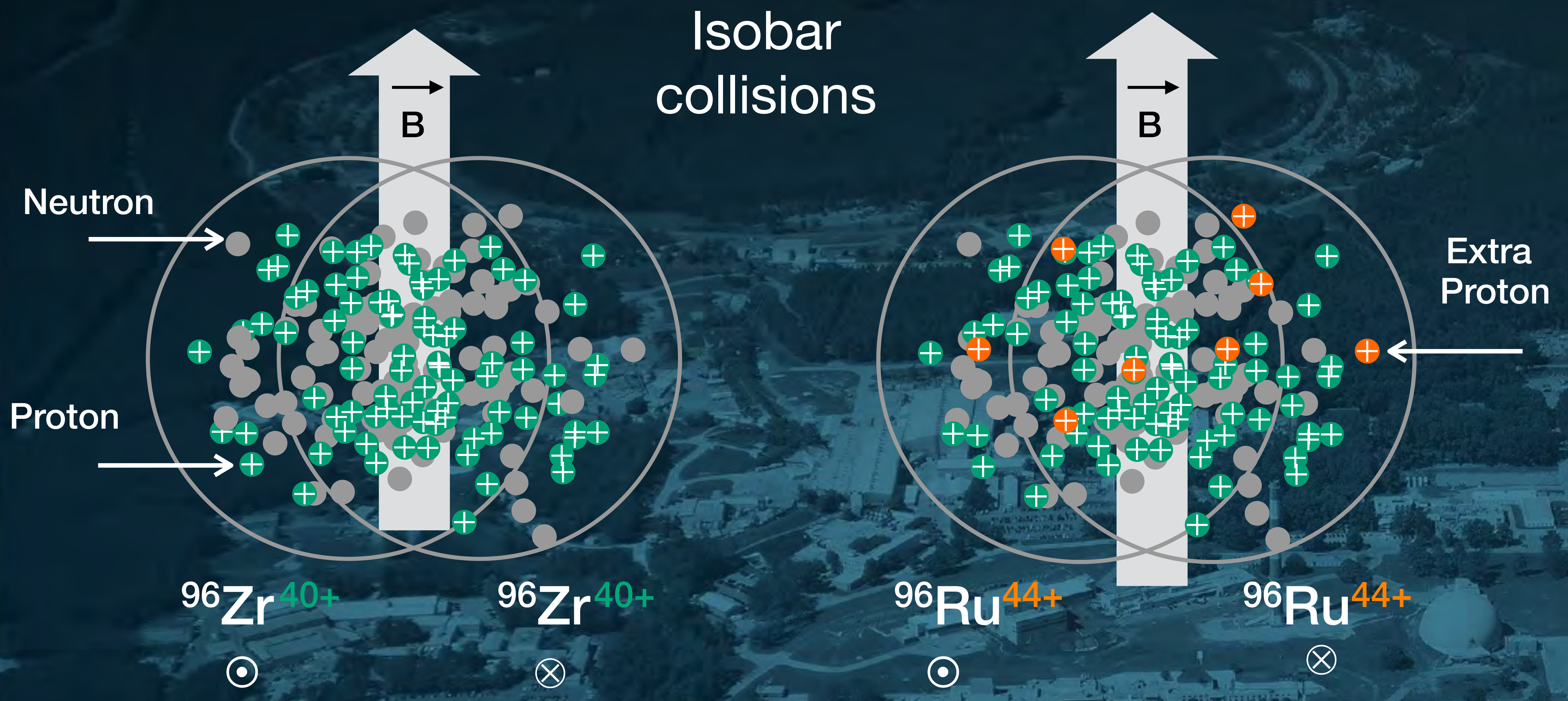


Blind analysis of isobar data for the CME search by the STAR collaboration

Prithwish Tribedy
(Brookhaven National Laboratory)

21st ZIMÁNYI SCHOOL WINTER WORKSHOP, Dec 6-10, 2021, Budapest

Based on: https://arxiv.org/abs/2109.00131

The person who originates a new idea is really not in a best position to follow it up. Because the person is so scared that something will turn up which will knock the whole idea on the head — Paul A.M. Dirac

Isobar program at RHIC: journey since 2018

Brookhaven National Laboratory

arXiv.org > nucl-ex > arXiv:2109.00131

Search...
Help | Adv

Nuclear Experiment

[Submitted on 1 Sep 2021]

Search for the Chiral Magnetic Effect with Isobar Collisions at $\sqrt{s_{NN}}$ = 200 GeV by the STAR Collaboration at RHIC

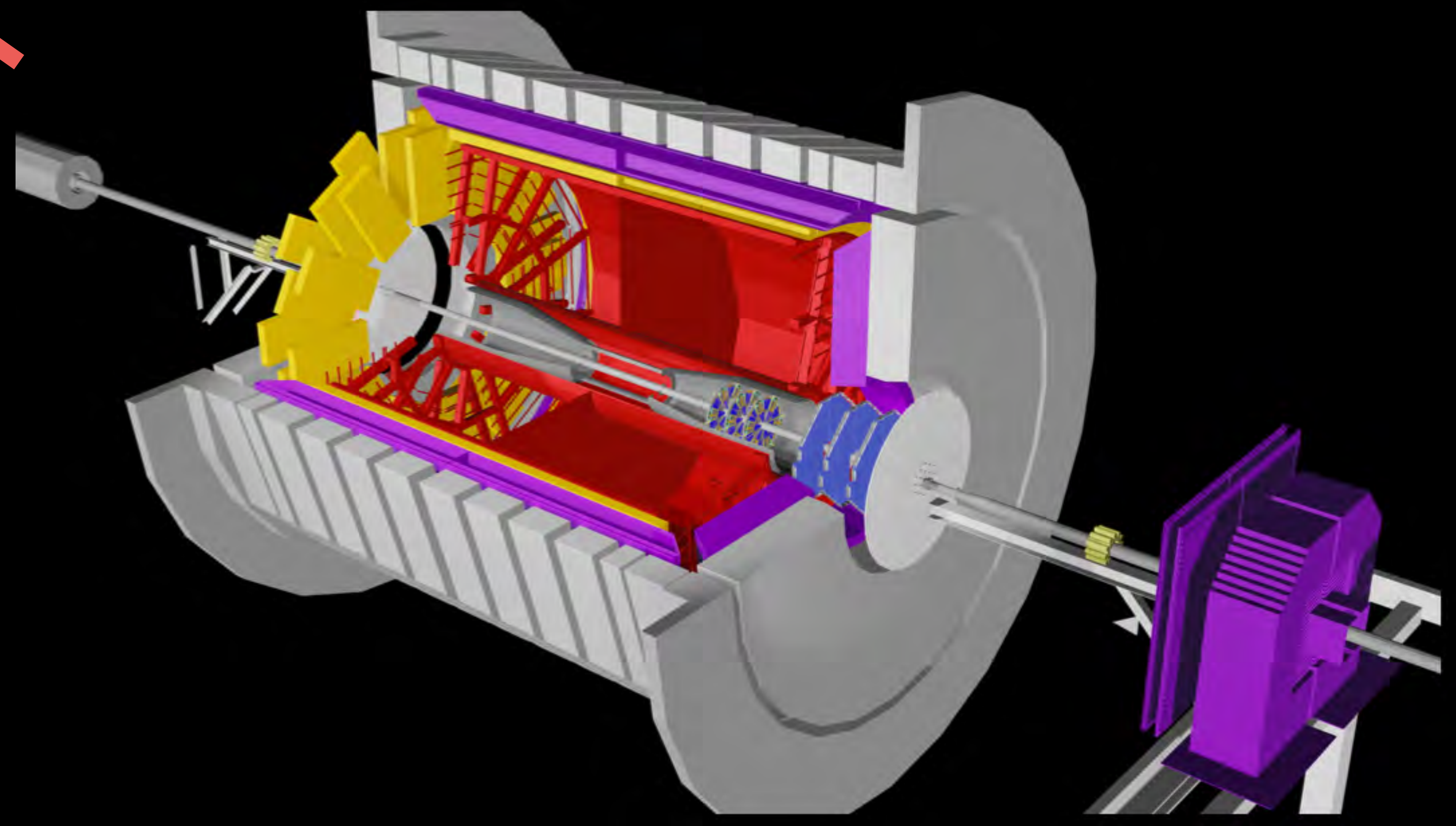
STAR Collaboration: M. S. Abdallah, B. E. Aboona, J. Adam, L. Adamczyk, J. R. Adams, J. K. Adkins, G. Agakishiev, I. Aggarwal, M. M. Aggarwal, Z. Ahammed, I. Alekseev, D. M. Anderson, A. Aparin, E. C. Aschenauer, M Ashraf, F. G. Atetalla, A. Attri, G. S. Averichev, V. Bairathi, W. Baker, J. G. Ball Cap, K. Barish, A. Behera, R. Bellwied, P. Bhagat, A. Bhasin, J. Bielcik, J. Bielcikova, I. G. Bordyuzhin, J. D. Brandenburg, A. V. Brandin, I. Bun X. Z. Cai, H. Caines, M. Calderón de la Barca Sánchez, D. Cebra, I. Chakaberia, P. Chaloupka, B. K. Chan, F-H. Chang, Z. Chang, N. Chankova-Bunzarova, A. Chatterjee, S. Chattopadhyay, D. Chen, J. Chen, J. H. Chen, Chen, Z. Chen, J. Cheng, M. Chevalier, S. Choudhury, W. Christie, X. Chu, H. J. Crawford, M. Csanád, M. Daugherity, T. G. Dedovich, I. M. Deppner, A. A. Derevschikov, A. Dhamija, L. Di Carlo, L. Didenko, P. Dixit, X. D J. L. Drachenberg, E. Duckworth, J. C. Dunlop, N. Elsey, J. Engelage, G. Eppley, S. Esumi, O. Evdokimov, A. Ewigleben, O. Eyser, R. Fatemi, F. M. Fawzi, S. Fazio, P. Federic, J. Fedorisin, C. J. Feng, Y. Feng, P. Filip, E. Fin Fisyak, A. Francisco, C. Fu, L. Fulek, C. A. Gagliardi, T. Galatyuk, F. Geurts, N. Ghimire, A. Gibson, K. Gopal, X. Gou, D. Grosnick, A. Gupta, W. Guryn, A. I. Hamad et al. (298 additional authors not shown)

The chiral magnetic effect (CME) is predicted to occur as a consequence of a local violation of $\mathcal{P}$ and $\mathcal{CP}$ symmetries of the strong interaction amidst a strong electro-magnetic field generated in relativistic heavy-ion collisions. Experimental manifestation of the CME involves a separation of positively and negatively charged hadrons along the direction of the magnetic field. Previous measurements of the CME-sensitive charge-separation observables remain inconclusive because of large background contributions. In order to better con e influence of signal and backgrounds, the STAR Collaboration performed a blind analysis of a large data sample of approximately 3.8 billion isobar collisions of $^{96}_{44}$Ru+$^{96}_{44}$Ru and $^{96}_{40}$Zr+$^{96}_{40}$Zr at $\sqrt{s_{NN}}$ = 200 GeV. Prior to the blind analysis signatures are predefined as a significant excess of the CME-sensitive observables in Ru+Ru collisions over those in Zr+Zr collisions, owing to a larger magnetic field in the former. A precision down to s achieved, as anticipated. e magnitudes of the pertinent observables between the two isobar systems. Observed differences in the multiplicity and flow harmonics at the matching centrality indicate that the magnitude of the C round is differe ies. No CME signature that satisfies the predefined criteria has been observed in isobar collisions in this blind analysis.

The versatility of RHIC and the unique capabilities of the STAR detector were crucial to the success of our program

Relativistic Colliders: Testing ground for QCD

Brookhaven National Laboratory



RHIC: know for species (U, Au, Ru, Zr, Cu, Al..) and energy (γ~100-3.85) maneuver capability

Study of QCD, the theory of strong interaction

$$\boxed{\mathcal{L}_{QCD} = \bar{\psi}_a \left(i(\gamma^\mu D_\mu)_{ab} - \cancel{m}\delta_{ab}\right)\psi_b - \frac{1}{4}G^c_{\mu\nu}G^{\mu\nu}_c}$$

The collisions aim to produce a medium of de-confined gluons and nearly massless quarks (chiral symmetry restored)

Let’s go through some basics of CME
(I know you had other talks, but this is a school !!

Three must read papers if you're interested in CME

Available online at www.sciencedirect.com
SCIENCE @ DIRECT
ELSEVIER
Physics Letters B 633 (2006) 260–264
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

Parity violation in hot QCD: Why it can happen, and how to look for it

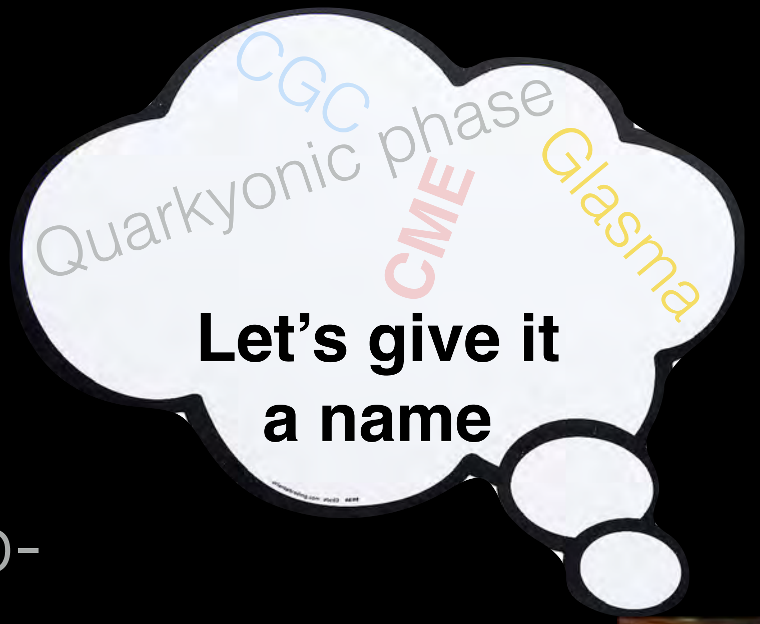
Dmitri Kharzeev

Physics Department, Brookhaven National Laboratory, Upton, NY 11973-5000, USA
Received 23 December 2004; received in revised form 27 October 2005; accepted 23 November 2005
Available online 7 December 2005

Early theory paper

Kharzeev, hep-ph/0406125

Also see : Kharzeev et al, hep-ph/9906401, Kharzeev et al, hep-ph/9804221



PHYSICAL REVIEW C **70**, 057901 (2004)

Parity violation in hot QCD: How to detect it

Sergei A. Voloshin
Department of Physics and Astronomy, Wayne State University, Detroit, Michigan 48201, USA
(Received 5 August 2004; published 11 November 2004)

First method paper

Voloshin, hep-ph/0406311

Also: Finch et al Phys.Rev.C 65 (2002) 014908

STAR ☆

Selected for a Viewpoint in *Physics*
PRL **103,** 251601 (2009) PHYSICAL REVIEW LETTERS week ending 18 DECEMBER 2009

Azimuthal Charged-Particle Correlations and Possible Local Strong Parity Violation

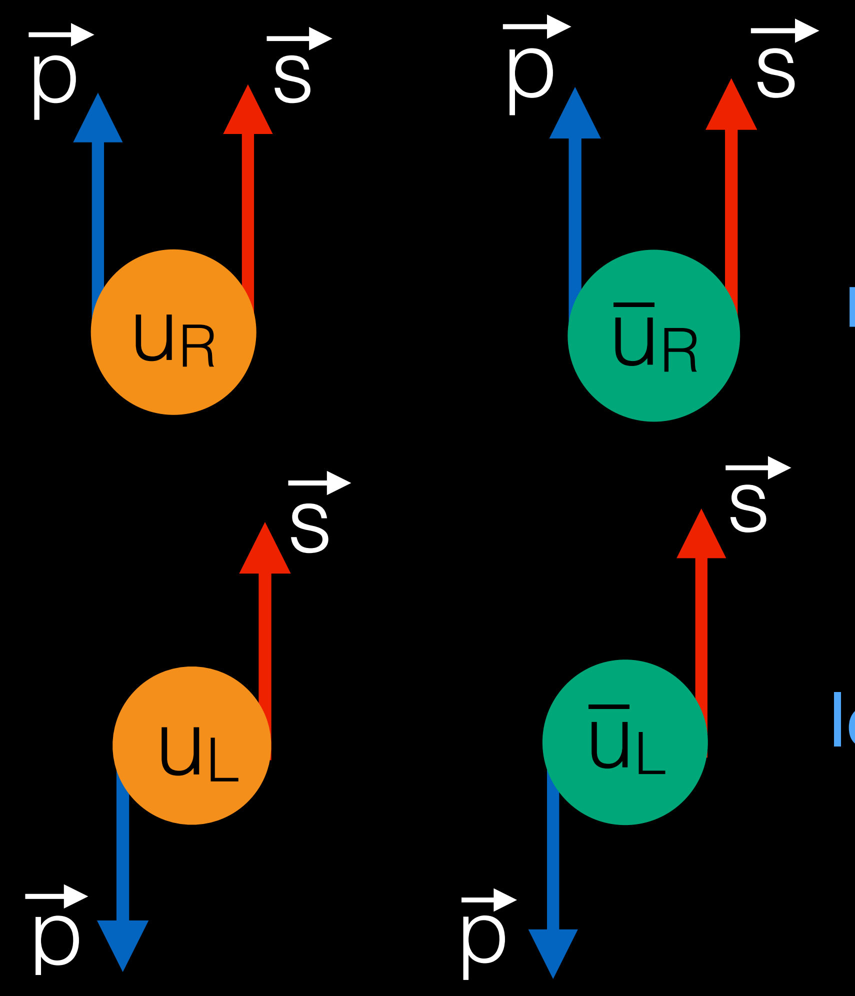
(STAR Collaboration)

First experimental paper

STAR collaboration, arXiv:0909.1739

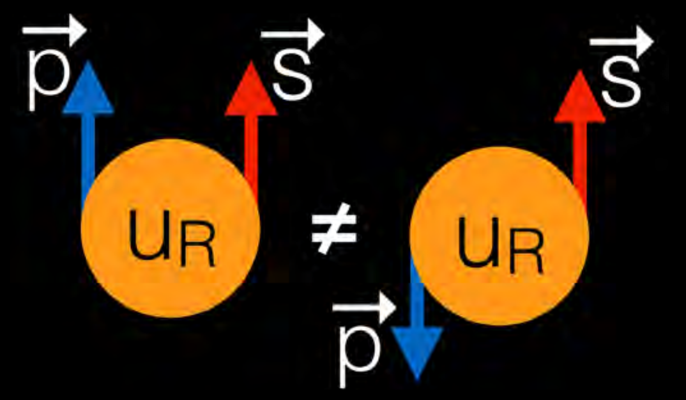
There are three key players in the game

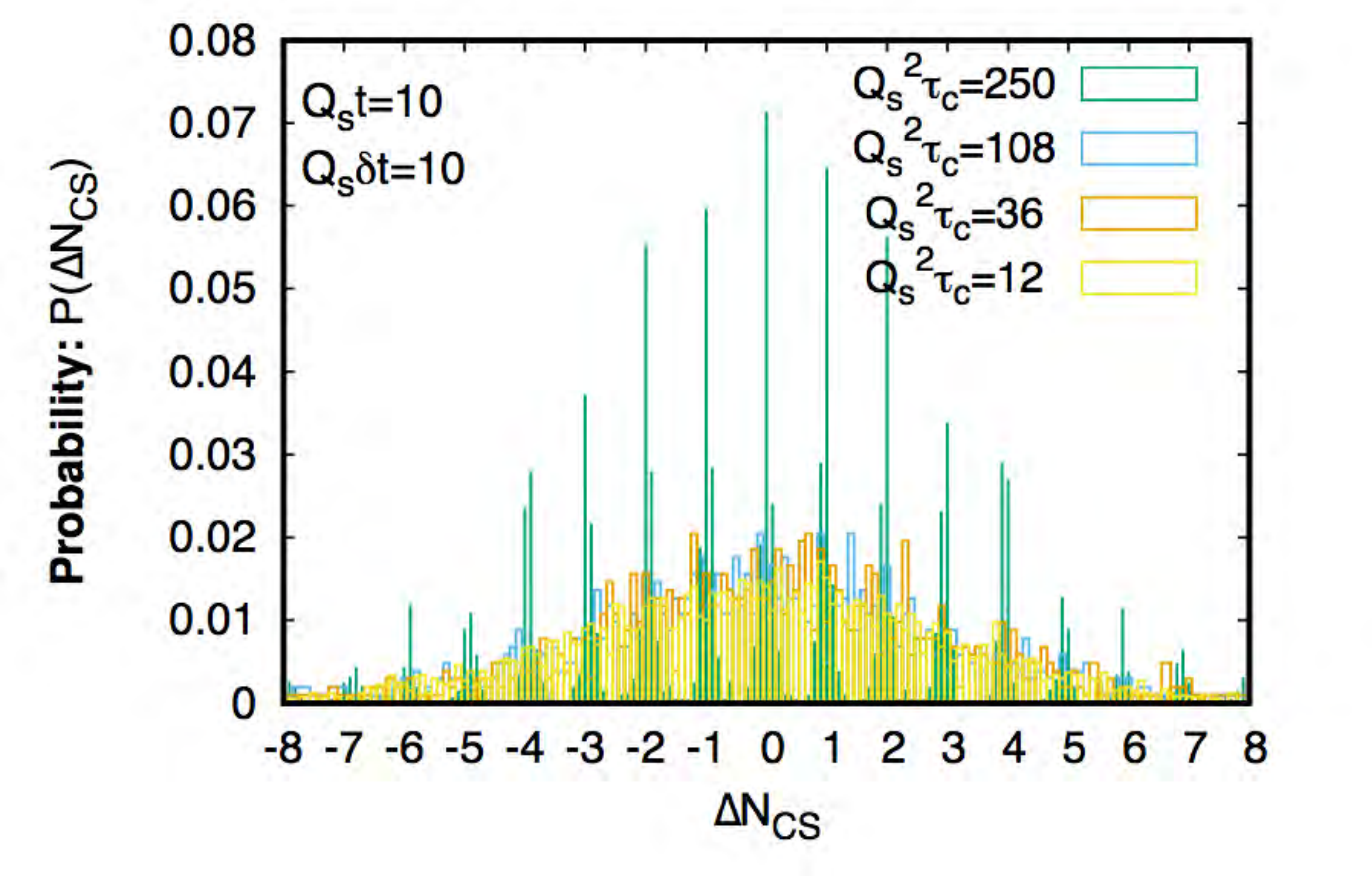
1 Deconfined medium of massless quark (chiral symmetry restored)



Kharzeev, McLerran,Warringa 0711.0950

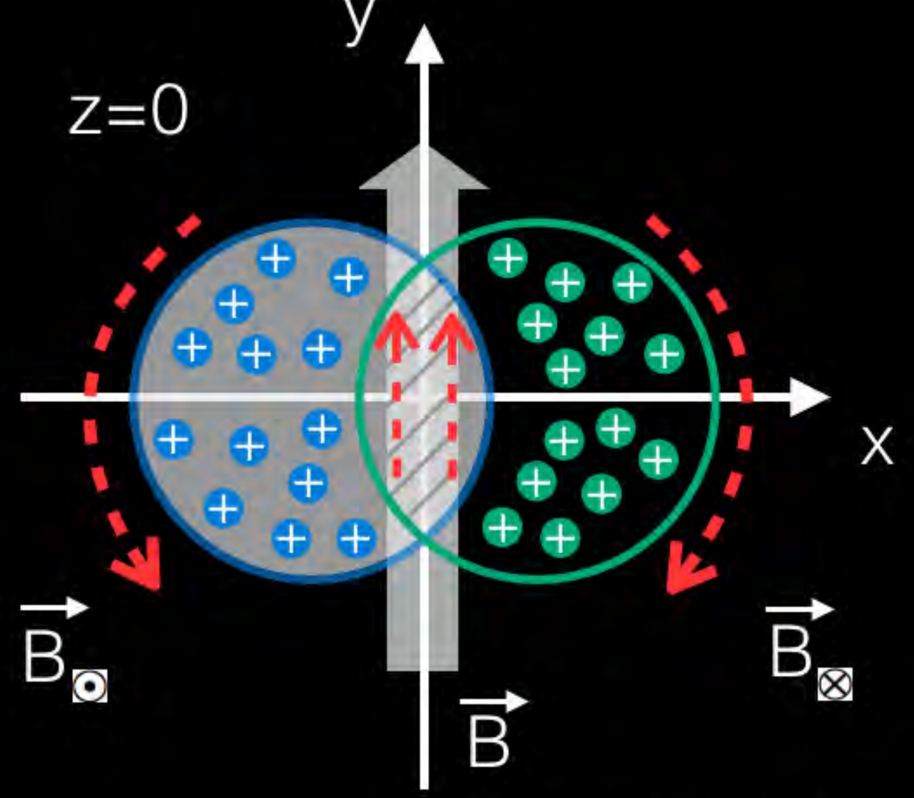
2 Mechanism to create imbalance of left & right handed quarks

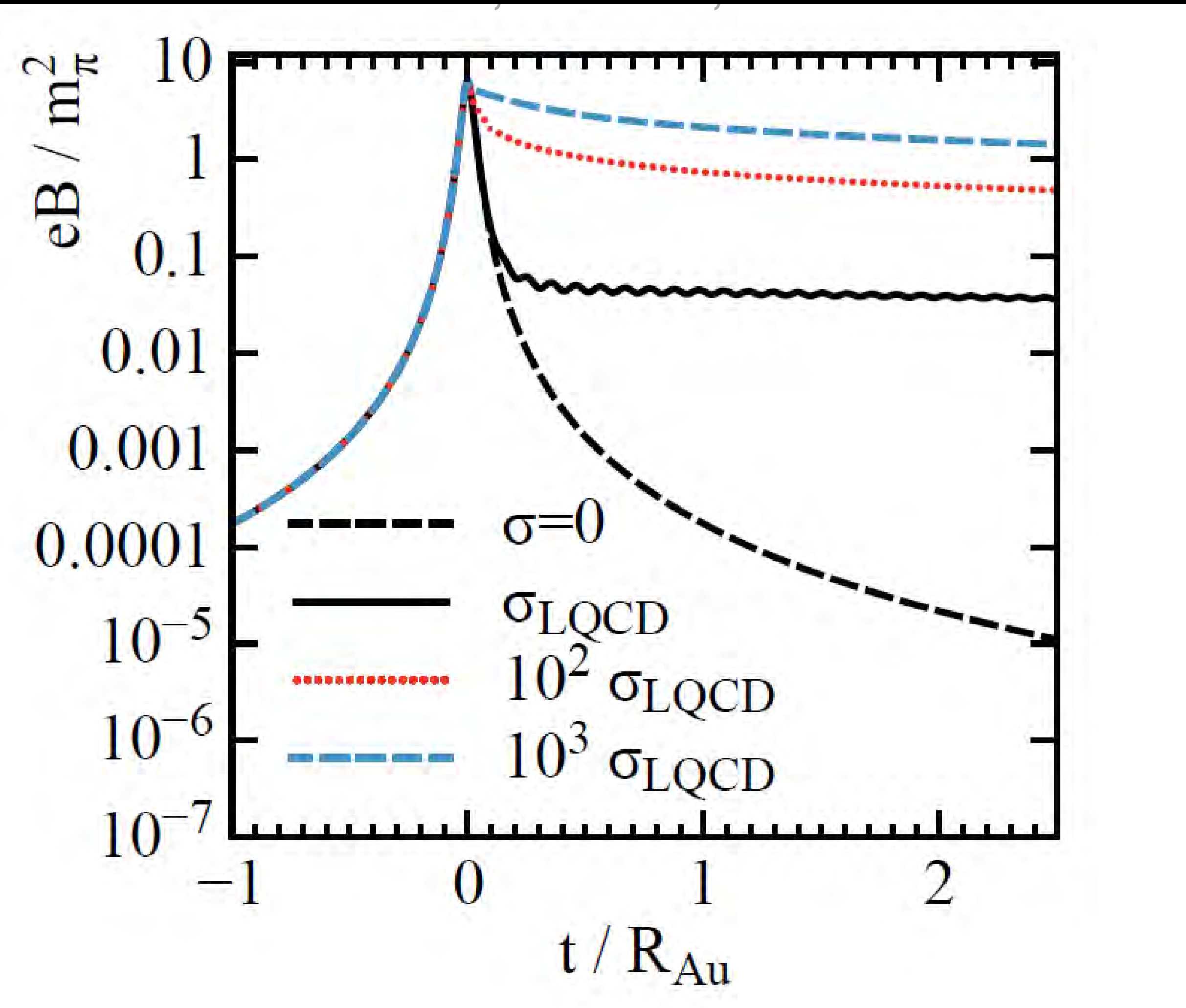




Kharzeev et al, hep-ph/0109253, Mace et al, 1601.07342
Muller et. al.1606.00342, Lappi et al,

