Presentation

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Specific heat of matter Produced in Pb-Pb collisions

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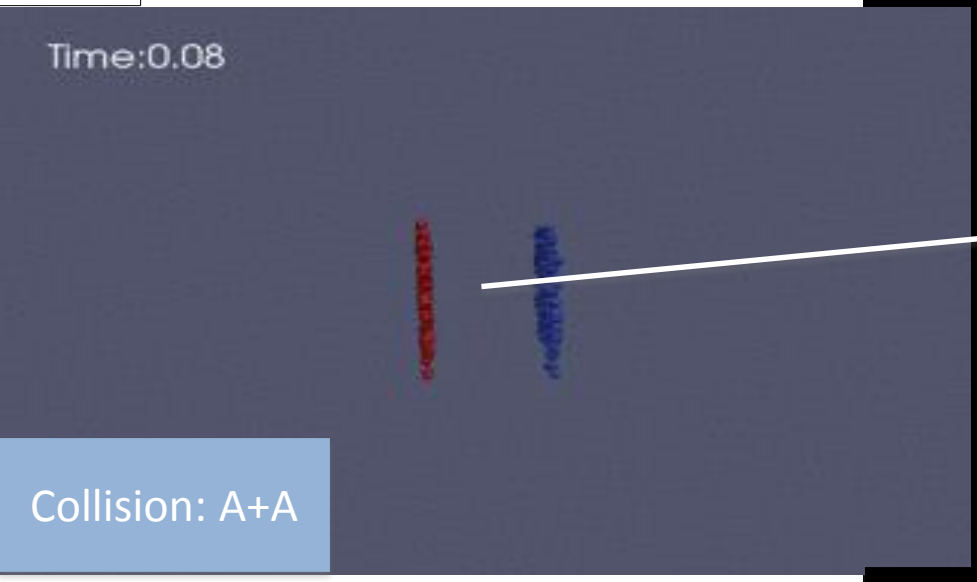
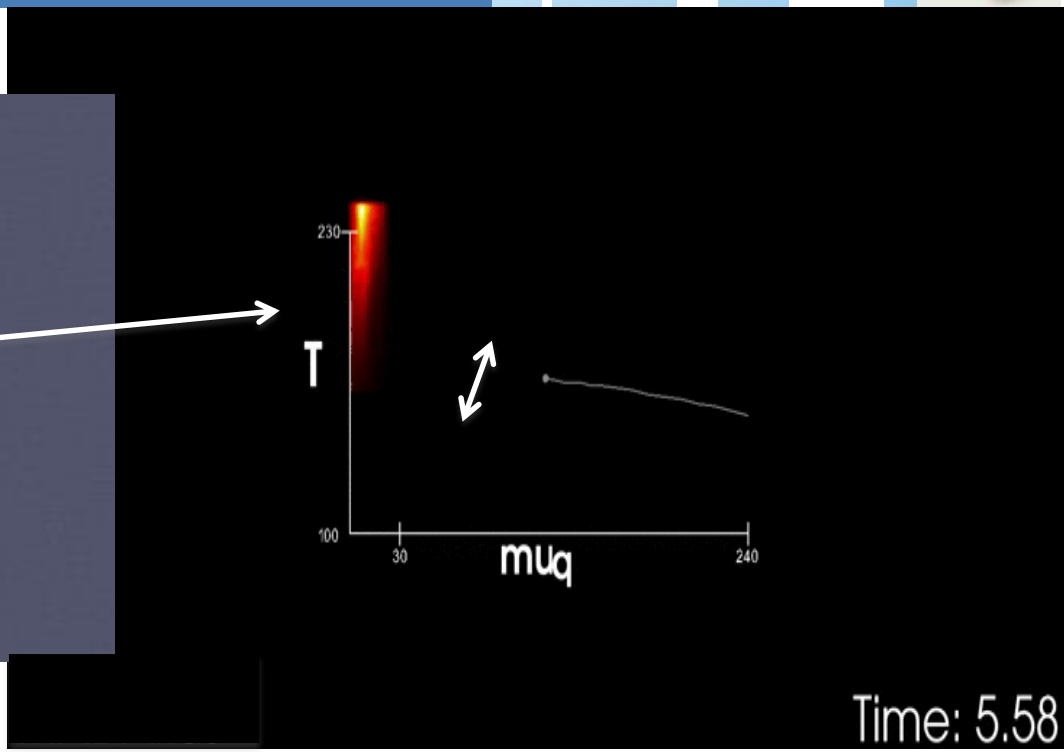
Rupa Chatterjee
Basanta K Nayak
&
VECC EHEP&A Group

E-by-E Fluctuations





- how fluctuation really transferred?
- what is the width?
- How much initial fluctuation retains ?
- Weather 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???

OUTLINE

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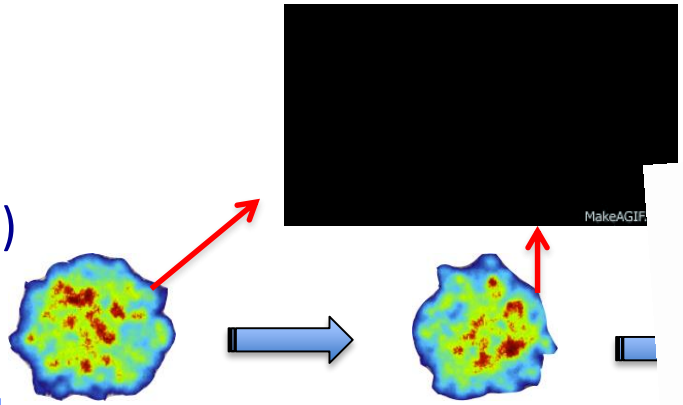
Temperature Fluctuation

(Motivation?? Review)

