Low Energy RHIC e-Cooler

DC gun test: commissioning plan

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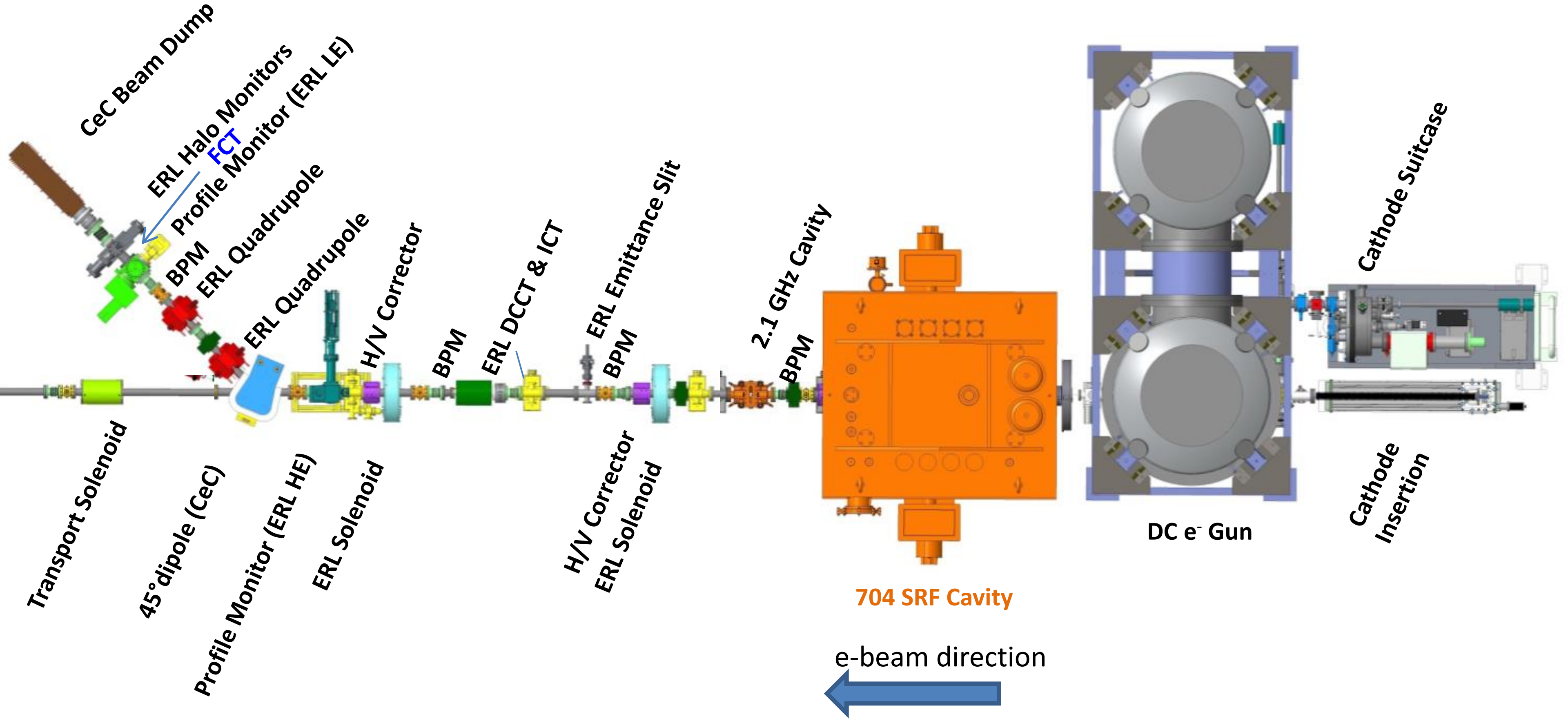
Aug-11, 2016

Purpose of this meetings

- Installation and schedule is well discussed during Joe's meetings (only short summary)
- We should discuss strategy/schedule/procedures/instructions required to make the commissioning task as smooth as possible.
- We will start discussion and collect feedbacks on issues relative to beam commissioning and pre-beam commissioning activities.

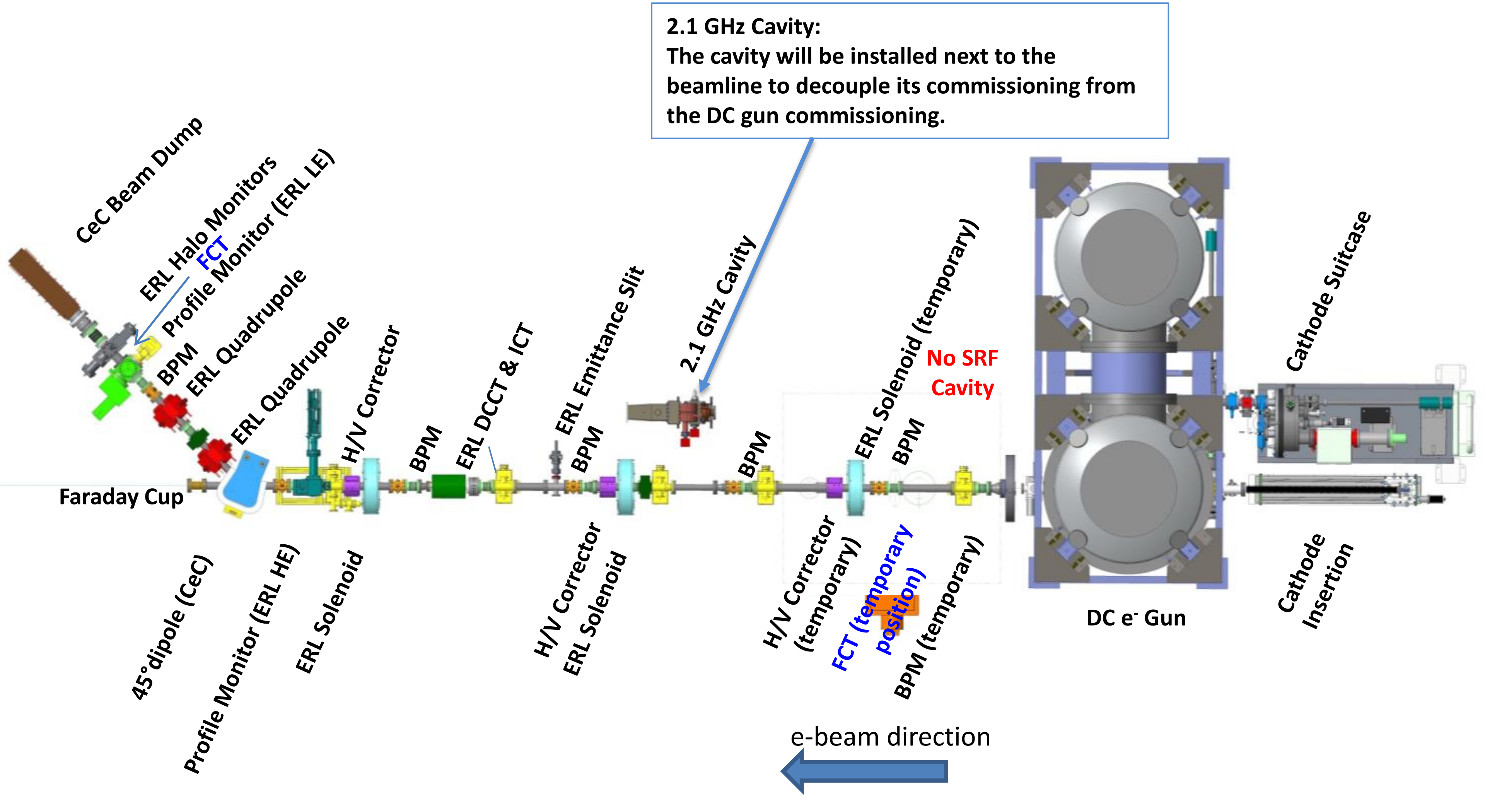
- We will use this meeting to share progress between different groups so we all will be at the same page of this project.

LEReC Injection section (zoom in)



DC gun test setup 2016-2017

no RF components in beam line



LEReC Gun test is the first stage of LEReC configuration.

The goal : test critical LEReC equipment in close to operation condition.

Components to be tested:

- Laser beam delivery system (laser, laser shaping, laser transport, laser pulse stability etc)
- Vacuum components with control
- Cathode manipulation system
- DC gun characterization (stability, maximum operation voltage, electron beam quality)
- Magnets, power supply.
- Beam instrumentation: charge and current measurements, beam position (response matrix) measurements, beam loss monitor system, beam profile and halo measurements
- Control system (timing system, machine protection system, control of laser, gun power supply, magnets power supplies, beam instrumentation)
- High average power beam extraction and beam dump system.

