Pseudo-rapidity dependence of inclusive photon multiplicity distribution at forward rapidity in STAR at RHIC Beam Energy Scan

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Abstract

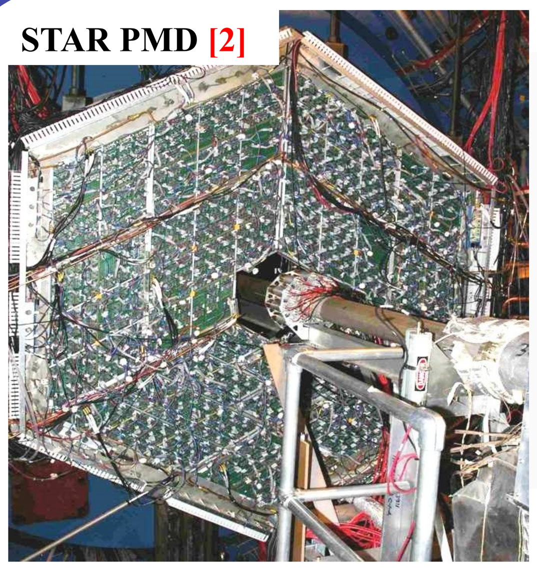
The main goal of the STAR experiment at Relativistic Heavy Ion Collider (RHIC) is to study the properties of the QCD matter at extremely high energy density and temperature, created in the heavy ion collisions. Photons are produced at all stages of the system created in a heavy ion collision, both directly and through decay of produced particles like π^0,η. Photon multiplicity, on an event-by-event basis, is an important measurement complementing the charged particle multiplicity in a heavy ion collision. Photon production at forward rapidity shows an energy independent longitudinal scaling as observed at $\sqrt{s_{NN}}$ = 62.4 and 200 GeV [1,2]. The Photon Multiplicity Detector (PMD) in the STAR experiment at RHIC measures inclusive photons in the pseudo-rapidity region $-3.7 \leq \eta \leq -2.3$. We present photon multiplicity and rapidity measurements in Au+Au collisions at $\sqrt{s_{NN}}$ = 39, 27 and 19.6 GeV for different event centralities. The results of measurements are compared with data at other energies and with heavy ion collision models.

Motivation

- The particle multiplicity measurements provide information on particle production mechanisms [3].
- The variation of particle density in pseudo-rapidity (η) with collision centrality can shed light on the relative contribution of soft and hard processes in particle production [3,4].
- Multiplicity measurements at forward rapidity can provide tests of ideas on initial conditions in heavy-ion collisions based on parton saturation [1].
- Measurement of inclusive photon multiplicity distributions and rapidity distributions complements measurement of charge particle multiplicity.

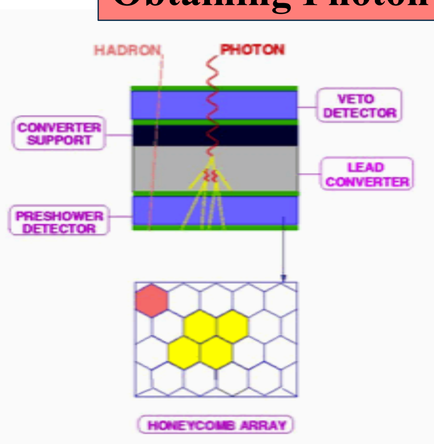
PMD Detector & Data Details

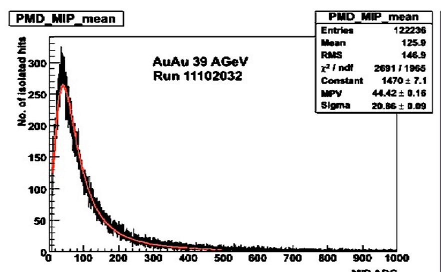
STAR PMD [2]



Photon Multiplicity Detector is installed in the forward region (-539 cm from the STAR vertex) of the STAR experiment to measure the multiplicity of photon in the pseudo-rapidity region $-3.7 < \eta < -2.3$.

