Experiment data indicates quantum entanglement may not exist

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Abstract –
Till date, all experiments prove existence of quantum entanglement based upon overall statistical correlations and thus demonstrating that Bell's inequality is violated. No detailed data analysis has been published yet. This article presents a first of its kind experimental analysis and it indicates that there is a real chance that entanglement may not be real. This is a huge claim by any means. But it is necessary to make such dramatic claim due to two reasons – 1) It is based upon experimental data and can be tested and verified. 2) So that the QM community makes an effort to analyze detailed data to scrutinize the reality of entanglement.

Due to large amount of data involved, experimentalists only look at data in an easily computable manner and do not scrutinize the raw data in full detail. When data of this experiment was analyzed at detail level, it was observed that existence of entanglement can not be settled until this kind of analysis is completed on data from multiple such experiments.

The natural and prompt reaction from many may be to look for faults with this analysis without presenting the evidence that such analysis has already been completed. For curious people, observation is odd enough to be probed further. The complacent ones will look only for the faults. If this observation does not trigger more of similar analysis, then it will demonstrate complacency of the QM world.

This article does not claim "classical mechanics" to be the solution, but it presents an intuitive mechanism that can explain statistical correlations without entanglement being necessary or entanglement being defined in a different way then it currently is.

The scope of this article is only statistical data. Anti correlation (when measured in the same angle) is always true, therefore it is not statistical in nature and is left out of scope. Moreover anti correlation can easily be explained as a direct consequence of conservation laws.

This is a statistical analysis of the experimental data used in a recent paper [M. Giustina et al, Phys. Rev. Lett. 115, 250401 (2015)]. The data for this analysis was graciously made available by the authors as a private communication. This analysis gives an indication that the outcomes may not be totally probabilistic and so, entanglement may not exists in its currently claimed form.

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Experiment and Data

This paper presents a statistical analysis of the experimental data used in a recent paper [M. Giustina et al, Phys. Rev. Lett. 115, 250401 (2015), arXiv:1511.03190].published at https://arxiv.org/abs/1511.03190. You may read the full article there. I will repeat relevant information here. Data of this experiment was **recorded in sequence of actual trials** which enables proper analysis.

1. A source of entangled photons sends entangles pairs – one photon to Alice and one to Bob.
2. Alice and Bob have detectors (polarization filters) which they can randomly set in one of the two directions. Alice's setups can be a1 or a2 and Bob's setups can be b1 or b2. All four setup combinations are a1b1, a1b2, a2b1, a2b2.
3. There are four different detectors used in the experiment. Because it would not have been possible to change the setup of a detector so frequently, this experiment used different detectors with fixed setup and directed the photons to each combination randomly. That makes it in total 4 detectors and four combinations.
4. If the photon passes the filter, a click is recorded. A click is represented by a "+" which is recorded in data as a "1".
5. If the photon does not pass the filter, there is no click, (means no +) and is recorded as other than "1", ("0" or "2").
6. The experiment sends ~ 3.5 billion trials in a one hour block, referred to as "second recorded block of data" on page 3 of supplementary pdf at https://arxiv.org/src/1511.03190v2/anc/supplemental_material_Vienna_20151220.pdf.
7. Each detector setup combination receives ~one fourth trials.
8. This article uses setup combination a1b1 to explain the observation. Number of valid trials sent to setup a1b1 is **875683769**.
9. A **"**++ **pair**" means Alice records a + and Bob records a +. A "**non** ++ **pair**" means at least one of them does not record a +.
10. Number of ++ pairs recorded in actual data for setup a1b1 is **141439**. This means on an overall basis, there are **(875683769–141439)/141439 = 6190.24** non ++ pairs between two ++ pairs.
11. Thus the average gap between two ++ pairs is 6190.24 non ++ pairs
12. QM predicted probability of getting a + at both detectors is represented as **P**++**(a1b1)** by the **green** bar on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf. **Green** bar also represent the probability at **1/6191.24** which is same as actual.

