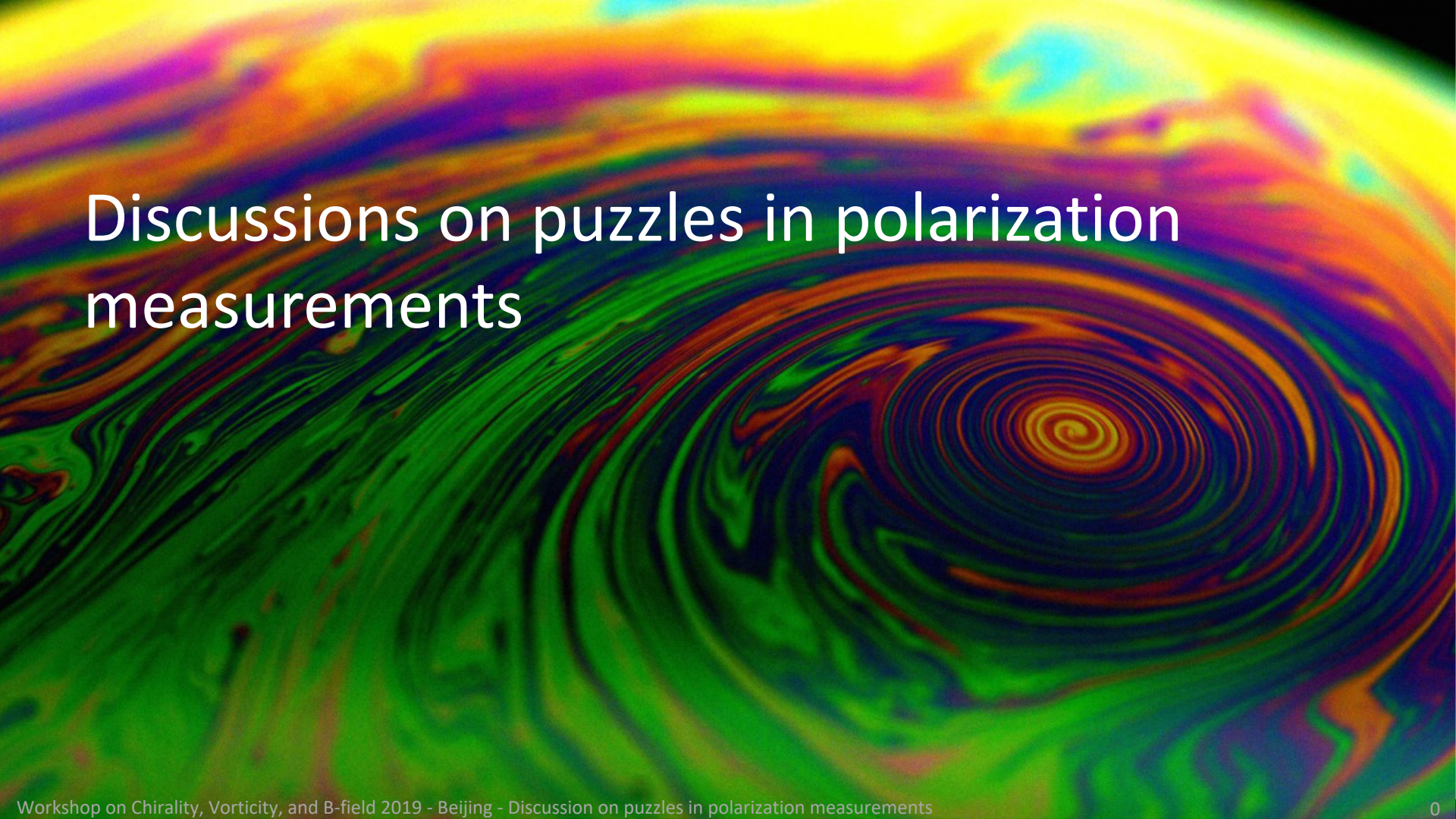
Discussions on puzzles in polarization measurements



Francesco Becattini, University of Florence and INFN

Vorticity and polarization in QGP: where do we stand?

OUTLINE

- Introduction
- Spin in a relativistic fluid: a theory outline
- Puzzles in polarization measurements
- Ongoing theoretical developments

Questions

- How important is non-equilibrium physics?
  - and how can we tell, experimentally?
  - is the devil in the discrepancies (with hydro) truly “in the fine details” or are we missing something more qualitative?

- Can we extract the magnetic field?
  - and can we “overconstrain” the CME/CVE paradigm?