Beam parameters

Parameters	LEReC requirement	DC gun test
Charge per pulse	130-200 pC	30-130 pC
Laser maximum rep rate	704 MHz	704 MHz
Macro bunch charge	4 nC (30x130pC, 20x200pC)	3.9 nC (30x130pC)
Macro bunch rep rate	9.3 MHz (CW)	9.3 MHz (low duty cycle)
Average current	35 mA	25 mA
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

DC gun test commissioning during Run17

Exemption (rad below 5mrem/hr, allowto run 25 kW at KE= 400kV)

At start up (low average current (average power <10W)):

- **Launch the first beam from the gun.**
- Beam instrumentation setup/calibration
- Measure beam parameters
- Commission timing and synchronization system
- Train personnel to operate LEReC photoinjector and support systems
- Measure QE and lifetime of the Multi Alkaline photocathode
- **Finalize cathode replacement procedure**
- **Commission high repetition rate MPS (current losses limitation, BPM signals, beam loss monitors)**

Few mA average current (used to be high average current)

Beam dump limit

Delivery 400keV x few mA electron beam to the dump <10kWatt

Needs clarification at what power level or other condition ARR is required?

Beam power limitations

- In normal operation DC gun voltage is fixed at 400kV. The highest gun voltage is limited by maximum power supply voltage.
- The average current is limited by average laser power and measured cathode QE.
- Ask for exemption up to 25kW average power for 400kV

Gun beam test: prerequisites

- All equipment installed, paper work, check off lists and training completed.
- Gun conditioned to 500kV all remote controls available.
- All magnets measured and satisfied requirements.
- Laser tested and synchronized with RHIC? or RF?
- **Timing system tested**
- Cathode deposited QE satisfied.
- Cathode transport system tested ready to use.
- All magnets polarity checked and coil connection confirmed.
- **Beam instrumentation/ control calibration without beam on the test-bench completed.**
- MPS is ready, tested (dry run)
- All controls are tested (dry run).
- GPMs and loggings are available. (dry run)
- Tools (applications) are developed and tested (dry run).
- u-metal shielding installed around open vacuum pipes.
- Permit to start beam test is received.

Each system leader has indicated that their system is ready for beam test:

- Vacuum,
- DC Gun,
- Laser and Laser transport
- Controls Timing system
- MPS,
- Instrumentation,
- Water

DC gun HV conditioning tests

The key goals :

- Test DC gun and gun power supply to reach voltage on 500kV.
- Verify that all systems work reliable and stable: controls, water, MPS, good vacuum.
- Reach 500kV and stay stable for an hour
- Dark current less than 0.5uA
- Develop and finalized DC gun operation procedure

Plan is to start gun conditioning at IP2 under the “DC gun test exemption “

DC Gun HV conditioning tests

- DC gun conditioning will be performed with dummy cathode plug inserted during gun assembly (in clean room bldg 912) (with no photo material deposited).
- The first LEReC DC gun conditioning will be carried out at Cornell university site. It will be performed by Cornell experts and BNL trainees.
- Other tests will be performed after receiving and installation gun at final location BNL RHIC IP2.
  - High voltage power supply/DC gun expert (on shift)
  - MPS, controls, instrumentation are required during first attempts, then on call
  - Vacuum, water, control and other experts (on call).
- The cathode HV conditioning may required if significant dark current observed after multi alkaline cathode installed.

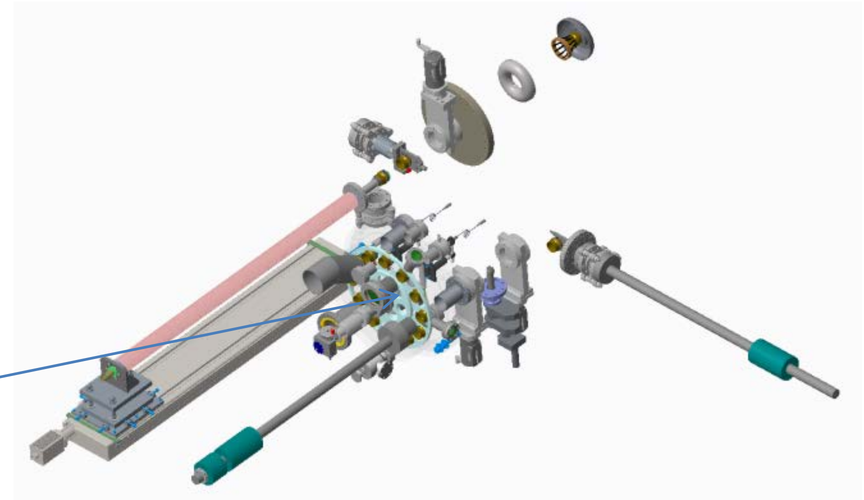
Condition gun at nights and on weekends

Need MCR/CAS support for sweep

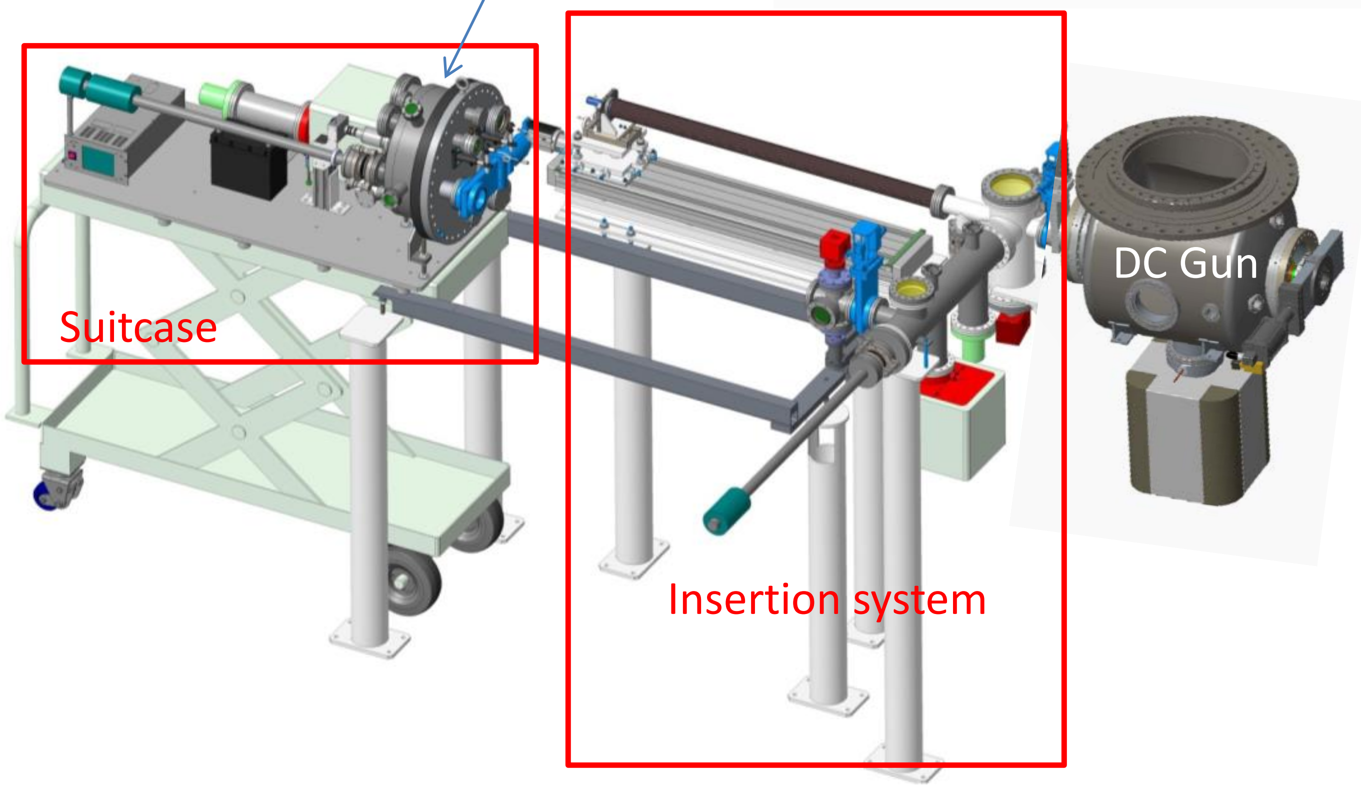
MCR support for conditioning?

