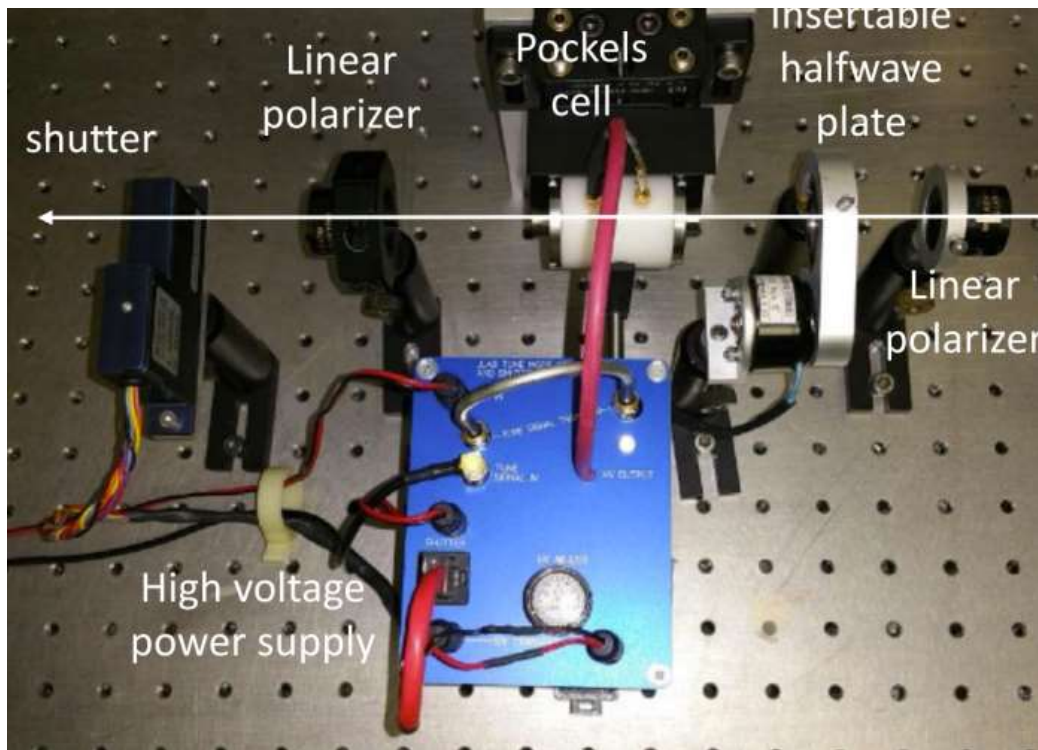
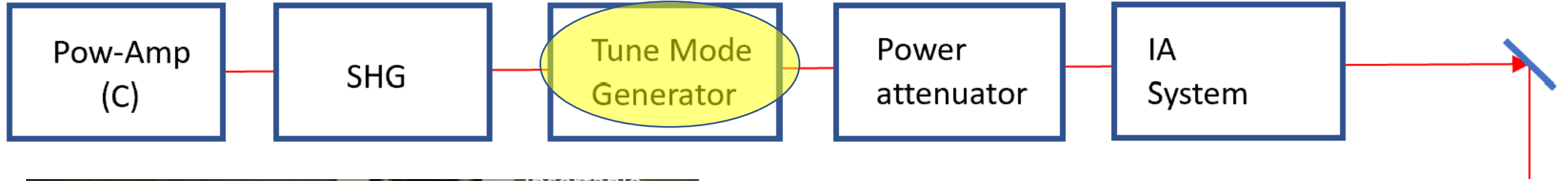

Drive Laser TMG Evaluation Meeting Presentation

Shukai Zhang

April 11, 2024

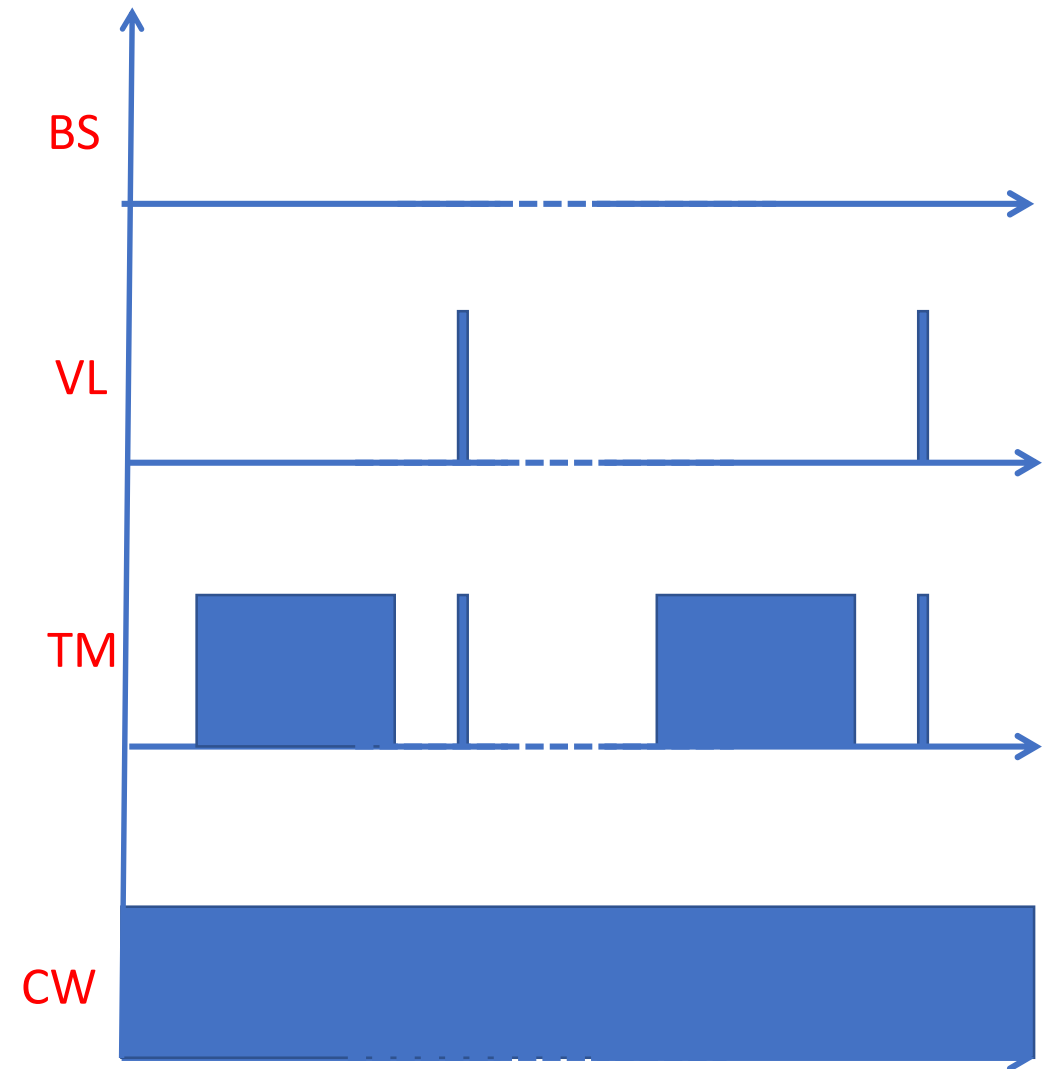
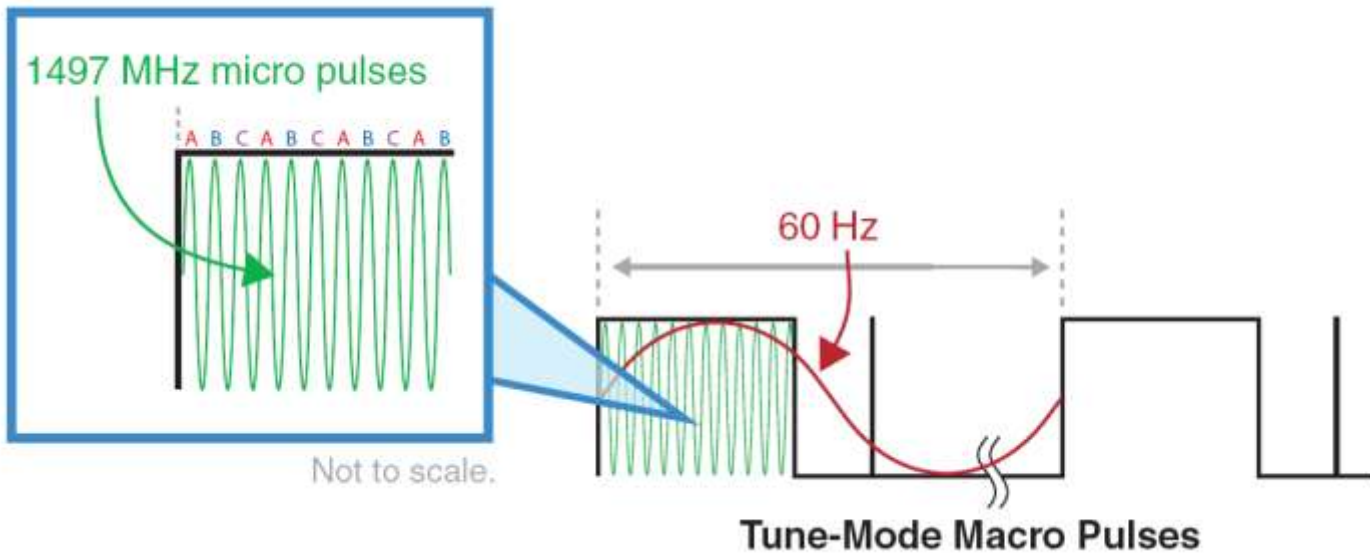
Tune Mode Generator (TMG)



