Report for the RHIC AGS Users Meeting Heavy Flavor Workshop

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RHIC/AGS Users Meeting 2025

RHIC 25:
A quarter century of discovery

Overview

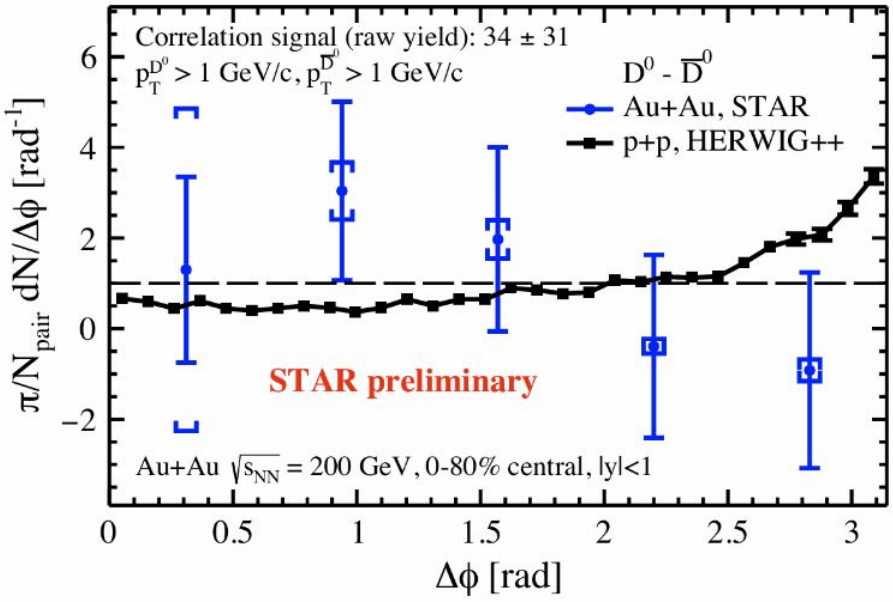
- Current RHIC experiments
- Results from our friends from the LHC
- Theoretical developments and the EIC

D0-anti D0 Correlations

- Weaker correlation is expected in heavy ion collisions compared to that in p+p collisions at $\Delta\phi \approx \pi$, due to energy loss and thermalization in QGP