3 Strong B-field

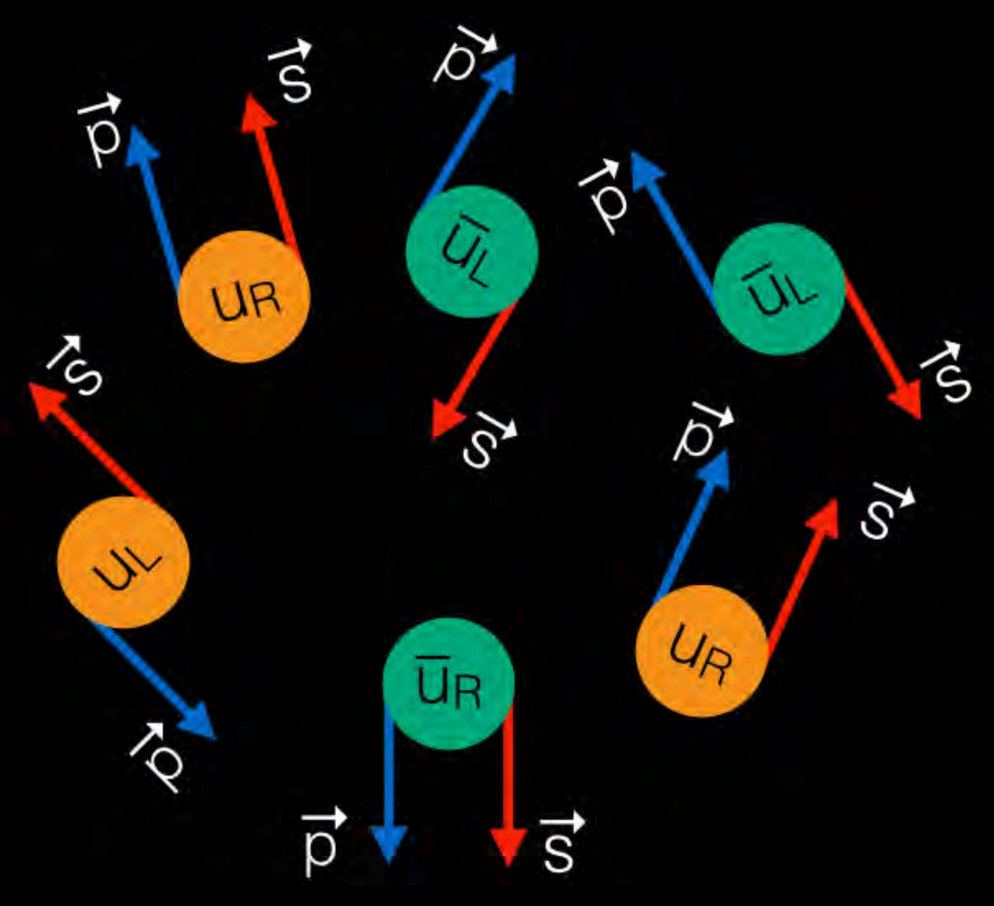


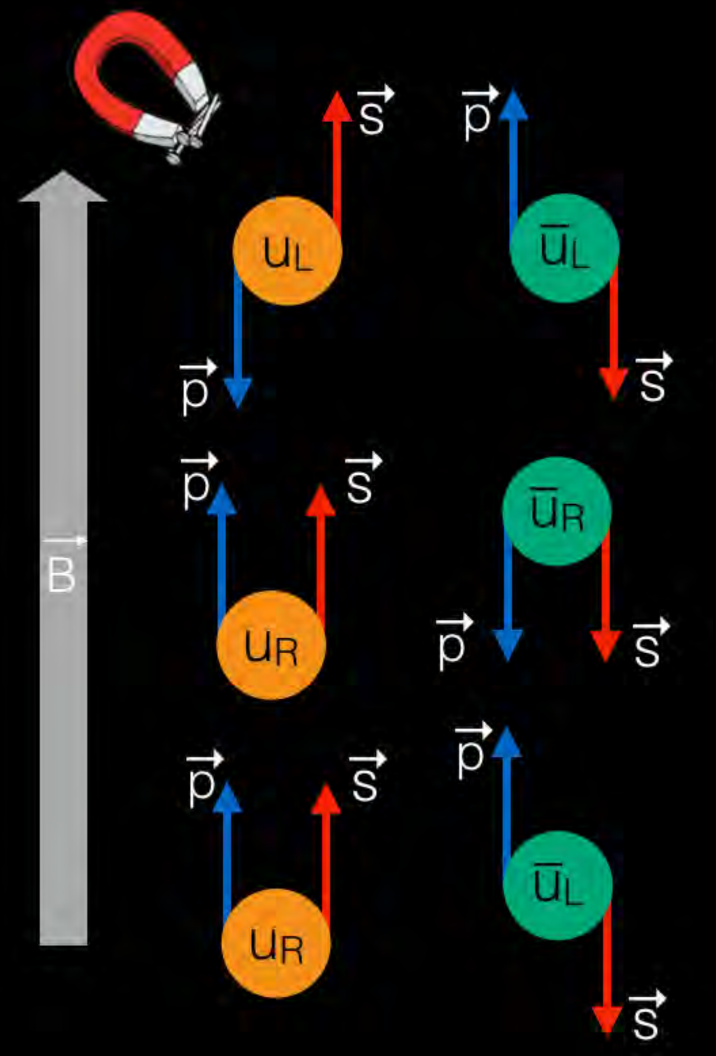


Kharzeev et al 0711.0950, Skokov et al 0907.1396, McLerran et al

Cartoon picture of CME in four steps

Massless Quarks
(Random orientations)





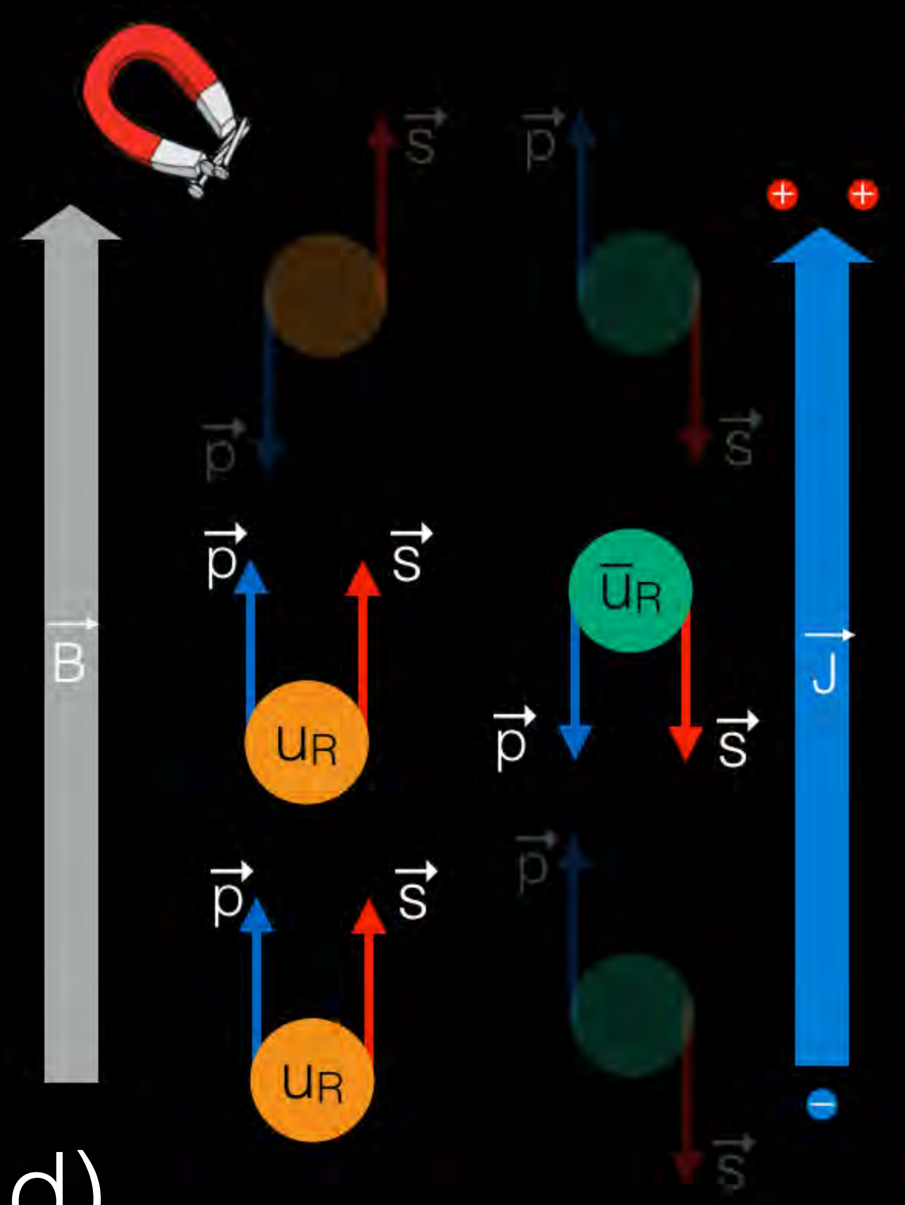
B-field
(Polarizes the quarks)

$$\vec{J} = \sigma_{\rm CME}\vec{B}$$

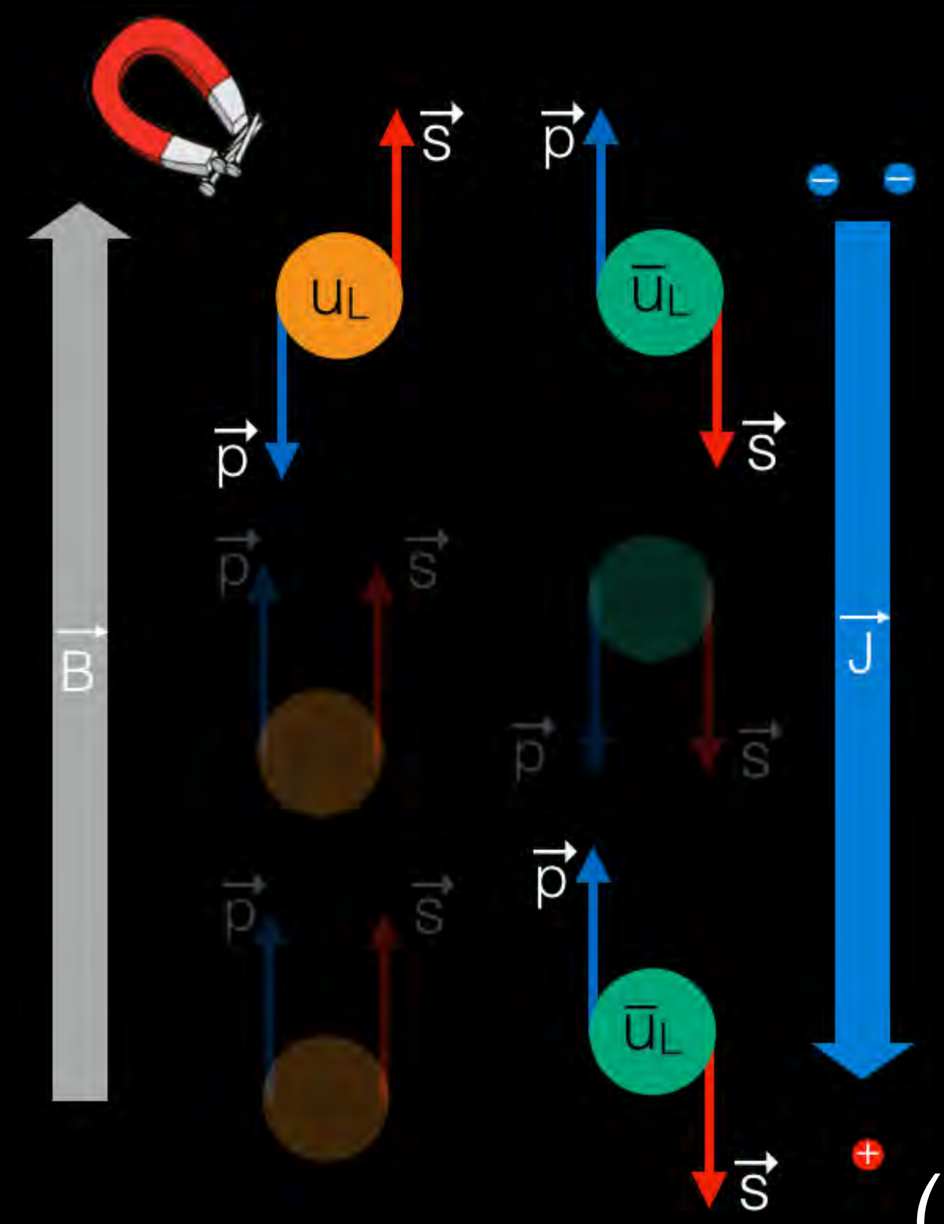
Parity-odd
T-odd

Parity-odd
T-even

Parity-even
T-odd



$u_R > u_L$
(Current along B-field)

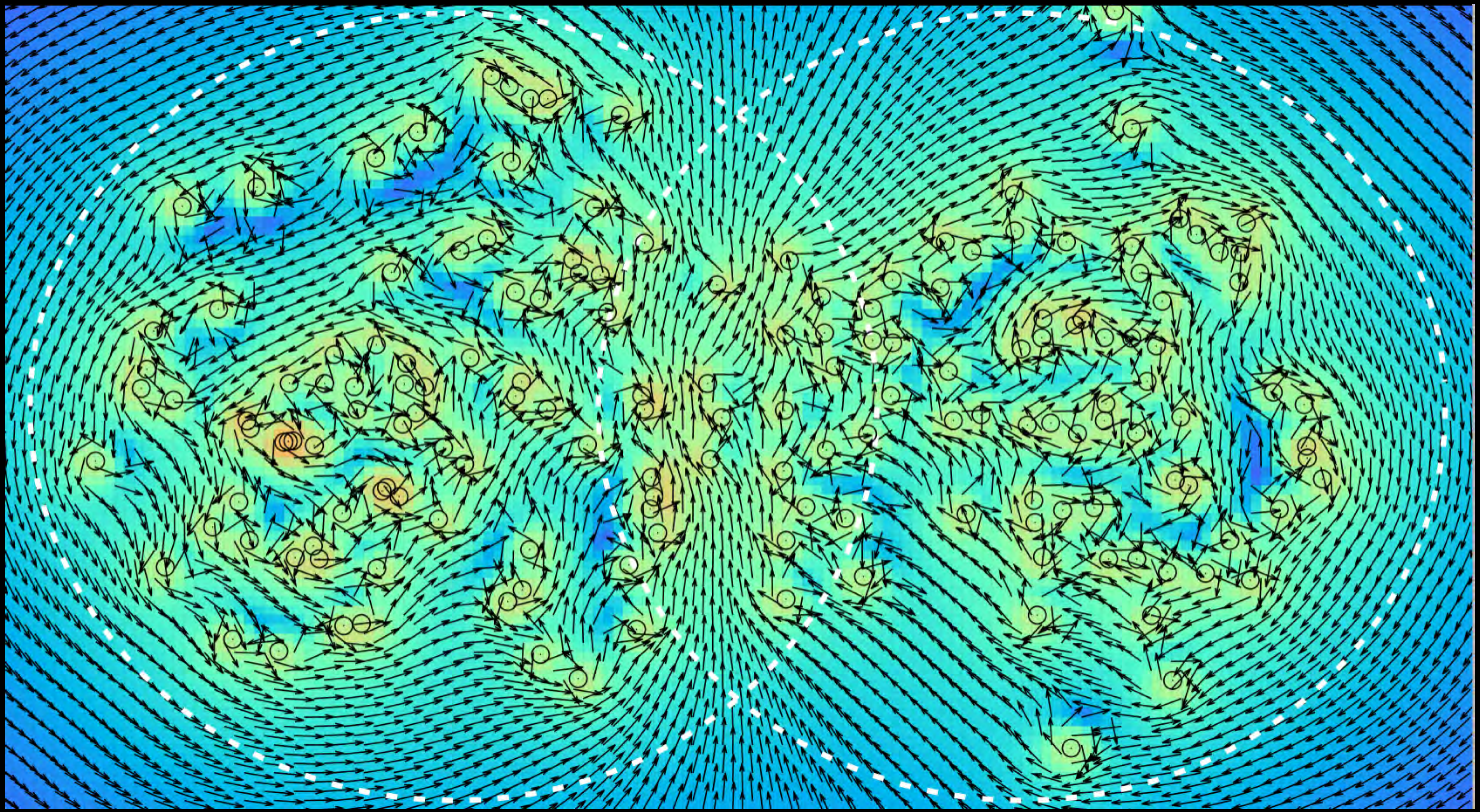


$u_R < u_L$
(Current anti-parallel to B-field)

Based on:

Beyond the cartoon picture: B-field profile in typical collisions

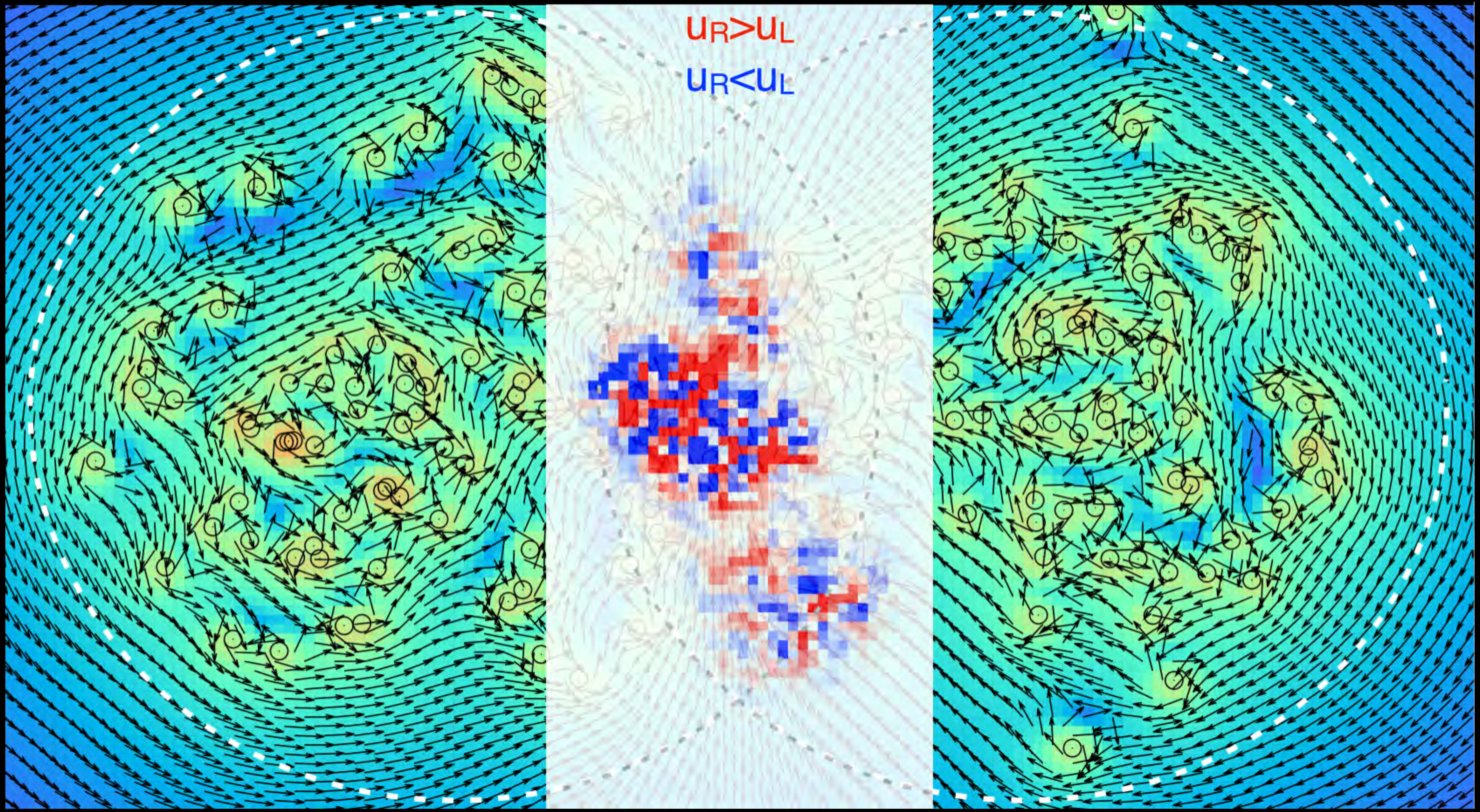
Pb+Pb @ 2.76 TeV, b=11.4 fm, N



Based on: Chatterjee, PT, PRC (R)

Beyond the cartoon picture: Axial charge profile in typical collisions

Pb+Pb @ 2.76 TeV, b=11.4 fm, N

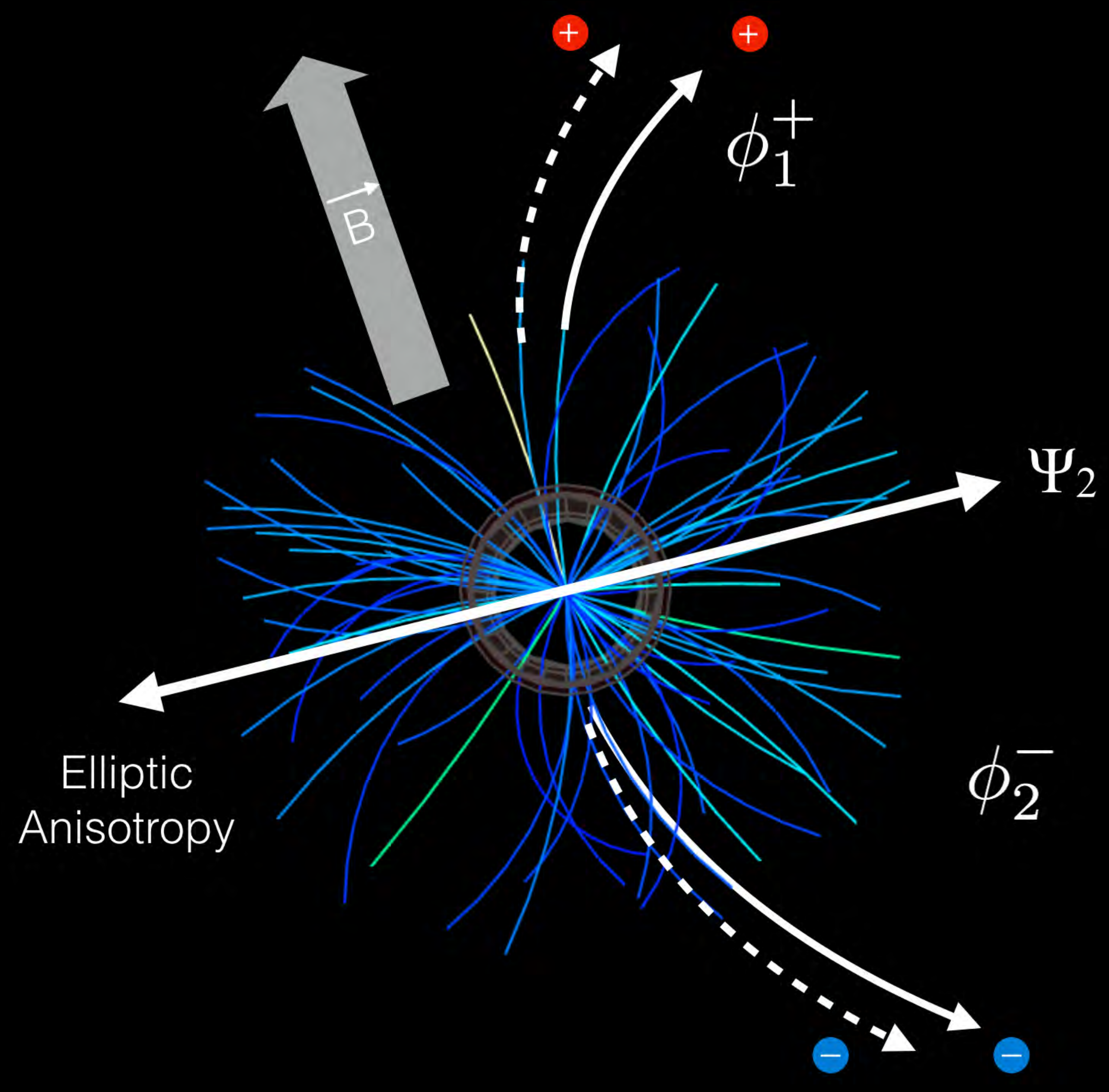


Based on: Lappi, Schlichting, PRD 97, 034034 (2018)

Let’s remind ourselves about the CME observables

How to measure charge separation due to CME ?

