

PHENIX data analysis and data preservation

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for PHENIX Collaboration

PAC 2023/09/11

Recent highlights and publication status

PHENIX papers since June 2022

PRL130,251901 (2023)	Cross section and A_{LL} of direct photons in $p + p$ at 510GeV	BNL and RIKEN news release
PRD107,112004 (2023)	A_N of π^0 in p+p and p+A	
PRD107,052012 (2023)	A_N of heavy flavor decay electrons	
PRD107,024907 (2023)	Flow in $p + Au, d + Au, ^3He+Au$	
PRC107,024914 (2023)	Low p_T direct photons in Au+Au at 39 and 62.4GeV	PRC Editor's suggestion
PRC107,014907 (2023)	ϕ in Cu+Au and U+U	
PRC106,064912 (2022)	ϕ in p+p,p+Al,d+Au, and ^3He+Au	
PRC105,064912 (2022)	Forward and Backward $\psi(2S)$ in $p + p, p + Al, p + Au$	PRC Editor's suggestion
PRC105,064902 (2022)	π^0 in $p + Al, p + Au, d + Au, ^3He+Au$	
arXiv:2303.12899	Suppression of high pT pi0 relative to direct photon in central d+Au	
arXiv:2303.07191	A_N of charged hadrons in p+p and p+A	
arXiv:2203.17187	Non-prompt direct photons in Au+Au 200 GeV	
arXiv:2203.17058	R_{AA} of $b \rightarrow e$ and $c \rightarrow e$	
arXiv:1805.04066	$\mu\mu, e\mu, ee$ correlations in $p + p$ 200 GeV	

9 papers published + 3 submitted

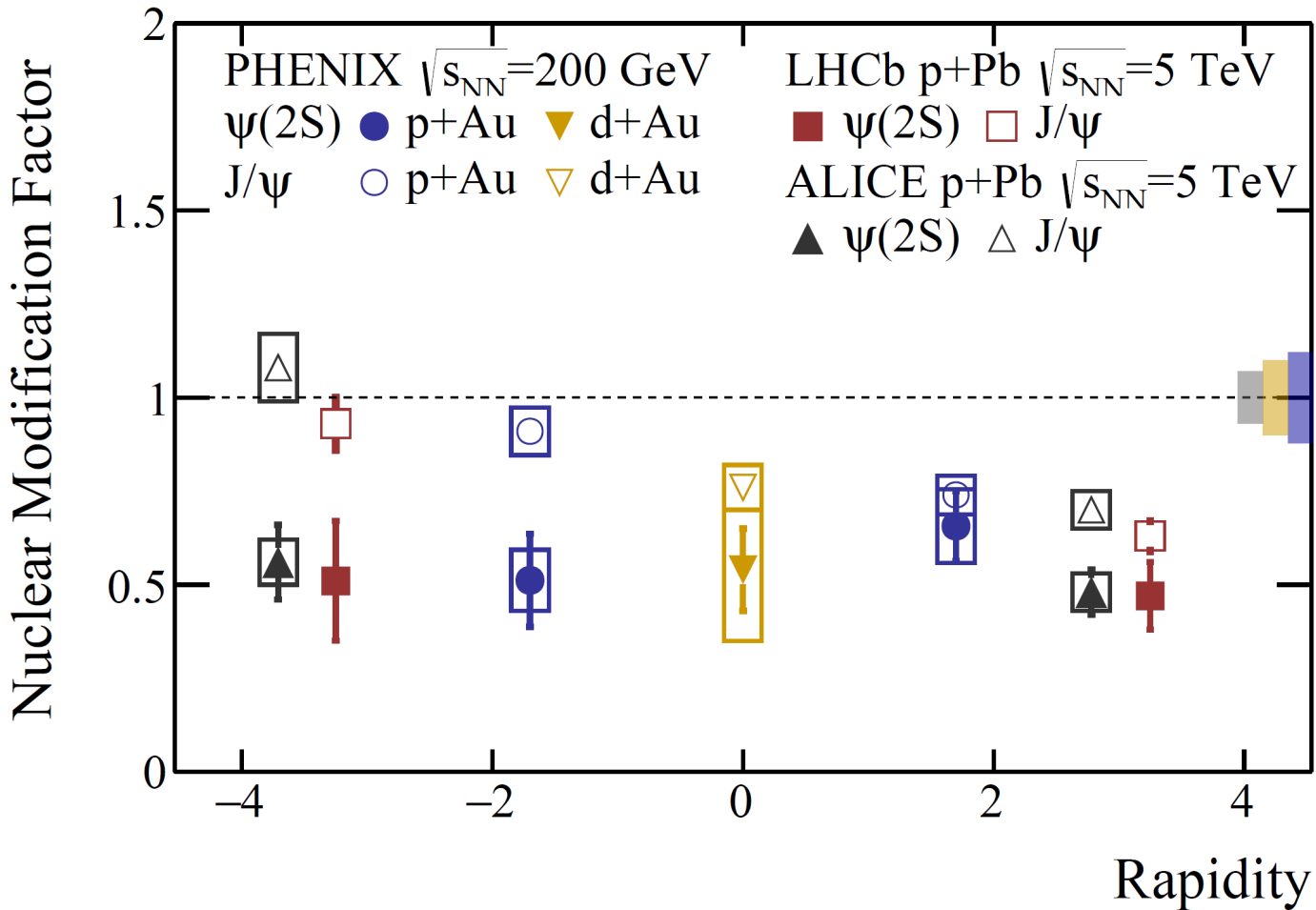
4+1 papers in Journal review

4 papers in internal review

$\psi(2S)$ suppression in p+Al, and p+Au

PHYSICAL REVIEW C **105**, 064912 (2022)

Editors' Suggestion



- Nuclear modification of $\psi(2S)$ in $p + Al$, and $p + Au$
- Forward (p-going):
 - similar suppression of J/ψ and $\psi(2S)$
 - Shadowing dominance
- Backward (A-going):
 - Stronger suppression of $\psi(2S)$ than J/ψ suggests **presence of final state effects in $p + A$**
- **PRC Editor's suggestion**