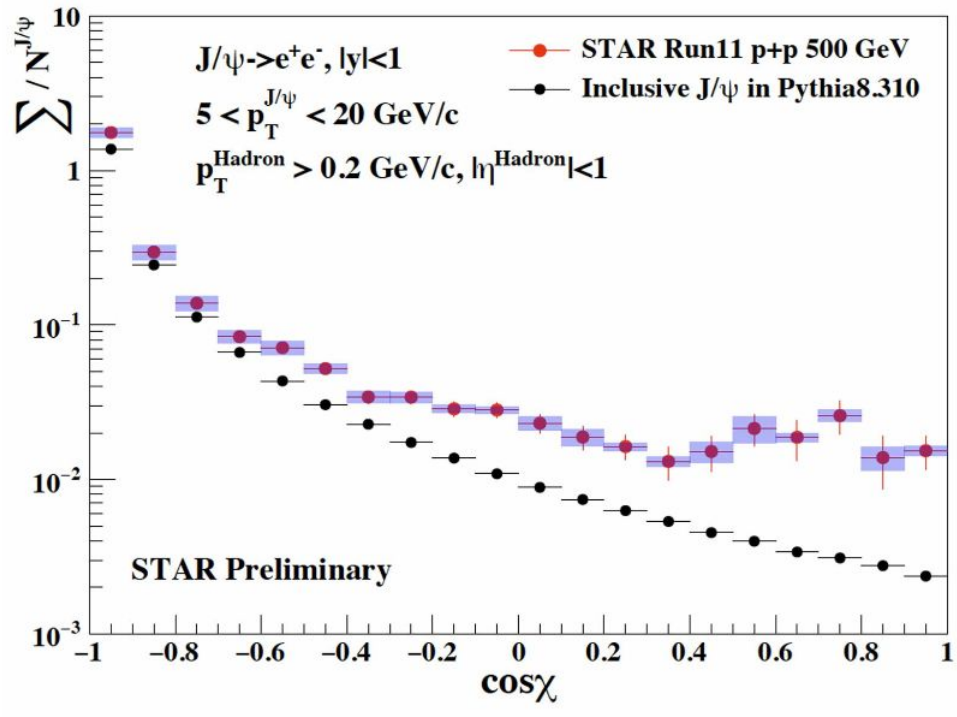
Phys. Lett. B 647 (2007) 366–370

Kaifeng Shen for STAR



- No azimuthal correlation is seen within current uncertainties

J/ψ Energy Correlators at STAR

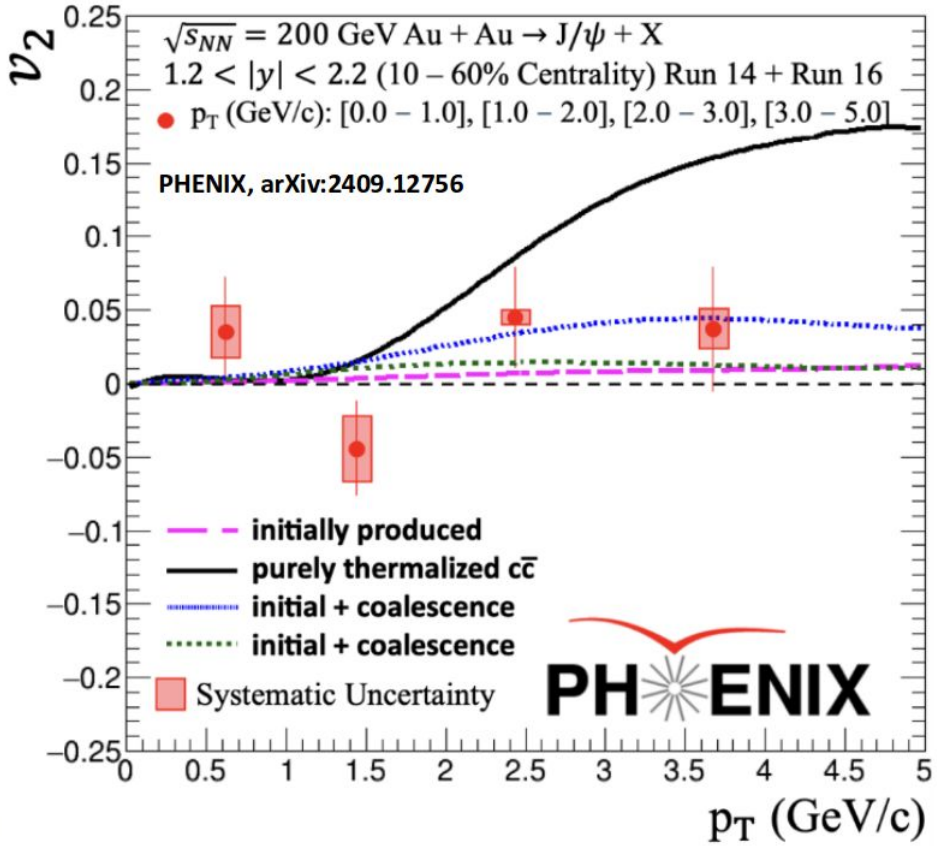


Kaifeng Shen for STAR

- The J/ψ energy correlator has been measured firstly at RHIC-STAR
- No significant cos(χ) dependence of the J/ψ energy correlator at cos(χ) > 0, while the measurement is different compared to that in pythia8 (~7σ)

First J/ψ flow v_2 at the Forward Rapidity

Ming Liu for PHENIX

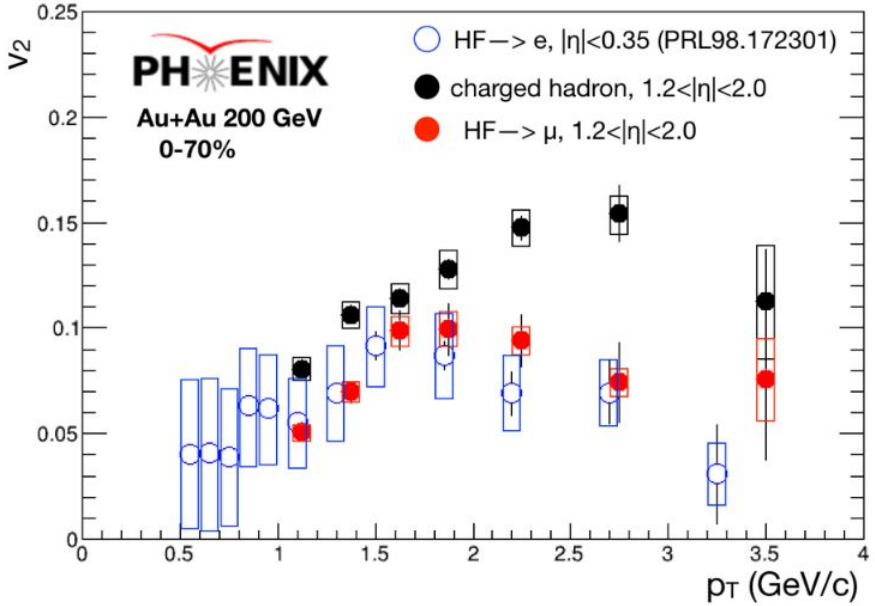


- PHENIX v2 in the forward rapidity, consistent with zero
  - Open charm, none-zero v2!
    - Light quark contributions?
  - J/Psi formation
    - weak "recombination" in the forward rapidity?

- Run2016 Au+Au, in progress
  - 4x more stat!