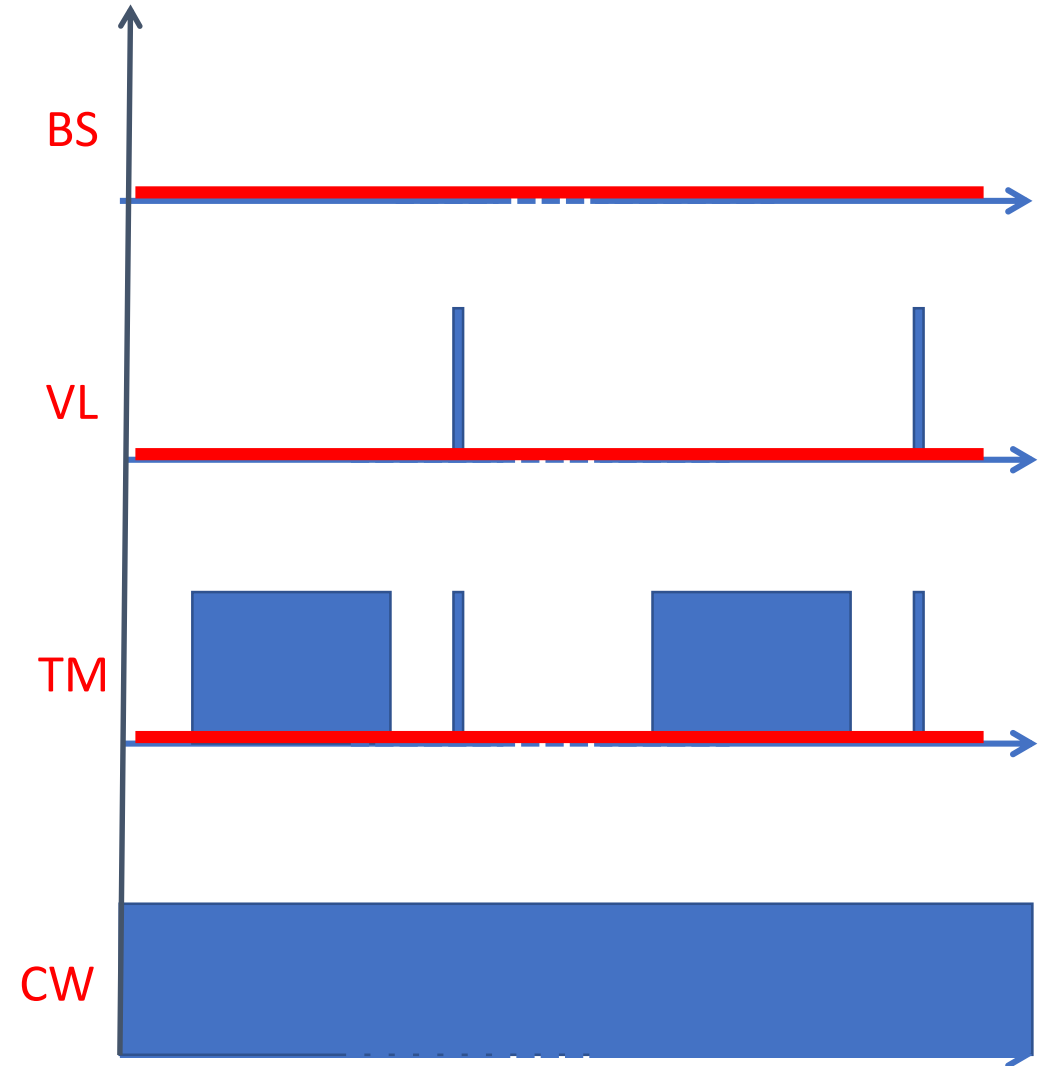
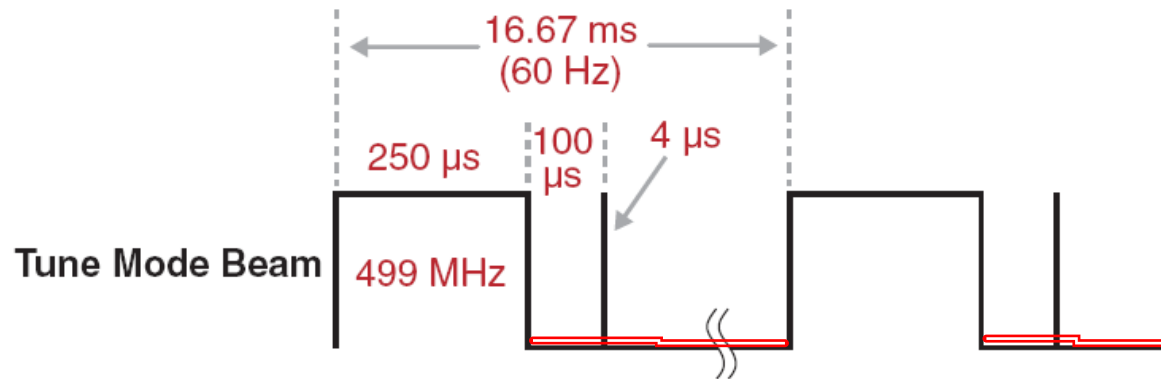
Combination of a Fast EO, polarizing optical elements and a slow mechanical shutter

- ***Provide time structures needed by CEBAF operation***
- ***Protect machine***

Time structures needed by CEBAF

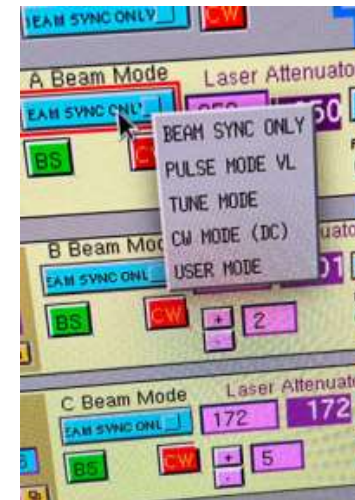
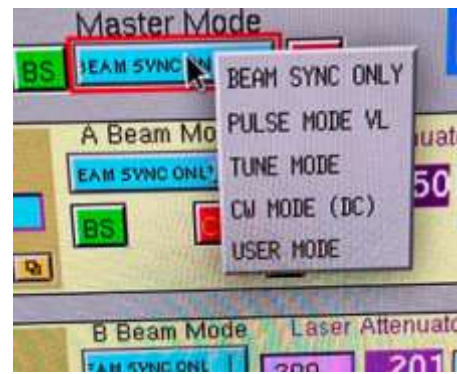


Week **background** due to limited optical switch contrast



CEBAF Beam/Machine Modes

Beam mode	Macropulse duration at 60 Hz	Duty factor	Tune mode generator Pockels cell	Tune mode generator halfwave plate	Shutter
OFF	N/A	0	ON	IN	CLOSED
Viewer limited	4–10 μ s	0.02–0.06%	ON	IN	OPEN
Tune mode	250 μ s ON, 100 μ s OFF, 4 μ s ON	1.52%	ON	IN	OPEN
CW	N/A	100%	OFF	OUT	OPEN



Recent CEBAF beam-strike/Vacuun incident

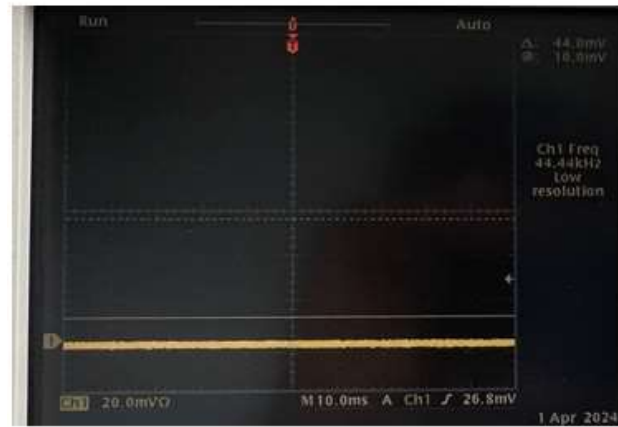
- 3/20/2024, Hall C lost beam.
 - Trouble-shooting showed mechanical shutter is good, the C laser TMG malfunctioning, replaced TMG. Machine resumed operation for a day
- 3/21/2024, vacuum problem in cebaf beam spreader, laser beam /power leak in BS mode. shutter did not seem closed.
- 3/22/2024, more extensive trouble-shooting performed, no
- Extensive trouble-shooting by CIS/SSG/AESCIS

CEBAF Beam Power & Pulse Structure

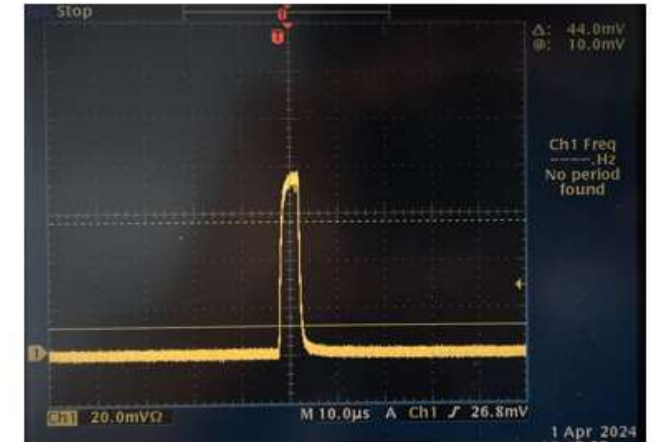
Laser power vs beam mode
Atten@1000

	A (mW)	B(mW)	C(mW)	D(mW)
BS	0	0	0	0
VL	0.55	0.13	1.62	0.018
TM	0.88	0.16	2.1	0.035
CW	77	18.4	198	5.3

