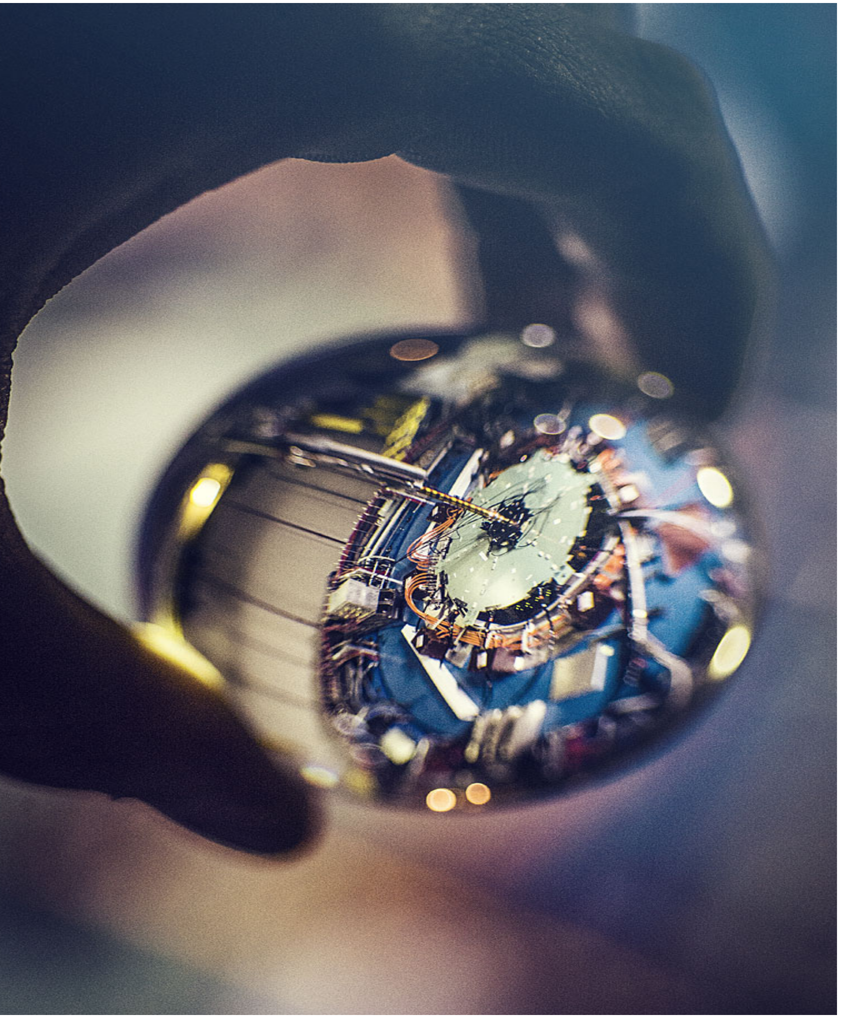
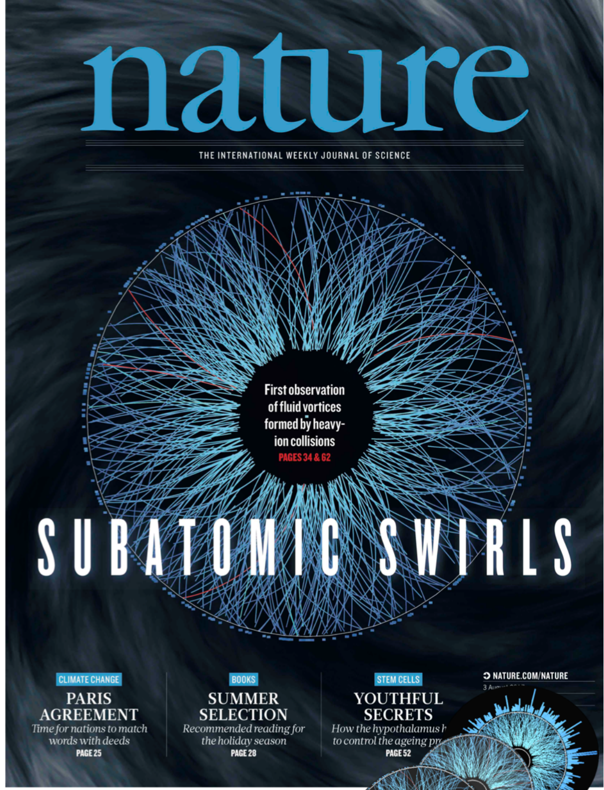
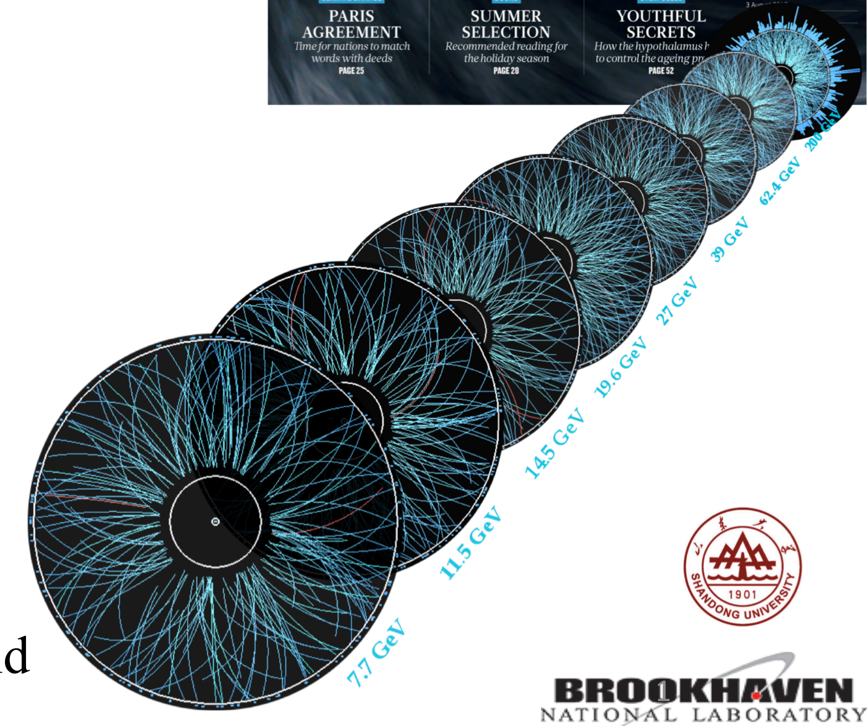
STAR Plan for future Heavy-Ion Physics



Zhangbu Xu
for the STAR Collaboration

- 2021+ Unique Physics cases
  - **nPDF**
    forward jets/γ/DY
  - **Viscosity [η/s(T)]**
    multiple harmonics and rapidity correlations
  - **Vorticity**
    Rapidity dependence of Global Hyperon Polarization
  - **Luminosity**
    dilepton yields,
    resolving photon puzzle
  - **Conductivity**
    Create and Probe Magnetic Field



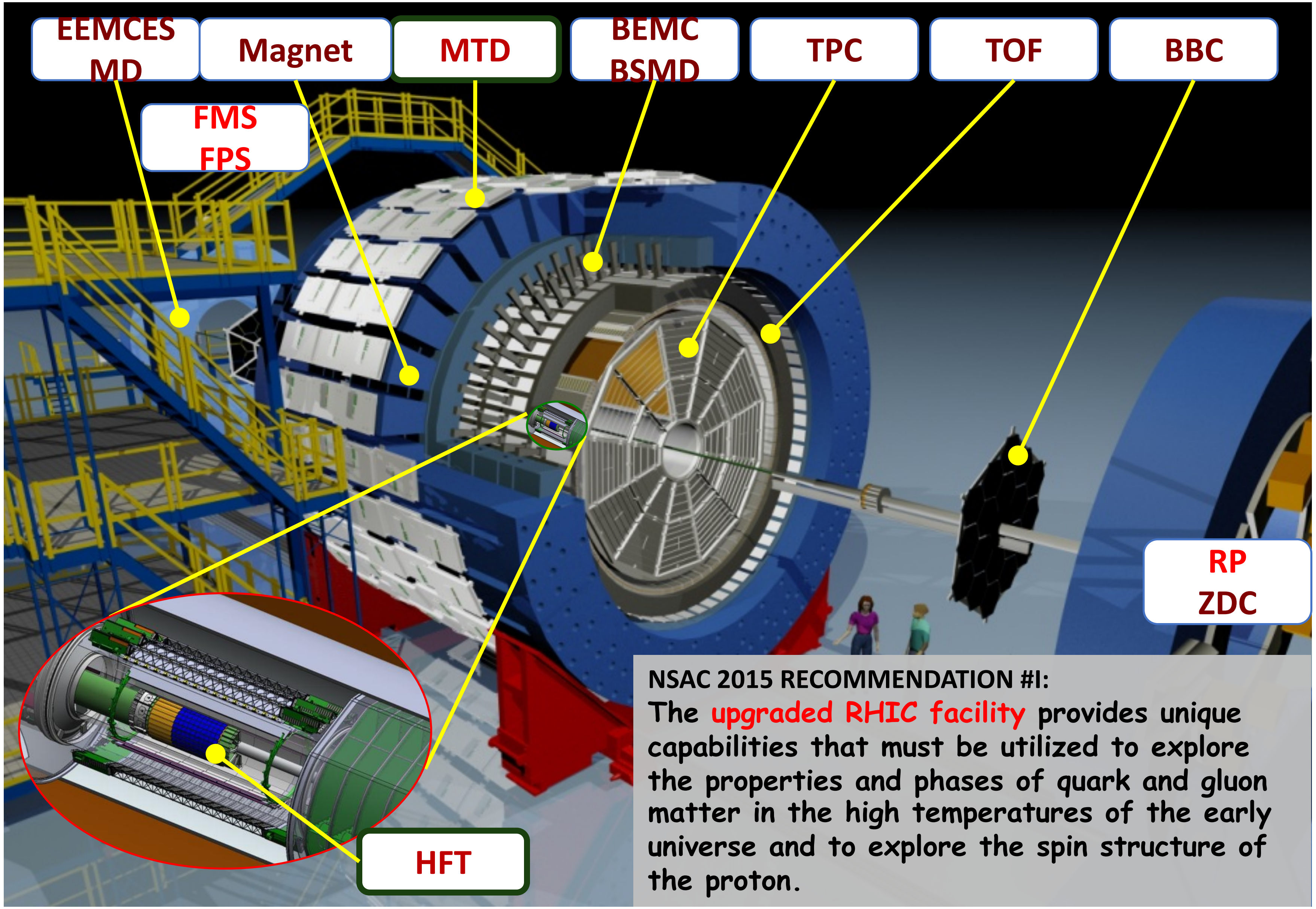


www.star.bnl.gov

The STAR experiment
at the Relativistic Heavy Ion Collider, Brookhaven National Laboratory