Open Heavy Flavor v_2 at the Forward Rapidity

Ming Liu for PHENIX



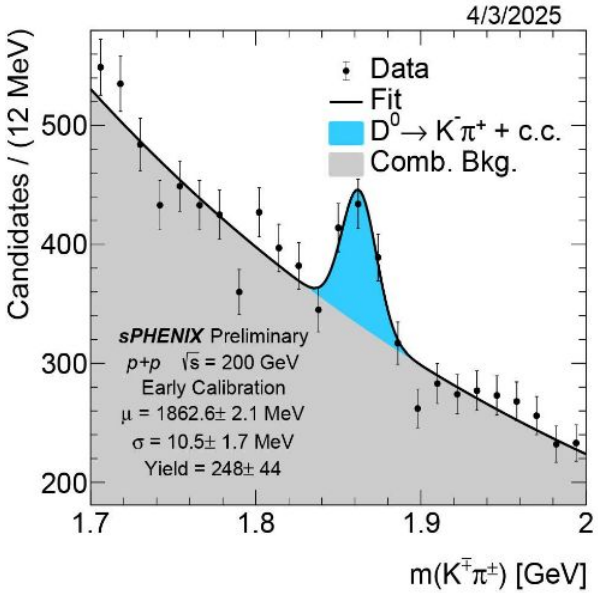
PHENIX, arXiv:2409.12715

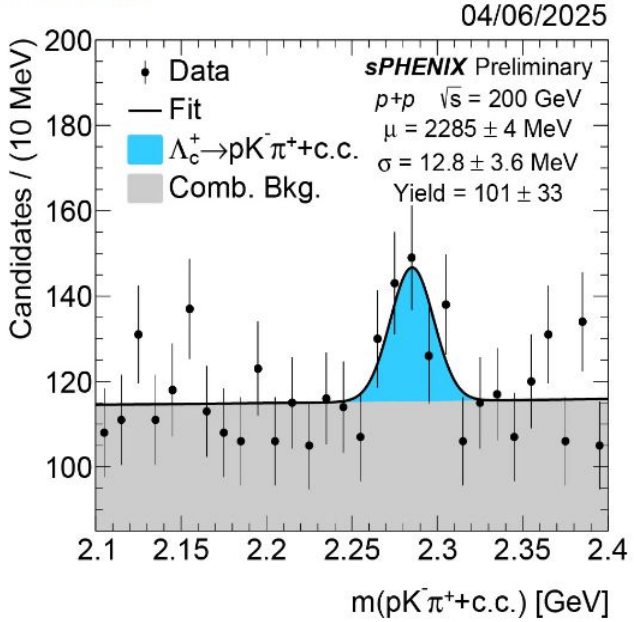
- First observation of none-zero open heavy flavor v2 at the forward rapidity
  - Consistent with mid-rapidity HF results
  - Smaller than light hadron v2
  - **Similar magnitude in central and forward rapidity!**

D^0 and Λ_c Reconstruction at sPHENIX

- sPHENIX took a large p+p dataset thanks to streaming readout
- We have our first heavy flavor signatures, including Λ_C^+ which is new to RHIC in p+p
- Use Λ_C^+/D^0 ratio to probe hadronization models