Measure charge separation across Ψ_2 using the correlator:



Voloshin,

$$\gamma^{\alpha,\beta} = \langle \cos(\phi_1^\alpha + \phi_2^\beta - 2\Psi_2) \rangle$$

CME case : $\gamma^{ss} \neq \gamma^{os}$

$$\gamma^{+-} = \cos(\pi/2 - \pi/2 + 0) = 1$$
$$\gamma^{++,--} = \cos(\pi/2 + \pi/2 + 0) = -1$$

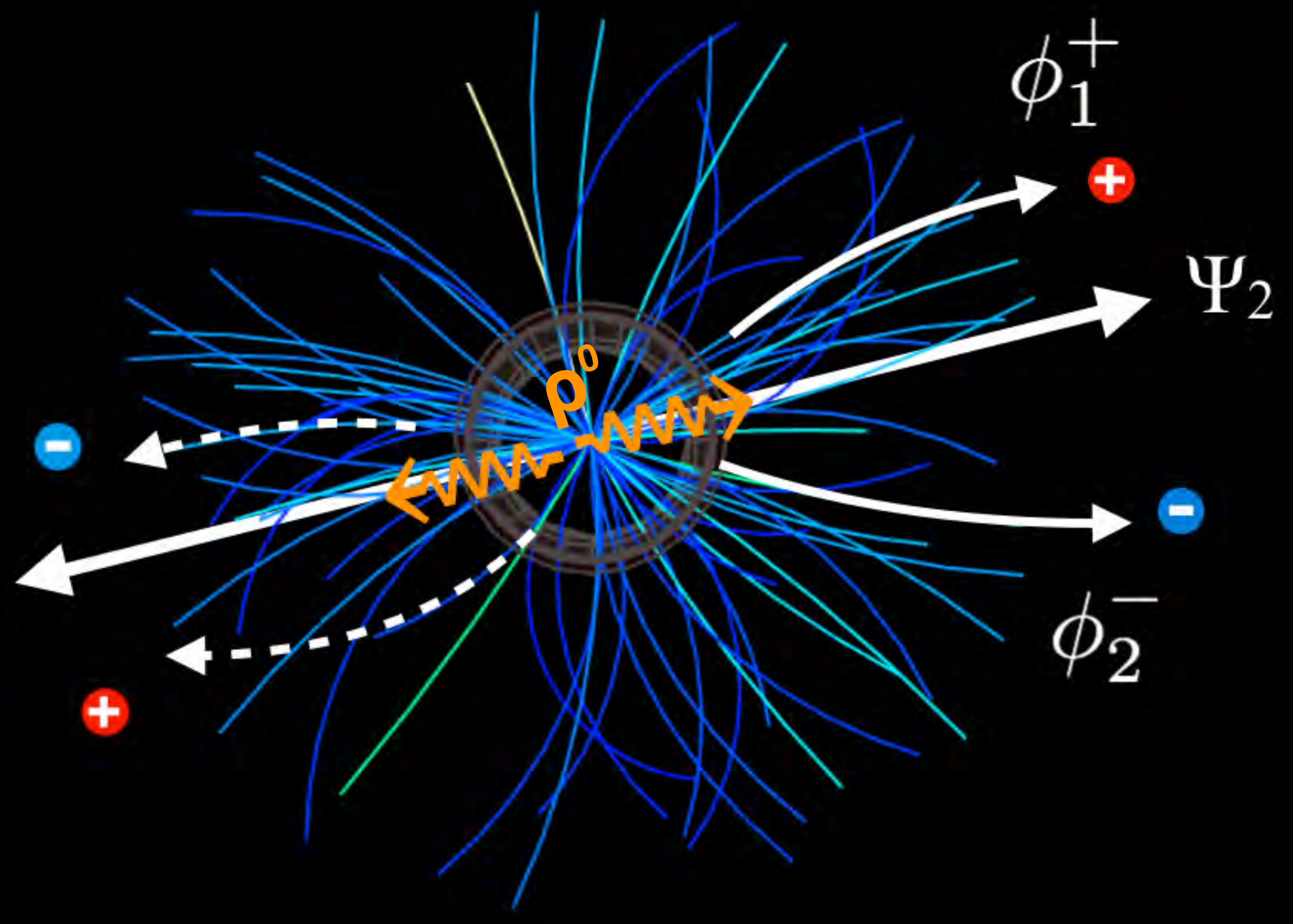
Quantity of interest:

$$\Rightarrow \Delta\gamma^{CME} = \gamma^{os} - \gamma^{ss} > 0$$

CME causes difference in opposite-sign & same-sign correlation

Major source of background: decay of neutral clusters

Measure charge separation across Ψ_2 using the correlator:



Voloshin,

$$\gamma^{\alpha,\beta} = \langle \cos(\phi_1^\alpha + \phi_2^\beta - 2\Psi_2) \rangle$$

Flowing resonance decay: $\gamma^{SS} \neq \gamma^{OS}$

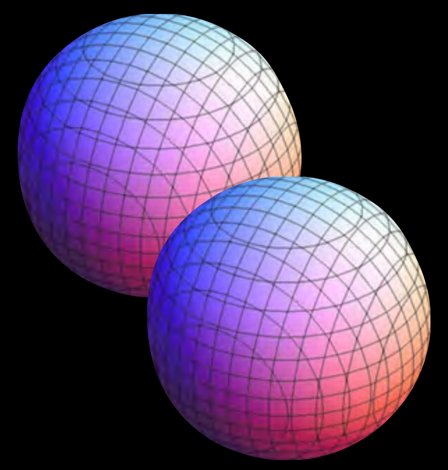
$$\gamma^{+-} = \cos(0+0+0) = 1$$
$$\gamma^{++,--} = \cos(0+\pi+0) = -1$$

Non-CME effect such as flowing resonance decay can lead to difference

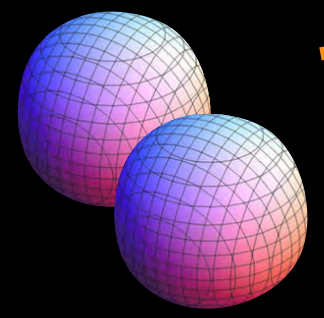
$$\Rightarrow \Delta\gamma^{reso} = \gamma^{OS} - \gamma^{SS} \propto \frac{v_2^{reso}}{N}$$

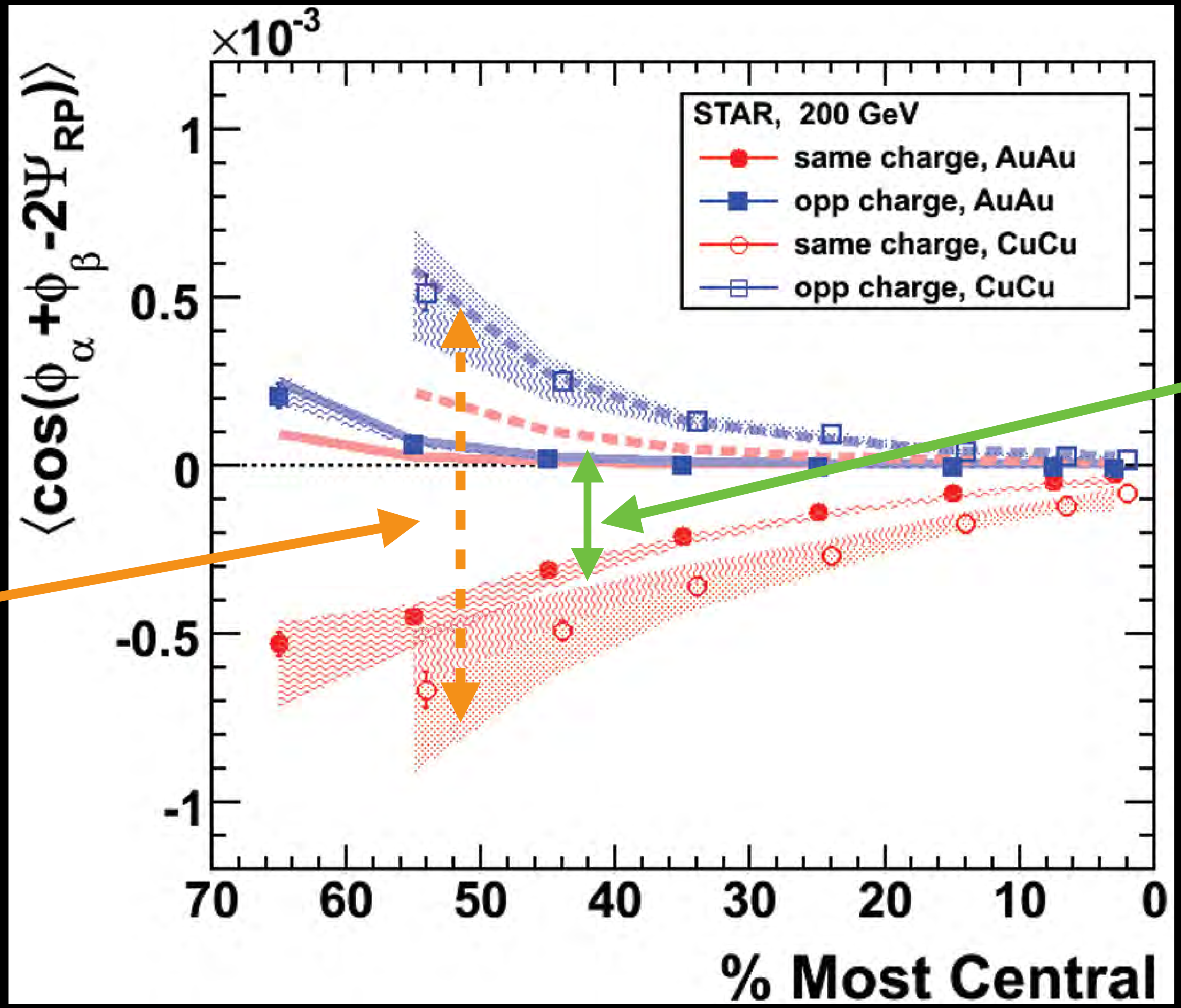
The first measurements at RHIC

Au+Au



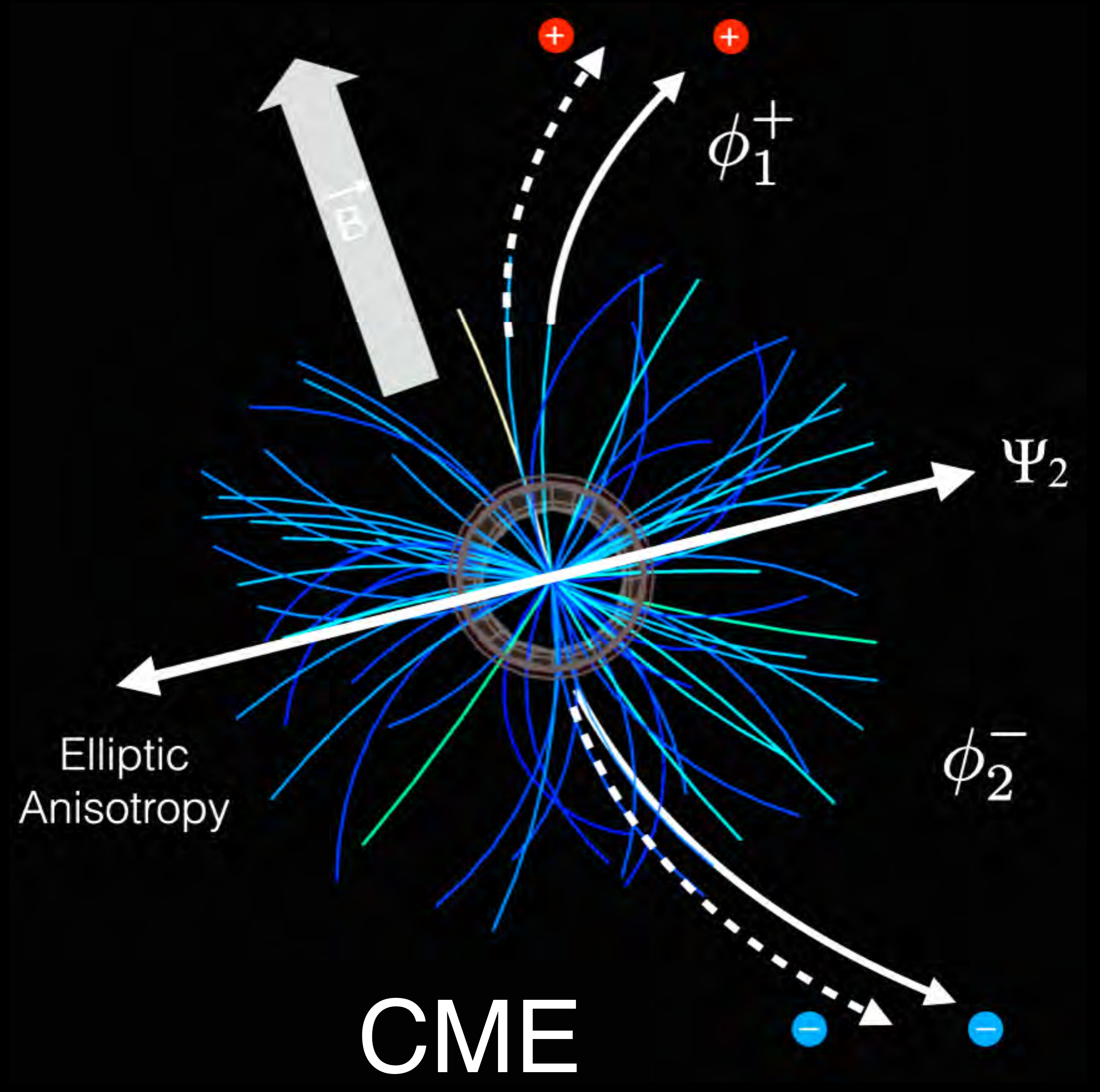
Cu+Cu





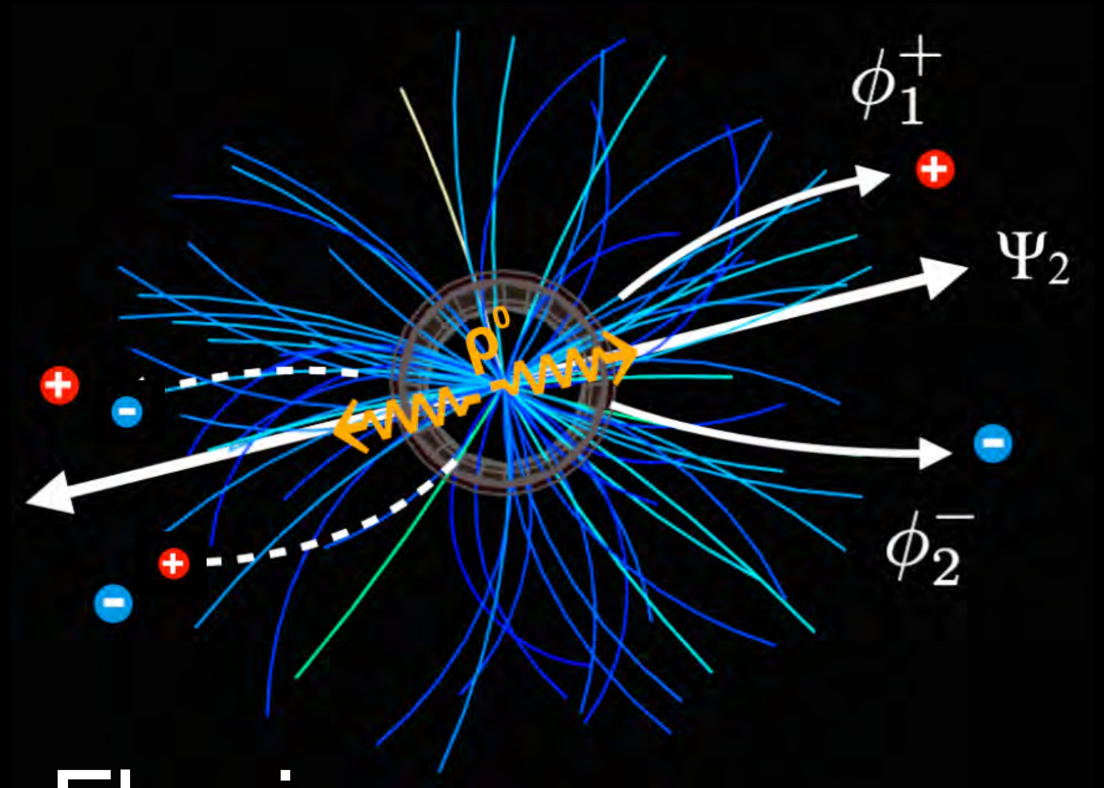
STAR collaboration, PRL 103, 251601 (2009

Three possible sources of charge separation



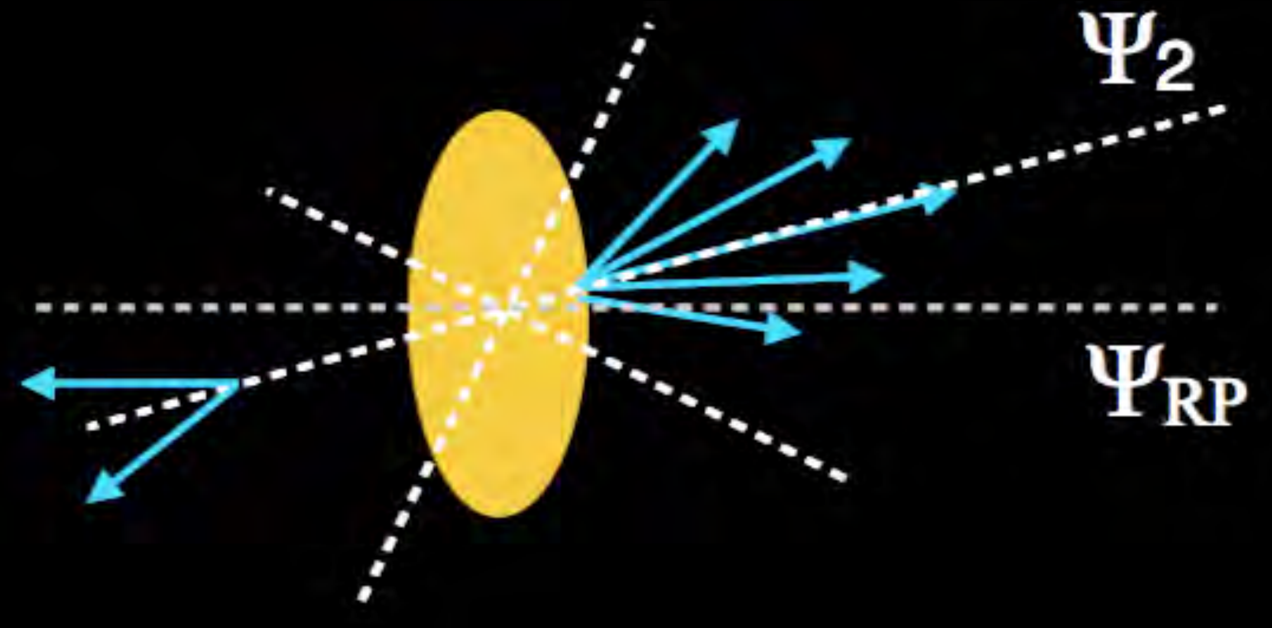
CME

\+



Flowing resonance

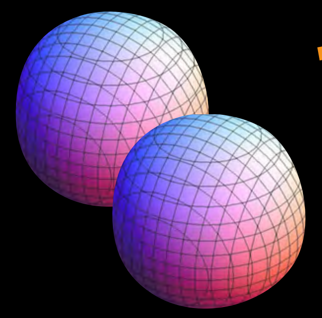
\+

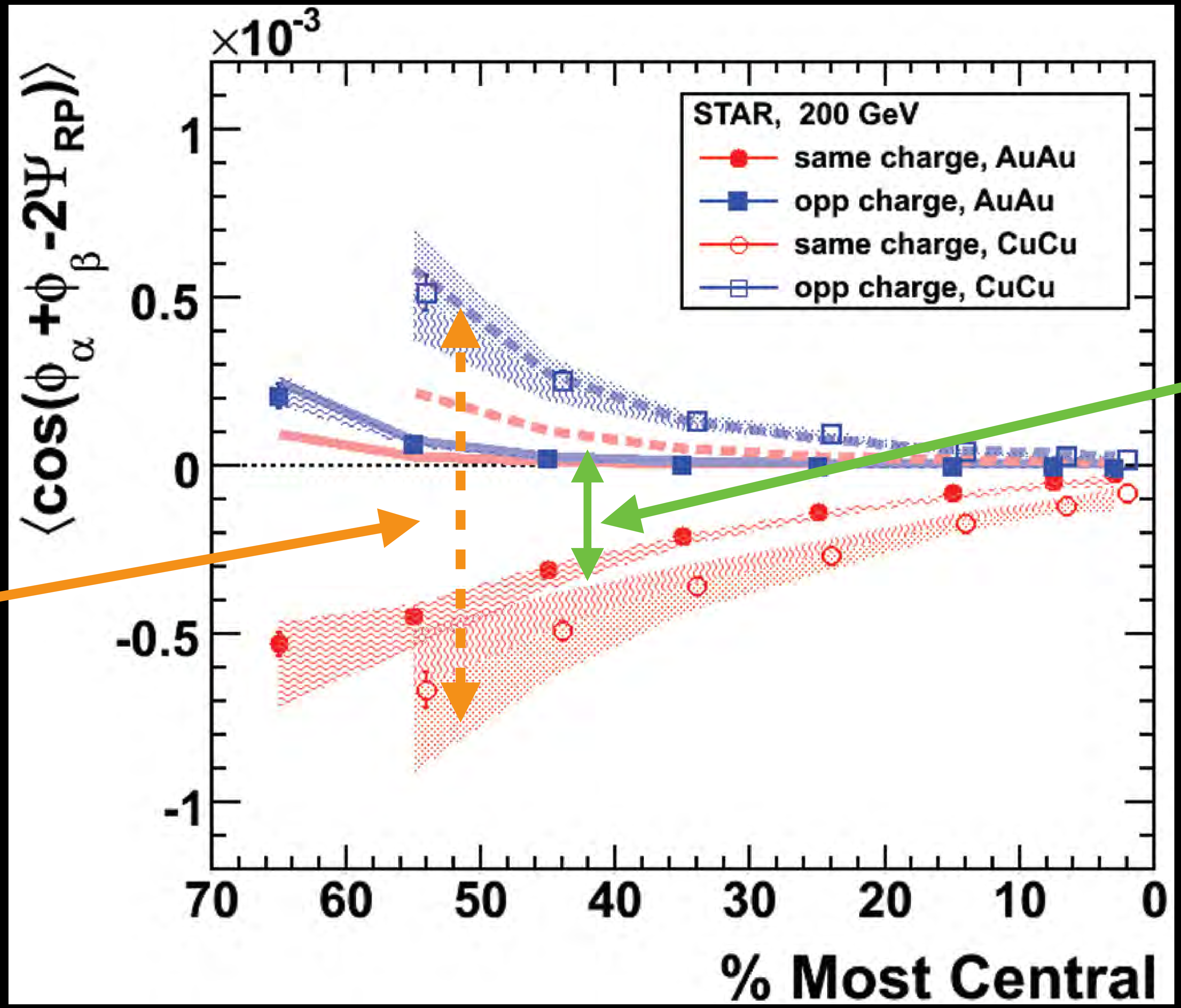


Di-jets (non-flow)

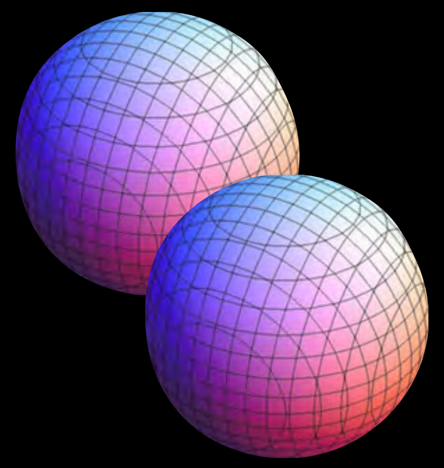
The first measurements at RHIC

Cu+Cu





Au+Au



STAR collaboration, PRL 103, 251601 (2009

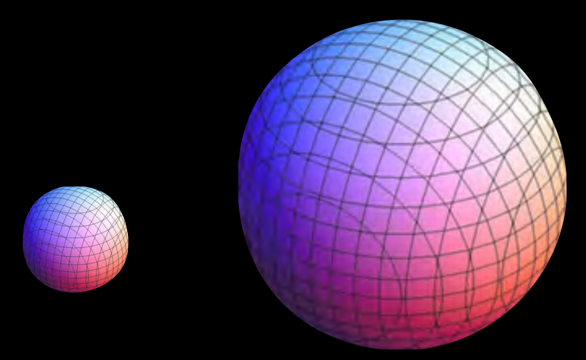
Significant charge separation observed, consistent with CME+ Background

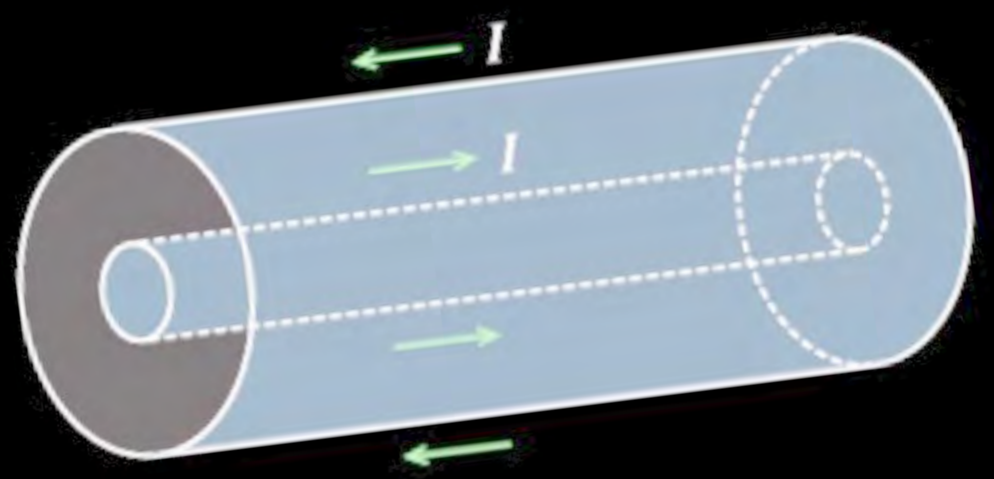
$$\Delta\gamma = \Delta\gamma^{CME} + k \times \frac{v_2}{N} + \Delta\gamma^{non-flow}$$

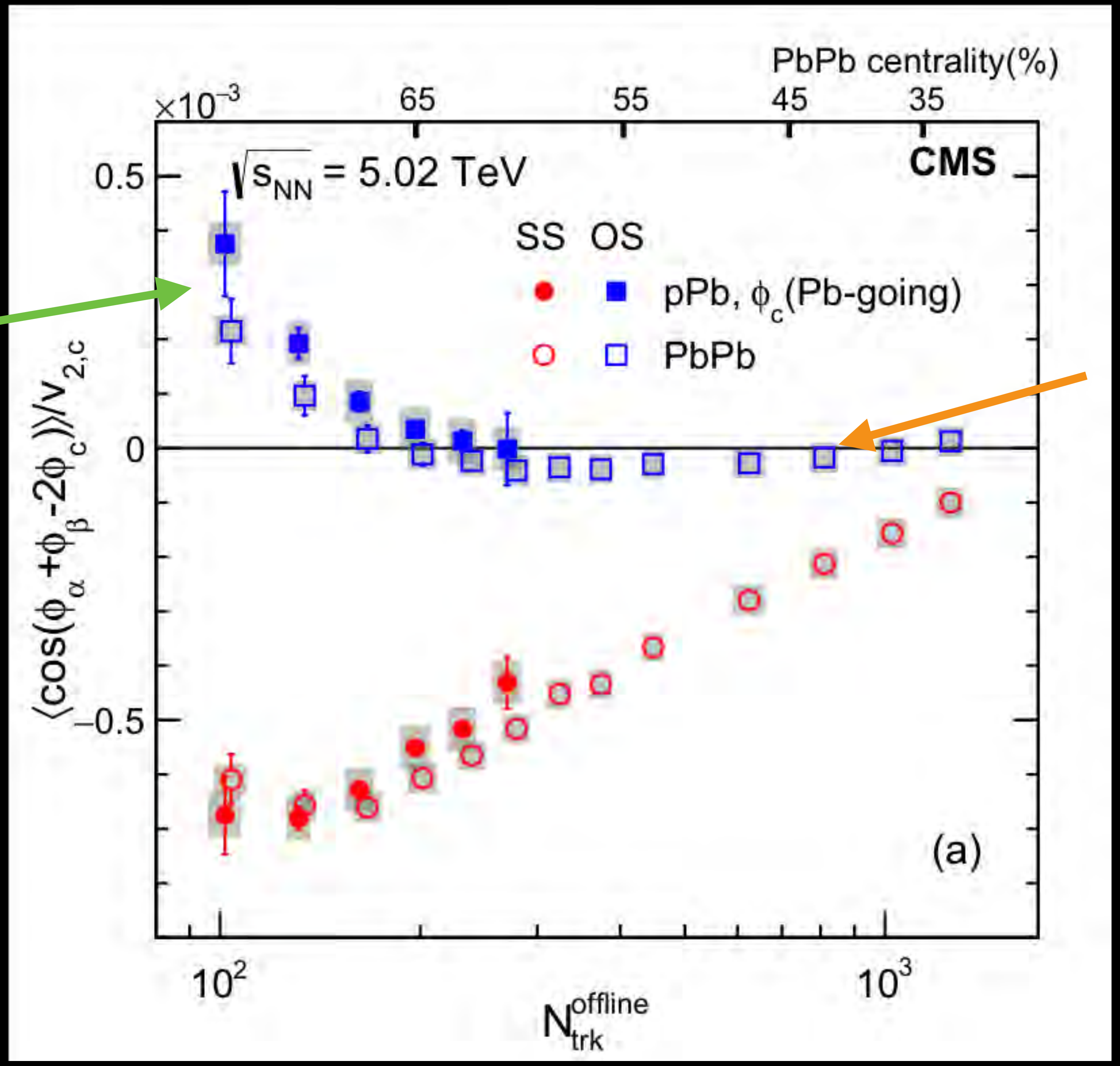
Measurement Signal Background-1 Background-2

