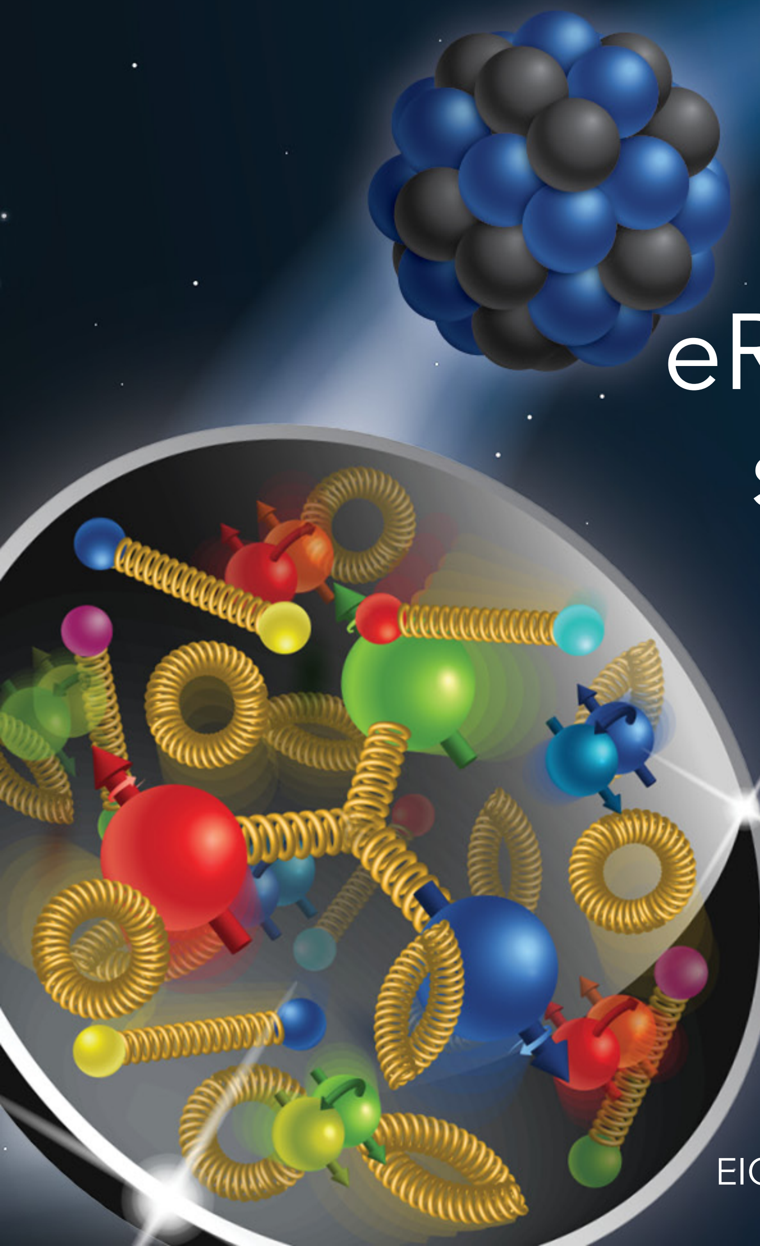

eRHIC polarized electron source and pre-Injector

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Collider accelerator department
eRHIC R&D
Brookhaven National Laboratory

Electron Ion Collider – eRHIC

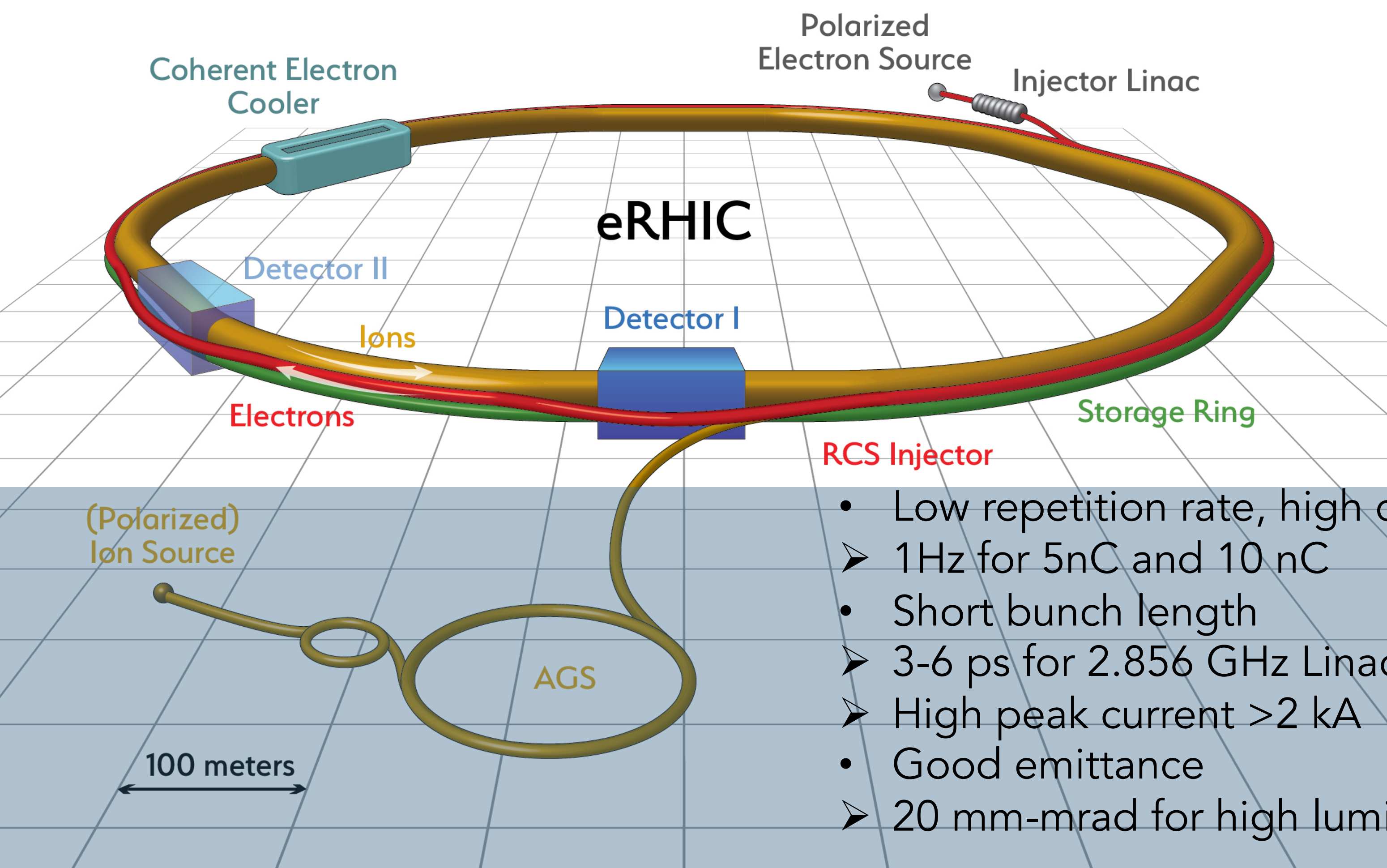
EIC Collaboration meeting 2018

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Polarized electron source and pre-injector requirements
- eRHIC polarized DC electron gun concepts
- Pre-injector concepts
- Spin considerations
- Laser, RF and Diagnostics
- R&D activates
- Summary

eRHIC pre-injector specifications



- Low repetition rate, high charge
  - ➢ 1Hz for 5nC and 10 nC
- Short bunch length
  - ➢ 3-6 ps for 2.856 GHz Linac
  - ➢ High peak current >2 kA
- Good emittance
  - ➢ 20 mm-mrad for high luminosity

eRHIC pre-injector parameters

	Nominal: High luminosity with cooling	Moderate luminosity without cooling
Bunch charge [nC]	5	10
RMS Bunch length [ps]	6	6
RMS Emittance [mm-mrad]	20	55
Frequency [Hz]	1	
Energy [MeV]	400	
Polarization [%]	80%-85%	

