First Lasing of FERMI@elettra seeded FEL

G. Penco

on behalf of the FERMI Team

THE FERMI@ELETTRA PROJECT

FERMI is a **Single-Pass**, **50 Hz**, **Seeded FEL facility** in the **Soft X-rays**:

- ❑ high peak power: from 0.3 to GW's range
- ❑ short temporal structure: from sub-ps to 10 fs time scale
- ❑ **tunable** wavelength: APPLE II-type undulators
- ❑ **variable polarization**: **horizontal/circular/vertical**

✓ peak brilliance $10^{30} – 10^{31}$ ph/sec/mm^2/mrad^2/0.1%bw

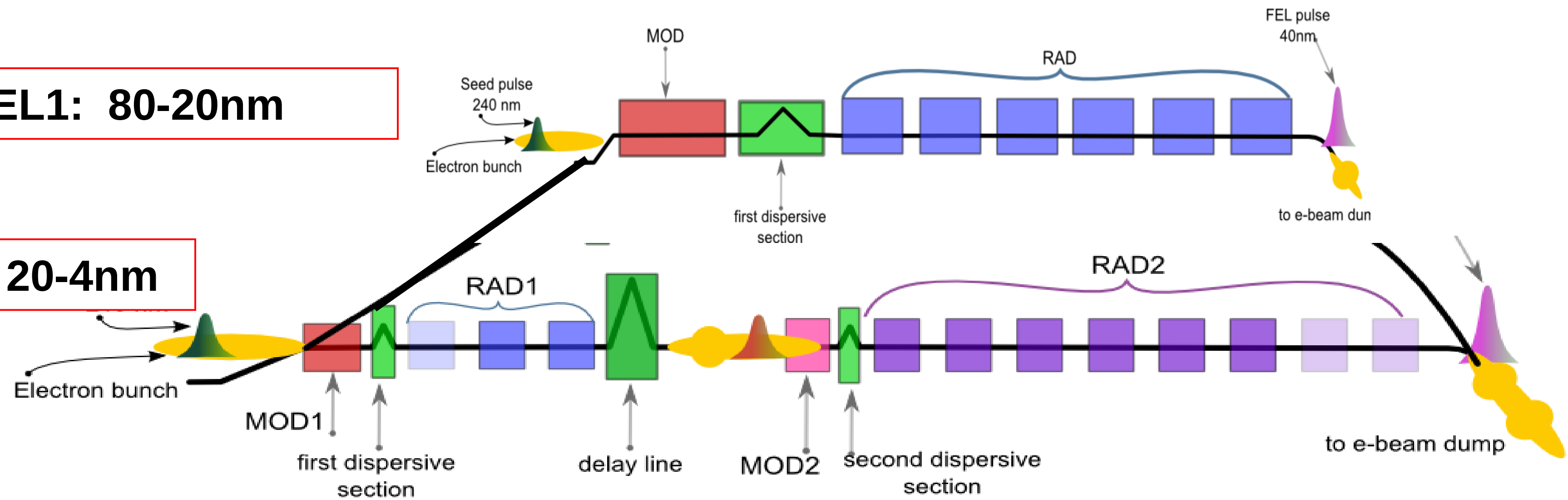
✓ flux $10^{12} – 10^{14}$ ph/pulse

✓ bandwidth ~ Fourier Transform Limit

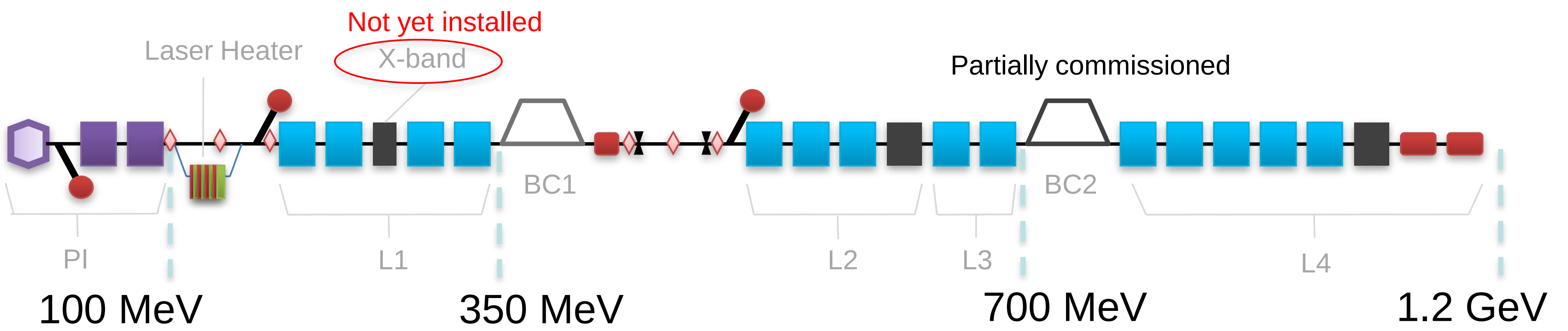
More details in M.Svandrlik poster **TUPB29**

