FEL at MAX-lab

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Workshop on the development of future linear electron-positron colliders
for particle physics studies and for research using free electon lasers
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Describing Free Electrons Lasers at MAX-lab could be a very simple job by simply stating that there is none. At the moment there are no applications on actually building an FEL either. This is the thruth but may be not the complete truth as we have ideas and perform development and in many aspects have plans for FEL activities in the future.

When regarding the FEL development it is also important to see how MAX-lab has taken on accelerator technical projects in the past. The basic principle has been not to drive the big technology breakthroughs, as this demands very high costs. Instead we have taken the role of a "good 2nd" when our resources are available implement the ideas to exactly the necessary level. We are thus especially following the different "proof of principle" experiments for SASE performed at DESY(Hamburg) and APS(Argonne).

The history of the laboratory started twenty years ago, or even earlier, at the physics department at Lund University. And some of the milestones are the following:

1979	The Racetrack microtron was ready
	Decision to build MAX I (500 MeV Storage ring)
1986	MAX I storage ring was ready
1991	Funding of MAX II (1.5 GeV storage ring)
1994	First injection into MAX II
1998	Funding of a new injector and storage ring

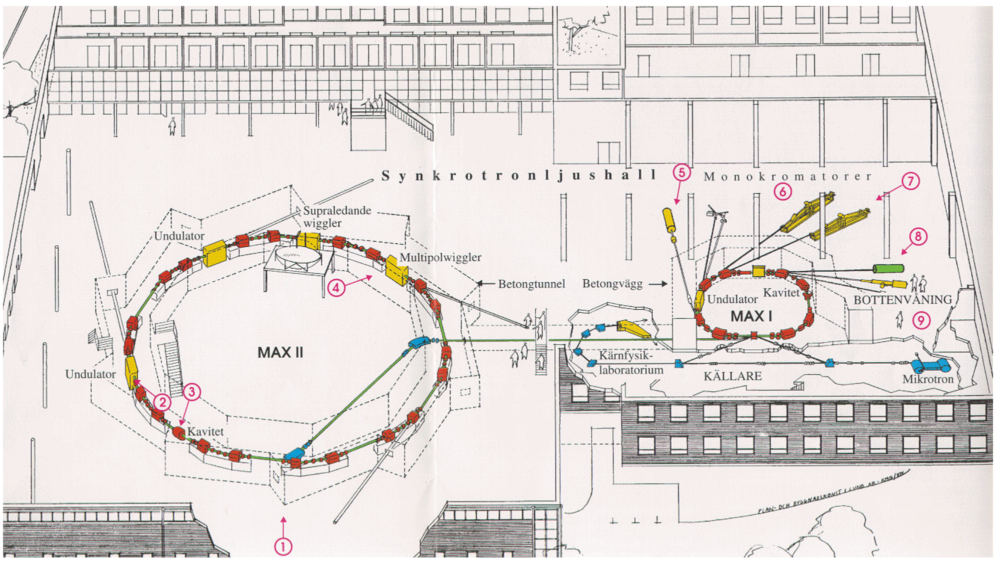


Figure 1. Overview of the MAX-laboratory.

1 FEL history

Despite not having any operating FEL at MAX there has over the years been Fel related research and plans. One of the earliest points occurred ten years ago when some sketchy experiments in Coherent Harmonic Generation were performed. (The technique uses an undulator through which an electron beam propagates. It is irradiated by a laser and due to energy exchange the electrons can be made to radiate coherently at higher harmonics of the laser). During the last years the laboratory has been involved in international collaborations for FEL projects, workshops and feasibility studies. Some points of interest are given below:

1989 Coherent harmonic generation (+Lund Laser Centre)
(*NIM A290 (1990)589*)
1996 Workshop: The scientific case of an IR-FEL at MAX-lab
(*ISRN LUNTDX/NTMX-7023-SE*)
1997 Prestudy of a VUV-FEL for MAX-lab
(*ISRN LUNTDX/NTMX-7024-SE*)
1998 EU project "Development of a combined SR and VUV FEL facility" at Elettra, Trieste
1998 Coherent 1 mm radiation from MAX I (Å. Andersson et.al.)
1998 Workshop: Current development of FELs
(*ISRN LUNTDX/NTMX-7028-SE*)
1999 "An RF-gun driven Recirculated linac as injector and FEL driver"
(*FEL-99 Hamburg*)
1999 EU project: "X-ray FEL pump-probe" at Hasylab

2 Current development

The development right now at MAX-lab is focused on a new 500 MeV linac system with an RF-gun, which is intended as an injector for the existing storage rings, and a new 700 MeV storage ring for synchrotron radiation.