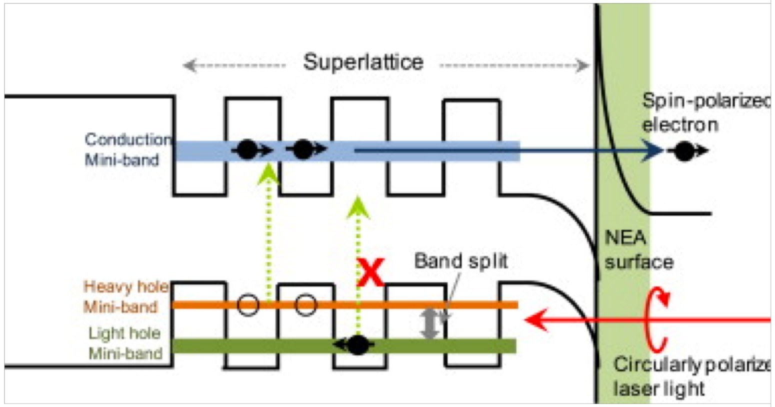
Overview of polarized electron DC guns

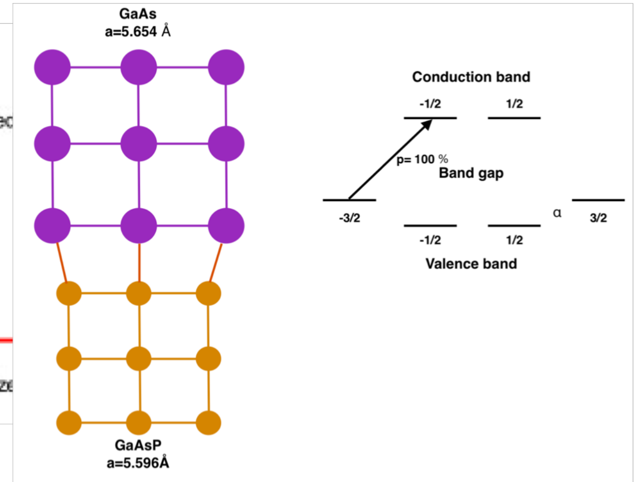
Laboratory	Photocathode	Polarization	Voltage	Bunch charge	I_pk	Repetition Frequency	I_avg
JLab[1]	GaAs-GaAsP	85%	100, 200kV	2 or 2.7pC	67~53mA	1.5 GHz	1~4mA
SLC[2]	GaAs-GaAsP	86%	120kV	16nC max	5 A	120 Hz	2uA
MAMI[3]	AlGaAs/InAlGaAs	85%	100kV	0.02pC		2.45 GHz	50 uA
Bonn-ELSA[4]	AlGaAs/InGaAs	80%	50kV	100nC	100mA	50 Hz	5 uA
MIT-BATES[5]	GaAsP	50-80%	60kV	250nC	12mA	600 Hz	20 or 200uA
Nagoya[6]	GaAs-GaAsP	92%	200kV	3.2 nC	3.2 A	20 Hz	50 uA
NIKHEF[7]	InGaAsP	80%	100kV	2 nC	2 mA	10 Hz	0.04uA
BNL	GaAs-GaAsP	85%	350kV	10 nC	5 A	1 Hz	10 nA

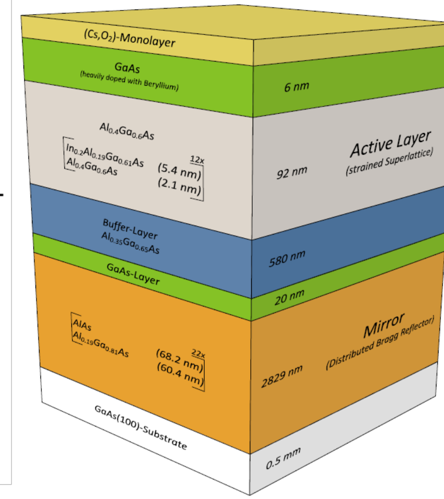
- 16 nC was achieved by SLC DC gun. It is beyond our nominal injector design.
- Can we make it better?
- Minimize beam loss
- Simplify maintenance

In operation
Shut down
In design

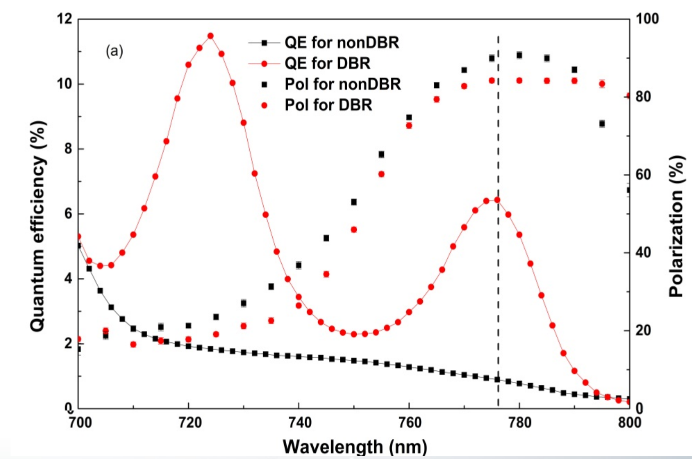
Superlattice GaAs photocathode





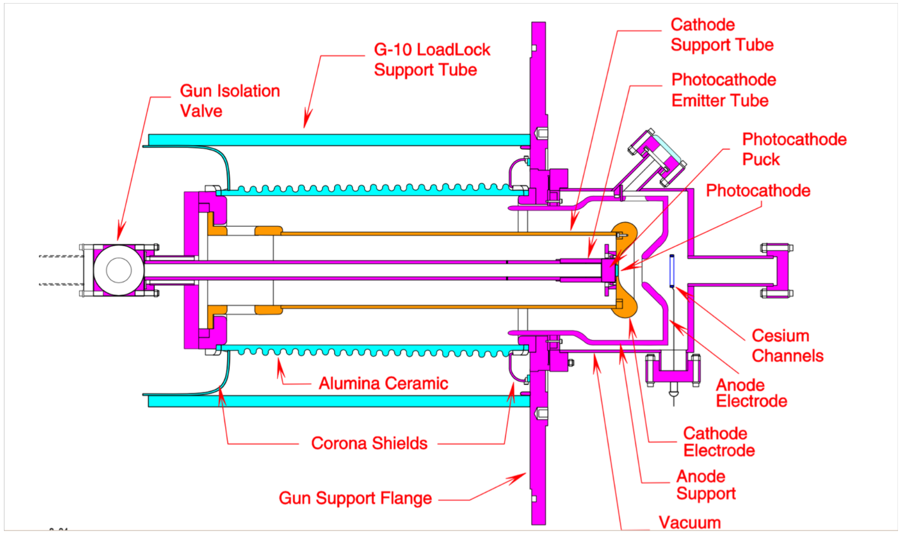


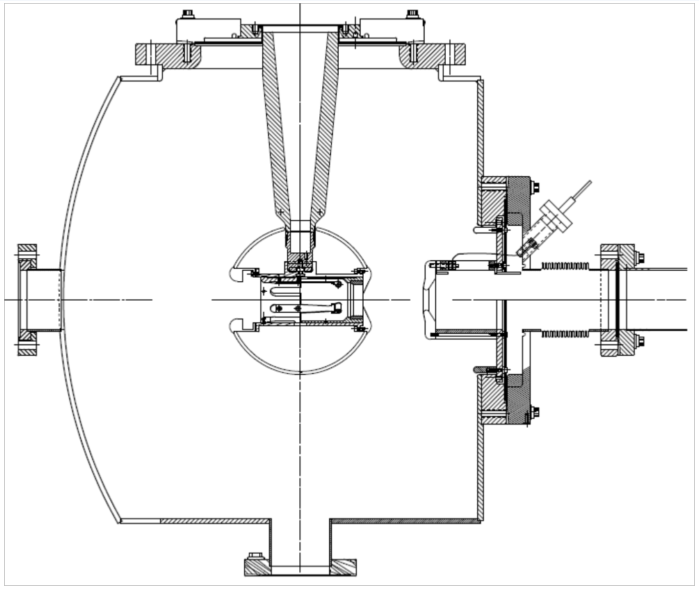
- Recent results from SVT/JLab using DBR super lattice GaAsP photocathode.
- QE is greater than 5%.
- Achieved 86% polarization at the peak.



Existing Gun concepts for eRHIC injector

SLC PES 120 kV gun	JLab 350 kV inverted gun





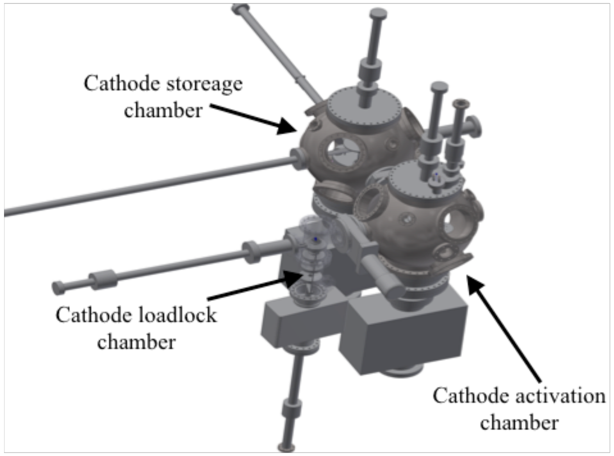
- First load-locked gun used at an accelerator
- High bunch charge, low avg. current, very long operating lifetime 。
- 4 days to replace photocathode. No separate load lock…

- Inverted shape has less out gassing surface and eliminated field emission to ceramic
- High average current, long operating lifetime.
- Separate load-lock for cathode replacement.
- 10^{-12} torr scale vacuum

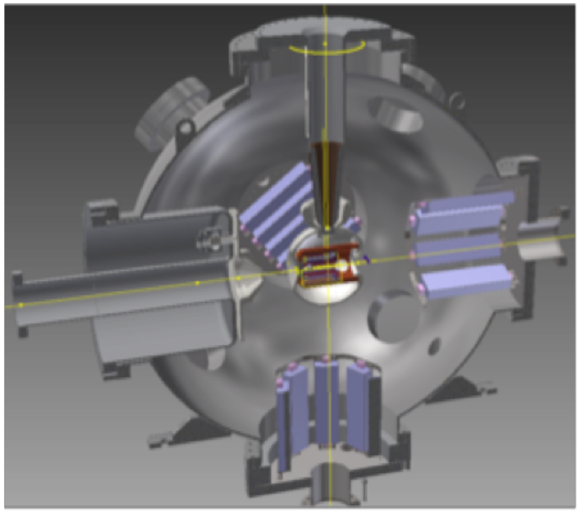
Comparison of guns

	SLC	Inverted gun (JLab)	Inverted gun in fabrication (BNL)
Voltage [kV]	120	350	350
Gradient [MV/m]	1.8	3.4	4.2
Cathode size [cm^2]	3	1.13	4.98
Bunch charge [nC]	16	0.003	10
Average current [uA]	5	4000	To be measured
Charge lifetime[C]	<1	80	To be measured
In-situ Cs evap.	Y	N	N
Biasable Anode	N	Y	Y

