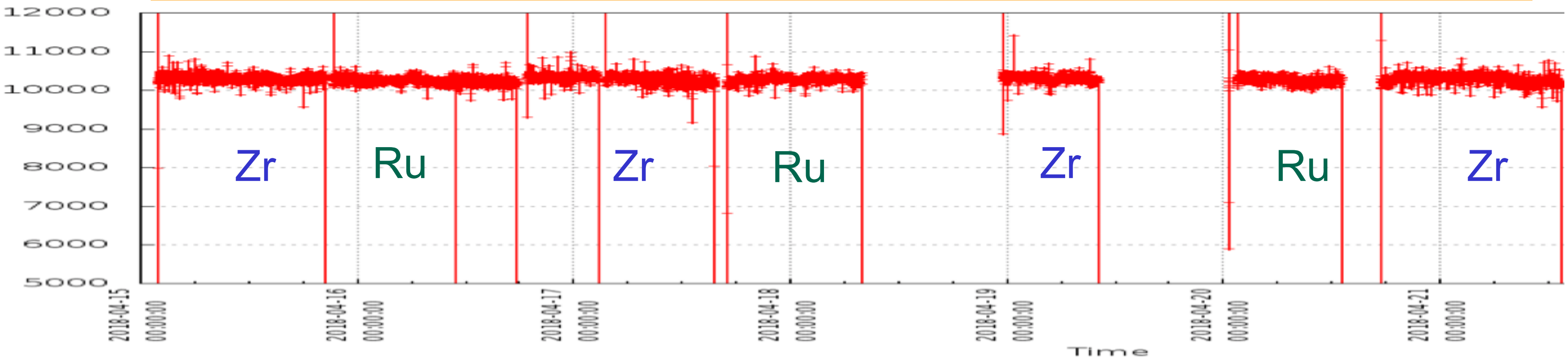
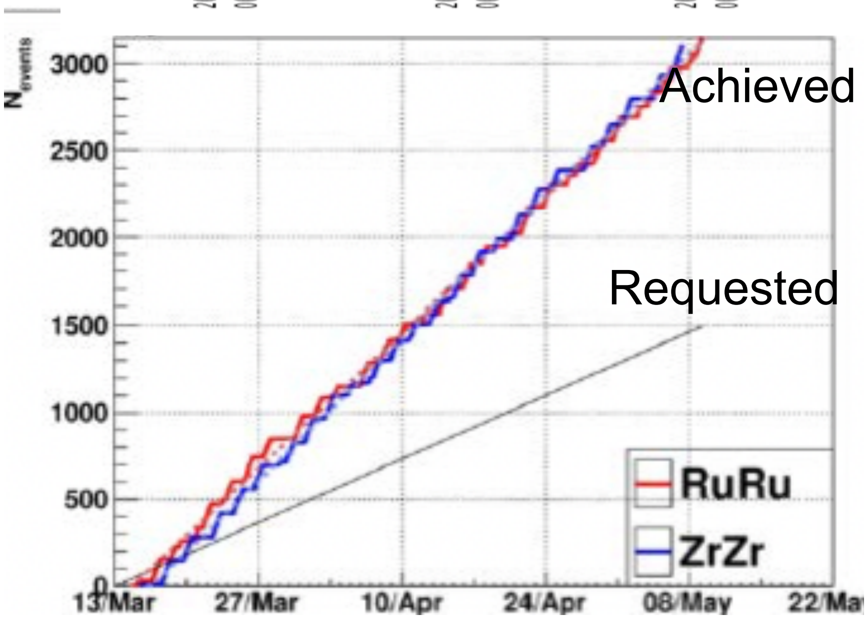
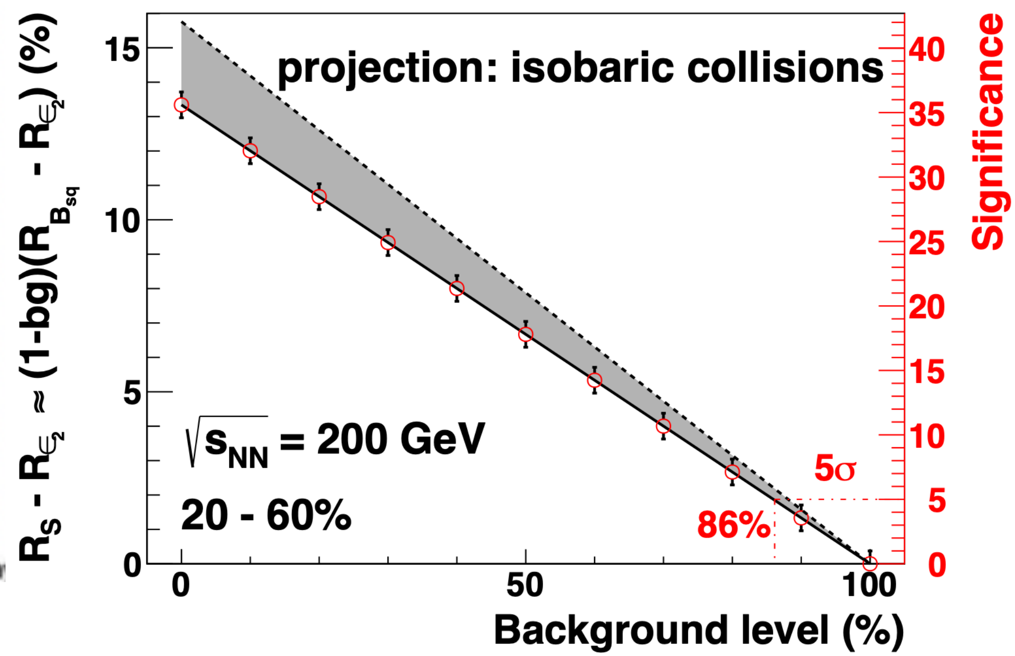
Isobar Run Analysis Progress

Aihong Tang (for the STAR Collaboration)

Isobar Data Taking at RHIC





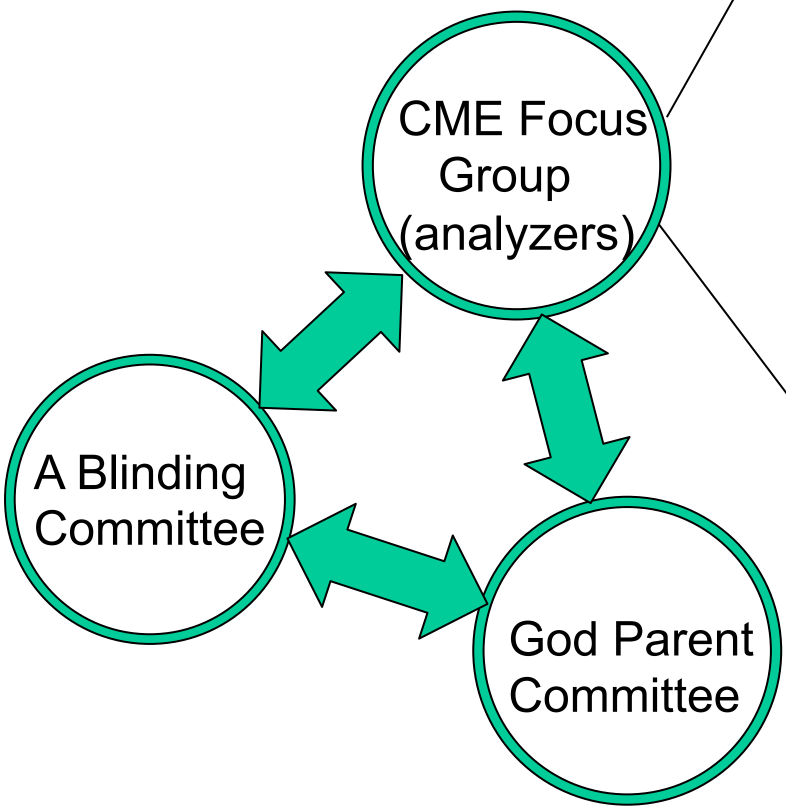


Took more than requested.
(2.3 and 2.5 B after calibration QA)

Anticipated significance with 2.5 B good evts.
5σ difference in $\Delta\gamma$ if bkg. is at ~86% level.

Isobar Analyses (5+1) in STAR

A large, collective effort



BNL, CCNU, Fudan, Huzhou, Purdue, SINAP, Stony Brook, Tsukuba, UCLA, UIC, Wayne State

Blind analyses (5 groups):

- $\Delta\gamma$, $\Delta\delta$, and κ.
- $\Delta\gamma$, $\Delta\delta$, $\Delta\gamma(\Delta\eta)$.
- $\Delta\gamma$ in PP/SP, $\Delta\gamma(M_{inv})$.
- $\Delta\gamma$ in PP/SP.
- $R(\Delta S)$ Correlator.

No-Blind analysis (1 group):

- Signed Balance Function.

Challenges :

- Coordination and synchronization. (among groups, as well as between groups and committees).
- Unify procedures in common.
- Identify run-by-run abnormalities before hand without actual seeing them.

……

See backup slides for key observables.

Isobar Blind Analyses in STAR

Case for CME :

$\Delta\gamma/v_2$ (Ru / Zr) > 1

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

κ (Ru / Zr) > 1

$\Delta\gamma^{\mathrm{Ru}} - a'r'\Delta\gamma^{\mathrm{Zr}} > 0$

$\Delta\gamma$ and its derivatives

R (Ru / Zr) concave shape

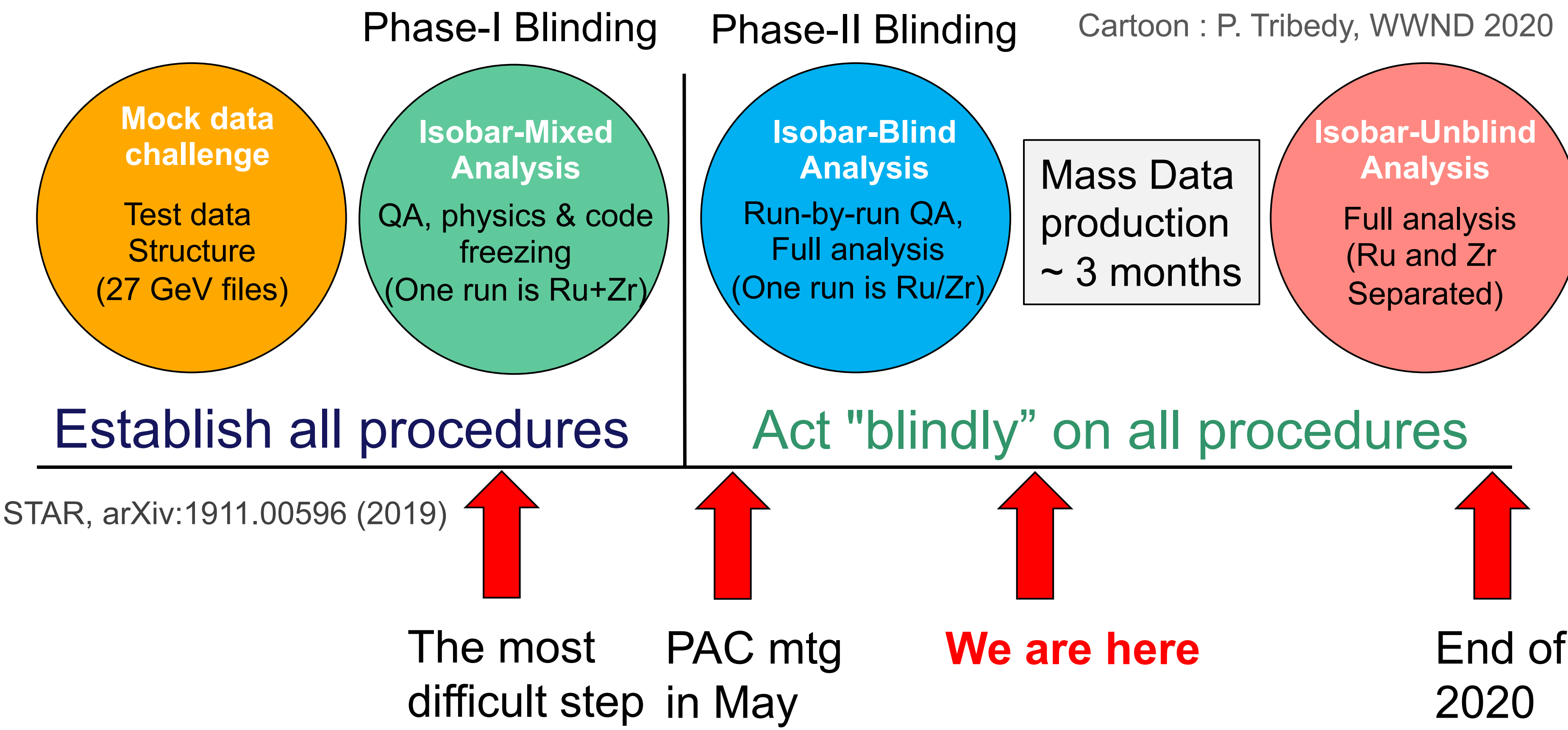
Correlation shape

$\mathrm{f}_{\mathrm{CME}}^{\mathrm{Ru+Ru}} > \mathrm{f}_{\mathrm{CME}}^{\mathrm{Zr+Zr}} > 0$

SP & PP + $\Delta\gamma$

See backup slides for details of key observables.

