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Comment on

Search for direct photons from S-Au collisions at 200 GeV/nucleon by the CERES Collaboration

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Abstract. In this note we comment on a recent publication in this journal by the CERES (NA45) Collaboration [1]. The authors report to have determined an upper limit on the direct photon yield relative to the decay photon yield in S + Au collisions of 14% and 7% by two different methods, respectively. We argue that these limits are unsupported by the results and analysis of the CERES data. The systematic error estimates quoted in the CERES analysis are consistently overly optimistic. Using more realistic estimates of the various error contributions and propagating them appropriately we arrive at a direct photon upper limit which at best is 20% of the inclusive photon yield, and most probably is much higher.

The authors of [1] have presented an analysis in which they report to demonstrate an upper limit on the production of excess direct photons in 200 AGeV S + Au reactions. They obtain upper limits, at the 90% confidence level, of 14% and 7% of the inclusive photon yield derived respectively by two different methods. This is a remarkable achievement by an experiment optimized to measure electron pairs. Dedicated photon experiments attempting to make similar measurements [2] have hardly achieved similar accuracy. The reported precision is even more remarkable in light of the fact that, as the authors report, only 2.3% of the photons produced are converted and available for measurement, of these less than 20% are identified in the experimental apparatus, and of those photons identified, 18% are background photons resulting from Dalitz decays. Furthermore, in the search for excess photons, the measured inclusive yield is to be compared to the expected photon yield arising from conventional background sources, predominantly radiative decays of π^0 and η mesons, none of which have been measured for the CERES experimental acceptance and event selection.

Since the low $p_\perp$ direct photon excess is expected to be small, if observable at all, in S+Au reactions [2] it is not surprising that this experiment can only set an upper limit. In setting an upper limit, the crucial issue for the experimental measurement is an accurate understanding and estimate of the systematic errors. As the quality and importance of the measurement is to be judged by its level of accuracy, we consider in detail the analysis of the systematic errors presented in [1] and we shall demonstrate that the authors have decidedly underestimated their systematic errors.

Apart from raising concerns about this particular measurement, our comments should be viewed in a broader context, since preparations are presently being made for the first generation of LHC experiments, notably ALICE, where the detection of direct photons is one of the aims. To decide, wether the “direct” or the conversion method is better suited for this purpose, a detailed knowledge of the advantages and disadvantages of the different methods is indispensible. For these reasons we have put considerable effort into the comparison of the methods and to study the corresponding systematic errors.

In the first method used by the authors an upper limit on the integrated direct photon production is extracted by studying the ratio r_γ, given in (1) of [1], which is the ratio of the integrated photon $p_\perp$ distribution, integrated from 0.4 GeV/c $\leq p_\perp \leq$ 2.0 GeV/c, to $dN_{ch}/d\eta$. This ratio is calculated from the experimental data, r_{data}, and compared to the same ratio calculated from simulation for photons arising from hadron decays, r_{hadr}. The ratio of these two ratios provides a determination of the possible direct photon yield in this $p_\perp$ region. A slight direct photon excess of 4% is determined in [1]. The systematic error on these two ratios is then used to set a direct photon upper limit.

Systematic errors in the measurement (r_{data})

Photon reconstruction efficiency:

A procedure for determination of the photon reconstruction efficiency is described: a spectrum of simulated photons is put through the simulated detector response and the identified photon spectrum is constructed. The ratio of the reconstructed to initial spectrum gives the efficiency. Obviously, due to the finite momentum resolution, the correction function depends on assumptions about the original distribution. Furthermore, due to uncertainties in the Cherenkov-Ring reconstruction and contaminations by fake rings, it will depend also on the local particle density in the apparatus. Usually, to take such effects into account in high precision measurements, an iterative procedure for a given particle density distribution is performed until the output distribution of the Monte-Carlo (MC) matches the observed experimental distribution. The input distribution of the MC is then considered the true one. However, despite the moderate momentum resolution and the strongly varying particle density within the angular acceptance window, no similar iterative procedure is described in [1] and no statement is made about how the original distribution was chosen. Instead, the authors state qualitatively that the strongly $p_\perp$ dependent correction function is insensitive to the shape of the assumed $p_\perp$ input distribution. Dispite the fact that the data are corrected by a correction function which varies from a factor of two to a factor of 6 over the range of $p_\perp$ used, they claim that the yield is determined with an extraordinarily small error of only +2.7%, –5%. Other experiments, such as [2], operating at 90%–100% photon reconstruction efficiency (compared to less than 0.5% in this experiment) have achieved just such a level of precision. However, in [2] the accuracy – after performing such an iterative procedure – is confirmed using the experimental data itself, i.e. analyses with very different cuts and associated efficiencies result in corrected photon distributions with deviations smaller than the quoted uncertainty of the reconstruction efficiency. Since no such crucial test is described in [1] it is difficult to believe such a small error estimate. A more prudent estimate would put a lower limit on the reconstruction efficiency of at least $\sigma \approx \pm$5%, and likely greater.

