High Current Polarized Electron Gun for eRHIC

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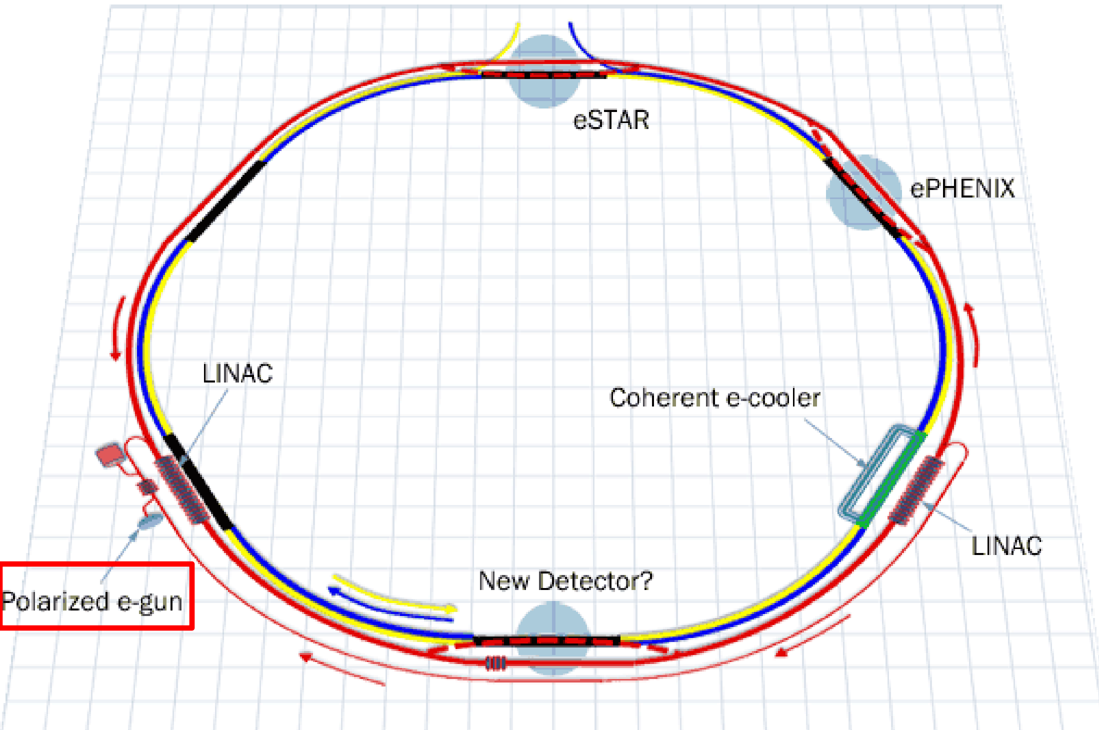
Motivation

ERL based eRHIC: Requires a very high current polarized electron gun.



eRHIC parameters

	p	e
Energy, GeV	50-250	5-21
Bunch charge, nC	32	5.3
Beam current, mA	415	50
Rms nor. Emittance, µm	0.18	20
Polarization,%	70	80
Luminosity,$cm^{-2}s^{-1}$	$1.5X10^{34}$	

What is the prior state of the art?

Polarized electron sources deliver either a high peak current, such as >5A achieved by the SLAC(High peak current, low average current)

Or a high average current, such as that up to 4mA reached by the Jlab. (Low peak current, high average current)

What we need?

High average current: 50mA; High Bunch charge:5.3nC; Long lifetime

Avoid surface charge limit:

Peak current 2.33A from 6mm diameter emission area

Long operation lifetime:

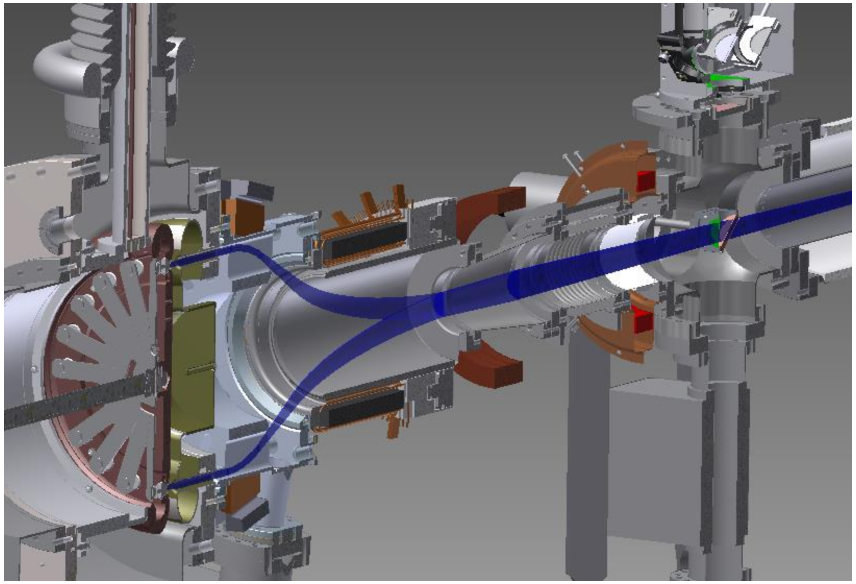
Funneling concept: 20 GaAs cathodes

Careful beam optics design: Reduce outgassing due to beam loss

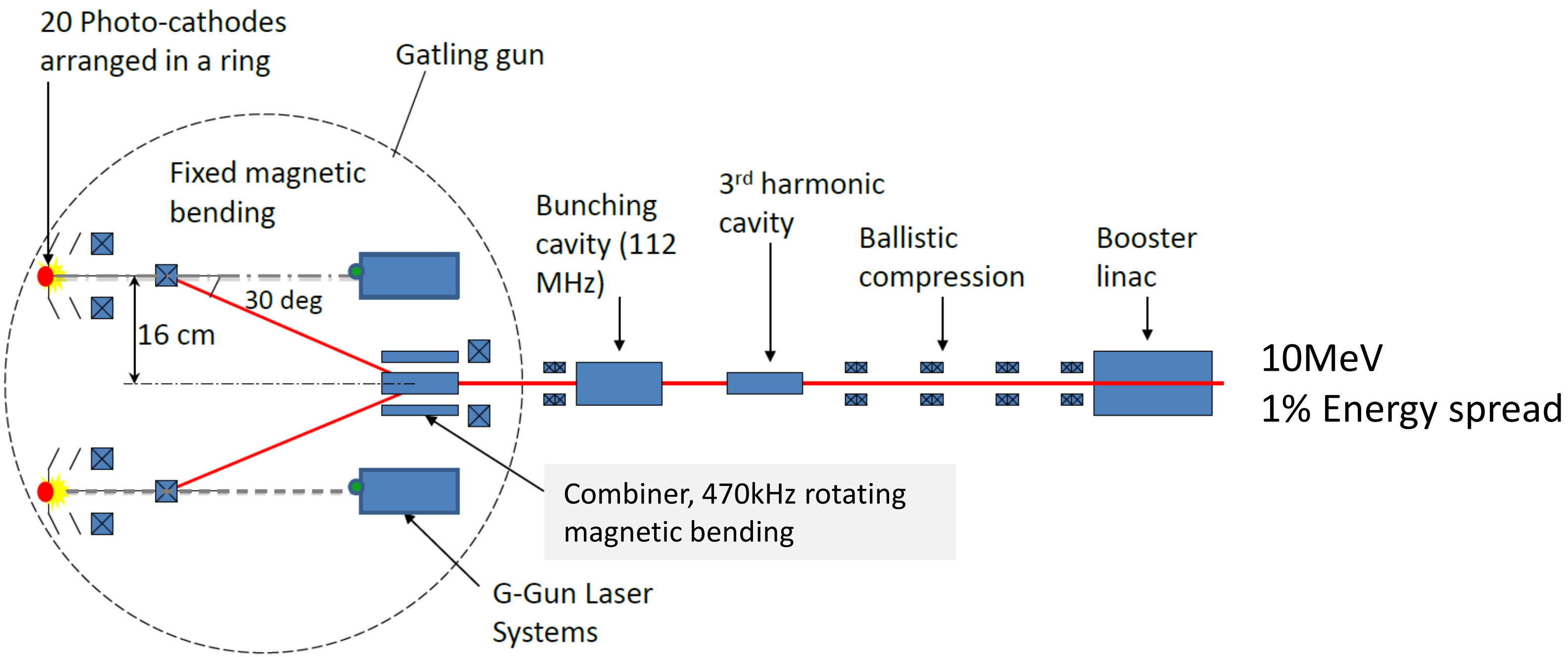
What is the objective charge lifetime?

eRHIC requirement:
Weekly cathode exchange, operation lifetime 85 hours(half week)
Average current :50mA
Charge lifetime: 15,300C
Charge lifetime per single cathode: 15300C/20=765C

Current state-of-the-art single cathode charge lifetime: 1000C @ 2.5mA



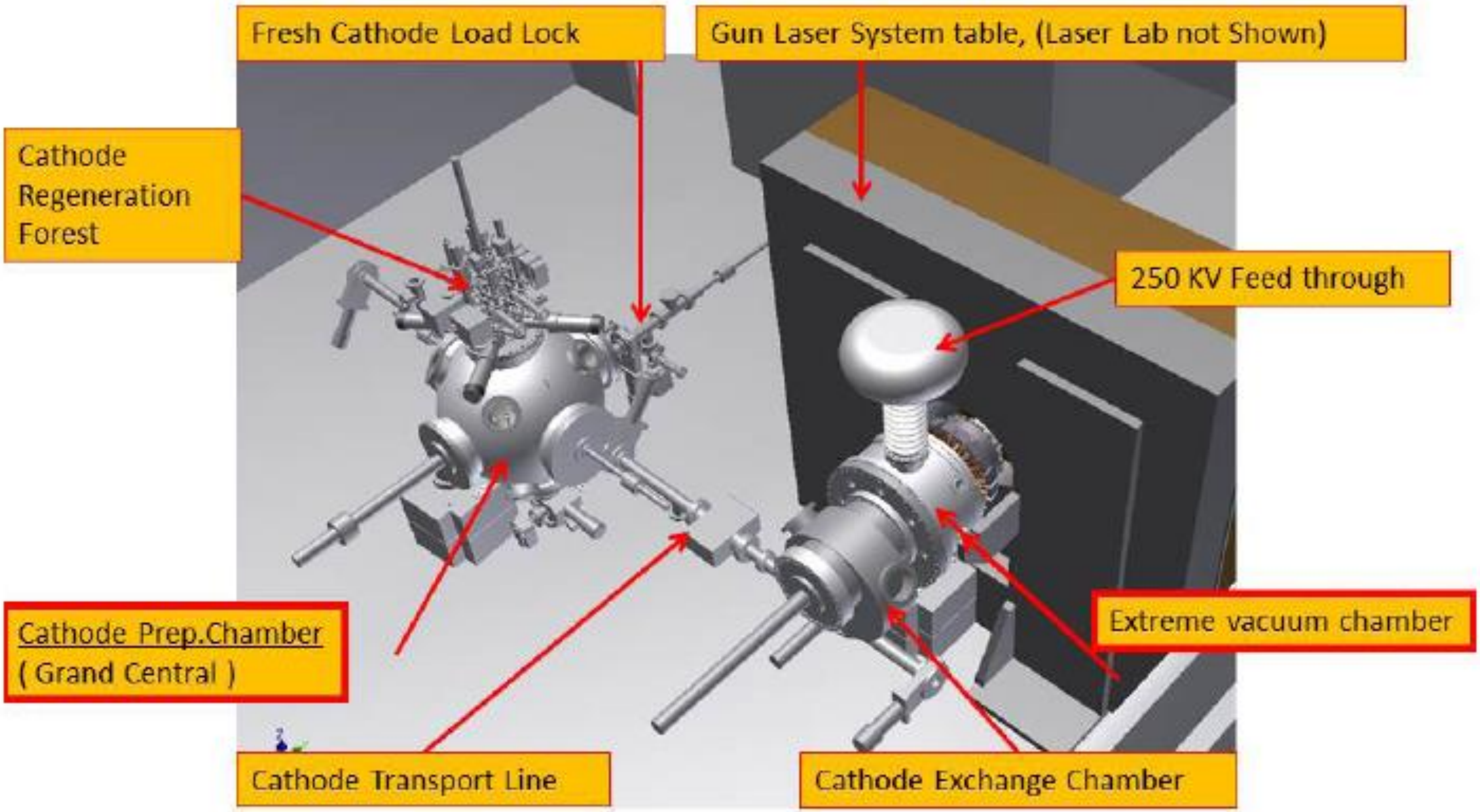
What we want to demonstrate?



