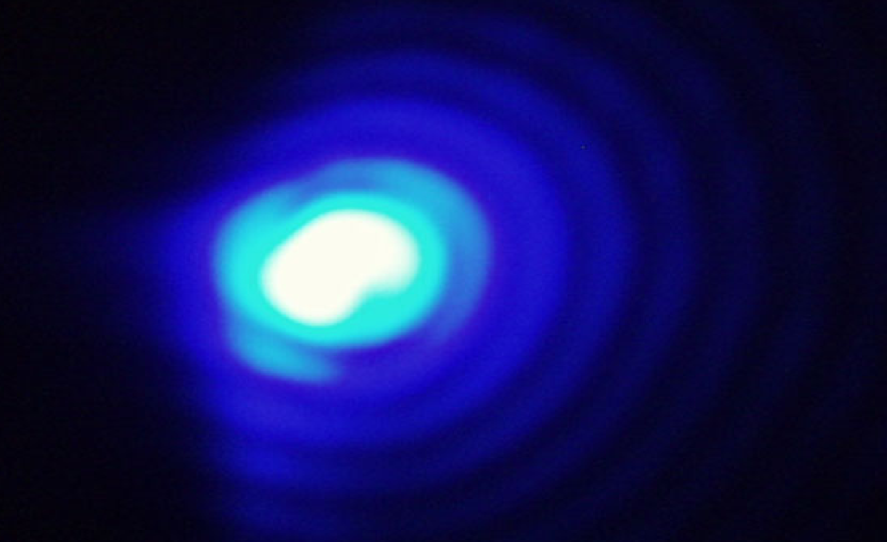
FEL Activity and Possible Developments at ELETTRA

R. P. Walker



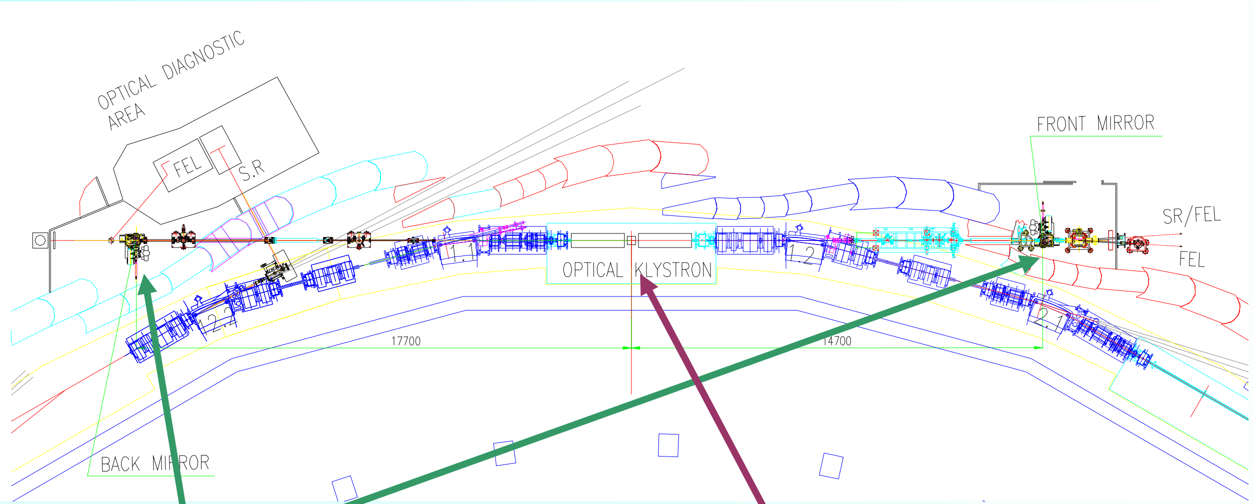
- **EUFELE -** **European Storage Ring FEL at ELETTRA**
- **VXFEL -** **Linac based VUV/SoftXray FEL Project**

EUFELE: European FEL at ELETTRA

- Jun. '97: 1st proposal to the European Commission
- May '98 **Start of 1st EC contract (May '98 - Apr. '01)**
- Aug. '99: Start of hardware installation
- Feb. 18th '00: Completion of installation
- Feb. 29th '00: **First lasing at 350 nm**
- May '00: **Lasing at 220 nm**
- Nov. '00: 180 mW extracted power at 250 nm
- Feb. 6th '01: **Lasing at 190 nm: WORLD RECORD**
- Jul. '01 330 mW at 250 nm
- Oct. '01 Lasing at 1.3 GeV
- Nov. '01 **560 mW** at 250 nm, 1.3 GeV, 37 mA
- Dec. 1st '01 **Start of 2nd EC contract (Dec. '01-Nov. '04)**

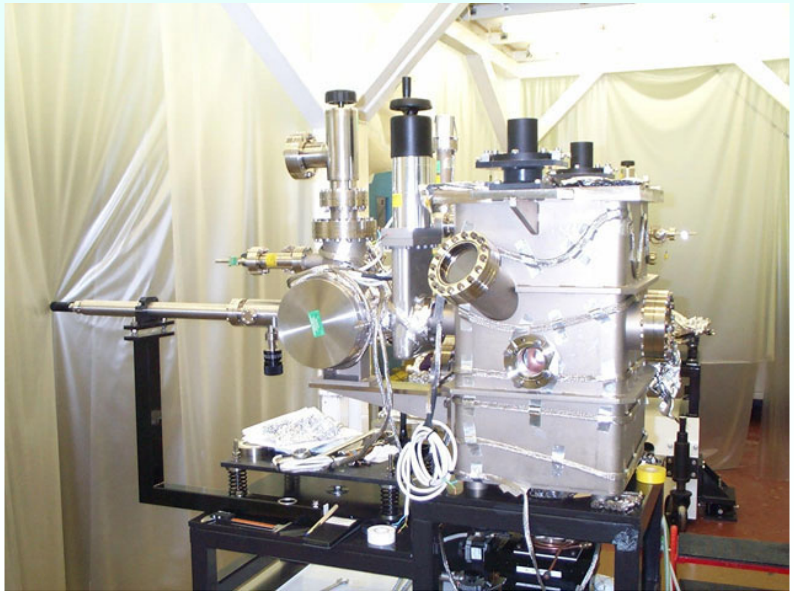
EUFELE: layout

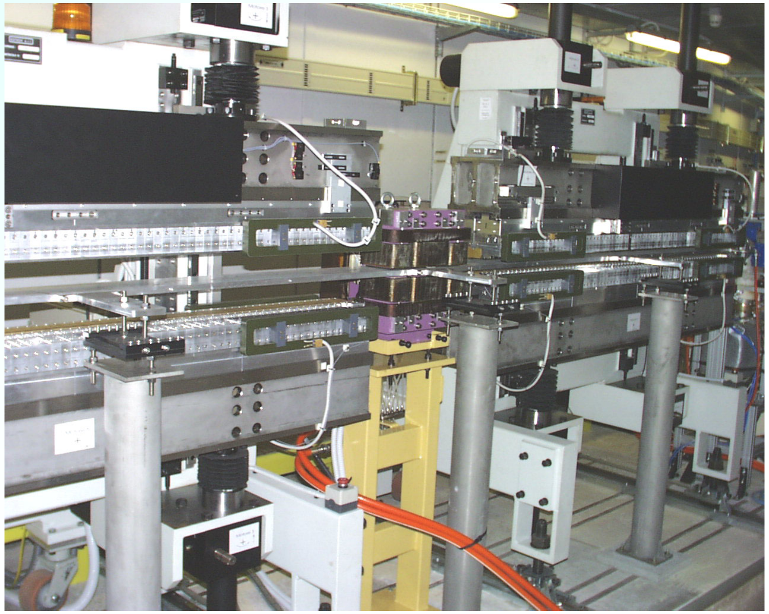
Satellite Workshop
Trieste, Dec. 5th, 2001



