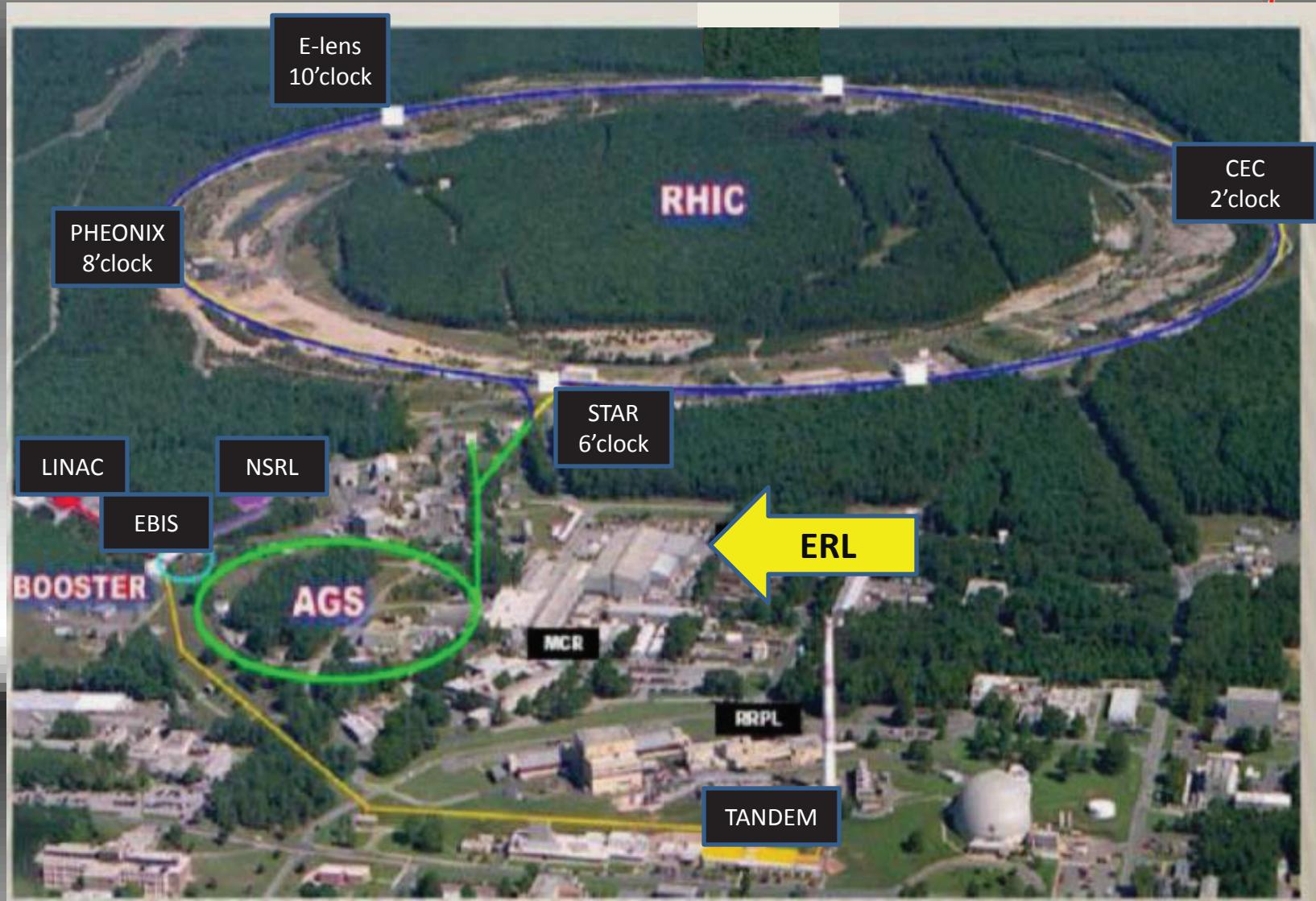


A close-up photograph of several interlocking metal gears of different sizes. The gears are polished, reflecting light, and show intricate tooth profiles. Some have circular holes or markings on them. The background is blurred, creating a sense of depth.

