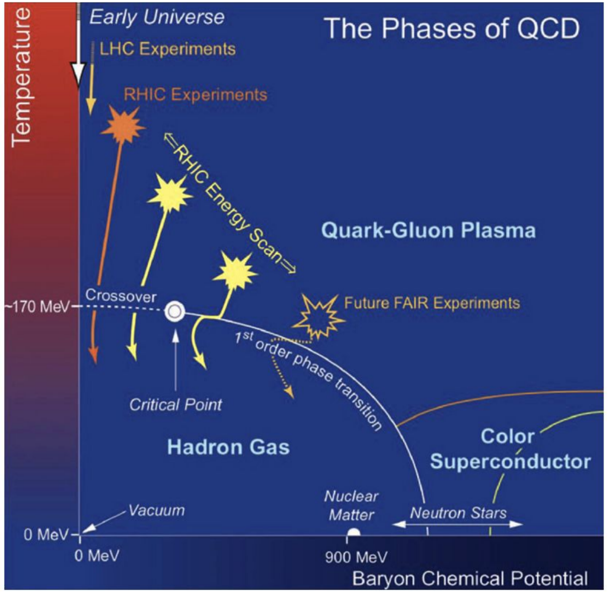
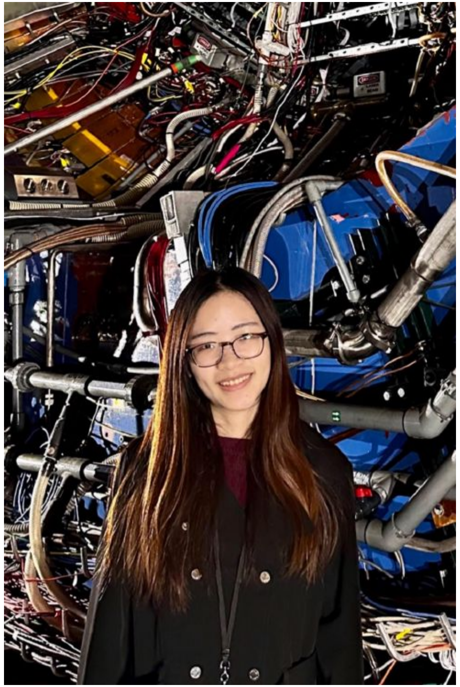
Workshop Report: Beam Energy Scan

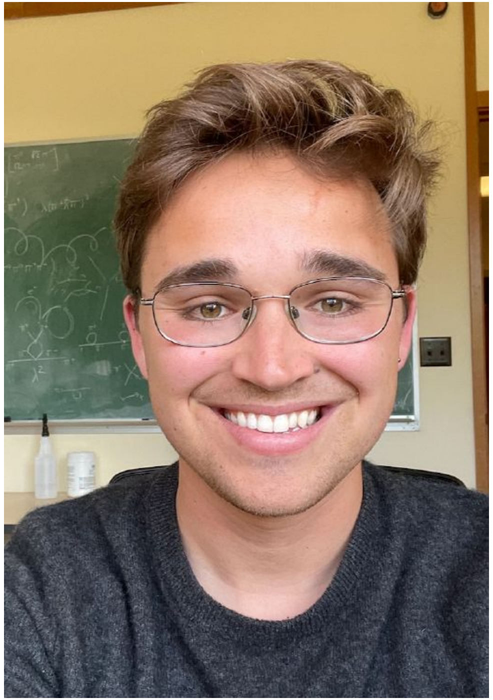
Yevheniia Khyzhniak
on behalf of BES Workshop