FEL1: 80-20nm

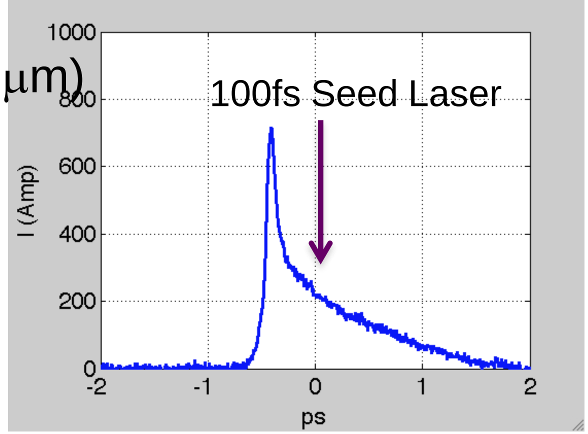
FEL2: 20-4nm



Linac Layout



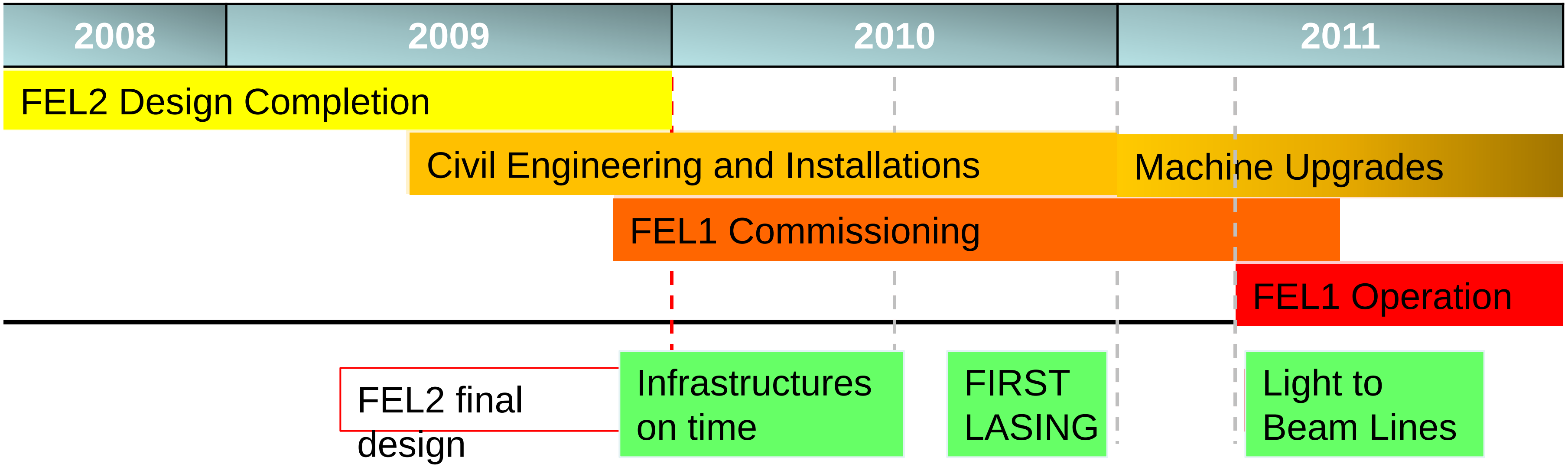
- ❑ **450pC - 5ps flat-top bunch** at the photo-injector ($\gamma\varepsilon_n \sim 1\ \mu m$)



- ❑ Some test on the Laser Heater but it will be optimized for FEL2 operation
- ❑ X-band cavity has not yet been installed
- ❑ Beam compressed @BC1 by about **a factor 5** (BC2 not used up to now)
- ❑ Nominal energy @ linac end: **1.2GeV** (reached 1.35GeV)

Seed laser / e^- beam
RMS Time jitter ~ 100fs

Design Goals & Achievements



	Parameter	FEL1	FEL2	Units
γ	Output Wavelength (fund.)	**65 - 20**	20 – 4	nm
	Peak Power	**0.5** – 5	> 0.3	GW
	Repetition Rate	**10**	50	Hz
e	Energy	**1.2**	1.5	GeV
	Peak Current (core)	**200 - 300**	800	A
	Bunch Length (fhwm)	**0.7 – 1.2**	0.7	ps
	Proj. Norm. Emittance	**3.0**	1.0	mm mrad
	Slice Energy Spread	0.20	0.15	MeV

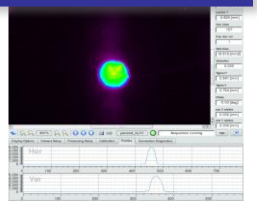
* achieved

COMMISSIONING

Injector ***~2.5 months:***

- 250pC – 5ps flat
- 100MeV
- $\gamma\varepsilon_n$=0.9 mm mrad

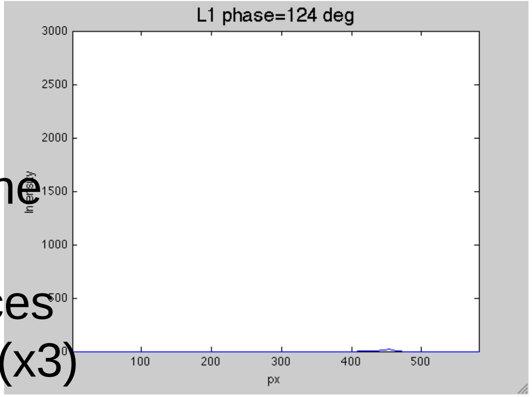
Aug. 19th '09: First e-beam



Linac and BC1

~3.5 months:

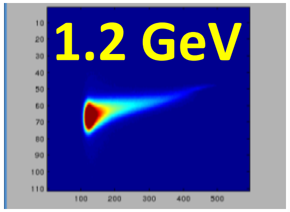
- 350pC – 5ps flat
- Transport through the linac
- First BC1 experiences
- Observed ε growth (x3) for CF~5



