Polarized electron source R&D and EIC pre-Injector Design

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SuperKEKB e-polarization Upgrade

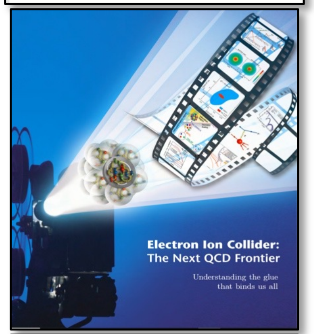
Nov. 10th 2022

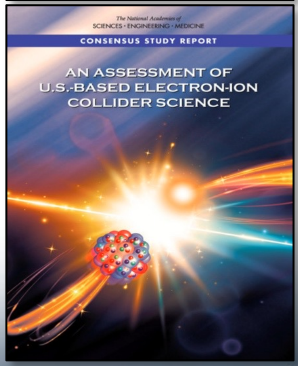
Electron-Ion Collider

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

Electron Ion collider Introduction

- Science goals
  - How does the mass of the nucleon arise?
  - How does the spin of the nucleon arise?
  - What are the emergent properties of dense systems of gluons?
- EIC Design Goals
  - High luminosity: $L=(0.1\text{-}1)\times10^{34}\ cm^{-2}\ s^{-1} \rightarrow$ 10-100 fb^{-1}
  - Collisions of highly polarized +/-70% e, p and light ion beams with flexible spin patterns
  - Large range of center of mass energies: E_{cm}=(20-140) GeV
  - Large range of ion species: protons–Uranium
  - Ensure accommodation of a second IR
  - Large detector acceptance
  - Good background conditions



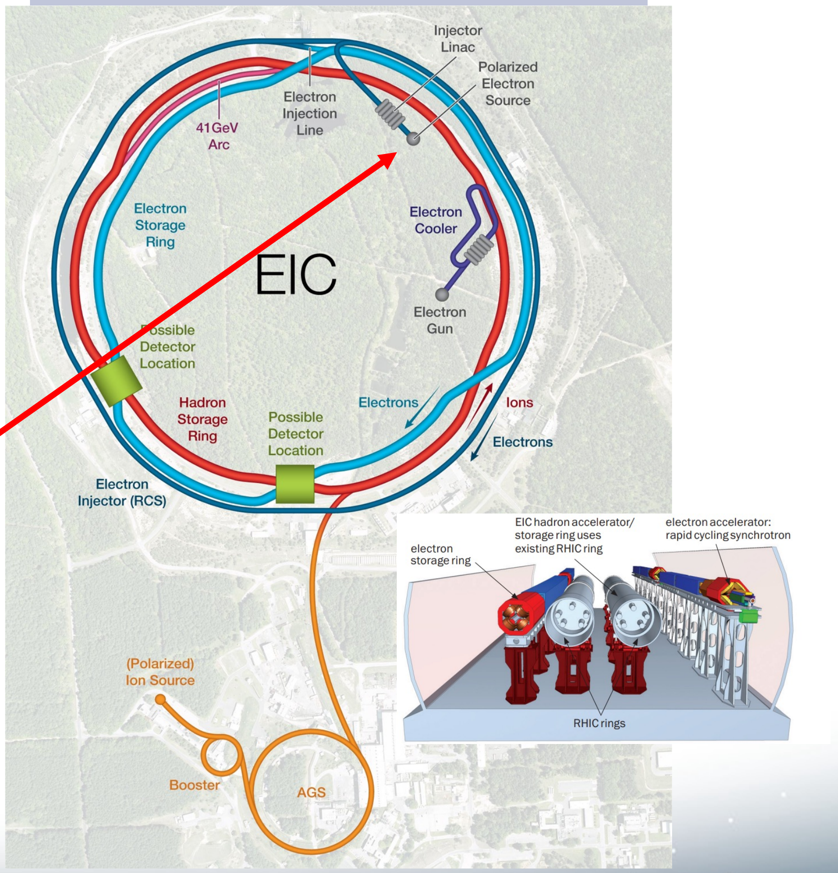


EIC Accelerators

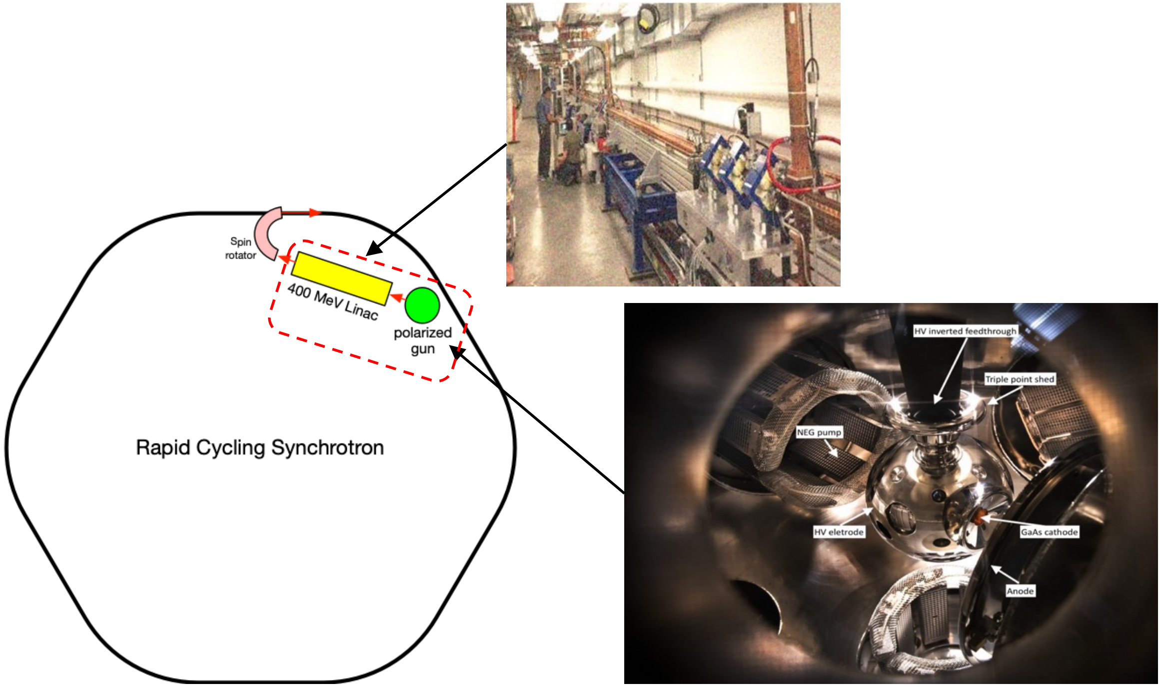
E_{cm} = 20 GeV -141 GeV
High luminosity goal: $L = 10^{34} cm^{-2} s^{-1}$

Design based on existing RHIC,
RHIC is well maintained, operating at its peak

- Hadron storage ring 40-275 GeV (existing)
  - RHIC Yellow(Blue) Ring
  - Many bunches, 1160 @ 1A beam current
  - Bright beam emittance
  - Strong hadron cooling (new)
- Electron storage ring (2.5–18 GeV, new)
  - Many bunches,
  - Large beam current (2.5 A) 10 MW S.R. power
  - s.c. RF cavities
- Electron rapid cycling synchrotron (new)
  - High charge polarized pre-injector
  - Spin transparent due to high periodicity



EIC Electron pre-injector

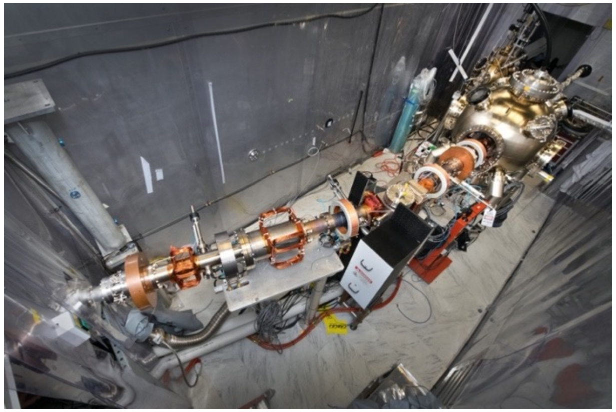


- 300 kV polarized HVDC gun generates 7nC x 8 polarized electron beam every second.
- 400 MeV pre-injector
- Rotate the electron spin direction from longitudinal to vertical

Polarized HVDC gun

EIC polarized electron source requirement

	EIC	Achieved in stable operation	R&D deliverable
Bunch charge [nC]	7	7.5 (12)	Y
Peak current [A]	3.8	4.8 (No SCL)	Y
Frequency [Hz]	1 (8 bunches)	1 (9000 bunches)	Y/N*
Voltage [kV]	300	300	Y
Average Current	56 nA	76.5 uA	Y
Polarization [%]	> 85%	Bulk (~35%)	Y/N**

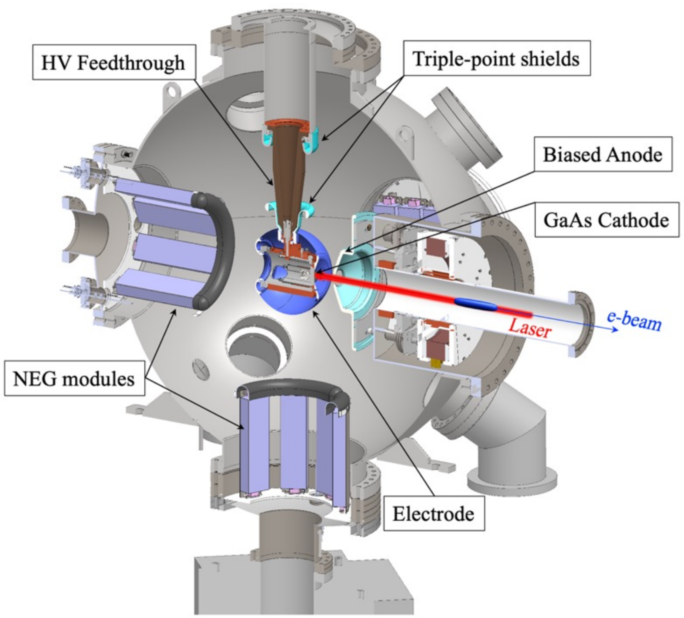


EIC polarized gun at Stonybrook Univ.

* Our laser rep. rate is 10 kHz
** Measure GaAs polarization at retarding field Mott polarimetry. Our gun beam line doesn't have Mott polarimeter.

EIC lifetime requirement in CDR : 24x7x3600x8= 4.8 e6 bunches /week for 2 weeks

HVDC gun design



New features includes:
- Active cathode cooling
- Large cathode
- Semiconductor jacket HV cable
- x,y,z moveable electrically insulated anode.

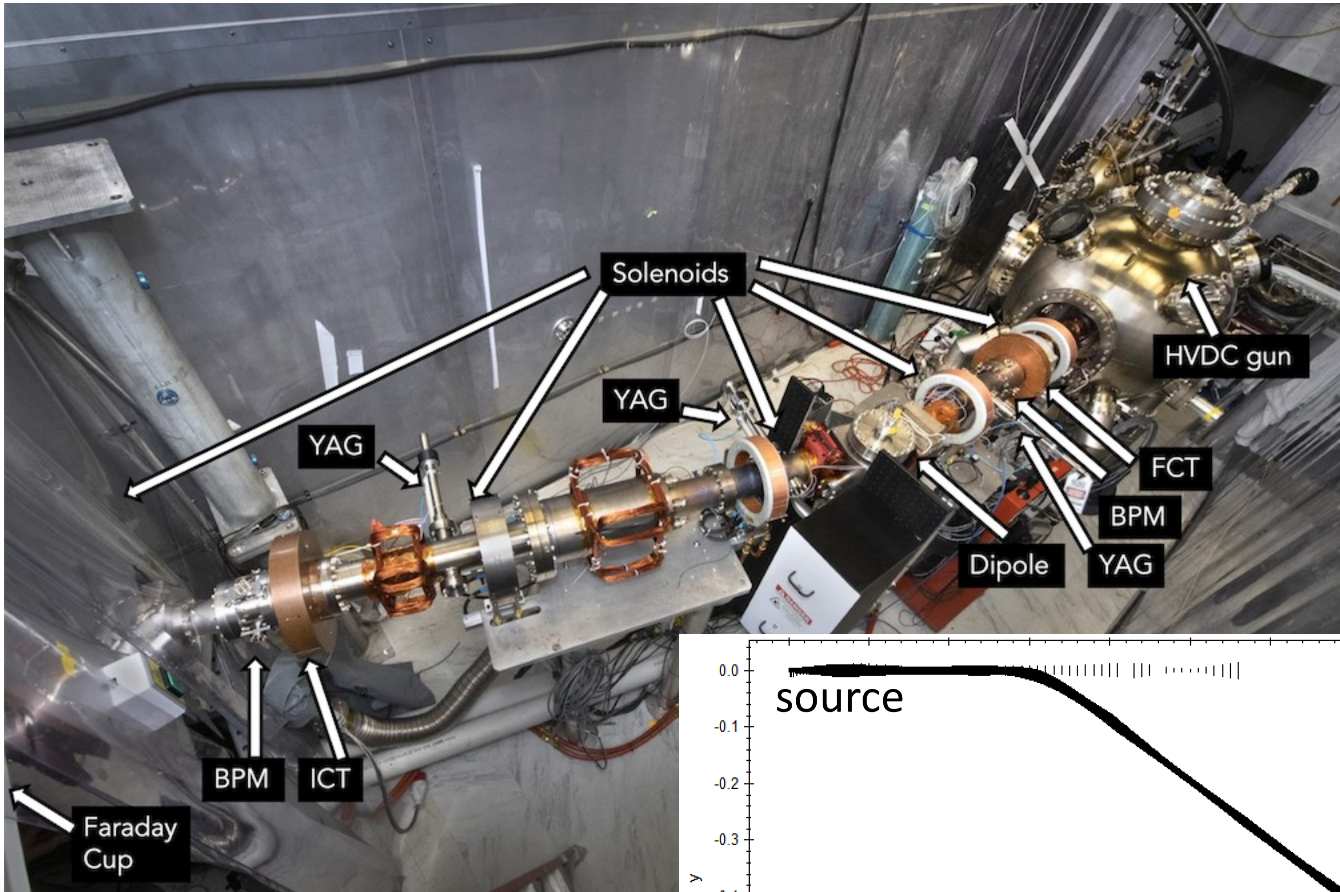
	Inverted gun
Ball diameter	20 cm
Chamber diameter	80 cm
Gap distance	5.7 cm
Voltage	350 kV
Cathode size	1.3 cm
Electrodes angle	22 degs
Cathode gradients	4.0 MV/m
Maximum gradient	9.8 MV/m
Anode diameter	2.2 cm
Peak current	4.8 A
Bunch charge	7 nC
N_emittance	3.6 mm-mrad
Pumping speed	35000 L/s
Anode bias	3000 V

Gun design include:
- high voltage feedthrough
- triple-point sheds
- Beam quality, envelop, halo
- NEG pump positioning.
- Electrode, anode outer shape

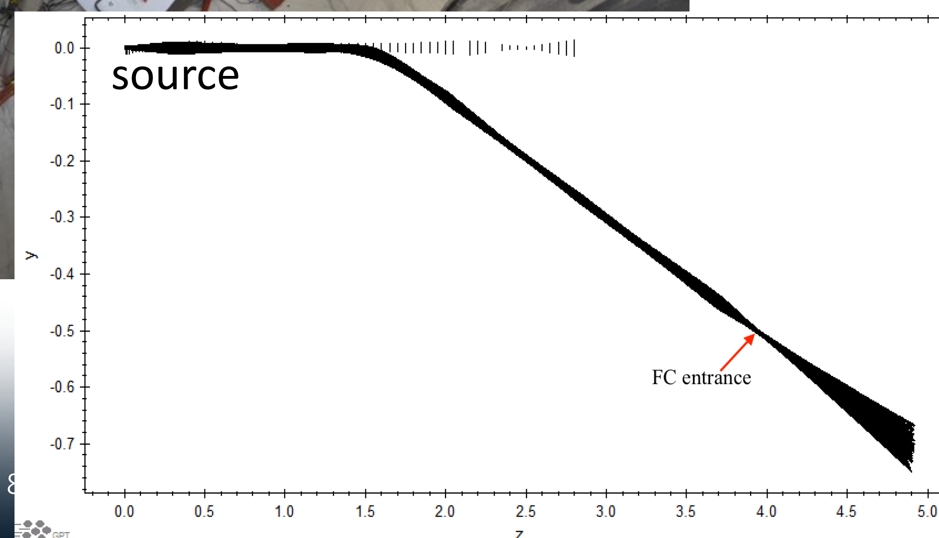
Main tools:
- Possion: 2D study
- Opera3D: triple point sheds kick.
- GPT 3D beam tracking, ion back tracking
- Python: field emission tracking, Ion back tracking

Maximum gradient @350 kV: 9.8 MV/m(gap nose, triple point shed)

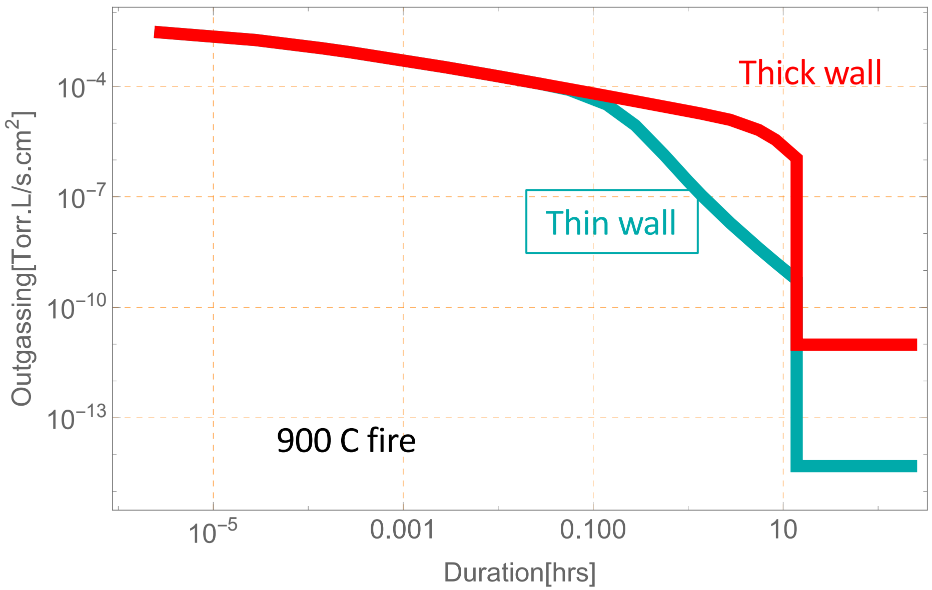
Test beam line at SBU

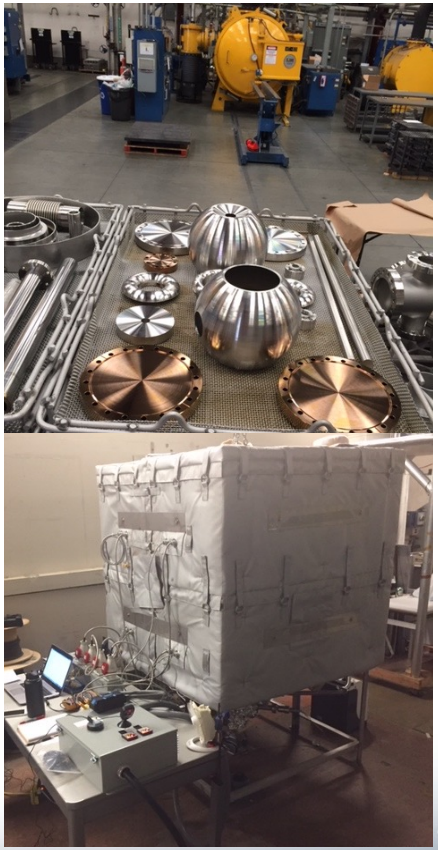


Beamline designed using 3D code GPT



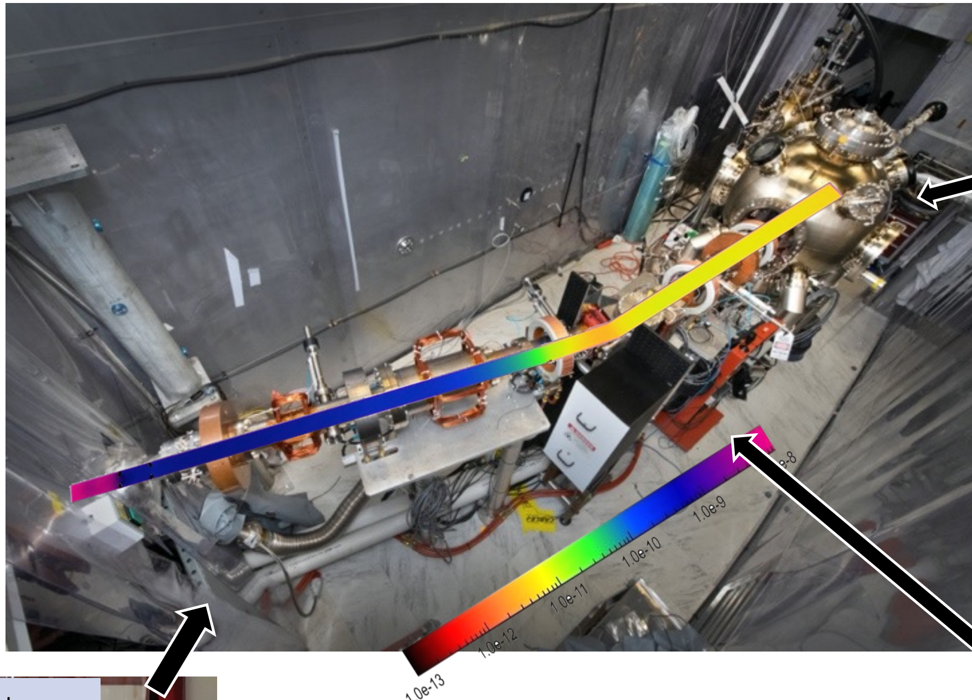
Achieve extremely high Vacuum





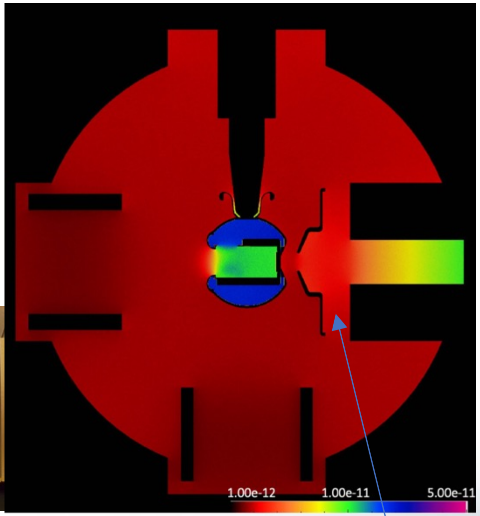
Thin wall+ 10 hrs 900 Cfire + week 400 C bake+ 20000 L/s pumping speed= extremely good vacuum