# Energy Recovery Linac's (ERL) Time Management System

Prerana Kankiya  
Brookhaven National Laboratory  
New York, USA

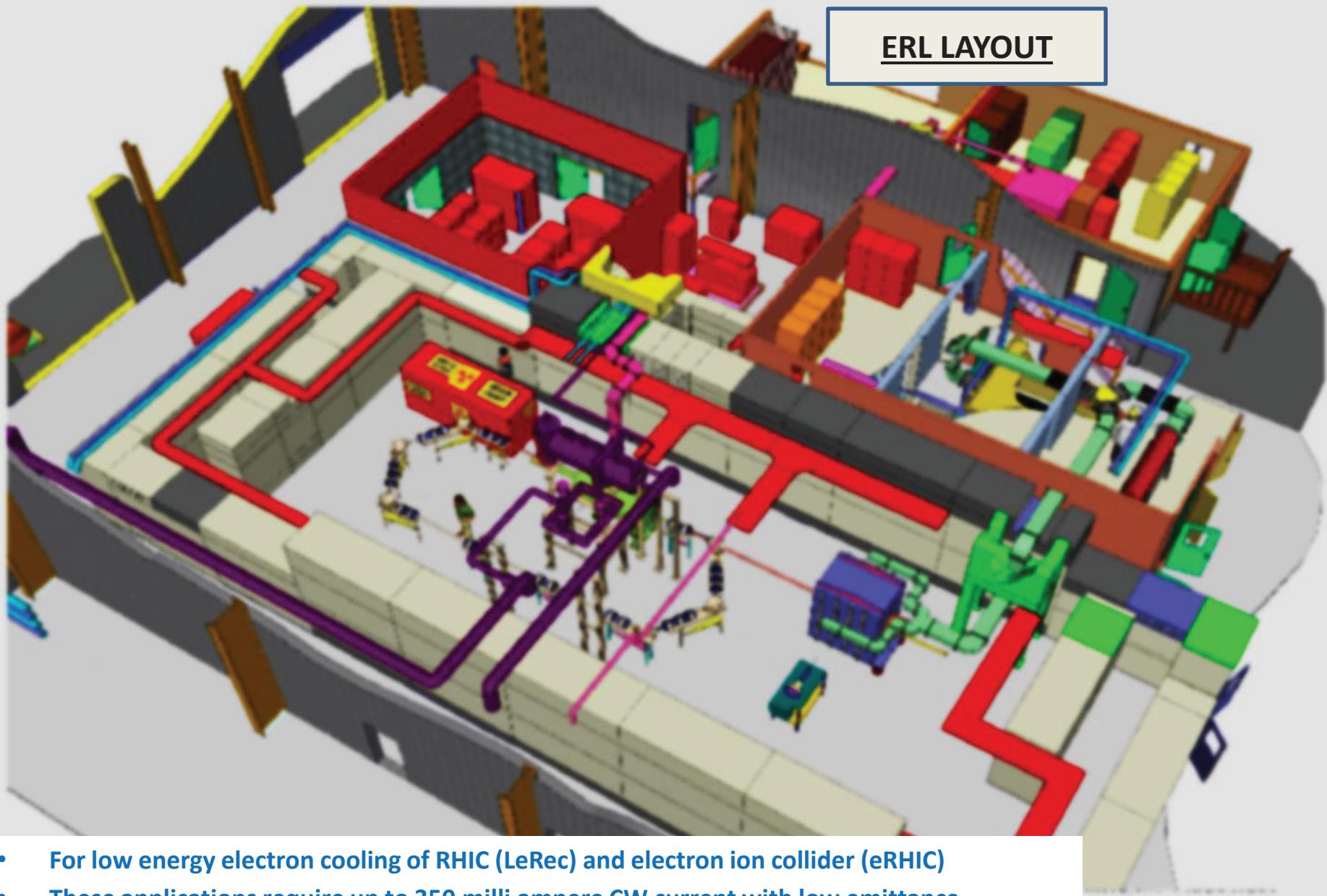


# Tell'em what you are going to tell



- Introduction to ERL and its timing needs
- Hardware components of timing system
- Beam structure
- Software algorithm and its features
- Test scheme and Operational results
- Operator interface
- Status and plans

## ERL LAYOUT

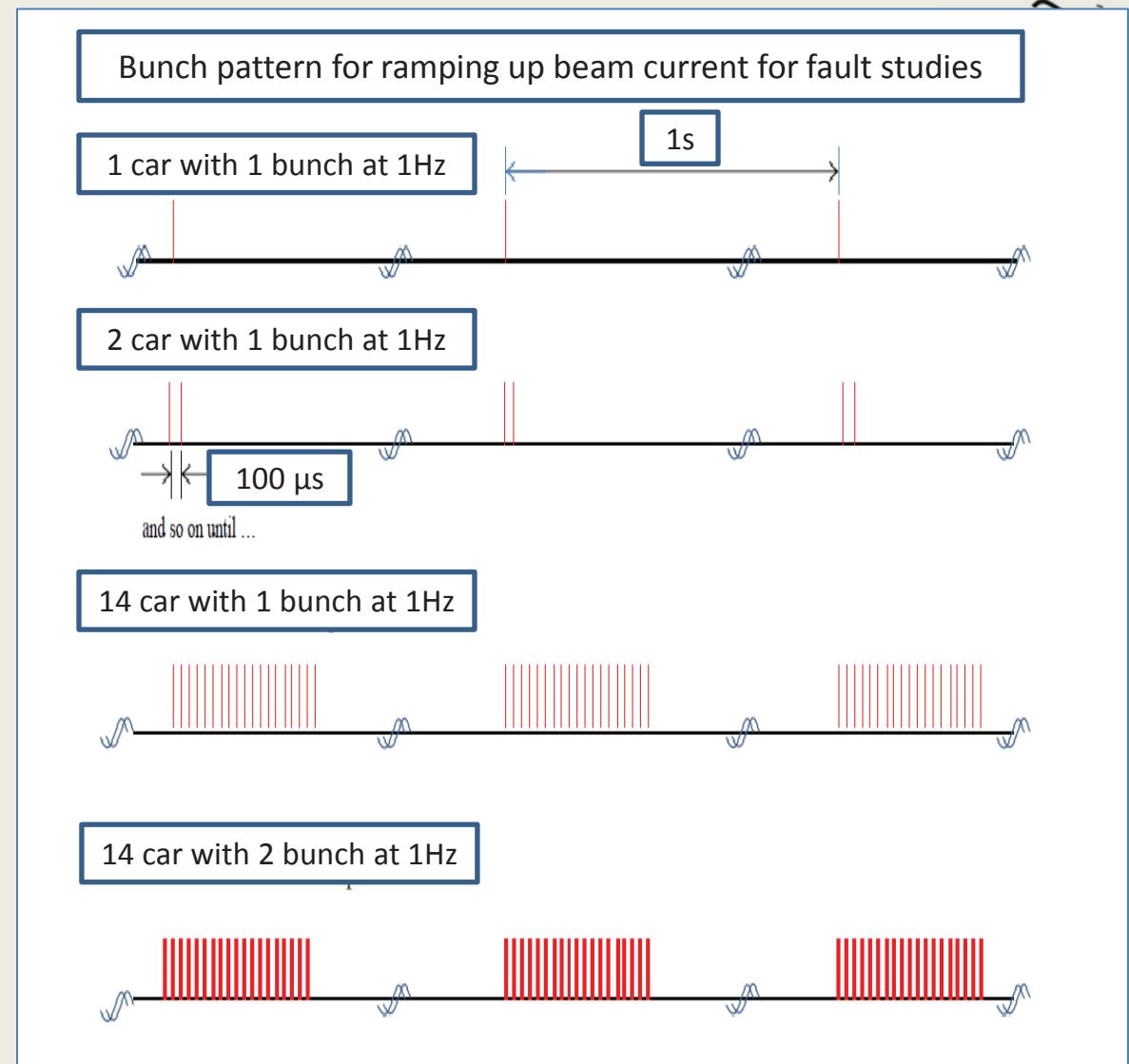
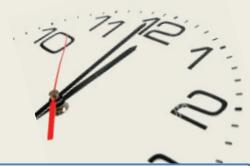


