Combinatorics in Estimating the Hodo 3of4 Trigger Livetime -

applying the incoherent approximation to an interpretable SHMS example

D. Mack

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Motivation

If our strategy is to “trust but verify” the electronic deadtime inferred from EDTM, then once in a while we need to do the verify part.

It helps if we have an interpretable case. For example: in Carlos Yero’s thesis, he finds a fairly stable EDTM deadtime of ~7%. (Fig 5.4 of his thesis.) Conditions were:

- Daq coincidence trigger rates of ~2.5 Hz. (so we can ignore the computer DT)
- EDTM rate of ~2 Hz. (so we can ignore the non-Poissonian correction to EDTM)
- HMS 3of4 rate of ~140Hz (so we can ignore the HMS electronic DT)
- No PID in the trigger (right or wrong, Carlos and I are consistently calculating the DT in the 3of4 hodo trigger)
- SHMS hodo plane rates of ~1MHz (oops)

which means that we can attribute nearly all his 7% total deadtime to electronic DT in the 3of4 hodo trigger in the SHMS. This seemed a bit high.

Can we understand this?

Hodo Logic Chain

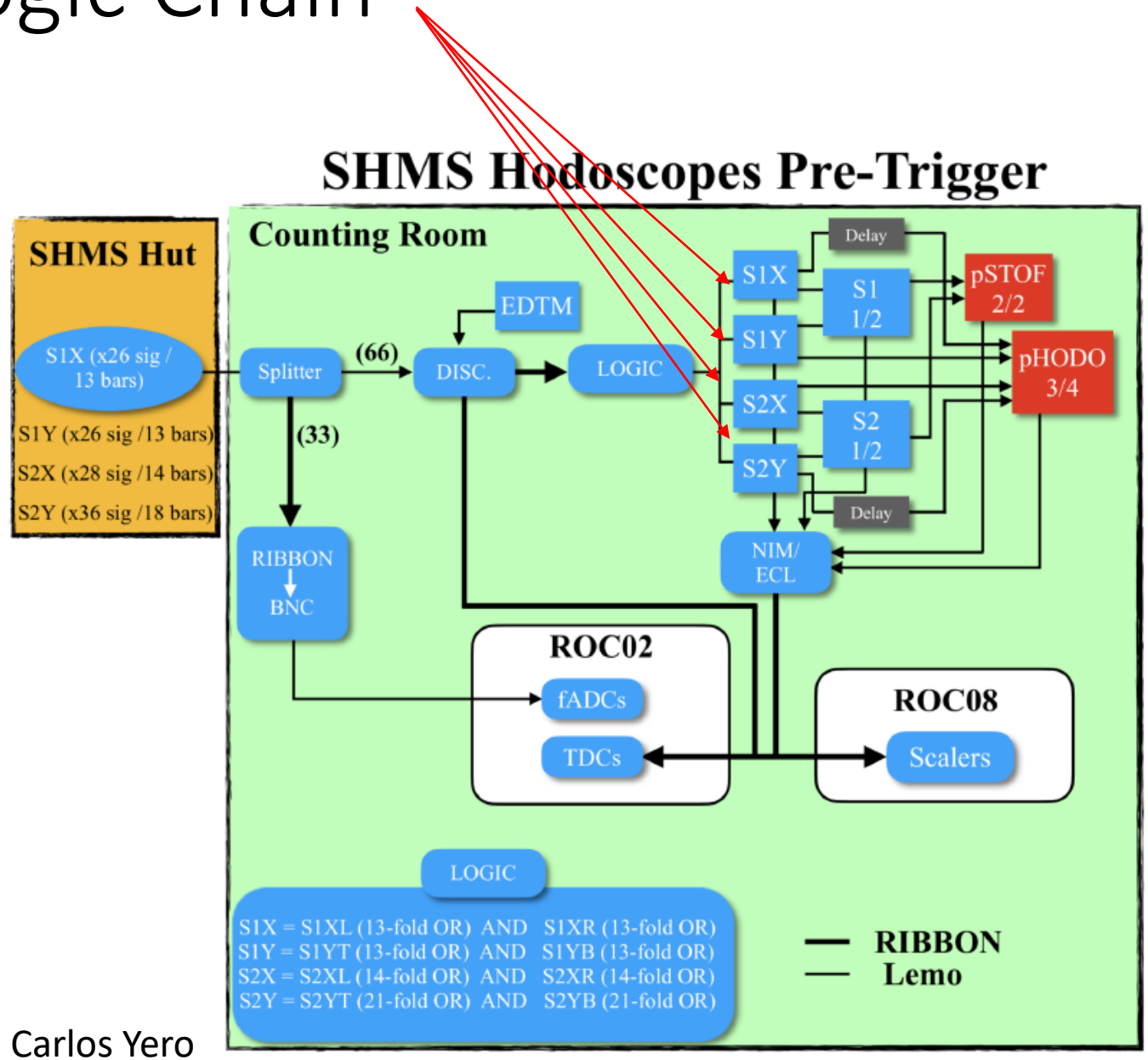
DT estimates are a lot easier if we can find a critical node that dominates, usually where rate and gate width are both large.

The critical nodes probably were and are the P/S 755 outputs which standardize the 4 hodo plane signals. (arrows on right) They were 100ns wide during commissioning when Carlos's data were taken*, and the rates are high in this section since S1X for example represents the OR of all the S1X paddles with double-ended hits in that plane.

The upstream Lecroy 4564 camac logic unit sees the same high rate but is basically deadtimeless; it does real-time logic operations corresponding to overlaps .

The widths of the upstream discriminator outputs are significant on this scale (60ns), but any one discriminator only sees the rate in a single paddle.

*Thanks, Dave G! It was later reduced to 50ns, but because of high rates, the P/S 755 outputs probably remain the critical node, so the formalism here and its Excel file implementation should work when the incoherent approximation is valid (most of the time).



