First Results of Commissioning DC Photocathode gun for RHIC Low Energy Electron Cooler (LEReC)

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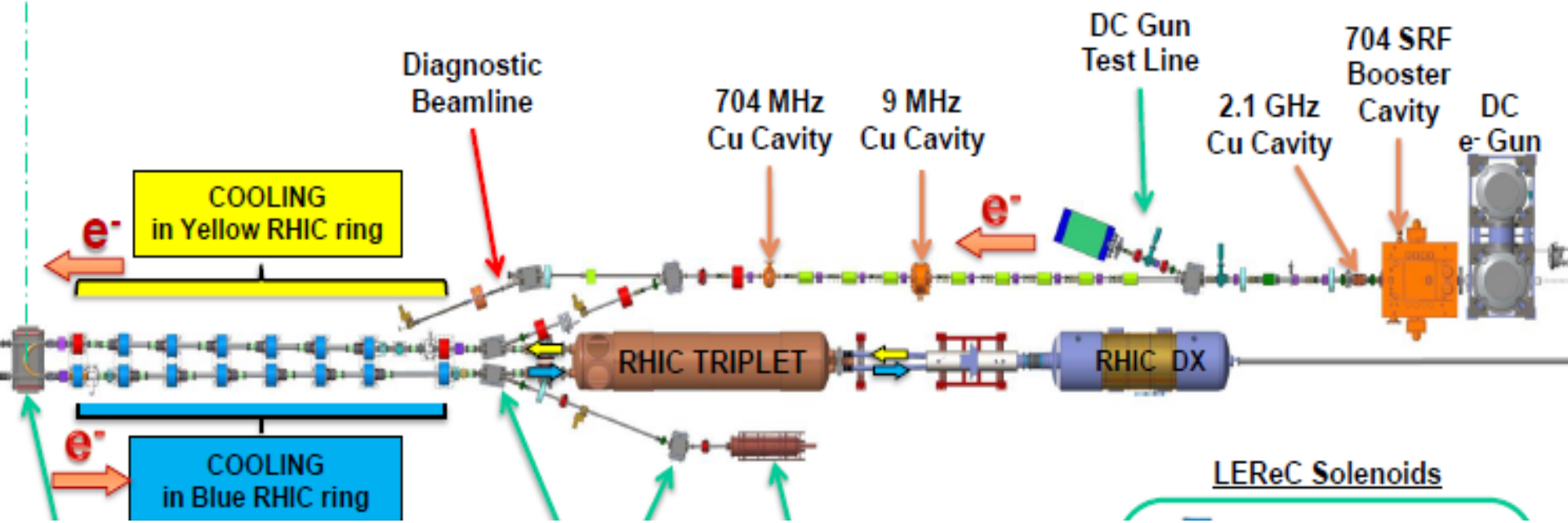
on behalf of LEReC team

Brookhaven National Laboratory

June 21, 2017, CERN

Low Energy RHIC electron Cooler



Non-magnetized bunched electron cooling of low energy RHIC requires electron beam energy in range of 1.6-2.6 MeV, with average current up to 45 mA, very small energy spread, and low emittance [*]

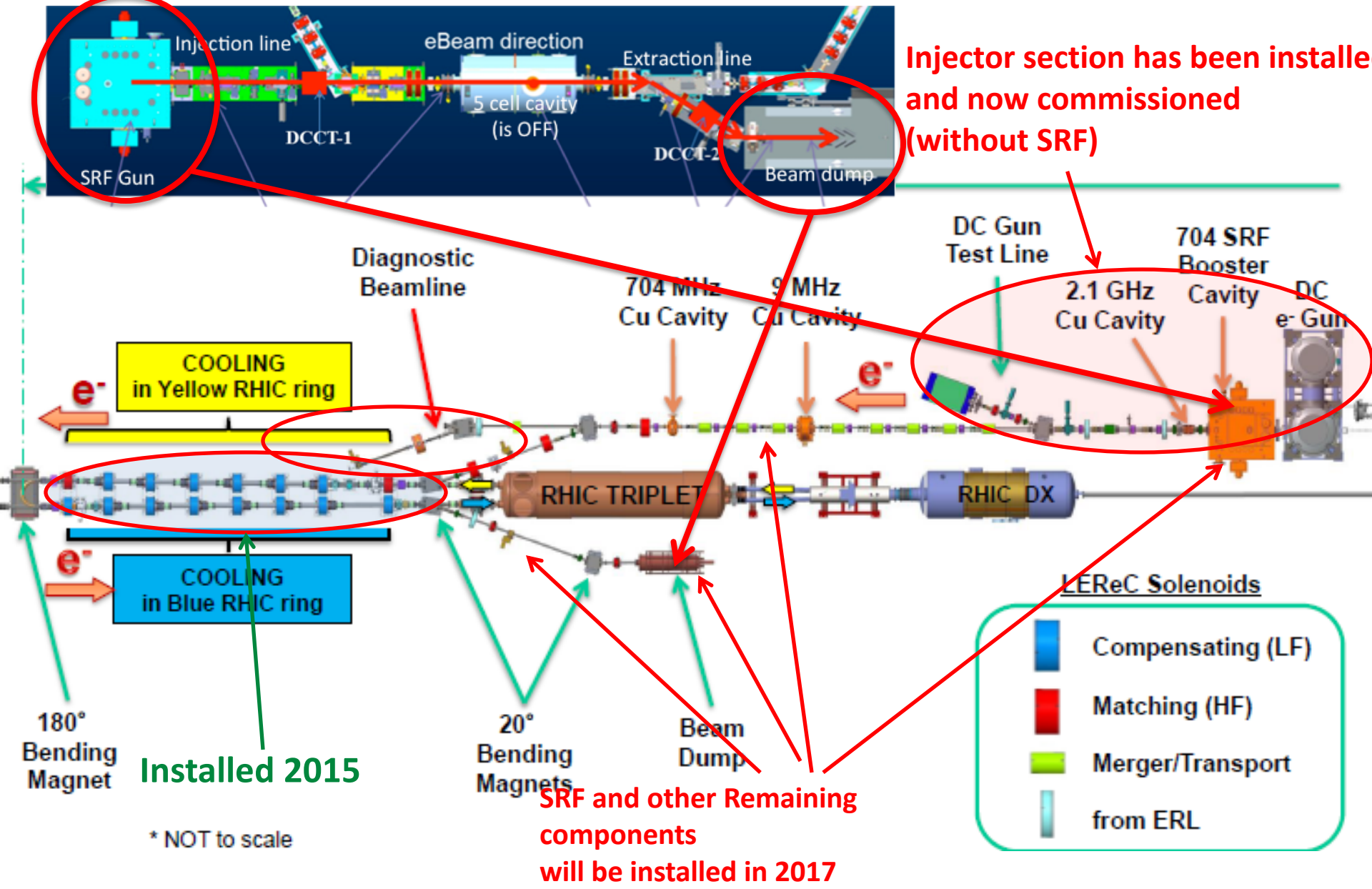
A 400 kV DC gun equipped with photocathode and laser delivery system will serve as a source of high quality electron beam.

Acceleration will be achieved by an SRF 704 MHz booster cavity and other RF components that are scheduled to be installed and ready for operating early 2018.

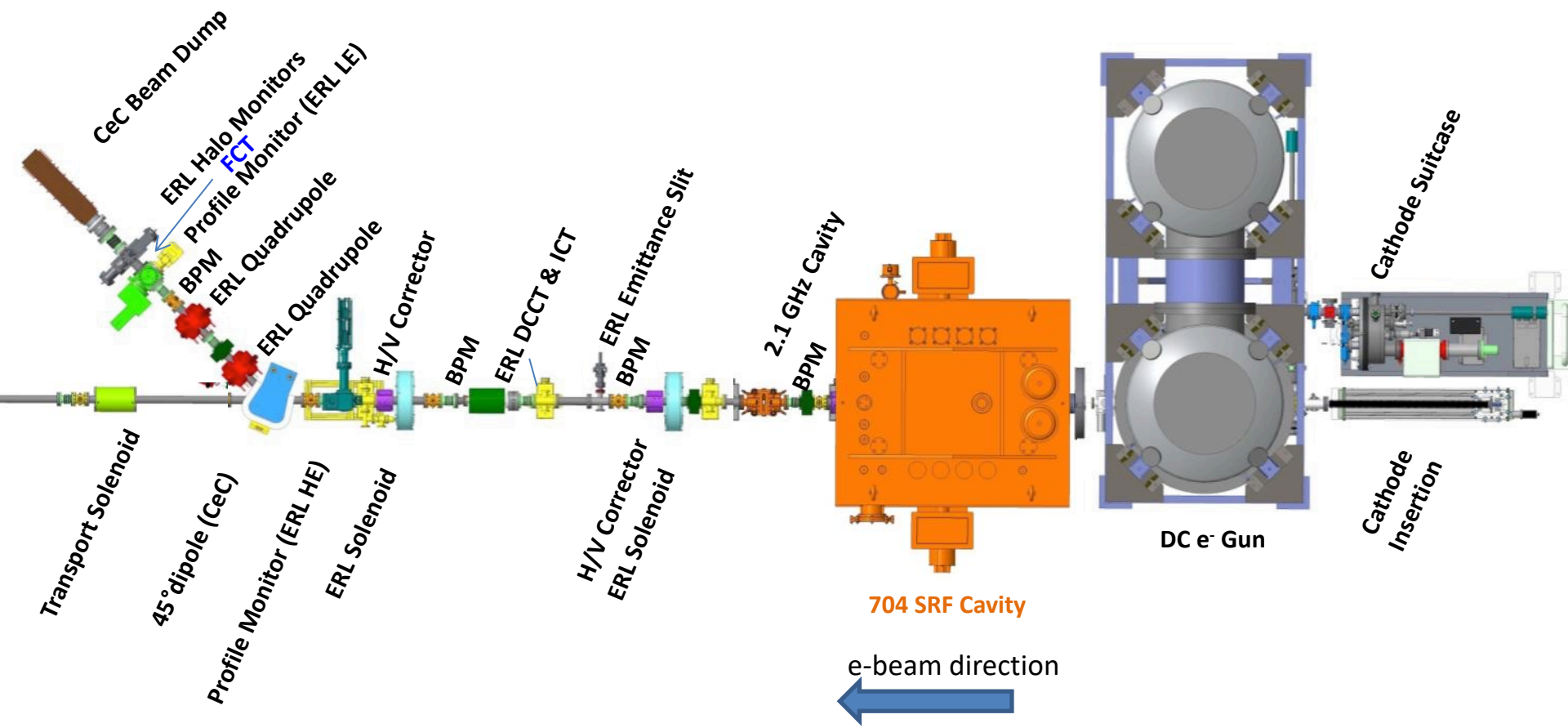
LEReC commissioning Spring 2018

*A. Fedotov, "Bunched beam electron cooling for Low Energy RHIC operation", ICFA Beam Dynamics letter, No. 65, p. 22 (December 2014).

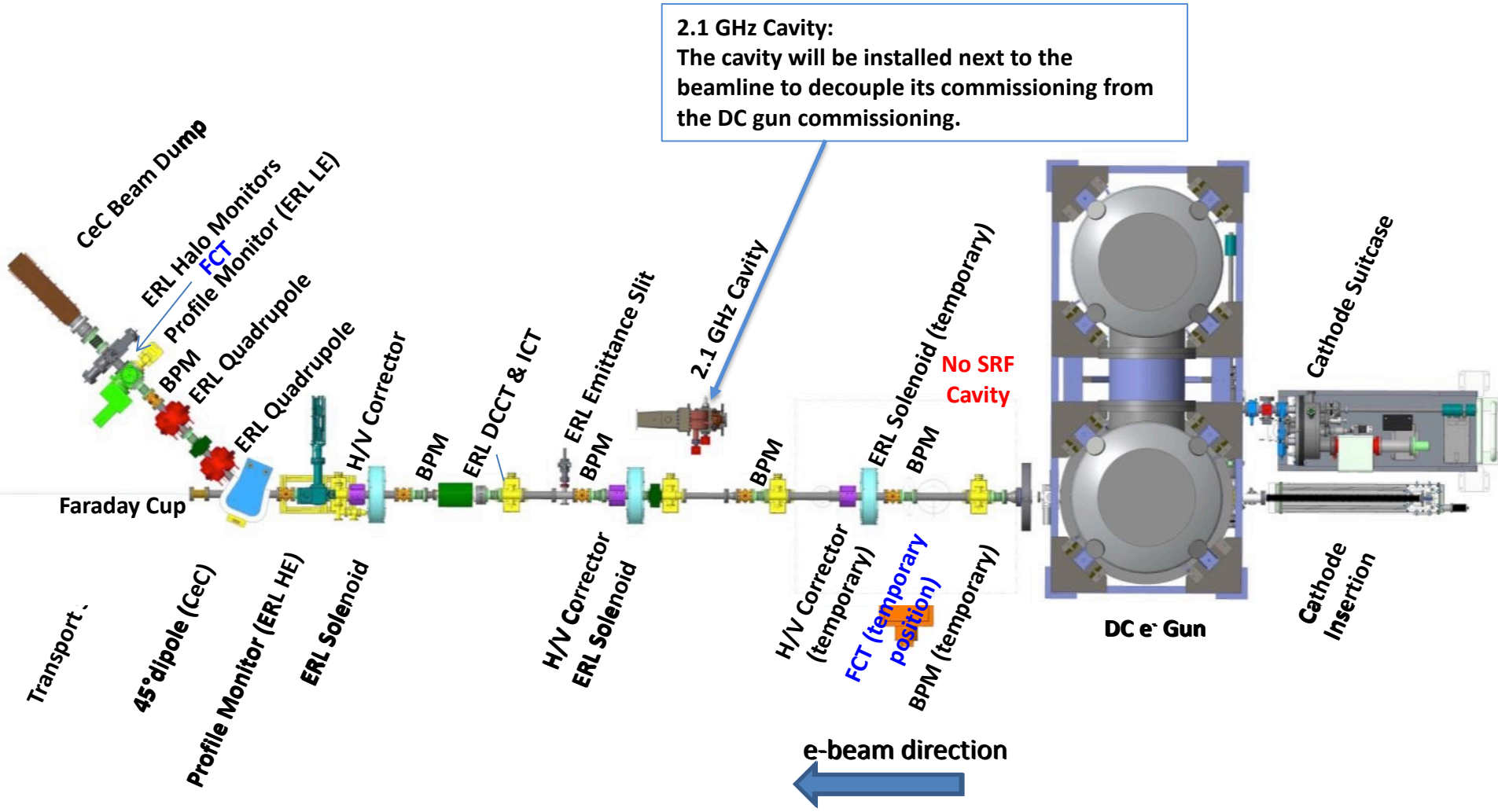
ERL components moved to LEReC location (RHIC IR2)



