PHENIX Highlights

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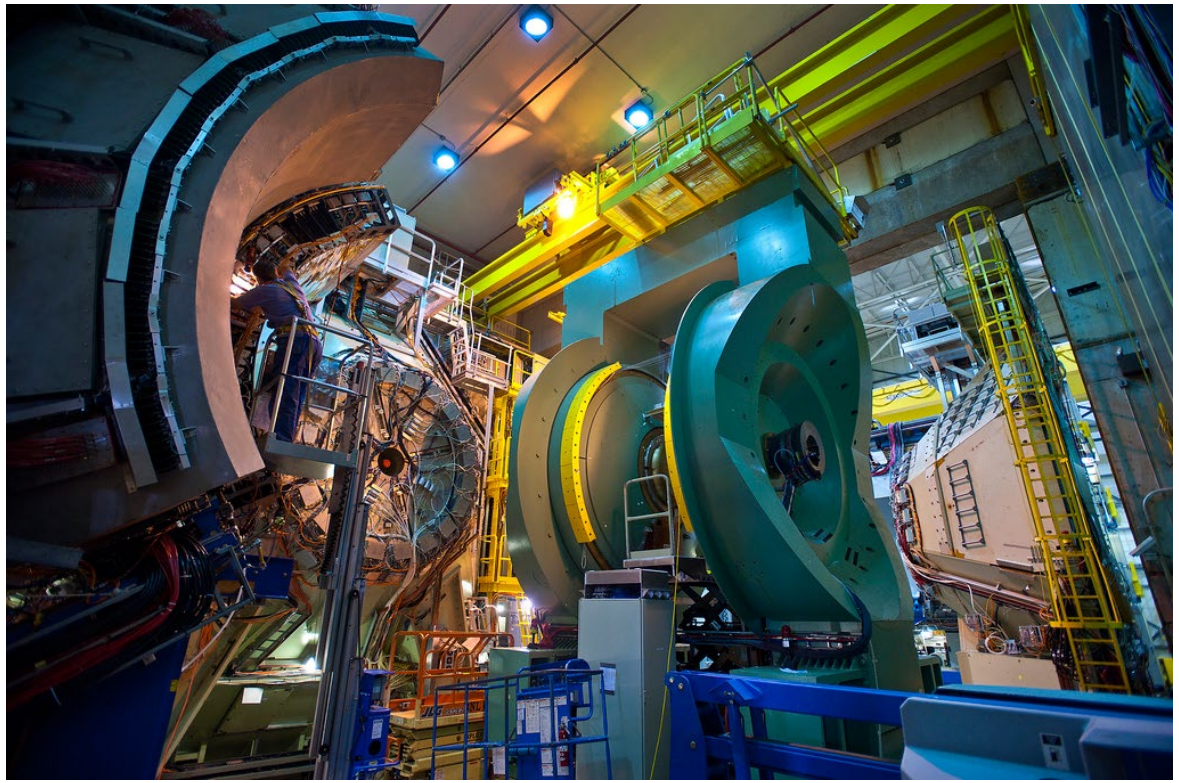
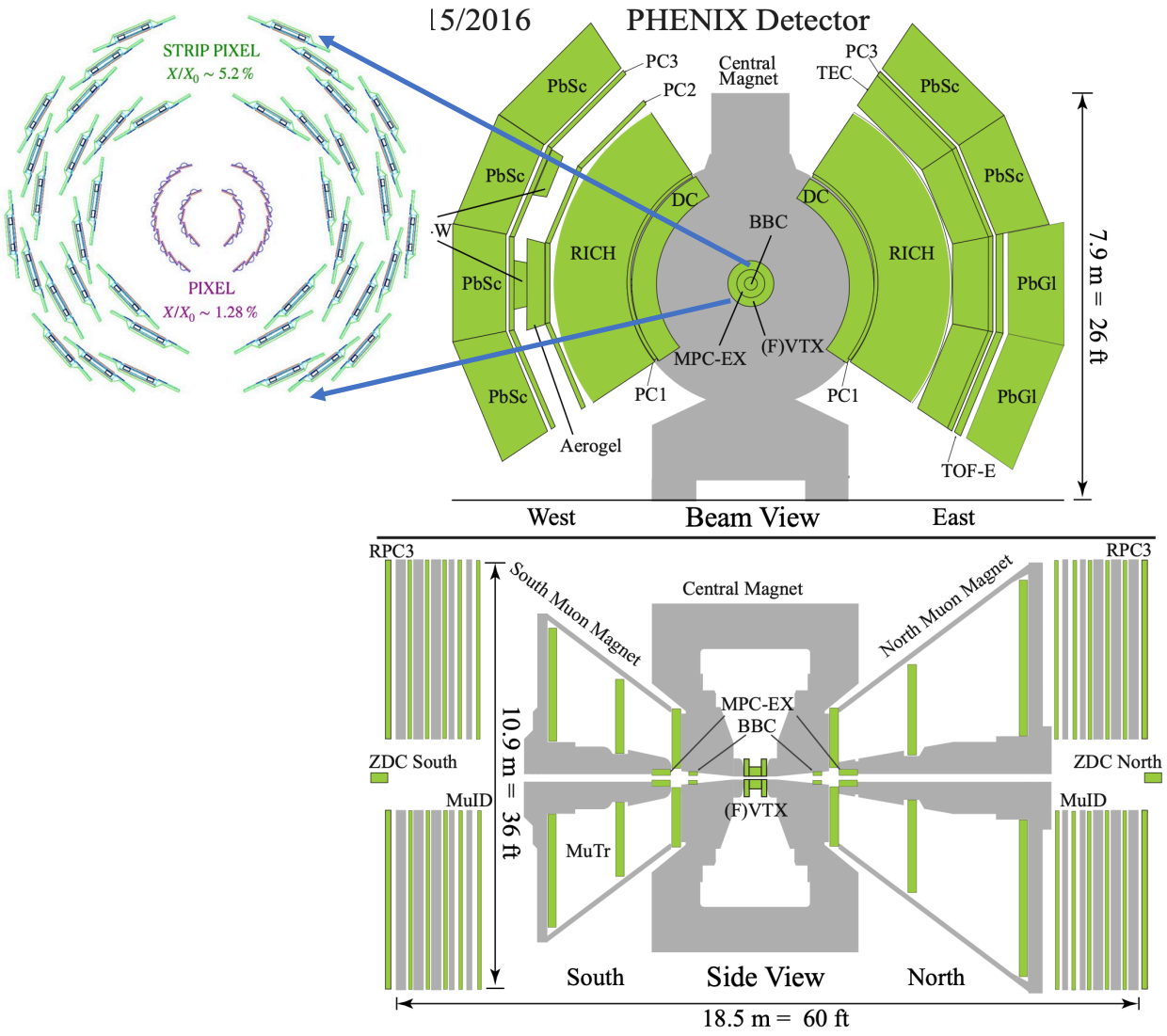
PHENIX experiment

Hadrons, electron, photons
$|\eta|<0.35$ $\Delta\Phi= 2 \times \pi/2$
CENTRAL ARMS

Muons
$-2.2<\eta<-1.2$ $1.2<\eta<2.2$ $\Delta\Phi=2\pi$
MUON ARMS



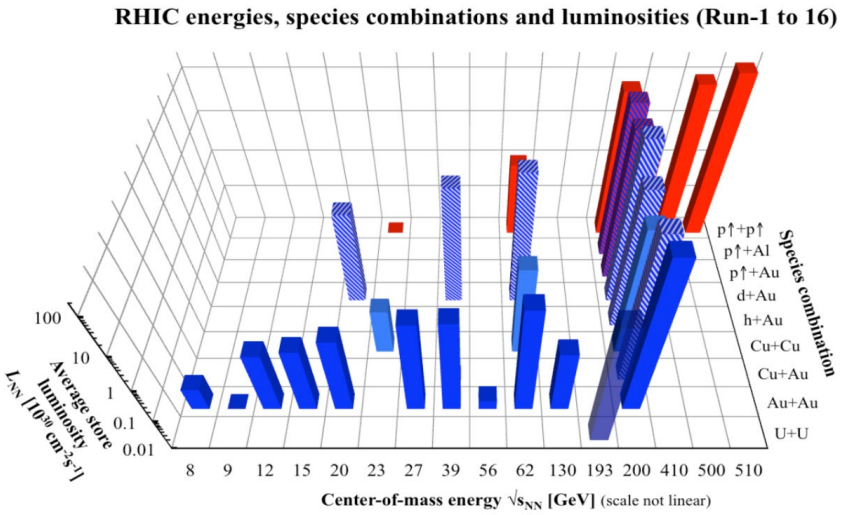


Data collected at PHENIX

Run	Species	Energy $\sqrt{s_{NN}}$ (GeV)	Integrated Luminosity (mb^{-1})
1 (2000)	Au+Au	56	1.0E-6
2 (2001/2002)	Au+Au	200	2.4E-5
	p+p	200	1.5E+5
3 (2003)	d+Au	200	2.7E+3
	p+p	200	3.5E+5
4 (2004)	Au+Au	200	2.4E+2
	Au+Au	62.4	9.0E+0
5 (2005)	Cu+Cu	200	3.0E+3
	Cu+Cu	62.4	1.9E+2
	Cu+Cu	22.4	2.7E+3
	p+p	200	3.4E+6
6 (2006)	p+p	200	7.5E+6
	p+p	62.4	8.0E+4
7 (2007)	Au+Au	200	8.1E+2
8 (2008)	d+Au	200	8.0E+4
	p+p	200	5.2E+6
9 (2009)	p+p	500	1.4E+7
	p+p	200	1.6E+7
10 (2010)	Au+Au	200	1.5E+3
	Au+Au	62.4	1.1E+2
	Au+Au	39	4.0E+4
	Au+Au	7.7	3.0E+2

Completed taking data in 2016

Many high impact analyses are still ongoing



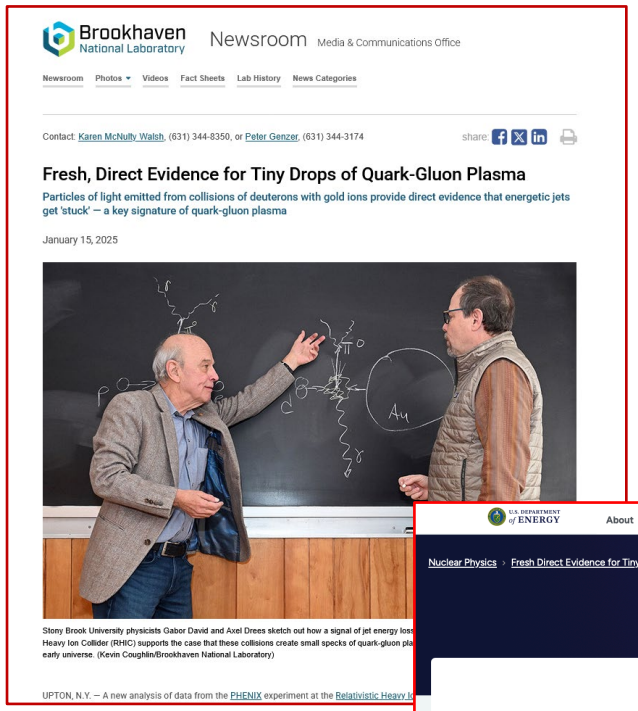
Run	Species	Energy $\sqrt{s_{NN}}$ (GeV)	Integrated Luminosity (mb^{-1})
11 (2011)	p+p	500	1.8E+7
	Au+Au	19.6	2.0E+0
	Au+Au	200	1.7E+3
	Au+Au	27	7.0E+0
12 (2012)	p+p	200	1.0E+7
	p+p	510	3.2E+7
	U+U	193	2.0E+2
	Cu+Au	200	5.0E+3
13 (2013)	p+p	510	1.6E+8
14 (2014)	Au+Au	14.6	4.0E+0
	Au+Au	200	7.5E+3
	^{3}He+Au	200	2.4E+4
15 (2015)	p+p	200	6.0E+7
	p+Au	200	2.0E+5
	p+Al	200	5.0E+5
16 (2016)	Au+Au	200	7.0E+3
	d+Au	200	5.0E+4
	d+Au	62.4	5.0E+3
	d+Au	19.6	8.0E+1
	d+Au	39	2.0E+3

