Science & Technology Facilities Council
ASTeC

An Electron source for PERLE

Tim Noakes (for Boris Militsyn)
STFC Daresbury Laboratory, UK

12 September 2017

Outline

- Injector specification
- Possible electron sources for PERLE injector
- Existing ERL injectors
  - ALICE ERL injector at STFC Daresbury Laboratory
- General concept for the PERLE injector
  - Beam generation
  - Beam acceleration and manipulation
  - Beam transportation and injection into the ERL ring
  - Laser systems for the injector
- Programme of Work
- Conclusion

General requirements for the PERLE electron source

- Major design goals
  - Deliver unpolarised and polarised beams to the PERLE accelerator
  - Test critical technologies required for LHeC

- Source specifications for PERLE
  - Bunch charge – 500 pC
  - RMS bunch length <3 mm
  - RMS energy spread < 10 keV
  - Normalised RMS beam emittance < 25 π·mm·mrad*
  - Initially proposed beam energy – 5 MeV*
  - Bunch repetition rate –harmonics of 801.6 MHz (e.g. 40.1 MHz)
  - Bunch time structure – regular with a gap for cleaning of trapped ions in the ERL ring

- Derived specifications
  - Maximum average beam current – 20 mA

*needs to be confirmed

Electron Sources

- Thermionic gun
  - High emittance
  - Does not allow for generation of polarised electrons
- Field Emission
  - Not used for accelerators - supressed to eliminate dark current!
- Photoinjectors
  - Pulsed beams by design
  - Low emittance, high average current and polarised beams all possible

Photocathodes

Material	Typical operational wavelength	Work function	Observed Q.E.	Laser power required for 20 mA	Observed maximum current	Observed operational lifetime
Sb-based family, unpolarised	532 nm	1.5-1.9 eV	4-5%	3.0 W	65 mA	Days
GaAs-based family, polarised	780 nm	1.2 eV*	0.1-1.0%	20.4	5-6 mA	Hours

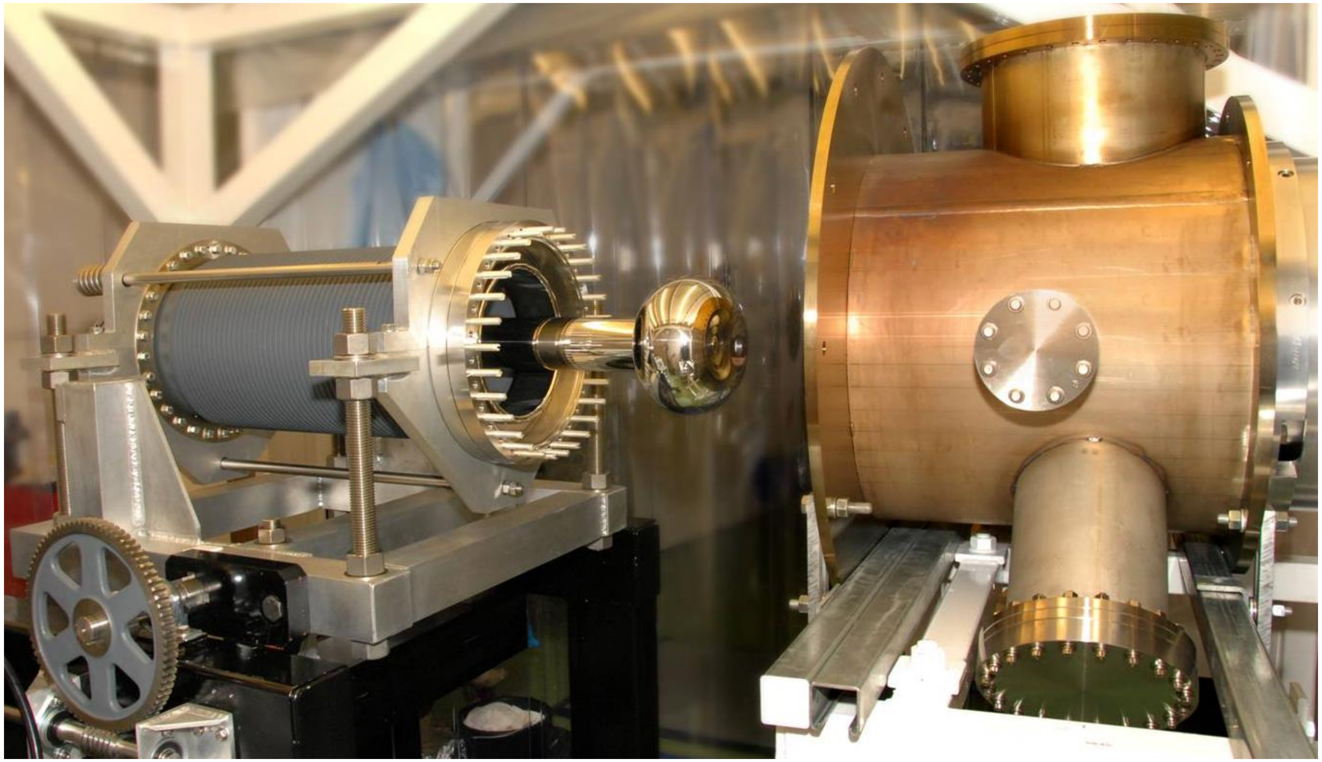
Both can provide high average current but require good vacuum for operation

