Coherent electron Cooling Proof-of-Principle Experiment

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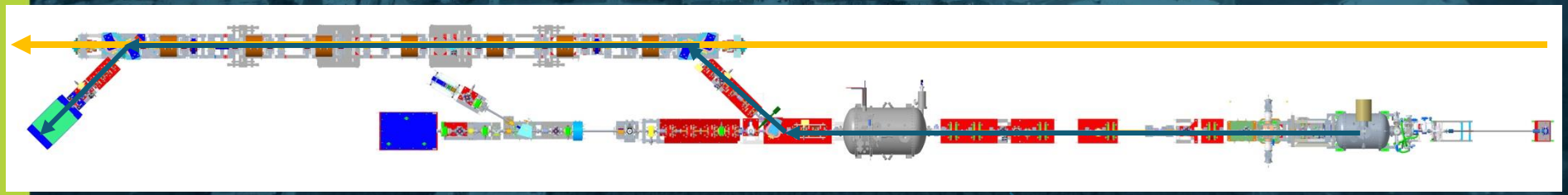
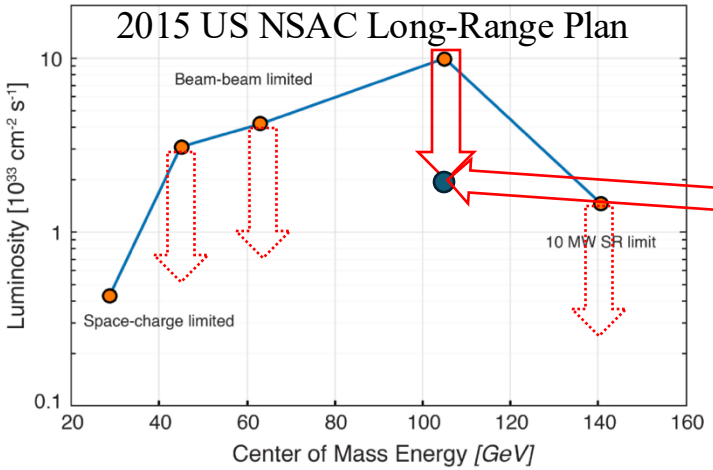
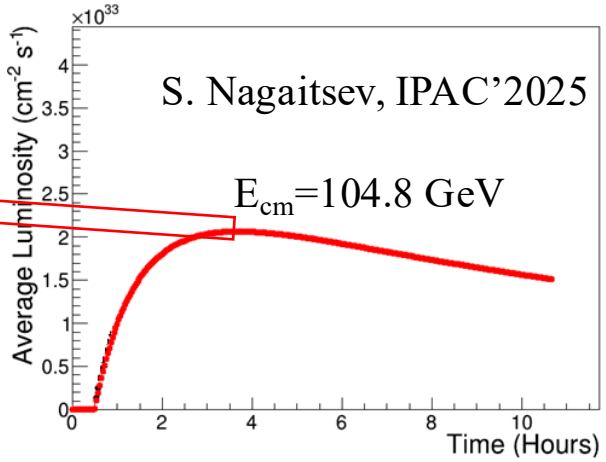


NPP 2025 PAC Meeting, October 16, 2025

Cool or Not To Cool? This is the question?

Up to 5X boost in EIC luminosity





NAS Assessment of U.S.-Based EIC Science: *The accelerator challenges are two fold: a high degree of polarization for both beams,* ***and high luminosity.***

Cooling proton beam at collision energy is considered to be a high risk : *It is currently excluded from the EIC project and is considered as* ***a possible future EIC upgrade***

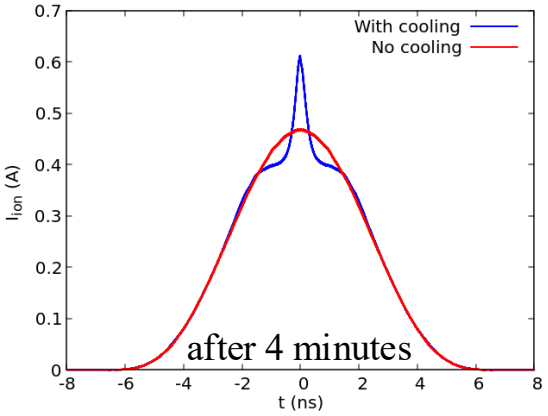
- ✓ Coherent electron Cooling (CeC) is a most promising technique to cool EIC proton beam at collision energy
- ✓ But the CeC is untested technique: it is easy on paper and very challenging in reality
- ✓ DOE, BNL and SBU invested ~ $45M in the CeC proof-of-principle demonstration experiment
- ✓ There is no other facility in the world where CeC can be tested
- ✓ Demonstration of CeC would provide confidence that EIC cooler could do the job
- ✓ CeC system is fully operational and stable
  - ✓ Necessary beam parameters were demonstrated
  - ✓ High gain Plasma-Cascade Amplification is demonstrated
  - ✓ Ion imprint in electron beam was experimentally observed
- ✓ Remaining challenge – we need dedicated time with access to the ion beam

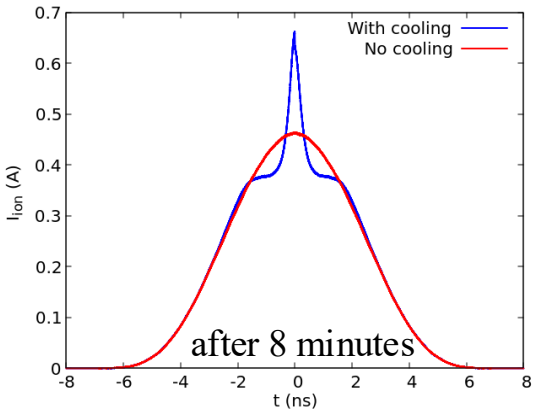
New mode of operation

- To maximize chances for success, we developed new mode of operation below the RHIC transition energy.
- Lower energy of operation would provide for better quality of ion beam and easier choice for electron beam parameters and better stability
- This mode of operation would also provide for significantly faster cooling
- We plan to cool low intensity ion bunches to speed-up the studies