- For low energy electron cooling of RHIC (LeRec) and electron ion collider (eRHIC)
- These applications require up to 350 milli ampere CW current with low emittance

# Required Bunch Structure

Group of **laser pulses** = **Bunch**  
Groups of **Bunches** = **car**  
Group of **Cars** = **Train**

Fig. 2 Bunch Train



# Required Bunch Structure



Fig. 2 Bunch Train

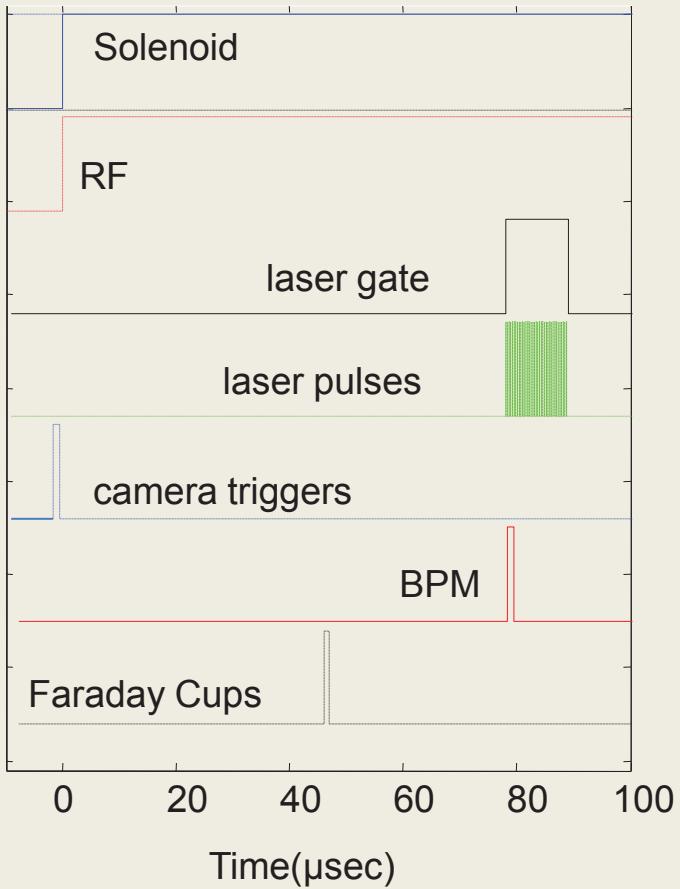
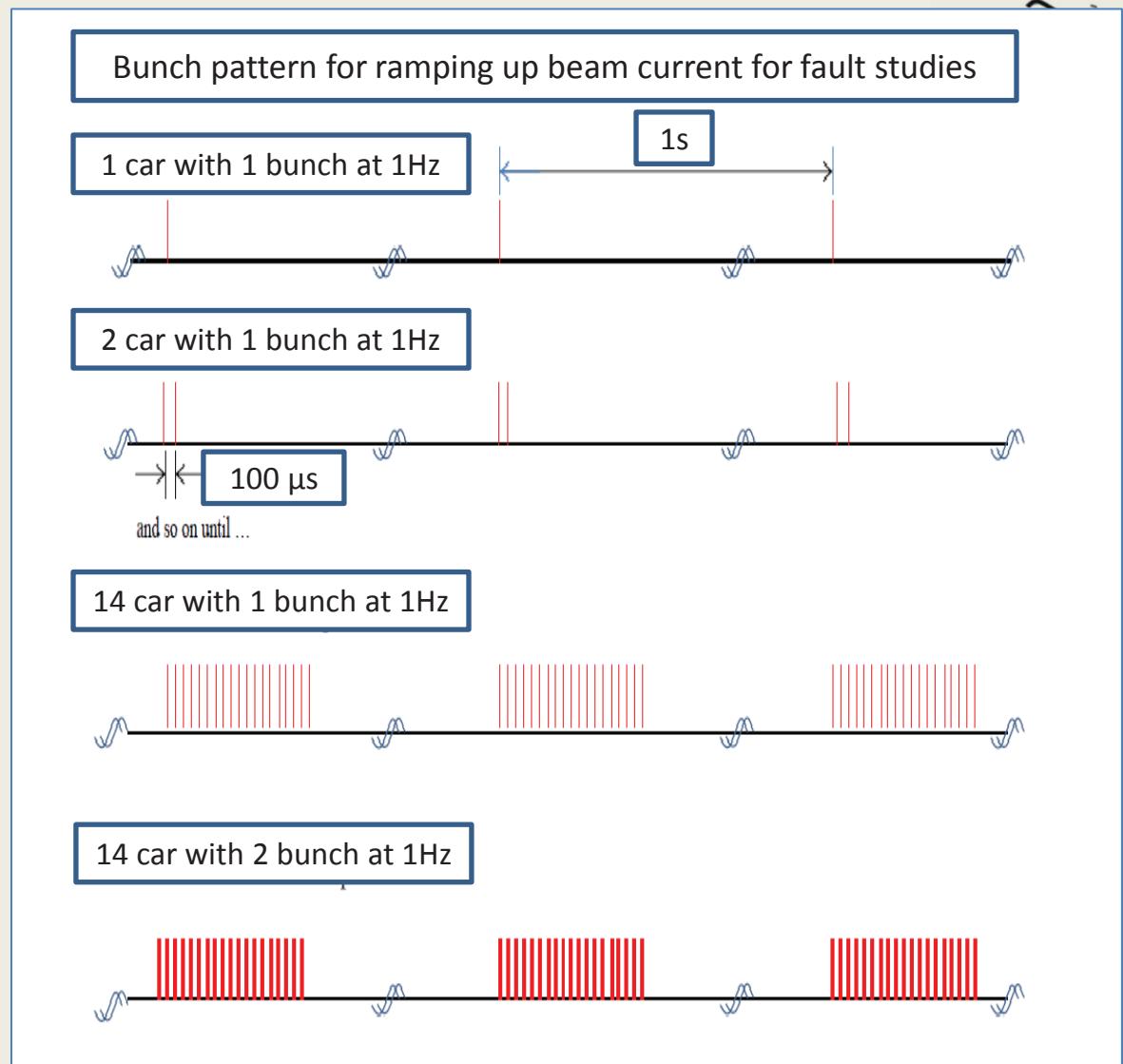
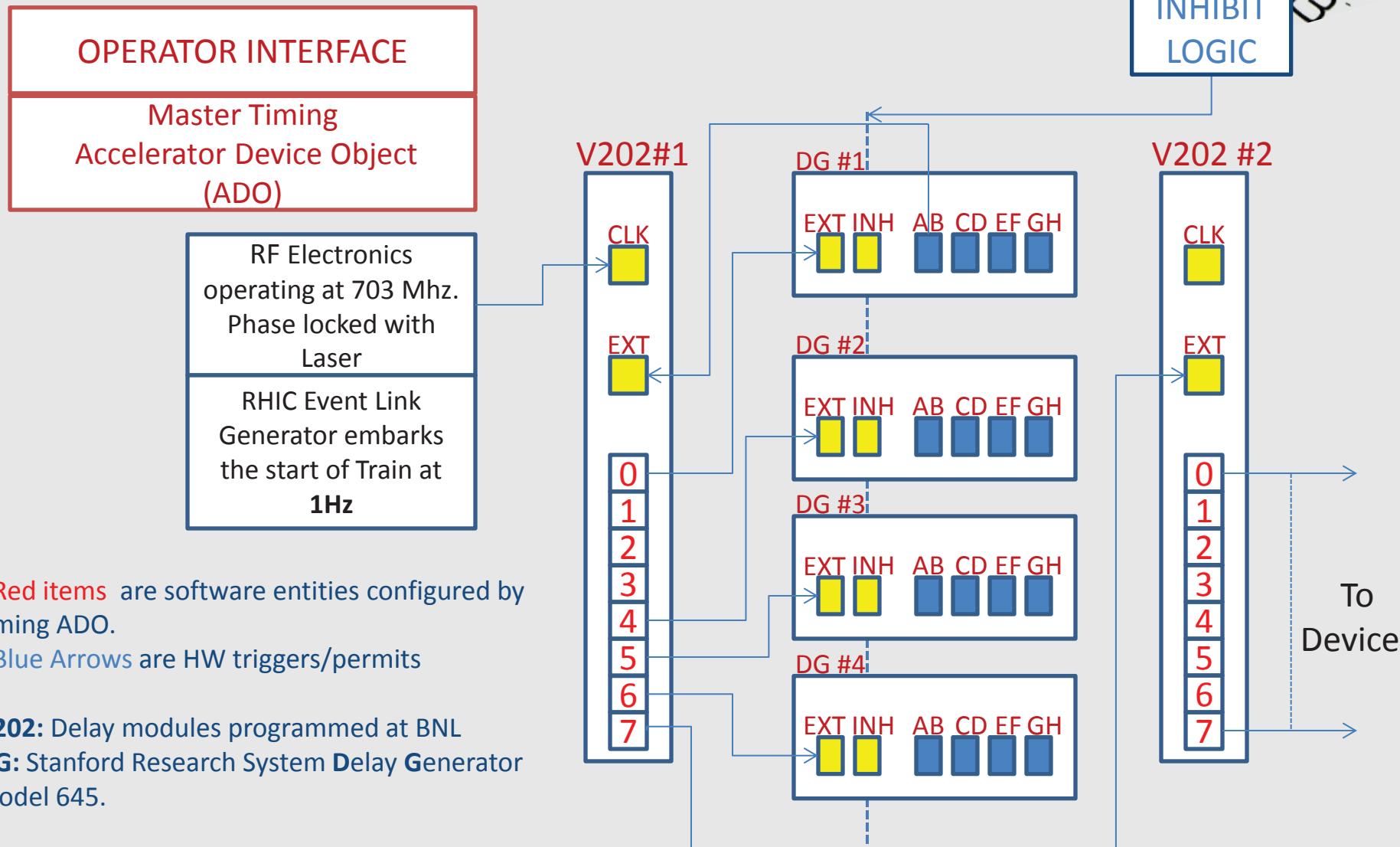


