Electron Source Simulations and Lab Plans at CLS

Xavier Stragier

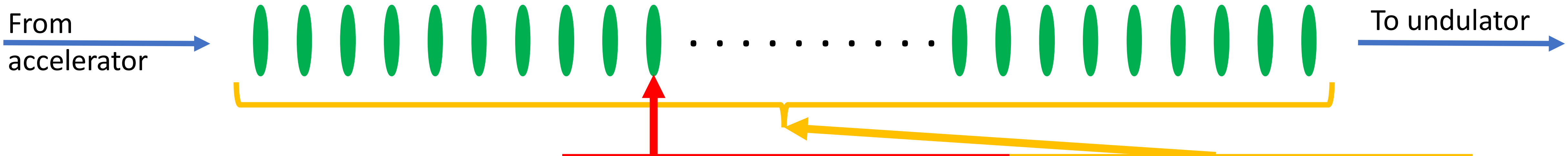
19 March 2024

IR FEL Workshop at TRIUMF

1) What are the electron beam properties for an IR FEL:

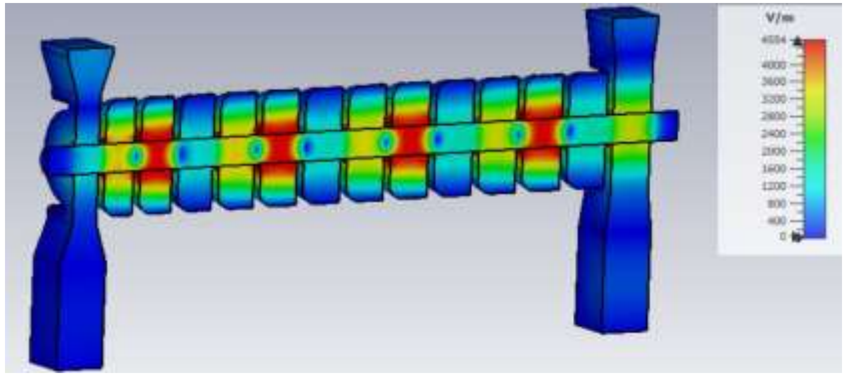
Required electron beam properties at the entrance of the IR undulators:

(Based on FELIX and Fritz Haber and discussion with Alan Todd)



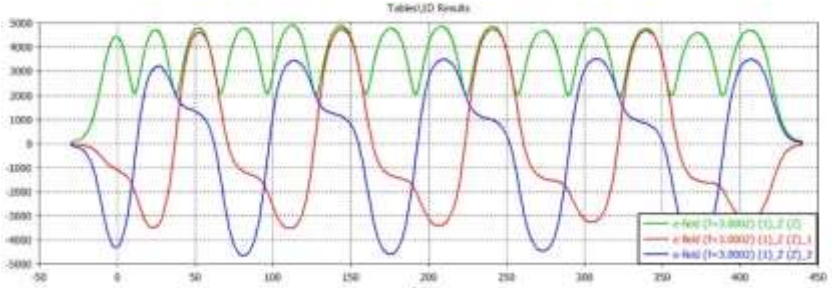
	Micro bunch (single electron bunch in a bunch train)	Macro bunch (1 complete bunch train)
Length	1-3 ps	10-20 μs
Charge	100-200 pC	1-5 μC
Average current	30-200 A	0.1 -0.5 A
Repetition rate (base frequency)	500 MHz-1 GHz	10 -20 Hz
Energy	15-50 MeV	15-50 MeV
Energy spread	0.1-0.3 %	0.1-0.3 %
Number of single electron bunches	1	10,000-20,000
Longitudinal emittance	50 keV-psec	-
Normalized emittance (x,y)	< 20 π mm.mrad	< 20 π mm.mrad

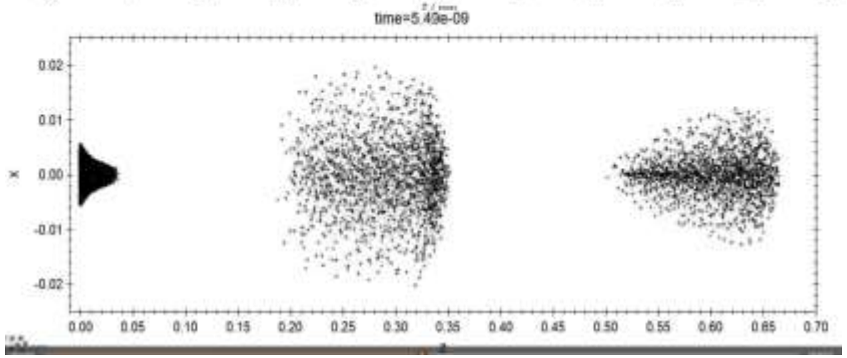
2) How can CLS assist in designing, simulating and/or testing of the e-source and beamline for IR FEL?