Definitions – (in context of setup (a1b1))

Expected gap - Per above #10 & #12, expected number of "non ++ pairs" between two adjacent "++ pairs" is 6190.24.

Cumulative Expected gap – Sum of Expected gap so far. It is simply (6190.24) times (the number of "++ pairs" so far).

Actual gap - (Number of "non ++ pairs" before this "++ pair") comes from the data, can be different for different "++ pairs".

Cumulative Actual gap – Total of actual gap so far.

Imbalance – (Expected gap – actual gap). Which is = (6190.24 – actual gap).

Accumulated imbalance – Total of imbalance so far. Or, total imbalance till this "++ pair".

Example calculation of cumulative imbalance for first two ++ pairs –
In the data, first ++ outcome was found at trial number 3050.
So, actual gap is 3049, predicted gap is 6190.24, imbalance = 6190.24 – 3049 = 3141.24, cumulative imbalance = 3141.24.
Second ++ outcome was found at trial number 10878.
So, actual gap = 10878 – 3050 – 1 = 7827, expected gap is 6190.24, imbalance = 6190.24 – 7827 = –1636.82.
Cumulative imbalance till this point is = (3141.24) + (– 1636.79) = 1504.45.

Table 1 demonstrates example calculations of cumulative imbalance till 14th ++ pairs

Plotting Graph - Figure 1 plots cumulative imbalance for the duration of the experiment – i.e. ~ 875 million trials of setup a1b1.

Words" expected", "predicted"," "average" and "overall" are all used to indicate the" Expected gap" in context of gap.

"Total imbalance", "cumulative imbalance", "cumulated imbalance", "accumulated imbalance" all mean same thing.

Observation

1. This article first uses setup combination **a1b1** as an example to explain the observation.
2. Then this paper presents same observation in other setup combinations.
3. Even though the trend may be very subtle, what makes it interesting is that same trend is seen in all four setup combinations.
4. The trend alone may be capable of indicating something other than probability, plus similar trend in all four setup combinations at the same time, strengthens the possibility of some mechanism other than just probability.
5. This observation should be scrutinized by analyzing data of existing experiments and/or by conducting more experiments.
6. This type of analysis requires the sequence of trials to be preserved in the recorded data.

What was analyzed?
The paper has analyzed cumulative imbalance over the duration of experiment. Just like looking at the evolving difference between total number of heads and total number of tails in a coin toss experiment.

Coin toss analogy -
Supposed you tossed a coin 280000 times with eventual outcome of 50% heads and 50% tails. And suppose, throughout this experiment, total number of heads only rarely exceeded total number of tails even though final outcome is 50% heads and 50% tails. I.e. number of tails takes a lead in the beginning, and the lead keeps building up till a peak, and then the lead starts clearing and clears till the end to make the eventual outcome 50/50. But the total lead rarely swings the other way, only in the very beginning or very end.

Suppose same thing happens if you do the experiment with four coins at the same time, in parallel. In all 4 coins throughout the experiment, total number of heads rarely exceeded total number of tails.

Can you really say this experiment consists of independent trials? Actually we can not. There are two possibilities –

1. Trials are not independent and something favors number of tails first, and then number of heads to make end result even.
2. We did not conduct sufficient number of trials and were never able to see the overall excess swing the other way.

Above type of observations have been made in data of the selected experiment, and both the possibilities should call for more analysis on data of similar experiments.

Table 1 – Example calculation of the accumulated imbalance in setup a1b1

Trial Sequence where a ++ trial is seen. Setup - (a1b1)	(A) – (Actual Gap) please see definitions on last page	(B) – (Cumulative Actual Gap) = Running total of (A)	(C) – (Cumulative Expected Gap) = Running total at ~6190.24 each line	(D) – (Accumulated Imbalance) = (C – B)
3050	3049	3049	6190.242848	3141.242848
10878	7827	10876	12380.4257	1504.425696
16118	5239	16115	18570.63854	2455.638544
17245	1126	17241	24760.85139	7519.851392
21024	3778	21019	30951.06424	9932.06424
25867	4842	25861	37141.27709	11280.27709
30002	4134	29995	43331.48994	13336.48994
34380	4377	34372	49521.70278	15149.70278
37949	3568	37940	55711.91563	17771.91563
38586	636	38576	61902.12848	23326.12848
49195	10608	49184	68092.34133	18908.34133
49278	82	49266	74282.55418	25016.55418
49471	192	49458	80472.76702	31014.76702
60155	10683	60141	86662.97987	26521.97987

What was observed?

