HEFTY Ethics and Heavy Flavor in Small Systems

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Figure 1: This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics (Nuclear Theory) under contract number DE-SC-0004014, the LLNL-LDRD Program under Projects 21-LW-034 and 23-LW-036, and the HEFTY Collaboration.

HEFTY Community Agreement

https://hefty.tamu.edu/code-of-conduct

Affiliation with the HEFTY Collaboration requires acknowledgment of and compliance with the Code of Conduct.

The main points of the Code of Conduct include:

Members are committed to maintaining a welcoming, inclusive and equitable environment by

- **practicing integrity and objectivity in discharging responsibilities to the collaboration;**
- **refraining from harassment and discrimination in all forms;**
- **evaluating the work of colleagues fairly and not trying to claim credit for the work of others;**
- **ensuring that multiple scientific and professional perspectives can be freely expressed without consequences and be received respectfully.**

Bystander intervention is encouraged, when it is safe to do so, if concerning conduct is observed.

Violations of this community agreement should be reported for investigation.

HEFTY Bylaws

Members and Roles:

- PI and co-spokespersons form the Executive Committee
- Co-investigators and other senior members are listed on HEFTY proposal
- Junior members are students and postdoc
- External collaborators and new members can join, e.g. KSU bridge position

Meetings: Define collaboration meetings, working group meetings and PI meetings

Working Groups: Working groups are convener led. The bylaws define the members, the timing of meetings (biweekly), required posting of minutes described

Publications:

- HEFTY publications require the HEFTY funding acknowledgment
- Authorship limited to those who made significant contributions, full collaboration is not required to be an author on each paper
- Preprints should be circulated to PIs for one week before submission to the arXiv and the journal of choice
- The corresponding data should be posted to arXiv with the manuscript.

Presentations: Similar to publications, logo should be shown on the title slide, posted for reporting purposes

Reporting: all members contribute to DOE reporting

Conduct: all members should follow the code of conduct and report violations

WG-2 Progress: HF Production in Small Systems

Co-PIs: Xin Dong (LBNL), Anthony Frawley (FSU), Tom Mehen (Duke), Jianwei Qiu(JLab), Ivan Vitev (LANL, convener through 7/2024), RV (LLNL/UC Davis, convener after 7/2024)

Junior members and affiliates: Vincent Cheung (LLNL), Weiyao Ke (was LANL, now CCNU), Haitao Li (Shandong U), Jia-Yue Zhang (JLab), Fred Olness (SMU)

Pushing the boundaries of heavy flavor theory in small systems while providing baseline calculations and cold matter effects for other working groups

Tasks and Milestones

Perform resummed NLO calculations for heavy quark production and analyze heavy flavor jet observables in $e+p$ and $p+p$ reactions to obtain novel constraints on parton fragmentation and intrinsic charm in the proton (LLNL+JLab-PD)

MS-2: Comprehensive theory of open heavy flavor production and hadronization in $p+p$ and $e+p$

Analyze quarkonium and open HF production in $p+A$ and $e+A$, combining EFTs, nuclear PDFs, and inelastic break-up reactions (LANL-PD+Duke-GS)

MS-8: Microscopic theory of quarkonia and open heavy flavor production on nuclear targets

