

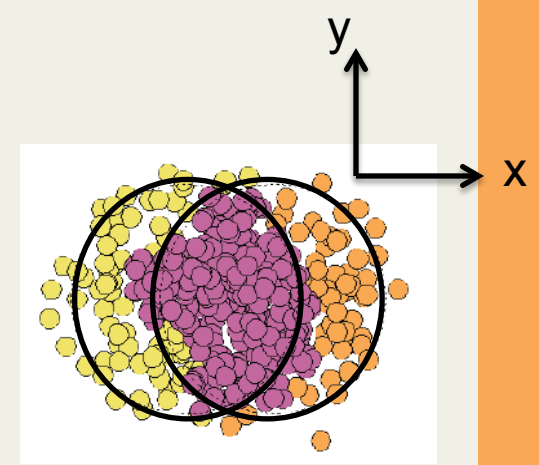
Measurements of Directed flow for charged hadron in $\sqrt{s_{NN}} = 200$ GeV Cu+Au collisions at RHIC-PHENIX

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University of Tsukuba

JPS 2014 Spring

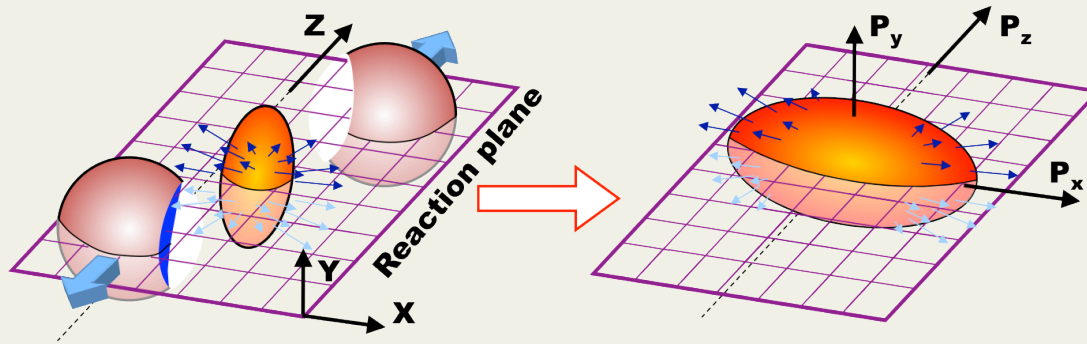


方位角異方性



- 反応関与部の粒子放出は
 - 核子のゆらぎを伴う初期形状
 - 粒子間の相互作用による集団的膨張の影響を受ける。

- 空間的異方性が運動量空間の異方性に転換されて、生成粒子の方位角異方性が生じる。

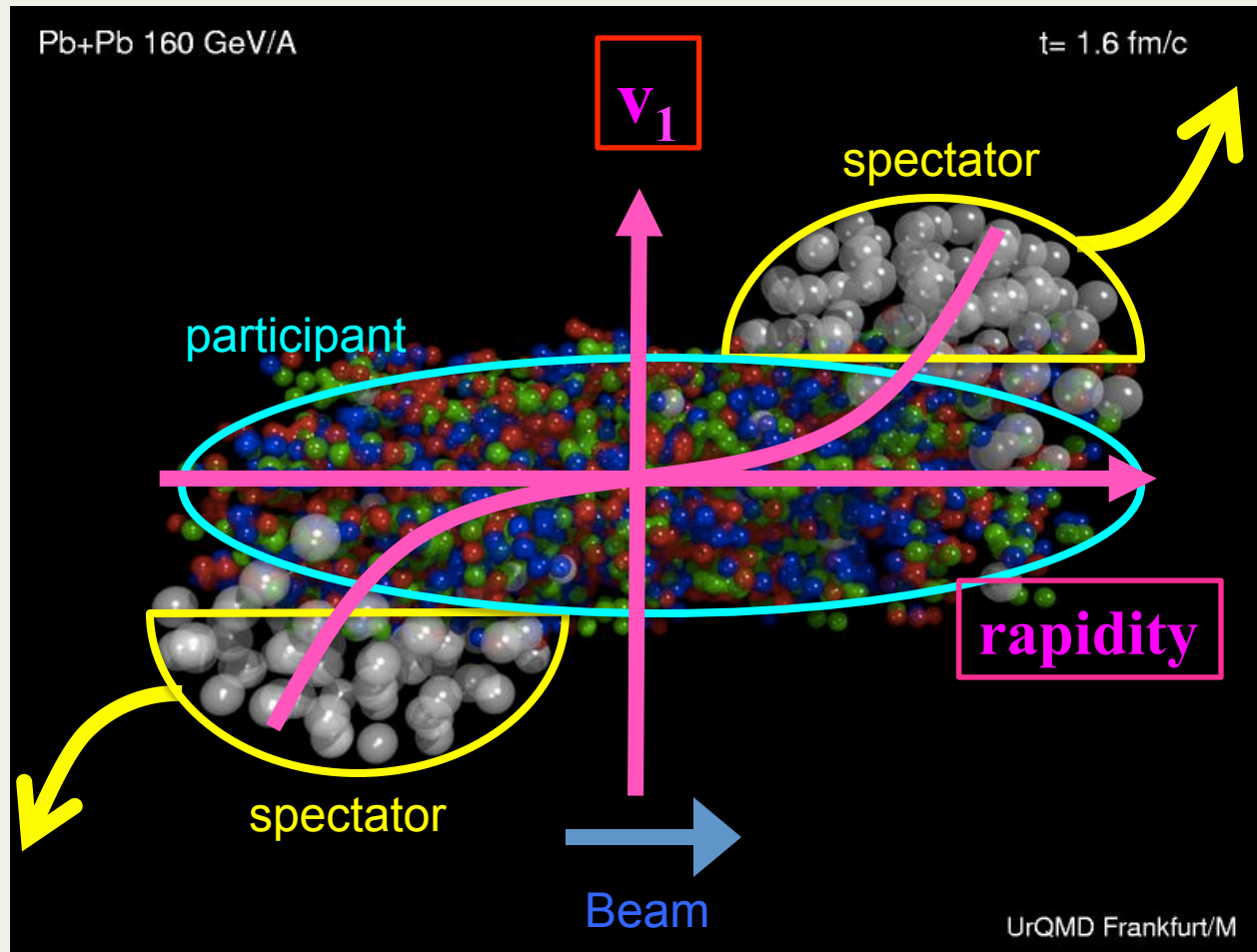


- 方位角異方性の強度 v_n

$$\frac{dN}{d(\phi - \Psi_n)} = N_0 \left(1 + \sum 2v_n \cos(n(\phi - \Psi_n)) \right)$$

$$v_n = \langle \cos(n(\phi - \Psi_n)) \rangle$$

Directed flow v_1



- Directed flow... Spectatorの方向に引きずられた粒子の集団運動の強度
→ It probes the very earliest stage of the collision

$$v_1 = \langle \cos(\phi - \Psi_1) \rangle$$

Participant and Spectator Planes

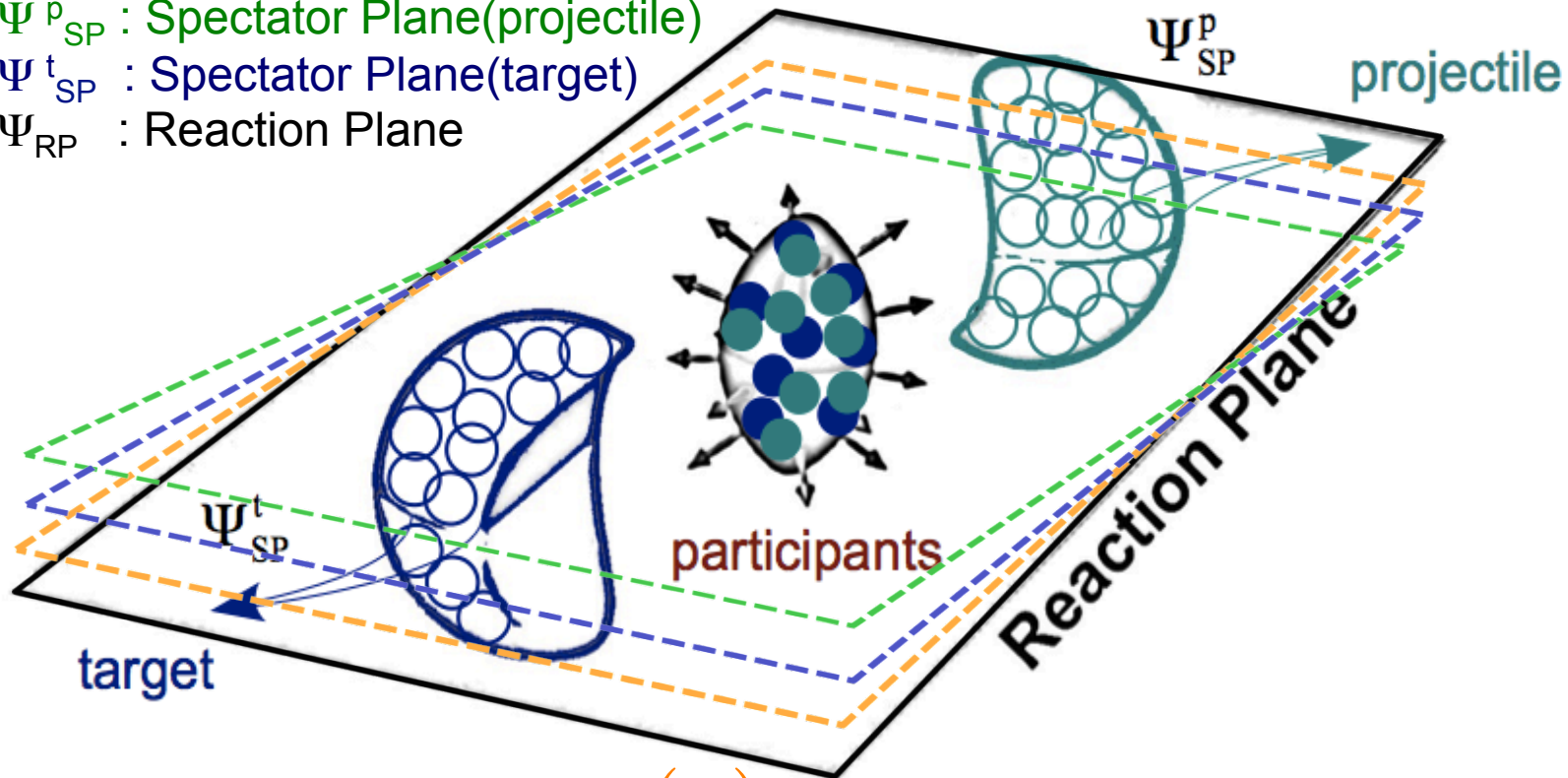
- 非中心衝突の場合
 - 2つの原子核の重なり合う部分…反応関与部(Participant)
 - 2つの原子核の重ならない部分…反応傍観部(Spectator)

$\Psi^{(n)}_{PP}$: Participant Plane

Ψ^{p}_{SP} : Spectator Plane(projectile)

Ψ^{t}_{SP} : Spectator Plane(target)

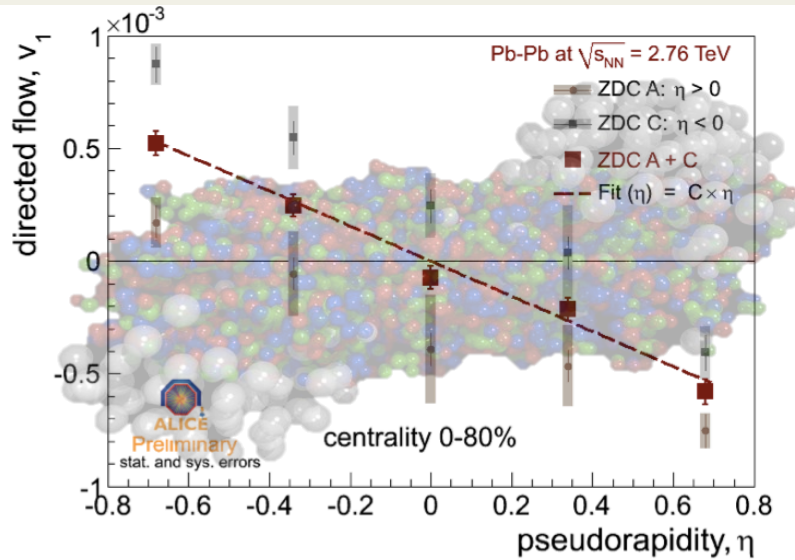
Ψ_{RP} : Reaction Plane



$$\Psi_{PP}^{(n)} \neq \Psi_{SP}^p \neq \Psi_{SP}^t \neq \Psi_{RP}$$

v_1^{odd} と v_1^{even}

ALICEによる結果(arXiv:1106.5425v1)



- 実験で得られる v_1^{exp} は、非対称成分 v_1^{odd} と対称成分 v_1^{even} で構成

$$v_1^{\text{exp}} = v_1^{\text{odd}} + v_1^{\text{even}}$$

- 非対称成分 : v_1^{odd} (probe flow in the RP)

$$v_1^{\text{odd}}(-\eta) = -v_1^{\text{odd}}(\eta)$$

$$v_1^{\text{odd}} = \frac{1}{2} \left[v_1 \{ \psi_{SP}^p \} + v_1 \{ \psi_{SP}^t \} \right]$$

- 対称成分 : v_1^{even} (sensitive to fluctuation)

