



The 18th International Conference on
Strangeness in Quark Matter (SQM 2019)
10-15 June 2019, Bari (Italy)

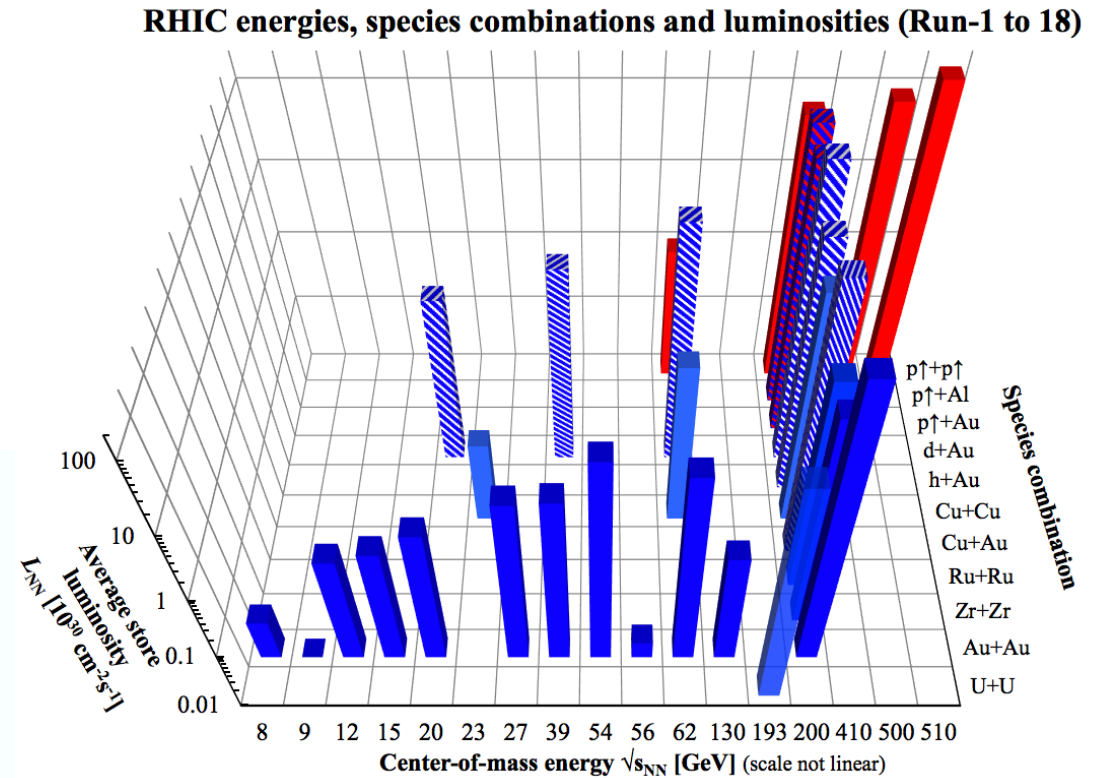
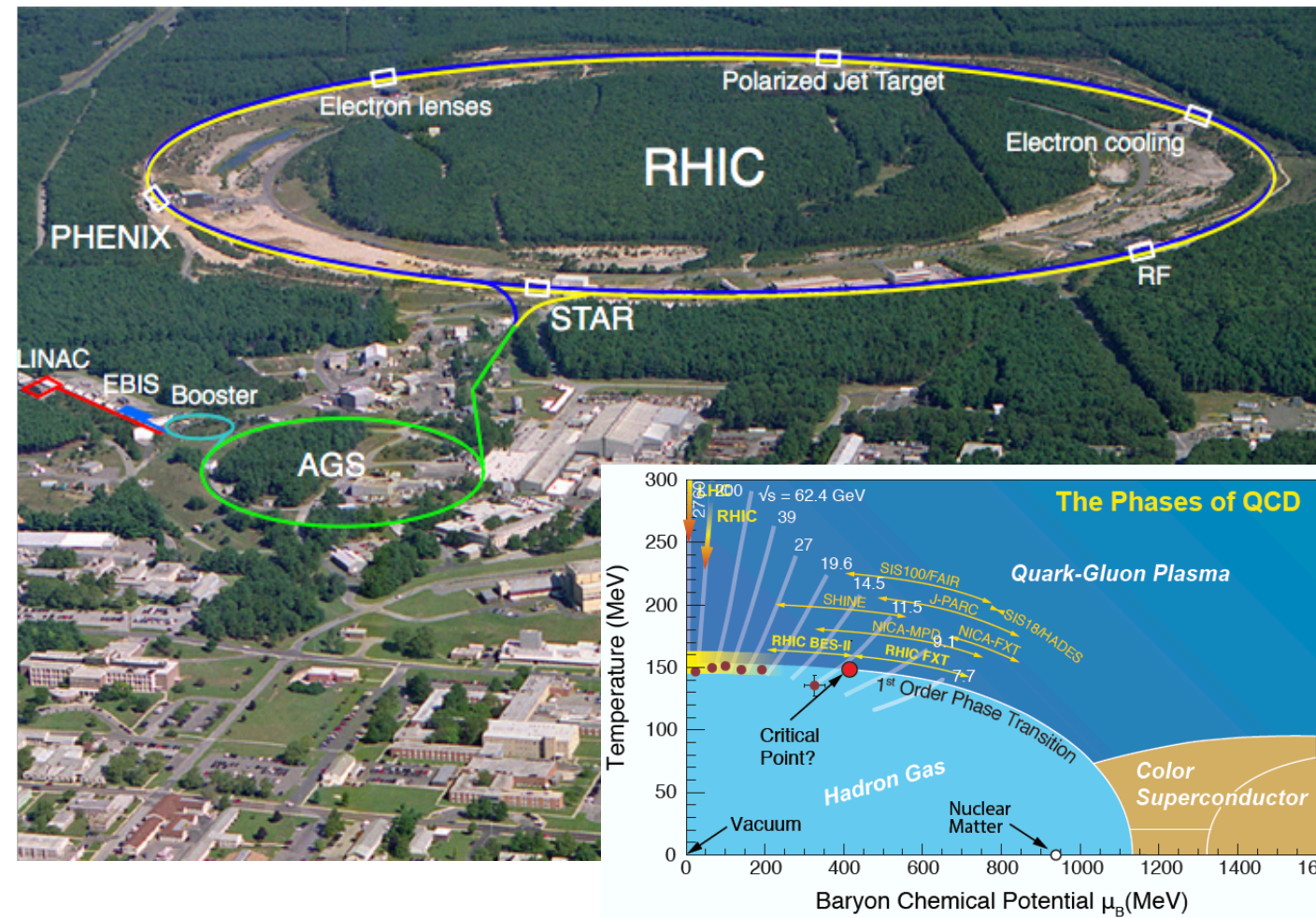


Detector Upgrades and Related Physics at RHIC

Zhenyu Ye

University of Illinois at Chicago

Relativistic Heavy Ion Collider



9 beam species, 15 beam energies

RHIC is a versatile machine to study QCD matter and phase transitions.

RHIC Run Plan for 2019-2025

Beam Energy Scan II with STAR iTPC, eTOF and EPD

- Low energy $\sqrt{s_{NN}} = 7.7, 9.1, 11.5, 14.5, 19.6$ GeV Au+Au with electron cooling
- Fixed target runs at 3.0, 3.5, 3.9, 4.5, 5.2, 6.2, 7.7 GeV
- Search for signs of critical phenomena in event-by-event fluctuations

2019
-
2021

Spin run with STAR Forward Upgrade

- 500 GeV polarized p+p
- Spin physics measurements complementary to EIC

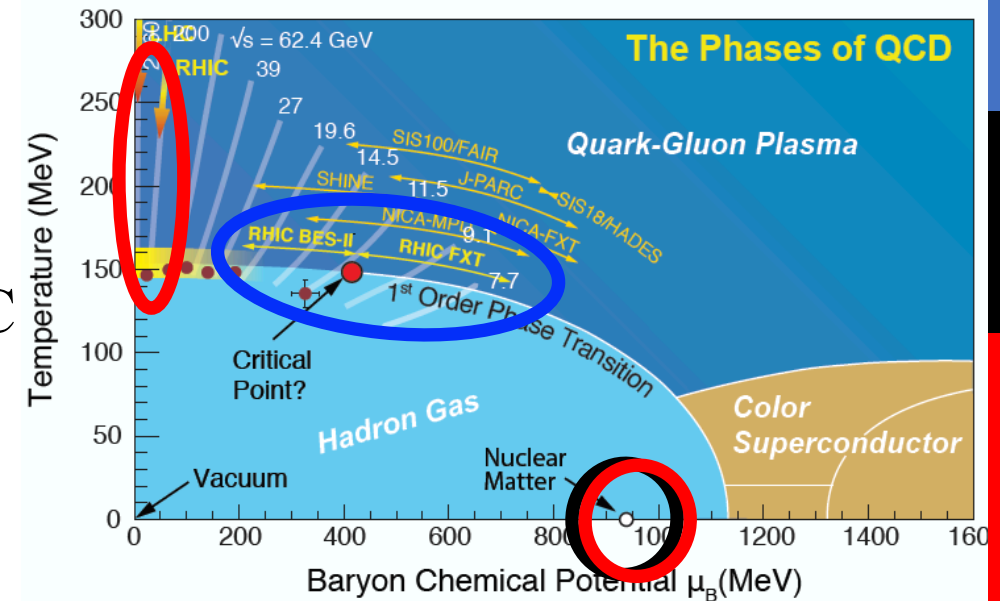
2022

Runs with sPHENIX and STAR:

- Top energy $\sqrt{s_{NN}} = 200$ GeV Au+Au, p+p, p+Au
- Precision measurements of open heavy flavor, Upsilon states and fully resolved jets
- Longitudinal structure of initial stage, global polarization, nuclear PDFs, gluon saturation

2023

-
2025



RHIC Run Plan for 2019-2025

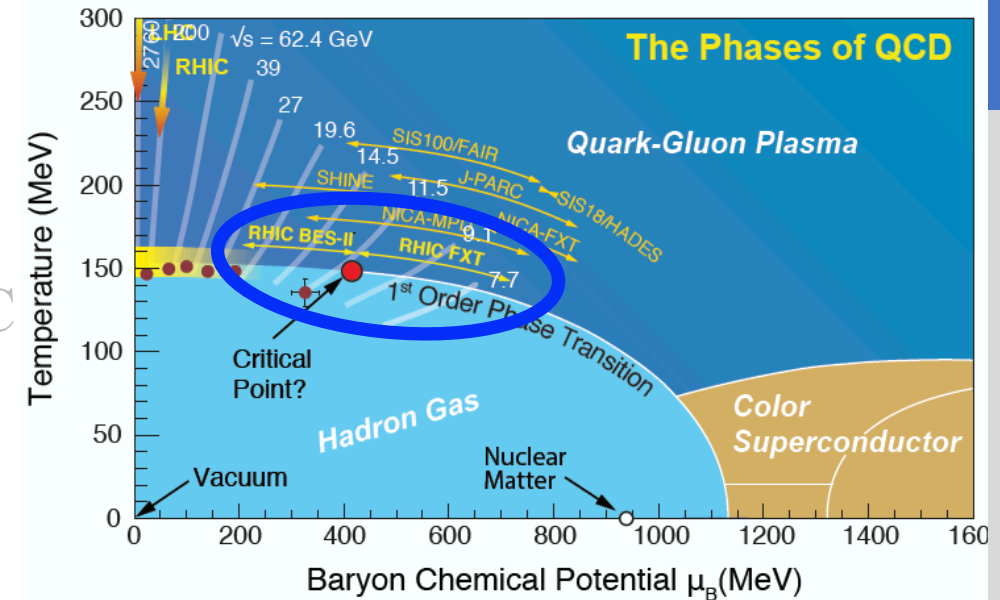
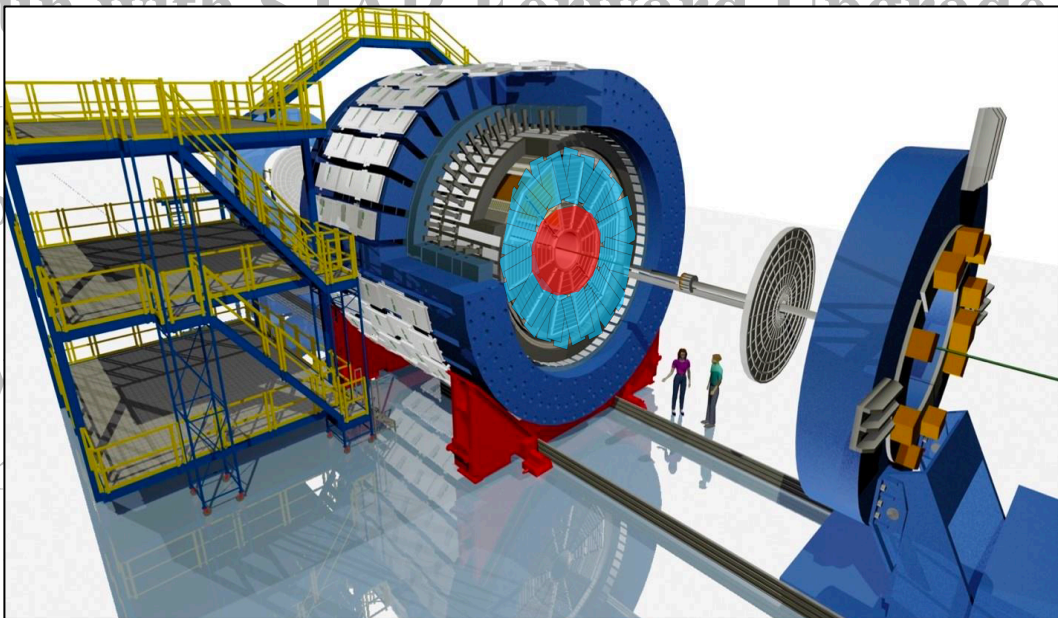
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2019
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2021

Spin runs with STAR Forward Upgrade

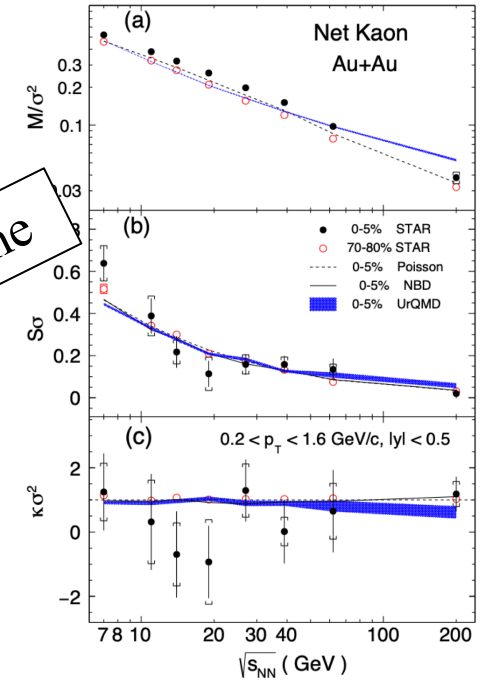
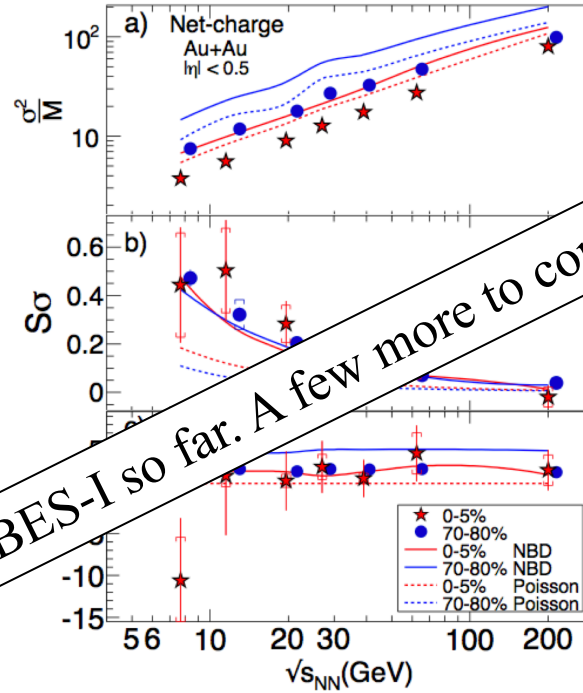
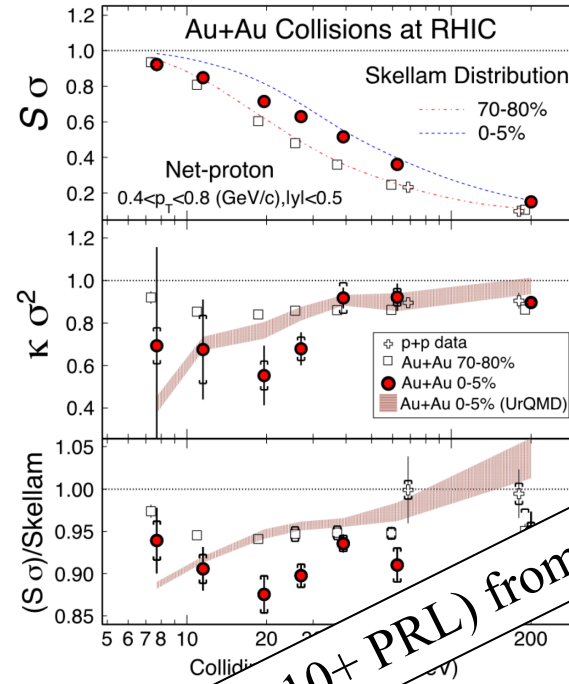
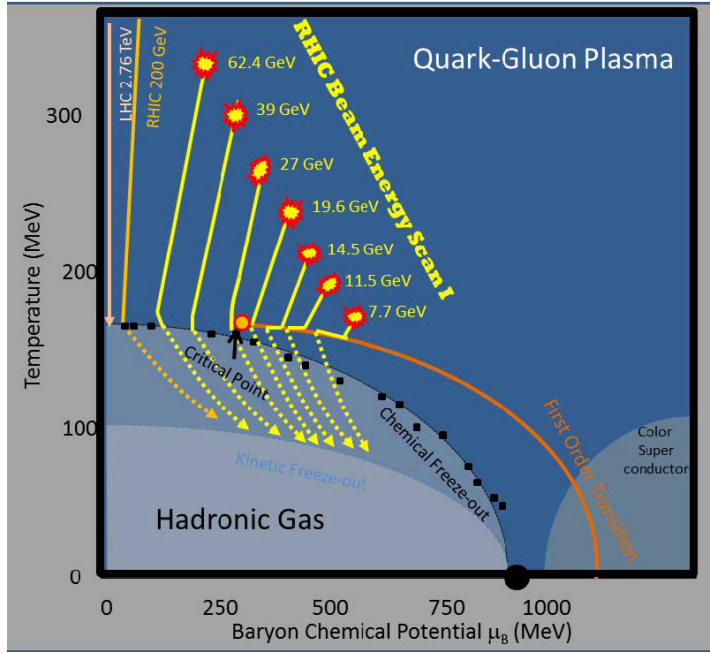
- 500 GeV Au
- Spin p
- Top en
- Precis