Carlos Yero

https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1028

Incoherent Rate Approximation

The first order deadtime probability at a critical node will simply be DT = rate * DPR. I take the double pulse resolution to be the P/S 755 output gate width.

The main approximation we're going to make is to assume that the blocking rate is incoherent, with no correlations between hits in different paddles. This is probably a good approximation for high Q2 electron scattering where most of PMT rate is background.

(The coherent case would be where the rate is mainly from good tracks, eg in low Q2 elastic scattering. If a track is blocked in S1X by another track that came 20ns earlier, for example, then it is likely to be blocked in the other planes as well. Fully coherent tracks are bad in that sense; the worst case scenario for blocking. It doesn't even matter if you have one plane or twelve.)

Since a real focal plane always has a mixture of incoherent and coherent rates, I'll put both on the plots to give you an idea of the model dependence

All Combos

Assume for plane i , that Li is the probability of being unblocked or “Live”, and Di is the probability of being ”Dead”. Of course, Li + Di = 1, for i = 1,4 . We can generate a list of all combos by multiplying out

(L1+D1)*(L2+D2)*(L3+D3)*(L4+D4)

and here they are (the multiplication signs are implicit):

L1L2L3L4	L1L2L3D4	L1L2D3L4	L1L2D3D4
L1D2L3L4	L1D2L3D4	L1D2D3L4	L1D2D3D4
D1L2L3L4	D1L2L3D4	D1L2D3L4	D1L2D3D4
D1D2L3L4	D1D2L3D4	D1D2D3L4	D1D2D3D4

If your eyes are glazing over, these are readily interpretable. Eg, the combo label “L1D2L3D4” means

“(Prob the 1st plane is Live) x (Prob the 2nd plane is Dead) x (Prob the 3rd plane is Live) x (Prob the 4th plane is Dead)”

Combos With ≥3 Planes Hit

There is 1 combo where all 4 planes are hit, and 4 combos where exactly 3 planes are hit.

L1L2L3L4	L1L2L3D4	L1L2D3L4	
L1D2L3L4			
D1L2L3L4			

Hence

Livetime_3of4 = L1L2L3L4 + L1L2L3M4 + L1L2M3L4 + L1M2L3L4 + M1L2L3L4

Let's plug in an approximate rate:

Rate in the SHMS = 1 MHz (the HMS had low rates)
DPR = 100ns
The deadtime for the 1st plane is M1 = R*DPR = 0.1, so H1=1-0.1 = 0.9, and similarly for the other 3 planes. So

Livetime_3of4 = 0.9*0.9*0.9*0.9 + 4*(0.9*0.9*0.9*0.1)
= 0.656 + 4*0.0729 =0.948

which is in the ballpark of Carlos's 93%. Let's take a closer look on the next slide with a more precise calculation:

3of4 Hodo Trigger Livetime

100ns gates

Mark J provided detailed scaler rates, and the data itself reminded me to correct those scaler rates for deadtime:

Plane	Scaler Rates (MHz)	True Rate (ie, corrected for DT) (MHz)	DT (first order using true rate)	LT = 1 - DT
S1X	9.80E-01	1.09E+00	1.09E-01	8.91E-01
S1Y	8.70E-01	9.53E-01	9.53E-02	9.05E-01
S2X	6.20E-01	6.61E-01	6.61E-02	9.34E-01
S2Y	1.80E+00	2.20E+00	2.20E-01	7.80E-01

Livetime_3of4 = L1L2L3L4 + L1L2L3M4 + L1L2M3L4 + L1M2L3L4 + M1L2L3L4

= 0.588 + 0.165 + 0.042 + 0.062 + 0.072

= 0.928

See the Excel spreadsheet.

which agrees well with Carlo's 93% result.

I was surprised how important it was to correct the scaler rates for deadtime. Because the typical per plane livetimes dropped to 90% during Carlos's production data taking, the electronic deadtime in the 3of4 trigger was starting to exponentiate.