Uncertainty of the momentum scale:

The momentum scale is said to be known to $\pm$ 2% resulting in an error of 2.3% on r_{data}. For a purely exponential distribution one expects that the uncertainty in the integrated photon yield above some lower $p_\perp$ cutoff p_c will scale like $e^{\delta p_c/p_0}$, where δ is the percentage uncertainty in the $p_\perp$ slope, p_0, or equivalently in the momentum scale. Taking the data of Fig. 5, the inverse exponential slope at $p_\perp$ = 0.4 GeV corresponds to appr. 150 MeV which would then translate into an error of r_{data} of 5.5%. Performing a full power-law fit to the data in Fig. 5 with a subsequent integration of the yield in $0.4 \leq p_\perp \leq 2.0$ GeV/c yields basically the same result, i.e. the quoted uncertainty appears to be underestimated by approximately a factor of 2.

Conversion probability:

The uncertainty in the photon convertor thickness enters directly in the uncertainty in r_{data}. The authors suggest incredulously that the 40 targets were produced independently and therefore that the uncertainty in the target thickness is only $10\%/\sqrt{40}$ = 1.5%. More likely, the 40 targets were produced in the same batch from the same foil or measured with the same measuring device such the errors in the target thicknesses are highly correlated. Furthermore, the other materials such as the silicon detectors and windows which contribute 44% of the total conversions are claimed to have negligible uncertainty in their conversion probability. The conversion probability uncertainty is claimed to be only $\pm$3%, arising solely from the statistics of the Monte Carlo simulation. Again a more prudent estimate would be that this uncertainty is at least $\pm$5% and probably greater.

Uncertainty of $dN_{ch}/d\eta$:

The authors of [1] claim that by measuring the total charge on their silicon pad detector which has 64 pads covering the region from $1.7 < \eta < 3.4$ they can determine the value of $dN_{ch}/d\eta$ at η = 2.4 with a 5% accuracy. Considering that this must include corrections for δ-electrons, conversions, and slow protons, as well as corrections for the varying acceptance with target position and the extrapolation from the integrated multiplicity measured to the inferred value at η = 2.4 assuming an unmeasured $dN_{ch}/d\eta$ distribution, it would seem that the quoted uncertainty of only 5% is again quite bold.

Systematic errors in the background calculation (r_{hadr})

The normalization of the measured photons to the background photons expected from conventional sources, most prominently $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ is the most critical problem in the data analysis for the reason that none of these background sources is measured within the experiment. As a consequence, the authors need to make assumptions about the $p_\perp$ and rapidity shapes as well as on the total integrated yields of these particles. To accomplish this task, the authors rely on transverse momentum spectra and inclusive charged particle measurements performed by other experiments for different systems, different pseudorapidity windows, and different trigger conditions and extrapolate these data, where necessary, to the acceptance covered by the CERES experiment.

Explicitly, the authors start from $p_\perp$ and y distributions measured by NA34, NA35, WA80, and CERES to determine the π^0 $p_\perp$ distribution. Each of these experiments has made a different measurement; NA34 has measured negative pions, NA35 has measured the sum of negative hadrons ($\pi^- + K^- + \overline{p} + \ldots$), WA80 has measured neutral pions (i.e. those particles which are intended to be inferred from this analysis), and CERES has again measured charged pions. The authors then argue to obtain "reasonable" fits to the available data and arrive, after assumptions about particle compositions, different trigger conditions, factorization of $d\sigma/dp_\perp$ and y (which is known to be violated by more than 10%), etc. at a systematic uncertainty of only +3.5%, –5.3% for the photon background. To check these numbers, we have taken tabulated data available from each of these experiments and for comparison, since only WA80 has

Table 1. Summary of various sources of systematic error entering in the CERES direct photon upper limit estimate. The CERES error estimates are shown together with our own estimates. Our total error estimates have been obtained by summing the individual error contributions quadratically. The CERES total error estimate has been obtained by a more sophisticated analysis

