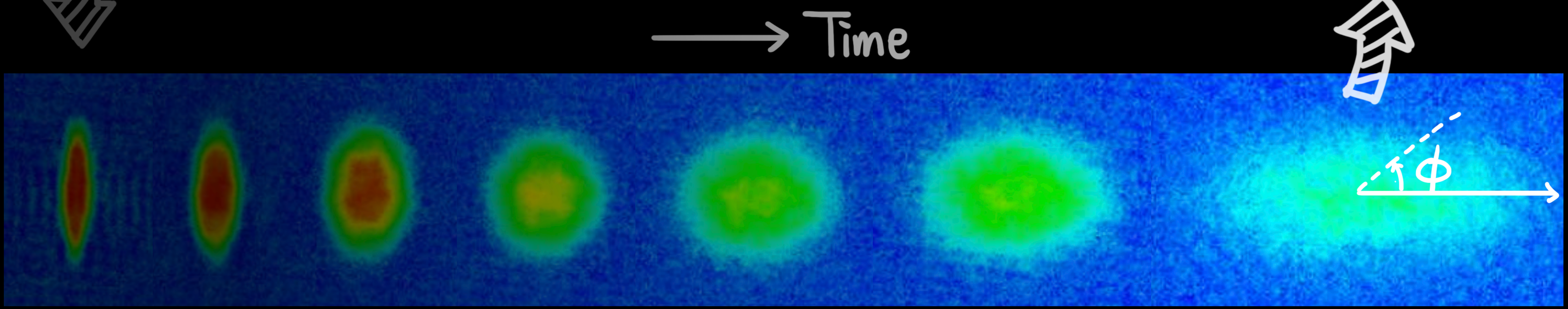


Existence of QGP ➜ Final-state particle azimuthal anisotropy

$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n\left(\phi - \Psi_n\right)\right]$$

➜ Elliptic $v_2 \neq 0$

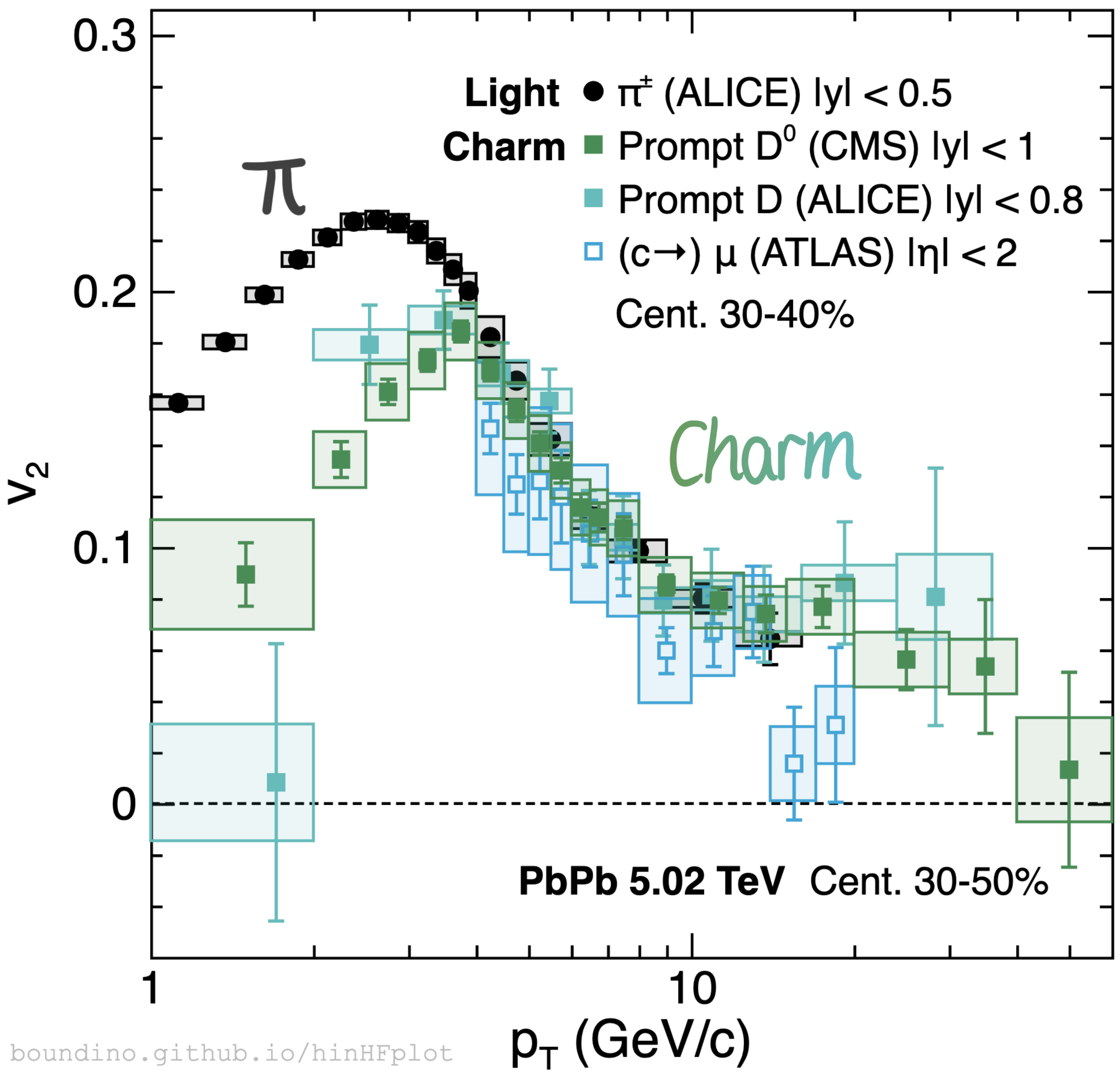




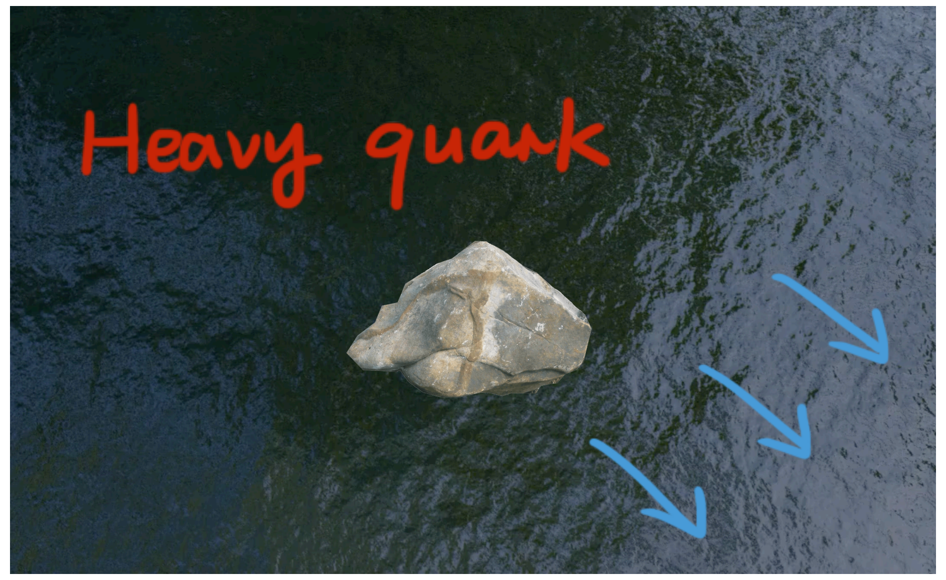
Pressure driven expansion

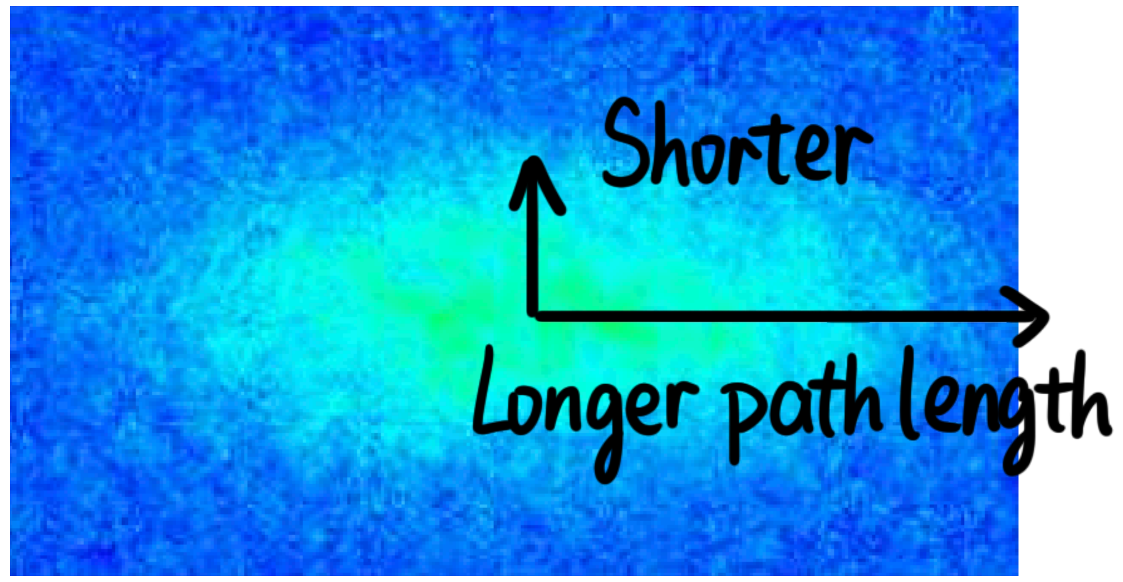
Science 298 (2002) 2179

Collective Flow Open Charm



- Significant non-zero open charm flow signal
  - Smaller v_2 than light hadrons at low p_T
  - Magnitude reflects thermalization degree

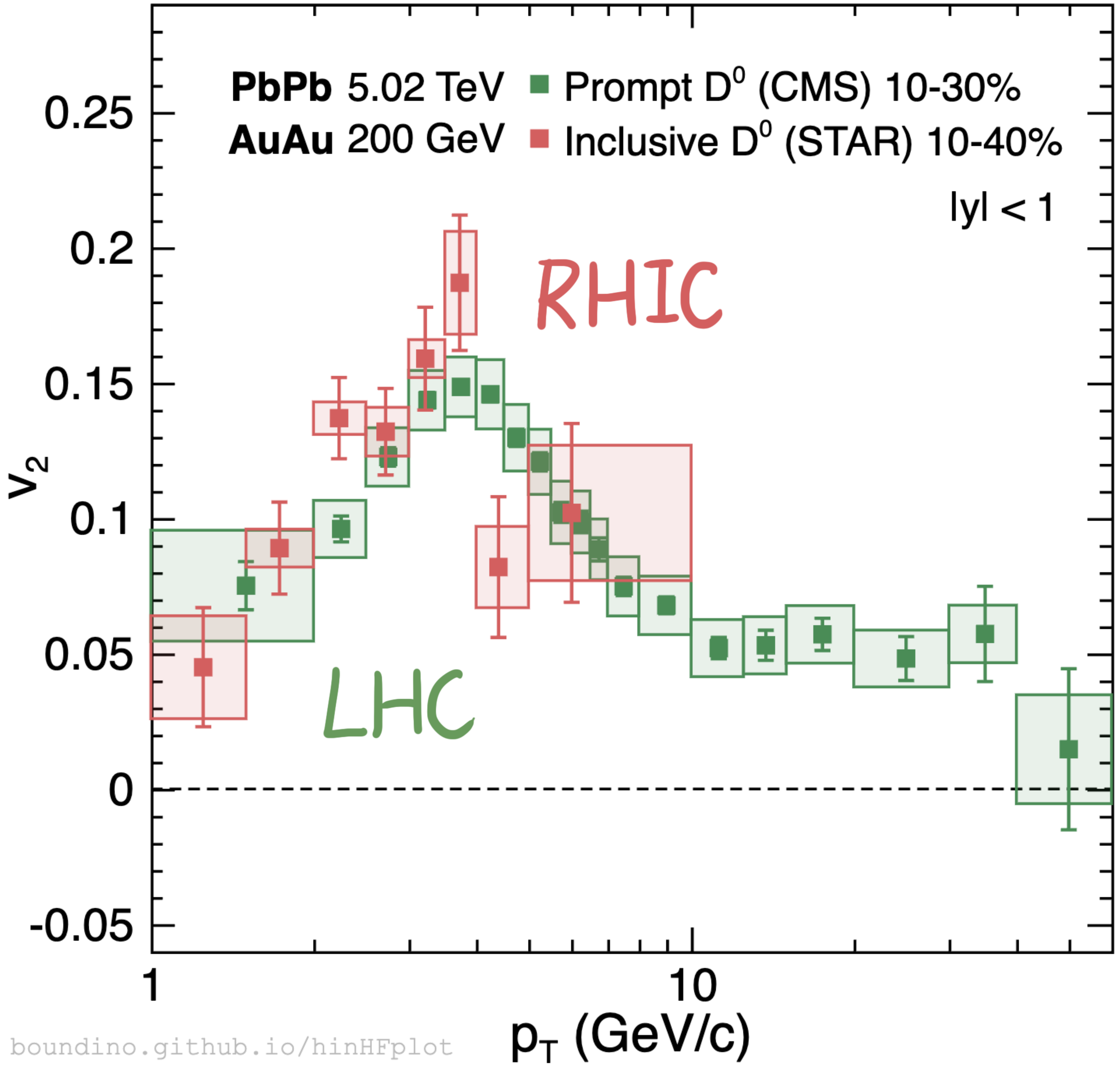




- Non-zero D meson v_2 up to high p_T
  - Same magnitude with light hadrons
  - Path-length dependence of energy loss

PLB 816 (2021) 136253 PLB 813 (2021) 136054 PLB 807 (2020) 135595

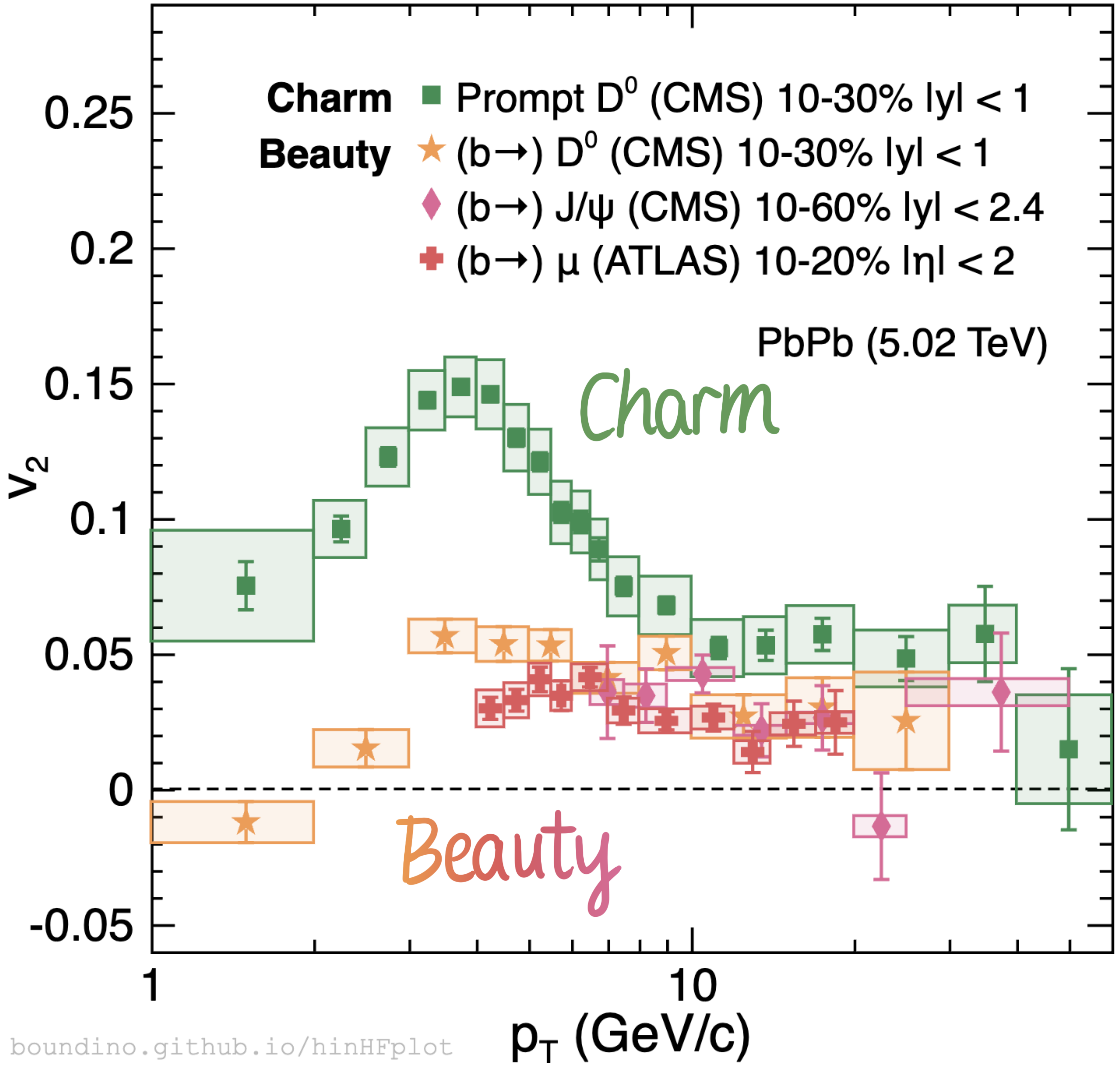
Open Charm Flow LHC vs RHIC



- Similar D v_2 between LHC PbPb 5 TeV and RHIC AuAu 200 GeV
  - despite different temperature & size?
  - decisive precision at sPHENIX

PLB 816 (2021) 136253 PRL 118 (2017) 212301

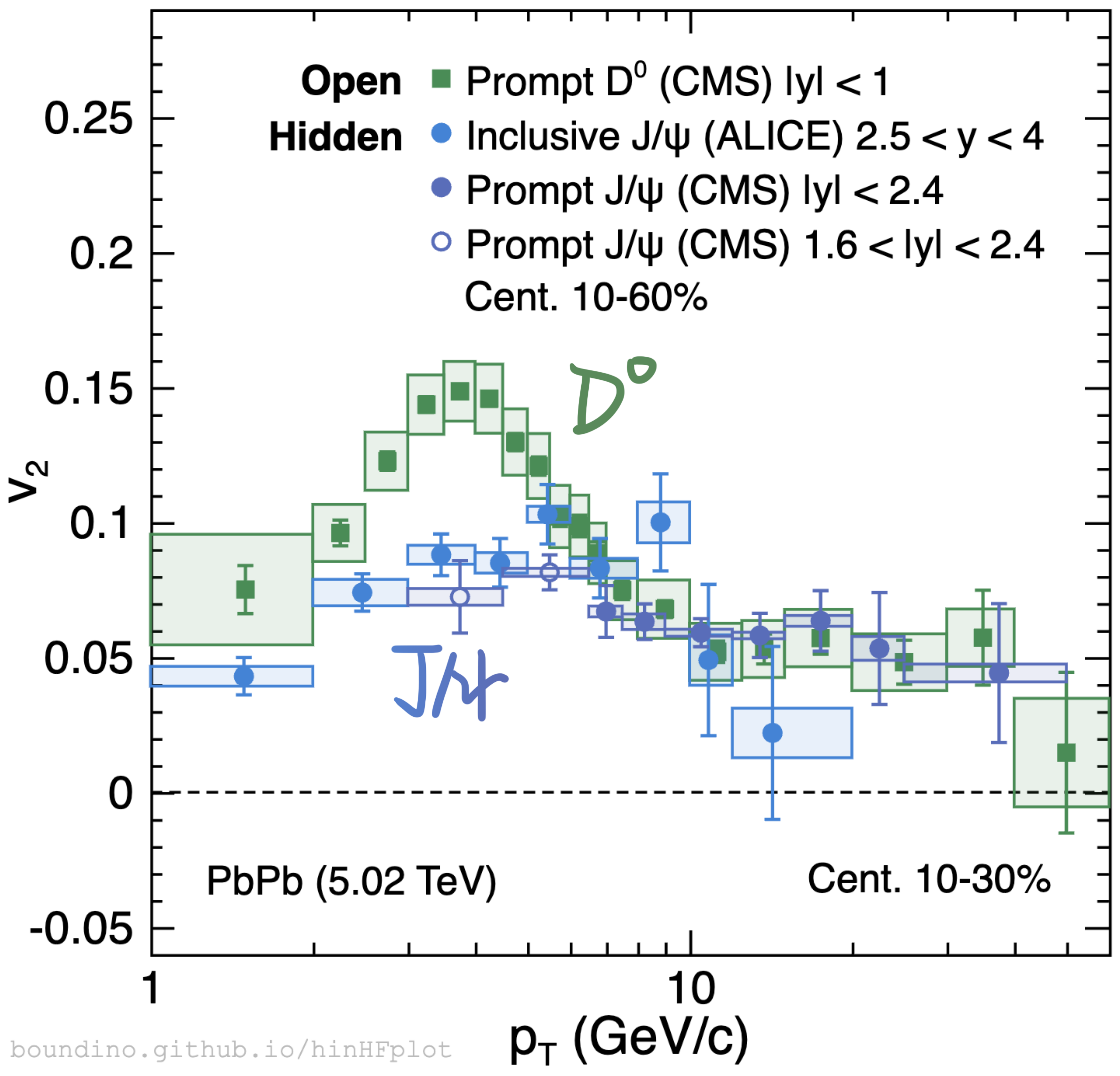
Collective Flow Open Beauty



- Significant non-zero open beauty flow signal
  - Smaller v_2 than charm hadrons at low p_T
    - Weaker collective flow behavior
  - Similar v_2 with open charm at high p_T
    - Path length dependence of energy loss

PLB 850 (2024) 138389 JHEP 10 (2023) 115 PLB 807 (2020) 135595

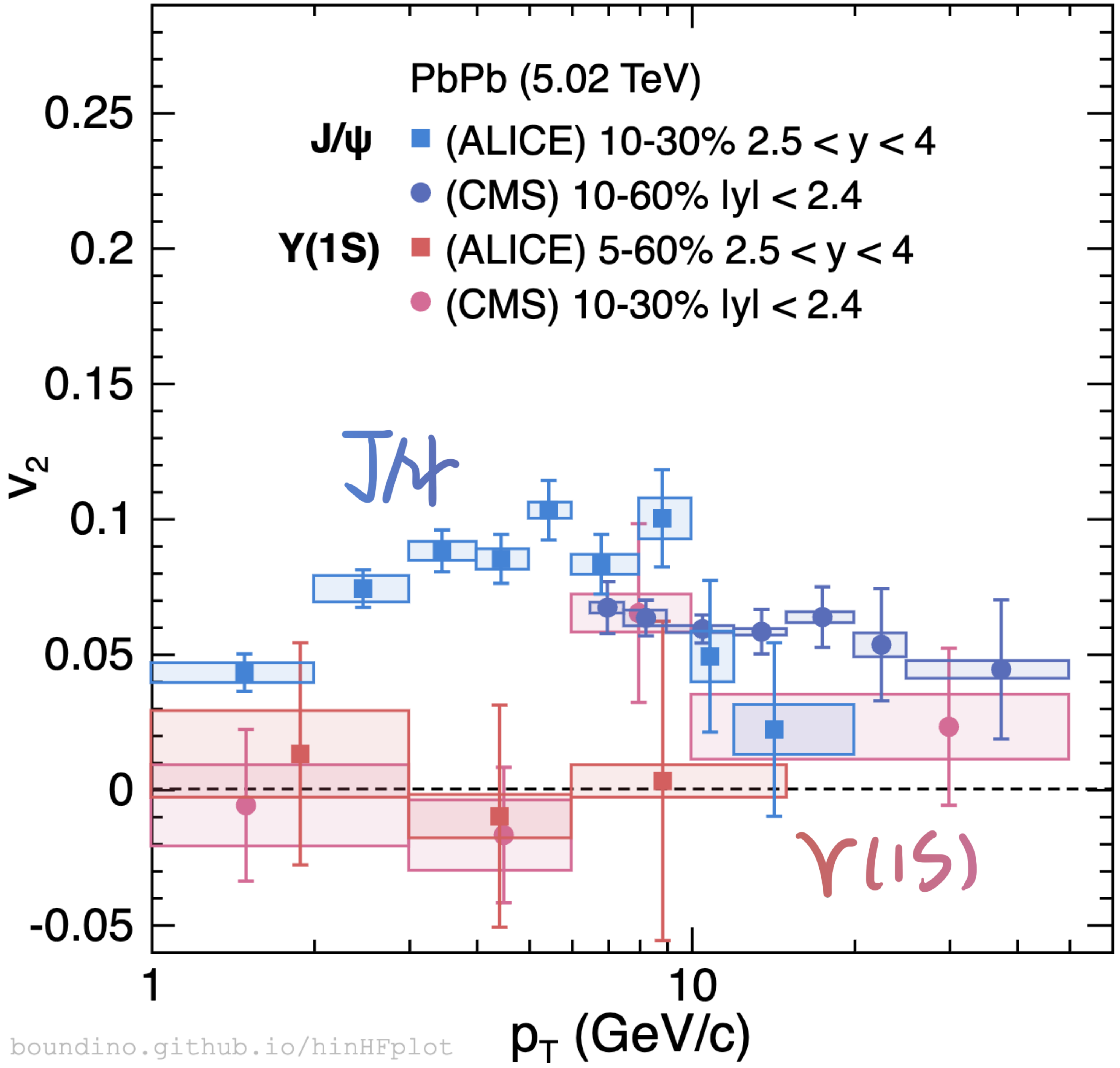
Collective Flow Charmonia



- Significant non-zero flow signal of J/ψ
  - Indicate significant contribution from uncorrelated regeneration

JHEP 10 (2020) 141 JHEP 10 (2023) 115

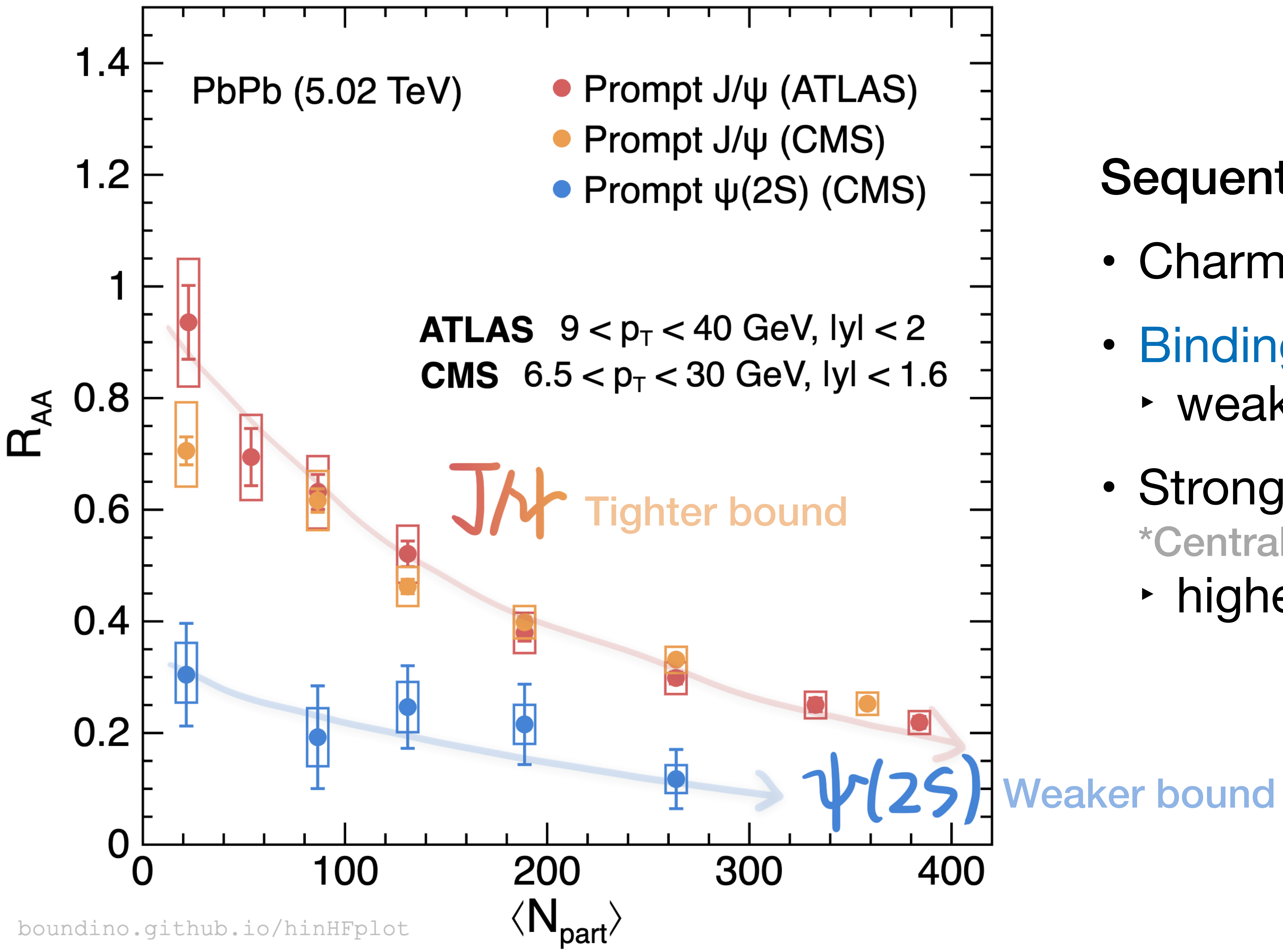
Collective Flow Bottomonia



- Significant non-zero flow signal of J/ψ
  - Indicate significant contribution from uncorrelated regeneration
- Υ(1S) v_2 consistent with 0
  - Regeneration of bottomonia should be small

