Summary

Jing Wang

CMS HIN Workshop

May 30, 2023

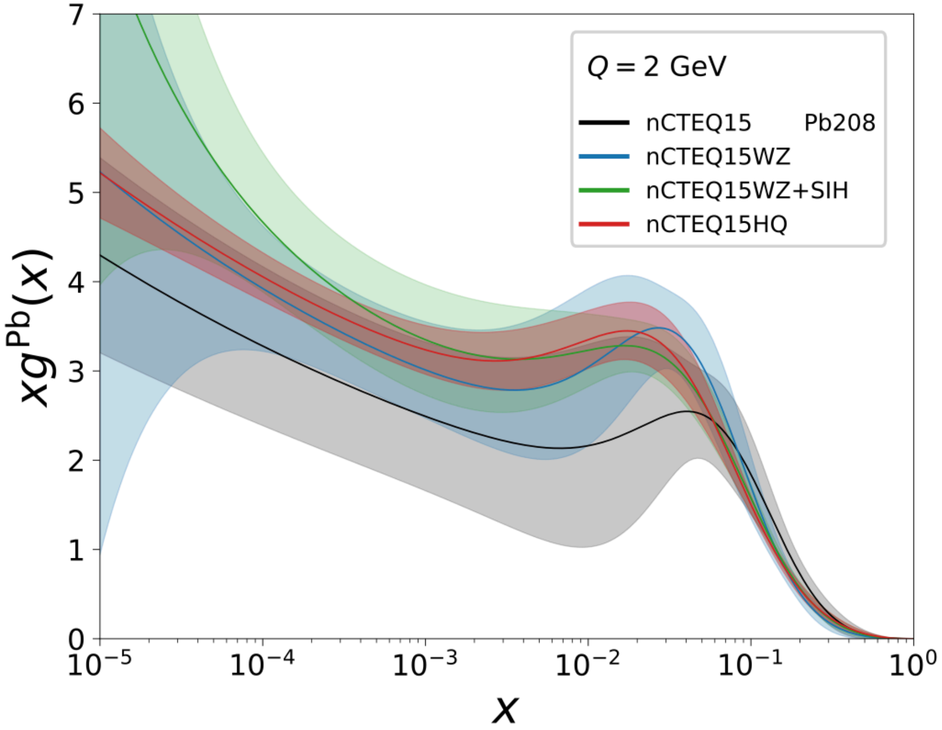
Difficult Summary

I asked AI…

Help me on a presentation to a group of people working for CMS…

Initial Conditions

- Impressive uncertainty reduction of nPDF from LHC
  - Heavy flavors, jets, Z/W, …
  - esp. for gluon sector & small x (~10^{-5})
  - Shadowing is confirmed, touching EMC region



Initial Conditions

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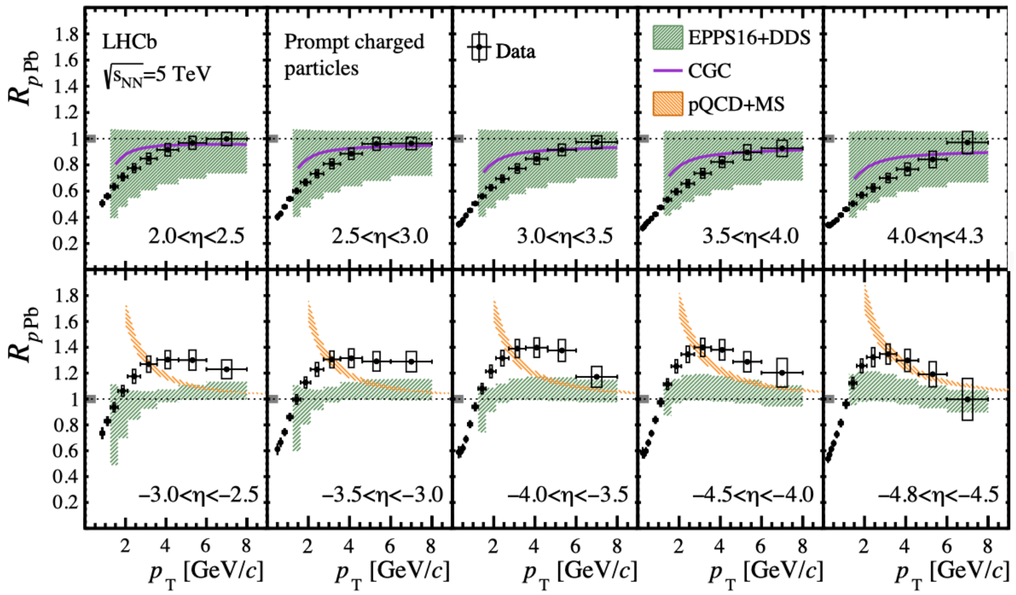
- What we can do next
  - Direct photon [minimum final state effects], DY not only resonance, high p_T light hadrons [simpler treat theoretically], beauty [Q, more perturbative]

