Azimuthal Anisotropy in central d+Au collisions at $\sqrt{S_{NN}}$=200GeV measured in PHENIX at the RHIC

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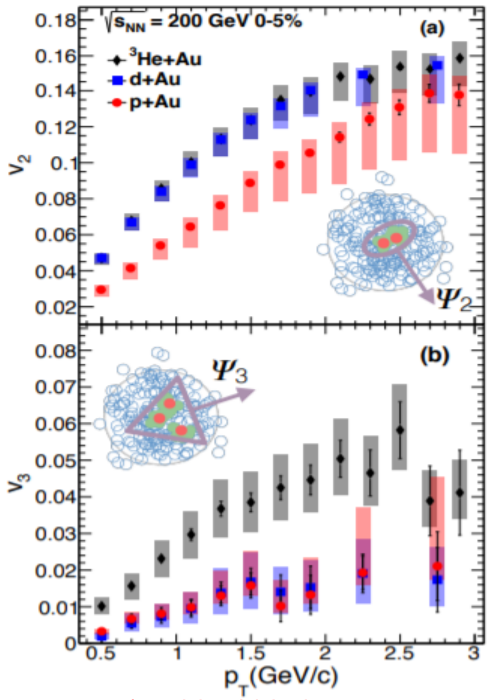
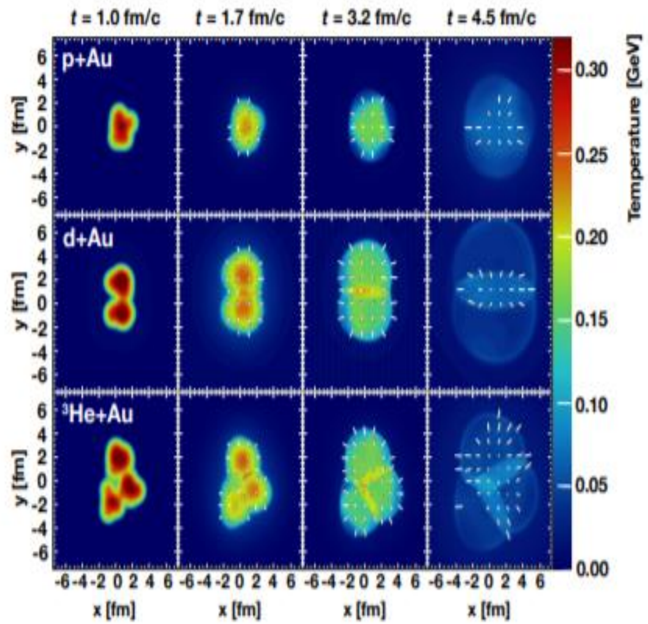
Contents

Introduction: Small System

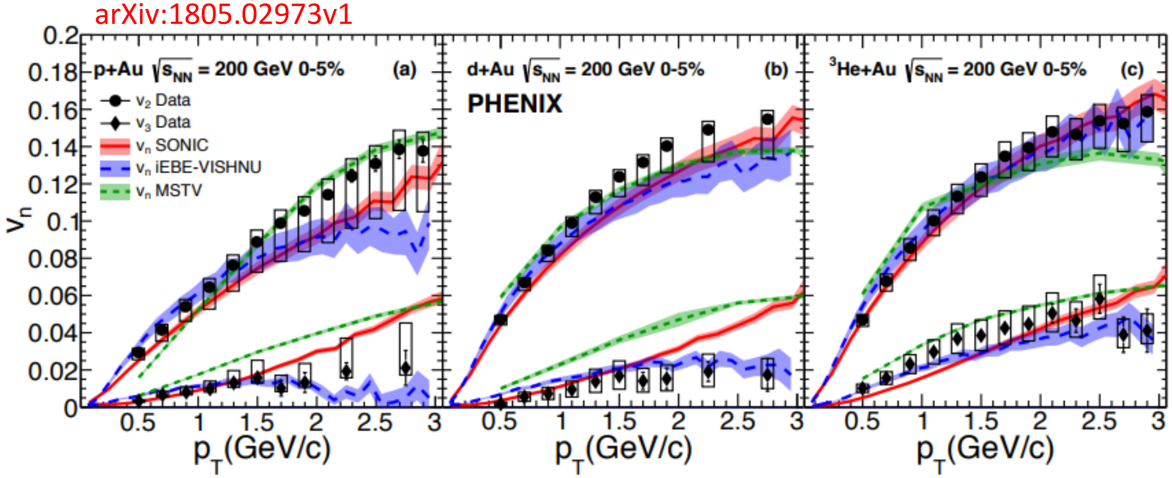
arXiv:1805.02973v1





Glauber model MC + Hydro dynamic revolution

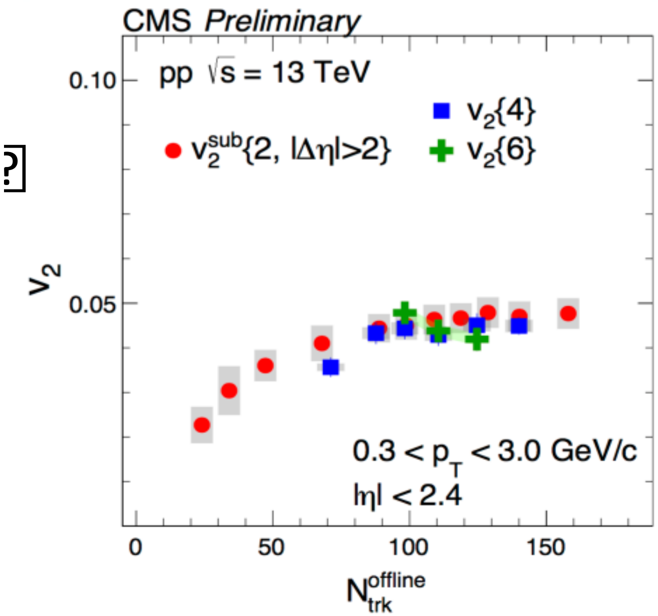
arXiv:1805.02973v1



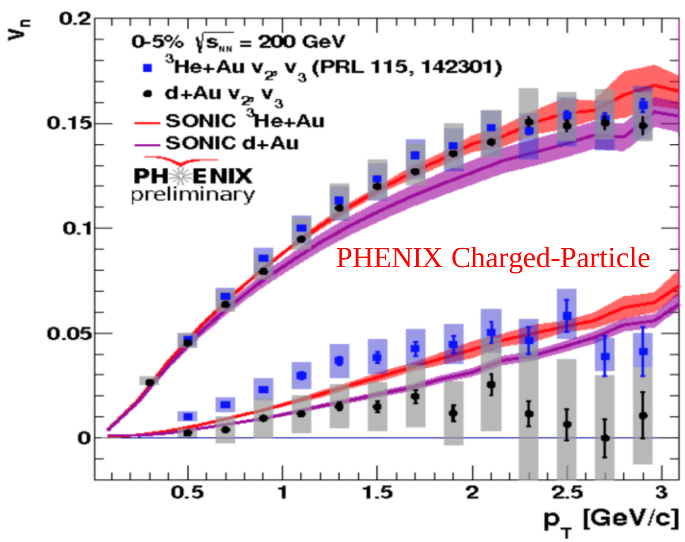
- v_2, v_3 are strongly correlated with initial geometry (pAu, dAu, HeAu : 200GeV)
- Comparison to Hydro dynamic model (SONIC, IEBE-VISHNU) and Initial state momentum correlation model (MSTV)
- Small system collective behavior is still need to be investigated

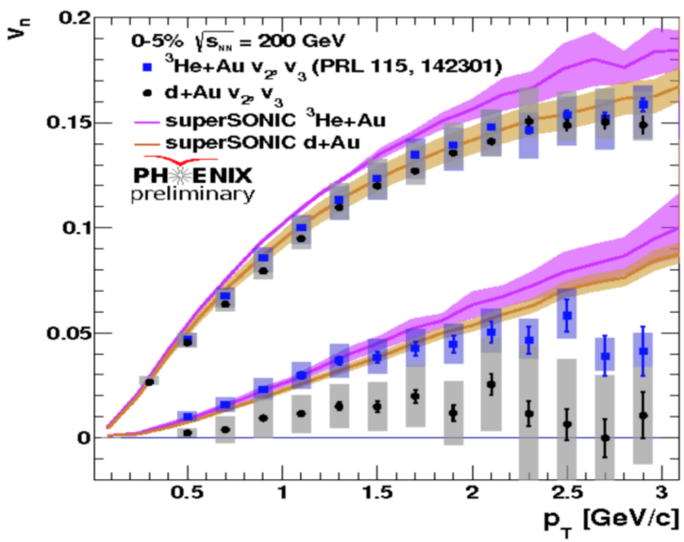
Introduction: Small System

- RHIC and LHC Showed in small systems (d+Au, p+Pb, pp) have similar collective behavior of heavy ion collision
- π^0 is reconstructed by 2 γ, measured by EM-calorimeter (easy to identify up to high Pt)
- Run16dAu200GeV (~2Bilion events)