Transfer line to Main Beam Dump

~1.5 months

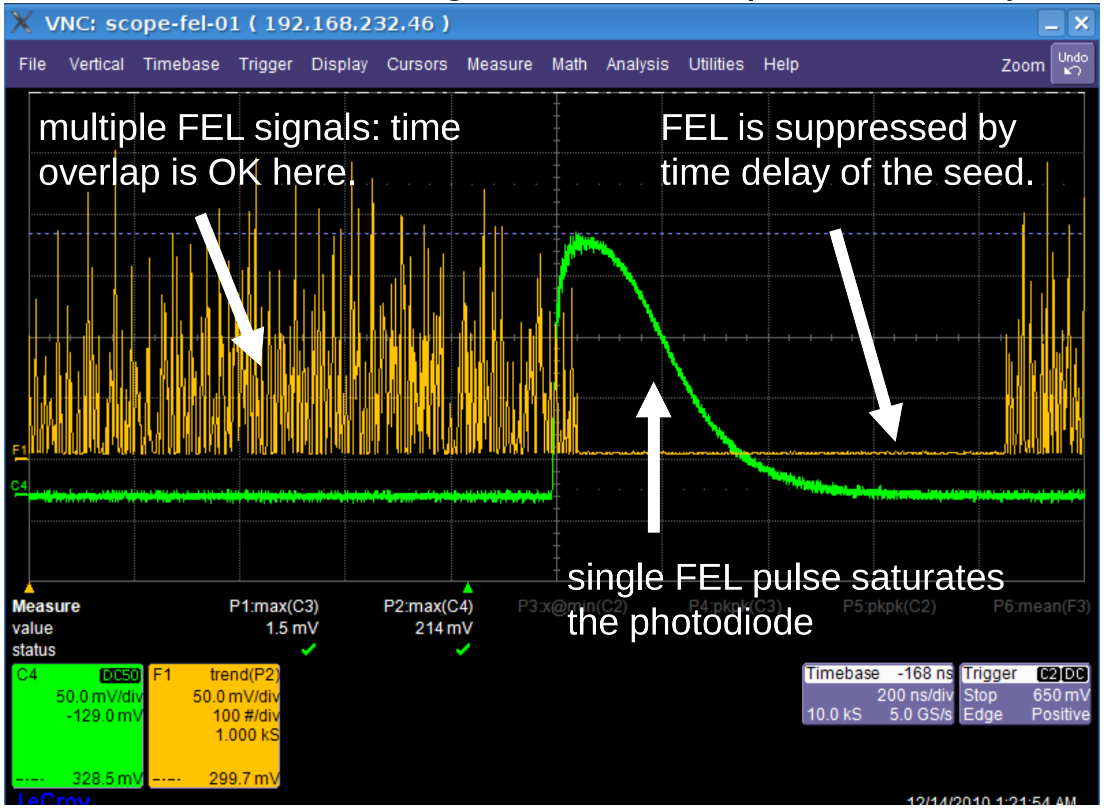
- E=1.2GeV, Q=350pC, CF~3
- Defined the reference traj before installing und.
- time jitter grows from 150fs to 400fs when CF~5
- $\gamma\varepsilon_n$ @1.2GeV ~ 4-5 μm



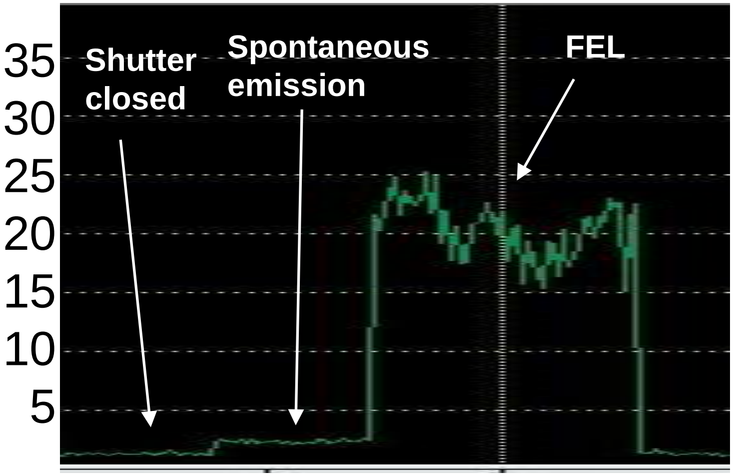
- **3 weeks** for installing FEL 1 undulators
- **1.5 months** of e-beam and seed laser commissioning …..

FIRST LASING AT 65-43 nm(Dec. 2010)

- **The 1st seeded FEL output was observed at 65 nm, on 2010, December 13.**
- **6 radiators** tuned with calibration tables. e-beam compressed softly, **~100A**.
- After spatial and temporal overlap of the seed laser (260nm, 160fs, 500 MW) with the e-beam, **seeded emission intensity overcame the spontaneous emission** by several orders of magnitude at the photodiode (~85 m far from the source point)



Shot-to-shot signal [a.u.] from atomic photo-ionization of Nitrogen at 10^{-5} mbar.

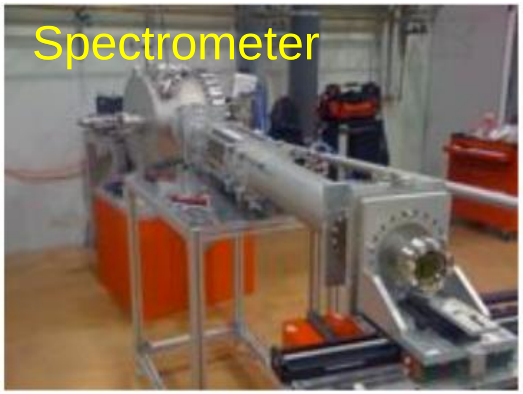


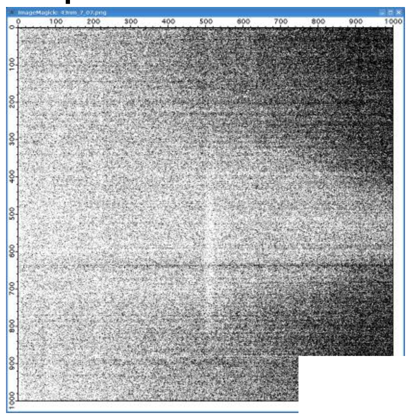
About 8×10^8 photons per pulse (at **43nm**), equivalent to **6nJ**.

