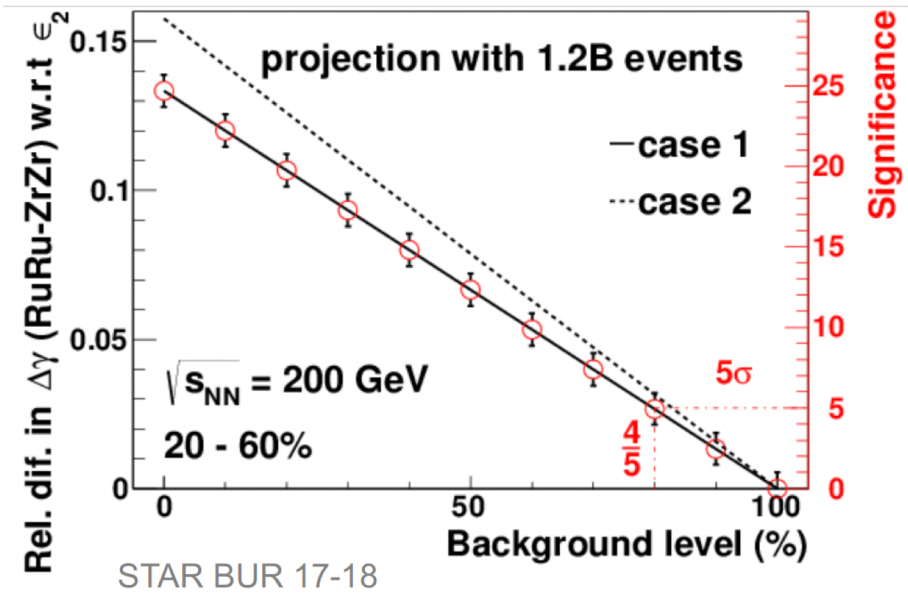
Isobar Run Analysis Progress

Evan Finch(SCSU) for the STAR Collaboration

Isobar Motivation:

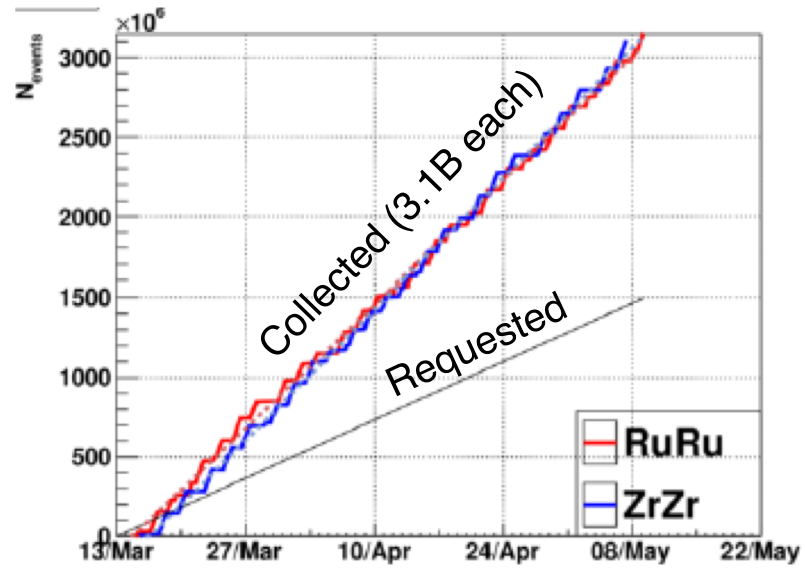
B-field related signal changes by ~18%
v_2 related background stays roughly the same