Science & Technology Facilities Council
ASTeC

Photocathode guns

- Normally conducting S- and L- band guns
  - Poor vacuum, not suitable for polarised beams
- Superconducting S- and L- band guns
  - Not mature technology, may be able to generate high current and/or polarised beams
- NC and SC VHF guns
  - Good vacuum, may be able to generate high current and polarised beams, low emittance
- DC guns
  - Mature technology for ERLs, good vacuum (XHV), record high average current, extensively used for polarised electrons, low cathode field and beam energy leading to higher emittance

DC guns operated with ERLs.
Horizontal design, TJNAF IR ERL/Daresbury ALICE



Typical performance for ALICE ERL operations

- 325 keV (350 keV possible)
- 1 μA average current (gun design 6.4 mA)
- 5-8 mm.mrad emittance
- 4-5 days cathode lifetime

DC guns operated with ERLs. Vertical design, JAEA-KEK for cERL and Cornell University

REVIEW OF SCIENTIFIC INSTRUMENTS **85**, 093306 (2014)

Design, conditioning, and performance of a high voltage, high brightness dc photoelectron gun with variable gap

Jared Maxson, Ivan Bazarov, Bruce Dunham, John Dobbins, Xianghong Liu,
and Karl Smolenski
Cornell Laboratory for Accelerator-Based Sciences and Education, Cornell University, Ithaca, New York 14853, USA

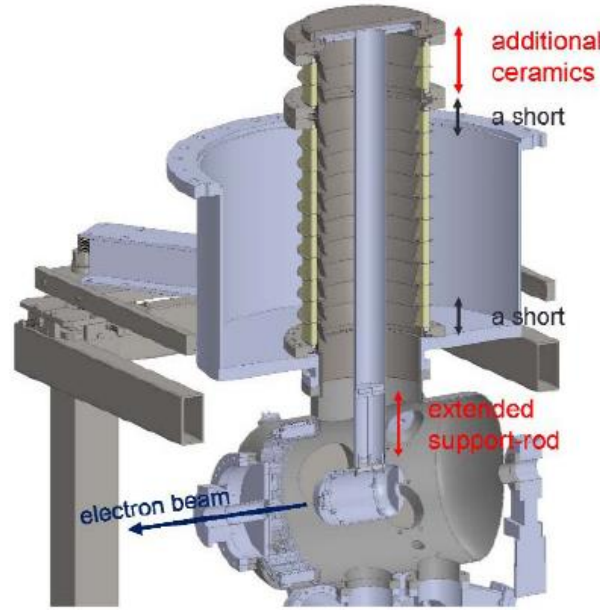
Operational parameters	
Conditioning voltage	500 kV
Operational voltage	400 kV
Operational current*	4 mA