Beam-line vacuum in experiment



Gun Vacuum
3BG gauge

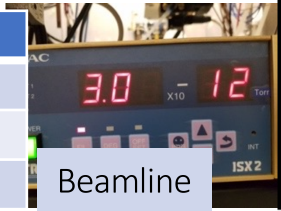
3BG gauge	Gun
Baseline	5-8 e-12
3uA	Low (c.c)
67.5 uA	2e-11,Low (c.c)



Beam dump

ULVAC gauge	Beam dump
Baseline	3-4 e-12
3 uA	3e-10
67.5 uA	1e-9

ULVAC gauge	Beam Line
Baseline	3-4 e-12
3 uA	5e-12
67.5 uA	1.5-3 e-11

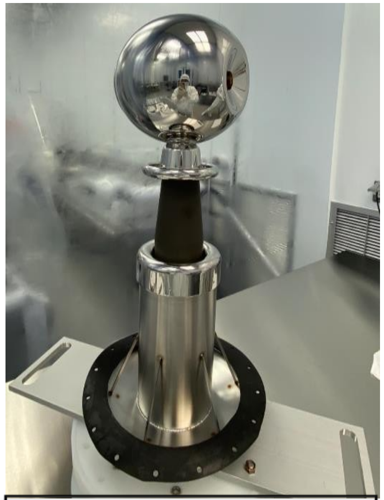


Beamline

We added gap in between the anode and the gun chamber to get extra conductivity

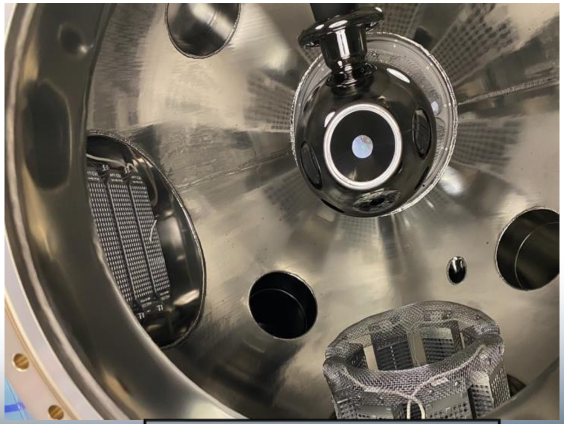
HV electrode treatment and installation

Polish at JLab

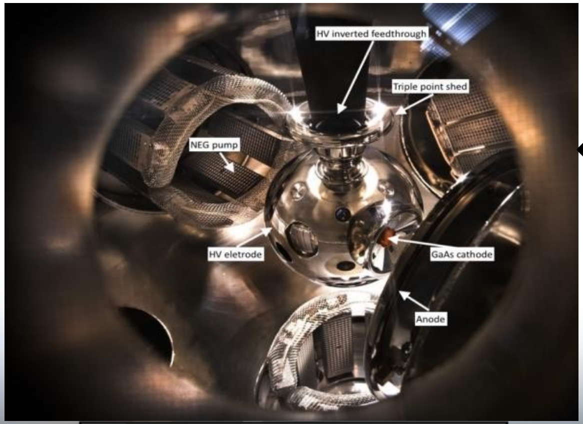


HPR at BNL SRF

Installation at SBU

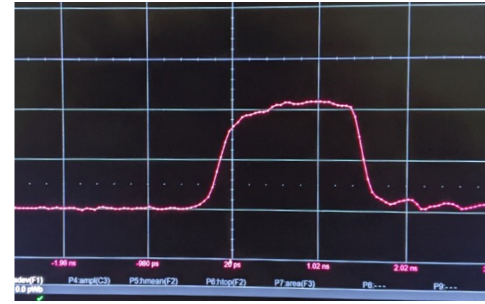


Alignment



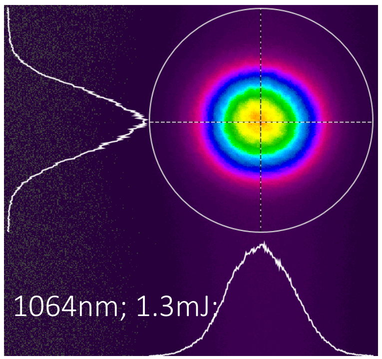
Final assembly

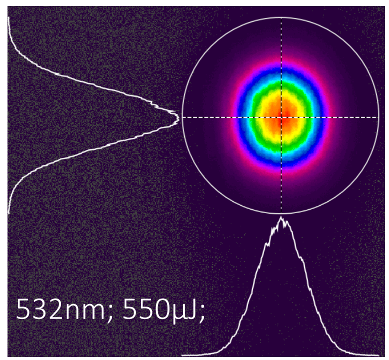
Polarized laser overview

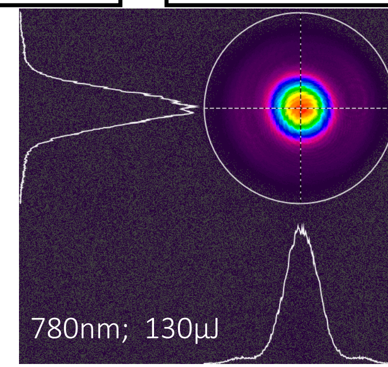


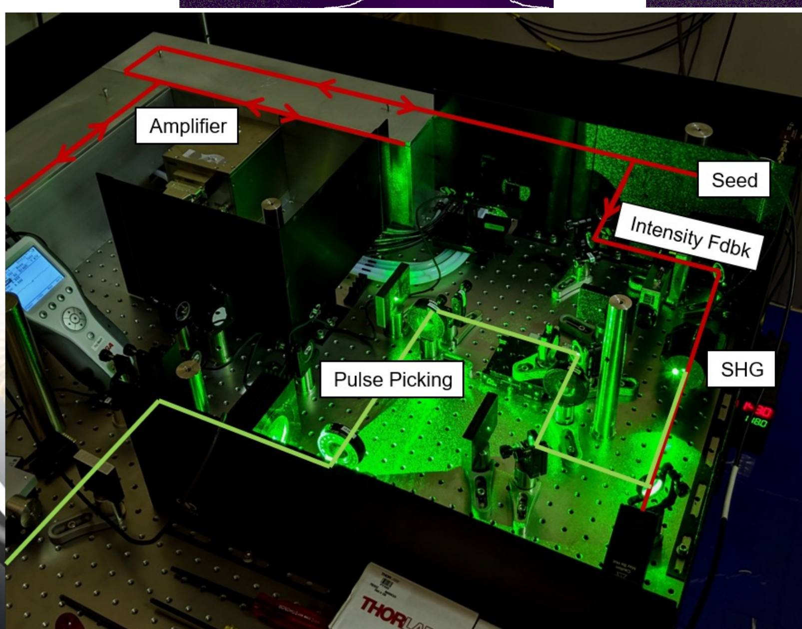
20MHz Seed → Regenerative Amplifier → SHG → Pulse Picker → OPA → Helicity & Intensity Control

780nm Pulsed Seed (feeds into the line between Pulse Picker and OPA)





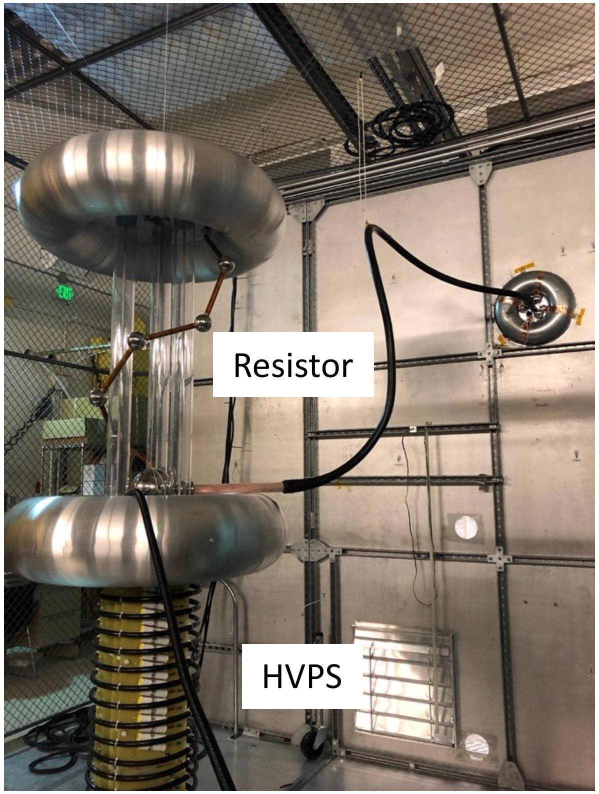


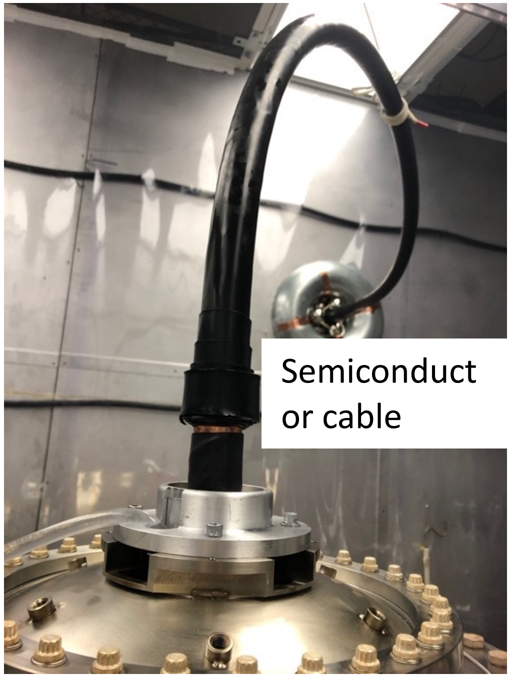


Parameter	Specification	Achieved
Repetition Rate	1-2Hz	1Hz-10kHz
Pulse Energy		
532nm	20μJ	500-800μJ
780nm	60μJ	130μJ
Longitudinal Profile	Flat or Gaussian	Flat
Flatness	5% (@780nm)	Flat
Transverse Profile	Gaussian	Gaussian
Pulse On/Off Contrast	70dB	>70dB
Jitter rms	10ps	5.5ps

Power supply and HV cable

- 400 kV Power supply is SF6 free set up.
- PS is 5 meter away from the gun within a grounded cage.
- Resistors for gun conditioning and 460 ohm resistor for beam operation.
- Custom designed Semiconductor jacket to redistribute the storage energy(50pF/ft, 46 Joules) into the DC gap if discharge happen

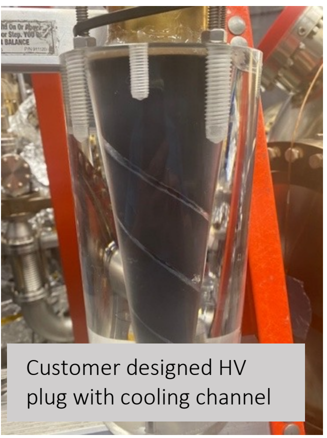


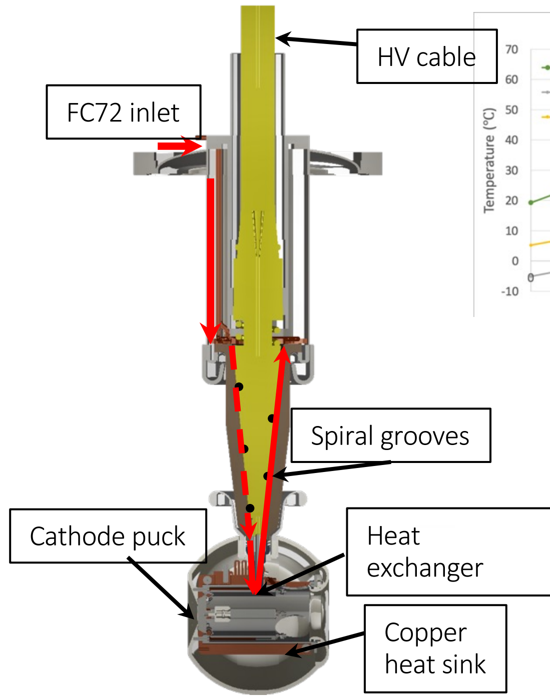


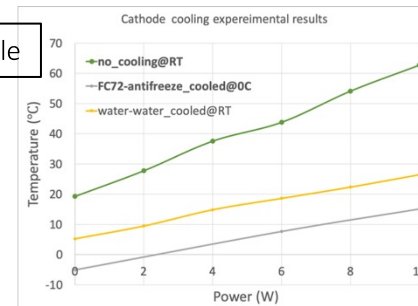
Active cooling of HVDC gun

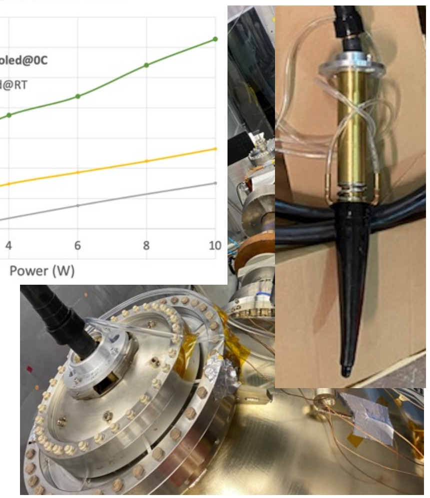
Aiming to absorb the laser power up to 10 W. We are collaborating with Dielectric Sci. developed the active cooling HV feedthrough.

Tested up to 410 kV with flow





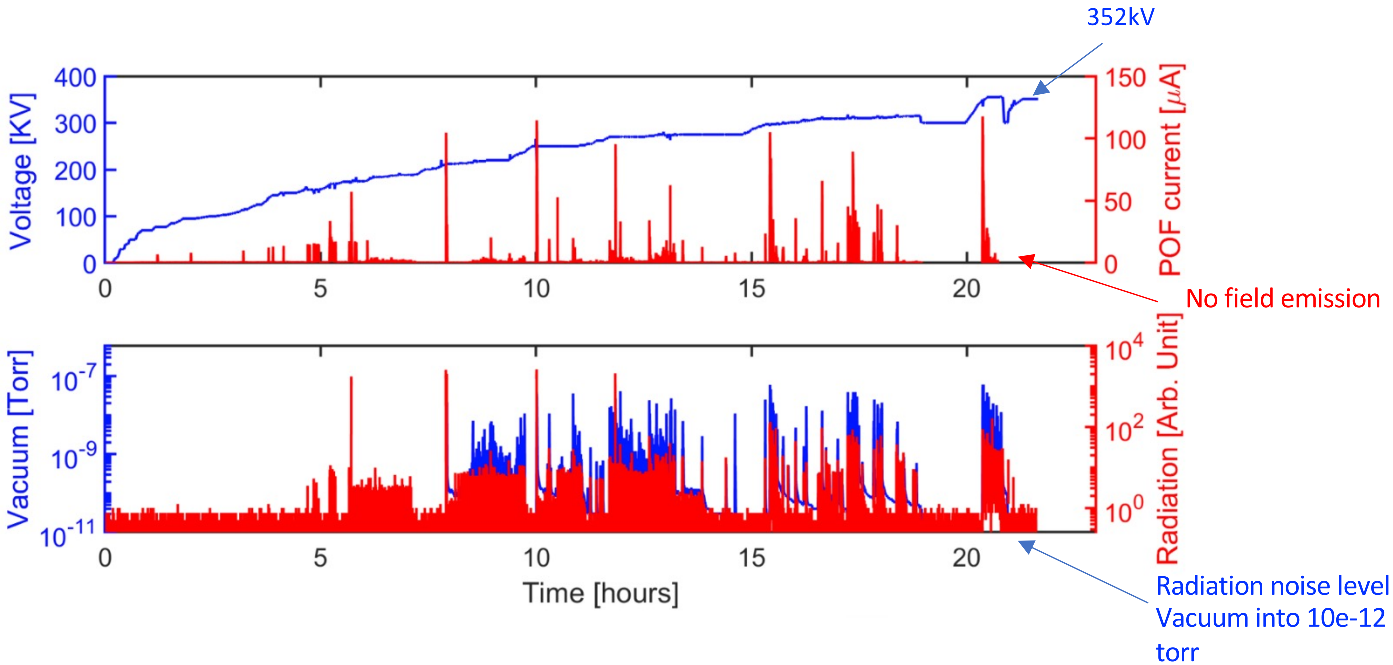




- Tested in the gun with FC 72. Operate @300-350 kV for more than 500 hrs . No failure.
- Maintain every 2-4 months.

It was designed for high current operation. Not necessary for EIC polarized source. But beneficial towards high current polarized/unpolarized gun.

HV conditioning

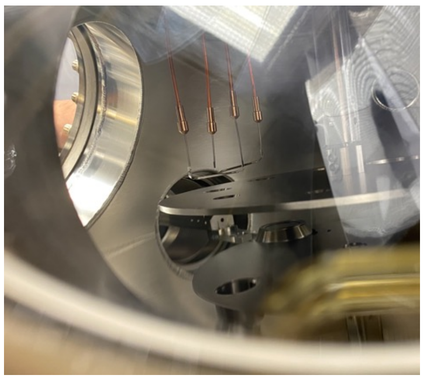
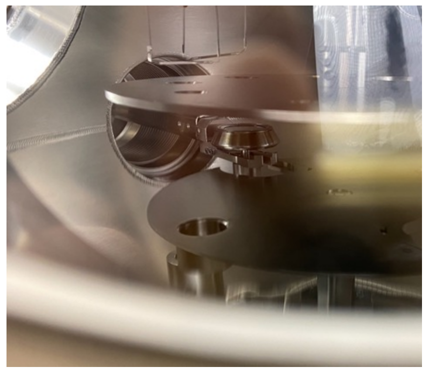
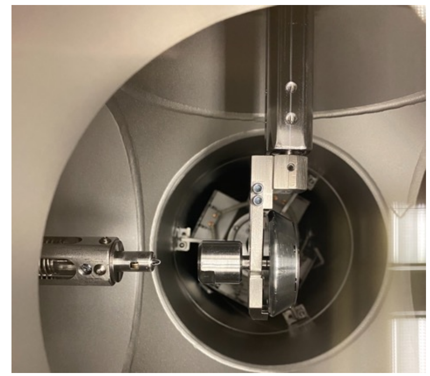
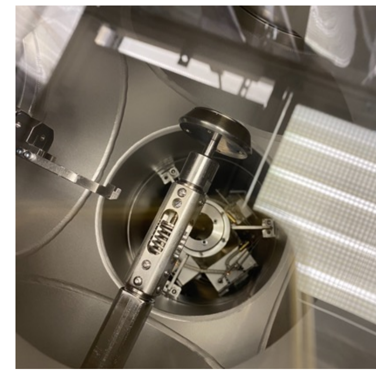


Gun conditioned at Dec. 2020(vacuum conditioning, total take 23 hrs, Cooling is on):

- Achieved gun design value 352 kV without field emission(without activated GaAs)
- Achieved gun design value 325 kV without field emission(with activated GaAs and new puck)

We didn't use inert gas conditioning

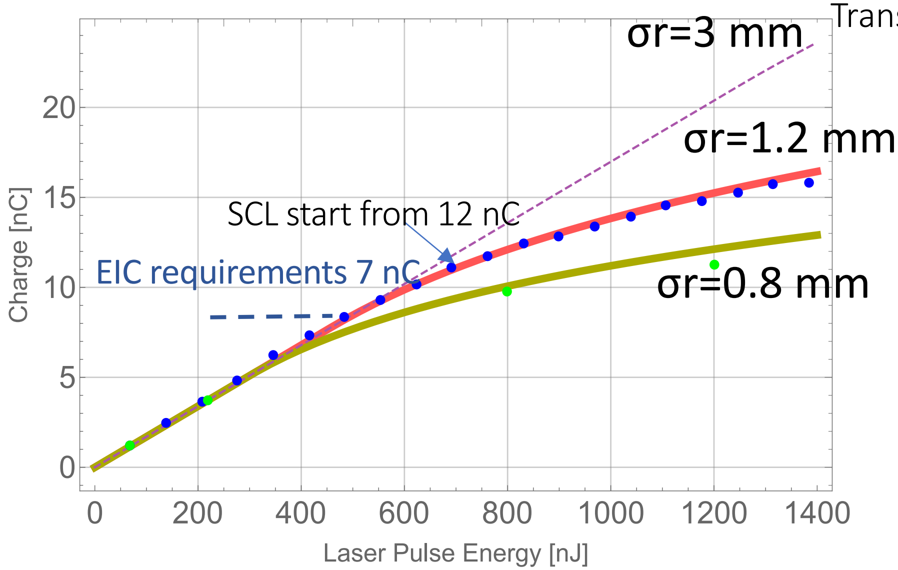
Cathode insertion

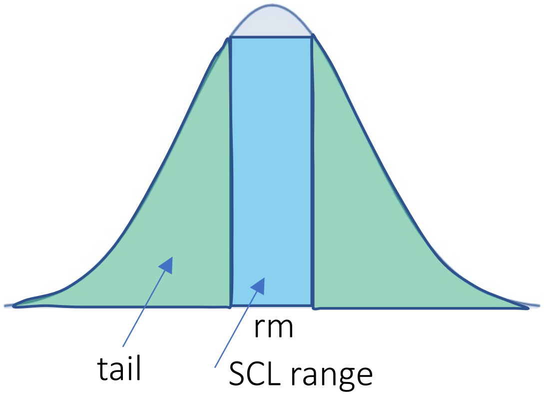






With several times practices, now can insert a cathode in ~20 mins.