BROOKHAVEN NATIONAL LABORATORY

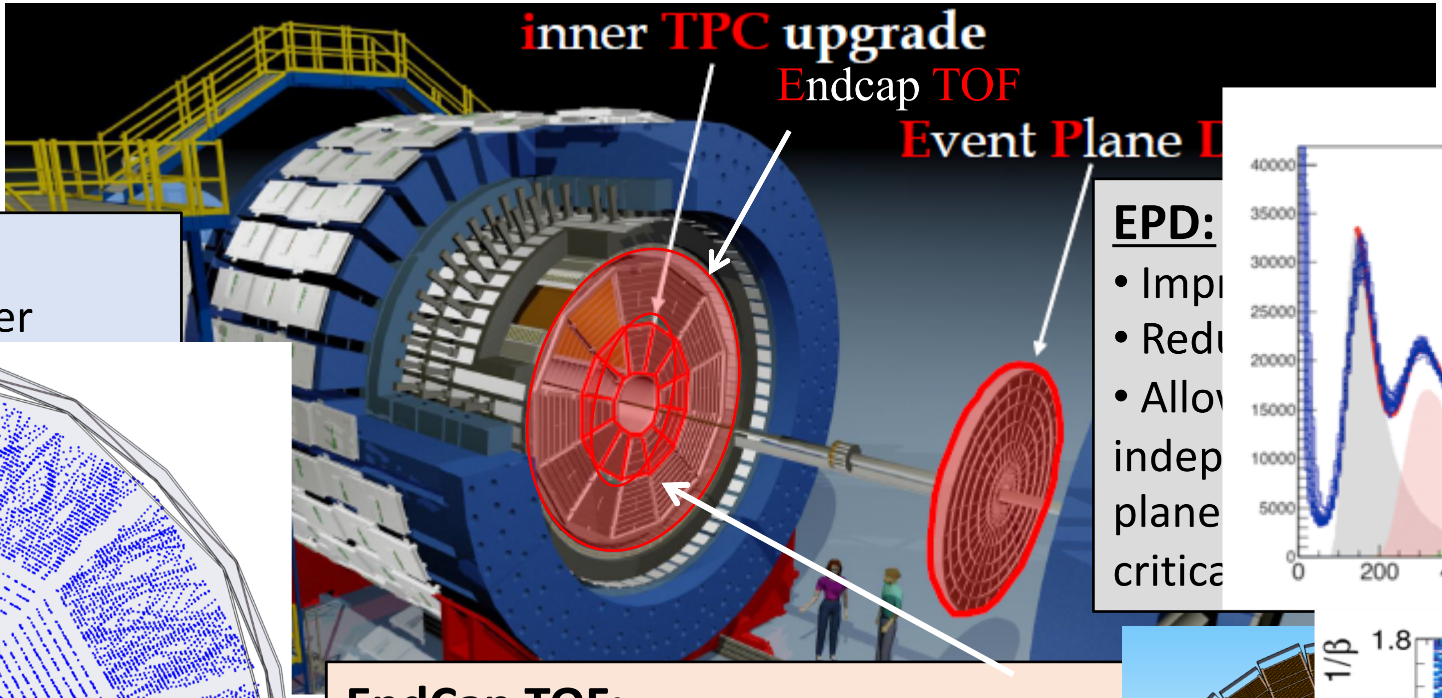
Current STAR Detector System



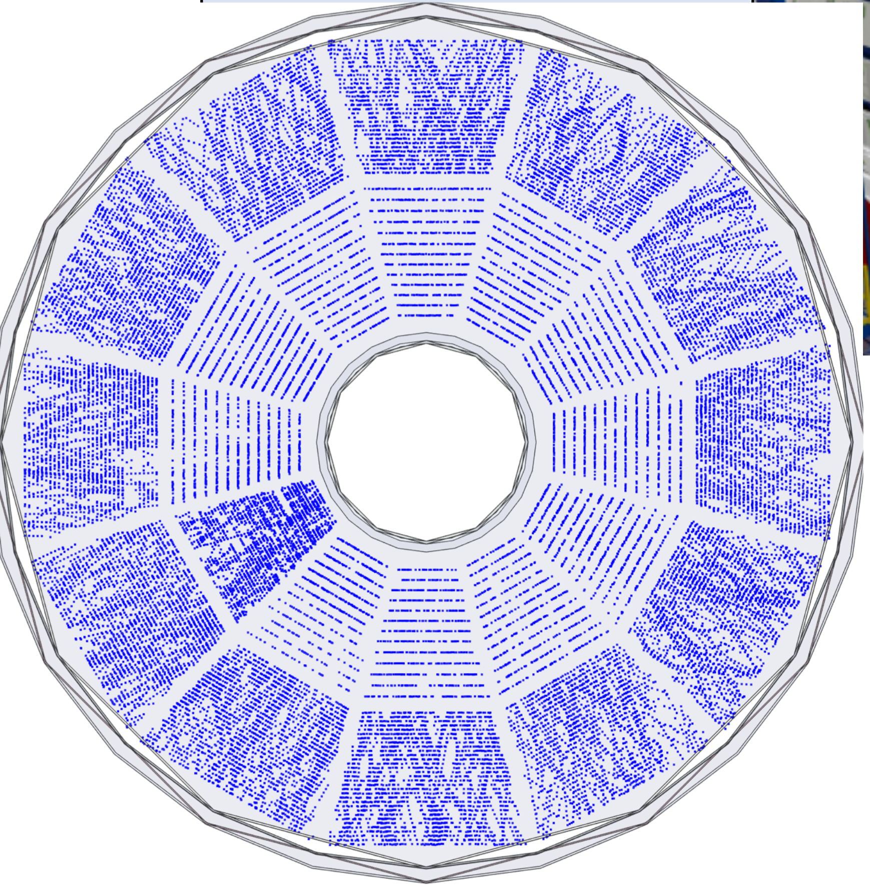
NSAC 2015 RECOMMENDATION #I:
The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.

x10^3 increases in DAQ rate (4000Hz) since 2000, most precise Silicon Detector(HFT 2014-16)

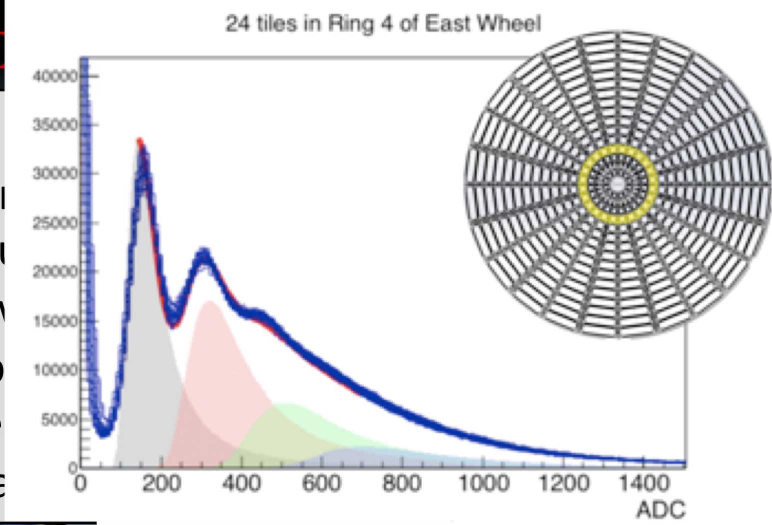
STAR Major Upgrades for BES-II



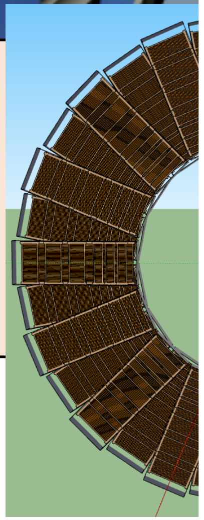
iTPC:
- Rebuilds the inner

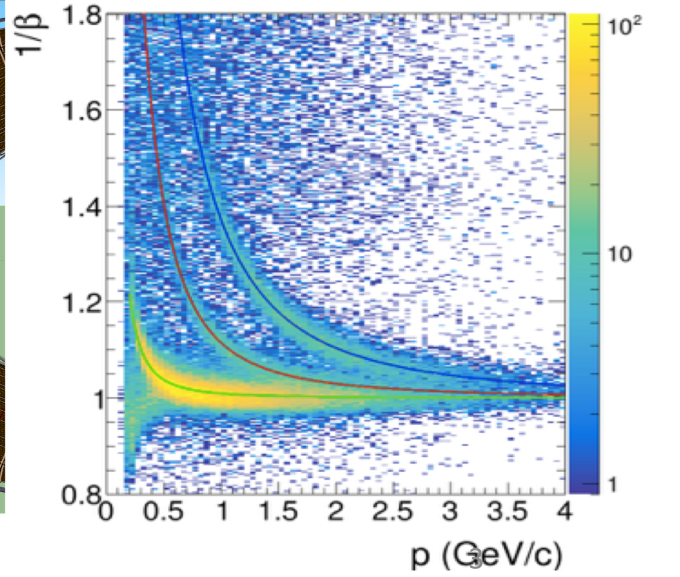


EPD:
- Impr
- Redu
- Allo
indep
plane
critica



EndCap TOF:
- Rapidity coverage is critical
- PID at η = 0.9 to 1.5
- Improves the fixed target program
- Provided by CBM-FAIR





Tracking and PID
From rapidity ±1
Extend to (±)1.5

The STAR Forward Upgrade

Detector	pp and pA	AA
ECal	~10%/√E	~20%/√E
HCal	~60%/√E	---
Tracking	charge separation photon suppression	$0.2<p_T<2$ GeV/c with 20-30% $1/p_T$

Forward Tracking System:

3 Silicon disks: at 90, 140, 187 cm from IR
Built on successful experience with STAR IST
- Single-sided double-metal mini-strip sensors
- Existing IST FEE, DAQ and cooling system

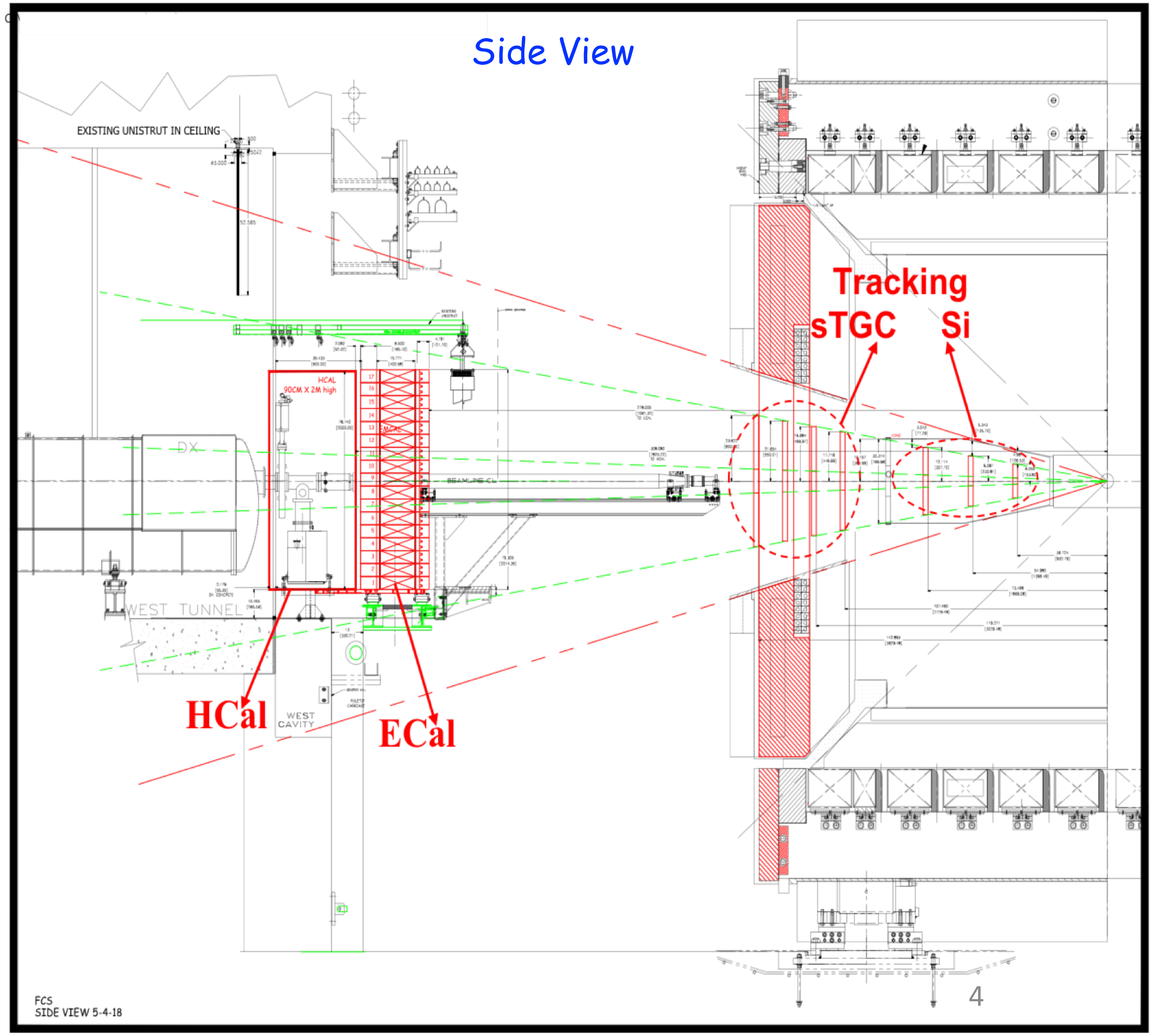
4 sTGC disks: at 270, 300, 330, 360 cm from IP
- Position resolution: ~100 mm
- Readout: reuse current STAR TPC electronics
- 1st sTGC prototype to be installed in STAR in 2019
  - 1/4 size of ATLAS sTGC