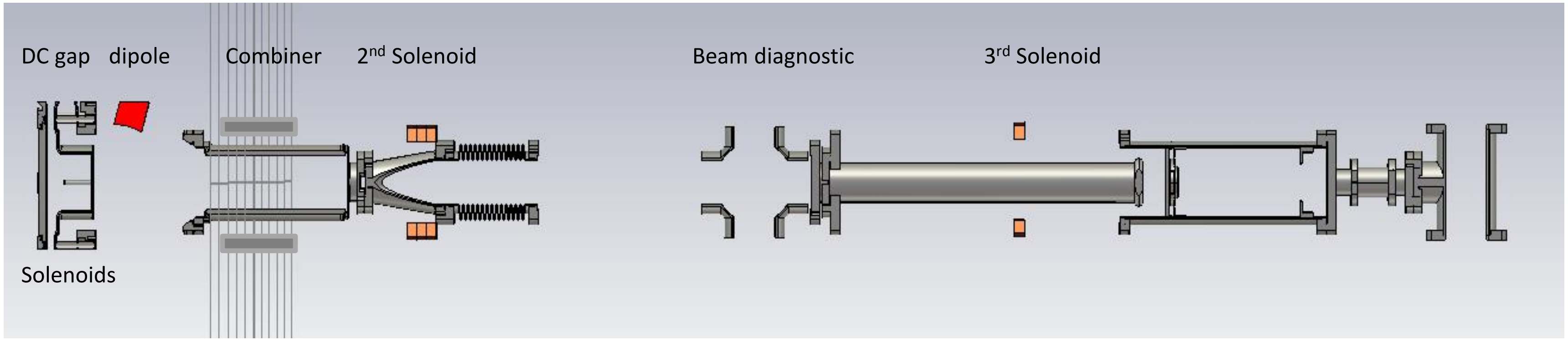
Single cathode:470 KHz*5.3nC=2.5mA
After funneling:9.4 MHz*5.3nC=50mA

We want to demonstrate the funneling principle:
The performance of an individual photocathode is not affected by the presence of other cathodes.
Then the charge lifetime will increase by a factor of 20.

Overall layout



Beam dynamics design

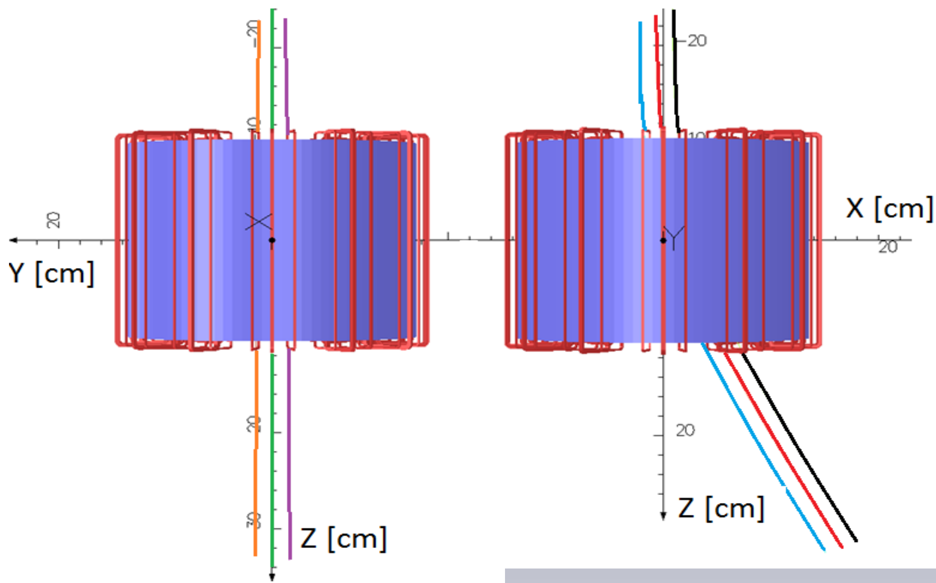


CST particle studio 3D beam dynamics study.

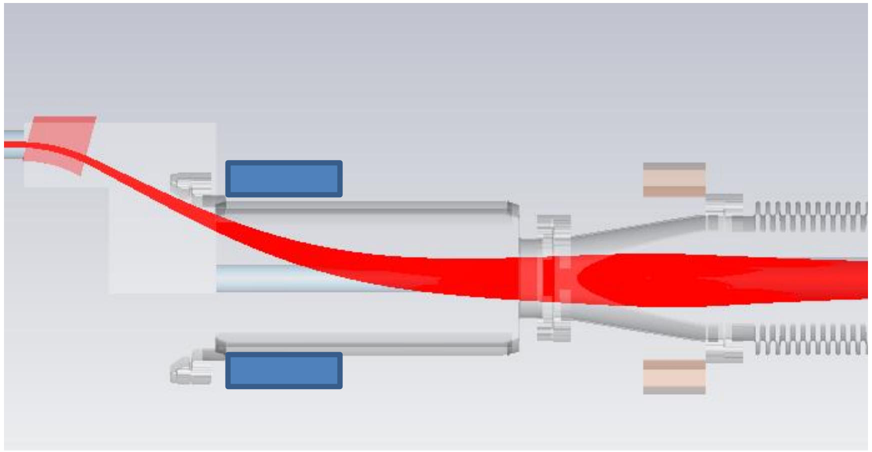
•Requirements:

1. Keep the beam far away from the beam pipe
2. Minimize the beam emittance
3. Focusing the beam into collection through the hole

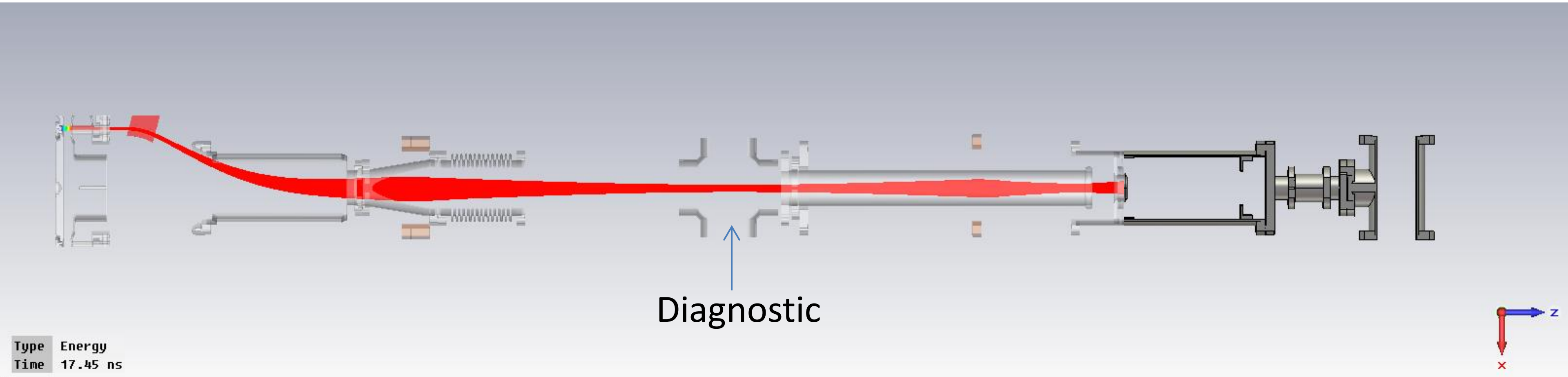
Beam combiner

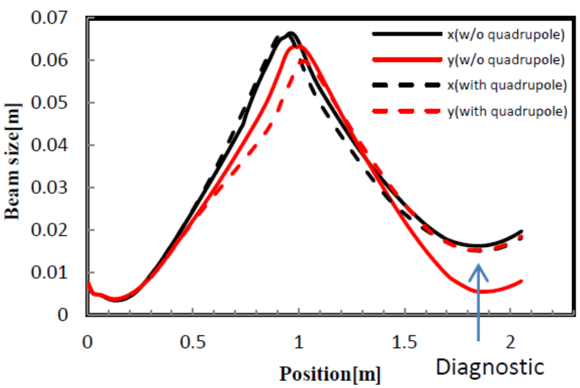


Single particle tracking shows:
•The integrated field is adjusted to bend the 220keV electrons by 29°
•With quadrupole corrections:
X’/Y’=8.7mrad/9.8mrad at exit of the gun