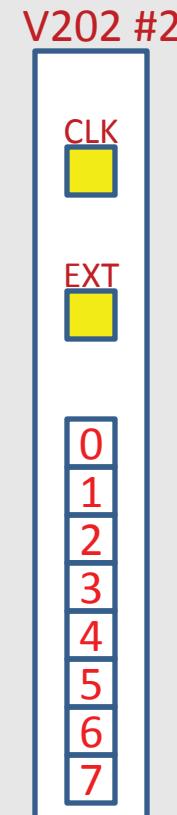
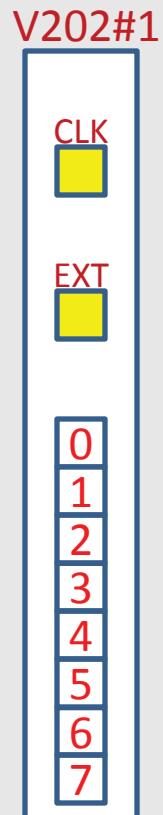
Fig. 1 Sequence of Triggers



# Building Blocks of the Timing System



# Building Blocks of the Timing System



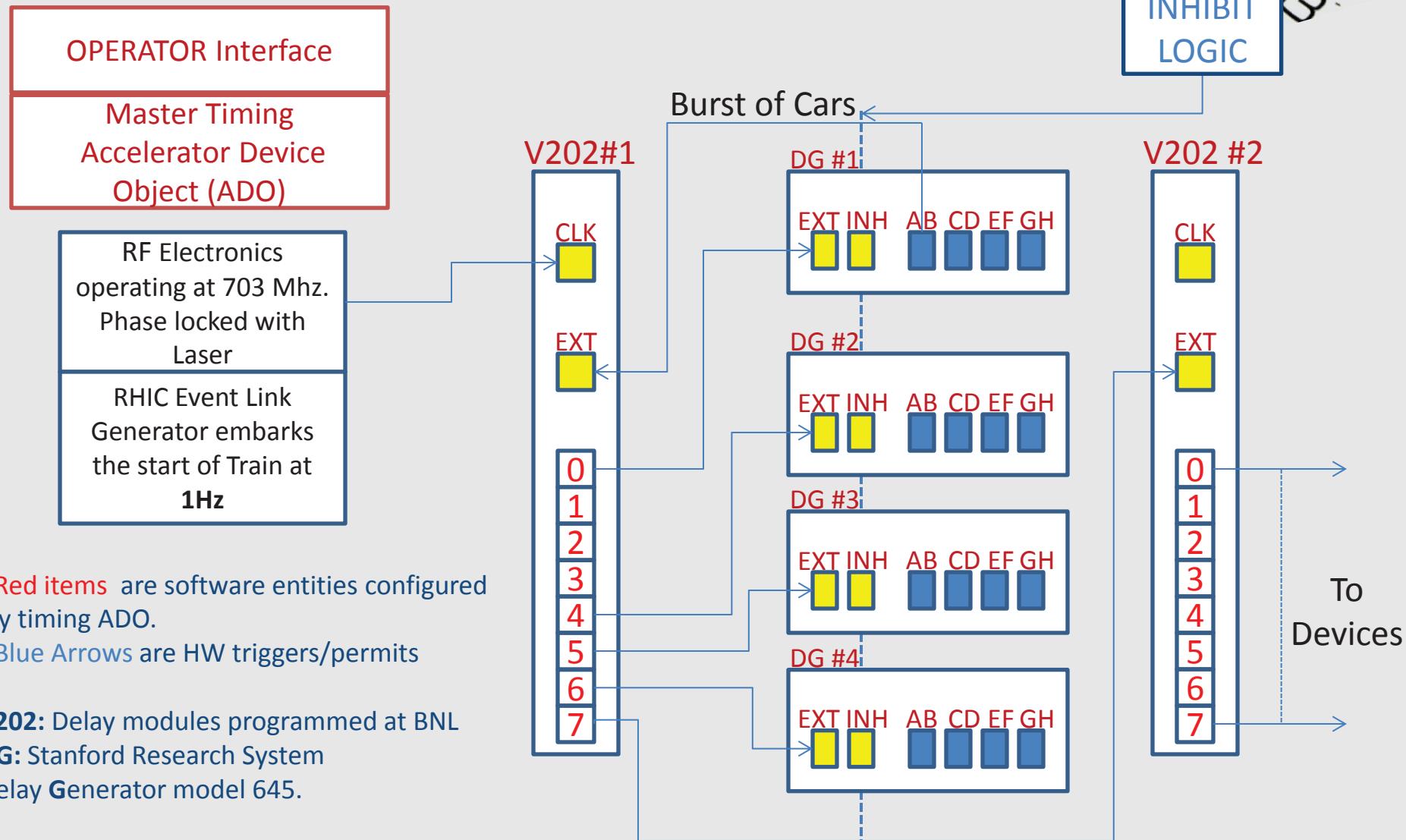
- Red items are software entities configured by timing ADO.
- Blue Arrows are HW triggers/permits

