Calculation of Specific Heat in 3 GeV FXT Au+Au

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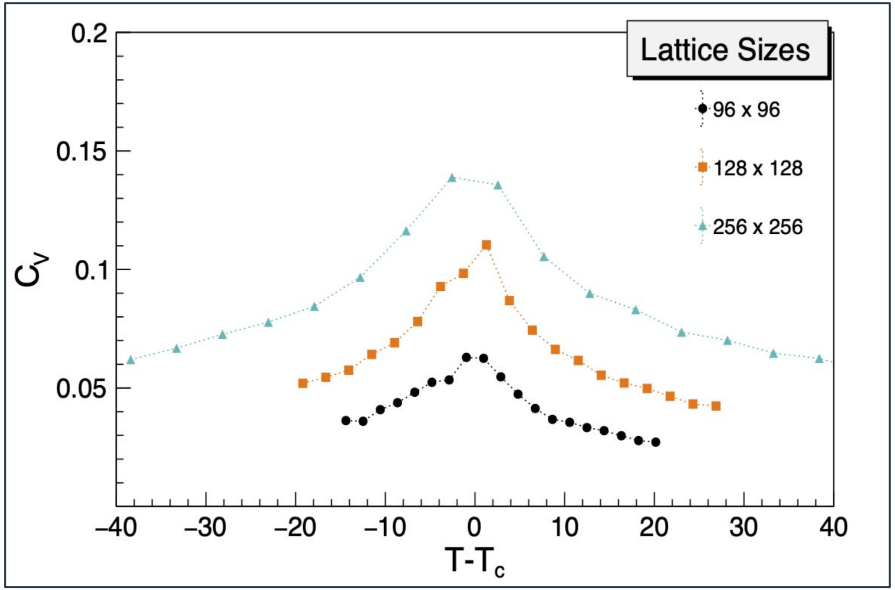
STAR Collaboration CF PWG Meeting

Motivation

- For a system undergoing phase transition, C_v is expected to diverge at the critical point.
- Thus the variation of thermal fluctuations with temperature can be effectively used to probe the critical point.
- In the 2D Ising Model we can see the divergence of C_v as we change the temperature of the system.



- Simulations from 2D Ising Model for C_v.

Objective

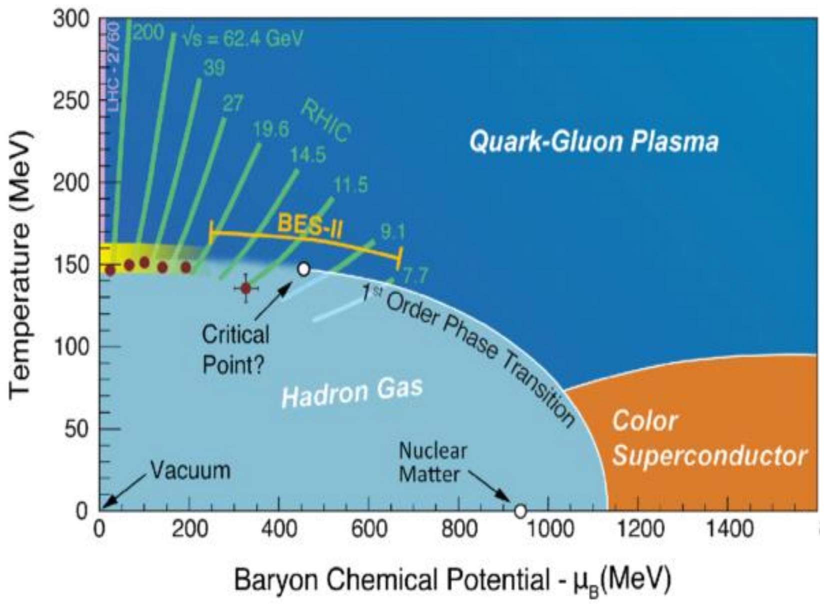
❖ Calculate C_v as a function of $\sqrt{s_{NN}}$, locate the critical point, where the analytical crossover becomes a 1st Order Phase Transition.

❖ $C_V = \left(\frac{\partial E}{\partial T}\right)_V$ Definition from Thermodynamics

❖ Heat Capacity, C of a system in thermal equilibrium connected to a bath at T can be computed from the event- by-event fluctuations of Energy:

$$C = \frac{(<E^2> - <E>^2)}{<T>^2}$$

arXiv:1601.05631



arXiv:2108.13867

Objective

- For a system in equilibrium, the event-by-event temperature fluctuation is controlled by the heat capacity:

$$P(T) \propto exp[-\frac{C}{2}\frac{(\Delta T)^2}{<T>^2}]$$

arXiv:1601.05631

- Specific Heat calculated from fluctuations in temperature:

$$\frac{1}{C} = \frac{<T^2> - <T>^2}{<T>^2}$$

- At kinetic freeze-out:

$$\frac{1}{C} = \frac{<T_{kin}^2> - <T_{kin}>^2}{<T_{kin}>^2}$$

arXiv:1601.05631

Caveat: Measuring the temperature of a single event based on the p_T distribution does not yield a very good precision.