CME search in small systems

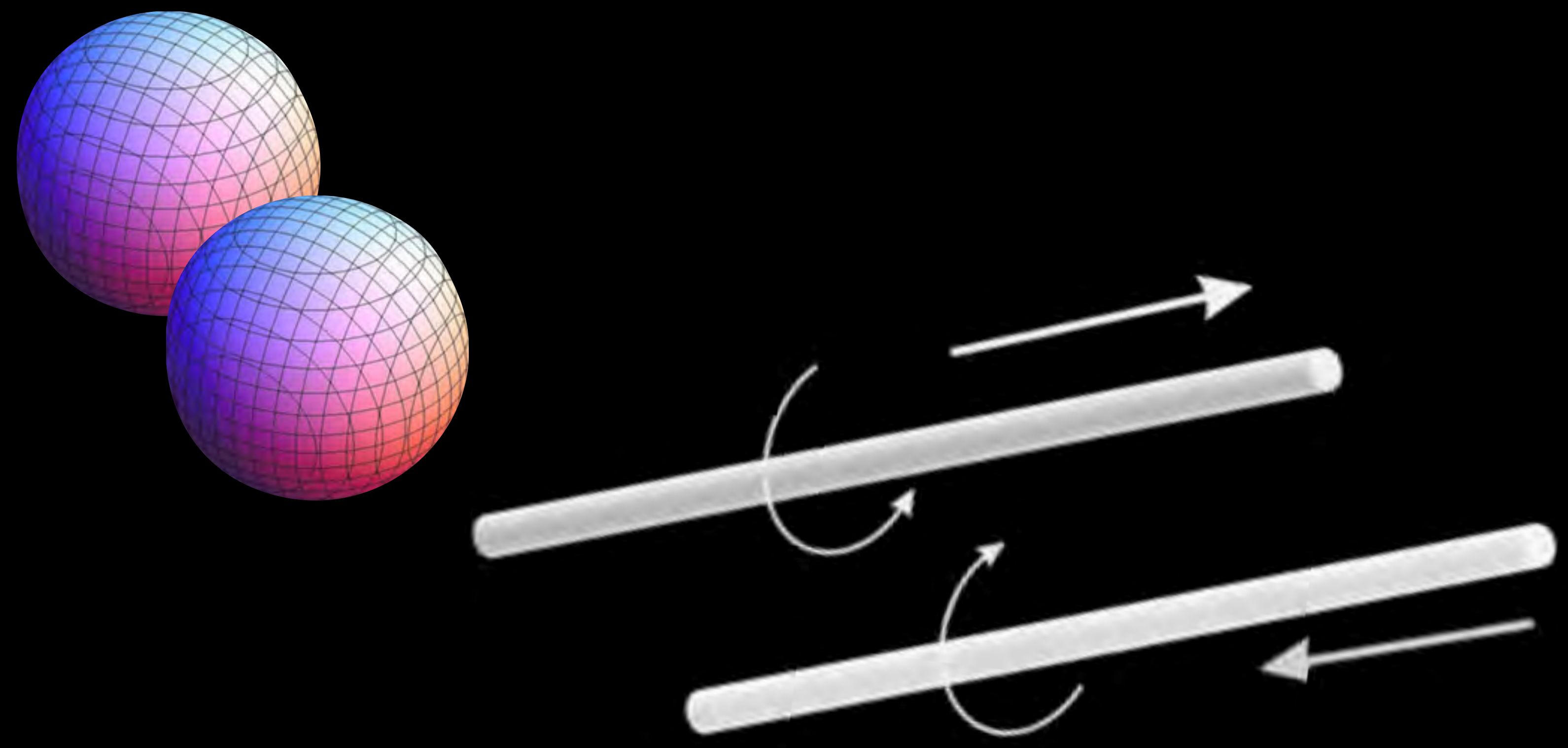
p+Pb







Pb+Pb



CMS collaboration, Phys. Rev Lett, 118 (2017) 122301

$$\begin{cases} \Delta\gamma^{A+A} = \Delta\gamma^{CME} + k \times \dfrac{v_2}{N} + \Delta\gamma^{non-flow} \\ \quad \| \qquad\quad \nparallel \qquad\quad \nparallel \qquad\quad \nparallel \\ \Delta\gamma^{p+A} = \cancel{\Delta\gamma^{CME}} + k \times \dfrac{v_2}{N} + \Delta\gamma^{non-flow} \end{cases}$$

Flow and non-flow contributions are too different, less control and difficult to prove if

$$\Delta\gamma^{CME} = 0$$

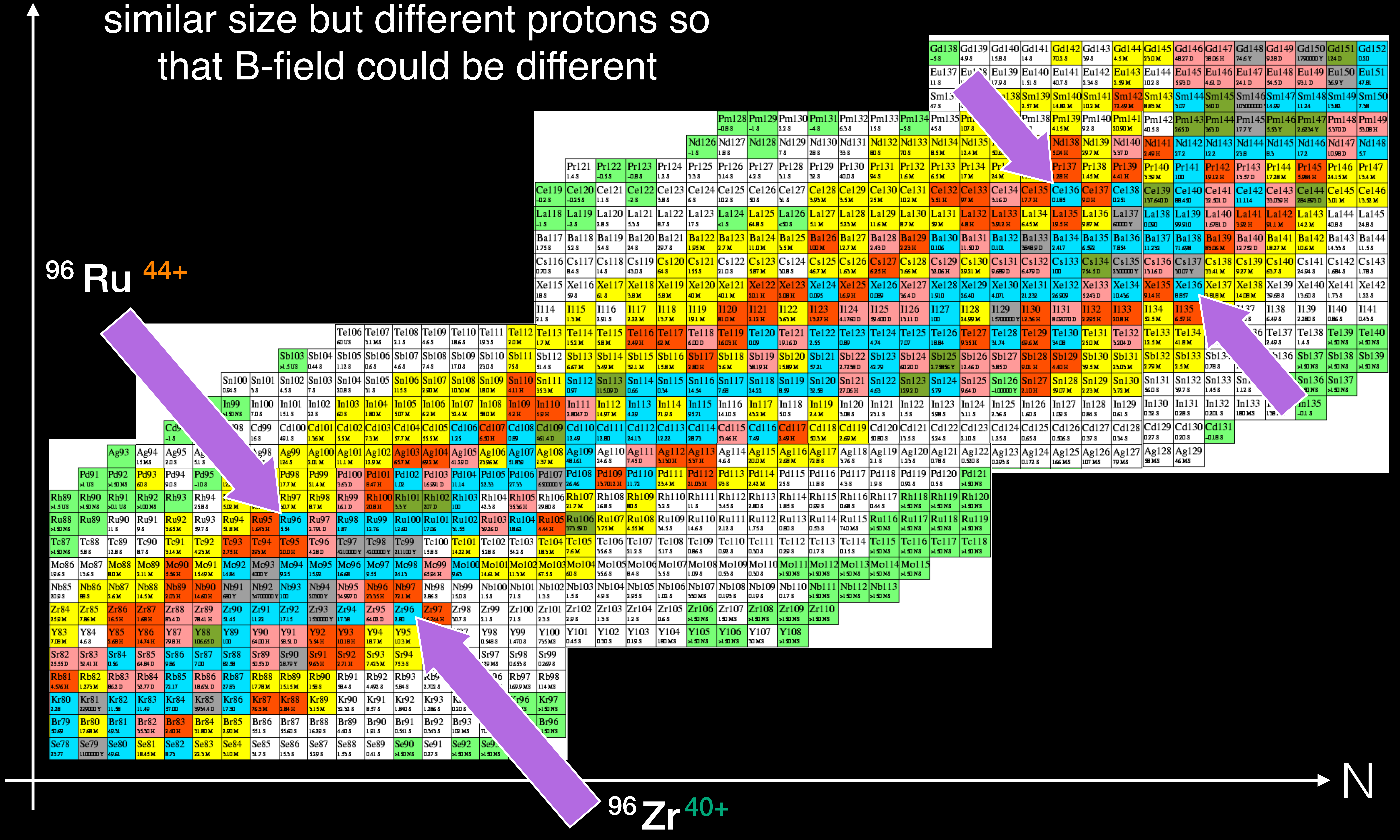
Two systems of very different sizes → limited control over background

This naturally leads to the idea of using two systems of similar sizes

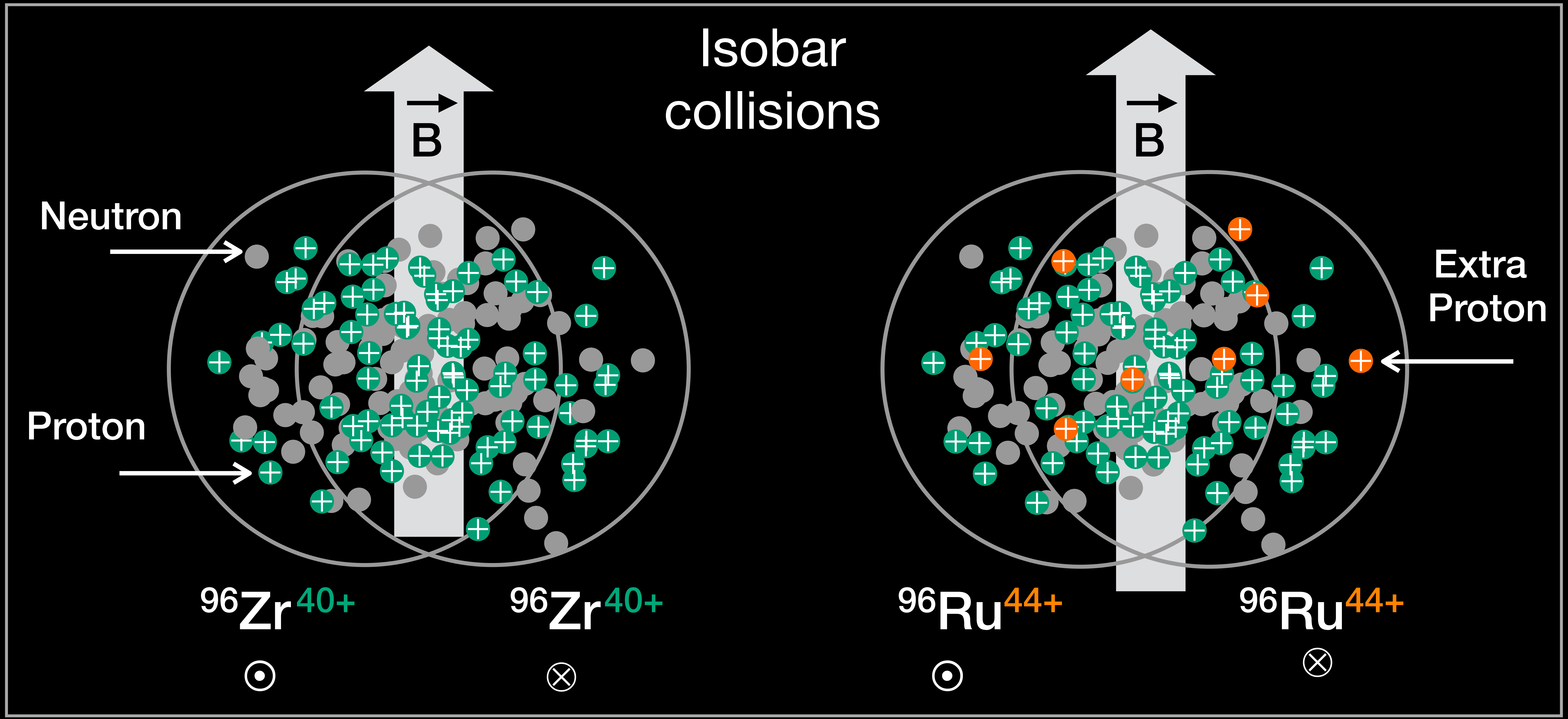
Isobar in the chart of nuclides

© http://www.nuclear.csdb.cn/nuclear/chart9.asp

Looking for elements which have similar size but different protons so that B-field could be different



Isobar collisions



Voloshin,

B-field square is 10-18% larger in Ru+Ru

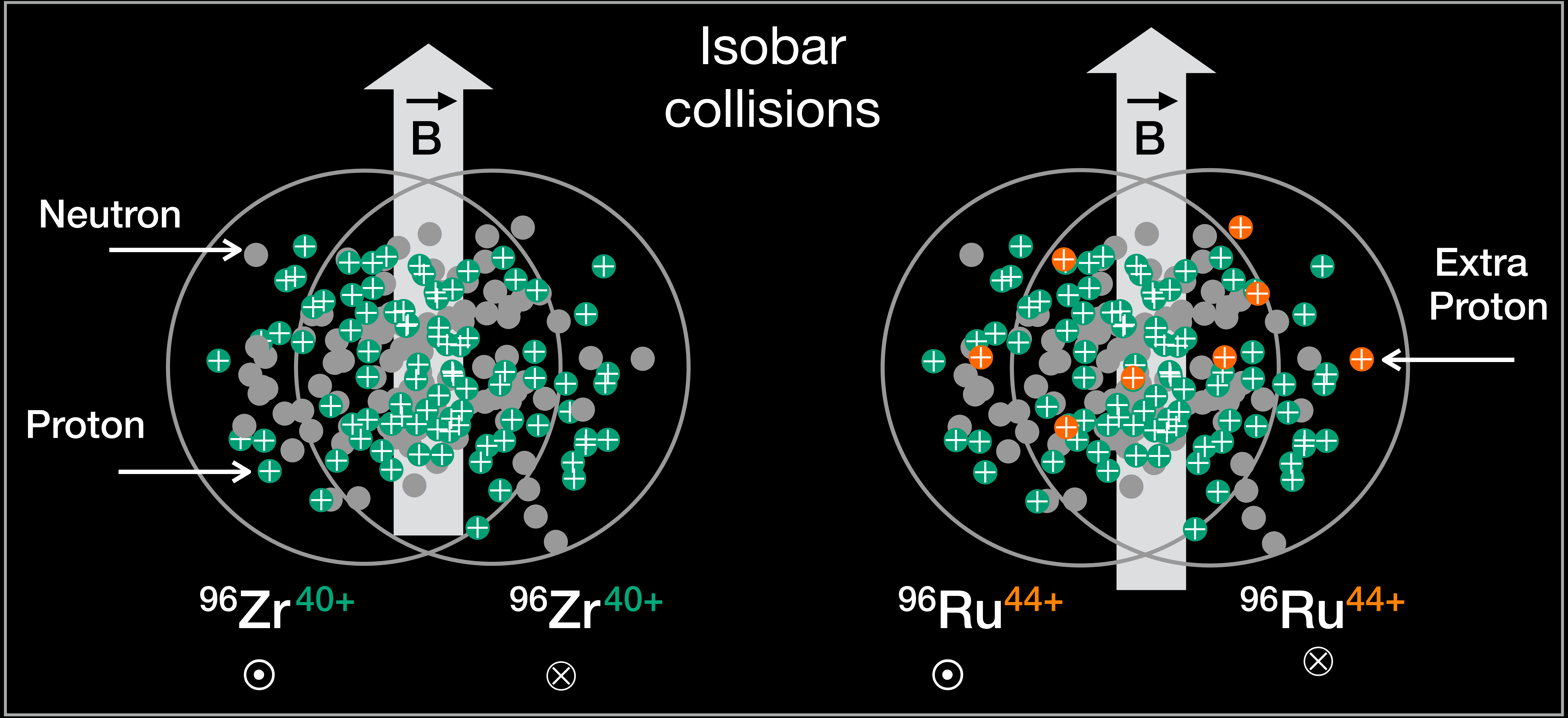
$$\Delta\gamma^{\text{Ru+Ru}} = \Delta\gamma^{CME} + k \times \frac{v_2}{N} + \Delta\gamma^{non-flow}$$

?? $\qquad \neq \qquad \approx \qquad \|$

$$\Delta\gamma^{\text{Zr+Zr}} = \Delta\gamma^{CME} + k \times \frac{v_2}{N} + \Delta\gamma^{non-flow}$$

Isobar collisions provide the best possible control of signal and background compared to all previous experiments

Isobar collisions



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$$?? \qquad \not\approx \qquad \approx$$

$$\Delta\gamma^{\text{Zr+Zr}} = \Delta\gamma^{CME} + k \times \frac{v_2}{N}$$

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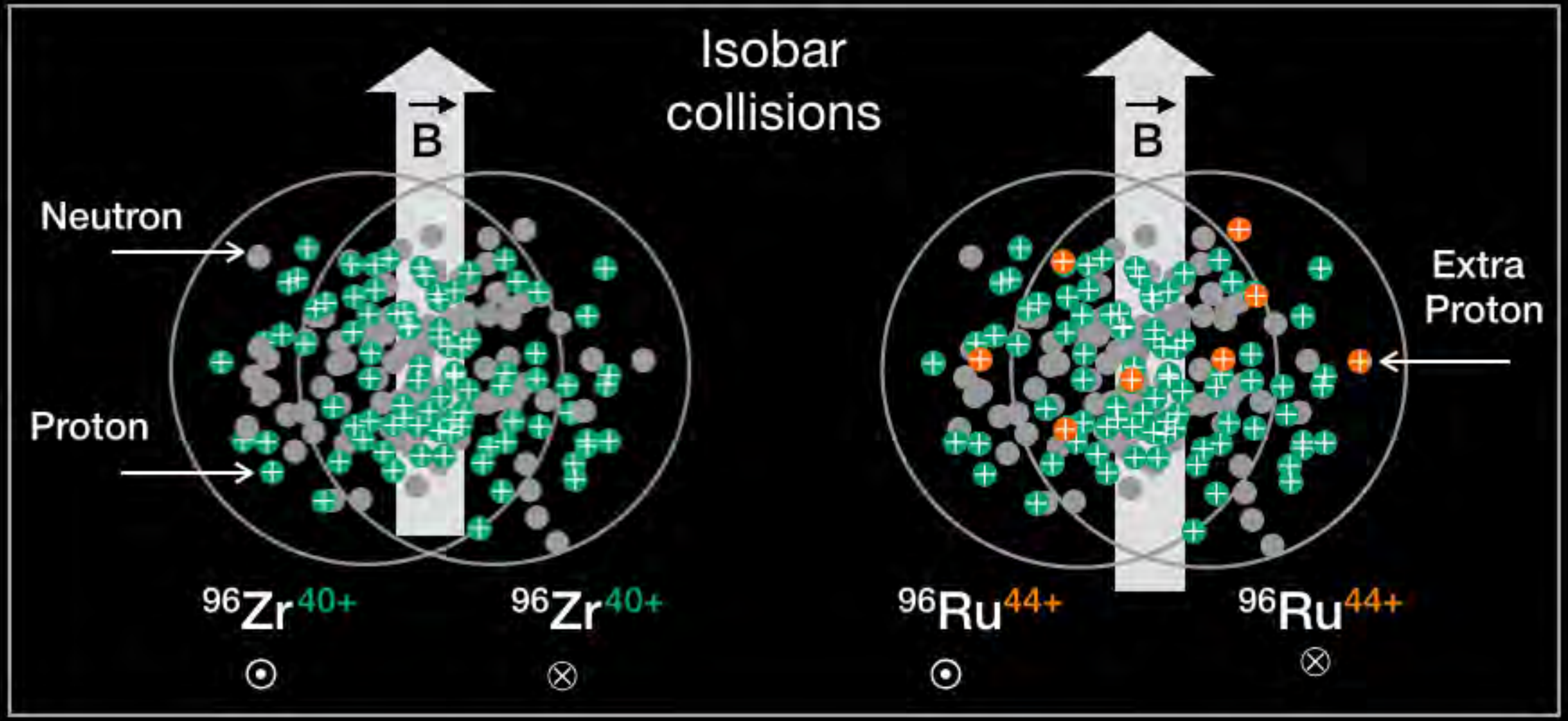
Isobar collisions



Voloshin,

B-field square is 10-18% larger in Ru+Ru

$$\Delta\gamma^{\text{Ru+Ru}} = \Delta\gamma^{CME} + k \times \frac{v_2}{N}$$

$$?? \qquad \not\approx \qquad \approx$$

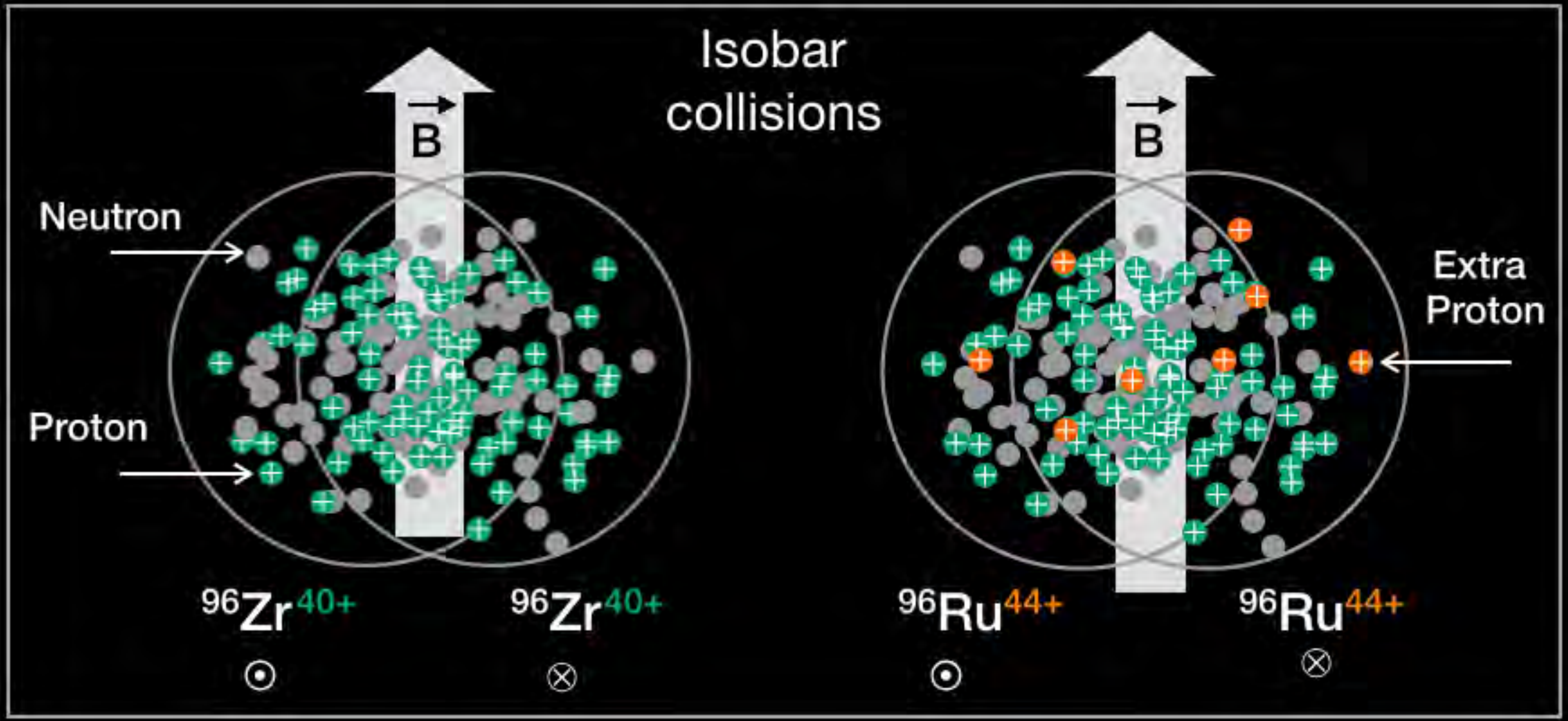
$$\Delta\gamma^{\text{Zr+Zr}} = \Delta\gamma^{CME} + k \times \frac{v_2}{N}$$

Isobar collisions provide the best possible control of signal and background compared to all previous experiments

If multiplicity (N) is same in two isobars:

$$\frac{(\Delta\gamma/v_2)_{\text{Ru+Ru}}}{(\Delta\gamma/v_2)_{\text{Zr+Zr}}} \approx 1 + \underset{\text{Unknown}}{f_{\text{CME}}^{\text{Zr+Zr}}}\,[\underbrace{(B_{\text{Ru+Ru}}/B_{\text{Zr+Zr}})^2 - 1}_{0.18}] > 1 \;\; (\text{for CME})$$

Isobar collisions



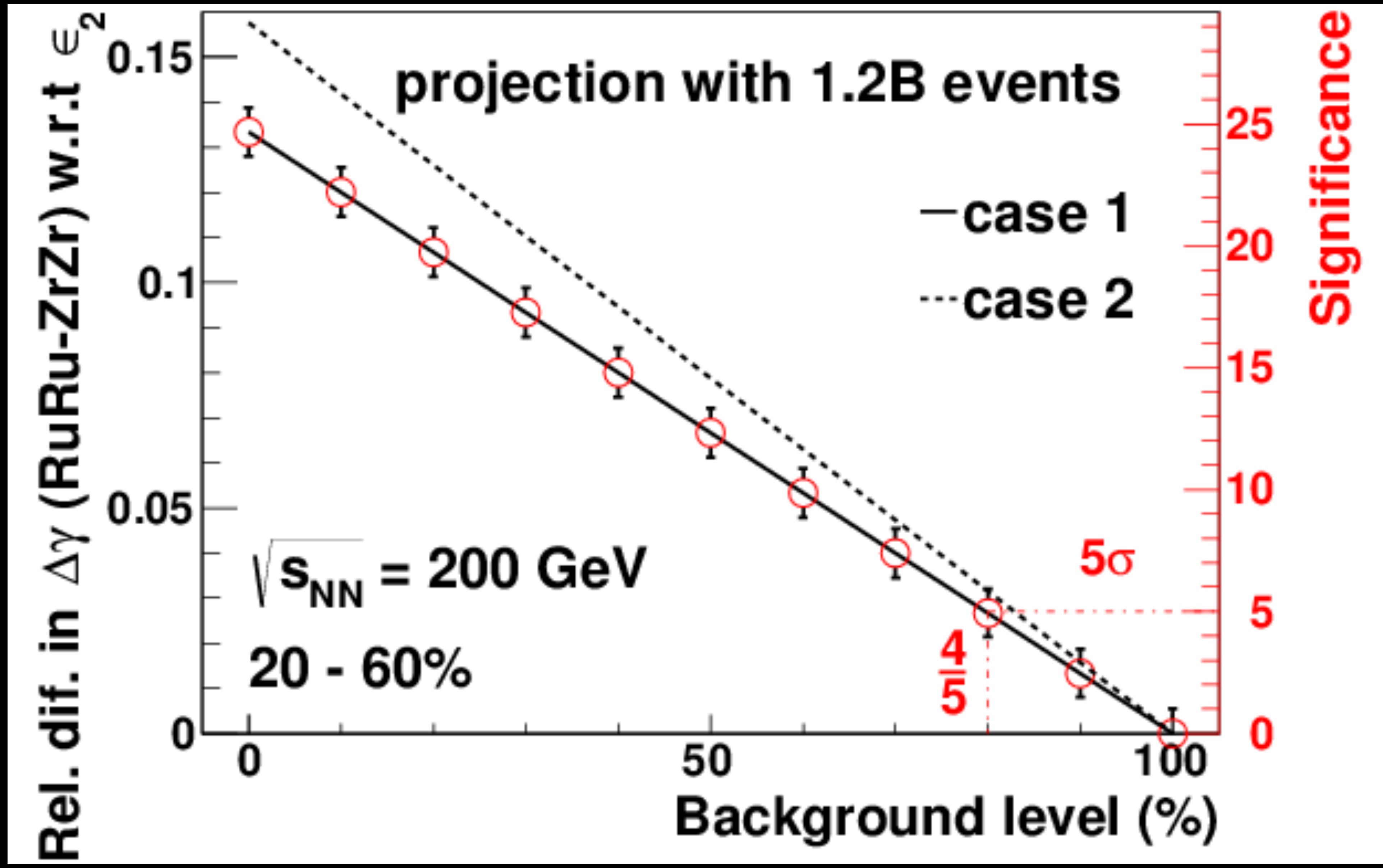
Voloshin,

B-field square is 10-18% larger in Ru+Ru

https://drupal.star.bnl.gov/STAR/system/files/STAR_BUR_Run1718_v22_0.pdf

$$\frac{(\Delta\gamma/v_2)_{\mathrm{Ru+Ru}}}{(\Delta\gamma/v_2)_{\mathrm{Zr+Zr}}} \approx 1 + \underset{\text{Unknown}}{f_{\mathrm{CME}}^{\mathrm{Zr+Zr}}}[\underbrace{(B_{\mathrm{Ru+Ru}}/B_{\mathrm{Zr+Zr}})^2 - 1}_{0.18}]$$

$$\boxed{> 1 \ (\text{for CME})}$$



$$(1 - f_{\mathrm{CME}}) \times 100\%$$

1.2 B collision events for each species can give 5σ significance for 20% signal level ($f_{CME} \sim 0.2$)

(A precision of 0.5% is needed !!)