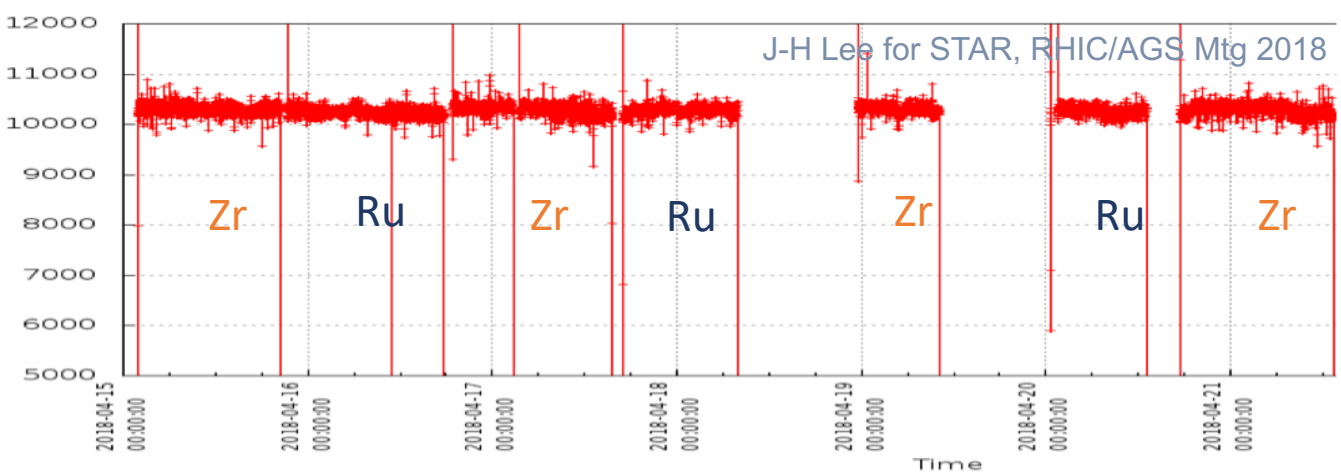


STAR BUR 17-18

$$\gamma \equiv \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$$

Data collected in 2018 RHIC run



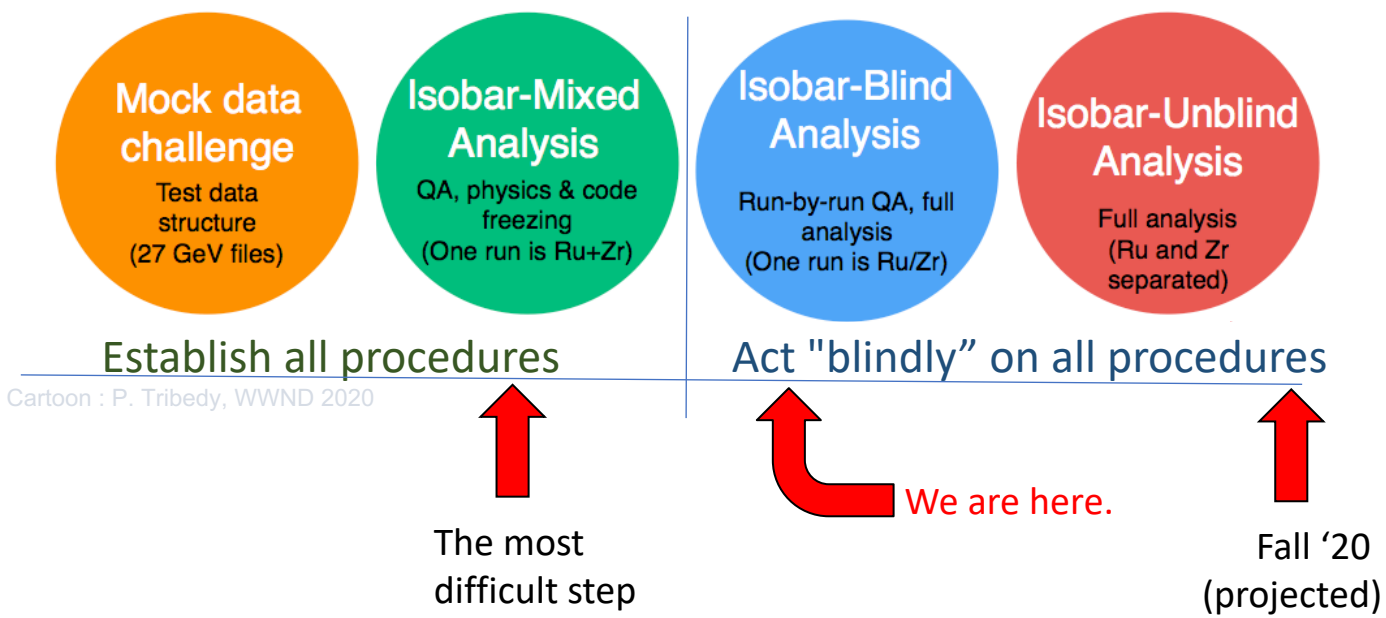


Interleaved fills for isobar species to minimize systematic differences between two species..

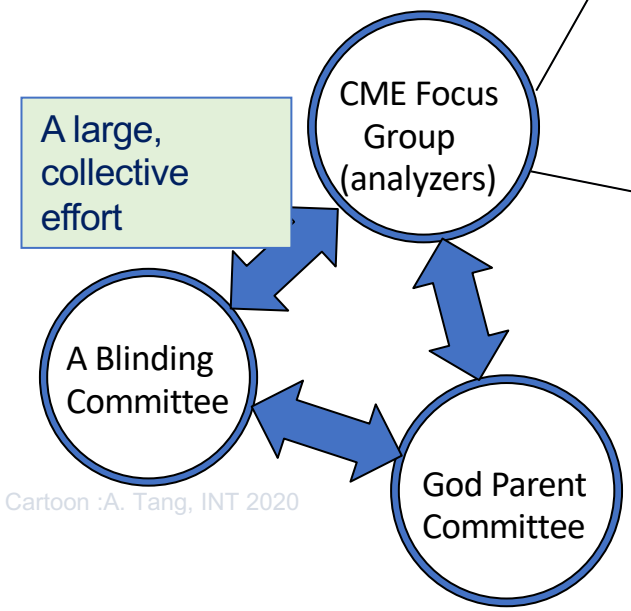
Isobar Blind Analysis : Procedure

- Program Advisory Committee Recommendation:
  - The PAC strongly recommends that any STAR publication regarding CME observables should contain the result after unblinding and without any additional corrections applied after unblinding that are deemed necessary by STAR. If such additional corrections are needed, then a paper containing both the unblinded and post-unblinded results should be published for reference in papers reporting the isobar data.

- STAR blinding committee: "Rules" for blind analysis: arXiv:1911.00596 (2019)



Blind Isobar CME Analyses: STAR Organization



Cartoon :A. Tang, INT 2020

Blind analyses (5 groups):

- UCLA: $\Delta\gamma$, $\Delta\delta$, and κ.
- BNL, Fudan: $\Delta\gamma$, $\Delta\delta$, $\Delta\gamma(\Delta\eta)$.
- Purdue: $\Delta\gamma$ in PP/SP, $\Delta\gamma$(Minv).
- WSU/Tsukuba: $\Delta\gamma$ in PP/SP.
- Stony Brook/UIC: R(ΔS) Correlator.

Analyzers meet weekly for discussion in CME focus group.

Blinding Committee decides on rule for blind analysis. Chair (J. Drachenberg) generally attends focus group meeting to monitor progress/answer questions/make sure rules are followed.

God-parent committee responsible for reviewing physics content of all analyses for publication. Chair (J. Dunlop) and members attend focus group meetings. GPC formed very early in analysis process (Aug '19) to oversee analysis from early stages.

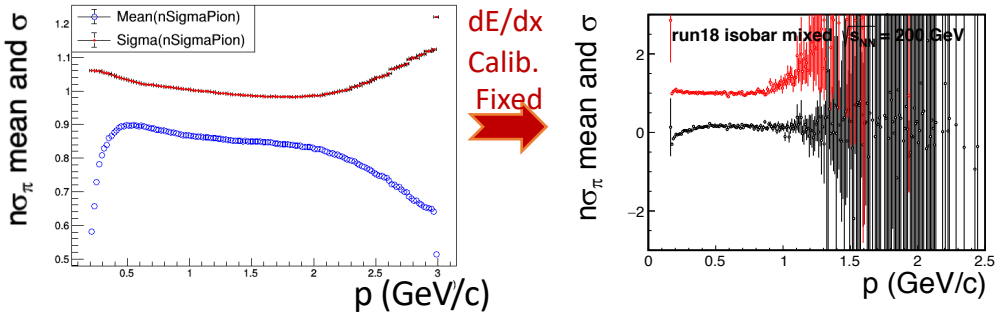
Isobar-Mixed Analysis (Step 1) Summary

What needed to be done to move on from Step 1?

