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Electron source for PERLE

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Outline

- Injector specification
- Possible electron sources for PERLE injector
- Existing ERL injectors
- Photoinjector R&D at STFC Daresbury Laboratory
  - Electron emitters. Photocathodes
  - Electron source. DC photocathode gun
- General concept of the PERLE injector
  - Beam generation
  - Beam acceleration and manipulation
  - Beam transportation and injection into the ERL ring
  - Laser systems for the injector
- Work to be done
- Conclusion

General requirements to the PERLE electron source

- Major design goals
  - Deliver unpolarised and polarised beams to the PERLE
  - Test critical technologies required for LHeC
- Source specifications according to the PERLE CDR
  - Maximum bunch charge 320 pC
  - RMS bunch length <3 mm
  - RMS energy spread < 10 keV
  - Normalised RMS beam emittance < 25 π·mm·mrad*
  - Bunch repetition rate – variable, harmonics of 801.6 MHz
  - Initially proposed beam energy – 5 MeV*
  - Bunch time structure – regular with a gap for cleaning of trapped ions in the ERL ring
- Derived specifications
  - Maximum average beam current – 12.8 mA

*-needs to be specified

Thermionic guns

- Grid modulated DC thermionic guns
  - Used in FEL-s (ELBE, FELIX, FHI)
  - Well established mature technology
  - Low cathode field
  - High emittance
  - Does not allow for generation of polarised electrons
  - Potentially able to generate high current
- Grid modulated VHF thermionic guns
  - Developed for BINP ERL, FAR-TECH Inc.
  - High emittance
  - Potentially able to generate high current
  - Does not allow for generation of polarised electrons

NCRF photocathode guns

- S - and L- band guns
  - Used for high brightness injectors for FEL (FLASH, LCLS, FERMI, SwissFEL, CLARA and others)
  - High cathode field
  - Pulsed operational mode (at a reasonable RF power)
  - Poor vacuum condition
  - Does not allow for generation of polarised electrons
- VHF guns
  - Developed as injector for LCLS-II at LBNL
  - Potentially able to generate high current
  - Potentially able to generate polarised electrons

SRF photocathode guns

- S - and L- band photocathode guns
  - Developed as injector for FELs and ERLs (HZ Dresden-Rossendorf, HZ Berlin, DESY, BNL)
  - Potentially able to generate polarised electrons
  - Potentially able to generate high current
- VHF photocathode gun
  - Developed as injectors for CW FELs and rings (University of Wisconsin, BNL, Naval graduate school)
  - Potentially able to generate polarised electrons
  - Potentially able to generate high current

DC photocathode guns

- Pros
  - Used and developed as ERL, FEL and polarised electron sources
  - Well established mature technology
  - Experience in operation at ERLs (DL,KEK,TJNAF)
  - Possibility to deliver beams with any time structure
  - Possibility to reach extra high vacuum conditions
  - Experience in delivery of polarised electrons (TJNAF, University of Mainz, MIT, Technical University of Darmstadt, SLAC, University of Bonn, NIKHEF)
  - Demonstrated record level of average current (Cornell University)
- Cons
  - Require very accurate high voltage design
  - Low beam energy
  - Low cathode field

Photocathodes for PERLE

Material	Typical operational wavelength	Work function	Observed Q.E.	Laser power required for 12.8 mA	Observed maximum current	Observed operational lifetime
Sb-based family, unpolarised	532 nm	1.5-1.9 eV	4-5%	1.9 W	65 mA	Days
GaAs-based family, polarised	780 nm	1.2 eV*	0.1-1.0%	13	5-6 mA	Hours

Beam emittance for the photocathodes is defined as

$$\epsilon_n = \sigma_\perp \sqrt{\frac{2E_{kin}}{3mc^2}} = 1 \cdot 10^{-3} \sigma_\perp$$

