Funneling multiple bunches of high-charge polarized electrons

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Outline

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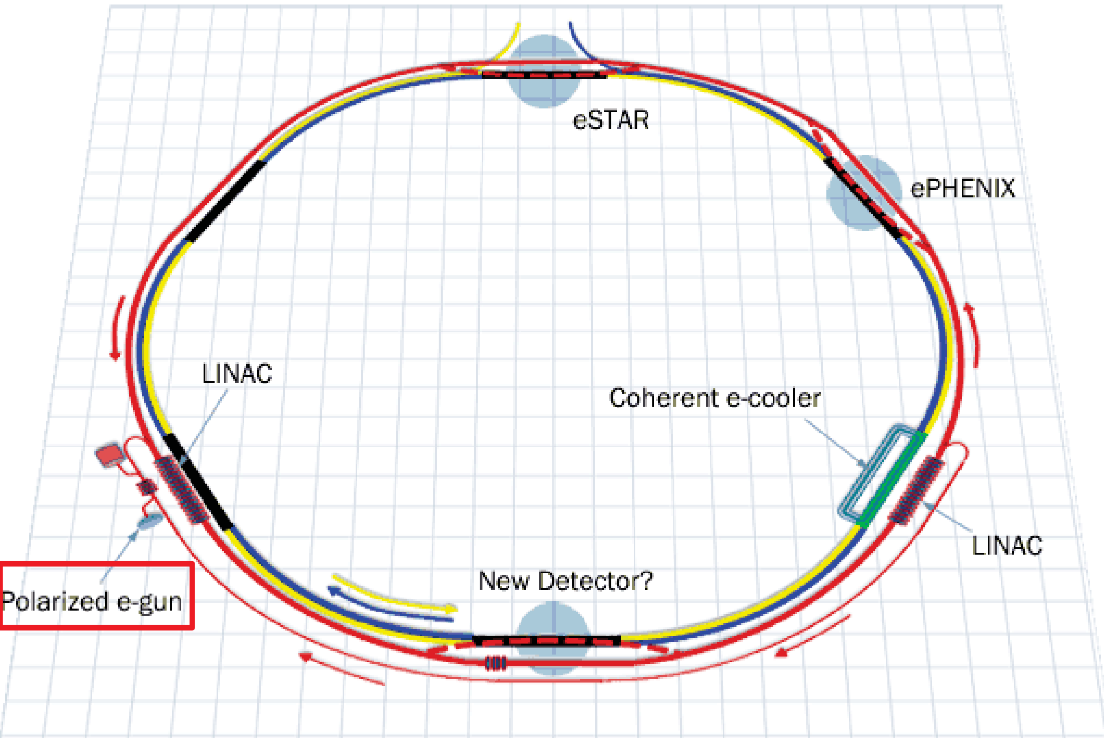
- Motivation
- Funneling gun design
  - Cathodes preparation
  - Beam optics design
  - Mechanical design
  - beam diagnostic
- Proof-of-Principle test
- Recent progress
- Summary

Motivation

ERL based eRHIC: The current proposed design for an EIC integrated with RHIC



eRHIC parameters

	p	e
Energy, GeV	325	20
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 want?
High average current: 50mA; High Bunch charge:5.3nC; Long lifetime

Avoid surface charge limit:
Peak current 2.33A from 6mm diameter emission area

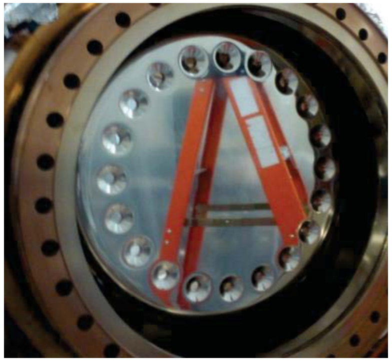
Long operation lifetime:
Gatling concept: 20 GaAs cathodes
Careful beam optics design: Reduce out gassing due to beam loss

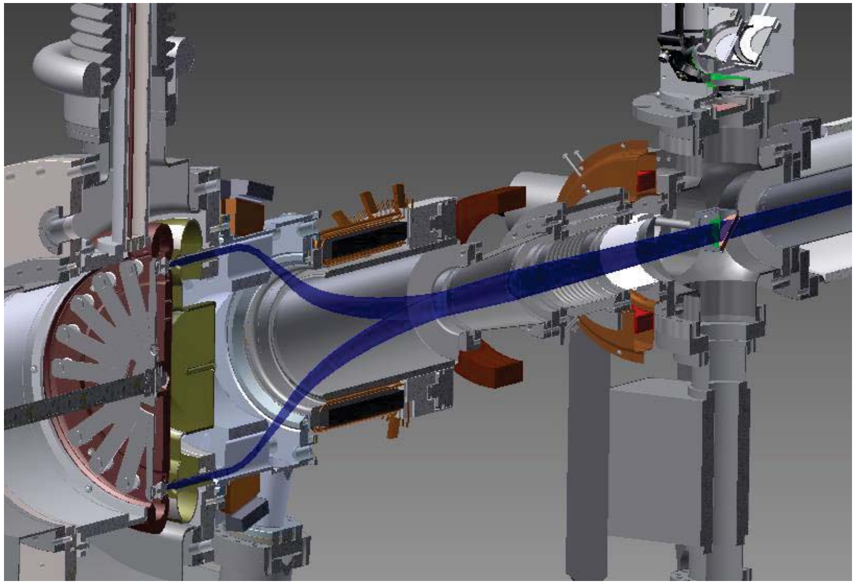
How we figure out?

eRHIC requirement:
Weekly cathode exchange, operation lifetime 85 hours(half week)
Average current :50mA
Charge lifetime: 15,300C

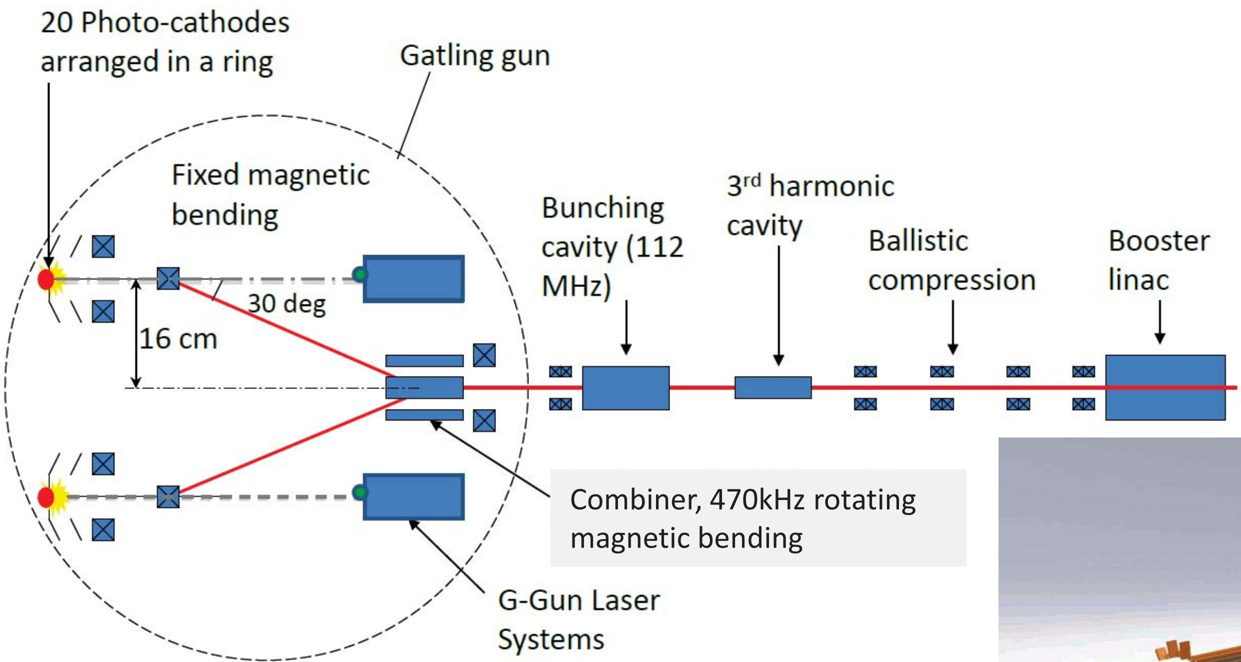
Current State-of-art single cathode charge lifetime: [1000C @ 2.5mA]

15300C/20=765C<1000C

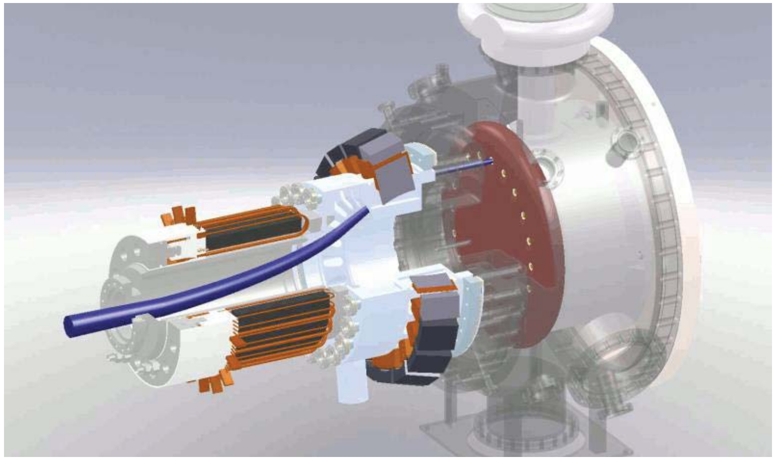




What we want to demonstrate?