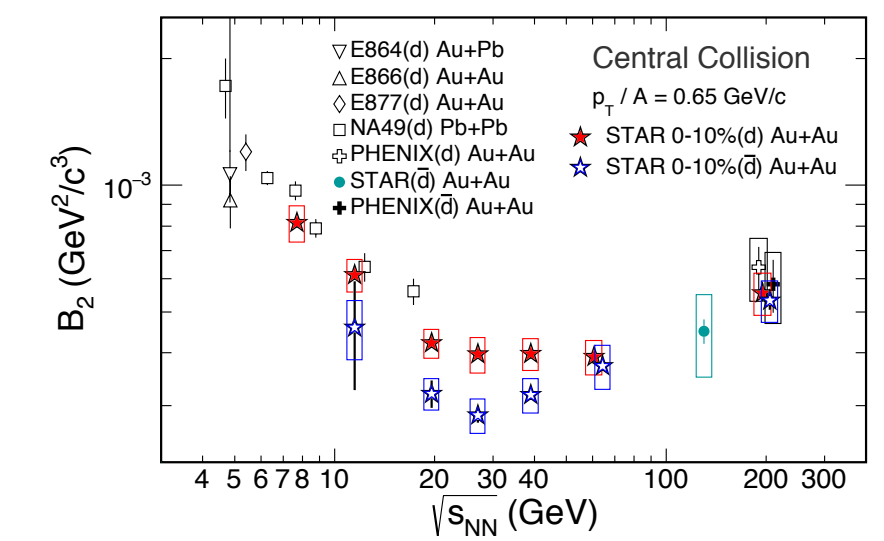
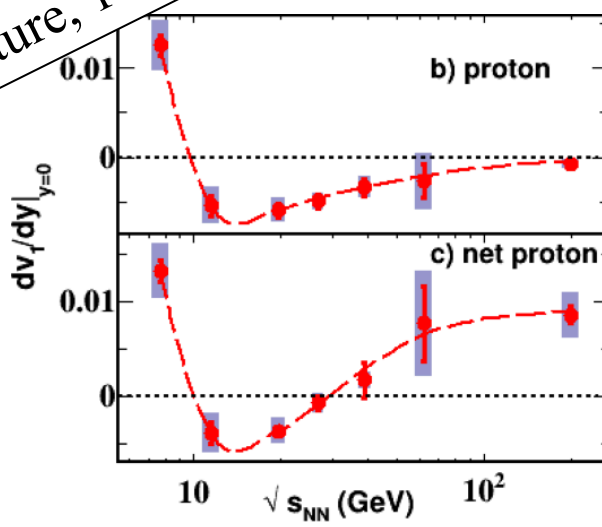
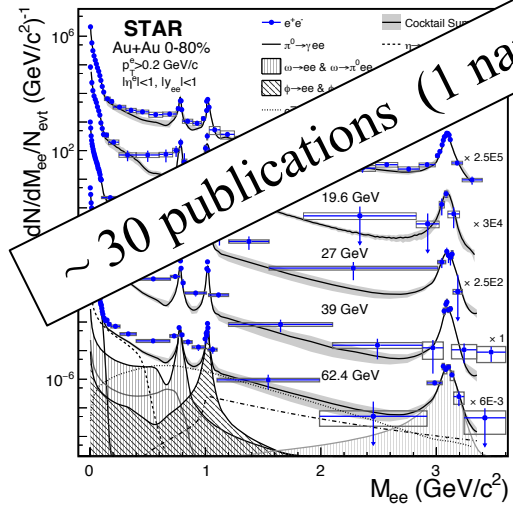
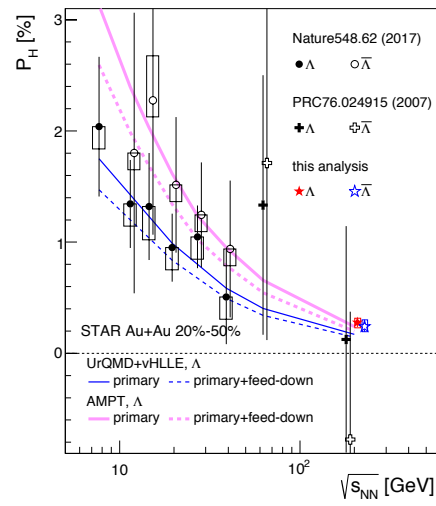
2022
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2023
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2025

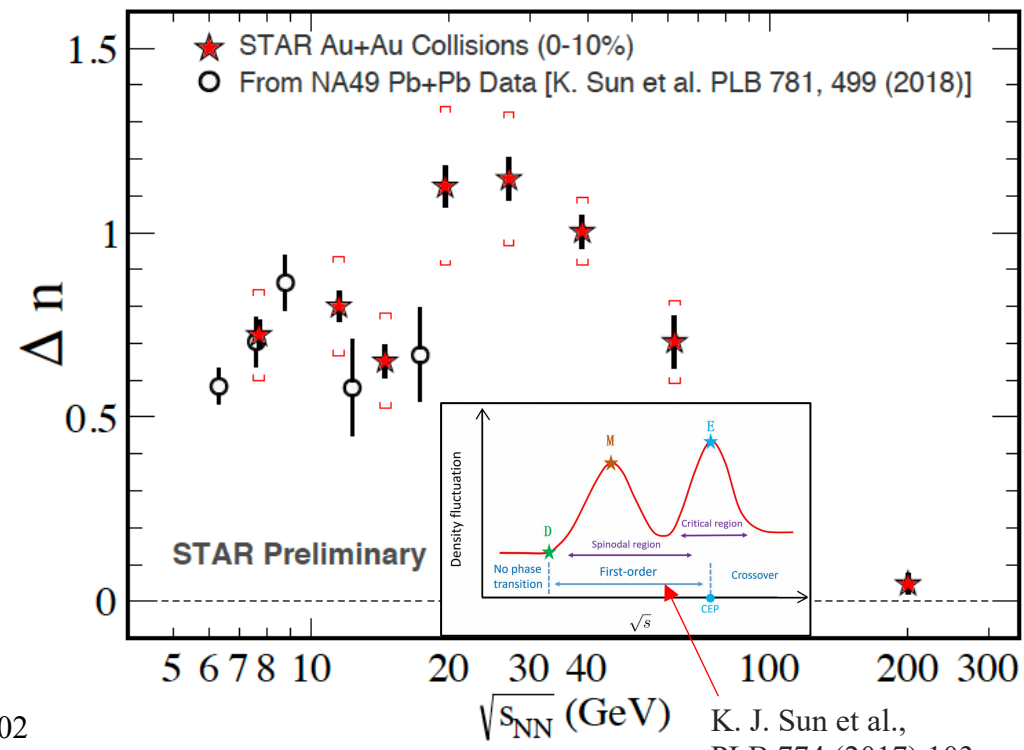
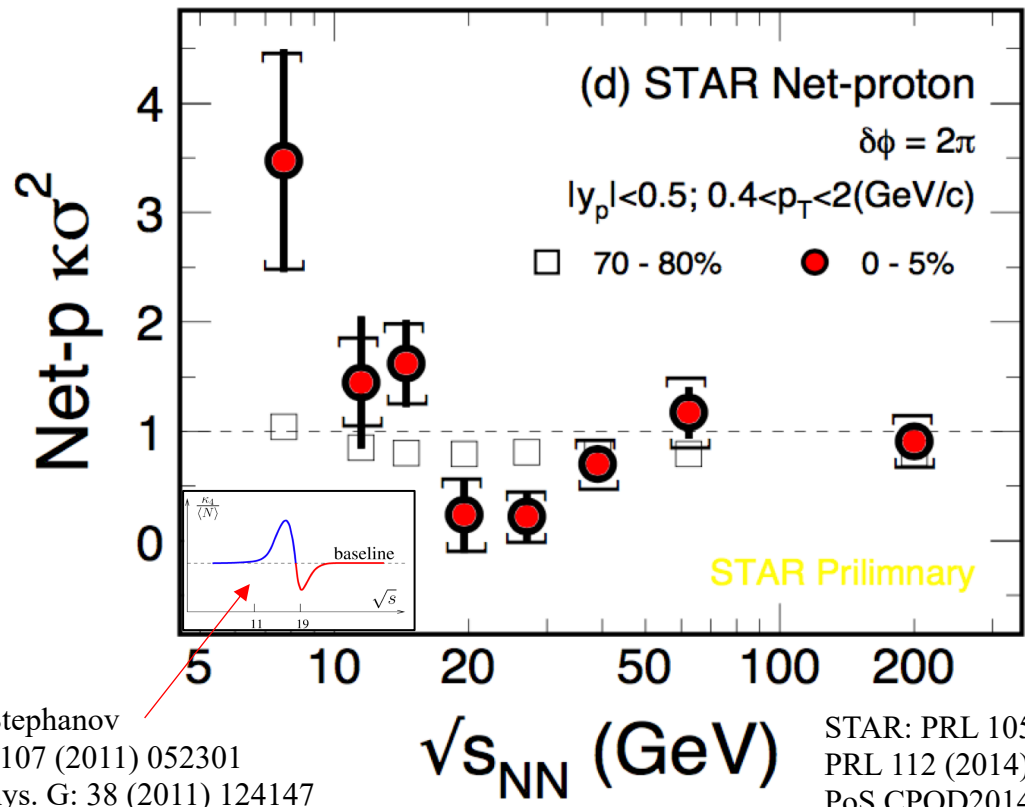
- Longitudinal structure of initial stage, nuclear PDFs, gluon saturation, small system

RHIC BES I Results (2010-2011)



~ 30 publications (1 nature, 10+ PRL) from BES-I so far. A few more to come





M. Stephanov
 PRL107 (2011) 052301
 J. Phys. G: 38 (2011) 124147

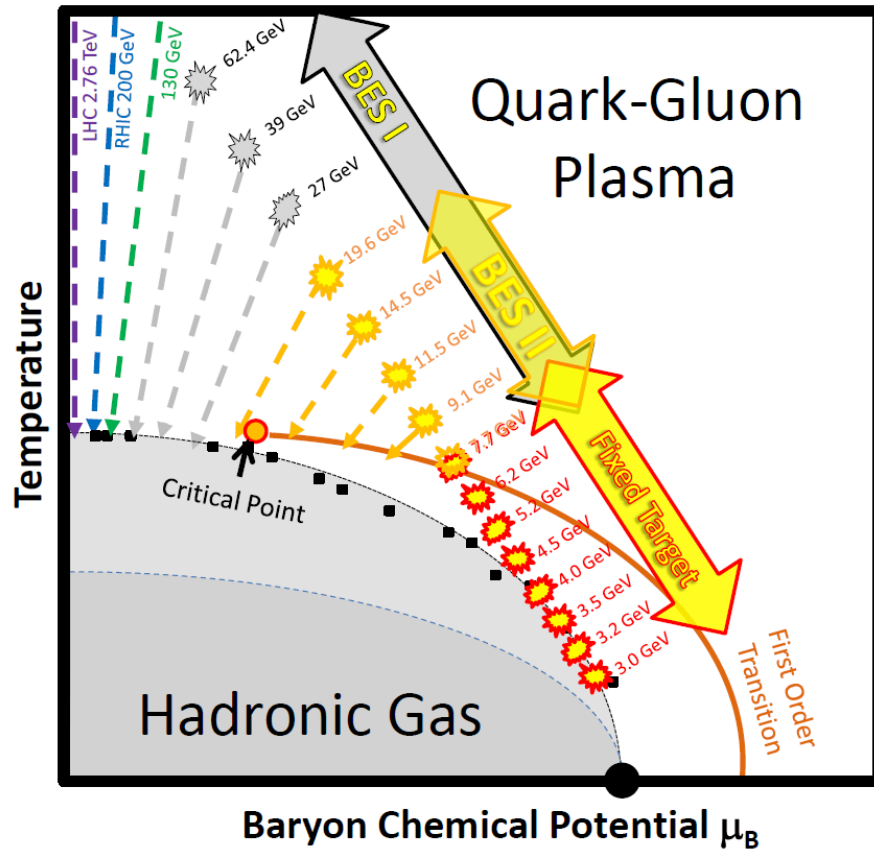
STAR: PRL 105 (2010) 022302
 PRL 112 (2014) 032302
 PoS CPOD2014 (2015) 019

K. J. Sun et al.,
 PLB 774 (2017) 103
 PLB 781 (2018) 499

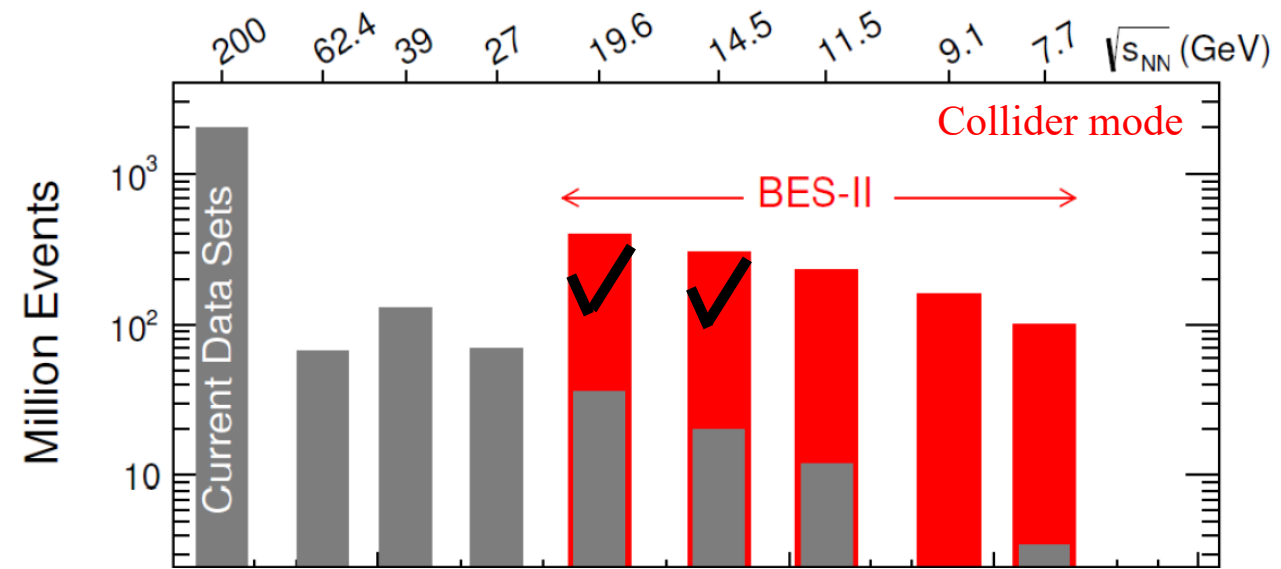
Motivation for BES Phase II program with improved data statistics and detectors

- QCD critical point
- first order phase transition
- turn-off of QGP signatures

RHIC BES II Program (2019-2021)

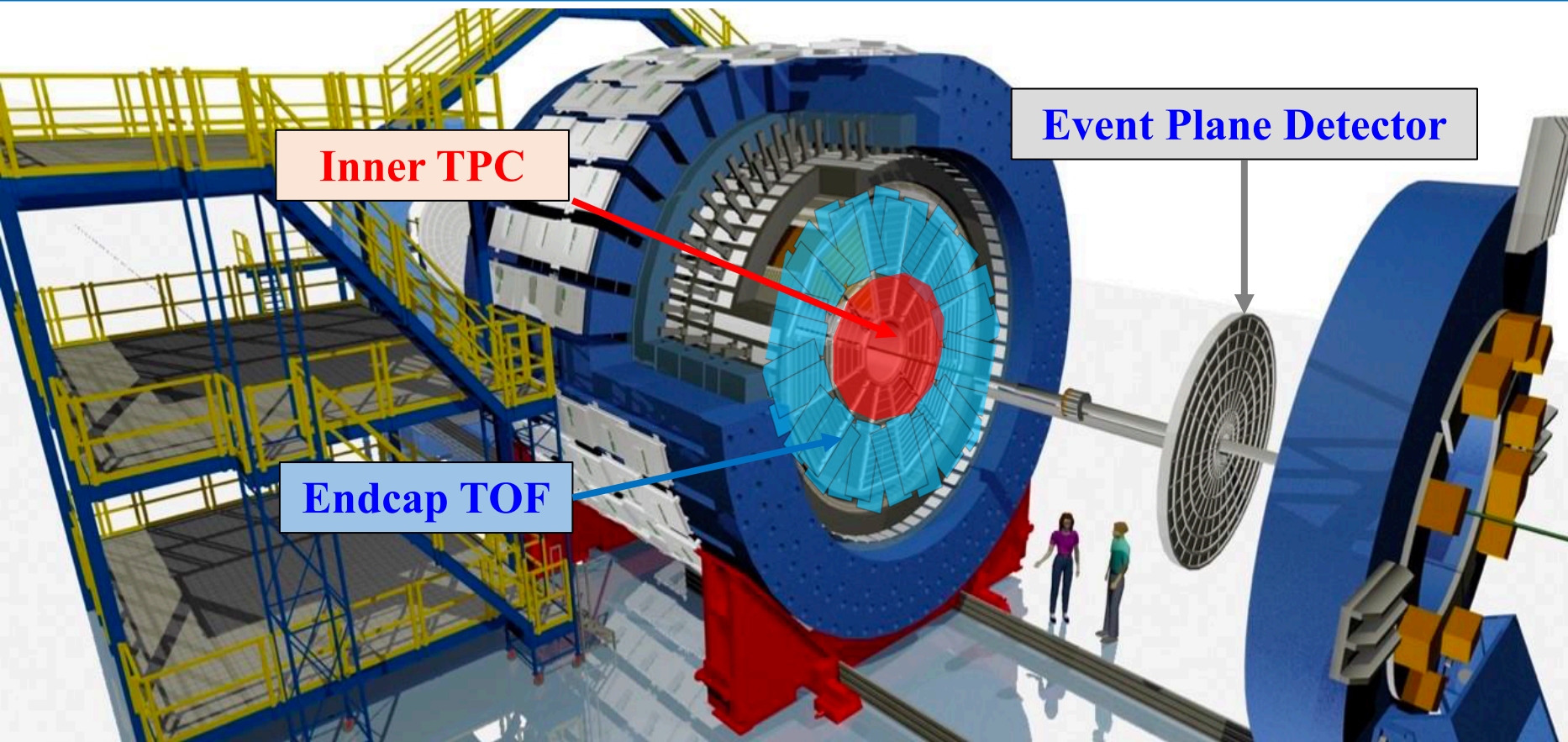


- QCD critical point
- first order phase transition
- turn-off of QGP signatures



Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events
9.8	19.6	205	4.5 weeks	400M
7.3	14.5	260	5.5 weeks	300M
5.75	11.5	315	5 weeks	230M
4.55	9.1	370	9.5 weeks	160M
3.85	7.7	420	12 weeks	100M
31.2	7.7 (FXT)	420	2 days	100M
19.5	6.2 (FXT)	487	2 days	100M
13.5	5.2 (FXT)	541	2 days	100M
9.8	4.5 (FXT)	589	2 days	100M
7.3	3.9 (FXT)	633	2 days	100M
5.75	3.5 (FXT)	666	2 days	100M
4.55	3.2 (FXT)	699	2 days	100M
3.85	3.0 (FXT)	721	2 days	100M