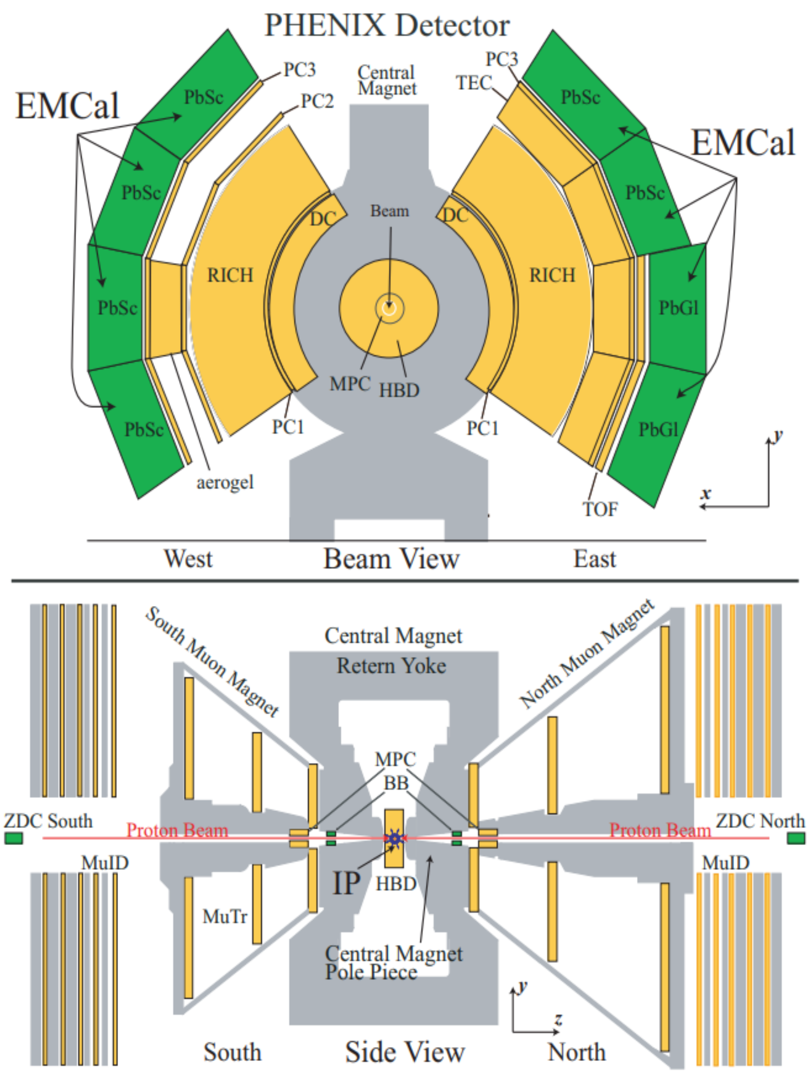


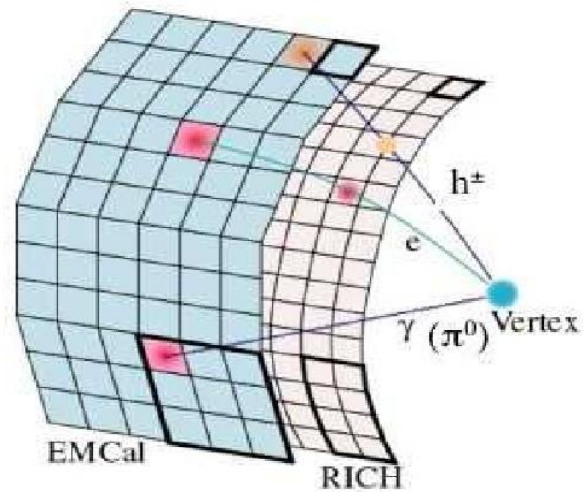
PRL 115, 142301





Detector Setup





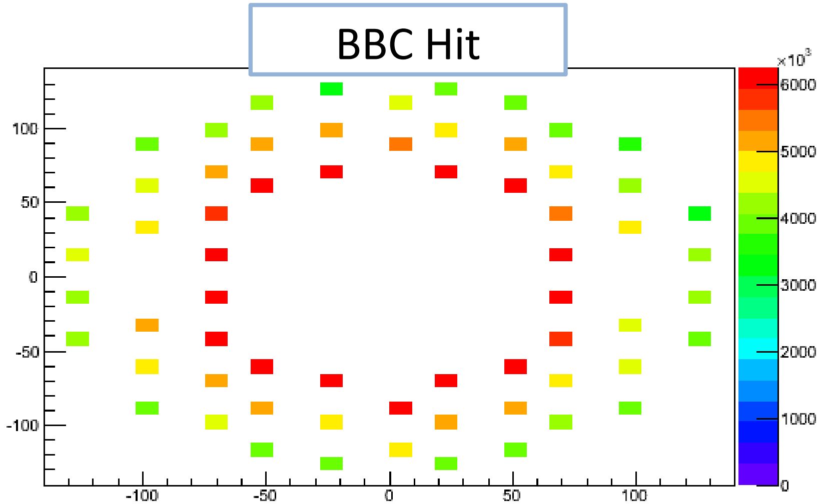
- EMCal (Central arm): $-0.5 < \eta < 0.5$: π^0
  - Consist of 8 sectors
  - Each sectors have 36x72 (48x96) channels

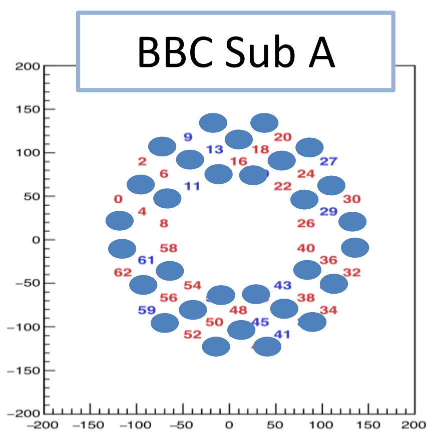
- BBC: $-3.8 < \eta < -3.1$
- FVTX: $-2.5 < \eta < -1.5$
- MPCEX: $-3.8 < \eta < -3.1$

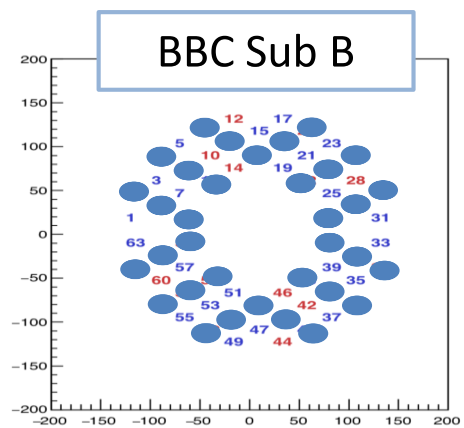
Reaction-Plane

- BBC used main Reaction plane detector because of statistics
- **DataSet : Run16 d+Au 200GeV MB trigger**

Event plane calibration : BBC Setup







- We divided BBCS into 2 sub part keeping its symmetric over φ angle
- Calibrated each sub event EP, crucial to calculate EP resolution

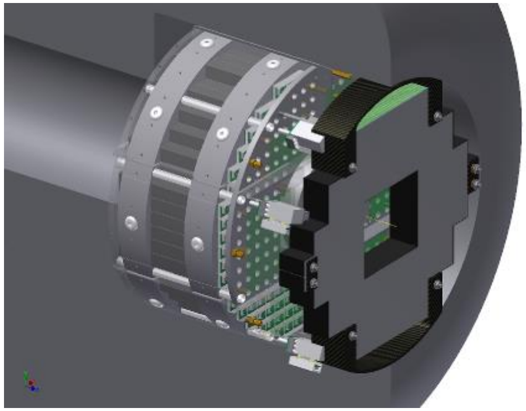
$$Q_n = |Q_n| e^{in\Psi_n} \equiv \frac{1}{N} \sum_j e^{in\phi_j}$$

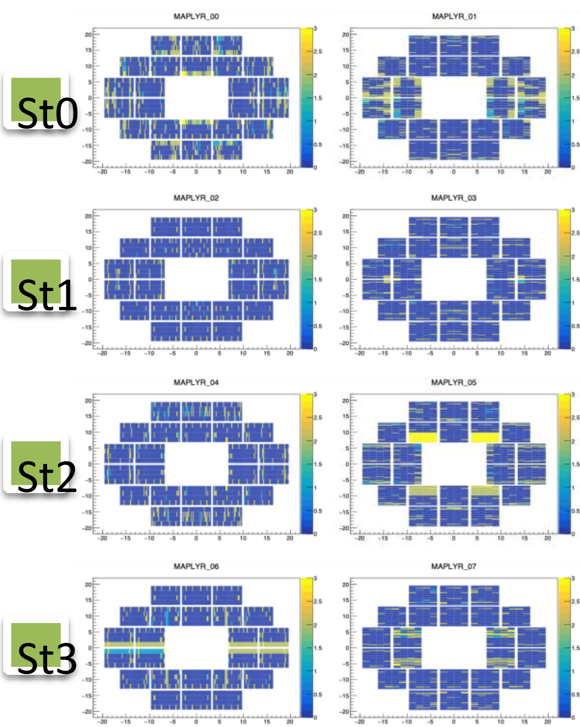
$Q_x = Re(Q_n)$, $Q_y = Im(Q_n)$

- Raw Q vectors are biased by detector acceptance, it needs Re-centering, Twisting, Rescaling, Flattening correction