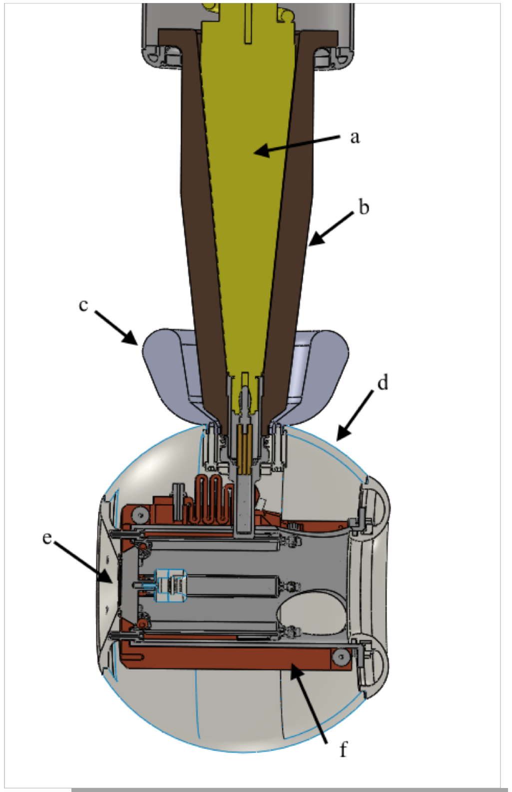
R&D Gun and cathode preparation



Cathode preparation system



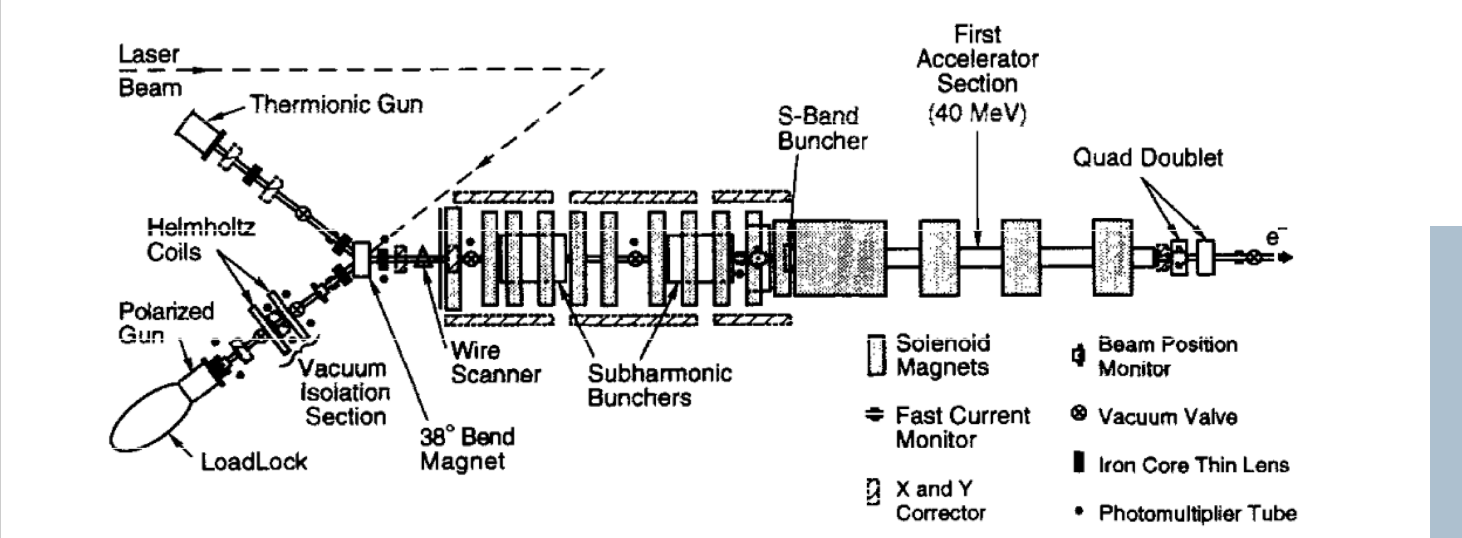
HV DC Gun



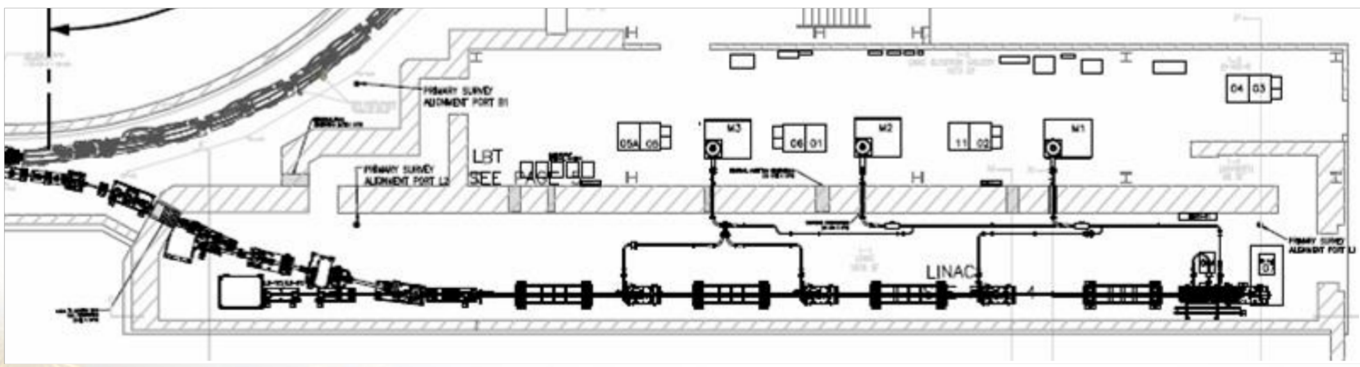
Gun electrode

The final gun will be similar to the R&D gun, except
- Optimized gun chamber
- Pumps locations and sizes
- Optimized Pierce shape (similar to SLC gun)
- Larger cathode

400 MeV pre-injector



- SLC linac
  12 nC
  200 MeV



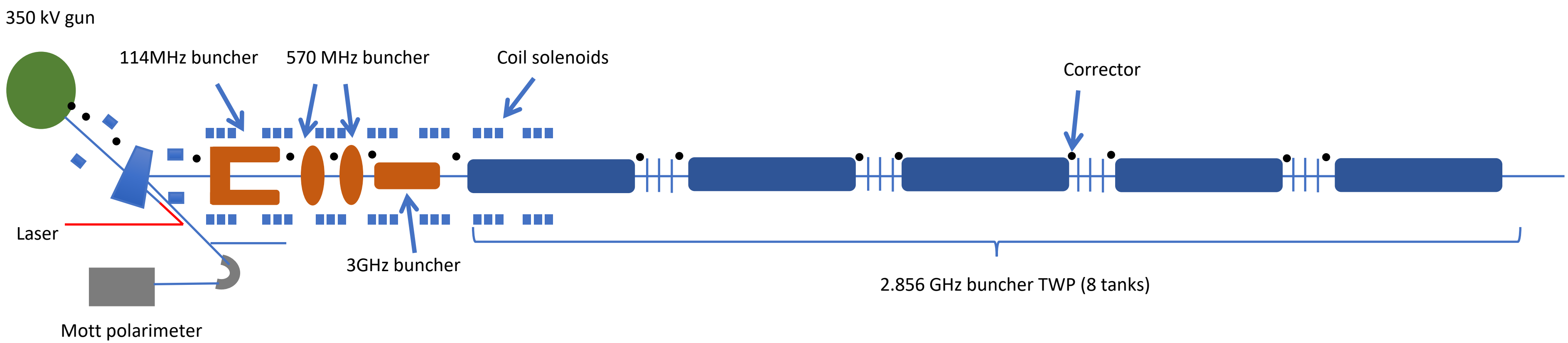
- NSLS II linac
  500 pC
  200 MeV

Pre-injector Linac frequency choice

Frequency	RF	Aperture	Solenoid	Beam quality	In operation	Cost
563 MHz	SRF	Large	Compensated	Good	NA	High
1.3 GHz	NRF	Moderate	Compensated	Moderate	ANL …	Moderate
2.856 GHz	NRF	Small	Continuous	Acceptable	SLAC, BNL…	Low

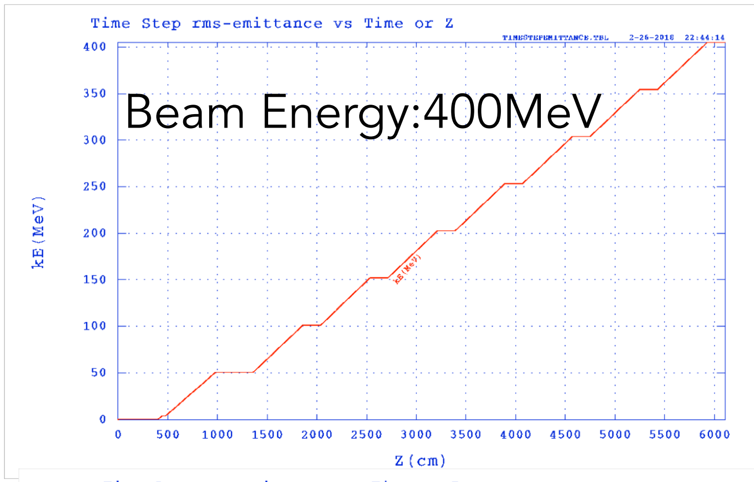
Considering the technical maturity and lower cost, 2.856 GHz Linac is our choice.

