Triangular Flow and Nonflow by 2-, 4-, and 6-Particle Cumulants from STAR

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Abstract Triangular flow (v_3) can arise from event-by-event fluctuations. Its connection to fluctuations in the initial state collision geometry may reveal hydrodynamic information of the collision system. Theoretical studies suggest its sensitivity to hydrodynamic evolution may even be stronger than elliptic flow (v_2). We present v_3 measurement by the 2-, 4-, and 6-particle cumulant method at $\sqrt{s_{NN}}$ = 200 GeV in Au+Au collisions by STAR. We compare our v_3 results to v_2, also from the multi-particle cumulant method. The 2-particle cumulant result contains nonflow contribution. We assess the nonflow effect by separating charges as well as applying a pseudo-rapidity gap. The 4- and 6-particle v_3 results are strongly affected (perhaps dominated) by v_3 fluctuations. Assuming Gaussian flow fluctuation, we further attempt to distinguish flow, flow fluctuation, and nonflow.

Introduction

Azimuthal distributions of hadrons produced in non- central heavy-ion collisions are anisotropic:

$$dN/d\phi \propto 1+\sum_{n=1}^{\infty} 2v_n \cos(n(\phi-\Psi_{nR}))$$

Coefficients v_n quantify the azimuthal anisotropies of different harmonics. The three lowest harmonics are called directed (v_1), elliptic (v_2), triangular (v_3) flow.

Hydrodynamic flows are important to measure because they reflect the equation of state of the related system. However, because the reaction plane is not known, experiments use particle azimuthal correlations (including the event-plane method) to measure the anisotropies. What's measured contains flow, flow fluctuation and nonflow.

Flow is many-body correlation. Meanwhile, nonflow is few-body correlation. It may be possible to determine the three quantities by the additional information of six-particle azimuthal moment.

The Cumulant Method

Azimuthal moments: $\langle 2\rangle_n = \left\langle e^{in(\phi_i-\phi_j)}\right\rangle = v_n^2+\delta_n$ (δ_n is nonflow)

$$\langle 4\rangle_n = \left\langle e^{in(\phi_i+\phi_j-\phi_k-\phi_l)}\right\rangle \approx v_n^4+4v_n^2\delta_n+2\delta_n^2$$

$$\langle 6\rangle_n = \left\langle e^{in(\phi_i+\phi_j+\phi_k-\phi_l-\phi_m-\phi_n)}\right\rangle \approx v_n^6+9v_n^4\delta_n+18v_n^2\delta_n^2+6\delta_n^3$$

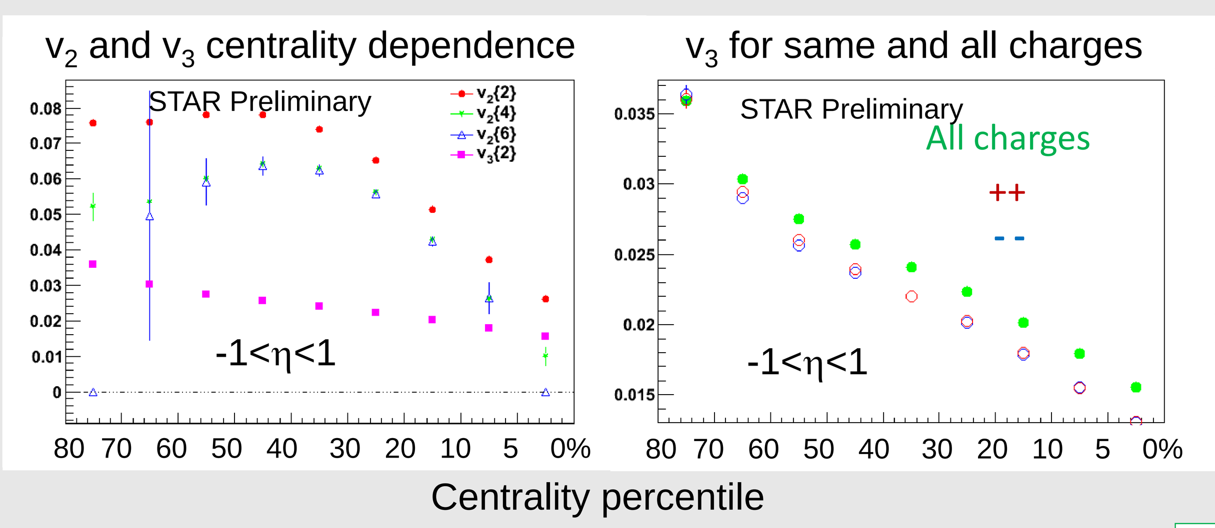
2-, 4-, 6-particle flow: $v_n\{2\}^2 \equiv \langle\langle 2\rangle\rangle_n$ (n = 3 for triangular flow)

