

Studying The Phases and Structure of QCD Matter : From RHIC to EIC

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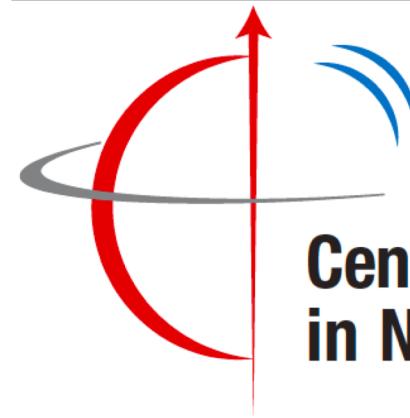
Shandong University



11/30/18

Daniel Brandenburg

Inaugural Symposium,
Center for Frontiers in Nuclear Science,
November 30, 2018
CFNS Center, Stony Brook University



**Center for Frontiers
in Nuclear Science**

A little bit about me

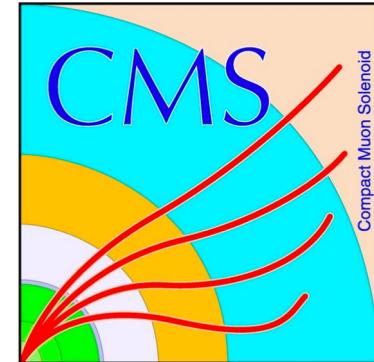
Born 4th of 6
(big family)

1991

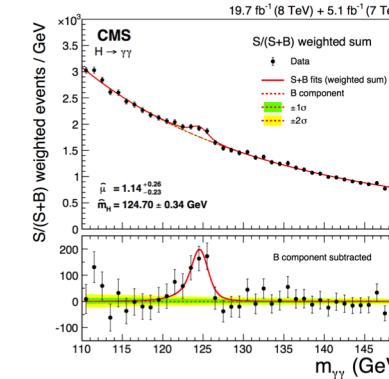


University of Florida
Physics & Math

2009



2013



2013

Rice University
PhD



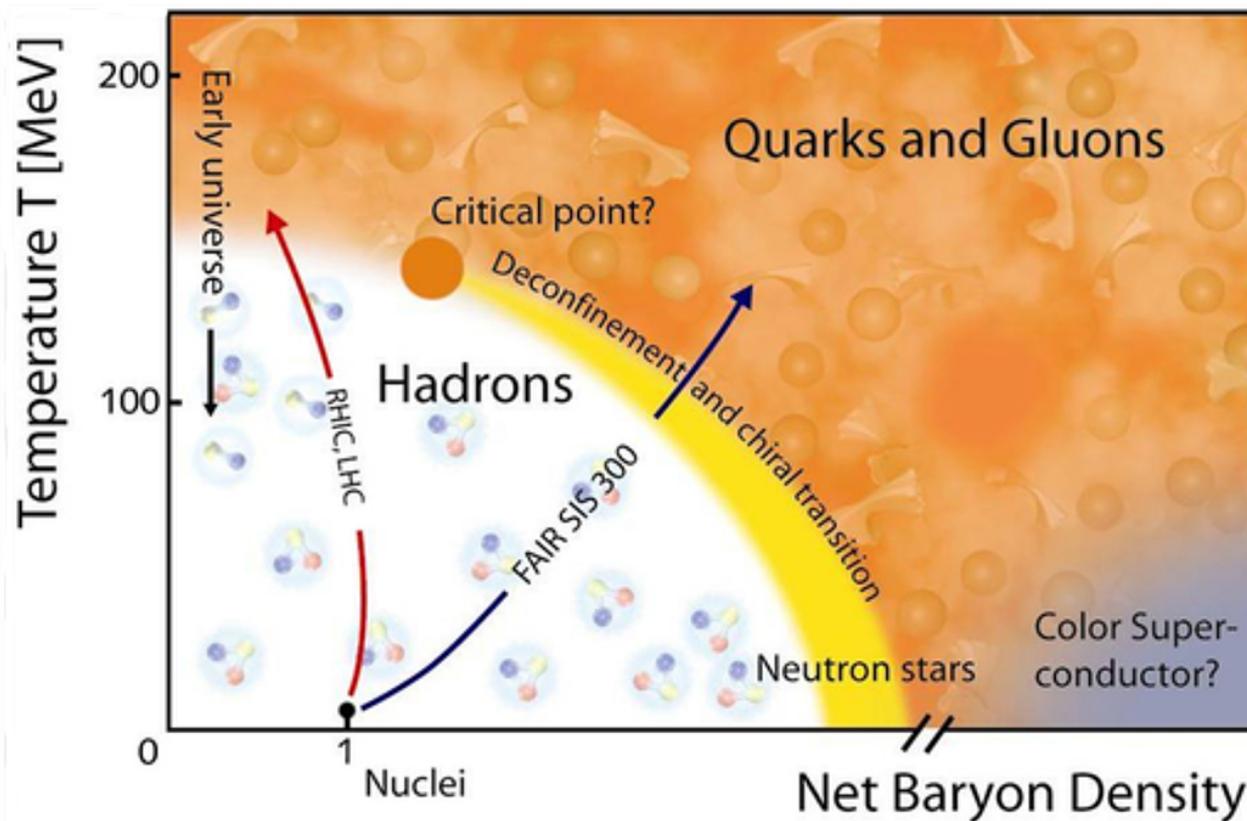
2018

BROOKHAVEN
NATIONAL LABORATORY

Post-Doc
Brookhaven National Lab

Daniel is my middle name – I've never used my first name (James)
I just became a father! So if I seem sleep deprived, it's because I am 😊

Studying the QCD phase diagram



Lattice QCD calculations show smooth crossover transition around $T_c \approx 150$ MeV for $\mu_B \approx 0$

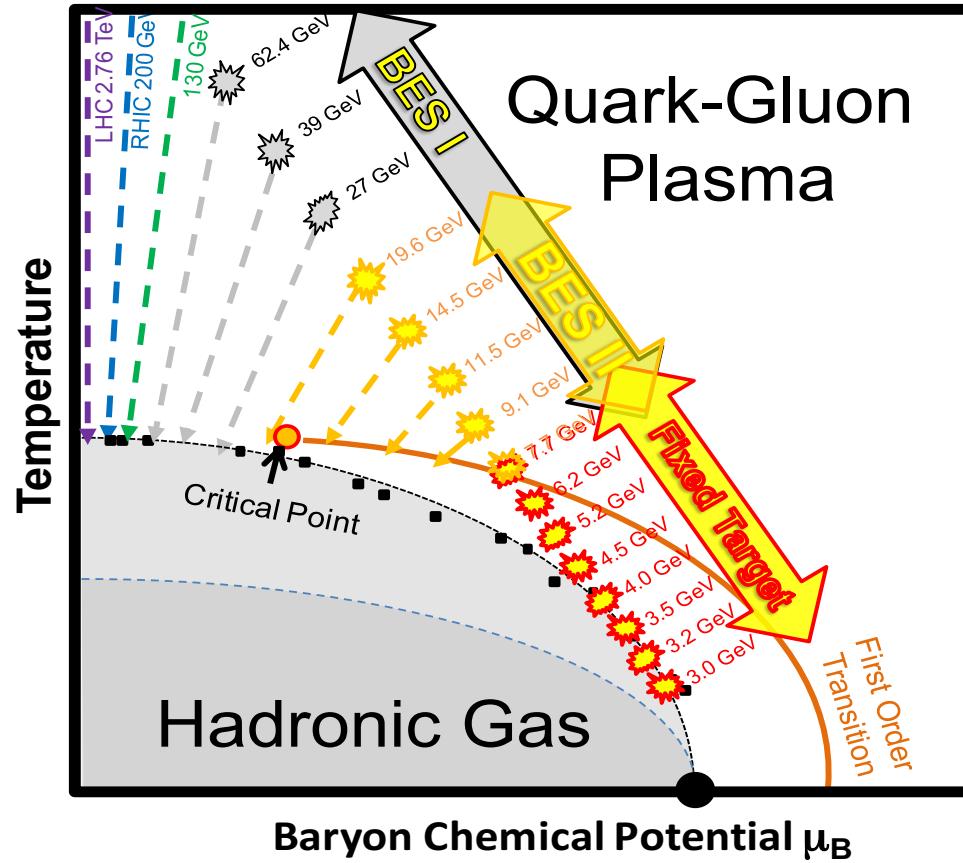
- Is there a 1st order phase transition at finite μ_B , and a critical point?
- What is the relationship between the chiral and deconfinement transitions?