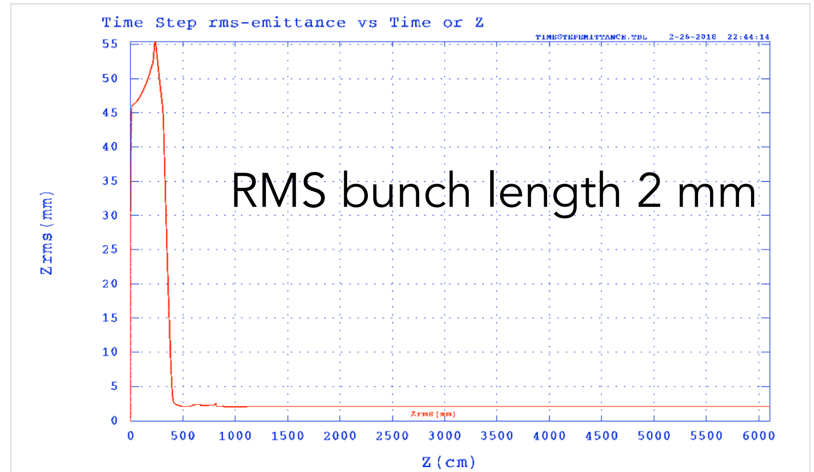
400 MeV beam line set up

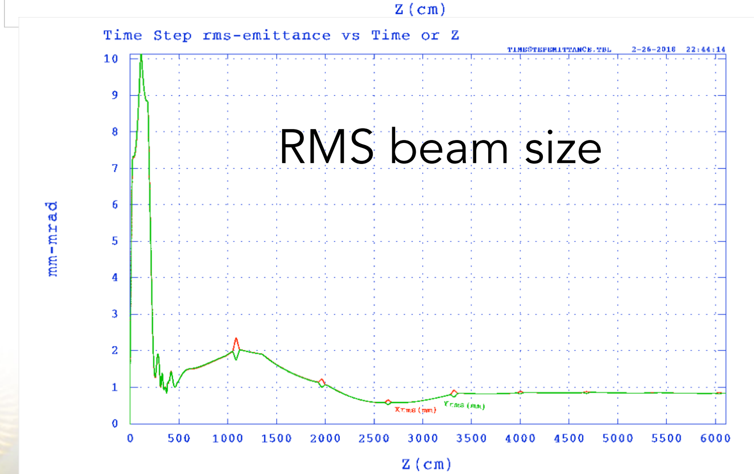


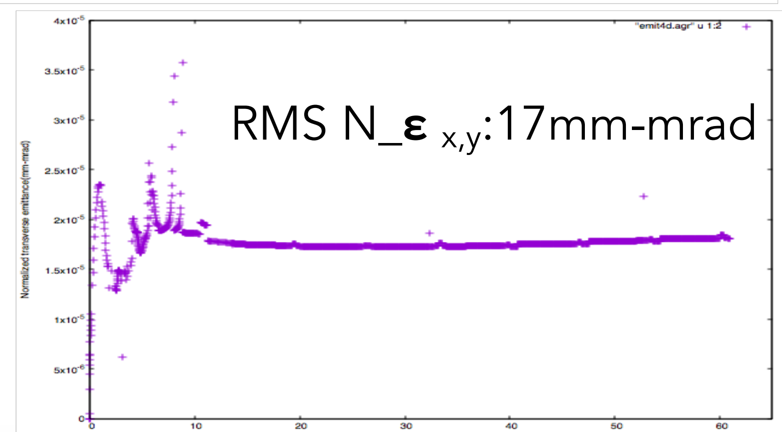
Both bunch charge 5n C and 10 nC cases have been simulated by Parmela 3.38.
➔ meets all the requirements.

