Quantum Entanglement - experiment data indicates balancing mechanism

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

Abstract –
This article presents analysis of experimental data. The data was acquired from a recently published experiment, the link to the published paper is https://arxiv.org/abs/1511.03190. The data analysis gives an indication that the outcomes may not be totally probabilistic and may be guided by some other mechanism. ***This article only presents an independent observation and is not meant in any way to comment on the originally published findings of the referred experiment from which the data was acquired.*** This article also does not dispute any quantum mechanics quantitative predictions. It only presents the observation made so that more experiments/analysis may be conducted if deemed necessary. As such, the observation pointed out is minor and its magnitude can be attributed to independent probability. But the same "cumulated imbalance" direction and trend in all four setup combinations is something that would be hard to attribute to probability alone. Also, the accumulated imbalance cleared for all four setups exactly at the same time.

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.

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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 **875678954**.
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 **(875678954 – 141439)/141439 = 6190.21** non ++ pairs between two ++ pairs.
11. Thus the average gap between two ++ pairs is 6190.21 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 **1/6191.21** 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 6190.21.

Cumulative Expected gap – Sum of Expected gap so far. It is simply (6190.21) 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 = (6190.21 – 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 6190.21, imbalance = 6190.21 – 3049 = 3141.21, cumulative imbalance = 3141.21.
Second ++ outcome was found at trial number 10878.
So, actual gap = 10878 – 3050 – 1 = 7827, expected gap is 6190.21, imbalance = 6190.21 – 7827 = –1636.79.
Cumulative imbalance till this point is = (3141.21) + (– 1636.79) = 1504.42.

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 ~6190.21 each line	(D) – (Accumulated Imbalance) = (C – B)
3050	3049	3049	6190.212848	3141.212848
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.

Trend of accumulated imbalance (a1b1) trials (Total imbalance never (negligible) went below zero). P++(a1b1) = 1/6191.21