It is observed that the accumulation of imbalance has a direction for a much longer range than could be expected by a probability mechanism. Moreover, the experiment data ends at first clearance of the accumulated imbalance. We do not know what would have been the trend after that. Same trend observed in all four setups. The imbalance being positive for > 96% of experiment duration has a very low chance.

The actual average (from data) is used here therefore the curve starts at zero and winds up at zero. But this fact does not prove that the curve is an artifact of the analysis. Predicted average is not available in the original experiment, which only provides J value on page 5.

The curve was drawn using different probabilities in the neighborhood of the actual value and the curve always has a clear direction, except that it does not wind up at zero in those cases.

Moreover, if QP predictions are accurate, the predicted probability (even though it is not available), can not be significantly far from the actual. Otherwise, the QM predictions will be in doubt.

It should also be noted that the original paper also proved Bell's inequality by using average from actual data.

Trend of accumulated imbalance (a1b1) trials (Total imbalance never (negligible) went below zero). P++(a1b1) = 1/6191.24

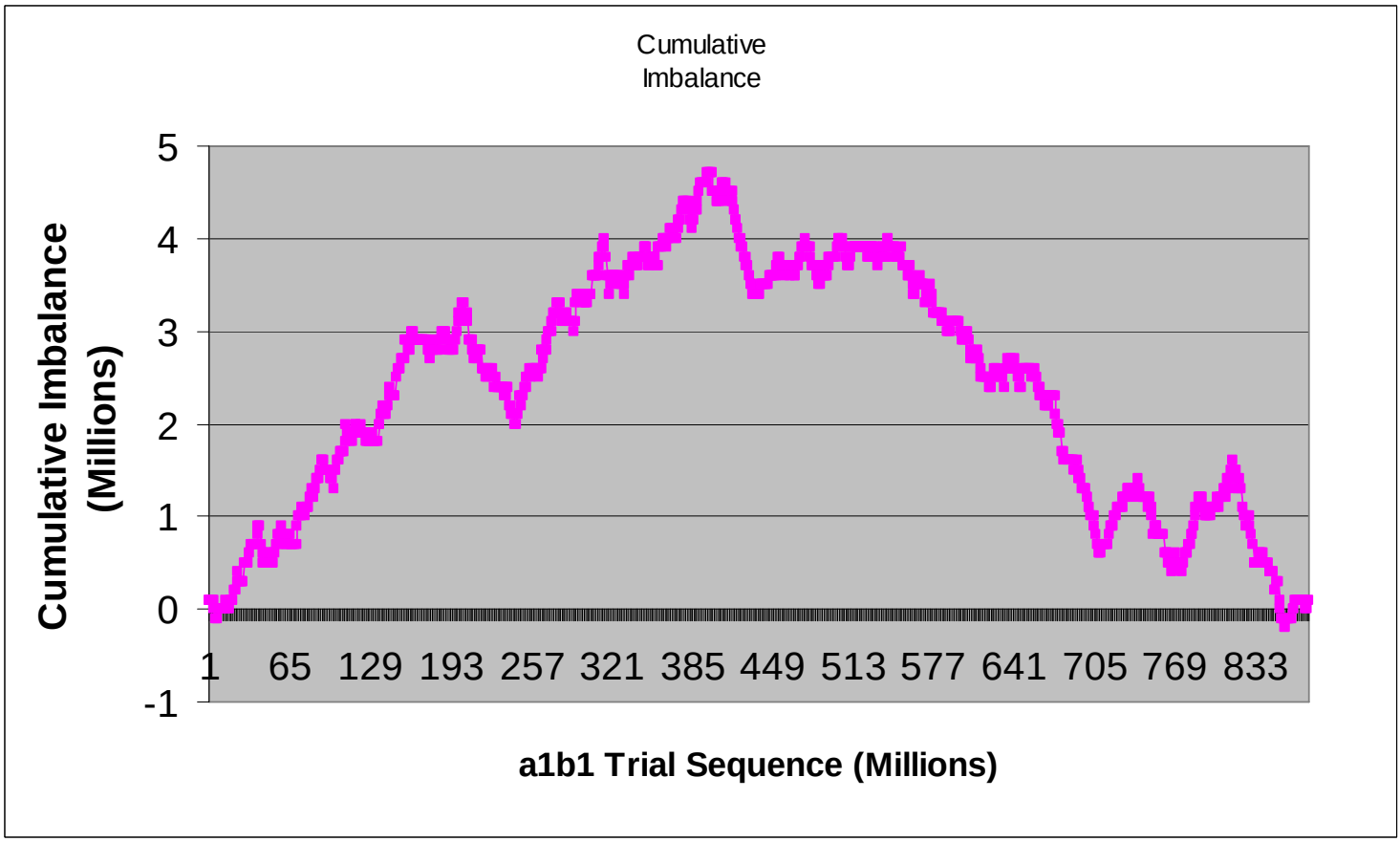

Figure 1 – Indication that the accumulation of imbalance has an overall direction till it reaches a peak and reverses the direction at the peak. Peak is at ~414 Million trials. Peak of cumulative imbalance is 4.7 million. A ++ appears to place peak at the ~middle of the graph (actual at 47% of total interval). Above zero count = 136721, below zero count = 4719, i.e. above zero = **96.7%** of time.

P++(a1b1) = 1/6191.24 represented by the **green bar** on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf.

This chart shows cumulated imbalance only in one side. We do not know how it would have looked if the experiment continued. Actually the experiment did continue for another 2.8 hours, but the findings were not reported in the paper. So the additional data blocks before and after the published data block can help further analysis.

Trend of accumulated imbalance (a1b2) trials (Total imbalance never (negligible) went below zero). P+0(a1b2) = 1/12886.44