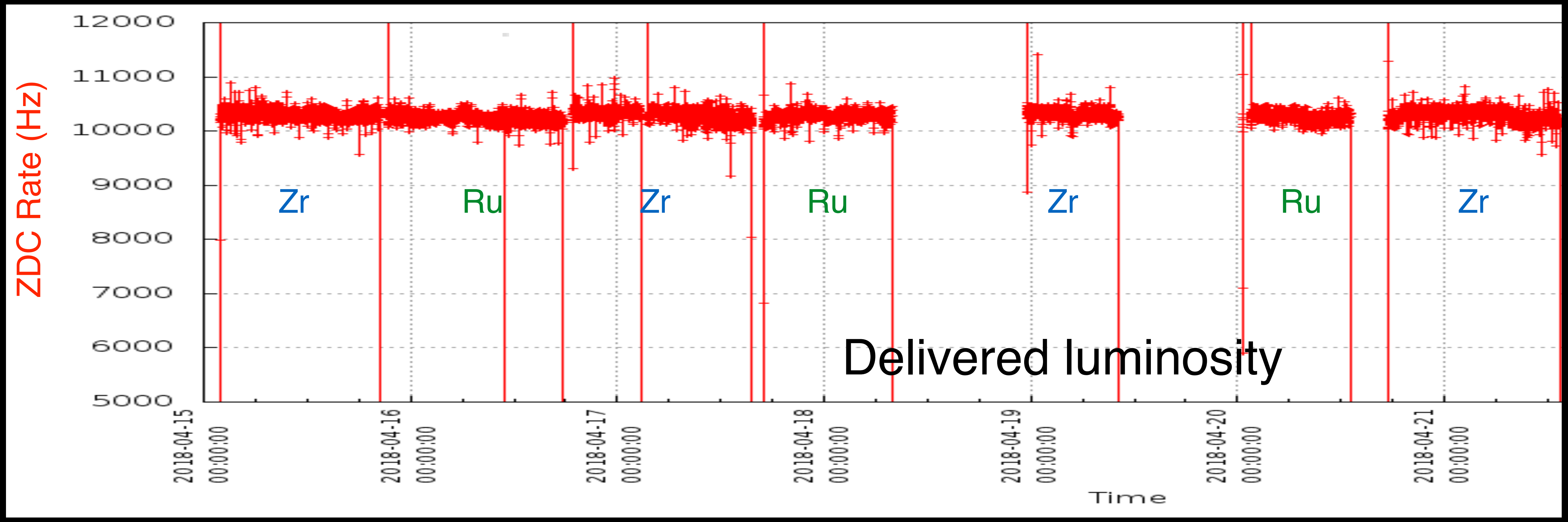
Details Of The Data Taking Of The Isobar Run

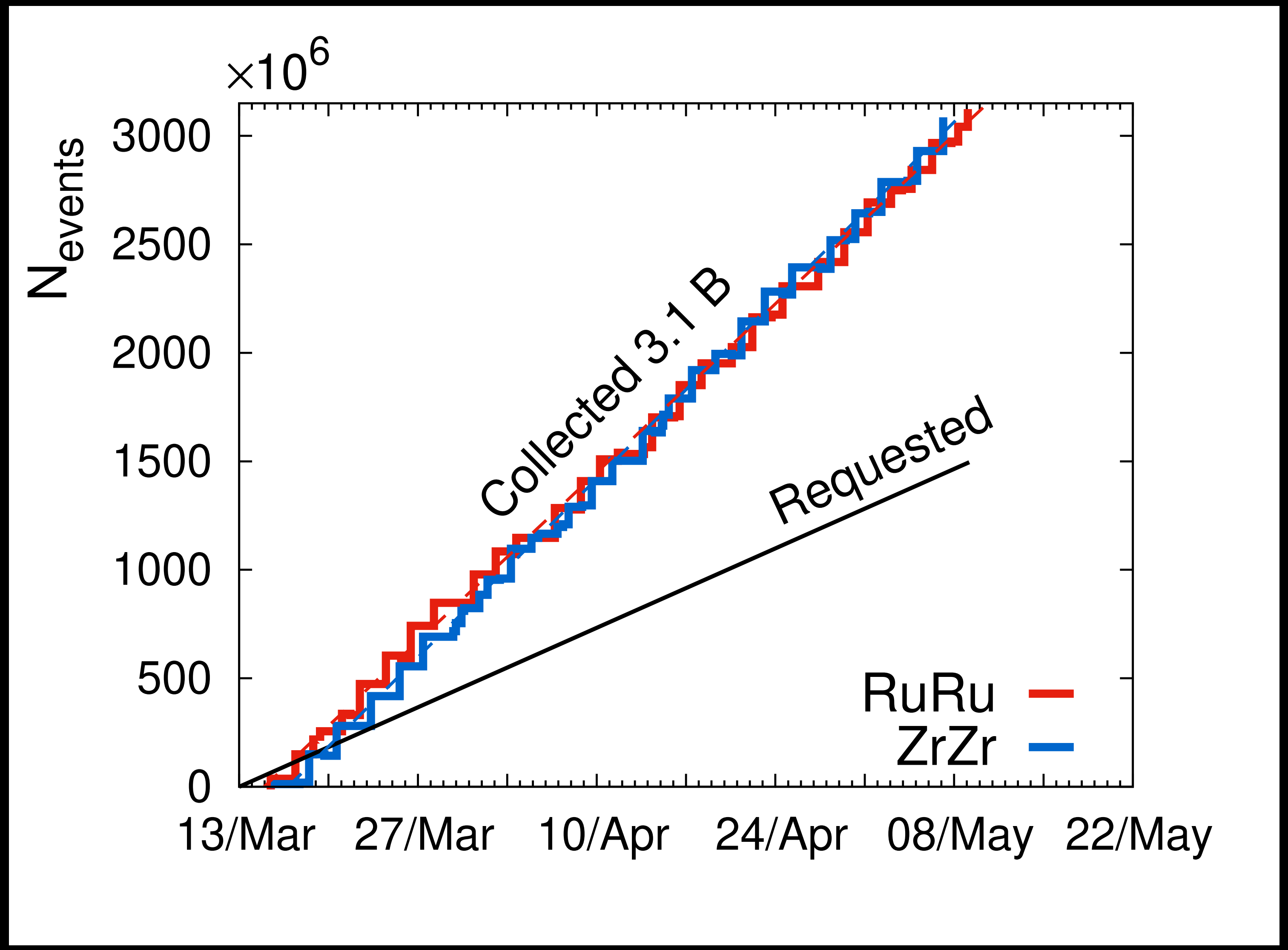
Brookhaven National Laboratory

G. Marr et al., in 10th International Particle Accelerator Conference (2019) pp. 28–32.

Goal: minimize the systematics in observable ratios, similar run conditions for both species

Two important steps:
1) Fill-by-fill switching
2) Level luminosity

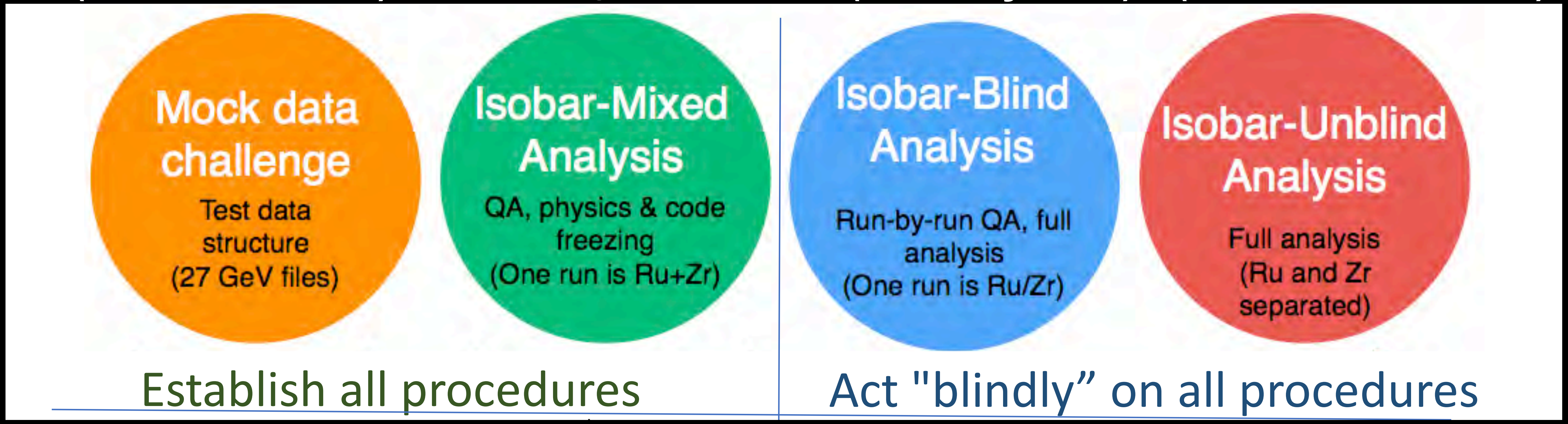




Blind analysis of the isobar data

Steps of Isobar blind analysis

Step-I (~2 months) | Step-II (~1 year) | Step-III (~1/2 year) | Step-IV (~2-3 months)

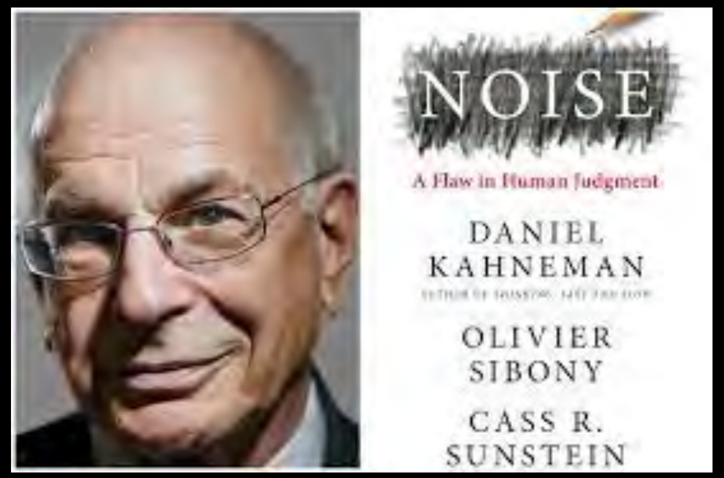


STAR Collaboration
Nucl.Sci.Tech. 32 (2021) 5, 48
arXiv:1911.00596 [nucl-ex]

- NPP PAC recommended a blind analysis of isobar data Blinding
- No access to species-specific information before last step
- Everything documented (not written → not allowed)
- Case for CME & interpretation must be pre-defined

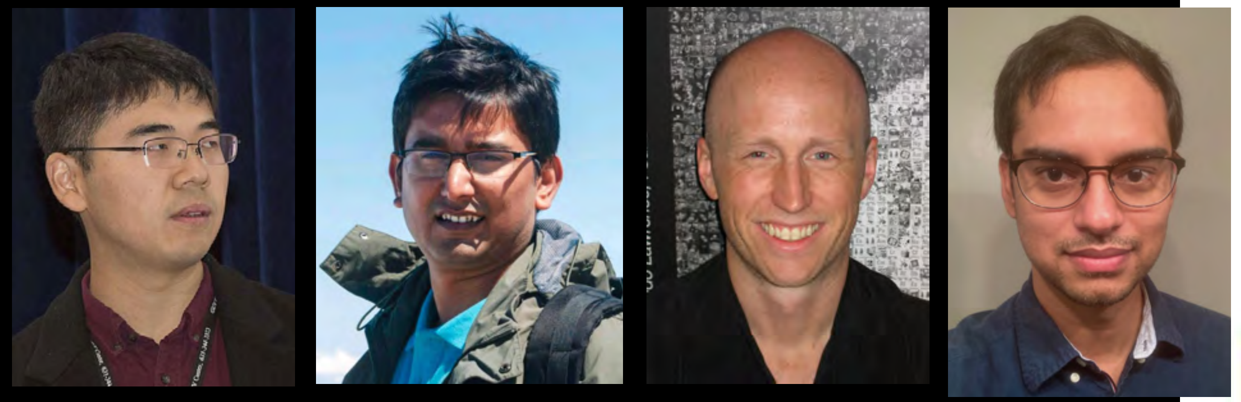
Quality assurance is done by pattern recognition algorithms to remove bias & noise

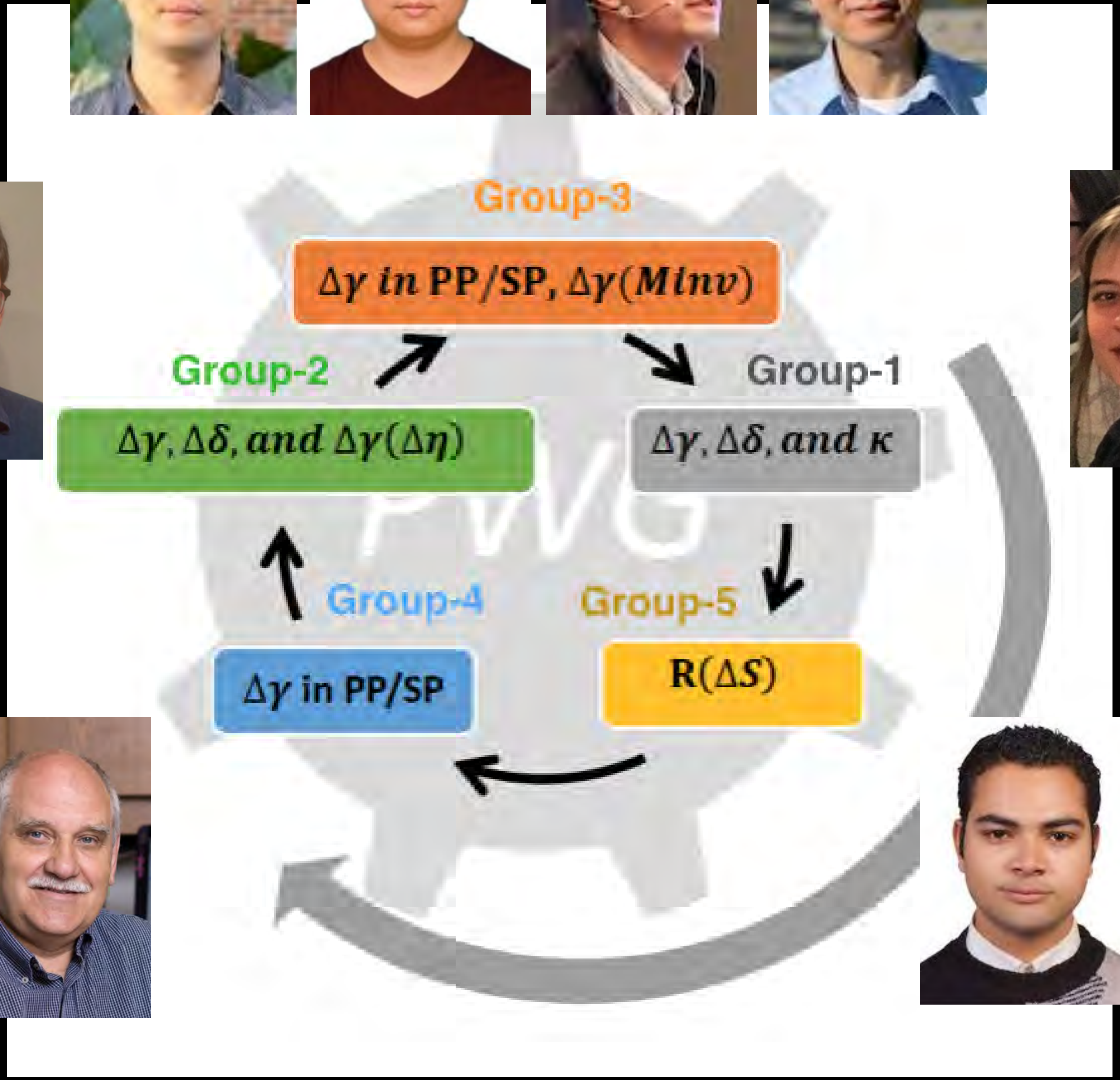
~~Huristics~~ ⇒ Algorithms



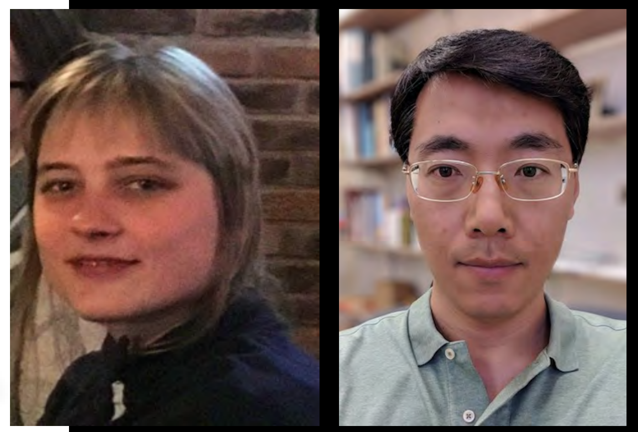
Five independent groups did isobar blind analysis

Purdue-Huzhou (group-3)
Yicheng Feng, Haojie Xu, Jie Zhao, Fuqiang Wang

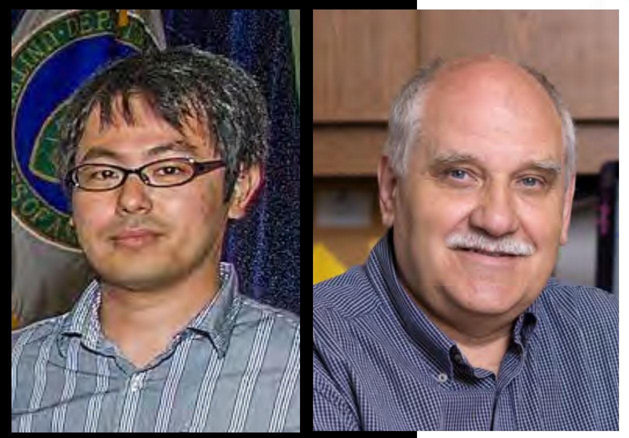




BNL-Fudan (group-2)
Yu Hu, Subikash Choudhury, Paul Sorensen, Prithwish Tribedy



UCLA (group-1)
Maria Sergeeva, Gang Wang

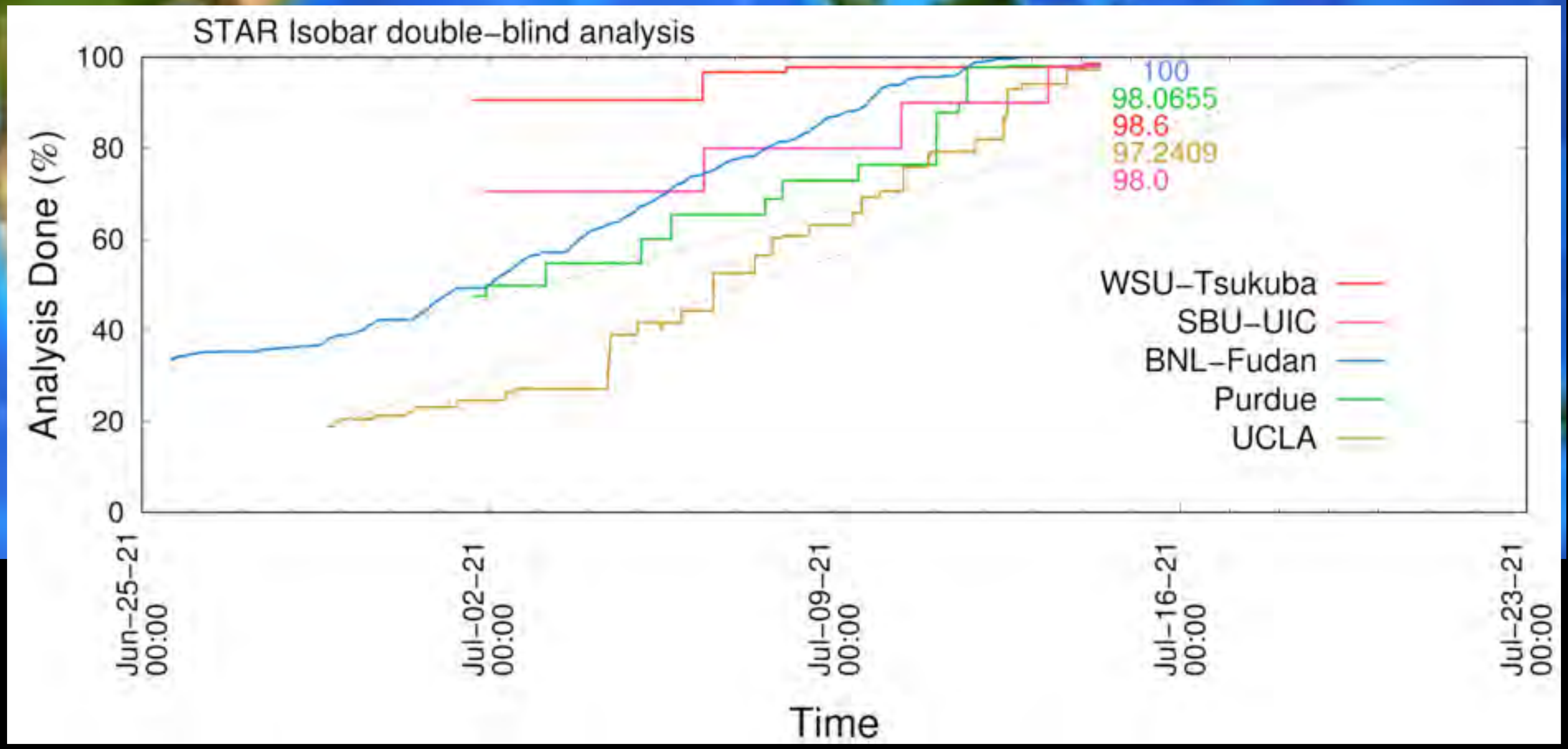


WSU-Tsukuba (group-4)
Takafumi Niida, Sergei Voloshin

SBU-UIC (group-5)
Niseem Magdy, Roy Lacey

Five independent groups will perform analysis, all codes must be frozen and run by another person, results have to directly sent for publication

How the isobar blind analysis was done



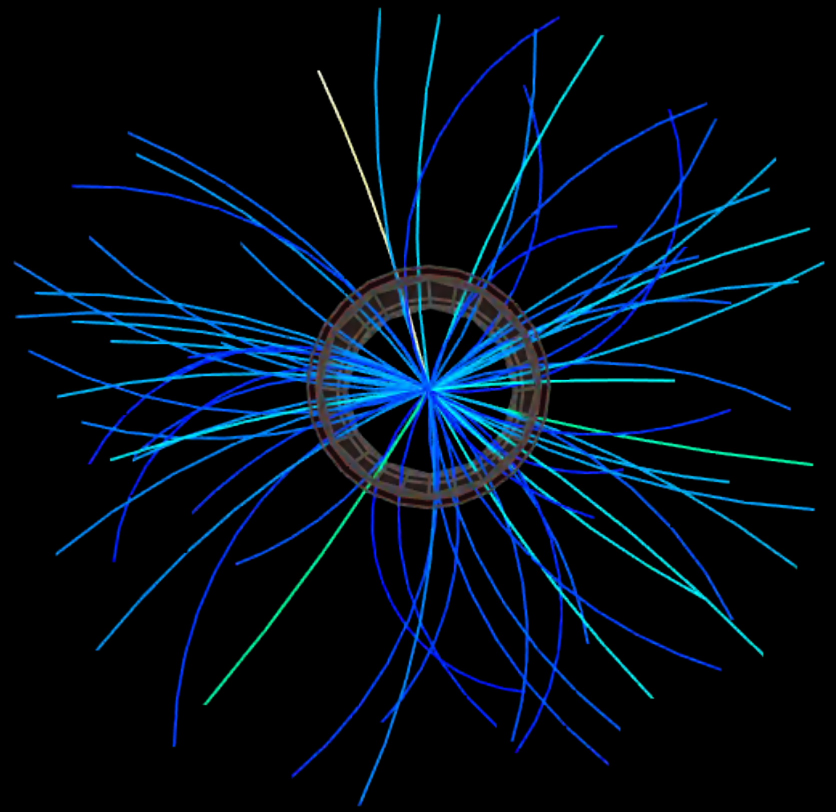
Different people run frozen codes

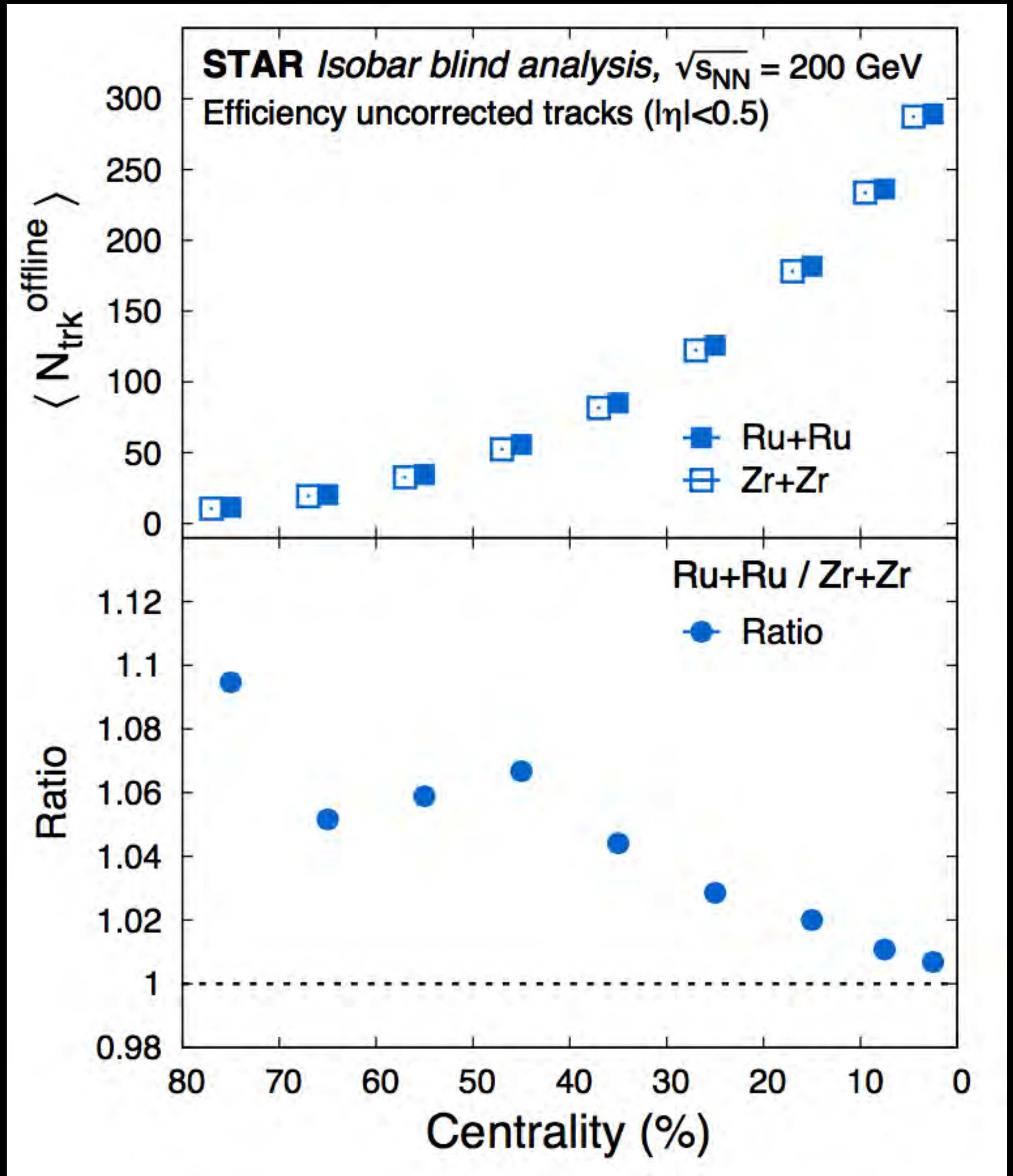
→ Analyzers open box → Directly publish the result

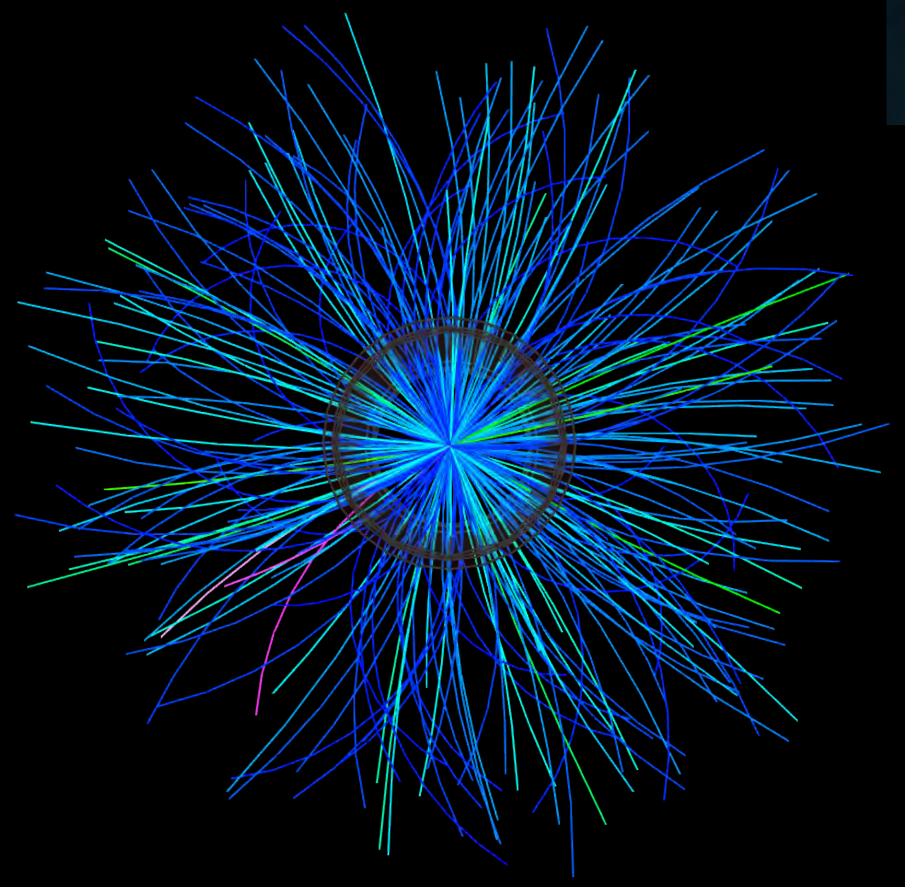
(Took all nodes of RHIC comp. facility for a month)

Results from Isobar blind analysis

Multiplicity difference between the isobars







Mean efficiency uncorrected multiplicity density is larger in Ru than in Zr in a matching centrality, this can affects signal and background difference between isobars

Quite unexpected result!!