mirror chambers

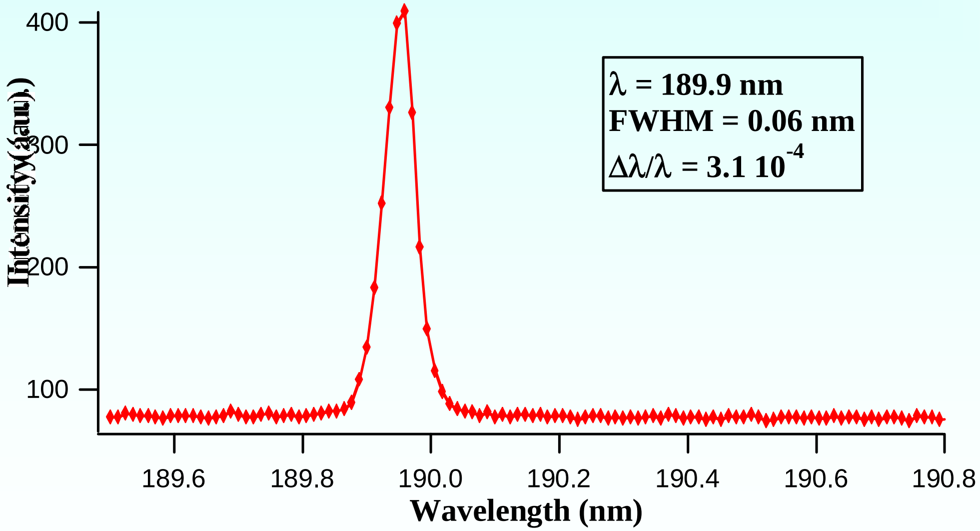
undulators

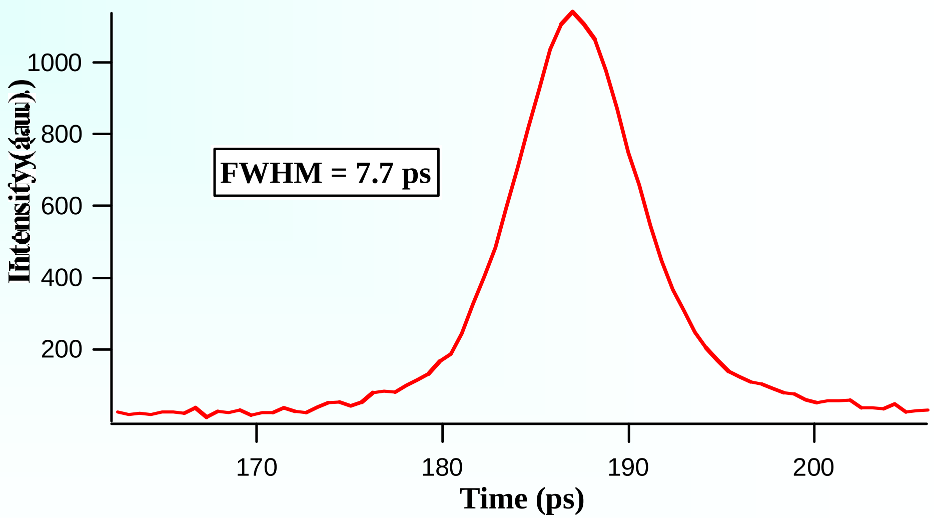




EUFELE: results

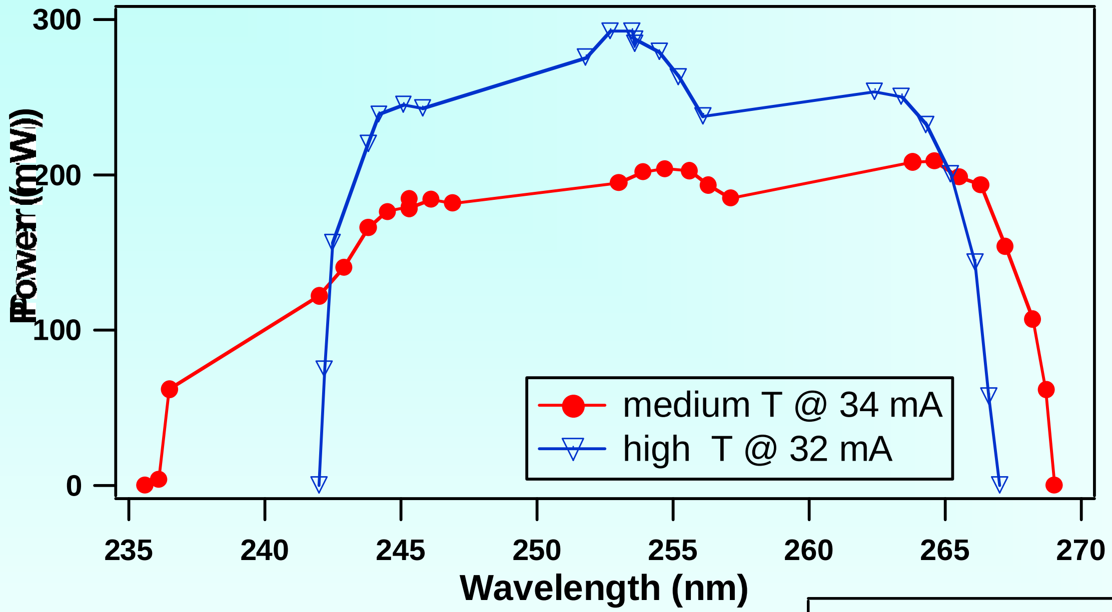
Wavelength (nm)	Multilayer type	$\Delta\lambda/\lambda$	Δt (ps)	x Fourier Limit†
350 - 356	Ta_2O_5/SiO_2	$4.2\ 10^{-4}$	8.9	7.2
235 - 255	$HfO_2/\ SiO_2$	$3.2\ 10^{-4}$	9.0	7.8
218 - 224	$Al_2O_3/\ SiO_2$	$2.2\ 10^{-4}$	8.2	5.5
189.7 - 200.3	$Al_2O_3/\ SiO_2$	$2.8\ 10^{-4}$	7.7	7.7

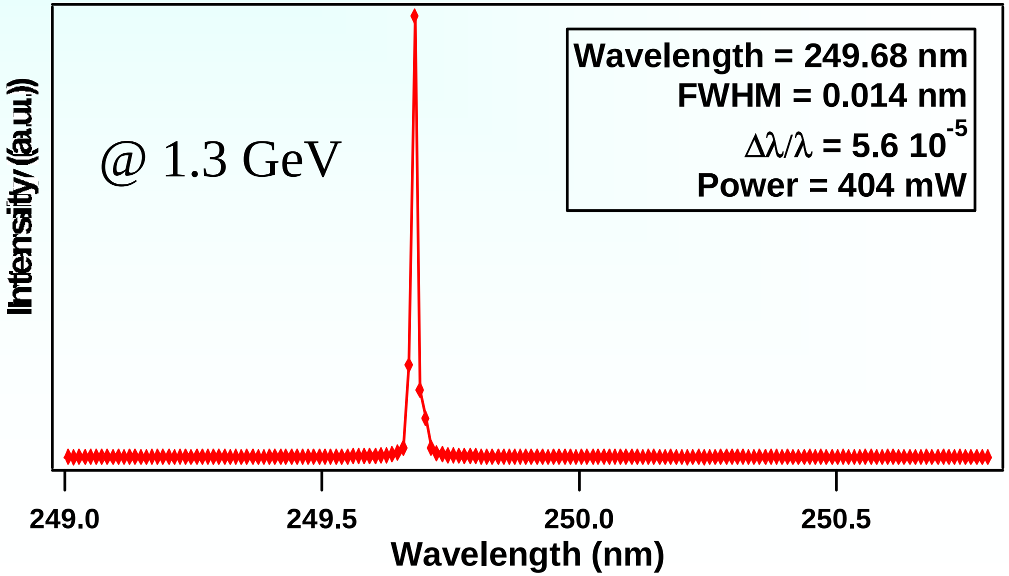




$$\dagger \quad \Delta t\,[\mathrm{FWHM,ps}]\,\frac{\Delta\lambda}{\lambda}\,[\mathrm{FWHM}] = 1.47\,10^{-6}\,\lambda\,[\mathrm{nm}]$$