Bunch charge and cathode lifetime

$785 \pm 1.3\ nm$
FWHM 1.64 ns
Longitudinal flattop
Transverse Gaussian





A Gaussian radial distribution on the cathode,

Surface charge density: $$\sum(r) = \frac{Q_{bunch}}{2\,\pi\,\sigma_r} e^{-\frac{r^2}{2\sigma_r^2}}$$

$$Q_{emitted} = Q_{scl} + Q_{tail}$$

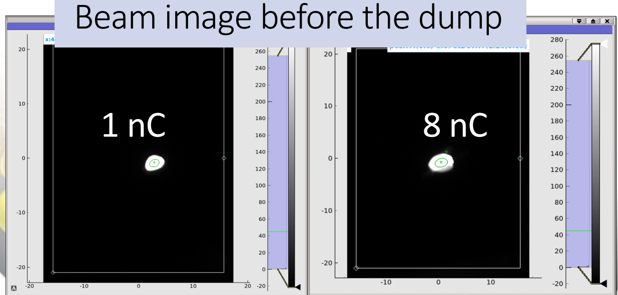
$$= \pi r_m^2\, J_{2d} + QE\,\frac{e\,E_{laser}}{\hbar\omega}\, e^{-\frac{rm^2}{2\sigma_r^2}}$$

Pencil shape 2D space charge limit:

$$J_{2d} = 2.33 \times 10^{-6} V^{3/2}/d(1 + \frac{d}{4r})$$

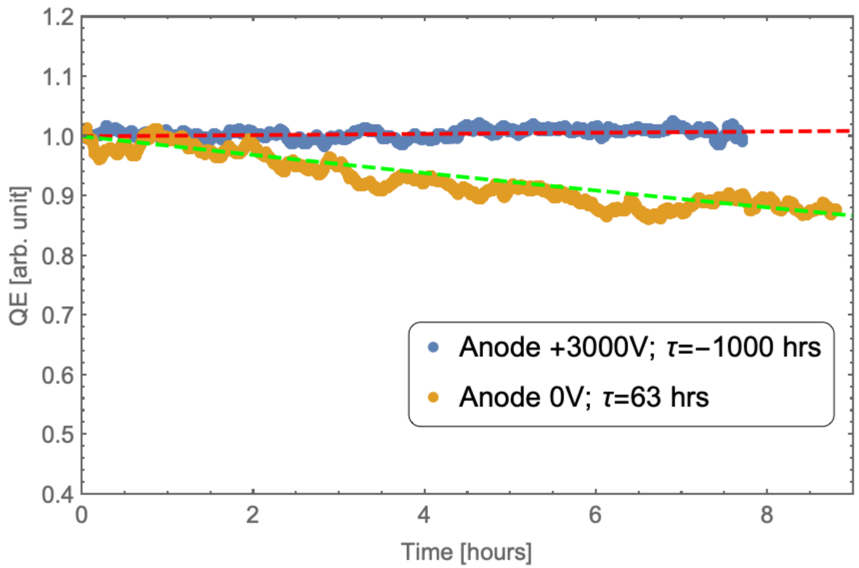
If rm>0, then space charge limit happen

Beam image before the dump



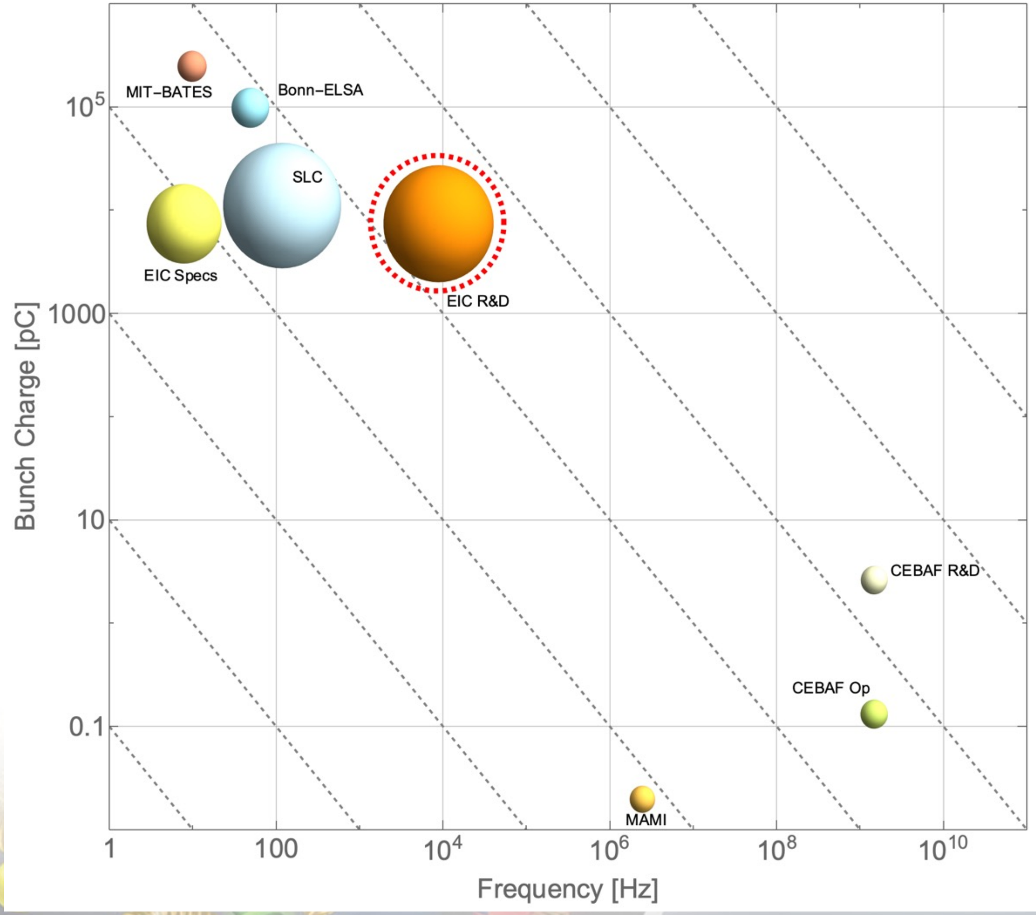
Beam shape looks good right before the beam dump
Large cathode size, we can increase the active area to get a higher charge(3 mm)

GaAs lifetime in the gun



- Bulk GaAs with 785 nm polarized laser; Gun operate at 300 kV. Run up to 67.5 uA.
- 7.5 nC bunch charge polarized beam, 5000 pulses/s ~37.5 uA;
    - With anode bias, we didn't observe QE drop.
    - Without anode bias 1/e lifetime is 63 hrs. Dominated by the outgassing from FC.
- Charge from 7 hours test= 33 weeks of EIC operation

Comparison with other operational and retired polarized gun



- The slope line shows the average current contour level.
- The ball diameter is representative of the peak current of the gun.
- The red dash line at EIC R&D shows the maximum achieved peak current of 8 A

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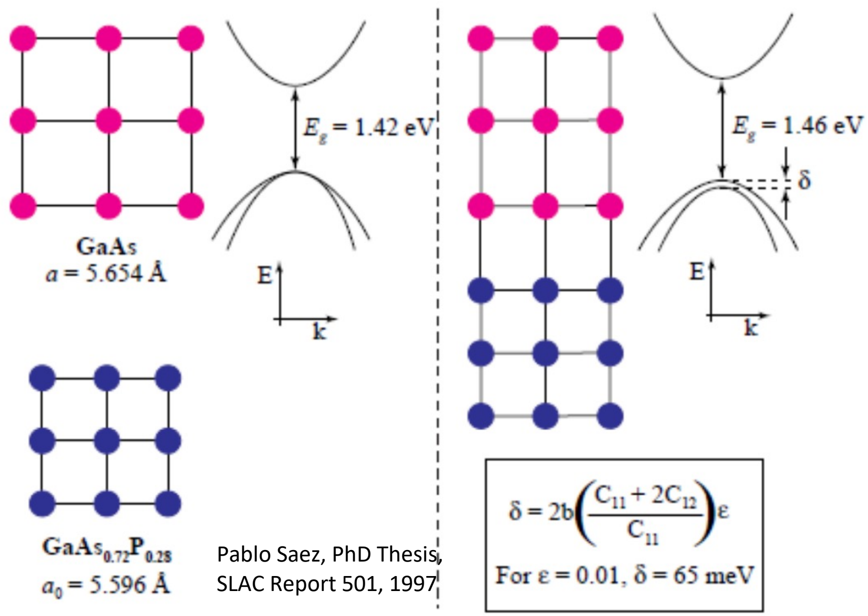
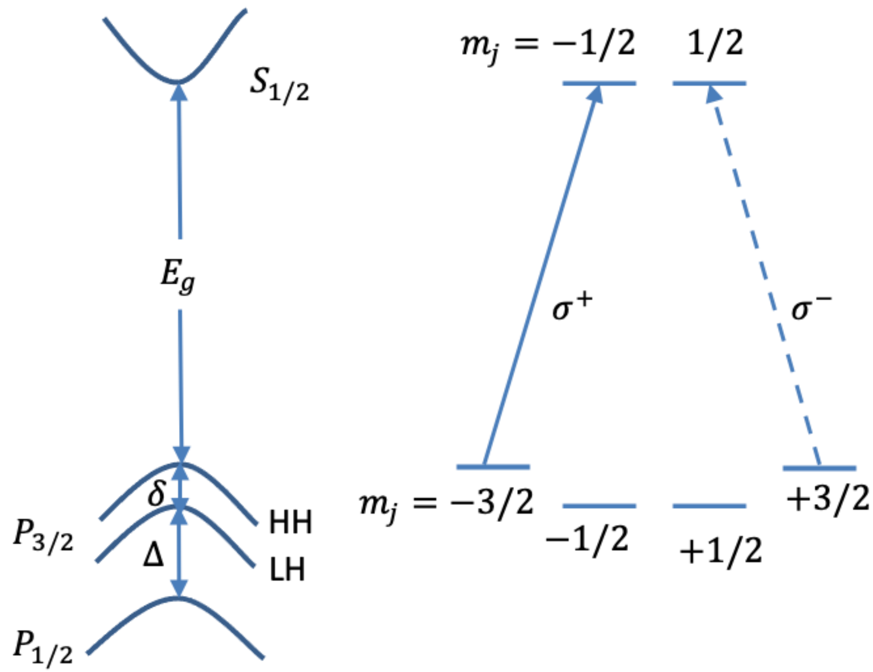
Polarized photocathode

Strained GaAs band energy level





- Lattice constants must differ enough to introduce a suitable strain (typical >1% lattice mismatch)
- The bandgap of the substrate layer must be larger than strained layer

For $E_g < h\nu < E_g + \delta$: $P = 100\%$

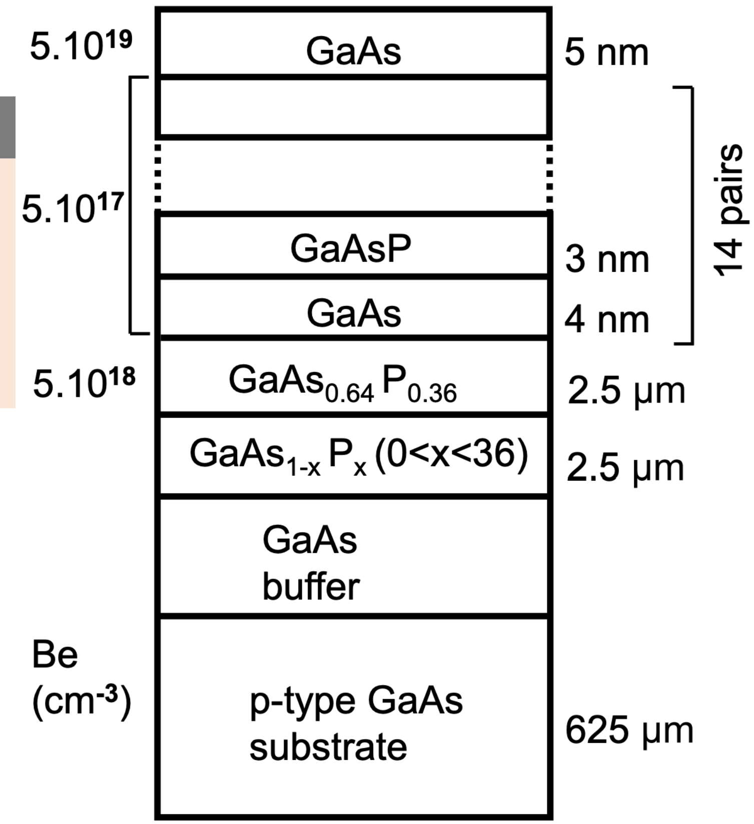
Strained superlattice photocathode

Strained Superlattice	Institute	QE	ESP
$GaAs/Al_{0.35}GaAs$	Nagoya	NA	71.2%
$GaAs/GaAsP_{0.36}$	SVT/SLAC	1.2%	86%
$GaAs/GaAsP_{0.34}$	Nagoya	0.5%	92%
$Al_{0.19}In_{0.2}GaAs/Al_{0.4}GaAs$	St. Peterburg	0.85%	92%

1. T. Omori, etc., Physical Rev. Lett. **67**, 3294 (1991)
2. T. Maruyama, etc., Appl. Phys. Lett. **85**, 2640 (2004)
3. T. Nishitani, etc., J. Appl. Phys. **97**, 094907 (2005)
4. Y. A. Mamaev, etc., Appl. Phys. Lett. **93**, 081114 (2008)

Typical results at 780 nm:
QE ~1%
ESP ~90%

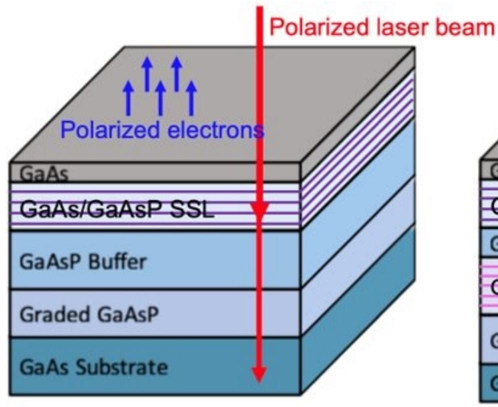
critical thickness limitation still exists on the overall thickness of the SL



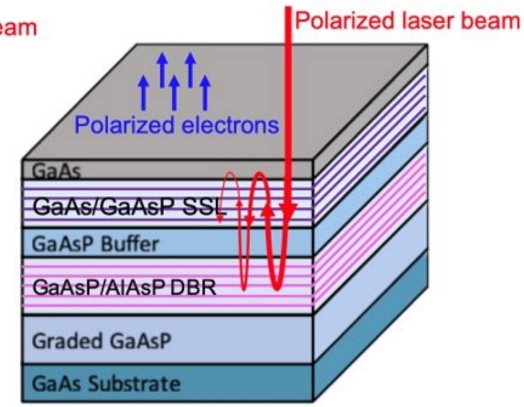
Sample manufactured by SVT Associates

1. W. Liu, etc., Appl. Phys. Lett. **109**, 252104 (2016)

DBR photocathodes

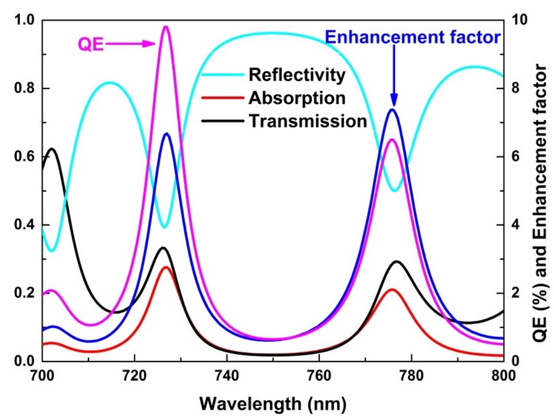


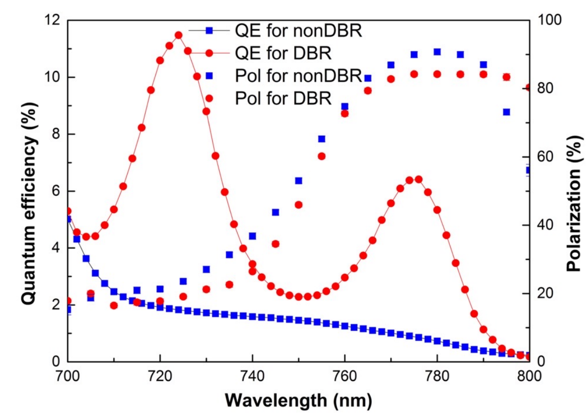
Standard strained superlattice (SSL) photocathode



Strained superlattice (SSL) photocathode with Distributed Bragg reflector (DBR)

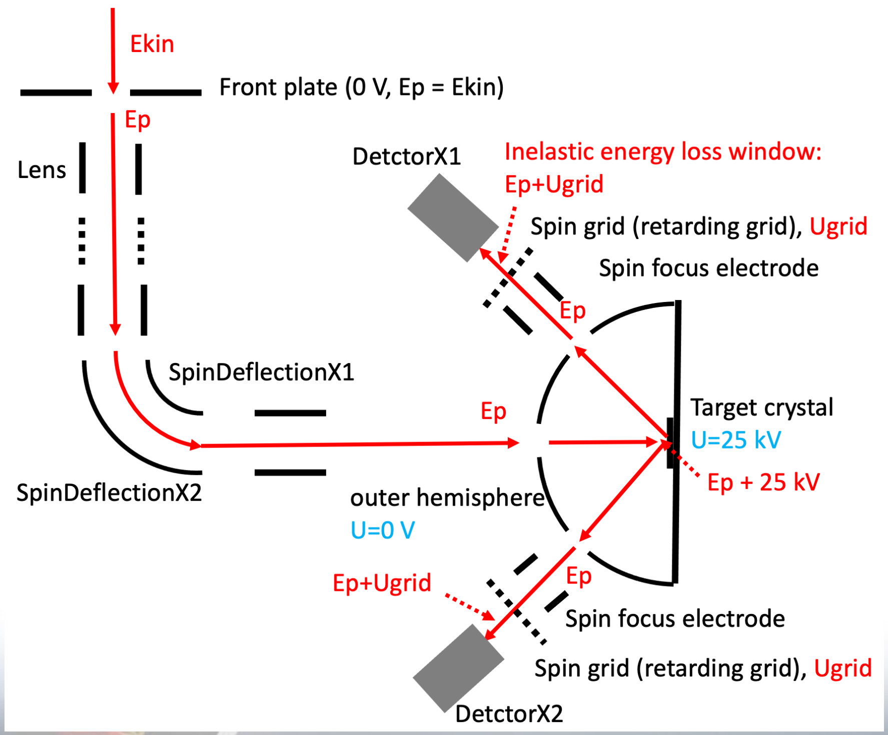
GaAs	5 nm	p=5×10^{19} cm^{-3}
GaAs/GaAsP SL	(3.8/2.8 nm) ×14	p=$5 \cdot 10^{17}$ cm^{-3}
$GaAsP_{0.35}$	750 nm	p=5×10^{18} cm^{-3}
$GaAsP_{0.35}$/ $AlAsP_{0.4}$ DBR	(54/64 nm) ×12	p=5×10^{18} cm^{-3}
$GaAsP_{0.35}$	2000 nm	p=5×10^{18} cm^{-3}
Graded $GaAsP_x$ (x = 0~0.35)	5000 nm	p=5×10^{18} cm^{-3}
GaAs buffer	200 nm	p=2×10^{18} cm^{-3}
p-GaAs substrate (p>10^{18} cm^{-3})		