Beam Energy Scan (BES) Phase 1

BES 1 : Au+Au collisions at 7.7, 11.5, 14.5, 19.6, 27.0, 39.0, and 62.4 GeV

Primary GOALS:

- Search for Conjectured QCD critical point
- Search for 1st order phase transition
- Search for the onset of key QGP signatures



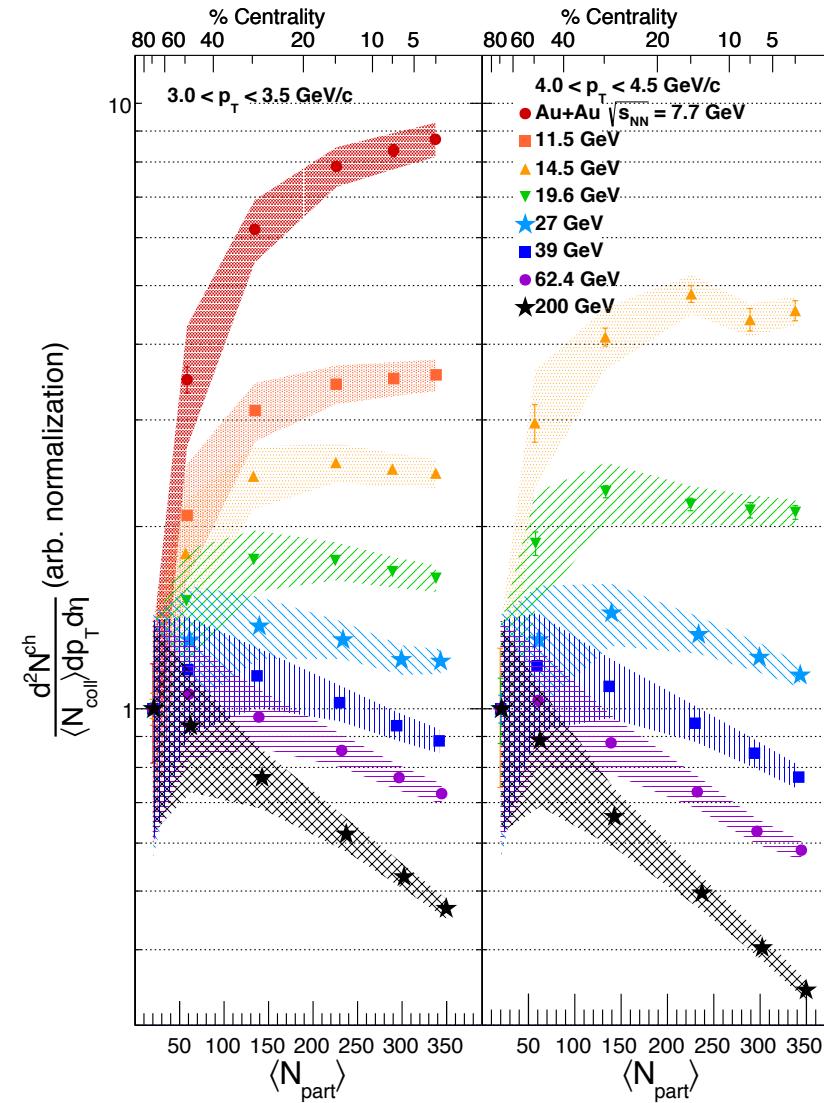
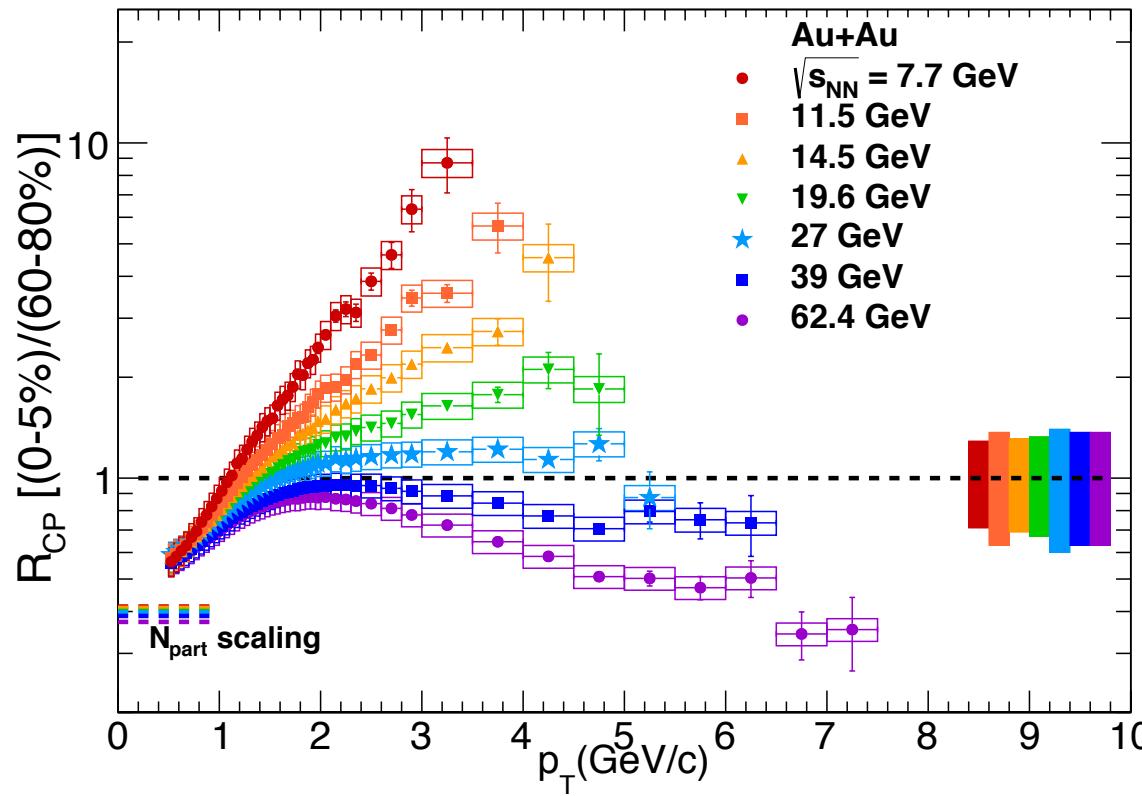
$\sqrt{s_{NN}}$ [GeV] =	7.7	11.5	14.5	19.6	27.0	39.0
$\sim \mu_B$ (in central collisions)[MeV]	420	315	260	205	155	115