LEReC Injection section (zoom in)



LEReC DC gun test setup 2016-2017



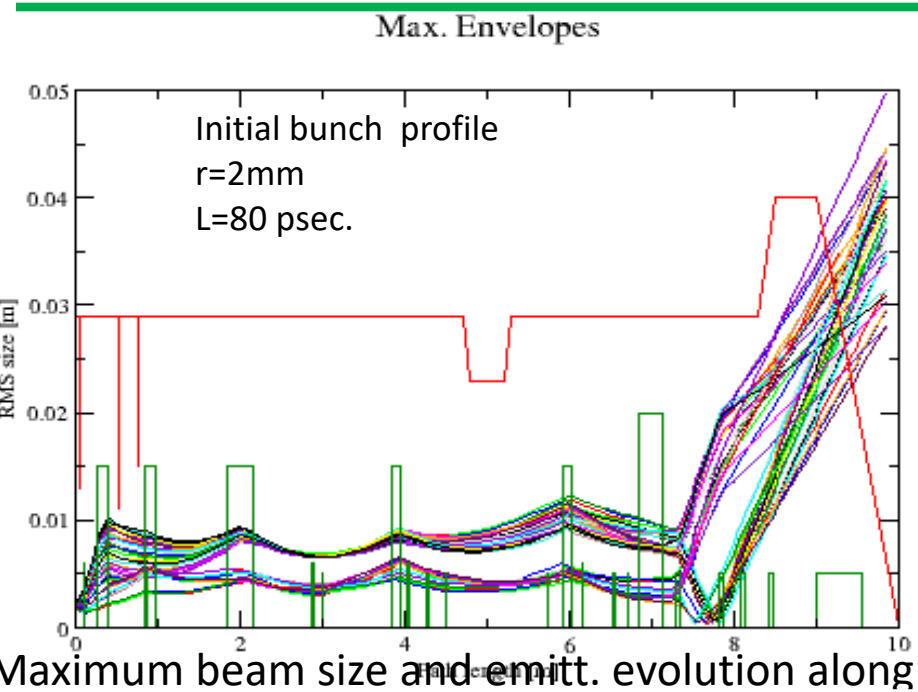
Gun test goal:

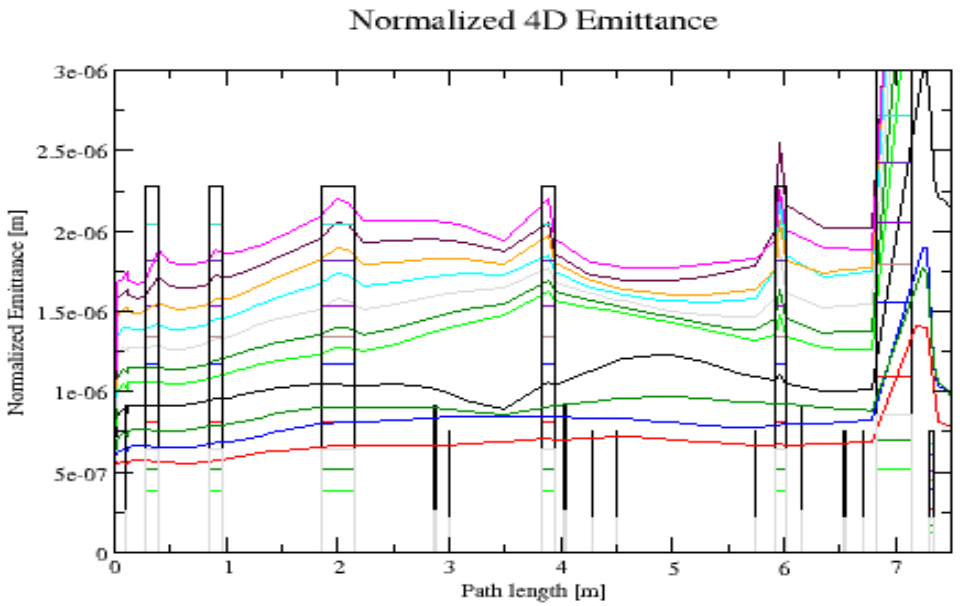
- Test the critical equipment in close to operation condition (Laser beam delivery system, Cathode QE, DC Gun, Beam Instrumentation)

Main beam parameters

Parameters	LEReC requirement	DC gun test
Charge per pulse	130-200 pC	130-200 pC
Laser maximum rep rate	704 MHz	704 MHz
Macro bunch charge	4 nC (30x130pC, 20x200pC)	4 nC
Macro bunch rep rate	9.3 MHz (CW)	9.3 MHz (Mpulses)
Average current	35 mA	25 mA
Gun voltage	400 kV	400 kV
Energies	1.6, 2.0, 2.6 MeV	0.4 MeV
Average dump power	56, 70, 91 kW	10 kW
RMS norm. emittance	< 2.5 um	< 2.5 um
RMS energy spread	<5e-4	n/a

Beam dynamics, magnets strength





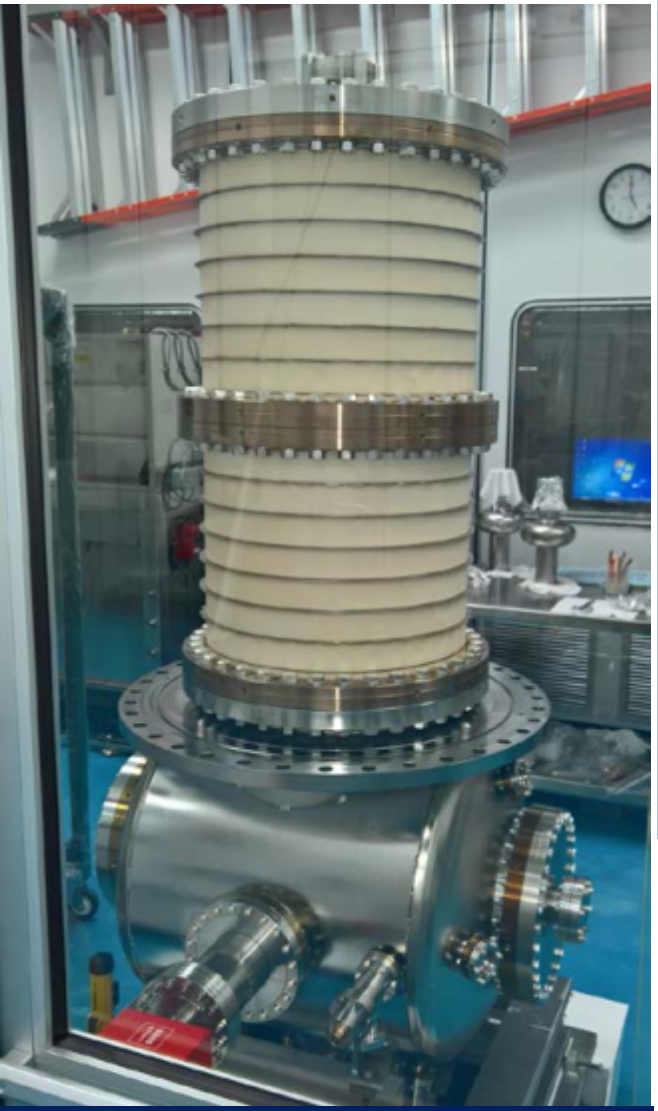
Maximum beam size and emitt. evolution along gun test beam line for different charge per bunch

Charge	lecs1-inj sol1	lecs1-inj sol2	lecs1-inj sol0	lecs1-inj sol3	lecs1-inj sol4	lecs1-inj q1i	lecs1-inj q2
30pC	183.8	194.0	109.3	172.3	172.3	1.25	-0.1
50pC	183.8	194.0	100.5	172.3	172.3	1.25	-0.1
70pC	226.0	206.5	131.2	192.0	192.0	0.75	-0.15
100pC	280.7	185.5	131.2	211.7	172.3	0.75	-0.15
130pC	310.2	101.3	109.3	132.9	132.9	0.6	-0.15
150pC	310.2	101.3	109.3	132.9	132.9	0.6	-0.15
180pC	310.2	101.3	109.3	132.9	132.9	0.5	-0.15
210pC	310.2	101.3	109.3	132.9	132.9	0.5	-0.15
240pC	310.2	101.3	109.3	152.6	132.9	0.5	-0.15
270pC	310.2	101.3	109.3	152.6	152.6	0.6	-0.25
300pC	310.2	101.3	109.3	172.3	152.6	0.5	-0.15

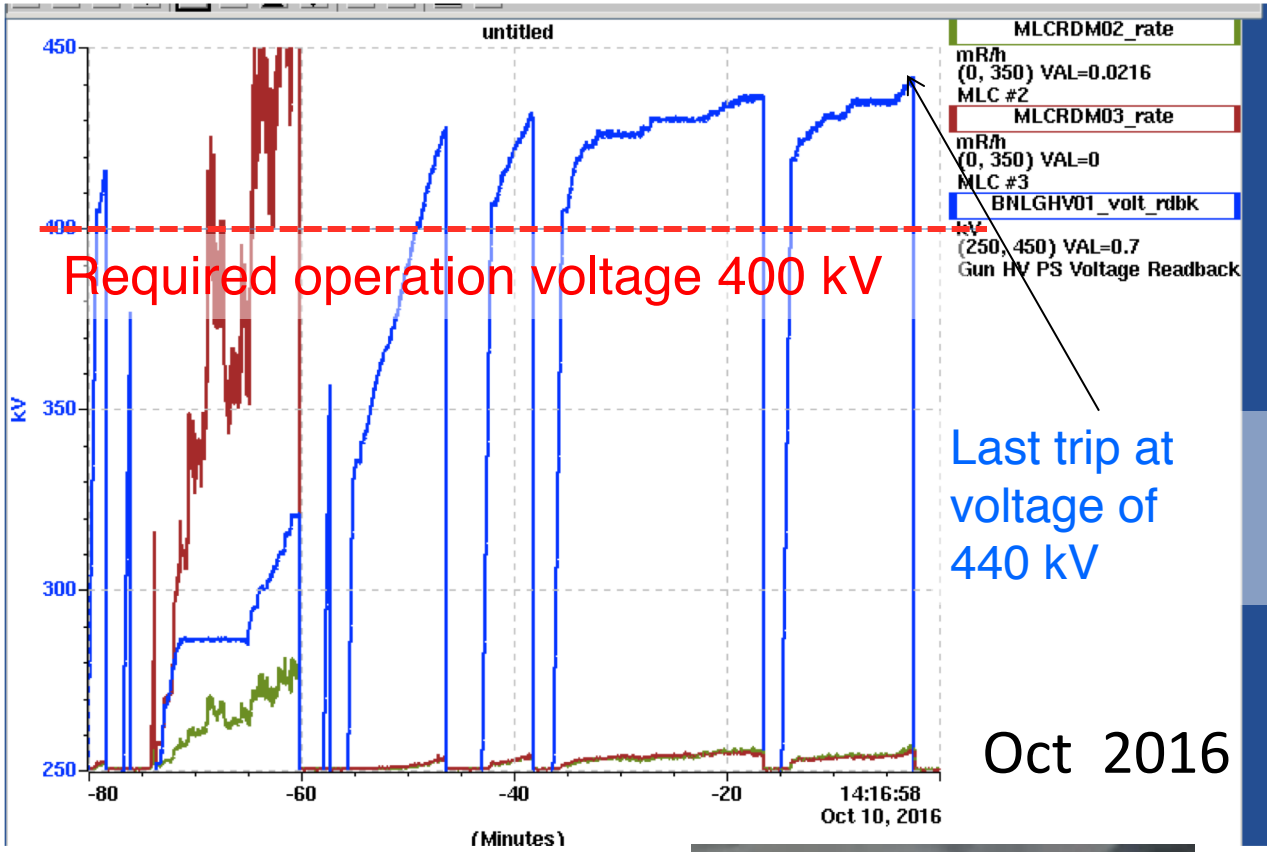
Table 1: Magnet strength. For solenoids the value is the peak filed in the center of the magnet. For quadrupoles the integrated gradient is listed. All values are in Gauss.

