PHENIX Data analysis

Y. Akiba (RIKEN/RBRC)
for PHENIX Collaboration

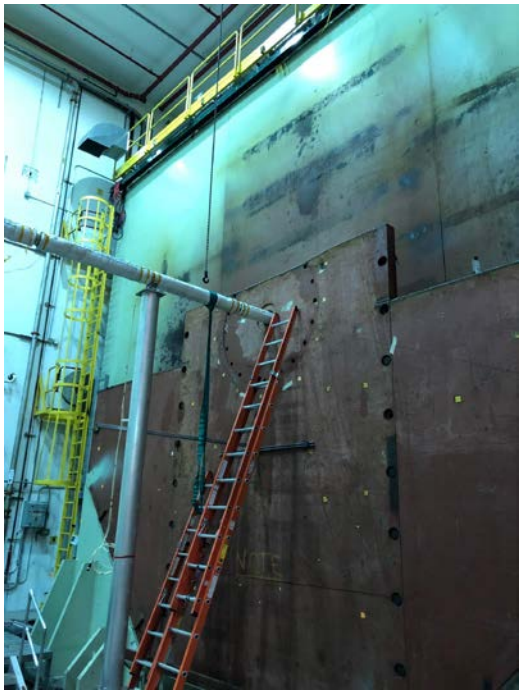
PAC2019 2019/06/10

PHENIX

PHENIX R&R Status

Last plate cut before prep for run

IR just before closing up for Run19



- Almost done! Final sections of North Arm backplate will be cut and removed at the end of Run19 (RHIC cryo off July 17)

PHENIX

Bonner Prize 2019 for Barbara Jacak

2019 Tom W. Bonner Prize in Nuclear Physics Recipient

Barbara V. Jacak
Lawrence Berkeley National Laboratory, University of California, Berkeley

Citation:

"*For her leadership in the discovery and characterization of the quark-gluon plasma, in particular for her contributions to the PHENIX experiment and its explorations of jets as probes.*"

Background:

or of Physics in 2008. In 2015, she was
essor of physics at UC, Berkeley. Her
heavy ion collisions, initially at the HELIOS
PHENIX Collaboration at RHIC. From 2007 to
Berkeley, she joined the ALICE Collaboration
of partons with hot, dense QCD matter. From
d Astronomy, chairing it in 2016 and 2017.
1996, and the Long Range Plan working
AGS Program Advisory Committee in 2005
ferences, and for national and international
ciety and of the American Association for the
the American Academy of Arts and

"For her leadership in the discovery and characterization of the quark-gluon plasma, in particular for her contributions to the PHENIX experiment and its explorations of jets as probes."

- This is 2nd Bonner Prize for a PHENIXian
- Bill Zajc received Bonner Prize in 2014
- YA received Nishina Memorial Prize in 2011

PHENIX

Publication Status

PHENIX

PHENIX papers since PAC2018

PRD99,092003	(2019)	$b \to e$ and $c \to e$ in pp at 200 GeV
PRC99,054903	(2019)	Two particle correlation with respect to event plane
PRC99,044912	(2019)	π^0 -hadron correlation in pp and pA
PRD99,072003	(2019)	dimuons from Drell Yan and bb decays in $p+p$ 200 GeV
PRC99,204903	(2019)	Event-by-event elliptic flow in AuAu 200 GeV
Nature P 15,214	(2019)	Evidence for Small QGP droplet
PRL121,022301	(2018)	$dN_{ch}/d\eta$ and v_2 in small systems
PRC98,054903	(2018)	π^0 and η in Cu+Au 200 GeV
PRC98,054902	(2018)	Low p_T direct photons in Cu+Cu
PRD98,092006	(2018)	$\phi \to \mu\mu$ in $p+p$ 510 GeV
PRD98 072004	(2018)	Direct photon and hadron correlation in $p+p$ 200 GeV
PRD98,032007	(2018)	A_L of $W \to \mu$
PRD98,012006	(2018)	A_N of forward J/ψ in p+A
PRC98,014912	(2018)	Long range correlation of high p_T hadrons in pp and d+Au
PRC97,064911	(2018)	HBT Levy fit analysis
PRC97,064904	(2018)	Identified hadron v_2 in pAu and ^{3}HeAu
arXiv:1805.04075		Scaling of low p_T direct photon yield (PRL proof)
arXiv:1903 07422		Forward hadron A_N in pAu
arXiv:1805.04066		$\mu\mu, e\mu, ee$ correlations in $p+p$ 200 GeV