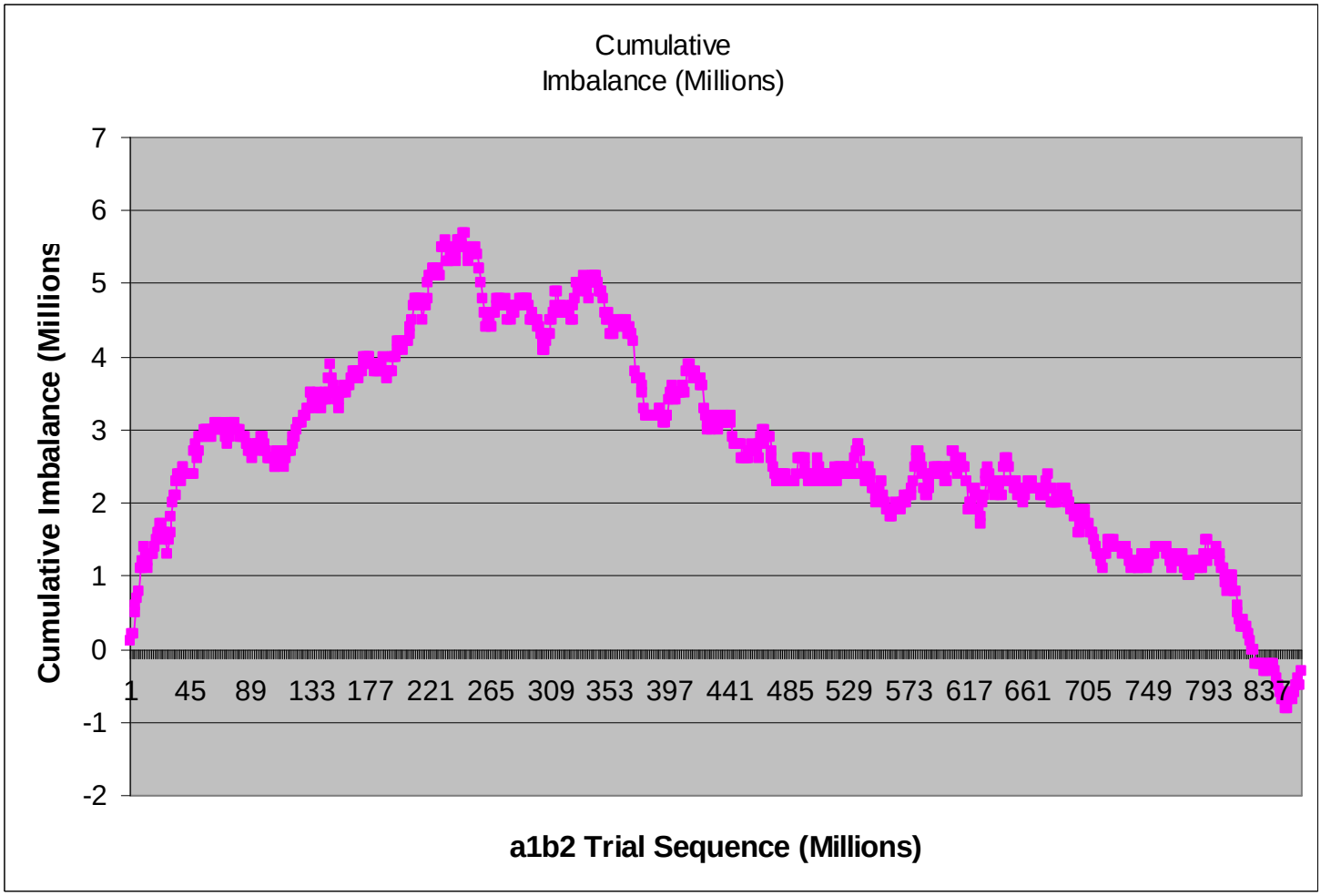

Figure 2 – Indication that the accumulation of imbalance has an overall direction till it reaches a peak and reverses the direction at the peak. Peak is at ~246 Million trials. Peak of cumulative imbalance is 5.6 million. A +0 appears to place peak at the left ~third of the graph (actual at 28% of total interval). Above zero count = 64360, below zero count = 3582, i.e. above zero = **94.7%** of time.

P+0(a1b2) = 1/12886.44 represented by the **bottom red bar** on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf.

Trend of accumulated imbalance (a2b1) trials (Total imbalance never (negligible) went below zero). P0+(a2b1) = 1/14910.65