Objective

- Effective temperature (T_{eff}).
- Calculated from <p_T> distributions.
- $T_{eff} = T_{kin} + f(\beta_T)$

$$\frac{1}{C} = \frac{(<T_{kin}^2> - <T_{kin}>^2)}{<T_{kin}>^2} \approx \frac{(<T_{eff}^2> - <T_{eff}>^2)}{<T_{kin}>^2}$$

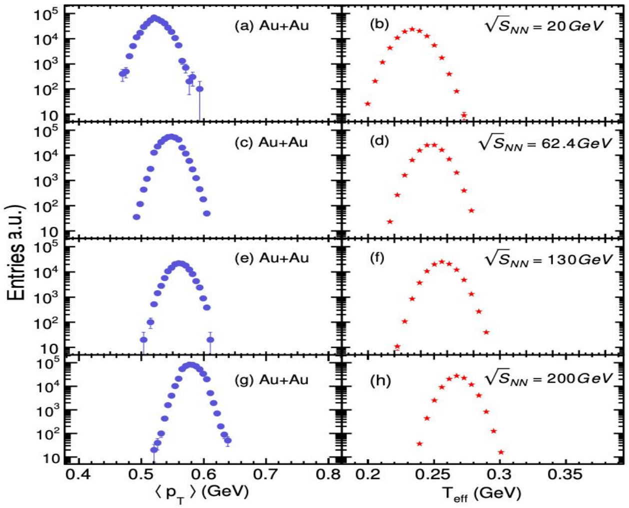


Fig. from Sumit Basu *et al* 2016 *J. Phys.: Conf. Ser.* 668 012043

Kinetic Freeze-out parameters

- The Kinetic freeze-out parameters are extracted using the SSH BW.

$$\frac{1}{2\pi p_T}\frac{d^2N}{dp_T dy} \propto \int_0^R r dr m_T I_0\left(\frac{p_T sinh\rho}{T_{kin}}\right) K_1\left(\frac{m_T cosh\rho}{T_{kin}}\right)$$

PRC48 (1993) 2462

- Using the blast wave we can find:
  - Kinetic freeze-out temperature T_{kin}.
  - Transverse radial flow
  - Flow profile n.