Forward Calorimeter System:

ECal:
- ❑ reuse PHENIX PbSC calorimeter with new readout on front phase

HCal:
- ❑ sandwich iron-scintillator plate sampling Calo

Same readout for both calorimeters → cost



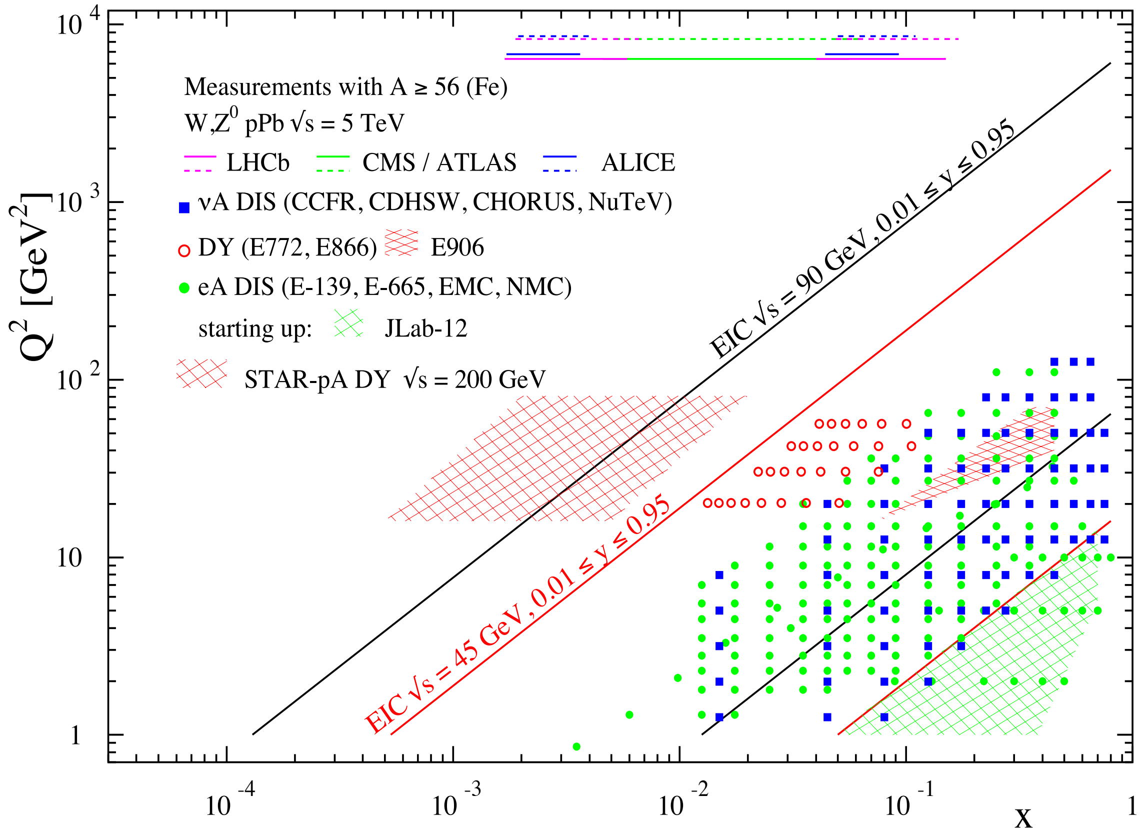
Nuclear PDF and Initial Conditions for A+A collisions