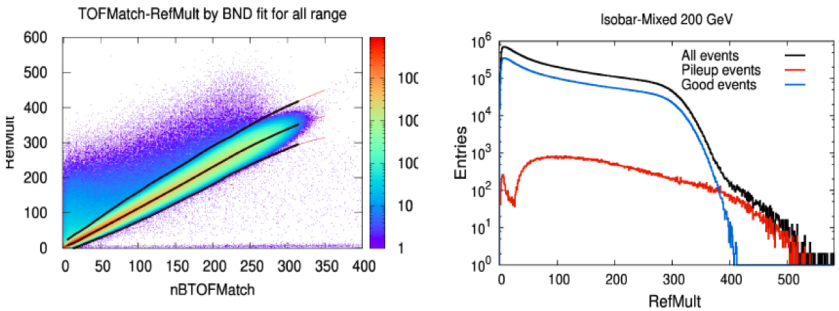
- Basic data QA checks: calibration and time-stability of data.
- Physics discussions on exact quantities to be shown in publications.
- Code checks and demonstration of consistency between groups.
- Systematic error methods agreed upon and frozen
- All analysis documented and approved by GPC.
- Code developed for automated run-by-run QA (step 2).

Isobar-Mixed Analysis (Step 1) Summary

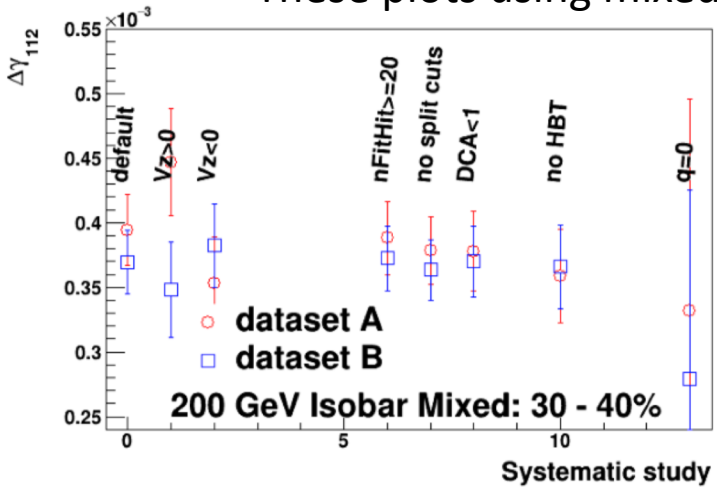
Calibration/stability check: TPC track energy loss

