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Development of high brightness, high repetition rate photoelectron injectors at STFC ASTeC

B.L. Militsyn on behalf of the photoinjector development team

Accelerator Science and Technology Centre
Science & Technology Facility Council, UK

IOP Institute of Physics

Nuclear and Particle Physics Divisional Conference (NPPD)

4–7 April 2011, University of Glasgow, UK

Outline: ASTeC activities in the development of high performance electron sources

- General remarks
- Physics of photoemission from high current photocathodes
  - Physics of III-V (GaAs photocathodes)
  - Cu photocathodes
  - Sb- and Te-based photocathodes
- Development of the electron injectors for ongoing and future projects:
  - MAX-IV short pulse photoinjector
  - Ultra-high brightness photoinjector facility for a Next Generation Light Source
  - Soft X-ray FELs photoinjector (NLS)
- Support for the current operational electron injectors
  - Operation of the ALICE photoinjector
  - Upgrade of the ALICE photoinjector

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Production of extra high brightness electron beams

- Emission
  - Thermal emission (medium brightness, poor controllability)
  - Field emission (high brightness, poor controllability)
  - Photoemission (medium brightness, good controllability)
- Acceleration
  - DC gun (low field, highly stable, acceptable environment for photocathodes, high repetition rate)
  - NC RF guns (high field, medium stability, low repetition rate)
  - SRF guns (medium field, high repetition rate)
- Compression
  - Velocity bunching
  - Magnetic compression

Ultimate demands on the emitted electron beam

$$\varepsilon_{n,rms} = \beta\gamma \frac{\lambda}{4\pi}$$

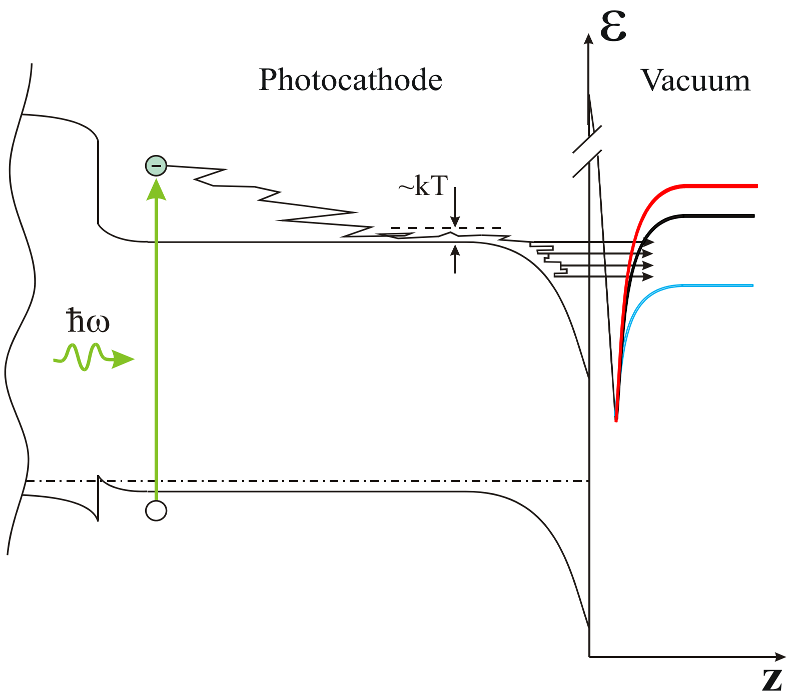
$$\varepsilon_{n,rms} = \sqrt{\overline{x^2}\,\overline{x'^2} - \overline{x \cdot x'}^2} = \sigma_\perp \sqrt{\frac{2E_i}{3mc^2}}$$

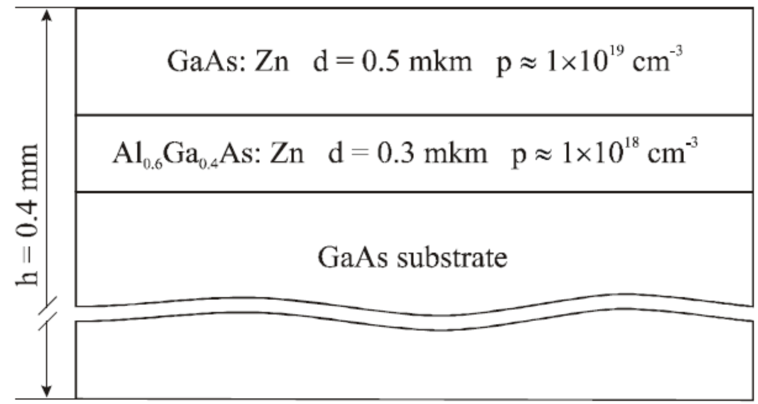
$$\sigma_\perp = \frac{1}{2}\sqrt{\frac{q}{\pi\varepsilon_0 E_c}}$$