where

$$E_{kin} = \hbar\omega - \varphi$$

$$\sigma_\perp = \frac{1}{2} \sqrt{\frac{q}{\pi \varepsilon_o \mathcal{E}_c}}$$

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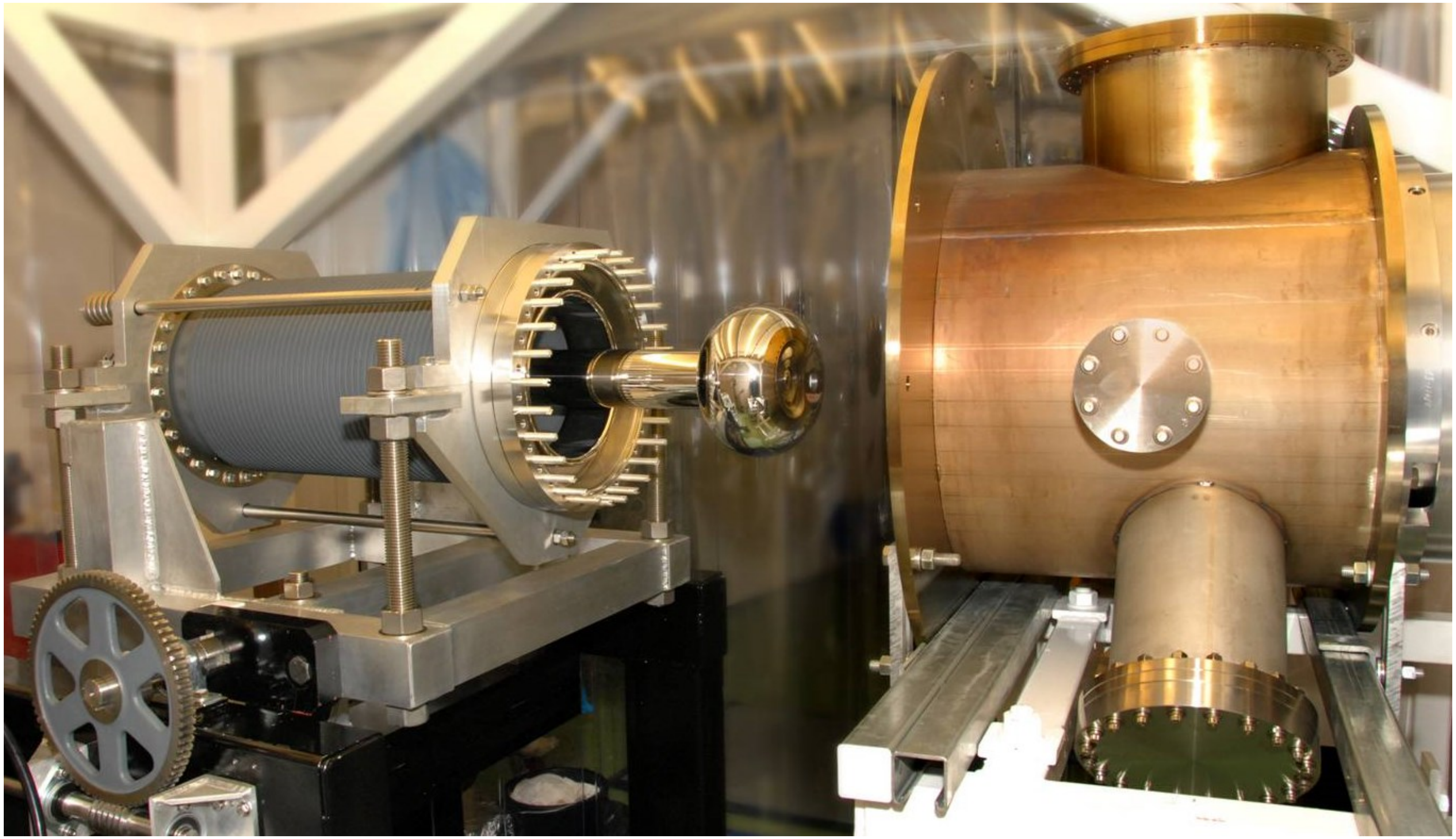
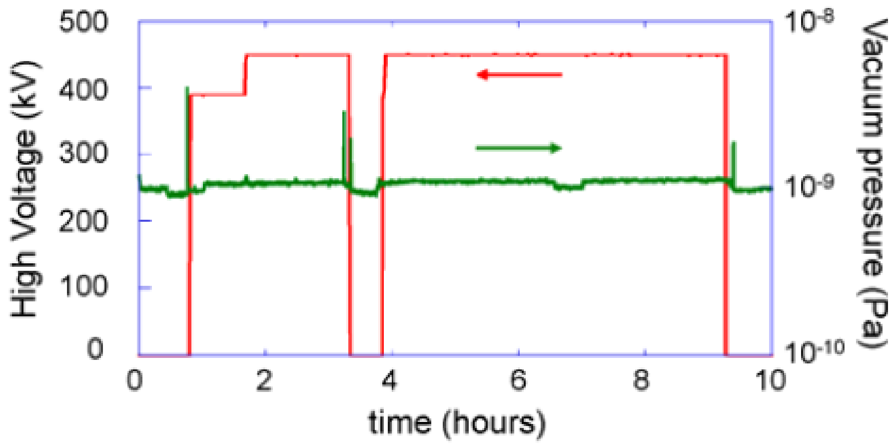
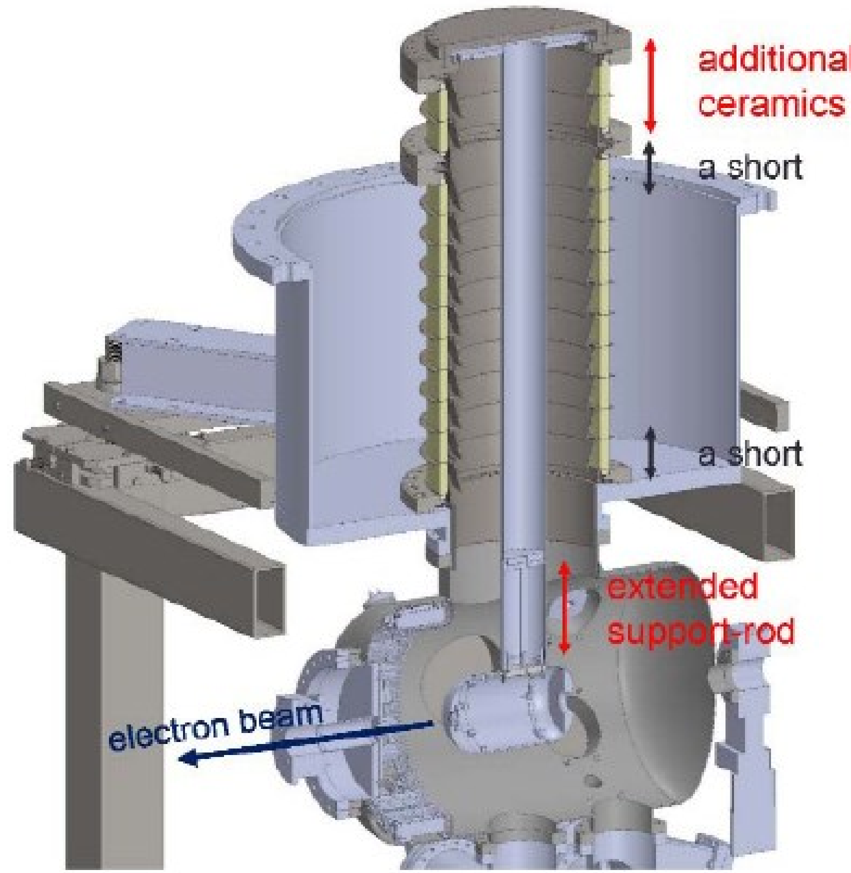
DC guns operated with ERLs.
Horizontal design, TJNAF IR ERL/Daresbury ALICE