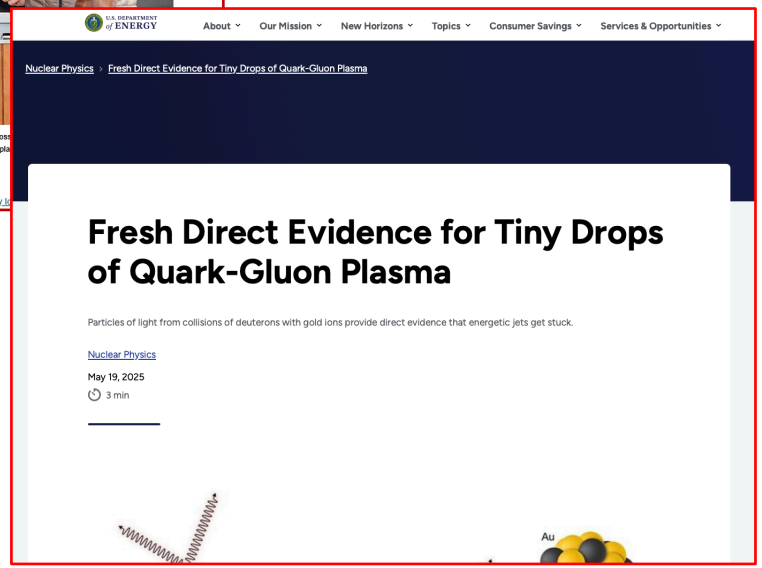
PHENIX talks and posters at this meeting

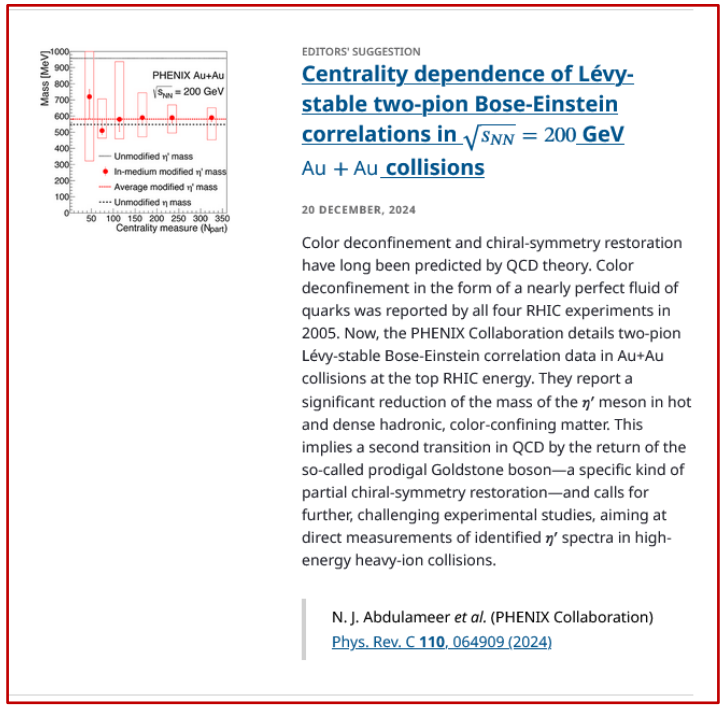
- Talks
  - Ming Liu, “PHENIX Heavy Flavor Overview”
    - HF workshop, at 10:00 on May 20
  - Devon Loomis, “EIC Physics in PHENIX”
    - ePIC/EIC workshop, at 11:00 on May 20
  - Ron Belmont, “Anisotropic flow measurements – PHENIX highlights and sPHENIX prospects”
    - Flow workshop, at 16:20 on May21

- Posters
  - Tongzhou Guo and Yuri Mitrankov, “Measurement of e+e- production in Au+Au collisions at 200GeV with PHENIX
  - Chaitanya Prasad, “PHENIX Results on Identified Hadron Spectra in Small and Large Systems”
  - Vassu Doomra and Adam Sharhan, “e+e- pair continuum in p+p collisions at $\sqrt{s_{NN}}$=200GeV”

Two highlights







Suppression of hadron yield in small systems

DOE highlight: https://www.energy.gov/science/np/articles/fresh-direct-evidence-tiny-drops-quark-gluon-plasma

- Possible bias in event selection for hard probes in small systems
- Using Direct Photons to minimize selection bias

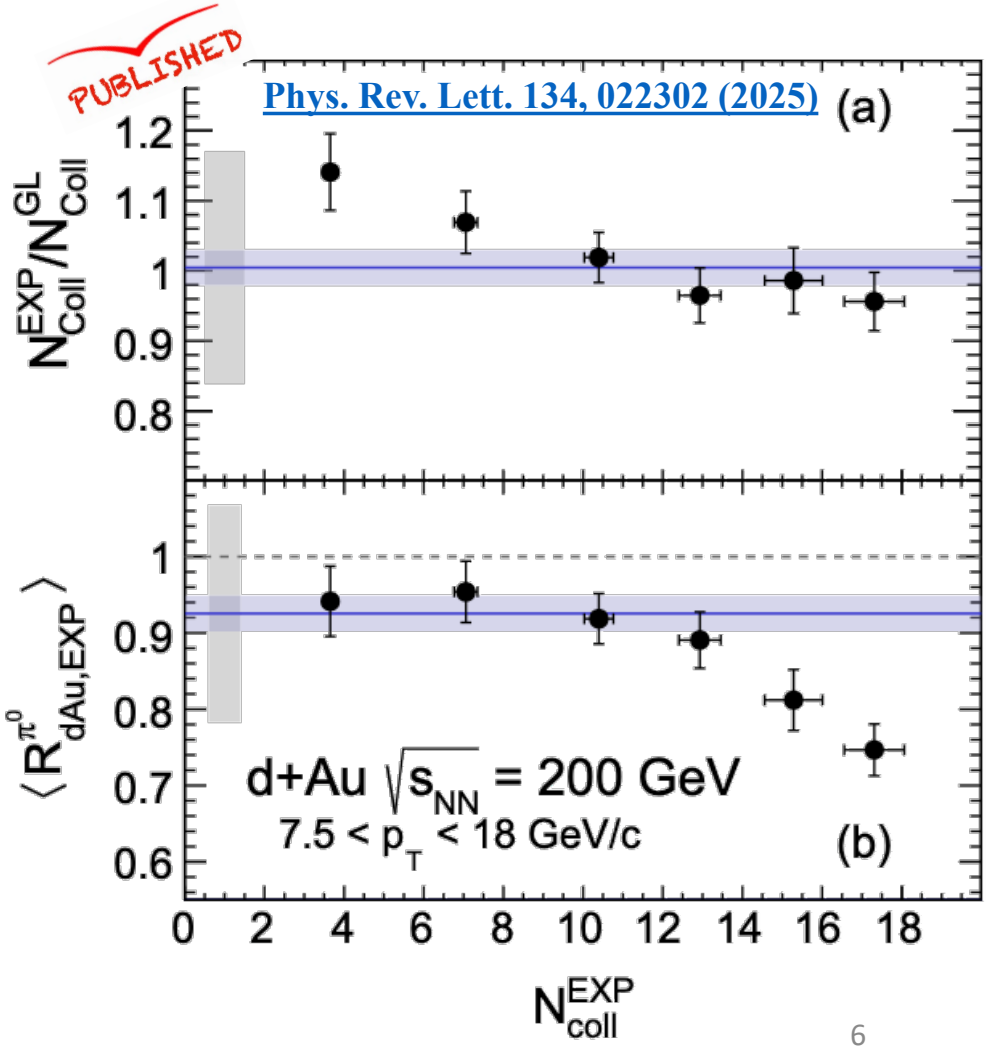
$$N_{coll}^{EXP} = \frac{Y_{AB}^{\gamma^{dir}}(p_T)}{Y_{pp}^{\gamma^{dir}}(p_T)}$$

- Redefining the Nuclear Modification Factor

$$R_{AB,EXP}^{\pi^0}(p_T) = \frac{Y_{AB}^{\pi^0}(p_T)}{Y_{pp}^{\pi^0}(p_T)} \times \frac{Y_{pp}^{\gamma^{dir}}(p_T)}{Y_{AB}^{\gamma^{dir}}(p_T)} = \frac{(\gamma^{dir}/\pi^0)^{pp}}{(\gamma^{dir}/\pi^0)^{AB}}$$

- Search for final state effects with simultaneous measurement of direct γ and π^0

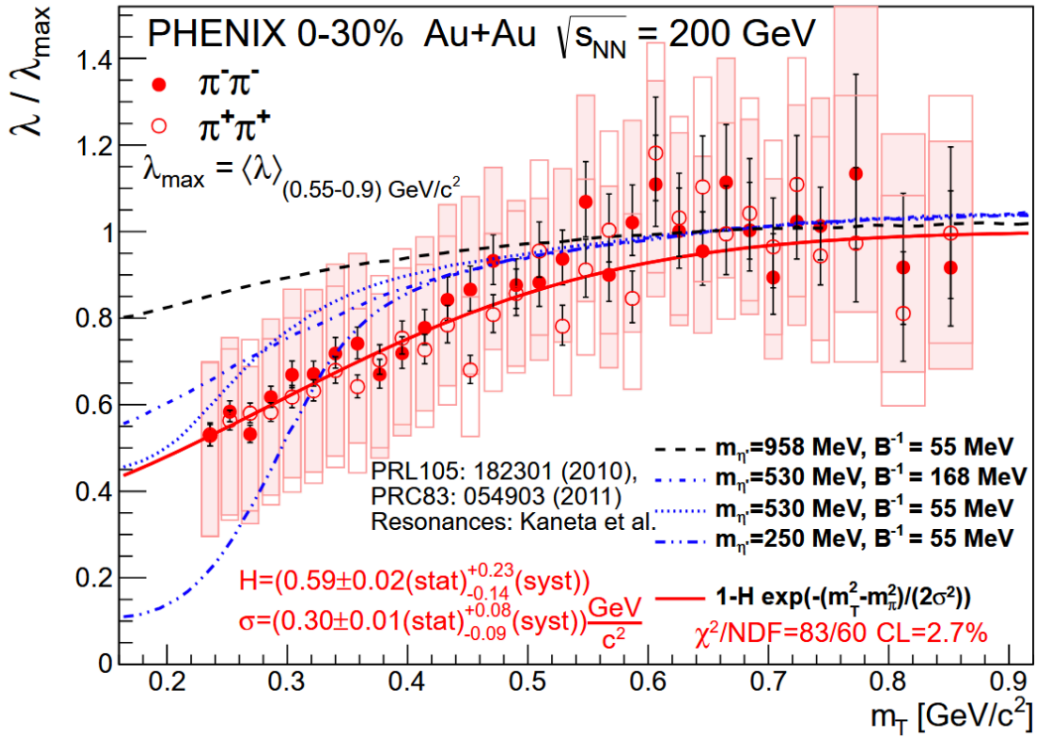
Significant 20% suppression of high p_T π^0 in central 0-5% d+Au collisions is seen compared to peripheral d+Au collisions