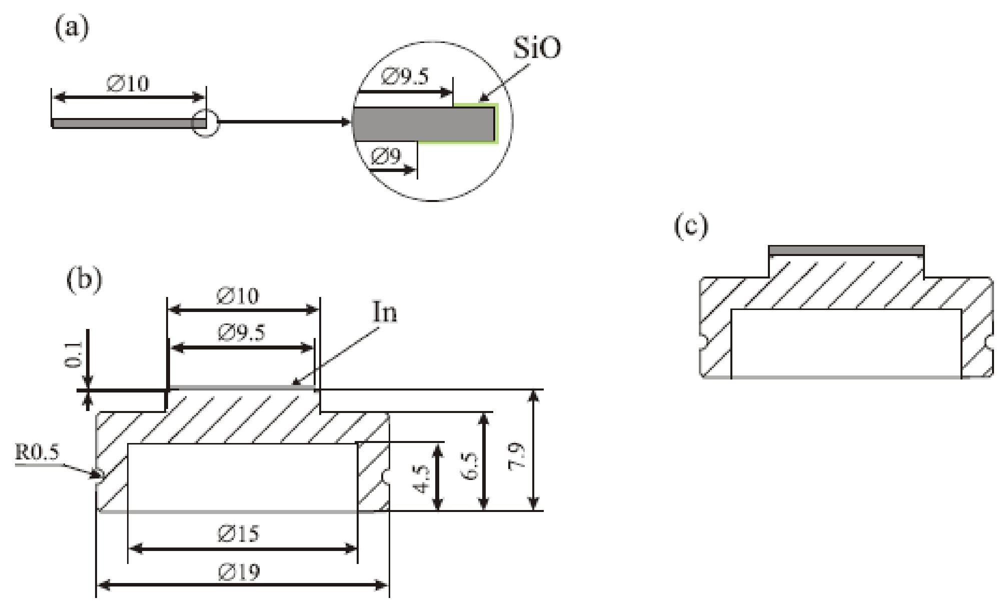
$$E_i = 1 \quad eV$$

Field strength	Technology	0.01 nC	0.1 nC	1.0 nC
10 MV/m	DC gun	0.11	0.34	1.08
20 MV/m	VHF gun	0.08	0.24	0.77
50 MV/m	L-band gun	0.05	0.15	0.48
100 MV/m	S-band gun	0.03	0.11	0.34

High average current GaAs photocathodes



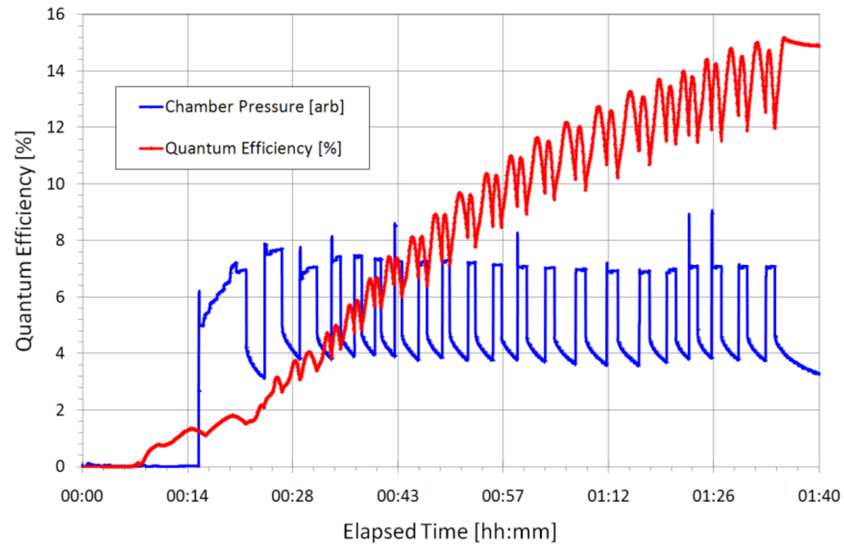




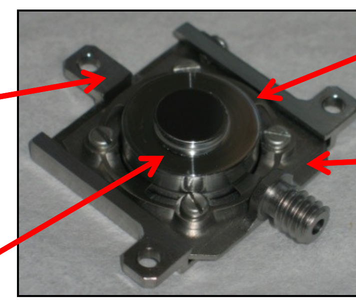
$\chi > kT \qquad E_i = h\nu - E_g - \chi$