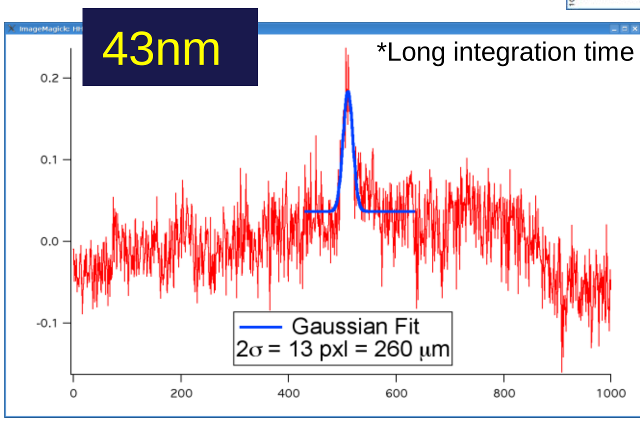
G. Penco

CHG seeded FEL measurements (Dec. 2010)

Seeded FEL mode has been possible and relative “easy” even if the electron beam was not fully optimized in terms of emittance and time jitter, and the photons diagnostics needed for FEL optimization was not completely available.

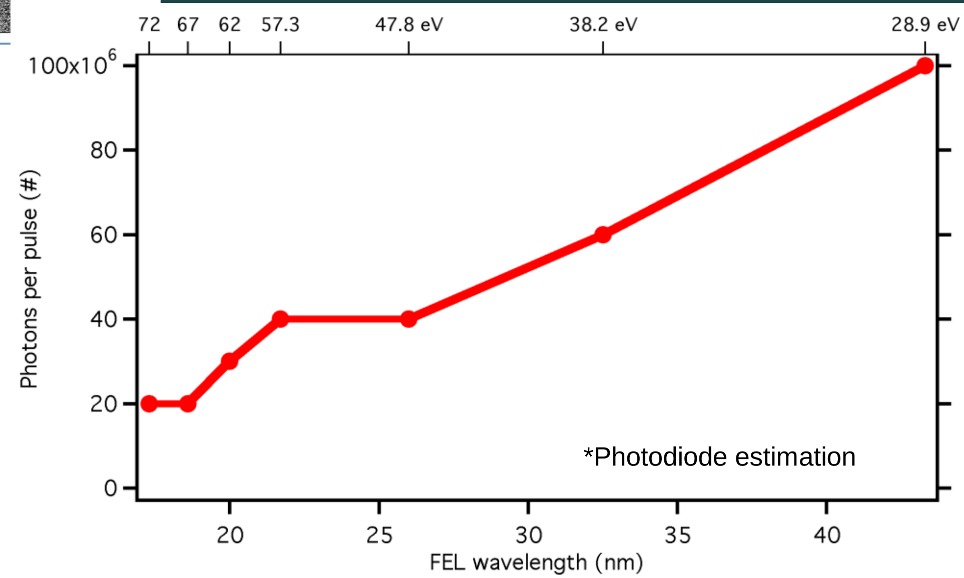






Estimated FWHM ~ 33meV =
3 x Fourier limit (for σ_t=250fs)

Validation of the mechanism: without optimizing too much, coherent up to the **15th harm. (17 nm)** !



Improvements of the FEL performance (5 months in 2011)

In order to improve the photons flux and the stability of the FEL light, we improved:

✓ electron beam time jitter

✓ photons diagnostics

✓ beam trajectory and optics matching in the spreader and undulator beamlines,

✓ electron beam emittance evolution along the machine;