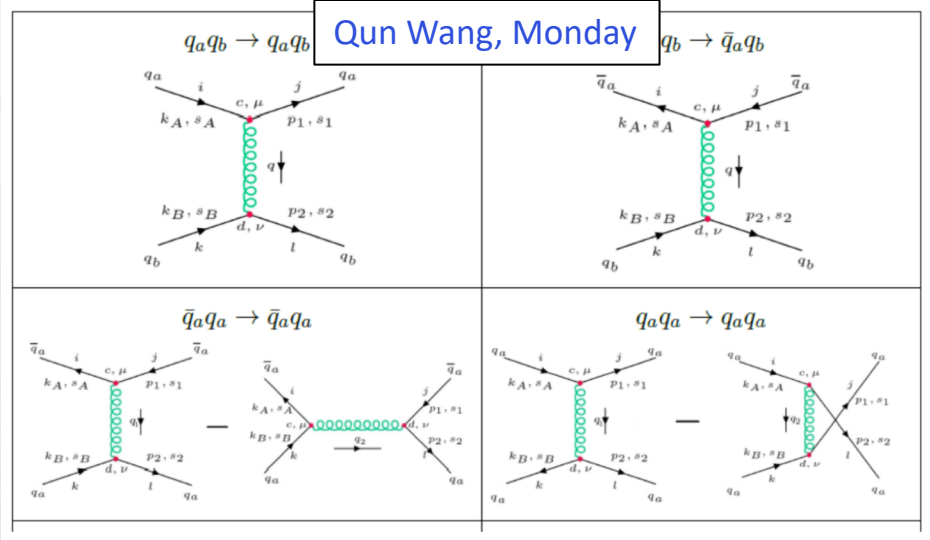
Final-state polarization

Certainly “related to” entrance-channel J

depends on **μscopic** details of quark **scattering** and **hadronization**?

- Liang, Wang, Ko, Sun, Voloshin, Gao, Chen, Deng, many others

First discussion/estimate -



Qun Wang, Monday

PRL 94, 102301 (2005) PHYSICAL REVIEW LETTERS week ending 18 MARCH 2005

Globally Polarized Quark-Gluon Plasma in Noncentral $A + A$ Collisions

Zuo-Tang Liang[1] and Xin-Nian Wang[2,1]

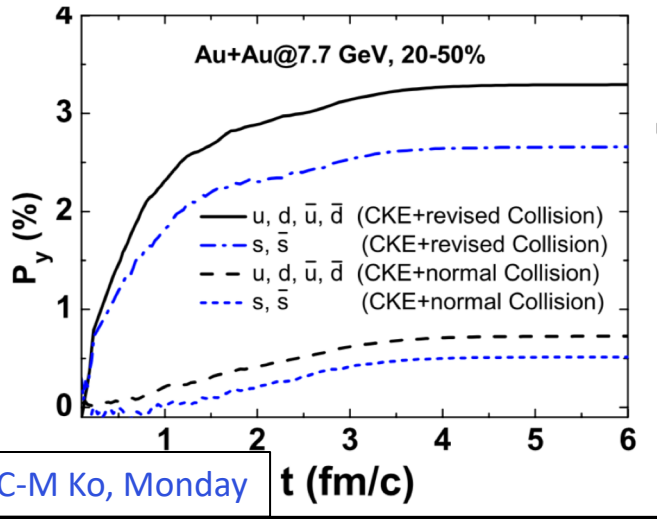
[1]*Department of Physics, Shandong University, Jinan, Shandong 250100, China*

[2]*Nuclear Science Division, MS 70R0319, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

(Received 25 October 2004; published 14 March 2005)

Produced partons have a large local relative orbital angular momentum along the direction opposite to the reaction plane in the early stage of noncentral heavy-ion collisions. Parton scattering is shown to polarize quarks along the same direction due to spin-orbital coupling. Such global quark polarization will lead to many observable consequences, such as left-right asymmetry of hadron spectra and global transverse polarization of thermal photons, dileptons, and hadrons. Hadrons from the decay of polarized resonances will have an azimuthal asymmetry similar to the elliptic flow. Global hyperon polarization is studied within different hadronization scenarios and can be easily tested.