EUFELE: high power, wide tunability



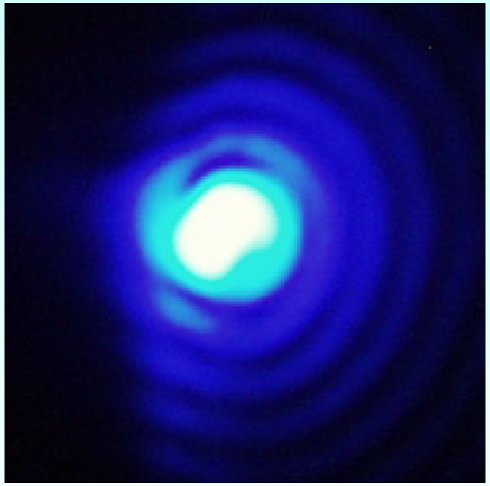


Δt (FWHM) ~ 30 ps,

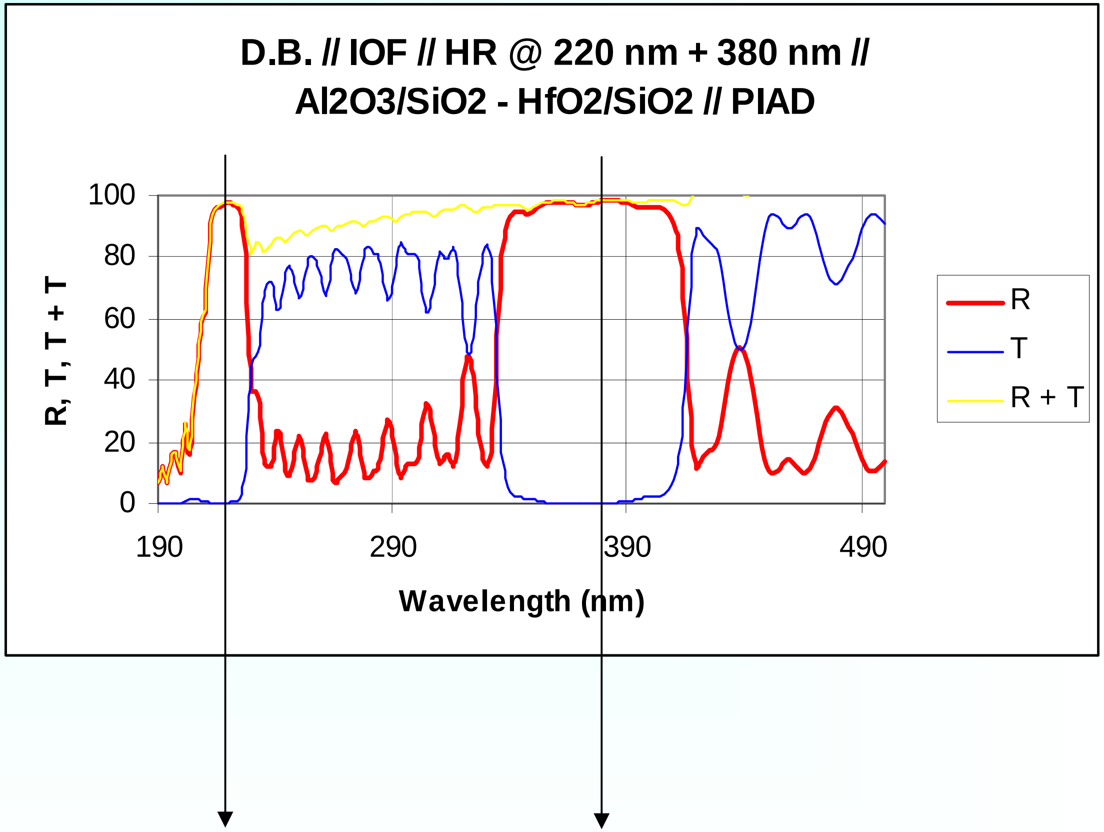
x 4.5 Fourier limit

EUFELE: other developments

Lasing with a multilayer coated (LZH) opaque silicon mirror, with 0.8 mm diam. hole :



Lasing with dual-band coated multilayer mirrors (IOF) :



@ 220 nm :
R = 97,9 %
T = 0,30%

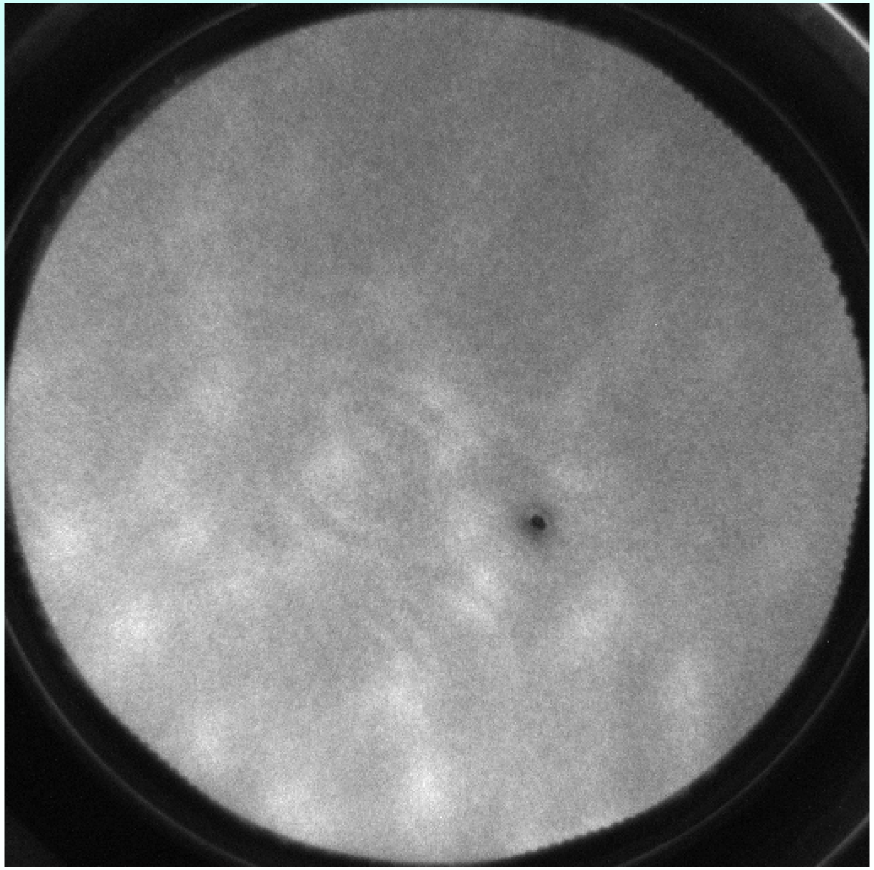
@ 380 nm :
R = 99,1 %
T = 0,25%

EUFELE: Present performance

Wavelength range	**190 - 355 nm**
Linewidth	**2 - 4 10^{-4}**
Pulse length	**8 - 9 ps**
Polarization	**circular**
Pulse rep. rate	**4.6 MHz**
Max. power	**560 mW (250 nm)**
Max. flux	**7 10^{17} photons/s**
Max. brilliance	**1.4 10^{20}**

EUFELE: First test experiments

Photoelectron Emission Microscopy using FEL light at the photothreshold



Work function contrast observed with 196 nm FEL light,

Pb islands grown in-situ on W(110)

Field of view: 5 µm

EUFELE: Future plans

Second EC RTD contract just started 1/12/01 :

"Development of the European Free-Electron Laser at ELETTRA as a VUV Research Facility"

Partners:

Sincrotrone Trieste	Italy (coordinator)
CEA/DSM	France
CLRC-Daresbury Lab.	England
CNRS-LURE	France
ENEA-Frascati	Italy
Fraunhofer Institute, Jena	Germany
Laser Zentrum Hannover	Germany

Project goals :

- Shorter wavelength: 155 nm (8 eV) target
  - VUV compatible beamline and monitoring
  - mirror development (ENEA, IOF, LZH)
- FEL beam stabilisation
  - necessary for experiments (esp. pump-probe)
- Experimental equipment development and
- Initial set of experiments (CLRC, CNRS, ST)