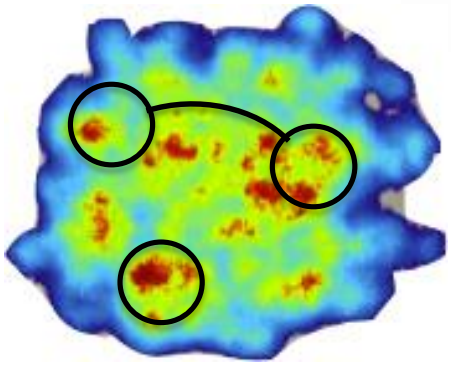


① Event-by Event : Global

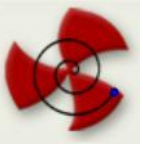
Model study → Previous Data → ALICE D

② Within The Event : Local

Model Study → Hydro → Data



Prelude



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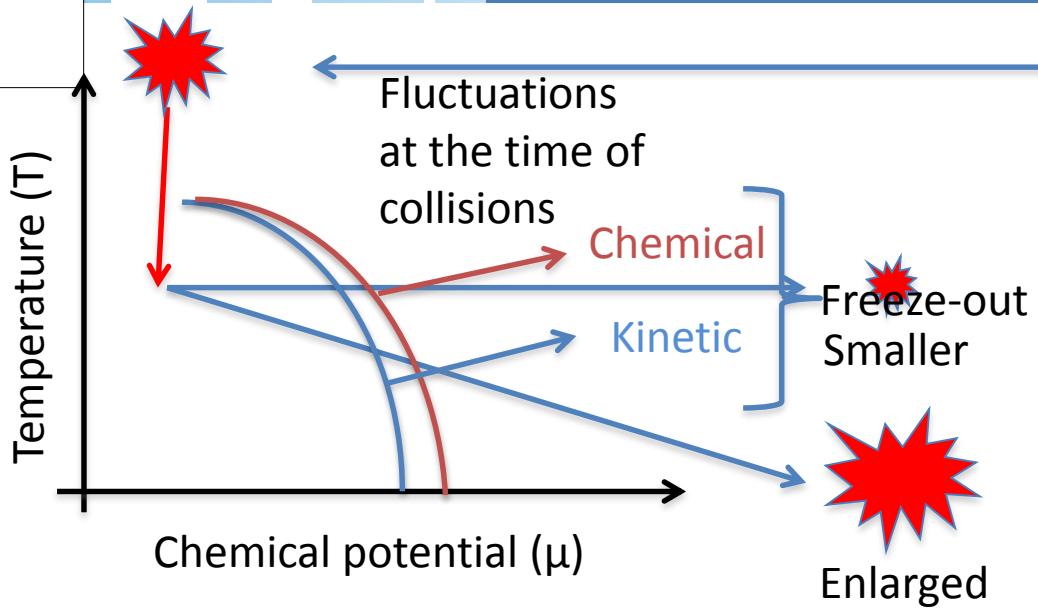
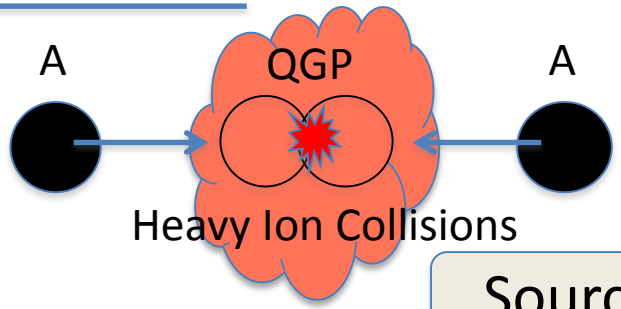
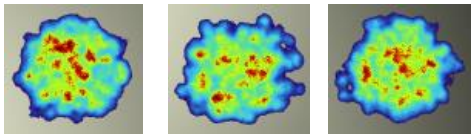




Sources

1. Initial State fluctuations



(Uli Heinz, arXiv:1304.3634)

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

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

2. Thermodynamical fluctuations

3. Statistical fluctuations

Def. Temperature

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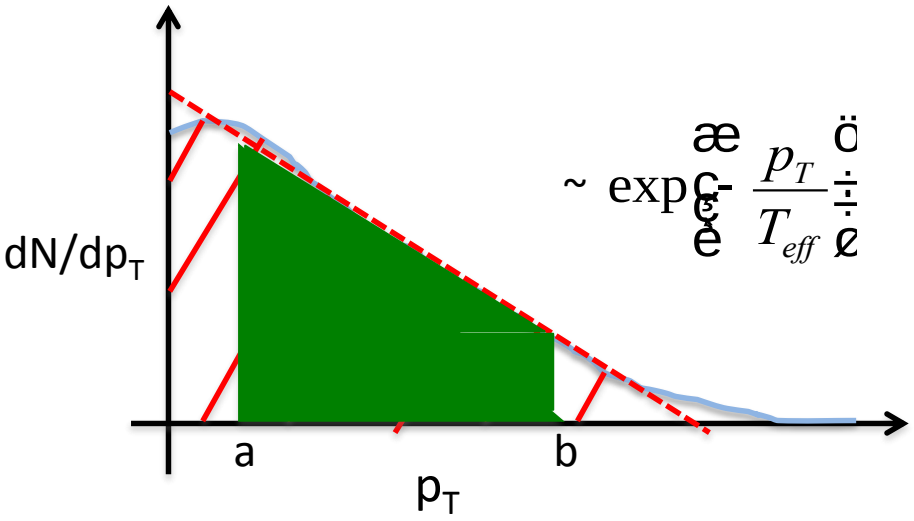
How to Measure Temperature?

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

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

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



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

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

Def. Sp. Heat

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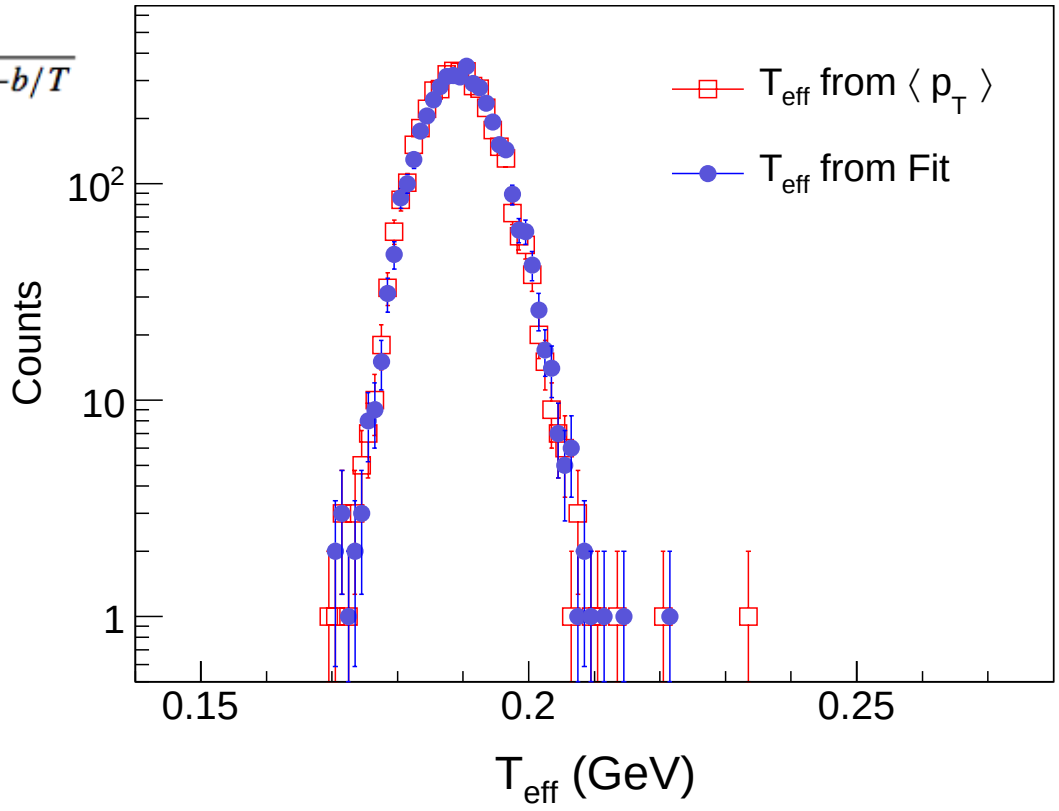
$$\langle p_t \rangle = 2T + \frac{a^2 e^{-a/T} - b^2 e^{-b/T}}{(a+T)e^{-a/T} - (b+T)e^{-b/T}}$$

$$T\mathrm{eff} = T_{\mathrm{kin}} + f(\beta_{\mathrm{T}}).$$

Blast-Wave (simultaneous)

We Define Heat Capacity

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



Sp. Heat

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

Dimensionless Quantity

Def. Temperature & Sp. Heat

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?