DOI: 10.1103/PhysRevLett.94.102301 PACS numbers: 25.75.Nq, 13.88.+e, 12.38.Mh



C-M Ko, Monday

Final-state polarization

Certainly “related to” entrance-channel J

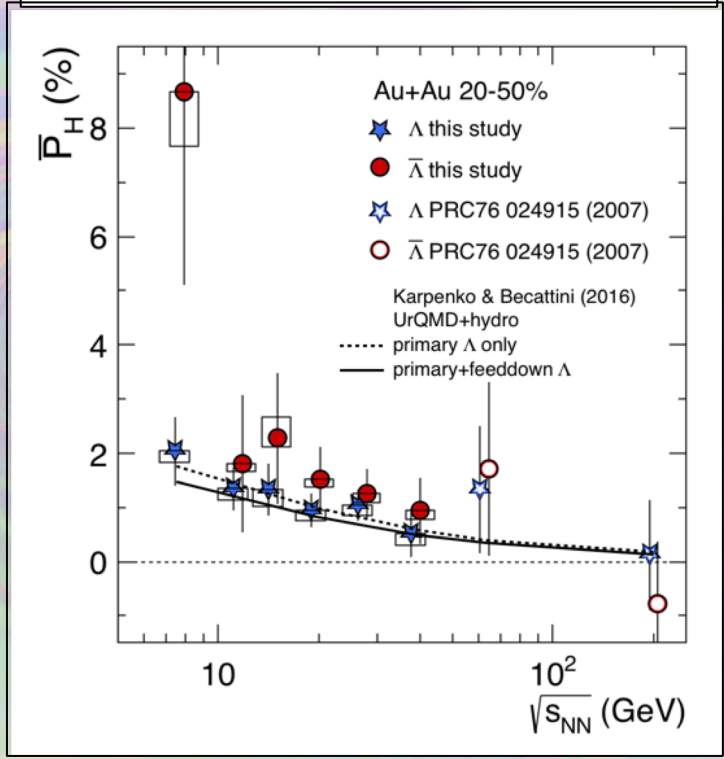
depends on **μscopic** details of quark **scattering** and **hadronization**?

- Liang, Wang, Ko, Sun, Voloshin, Gao, Chen, Deng, many others

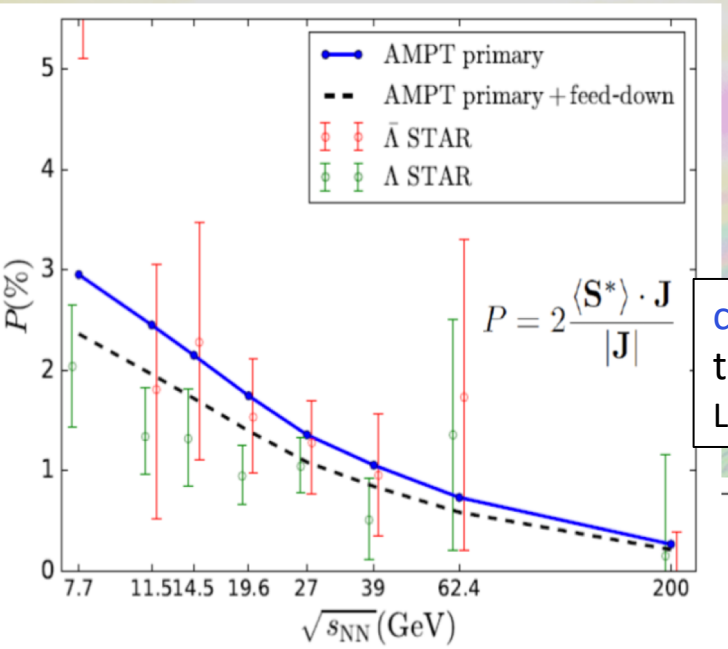
… or… like so much else in HIC, is it dominated by equilibrium physics?

- the level of agreement with hydro *pre*diction was almost “suspicious.”
- reminiscent of similar Blast-wave agreement with non-identical particle femtoscopy

First observation confronts prediction



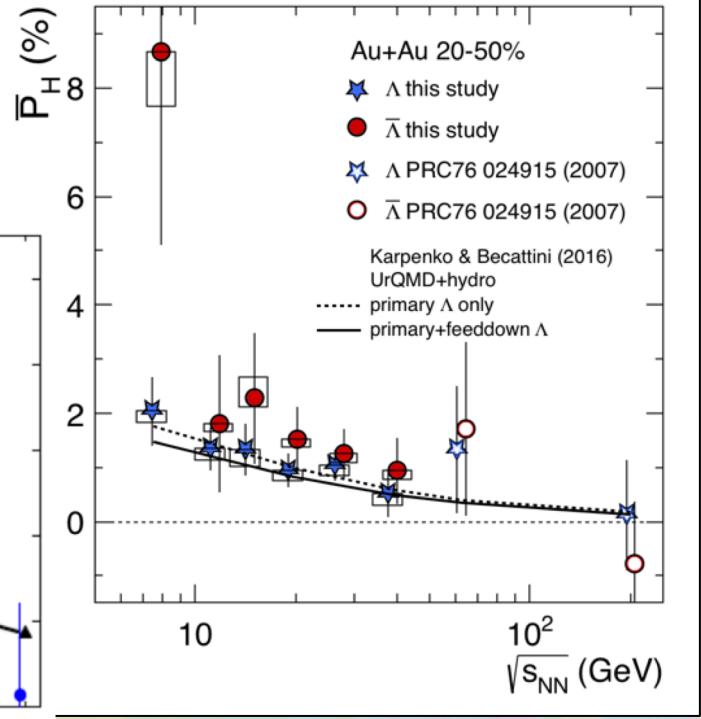
Occam's Razor…?