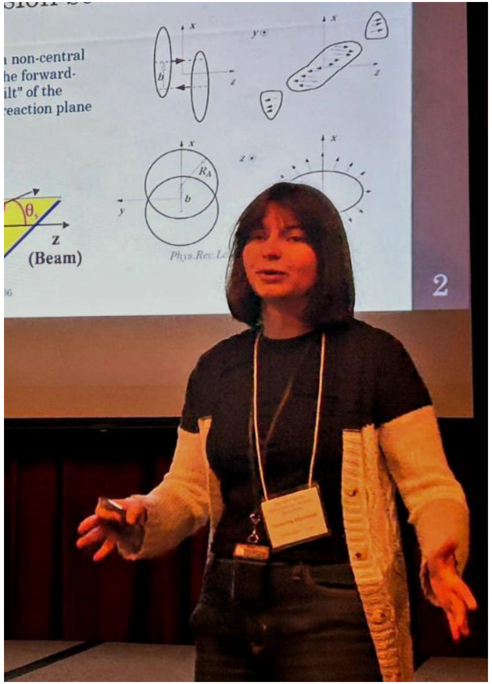
3 Organizers



Zhiwan Xu



Zach Sweger

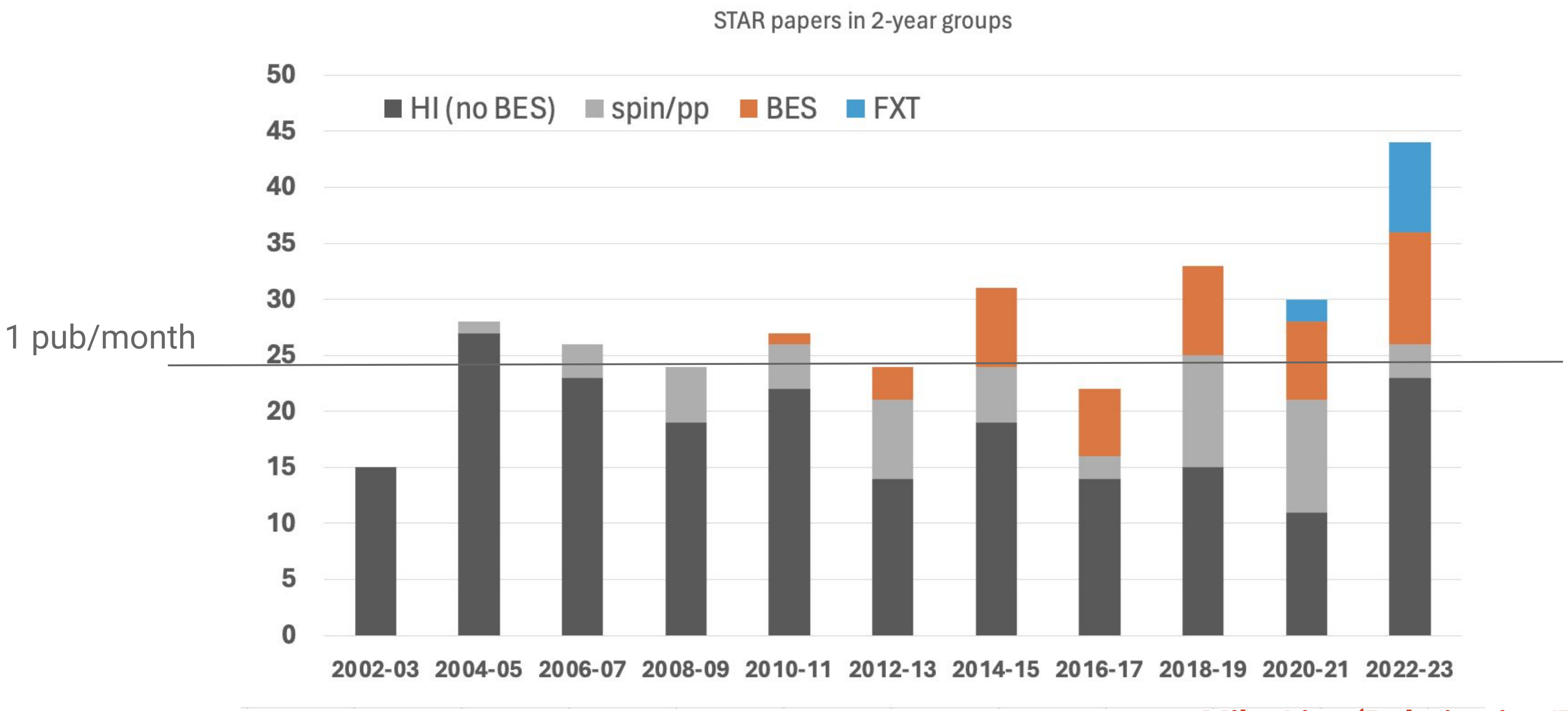


Yevheniia Khyzhniak

11 talks
Each talk 30 min
… and in some cases 1 hr…

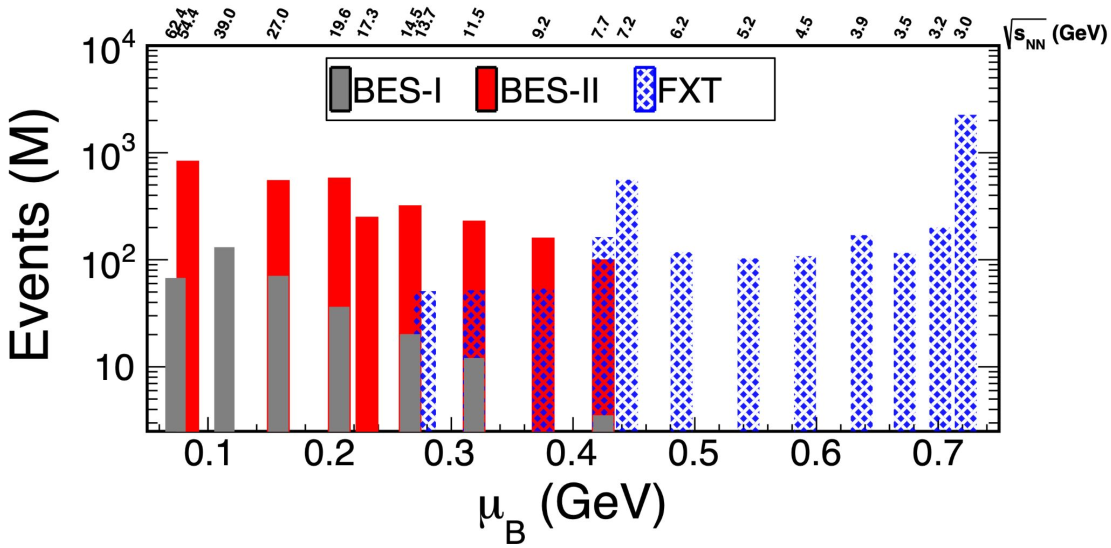
09:15	**BES Overview** **Speaker:** Lijuan Ruan (Brookhaven National Laboratory)
09:45	**Endcap Time-of-Flight Detector in BES** **Speaker:** Yannick Soehngen (University of Heidelberg)
10:15	**Coffee break**
10:30	**Hypernuclei Production** **Speaker:** Iouri Vassiliev (GSI Helmholtzzentrum fur Schwerionenforschung GmbH)
11:00	**BES Theory Overview** **Speaker:** Dekra Almaalol (University of Illinois at Urbana-Champaign)
11:30	**High-Order Moments and EoS Theory Overview** **Speaker:** Volodymyr Vovchenko (Lawrence Berkeley National Laboratory)
12:00	**No Host Lunch Break**
14:00	**Dielectron Analysis in BES** **Speaker:** Chenliang Jin (Rice University)
14:30	**Fluctuations in BES Overview** **Speaker:** Yige Huang (CCNU IOPP STAR)
15:00	**Flow in BES Overview** **Speaker:** Emilie Duckworth (Kent State University)
15:30	**Coffee break**
15:45	**Polarization/Femtoscopy Overview** **Speaker:** Michael Lisa (Ohio State University)
16:30	**Magnetic Field Effect in v1 Splitting and Non-interdependent Flow in BES** **Speaker:** Aditya Prasad Dash (University of California Los Angeles)
17:00	**CME Overview** **Speaker:** Yicheng Feng (Purdue University)

BES addition STAR journal publications

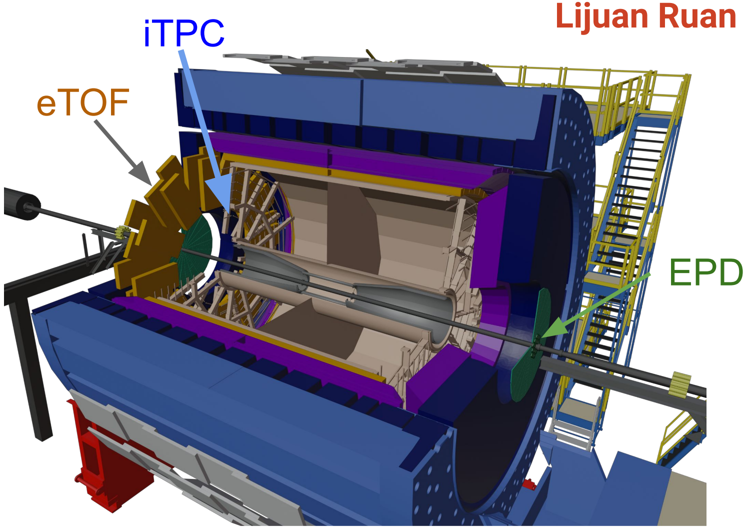


Mike Lisa (Polarization/Femtoscopy)

Successful Completion of Beam Energy Scan Program by STAR



Lijuan Ruan

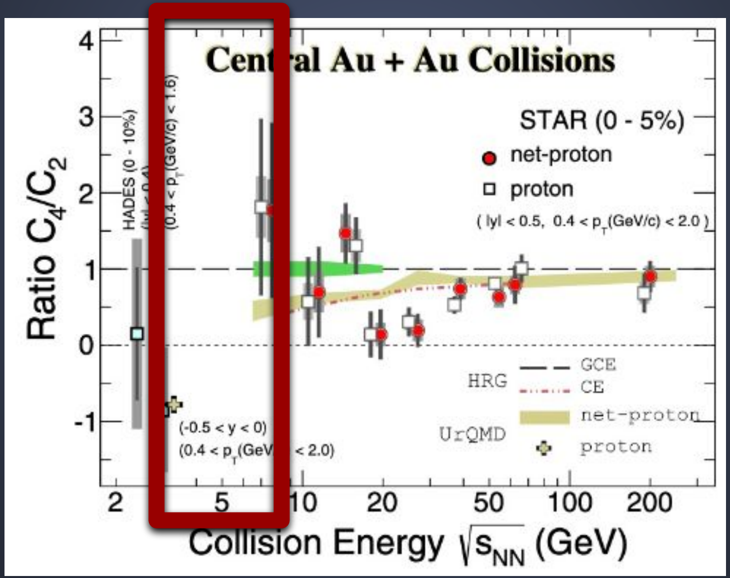


7 energies between 7.7 - 27 GeV (collider mode)
12 energies between 3.0 - 13.7 GeV (FXT mode)
→ high statistics data cover a broad range of T-μ_B

Three major detector upgrades:
TPC += iTPC, TOF += eTOF, BBC += EPDs
→ wider midrapdity acceptance, improved particle identification, event-plane resolution

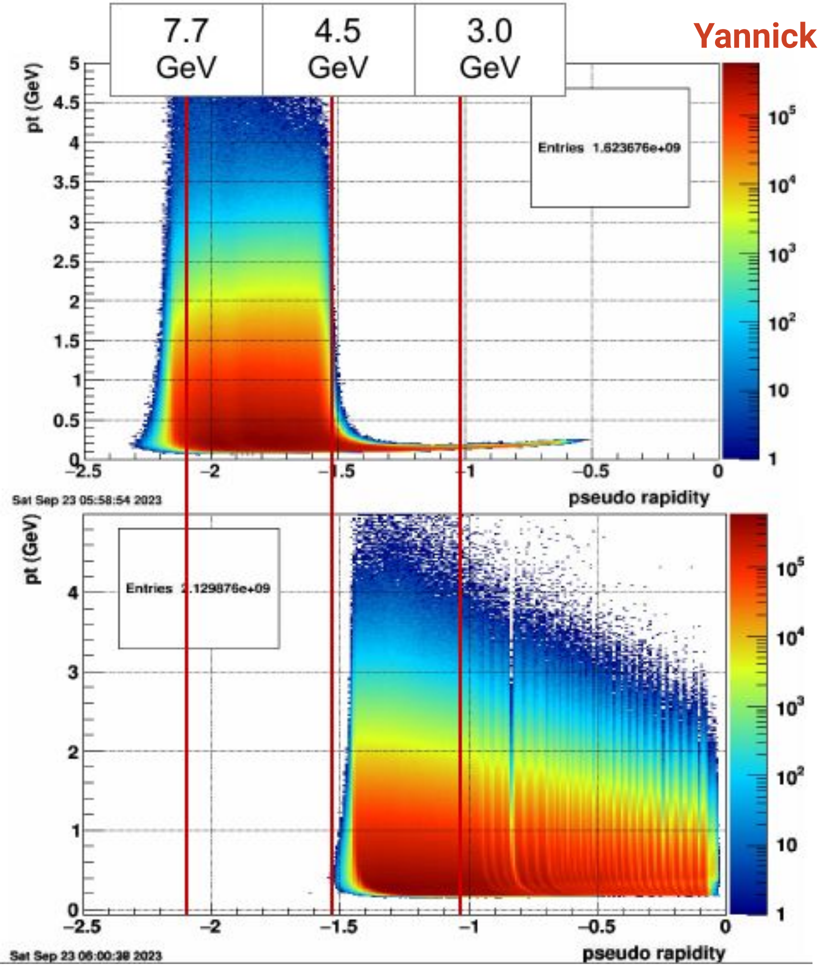
STAR conducted detailed measurements with high statistics data using an enhanced detector as part of the RHIC BES program

STAR Endcap Time-of-Flight Detector in BES



High statistics data sets with EToF bridging the gap from 3.5 GeV to 7.7 GeV now

Yannick Soehngen



EToF

BToF

Acceptance at 4.5 GeV
Red lines : Mid rapidity at 3, 4.5 and 7.7 GeV

Yannick Soehngen

STAR Endcap Time-of-Flight Detector in BES

Energy (GeV) $\sqrt{s_{nn}}$	14.5	19.6	11.5	3.5	7.7	4.5	6.2	5.2	3.9	7.2	9.2	7.7	11.5	13.7	3.0	9.2
Year	2019		2020									2021				
Mode	Collider			Fixed Target							Collider		Fixed Target			
Status	flawed		produced									cal			wip	
Nr. of Events	320 M	580 M	230 M	100 M	100 M	100 M	100 M	100 M	100 M	320 M	160 M	100 M	50 M	50 M	2 B	50 M
Dmg	XX	XX								X	X	X	X	X	X	X

EToF Calibration Status

Plenty of data featuring EToF available

- All FXT 2020 data sets are calibrated (7 energies from 3.5GeV to 7.7 GeV)
- 3 Collider data sets including the overlap energy at 7.7GeV are calibrated
- Large 3.0 GeV FXT 2021 data set (2B events!) calibration close to final