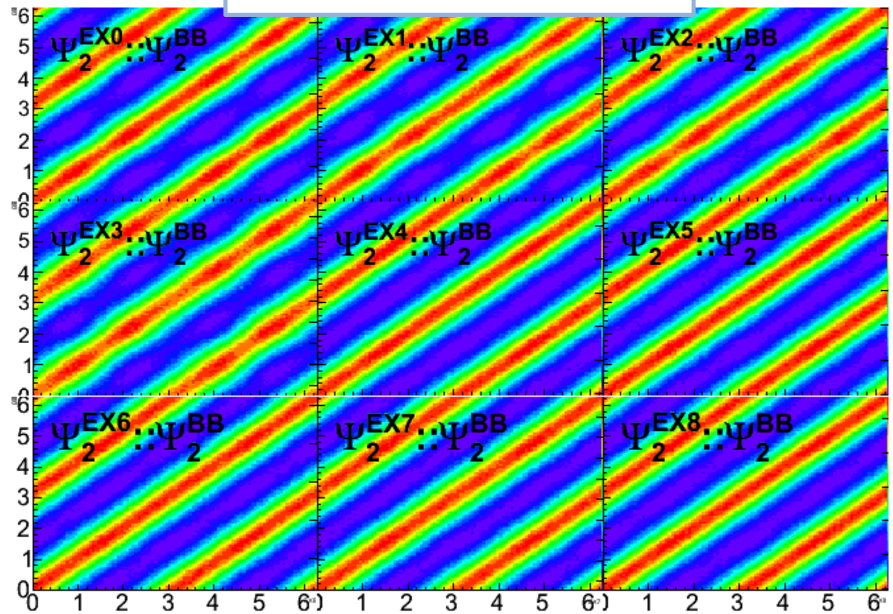
64 channels with Chrenkov radiator + PMT

Event plane calibration : MPCEX Setup



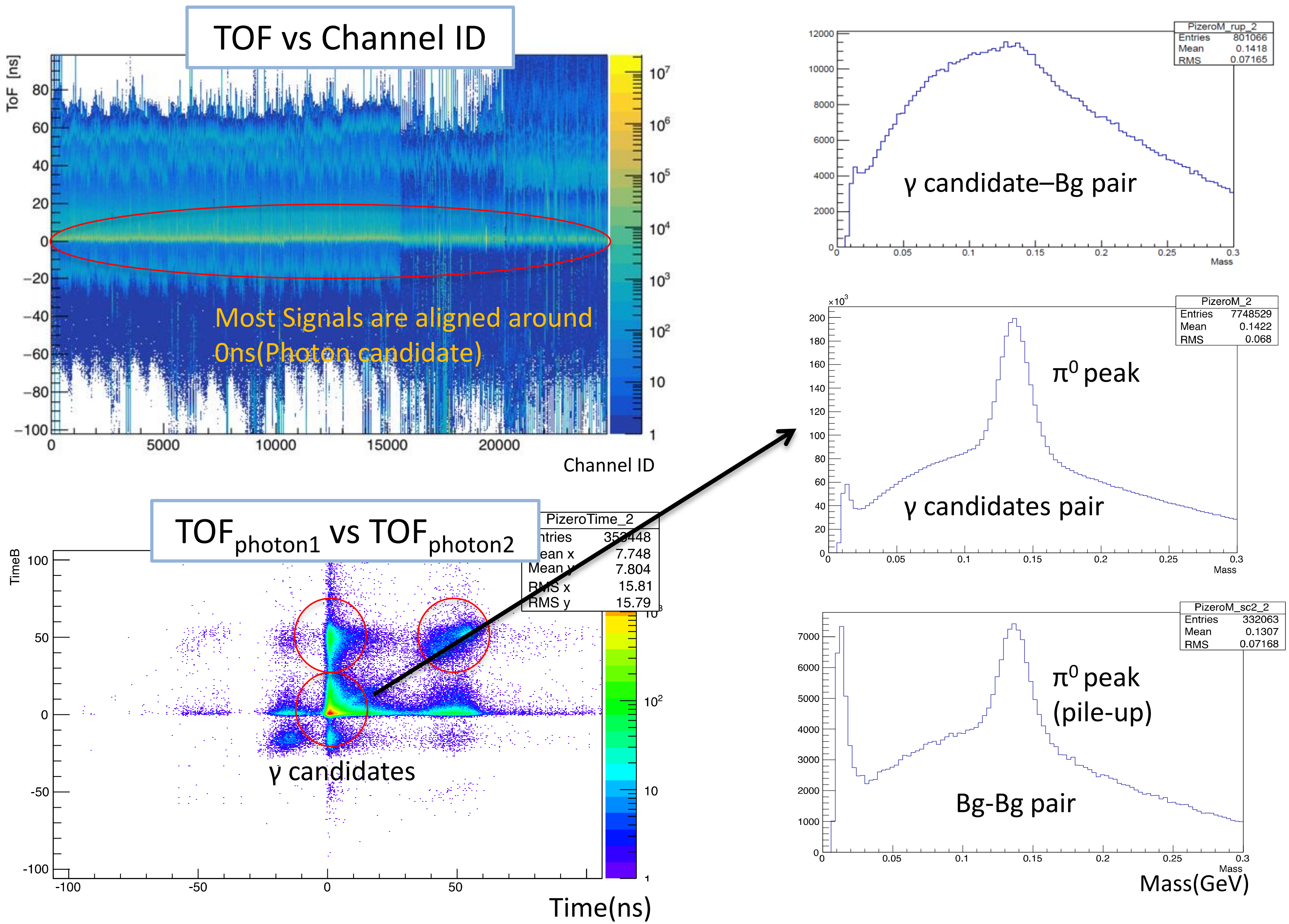


BBC EP vs MPCEX EP

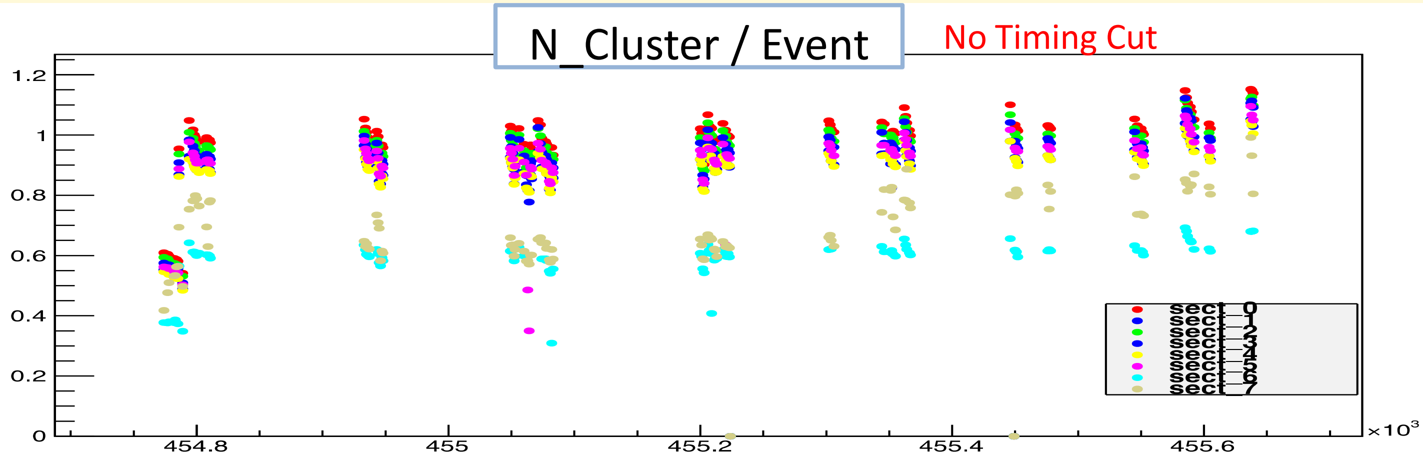


- MPCEX has 8 layers of silicon EM shower calorimeter that sampling shower energy induced by tungsten layer
- Very good spacial discriminating, less statics for flow measurement
- Correlation with BBC EP after re-centering and flattening calibration