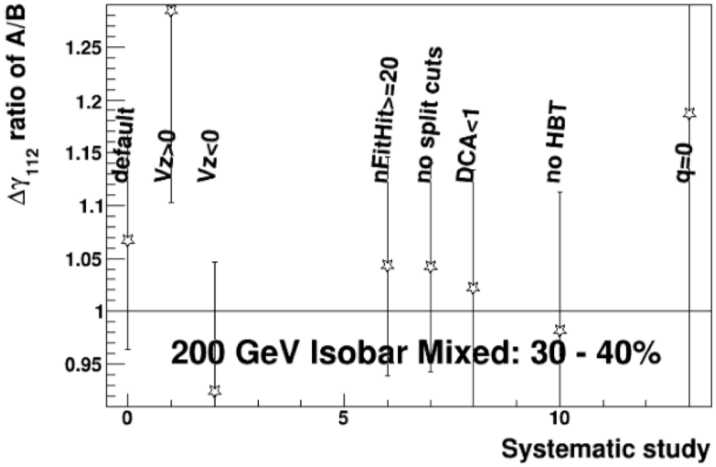


Pile-up event rejection



These plots using mixed-isobar data, <1% of total statistics

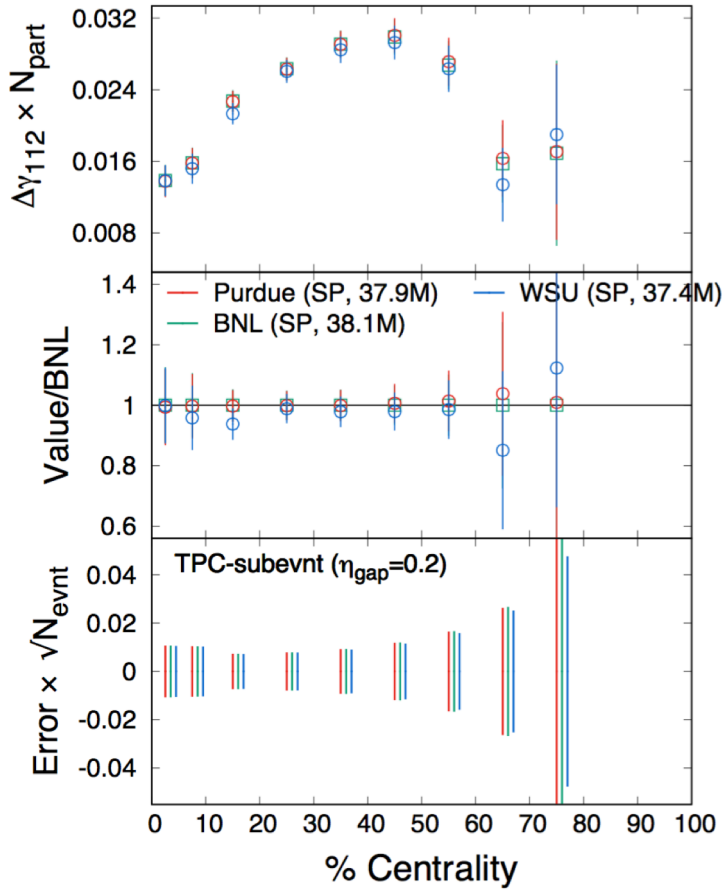


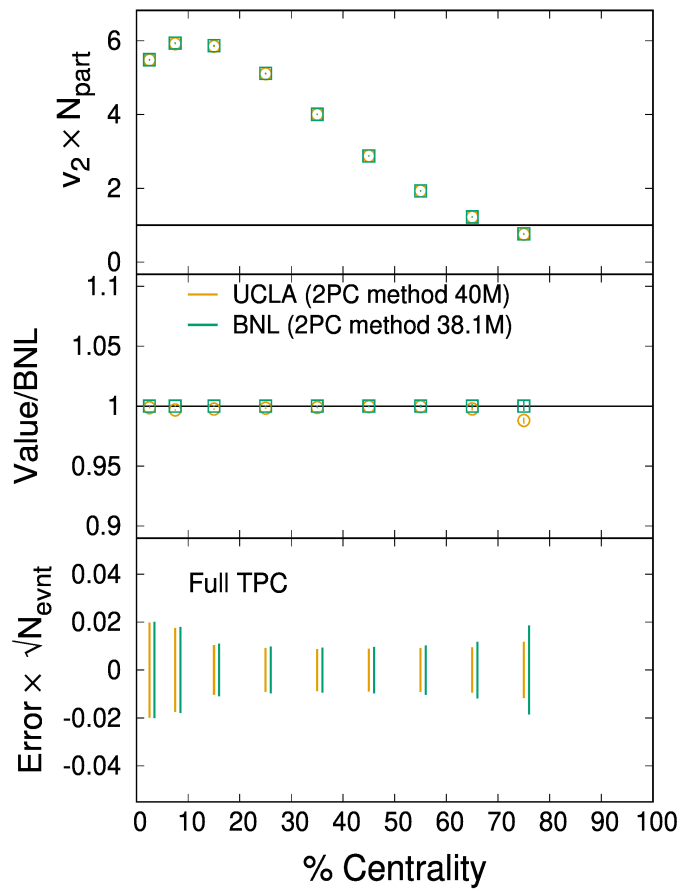


Divide 40M event iso-mixed sample into A and B, analyzing $\Delta\gamma, \Delta\delta$, v_2 ratios with systematic cuts to look for any issues, ensure stat error has expected scaling

Isobar-Mixed Analysis (Step 1) Summary

Check that different groups have "exact" agreement on calculation of and v_2 with iso-mix data

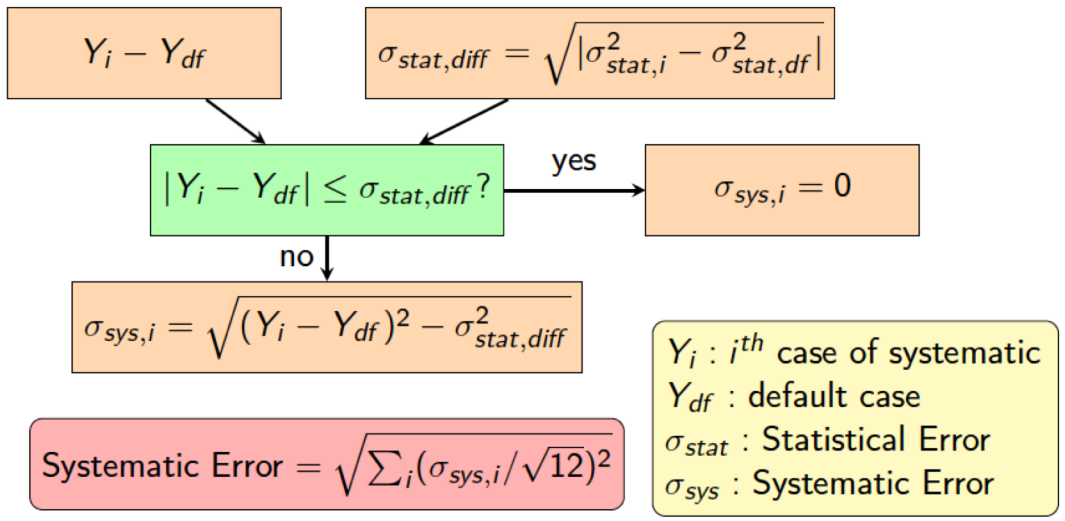




In addition: Each groups' analysis codes has been checked by another analysis group at least to the level to make sure the code runs and produces plots as advertised (in some cases, more detailed checks were done).

Isobar-Mixed Analysis (Step 1) Summary

Systematic errors: Each cut will be varied to one additional value, statistical contributions will be subtracted out, and then systematics added in quadrature



Flowchart :BNL/Fudan Analysis Note

All groups will use the same systematic cuts for basic quantities.

Isobar-Mixed Analysis (Step 1) Summary

What needed to be done to move on from Step 1?

- Basic data QA checks: calibration and time-stability of data.
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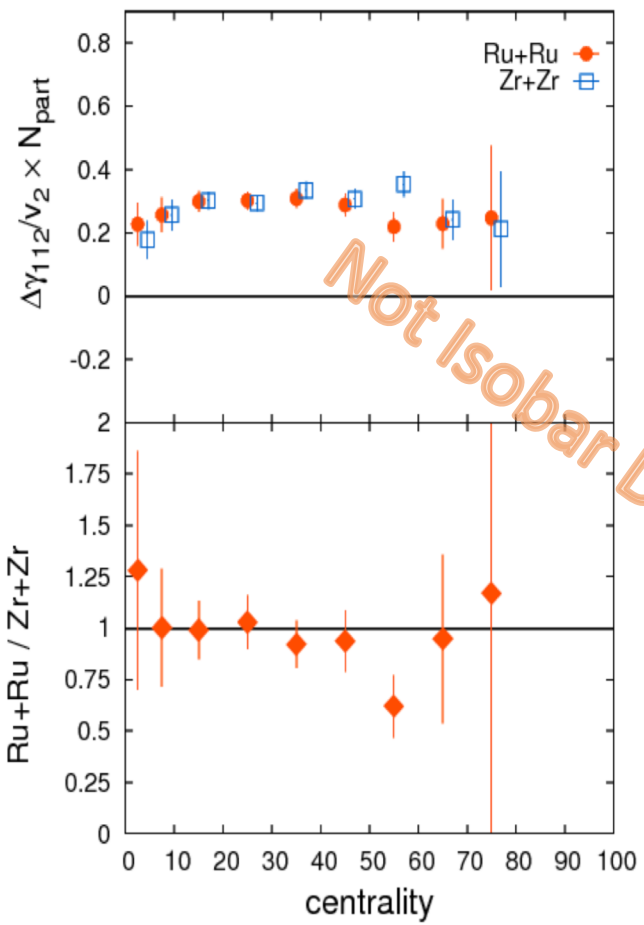
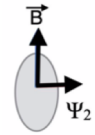
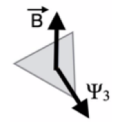
Isobar Analysis (BNL/Fudan) : $\Delta\gamma/v_2$ isobar ratio, further background studies