Parameter	Mode 1	Mode 2
γ, relativistic factors of the beams	19.57	28.5
Au ion beam energy, GeV/u	18.2	26.5
Electron beam energy, MeV	10	14.56
Peak current, A (core, 50% of the beam)	≥ 22	≥ 45
Normalized emittance (core, > 50% of the beam), μm rad	≤ 1.5	≤ 1.5
RMS relative energy spread (core, > 50% of the beam), 10^{-4}	≤ 2	≤ 2
Energy flat top (core, > 50% of the beam), $\lvert 10^4\, \delta\gamma/\gamma \rvert$	< 1.5	<1.5

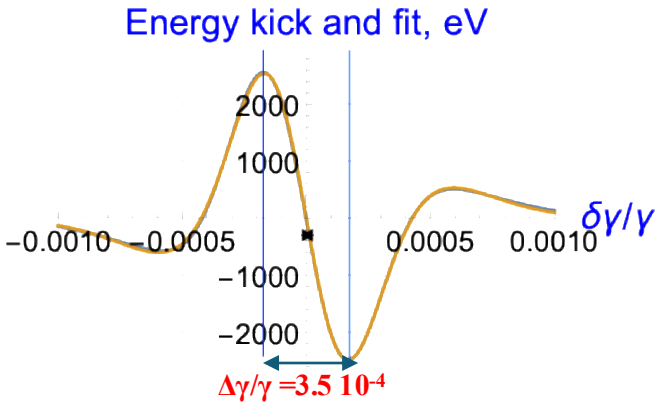
Simulation of cooling on the bunch with 2×10^8 ions

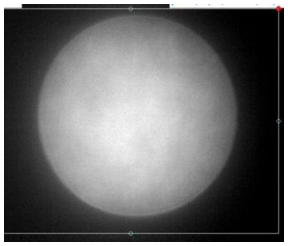




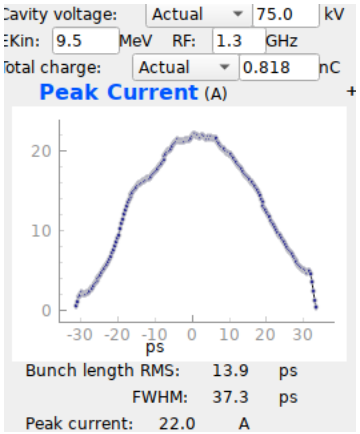
Simulations are goon but experimental data is more important: *CeC operates with electron beam beam parameters equal to better than the requirements: sample from September 18, 2025*

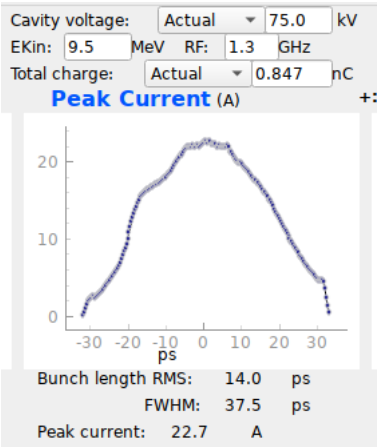
Required: $\varepsilon_{norm} < 1.25$ μm