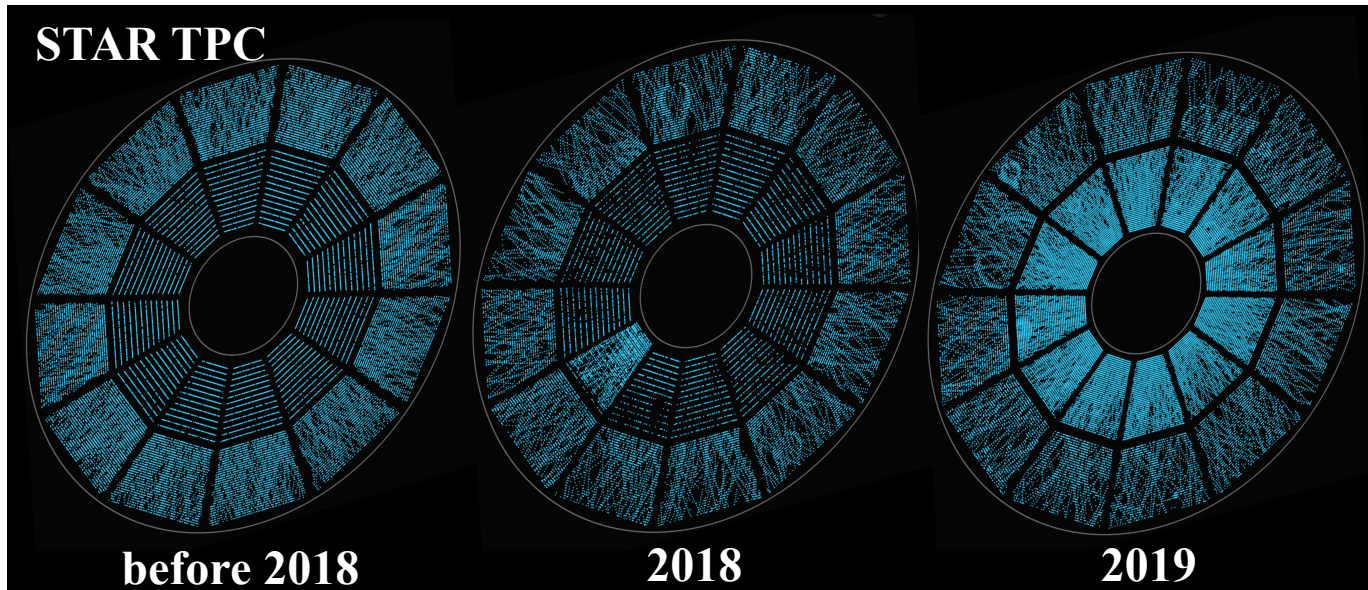
STAR Upgrade for BES II



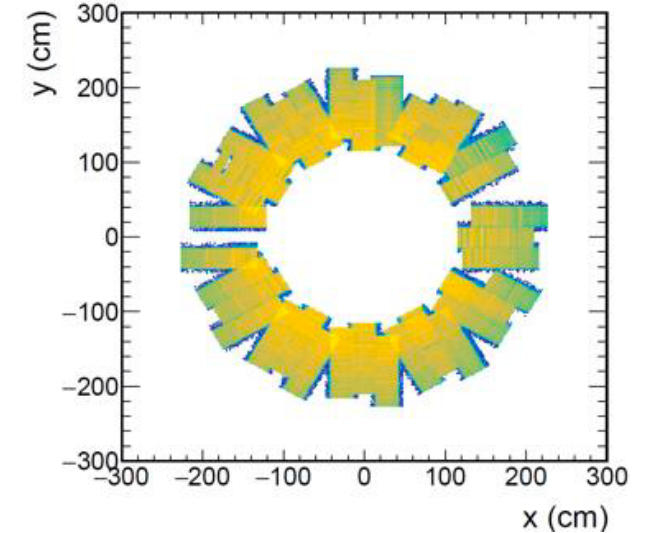
- Tracking and PID**
 TPC: $|\eta| < 1$
iTPC: $1 < |\eta| < 1.5$
 TOF: $|\eta| < 1$
eTOF: $-1.6 < \eta < -1$
 BEMC: $|\eta| < 1$
 EEMC: $1 < \eta < 2$
 HFT (2014-2016): $|\eta| < 1$
 MTD: $|\eta| < 0.5$
- MB trigger and event plane reconstruction**
 BBC: $3.3 < |\eta| < 5$
EPD: $2.1 < |\eta| < 5.1$
 VPD: $4.2 < |\eta| < 5$
 ZDC: $6.3 < |\eta|$
- Future upgrades**
 FCS (2021+): $2.5 < \eta < 4$
 FTS (2021+): $2.5 < \eta < 4$

iTPC upgrade	EPD upgrade	eTOF upgrade
Continuous pad rows Replace all inner TPC sectors	Replace Beam Beam Counter	Add CBM TOF modules and electronics (FAIR Phase 0)
$ \eta < 1.5$	$2.1 < \eta < 5.1$	$-1.6 < \eta < -1.1$
$p_T > 60$ MeV/c	Better trigger & b/g reduction	Extend forward PID capability
Better dE/dx resolution Better momentum resolution	Greatly improved Event Plane info (esp. 1 st -order EP)	Allows higher energy range of Fixed Target program

STAR iTPC and eTOF Performance

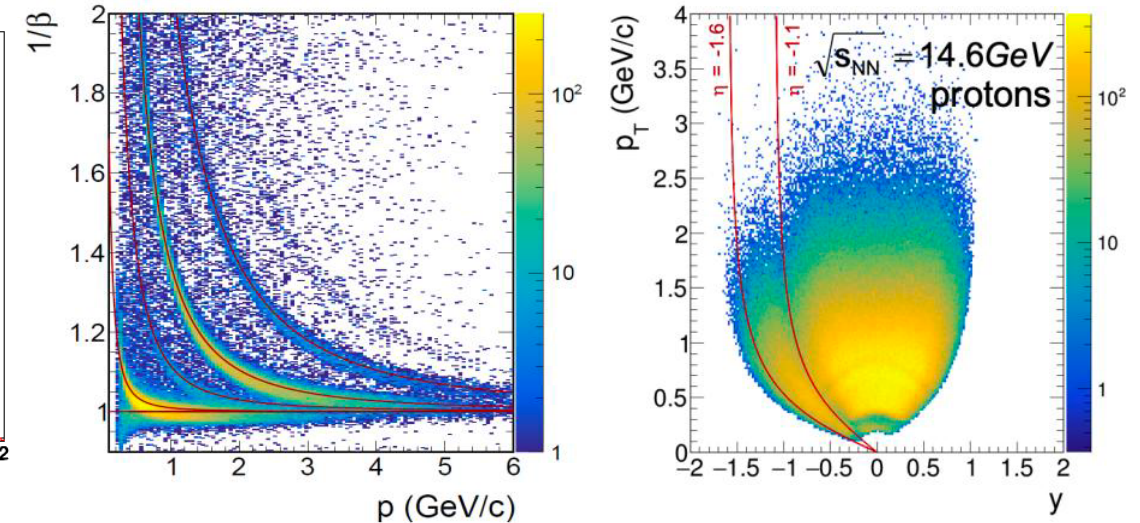
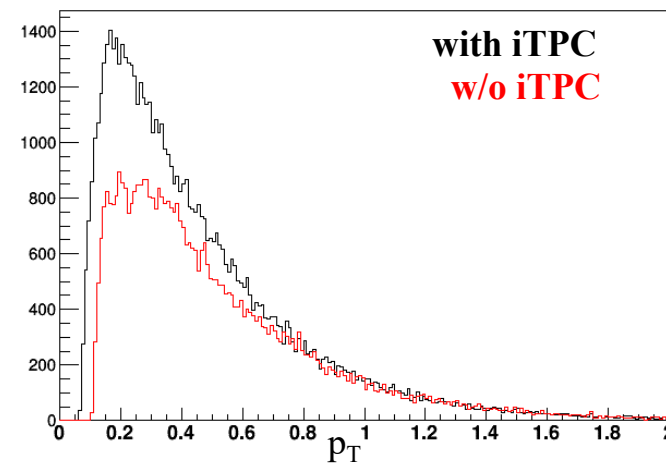
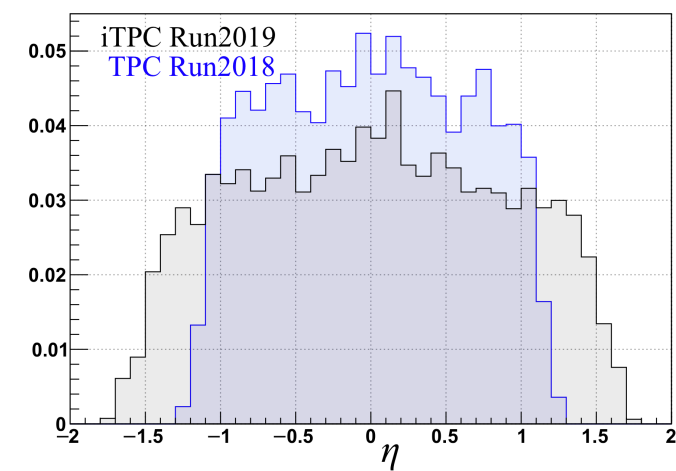