$$\rho = tanh^{-1}\beta_T$$

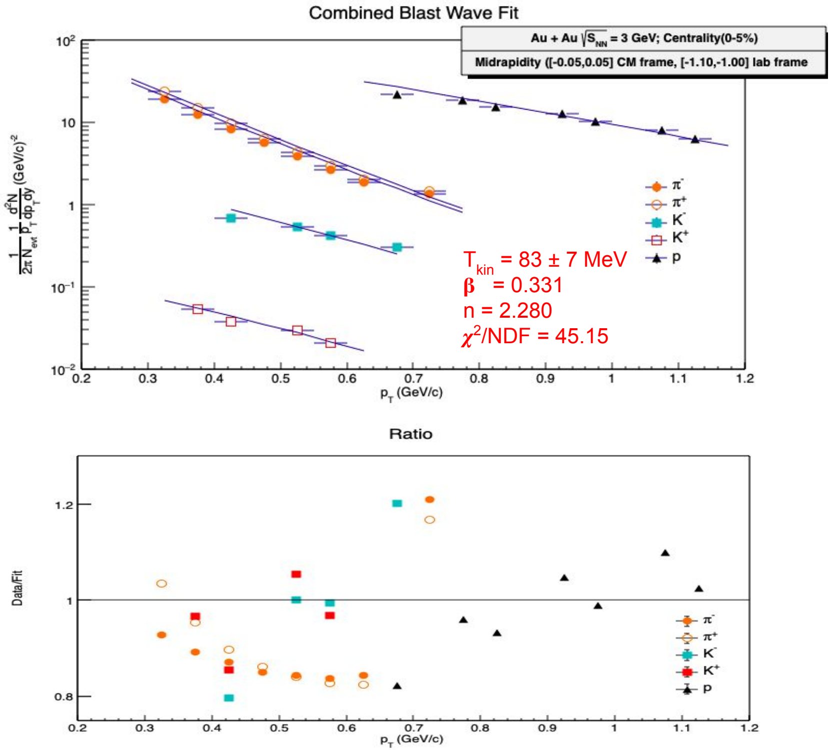
$$<\beta_T> = \frac{2}{2+n}\beta_s$$

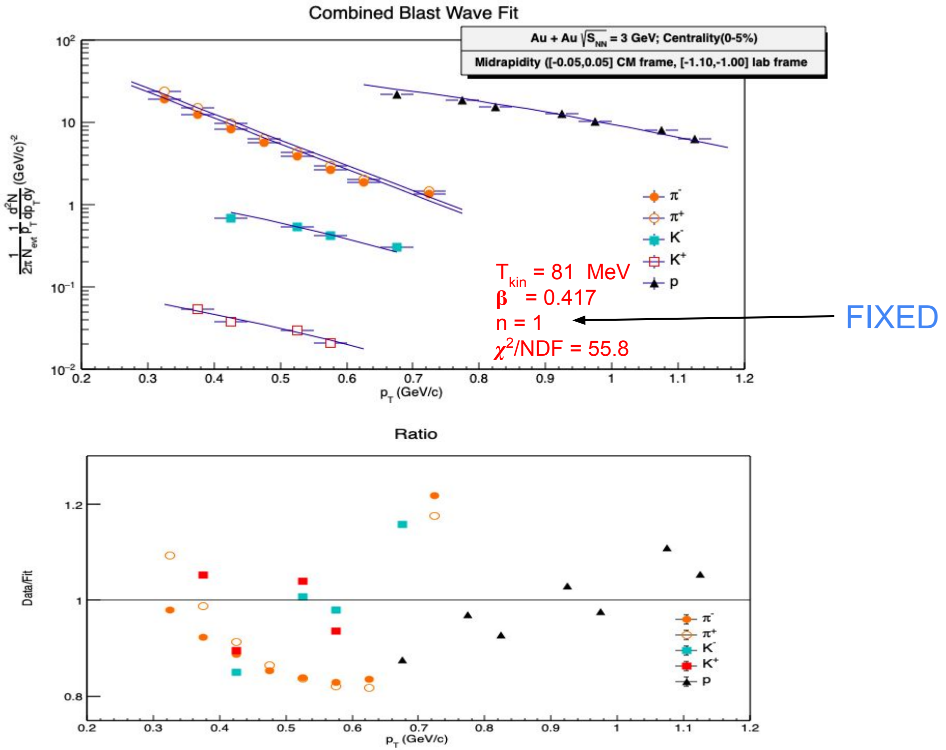
- 3 Fit parameters.

☆ ρ : Is the boost angle.

☆ β_s : Is the surface velocity of the thermal source and n is the flow profile.

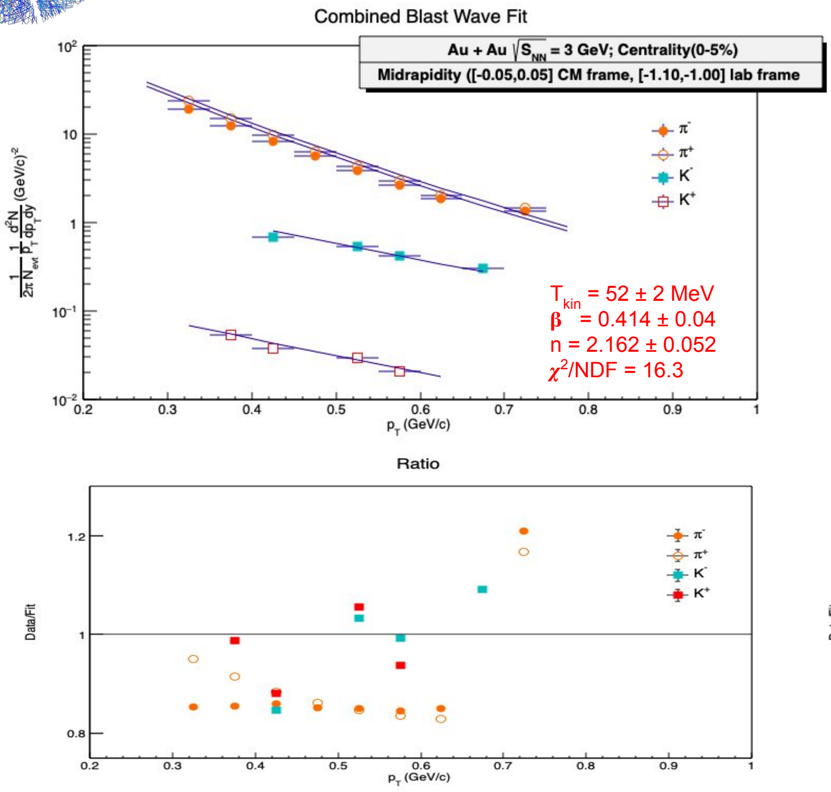
Kinetic Freeze-out parameters

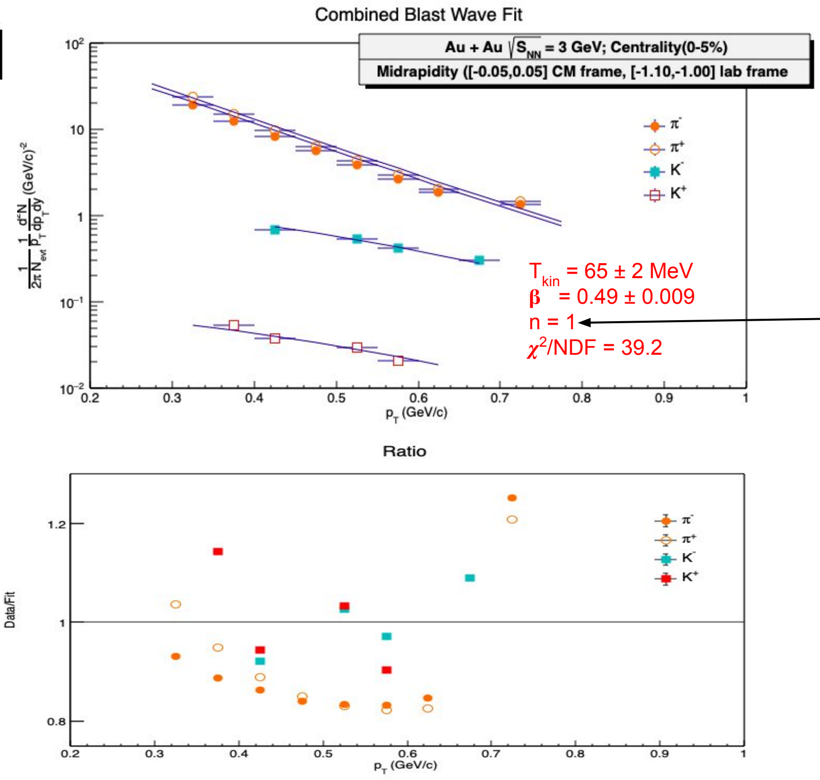




*Obtained the Spectra from Ben Kimelman (UC Davis)

