

Specific heat of matter Produced in Pb-Pb collisions

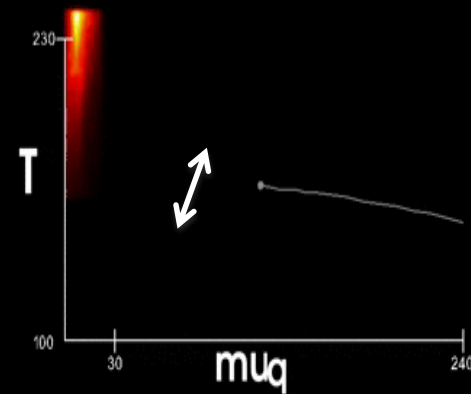
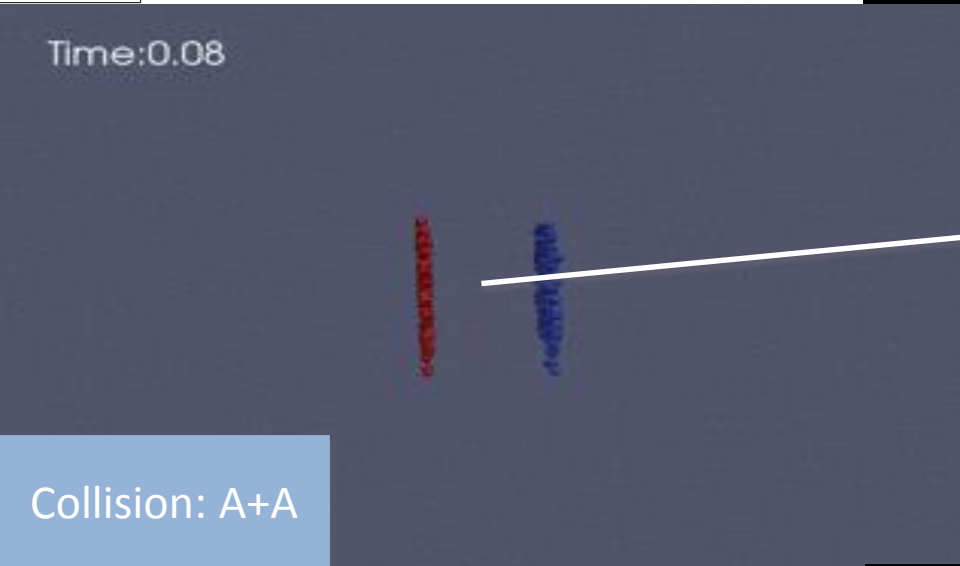
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Supervisor: [Prof. Tapan K Nayak](#)

Alexander Philipp Kalweit
Roberto Preghenella
Sandeep Chatterjee
Rupa Chatterjee
Basanta K Nayak

&

VECC EHEP&A Group



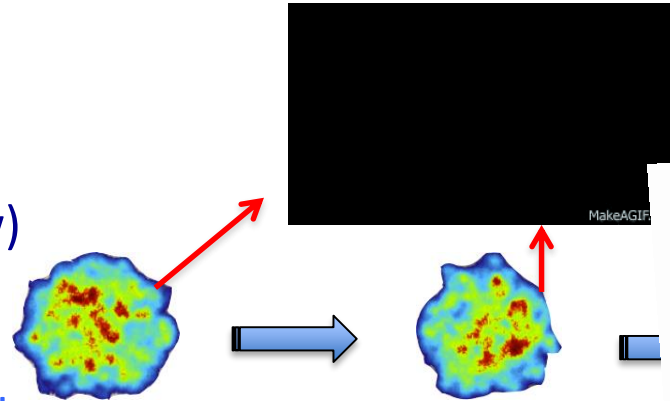
Time: 5.58

- how fluctuation really transferred?
- what is the width?
- How much initial fluctuation retains ?
- Whether there is spatial patches in the temperature distribution?
- Is it 1 to 1 corresponds?
- Whether that fluctuation changes from meson to baryon to strange particles

If we find something then what???

Temperature Fluctuation

(Motivation?? Review)

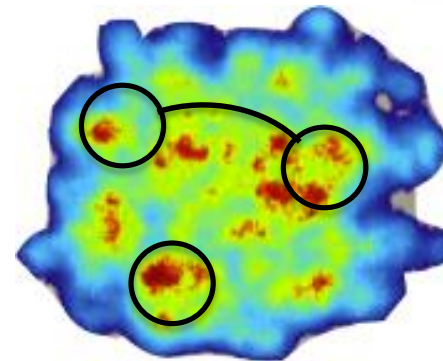


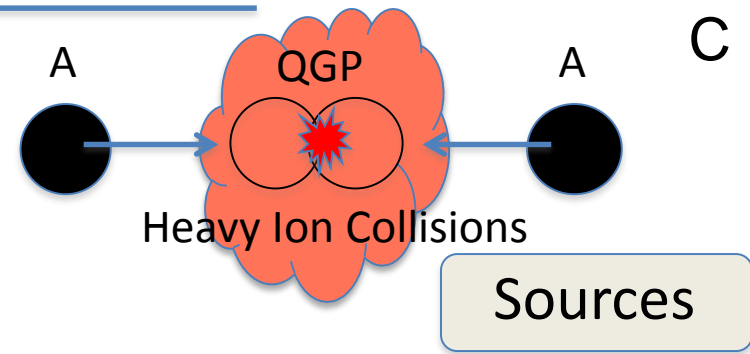
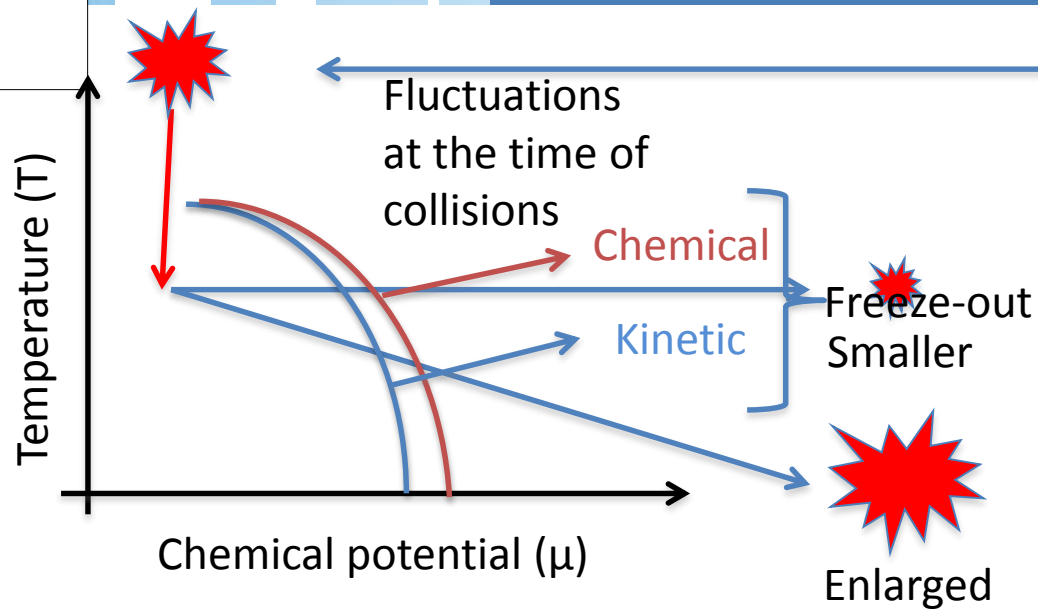
① Event-by Event : Global

Model study \rightarrow Previous Data \rightarrow ALICE L

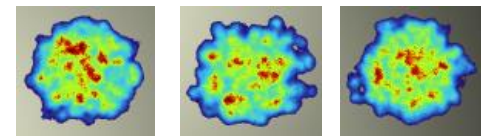
② Within The Event : Local

Model Study \rightarrow Hydro \rightarrow Data





1. Initial State fluctuations



(Uli Heinz, arXiv:1304.3634)

2. Thermodynamical fluctuations

3. Statistical fluctuations

$$\frac{1}{C_V} = \left(D T_{eff}^{ebye} / \langle T_{eff}^{ebye} \rangle \right)^2$$