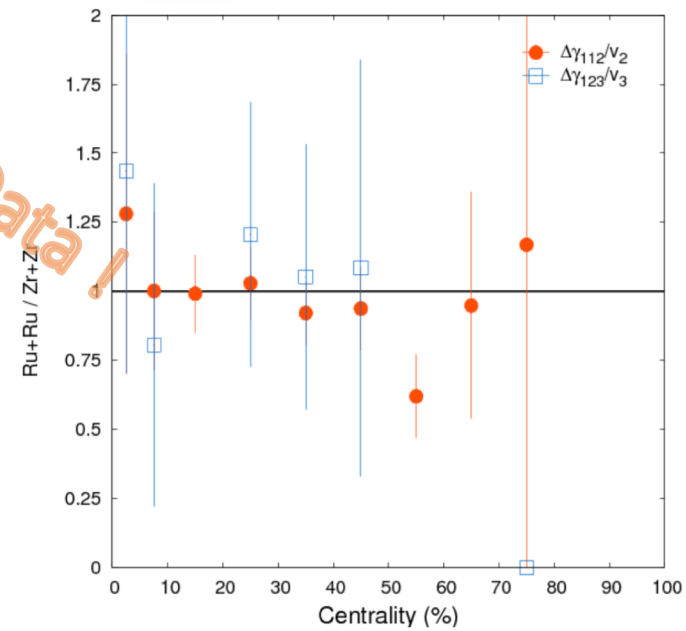
$\gamma_{112} = \langle \cos(1\phi_\alpha + 1\phi_\beta - 2\Psi_2) \rangle$

Sig + bkg.



$\gamma_{123} = \langle \cos(1\phi_\alpha + 2\phi_\beta - 3\Psi_3) \rangle$

Bkg. only



Not Isobar Data !

Supportive of CME would be:

$\Delta\gamma_{112}/v_2$ (Ru / Zr) > 1

$\Delta\gamma_{112}/v_2$ (Ru / Zr) > $\Delta\gamma_{123}/v_3$ (Ru / Zr)

$\Delta\gamma_{112}/v_2$ (Ru / Zr) > $\Delta\delta$ (Ru / Zr)

S. Voloshin, Phys. Rev. C 70 057901 (2004)

F. Wang PRC 81 064902 (2010)

S. Pratt, S. Schlichting and S. Gavin, PRC 84 024909 (2011)

S. Schlichting and S. Pratt, PRC 83 014913 (2011)

A. Bzdak, V. Koch, and J. Liao , Lect. Notes Phys. 871, 503 (2013)

A. Tang, Chin. Phys. C 44 No.5 054101 (2020)

…

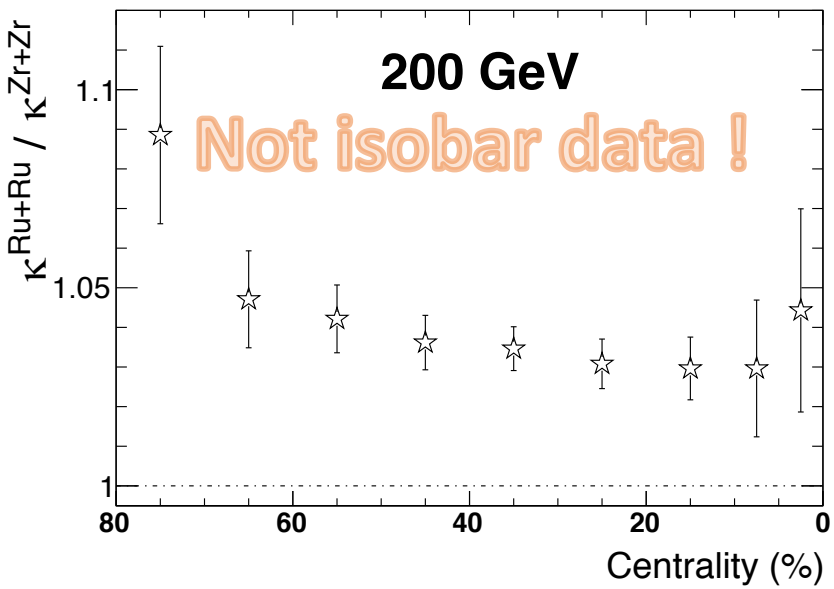
Isobar Analysis (UCLA) : $\Delta\gamma$, $\Delta\boldsymbol{\delta}$, and $\boldsymbol{\kappa}$

$$\gamma = \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$$
$$\delta = \langle \cos(\phi_\alpha - \phi_\beta) \rangle$$

If all "signal" is flow-related background, $\Delta\gamma \sim \Delta\delta \cdot v_2$,

motivates

$$\kappa \equiv \frac{\Delta\gamma}{\Delta\delta \cdot v_2}$$



Supportive of CME:

κ (Ru / Zr) > 1

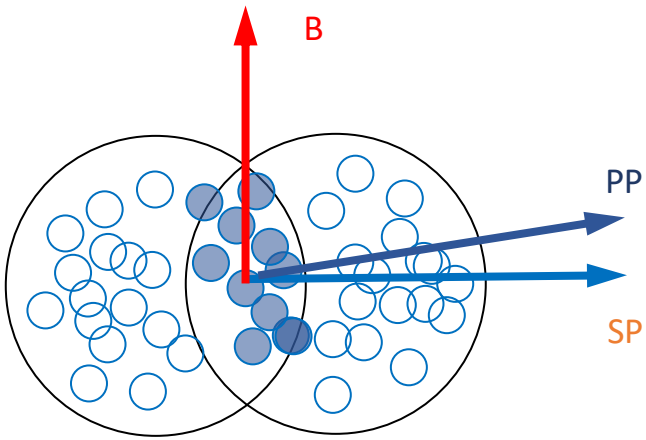
A. Bzdak, V. Koch, J. Liao Lect. Notes Phys. 871 503 (2013)
S. Shi, H. Zhang, D. Hou, and J. Liao arXiv : 1910.1401

Isobar Analysis (Purdue, WSU/Tsukuba) : Participant Plane (PP) / Spectator Plane (SP)

Magnetic Field correlated more highly with Spectator plane, flow background more highly with participant plane.