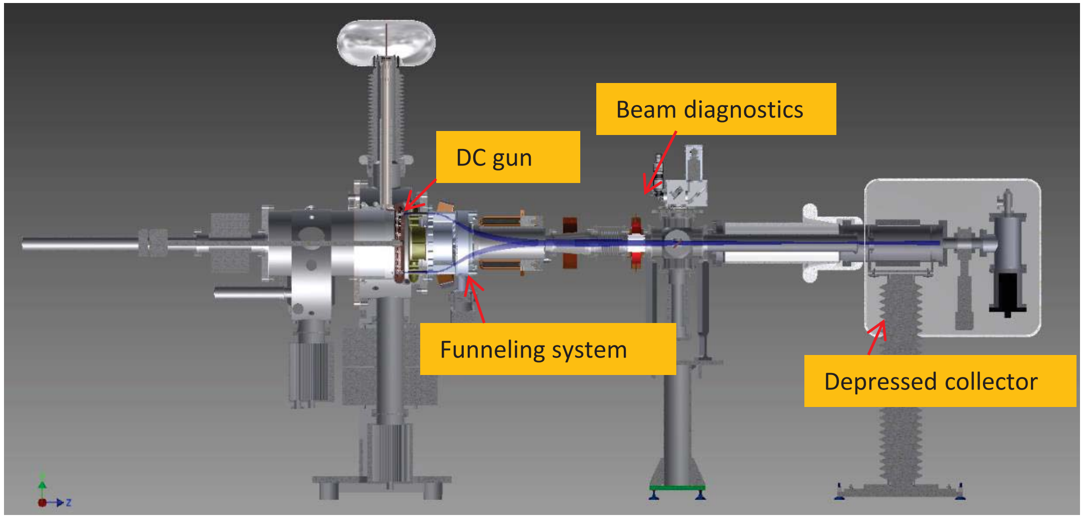
10MeV
1% Energy spread

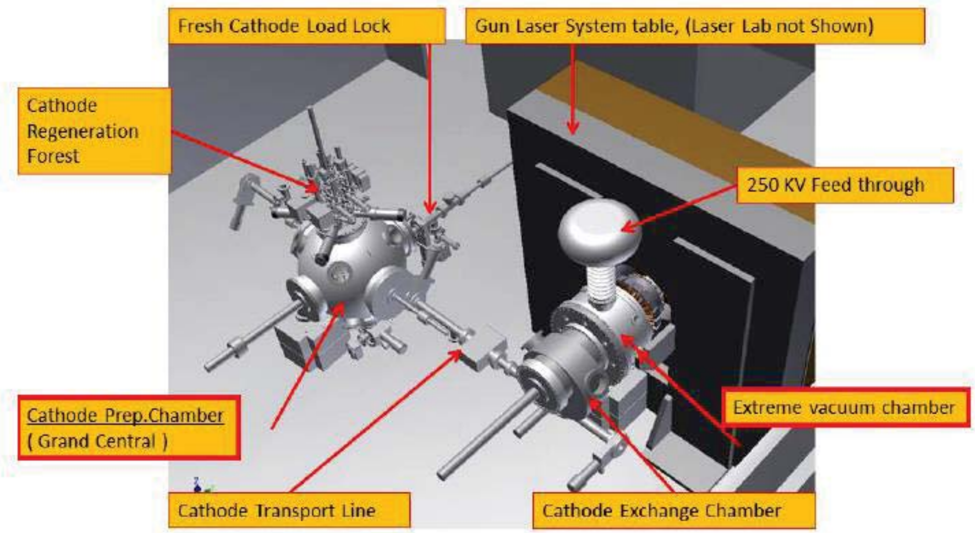


Single cathode:470 KHz*5.3nC=2.5mA
After funneling:9.4 MHz*5.3nC=50mA

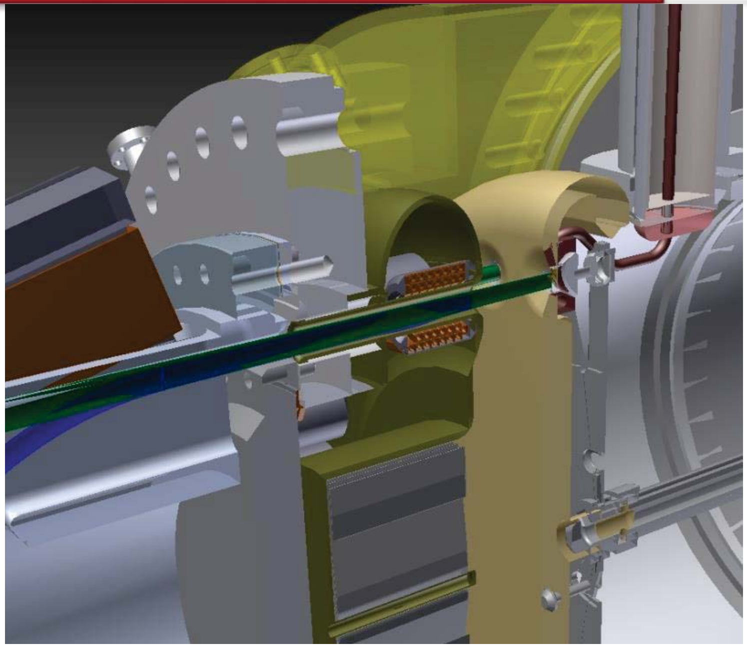
We want to demonstrate:
The performance of an individual photocathode is not affected by the presence of other cathodes.
The charge lifetime will increase 20 times.

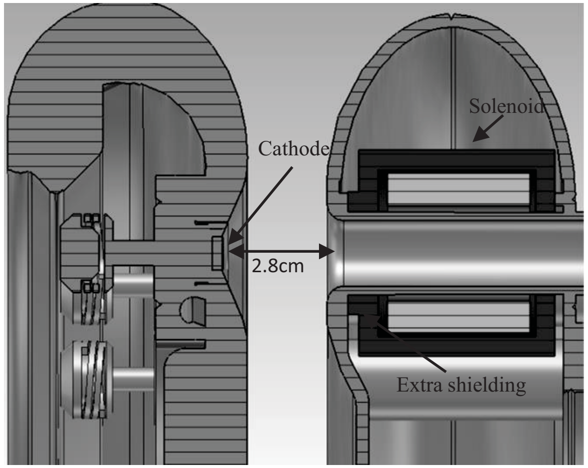
Phase one layout



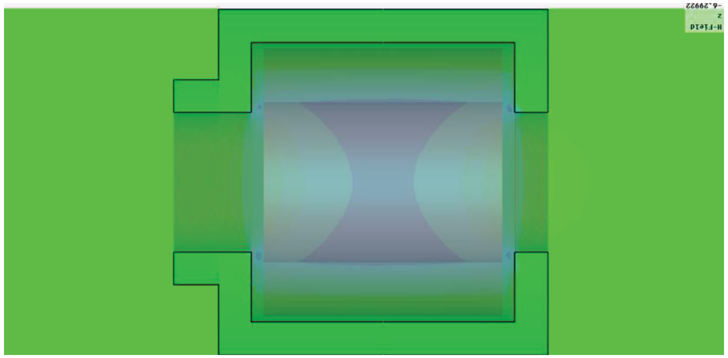


DC and solenoids

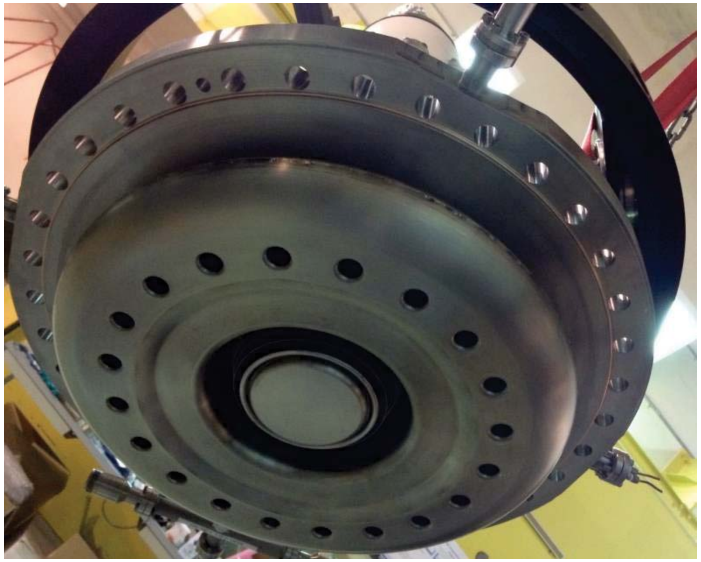




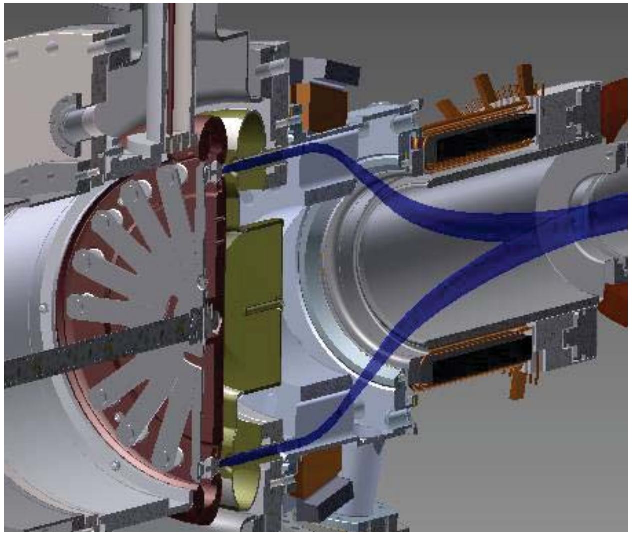
DC gap:2.8cm
Charge to:220kV
SCL:7A
Maximum field:5.3MV/m