(L. Stodolsky, Phys. Rev. Lett. 75, 1044 (1995))

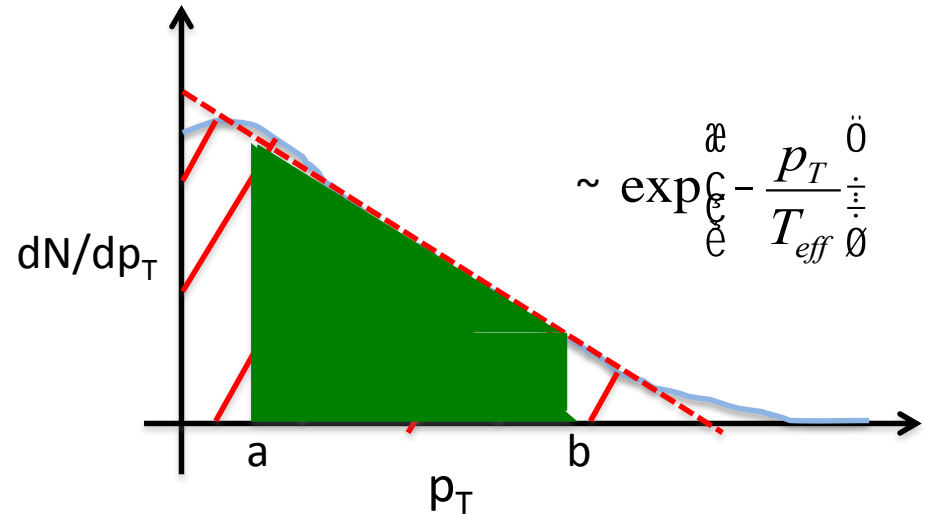


How to Measure Temperature?

- But limit is the problem : and fit uncertainty as well
- Low multiplicity

$$\langle m_T \rangle = \frac{\int_0^\infty p_T dp_T m_T \exp(-m_T/T_{eff})}{\int_0^\infty p_T dp_T \exp(-m_T/T_{eff})} = \frac{2T_{eff}^2 + 2m_0 T_{eff} + m_0^2}{m_0 + T_{eff}}$$

$$\langle m_T \rangle = \frac{2T_{eff}^2 + 2m_0 T_{eff} + m_0^2}{m_0 + T_{eff}}$$



$$\langle p_t \rangle = \frac{\int_a^b p_t^2 F(p_t) dp_t}{\int_a^b p_t F(p_t) dp_t}$$

$$\langle p_t \rangle = 2T + \frac{a^2 e^{-a/T} - b^2 e^{-b/T}}{(a + T)e^{-a/T} - (b + T)e^{-b/T}}$$



$$\langle p_t \rangle = 2T + \frac{a^2 e^{-a/T} - b^2 e^{-b/T}}{(a+T)e^{-a/T} - (b+T)e^{-b/T}}$$

$$T_{\text{eff}} = T_{\text{kin}} + f(\beta_T)$$

Blast-Wave (simultaneous)

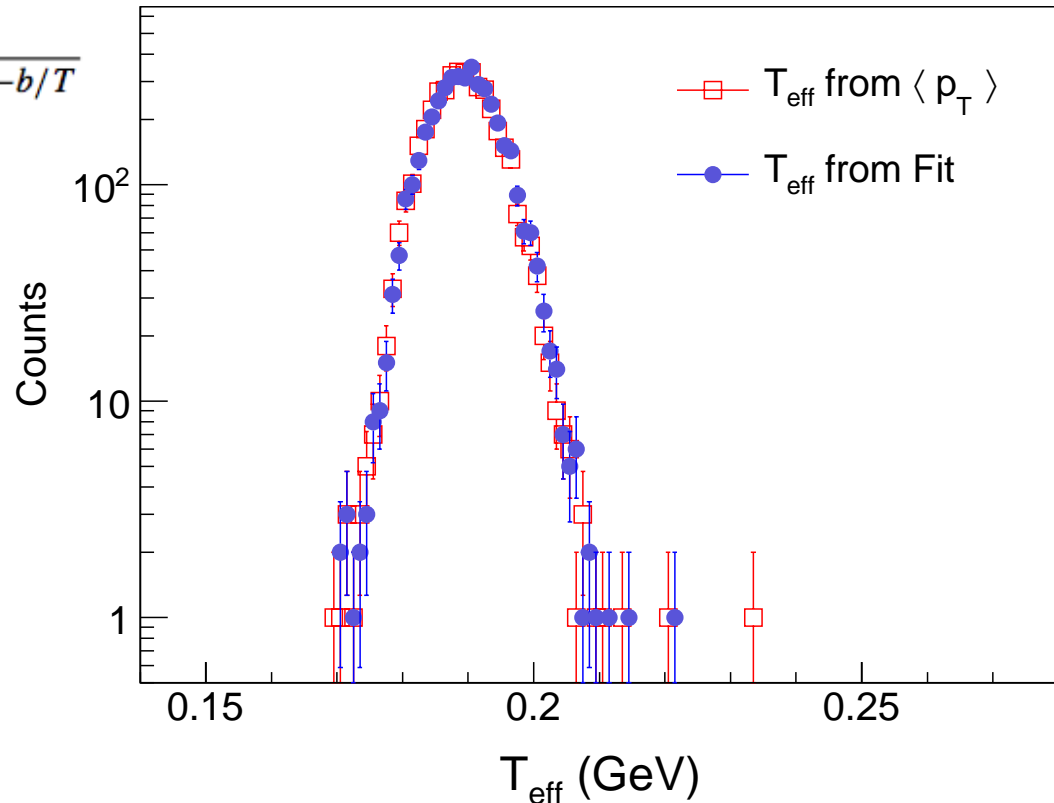
We Define Heat Capacity

$$\frac{1}{C} = \frac{(\Delta T_{\text{kin}}^2)}{T_{\text{kin}}^2} \approx \frac{(\Delta T_{\text{eff}}^2)}{T_{\text{kin}}^2}$$

Sp. Heat

$$c_v = \frac{C}{\langle n \rangle} = \frac{C}{VT^3}$$

Dimensionless Quantity





R. Gavai, S. Gupta and S. Mukherjee [1] predict in “quenched QCD” at $2T_c$ and $3T_c$ that the specific heat, c_V/T^3 , differs significantly from the value for an ideal gas—15 compared to 21 (see Fig. 1). Can this be measured?