PRL 123 (2019) 192301 PLB 819 (2021) 136385

Charmonia in QGP Sequential Melting



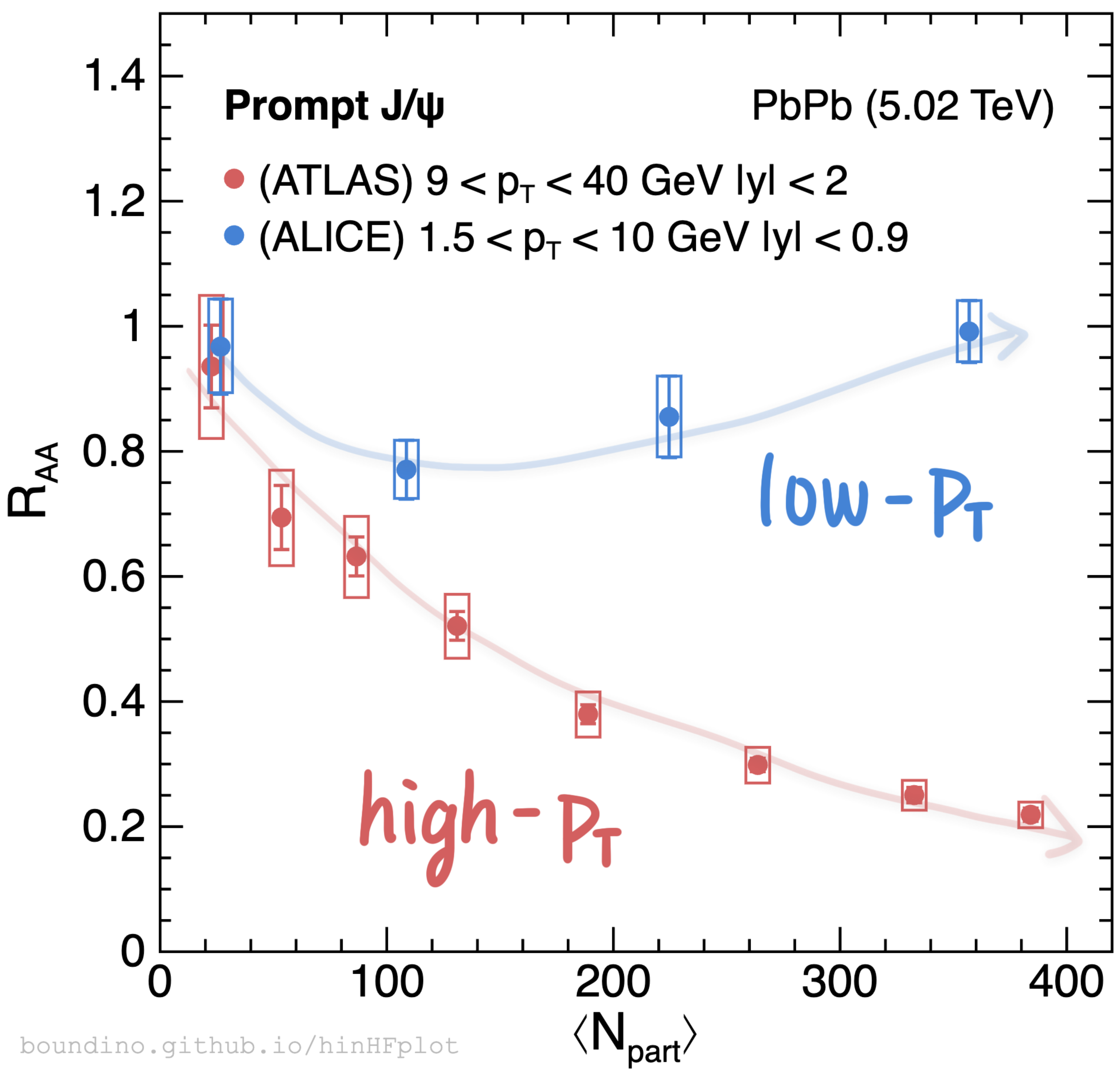
EPJC 78 (2018) 762 EPJC 78 (2018) 509 EPJC 78 (2018) 509

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

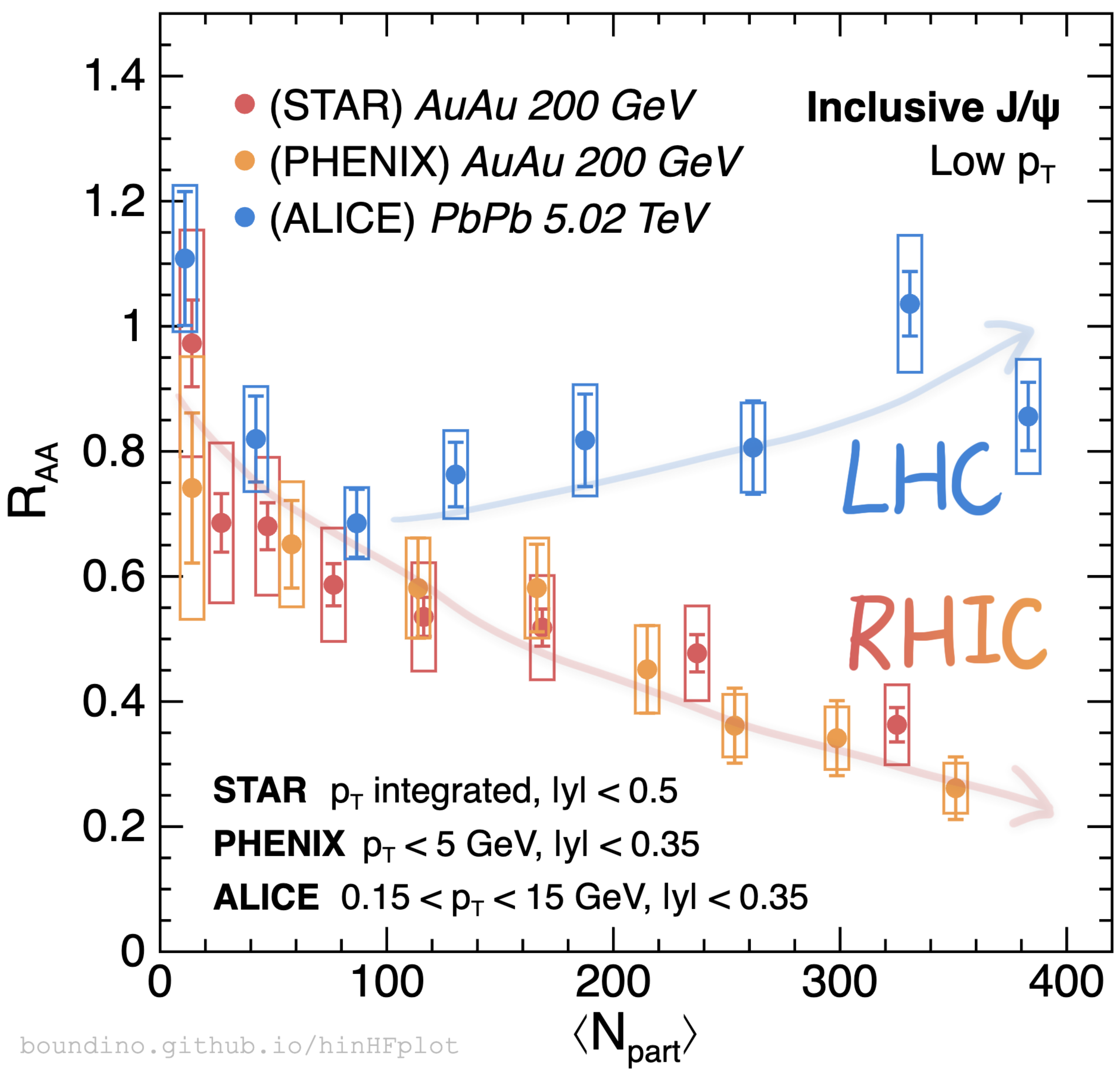


EPJC 78 (2018) 762 JHEP 02 (2024) 066

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

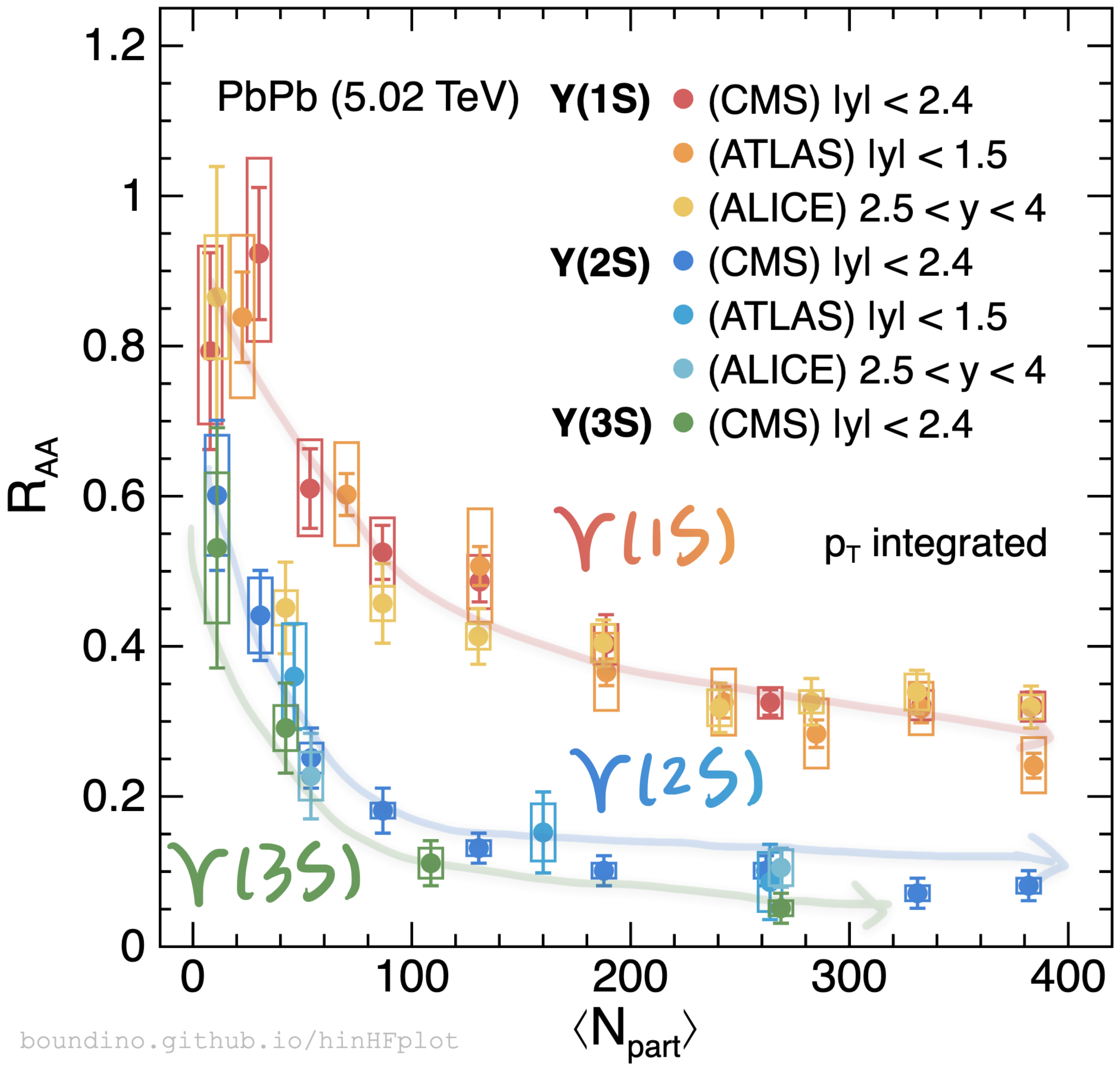


PLB 797 (2019) 134917 PRL 98 (2007) 232301 PLB 849 (2024) 138451

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 $\sigma_{c\bar{c}}$

Bottomonia in QGP

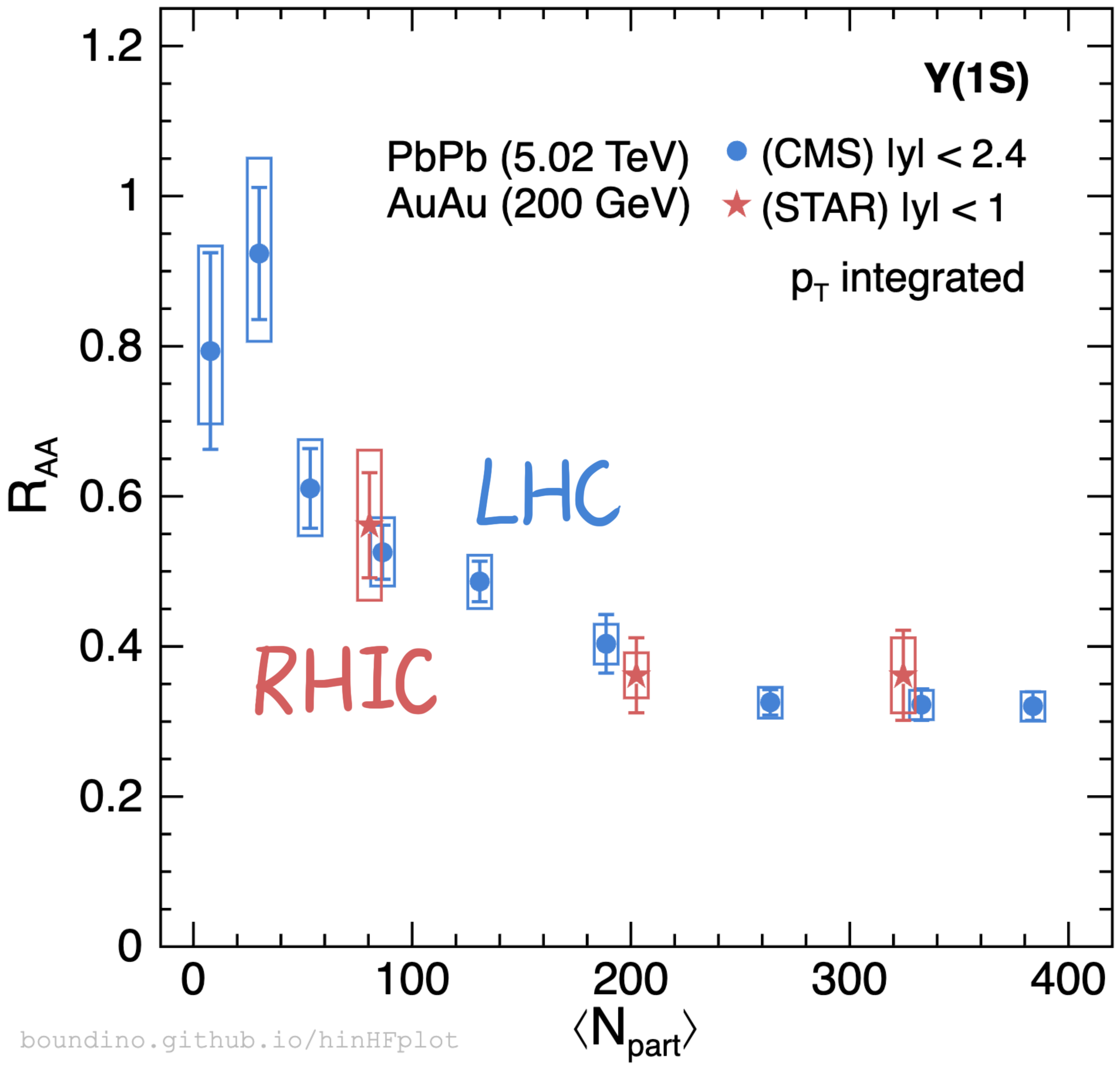


Sequential melting

- 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

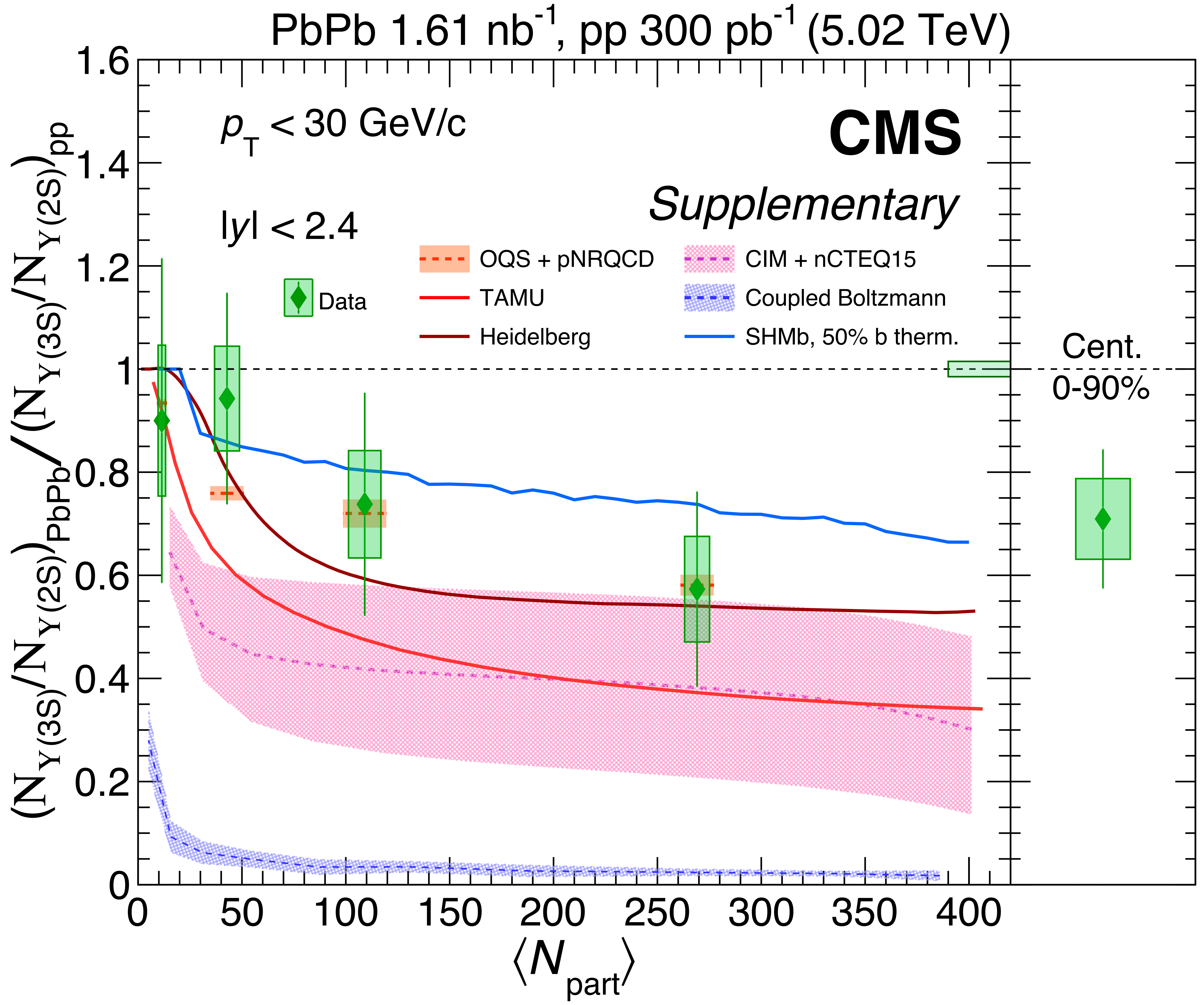


Happy with dissociation + regeneration picture?

- 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

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

Heavy Quarkonium Production Challenge

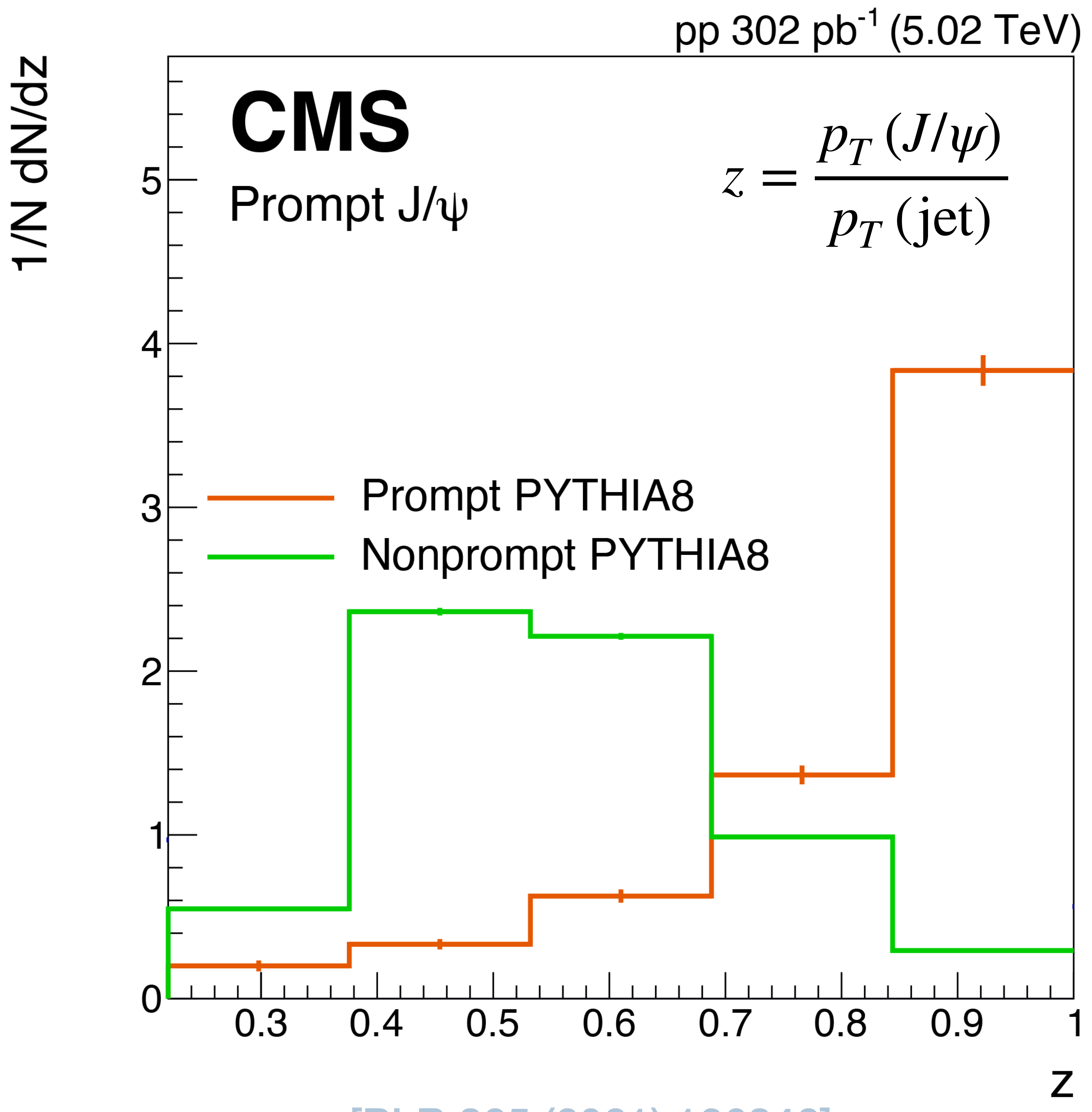


[2303.17026]

More excited states Υ(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]

