Multiplicity-dependent di-hadron correlations with identified leading hadrons in $\sqrt{s_{NN}}$=200 GeV d+Au collisions at STAR

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Session ML: Hard Probes in High Energy Heavy Ion Collisions

Outline

- **Introduction**
  - Quark Gluon Plasma (QGP) in small systems?
  - Identified di-hadron correlation in Au+Au collisions
- **Motivation**
- **Analysis**
  - Analysis flow
  - STAR detectors
  - Correlation measurement
    - $\Delta\varphi$-$\Delta\eta$ correlation
    - Multiplicity-dependent $\Delta\varphi$ correlations (short-range)
    - Multiplicity-dependent $\Delta\varphi$ correlations (long-range)
- **Summary**

QGP (Quark Gluon Plasma) in small systems?

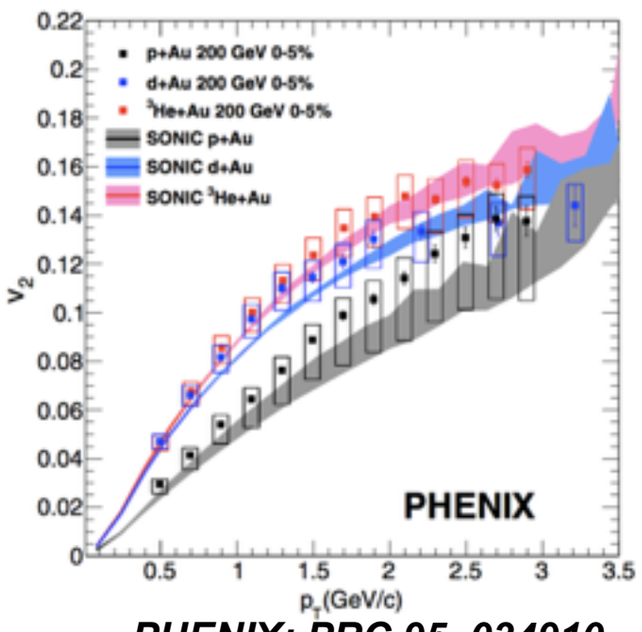
- ***QGP***
  - ✓ Created with **high temperature and high density**.
  - ✓ Quarks and Gluons are released from the confinement within hadron by strong interaction.

→

- ***Heavy Ion Collisions***
  - ✓ Temperature and density is high enough to create QGP.
  - ✓ Accelerate heavy ions close to the **speed of light** and collide them.
  - ✓ Performed at RHIC and LHC.

- **Some probes of QGP**
  - ✓ ***Jet quenching***: Group of high p_T particles loses energy when going through hot and dense matter.
  - ✓ ***Elliptic flow (v_2)***: Initial spatial condition is converted to momentum anisotropy. Sensitive to initial conditions.

- ***Some QGP-like signals are found not only in A+A collisions but also in small collision systems.***
  - ✓ v_2 has been measured at RHIC in p+Au, d+Au, and ^{3}He+Au.
  - ✓ Ridge-structure was observed at LHC in high multiplicity *p*+*p* collisions.



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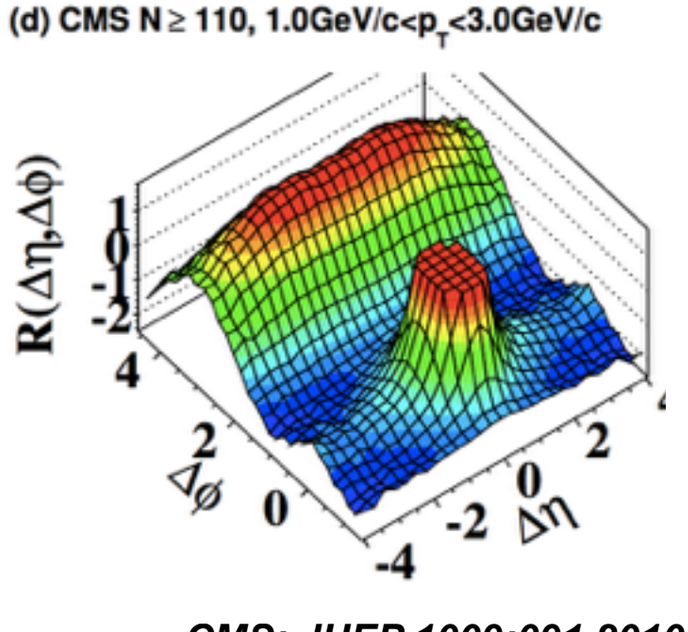


CMS: JHEP 1009:091,2010

Identified di-hadron correlations in Au+Au collisions

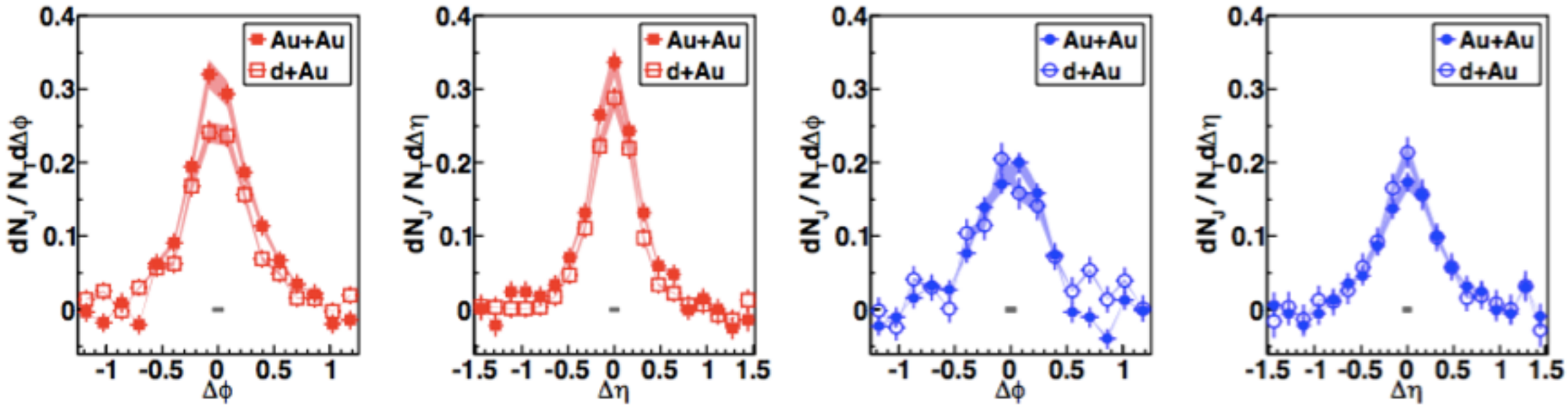
- **Di-hadron correlations with identified leading hadrons have been measured in $\sqrt{s_{NN}}$=200 GeV Au+Au central collisions, where QGP is thought to be created.**
  - ✓ **What was observed for jet-like correlation? ($|\Delta\phi|<0.78$ and $|\Delta\eta|<0.78$)**
    - **Yield enhancement** is observed with ***π*-triggers in central Au+Au collisions** over **d+Au minimum bias**, but not with **non-*π* triggers**.
  - ✓ **What causes enhancement?**
    - Jet quenching and medium-induced modification of fragmentation functions.