Obtaining Photon Multiplicity using PMD





Cleanup and Calibration: Channels giving unstable or bad data are identified and removed from analysis
ADC Normalization: Gain of each PMD channel is estimated using isolated hits for each channel. ADC of a channel is corrected for gain.
Clustering : All connected hits were grouped together to make a Cluster.
Photon-Hadron Discrimination: Cluster size > 1 cell & Cluster ADC > N*MIP ADC selected
(where N=3 for 39 GeV and 2.5 for 19.6 GeV)
Efficiency, Purity & Geometry correction:
$N_\gamma = N_{\gamma\text{-like}}$ *Efficiency / (Purity* Acceptance)

Isolated hits were collected for each channel and used for gain normalization in two steps.

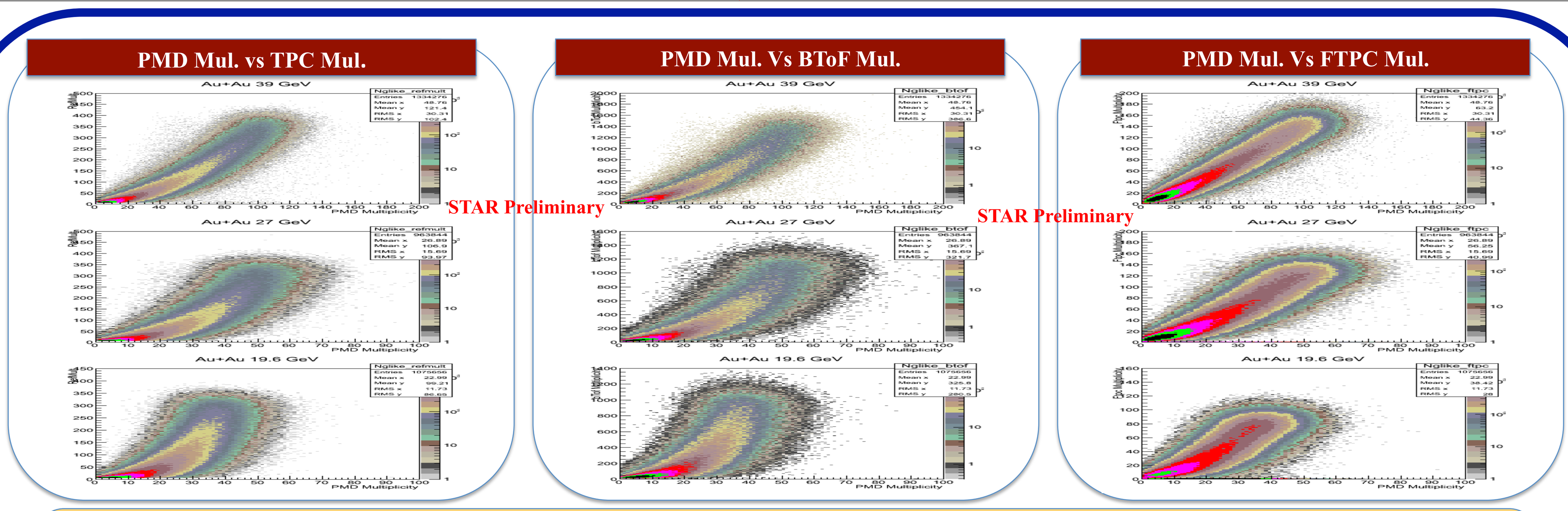
1- Normalization of all cells within an SM-Chain combination.

2- Normalization of SM-Chain combinations with respect to each other

After normalization the ADC of the isolated cells, expected due to Minimum Ionizing charged particles (MIP) is shown at left with a Landau fit.

QA Plots

PMD Mul. vs TPC Mul. | PMD Mul. Vs BToF Mul. | PMD Mul. Vs FTPC Mul.