We may not need to rump solenoid for different charges

BNL DC gun performance during HV conditioning at Cornell

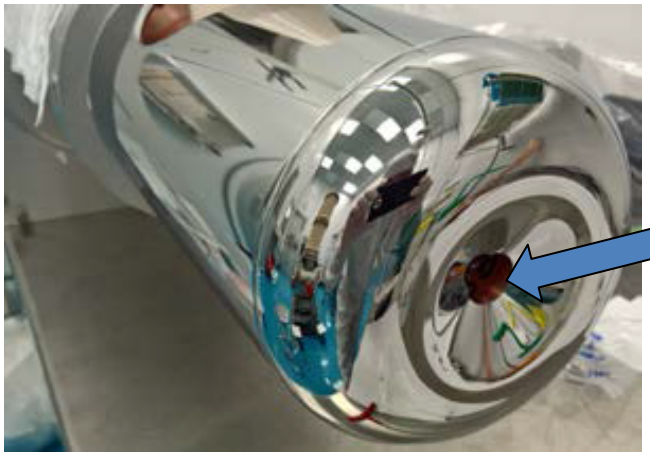


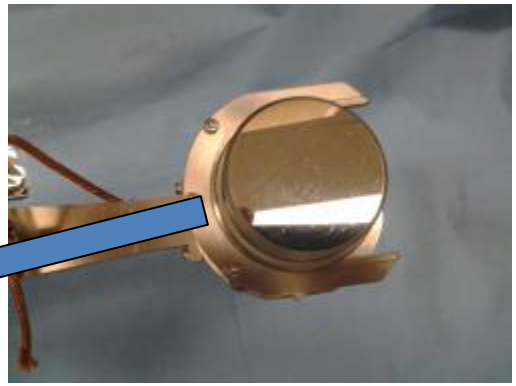
Designed, built and conditioned at Cornell University



Last trip at voltage of 440 kV

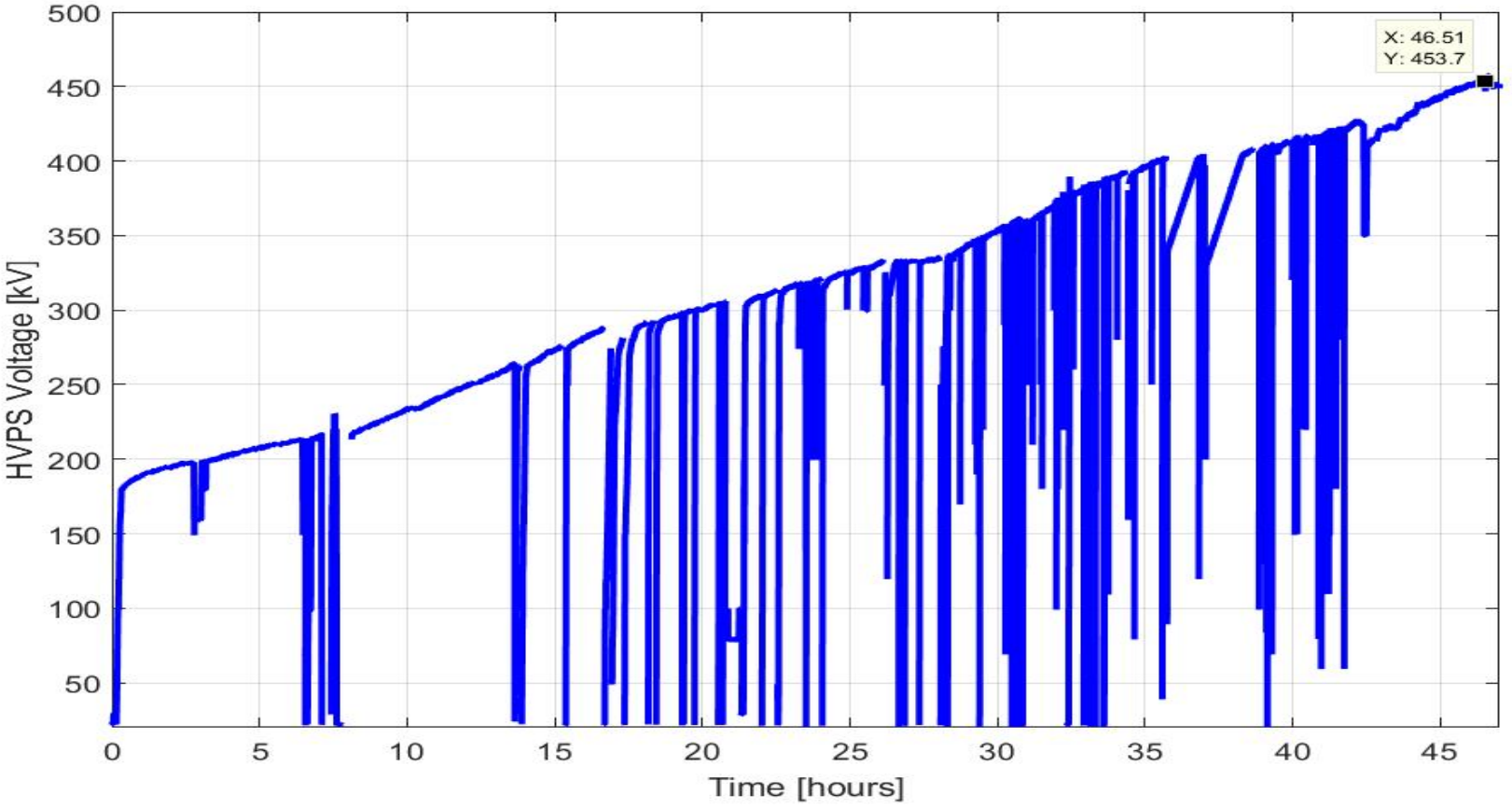
Oct 2016





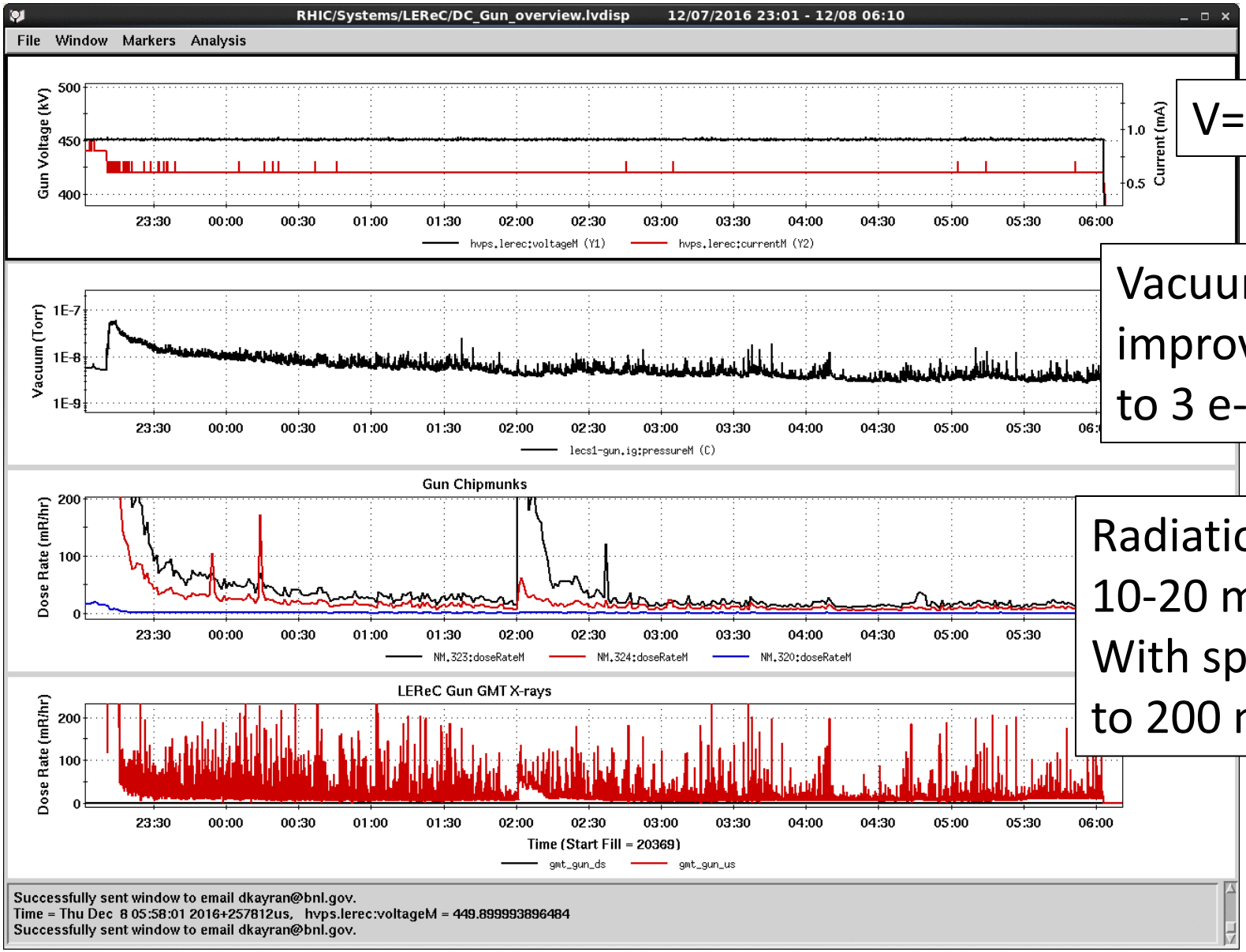
Molybdenum cathode plug

Conditioning at BNL



- DC gun has been tested upto 430kV at Cornell (Oct 2016)
- DC gun HV conditioning starts at BNL Nov. 28, 2016
- DC gun reached 456kV by Dec 7, 2016
- Stable for 7 hours at 450kV

DC Gun at 450 overnight run (7hours)