5nC: High luminosity with cooling

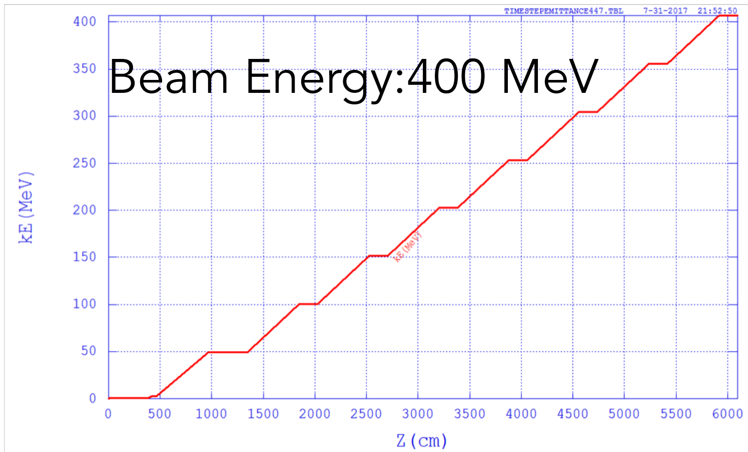


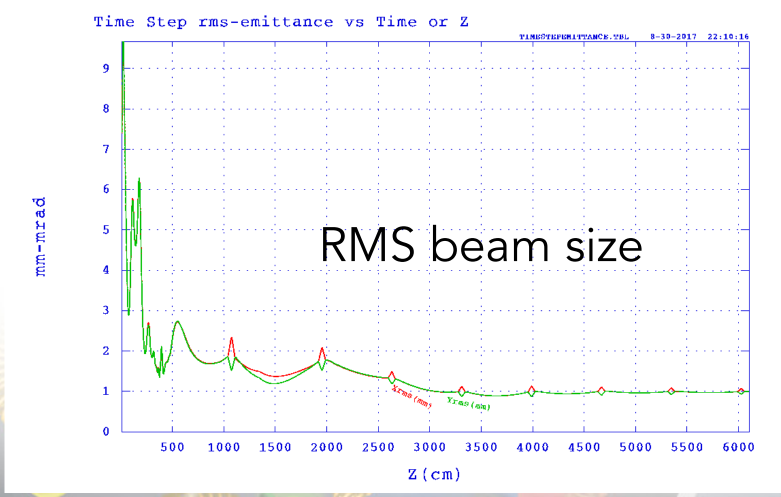


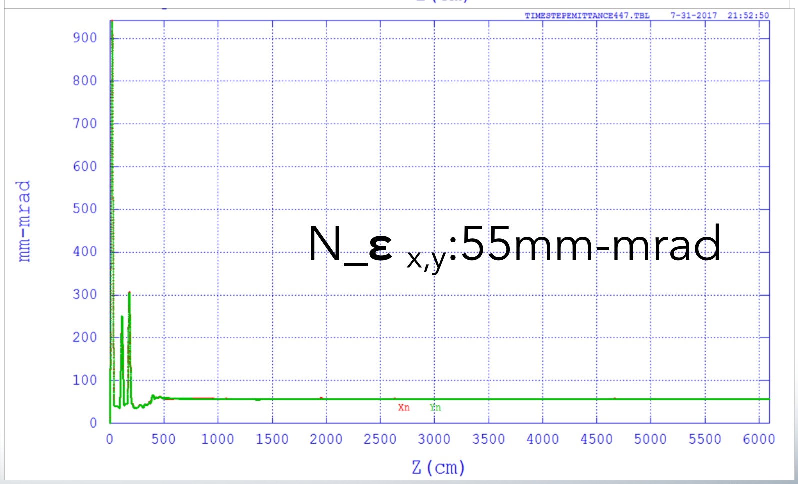




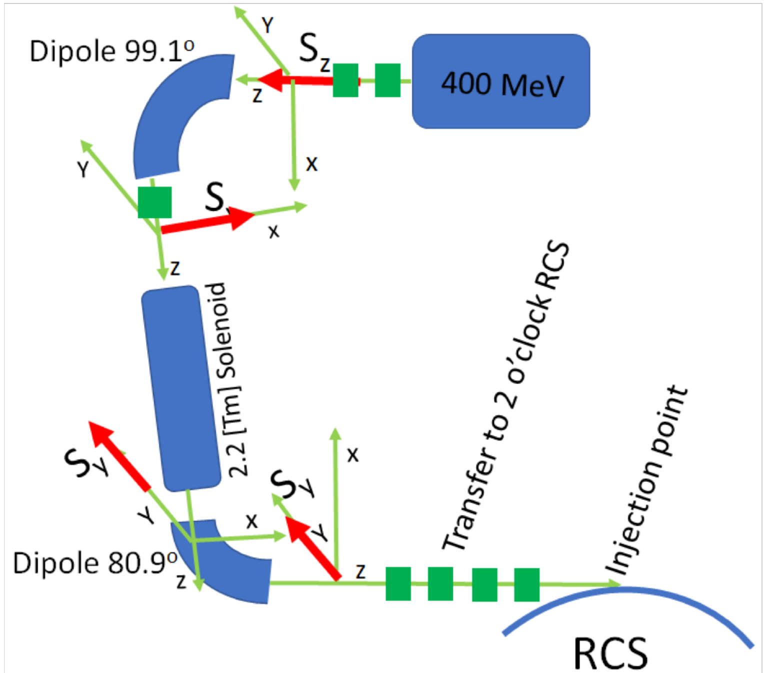
10 nC :Moderate luminosity

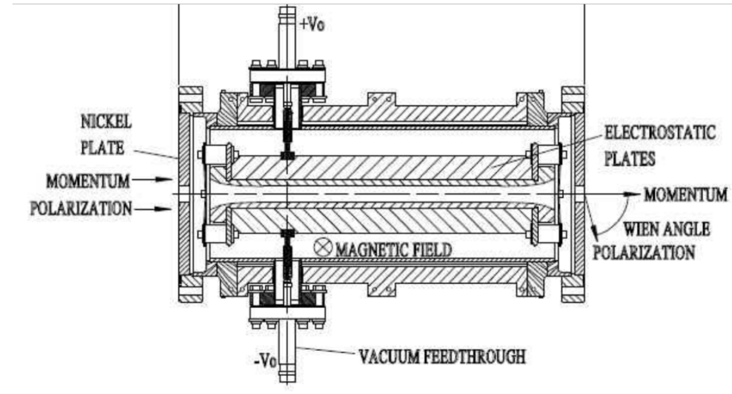


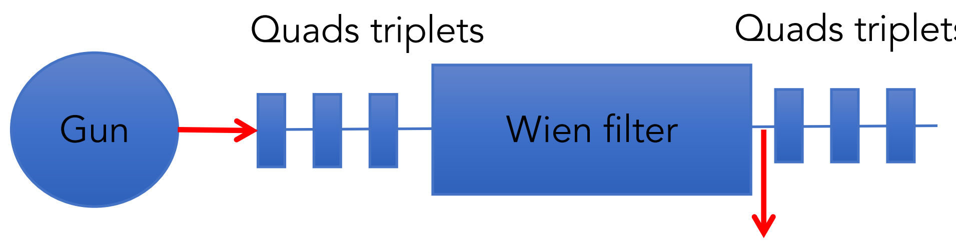




Spin considerations in pre-injector

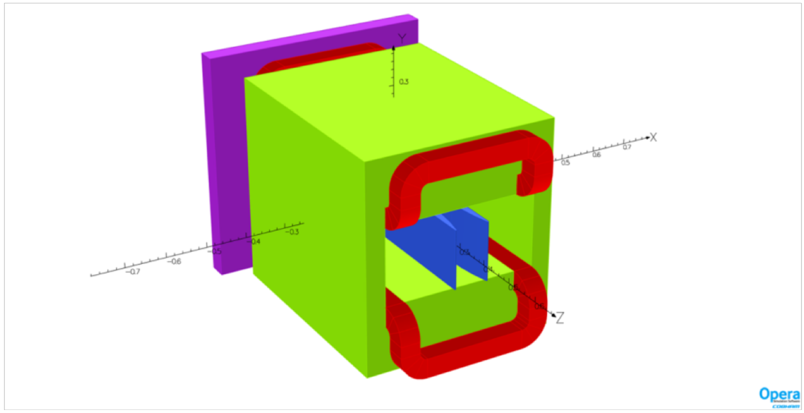


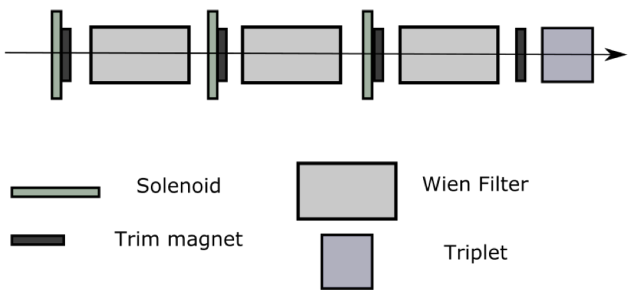




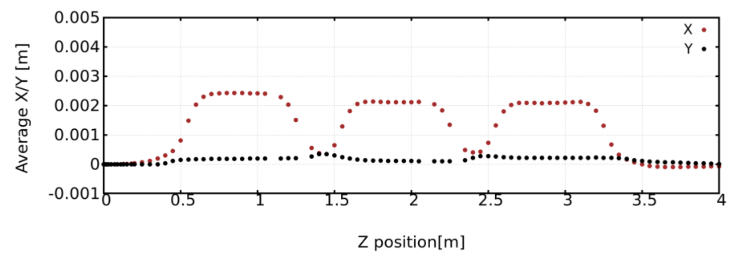
	Energy Range	Energy acceptance	Realizable
Dipole+solenoid	>100 MeV	Small	SLC
Wien filter	< 400 KeV	Large	Jlab, Mainz(small charge and small energy)

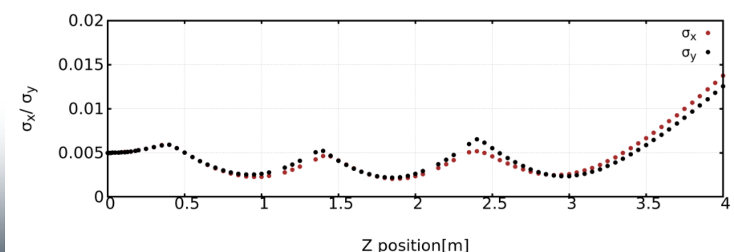
Wien filter





Parameter	Value
Bunch charge	10 nC
Energy	350 KeV
L	0.5 m
E_x	0.98 MV/m
B_y	0.00407 T
Electrode gap	5 cm

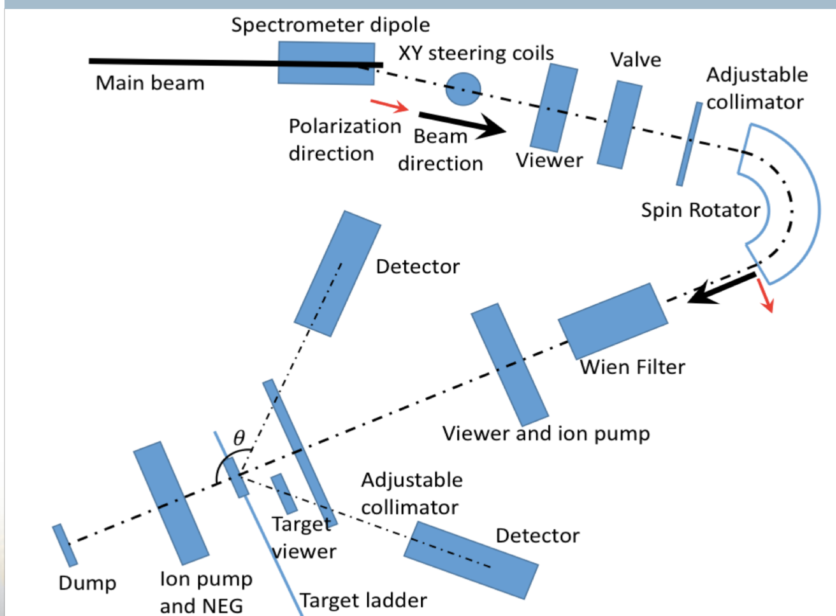




Three-segment Wien filter has been studied to rotate electron spin by 90°

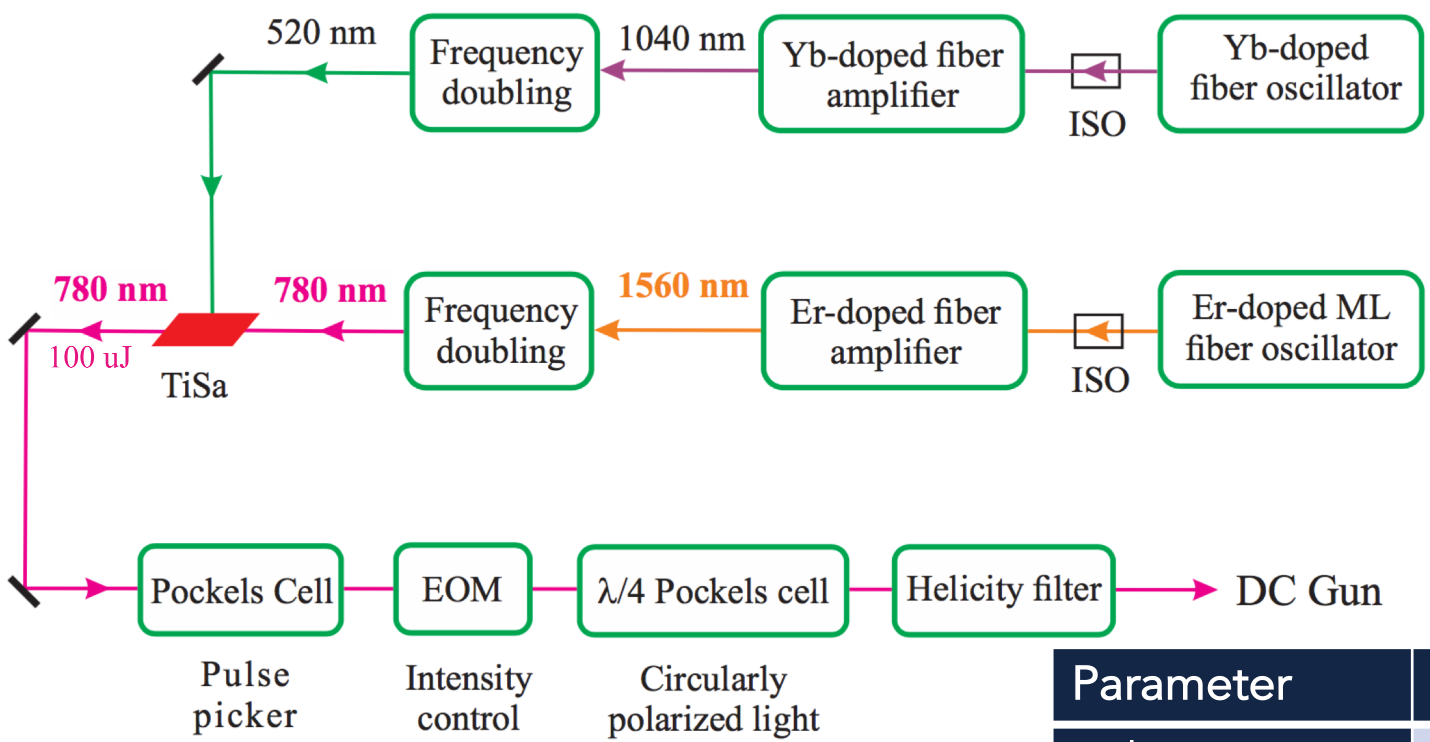
Mott polarimeter

- High voltage Mott polarimeter placed at gun diagnostic beamline where beam energy is 300-350 keV.
- Can be simplified if using Wien filter to rotate the spin.