A single correlation band is observed between all multiplicities. In the case of PMD multiplicity v/s TPC (I column) and BToF (II column), the correlation band is almost linear for 39 GeV but shows a clear bending for 27 and 19.6 GeV. The bending in correlation plots can be qualitatively understood by realizing that with decreasing collision energy, the beam rapidity decreases and gets closer to the acceptance range of PMD. Possible differences between the particle production at mid rapidity and forward rapidity may lead to other phenomena that may give an extra yield on the PMD even for peripheral collisions FTPC detector is also at forward rapidity so we expect a much smaller bending of the correlation band between FTPC Multiplicity (III col.).

Efficiency and purity of photon sample

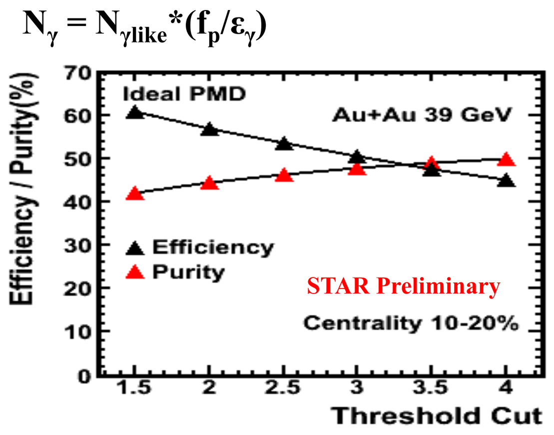
HIJING (AMPT) events are propagated through STAR-GEANT to get simulated data. From this data we obtain

N_γ : Total no. of photons from the event generator incident on PMD
$N_{\gamma like}$: Total number of clusters on PMD clearing threshold conditions
N_{cls} : Number of Photon clusters above the photon hadron discrimination condition i.e number of correctly Identified photons

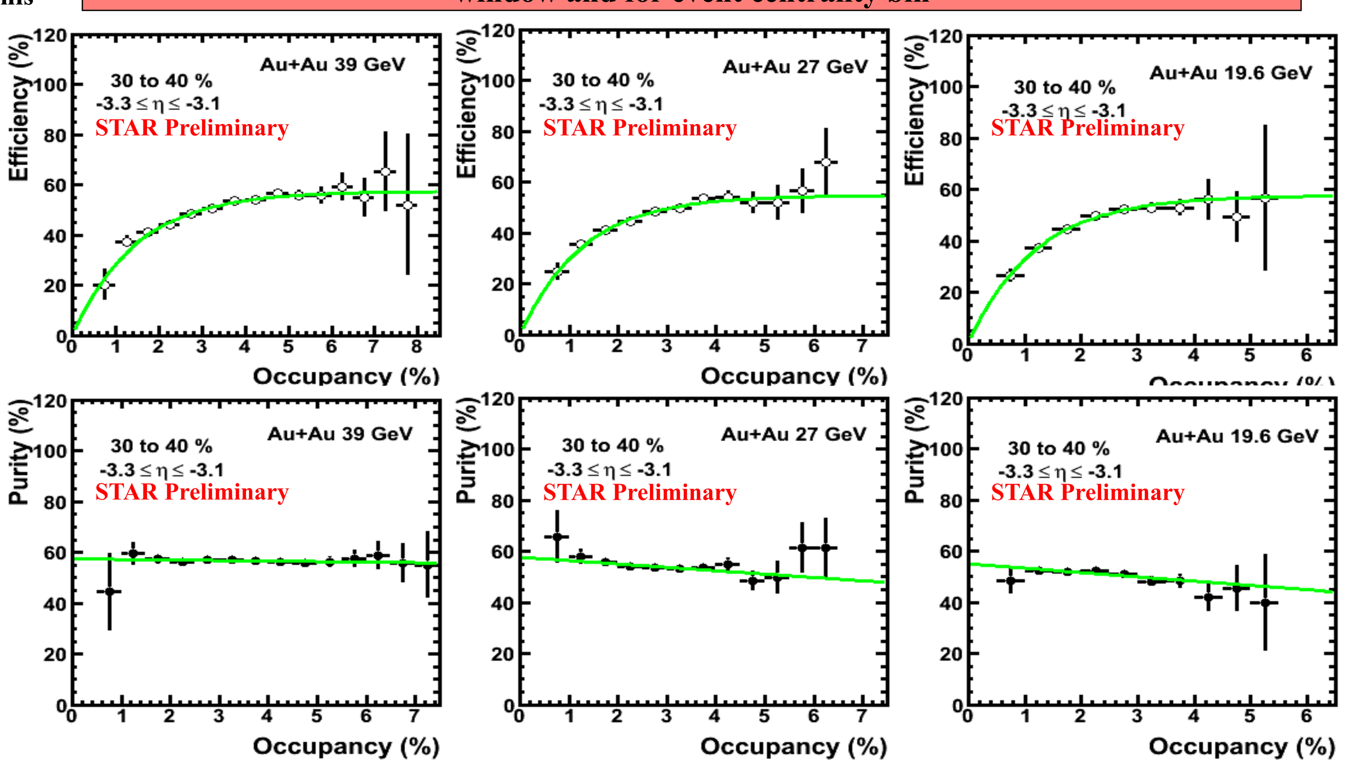
$$\text{Purity} = f_p = N_{cls} / N_{\gamma like}$$