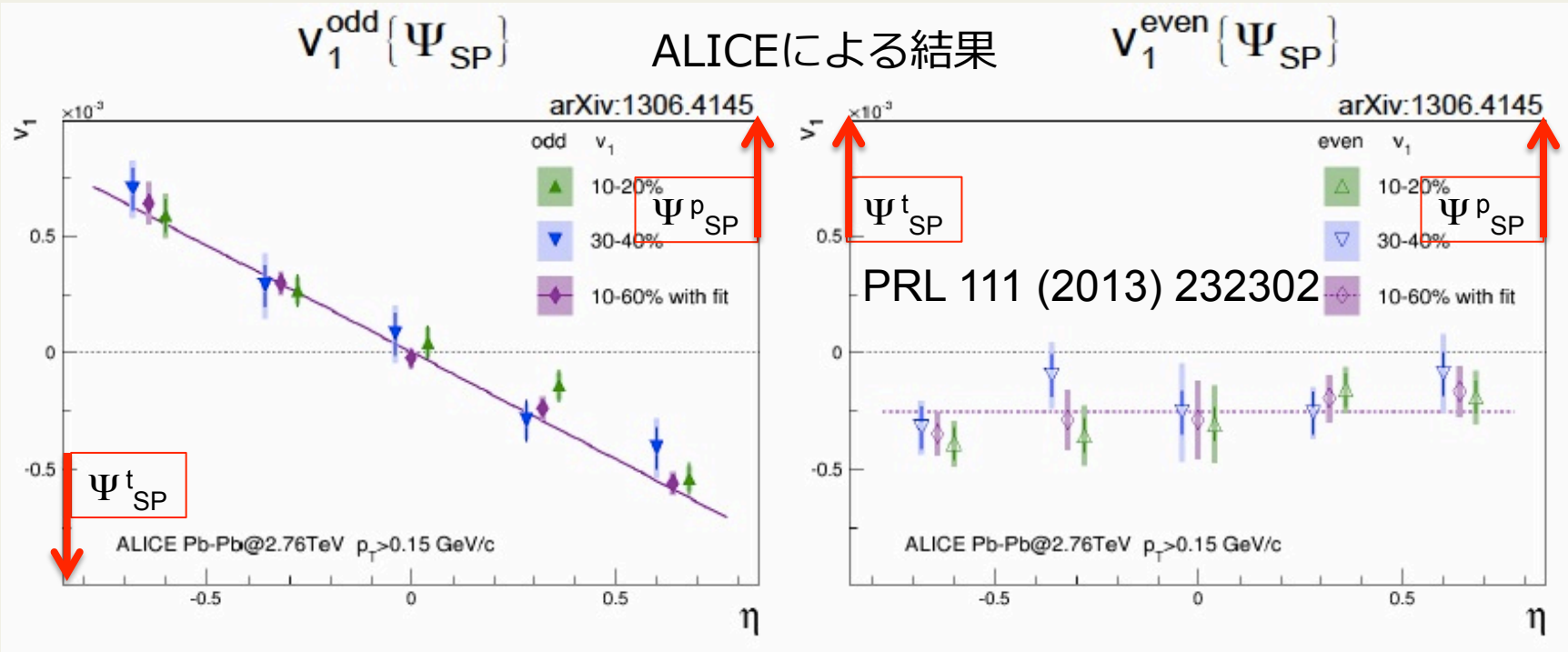
$$v_1^{\text{even}}(-\eta) = v_1^{\text{even}}(\eta)$$

$$v_1^{\text{even}} = \frac{1}{2} \left[v_1 \{ \psi_{SP}^p \} - v_1 \{ \psi_{SP}^t \} \right]$$

- Target side Plane か
Projectile side Planeか
によって v_1 は異なる
→ Spectatorの独立なゆらぎ
による v_1^{even} (対称成分)

Rapidity dependence of v_1^{odd} and v_1^{even}

- ◇ 非対称成分: v_1^{odd} (probe flow in the RP)
- ◇ 対称成分: v_1^{even} (sensitive to fluctuation)



$$v_1^{\text{odd}}(-\eta) = -v_1^{\text{odd}}(\eta)$$

$$v_1^{\text{even}}(-\eta) = v_1^{\text{even}}(\eta)$$

$$v_1^{\text{odd}} = \frac{1}{2} \left[v_1 \{ \psi_{SP}^p \} + v_1 \{ \psi_{SP}^t \} \right]$$

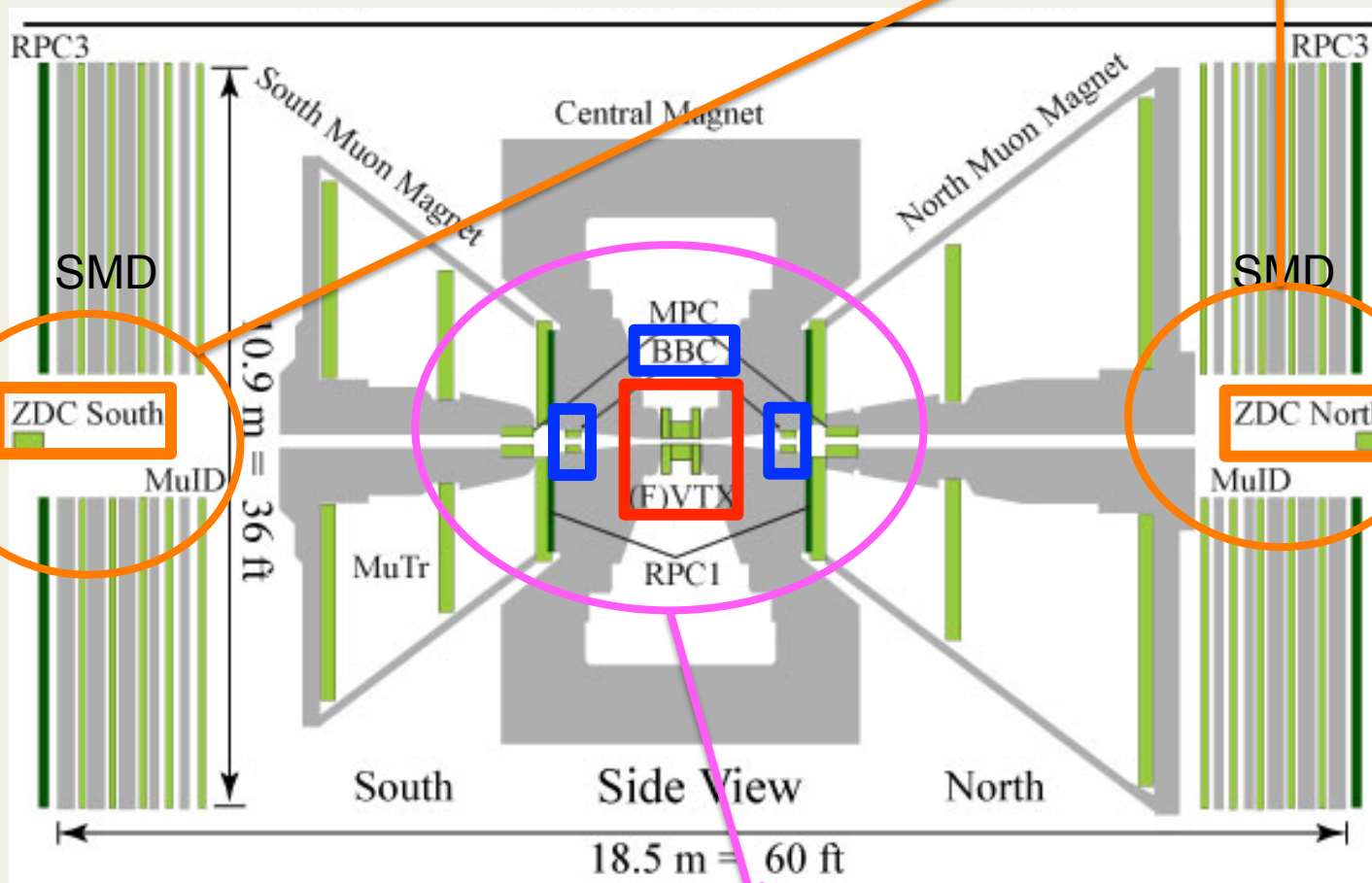
$$v_1^{\text{even}} = \frac{1}{2} \left[v_1 \{ \psi_{SP}^p \} - v_1 \{ \psi_{SP}^t \} \right]$$

RHIC-PHENIX実験

BBC : $3.0 < |\eta| < 3.9$

FVTX : $1.0 < |\eta| < 3.0$

反応傍観部の粒子を検出
SMDは傍観部の重心を計算



反応関与部から放出される粒子を検出

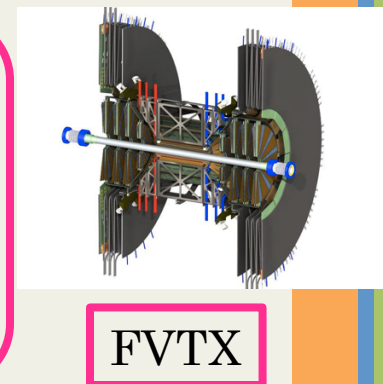
- Beam Beam Counter (BBC)

ビーム軸近傍、ビーム軸前後方にひとつずつ設置。
中心衝突度の決定など。



- Forward Silicon Vertex Tracker (FVTX)

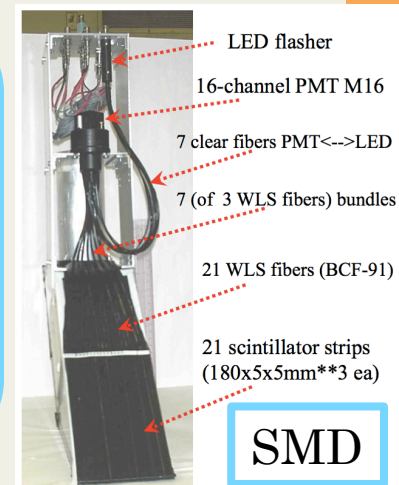
2012年から新たに設置。ビーム軸近傍、ビーム軸前後方にひとつずつ設置。衝突位置精度、MuTrのトラッキング精度の向上。



- Shower Max Detector (SMD)

衝突傍観部の中性子のエネルギー損失を測る

Zero Degree Calorimeter (ZDC) の第1モジュールと第2モジュールの間に設置。傍観部のシャワーの重心を計算。

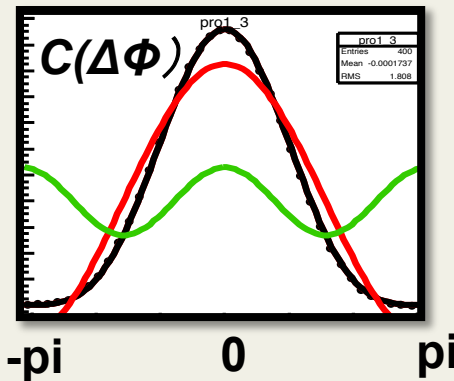


2 粒子相関法で v_n を測定する

- 得られた $C(\Delta\Phi)$ を以下の関数でフィットする。

$$C(\Delta\phi) \equiv \frac{Y_{real}(\Delta\phi)}{Y_{mixed}(\Delta\phi)} \cdot \frac{\int Y_{mixed}(\Delta\phi) d(\Delta\phi)}{\int Y_{real}(\Delta\phi) d(\Delta\phi)}$$

$$\frac{dN}{d(\phi_1 - \phi_2)} = N_0 (1 + 2P_1 \cos(\phi_1 - \phi_2) + 2P_2 \cos(2(\phi_1 - \phi_2)) + \dots)$$



- $N_0(1.0 + 2.0v_1 \cos \Delta\Phi)$
- $N_0\{1.0 + 2.0v_2 \cos(2\Delta\Phi)\}$
- $N_0\{1.0 + \sum 2.0v_n \cos(n\Delta\Phi)\}$
($n=1 - 4$)