EUFELE: Experimental programme

Goal : exploit the unique properties of the FEL, starting now (limit 6.5 eV) and in parallel with the source development (up to 8 eV)

i) Flux hungry experimental techniques for FEL only ("one colour" experiments) :

Photoelectron emission microscopy, PEEM (Sincrotrone Trieste)

- work function lateral contrast with PEEM in total yield mode
- with higher FEL energy, use of SPE-LEEM (with energy filter)

Time resolved spectroscopy (CNRS-LURE)

- magnetic systems studied with trains of FEL pulses
- study of the dynamics of magnetization reversal

Spectroscopy on clusters (CLRC-Daresbury)

- energy and spin analysis of photoelectrons in nanoscale clusters

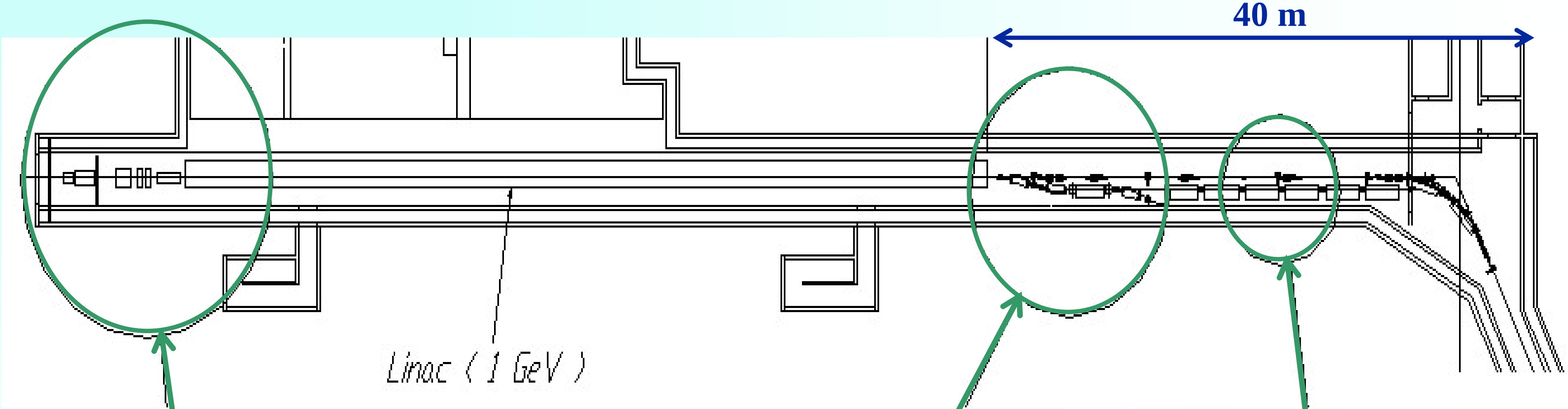
ii) Pump-probe ("two colour") experiments combining FEL + synchrotron radiation

- study of excited states in molecules (10 ps - 200 ns window)
  FEL + soft X-rays and FEL + Infrared

VUV to Soft-Xray FEL using the ELETTRA linac

Satellite Workshop
Trieste, Dec. 5th, 2001

Proposal by INFM/ST to the MURST
"Special Fund for Research of Strategic Interest"



high brightness photo-injector

FEL equipment in parallel to the existing injection line

- during booster construction : parallel use of the ELETTRA linac for FEL tests
- after booster construction : full availability for further FEL development and experimental exploitation

Scope of the project

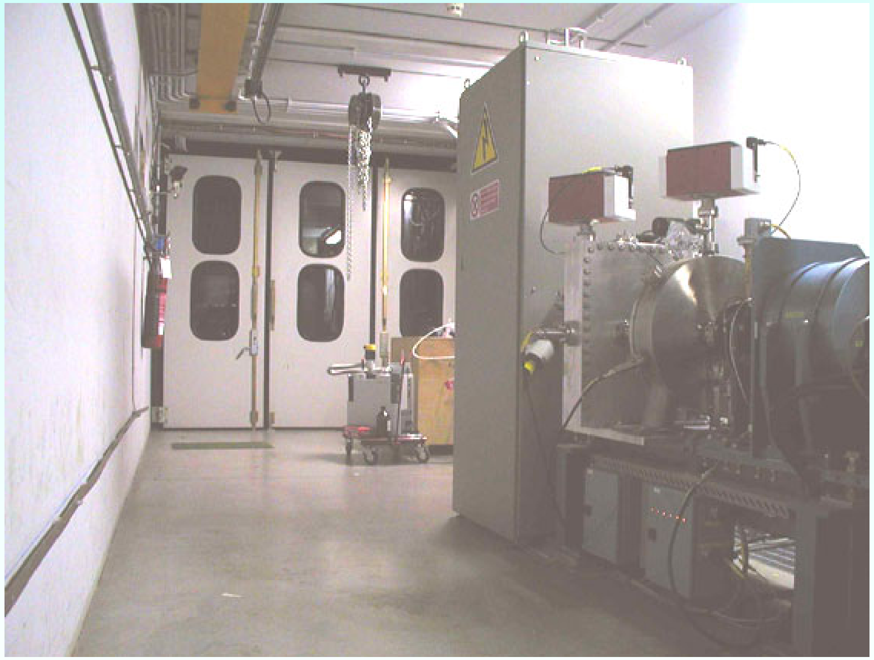
Make use of existing resources for a cost-effective, comprehensive R&D programme on FEL-based 4th Generation Light Sources :

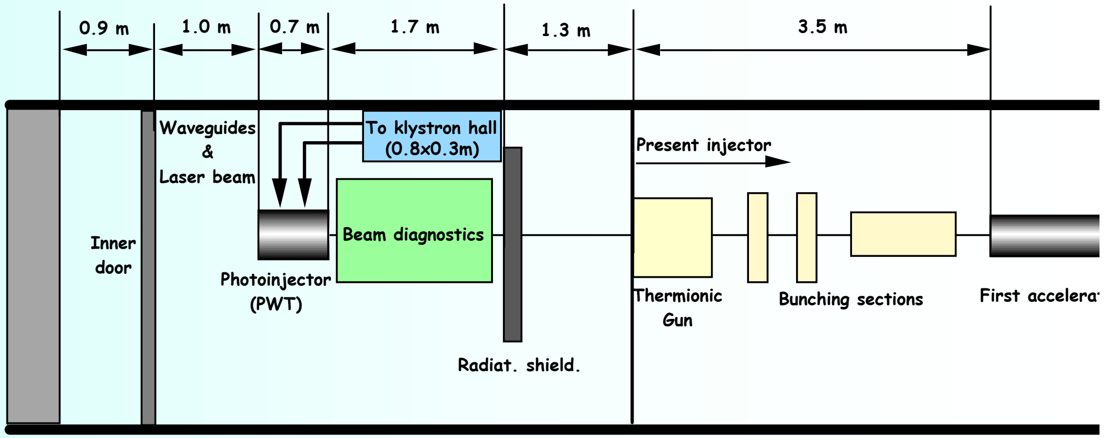
- high brightness electron sources
- bunch compression systems
- transport of high current density beams
- diagnostic for electrons and photons
- high precision, multi-segment undulators
- alternative FEL schemes
  (seeding, harmonics etc.)
- optics for focusing and compression
- new experimental techniques