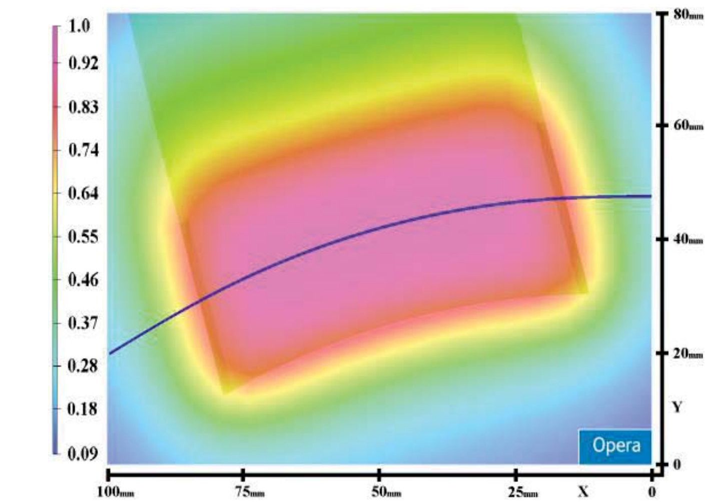


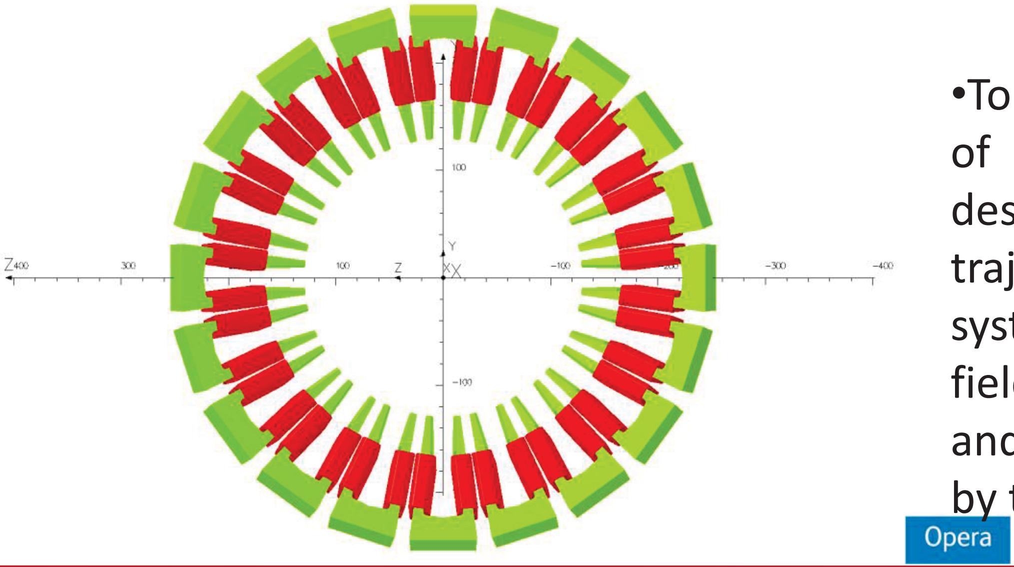
Max field:660G
Integral : 0.260 T-cm



Statics Dipole Magnet

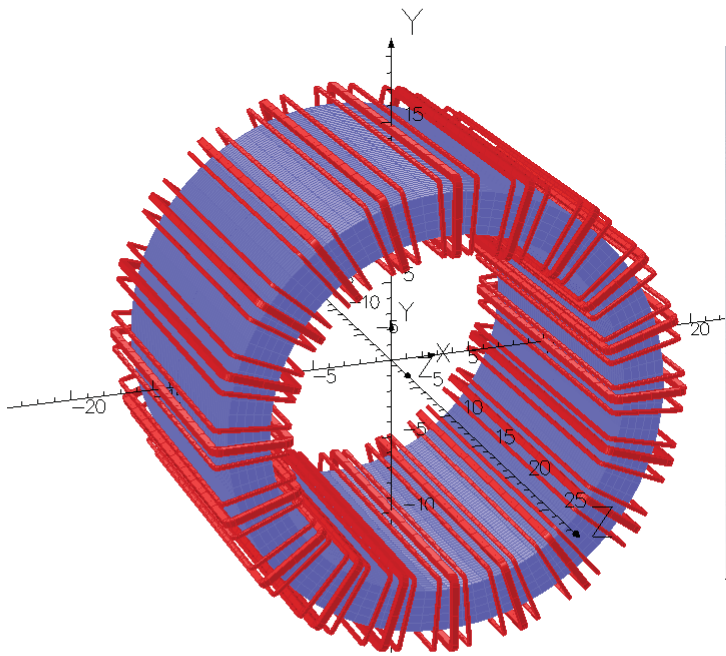


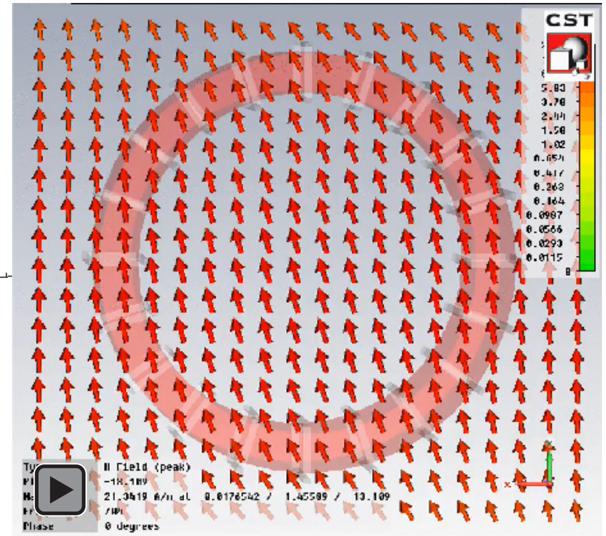


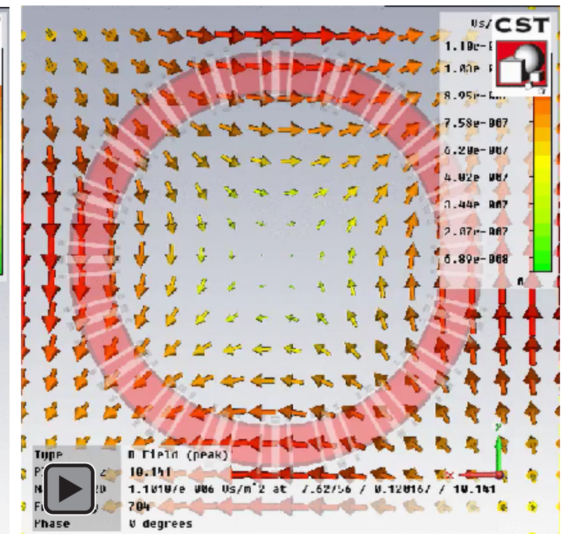


•To preserve the longitudinal direction of electron spin polarization, we designed compensated dogleg trajectories in the beam's funneling system encompassing fixed bending fields generated by 20 dipole magnets, and a rotating bending field generated by the magnetic combiner.