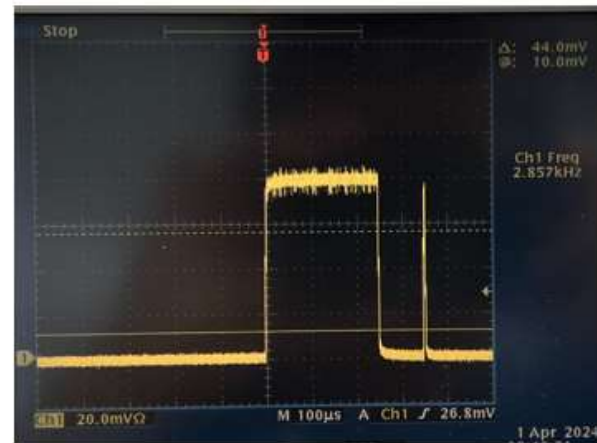
A Laser Pulse traces



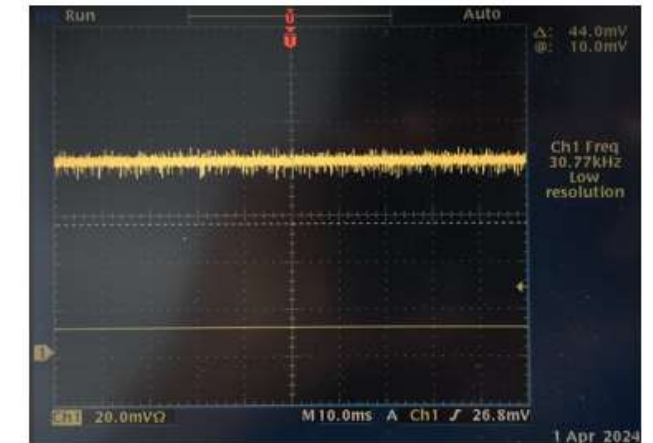
BS



VL

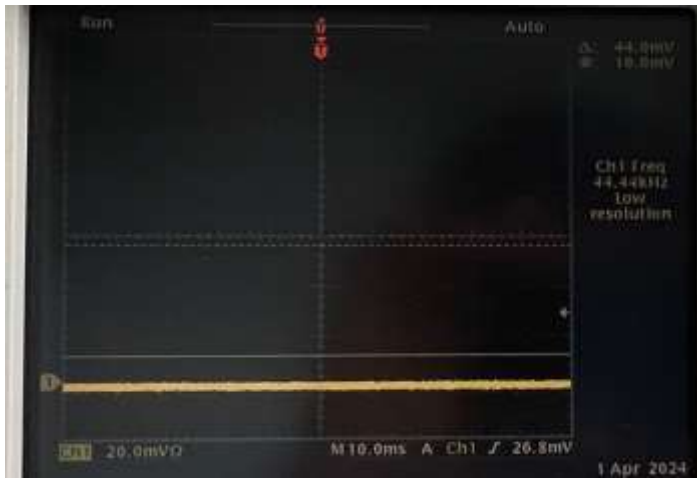


TM1

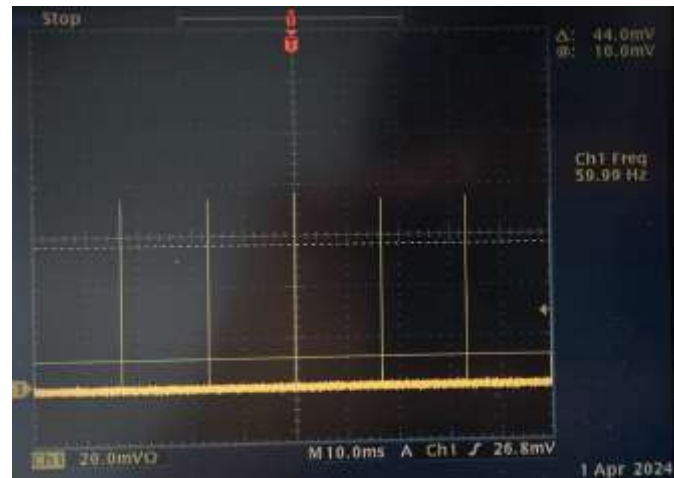


CW

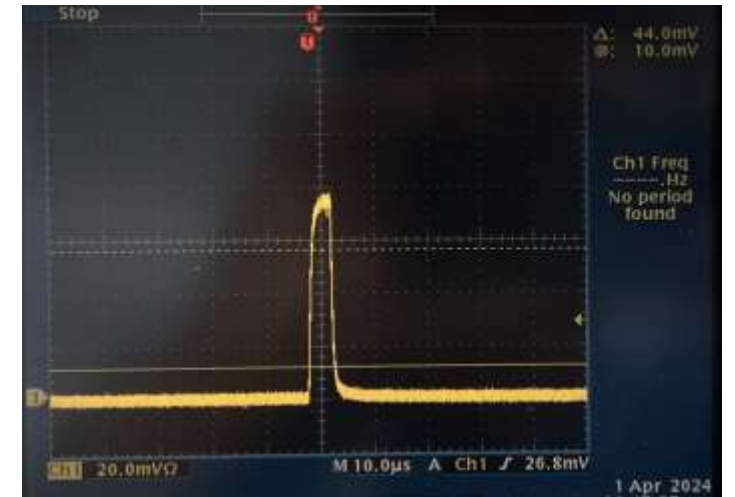
CEBAF Beam Power & Pulse Structure



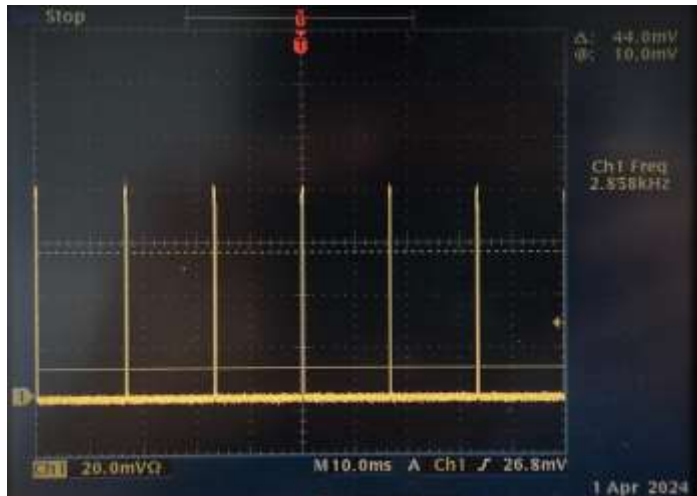
BS



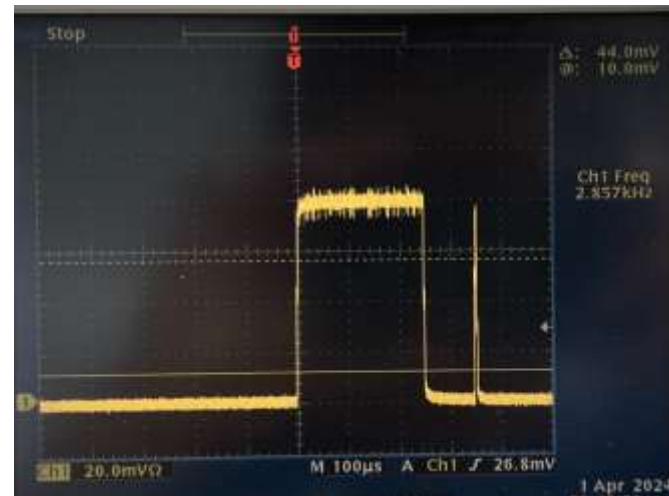
VL1



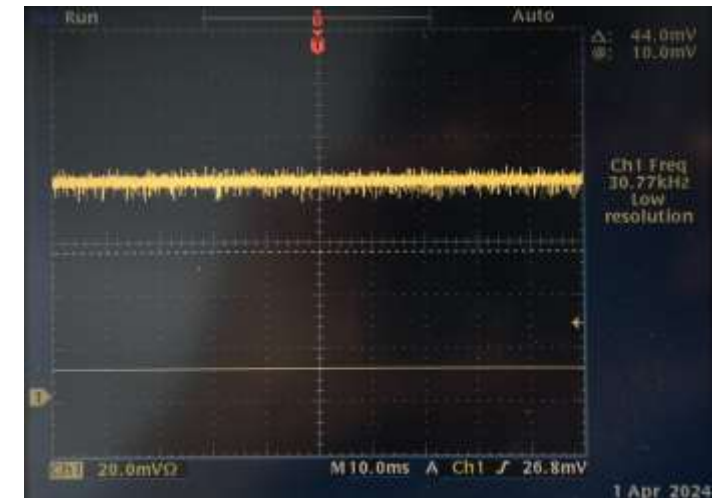
VL2



TM1



TM2

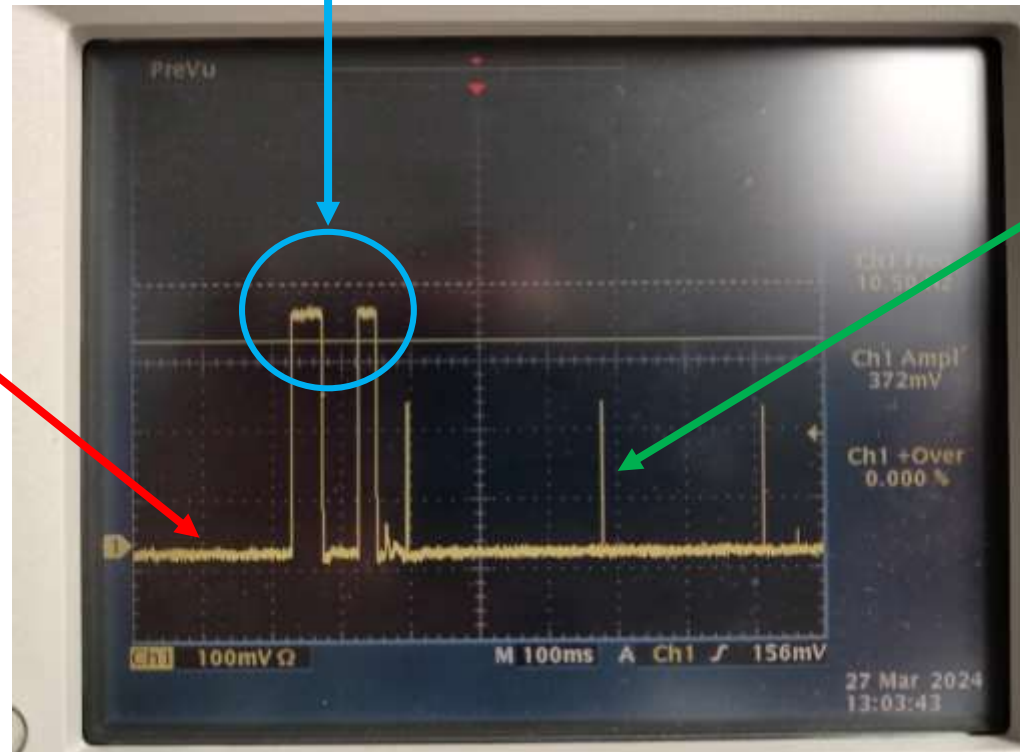


CW

<u>Beam Mode</u>	<u>Pockels cell High Voltage</u>	<u>half wave plate</u>	<u>Shutter</u>
Beam OFF	OFF	Inserted	Closed
Viewer-Limited	Pulsing	Inserted	Open
Tune	Pulsing	Inserted	Open
CW	OFF	Retracted	Open

During transition to Viewer Limited this long (10's msec) would normally be shuttered