eTOF 2019



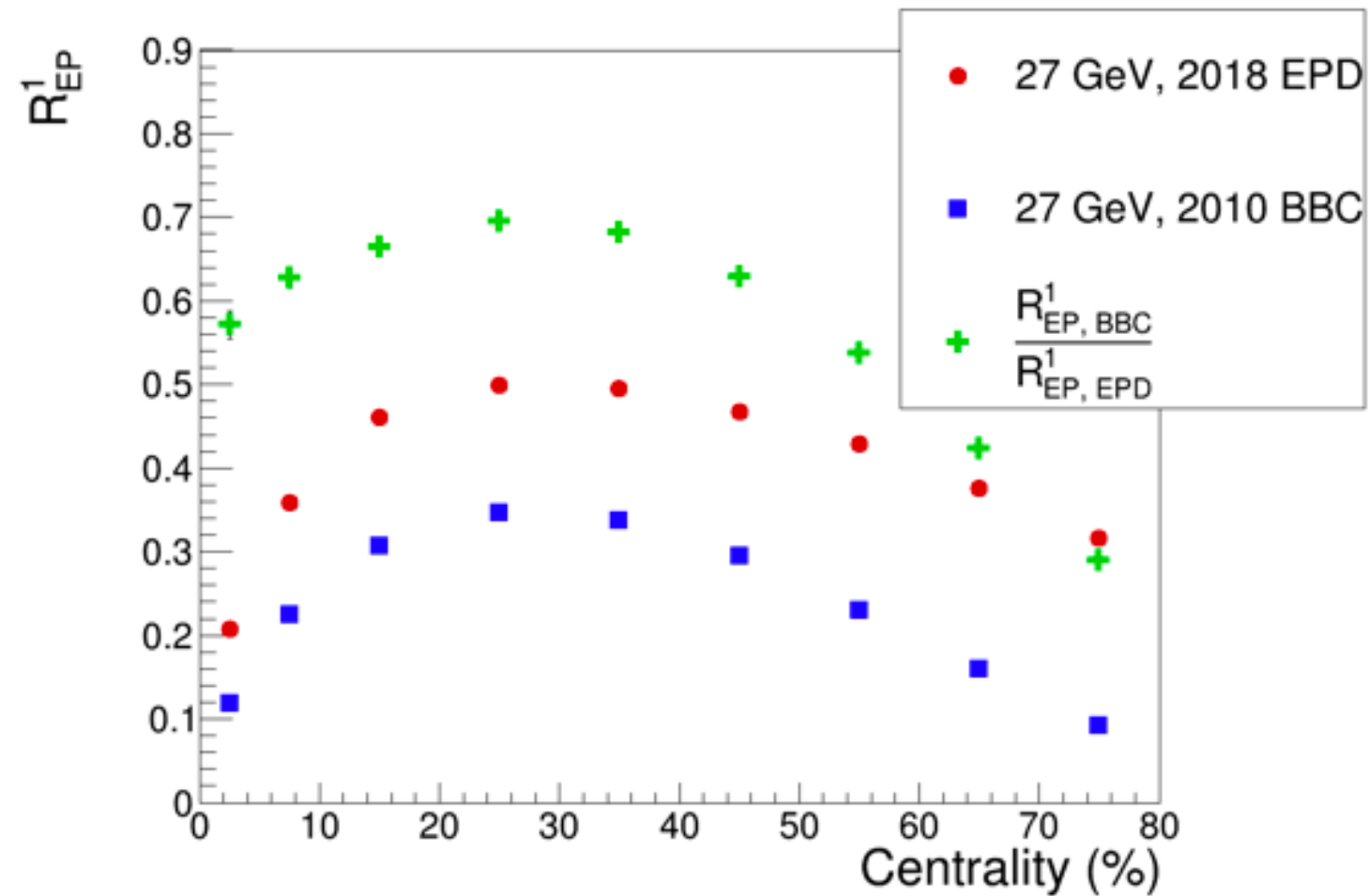
3.9 GeV fixed target test run

Identified protons in Au+Au 14.6 GeV

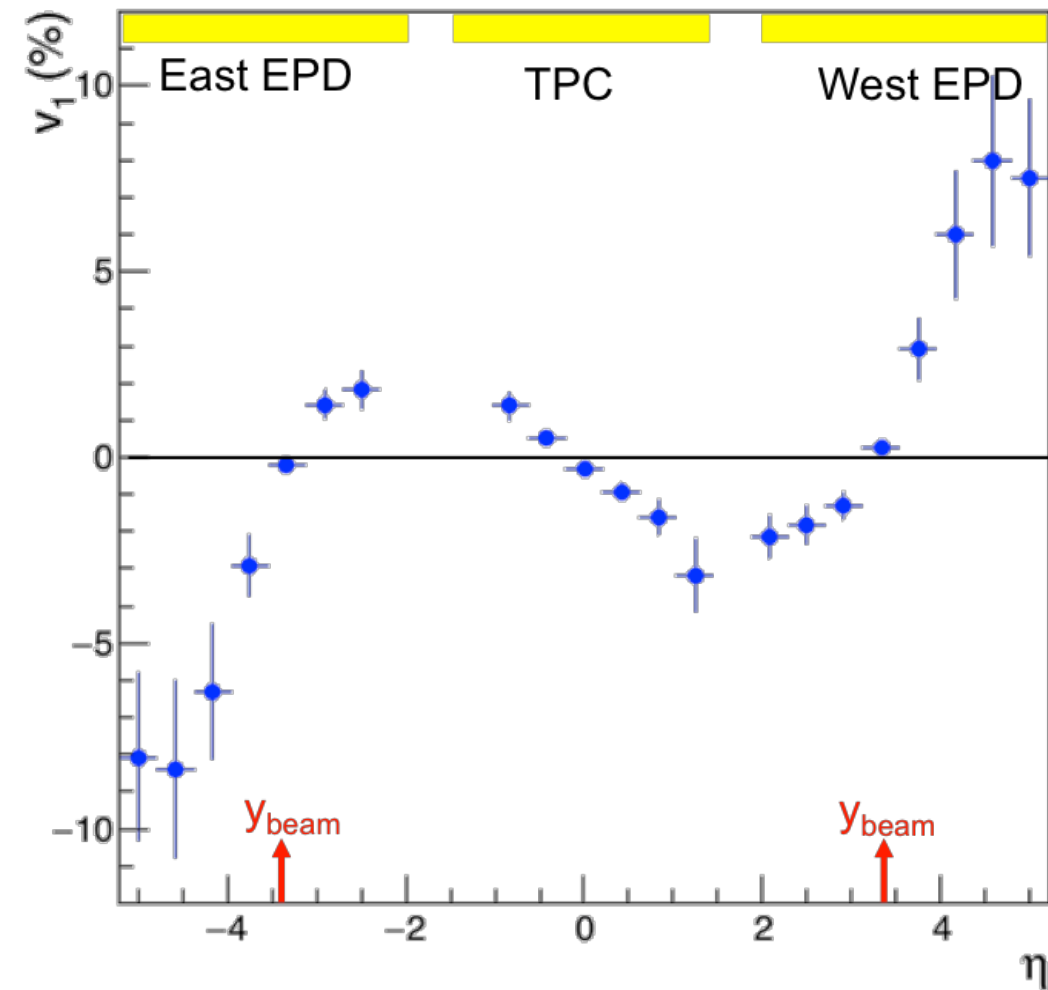


iTPC and eTOF detector upgrades improve STAR acceptance and PID performance

Au+Au 27 GeV

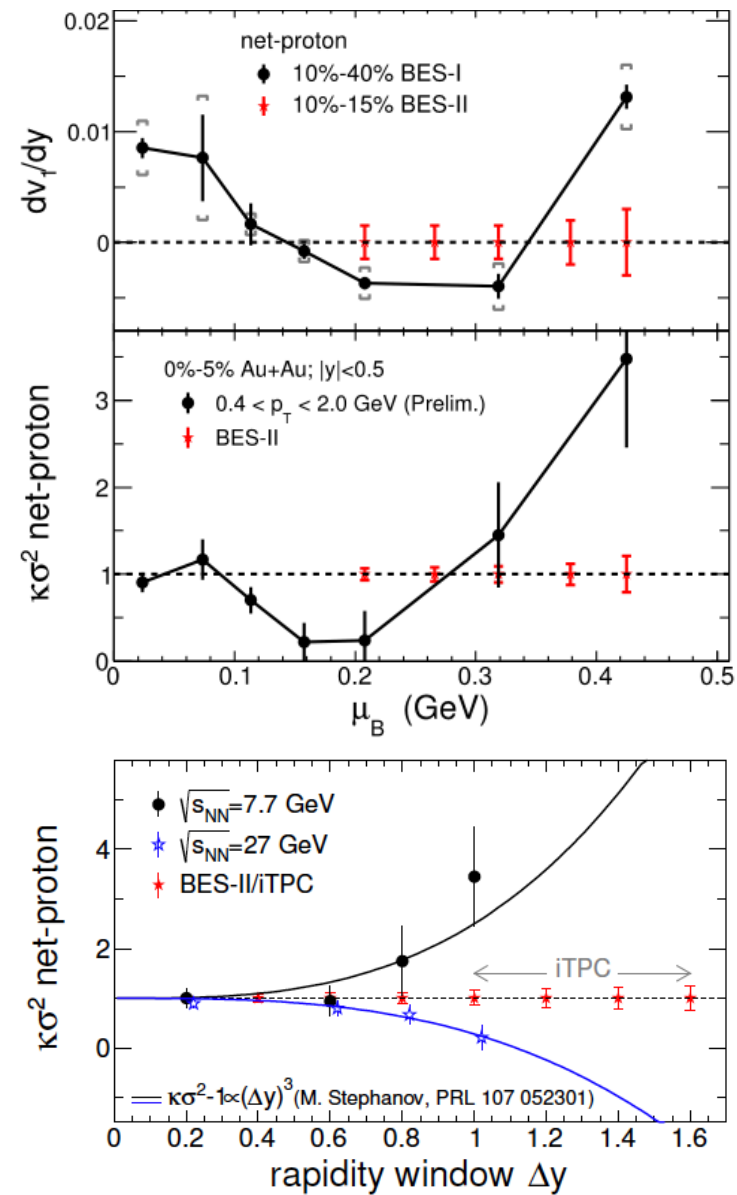


Corrected v_1 30-60%

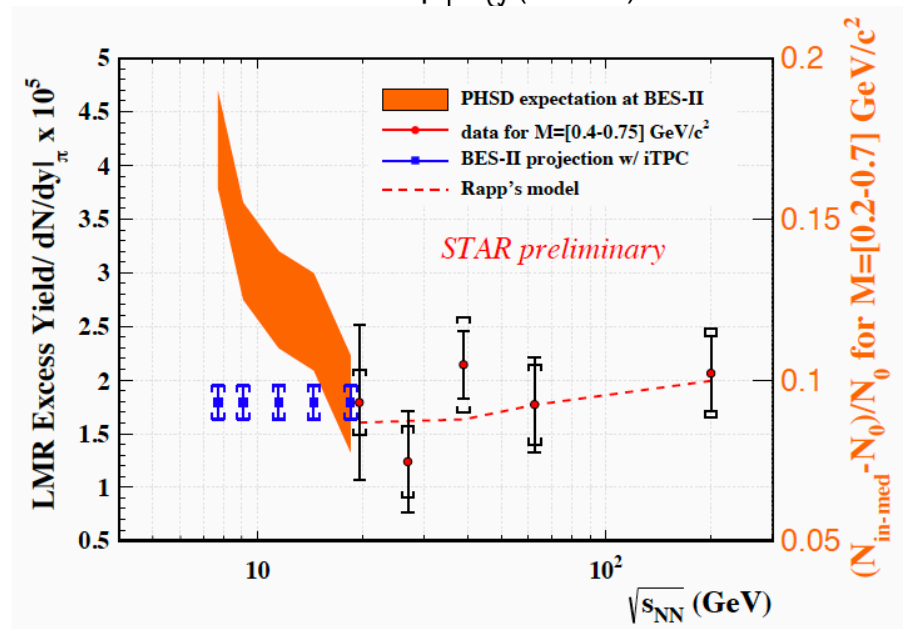
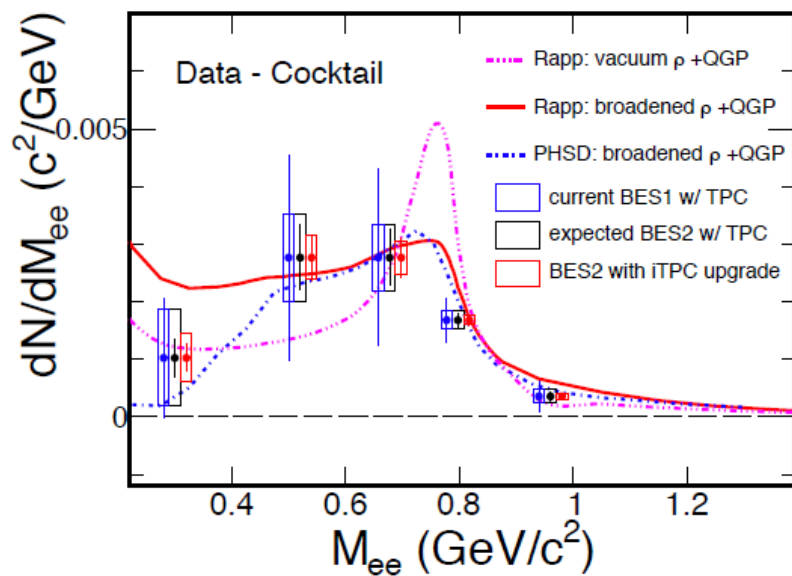
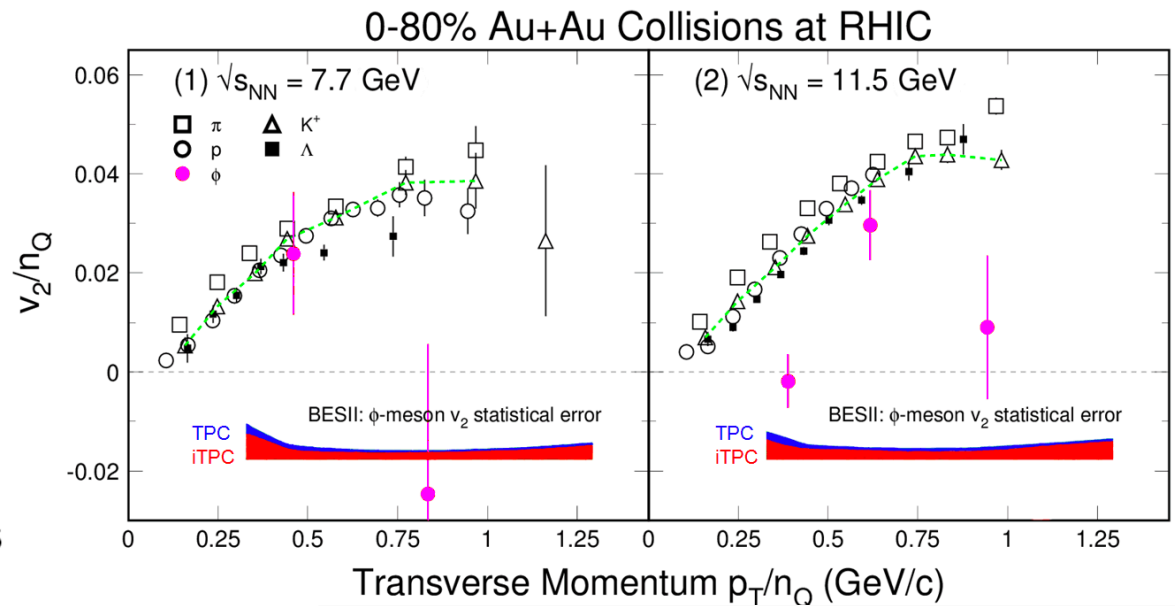
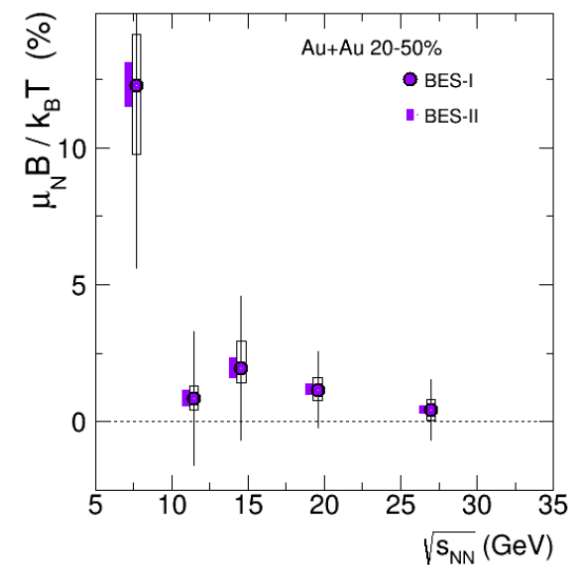
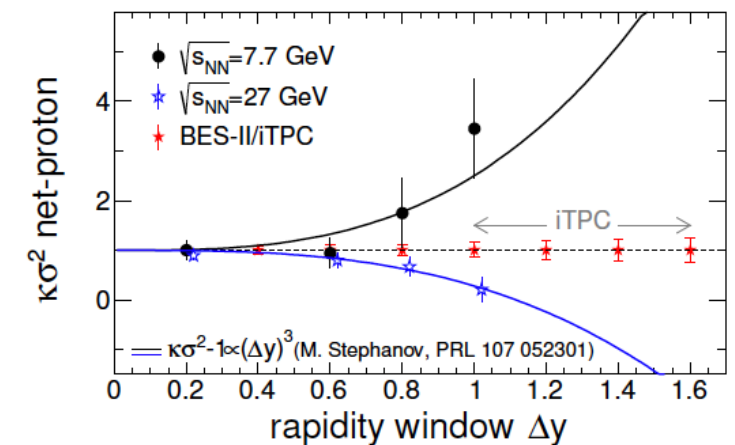
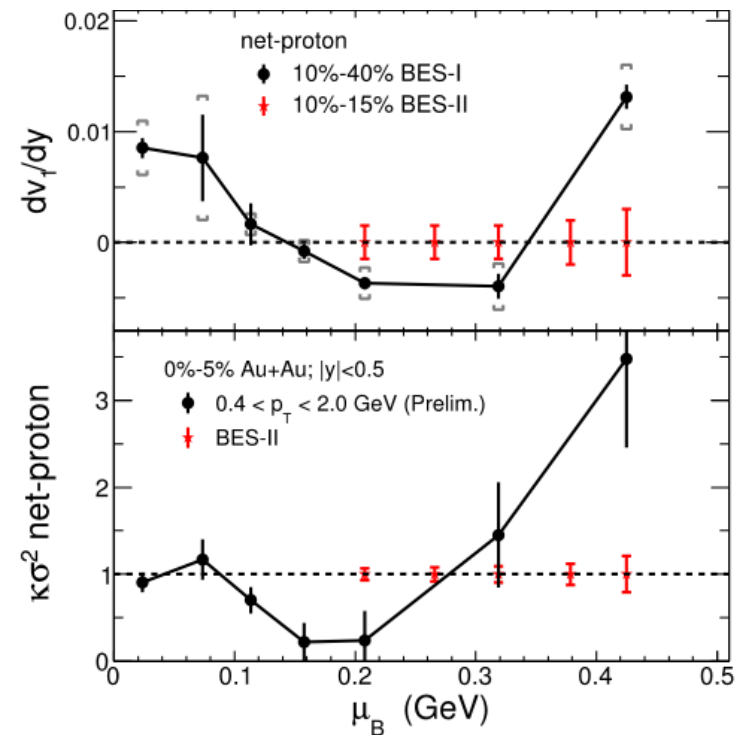


EPD improves event plane resolution and allow for forward centrality determination

STAR BES II Projections



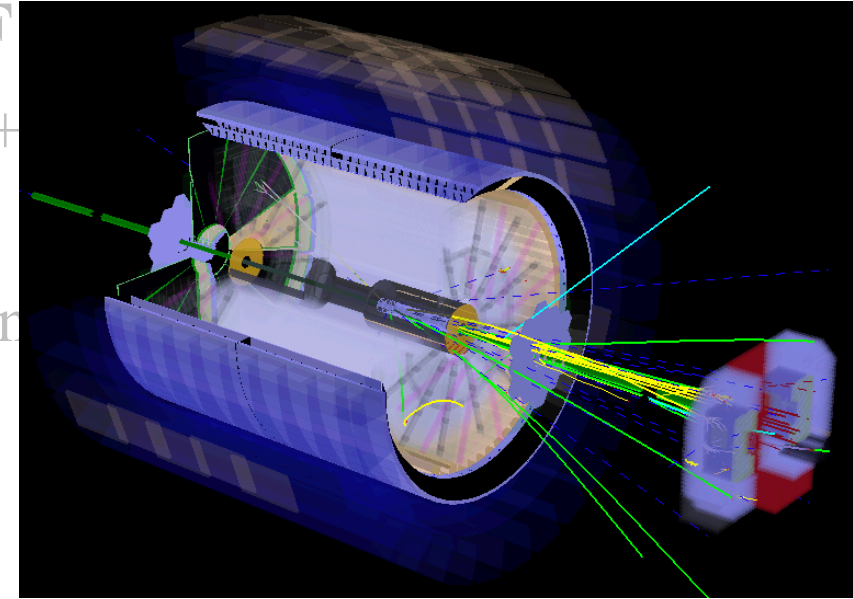
STAR BES II Projections



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2019
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2021

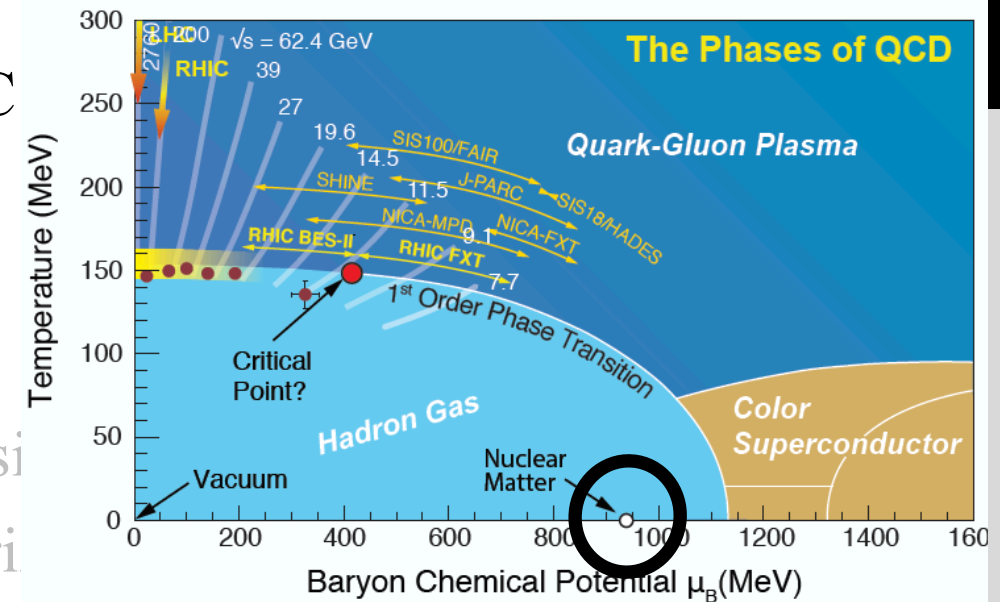
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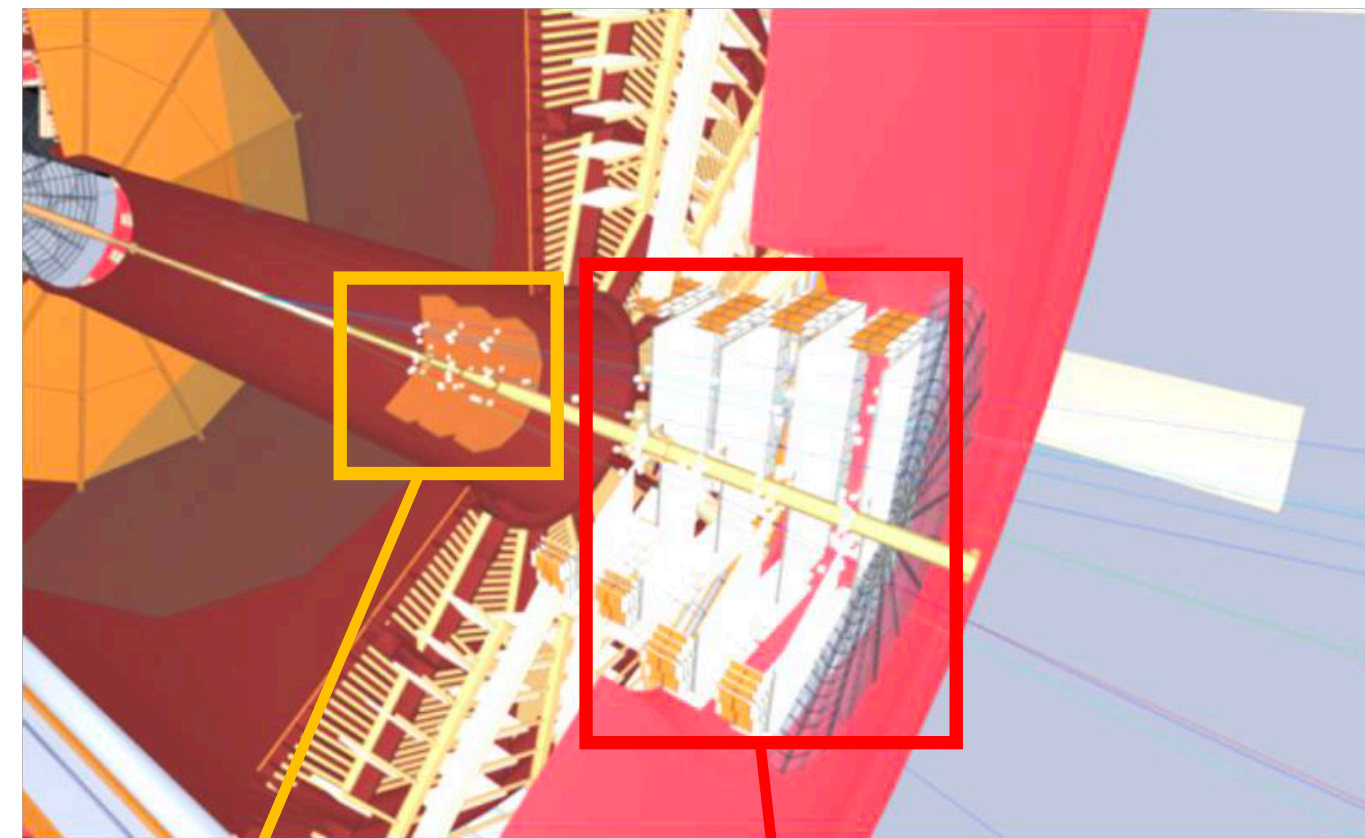
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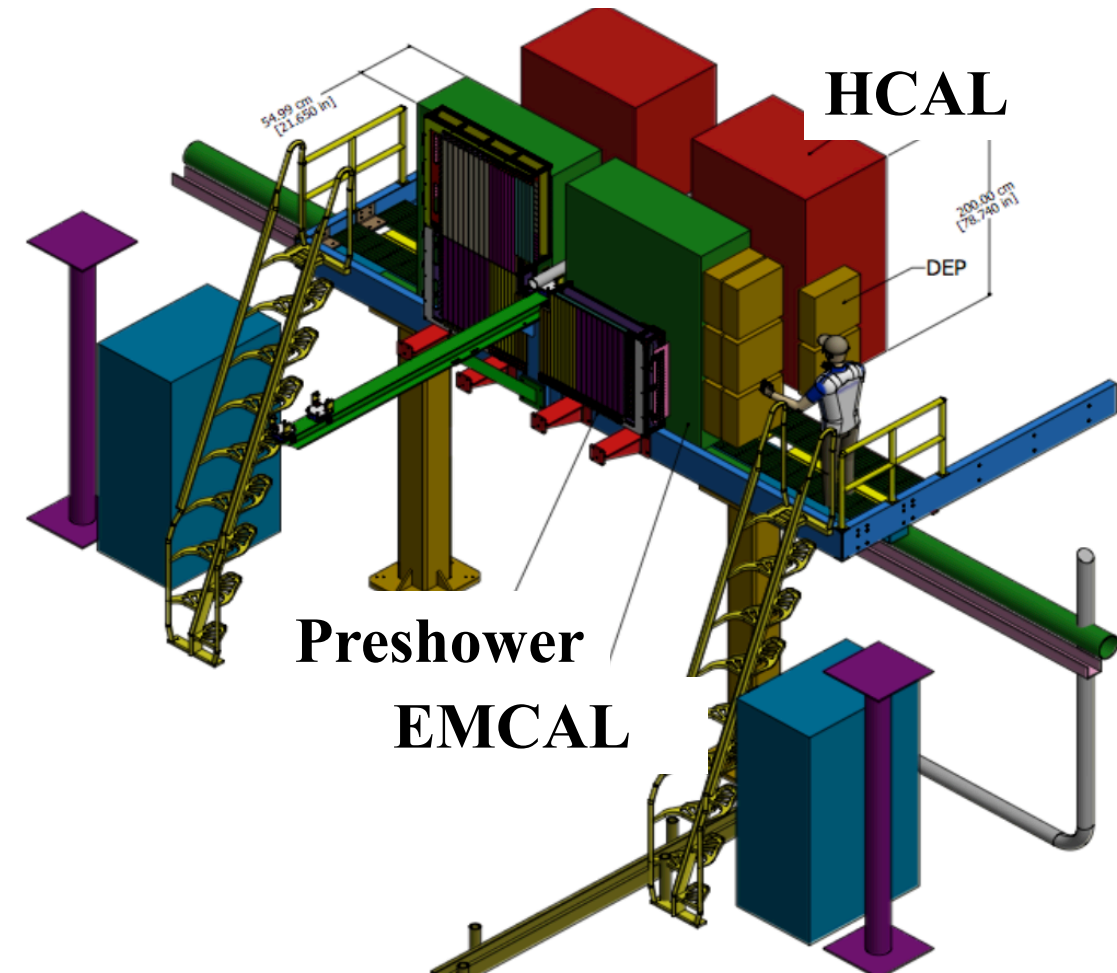
2023
-
2025