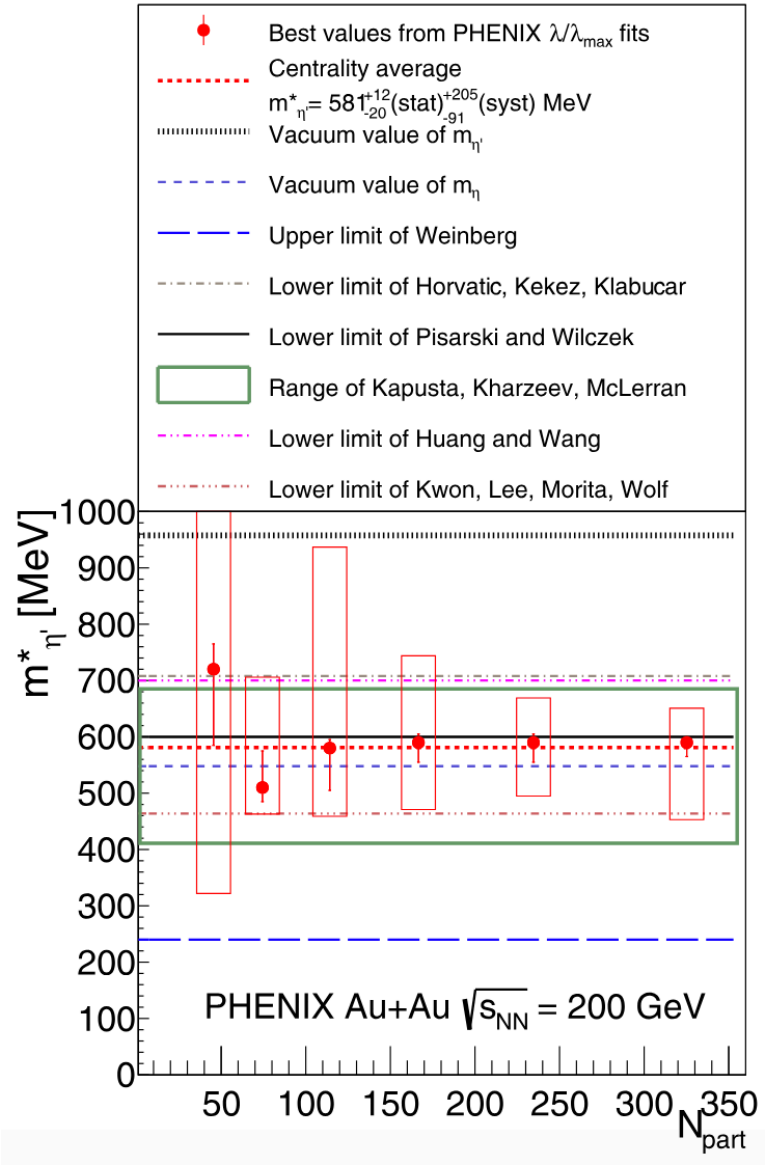


Hint of U(1) transition

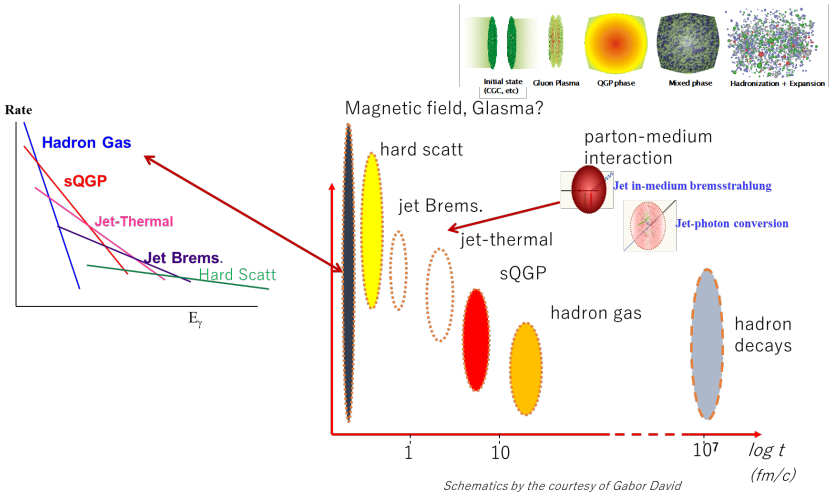
- Levy HBT results are not inconsistent with theoretical models including in-medium mass modification of η'
- It calls for direct measurement of η' mass

Phys. Rev. C 110, 064909 (2024)





Important penetrating probe: photons

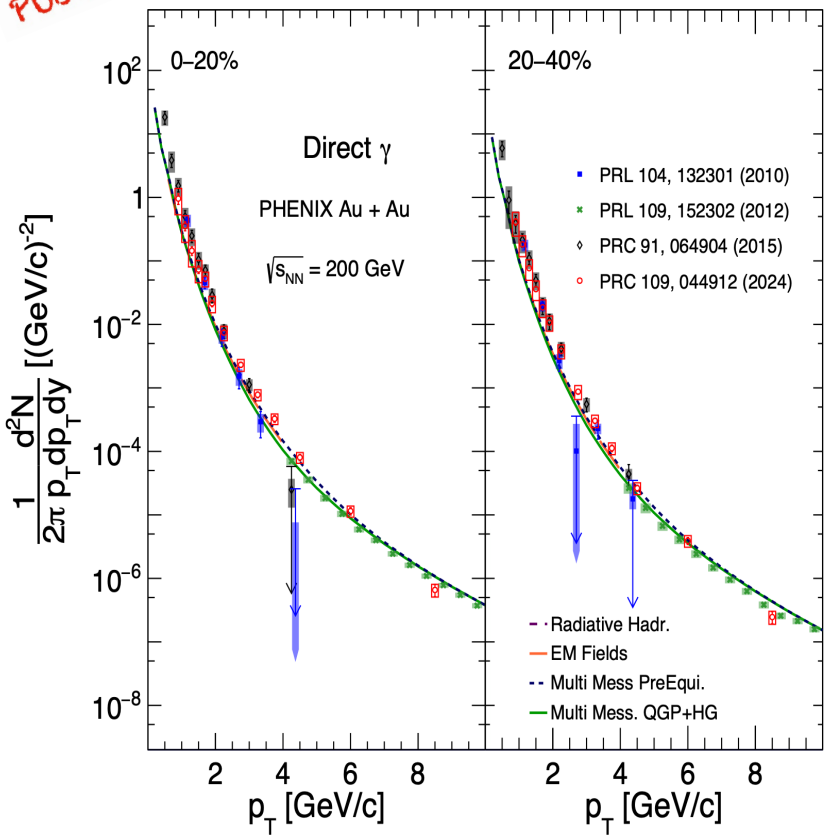


Schematics by the courtesy of Gabor David

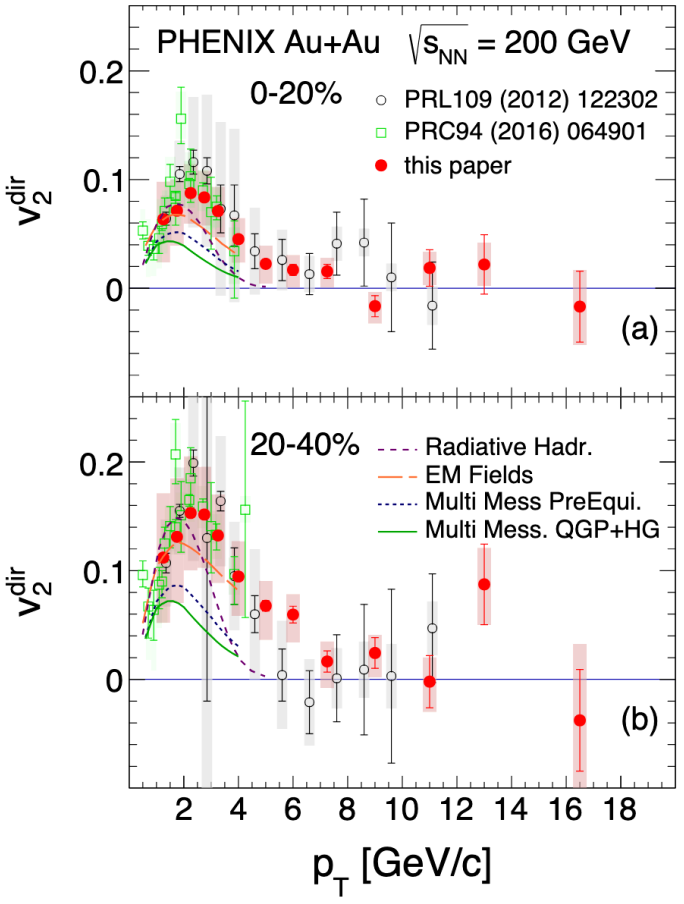
Direct photons from nuclear medium

PUBLISHED

Phys. Rev. C 109, 044912 (2024)



arXiv:2504.02955

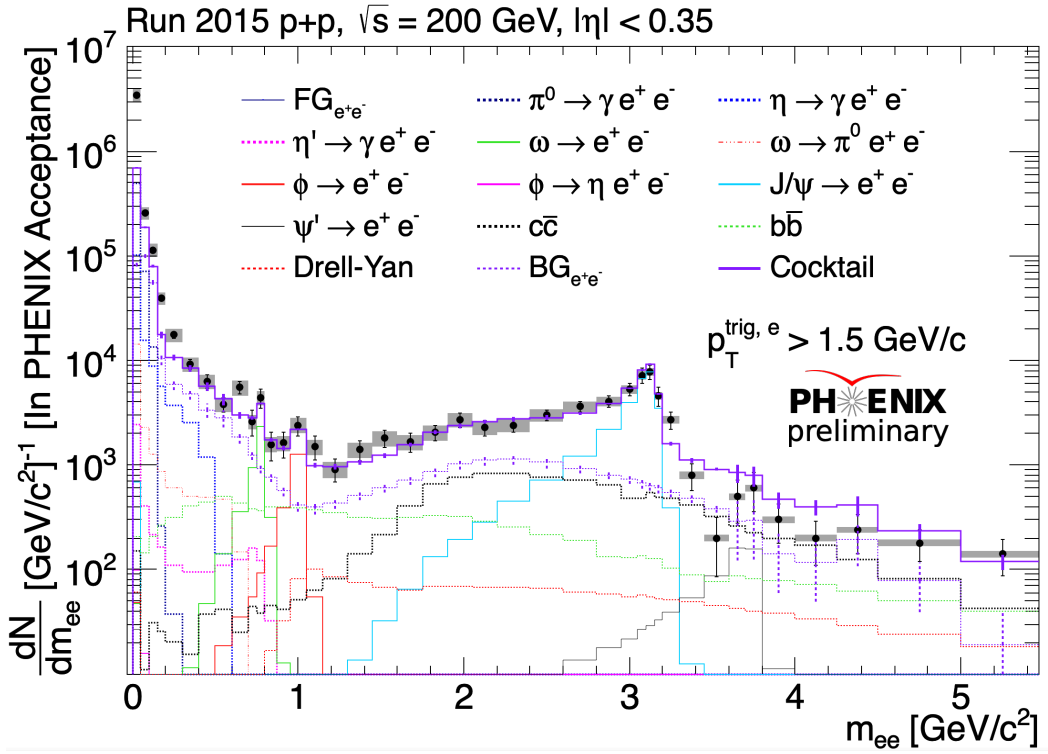


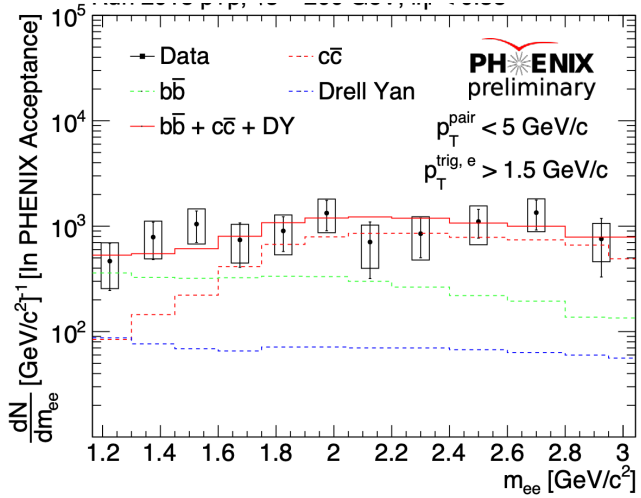
- A set of yields and flow is a standard package for the direct photon measurement