3of4 Hodo Trigger Livetime vs Rate
100ns gates

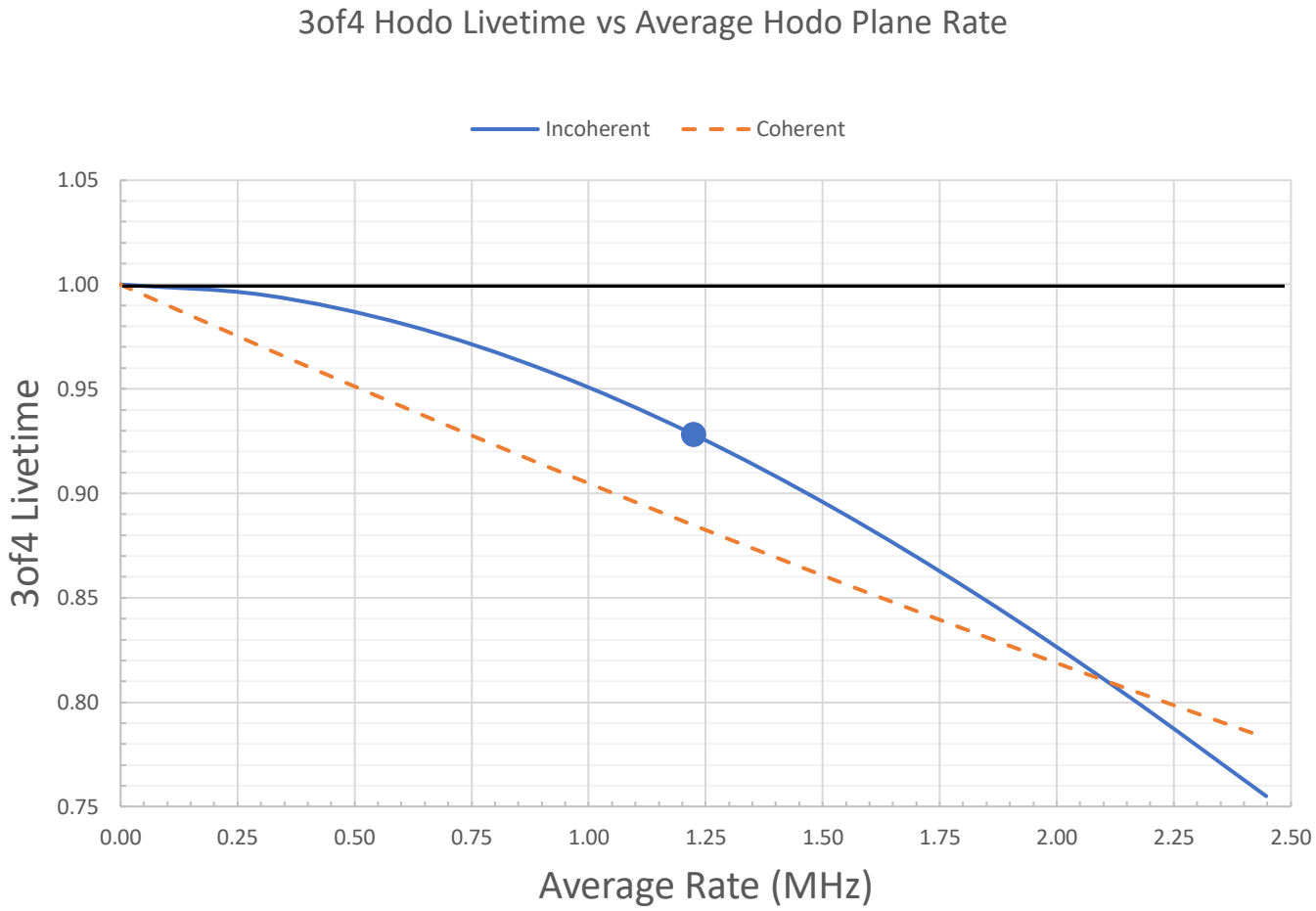
The incoherent model pretty much nailed Carlo's EDTM predicted livetime. (blue curve)

Maybe dumb luck. Need more examples.

There is some model dependence because real focal plane rates have at least some coherent admixture from tracks. It's hard to estimate the uncertainty.

A 100% coherent model using Carlo's average rates would look like the orange, dashed curve.

About 15% of Carlos's rates were coherent, so a better estimate might drop the predicted livetime by another percent.



We SHOULD be in a Much Better Place Now

50ns gates!

Plane	Scaler Rates (MHz)	True Rate (ie, corrected for DT) (MHz)	DT (first order using true rate)	LT = 1 - DT
S1X	9.80E-01	1.03E+00	5.15E-02	9.48E-01
S1Y	8.70E-01	9.10E-01	4.55E-02	9.55E-01
S2X	6.20E-01	6.40E-01	3.20E-02	9.68E-01
S2Y	6.20E-01	6.40E-01	3.20E-02	9.68E-01

The 3of4 deadtime drops super fast as soon as you make improvements:

- when I assume the present 50 ns wide gates and the same true rates, the efficiency increases to 98.3%, and
- when I assume both 50 ns wide gates and S2Y rate ~ S2X (rather than 3x higher), then the efficiency increases to 99.1%.

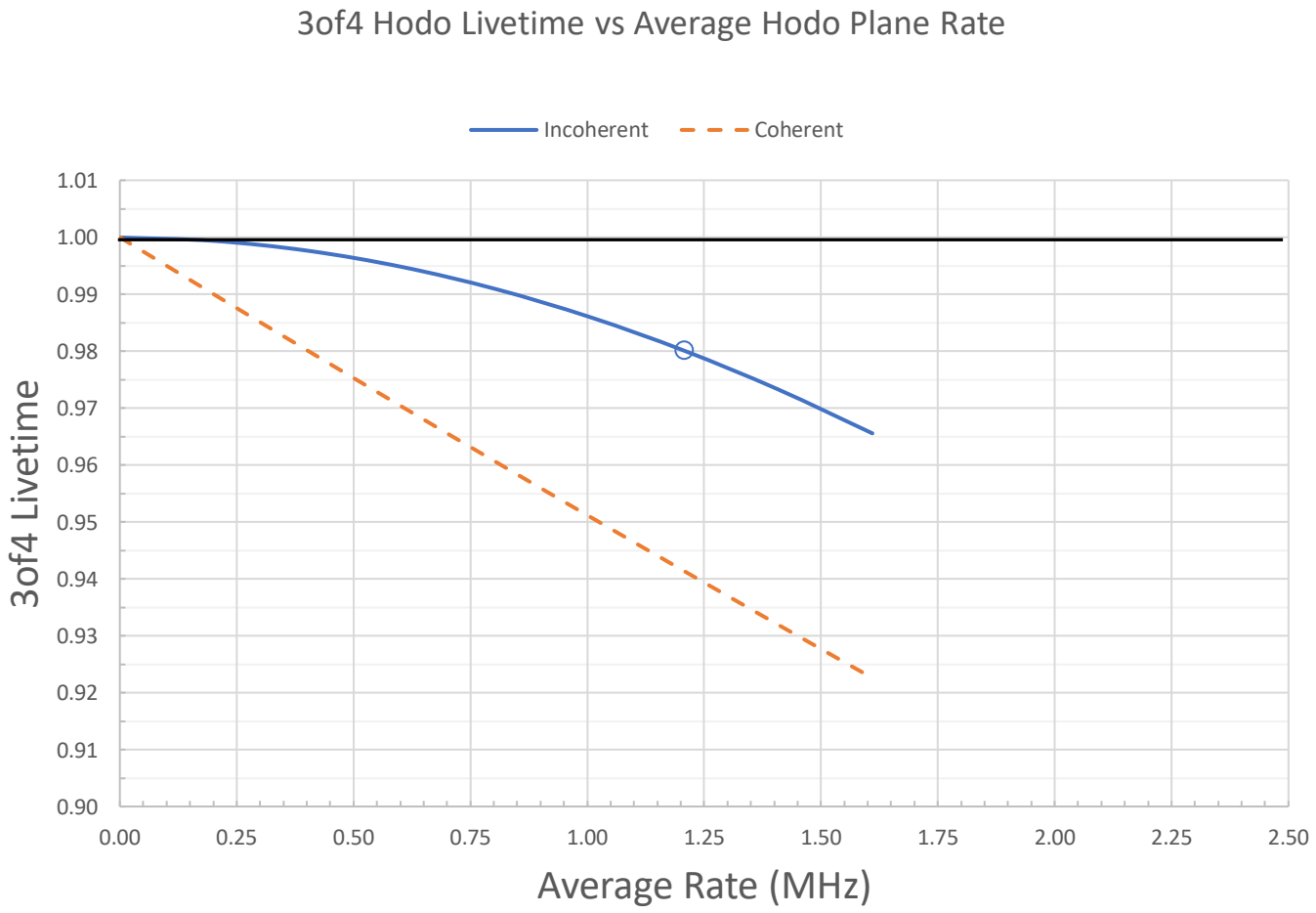
Wrt electronic deadtime, we seem to be in MUCH better shape now compared to during commissioning.