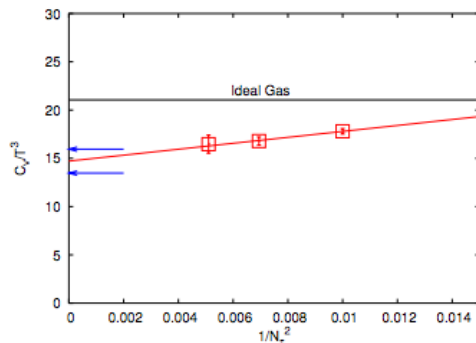
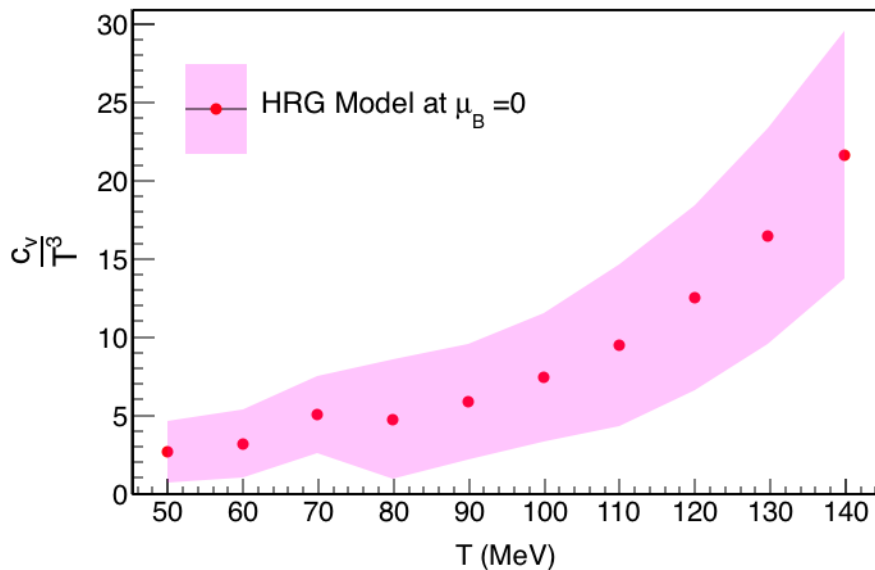
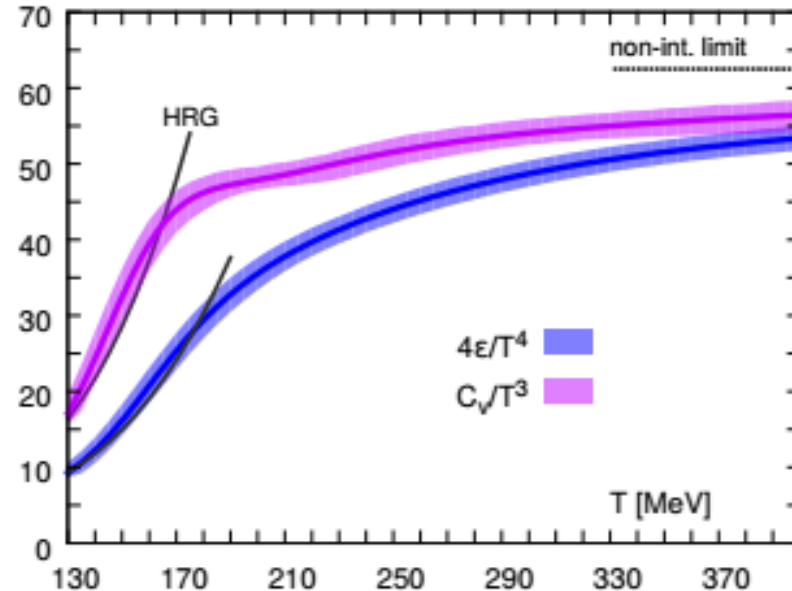


FIG. 1: Gavai, *et al.*, prediction for c_V/T^3 [1].



A. Bazavov et.al.

Phys. Rev. D 90, 094503 (2014)



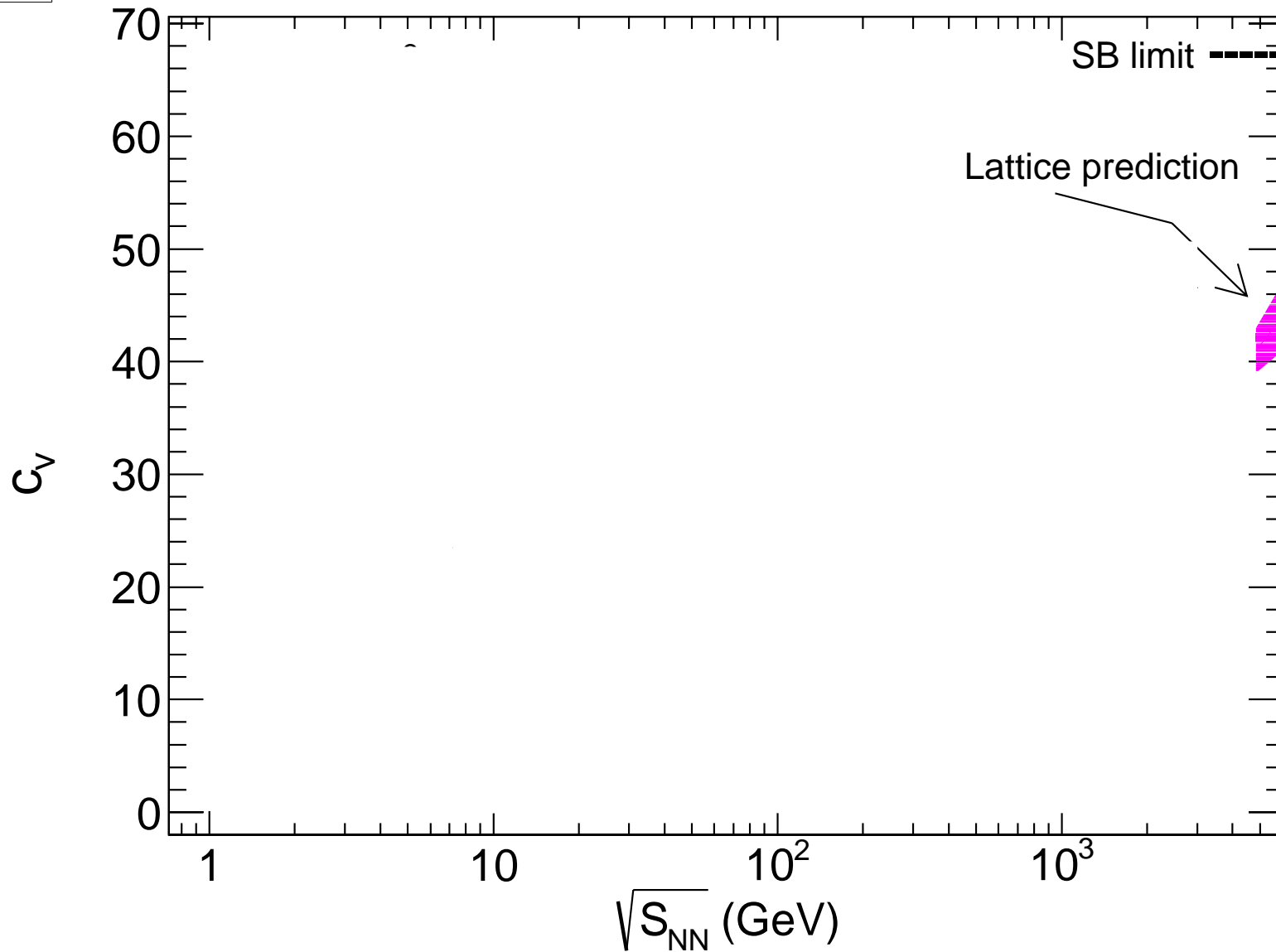
Def. Temperature & Sp. Heat

7



VEC
C

[arXiv : 1601.05631](https://arxiv.org/abs/1601.05631)