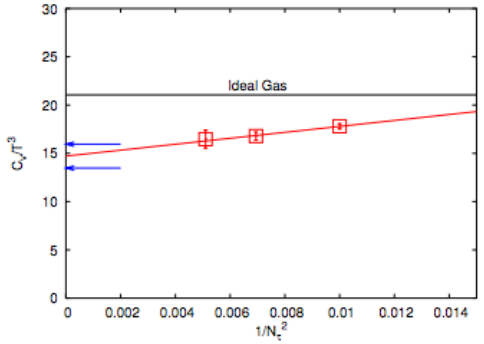
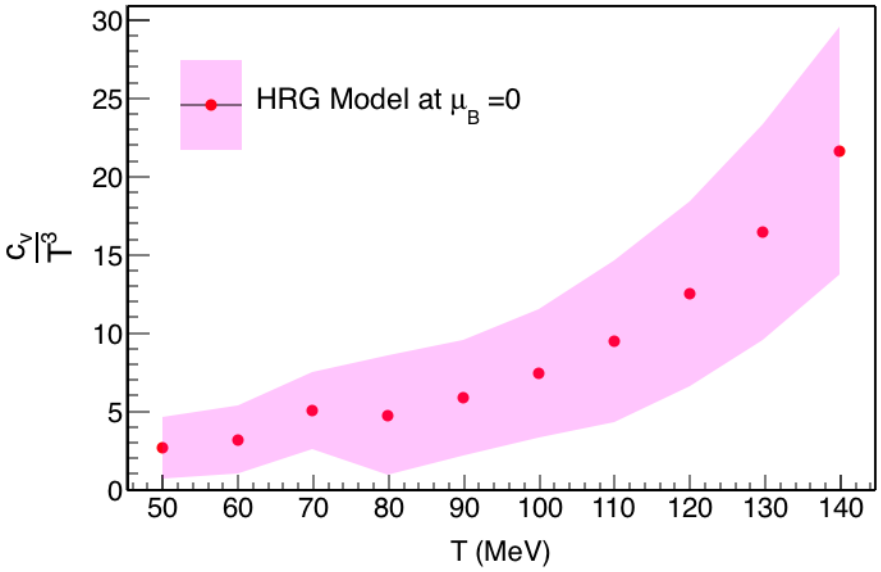
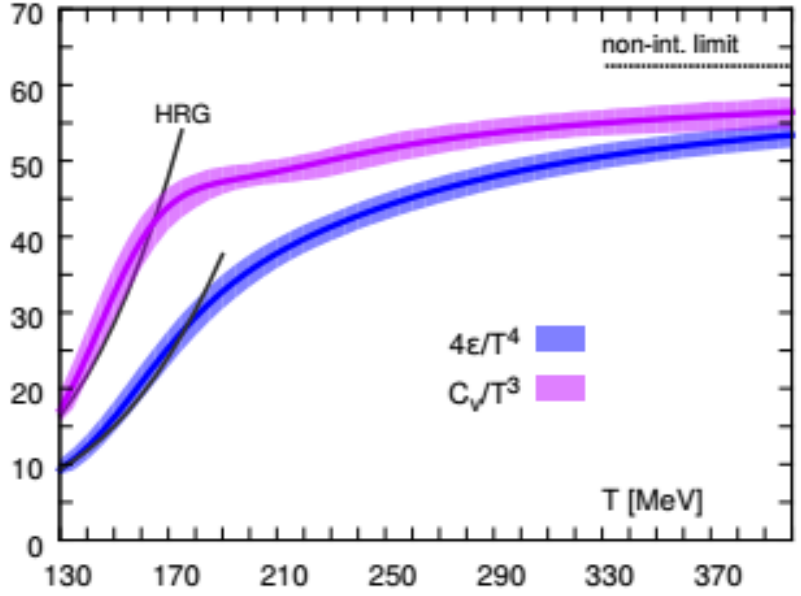


FIG. 1: Gavai, *et al.*, prediction for c_v/T^3 [1].

