# Funneling multiple bunches of high-charge polarized electrons

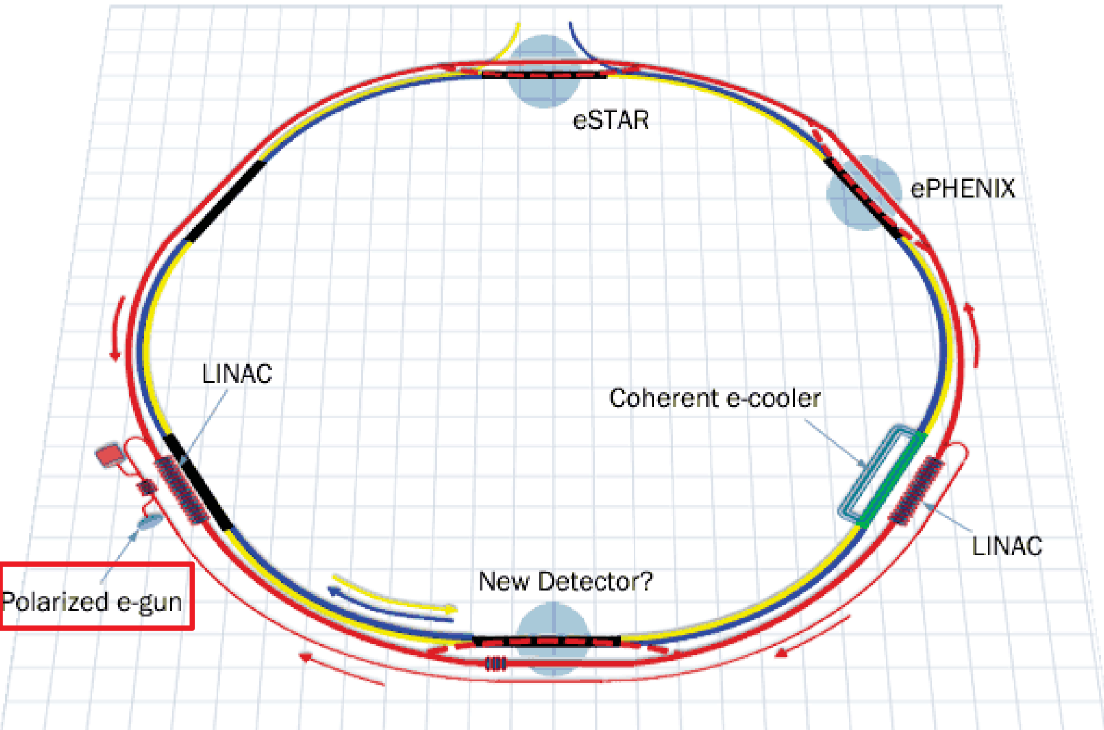
Erdong Wang
On behalf of the Funneling gun group
Brookhaven National Laboratory

# Outline

- 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

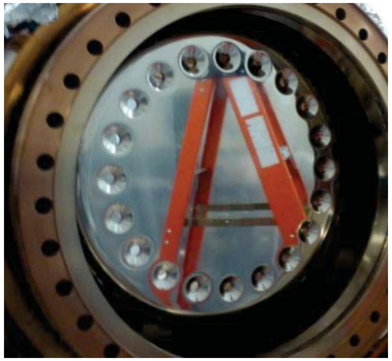
Long operation lifetime:
Gatling concept: 20 GaAs cathodes
Careful beam optics design: Reduce out gassing due to beam loss

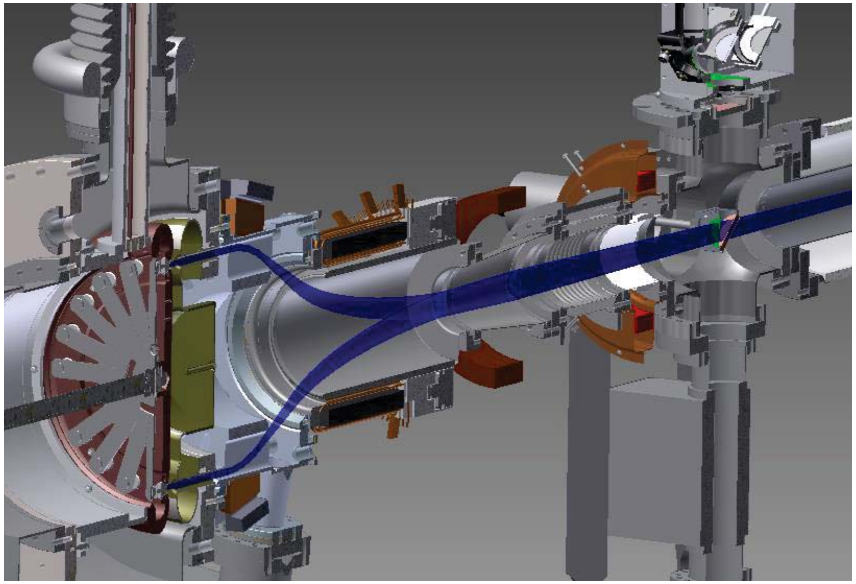
# How we figure out?