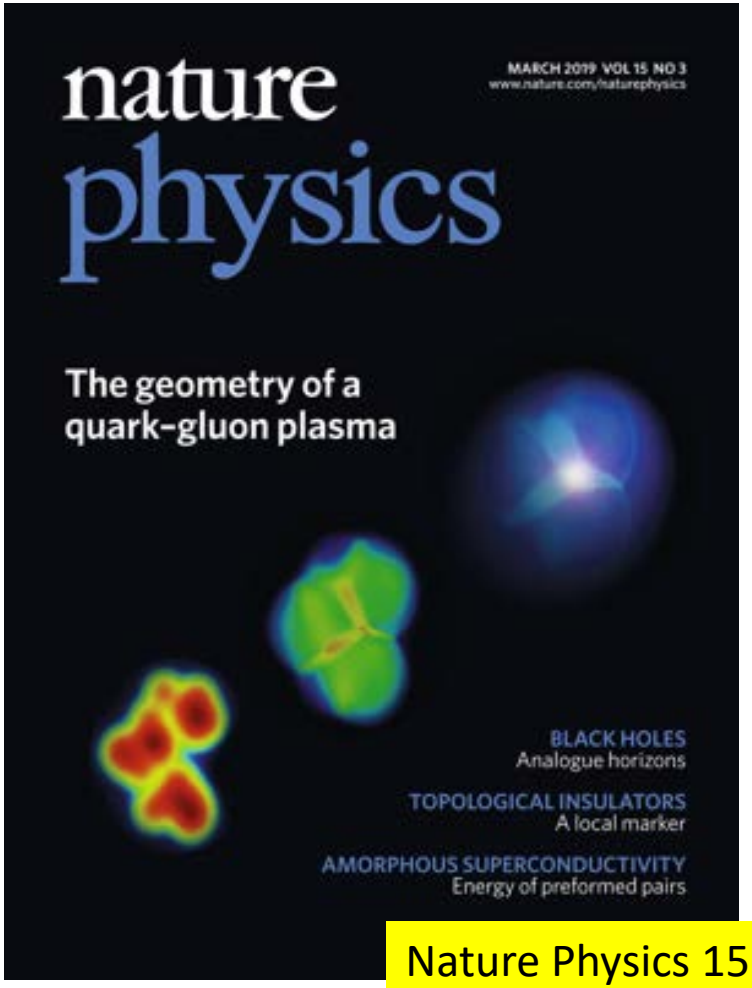
PHENIX

Publication in the last 12 months

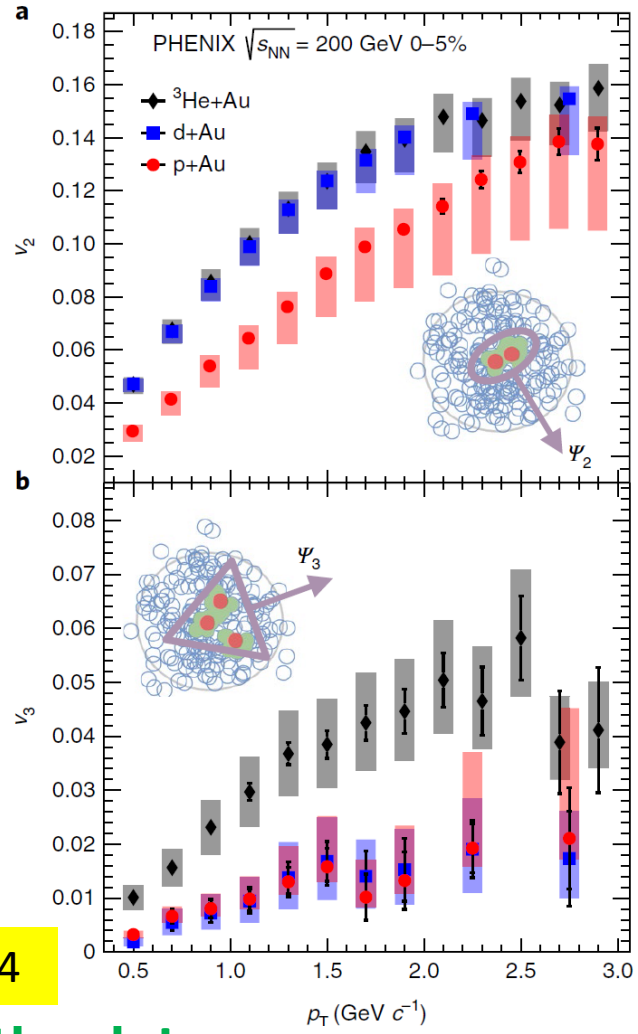
- 16 papers published + 1 in proof since last PAC
  - Nature Physics: small QGP droplets
    - First PHENIX paper accepted by Nature Physics
  - PRL: v_2 and $\frac{dN_{ch}}{d\eta}$ in p+A, d+Au, and ^{3}He+Au
  - PRL proof: scaling of low p_T direct photon yield
  - PRD: $b \to e$ and $c \to e$ in $p + p$
- 2 papers in journal review. Expect that they will be accepted soon
  - PRL(review) Suppression of A_N of hadrons in $p + A$
  - PRD(review) $ee, \mu\mu, e\mu$ correlations in pp 200 GeV