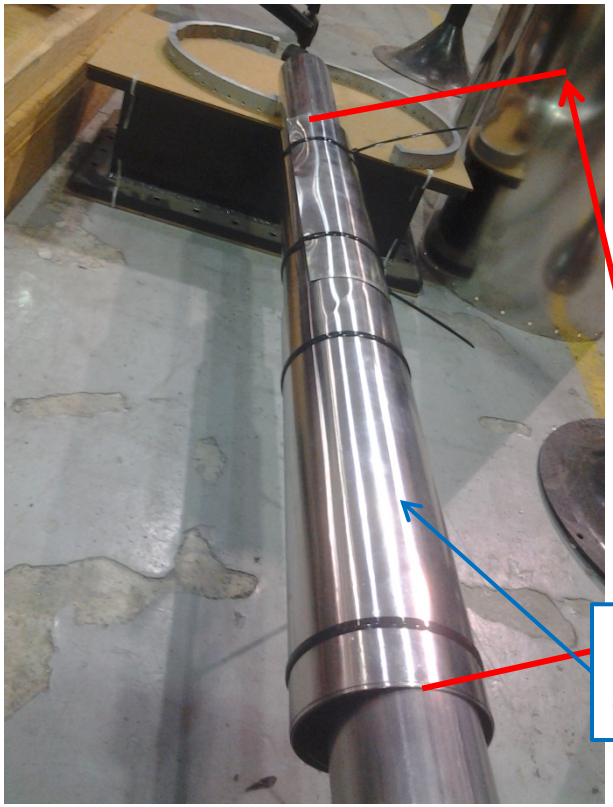


V=450kV

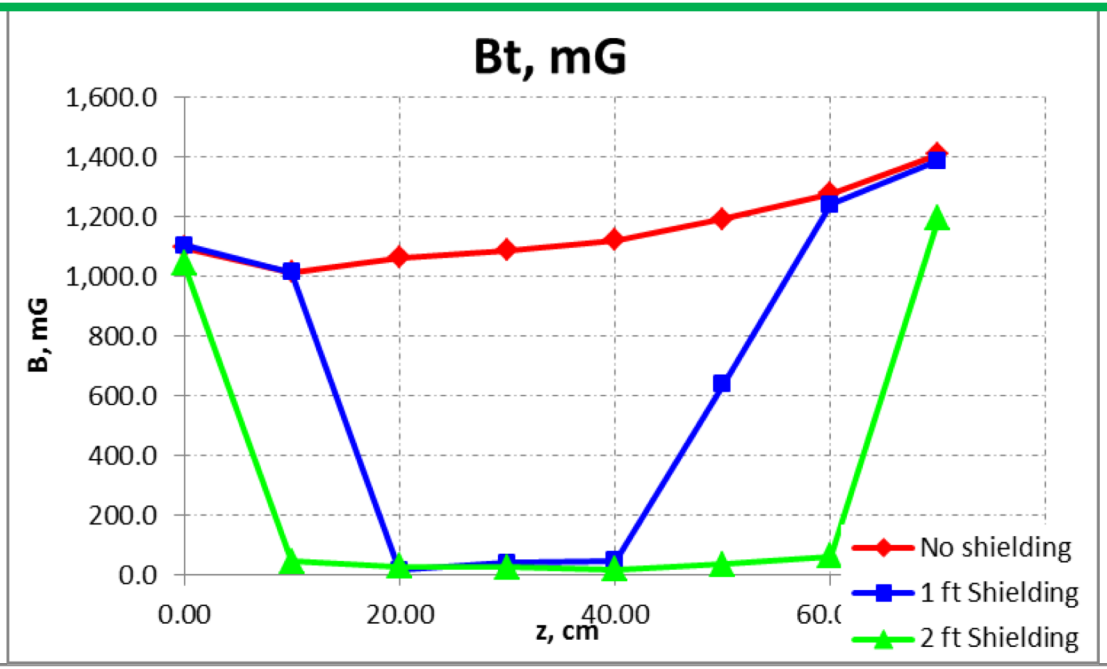
Vacuum improved: 1e-8 to 3 e-9

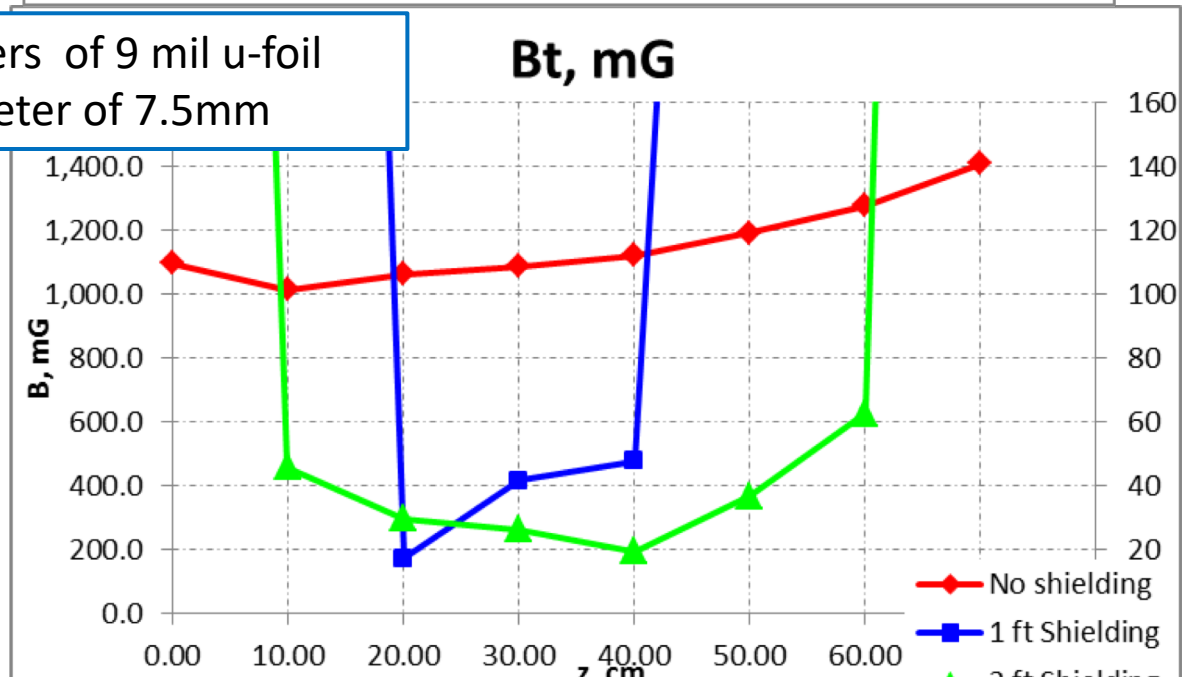
Radiation level 10-20 mR/hr
With spikes up to 200 mR/hr

Transport line shielding test (Dec, 14-2016)



3 layers of 9 mil u-foil
diameter of 7.5mm



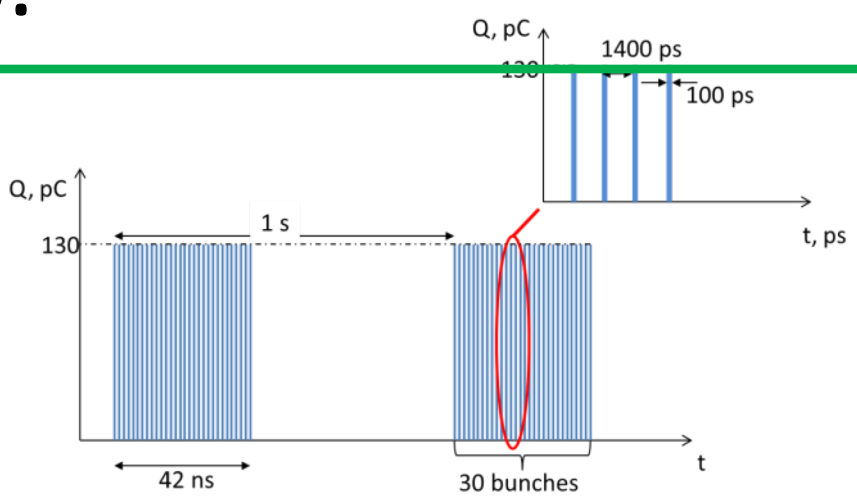


Without shielding ~1Gauss
With shielding 20-40mgauss
Shielding efficiency >20

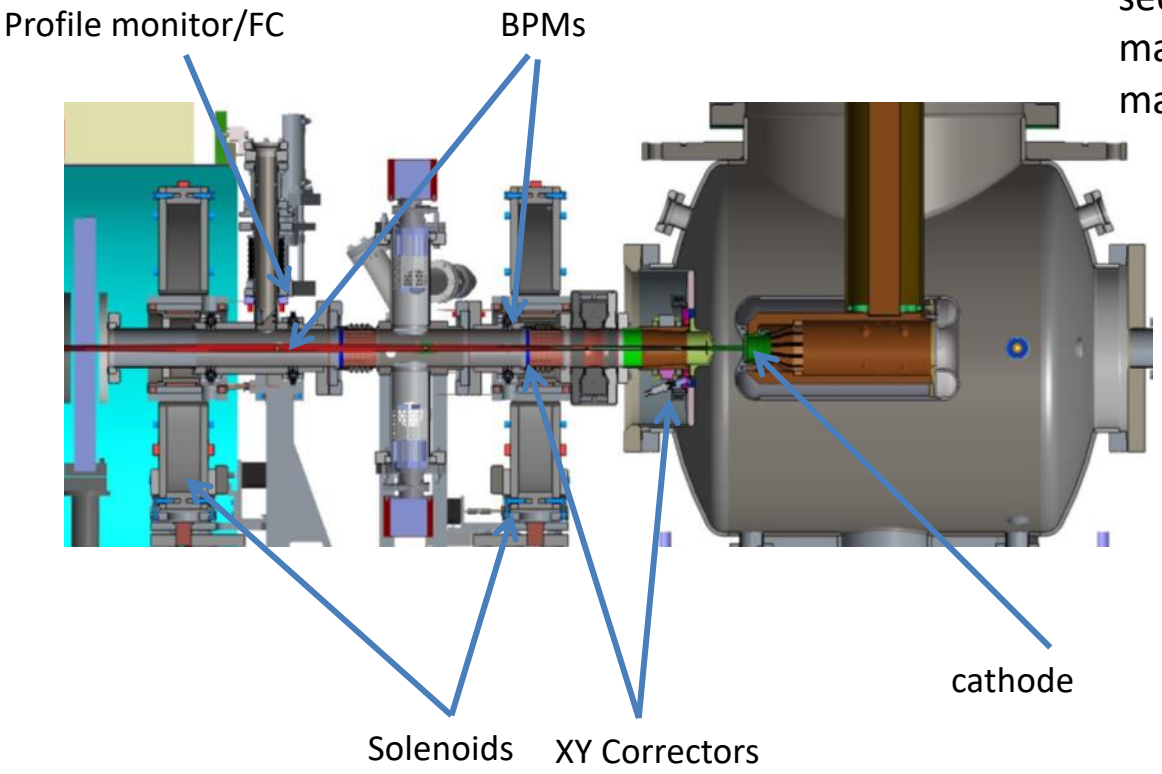
First beam test setup.

- Start up mode (few macro pulses)

Main parameters:
Laser spot size 2 mm
Laser pulse 80 psec flat distribution.
Laser spot location on the center of the cathode.
Gun voltage 400kV.
Fast mechanical shutter is set to limit laser duty cycle to 0.5% (pulse duration 5msec)



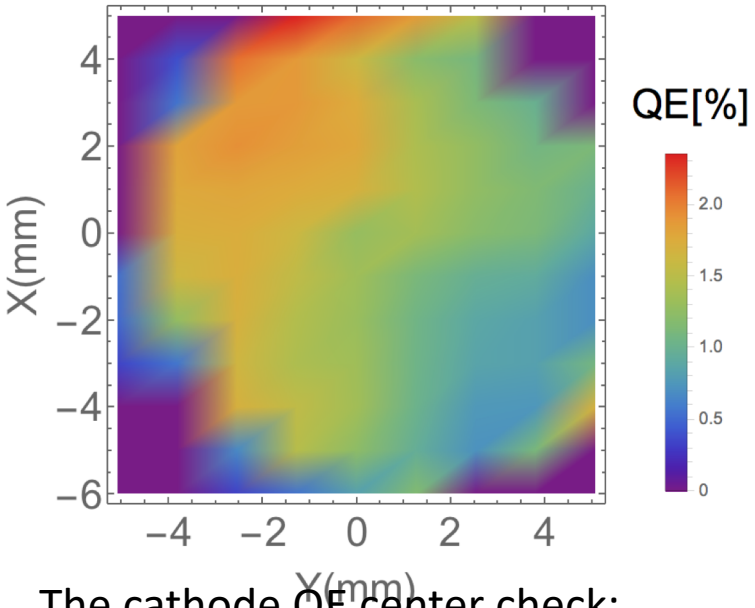
1 macro-pulse of 30 bunches per 1 second; each bunch is up to 130 pC;
macro bunch 4 nC,
maximum current I=4nA.



QE confirmation
If charge FC is low then 30 pC adjust laser intensity accordingly to reach desirable charge.

Cathodes (Na-K-Sb)

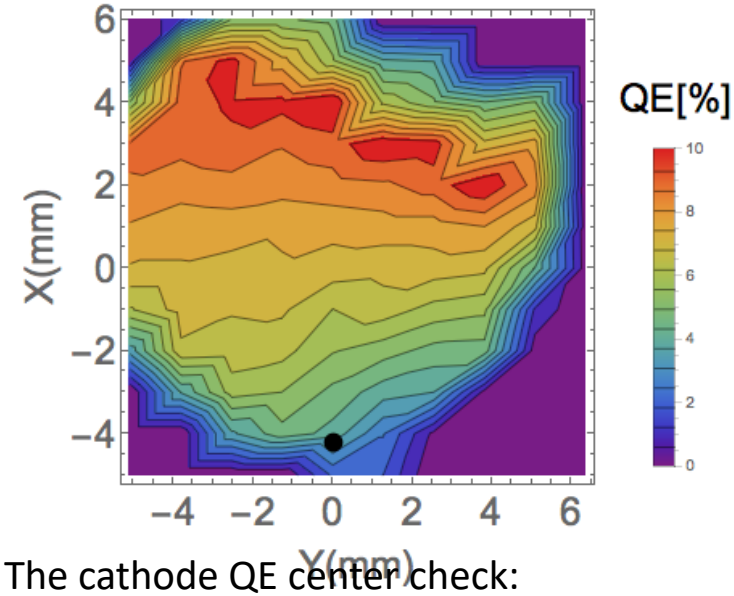
#1



The cathode QE center check:

- in lab: 1.8 %

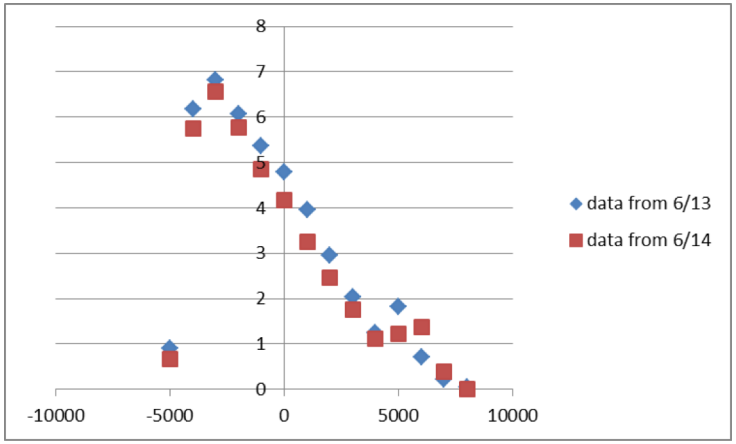
#2b



The cathode QE center check:

- in lab: 7%
- before bake: 6.3%.
- after load-lock baking: 0.35%.