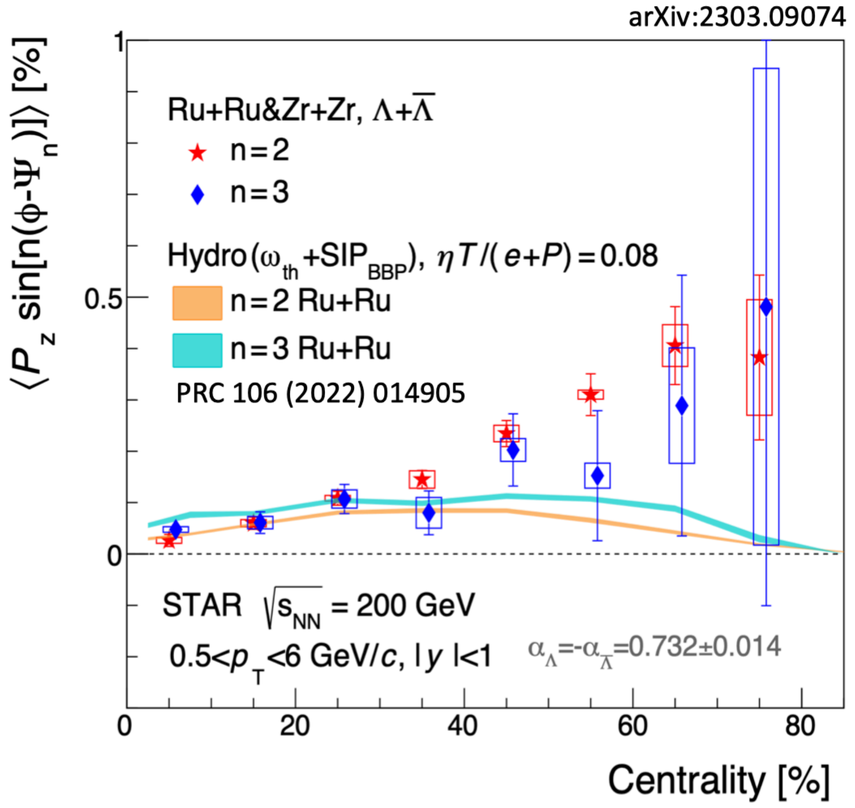
Some questions…
- How to combine UPC?
- How much uncertainty correlation helps in global fits?
- Have we addressed the other effects properly?
  - Saw discrepancy (light hadron & HF at backward)
  - Hadronization modification
- Factorization → underlying mechanisms



Soft Hadrons

- High precision in experiments

- Feed global analysis more ➜ new opportunities in
  - New observables
    - Polarization ~ shear
    - Thermal photon ~ temperature
    - Longitudinal deccorelation
    - Correlation between observables



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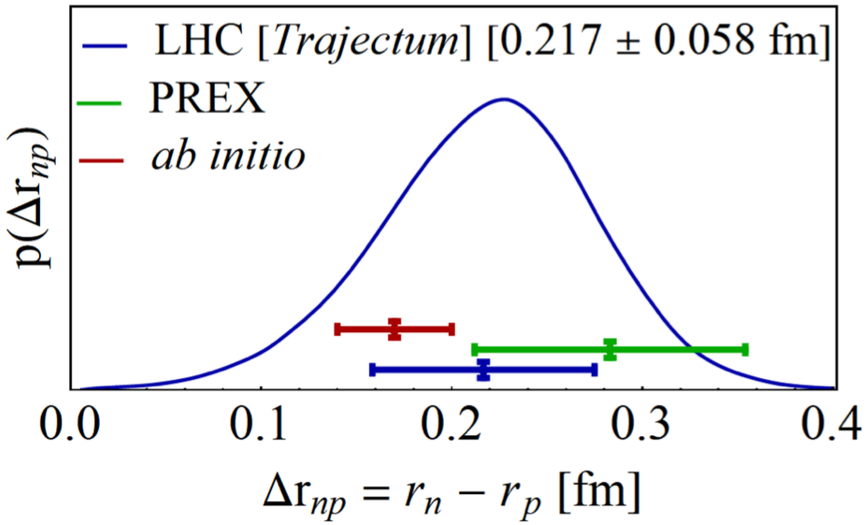
    - Nuclear structure, nucleus profile (neutron skin)
    - Interesting in its own right, but also relevant