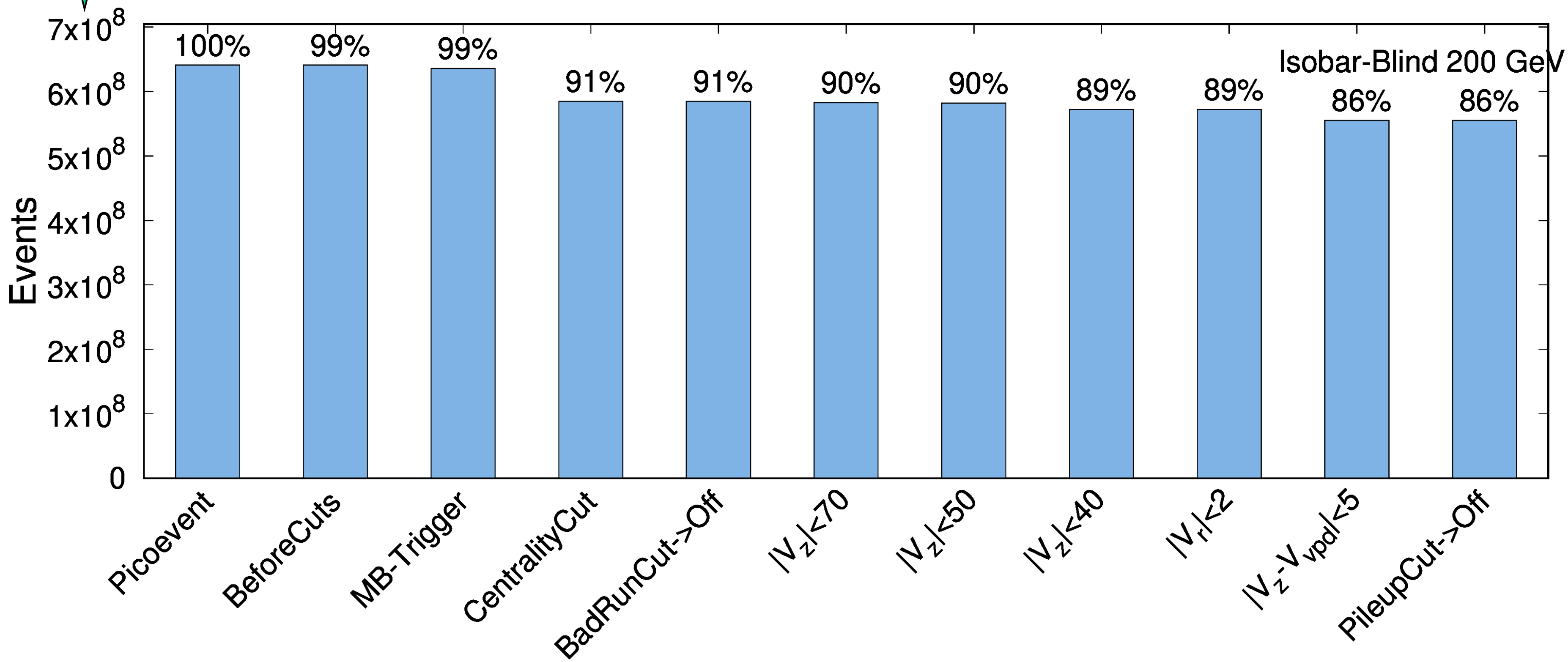
Isobar Blind Analysis : Procedure



- 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.

Isobar Blind Analysis : Anticipated Fraction of Good Evts

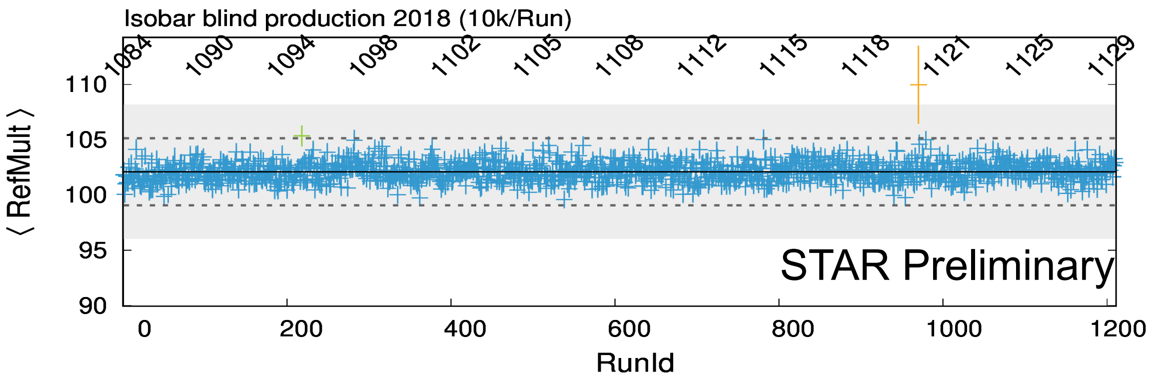
Only a small fraction of total

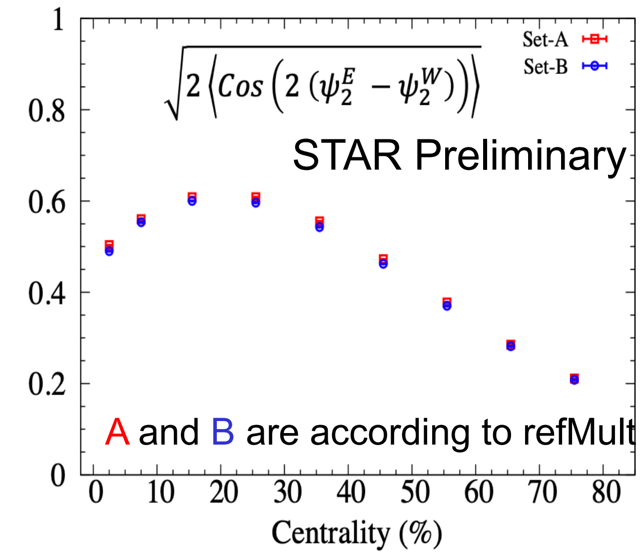


With extra 2-4% loss due to bad runs, expect ~80% good events fraction. Number of good events that will enter analyses are expected to be 1.85B for species A, and 2B for species B.

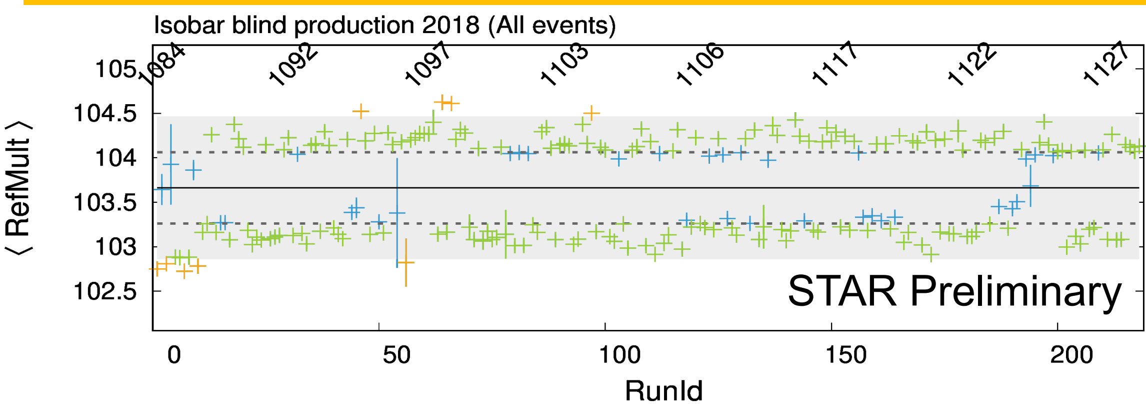
Isobar Blind Analysis : Selected QA from Phase-II Blinding

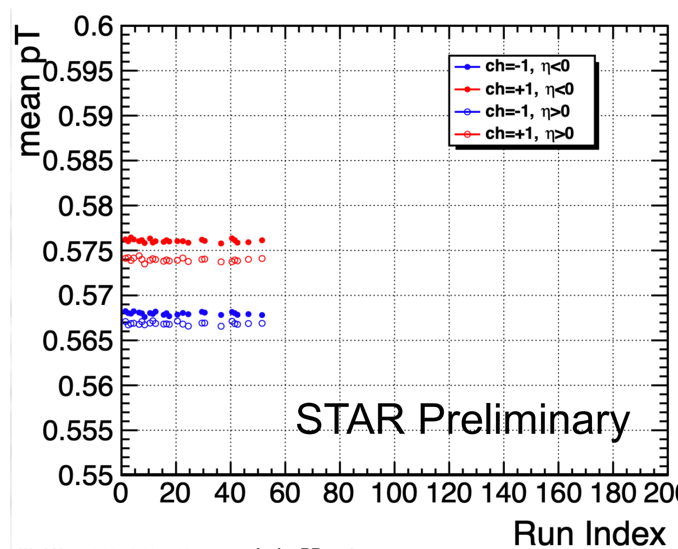
~10k events from each run, 100% runs processed.





100% events from each run, ~10% runs processed.

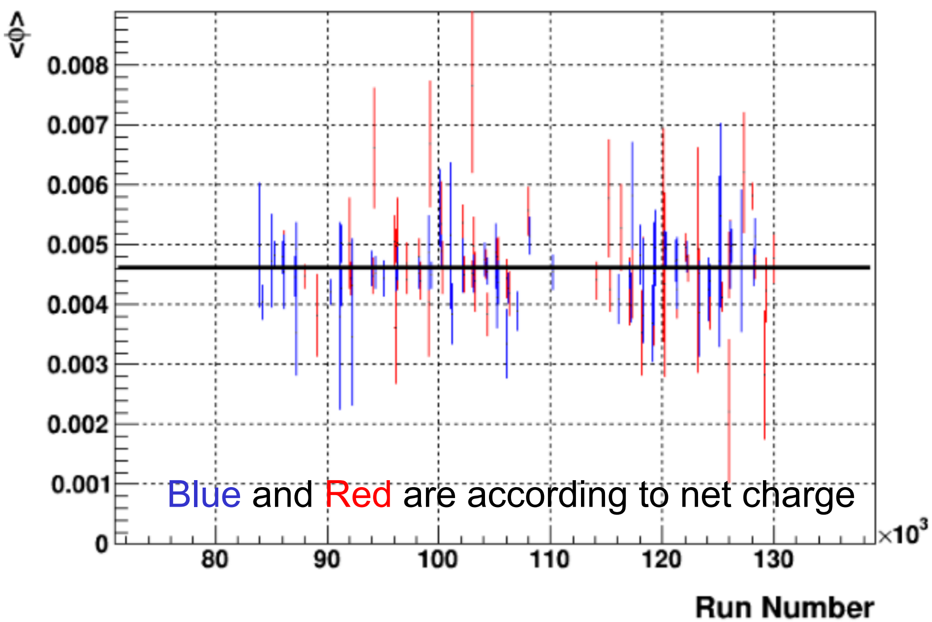


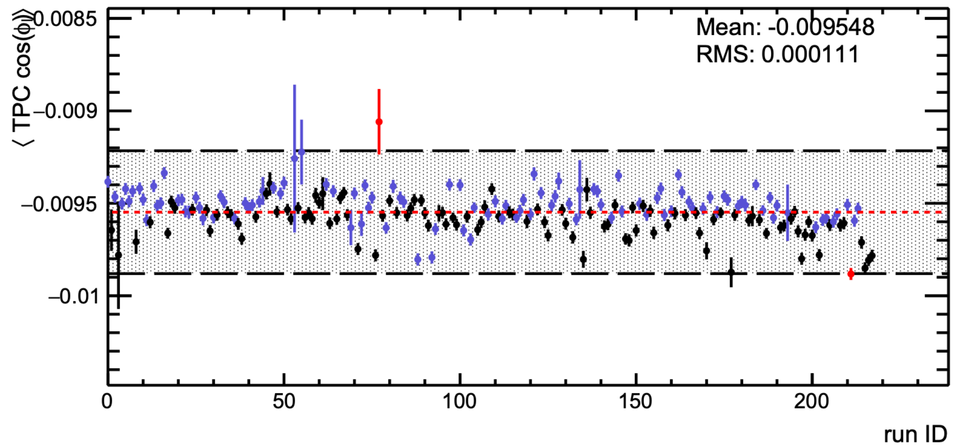


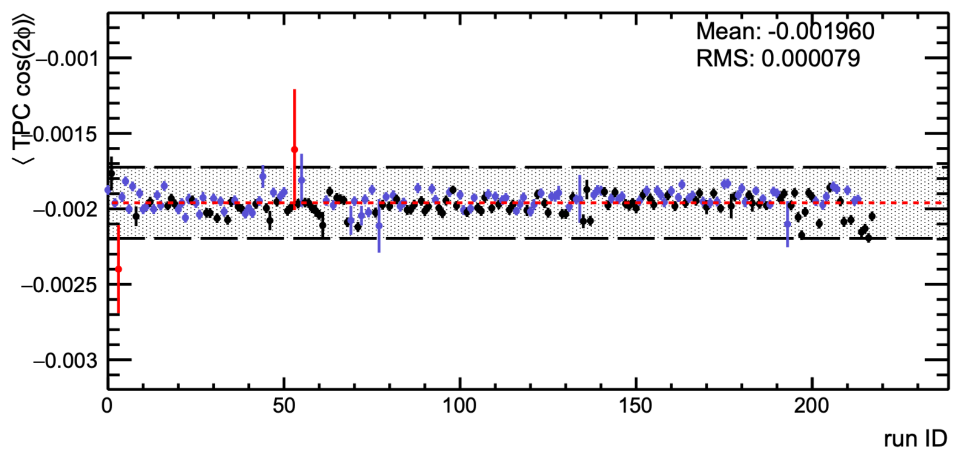
~ 1.5-2% difference in EP, mean p_t and multiplicity. Splitting due to physics.