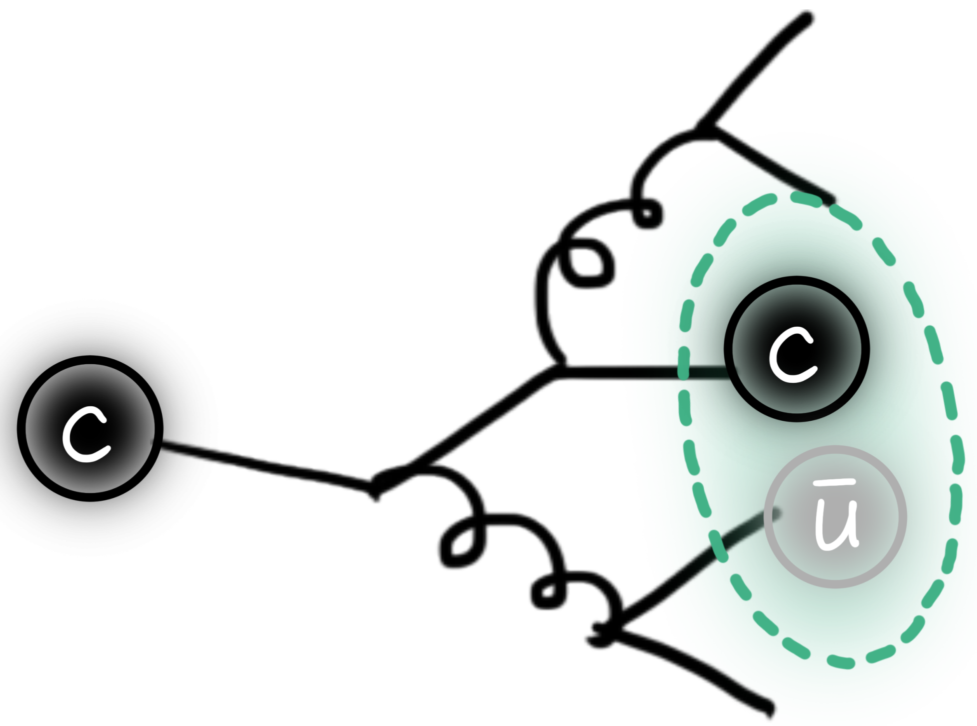
Early bound state picture

- Few surrounding jet activities

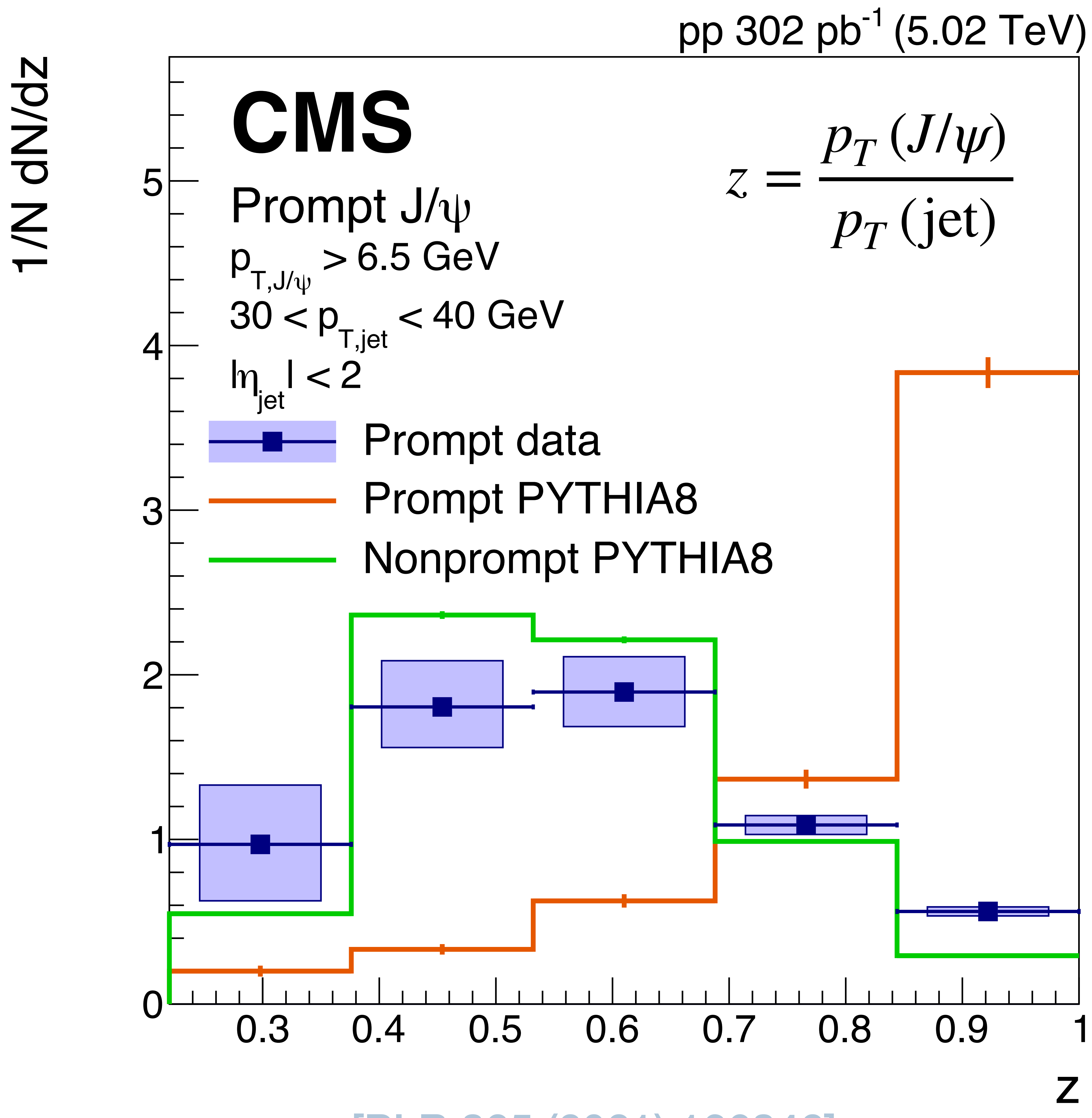
Late jet fragmentation picture

How open heavy flavors are formed

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



J/ψ Production Potential Jet Fragmentation

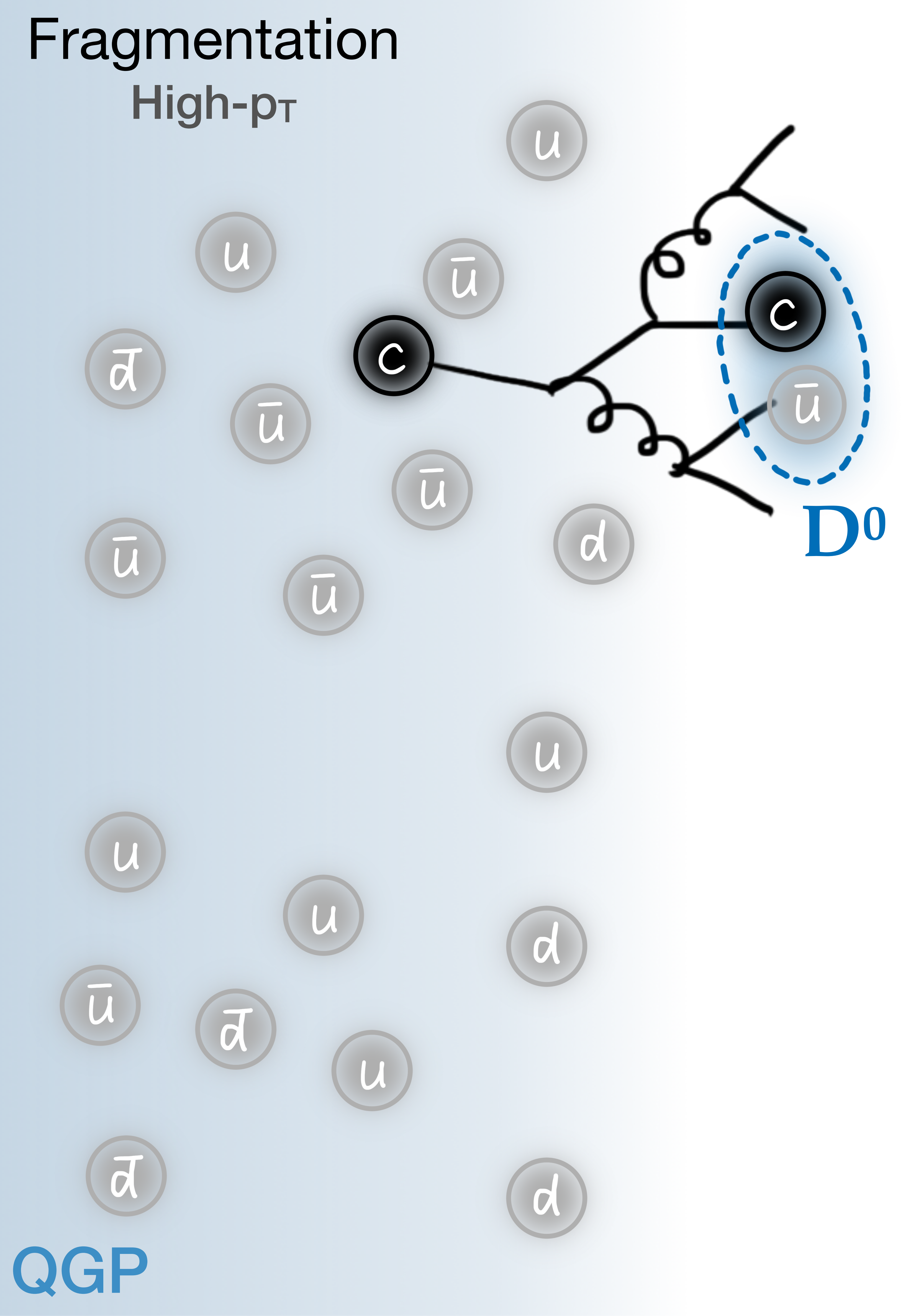


[PLB 825 (2021) 136842]

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

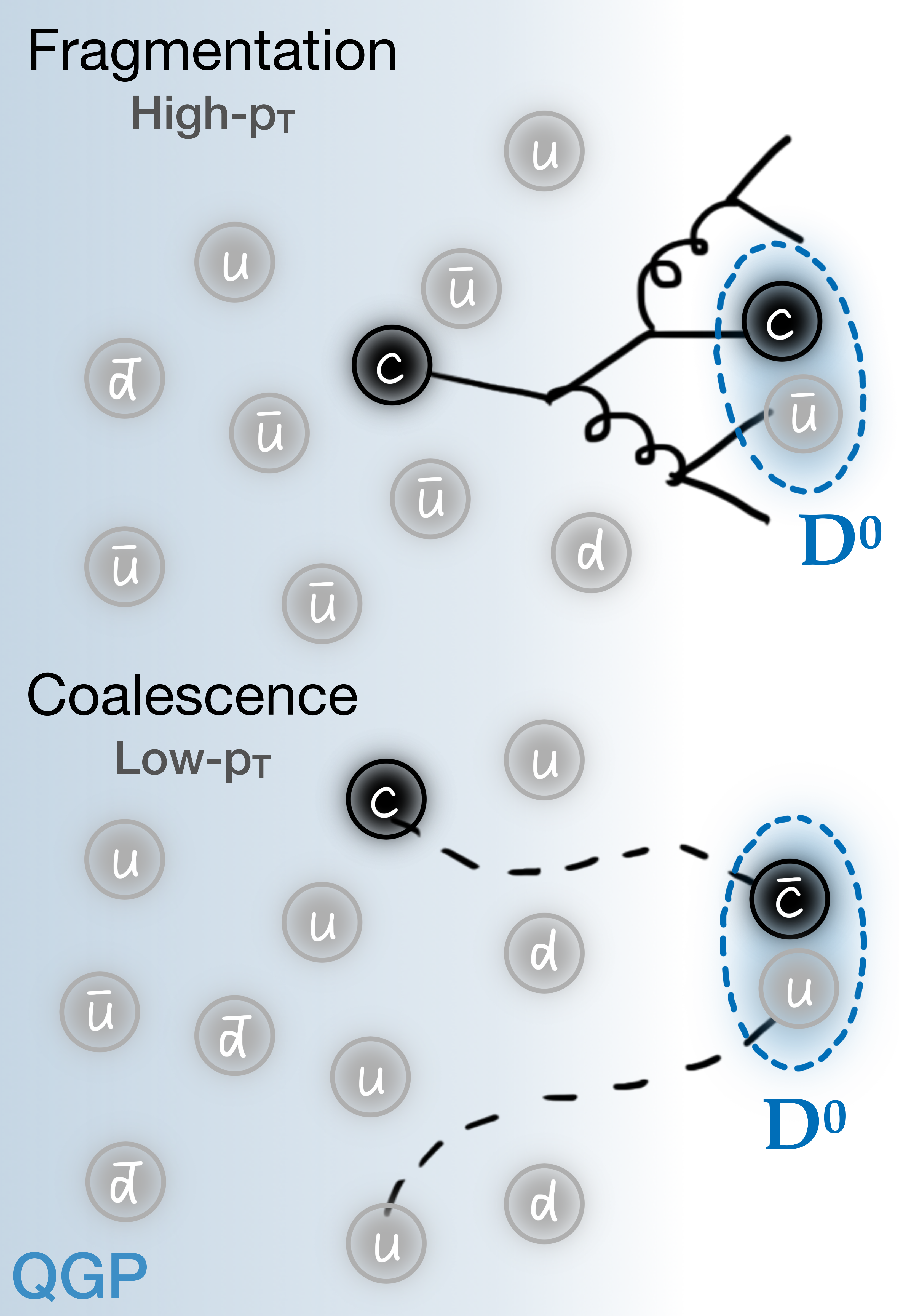
Open HF Hadrons Really from Fragmentation?



Hadronization Non-perturbative problem

- Fragmentation universality assumed across collision systems
  - Default scheme in generators, constrained by measurements in e^+e^- and ep collisions
  - Successful in HF meson production in pp

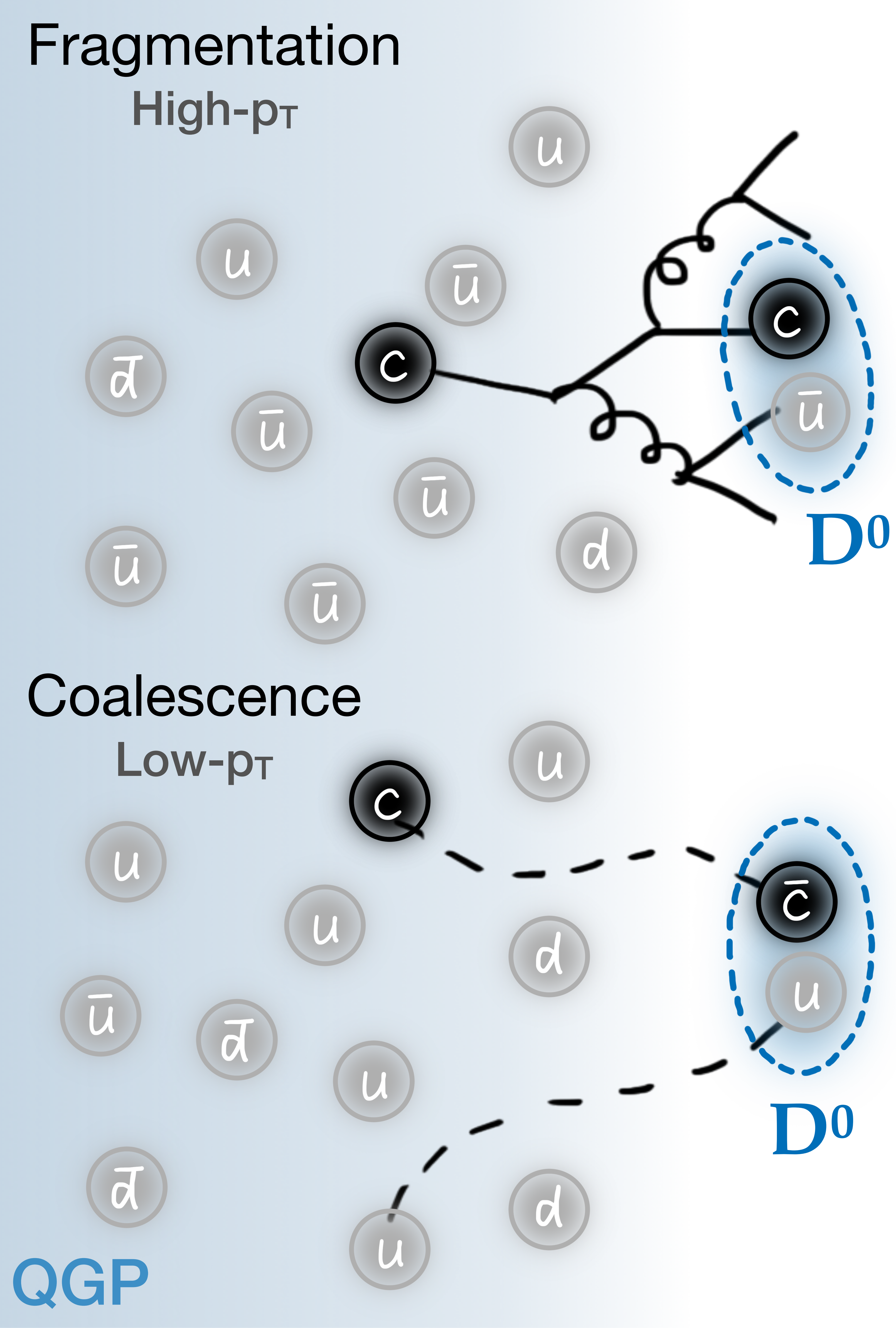
Open HF Hadrons Really from Fragmentation?



Hadronization Non-perturbative problem

- Fragmentation universality assumed across collision systems
  - Default scheme in generators, constrained by measurements in e^+e^- and ep collisions
  - Successful in HF meson production in pp
- Modification of hadronization expected in medium
  - Fragmentation + coalescence (combination with partons from medium)

Hadronization Study In Experiments



Hadronization Can only measure hadrons in experiments

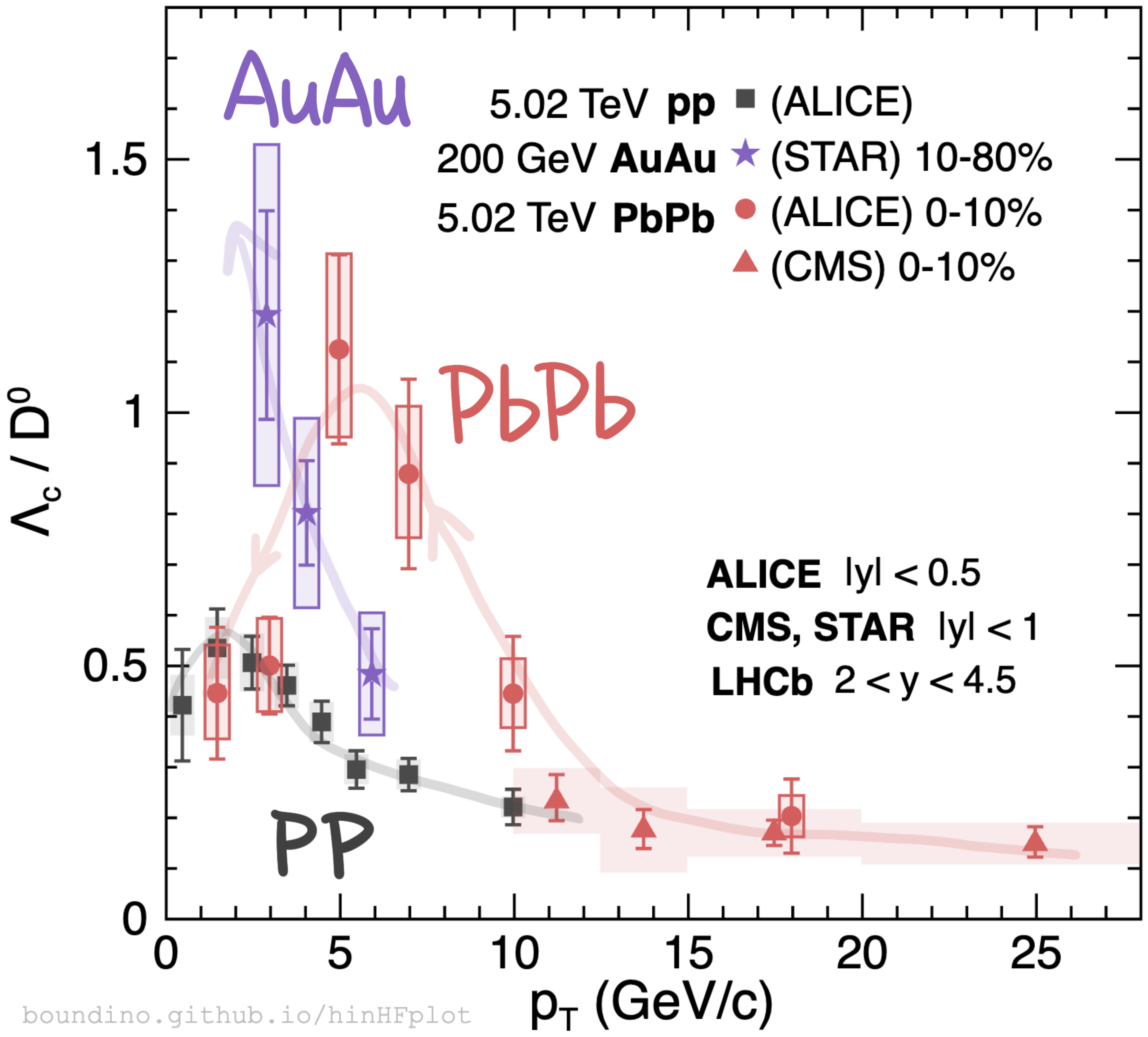
- Fragmentation universality and parameters of hadronization models need to be tested and constraint by data
  - Hadrons with different quark content as experimental proxy

If there is coalescence

Higher D_s / D^0 expected
strangeness enhancement

Higher Λ_c / D^0 expected
more valence quarks

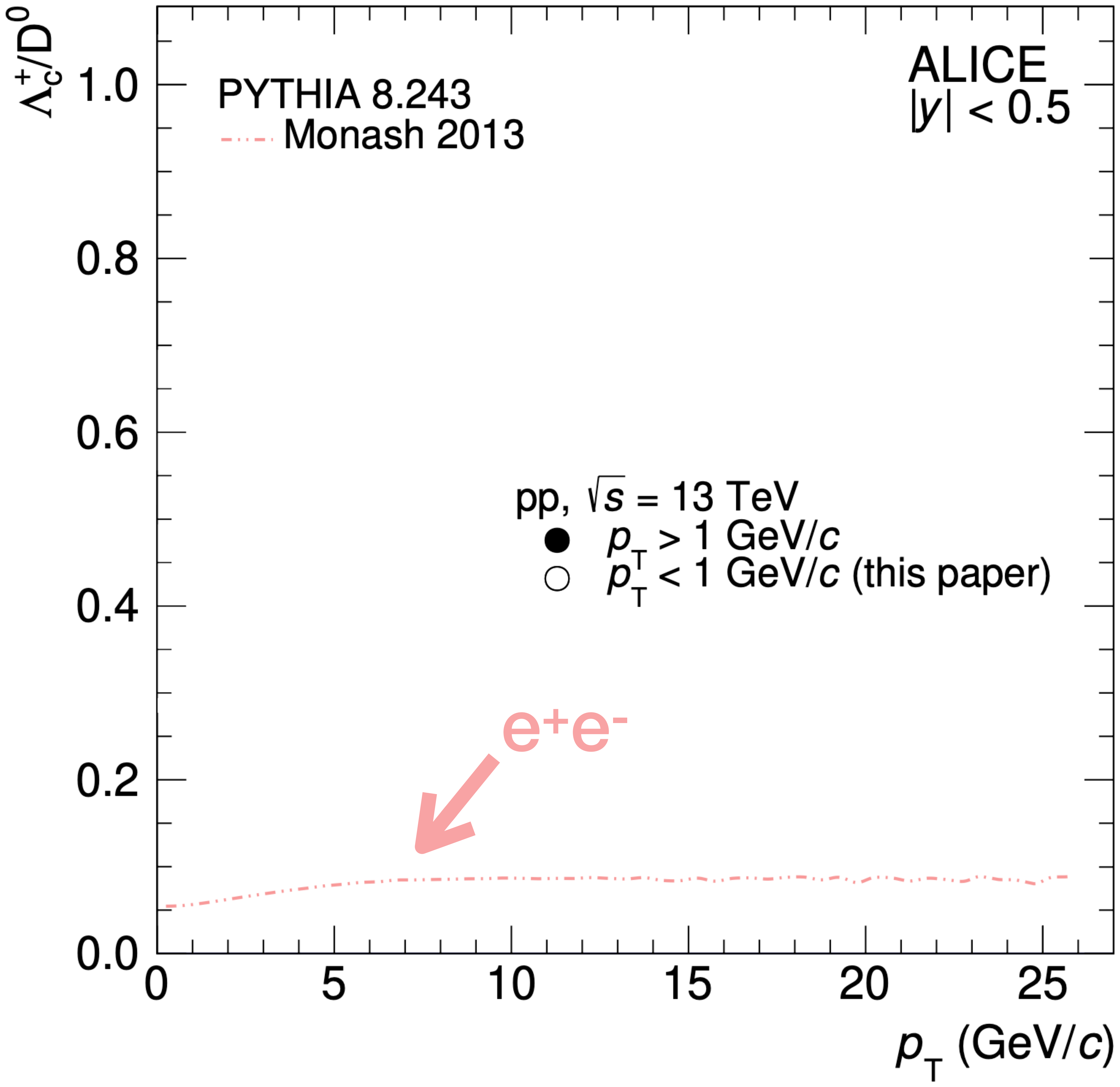
Coalescence Charm Baryon Λ_c in AA Collisions



- Significant larger Λ_c / D^0 in AA compared to pp at intermediate p_T
  - Consistent with coalescence picture

JHEP 01 (2024) 128 PLB 839 (2023) 137796 PRL 124 (2020) 172301 PRC 107 (2023) 064901

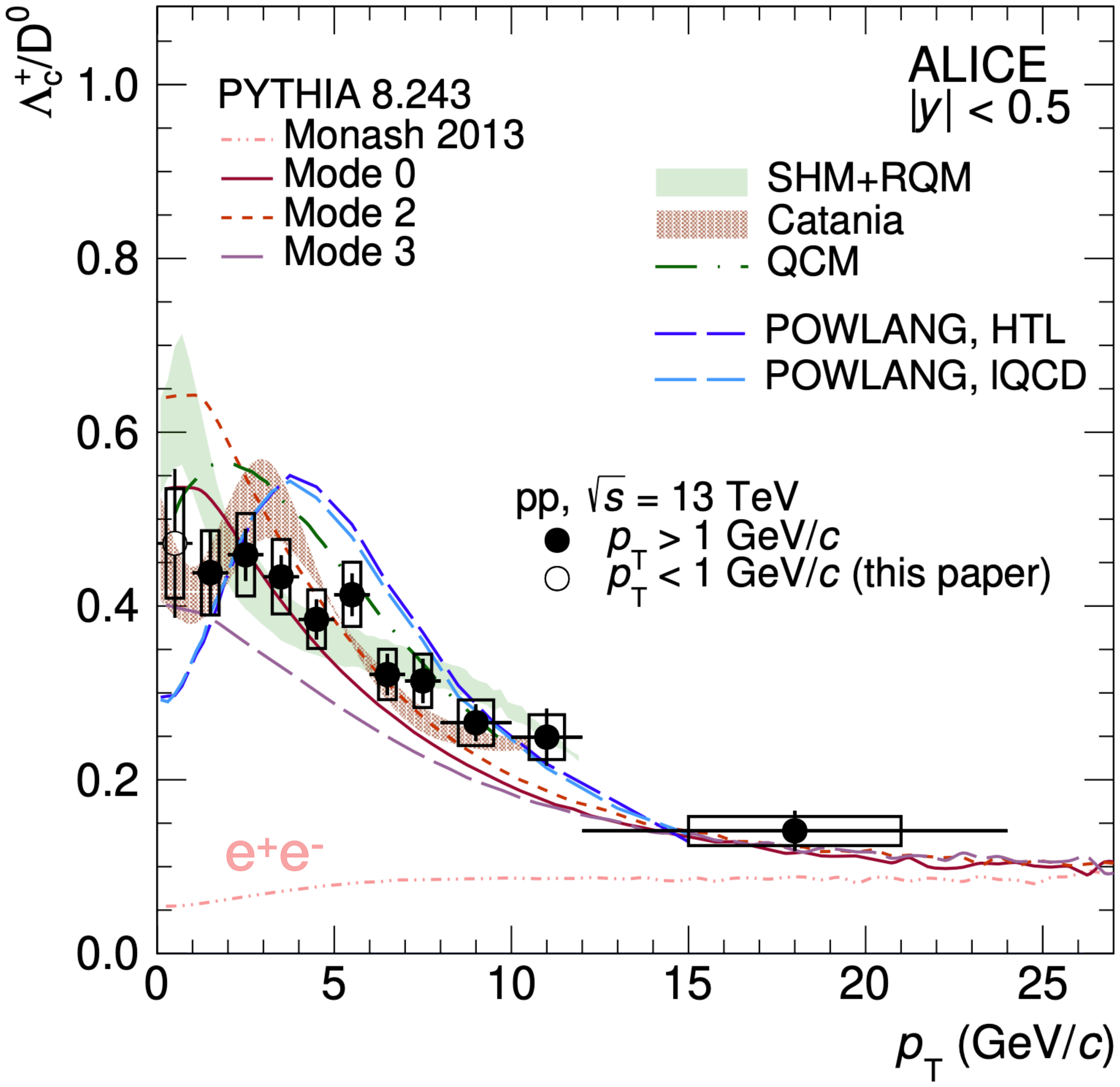
Charm Baryon Λ_c Hadronization in pp



[JHEP 12 (2023) 086]

- Fragmentation function constrained by e^+e^- predicts Λ_c / D^0 to be 0.05 - 0.1 in pp
  - Weak p_T dependence

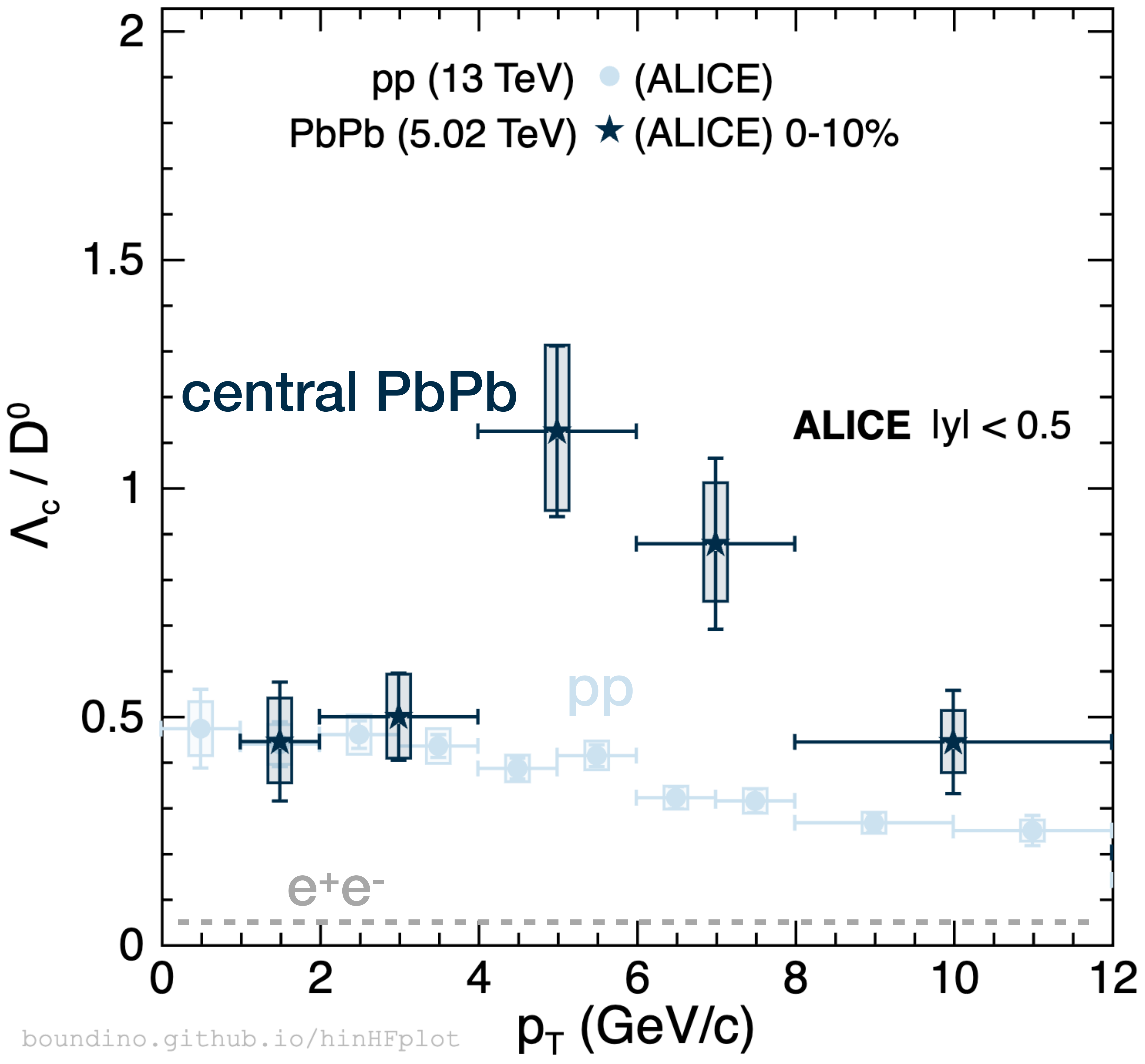
Charm Baryon Λ_c Hadronization in pp



- 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

[JHEP 12 (2023) 086]