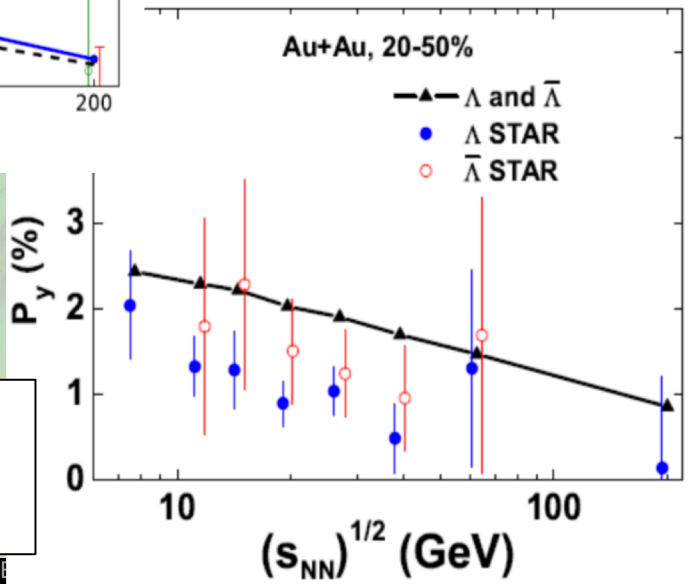


coarse-graining non-equil
to find ω
Li, Pang, QW, Xia, PRC(2017)

"just" hydro and…

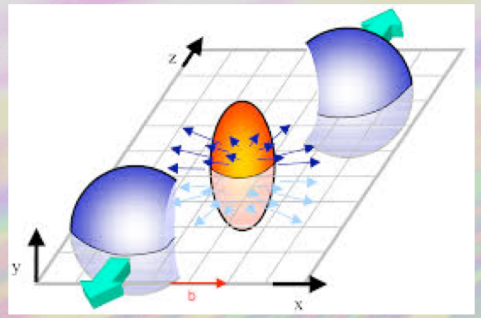
$$\text{Prob} \sim \exp\left(-E/T + \mu_B B/T + \vec{\omega}\cdot\vec{S}/T + \vec{\mu}\cdot\vec{B}/T\right)$$

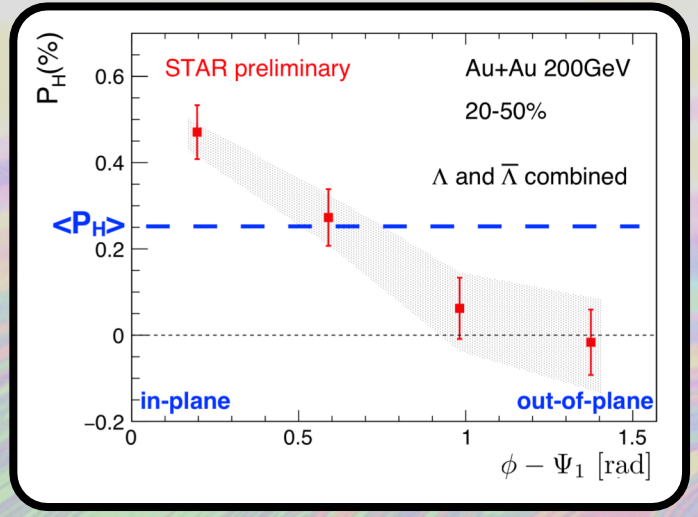


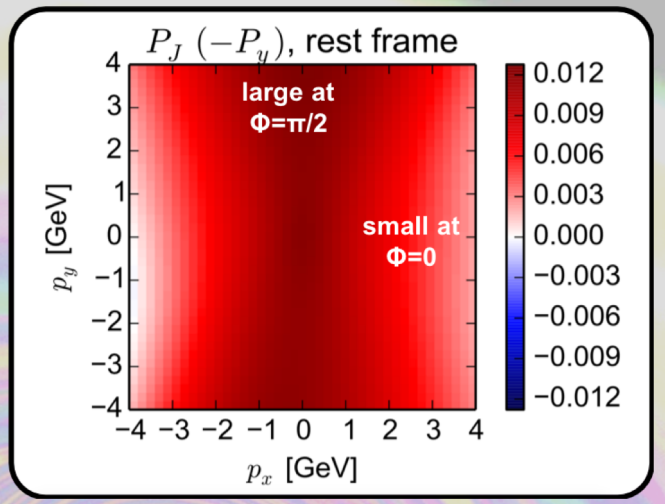


CK+AMPT → polarized quarks
→ hadrons via coalescence
Sun, Ko, PRC(2017)