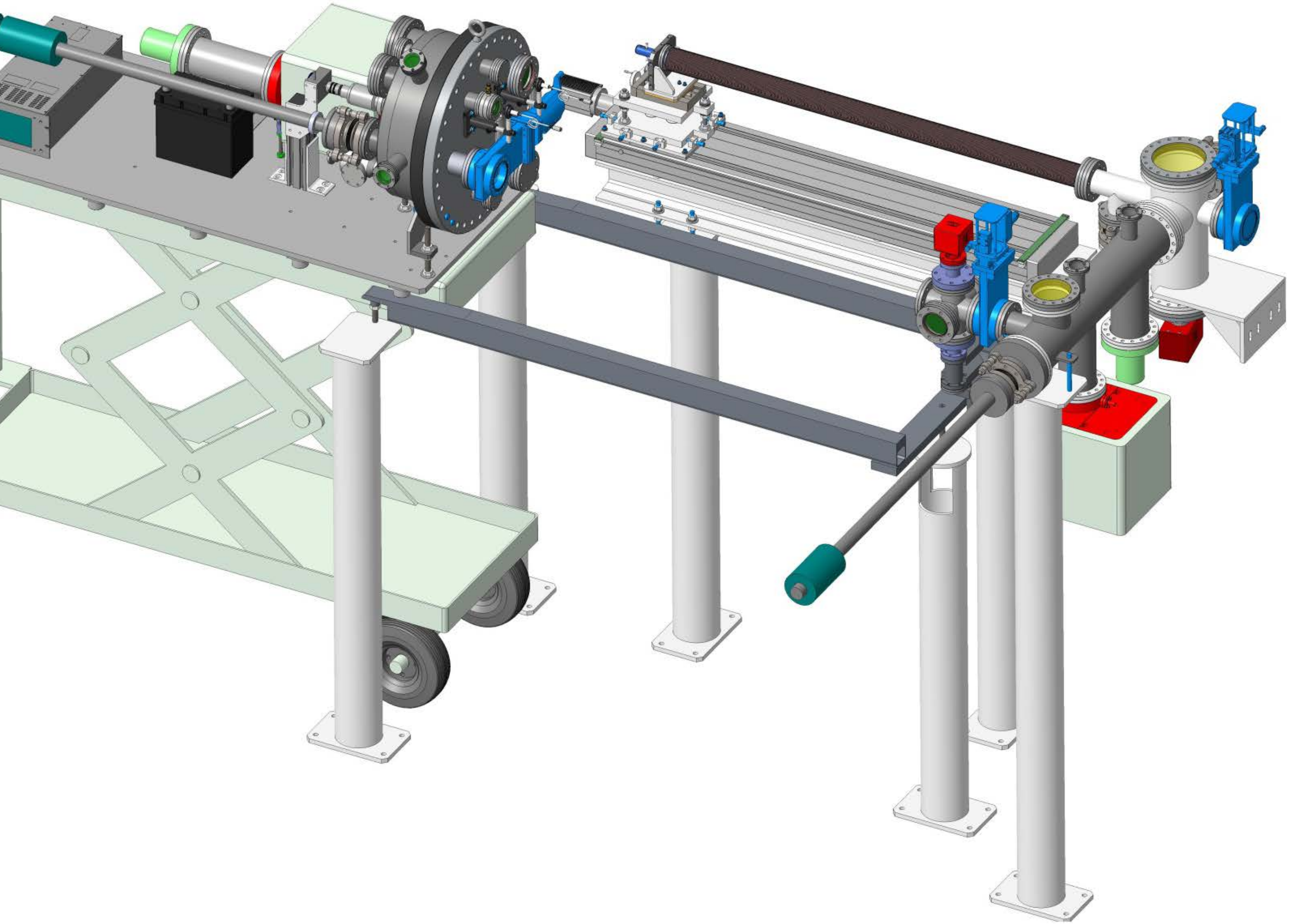
Cathode delivery system

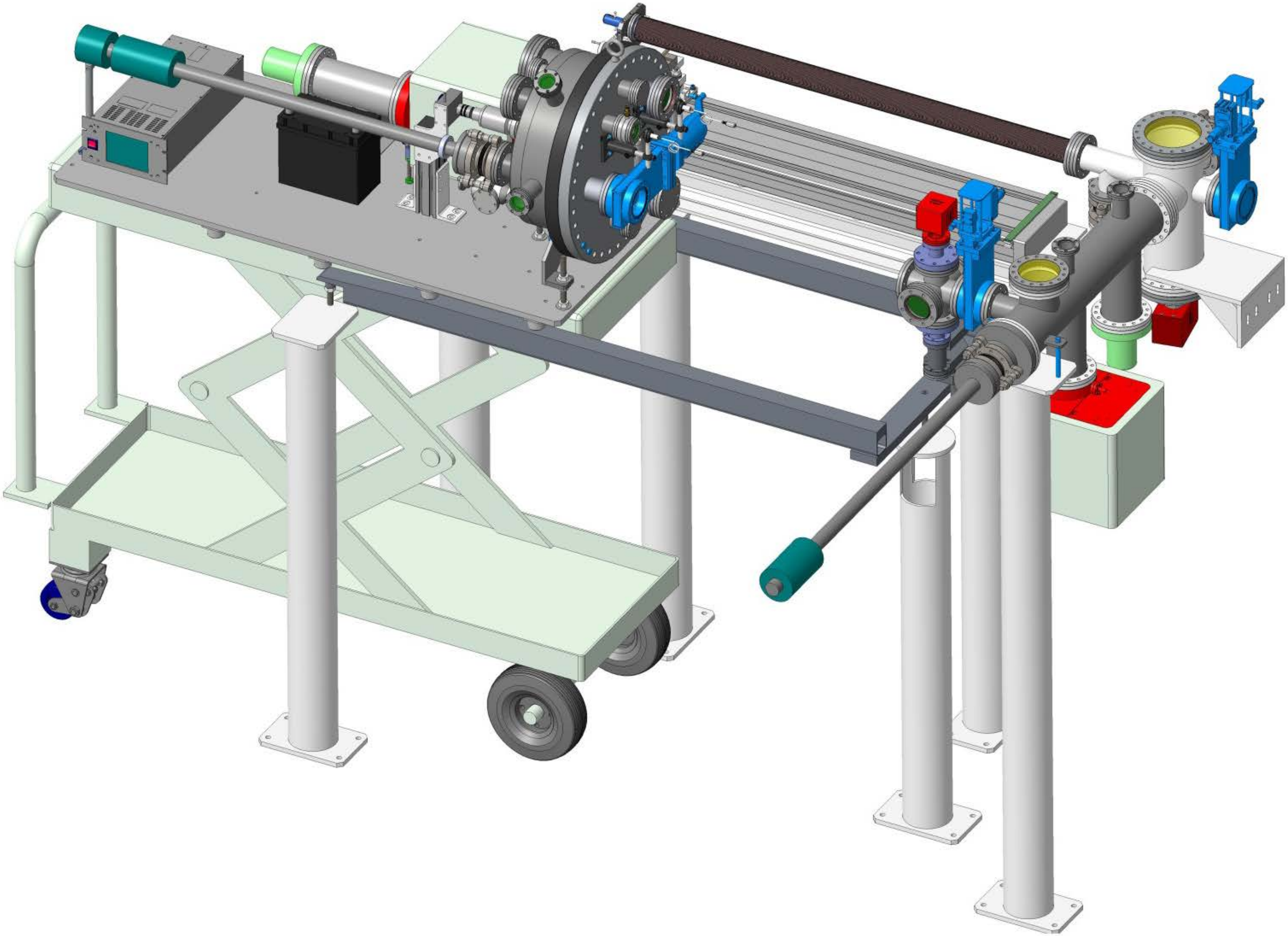
- Deposition
- Transport (suitcase) system
- Insertion