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

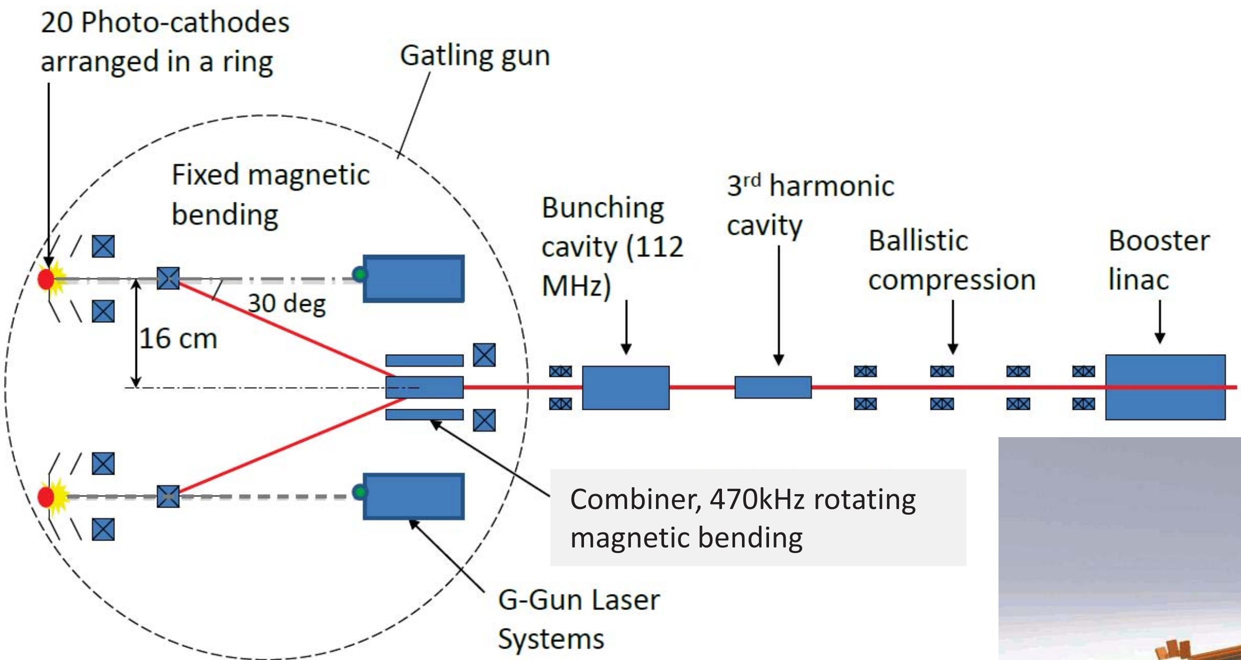
15300C/20=765C<1000C



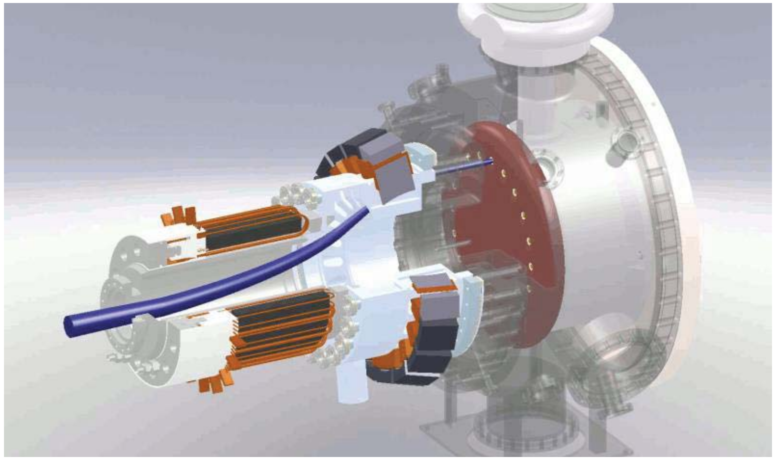


# What we want to demonstrate?

BROOKHAVEN NATIONAL LABORATORY



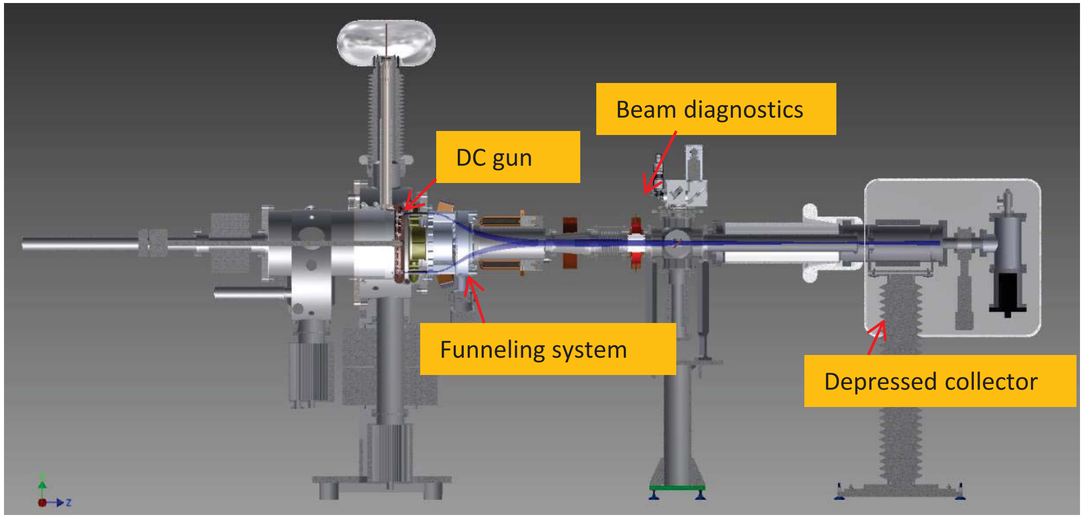

10MeV
1% Energy spread

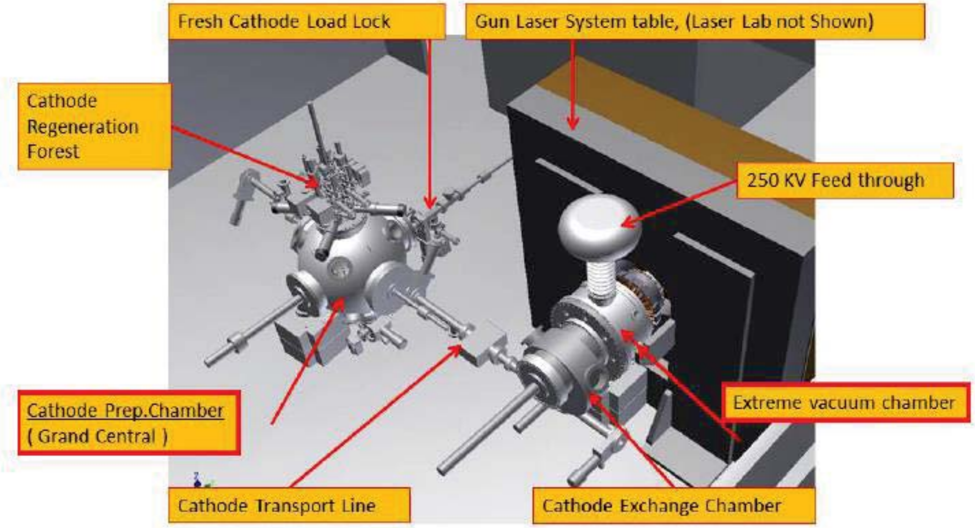


Single cathode:470 KHz*5.3nC=2.5mA
After funneling:9.4 MHz*5.3nC=50mA

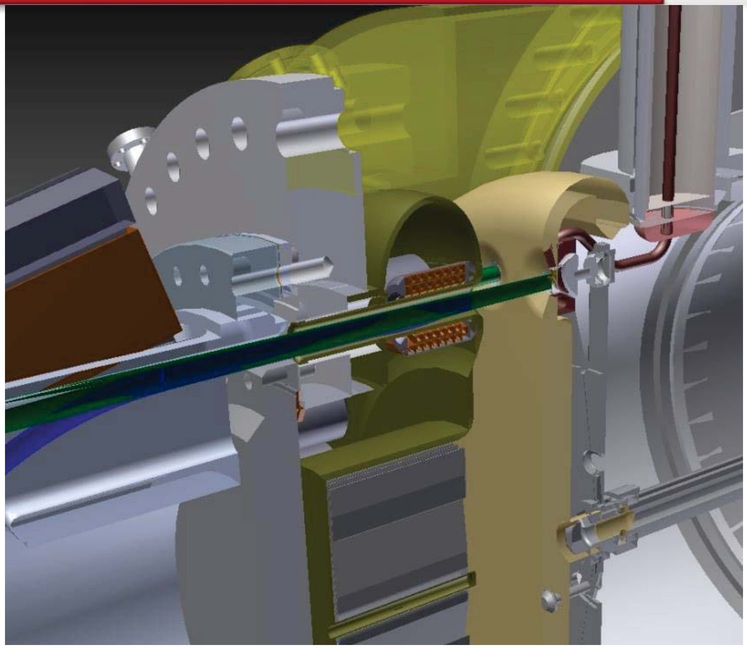
We want to demonstrate:
The performance of an individual photocathode is not affected by the presence of other cathodes.
The charge lifetime will increase 20 times.