* - in the booster cryomodule

THPOW008 Proceedings of IPAC2016, Busan, Korea

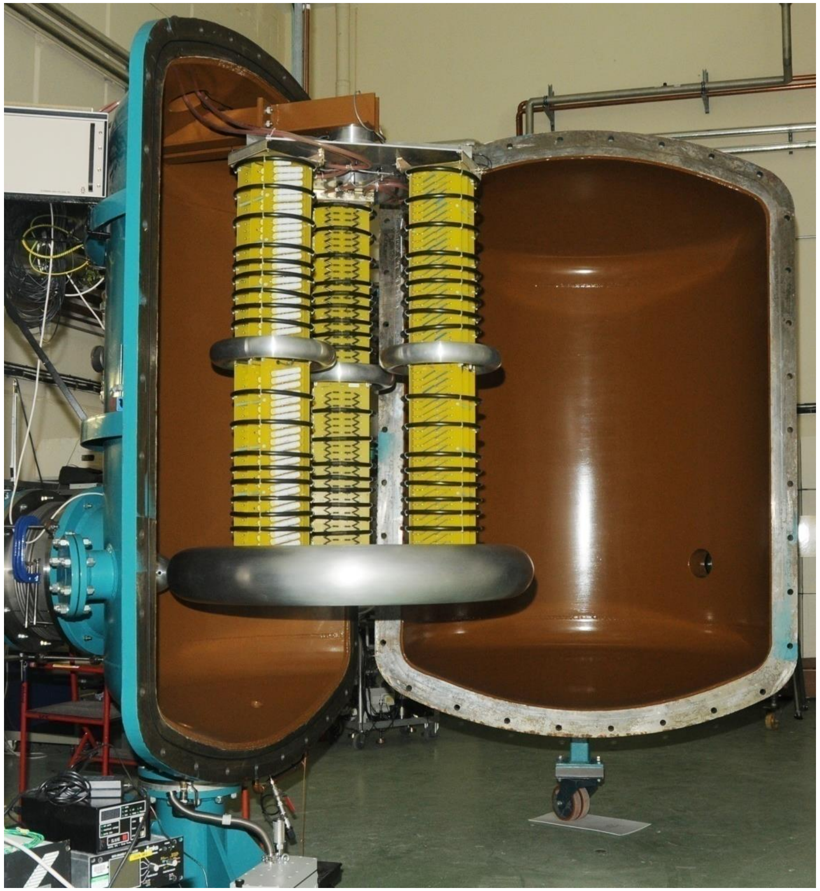
DC PHOTOEMISSION GUN UPGRADE AT THE COMPACT ERL

N. Nishimori[#], R. Hajima, R. Nagai, M. Mori, QST, Tokai, Naka, Ibaraki 319-1106, Japan
M. Yamamoto,Y. Honda, T. Miyajima, T. Uchiyama, KEK, Oho, Tsukuba, Ibaraki 319-1195, Japan



Maximum Voltage 548 kV
Operational Voltage 450 kV
Operational current 1 mA
with GaAs