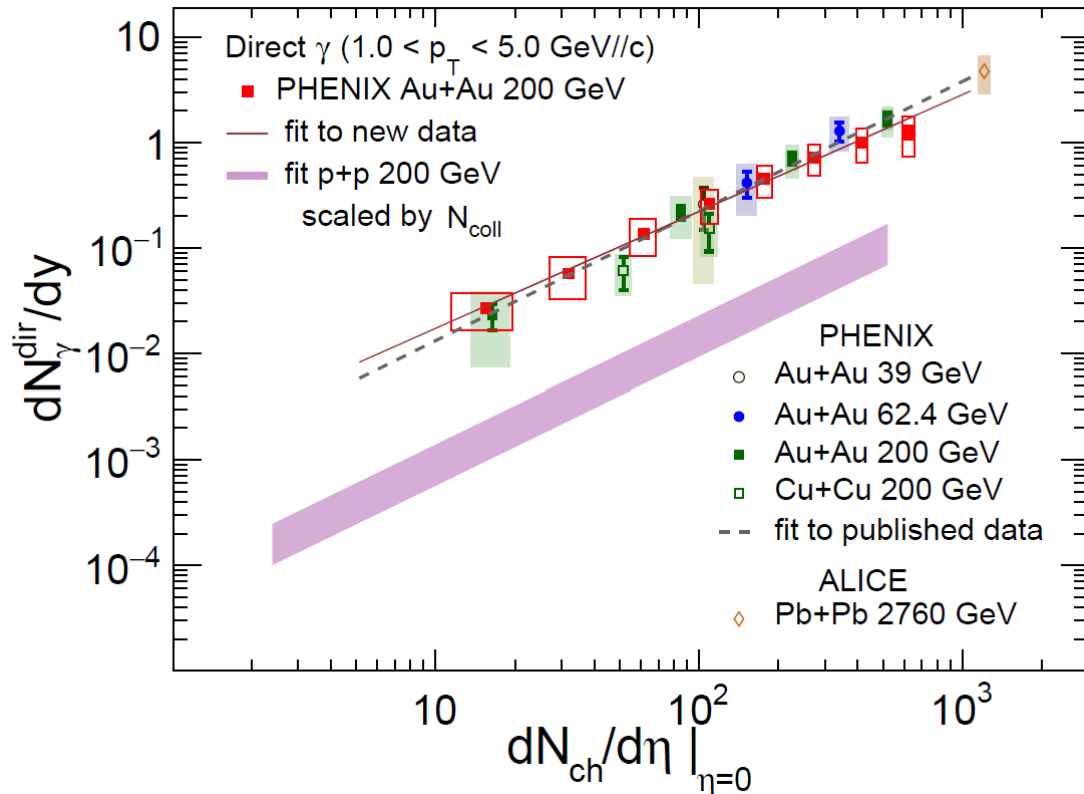
Unique capability of PHENIX



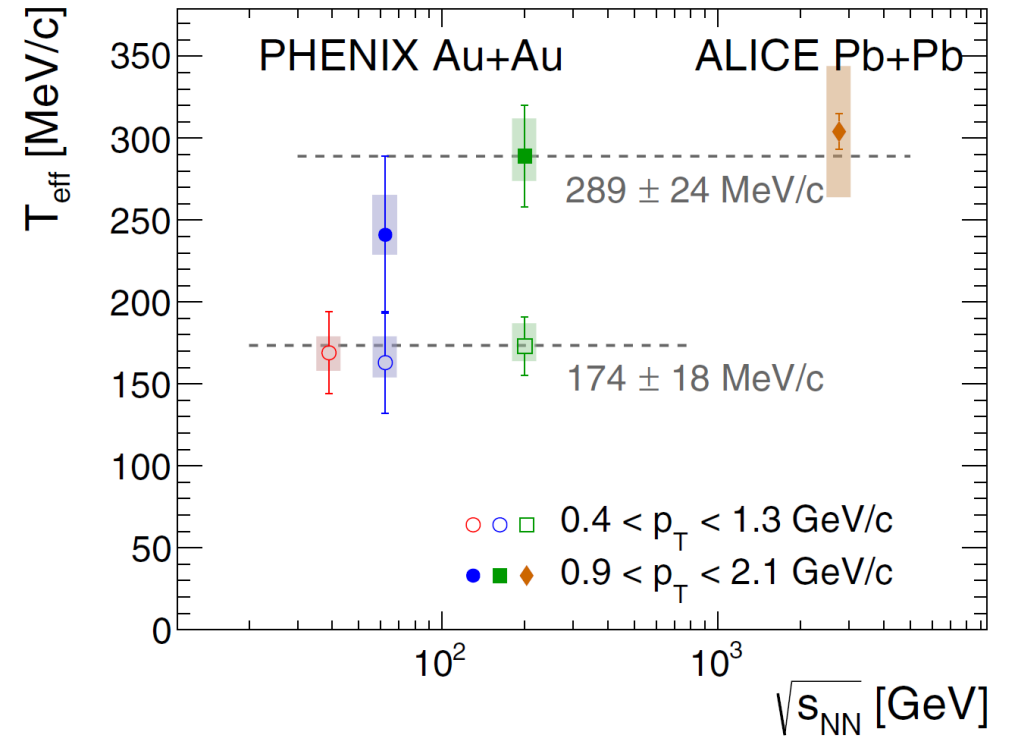
Low p_T direct photons

arXiv:2203.17187 (2022)

PHYSICAL REVIEW C **107**, 024914 (2023)



Editors' Suggestion

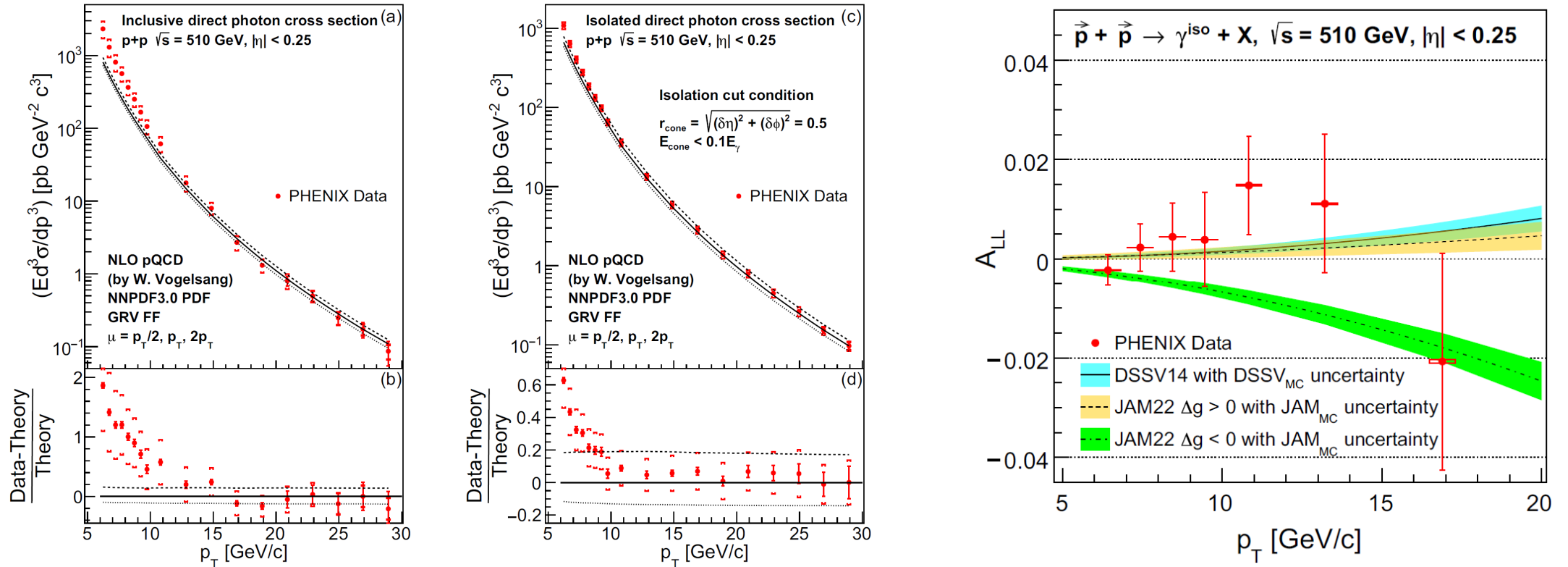


- Systematic measurement of direct photons in various systems and beam energy in wide p_T range:
- Paper of measurement at 39 and 63 GeV was PRC *editors suggestion*.

Direct photon A_{LL}

PHYSICAL REVIEW LETTERS 130, 251901 (2023)

Measurement of Direct-Photon Cross Section and Double-Helicity Asymmetry at $\sqrt{s} = 510$ GeV in $\vec{p} + \vec{p}$ Collisions

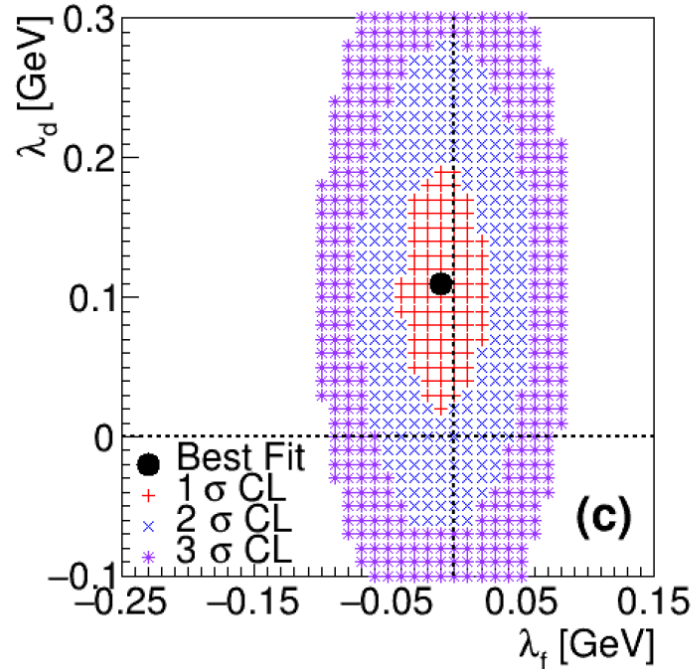
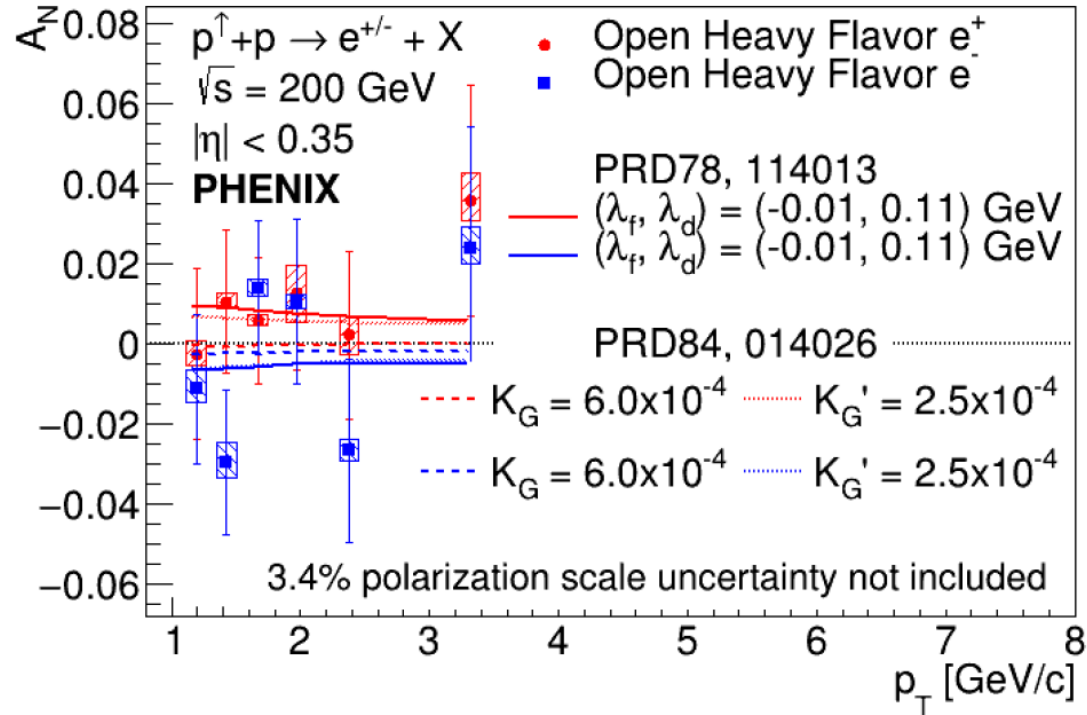