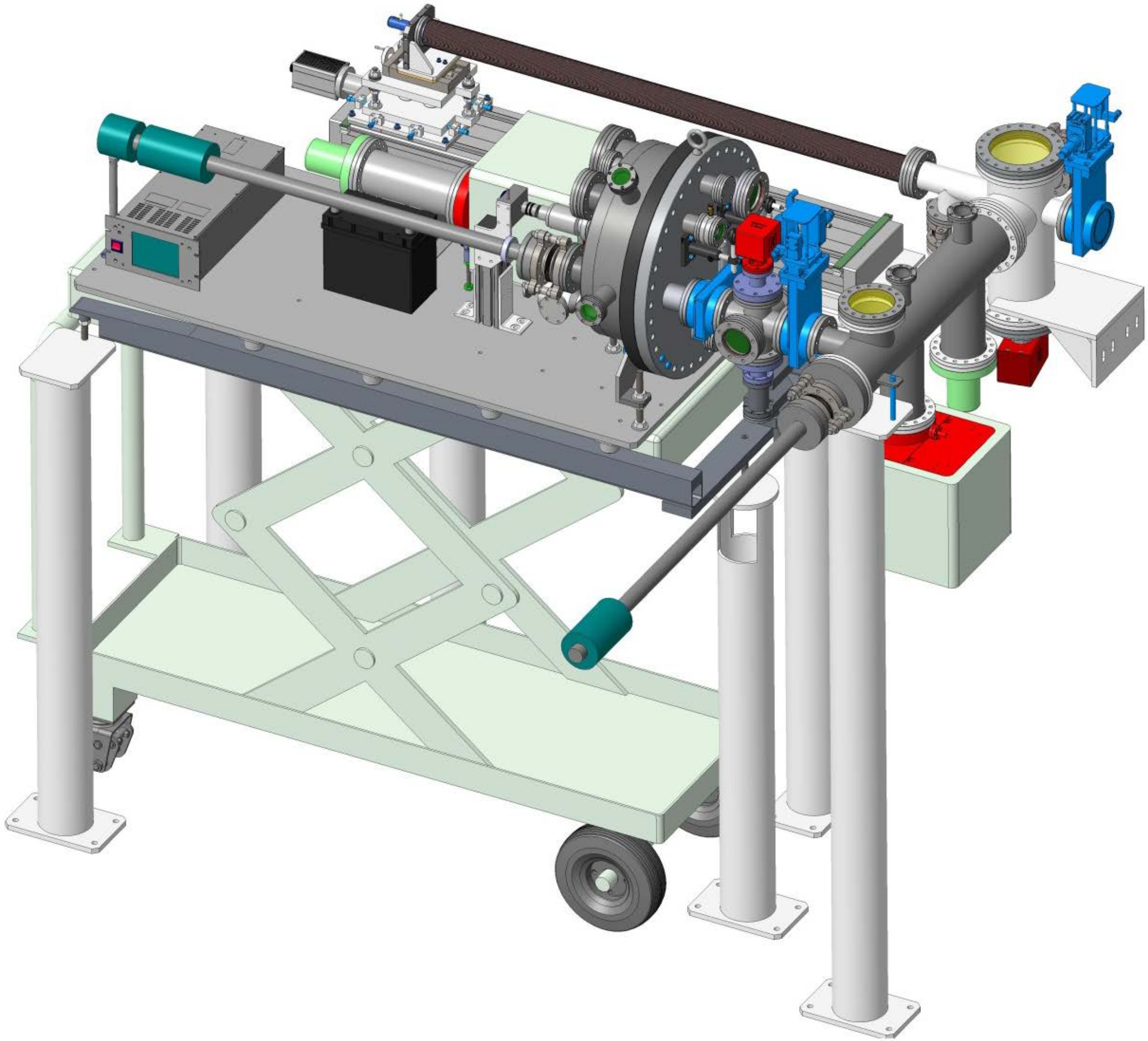


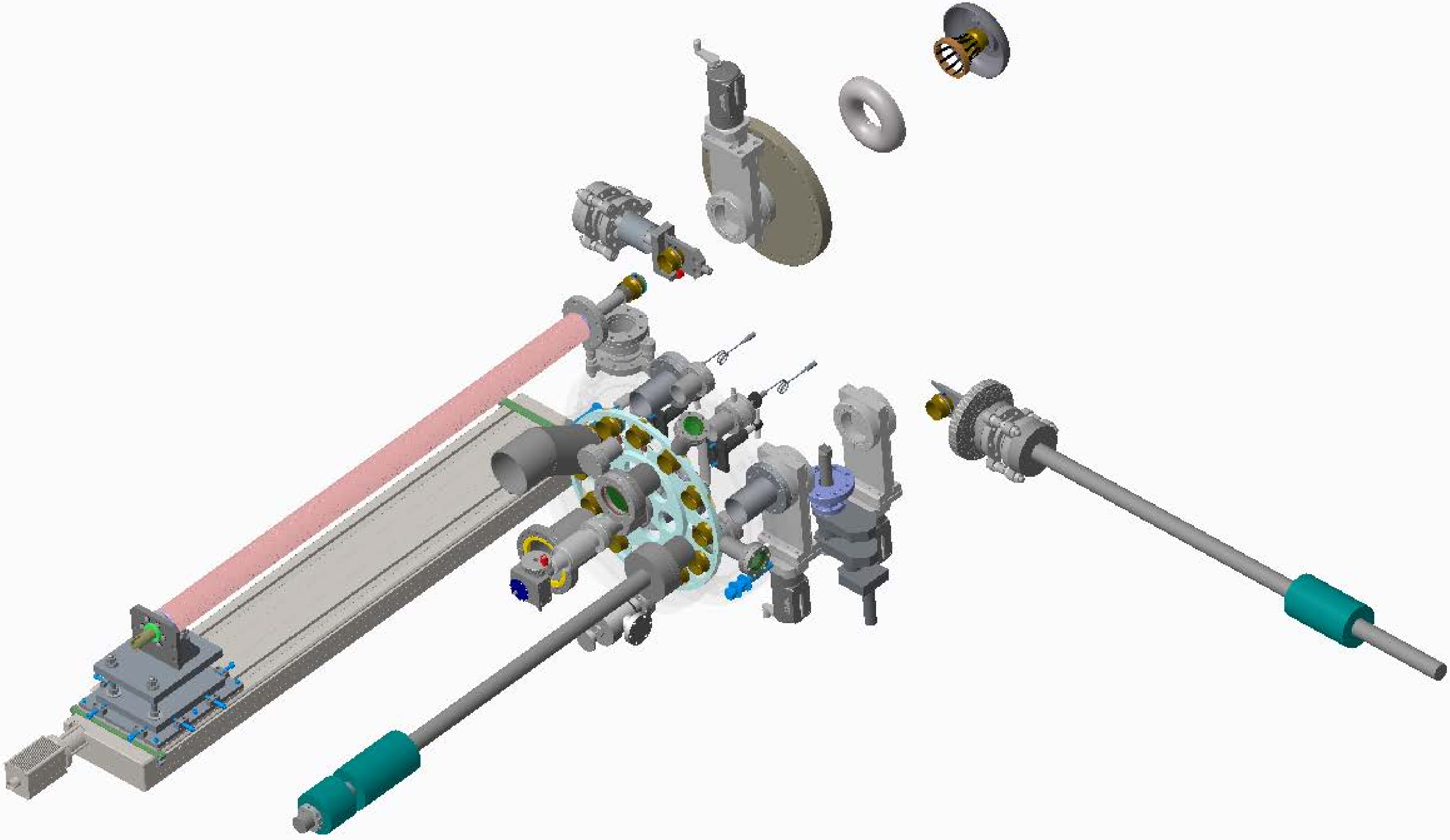
"12 cathodes Fair wheel"



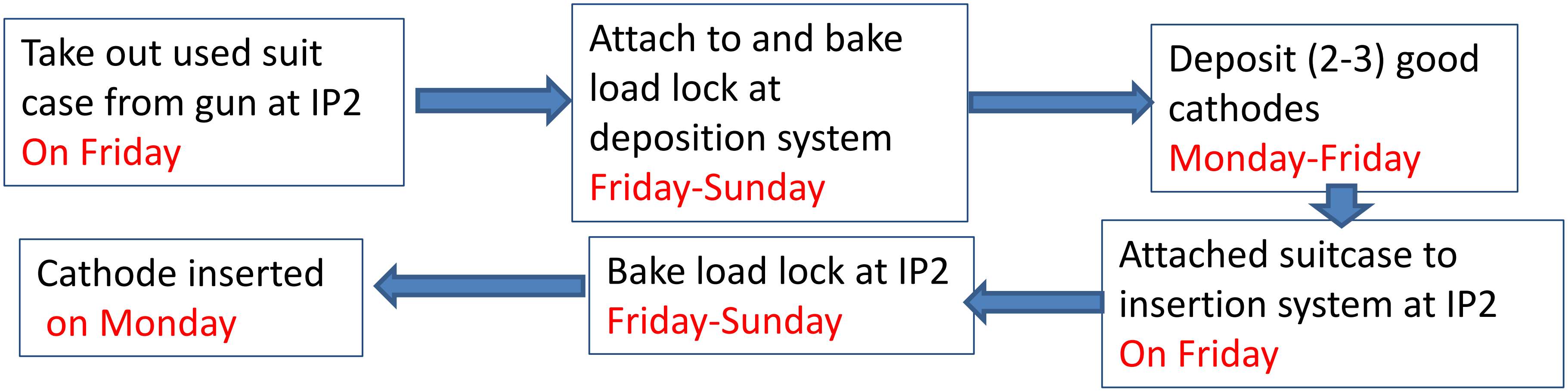








10 days cathodes turn around concept.



- In LEReC operation there will be 3 suitcases (fair wheels) with 12 cathodes each.
  - Suitcase #1 is attached to the cathode transport system (in use)
  - Suitcase #2 is attached to cathode deposition system (cathodes growing)
  - Suitcase #3 is filled with 12 cathodes in transition.