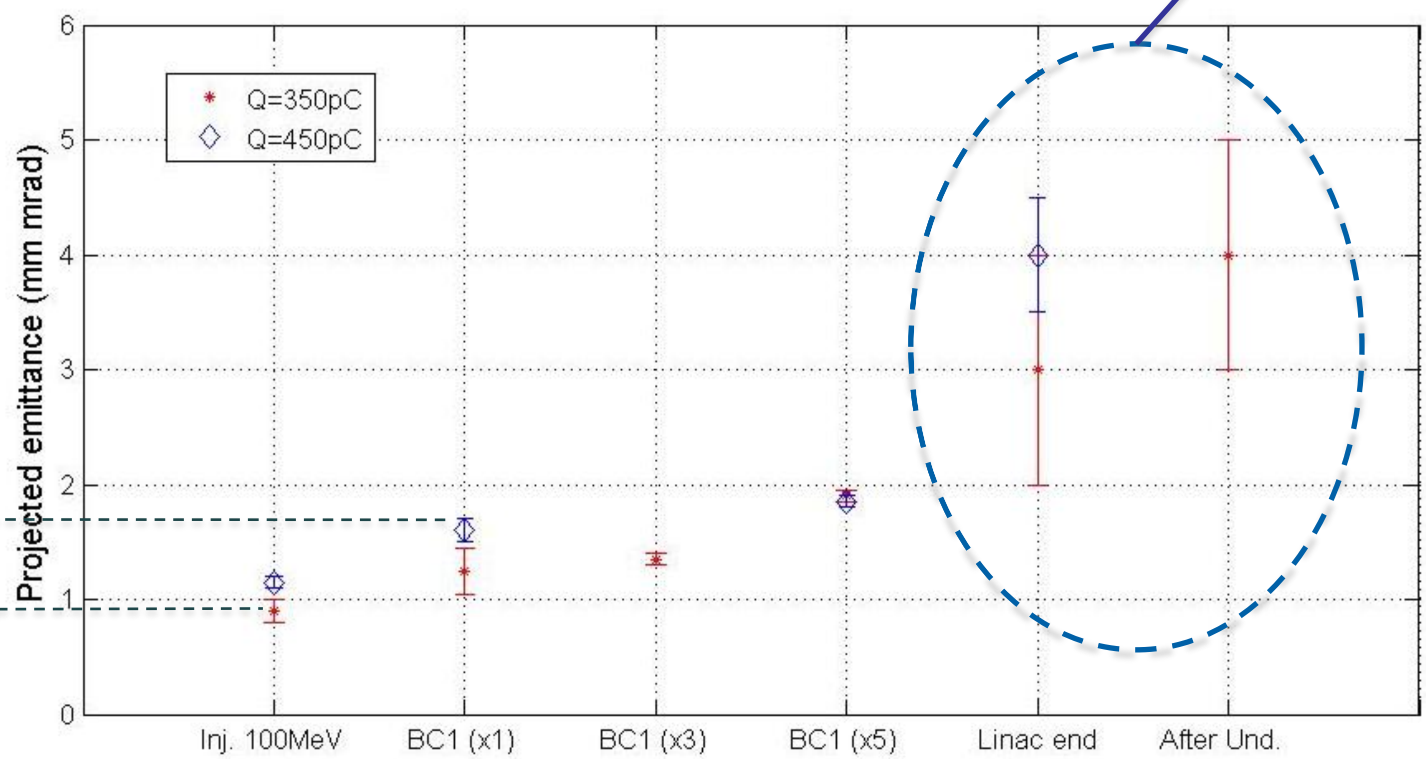
✓ we increased the bunch charge to 450pC (5ps flat-top at the cathode): this required only a fine tuning of the photo-injector optics.

Projected Emittance along the machine

Trasv. Wakefields effects were improved but not completely: we are going to install high energy deflecting cavity to optimize the beam traj in the linac

Note: *Increasing the charge by 30% did not sensible deteriorate the emittance*

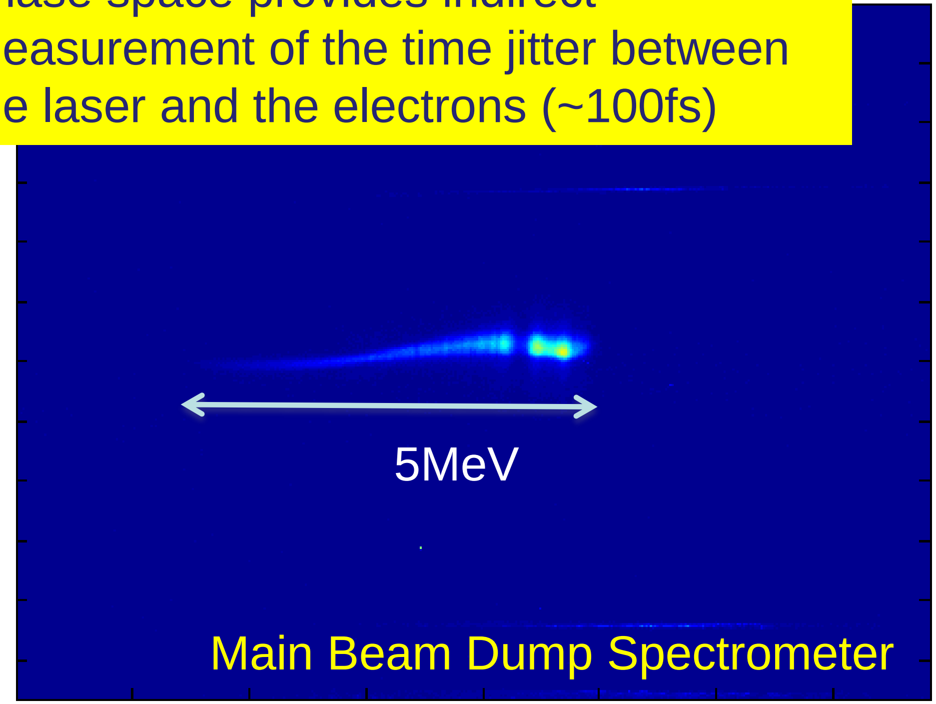
growth~30%



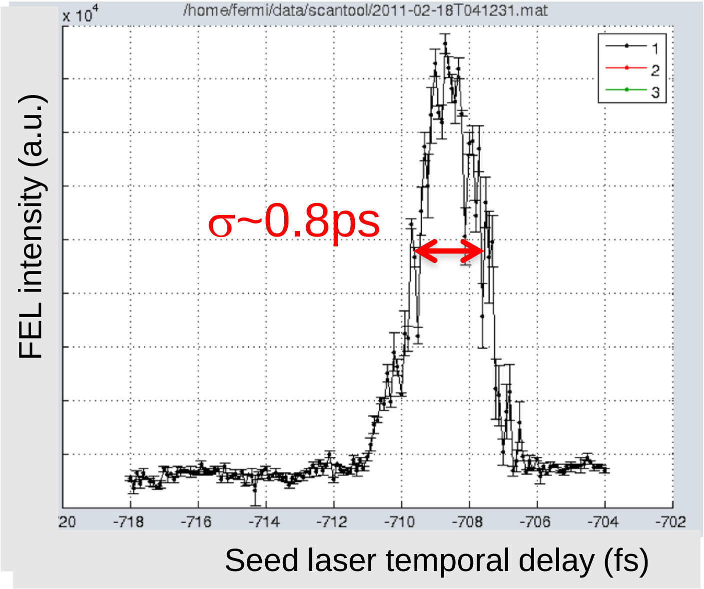
Time jitter

We found out that the main source of the electron bunch time jitter growth versus compression factor came from the RF phase jitter (estimated about 0.3° S-band). Acting on the LLRF parameters, the RF phase jitter was kept around 0.1° and we measured after the bunch compressor a time jitter of ~ 100fs (CF from 1 to 10).