measure nPDF in a x-Q^2 region where nuclear effects are large

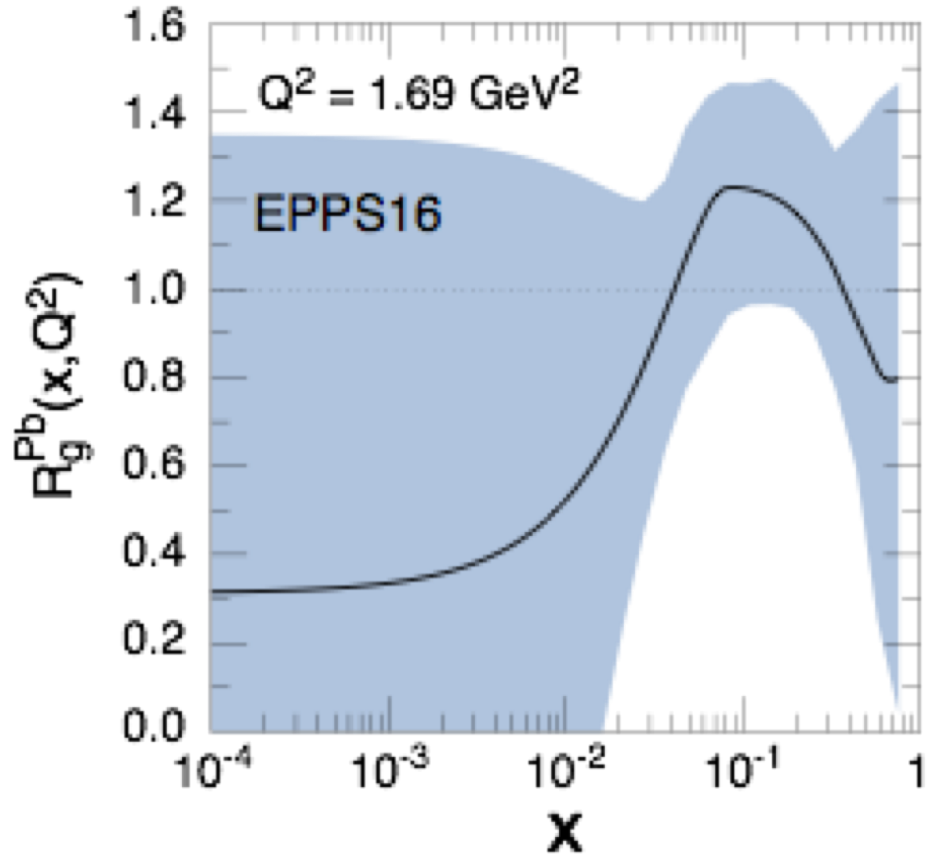
$Q^2 > Q_s^2$ over a wide range in x

Forward upgrade essential

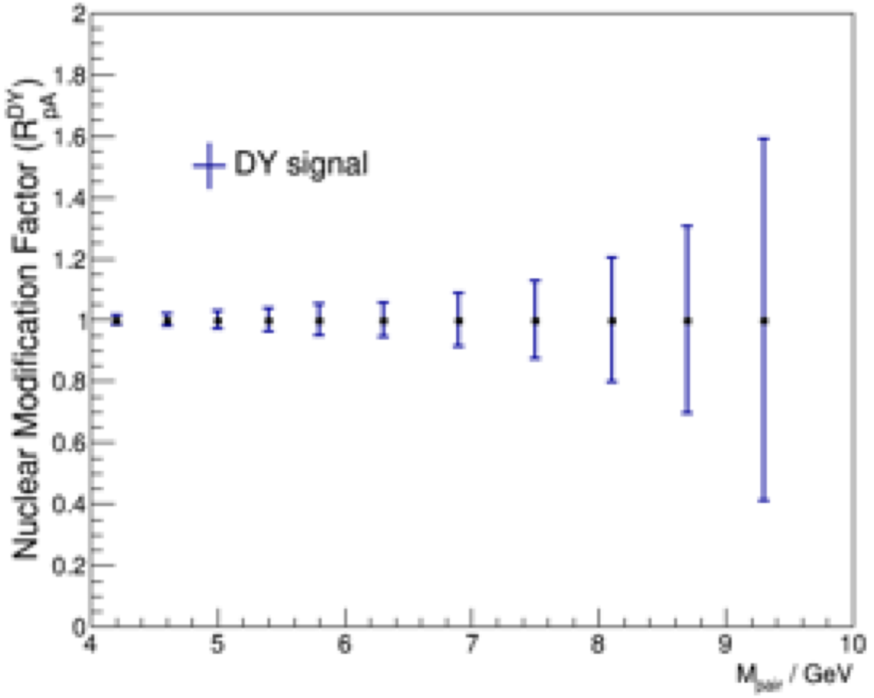
pA@RHIC: unique kinematics



Current knowledge

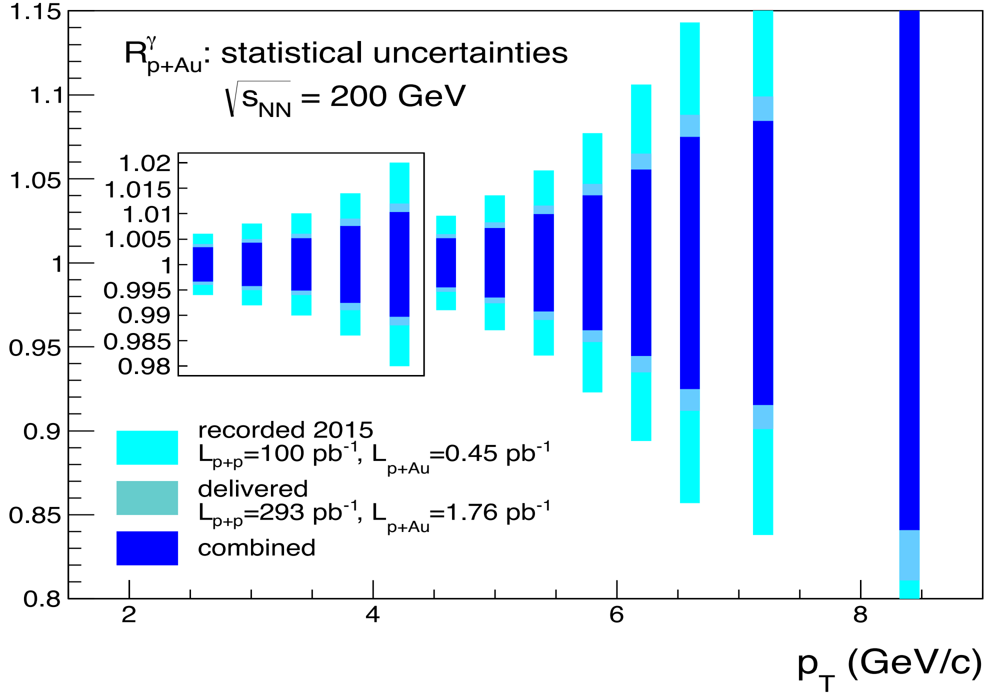


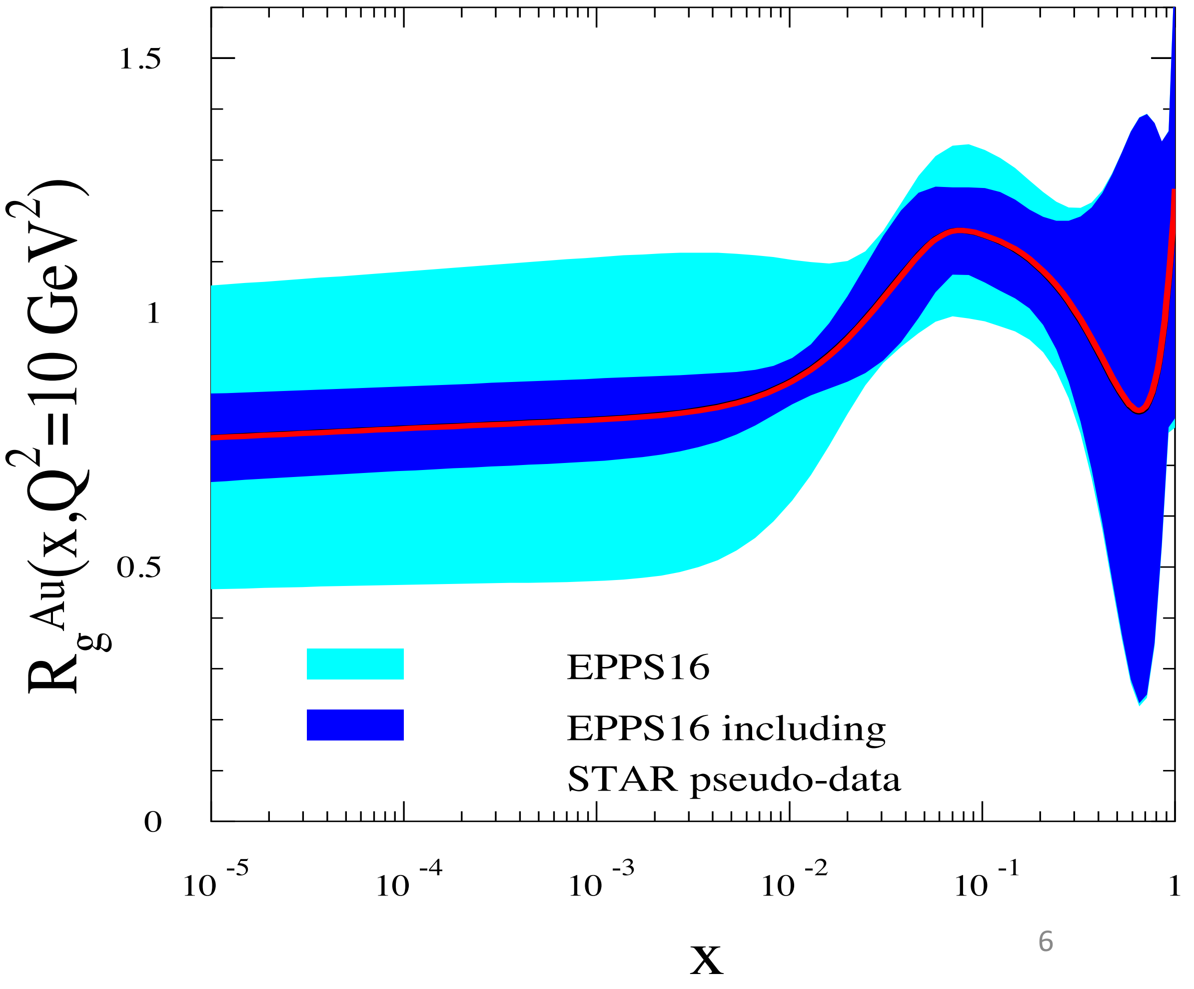
Forward DY and Photon Measurements



DY and direct photon R_{pA} give significant constraints on nPDF
Important input for initial condition in heavy-ion collisions

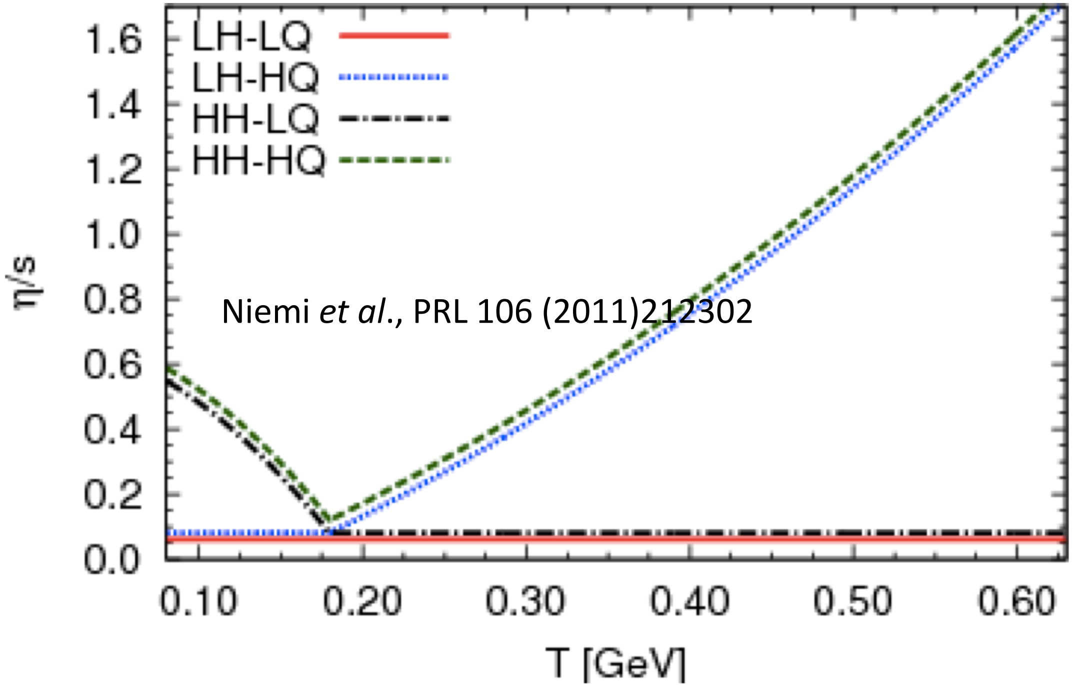
Forward upgrade essential



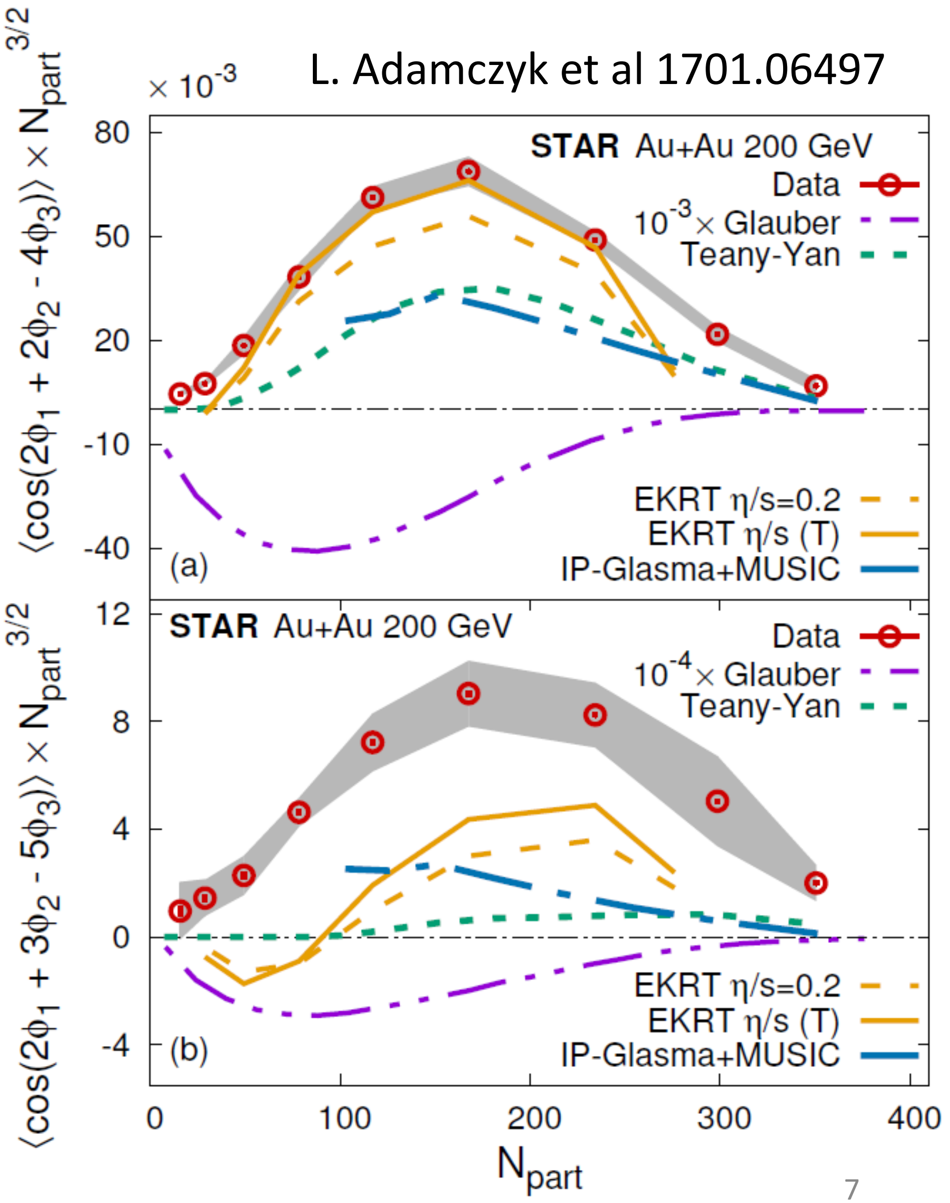


Temperature Dependent Viscosity

2015 US Nuclear Long Range Plan (#22):
comparative analyses of the wealth of bulk observables being measured hint that the hotter QGP created at the LHC has a somewhat larger viscosity.
This temperature dependence will be more tightly constrained by upcoming measurements at RHIC and the LHC.



