Results from PHENIX

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https://www.colorado.edu/physics/2013/12/09/quark-gluon-droplets-discovered-bnls-phenix-experiment
4-spectrometer arms

- Central detector $|\eta| < 0.35$
- Forward/backward detector $1.2 < |\eta| < 2.2$

Ended operations in 2016 but still produce new results from the large data acquired during its final years.
Au + Au
b/c quark $R_{AA}$

- Beauty is less suppressed than charm
Consistent with zero at forward rapidity, different from the LHC results.

May indicate absence of charmonium regeneration in the forward rapidity region at RHIC energies.
Jet substructure

- New analysis of jet substructure
  - $R = 0.3$
  - $12.0 \text{ GeV/c} < p_T < 14.5 \text{ GeV/c}$
- Analysis ongoing with p+Au, results coming soon!

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Jet substructure

- New analysis of jet substructure
  - $R = 0.3$
  - $20.5 \text{ GeV}/c < p_T < 24.5 \text{ GeV}/c$
- Analysis ongoing with p+Au, results coming soon!
J/ψ yield in p+p

- J/ψ yield exhibits large dependence on local track multiplicity
- Usually attributed to multi-parton interactions
J/ψ yield in p+p

**RED** = Tracklets $N_{ch}^N(1.2 < \eta < 2.4)$
[inclusive, dimuon subtracted]

**Green** = J/ψ (1.2 < $y_{J/\psi}$ < 2.2)

**Blue** = J/ψ (-2.2 < $y_{J/\psi}$ < -1.2)

- J/ψ yield vs multiplicity significantly reduced when looking at J/ψ and multiplicity in separate rapidity windows
  - Looking at J/ψ and multiplicity in the same rapidity window but removing the $\mu^+ \mu^-$ from the multiplicity
- Important implications for MPI picture

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Au+p,X
J/ψ and ψ(2S) nuclear modification factor

- J/ψ modification consistent with initial state effects alone at forward and backward rapidity
- ψ(2S) modification indicates presence of final state effects at backward rapidity
  - Presence of co-movers? QGP?

arXiv:2202.03863

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J/ψ and ψ(2S) nuclear modification factor

Similar patterns for J/ψ and ψ(2S) found at RHIC and LHC

arXiv:2202.03863

PHENIX $\sqrt{s_{NN}}=200$ GeV
LHCb p+Pb $\sqrt{s_{NN}}=5$ TeV
ALICE p+Pb $\sqrt{s_{NN}}=5$ TeV
Nuclear modification of $\pi^0$ in small systems

- Minimum bias collisions shown
- Cronin enhancement at intermediate $p_T$
  - Lighter target shows smaller enhancement ($p+Al < p+Au$)
  - Heavier projectile shows smaller enhancement ($3He+Au < d+Au < p+Au$)
Nuclear modification of $\pi^0$ in small systems

- Considerable centrality dependence—suppression in central, enhancement in peripheral
- Peripheral enhancement not new, but still difficult to understand...
Direct photons and π^0 in small systems

- Can use non-modification of photons to correct for bias in N_{coll} determination
- Resolves a decade-long mystery of apparent enhancement in peripheral collisions
- Small but non-negligible suppression in central collisions
  - EMC effect? QGP?
• $\phi$ similar to $\pi^0$ with a few hints of a slight enhancement relative to $\pi^0$
φ meson in small systems

- φ nuclear modification reasonably well-described by PYTHIA Angantyr, but overall system size ordering is missed

\[ \phi \rightarrow K^+K^- \]

PhENIX

\[ \frac{S_{NN}=200 \text{ GeV}, |y|<0.35}{p_{T}(\text{GeV/c})} \]

\[ p+Al, 0\% - 100\% \]

\[ p+Au, 0\% - 100\% \]

\[ d+Au, 0\% - 100\%, \text{ PRC 83, 0249} \]

\[ ^{3}\text{He}+Au, 0\% - 100\% \]

arXiv:2203.06087
**φ meson in small systems**

- Also reasonably well-described by PYTHIA with nPDFs, but overall system size ordering is missed

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![Graphs showing $R_A$ vs $p_T$ for different reactions and conditions.](image)

- $|s_{NN}| = 200$ GeV, $|v| < 0.35$
- $p+Al, 0\% - 100\%$
- $\phi \rightarrow K^+K^-$
- $d+Au, 0\% - 100\%, PRC 83, 024909$
- $^3He+Au, 0\% - 100\%$

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arXiv:2203.06087
\( v_n \) in small systems

- All new analysis using two-particle correlations with event mixing instead of event plane method used in Nature Physics publication
  - Very different sensitivity to key experimental effects (beam position, detector alignment)
- Uses same detector combination as used in Nature Physics publication
Data and Analysis Preservation (DAP)

- Knowledge management: analysis preservation is more than just software preservation
- Minimum goal: reproducibility of (newly) published result (in principle "forever")
  - new, standardized analysis notes (template-based), mandatory since 2020
  - all analysis codes, macros, auxiliary files stored in HPSS since 2020
  - published data uploaded in HEPData (since 2020)
  - older publications uploaded retroactively – **undergraduate assistants hired at UTK!**
    - currently 62 uploads from about 200 PHENIX publications, growing
- Maximum goal: making re-analysis (with different conditions) possible "forever", in principle even for "outsiders"
  - Docker/REAna ("Reproducible Analysis")
  - high $p_T$ direct photons in d+Au already implemented
  - Plan to do the same with at least one of each signature PHENIX analysis
    (muons, dielectrons, spin asymmetry, hadron flow, etc.)
- Availability: everything in github (private access) and Zenodo (public access)
- First from RHIC to publish data and simplified analysis tools on CERN OpenData for the general public
- All info available from the new “DAP website” https://www.phenix.bnl.gov/ in Analysis tab
Conclusions

- A still vibrant PHENIX collaboration despite competing efforts
- PHENIX physics program still unique in several studies of QCD and QGP
- Students who came after PHENIX ended of operation are a vital part of PHENIX collaboration and responsible for many more discoveries

Many more interesting and important measurements from PHENIX coming soon!