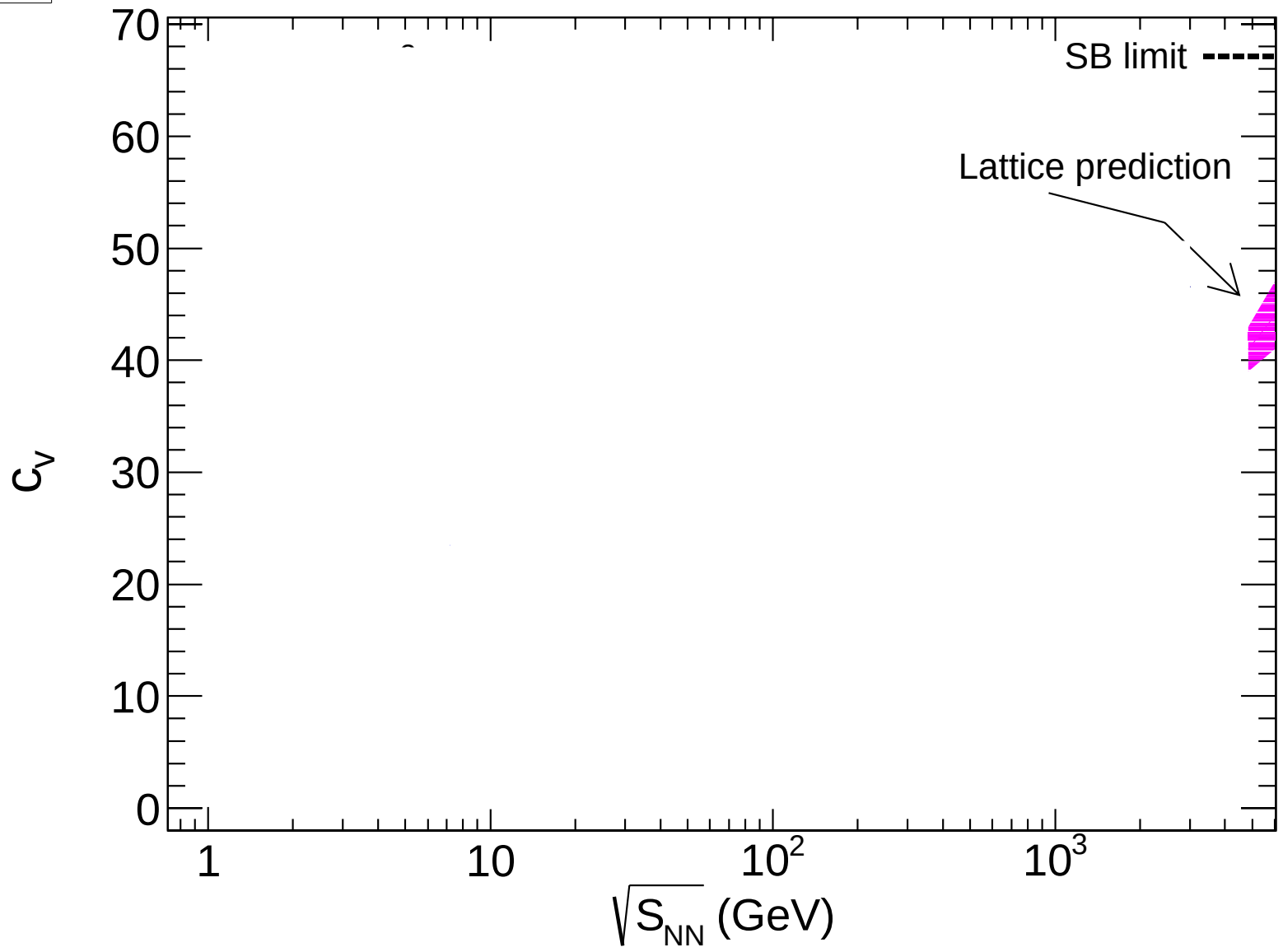


A. Bazavov et.al.
Phys. Rev. D 90, 094503 (2014)



Def. Temperature & Sp. Heat

arXiv : 1601.05631



Def. Temperature & Sp. Heat

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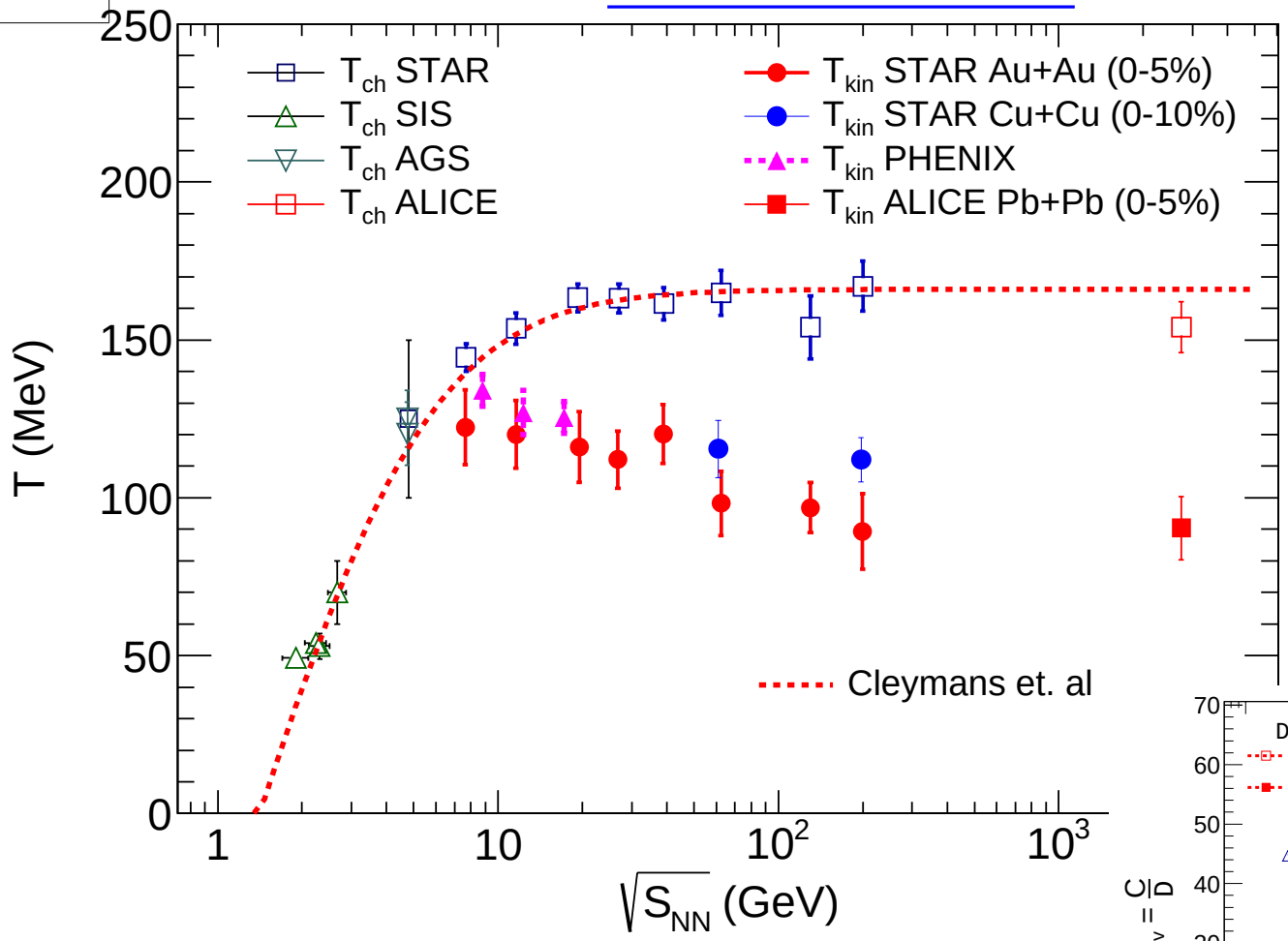
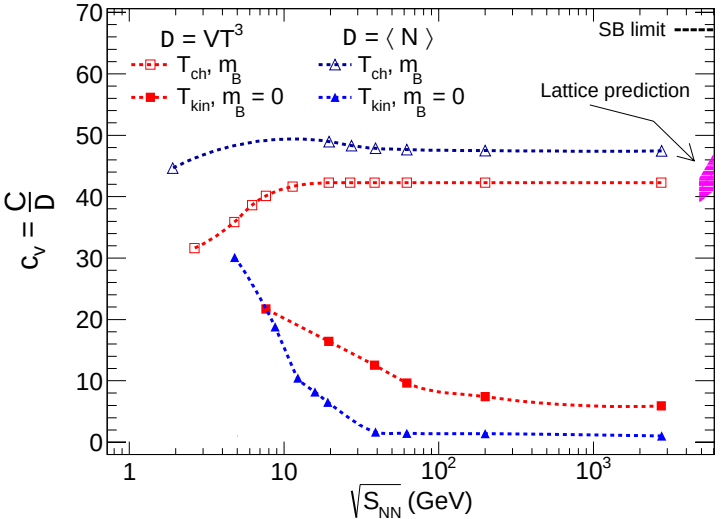
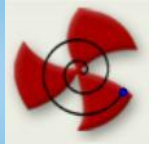
arXiv : 1601.05631