$$v_n\{4\}^4 \equiv 2\langle\langle 2\rangle\rangle_n^2-\langle\langle 4\rangle\rangle_n$$

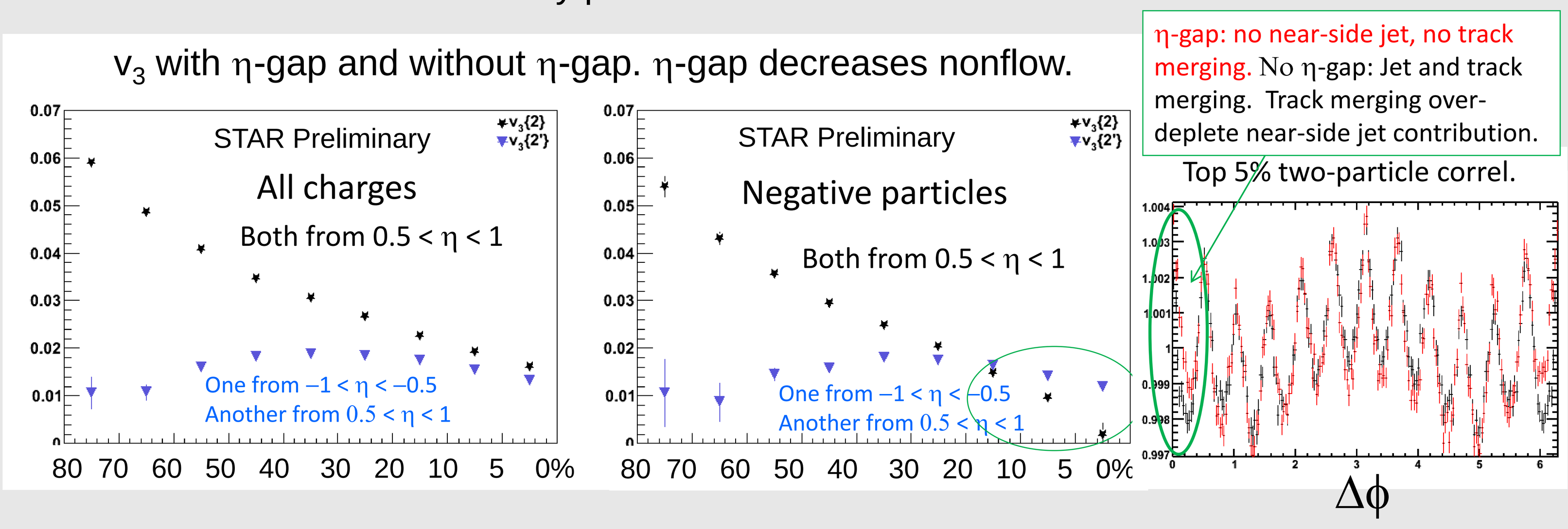
$$v_n\{6\}^6 \equiv \left(\langle\langle 6\rangle\rangle_n - 9\langle\langle 2\rangle\rangle_n\langle\langle 4\rangle\rangle_n + 12\langle\langle 2\rangle\rangle_n^3\right)/4$$