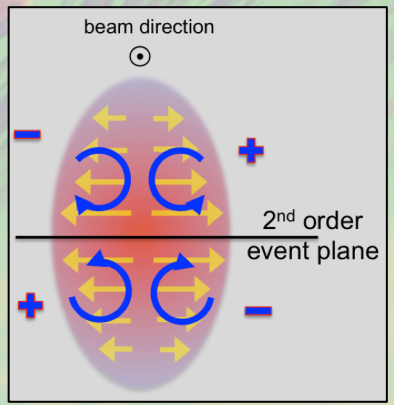
Azimuthal dependence of P_y

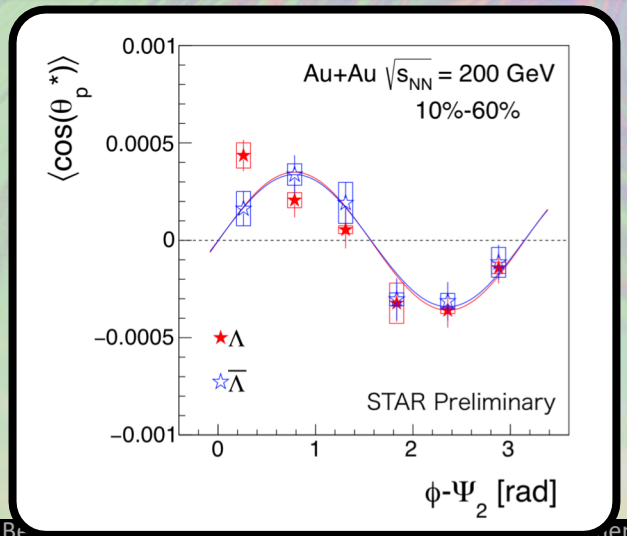


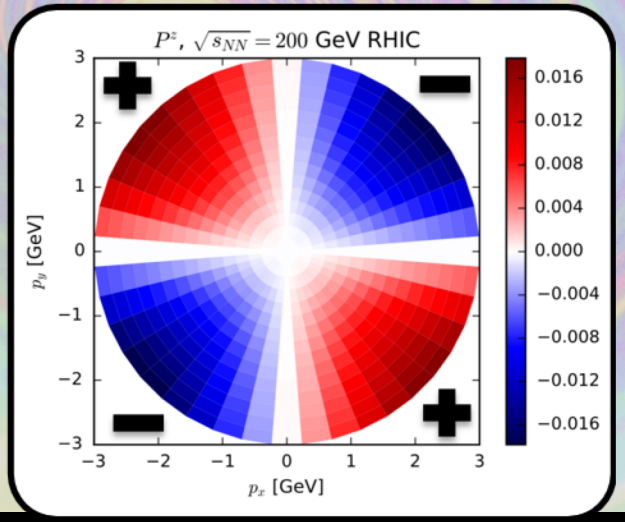




Azimuthal dependence of P_z







Similar to early RHIC days with flow and hydro?

- general agreement excellent on the right track!
  - early thermalization (though... how?)
  - ”perfect” fluid. Simplification of soft sector
- quantitative disagreement with more detailed observations
  --> important qualitative lessons!
  - initial state
  - viscosity
  - ...

... or...

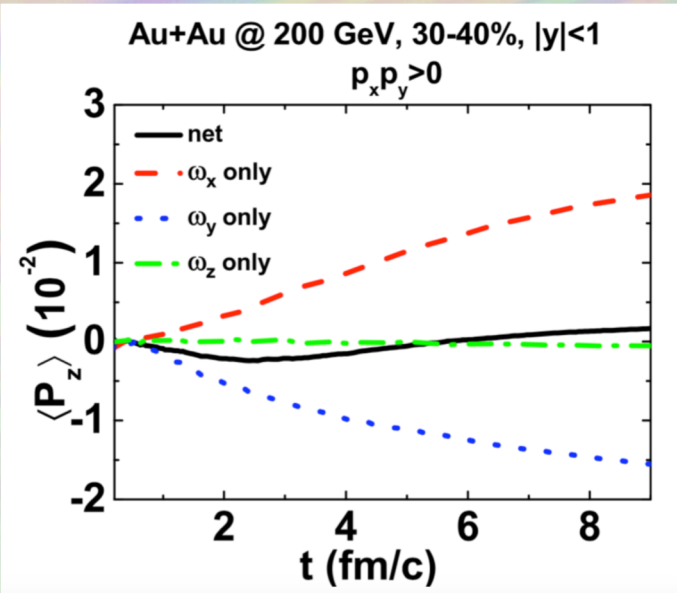
- global polarization is a crude enough signal that “any” approach works
- finer details are driven by…. (much?) finer (quantitative?) details