ALICE photocathode gun 500 kV power supply

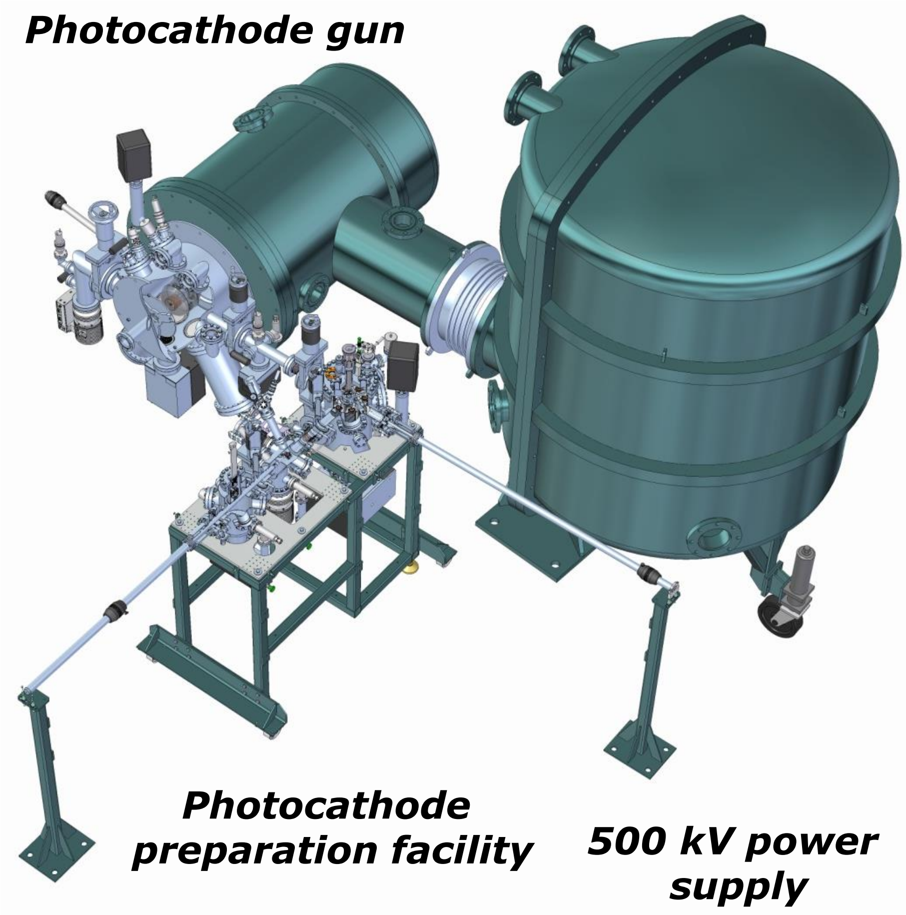


I_{max}=8 mA
U_{max}=500 kV

Upgrade to 20 mA possible
(~ € 90 K)

Science & Technology Facilities Council
ASTeC

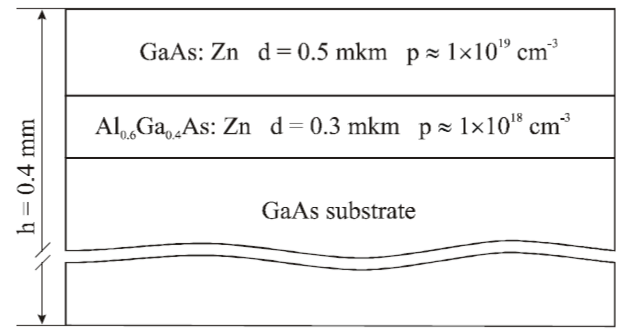
ALICE photocathode gun. Upgrade scenario