Isobar Blind Analysis : Selected QA from Phase-II Blinding

~100% events from each run, ~10% runs processed.

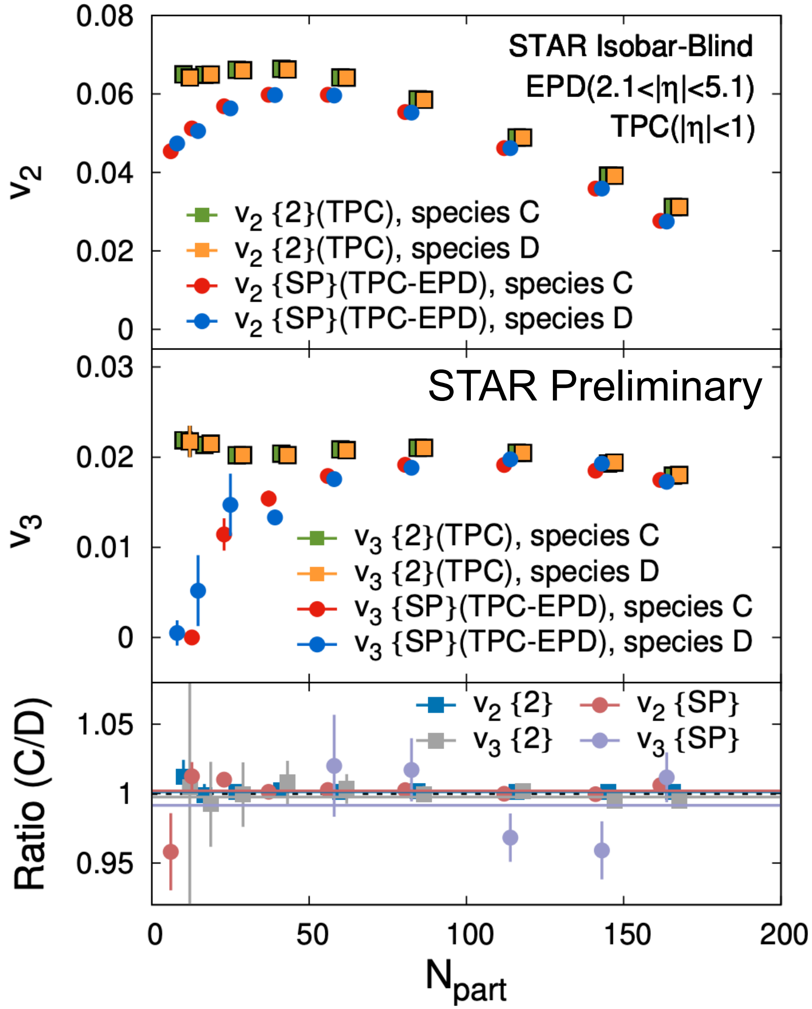






Stable detecting efficiency in azimuth.

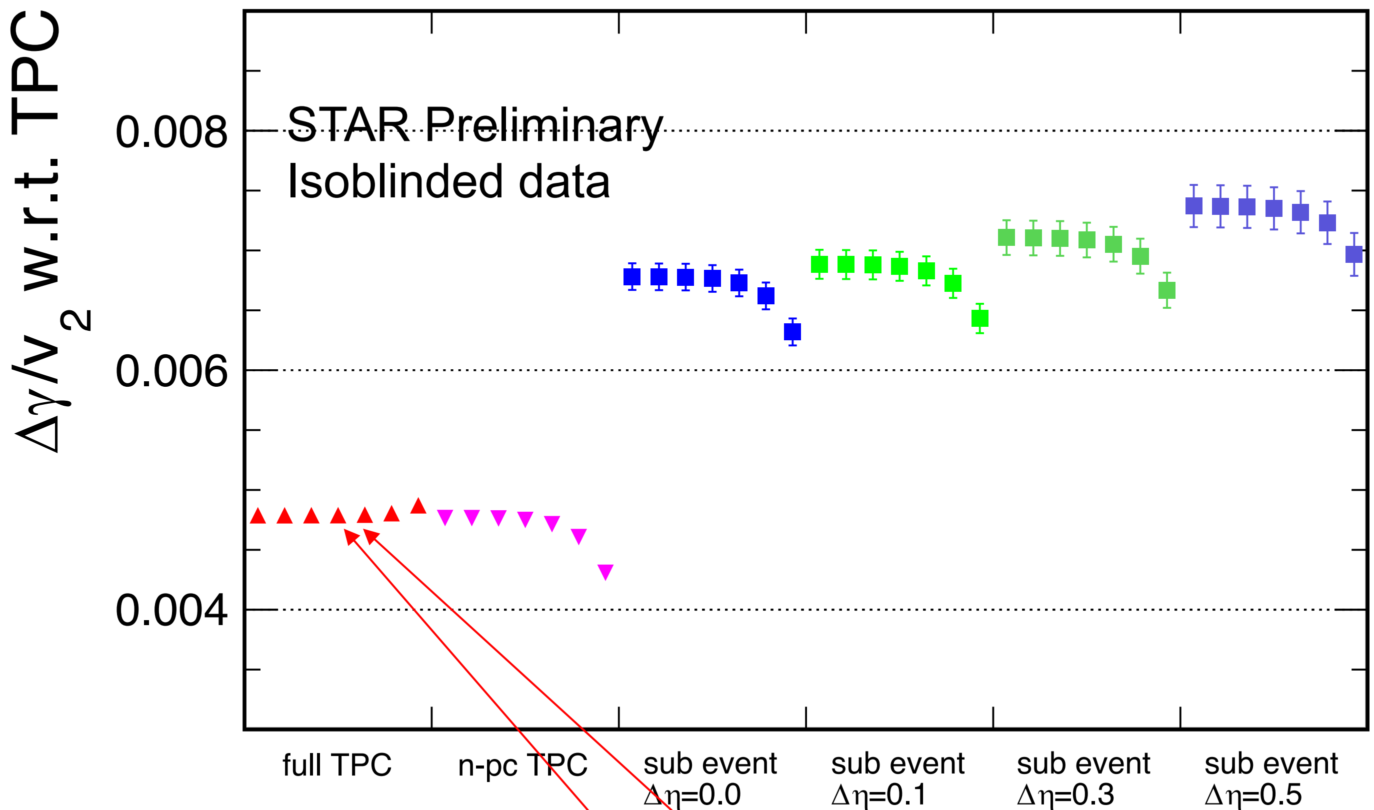
Isobar Blind Analysis : Selected QA from Phase-II Blinding



Event Plane Detector effectively reduces nonflow background.

C and D : randomly divided samples.

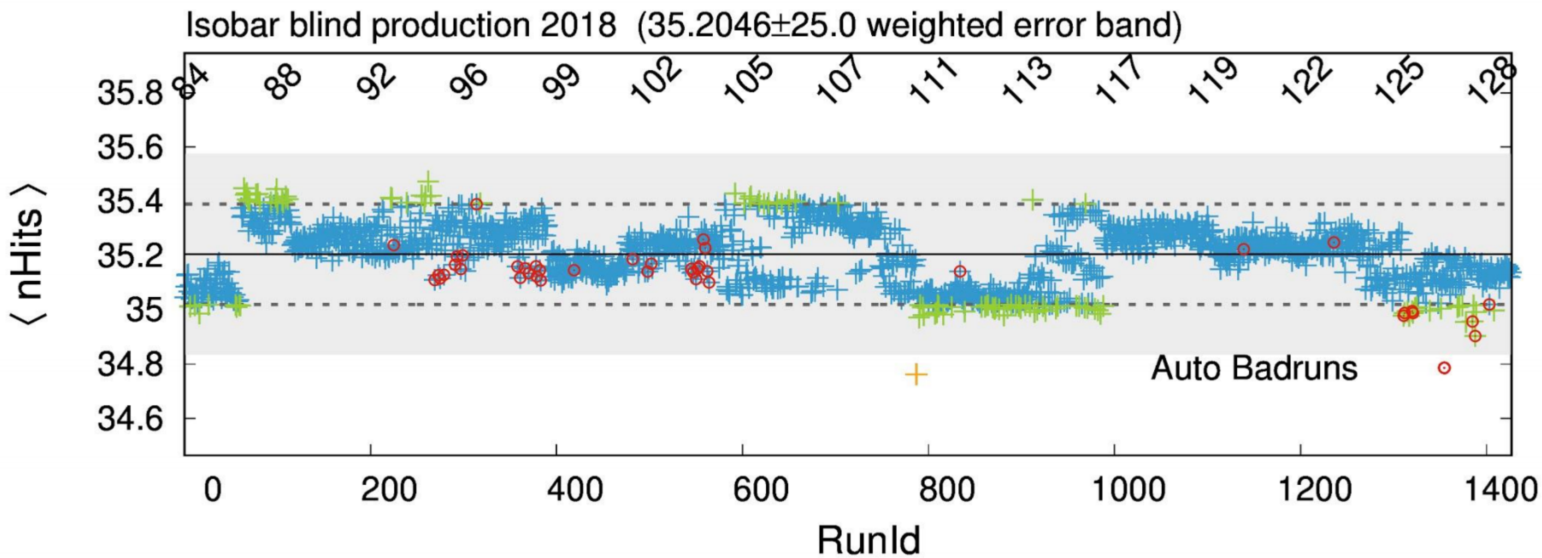
Isobar Blind Analysis : Selected Studies from Phase-II



From left to right in each color group : narrow to wider bin width
(0.625%, 1.25%, 2.5%, 5%, 10%, 20%, 40%)

Effect of centrality bin width is not an issue for STAR standard centrality bin.

Isobar Blind Analysis : Selected Studies from Phase-II



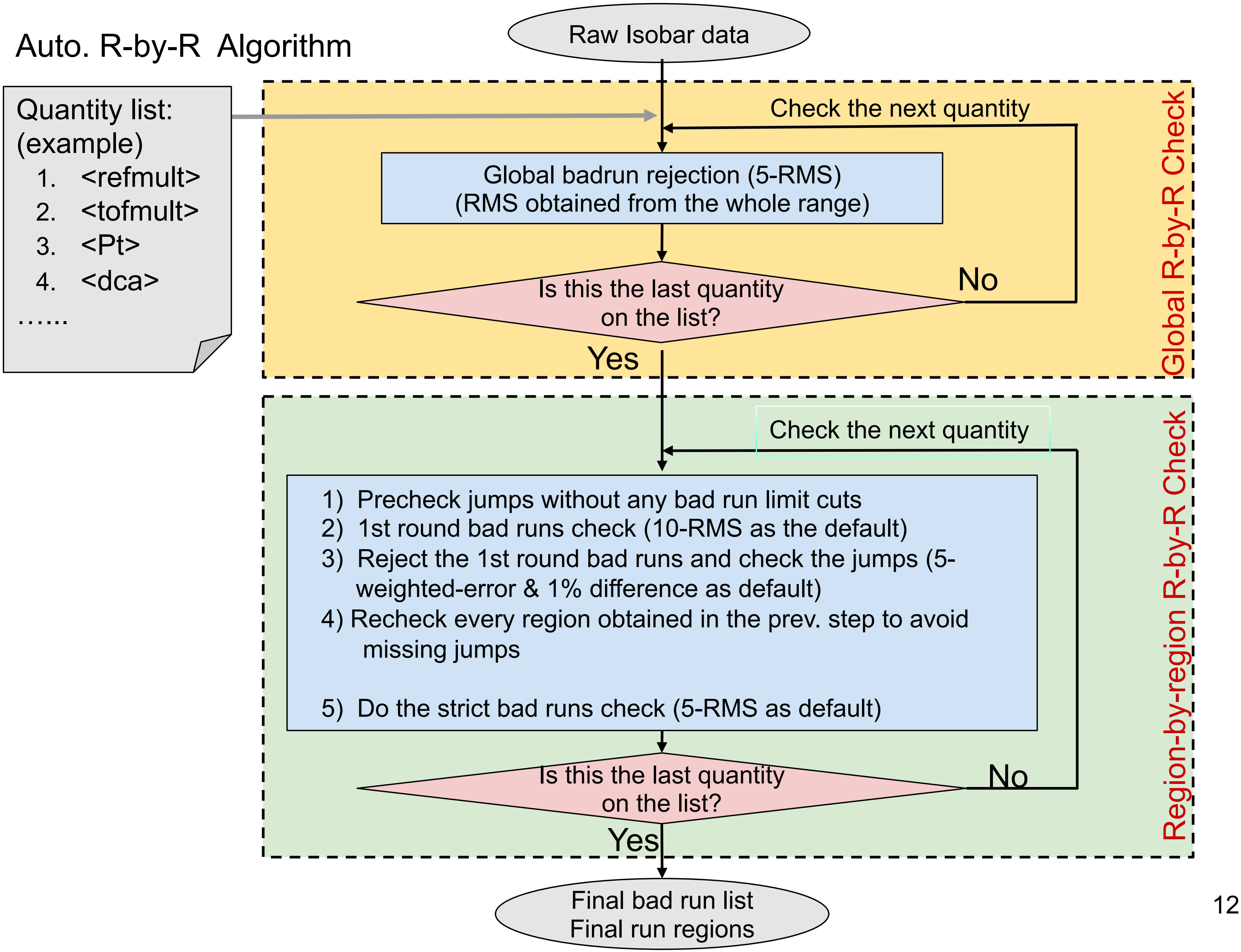
Jumps observed in <nHits> which is not included in every group's check list . Run numbers are scrambled on purpose ⟹ jump-positions for now are artificial.