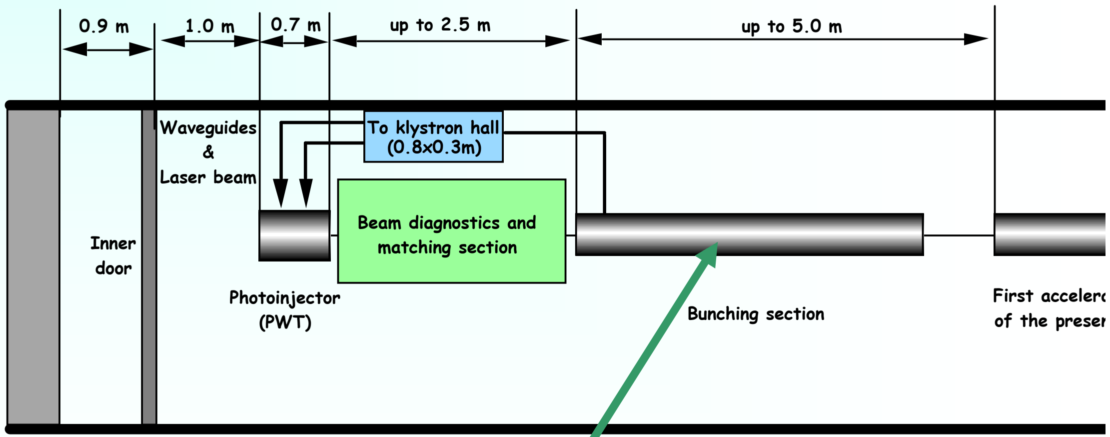
view downstream of the 1 GeV linac

Photoinjector Layout

Phase 1 - photoinjector development in the existing space upstream of the present gun





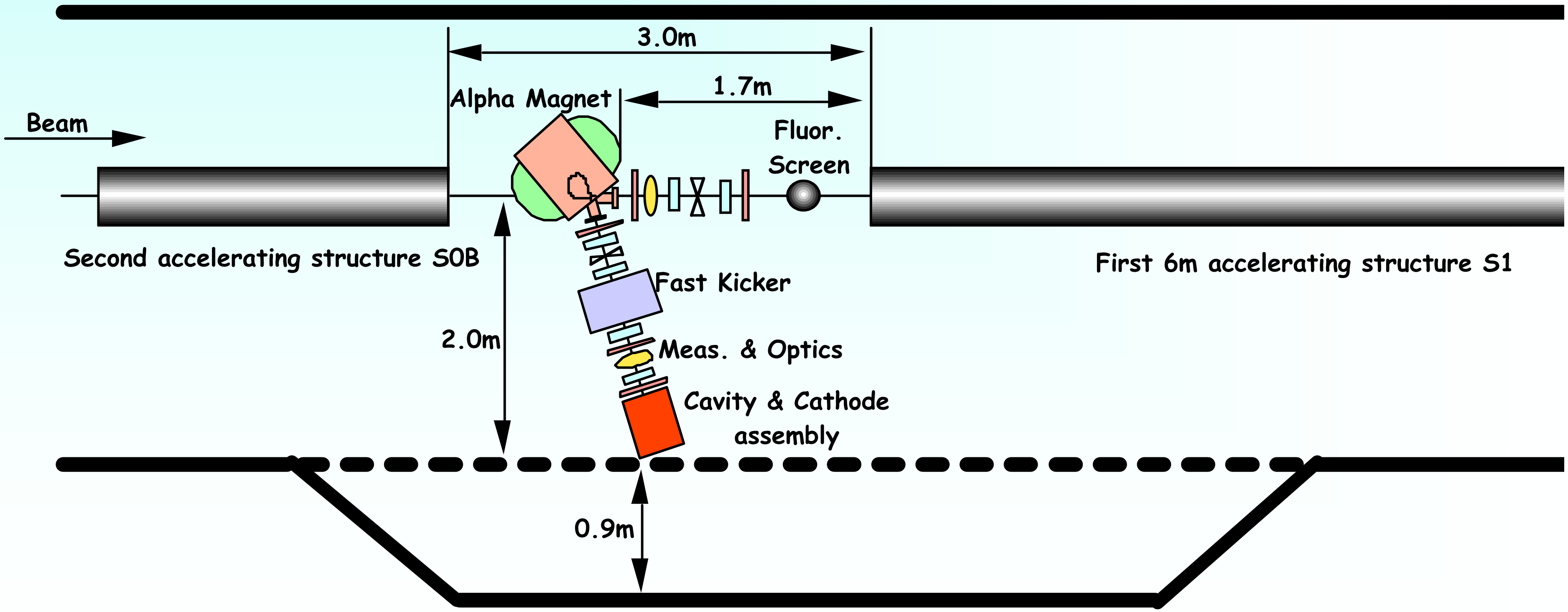


Phase 2 - replace existing gun with photoinjector + compression section

linear bunch compression section

Thermionic r.f. gun

- **Reliability :** guarantee ELETTRA injection, rather than rely on photoinjector
- **Cost saving :** can be built more quickly than the photoinjector, allowing existing d.c. gun, buncher etc. to be used for booster injector



Type of FEL

Seeding - reduce intensity fluctuations
higher spectral brilliance

+

Harmonic generation - efficient approach to shorter wavelengths

Seeding with external laser beam:

- R. Bonifacio et al., Nucl. Instr. Meth. A296 (1990) 787. ("Resonant Frequency Tripling")
- L.H Yu, Phys. Rev. A 44 (1991) 5178. ("High Gain Harmonic Generation")

Seeding with oscillator FEL:

- F. Ciocci et al., Il Nuovo Cimento 106A (1993) 1757.

Original proposal based on the oscillator/amplifier, with Al mirrors:
wide tunability: oscillator 300-120 nm, amplifier 100-40 nm.

Another possibility : seeding with Regenerative amplifier FEL (RAFEL) ??

Parameter optimisation

Electron beam:

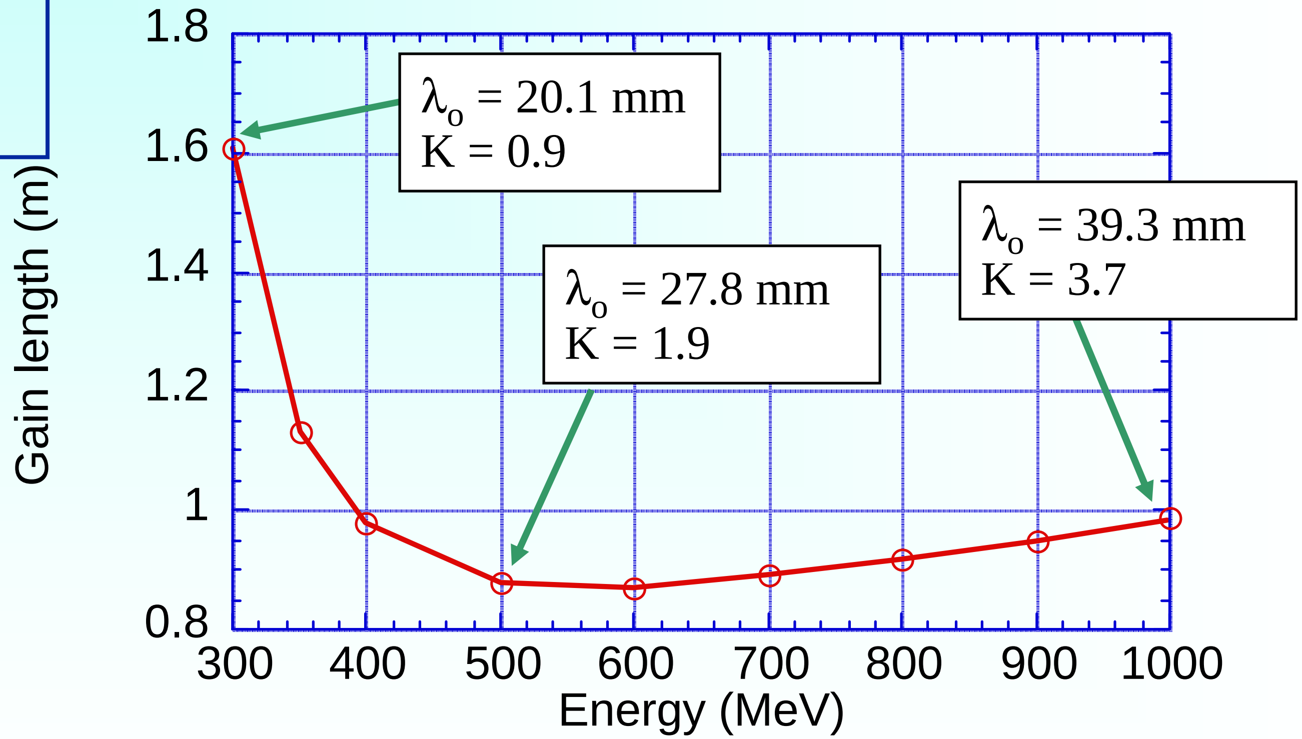
Q	0.4 nC
I_{peak}	600 A
σ_t	0.25 ps
ε_n	2 mm mrad
σ_E	0.4 MeV

Based on undulator segments of ~ 2 m

$\langle\beta\rangle = 6$ m

Amplifier at 40 nm

(neglecting effect of seeding...)