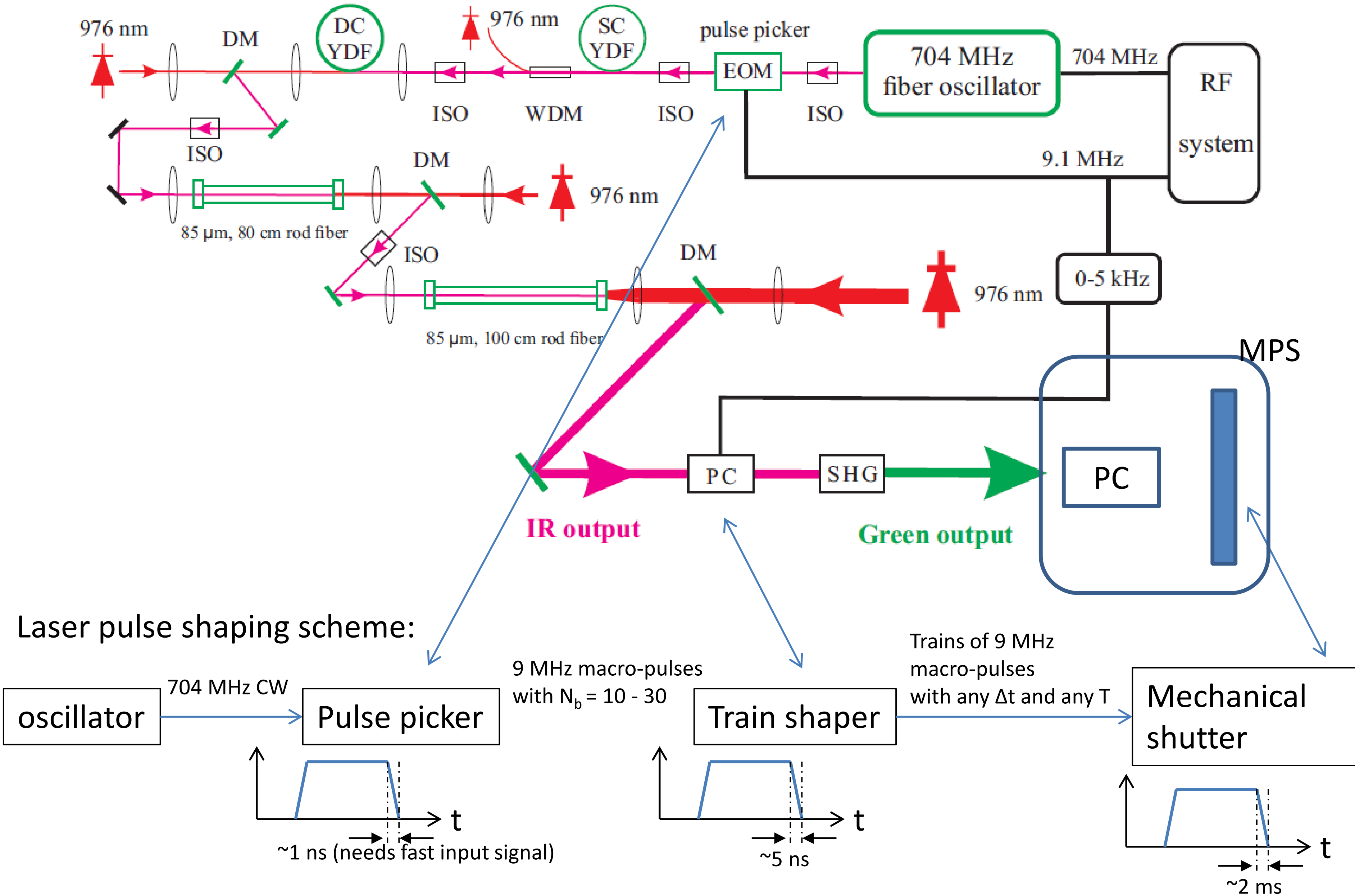
One of the goal to gun test is study concept/performance of fair wheel system.

Only one fair wheel capable to store and transport 12 cathodes will be available.
Time to deposit one cathode is about 2 days.

The optimized turn around time is 10 days.

In order to optimize commissioning time there will be two more crosses (suitcases) capable to hold one or two cathodes.

LEReC Laser system



Possible laser for very low power operation

Picolo AOT-1 by Innolas
Rep-rate up to 5 kHz
Wavelength 532 nm
Pulse energy up to 6 µJ
Pulse duration 0.7 ps
Average power up to 30 mWatt

Bunches are long but for test with out RF should be fine.

Important dates from LEReC installation schedule

Gun conditioning at Cornell starts	8/15/2016
Low power test exemption received	10/01/ 2016
DC Gun installed conditioning starts at BNL	10/18/2016

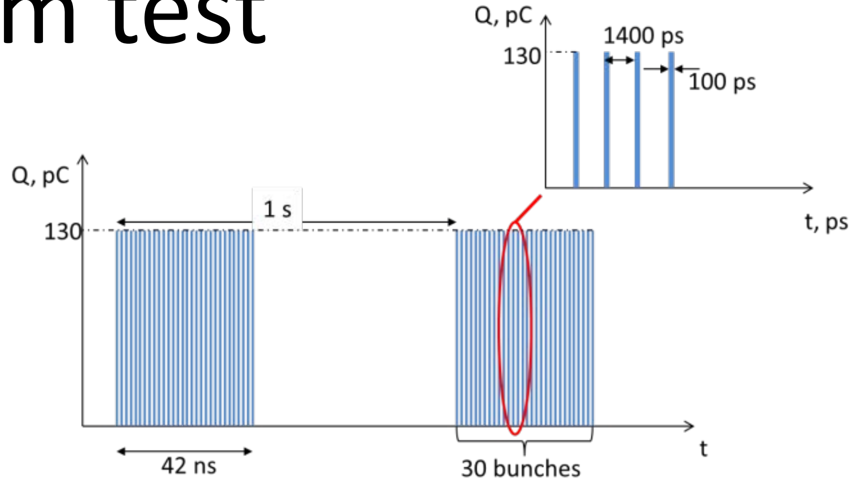
Condition gun at nights and on weekends while continue installation

Laser optics tables installed	11/17/2016
Laser transport complited and laser aligned	12/01/2016
All DC gun test components installed:	12/01/2016
magnets and power supplies,	
beam instrumentation and diagnostic electronics	
MPS electronics, controls	
beam dump,	
vacuum components,	
cable trays installed and cables pulled	
Cathode transfer system in placed and baked	12/01/2016

Magnets polarity check	12/15/ 2016
Dry run control, instrumentation, MPS	12/15/ 2016
Few cathodes with >1% QE ready to be inserted in the gun	01/15/2017
Gun test starts (RHIC 17 run starts)	01/15/2017

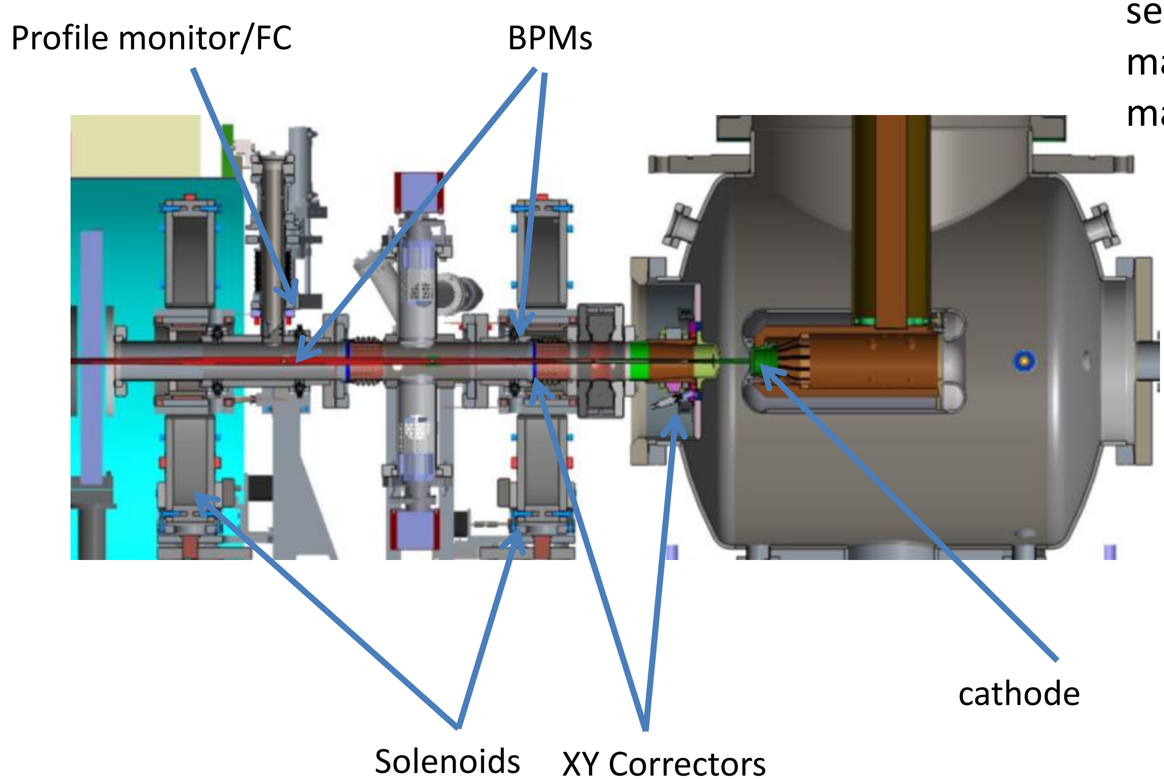
First beam test

- Start up mode (single macro pulse)