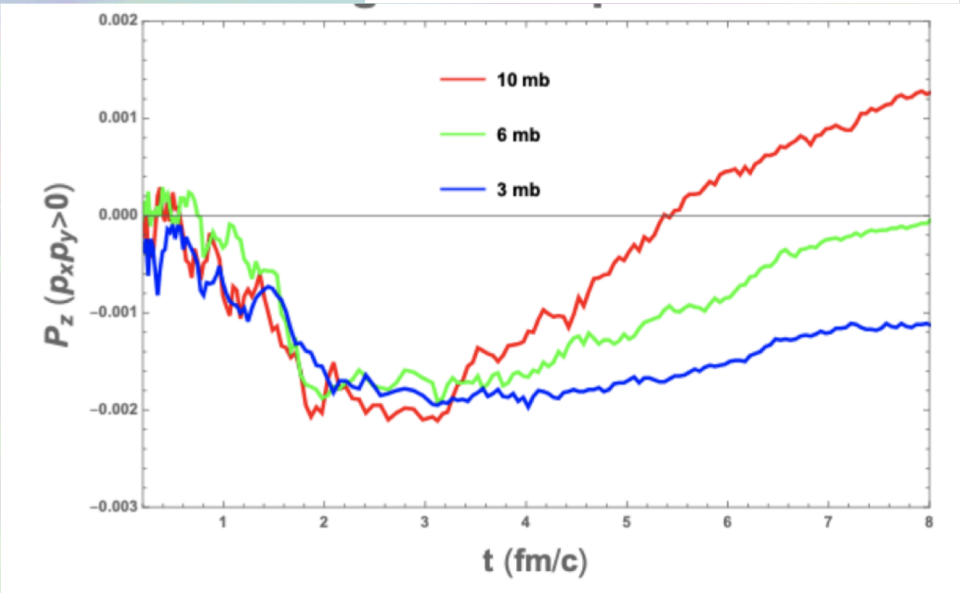
C-M Ko's talk, Monday.

Must "fine tune" parameters of microscopic models, to understand polarization systematics?

- qualitative insights possible?

Sun & Ko, PRC 99, 011903 (R) (2019)





(Also: s quarks slightly less longitudinally polarized than u,d quarks)

General question – why hydro + equipartition fails?

- Something missing in present hydro?
- Qualitative misunderstanding of early state?
- Equilibrium/equipartition paradigm is wrong? Hadronization details matter.
- Fine details of non-equilibrium dynamics *dominate* all but crudest measures.

General question – why hydro + equipartition fails?

- Something missing in present hydro?
  - Qualitative lesson possible!
- Qualitative misunderstanding of early state?
  - Qualitative lesson possible!
- Equilibrium/equipartition paradigm is wrong? Hadronization details matter.
  - Finally insight on this important issue, from soft sector?!
- Fine details of non-equilibrium dynamics *dominate* all but crudest measures.
  - If a matter of fine tuning, this would be unfortunate (IMHO*)

* In Mike's Humble Opinion

General question – why hydro + equipartition fails?

- Something missing in present hydro?
- Qualitative misunderstanding of early state?
- Equilibrium/equipartition paradigm is wrong? Hadronization details matter.
- Fine details of non-equilibrium dynamics *dominate* all but crudest measures.

FIRST CLASS (spin formula not adequate)

- Decay of resonances ? *(We now have an answer: NO* – See talk by G. Q. Cao and Hui Li)
- Need of dissipative corrections (viscosity-like) ?
- Need of second-order corrections ?
- Local equilibrium of spin not reached ? (Kinetic spin theory)
- Evidence for the need of a spin tensor ? (see talks by A. Kumar, R. Ryblewski, E. Speranza)

SECOND CLASS (disagreement of thermal vorticity)

- Are hydro initial conditions correct ?
- Do we have a good hydro model to predict thermal vorticity in the late stage?

General question – why hydro + equipartition fails?