Quantity: Source of Error	Quoted CERES value (%)	Equiv. upper RMS value (%)	Our estimate RMS value (%)
r_{data}:			
γ reconstruction efficiency	[-5.,+2.7]	+0.8	+5.0 (+10.0)*
Parametrization of efficiency	$\pm$2.0	+2.0	+2.0
$p_\perp$ uncertainty and integration	$\pm$2.3	+2.3	+5.0
π^0 Dalitz decay contribution	$\pm$5.0	+5.0	+5.0
Conversion probability	$\pm$3.0	+3.0	+5.0 (+10.0)*
Charged particle density	$\pm$5.0	+5.0	+5.0
Total upper error $\sigma_{r_{data}}$	(+6)	+8.3 (+9.7)	+11.4 (+13.4)
r_{hadr}:			
π^0 $p_\perp$ shape	[-5.3,+3.5]	+1.0	+5.0 (+10.)*
π^0 rapidity distribution	[-3.9,+2.4]	+0.7	+2.4
η/π^0 scaling	$\pm$4.0	+4.0	+4.0
n_{π^0}/N_{ch} normalization	$\pm$5.4	+5.4	+5.4 (+10.)*
Total upper error $\sigma_{r_{hadr}}$	(+7)	+6.8 (+8.0)	+8.7 (+10.2)
Total upper error $\sigma_{r_{data}/r_{hadr}}$	(+9)	+10.7 (+12.6)	+14.3 (+16.9)
90% CL upper limit on direct photons ($4\% + 1.28 \cdot \sigma_{r_{data}/r_{hadr}}$)	14%	17.7%	20.1%

Quantities in () on total errors indicate FWHM/2 values, as quoted in [1].
* Reasonable conservative estimate (not used here)

measured *absolute* cross sections, have normalized the $p_\perp$ distributions at 0.8 GeV/c. Such a test exhibits at least an $\approx \pm 25\%$ variation of the cross section ratios in the common $p_\perp$ range of the experiments. Because of the unknown absolute cross sections, i.e. the unknown $p_\perp$ value where these spectra should be normalized to each other, this error will have to enter directly to the background calculation and will obviously be much larger than +3.5%, –5.3%. If the authors instead normalize the different data sets to the total integrated yields (which method was used is not described in the paper) the calculation will have to include instead assumptions about an extrapolation of the different $p_\perp$ distributions to $p_\perp = 0\,\mathrm{GeV}/c$ which again will have much larger errors than quoted above. On top of this, in order to put constraints on the photon yield from π^0 decay, any procedure based on charged pions will have to make assumptions about the relative particle compositions which will increase the uncertainty further.

Interestingly, the quoted CERES error is similar to or even less than the error quoted by WA80 [2] for the π^0 $p_\perp$ distribution. WA80 has measured the distribution with the best precision available in nuclear reactions and without any assumptions. Thus, it is questionable how utilization of data measured under hardly comparable conditions and mostly with very moderate precision combined with many assumptions can constrain the π^0 result as well or better than the direct measurement. We therefore conclude, that the authors have underestimated their uncertainty again by at least a factor of two.

The actual normalization of the calculated background to the shape of the measured photon spectrum in CERES is obtained using the 4π integrated ratio n_{π^0}/N_{ch}. This quantity has been measured with a quoted 5% uncertainty in the forward hemisphere of 400 GeV/c pp collisions [3]. To extrapolate this measurement for the purpose of this paper to central 200 AGeV S + Au reactions, the authors make various assumptions about baryon rapidity shifts caused by different amounts of nuclear stopping and assume furthermore, that the composition of produced particles remains unchanged in the two systems. This scaling assumption is well known to be violated since strange particles (K/π, etc.) are produced much more abundantly in central heavy-ion collisions than in pp collisions. Despite these problems, the authors arrive at an overall error of only 5.4% (5% of which are from the measurement in [3] itself), which again appears to be significantly underestimated.

To summarize these points, the authors claim to have determined the expected number of photons in their acceptance and centrality selection with an accuracy which meets or exceeds that obtained by other experiments which have actually measured the background hadron sources without any assumptions and extrapolations. This has been done using the charged particle multiplicity as the only measured quantity. This is quite a remarkable claim which however appears unsubstantiated by a closer look at the systematic errors.