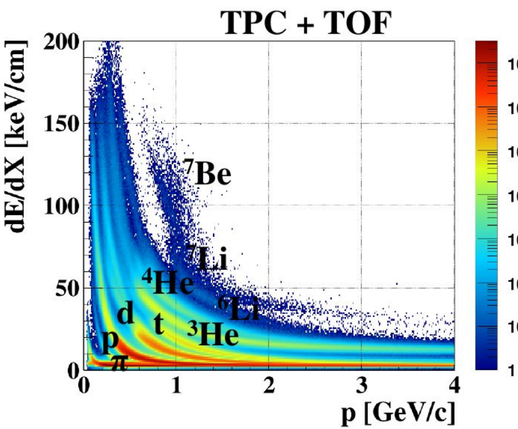
Physics analysis using EToF ongoing

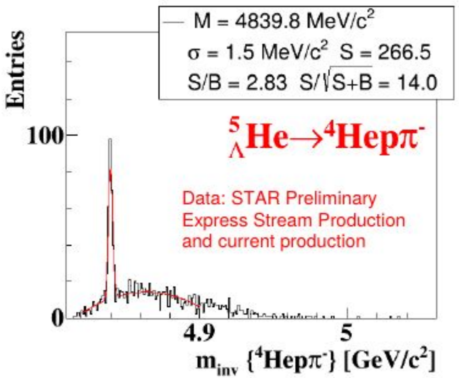
- Proton fluctuation analysis making good progress
- Hypernuclei reconstruction benefiting from inclusion of EToF information
- Investigation of baryon chemical potential prioritized after production

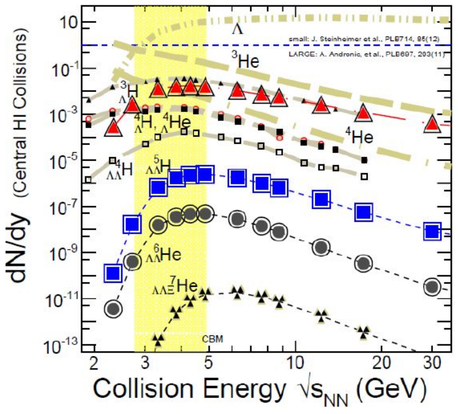
Iouri Vassiliev

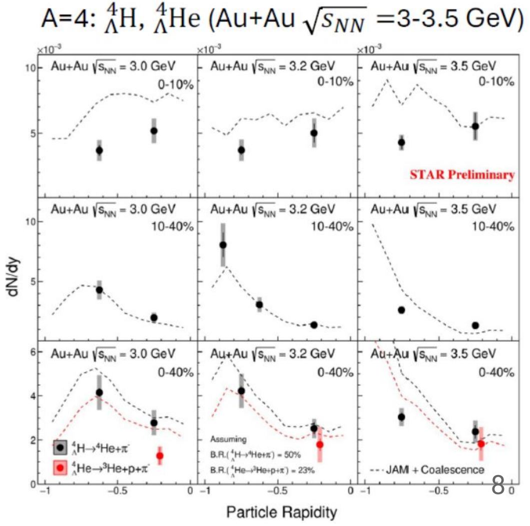
Hypernuclei Production

- The dE/dX spectra of π, p, d, t, ^{3}He, ^{4}He particles at 3.5 GeV (fixed target mode) and heavy fragments up to ^{7}Be are clearly seen
- Observation of hyper helium ($^{5}_{\Lambda}He$) with significance of 14σ was shown
- First measurement of dN/dy of hypernuclei in HI collisions -> New challenges for the models
- New data provide first constraints for hypernuclei production models in the high-baryon-density region









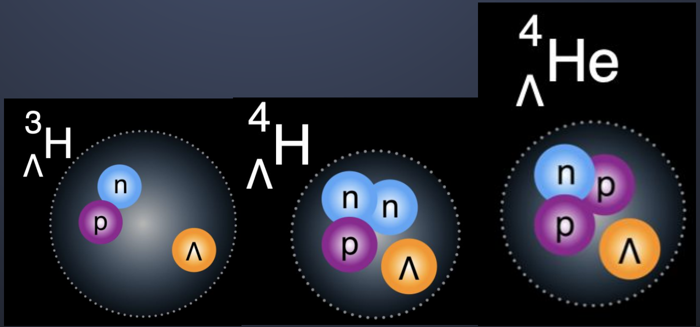
Iouri Vassiliev

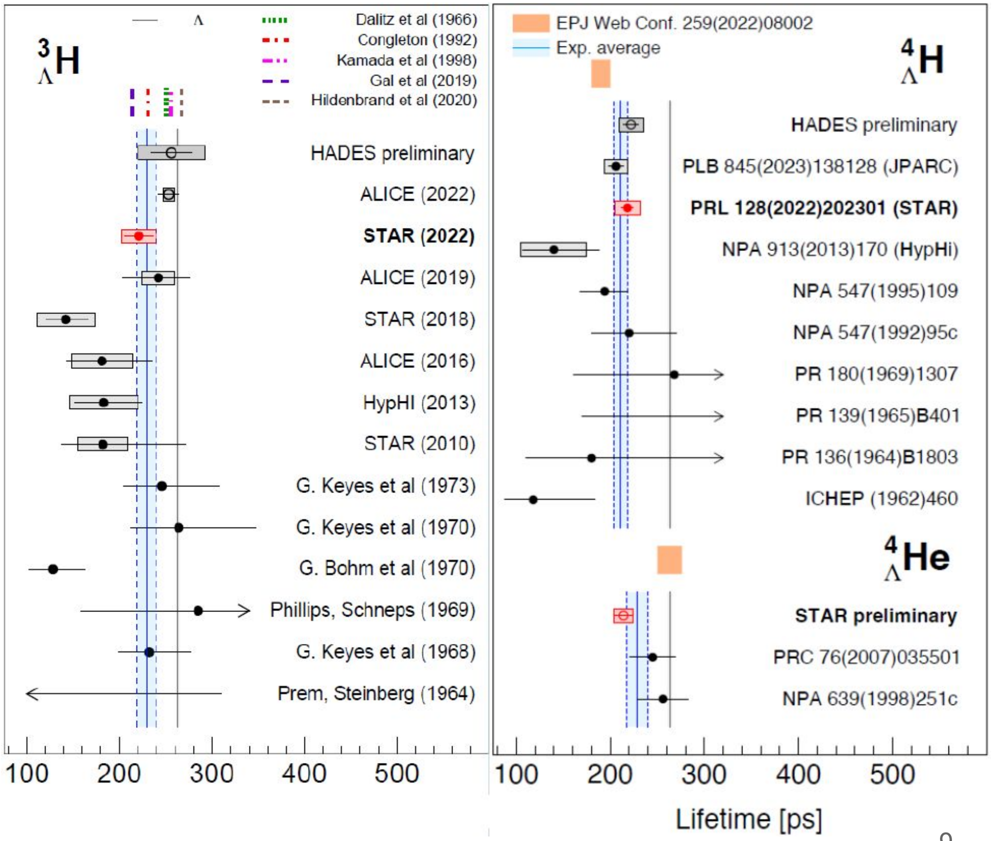
Hypernuclei Production

$^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H and $^{3}_{\Lambda}$He lifetimes measured with improved precision

$^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H lifetimes shorter than lifetime of Λ (with 1.8σ and 3.0σ)

Consistent with theoretical calculations including pion FSI

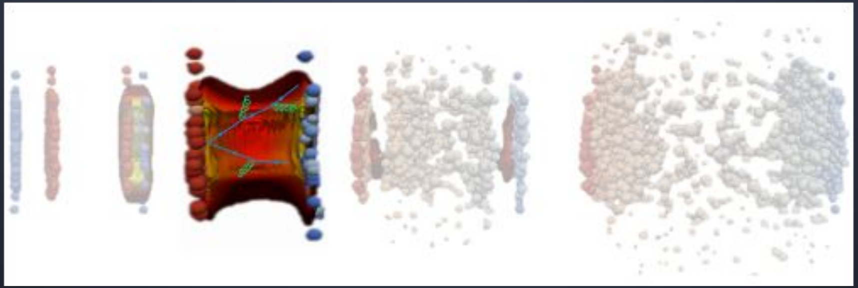


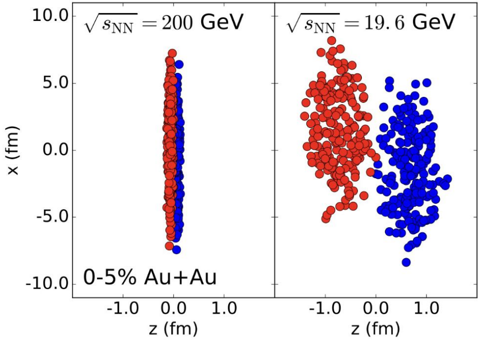


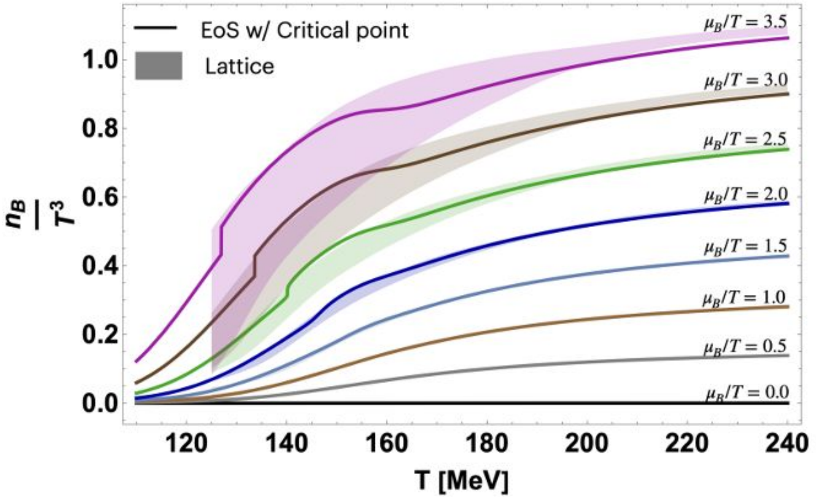
Dekra Almaalol

BES Theory Overview

- Goal is to develop a comprehensive modelling of heavy ion collisions for low energy
- Improving poorly understood initial state geometry, fluctuations, conserved charge: baryon stopping (B), strangeness (S) & electric charge (Q)
- Temperature dependence of viscosity
- Improved equation of state
- Improved freeze-out-model