By studying identified di-hadron correlations:
- **Recombination process in the QGP**
- **Difference between baryon and meson.**
  - **Production mechanism (recombination vs fragmentation)**

PLB 751, 233 (2015)
Multiplicity
- Au+Au: 0-10%
- d+Au: Minimum bias

p_T^{trig}: 4.0-5.0 GeV/*c*
p_T^{asso}: 1.5-4.0 GeV/*c*

π triggers **non-π triggers**



STAR: PLB 751, 233 (2015)

Motivation

- **STAR, PLB 751, 233 (2015) studied identified di-hadron correlations in Au+Au (Central) and minimum bias d+Au collisions.**

  ✓ STAR collected a large new data set of d+Au collisions in 2016.

  - 6 times larger compared to 2008 d+Au data set
  - **This presentation: Conservative pileup mitigation with HFT (HFT was installed to improve vertex and DCA resolution)**

    → No statistical improvement yet

✓ What can be seen in multiplicity-dependent d+Au collisions?

Measure multiplicity-dependent di-hadron correlations with identified leading particles.

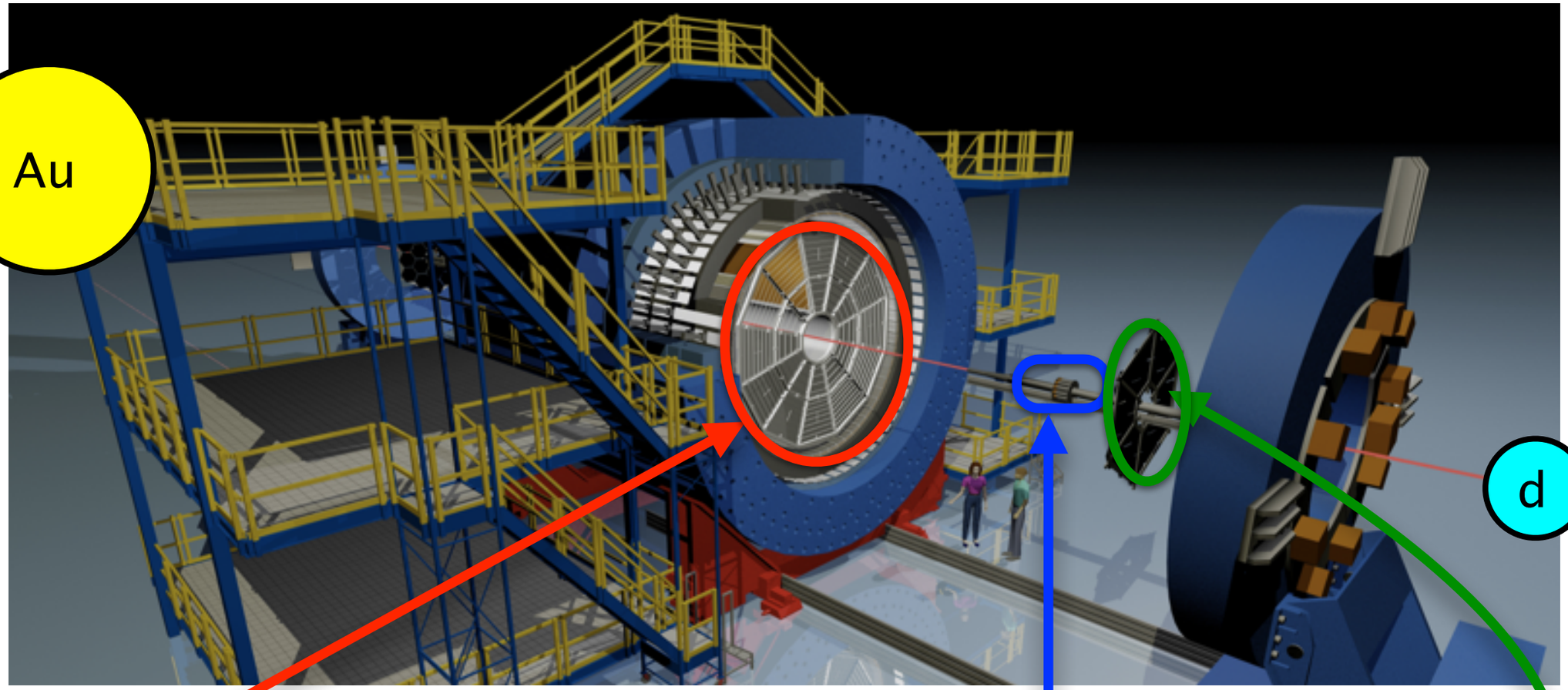
✓ ***Shape of short-range correlations***

✓ ***Strength of long-range correlations***

STAR Detectors

Au-going (η<0)

d-going (η>0)



TPC (Time Projection Chamber)

- $0<\phi<2\pi$ and $|\eta|<1.0$
- Track reconstruction
  - ✓ p_T, η, ϕ
- Event characterization
  - ✓ Multiplicity and vertex position
- Particle identification
  - ✓ Energy loss in the gas

VPD (Vertex Position Detectors)

- Event characterization
  - ✓ Vertex position
- Event Trigger

BBC (Beam Beam Counter)