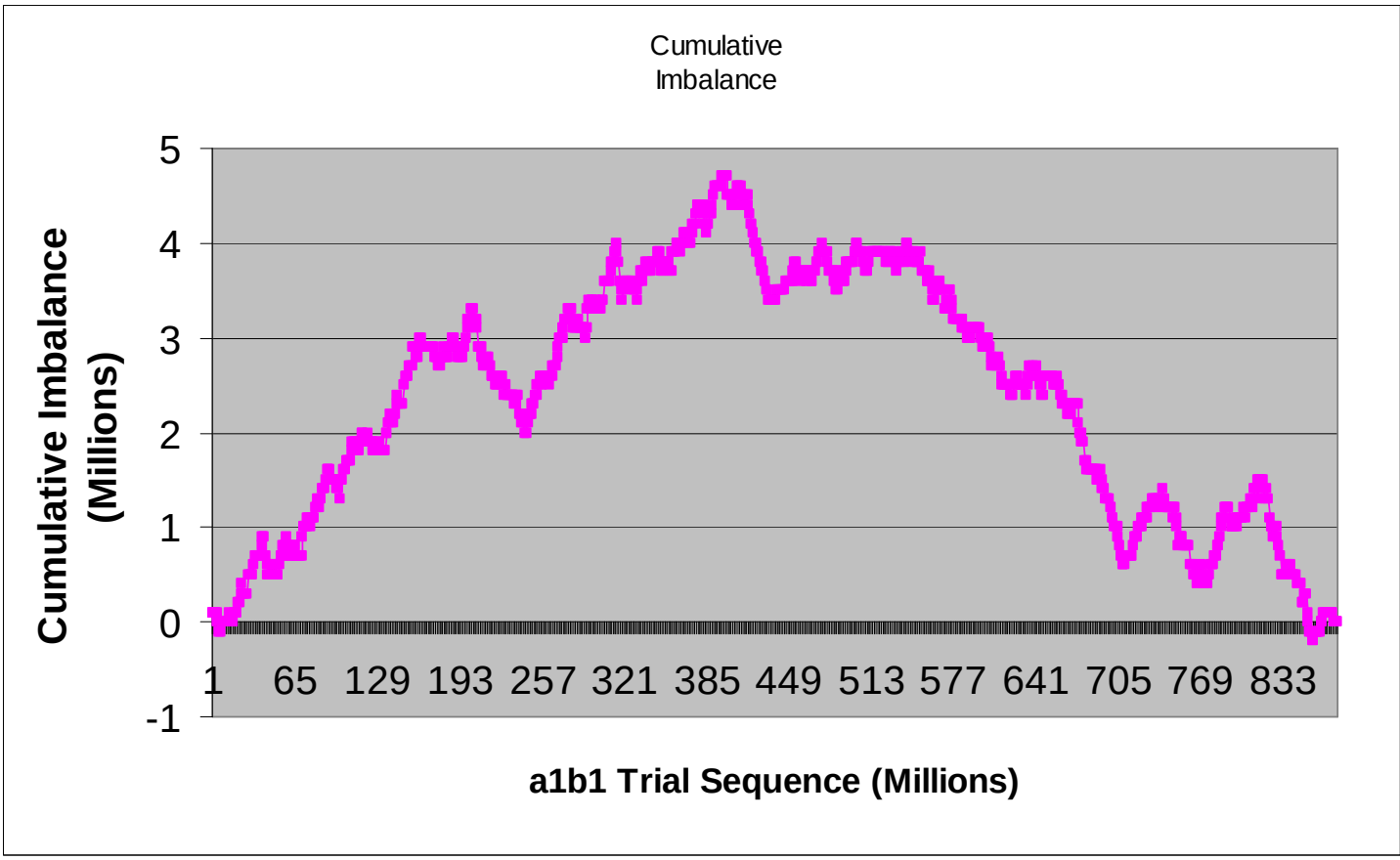

Figure 1 – Indication that the accumulation of imbalance has an overall direction till it reaches a peak and reverses the direction at the peak. Peak is at ~414 Million trials. Peak of cumulative imbalance is 4.7 million. A ++ appears to place peak at the ~middle of the graph (actual at 47% of total interval). Above zero count = 136644, below zero count = 4795, i.e. above zero = **96.6%** of time.

P++(a1b1) = 1/6191.21 represented by the **green bar** on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf.

Gaps->	Average Before Peak	Overall Average	Average After Peak
	6125.564448	6190.212848	6249.607877
Delta %	**-1.044364736**		**0.959498975**
	(After - Before) Delta%	**2.003863711**	