Beam Combiner







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

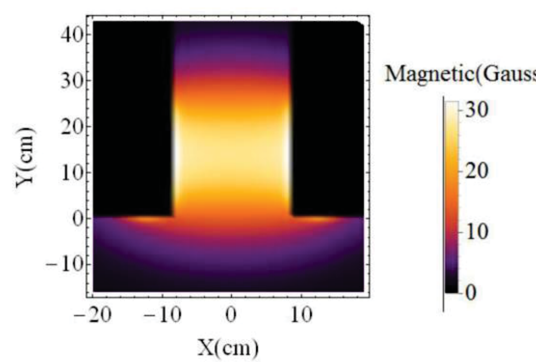
$I(t)=I_{od}*\cos(\omega t+\phi)$ where $I_{od}=70.7A$

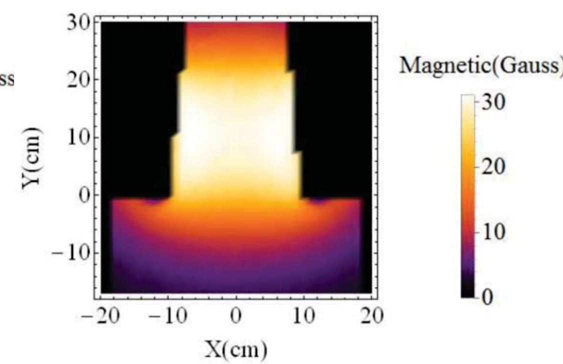
$I(t)=I_{oq}*\cos 2(\omega t+\phi)$ where $I_{oq}=1.54A$

B(0,0,0)=25.04G

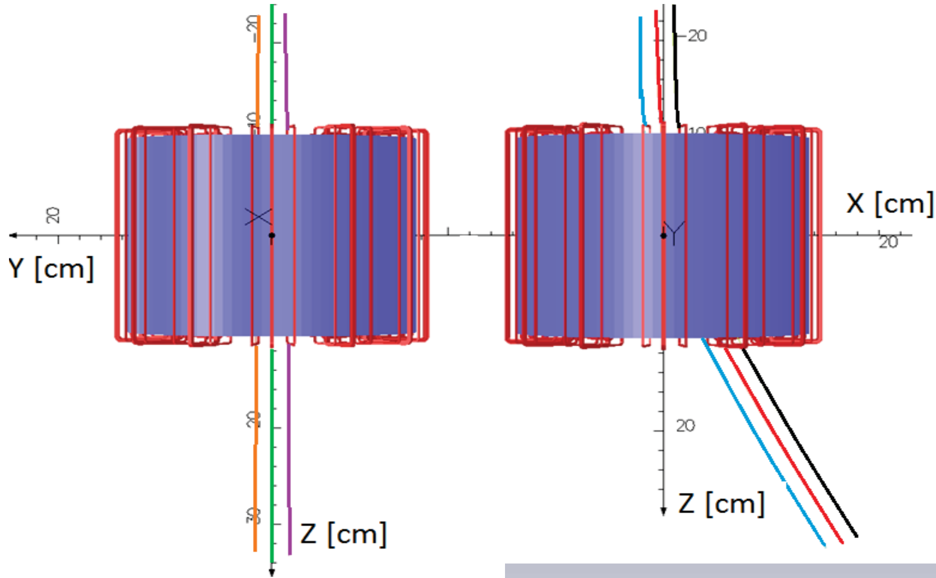
Freq=470kHz

Bending angle=29 degrees

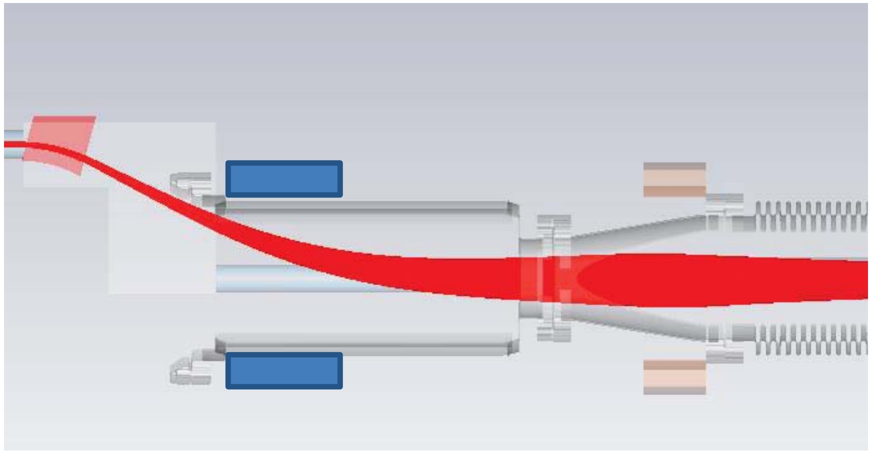




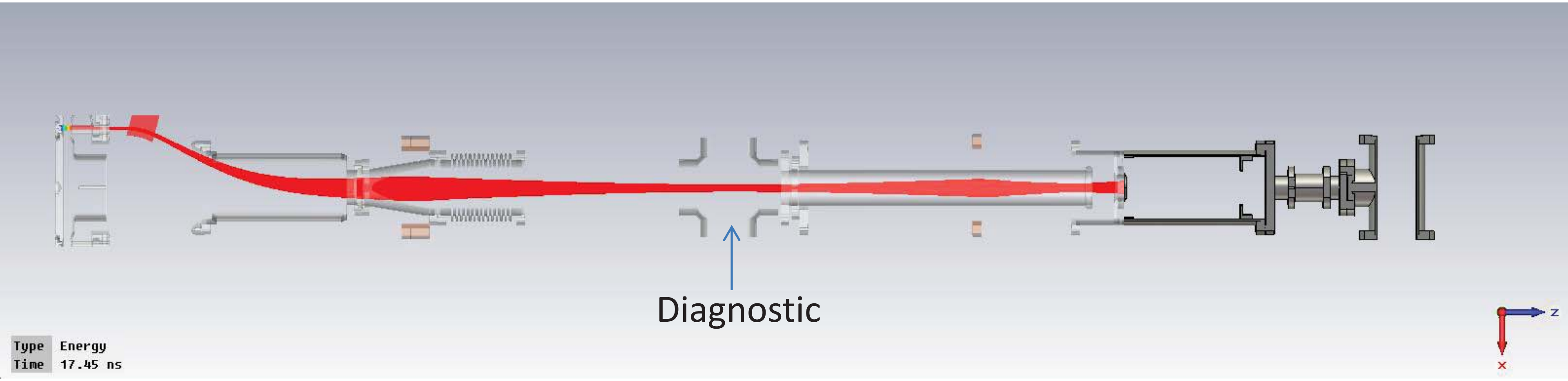
Beam combiner

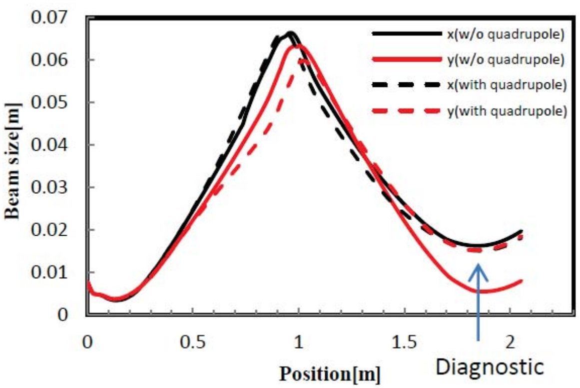


Single particle tracking shows:
•The intergrated field is adjusted to bend the 220keV electrons by 29°
•converging angle w/t quadrupole: X'/Y'=2.5mrad/15.7mrad
•With quadrupole X'/Y'=8.7mrad/9.8mrad

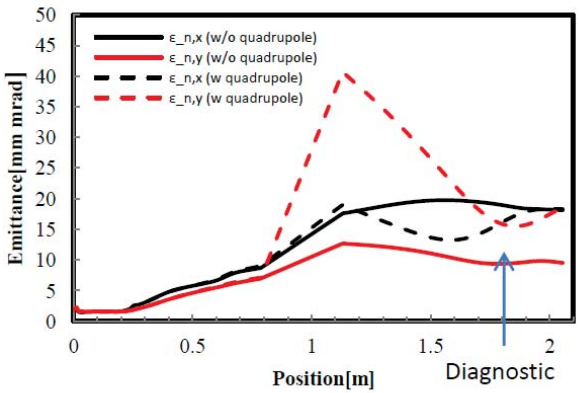


Beam dynamics





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

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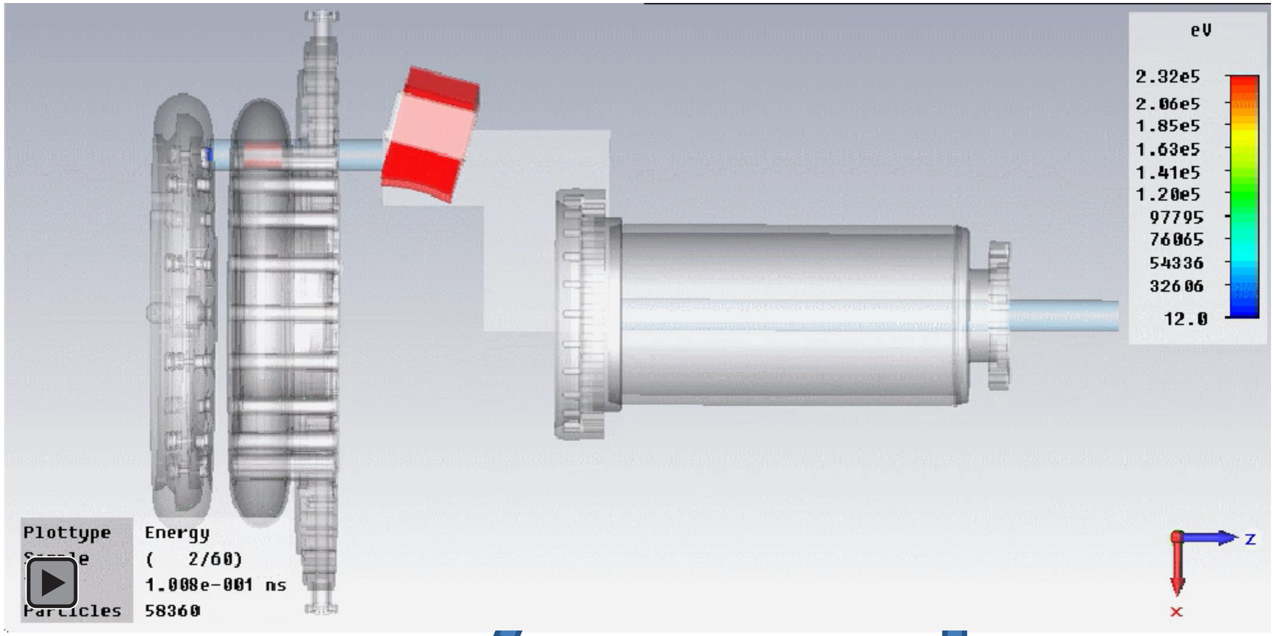