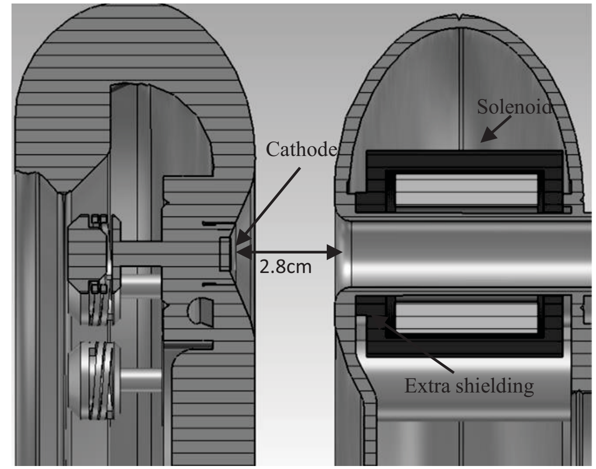
# Phase one layout



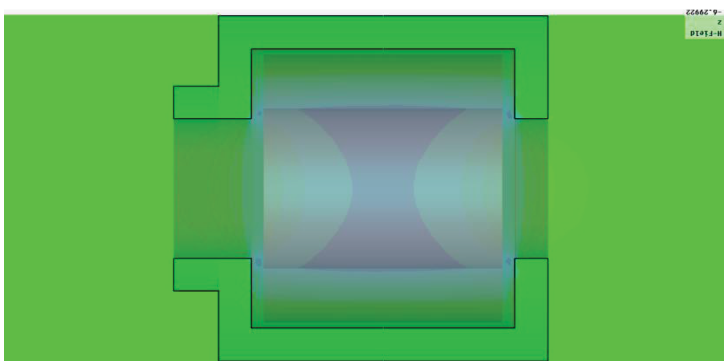



# DC and solenoids

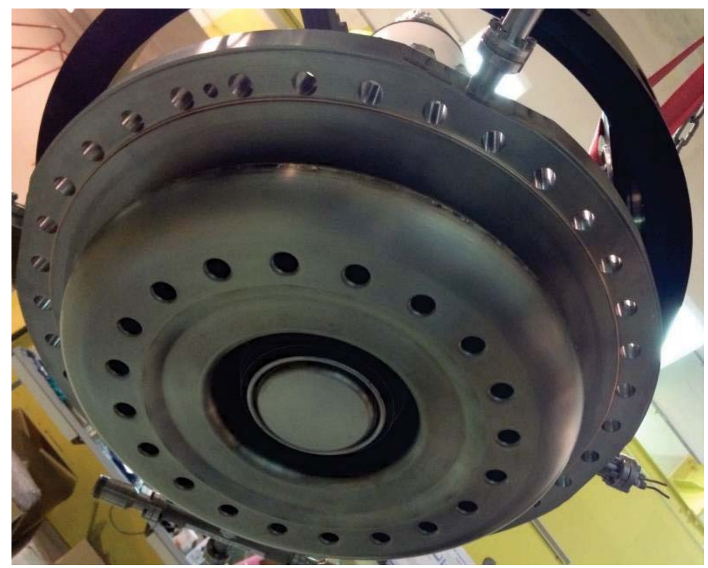




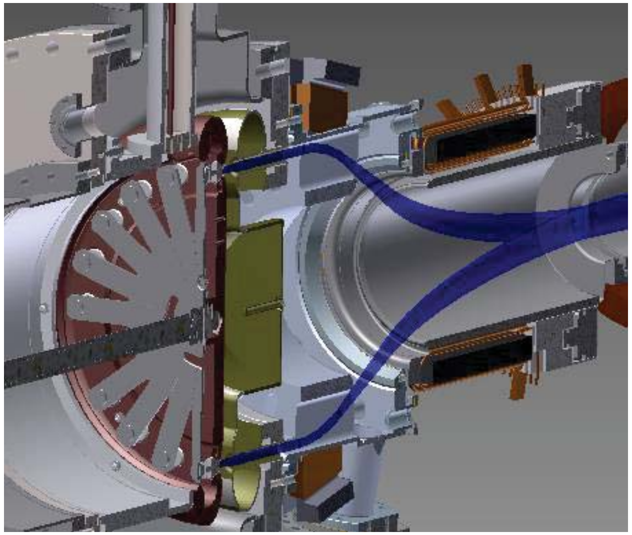

DC gap:2.8cm
Charge to:220kV
SCL:7A
Maximum field:5.3MV/m



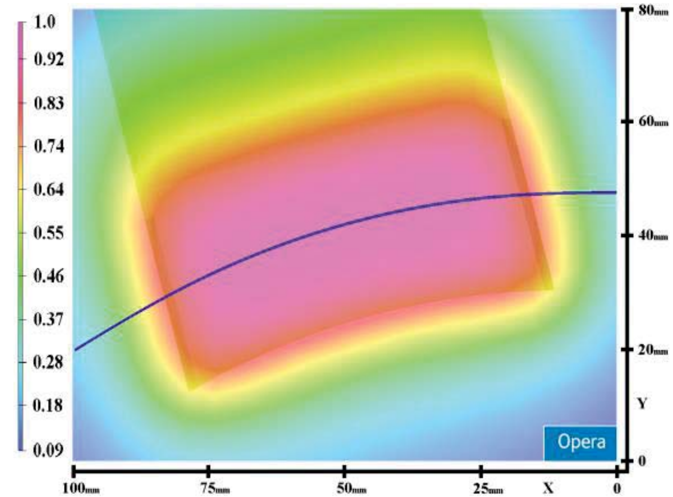
Max field:660G
Integral : 0.260 T-cm

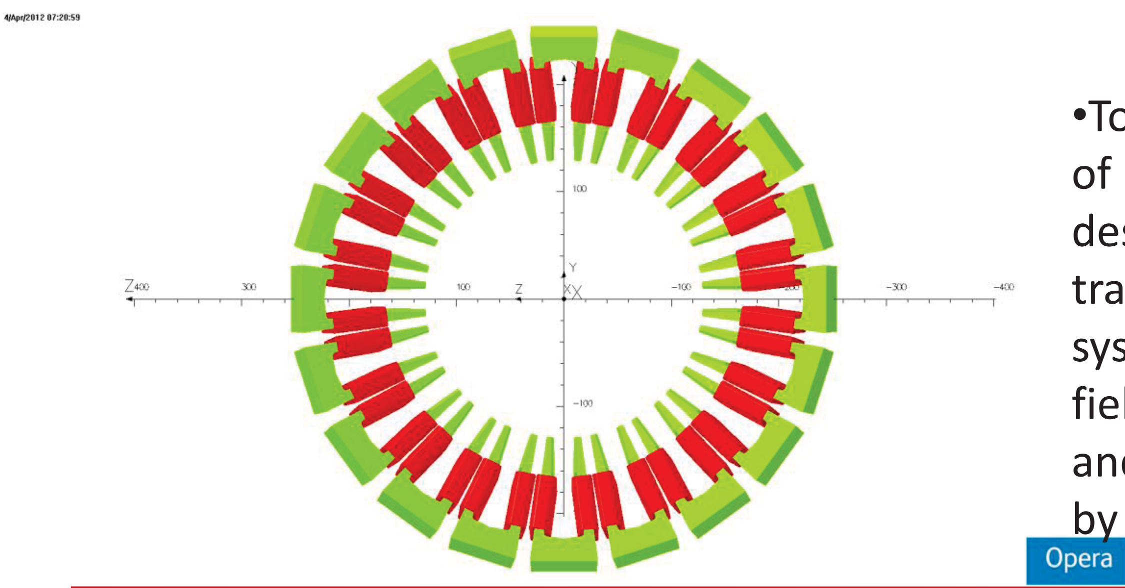


# Statics Dipole Magnet



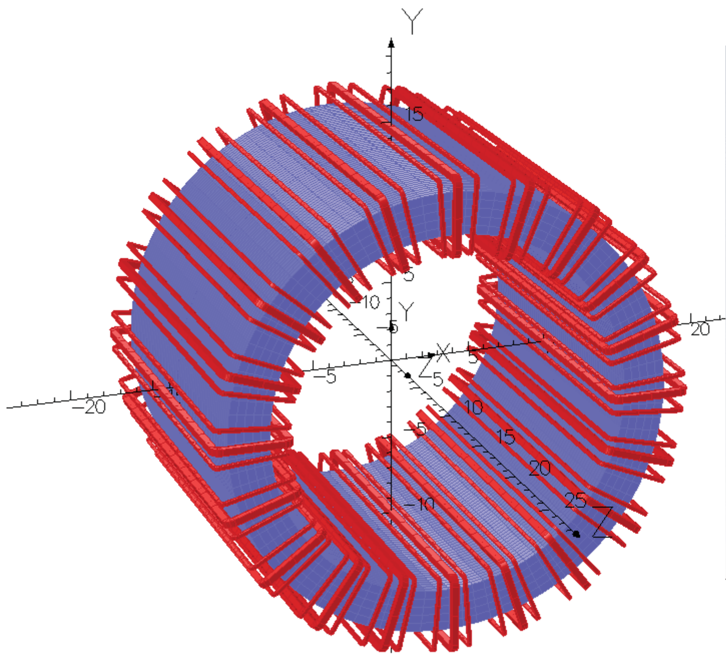
Normalized to 110G

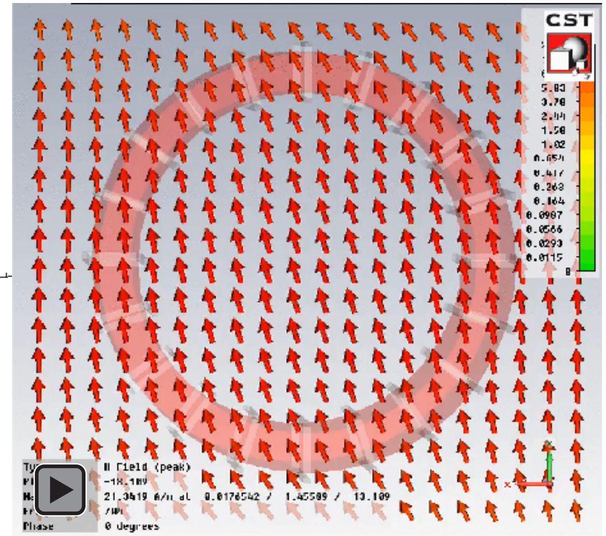


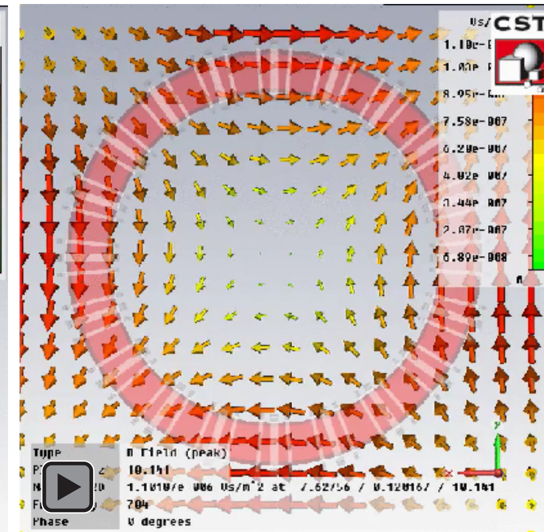




•To preserve the longitudinal direction of electron spin polarization, we designed compensated dogleg trajectories in the beam's funneling system encompassing fixed bending fields generated by 20 dipole magnets, and a rotating bending field generated by the magnetic combiner.