Compact Mott detector performance

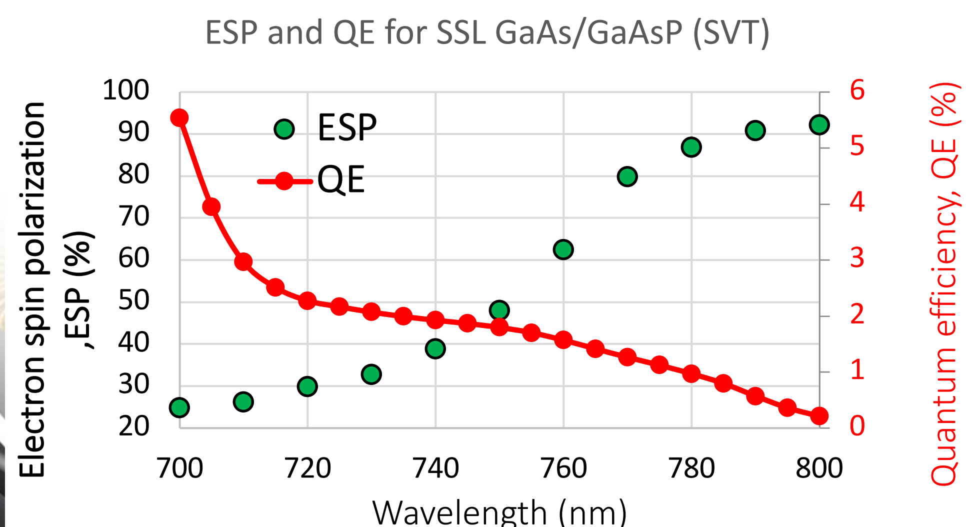
- Sherman function depends on detector design, target voltage and quality of target crystal
- Typical value: $S_{eff} = 0.1 \sim 0.3$ for 20-25 kV

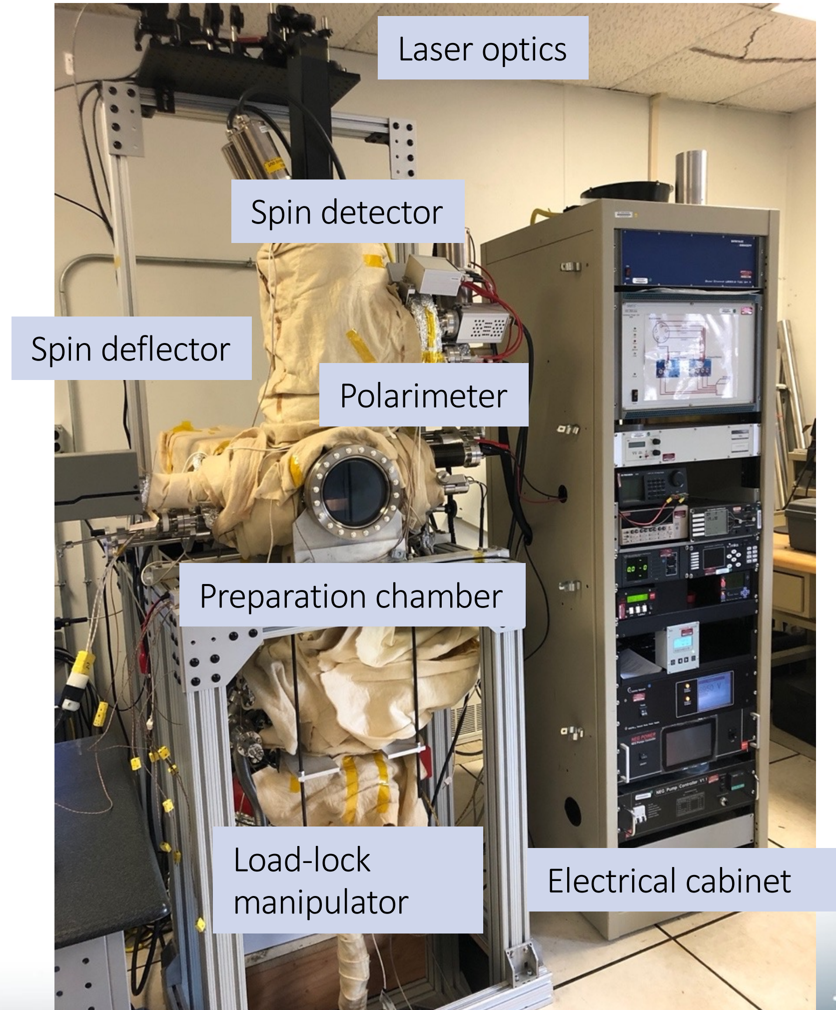


Specs Mott polarimeter system

- We established polarization measurement for polarized electron source using mini-Mott.
- Several SL-GaAs samples(SVT ,Sadia, ODU) have been measured.

SVT(USA) was the best vendor. Expert moved to Acken Inc(China). 6 wafers order submitted(delayed due to Shanghai lock down, delivery time Aug. 22nd)
US SL-GaAs vendor is growing (ODU, Sadia, et,al). We expect the US supply train will be restored by the EIC start operation.

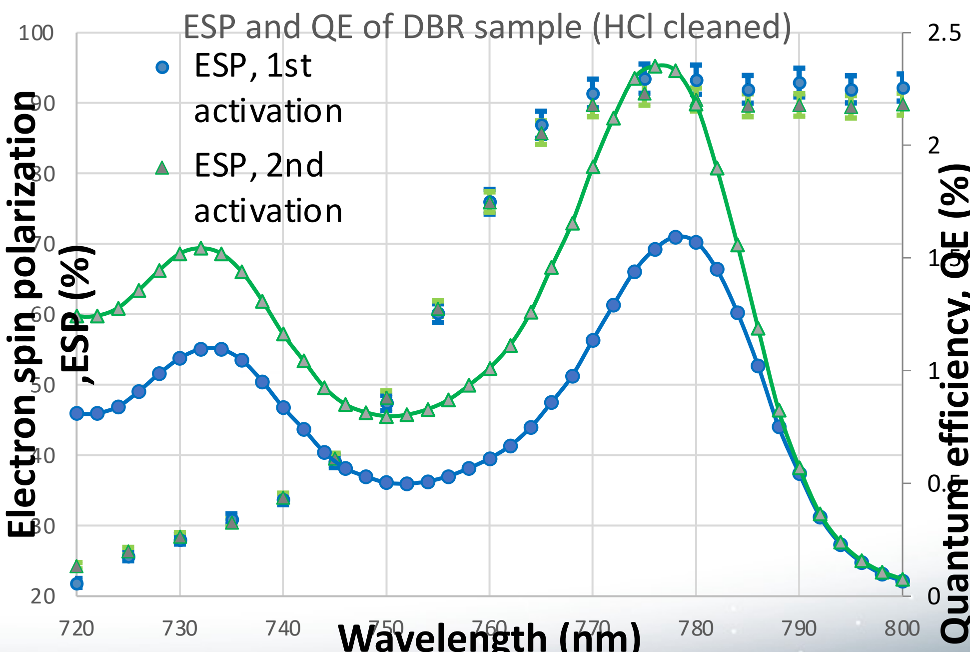




MOCVD photocathode progress

Jlab, ODU and BNL: GaAs/GaAsP SSL with AlGaAs/GaAsP DBR
Best performance: QE=2.35%, ESP=92%
Inexpensive compared to MBE.

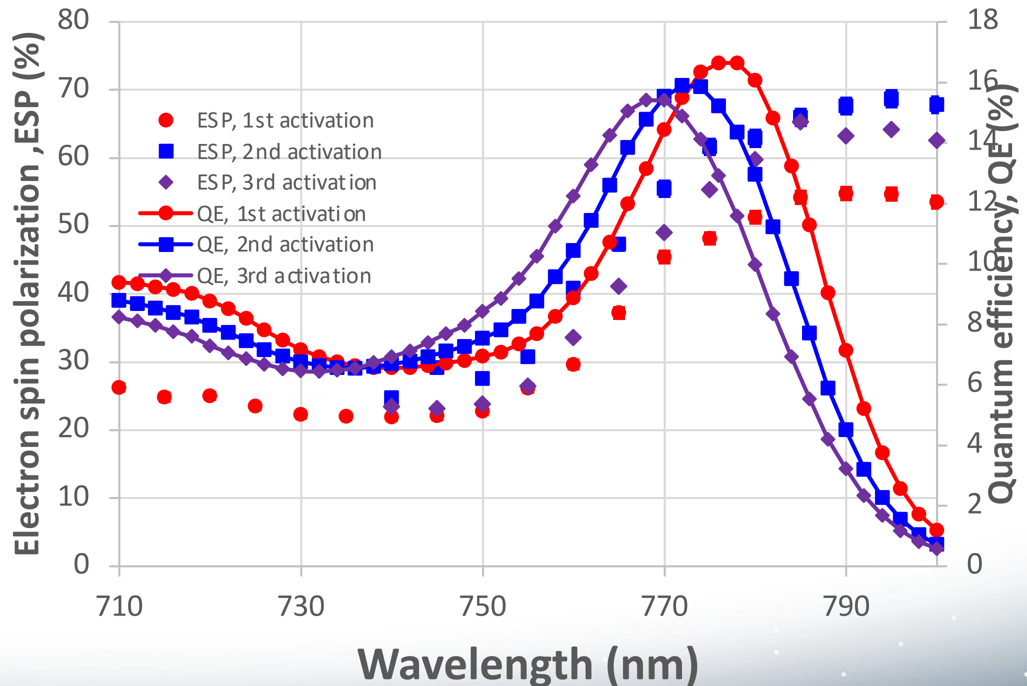
GaAs	5 nm	p=5 × 10^{19} cm^{-3}
GaAs/GaAsP SL	(3.8/2.8 nm) ×14	p=5 · 10^{17} cm^{-3}
$GaAsP_{0.35}$	750 nm	p=5 × 10^{18} cm^{-3}
$GaAsP_{0.35}$/ $AlAsP_{0.4}$ DBR	(54/64 nm) ×12	p=5 × 10^{18} cm^{-3}
$GaAsP_{0.35}$	2000 nm	p=5 × 10^{18} cm^{-3}
Graded $GaAsP_x$ (x = 0~0.35)	5000 nm	p=5 × 10^{18} cm^{-3}
GaAs buffer	200 nm	p=2 × 10^{18} cm^{-3}
p-GaAs substrate (p>10^{18} cm^{-3})		



MBE photocathode progress

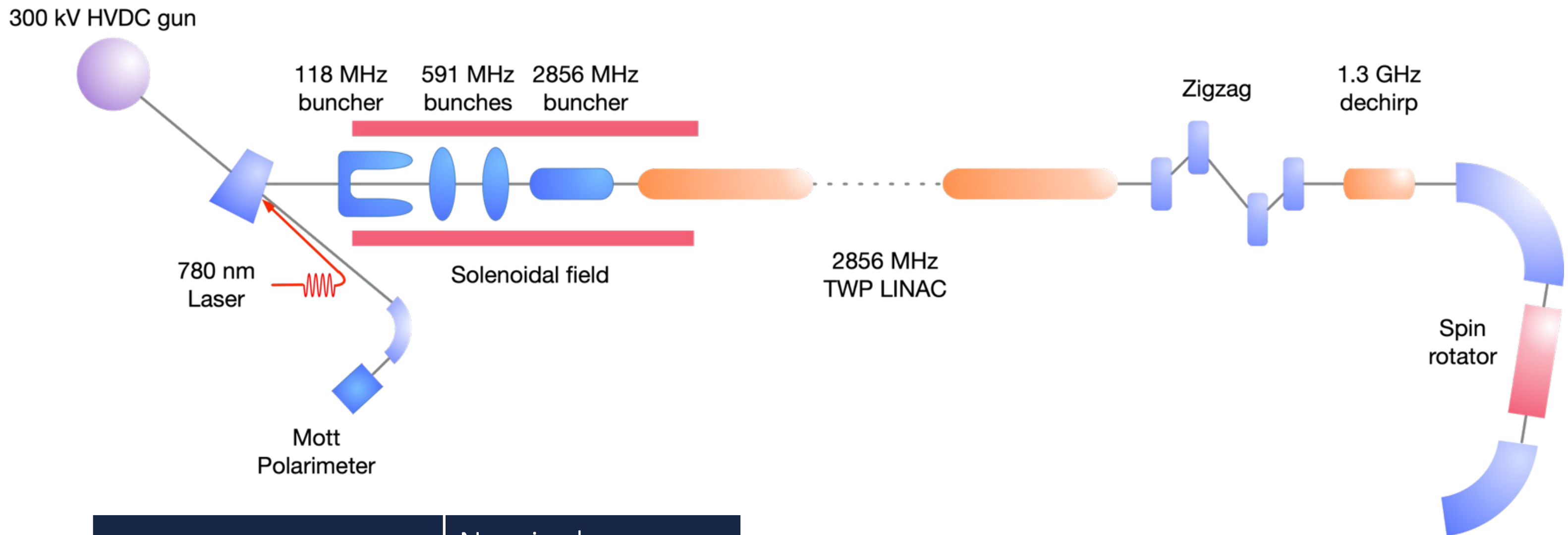
BNL and Sandia: SC GaAs/GaAsP SL with AlGaAs/GaAsP DBR
2 DBR samples
Best performance: QE=16%, ESP=61%

GaAs	5 nm	$p = 5x10^{19}$ cm^{-3}
$GaAs/GaAs_{0.62}P_{0.38}$	(4/4 nm) x30	$p = 5x10^{17}$ cm^{-3}
$GaAs_{0.81}P_{0.19}$ (+2.6%)	309 nm	$p = 5x10^{18}$ cm^{-3}
$AlAs_{0.81}P_{0.19}/GaAs_{0.81}P_{0.19}$	(66.7/56.4 nm) x 10	$p = 5x10^{18}$ cm^{-3}
$GaAs_{0.81}P_{0.19}$	2000 nm	$p = 5x10^{18}$ cm^{-3}
$GaAs\text{->}GaAs_{0.81}P_{0.19}$	2750 nm	$p = 5x10^{18}$ cm^{-3}
GaAs buffer	200 nm	$p = 5x10^{18}$ cm^{-3}
GaAs substrate		$p > 1x10^{18}$ cm^{-3}



Pre-injector design

Pre-injector beam line set up

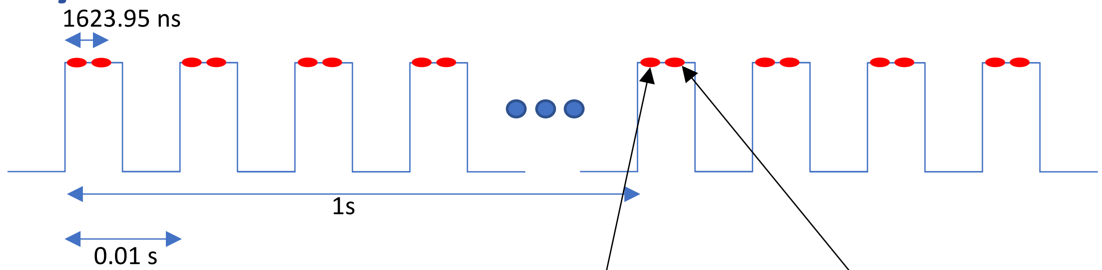


	Nominal
Bunch charge [nC]	7
Bunch length [ps]	40
Energy spread dp/p	2.5e-3
Frequency [Hz]	1Hz w 8 bunches
Energy [MeV]	400
Polarization [%]	85%
Lifetime	>2 weeks

- 2.856 GHz Buncher and Linac (6-8 tanks)
- 2 x 591 MHz Buncher
- 118 MHz Buncher
- Need R56 to rotates the bunch in longitudinal phase space to reduce energy spread
- 1300 MHz dechirp cavities

RF Frequency choice

Constrains:
2856 Linac rep. freq<120 Hz
1st buncher freq<150 MHz
3 us >Laser pulse space: >50 ns
Dechirp <1.5 GHz



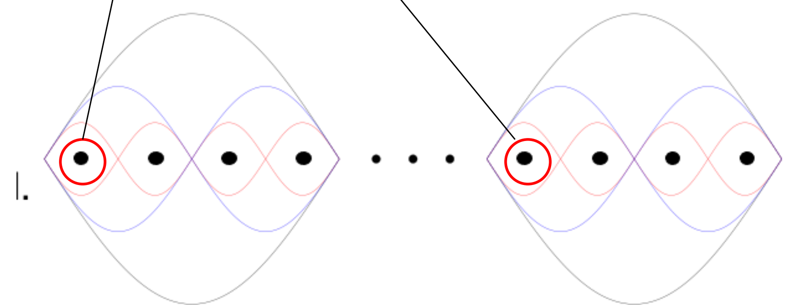
Preinjector Frequency set up:

- C_RCS=3846.17 m
- tau_RCS=12.83 us
- 24/tau_RCS=1870.696 kHz (laser rep. frequency *M)

- When M=3; laser bunch spaceing= **1623.95 ns**

All preinjector frequency is N/M*1870.696kHz : M, N are integer.

- The lowest RF freq of preinjector =63*1870.696kHz =**117.85 MHz**
- Sub-harmonic freq buncher=316*1870.696=**591.14 MHz**
- Linac freq=1527*1870.696 kHz=**2856.5538 MHz**
- Dechirp freq.=695*1870.696kHz=**1300.13 MHz**

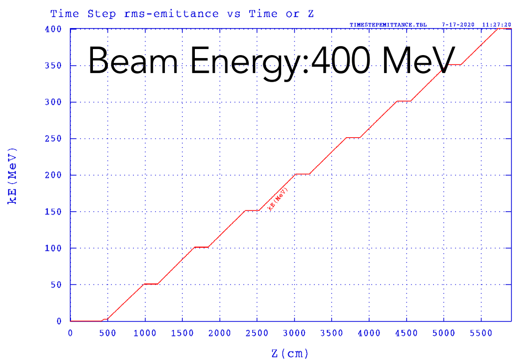


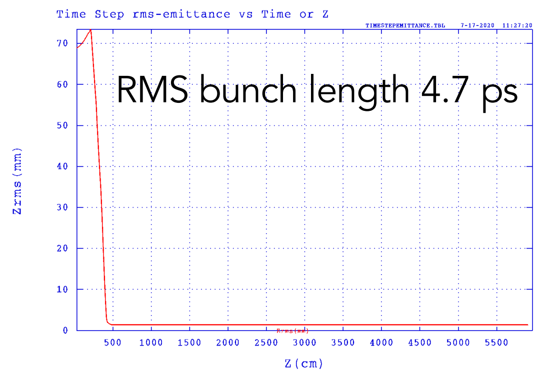
Frequency	Harmonic	Factorization
591.15 MHz	7584	$2^5 \times 3 \times 79$
295.57 MHz	3792	$2^4 \times 3 \times 79$
147.79 MHz	1896	$2^3 \times 3 \times 79$

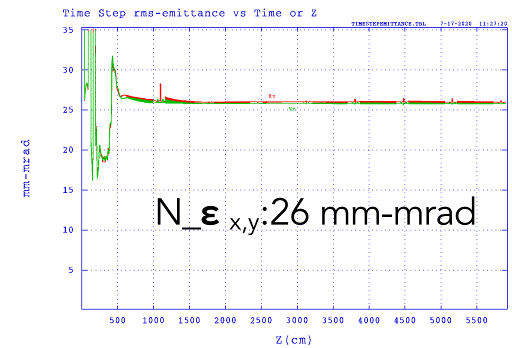
≈24

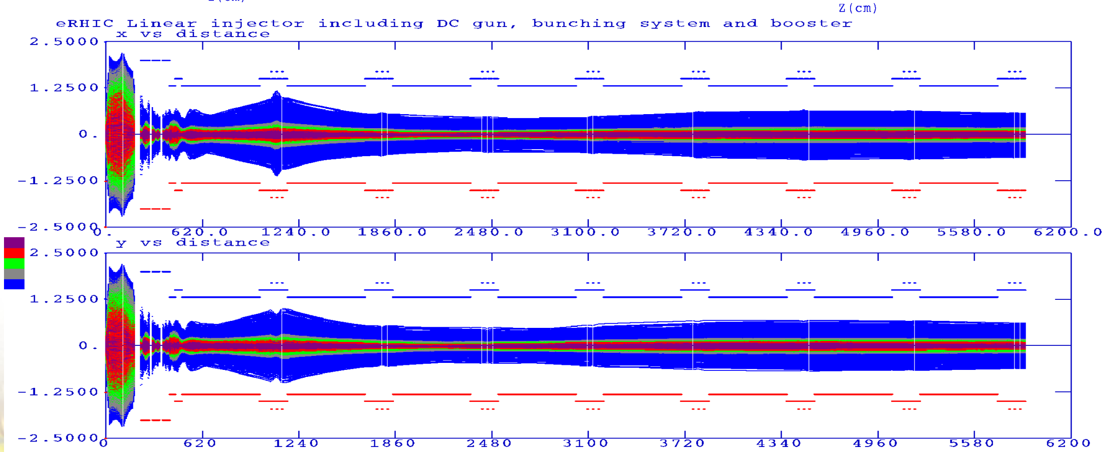
Setting $t_{laser} = N \frac{t_{RCS}}{24}$ makes all the phase relationships repeat every few RCS turns.