Alex Patton for sPHENIX

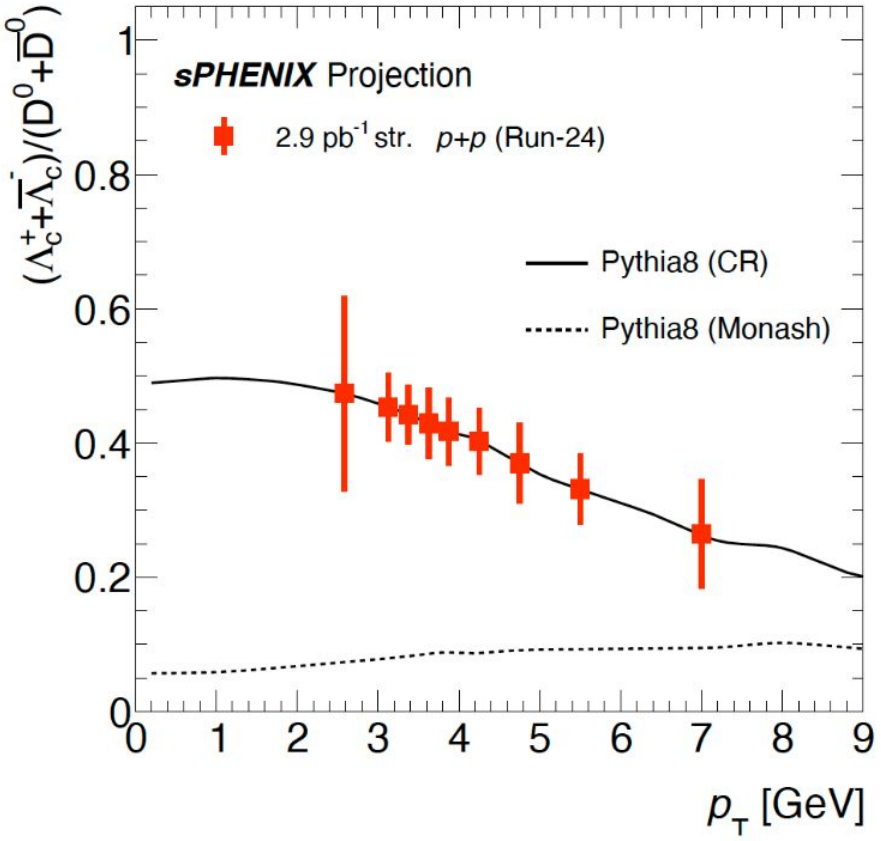




Projection for Λ_c/D^0 ratio at sPHENIX

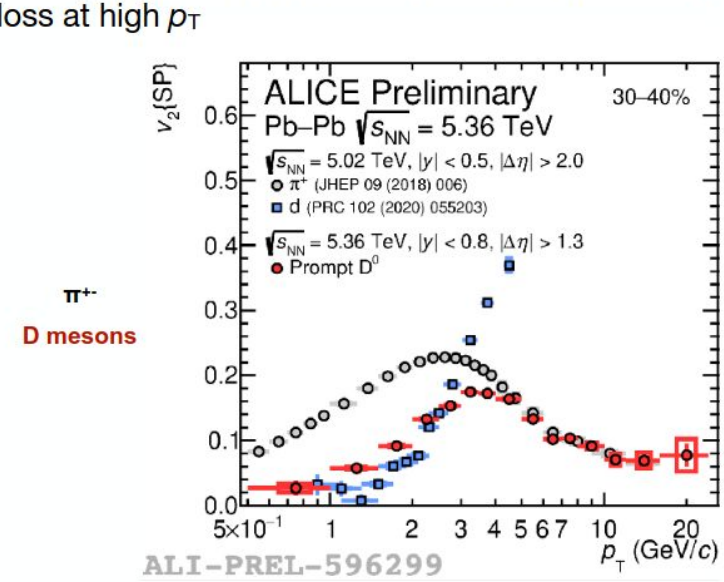
Alex Patton for sPHENIX

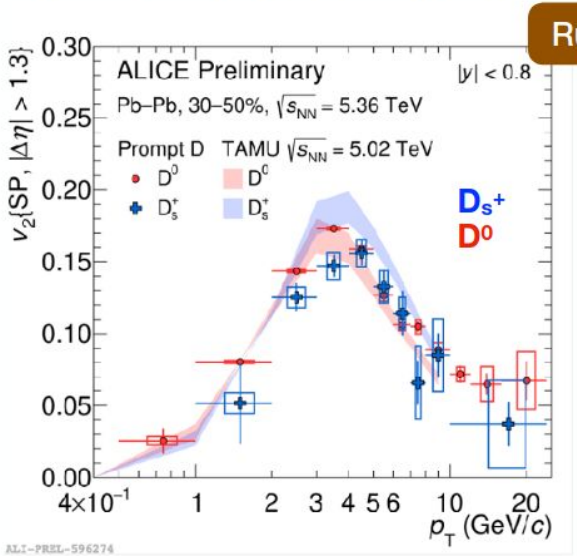
- First measurement of p+p Λ_C^+/D^0 at RHIC
- Huge benefit from streaming readout
- Need good understanding of tracking efficiency for this measurement



v_2 of Charm Quarks

Heavy Flavor v_2: quantify HQ interaction strength at low p_T and constrains its path length dependent energy loss at high p_T





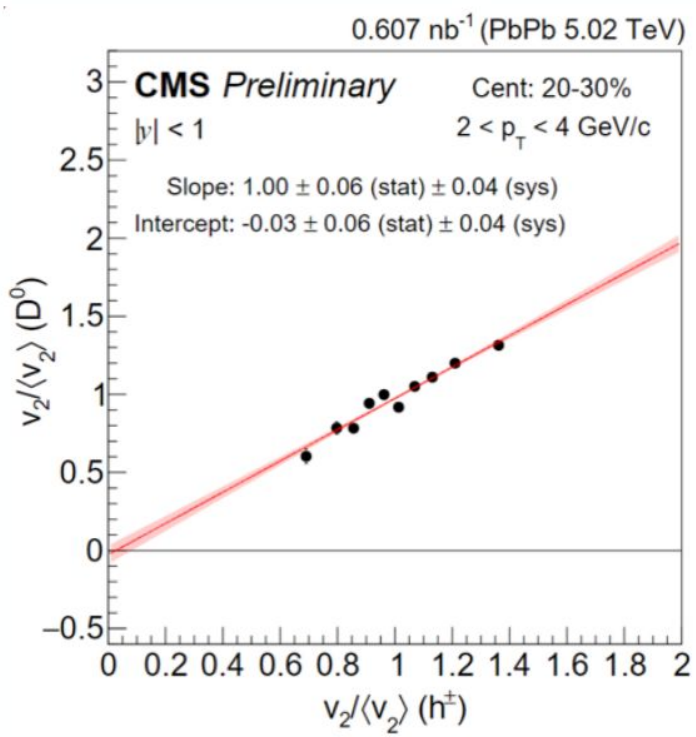
Deepa Thomas for the LHC experiments

- D^0 meson v_2 measured to very low p_T < 1 GeV/*c*
- Low p_T: $v_2(\pi^{+-}) > v_2(D)$
  - D-meson v_2 from charm quark flow + recombination with the light-flavor quark
- High p_T: $v_2(\pi^{+-}) \sim v_2(D)$
  - Path length dependent E.loss

D_s^+ v_2 close to non-strange D v_2
—> tendency to be smaller up to p_T = 4 GeV/c (different contribution of hadronic phase?)