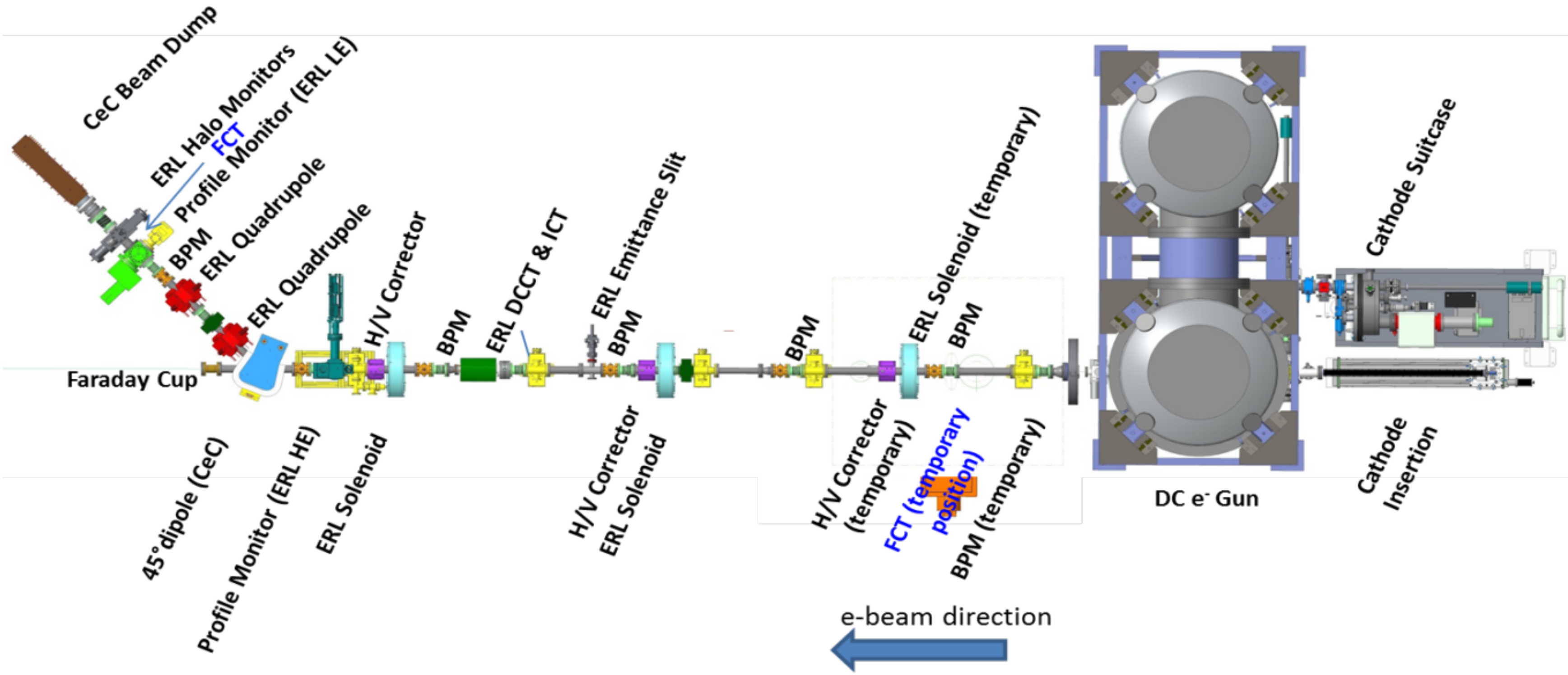
Main parameters:
Laser spot size 2 mm
Laser pulse 80 psec flat distribution.
Laser spot location on the center of the cathode.
Gun voltage 400kV.
Fast mechanical shutter is set to limit laser duty cycle to 0.5% (pulse duration 5msec)

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.

Gun to dump propagation an beam measurements

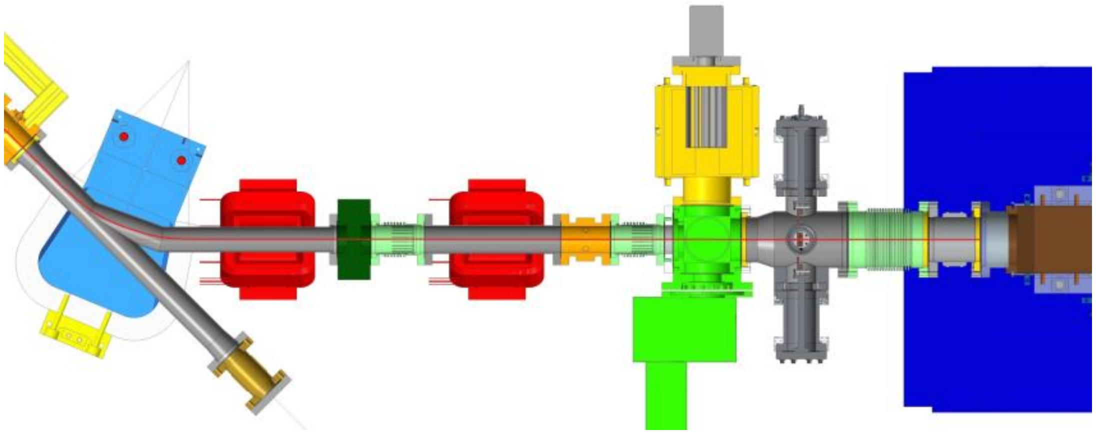


Required instrumentation:

Laser power meter, DC gun current meter.
Beam profile monitor with FC.
Gun, Transport line, beam dump line beam position monitors (BPMs), FCTs, ICT, Transport line and beam dump line profile monitors (PMs). straight line FC, beam dump FC.

QE: laser power and beam current
Charge per pulse: ICT, FCT
Emittance: set of slits
Energy measurements: 2 BPMs time of flight and/or dipole measurements

Beam dump extraction line.



- Consist of CEC type 45 degrees chevron dipole, 2 ERL types quadrupoles with trims (one horizontal, one vertical correction). BPM, PM, 2D halo monitor system, FCT

- Terminated by 10KWatt CEC type beam dump serves as a Faraday cup.

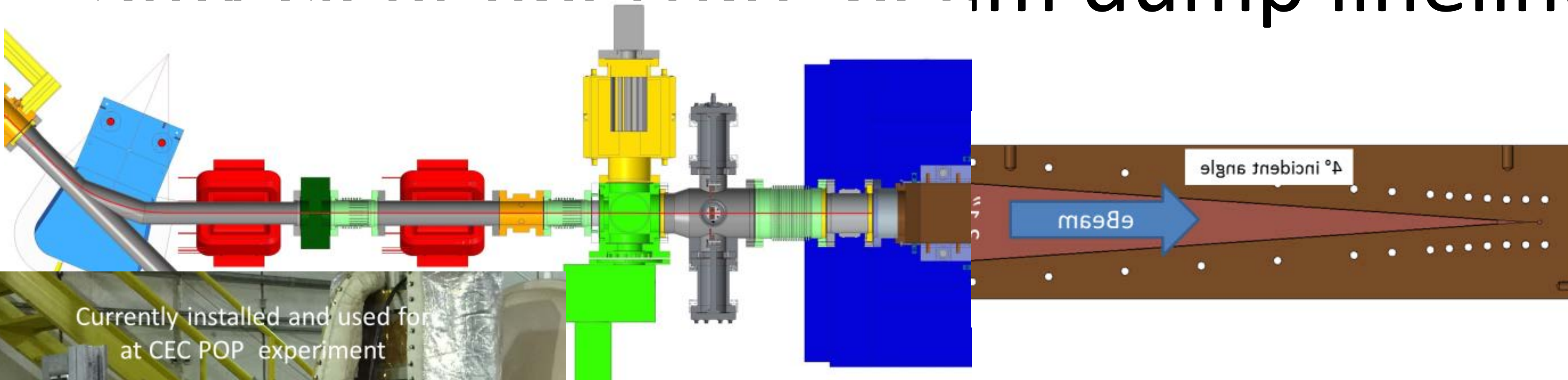
- This line will be used for beam energy and energy spread measurements, transvers and longitudinal halo studies.