We SHOULD be in a Much Better Place Now

50ns gates

I had to expand the vertical scale.

2% at 1 MHz is not insignificant, but seems reasonable.



Maybe we can augment the old rule of thumb:

"Exceeding 1 MHz is risky for precision measurements…"

with

"…but properly applying Brad et al's EDTM total livetime corrections might save your data."

Combos With 2 planes hit, with 1 hit in S1 and 1 hit in S2

I always assumed the 2of4 efficiency must be very, very close to 100%. Seems unlikely during the commissioning period. Let's take a closer look.

In addition to the previous 5 combos, there are 4 additional combos that can make 2of4 trigger.

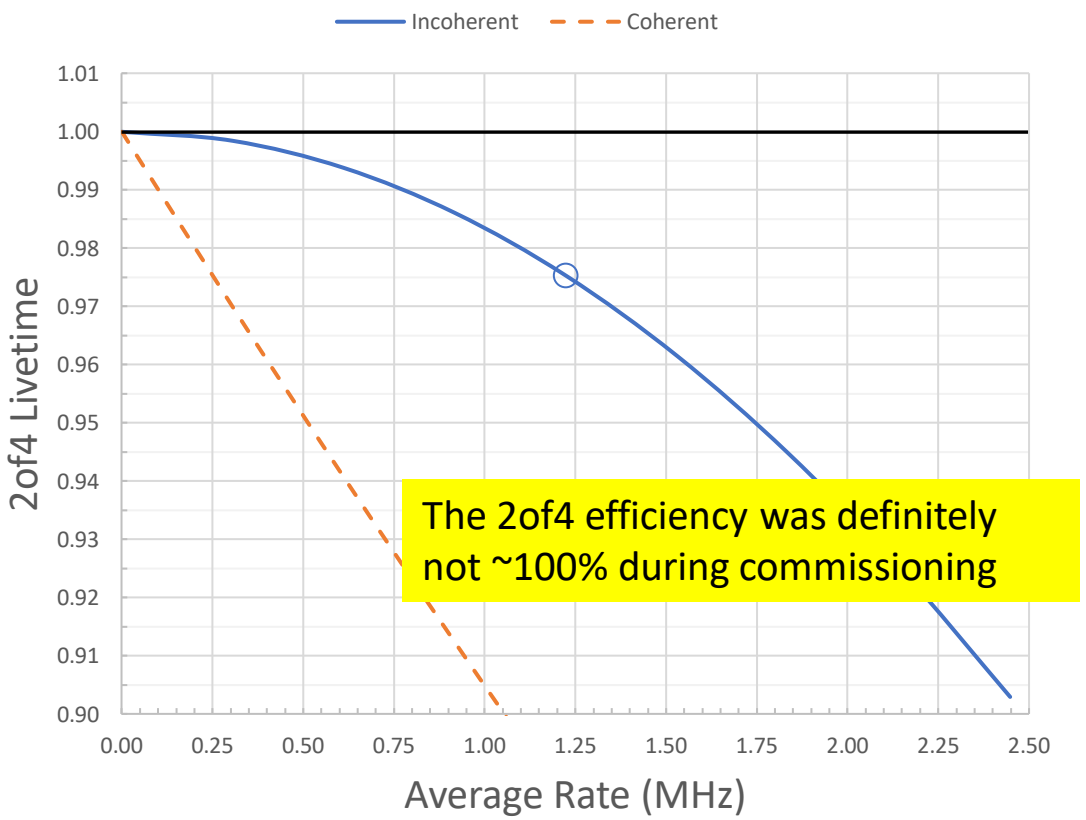
L1L2L3L4	L1L2L3D4	L1L2D3L4	
L1D2L3L4	L1D2L3D4	L1D2D3L4	
D1L2L3L4	D1L2L3D4	D1L2D3L4	