Forward Tracking System $2.5 < \eta < 4$

Forward Calorimeter System $2.5 < \eta < 4$



Silicon + small-Strip Thin Gap Chamber

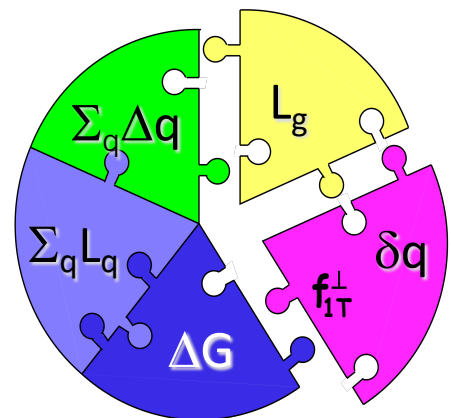


**Preshower
EMCAL**

HCAL

DEP

STAR Forward Upgrade for Polarized p+p in 2022



- Gluon Helicity ΔG

$$\int_{0.05}^1 \Delta g(x) dx = 0.126 \pm 0.023$$

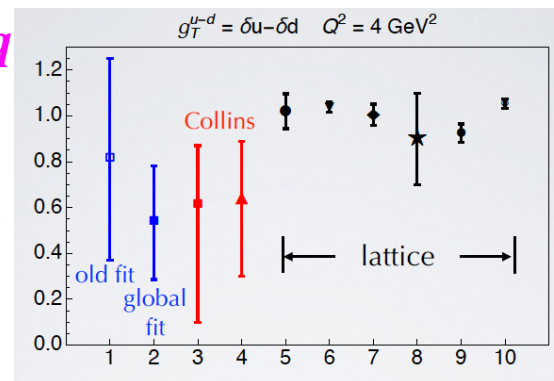
$$\int_{0.001}^1 \Delta g(x) dx = 0.296 \pm 0.108$$

- Proton Tensor Charge δq

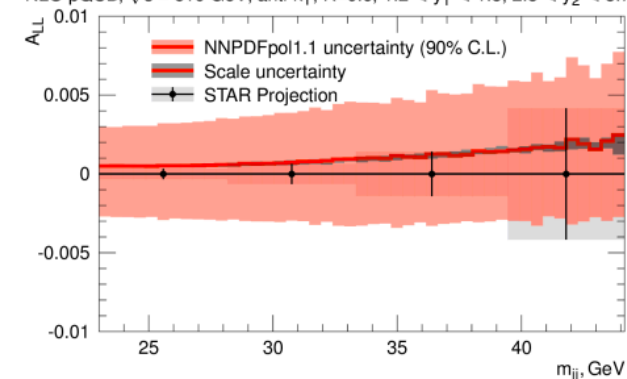
$$\int_0^1 (h_1^q(x) - h_1^{\bar{q}}(x)) dx$$

needed for BSM search

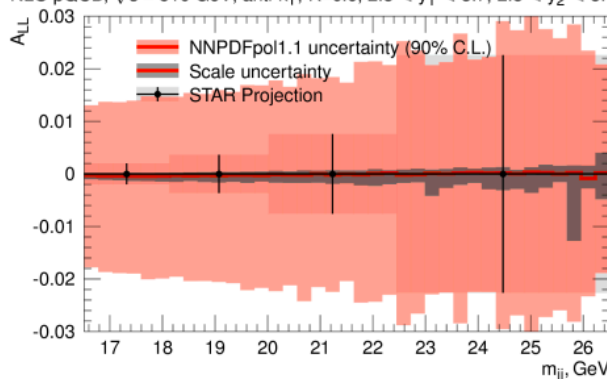
- TMD evolution



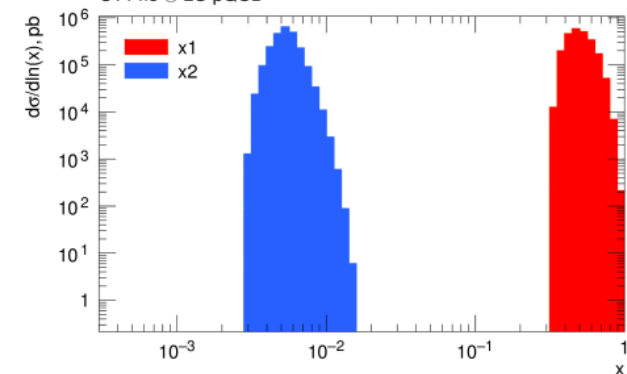
NLO pQCD, $\sqrt{s} = 510$ GeV, anti- k_T , $R=0.6$, $1.2 < y_1 < 1.8$, $2.8 < y_2 < 3.7$



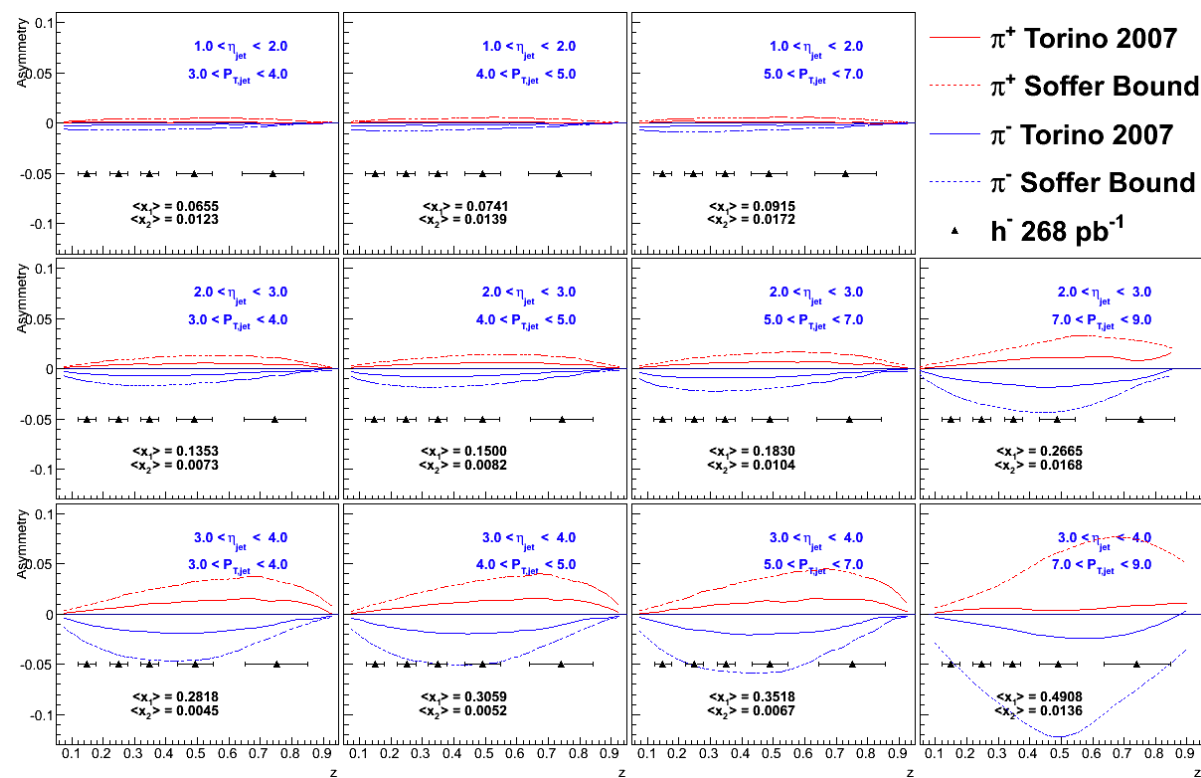
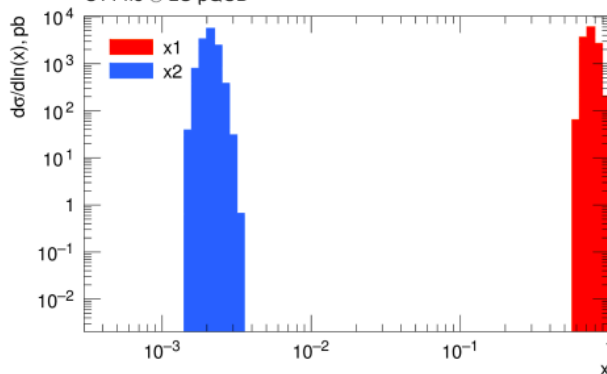
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CT14lo \otimes LO pQCD



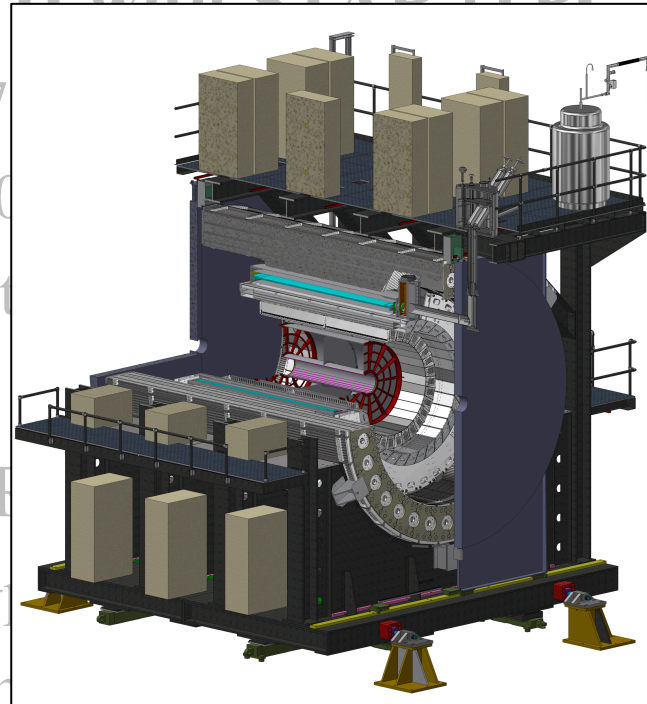
CT14lo \otimes LO pQCD



RHIC Run Plan for 2019-2025

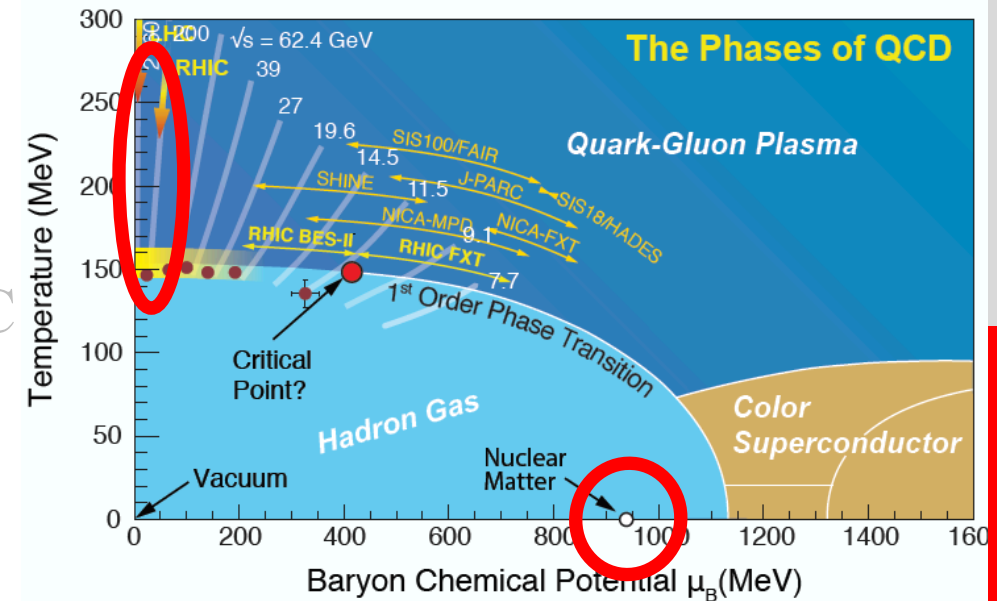
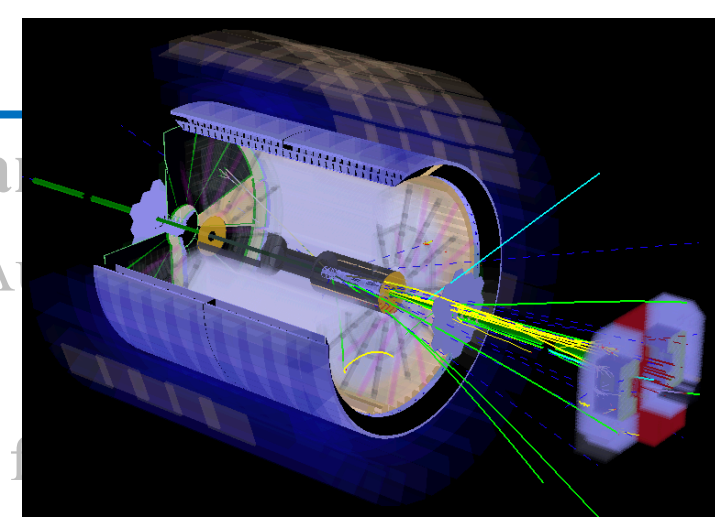
Beam Energy Scan II with STAR, iTPC, eTOF and PHENIX

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- Fixed target runs at 3.0 GeV Au+Au
- Search for signs of criticality



Spin run with STAR

- 500 GeV polarized p+p
- Spin physics measurements



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2021

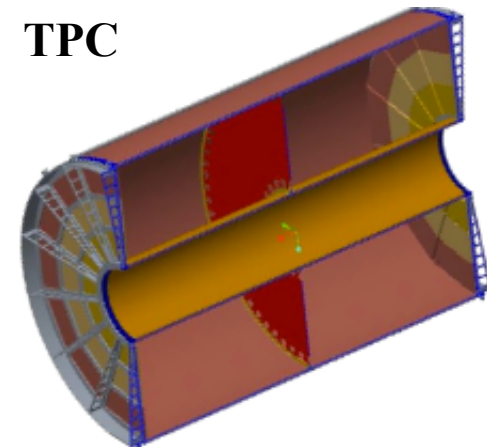
2022

2023

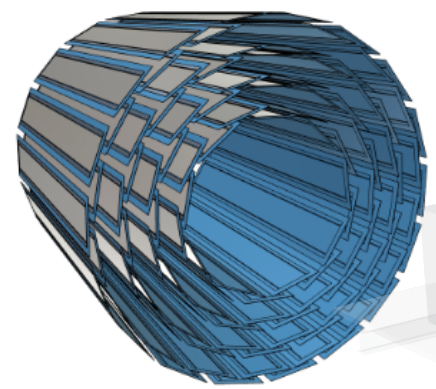
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2025

sPHENIX Experiment

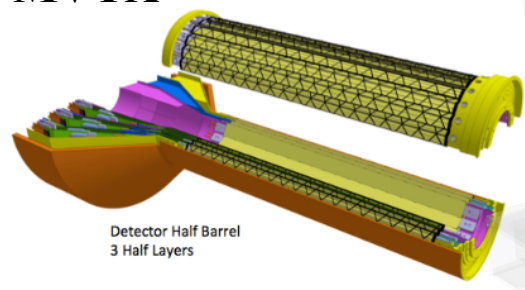
TPC



INTT

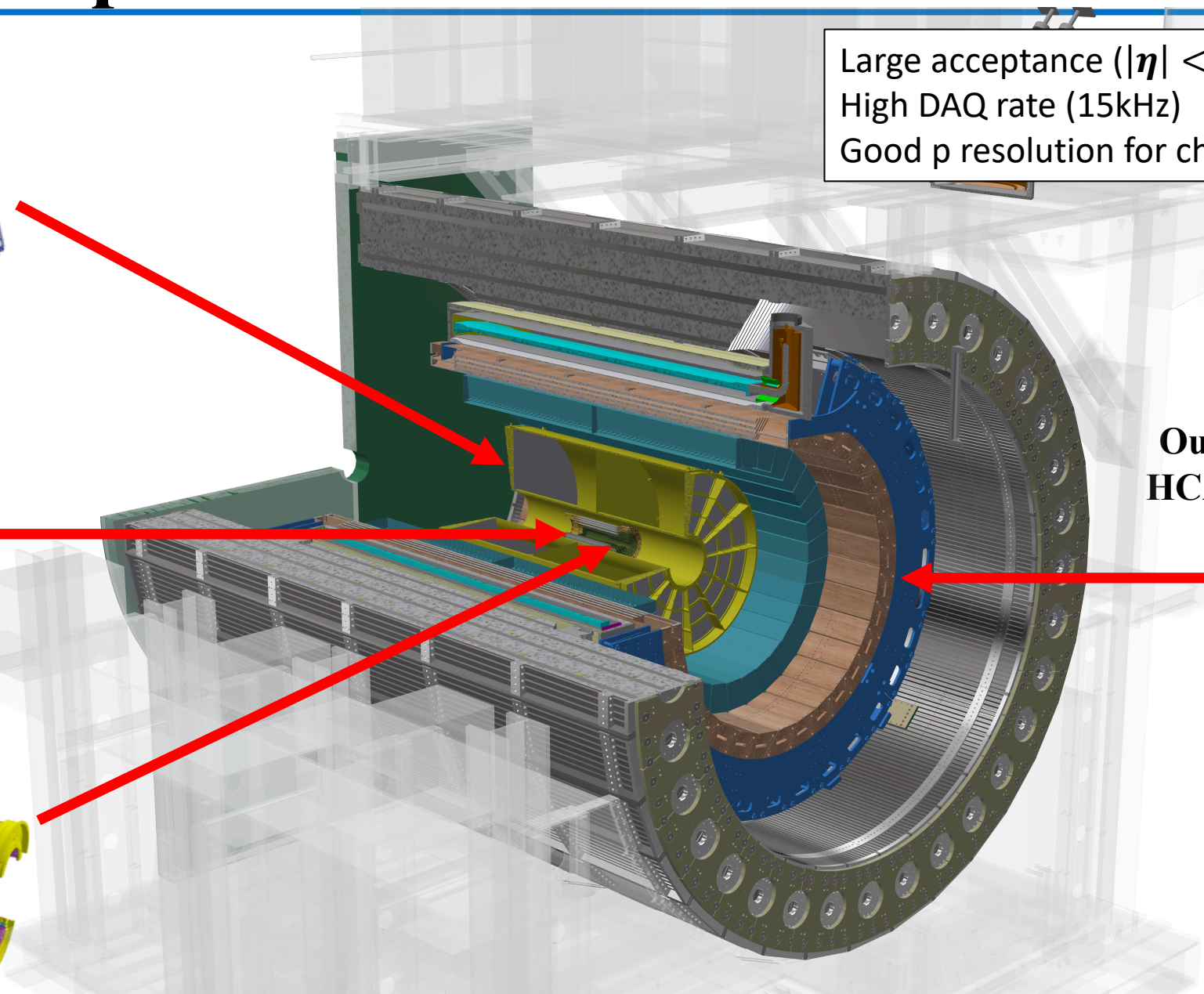


MVTX

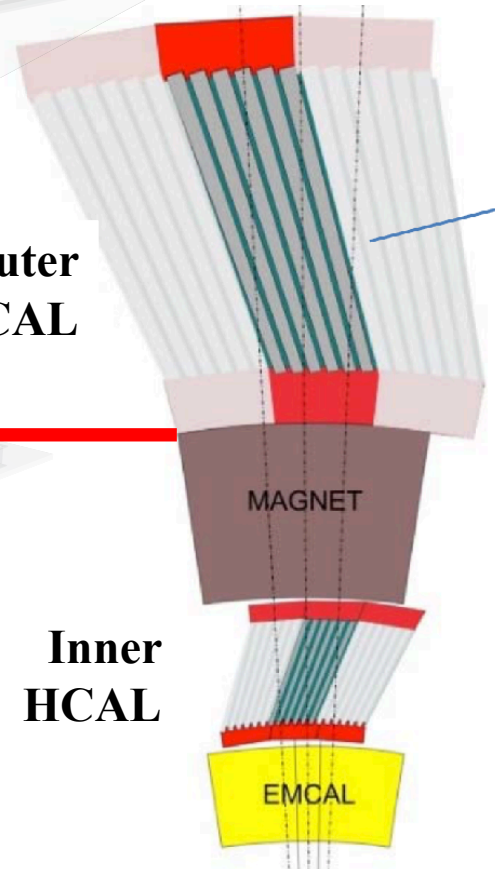


Detector Half Barrel
3 Half Layers

Large acceptance ($|\eta| < 1.1$, full 2π)
High DAQ rate (15kHz)
Good p resolution for charged particles and jets