- Determined that the gluon polarization is positive
- This is one of the original goal of RHIC spin physics program
- BNL and RIKEN news release

Unique capability of PHENIX PHENIX

Heavy Flavor A_N

PRD107,052012 (2023)



$$A_N(p^{\uparrow}+p \rightarrow \text{HF}(e^{+/-}) + X)$$

$$\sqrt{s} = 200 \text{ GeV}$$

$$|\eta| < 0.35$$

PHENIX

Theory: PRD78, 114013

$$A_N^{D^0/\bar{D}^0 \rightarrow e^{+/-}}(\lambda_f, \lambda_d)$$

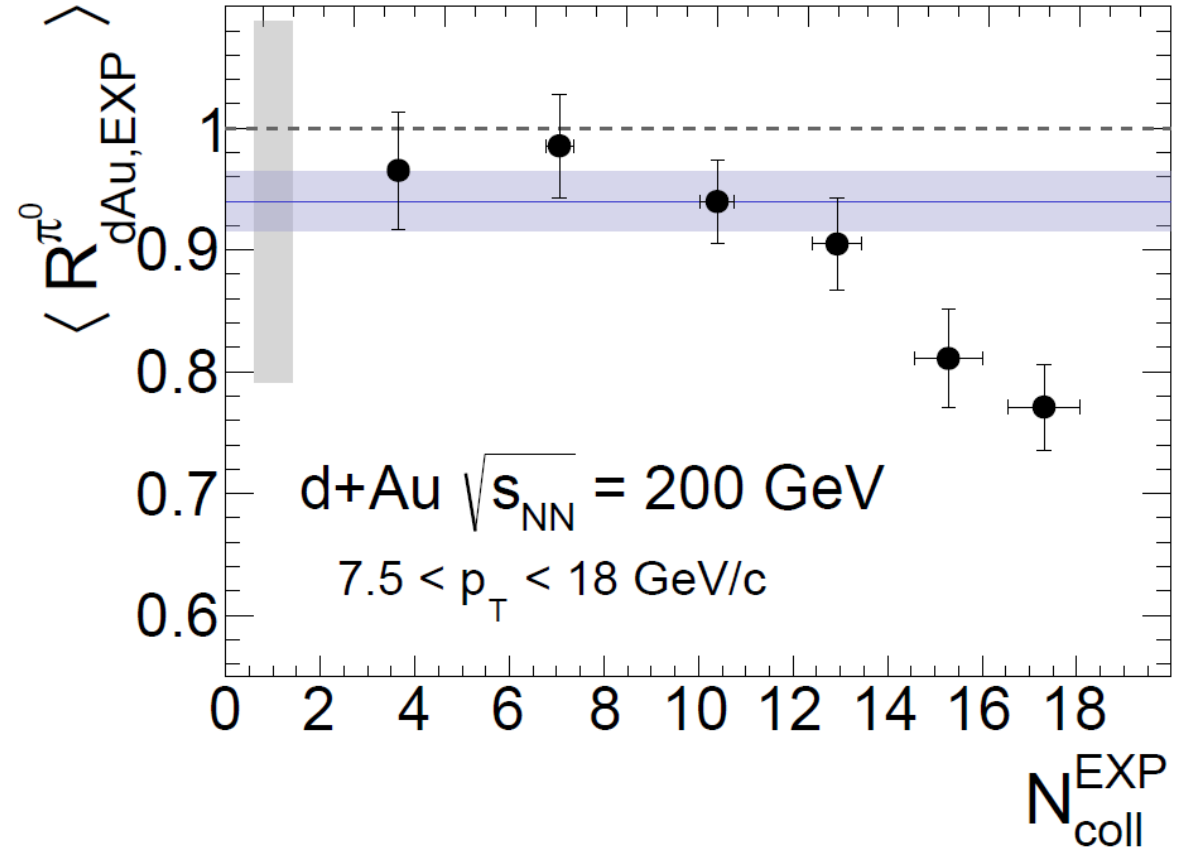
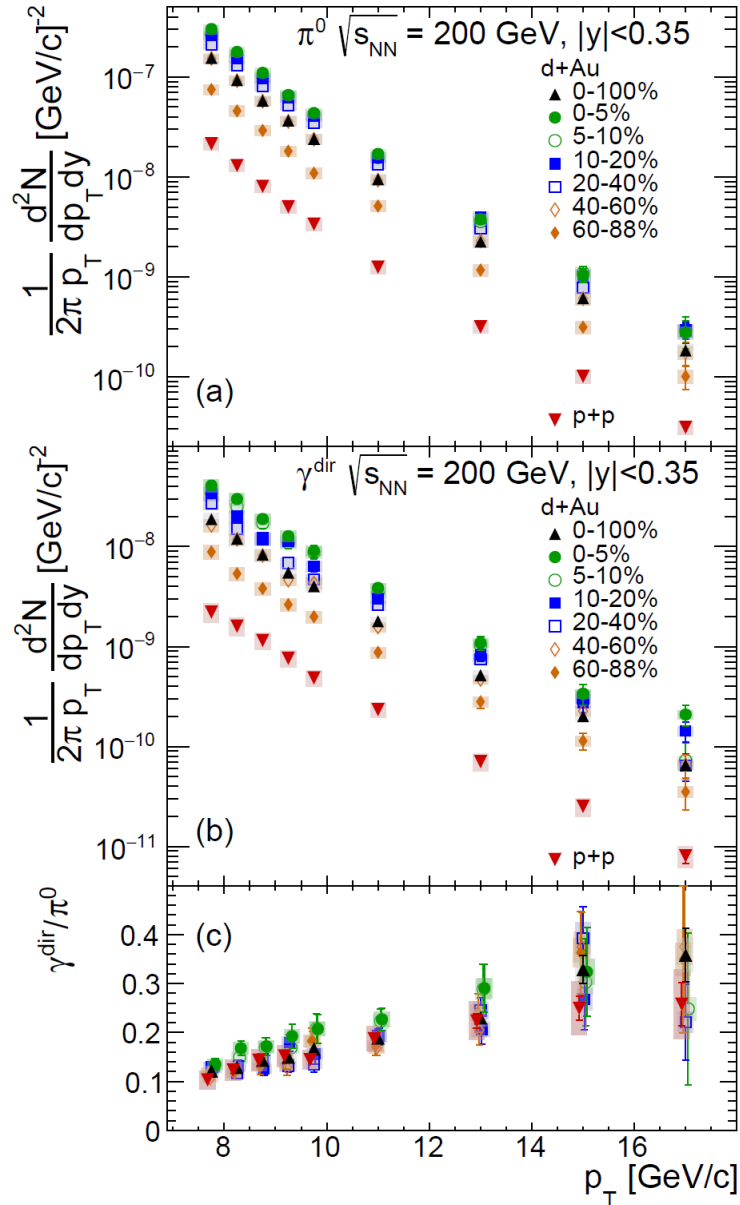
- Measurement of A_N of heavy-flavor decay electrons
- **Constraints on parameters of Tri-Gluon model by Z.Kang and J.W.Qiu**
 - The first measurement on the model parameters (λ_f, λ_d) of the model