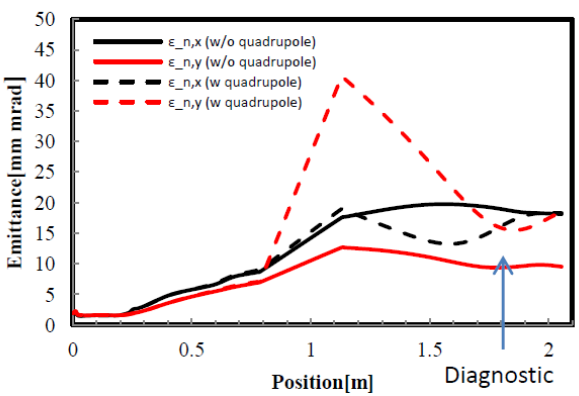


Beam dynamics





Beam size vs position

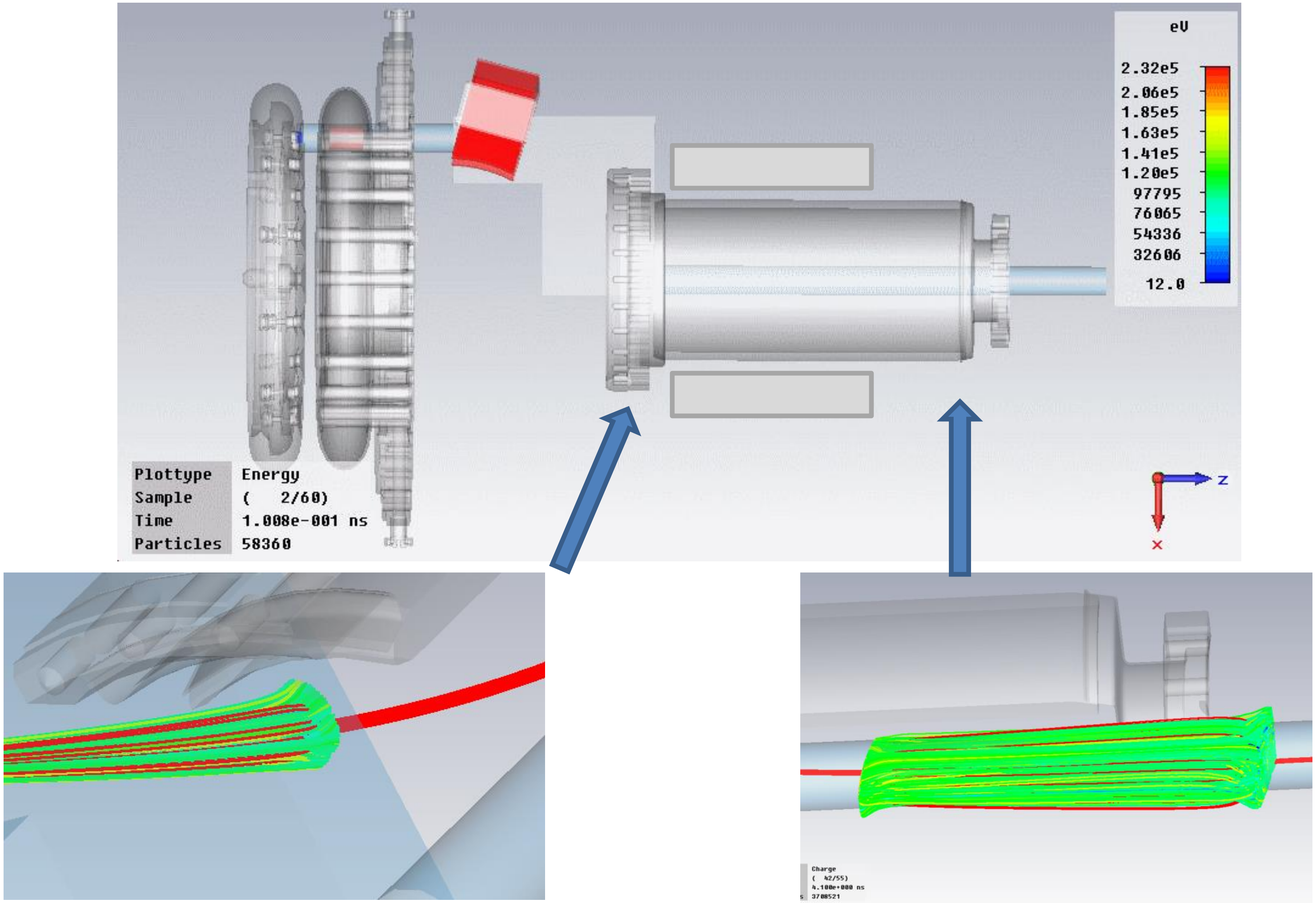


Emittance vs position

Particles tracking with SC on diagnostic :

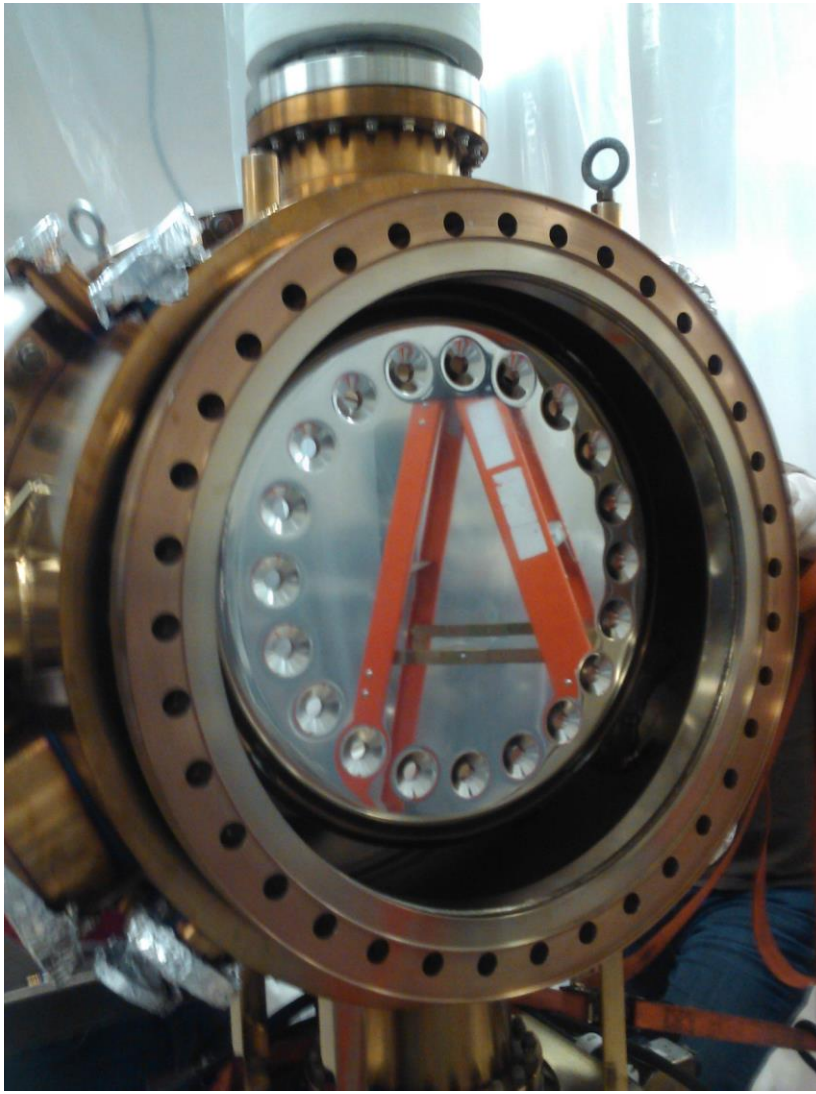
- Divergence angle: X'/Y'=23.6mrad/25.1mrad
- Beam profile: X/Y=15.0mm/15.2mm
- $\varepsilon_{n,x}$/ $\varepsilon_{n,y}$ =17mm mrad/14.9mm-mrad
- Energy spread=8keV(97% particle)

PIC beam tracking

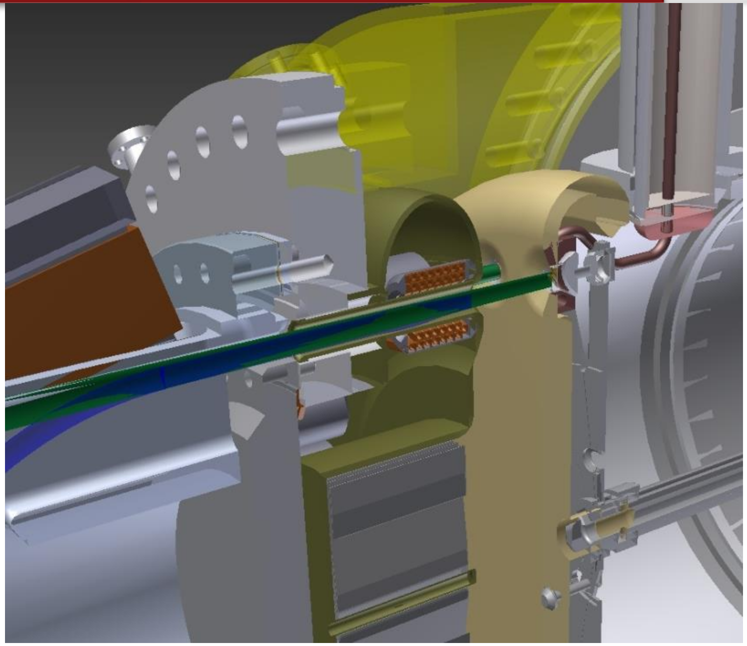


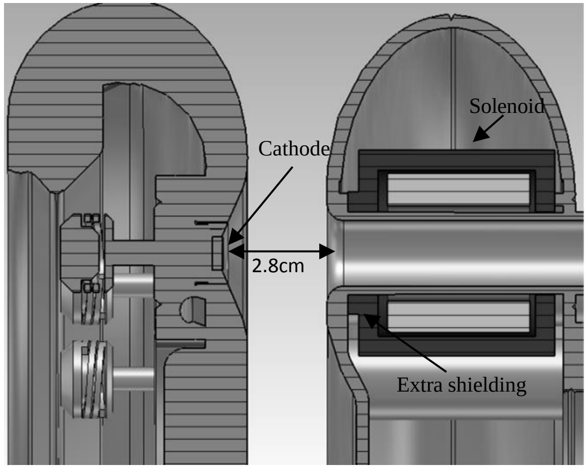
- The sample halo particles are tracked under the field generated by the beam.
- There is no beam loss on the combiner tube base on Particle core model