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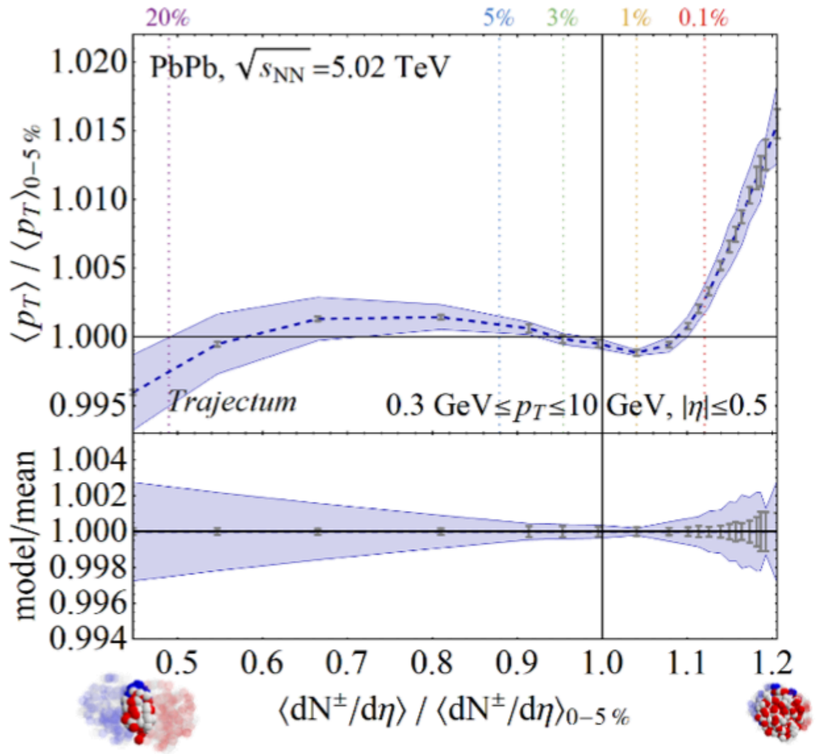
  - New conditions - Ultra-central collisions
    - Zero/constant impact parameter & temperature fluctuations
    - Better hydro, probe nuclear structure