Unique capability of PHENIX



π^0 and direct photon in d+Au

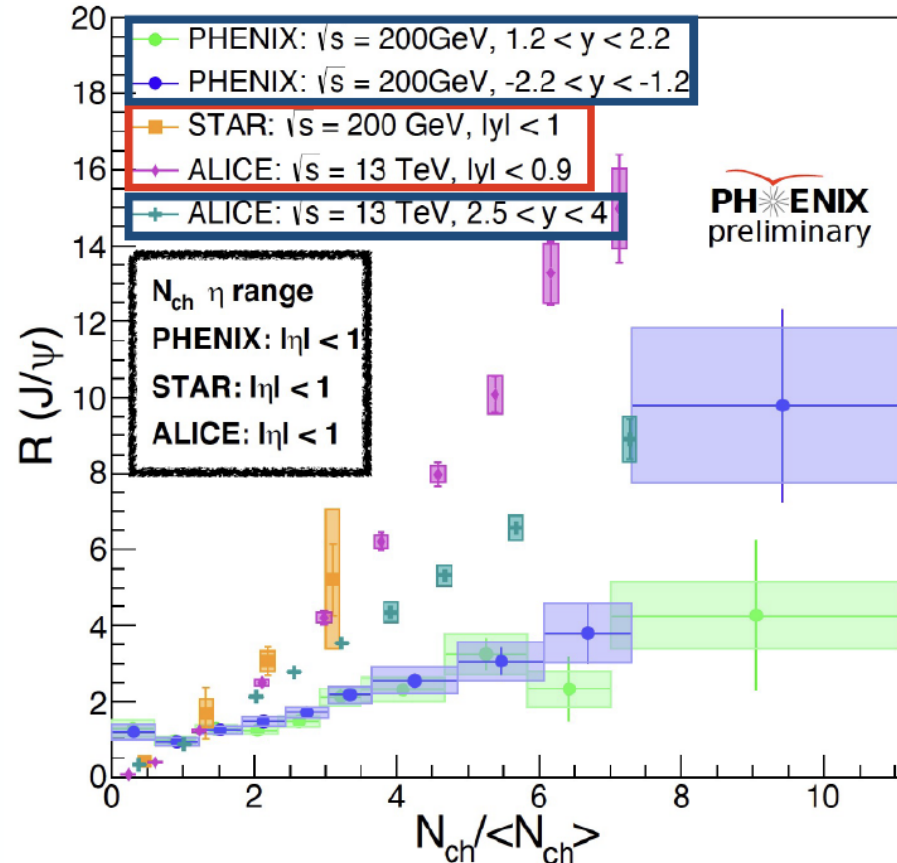
arXiv:2303.12899



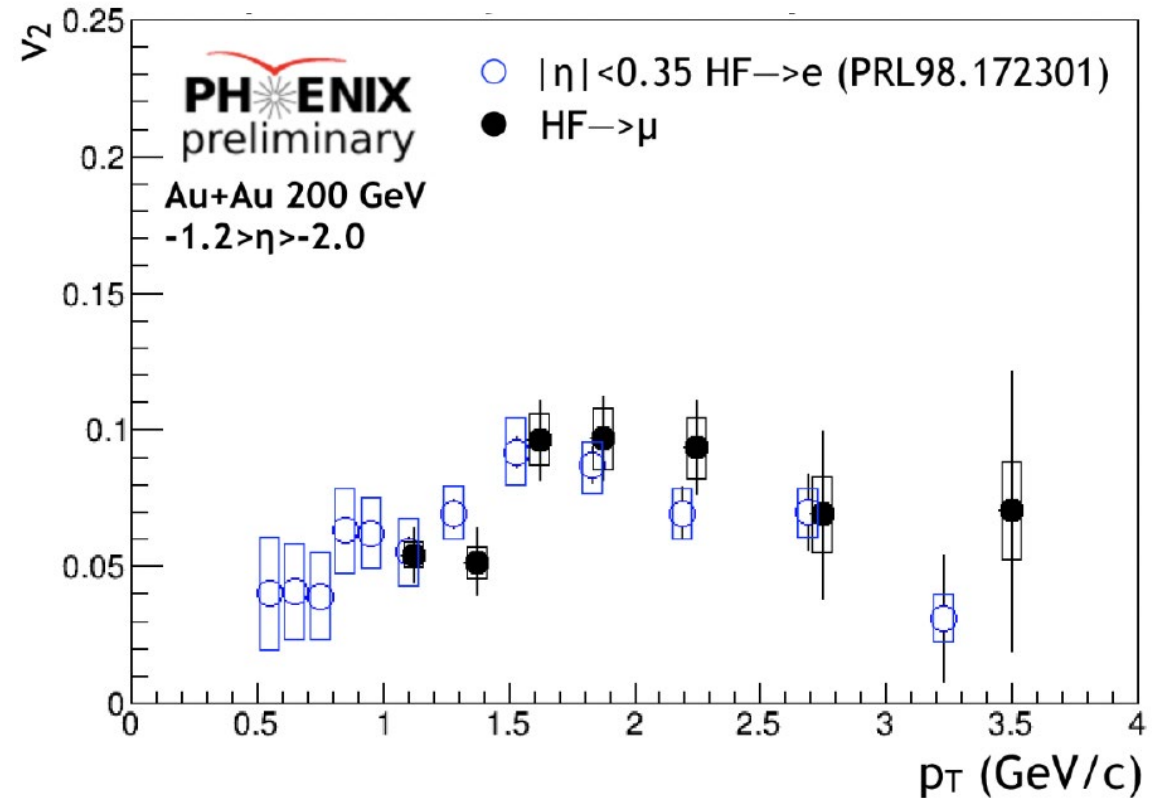
- π^0 is suppressed relative to direct photon in central d+Au
- Evidence for π^0 suppression in most central d+Au

New results shown in the Quark Matter 2023 (1)

N_{ch} dependence of $\psi(2S)$ vs J/ψ ratio in p+p

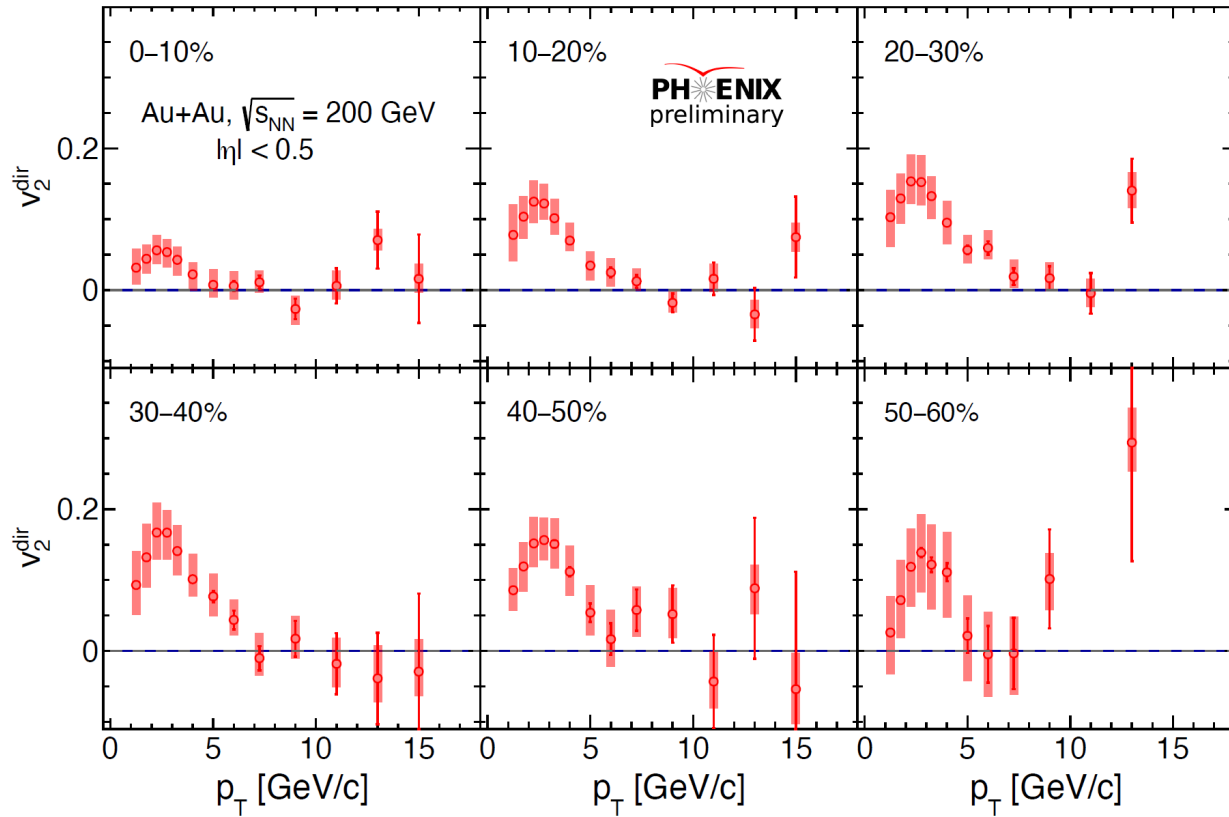


v_2 of Heavy flavor in forward rapidity

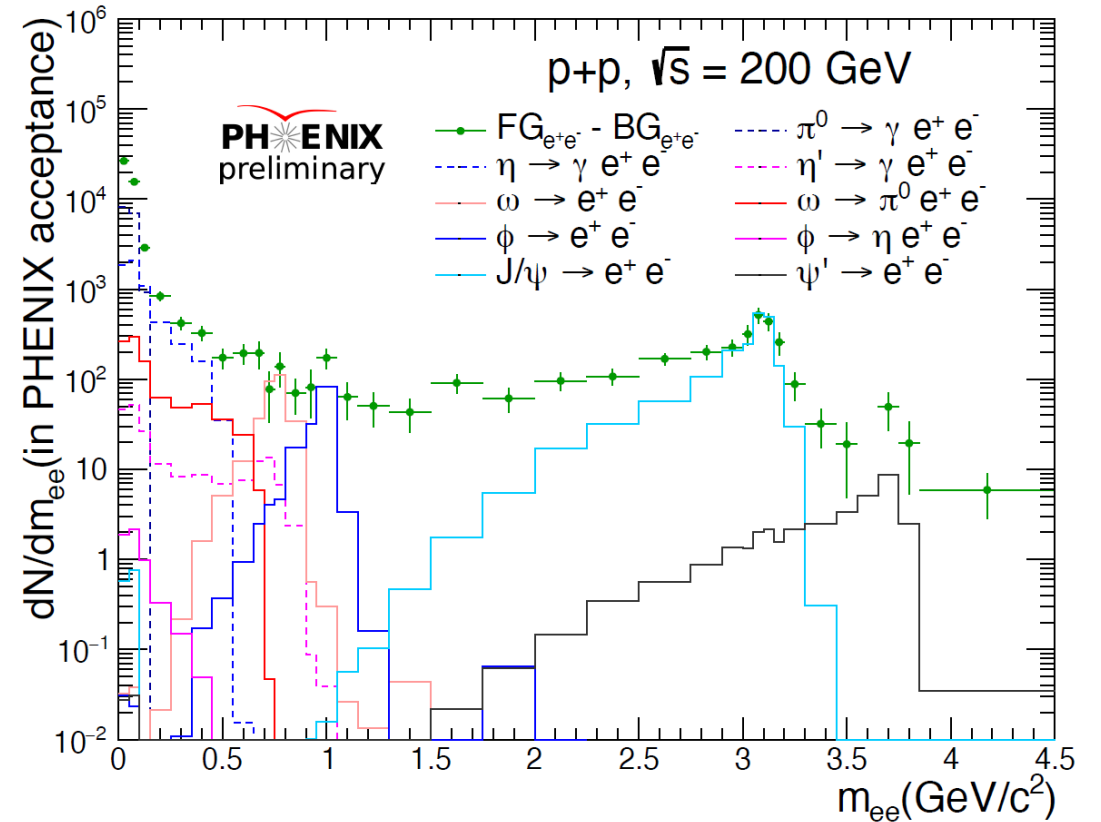


New results shown in the Quark Matter 2023 (2)

v_2 of direct photon in Au+Au



$e^+ e^-$ in p+p



- v_2 of direct photon from RUN14. RUN16 data will double the statistic
- $e^+ e^-$ measurement in p+p is the proof of principle for IMR thermal $e^+ e^-$ pair measurement in Au+Au