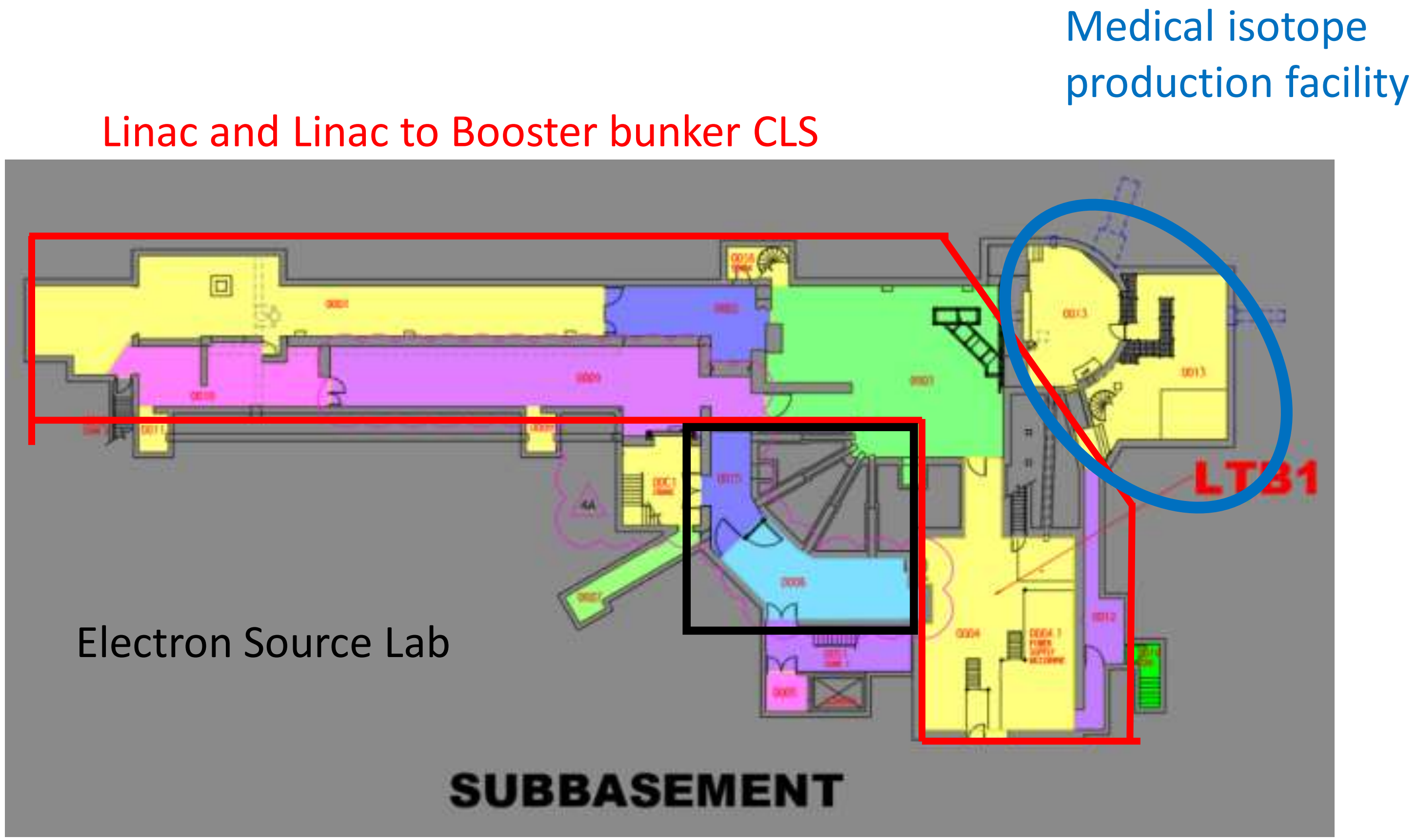
Can help with :

- Electron source and beamline design
- EM simulations of the different components (CST/HFSS/COMSOL)
- Beam dynamics simulations by tracking electron bunch through the complete beamline from source (GPT)
- Optimization of the different components for optimal beam quality
- Installing, testing and operating of the complete setup.