EMCal calibration: Timing calibration

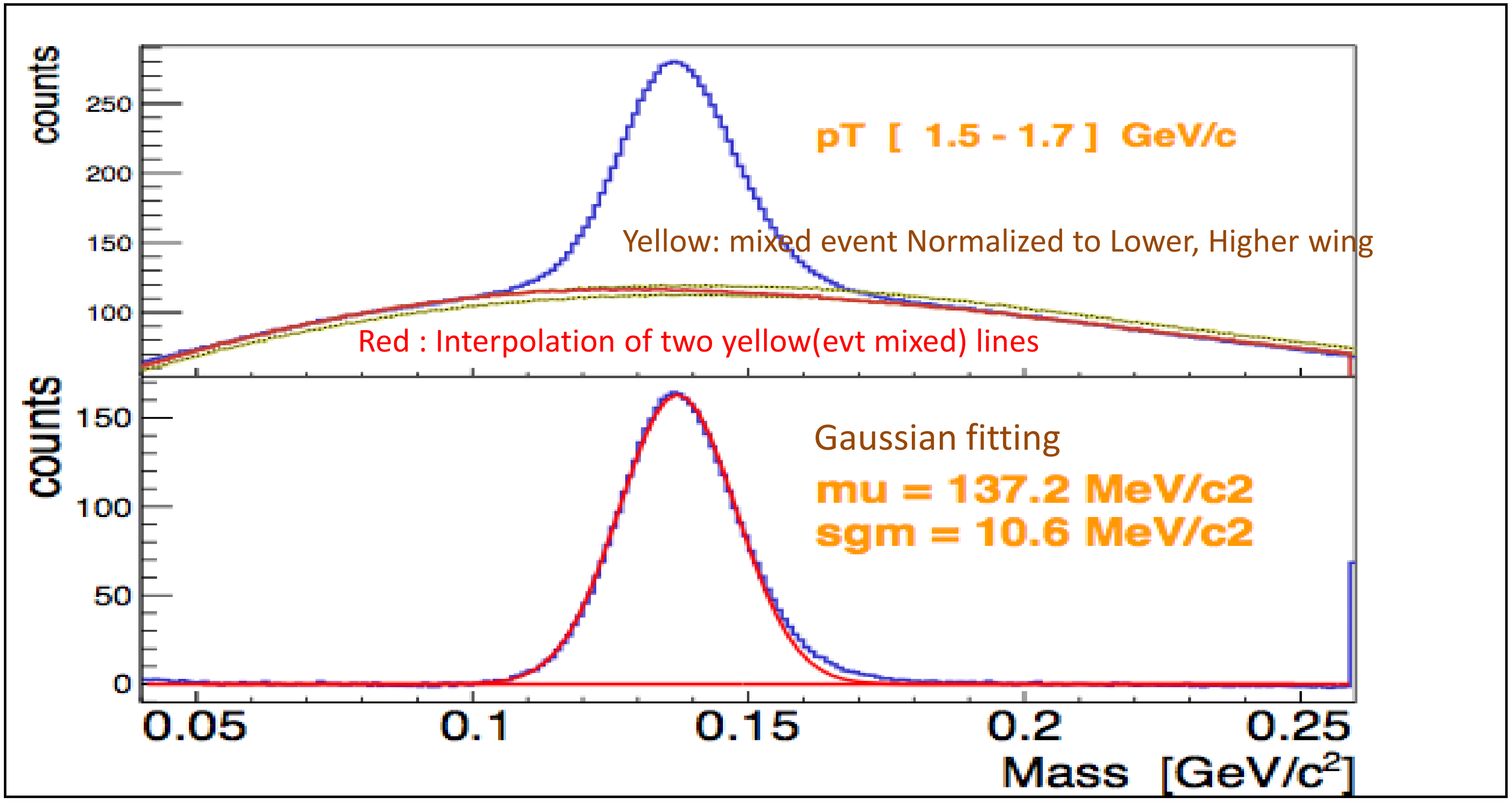


RunQA : # of EMCal Cluster per Event(Run16dAu200)



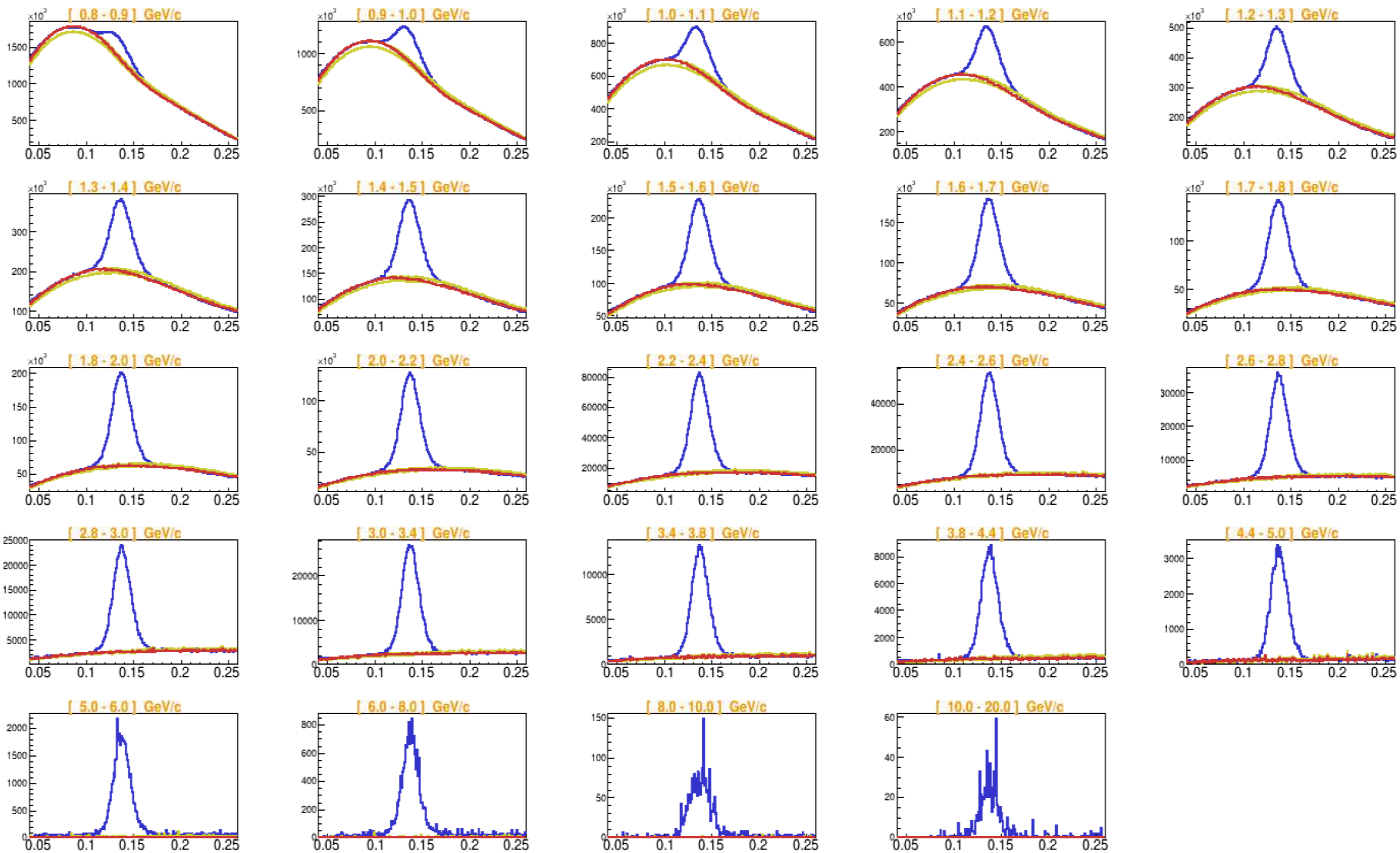
- We Applied 5ns timing cut on Run16dAu200GeV and 15ns on Run15pp200GeV because pp data has worse timing resolution (~5ns) (Run15pp data has worse timing resolution because of worse timing resolution of BBC)
- Number of cluster per events become flatten after timing cut, implying it effectively backgrounds by pile-up

Signal Extraction : Background Estimation

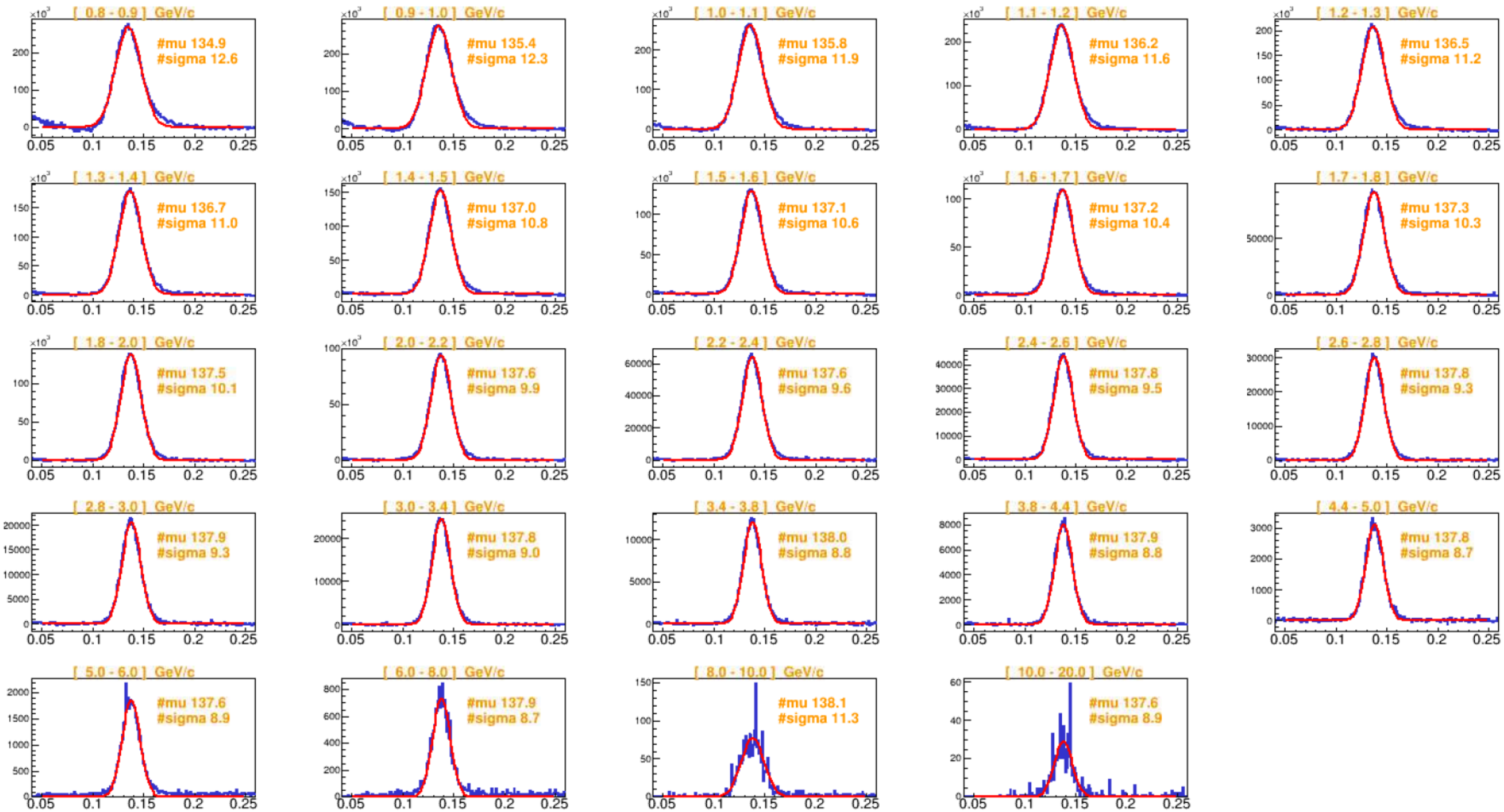


- We made event mixed background to estimate background distribution but when it has small disagreement depends on which area used for normalization
- To minimize error, we mixed 2 normalization by interpolation one is by lower tail and the other one is by high tail
- Extracted S/B ratio based on this study
- Tested effect of different normalization as systematic study