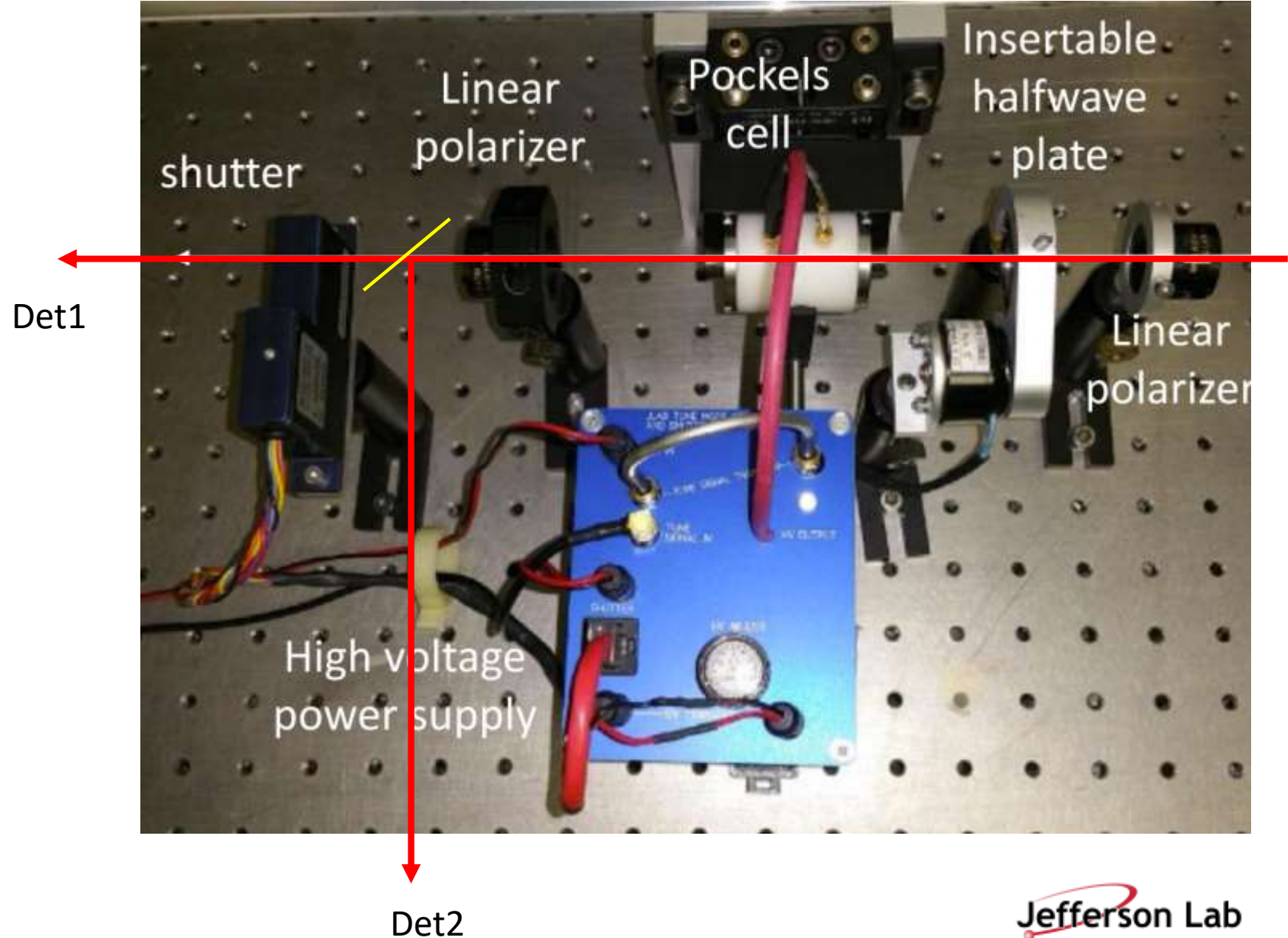
Archiver data shows shutter was **open** during Beam Sync



Shutter would then open, allowing Viewer Limited pulses (0.004 msec) to pass

Recent Test: UITF Laser TMG temporal behavior vs beam mode

- Detector 1 (Yellow Oscscope traces) located after shutter
- Detector 2 (Purple Oscscope traces) located before shutter
- FSD triggered from UITF EPICS

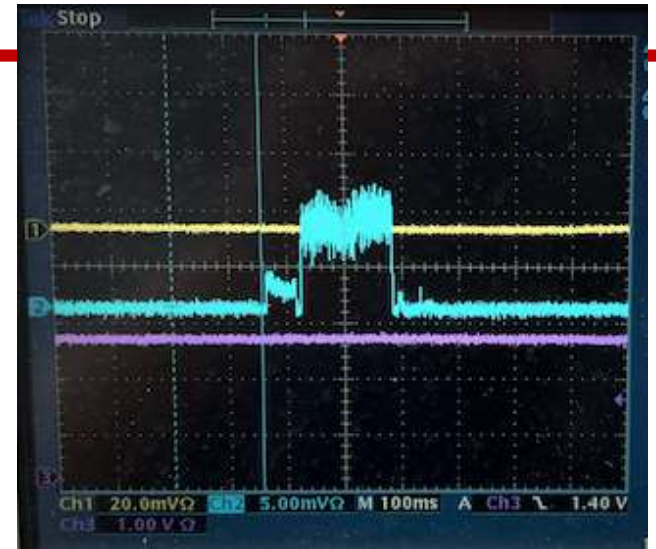


UITF Laser TMG temporal behavior vs beam mode

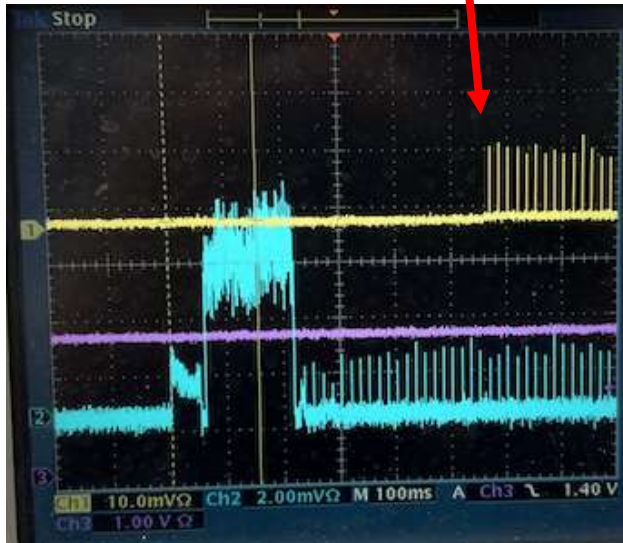
Blue: before shutter
 Yellow: After shutter
 Purple: FSD
 Date: 4/5/2024

No FSD

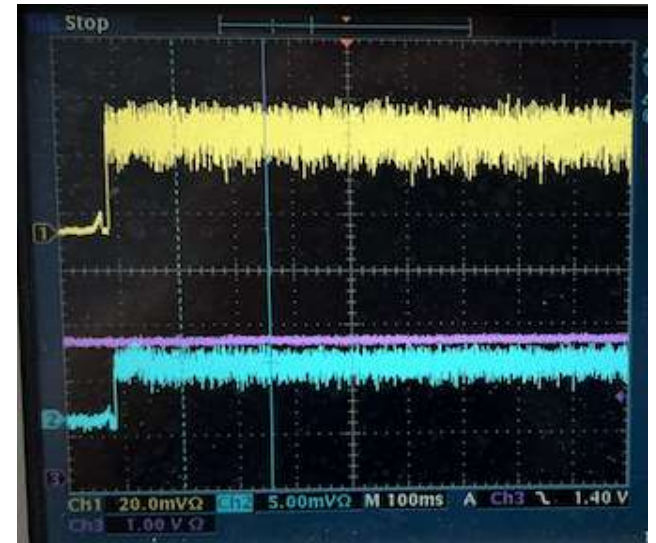
		Final			
		BS	VL	TM	CW
Initial	BS	n/a	2	3	4
	VL	5	n/a	7	8
	TM	9	10	n/a	12
	CW	13	14	15	n/a



BS-VL



BS-TM



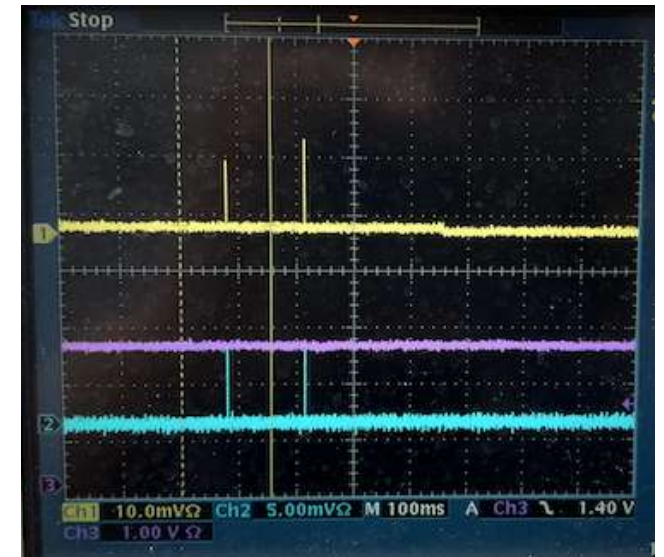
BS-CW

BS-BS

Delay

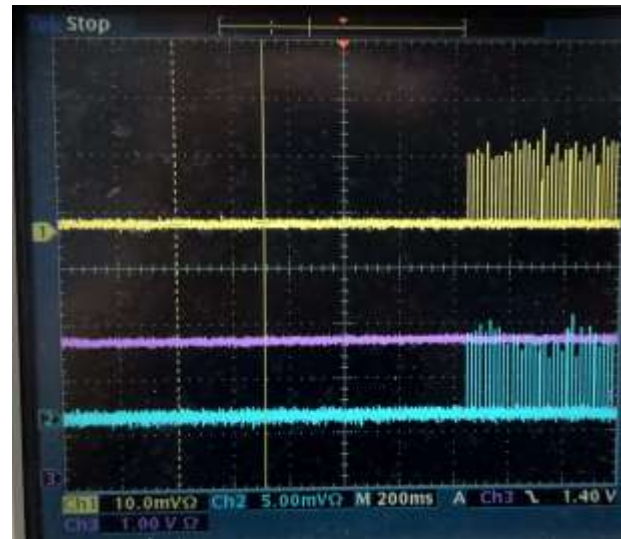
Blue: before shutter
 Yellow: After shutter
 Purple: FSD
 Date: 4/5/2024