PHENIX publications

- **218 physics papers published/accepted**

- Phys. Rev. Lett. 76
- Phys. Rev. C90
- Phys. Rev. D 46
- Nature Physics 1
- Phys. Letter B 4
- Nucl. Phys. A 1

- **Total citation: ~33000**

- Topcite 1000+ 2
 - 500-1000 8
 - 250-500 21
 - 100-250 62
 - 50-100 48

PHENIX White Paper: 3486 cites

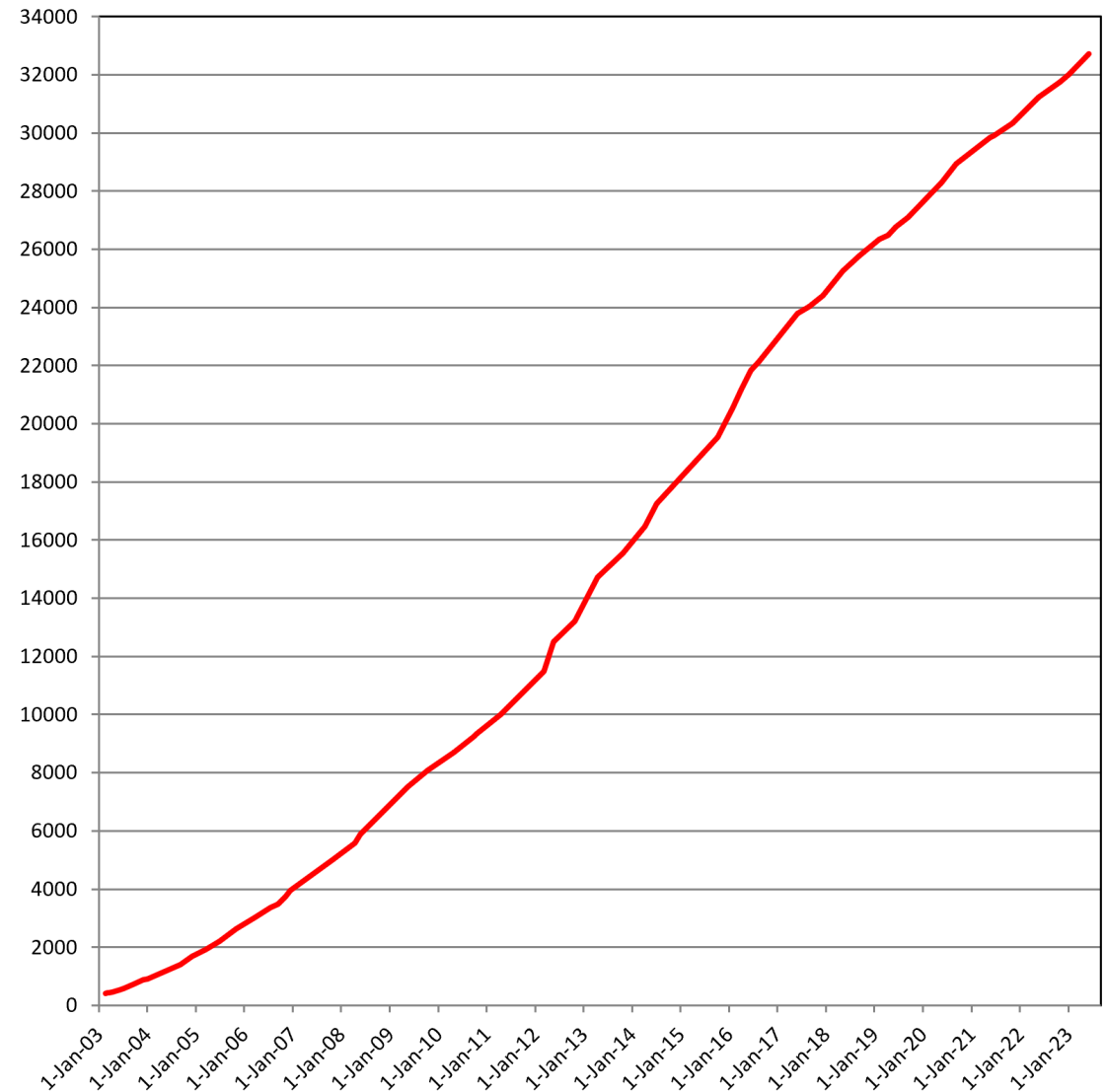
Jet quenching discovery: 1187 cites

Nature P paper: 262 citations

141 physics papers in topcite 50+

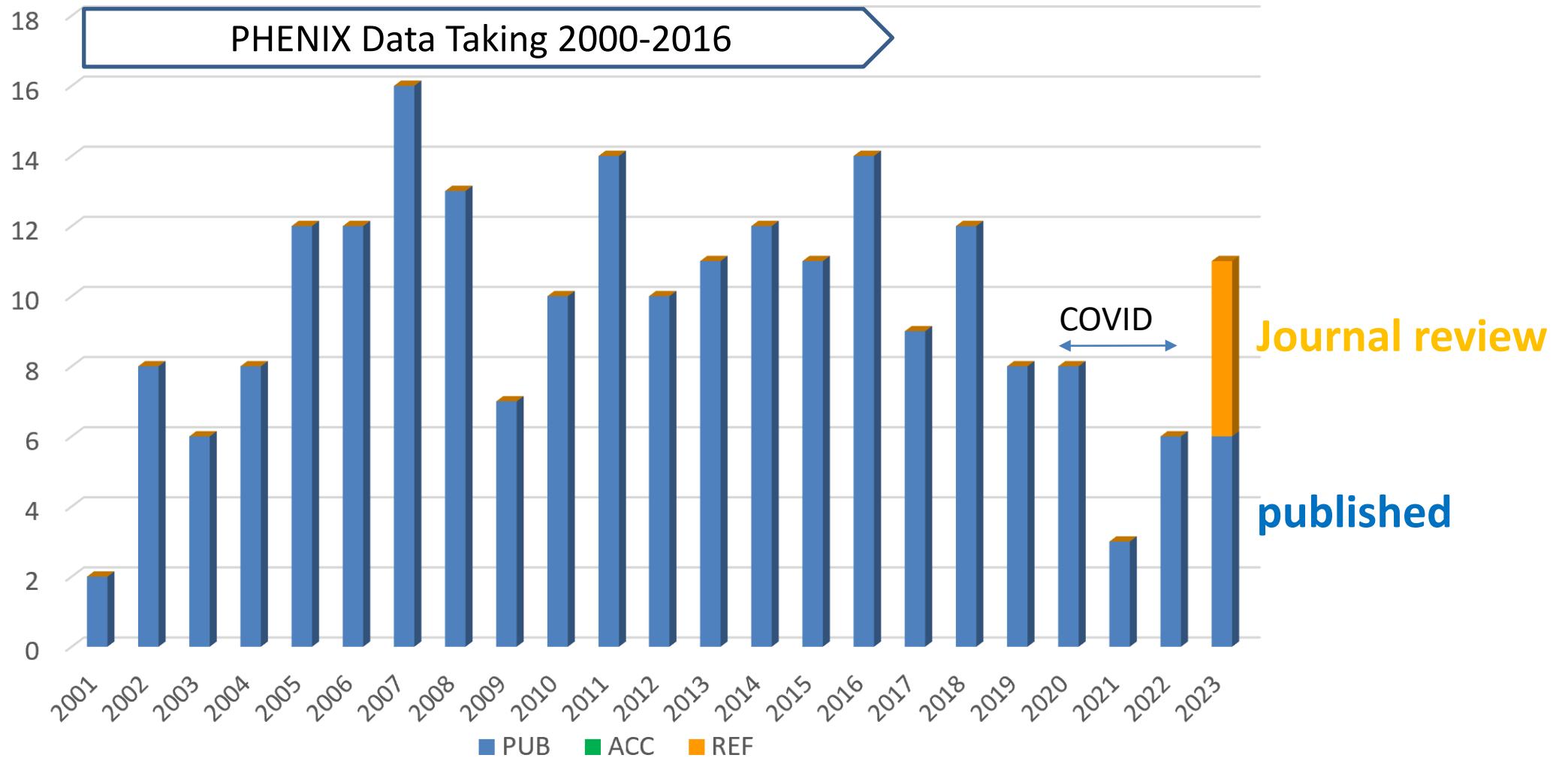
(163 if proceedings and detector papers are included)

Cumulative Citations of PHENIX papers



PHENIX publications

Published PHENIX papers in each year



- 6 papers published in 2023, 5 papers under journal review

Award: S and T award by the Minister of MEXT



YA received

“Commendation for Science and Technology by the Japanese Minister of Education, Culture, Sports, Science and Technology (Research Category)”

for

“Research of high temperature and high density matter through relativistic heavy-ion collisions”