H-J. Xu et al., Chin. Phys. C 42 084103 (2018)

S. Voloshin, Phys. Rev. C 98 054911 (2018)



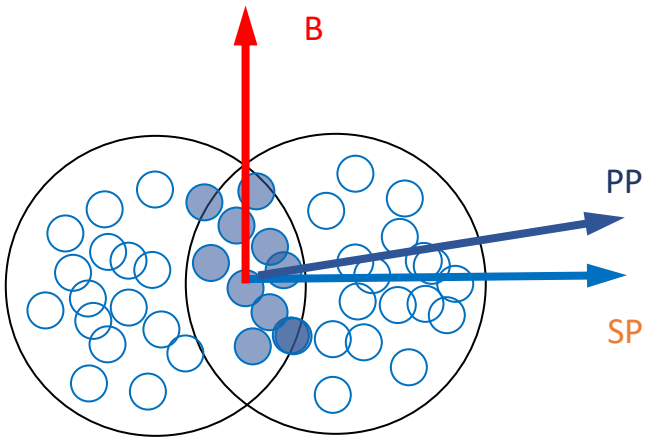
PP : maximum background

SP : maximum signal

Isobar Analysis (WSU/Tsukuba) : Participant Plane (PP) / Spectator Plane (SP)

Magnetic Field correlated more highly with Spectator plane, flow background more highly with participant plane.

S. Voloshin, Phys. Rev. C 98 054911 (2018)



PP : maximum background

SP : maximum signal

WSU/Tsukuba analysis: $\frac{(\Delta\gamma/v_2)_{ZDC}}{(\Delta\gamma/v_2)_{TPC}}$: For each isobar (supportive of CME would be > 1)

$$\frac{(\Delta\gamma/v_2)_{Ru}}{(\Delta\gamma/v_2)_{Zr}} = 1 + f[(B_{Ru}/B_{Zr})^2 - 1]$$

f is the fraction of CME signal, can be extracted from isobar ratio, with the assumption of magnetic field ratio

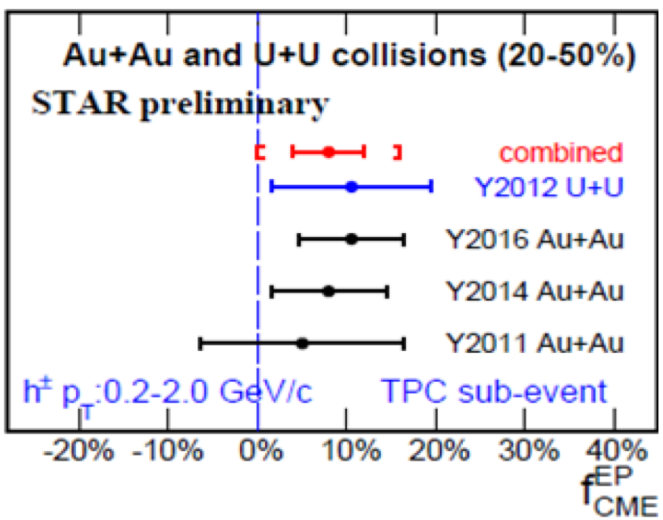
Supportive of CME would be : $\Delta\gamma/v_2$ (Ru / Zr) > 1

Isobar Analysis (Purdue) : Participant Plane (PP) / Spectator Plane (SP)

$$f_{CME}^{PP} = \frac{\frac{\Delta\gamma\{SP\}}{\Delta\gamma\{PP\}}/a - 1}{1/a^2 - 1}$$

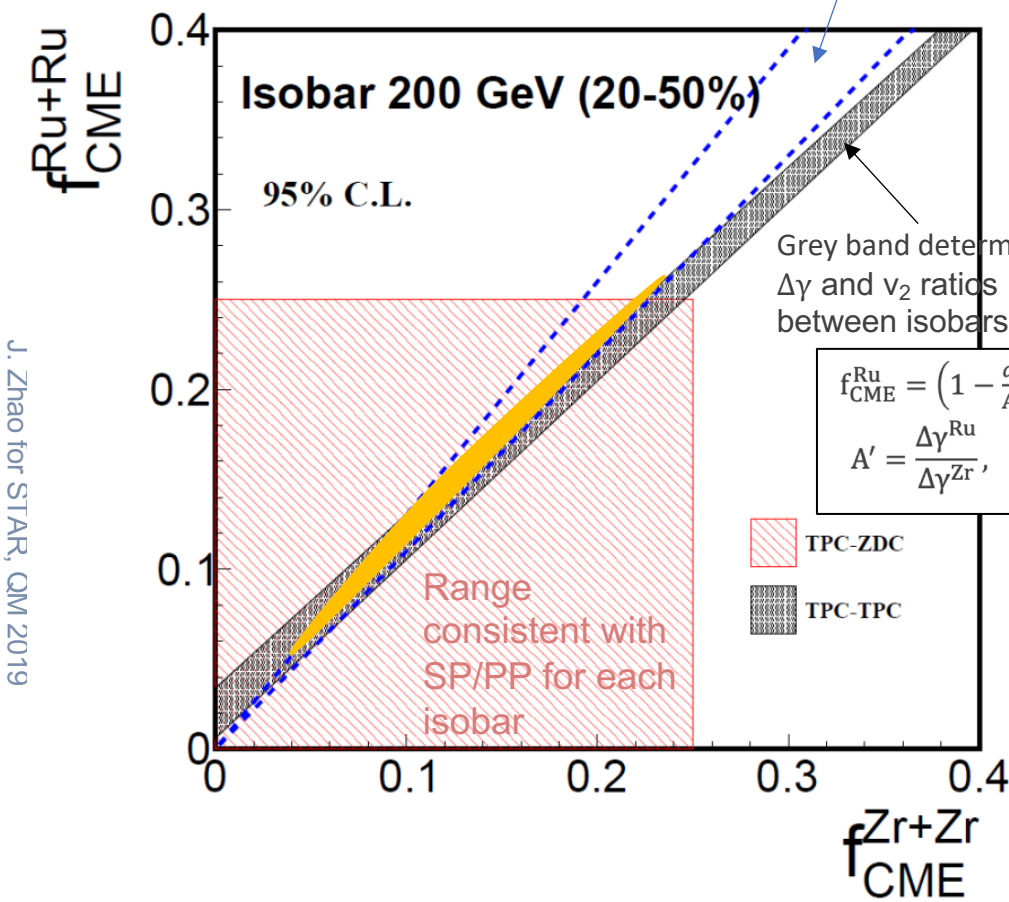
$a = \langle \cos 2(\Psi_{PP} - \Psi_{SP}) \rangle$

