As a general comment, which could be of interest, there is a CMS paper written on pp to gamma gamma to mu+mu- (using TOTEM). It is PPS-17-001
(published in JHEP), AN-2016/481. They also use muon acoplanarity. The initial colliding system and the study is different (no neutron emission) but could
be interesting to check some parts related to gamma gamma --> mu mu.

- As we discussed in the ARC meeting, we would like to focus on the main physics point because the results will target a letter.

Abstract: I don't see clearly the relation between the emission of forward neutrons by the Pb nuclei and the smaller impact parameter interaction.
ok, it is clear after reading the introductory lines in section 5.2.

- Great. The introduction of the paper also includes the discussion of the relations between the forward neutron multiplicity and impact parameter of UPC

Pt of photons depend on transverse impact parameter of collision? But the first quantity is independent of any collision, of the presence of a second
nuclei, isn't it? This is in fact the hypothesis mentioned in L54-55. Ok again, this is part of the conclusion.

- Yes. This is the main physics message delivered by this analysis, which is essential to understand the puzzle of observed pt or accoplanarity broadening of dimuon pairs from photon-photon scattering in non-UPC collisions at RHIC and LHC.

What drives the mass region chosen: 8 to 60 GeV? Why stopping at 60 and not continuing up to 70 GeV? Do you have already the presence of Z bosons?

- We would like to avoid the potential impact of Z bosons although we do not observe Z boson in this analysis (30 counts between 70 and 100 GeV with flat distribution). Meanwhile, the statistics of dimuon pairs with M>60 GeV is low, which makes a tiny impact on this analysis.

L47-48: Ref 12 is also LHC. Don't know what difference you establish here between references [8-12] and [13-16]

- Refs [8-12] are the results from UPC collisions, which conventionally study photon induced interactions.
- Refs [13-16] are photon induced studies in non-UPC collisions, which open a new way to use the products from photon induced interactions to study the properties of hot QGP medium

Table 1: How is the HIForward dataset defined? Which triggers go there?

- The HIForward PD basically includes all UPC related triggers. The triggered events have no activity in one HF or both HFs but have activity in the CMS tracker.

L85: What is a "L1 muon with loose trigger quality"? Is there a pT threshold? At least 2 muon chambers fired?

- Added more information in the analysis note. The L1 muon in this analysis requires at least two muon stations fired and has no pt threshold requirement.

L91-92: How is a primary vertex reconstructed in these evts where there is only 1-2 tracks? Can you please give details on the "pprimaryVertexFilter"?

- ”pprimaryVertexFilter” filter requires “not fake vertex” && |Vz| <= 25 cm && |Vr| <= 2 cm (Vr is transverse radius of vertex) && tracksSize >= 2 (here, track is general track).
- To reconstruct a primary vertex, at least two tracks are required in ”pprimaryVertexFilter” filter.

L99-102: You decide what is noise and what signal in HF calorimeters by selecting 99% of the energy deposited in the leading tower in the case of
No_BPTX evts. Have you checked the same distribution in Fig 1 for cases of very peripheral PbPb collisions, where some (small) energy is deposited
in HF, coming from an inelastic collision? It could be that you would be in need to place the threshold cut to energy values less than 99%.

- We did apply the HF threshold cuts (<=7.3 GeV in HF_plus and <=7.6 in HF_minus) to reject inelastic collisions in this analysis.
- In the NO_BPTX events, the HF response is purely from noise, thus we expect the same distribution in very peripheral inelastic collisions shifts to right (large). But we did not explicitly draw this distribution.

L105: Can you please state what angular (pseudorapidity) region covers the HF and the ZDC?

- Added the pseudorapidity coverages for both detectors: HF with 2.9<|eta|<5.2 and ZDC with |eta|>8.3

L113: "be matched with at least one segment...": Does the trigger require already the presence of segments matched in at least 2 muon stations?
If that is the case, the offline requirement would be looser than the trigger. So, at least for the muon that fired the trigger 2 segments should be required.
at offline level, instead of 1.

- L110-116 just lists the standard requirements of soft muon. Regarding trigger muon, we did additional check whether the soft muon is triggered muon or not. Single muon UPC triggered data set is used in this analysis, therefore, at least one soft muon is required to be triggered muon during the pairing process as listed in Sec. 5.1 of AN

L114: "within 3 sigma": 3 sigma of what? of the extrapolated tracker track to the muon chamber in study?