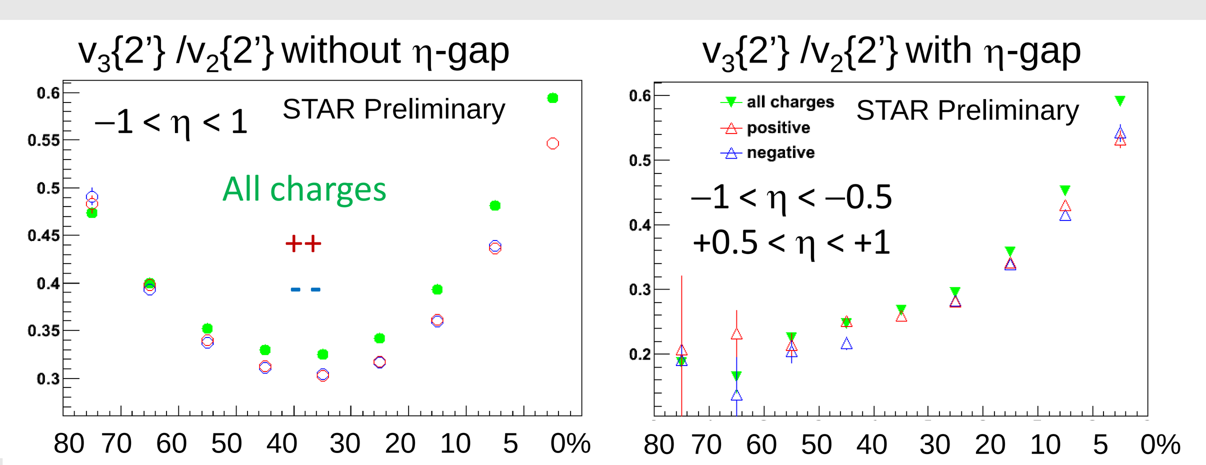
Average is weighted by number of particle combinations.
Q-cumulant method: Bilandzic, Snellings, Voloshin, PRC83, 044913 (2011).

Nonflow Effect



- Same charges 2-particle flow is smaller than all charges.
- Same charge correlation contains less nonflow.



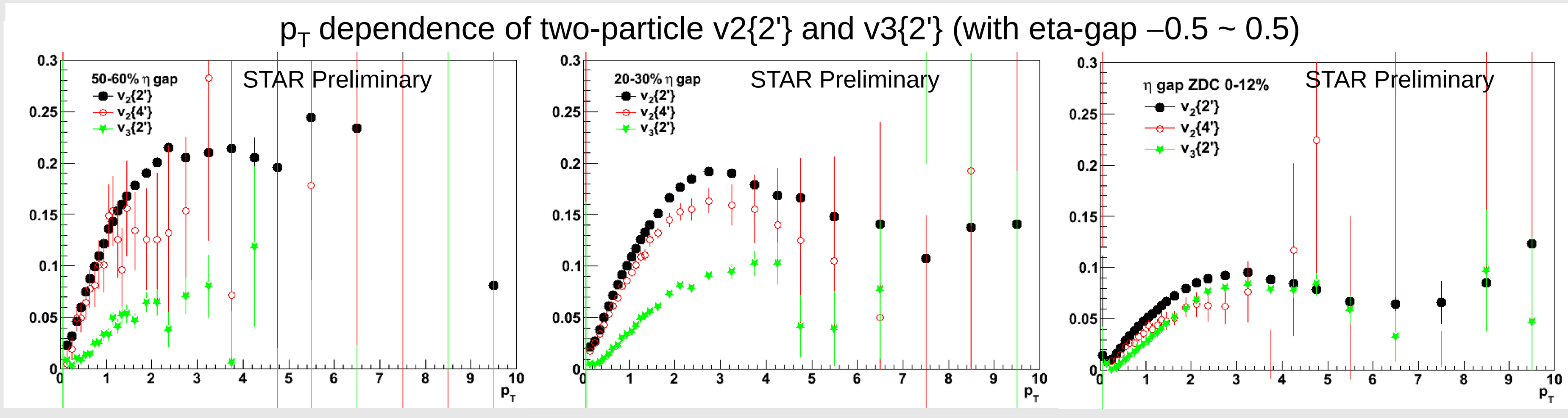


- η-gap removes near-side jet-like correlation nonflow.
- Nonflow effect on $v_3\{2'\}/v_2\{2'\}$ significant in peripheral collisions.