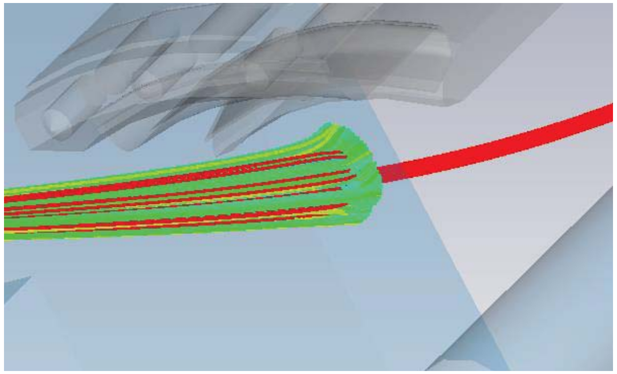

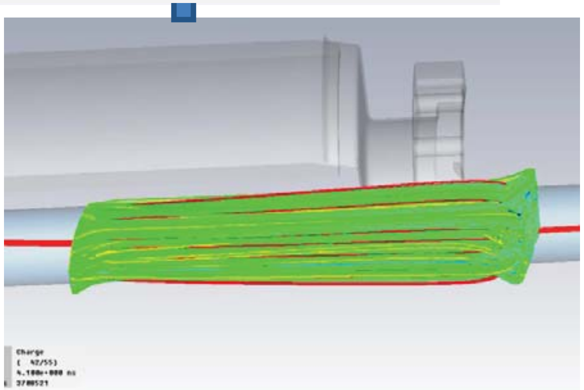

- The beam halo cannot form at beginning and end of combiner.
- There is no beam loss on the combiner tube base on Particle core model

Vacuum design

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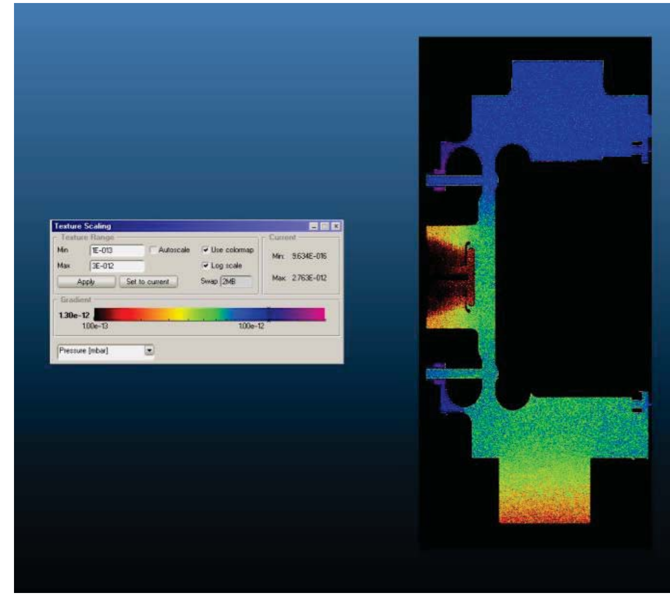
Transferring chamber: NEG 1500l/s
Design vacuum:10^{-12} torr scale
Test vacuum now:**$8*10^{-12}$torr**

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**

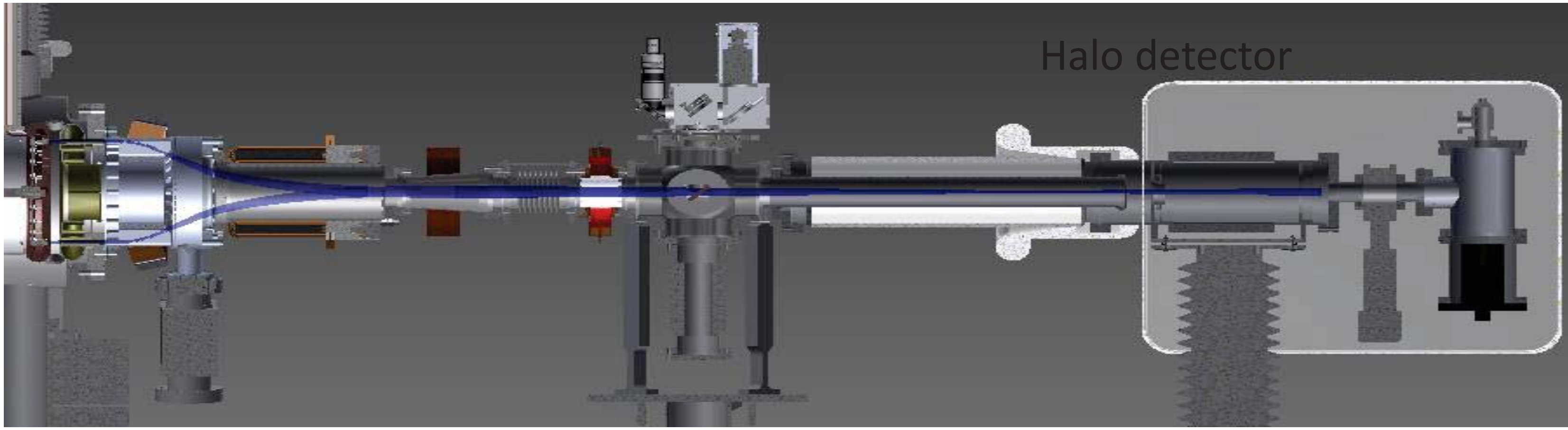
Combiner:6000l/s
Design vacuum:$1*10^{-11}$ torr

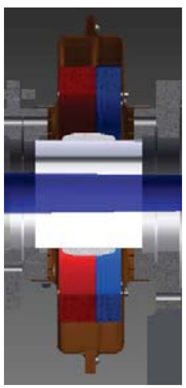
Exchange chamber:4000l/s
Design vacuum:$1*10^{-12}$torr
Total:20,000L/s



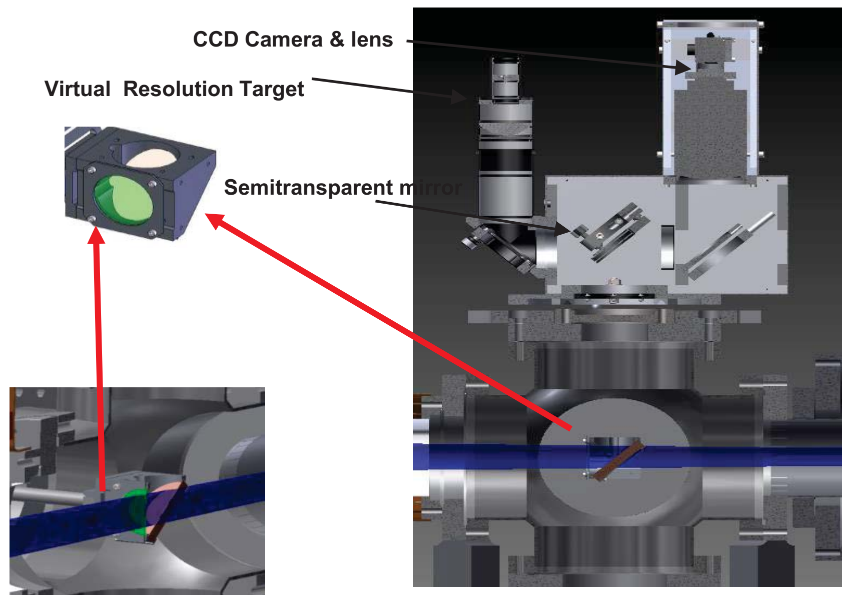
Gun vacuum vessel material:
Vacuum fired SS 316L($2*10^{-13}$ Torr L/cm^2 s)
Anode material:
Ti($2*10^{-15}$ Torr L/cm^2 s)