Pre-injector simulation



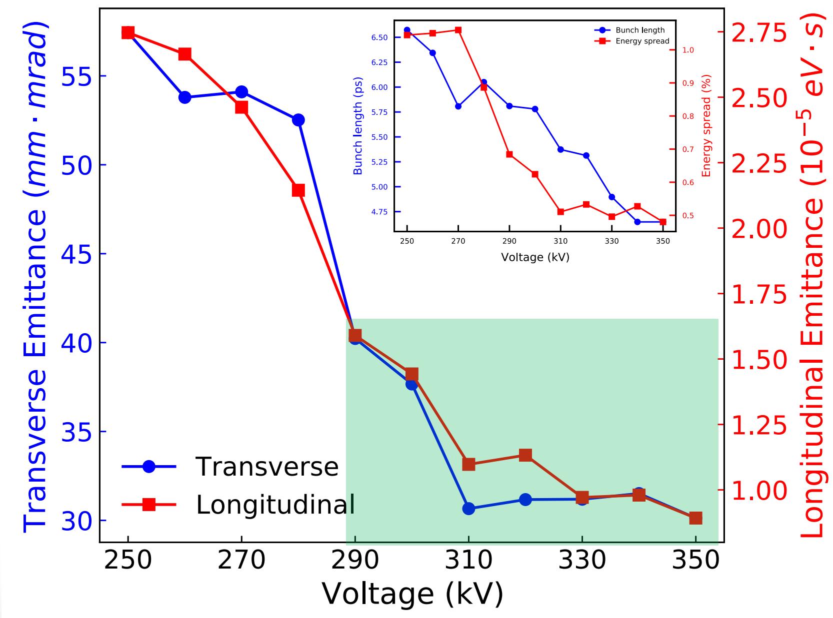


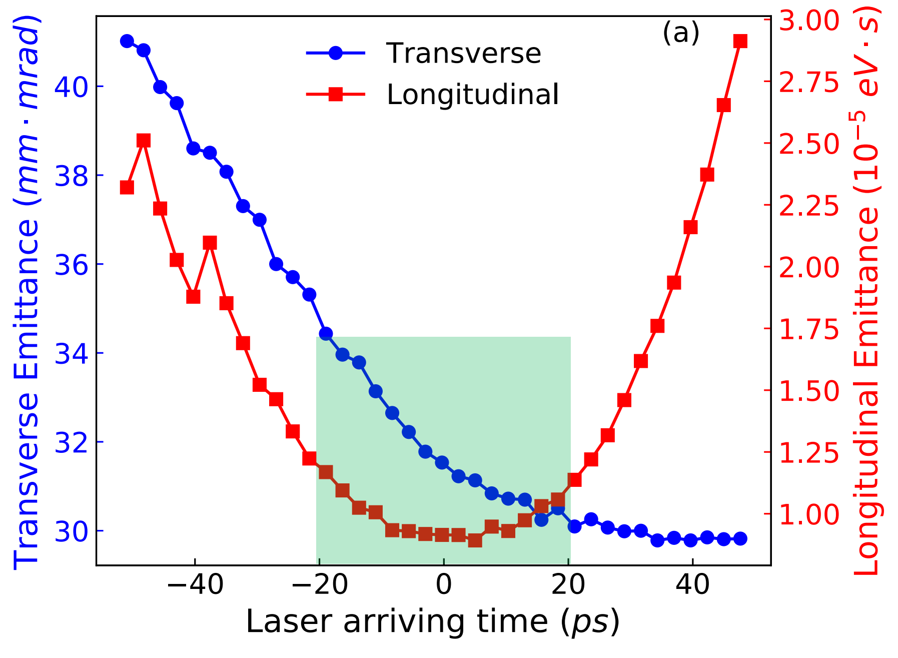




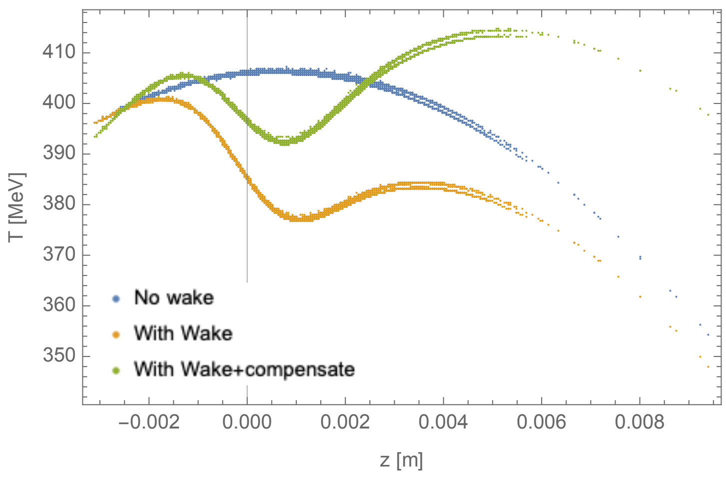
Simulation preformed using parmela 3.4
Beamline was designed for up to 10 nC

Gun voltage and laser jitter requirements





LINAC RF wake consideration



With Wake

```
RMS bunch length = 0.0014168 [m]= 0.0472595 [ps]
RMS dp/p = 0.0215621
Energy = 388.931 [MeV]
RMS longitudinal emittance = 0.0000305493[m]
```

Wake induced energy change:

Off crest

$$U(z) = U_0 + U_0' z + \frac{U_0'' z^2}{2} + \cdots$$

Increase voltage

Higher freq correction

With Wake+Skew Linac phase

```
RMS bunch length = 0.0014168 [m]= 0.0472595 [ps]
RMS dp/p = 0.0123214
Energy = 400.205 [MeV]
RMS longitudinal emittance = 0.000017457[m]
```

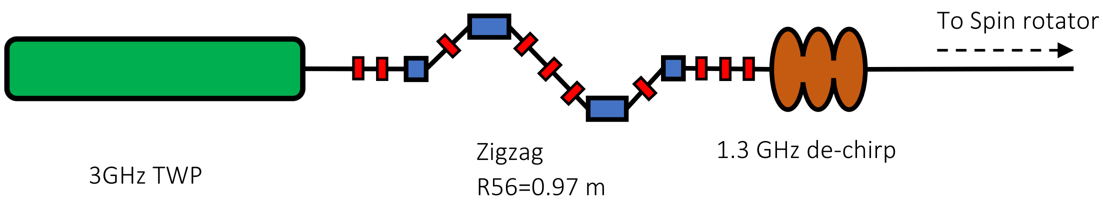
Required longitudinal emittance:
40ps x 0.025=0.00003 [m]

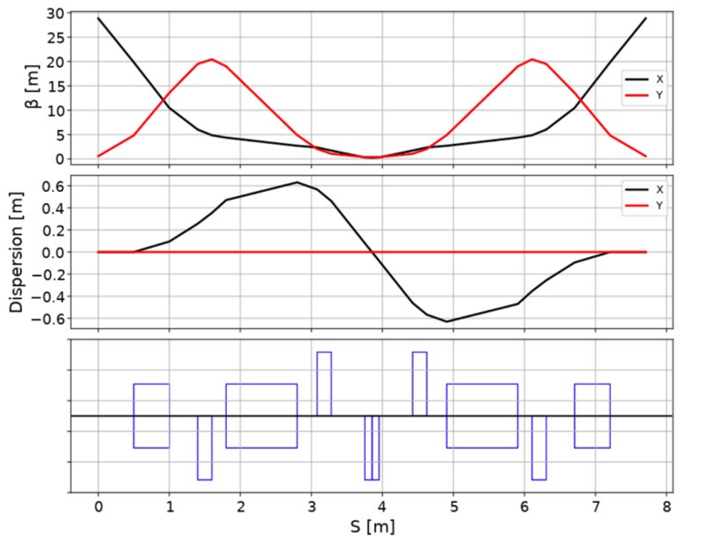
We need to increase Linac gradient for compensation:

```
field enhance factor =1.17411x 10 MV/m
```

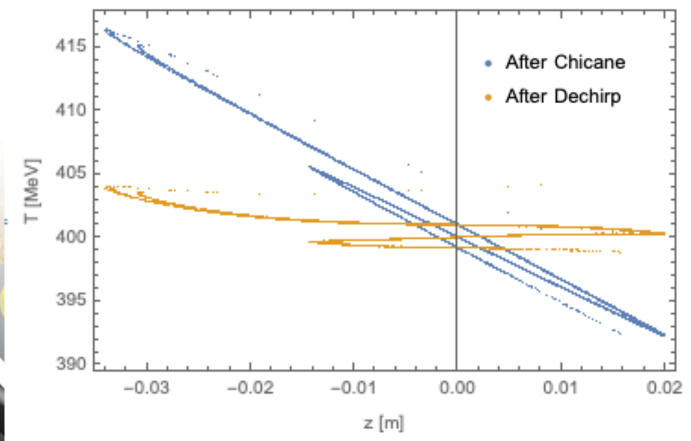
Longitudinal Phase space manipulation

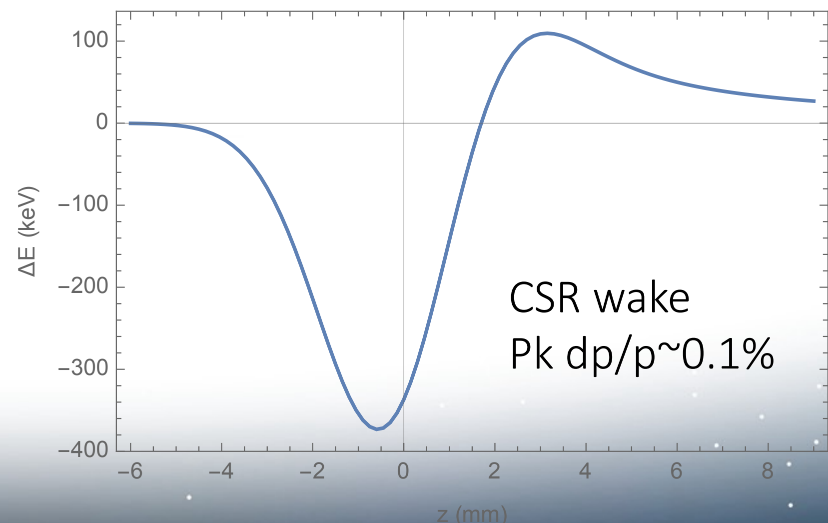
RF curvature dominated dp/p~ 0.56% vs RCS dp/p requirement <0.25%





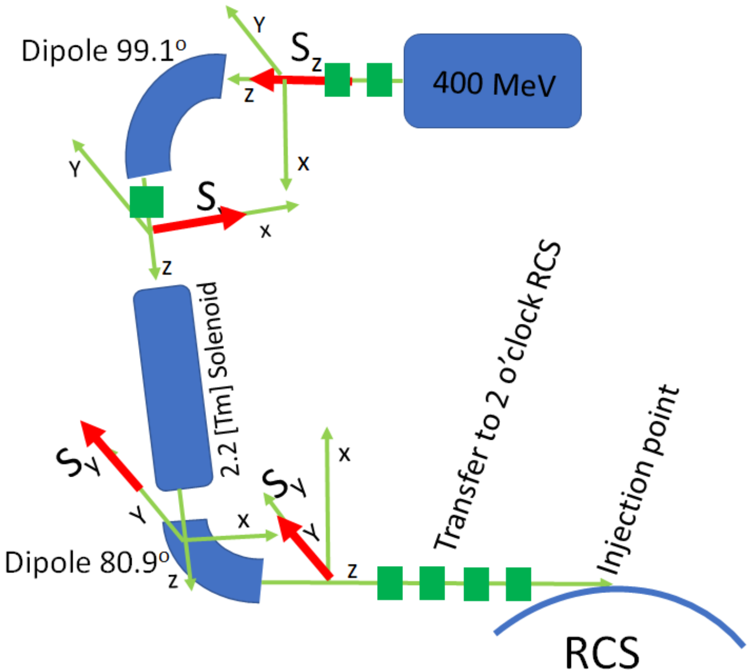

```
R56 =-0.97[m]
RMS length = 0.0120406[m]
RMS dp/p = 0.0017115
dechirp peak gradient = 15.5 [MV/m]
dechirp frequency = 1300 [MHz]
```

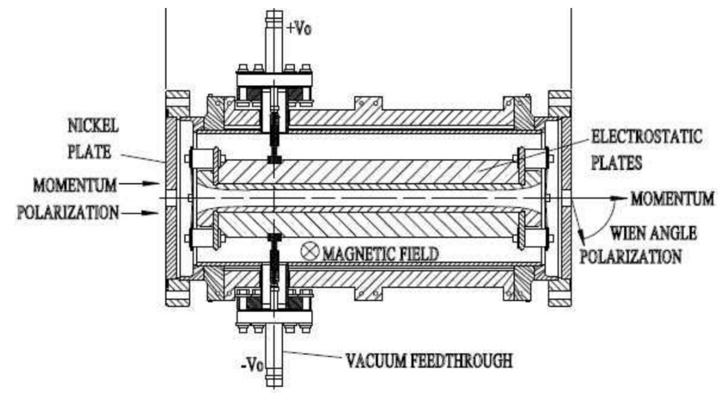


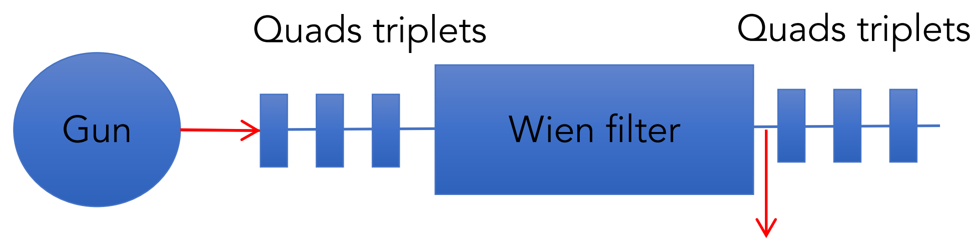


Spin rotator

Spin considerations in pre-injector

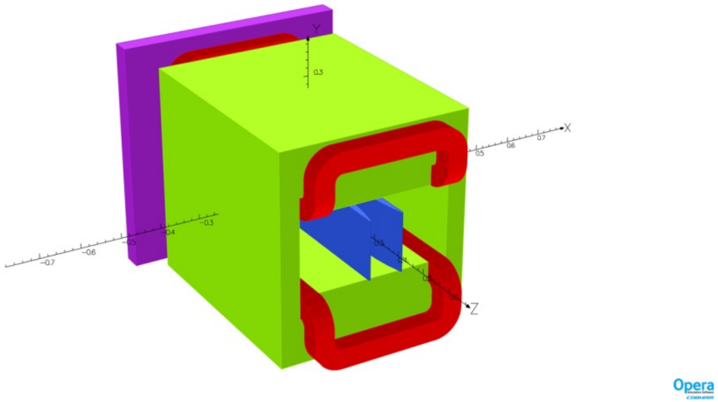


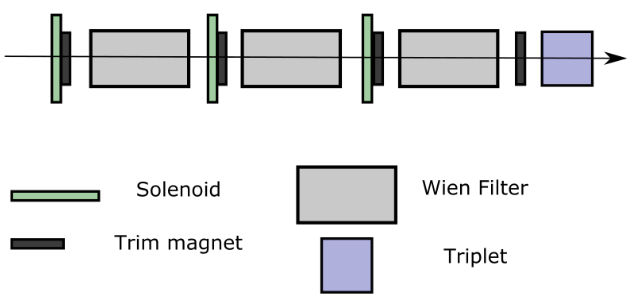




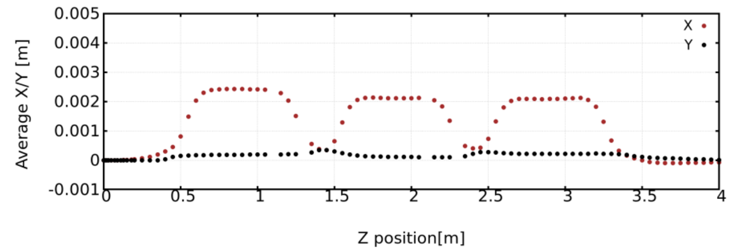
	Energy Range	Continuous solenoidal field in pre-injector	Energy acceptance
Dipole+solenoid	>100 MeV	Yes	Small
Wien filter	< 400 KeV	No	Large

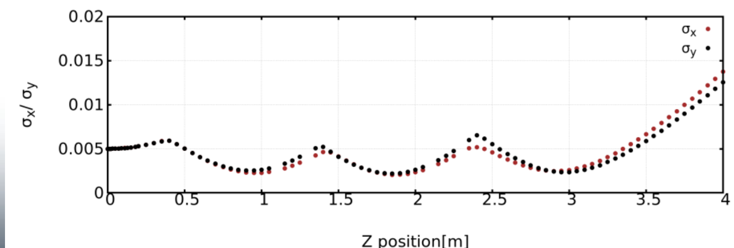
Backup: Wien filter





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



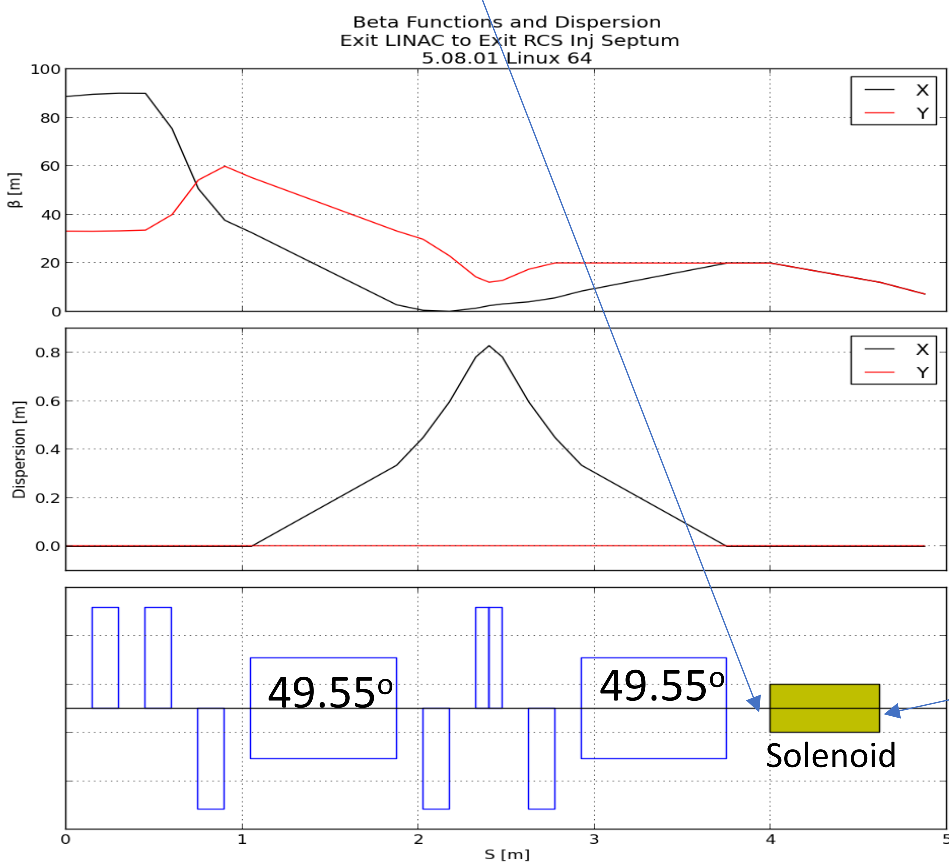


- Three-segment Wien filter has been studied to rotate electron spin by 90°
- 7 nC@350keV charge space charge is too high. WF needs R&D