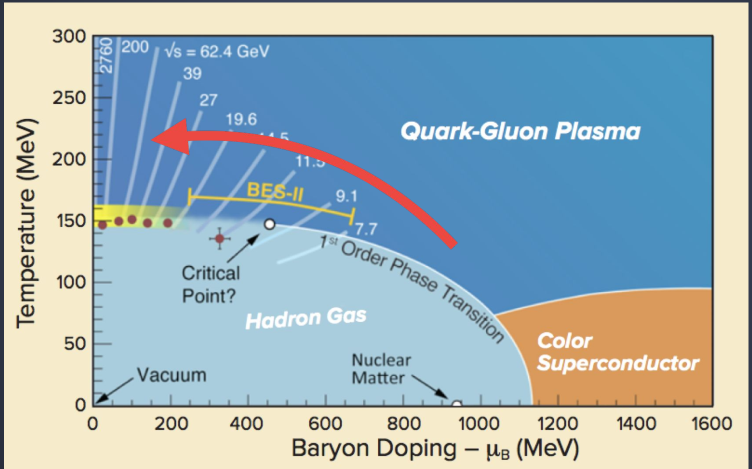




Refined modeling of heavy ion collisions at lower energies, along with new tools and data-model comparisons, is vital for the BES program's interpretative success

Net-proton higher order moments

Primary driver of RHIC Beam energy scan in the context of search for critical point



Two main observables:

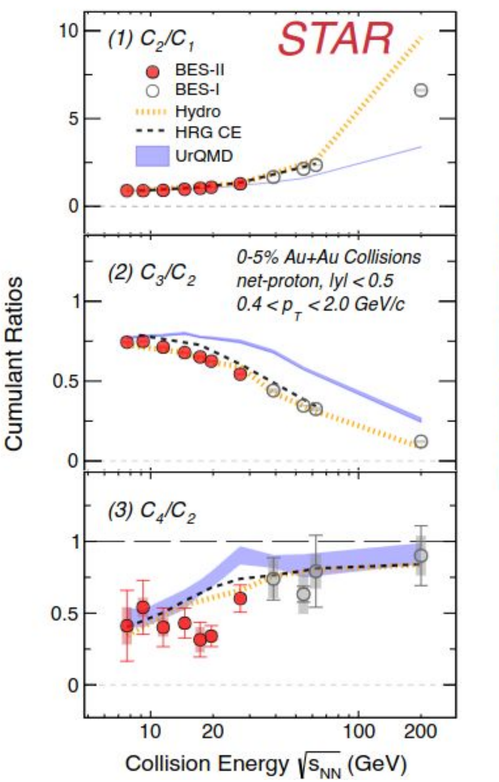
Cumulant ratios: C_2/C_1 , C_3/C_2 , C_4/C_2 $\qquad C_n \sim \langle \delta N^r \rangle$

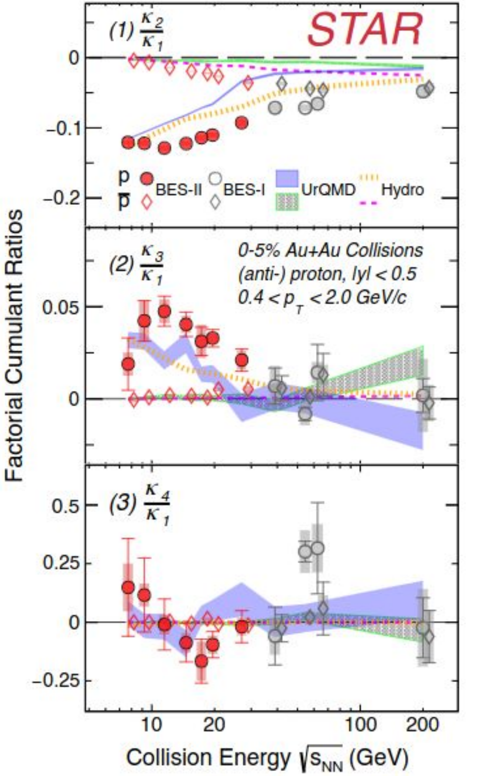
Factorial cumulants: κ_2/κ_1 , κ_3/κ_1, κ_4/κ_1

$$\kappa_n \sim \langle N(N-1)(N-2) \rangle$$

BES-II results: energy dependence & comparison to baseline is highlighted

Yige Huang



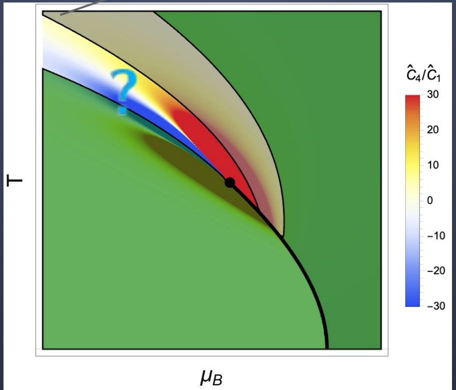


Implication of the STAR BES-II results in the context of CP search is under discussion in the community

Volodymyr Vovchenko

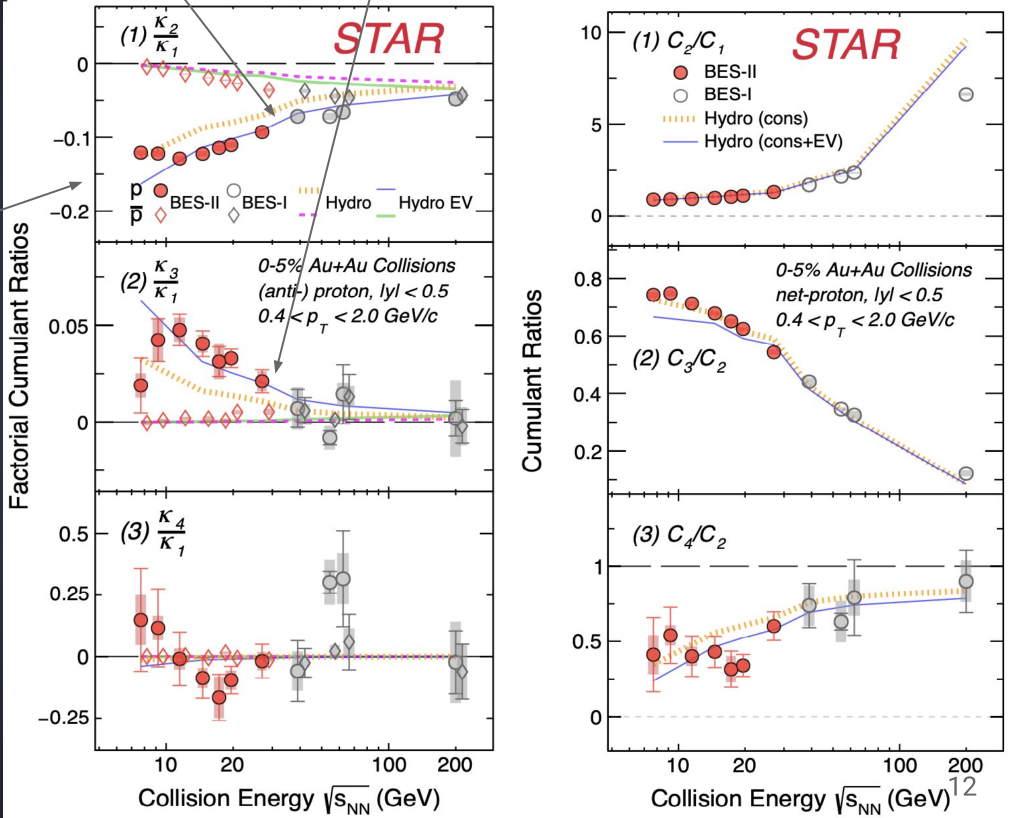
High-Order Moments and EoS Theory Overview

- Factorial cumulants may be more instructive than ordinary cumulants
- Deviations from available non-critical baseline at < 20 GeV



Need precise handle on non-critical contributions

baseline > 0 & baseline < 0



Baseline model comparison to STAR data updated

Dilepton analysis

Chenliang Jin

Dilepton act as Spectrometer, Thermometer, Chronometer, with BES-I&II data help map QCD phase diagram

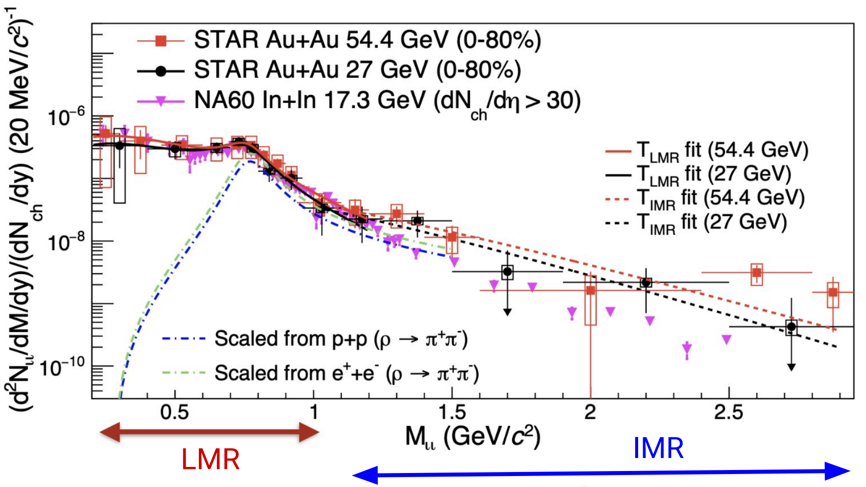
As Thermometer:

Low mass range:

- Results indicate the thermal radiation from hadronic gas is mainly produced around the phase transition
- Close to LQCD prediction