- Uncertainty can be controlled with ratio to some reference



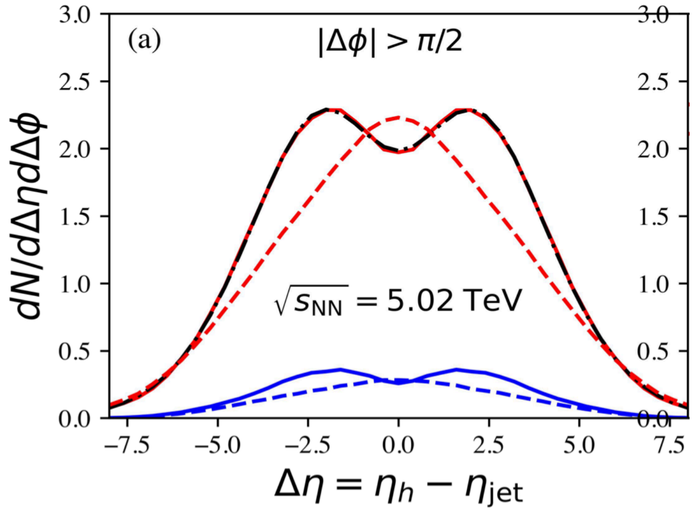
Hard Probes

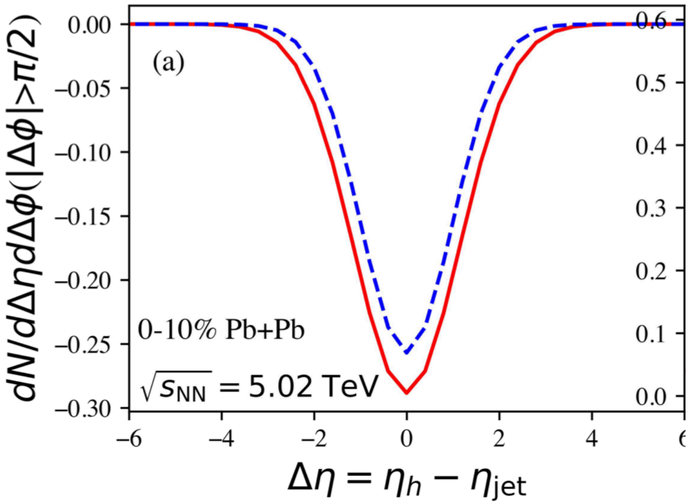
- Heavy hope on hard probes, as colored particles with known four-momentum initially far from thermalization, to tell us
  - How does QGP emerge from an asymptotic free gauge theory
  - Substructure of QGP when probed at various length scales
  - QGP transport properties to very high temperature

- How do we answer these questions by a translation of the observables?

Medium Response

- Extracting information from medium response
  - Extend to diffusion wake study to 3D
  - Sensitivity studied to
    - Energy loss
    - Shear viscosity
    - EoS
  - Smaller smearing effect for gamma-jet than Z-jet
  - Subtraction of MPI feasible in the model





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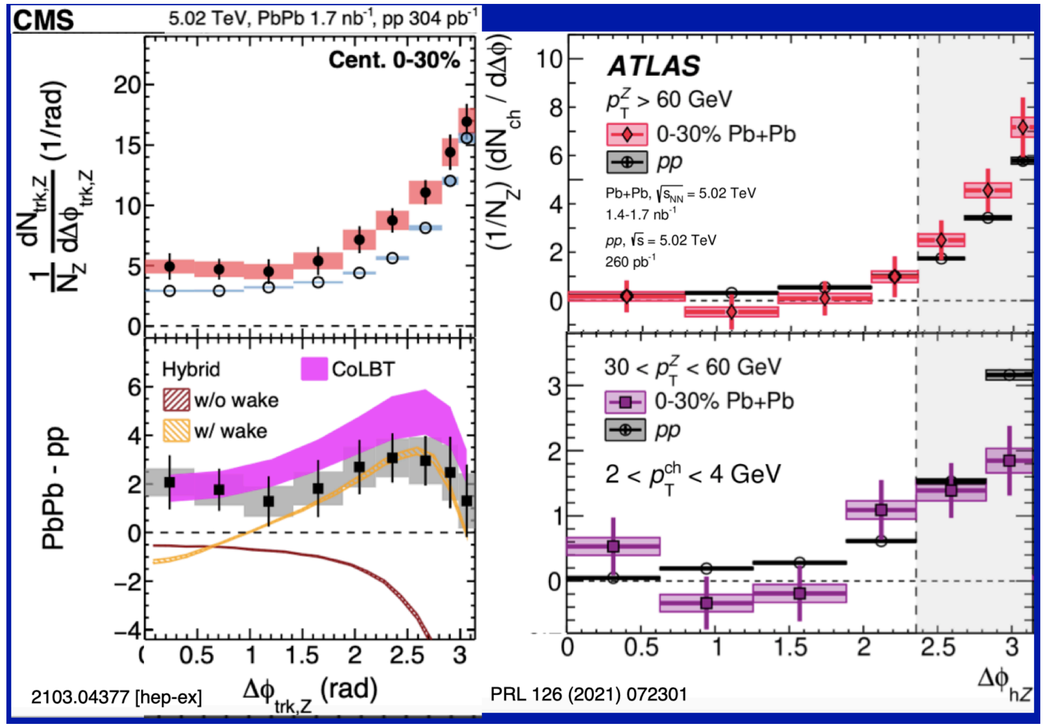
  - Definition of background matters
    - Clear features of each contribution will help design experiments



Heavy Flavors

- Capability to constrain multiple effects
  ~ Weak constraint on each effect

- Detailed comparison between hadronization models ongoing, about different
  - Fragmentation function
  - Wigner function
  - Excited states considered