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





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

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

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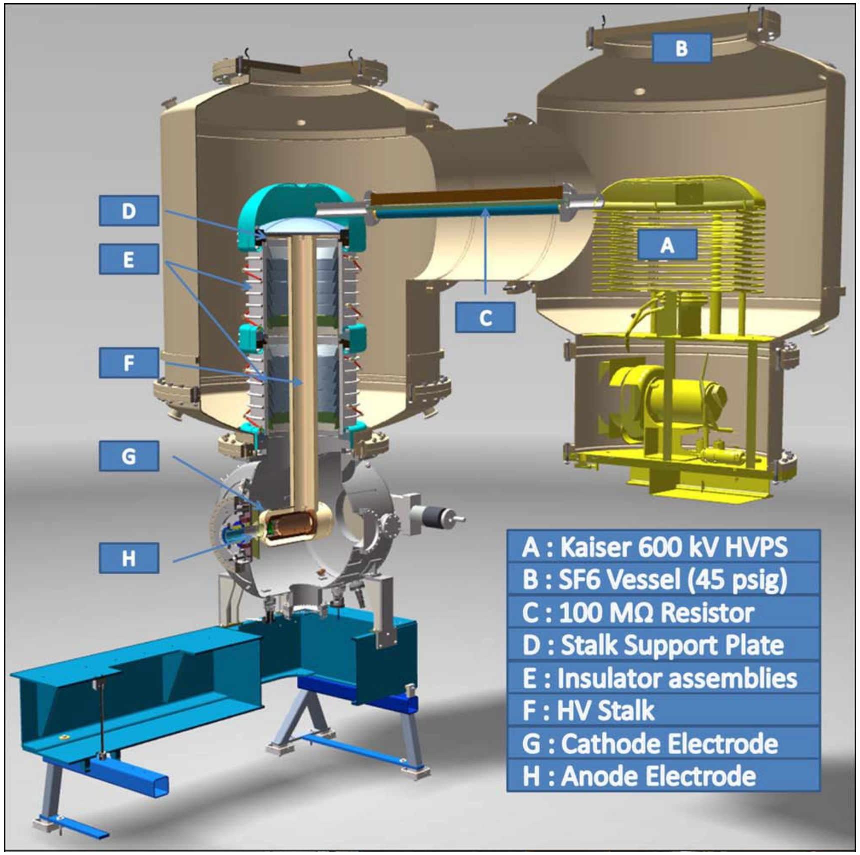
DC guns, designed for ERLs. Vertical design, Cornell University



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

* - in the booster cryomodule

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

Q (pC)	I_{peak} Target (A)	I_{peak} (A)	ε_n Target (95%, μm)	ε_n (95%, μm)	$\varepsilon_{n,th} / \varepsilon_n$
20	5	5	0.25	H: 0.18, V: 0.19	60%
100	10	11.5	0.40	H: 0.32, V: 0.30	80%
300	30	32	0.60	H: 0.62, V: 0.60	70%