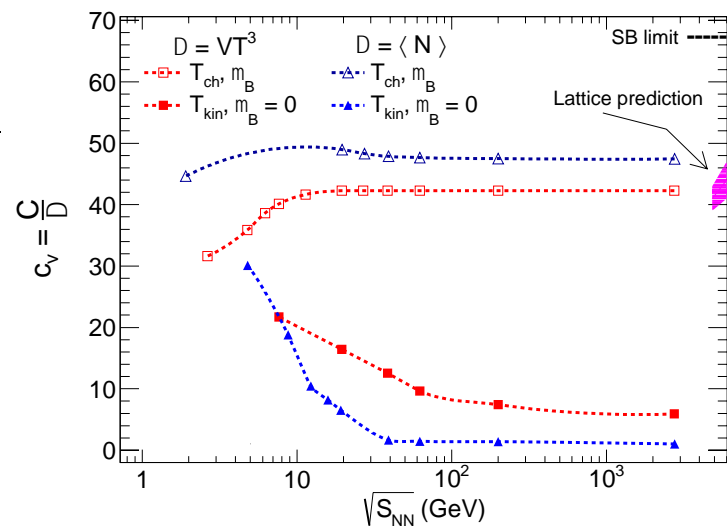
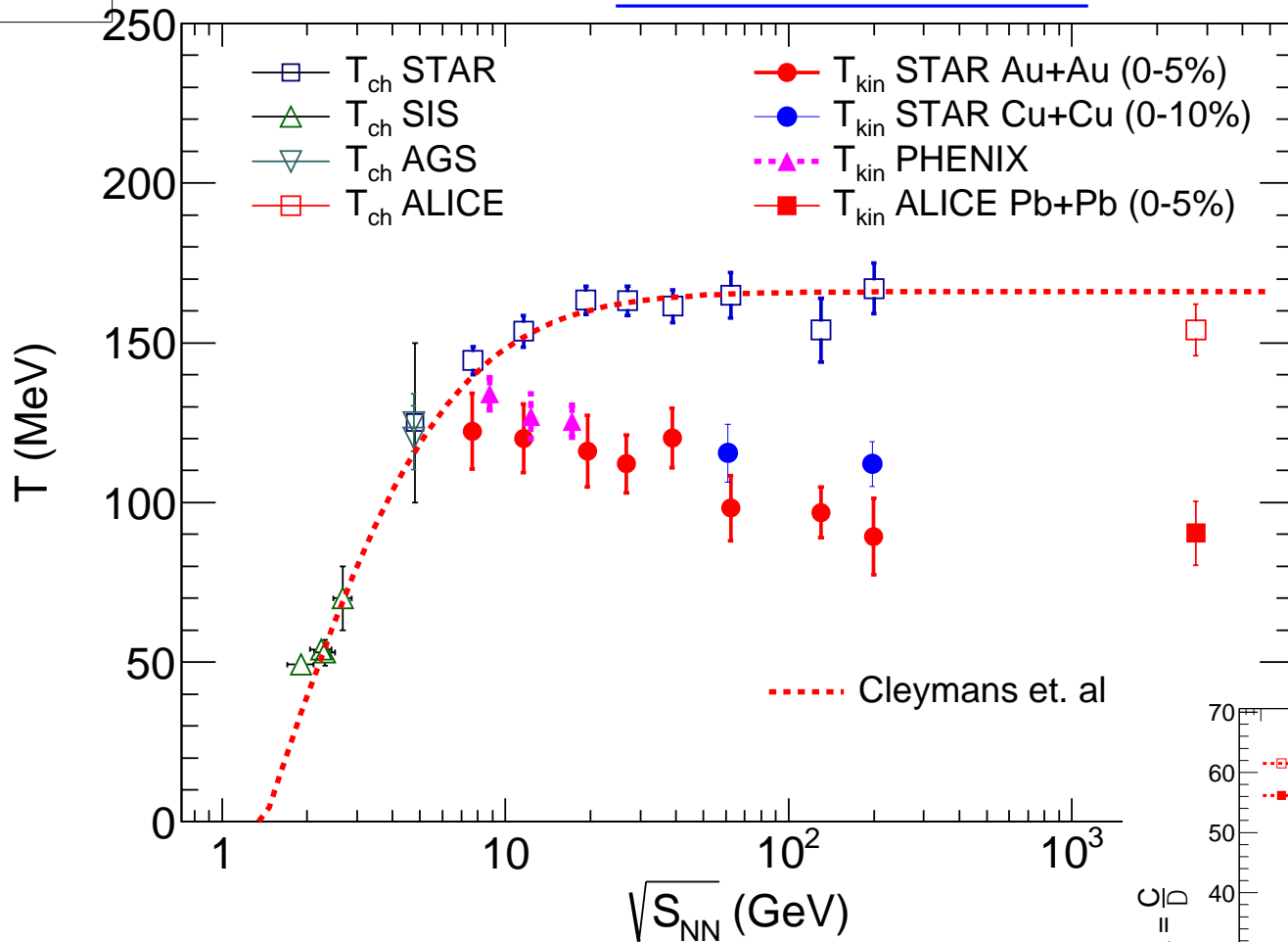
Def. Temperature & Sp. Heat

8



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C

[arXiv : 1601.05631](https://arxiv.org/abs/1601.05631)



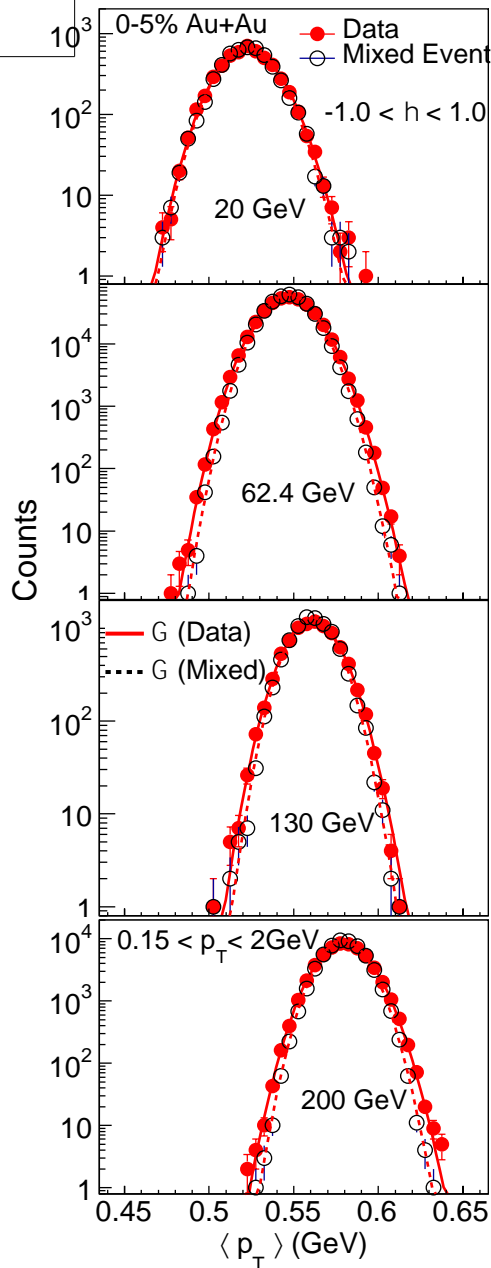


TABLE I: Parameters for the gamma distributions shown in Fig. 1. The gamma distribution is given by the form $f(x) = \frac{x^{\alpha-1} e^{-x/\beta}}{\Gamma(\alpha)\beta^\alpha}$ where $\alpha = \frac{\mu^2}{\sigma^2}$ and $\beta = \frac{\sigma^2}{\mu}$ in GeV/c. μ is the mean in GeV/c and σ is the standard deviation in GeV/c.

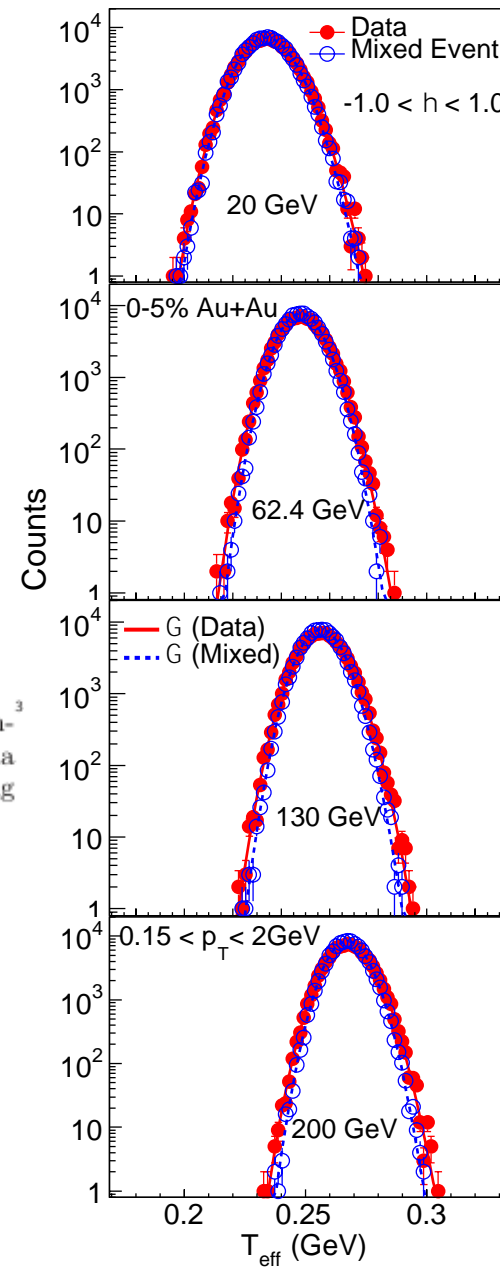
Case	α	β	μ	σ
20 GeV Real	1096	4.772×10^{-4}	0.5228	0.01579
20 GeV Mixed	1199	4.360×10^{-4}	0.5227	0.01510
62 GeV Real	1445	3.786×10^{-4}	0.5471	0.01439
62 GeV Mixed	1743	3.139×10^{-4}	0.5470	0.01310
130 GeV Real	1556	3.608×10^{-4}	0.5614	0.01423
130 GeV Mixed	1917	2.927×10^{-4}	0.5612	0.01282
200 GeV Real	1853	3.129×10^{-4}	0.5799	0.01347
200 GeV Mixed	2373	2.443×10^{-4}	0.5799	0.01190

STAR, Phys. Rev. C 72, 044902



TABLE I: The event-by-event T_{eff} distributions for central (top 5%) Au+Au collisions are fitted by the gamma function. Table gives the fit parameters, α and β along with mean (μ) and standard deviation (σ).