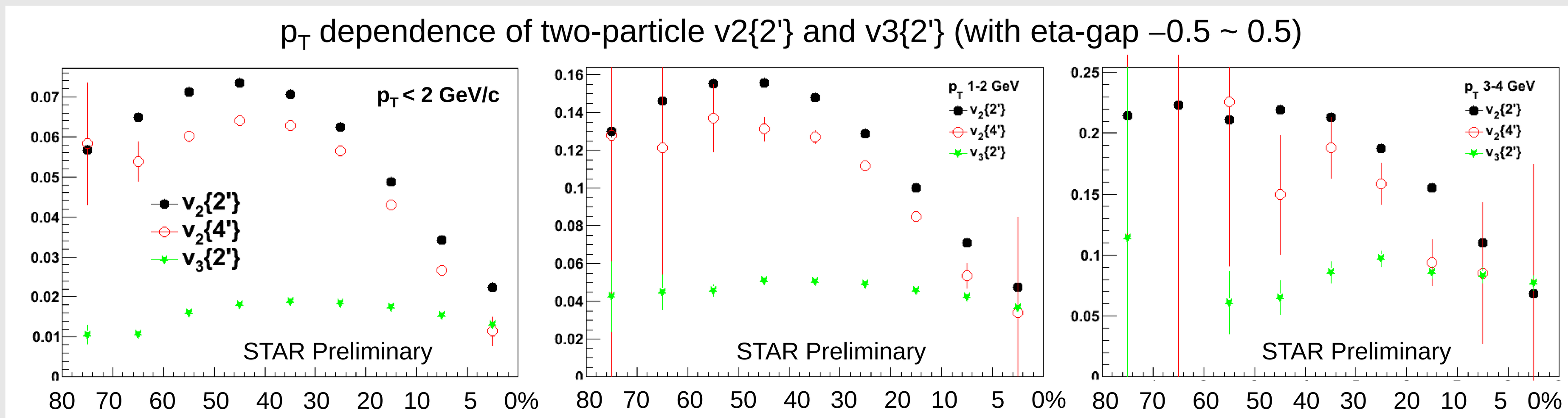
Results without η-gap contain significant nonflow from near-side jet-like correlations. η-gap largely removes this nonflow.