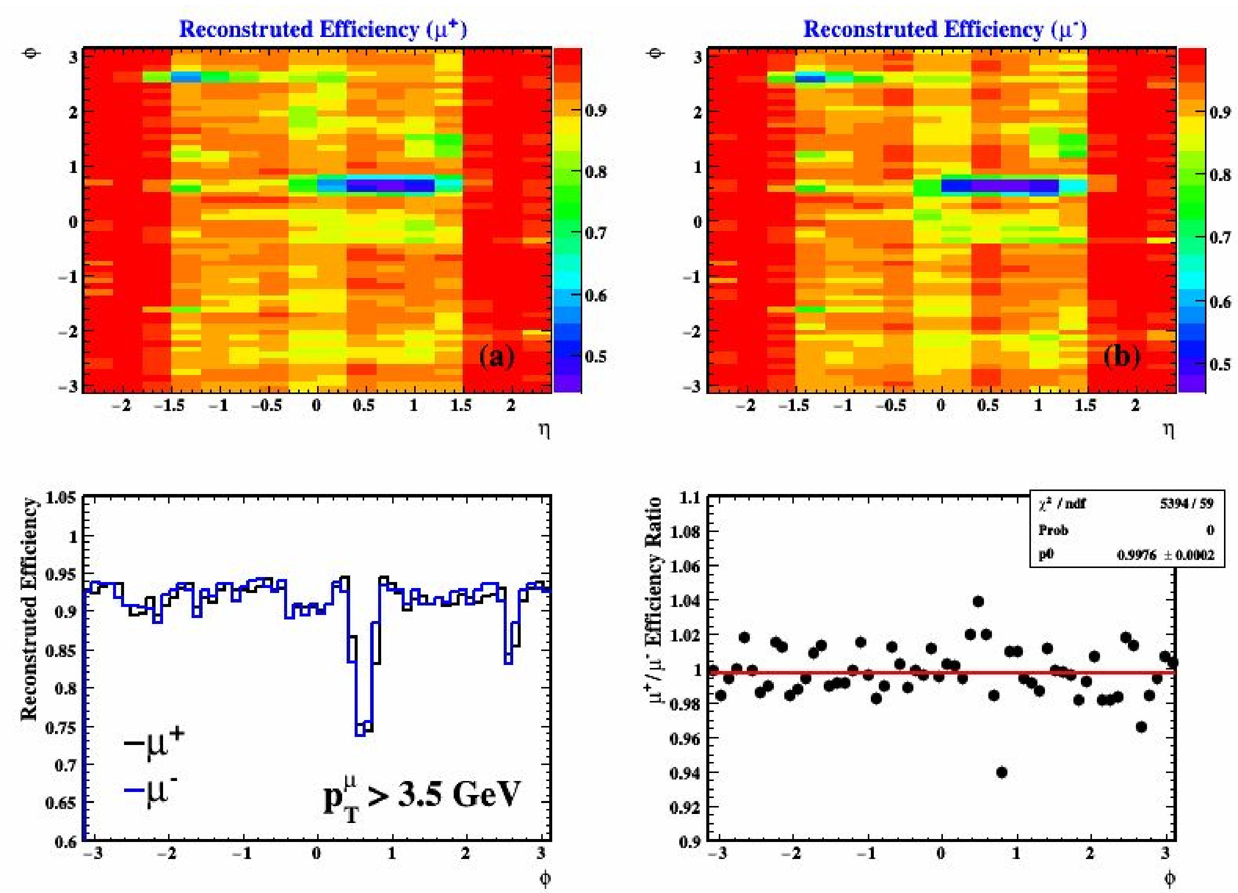
- Pull of the difference between extrapolated and measured points in local x and y is less than 3

L124: "both denominator and numerator use GEN variables" : I would say the numerator (RECO) uses reconstructed variables?