- Event Trigger
- Multiplicity determination

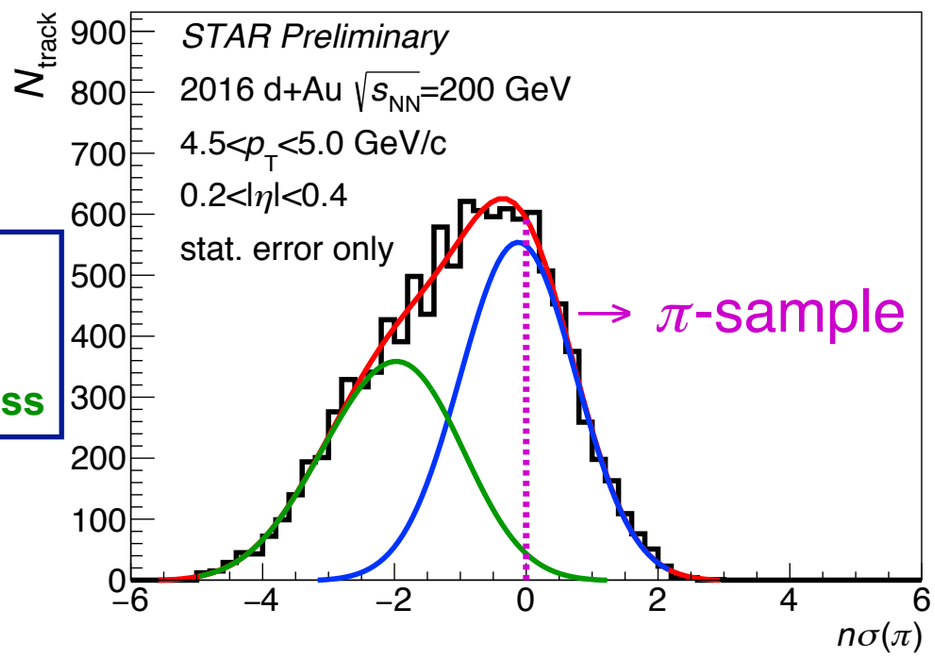
Analysis flow

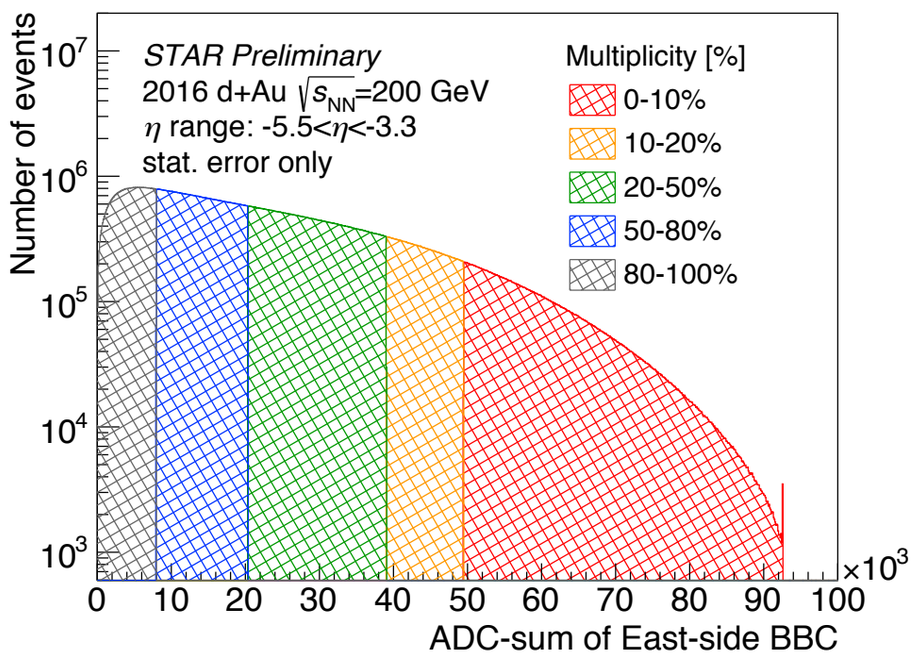
- **Data set: Minimum bias d+Au at $\sqrt{s_{NN}}$=200 GeV collected by STAR in 2016**
- **Multiplicity bin:** Decided by measured raw charge-sum of BBC (East-side, Au-going).
- **Two-particle correlations**
  - **Normalized the peak height to be unity. (Efficiency correction is work in progress)**

$$C(\Delta\phi) = \int \left[\frac{Y_{\mathrm{real}}(\Delta\phi,\Delta\eta)}{Y_{\mathrm{mix}}(\Delta\phi,\Delta\eta)} \frac{\int Y_{\mathrm{mix}}(\Delta\phi,\Delta\eta) d\Delta\phi d\Delta\eta}{\int Y_{\mathrm{real}}(\Delta\phi,\Delta\eta) d\Delta\phi d\Delta\eta} \right] d\Delta\eta \quad , \quad C'(\Delta\phi) = \frac{1}{\max - \min} C(\Delta\phi)$$

  - Event mixing is done with similar BBC-multiplicity and *z*-vertex events.
  - Pedestal is subtracted by using average of 1.0<|*Δφ*|<1.5 of *C*(*Δφ*).
- **Track merging and splitting correction**
- **Particle Identification**
  - Charged-hadron, charged-pion, and charged-non-pion are selected by *nσ* of pion.
    - *nσ*(*π*): Ionization energy loss in the TPC, normalized by resolution.
    - **Pure *π*: selected via *nσ*(*π*)>0**
    - **Non-*π* sample: Purify *nσ*(*π*)<0 by statistical subtraction of remaining pions.**