# Beam Combiner






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

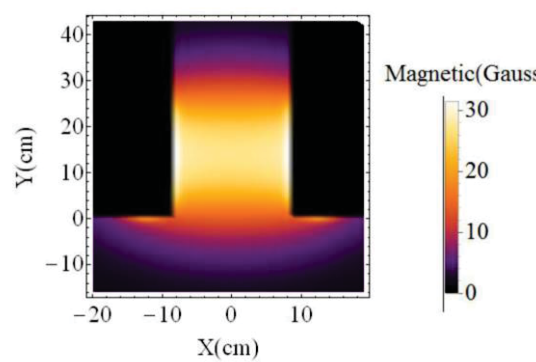
$I(t)=I_{od}*\cos(\omega t+\phi)$ where $I_{od}=70.7A$

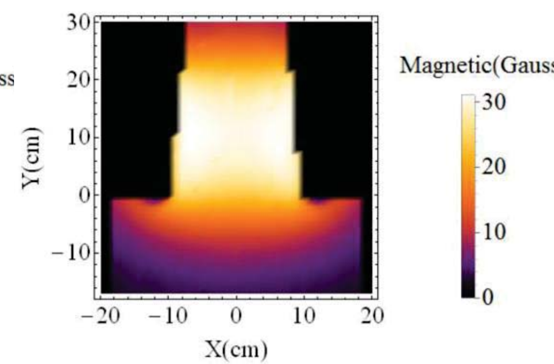
$I(t)=I_{oq}*\cos2(\omega t+\phi)$ where $I_{oq}=1.54A$

$B(0,0,0)=25.04G$

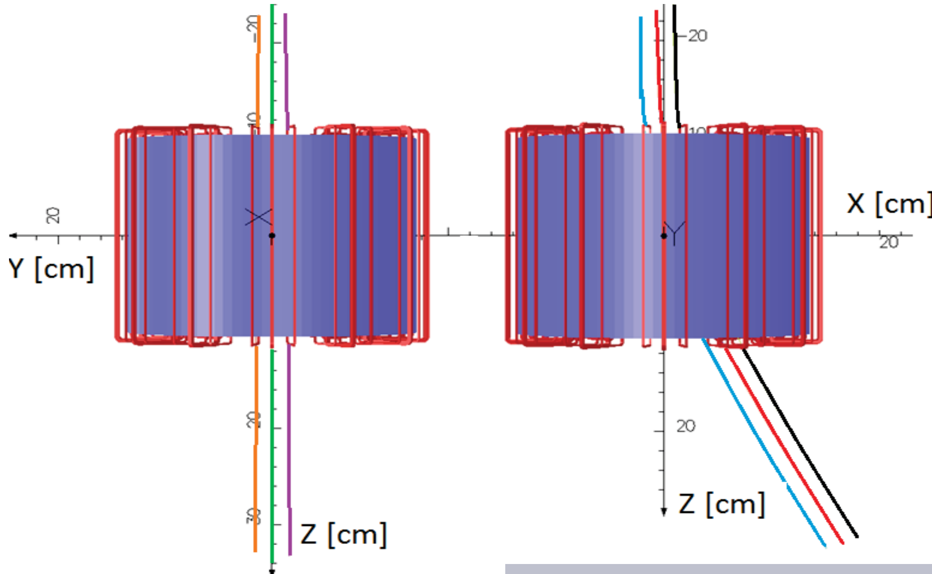
Freq=470kHz

Bending angle=29 degrees

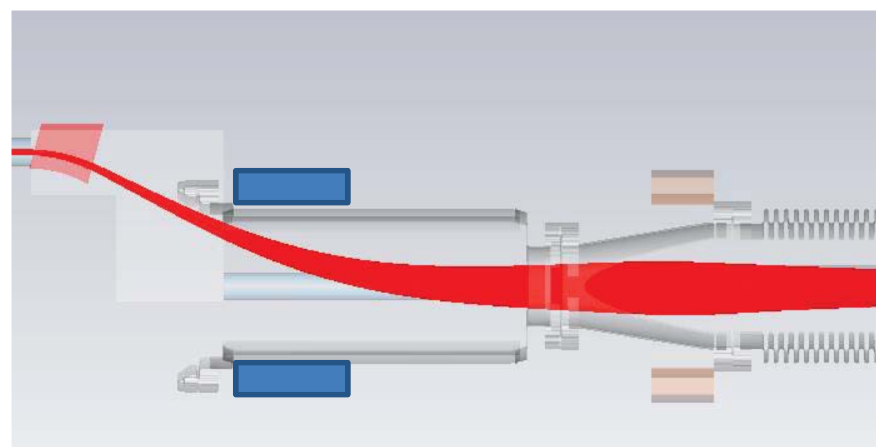


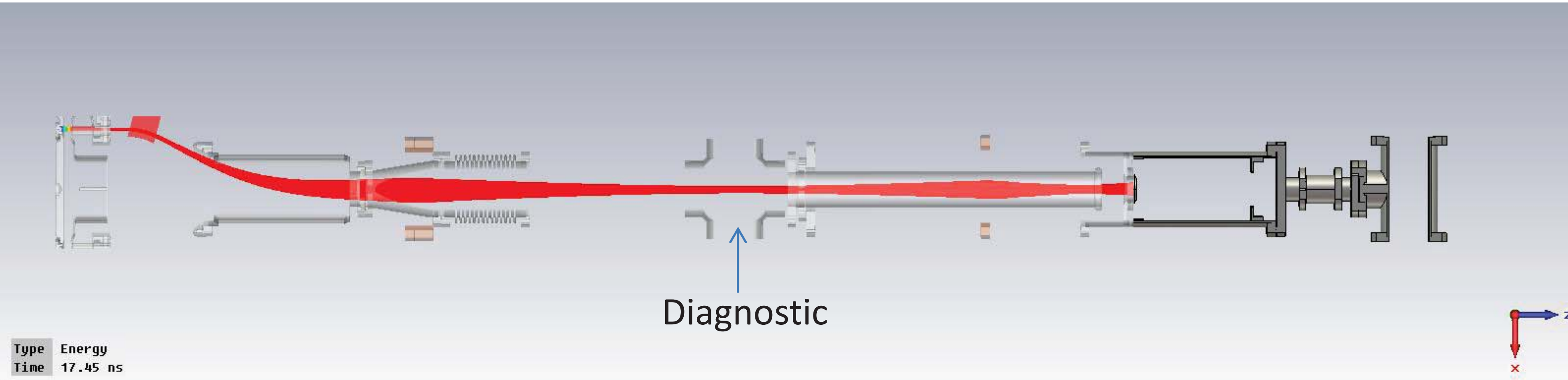
# Beam combiner

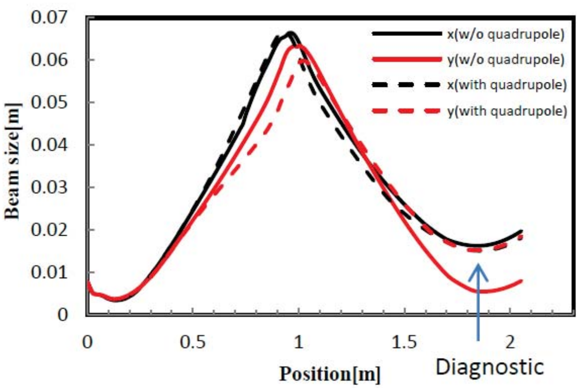



Single particle tracking shows:
•The intergrated field is adjusted to bend the 220keV electrons by 29°
•converging angle w/t quadrupole: X’/Y’=2.5mrad/15.7mrad
•With quadrupole X’/Y’=8.7mrad/9.8mrad