Analysis status

Datasets of PHENIX

year	Beam, E(GeV)	Recorded data (pp equiv)	upgrade	Physics
2016	AuAu 200 dAu 200 dAu 62,39,20	2.3/nb (90/pb) 15B events 1G & 73/nb (29/pb) 0.6G 0.1G, 8M	VTX,FVTX MPC-EX	Heavy Flavor Gluon nPDF Small QGP
2015	pp 200 pAu 200 pAl 200	23/pb 80/nb (16/pb) 275/nb (7.4/pb)	VTX, FVTX	Heavy Flavor Transverse spin CNM, small QGP
2014	AuAu 200, 15 ³ HeAu 200	2.3/nb (90/pb) 15 B events 25/nb (15/pb)	VTX, FVTX	Heavy Flavor Small QGP
2013	pp 510	240/pb	W-trigger	Anti-quark spin Gluon spin
2012	pp 510 pp 200 CuAu 200 UU 193	50/pb 4/pb 5/nb (60/pb) 0.17/nb (10/pb)	W-trigger VTX, FVTX	Anti-quark spin Transverse spin Heavy flavor Geometry
2011	pp 510 AuAu 200 AuAu 19, 27	28/pb 0.8/nb (32/pb)	W-trigger VTX	Anti-quark spin Heavy flavor BES-I
2010	AuAu 200 AuAu 62,39,7	1.1/nb (44/pb)	HBD	Low mass ee BES-I

nDST production is complete

Analysis map update: key analyses

On-Going Key analysis ◦		
Topic ◦	Leading group ◦	Time line ◦
R_{AA} of $b \rightarrow e$ and $c \rightarrow e$ ◦	RIKEN; Nara Women ◦	Under review at PRC ◦
v_2 of $b \rightarrow e$ and $c \rightarrow e$ ◦	RIKEN; Nara Women ◦	Submit in 1 year ◦
Flow of J/ψ ◦	Vanderbilt ◦	Submit in 1 year ◦
High p_T direct photon in $d+Au$ ◦	Stony Brook, Debrecen ◦	Submitted to PRL ◦
High p_T direct photon in $p+Au$ ◦	Stony Brook, Debrecen ◦	Preliminary by QM2023 ◦ Submit in 1 year ◦
High p_T direct photon in $He3+Au$ ◦	Stony Brook, Debrecen ◦	Submit in 1 years ◦
Direct photons R_{AA} in RUN14 $Au+Au$ ◦	Stony Brook ◦	Under review at PRC ◦
Direct photon v_2 in RUN14 ◦	Stony Brook ◦	Submit in 1 year ◦
Low p_T direct photons in $Cu+Au$ ◦	Stony Brook ◦	Submit in 2-3 years ◦
Low p_T direct photons in small systems ◦	Stony Brook ◦	Submit in 1 year ◦
Direct γ -hadron correlations in $Au+Au$ (RUN14) ◦	Georgia State University ◦	Submit in 2-3 years ◦
IMR e^+e^- in RUN14+15+16 ◦ ($AuAu$ and pp) ◦	Stony Brook ◦	Preliminary for pp for QM2023 ◦
Heavy flavor single electron in $p+Au$ ◦	Baruch ◦	Publish in 1 year ◦
Heavy Flavor electron A_N ◦	U. Michigan ◦	Published in PRD ◦
J/ψ vs N_{ch} in $p+p$ ◦	LANL, Pusan ◦	Submit in 1 year ◦
$\psi(2S)/J/\psi$ vs N_{ch} in $p+p$ ◦	LANL, Pusan ◦	Preliminary for QM2023 ◦ Submit in 1 year ◦
HF v_2 in $AuAu$ in RUN14+16 ◦	Vanderbilt ◦	Preliminary by QM2023 ◦

Key analysis needs additional funding ◦

- $b \rightarrow e, c \rightarrow e$ with VTX (RUN14+16) ◦
- $b \rightarrow \mu, c \rightarrow \mu$ with FVTX (RUN14+16) ◦
- Intermediate mass dilepton (RUN14+16) ◦

- As part of recommendation of the 2021 site visit, “analysis map” showing status and responsibilities of analyses was reported to DOE.
- This is the update of “analysis map” since the S and T review in November 2022.
- **Heavy Flavor electron A_N was published on schedule**
- **High p_T direct photon in $d+Au$ was submitted to PRL on schedule**
- Other key analyses are making progress

Analysis map update: on-going analyses

On-Going analysis ◦		
Topic ◦	Leading group ◦	Time line ◦
$\pi^\pm, K^\pm, p, \bar{p}$ in $p+A, {}^3\text{He}+Au$ ◦	St. Petersburg ◦	First release in 2023/08 ◦
π^0 v_2 in Cu+Au ◦	St. Petersburg ◦	Preliminary 2023/03 ◦
Centrality dependence of Levy HBT in Au+Au ◦	Etövös University ◦	Second release in 2023/03; submit in 1 year ◦
π^0, η and prompt photon in Au+Au (RUN14+16) ◦	Debrecen University ◦	Preliminary in half year ◦
$B \rightarrow J/\psi$ in $p + p$ ◦	BNL ◦	Submit in 1 year ◦
$B \rightarrow J/\psi$ in Au+Au ◦	BNL ◦	Submit in 2 years ◦
ϕ R_{AA} in Au+Au (RUN14) ◦	Georgia State University ◦	Submit in 1 year ◦
ϕ R_{pA} in small systems ◦	Georgia State University ◦	Submit in 1 year ◦
π^0 – hadron correlations in Au+Au (RUN10+11+14) ◦	Georgia State University ◦	Two PPGs formed ◦
Jets in Cu+Au ◦	Iowa State University ◦	Submit in 1 year ◦
Jets in p+p, p+Al, p+Au ◦	Iowa State University ◦	Submit in 1 year ◦
π^0, η in forward rapidity with MPC-EX in d+Au ◦	Iowa State University ◦	Submit in 1 year ◦
Forward EM cluster A_{LL} at 510 GeV ◦	Stony Brook ◦	Preliminary in 1 year ◦
Forward neutron A_N at 63 and 510 GeV ◦	Stony Brook ◦	Submit in 1 year ◦
Midrapidity π^0 and η A_N in $p + A$ at 200 GeV ◦	U. Michigan ◦	Published in PRD ◦
Forward η cross section and A_N at 500 GeV ◦	U. Michigan ◦	Submit in 1 year ◦
Forward hadron v_2 in AuAu ◦	Vanderbilt ◦	Preliminary in 1 year ◦

- Midrapidity π^0 and η A_N was published on schedule
- Other analysis are making progress
- We don't have a new analysis added to the list
- A few analyses are removed from the list due to lack of the resource
- Collaboration is working to completing the existing analyses.

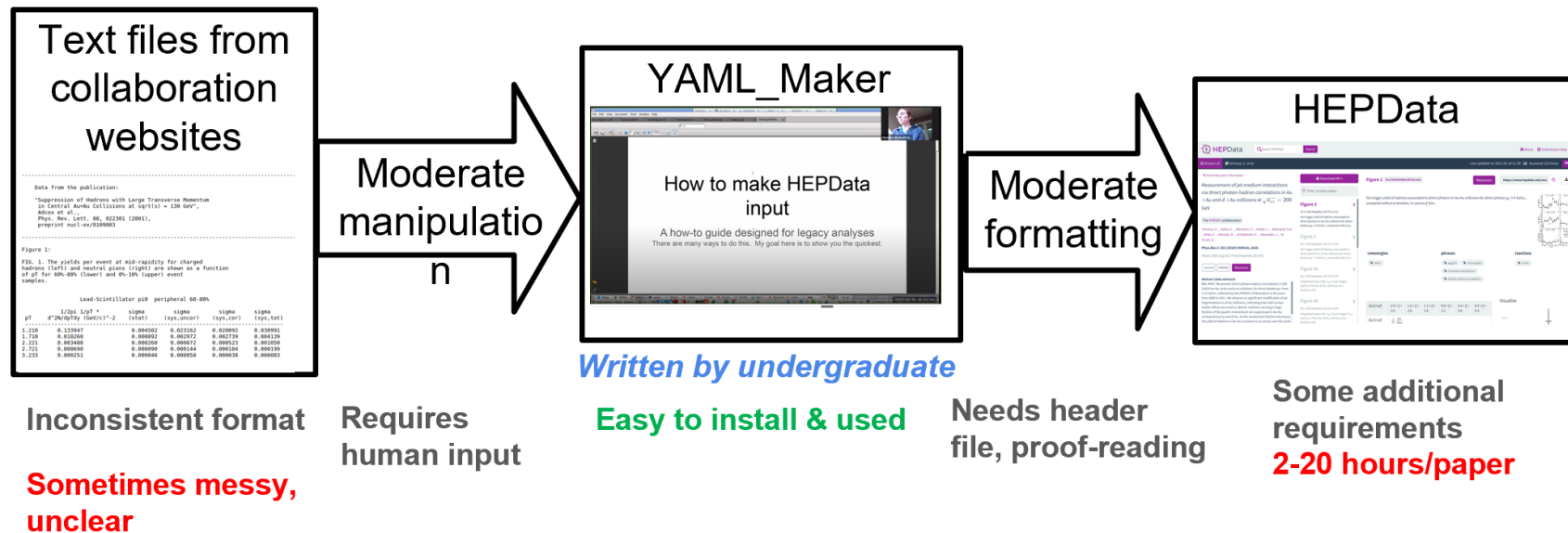
Data and Analysis Preservation

PHENIX DAP Overview

- Data and Analysis Preservation (DAP) was prioritized in PHENIX in 2019, and in 2021-2022 we maintained steady progress in previously established work areas
 - The PHENIX website
 - Zenodo digital repository at CERN
 - The HEPData portal
 - REANA (the Reproducible Analysis framework)
- Significant progress in **HEPData** and **REANA** since S and T review 2022

HEPData

Formatting data for HEPData



- As part of DAP effort, PHENIX start publishing data in HEPData
 - New papers required to publish the data in HEPData
 - started publishing data of old papers, but progress was slow.
- August 2022: C. Nattrass (UTK) made supplemental grant proposal to cover undergraduate to format PHENIX data for HEPData.