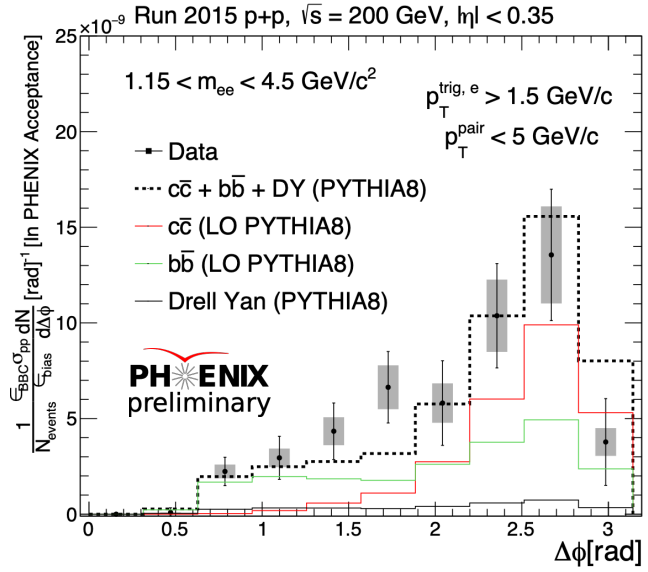
Sources	p_T	v_2	v_3	v_n t-dep.
Hadron-gas	Low p_T	Positive and sizable	Positive and sizable	→
QGP	Mid p_T	Positive and small	Positive and small	↗
Primordial (jets)	High p_T	~zero	~zero	→
Jet-Brems.	Mid p_T	Positive	?	↗
Jet-photon conversion	Mid p_T	Negative	?	↘
Magnetic field	All p_T	Positive down to p_T=0	Zero	↘

Disentangling charm and bottom in dileptons

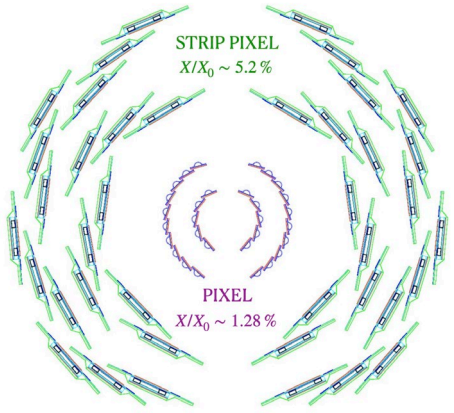
- Run2015 p+p data (200GeV)
- Heavy flavor and Drell-Yan contributions obtained from LO PYTHIA reproduce the data reasonably well

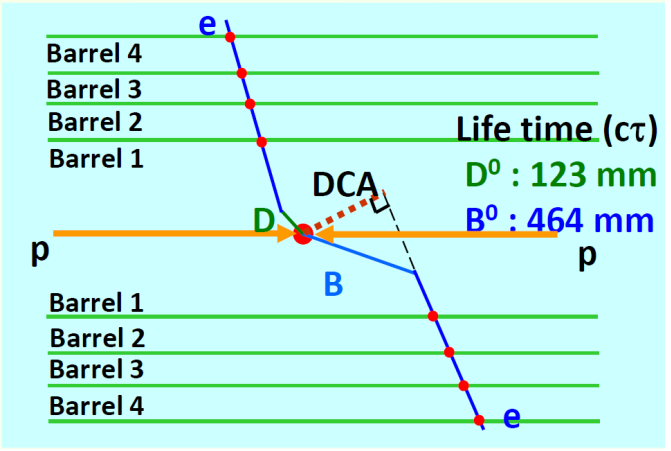






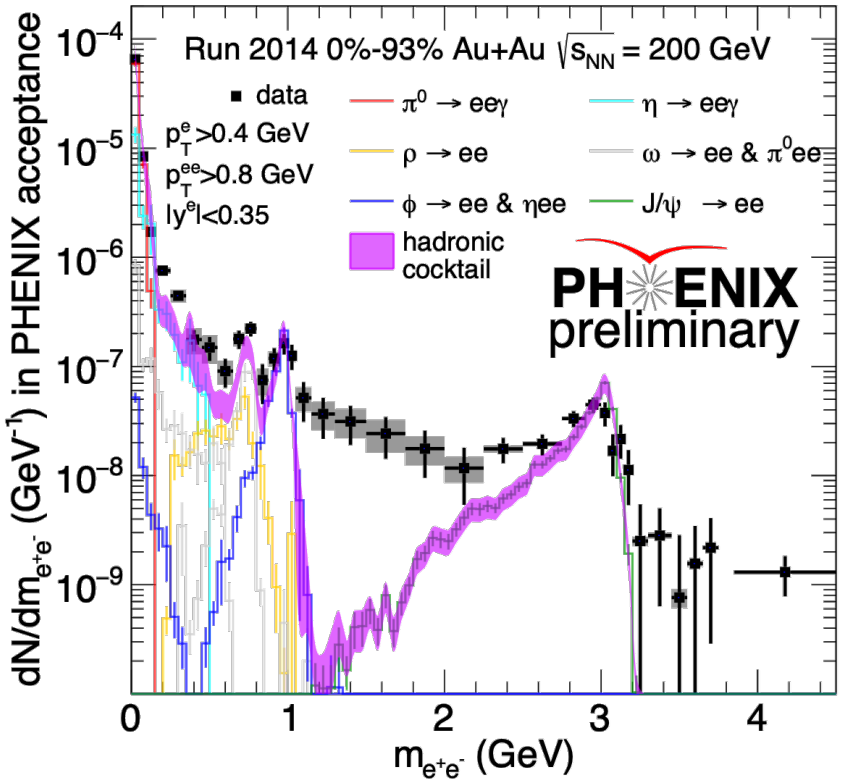
VTX for heavy flavor separation

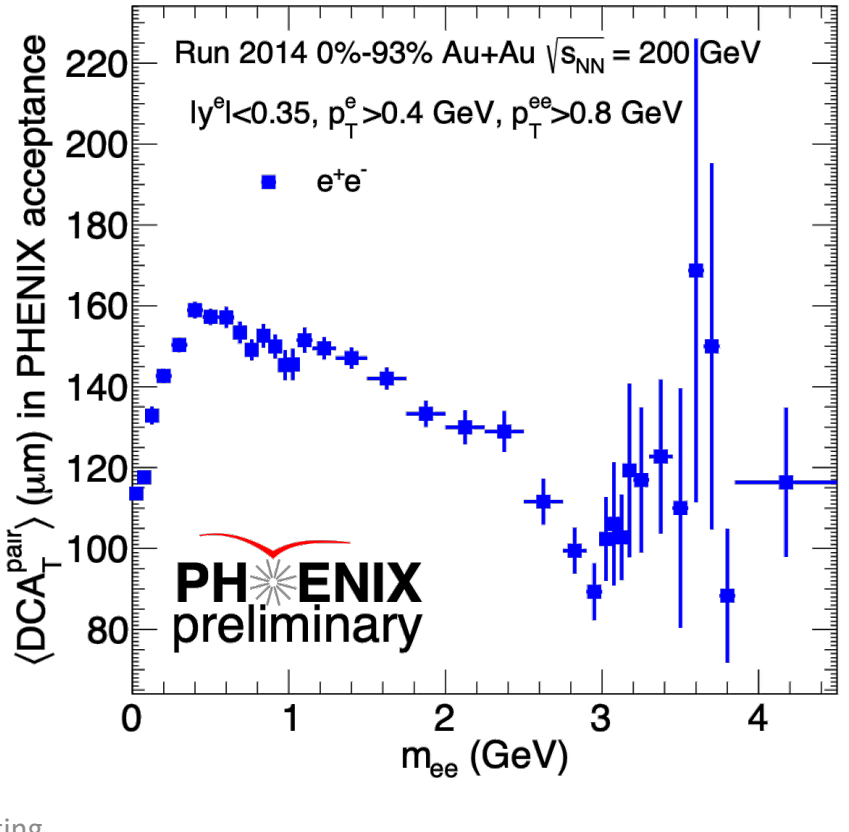




Separating contributions in dileptons

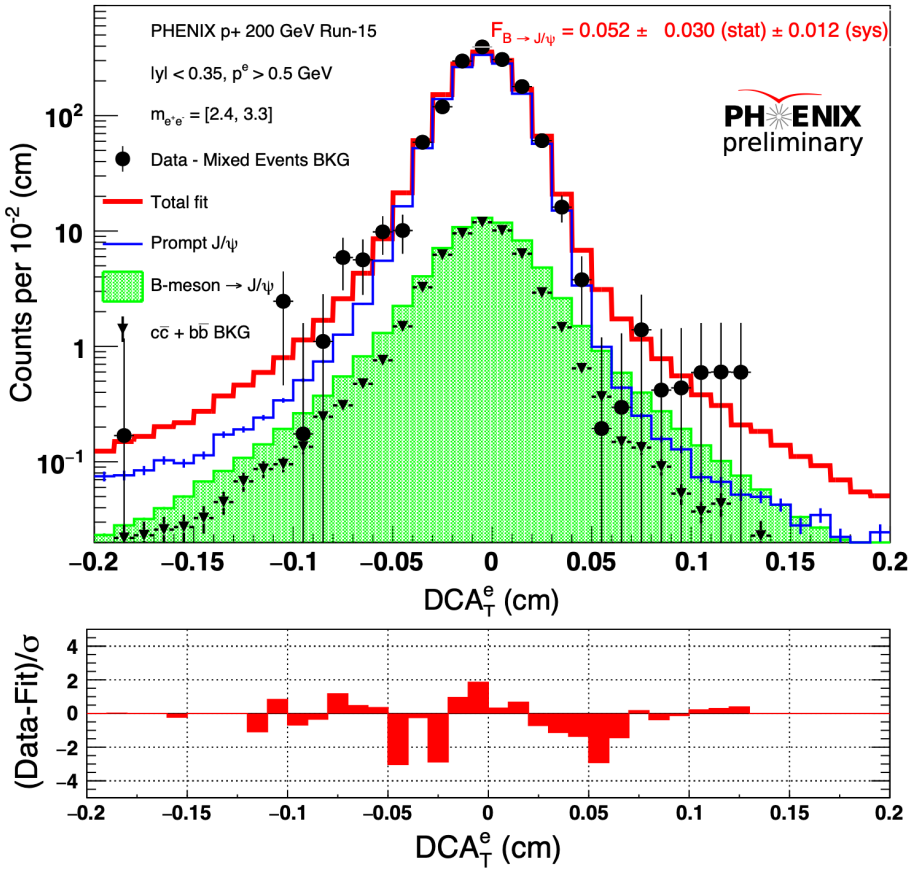
- Run2014 Au+Au data (200GeV)
- First attempt at RHIC to experimentally disentangle the heavy flavor and thermal contribution using the DCA technique in the intermediate mass region