$n\sigma(\pi)$
Triple Gauss
π-Gauss
p-Gauss + K-Gauss

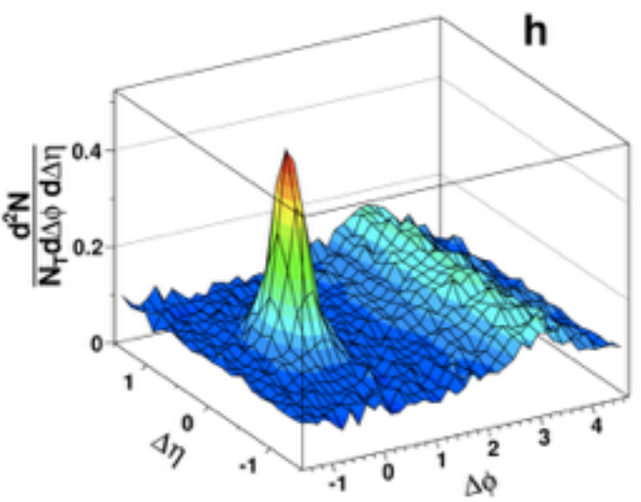


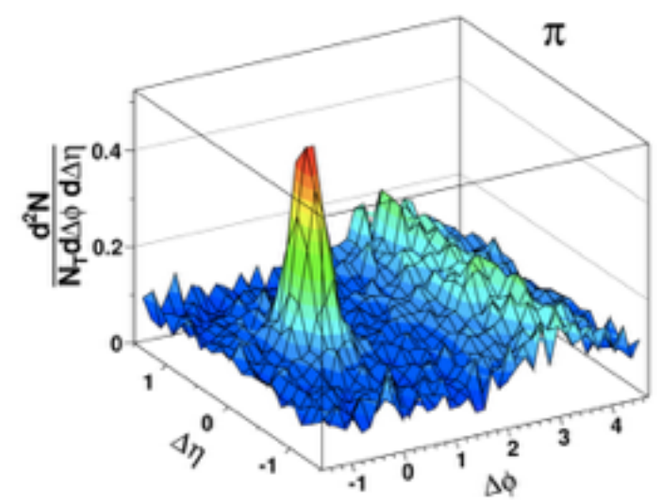


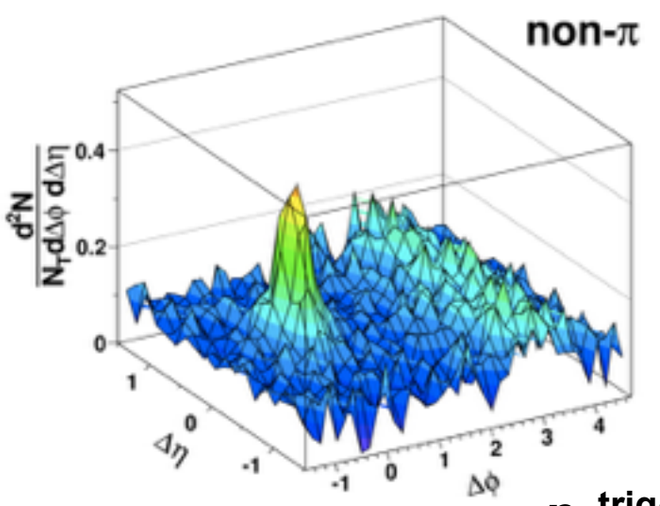
Correlation measurement

Compare normalized $C(\Delta\Phi, \Delta\eta)$ correlation with published result.

- **Efficiency correction is not applied to 2016 results.**
- **Similar structure can be seen between two results.**
  - **Shape of correlation**
  - **Difference between π-trigger and non-π-trigger**
    - Ratio of jet-like yield between π and non-π is consistent.

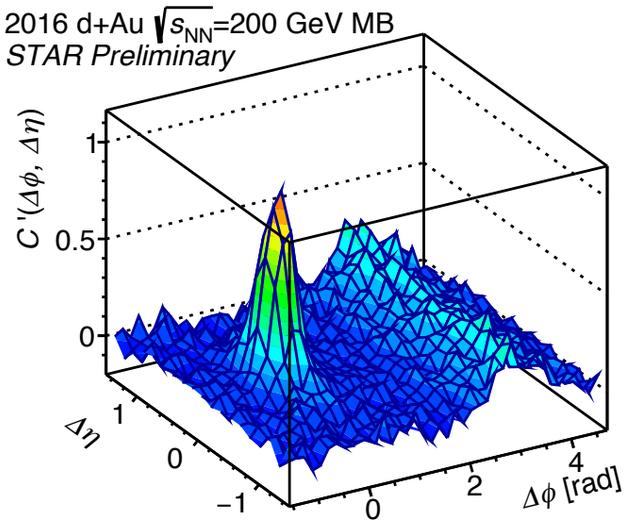




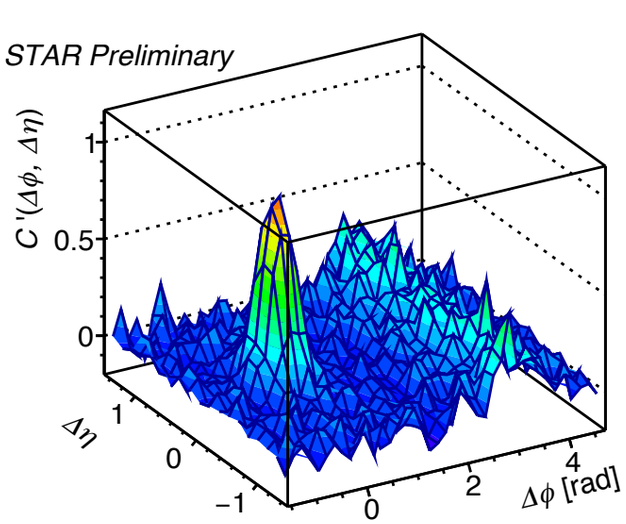


STAR:
PLB 751, 233, (2015)

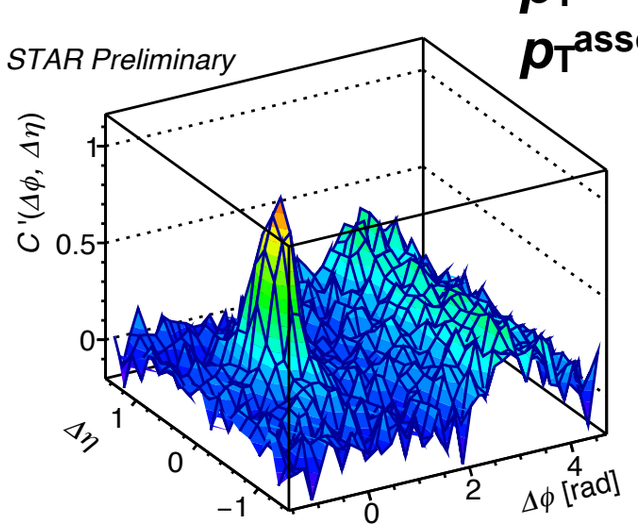
p_T^{trig}=4.0-5.0 GeV/*c*
p_T^{asso}=1.5-4.0 GeV/*c*