Heavy Flavors

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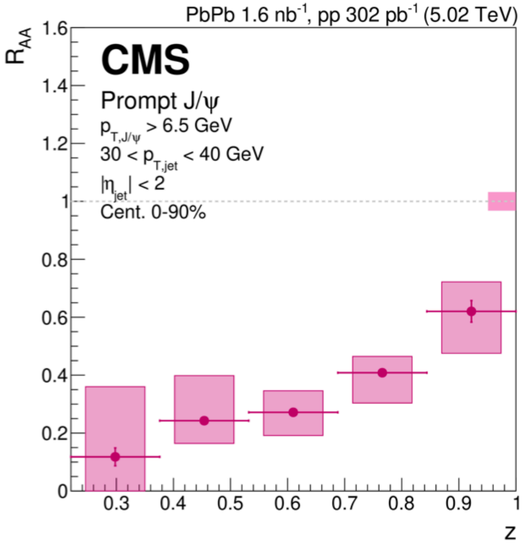
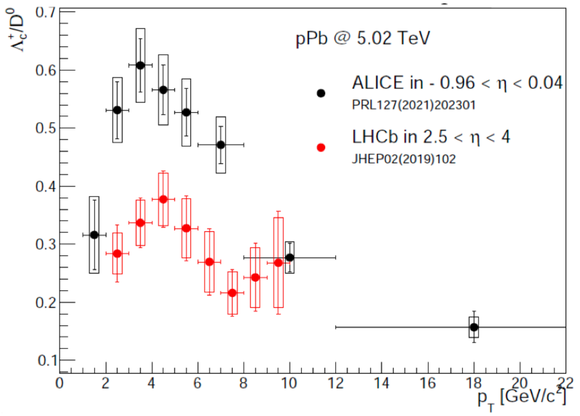
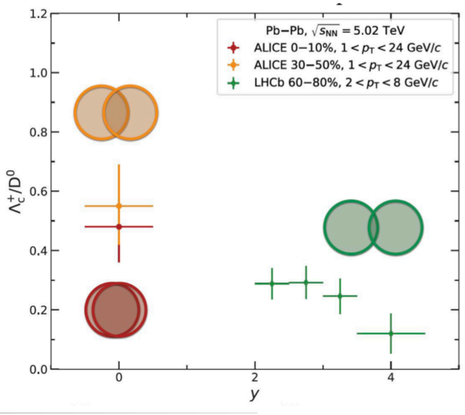
- Detailed comparison between hadronization models ongoing

- High-precision era ➜ higher requirement of systematics control

- But have we made the most of the existing measurement results?
  - More results should be taken into account
    - FF of b-jet, J/ψ and Λ_c; D-jet correlation; $v_2\{4\}$, v_3
  - Puzzles waiting for answers
    - Rapidity dependence of baryon/meson ratio
    - Different N_{trk} dependence for light & heavy flavors