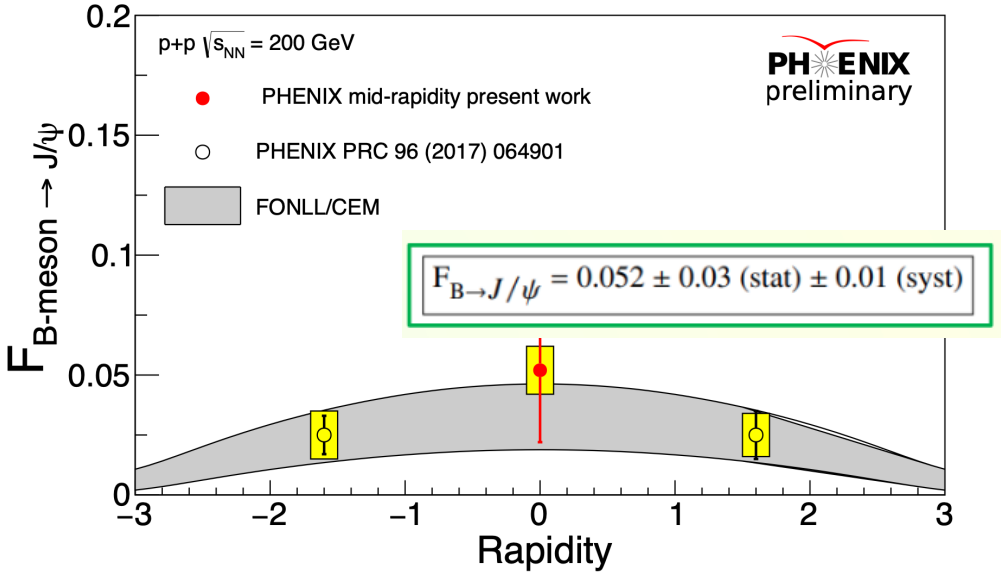


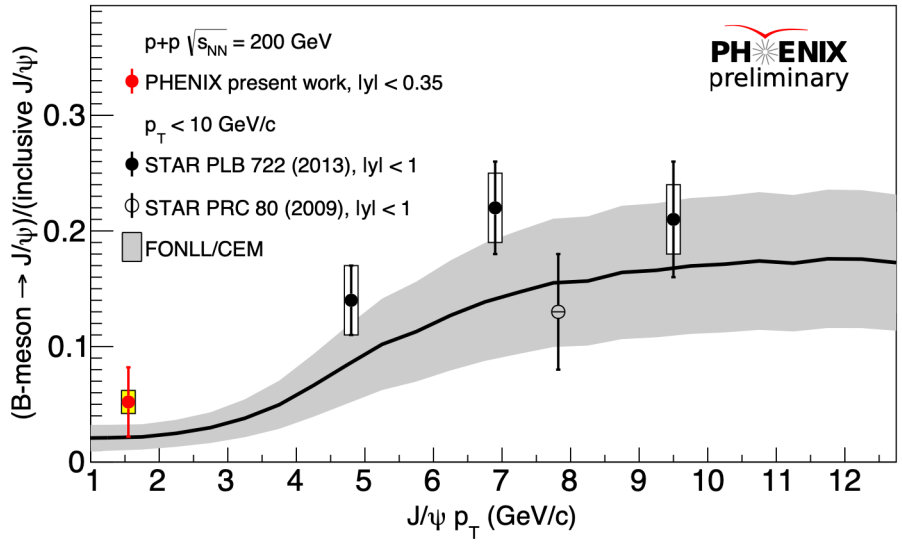


B→J/ψ using DCA* technique

- Run2015 p+p data (200GeV)
- Fixed-order-next-to-leading-logarithm plus color-evaporation-model (FONLL+CEM) describes data well
  - Good handle to disentangle heavy flavors





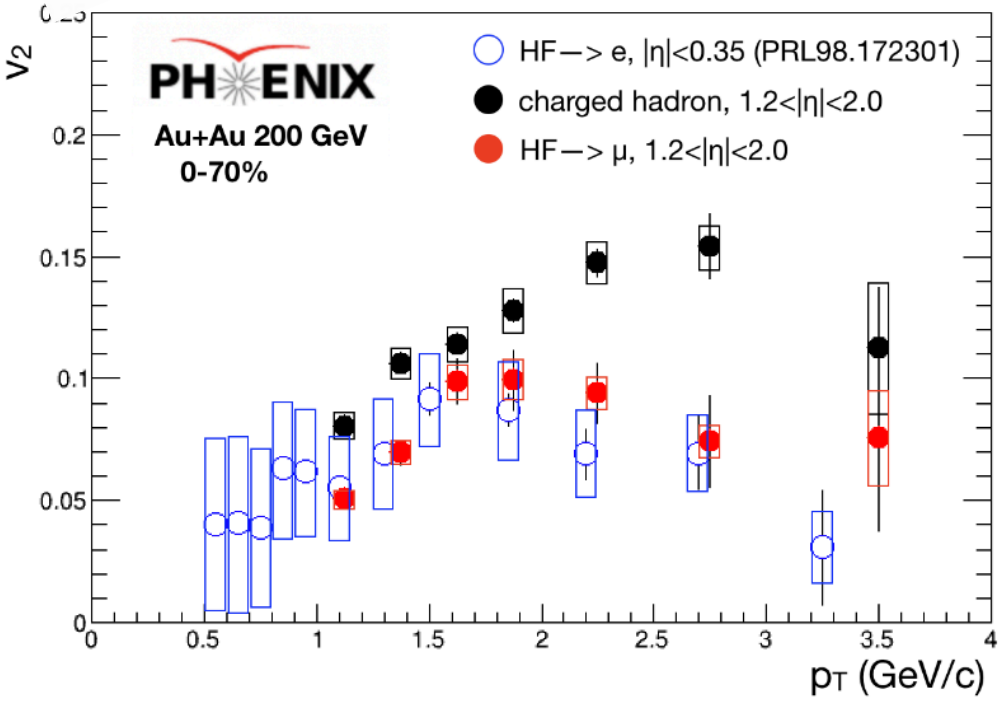


Heavy flavor flows?

- Run2015 Au+Au data (200GeV)
- First observation of significant heavy flavor v_2 at the forward rapidity
- Forward J/ψ v_2 at RHIC is consistent with zero

FINAL

arXiv:2409.12715



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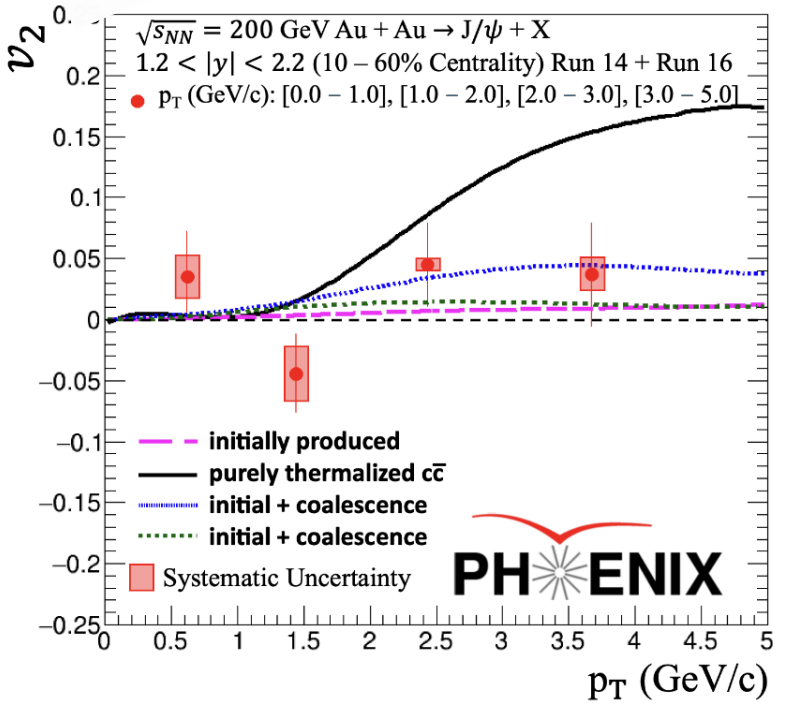
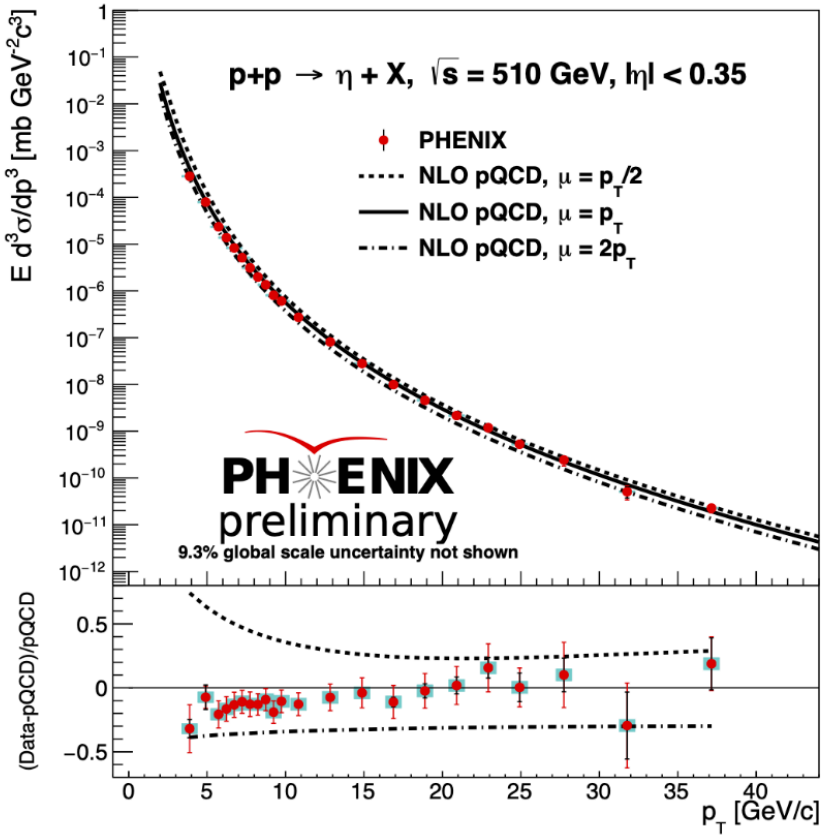
arXiv:2409.12756