Parameter name	value
Beam energy	300-350 keV
Beam bend degree by spin rotator	143°
Voltage of spin rotator	244.5 d/R kV
Scattering degree,	136°
Detector count rate	1.69e3 Hz/(nA.um)
Corresponding time for P = 0.1%	1.36 s

High pulse energy hybrid Laser

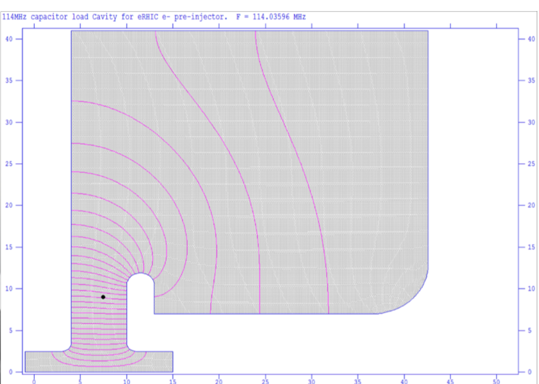


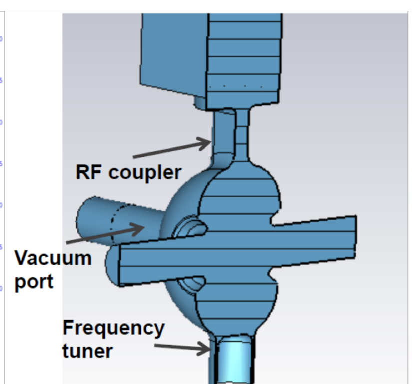
Two lasers will be placed.
One for operation; another one for hot spare.

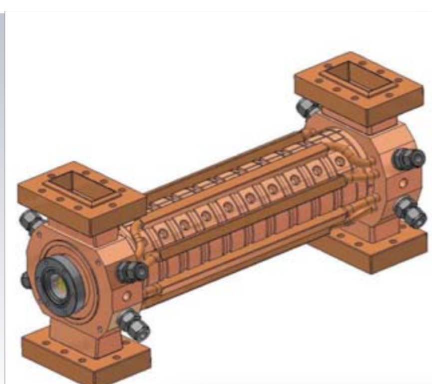
Parameter	Value
Pulse energy	16 uJ
Length	1-2.5 ns
Rep. Rate	1 Hz ,up to 27.8 MHz
Wave length	780 nm

Linac cavities

	114 MHz	571 MHz	2.856 GHz	2.856 GHz
Rep. Freq	1Hz			
Function	Buncher			Booster
Shape	Capacitor loaded	Re-entrance	Traveling wave	Traveling wave
Gap voltage	500 kV	600 kV/500 kV	15 MV	50 MV
Duty factor	0.02%			
Peak power	52 kW	35 kW		







Potential R&D topics

- Cathode lifetime modeling and experiments
- New high polarization cathode and related simulation
- Large cathode gun experiments
- Extremely high vacuum studies
- Beam halo induced beam loss, Beam dynamics studies

From EIC Collaboration meeting 2017

Lifetime study on Cs_2Te(CsO) coated GaAs

A study of an electron affinity of cesium telluride thin film

H Sugiyama[1], K Ogawa[2], J Azuma[2], K Takahashi[2], M Kamada[2], T Nishitani[3], M Tabuchi[4], T Motoki[5], K Takashima[5], A Era[5] and Y Takeda[6]

[1] Accelerator Laboratory, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801 Japan.

6th International Particle Accelerator Conference | IPAC2015, Richmond, VA, USA | JACoW Publishing
ISBN: 978-3-95450-168-7 | doi:10.18429/JACoW-IPAC2015-TUPWA062

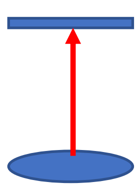
GaAs PHOTOCATHODE ACTIVATION WITH CsTe THIN FILM

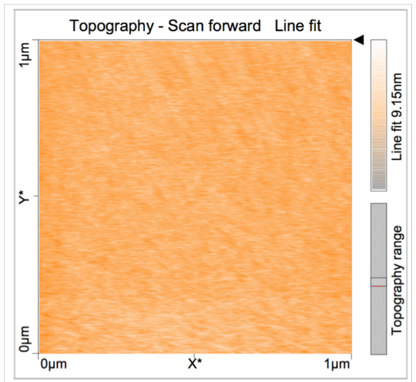
Masao Kuriki[#1], Yuji Seimiya[#2], Kazuhide Uchida[#3], HU/AdSM, Higashi-Hiroshima, Japan
Shigeru Kashiwagi, Tohoku University, Sendai, Japan

Rugged spin-polarized electron sources based on negative electron affinity GaAs photocathode with robust Cs_2Te coating

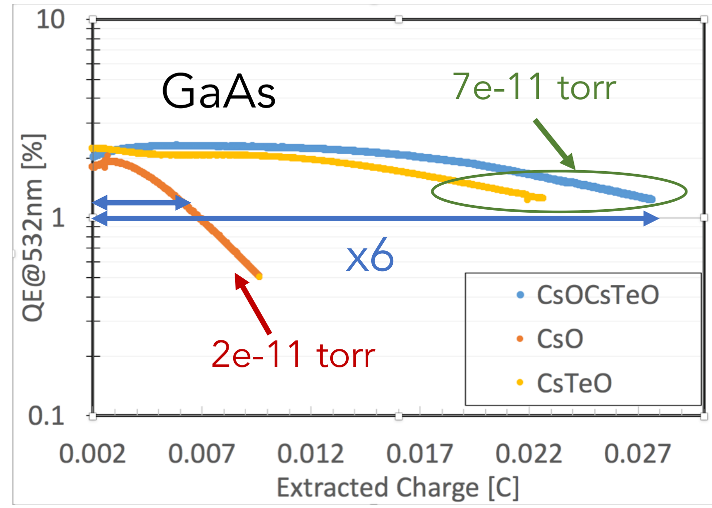
Jai Kwan Bae, Luca Cultrera, Philip DiGiacomo, and Ivan Bazarov

Citation: Appl. Phys. Lett. **112**, 154101 (2018); doi: 10.1063/1.5026701





540 °C heat treatment
Roughness:1.8-3.9 nm

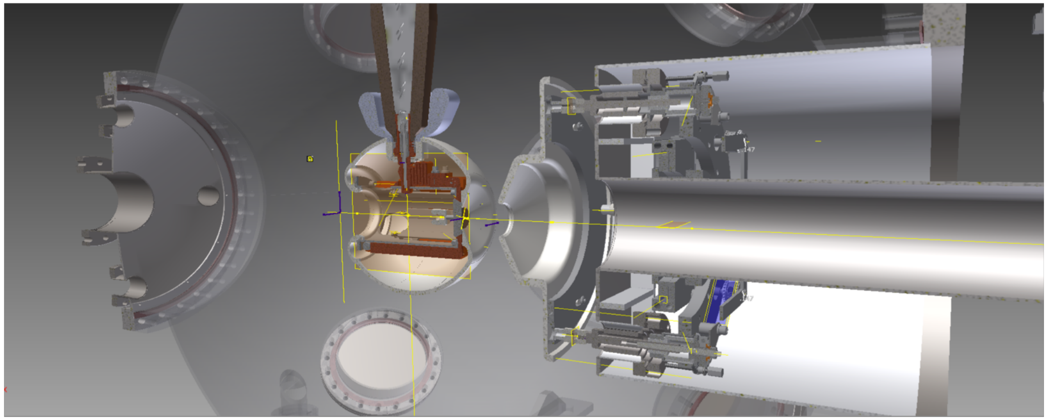


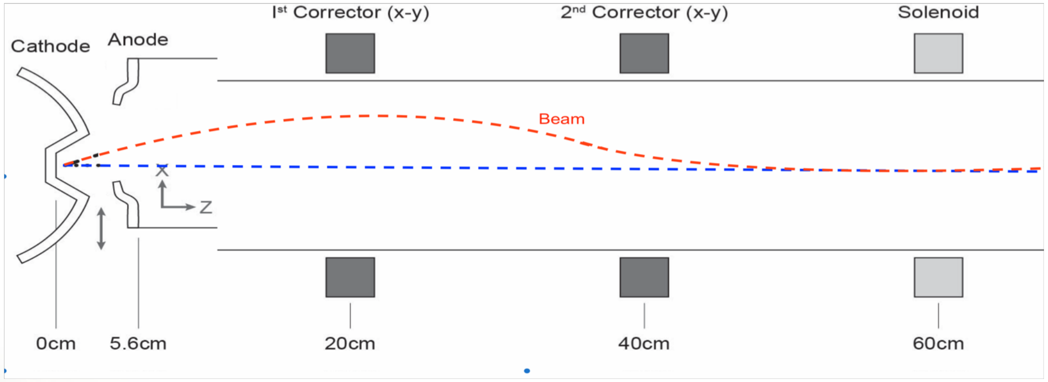
Te source in Saes dispenser

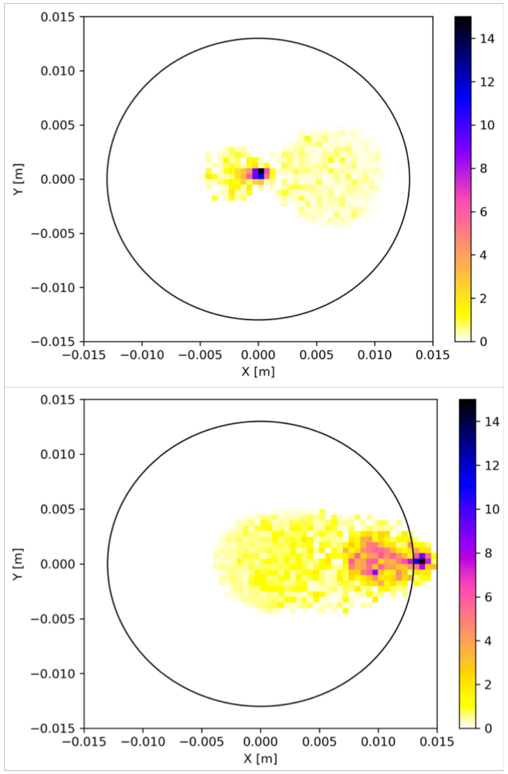
Trying GaAs/GaAsP and CsI coating now.