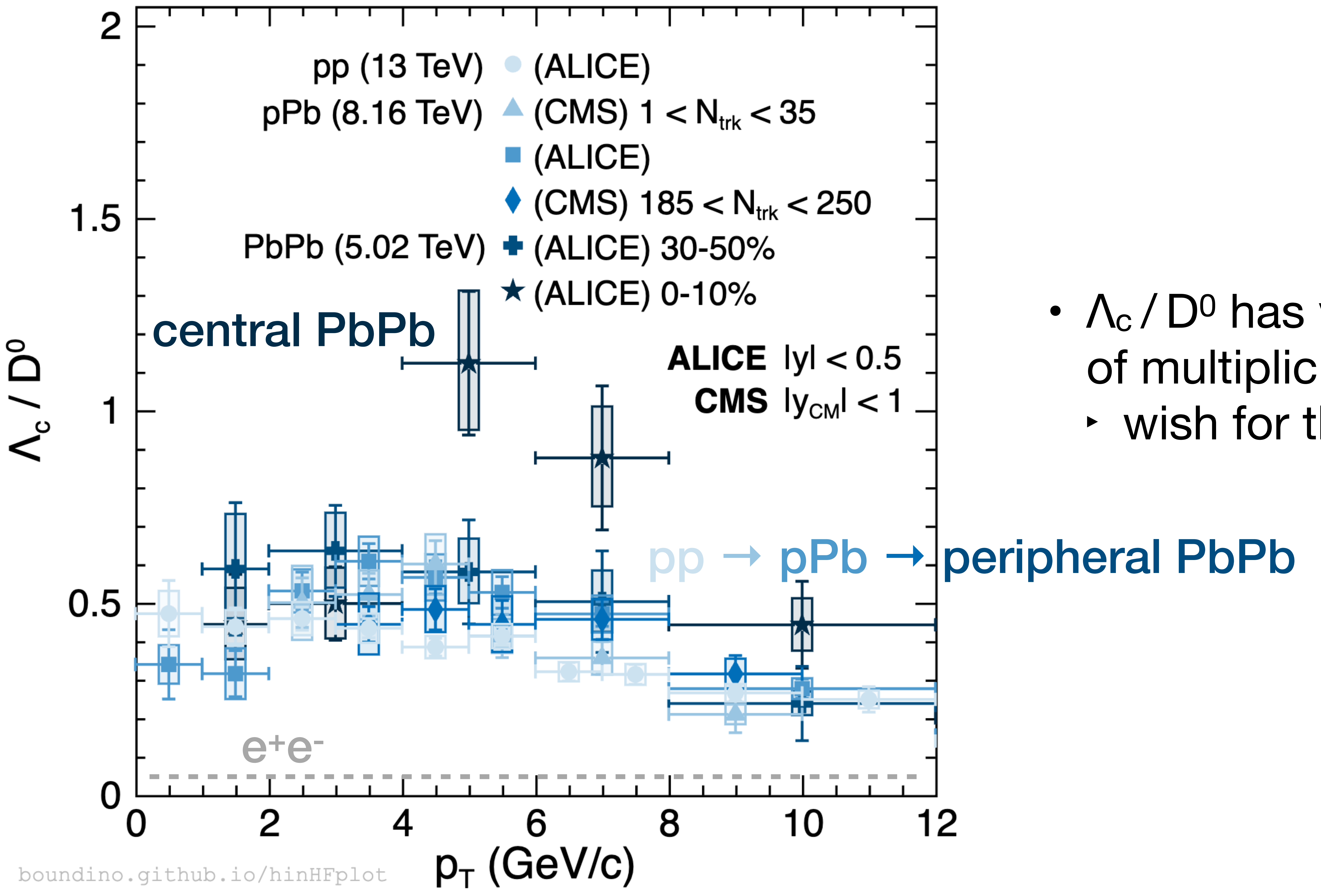
Charm Baryon Λ_c From e^+e^- to AA



- One picture for all collision systems?
  - Connect pp and PbPb by intermediate pPb and multiplicity variations

PLB 839 (2023) 137796 JHEP 12 (2023) 086

Charm Baryon Λ_c From e^+e^- to AA

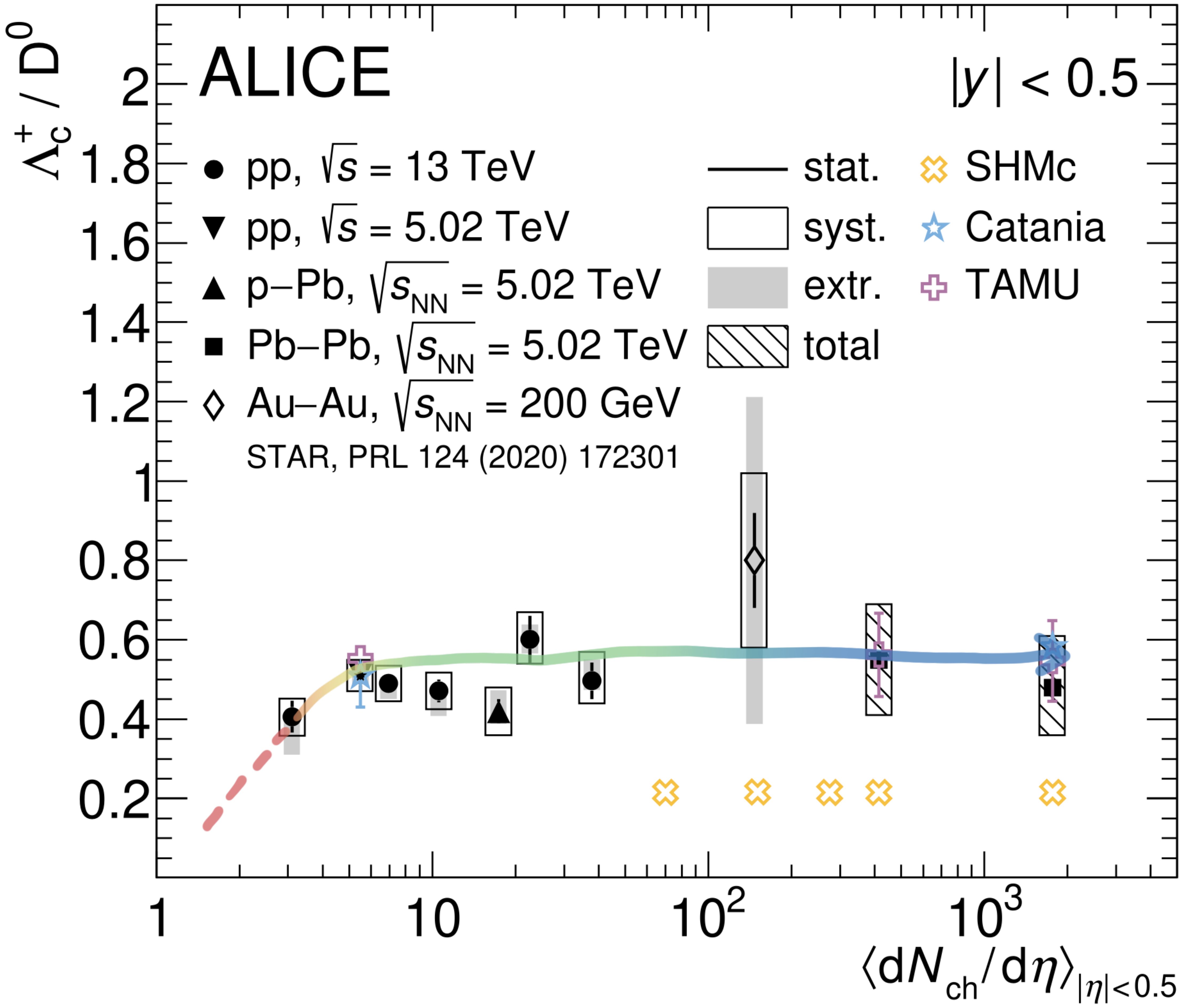


- Λ_c / D^0 has very mild changes over a wide range of multiplicity from pp to peripheral AA
  - wish for theoretical calculations in pPb

PRC 107 (2023) 064901 CMS-PAS-HIN-21-016

Hadronization in One Picture p_T-Integrated Λ_c

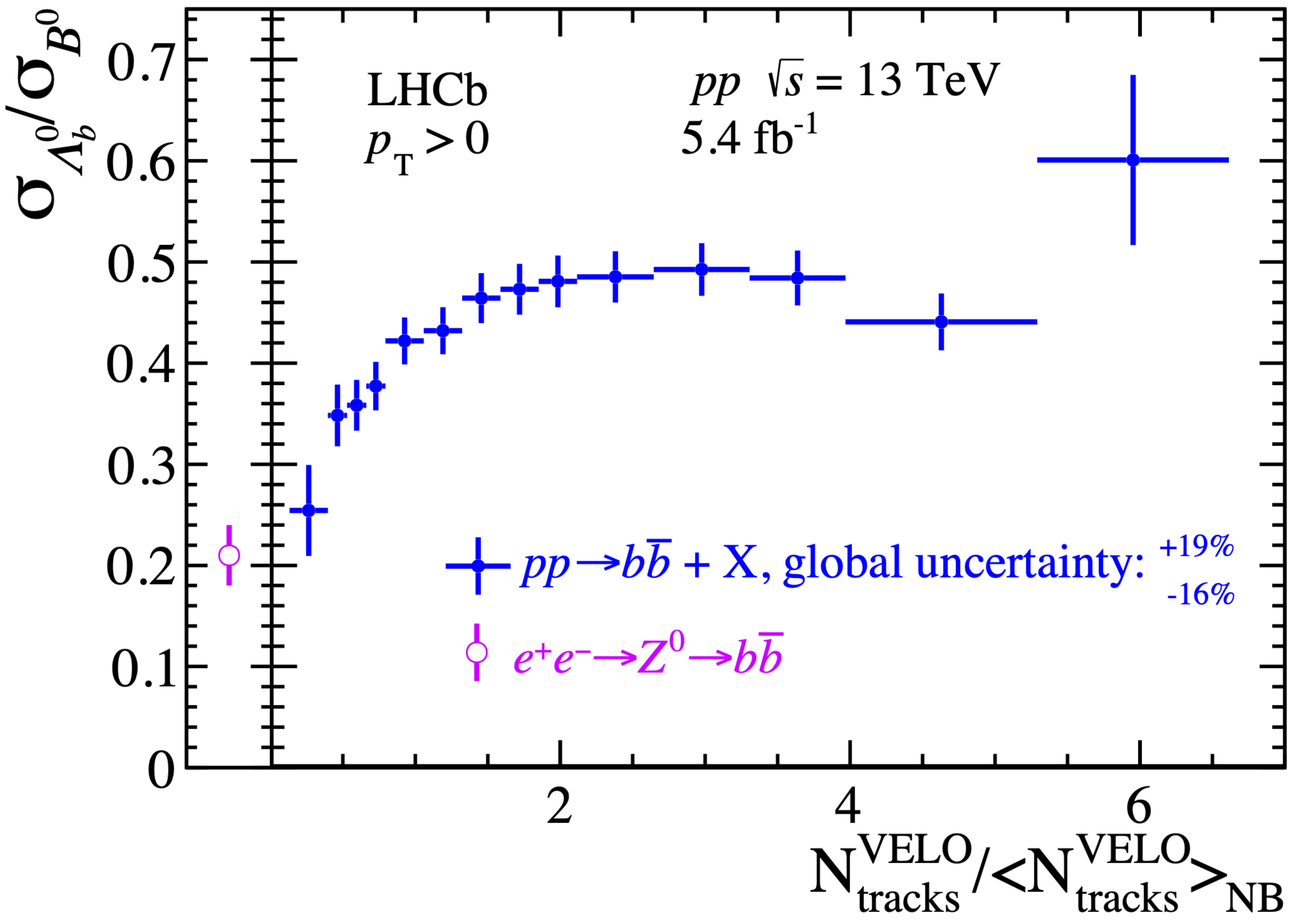
p_T-Integrated



[PLB 839 (2023) 137796]

- p_T-Integrated Λ_c / D^0 increases dramatically at small multiplicity from e^+e^- to low-multiplicity pp
  - but no result there
- Λ_c / D^0 has very mild changes over a wide range of multiplicity from pp to peripheral AA
  - for both integrated yields and p_T dependence
- p_T-Integrated Λ_c / D^0 keeps same but p_T redistributed from peripheral to central AA
  - need better precision though

Hadronization in One Picture Λ_b/B^0 vs Multiplicity

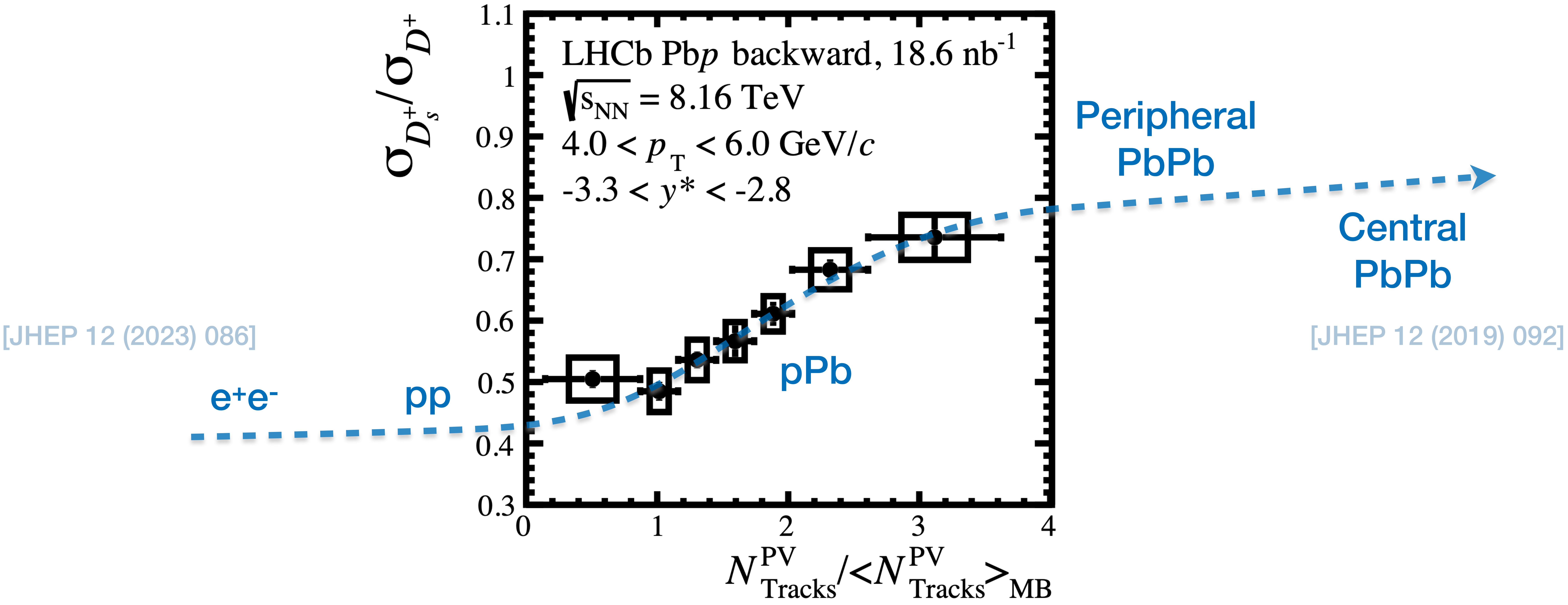


- Similar observations for beauty sector at low multiplicity environment
  - No results in larger collisions

[PRL 132 (2024) 081901]

Hadronization in One Picture Strangeness Mesons

[arXiv:2311.08490]

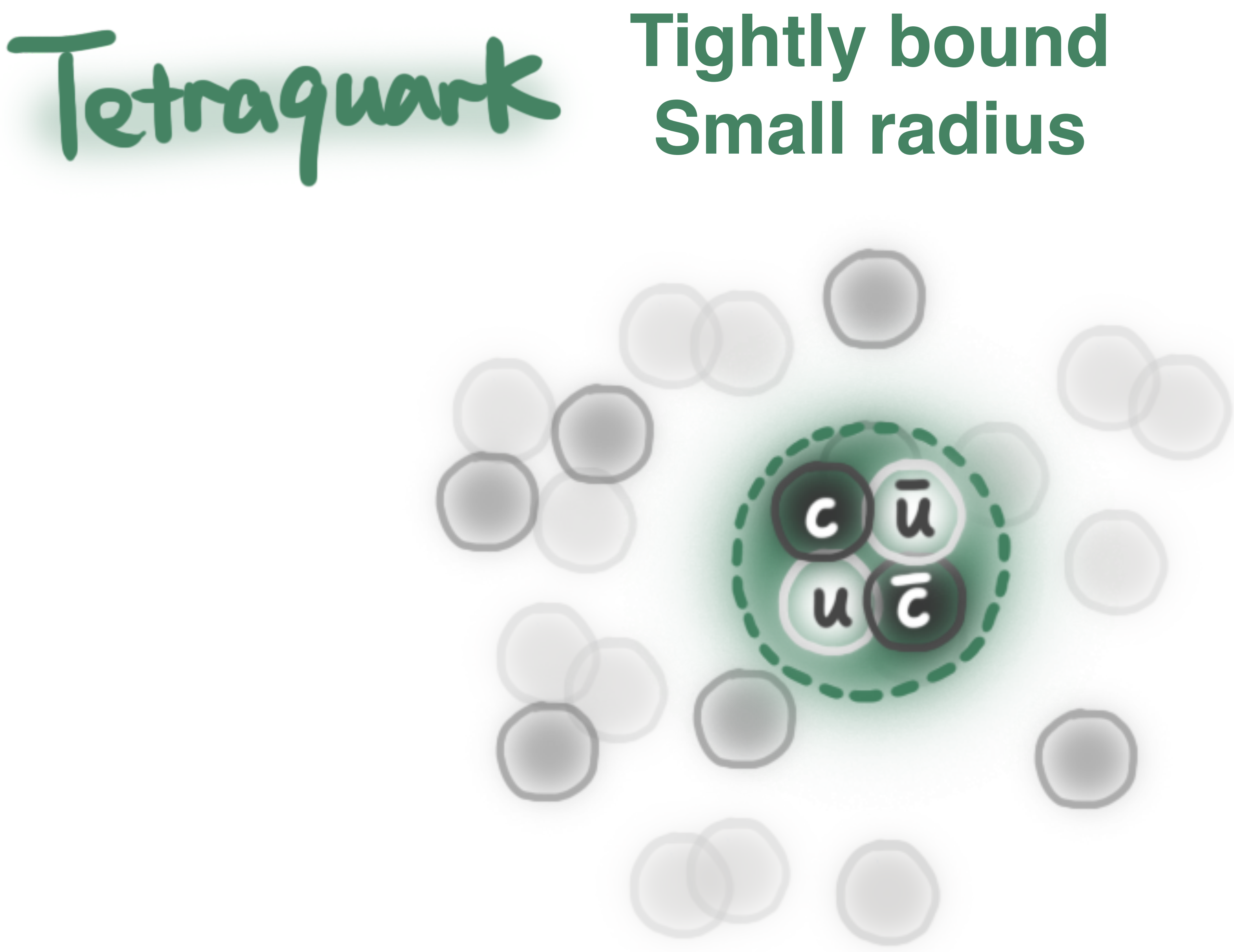


- Very different behavior of D_s/D compared to Λ_c/D ➜ Simultaneous descriptions by models?

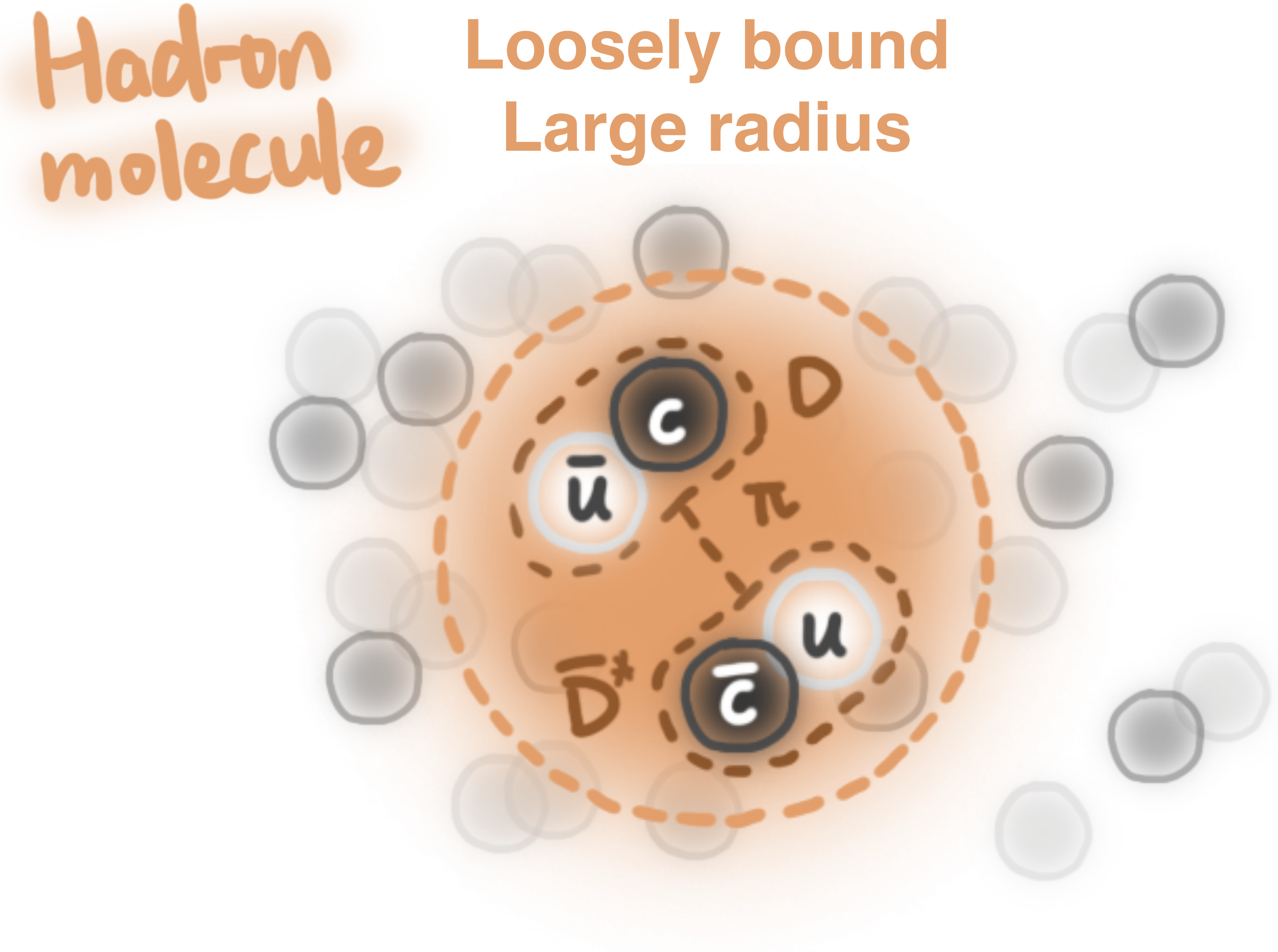
Production Mechanism Probe Exotica Structure

20-year debate of X(3872) nature

Discriminate nature of exotica in heavy-ion collisions (color dense environments)



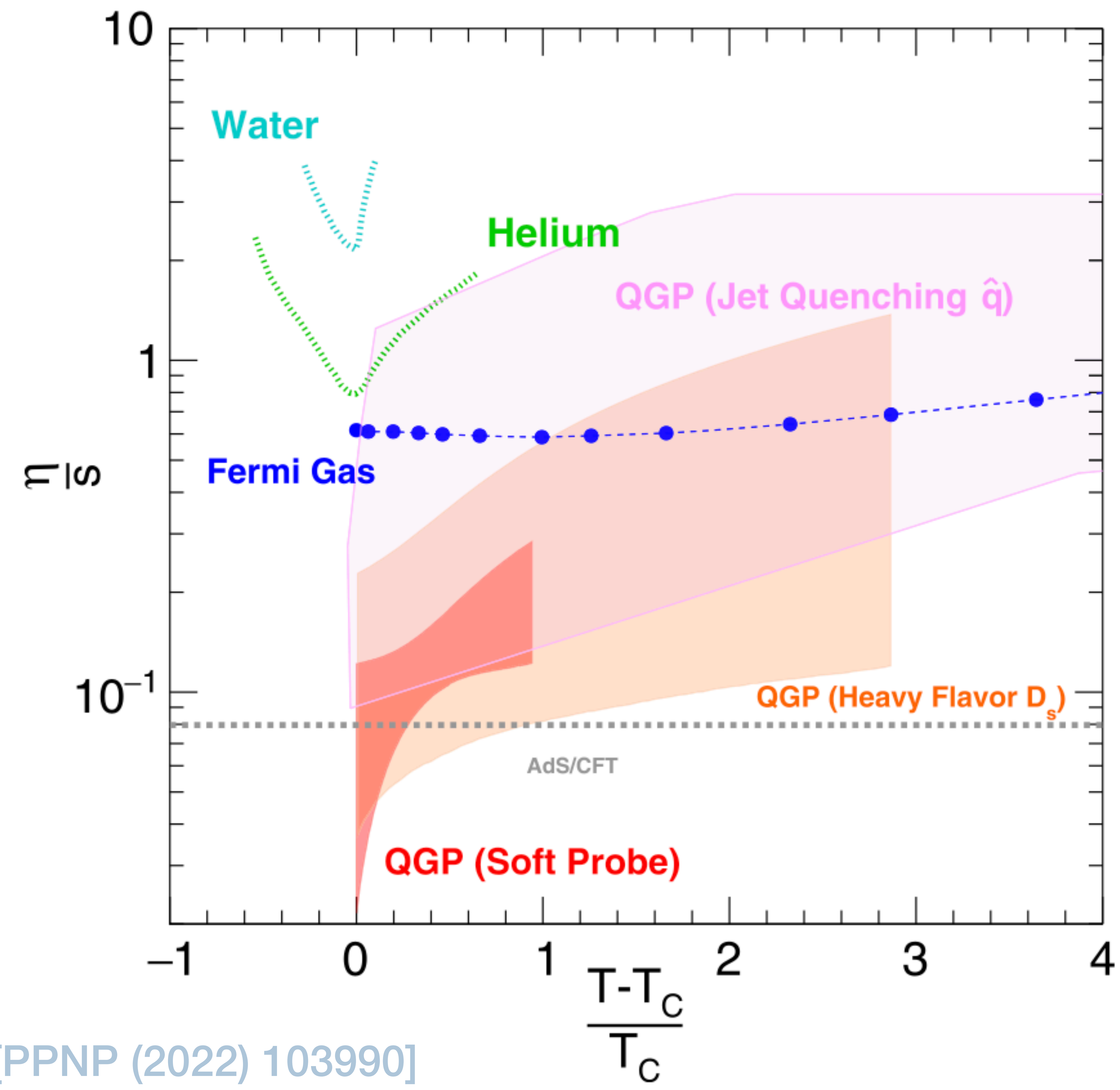
Tightly bound
Small radius



Loosely bound
Large radius

Will be discussed in Su Houng's talk [link]

Let Probes Be Probes



[PPNP (2022) 103990]

- Specific shear viscosity η/s derived by HF D_s
  - Consistent with soft probe
    - Sizable uncertainty though
  - Hard probes → unique high temperature
- Need substantial efforts to achieve
  - Observables › properties
  - Phenomenology › microscopic structure

Enjoy More!