J. Cleymans, H. Oeschler, K. Redlich, and S. Wheaton, Phys. Rev. C73 (2006) 034905

Energy dependence of jet quenching

Phys. Rev. Lett. 121, 032301 (2018)

$$R_{CP} = \frac{\langle N_{coll} \rangle_{\text{Peripheral}}}{\langle N_{coll} \rangle_{\text{Central}}} \frac{\left(\frac{d^2 N}{dp_T d\eta} \right)_{\text{Central}}}{\left(\frac{d^2 N}{dp_T d\eta} \right)_{\text{Peripheral}}}$$



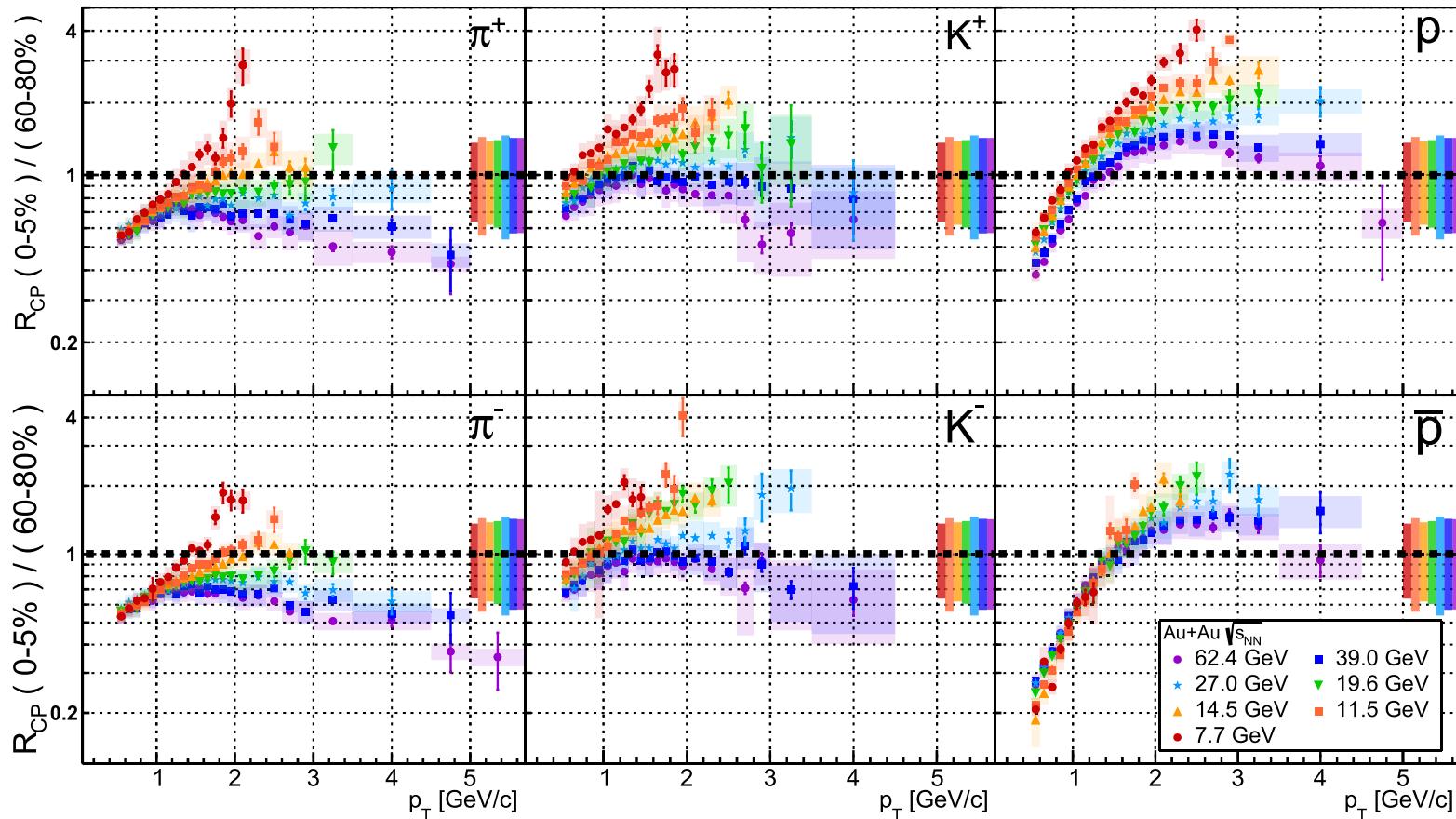
More differential approach by looking at N_{coll} scaled yields:

$$Y(\langle N_{part} \rangle) = \frac{B}{\langle N_{coll} \rangle} \frac{d^2 N}{dp_T d\eta} (\langle N_{part} \rangle)$$

Evidence of suppression effects down to $\sqrt{s_{NN}} = 14.5 \text{ GeV}$

Smooth trend from significant suppression ($\uparrow \sqrt{s_{NN}}$) to enhancement ($\downarrow \sqrt{s_{NN}}$)

Energy dependence of jet quenching

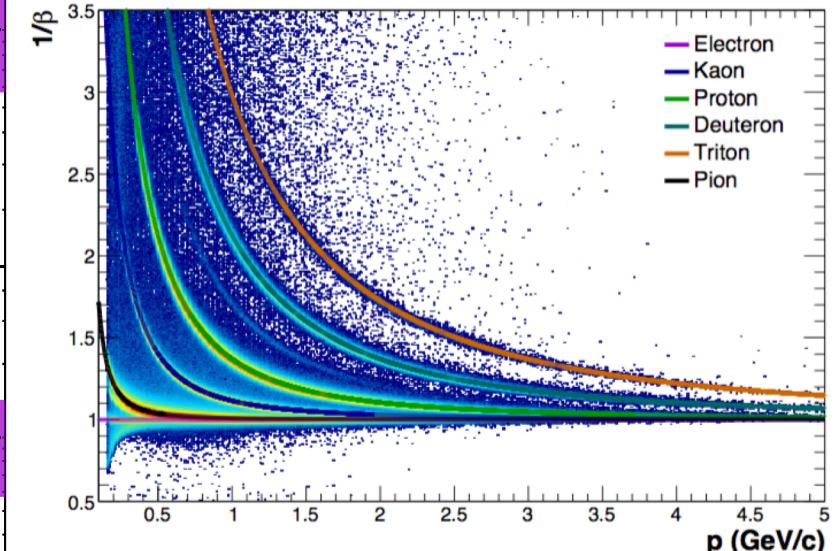


Phys. Rev. Lett. 121, 032301 (2018)