No FSD

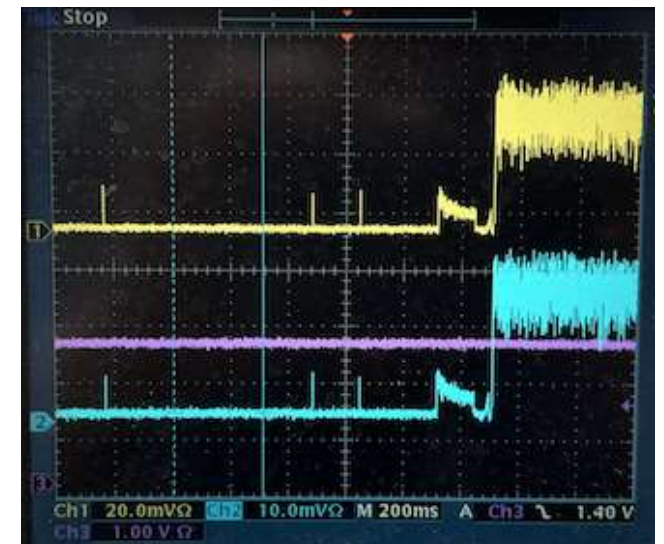


BS-BS

VL-BS



VL-TM

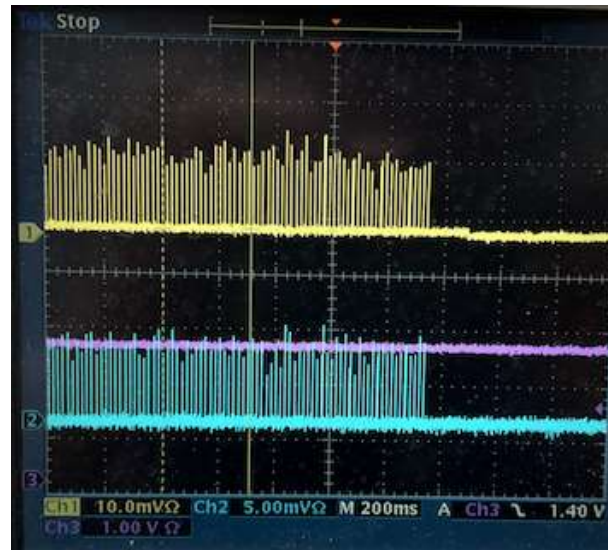


VL-CW

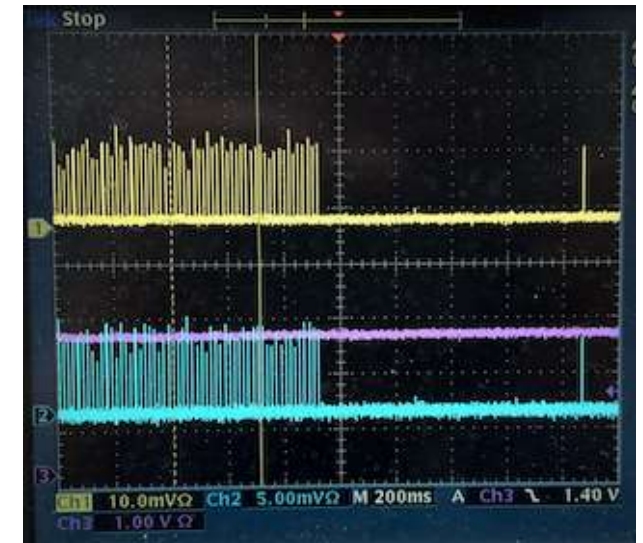
		Final			
		BS	VL	TM	CW
Initial	BS	n/a	2	3	4
	VL	5	n/a	7	8
	TM	9	10	n/a	12
	CW	13	14	15	n/a

Blue: before shutter
 Yellow: After shutter
 Purple: FSD
 Date: 4/5/2024

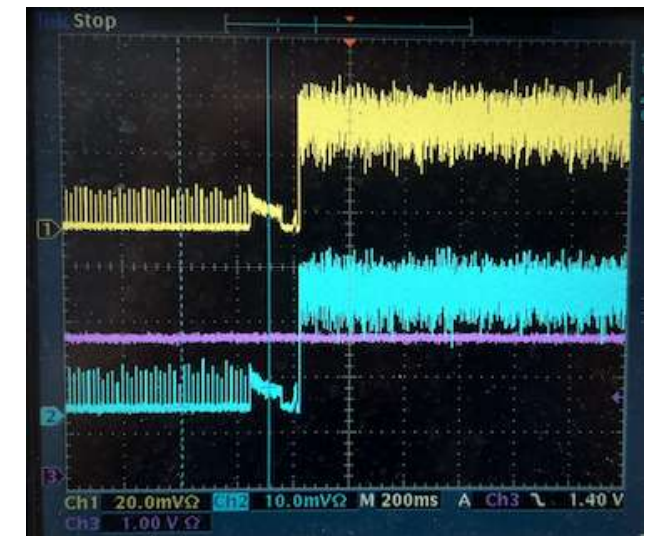
No FSD



TM-BS



TM-VL



TM-CW

TM-TM

Final

	BS	VL	TM	CW
BS	n/a	2	3	4
VL	5	n/a	7	8
TM	9	10	n/a	12
CW	13	14	15	n/a

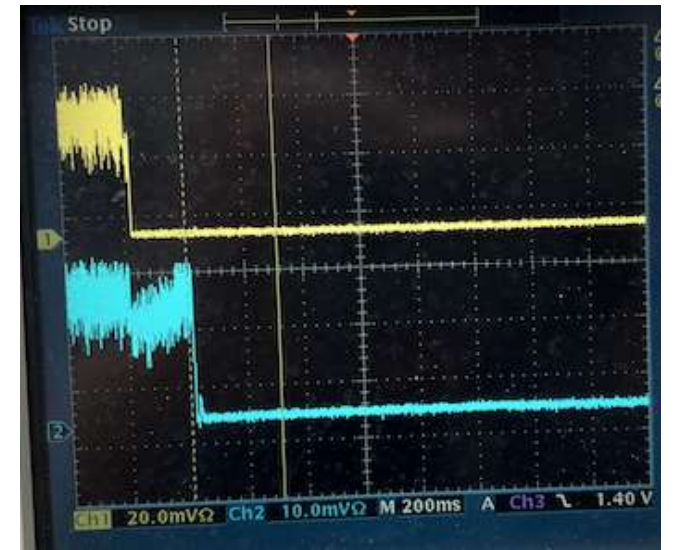
Initial

Blue: before shutter
 Yellow: After shutter
 Purple: FSD
 Date: 4/5/2024

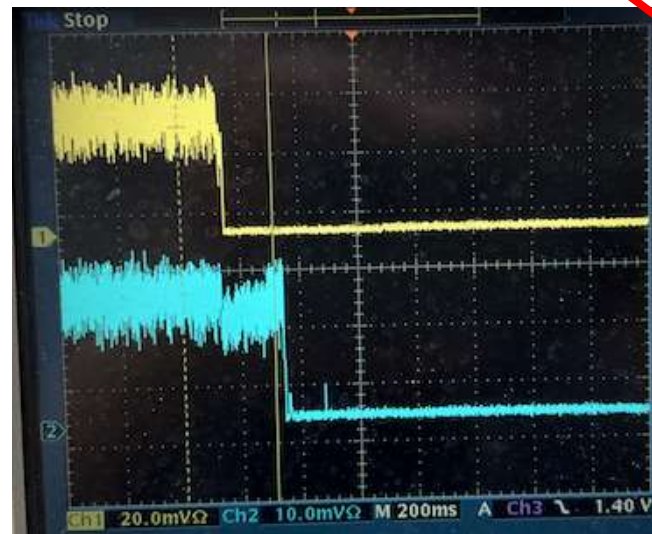
No FSD

		Final			
		BS	VL	TM	CW
Initial	BS	n/a	2	3	4
	VL	5	n/a	7	8
	TM	9	10	n/a	12
	CW	13	14	15	n/a