#3

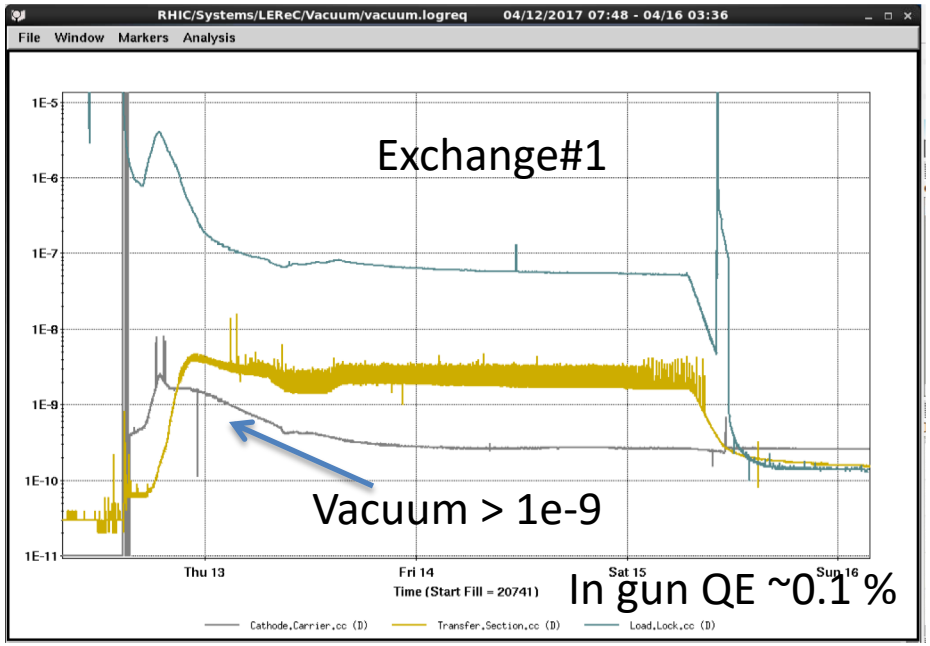


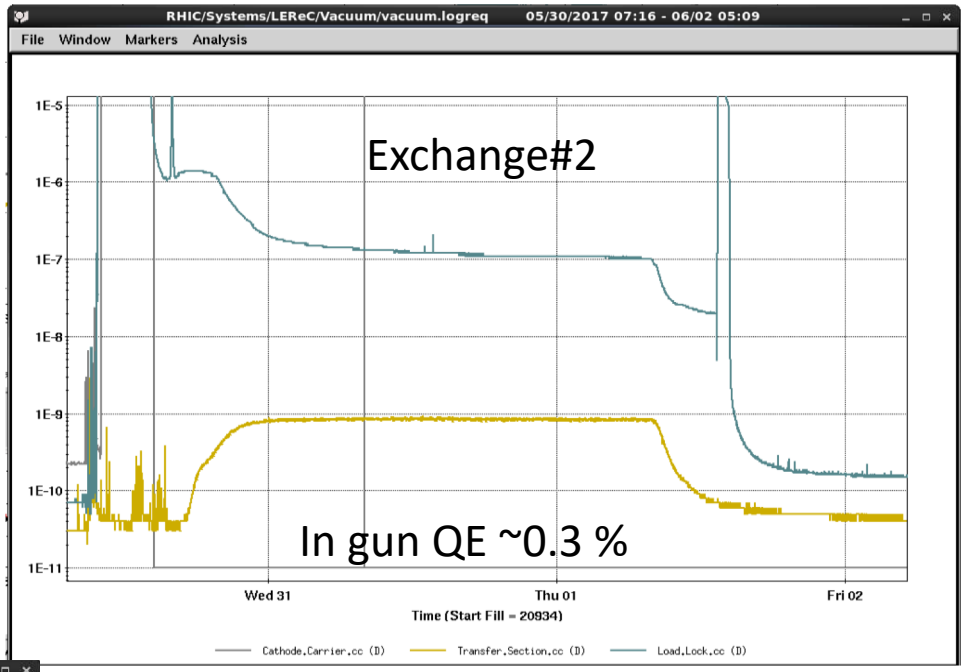
The cathode QE center check:

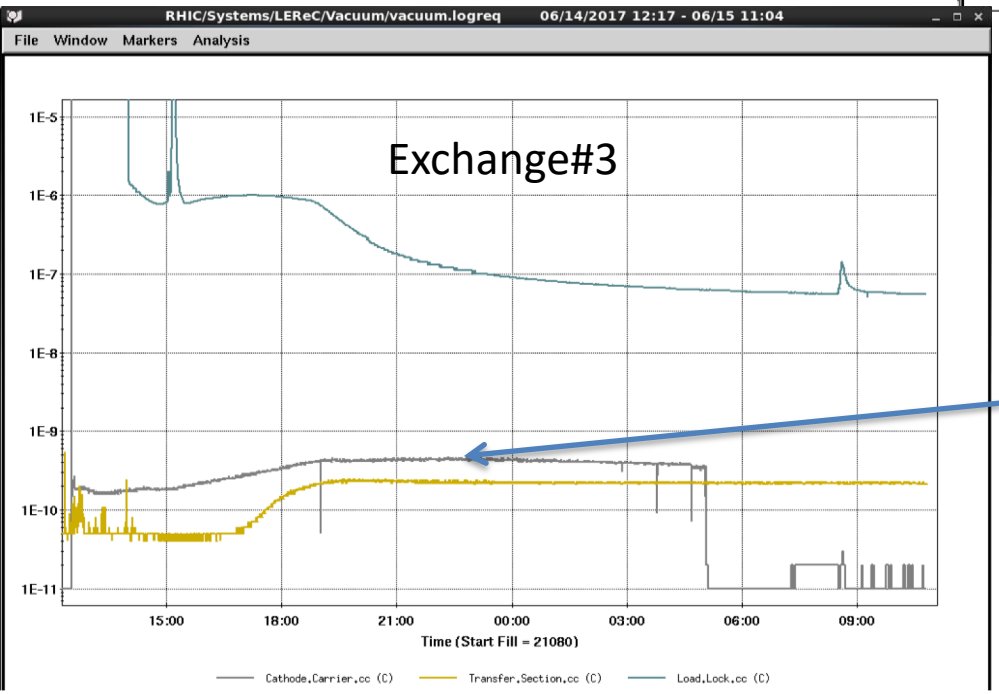
- in lab: 4 %

* More details T. Rao talk on Monday

Vacuum during load lock baking







Shorter bake time, gate valve cooling, retract cathode as far as possible from baking section

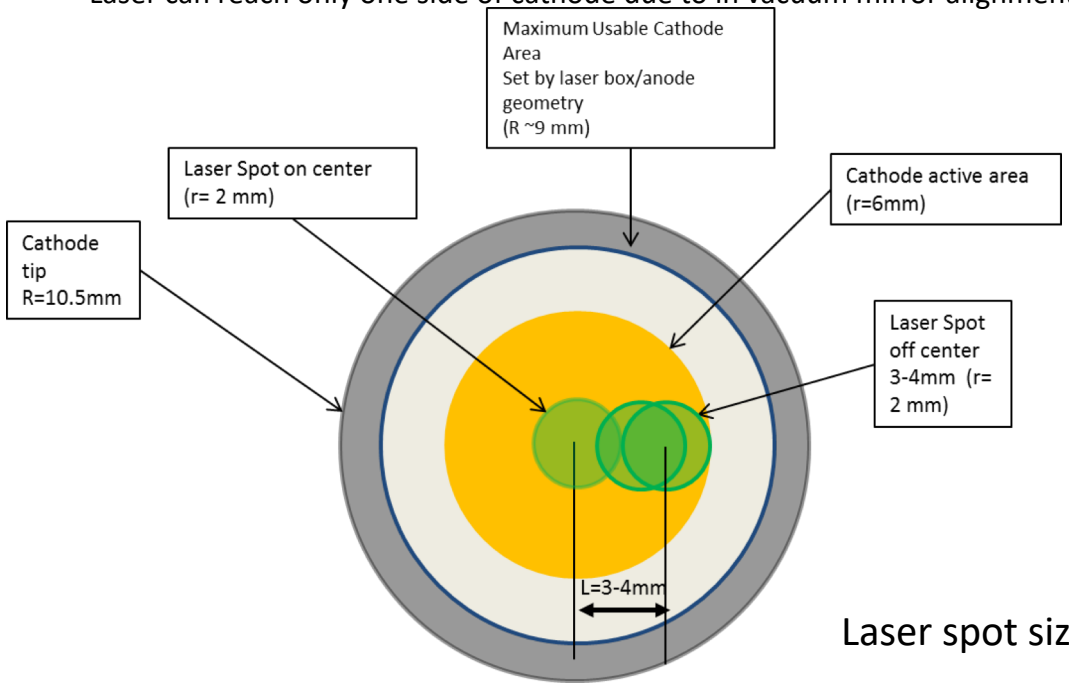
Vacuum < 1e-9

In gun checked QE ~1.2 %

LEReC Cathodes operations summary so far.

	Suitcase	Grow	Inserted	Removed	Lamp DC (POF)	Bunch Charge	Lab QE	In Gun QE (est)
Cath#1	#2	Jan 30	Apr 17	May 30	40 nA	25 pC	1.7%	0.1%
Cath#2b	#1	May 17	June 2	June 14	40 nA	33 pc	7%	0.3%
Cath#3	#2	June 13	June 16		150 nA	130 pC	4%	1.2%

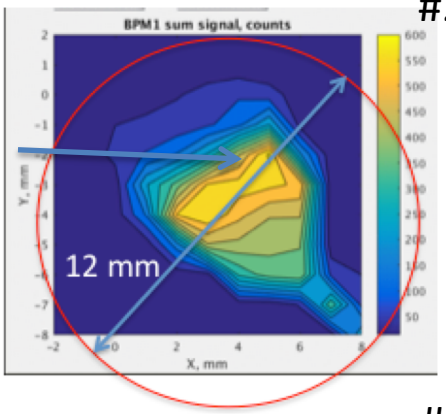
Laser can reach only one side of cathode due to in vacuum mirror alignment



QE scan in BPM sum signal

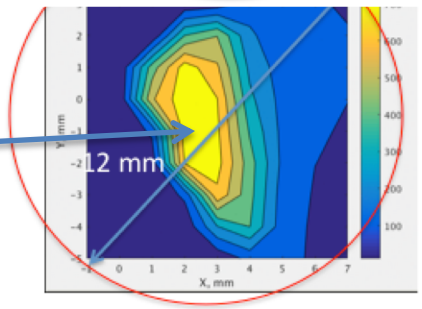
#2b

QE=0.3%



#3

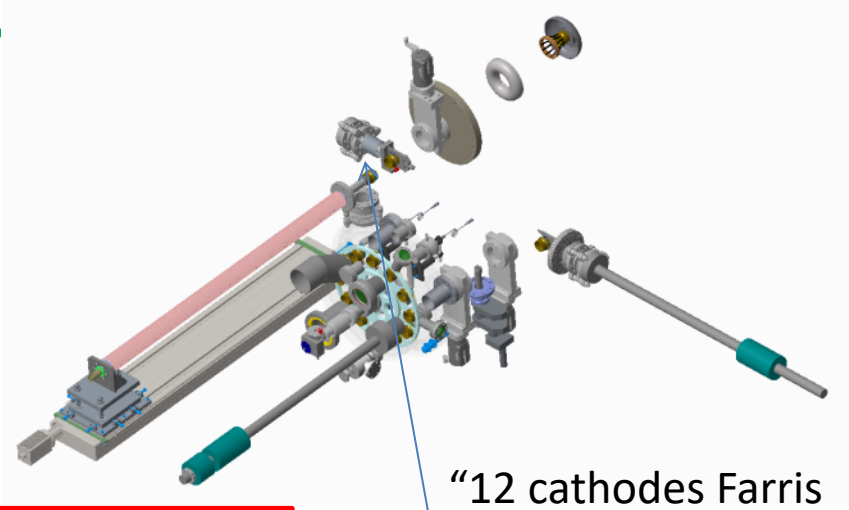
QE=1.2%



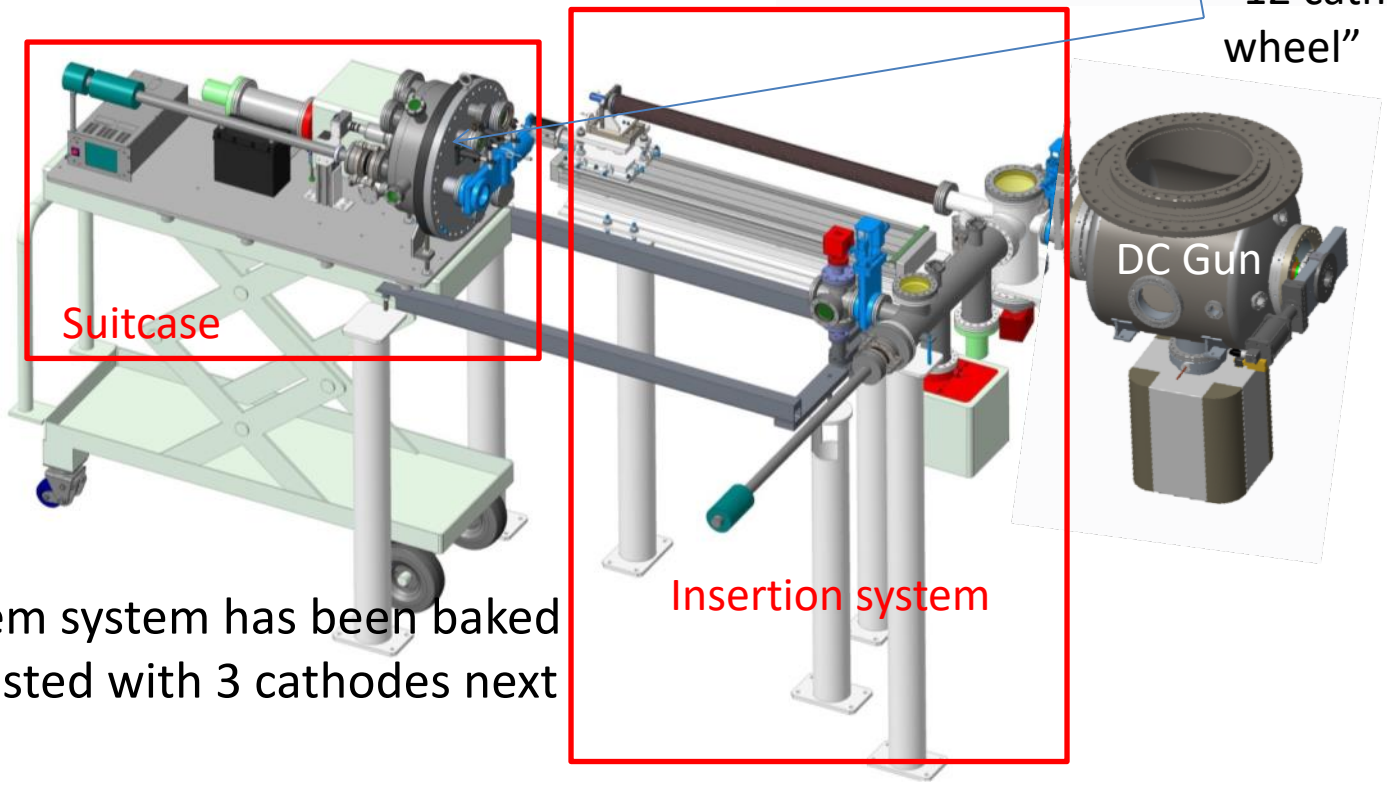
Laser spot size r= 2mm

Cathode delivery system

- In order to reduce down time due to cathode exchange we build 12-cathode transport system
- It will require one long access to swap systems and short access for replacing cathode cathode