$\sqrt{s_{NN}}$ (GeV)	Case	α	β (GeV)	μ (GeV)	σ GeV
20	data	658.53	3.556×10^{-4}	0.2341	0.00912
	mixed	724.56	3.229×10^{-4}	0.2339	0.00869
62	data	860.20	2.885×10^{-4}	0.2482	0.00846
	mixed	1043.67	2.378×10^{-4}	0.2481	0.00768
130	data	920.25	2.789×10^{-4}	0.2566	0.00846
	mixed	1140.12	2.249×10^{-4}	0.2564	0.00759
200	data	1078.23	2.483×10^{-4}	0.2677	0.00815
	mixed	1387.56	1.927×10^{-4}	0.2674	0.00718



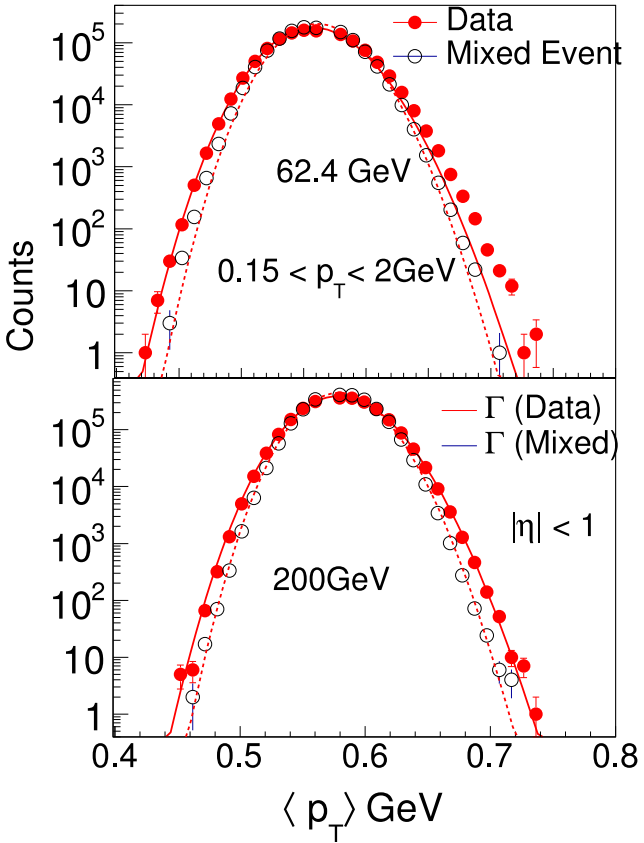


TABLE II: Gamma distribution parameters for event-by-event $\langle p_t \rangle$ distributions for data and mixed events in central (0%-10%) Cu+Cu collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV.

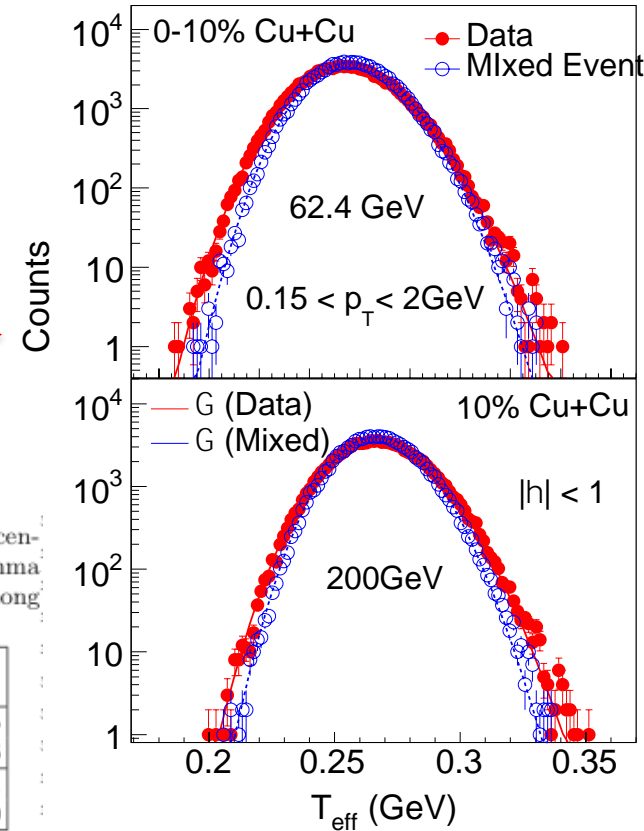
Collision type (AA)	α	β ($\times 10^{-3}$ GeV/c)	μ (GeV/c)	σ (GeV/c)
Cu 200 (data)	476	1.22	0.5805	0.02660
Cu 200 (mixed)	634	0.92	0.5807	0.02310
Cu 62.4 (data)	358	1.56	0.5603	0.02960
Cu 62.4 (mixed)	457	1.23	0.5602	0.02621

STAR, Phys. Rev. C 87, 064902



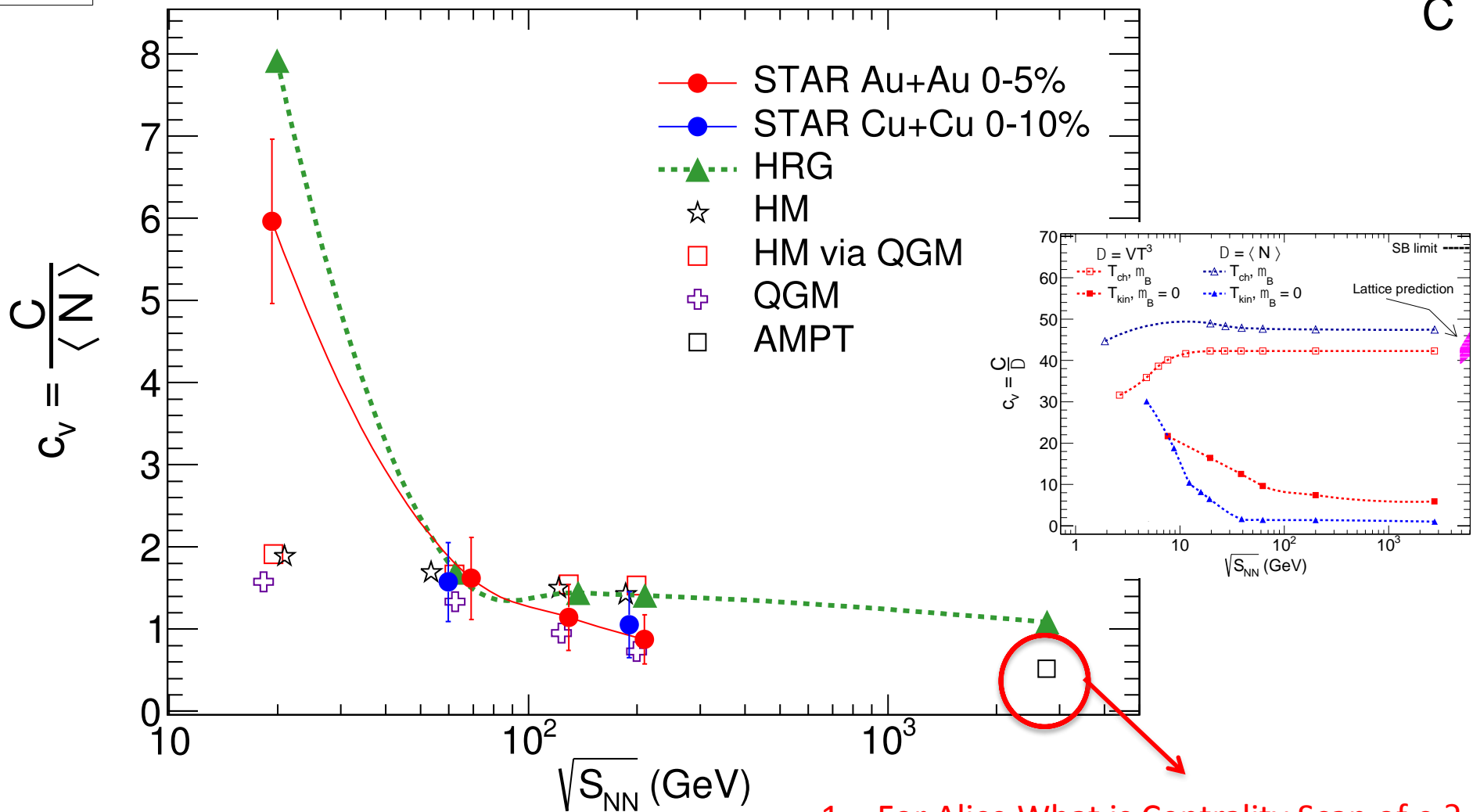
TABLE II: The event-by-event T_{eff} distributions for central (top 10%) Cu+Cu collisions are fitted by the gamma function. Table gives the fit parameters, α and β along with mean (μ) and standard deviation (σ).