More differential measurements through particle identification

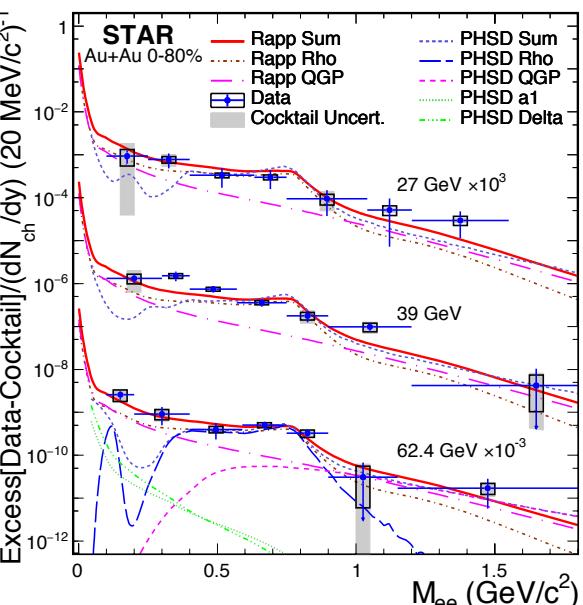
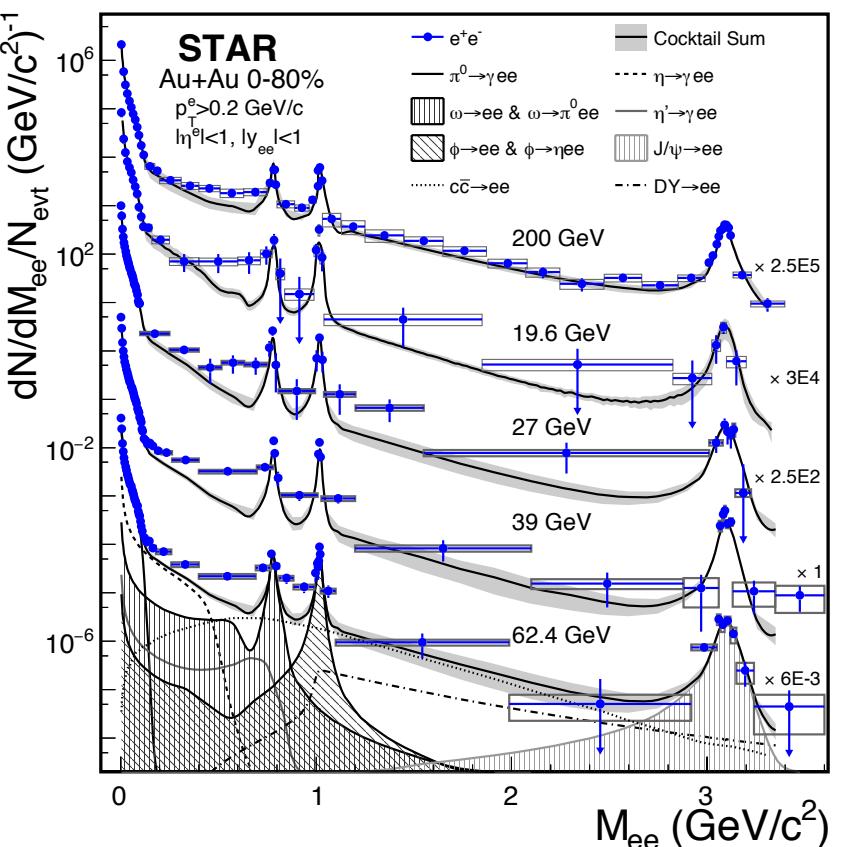
- Pions show suppression at lower energies than inclusive hadrons
- Pions are more sensitive probe of jet-quenching
- Only possible with particle identification using Time-of-Flight

TOF Calibration and Software coordinator for 4 years



Year	Collision System and $\sqrt{s_{NN}}$ (GeV)	VPD Single PMT Resolution (ps)	Stop-side resolution (ps)	Total Resolution (ps)
2012	$p + p$ 200	100	70	120
	$p + p$ 510	100	70	120
	$U + U$ 193	70	70	75
	$Cu + Au$ 200	92	75	78
2013	$p + p$ 510	133	80	150
2014	$Au + Au$ 14.5	170	84	146*
	${}^3He + Au$ 200	96	79	125*
	$Au + Au$ 200	68	70	73
2015	$p + p$ 200	122	75	113
	$p + Au$ 200	122	90	98
2016	$Au + Au$ 200	78	74	75
	$d + Au$ 200	114	85	88
	$d + Au$ 62.4	126	90	95
	$d + Au$ 39	152	83	121*
	$d + Au$ 19.6	160	83	128*
2017	$p + p$ 510	137	90	114
	$p + p$ 510 RHICf	125	82	101

STAR Dilepton measurements



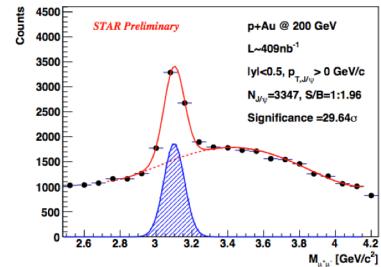
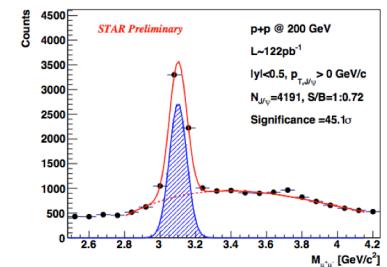
[arxiv:1810.10159](https://arxiv.org/abs/1810.10159)

Time-Of-Flight detector provides excellent electron identification at STAR

Robust e^+e^- program at STAR for many years:

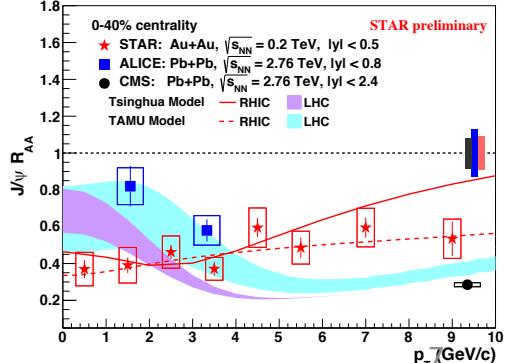
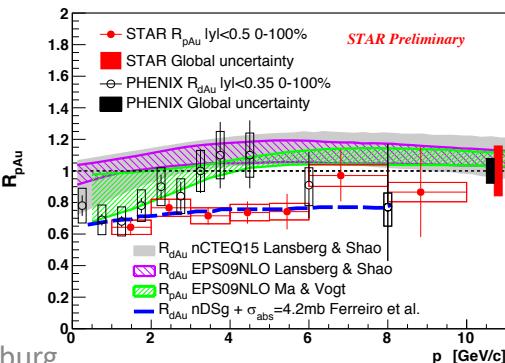
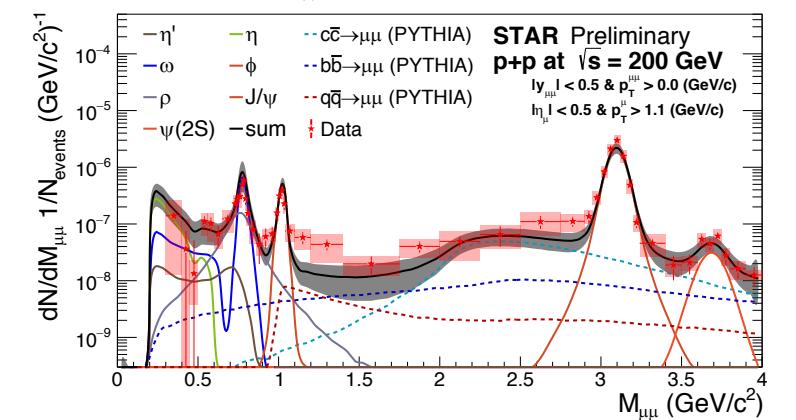
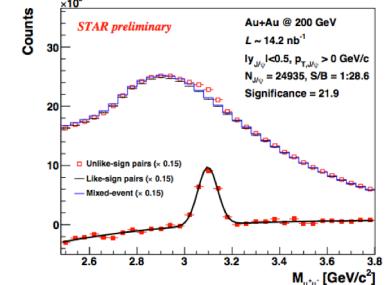
- Explored the energy dependence of in-medium ρ meson broadening
- Link to chiral-symmetry restoration – chiral phase transition