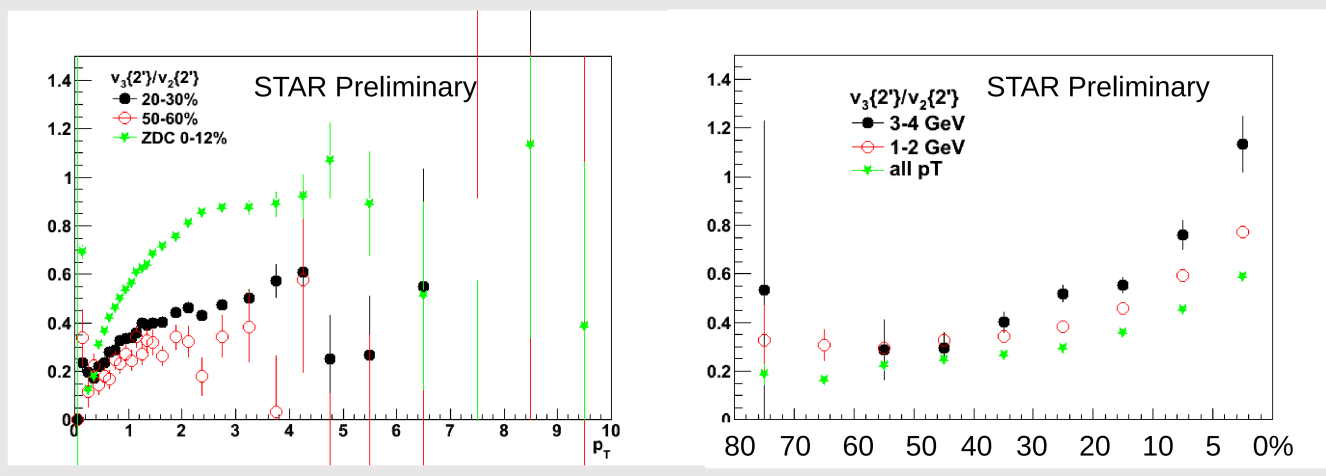
Results with η-Gap

p_T dependence of two-particle v2{2'} and v3{2'} (with eta-gap –0.5 ~ 0.5)



p_T dependence of two-particle v2{2'} and v3{2'} (with eta-gap –0.5 ~ 0.5)





Away-side jet nonflow cannot be removed by η-gap, and should still be present.

Attempt to Disentangle Flow, Fluctuation, Nonflow

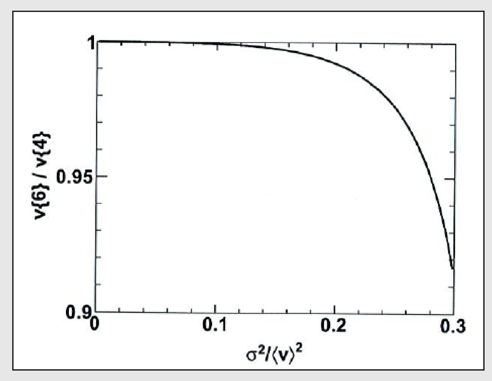
If the flow fluctuation is Gaussian in v_n: $\frac{dN}{dv_n} = \frac{1}{\sqrt{2\pi}\sigma_n}\exp[-\frac{(v_n-\langle v_n\rangle)^2}{2\sigma_n^2}]$

then the 2-, 4-, 6-particle flow can be rewritten as follows:

$$v_n\{2\}^2 \equiv \langle\langle 2\rangle\rangle_n = \langle v\rangle_n^2+\sigma_n^2+\delta_n$$

$$v_n\{4\}^4 \equiv 2\langle\langle 2\rangle\rangle_n^2-\langle\langle 4\rangle\rangle_n \approx \left(\langle v\rangle_n^2-\sigma_n^2\right)^2-2\sigma_n^4$$

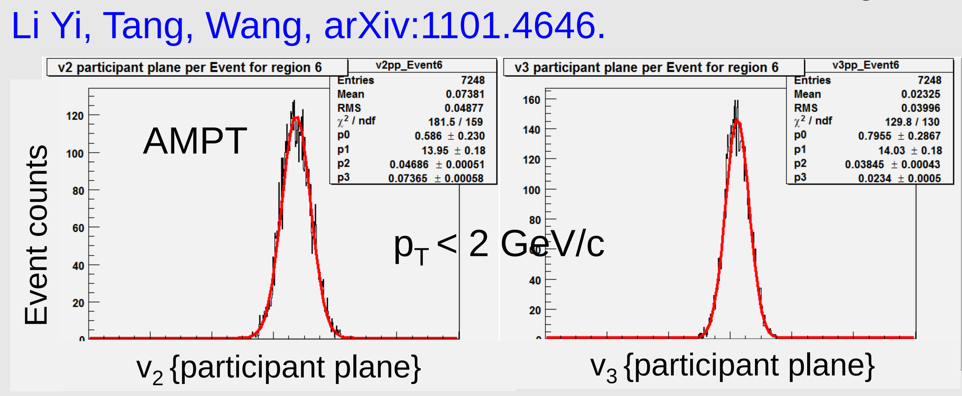
$$v_n\{6\}^6 \equiv \left(\langle\langle 6\rangle\rangle_n - 9\langle\langle 2\rangle\rangle_n\langle\langle 4\rangle\rangle_n + 12\langle\langle 2\rangle\rangle_n^3\right)/4 \approx \langle v\rangle_n^4\left(\langle v\rangle_n^2-3\sigma_n^2\right)$$