WG-2 Highlights: Small systems in hadronic collisions

Intrinsic Charm Production with SMOG at LHCb

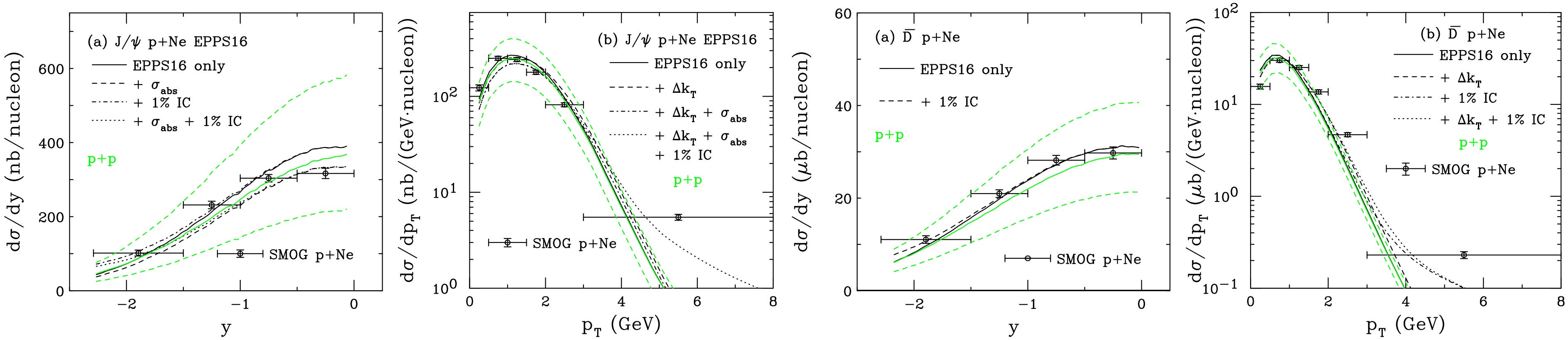
RV, Phys. Rev. C 108 (2023) 015201 (arXiv:2304.09356) (MS-2 + MS-8)

J/ψ **and** $\overline{D}$ **production with SMOG (fixed target** $p+\mathrm{Ne}$, $p+\mathrm{He}$ **and** $p+\mathrm{Ar}$ **collisions at** $\sqrt{s_{NN}} = 69$, **87.7, and 110.4 GeV respectively)**

Production was assumed to be a combination of perturbative production in the Color Evaporation Model at NLO with cold matter effects of modification of the parton densities, intrinsic transverse momentum broadening, and nuclear absorption (for J/ψ**) with intrinsic charm production**

Two left figures are J/ψ y **and** p_T **distributions; two right figures are** $\overline{D}$ y **and** p_T **distributions for** $p+\mathrm{Ne}$ **collisions at** $\sqrt{s} = 69$ **GeV**

Green curves are $p+p$ **uncertainty bands, intrinsic charm (dotted curves) become important at largest negative rapidity and highest** p_T



Bottomonium feed down at $\sqrt{s_{NN}} = 5.02$ TeV

(MS-2 + MS-8)

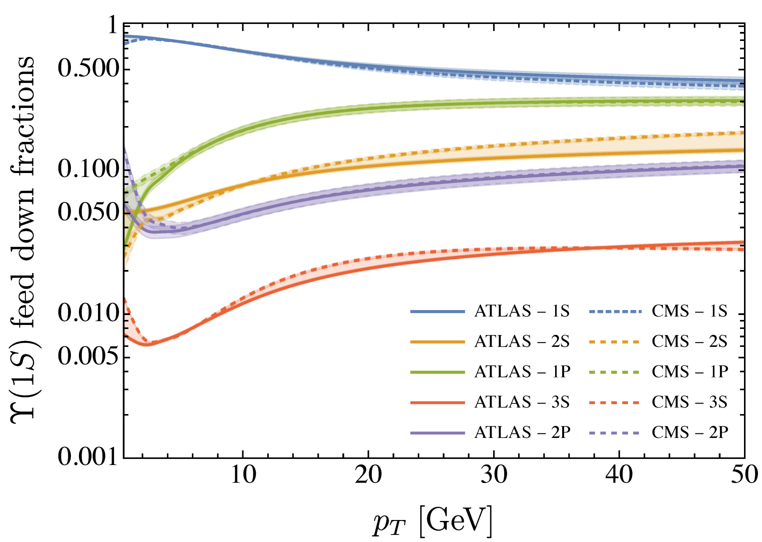
- J. Boyd, M. Strickland, and S. Thapa, Phys. Rev. D 108, 094024 (2023), performed a data-driven analysis of the p_T dependence of bottomonium feed down.
- ATLAS/CMS/LHCb data indicate strong momentum dependence below $p_T = 10$ GeV (see figures).
- Direct production at $\langle p_T \rangle$ accounts for $\sim 76\%$ of both $\Upsilon(1S)$ and $\Upsilon(2S)$ production (see tables).
- This rules out the possibility that $\Upsilon(1S)$ suppression in $\sqrt{s_{NN}} = 5.02$ TeV AA collisions ($R_{AA} \sim 35\%$) is solely due to the suppression of excited states.