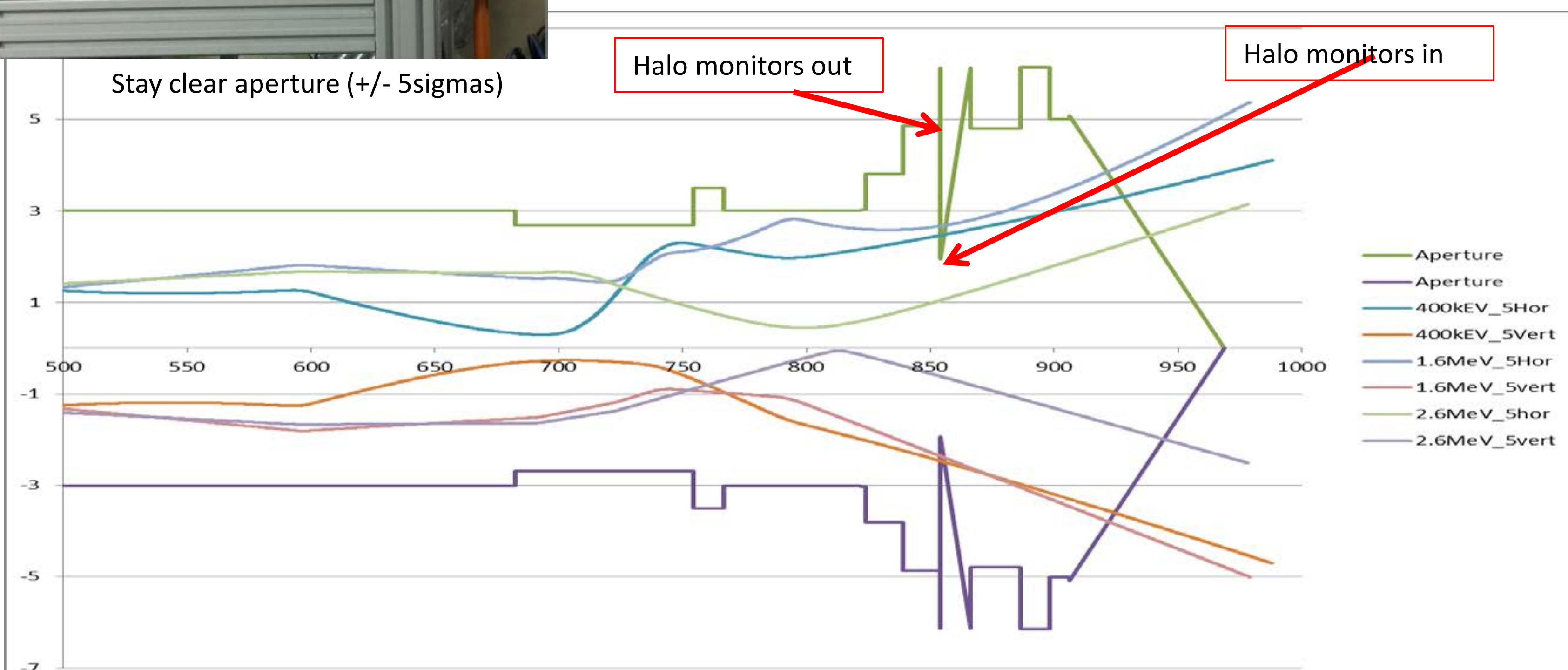
MPS consideration

- It is important that the beam is not only properly enlarged, but that it is also correctly positioned in the beam stop.
- A halo monitor system at the entrance to the beam dump will assure the correct beam size and position.
- upstream BPMs will assure the correct entrance angle.

- Each jaw element is a low-efficiency Faraday cup,
- thus must be thick enough to assure beam electrons are stopped.
- Interlocks on:
  - the amplitude quadrupole over-focusing??
  - the beam centroid is properly centered on the stop.

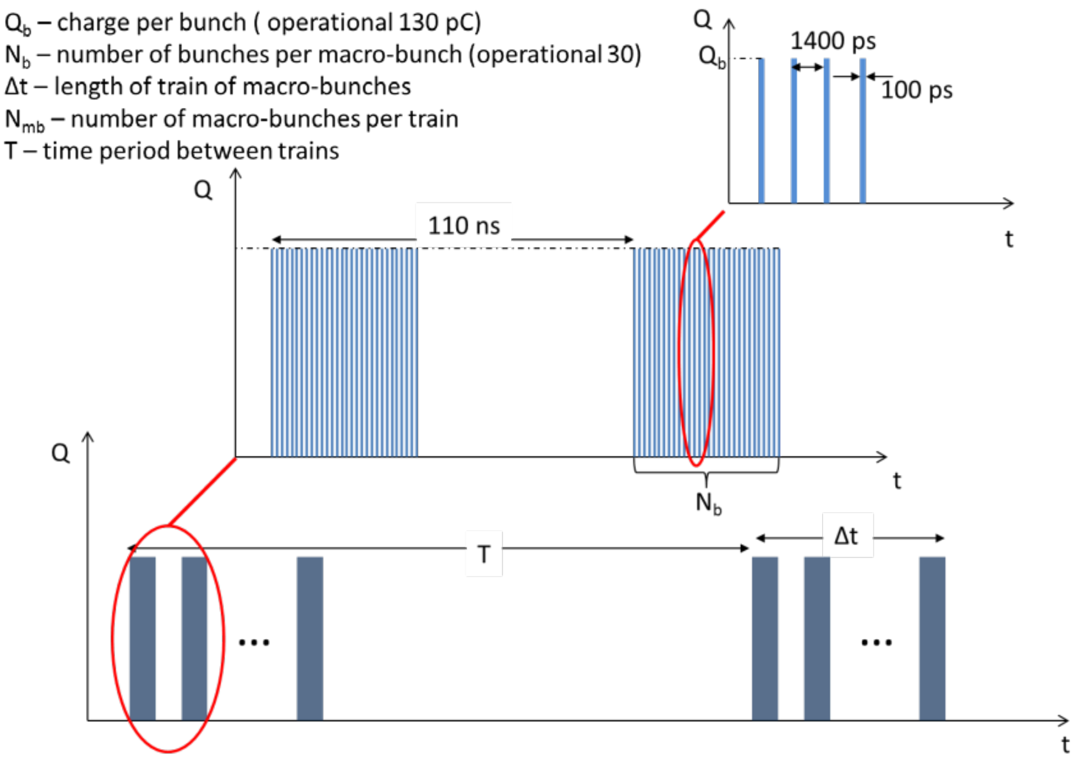
Stay clear aperture beam dump lineline





Low power (pulsed mode)

Goals:
Prepare all systems to full current operation.
Setup and test MPS in transition mode.
Set up beam loss monitors system
Set up DC current transformer.
Study gun performance for increased current.



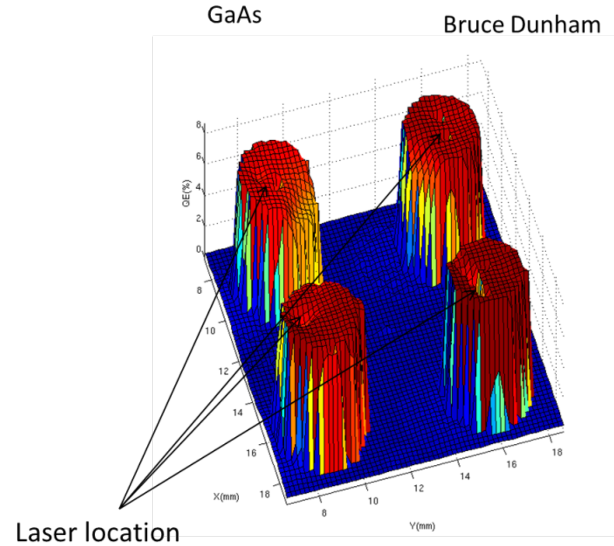
Main parameters:
Laser spot size 2 mm
Laser pulse 80 psec flat distribution.
Laser spot location on the center of the cathode.
Gun voltage 400kV.
Maximum charge per bunch 130pC
Maximum charge per macro bunch 30x130=3.9nC
Maximum average current 25 uA.
Maximum power 10 Watts

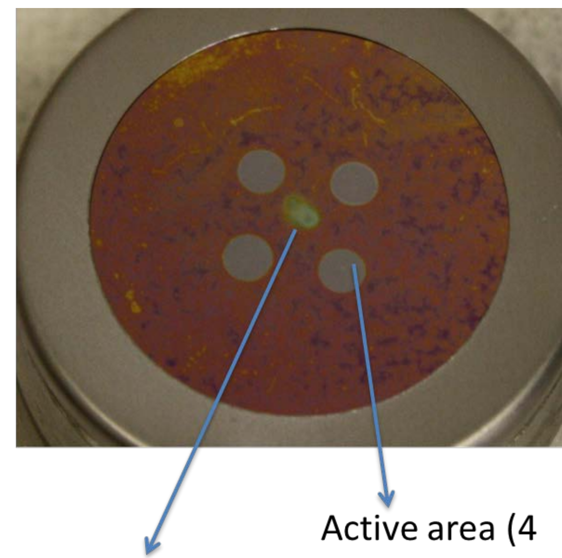
Fast mechanical shutter is set to limit laser duty cycle to 0.5% (5msec pulse duration).