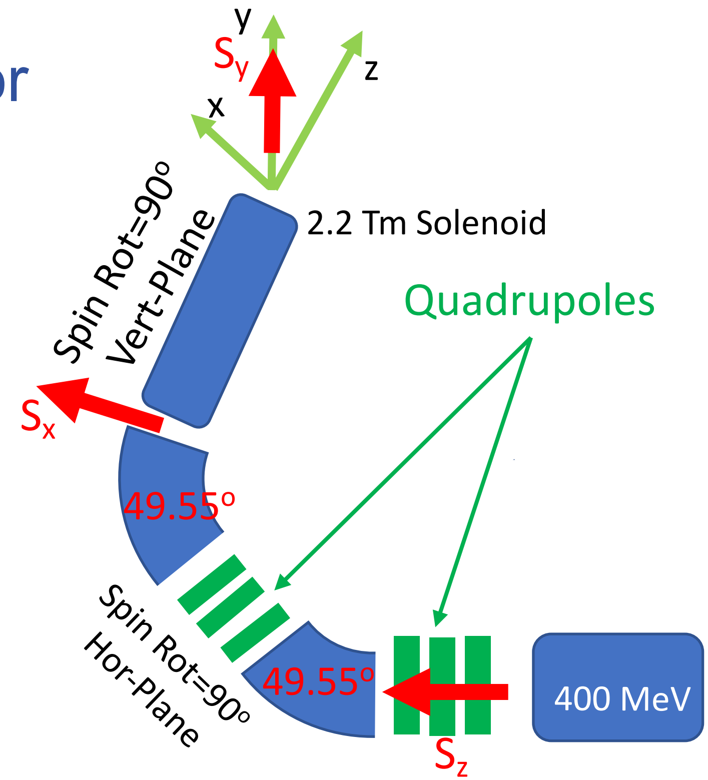
Beam Optics constrains on Spin Rotator

$\sigma_x = \sigma_y \quad \eta_x = 0 \quad \eta_y = 0$

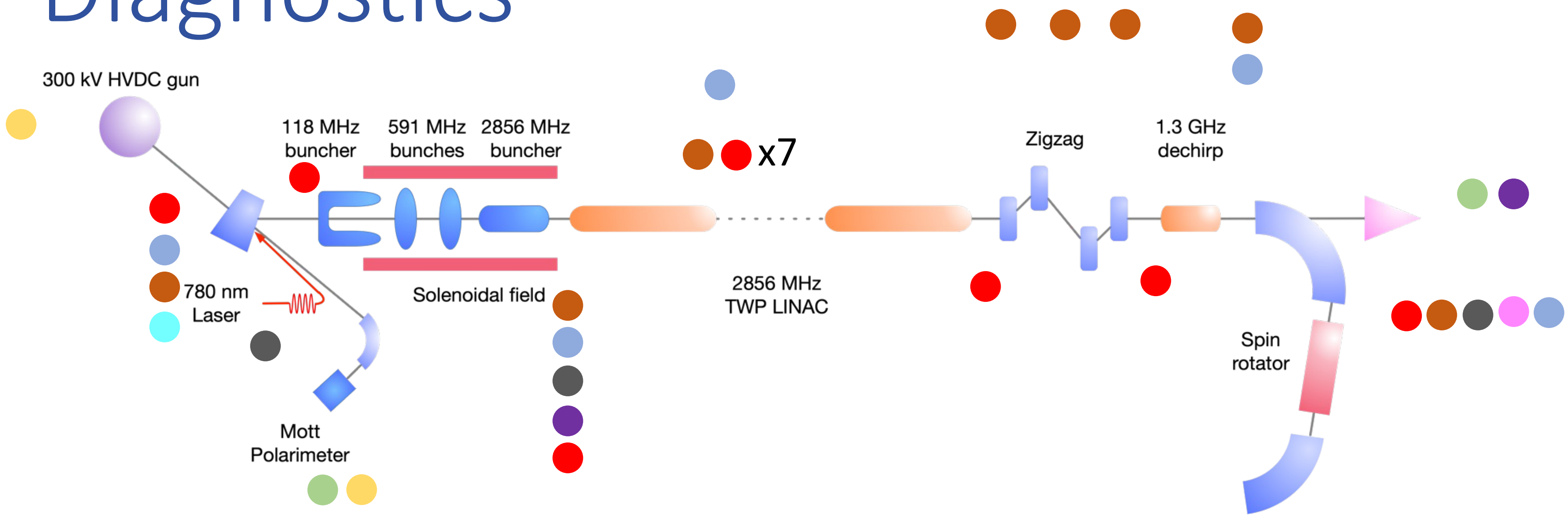
$\alpha_x = 0 \quad \alpha_y = 0$



Beam Uncoupled & Achromatic



Diagnostics

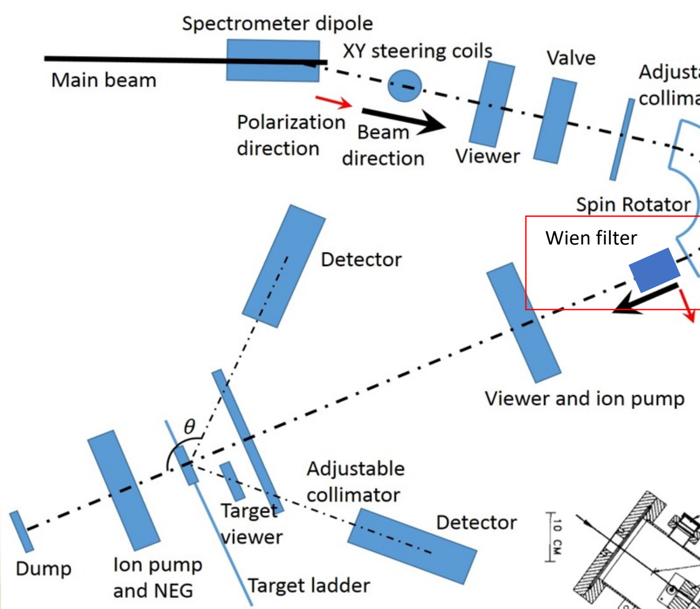


Bunch length: streak camera	purple	2
Faraday cup	green	2
Profile: YAG/OTR/WS	orange	12
Charge: ICT,FCT,WCM	light blue	6
Position: BPM	red	13
Emittance: Slit	cyan	1
Loss: BLM	dark grey	3
Spin: Mott	yellow	2
Energy spread: dipole	pink	1

Spin diagnostic beamline

- High voltage Mott polarimeter placed at gun diagnostic beamline where beam energy is 280-350 keV.
- Using bending and small Wien filter to tune the spin direction

Parameter name	value
Beam energy	280-350 keV
Beam bend degree by spin rotator	143°
Voltage of spin rotator	244.5 d/R kV
Scattering degree	136°

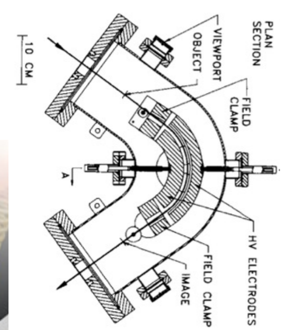


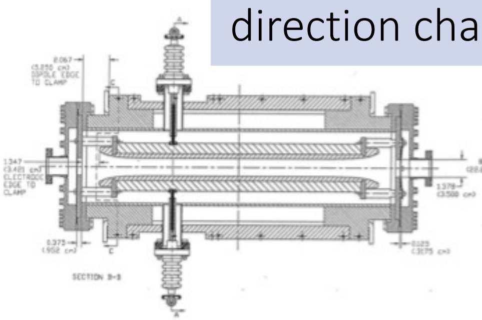
$$\frac{ZeG}{mc\beta}\int B_{\perp}dl$$ Spin rotation angle

$$\frac{Ze}{m\gamma c\beta}\int B_{\perp}dl$$ Velocity rotation angle

$G\gamma=0.0018$

The 1st dipole caused spin direction change is negligible.





Summary

- Polarized gun R&D
  - We have designed and commissioned a HVDC polarized electron gun to meet the EIC polarized electron beam requirement.
  - This gun employs various novel concepts, including a cathode cooling system which could be implemented in future high current electron sources.
  - The gun was conditioned up to 350 KV without any field emission and was consistently operated at 300 KV.
  - High bunch charge, up to 16 nC, beam was generated from bulk GaAs photocathodes using a 785 nm laser.
  - Gun performance, including operational lifetime, exceeds all EIC requirements. Lifetime experiments with up to 37.5 uA level average currents, with biased anode, show no observable QE decay over 15 hours.
  - The polarization measurement Mott polarimeter has been established.
  - SL-GaAs supply train is in much better shape compared to last year.
- Pre-injector design
  - We designed a preinjector for 7 nC bunch charge using 2856 MHz Linac
  - The Parmela simulation shows the beam can meet the EIC requirement.
  - Jitter, RF wake, CSR wake have been considered in the design
  - Diagnostics plan has been generated.
  - Ready to discuss with vendor and make it more mature.

Thanks !

Questions?

Back up

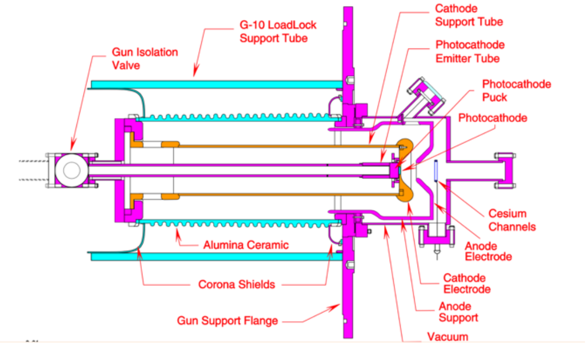
Overview polarized guns in the world

Laboratory	Voltage	Bunch charge	I_pk	I_avg
JLab[1]	100, 200kV	2 or 2.7pC	67~53mA	Up to 4mA
SLC[2]	120kV	8-16 nC	3 A	2uA
MAMI[3]	100kV	0.02 pC		50uA
Bonn-ELSA[4]	50kV	100 nC	100mA	5uA
MIT-BATES[5]	60kV	250 nC	10mA	20 or 120uA
Nagoya[6]	200kV	1.25 nC??	2A??	NA
NIKHEF[7]	100kV	2us	NA	0.04uA
EIC	300kV	7-16 nC	4.8 A*	3 uA, up to 76 uA

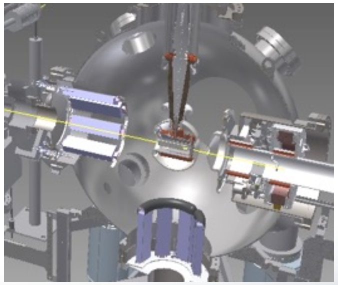
* 1.6 ns laser; 3.5-8 A; No charge limit up to 4.8 A

In operation
Shut down
EIC gun achieved

SLC PES 120 kV gun



- First load-locked gun used at an accelerator
- High bunch charge, low avg. current
- Four days to activate photocathode,



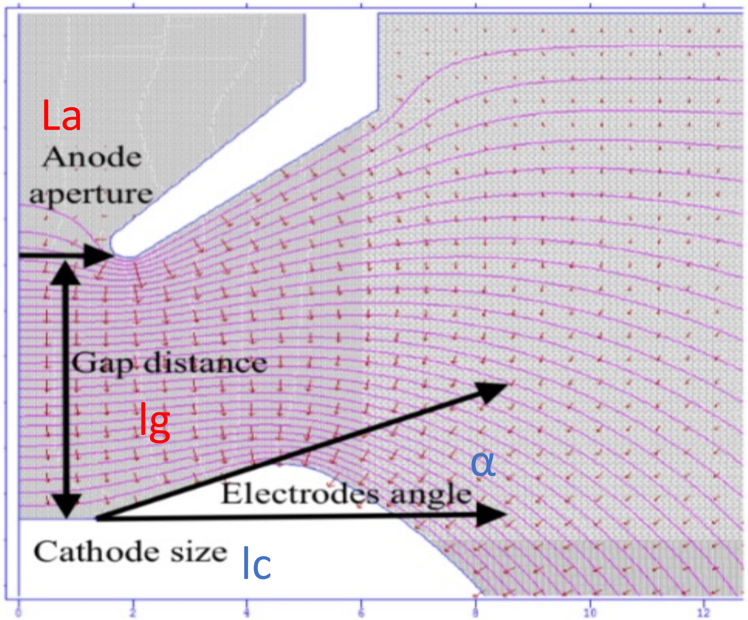
- Inverted gun, first cooled cathode set up
- High voltage
- Lifetime > month

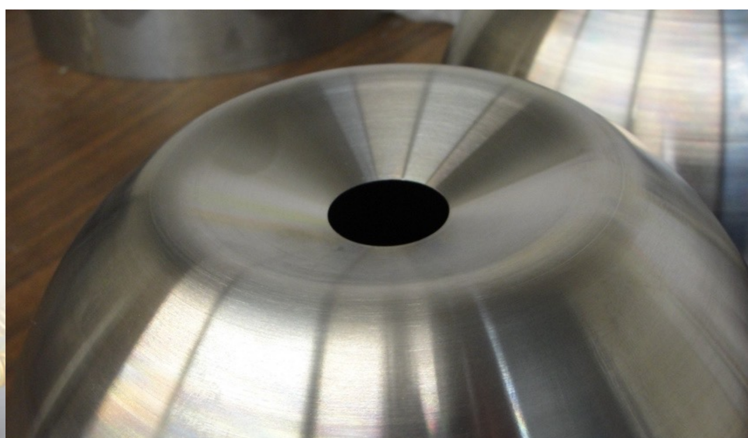
EIC polarized electron source development scope change

	ERL eRHIC (abandoned)	EIC
Bunch charge [nC]	5.3	5.5-7
Bunch length [ps]	1760	20-40
Energy spread dp/p	1e-3	2.5e-3
Frequency [Hz]	1.2 M	1 (8 bunches)
Energy [MeV]	20	400
Average Current	6.3 mA	28-56 nA
Polarization [%]	> 85%	

- By change the scope, our planned beam dump , differential pumping, laser and MPS are not available.
- Limited up to 76 uA average current>> EIC requirements.

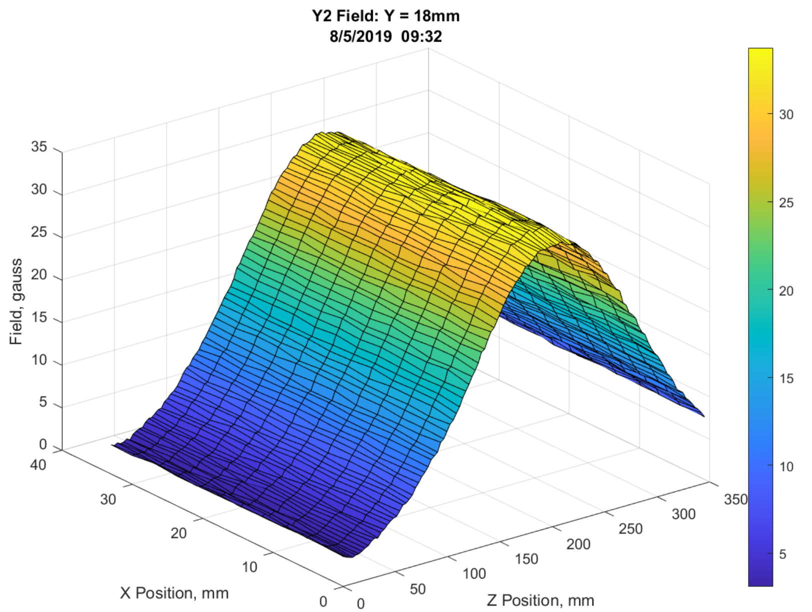
BNL Large Cathode Prototype Gun Parameters

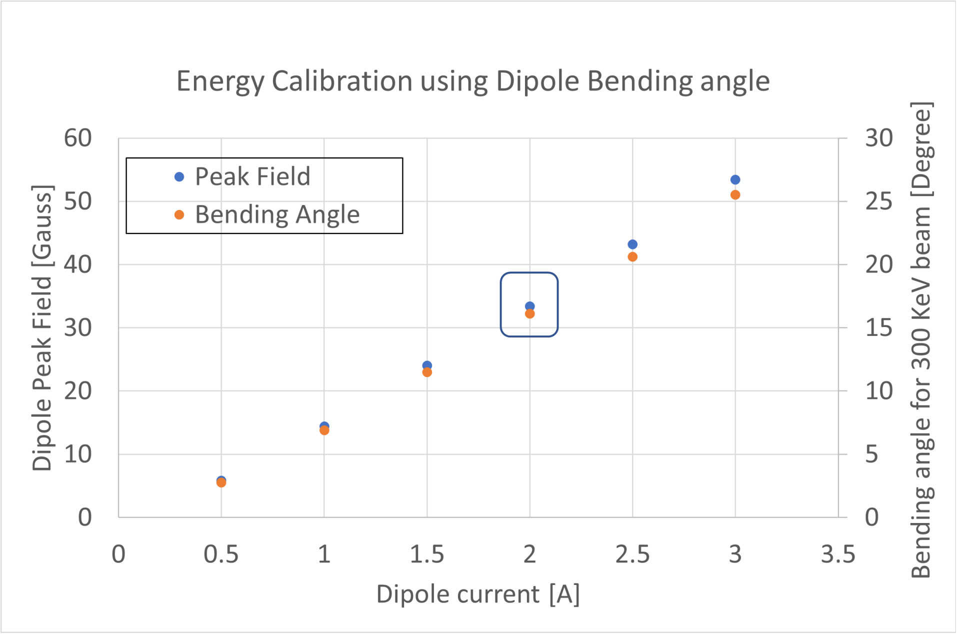




	Inverted gun
Ball diameter	20 cm
Chamber diameter	80 cm
Gap distance (lg)	5.7 cm
Voltage	350 kV
Cathode radius (lc)	1.3 cm
Electrodes angle (**α**)	22 degs
Cathode gradients	3.8 MV/m
Maximum gradient	<10 MV/m
Anode radius(la)	1.7 cm
Pumping speed	20000 L/s
Anode bias	3000 V
Peak Current	4 A
Charge	7 nC
Target emittance	3.4 mm-mrad

Beam energy calibration using Dipole

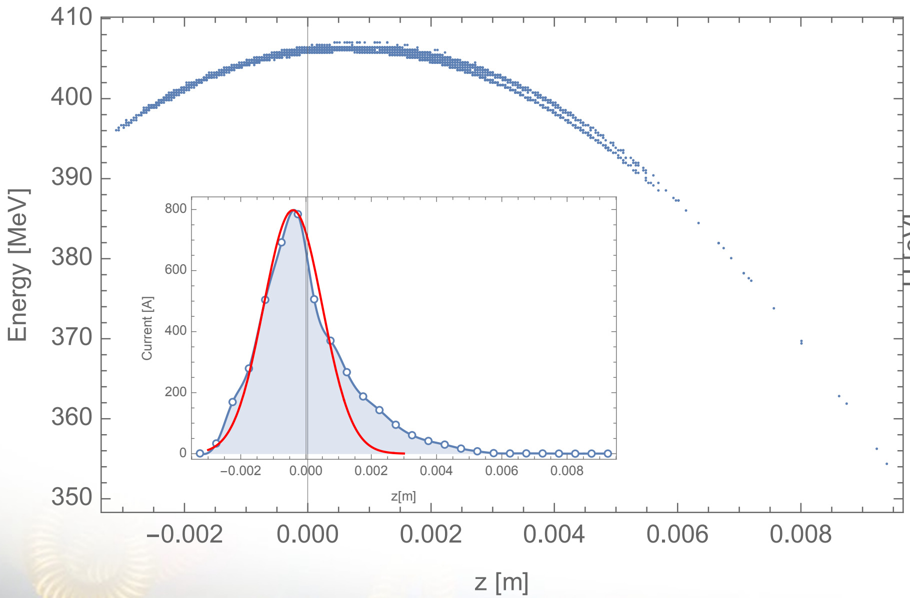


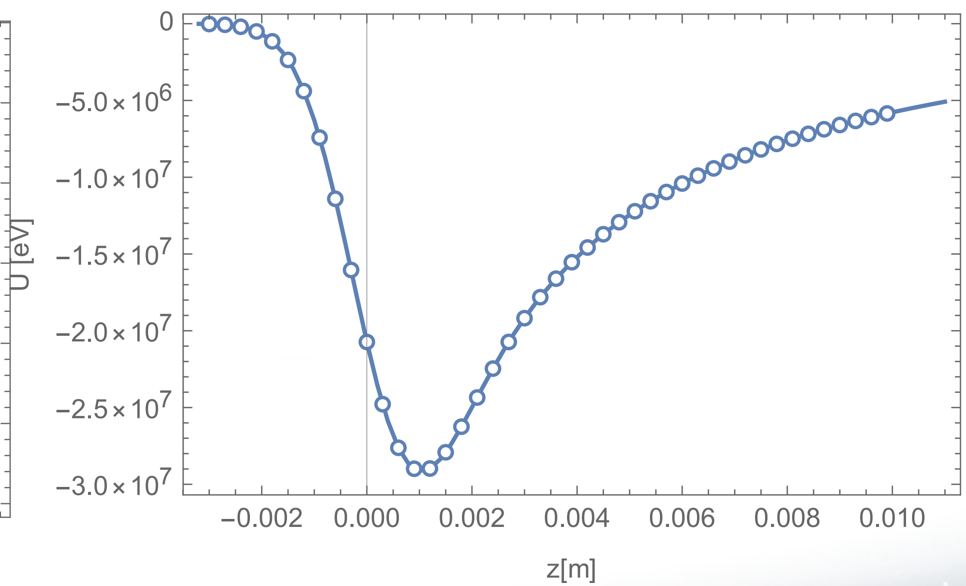


- Dipole field profile along beam path and peak field Vs applied current was measured
- Using the known bending angle (16 degrees) and measured field profile (using the current applied to the magnet during operation), the energy of the electron beam was calibrated.