HF vs LF v_2

Study of the correlation between v_2 of D^0 and the charged hadrons



Deepa Thomas for the LHC experiments

Vary initial eccentricity by Event Shape Engineering q_2 while keeping same centrality

D^0 v_2 exhibits an approximate linear proportionality to the bulk flow

D^0 v_2 is entirely driven by initial shape as light flavors

J/ψ in 4 muon channel

J/ψ in 4-mu

$$\frac{\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-)}{\mathcal{B}(J/\psi \to \mu^+\mu^-)} = \frac{N(J/\psi \to \mu^+\mu^-\mu^+\mu^-)}{N(J/\psi \to \mu^+\mu^-)} \Big/ \frac{\epsilon_{J/\psi \to \mu^+\mu^-\mu^+\mu^-}}{\epsilon_{J/\psi \to \mu^+\mu^-}}$$

where:

$(11.92 \pm 0.02)\%$

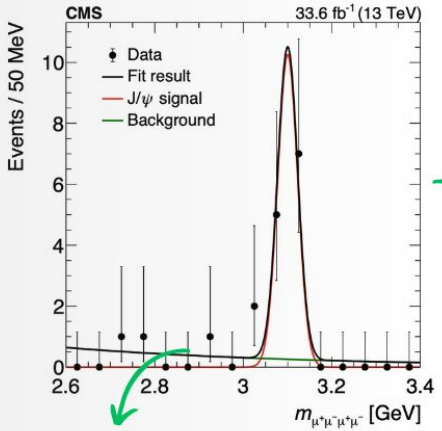
$N(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = 11.6^{+3.8}_{-3.1}$

The significance of the signal is above 7 standard deviations, evaluated from the likelihood ratio of the default signal+bkg fit and the bkg-only fit

$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = [10.1^{+3.3}_{-2.7}\,(\text{stat}) \pm 0.4\,(\text{syst})] \times 10^{-7}$

Standard Model prediction:

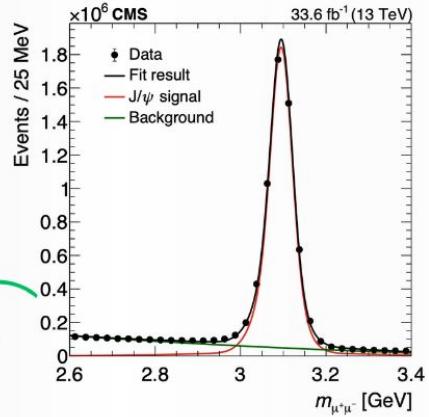
$(9.74 \pm 0.05) \times 10^{-7}$



CLICK ME

CrystalBall + Gaussian

$N = 11.6^{+3.8}_{-3.1}$



$N = (5770 \pm 3) \times 10^3$

Maria Elena Ascoti for the LHC experiments

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Triple J/ψ in CMS

Triple-J/ψ in CMS

- Data analysis starts by selecting **events with > 6 muons**, each passing the p_T and η criteria
- The muons are then paired to reconstruct the charmonia candidates within the kinematical and mass range acceptance.
- All selected muon pairs are further required to **share the same primary vertex (PV).**

For all muons	$p_T > 3.5\,\text{GeV}$ for $\lvert\eta\rvert < 1.2$ $p_T > 2.5\,\text{GeV}$ for $1.2 < \lvert\eta\rvert < 2.4$
For all J/ψ mesons	$p_T > 6\,\text{GeV}$ and $\lvert y\rvert < 2.4$ $2.9 < m_{\mu^+\mu^-} < 3.3\,\text{GeV}$

The total events found are:

$$N_{\text{sign}}^{3J/\psi} = 5.0^{+2.6}_{-1.9} \quad + \quad N_{bkg} = 1^{+1.4}_{-0.8}$$

6.7 STD. DEV. FROM THE NULL HYPOTESIS

$$\sigma(pp \to J/\psi J/\psi J/\psi X) = 272 + 141(\text{stat}) \pm 17(\text{syst})\text{fb}$$

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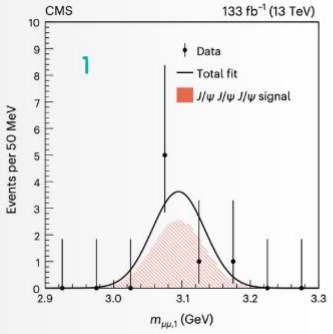
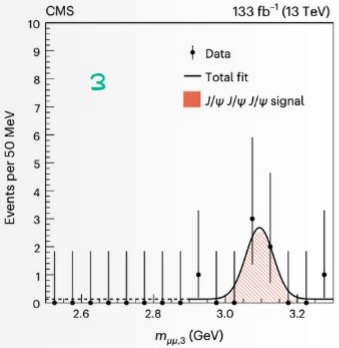
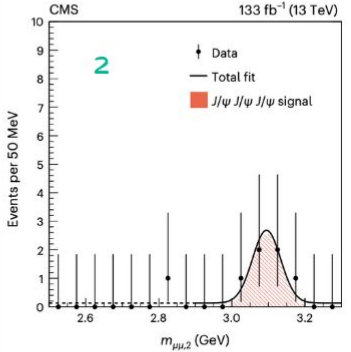
Maria Elena Ascoti for the LHC experiments





CLICK ME!



6 % SPS
74% DPS
20% TPS

Phenomenology with Dissociation and Regeneration

- **Texas A&M University (TAMU) model**

$$\frac{\mathrm{d}N_{\mathcal{B}}(\tau)}{\mathrm{d}\tau} = -\Gamma_D[T(\tau)]\Big(N_{\mathcal{B}}(\tau) - N_{\mathcal{B}}^{\mathrm{eq}}[T(\tau)]\Big)$$