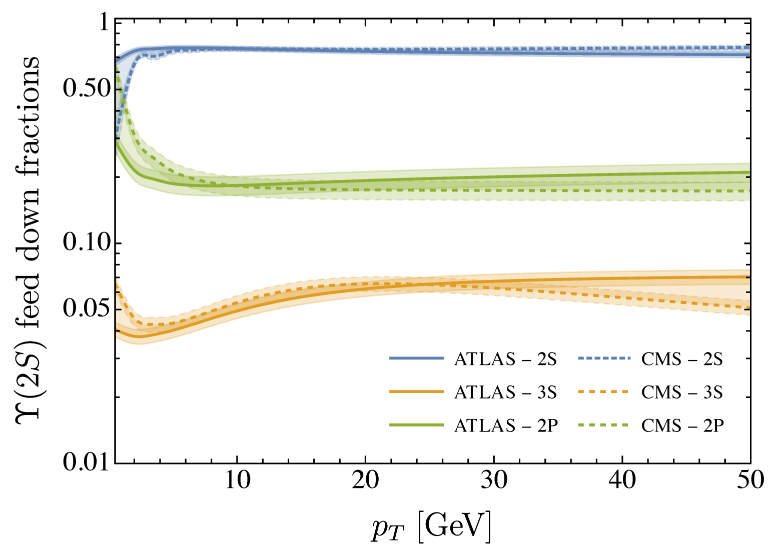
ATLAS + LHCb - 1S	
State	$\langle p_T \rangle$ feed-down fraction
$\Upsilon(1S)$	0.763 ± 0.010
$\Upsilon(2S)$	0.0625 ± 0.0019
$\chi_b(1P)$	0.127 ± 0.009
$\Upsilon(3S)$	0.00786 ± 0.00018
$\chi_b(2P)$	0.039 ± 0.004

ATLAS + LHCb - 2S	
State	$\langle p_T \rangle$ feed-down fraction
$\Upsilon(2S)$	0.774 ± 0.018
$\Upsilon(3S)$	0.0429 ± 0.0032
$\chi_b(2P)$	0.183 ± 0.018

CMS + LHCb - 1S	
State	$\langle p_T \rangle$ feed-down fraction
$\Upsilon(1S)$	0.767 ± 0.010
$\Upsilon(2S)$	0.0561 ± 0.0018
$\chi_b(1P)$	0.129 ± 0.009
$\Upsilon(3S)$	0.00778 ± 0.00018
$\chi_b(2P)$	0.040 ± 0.004

CMS + LHCb - 2S	
State	$\langle p_T \rangle$ feed-down fraction
$\Upsilon(2S)$	0.758 ± 0.019
$\Upsilon(3S)$	0.0464 ± 0.0035
$\chi_b(2P)$	0.195 ± 0.019