- Something missing in present hydro?
  - ?
- Qualitative misunderstanding of early state?
  - try tunes
- Equilibrium/equipartition paradigm is wrong? Hadronization details matter.
  - Use different particle types
- Fine details of non-equilibrium dynamics *dominate* all but crudest measures.
  - small systems, pT dependence…

* In Mike's Humble Opinion

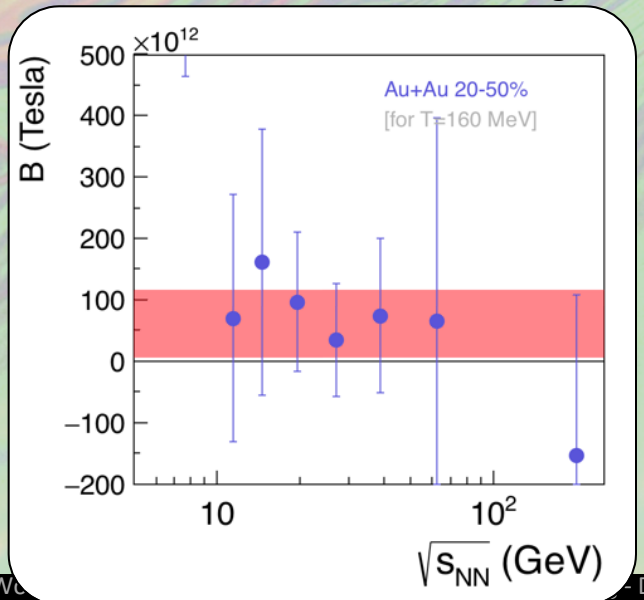
Can/will we measure the B-field?

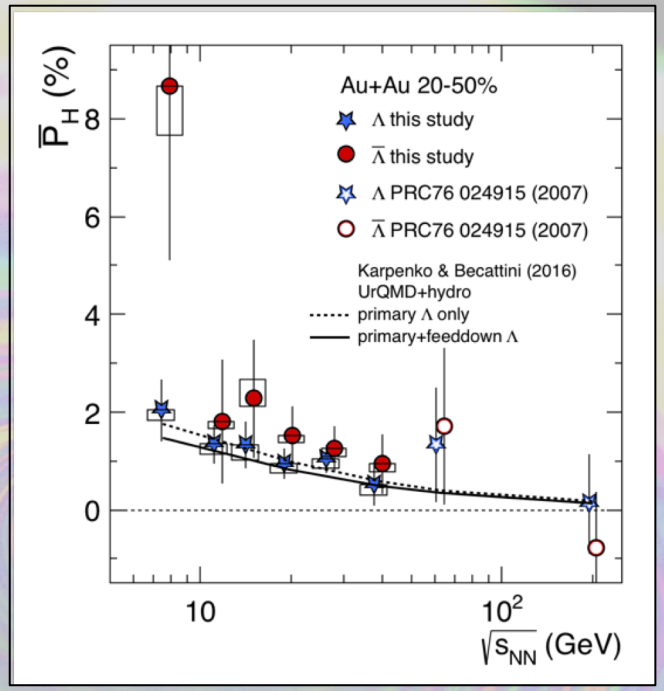
$$\text{Prob} \sim \exp\left(-E/T + \mu_B B/T + \vec{\omega}\cdot\vec{S}/T + \vec{\mu}\cdot\vec{B}/T\right)$$

for small polarization:

$$P_\Lambda \approx \frac{1}{2}\frac{\omega}{T} - \frac{\mu_\Lambda B}{T} \qquad P_{\bar{\Lambda}} \approx \frac{1}{2}\frac{\omega}{T} + \frac{\mu_\Lambda B}{T}$$

(plus feed-down effects, which are larger for B than vorticity)





$$\langle B \rangle_{\sqrt{s}} = 6.0 \pm 5.5 \times 10^{13}\ \text{T} \approx 0.6 \pm 0.55\ m_\pi^2$$

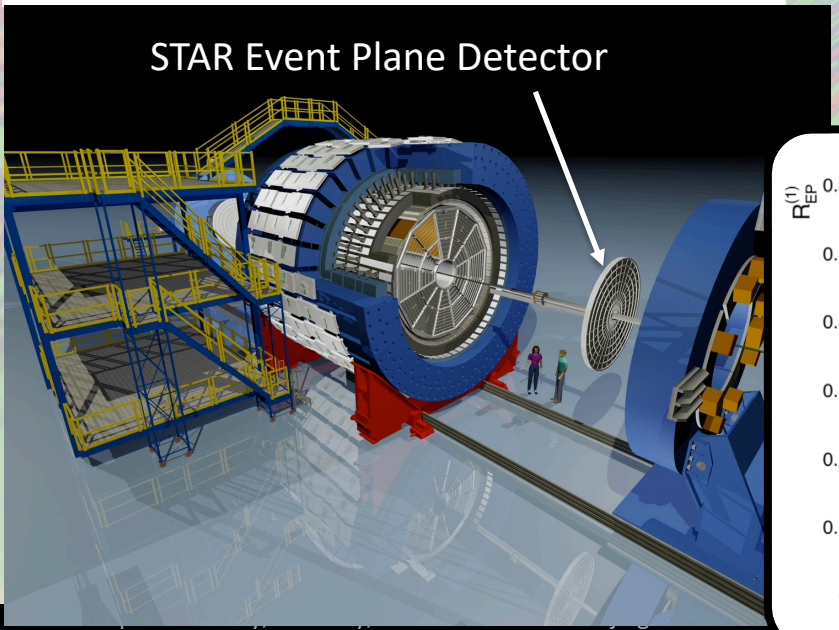
- On the large side, but not insanely so.
- uncertainties too large