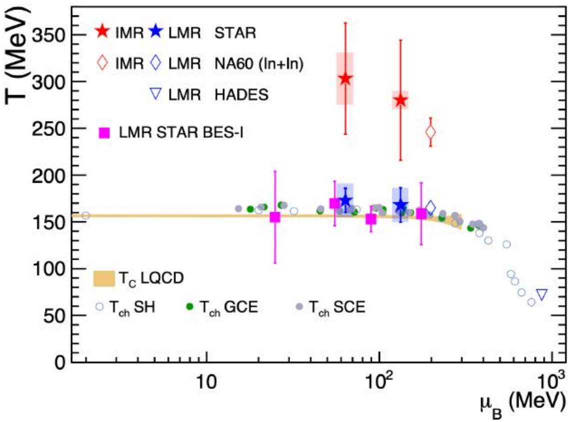
Intermediate mass range:

- Thermal dileptons mainly emitted from QGP phase



$T_{LMR}^{54.4\,GeV} = 172 \pm 12(stat.) \pm 18(sys.)$ MeV $T_{IMR}^{54.4\,GeV} = 303 \pm 59(stat.) \pm 28(sys.)$ MeV

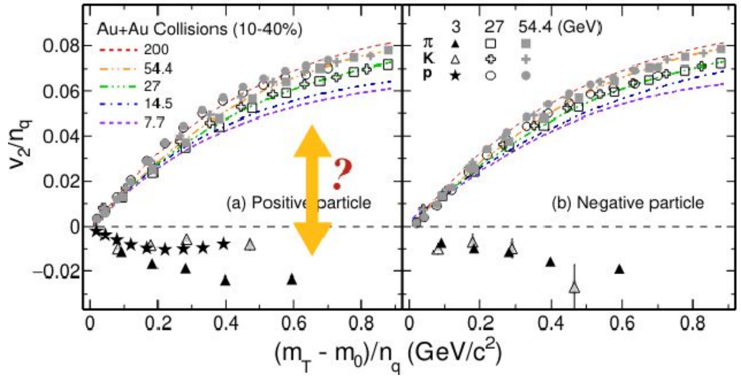
$T_{LMR}^{27\,GeV} = 167 \pm 21(stat.) \pm 18(sys.)$ MeV $T_{IMR}^{27\,GeV} = 280 \pm 64(stat.) \pm 10(sys.)$ MeV

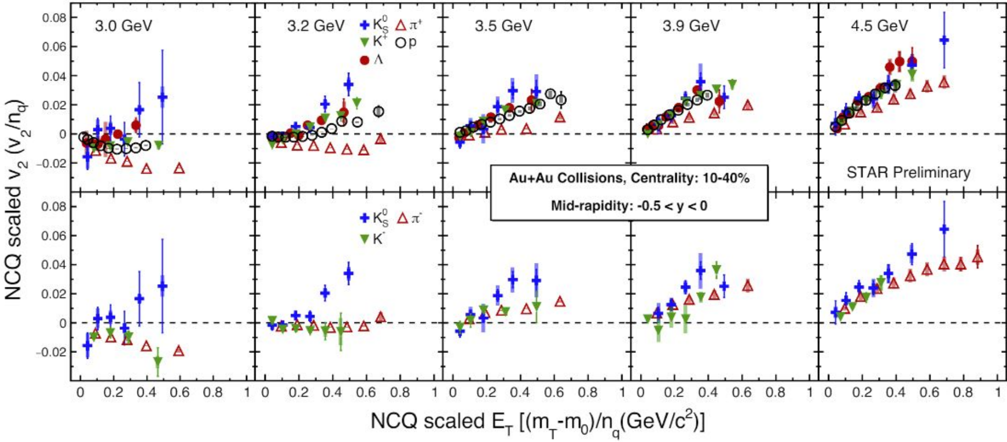


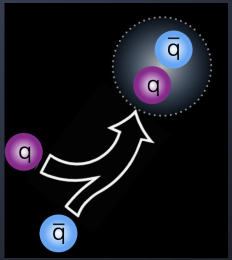
Emilie Duckworth

Flow in BES

- Partonic collectivity key signature of QGP
- See partonic collectivity in NCQ scaling from BES I
- NCQ scaling becomes gradually better with energy increasing
- Violation seen at the lowest energy showing absence of partonic phase







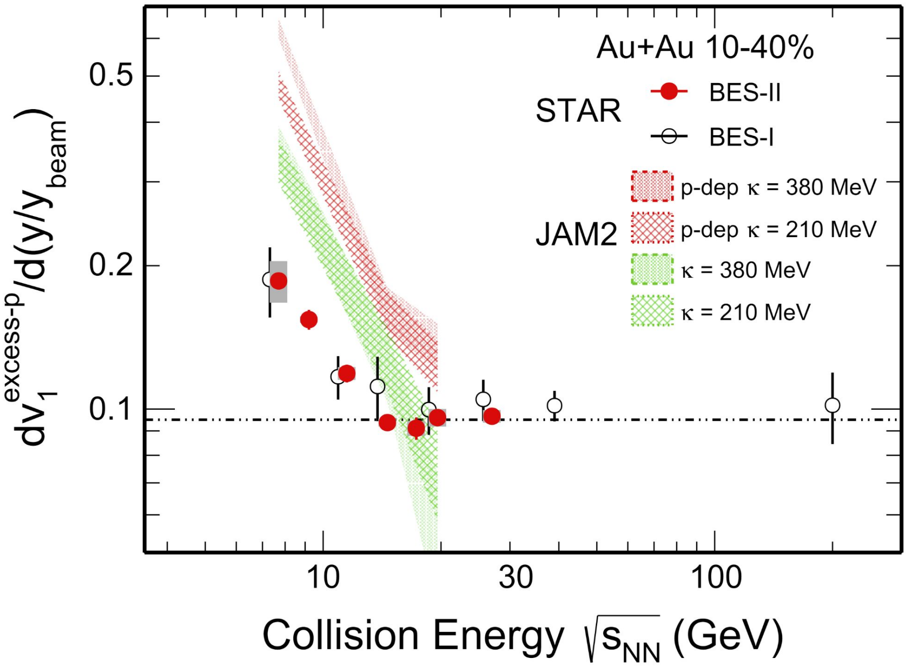
Emilie Duckworth

Flow in BES

- Rapidity slope of directed flow of excess proton primarily from baryon transport measured
- Trivial effect of beam-rapidity change removed
- Below 14.6 GeV JAM model overpredict the magnitude of the data
- Adding momentum dependence to the potential increases this overprediction

$$N_p v_{1,p} = N_p v_{1,medium} + (N_p - N_{\bar{p}}) v_{1,excess}$$

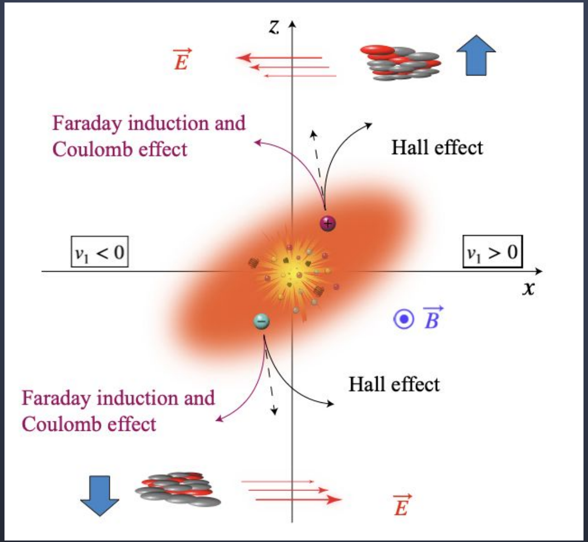
$$y_{beam}(\sqrt{s_{NN}}) = \cosh^{-1}(\sqrt{s_{NN}}/m_p)$$

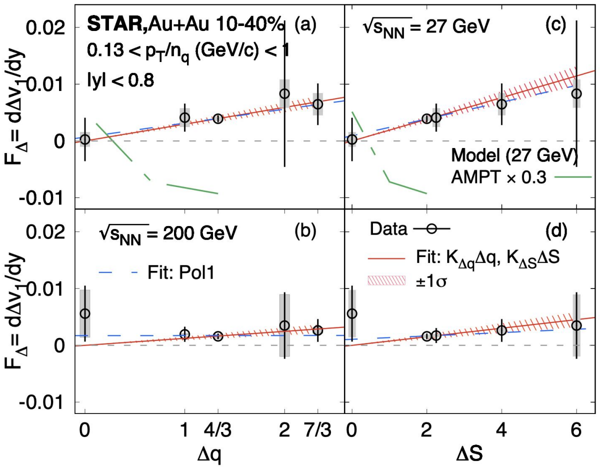


v_1 splitting & EM−field

Aditya Prasad Dash

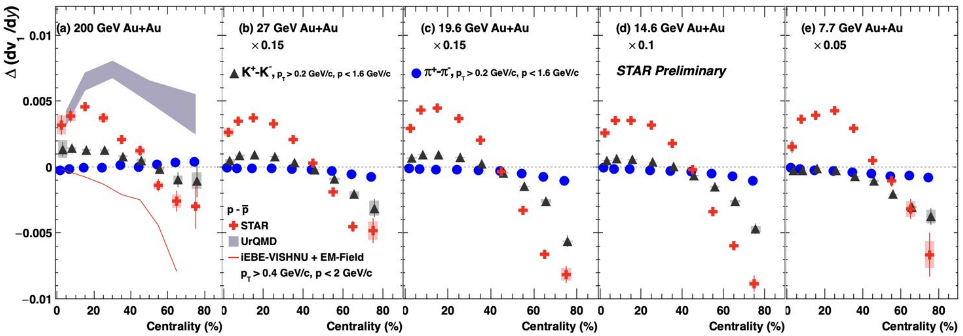
- EM-field in heavy ion collisions is predicted to lead to difference in v_1 for positive and negative particles
- Competition of Hall and Faraday+Coulomb effect determines the sign of v_1 splitting