Variation is small. The original jump-checking algorithm, although works for most cases, cannot cope with small variations like this.

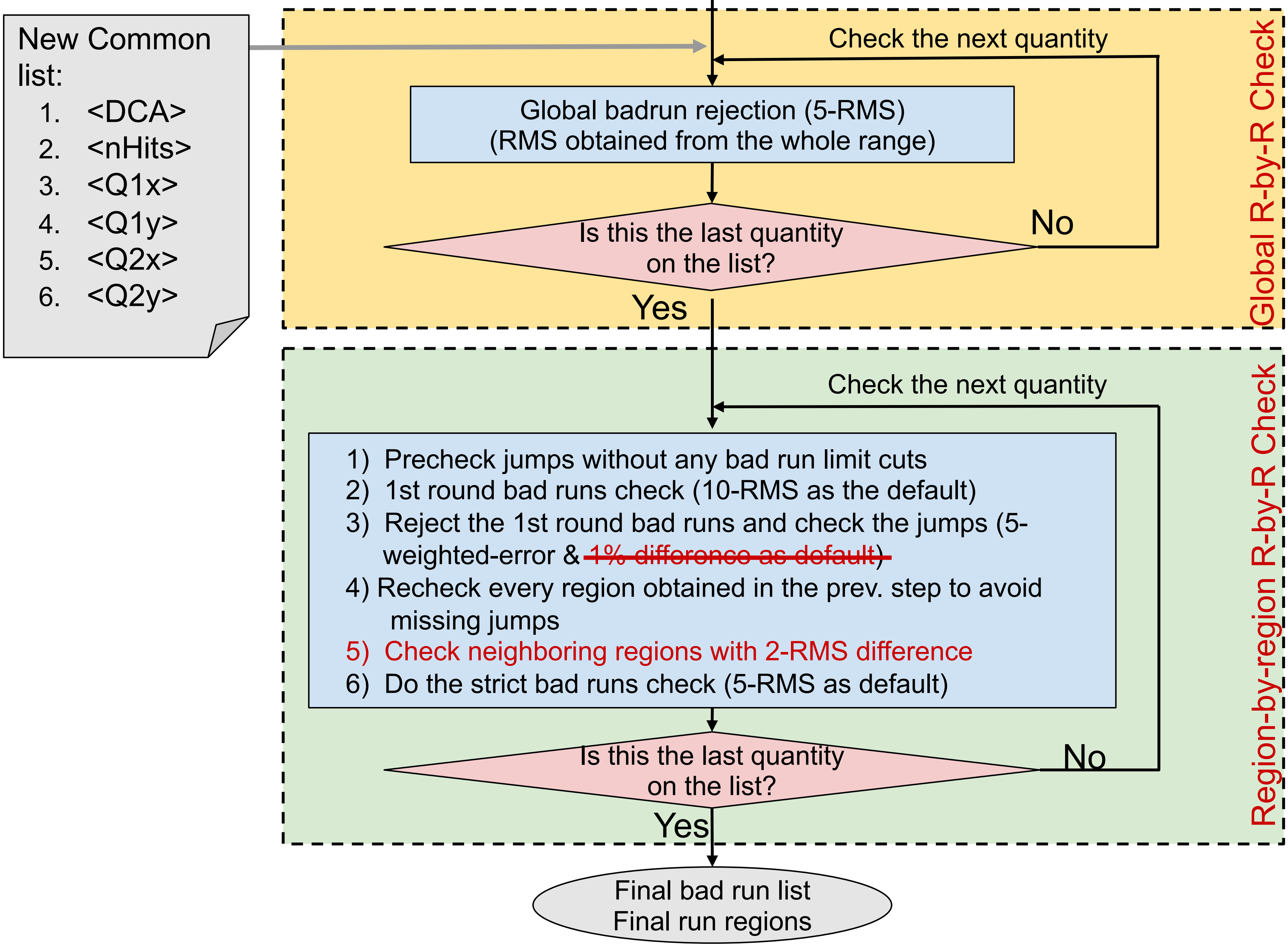
So far no evidence is found that this will affect physics. It will be re-assessed with full statistics of unblinded isobar data.

After analyzing data as-documented, results from all groups will be re-checked with new algorithms/criteria for a few key QA quantities :
<DCA>, <nHitsFit>, <Q1x>, <Q1y>,<Q2x>,<Q2y>

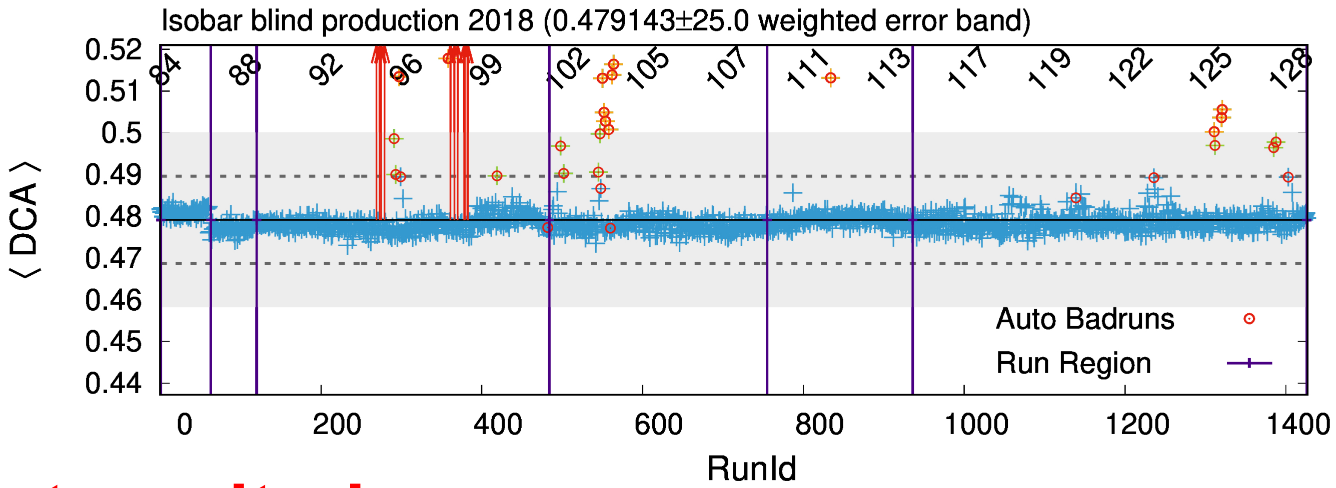
Auto. R-by-R Algorithm



Algorithm with extra criteria:



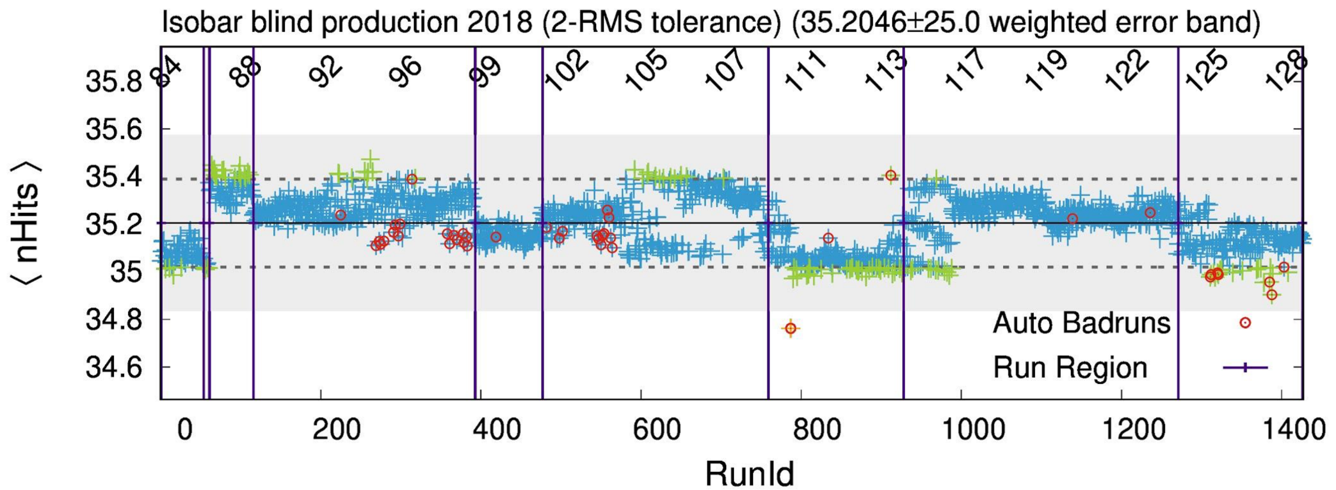
Default algorithm



Example Quantity List:

1. <refmult>
2. <tofmult>
3. <Pt>
4. <eta>
5. <DCA>
6. <Q2x>
7. <Q2y>

Extra criteria



New Common list:

1. <DCA>
2. <nHits>
3. <Q1x>
4. <Q1y>
5. <Q2x>
6. <Q2y>

Extra algorithm/criteria has been tested with phase-II data.

Isobar Blind Analysis : Going on in Parallel

Centrality definition :
Being worked on by an independent group which can access unblinded data.

Regions / Bad runs :
Code has been passed on to an independent person who can access unblinded data and will run the code as-it-is.

Full Data Production :
Phase-II concluded. With green light from STAR management, the production has started (takes ~ 3 months to finish).

Isobar Blind Analysis : Paper Publication Strategy

Discussion of paper publication strategy is on going. Current consensus is that STAR will publish a short paper with key plots, accompanied by a long paper with all necessary details. For each group, observables and money plots have already been presented (with mock data points) and discussed.

The focus between now and full unblinding would be the actual structure of the paper and possibly the paper writing.

GPC is in place since Aug. 2019 and is ramping up the discussion already.

Summary

STAR's blind analysis of isobar data has passed phase-II. Intensive QA has been performed, quite a few QA-related issues have been identified and resolved.

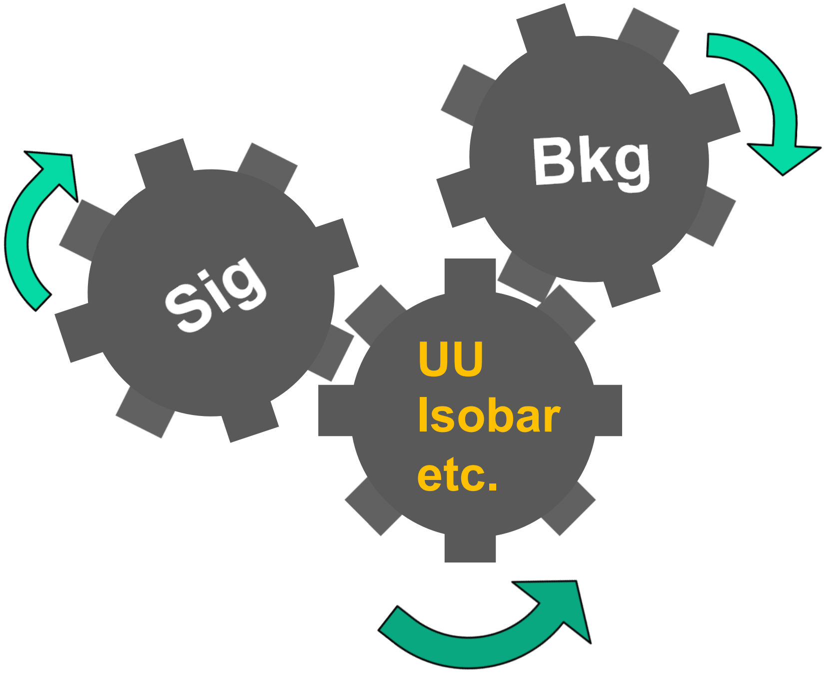
The next step is full data production (~ 3 months) followed by analysis of un-blinded data.