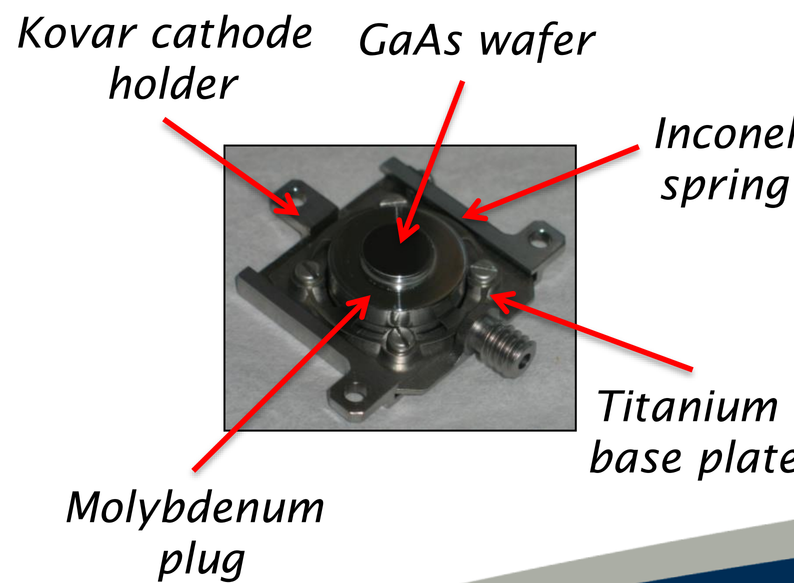


Upgrade of the gun allows

- Reduce the down time for photocathode activation and allow ALICE operation at higher bunch charge
- Remove activation/caesiation procedure from gun
  - Improve vacuum in the gun
  - Reduce contamination of the high voltage electrodes with Cs and other products of activation
- Make photocathode activation more controllable
- Allows experiments with different types of photocathode

ALICE gun upgrade.
Photocathode preparation facility

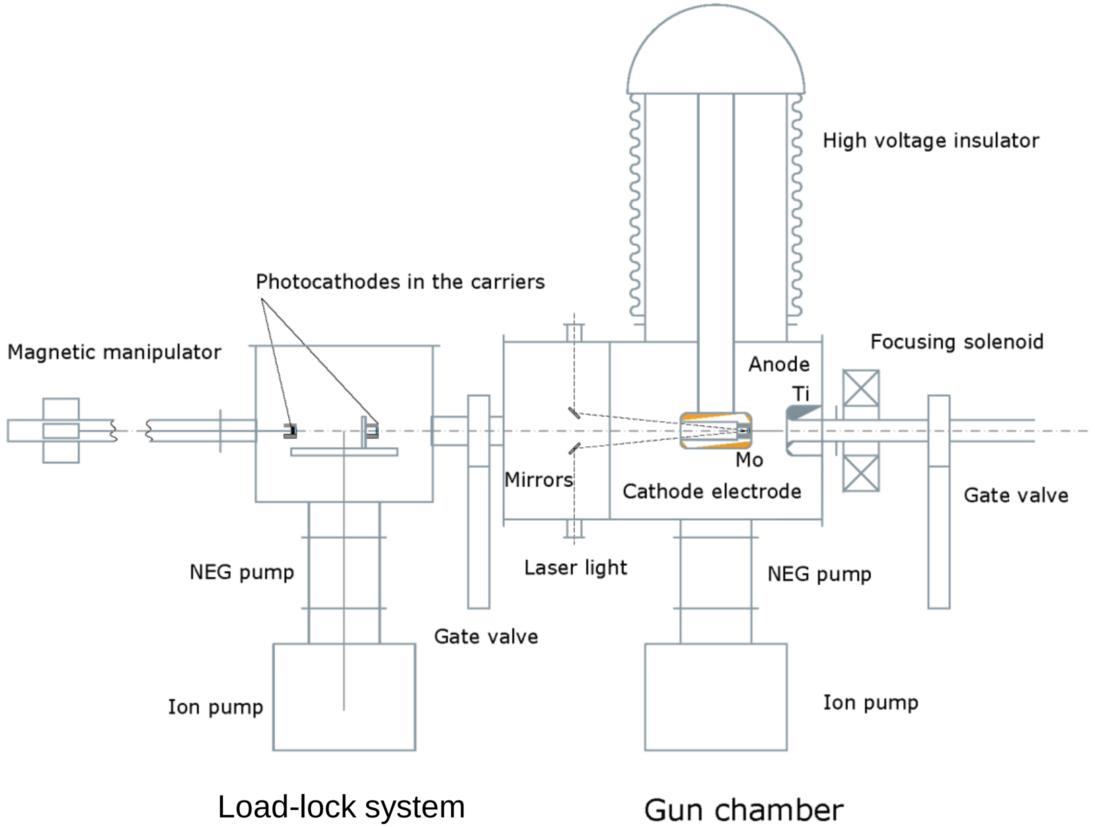




- GaAs photocathode preparation facility designed for ALICE gun upgrade. (16% QE achieved)
- Not suitable for Sb based cathodes
- Sample transfer to ‘mock gun’ vessel successfully tested.