Central events (10-40%): consistent with dominant Hall effect

Peripheral events (40-100%): consistent with dominant Faraday + Coulomb effect



Observation consistent with EM-field effect seen, stronger effect at lower energies, alternative explanation under investigation

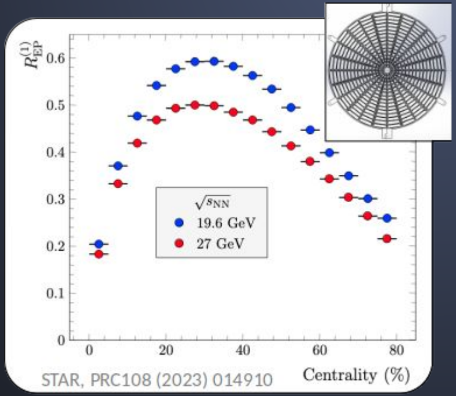
Polarization

Michael Lisa

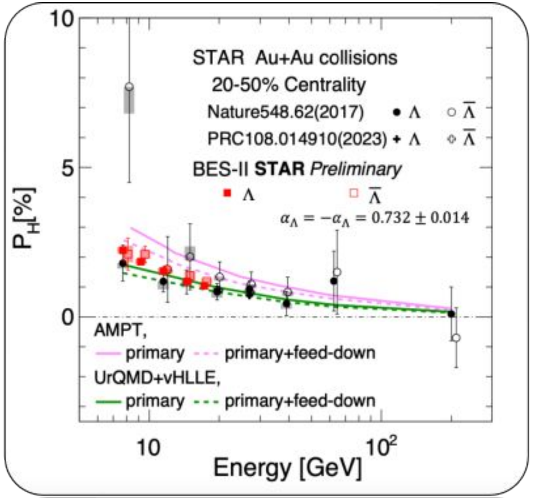
BES-I: hyperon polarization, discovery from BES program

Vortical structure of the medium revealed

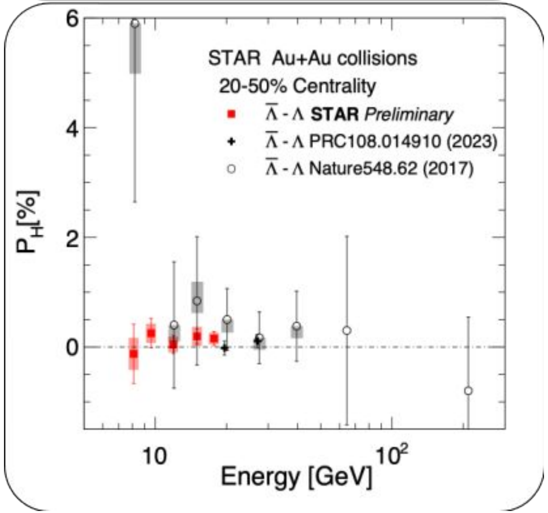
BES-II: Is there difference between Lambda & Lambda-bar due to B-field & magnetic moment ?



Improved EP resolution (BBC->EPD), higher statistics data with BES-II enables us to study B-field driven splitting of polarization



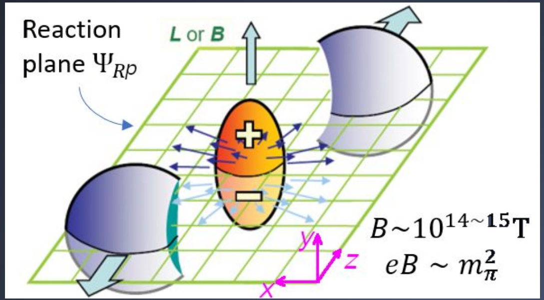
Improved, high-precision Lambda, Xi polarization measured with BES-II data from STAR collaboration



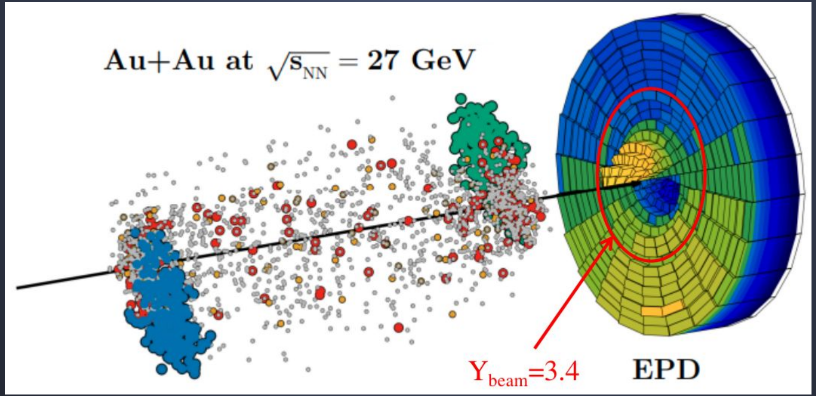
No observable difference between Lambda and anti-Lambda polarization expected due to B-field is observed

Chiral Magnetic Effect

Yicheng Feng



The precondition of CME changes with energy: B-field, de-confined medium with chiral symmetry restoration

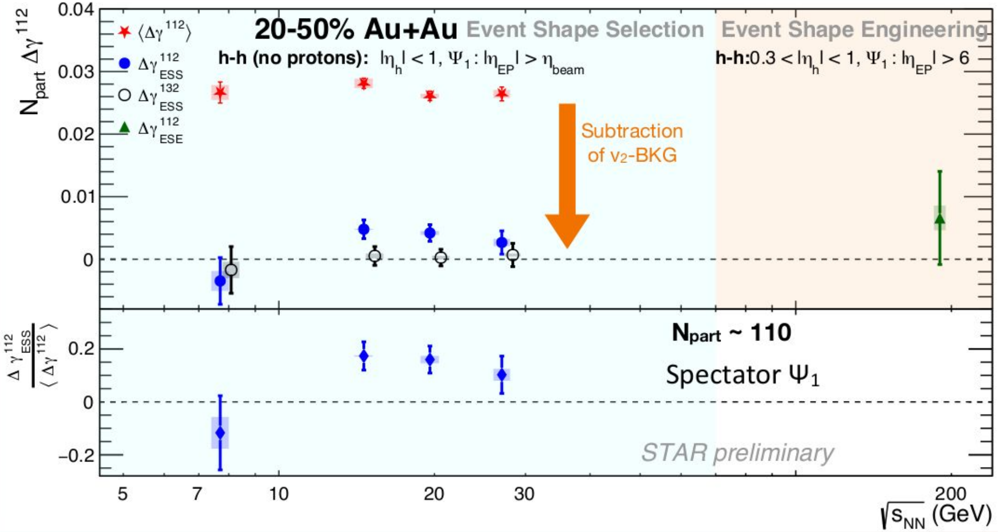


STAR EPD enables forward proton-rich plane that is highly correlated to B-field: perfect for CME search

Major challenge: suppression of non-CME background

Isobar program provided strong constraint on CME search at top RHIC energy → How about low energies?

High statistics data from BES-II, new event-shape-selection (ESS) approach provide large background reduction → opportunity to revisit CME search with energy

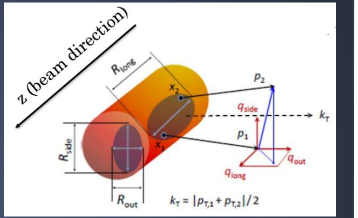


New BES analysis show a upper limit of CME signal with 3-sigma significance with apparent energy dependence: more studies ongoing on ESS method, nonflow, other technique & more data coming from STAR

Femtoscopy

Femtoscopy allows one to explore:

- Size of the emission source
- Lifetime of source
- Emission duration
- System dynamics
- Source shape
- Orientation

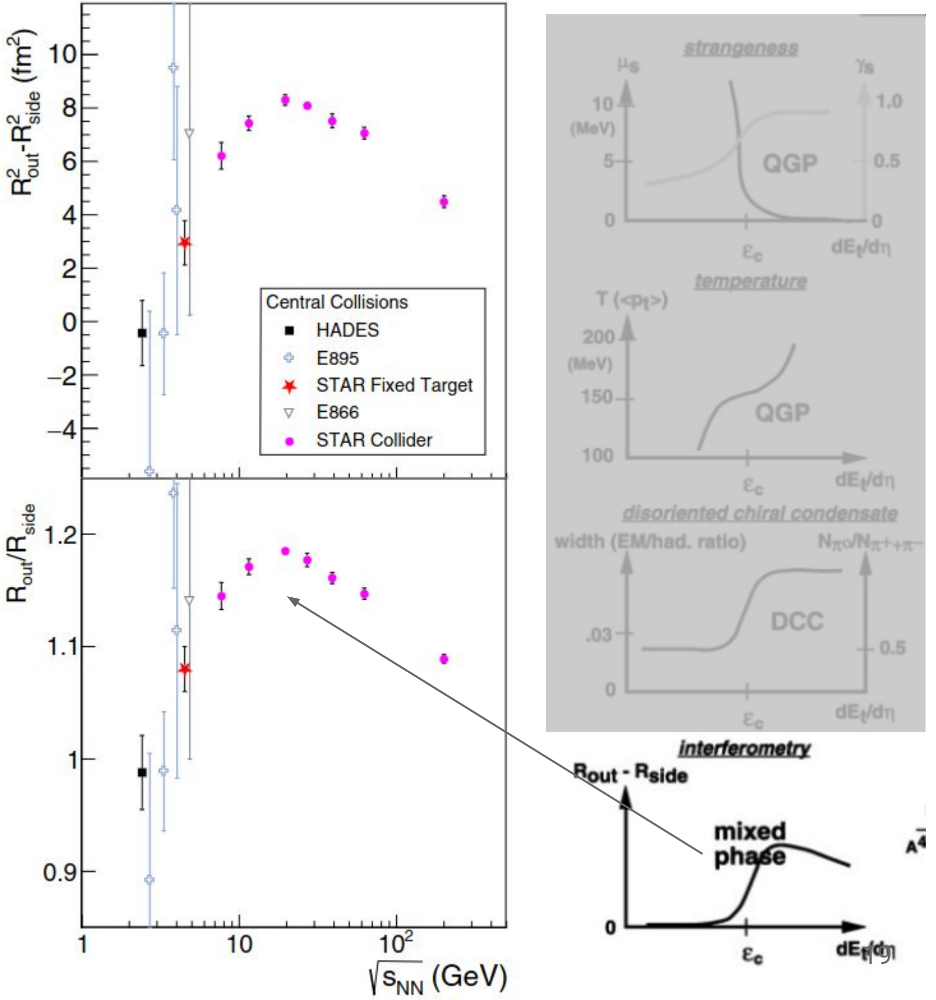


One of the most-anticipated ”golden” signatures of QGP formation at RHIC

- generic expectation
- magnitude unclear

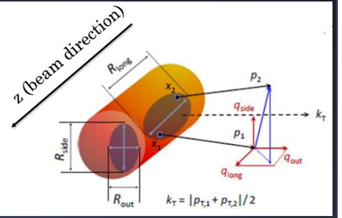
This golden signature is clearly seen … but barely touched by theory community!