Backup Slides

Understanding the Background

1. Turn off background (event shape engineering, $\Delta\gamma(M_{inv})$).
2. Turn off signal (small system).
3. Vary background only (Ultra-central U+U vs. Au + Au).
4. Vary signal only (Isobaric collisions).

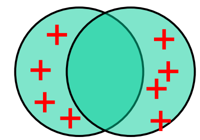
Play with it and learn !



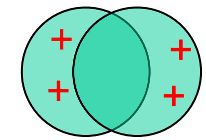
Understanding the Background : Vary signal

(Isobar collisions)

Signal driver (B)	←	**Vary**
Background driver (v_2)	←	**Fixed**

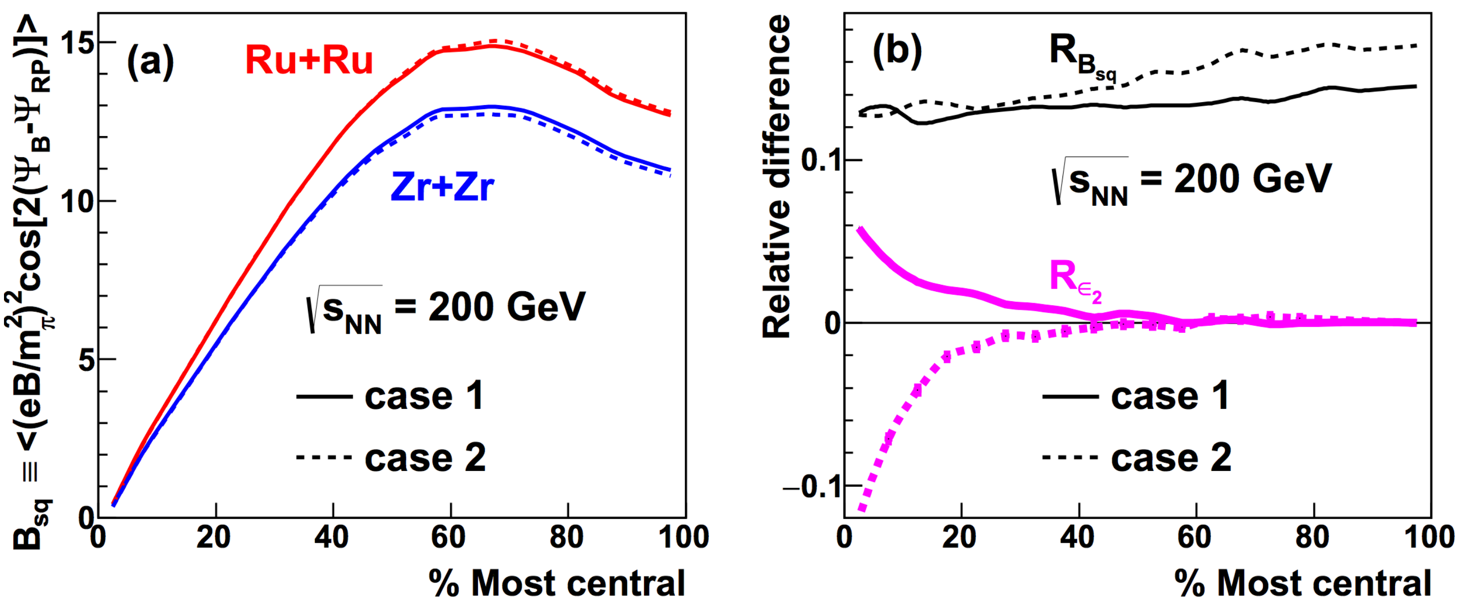


midcentral



$^{96}_{44}Ru+^{96}_{44}Ru$: $^{96}_{40}Zr+^{96}_{40}Zr$

ε_2 (Ru+Ru) ~ ε_2 (Zr+Zr)
B (Ru+Ru) > B (Zr+Zr)



W. Deng, X-G. Huang, G. Ma and G. Wang, PRC 94 041901 (2016)

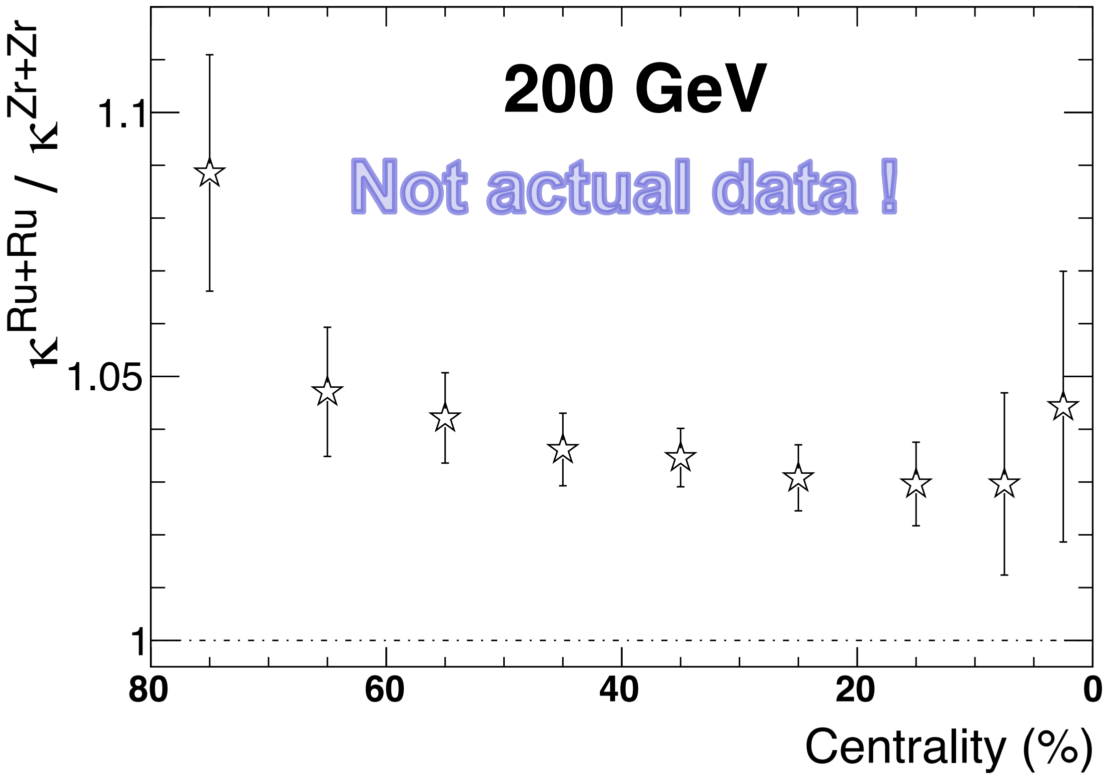
Isobaric collisions : great potential for checking signal response.

Isobar Analysis (Grp 1) : $\Delta\gamma$ and $\Delta\delta$

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

When there is pure background, $\Delta\gamma \sim \Delta\delta \cdot v_2$,

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



Case for CME :

κ (Ru / Zr) > 1

Test isobar systems with pure background assumption.

S. Voloshin, Phys. Rev. C 70 057901
A. Bzdak, V. Koch, J. Liao Lect. Notes Phys. 871 503 (2013)
S. Shi, H. Zhang, D. Hou, and J. Liao arXiv : 1910.1401
+ many others

Isobar Analysis (Grp 1) : $\Delta\gamma$ and $\Delta\delta$

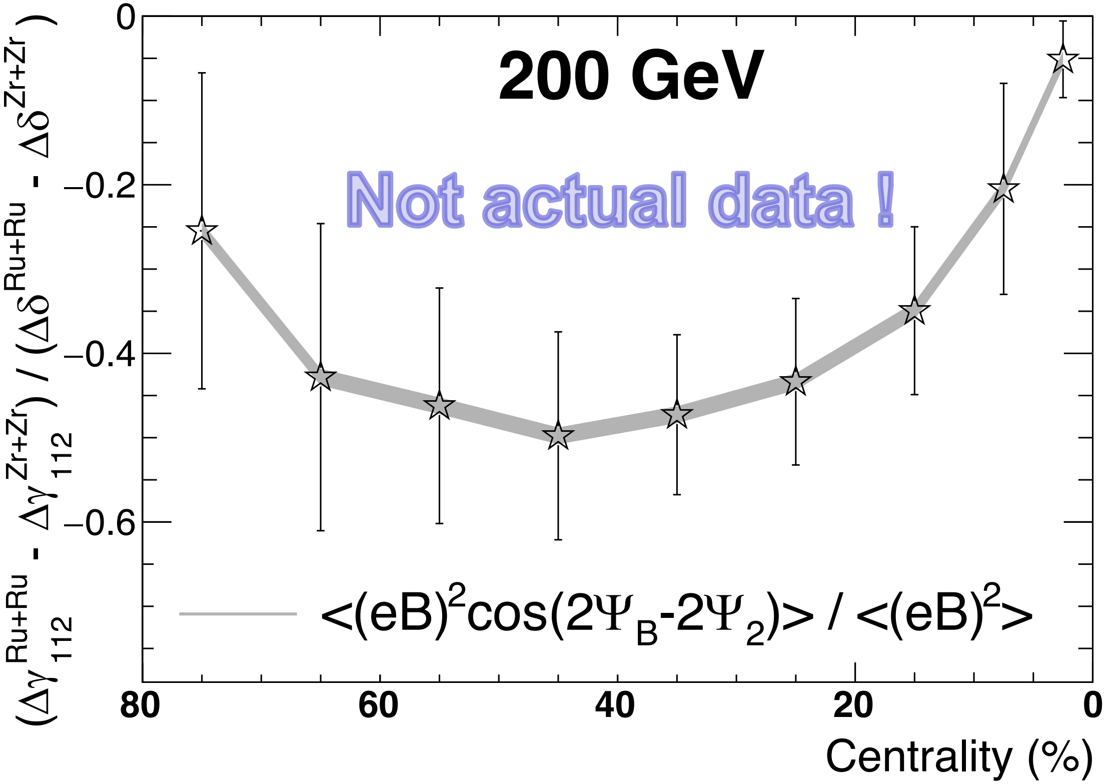
$\gamma = \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$

$\delta = \langle \cos(\phi_\alpha - \phi_\beta) \rangle$

When there is pure signal,

$\Delta\gamma \sim 2\langle a_1^2 \cos(2\Psi_B - 2\Psi_{EP}) \rangle$

$\Delta\delta \sim -2\langle a_1^2 \rangle$,



motivates $\dfrac{\Delta\gamma\{\text{Ru}-\text{Zr}\}}{\Delta\delta\{\text{Ru}-\text{Zr}\}}$

$$\left.\frac{\Delta\gamma\{\text{Ru}-\text{Zr}\}}{\Delta\delta\{\text{Ru}-\text{Zr}\}}\right|_{v_2} \approx \langle \cos(2\Psi_B - 2\Psi_{EP}) \rangle^{[1]}$$

Case for CME :

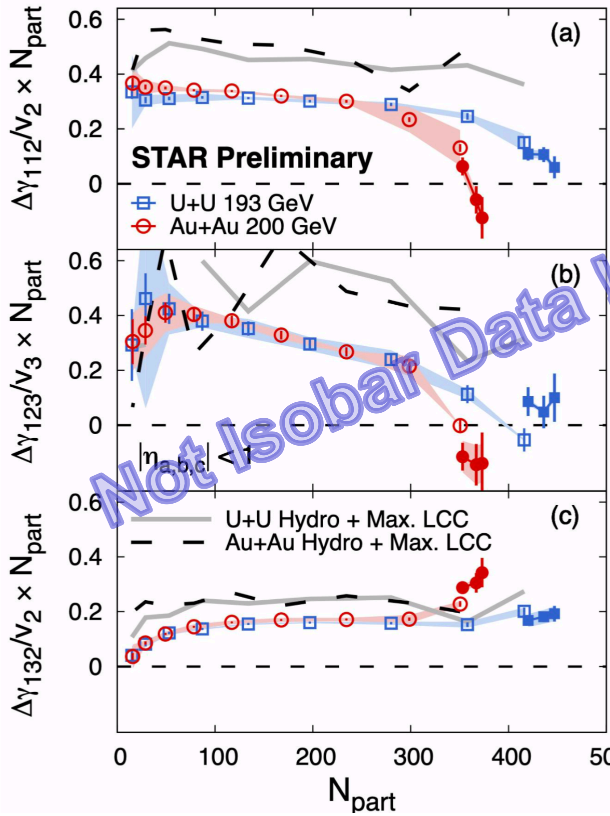
κ (Ru / Zr) > 1

Check isobar systems with a relatively clean ratio

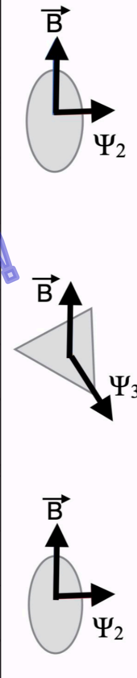
S. Voloshin, Phys. Rev. C 70 057901
A. Bzdak, V. Koch, J. Liao Lect. Notes Phys. 871 503 (2013)
S. Shi, H. Zhang, D. Hou, and J. Liao arXiv : 1910.14010
+ many others

[1]Assume same v_2, which can be attempted by event shape selection.