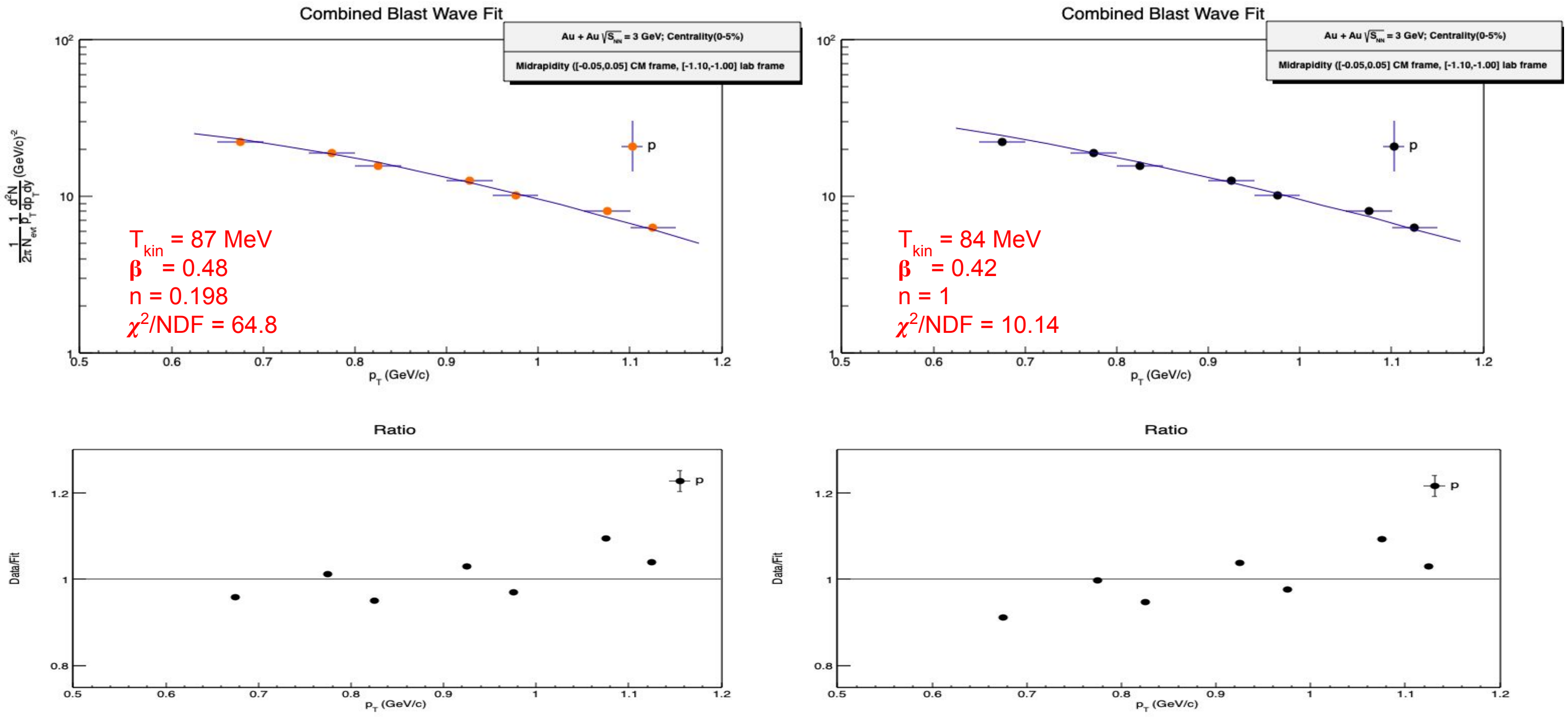
Kinetic Freeze-out parameters





FIXED

Kinetic Freeze-out parameters

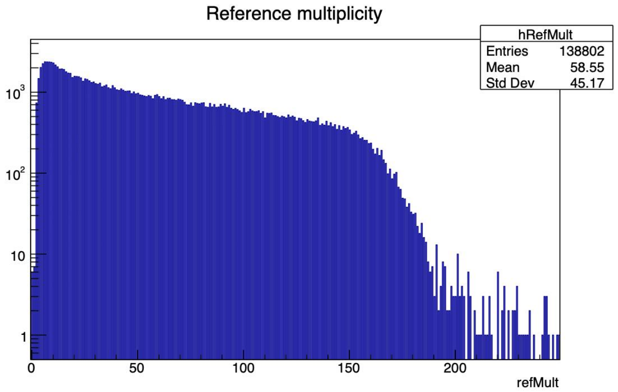


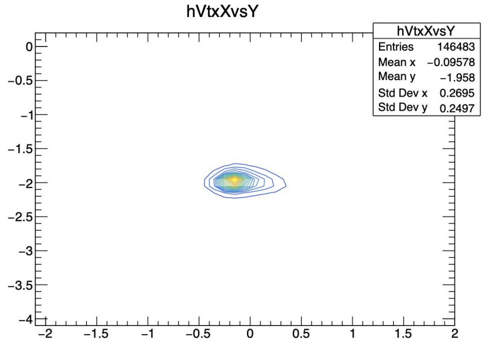
Kinetic Freeze-out parameters

$\sqrt{s_{NN}}(GeV)$	Fit	n	$T_{kin}(MeV)$	$<\beta>$	$\frac{\chi^2}{NDF}$
200	$\pi^{\pm}, K^{\pm}, p\bar{p}$	0.817 ± 0.025	88 ± 5	0.594 ± 0.012	0.186
200	$\pi^{\pm}, K^{\pm}$	0.842 ± 0.167	84 ± 24	0.602 ± 0.078	0.06
62.4	$\pi^{\pm}, K^{\pm}, p\bar{p}$	0.61 ± 0.04	97 ± 1	0.554 ± 0.01	0.63
62.4	$\pi^{\pm}, K^{\pm}$	0.917 ± 0.094	88 ± 7	0.57 ± 0.031	0.16
14.5	$\pi^{\pm}, K^{\pm}, p\bar{p}$	0.991 ± 0.123	120 ± 2	0.431 ± 0.011	0.29
14.5	$\pi^{\pm}, K^{\pm}$	1.361 ± 0.191	125 ± 4	0.385 ± 0.013	0.25