L. Adamczyk et al 1701.06497



Multiple Flow Harmonic Correlations

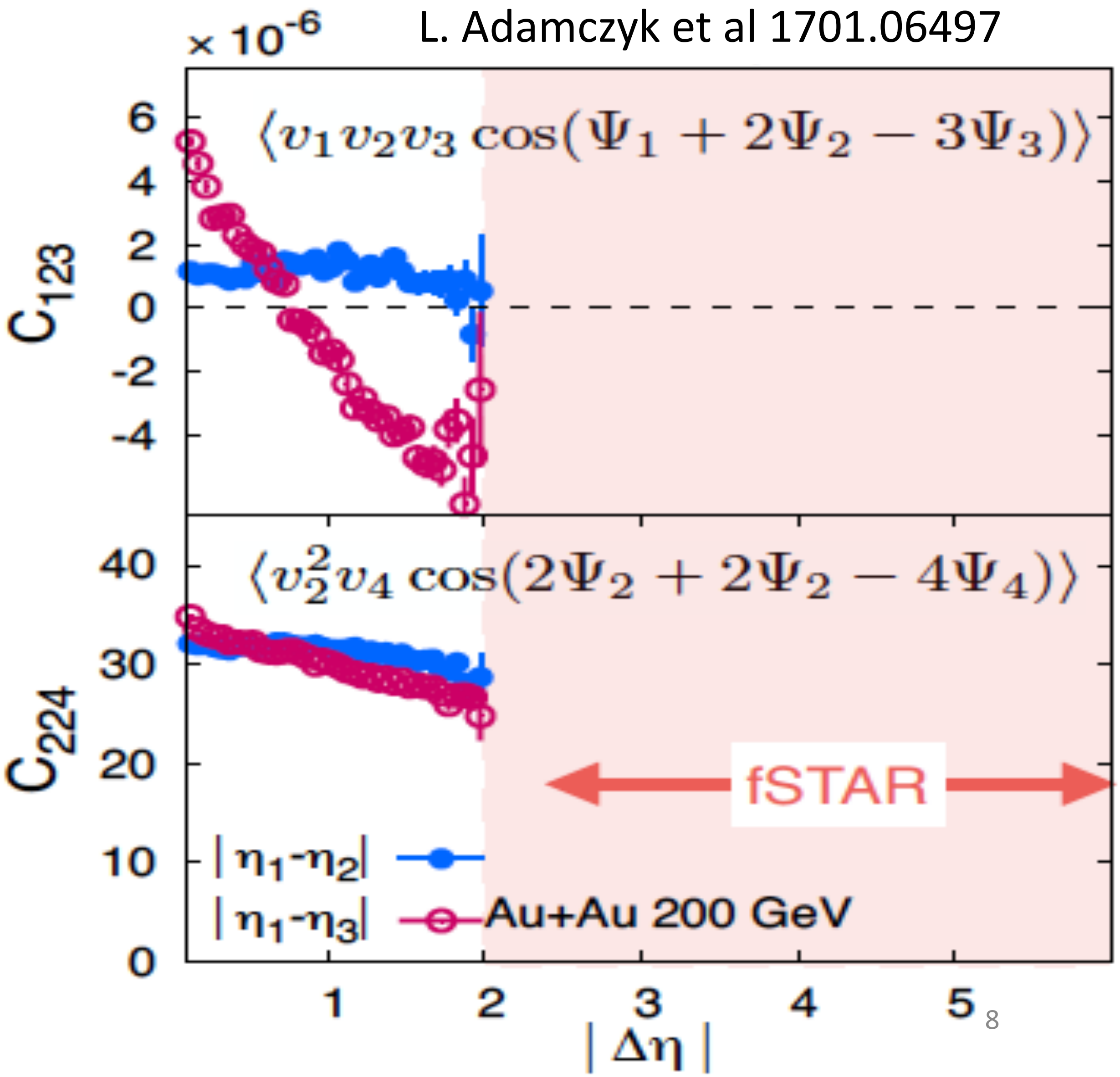
- Sparse RHIC data for higher order flow harmonics (v_3, v_4, v_5) & rapidity density correlations/fluctuations

Why do we need wider window in rapidity?
- Flow like correlations are early time long-range → large $\Delta\eta$
- Background comes from Jets & non-flow → small $\Delta\eta$

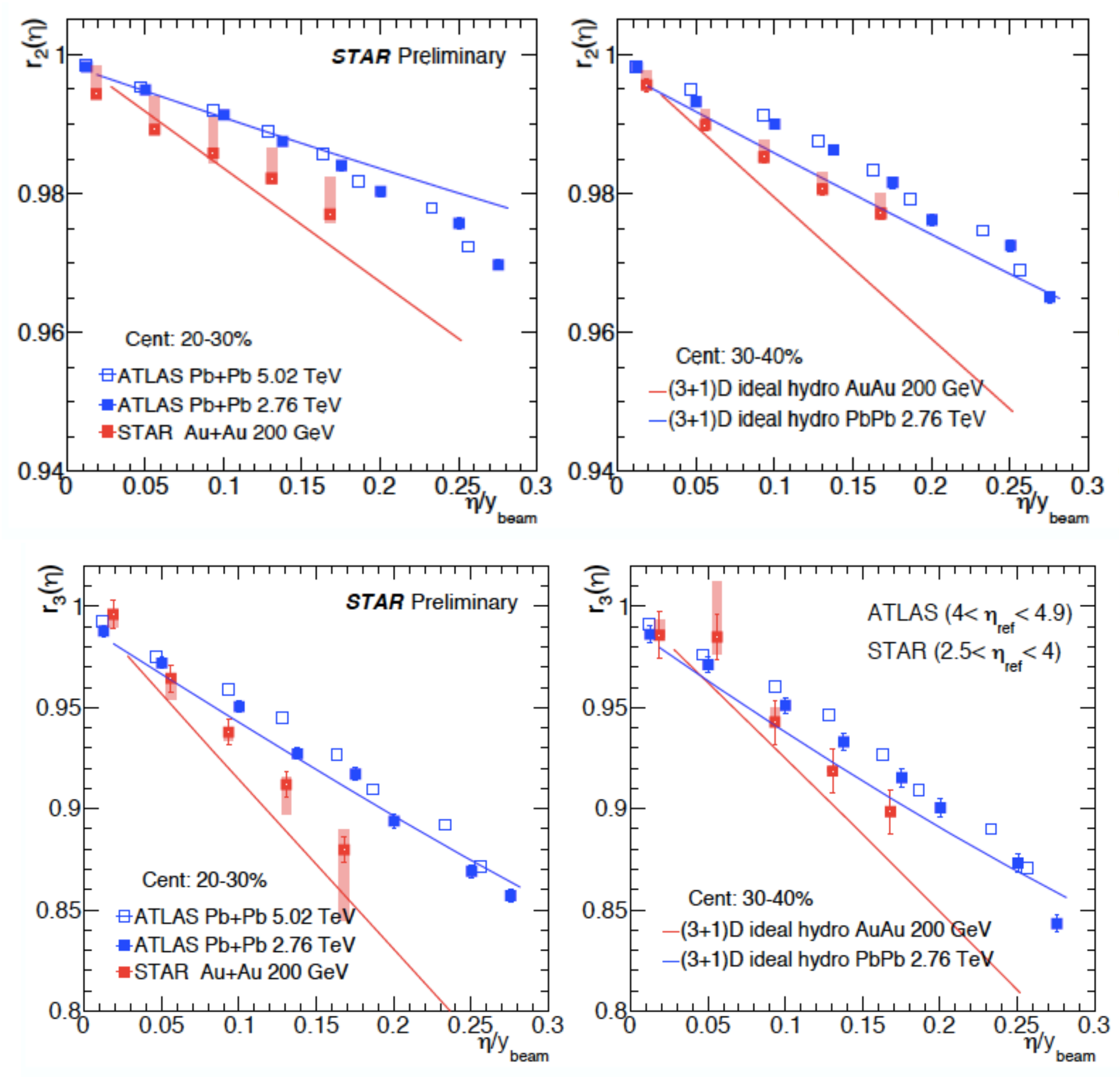
Precise extraction of flow (azimuthal correlations) requires measurements over wide window of rapidity