Bottomonium suppression in 5.02 and 8.16 TeV $p + \mathrm{Pb}$ collisions

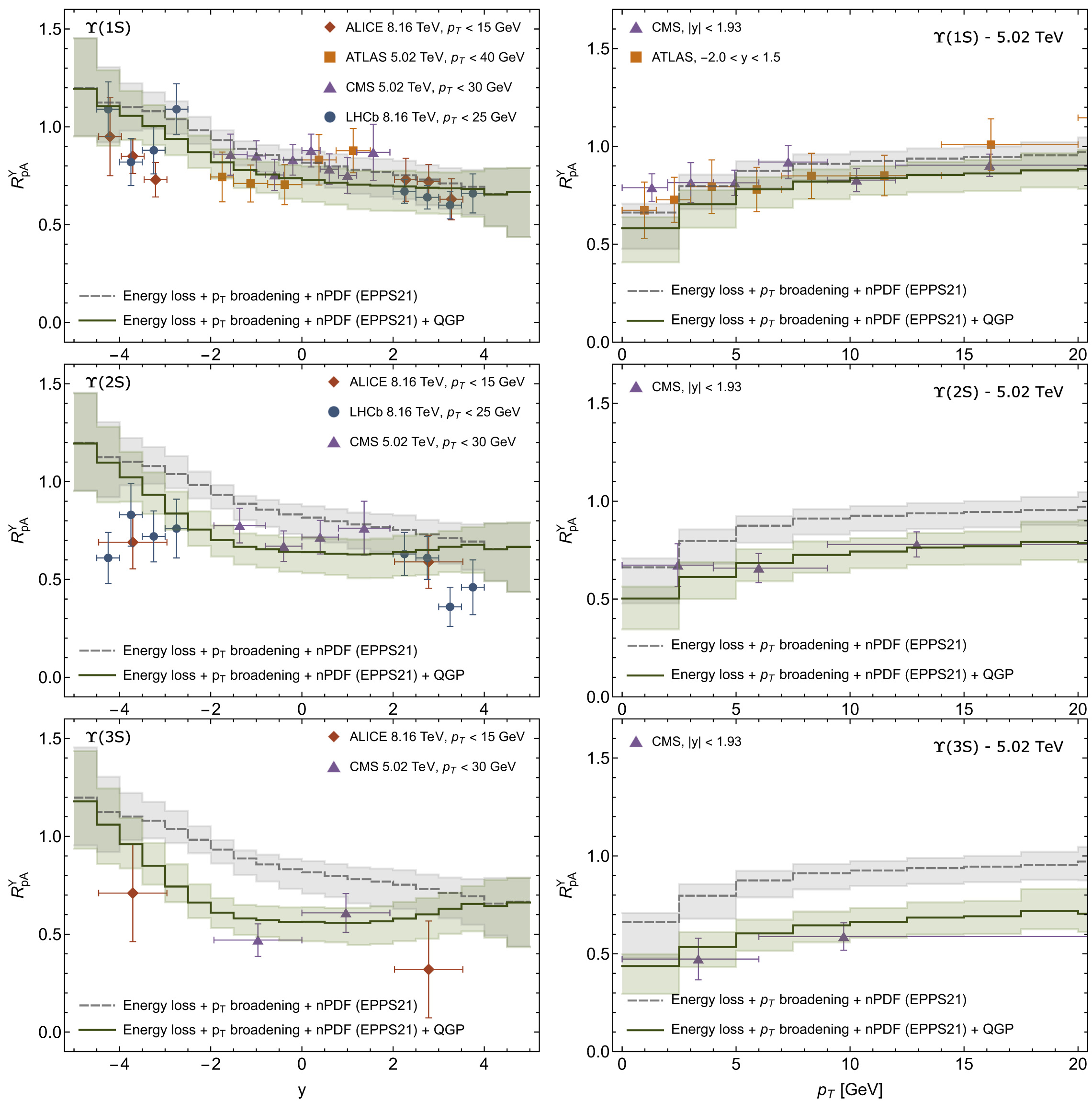
M, Strickland, S. Thapa and RV, arXiv:2401.16704 (Phys. Rev. D, in press) (MS-2 + MS-8)

Comprehensive look at Υ suppression in cold (+ hot) matter (WG-2 + WG-4 collaboration)

- **nPDF effects included with EPPS21, calculated in the color evaporation model with intrinsic k_T broadening in $p + p$ collisions**
- **Energy loss and momentum broadening in media include a la Arleo and Peigne**
  - **Coherent energy loss with quenching parameter $\hat{q}$**
  - **Transverse momentum broadening in medium, $\delta p_T = (\ell_A^2 - \ell_p^2)^{1/2}$ with $\ell_A^2 = \hat{q} L_A$**
- **NLO pNRQCD + Open Quantum Systems (hot matter)**
  - **Lindblad equation including singlet-octet, octet-singlet and octet-octet transitions**
  - **3+1D anisotropic hydrodynamic background**
  - **Temperature dependence of hydro enables differences in suppression between $\Upsilon(n\mathrm{S})$ states**
- **Excited state feed down as in PRD 108, 094024 (2023)**

$$R_{pA}^{\Upsilon} = R_{pA}^{\mathrm{EPPS21}} \times R_{pA}^{\mathrm{eloss},\delta p_T} \times R_{pA}^{\mathrm{HNM}}$$