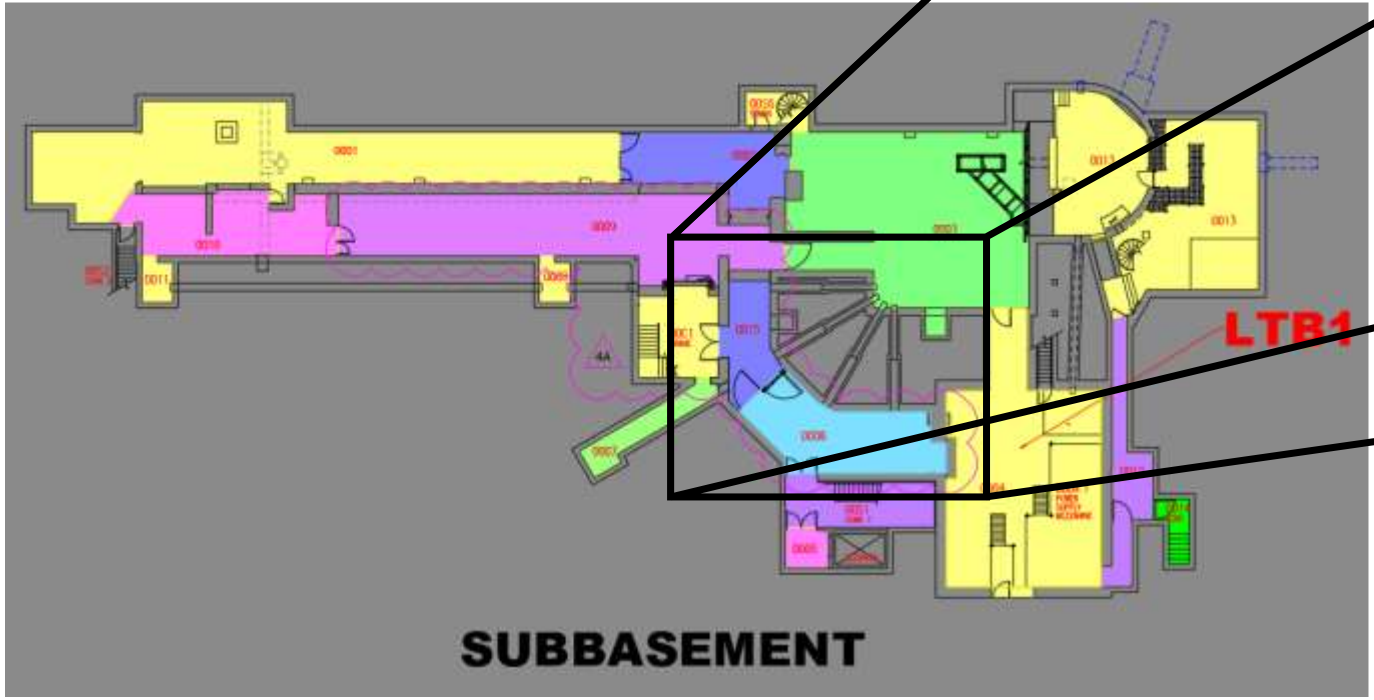


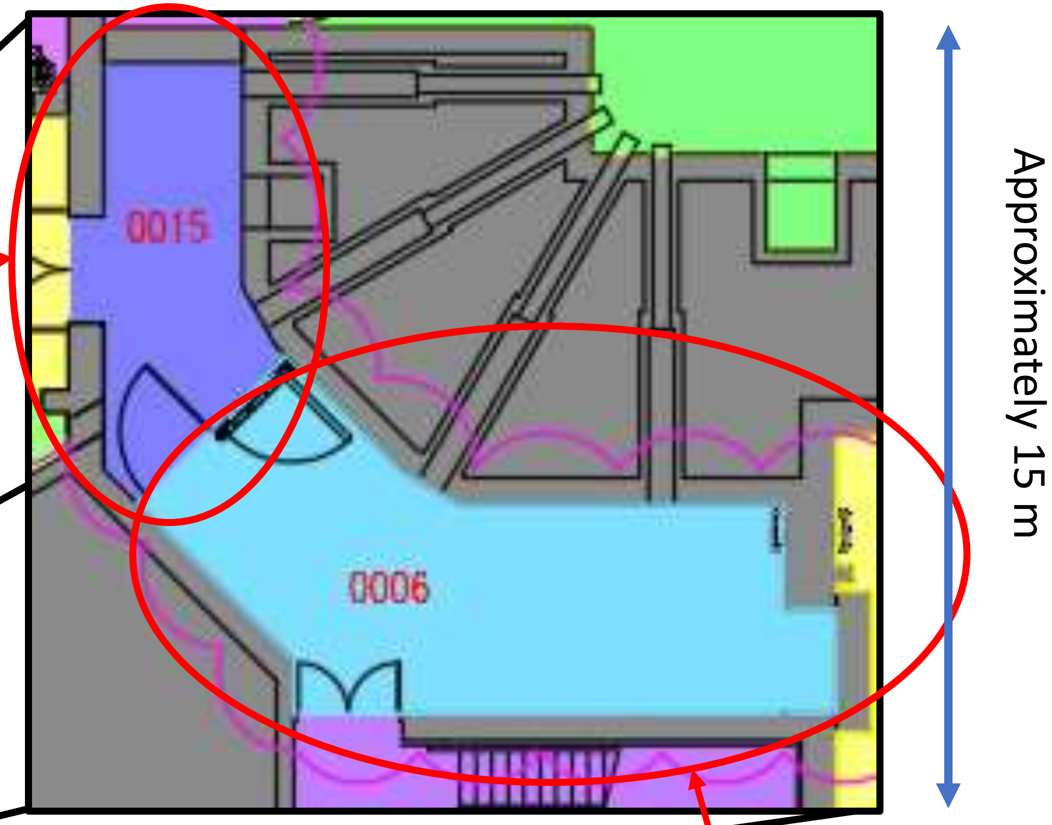
3) CLS lab facility : Electron source lab location at CLS



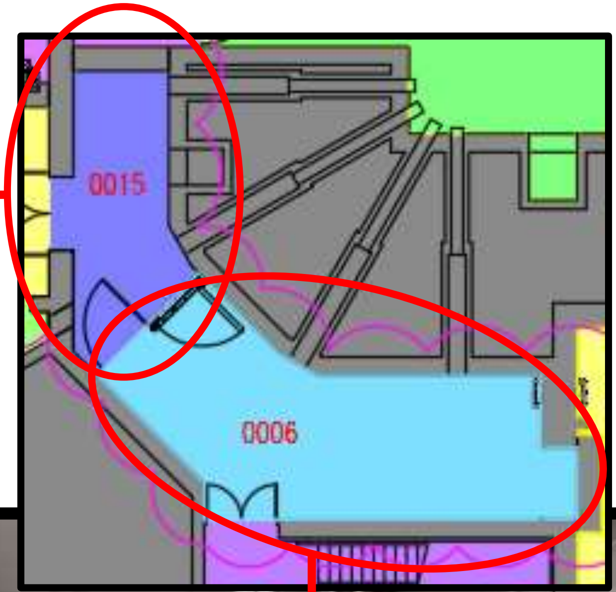
All 3 bunkers labs are independent accessible of each other at all times!!