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) = 1/13051.25

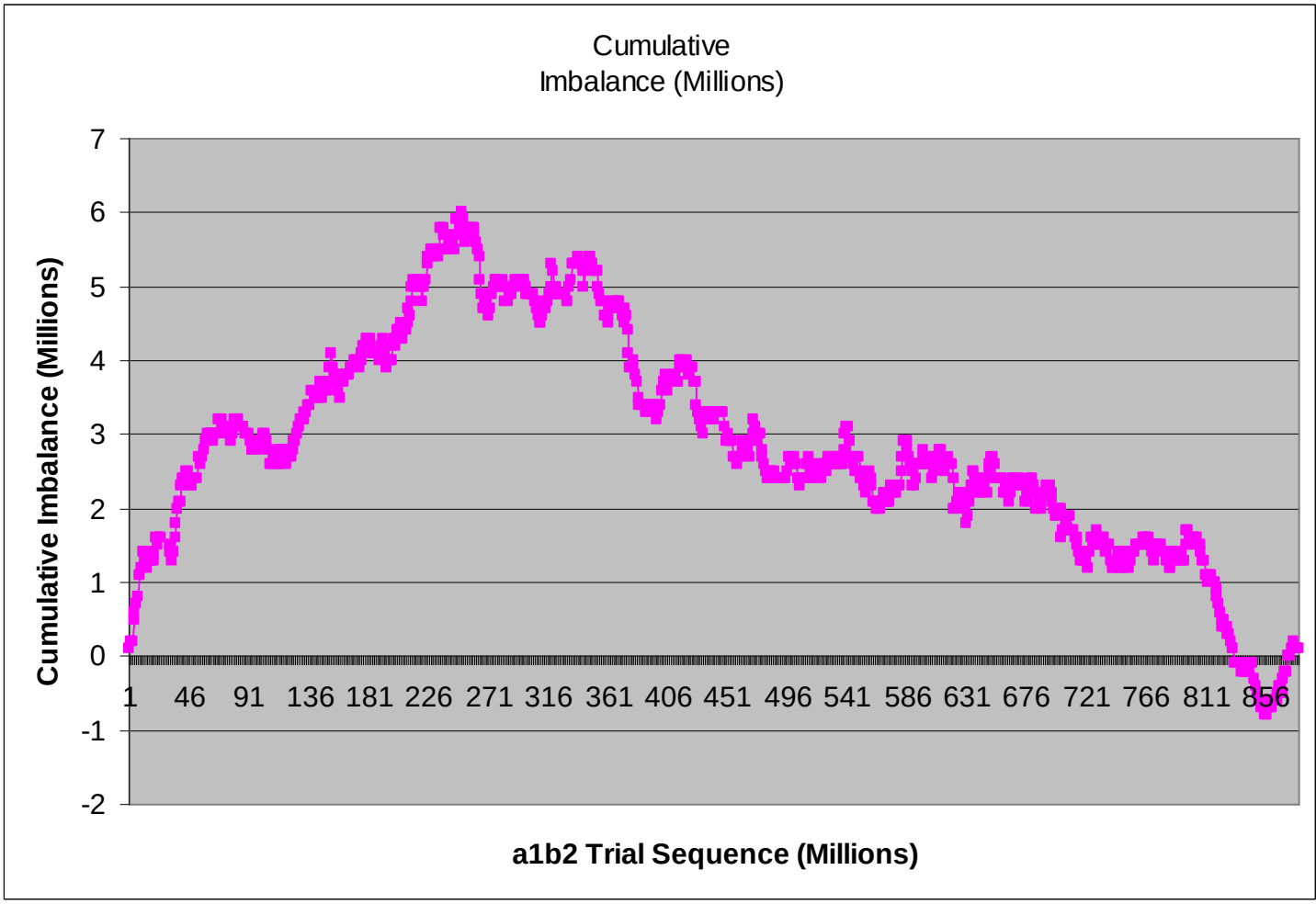

Figure 2 – Indication that the accumulation of imbalance has an overall direction till it reaches a peak and reverses the direction at the peak. Peak is at ~246 Million trials. Peak of cumulative imbalance is 6 million. A +0 appears to place peak at the left ~third of the graph (actual at 28% of total interval). Above zero count = 63546, below zero count = 3536, i.e. above zero = **94.7%** of time.

P+0(a1b2) = 1/13051.25 represented by the **bottom red bar** on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf.

Gaps->	Average Before Peak	Overall Average	Average After Peak
	12743.78551	13050.25429	13170.61053
Delta %	**-2.348373945**		**0.922252099**
	(After – Before) Delta%	**3.270626043**	

Trend of accumulated imbalance (a2b1) trials (Total imbalance never (negligible) went below zero). P0+(a2b1) = 1/14952.40