Cathode assembly

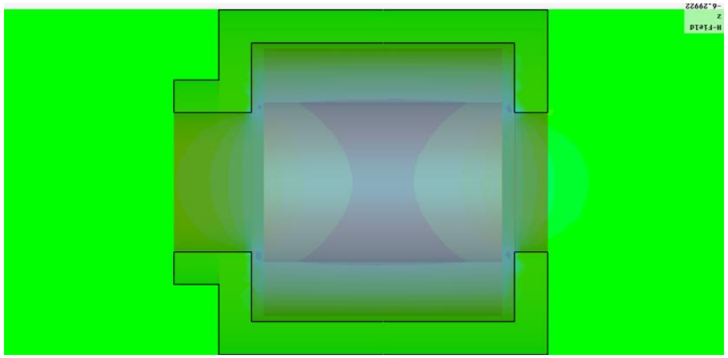


Cathode-anode and solenoids

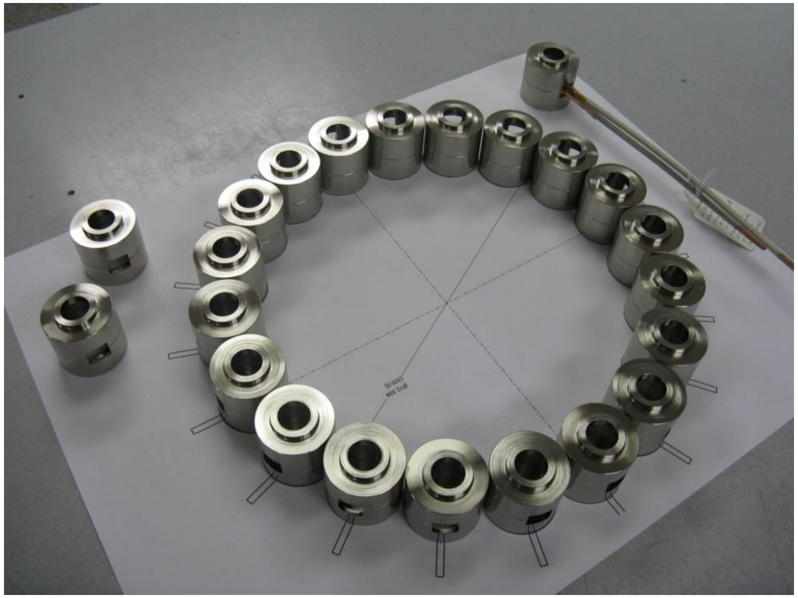




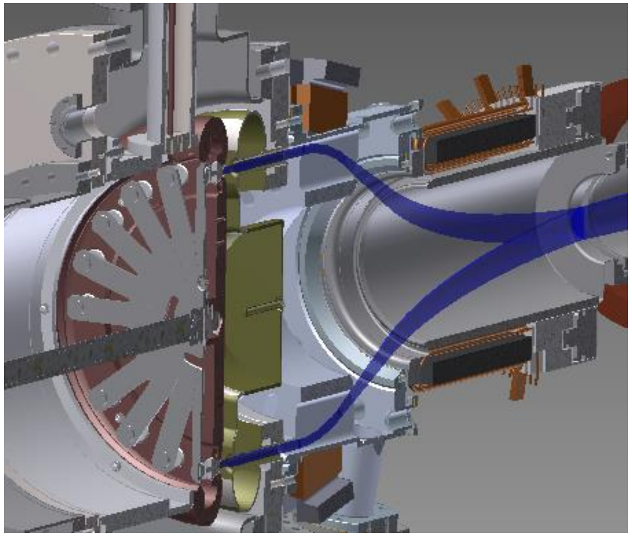
DC gap:2.8cm
Charge to:220kV
SCL:7A
Maximum field:5.3MV/m

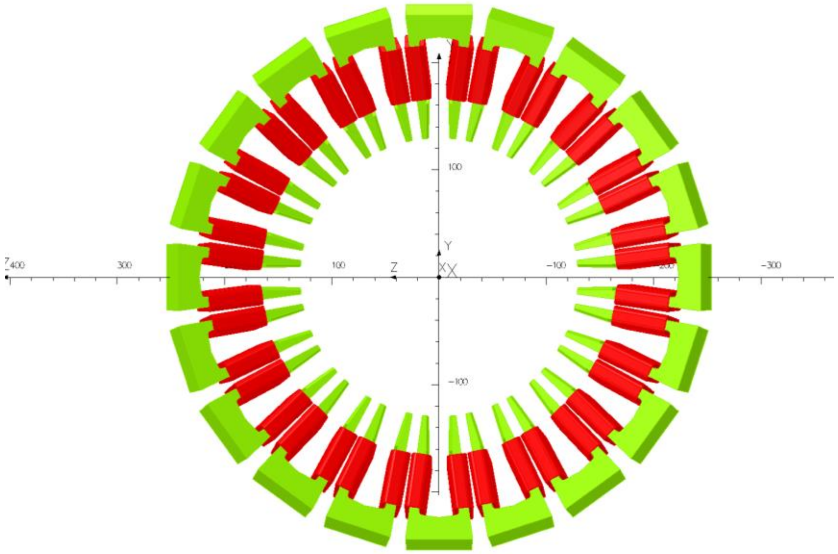


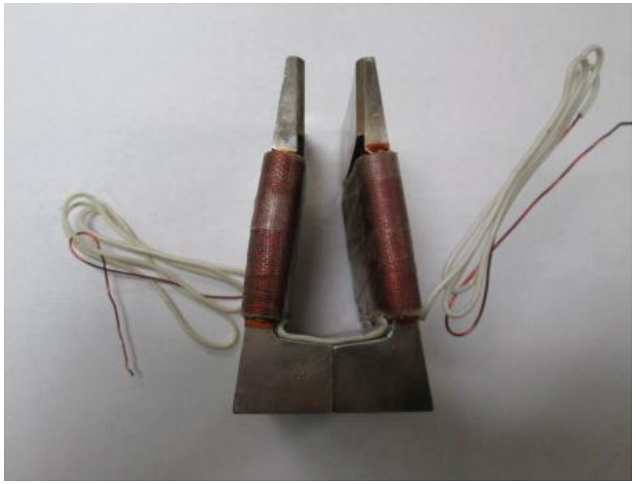
Max field:660G
Integral : 0.260 T-cm



Static Dipole Magnets

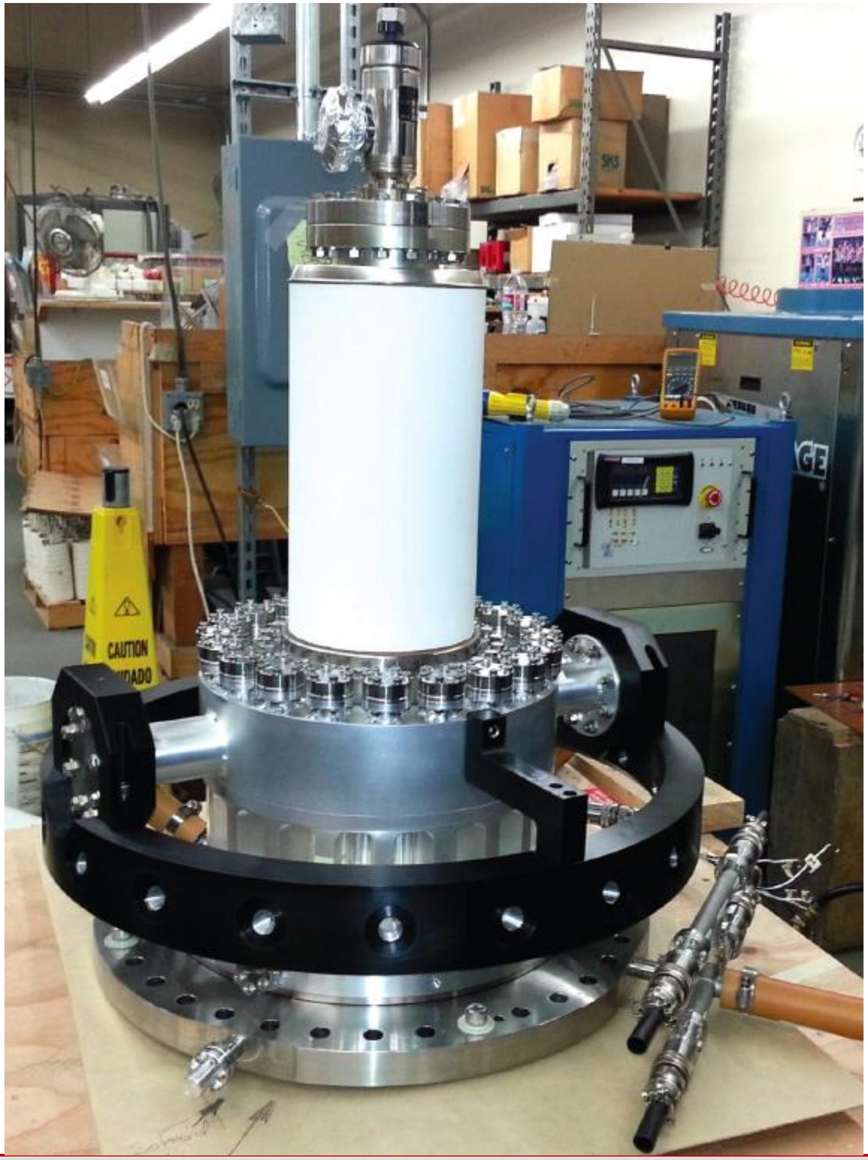


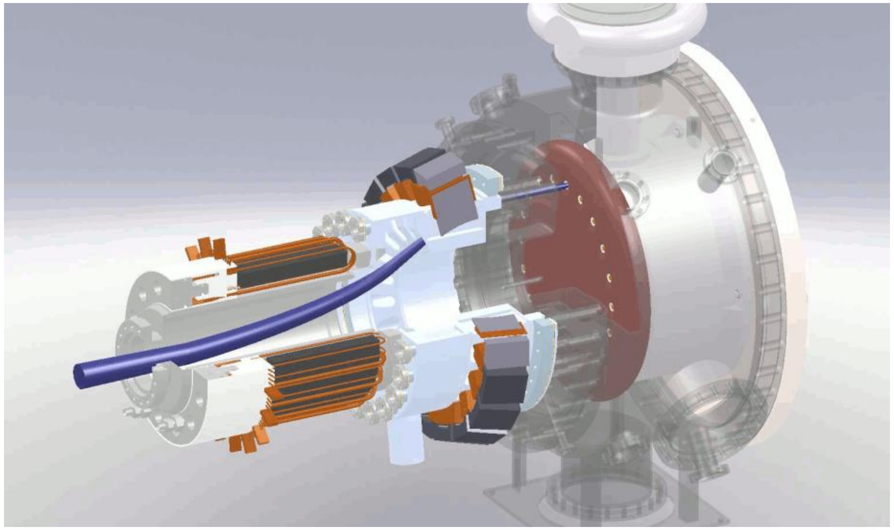




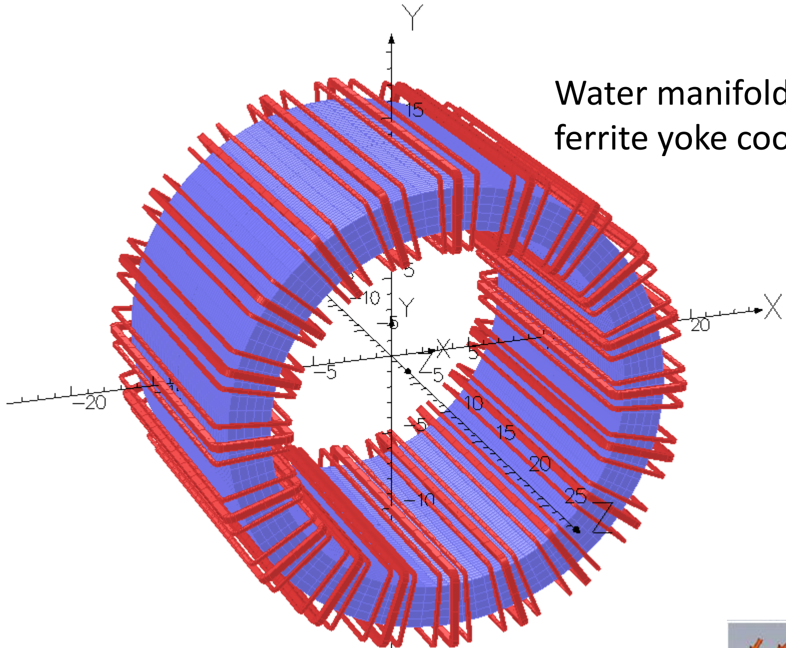
•To preserve the longitudinal direction of electron spin polarization, we designed compensated dogleg trajectories in the beam's funneling system encompassing fixed bending fields generated by 20 dipole magnets, and a rotating bending field generated by the magnetic combiner.