- The reason for using GEN quantities in the numerator is to avoid the efficiency larger than 1 in relatively higher muon pt bin because of the smearing effect (even the effect is tiny, but our muon pt falls exponentially). Using GEN variables in numerator is not an issue in this analysis because of the excellent resolution for low pt muon (<~30 GeV). We also did a closure test using the MC simulation and confirmed our current method can correct the reconstructed distributions back to true ones (please see the plot in the response to comments on Fig. 17 and 18)

Fig 2: While the pt-eta dependence is "as expected", the pt-phi dependence has a strange inefficiency around phi ~0.5 (also slightly present in phi ~2.5)
for pt below 10 GeV. Do you know the cause of it? Have you checked with muon DPG experts?
Is it concentrated in a particular eta region? DT-CSC
Overlap region?

- Per request of Alice, the convener of Muon POG, we generated 2D matching efficiency plots as a function of phi vs. eta for muon with pt>3.5 GeV attached below. We can find 2 areas with low efficiency and already pointed this plot to Alice.



L131: The pT resolution is better studied with 1/pT dependence (track curvature) since this variable has a gaussian behaviour. Thus one would do
(1/pT_reco - 1/pT_gen) / 1/pT_gen. It would not give a much different result in any case.

- We agree 1/pt is better. We only check the performance and do not use the resolution number in this analysis, so the current one should be OK, as you commented.

L140: What is it meant by "official T&P scaling factors"? Those derived by Muon POG, HIN PAG, HIN Dimuon group?

- Derived by HIN-dilepton PInG

L141: "serve as an upper limit...": Does it mean you apply this SF as corrections to the MC simulated evts or you don't apply them but use them as syst. Uncertainty?

- We only did cross check of the effects caused by TnP SFs and found the effect is super tiny (<0.3% on <alpha> and <0.05% on <M>), therefore, we decide not to apply TnP SFs and not to consider the corresponding systematic uncertainty in this analysis

L144: What are the differences between a soft muon and a hybrid soft muon?

- "hybrid soft muon" = "soft muon (official)" - “high purity” + “global muon”

Fig 6, 7: These SF have been derived in "hadronic PbPb collisions".
I guess this means in inelastic PbPb collisions, not UPC ones, right?

- Yes

L148-153: These lines are not very clear. What is the kinematic region addressed in the analysis? muon pt > 3.5 GeV and abs(eta) less than 2.4, or
different pt thresholds depending on eta?

- We used a constant pt threshold (pt>3.5 GeV) for |eta|< 2.4

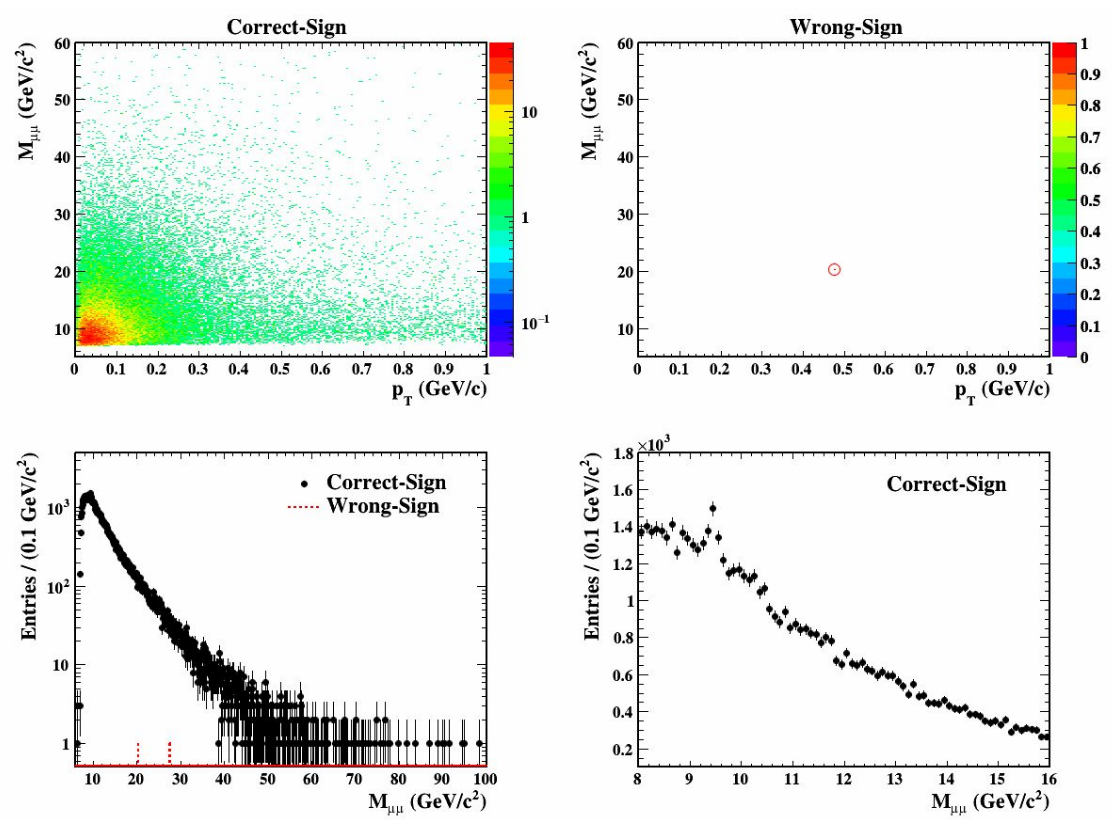
In the end, all this paragraph tries to justify the use of SF = 1 (use of MC efficiencies) and the small differences include as systematic uncertainty, right? However, Fig 8 shows differences of up to 5-10% in the mid-rapidity region for muon pt less than 5 GeV. Even if these values correspond to hybrid soft muons and are expected to be smaller for soft muons, isn't it a too hard assumption to take them as 1?