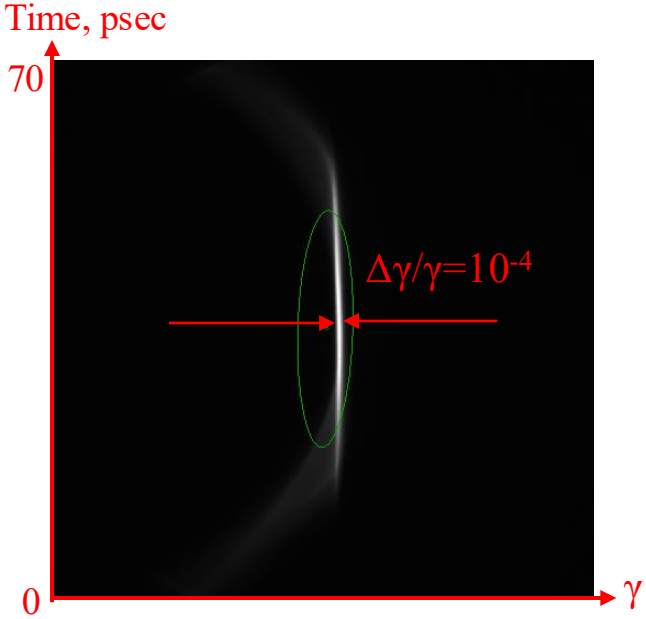


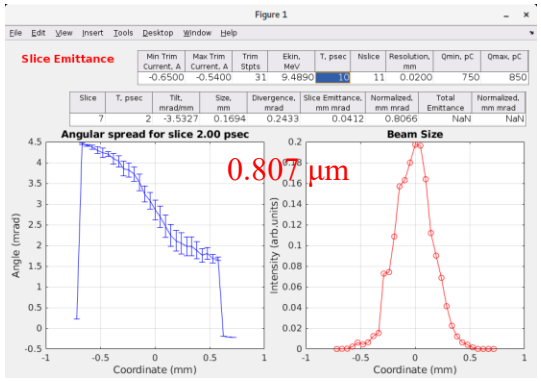


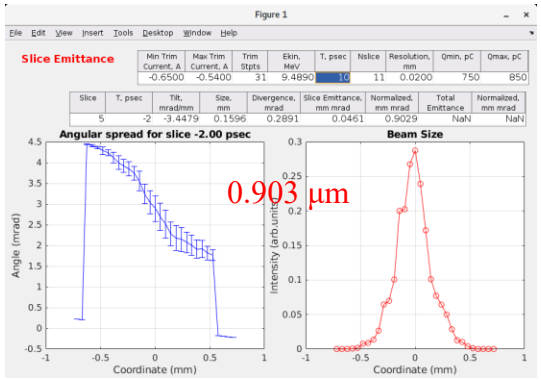
Peak current: >20 A

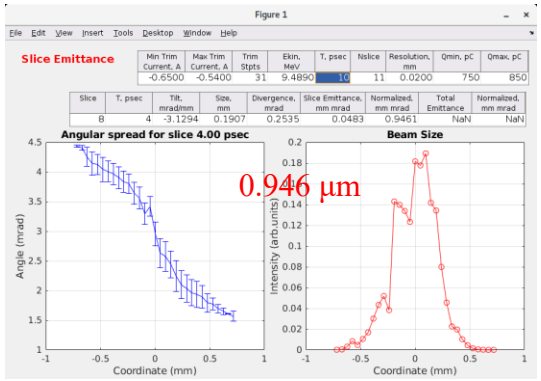




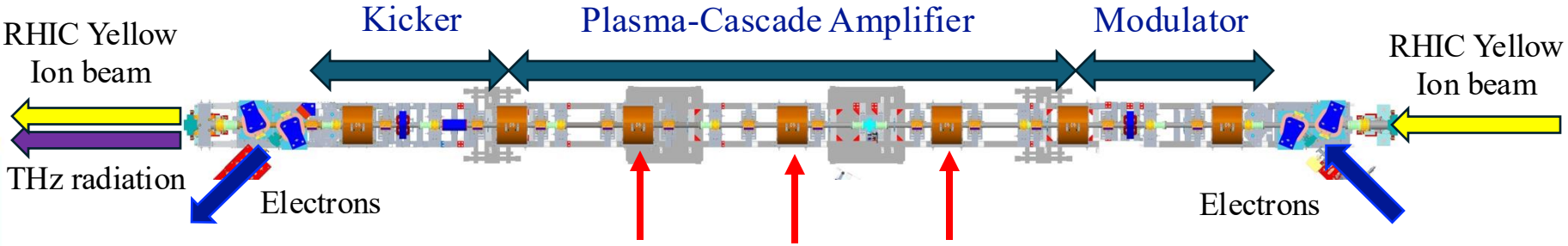








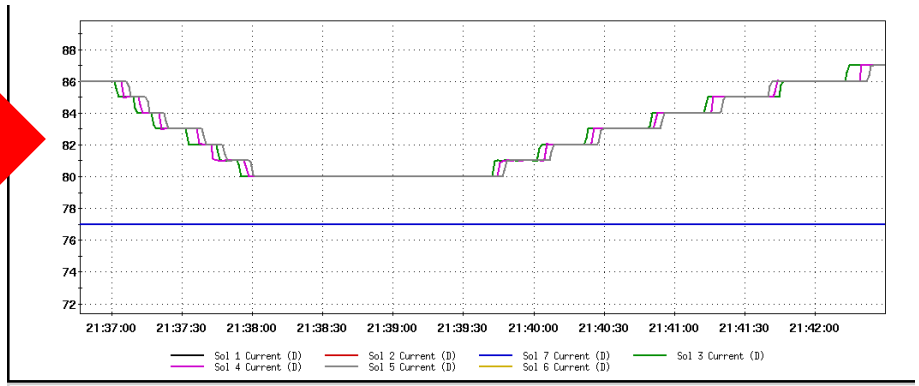
CeC guts: Plasma-Cascade Amplifier (PCA)



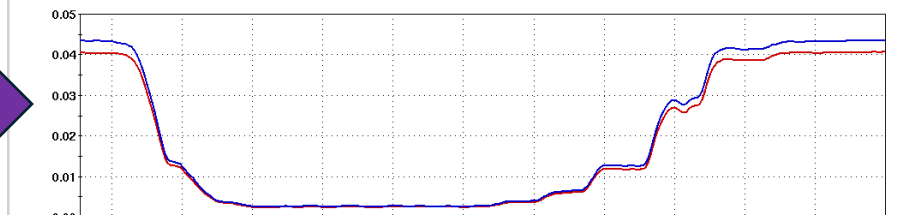
Plasma-Cascade Amplifier is a parametric amplifier: strong focusing solenoids caused periodic modulation of the beam radius and corresponding modulation of plasma frequency. It results in exponential growth of density modulation induced by ions in the modulator.

Classical PCA: changing strength of PCA solenoids result in dramatic increase of the THz radiation: September 22, 2025