Comparison to LHC Data



WG-2 Highlights: Looking ahead to the EIC

Polarized J/ψ Production via SIDIS

M. Copeland, S. Fleming, R. Gupta, R. Hodges, and T. Mehen (MS-2)

Polarized J/ψ production from polarized partons in Semi-Inclusive Deep-Inelastic Scattering (SIDIS) calculated with Nonrelativistic QCD (NRQCD)

Photon-gluon fusion calculated to $\mathcal{O}(\alpha_s^2)$; fragmentation processes to $\mathcal{O}(\alpha_s)$

18 novel spin-dependent transverse momentum dependent (TMD) fragmentation functions that provide new tests of NRQCD and give access to little known gluon TMDs

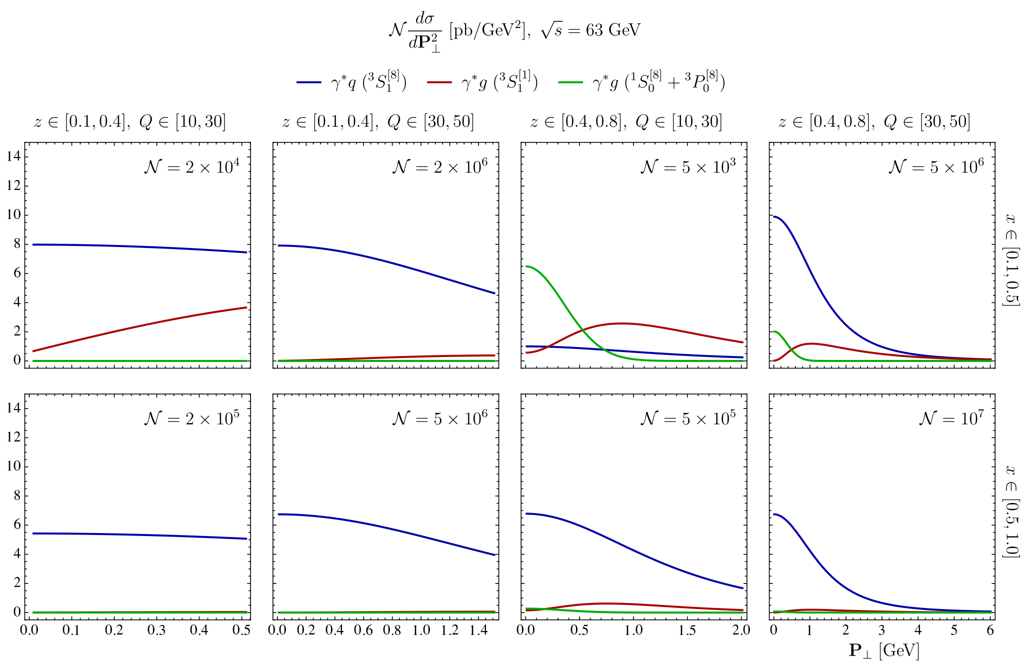


Figure 2: Binned contributions to the cross section for longitudinally polarized J/ψ production for different production mechanisms. From Phys. Rev. D **109** (2024) 054017 (arXiv:2308.08605); Phys. Rev. D **in press** (2024) (arXiv:2310.13737).