UTK HEPData Team



Joseph Beller



Micah Hillman



Nik Nelson

Graduated May 2023
head undergrad



Josie Hakanson



Shannon Harris



Christal Martin



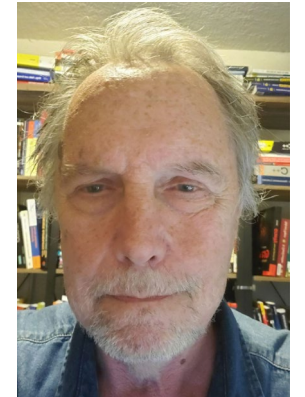
Tom Krobatsch



Christine Nattrass
Supervisor



Andrew McAninch



Hugh Jones

20-25 undergraduates total, approximately 40% female and 30% URM. Pictures shown for significant contributors.

Dozens of people helped with reviews but of note are: Cesar Da Silva (LANL), Krista Smith (LANL), Roli Esha (Stony Brook), Ron Belmont (UNC Greensboro), Axel Drees (Stony Brook), Takahito Todoroki (BNL/RIKEN), Takao Sakaguchi (BNL), Sasha Bazilevsky (BNL), Christine Aidala (UMich), Ralf Siedl (RIKEN)

PHENIX in HEPData

September 2023

- 192 total entries
 - 28 before 2020
 - 125 from UTK undergraduates
 - Plus 22 in progress
 - 39 from the previous effort
- Data of almost all of 218 PHENIX paper is to be published in HEPData

The screenshot shows the HEPData website interface. At the top, there is a search bar with the text "Search HEPData" and a "PHENIX" filter button. The search results are displayed in a list format. The first result is titled "Transverse single-spin asymmetry of midrapidity π^0 and η mesons in p +Au and p +Al collisions at $\sqrt{s_{NN}} = 200$ GeV". The second result is titled "Measurement of ϕ -meson production in Cu+Au at $\sqrt{s_{NN}} = 200$ GeV and U+U at $\sqrt{s_{NN}} = 193$ GeV". The interface includes a sidebar with filters for Collaboration (PHENIX: 162), Subject_areas (nucl-ex: 133, hep-ex: 67, nucl-th: 1), Phrases (transverse momentum: 33, mid-rapidity: 19, midrapidity: 16), Reactions ($p p \rightarrow$ CHARGED X: 23, Au Au \rightarrow CHARGED X: 21, d Au \rightarrow CHARGED X: 10), and CM Energies (GeV). A date histogram shows the distribution of entries from 2001 to 2023. The main content area displays the abstract and data tables for the selected results.

REANA

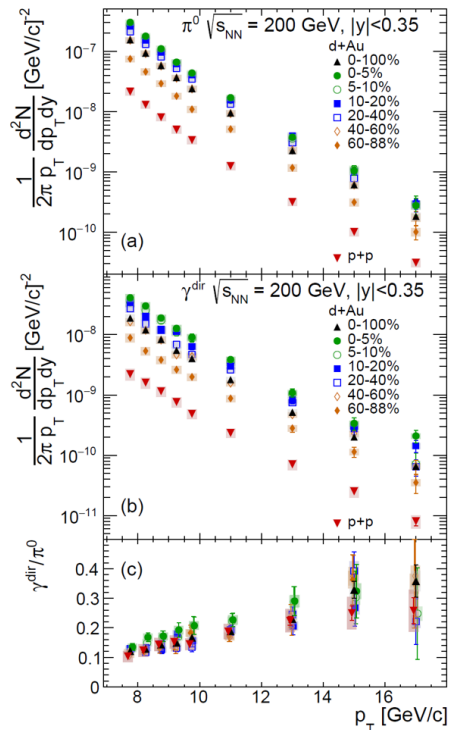
- REANA is a framework of analysis preservation
 - Analysis environment (libraries, etc) are in container (Docker)
 - Workflow in YAML
- In the S&T review, we reported that we started implementing full analysis chain of one of key analyses in REANA @ BNL
 - d+Au pi0 and direct photon
 - Implementation of data/analysis part is now completed

The screenshot shows the REANA website homepage. At the top, there is a navigation bar with links for Home, Examples, Get Started, Documentation, News, Roadmap, Contact, and Blog. The main heading is 'reana' in a large, bold font, with 're' in red and 'ana' in dark blue. Below the heading is the tagline 'Reproducible research data analysis platform'. The page is divided into four columns, each representing a key feature: Flexible, Scalable, Reusable, and Free. Each column contains a brief description and several logos of supported technologies or partners. The 'Flexible' column mentions 'Run many computational workflow engines' and lists 'COMMON WORKFLOW LANGUAGE' and a blue triangle logo. The 'Scalable' column mentions 'Support for remote compute clouds' and lists 'kubernetes', 'HTCondor', and 'slurm'. The 'Reusable' column mentions 'Containerise once, reuse elsewhere. Cloud-native.' and lists Docker and a logo with a blue 'S'. The 'Free' column mentions 'Free Software. MIT licence. Made with ❤ at CERN.' and lists the CERN logo.

REANA

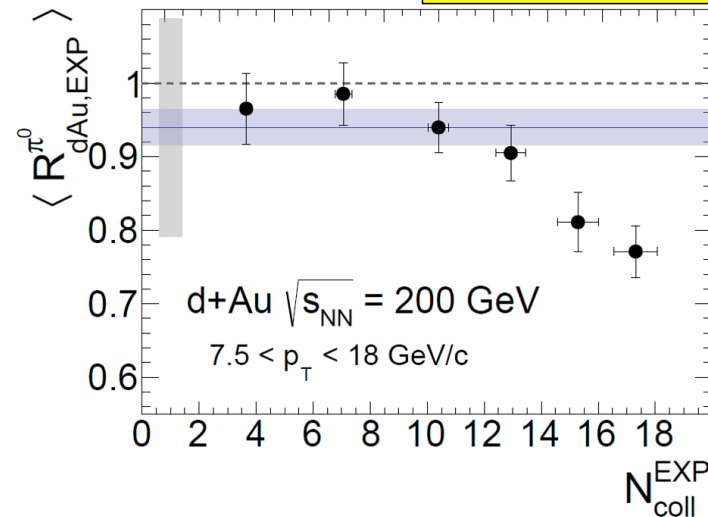
Copy of slide #8

π^0 and direct photon in d+Au



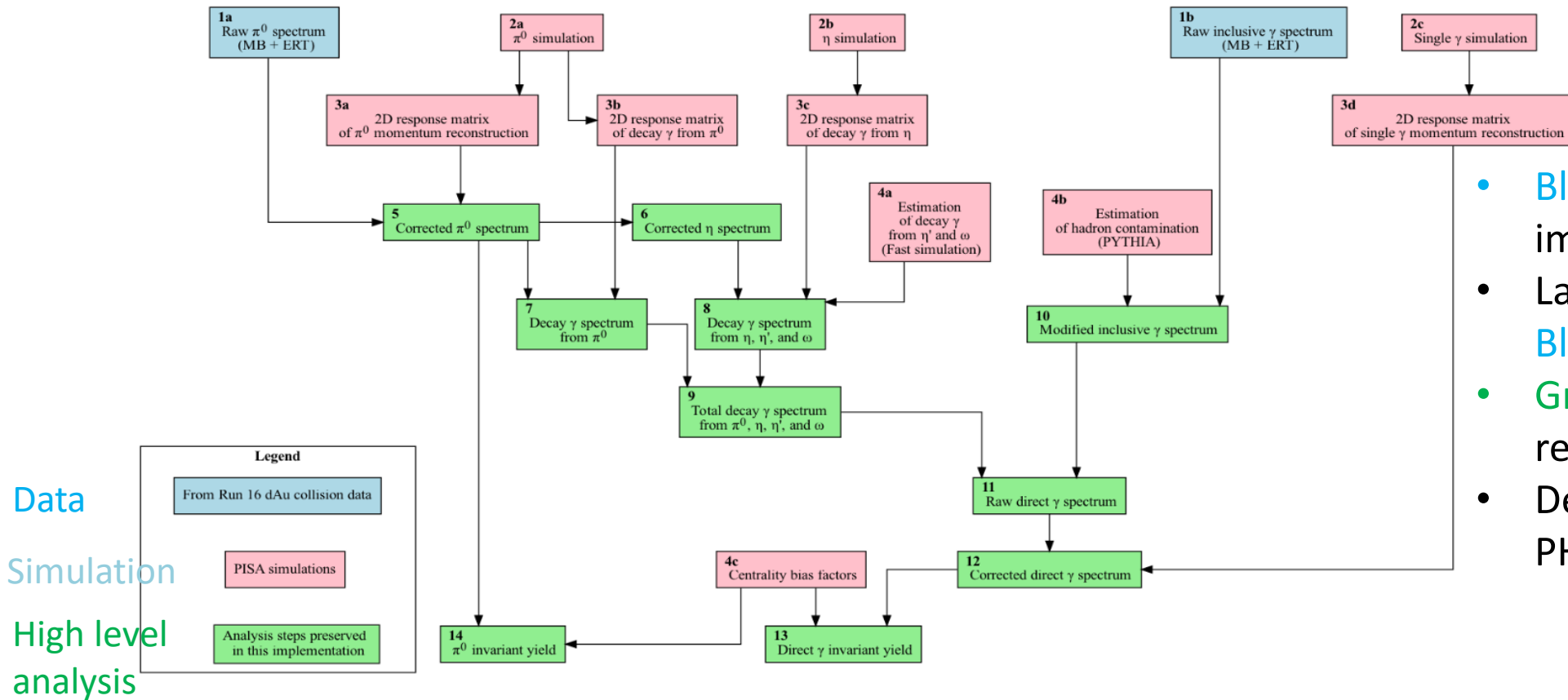
- π^0 is suppressed relative to direct photon in central d+Au
- Evidence for π^0 suppression in most central d+Au