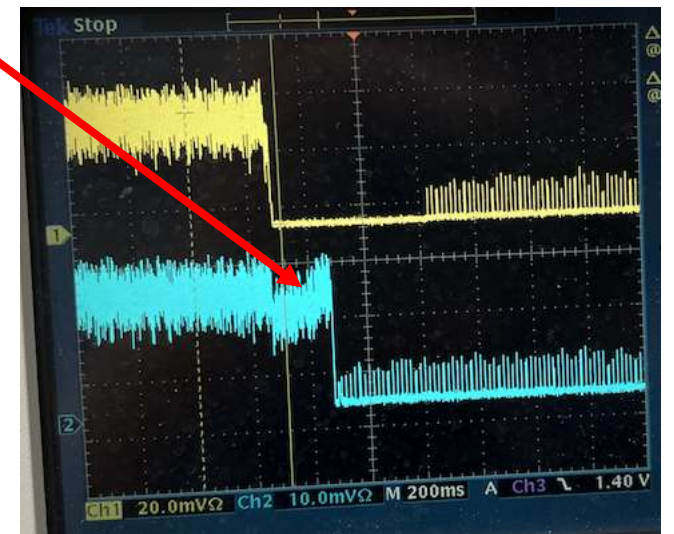
Delay



CW-BS



CW-VL



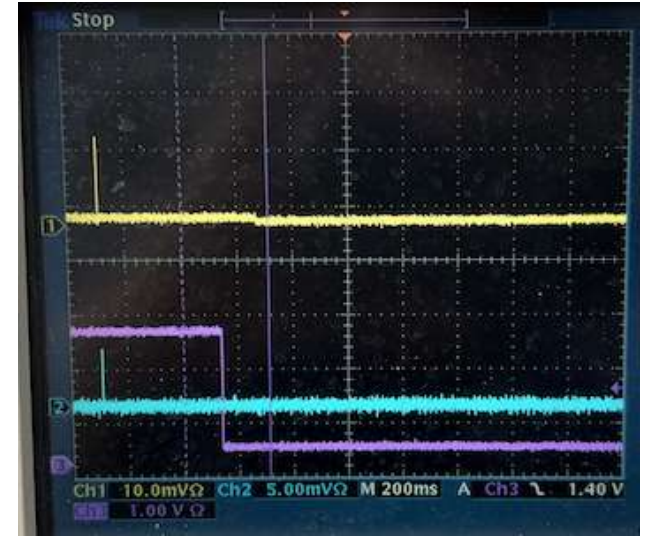
CW-TM

Blue: before shutter
 Yellow: After shutter
 Purple: FSD
 Date: 4/5/2024

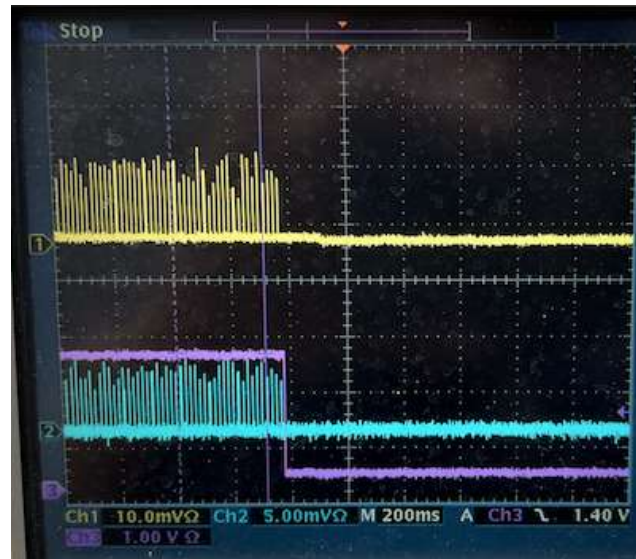
FSD from Static mode

Initial		BS
	BS	n/a
	VL	5
	TM	9
	CW	13

Delay



VL-BS



TM-BS



CW-BS

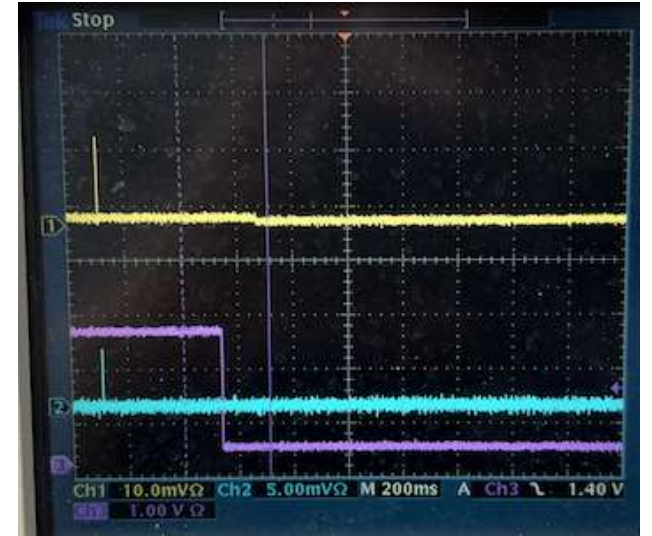
BS-BS

Blue: before shutter
 Yellow: After shutter
 Purple: FSD
 Date: 4/5/2024

FSD from Static mode

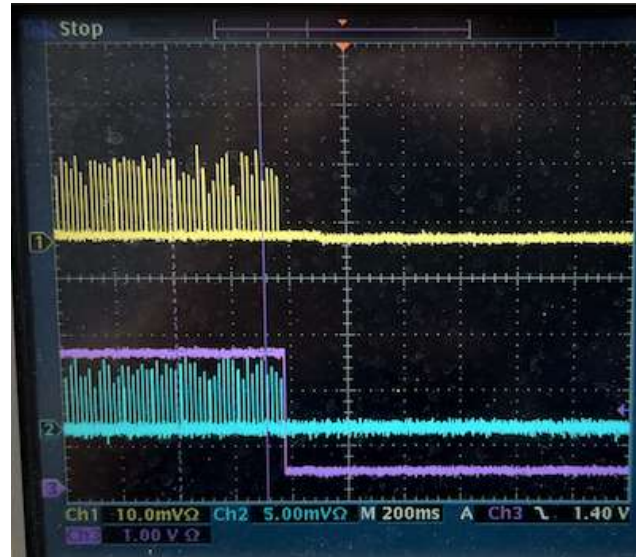
Initial		BS
	BS	n/a
	VL	5
	TM	9
	CW	13

Delay



VL-BS

BS-BS



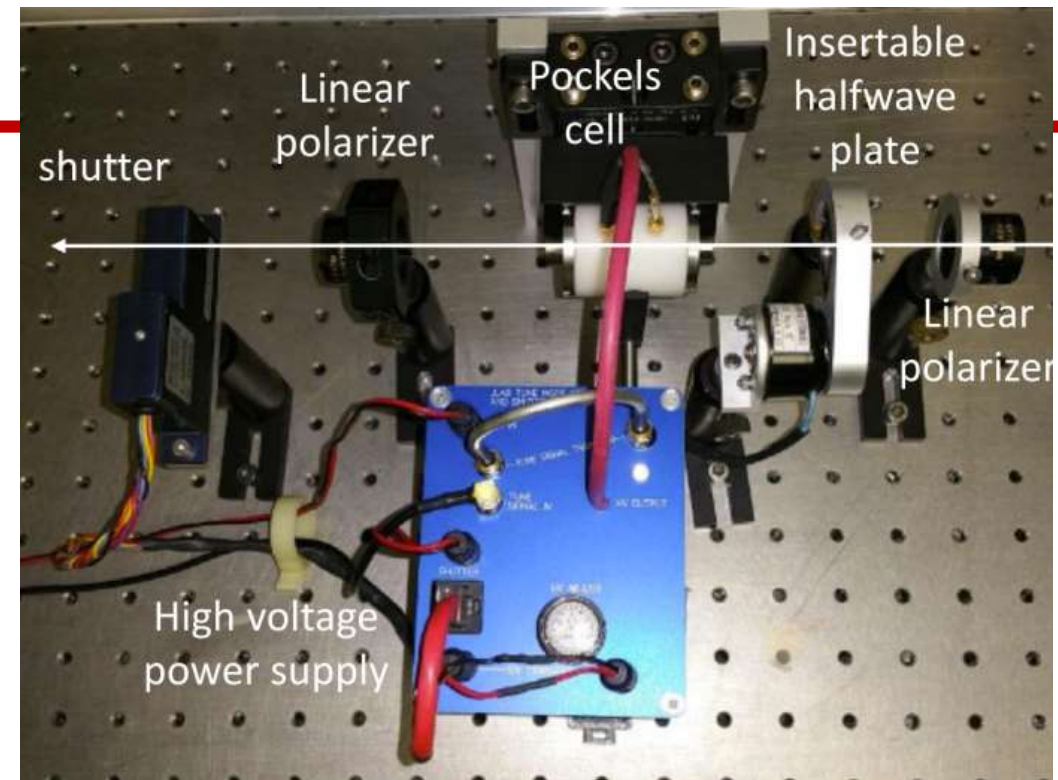
TM-BS



CW-BS

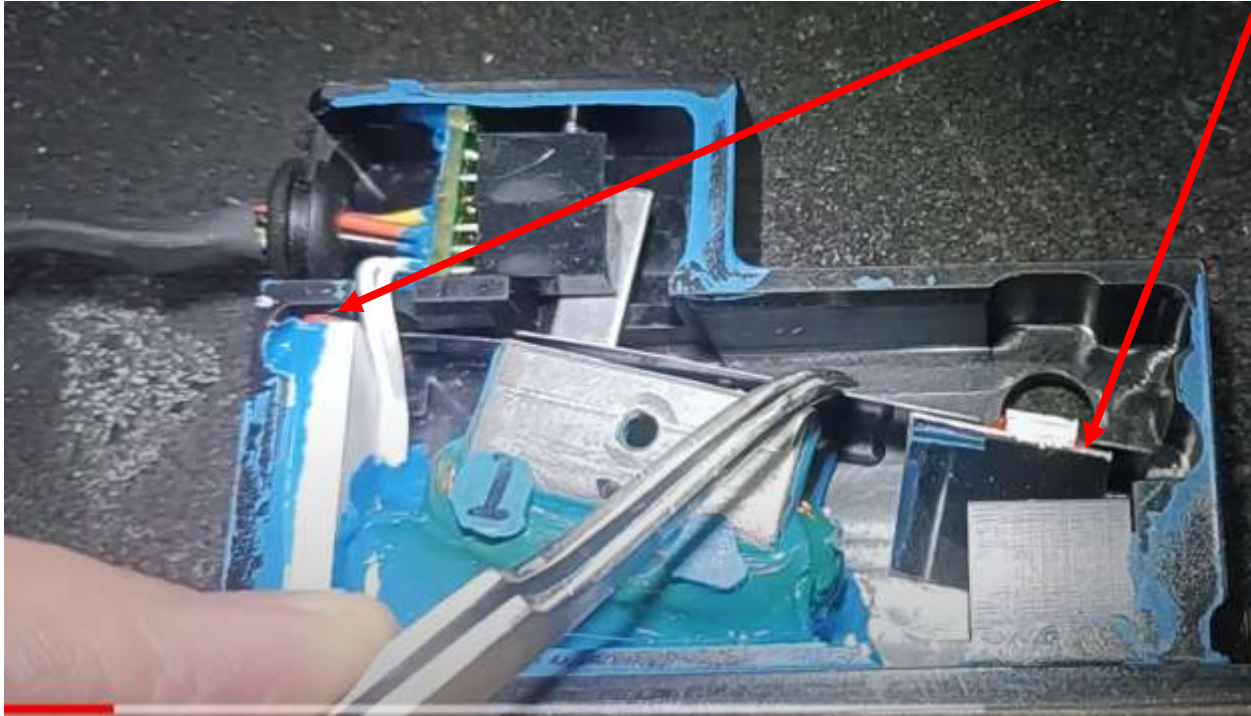
What may go wrong?

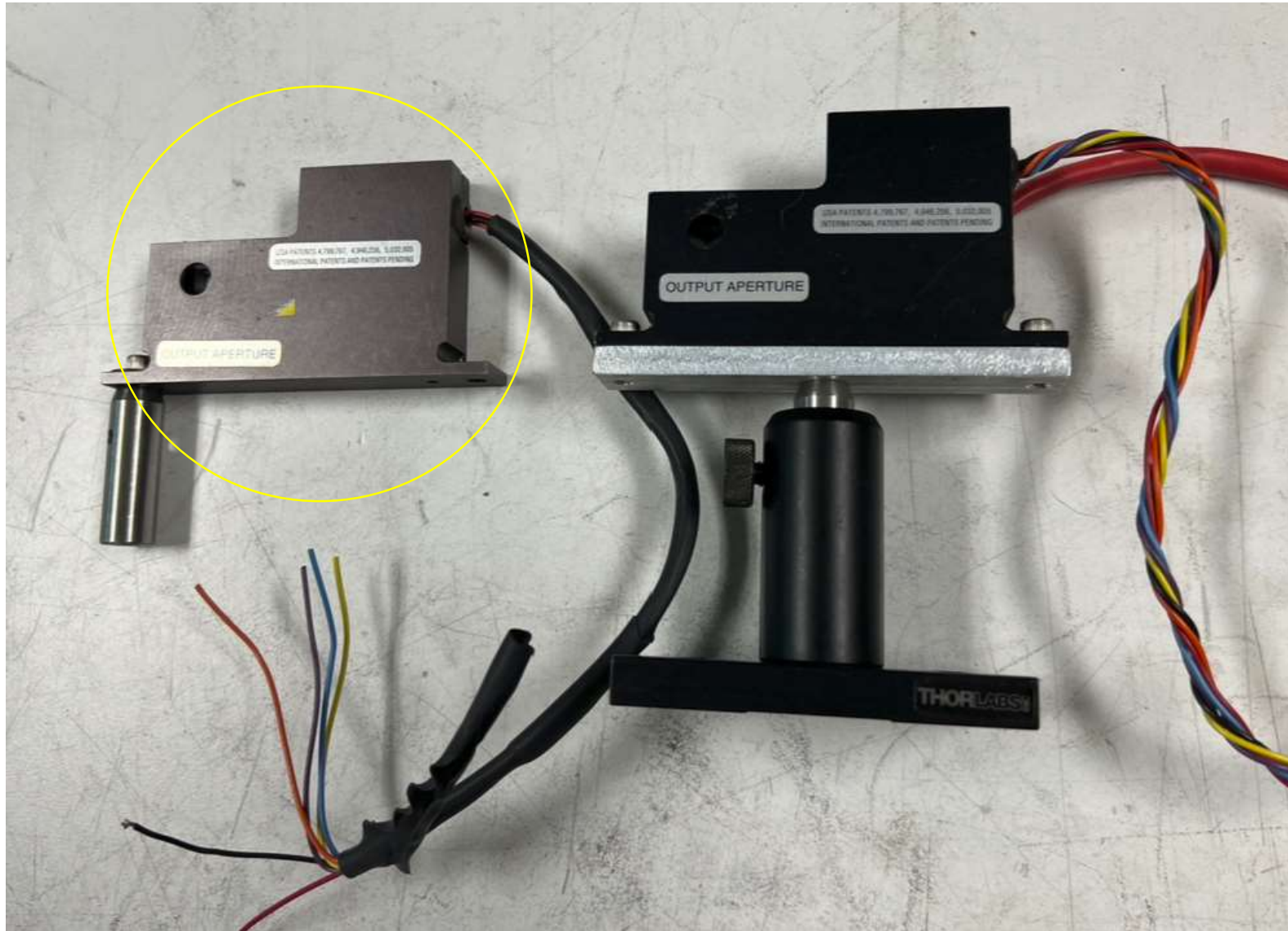
- Attenuator setting too high (280), laser power 10s x more than routinely set value
- Shutter open?
 - Triggers – controls to TMG seem fine
 - Shutter needs DC voltage to keep open
 - Mechanical?
 - Shutter has been on its holder
 - A chance that laser beam may go above the shutter due to loosen screw