- 3-sub method で v_n を計算

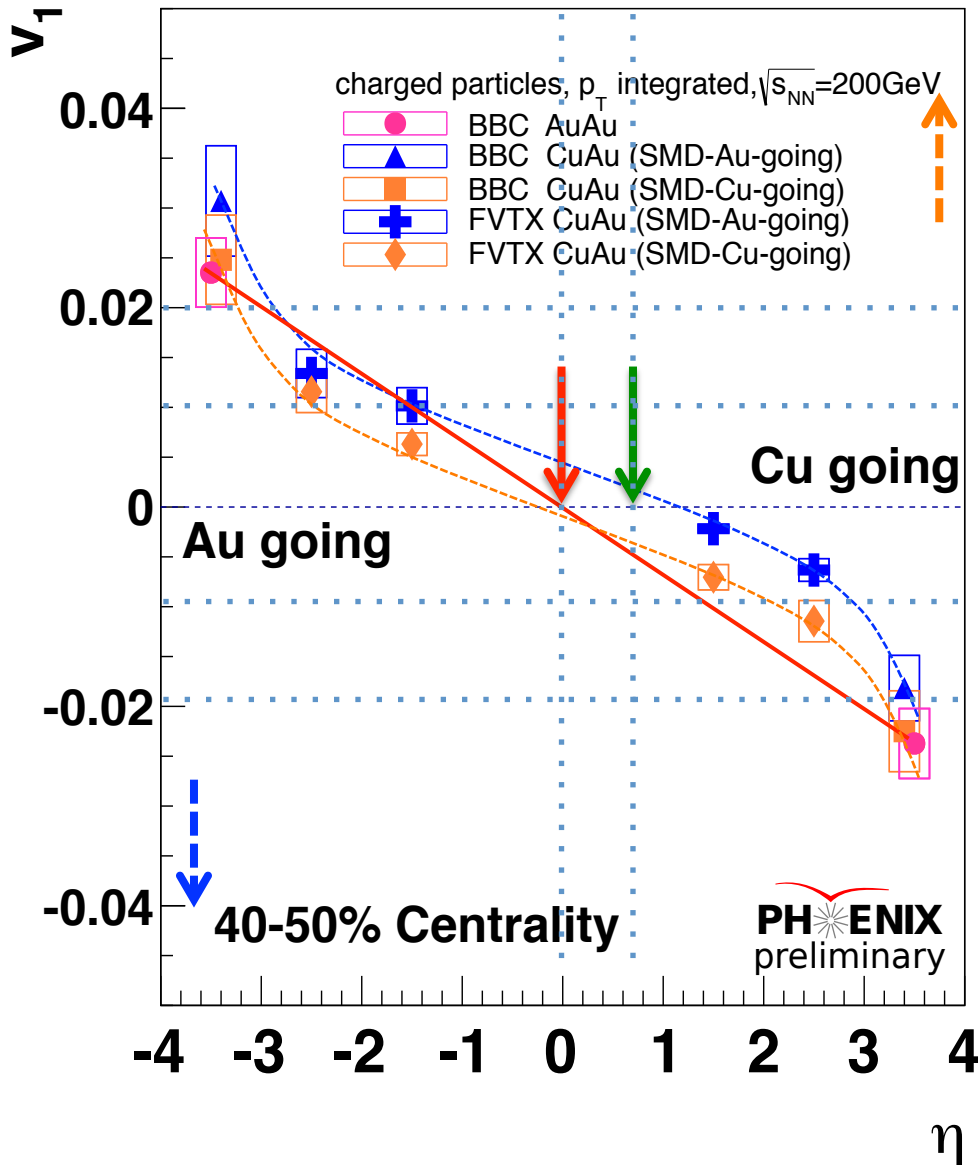
$$P_n^{a,b} = v_n^a \cdot v_n^b \quad (a, b = A, B, C)$$

$$v_n^a = \sqrt{\frac{(v_n^A \cdot v_n^B) \cdot (v_n^A \cdot v_n^C)}{(v_n^B \cdot v_n^C)}}$$

$$v_n^{CNT} = \frac{P_n^{SMD, CNT}}{v_n^{SMD}} = \frac{(v_n^{SMD} \cdot v_n^{CNT})}{v_n^{SMD}}$$

Rapidity dependence of v_1

--- Φ_1 spectator (Au side $\eta < 0$)
--- Φ_1 spectator (Cu side $\eta > 0$)



- Cu going Planeと Au going Planeで v_1 の値は異なる
- v_1 の符号反転する η の位置が Au+Au と Cu+Au で異なる

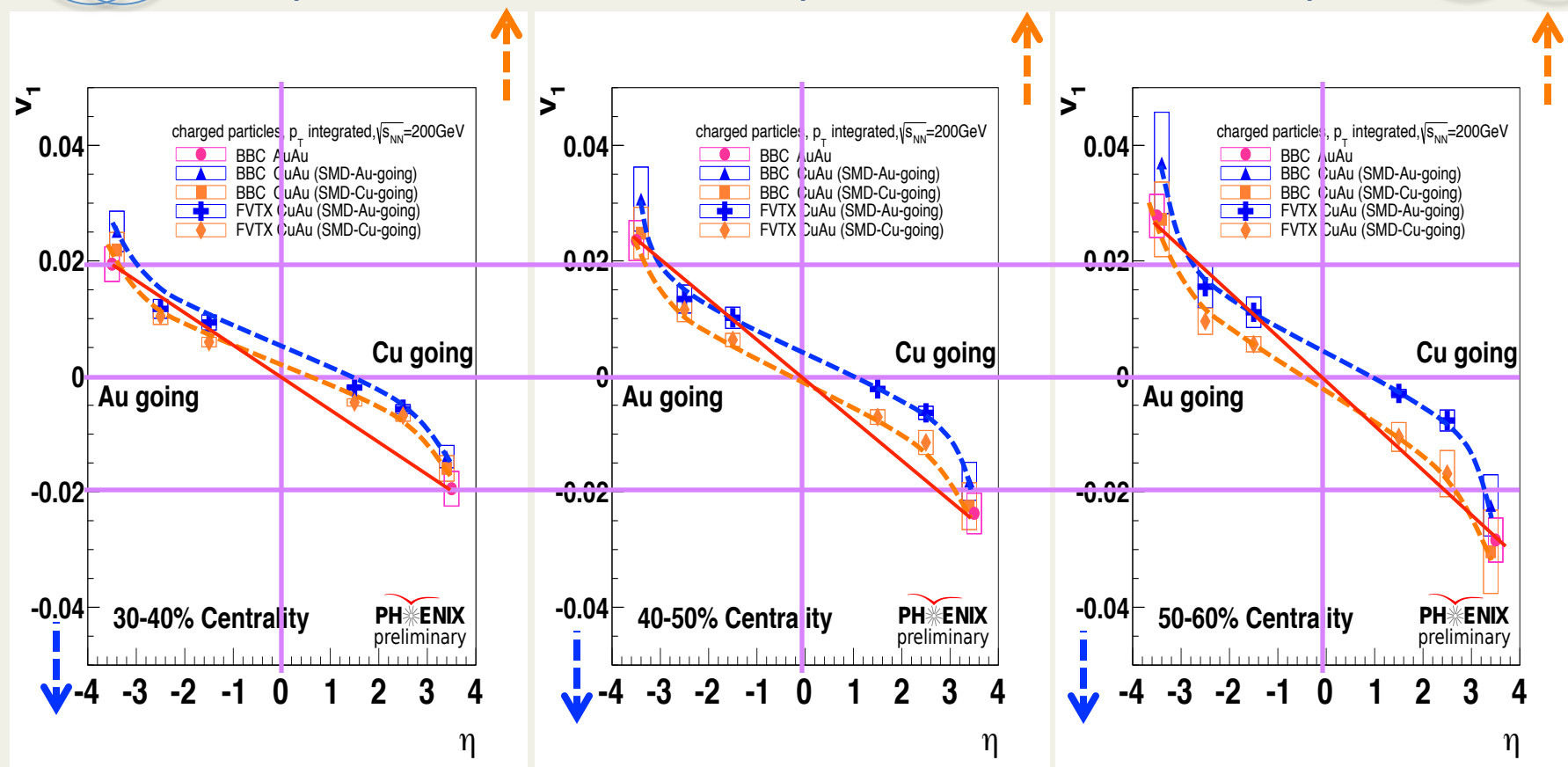
Rapidity dependence of v_1

--- $\Phi_1^{\text{spectator}}$ (Au side $\eta < 0$)
--- $\Phi_1^{\text{spectator}}$ (Cu side $\eta > 0$)

Centrality 30-40%

Centrality 40-50%

Centrality 50-60%

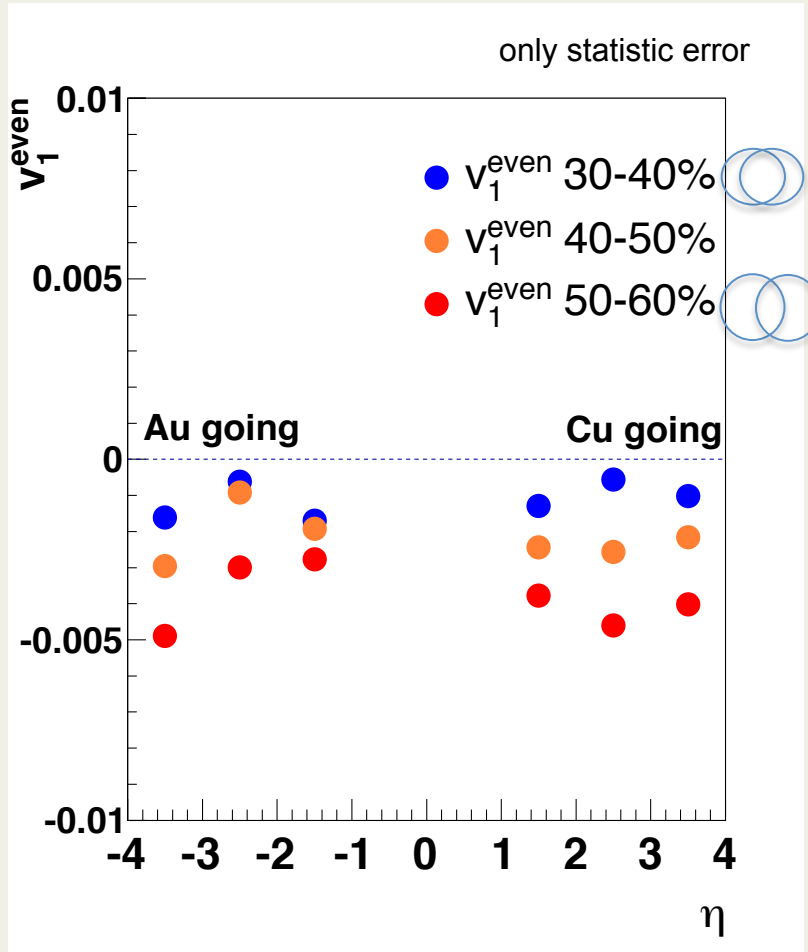
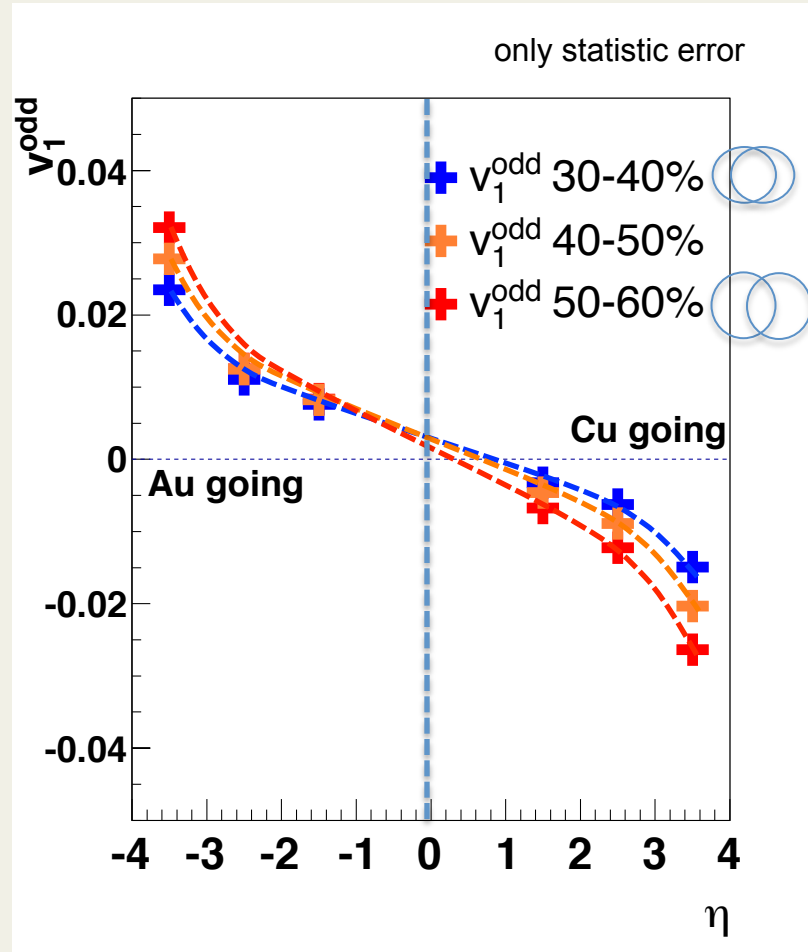


- $v_1^{\text{odd}}, v_1^{\text{even}}$ 成分ともに周辺衝突ほど大きくなる傾向

Rapidity dependence of v_1^{odd} and v_1^{even} in Cu+Au

◇ 非対称成分: v_1^{odd}

◇ 対称成分: v_1^{even}



- v_1^{odd} と v_1^{even} の Centrality 依存性を確認
- CuAu v_1^{odd} の符号反転する η の位置が、 $\eta = 0$ からパネル右へシフト