h-trigger



π-trigger



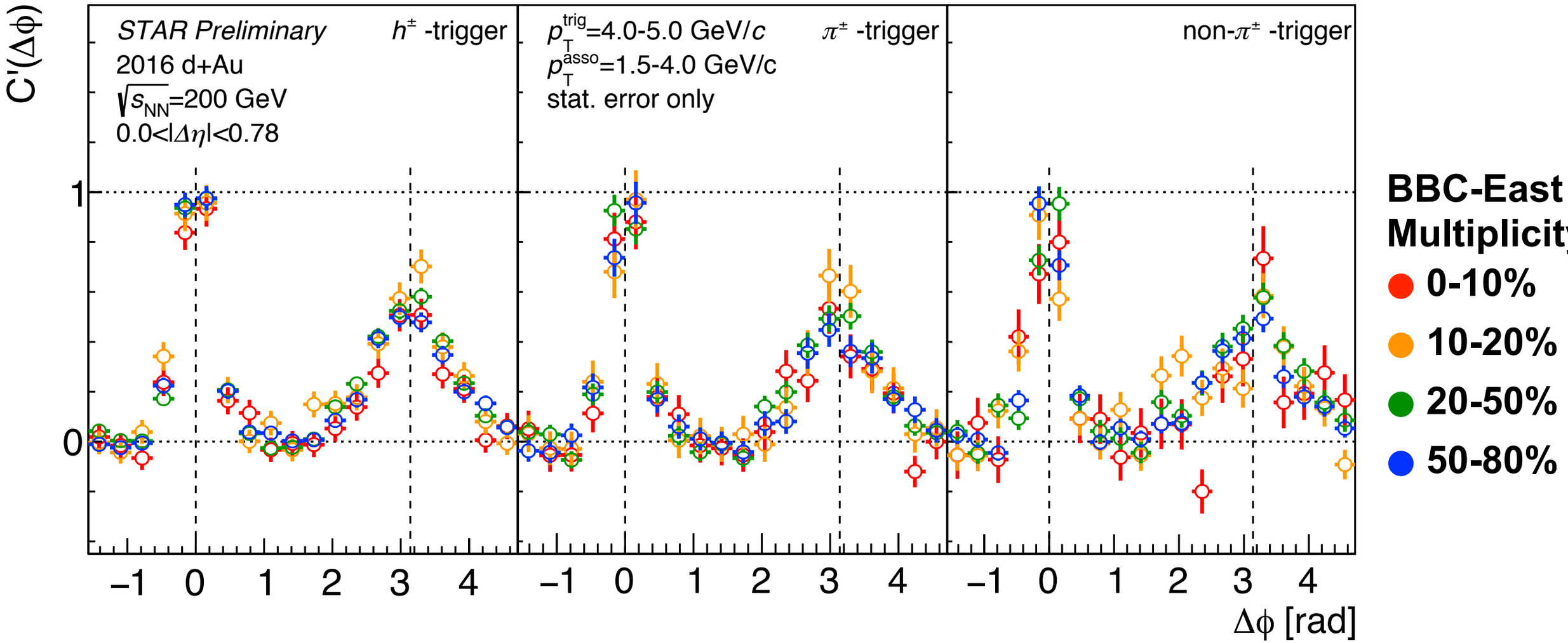
non-π-trigger

2016 analysis
- ***Pedestal is subtracted***
- ***Background amplitude is small. Neglecting flow effects on jet-like peak.***
- ***Height scaled to unity.***

Correlation measurement

Compared shape of correlation among different BBC multiplicity bins.

- Efficiency correction is work in progress.



Most multiplicity bins seem to show similar correlation shape.

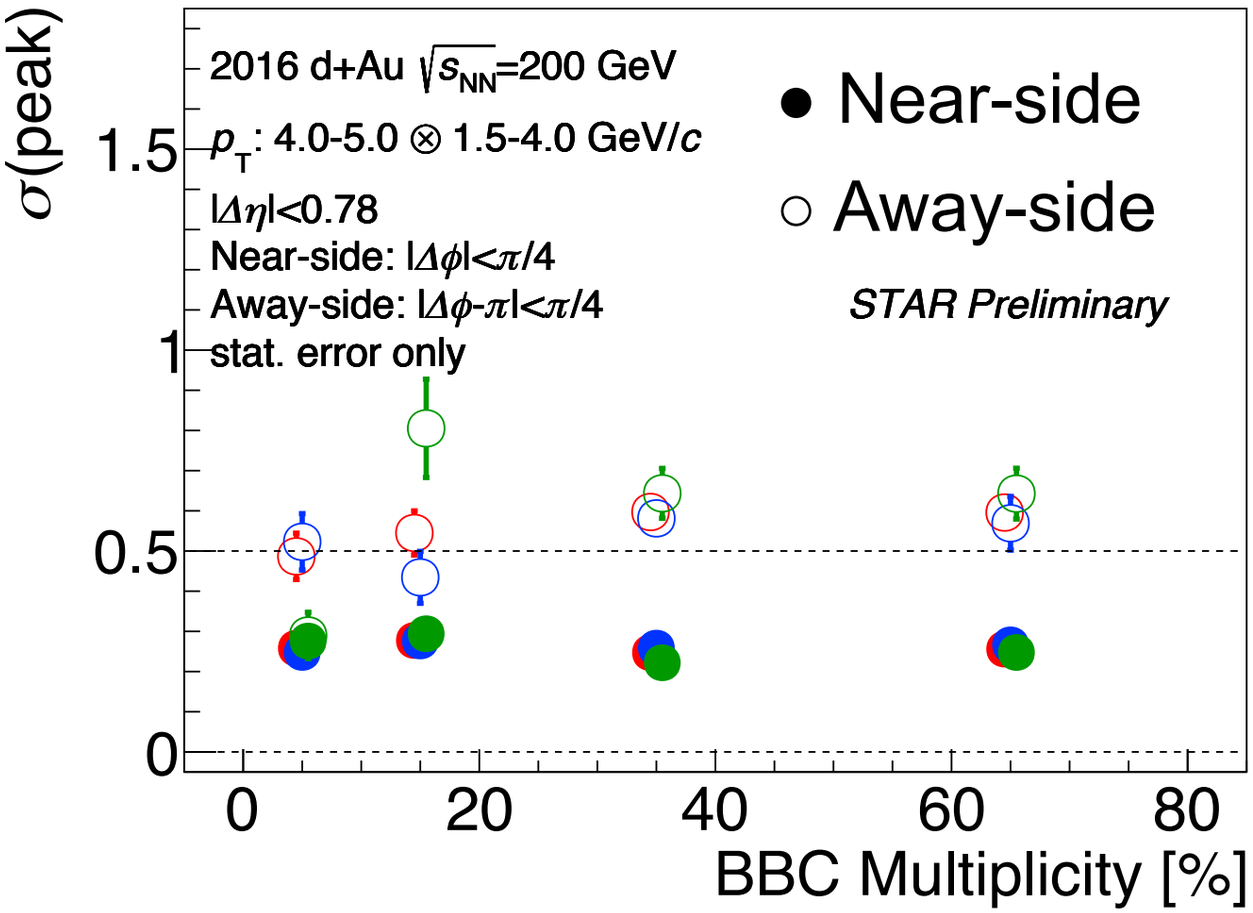
- Detailed study of shape by measuring width of peak will be presented on the next slide.