Forward upgrade essential

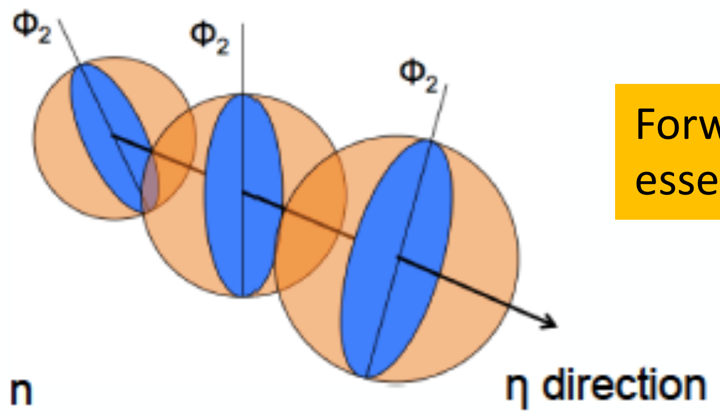
L. Adamczyk et al 1701.06497



Rapidity Decorrelation and Initial State Fluctuations



Torque/twist of event plane



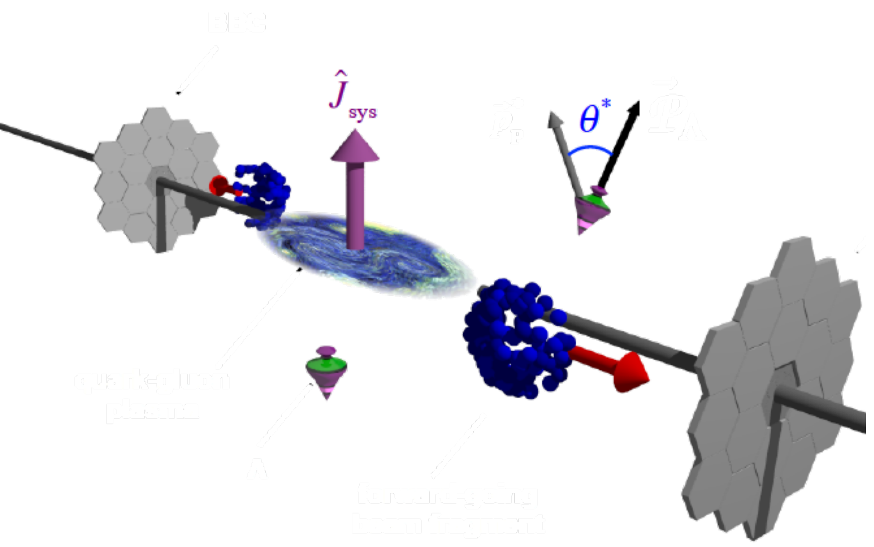
Forward upgrade + EPD essential

$$\Psi_n(\eta_1) \neq \Psi_n(\eta_2)$$

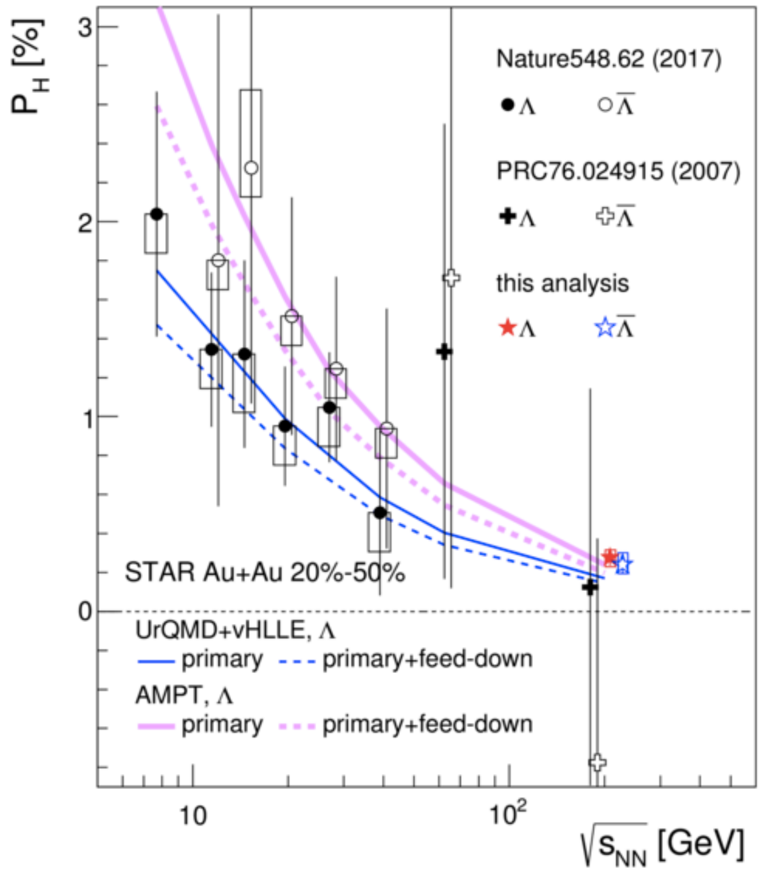
- Rapidity decorrelation sensitive to initial state fluctuations
- Observe large flow decorrelation in longitudinal direction at RHIC
- (3+1)D hydrodynamics tuned for LHC, over-predicts decorrelation at RHIC
- Large uncertainty at RHIC with FTPC and FMS

Global Hyperon Polarization in QGP

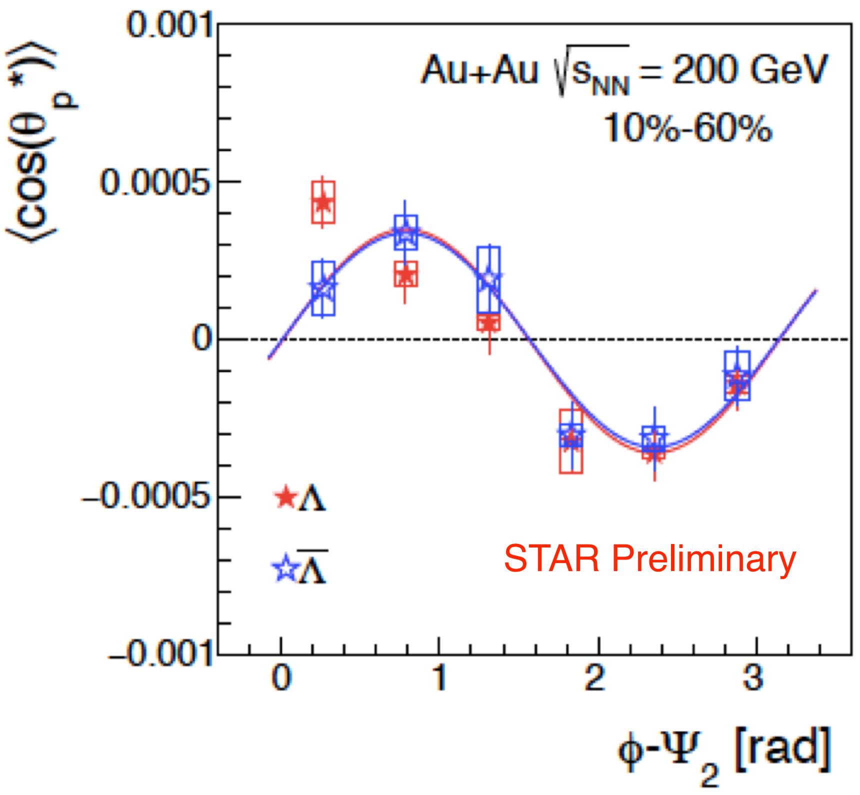
new tool to study QGP and relativistic Quantum fluid Vorticity in general



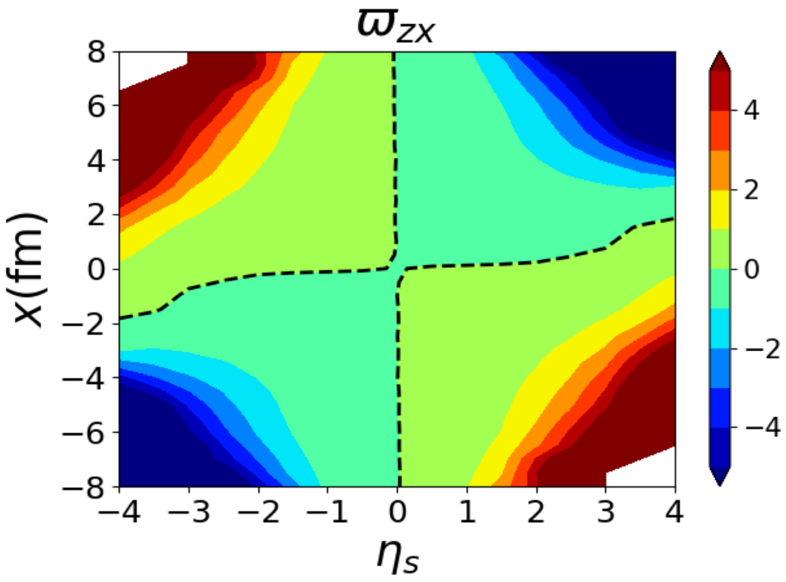
Non-zero global angular momentum transfer to hyperon polarization

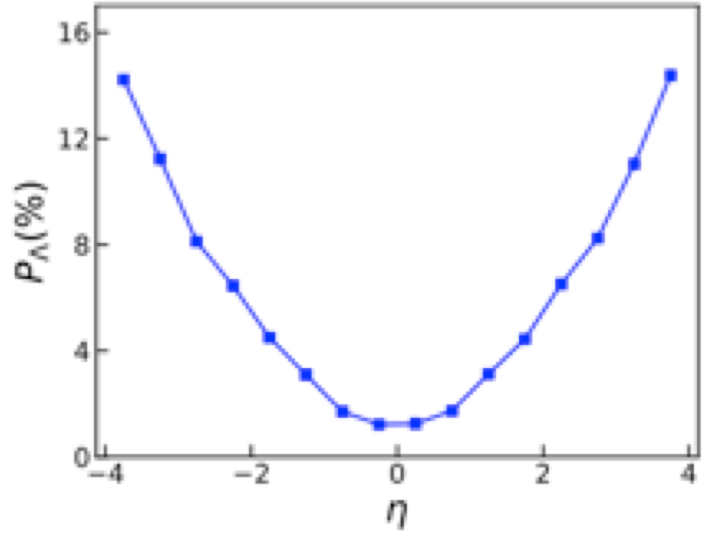


First observation of quadrupole structure of polarization along beam direction;
"sign" opposite to hydro prediction



Rapidity Dependent Global Polarization



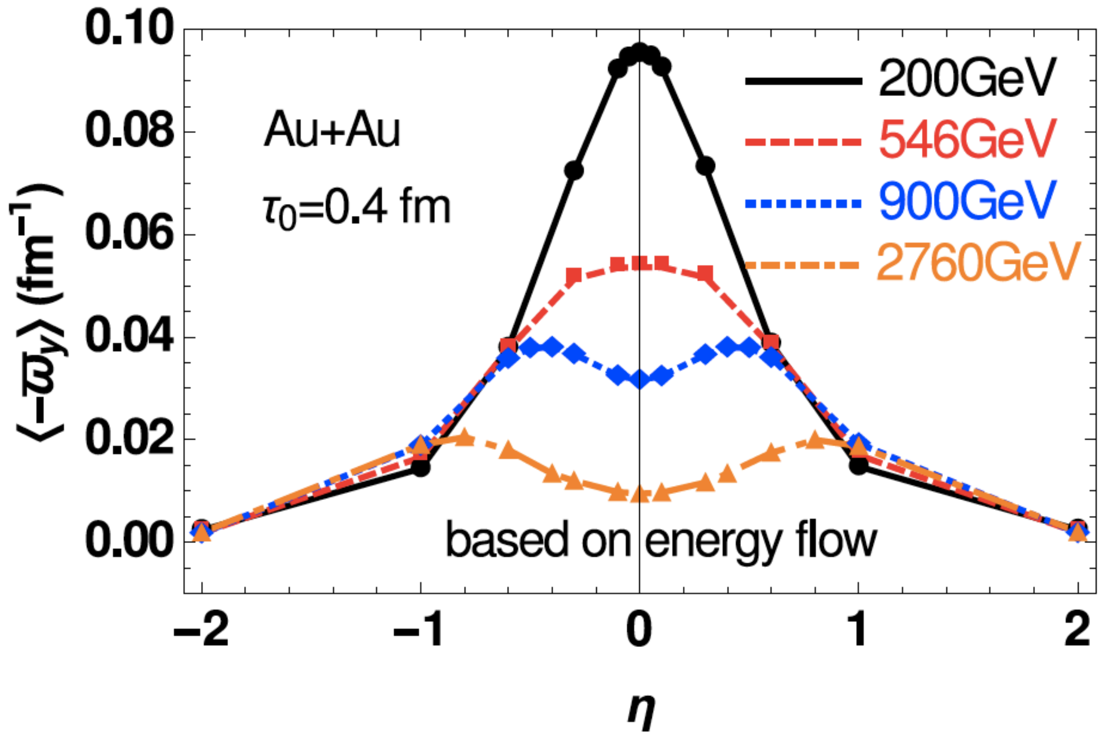


Polarization increases with viscosity and decreases with thermalization,

Rapidity dependence is key;

Different models predict opposite rapidity trend

Forward upgrade + EPD + iTPC essential



Hydrodynamic calculations:
Li,Pang,Wang & Xia, PRC 96 (2017) 054908; (private comm.)
F. Beccattini et al. EPJC 75(2015)406; arXiv:1501.04468

HIJING with energy flow:
Deng & Huang, PRC 93 (2016) 064907

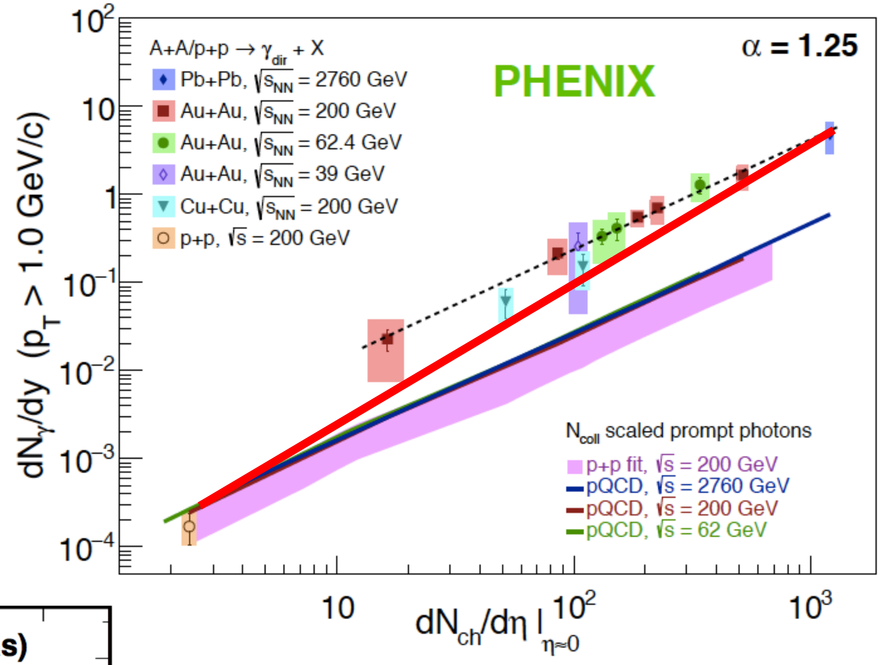
Quantifying Chiral Symmetry Restoration and Thermal Radiation