PHENIX

Evidence for small QGP droplets

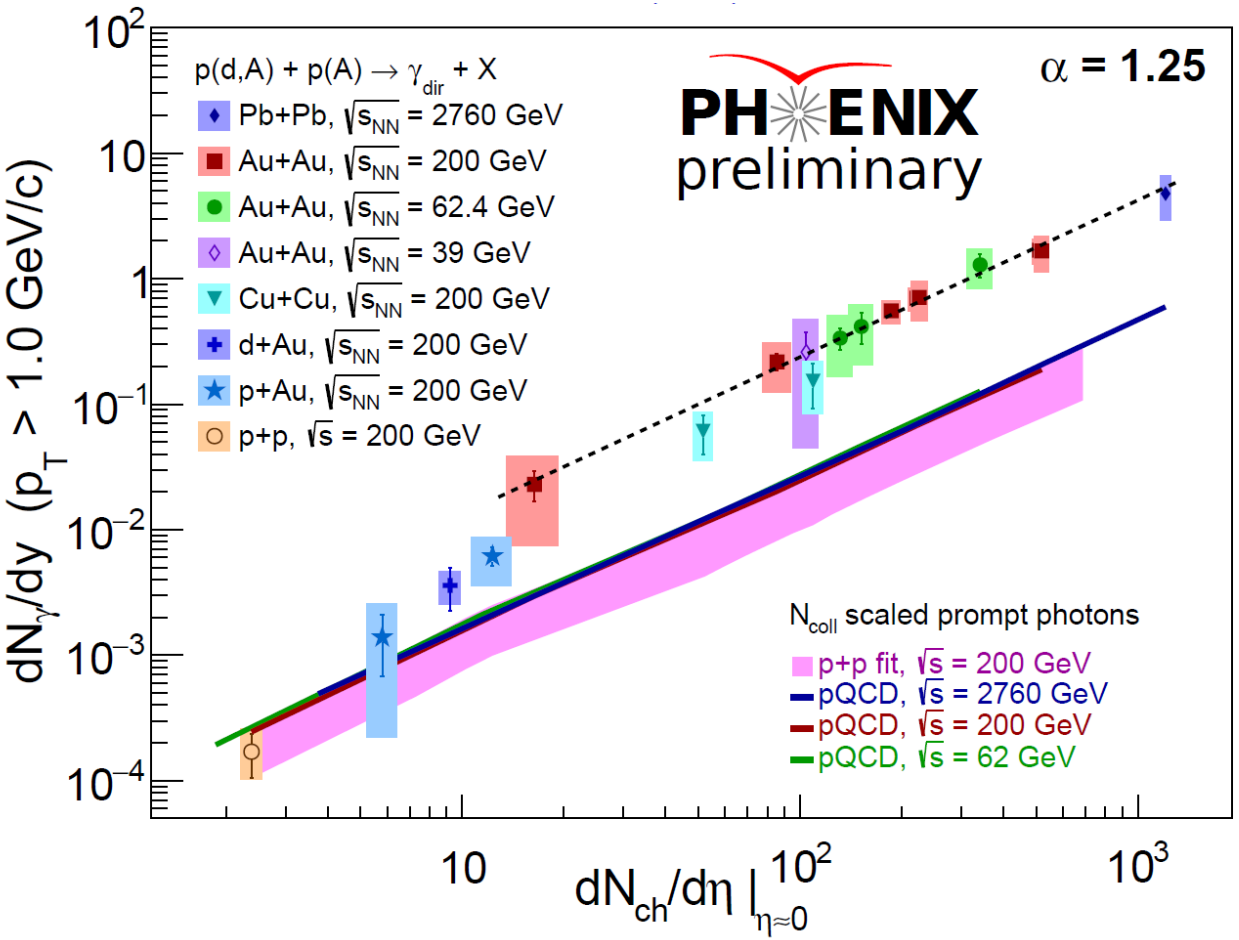


Nature Physics 15(2019) 3,214



- **Formation of QGP droplets describes the data**
  - **There is *no viable alternative*-theoretical explanation of the data**
- **Featured in the cover of March 2019 issue of Nature Physics**

