High Current Polarized Electron Gun for eRHIC

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Motivation

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

E.R.H.I.C. Parameters

<table>
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<tbody>
<tr>
<td>Energy, GeV</td>
<td>50-250</td>
<td>5-21</td>
</tr>
<tr>
<td>Bunch charge, nC</td>
<td>32</td>
<td>5.3</td>
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<tr>
<td>Beam current, mA</td>
<td>415</td>
<td>50</td>
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<tr>
<td>Rms nor. Emittance, µm</td>
<td>0.18</td>
<td>20</td>
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<tr>
<td>Polarization,%</td>
<td>70</td>
<td>80</td>
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<tr>
<td>Luminosity, cm⁻²s⁻¹</td>
<td>1.5X10³⁴</td>
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What is the prior state of the art?

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

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

What we need?
High average current: 50mA; High Bunch charge: 5.3nC; Long lifetime

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

Long operation lifetime:
Funneling concept: 20 GaAs cathodes
Careful beam optics design: Reduce outgassing due to beam loss
What is the objective charge lifetime?

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

Current state-of-the-art single cathode charge lifetime: 1000C @ 2.5mA
What we want to demonstrate?

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

- Fresh Cathode Load Lock
- Gun Laser System table, (Laser Lab not Shown)
- Cathode Regeneration Forest
- 250 KV Feed through
- Cathode Prep.Chamber (Grand Central)
- Extreme vacuum chamber
- Cathode Transport Line
- Cathode Exchange Chamber
Beam dynamics design

CST particle studio 3D beam dynamics study.

• Requirements:
  1. Keep the beam far away from the beam pipe
  2. Minimize the beam emittance
  3. Focusing the beam into collection through the hole
Single particle tracking shows:
• The integrated field is adjusted to bend the 220keV electrons by 29°
• With quadrupole corrections: \(X'/Y' = 8.7\text{mrad}/9.8\text{mrad}\) at exit of the gun
Beam dynamics

Particles tracking with SC on diagnostic:
- Divergence angle: \( X'/Y' = 23.6 \text{mrad} / 25.1 \text{mrad} \)
- Beam profile: \( X/Y = 15.0 \text{mm} / 15.2 \text{mm} \)
- \( \varepsilon_{n,x} / \varepsilon_{n,y} = 17 \text{mm mrad} / 14.9 \text{mm-mrad} \)
- Energy spread = 8keV (97% particle)
PIC beam tracking

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

Max field: 660G
Integral: 0.260 T-cm

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

Extra shielding

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Static Dipole Magnets

• To preserve the longitudinal direction of electron spin polarization, we designed compensated dogleg trajectories in the beam’s funnelling system encompassing fixed bending fields generated by 20 dipole magnets, and a rotating bending field generated by the magnetic combiner.
Anode assembly and combiner drift tube
Beam Combiner

- Bending the beam by dipole
- Equalize the focusing by quadrupole
- Parameters:
  - $I(t) = I_{od} \cos(\omega t + \phi)$ where $I_{od} = 70.7\, \text{A}$
  - $I(t) = I_{oq} \cos^2(\omega t + \phi)$ where $I_{oq} = 1.54\, \text{A}$
  - $B(0,0,0) = 25.04\, \text{G}$
  - $\text{Freq} = 470\, \text{kHz}$
  - Bending angle = 29 degrees

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Vacuum design

Transfer chamber: NEG 1500l/s
Design vacuum: $10^{-12}$ torr scale
Test vacuum now: $8\times10^{-12}$ torr

Gun chamber: 8,000l/s
Design vacuum: $6\times10^{-13}$ torr
Test vacuum now: $<5\times10^{-12}$ torr

Combiner: 6000l/s
Design vacuum: $1\times10^{-11}$ torr

Exchange chamber: 4000l/s
Design vacuum: $1\times10^{-12}$ torr

Total: 20,000l/s

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

Gun vacuum vessel material:
Vacuum fired SS 316L ($2\times10^{-13}$ Torr L/cm$^2$ s)
Anode material:
Ti ($2\times10^{-15}$ Torr L/cm$^2$ s)

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

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Vacuum in cesiation chamber

Pressure Vs Time

- Ramping up the temperature to 150°C
- Degassing sample and Cs source
- Activating NEG’s
Beam diagnostics

Fast Current Transformer & Integrating Current Transformer

CCD Camera & lens
Virtual Resolution Target
Semitransparent mirror

Halo detector
Cathode preparation

![Graph showing Quantum Efficiency at 650 nm (%) vs Activation Time [s]. The graph highlights a 'Cesium Peak' and a 'Signal rise due to Oxygen deposition'.]
Gun
High voltage power supply

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

Cathode preparation chamber: about $5 \times 10^{-10}$ torr
Gun chamber: $6.8 \times 10^{-11}$ 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

1 sec
Two beams decay test

• The lifetime of combined beams was 1980s, slightly longer than single cathode lifetime 1520s (single beam test). It indicates QE was not reduced by funnelling.
• When first beam is unstable, the beam hit to beam pipe and caused outgassing, only the first cathode QE decay, second cathode didn’t affect by first one.
Summary

• Gun design includes vacuum, mechanism, beam optics, beam dump, beam instrumentations was done.
• 3D beam dynamics simulation was done.
• Good QE GaAs photocathode was activated.
• Gun fabricated, assembled and tested by industry.
• Two low current beams were combined.
• The 3Gohm resistor between gun and power supply limited our current and high voltage condition.
• Energy spread and the sextuple field of combiner make long beam shape on the YAG.
• At a few hundreds nano-amper current level, the test indicates #1 beam will not affect #2 cathode lifetime. No cathode cross talk observed.
• Current status: Initial beam test done, the system has been shipped to our laboratory for high-current tests.
• High current proof of principle test is scheduled in early next year.
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Thanks for your attention!
• With collector voltage higher than the primary electron energy spread the returned primary electron current does not exceed 0.1% of the primary electron beam current

• The penetration of the secondary and backscattered electrons into the beam pipe is completely eliminated