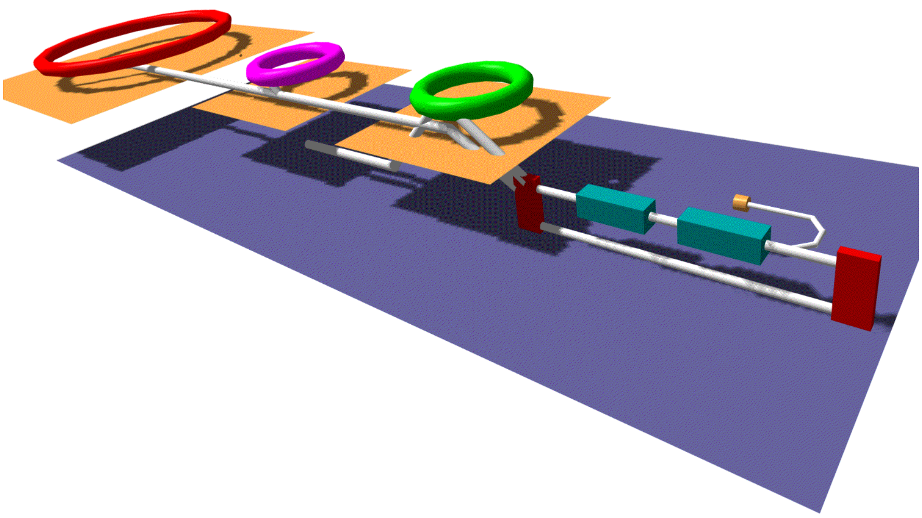


Figure 2. The accelerators at MAX-lab. The new injector closest to the right and the new storage ring in the middle.

2.1 RF-gun

The new system carries a lot of possibilites beyond the use as a new injector. The electron source will be a newly deveopled thermionic RF-gun, which brings us into a new domain. The charge and emittance from this kind of gun is superior to the traditional types and will allow us to generate a beam suitable for an FEL. The developed structure will also be able to carry us into the field of photo RF-guns which is the key to generating the intense electron beams for short wavelength FELs.

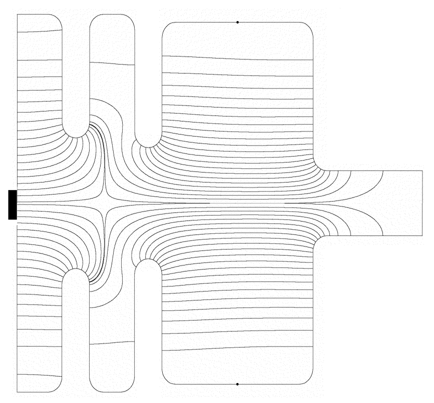


Figure 3. Layout of the thermionic RF-gun developed at MAX-lab.

Table 1. Parameters for the thermionic RF-gun

Power dissipation	2.02			MW @ 81.4 MV/m on axis
Q	15030			
Shunt impedance	60.6			MOhm/m
Maximum electric field on axis	81.4			MV/m
Maximum electric field on boundary	97.4			MV/m @ 81.4 MV/m on axis
Frequency	2999.15			MHz (dependent of mesh size)
Beam kinetic energy	2.3			MeV (kinetic ⇒ 2.8 total)
Rise time	0.42			µs
Input coupling	3			
Coupling between cavities	2.64			
	0 mA	**100 mA**	**600 mA**	
Beam power	0	0.23	1.38	MW (@ dE=2.3 MeV)
Energy spread	< 1	3.4	29	KeV (total)
Pulse length	0.26	0.37	0.97	ps (total) ≈ deg (total)
Emittance	0.09	0.43	1.3	π mm mRad (@ E=2.8 MeV)
Emittance, norm	0.48	2.4	7.0	π mm mRad

An Rf-gun, and a thermionic one in particular, needs to be followed by an energy filter. A ususal solution is an alfa-magnet, but we have chosen a more flexible system consisting of two bending magnets and quadrupoles. The energy tail in the electron distribution can be filtered at the dispersion point in the middle of the filter. The filter can also be tuned to perform some bunch compression.