A. Bartnik, ERL'2015

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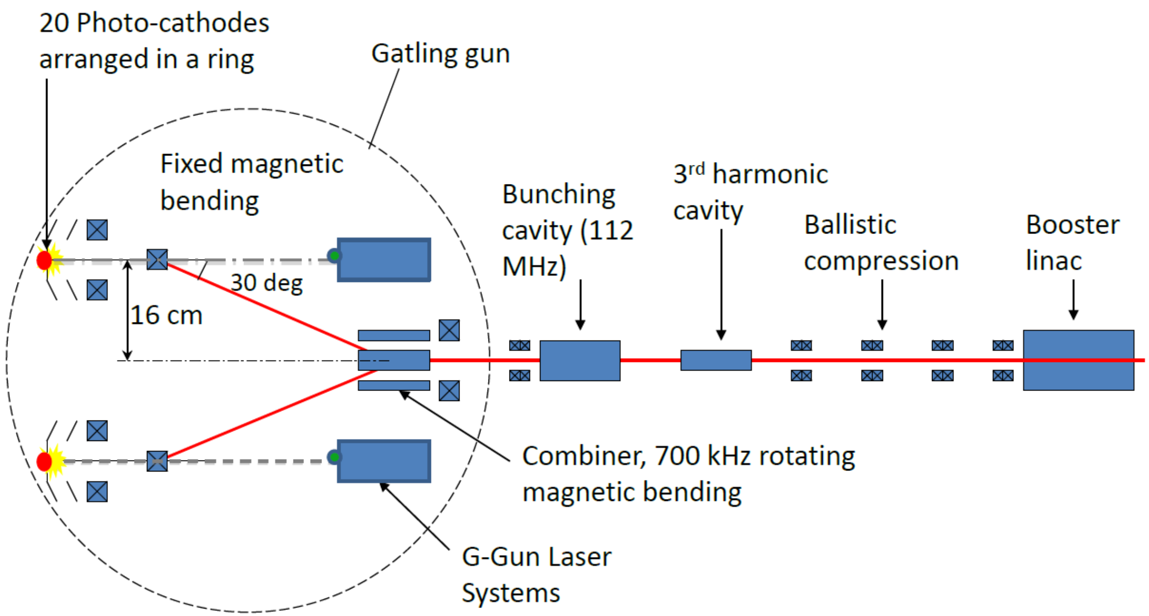
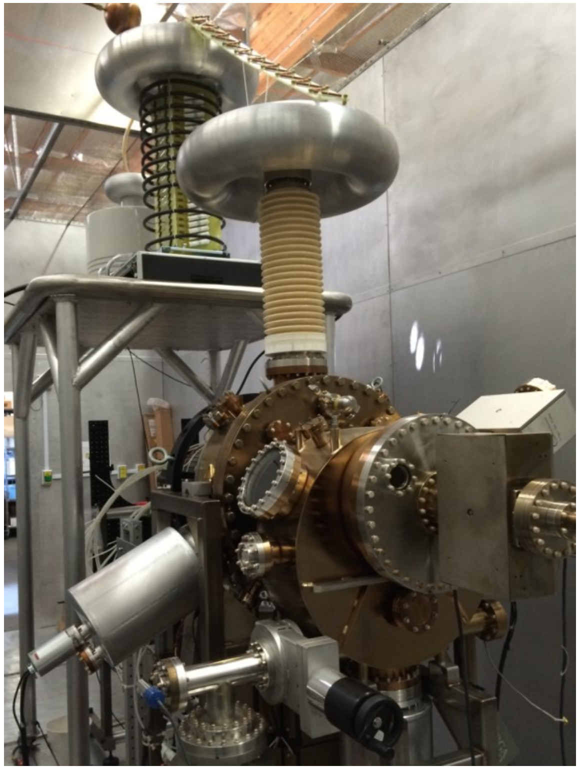
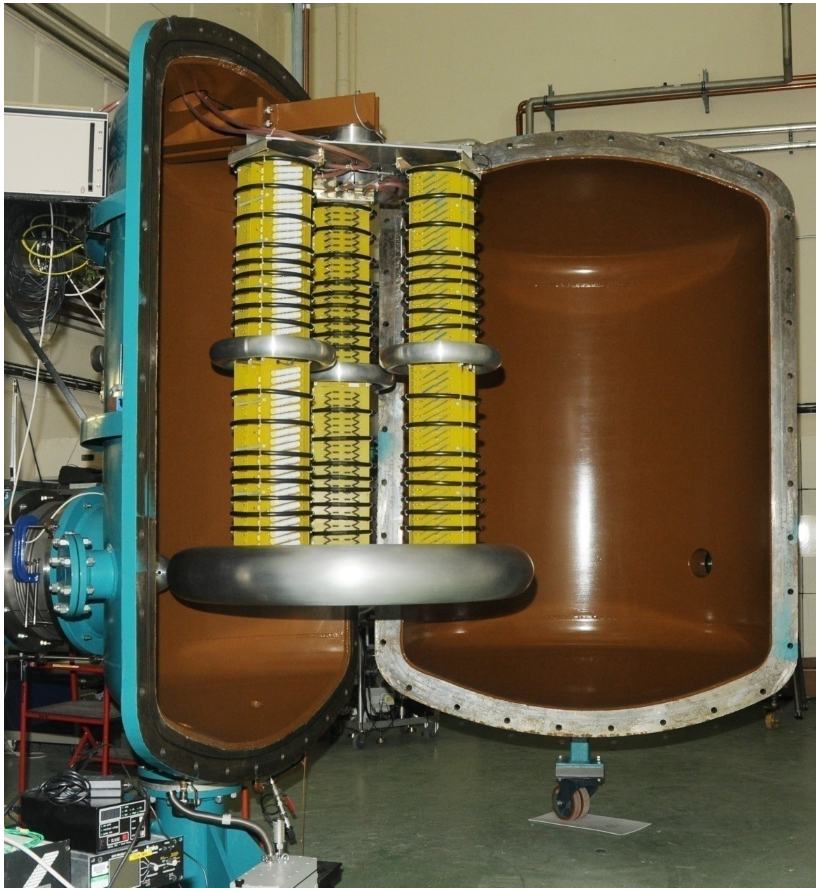
DC guns, designed for ERLs.
Funneling gun, BNL

Maximum gun voltage	220 kV
Maximum beam current	50 mA
Photocathode	GaAs type
Number of photocathode	20
Bunch charge	5.3 nC