Confirm that electron bunch time structure is one macro pulse per second using scope signal, ICT, FCT
Test all necessary MPS input signals and interlock responses.
Gradually increase numbers of macro bunches Δt – length of train of macro-bunches

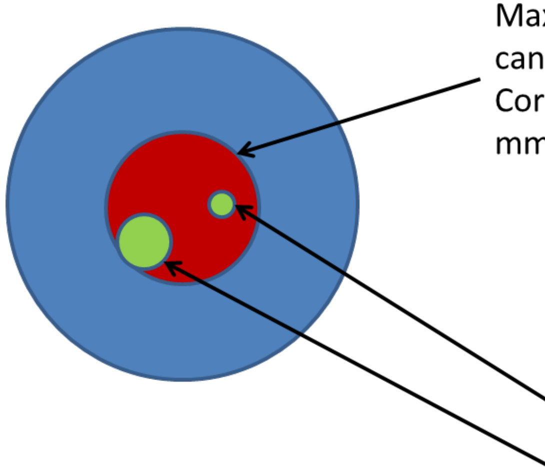
Off center operation

- At any commissioning step if cathode on center QE is dropped below 0.1%:
- Switch to single macro bunch operation.
- Move laser off the cathode center by 2-3 mm.
- Set up anode corrector and first on solenoid corrector to compensate laser offset.
- Try use single cathode as long as practically possible.





Each active area also experiences local damage due to ion back streaming.



Current ramp up?

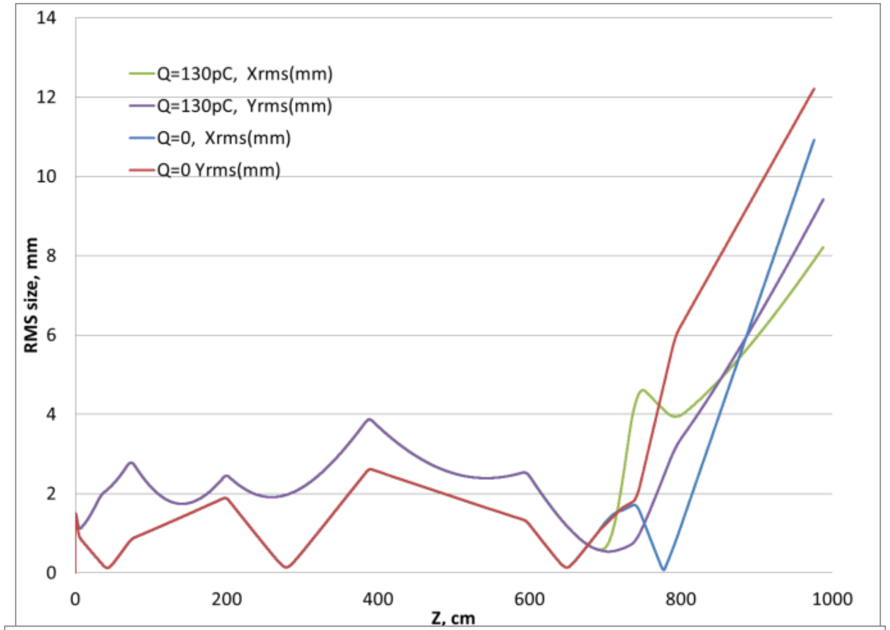
Space charge effects to beam dynamics. Preferable scenario could be keeping charge per pulse constant while increasing numbers of macro-pulses.

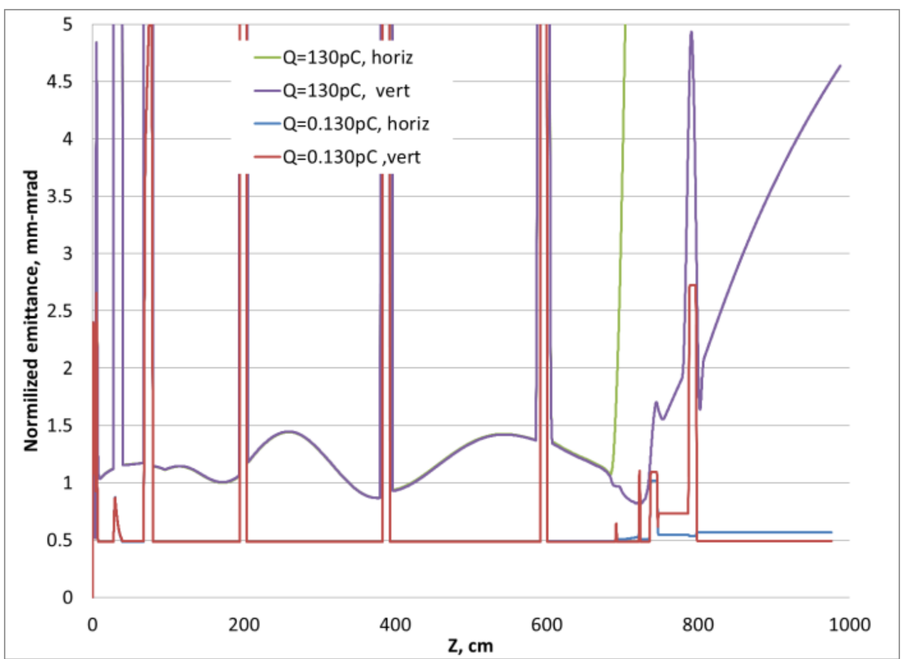
Alternative could be ramping up charge while keep pulse pattern untouched.

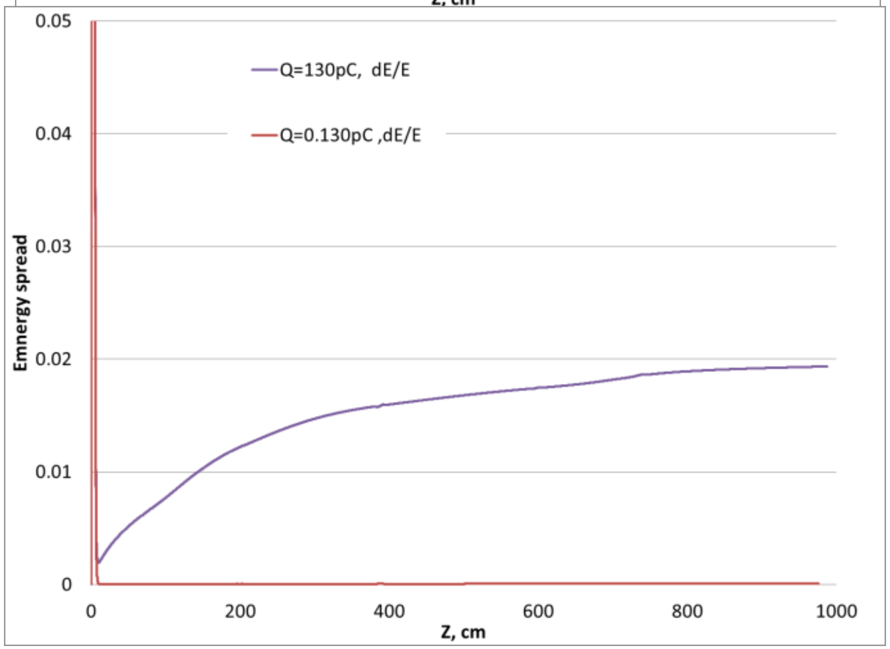
Most likely beam ends up in beam dump.

But we will not have instruments to measure beam position during charge ramp up.

Beam quality for Q=130pC vs Q=0.130 pC







High power gun test

- High power test is possible after receiving ARR?? and DOE approval
- Gun low power test is finished
- MPS tested
- OPMs are finalized
- Test results are discussed and understood

Goals:
Bring the system to high current operation
Test instrumentation at high current operation
Test MPS at high current operation
Study gun performance for high current operation.

Gradually increase beam power (average current) by increasing macro pulse numbers current 10x:10W (25uA)-> 100 W (250uA) 1kW (2.5mA) -> 10kW (25mA)
Monitor beam losses and any temperature rise.
Conduct radiation surveys at each power increasing step.
At each step discus results with RSC chair