Signal Extraction : Background Estimation(dAu200)

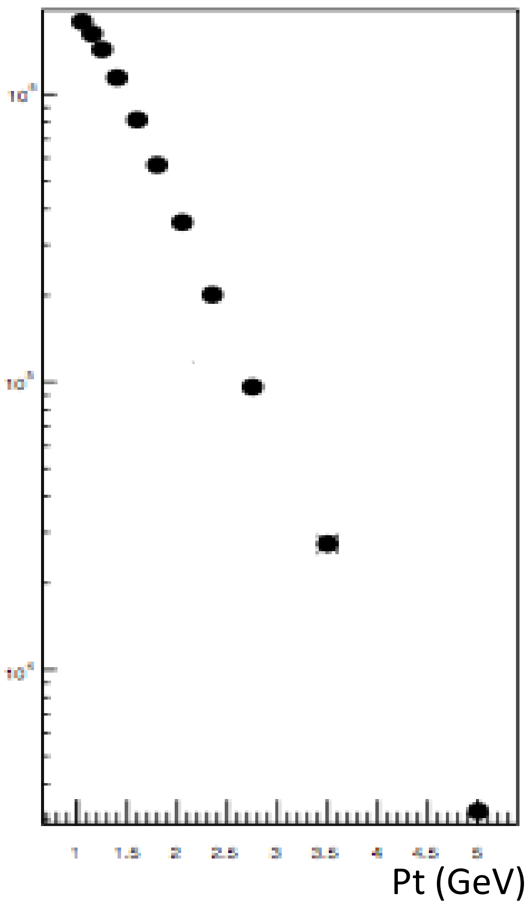


Signal Extraction : After subtraction(dAu200)