***Nothing can be 100% safe,
Fail Safe May not Be Safe!***

- Shutters may get heated up to high temperature
- High Temp may melt the glues
- The cantilever may fall, leave the shutters open

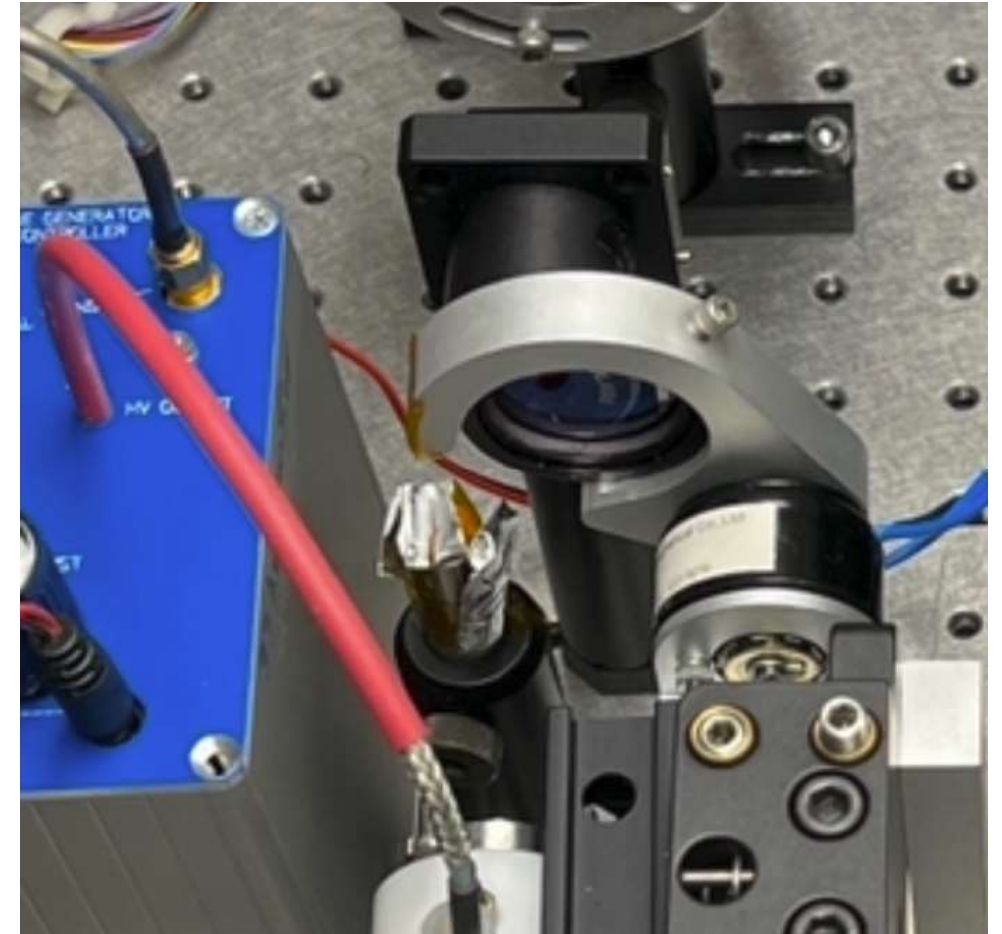
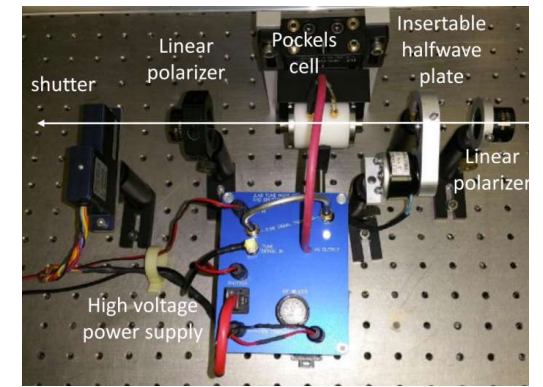




A deeper look into TMG

An even worse scenario, assuming the HWP fails, then what would happen

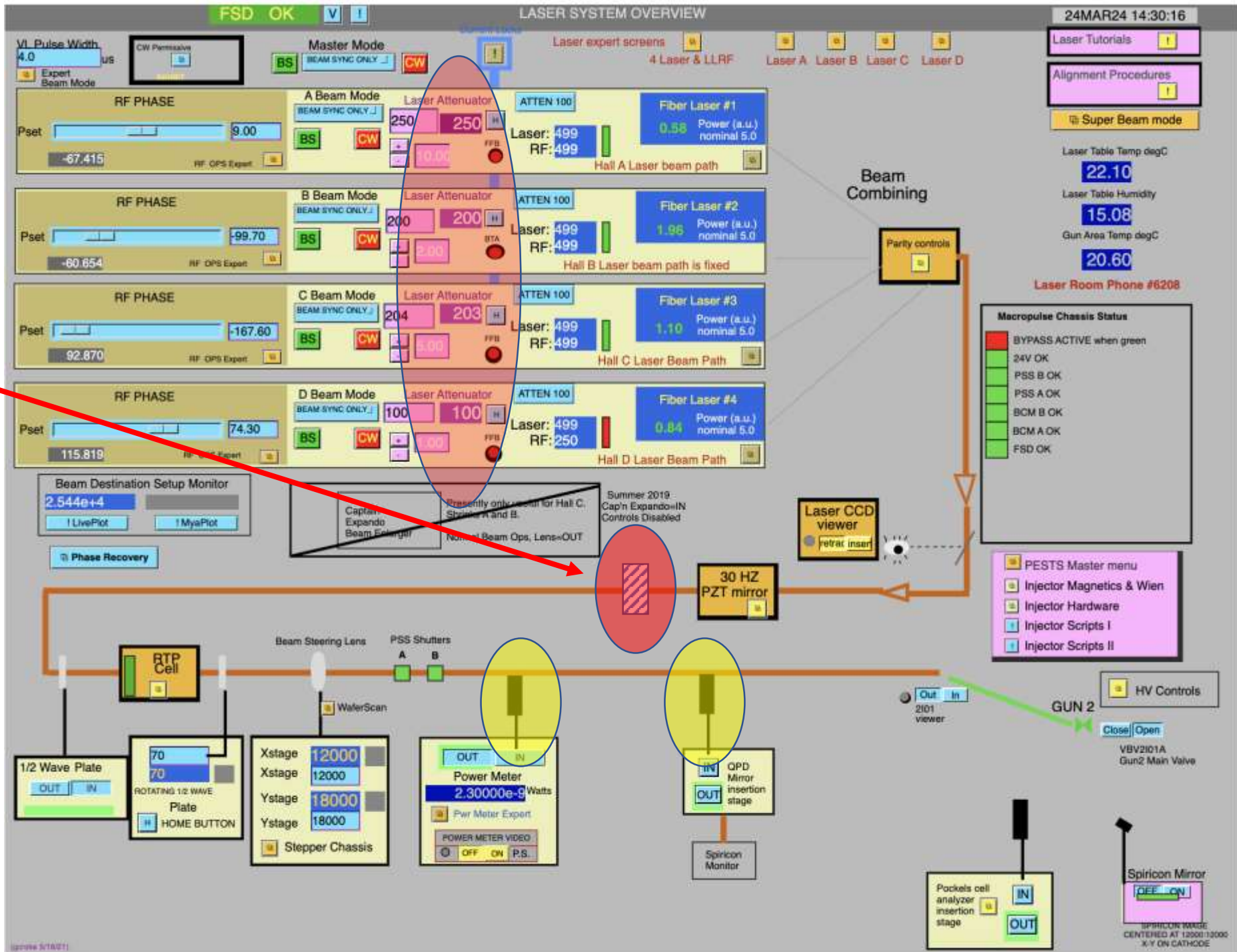
- BS mode – 100% power, shutter closed
 - VL/TM mode – >99% laser power going thru, shutter open
 - CW mode – 100% power going thru, shutter open
- ✓ *It's necessary to monitor HWP position*
- ✓ *Control follows if needed*



Risk Mitigation

Near terms: this additional shutter could be **the simplest and most reliable approach** to prevent similar incident to occur.