Outer
HCAL

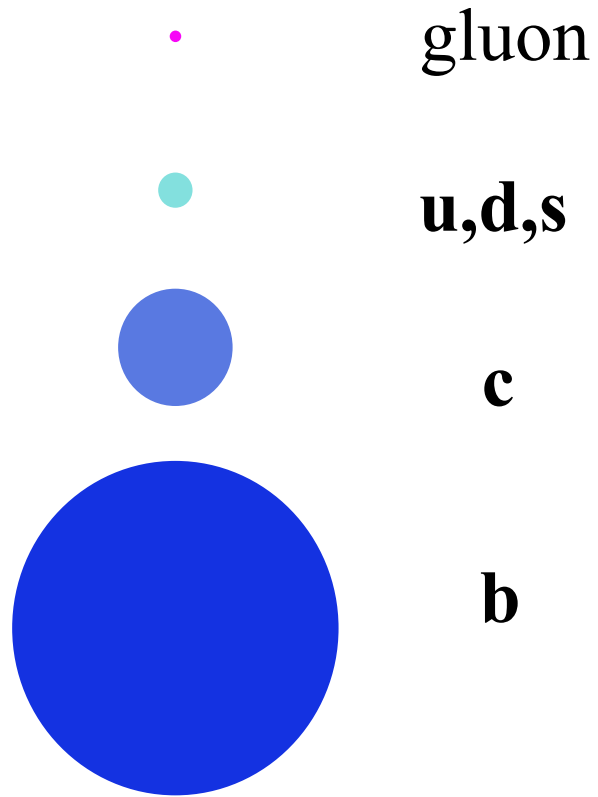


Inner
HCAL

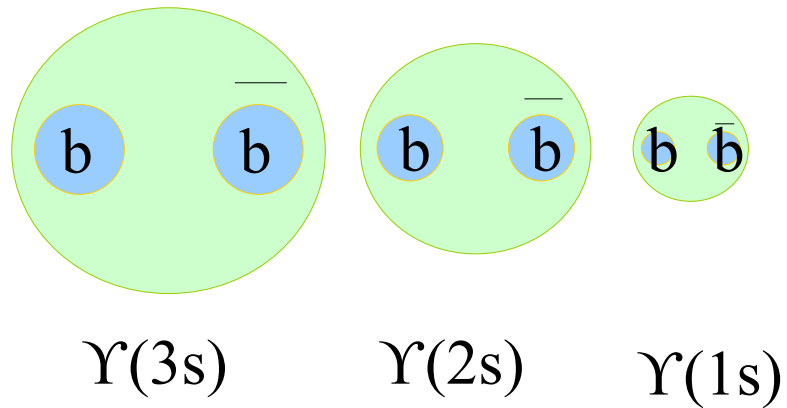
EMCAL

sPHENIX Physics Probes

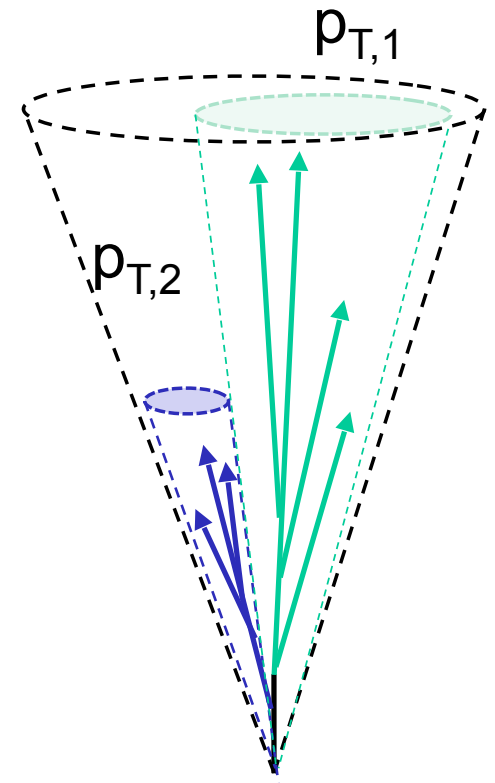
Parton energy loss



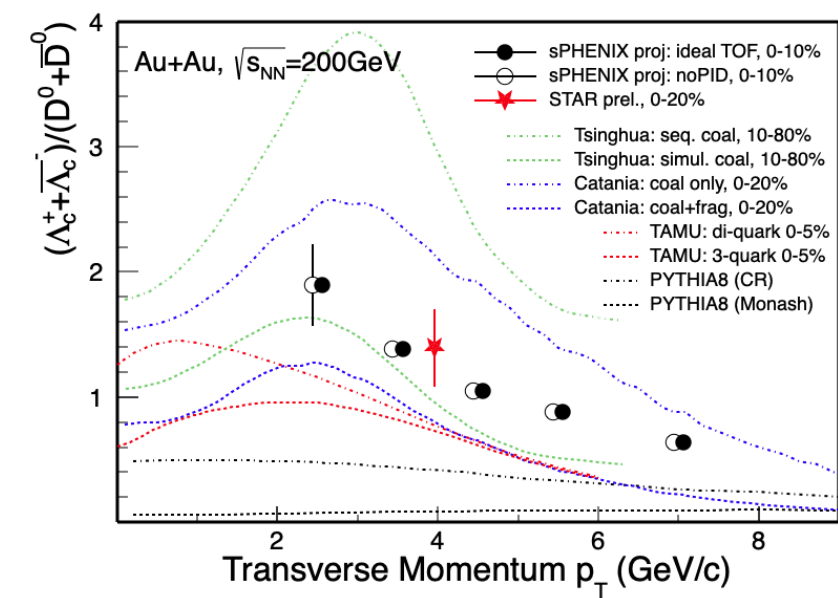
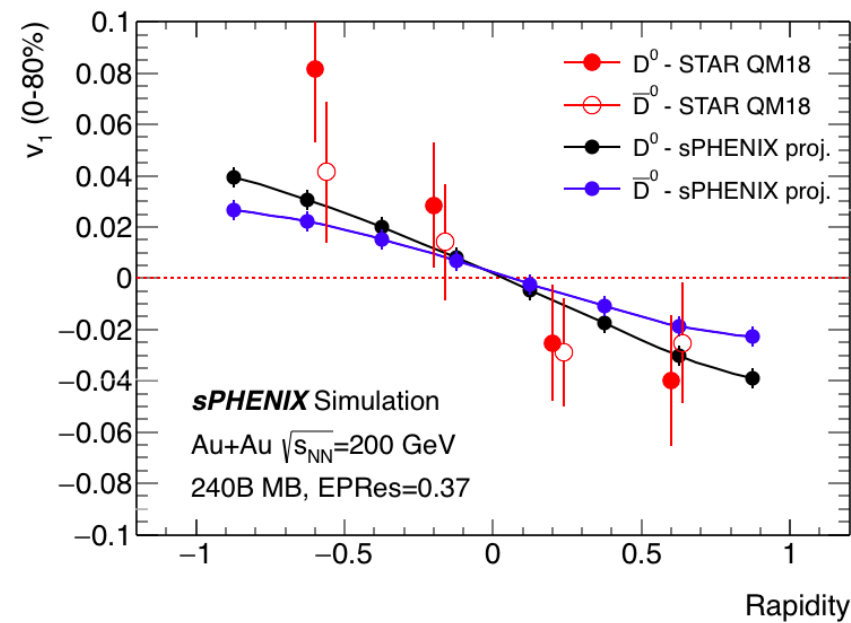
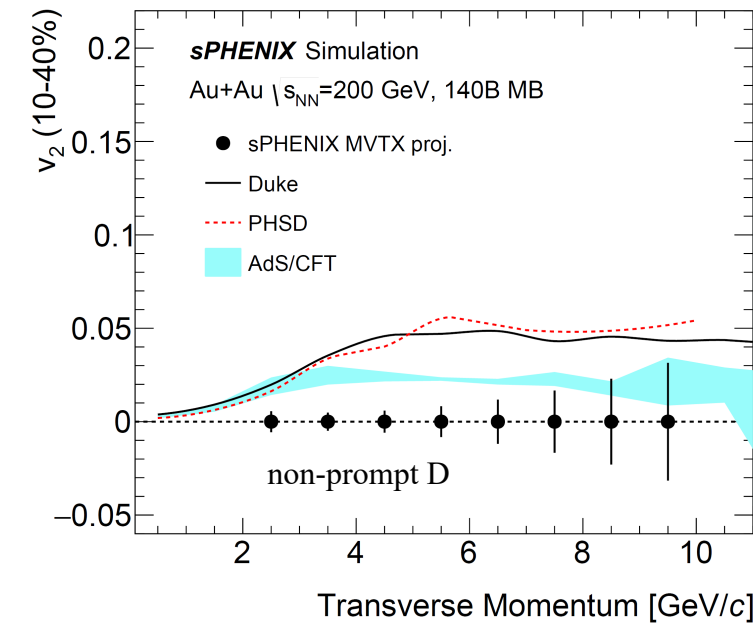
Quarkonium spectroscopy



Jet structure



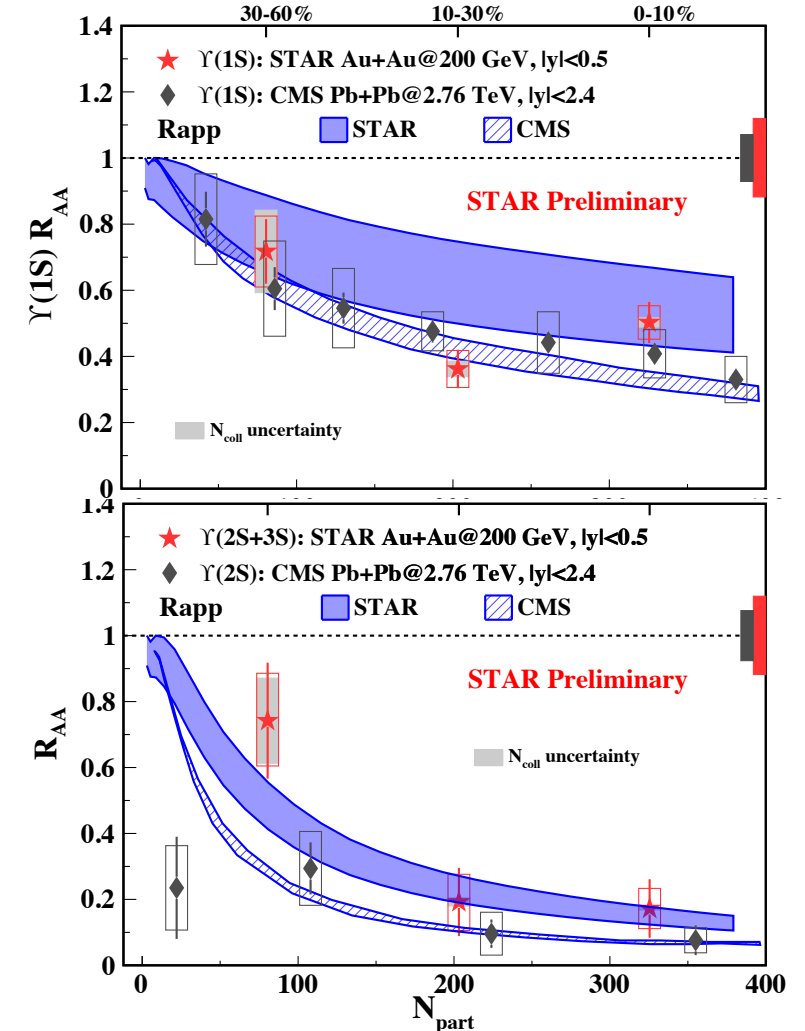
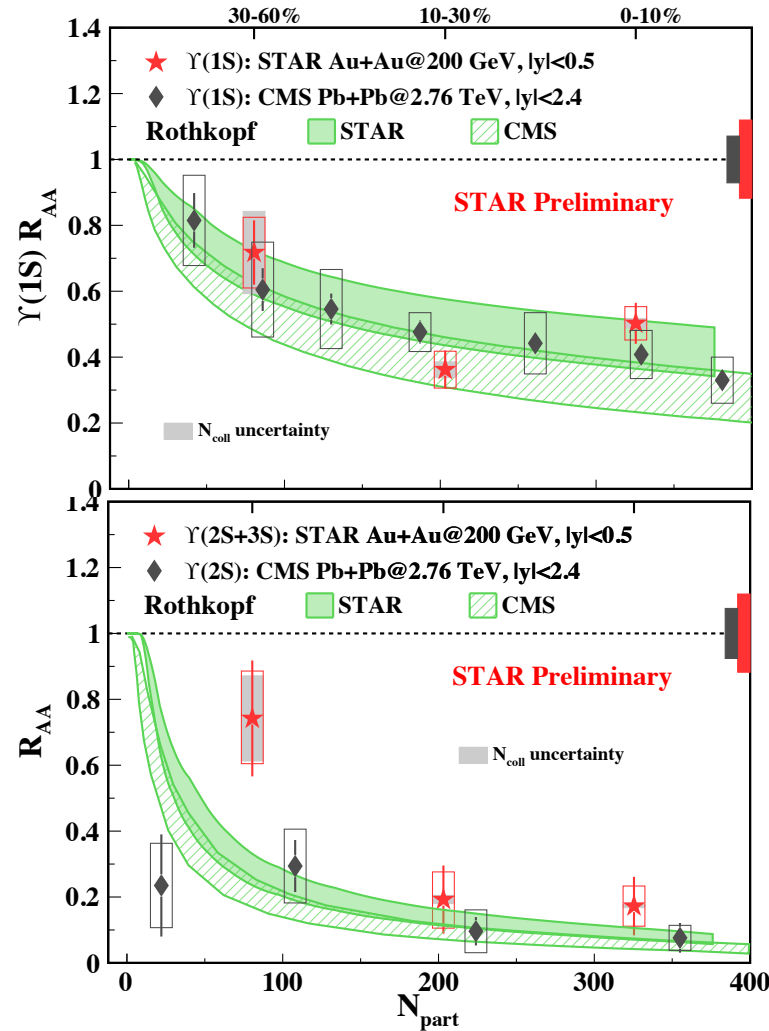
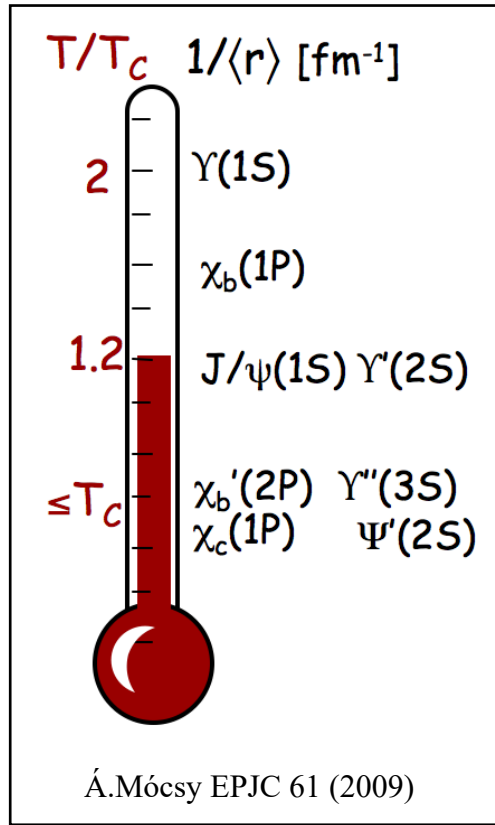
sPHENIX MVTX