V202: Delay modules programmed at BNL

DG: Stanford Research System

Delay Generator model 645.

# Building Blocks of the Timing System





# Algorithm

**Goal: LASER is last device to be fired**

- Set response time of all diagnostics, done by system experts manually. ( $\delta_{dev}$ )
- Find device with maximum response time ( $\delta_{max}$ )  
$$\delta_{max} = \text{MAX}(\delta_{dev1} + \delta_{dev2} + \delta_{dev3} + \delta_{dev4} + \delta_{dev5} \dots)$$
- Calculate total insertion delay due to 4 DG645 boxes.  
( $\text{InsertionDelay}_{max}$ )
- Set delay ( $T_{dev}$ ) of each channel to

$$T_{dev} = \delta_{max} + \text{InsertionDelay}_{max} - \delta_{dev}$$



# EASE OF USE

- Calculate and compensate insertion delays of each DG645 unit.
- Calculate delays in clock ticks of laser and internal clock when in test and operation mode.
- Change trigger properties based on change in train properties.
- Check for **Beam Power Limits**.
- Cater to electronics with special needs and supply reset triggers based on time constant of each.

# User Interface



Page	PPM	Device	Data	Tools	Buffer	Help
MASTER CONTROLS			Calculate Gates And Send			
erlTimingCtrl.MasterADO	SET DELTA DEVICE(sec)	SET WIDTH(sec)	PULSE WIDTH(sec)	PULSE DELAY(sec)		
DELAY GENERATOR #2						
Communication Status	Active			Note: PULSE DELAY(ch) = INSERT_DEL + MAX_DELTA_DEV -DELTA_DEV(ch)		
Insertion Delay	0					
Laser	0	Laser Gate Set By Timing ADO ->				
Laser Gate Duplicate			0.0003	8.00186e-05		
ERL_IIC12.1 trigg	1.4e-05		0.0003	8.00186e-05		
DELAY GENERATOR #3		1.5e-05	1.5e-05	6.60186e-05		
Communication Status	Active					
Insertion Delay	1.165e-08					
Faraday reset Mask	6.5e-05		5e-05	0.0001450186		
DCTT Gate	7e-05		0.00023	0.0001500186		
DELAY GENERATOR #4						
Communication Status	Active					
Insertion Delay	1.86e-08					
ERL ICT Interlock Reset	6.2e-05		1.2e-05	1.2e-05	1.8e-05	
ERL FC Interlock Reset	6.2e-05		1.2e-05	1.2e-05	1.8e-05	
ERL FC Interlock Start	1e-07		0.0003	0.0003	7.95e-05	
ERL ICT Interlock Start	1e-07		1e-05	1e-05	7.99e-05	
V202 VME1 CONTROLS	delayS	pulseLengthS	clockC	trigSourceC	pulsePolarity	pulseEnabl
delay_912erl-vme1.TestSignalScope	2	10	1MHz	Ext	Pos	On
delay_912erl-vme1.DCCTTrigger	0	2345	1MHz	Ext	Pos	On
delay_912erl-vme1.SignalScope	1	2345	1MHz	Ext	Pos	On
delay_912erl-vme1.GigECamera	34	2345	1MHz	Ext	Pos	On
delay_912erl-vme1.HlxBLMGate	2345	50	1MHz	Ext	Pos	On
delay_912erl-vme1.HlxBLMReset	4653000	50	1MHz	Ext	Pos	On
delay_912erl-vme1.E_PMT	0	2345	1MHz	Ext	Pos	On
delay_912erl-vme1.Kithely2001PMT	0	100	1MHz	Ext	Neg	On
V202 VME3 CONTROLS		The External clock freq = 4.69MHz				
delay_912erl-vme3.StartTrainDG1	423000	50	1MHz	Event	Pos	On
delay_912erl-vme3.3123Ext	50	50	1MHz	PrevStart	Pos	On
delay_912erl-vme3.3122Ext	2345	100	1MHz	PrevStart	Pos	On
delay_912erl-vme3.LiberaPBM	423000	50	1MHz	Event	Pos	On
delay_912erl-vme3.ExtTrigD2	1	50	1MHz	Ext	Pos	On
delay_912erl-vme3.ExtTrigD3	1	50	1MHz	PrevStart	Pos	On
delay_912erl-vme3.ExtTrigD4	1	50	1MHz	PrevStart	Pos	On
delay_912erl-vme3.V202Vme1	78	50	1MHz			
Set Test Mode		Clock Source				
Set Laser Mode		INTERNAL				
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Thu Aug 13 17:29:48 2015: Get and Async requests complete.						
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Burst Count is  
Number of Cars to be  
generated