H-J. Xu et al., Chin. Phys. C 42 084103 (2018)



J. Zhao for STAR, QM 2019
arXiv:2002:09410

Theoretical Input:
Range of B-field
ratio Ru/Zr
$f_{CME}^{Ru} \approx (1 + \Delta B^2) f_{CME}^{Zr}$



$$f_{CME}^{Ru} = \left(1 - \frac{a'}{A'}\right) + \frac{a'}{A'} f_{CME}^{Zr}$$

$$A' = \frac{\Delta\gamma^{Ru}}{\Delta\gamma^{Zr}}, \quad a' = \frac{v_2^{Ru}}{v_2^{Zr}}$$

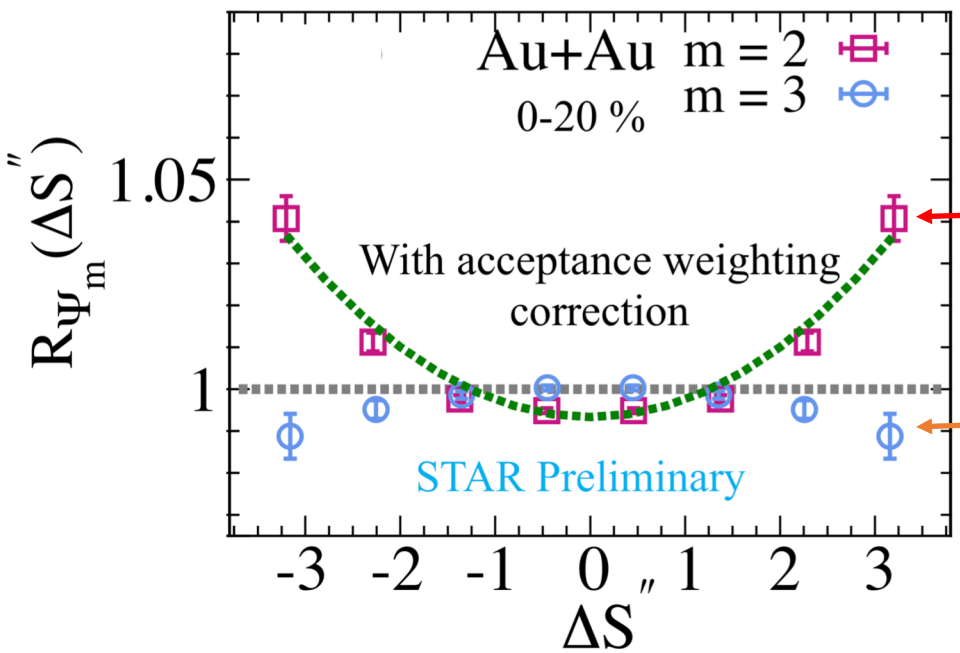
Isobar Analysis (SBU/UIC) : R(ΔS) Correlator

1) EbyE out-of-plane v_1 difference between +/- charge ΔS.

2) Removal of trivial contribution $$C(\Delta S) = \frac{N_{real}(\Delta S)}{N_{shuffled}(\Delta S)}$$

3) Look for out-of-plane excess $$R(\Delta S) = \frac{C^{\perp}(\Delta S)}{C(\Delta S)}$$

4) Repeat with Ψ_3 EP for baseline.