$\chi < 0 \qquad E_i = h\nu - E_g - \chi$

GaAs photocathode preparation facility

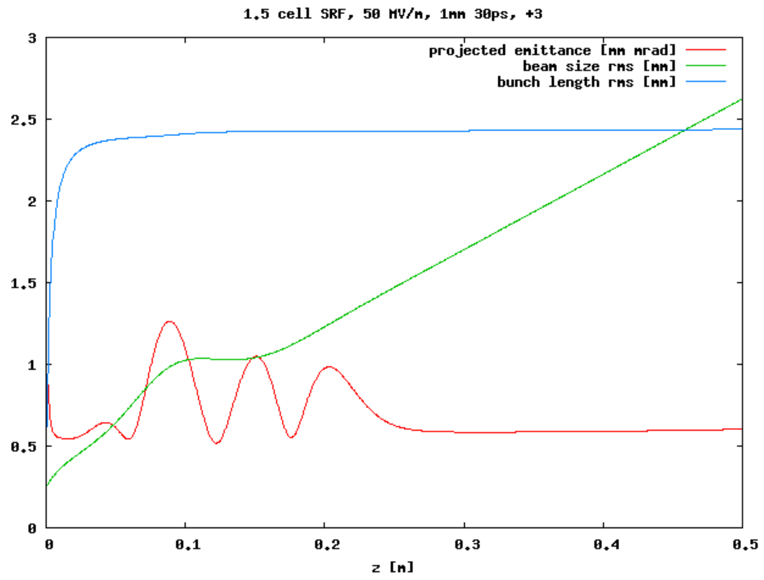


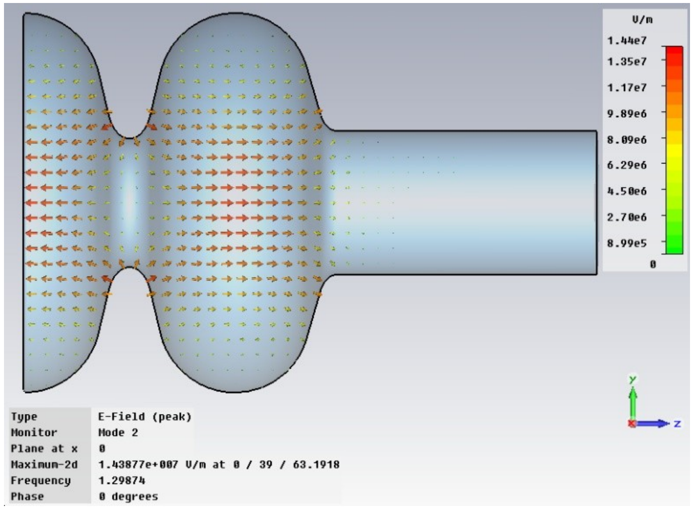
K.J. Middleman et al., PESP2010



High repetition rate NLS injector concept
1½ cell L-band SRF gun

1.5 Tesla cells at 50 MV/m → 4.5 MeV





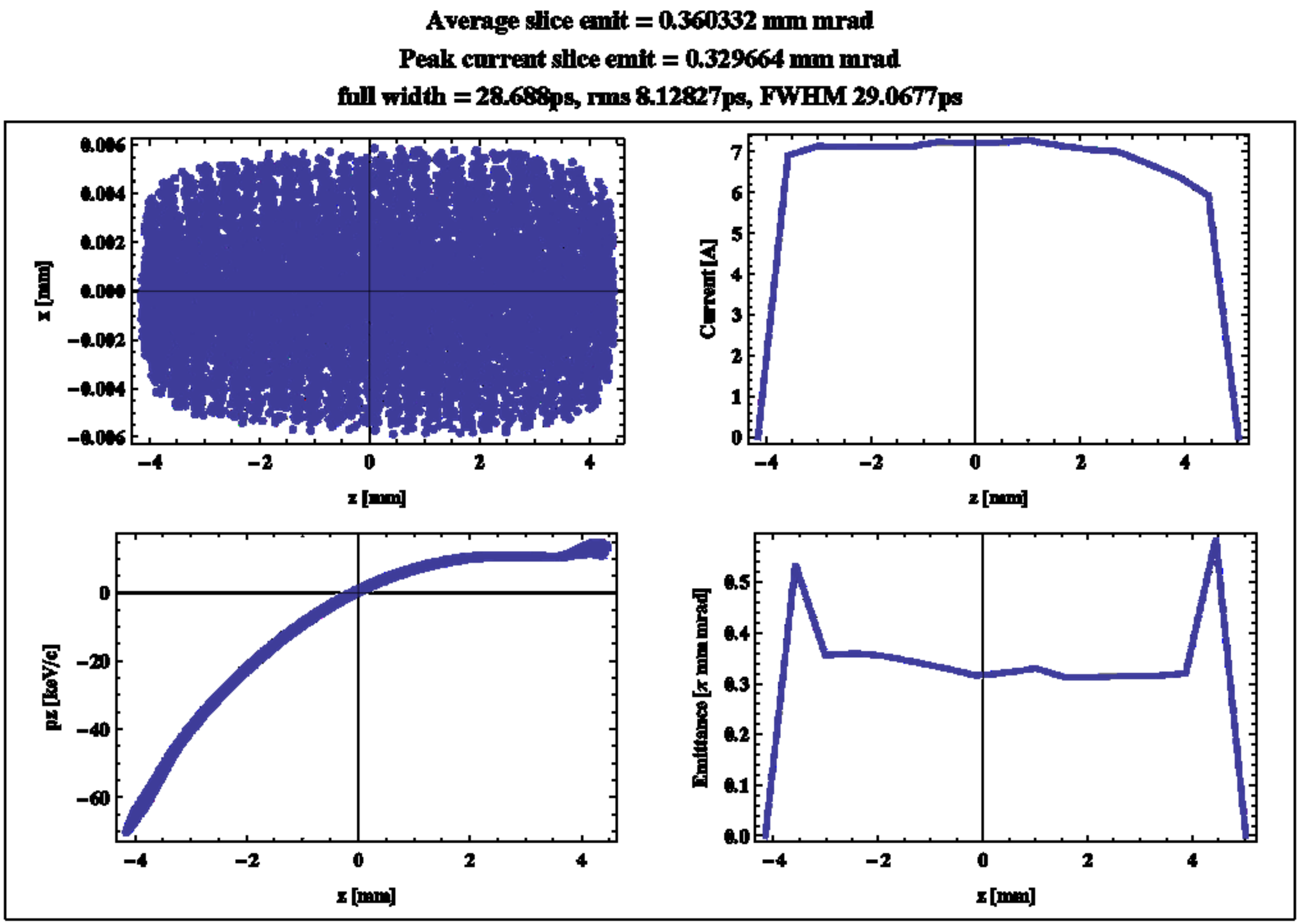
TUPEC016 Proceedings of IPAC'10, Kyoto, Japan