Choose 500 MeV to leave scope for future reduction in wavelength.

Oscillator at 120 nm

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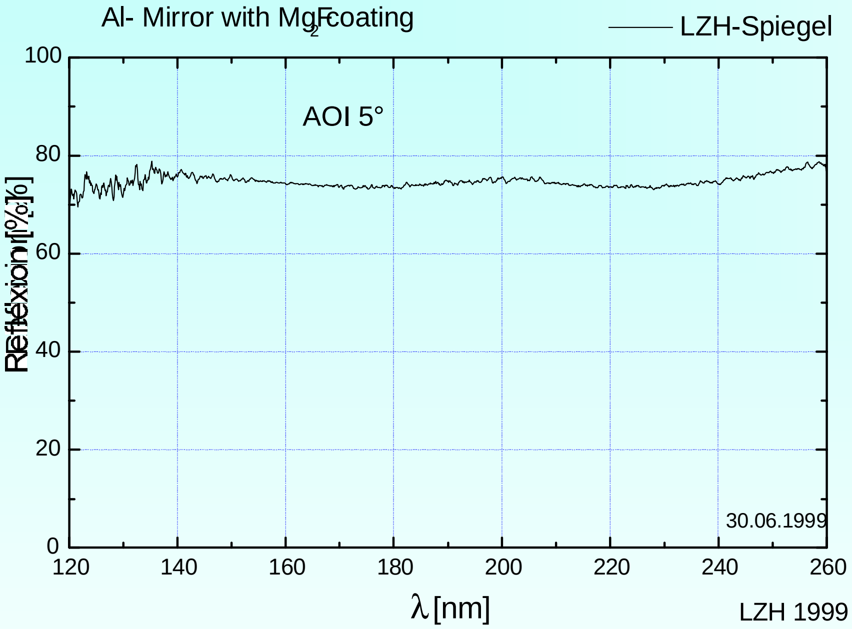
Al mirrors, reflectivity R ≥ 70 % at 120 nm:



Lasing condition (1+G) $R^2 > 1$,

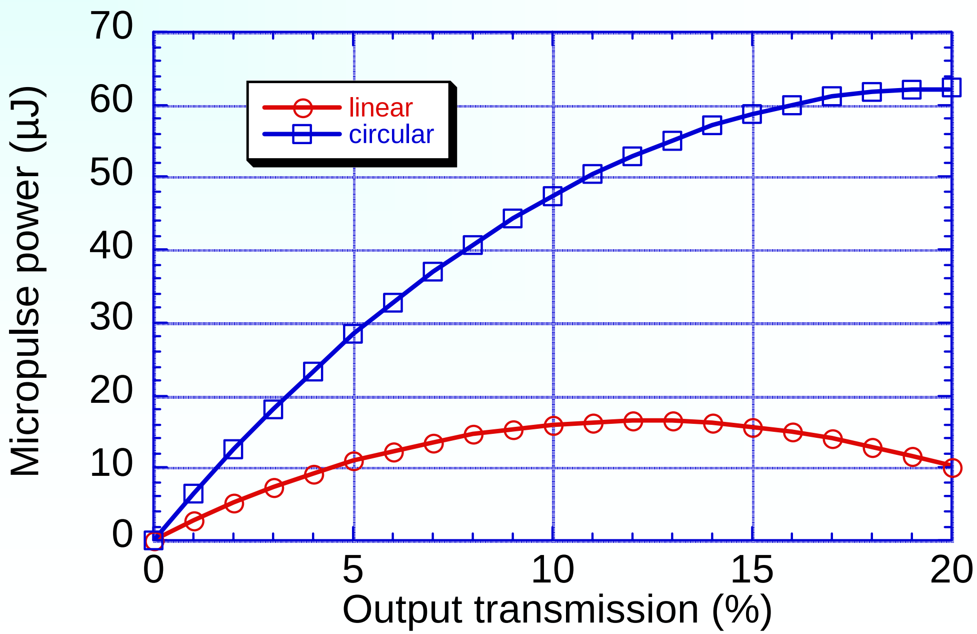
→ $G \geq 1.04$

With given electron beam parameters, no problem to achieve sufficient gain for sufficiently low rise time (< 0.5 µs) and good output power, with short undulator length ≤ 2 m:

$\lambda_o = 42.0$ mm

circular polarization
K = 2.1, G = 3.9

linear polarization
K = 3.0, G = 2.2



Phase 1 parameters

Electron beam:

E	500 MeV
Q	0.4 nC
I_{peak}	600 A
σ_t	0.25 ps
ε_n	2 mm mrad
σ_E/E	$0.8\ 10^{-3}$

Oscillator at 120 nm

Polarization	variable
t_{laser}	2.0 μs
$E_{mic.}$	20 μJ
$P_{mic.}$	30 MW
$P_{av.}$	20 mW
Photon flux	$1\ 10^{16}\ s^{-1}$
Av. brilliance†	$3\ 10^{19}$
Pk. brilliance†	$5\ 10^{28}$

Amplifier at 40 nm

Polarization	linear
t_{laser}	1.0 μs
$E_{mic.}$	300 μJ
$P_{mic.}$	490 MW
$P_{av.}$	150 mW
Photon flux	$3\ 10^{16}\ s^{-1}$
Av. brilliance†	$8\ 10^{20}$
Pk. brilliance†	$2\ 10^{30}$

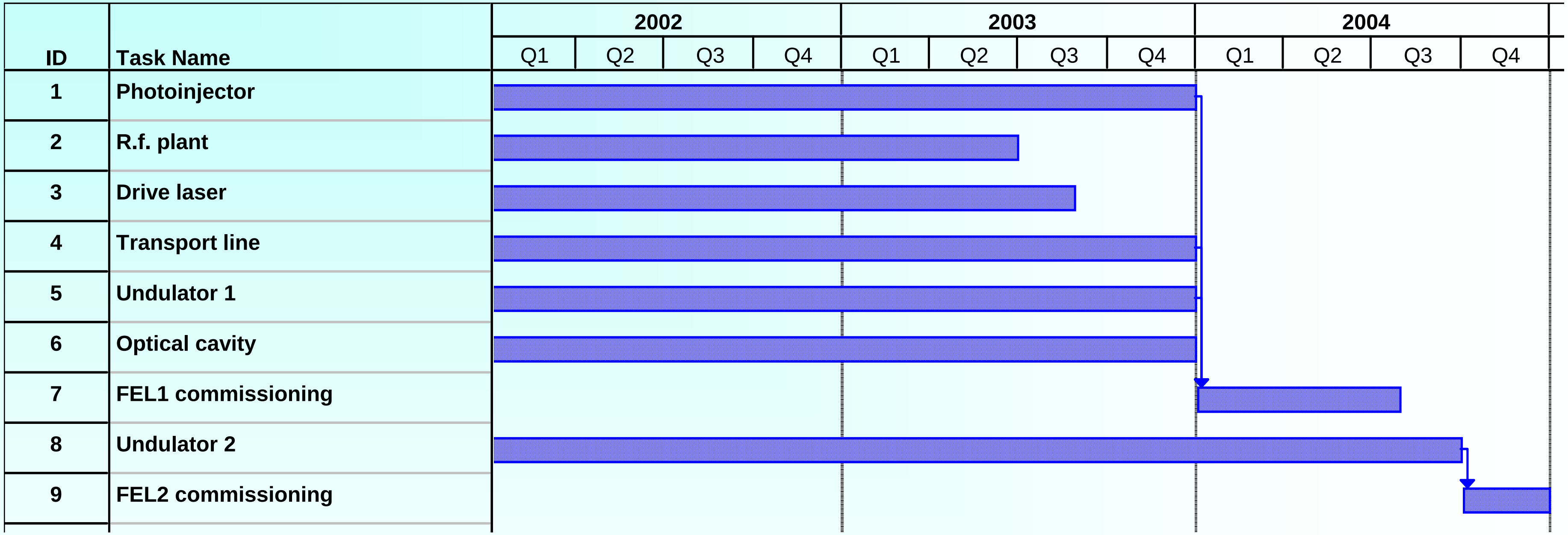
† photons/s/0.1%bw/mm^2/mrad^2

Assuming :