Michael Lisa



Michael Lisa

Femtoscopy Overview



Femtoscop

- Size
- Lifeti
- Emis
- Syst
- Sour
- Orientation

The behavior is consistent with the interpretation of a minimum of the compressibility around T_c during hadron emission, but a firm conclusion will require a detailed theoretical analysis, which is not yet available.

\- Harris & Müller, "QGP Signatures Revisited" arxiv:2308.05743

One of the most-anticipated "golden" signatures of QGP formation at RHIC

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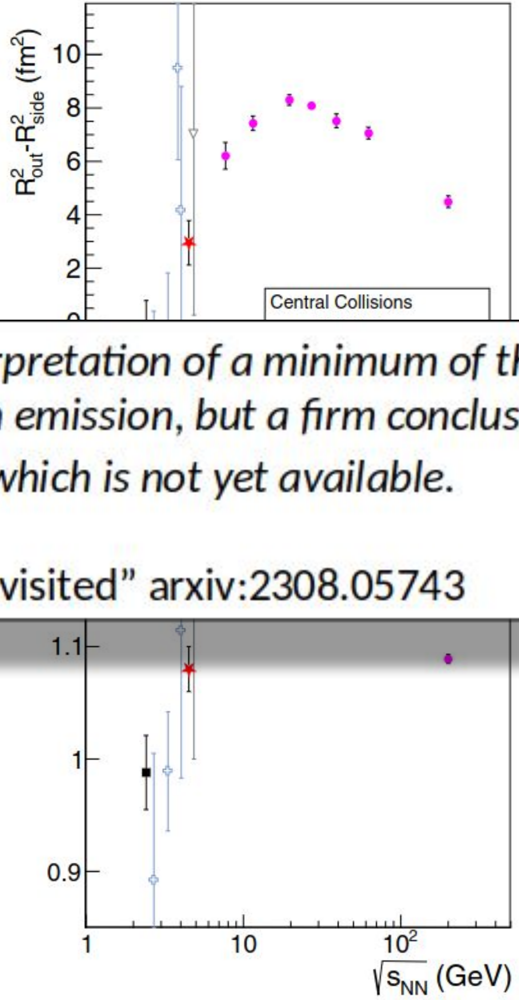
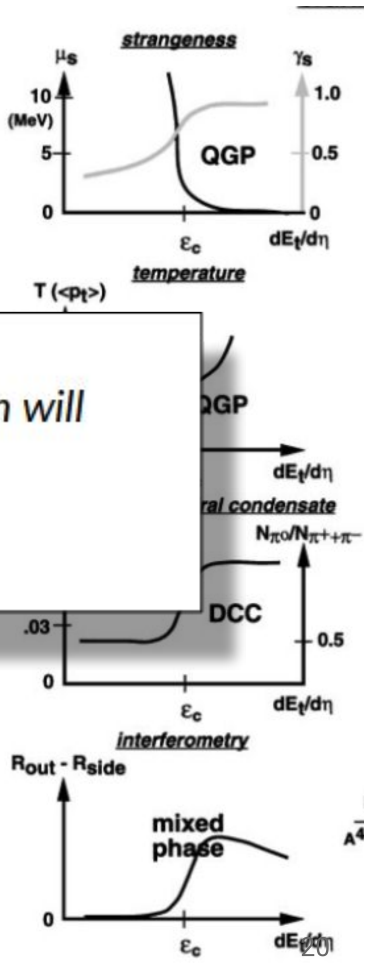
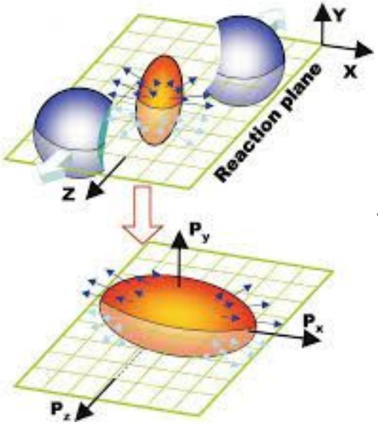
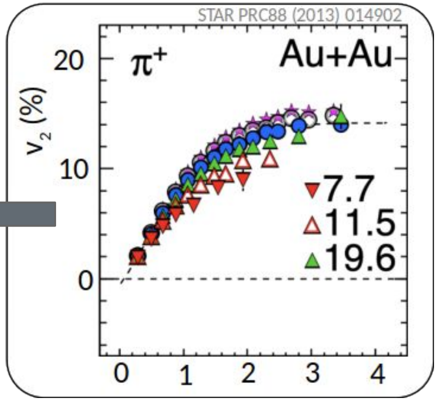




Femtoscopy

Michael Lisa



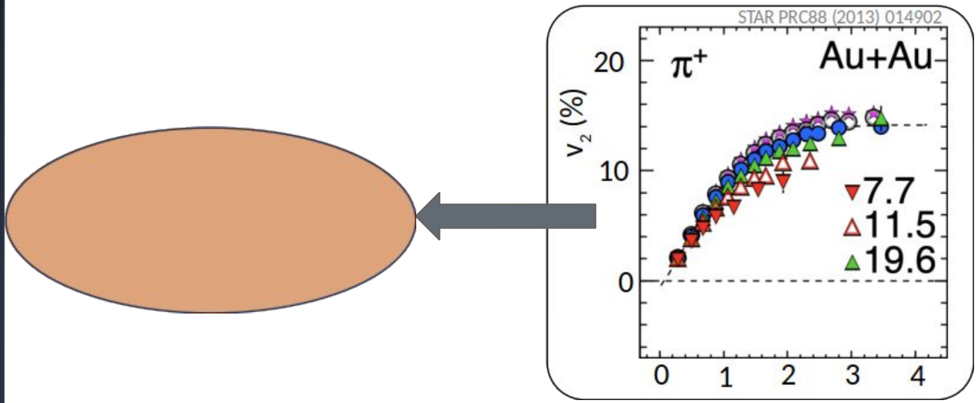


In momentum space emission source extended in-plane

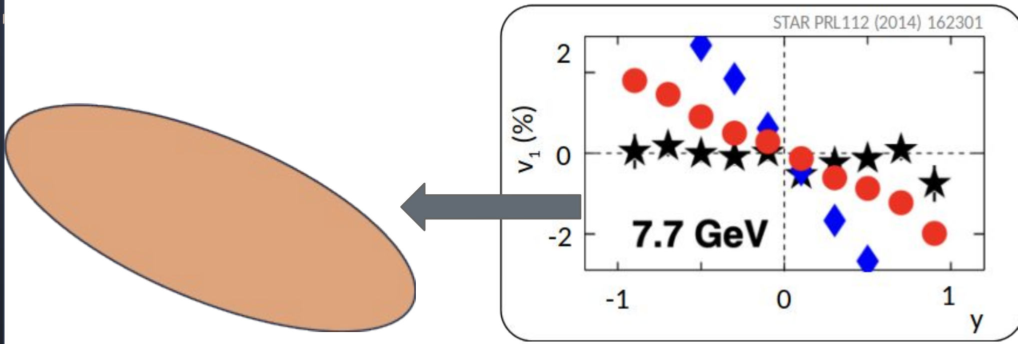
Michael Lisa

Femtoscopy

What is the situation in coordinate space?