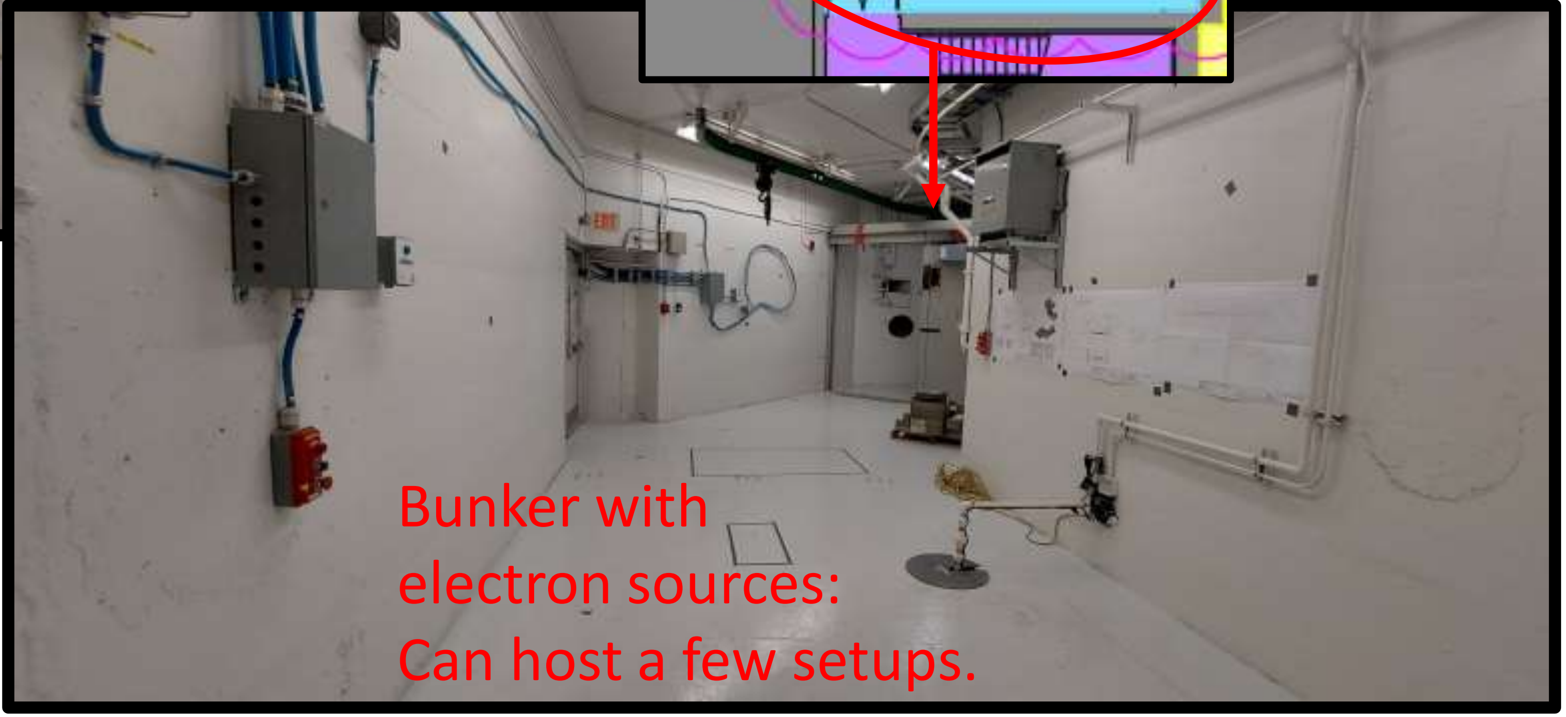
3) Electron source lab location at CLS





3) Status of Electron source lab January 2024:





Still waiting for :

- 1 radiations doors to be installed
- 1 fire safety doors
- Permits from city
- Class 2 radiation lab permit
- Some Infrastructure

➔ ESL to be ready by the end of 2024

4) Possible e-sources for IR FEL (to my opinion at this moment)

- 4.1 Thermionic DC source with modulating grid at 500 MHZ - 1 GHz
  ➔ 'Standard' design to play safe (FELIX, Fritz Haber, new LINAC source at CLS)
- 4.2 Thermionic RF source (MAX IV injector for synchrotron)
  ➔ Can generate similar bunches, but at higher rep rate (3GHz) and better normalized emittance < 5 μm.

e-sources with superior beam quality but 'overkill' for an IR FEL (or not???)

- 4.3 DC photo e-source at high repletion rate (>500 MHz), Cornell Type electron source:
  ➔ Problem: complex and big footprint.
- 4.4 Thermionic LaB_6 /CeB_6 DC e-source in combination with higher harmonics RF cavity to chop and compress the beam
  ➔Very promising to be cheap, easy, reliable, compact but still in experimental phase.

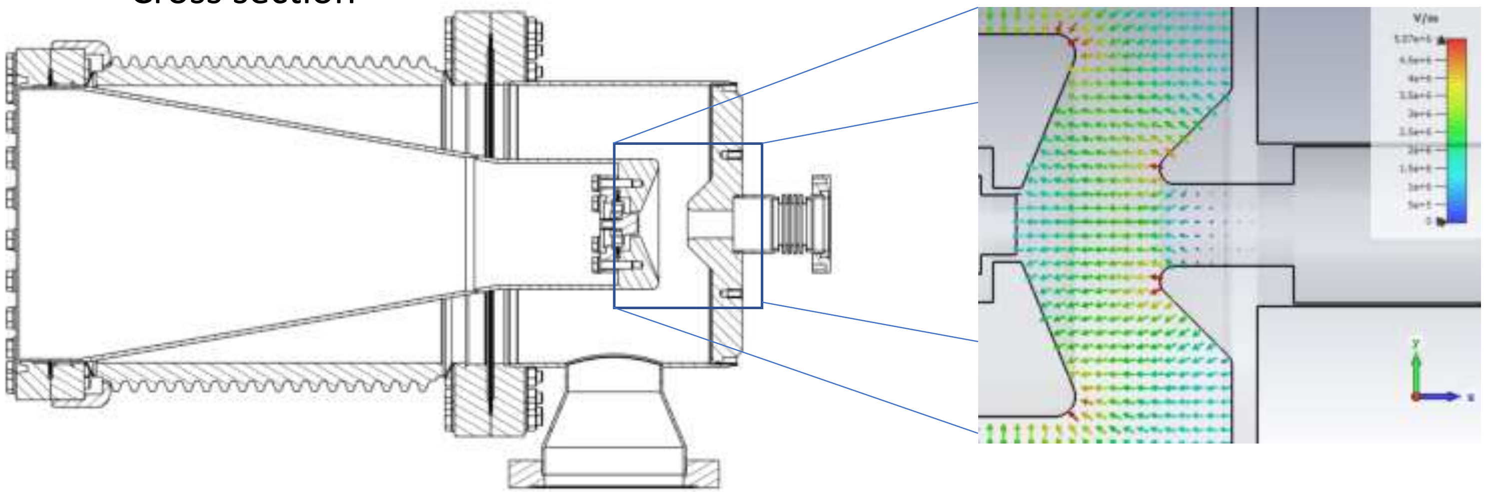
4.1) Thermionic DC e-source with a modulating grid:

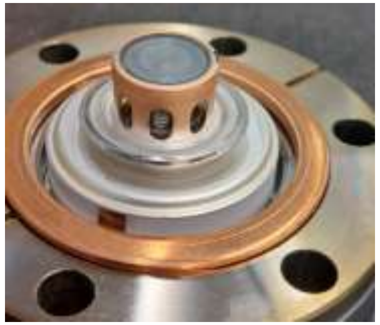
- Felix and Fritz Haber design

CLS source being tested at RI

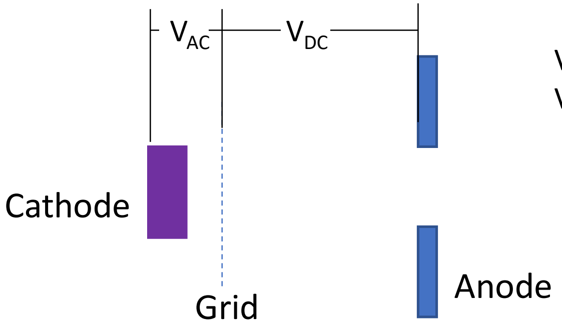
Cross section

Electric fields e-source





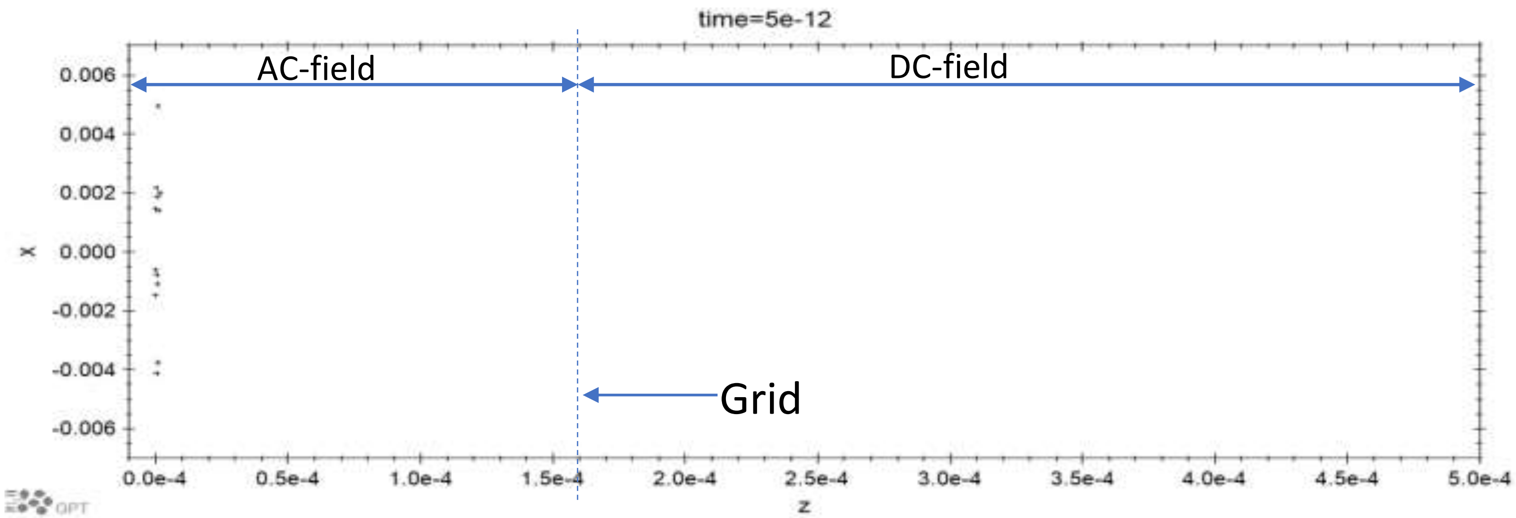
Cathode grid assembly



V_{AC} = ~ 10-50 V
V_{DC} = ~ 100 kV

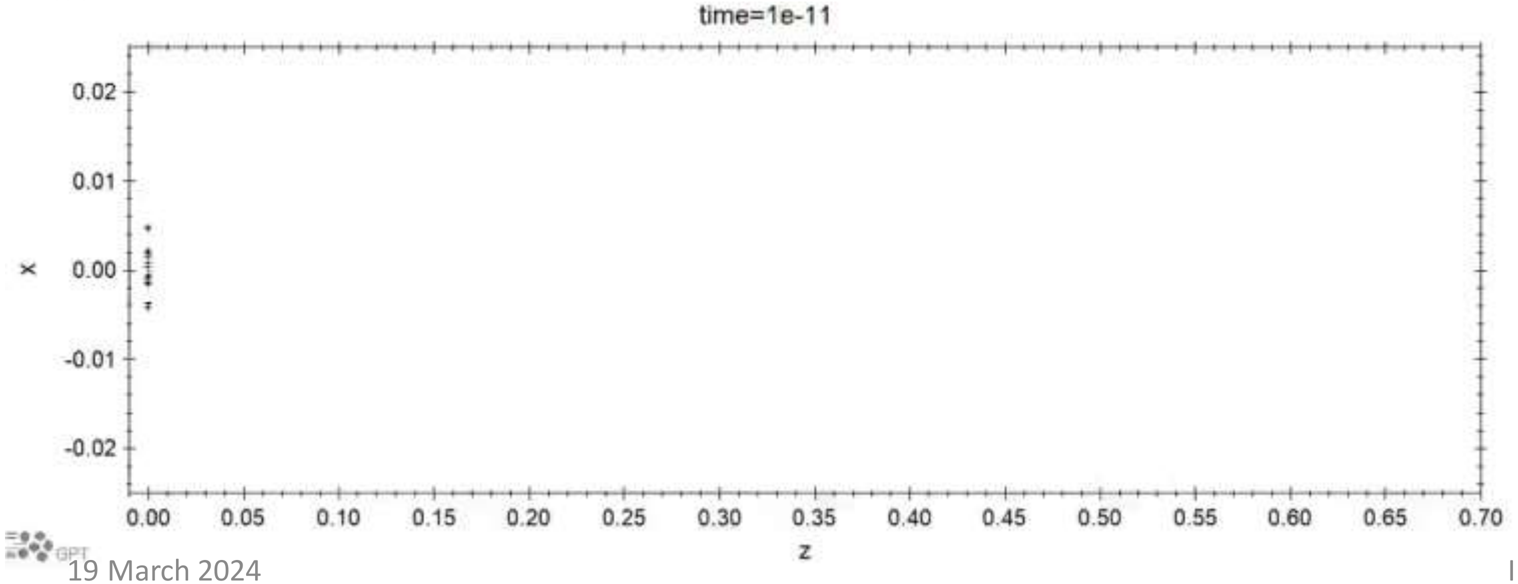
Cathode-Grid distance ~ 150 µm

4.1) Thermionic DC e-source with a modulating grid: Beam dynamics simulations



'Grid effect': first 0.5mm

Micro and Macro Beam properties of this source satisfies All IR FEL requirements!!!