Low p_T direct photons



AuAu
arXiv:1805.04084
Accepted by PRL

Cu+Cu
PRC98 054902(2018)

- Scaling means similar photon source across beam energies

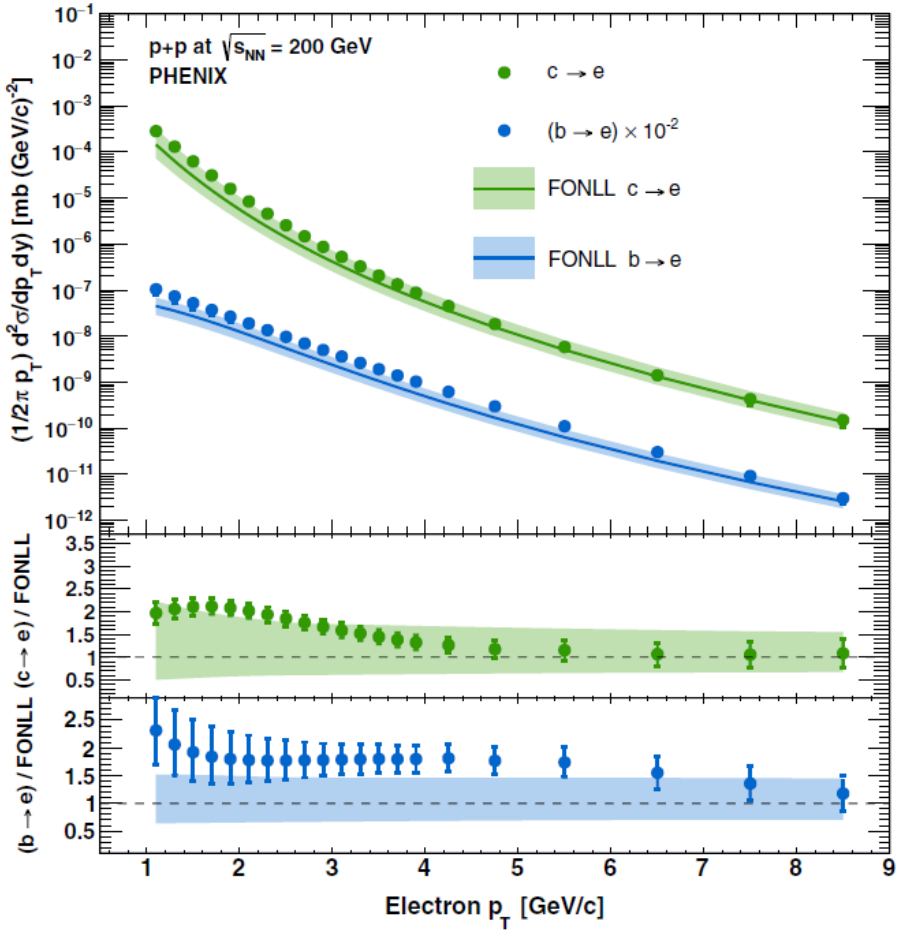
→ Most photons are emitted at the phase transition

Au+Au paper is accepted by PRL (in proof). Cu+Cu paper published

- Evidence for Photon enhancement in $p + A$ and d+Au

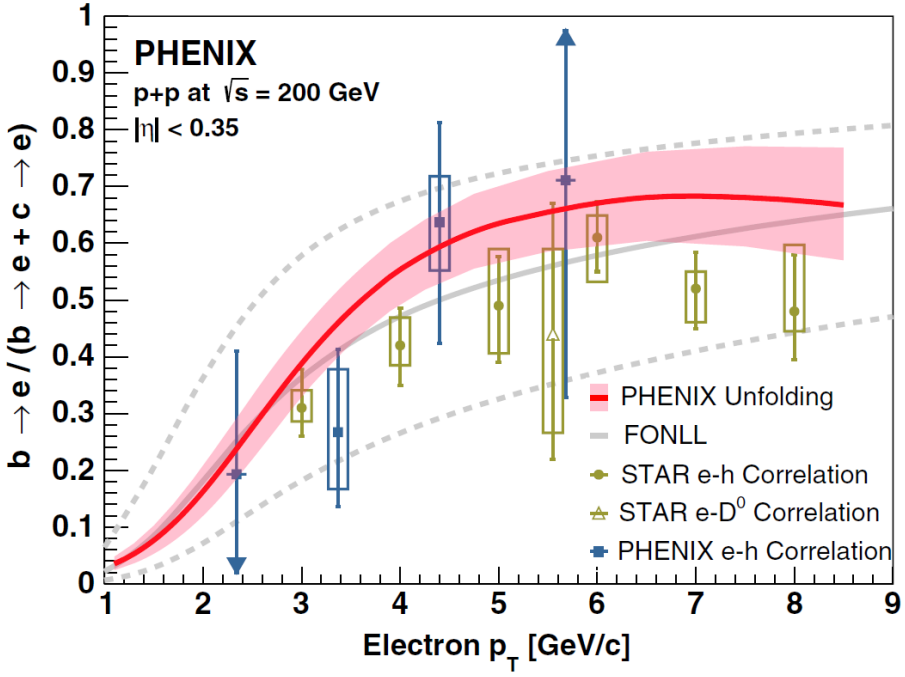
→ Support QGP formation in small systems