Bunch Width is  
the length of  
the car

FECs/Development/ERL/Timing/TimingExpertOnly

Page PPM Device Data Tools Buffer Help

MACROBUNCH CHARACTERISTICS

Communication Status	Active	Burst Count	Bunch Frequency	Bunch Width	Beam Current	Laser Beam Power	Efficiency(Amps/W)
erlTimingCtrl.MasterADD	1	2000	5e-06	0.0001	2	0.0003	
DG645.ERL.1	0	0.0005	ENABLE				

LASER RF OK GATING

PROTECTION ON/OFF	ON/OFF	ON/OFF STATUS	FAULT STATUS
OFF	DISABLED	OK	
0.0001	(Sec)		
0.001	(Sec)		

PHASE/AMPL WINDOW COMP

LIVE READBACK	LIMIT (HIGH)	LIMIT (LOW)	
1004.5	1.25e+06	1.15e+06	(VOLTS)
-19.7369	180	-180	(DEG)

(6,6) blank cell Nudge: 0

Mon Sep 21 17:40:35 2015: copying parameter values to buffer.  
Mon Sep 21 17:40:35 2015: Get and Async requests complete.

Bunch Frequency  
is the spacing  
of the cars

Number of laser pulses in a car =  $9.38 \text{ MHz} * \text{Bunch Width}$

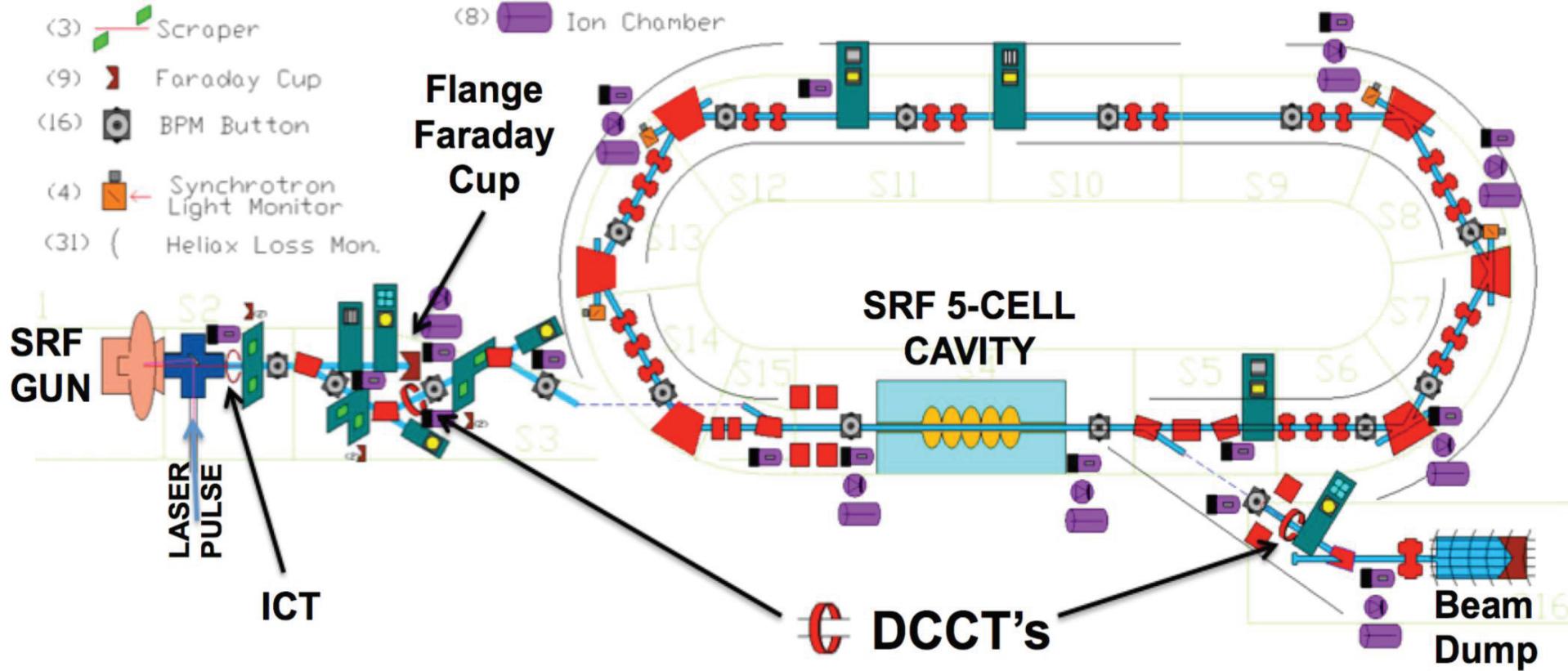
# Beam Diagnostic Systems



- (2) DTR Screen
- (3) HE YAG Screen
- (1) Pepper Pot
- (1) Emittance Slit
- (2) Flag Target Screen
- (3) LE YAG Screen
- (3) Scraper
- (9) Faraday Cup
- (16) BPM Button
- (4) Synchrotron Light Monitor
- (31) Heliox Loss Mon.