Topics not covered

- Medium effects in small systems
- Probes of nuclear PDF
- Detection of early EM fields
- Diffusion measurements with correlations
- Hadronization studies with
  - other baryons
  - fragmentation functions
- Polarizations

…

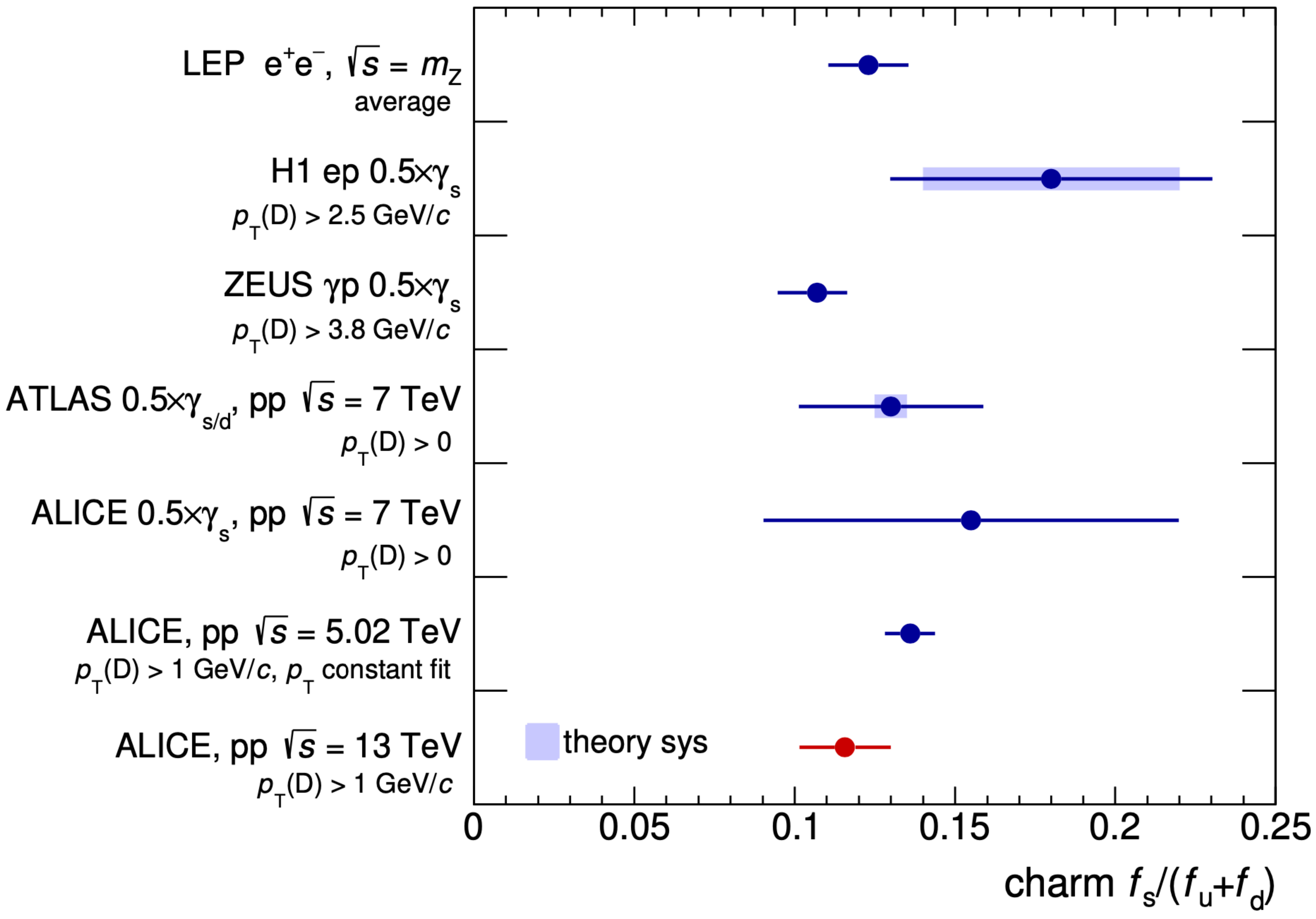
🔗 Heavy flavor result playground

Get to know the fruitful heavy flavor measurements by different experiments

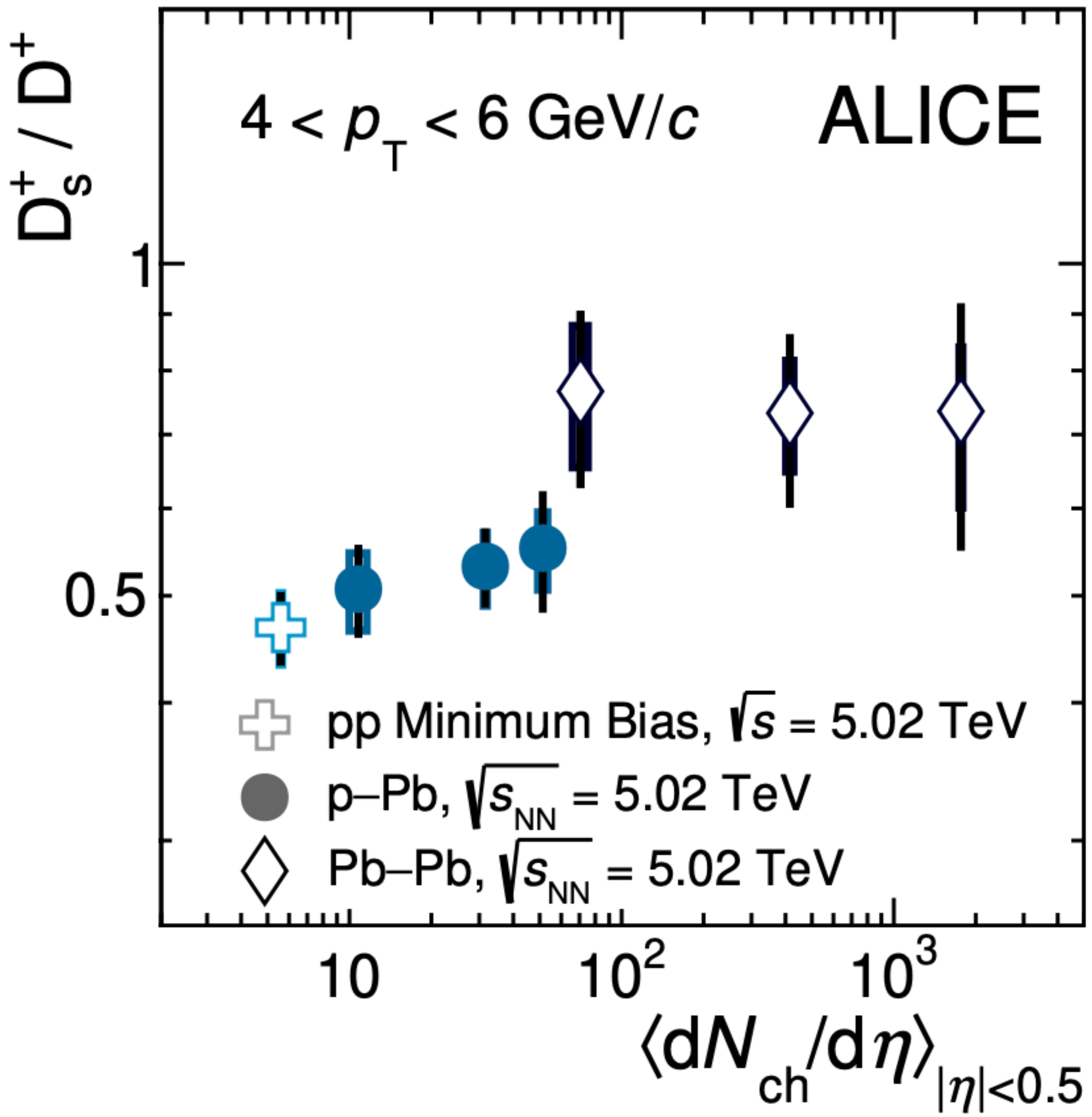
🔗 Heavy flavor in HI publications


Isabelle
Thanks for your attention!

Hadronization Strangeness Mesons

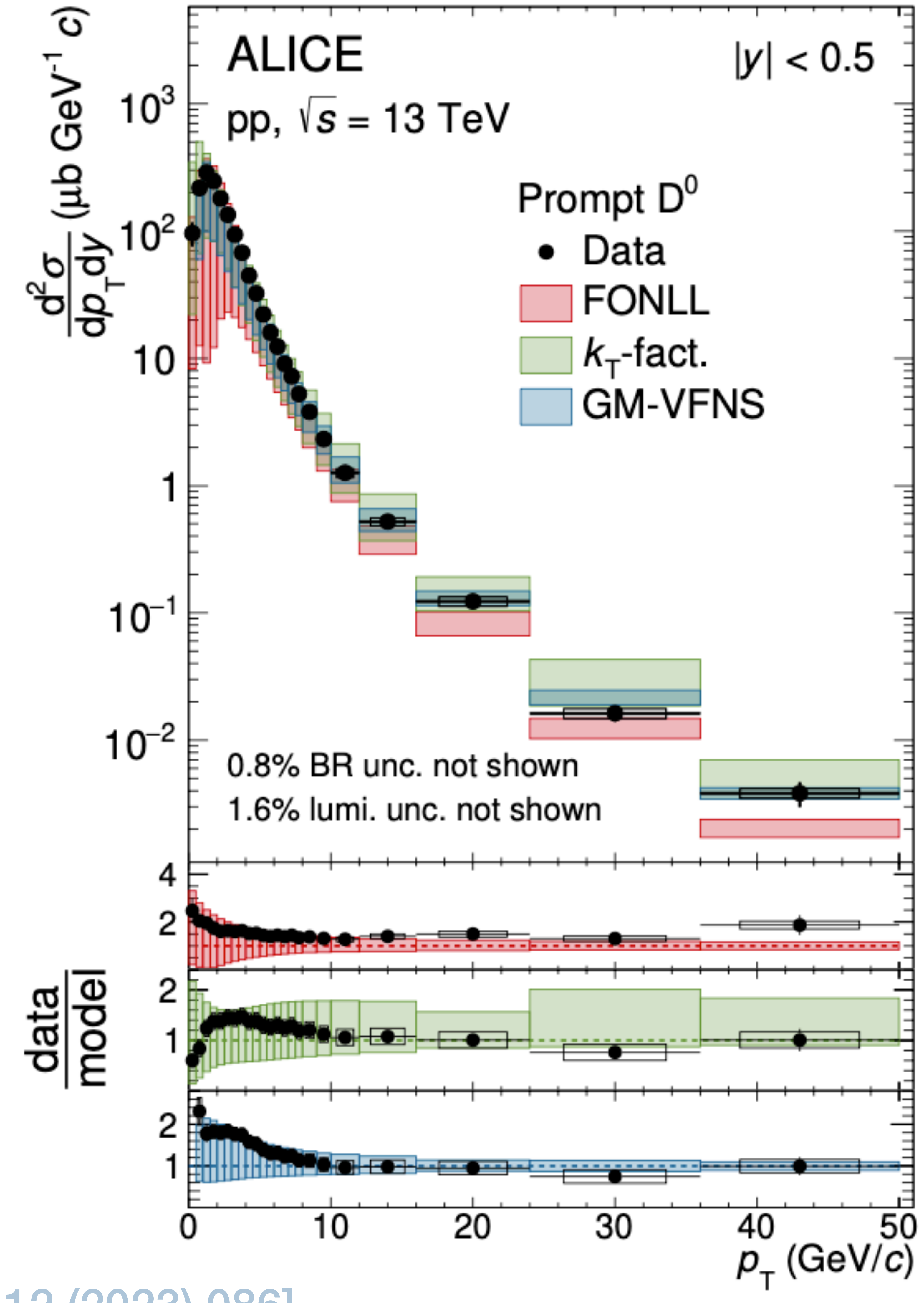


[JHEP 12 (2023) 086]



[JHEP 12 (2019) 092]

Initial Production pQCD Test



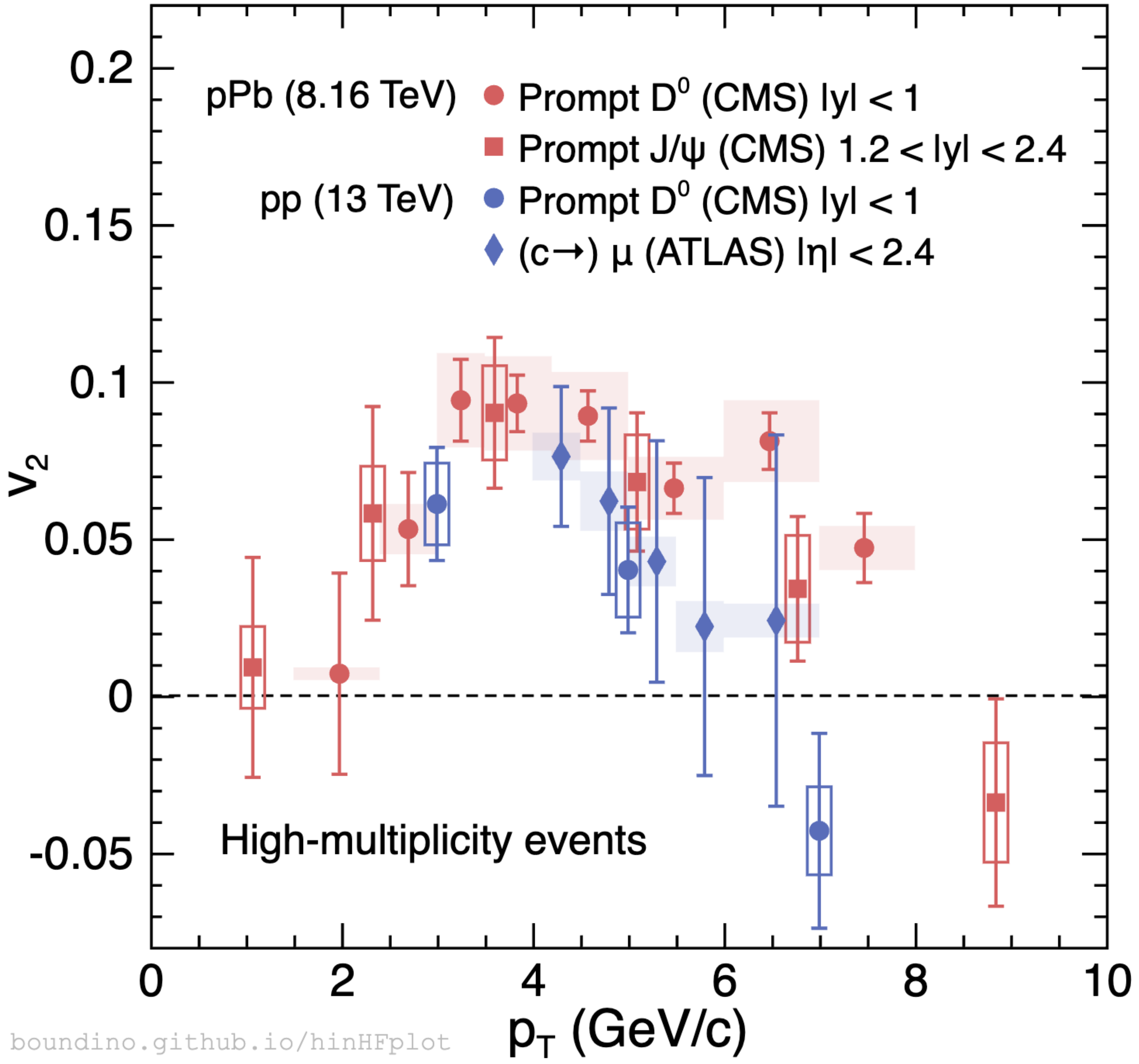
[JHEP 12 (2023) 086]

- Measurements can be described by pQCD calculations with sizable theoretical uncertainty at low p_T
  - Different factorization schemes
- Dominant theoretical uncertainties
  - Factorization and renormalization scale, PDF
  - Can be constrained by high-precision measurements
    - Simultaneous constraints by varying collision energy and rapidity

Small Systems Being Hot Really Matters?

Observations in AA collisions: Can be (kinda) understood in QGP		Observations in pp/pA collisions: Small systems where no QGP is expected
Strong suppression	Jet quenching	No energy loss observed yet
Enhancement of baryon production	Coalescence	Hadronization modification in pp/pA
Collective flow	Pressure driven medium expansion	?
$Q\bar{Q}$ sequential suppression	Dissociation as per binding energy	?

Small Systems Collective Behaviors

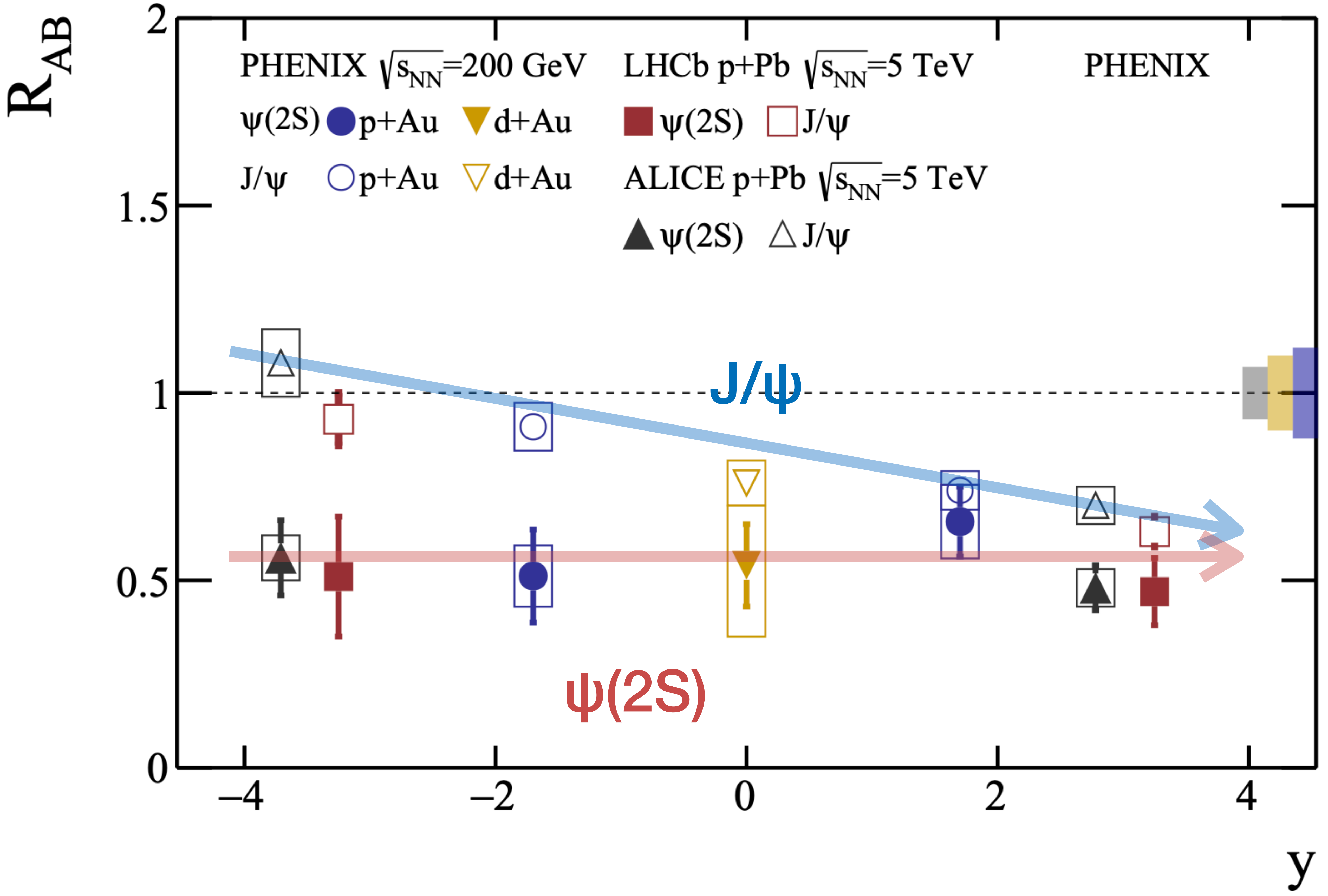


- Non-zero v_2 of charm hadrons in high-multiplicity pp and pPb collisions
- Source of flow signals not decisive
  - Maybe initial transverse momentum correlation in CGC framework
  - Maybe small QGP medium in final states

PRL 121 (2018) 082301 PLB 813 (2021) 136036 PLB 791 (2019) 172 PRL 124 (2020) 082301

Small Systems Quarkonia Sequential Suppression

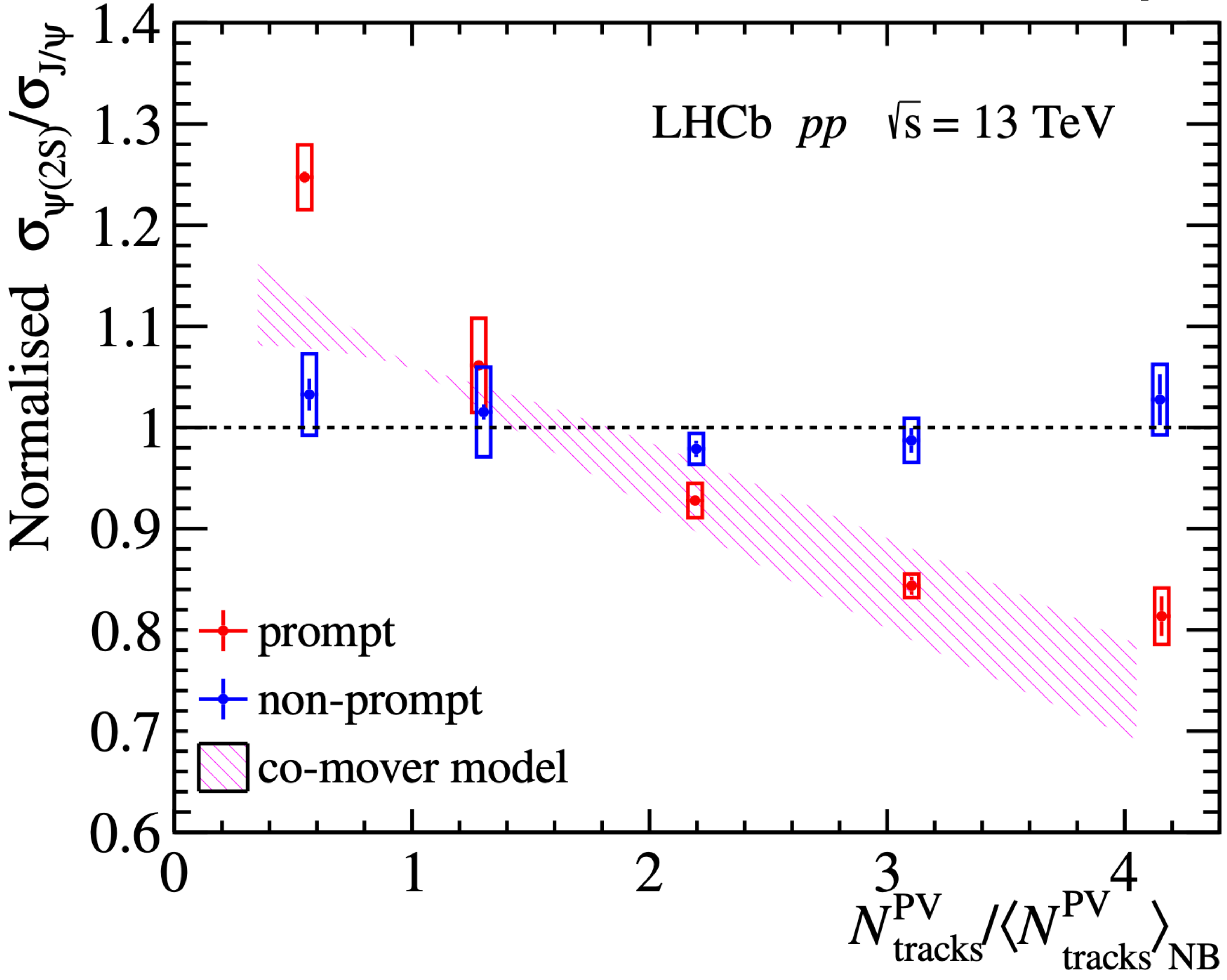
J/ψ or ψ(2S) R_{pA} vs y



- Not surprising J/ψ R_{pA} is not unity
  - Nuclear PDF
  - Initial coherent energy loss
- These initial state effects cannot explain different R_{pA} of J/ψ and ψ(2S)

Small Systems Quarkonia Sequential Suppression

Normalized ψ(2S) / J/ψ vs multiplicity



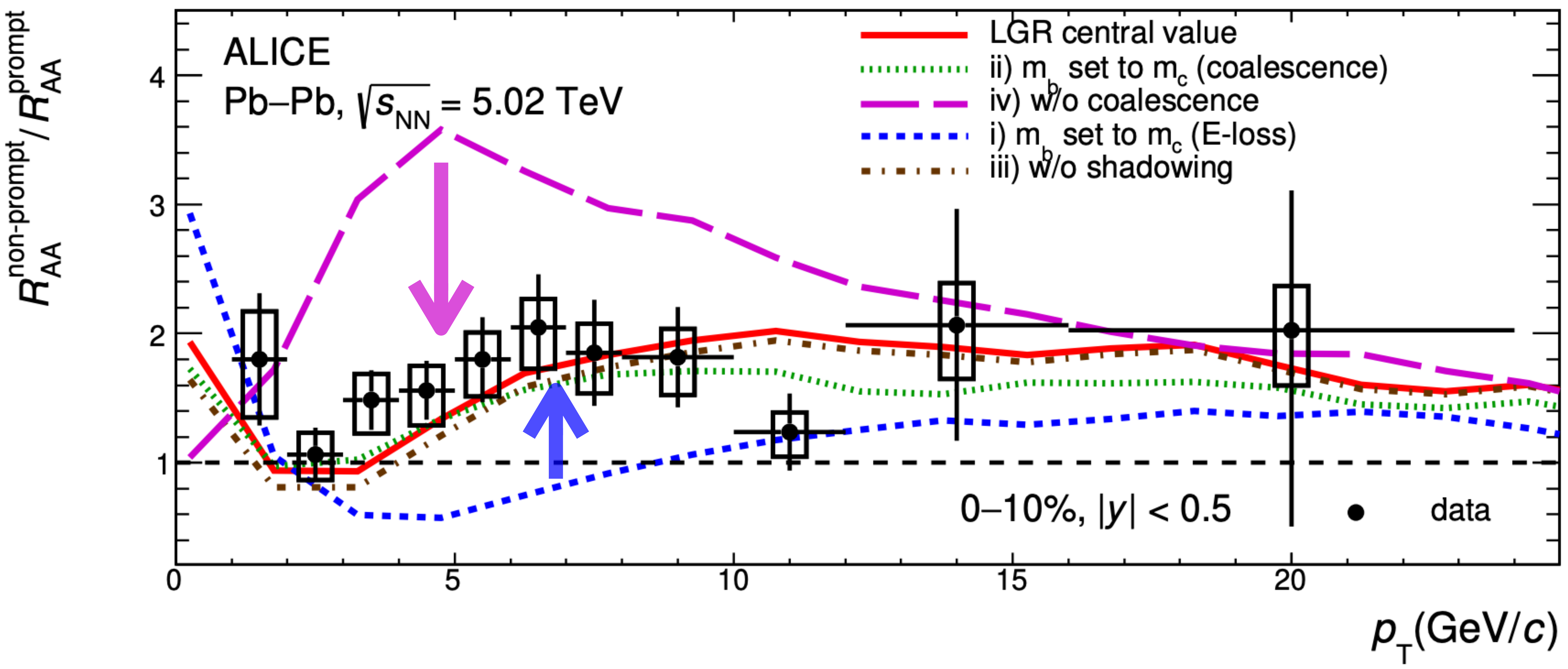
[JHEP 05 (2024) 243]

- Double ratio of ψ(2S) to J/ψ
  - Cancel initial state effects
- Vary multiplicities
  - Examine potential final state effects
    - comover dissociation
    - small medium droplet created

R_{AA} Flavor Dependence

Non-prompt D R_{AA} / Prompt D R_{AA}

Beauty / charm



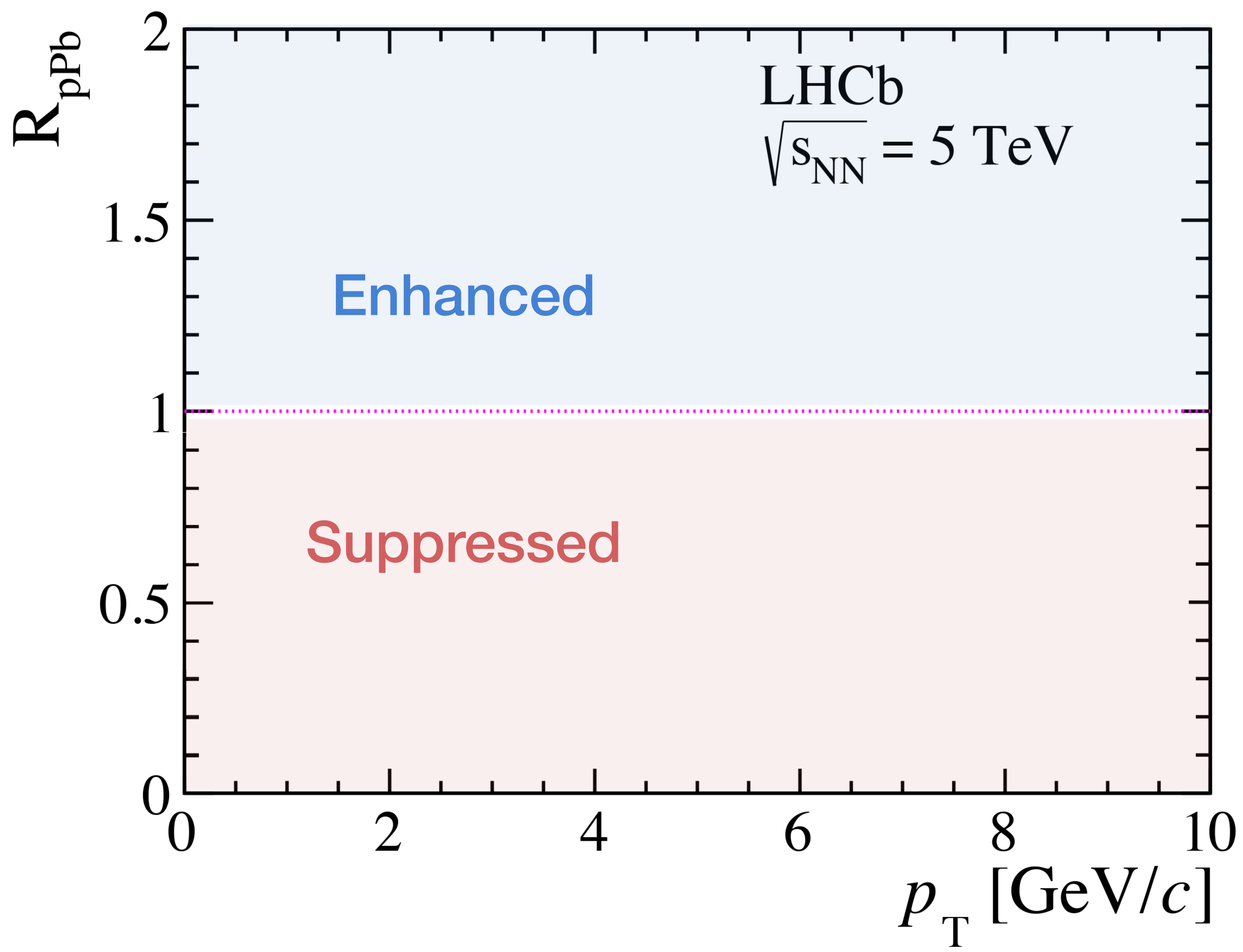
[JHEP 12 (2022) 126]

nPDF *small effect*
- Simultaneous effect on charm and beauty

Mass dependent energy loss
significant effect
- Enhance difference between c and b

Hadronization
significant effect
- Reduce diff between c and b

Initial Production Nuclear Modification



Is initial production in A-A collisions just superposition of nucleon-nucleon collisions?