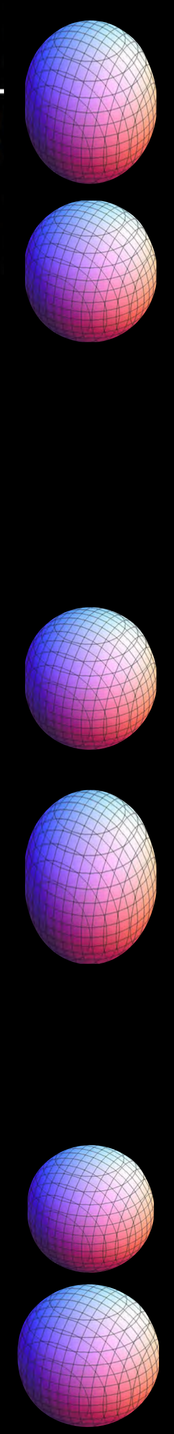
What is the size/shape of the isobar nuclei?

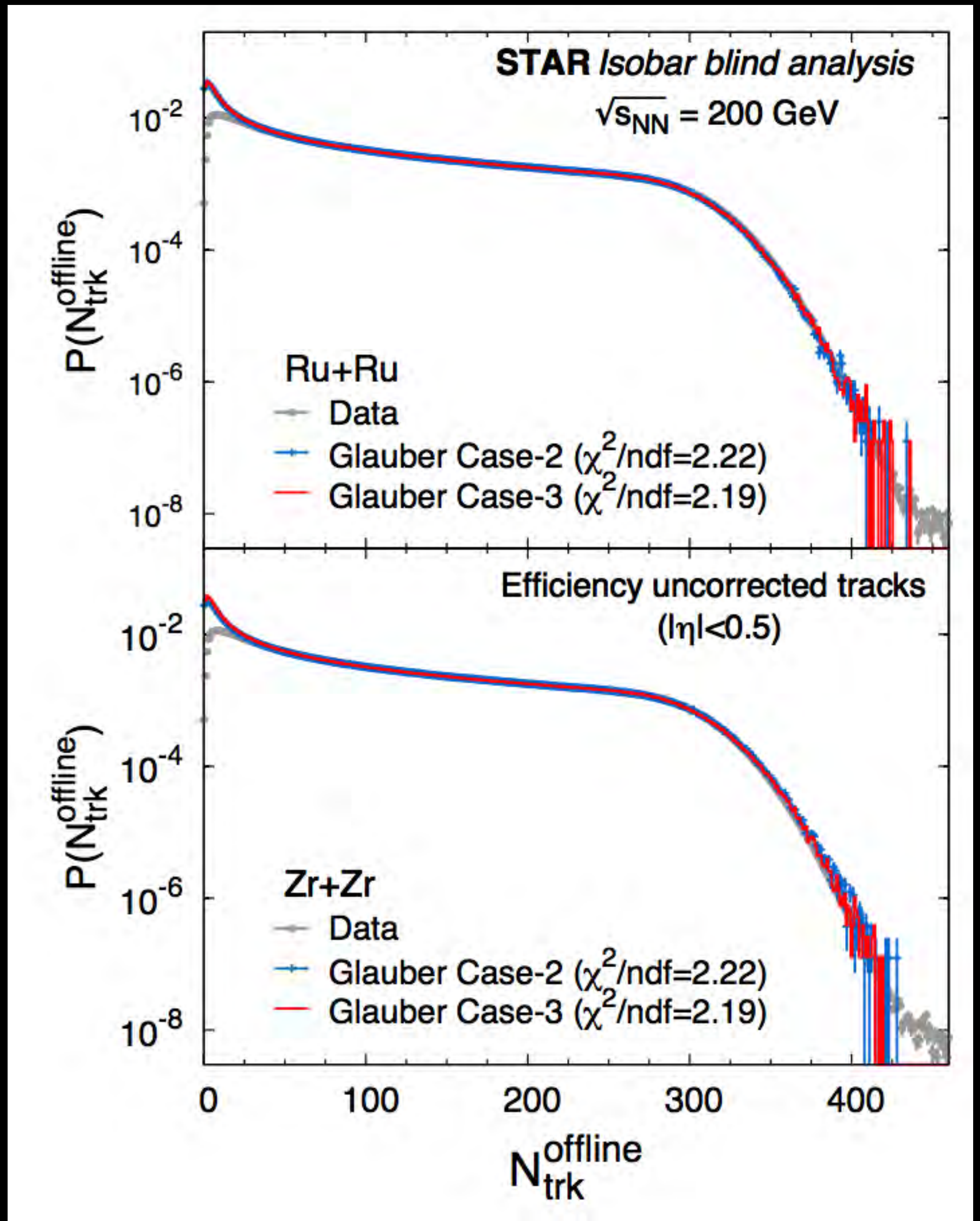
Blind analysis: we decided to compare observables at same centralities between isobars

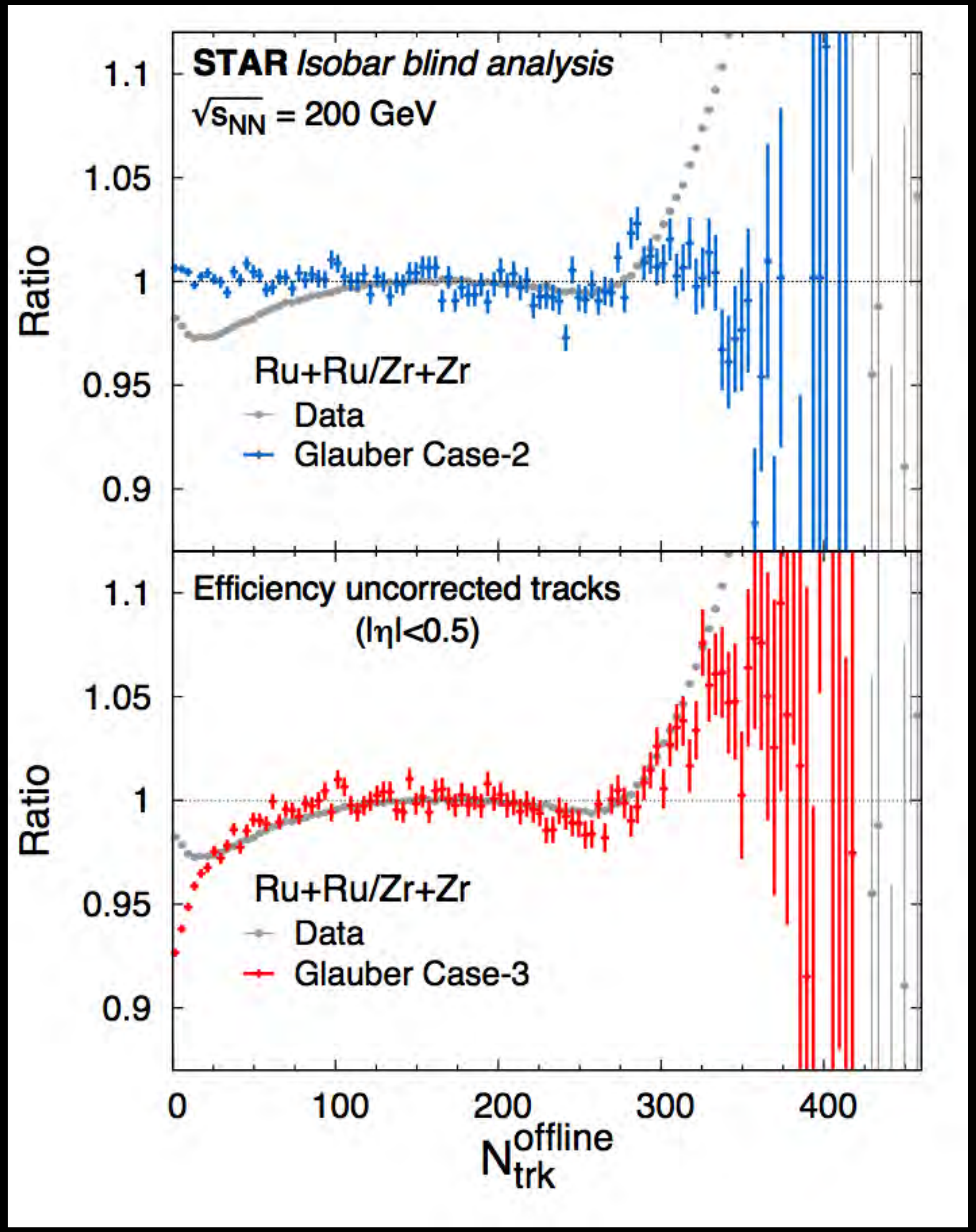
Case-1 [83]			
Nucleus	R (fm)	a (fm)	β_2
$^{96}_{44}$Ru	5.085	0.46	0.158
$^{96}_{40}$Zr	5.02	0.46	0.08

Case-2 [83]			
Nucleus	R (fm)	a (fm)	β_2
$^{96}_{44}$Ru	5.085	0.46	0.053
$^{96}_{40}$Zr	5.02	0.46	0.217

Case-3 [113]			
Nucleus	R (fm)	a (fm)	β_2
$^{96}_{44}$Ru	5.067	0.500	0
$^{96}_{40}$Zr	4.965	0.556	0





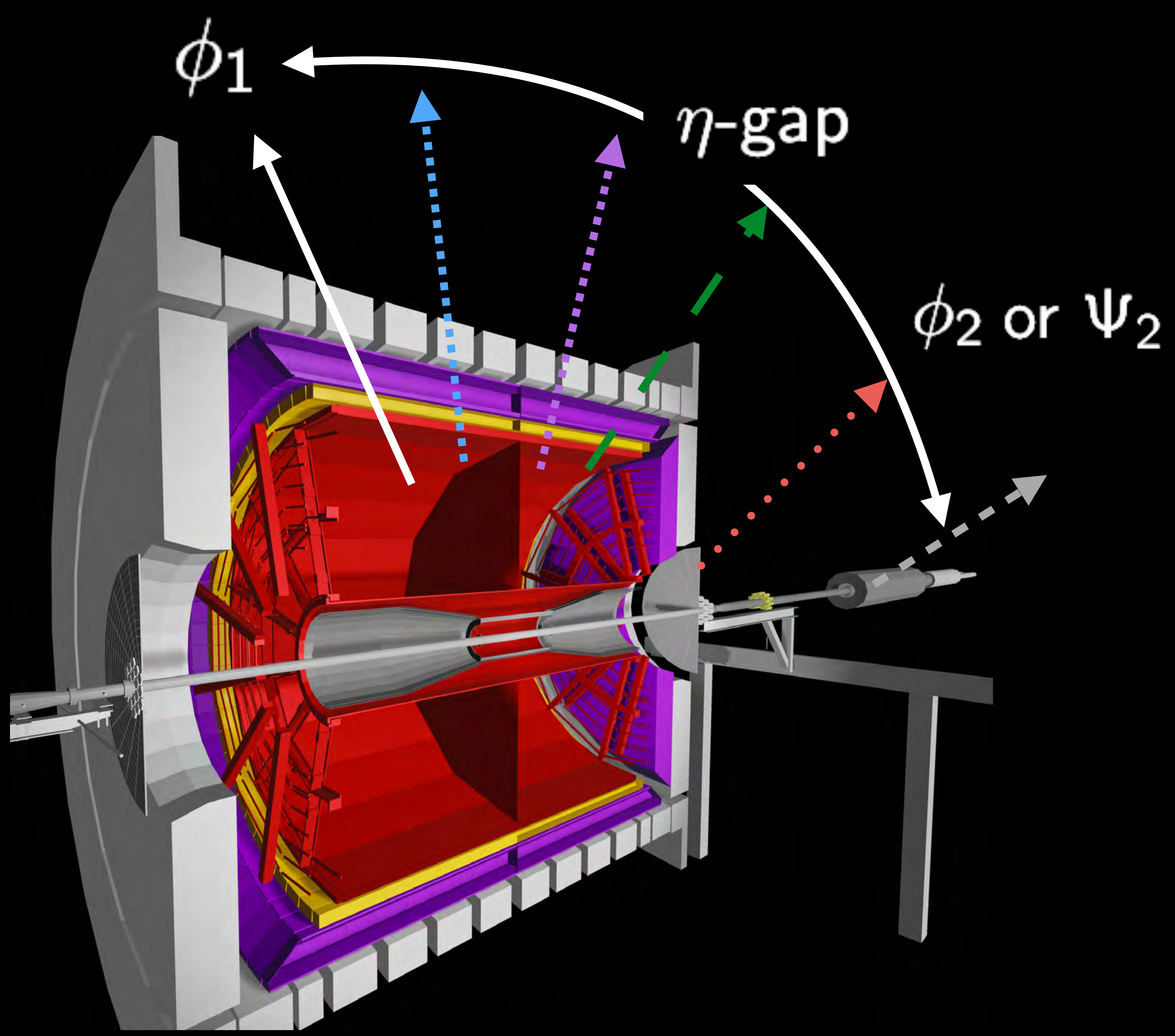


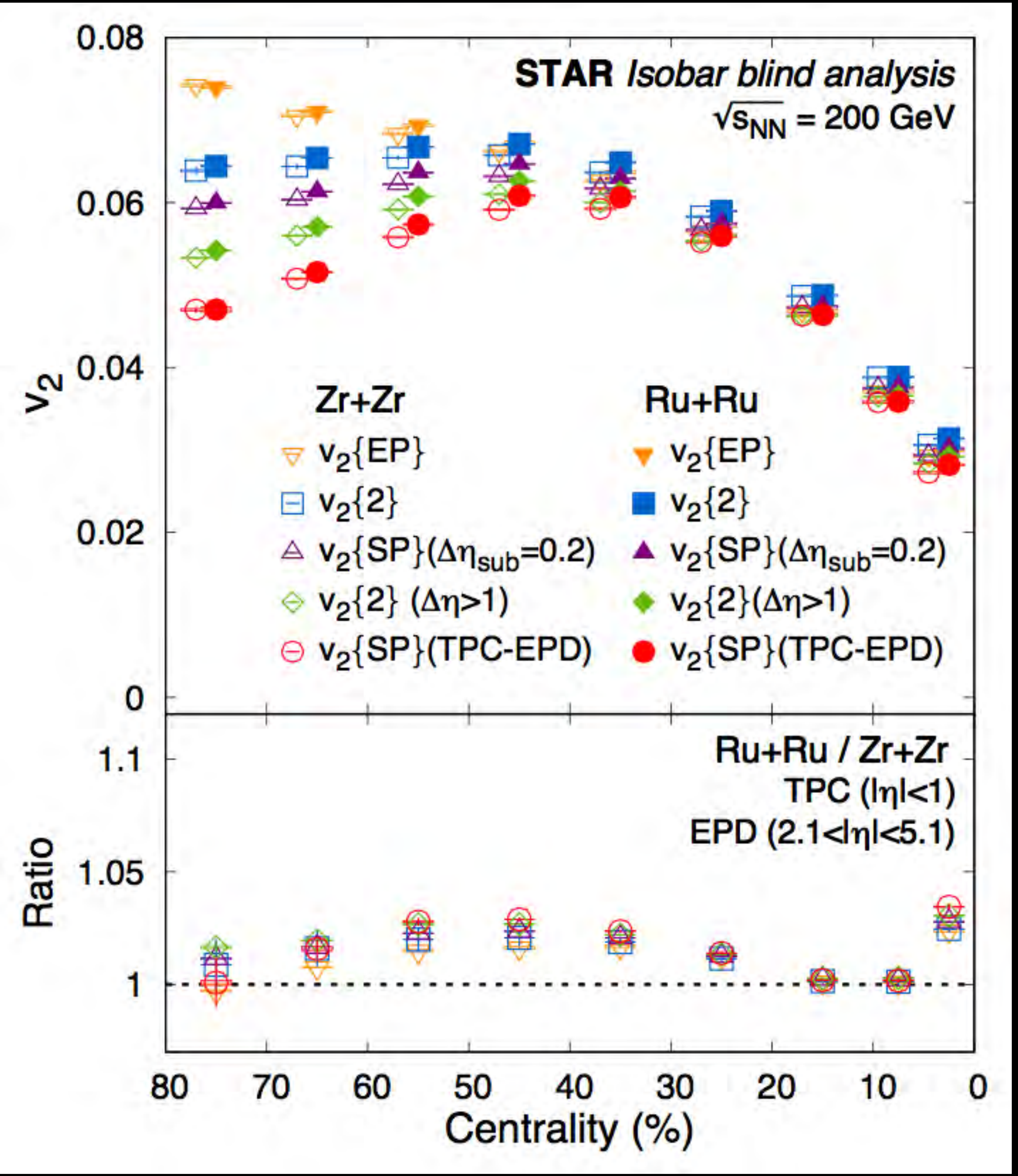
See references in:
[83] Deng et. al., Phys. Rev. C 94, 041901 (2016), arXiv:1607.04697 [nucl-th].
[113] Xu et. al., Phys. Rev. Lett. 121, 022301 (2018), arXiv:1710.03086 [nucl-th].

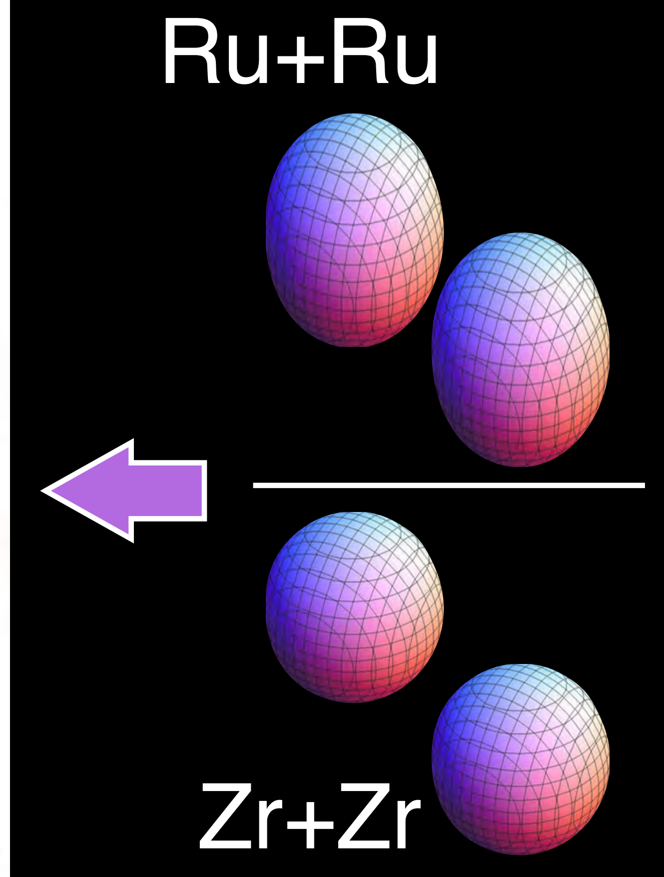
MC-Glauber with two-component model used to describe uncorrected multiplicity distribution. WS parameters with no deformation (thinker neutron skin in Zr) provides the best description of the multiplicity distributions

Elliptic anisotropy measurements

$$v_2\{EP\} = \langle \cos(2\phi_1 - 2\Psi_2) \rangle$$





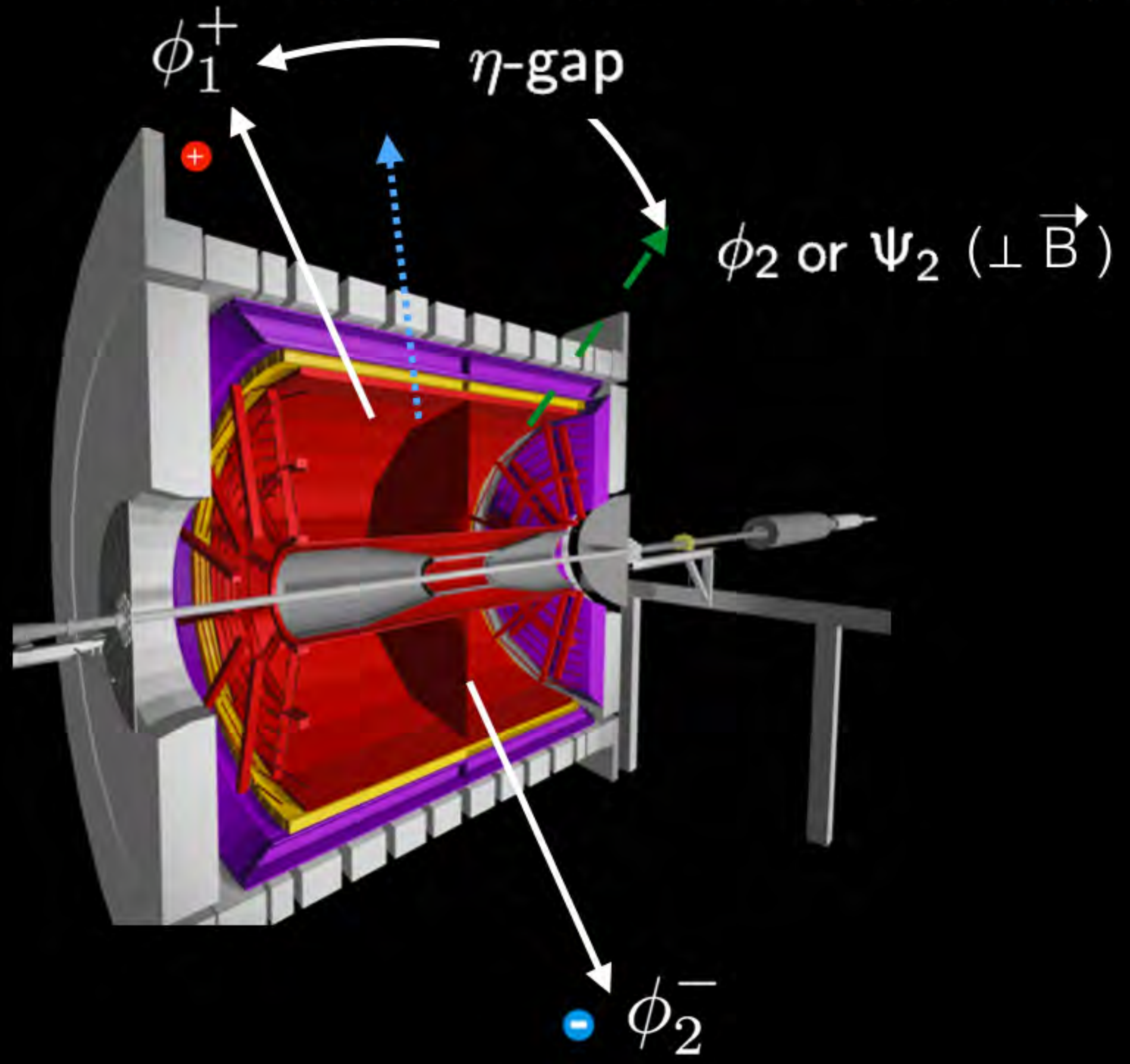


v_2 studied η-gap, ratio deviates from unity indicating difference in the shape, nuclear structure between two isobars (larger quadruple deformation in Ru+Ru)