#(bound state) change rate

Equilibrium number, time-dependent

- Dissociation rate from $g + \mathcal{B} \to Q + \bar{Q}$

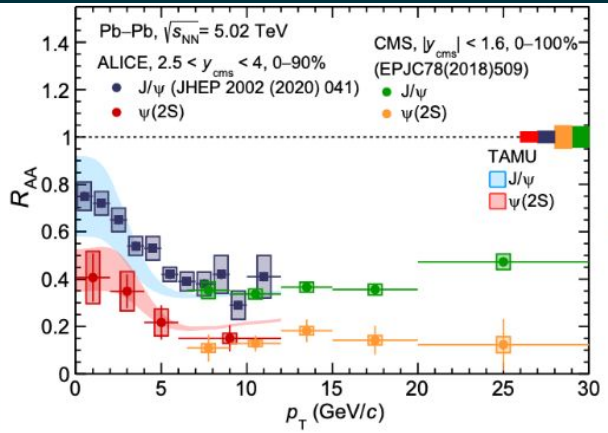
  $2 \times (q/g + Q \to q/g + Q)$

- Phenomenological factors, interference

- New development:
  T-matrix summation + lattice input

Wu, Tang, Rapp, 2503.10089

Xiaojun Yao for Quarkonia theory



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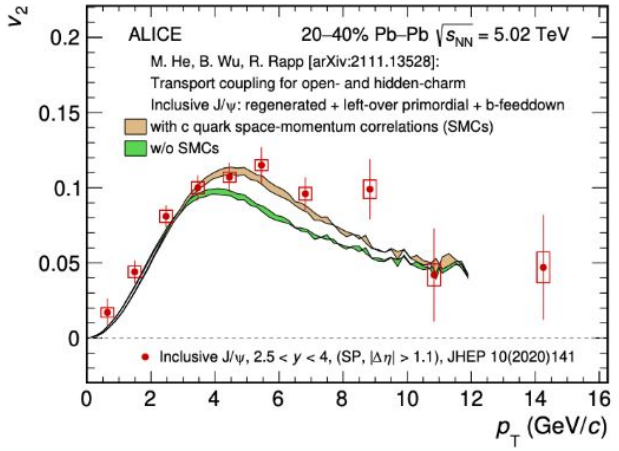
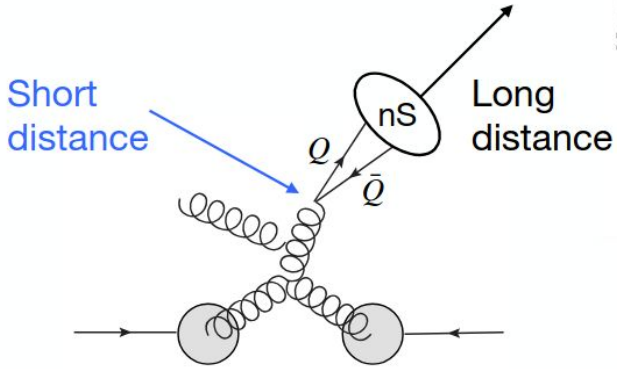


2005.14518

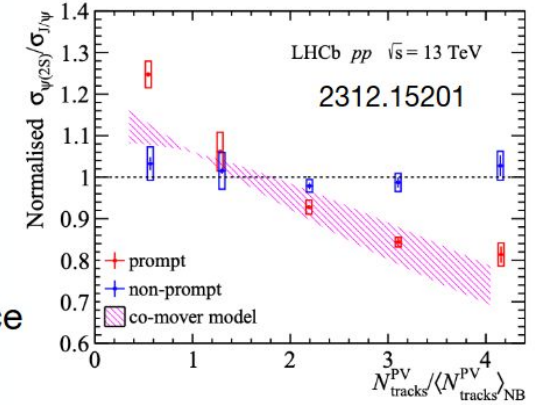
Quarkonium Production from AA to pp, pA

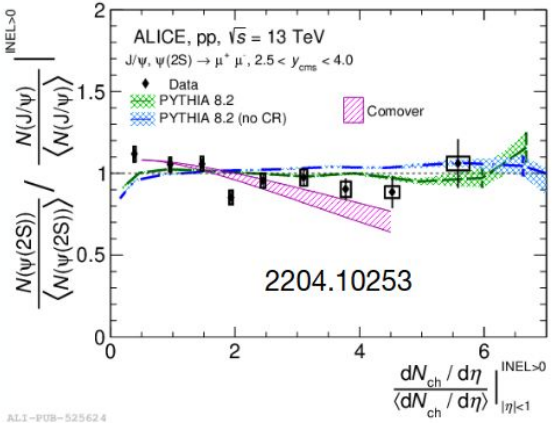
- $\frac{\psi(2S)}{J/\psi}$ **v.s. event activity in pp**

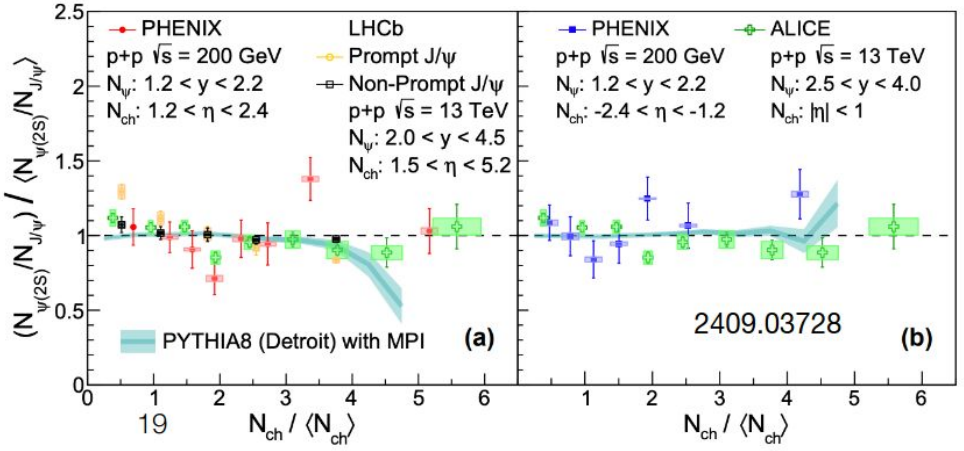


Universality of long-distance may break down in pp?