$$\text{Efficiency/Acc } (\varepsilon_\gamma) = N_{cls} (\text{due to } \gamma)/N_\gamma$$

$$N_\gamma = N_{\gamma like} * (f_p/\varepsilon_\gamma)$$



The efficiency and purity has been studied as a function of occupancy for each rapidity window and for event centrality bin



$$Efficiency = A*(1-\exp\{-(Occ+0.0005)/B\})$$

We have fitted a function to efficiency that is written in green box and also a polynomial of order 1 is fitted to purity. These fit functions are used to obtain efficiency and purity in data according to observed occupancy.

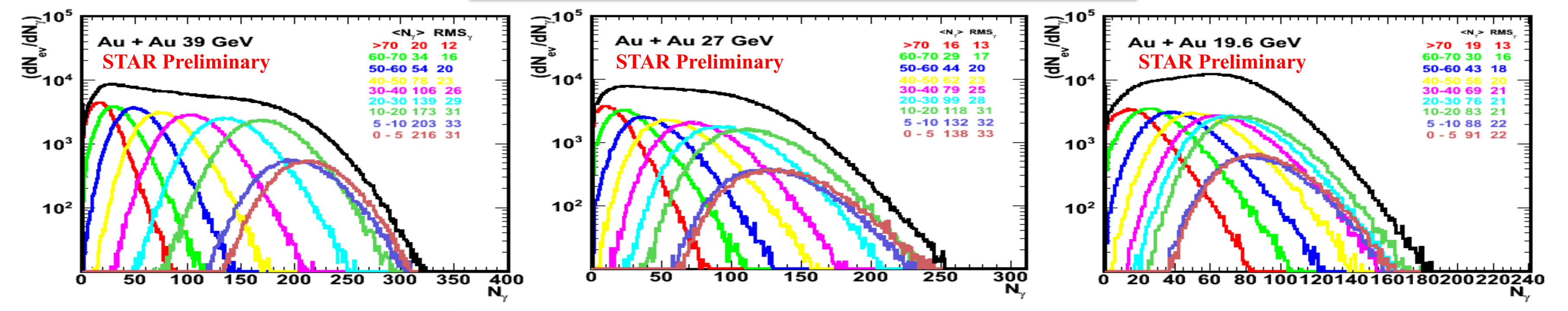
Systematic errors

The systematic errors on photon multiplicity and rapidity distributions have been estimated for the following.