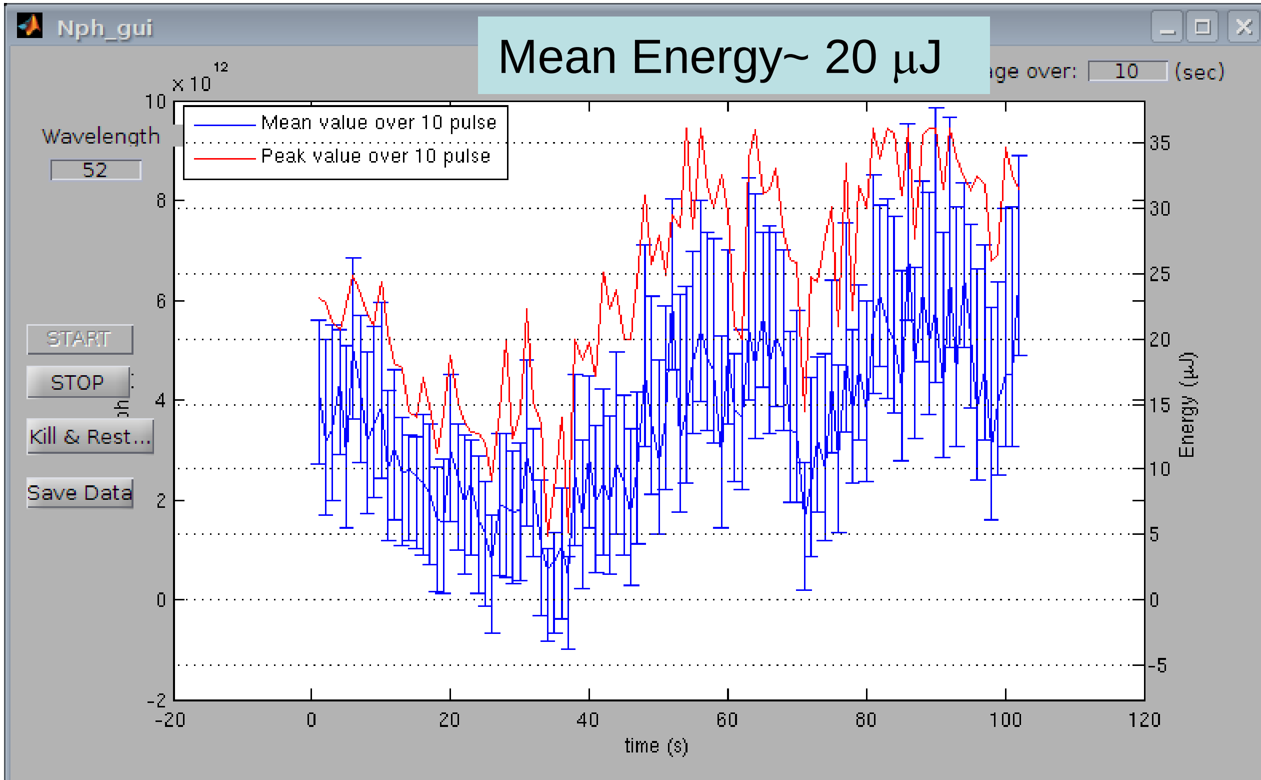
Seed Laser "foot-print" in electron long. phase space provides indirect measurement of the time jitter between the laser and the electrons (~100fs)

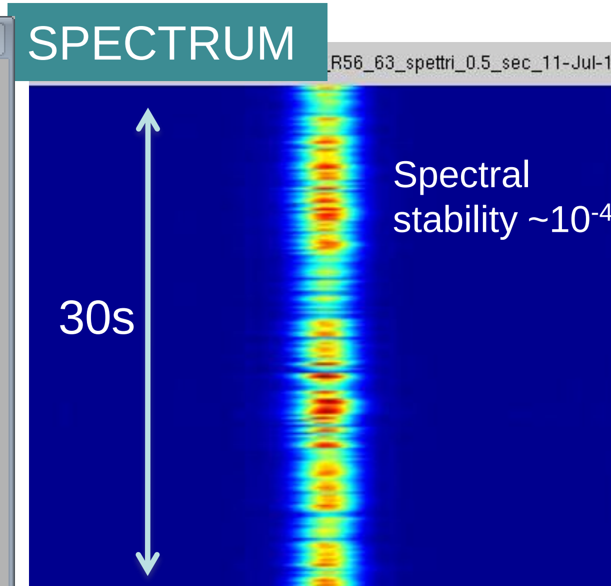


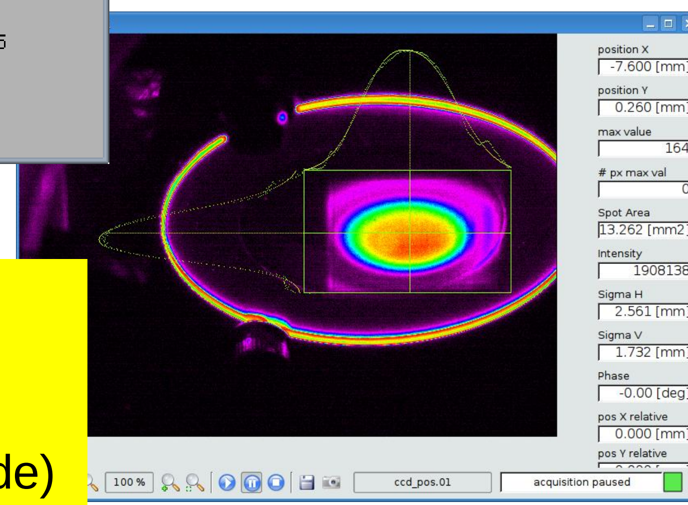
Seed laser temporal delay scan vs FEL intensity provides information about the "active" temporal profile of the electron bunch