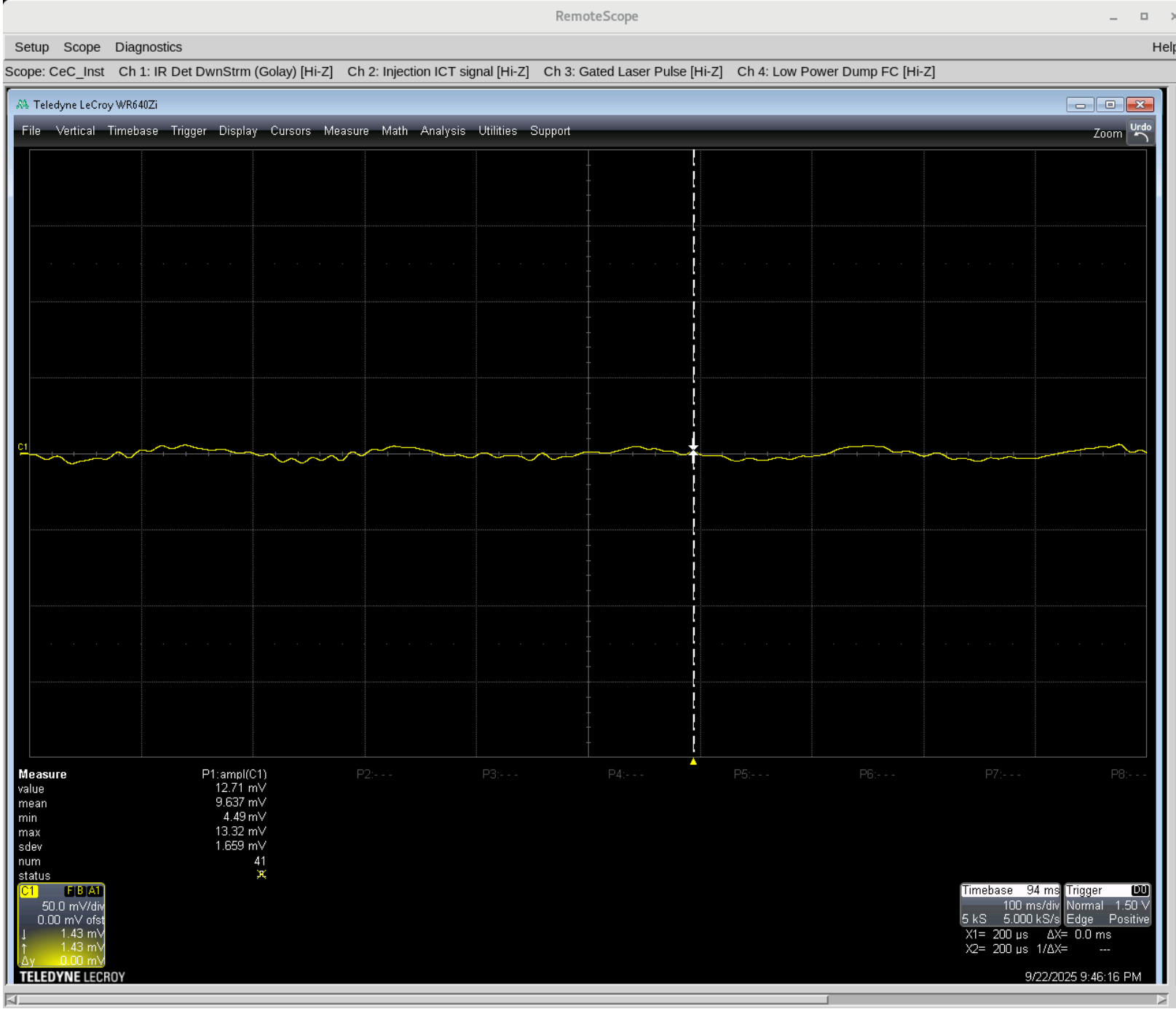
Current in PCA solenoids



Measured THz power a.u.