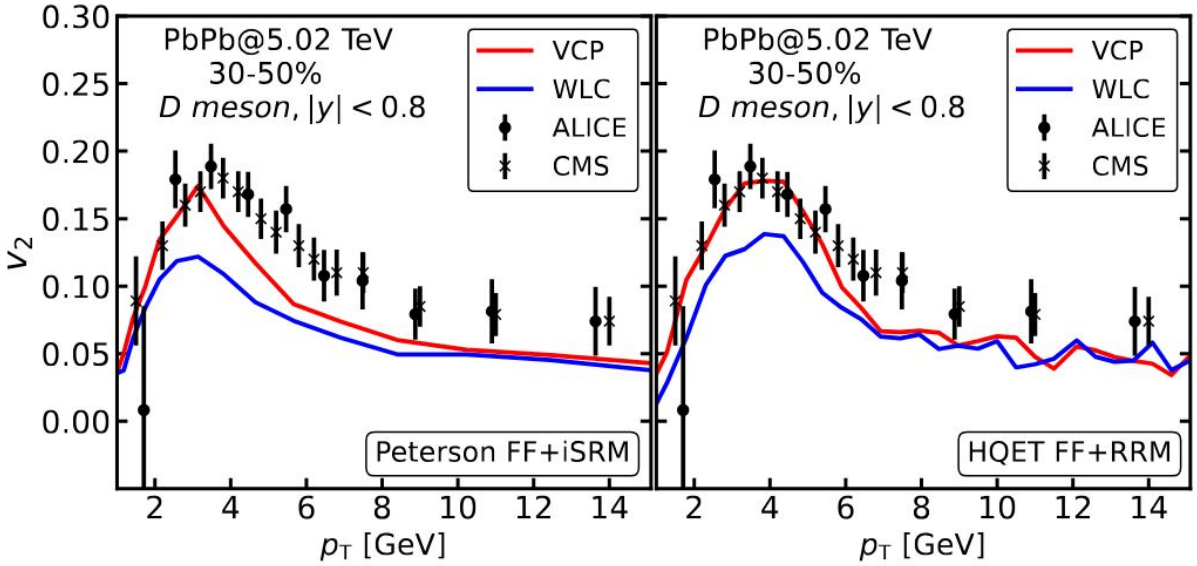
Xiaojun Yao for Quarkonia theory







Elliptic flow: v_2 in open HF



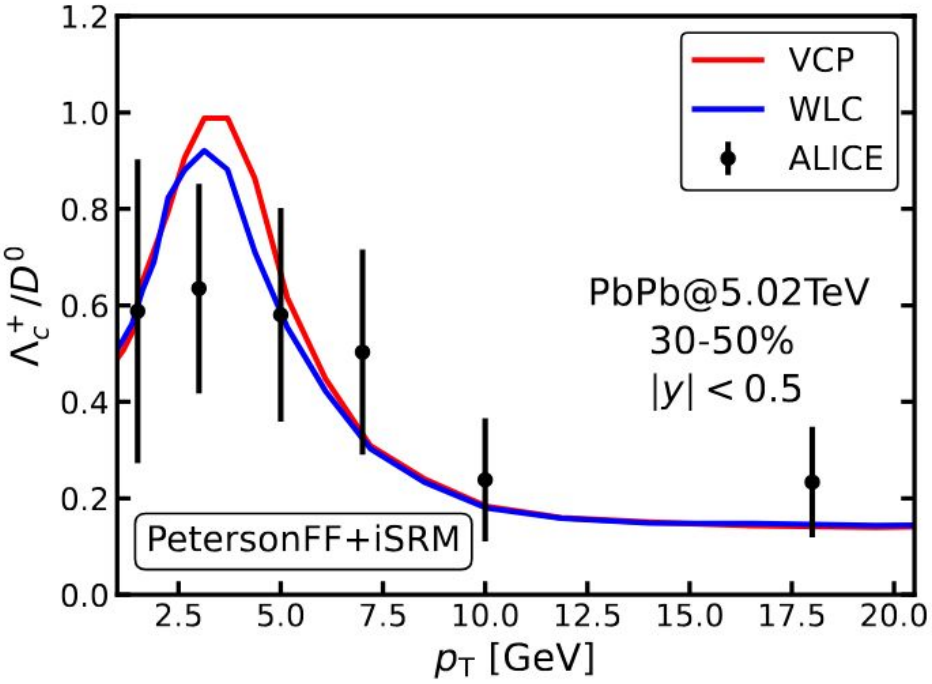
Yu Fu for open HF theory and HEFTY Collaboration

- Larger sensitivity to in-medium QCD force

ALICE:*PLB*813(2021)
CMS:*PLB*816(2021)