$\sqrt{s_{NN}}$ (GeV)	Case	α	β (GeV)	μ (GeV)	σ GeV
62	data	211.88	12.040×10^{-4}	0.2550	0.0175
62	mixed	271.94	9.455×10^{-4}	0.2571	0.0156
200	data	277.08	9.687×10^{-4}	0.2684	0.0161
200	mixed	370.71	7.278×10^{-4}	0.2698	0.0140





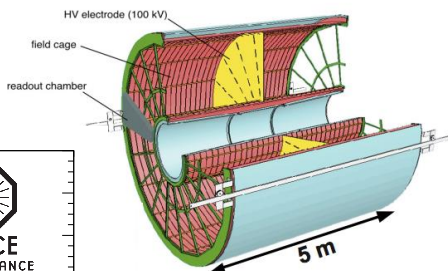
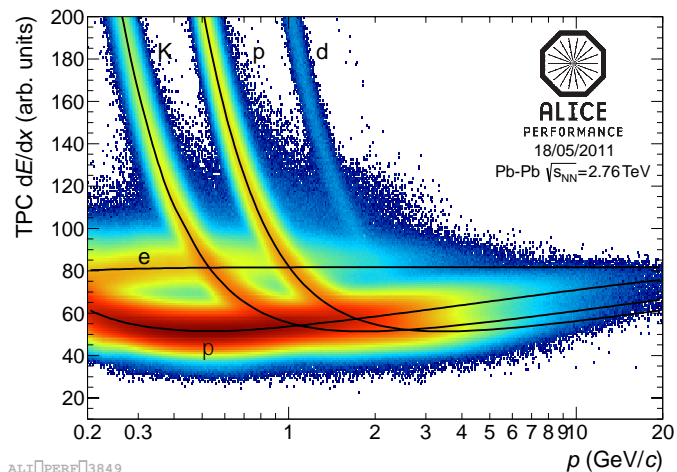
[arXiv : 1601.05631](https://arxiv.org/abs/1601.05631)



1. For Alice What is Centrality Scan of c_v ?
2. What about the species dependency?

HBN

TPC --> dE / dx

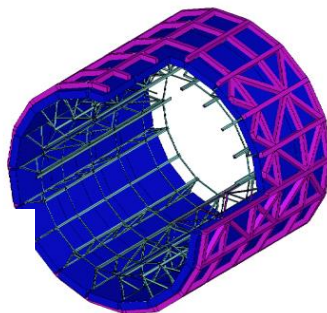
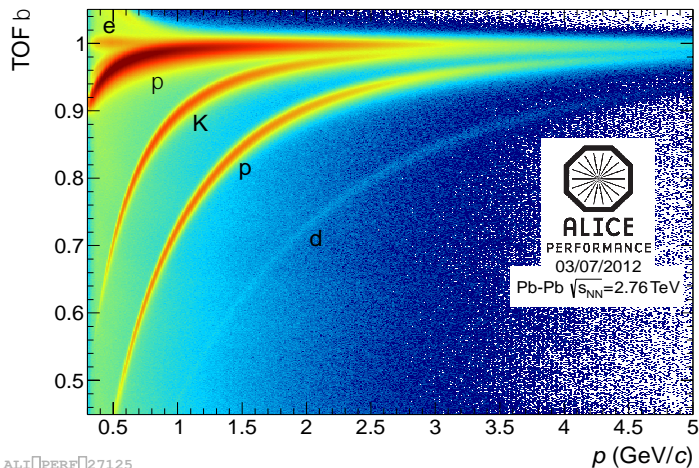


PID Techniques

1. Gaussian unfolding
2. TFractionFitter unfolding
3. Landau + Gaussian PID
4. $n\sigma$ (N sigma) PID

$$nS_{TPC} = \frac{dE / dx_{Measured} - \langle dE / dx \rangle_{Expected}}{S}$$

TOF --> $\beta = d / c\Delta t$



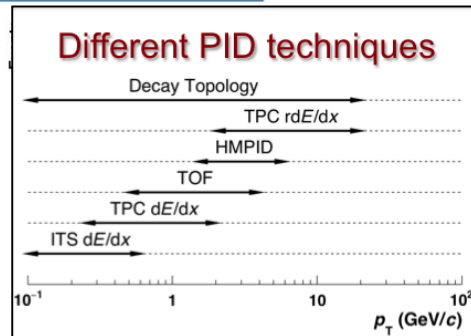
$$nS_{TOF} = \frac{(time_{hit} - timeZero) - time_{expected}(p, m, L)}{\sigma_{PID(TOF)}}$$

the timeZero for the event (measured/estimated in different ways)

the time measurement made by the TOF detector

This is computed, during reconstruction by ALICE core central tracking ('integrated times')

$$\sigma_{PID(TOF)} = \sqrt{\sigma_{TOF}^2 + \sigma_{timeZero}^2 + \sigma_{tracking}^2}$$



Data/MC Sets & Cuts

11



VEC

Data Set & Trigger

MC simulation	DATA Used in the Analysis
LHC11a10a_bis , kMB , Available Statistics	LHC10h , kMB , Available Statistics

Event selection

Centrality : 0-5% by V0M ,
Quality : pass 2
Vertex : N contributors > 0 for primary vertex
Data Type : AOD (AOD090 for MC and AOD086 for data)
: AOD (AOD162 for MC and AOD160 for data)

Track Selection

Filter bit : **768 , 272,**
Rapidity Cut : -0.5 to 0.5 (for identified particle)
Eta Cut : -0.8 to 0.8
Run No
 P_T Cut : 0.2 to 2.2 GeV/c

39510, 139507, 139505, 139503, 139465, 139441, 139440, 139438, 139437, 139360, 139329, 139328, 139314, 139310, 139309, 139173, 139107, 139105, 139042, 139038, 139037, 139036, 139029, 139028, 138980, 138979, 138978, 138977, 138872, 138871, 138870, 138837, 138732, 138730, 138666, 138662, 138653, 138652, 138638, 138624, 138621, 138583, 138582, 138579, 138578, 138534, 138469, 138442, 138439, 138438, 138396, 138364, 138359, 138225, 138201, 138200, 138197, 138192, 138190, 137848, 137843, 137752, 137751, 137748, 137724, 137722, 137718, 137704, 137693, 137692, 137691, 137686, 137685, 137639, 137638, 137608, 137595, 137549, 137544, 137541, 137539, 137443, 137441, 137440, 137439, 137434, 137432, 137431, 137430, 137366, 137243, 137236, 137235, 137232, 137231, 137162, 137161

Filter bit 768 :

SetMinCrossedRowsTPC(120)

SetMaxFractionSharedTPCClusters(0.4)

SetEtaRange(-0.9,0.9)

GetStandardITSTPCTrackCuts2010(kTRUE,1)