- Right, we decide not to apply TnP SFs on MC simulation and not to consider the corresponding systematic uncertainty after carrying out the cross check based on the following reasons:
  1) The reported mass region in this analysis is 8<M<60 GeV, so the daughter muon pt starts from ~4 GeV in the mid-rapidity region. The difference for hybrid muon with pt>4 GeV in mid rapidity shown in Fig.8 is within ~3%. Moreover, Fig. 8 shows the results for L2 trigger in inelastic PbPb collisions and we expect SFs for L1 trigger in UPC are smaller and flatter.
  2) we compared the results between with and without applying SFs of hybrid muons (the trigger is L2) shown in Figs. 6-8 and found the difference between these two scenarios is

<0.3% on <alpha> and <0.05% on <M>, much smaller than statistical and other systematic uncertainties.

Fig 9: Suggestions:
- the numerical scale in ColZ in the scatter (2D) plot is not seen.
- right hand side plot (Wrong-sign): replace the marker (point) by a circle or asterisk, to make the entries visible.
- add a fourth plot, with a zoom of the 1D mass plot on the bottom-left, say 0 to 20 GeV, in order to see the Upsilon peak.

- Incorporated all of them in updated AN, which will be upload to CADI when we finish all the comments from ARC members



L168: Cut in dimuon mass between 8 and 60 GeV. It does not look like this cut is applied in the distributions from Fig 9. Most probably it is applied later. Which cuts are applied to draw Fig 9?

- All the cuts listed in the AN except mass selections. Explicitly mentioned Fig. 9 is without pair mass selection in updated AN.

Fig 10: What physical quantity is behind the ZDC ADC counts? energy deposited by particles hitting it? If the process of neutron emission is symetrical in +/-, does the height of the 1n peaks give idea of the relative ZDC plus / minus efficiencies?