INITIAL DESIGN OF A SUPERCONDUCTING RF PHOTOINJECTOR OPTION FOR THE UK'S NEW LIGHT SOURCE PROJECT

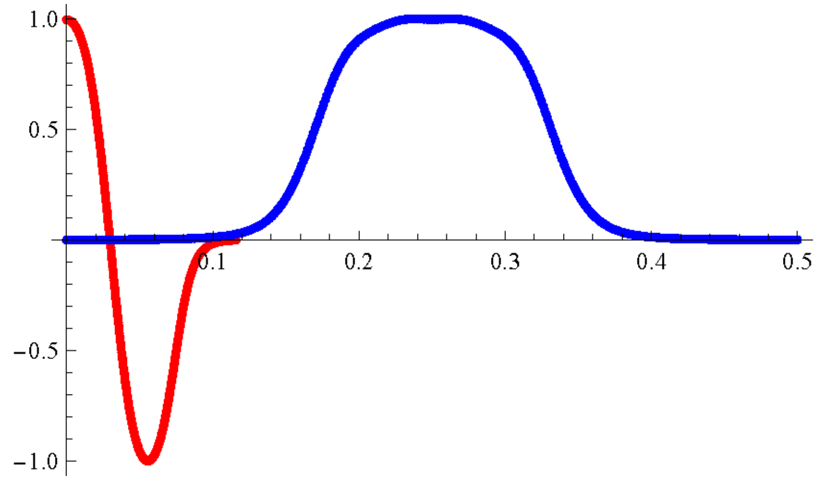
J.W. McKenzie* & B.L. Militsyn, STFC Daresbury Laboratory, ASTeC & Cockcroft Institute, UK

Laser:	
Pulse duration (full width)	30 ps
Spot diameter	1 mm
Gun:	
Launch phase	+3°
Initial thermal energy	0.7 eV (Cs_2Te)
Bunch charge	200 pC