まとめと今後

- まとめ

- ◇ v_1 の η 依存性 in Cu+Au

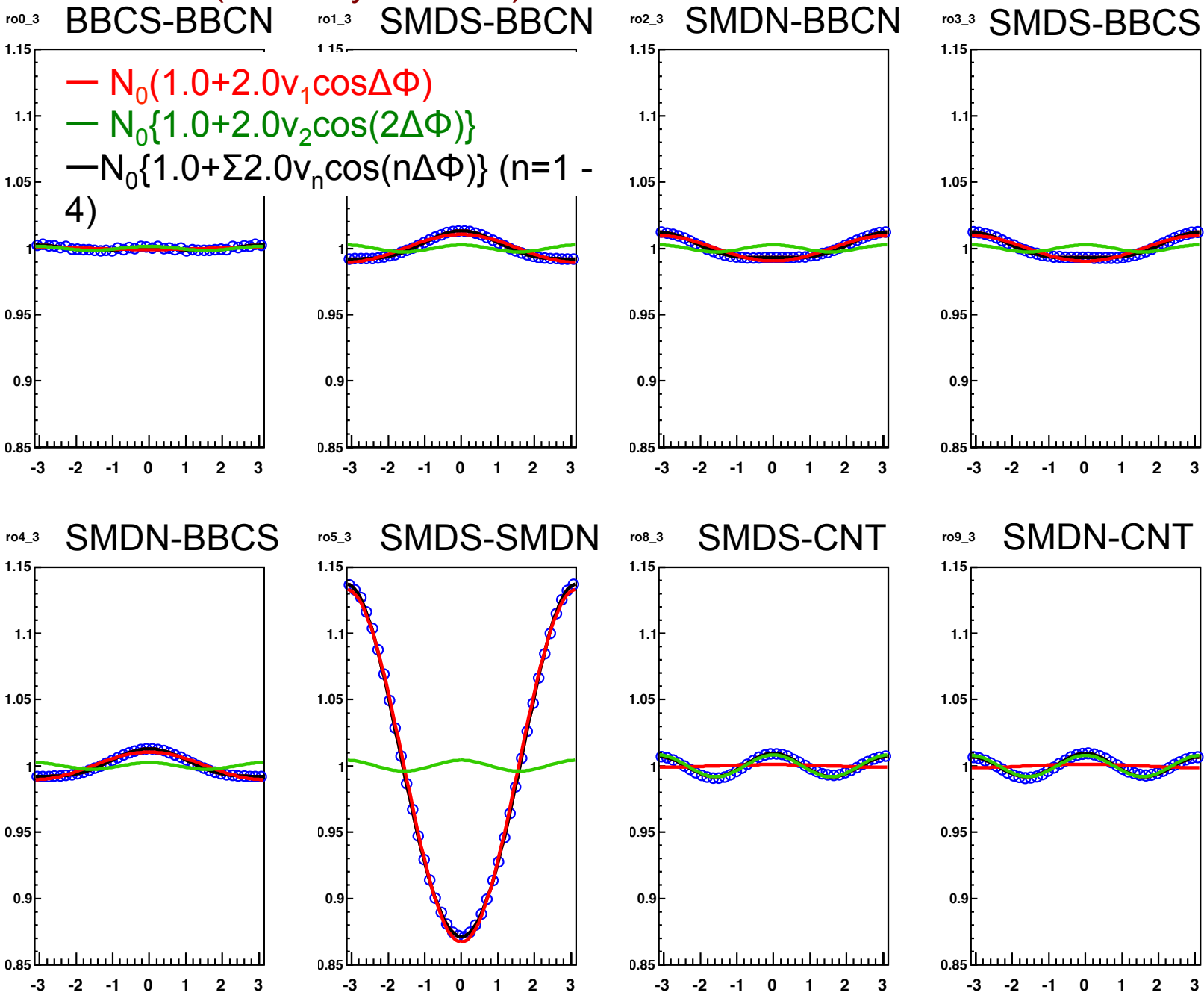
- ALICE実験で得られている結果と近い振る舞いが、PHENIX実験でも測定できることを確認
- v_1^{odd} 成分と v_1^{even} 成分のCentrality依存性を確認
- CuAu v_1^{odd} が AuAu v_1^{odd} に対して、 v_1^{odd} 方向または η 方向へのシフトを確認

- 今後

- Cu+Auデータと同様の η 領域で、Au+Auデータでも測定し、比較。
- 符号反転する η 位置のシフトをさらに検証していく必要がある。

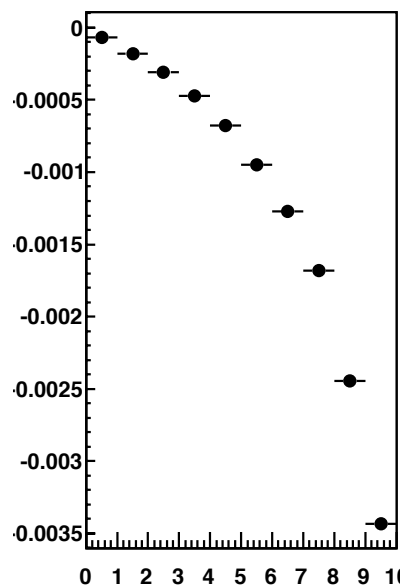
Back up

correlation function (centrality 30~40%)