Isobar Analysis (Grp 2) : $\Delta\gamma$ and $\Delta\delta$



P. Tribedy for STAR, WWND 2020



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

Sig + bkg.

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

Bkg. only

$\gamma_{132} = \langle \cos(1\phi_\alpha + 3\phi_\beta - 2\Psi_2) \rangle$

Bkg. dominant

In addition the $\Delta\boldsymbol{\eta}$ dependence of $\Delta\boldsymbol{\gamma}$ will be explored.

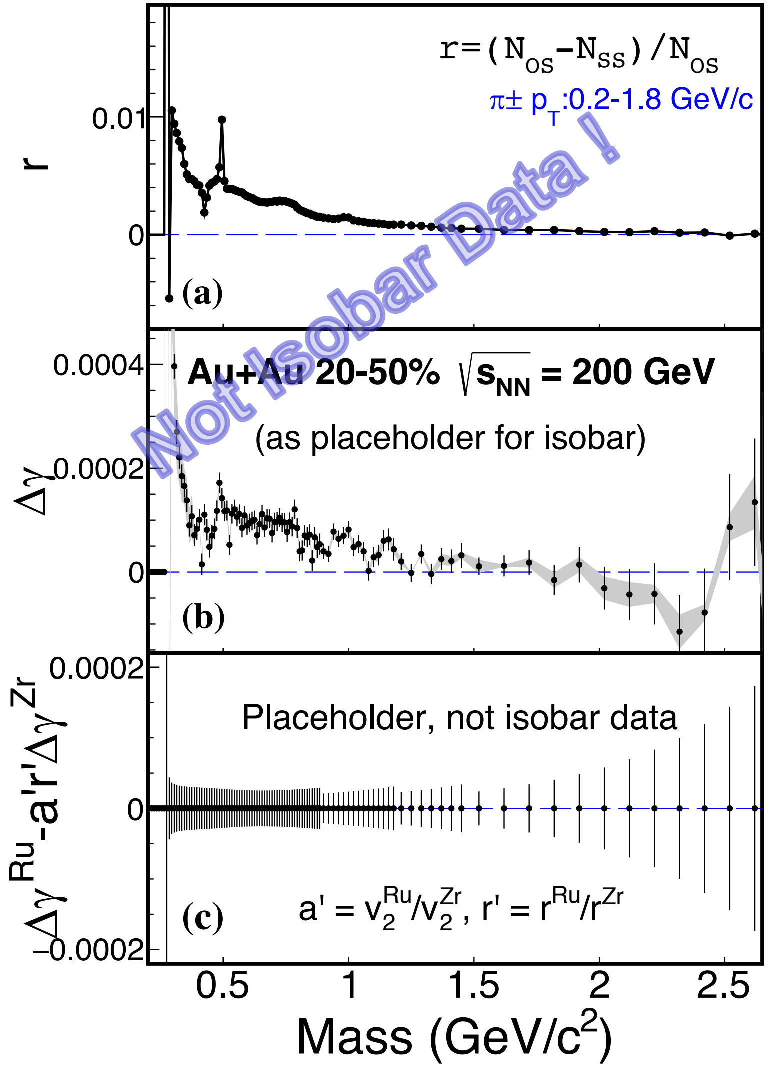
Case for CME :

$\Delta\gamma_{112}/v_2$ (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)

Isobar Analysis (Grp 3) : $\Delta\gamma(M_{inv})$

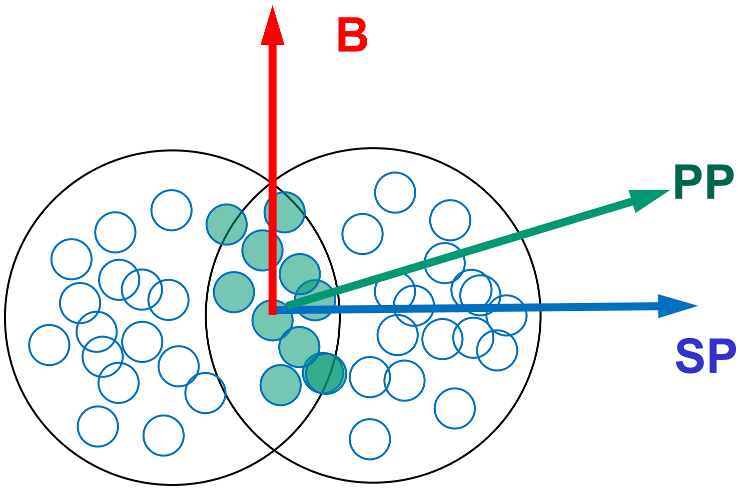


$$\Delta\gamma\,(m_{inv}) = r(m_{inv})\langle\cos(\phi_\alpha + \phi_\beta - 2\phi_{reso.})\rangle\, v_{2,reso.} + \Delta\gamma_{\,CME}$$

Case for CME :

$$\Delta\gamma^{Ru} - a'r'\Delta\gamma^{Zr} > 0$$

Isobar Analysis (Grp 3) : Participant Plane (PP) / Spectator Plane (SP)



$$\Delta\gamma = \Delta\gamma^{\text{sig}} + \Delta\gamma^{\text{bg}}$$

PP : maximum background

$$\Delta\gamma^{\text{bg}}\{PP\} = \frac{\Delta\gamma^{\text{bg}}\{SP\}}{a}$$

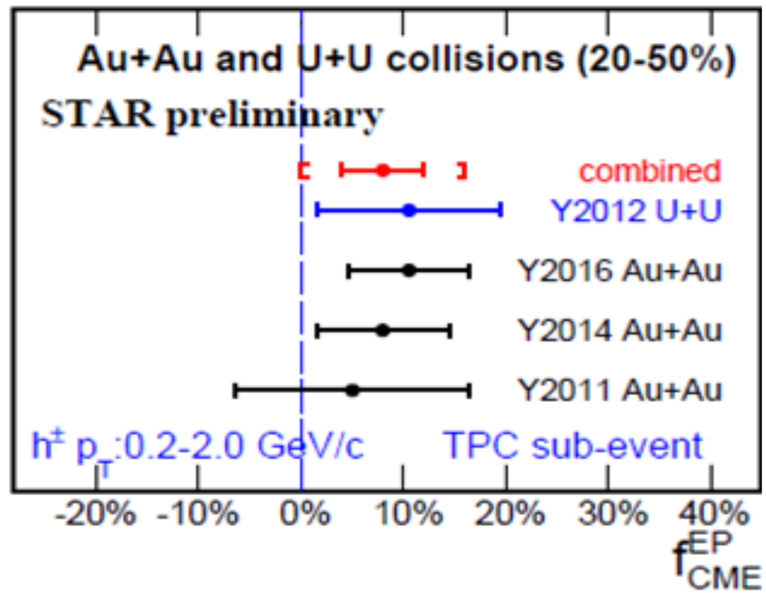
SP : maximum signal

$$\Delta\gamma^{\text{sig}}\{SP\} = \frac{\Delta\gamma^{\text{sig}}\{PP\}}{a}$$

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

$$a = \langle\cos 2(\Psi_{PP} - \Psi_{SP})\rangle \approx \frac{v_2^{ZDC}}{v_2^{TPC}} < 1$$

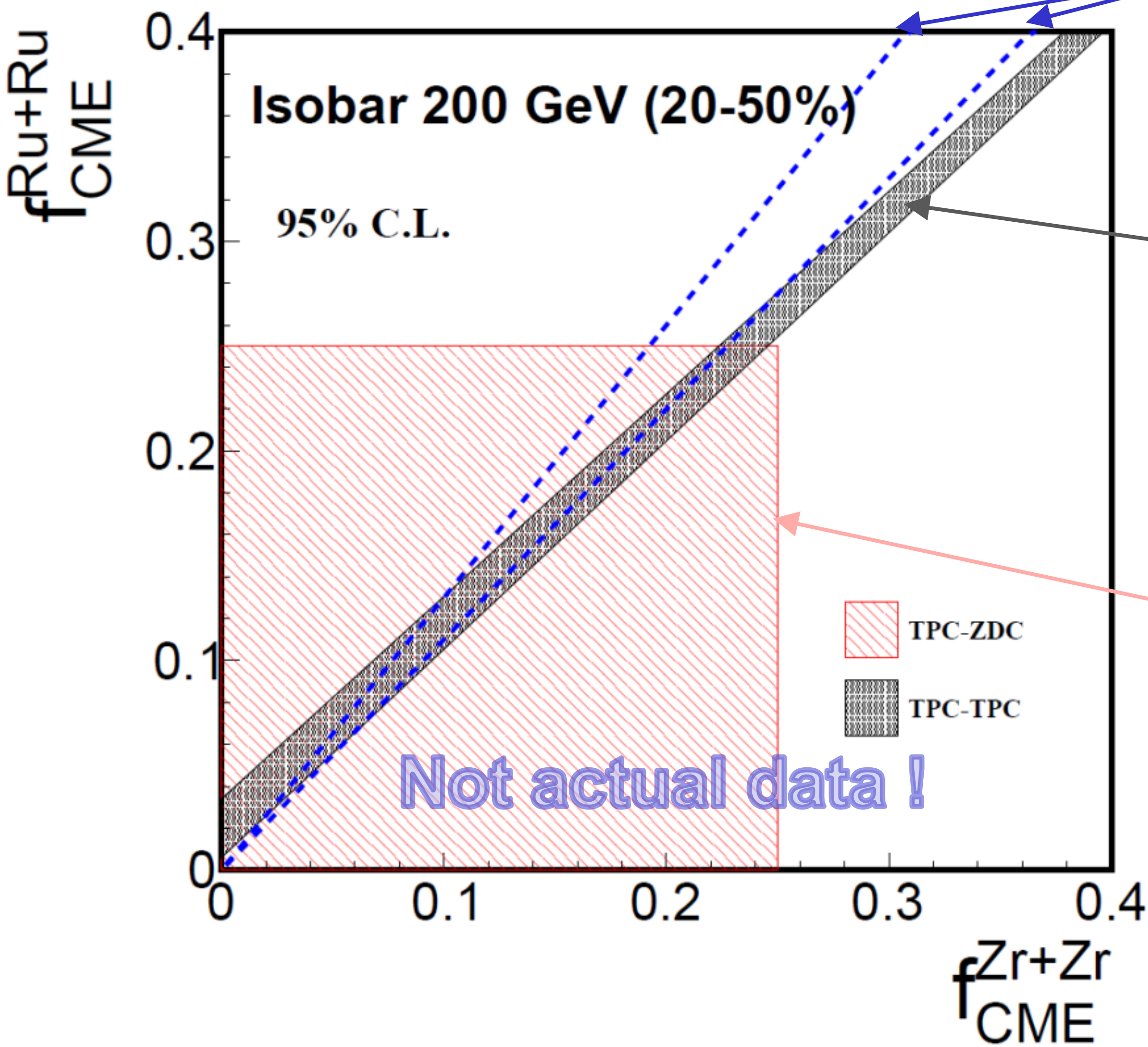
H-J. Xu et al., Chin. Phys. C 42 084103 (2018)



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

Flow bkg is usually positively correlated with signal ➡ Difficult to disentangle.
This troublesome pattern can be broken by switching between PP and SP.