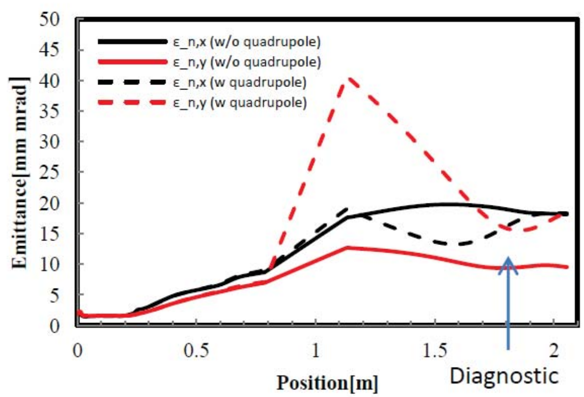


# Beam dynamics




**Beam size vs position**

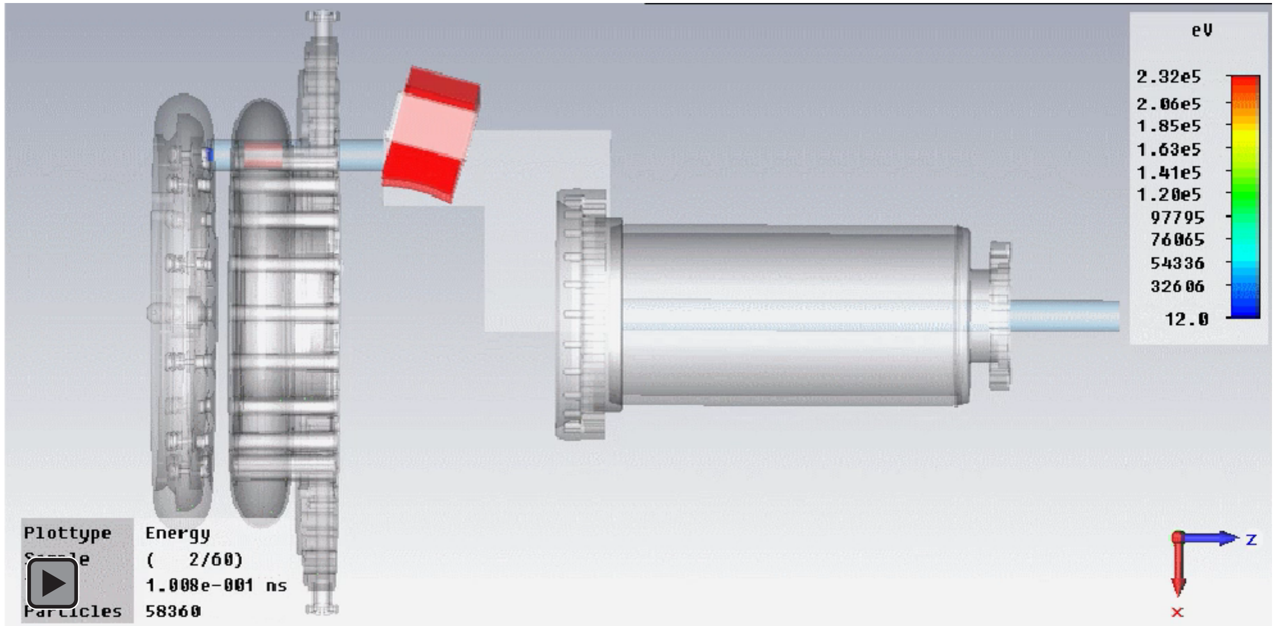


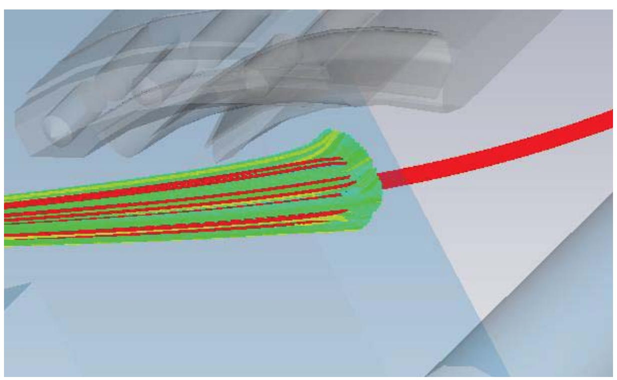

**Emittance vs position**

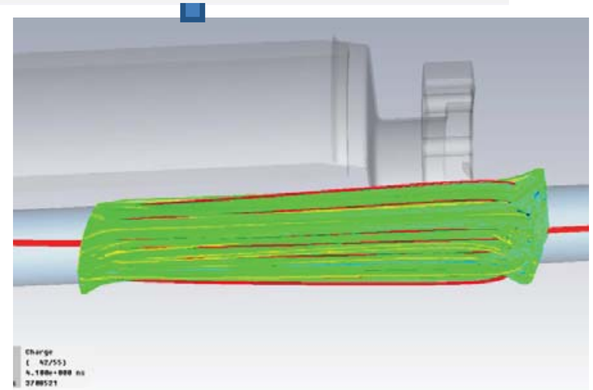
Particles tracking with SC on diagnostic :

- 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





•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

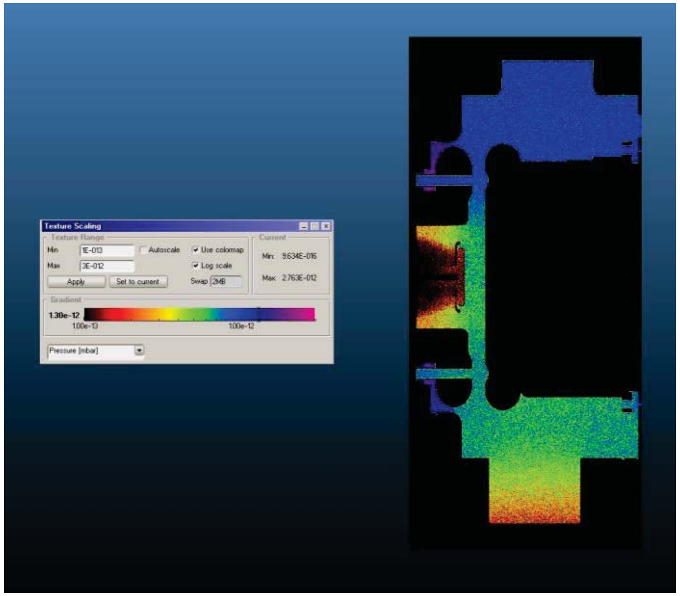
Transferring chamber: NEG 1500l/s
Design vacuum:$10^{-12}$ torr scale
Test vacuum now:**$8*10^{-12}$torr**

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**

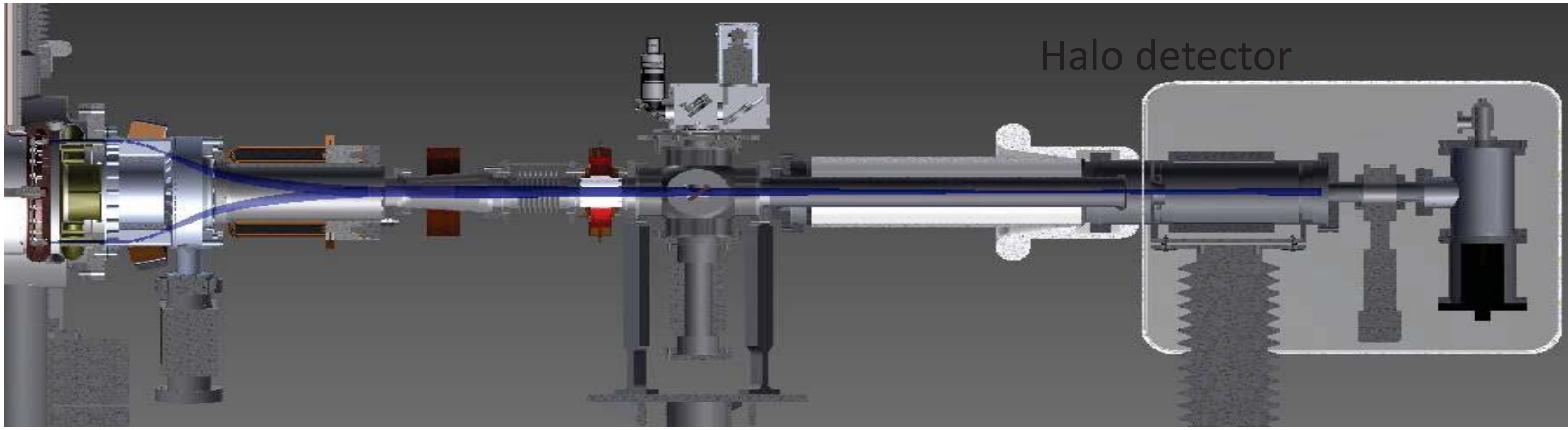
Combiner:6000l/s
Design vacuum:$1*10^{-11}$ torr

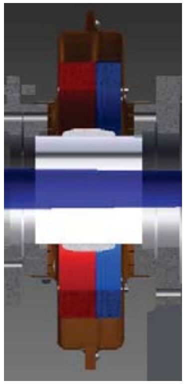
Exchange chamber:4000l/s
Design vacuum:$1*10^{-12}$torr
Total:20,000L/s



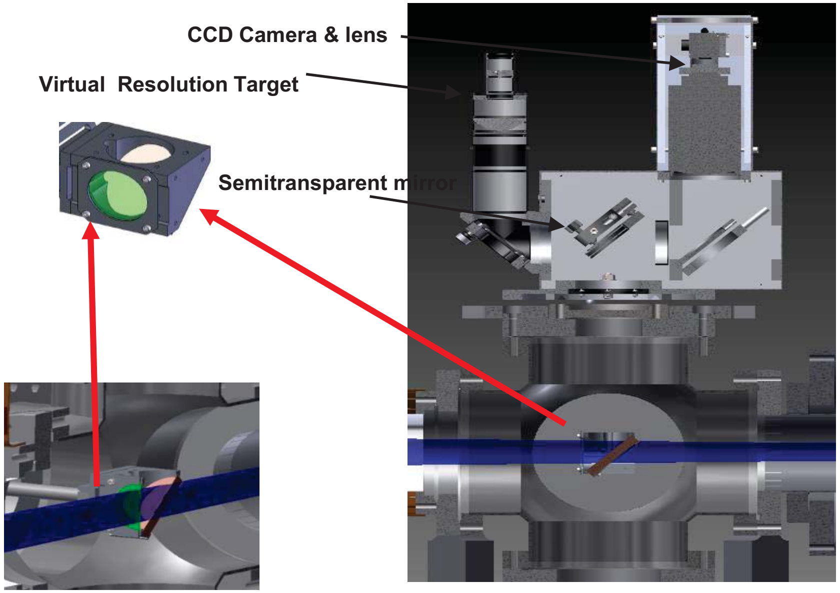

Gun vacuum vessel material:
Vacuum fired SS 316L($2*10^{-13}$ Torr L/cm$^2$ s)
Anode material:
Ti($2*10^{-15}$ Torr L/cm$^2$ s)