Def. Temperature & Sp. Heat



VEC C

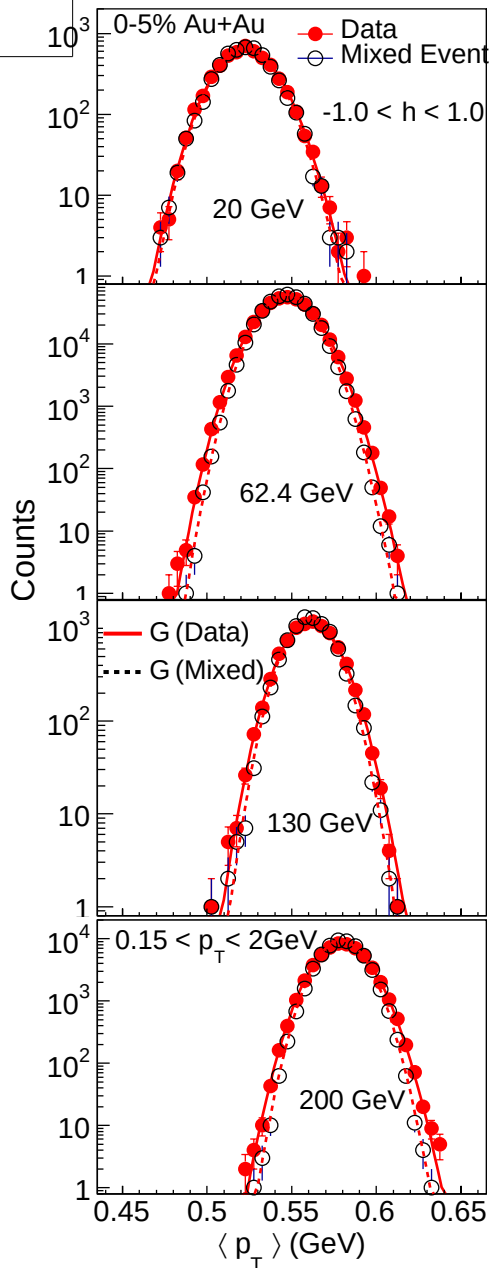


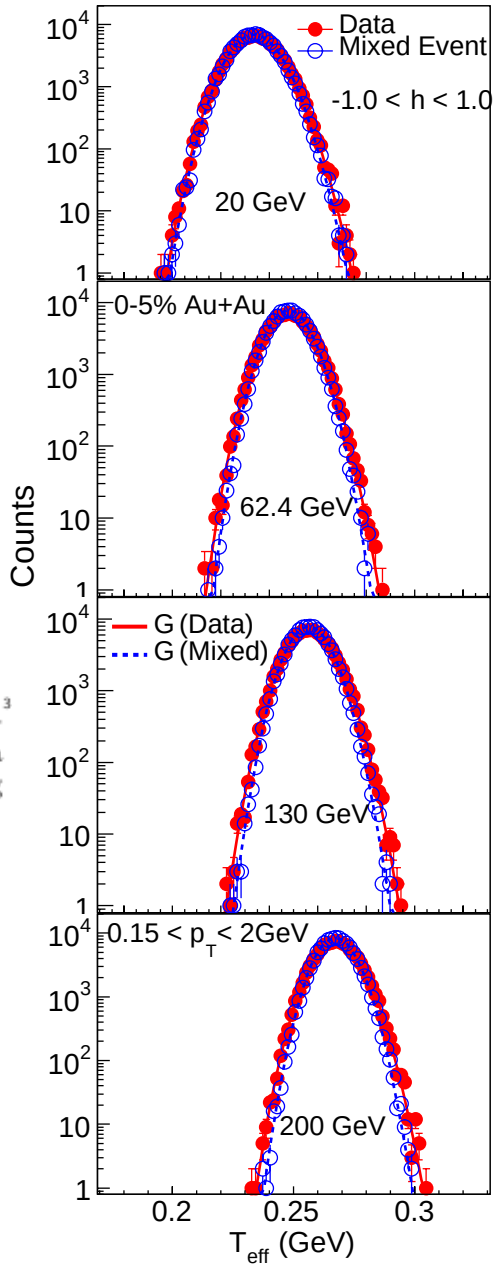
TABLE I: Parameters for the gamma distributions shown in Fig. 1. The gamma distribution is given by the form $f(x) = \frac{x^{\alpha-1}e^{-x/\beta}}{\Gamma(\alpha)\beta^{\alpha}}$ where $\alpha = \frac{\mu^2}{\sigma^2}$ and $\beta = \frac{\sigma^2}{\mu}$ in GeV/c. μ is the mean in GeV/c and σ is the 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 $T_{\rm eff}$ distributions for central (top 5%) Au+Au collisions are fitted by the gamma function. Table gives fhe fit parameters, α and β along with mean (μ) and standard deviation (σ).

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



Def. Temperature & Sp. Heat

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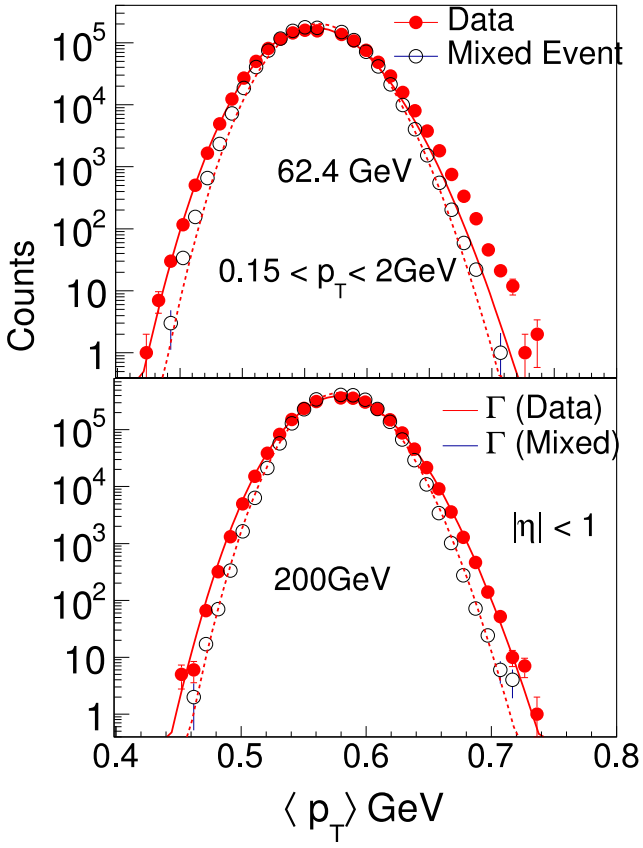


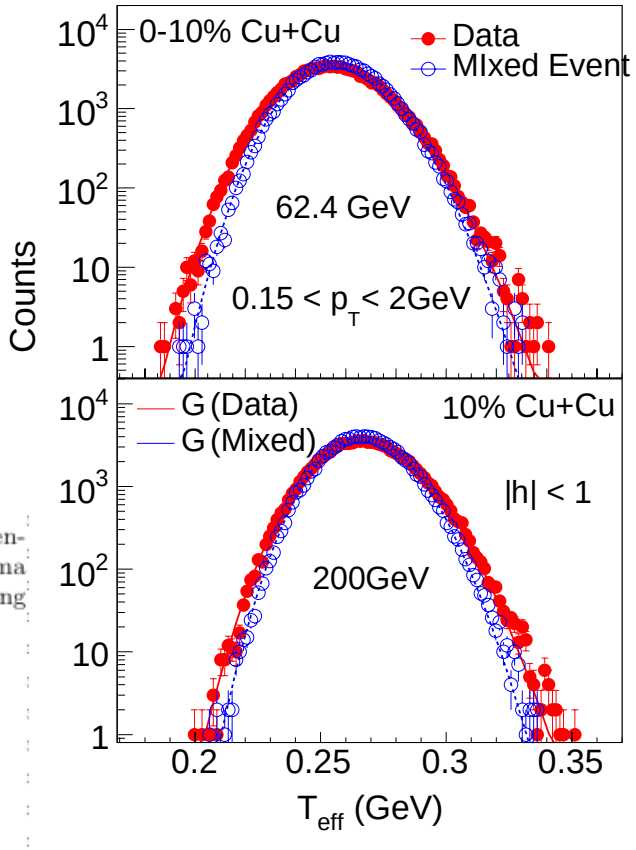
TABLE II: Gamma distribution parameters for event-by event $\langle p_t \rangle$ distributions for data and mixed events in centra (0%-10%) Cu+Cu collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV.

Collision type (AA)	α	β ($\times 10^{-4}$ 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 $T_{\rm eff}$ distributions for central (top 10%) Cu+Cu collisions are fitted by the gamma function. Table gives th fit parameters, α and β along with mean (μ) and standard deviation (σ).