- **3 m oscillator cavity length, 20 ns pulse separation (50 MHz)**
- **3 μs linac pulse length (SLED off)**
- **oscillator rise-time < 1 μs**
- **2 μs oscillator pulse, 1 μs amplifier pulse**

Timescales, Cost

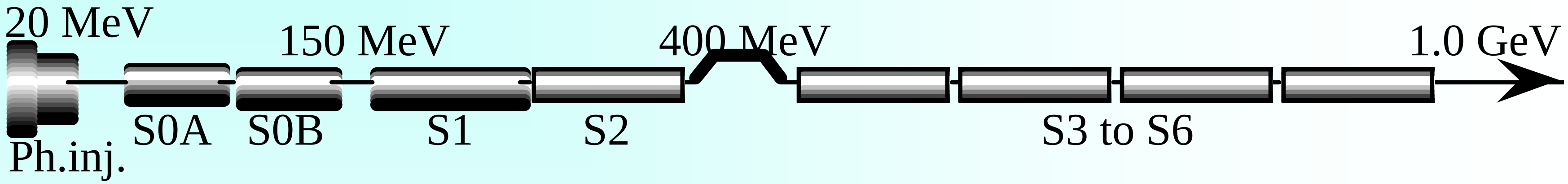
Outline schedule:



Cost: 5.2 MEUR excl. personnel, overheads

Phase 2: 10 nm

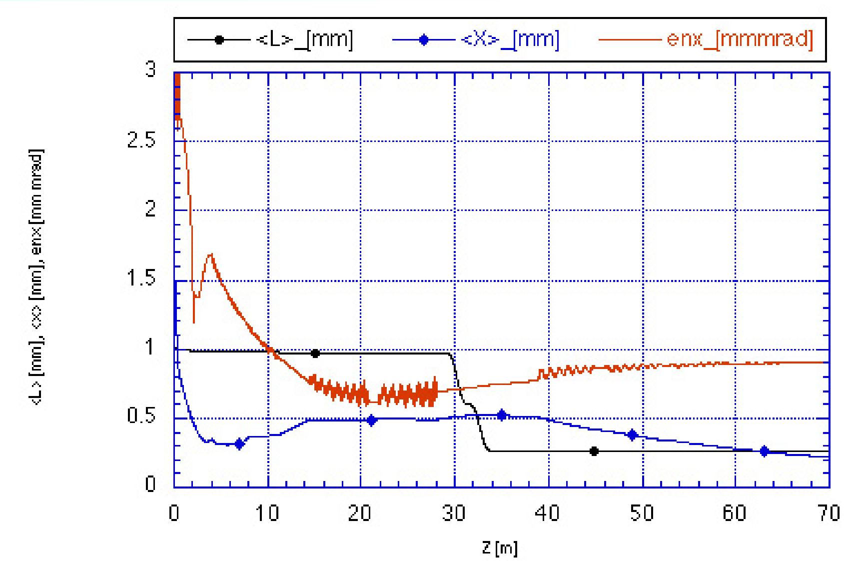
With full linac availability, can insert a magnetic compression section for operation at shorter wavelength - down to 10 nm



Earlier studies[†] showed that high performance can be achieved :

$I_{peak} = 3$ kA
$\varepsilon_n < 1$ mm mrad
$\sigma_E/E = 0.4$ %

@ 1 GeV



† G.D'Auria, M. Ferrario, L. Serafini et al., Proc. Linac Conf. 2000

Phase 2: 10 nm

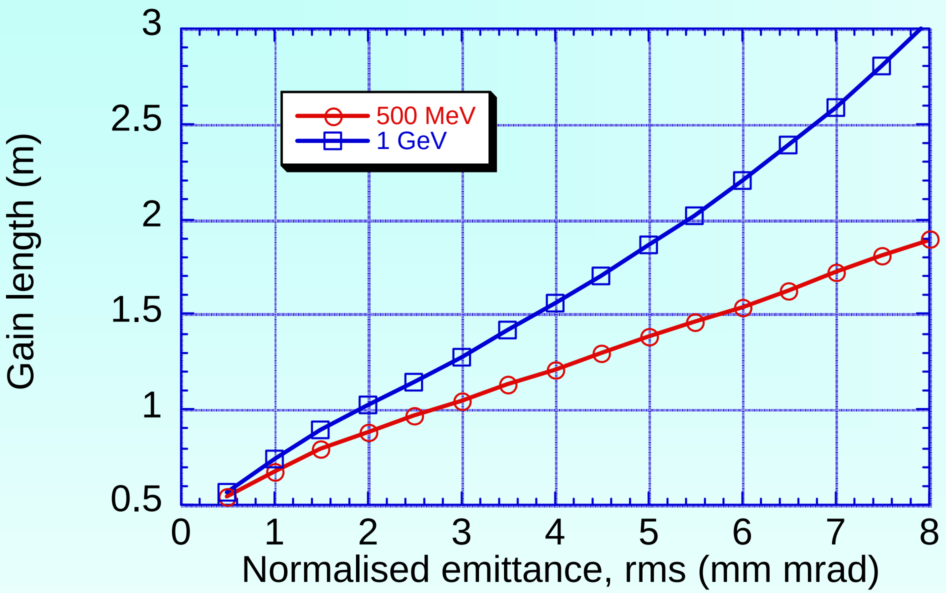
Electron beam:

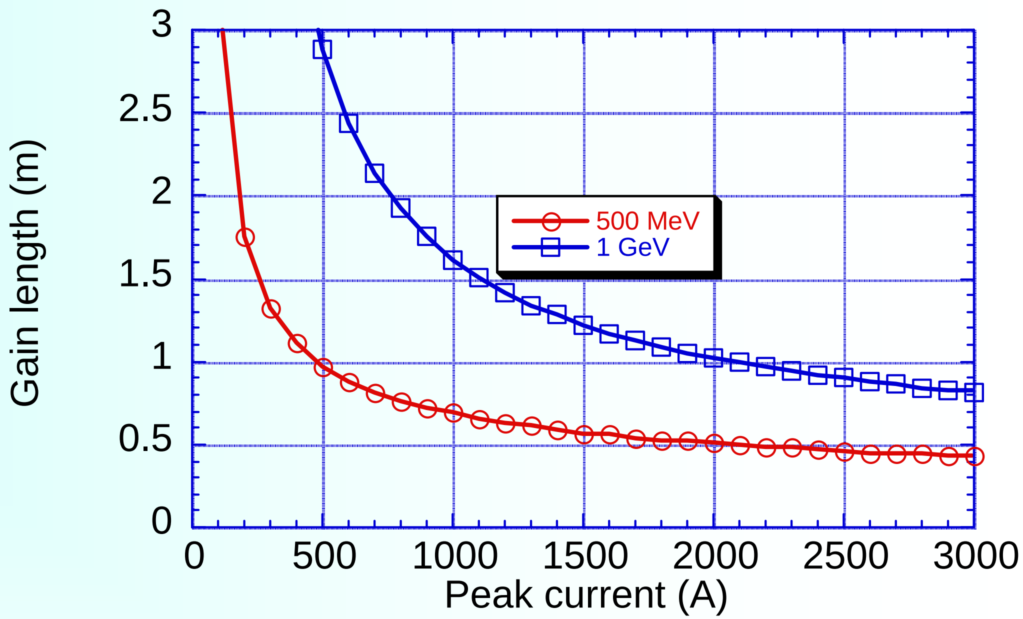
E	1 GeV
Q	1 nC
I_{peak}	2000 A
σ_t	0.2 ps
ε_n	2 mm mrad
σ_E/E	$1\ 10^{-3}$