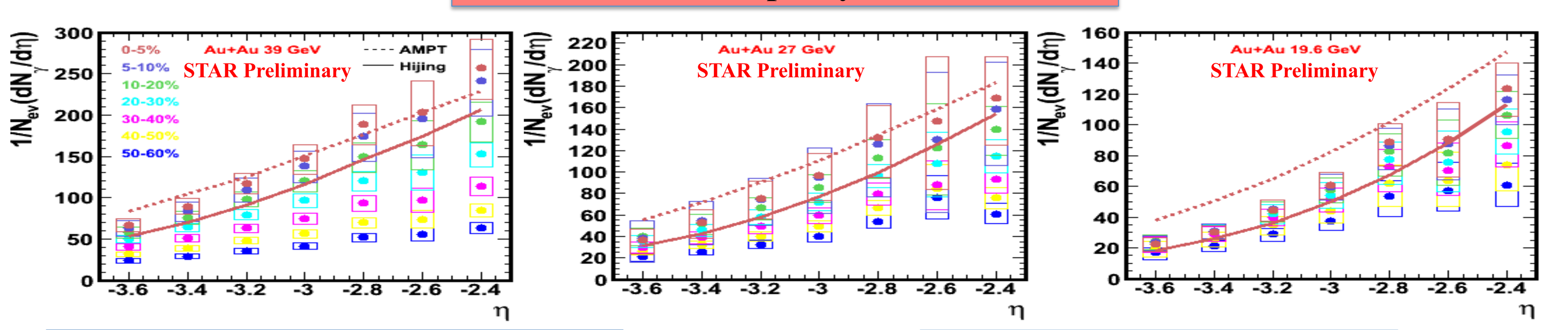
- ✓ Uncertainty in estimates of efficiency and purity values.
  (~10% for all except the most peripheral events towards beam rapidity ~15%)
- ✓ Variation in choice of photon-hadron discrimination threshold condition.
  (less than ~3% for 0-50% centrality events. For peripheral events increase to ~15% towards midrapidity)
- ✓ Non-uniformity of the detector response.
  (~10%; for -2.7<eta<-2.5 bin ~15% for 39 GeV but 40% for 27 GeV)

Results

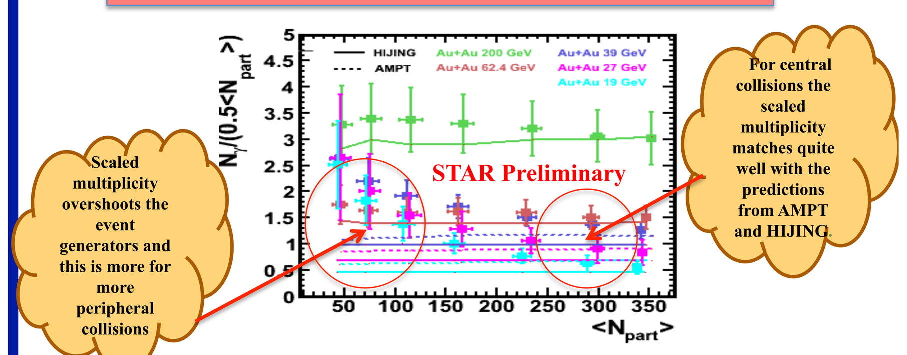
Multiplicity Distributions



Photon Pseudorapidity Distributions

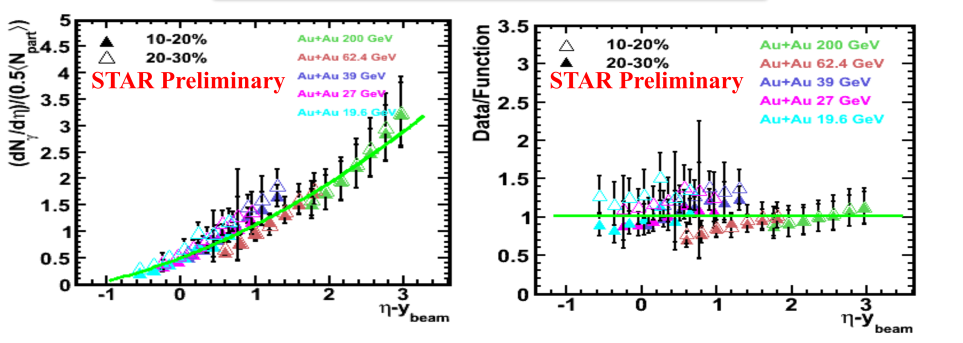


Scaling of Photon Production



The number of photons per participating nucleon pair as a function of average number of participating nucleons for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 [3], 62.4 [4], 39, 27 and 19.6 A GeV within $3.7 \leq \eta \leq 2.3$. The Errors shown are systematic errors.

