Report on the CME Task Force

The following slides are based on the work of the task force
Composition of the Task Force

Chairs:
Paul Sorensen
Vladimir Skokov

Members:
Volker Koch
Soeren Schlichting
Jim Thomas
Sergei Voloshin
Gang Wang
Ho-Ung Yee

Ex Officio:
Berndt Mueller
Based on the suggestion of the 2015 RHIC Program Advisory Committee, BNL ALD Berndt Mueller formed a task force with the following charge:

“Given the significant new advances since the original measurements, and given that the RHIC heavy ion program has a limited number of years remaining to make relevant measurements, it is now urgent to reevaluate the status of our understanding of the evidence for or against the observation of the chiral magnetic effect in heavy ion collisions and to identify specific crucial measurements that can help clarify whether strong parity violation has been observed in heavy ion collisions. The RHIC Program Advisory Committee has recommended the formation of a working group to

1) provide a critical assessment of the present state of understanding,
2) map out a strategy for how best to use the present suite of measurements (perhaps supplemented by other information that can be drawn from data already on-tape) to address open questions of interpretation, and
3) to investigate whether there are other measurements that can be performed at RHIC (such as running with nuclear isobars as suggested by STAR) to help resolve open questions.”
Run time at RHIC is limited.

Opportunities to accommodate proposals for new collision species like nuclear isobars are limited

2017 may be the last opportunity

But running time is precious, resources are limited, so any proposal needs a strong motivation
Assessment of Present Understanding

Uncertainties (particularly in the size and duration of the B-field) lead to orders-of-magnitude uncertainty in expectations for charge separation from CME.

Several measurements and model calculations are suggestive of large contributions from background: measurements could be entirely from background.

On the other hand, a wide range of measurements continue to accumulate that fall in line with basic expectations.

Given this, progress seems to require:
- Advances in anomalous hydro to realistically assess expectations
- A better understanding of the magnitude of the B-field
- A way to determine what portion of the signal is related to the B-field
Assessment of Present Understanding

For example: studies of the balance function vs the reaction plane compared to models of charge conservation at freezeout suggest the signal may be completely from background.

Charge conservation at freeze-out boundary

Charge pairs with collimation from reaction plane dependent boost

Assessment of Present Understanding

But, realistic expectations of CME may look very similar to background models.

CME in flowing background, add fluctuations, noise, etc. We shouldn’t count on expectations from simplistic cartoons which are inevitably found to be too simple.

Theory advances will help but depend on assumptions about the B-field.

Strategy to Address Questions of Interpretation

What can and should be done?

1) More analyses can be performed on the data (are they likely to prove decisive?)
   -new analyses should be shown to be interpretable, better than previous methods, and/or to provide truly new information
   -conclusions based on semi-qualitative arguments should be avoided
   -charge dependent $<\cos(m\varphi_1+n\varphi_2-(m+n)\varphi_3)>$ measurements can be extended to higher $m,n$.
   -particularly in U+U, event shape engineering and geometry engineering using ZDC’s can be further explored
   -adding particle identification to measurements

2) Are theory/model advances likely to lead to a resolution?
   Given the complexity of the problem, this seems unclear.

3) Will a study with nuclear isobars help?
   see following slides
Evaluation of Running with Nuclear Isobars

Isobars: nuclei with the same mass number but different charge

Stable isobar pairs with $\Delta Z=4$ and natural abundance $> 0$

- $^{96}_{40}Zr + ^{96}_{40}Zr$ vs. $^{96}_{44}Ru + ^{96}_{44}Ru$ preferred by CAD
- $^{124}_{50}Sn + ^{124}_{50}Sn$ vs. $^{124}_{54}Xe + ^{124}_{54}Xe$ not promising
- $^{130}_{52}Te + ^{130}_{52}Te$ vs. $^{130}_{56}Ba + ^{130}_{56}Ba$ still possible
- $^{136}_{54}Xe + ^{136}_{54}Xe$ vs. $^{136}_{58}Ce + ^{136}_{58}Ce$ not promising

Would make it possible to change the B-field about 20% while most other variables are fixed. But,

- how well do we understand the magnetic field?
- how well do we understand the effect of the nuclear geometry?
- how discerning will the measurements be?
Evaluation of Running with Nuclear Isobars

Calculations and measurements of deformations disagree

\[ \beta_2(^{96}\text{Zr}) = 0.080 \] (electron scattering) \[ \beta_2(^{96}\text{Ru}) = 0.158 \] (electron scattering)

\[ \beta_2(^{96}\text{Zr}) = 0.217 \] (model calculation) \[ \beta_2(^{96}\text{Ru}) = 0.053 \] (model calculation)

For deformed nuclei and finite sized nucleons, parameters can’t be blindly plugged in to Woods-Saxon distribution


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Evaluation of Running with Nuclear Isobars

Magnetic Field Calculations Revisited (Skokov):
- $B$ integrated over 1fm spot centered at most dense region
- Centrality intervals based on number of produced particles
- $B$ calculated at $t=0$
- Point like protons

The strength of the field remains proportional to $Z$

For centralities of interest, the strength of the field is independent of $\beta_2$.
Evaluation of Running with Nuclear Isobar

How discerning will the measurements be (Wang)?

Parameterize observed charge separation vs CME expectation

Use parameterization to convert CME calculation to expected signal for Ru+Ru and Zr+Zr

Note: charge separation from CME is expected to go as $(eB)^2 \cos[2(\psi_B - \psi_{RP})]$
Evaluation of Running with Nuclear Isobar

How discerning will the measurements be (G. Wang)?

expected signal from parameterization and model calculations (0% background)

assume $\Delta \gamma \propto x^*\text{background} + (x-1)^*\text{CME}$
calculate how well the CME part of the signal can be measured

If the background* contribution to $\Delta \gamma$ is less than 70% (88%) the CME contribution to $\Delta \gamma$ will be determined with a significance better than 5$\sigma$ (2$\sigma$)

Assuming that currently the background could be anywhere from 0% to 100%, an isobar run could reduce the 2$\sigma$ uncertainty band on the CME effect by a factor of ~10.

*assuming the background is independent of the magnetic field
Tentative Comments

There remain analyses likely to provide some help in clarifying the relevance of CME, but *no analysis appears likely to be decisive*.

If realistic models of CME effects look too similar to backgrounds, reliable handles on the effect of the B-field may prove crucial.

Uncertainty in the duration of the B-field will probably remain a *key challenge* to making reliable predictions for the CME effect.

So far, the *isobar program looks promising*: as long as the isotopes can be acquired there seem to be no showstoppers.

We are open to your input and guidance.