- p-A collisions to test these kind of effects
  - Ion as collision particles
  - No medium effect expected

- Observable of particle yield modification in pA collisions compared to pp

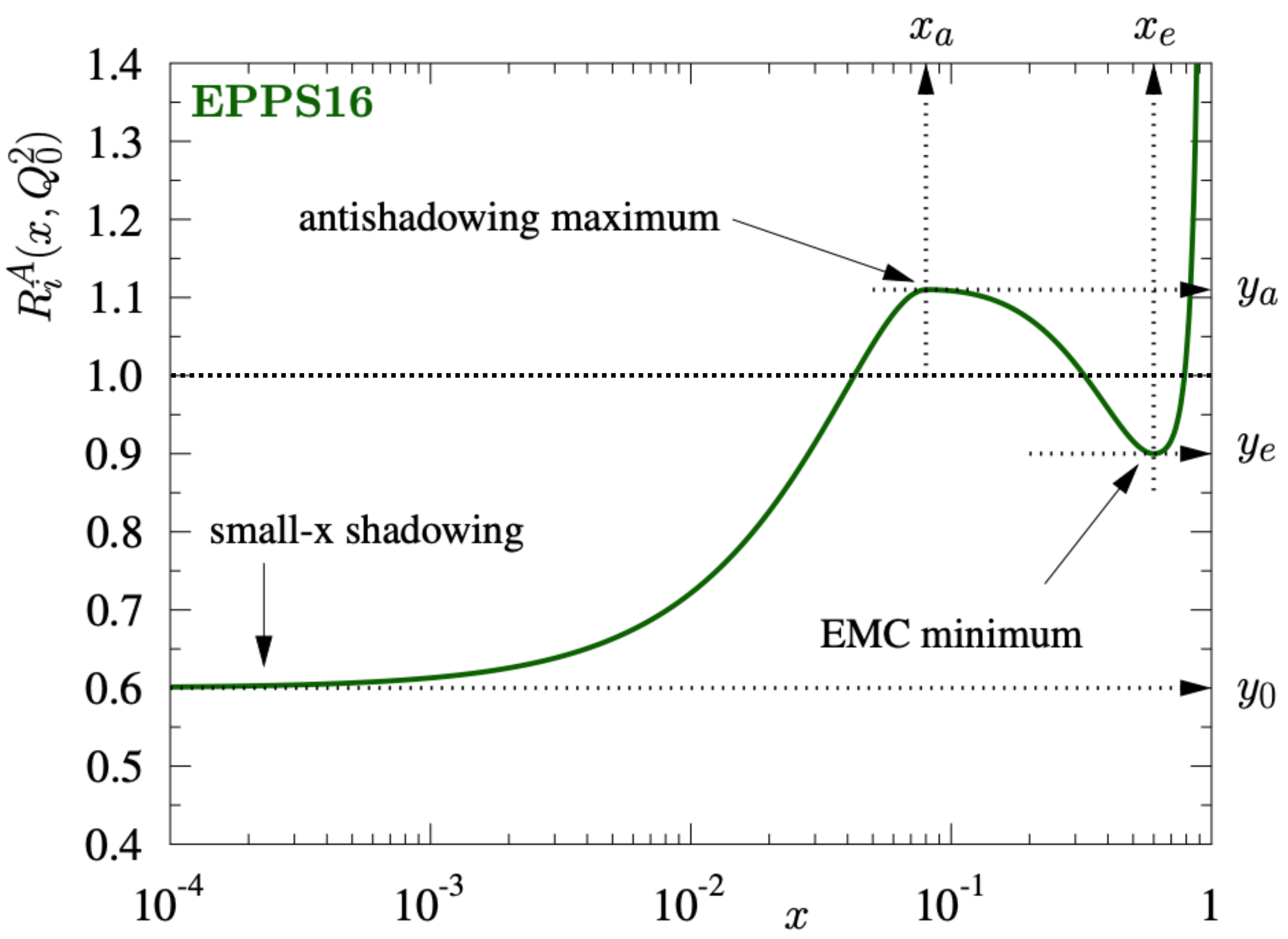
$$R_{pA} = \frac{d\sigma_{pA}/dp_T}{A\, d\sigma_{pp}/dp_T} \quad \begin{matrix} \leftarrow \text{pA} \\ \leftarrow \text{pp} \end{matrix}$$

  - R_{pA} should be 1 in the naive picture above

Initial Production Nuclear PDF

Illustration of nPDF / proton PDF

Parton Distribution Function



[EPJC 77 (2017) 163]

- For low-p_T D mesons in A-A collisions

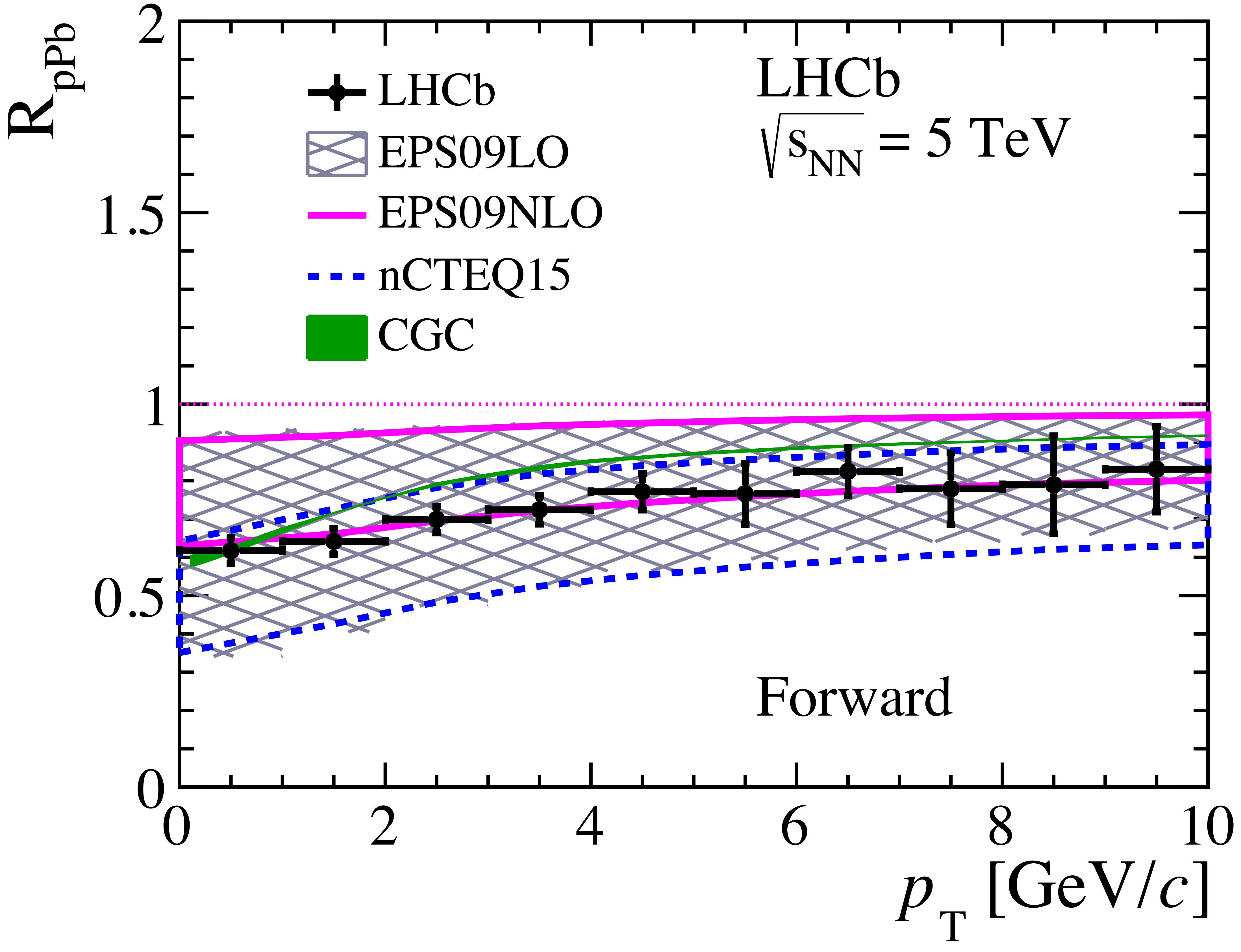
$$x \sim 2\frac{\sqrt{(m_D^2 + p_T^2)}}{\sqrt{s_{NN}}}e^{-y}$$

  - $x \sim 10^{-3}$-10^{-2} for mid-rapidity
  - mix of $x \sim 10^{-5}$-10^{-4} and $x \sim 10^{-2}$-10^{-1} for LHCb rapidity

- In most cases for HF hadrons, nPDF leads to
  - suppression at low p_T shadowing
  - mild enhancement at very high p_T anti-shadowing

Initial Production Nuclear PDF

Forward D^0 R_{pPb}

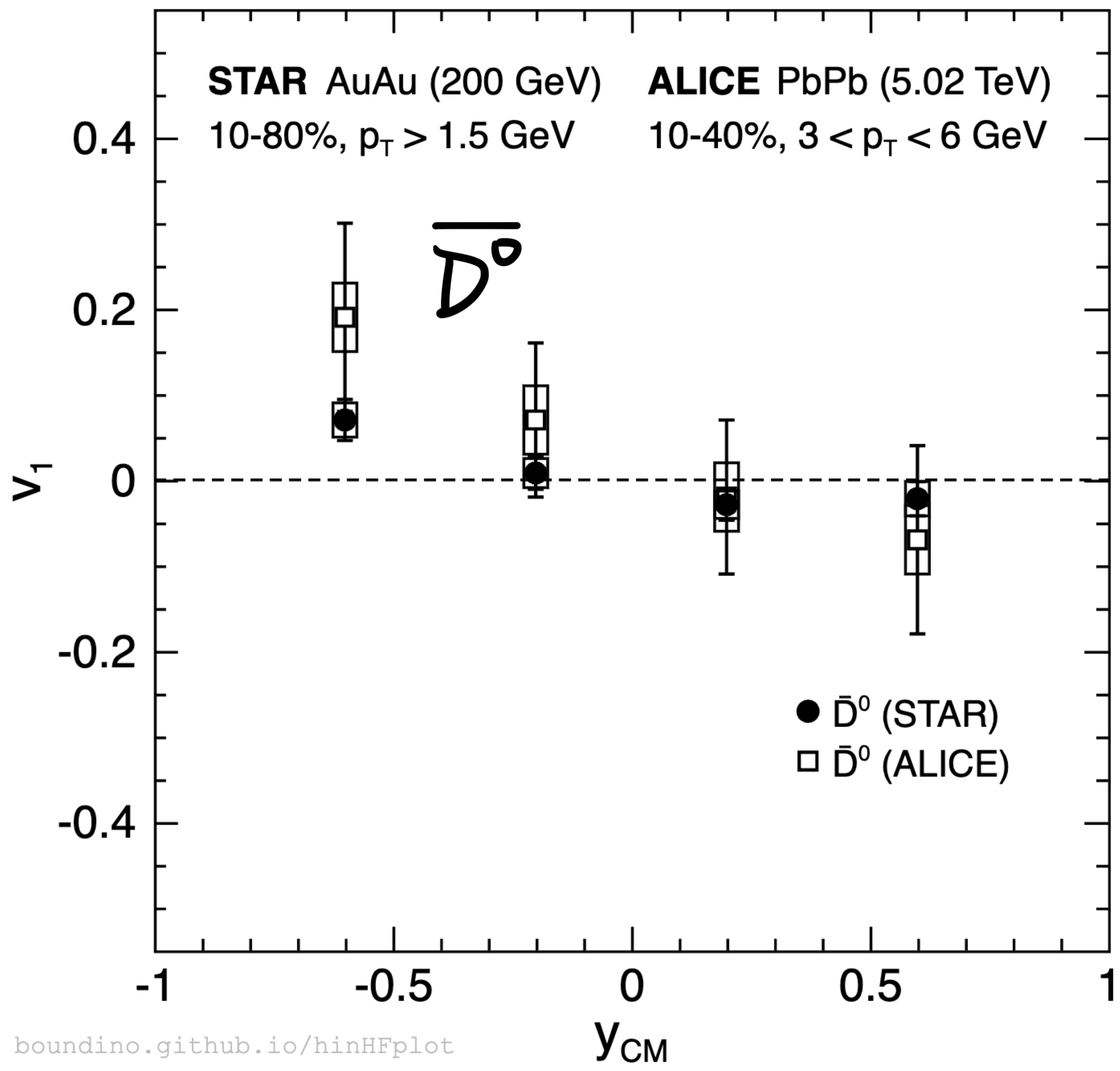


[JHEP 10 (2017) 090]

- D^0 suppressed at low p_T in forward rapidity in pA
  - Nuclear PDF model can describe it
    Nucleons in ions have different PDF from free protons
- nPDF is common input for theoretical calculations
  Not limited to heavy flavors
  - constrained by different probes, among them
  - heavy flavors are important probes for gluon nPDF
  - gluon nPDF is one of the poorest constrained

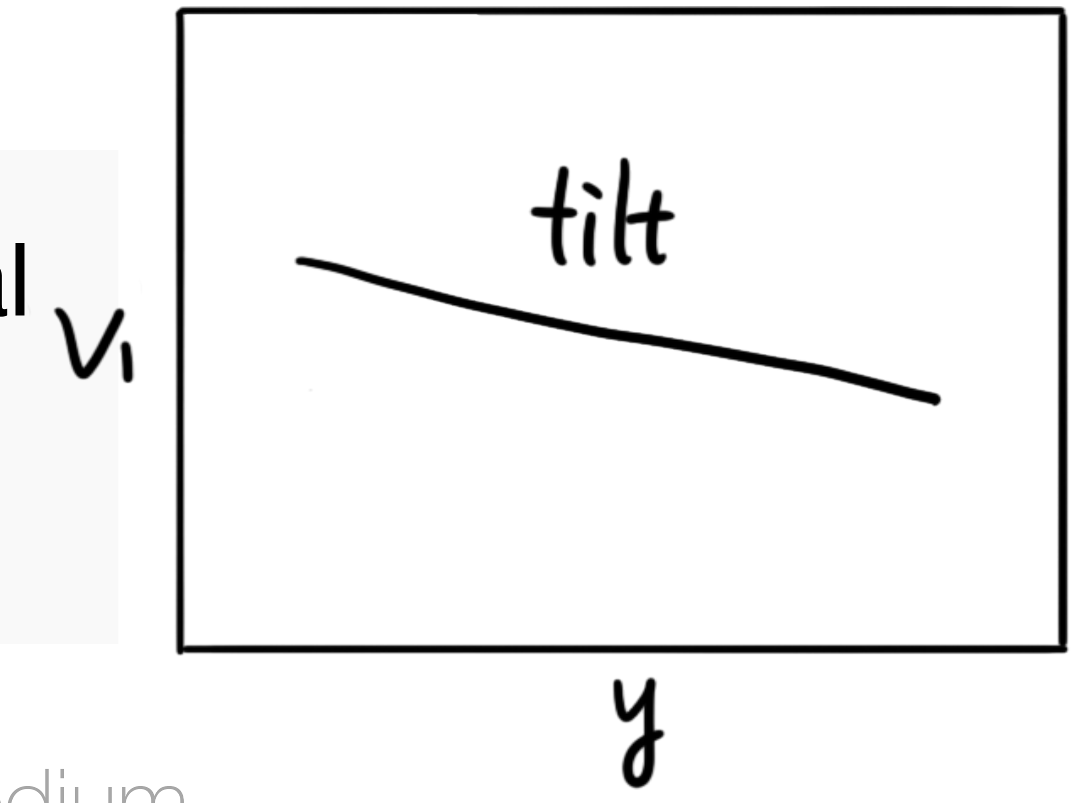
HF Probe Initial Condition Tilt of Medium

v_1 vs. y in PbPb, AuAu

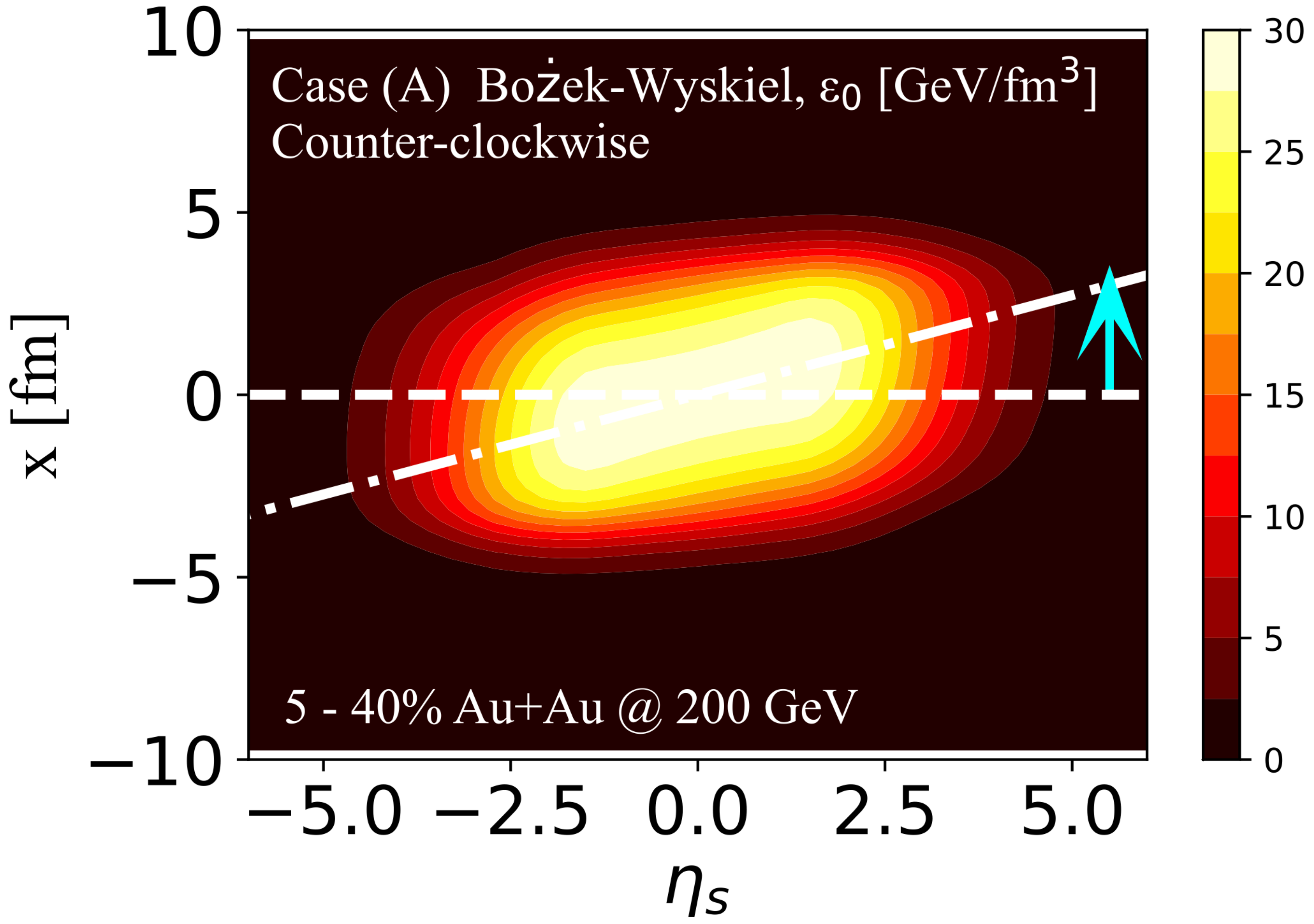


PRL 125 (2020) 022301
PRL 123 (2019) 162301

- Tilt → Longitudinal structure of initial energy density distribution ➡ Non-zero (rapidity-dependent) v_1