Isobar Analysis (Grp 3) : Participant Plane (PP) / Spectator Plane (SP)



By B diff. between isobars (theory input)

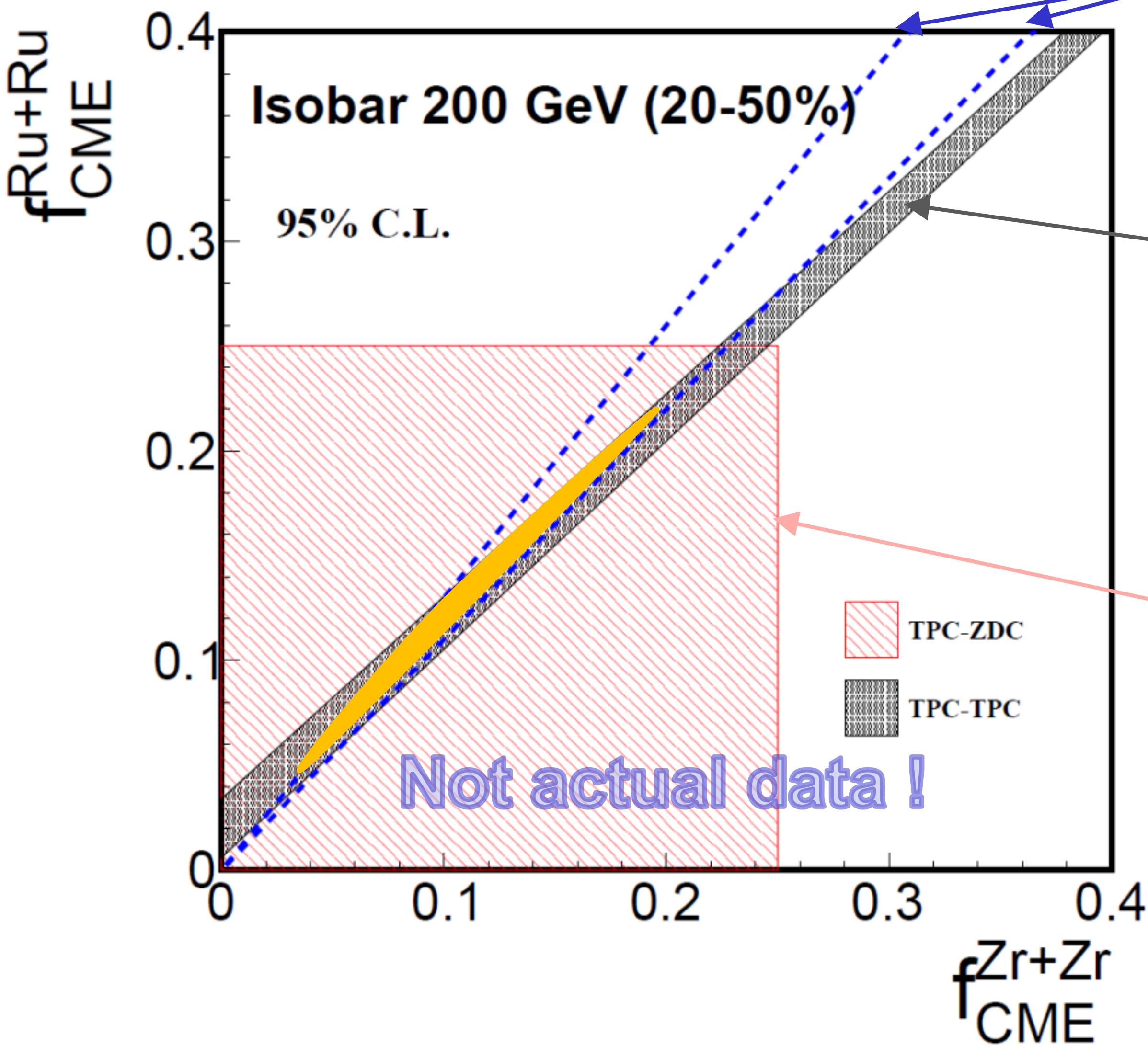
By Δγ and v_2 ratio between isobars.

By SP/PP measurements, separately for isobars

Case for CME :

$$f_{CME}^{Ru+Ru} > f_{CME}^{Zr+Zr} > 0$$

Isobar Analysis (Grp 3) : Participant Plane (PP) / Spectator Plane (SP)



By B diff. between isobars (theory input)

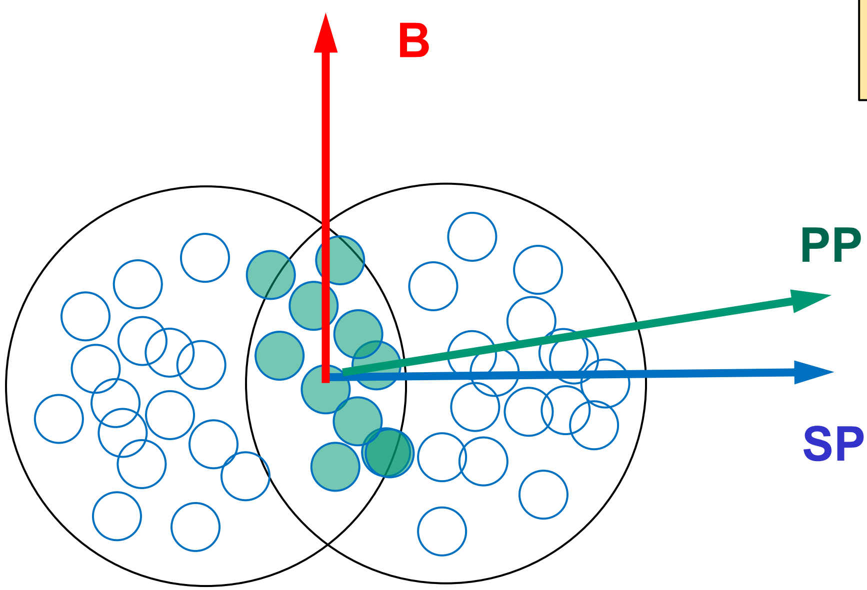
By Δγ and v_2 ratio between isobars.

By SP/PP measurements, separately for isobars

Case for CME :

$$f_{CME}^{Ru+Ru} > f_{CME}^{Zr+Zr} > 0$$

Isobar Analysis (Grp 4) : Participant Plane (PP) / Spectator Plane (SP)



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

f is the fraction of CME signal

PP : maximum background

SP : maximum signal

Case for CME : $\Delta\gamma/v_2$ (Ru / Zr) > 1

Flow bkg is usually positively correlated with signal ➡ Difficult to disentangle.
This troublesome pattern can be broken by switching between PP and SP.

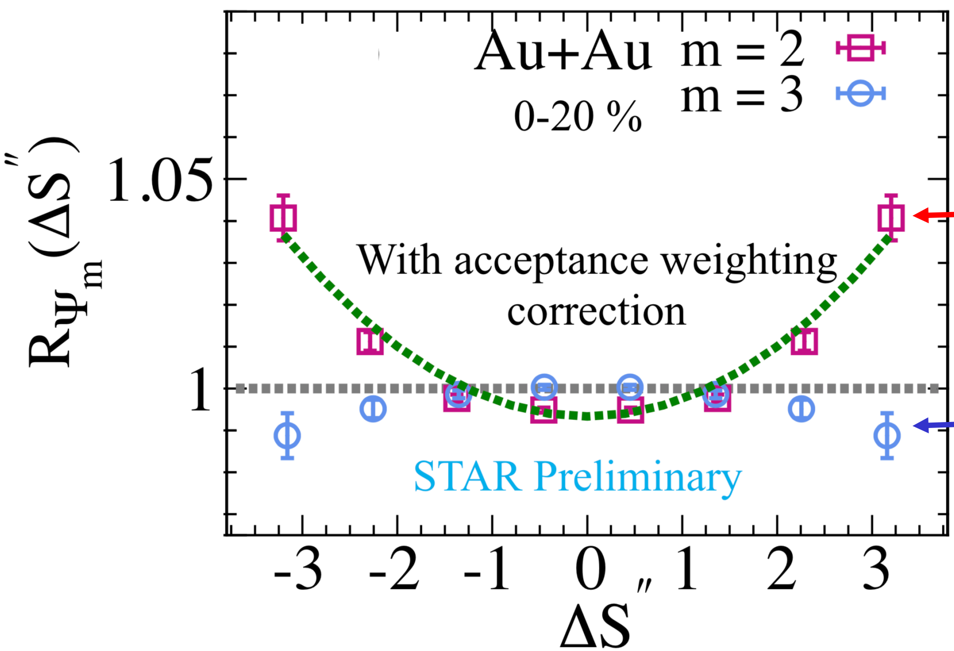
S. Voloshin, Phys. Rev. C 98 054911 (2018)

Isobar Analysis (Grp 5) : 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 $R(\Delta S) = \frac{C^{\perp}(\Delta S)}{C(\Delta S)}$



N. Magdy for STAR, WWND 2019

4) Repeat with Ψ_3 EP for baseline.

Signal, U-shape

Background

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

Isobar Analysis (Grp 5) : R(ΔS) Correlator

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

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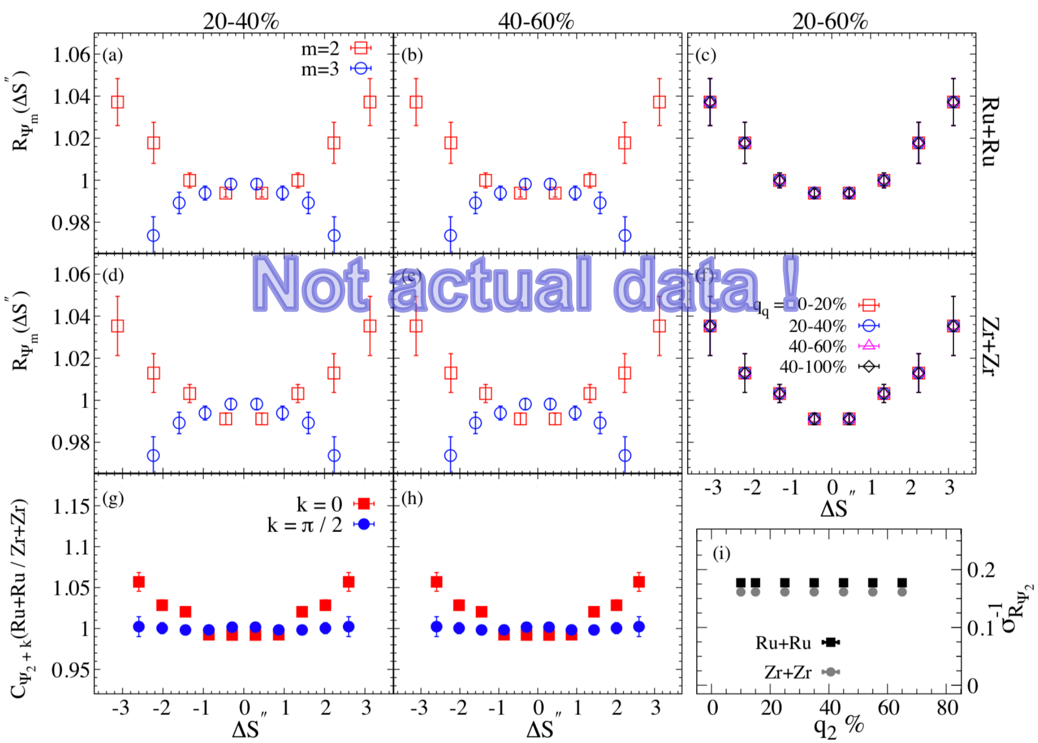


4) Repeat with Ψ_3 EP for baseline.

Intend to measure :
Sig. & bkg from each isobar.
Difference in sig. & bkg between isobars.

Case for CME :
R (Ru / Zr) concave shape

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

Isobar Analysis (Grp 6) : Signed Balance Function

1) EbyE count +/- pair's momentum ordering in in- and out-of-plane direction.

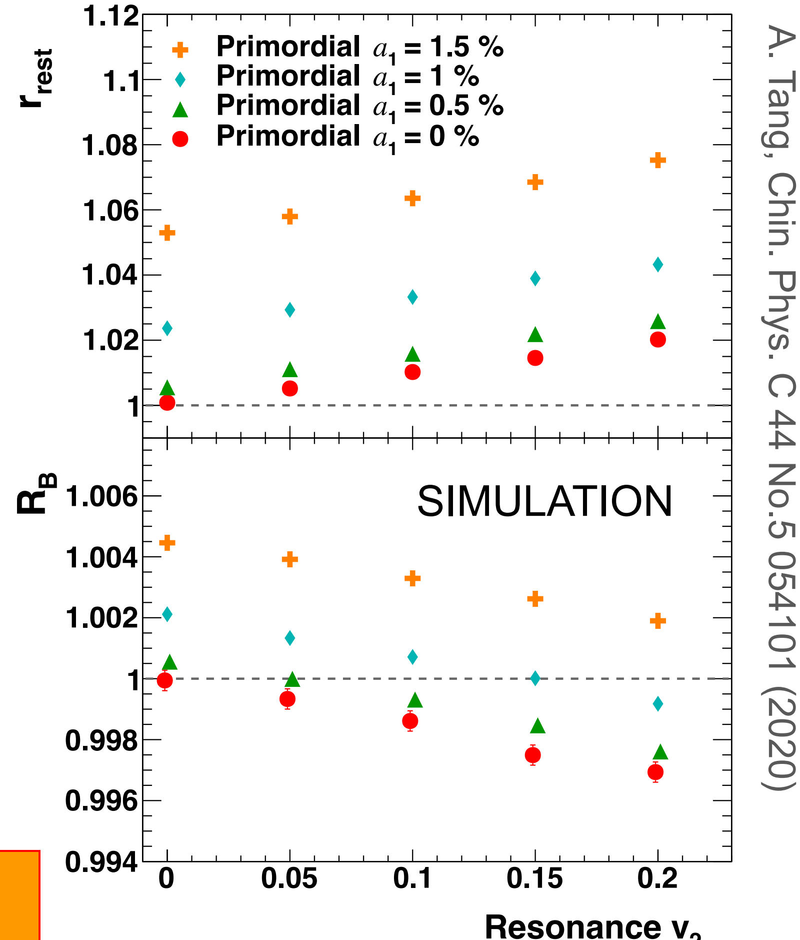
2) EbyE count net-ordering ΔB.