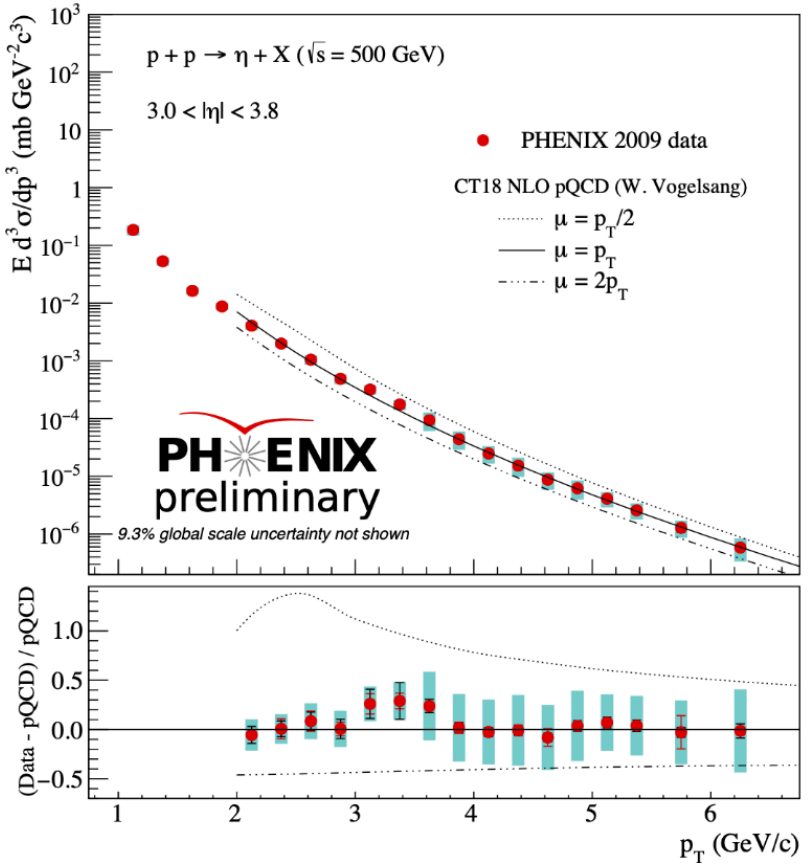


News from p+p

η cross-section in 510GeV p+p

- Simultaneous measurement of η cross-section across rapidity improves global fragmentation fit
- Baseline for A+A collisions

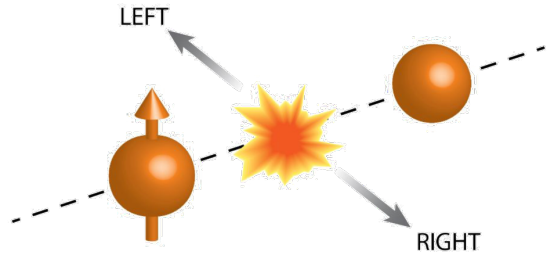


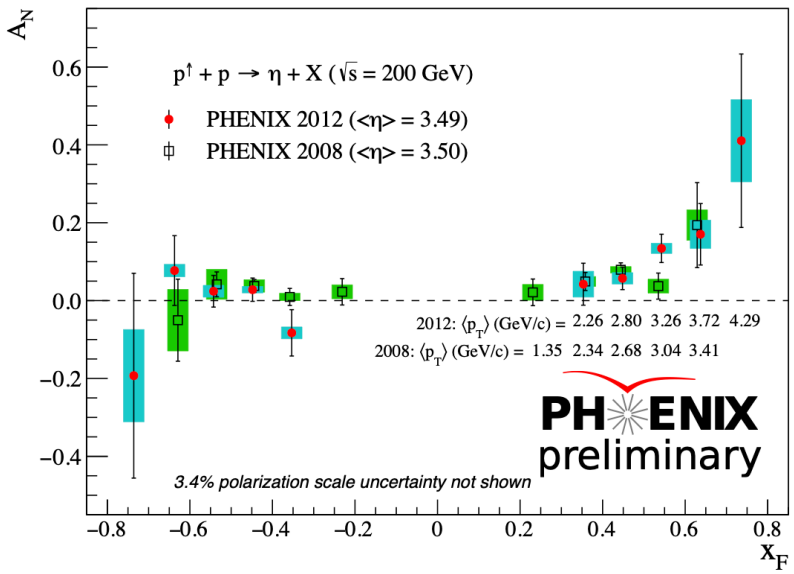


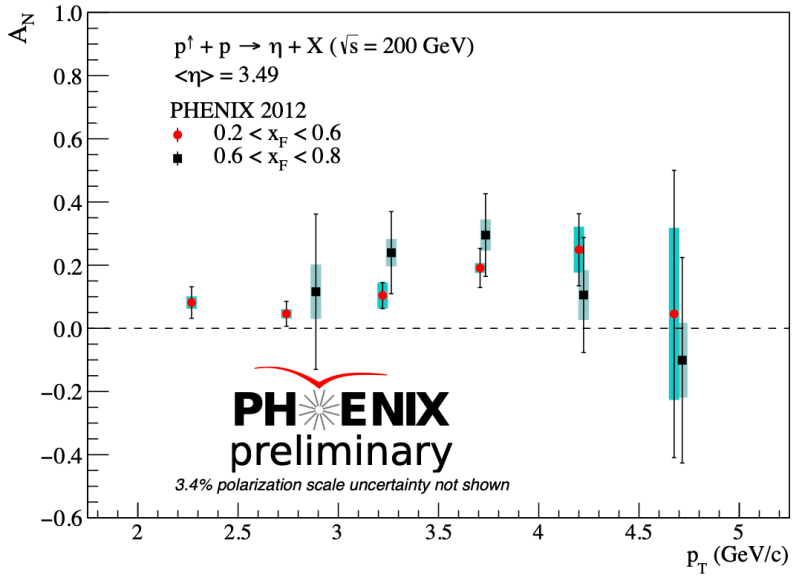
Forward η meson TSSA in 200GeV p+p

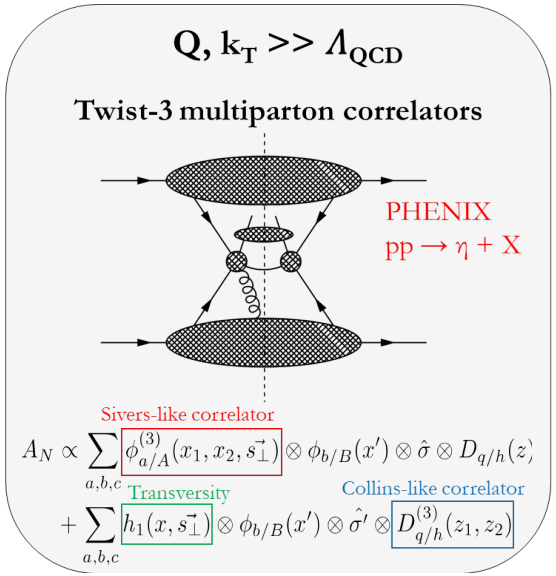
- Origin of A_N: Nonperturbative spin-momentum correlations:
  - η probes higher x_F compared to π^0
- Large positive asymmetry was observed
  - Consistent with previous measurements and π^0 with higher x_F reach
- Hint of a decrease in the asymmetry at high x_F at increasing p_T ?
  - Predicted in twist-3 phenomenology of the light meson A_N

Transverse single spin asymmetries (TSSA)



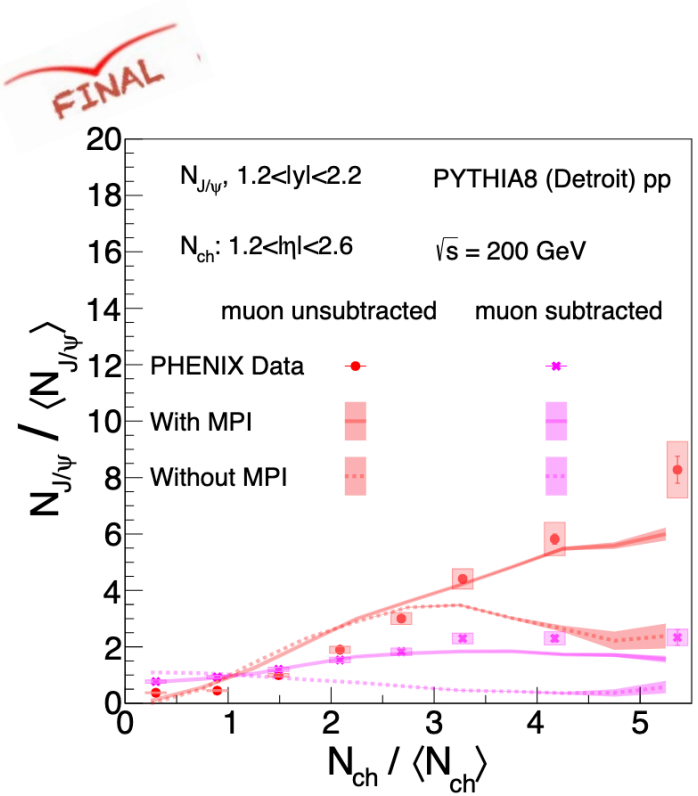


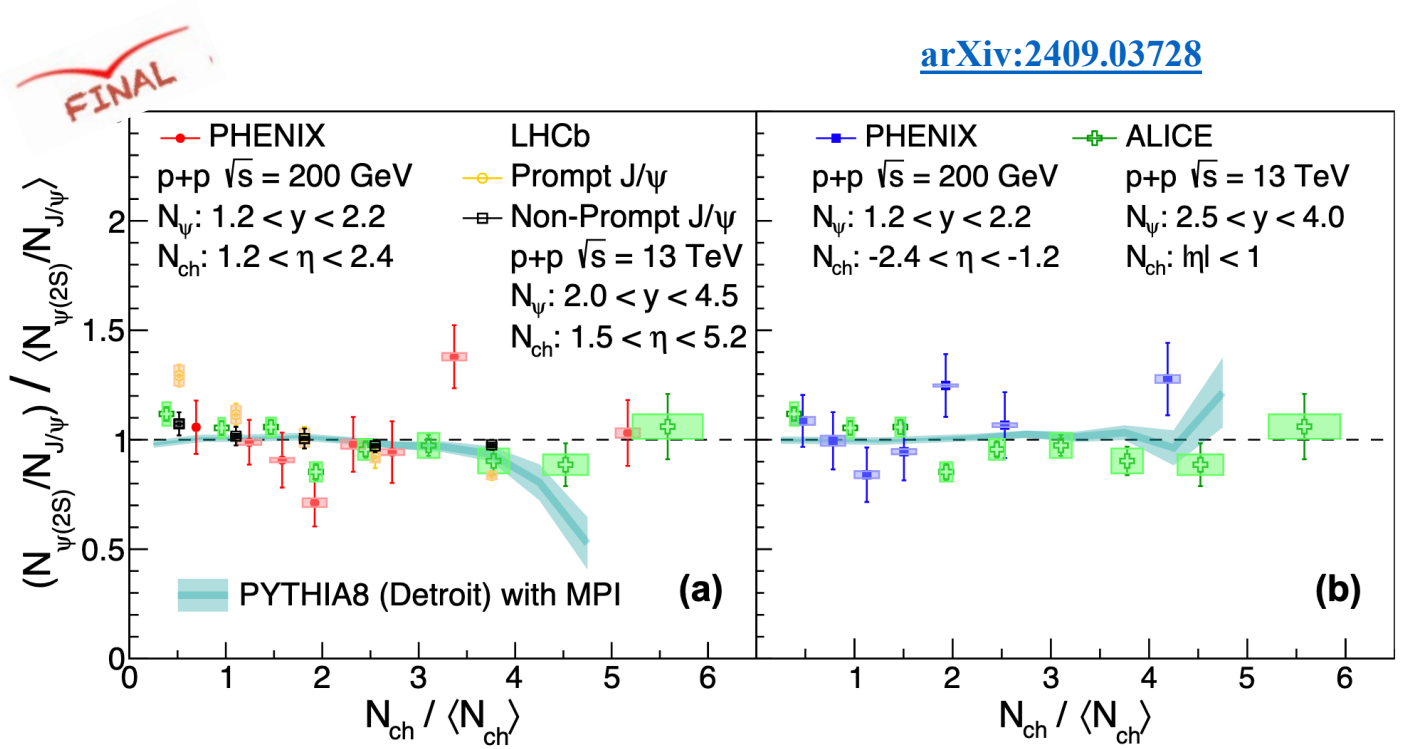




Violent p+p collisions?