$\sqrt{s}_{\rm NN}$ (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



Def. Temperature & Sp. Heat

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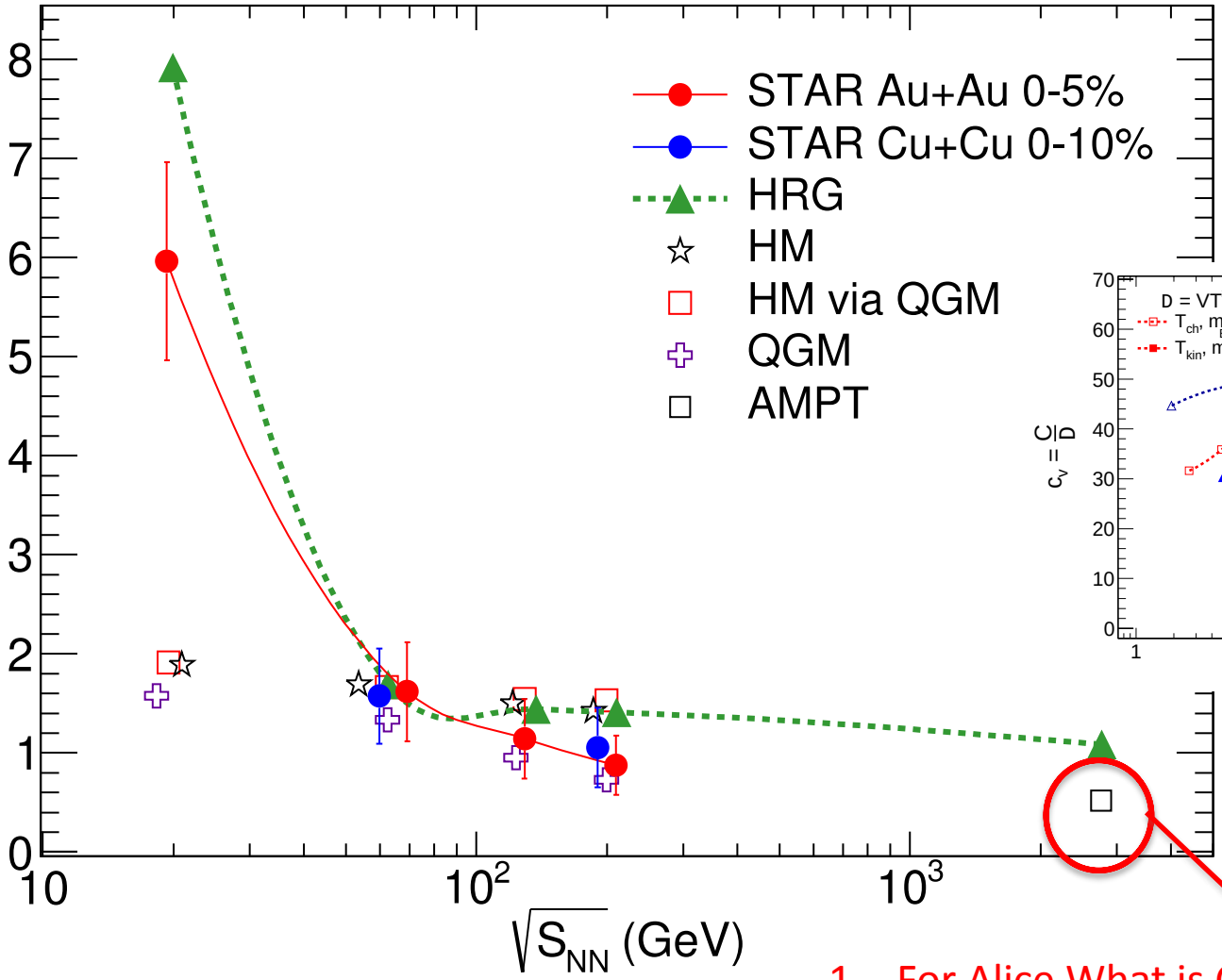
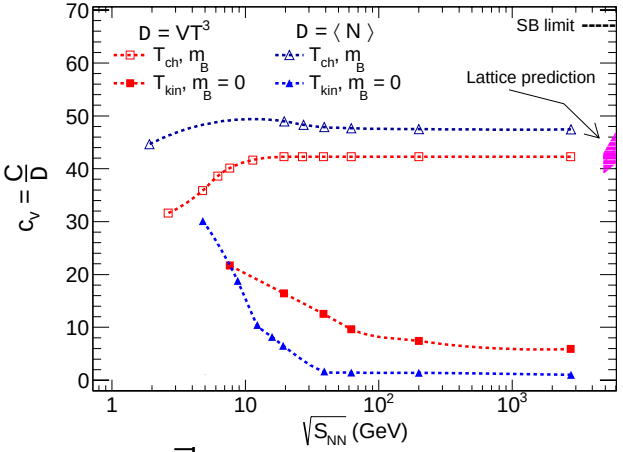
arXiv : 1601.05631

$c_V = \frac{C}{\langle N \rangle}$





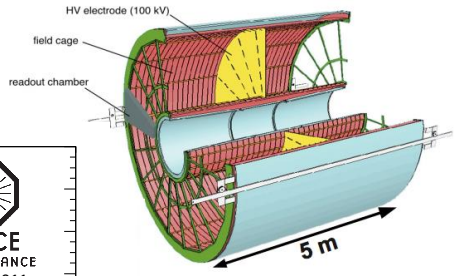
1. For Alice What is Centrality Scan of c_v?
2. What about the species dependency?

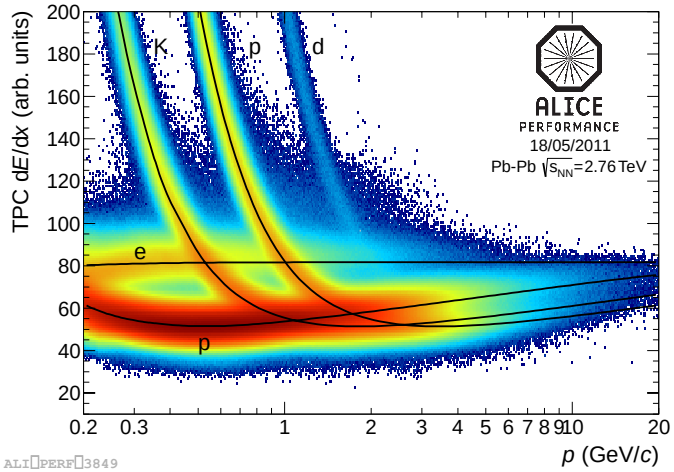
Detector performance & PID Techniques

HBNI

VECC

TPC --> dE / dx

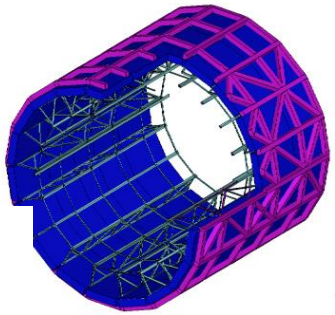




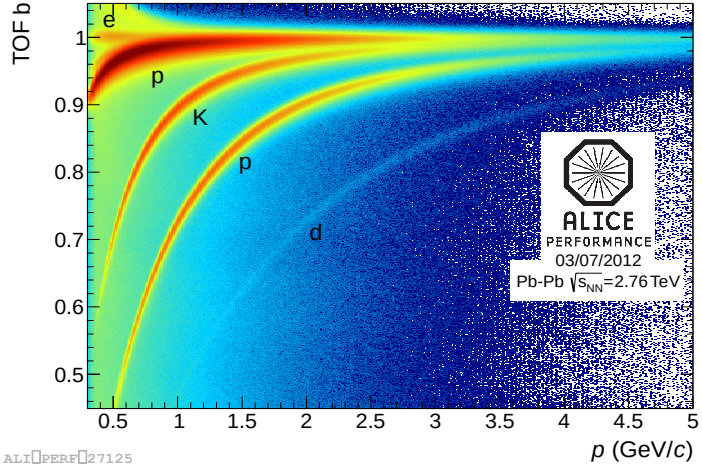
PID Techniques

1. Gaussian unfolding
2. TFractionFitter unfolding
3. Landau + Gaussian PID
4. nσ (N sigma) PID

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



TOF --> β = d / cΔt



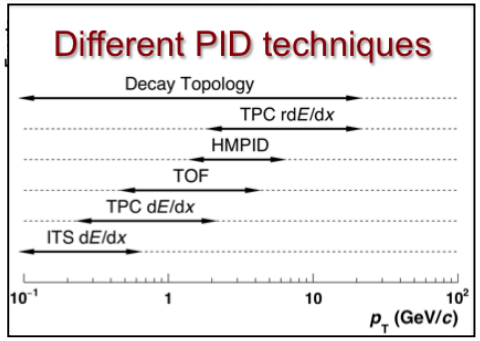
$$nS_{TOF} = \frac{(time_{hit} - timeZero) - time_{expected}(p,m,L)}{\sigma_{PID(TOF)}}$$

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

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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
P_T Cut	:	0.2 to 2.2 GeV/c

Run No

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)