HF quarks are produced early: may carry early dynamical info of the medium

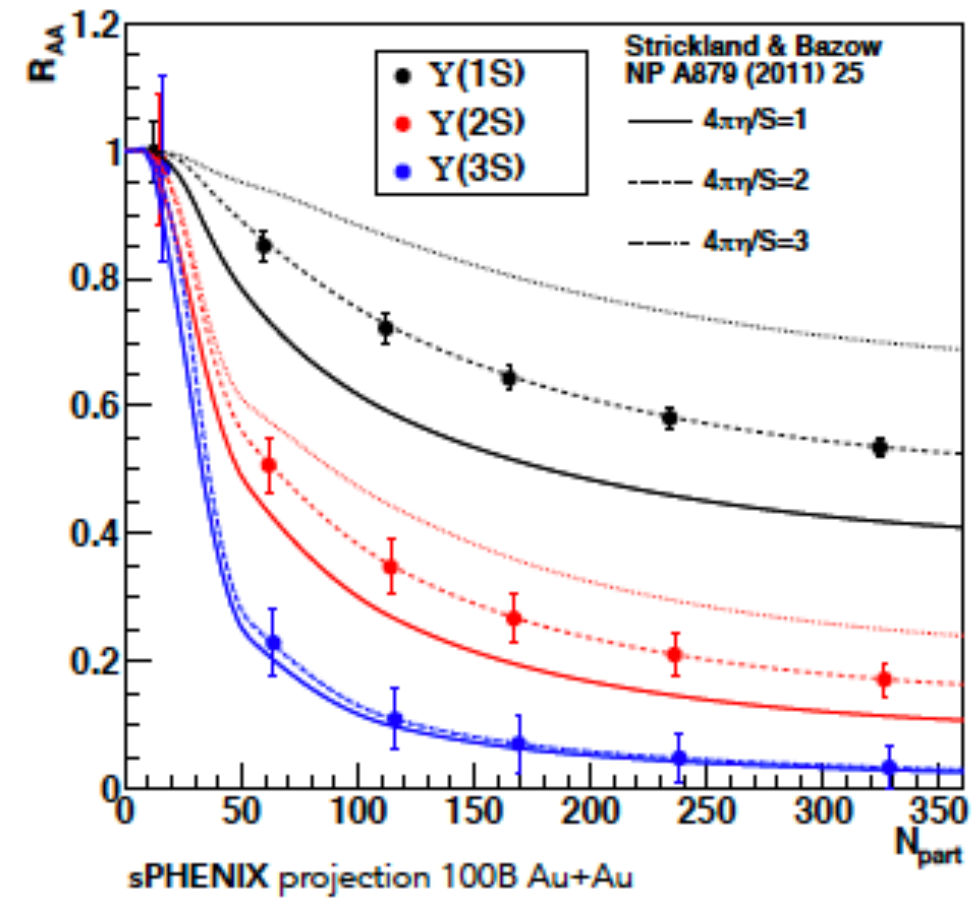
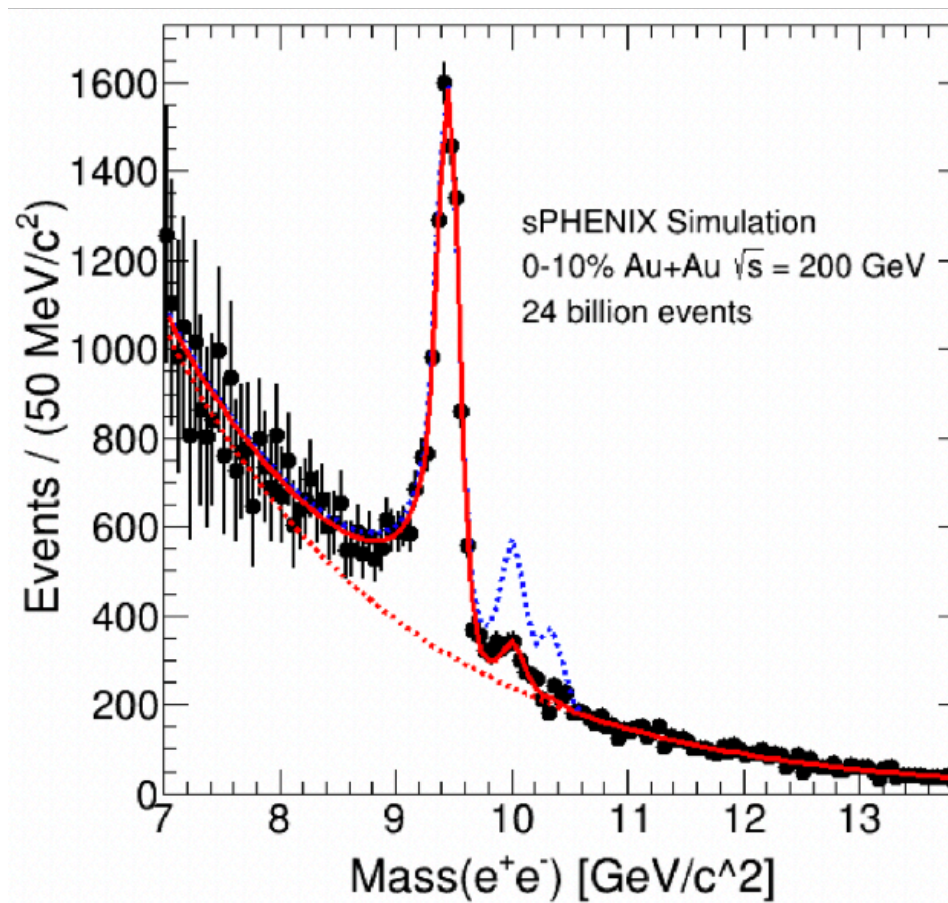
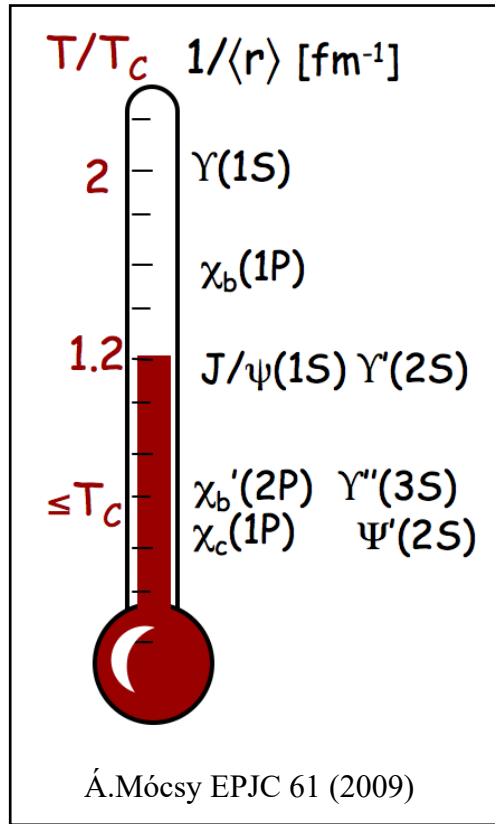
1. Charm quarks flow with the medium. How about bottom quarks?
2. Significant $D^0 + \bar{D}^0$ v_1 . Do the D^0 and \bar{D}^0 v_1 differ due to initial EM field?
3. Enhancement of Λ_c / D^0 ratio at $3 < p_T < 6$ GeV/c. How about low p_T ?

Upsilon Measurement by STAR in 2011-2016



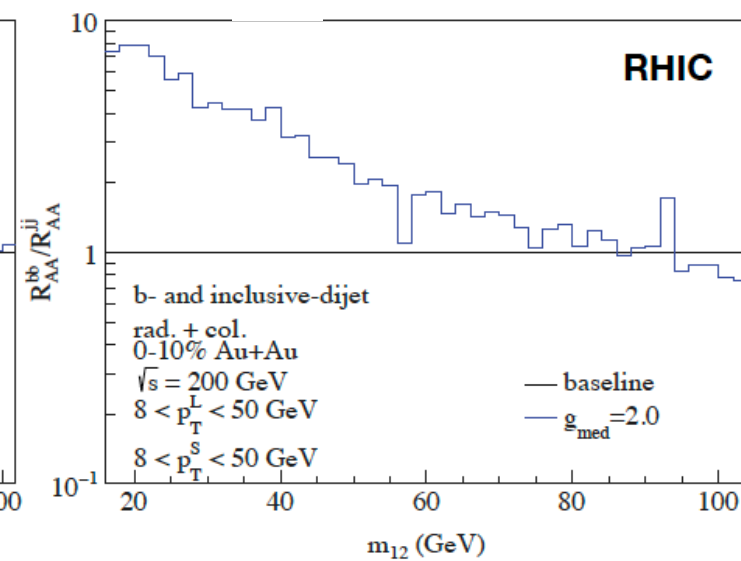
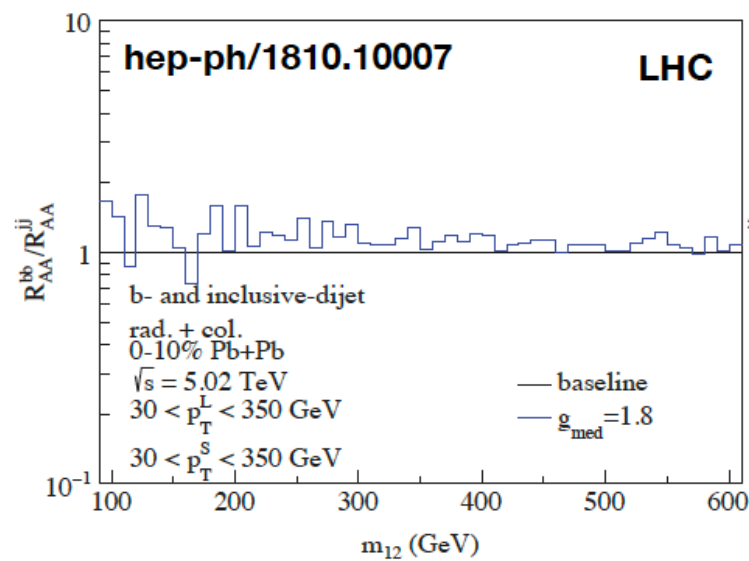
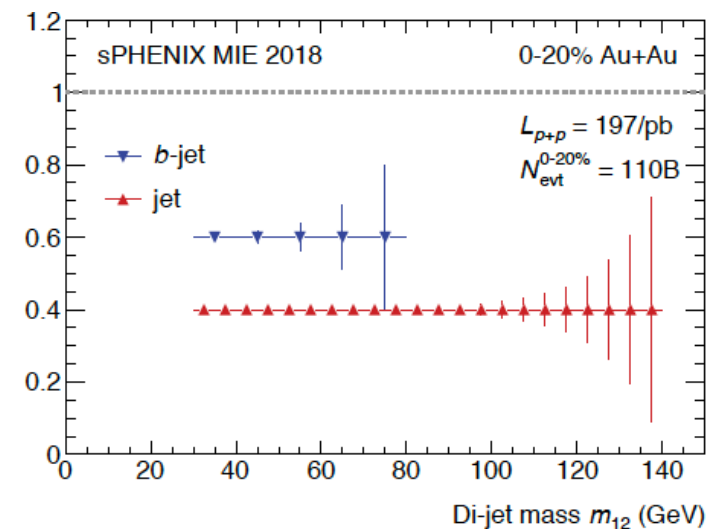
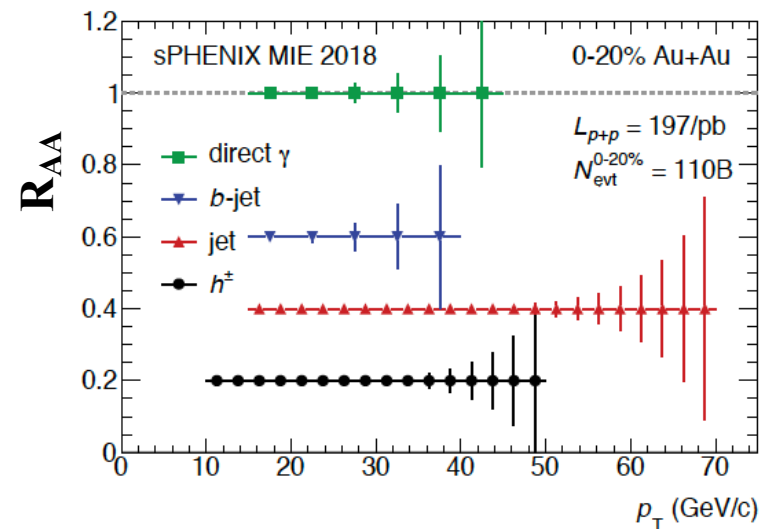
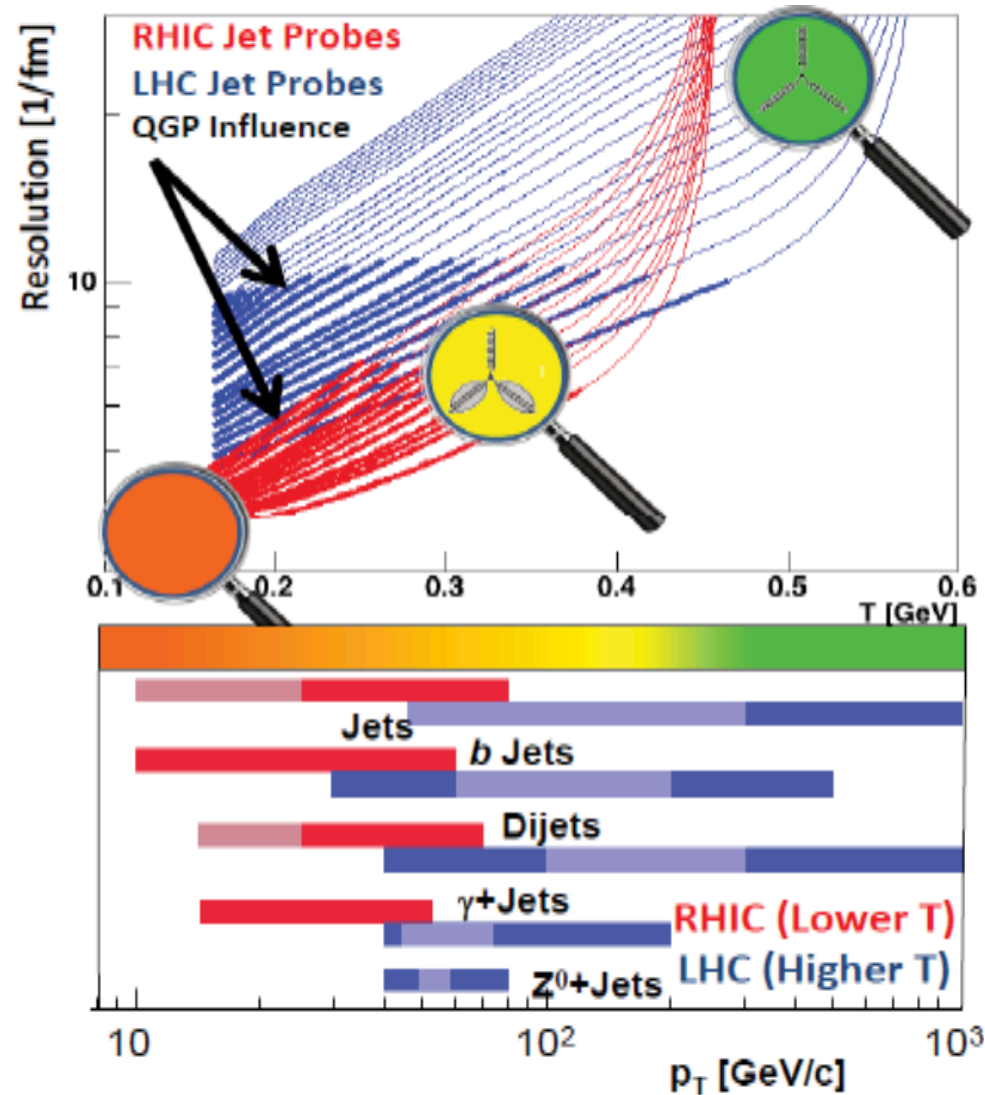
Quarkonia with different binding energies: QGP “thermometer”
 Are the suppression levels for Upsilon states similar at RHIC and LHC?

Upsilon Measurement Projection by sPHENIX



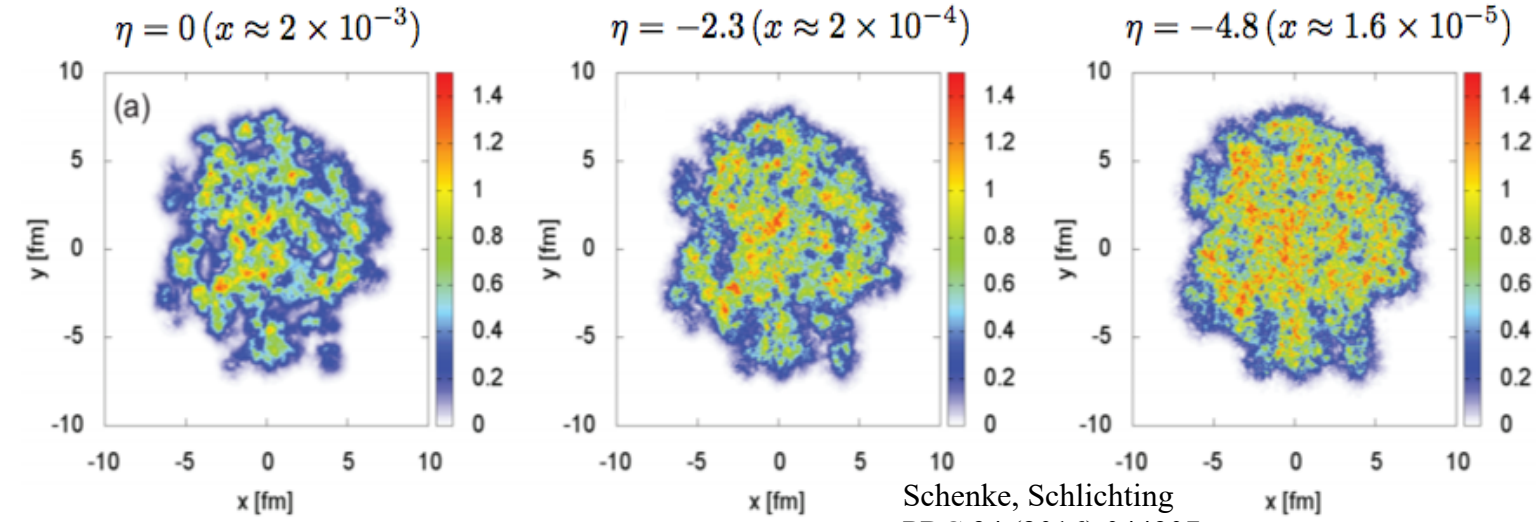
Quarkonia with different binding energies: QGP “thermometer”
 Are the suppression levels for Upsilon states similar at RHIC and LHC?