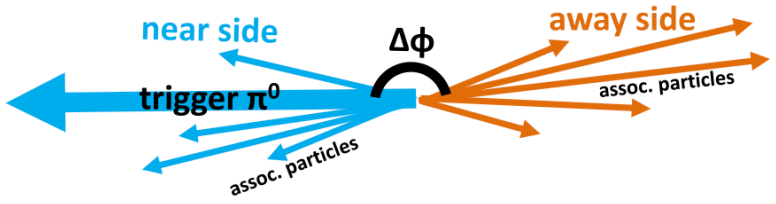
- Particle multiplicity dependence of J/ψ and ψ (2s)
- PHENIX data can only be described by PYTHIA calculations that include MPI effects



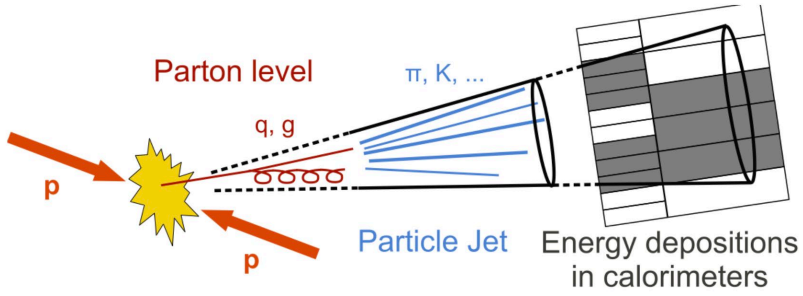


Jets: a golden probe

- Au+Au



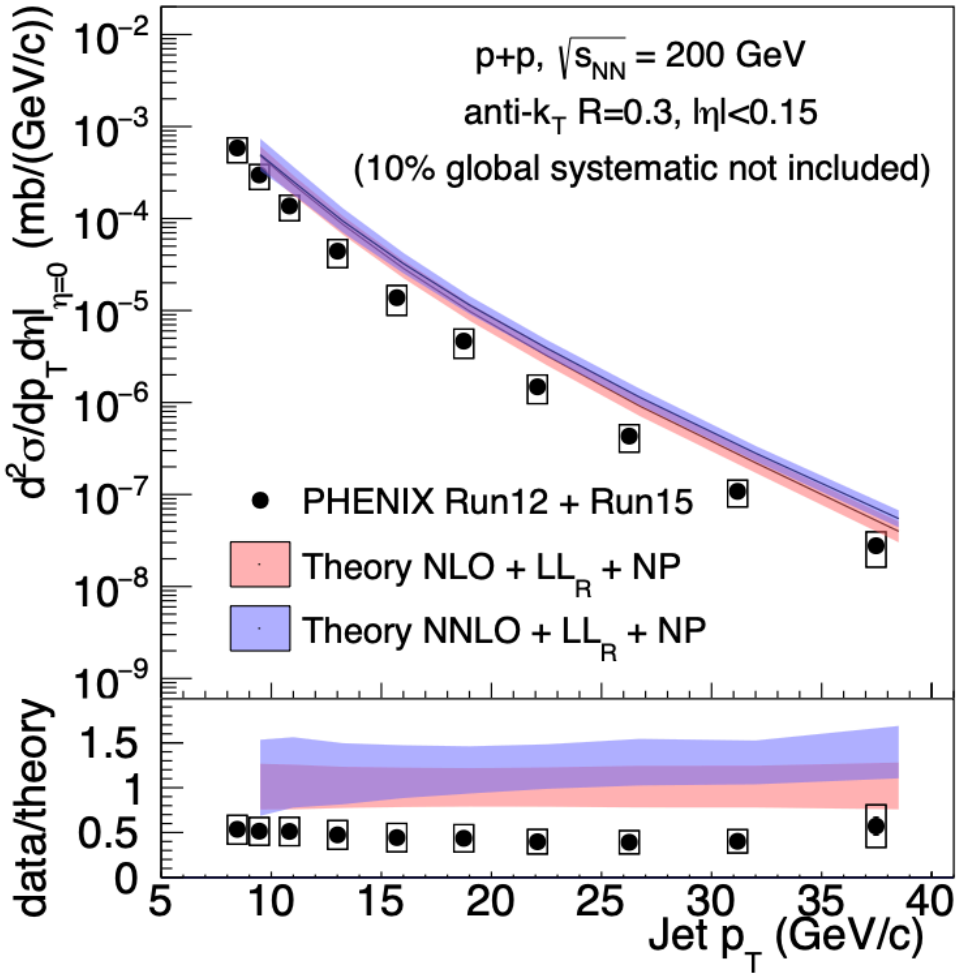
- p+p



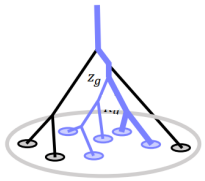
Jet cross-section in p+p

- Both NLO and NNLO overpredicts data
  - May be a limitation of the procedure used to translate from partonic to hadronic cross section
- Same trend as STAR data comparison to NLO without LL_R at LHC
  - NLO predictions overestimate the jet cross section at small R, while the agreement is better at larger values of R.
- Difference indicates importance of non-perturbative corrections at low jet p_T and R.

arXiv:2508.11144 (accepted for publication in PRD)

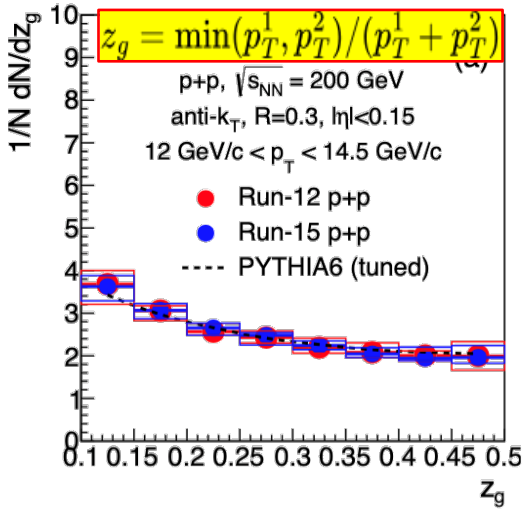


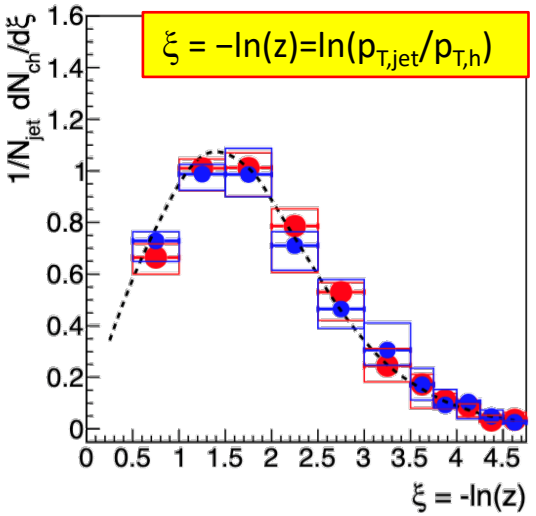
Jet structure in p+p

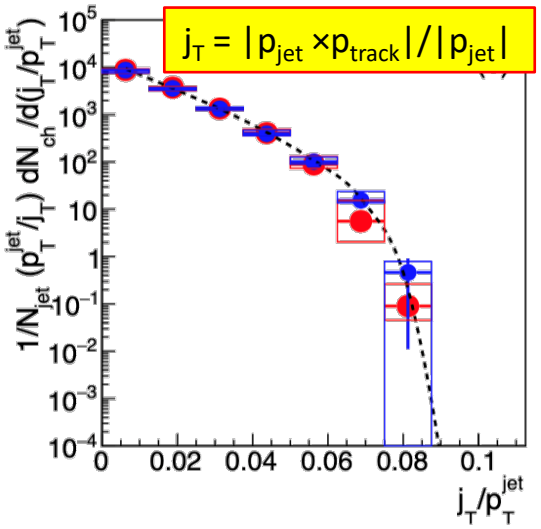


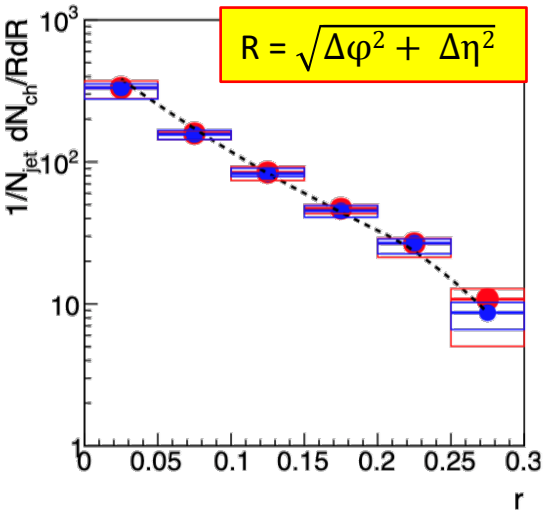
- Z_g dist in good agreement with STAR
  - Phys. Lett. B 811, 135846 (2020)
  - Note STAR (R=0.2,0.4) and PHENIX (R-0.3)
  - Shift to lower z_g and with increasing jet p_T
  - Higher asymmetric splitting at higher p_T
- Z (=exp(-ξ)): trend is similar as z_g
  - "per constituent" variable.
- j_T doesn't increase as much as p_T increases.
- Increase at low R with increasing jet p_T
  - Higher particle density in the core of the jet at higher jet p_T
  - Consistent with increasing fraction of quark jets at higher jet p_T

arXiv:2508.11144 (accepted for publication in PRD)



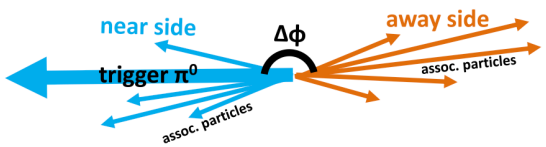






Jet modification in Au+Au

- Flow and background were subtracted off from two-particle $\Delta\phi$ correlation
- Transition from suppression at high p_T to enhancement at low p_T
- Hybrid model with medium response consistent with results



$$\Delta_{AA}(\Delta\phi) = \frac{dN^{\mathrm{AuAu}}_{\pi^0-h}}{d\Delta\phi} - \frac{dN^{pp}_{\pi^0-h}}{d\Delta\phi}.$$