3	$\pi^{\pm}, K^{\pm}, p$	1	81	0.415 ± 0.05	0.74
3	$\pi^{\pm}, K^{\pm}$	1	69 ± 5	0.465 ± 0.027	0.44
3	$\pi^{\pm}, K^{\pm}, p$	1.415 ± 0.447	81 ± 1	0.386 ± 0.022	0.71
3	$\pi^{\pm}, K^{\pm}$	1.9 ± 0.34	54 ± 12	0.431 ± 0.031	0.26

*Systematics of 5%

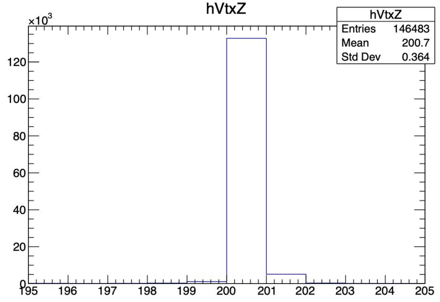
$\langle p_T \rangle$ Distributions





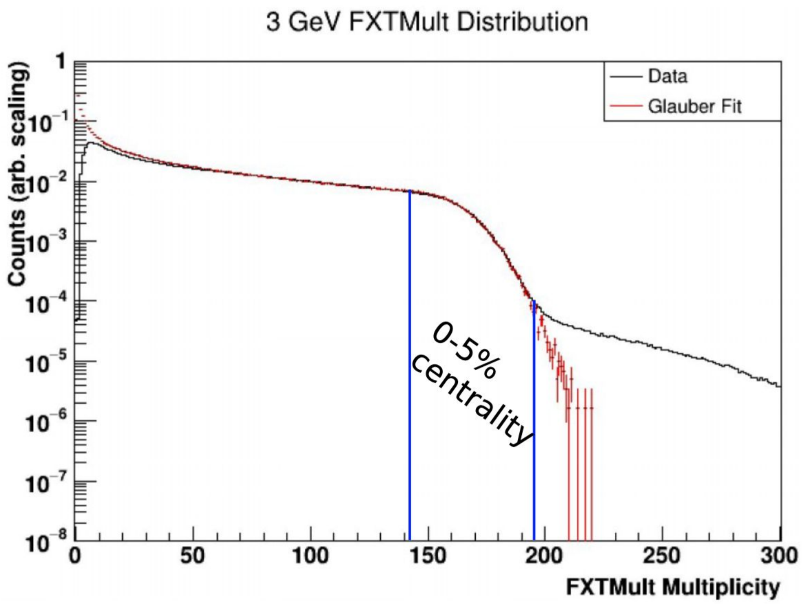
Acceptance Cuts:

- Fixed Target, run 2018 data production, 3 GeV Au+Au collision, y_c.m. ≈1.045
- $198 < V_z < 202$ cm
- V_r<1.5 cm about beam spot centered around [0,-2].
- Trigger ID 620052 and 620053 (Min.Bias)
- DCA < 3.0 cm
- NhitsFit/NHitsMax > 0.51
- 0.5 M Events analysed (Rest ongoing)