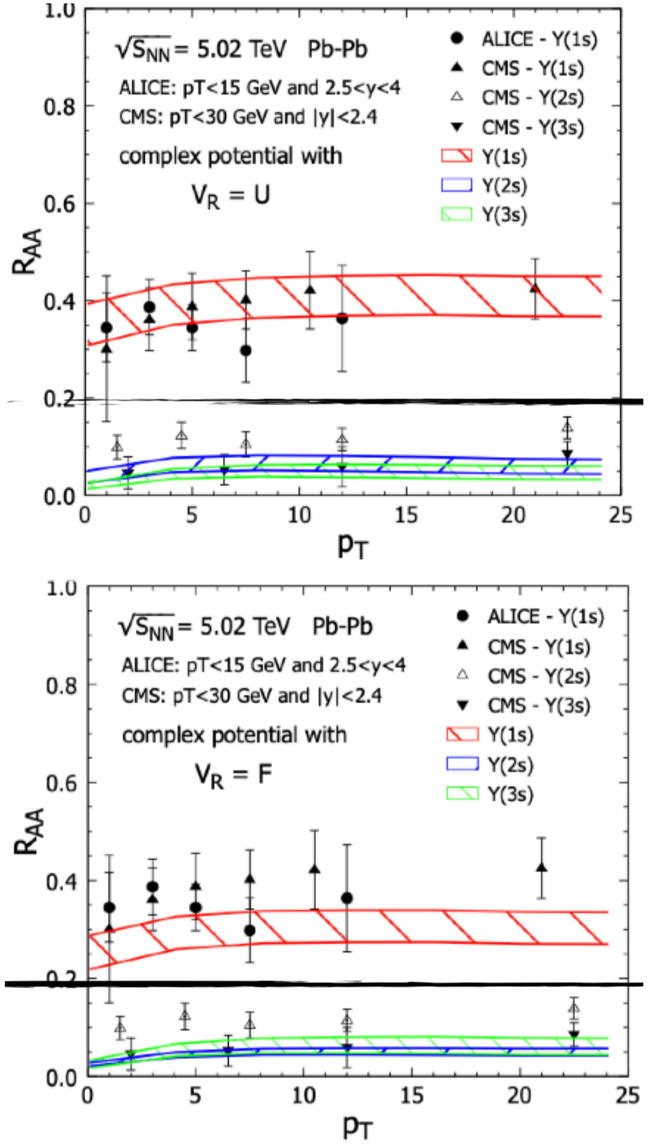




Quarkonia

- Excited states are important
  - Constrain feed-down contribution
  - Distinguish heavy-quark potential

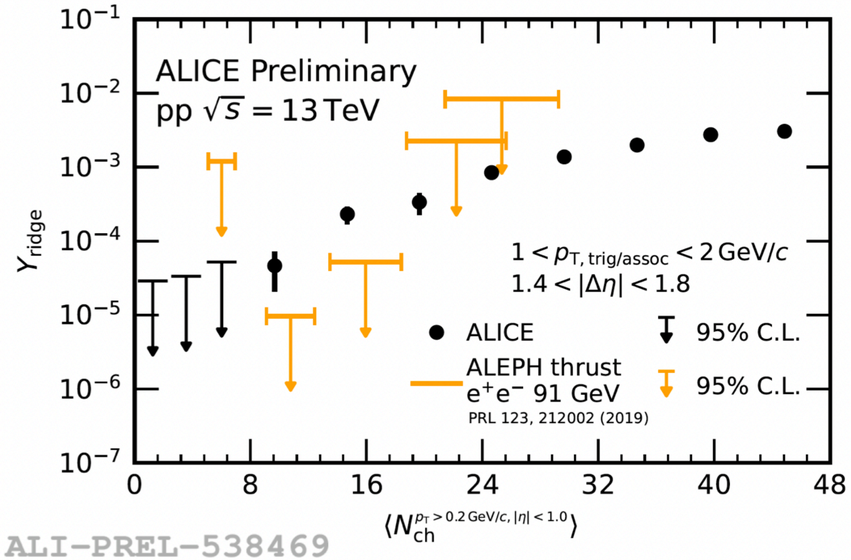
- New opportunities in polarization
  - Sensitive to both J/ψ production mechanisms and the QGP rotation
  - Try to avoid the trap of weak constraint on both

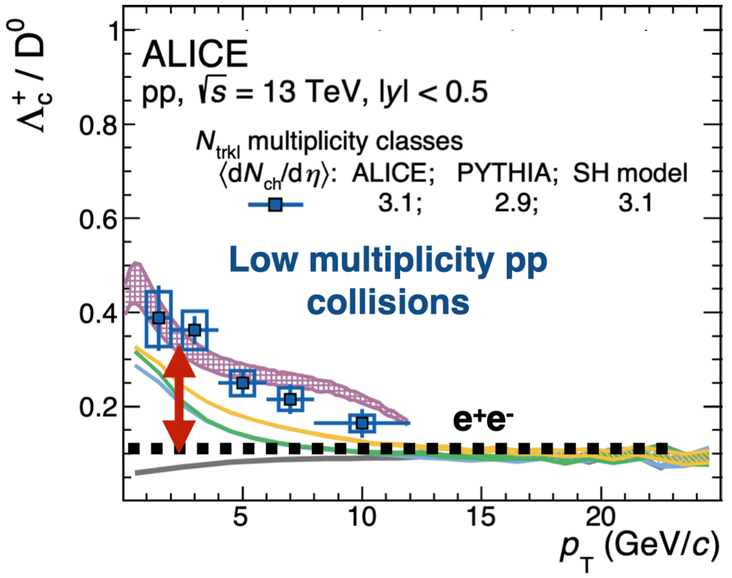


Small Systems

- "QGP-like" effects in small systems
  - Collectivity, hadronization modification, sequential suppression of quarkonia, strangeness enhancement, no energy loss

- Dominant source of each observation can be different
  - e.g. collectivity and hadronization modification are different between pp and ee, but the reason can be very different





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- All the observation should be taken into account at the same time in the models, e.g.
  - What is the effect on collectivity from the CR implemented to describe hadronization in small systems
  - Can the hot spot initial condition describe v_3?