e-source + first 0.7 m

4.2) Thermionic RF e-source:

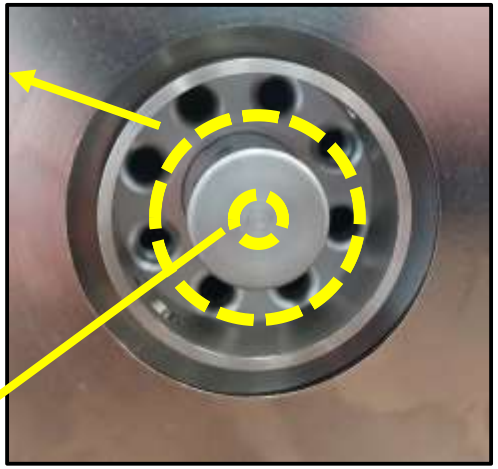
Thermionic emitter in a RF cavity with a high electric field strength
➔ Already produces separate electron bunches at exit of the e-source.

- Gun adjusted to 2.856 GHz
- 3D model received from MAX lab
- Fields simulated in COMSOL

MAX IV
New features of the MAX IV thermionic pre-injector
J. Andersson*, D. Olsson*, F. Curbis, L. Malmgren, S. Werin

The design of a 3 GHz thermionic RF-gun and energy filter for MAX-lab
B. Anderberg, Å. Andersson, M. Demirkan, M. Eriksson, L. Malmgren, S. Werin*

BaO Emitter



Stored at CLS

Cross section e-source

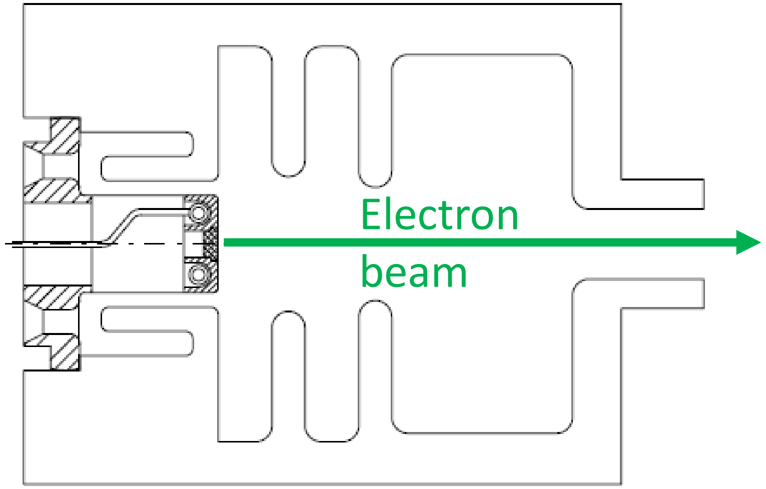
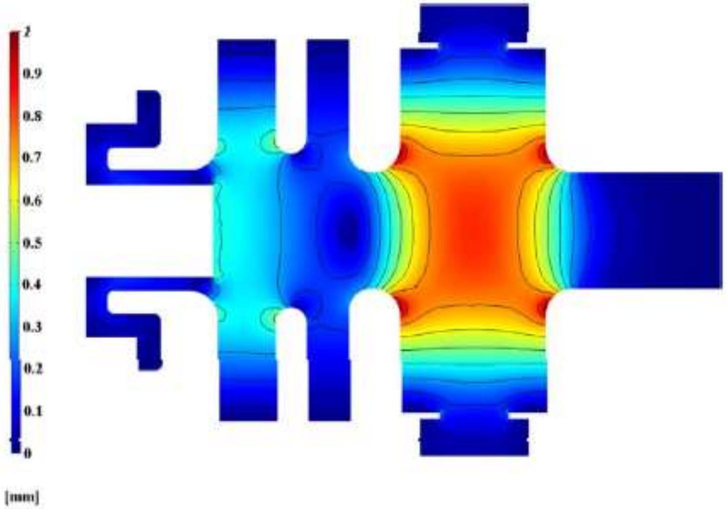


Fig. 1. Layout of gun, RF-choke and cathode.