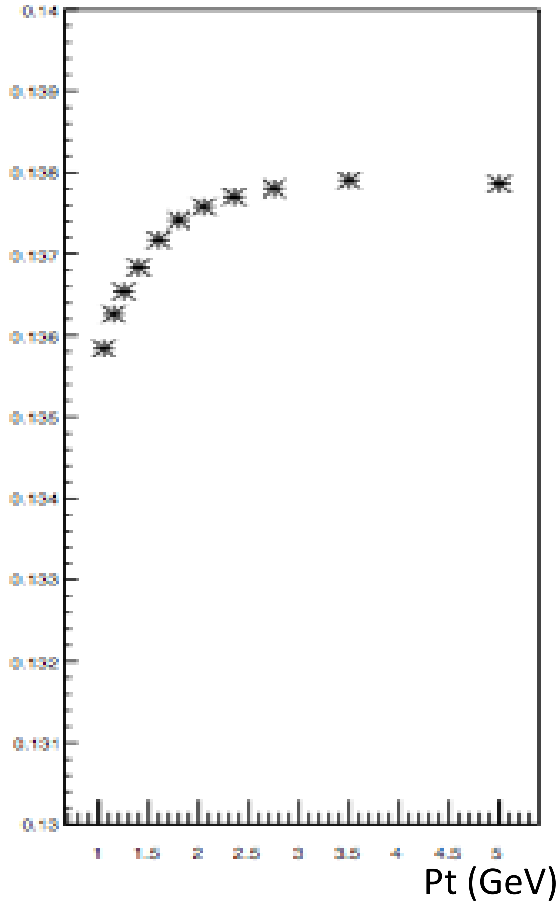


π⁰ Raw dN/dPt, Mass Peak, Mass resolution

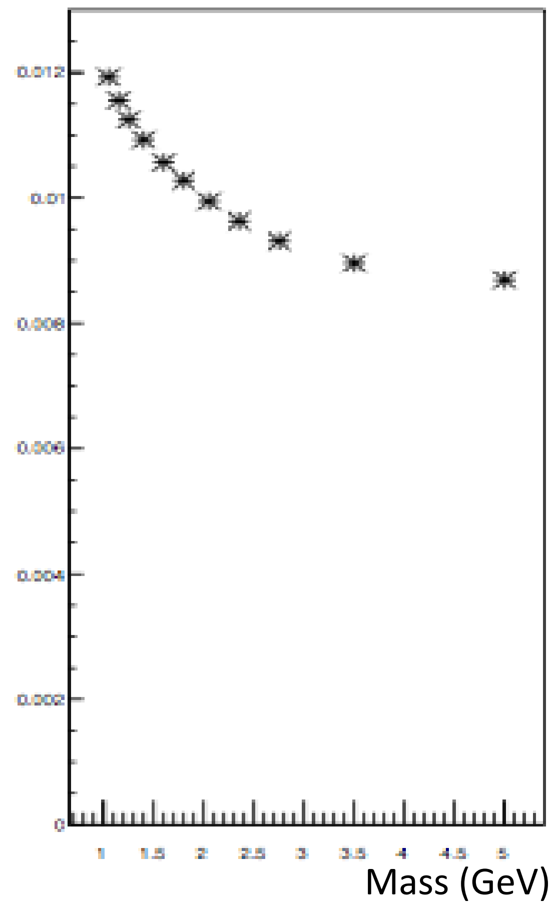
π^0 Raw dN/dPt



Mass Peak

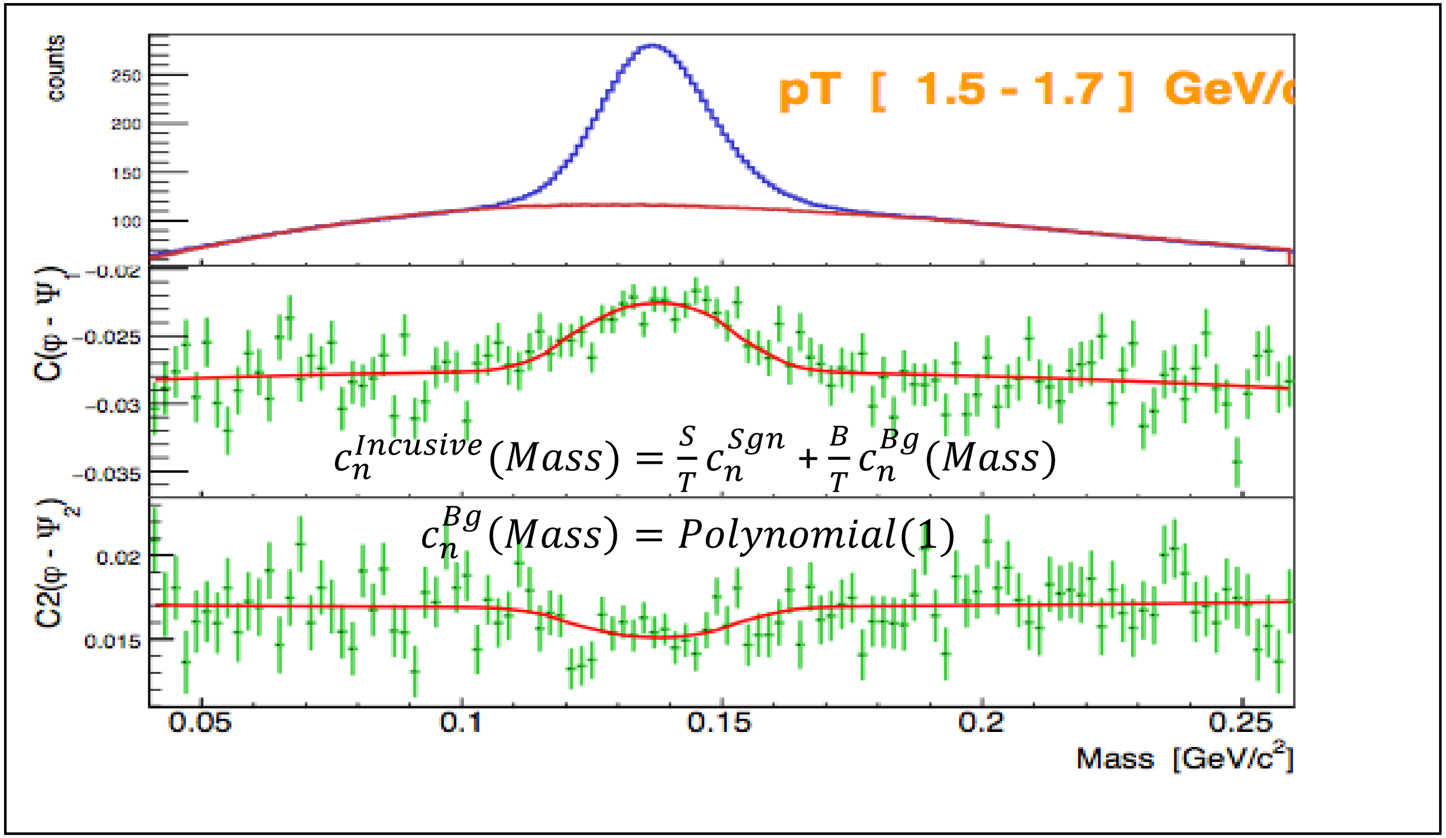


Mass Resolution



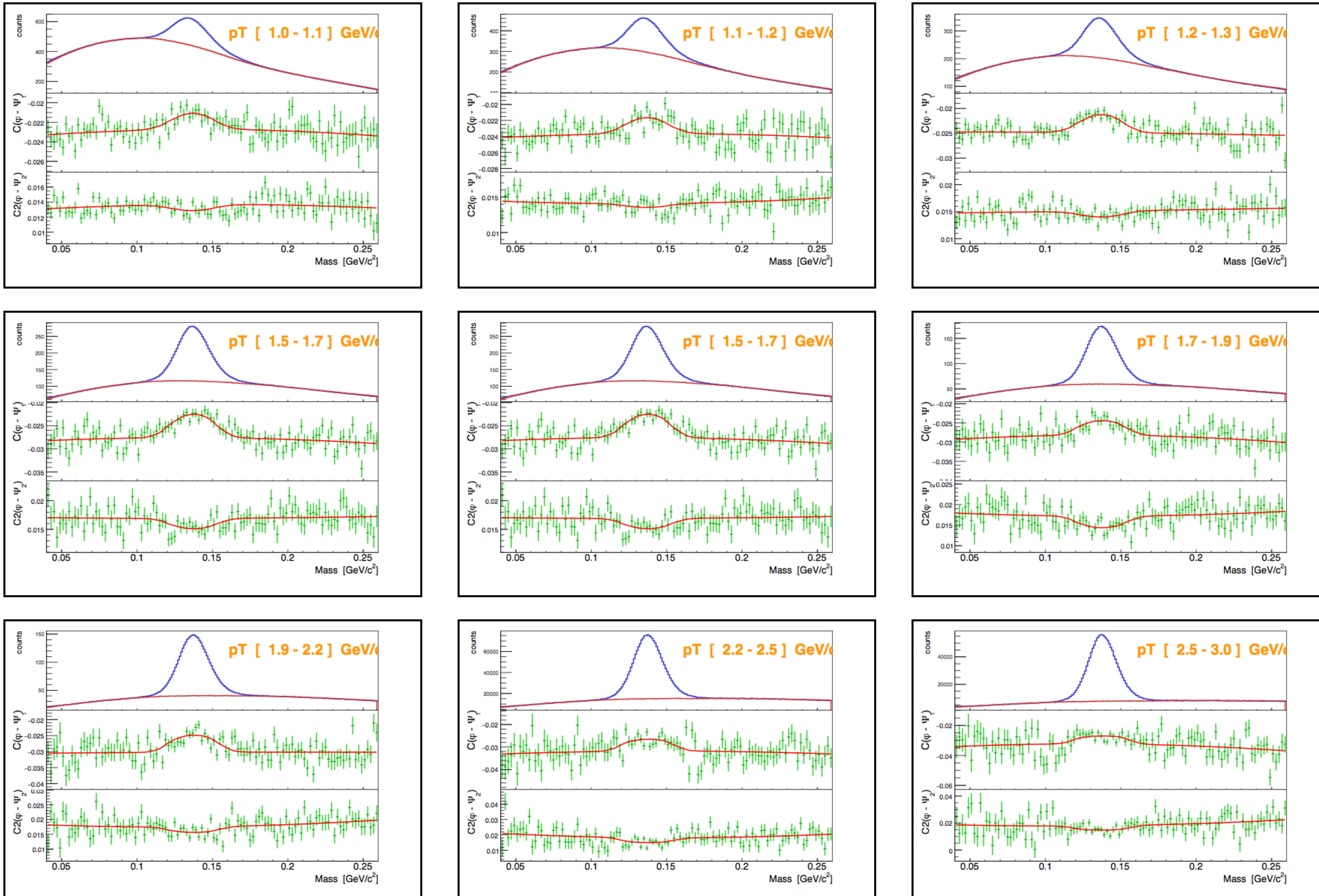
- No efficiency correction on dN/dPt, only statistical errors are show
- Mass peak, resolution showing reasonable behavior that imply we found good π^0 candidate

Measuring C_n



- For each mass bin (green points) we measured $c_n^{Incusive}$ values
- Assuming true c_n^{Sgn} (from π^0) values are fixed and c_n^{Bg} are smoothly changing represented by various polynomials (0, 1, 2 : Pol1 is default)
- By applying S/B ration we found page 16 we can fit $c_n^{Incusive}$ distribution and estimate true c_n^{Sgn} values (Where S : signal, B : Background, T : Total)

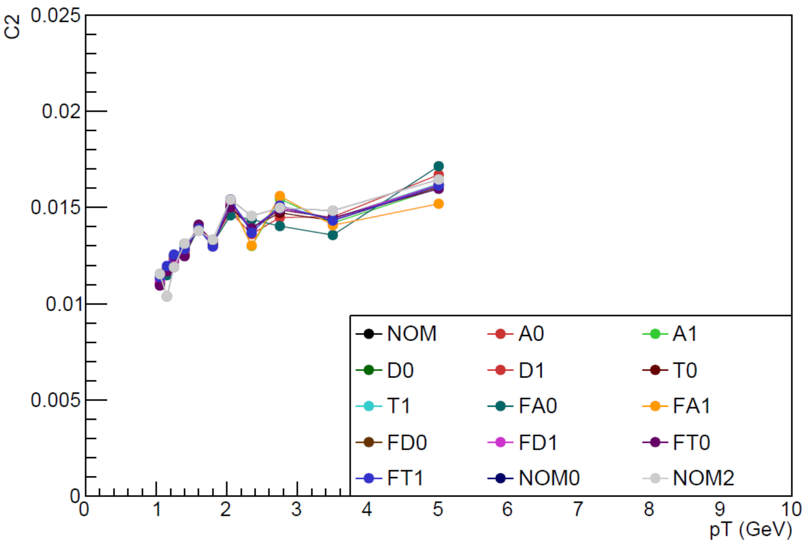
Measuring C_n

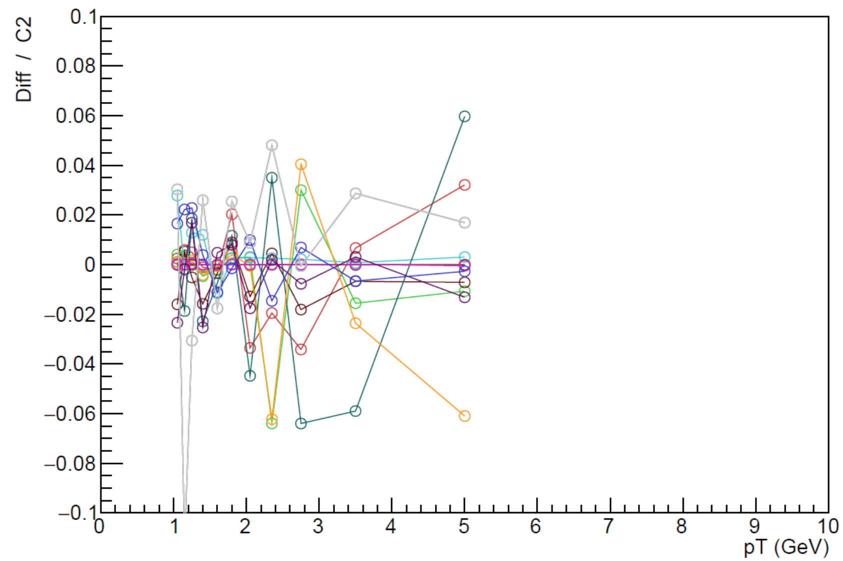


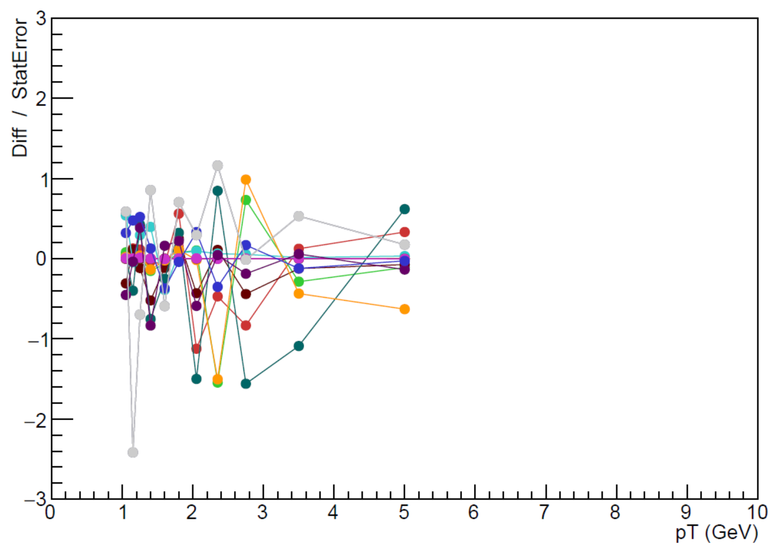
Systematics study

- PhotonCuts
  - Emcal Timing cut: Default 5ns, Test +- 4, +-6
- PairCuts
  - Distance between clusters : 8cm, Test 7cm, 9cm
  - Pair Energy Asymmetry : 0.8, Test 0.65, 0.9
- Signal extraction
  - Range of evt mixed normalization : Test Low, High
  - C2 background function: Poly(1), Test Poly(0), poly(2)