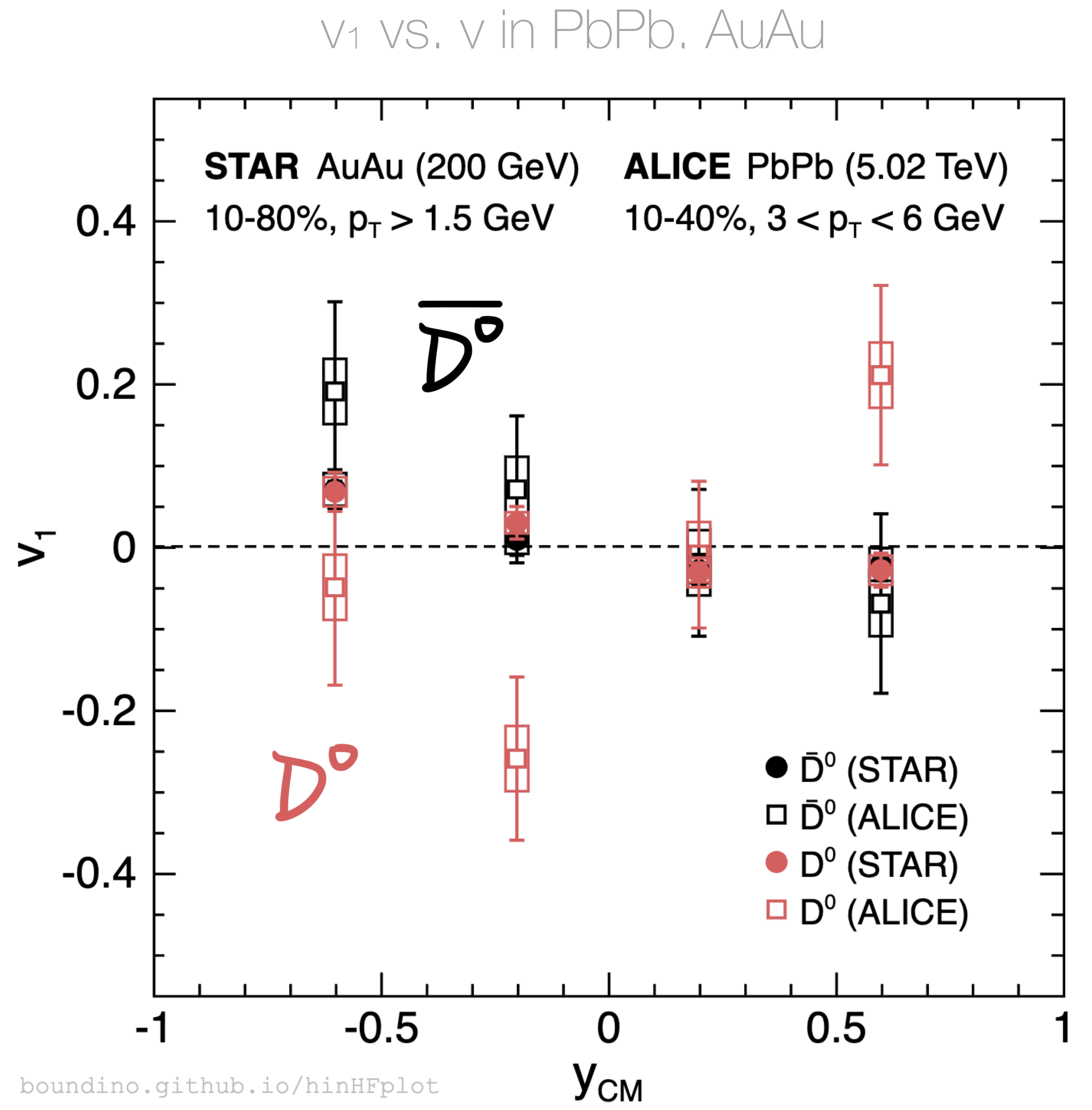


Counter clockwise tilt of the medium



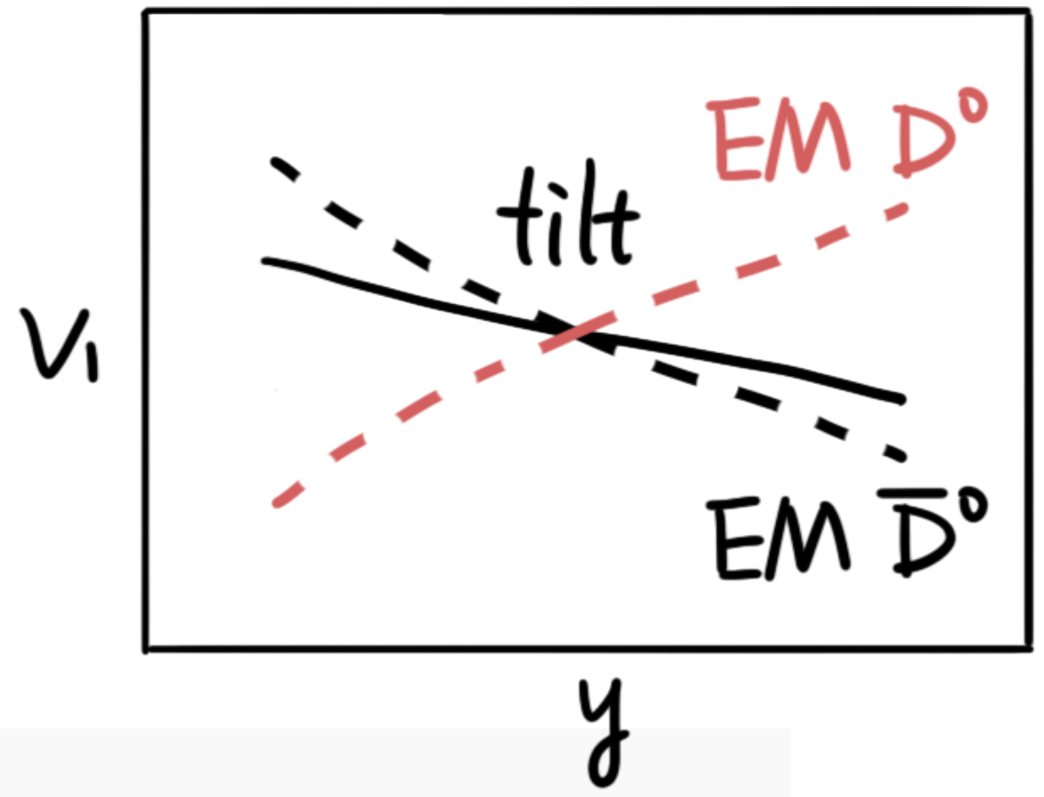
PRC 105 (2022) 034901

HF Probe Initial Condition Strong EM Field



PRL 125 (2020) 022301
PRL 123 (2019) 162301

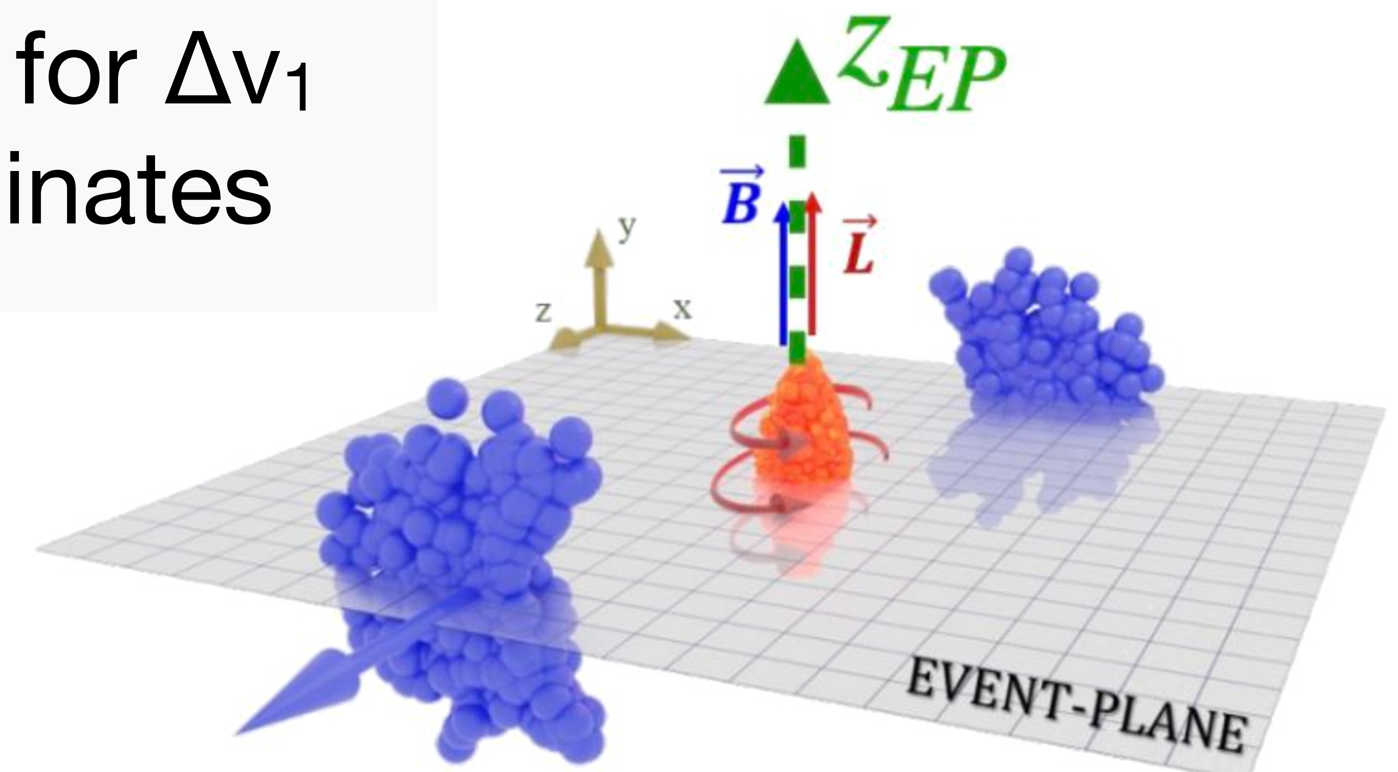
- Tilt → Longitudinal structure of initial energy density distribution
  ➡ Non-zero (rapidity-dependent) v_1



- Strong EM field emerges at early stage
  - Decays quickly → unique chance for heavy flavors

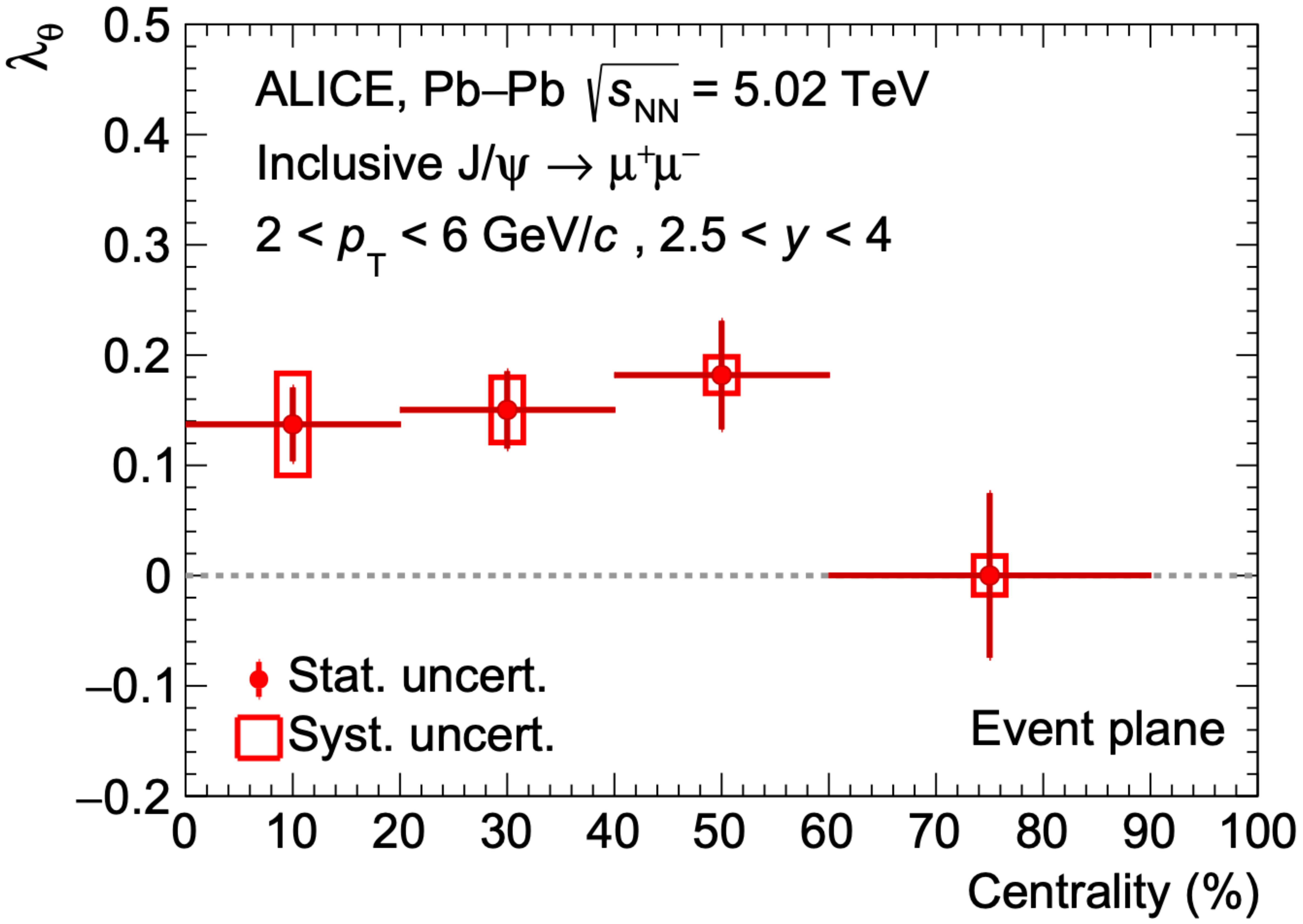
  ➡ Split v_1 of c and $\bar{c}$ → non-zero (rapidity-dep) Δv_1

- Difference b/w LHC and RHIC for Δv_1
  - Possibly different effect dominates



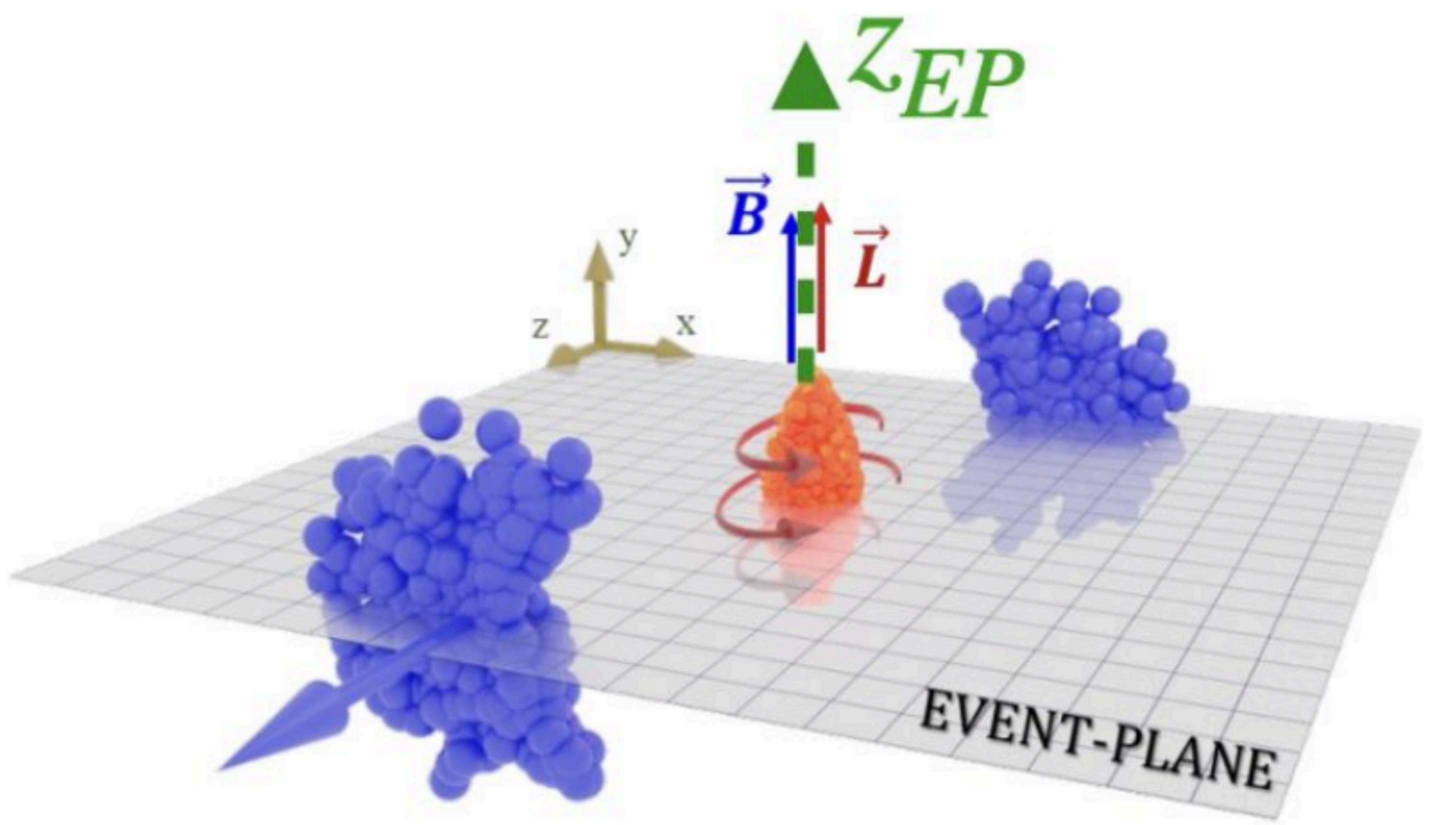
J/ψ Polarization Initial B Field, Vorticity

J/ψ Polarization

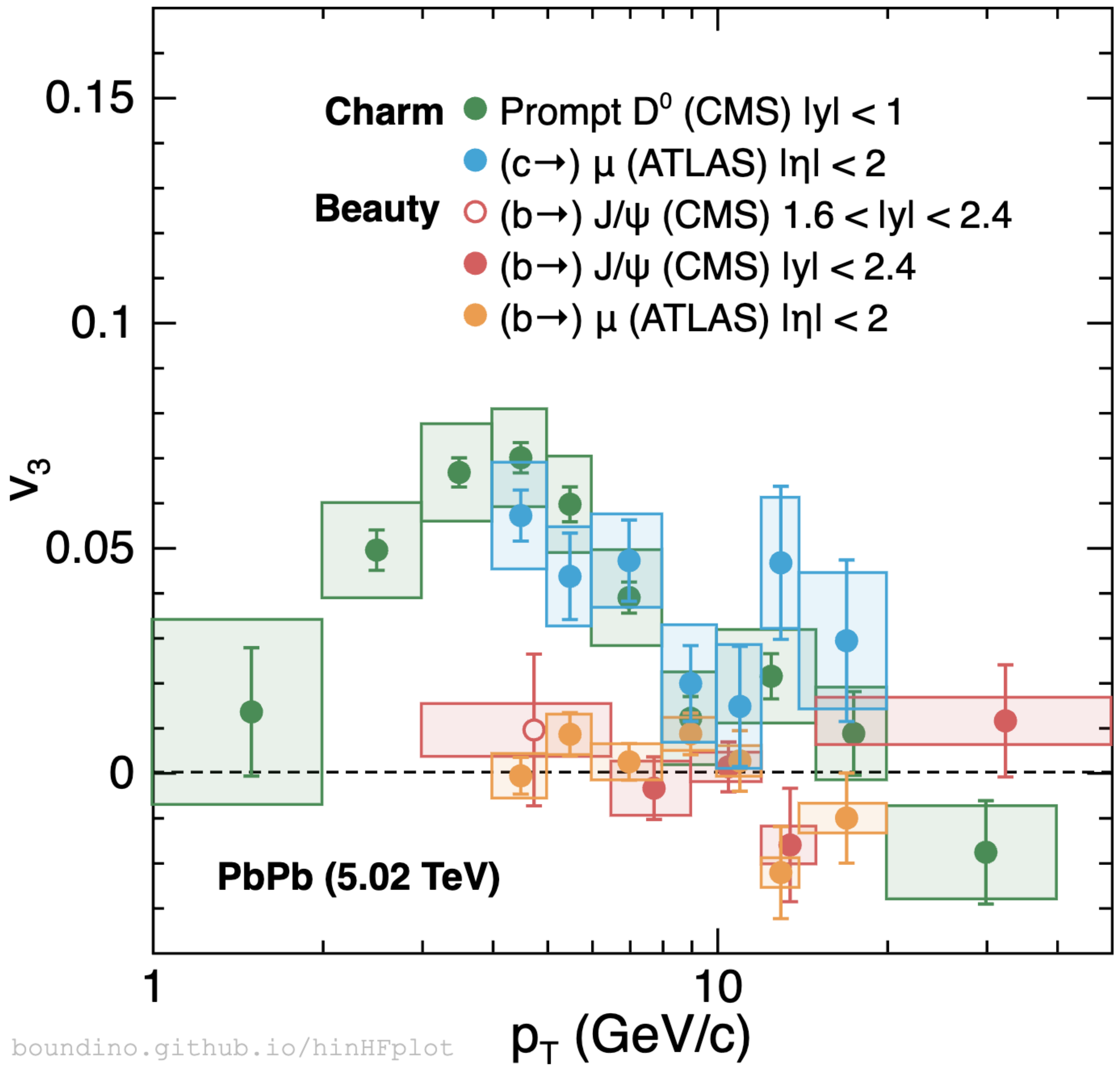


arXiv:2204.10171

- $\lambda_\theta > 0$ → Transverse polarization in the direction perpendicular to the reaction plane
  ➜ connected with
  - Strong magnetic field
  - Rotation at early stage via spin-orbit coupling



HF Probe Fluctuations Initial Geometry

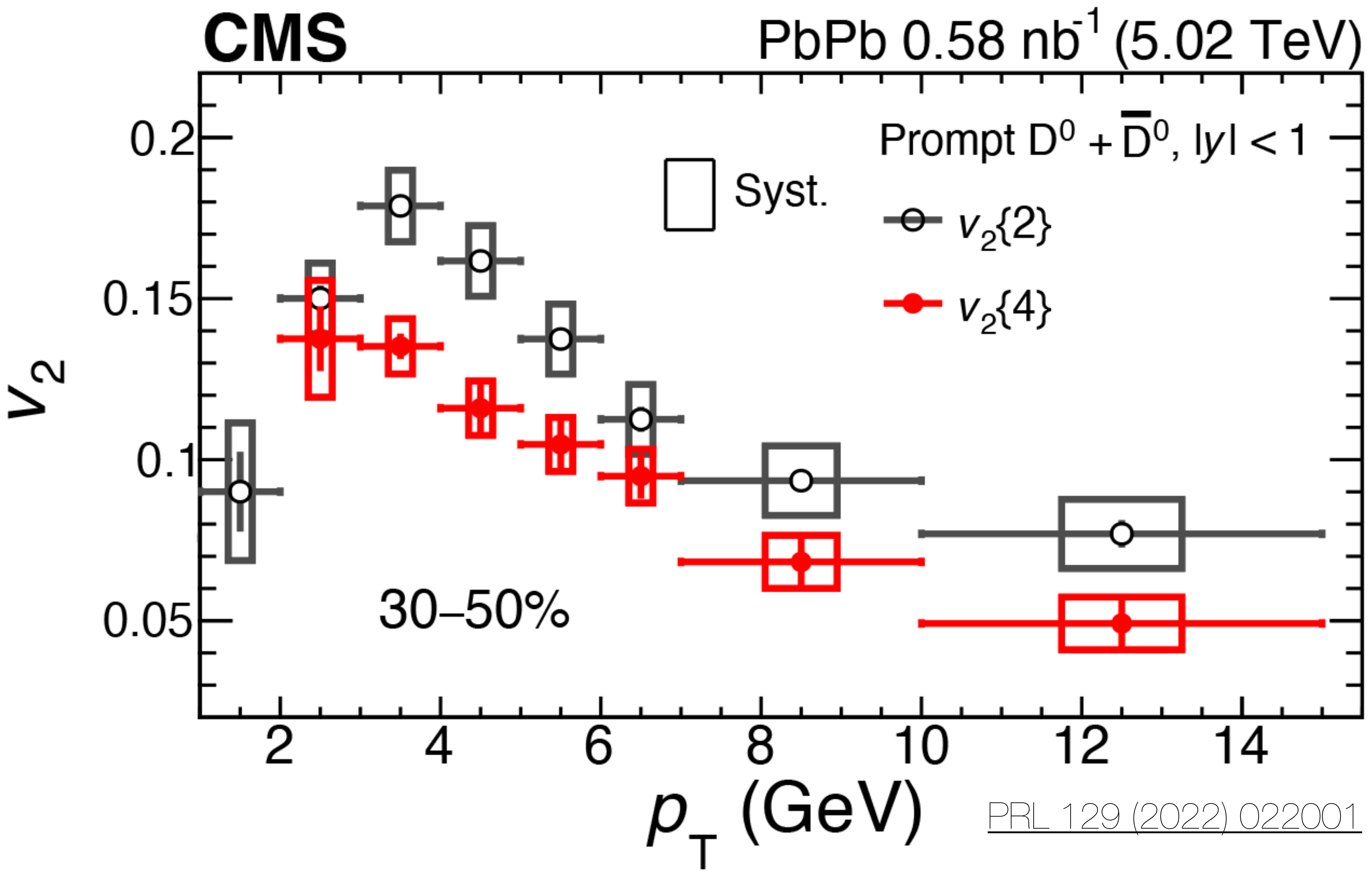


- High-order vn probes event-by-event fluctuation of initial geometry
  - Similar to soft probes but different length-wave probes

PLB 816 (2021) 136253 CMS-PAS-HIN-21-008
PLB 807 (2020) 135595 PLB 807 (2020) 135595

HF Probe Fluctuations Energy Loss

D^0 4-particle correlation $v_2\{4\}$



PRL 129 (2022) 022001

- Probe event-by-event fluctuation
  - $v_2\{2\}^2 \approx \langle v \rangle^2 + \sigma^2$
  - $v_2\{4\}^2 \approx \langle v \rangle^2 - \sigma^2$

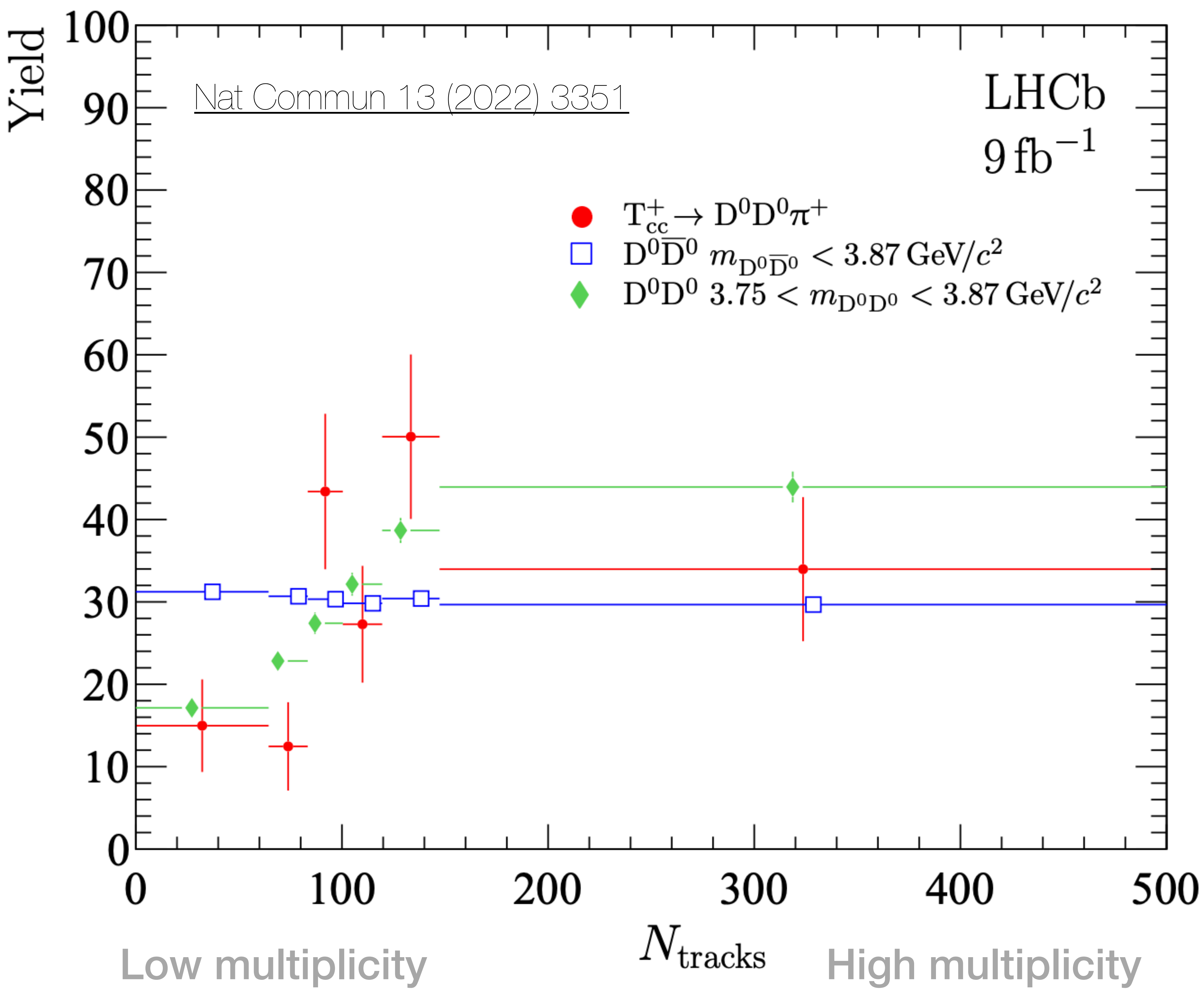
  flow fluctuation

- Indeed $v_2\{4\} < v_2\{2\}$ for D^0
  - Provide additional constraints

- v_2 fluctuations from both initial geometry (soft) and energy loss (hard)

Exotica T_{cc} in High Color Density Environment

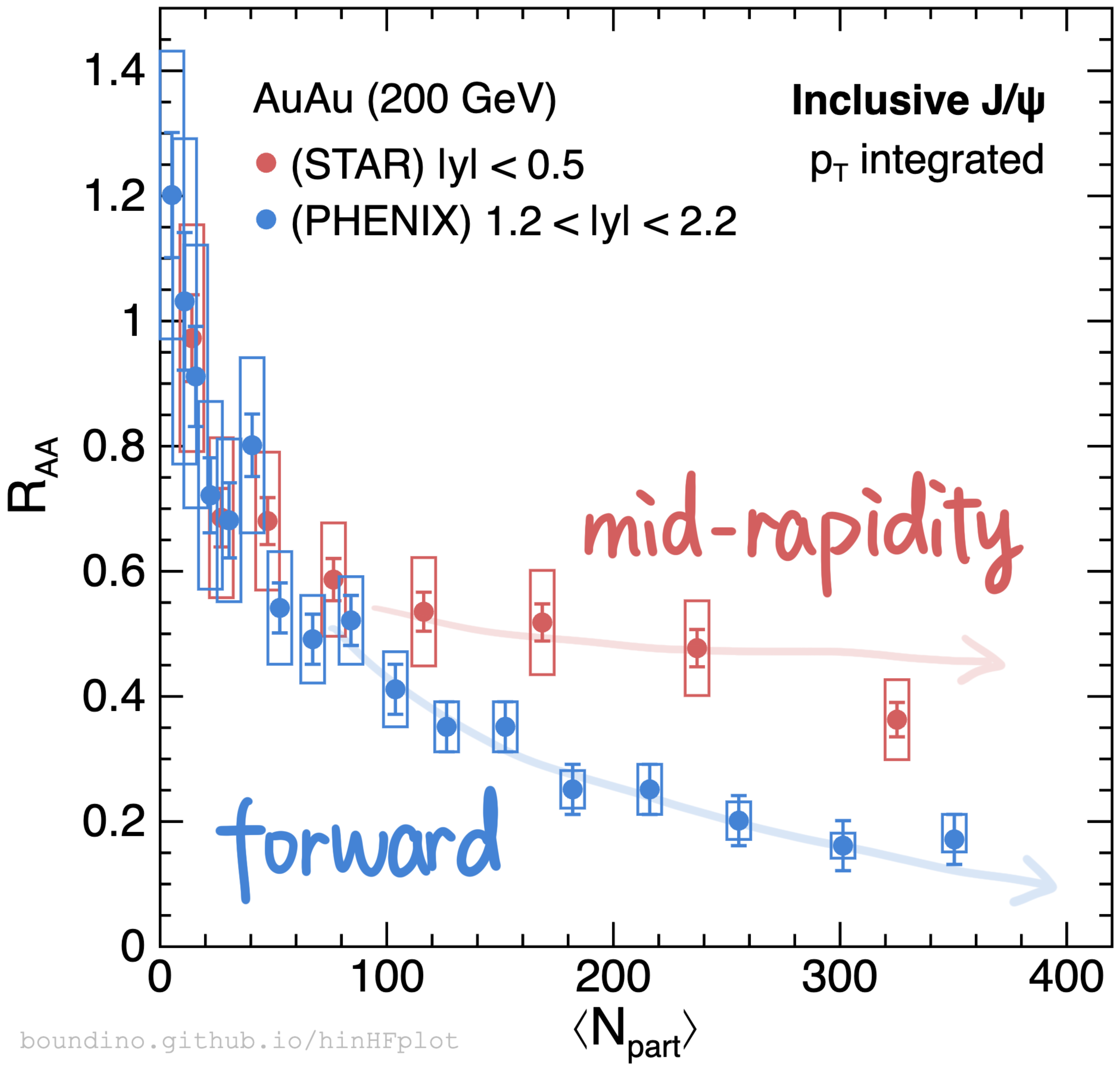
Tcc yield vs. multiplicity in pp



Low multiplicity
High multiplicity

- Similar idea applied on another exotic T_{cc}
- No suppression in high multiplicity
  - Different response as X(3872) to the color dense environment