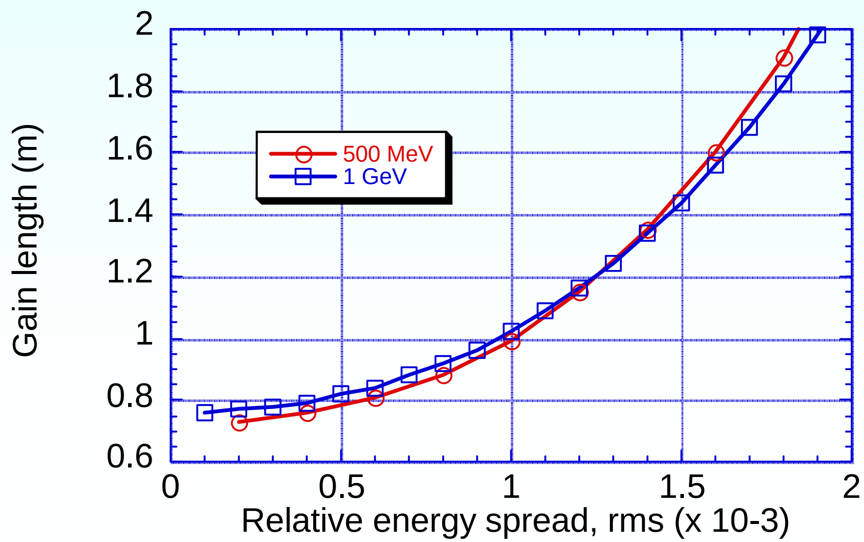
Amplifier at 10 nm

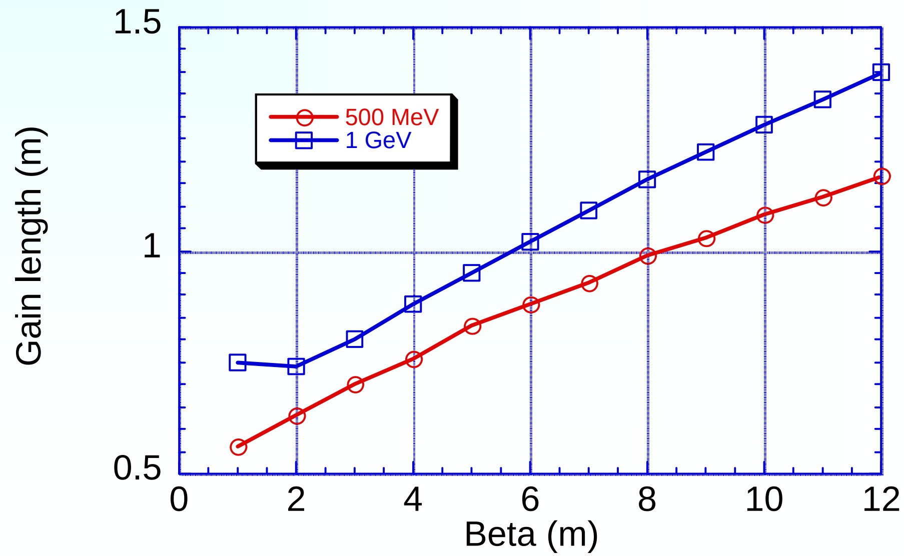
Polarization	linear
Gain length	1.0 m
t_{laser}	1.0 μs
$E_{mic.}$	1.3 mJ
$P_{mic.}$	2.6 GW
$P_{av.}$	650 mW
Photon flux	$3\ 10^{16}\ s^{-1}$
Av. brilliance†	$1\ 10^{20}$
Pk. brilliance†	$5\ 10^{29}$

Parameter sensitivity

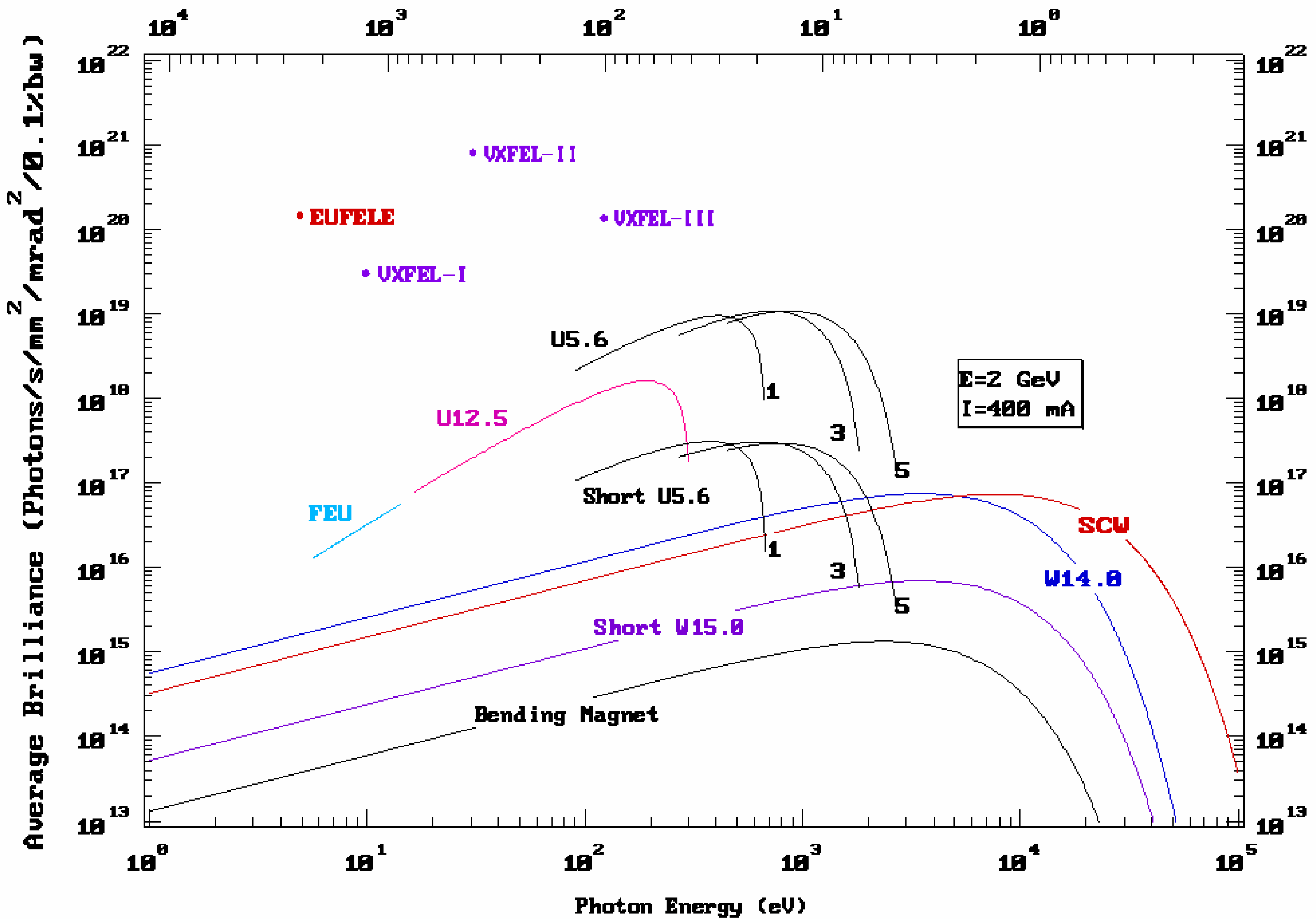








Summary


Average Brilliance (Photons/s/mm²/mrad²/0.1%bw)
Photon Energy (eV)
VXFEL-II
EUFELE
VXFEL-III
VXFEL-I
U5.6
U12.5
Short U5.6
FEU
SCW
W14.0
Short W15.0
Bending Magnet
E=2 GeV
I=400 mA
1
3
5

Satellite Workshop
Trieste, Dec. 5th, 2001

Summary