Efficiency & Spectra

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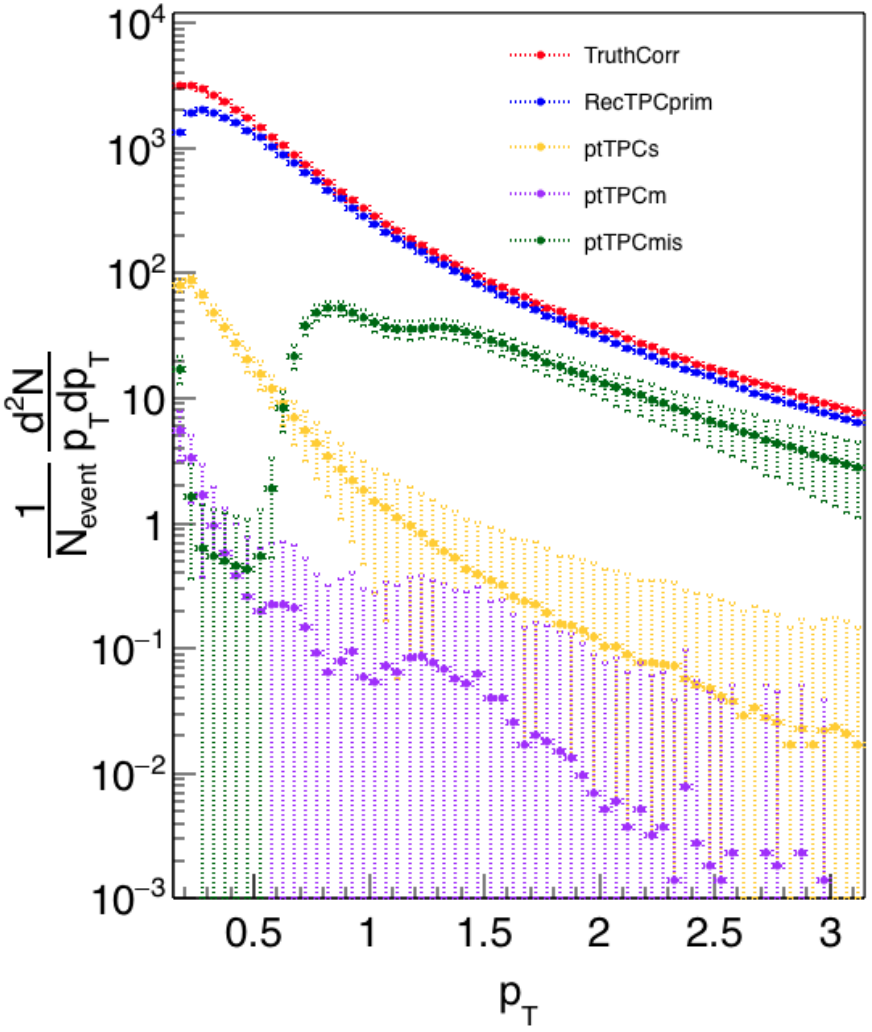
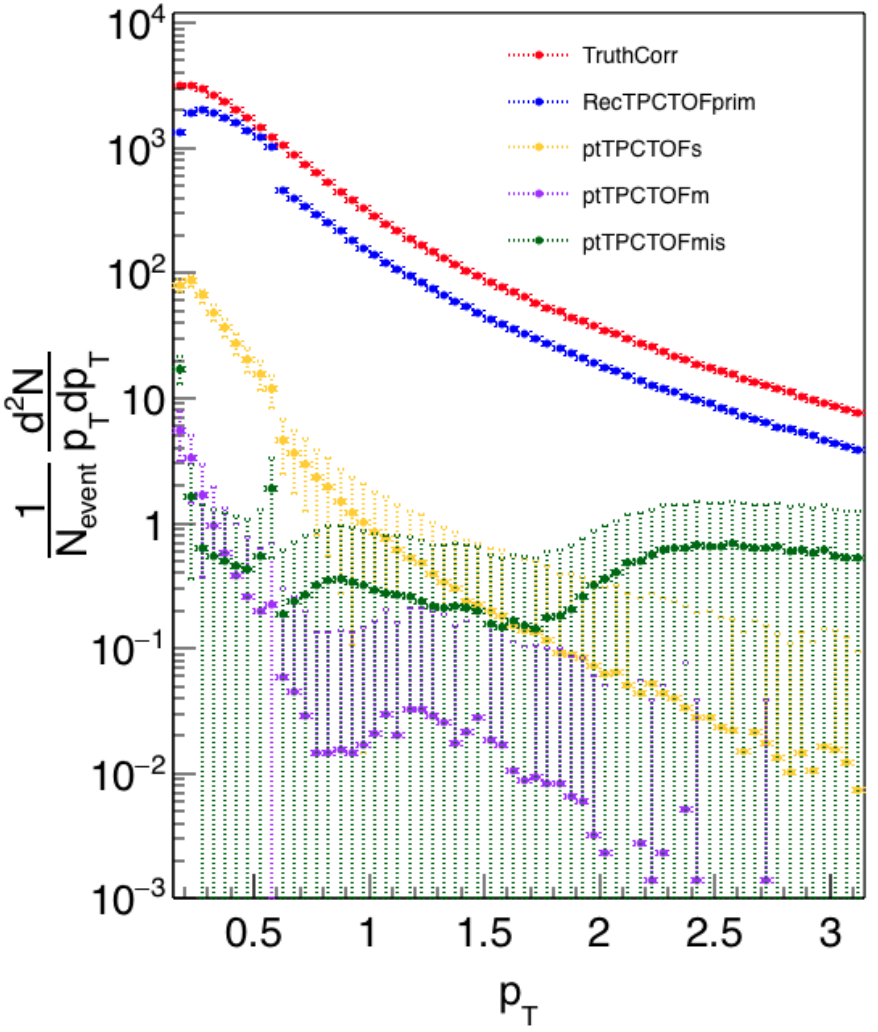
TPC



TPC+TOF



Corrected Spectra

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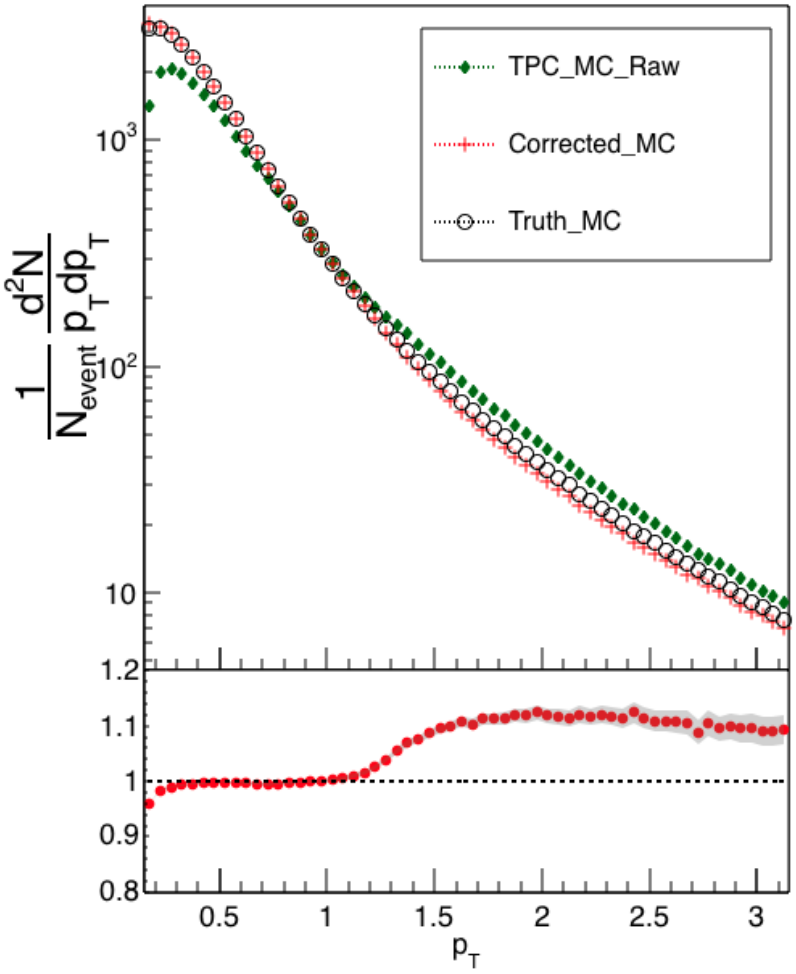
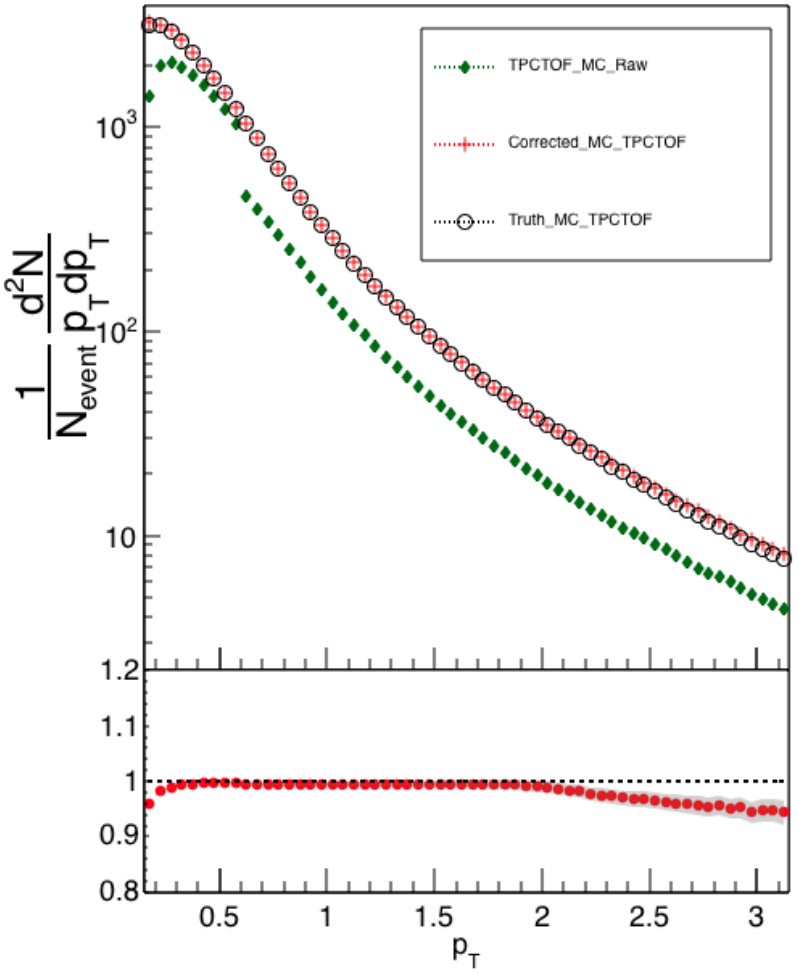
TPC