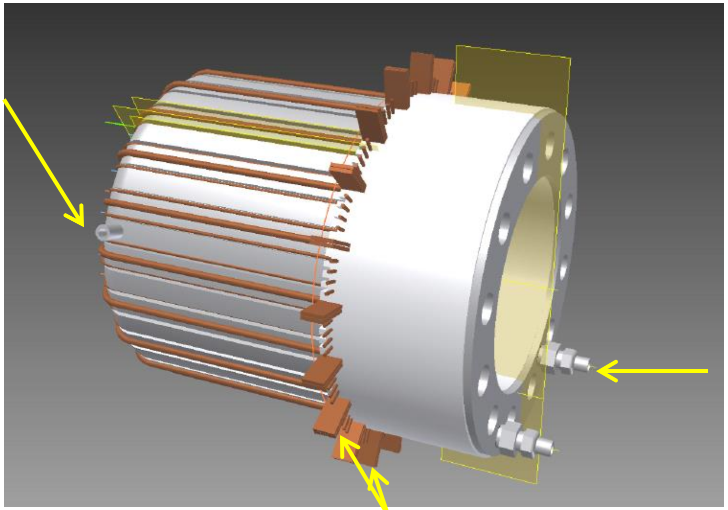
Anode assembly and combiner drift tube





Beam Combiner





- Bending the beam by dipole
- Equalize the focusing by quadrupole
- Parameters:

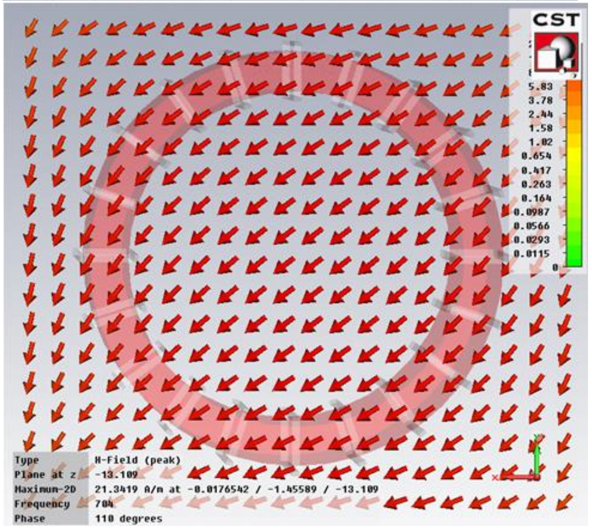
$I(t)=I_{od}*\cos(\omega t+\phi)$ where $I_{od}=70.7A$

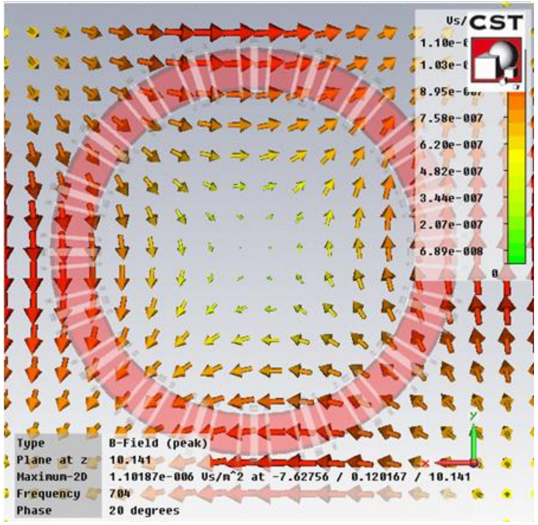
$I(t)=I_{oq}*\cos2(\omega t+\phi)$ where $I_{oq}=1.54A$

B(0,0,0)=25.04G

Freq=470kHz

Bending angle=29 degrees





Vacuum design

Transfer chamber: NEG 1500l/s
Design vacuum:10^{-12} torr scale
Test vacuum now:**$8*10^{-12}$torr**

Vat Lab 3BG vacuum (**super**) gauge has <10^{-13} Torr resolution

Gun chamber: 8,000l/s
Design vacuum:$6*10^{-13}$ torr
Test vacuum now:**<$5*10^{-12}$torr**

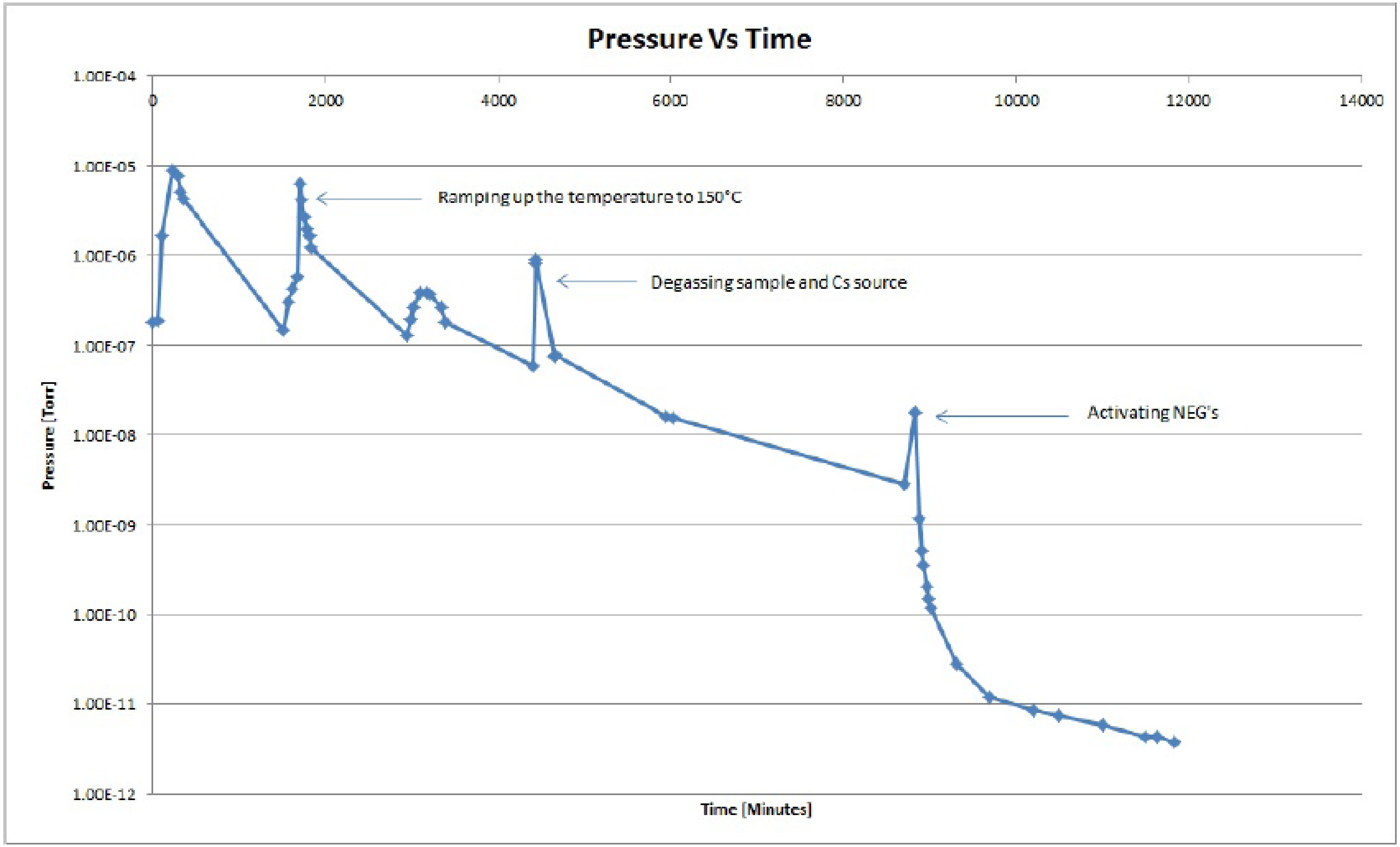
Combiner:6000l/s
Design vacuum:$1*10^{-11}$ torr

Exchange chamber:4000l/s
Design vacuum:$1*10^{-12}$torr
Total:20,000L/s

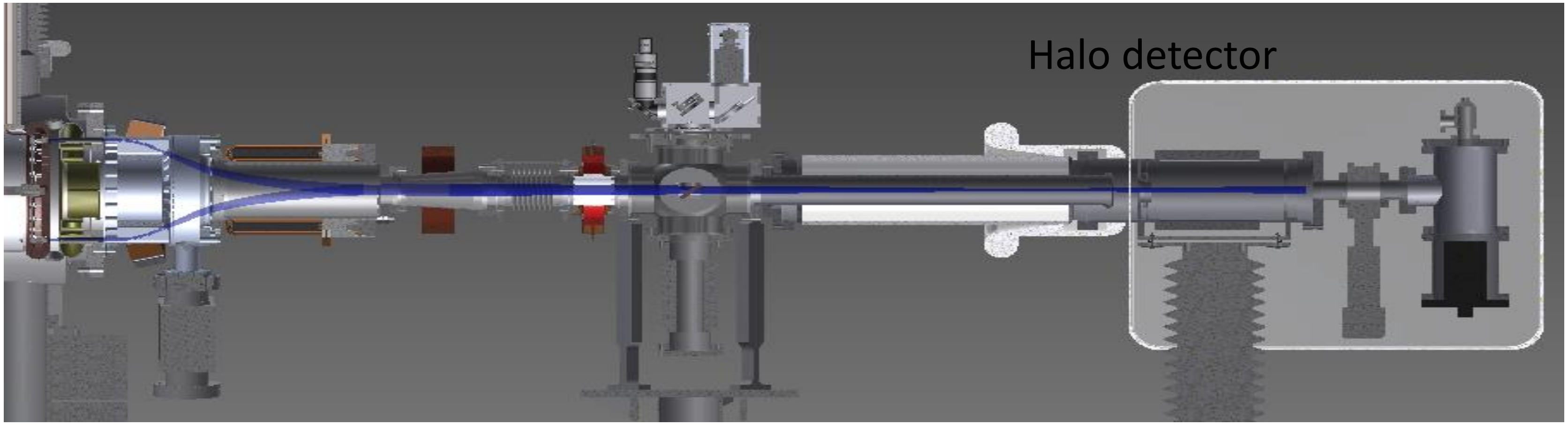
Compare to other guns:
- China IHIP ERL DC gun: 18000L/s
- Japan JAEA ERL DC gun: 16000L/s

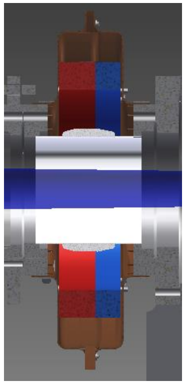
Gun vacuum vessel material:
Vacuum fired SS 316L($2*10^{-13}$ Torr L/cm^2 s)
Anode material:
Ti($2*10^{-15}$ Torr L/cm^2 s)