$\langle p_T \rangle$ Distributions

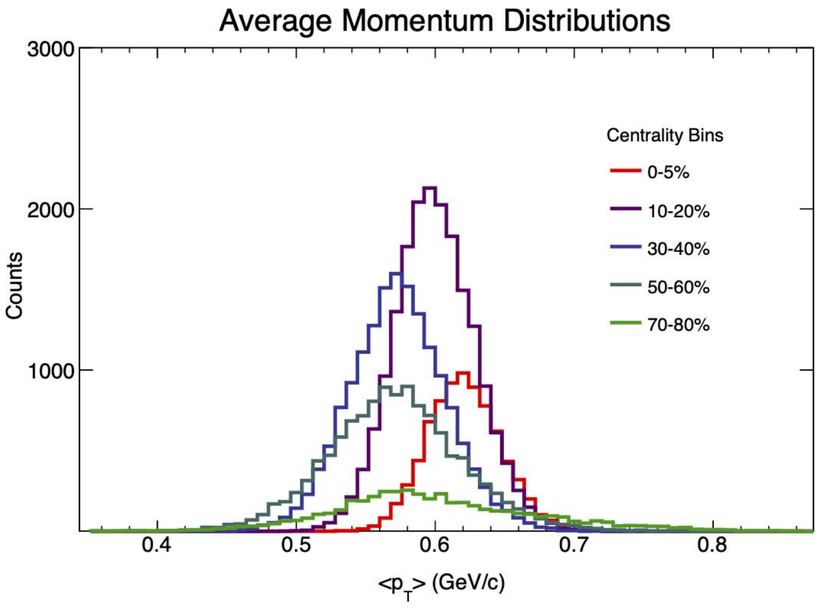
Centrality Definition:

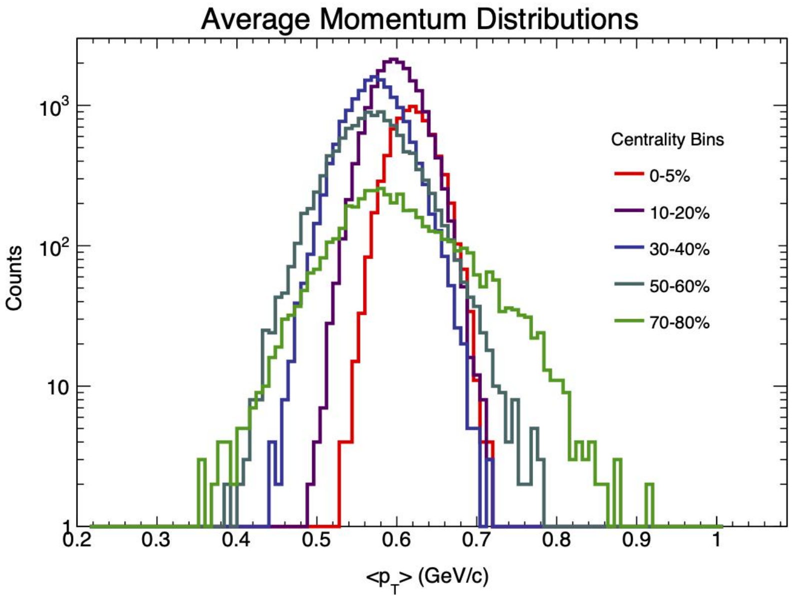


Centrality Bin	FXTMult Cuts (inclusive)
0-5%	195-142
5-10%	141-120
10-20%	119-86
20-30%	85-61
30-40%	60-42
40-50%	41-27
50-60%	26-17
60-70%	16-9
70-80%	8-5

❖ *Pile-up cut at 195

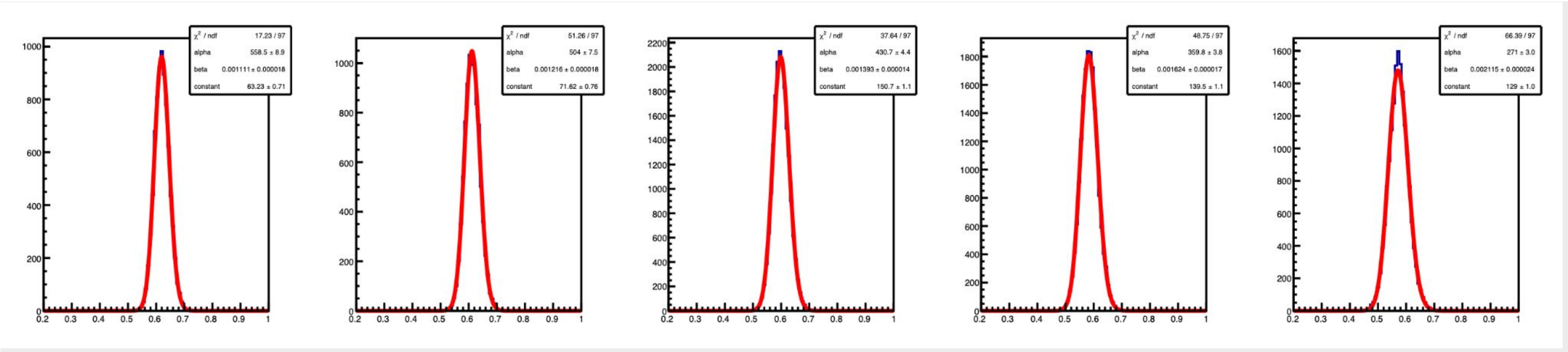
$\langle p_T \rangle$ Distributions





- All charged particles
- $0.15 < p_T < 2.0$ (GeV/c)
- $-2 < \eta < 0$

$\langle p_T \rangle$ Distributions



0-5% 10-20% 30-40% 50-60% 70-80%

It has been observed that the $\langle p_T \rangle$ distributions are nicely described by using the gamma (Γ) distribution.