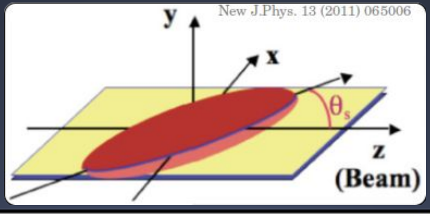
In momentum space emission source extended in-plane

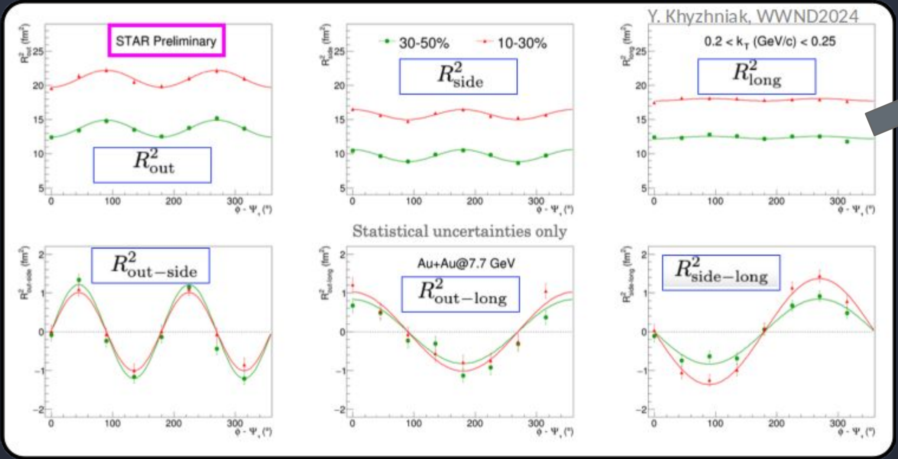


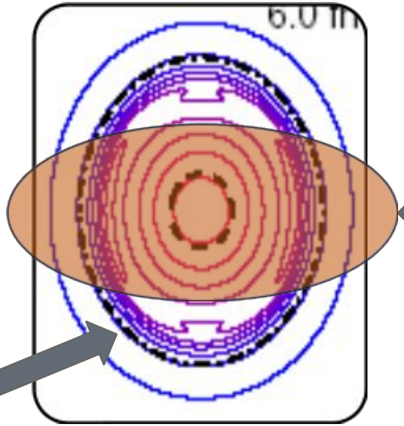
Negative pion tilt in momentum space

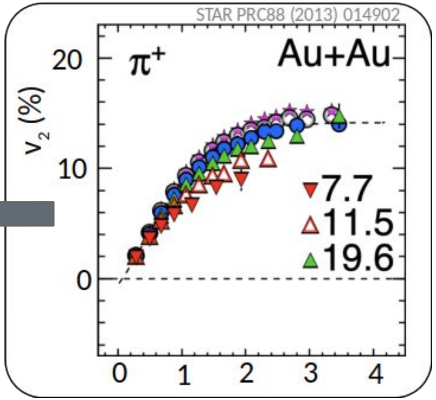
Michael Lisa

Femtoscopy

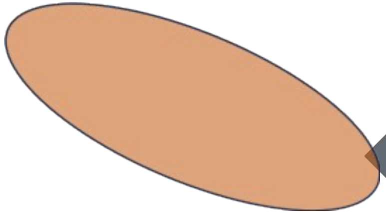


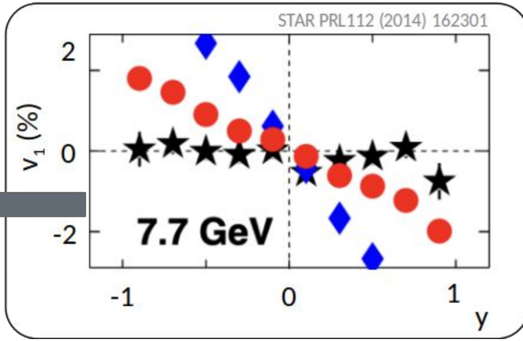






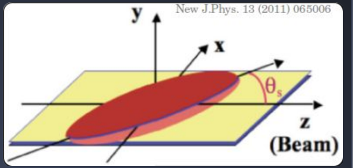
Femtoscopy shows out-of-plane extension in the coordinate space => stronger in-plane pressure gradients => leading to positive v_2

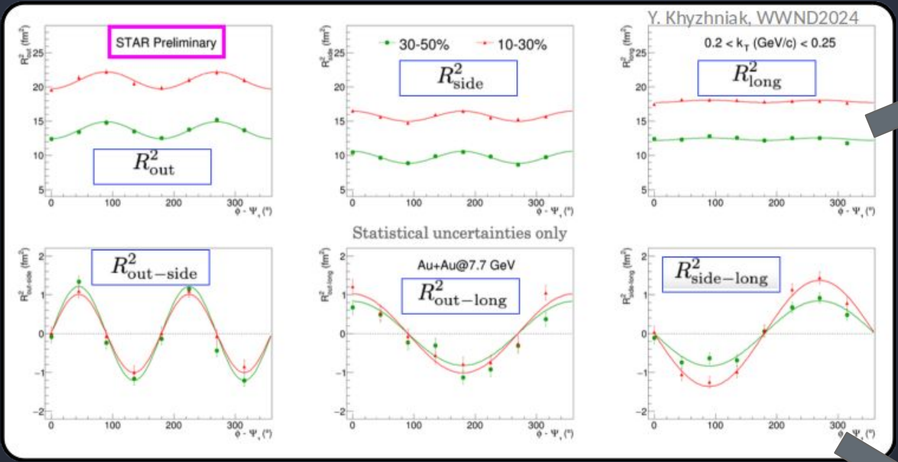


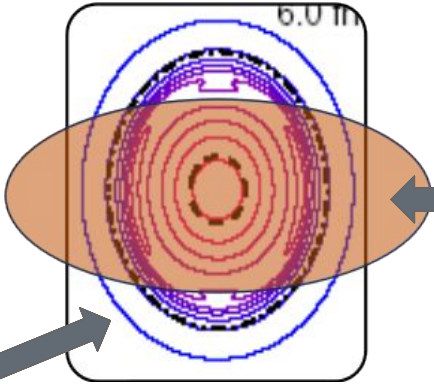


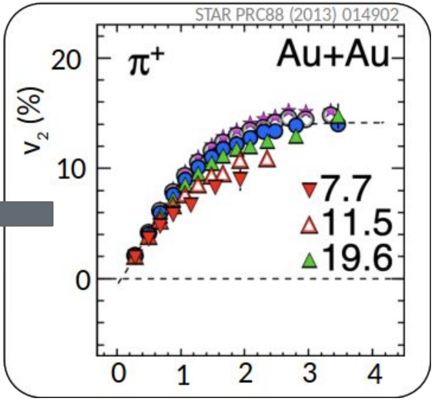
Femtoscopy

Michael Lisa

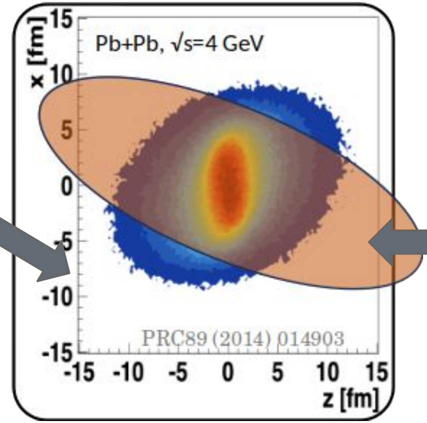


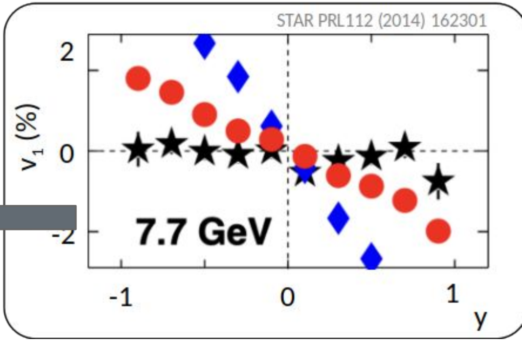






Same reasoning for v_1 existence = stronger pressure gradients along shorter axis of the tilted source? Not determined, but studies are ongoing





What does the spatial tilt tell us about the (anti)flow at midrapidity?

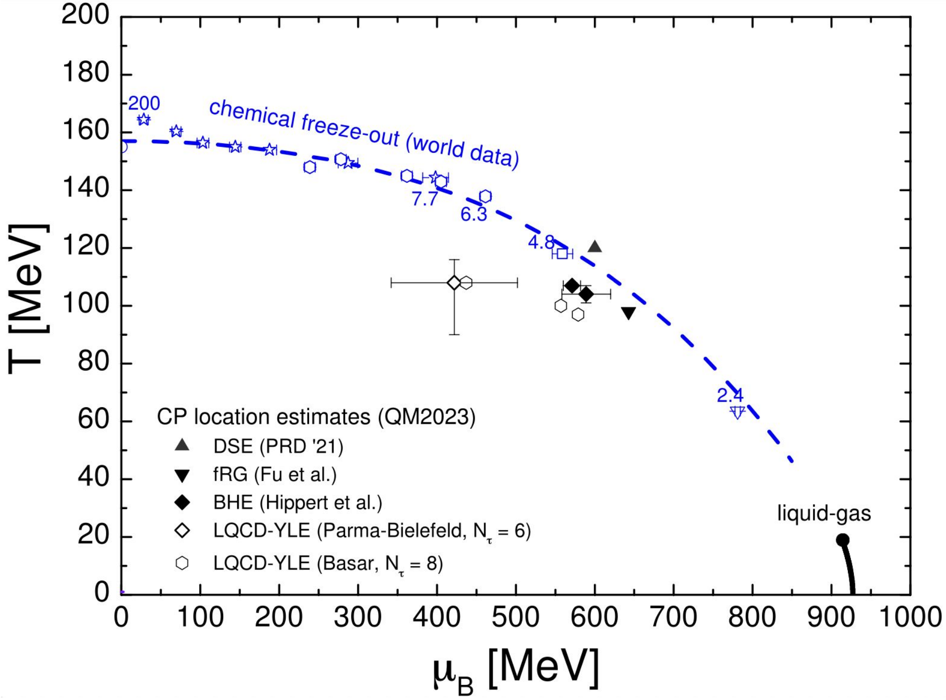
There is no summary, because it’s already summary of summaries……..

Thanks for the attention!

Volodymyr Vovchenko

High-Order Moments and EoS Theory Overview

- Recent estimates from theory put the possible CP at -110 MeV, -600 MeV
- Motivates the search with heavy-ion collisions at energies at GeV



Polarization

Michael Lisa

Blast-wave is not hydrodynamics

Full hydrodynamic calculation: vorticity alone predicts a polarization with incorrect sign!

- "longitudinal polarization sign puzzle"

Shear-induced polarization generates (large) polarization, that competes

- different groups have different formulations, with different trends and admixtures

New STAR BES results may yield insight on this fundamental question