"12 cathodes Farris wheel"



- One system system has been baked
- Will be tested with 3 cathodes next month

First photocurrent observed

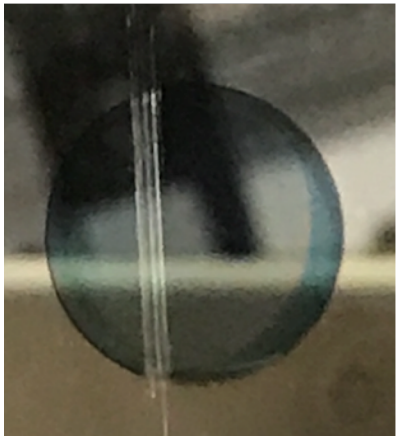
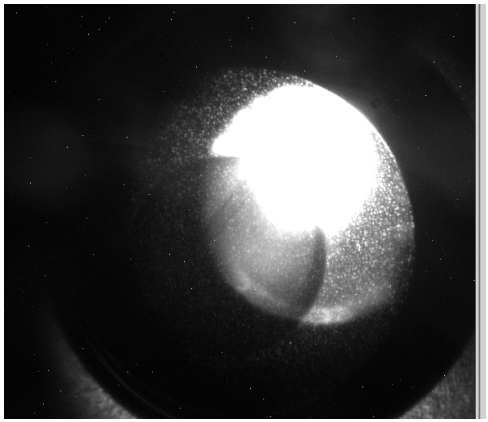
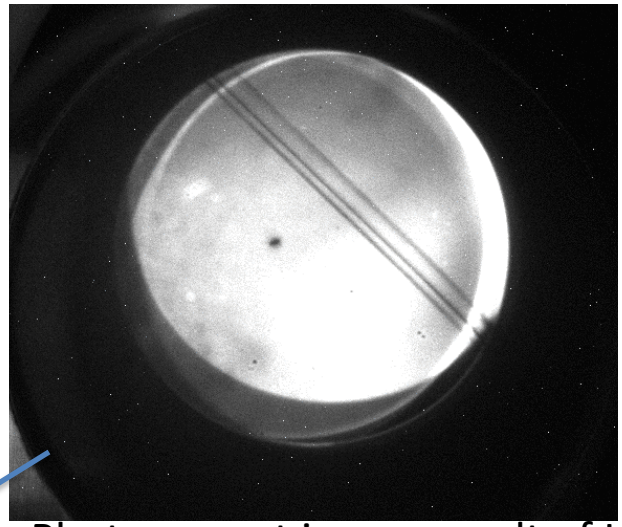


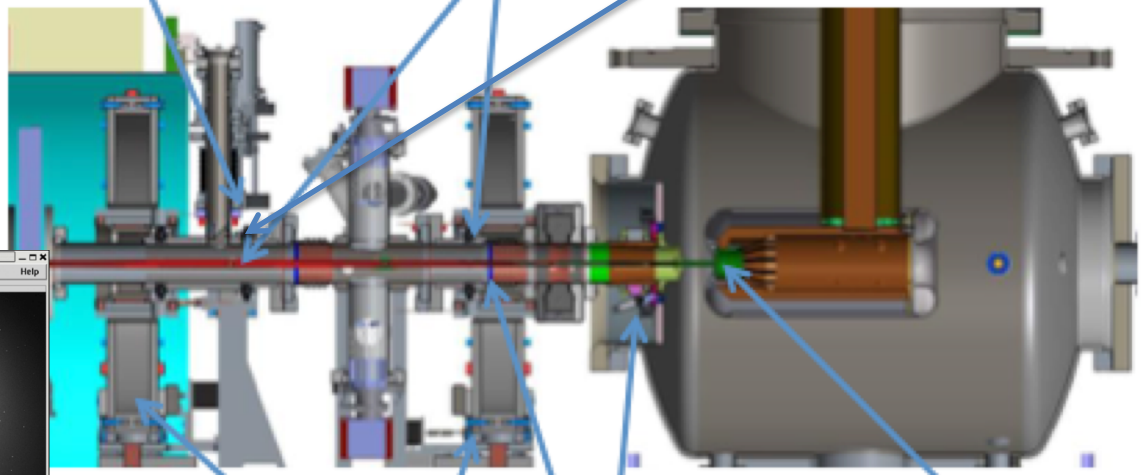
Photo cathode visible light image before installation



Cathode camera image with LED lamp on



Photocurrent image result of LED (beam profile monitor)



PM1 with illumination lamp on

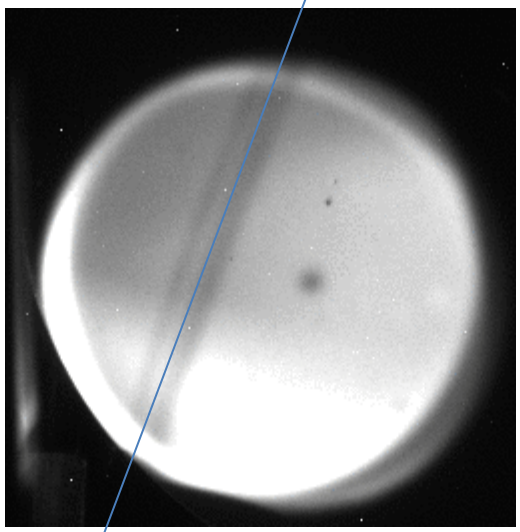
Beam (strips) based solenoid calibration check

Inj.sol1 YAg1

-dI

+dI

I=-7A



Positive current should rotate electrons clockwise

KE=300keV
Brho=2.1kG*cm
From magnetic measurements
Bdz/I=0.783kG*cm/A

I1-I2=14 A

Measured rot. angle 154 degree
With current change +/-7A

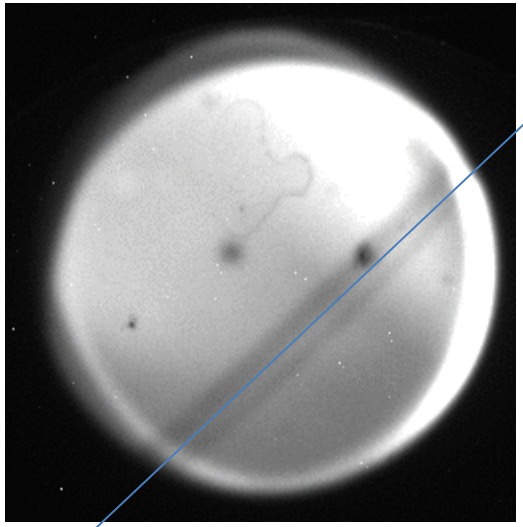
Expected angle 150 degree

Beam (strips) based solenoid calibration check

Inj.sol1 YAg1

-dI

I= 7A



+dI

Positive current should rotate electrons clockwise

KE=300keV
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From magnetic measurements
Bdz/I=0.783kG*cm/A

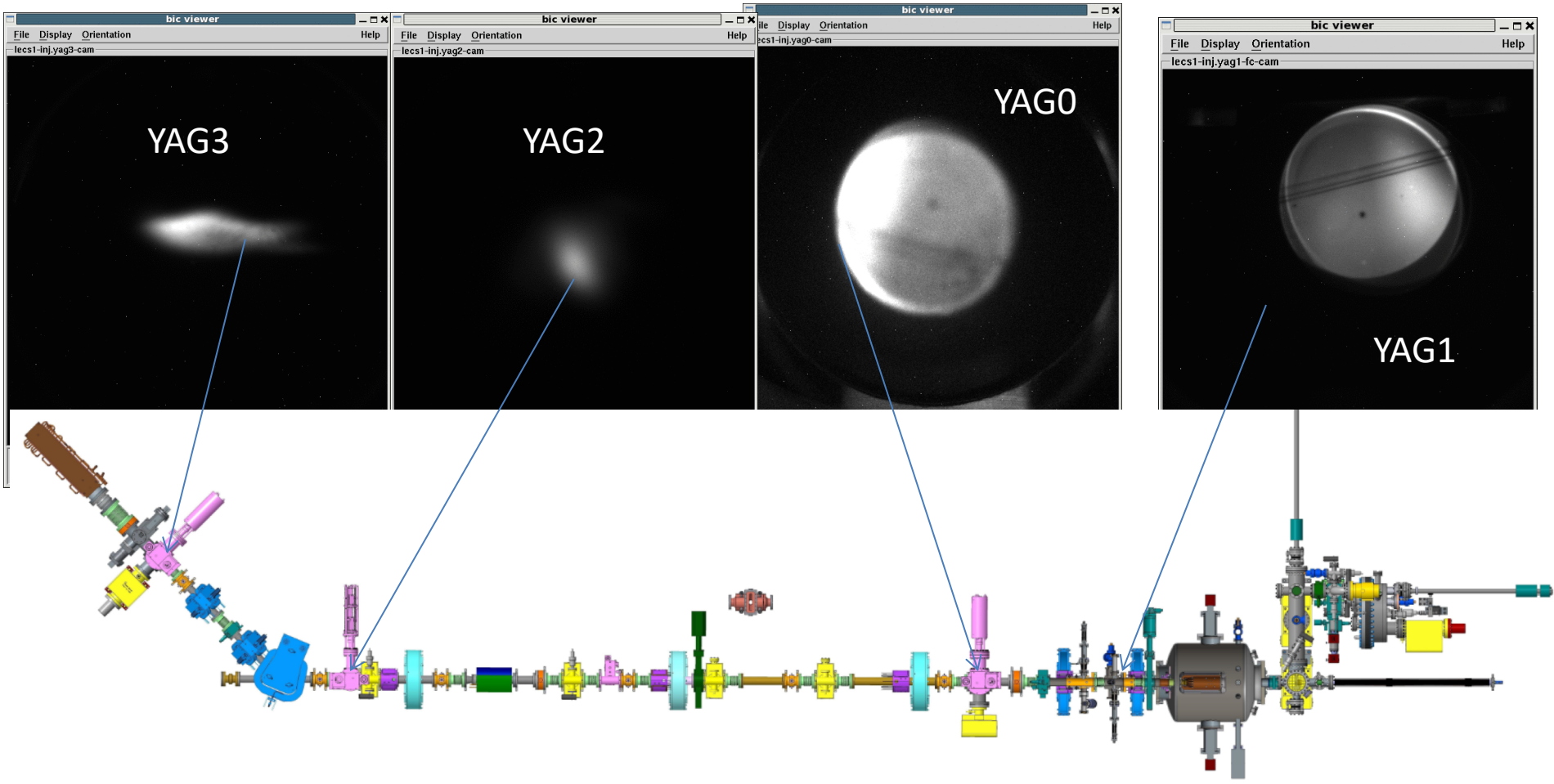
I1-I2=14 A

Measured rot. angle 154 degree
With current change +/-7A

Expected angle 150 degree

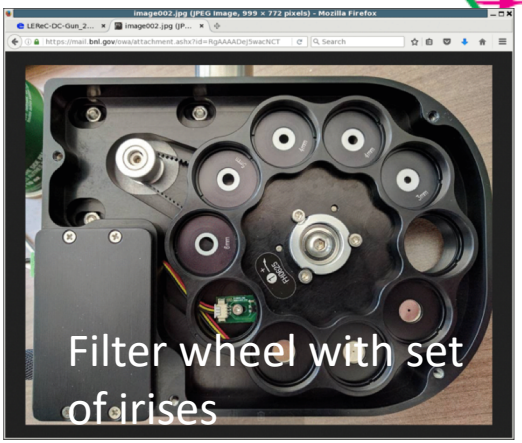
Gun to dump propagation

May 5, 2017, Lamp-beam



LEReC Laser system

976 nm
DM
DC YDF
976 nm
SC YDF
pulse picker
EOM
704 MHz fiber oscillator
704 MHz
RF system
ISO
WDM
ISO
ISO
ISO
DM
9.1 MHz
976 nm
85 μm, 80 cm rod fiber
ISO
DM
976 nm
0-5 kHz
85 μm, 100 cm rod fiber
MPS
PC
SHG
PC
IR output
Green output



Laser pulse shaping scheme:

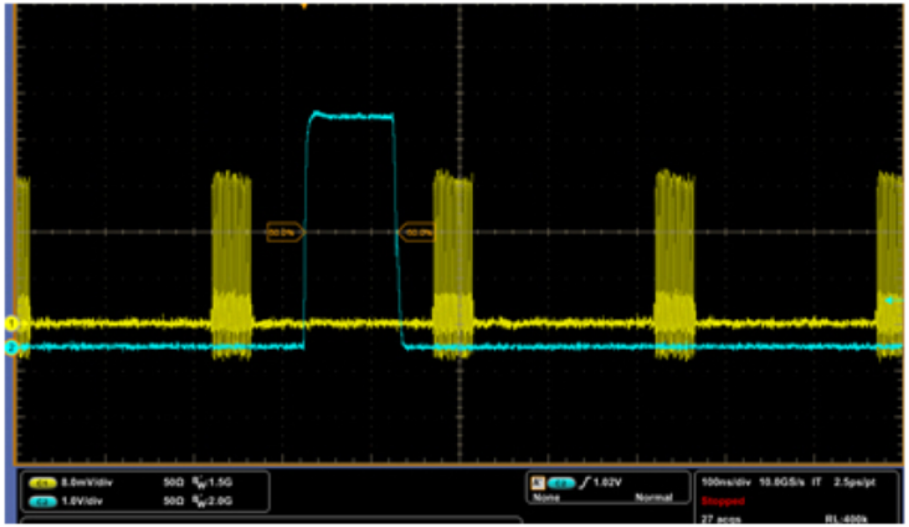
oscillator
704 MHz CW
Pulse picker
t
~1 ns (needs fast input signal)