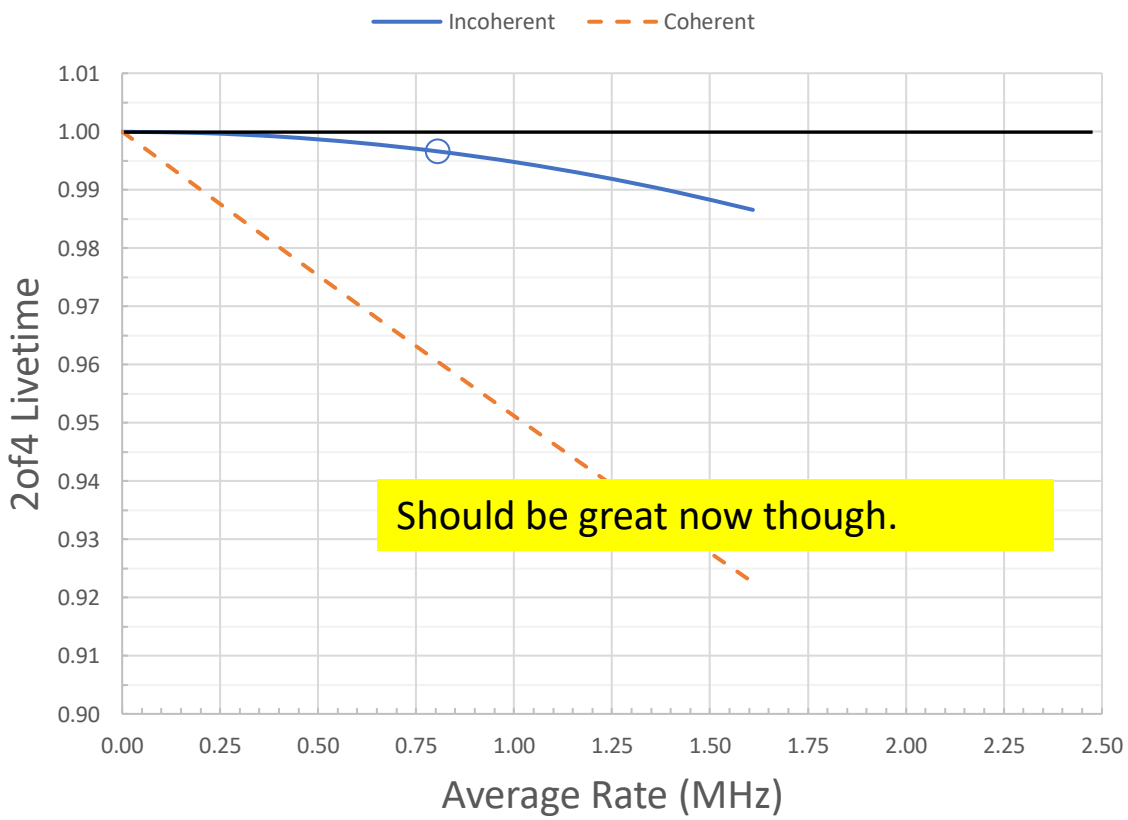
Hence

Livetime_2of4 = L1L2L3L4 + L1L2L3M4 + L1L2M3L4 + L1M2L3L4 + M1L2L3L4 + L1D2L3D4 + L1D2D3L4 + D1L2L3D4 + D1L2D3L4

See next slide for Excel plot for 100ns and 50ns.

2of4 Hodo Trigger Livetime vs Rate
100ns vs 50ns





Possible Improvements

Mark suggests a more general, but still simple calculation along the lines of

Livetime_3of4 = Livetime_coherent(3of4 rate)*Efficiency_incoherent(Total rate – 3of4rate)

Ie, use the 3of4 rate to estimate the fully coherent track rate. This would interpolate nicely. I can quickly implement that in the Excel file and check to make sure it's stable. It won't be exact because

- no cross terms (which might be important if coherent fraction gets up to ~50% - but if the coherent fraction is that high, the experiment is very unlikely to be running at hodo plane rates of ~ 1 MHz)

- ignores partially coherent, stubby tracks that hit S1X and S1Y but miss S2, eg, the dipole iron showers. (I don't remember if we even have the scaler information to assess this.)

This may be getting to the point though where the simple simulation needed to test the simple analytic formulae is going to replace the simple analytic formula.

Summary

It looks like we can understand why EDTM reported 7% electronic deadtime in the hodo 3of4 trigger in Carlos's data. It was mainly a combination of

- MHz scale hodo plane rates, and
- 100ns wide gates

It would be nice to have more examples (in general, need the CLT, the EDTM total LT, and scaler outputs for both spectrometers). There's a lot I don't understand about the role of cuts.

The same model predicts that, now that the gates are reduced to 50ns, and S2Y thresholds are optimized, for Carlos's same kinematics the electronic deadtime would drop to a very reasonable 2%.

During commissioning, the 2of4 trigger efficiency was sometimes not as close to 100% as one would like. Presumably EDTM would keep track of this, as well as nodes in the PID trigger electronics with very high Cerenkov rates which were not examined here.

Along with these slides, at https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1063 there is an Excel file which calculates the 3of4 and 2of4 electronic livetimes. Just plug in your hodo plane rates and gate widths.

Will implement a reasonable incoherent+coherent calculation in Excel. But it shouldn't be too hard to simulate.

Mark now has a trigger history at https://hallcweb.jlab.org/wiki/index.php/Trigger_History .

Backups

Cross Check

Mark J has a back of the envelope calculation that is so clever it makes my head spin.

Start with all the combos

L1L2L3L4
L1L2L3D4
L1L2D3L4
L1D2L3L4
D1L2L3L4
L1D2L3D4
L1D2D3L4
D1L2L3D4
D1L2D3L4
D1D2L3L4
L1L2D3D4
L1D2D3D4
D1D2L3D4
D1D2D3L4
D1L2D3D4
D1D2D3D4

Instead of calculating the livetime by adding probs for combos with 3 planes, calculate the deadtime by adding probs for combos w/o 3 planes
(Looks grim. I would turn around and run away screaming at this point lol.)