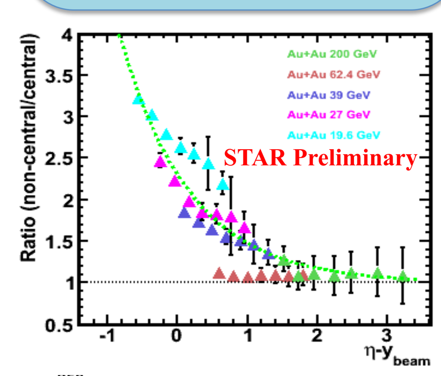
Longitudinal Scaling

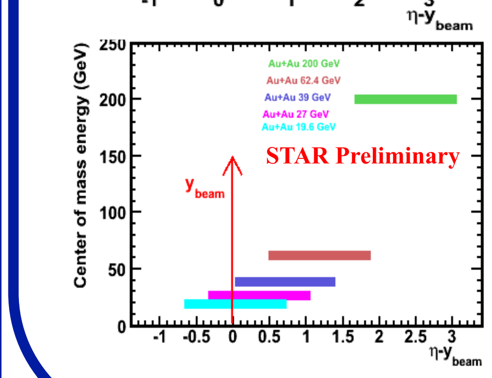


[Left Panel] Photon pseudorapidity distributions per participant pair for 10-20% and 20-30% collision centrality as a function of pseudorapidity shifted by the beam rapidity for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 [3], 62.4 [4], 39, 27, and 19.6 GeV. Errors are systematic only, statistical errors are negligible in comparison. The solid line is a second order polynomial fit to the data points. [Right Panel] Ratio of the data points to fit function with Npart scaling.

Possible explanations for scaling deviations

To understand the deviation we have plotted non-central (30-40%) / central (0-5%) $dN_\gamma/d\eta$ and the observed increase clearly shows extra source of $N_{\gamma like}$ signal in peripheral collisions. [5]





The total number of photon sources can be written as :- $N' = 0.5*Npart + X*Nspect$

Where Nspect = 197- 0.5*Npart and X is expected to be dependent on the rapidity coverage of PMD with respect to the beam rapidity as well as relative contribution of photons from a spectator as compared to photons from a participant. Assuming that the Spectator fragments have a Gaussian distribution about the beam rapidity

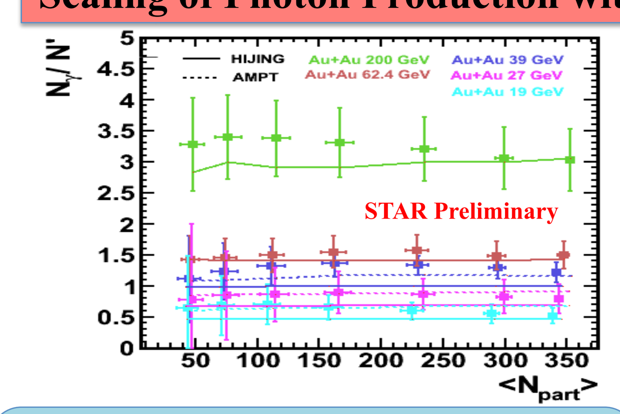
$$X = C\frac{2}{\sqrt{\pi}}\left[\int_{x_1}^{x_2} e^{-t^2}dt\right]$$

$x_1 = \eta_{min} - y_{beam}$
$x_2 = \eta_{max} - y_{beam}$
$t = \eta - y_{beam} / \sigma\sqrt{2}$

$X_{62.4}$ and X_{39} were estimated by inspection of data to be 0.03 and 0.18 respectively. Using $X_{62.4}$ and X_{39}, the proportionality constant C and the σ of the Gaussian is estimated to be 0.193 and 0.345 respectively. The same value of C and sigma were used to estimate X_{27} and X_{19} and applied to data.