DC photocathode gun - Future concepts

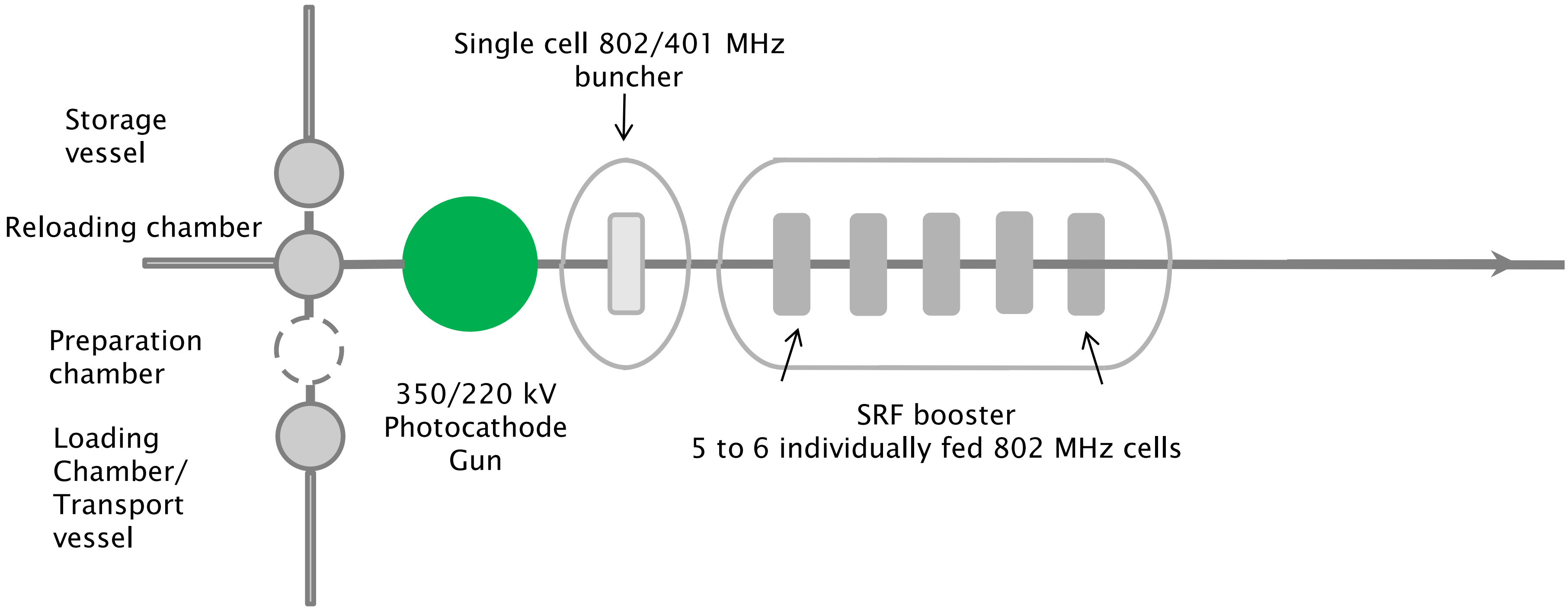
Maximum gun voltage, KV	400
Operational voltage, kV	350/220
Average current, mA	20.0 mA
Photocathode	Sb-type/ GaAs-type
Photocathode illumination	Rear
Photocathode substrate	Sapphire
Gun HV power supply	Integrated mono-block (not shown)
Gun insulator	Al_2O_3 segmented shielded