In Table 1 we list the various systematic error contributions given in [1] for the direct photon upper limit estimate. The error values quoted in [1] are listed together with values which we would quote being only moderately more conservative than in [1]. Assuming that the various sources of errors are uncorrelated and that they may be added quadratically results in a 90% CL direct photon upper limit of at least 20%. More reasonable conservative error estimates, as suggested by the above discussion, would result in a significantly higher upper limit. In this table we also show that by simply summing the CERES error estimates quadratically, rather than using their convolution procedure, the direct photon upper limit is nearly 18% rather than 14%.

Multiplicity dependence of the photon production

The second method of analysis described in Sect. 5 of [1] attempts to extract information about the production of direct photons through the multiplicity dependence of the inclusive photon yield. In this method an upper limit is obtained on the coefficient α of a possible term which is quadratic in the reconstructed $dN_{ch}/d\eta$. This is an interesting approach which avoids the above noted problems of absolute normalization. However, it must be emphasized that such a measurement provides at best only indirect information about a possible direct photon excess. On general theoretical grounds it might be expected that the direct photon production should scale like the square of the local charge density in the hot dense medium, but it is obvious that the observed variation in the reconstructed $dN_{ch}/d\eta$ is not directly related to a change in the local charge density. That is, it is extremely unlikely that the observed factor of nearly four increase in $dN_{ch}/d\eta$ corresponds to a factor of four increase in local density and hence an expected factor of 16 increase in direct photon production. Thus, extracting an upper limit on the quadratic dependence of the total photon production on the reconstructed $dN_{ch}/d\eta$ cannot be said to correspond to an upper limit on the direct photon production without some estimation of this dilution factor, which is most probably a very large factor. Other effects such as resolution of the multiplicity measurement will further dilute any such correlation. Therefore, to discuss upper limits on the quadratic coefficient in the same context as a discussion of the direct photon upper limit without clarification of their weak relationship is extremely misleading. A direct photon upper limit is probably many times greater than the determined upper limit on the quadratic dependence.

Furthermore, what is determined in [1] is an upper limit on the quadratic coefficient, α. It cannot be translated into an upper limit on the percentage of direct photons having a quadratic dependence on $dN_{ch}/d\eta$ without specifying a value for $dN_{ch}/d\eta$. Therefore it is again misleading to quote a "limit of 7% (90% CL) for the strength of a photon source with a quadratic multiplicity dependence." as in the conclusion and abstract of the paper without stating that this corresponds to the value at $dN_{ch}/d\eta$ = 131. Quoted in these terms the limit could be reduced arbitrarily by chosing a lower multiplicity, or would increase by nearly a factor of two for the highest multiplicities measured.

Although discussed in much less detail than for the first analysis method, the errors quoted for this analysis again appear to be severely underestimated. It is curious that the total systematic errors in some cases seem to be less than or equal to some of the individual error contributions. Furthermore, simply accepting the quoted final errors one calculates an upper limit which is more than 20% greater than the upper limit which is quoted. Finally, we believe that there is a major source of uncertainty which is not discussed but which brings into question the results and conclusions of this entire analysis.

The problem is twofold: (*i*) if true at all, the assumption of a squared multiplicity scaling of photons over neutral pions holds for the full phase space integrated yields only, whereas in this experiment charged pions and photons are reconstructed only in a limited rapidity range and at rather large transverse momenta. (*ii*) dN/dy as well as the $p_\perp$ spectra of pions and photons are known to depend themselves on centrality, i.e. on the multiplicity of particles. Here, we shall only estimate the effect caused by the change in the transverse momentum spectra when going from peripheral to central collisions. For simplicity, we will again start with exponential distributions for which the numbers given below are easy to verify. Assuming an inverse slope parameter of pions $1/p_\perp dN/dp_\perp \propto \exp(-p_\perp/p_0)$ with p_0 increasing from 200 to 220 MeV when going from peripheral to central collisions [4], the fraction of observed pions in the $p_\perp$ range from 1.3 – 2.5 GeV/c will increase by 66%. The decay photons, on the other hand, can be rather well described by $dN/dp_\perp \propto \exp(-p_\perp/p_0)$, with p_0 increasing from 190 to 210 MeV/c. The yield observed in 0.4 $\leq p_\perp \leq$ 2.0 GeV/c will then increase by 22%, so that one expects n_γ/N_π in the acceptance of CERES to drop by more than 25%. In a more detailed analysis we have verified this analytical estimate by performing a full Monte-Carlo simulation of the π^0 decay, including the photons from η decay [5], and taking into account the CERES experimental acceptance. The result is basically unchanged, i.e. we find a drop of n_γ/N_π by