I_{sol}=82 A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Teledyne LeCroy WR640Zi
File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Support
Zoom
C1
Measure
value 12.71 mV
mean 9.637 mV
min 4.49 mV
max 13.32 mV
sdev 1.659 mV
num 41
status
P1:ampl(C1)
C1 50.0 mV/div 0.00 mV ofst
1.43 mV
1.43 mV
Δy 0.00 mV
Timebase 94 ms 100 ms/div 5 kS 5.000 kS/s
Trigger Normal 1.50 V Edge Positive
X1= 200 µs ΔX= 0.0 ms
X2= 200 µs 1/ΔX= ---
TELEDYNE LECROY
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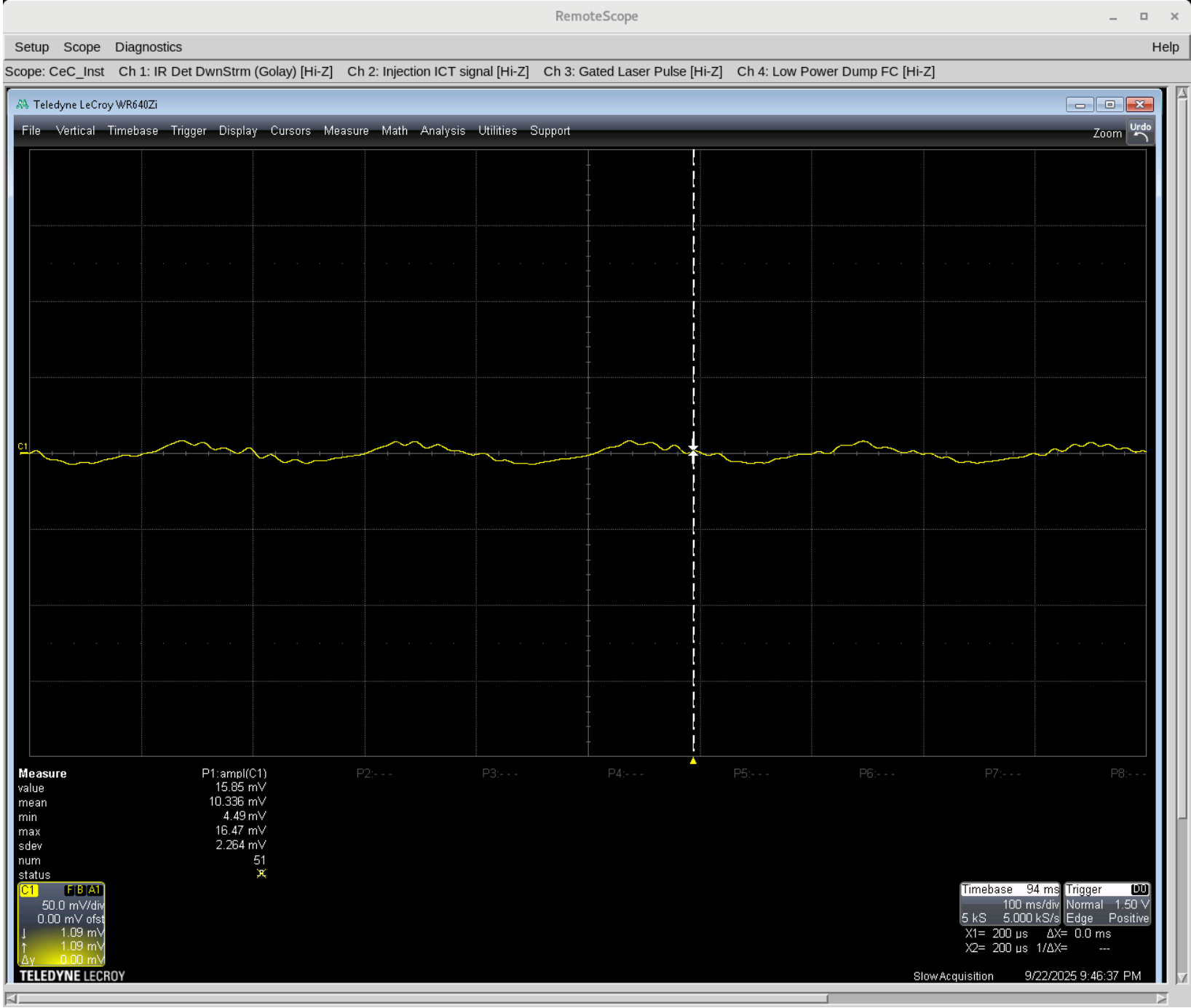
I_{sol}=83 A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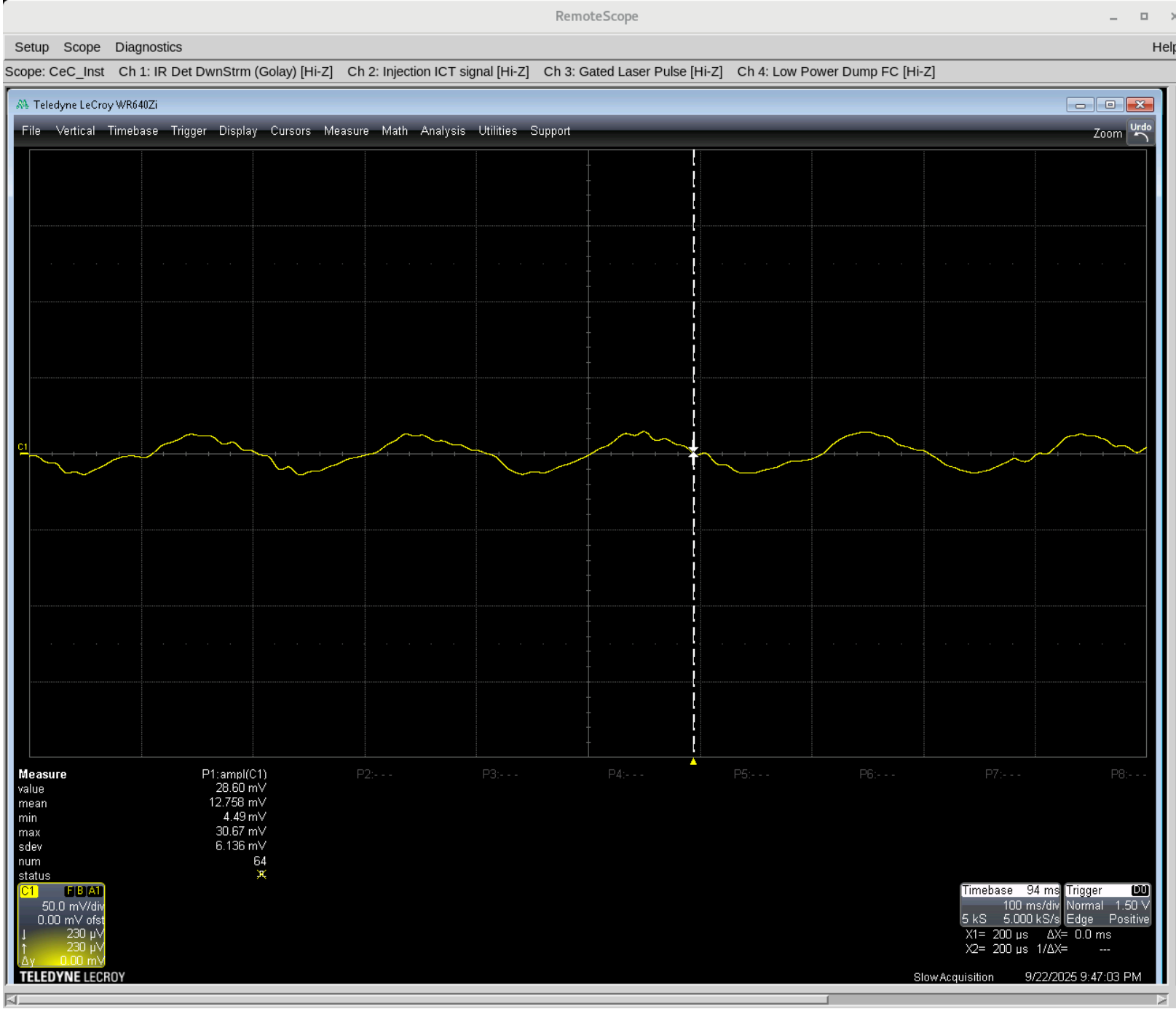
Teledyne LeCroy WR640Zi
File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Support
Zoom
C1
Measure
value 15.85 mV
mean 10.336 mV
min 4.49 mV
max 16.47 mV
sdev 2.264 mV
num 51
status
P1:ampl(C1)
C1 50.0 mV/div 0.00 mV ofst
1.09 mV
1.09 mV
Δy 0.00 mV
Timebase 94 ms 100 ms/div 5 kS 5.000 kS/s
Trigger Normal 1.50 V Edge Positive
X1= 200 µs ΔX= 0.0 ms
X2= 200 µs 1/ΔX= ---
TELEDYNE LECROY
Slow Acquisition 9/22/2025 9:46:37 PM