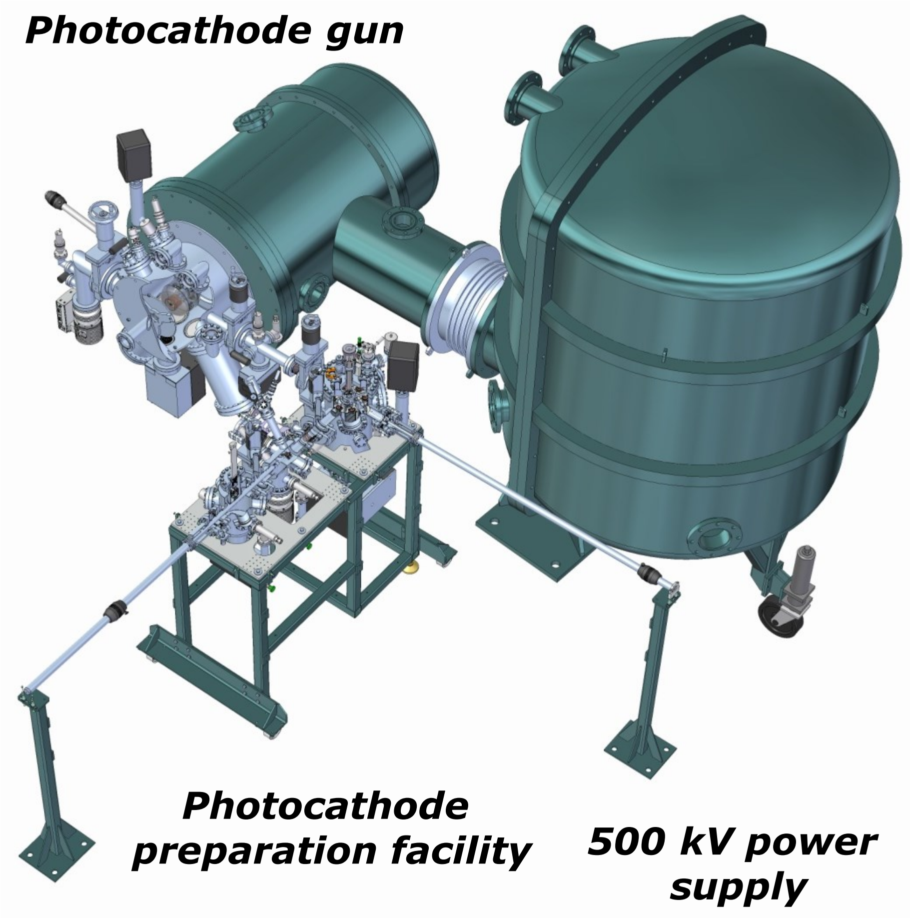


ALICE photocathode gun 500 kV power supply



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

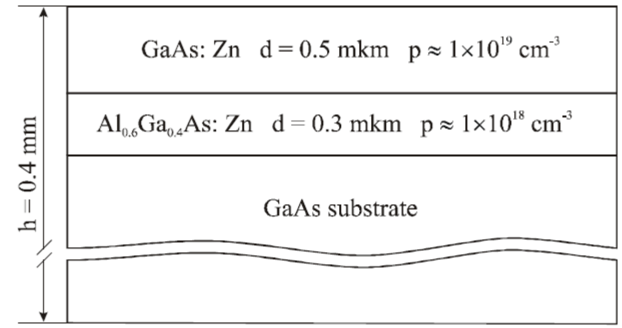
ALICE photocathode gun. Upgrade scenario

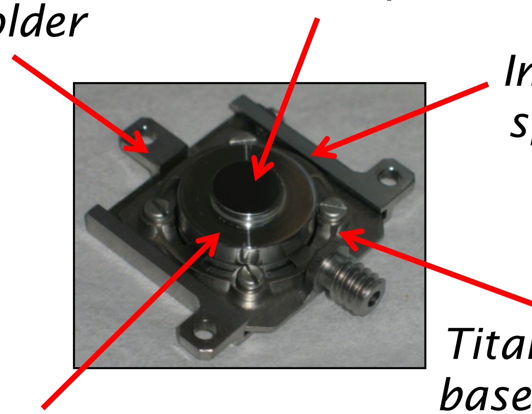


Upgrade of the gun allows to

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

ALICE gun upgrade.
Photocathode preparation facility





GaAs photocathode preparation facility designed for 4GLS and ALICE gun upgrade.