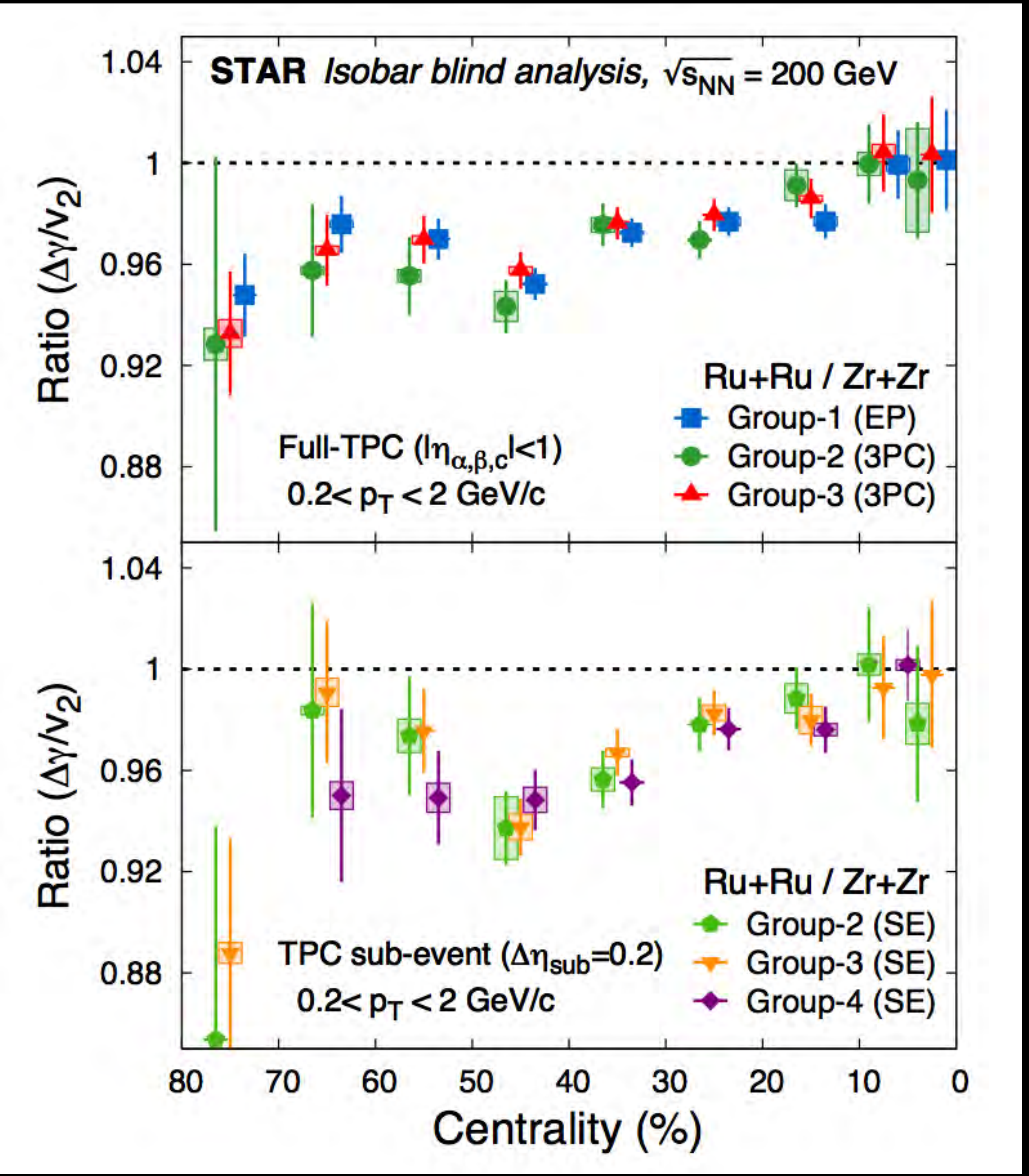
CME sensitive observables

Charge separation scaled by elliptic flow

$$\gamma_{112}\{\mathrm{EP}\} = \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_2^{\mathrm{TPC}}) \rangle$$



$$\frac{(\Delta\gamma/v_2)_{\mathrm{Ru+Ru}}}{(\Delta\gamma/v_2)_{\mathrm{Zr+Zr}}} \approx 1 + \underset{\substack{\uparrow \\ \text{Unknown}}}{f_{\mathrm{CME}}^{\mathrm{Zr+Zr}}} \underbrace{[(B_{\mathrm{Ru+Ru}}/B_{\mathrm{Zr+Zr}})^2 - 1]}_{0.18}$$



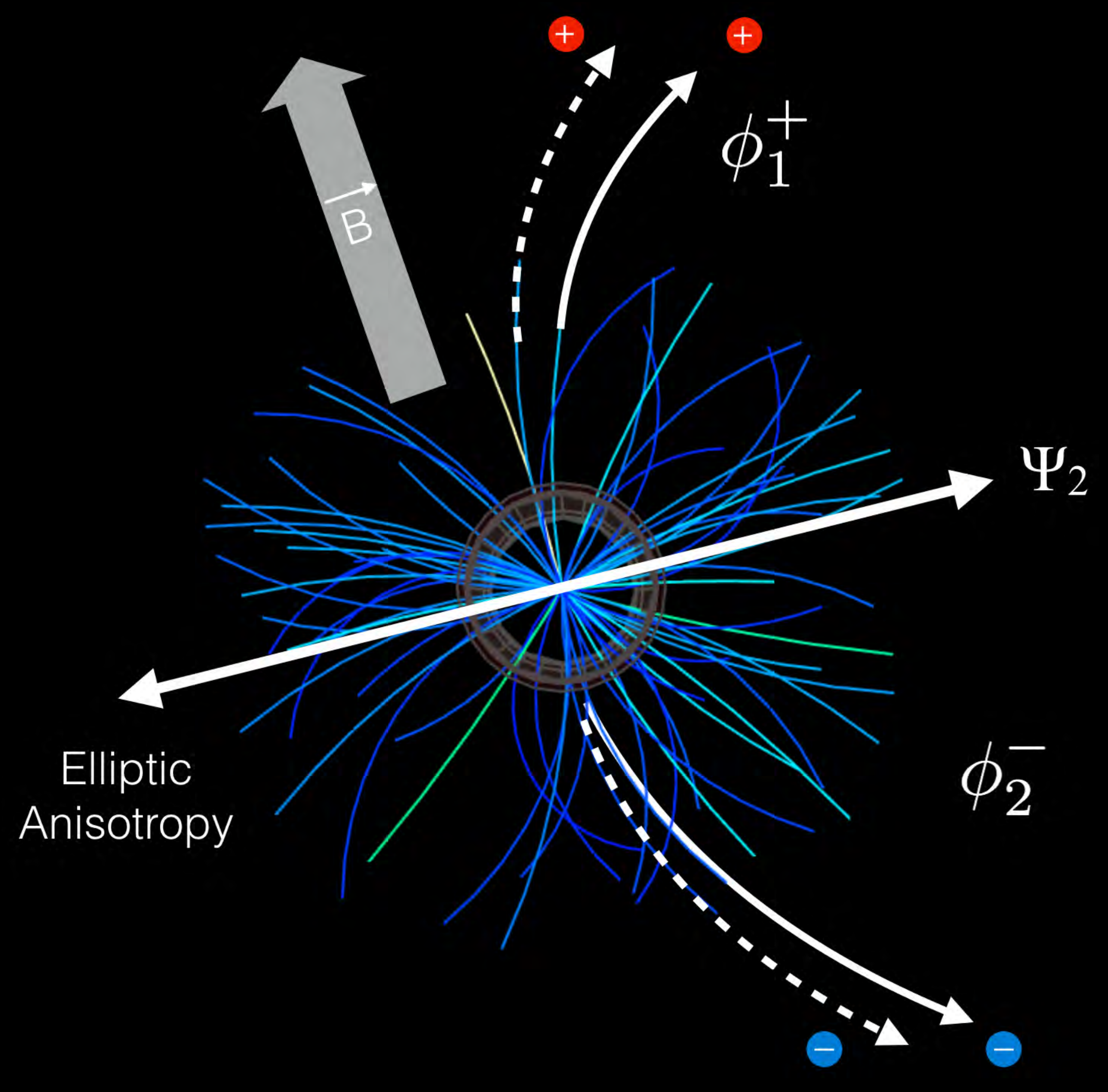
Pre-defined criteria for CME

$$\frac{(\Delta\gamma/v_2)_{\mathrm{RuRu}}}{(\Delta\gamma/v_2)_{\mathrm{ZrZr}}} > 1$$

NOT seen!!

Experimental baseline-2: Randomize correlation with B-field

B-field is correlated to Ψ_2 plane



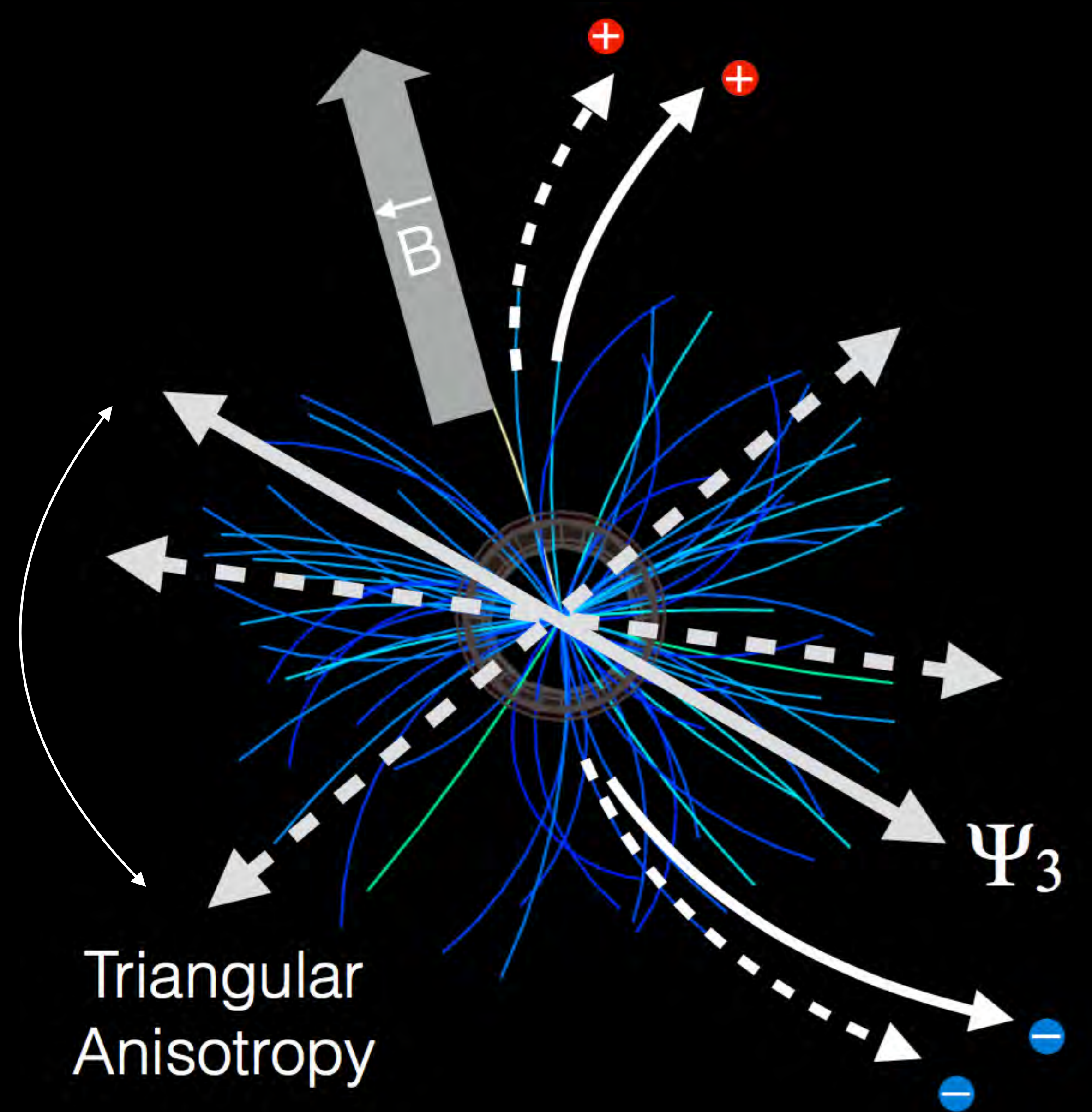
$$\gamma_{112} = \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_2) \rangle$$

Signal (B-field) + Background ($\propto v_2$)

Old criterion for CME:

$$\frac{(\Delta\gamma/v_2)_{\mathrm{RuRu}}}{(\Delta\gamma/v_2)_{\mathrm{ZrZr}}} > 1$$

B-field is not-corrected to Ψ_3 plane



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

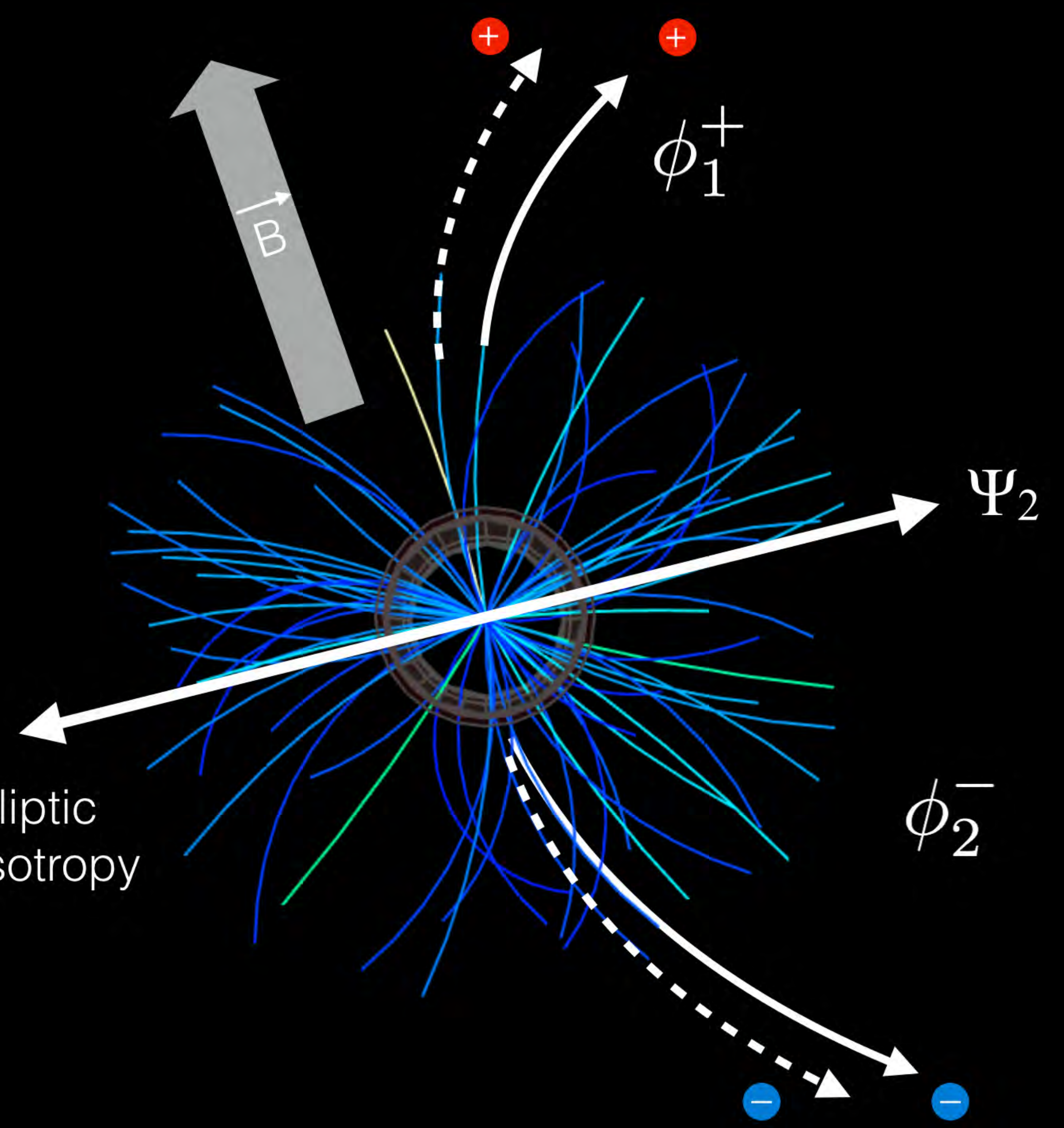
Background only ($\propto v_3$)

New criterion for CME:

$$\frac{(\Delta\gamma_{112}/v_2)^{RuRu}}{(\Delta\gamma_{112}/v_2)^{ZrZr}} > \frac{(\Delta\gamma_{123}/v_3)^{RuRu}}{(\Delta\gamma_{123}/v_3)^{ZrZr}}$$

Experimental baseline-1: Ignore B-field direction

Charge separation correlated to event plane



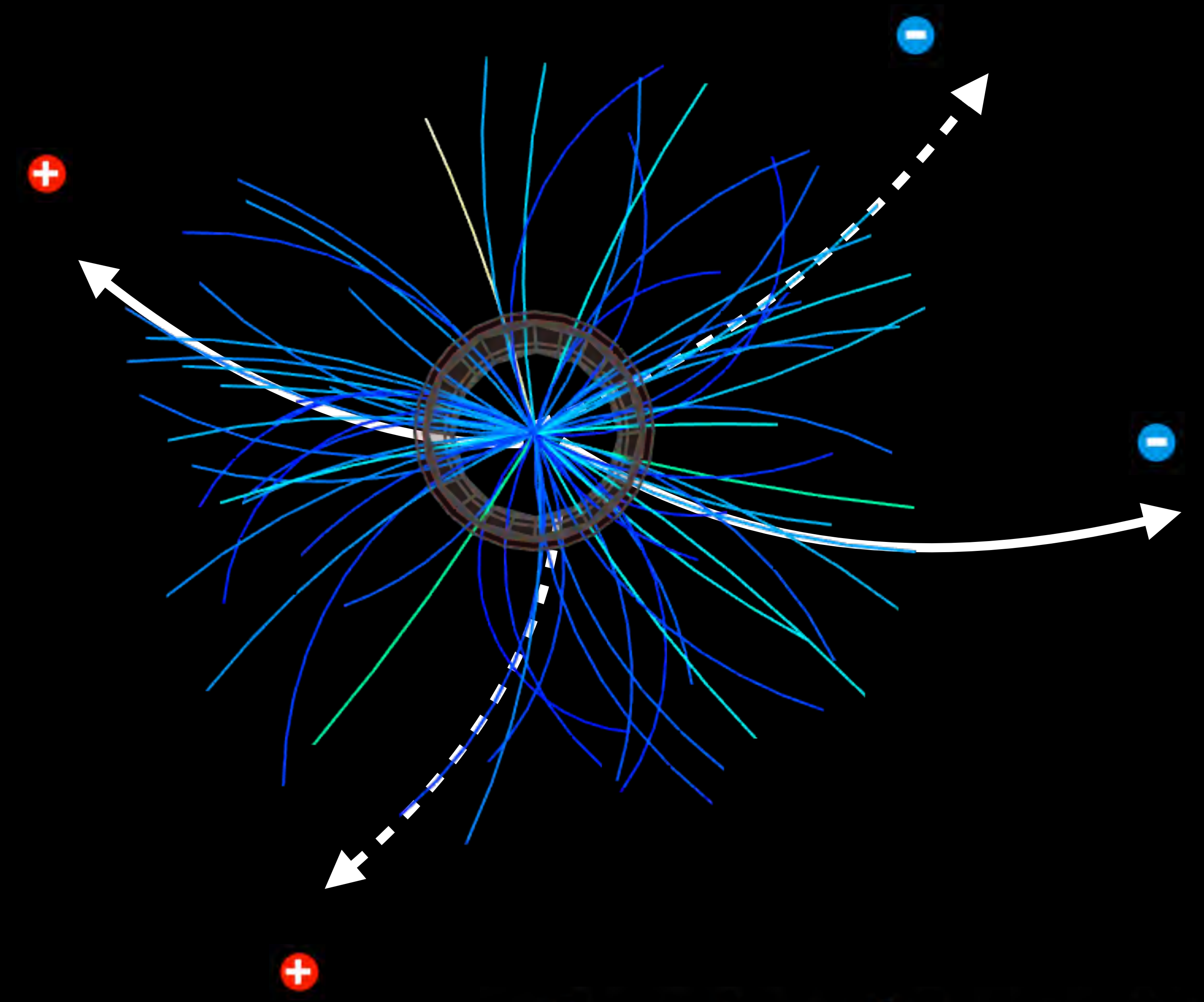
$$\frac{(\Delta\gamma/v_2)_{\mathrm{Ru+Ru}}}{(\Delta\gamma/v_2)_{\mathrm{Zr+Zr}}} \approx 1 + \underset{\substack{\uparrow \\ \text{Unknown}}}{f_{\mathrm{CME}}^{\mathrm{Zr+Zr}}} \underbrace{[(B_{\mathrm{Ru+Ru}}/B_{\mathrm{Zr+Zr}})^2 - 1]}_{0.18}$$

Old criterion for CME:

$$\frac{(\Delta\gamma/v_2)_{\mathrm{RuRu}}}{(\Delta\gamma/v_2)_{\mathrm{ZrZr}}} > 1$$

$\Longleftrightarrow$

Charge separation NOT correlated to event plane



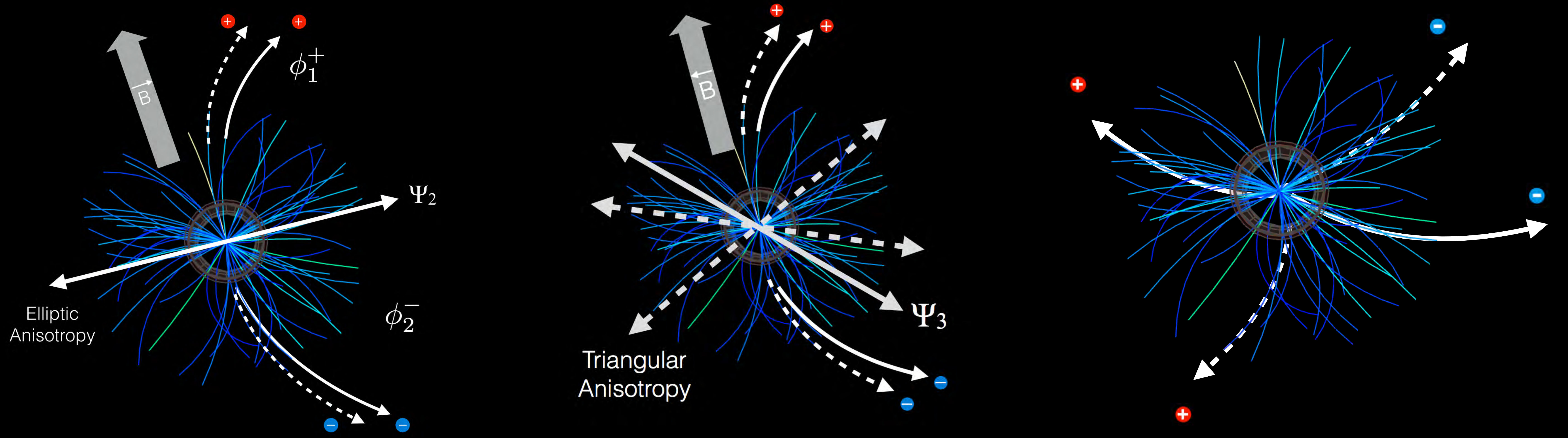
$$\delta \equiv \langle \cos(\phi_\alpha - \phi_\beta) \rangle$$

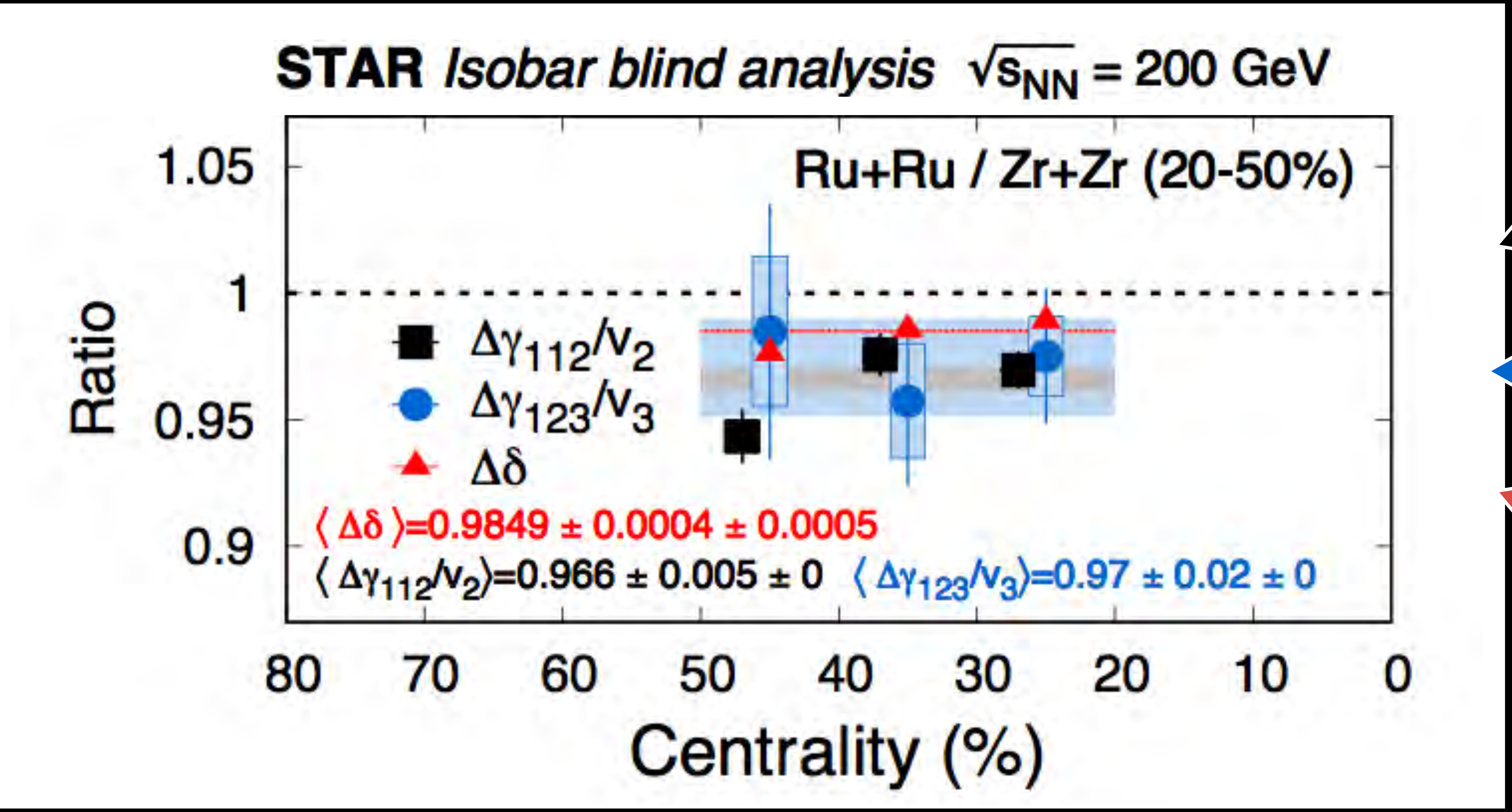
$$\Delta\delta = \delta(OS) - \delta(SS)$$

New criterion for CME:

$$\frac{(\Delta\gamma/v_2)_{\mathrm{RuRu}}}{(\Delta\gamma/v_2)_{\mathrm{ZrZr}}} > \frac{(\Delta\delta)_{\mathrm{RuRu}}}{(\Delta\delta)_{\mathrm{ZrZr}}}$$

Baseline measurement to put further constraints





$$\frac{(\Delta\gamma/v_2)_{\mathrm{RuRu}}}{(\Delta\gamma/v_2)_{\mathrm{ZrZr}}} > 1$$

Black above unity

$$\frac{(\Delta\gamma_{112}/v_2)^{RuRu}}{(\Delta\gamma_{112}/v_2)^{ZrZr}} > \frac{(\Delta\gamma_{123}/v_3)^{RuRu}}{(\Delta\gamma_{123}/v_3)^{ZrZr}}$$

Black above blue

$$\frac{(\Delta\gamma/v_2)_{\mathrm{RuRu}}}{(\Delta\gamma/v_2)_{\mathrm{ZrZr}}} > \frac{(\Delta\delta)_{\mathrm{RuRu}}}{(\Delta\delta)_{\mathrm{ZrZr}}}$$

Black above red

Data not compatible with any of the pre-defined CME signatures!!