L1D2L3D4
L1D2D3L4
D1L2L3D4
D1L2D3L4
D1D2L3L4
L1L2D3D4
L1D2D3D4
D1D2L3D4
D1D2D3L4
D1L2D3D4
D1D2D3D4

(Basically, working from the opposite end of the binomial distribution.)

Since the DT of a plane is small, keep only the lowest order terms, ie terms missing exactly 2 planes
(the key insight. Looks nicer.)

L1D2L3D4
L1D2D3L4
D1L2L3D4
D1L2D3L4
D1D2L3L4
L1L2D3D4

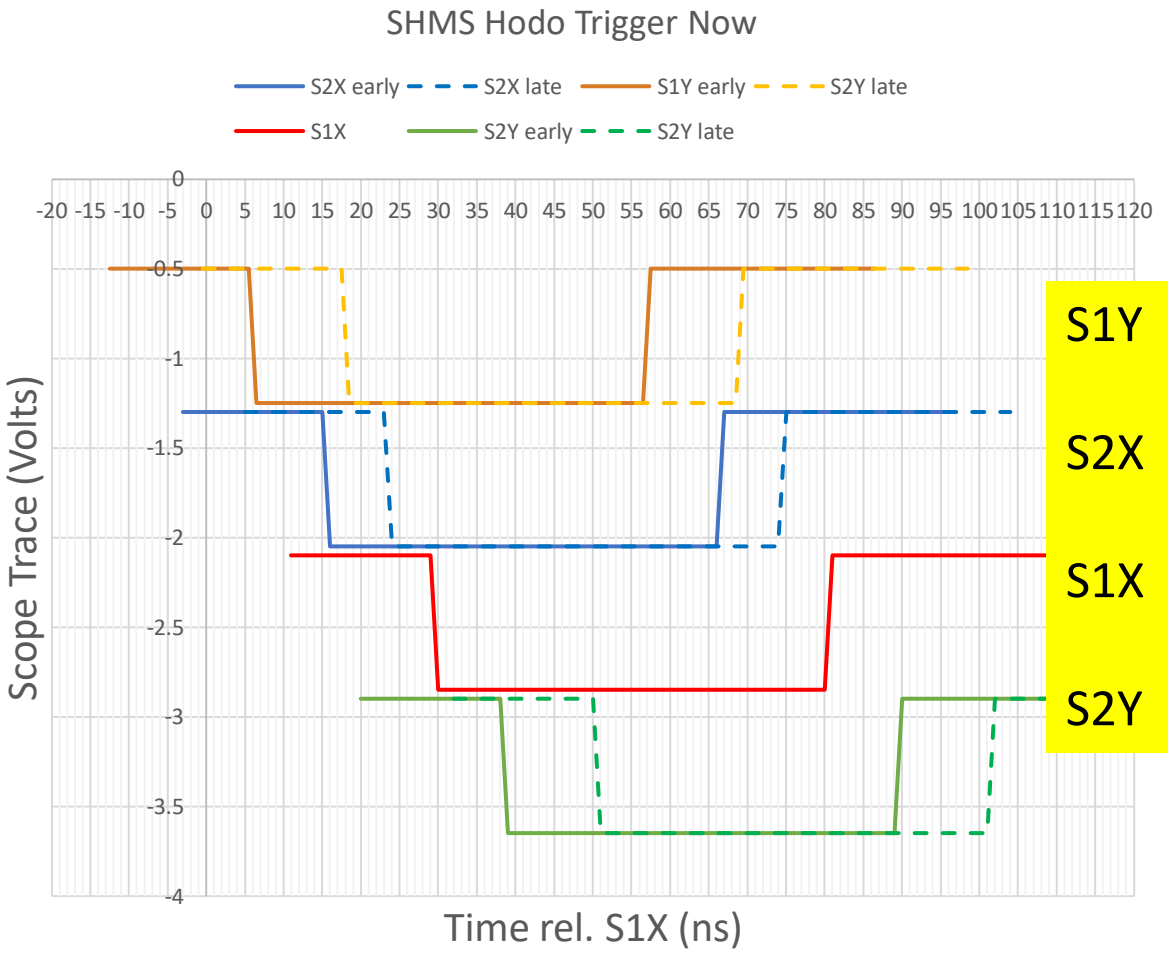
Just going for a rough estimate, so take those L terms to be ~1
(looks nicer still)

D2D4
D2D3
D1D4
D1D3
D1D2
D3D4

So you get a formula with a ~20% uncertainty which fits on the back of a coconut.
For 1 MHz and 100ns wide gates, this would yield 6% DT which is not far from the full calculation.

How, Exactly, do Logic Pulses Get Blocked?