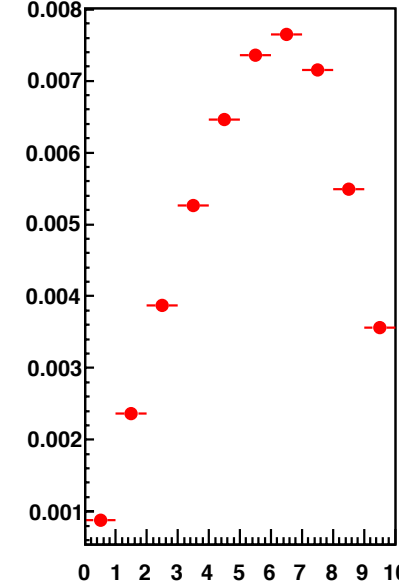


parameter v1*v1

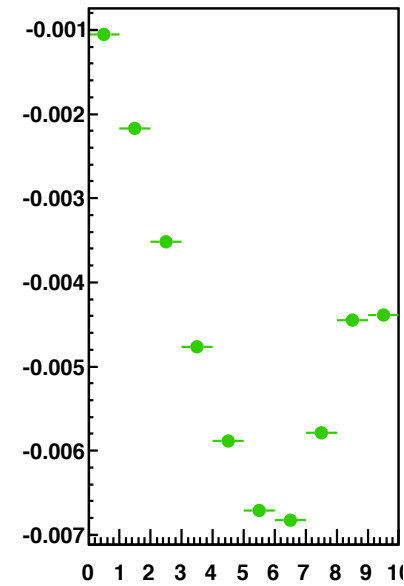
ram0_0 BBCS-BBCN



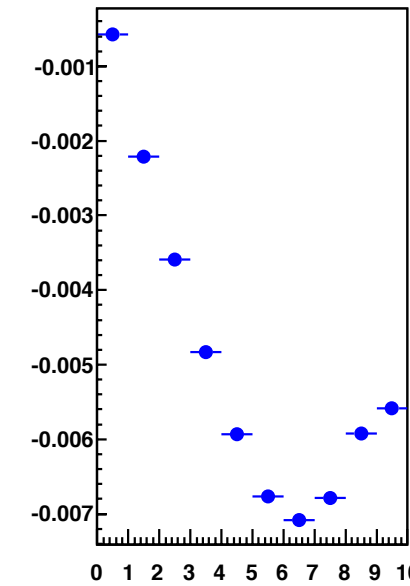
ram1_0 SMDS-BBCN



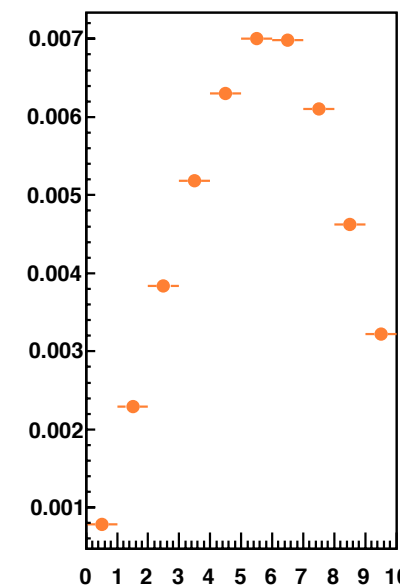
ram2_0 SMDN-BBCN



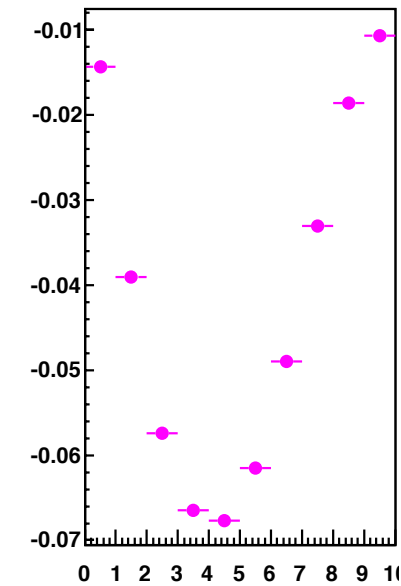
ram3_0 SMDS-BBCS



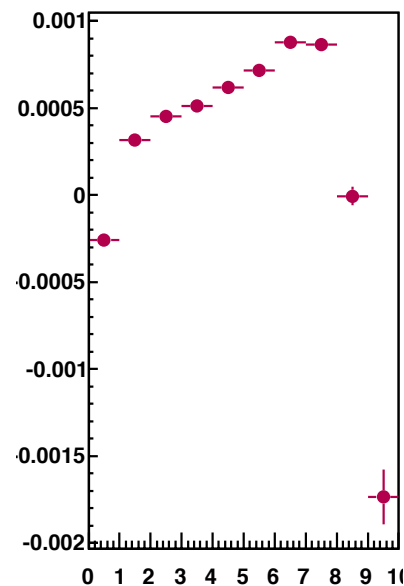
ram4_0 SMDN-BBCS



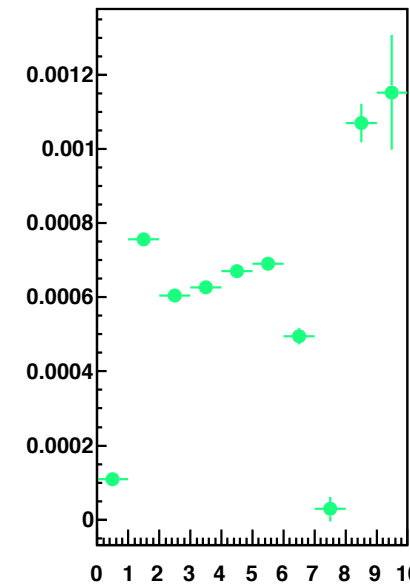
ram5_0 SMDS-SMDN



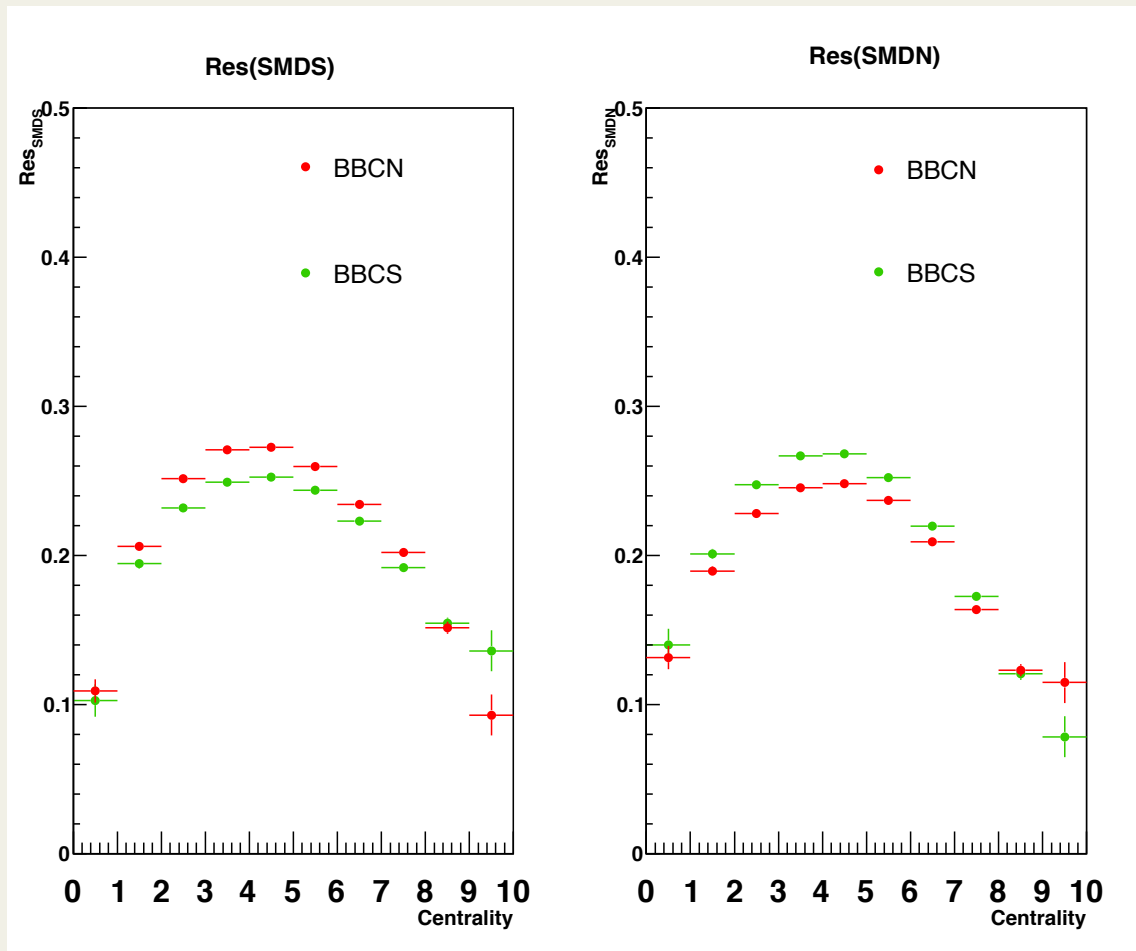
ram8_0 SMDS-CNT



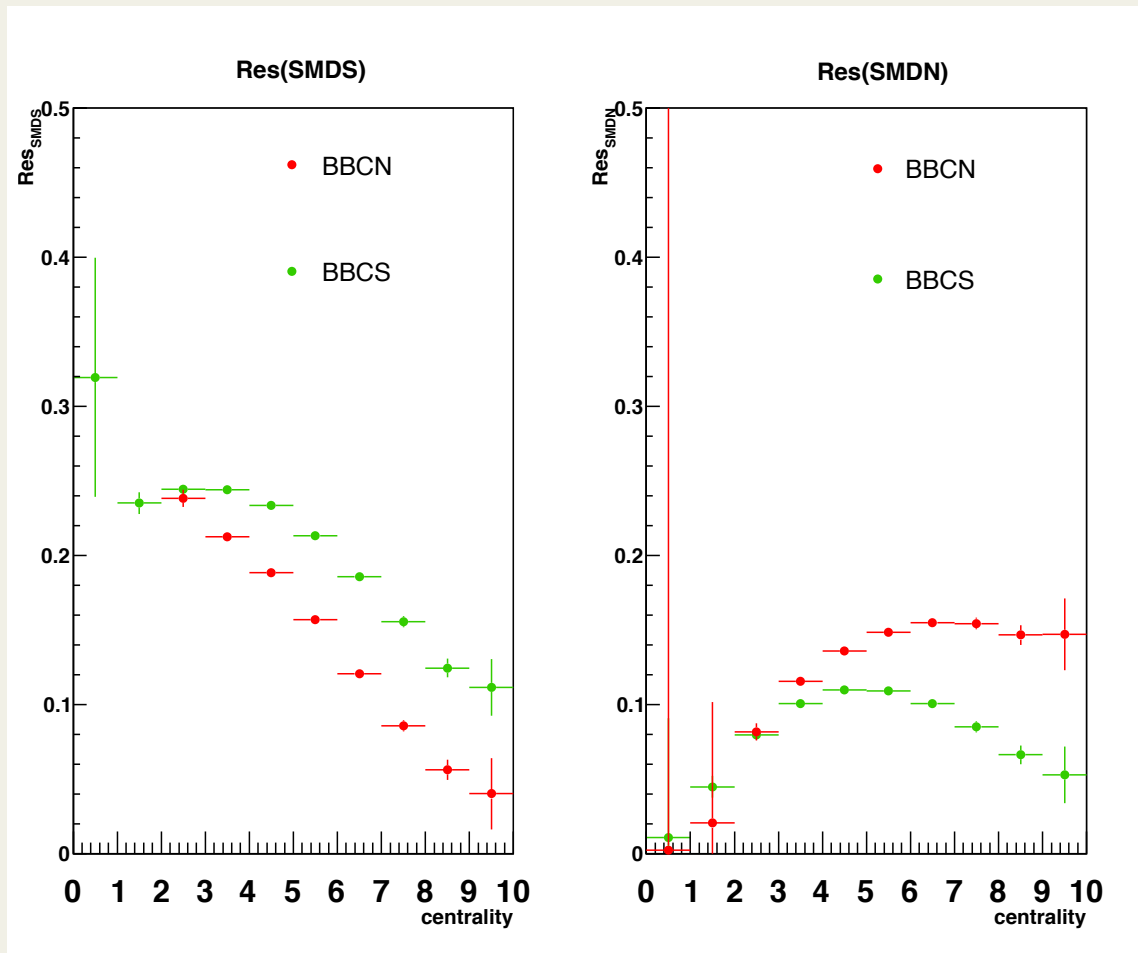
ram9_0 SMDN-CNT



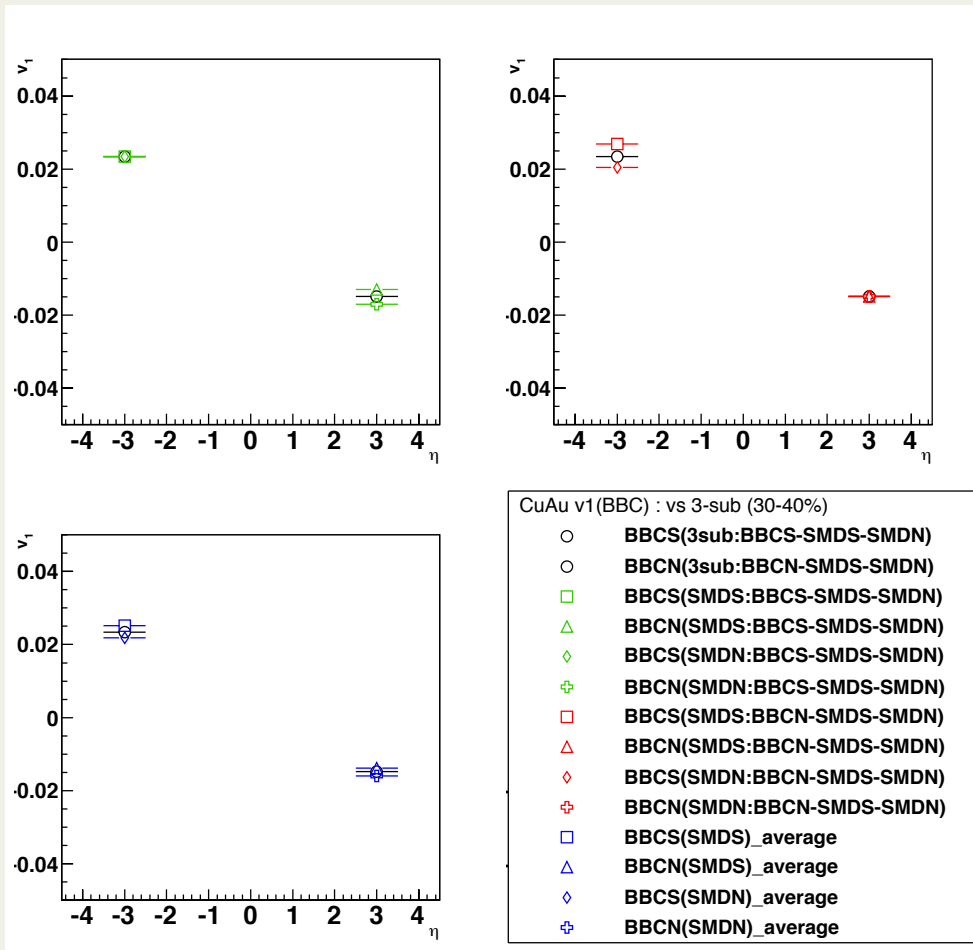
Res(SMD) in AuAu



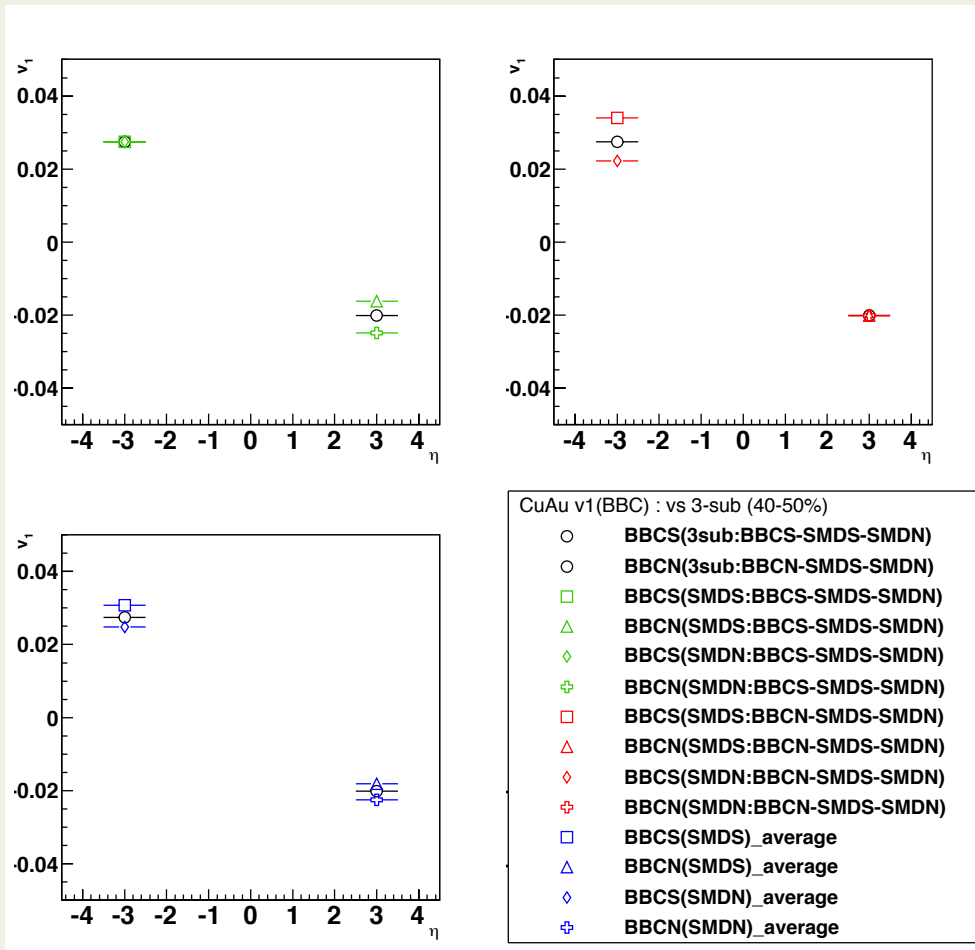
Res(SMD) in CuAu