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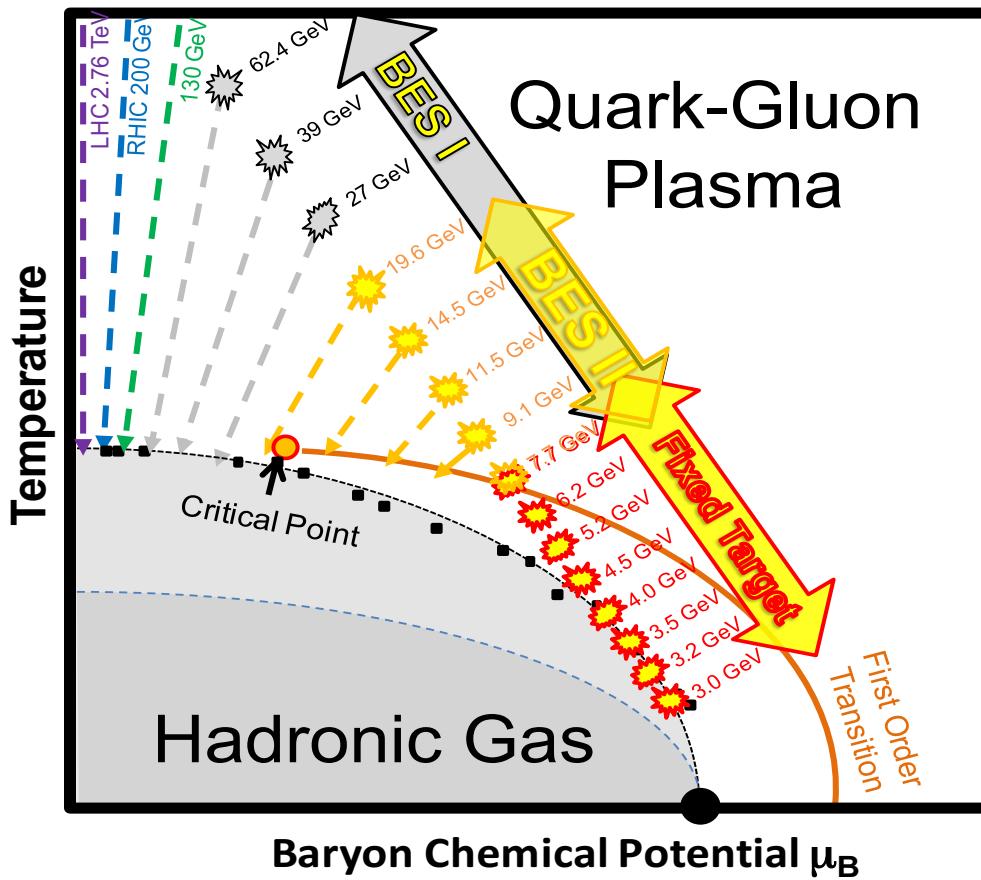
Muon Telescope Detector

- $\mu^+\mu^-$ program complements e^+e^-
- J/ψ in p+p, p+A, A+A
- $\mu^+\mu^-$ continuum



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Beam Energy Scan II and Fixed Target Program

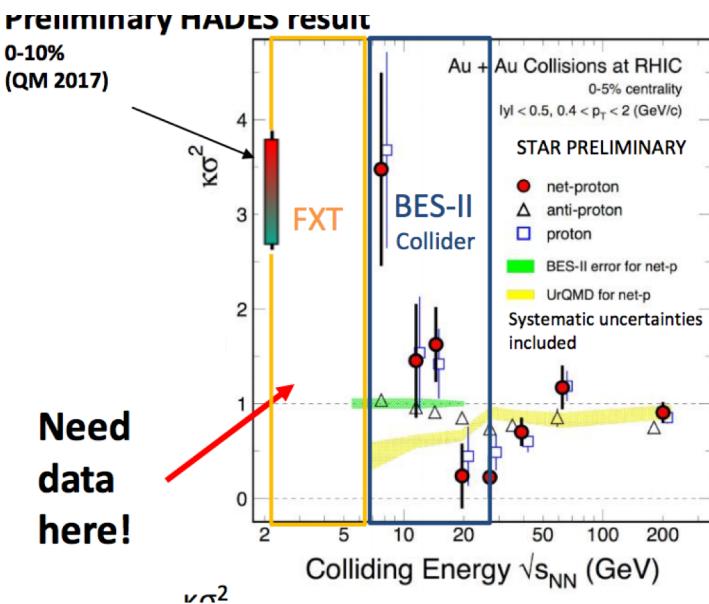
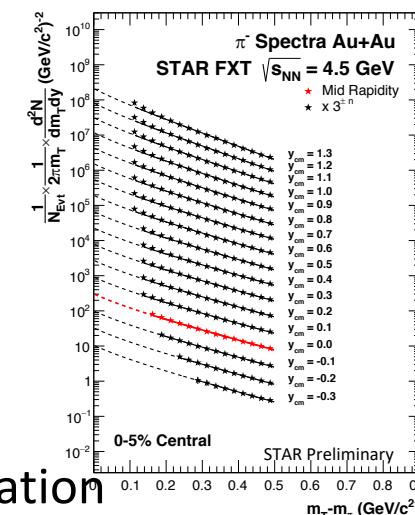


STAR Fixed Target Mode :