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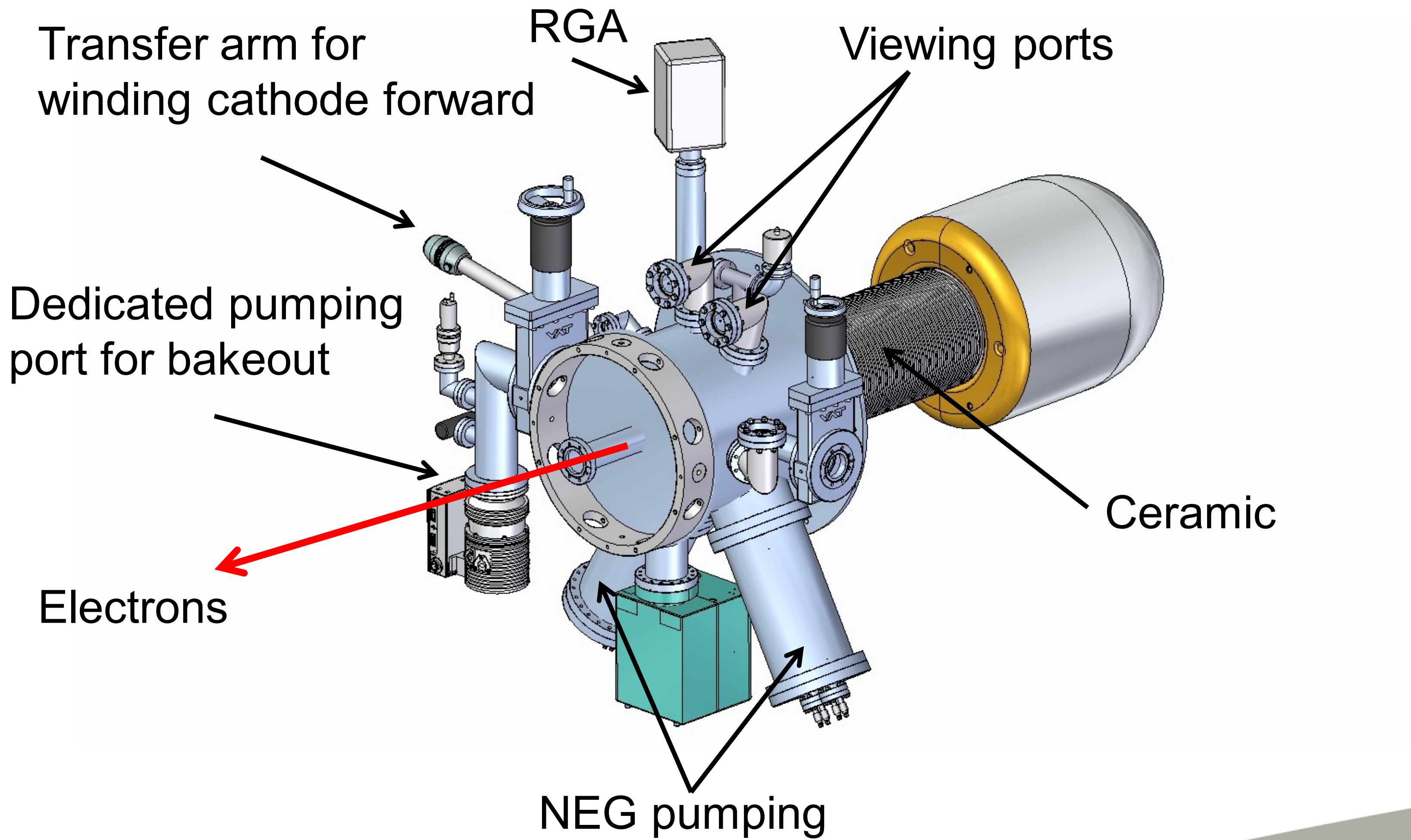
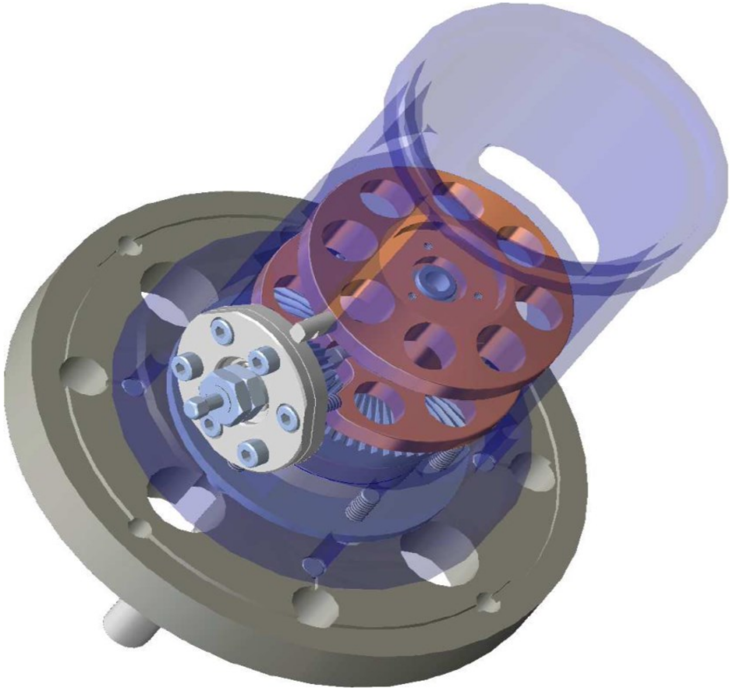
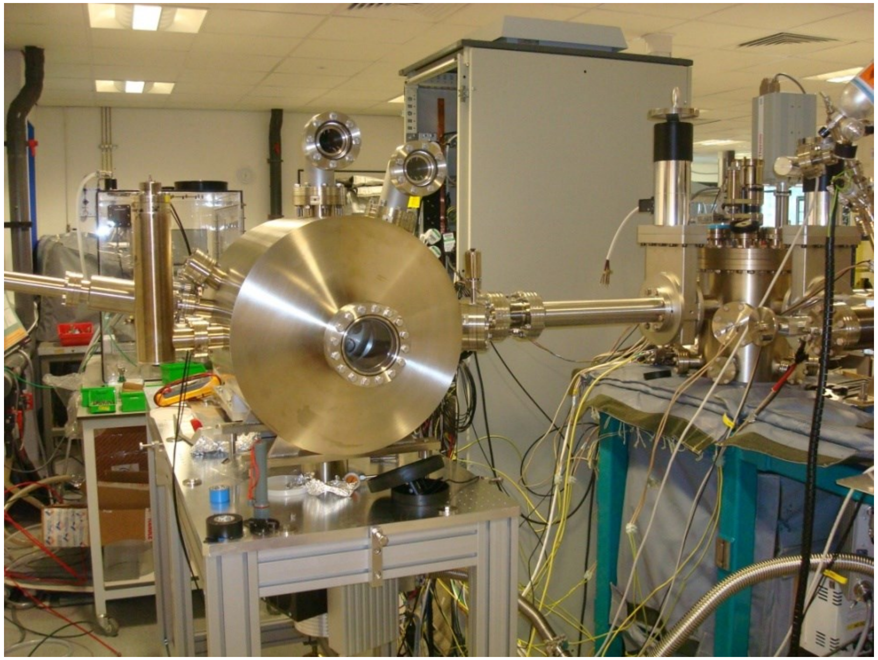
ALICE gun upgrade. Gun chamber



ALICE gun upgrade. Gun prototype

Cathode ball mechanism based a bevel gear for winding the cathode forward and backward