I_{sol}=84 A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Setup Scope Diagnostics Help
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Teledyne LeCroy WR640Zi
File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Support
Zoom
C1
Measure
P1:ampl(C1)
value 28.60 mV
mean 12.758 mV
min 4.49 mV
max 30.67 mV
sdev 6.136 mV
num 64
status
C1 F B A1
50.0 mV/div
0.00 mV ofst
230 µV
230 µV
Δy 0.00 mV
TELEDYNE LECROY
Timebase 94 ms
100 ms/div
5 kS 5.000 kS/s
X1= 200 µs ΔX= 0.0 ms
X2= 200 µs 1/ΔX= ---
Trigger
Normal 1.50 V
Edge Positive
Slow Acquisition
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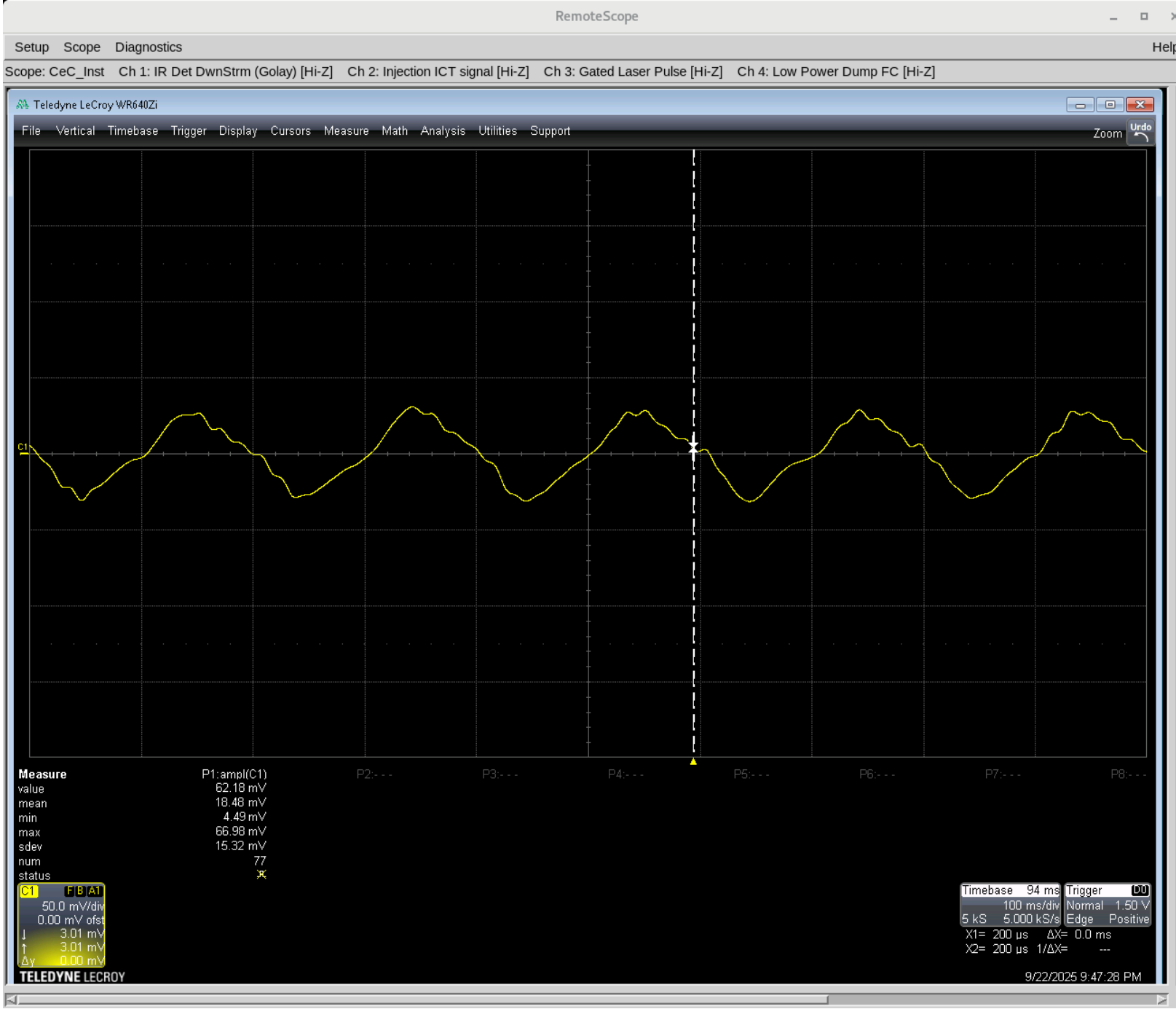
I_{sol}=85 A