Conclusion and outlook

- Considerable progress: recent LHC precision data provide strong constraints to nPDF down to $x \sim 10^{-6} - 10^{-5}$. Previously RHIC data can constrain nPDF to $x \sim 10^{-3}$
- Significant suppression confirmed in forward rapidity, suppression particularly strong in lower Q^2
- Tensions with nPDFs observed (LHCb data in backward rapidity, ALICE W data…)
- Still looking for signs of gluon saturation

- LHC Run3/4 prospects:
  - New pPb run with increased statistics: more valuable measurement can become possible:
    - B hadrons, direct photon in forward rapidity, Drell-Yan
  - New pO run: knowledge of nPDF in medium size nucleus crucial in understanding initial state physics

Summary and outlook

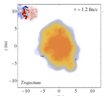
- I reviewed:
  - The frameworks used in most recent global analyses of nPDFs
  - Some highlights on data inclusion
- New developments in the last ~two years:
  - Relaxed cuts (EPPS, KSASG, nCTEQ)
  - NC DIS: New JLAB CLASS and Hall-C data (EPPS, KSASG, nCTEQ)
  - CC DIS: Reanalysis confirms unreconcilable tension (nCTEQ)
  - New processes useful for gluon and low x:
    - Heavy quarks (EPPS, nCTEQ, nNNPDF)
    - Dijets (EPPS, nNNPDF)
    - Direct photons (nNNPDF)
- Personal wish list: (di-)jets, direct photons, $t\bar{t}$, low mass DY/W/Z, light hadrons
- Overall: nPDF extraction is a very active field with a rich future ahead

Discussion

Exciting progress using global analyses

- Heavy ion collisions towards percent level precision
- Still interesting measurement potential: extremely ultracentral
- Nuclear structure becoming relevant and interesting

Oxygen collisions to be performed at the LHC summer 2024!



Where to go?

QGP temperature

- "Direct photon puzzle" also at LHC?
- Possible thermal dilepton results from Run3&4?

QGP vorticity

- Local polarization for Xi, Omega at LHC
- v_n-$P_{z,n}$ correlation
- System size dependence (XeXe, OO…)

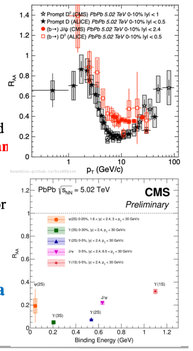
QGP longitudinal decorrelation

- Extend studies to bridge small and large system, e.g. OO
- Possible PID studies? What do we learn from it?

And much more…

Summary

- **Findings from heavy flavor measurements at LHC so far:**
  - **Energy loss**: measured R_{AA} and flow consistent with **mass hierarchy of energy loss $\Delta E_c > \Delta E_b$**. Need to improve measurement precision for **low p_T charm hadrons, charm baryons and bottom hadrons and new observables** to better understand energy loss mechanisms.
  - **Hadronization**: **coalescence is important for hadronization in pp/pA/AA collisins, modification to charm quark hadronization in QGP observed**. Need to improve measurement precision and kinematic coverage for **charm baryons an bottom hadrons** to better understand heavy quark hadronization mechanisms.
  - **Quarkonia**: **sequential suppression observed for both charmonia and bottomonia**. Need to improve measurement precision and kinematic coverage for **excited charmonium and bottomonium states** to understand feed-down, color screening and regeneration
  - **Studies started**: exotic particles, D and J/psi in jets, correlations …
- **LHC Run3+4 with newly upgraded detectors and much larger data samples will help us to better understand HQ, QGP and more!**



Summary

1. Jet-induced medium response can help us glean QGP properties.

2. With MPI subtraction, we can get signal of diffusion wake at LHC.

3. There is a unique signal of DF-wake in rapidity distribution of jet-hadron correlation.

4. By double Gaussian fit method, we studied DF-wake valley's sensitivity to jet energy loss, shear viscosity and EoS.

5. Using gamma-hadron correlation is a good chocie to look for the signal of diffusion wake.

Summary

- Pb-Pb UPCs at the LHC provide the largest cross sections ever studied for γγ collisions over the $W_{\gamma\gamma}$ = 1 – 100 GeV:
  Unique (B)SM physics programme open for study!
- Many measurements carried out so far:
  - Exclusive dielectron & dimuon production (high-statistics samples).
  - Observation of light-by-light scattering
  - Best limits on low-mass axion-like particles (also gravitons)
  - Observation of exclusive ditau production: Best (g-2) for tau at reach
  - …
- Experimental studies reaching few % uncertainties.
  Theoretical calculations catching up in precision.
  NLO QED corrections relevant for precision studies!
- Many interesting photon-photon processes awaiting for measurement…
  (contact me if you are interested in any new analysis... ;-))