2856MHz RF wake consideration

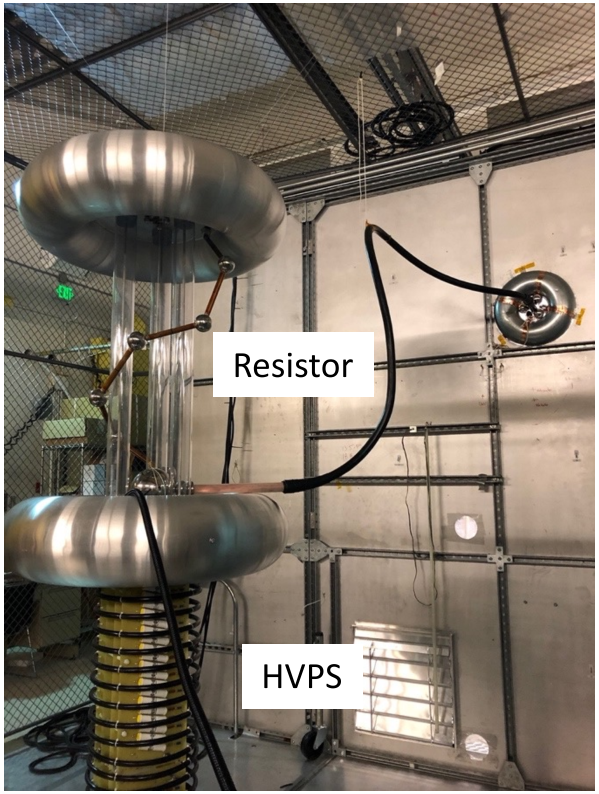
- The beam distribution from Parmela
- Fitted with Gaussian distribution. σ=0.9 mm

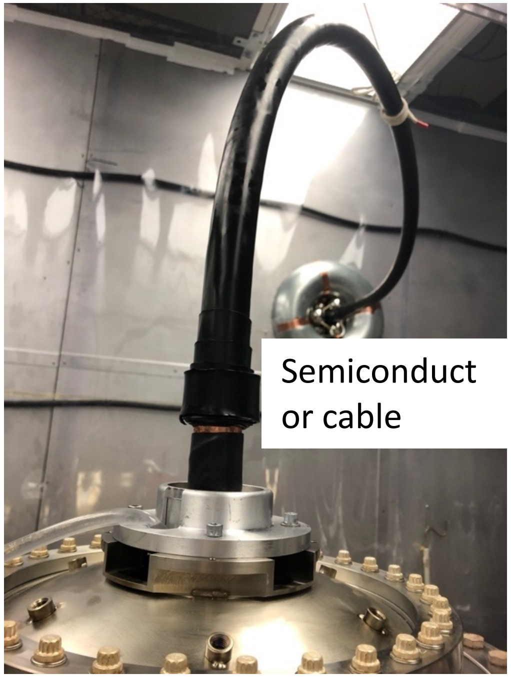




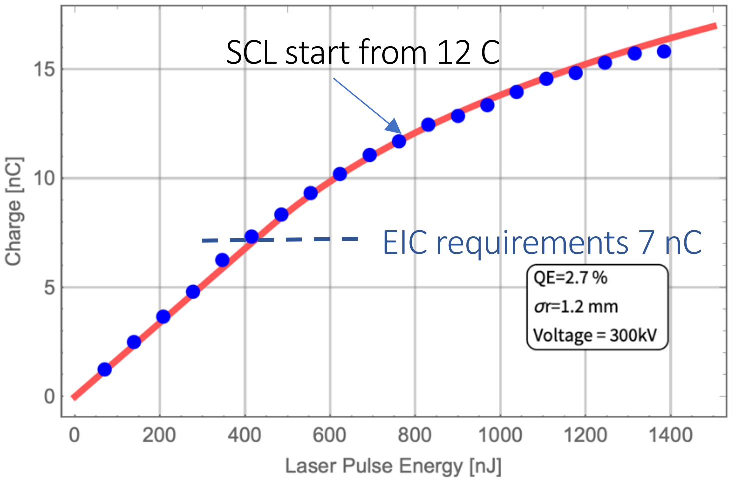
Power supply and HV cable

- 400 kV Power supply is SF6 free set up.
- PS is 5 meter away from the gun within a grounded cage.
- Resistors for gun conditioning and 460 ohm resistor for beam operation.
- Custom designed Semiconductor jacket to reduce the storage energy(50pF/ft, 46 Joules) into the DC gap if discharge happen

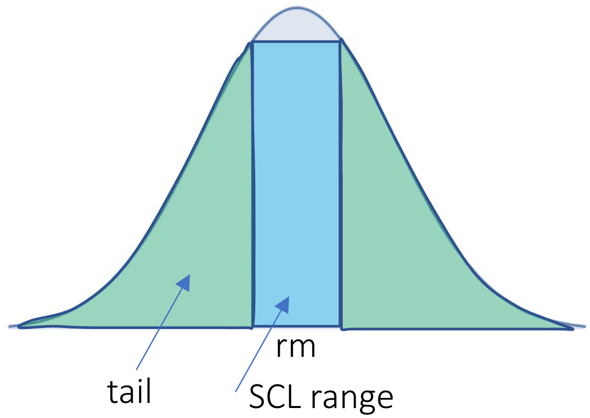




Space charge limit



$785 \pm 1.3\ nm$
FWHM 1.64 ns
Longitudinal flattop
Transverse Gaussian



A Gaussian radial distribution on the cathode,

$$\text{Surface charge density:} \Sigma(r) = \frac{Q_{bunch}}{2\,\pi\,\sigma_r} e^{-\frac{r^2}{2\sigma_r^2}}$$

$$Q_{emitted} = Q_{scl} + Q_{tail} = \pi r_m^2\, J_{2d} + QE\, \frac{e\, E_{laser}}{\hbar\omega} e^{-\frac{rm^2}{2\sigma_r^2}}$$

Pencil shape 2D space charge limit:

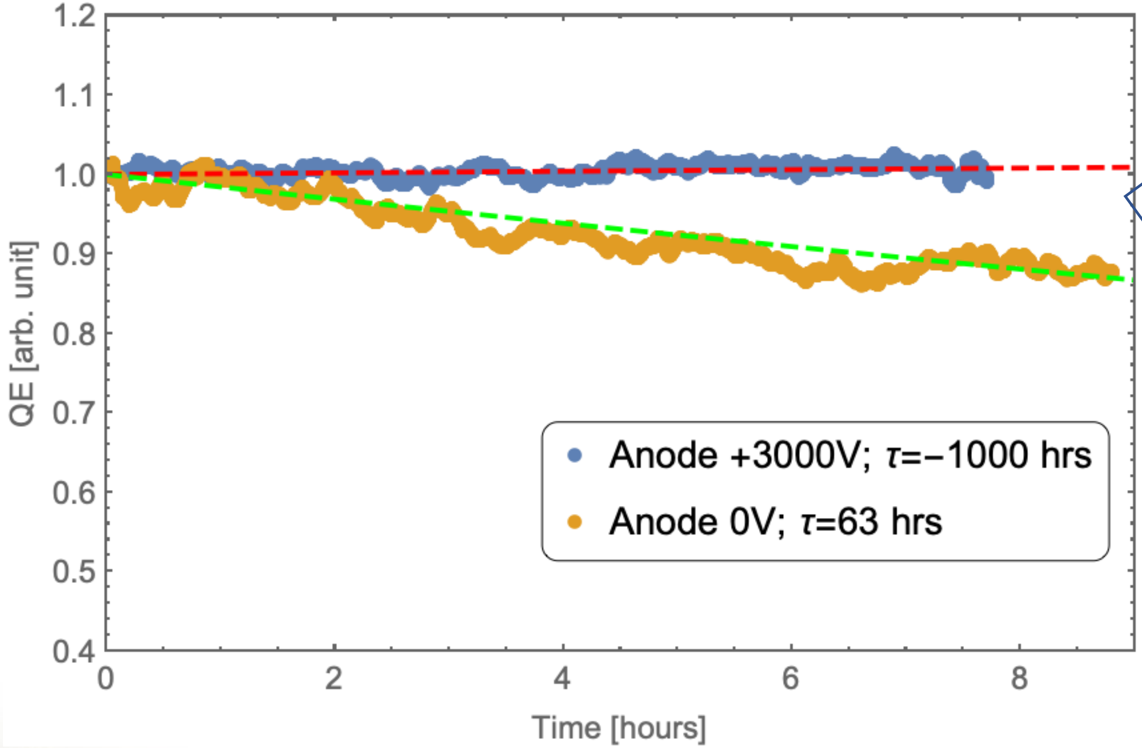
$$J_{2d} = 2.33 \times 10^{-6} V^{3/2}/d(1 + \frac{d}{4r})$$

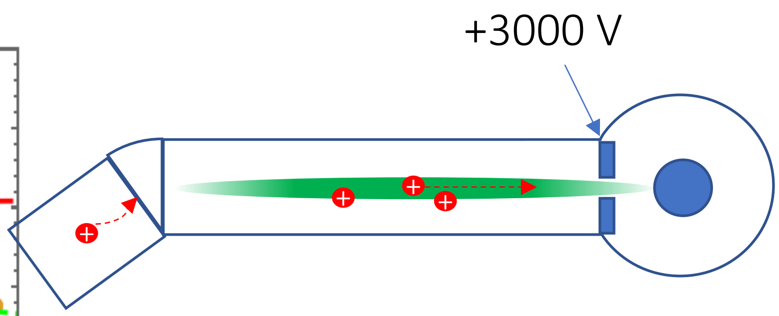
If rm>0, then space charge limit happen

Beam image before the dump

Cathode activation size is 6 mm in diameter, while our cathode size is 2.6 cm. We can get higher charge if have large activation area.

Cathode lifetime with and without anode bias



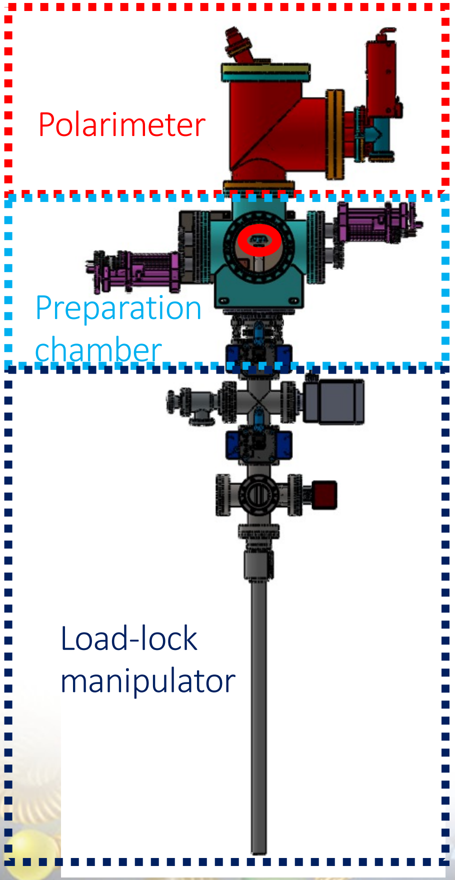


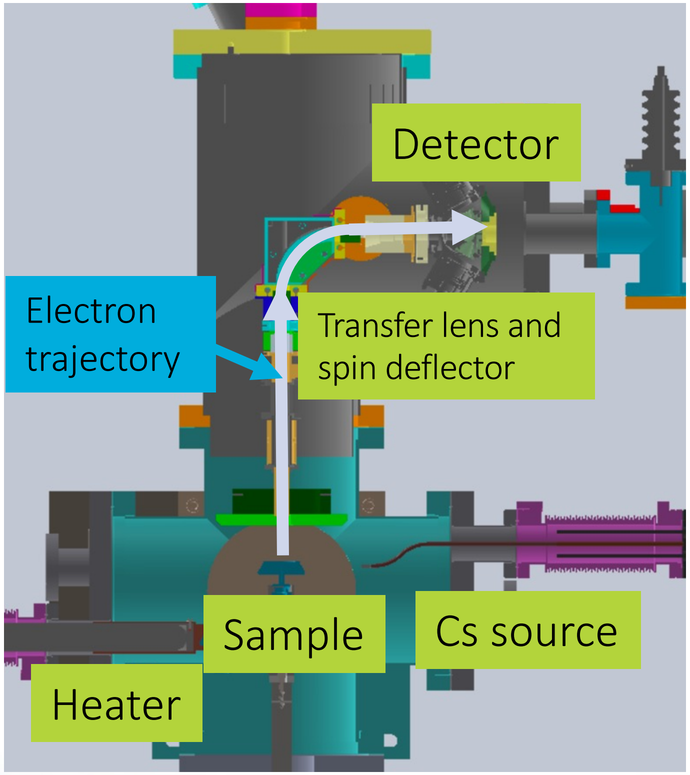
- Our 16 deg bending eliminate the ions from FC.
- The ions from gun to 1st bend can be blocked by biased anode.

- Using 7.5 nC bunch charge polarized beam, 5000 pulses/s ~37.5 uA;
- With anode bias, we didn't observe QE drop.
- Without anode bias 1/e lifetime is 63 hrs. Dominated by the outgassing from FC.
- Charge from 7 hours test= 33 weeks of EIC operation

Established polarization measurement

It is for GaAs polarization measurement, not suitable for gun beam.





The system at 966 has 3 parts:

- Load-lock manipulator (BNL)
- Preparation chamber (BNL)
- Polarimeter (*Specs*)

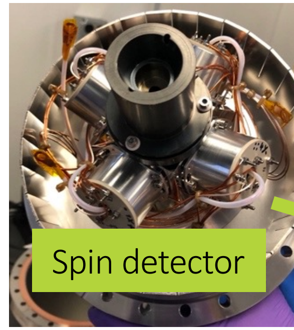
•Feature of the system:

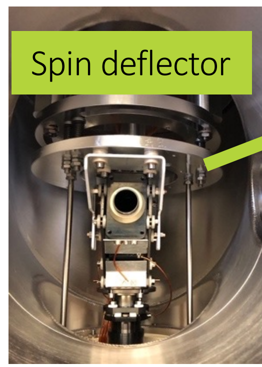
- The load-lock system is matched to the polarized gun load-lock.
- Use the same cathode puck as the gun puck.
- The Mott system is light source II beamline compatible.

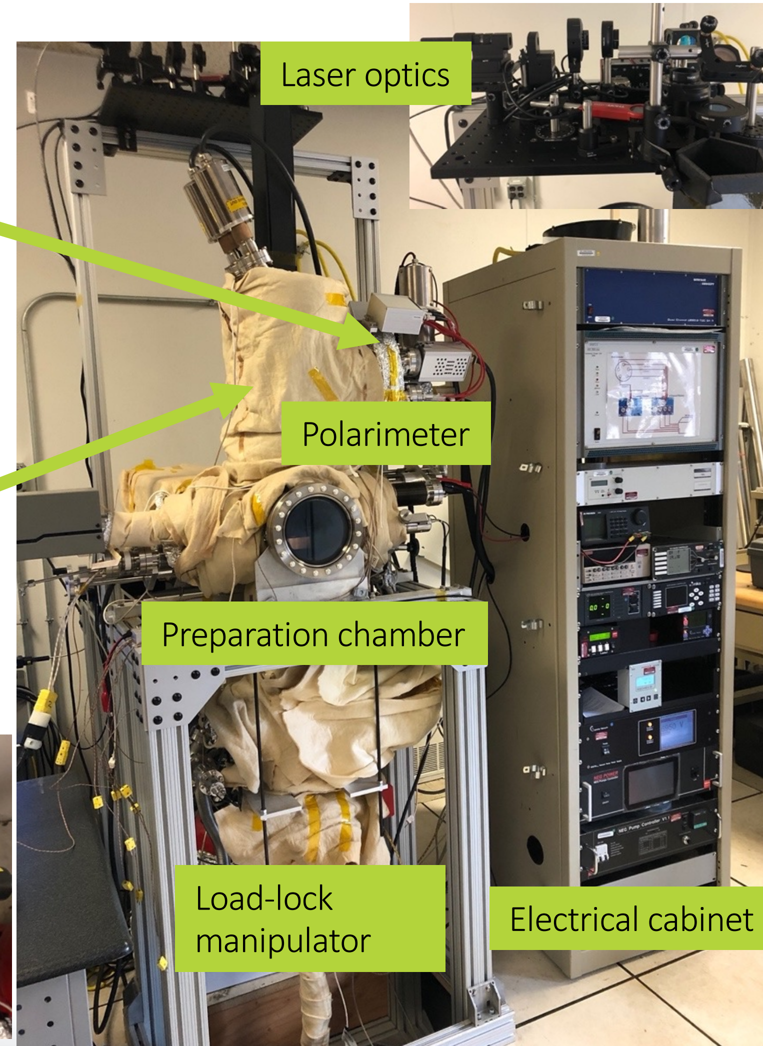
Specs Mott polarimeter system Overview

@Wei

- Laser: 450 -850 nm, 1-5 mW/nm
- Voltage: up to 25 kV
- Vacuum: low 10^{-11} torr
- Photocurrent: <1 mA

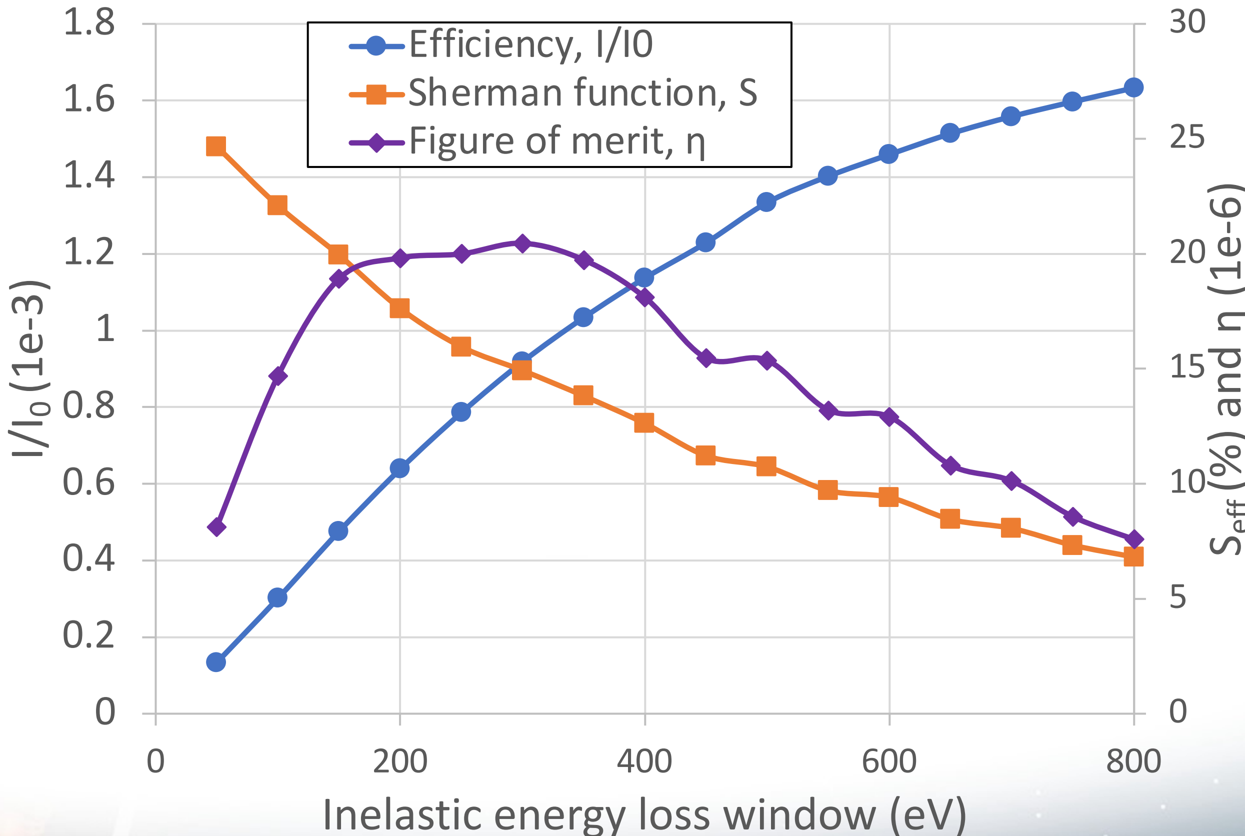






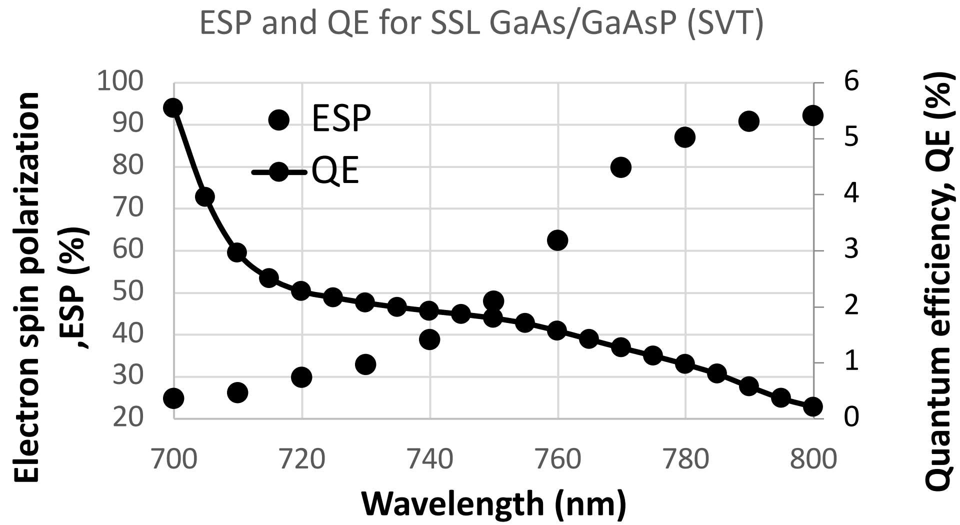
Polarimeter performance

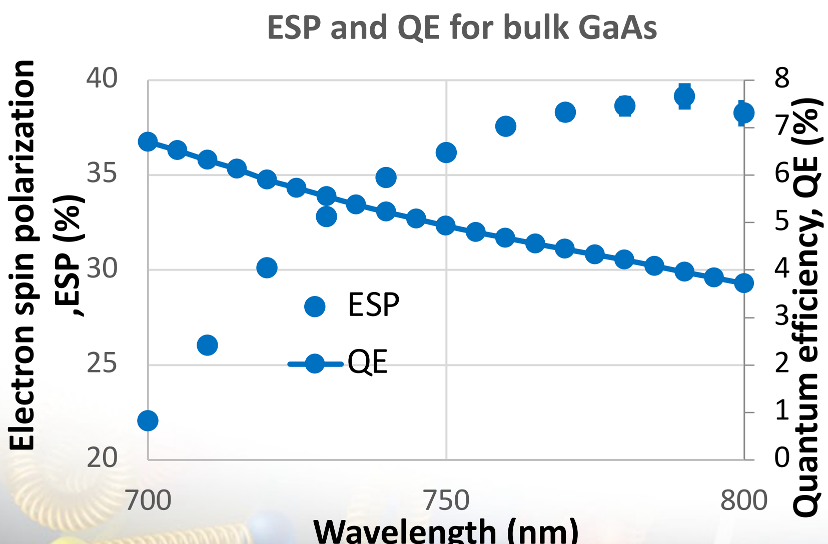
- The initial energy of electron from photocathode is 200 eV
- The Sherman function is almost linear for ΔE<200 eV
- The theoretical effective Sherman function is 0.27