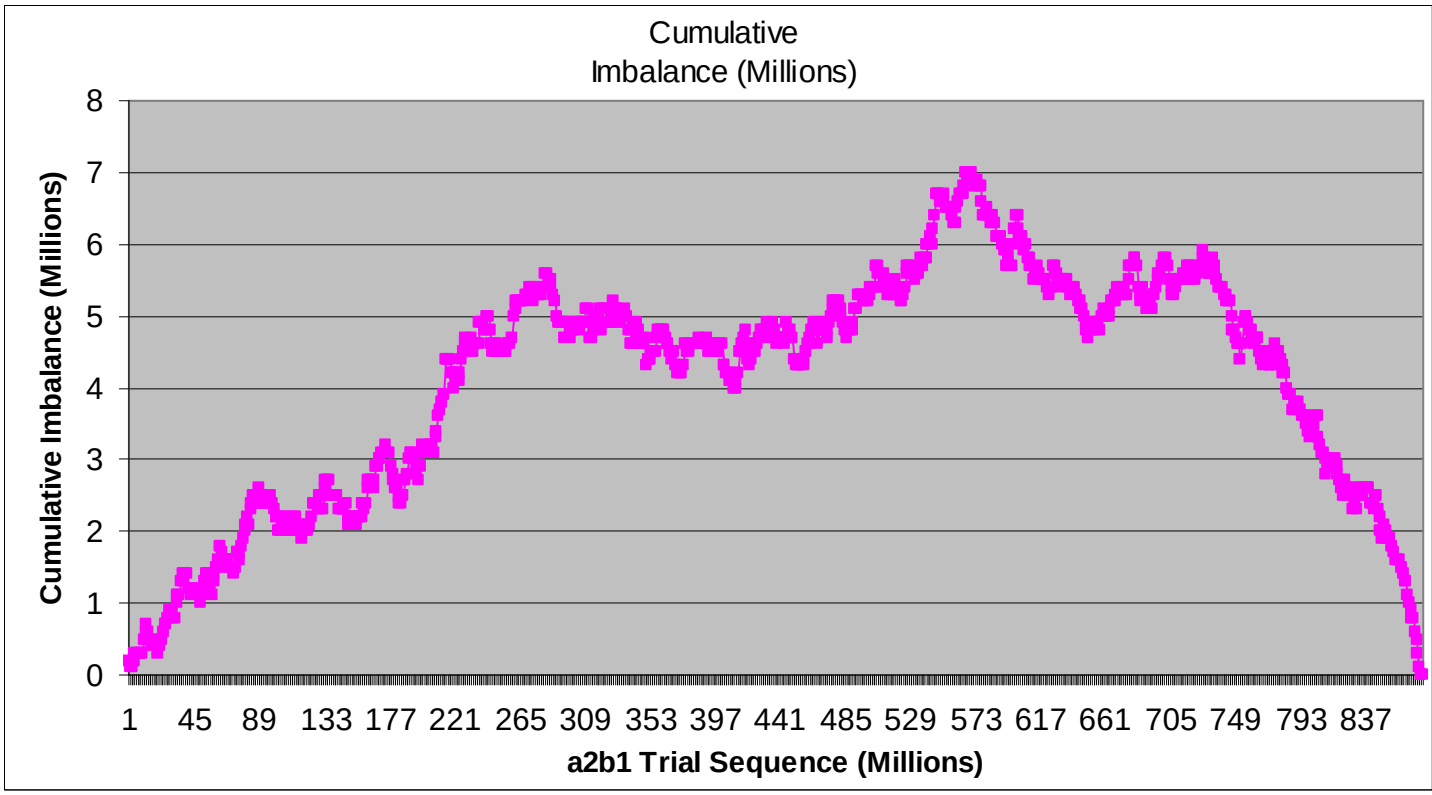

Figure 3 – Indication that the accumulation of imbalance has an overall direction till it reaches a peak and reverses the direction at the peak. Peak is at ~571 Million trials. Peak of cumulative imbalance is 7 million. A 0+ appears to place peak at the right ~third of the graph (actual at 65% of total interval). Above zero count = 58459, below zero count = 119, i.e. above zero = **99.8%** of time.

P0+(a2b1) = 1/14952.40 represented by the **second red bar** on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf.

Gaps->	Average Before Peak	Overall Average	Average After Peak
	14773.75315	14951.40445	15294.03449
Delta%	**-1.1881914**		**2.291624468**
	(After – Before) Delta%	**3.479815868**	

Trend of accumulated imbalance (a2b2) trials (Total imbalance never (negligible) went below zero). P++(a2b2) = 1/104319.02