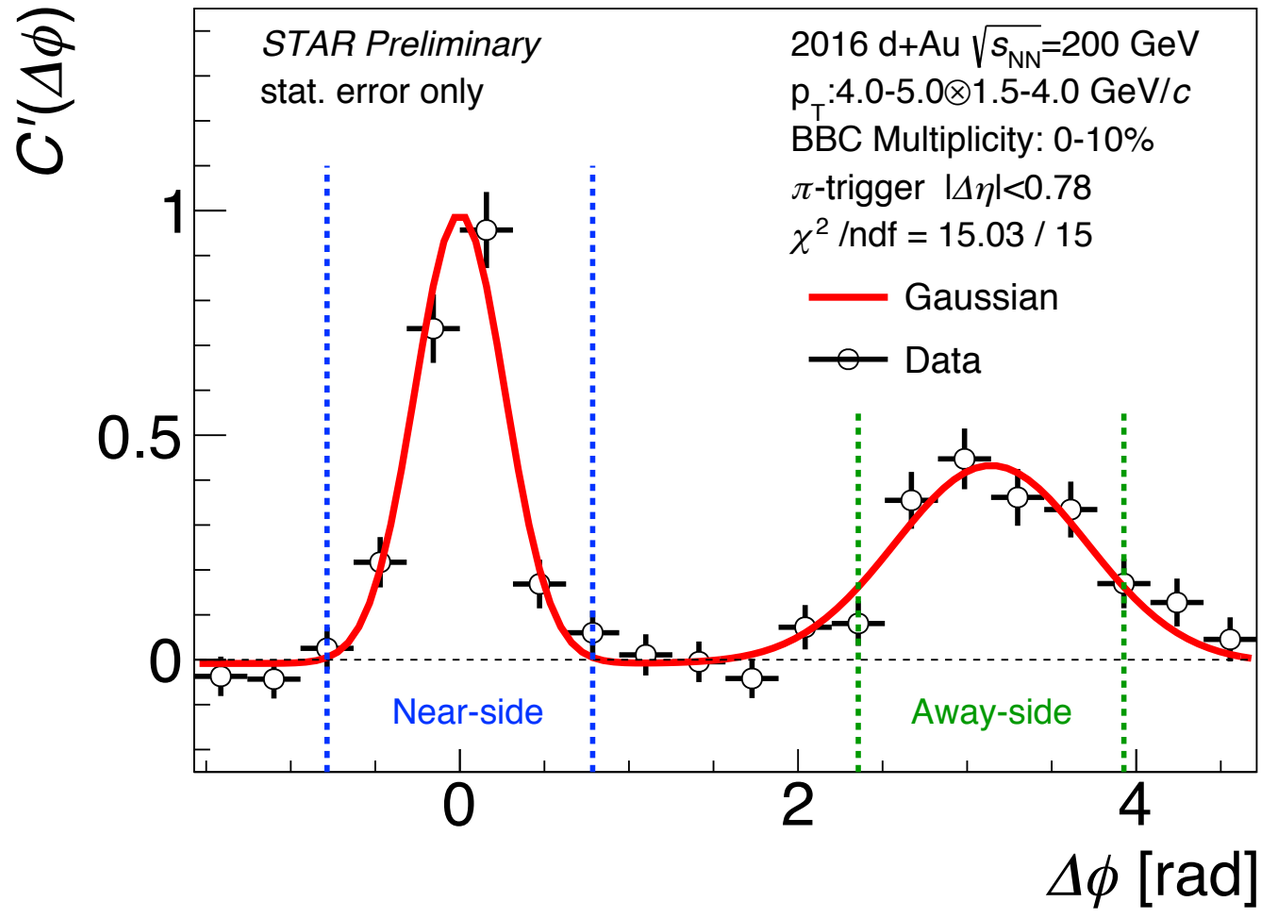
Correlation measurement: width of peak

Measured peak width by fitting normalized correlation with a Gaussian.

- Peak position of near-side and away-side is fixed to 0 and π.

$$F(\Delta\phi) = p_0 \exp\left[-\frac{\Delta\phi^2}{2\sigma^2(N)}\right] + p_1 \exp\left[-\frac{(\Delta\phi-\pi)^2}{2\sigma^2(A)}\right] + p_2$$





Near-side correlation

- **No significant multiplicity or trigger particle dependence is observed.**

Away-side correlation

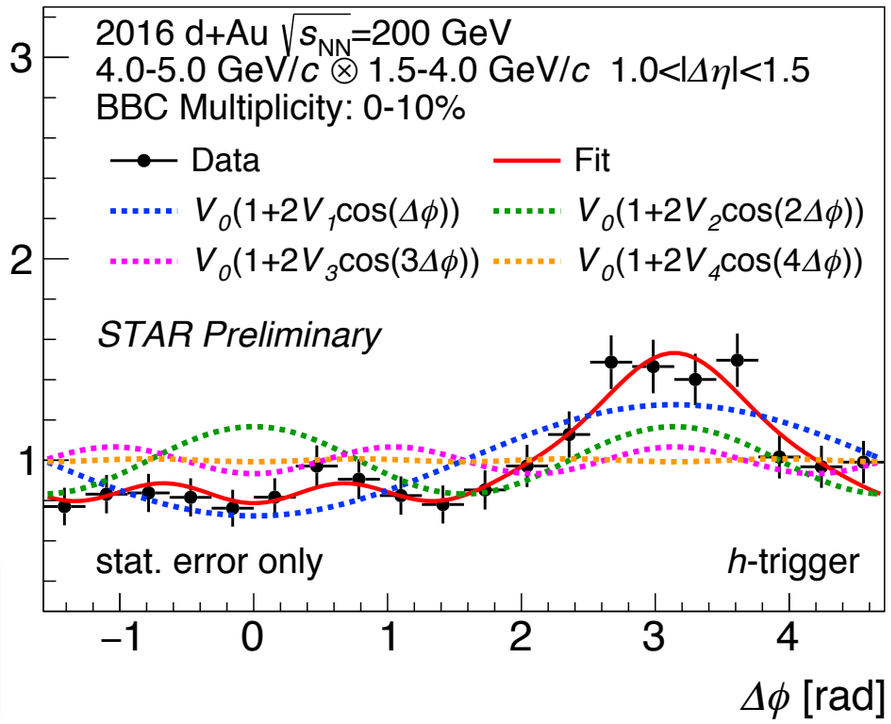
- **No significant multiplicity dependence is observed.**