EM simulations

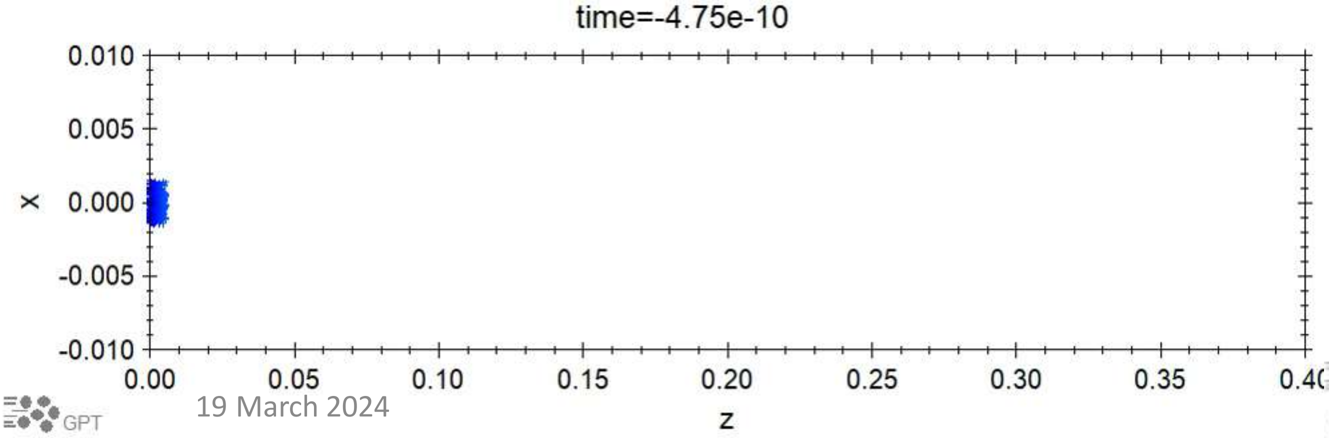


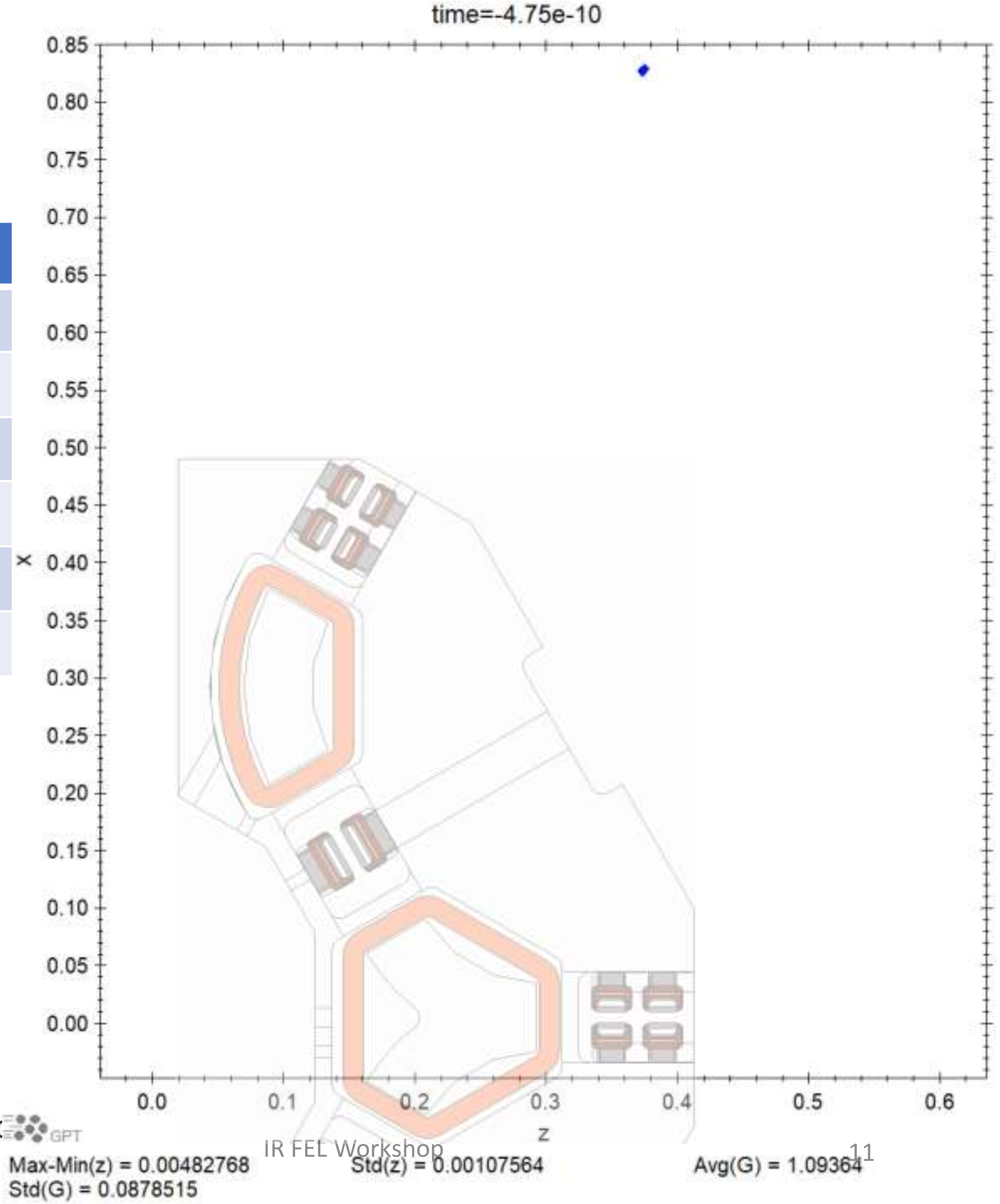
The design of a 3 GHz thermionic RF-gun and energy filter for MAX-lab
B. Anderberg, Å. Andersson, M. Demirkan, M. Eriksson, L. Malmgren, S. Werin*

4.2) Beam dynamic simulations Thermionic RF e-source:

Single bunch beam properties	At exit e-source	At exit energy filter
Average Energy [MeV]	1.7	2.35
Energy spread [keV] (rms)	510	24
Energy spread % (rms)	30	1
Bunch radius [mm] (rms)	1	1.9
Bunch length [ps] (rms)	~200	0.8
Normalized emittance [µm]	~30-40	4