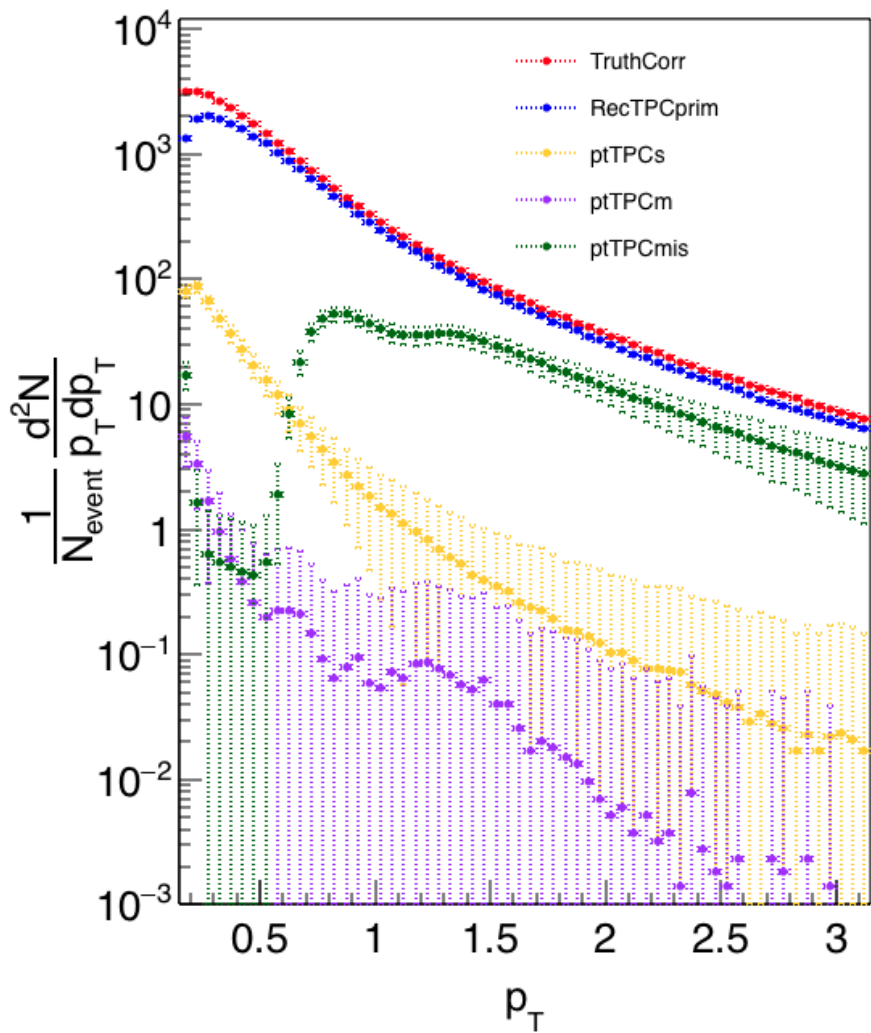
SetMaxChi2PerClusterITS(36)

SetMaxChi2TPCConstrainedGlobal(36)

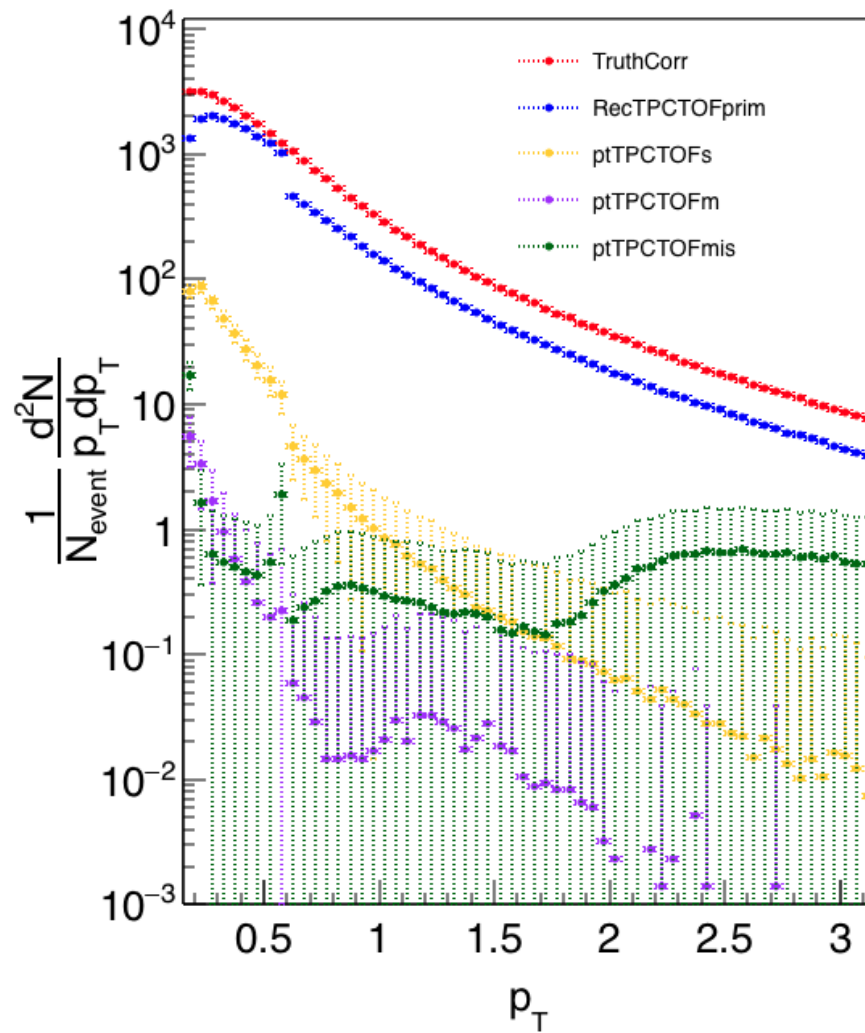
SetPtRange(0.15,1e10)