- Yes, ZDC ADC represents deposited energy

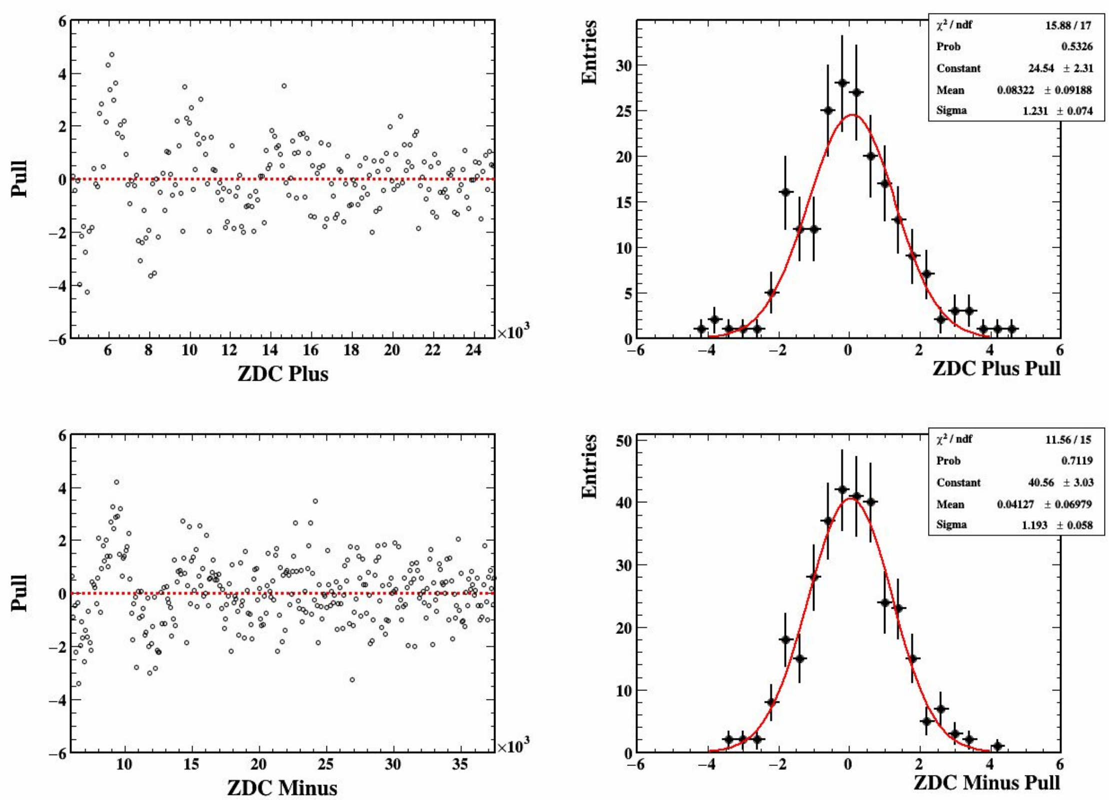
- The ZDC efficiency is basically 100%. I assume the “height” of the neutron peak you mentioned here is the measured statistics of 1n or 2n by ZDC. Yes, the statistics of 1n or 2n peaks recorded by ZDC Plus and ZDC Minus are more or less the same as shown in Figs. 10(b) and 10(c).

L193: How can it be that you have standalone muons, without an associated tracker track, in such a clean environment?

- As we discussed in the ARC meeting, standalone muons are not used in this analysis. We just want to express that we require events to have at least one muon pair regardless of the muon ID type when we analyze the ZDC response.

Fig 11: The x-axes in both figures are ZDC ADC counts? Have you stopped at 2n gaussians and not considered higher number ones?
Please project onto the y-axes and see the pull distribution and its width.

- Yes, the x-axis is measured ZDC ADC value (energy). We have no capability to disentangle the >=3n samples, so we stopped at 2n gaussians
- Added the pull distribution and its width in updated AN, as shown in figure below



Eq 3: Definition of Asymmetry. The sign in the denominator is wrong.

- Good catch. Fixed in the updated AN

Fig 13: Which is the Glauber MC? Any in Table 2?

- The GammaGamma2MuMu sample listed in Tab. 2

Fig 17 & 18: Not sure to understand. Here the MC histogram is the generated quantity, i.e. the MC truth, without being affected by acceptance or detector efficiencies. Are you deriving the now pair efficiency by dividing data / generated MC? Can you do a closure test correcting the data with the pair efficiencies as mentioned in the text and given in Eq 4, to see one recovers the MC histogram?

- The MC histograms shown in Figs. 17 and 18 (black histograms in left panels) are filtered by the CMS acceptance (pt>3.5 GeV, |eta|<2.4 and |y_mumu|<2.4) but not affected by detector efficiencies
- The efficiencies shown in right panels of Figs. 17 and 18 are derived by dividing blue histograms by black histograms shown in left panels.
- We did the closure test and demonstrated the current efficiency correction method can recover the reconstructed histograms (blue) to MC histograms (black) shown in left panels in Figs. 17 and 18. The closure test results can be found in the figure below, the small derivation for extremely small alpha is caused by detector resolution, which causes 0.7% on LO <alpha> result (GEN <alpha> = 1.35e-3 vs. RECO <alpha> = 1.36e-3).