$b \rightarrow e$ and $c \rightarrow e$ in $p + p$



PHYSICAL REVIEW D **99,** 092003 (2019)

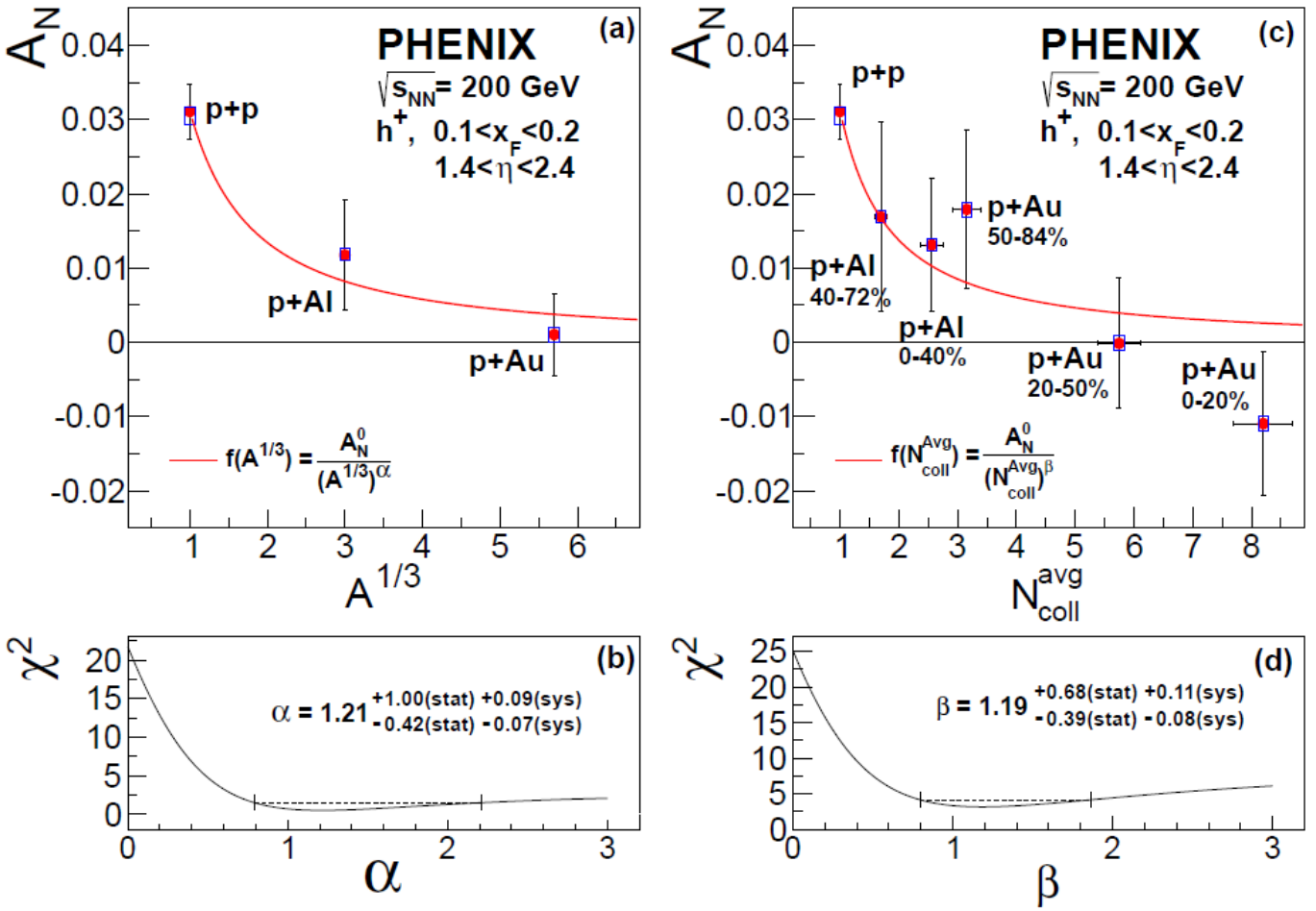
Measurement of charm and bottom production from semileptonic hadron decays in $p+p$ collisions at $\sqrt{s}=200$ GeV