- Vertical segmented insulator
- Rear insertion of photocathodes
- Photocathodes grown on sapphire substrates for rear laser illumination
  - For GaAs/GaAsP photocathodes 1.6% QE with 92% polarisation has been achieved (Nagoya University)

Science & Technology Facilities Council ASTeC

Proposed layout of the PERLE photoinjector



- 350/220 kV DC gun
- Photocathode preparation and storage facilities
- Single cell normally conducting buncher (802 or 401 MHz)
- 5-6 cell SRF booster with individually fed 802 MHz cells

Photoinjector operation scenarios

- Photocathodes have limited lifetime and need to be replaced regularly
  - Unpolarised regime
    - Sb based photocathodes (Cs_3Sb, KCs_2Sb)
    - Stock of photocathodes are prepared off-site and brought to the photoinjector in a transport vessel
    - Photocathode are loaded into the storage vessel
    - Photocathodes are transferred one by one into the gun and operated until their QE drops to critical level
  - Polarised regime
    - Strained GaAs (e.g. GaAs/GaAsP superlattices)
    - Photocathodes are activated on-site and if possible stored in a storage vessel

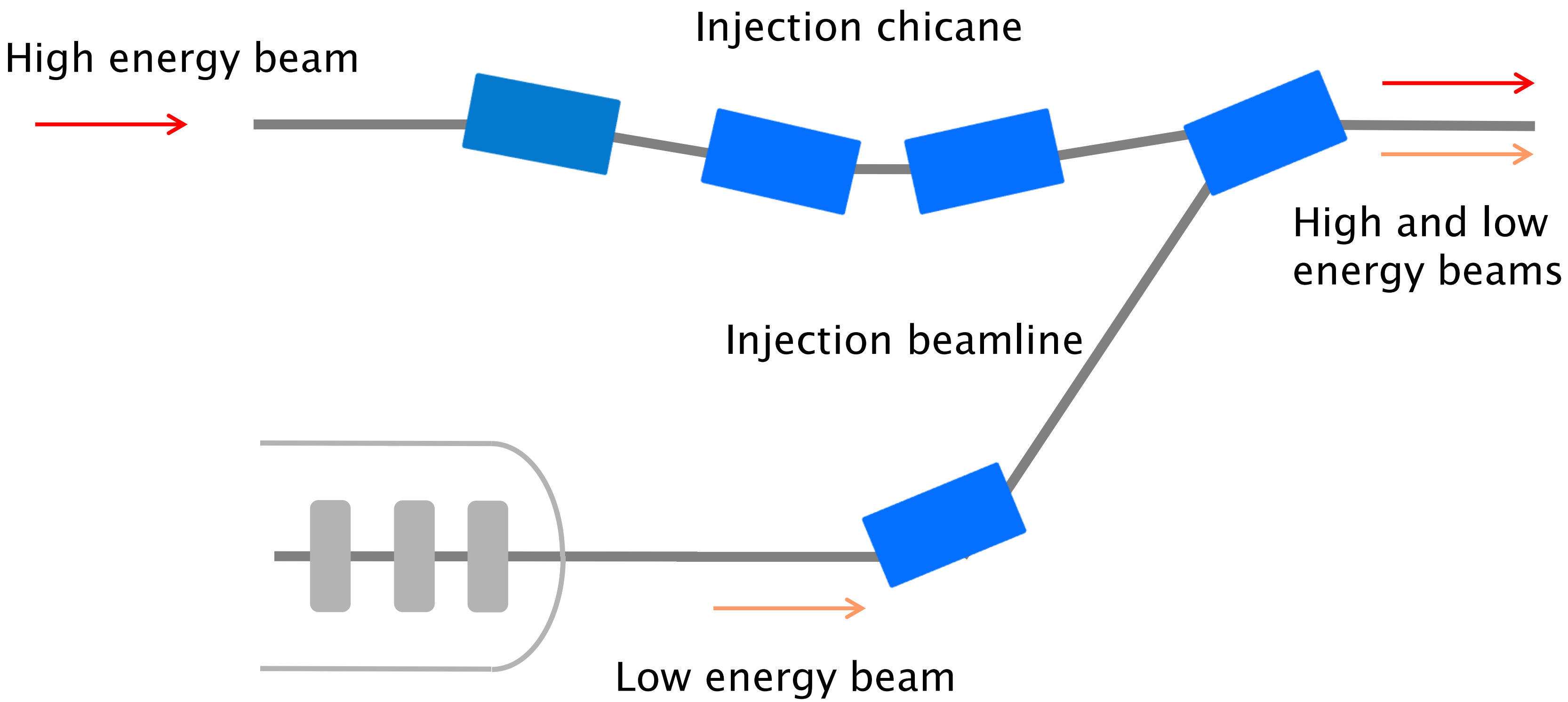
Gun operational voltage and cathode field