O. Rahman, J. Biswas, M. Gaowei, W. Liu, E. Wang

Extend the lifetime by kicking electrons



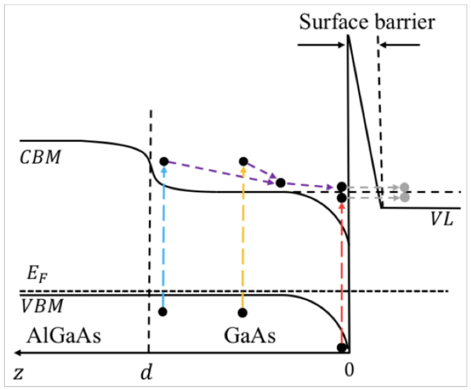


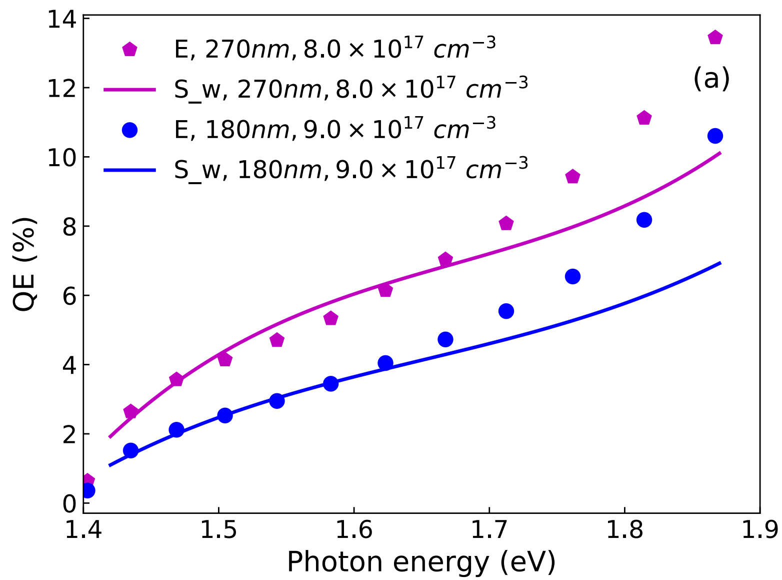


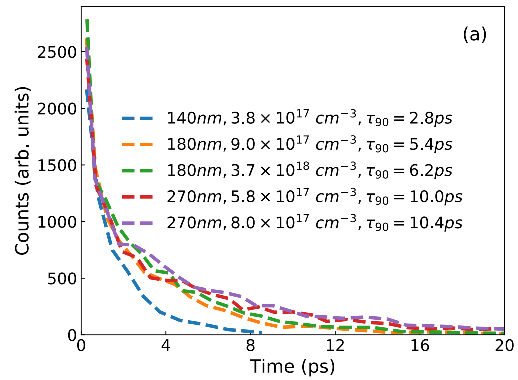
- Lifetime will be at least doubled with off-center anode scheme.
- Emittance increases only 20% compare to centered laser/anode.

O. Rahman, E.Wang, J. Skaritka, J. Biswas
Paper in preparation

MC simulation of heterojunction GaAs cathode







- Thinner and lower dopant density samples provide short electron bunches

- Simulated photoemission spectrum response, matchs to experimental results well.
- Considered the heterojuction between GaAs/AlGaAs, and surface barrier.
- Once consider the spin dynamics, could simulate other spin electronics.

W. Liu M. Poelker, C. Sinclair, E. Wang
Paper in preparation

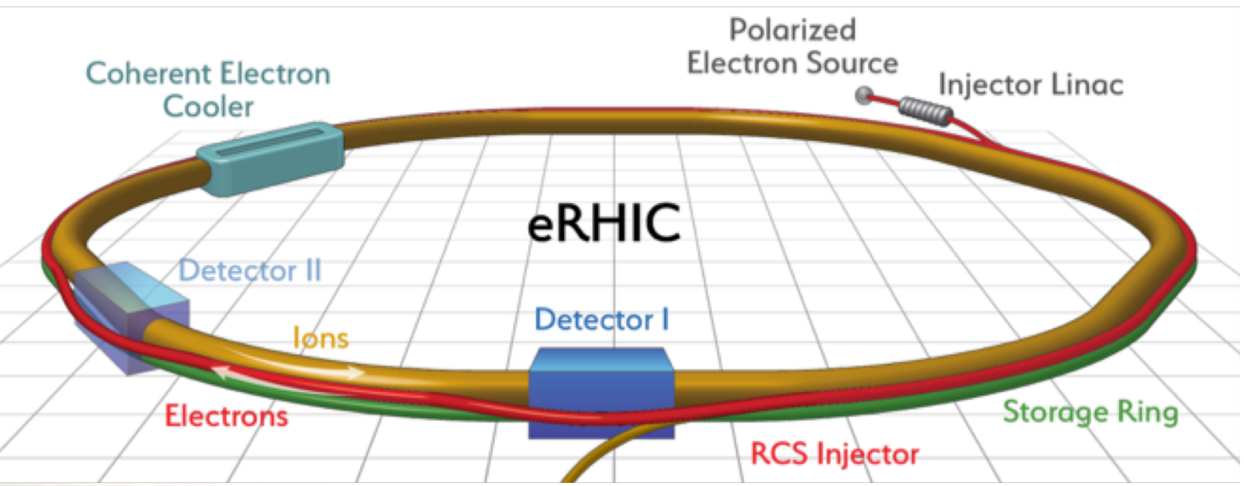
Summary

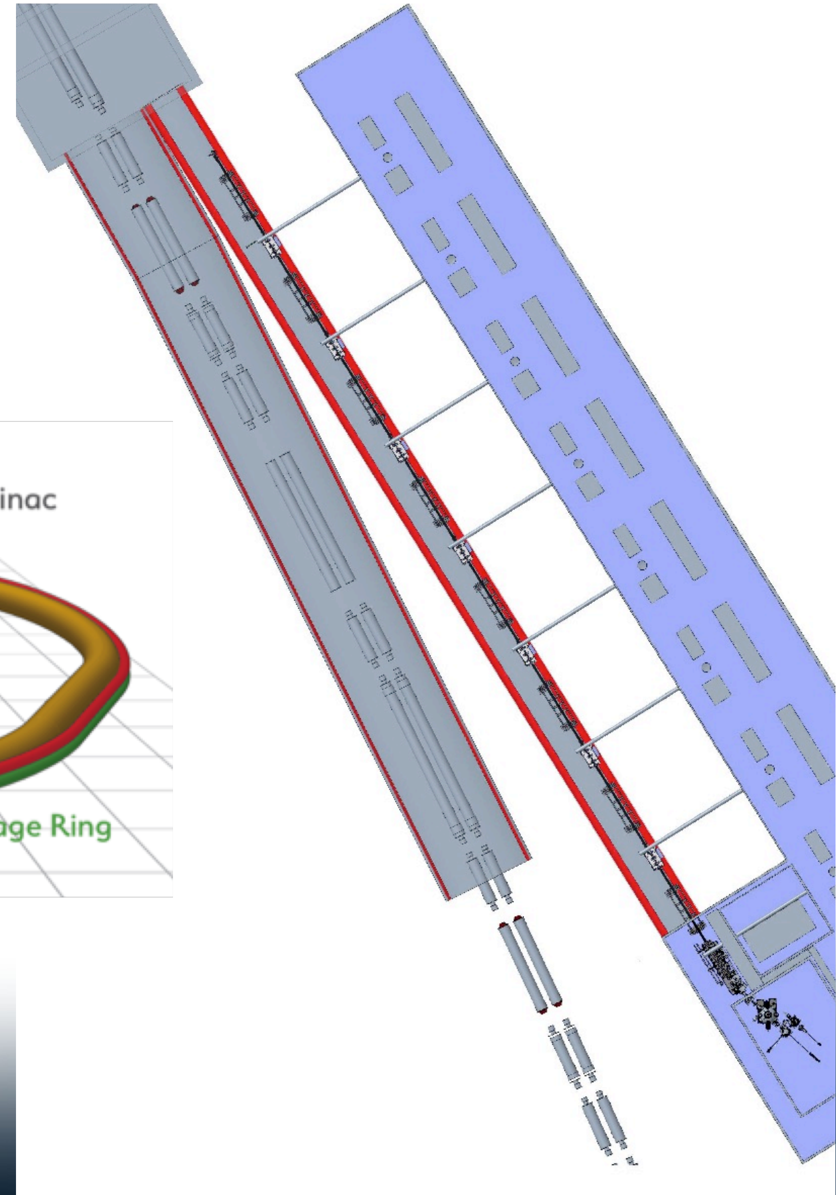
eRHIC source design has no risks:
Dr. Charles Sinclair: "If the ring-ring eRHIC parameters are really 10 nC and 1 Hz, then I think you will have no problem at all. Several laboratories have demonstrated ***performances well above this level****".*

- The eRHIC polarized electron source needs to generate high charge (10nC) and high polarization of the electron beam. Both SLC PES gun and JLab inverted guns are being considered. 12.5 nC bunch charge has been demonstrated from a DC gun using SL-GaAs photocathode.
- 400 MeV pre-injector has been simulated. Meets the requirements.
- All electron spin requirements have been integrated into pre-injector design.
- The gun R&D activates are in progress.

Thank you for your attention !