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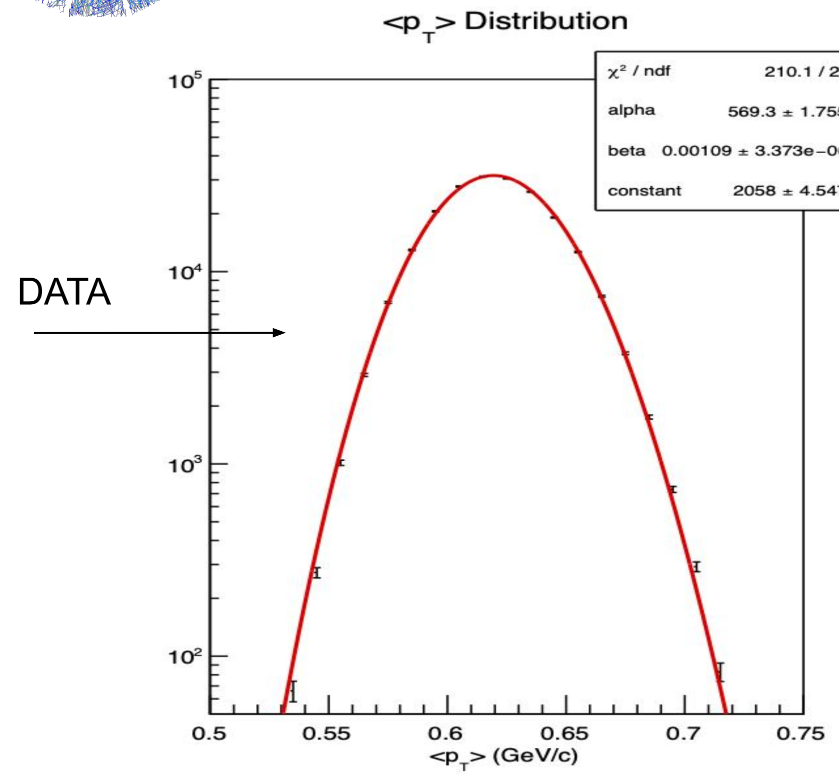
$$f(x) = \frac{x^{\alpha-1} e^{\frac{-x}{\beta}}}{\Gamma(\alpha)\beta^{\alpha}}$$

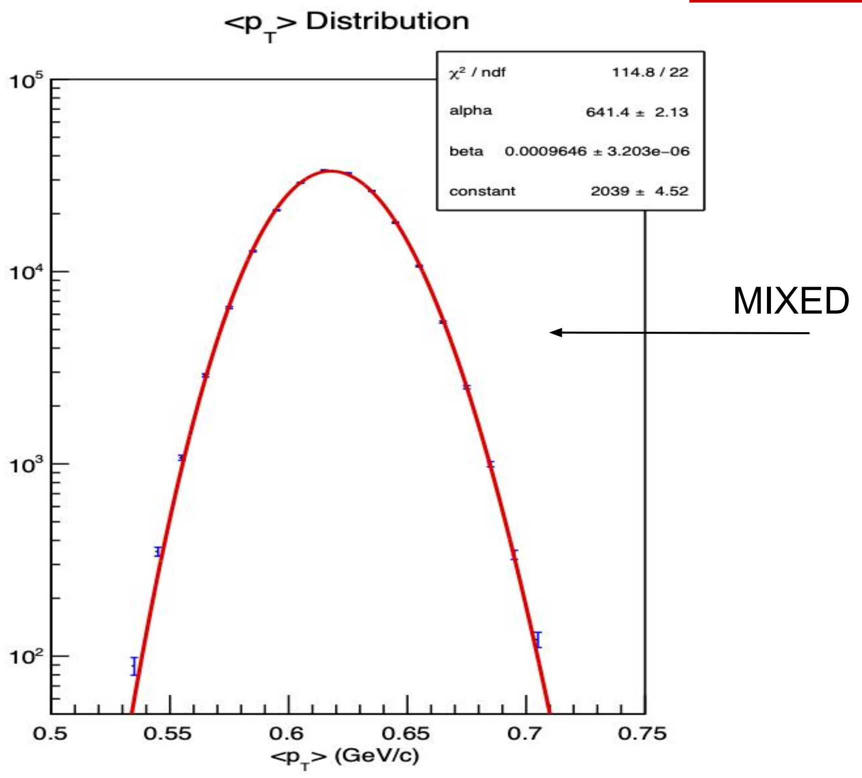
Mixed Event Analysis

- In order to establish whether the observed fluctuations are partly dynamical in nature, we need to disentangle statistical effects i.e. effects due to the finite number of particles in the final state of the collision.