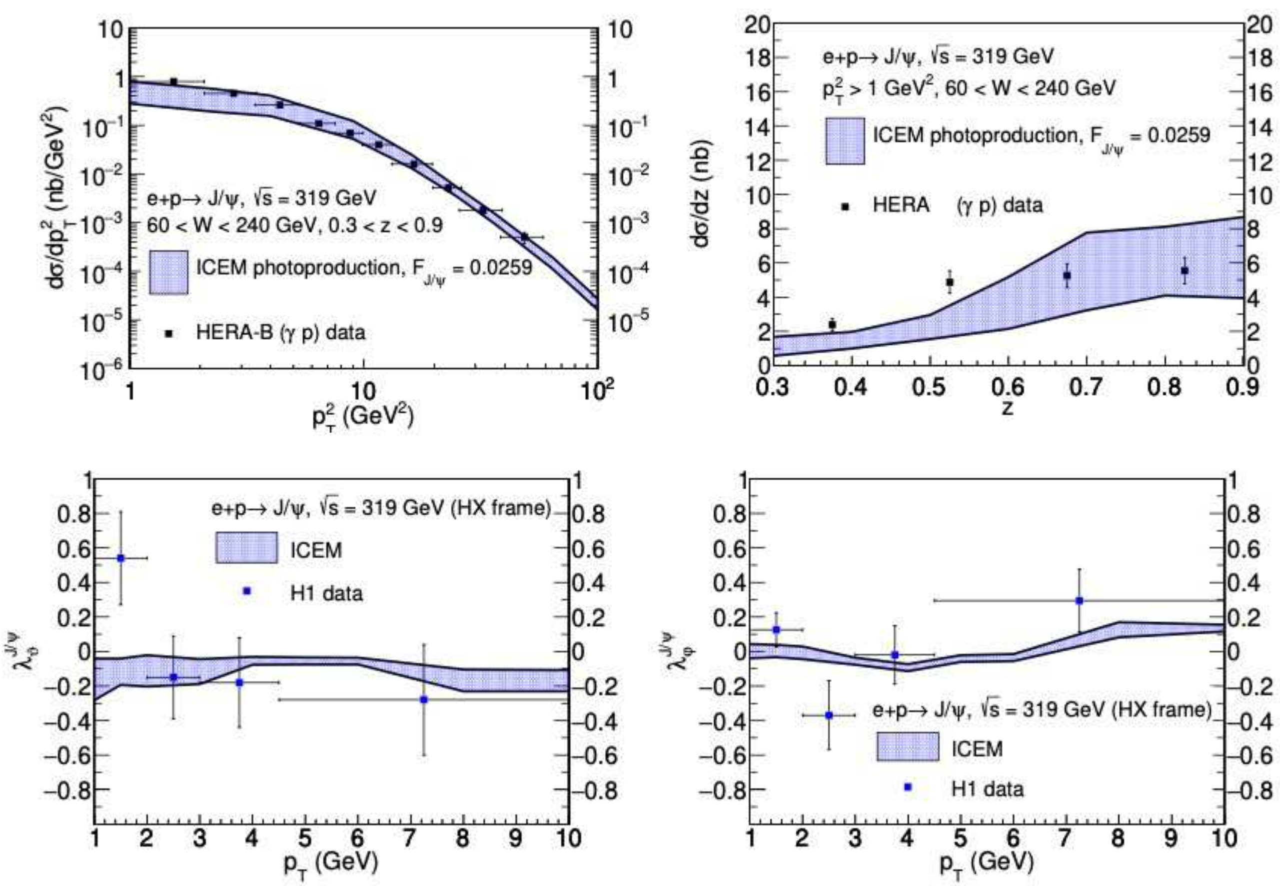
J/ψ Photoproduction in $e+p$ Collisions

V. Cheung and RV, in preparation (MS-2)

First photoproduction calculation in the Improved Color Evaporation model (ICEM), including polarization

Calculations performed at low Q^2 and compared our calculations to polarized and unpolarized HERA photoproduction data [Eur. Phys. J. C 68, 401 (2010)]

Top plots: unpolarized production; bottom plots: polarized – polar (left) and azimuthal (right) asymmetries in the helicity (HX) frame



WG-2 Summary

Significant progress in WG-2, several publications and others in preparation

- **Contribution from Intrinsic Charm Production to Fixed-Target Interactions with the SMOG Device at LHCb, R. Vogt, Phys. Rev. C 108, 015201 (2023) (arXiv:2304.09356).**
- **Transverse momentum dependent feed-down fractions for bottomonium production, J. Boyd, S. Thapa and M. Strickland, Phys. Rev. D 108,094024 (2023) (arXiv:2307.03841).**
- **Polarized TMD fragmentation functions for J/ψ production, M. Copeland *et al.*, Phys. Rev. D 109 (2024) 054017 (arXiv:2308.08605).**
- **Polarized J/ψ production in semi-inclusive DIS at large Q^2: Comparing quark fragmentation and photon-gluon fusion, M. Copeland *et al.*, Phys. Rev. D in press (arXiv:2310.13737).**
- **Bottomonium suppression in 5.02 and 8.16 TeV p-Pb collisions, M. Strickland, S. Thapa and R. Vogt, Phys. Rev. D in press (arXiv:2401.16704).**
- **J/ψ Photoproduction in $e + p$ Collisions in the Improved Color Evaporation Model, V. Cheung and R. Vogt, to be submitted to Phys. Rev. D.**
- **Tetraquarks from Intrinsic Heavy Quarks, R. Vogt, to be submitted to Phys. Rev. D.**