Systematics study : C2

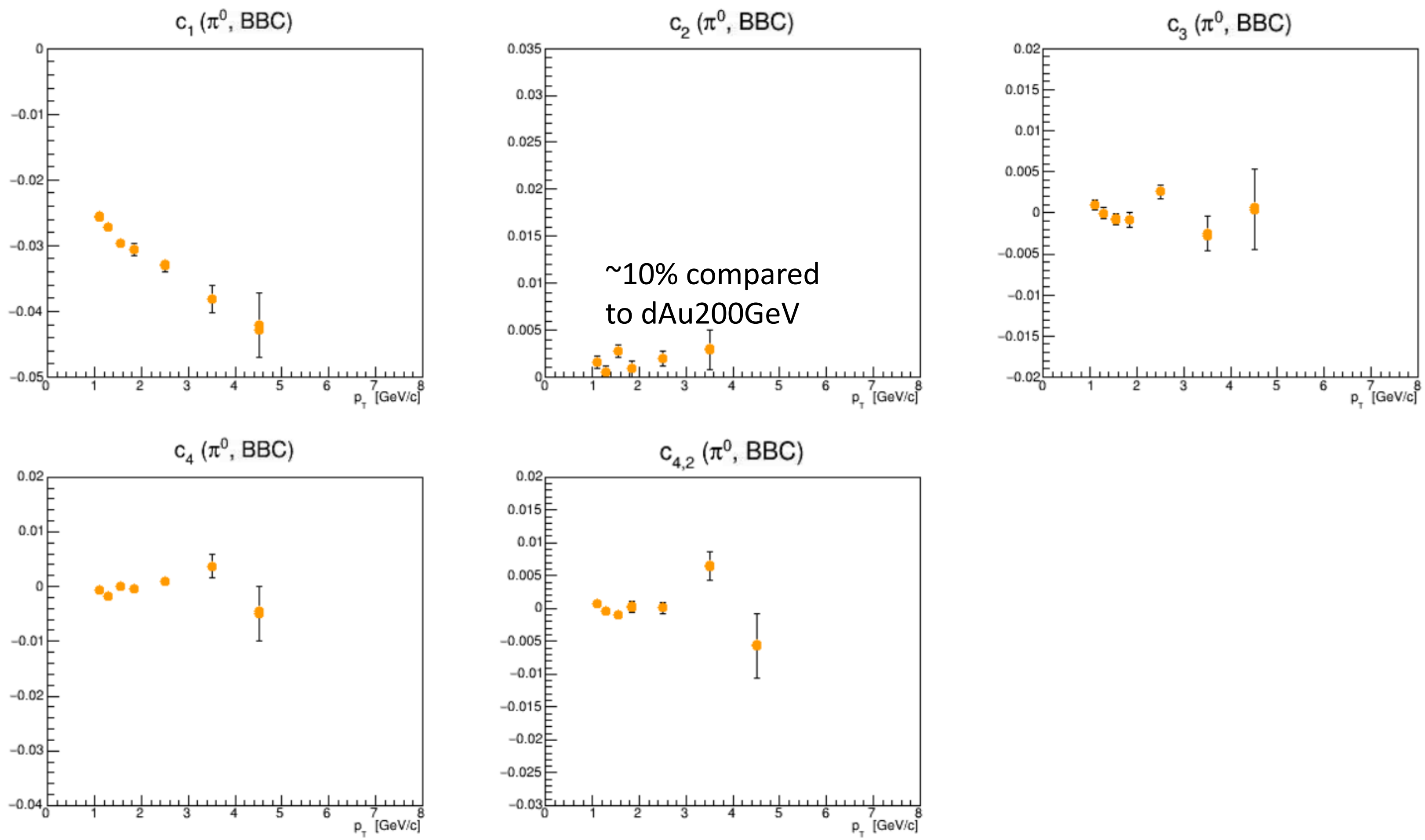






- A : Asymmetry, D : Distance, T : Timing, NOM : Polynomial order, 0 : Bottom limit, 1 : Top limit, F is full range and without F, its half range
- Systematic error is about ~2-6 % which is comparable with statistical error

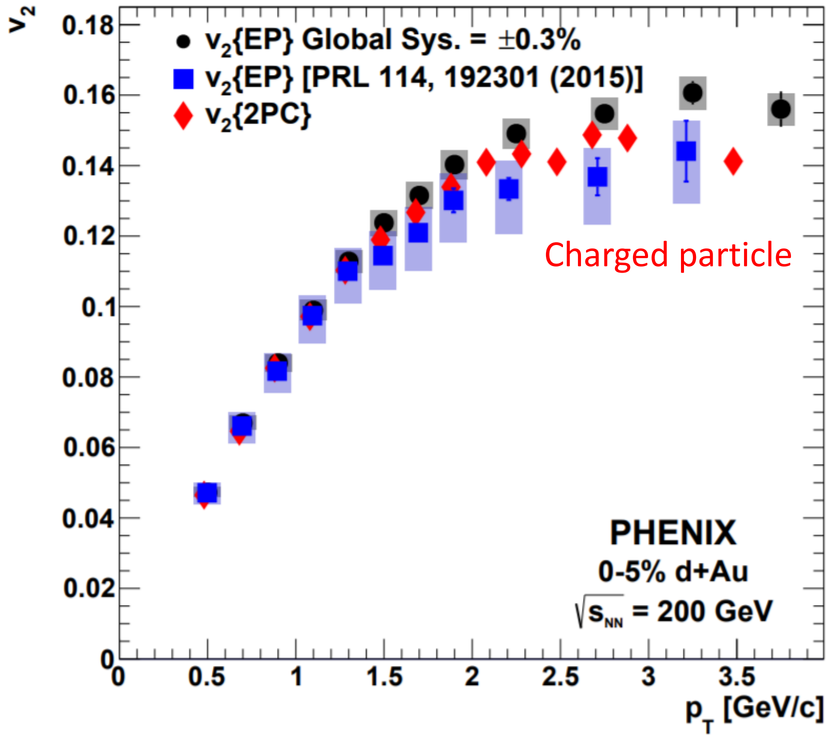
Non-flow study : Run15pp200



- To estimate non-flow contamination in dAu flow, we measured flow on pp as well with same method

π^0 C_2 (BBC EP, with systematics)

PRL 120, 062302



- Good Agreement with published data (0.107 EP resolution)
- Non-flow from pp200 data is not accounted
- To get approval we need to fix issue on event plane calibration

To be done

- We found EP calibration issue and fixing it
- Add Non-flow component as systematic error
- Request approval to PWG group
- Scalar product, Cumulant method on progress
  - Complementary measurement to EP method
- Comparison with AMPT, Hydro dynamic model

Backup

Ep resolution : 2sub event

Definition of resolution

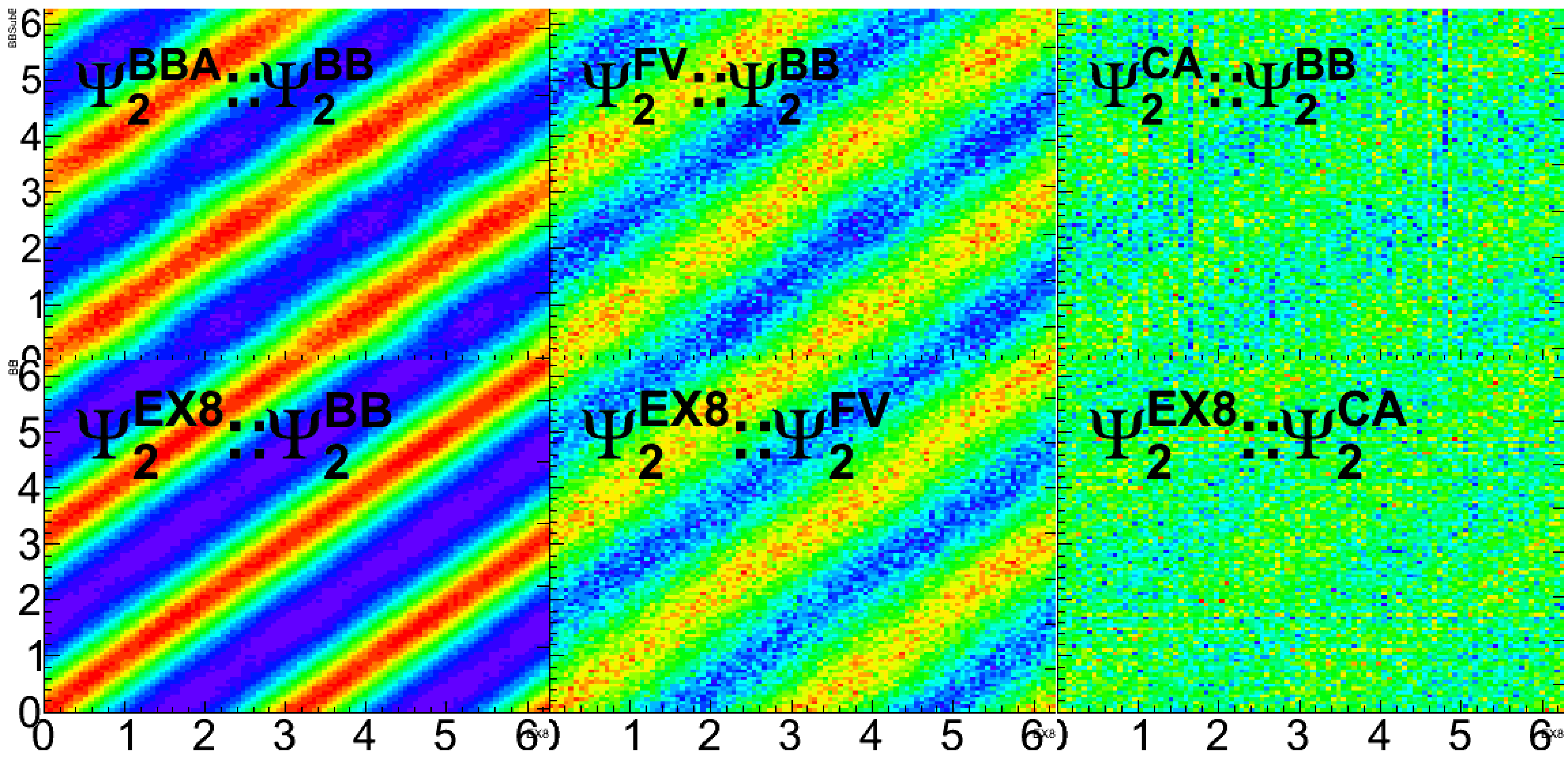
$$R \equiv \left\langle e^{in(\Psi_n - \Phi_n)} \right\rangle = \left\langle \frac{Q_n}{|Q_n|} e^{-in\Phi_n} \right\rangle$$