- (2) Infrared Camera
- (2) DC Current Transformer
- (1) Integrating Current Transformer
- (16) PMT
- (8) PIN Diode
- (8) Ion Chamber

- Solenoid
- Quadrupole
- Dipole

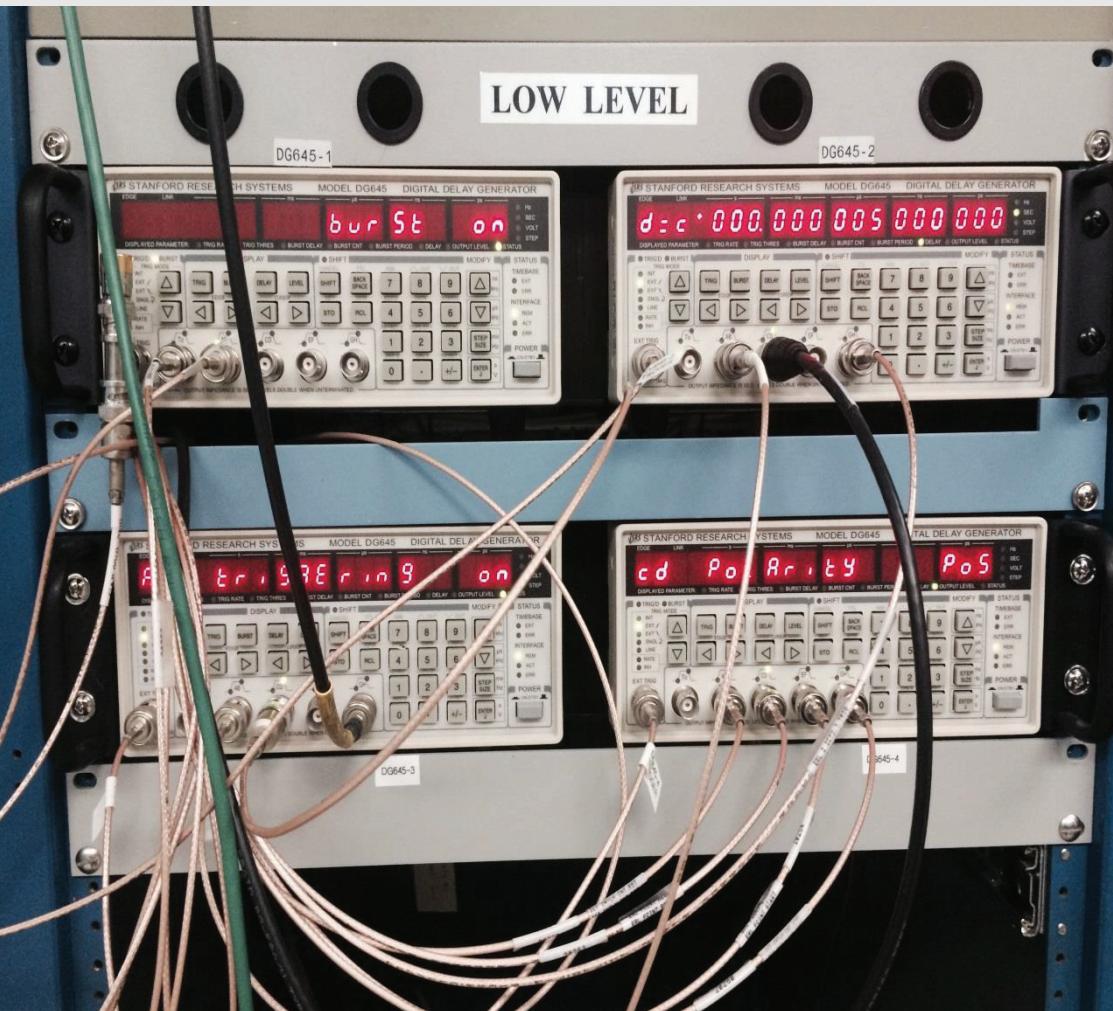


# Putting It All Together





# Truth Be Told!



- 4 pulse outputs
- 8 delay outputs
- <25 ps rms jitter
- Trigger rates to 10 MHz

## Limitations:

- Cannot disable individual output channel
- Rate error status limits the configurable delay value range
- Pre-scale trigger factor is not synchronized with external trigger.



# SUMMARY

- Electron beam was generated. Yay!
- Fault studies are underway utilizing the synchronized beam instruments and diagnostics at ERL.
- Work continues to improve operator interface to minimize user intervention and include more systems.
- MRF Timing system or White Rabbit are potential options for future stand alone research project.

# THANK YOU!