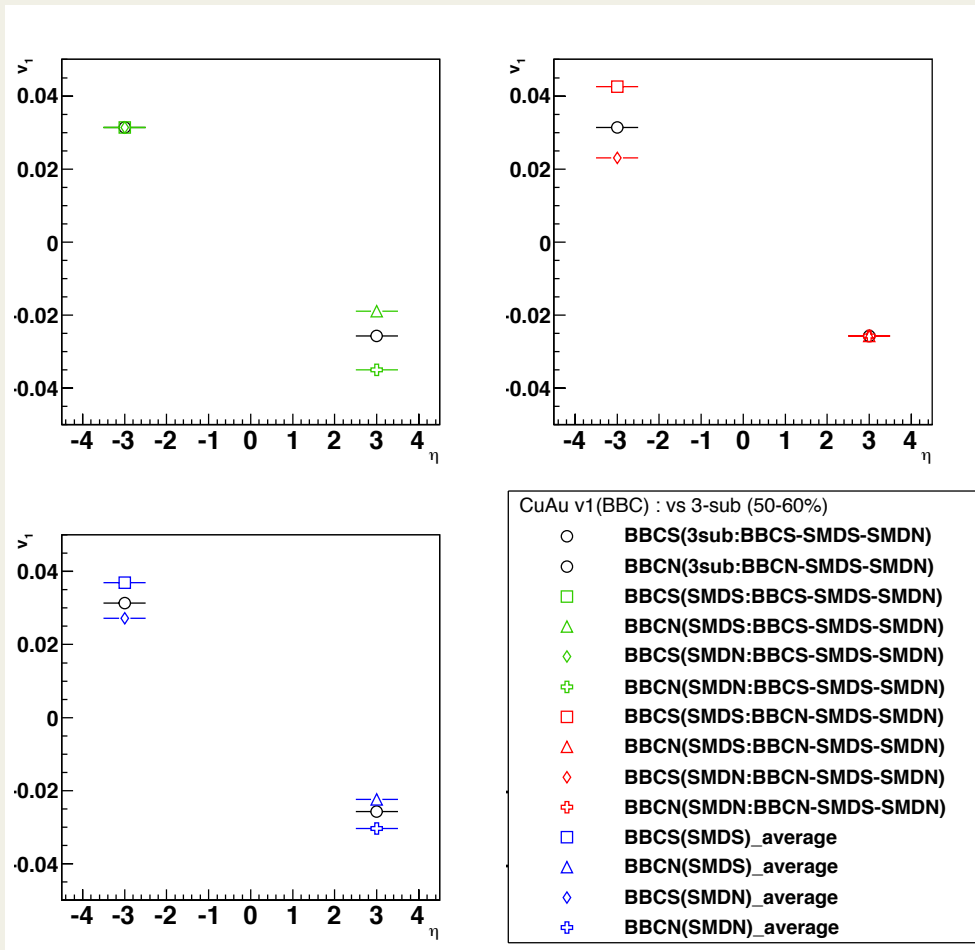
BBC 30-40% CuAu



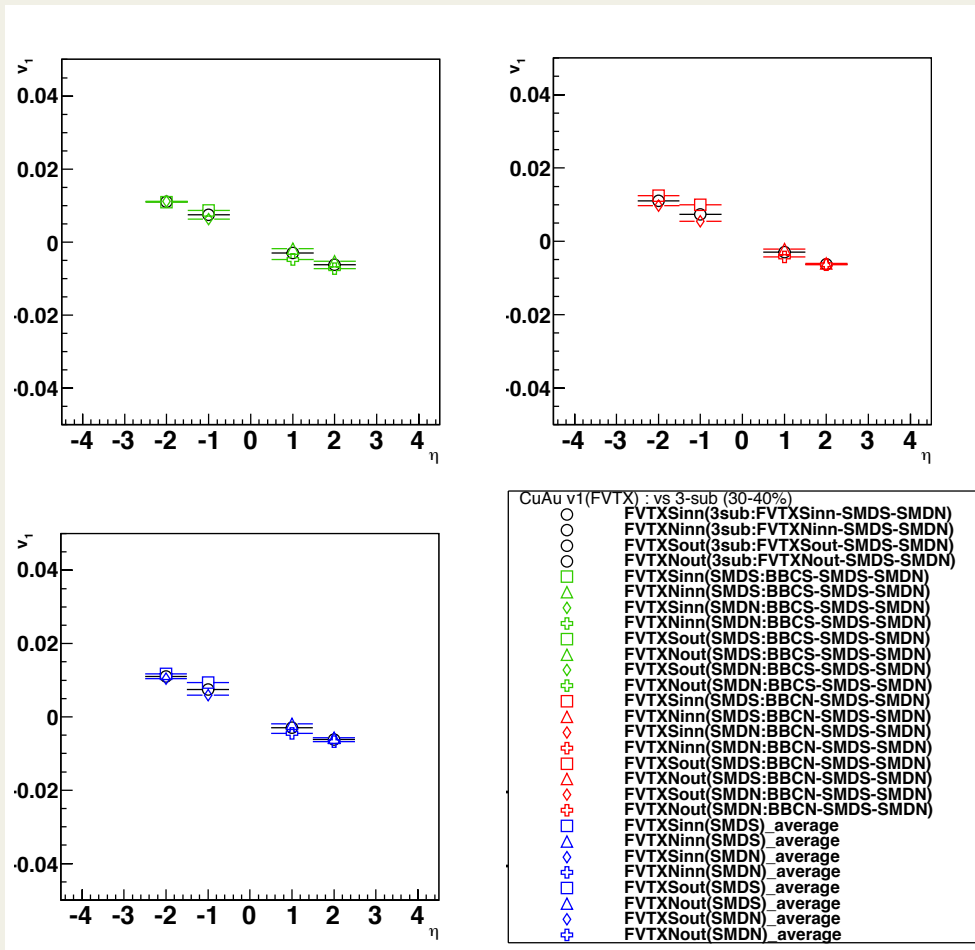
BBC 40-50% CuAu



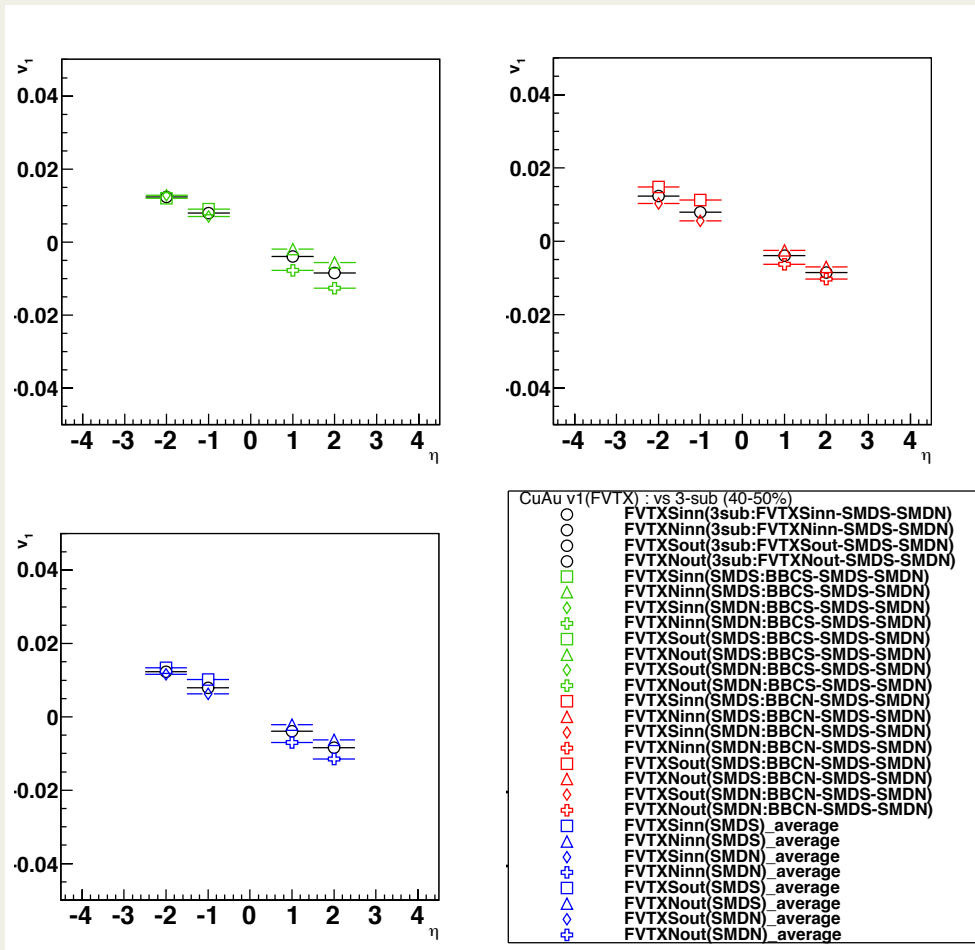
BBC 50-60% CuAu



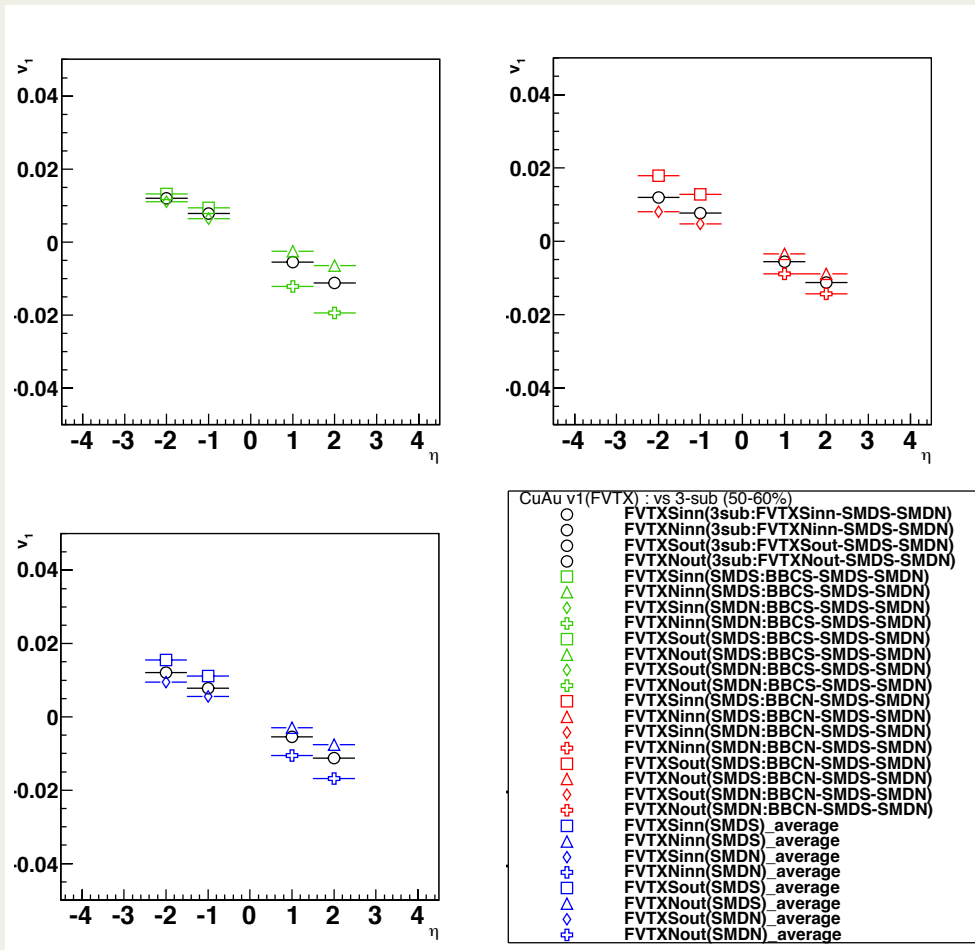
FVTX 30-40% CuAu



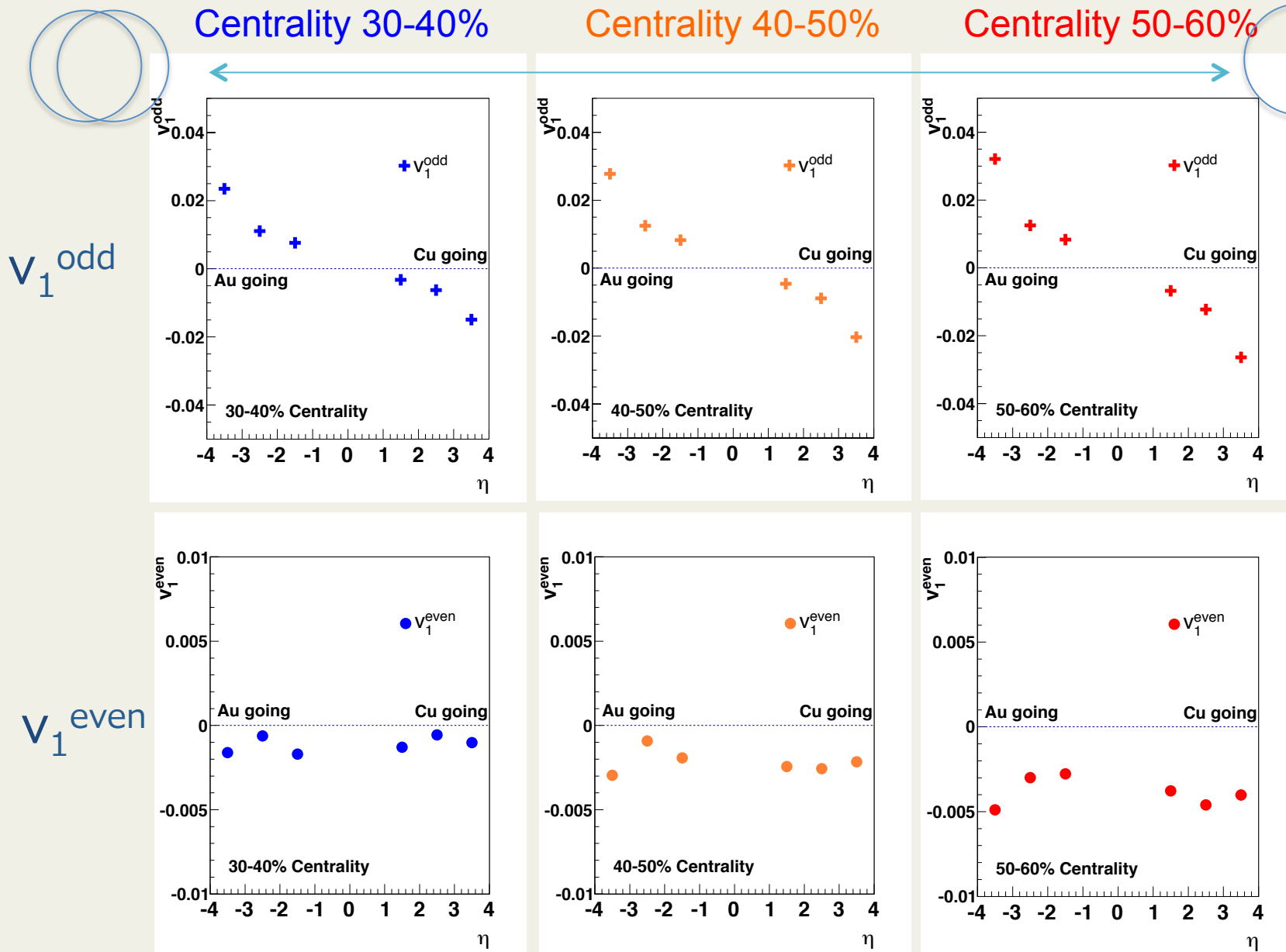
FVTX 40-50% CuAu



FVTX 50-60% CuAu

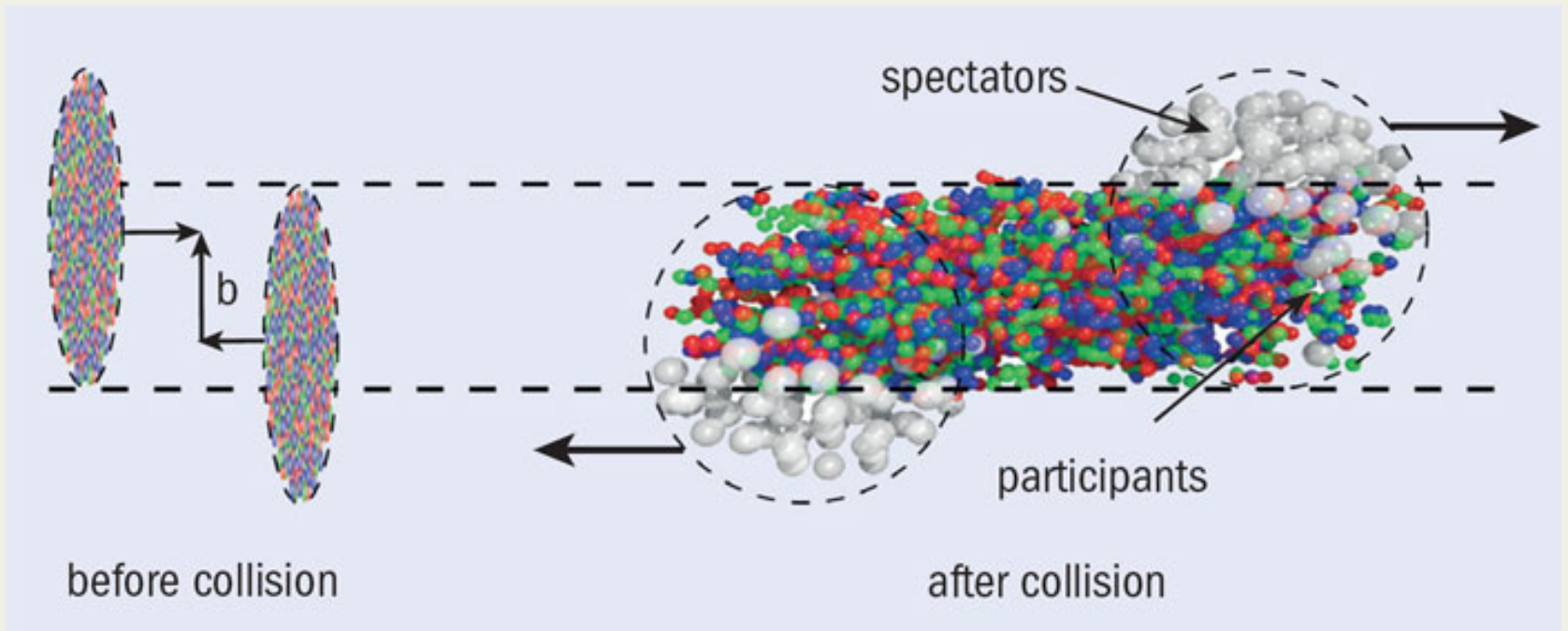


Rapidity dependence of v_1^{odd} and v_1^{even} in Cu+Au



- v_1^{odd} と v_1^{even} の Centrality 依存性を確認

Participant – Spectator 描像



- 光速近くまで加速された原子核は、ローレンツ収縮によりパンケーキ状になる。
- 非中心衝突の場合、
 - 2つの原子核の重なり合う部分…反応関与部(Participant)
 - 2つの原子核の重ならない部分…反応傍観部(Spectator)
- 反応傍観部は衝突前の運動量をほぼ保っていると考えられるため、反応関与部と反応傍観部は引きはがされる。