QUARK–GLUON PLASMA AND HADRONIC PRODUCTION OF LEPTONS, PHOTONS AND PSIONS

E.V. SHURYAK
Institute of Nuclear Physics, Novosibirsk, USSR

Received 16 March 1978

The best known example is dilepton production ($\mu^+\mu^-$, e^+e^-), in which deviations from the Drell–Yan model [1] for dilepton mass $M \lesssim 5$ GeV reach a factor

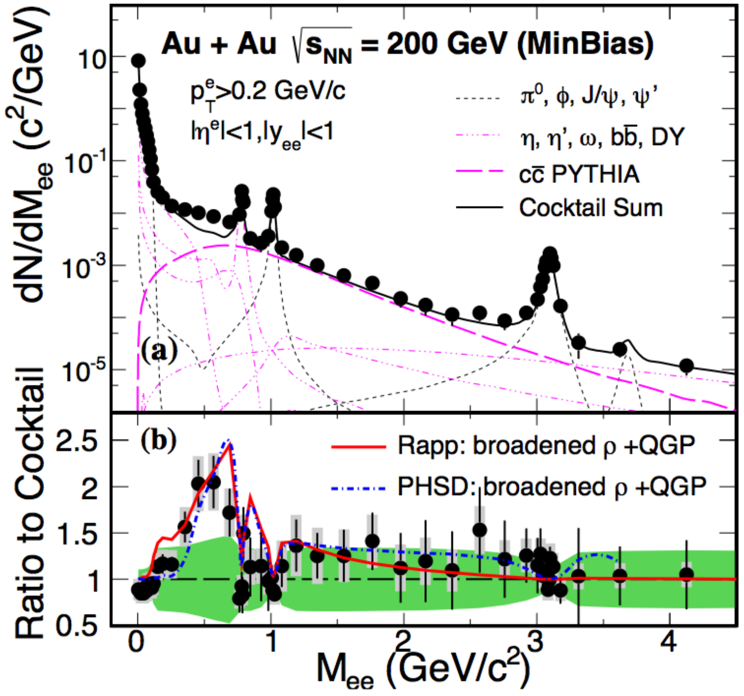


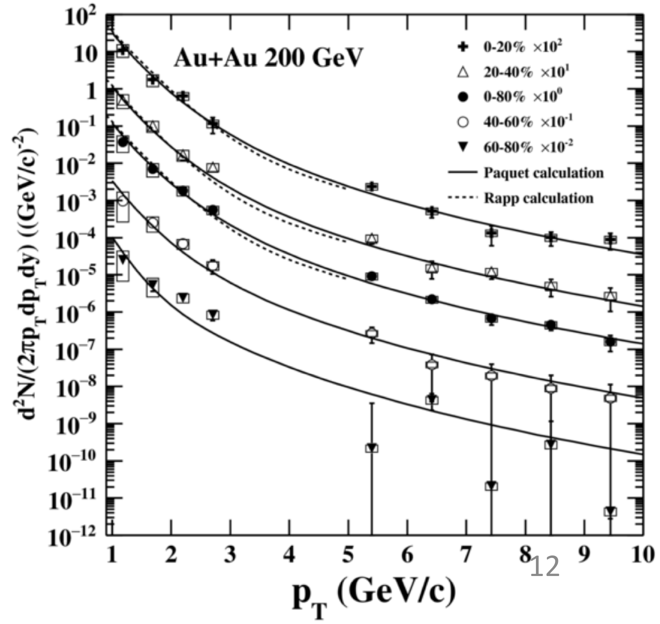
Photon Puzzle:
yields of photons above model prediction at RHIC
photon v_2 systematically above model

STAR at RHIC:
virtual photon spectra match Model
Low-mass dilepton excess matches model

Important to resolve the puzzle

STAR, PRL113(2014)





Thermal Dilepton at Low and Intermediate Mass

iTPC upgrade essential

Mid-rapidity:

e^+e^- measurement at $\mu_B \sim 0$

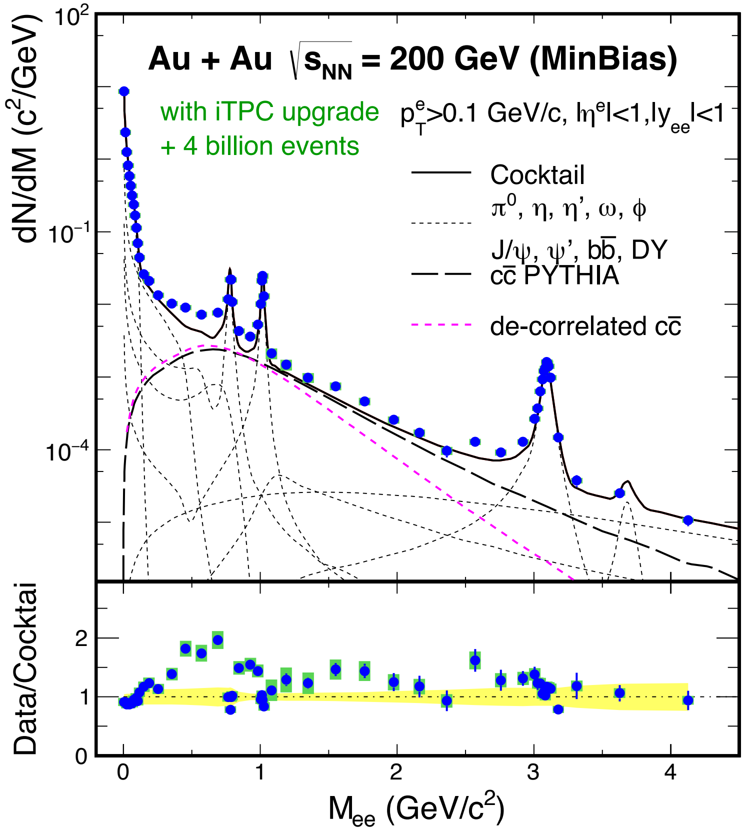
- Connection to chiral symmetry restoration
- Thermal radiation from QGP:

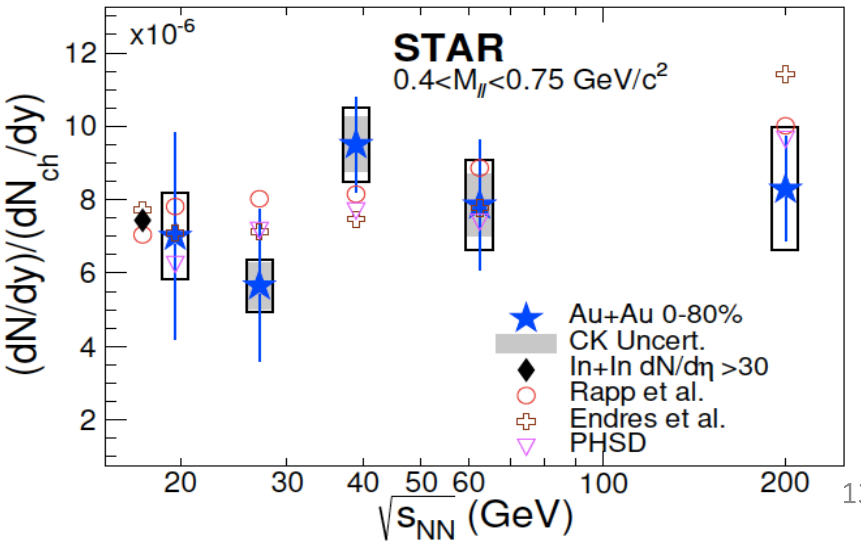
Low-mass di-lepton emission:
T, total baryon density, and life time; more importantly dynamics of approaching Chiral Symmetry

The slope T in IMR:
the true average temperature T of the medium.

(no blue shift by flow)

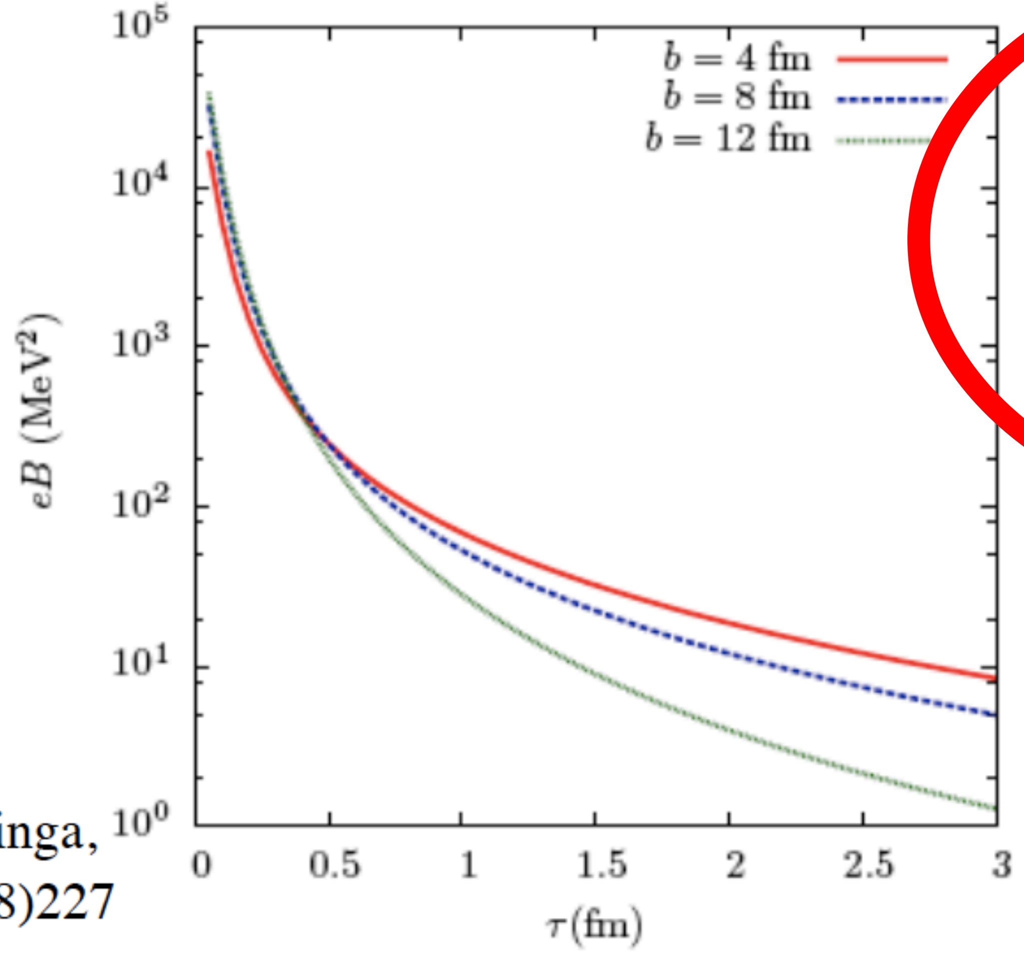
Improvement:
Factor 2 smaller systematic uncertainties
Factor 5.5 more statistics





Heavy ion collisions as a source of the strongest magnetic fields available in the Laboratory

Also:
V. Skokov,
V. Toneev,
A. Illarionov...