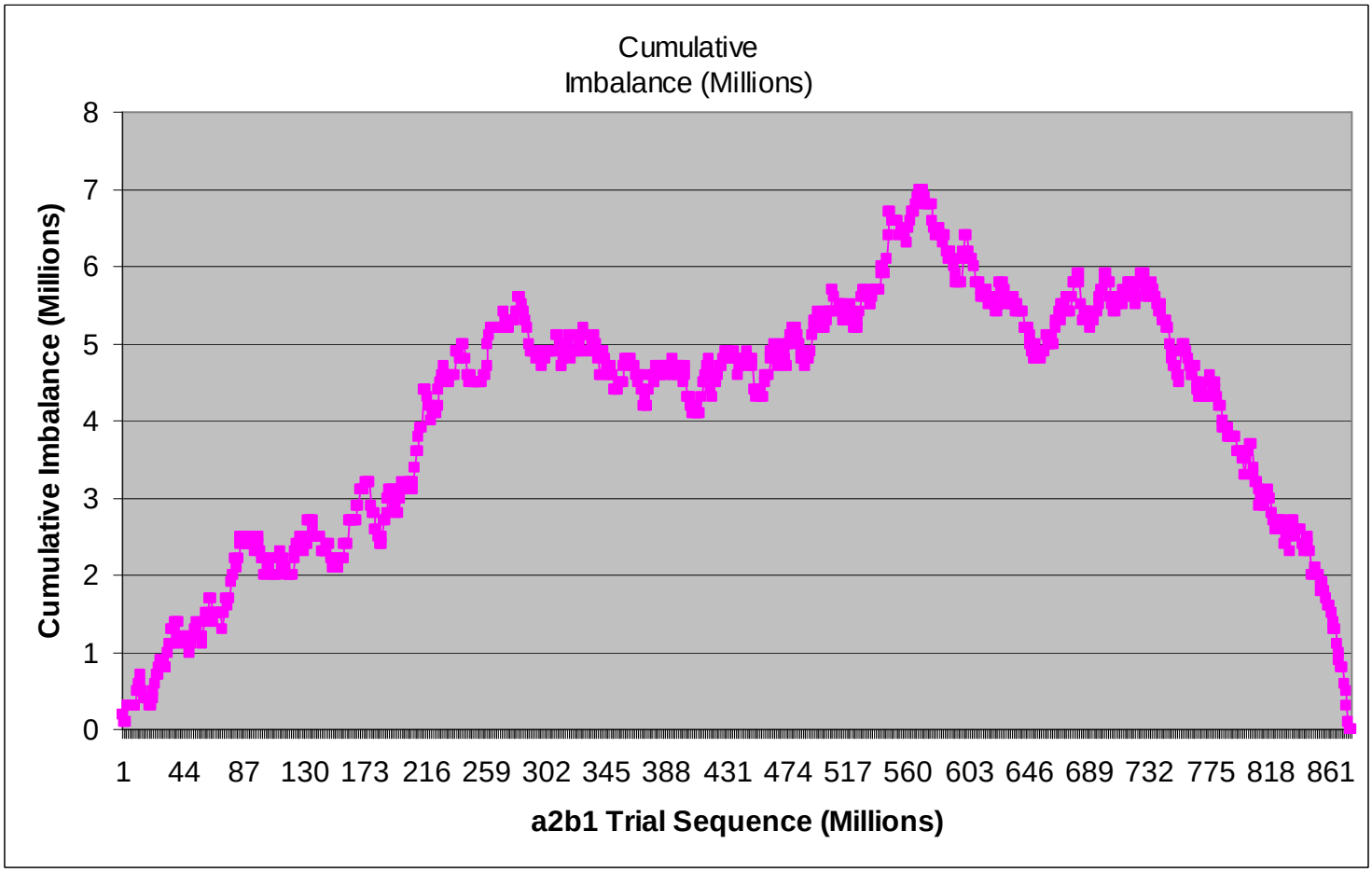

Figure 3 – Indication that the accumulation of imbalance has an overall direction till it reaches a peak and reverses the direction at the peak. Peak is at ~571 Million trials. Peak of cumulative imbalance is 7 million. A 0+ appears to place peak at the right ~third of the graph (actual at 65% of total interval). Above zero count = 58630, below zero count = 113, i.e. above zero = **99.8%** of time.

P0+(a2b1) = 1/14910.65 represented by the **second red bar** on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf.

Trend of accumulated imbalance (a2b2) trials (Total imbalance never (negligible) went below zero). P++(a2b2) = 1/104349.41