Beam diagnostic



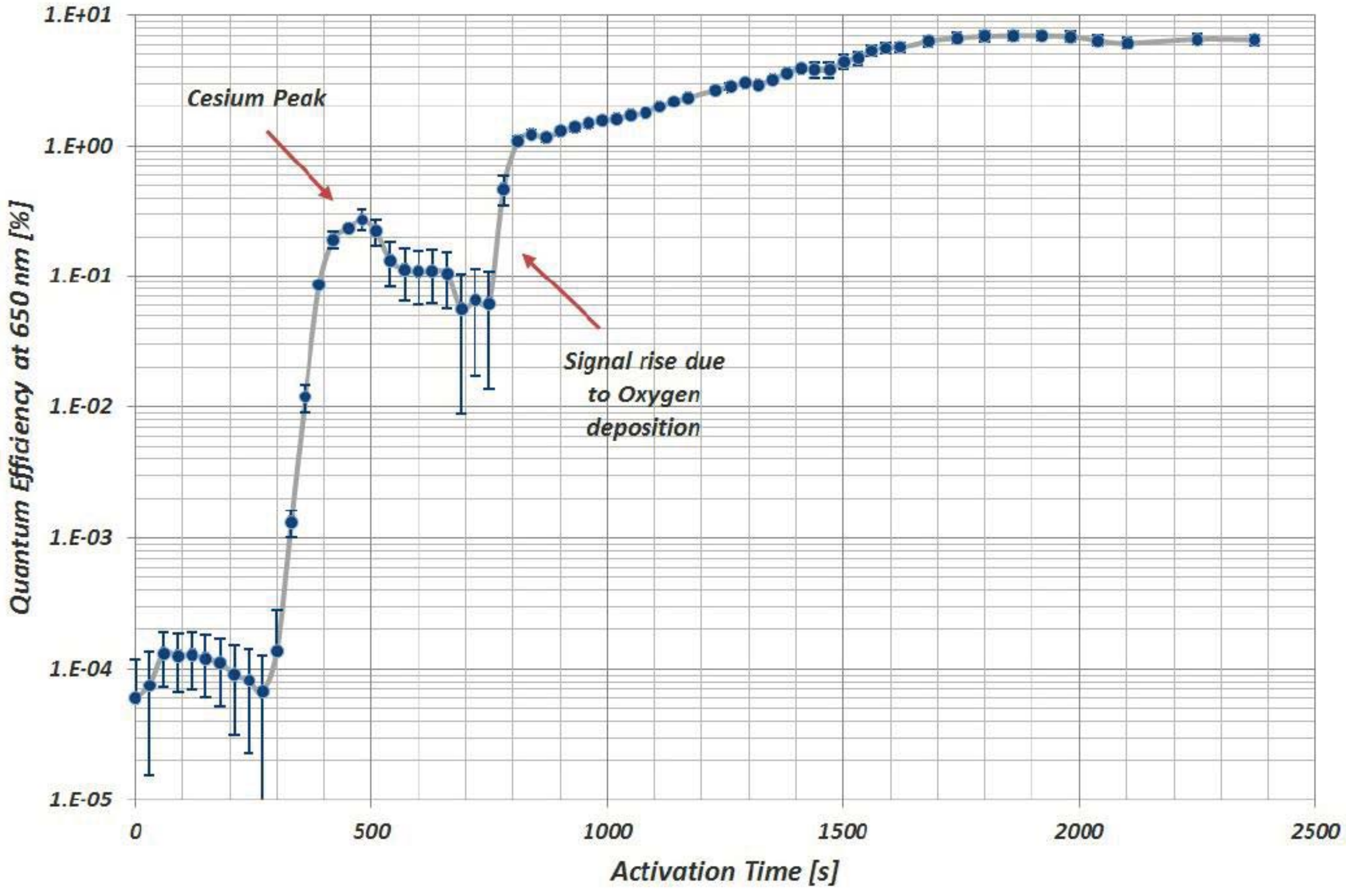


Fast Current Transformer &
Integrating Current Transformer

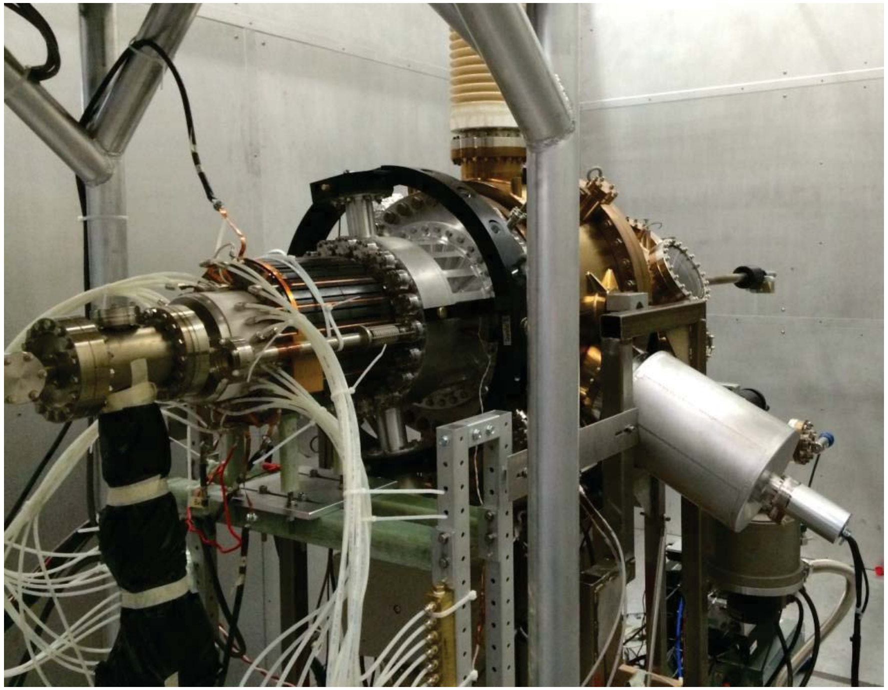


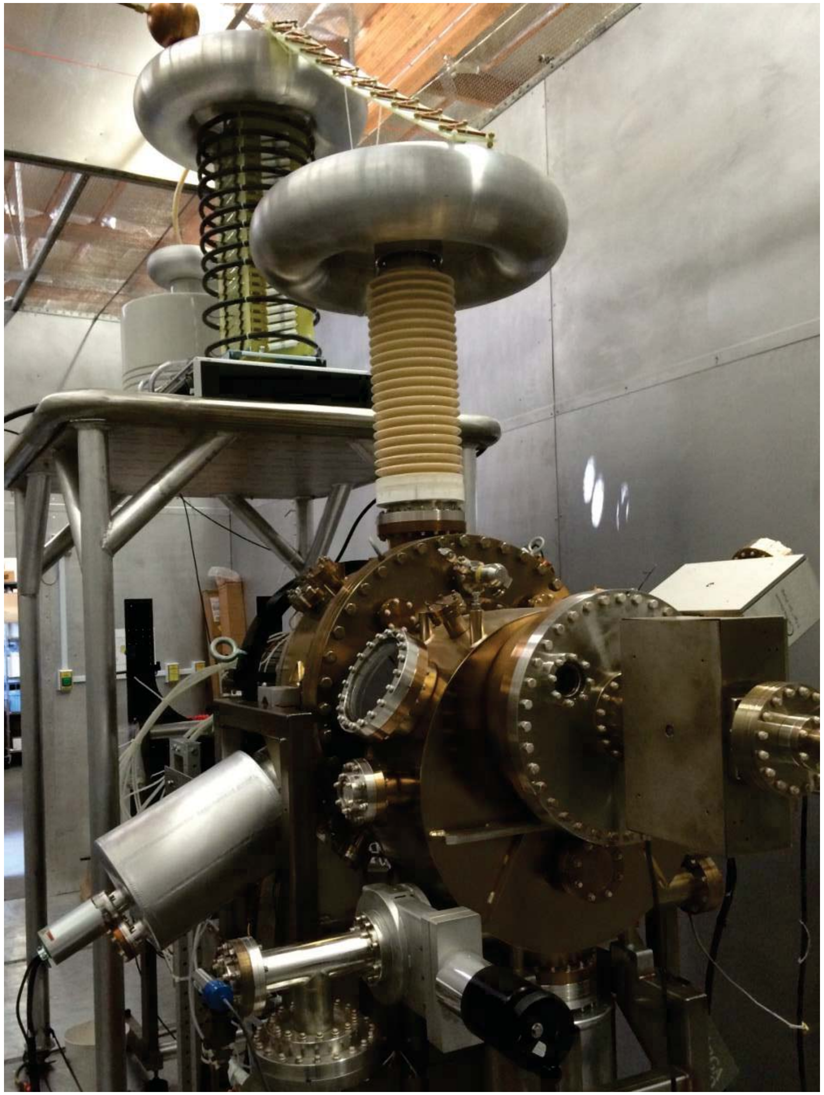
Courtesy of D.Gassner

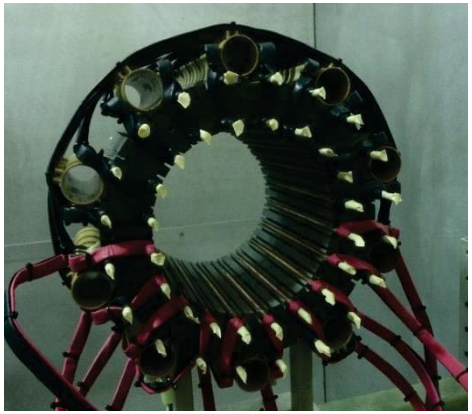
Cathode preparation



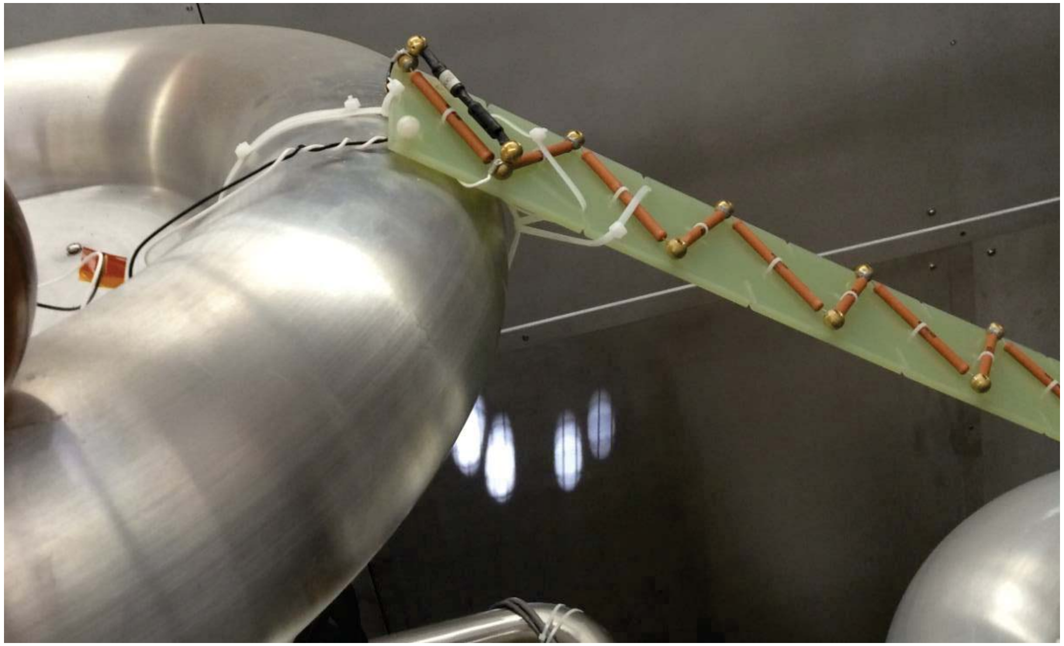
Gun





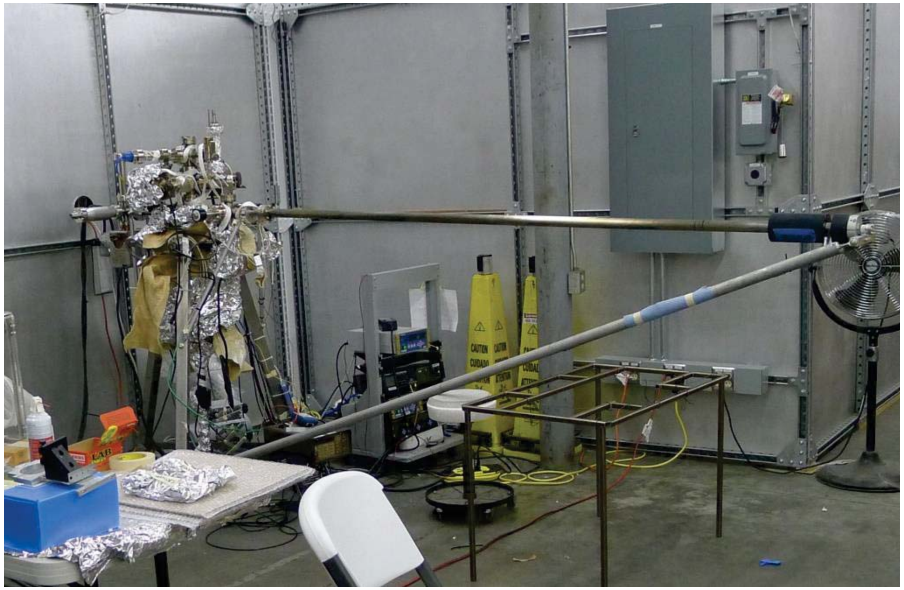


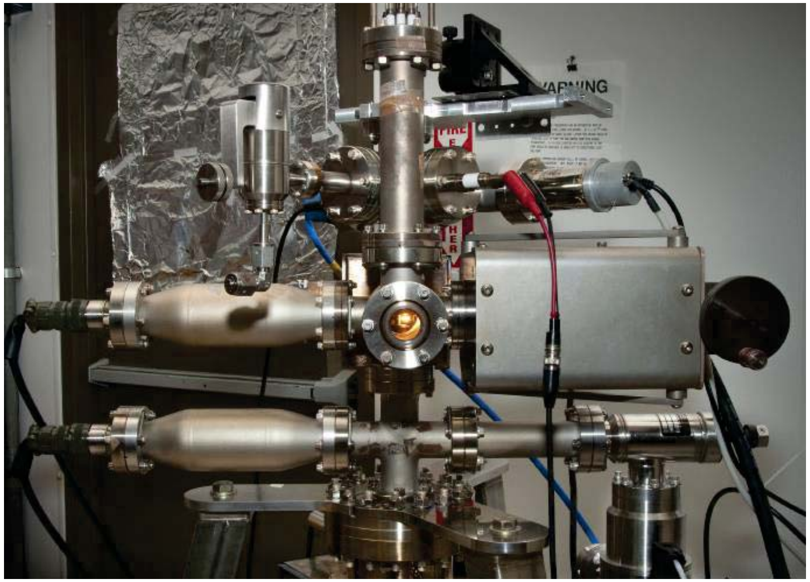
High voltage power supply