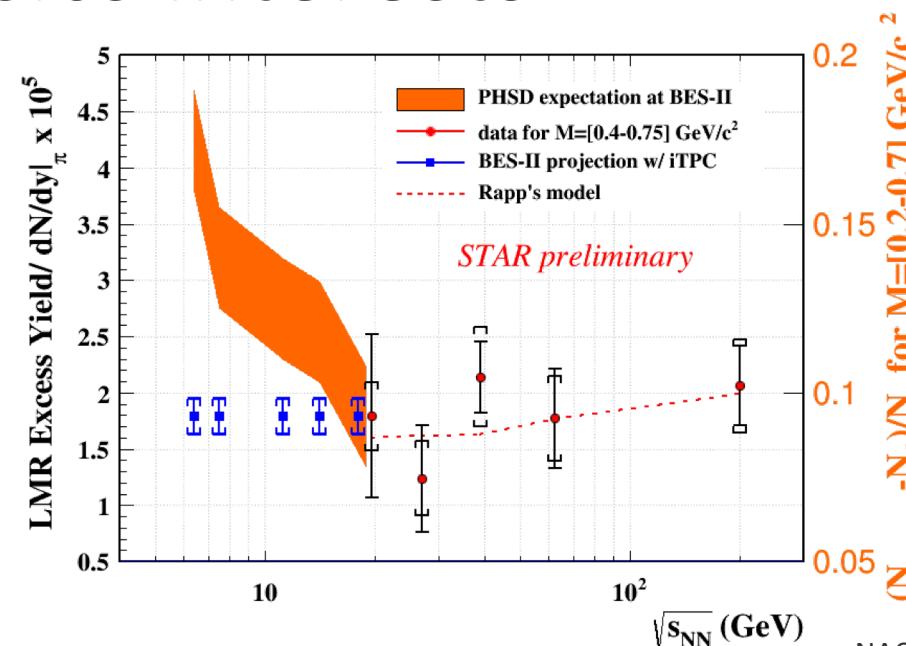
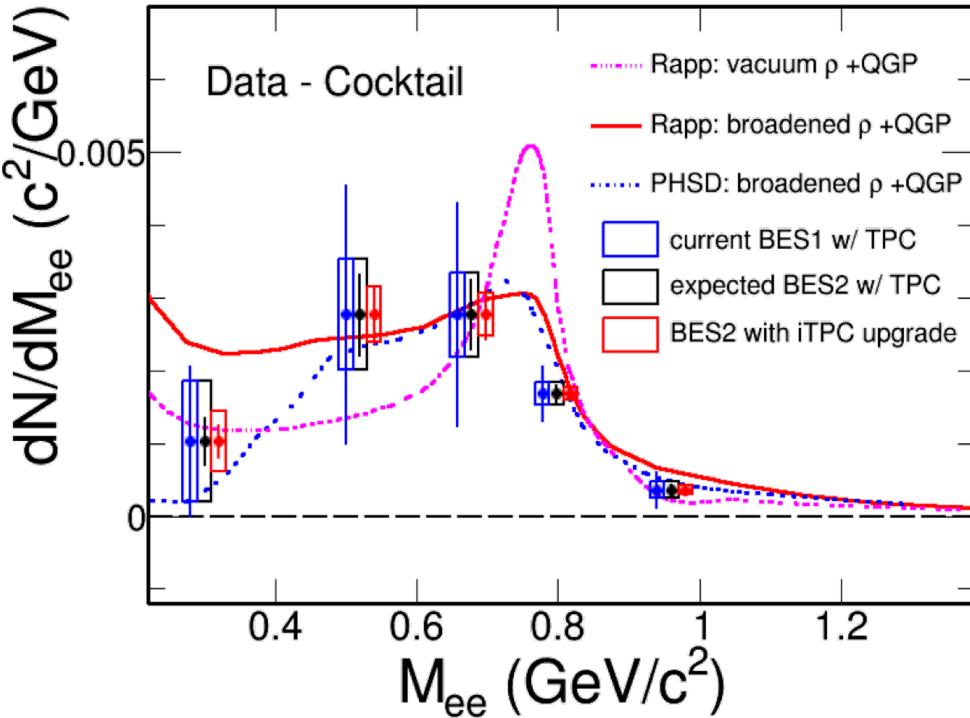
- Successfully demonstrated with several test runs
- First paper with spectra, flow, and HBT results in preparation
- Will provide Au+Au collisions at $\sqrt{s_{NN}} = 3.0 - 7.7$ GeV

BES II : Refine and improve understanding from BES I
Crucial to explore above **and** below (expected) location of critical point

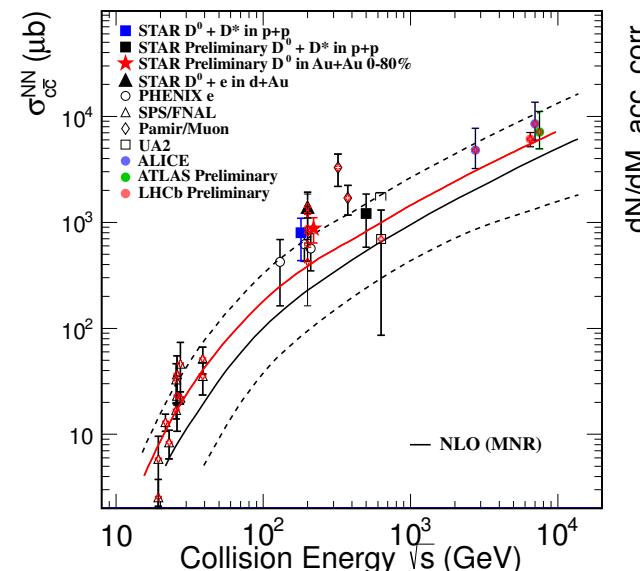
BES II **Collider** Mode :
 $\sqrt{s_{NN}} = 19.6, 14.5, 11.5, 9.6, 7.7$ GeV



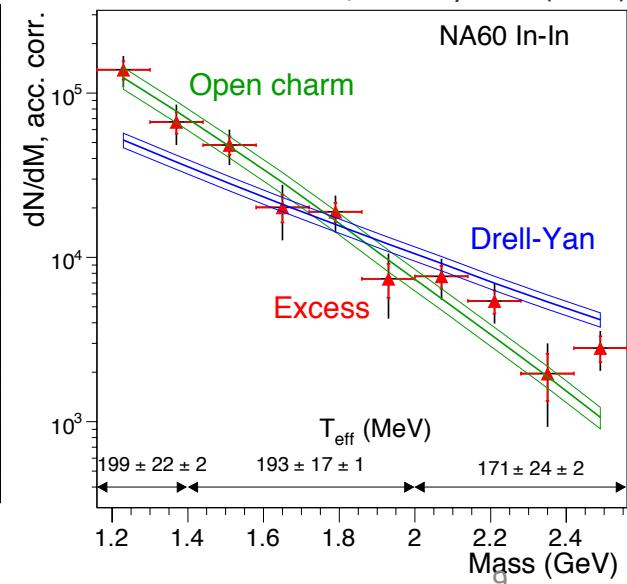
Beam Energy Scan II Physics Interests



Ruan, Rapp – TPD'14



NA60 Collaboration, Eur. Phys. J. C (2009) 61



Linking top RHIC energies with SPS, FAIR energies

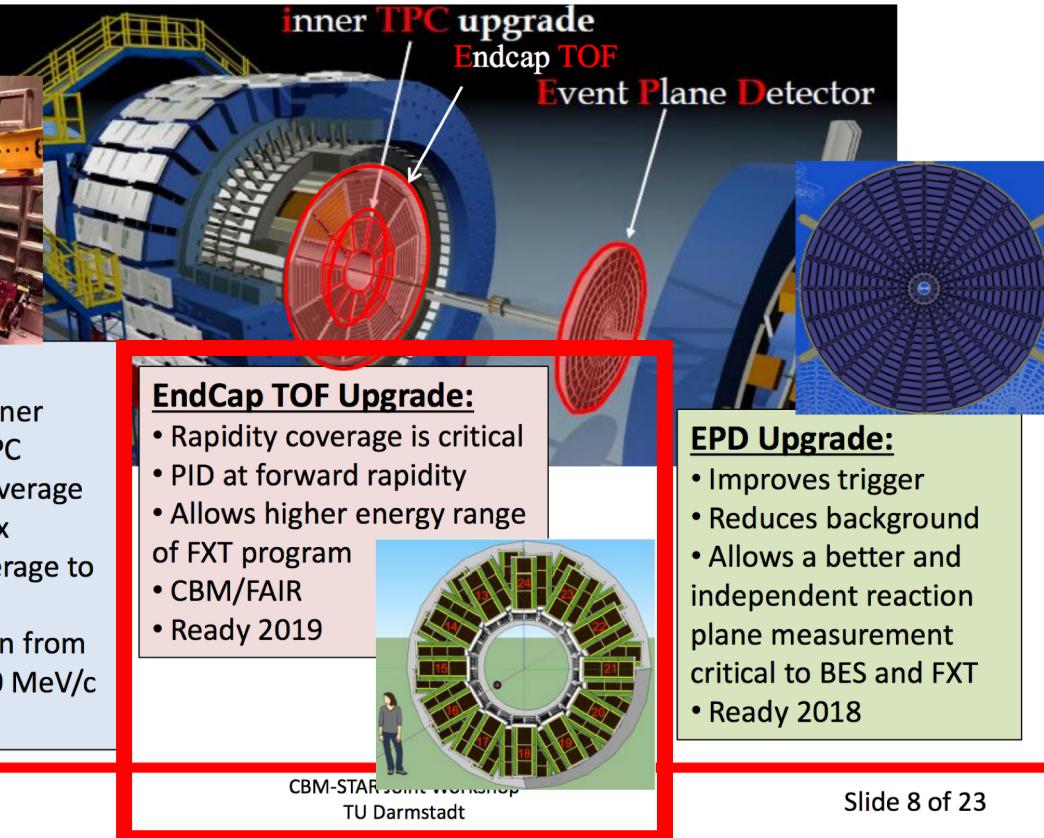
- At lower energies: probe lifetime + total baryon density + temperature