In a conducting plasma, Faraday induction can make the field long-lived:
K.Tuchin, arXiv:1006.3051

QGP as conductor

NB: magnetic flux is conserved in MHD! - expect the effect at LHC

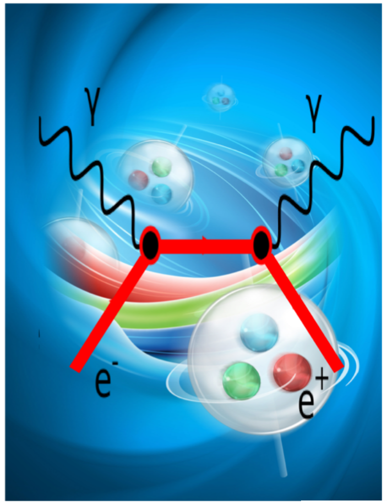
DK, McLerran, Warringa, Nucl Phys A803(2008)227

Fig. A.2. Magnetic field at the center of a gold-gold collision, for different impact parameters. Here the center of mass energy is 200 GeV per nucleon pair ($Y_0 = 5.4$).

D. Kharzeev

QUARK MATTER ANNECY 2011

Probe Magnetic Field and QGP Conductivity



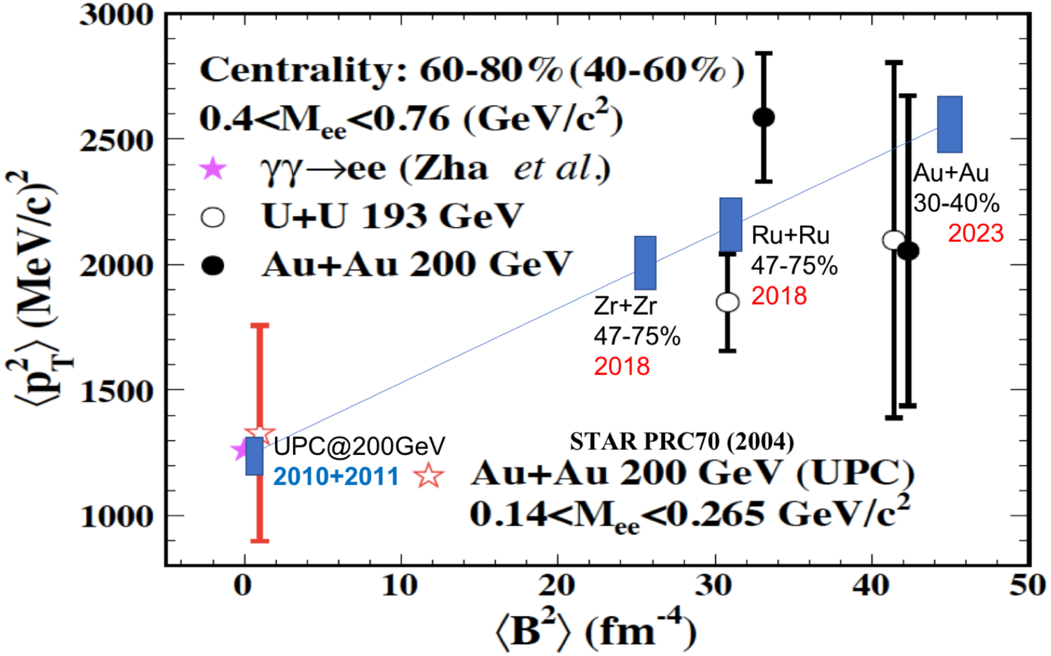
e+e- pair from Photon-photon collisions generated by the passing of target and projectile nuclei, accompanying formation of QGP

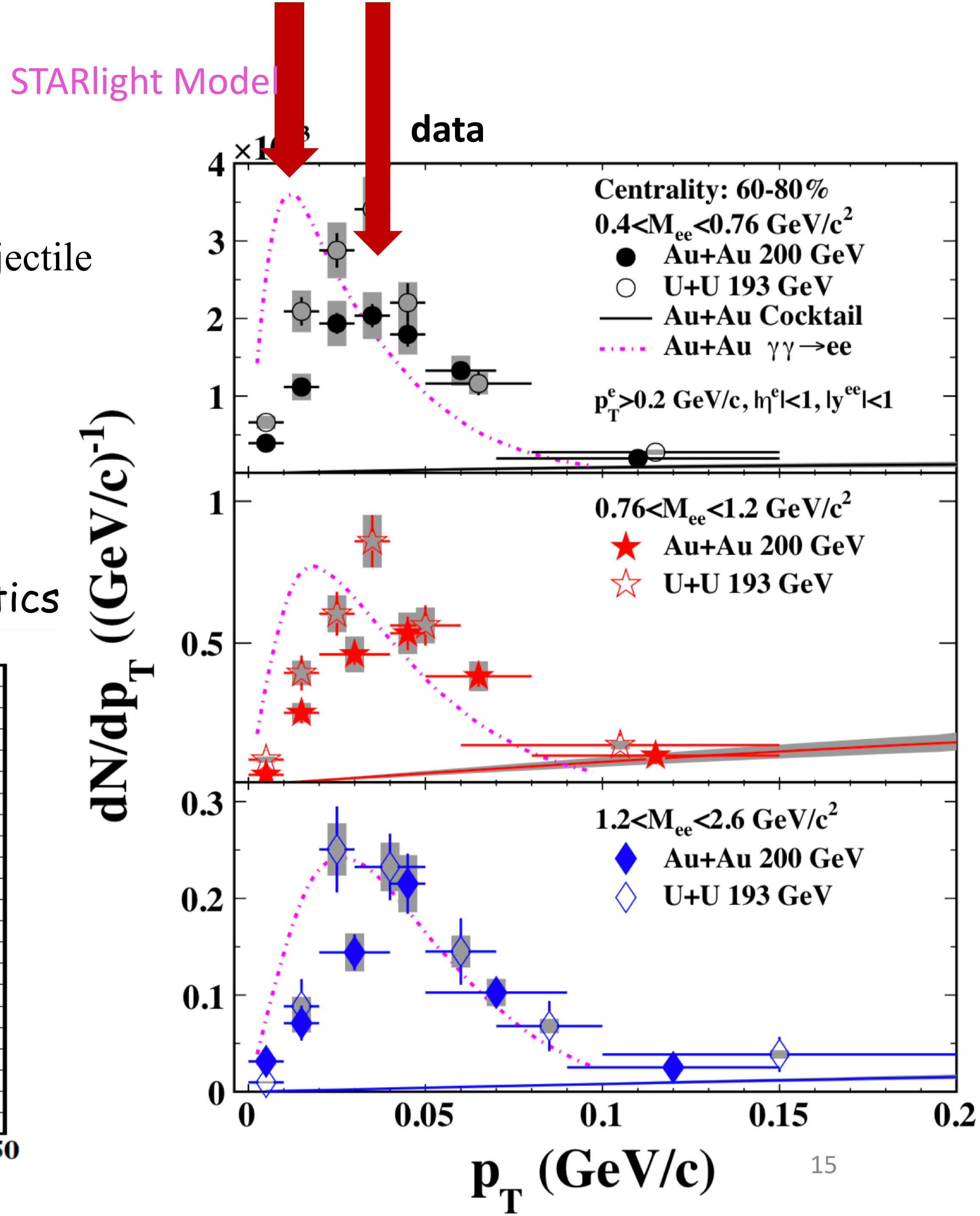
Spectra peaks at p_T=30-50MeV, right magnitude to be very sensitive to magnetic field

Clean probe with unique characteristics

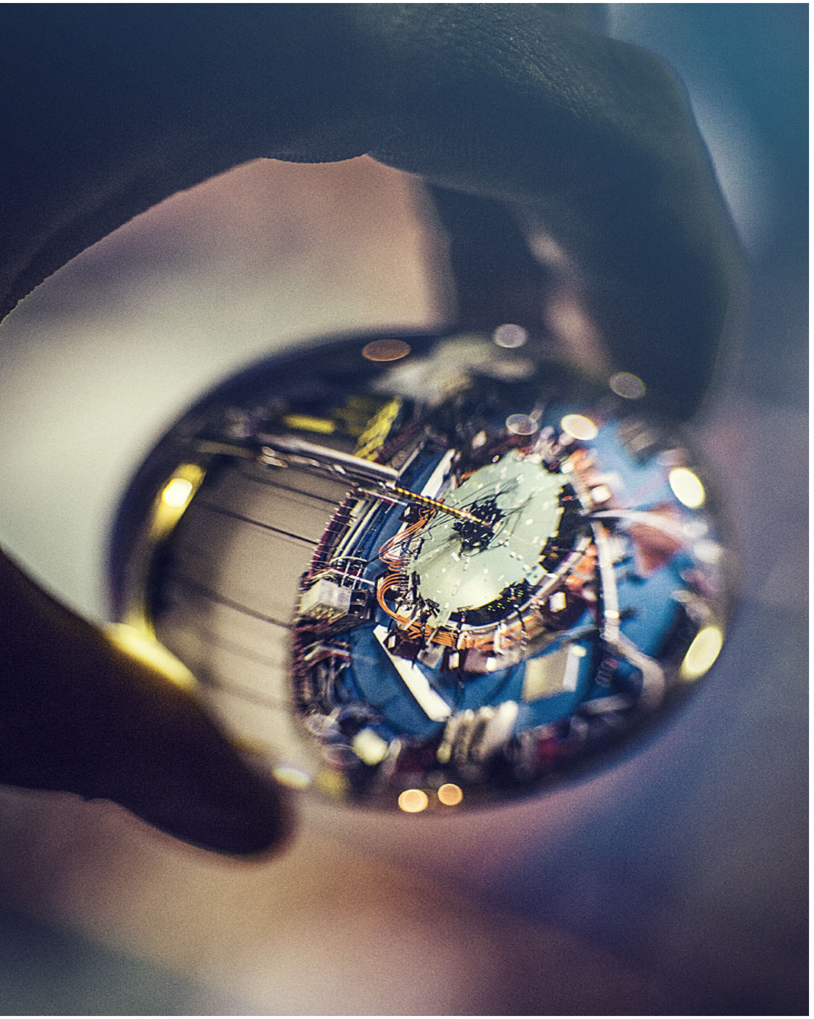
iTPC upgrade essential

Need more statistics for mid-central centrality





Summary on STAR future 2021+



- Quantitatively improve nuclear PDF
- Quantifying QGP properties of Viscosity, understanding mechanics of Vorticity and polarization
- Quantifying degree of freedom and resolving photon puzzle
- Potential new study of QGP properties: Conductivity
- Jets, Quarkonia, Beam Energy Scan phase II and many other measurements