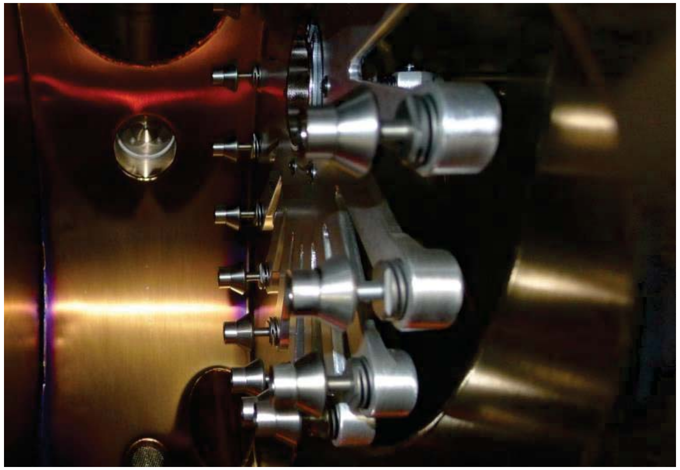


250kV power supply
2.888Gohm resistor series connect between gun and power supply for safety.

Cathode preparation and transport



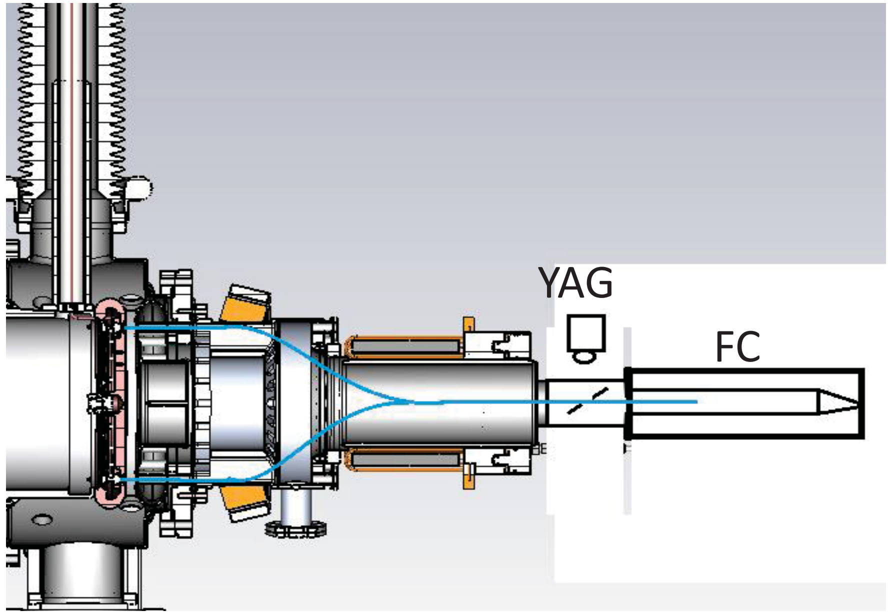


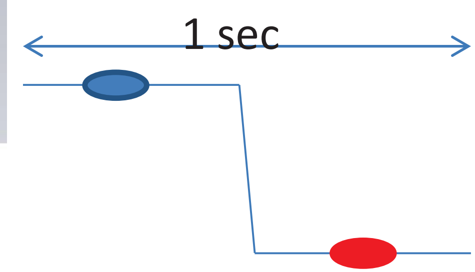


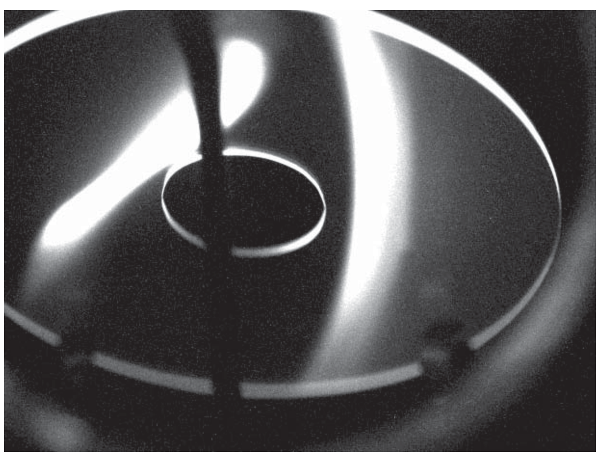
Cathode preparation chamber: about $5X10^{-10}$ torr
Gun chamber: $6.8X10^{-11}$ torr during test
(It got into 10^{-12} torr earlier)