Vacuum in cesiation chamber

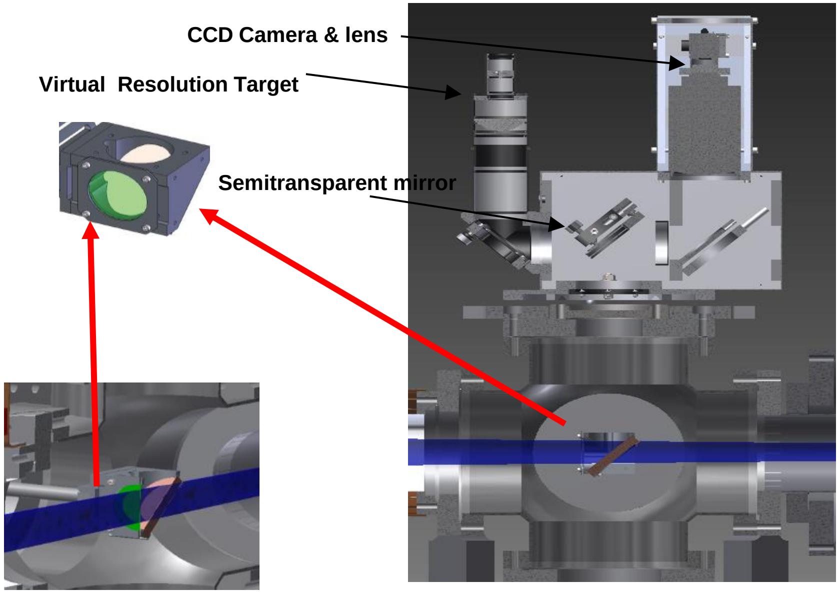


Beam diagnostics

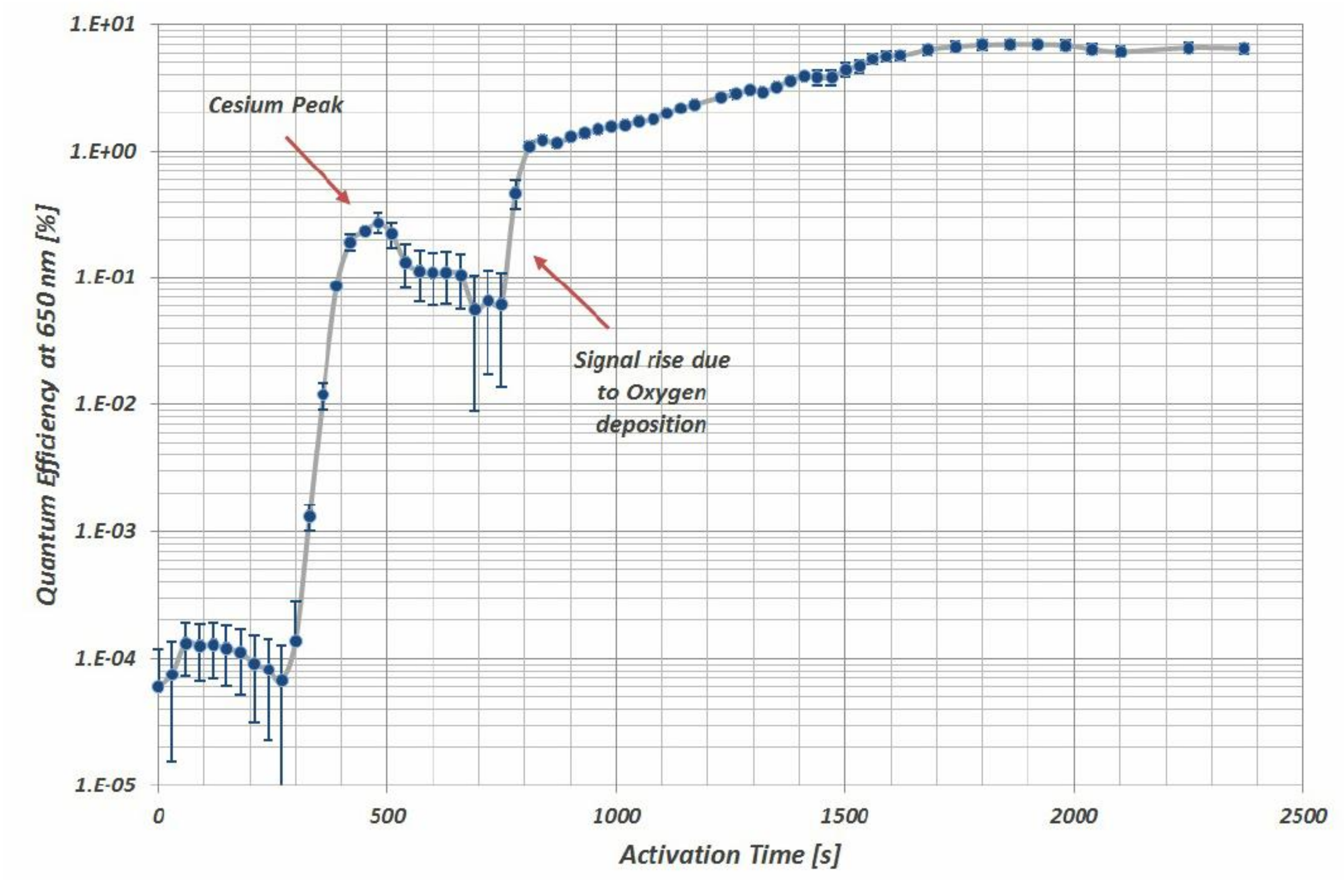




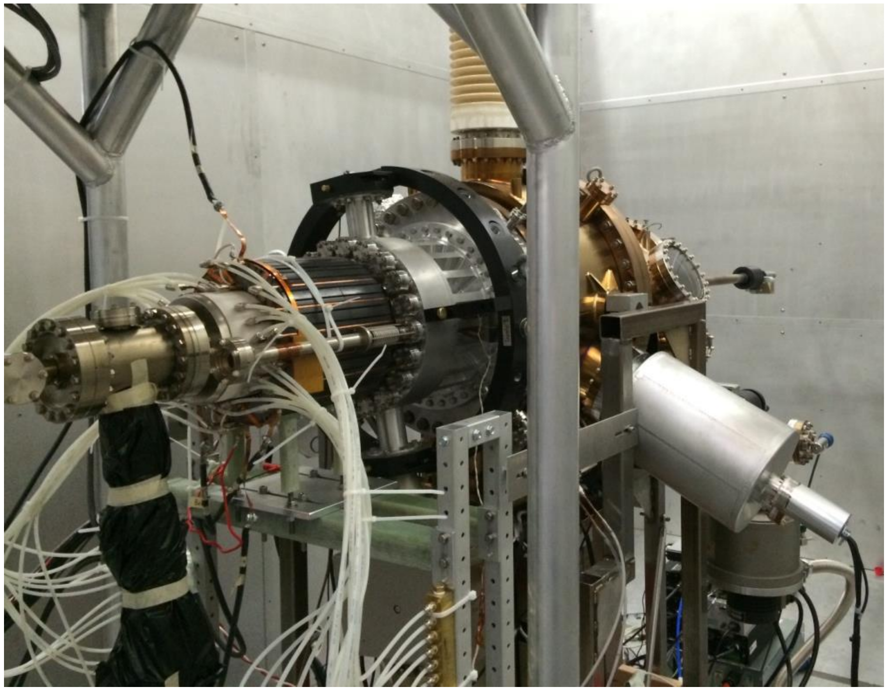
Fast Current Transformer &
Integrating Current Transformer