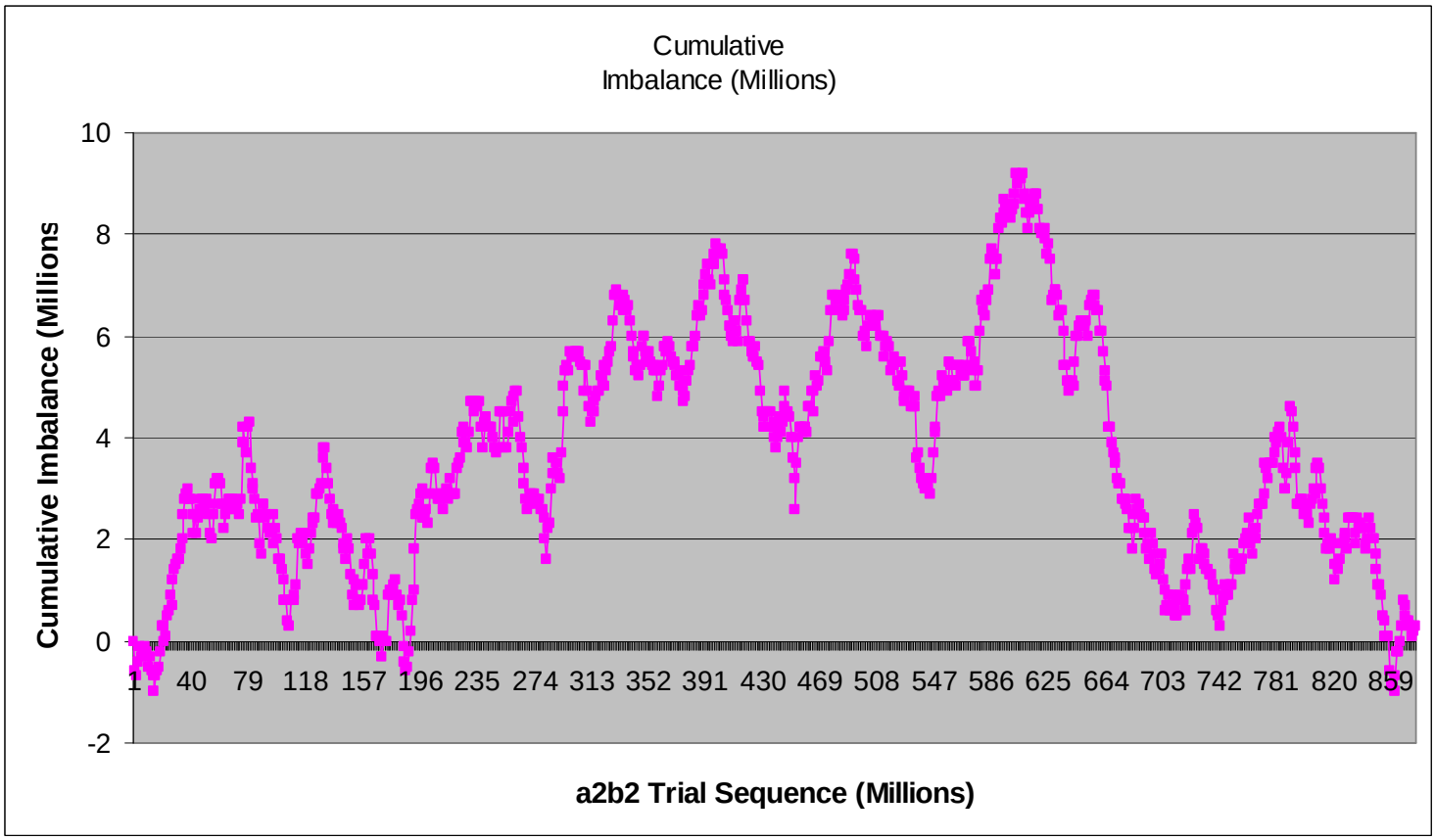

Figure 4 – Indication that the accumulation of imbalance has an overall direction till it reaches a peak and reverses the direction at the peak. Frequent and sharp Local peaks may be due to large overall average gap which can cause quick buildup and clearing of cumulated imbalance. Peak is at ~608 Million trials. Peak of cumulative imbalance is 9 million. Frequent local peaks due to very low probability may have shifted the buildup of main peak to right of the middle (actual at 69%). Above zero count = 7960, below zero count = 433, i.e. above zero = **94.8%** of time.

P++(a2b2) = 1/104349.31 represented by the **third red bar** on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf.