Jet Measurement Projections by sPHENIX

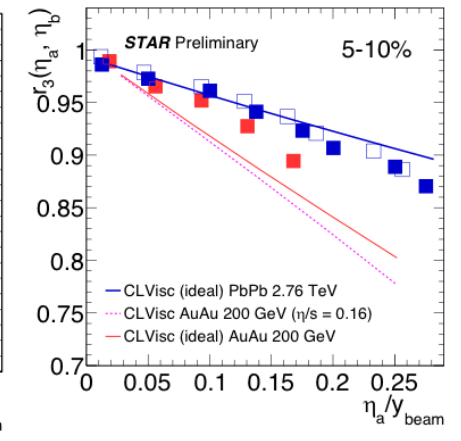
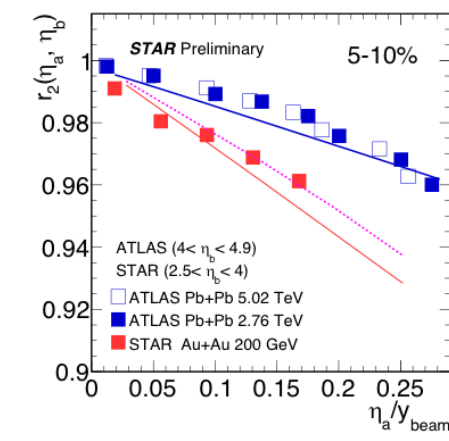


Precision measurements of modifications to jet yield and structure to characterize QGP

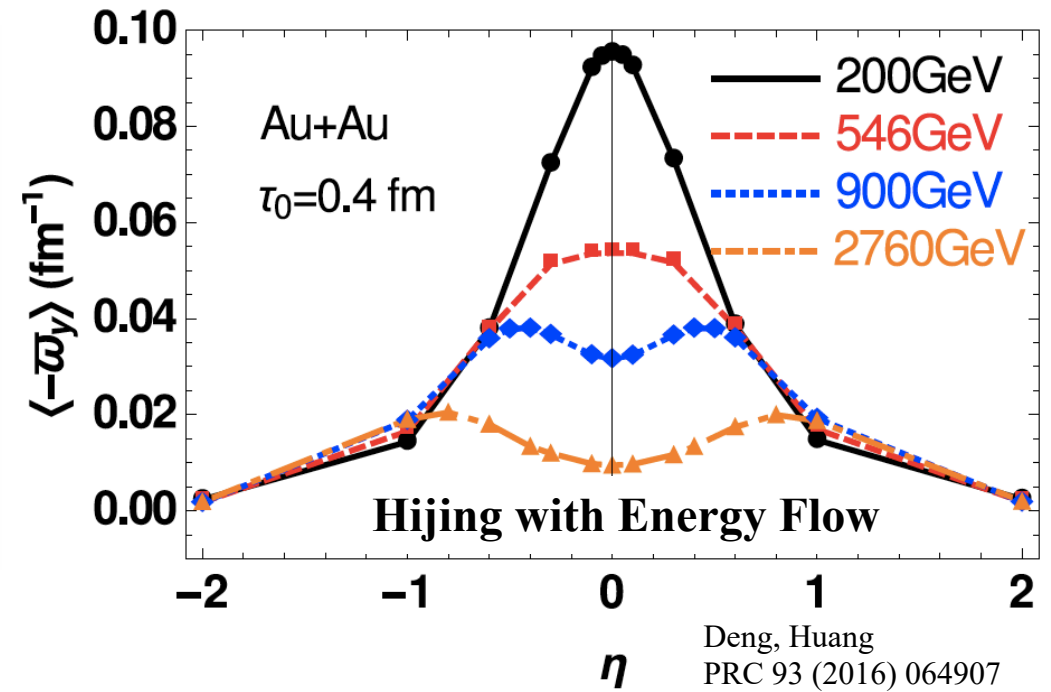
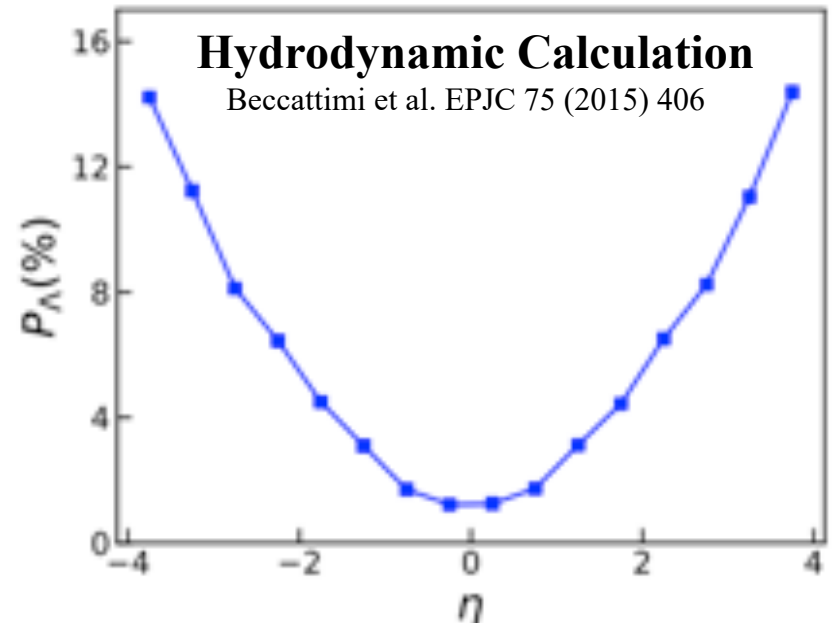
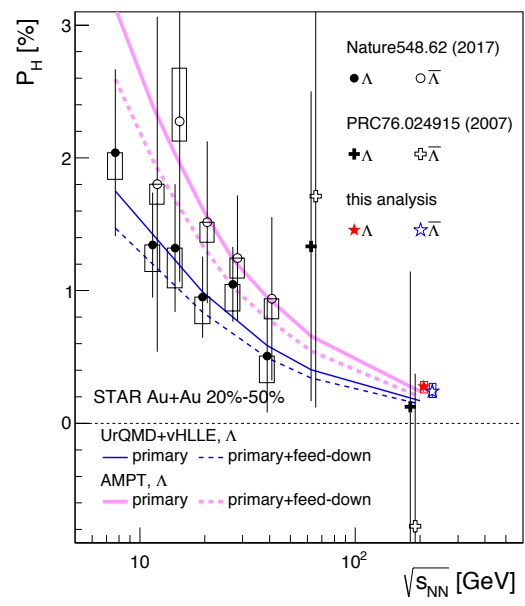
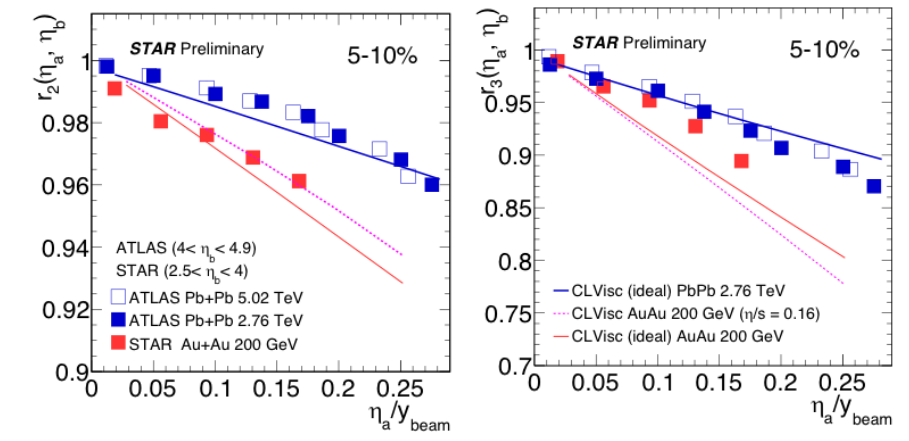
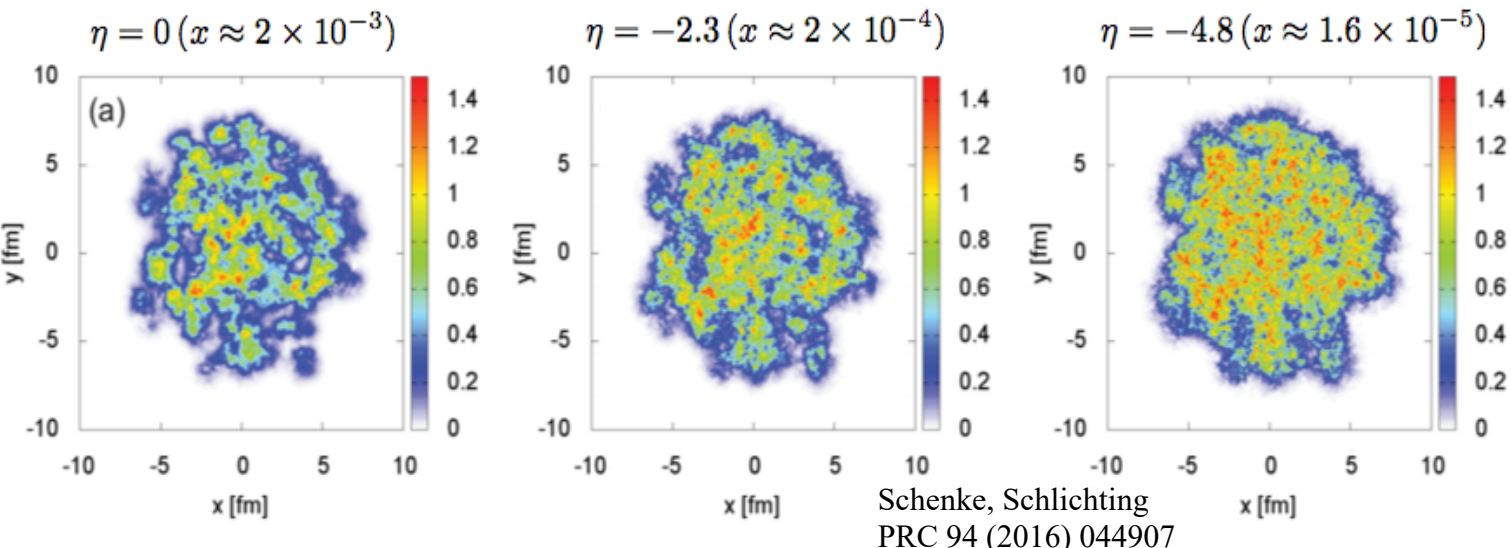
STAR Forward Physics from 2023-2025 Au+Au Run



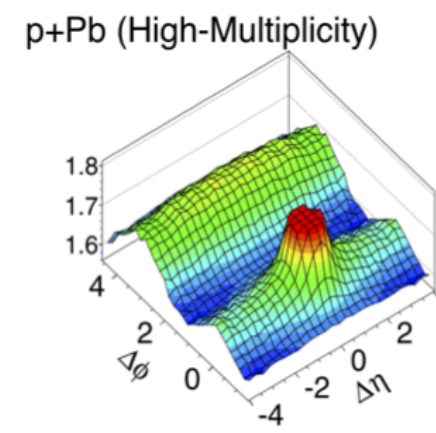
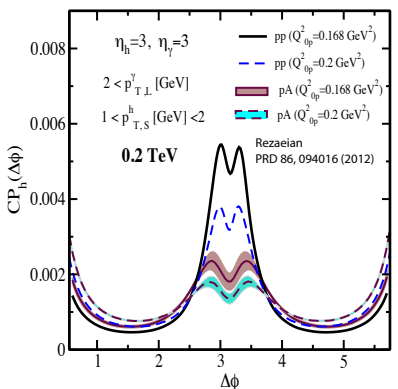
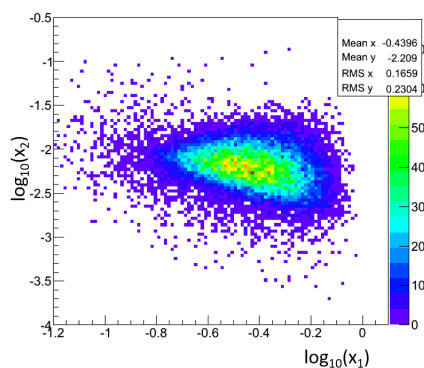
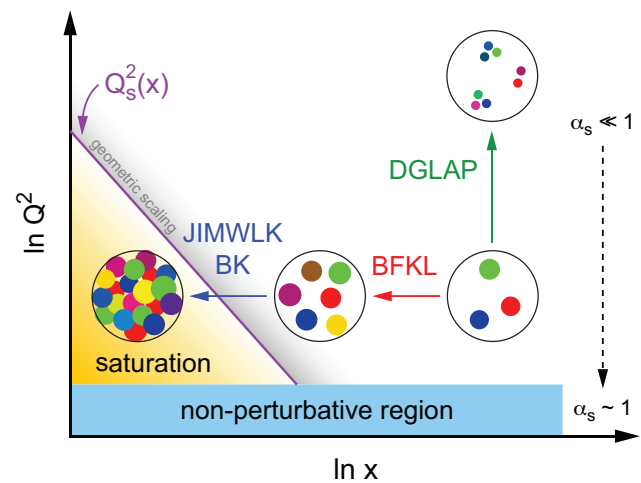
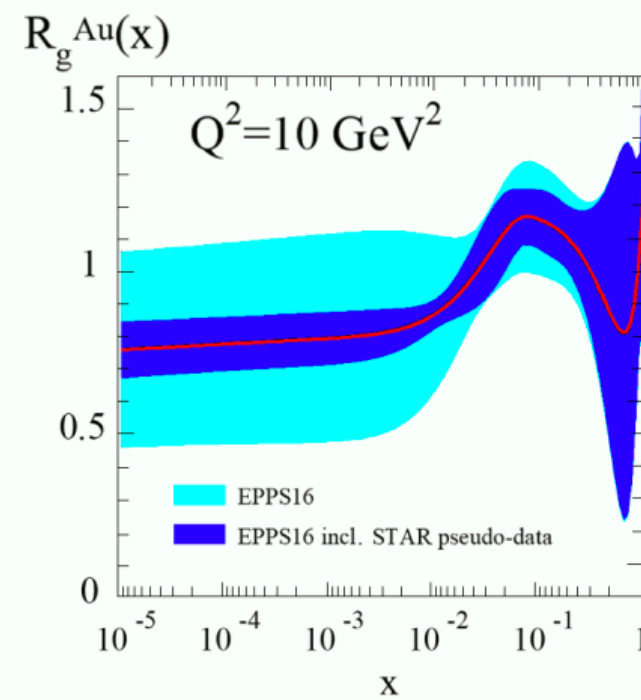
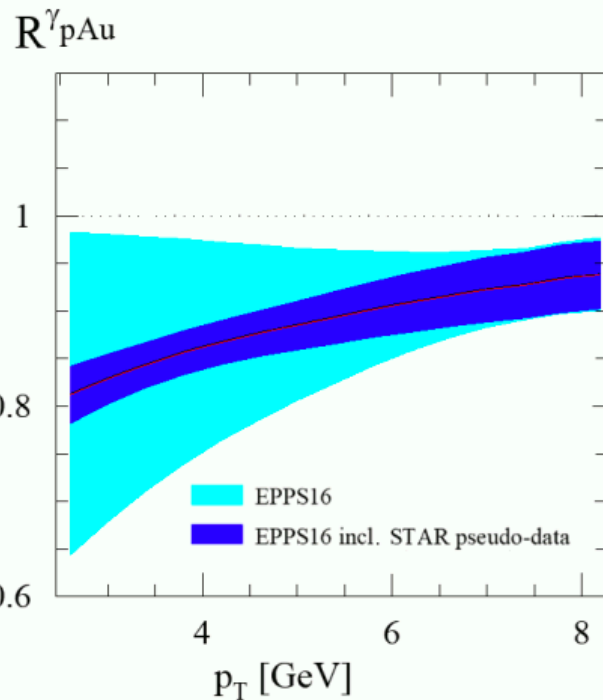
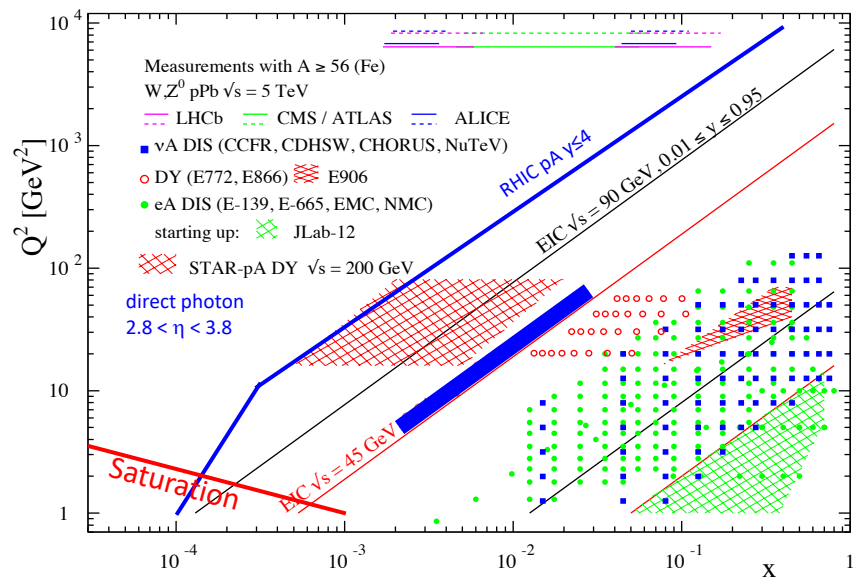
Schenke, Schlichting
PRC 94 (2016) 044907



STAR Forward Physics from 2023-2025 Au+Au Run



STAR Forward Physics from 2023-2025 p+Au Run



RHIC Run Plan for 2019-2025

Beam Energy Scan II with STAR iTPC, eTOF and EPD

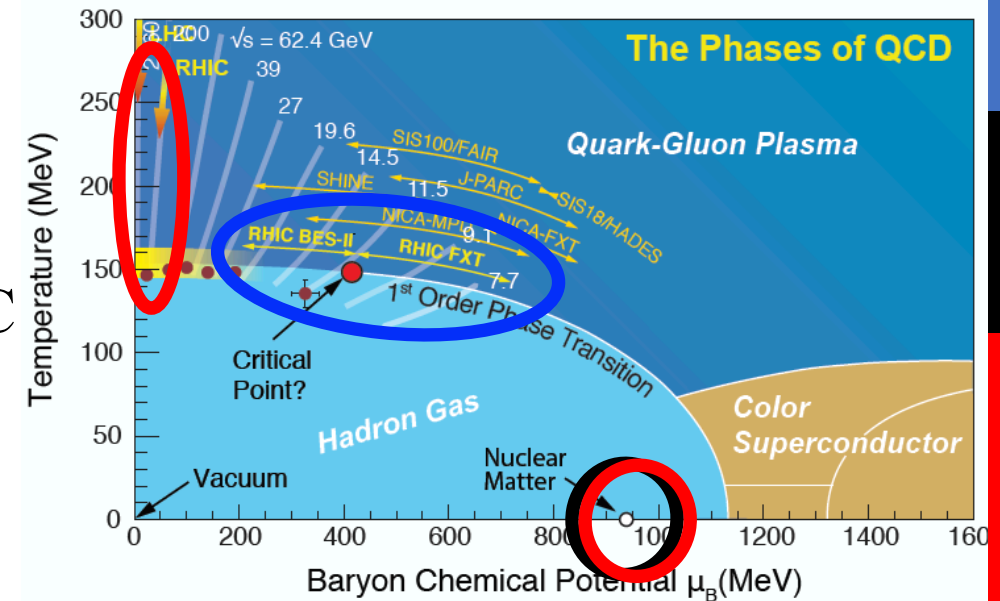
- Low energy $\sqrt{s_{NN}} = 7.7, 9.1, 11.5, 14.5, 19.6$ GeV Au+Au with electron cooling
- Fixed target runs at 3.0, 3.5, 3.9, 4.5, 5.2, 6.2, 7.7 GeV
- Search for signs of critical phenomena in event-by-event fluctuations

Spin run with STAR Forward Upgrade

- 500 GeV polarized p+p
- Spin physics measurements complementary to EIC

Runs with sPHENIX and STAR:

- Top energy $\sqrt{s_{NN}} = 200$ GeV Au+Au, p+p, p+Au
- Precision measurements of open heavy flavor, Upsilon states and fully resolved jets
- Longitudinal structure of initial stage, global polarization, nuclear PDFs, gluon saturation



2019

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2021

2022

2023

-

2025