Distinguish between models: PHSD and Rapp

- Show evidence for chiral symmetry restoration?
- Reduced charm cross-section \rightarrow pristine measurement of medium temperature through intermediate mass dilepton spectra e.g. NA60 thermal dimuons

Endcap Time of Flight Upgrade

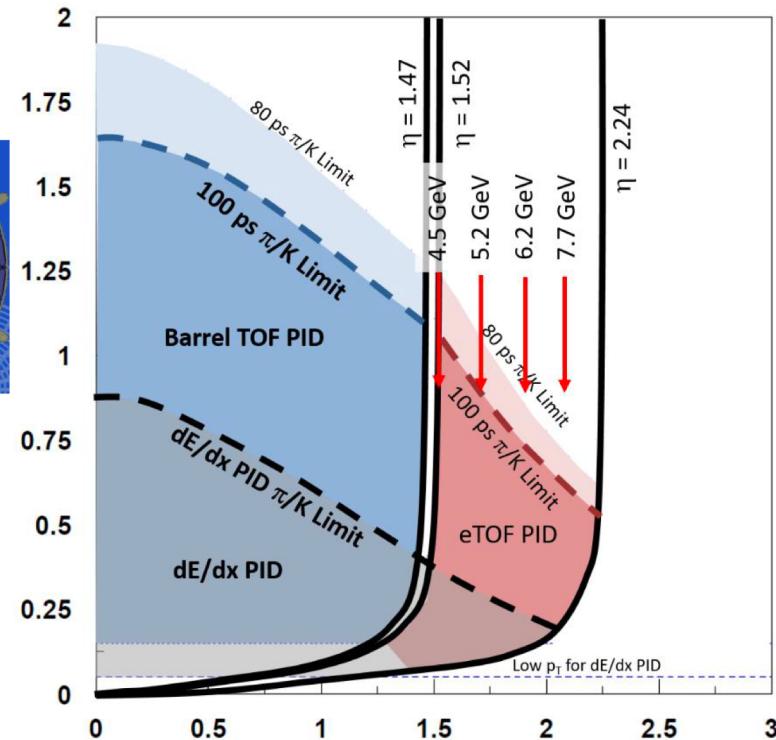
- Leading role in the integration of the eTOF detector into STAR



Slide 8 of 23

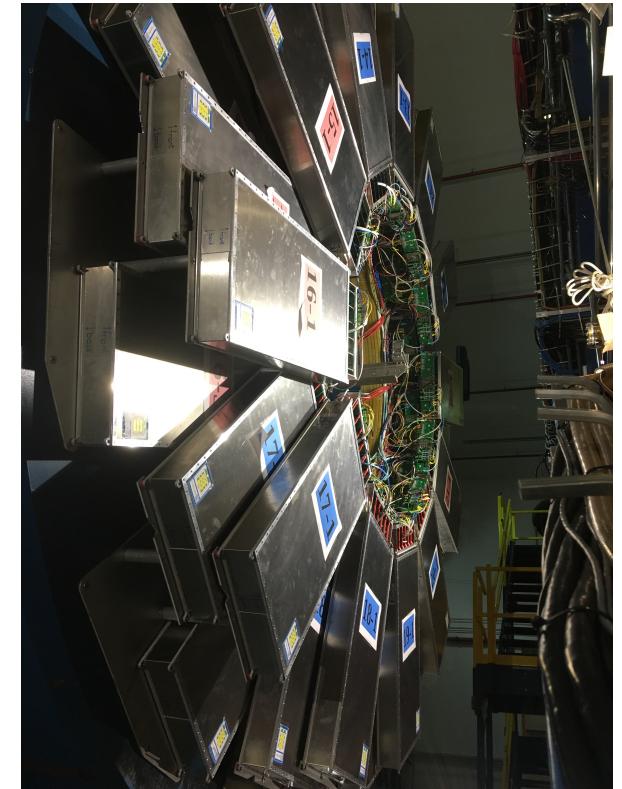
Demonstrated successful operation during 2017 beam with 3 eTOF modules

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Additional coverage is crucial for Fixed Target Program

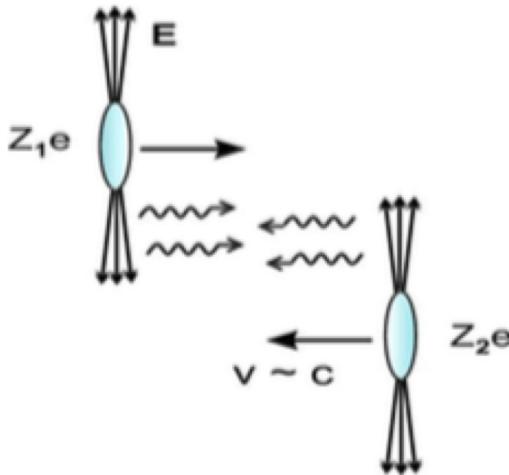
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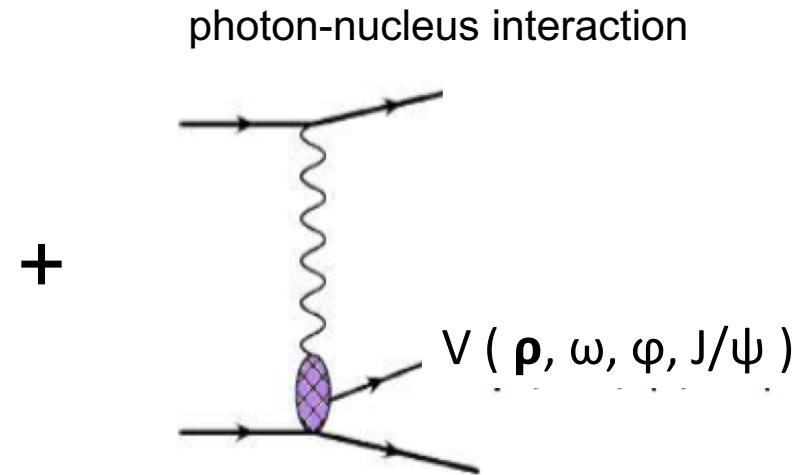
Just finished installation of the full eTOF at STAR