# Beam diagnostic



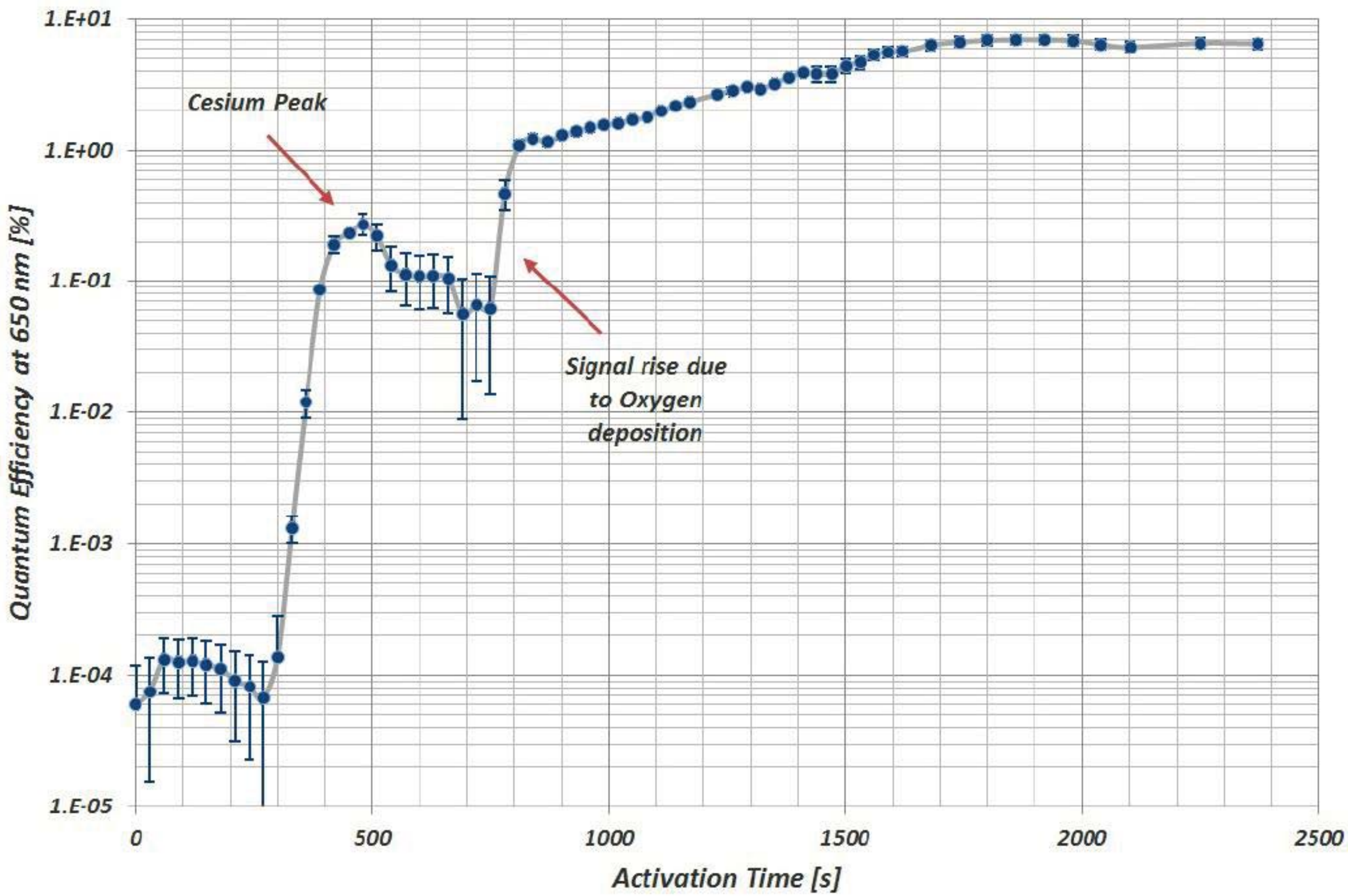



Fast Current Transformer &
Integrating Current Transformer

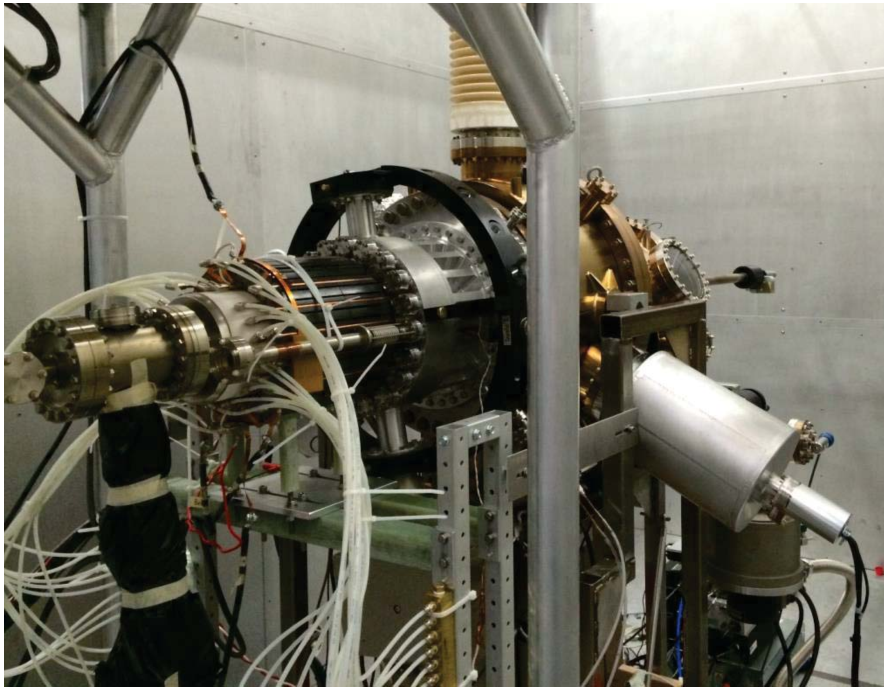


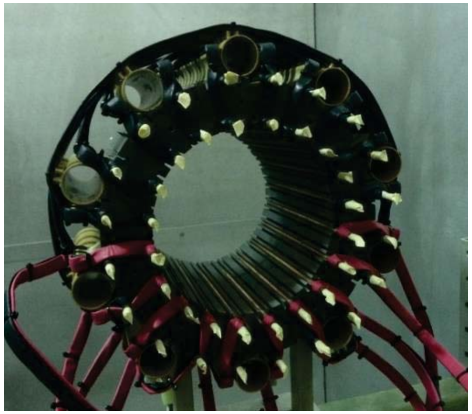

Courtesy of D.Gassner

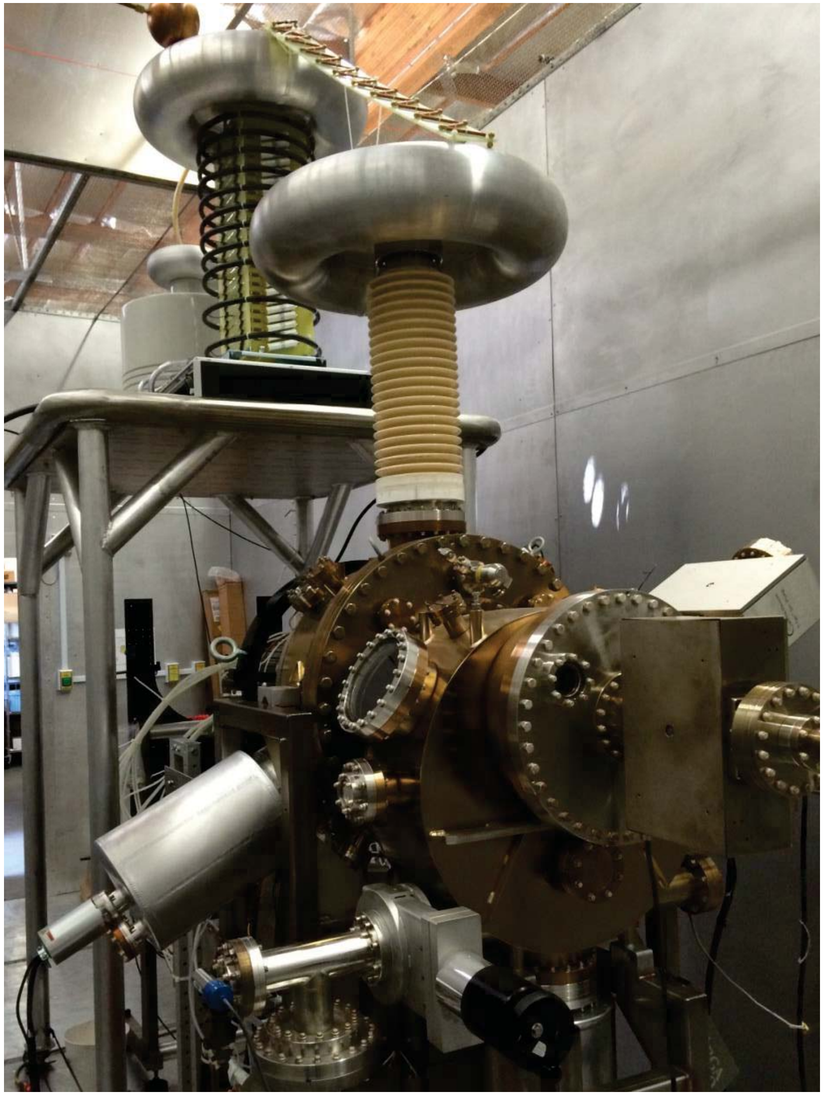