- High cathode operational field:
  - Allows for generation of the beams with low emittance
  - Increases field emission
  - Generates dark current and halo in polarised electron regime
  - The halo dilutes polarisation in polarised regime
- High gun voltage
  - Preserves low beam emittance
  - Impedes spin manipulation
- Two operational voltage scheme may be considered as a compromise to fulfil both regimes
  - 350 kV for unpolarised beams
  - 220 kV for polarised beams

Buncher and booster

- Buncher
  - Velocity modulation of the beam requires buncher voltage of about 1 MV
  - Buncher frequency is defined by the bunch length at the buncher and for 500 pC bunch charge a main harmonic of 802 MHz is acceptable.
  - Gap should be as short as possible to prevent essential energy sag in the buncher
- Booster
  - Accelerate the beam to 5 MeV
  - It requires RF power (CW) of about 100 kW
  - Number of cells (5-6) is defined by the power distribution – first two cavities far from crest
  - ***Individual control and coupling*** for at least first two cells

Typical ERL injection scheme



Beam injection studies required to ensure sufficient emittance preservation

Laser system specification for 20 mA electron source

Lase wavelength, nm	532 (unpolarised mode)	780 (polarised mode)
Laser pulse repetition rate, MHz	Variable	40.1
Energy in the single pulse at photocathode, QE=1%, nJ	48* (at 40.1MHz)	
Average laser power at photocathode, QE=1%, W	1.9	
Energy in the single pulse at photocathode, QE=0.1%, nJ		326
Average laser power at photocathode, QE=0.1%, W		13
Lase pulse duration, ps FWHM	80*	80*
Lase pulse rise time, ps	8*	8*
Lase pulse fall time, ps	8*	8*
Spot diameter on the photocathode surface, mm	4*	4*
Laser spot shape on the photocathode surface	Flat top	Flat top

* - at photocathode surface

Proposed Programme of Work:

- Optimisation of the DC gun – conceptual design, electrode system, beam dynamics, photocathode cooling
- Conceptual design of the photocathode transport system for Sb and GaAs based options
- Selection of the buncher frequency and preliminary buncher design
- Conceptual design of the booster – number of cells, gradients etc.
- Optimisation of the beam transport through the booster at the proposed injection energy
- Selection of the injection scheme
- Start-to-end beam dynamics simulations and optimisation of the injection energy if necessary
- More accurate costings for proposed gun design
- Technical design not envisaged!

Conclusion

- A 5 MV injector of unpolarised (and polarised) electrons for PERLE facility is envisaged
  - Proposed scheme of the PERLE injector is based on 350/220 kV DC photocathode gun
  - Proposed photocathode materials are Sb-based photocathodes as unpolarised source and GaAs-based wafers as a source of polarised electrons.
  - The photocathode gun design should allow for operation with both types of photocathode
  - The proposed scheme of beam formation is based on 802/401 MHz buncher and a 5-6 cell 802 MHz booster
  - A detailed conceptual design of the beam injection scheme needs to be developed