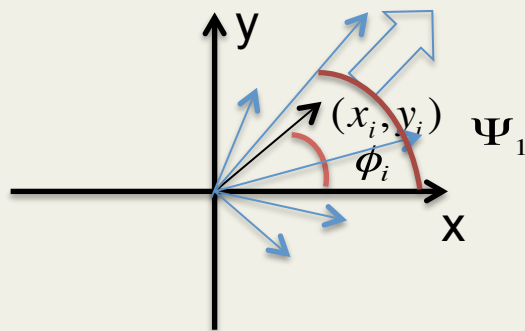
方位角異方性

- 方位角異方性の強度はイベント平面に対する放出粒子の分布をフーリエ級数展開することで得られるフーリエ係数で表される。

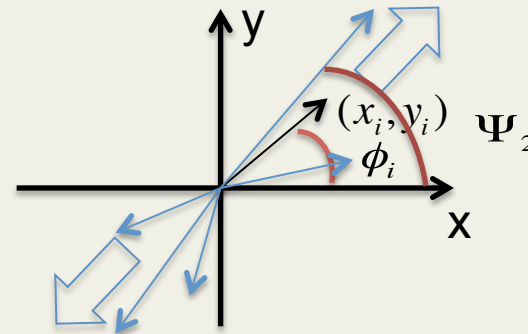
$$\frac{dN}{d(\phi - \Psi_n)} = N_0 \left(1 + \sum 2v_n \cos(n(\phi - \Psi_n)) \right)$$

$$v_n = \langle \cos(n(\phi - \Psi_n)) \rangle$$

v_1 : 指向的異方性



v_2 : 楕円的異方性

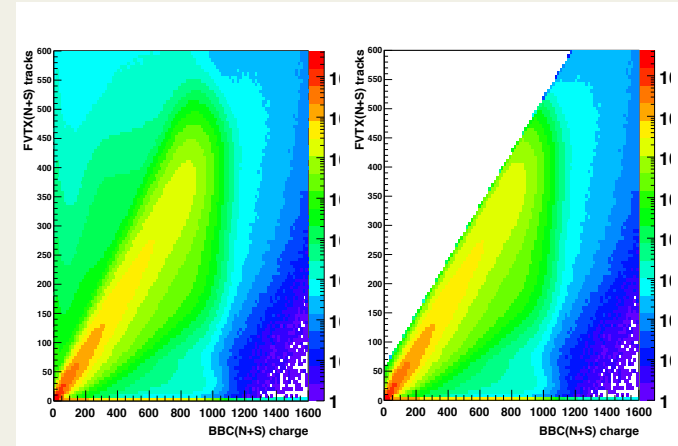


Analysis Issues (~2 slides)

- What were the main issues in the analysis?

Check the quality of FVTX tracks

FVTX track



BBC charge

- What was the resolution for these issues?

I asked FVTX expert about it.

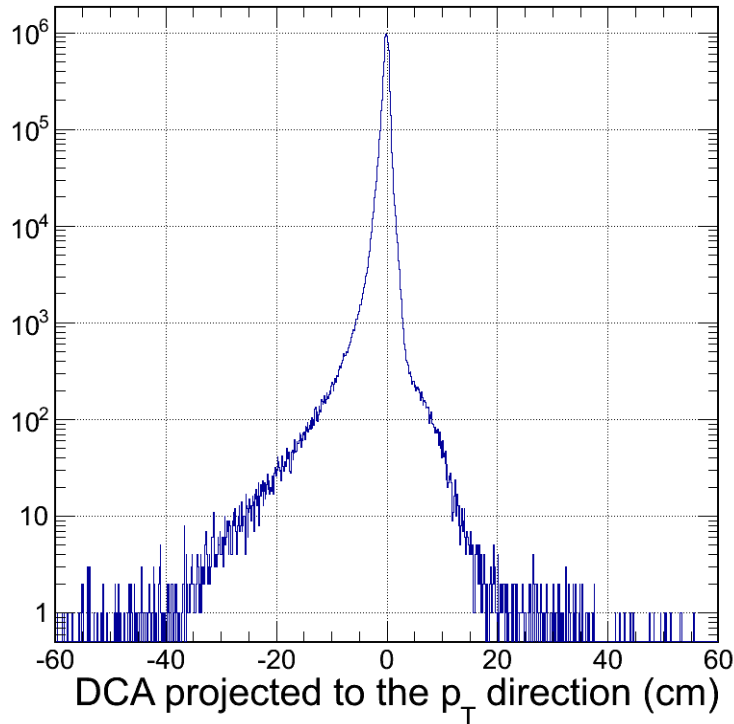
1. The FVTX track occupancy ~3%
2. No hot channel
3. The number of fake tracks ... very small
4. The fake tracks (we can see in FVTX tracks vs BBC charge) are not correlated with hits in MuTr systems

Estimating BG

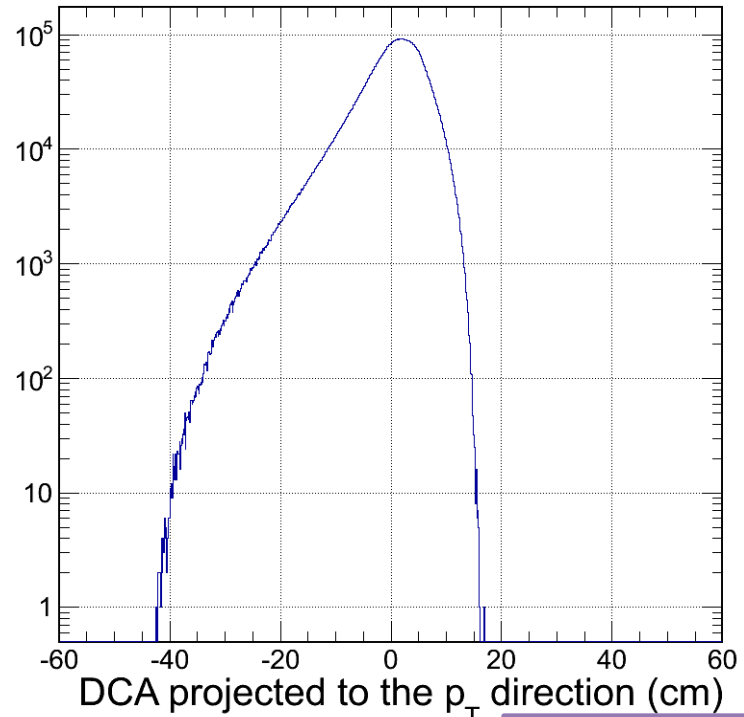
✓ respect to BBC vertex

✓ respect to a fake vertex

DCA with respect to BBC vertex $(0,0, Z_{\text{BBC}})$, $1 < |\eta_{\text{FVTX}}| < 3$



DCA with respect to a fake vertex $(0,0, \text{random})$, $1 < |\eta_{\text{FVTX}}| < 3$



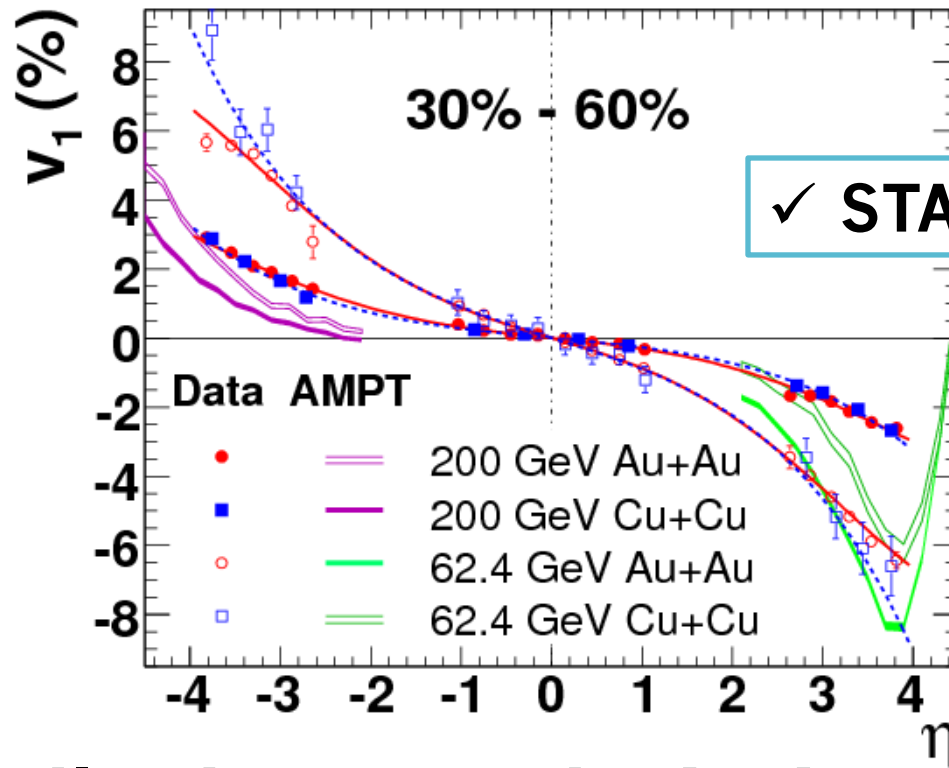
Jin HUANG's plot

- ✓ 97.5% of tracks fall within $|DCA_R| < 2\text{cm}$
- ✓ The order of BG is too small

Relation to Previous Analyses

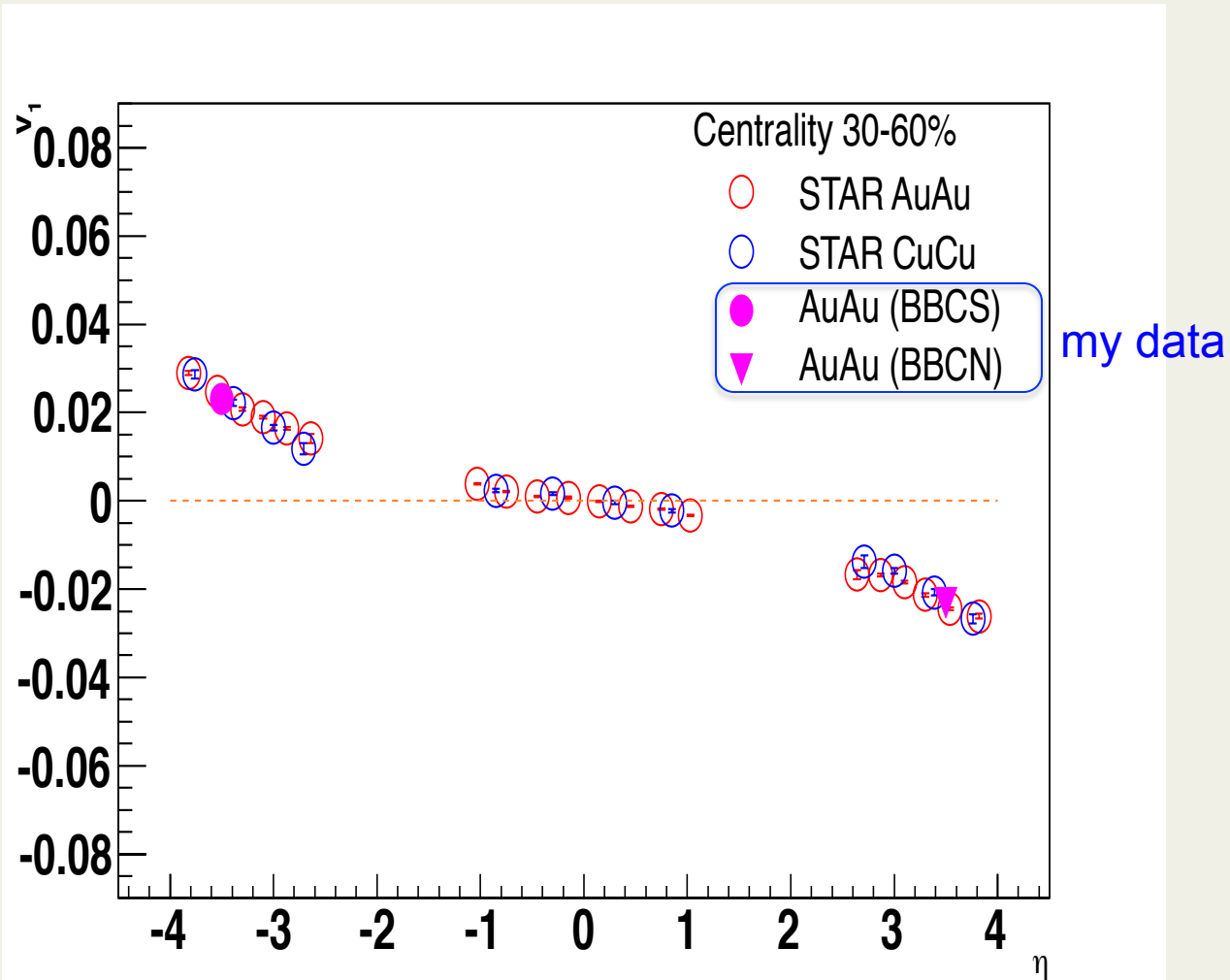
- Are there any non-PHENIX results for this observable? (STAR's result)