TPC+TOF



ALICE Result (Uncorrected)

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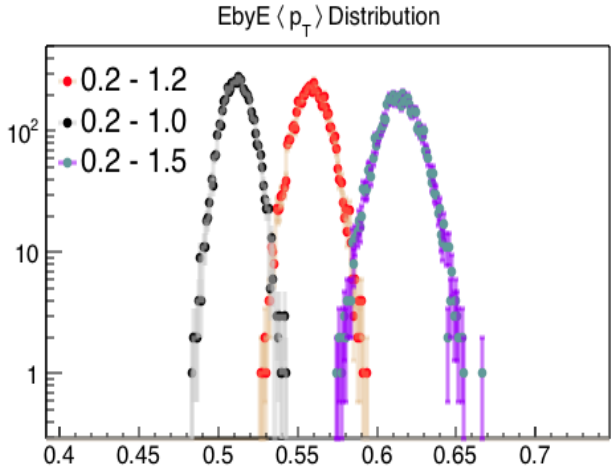

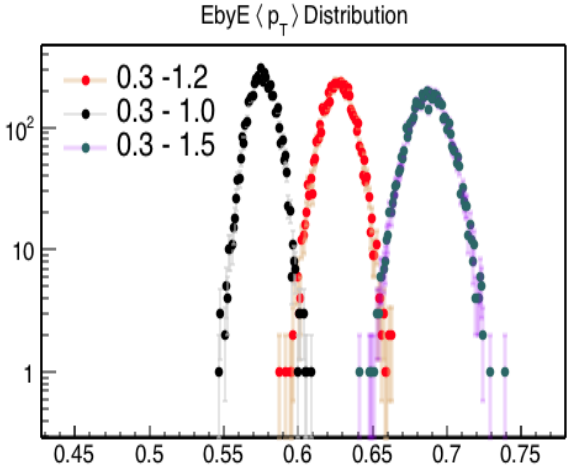

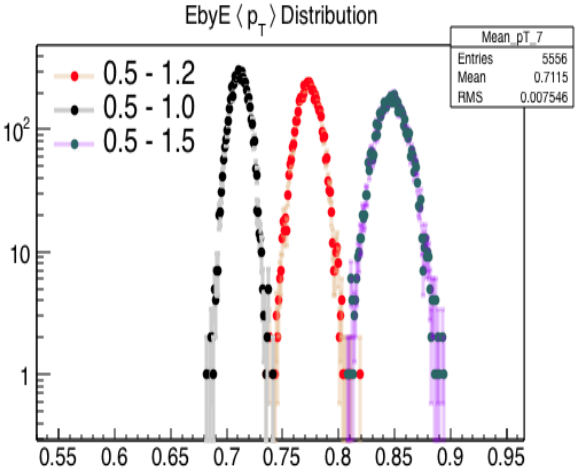

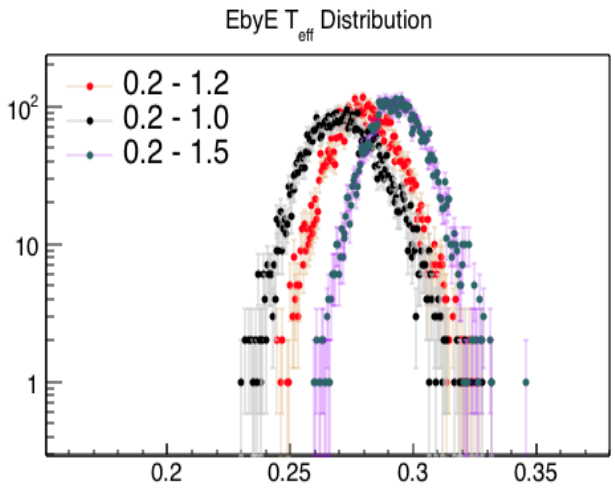

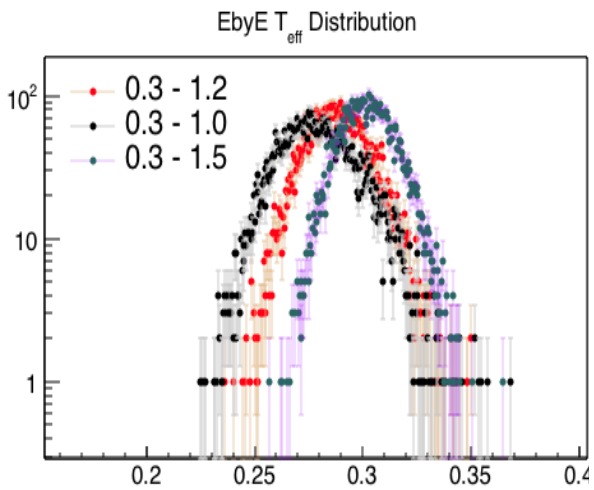

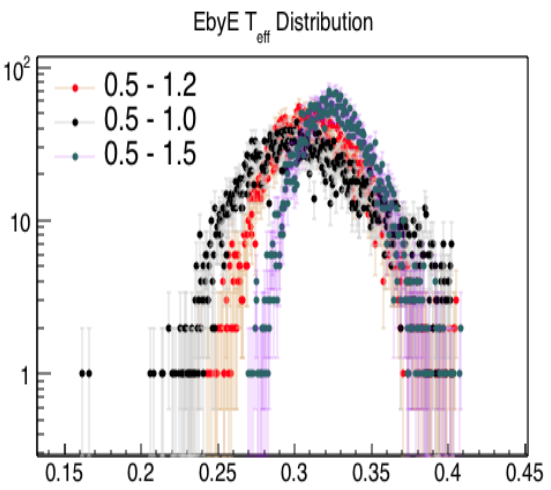

Questions

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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.