NLS injector. Beam parameters

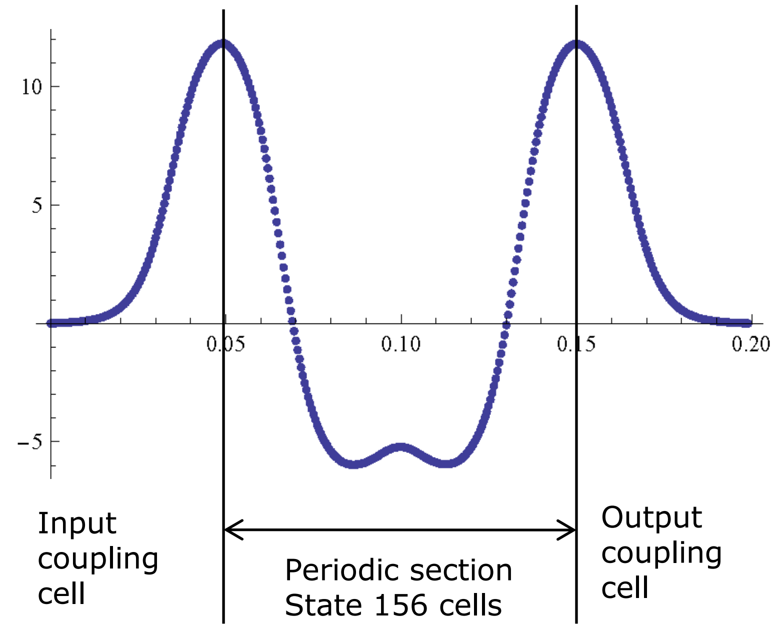


MAX-IV high brightness injector. General considerations



1.5-cell FERMI type S-band gun with Cu photocathode

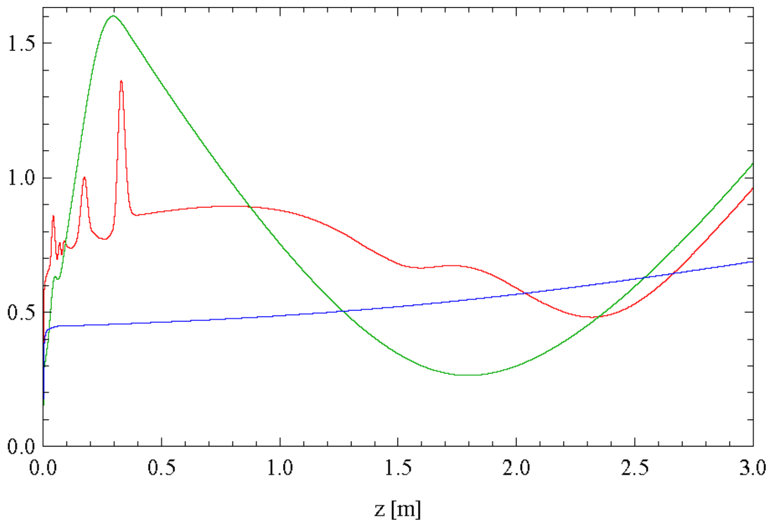
5 m long S-band 2π/3 travelling wave linac



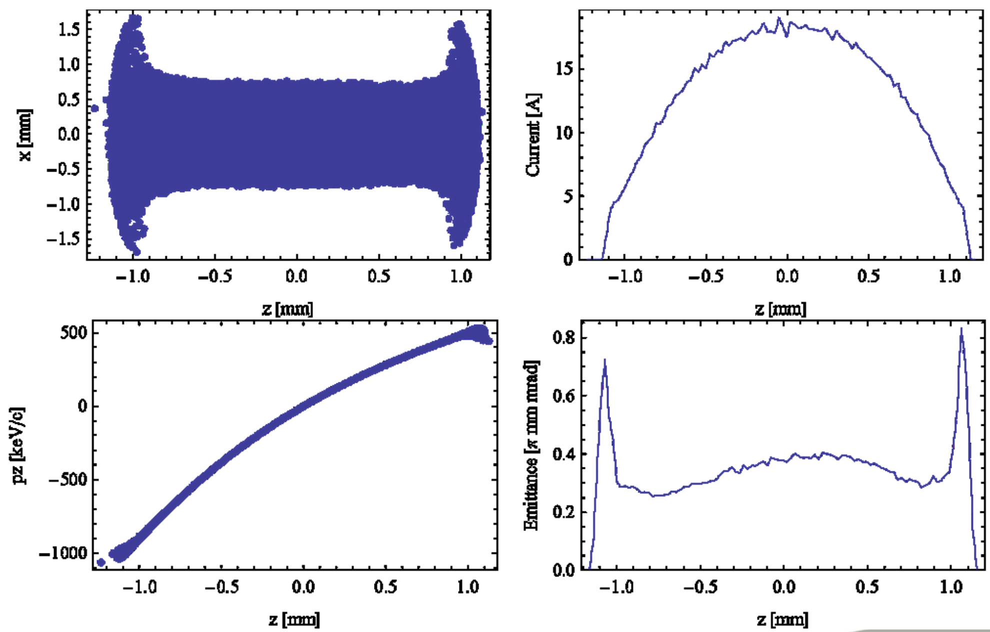
BUNCH COMPRESSION BY LINEARISING ACHROMATS FOR THE MAX IV INJECTOR

S. Thorin, M. Eriksson, S. Werin MAX-lab, Lund, Sweden
D. Angal-Kalinin J. McKenzie, B. Militsyn, P. Williams, STFC/DL/ASTeC, Daresbury, UK

MAX-IV high brightness injector. Emittance compensation scheme optimisation results