FEL at 52nm (Q=350pC, I ~ 200A)







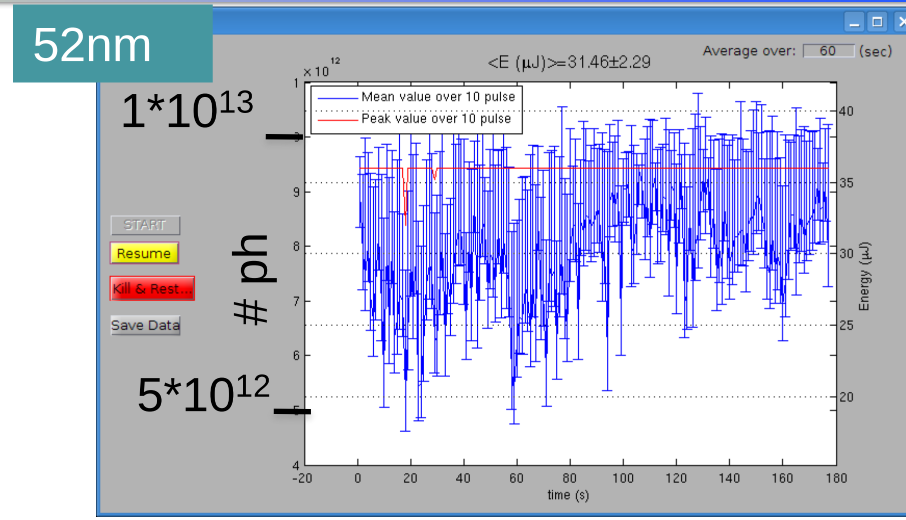
Transverse FEL spot on YAG screen (TEM00 mode)

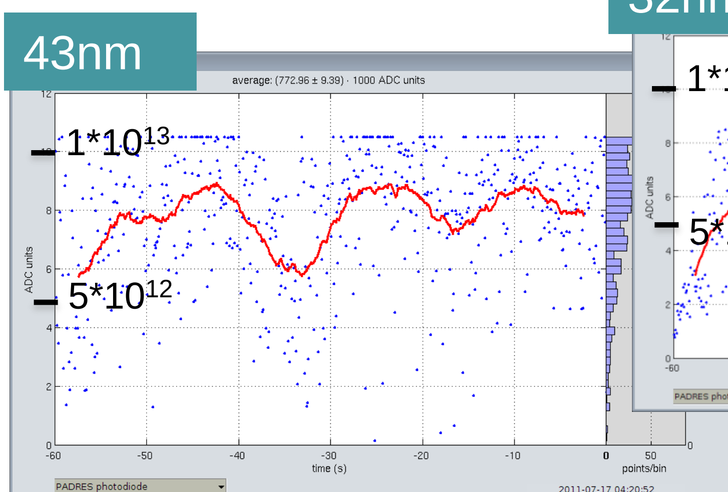
More details in E.Allaria talk **WEOBI1**

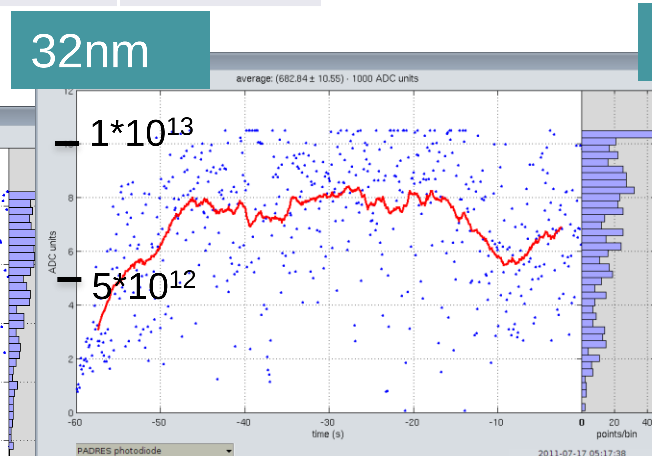
FEL obtained for Q=450pC, I~300A

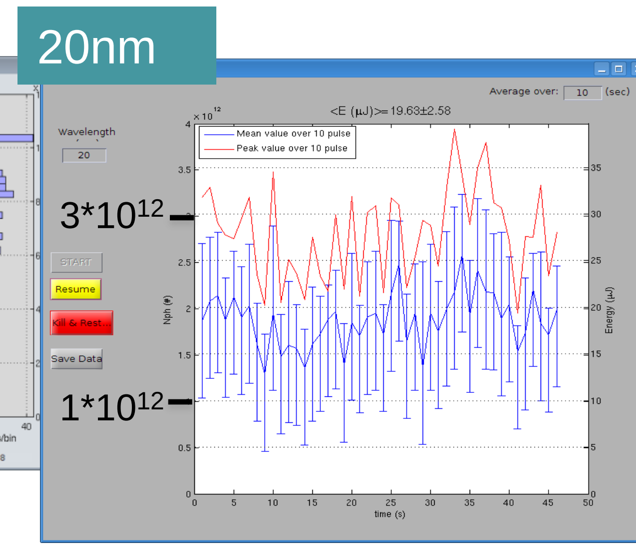
* Photodiode saturates at ~10^{13} photons