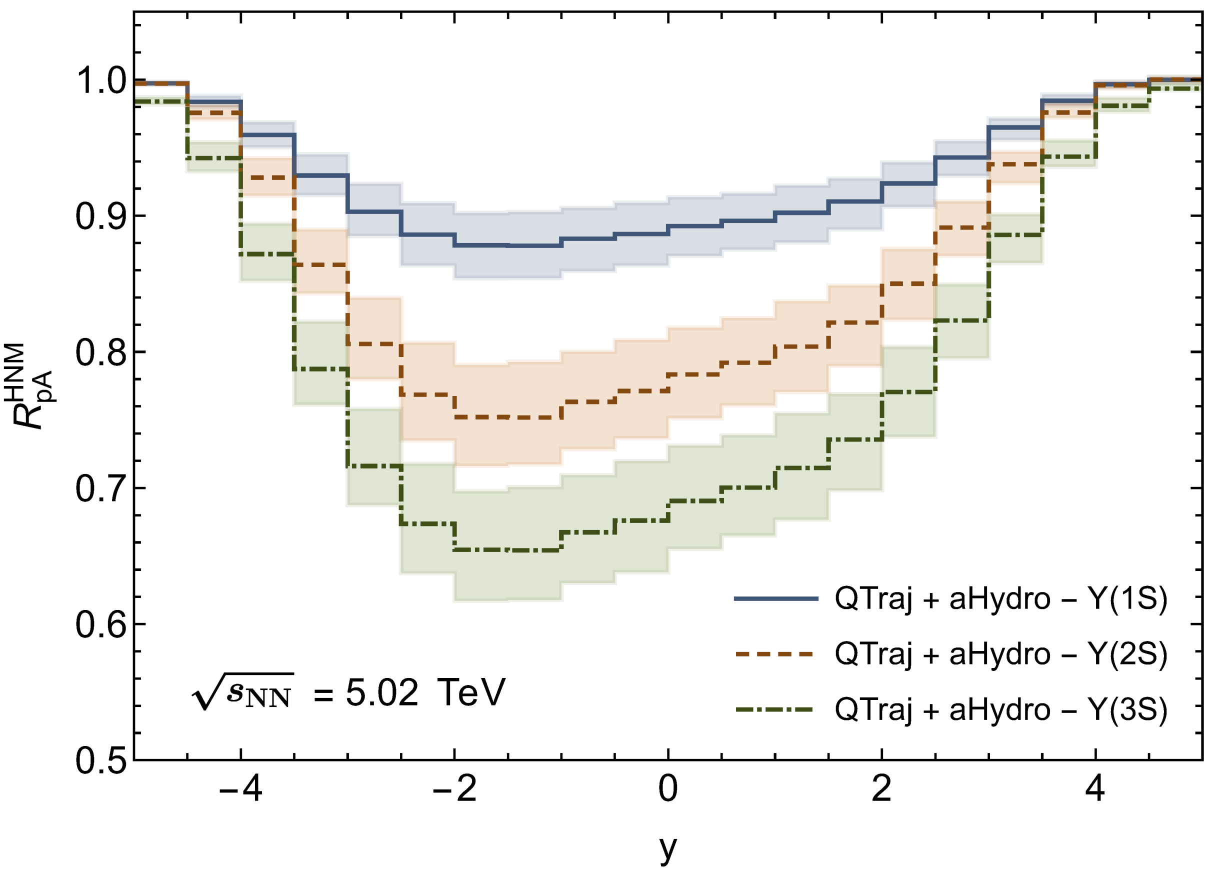
Large number of presentations at conferences and workshops