Challenges to pre-defined CME baseline and upper limit

Limited Post-blind analysis: modified CME baseline

Challenge: Multiplicity turned out to be different for the two isobar, was not know before blind analysis, dilution of signal & background ~ 1/multiplicity, this effect is different for two species

Blind analysis criterion for CME: $\frac{(\Delta\gamma/v_2)_{\mathrm{RuRu}}}{(\Delta\gamma/v_2)_{\mathrm{ZrZr}}} > 1$

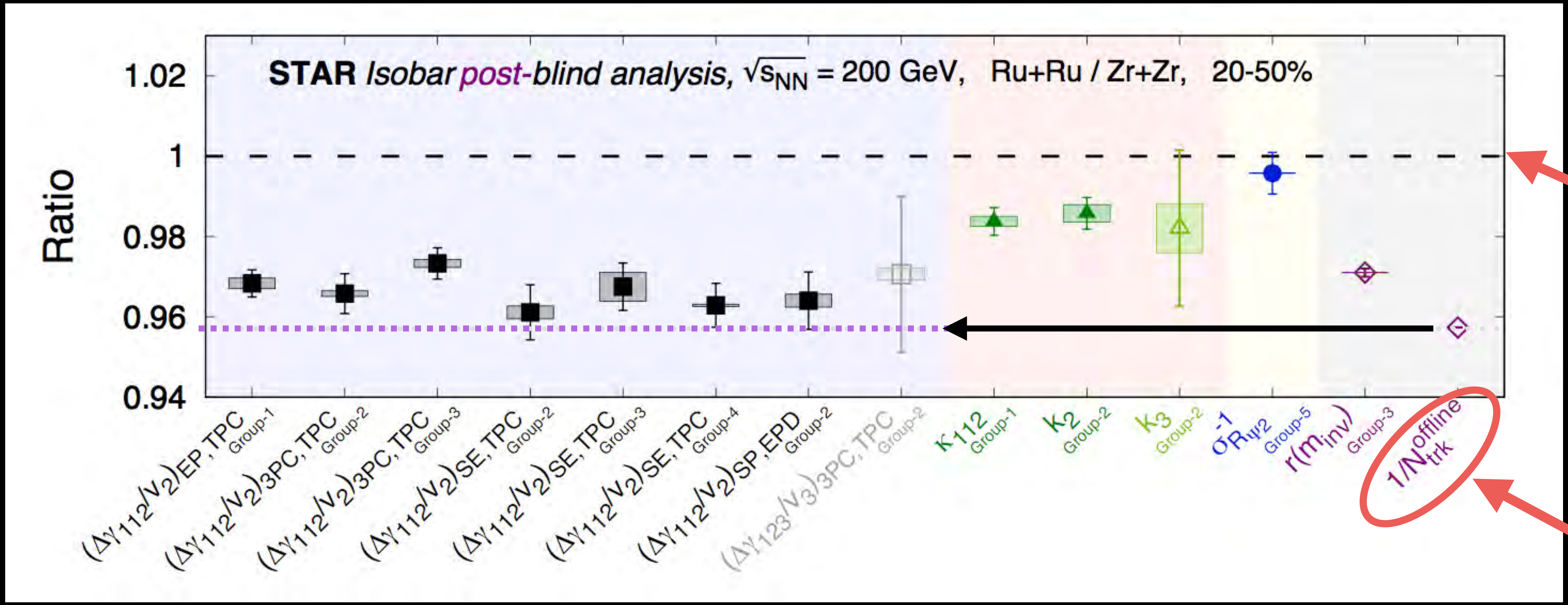
$$\Delta\gamma^{\text{Ru+Ru}} = \Delta\gamma^{CME} + k \times \frac{v_2}{N}$$

?? $\qquad \nparallel \qquad \wr\wr$

$$\Delta\gamma^{\text{Zr+Zr}} = \Delta\gamma^{CME} + k \times \frac{v_2}{N}$$

Post-blinding criterion for CME:

$$\frac{(\Delta\gamma/v_2)_{\mathrm{RuRu}}}{(\Delta\gamma/v_2)_{\mathrm{ZrZr}}} > \frac{(1/N_{\mathrm{ch}})_{\mathrm{RuRu}}}{(1/N_{\mathrm{ch}})_{\mathrm{ZrZr}}}$$



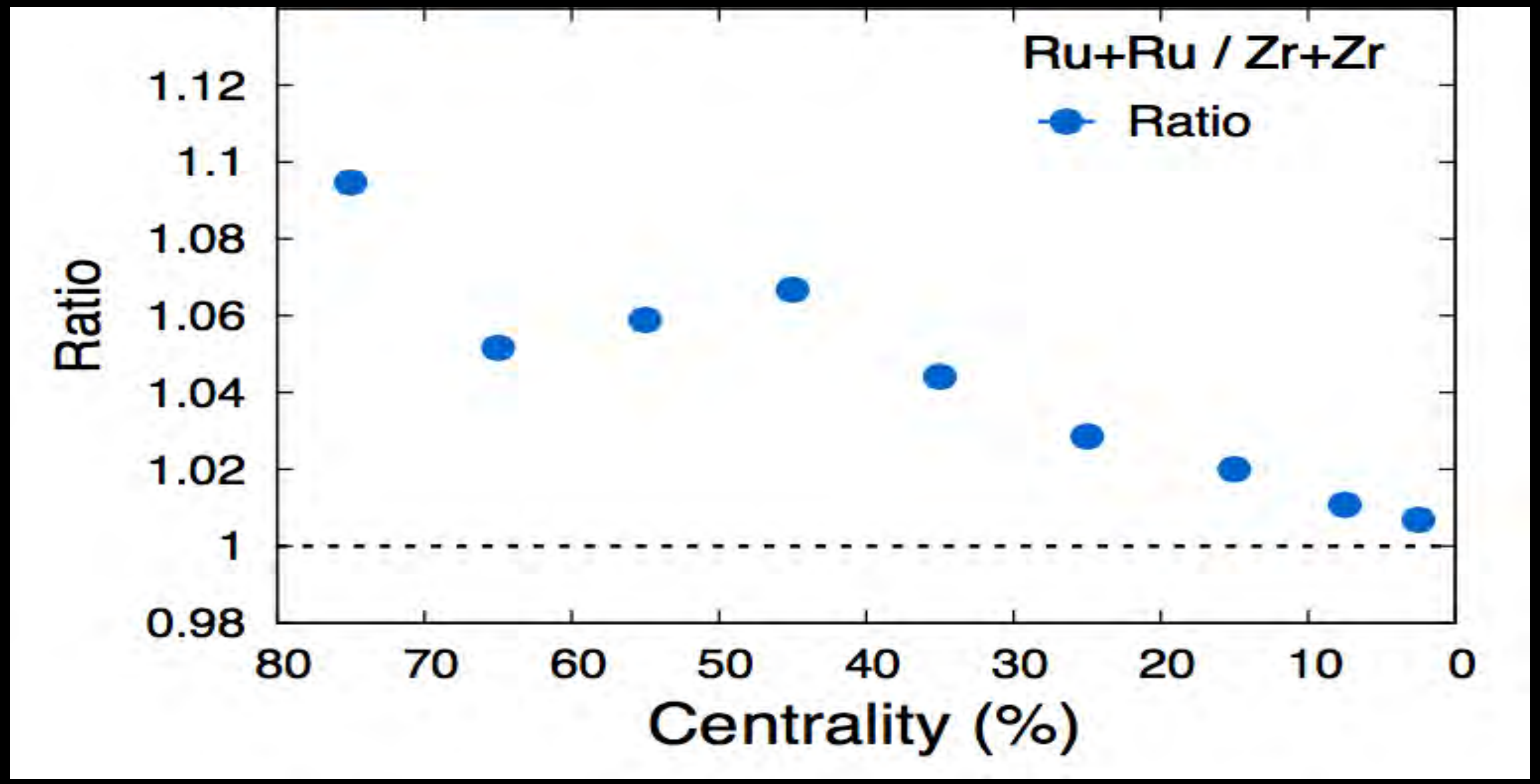
Blind analysis baseline

Post-blinding modified baseline

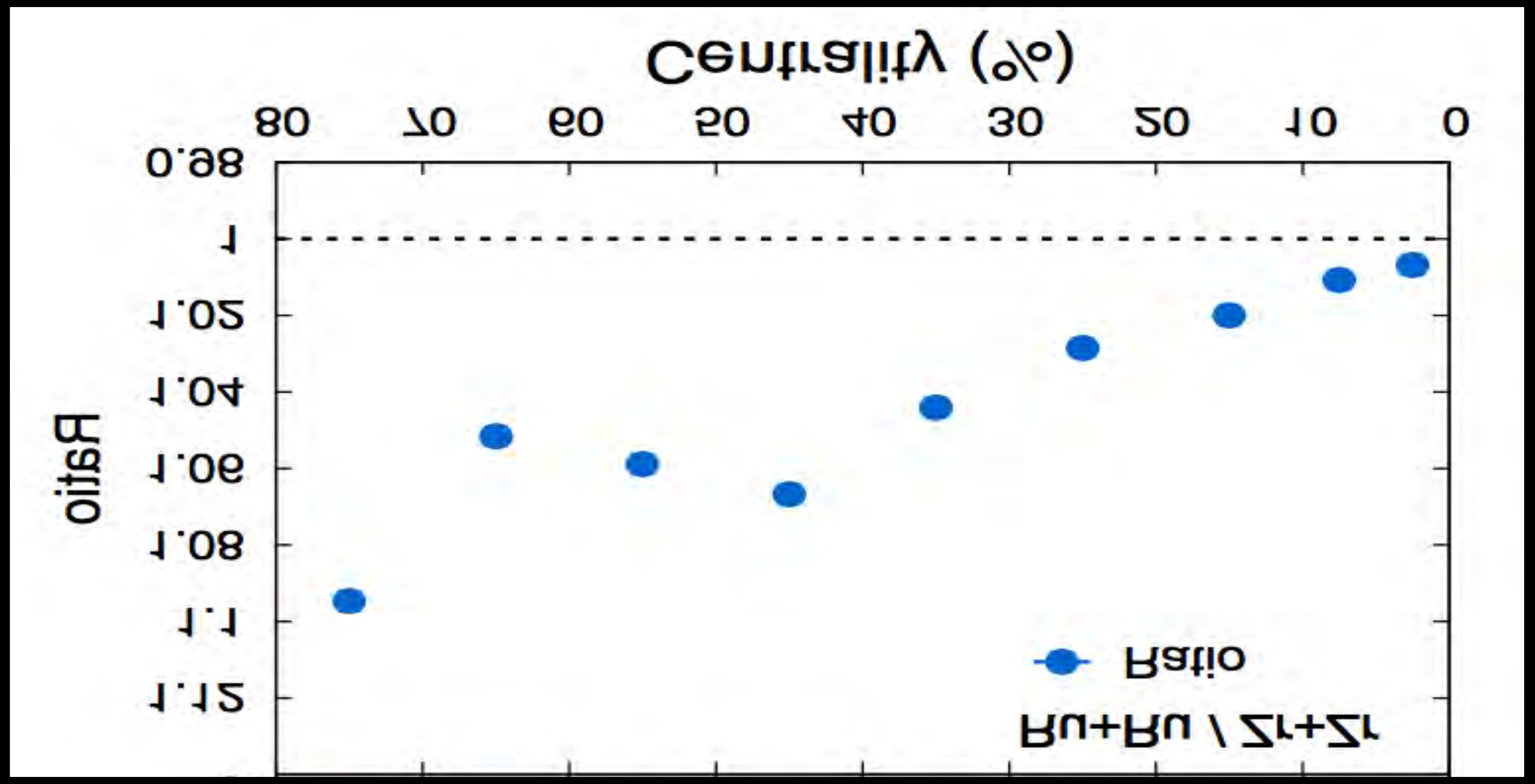
Limited Post-blind analysis: modified CME baseline

$$\frac{(N_{\mathrm{ch}})_{\mathrm{RuRu}}}{(N_{\mathrm{ch}})_{\mathrm{ZrZr}}}$$

Multiplicity is larger in Ru+Ru



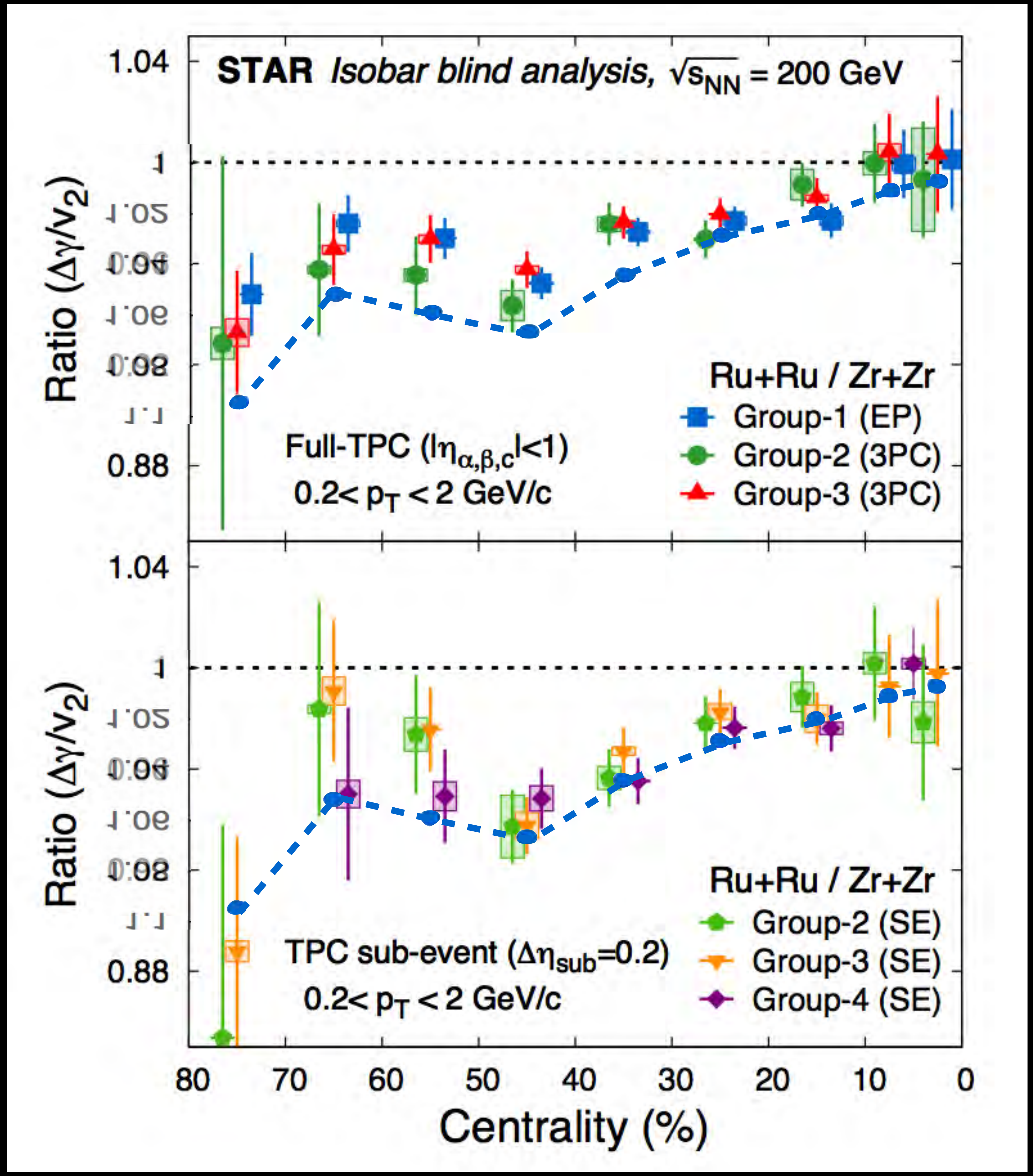
Flip



overlay

Change of baseline from "1" to 1/multiplicity

$$\frac{(\Delta\gamma/v_2)_{\mathrm{Ru+Ru}}}{(\Delta\gamma/v_2)_{\mathrm{Zr+Zr}}} \leftrightarrow \frac{N_{\mathrm{Zr+Zr}}}{N_{\mathrm{Ru+Ru}}}$$



Dilution ~ 1/multiplicity is more in Ru+Ru

$$\frac{(1/N_{\mathrm{ch}})_{\mathrm{RuRu}}}{(1/N_{\mathrm{ch}})_{\mathrm{ZrZr}}}$$

Investigation is on to extract a CME upper-limit

Summary

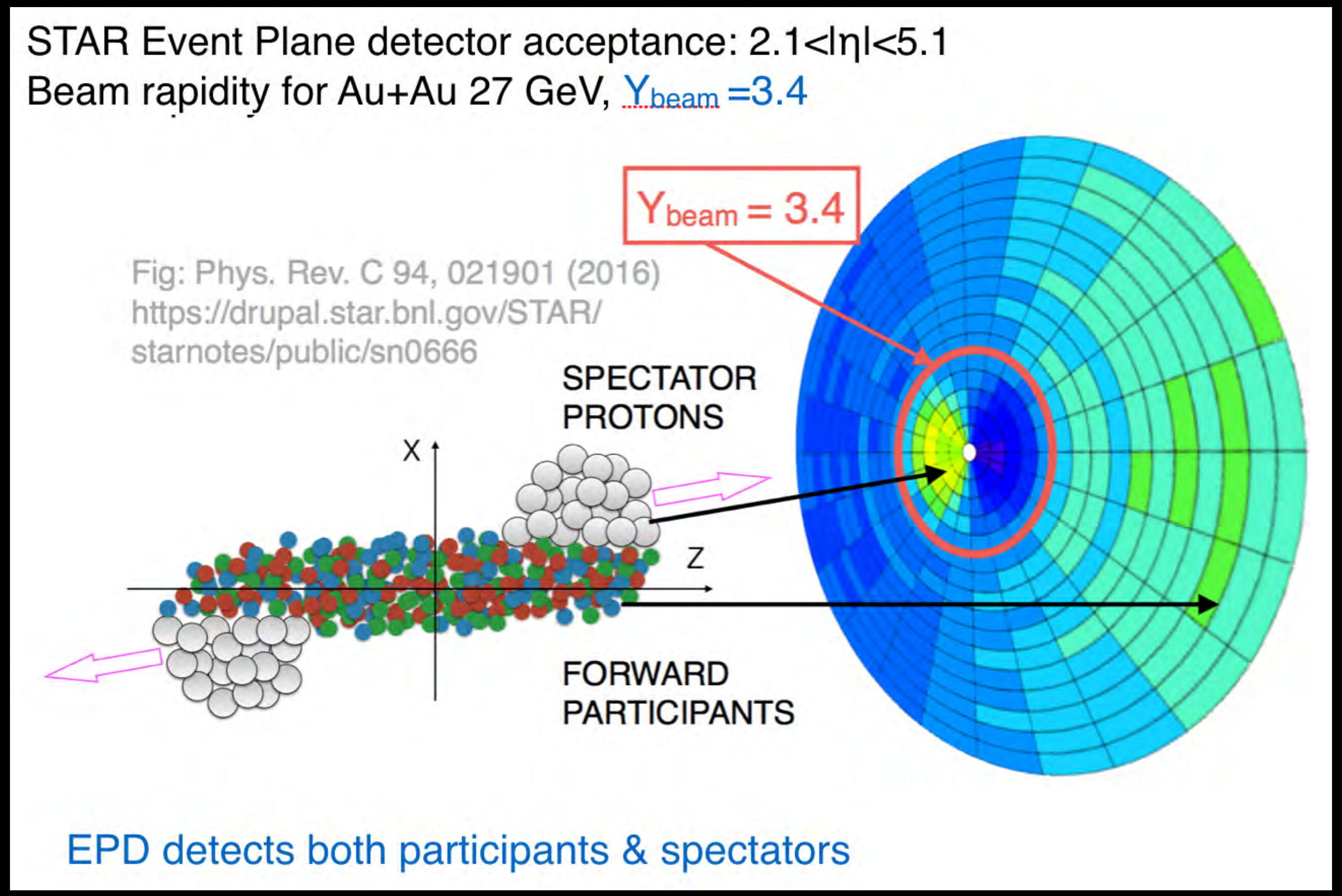
Experimental test of CME in isobar collisions performed using a blind analysis

A precision down to 0.4% achieved but no pre-defined signature of CME is observed

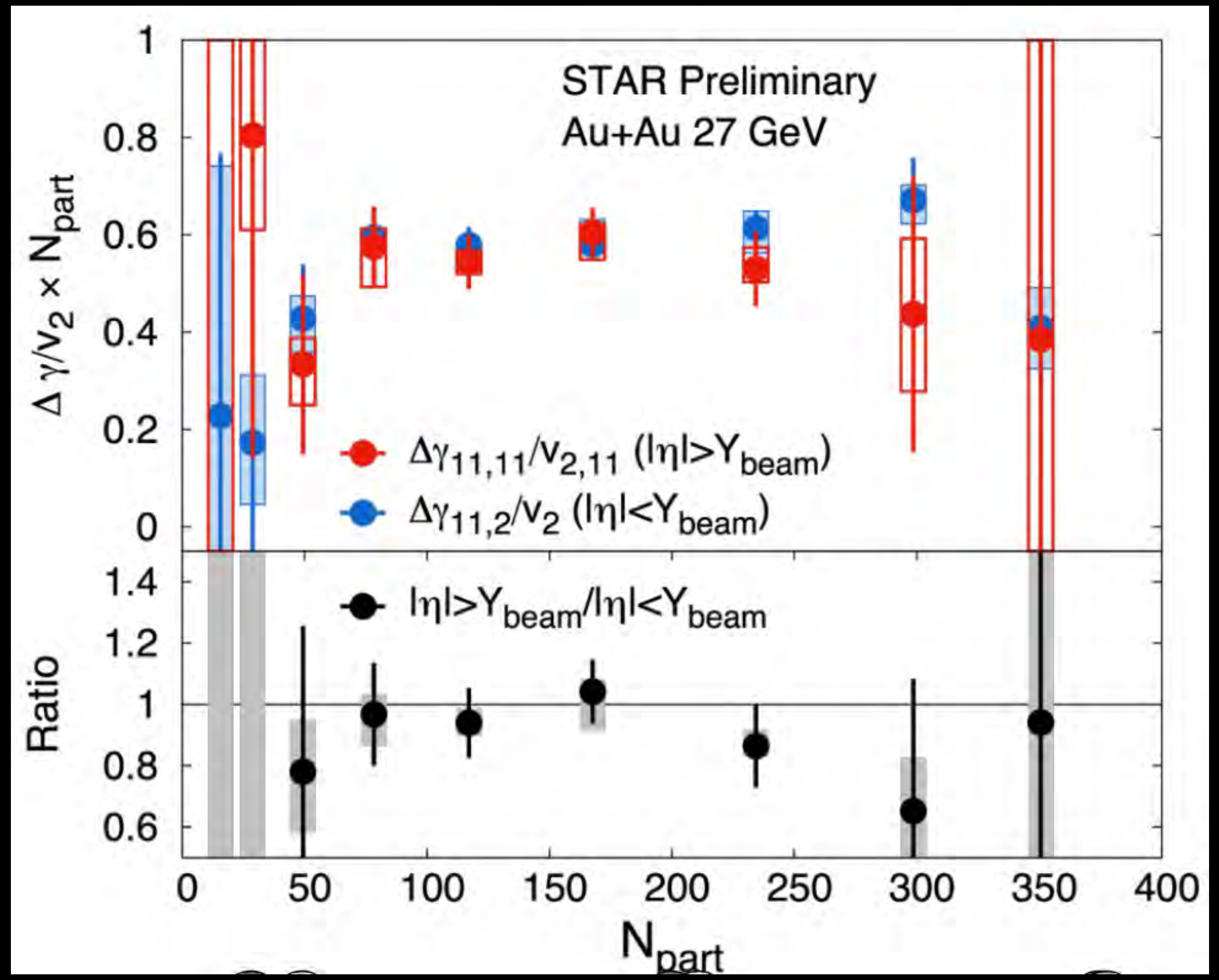
Primary CME observable $\Delta\gamma/v_2$ baseline is affected by the multiplicity difference (4% in 20-50%), post-blind analysis is needed to search for residual CME signal

CME search has been narrowed down, future program will look for upper limit (1% level)

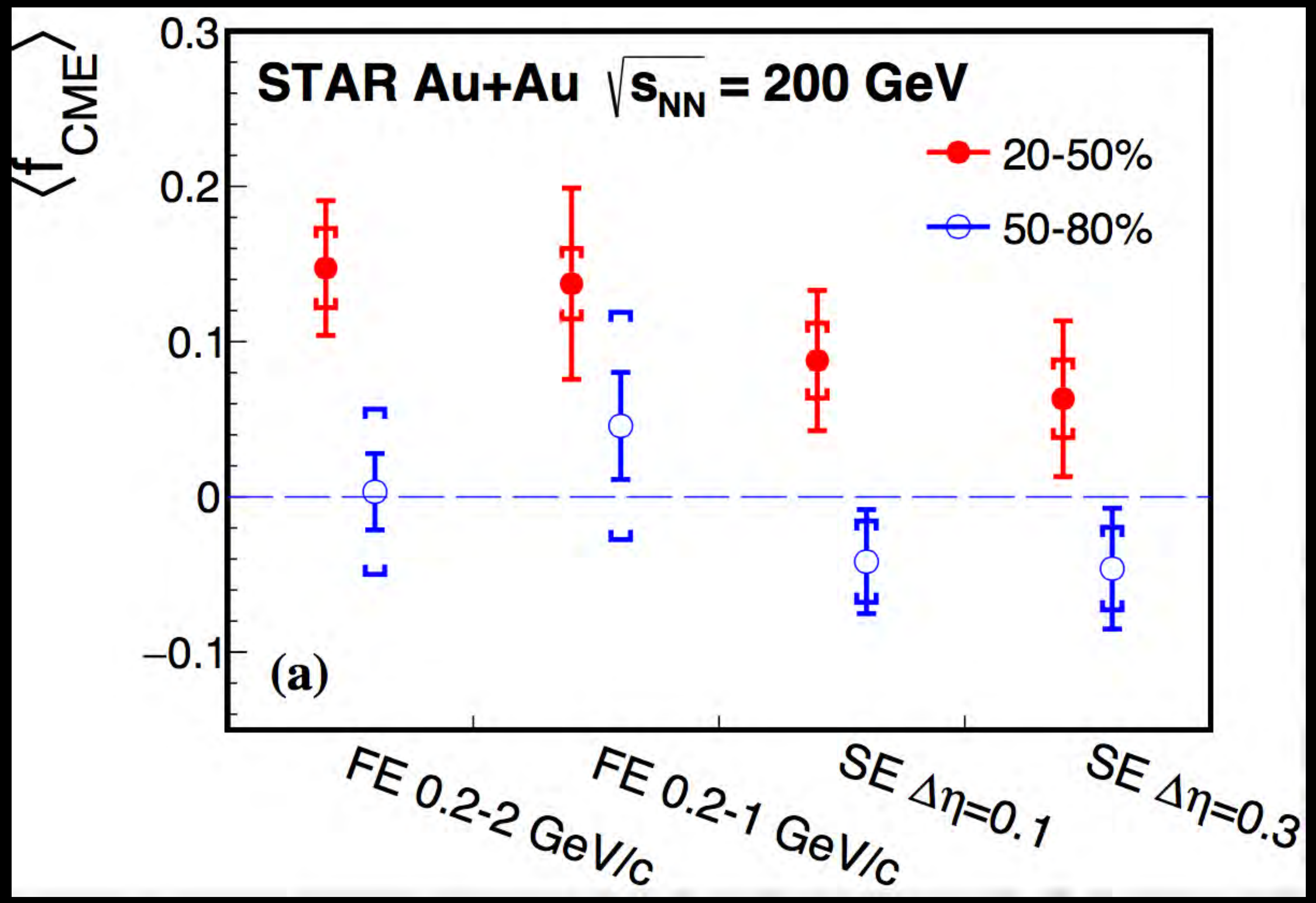
Better detector to determine B direction



RHIC energy scan for CME search



2023 High statistics Au+Au run



Thank You