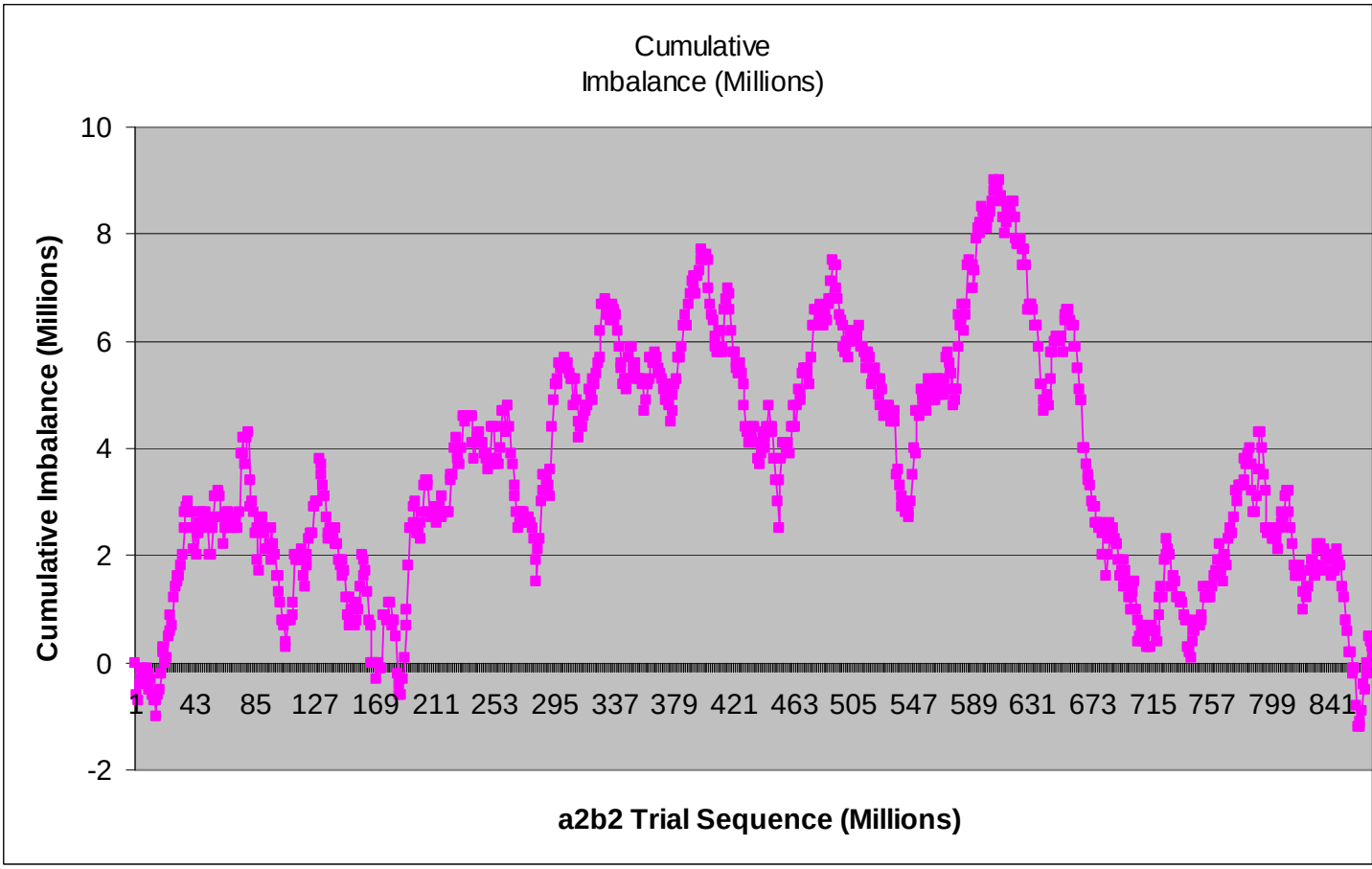

Figure 4 – Indication that the accumulation of imbalance has an overall direction till it reaches a peak and reverses the direction at the peak. Frequent and sharp Local peaks may be due to large overall average gap which can cause quick buildup and clearing of cumulated imbalance. Peak is at ~608 Million 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 = 7867, below zero count = 525, i.e. above zero = **93.7%** of time.

P++(a2b2) = 1/104319.02 represented by the **third red bar** on page 5, figure 3 of http://arxiv.org/pdf/1511.03190v2.pdf.

Gaps->	Average Before Peak	Overall Average	Average After Peak
	102795.3109	104318.0249	107787.991
Delta %	**-1.459684473**		**3.326334195**
	(After - Before) Delta%	**4.786018668**	

Points to be noted -

1. All four detectors stayed above zero the whole time, and still reached QM predicted values exactly at the same time. That appears to be too much of a coincidence. Setup a2b1 (Figure 3) had to even rush to achieve the match towards the end.
2. Graphs show very little or negligible presence below zero.
3. Cumulated imbalance of all setups reaches zero at the same time while probabilities of different setups are very different.
4. 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.
5. 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.
6. If the trials are found to be dependent, then Bell's inequality should not apply to entanglement correlations.

Conclusion(s)

1. The observation is very subtle, but due to unidirectional bias **consistent in all four setup combinations**, it also 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.

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.