Unique capability of PHENIX



- First PHENIX analysis in REANA
- This is one of the key results, now submitted to PRL
- Help from NPSS for implementation
- Input from analyzers is essential
- People
 - Maxim Potekhin
 - Dmitry Smirnov
 - Niv Ram
 - Gabor David

REANA: d+Au analysis work flow

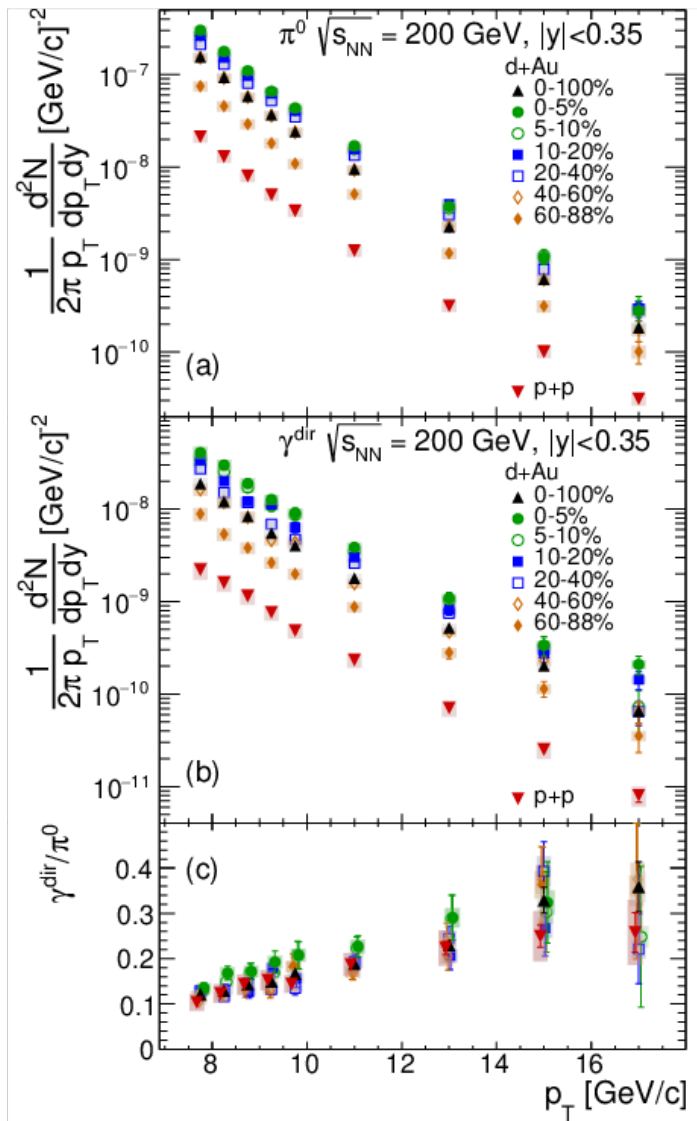


- Blue and Green steps are implemented in REANA
- Large scale production of Blue (DST->pDST) is by Taxi
- Green steps can be repeated in a few hours
- Detailed documentation in PHENIX DAP site

- The analysis page located at <https://www.phenix.bnl.gov/analysis/dAuPi0Photon.html> serves as the central hub for preserving PHENIX's "Direct γ in d+Au collisions" analysis, ensuring its longevity and reproducibility over time
- The analysis steps outlined by the blue and green boxes in the flowchart have been encapsulated within a containerized environment, bolstering their future reproducibility
- The outputs of the PISA simulation steps (pink boxes) are presently drawn from Niveditha Ramasubramanian's original work
- Essential data, including response matrices, is uploaded into the [Zenodo repository](#), accompanied by a unique DOI, thus ensuring its enduring preservation

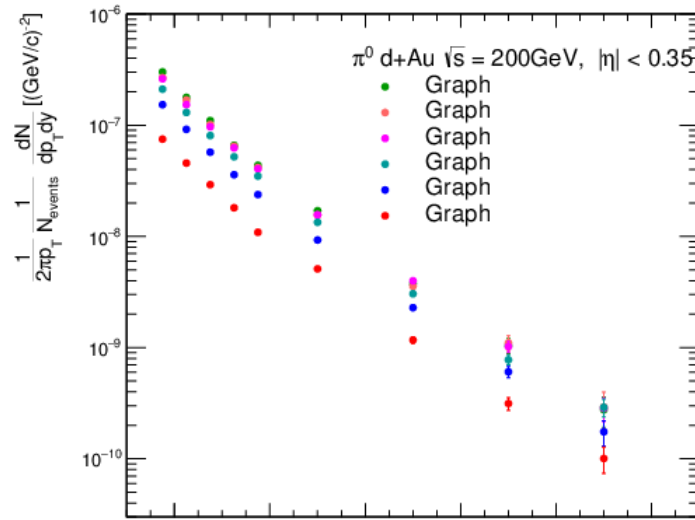
REANA: d+Au analysis

Published π^0 and γ spectra

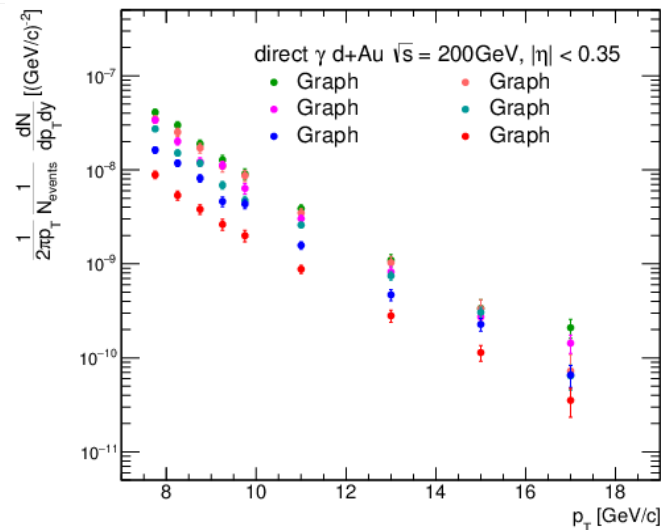


π^0

Same spectra from REANA / Docker



γ



REANA: Lessons learned and Future Plan

- Implementing **high level analysis** of the d+Au direct photon and π^0 took about 6 months
 - needs heavy involvement from the actual analyzer
 - needs about 1 FTE on the BNL side
- Current d+Au implementation is just to reproduce the published results. Ideally, we want to preserve analysis such that the data can be re-analyzed in different ways. This requires further effort

Future Plans

- Implement more key analyses in the same level
 - J/ψ in dimuon arms (starting)
 - Di-electron and direct photons with conversion
 - Heavy flavor in central arms/VTX
- Requires resources and support to complete these plans

DAP: Needs dedicated resource

- PHENIX completed data taking in 2016
 - High statistic data in 2012-2016 remain to be analyzed
 - These data sets with unique PHENIX capability are still the best data sets for many important analysis
 - Preserving the knowledge to analyze the PHENIX data is essential to extract physics
- PHENIX effort sets precedent for sPHENIX and STAR as RHIC shut down in 2025
- DAP effort needs both of support of computing experts and physics analyzer
 - REANA implementation of the d+Au analysis required > 0.5 FTE x 6 months for both effort
- PHENIX is working on DAP, but its effort is limited by available resource
 - DAP effort cannot be sustained by volunteer work by collaborators
 - DAP competes for resource with other needs, and tends to be considered as “less urgent”
 - Even for a small amount, a dedicated resource will make a big difference

Summary

- PHENIX completed its data taking in RUN16
- Publication status
 - PHENIX continues to publish high impact results, but with reduced rate
 - Publishing ~8 papers per year
 - Focusing on topics with unique capabilities of PHENIX
 - More resources are needed for analysis and publication of key physics topics
 - Support to PHENIX analysis is essential to continue it
- Data and Analysis preservation
 - Publishing PHENIX data in HEPData --- almost complete
 - First attempt to preserve a full analysis chain in REANA
 - Dedicated resource is needed to continue this effort