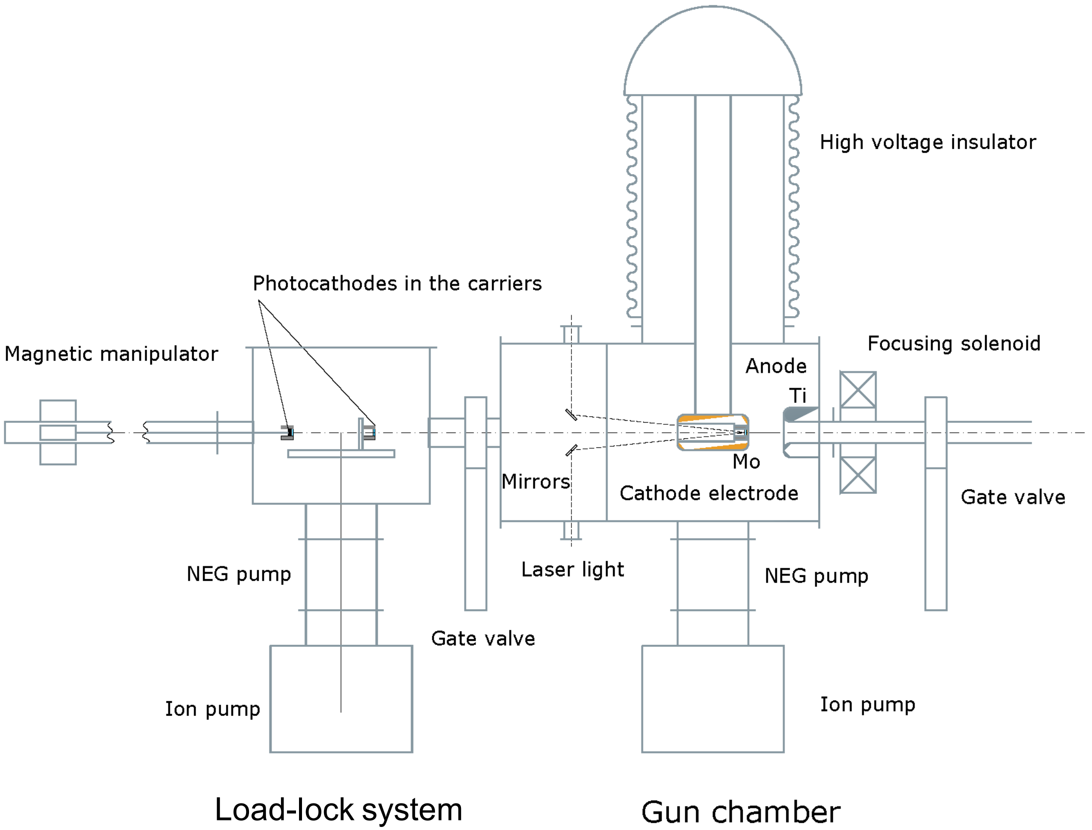




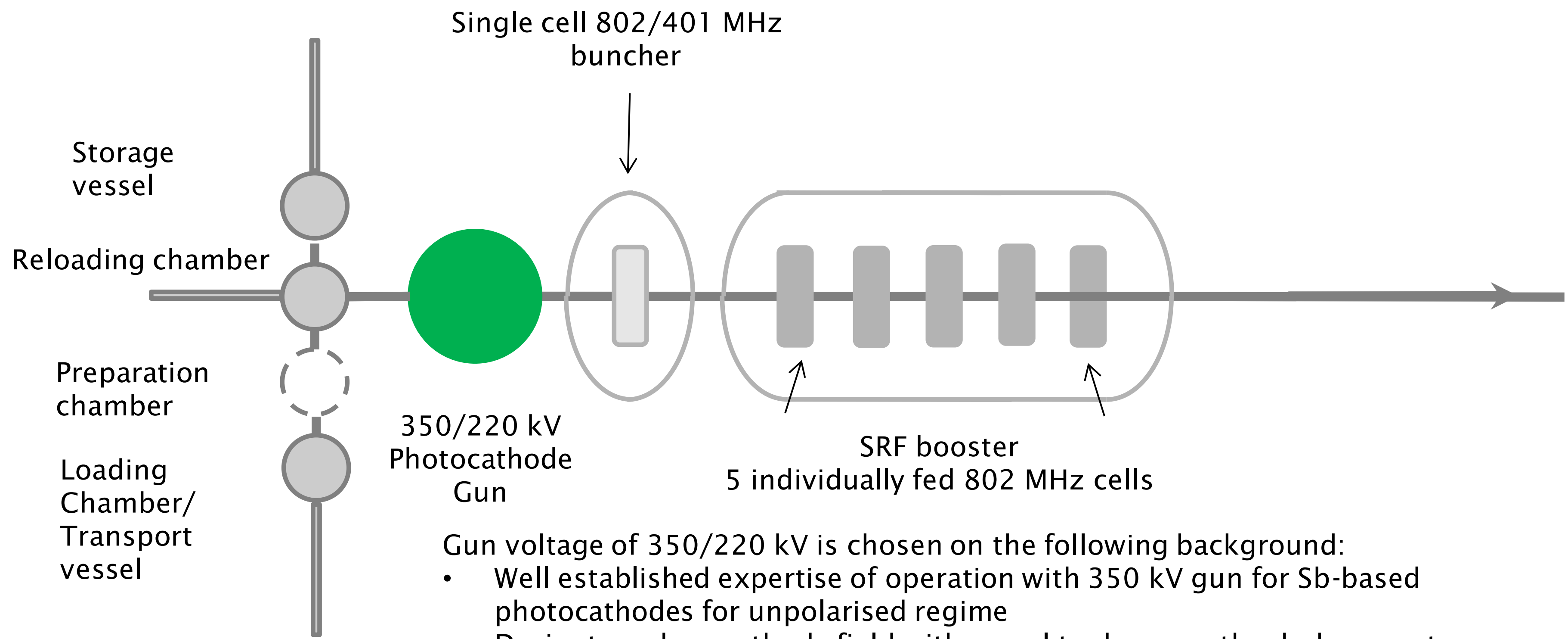
Mock gun built to test the cathode transfer mechanism. Now Transverse Energy Spread Spectrometer (TESS)

DC photocathode gun. Future concepts

Maximum gun voltage, KV	400
Operational voltage, kV	350/220
Average current, mA	12.8 mA
Photocathode	Sb-type/ GaAs-type
Photocathode illumination	Backward
Photocathode substrate	Sapphire
Gun HV power supply	Integrated mono-block (not shown)
Gun insulator	Al_2O_3 segmented shielded



General layout of the PERLE photoinjector



Gun voltage of 350/220 kV is chosen on the following background:

- Well established expertise of operation with 350 kV gun for Sb-based photocathodes for unpolarised regime
- Desire to reduce cathode field with a goal to decrease the dark current from GaAs type photocathodes which have low work function of 1.2 eV (polarised regime) leads to propose operation at lower voltage 220kV. As requirement to emittance is modest, high cathode field is not required.