Signal, U-shape

Background

Supportive of CME would be:
R (Ru / Zr) concave shape

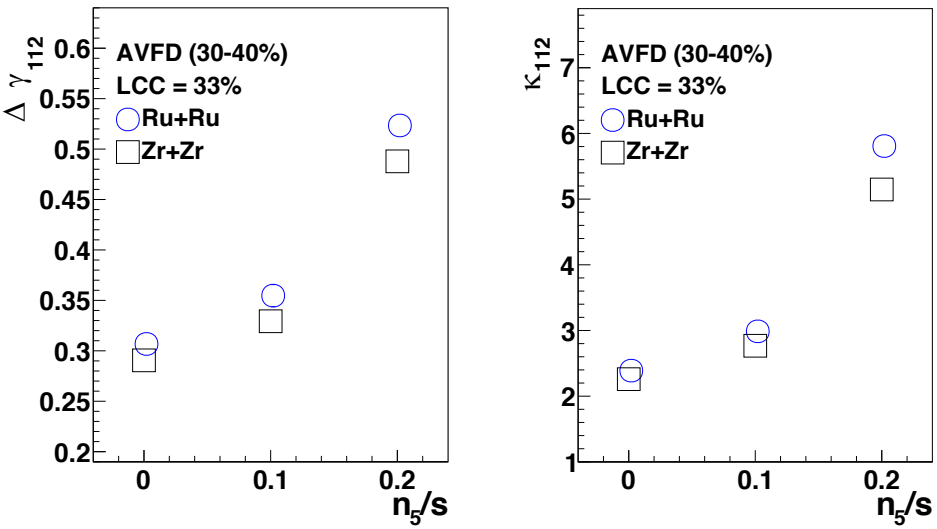
N. Magdy for STAR, WWND 2019

N. Magdy, S. Shi, J. Liao, N. Ajitanand and R. Lacey Phys. Rev. C 97 061901 (2018)

Other CME isobar analyses

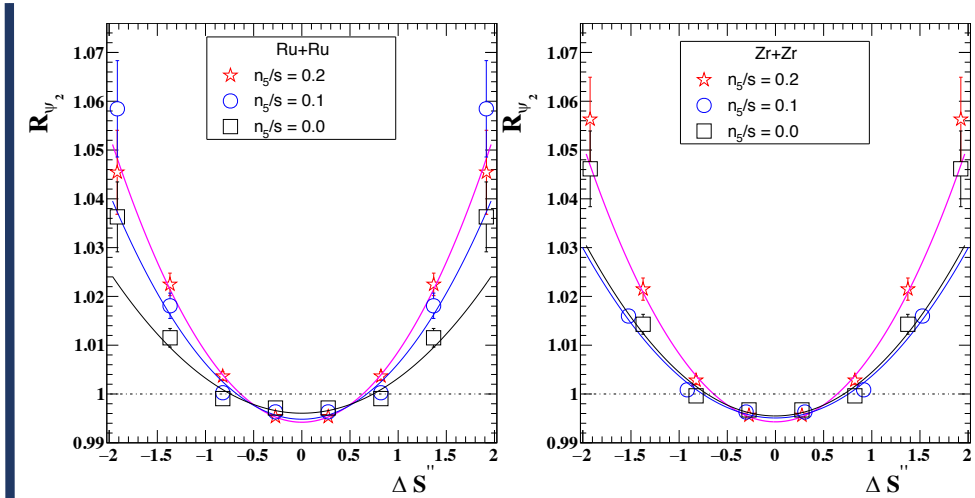
- $\Delta\boldsymbol{\gamma}(m_{inv})$
- $\Delta\boldsymbol{\gamma}(\Delta\boldsymbol{\eta})$
- $\Delta\boldsymbol{\gamma}$ using EPD, BBC, ZDC reaction plane
- Signed balance function (BNL/CCNU/SINAP) analysis not part of the blind analysis (results will come later)

Observables' Response to Signal in AVFD



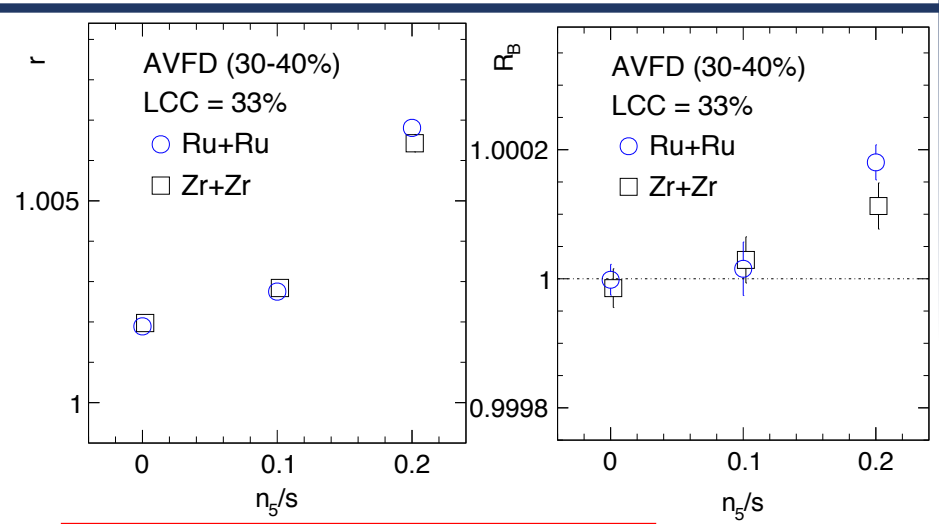
γ -correlator

20 M evts



R(ΔS)-correlator

20 M evts



Signed Balance Function

50 M evts

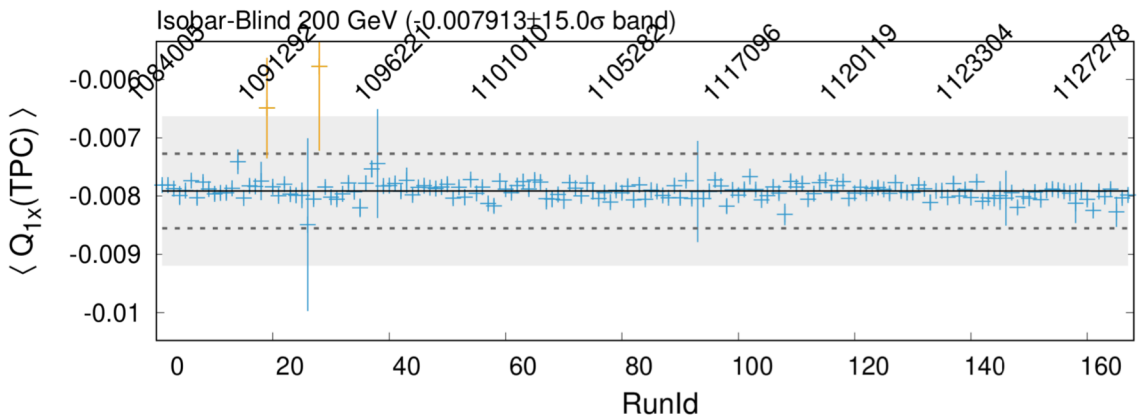
Frozen codes are being run to analyze AVFD events (still accumulating/analyzing more events).

Work in progress, independent of blind analyses.

- Connection between observables can be made with realistic CME model.
- Serve as guidance when comparing results across different methods.

Timeline for completion of blind analysis

- Step 2 (running small samples of each run for Run-by-Run QA)
  - production will take ~1 month, analyzers have started QA checks of data.



  - Run-by-run QA is already coded, should add little additional time
  - During this time, GPC will continue discussion of first publication.
- Step 3 (full production run and analysis)
  - Production will take ~ 3 months. The main thinking for analysis is done, and computation can largely be run in parallel with production.
- Results projected to be ready (internally to STAR) in the Fall.