By Factorization assumption

$$\left\langle \frac{Q_{nA}}{|Q_{nA}|} \frac{Q^*_{nB}}{|Q_{nB}|} \right\rangle_{|v_n} = \left\langle \frac{Q_{nA}}{|Q_{nA}|} e^{-in\Phi_n} \right\rangle_{|v_n} \left\langle \frac{Q_{nB}}{|Q_{nB}|} e^{-in\Phi_n} \right\rangle$$

$$= \left| \left\langle \frac{Q_{nA}}{|Q_{nA}|} e^{-in\Phi_n} \right\rangle_{|v_n} \right|^2 = R(v_{nA})^2$$

EP correlation



Cumulant method

2Particle correlation is

$$\langle\langle 2\rangle_n\rangle = \langle\langle \exp n\imath\left(\varphi_i - \Psi_n + \Psi_n - \varphi_j\right)\rangle\rangle$$
$$= \langle\langle \exp n\imath\left(\varphi - \Psi_n\right)\rangle\langle \exp n\imath\left(\Psi_n - \varphi\right)\rangle\rangle = \langle v_n^2\rangle$$

Expand P·Q* (P, Q is q vectors from interested particles and RP detector) we have

$$\langle 2\rangle_{n;p,Q} = \frac{p_n Q_n^* - m_q}{m_p M - m_q}$$

Where m_p is multiplicity of interested particles and M is multiplicity of RP detector and m_q is multiplicity of particles belongs to both group.
Similarly 4 particle correlation is defined

$$d_n\{4\} \equiv \langle\langle 4\rangle_{n;p,Q,q}\rangle - 2\langle\langle 2\rangle_{n;p,Q}\rangle\langle\langle 2\rangle_{n;Q,Q}\rangle$$

Cumulant method

$$\langle 4\rangle_{n;p,Q,q} = [p_n Q_n^* |Q_n|^2 - q_{2n} Q_n^* Q_n^* - p_n Q_n Q_{2n}^* + q_{2n} Q_{2n}^* - 2M\, p_n Q_n^* \\ - 2m_q |Q_n|^2 + 7 q_n Q_n^* - Q_n q_n^* + 2 p_n Q_n^* + 2 m_q M \\ - 6 m_q] / \left(m_p M - 3m_q\right)(M-2)(M-1)$$

Because we are interested in π^0 not RP detector

$$v_n\{2\} = \frac{d_n\{2\}}{\sqrt{r_n\{2\}}} \qquad v_n\{4\} = -\frac{d_n\{4\}}{\sqrt[4]{-r_n\{4\}}^3}$$

Where d_n is correlation from interested particles and r_n is correlation from RP particles

If we consider event by event fluctuation of flow

$$v_n\{2\} = \langle v_n^2\rangle^{1/2} \qquad v_n\{4\} = \left(-\langle v_n^4\rangle + 2\langle v_n^2\rangle^2\right)^{1/4}$$

Are given in previous discussion

If we consider Gaussian fluctuation average over many events it gives

$$\mathrm{v_n}\{2\} \simeq \langle \mathrm{v_n}\rangle + \frac{\sigma^2}{2\langle \mathrm{v_n}\rangle} \qquad \mathrm{v_n}\{4\} \simeq \langle \mathrm{v_n}\rangle - \frac{\sigma^2}{2\langle \mathrm{v_n}\rangle}$$

Cumulant method

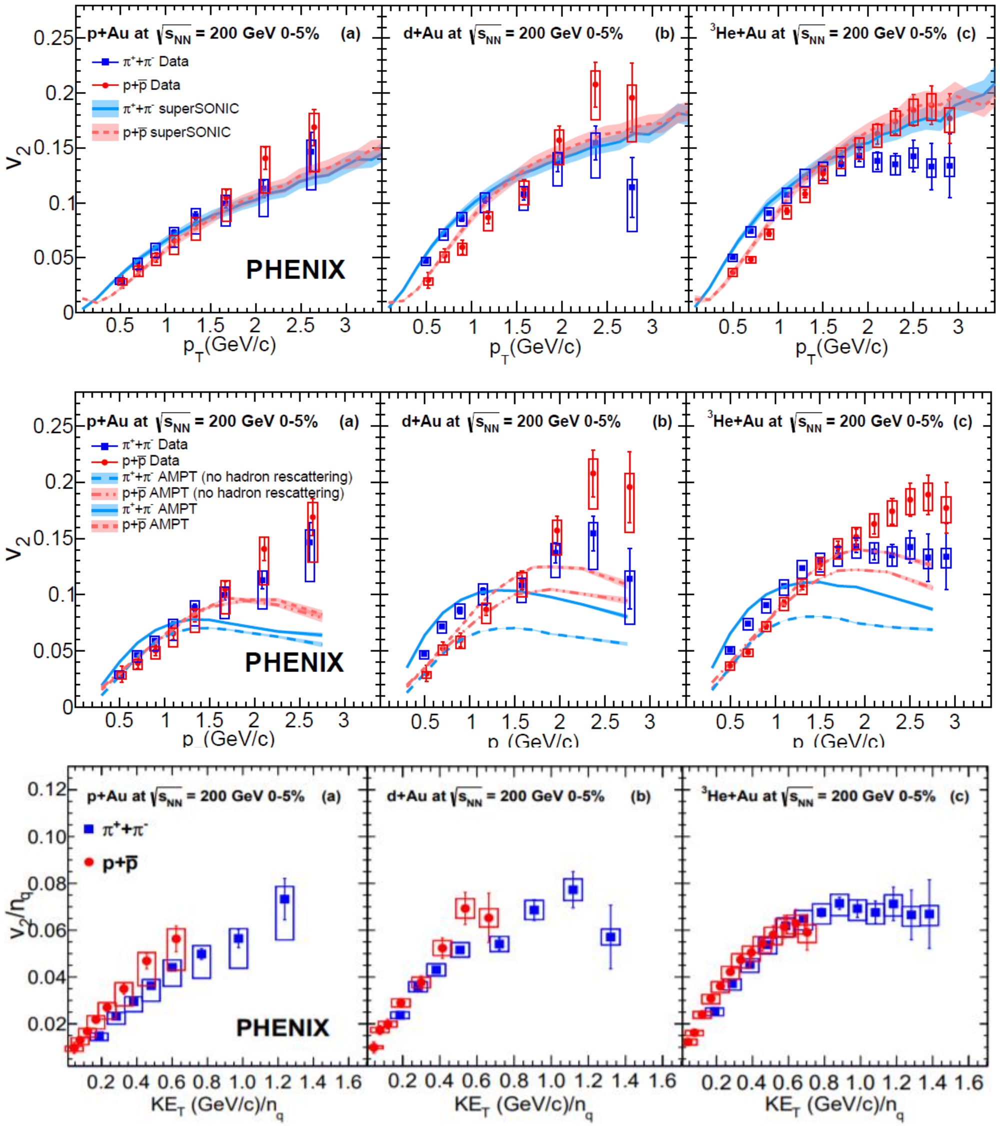
Or with Bessel Gaussian type fluctuation

$$v_n\{2\}^2 \simeq \langle v_n \rangle^2 + 2\sigma^2 \qquad v_n\{4\} \simeq \langle v_n \rangle$$

Cumulant method gives not only v_n but also fluctuation, without consider non-flow contamination

Small System

arXiv:1710.09736v2



- Comparing proton and charged hadron v_2 on different systems (pAu, dAu, HeAu : 200GeV)
- Clear mass splitting is observed in dAu, HeAu
- Quark number scaling is observed in dAu, HeAu
- Hydro model prediction matches with data but failed to reproduce mass splitting
- AMPT model predictions match with data but under estimates v_2 in high pt region (>2GeV)

Emcal Timing resolution(dAu200)