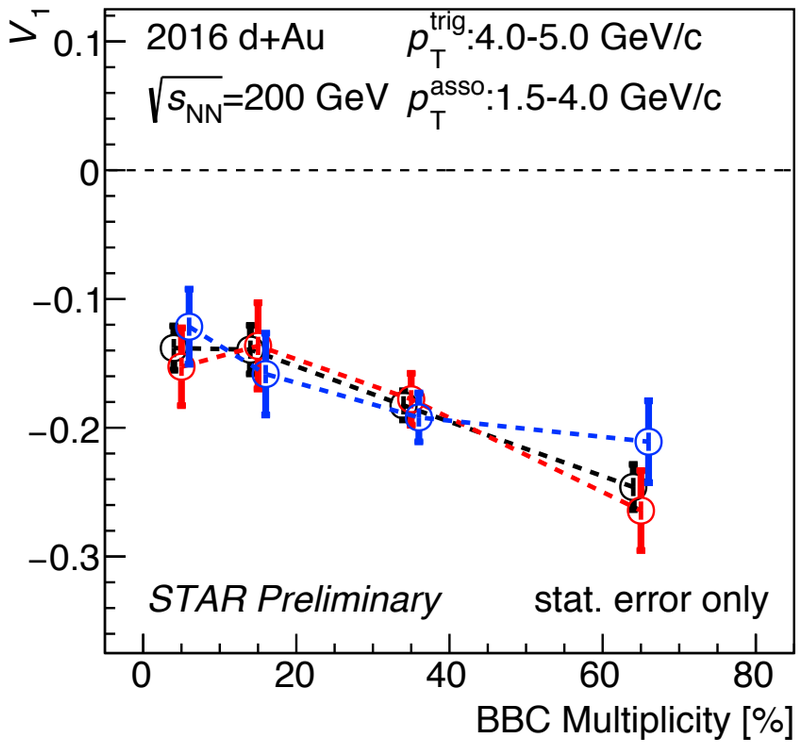
Correlation measurement

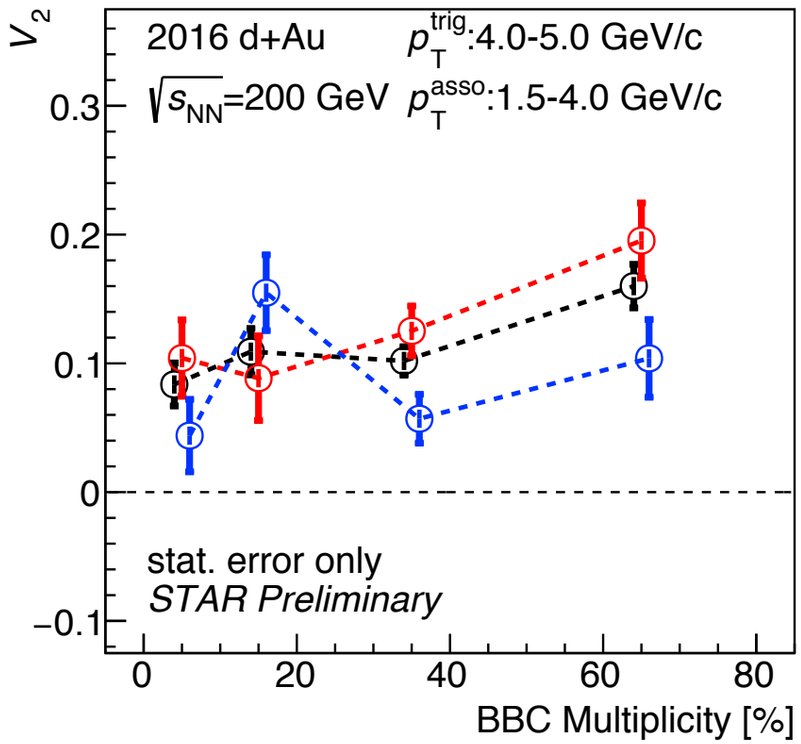
Fitted parameter of long-range (1.0<|$\Delta\eta$|<1.5) correlation.

- Fitting function: Fourier expansion up to 5th order.
- Note: Harmonics are driven by away-side yield.
- $|V_n|$ (n>=3) is small compared to uncertainty.
  - only V_1 and V_2 are shown.

$$F(\Delta\phi) = V_0\left[1 + \sum_{n=1}^{5} 2V_n \cos\left(n\Delta\phi\right)\right]$$







Triggers
- ***h*-trigger**
- ***π*-trigger**
- **non-*π*-trigger**

- **Weak multiplicity dependence of V_1 is observed for both triggers.**
- **No significant multiplicity dependence of V_2 is observed for both triggers.**
- ***No significant trigger dependence can be seen.***

Summary

First measurement in:

- **Jet-like yield at short-range ($|\Delta\eta|<0.78$)**
  - Near-side shape shows no multiplicity dependence for all three triggers.
- **Away-side and long-range ($1.0<|\Delta\eta|<1.5$) correlation**
  - 1st order Fourier component has weak multiplicity dependence.
  - 2nd order Fourier component has no significant multiplicity dependence.
- **Almost the same number of triggers even this dataset has a larger number of events.**
  - Pileup mitigation with HFT: No statistics improvement w.r.t 2008 results yet.

Short-range results indicate no-multiplicity dependence in d+Au.

Long-range results may indicate multiplicity dependence in d+Au.

Coming soon:

- Improve pileup mitigation to take advantage of the larger 2016 data set.
- Systematic uncertainties

Back up slides

Track merging and splitting correction (1)

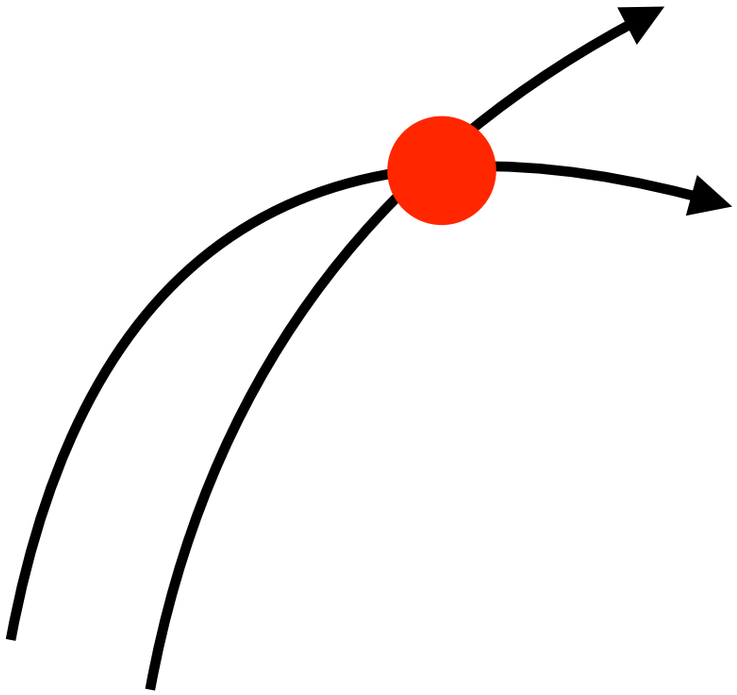
- Need to remove merged track and ghost track
  - ✓ **Merged-track**: 2 tracks seems to be 1 track, since the are too close.
  - ✓ **Split track**: 1 track seems to be 2 tracks, since it hits on 2 pads.