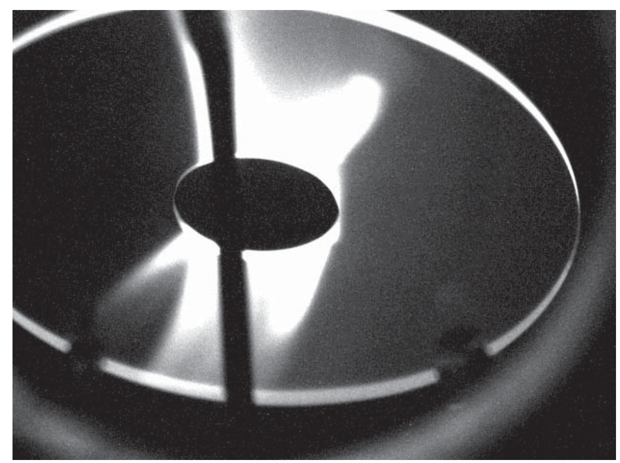
Test of two cathodes combined

- •Trigger Freq.: 1 Hz
- •Beam Frequency: 2 Hz
- •Bunch length: 0.1 s
- •Beam energy: 14 keV
- •Camera exposure:1 sec
- •Pressure: $6*10^{-11}$ torr





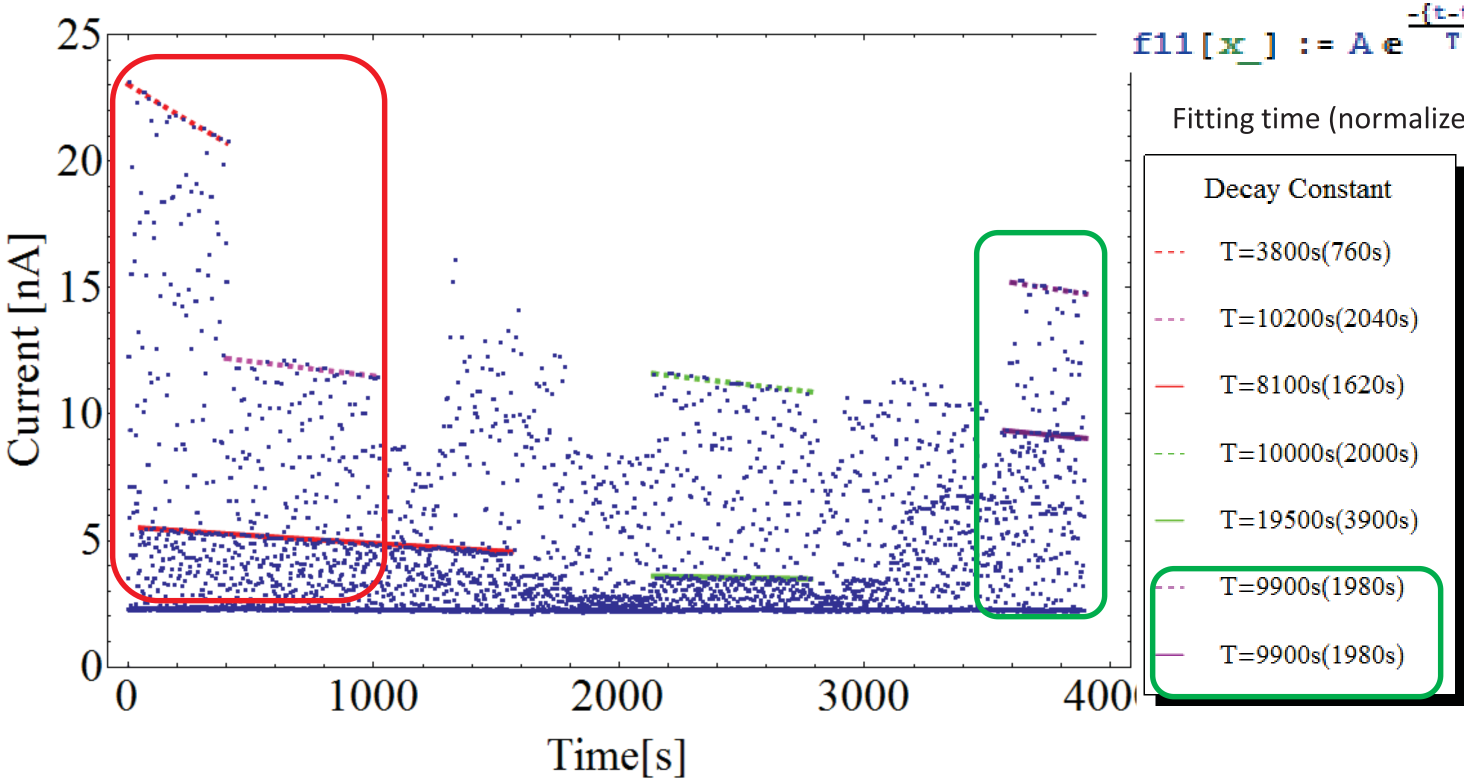




Two beams decay constant

$$f11[x\_] := A\, e^{\frac{-(t-t0)}{T}} \;/;\; t0 < x < t1;$$

Fitting time (normalized to DC beam)



Duty factor:5

- The lifetime of beam combined is 1980s which longer than single cathode lifetime 1520s(single beam test). It indicates QE no reduce due to another cathode emission.
- When first beam is unstable, the beam hit to beam pipe and outgassing, only first cathode QE decay, second cathode didn't affect by first one.

Future Plan

- Conditioning the gun to 110kV
- Reach 10^{-12} scale vacuum in DC gun vessel
- Generate 2.5mA current from super-lattice GaAs photocathode.
- Combine four beams to get 10 mA current.
- Funneling proof of principle test.
- Study cathode charge lifetime, beam quality, beam halo and beam polarization.

Summary

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- 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.

Acknowledgements

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- BNL, Laboratory Directed Research and Development (LDRD)

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Thanks for your attention!

Back up 1 Beam parameters

Parameter	Value
Bunch charge at cathode	3.5nC(5.3nC)
Longitudinal charge distribution at cathode	Gaussian distribution(σ=1.5ns)
Transverse charge distribution at cathode	Uniform
Bunch length at cathode	1.5ns(2.25nC)
Bunch radius at cathode	4mm
Thermal normalized emittance, $\varepsilon_{n,th}$	0.5 μm/mm(rms); Total thermal emittance=2μm
Single cathode average current	2.5mA
Repetition rate for one cathode	704kHz(470kHz)
DC gap voltage	220kV
Combiner	Center field=24.5G;Physical length=20cm
First solenoid	Maximum field=560G; Physical length=5.4cm
Second solenoid	Maximum field=184G; Physical length=10.5cm
Third solenoid	Maximum field=366G; Physical length=6.3cm

Gatling Gun Laser System Design Concept

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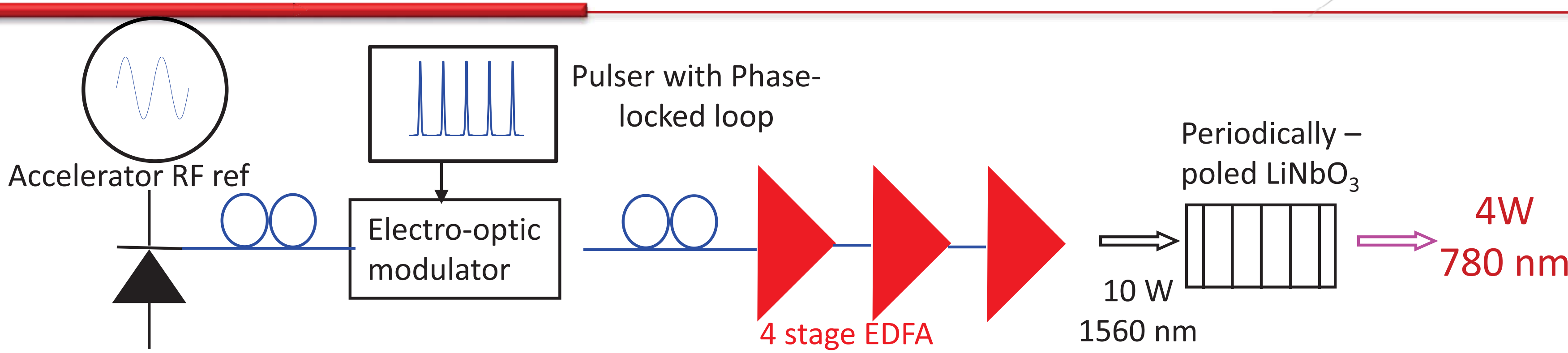

parameter	unit	spec	comment
wavelength	nm	780	
repetition rate	kHz	704	14.07 MHz / 20 cathodes
pulse energy at photocathode	uJ	2.8	QE=0.2% & 3.5 nC bunch chg
average laser power needed at cathode	W	2	assuming QE=0.2%
avg laser power output	W	4	
pulse width	nsec	1.5	Gaussian FWHM
jitter	psec	10	rms
amplitude stability		1.00E-03	requires noise-eater
contrast		1.00E-06	

- 10 W Erbium doped fiber amplifier (EDFA) system at 1560 nm, frequency doubled in periodically-poled $LiNBO_3$
- Continuous Wave distributed feedback laser (CW DFB) + electro-optic modulation for pulse source
- control of pulse shape, low jitter
- Frequency double to 780 nm in periodically poled material (40% efficiency)
- Design allows flexibility in pulse parameters

Courtesy of B. Sheehy