# Cathode preparation



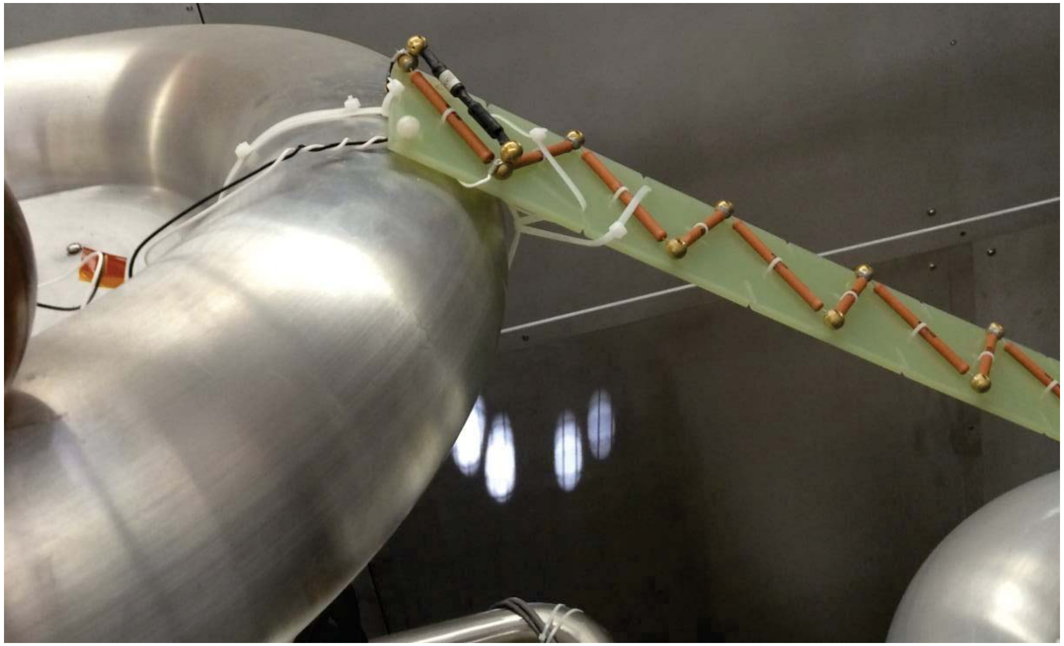
# Gun





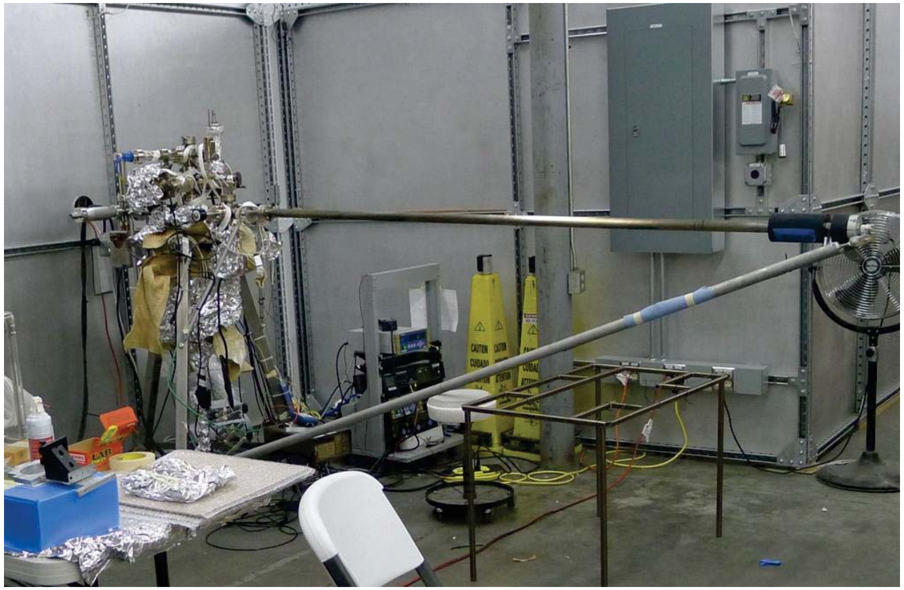


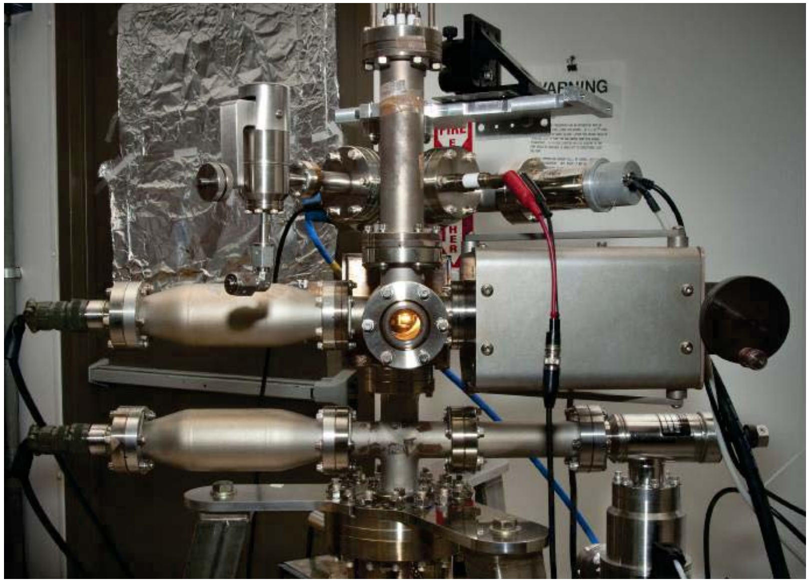
# High voltage power supply

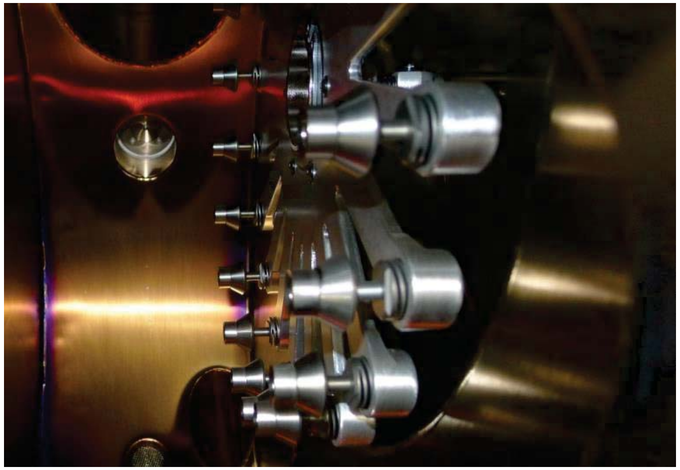


250kV power supply
2.888Gohm resistor series connect between gun and power supply for safety.