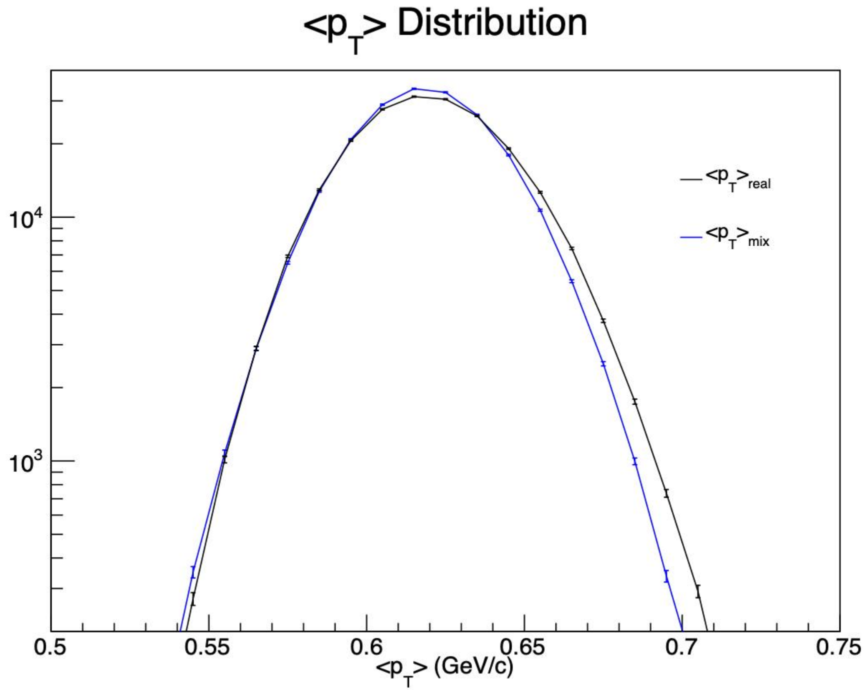
- The Mixed event reconstruction makes synthetic events with tracks from different events to remove any kind of correlations.

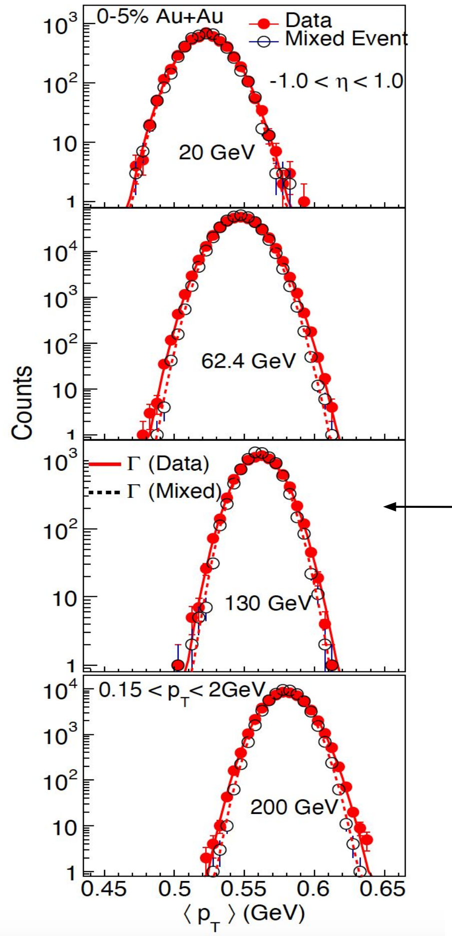
Mixed Event Analysis





Mixed Event Analysis





Published Analysis

Phys. Rev. C 94, 044901 (2016)

Mixed Event Analysis

$$f(x) = \frac{x^{\alpha-1} e^{\frac{-x}{\beta}}}{\Gamma(\alpha)\beta^{\alpha}}$$

From the fit parameters α, $\boldsymbol{\beta}$
We can calculate μ and σ:

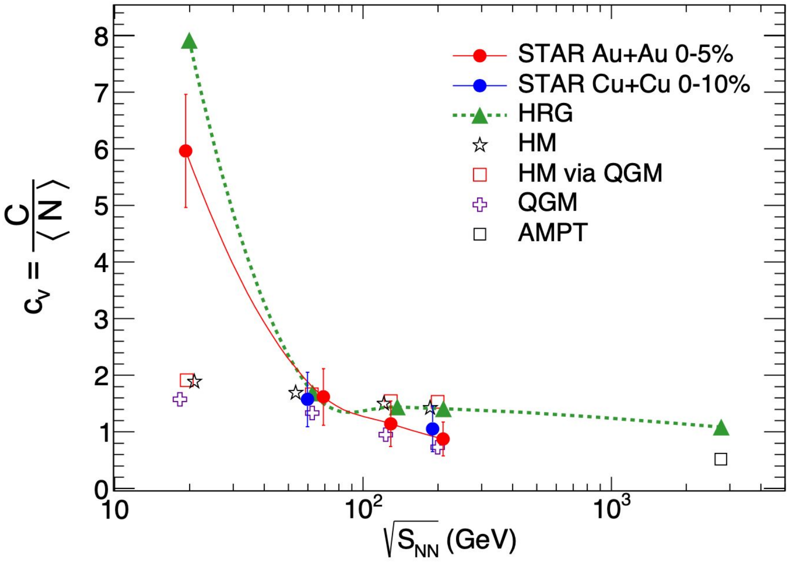
- $\mu = \alpha\boldsymbol{\beta}$
- $\sigma^2 = \alpha\boldsymbol{\beta}^2$

Case	α	$\boldsymbol{\beta}$ (GeV)	μ (GeV)	σ (GeV)
Data	569.3	1.09×10^{-3}	0.6205	0.0260
Mixed	641.4	9.64×10^{-4}	0.6186	0.0244

Next Steps

Working on:

1. Running on RCF (all possible events)
2. Working on i-HRG to obtain baseline
3. Systematics



Phys. Rev. C 94, 044901 (2016)

Thank you for your attention