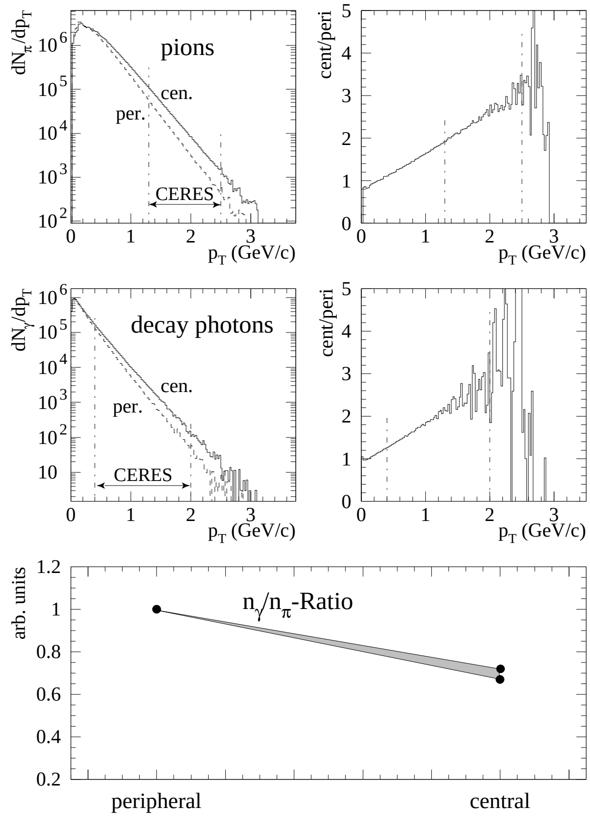

Fig. 1. Simulation results to estimate the effect of changes in the spectral shape to n_γ/N_π. The two upper left histograms show the π^0 and decay photon spectra, respectively. *Full lines* are for central events, and *dashed lines* for peripheral events. The integration intervals used by CERES are indicated. The upper right spectra show the ratios of the individual distributions and demonstrate that the amount of change between central and peripheral events is taken conservatively. The bottom figure shows the expected drop in the observed n_γ/N_π ratio. The upper bound is for exponential π^0 distributions with slope parameters as given in the text, and the lower point is for a power law spectrum describing the experimental π^0 WA80 data

approx. 25%. Furthermore this might be considered a lower bound on the expected variation since pure exponential distributions have been assumed down to very low p_T. The assumption of power-law π^0 $p_\perp$ spectra as seen by WA80 and other experiments for peripheral and central reactions [4], results in a drop by approx. 33%. These calculations and their results are illustrated in Fig. 1, where the original π^0 spectra (power law spectral shape in $d\sigma/dp_T^2$) as well as their photon-decay spectra are plotted. Since a drop as seen in the bottom graph would be easily visible in Fig. 6 of [1], one is puzzled to understand what might have compensated for it.

To summarize this point, any measurement based on integrating photons or pions, in a range whose lower limit in $p_\perp$ is well above m_π will be *inherently* unable to distinguish between a change in overall number of particles *vs* a change in the slope/shape of the distribution down to very low $p_\perp$. The experiment is unable to control the systematic variations of n_γ/N_π which are of the order of 25% or more. Nevertheless the authors claim to have measured this quantity to 5% accurate.

Summary and conclusion

In conclusion, the major task of an experiment presuming to present an upper limit measurement is to make a reliable assessment of the errors of the measurement. Setting an upper limit on direct photon production in the CERES experiment is a formidable task. The experiment measures only less than 0.5% of the photons in their acceptance. From this they must subtract the photon background contribution arising dominantly from the decay of π^0 and η mesons. These dominant background photon sources are not measured within CERES. Yet a 90% CL direct photon limit of 14% or 7%, depending on method of analysis, is claimed. A critical reader cannot help but be skeptical. The analysis presented in [1] generally does not present results to support their error estimates. According to our own estimates and investigations most of the error estimates presented in [1] are overly optimistic, as we have indicated in this comment. More careful consideration of the possible errors in the extraction of the integrated direct photon yield would indicate a 90% CL upper limit of no lower than 20%, and most likely much higher. The method of analysis of the quadratic dependence of the photon yield on $dN_{ch}/d\eta$ has large systematic uncertainties which have not been adequately addressed in [1]. With the present understanding, the limits on the quadratic dependence cannot be used to infer anything of significance on the direct photon production.

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