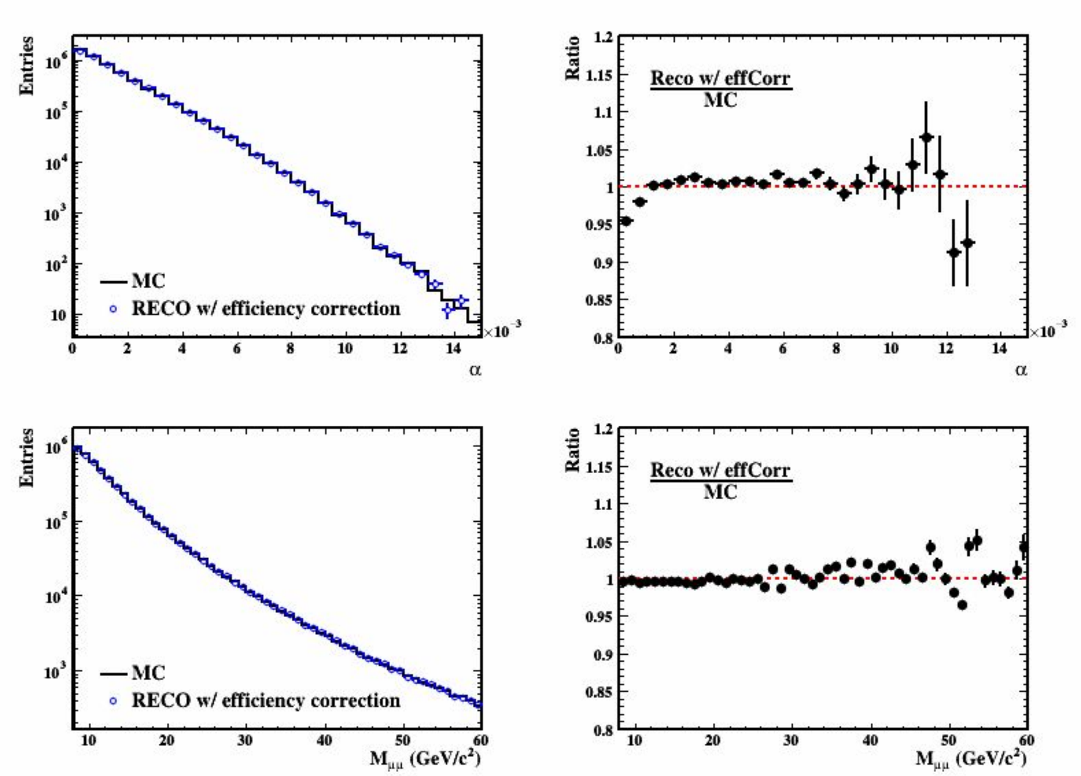


Fig 20-21: Pileup correction: the effect of the correction must be evt migration to other categories with less number of neutrons.Indeed it is seen there are less number of evts in each category after the correction, but the 0p0m category should result with a higher number of evts after the correction. Is it really so? the logarithmic scale does not allow to see it.

- Yes, for the 0p0m category, the corrected statistics is larger than the measured one (with pileup). This is because we have ~10.5% 0p0m events migrate into higher measured neutron multiplicity class.

Fig 27: Besides an increase in the width of this component with the neutron category there is also a drift of the peak position (scale effect). Has it been taken into account.?

- The peak position and width of the distribution in Fig. 27 reflect the nominal value and the statistical uncertainty, respectively, as shown in our final physics plot (Fig. 47 upper panel in AN)

Fig 32: Where is the first order polynomial (straight line) shown?
The syst uncertainty tends to be large (up to 40%) in acoplanarity regions already out of the LO contribution (alpha ~0.05 - 0.1). See Fig 24.

- The red line is the first order polynomial because x-axis is in logarithmic scale
- The systematic uncertainties shown in Figs. 32, 35, 36 and 40 are for the alpha spectra (LO+HO) as shown in Fig. 45.

L449: "Each distribution is normalized to unity over the measured range". Not sure to understand where are these normalized distributions shown.

- Figure 45 shows all the normalized distributions.