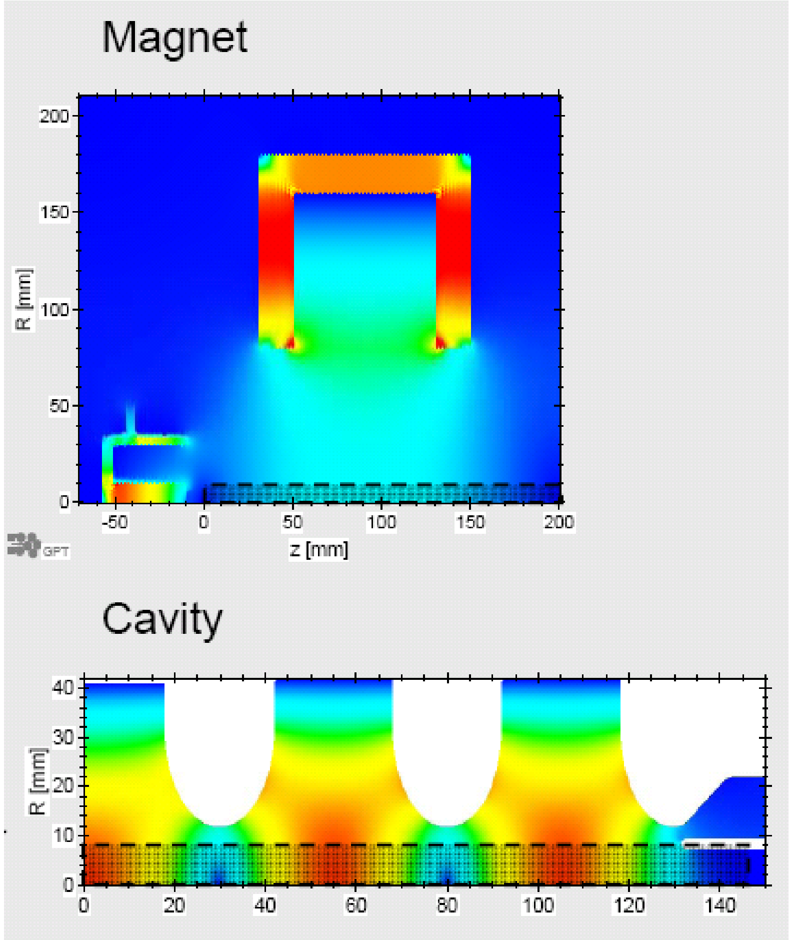


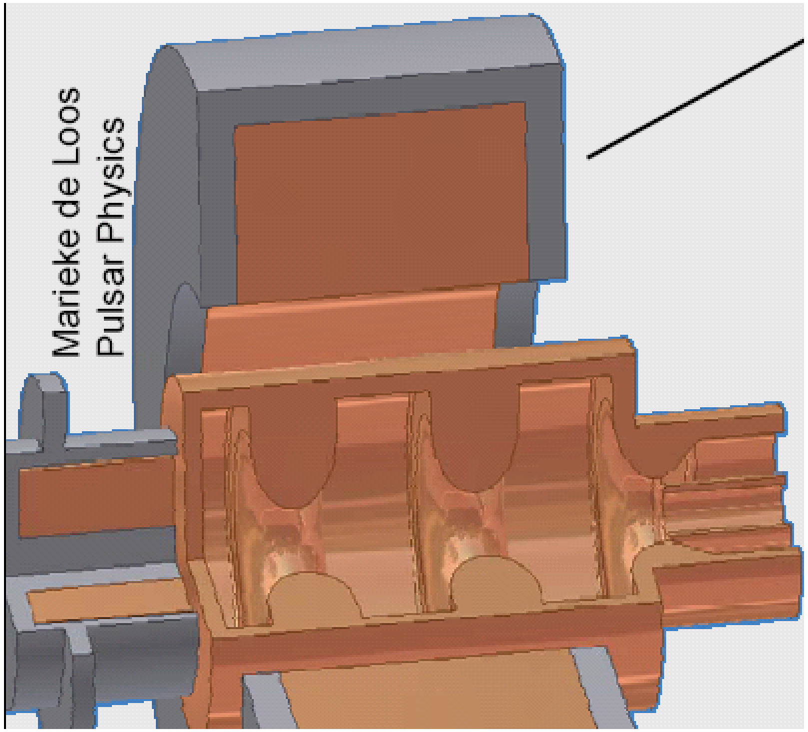
Beam size (rms)	0.317	mm
Projected emittance	0.396	mm mrad
Average slice emittance	0.350	mm mrad
Peak current	19	A
Bunch length (rms)	1.79	ps
Bunch length (full)	7.87	ps
Energy spread (full)	1.59	MeV
Energy	104.2	MeV



Bunch charge	100	pC
Laser spot diameter	1	mm
Laser pulse width	5	ps
Laser rise/fall times	1	ps
Initial thermal energy	0.75	eV
Gun peak field	100	MV/m
Gun phase	- 5	°
Solenoid peak field	0.192	T
Linac entrance position	1.85	m
Linac peak field	26.25	MV/m
Linac phase	+ 5	°

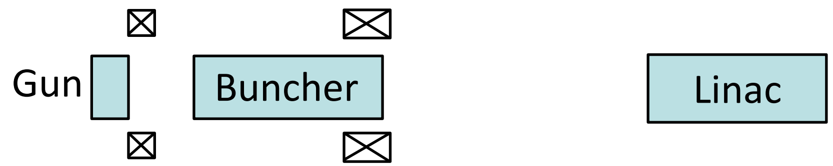
Ultra high brightness photoinjector, based on a 2.5-cell S-band gun