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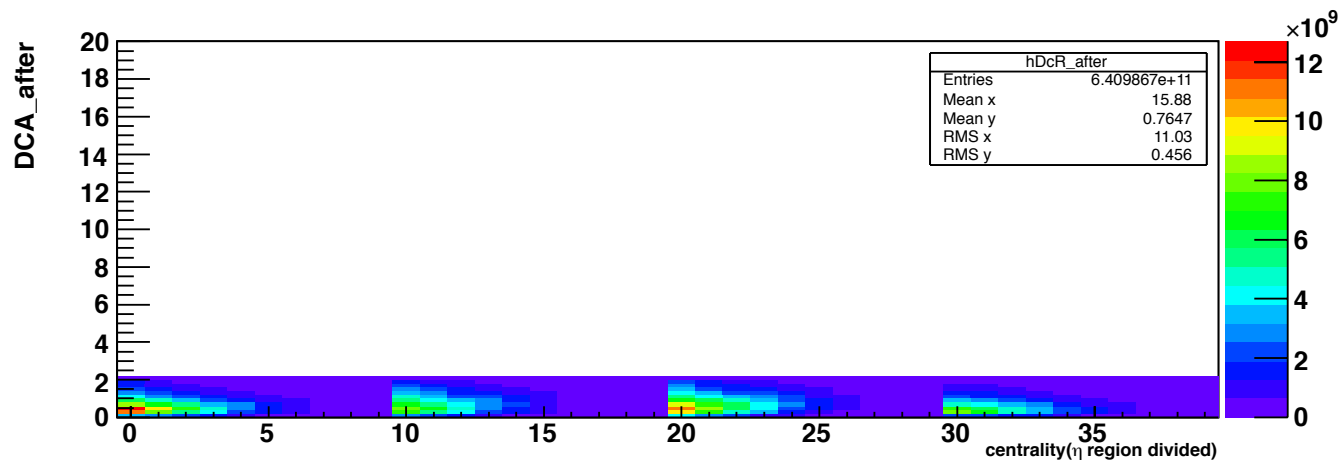
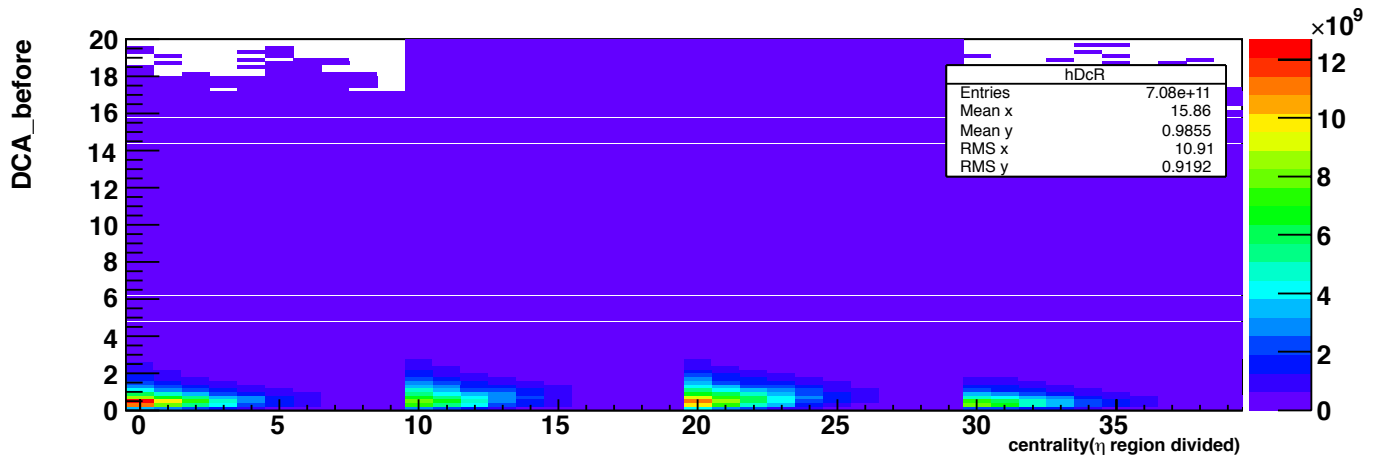
- It's similar between in AuAu and in CuCu

Comparison with STAR Results



- It's similar to STAR's result in $|\eta|=3.5$

DCA distribution



RUN11 Au+Au 200GeV with VTX standalone tracks

Hiroshi Nakagomi's analysis
from this master thesis

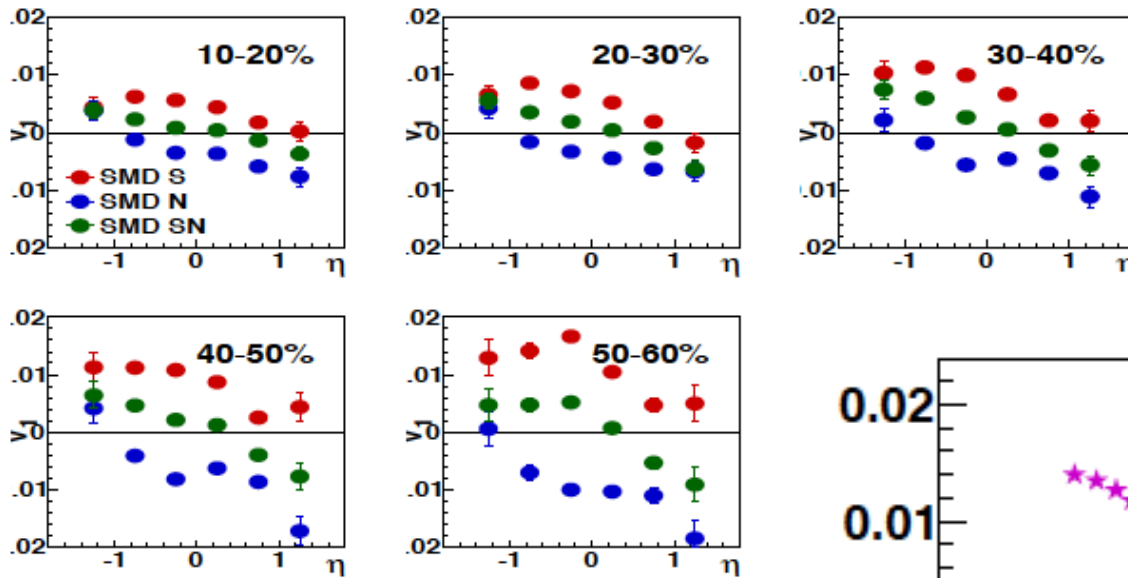


図 4.8 v_1 の η 依存性

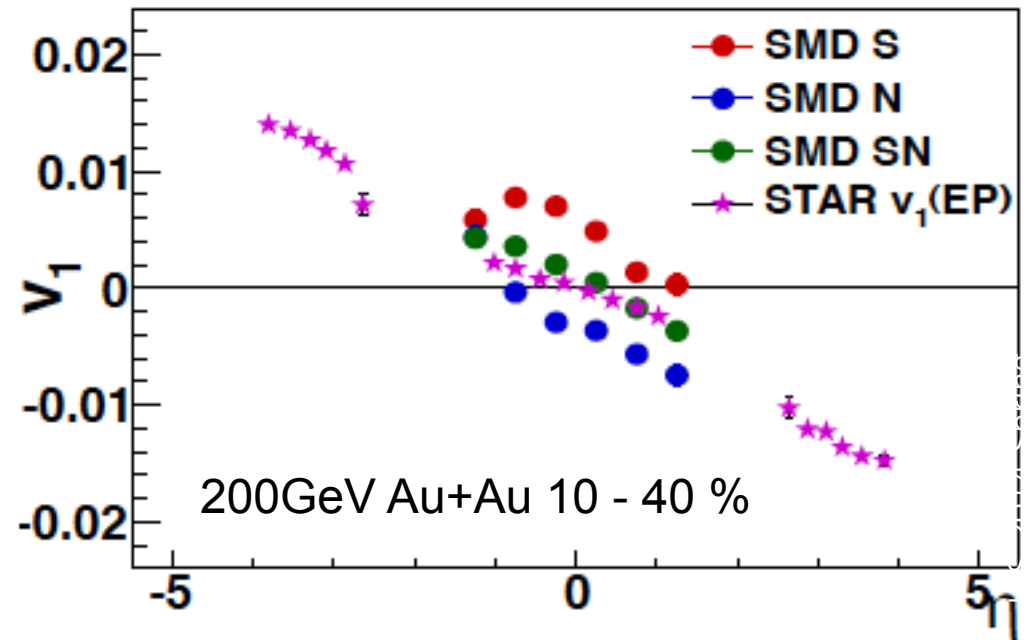
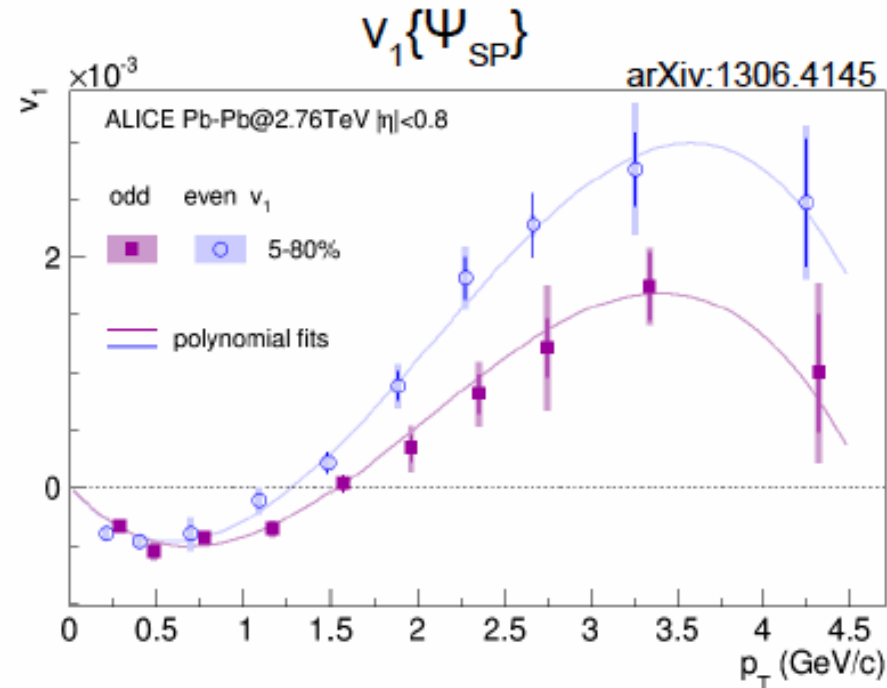
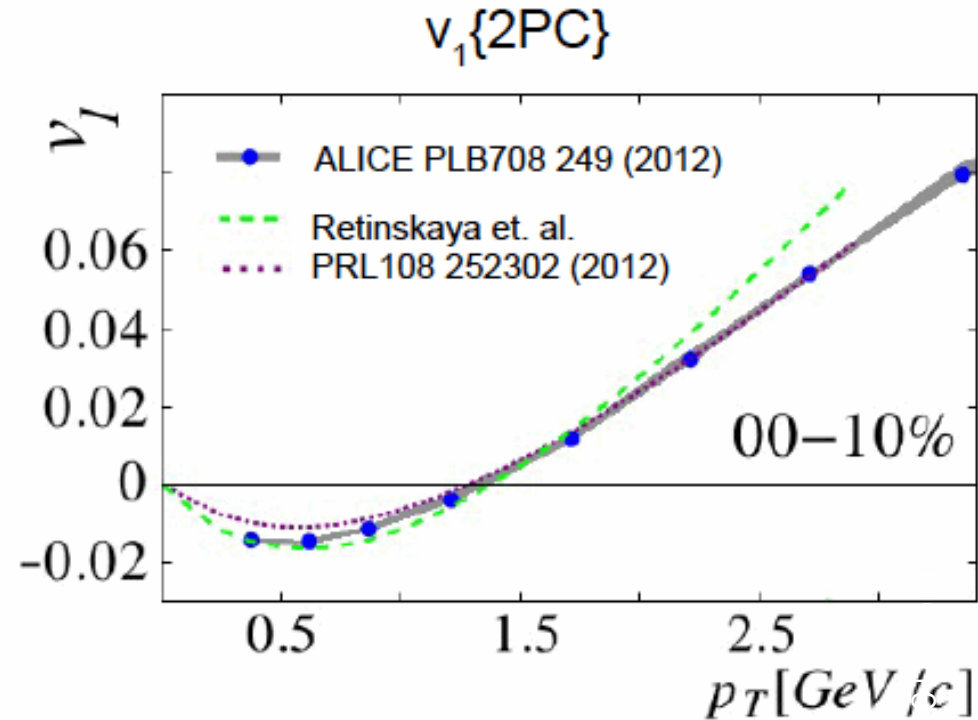


図 4.7 STAR 実験で測定された v_1 と比較したプロット

p_T dependence of v_1



PRL 111 (2013) 232302



Amazing similarities of $v_1(p_T)$ shapes for these 3 cases, while $v_1\{2PC\}$ is much larger by more than factor of 10.