- $b \rightarrow e$ and $c \rightarrow e$ are separated by VTX
- Baseline for R_{AA} of $b \rightarrow e$ and $c \rightarrow e$

Suppression of A_N in p+A

arXiv:1903.07422



A_N of positive hadrons in pAu is suppressed compared with p+p

A-independence hypothesis of TSSA is clearly disfavored

PHENIX publications

- **194 physics papers published/accepted**
  - Phys. Rev. Lett. 73+1
  - Phys. Rev. C 79
  - Phys. Rev. D 36
  - Nature Physics 1
  - Phys. Letter B 4
  - Nucl. Phys. A 1
- **Total citation: ~26800**
- Topcite 1000+ 2
  - 500-1000 6
  - 250-500 19
  - 100-250 48
  - 50-100 45

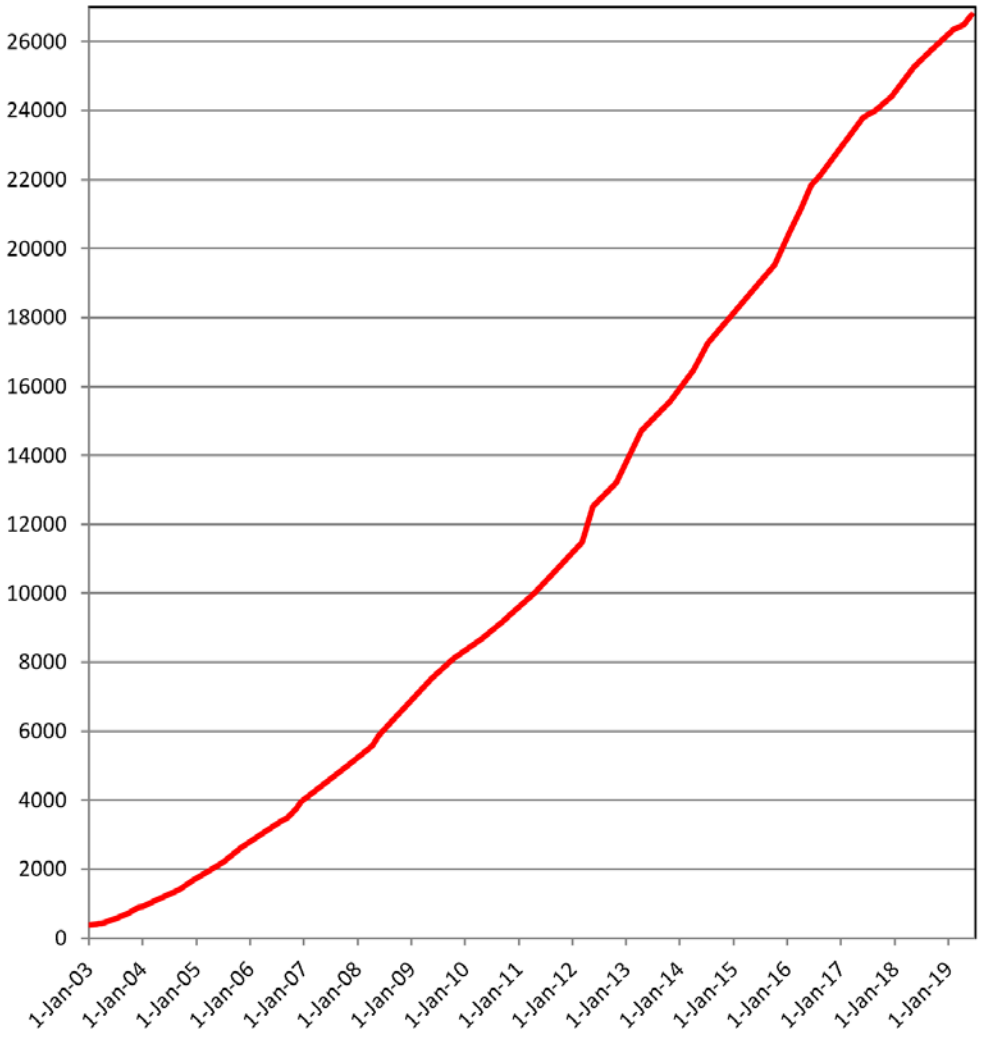
PHENIX White Paper: 2685 cites

Jet quenching discovery: 1039 cites

120 physics papers in topcite 50+

(140 if proceedings and NIM papers are included)