RemoteScope
Setup Scope Diagnostics Help
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Teledyne LeCroy WR640Zi
File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Support
Zoom
C1
Measure
value 62.18 mV
mean 18.48 mV
min 4.49 mV
max 66.98 mV
sdev 15.32 mV
num 77
status
P1:ampl(C1)
P2:- - -
P3:- - -
P4:- - -
P5:- - -
P6:- - -
P7:- - -
P8:- - -
C1 F B A1
50.0 mV/div
0.00 mV ofst
3.01 mV
3.01 mV
Δy 0.00 mV
Timebase 94 ms
100 ms/div
5 kS 5.000 kS/s
Trigger
Normal 1.50 V
Edge Positive
X1= 200 µs ΔX= 0.0 ms
X2= 200 µs 1/ΔX= ---
TELEDYNE LECROY
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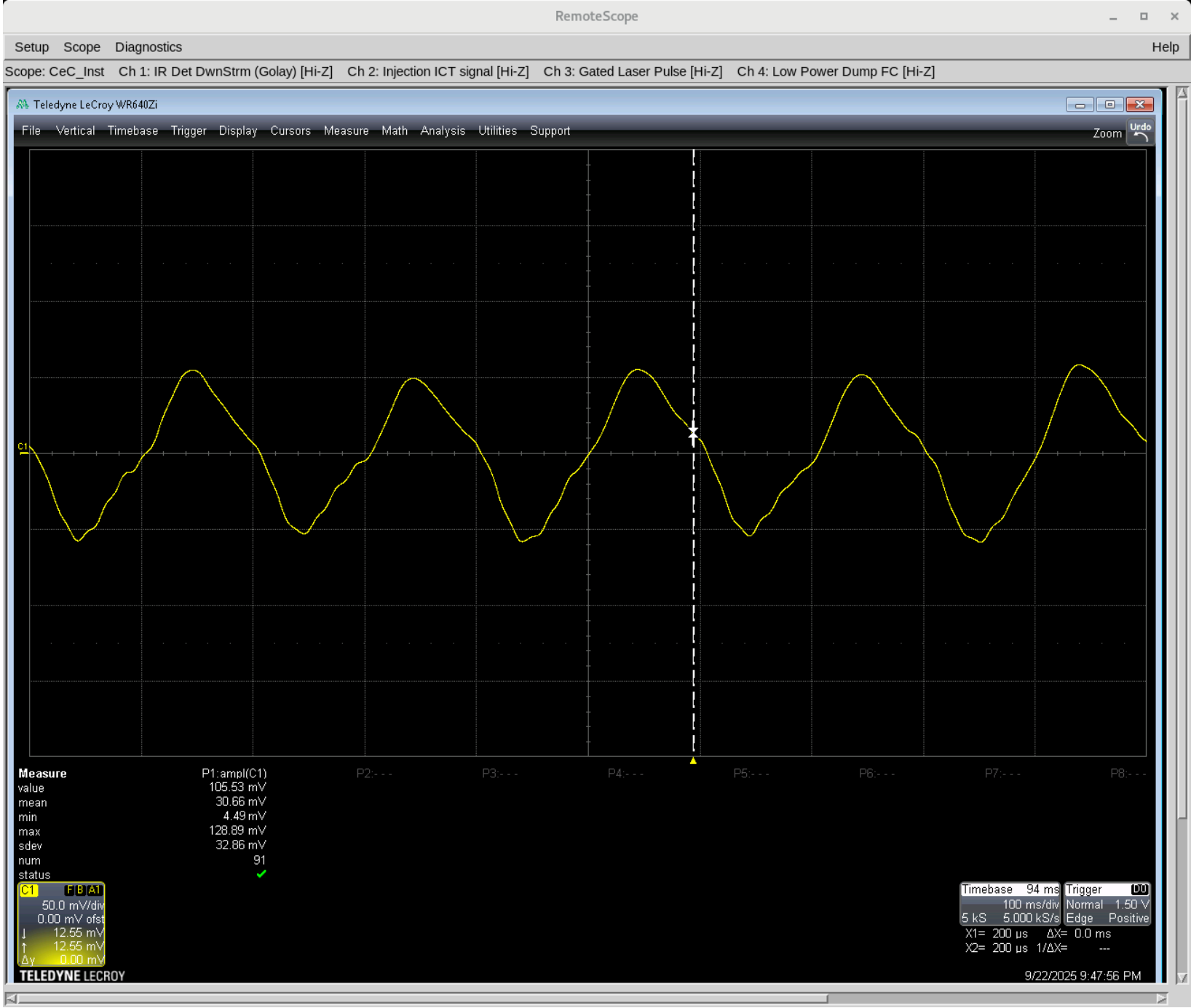
I_{sol}=86 A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Setup Scope Diagnostics Help
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Teledyne LeCroy WR640Zi
File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Support
Zoom
C1
Measure
value 105.53 mV
mean 30.66 mV
min 4.49 mV
max 128.89 mV
sdev 32.86 mV
num 91
status
P1:ampl(C1)
C1 50.0 mV/div 0.00 mV ofst
12.55 mV
12.55 mV
Δy 0.00 mV
Timebase 94 ms 100 ms/div 5 kS 5.000 kS/s
Trigger Normal 1.50 V Edge Positive
X1= 200 µs ΔX= 0.0 ms
X2= 200 µs 1/ΔX= ---
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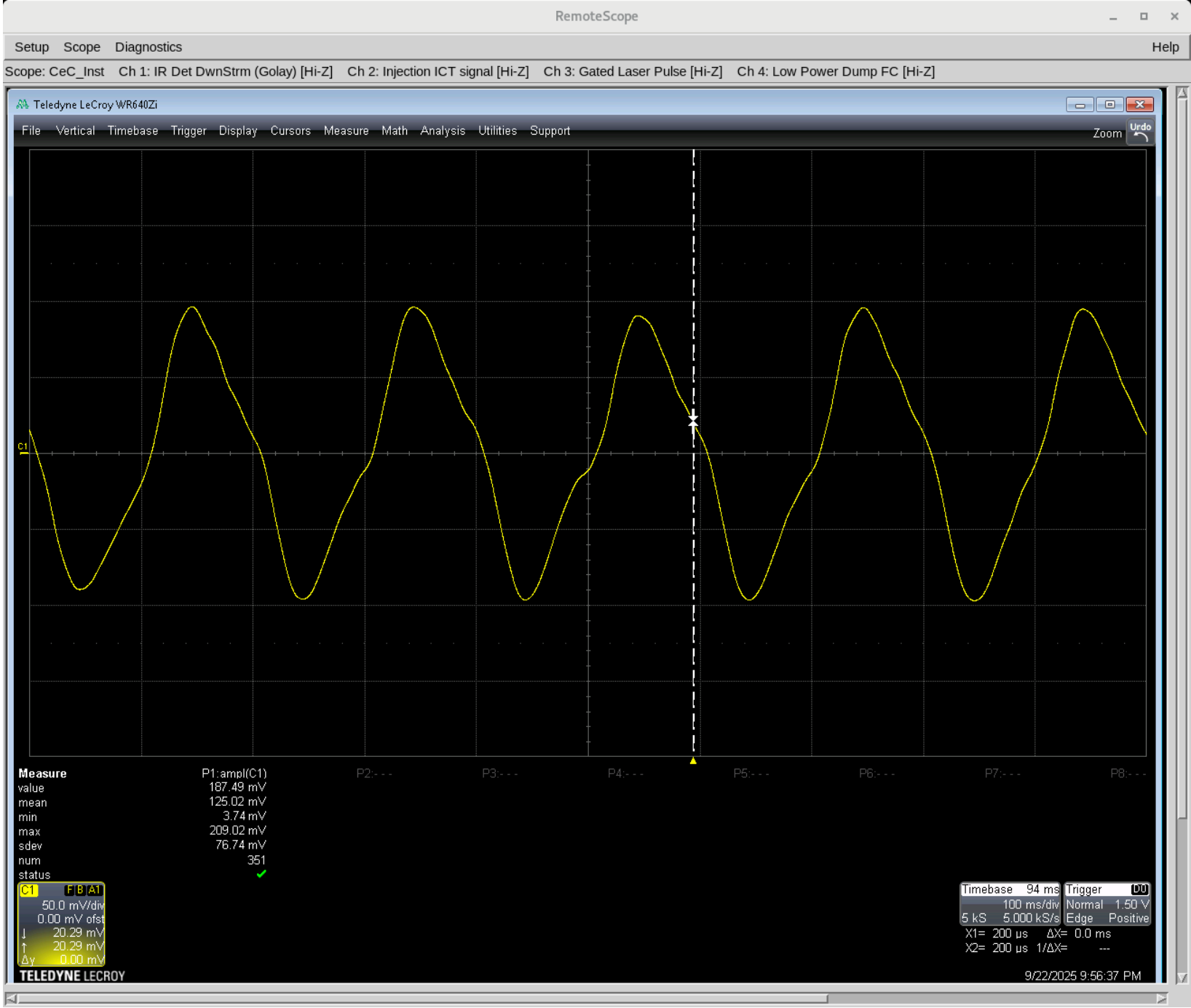
I_{sol}=87A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Teledyne LeCroy WR640Zi
File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Support
Zoom
C1
Measure
value 187.49 mV
mean 125.02 mV
min 3.74 mV
max 209.02 mV
sdev 76.74 mV
num 351
status
P1:ampl(C1)
C1 50.0 mV/div 0.00 mV ofst 20.29 mV 20.29 mV 0.00 mV
Timebase 94 ms 100 ms/div 5 kS 5.000 kS/s
Trigger Normal 1.50 V Edge Positive
X1= 200 µs ΔX= 0.0 ms
X2= 200 µs 1/ΔX= ---
TELEDYNE LECROY
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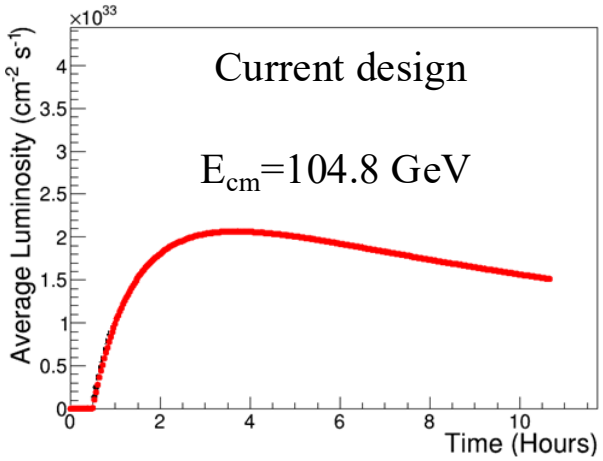
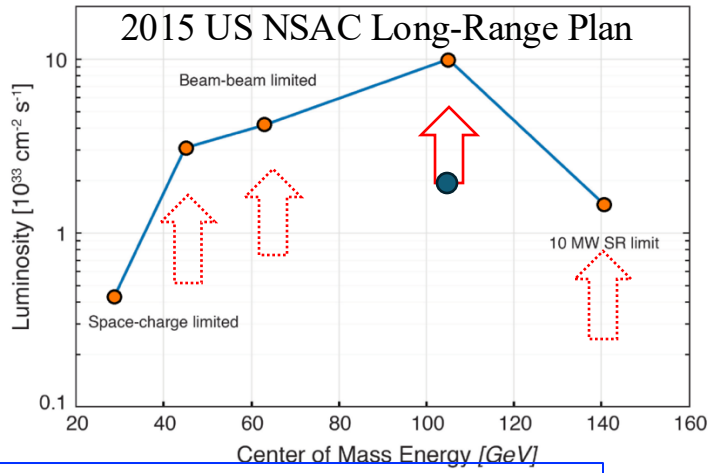
Good chance to demonstrate technique for future EIC upgrade