Baryon to meson ratio: Λ_c/D^0

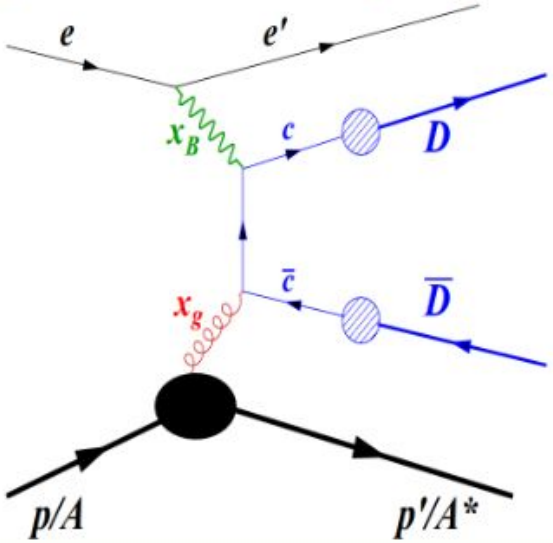
Yu Fu for open HF theory and HEFTY Collaboration



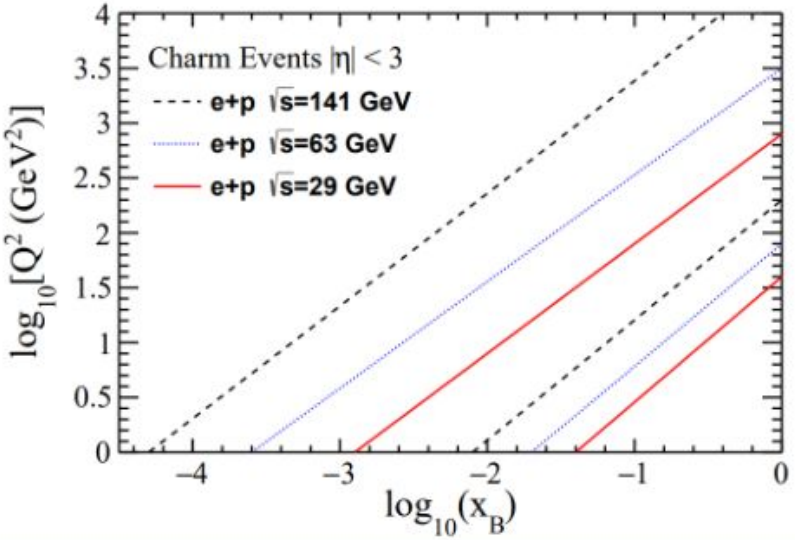
- Systematic investigation of hadro-chemistry underway

EIC Kinematic reach

M. Kelsey, et. al., PRD 104 (2021) 054002



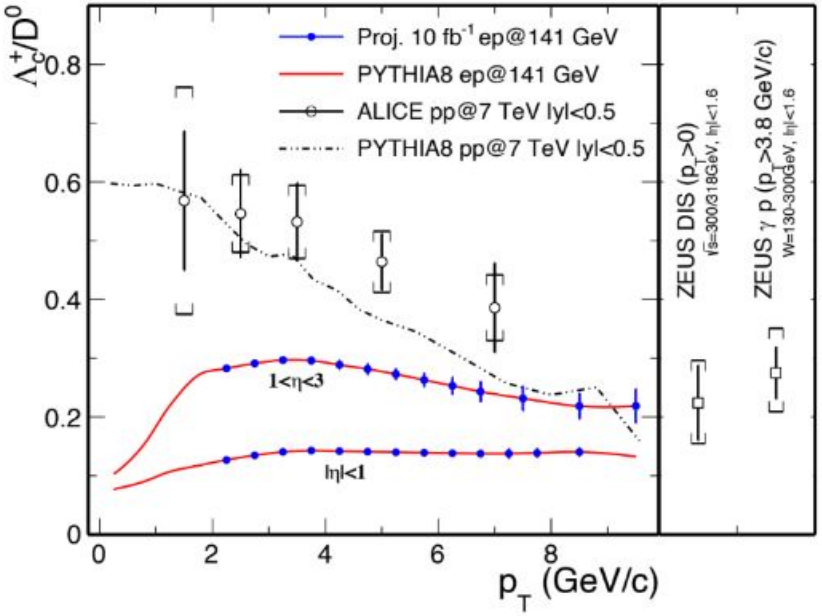
Bishoy Dongwi for EPIC



- Unique and direct access to gluons, especially at high x
- Broad kinematic coverage:
  - Probe intrinsic charm

Charm quark fragmentation

Bishoy Dongwi for EPIC



J. Arrington, et. al., arXiv:2102.08337

- Gain new insights into charm fragmentation ep vs. pp collisions
- DIS ratio R_{Λ_c/D^0} vs. p_T
- Projections: `e+p 141 GeV, forward & central rapidity, 10 fb`$^{-1}$ **(No full ePIC recon.)**

Summary

- Many exciting developments spanning RHIC, LHC, and the EIC
- Much complimentary work is on going at RHIC and LHC experiments in heavy flavor, and phenomenological developments can hopefully be stress tested on both sides of the Atlantic
- Results include progress on MC modeling, hadronization, flow, and under constrained aspects of QCD
- On the RHIC side looking forward to more STAR and PHENIX results, first results for HF from sPHENIX and towards the EIC