Cumulative Citations of PHENIX papers



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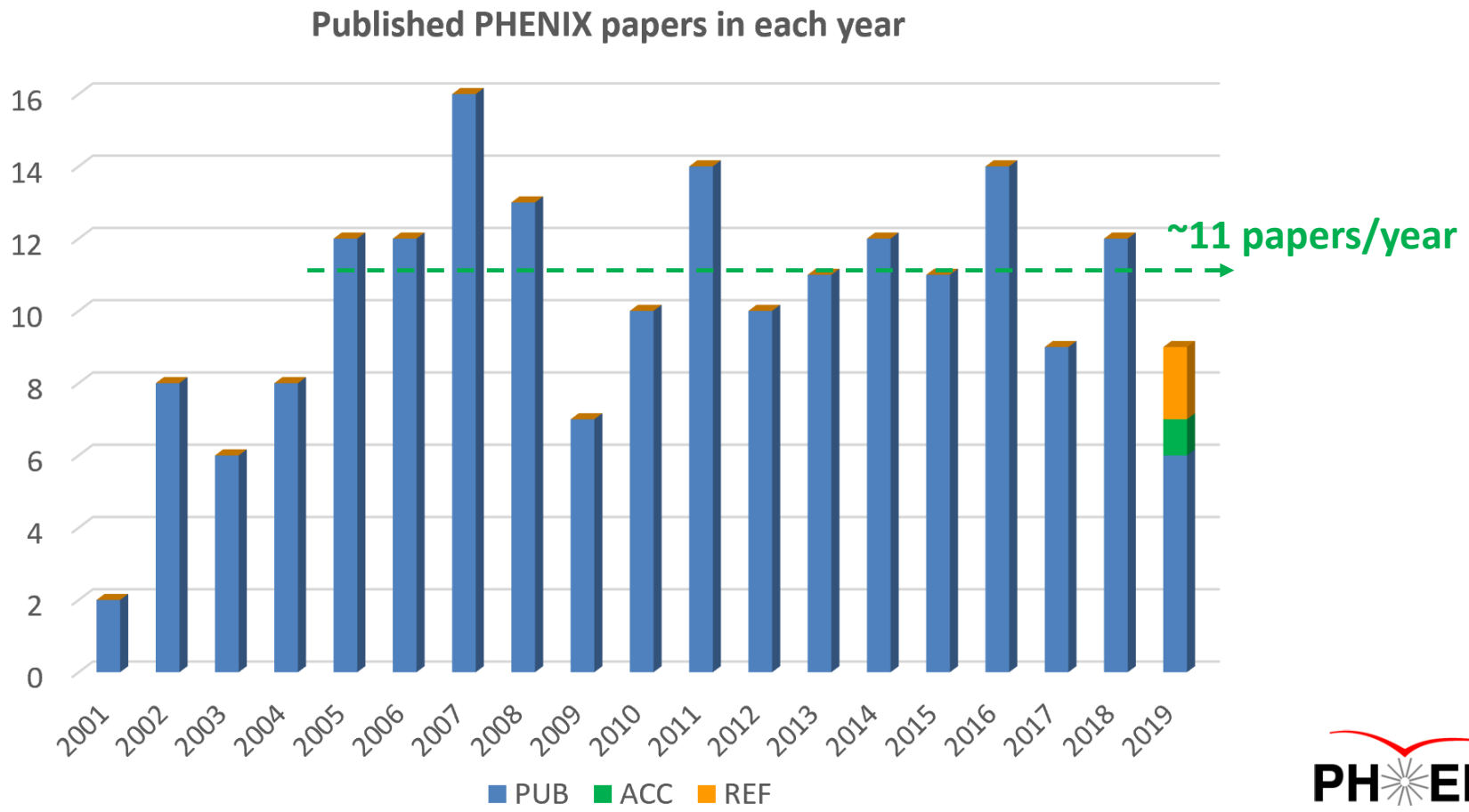
PHENIX publications

- ~11 papers per year since 2005
- 6 papers published in 2019 so far (+1 accept + 2 in review)
- 3 years to complete publication of major results



Data analysis Status and outlook

Golden 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

Many physics topics with variety of high statistics datasets

3 years to complete publication of key results

Data Production Status

RUN	beam	VTX/FVTX/Muon (heavy flavor)	Central Arm flow	Central Arm EM (γ, e)	MPC/EX (small-x)
16	Au+Au 200	**Starting**	**DONE**	**DONE**	N/A
	d+Au BES	Needs calibration, 2019	**DONE**	**DONE**	calibration
15	p+p 200	**DONE**	**DONE**	**DONE**	N/A
	p+Au 200	**DONE**	**DONE**	**DONE**	
	p+Al 200	N/A	**DONE**	**DONE**	
14	Au+Au 200	**DONE**	**DONE**	**DONE**	N/A
	3He+Au 200	2019	**DONE**	**DONE**	