Backup

Hot Matter R_{pA} as a Function of Rapidity

Higher T in the Pb-going direction

Strongest suppression on Υ(3S) state

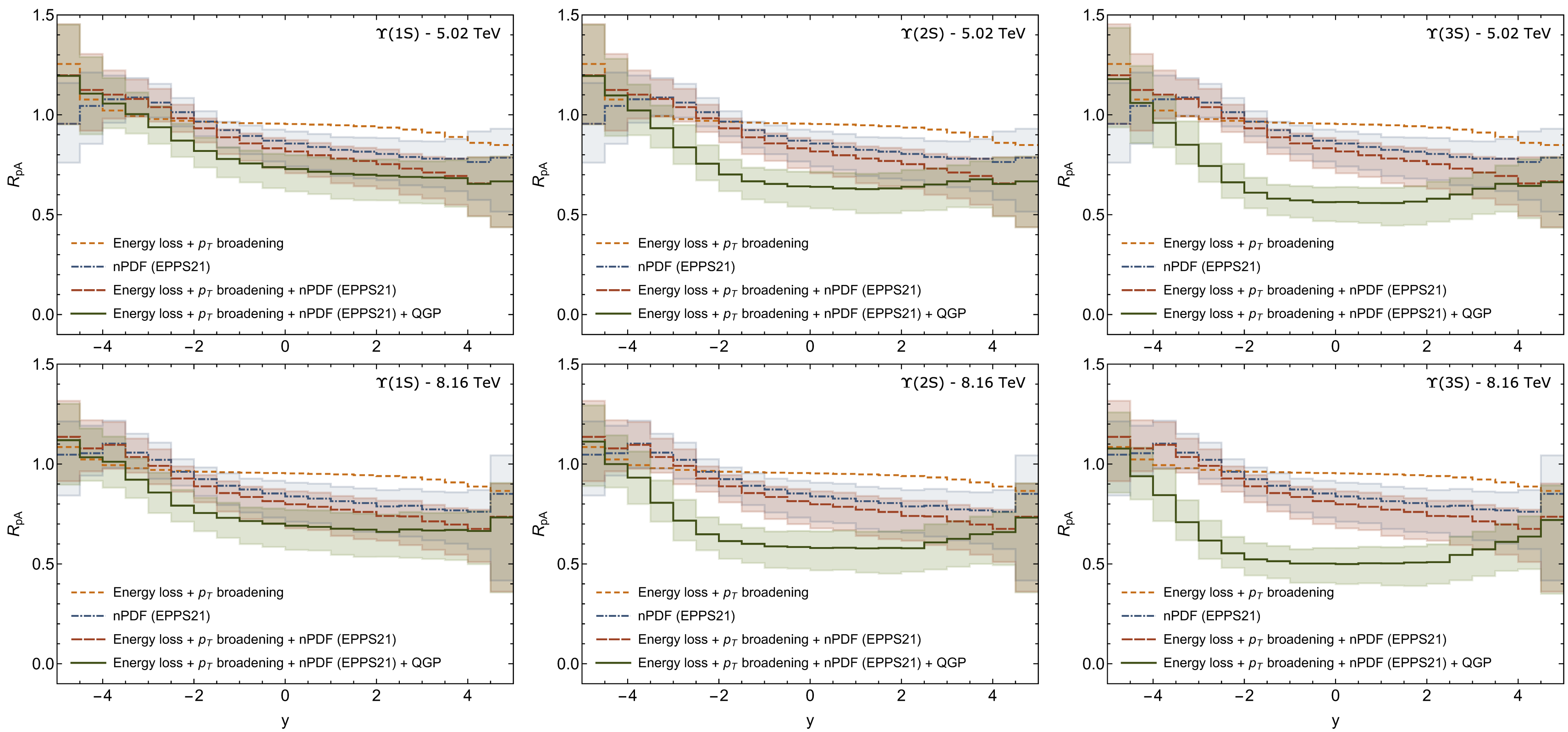


Individual Contributions as Function of Rapidity

Little difference in energy dependence ($\sqrt{s_{NN}} = 5.02$ TeV (top) and 8.16 TeV (bottom))

Only difference between states is due to the hot matter contribution

Note that at high and low y, the hot matter effects disappear and green band (with QGP) and brown band (including only cold matter effects) merge



Tetraquark Production with Intrinsic Charm

RV, in preparation (MS-2)