# Cathode preparation and transport



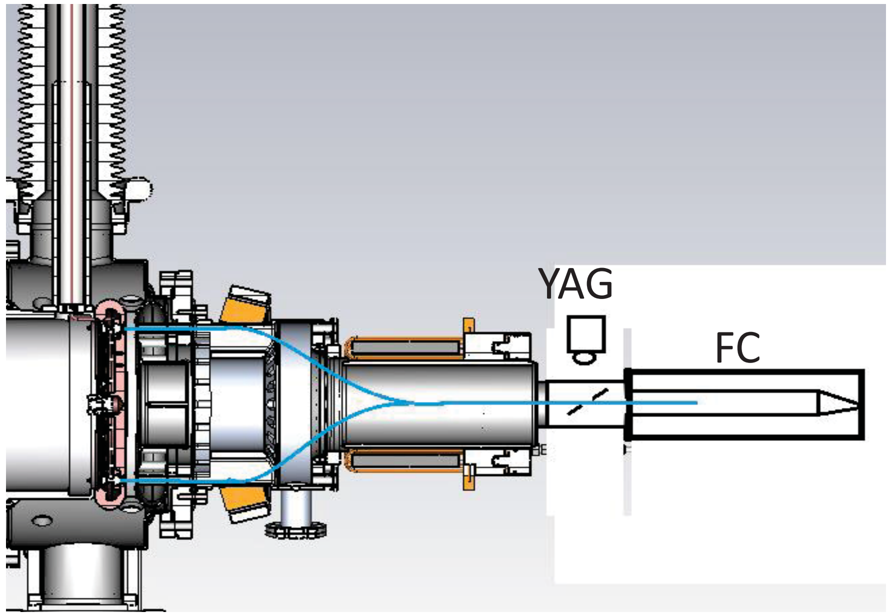


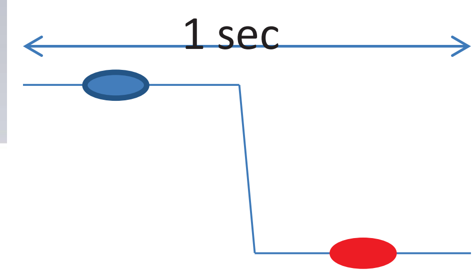


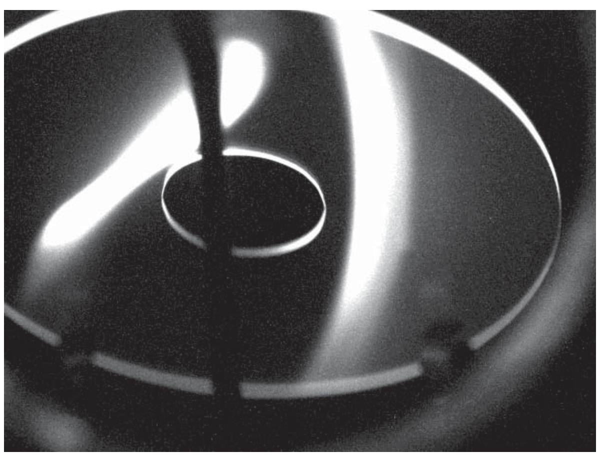
Cathode preparation chamber: about $5X10^{-10}$ torr
Gun chamber: $6.8X10^{-11}$ torr during test
(It got into $10^{-12}$ torr earlier)

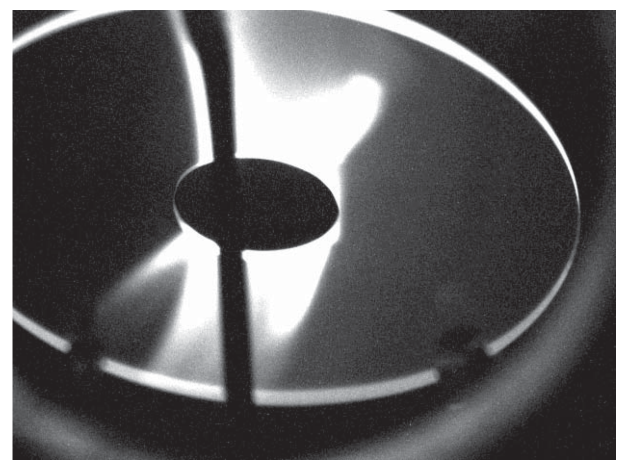
# Test of two cathodes combined

- •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

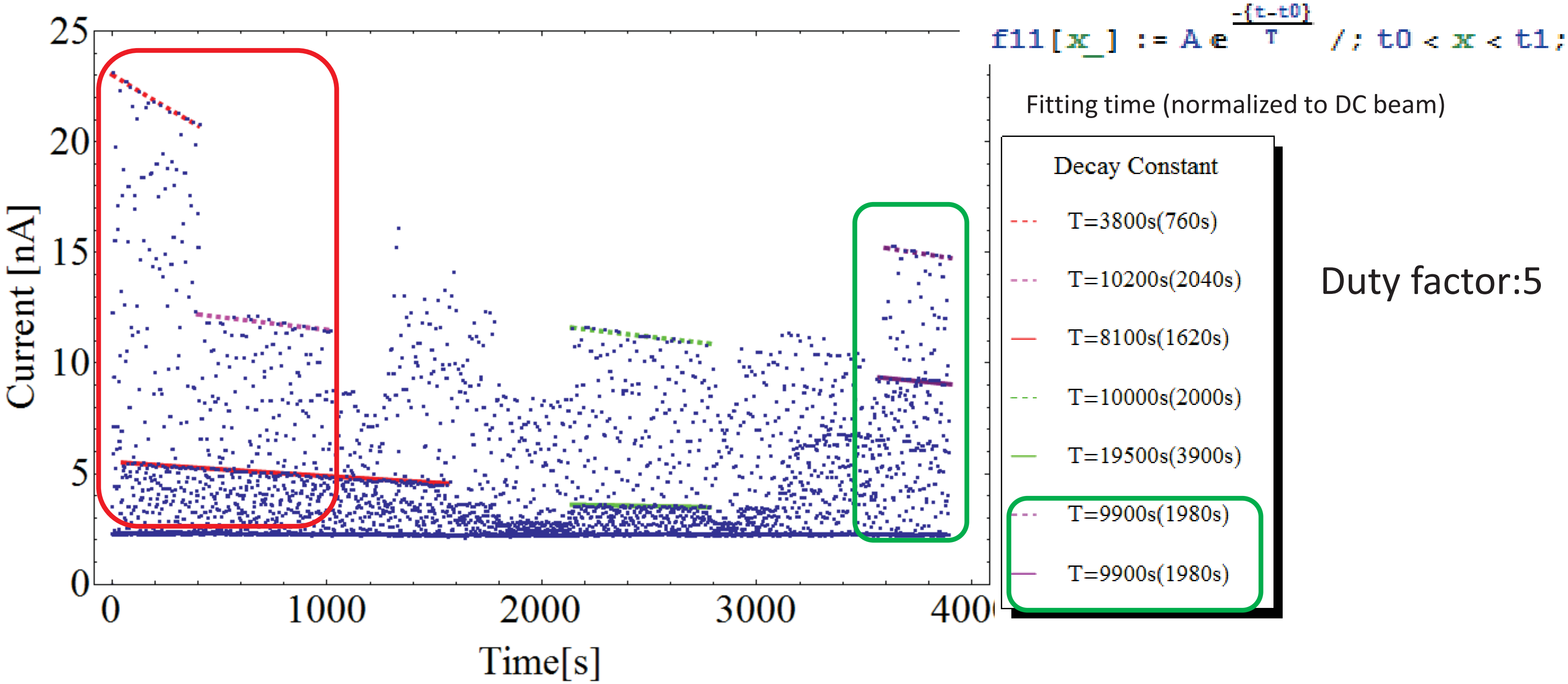




# Two beams decay constant




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

- 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

Ilan Ben-Zvi(PI), David M Gassner, Robert Lambiase, Wuzheng Meng, Alexander I. Pikin, Omer Rahman, Triveni Rao, Eric Riehn, John Skaritka, Brian Sheehy, Vladimir Litvinenko, Qiong Wu

MDC Corporation, Transfer Engineering Inc.,
Atlas Technologies, SAES Getters, Thermionics,
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)

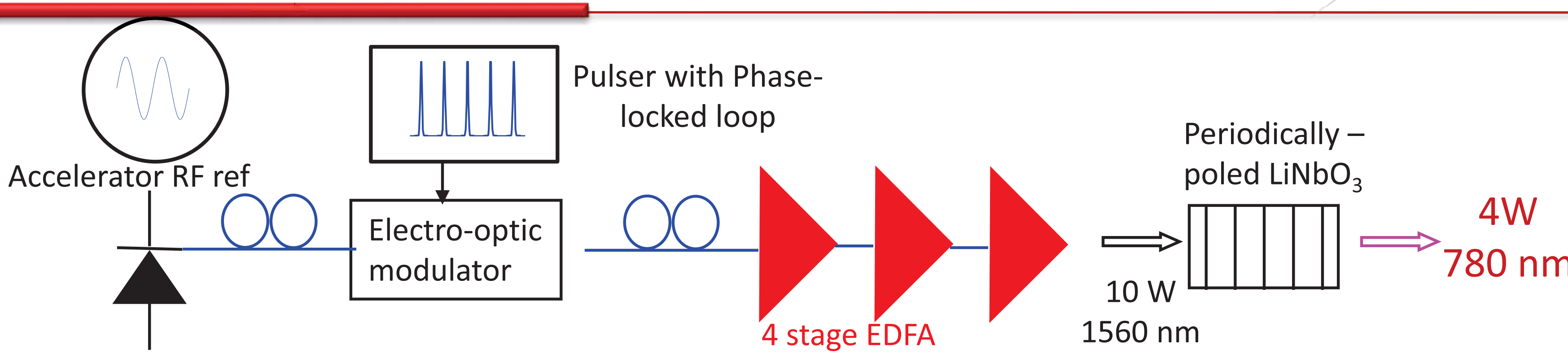
Thanks for your attention!

# Back up 1 Beam parameters

| Parameter | Value |
|---|---|
| **Bunch charge at cathode** | 3.5nC(5.3nC) |
| **Longitudinal charge distribution at cathode** | Gaussian distribution($\sigma$=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

BROOKHAVEN NATIONAL LABORATORY




| 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