Summary

I. *Open Heavy Flavor*

- *Heavy quark can help us to understand the hadronization mechanism in the QGP. Model comparsion is very important to go forward.*
- *EPOS4+HQ can give a good description of all heavy flavor hadrons production in both pp and AA, from RHIC to LHC.*

II. *Quarkonium*

- *The in-medium properties mostly can be absorbed in the finite-temperature potential, which with both real and imaginary part. Recent lattice QCD results and theoretical study show a very weak color screening but a large imaginary part.*

III. *Heavy flavor rare/exotic states*

- *The production of B_c, Ξ_{cc}, Ω_{ccc}, $X(6900)$ are largely enhanced in heavy ion collisions!*
- *It is possible to probe the inner structure of tetraquark states, such as X(3872), in heavy ion collisions.*

Looking forward to more experimental results!

Conclusions and outlook

- LHC data show evidence for decoherent energy loss. Jet quenching depends strongly on the branching width.
- Enhancement of low-p_T particles at the edge of the jet supporting medium response is observed. Jet core remains unmodified.

We are starting to relate the jet modifications observed in the experiments with the properties of the QGP.
But
In a steep falling p_T spectrum ($\sigma \sim p_T^{-6}$) the population in each bin is composed essentially by jets that suffered few or no energy loss (e.g. 1812.05111 and references therein).
Comparing observables as a function of reconstructed jet p_T ranges imply:
- lower p_T ranges have larger mixing of jets that born differently. More than a physics feature, it is a mess and makes data interpretation very model dependent.
- …

—> enriched samples of jets that were modified are needed for complex observables.

Helena Santos, HI CMS Workshop, Trento 2023

Summary and topics for discussion

Collectivity:
- Is there a common dynamic origin for collectivitiy in small and large systems?
  - Is "QGP" a misleading concept for small system?
- What does the observation of a sizeable charm v_2 tell us about the nature of the medium?
  - Does it favour a initial-state interpretation?

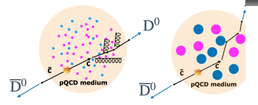
Modification of hadronization in all hadronic collisions (w.r.t. e⁺e⁻):
- what is the connection between hadronization modification and the HQ degree of equilibration?

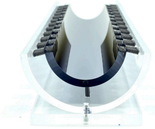
No clear evidence of jet quenching in small systems:
- consistent with the evidence for the final-state interactions?
- is quenching there but it is just too small? how much quenching (%) would one expect?

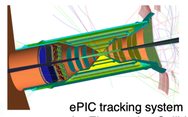
thank you for your attentic

Conclusions and (some) open questions

Heavy-ion program being extended till ~2040:
with high-resolution and high-rate experiments
→ microscopic description of in-medium dynamics
with rare HF hadrons, correlations, HF jets (more in the LoI)







ePIC tracking system
at the Electron-Ion Collider

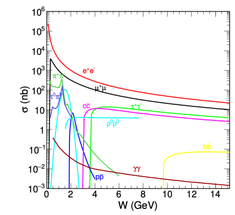
Heavy-ion physics is driving the developments of new detector technolog
with big on future experimental programs

A relevant open question for Run 5 and 6 heavy-ion runs :
- which ion species to maximize the physics impact of Run 5 and 6?
- what is the smallest ions for quenching physics?

thank you
for your attenti

Conclusion

- EPA in the impact parameter space
- Fourier transform of the charge distribution
- Multidimensional integrals → differential cross section
- Description of experimental data for UPC
- Predictions include the experimental acceptance
- Electromagnetic excitation - ZDC
- Collaboration - theoreticians and experimenters
- Future:
  - more forward/backward region
  - lower p_t



Thank you

Summary of summary — The most useful slide…


Isabelle
Thanks for your attention!
Thanks to all the speakers!

Ultra-Peripheral Collisions

- Make the most of the huge EM fields in heavy ion collisions

- Light-by-light scatterings
  - 8.8σ observation with (2015+18) data
- Axion-like particles searches
  - Low mass 5 ~ 100 GeV
- Tau lepton (g-2)
- …