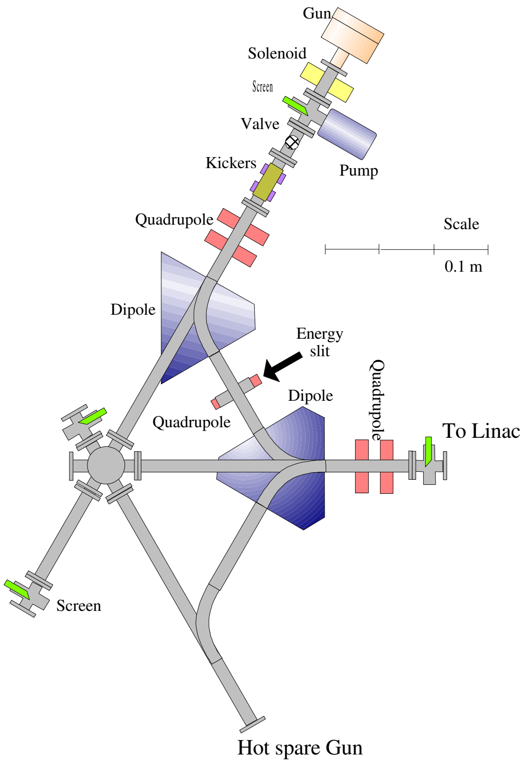
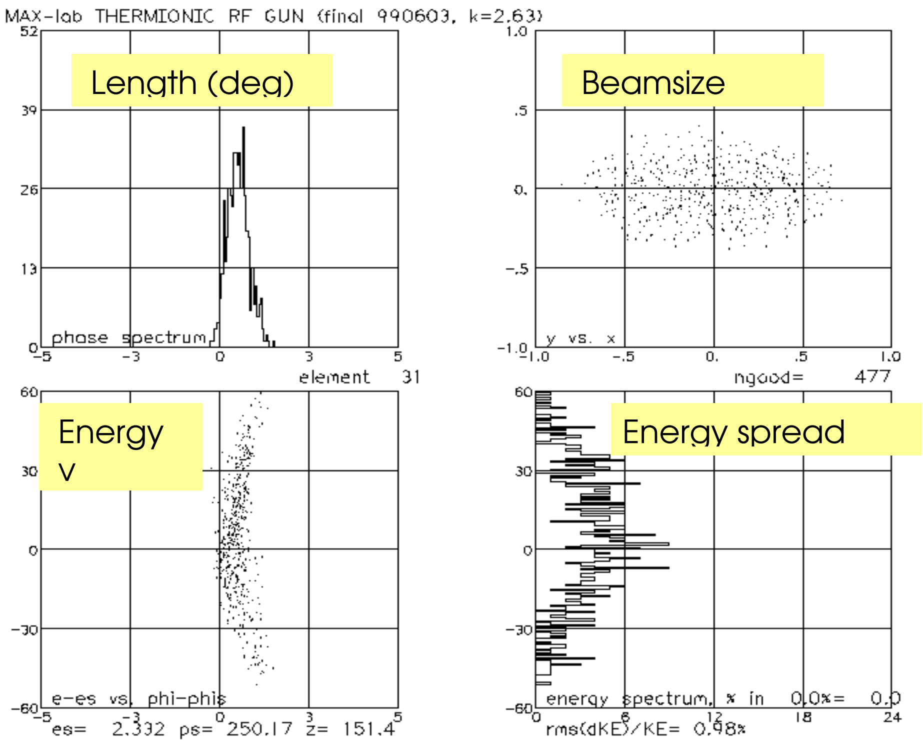


Figure 4. Energy filter.

By use of the energy filter an electron beam with excellent qualities will be achieved.

Figure 5. Electron beam characteristics after the energy filter.