From 2 X to 5X* boost in EIC luminosity





Demonstration of CeC would provide confidence that future EIC cooler could do the job

Request for dedicated time for CeC demonstration

- ✓ Coherent electron Cooling system performing very well and most of the tuning is done in parasitic mode
- ✓ RHIC ramp to CeC energy of 18.2 GeV/u was successfully developed during 4 hours of dedicated time
- ✓ This progress significantly reduced time required for the CeC experimental demonstration
- ✓ We request x 12=hour shift pf dedicated time

1. Match relativistic factors of ion and electron beams (using relaxed lattice) – 1 shift
2. Align ion and electron beams in PCA lattice, match e-beam into the PCA lattice - 2 shifts
3. Observe High-Gain Plasma-Cascade amplification with CW e-beam and observe ion beam heating – 1 shift
4. Tune the e-beam energy (tuning range is $\delta\gamma/\gamma = \{0,+8\times10^{-4}\}$, step of 10^{-4}. to observe signs of cooling – 2 shifts
5. Optimize Coherent electron Cooling – 3 shifts

Total request: 4.5 days (9 12-hour shifts) of dedicated time

* Possibility of lumi gain above 2X is my (VL) opinion which is not endorsed by C-AD management

Back-up slide

Luminosity models: ‘perfect cooling’ vs no cooling