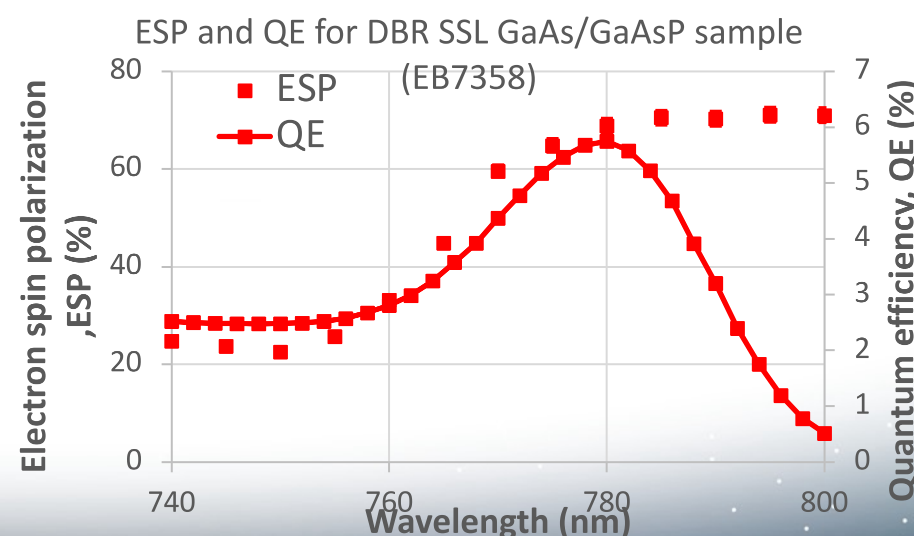


Measured ESP

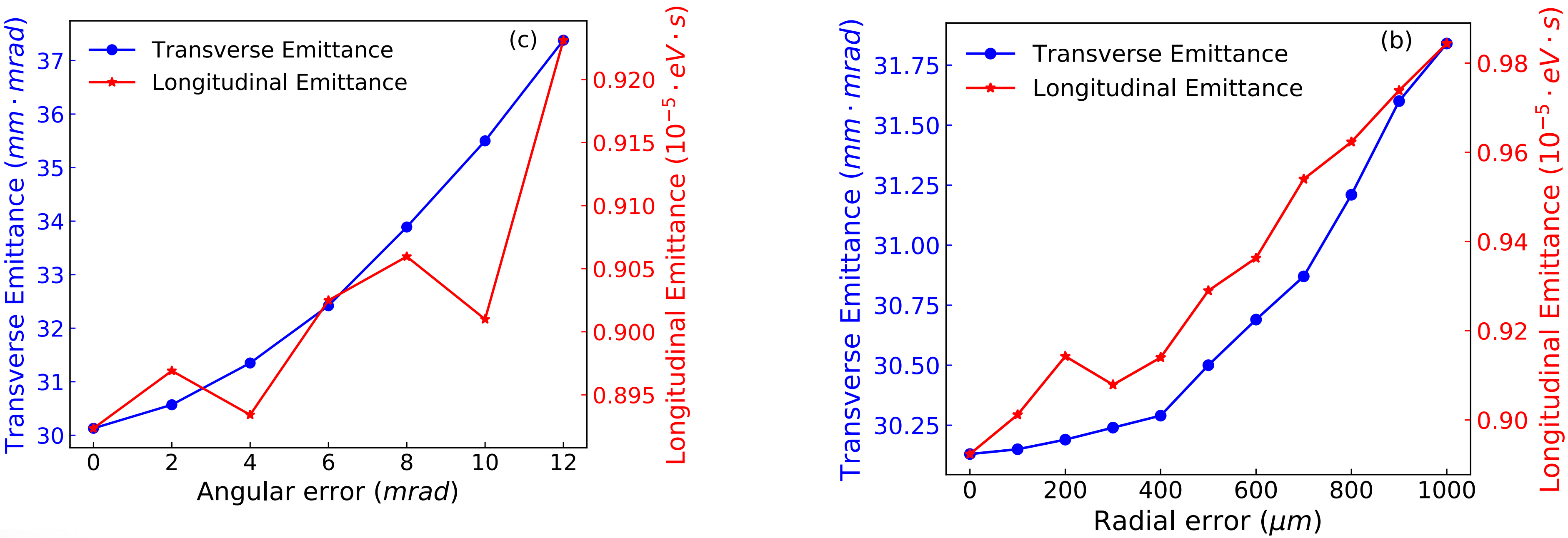
- Several GaAs samples have been measured.
- Reasonable ESP for bulk GaAs and SSL GaAs/GaAsP photocathodes are obtained with error < 2% of the value





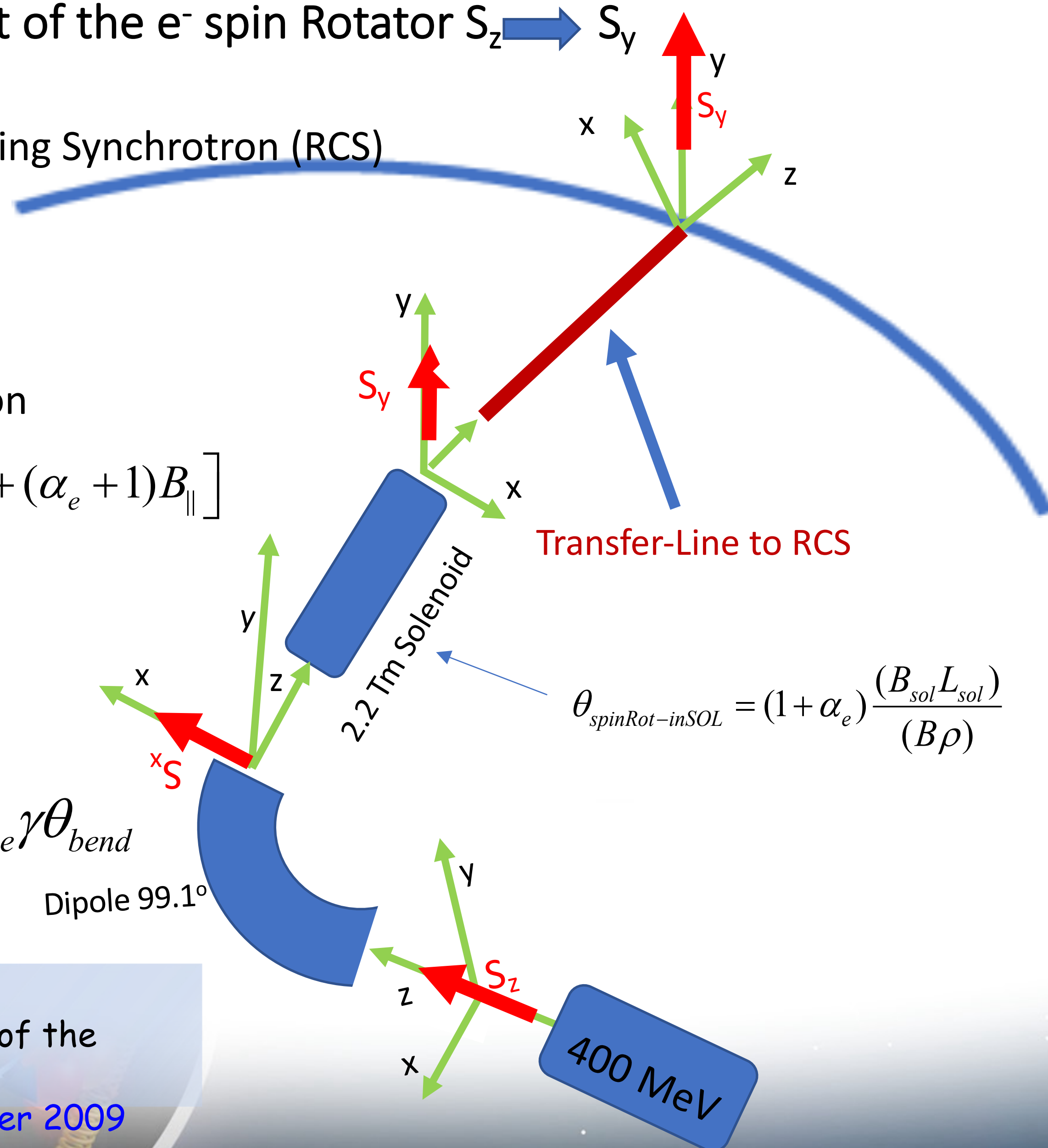


Linac error study



The Spin Rotator

Schematic layout of the e⁻ spin Rotator $S_z \rightarrow S_y$



BMT equation

$$\frac{d\vec{S}}{dt} = \frac{e}{m\gamma c}\left[(\alpha_e\gamma + 1)B_\perp + (\alpha_e + 1)B_\parallel\right]$$

$\alpha_e = 0.00115965$

$$\theta_{spinRot-inSOL} = (1+\alpha_e)\frac{(B_{sol}L_{sol})}{(B\rho)}$$

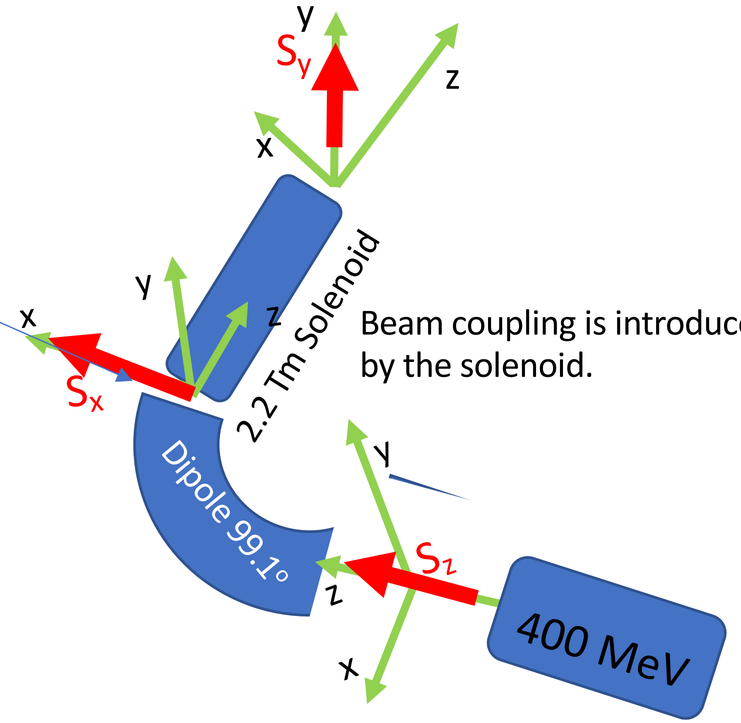
$$\theta_{spinRot-inDip} = \alpha_e \gamma \theta_{bend}$$

Ken Moffeit, SLAC 2009
Linear Collider Workshop of the Americas
29 September to 3 October 2009

Beam Optics constrains:

To avoid beam coupling by solenoid:

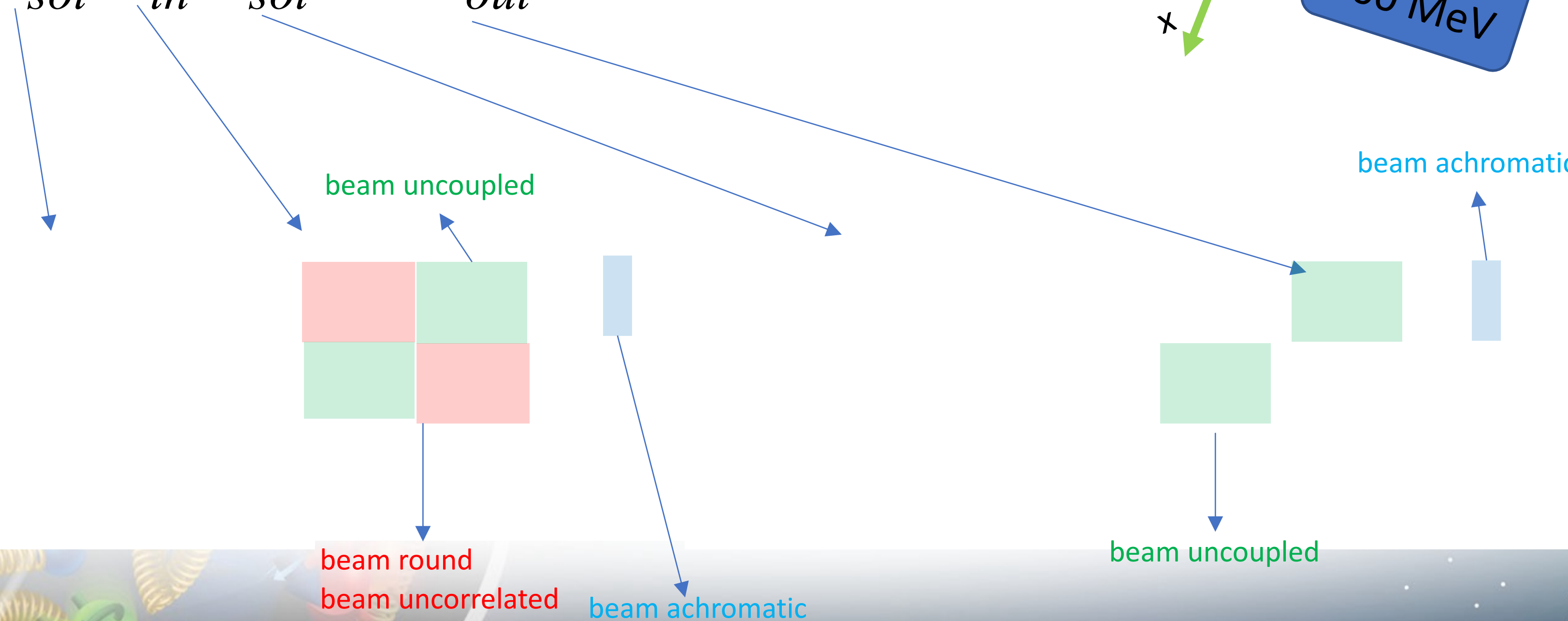
Round and achromatic beam at solenoid entrance



Beam coupling is introduced by the solenoid.

"Round" and achromatic Beam Transfer in Solenoid

$$R_{sol}\sigma_{in}R_{sol}^{T} = \sigma_{out}$$



Longitudinal Phase space manipulation

RF curvature dominated dp/p~ 0.56% vs RCS dp/p requirement <0.25%

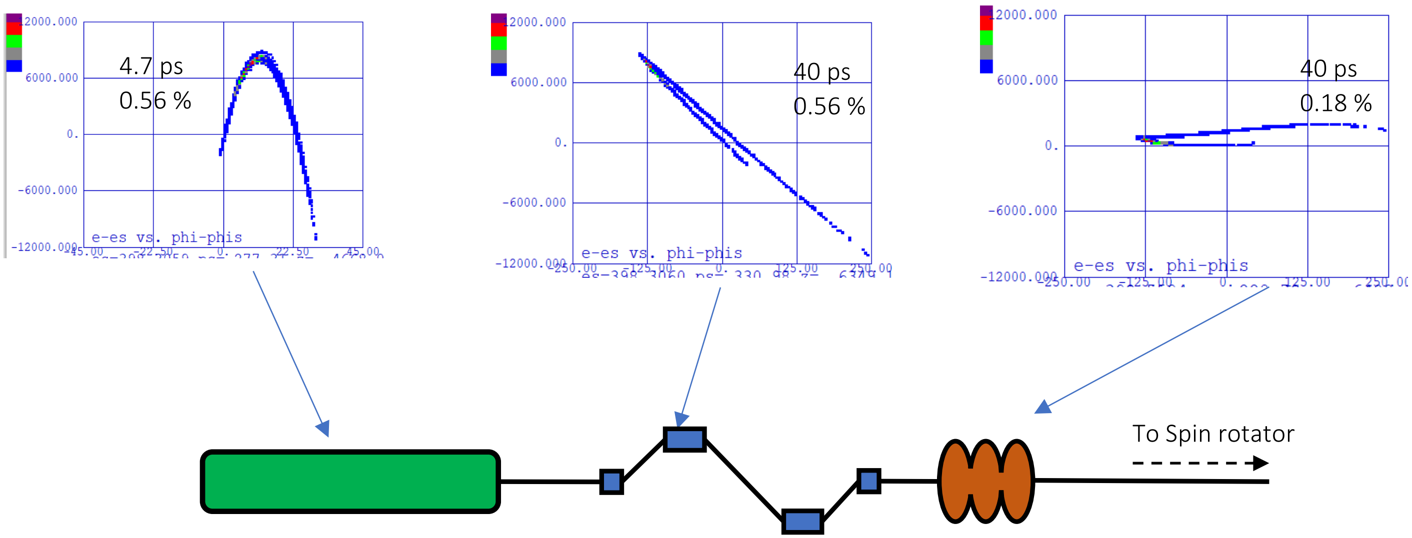


Table 1: Cavity Design Parameters

Parameter	Unit	Value
Operating frequency	MHz	1300
Particle velocity	relative	1.0
Nominal gradient E_0T	$\frac{MV}{m}$	12.5
Maximal gradient E_0T	$\frac{MV}{m}$	14.0
Nominal energy gain	MeV	20.18
Maximal surface field	$\frac{MV}{m}$	40.0
Maximal RF pulse power	MW	8.6
Maximal RF pulse length	μks	900
Nominal repetition rate	Hz	5
Aperture diameter	mm	30.0
Number of periods		14
Required Q-factor	at $20C^o$	20100
Operating temperature	C^o	≈ 44
Residual gas pressure	$Torr$	$\leq 10^{-7}$

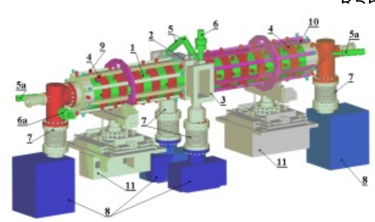
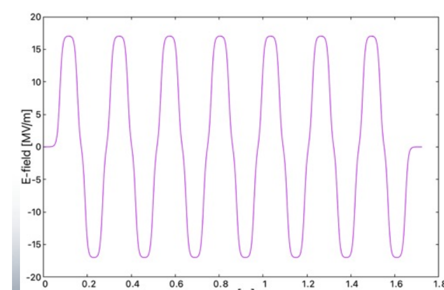


Figure 1: Scheme of the booster cavity. 1 - regular cells, 2 - RF coupler cell, 3 - RF input flanges, 4 -RF probes, 5 - photo multipliers, 5a - reserve photo multipliers, 6 - vacuum gauge, 6a- reserve vacuum gauge, 7 - pumping tubes with bellows, 8 - ion pumps, 9 - internal cooling circuit outlets, 10 - outer cooling circuit, 11 - support and adjustment.



Electron-Ion Collider