Photoinjector operation scenarios

- Photocathodes have limited lifetime and need to be regulary replaced
- Unpolarised regime
  - Stock of photocathodes are prepared off site and brought to the photoinjector in a Transport Vessel
  - Photocathode are reloaded to the storage vessel
  - Photocathodes one by one are transferred to the gun and operated until their QE drops to critical level
  - When last photocathode is loaded to the gun stock renewed
- Polarised regime
  - Photocathode is activated on site and if possible stored into storage vessel

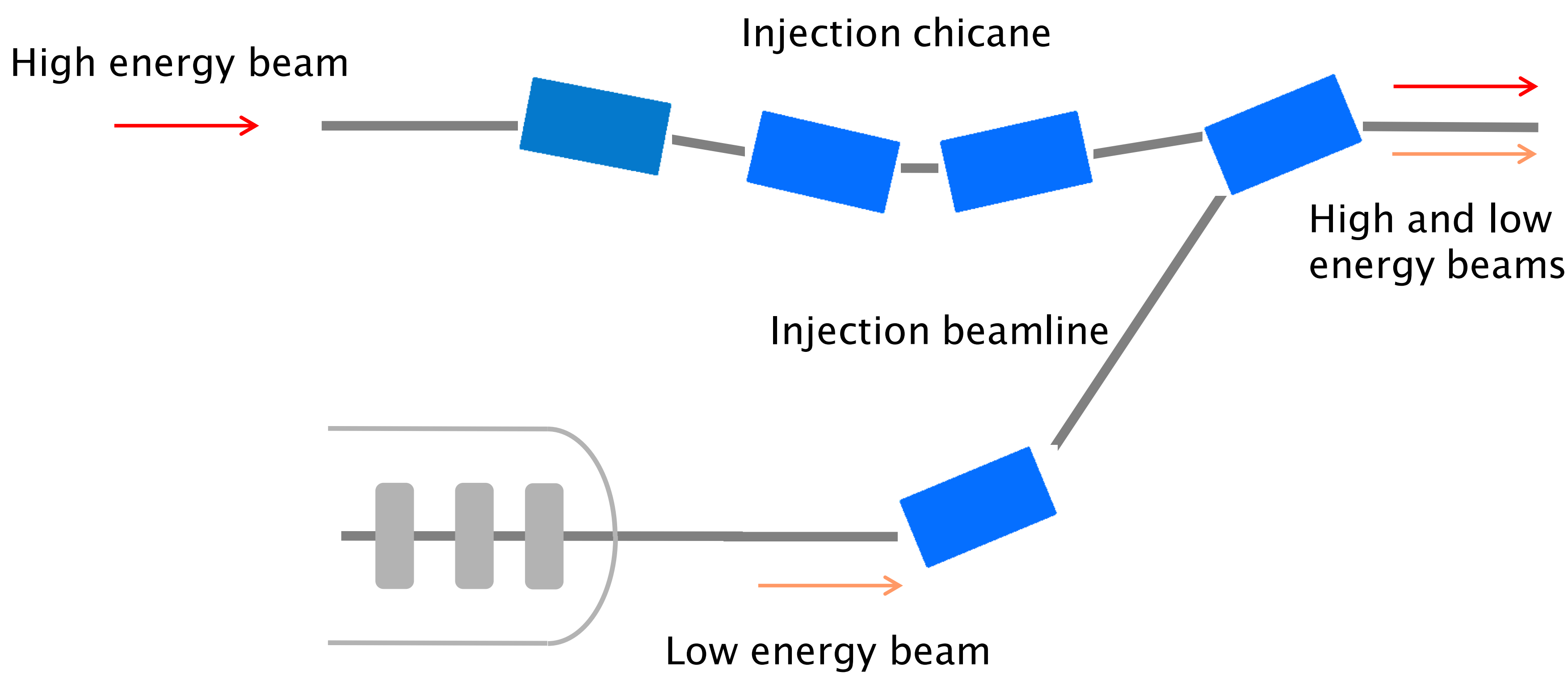
Gun operational voltage and cathode field

- High cathode operational field:
  - Allows for generation of the beams with low emittance
  - Increases field emission
  - Generates dark current and halo in unpolarised electron regime
  - The halo dissolves 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

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 320 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 64 kW
  - Number of cells (4-5) 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



Laser system specification for 12.8 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

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To do:

- 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
- S2E beam dynamics simulation and optimisation of the injection energy if necessary

Conclusion

- It is possible to build a 5 MV injector of unpolarised electrons for PERLE facility
  - Proposed scheme of the PERLE injector based on 350/220 kV DC photocathode gun
  - Proposed photocathode material – Sb based photocathode as unpolarised source and GaAs based wafers as a source of polarised electrons.
  - The photocathode gun design should allow for operating with both type of photocathodes
  - Proposed scheme of the beam formation based on 802/401 MHz buncher and 4 cells 802 MHz booster
  - Proposed beam injection scheme but details need to be specified