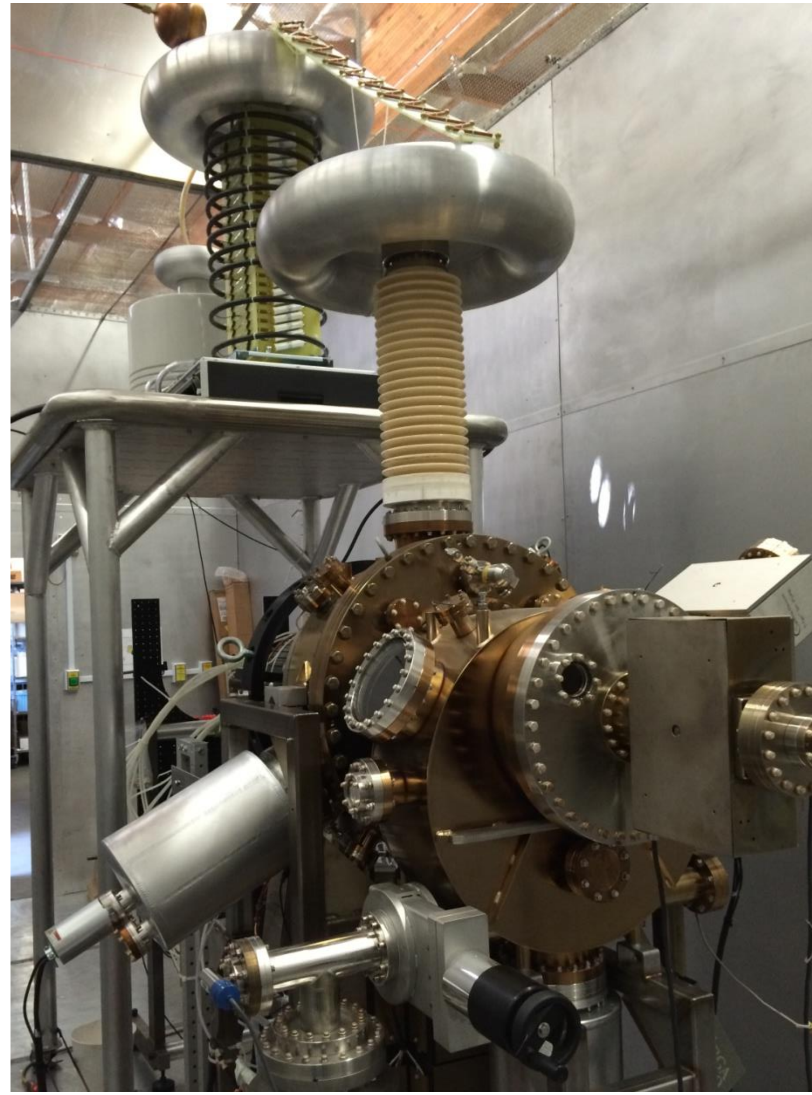


Cathode preparation

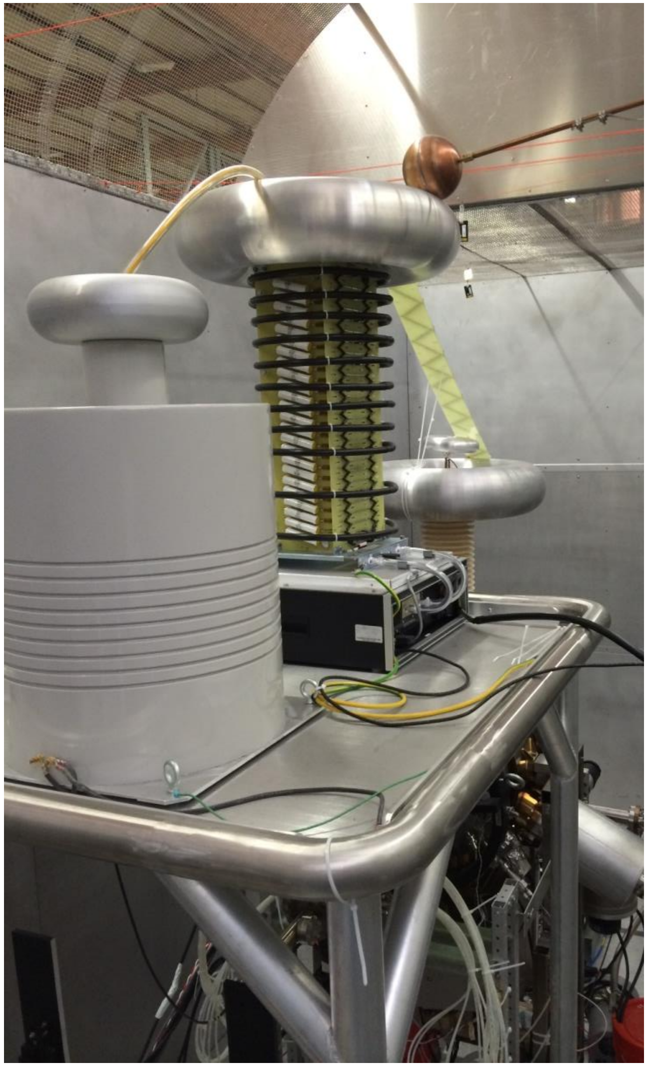


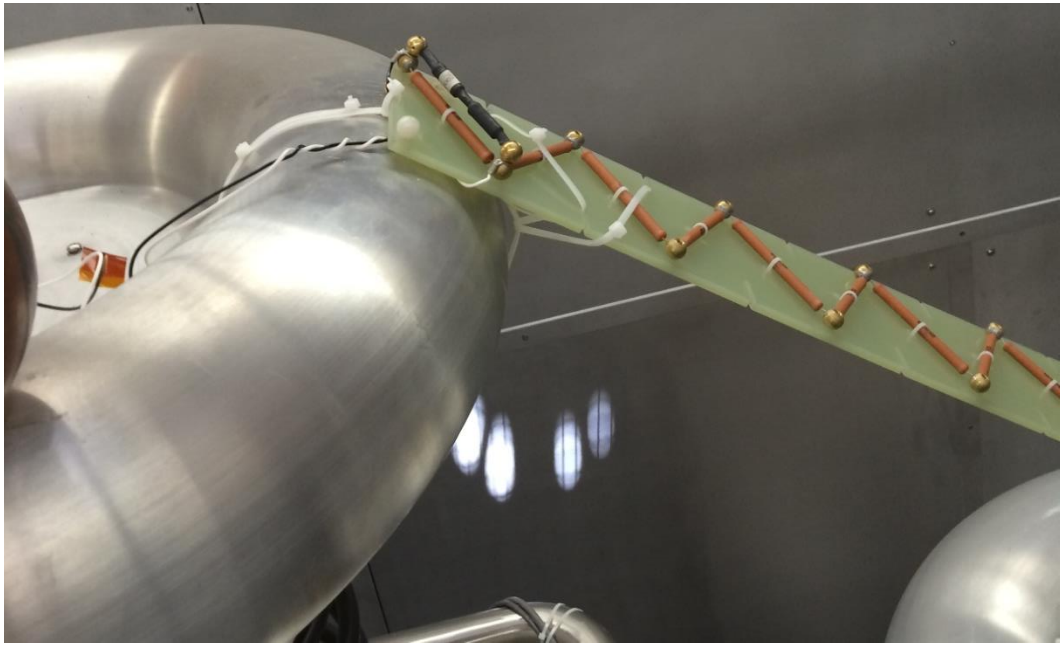
Gun





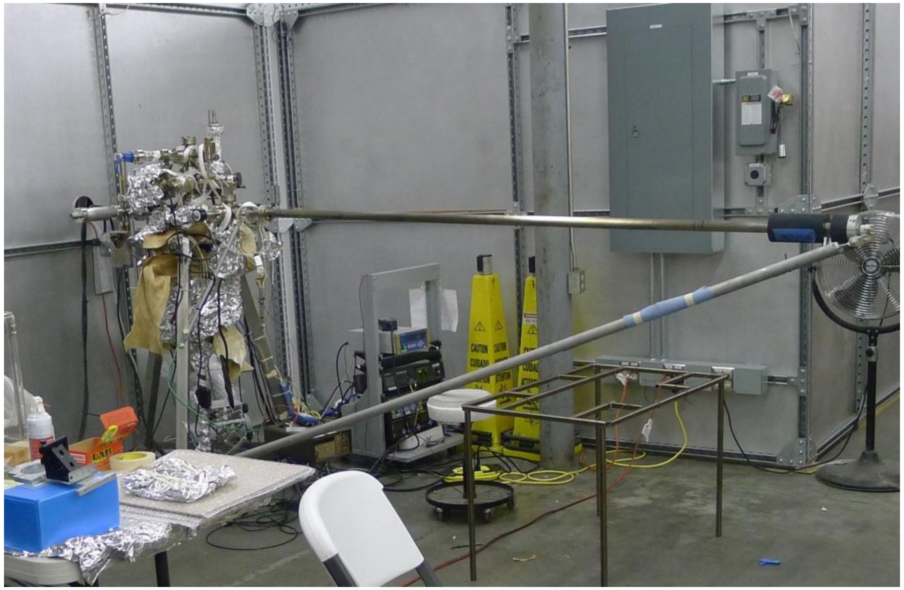
High voltage power supply

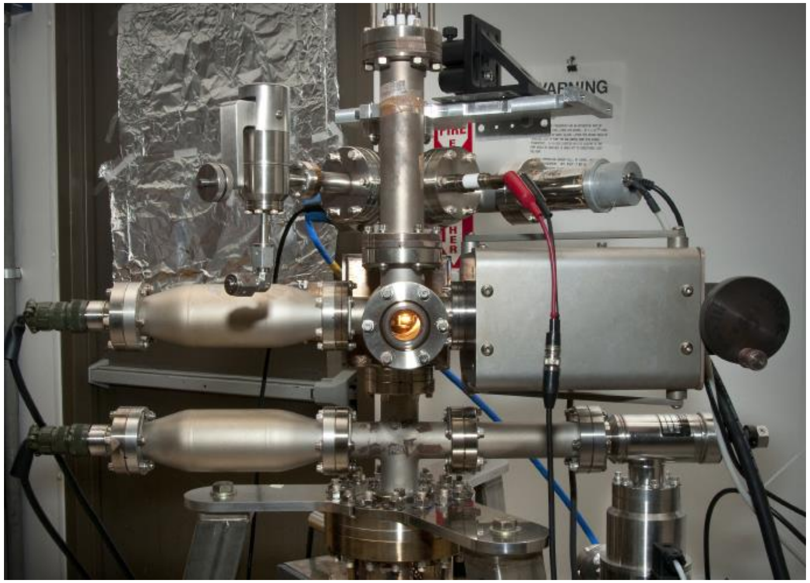


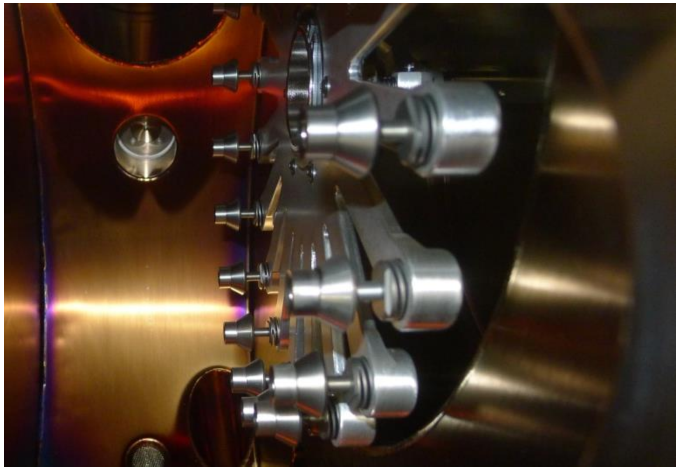


250kV power supply
2.888Gohm resistor series connect between gun and power supply

Cathode preparation and transport



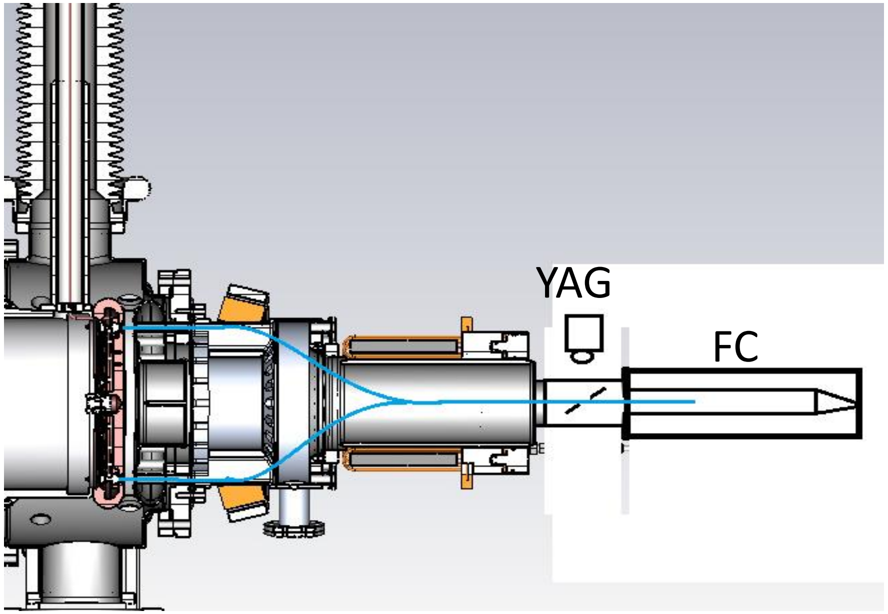


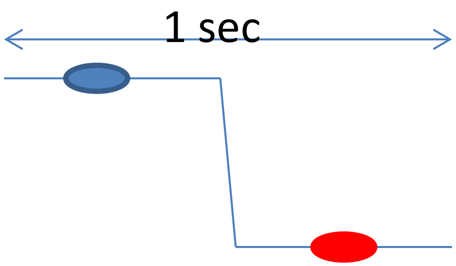


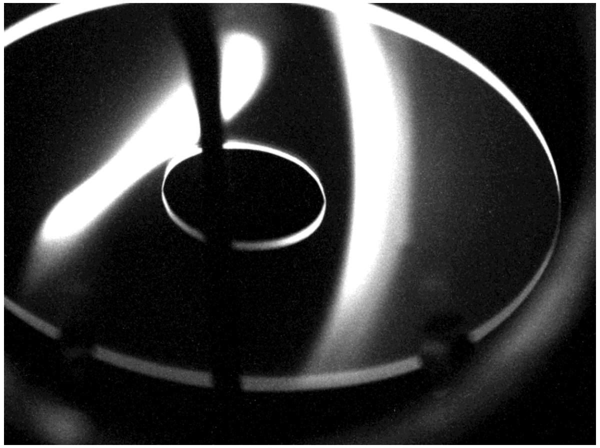
Cathode preparation chamber: about $5X10^{-10}$ torr
Gun chamber: $6.8X10^{-11}$ torr during test
(It got into 10^{-12} torr earlier)