- Run16AuAu ~ 6 months of CPU each

Focus on key analysis topics

- PHENIX has variety of high statistics data from RUN10 to RUN16
- Physics output is limited by the analysis workforce, not the amount of the data.
- It is important to focus on important physics topics that PHENIX has strength
  - Flow in large and small system
  - Low p_T direct photons
  - High p_T direct photons
  - Open HF (VTX/FVTX)
  - Quarkonia
  - Direct photon – jets correlation
- Extract property parameters (η/s , $\hat{q}$, $\Delta E(L)$, …) of QGP and PDF from “global analysis”.

PHENIX

On-going Heavy ion analysis towards QM2019

Small systems p+Au, d+Au, ^{3}He+Au
Collectivity in small system
High p_T π^0, η in small systems
$\phi \rightarrow KK$ in small systems
J/ψ in small systems
Jets in small systems

Jets and high p_T
Direct γ −hadron correlation in AuAu
π^0 −hadron correlation in AuAu
ϕ, K_S, K^* in Cu+Au
ϕ, K_S, K^* in U+U

EM probes
Drell Yan in $p + A$
Low p_T direct γ in small systems
Low p_T direct γ yield in AuAu
Low p_T direct γ flow

Heavy flavor
$b \rightarrow e, c \rightarrow e$ R_{AA} in mid-rapidity
$b \rightarrow e, c \rightarrow e$ flow in mid-rapidity
$b \rightarrow \mu, c \rightarrow \mu$ in forward in p+p
$B \rightarrow J/\psi$ in p+p
bb correlations in $p + A$

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On-going HI analysis (beyond QM19)

Au+Au 200 GeV RUN14+16
Open heavy flavor spectra and flow with b/c separation
J/ψ flow and yield
π^0, γ-hadron correlation
Direct photon at low and high p_T
UPC dimuons and J/ψ

RUN14+16 PHENIX recorded ~30 Billion minimum bias Au+Au events with VTX/FVTX

Small systems p+Au, d+Au, ^{3}He+Au
Open heavy flavor spectra and flow with b/c separation
J/ψ , $\psi(2S)$ R_{AA} and flow
π^0, γ-hadron correlation
Jets in small systems
Direct photon at low and high p_T

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On going Spin/p+p/CNM analysis

CNM
Forward pi0 in d+Au with MPC-EX
Forward direct photons in d+Au with MPC-EX
High pT direct photons in pA and HeA
Direct photon at low and high p_T
p+p unpol
J/Psi polarization
Direct photon cross section in pp at 510 GeV
A_N
Very forward neutron AN (pT)
Heavy flavor electron/muon AN
Pi0/eta AN in pp and pA
A_{LL}
Forward EM cluster ALL in 200 GeV pp
Charged pion ALL in 510GeV pp
Jet ALL in 510 GeV pp

Workforce for PHENIX analysis

- Current workforce (Survey spring 2019)

MA/MS student	3.0 FTE
PhD students	31.3 FTE
Postdocs	5.8 FTE
Senior Scientist	3.9 FTE
Total	44.0 FTE

- US University groups are committed in PHENIX analysis now. They are moving to sPHENIX
  - sPHENIX start taking data in CY2023
- Maintaining the current level of workforce for PHENIX analysis is essential to complete all Key analysis before the start of sPHENIX
- In discussion with DOE for additional resource to the US University groups of PHENIX

Need for service work of analysis

- Service works for data analysis are essential to keep the physics analsys productivity
  - Recalibration
    - Many recalibrators not ready for recent runs
    - Vital for high statistics RUN14-16 data
  - Documentation
    - Good documentation is needed to keep the data analyzable in future
  - Simulation
    - Tuning of PHENIX Geant3 simulator for each runs
    - Need Simulation coordinator
- In discussion with DOE for additional resource in the US University groups of PHENIX

Summary

- PHENIX completed its data taking in RUN16
  - Removal and Repurposing is basically completed
- Publication status
  - PHENIX continues to produce high impact results
    - Publishing ~11 papers per year, ~2000 citations/year
  - highlights
    - Evidence for small QGP droplets in small systems
    - Scaling of low pT direct photon
    - b and c production in p+p
    - Suppression of AN in pA
- Status of Data analysis and outlook
  - DST production except for heavy flavor measurement in RUN16 are basically completed
  - Physics output is limited by workforce for the analysis
  - Many on-going physics analysis topics
  - Keeping the level workforce is essential to complete key analyses before the start of sPHENIX

PHENIX