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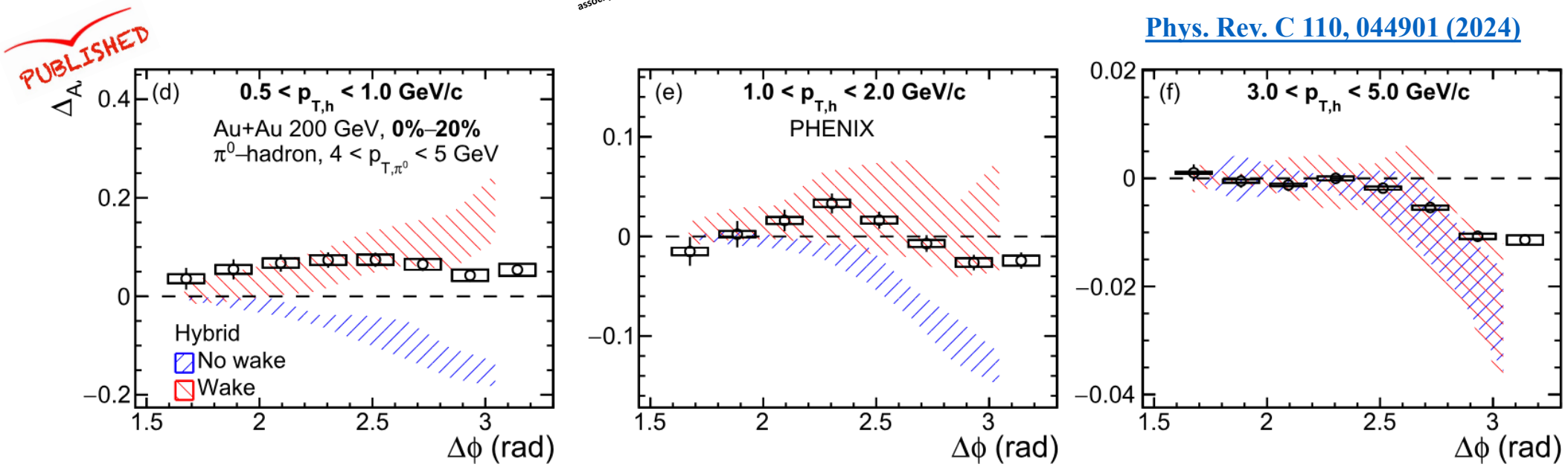
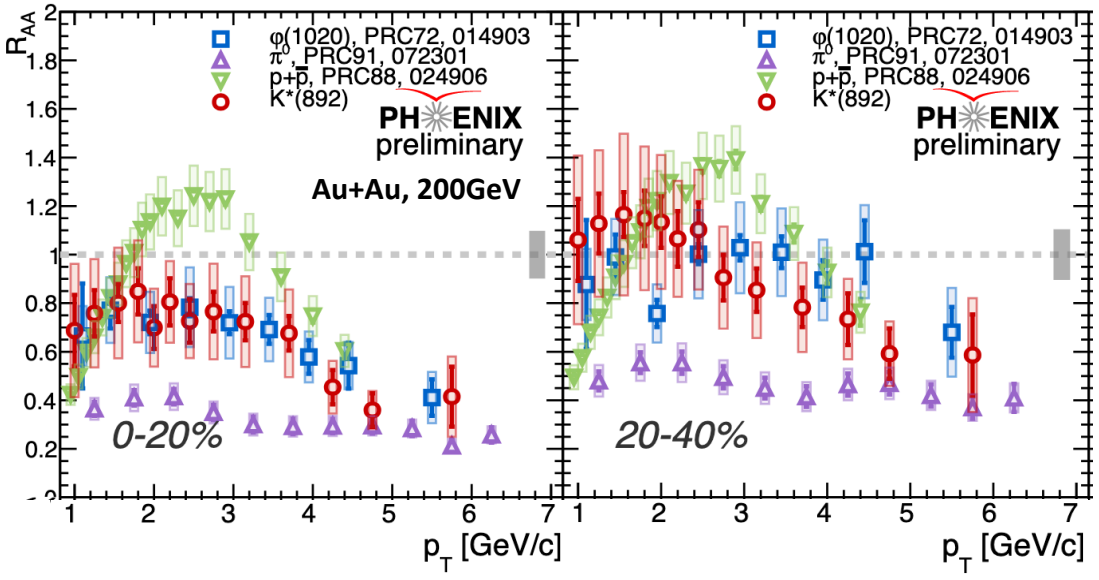
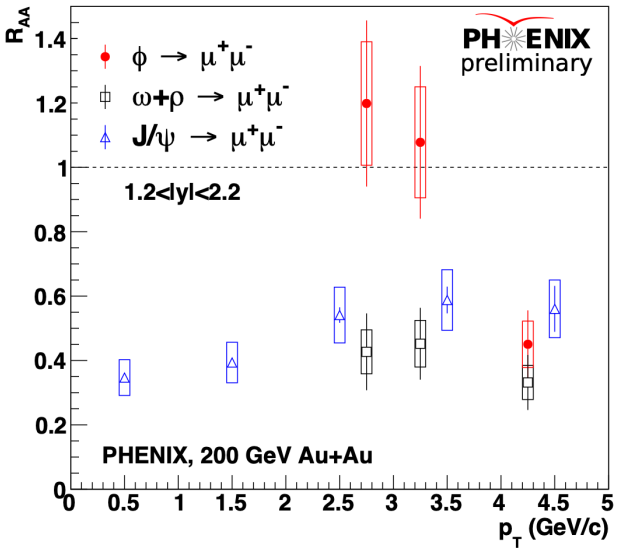
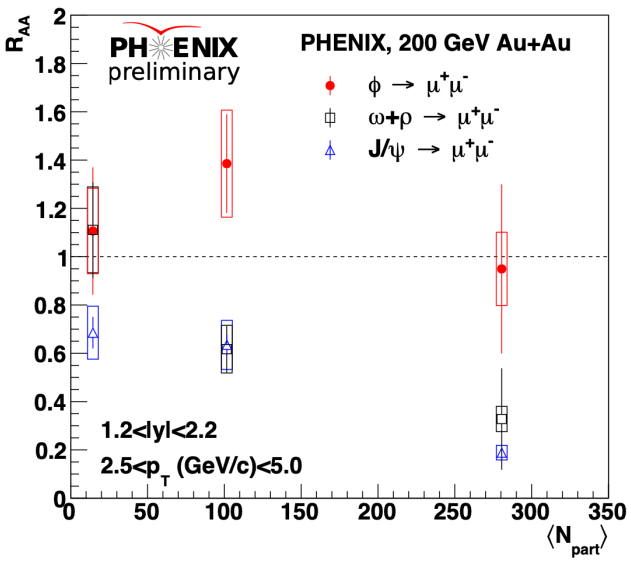


Conventional probes are getting even richer

A snapshot: Evidence of strangeness enhancement at mid- and forward rapidity



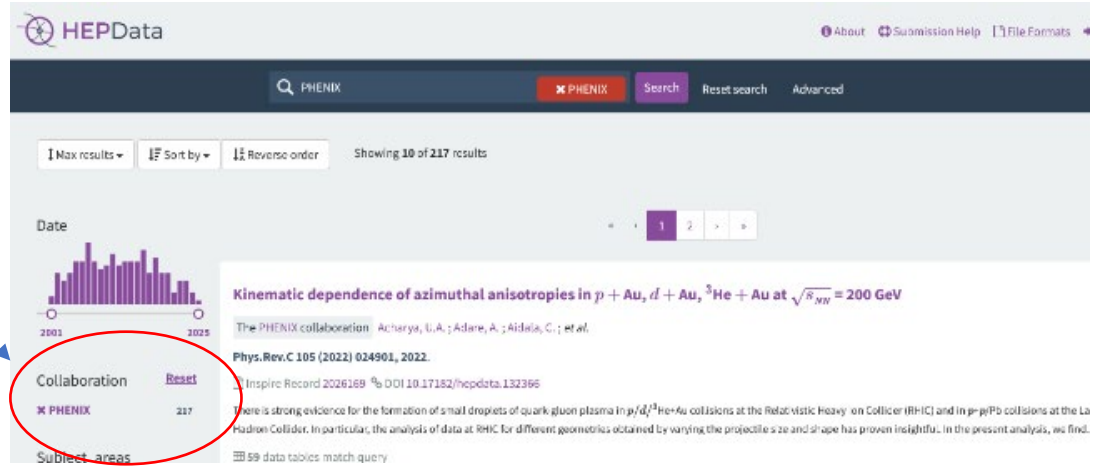




Single hadron spectra and flow measurement continues

Data preservation foreseeing decades to come

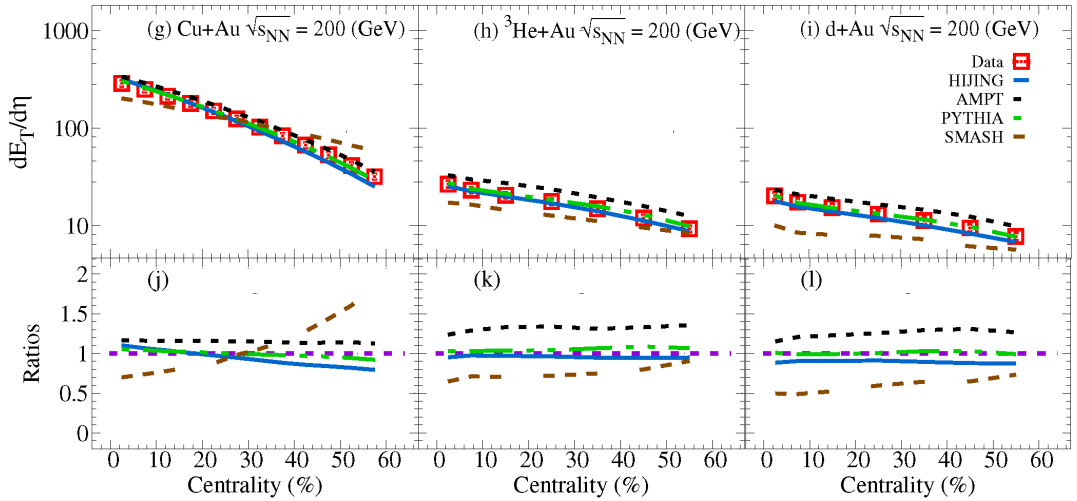
- 217/227 PHENIX papers on HEPData.



- Implemented REANA as a framework of analysis preservation
  - Analysis environment (libraries, etc) are in container (Docker)
  - Workflow in YAML
  - π^0 and direct γ d+Au analyses implemented

- Tring to adopt common analysis frameworks
  - Rivet framework (https://rivet.hepforge.org/)
    - e.g. https://github.com/cnattras/RIVETAnalyses
  - One can produced plots from simulation data with PHENIX analysis method.

Rivet analysis of $dE_T/d\eta$ using PHENIX data
(by the courtesy of C. Nattrass and UTK group)



Summary

- PHENIX has been producing new and significant results for 25 years.
  - And still making progress.

- Latest highlight includes:
  - Direct photons as baseline for small system collisions
  - Extended HBT measurement to get insight into U(1)
  - Multi-D differential measurements of direct photons
  - Separating heavy flavor contribution using DCA
  - TSSA measurement extended to higher x_F and p_T using η
  - Heavy flavor production in violent p+p collisions
  - Extensive study of light flavor mesons and baryons across different collision systems

- PHENIX is eager on storing data and analysis procedures into publicly available sites
  - HEPDATA, REANA, RIVET…
  - PHENIX data can be used to produce new results in the next decades.