TPC

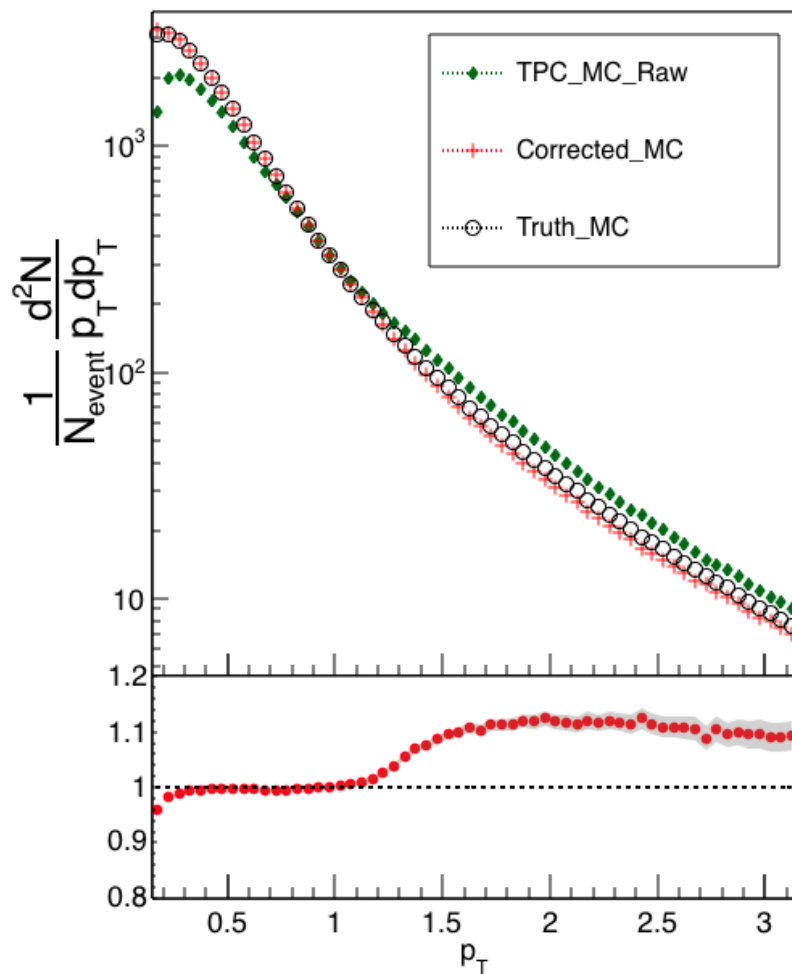


TPC+TOF

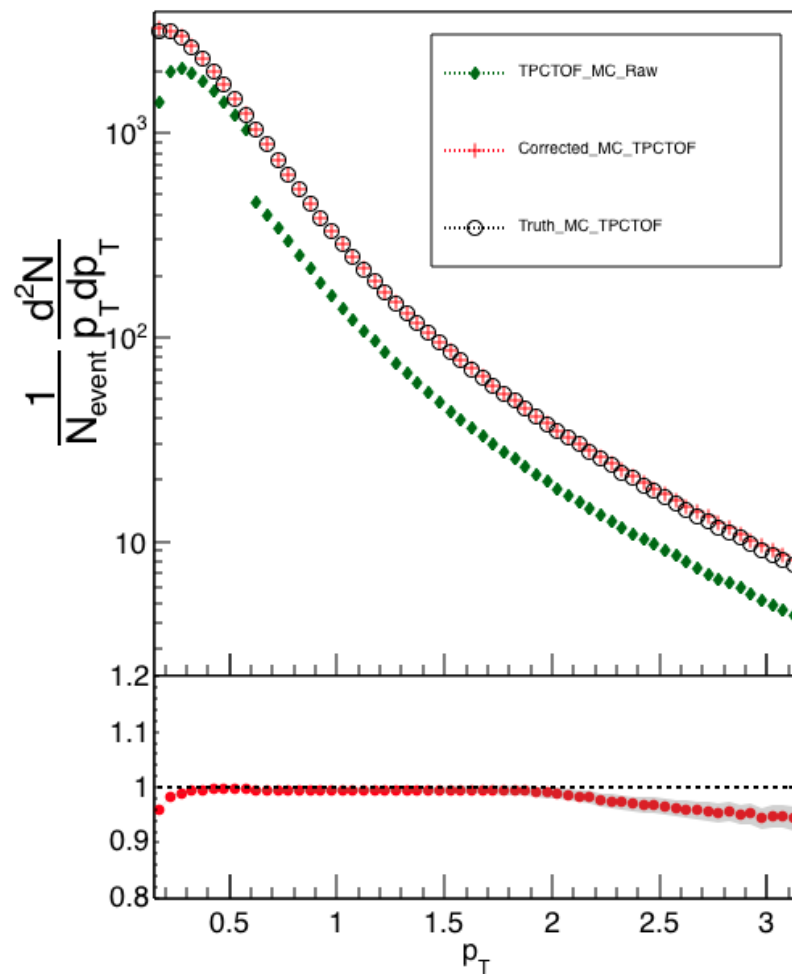




TPC

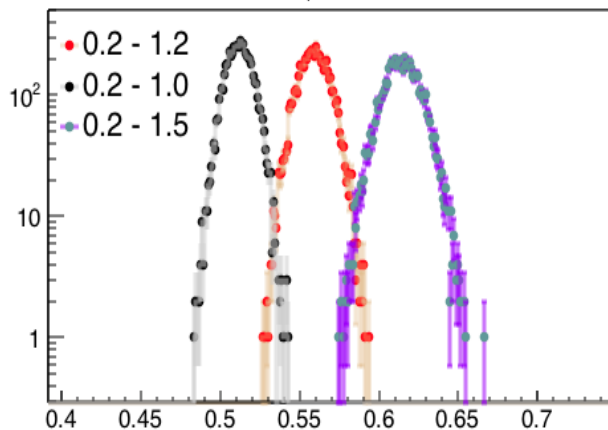


TPC+TOF

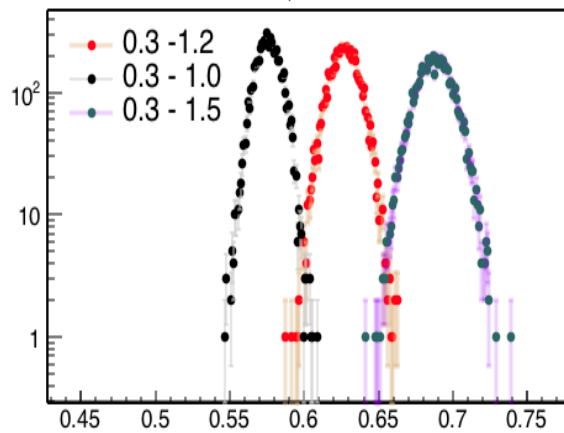


ALICE Result (Uncorrected)

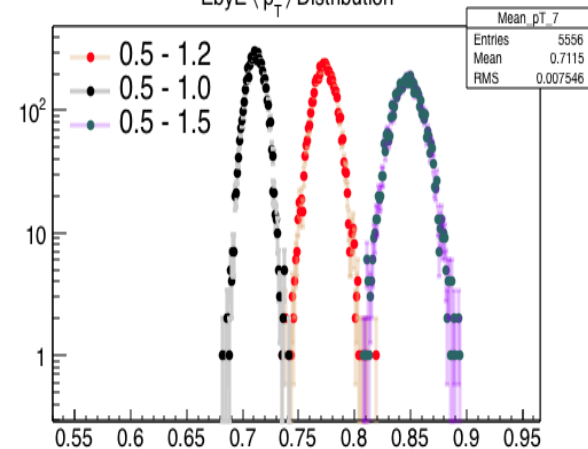
EbyE $\langle p_T \rangle$ Distribution



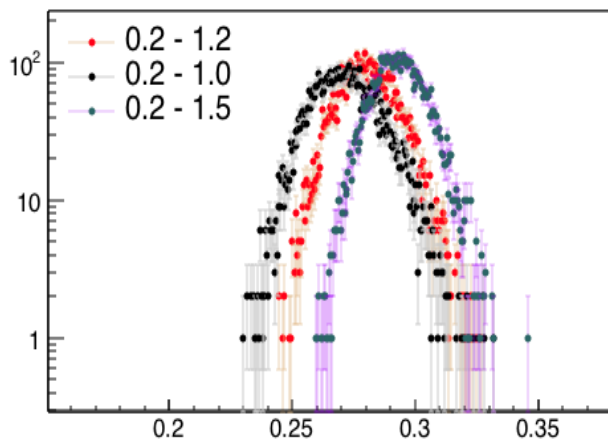
EbyE $\langle p_T \rangle$ Distribution



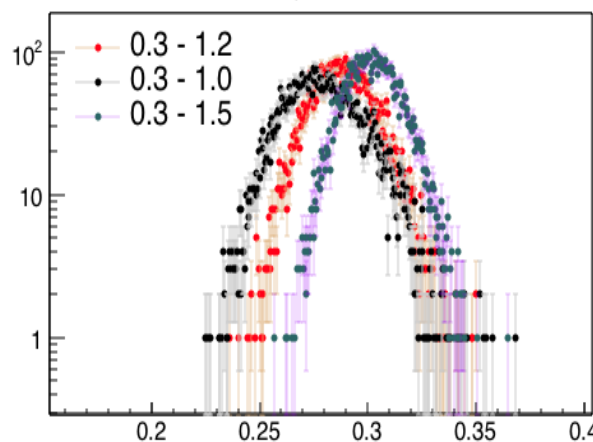
EbyE $\langle p_T \rangle$ Distribution



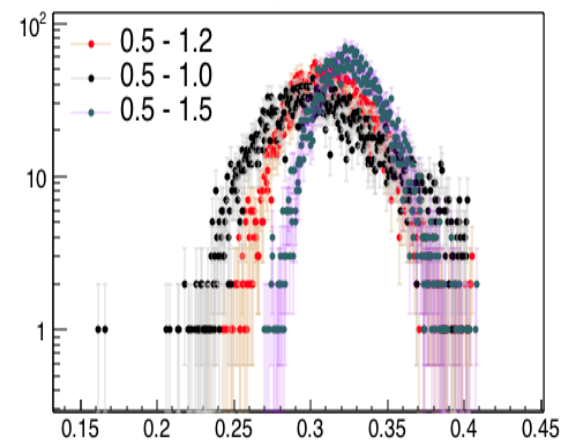
EbyE T_{eff} Distribution



EbyE T_{eff} Distribution



EbyE T_{eff} Distribution



Questions



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1. The Systematics and other checks are on going (effects of jet, flow fluctuations)
2. It will be a nice study on 5.02 TeV as multiplicity is high
3. For local details effects need to be discussed.