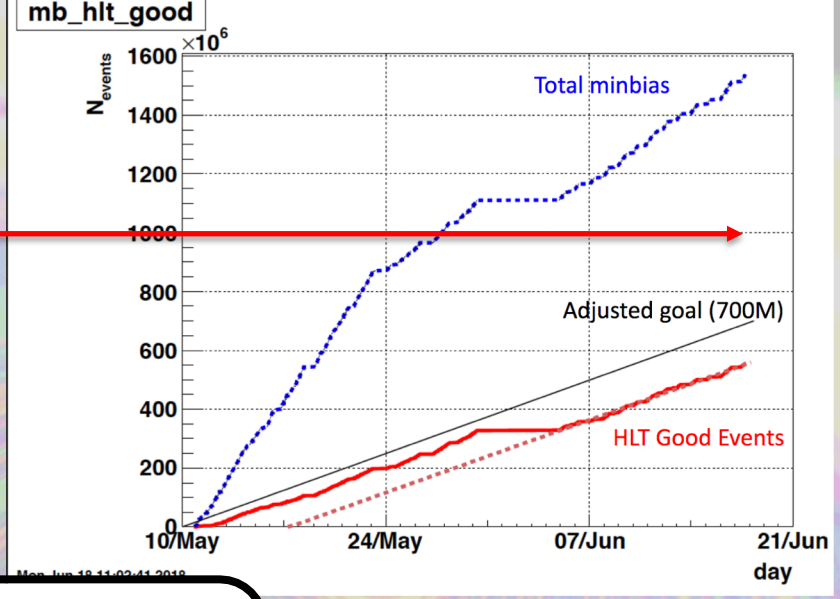
B-field through splitting in Au+Au @ 27 GeV?

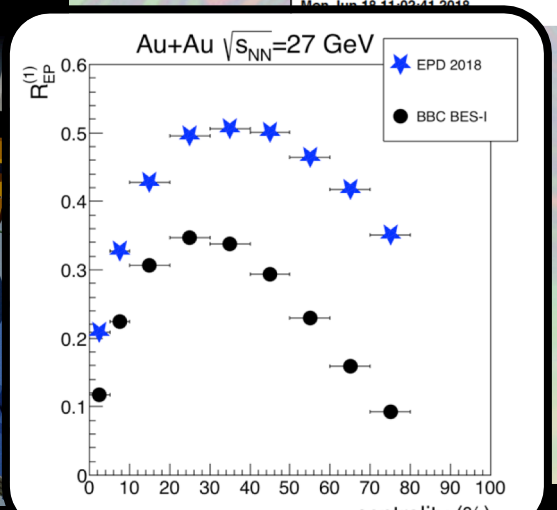
Dedicated run in 2018 Goals:

✗ long run → 1B events

✓ detector upgrade → increase event plane resolution x2







$$\delta \bar{P}_{\mathrm{H}} \propto \left(R_{\mathrm{EP}}^{(1)} \sqrt{\#\,\Lambda} \right)^{-1}$$

B-field in 27 GeV?

- Splitting? Analysis underway. Stay tuned for QM'19!
- Other mechanisms for splitting?
  - e.g. Csernai, Kapusta, Welle, 2019. But no quantitative (or even qualitative) prediction

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- Can we "overconstrain" CME/CVE equations?
  - too simplistic?

$$\vec{J} = \frac{N_c \mu_5}{2\pi^2}[\underbrace{\mathrm{tr}(VAQ)\vec{B}}_{CME} + \underbrace{\mathrm{tr}(VAB)2\mu_B\vec{\omega}}_{CVE}]$$

μ_5 : characterizes fluctuations in N_{CS}

$J_E = \frac{N_c \mu_5}{3\pi^2} B \quad \rightarrow$ separation of +/- along $\vec{B}$

$J_B = \frac{N_c \mu_5}{\pi^2} \mu_B \omega \quad \rightarrow$ separation of B/$\overline{\mathrm{B}}$ along $\vec{\omega}$

6 variables: $B, \omega, \mu_B, \mu_5, J_E, J_B$

2 equations

ω measured

μ_B measured

J_E measured??

J_B ??

B Try!