9 MHz macro-pulses with N_b = 10 - 30
Train shaper
t
~5 ns

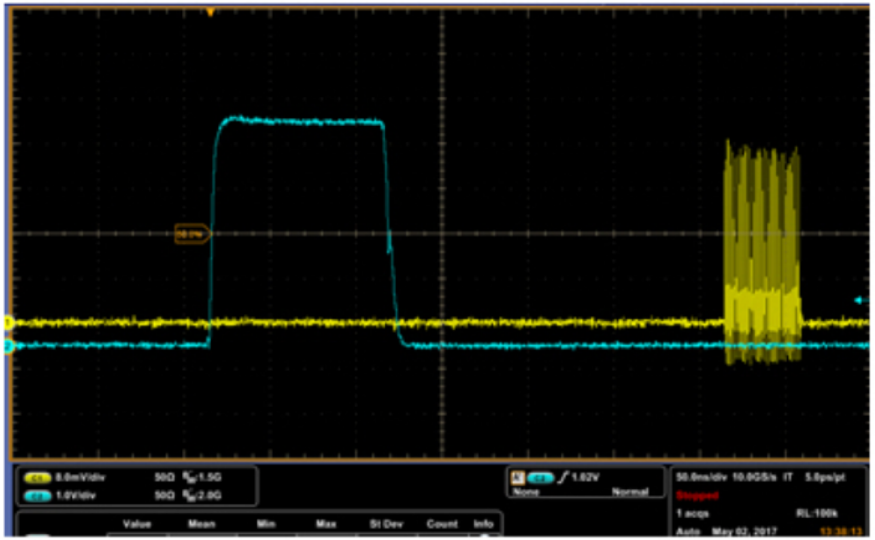
Trains of 9 MHz macro-pulses with any Δt and any T
Mechanical shutter
t
~2 ms

Laser single mucropulse operation

9 MHz bunch pulses



Single macro-bunch: 30 pulses/bunch



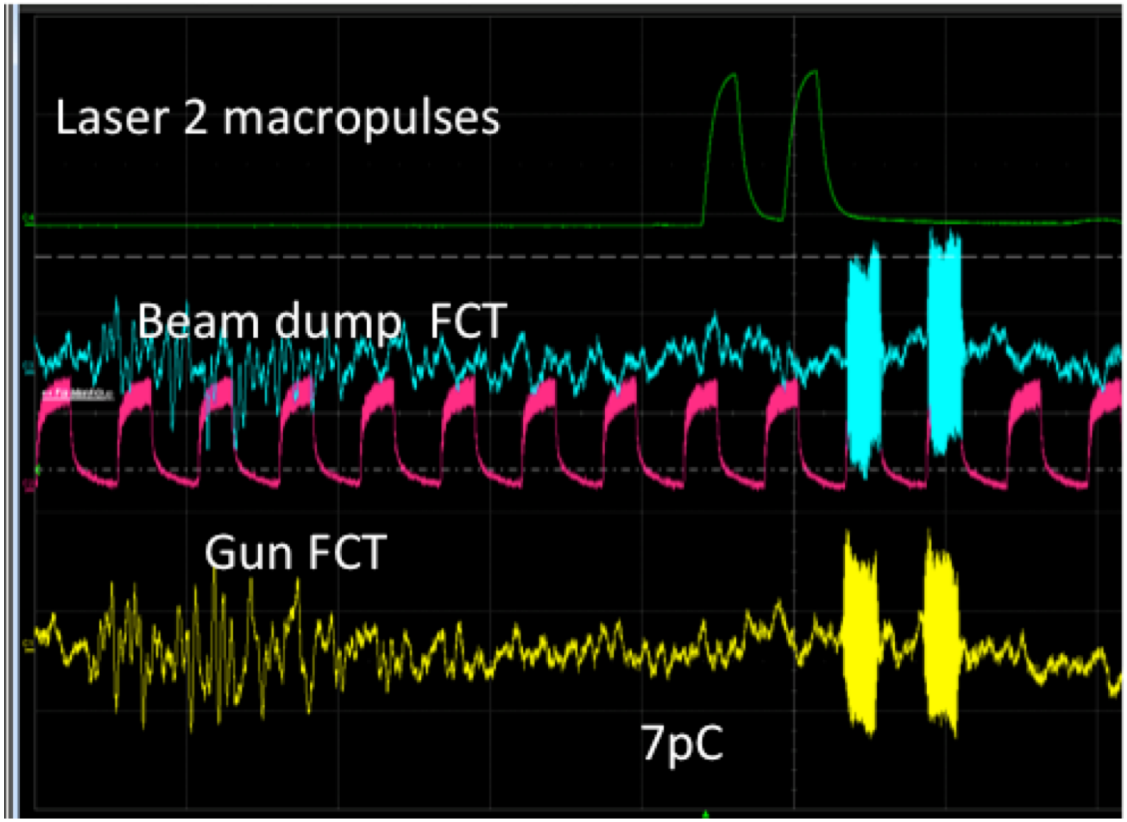
Laser macro pulse selection demonstrated extinction ratio of 1: 2E5 (5E- 6)

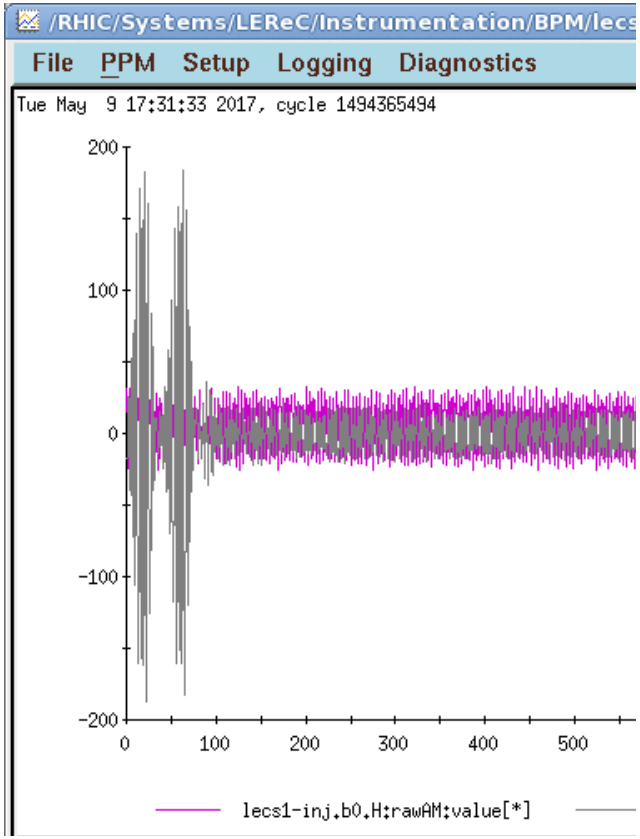
With fast mechanical shutter opened window 5 msec

It gives leakage current /single beam pulse ratio = 25%

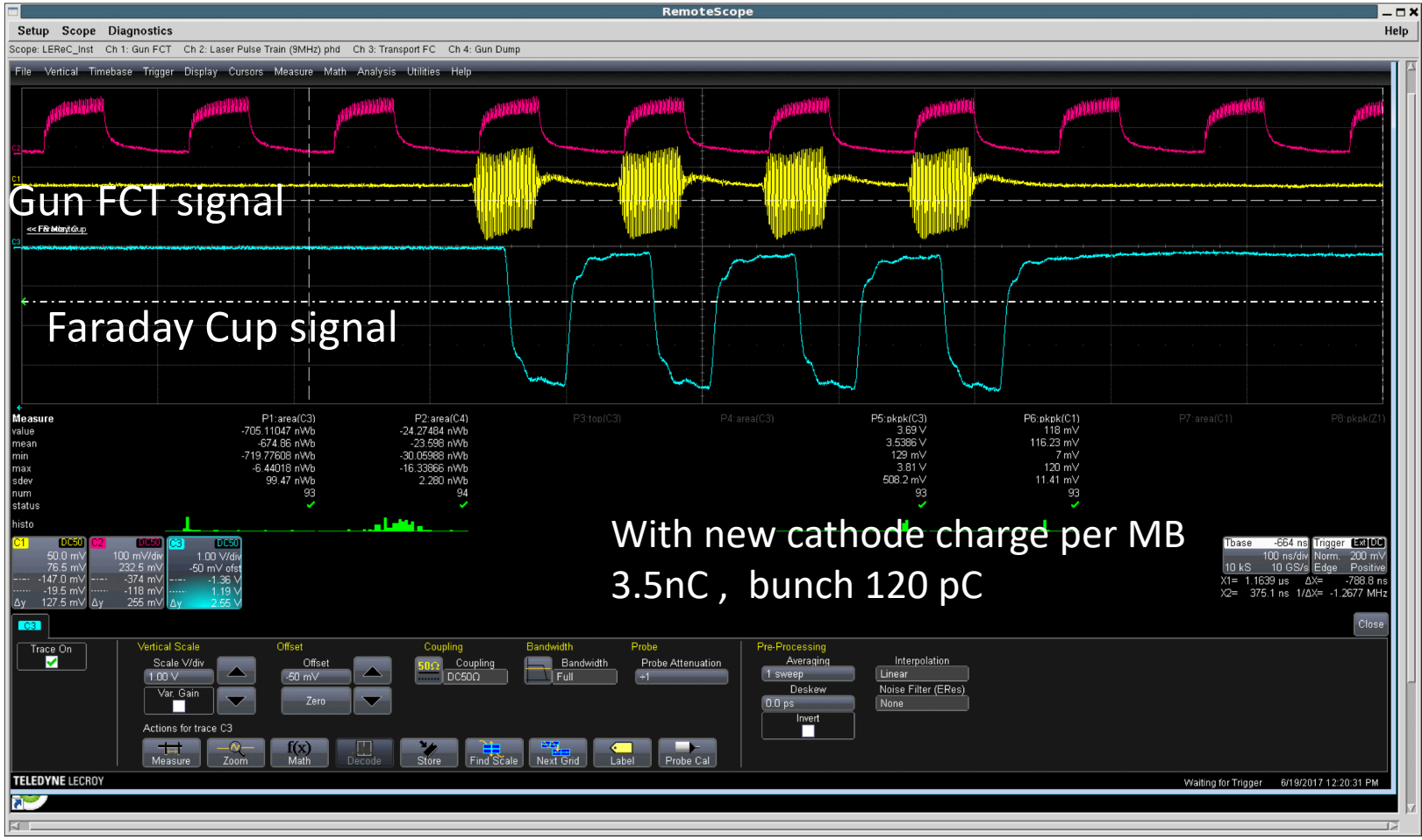
1st time observed pulsed beam at FCTs and BPM signals

After better laser alignment (~7 pC charge per bunch)