Back up

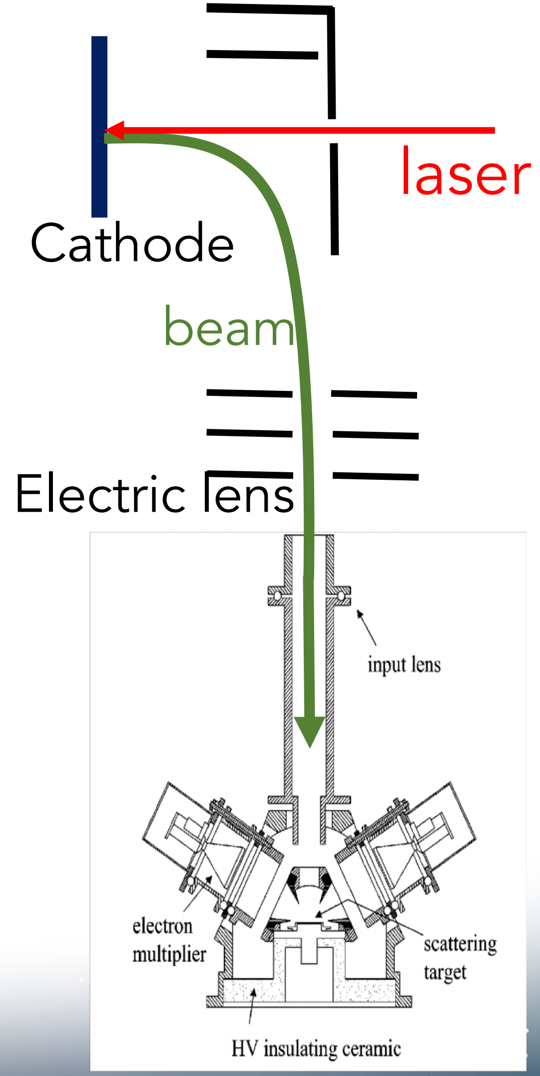

Polarized
Electron Source
Coherent Electron
Cooler
Injector Linac
eRHIC
Detector II
Ions
Detector I
Electrons
Storage Ring
RCS Injector



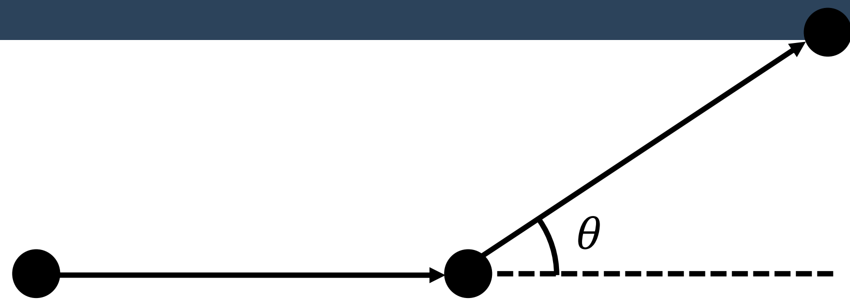
Retarding field Mott polarimeter

- Measure the photocathode emission electrons polarization.
- Place at preparation chamber.
- Commercially available.

Parameter name	value
Beam energy	20 keV
Beam bend degree	90°
Scattering degree,	120°
Detector count rate	3.8e5 Hz/(nA.um)



Electron transportation-scattering angle



- For isotropic scattering processes:

$$\cos\theta = 1 - 2r$$

- For anisotropic scattering processes:

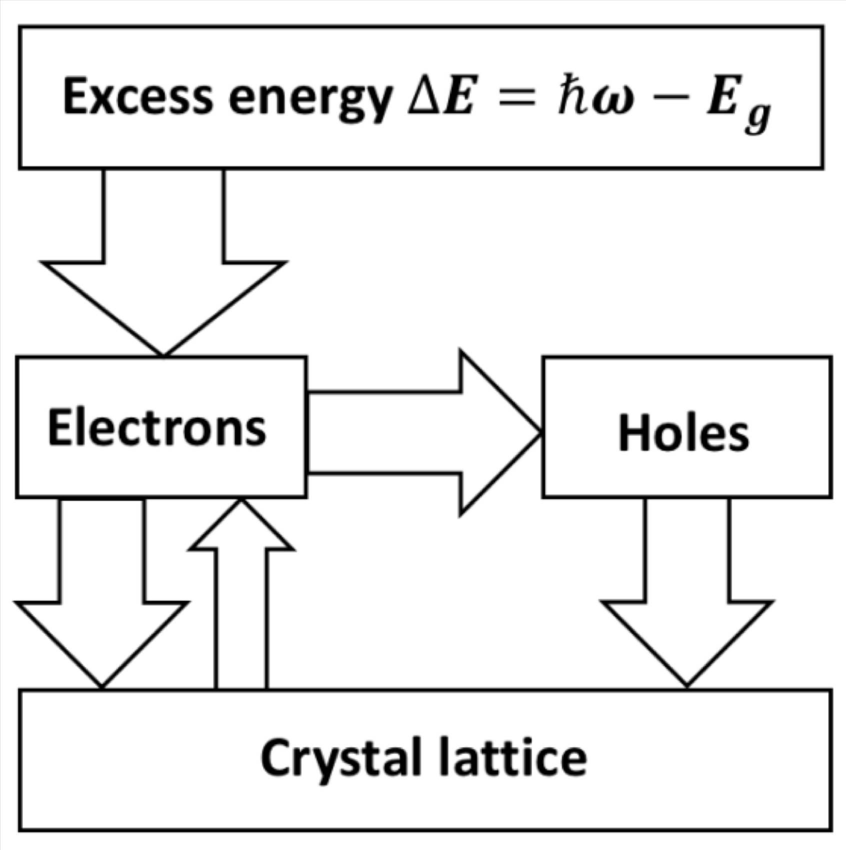
$$\cos\theta = \frac{(1+\xi) - (1+2\xi)^r}{\xi}, \xi = \frac{2\sqrt{\gamma_{E_k}\gamma_{E_{k'}}}}{\left(\sqrt{\gamma_{E_k}} - \sqrt{\gamma_{E_{k'}}}\right)^2} \quad (POP)$$

$$\cos\theta = 1 - \frac{2r}{1 + b(1-r)} \quad (Coulomb)$$

C. Jacoboni and L. Reggiani, Rev. Mod. Phys. **55**, 645 (1983)
D. Vasileska and S.M. Goodnick, https://nanohub.org/resources/9109

Electron transportation-energy flow

- Electrons obtain energy from photon
- Electrons exchange energy with holes and crystal lattice
- Electron reach a steady-state distribution after a series of scattering



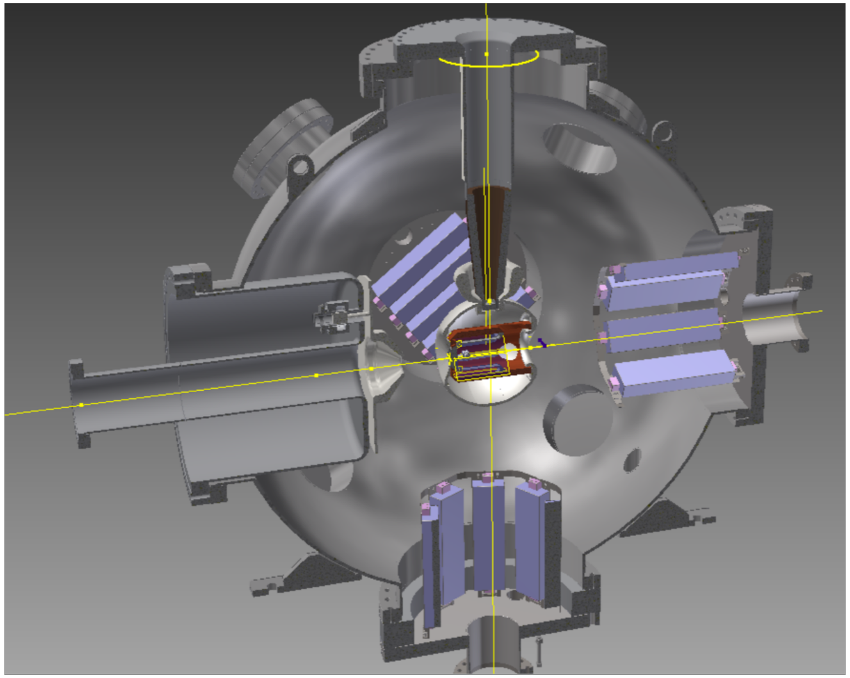
Polarized gun R&D

The polarized gun R&D goal:

- High average current (6~50 mA), high bunch charge (5.3 nC) large cathode inverted gun for L-R eRHIC source.
- High bunch charge (50 nC) for R-R eRHIC source.

Sub-R&D items:

- Achieve and measure XHV
- High power laser
- Ion back bombardment
- Surface charge limit measurement
- Lifetime as the function of charge
- Beam halo reduction studies
- Cathode cooling



BNL 1ST inverted gun in fabrication

Vacuum

- Cathode system 10^{-12} torr
- Gun 10^{-12} torr
- Beam line near the gun low 10^{-11} torr
- Linac 10^{-11} torr

SIP+NEG

eSource Lab in CAD

- Necessary to build a polarized electron source onsite.
- Most of the floor space is dedicated for the ATF-II project. Recently it was determined the second experimental hall of the ATF-II project will not be constructed for at least the next 5 years. CAD management has agreed to lend this space to be used as the polarized source laboratory.
- The Electron Source R&D facility will be located in the same building as other important facilities that will support it's efforts.
  - Two class 100 particle free clean rooms
  - Large In-vacuum bake out oven
  - Deionized water source and large high pressure rinsing facilities.
  - 2K system and Cryogenic refrigerator
  - Technical work force
  - Large overhead crane

eSource Lab layout