Charmonia in QGP Other Effects



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

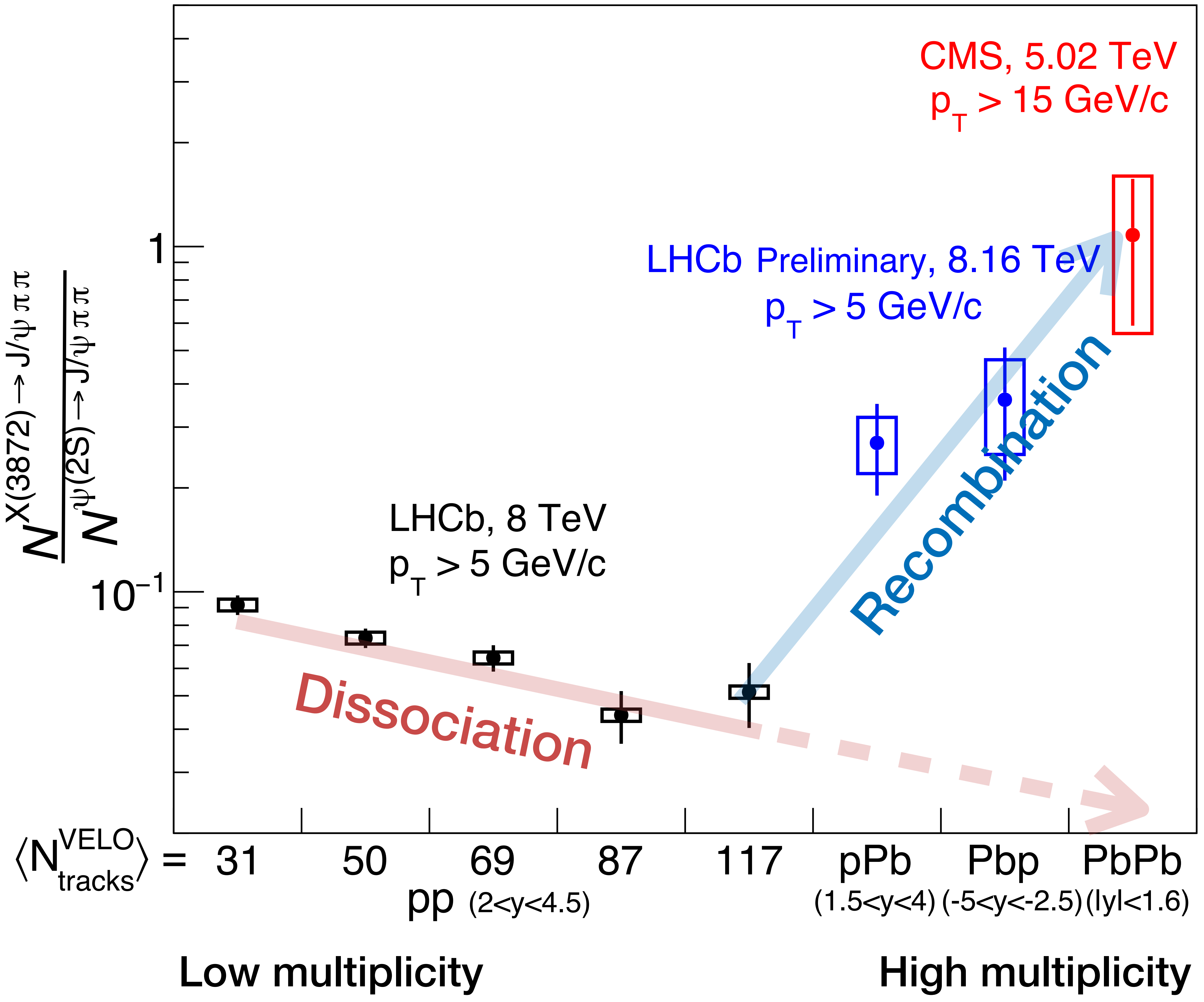
Cold nuclear matter effects

*Not saying rapidity dependence is due to CNM

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

Apply Production Mechanism Probe Exotica Structure

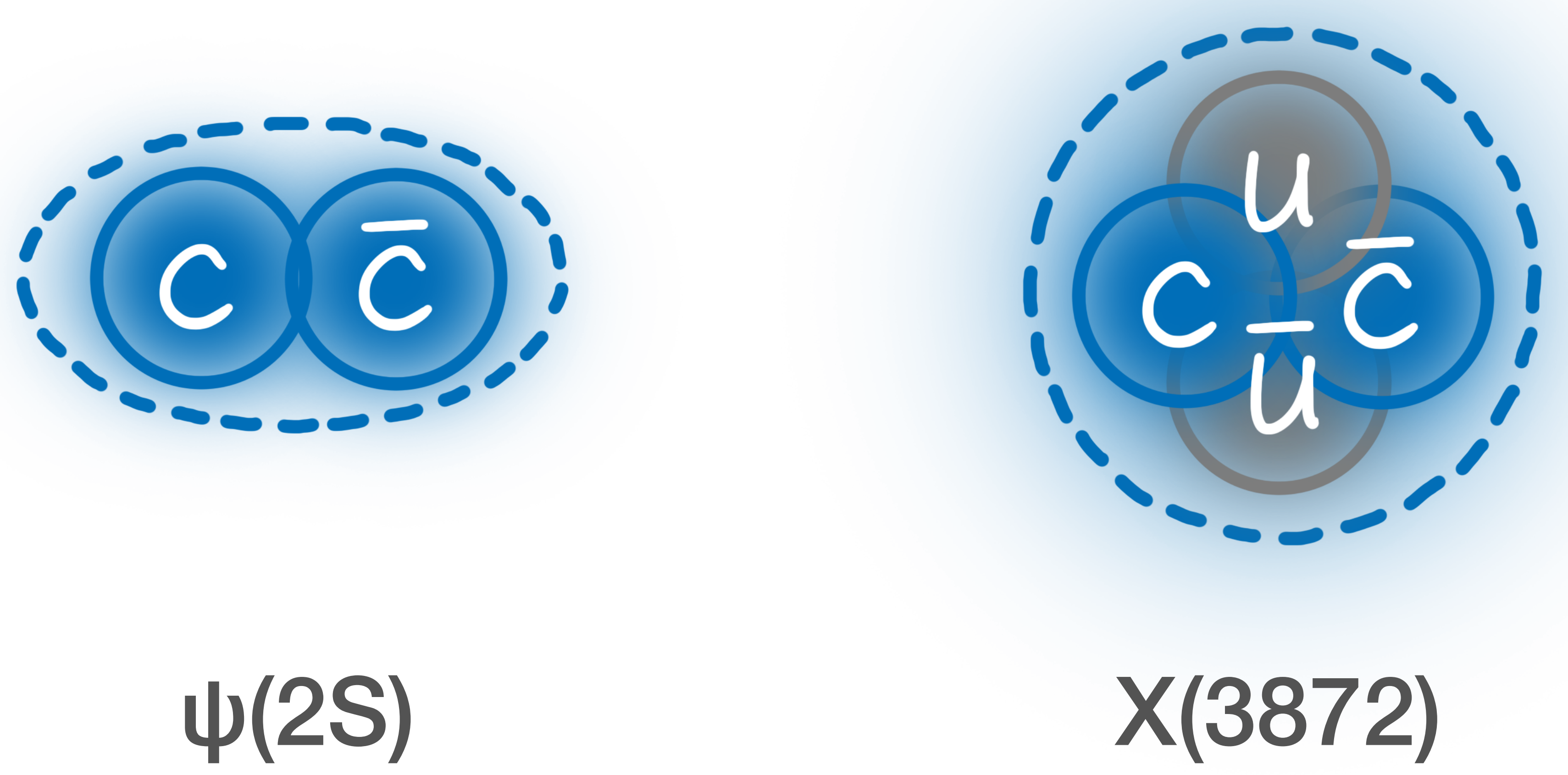
X(3872) / ψ(2S) across collision systems



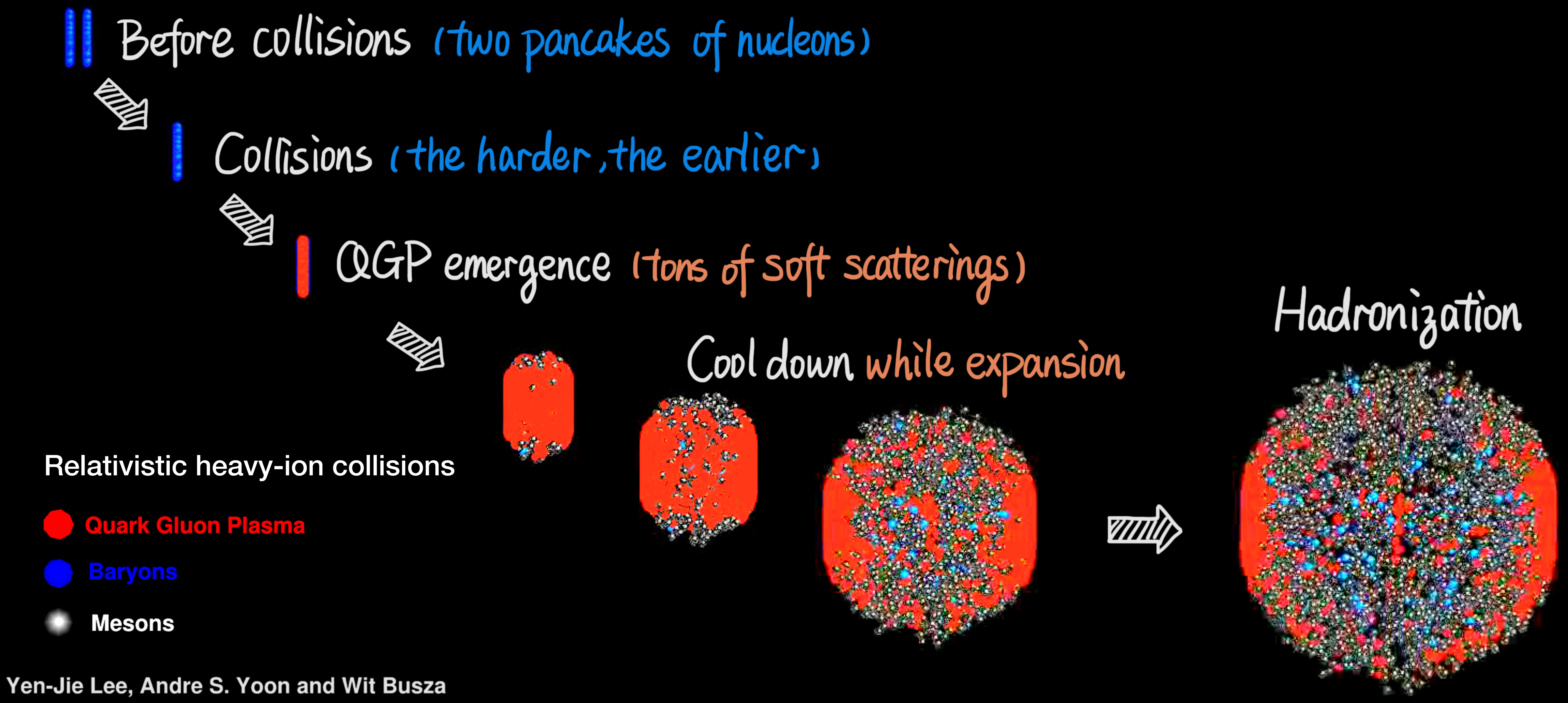
[2402.14975]

X(3872) to ψ(2S) yield ratio across collision systems

- Dissociated by interactions with comovers (pp/pPb) or medium (PbPb)
  - Different binding energy
- Enhanced via recombination



Relativistic Heavy-Ion Collisions

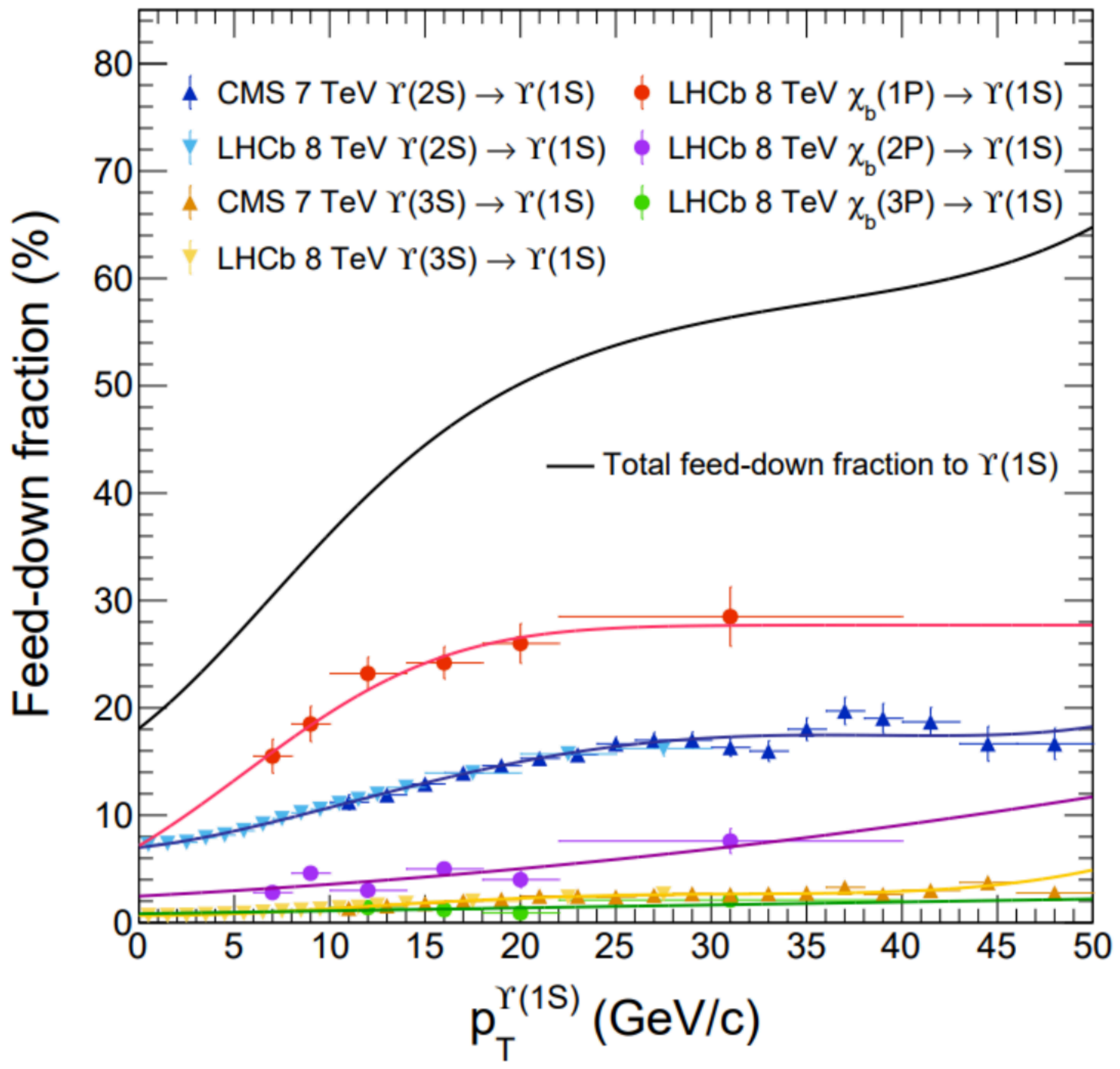


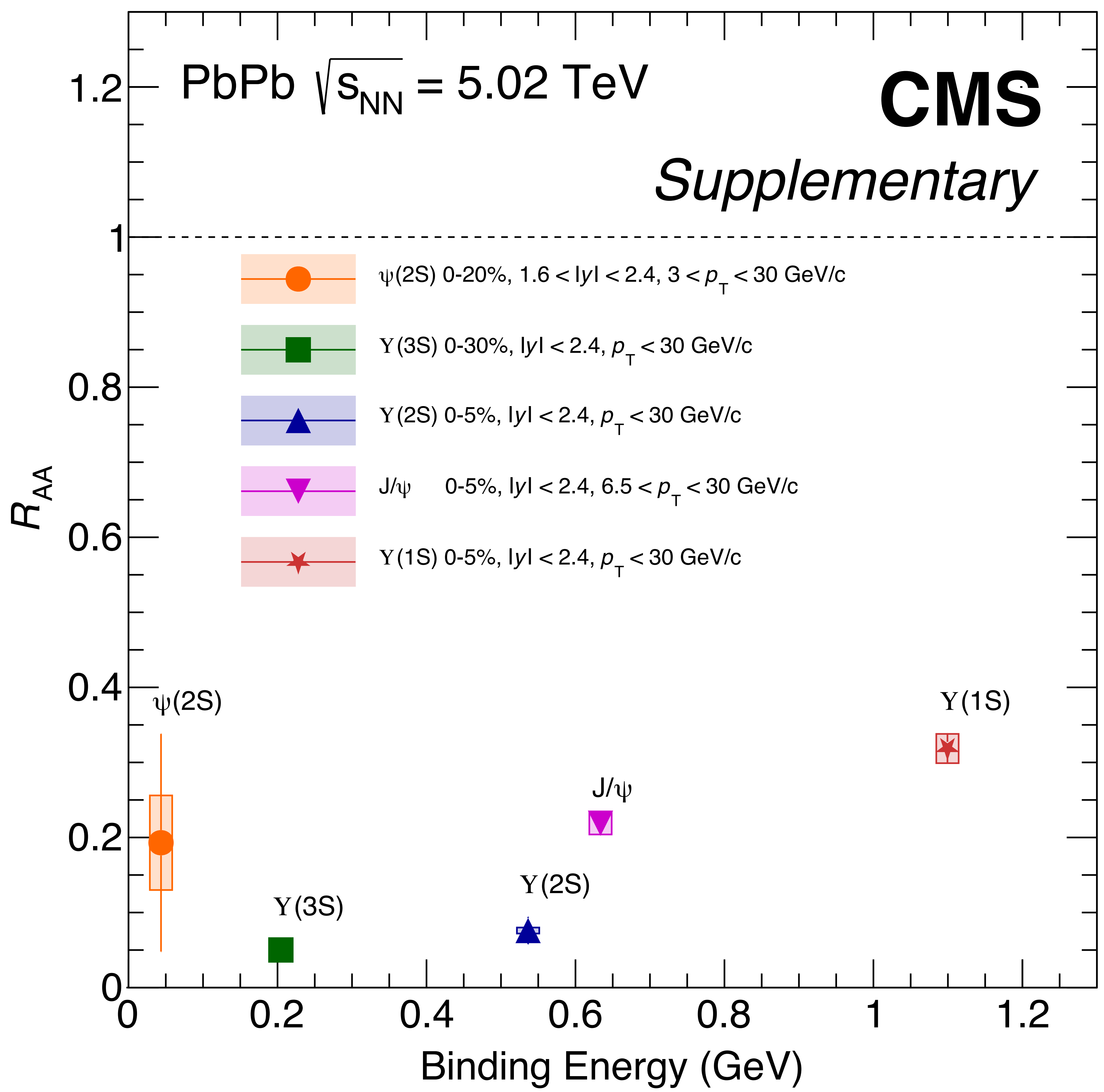
Luminosity Projection Conservative

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}

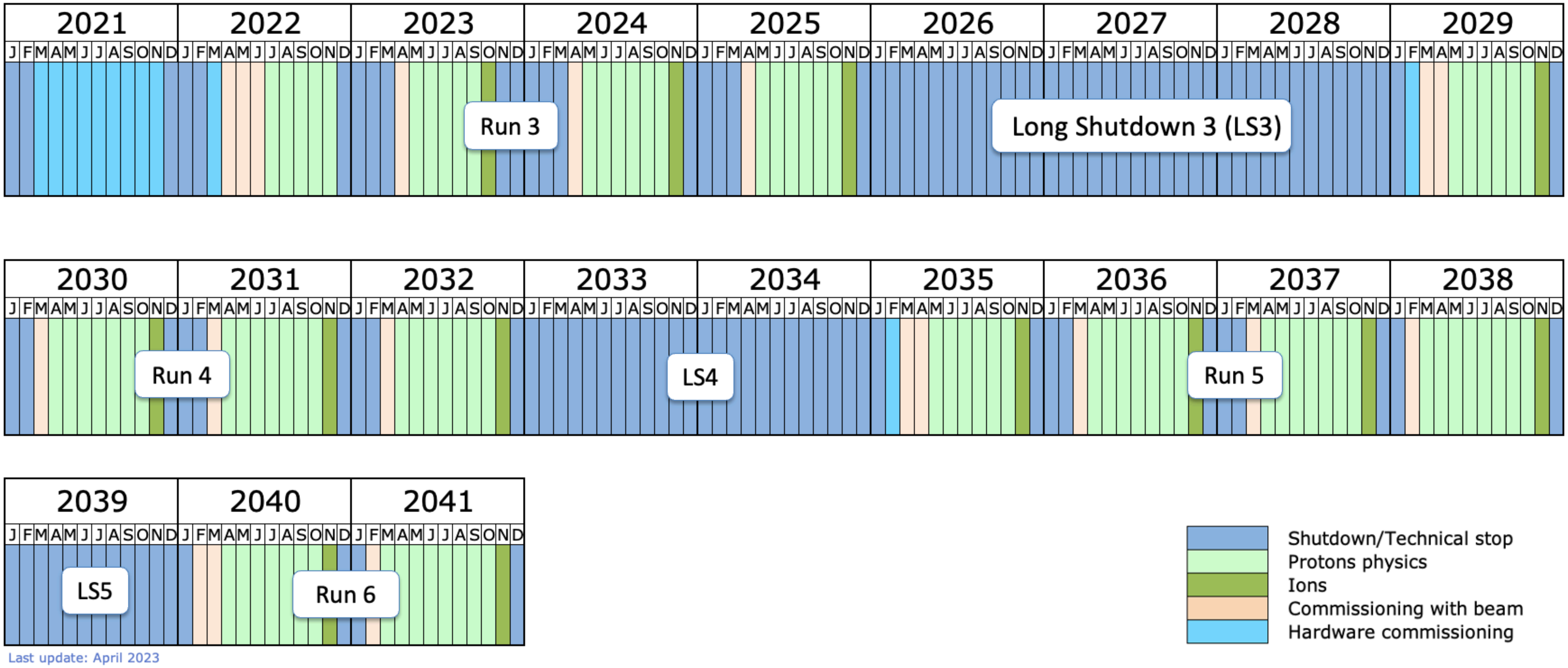
Table 1: Projected LHC performance: For various collision systems, we list the peak luminosity L_{AA}, the average luminosity $\langle L_{AA} \rangle$, the luminosity integrated per month of operation $\mathscr{L}_{AA}^{month}$, also rescaled to the nucleon–nucleon luminosity $\mathscr{L}_{NN}^{month}$ (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

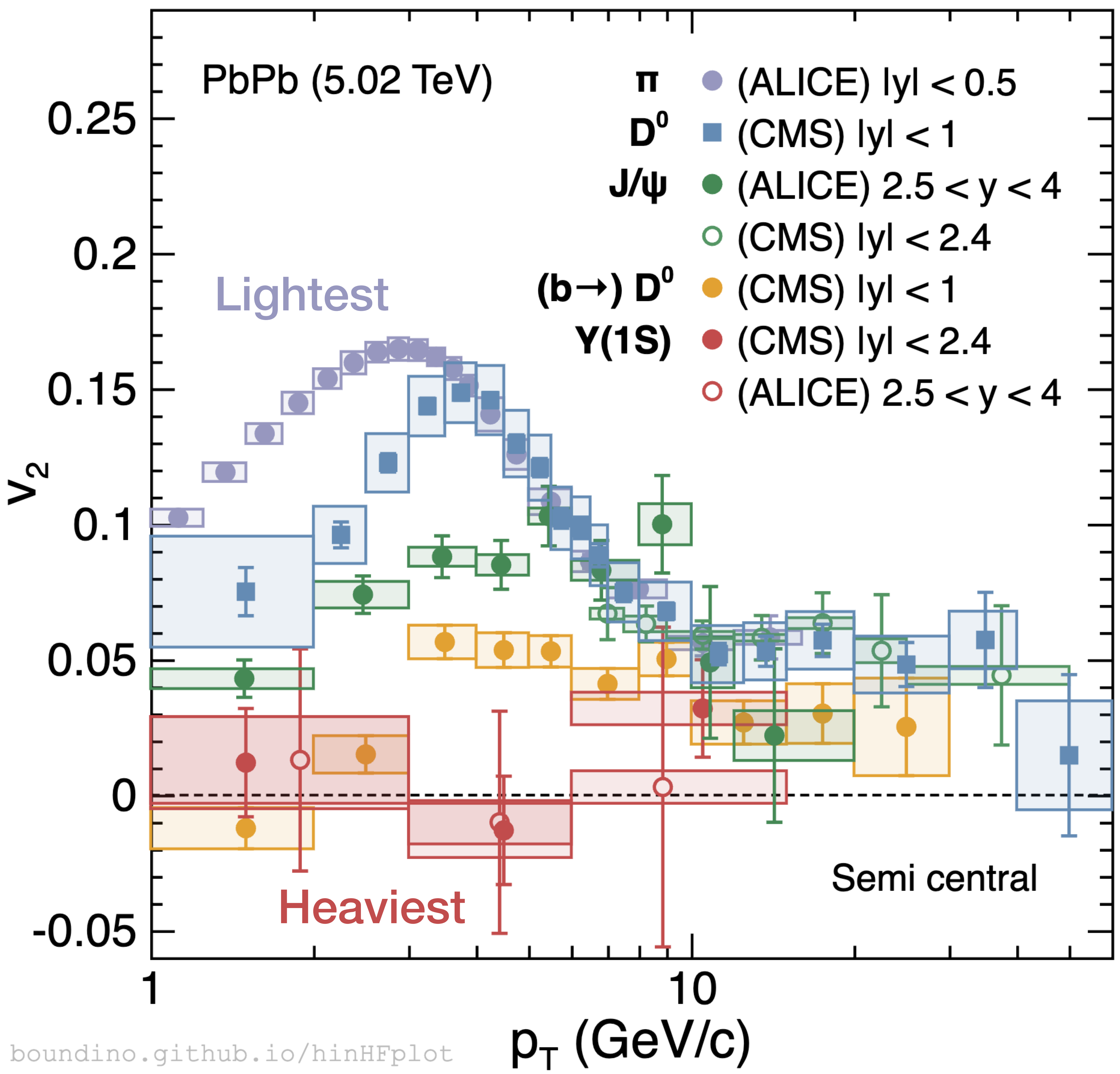




Beam Schedule Long Term



Collective Flow Mass Hierarchy Including Quarkonia



- v_2 hierarchy from lightest to heaviest hadrons

Happy with the flow picture?
Sorry…
Quarkonia actually have different stories

JHEP 10 (2020) 141 JHEP 10 (2023) 115 PLB 819 (2021) 136385 PRL 123 (2019) 192301

Hadronization Strangeness Mesons

Extension for Homework

- Using the same way we read Λ_c and Λ_b results, understand what is the current picture from the measurements of strangeness hadrons

- D_s/D^+ in PbPb PLB 827 (2022) 136986 ALICE
- B_s/B^+ in PbPb PLB 829 (2022) 137062 CMS
- D_s/D^+ vs multiplicity in pPb 2311.08490 LHCb
- B_s/B^0 vs multiplicity in pPb PRL 131 (2023) 061901 LHCb
- D_s/D^+ vs multiplicity in pp PLB 829 (2022) 137065 ALICE