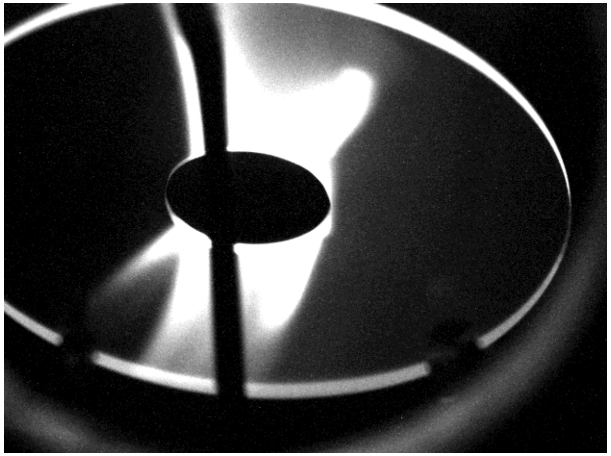
Test of two cathodes combined

- Trigger Freq.: 1 Hz
- Beam Frequency: 2 Hz
- Bunch length: 0.1 s
- Beam energy: 14 keV
- Camera exposure:1 sec

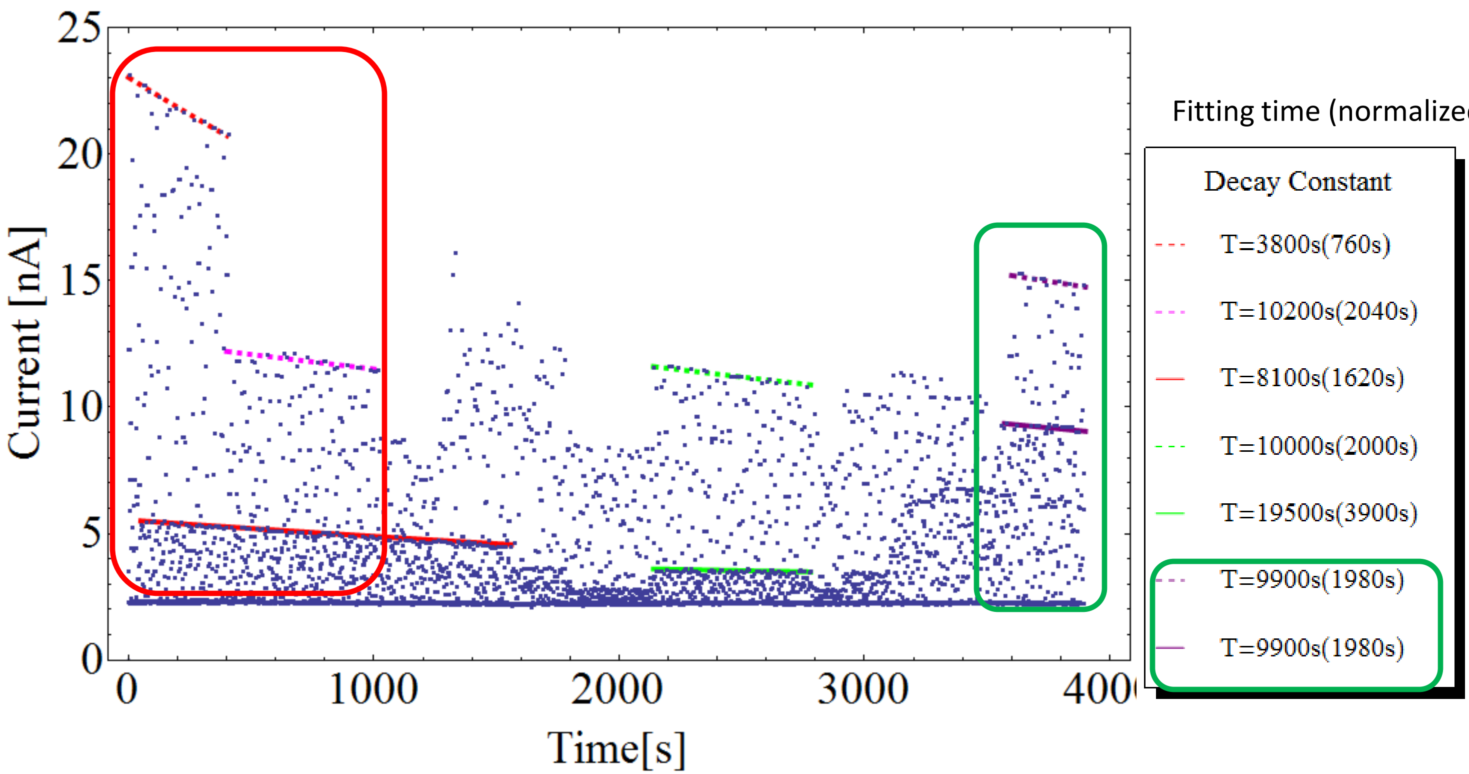








Two beams decay test



Duty factor:0.2

•The lifetime of combined beams was 1980s, slightly longer than single cathode lifetime 1520s (single beam test). It indicates QE was not reduced by funneling.

•When first beam is unstable, the beam hit to beam pipe and caused outgassing, only the first cathode QE decay, second cathode didn't affect by first one.

Summary

- Gun design includes vacuum, mechanism, beam optics, beam dump, beam instrumentations was done.
- 3D beam dynamics simulation was done.
- Good QE GaAs photocathode was activated.
- Gun fabricated, assembled and tested by industry.
- Two low current beams were combined.
- The 3Gohm resistor between gun and power supply limited our current and high voltage condition.
- Energy spread and the sextuple field of combiner make long beam shape on the YAG.
- At a few hundreds nano-amper current level, the test indicates #1 beam will not affect #2cathode lifetime. No cathode cross talk observed.
- Current status: Initial beam test done, the system has been shipped to our laboratory for high-current tests.
- High current proof of principle test is scheduled in early next year.

Acknowledgements

MDC Corporation, Transfer Engineering Inc.,
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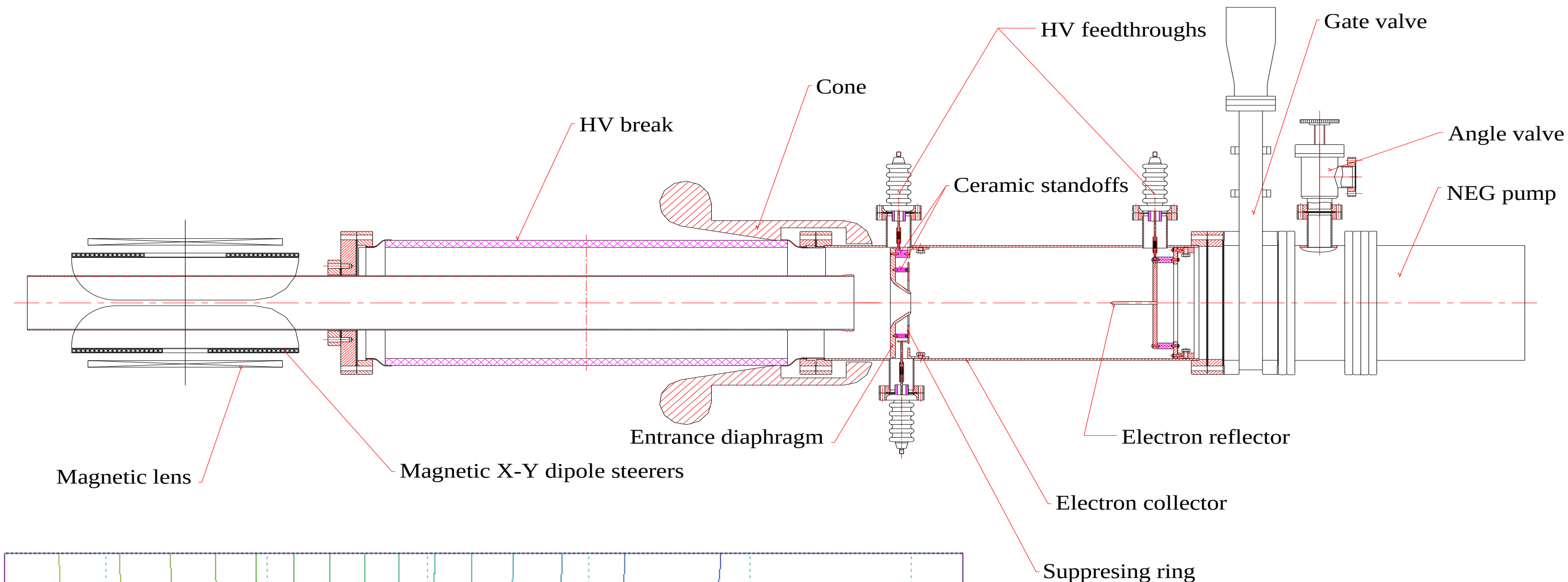
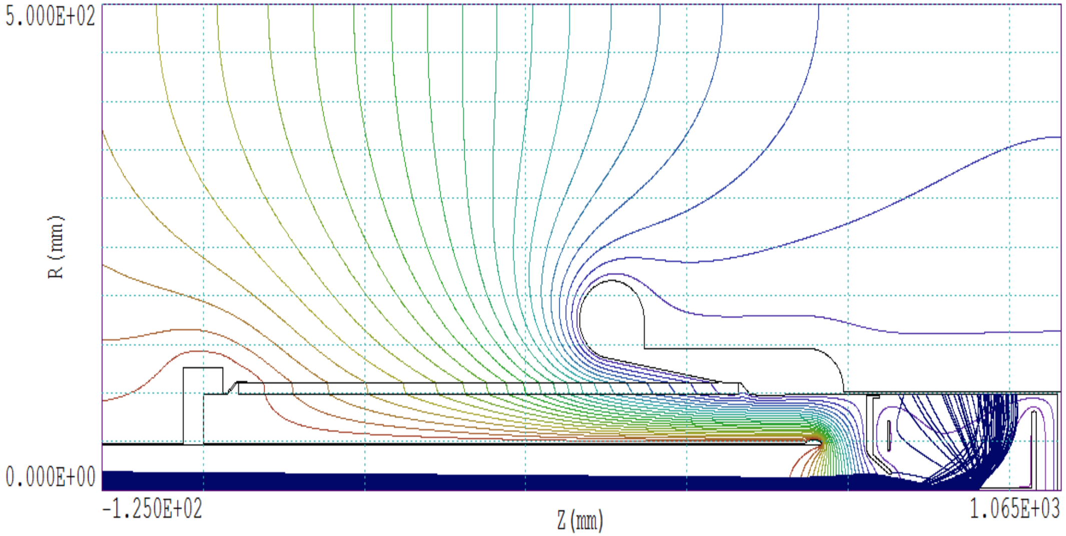
Pascal Technologies, Gamma Vacuum, Stangenes Industries

- Brookhaven Science associates, LLC under Contracts No.DE-AC02-98CH10886 with the U.S.DOE
- BNL, Laboratory Directed Research and Development (LDRD)

Thanks for your attention!

Depressed collector





- With collector voltage higher than the primary electron energy spread the returned primary electron current does not exceed 0.1% of the primary electron beam current
- The penetration of the secondary and backscattered electrons into the beam pipe is completely eliminated