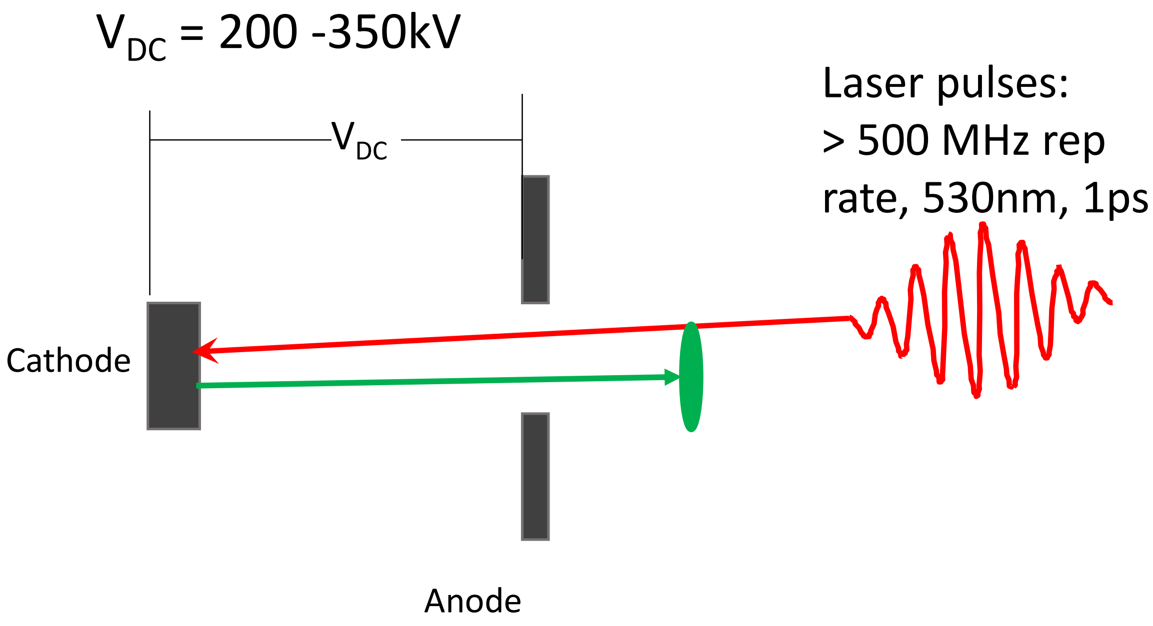
For 0.3A extraction current at cathode ➔ ~ 25 pC of charge per single bunch after filter (3 A is maximum extraction current)





4.3) DC photo source at high rep rate:

Cornell type e-source

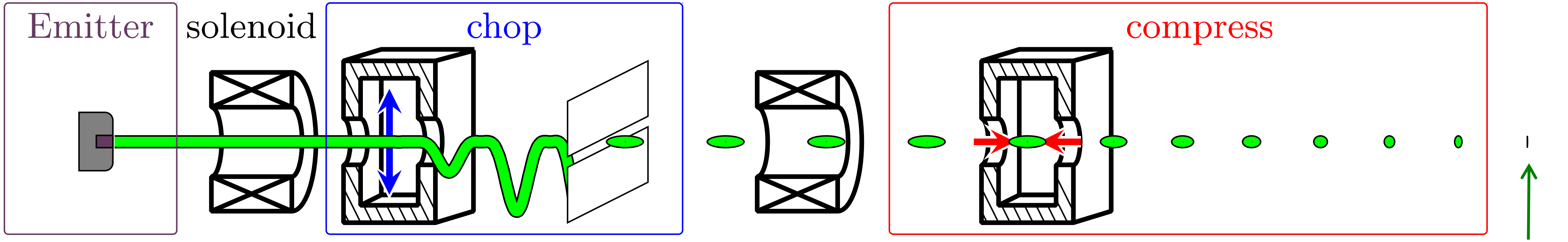


Superior beam quality…..but:

- Requires high rep rate laser
- laser scientist/technician,
- replaceable semi-conductor cathodes
- ultra high vacuum
- big footprint
- expensive

Not pulsed, but continues beam at laser rep rate!

4.4) Thermionic DC source with higher harmonic cavities:

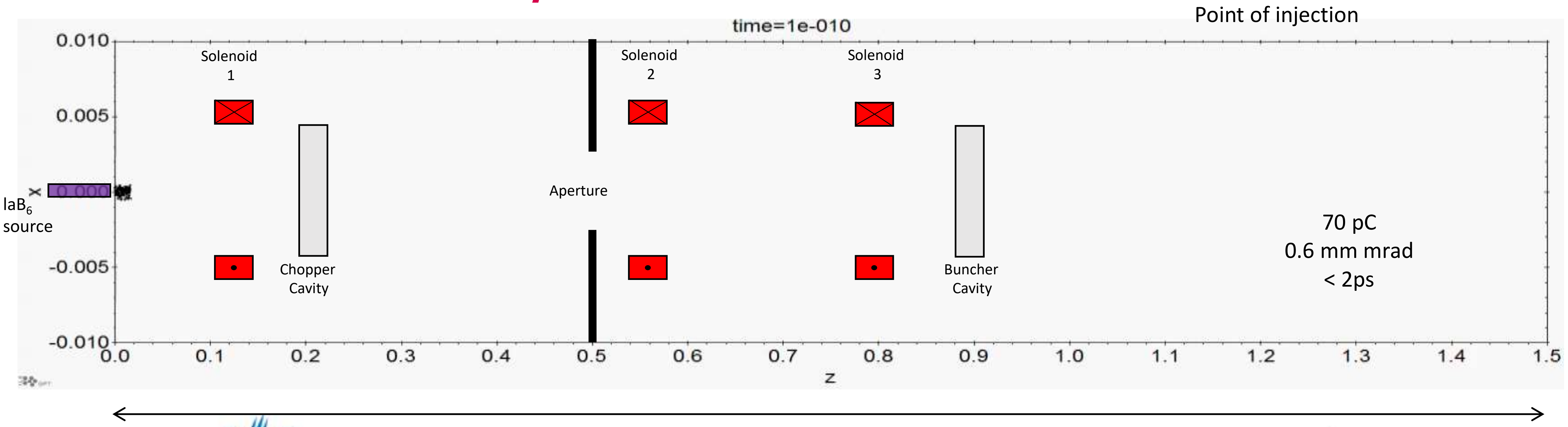


LaB_6 source

TU/e Technische Universiteit Eindhoven University of Technology

Courtesy: Wiebe F. Toonen

Point of injection



Conclusions.

- The electron source lab at CLS should be ready by the end of 2024. If desire, components that generate radiation can be tested in the lab.
- CLS can assist and help with e-source/accelerator/ beamline design , EM simulation, beam dynamics simulation, and testing of these components.
- Thermionic DC electron source with a modulating grid is the most straightforward option but Thermionic RF source is worth investigating as alternative because of it can have beam quality and higher rep rate → more IR power
- 'Alternative sources' probably not the best option at this moment as they are still in an experimental phase and might cause delay and reliability issues.

Thank You!