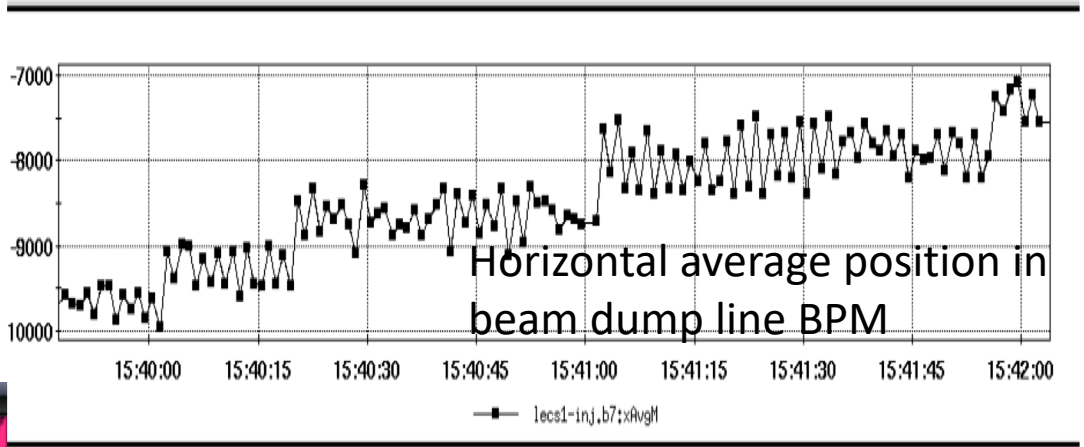


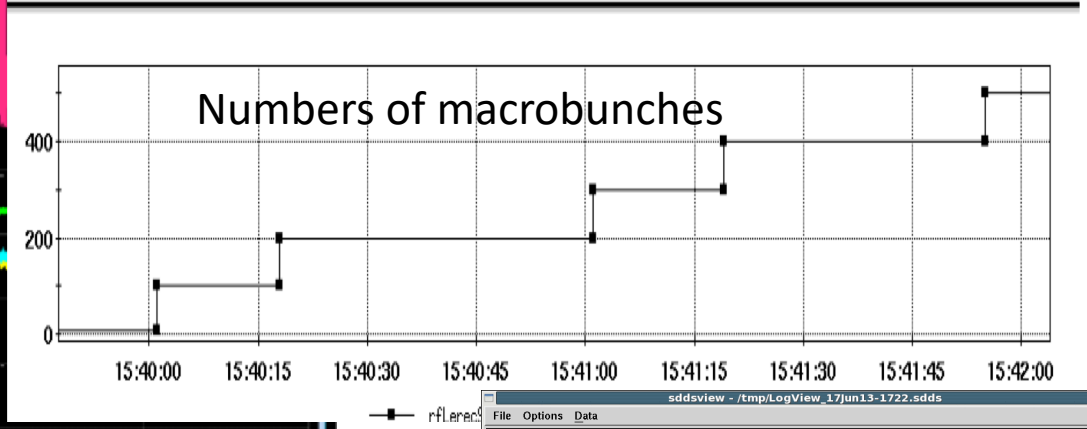
Pulsed beam operation

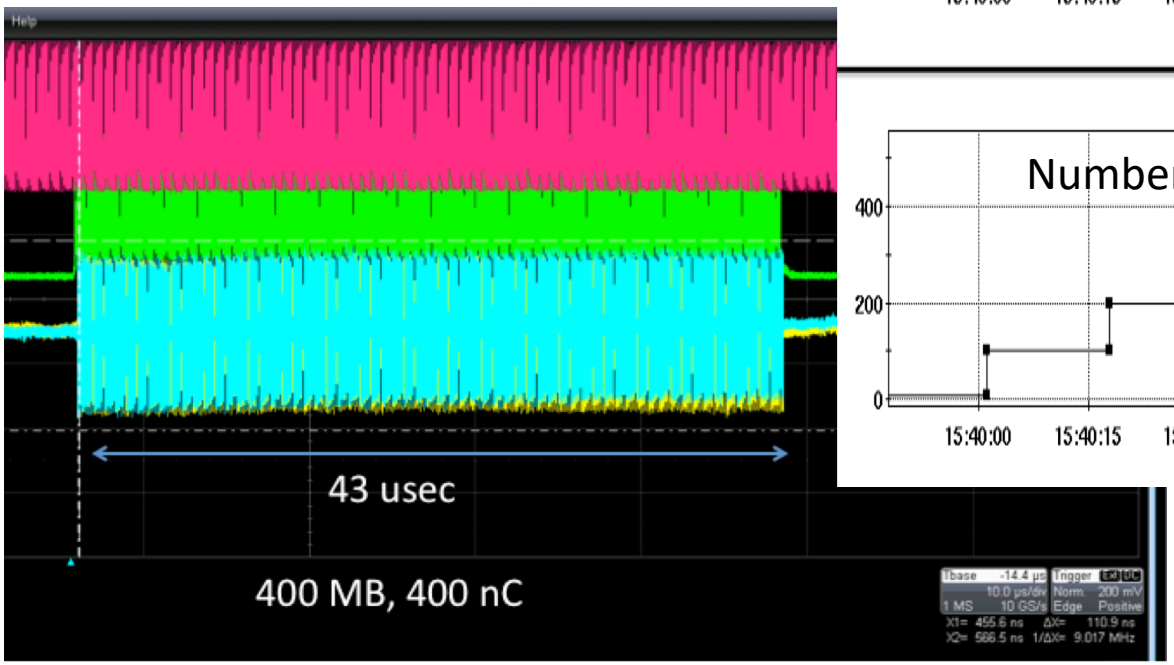


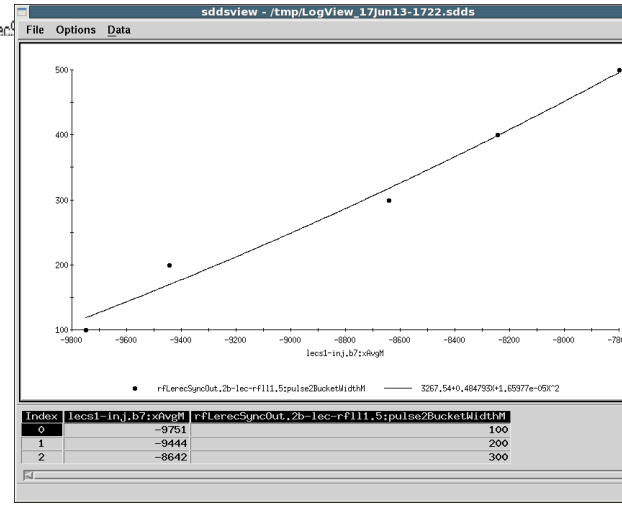
100-500 Macro Bunches test

Magenta 9.3MHz lR laser photo diode
Green: after PC and doubling crystal green laser photo diode
Yellow gun FCT
Cyan dump line FCT



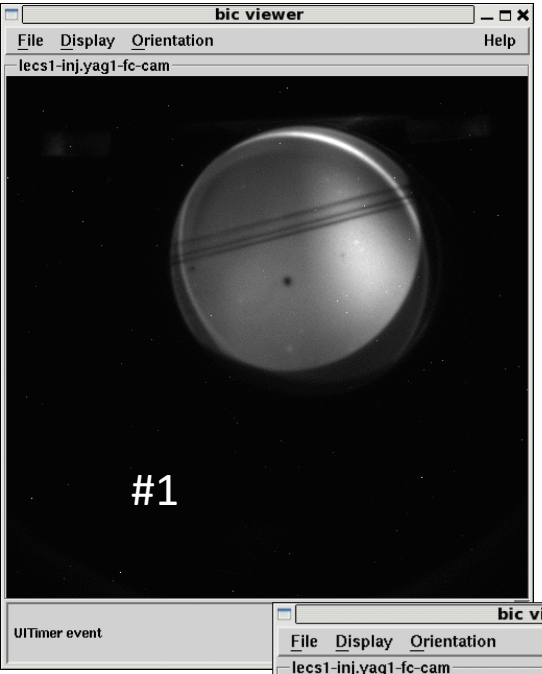


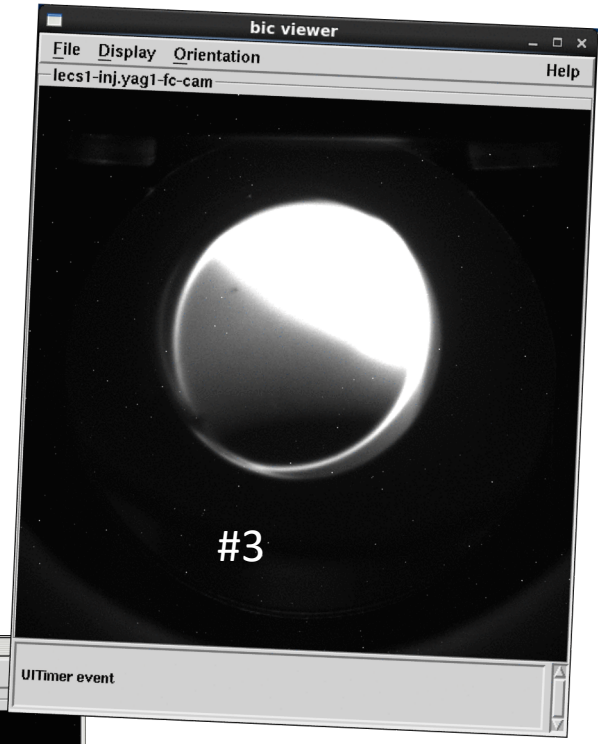


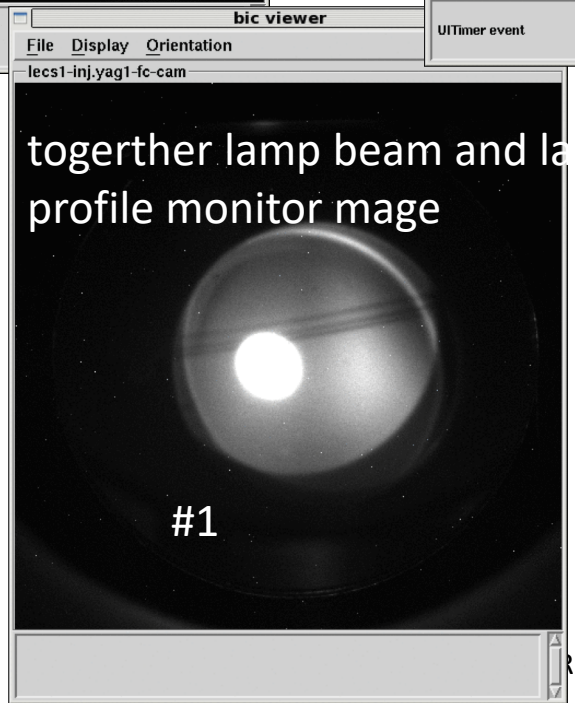


Dump FCT is showing losses towards the end BMP average position moved
Gun beam loading.

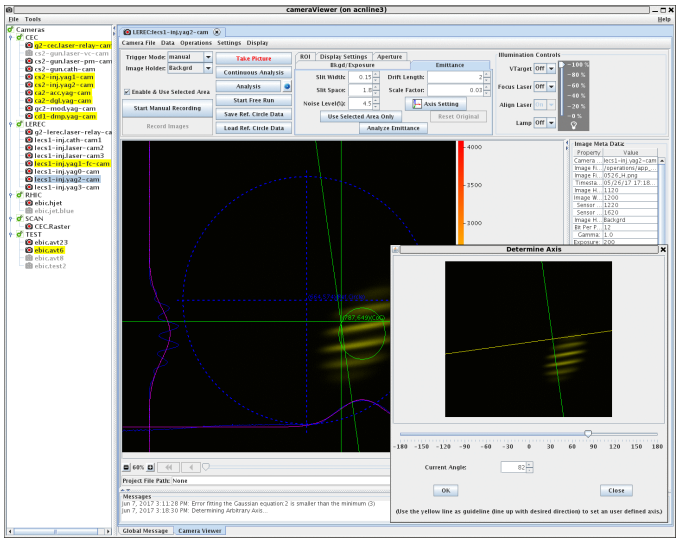
Cathode QE map snap shots

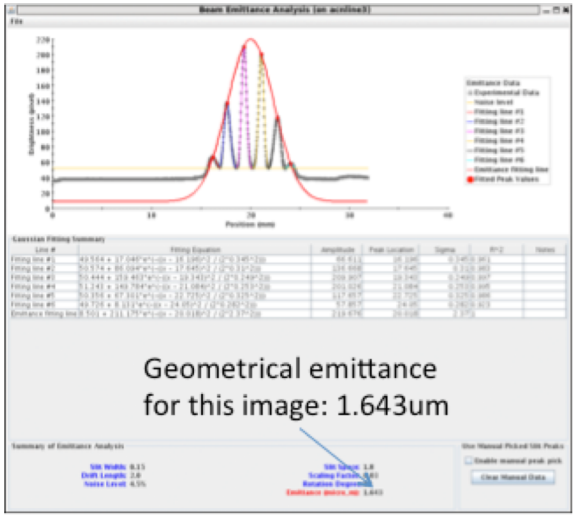






Few attempts for emittance measurements





Beam image with vertical slits (large)
Small beam is due to unwanted laser leakage

Attempt for solenoid scan

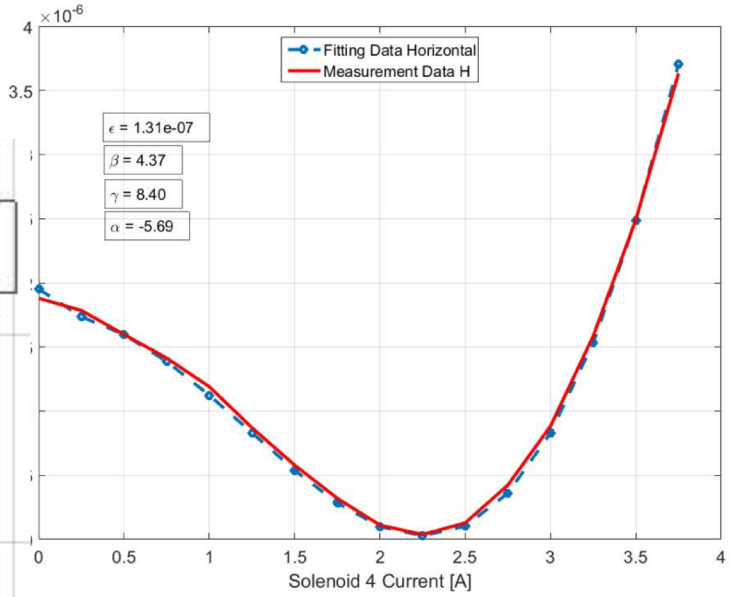
At nominal charge profile monitor camera image saturated.
Laser intensity reduced to 5%
Solenoid scan at very low charge

ϵ = 1.31e-07

β = 4.37

γ = 8.40

α = -5.69



Mile stones

HV DC gun installed and conditioned up to 450 kV	Nov-Dec 2017
Cathode with QE > 2% has been grown	Jan 2017
Beam line components installation completed	Mar 2017
DC gun routinely operates with beam at 400kV	Apr 2017
First DC beam (lamp beam) delivered to beam dump	Apr 2017
Laser with time system ready for beam test	May 2017
Beam diagnostics has been tested with beam	Apr-June 2017
Beam with charge 130 pC per pulse delivered	June 16, 2017
Beam studies starts	

Summer 2017 plans (before SRF booster installation start)

Measure beam quality at design charge 130-200 pC
Test multi-cathode transport system (Ferris Wheel)
Increase operation current to 10-20 mA
Study cathode life time in transport system and in operation

SUMMARY

- To reduce risk we start testing DC gun photoinjector for LEReC during RHIC Run 17.
- Gun test is designed to provide initial studies of DC gun performance and test key concepts for LEReC commissioning: MPS operation, cathode delivery system, laser system, high average current capability etc.
- The beam line optics is flexible enough to accommodate different charges required for later stages of LEReC operation.
- Bunch charge 130 pC with k. energy 400keV delivered to beam dump
- Beam instrumentations have been tested/cross calibrated
- We are looking forward to carry out beam quality studies and start gradually increase current

Thank you!