SHMS Hodo Trigger Now



Eric Pooser, Dec 2019, https://logbooks.jlab.org/entry/3752072

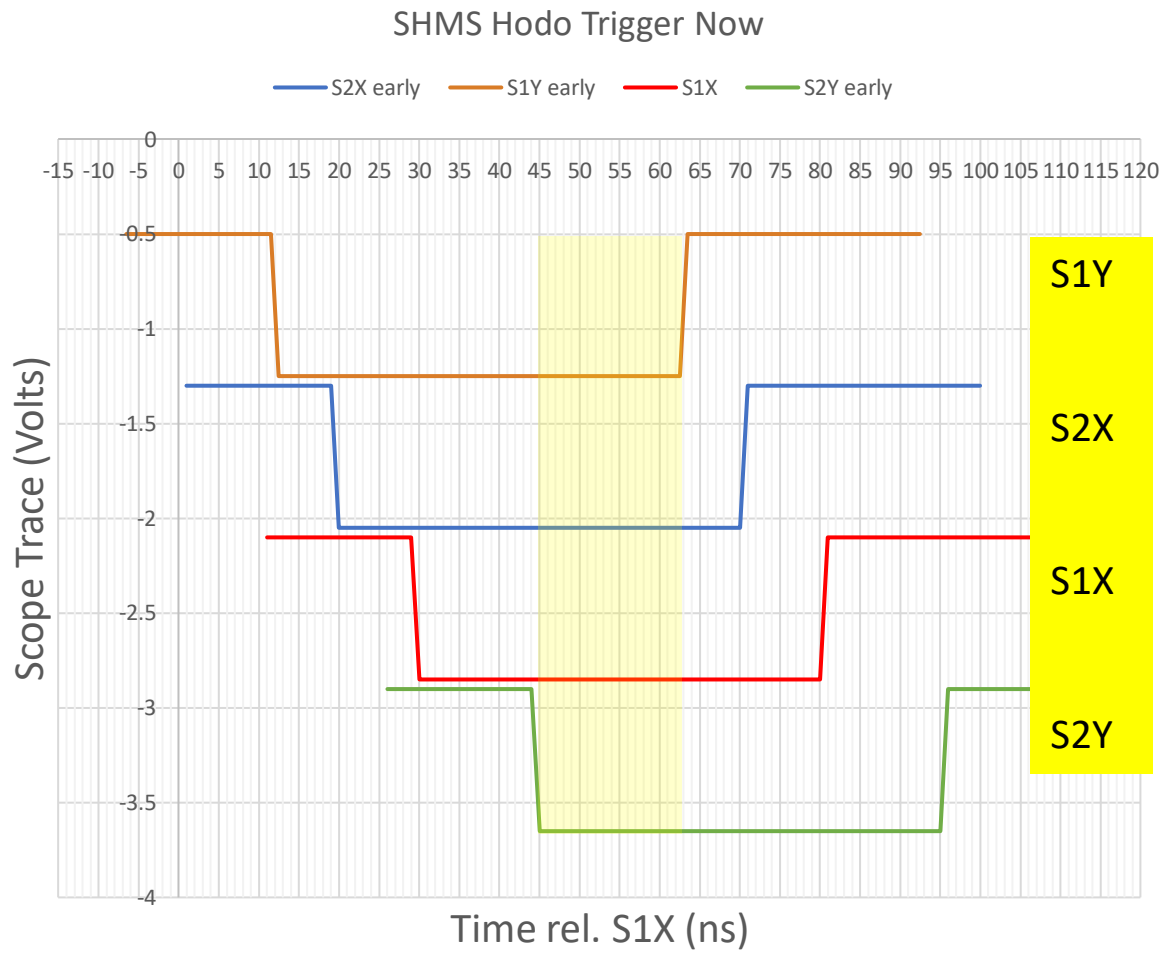
Above is my Excel approximation, including the jitter bands.

Nominal Hodo 3of4 Timing

This is the present timing if I average away the jitter.

Input gates to the 3of4 coincidence units in this example are 50 ns wide.

Timing of the hodo 3of4 is nominally set by S1X.



Making the coincidence with increasingly delayed gates this way has implications I don't fully understand:

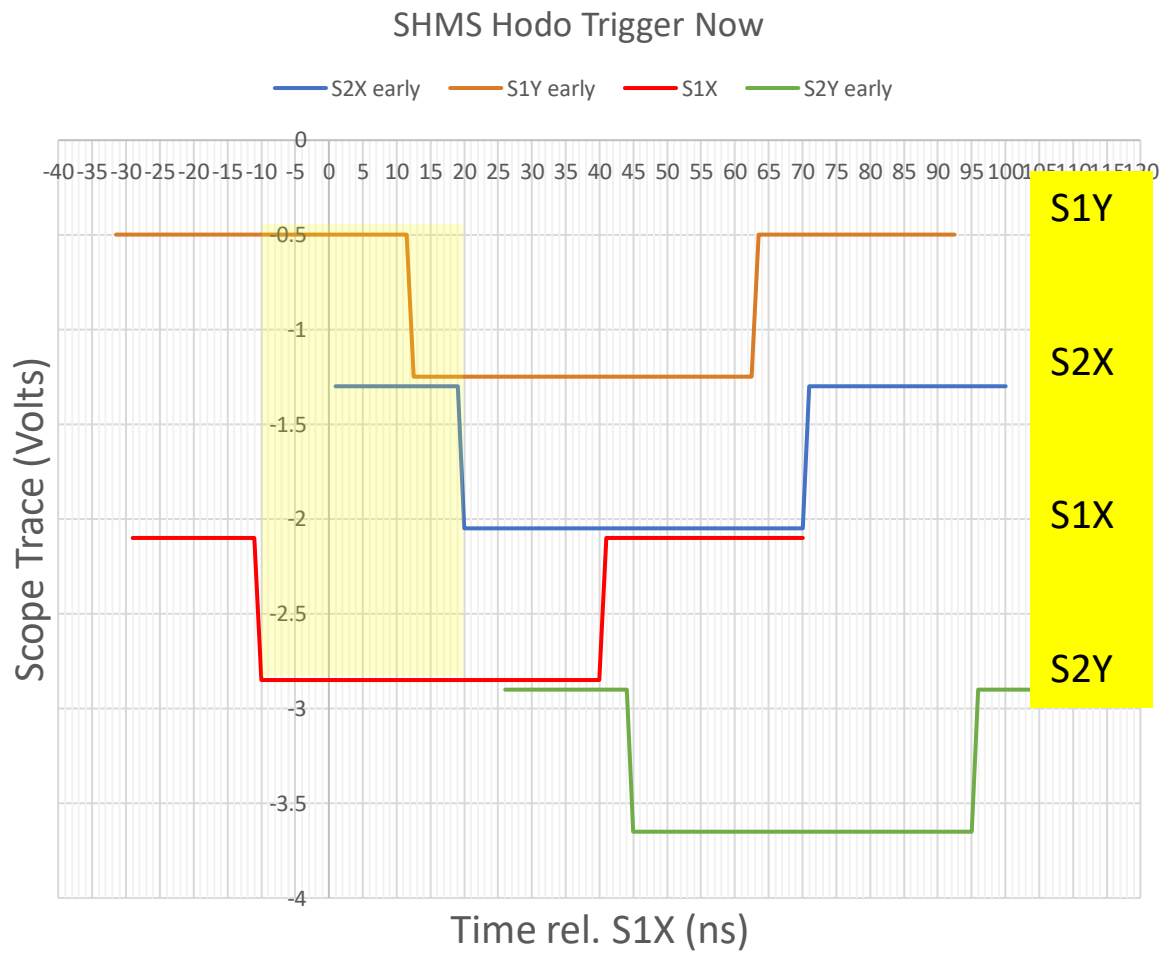
- There is only ~15ns of slop in accepting all four planes.
- The broken symmetry means more likely to lose an early hit in S1Y, less likely to lose an early hit in S2Y.