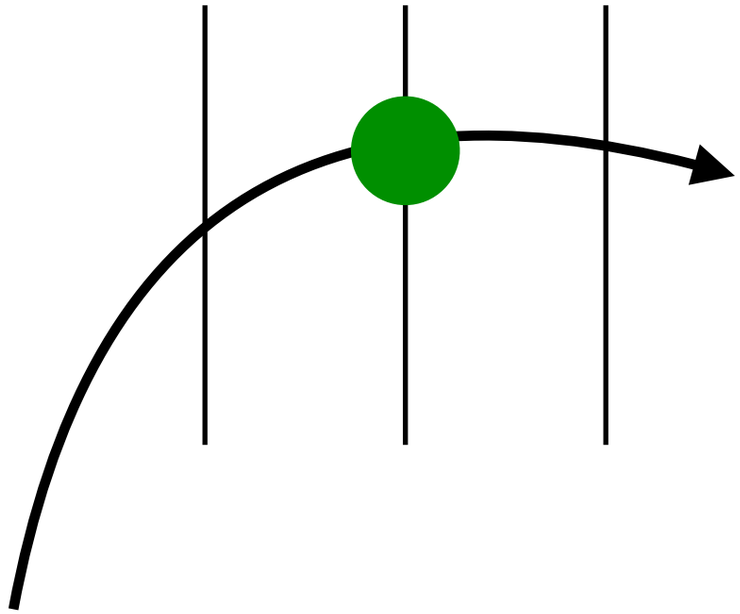
Steps to decide parameter of pair-cut.

1. Calculate $\Delta\varphi^*$ by two points of radius(R [m]).
   - R=0.85 and 1.15
2. Make 2 dimensional-histograms of $\Delta\varphi^*$ v.s. $\Delta\eta$.
3. Remove bump around ($\Delta\varphi^*$, $\Delta\eta$) = (0, 0)

$$\phi^* = \phi - \arcsin\left(\frac{0.3 \cdot q \cdot B \cdot R}{2p_T}\right)$$

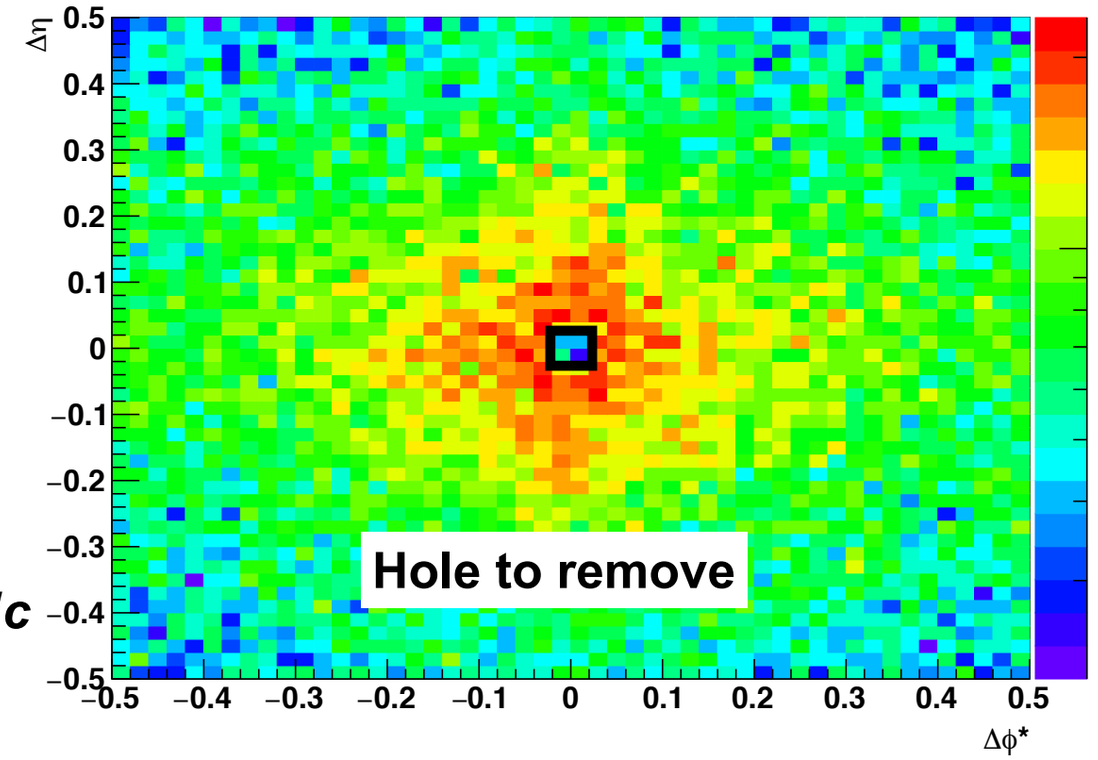
- φ*: azimuthal angel inside TPC
- φ: azimuthal angle of selected particle
- q: charge of particle(+1 or -1)
- B[Tesla]: magnetic field of TPC
- R[m]: radius of selected point
- p_T[GeV/c]: traverse momentum





Track merging and splitting correction (2)

- Remove hole around (Δφ*, Δη) = (0, 0).
  - ✓ Cut parameter is decided.
  - ✓ Parameter is decided by each charge combination.
  - ✓ Do not use the pairs in the hole.



R=0.85 m, 1.5<p_T<5.0 GeV/c
Minimum bias

R=0.85 m				
Charge Combination	(+, +)	(+, -)	(-, +)	(-, -)
$\Delta\varphi^*$	$\lvert\Delta\varphi^*\rvert$<0.02	-0.06<$\Delta\varphi^*$<-0.02	0.00<$\Delta\varphi^*$<0.06	$\lvert\Delta\varphi^*\rvert$<0.02
$\Delta\eta$	$\lvert\Delta\eta\rvert$<0.02	$\lvert\Delta\eta\rvert$<0.02	$\lvert\Delta\eta\rvert$<0.02	$\lvert\Delta\eta\rvert$<0.02
R=1.15 m				
$\Delta\varphi^*$	$\lvert\Delta\varphi^*\rvert$<0.02	-0.06<$\Delta\varphi^*$<0.00	0.00<$\Delta\varphi^*$<0.04	$\lvert\Delta\varphi^*\rvert$<0.02
$\Delta\eta$	$\lvert\Delta\eta\rvert$<0.02	$\lvert\Delta\eta\rvert$<0.02	$\lvert\Delta\eta\rvert$<0.02	$\lvert\Delta\eta\rvert$<0.02

Gauss fit of all multiplicity and trigger particle bin

p_T: 4.0-5.0 x 1.5-4.0 GeV/*c*, stat. error only
left to right: multiplicity(most central to most peripheral and minimum bias)
top to bottom: *h*, π, and non π trigger

$$F(\Delta\phi) = p_0 \exp\left[-\frac{\Delta\phi^2}{2\sigma^2(N)}\right] + p_1 \exp\left[-\frac{(\Delta\phi-\pi)^2}{2\sigma^2(A)}\right] + p_2$$