When flow fluctuation is small relatively to the average flow, 6- and 4-particle flows are approximately equal. Higher order harmonics do not provide new information. On the other hand, if flow fluctuation is large in respect to the average flow, 6-partcle flow differs from 4-particle flow with Gaussian ansatz.

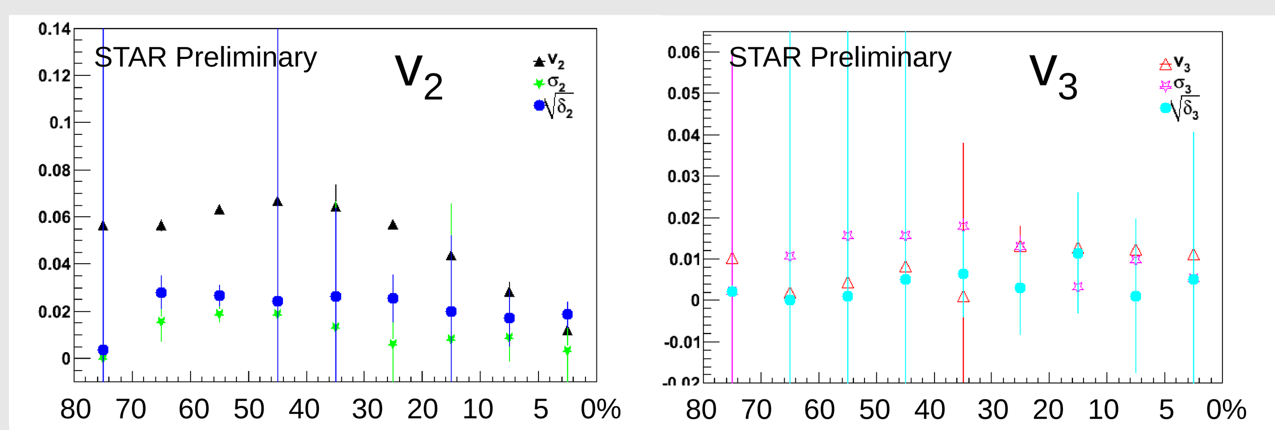
Odd harmonic anisotropic v_3 is dominated by fluctuation. The fluctuations and the averages are likely on the same order. It is, therefore, hopeful that the triangular flow, flow fluctuation, and nonflow can be disentangled by by 2-, 4-, 6-particle cumulant method. More detail: Li Yi, Tang, Wang, arXiv:1101.4646.

Is flow Gaussian in v_n? Not clear.
It is possible that flow is strictly proportional to initial eccentricity and the x and y components of the eccentricity are Gaussian. Then it is shown that higher order harmonics provide identical information as in $v_n\{4\}$ [S.A. Voloshin *et al*., Phys. Lett. B659, 537 (2008).]



v_2 and v_3 from AMPT are nearly Gaussian. However, they may be dominated by statistical fluctuations.

First Attempt of Disentangled Results



v_2 and v_3 with η-gap (–0.5 ~ 0.5). Min-Bias trigger data.

- Error bars are large.
- Analyzing more statistics.

Conclusions

- 2-, 4-, 6-particle cumulant flows are reported.
- η-gap largely removes near-side jet-like nonflow.
- Additional nonflow (e.g. away-side jet-like correlation) should still be present.
- Decomposition (with Gaussian flow fluctuation assumption) may be promising.

Also see STAR posters: Yadav Pandit #17, Jim Thomas #43.

The STAR Collaboration: http://drupal.star.bnl.gov/STAR/presentations

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