Points to be noted -

1. Graphs show very little or negligible presence below zero.
2. Even though the peak accumulation of bias is 1 to 2.34 % in terms of average, but it is a consistent build-up in all 4 setups and, it can be just strong enough to tilt the balance at the time. 1 to 2.34 percent imbalance accumulation may not be large enough to differentiate from probabilistic distribution, but the consistent direction of cumulated imbalance in all 4 setups is something that would be hard to expect from a truly probabilistic outcome.
3. The original experiment article states *"We closed the memory loophole by computing the statistical significance of the violation without assuming independently and identically distributed experimental trials"* on page 5 of http://arxiv.org/pdf/1511.03190v2.pdf. That means even per original paper, the possibility of dependent data is not ruled out. Dependent data itself can mean imbalance (or memory) in some form or other.
4. If the trials are found to be dependent, then Bell's inequality should not apply to entanglement correlations. Because in that case, the imbalance steers the averages towards QM predicted value and violation of Bell's inequality is no surprise.

Simplifying "entanglement" by separating anti correlation and statistical correlation

1. Whole confusion is created by mixing two things and then applying Bell's inequality on the mix.
2. To understand this, two things need to be separated first - Anti correlation and Statistical correlation.
3. **Anti correlation** - This is a direct consequence of conservation laws. Meaning the two particles will have opposite spin in order to conserve angular momentum. They will have opposite spin irrespective of when and where they are measured. This is just like two shoes of a pair being examined at different places. It can not be probabilistic because probability never guaranties an outcome. Anti correlation is a guaranteed outcome, so has to be enforced by a law and not by probability. Hence, it is enforced by conservation law in the form of kind of hidden variables. No communication is necessary, let alone faster than light! Anti correlation has nothing to do with Bell's inequality.
4. **Statistical correlation** - This is a game of averages and is totally different from anti correlation. It is guided by nature over a period of time by balancing for example, angular momentum. To solve the statistical correlation part of puzzle, the data analysis presented in this paper needs to be used to further scrutinize the reality of entanglement. In this case too, FTL is not necessary. Sub c speeds are sufficient to guide the statistical correlation over the duration of experiment. This is basically conservation laws working over a period of time rather than working instantaneously. So much effort is spent on proving non-locality between particles of same pair. This effort may not be necessary at all. Because, previous measurements can influence subsequent measurements without need of any FTL. This is what needs to be probed.
5. With this partition of anti correlation and statistical correlation, and further data analysis, there are good chances that non-existence of entanglement will be proved.

Conclusion(s)

1. The observation is very subtle, but due to unidirectional bias **consistent in all four setup combinations**, it indicates a possibility of tilting bias over time. Further research and analysis can help rule in/out any mechanism other than independent probability.
2. The distribution on first look does appear amazingly similar to that of an independent probability, but all four setups having bias in same direction, at majority of the time and then clearing the bias at the same time, should call for probing of independence vs. dependence of trials in data from similar experiments.
3. The magnitude of the cumulative imbalance is likely not beyond probabilistic limits. ***And that may be the reason that experimentalists never suspected it as anything other than probabilistic. The small magnitude of imbalance can give impression of probabilistic behavior to anyone who does not pay attention to the direction of the imbalance.*** Percent durations of the experiment for which the cumulative imbalance stayed in one (and same) direction are a1b1 (96.7%), a1b2 (94.7%), a2b1 (99.8%), a2b2 (94.8%). This could be difficult to explain in terms of probability.
4. Until this kind of analysis is not completed on multiple experiments, existence of entanglement will remain in doubt.
5. Suspect is some kind of balancing mechanism that guides the experiment over its duration, in order to conserve angular momentum (for example, in case of spin) over duration of experiment.

References:

1. https://arxiv.org/abs/1511.03190 The experiment from which the data was used for this data distribution analysis.
2. General use of physics.stackexchange.com for double checking on different well known concepts.

Contributions:

1. I sincerely thank Ms Marissa Giustina ***for graciously making the experimental data available*** for this analysis in the form of raw file along with some notes/readme/data key.
2. Special thanks to Vijayan Thanasekaran – Helped by writing a C++ program to extract data values from the experiment's raw binary data file into a text file.
3. My sincere thanks to the physics SE moderator community for helping me to improve the writing of this paper so it can communicate the observation in a clearer manner.