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Nuclear structure and properties

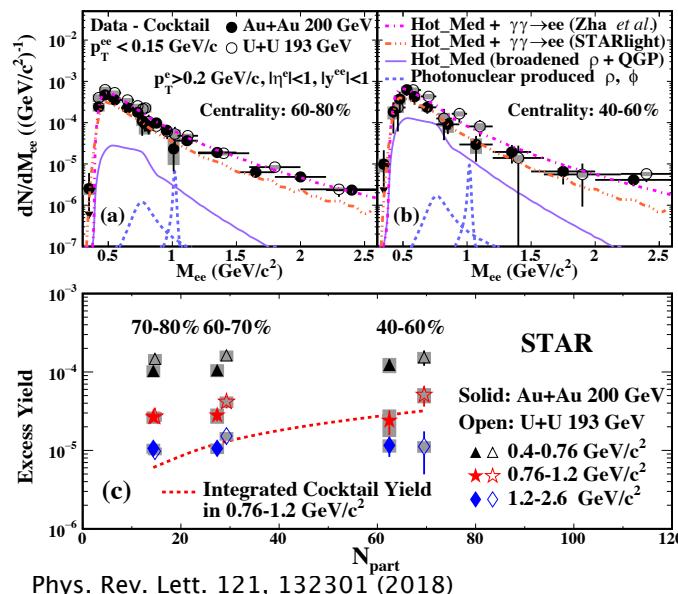


photon-photon interaction



photon-nucleus interaction

- Highly contracted EM fields = photon collider
- Preview of EIC-era physics
- Strong coupling ($Z\alpha_{EM} \sim 0.6$) results in large cross sections
- Not just in ultra peripheral collisions!
- **Significant $\gamma\gamma \rightarrow l^+l^-$ production observed in peripheral A+A collisions**
- Photon-pomeron interactions : sensitive to nuclear gluon distribution



Quark Matter 2017:
Presented first observation
of $\gamma\gamma \rightarrow e^+e^-$ in peripheral
A+A collisions

Novel probe of initial EM
field and maybe sensitive to
medium properties
(conductivity, lifetime of B
field)

EIC Detector Hardware R&D

Successful EIC needs innovative detectors and technologies

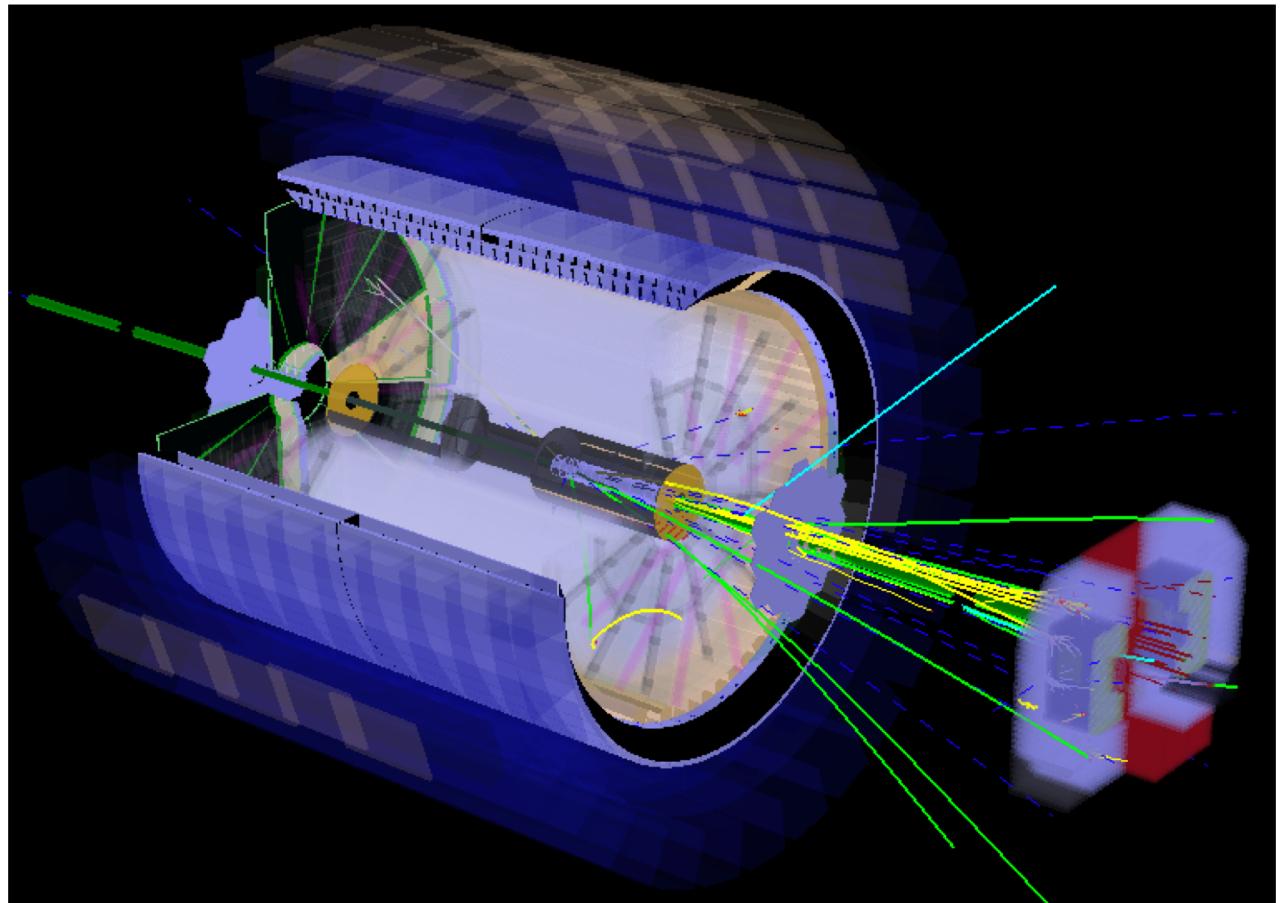
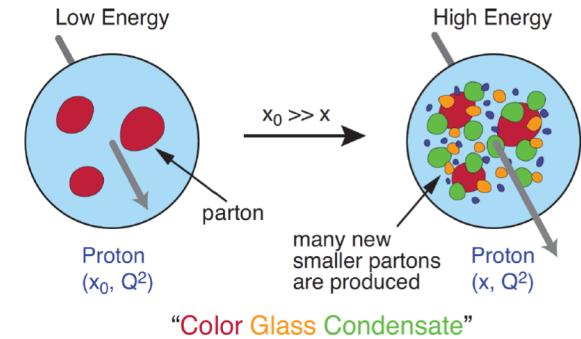
Developing Forward Tracking System (FTS) : Tracking + Calorimetry

- Symbiotic with STAR Forward Upgrade
- Integrate detector prototypes into STAR
- Test detector prototypes with collisions in 2019
- Dedicated p+p and p+A program in ~2021

Address fundamental questions of QCD:

- 3D structure of protons
- Gluon density at high energy, saturation?
- How nuclear environment effects quark and gluon interactions

➤ STAR FTS Software coordinator



Looking to the future

Exciting time to be starting a career in nuclear physics!

I'm looking forward to the next 10 years helping to build the EIC and many more years to learn from it