Example of a Single Earlier Hit

S1X has the highest rate. There is a ~10% chance in Carlos's data that there will be an earlier hit in S1X which blocks the real hit in that plane .

If there is a noise hit in S1X which is say 40 ns earlier, then S2X will set the timing. Fine. The hodo 3of4 trigger can still accept the good event albeit with potentially corrupt timing in S1X.

(Depending on the degree of software filtering, both beta and the wire chamber resolutions might be visibly deteriorating.)

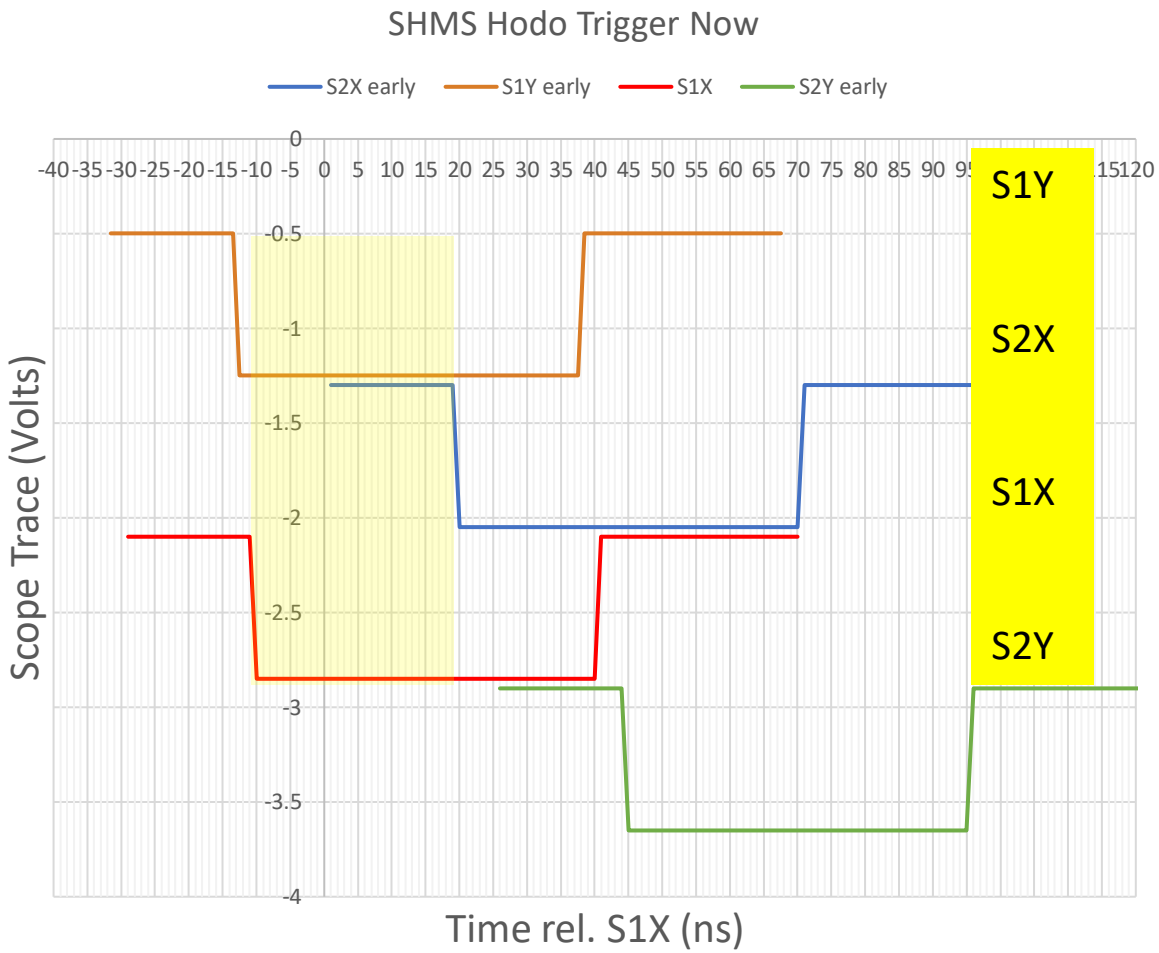


Example with Two Earlier Hits

Two hits now: S1X still 40ns earier, and S1Y 25ns earlier

S2X will still set the timing. Fine. The hodo 3of4 trigger can still accept the good event albeit with potentially corrupt timing in S1X and S1Y.

(Depending on the degree of software filtering, both beta and the wire chamber resolutions might be visibly deteriorating.)



Very early hits in S1Y and S2X can truly block the hodo3of4 trigger. But in general the problem seems to be more a question of how much corruption of the timing information corruption one wants to accept, which is cuts dependent and depends some consistency between EDTM Events and data events for EDTM to be useful. I need to think about this much more.