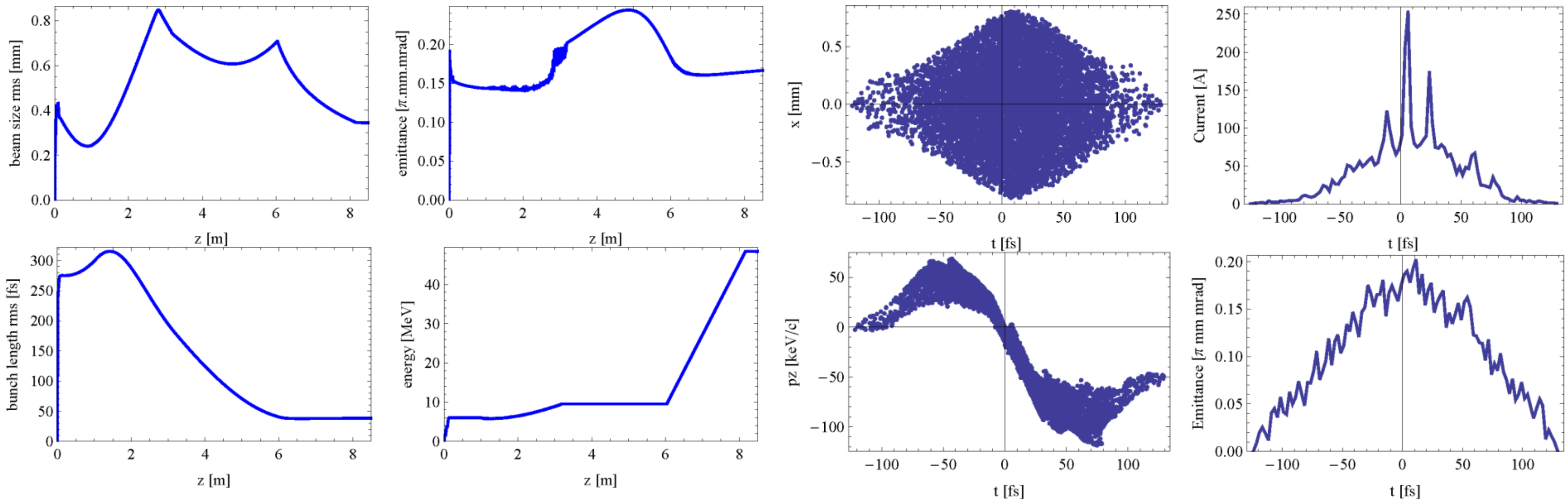




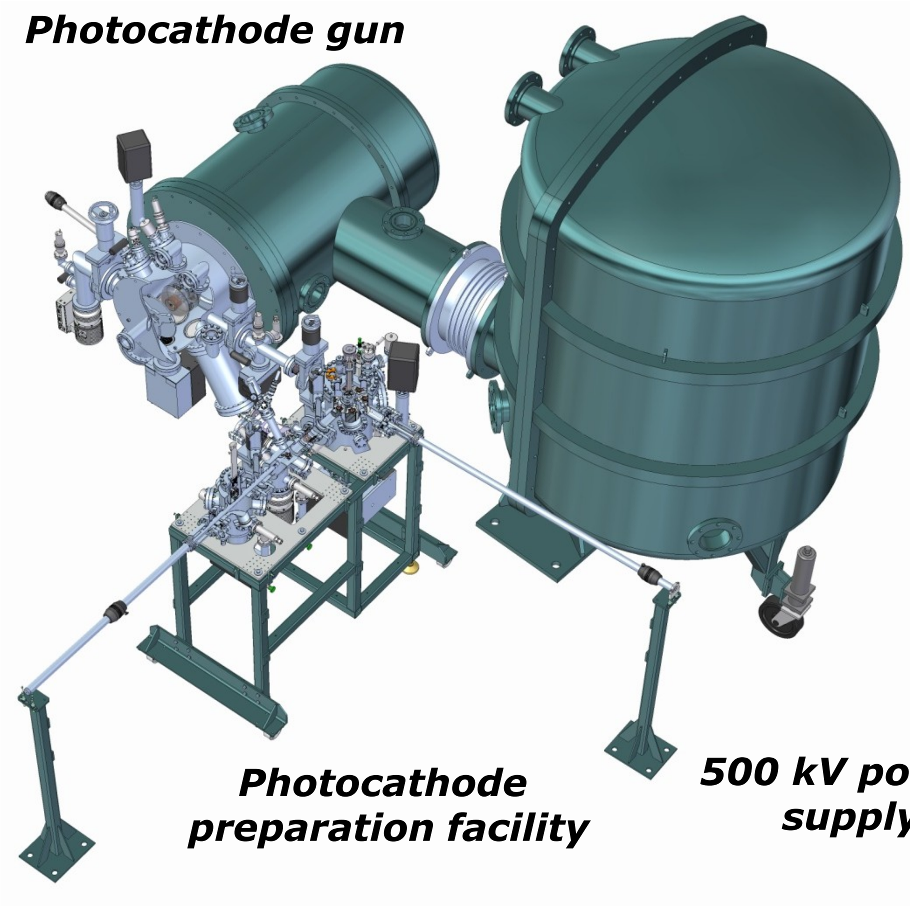
See poster of J.W. McKenzie for details

ASTRA simulations of the dynamics in the 2.5-cell gun





ALICE DC photocathode gun upgrade

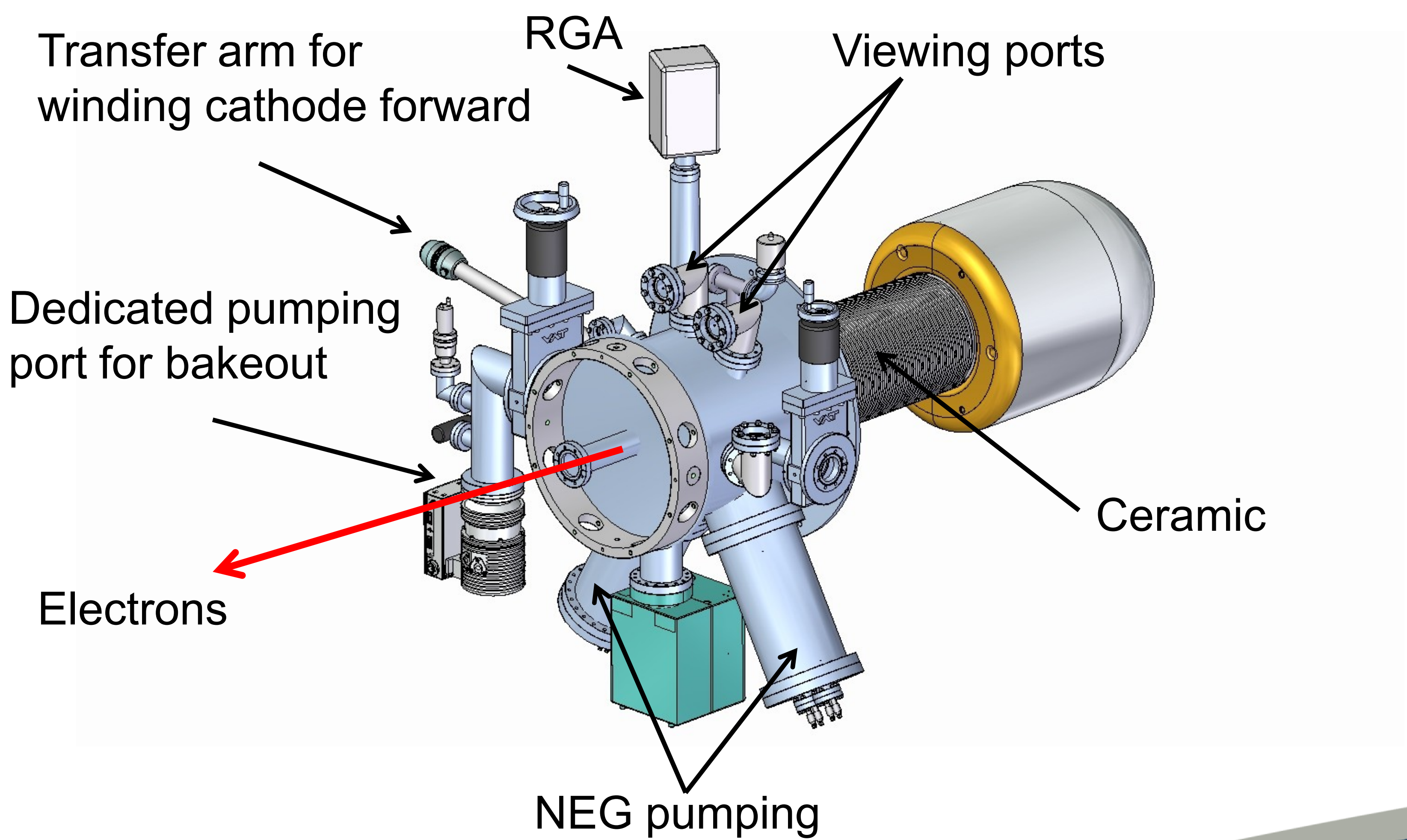


Upgrade of the gun allows

- 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

See poster of L.B. Jones for details

ALICE gun upgrade. New gun chamber



Conclusion

- ASTeC is successfully leading experimental work in the development of high current, high repetition rate photocathodes and photoinjectors, with the following particular successes:
  - High current GaAs and GaAsP photocathode technology has been successfully developed and implemented at ASTeC in collaboration with Institute of Semiconductor Physics, Novosibirsk
  - Photocathodes designed for 4GLS and ALICE have been manufactured and their activation technology developed to reach quantum efficiencies as high as 20%
  - An ALICE gun upgrade utilising GaAs and GaAsP has been designed and manufactured. The gun chamber is now undergoing commissioning.
- Significant effort have been concentrated on design of a high repetition rate injector for a national soft X-ray light source NLS
- ASTeC concentrates efforts on design of ultra high brightness photoinjectors on the basis of both existing photocathode and accelerating technologies and technologies which are still under development
  - Design of the high brightness injector for MAX-IV SR facility
  - Design of a ultra high brightness injector facility at ASTeC