Only need to be synchronized with the 4 shutters, i.e. open/close with any of them



Risk Mitigation

Enhanced Procedure: multi-point check out

Tune Mode Generator Hot Check-Out (HCO) checklist (version 2, 4/2/24)

Staff performing HCO: _____

Date: _____

Step 1 – Visual inspection (indicate n/a if laser not tested)

- Indicate pass (✓)/fail(✗) for each function.

a. Hall A (Serial #s TMG/TMG-, Waveplate/, Shutter/)

- _____ - Beam Sync (shutter closed, waveplate in)
- _____ - Viewer Limited (shutter open, waveplate in)
- _____ - Tune Mode (shutter open, waveplate in)
- _____ - Continuous Wave (shutter open, waveplate out)

v. Notes _____

Tune Mode Generator Hot Check-Out (HCO) checklist (version 2, 4/2/24)

Staff performing HCO: _____
Date: _____

Step 1 – Visual inspection (indicate n/a if laser not tested)
• Indicate pass (✓)/fail(✗) for each function.

a. Hall A (Serial #s TMG/TMG-, Waveplate/, Shutter/)

- _____ - Beam Sync (shutter closed, waveplate in)
- _____ - Viewer Limited (shutter open, waveplate in)
- _____ - Tune Mode (shutter open, waveplate in)
- _____ - Continuous Wave (shutter open, waveplate out)

v. Notes _____

b. Hall B (Serial #s TMG/TMG-, Waveplate/, Shutter/)

- _____ - Beam Sync (shutter closed, waveplate in)
- _____ - Viewer Limited (shutter open, waveplate in)
- _____ - Tune Mode (shutter open, waveplate in)
- _____ - Continuous Wave (shutter open, waveplate out)

v. Notes _____

c. Hall C (Serial #s TMG/TMG-, Waveplate/, Shutter/)

- _____ - Beam Sync (shutter closed, waveplate in)
- _____ - Viewer Limited (shutter open, waveplate in)
- _____ - Tune Mode (shutter open, waveplate in)
- _____ - Continuous Wave (shutter open, waveplate out)

v. Notes _____

d. Hall D (Serial #s TMG/TMG-, Waveplate/, Shutter/)

- _____ - Beam Sync (shutter closed, waveplate in)
- _____ - Viewer Limited (shutter open, waveplate in)
- _____ - Tune Mode (shutter open, waveplate in)
- _____ - Continuous Wave (shutter open, waveplate out)

v. Notes _____

Step 2 – Waveplate (indicated ✓ for checked, n/a if laser not tested)

- Perform test with fixed attenuator
- Record trace on a scope

a. Hall A (Serial #s _____, power = _____ dBm)

- _____ - Beam Sync (4 qps/10)
- _____ - Viewer Limited (20 qps/10)
- _____ - Viewer Limited (20 qps/10)
- _____ - Tune Mode (20 qps/10)
- _____ - Tune Mode (20 qps/10)
- _____ - Continuous Wave (20 qps/10)

v. Notes _____

b. Hall B (Serial #s _____, power = _____ dBm)

- _____ - Beam Sync (4 qps/10)
- _____ - Viewer Limited (20 qps/10)
- _____ - Viewer Limited (20 qps/10)
- _____ - Tune Mode (20 qps/10)
- _____ - Tune Mode (20 qps/10)
- _____ - Continuous Wave (20 qps/10)

v. Notes _____

c. Hall C (Serial #s _____, power = _____ dBm)

- _____ - Beam Sync (4 qps/10)
- _____ - Viewer Limited (20 qps/10)
- _____ - Viewer Limited (20 qps/10)
- _____ - Tune Mode (20 qps/10)
- _____ - Tune Mode (20 qps/10)
- _____ - Continuous Wave (20 qps/10)

v. Notes _____

d. Hall D (Serial #s _____, power = _____ dBm)

- _____ - Beam Sync (4 qps/10)
- _____ - Viewer Limited (20 qps/10)
- _____ - Viewer Limited (20 qps/10)
- _____ - Tune Mode (20 qps/10)
- _____ - Tune Mode (20 qps/10)
- _____ - Continuous Wave (20 qps/10)

v. Notes _____

Step 4 – Disconnect hot (checked) steps in electronic logbook

- Attach checklist and scope trace to ELOG/FOOD entry

Risk mitigation

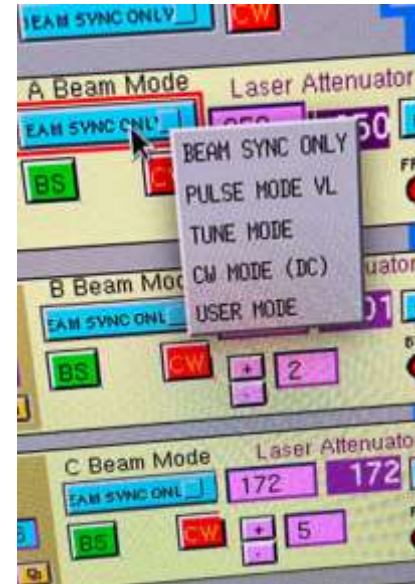
Immediate/short-term

- Laser power automatically go to minimum Ops setting such as “Atten/100” when switching mode
- Additional shutter

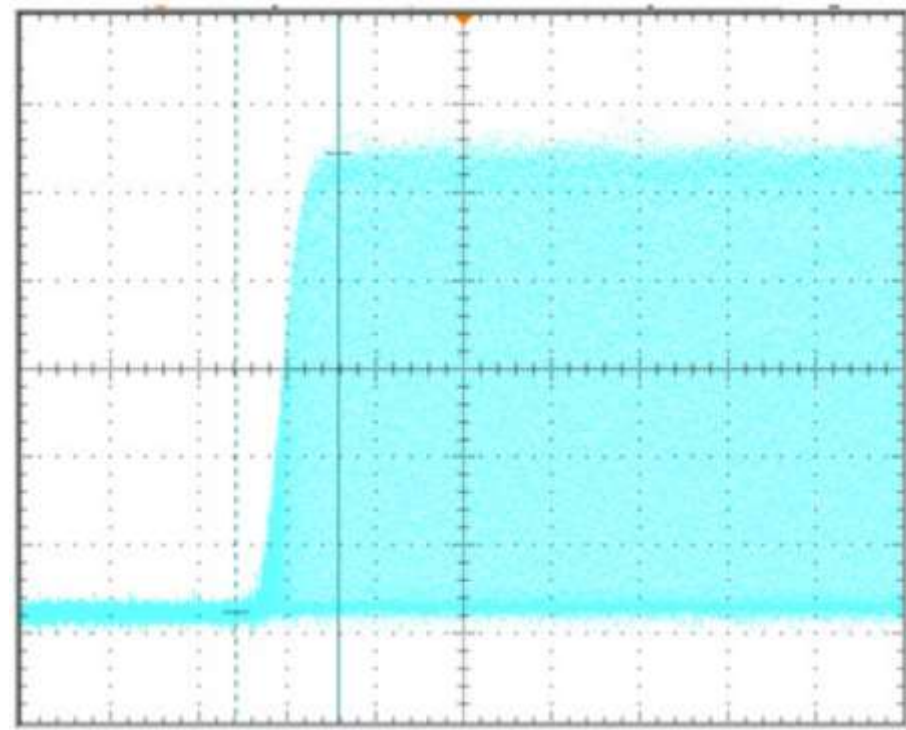
Long-term

- Implement **variable rep rate**, 1, 15, 30, to 60 Hz (existing, fixed)
- Go to “**B. Sync**” mode and the **lowest rep rate** (1Hz) whenever beam mode/machine status changes. Laser power detector goes in prior to “Beam Permit”
- Increase **pulse contrast**, new crystal
- Shutter open/close status signal-**position sensors**
- Realtime beam mode monitoring / **Oscope signal** to MCC
- More frequently **check up** on system parameters
- Faster shutters
- Improve procedures

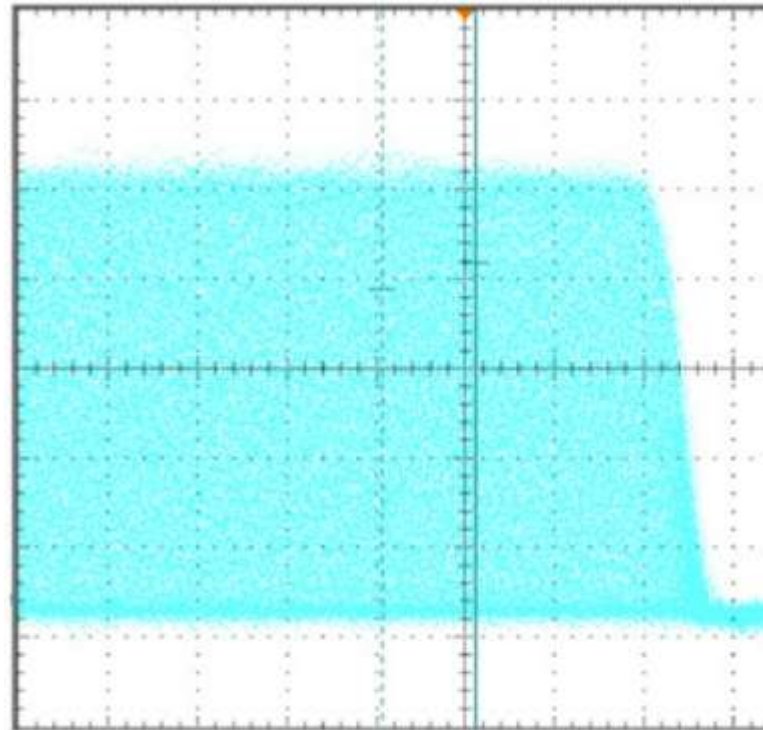
Rename the attenuator? The attenuator reading scaling (0 up to 1000) may cause confusion, max attenuation is x1000, which actually gives the max laser power!



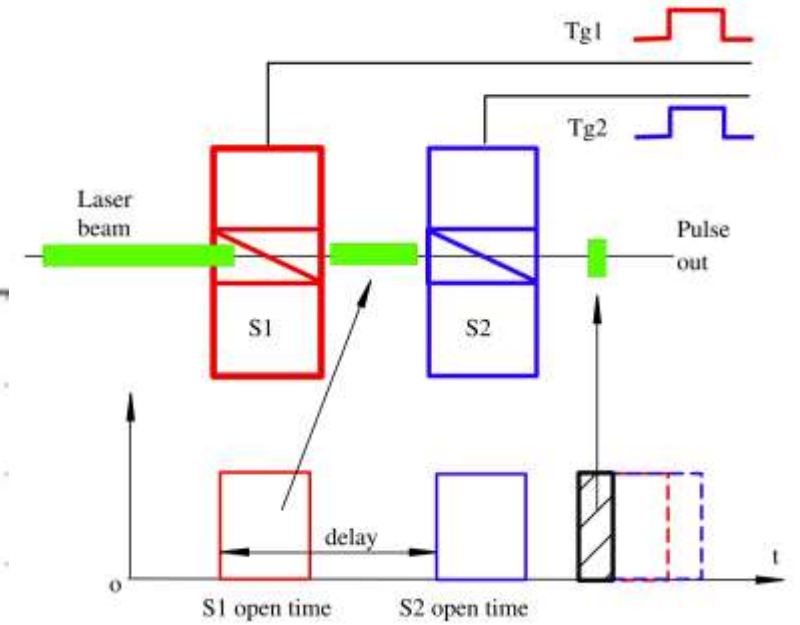
Safer – Use of much faster shutter



Vertical 5mV/Div Horizontal 100μs/Div



Vertical 5mV/Div Horizontal 100μs/Div



S. Zhang, etc., "A simple gating technique for high-average-current photo-injectors", Nuclear Instruments and Methods in Physics Research A 629 (2011) 11–15

Safer – much faster shutter