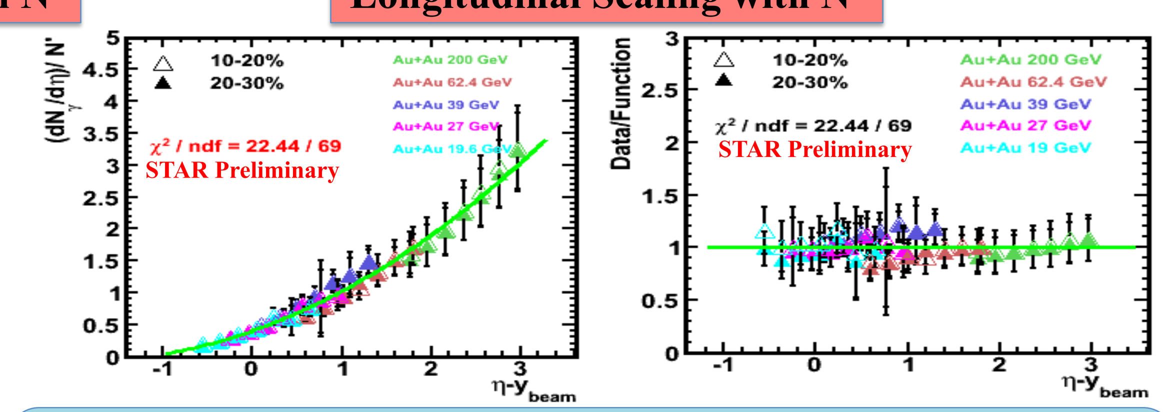
Colliding system (Au+Au)	Maximum emission angle of gamma from spectator (mrad)	Beam Rapidity	X value
200 GeV	9.38	-5.36	0.0
62.4 GeV	30.06	-4.19	0.03
39 GeV	48.10	-3.73	0.18
27 GeV	69.48	-3.36	0.323
19.6 GeV	95.71	-3.04	0.370

Scaling of Photon Production with N'



The number of photons scaled with N' as a function of average number of participating nucleons for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 [3], 62.4 [4], 39, 27 and 19.6 GeV within $3.7 \leq \eta \leq 2.3$. Errors shown are systematic errors.

Longitudinal Scaling with N'



[Left Panel] Photon pseudorapidity distributions normalized by the proposed factor N' for 10-20% and 20-30% collision centrality as a function of pseudorapidity shifted by the beam rapidity for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 [3], 62.4 [4], 39, 27, and 19.6 GeV. Errors are systematic only, statistical errors are negligible. The solid line is a second order polynomial fit to the data points. [Right Panel] Ratio of the data points to fit function with N' scaling.

Summary

1 We have measured photon multiplicity in pseudo-rapidity region $-3.7< \eta <-2.3$ for Au + Au collisions at $\sqrt{s_{NN}}$ = 39, 27 and 19.6 GeV. We find that for central collisions the data is in good agreement with event generators (AMPT for 39 GeV and HIJING for 27 & 19 GeV)

2 The photon multiplicity per participating nucleon pair was observed to be independent of collision centrality, energy and colliding system for 200 GeV and 62.4 GeV but no independence was observed for peripheral collisions at 39, 27 & 19.6 GeV.

3 This deviation can be explained byadditional photons from excited spectators. We propose a scaling factor which includes a contribution from participants as well as a contribution from spectators.

4 The photon multiplicity when scaled with the proposed factor shows independence with event centrality at 39, 27 & 19 GeV also. The photon production per unit rapidity, scaled by the new term, as a function of η-y_{beam} becomes longitudinal scaling even beyond the beam rapidity.

References

[1] PHENIX Collaboration, K. Adocx et al., Phys Rev. Lett. 86(2001) 3500

[2] STAR Collaboration, Nucl.Instrum.Meth. A499 (2003) 751-761

[3] STAR Collaboration, J. Adams et al., Phys. Rev. C73 (2006) 034906

[4] STAR Collaboration, (B.I.Abelev, et al.) Nucl.Phys.A 832 (2010) 134-147

[5] PHOBOS Collaboration, B.B.Back et al., Phys.Rev.Lett., 91(2003) 052303

[6] Edwin Norbeck and Yasar Onel. Photons from spectators. Journal of Physics: Confrence Series 389 (2012) 012041

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