3) Excess ΔB fluct. out-of-plane $r = \frac{\sigma_{\Delta B}^{\perp}}{\sigma_{\Delta B}}$

4) Rest frame enhancement $R_B = \frac{r_{rest}}{r_{lab}}$

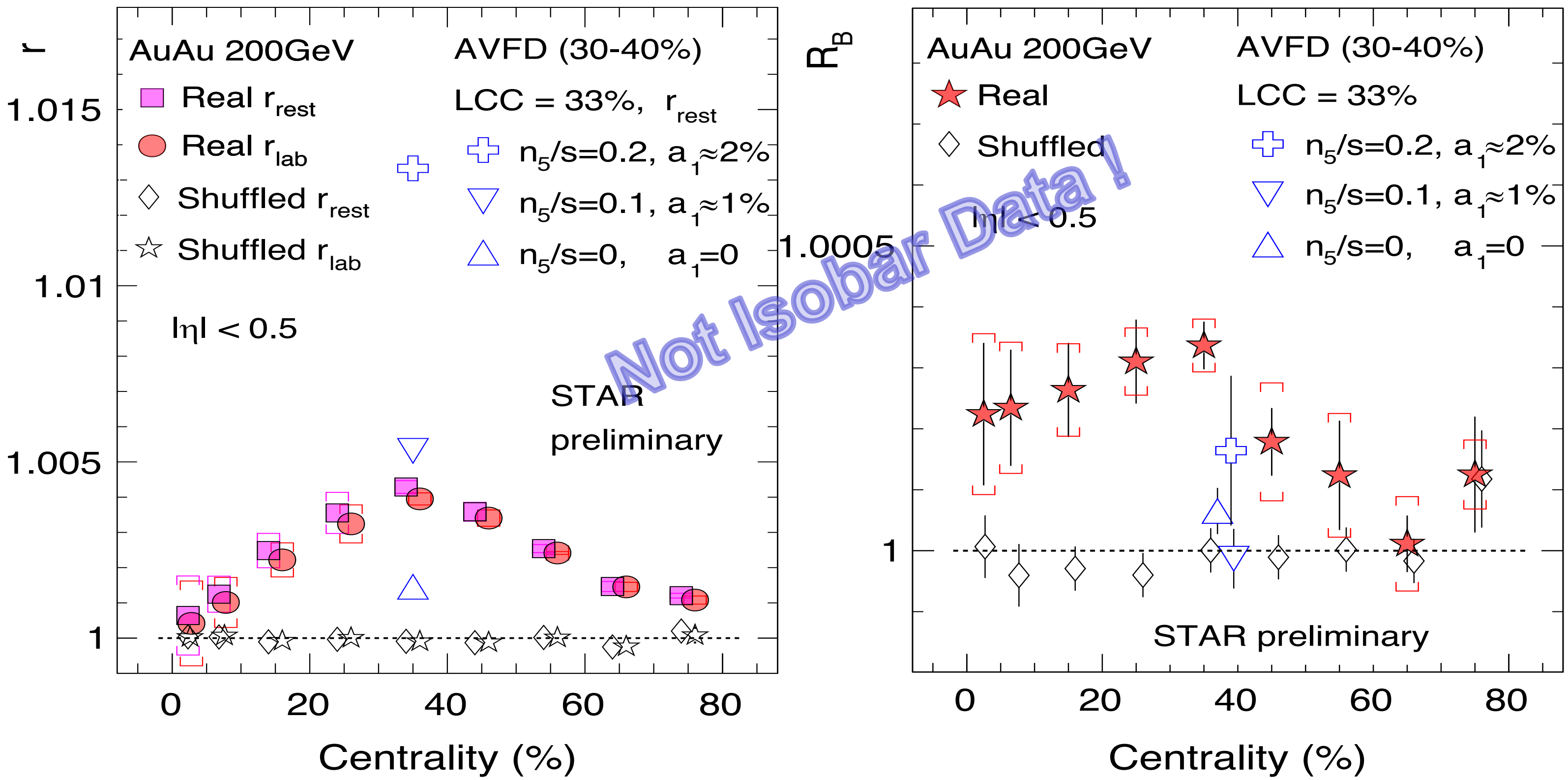
Resonance daughters have no v_2 in rest frame ➡ r_{rest} tends to closer to 1 than r_{lab}.

r and R_B : Similar response to signal, opposite response to bkg.



Not participated in blind analyses

Isobar Analysis (Grp 6) : Signed Balance Function

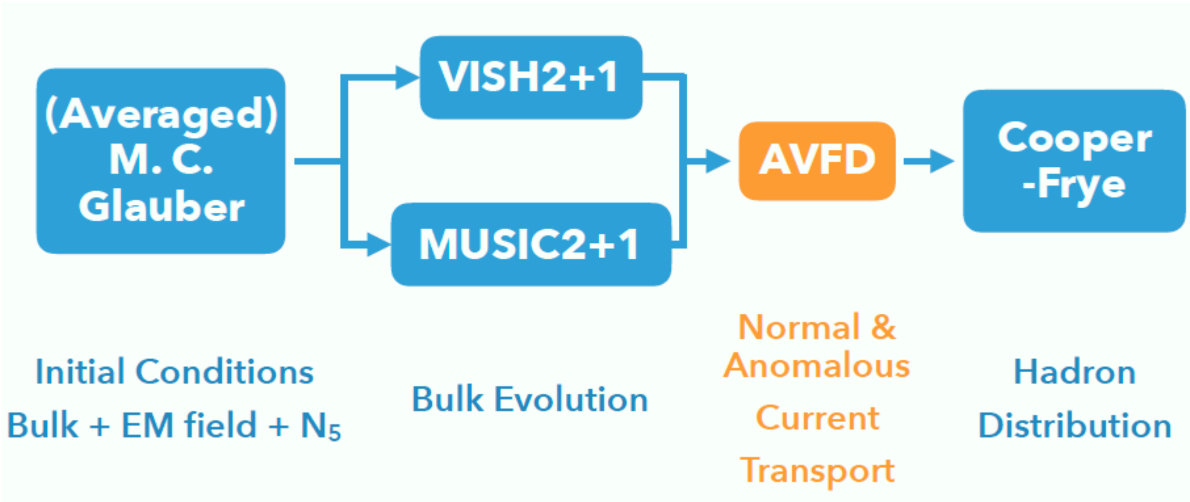


Y. Lin for STAR, QM 2019

Case for CME : $r > 1$, $R_B > 1$
r (Ru / Zr) > 1
R_B (Ru / Zr) > 1

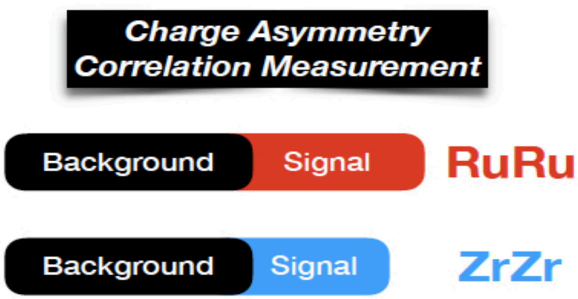
Not participated in blind analyses

Observable's Response to Signal in AVFD



AVFD Version Beta 1.0

The initial state fluctuations are fully accounted for by event-wise sampling for bulk entropy density and the fermion axial charge density (n_5/s).

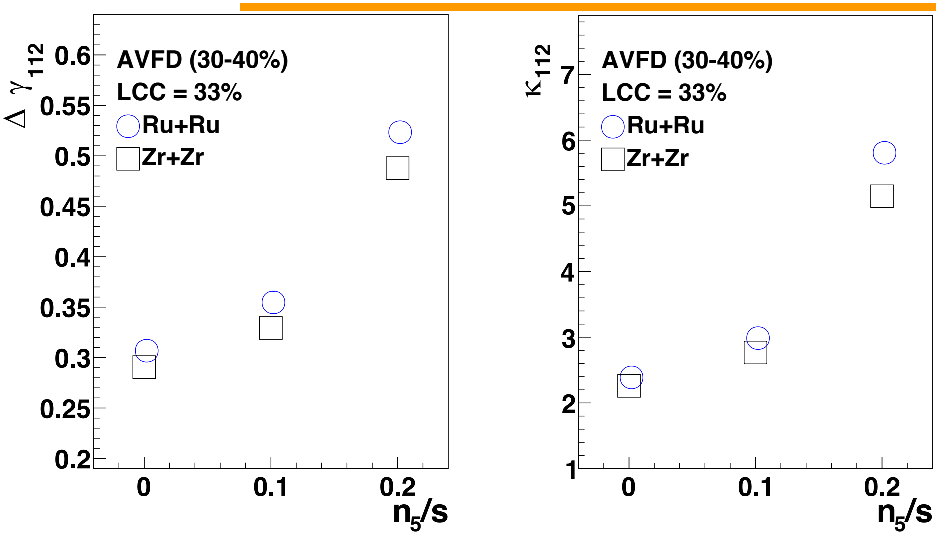


	$n_5/s=0$	$n_5/s=0.10$	$n_5/s=0.2$
Ru	$a_1 = 0$	$a_1 \approx 0.75\%$	$a_1 \approx 1.49\%$
Zr	$a_1 = 0$	$a_1 \approx 0.69\%$	$a_1 \approx 1.38\%$

Three cases of AVFD evts are generated for each isobar.

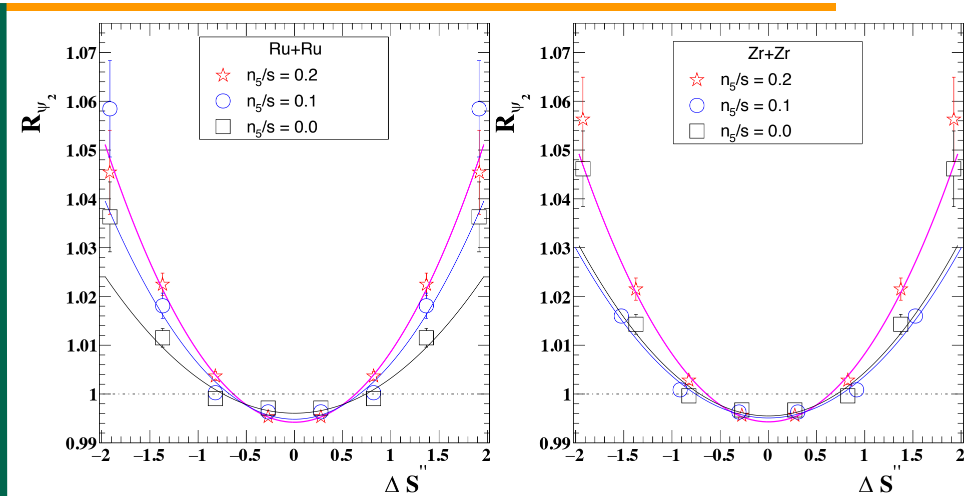
1st generation (smooth initial condition, no bkg.):
S. Shi, Y. Jiang, E. Lilleskov and J. Liao. Annals of Physics 394 *50-72 (2018)*
Y. Jiang, S. Shi, Y. Yin and J. Liao, Chin. Phys. C 42, No.1, 011001 (2018)
2nd genefation (ebye initial cond., LCC and hadron cascade. Used in this work):
S. Shi, H. Zhang, D. Hou, and J. Liao. arXiv:1910.14010

Observable's Response to Signal in AVFD



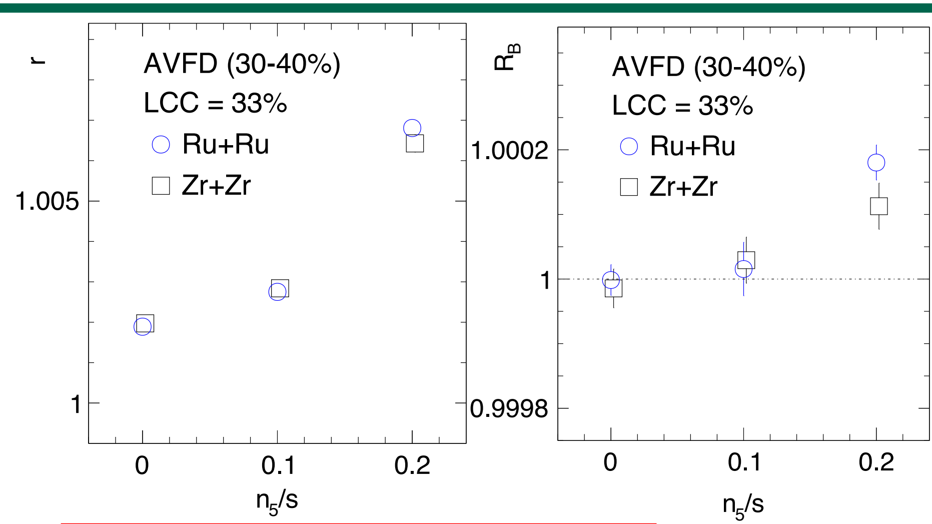
γ -correlator

20 M evts



R(ΔS)-correlator

20 M evts



Signed Balance Function

50 M evts

Frozen codes are being tested with AVFD events (still accumulating/analyzing more evts).

Working 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.