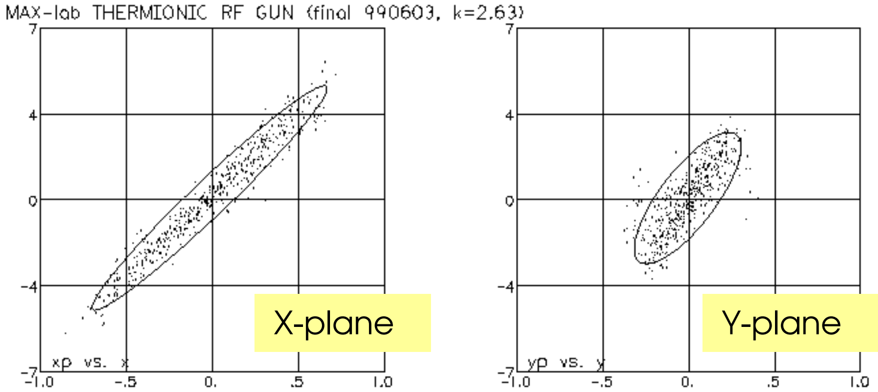


Figure 6. Electron beam emittance.

2.2 Linac system

The linac will carry the electron beam up to 500 MeV, or intermediate energies, conserving most of the characteristics of the high intensity beam from the RF-gun and energy filter. Data on the linac system can be found below.

Table 2. Data on the recirculated linac system

Length	5.2	m
R sh	52	MΩ/m
Q	10.000	
Damping	0.5	
Fill time	0.7	µs
Decay time	1.38	µs
Phase shift	3.8	µs
Frequency	3	GHz
Klystron power	35	MW
Energy gain (no SLED, 0 A)	77.35	MeV
Energy gain (SLED, 0 A)	138.7	MeV
Energy gain (SLED, 50 mA)	136.5	MeV
Peak gradient increase by SLED	x 2.63	
Peak integrated gradient increase by SLED	x 1.793	

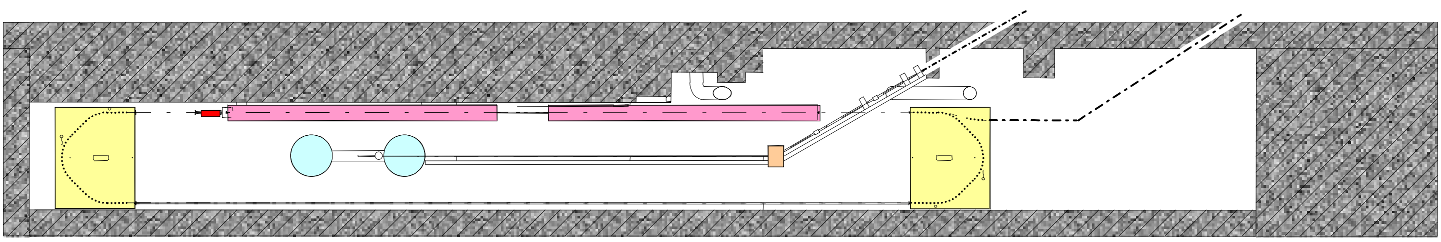


Figure 7. The injector system.

2.3 Research and development

The tools above will not only give opportunities in future FEL applicaitons they will also help to develop techniques and knowledge about several key topics in FEL design:

RF-gun

- Emittance compensation (trans/long)

- Back bombardment
- Photo RF-gun
- Cathode materials
- Laser tech. (Lund Laser Centre)
- Multicell structures

Linac
- Compression schemes
- Recirculation
- Energy recovery

Compression
- Space charge
- Optics
- Coherent radiation

3 Capacities as an FEL driver

What is even more interesting is the capacities that this kind of driver has as a driver for FEL. One can point out three different areas in which the new system will be able to operate as a driver.

3.1 IR-FEL

In an infre red FEL a low energy beam is used in an optical cavity configuration. Wavelengths from 5 to 100 µm can be generated. The driver as designed today will be able to produce this beam if the klystron pulse for the RF-gun can be elongated.

3.2 Storage ring FEL in the visisble

The new storage ring will be built to be able to house a Storage ring FEL. Development of this kind of system is performed in a EU-project for such an FEL at ELETTRA, Trieste. Possible operating conditions are found below.

Table 3. Storage ring FEL paramters

Undulator	Period (m)	0.04
	# periods	50
	K-value	3
	Length (m)	2
	Wavelength (nm)	200
e-beam	$\varepsilon_{\text{norm hor}}$ (2π m Rad)	9.4e-5
	Coupling (%)	10
	Peak current (A)	50
	Average current (mA)	20
	Energy (MeV)	500
	Energy spread (σ_E/E)	5e-4
Results	Gain	0,25
	Power extracted (W)	0,85
	Reduction factors (total)	0,89

3.3 UV SASE FEL

The most tempting performance is what can be achieved in SASE (self amplified stimulated emission) FEL mode. To judge the parameters a similar system has been studied, the LEUTL at APS, Argonne, and similar undulators have been simulated with the electron beam from the MAX-lab linac injector. The results show that the new Max injector will be able to drive a SASE FEL in the wavelength region of 500 to 100 nm. To reach shorter undulators and more relaxed performance a photo RF-gun would help.

Table 4. Undulator and electron beam characterstics in the simulations.

On-axis undulator strength (kG)	10.06
Undulator period (cm)	3.3
K	3.1
Undulator length (m)	2.4

$\Delta E/E$ (%)	0.025
ε_n (π mm-mrad)	6
I_{pk} (A)	200
σ_z (ps)	0.5
Energy (MeV)	125-500

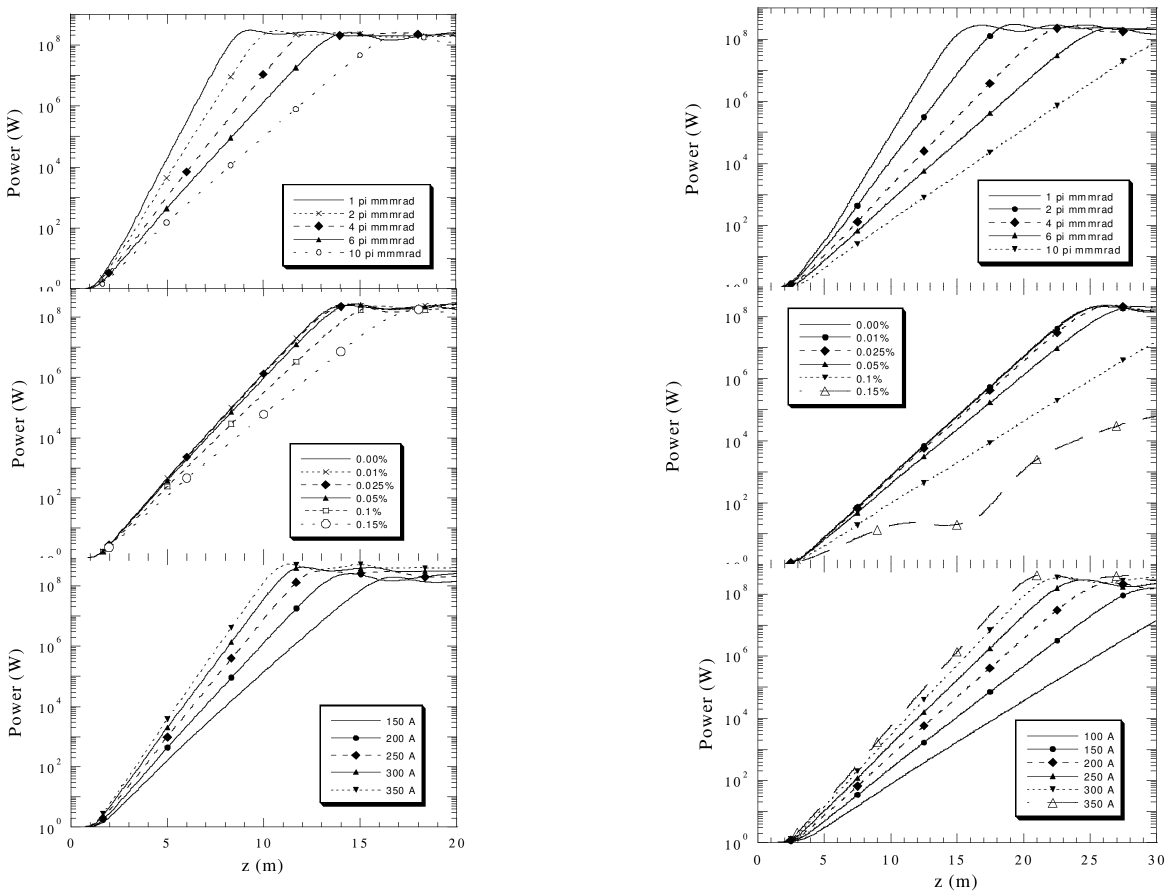


Figure 8. Power as a function of undulator length. Scans over emittance, energy spread and peak current. A) 250 MeV 500 nm, b) 500 MeV 100 nm. [Simulations by: Sandra Biedron (MAX-lab / APS) and Henry Freund]