λ nm	Number of photons	E μJ	ΔE_{FWHM} meV	$\Delta E_{FWHM}/E$
52.5	$>10^{13}$ (*)	>40	30	$1.3*10^{-3}$
43.3	$>10^{13}$ (*)	>45	35	$1.2*10^{-3}$
32.5	$>10^{13}$ (*)	>55	45	$1.2*10^{-3}$
20	$4*10^{12}$	40	50 100 shots	$8*10^{-4}$ 100 shots





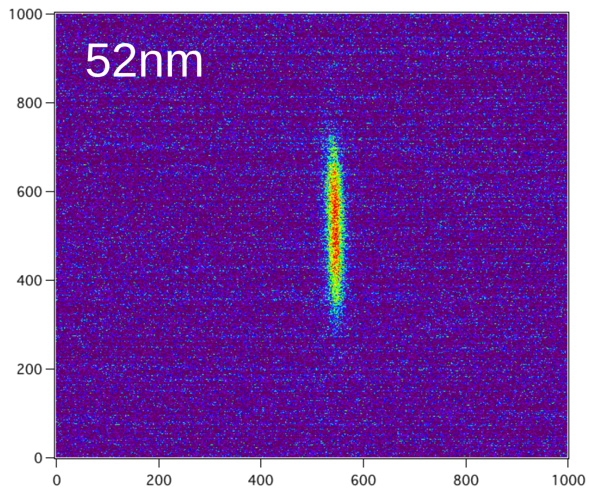


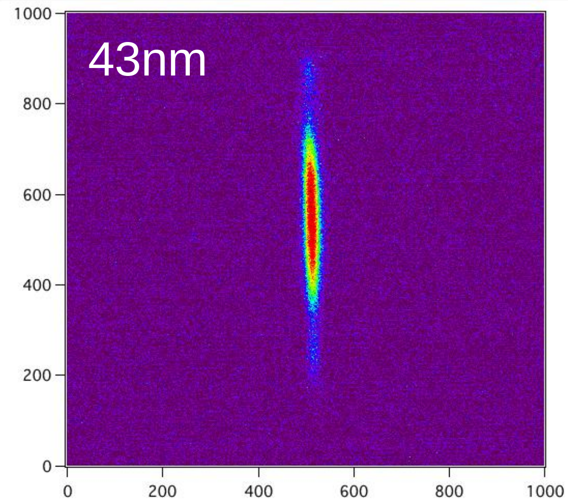


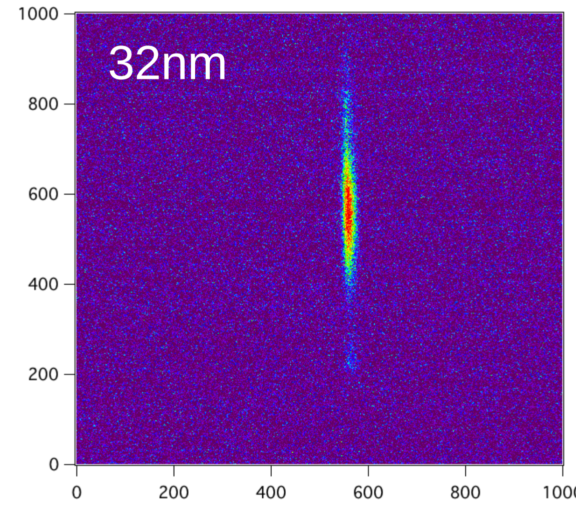
REF: M. Zangrando, C. Svetina

* *Photodiode Calibration to be confirmed

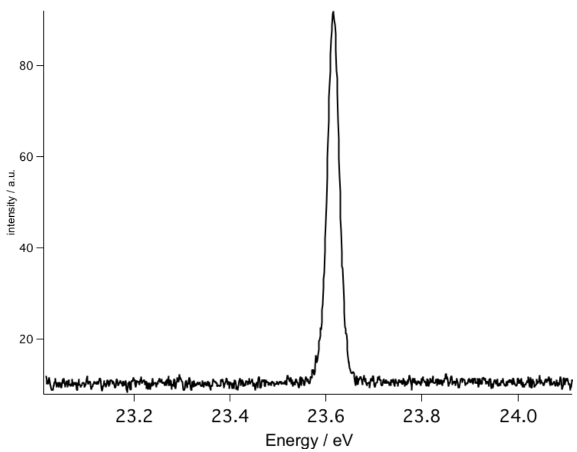
Measured HGHG seeded-FEL spectrum



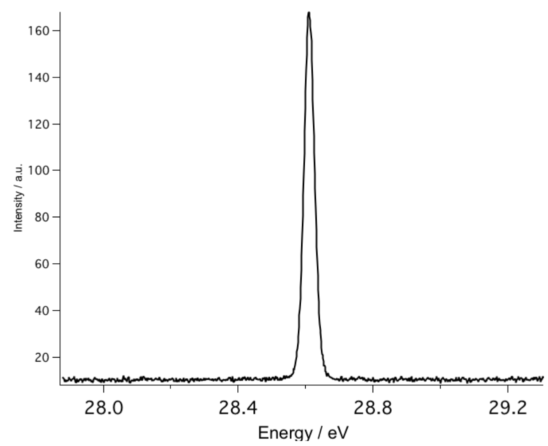




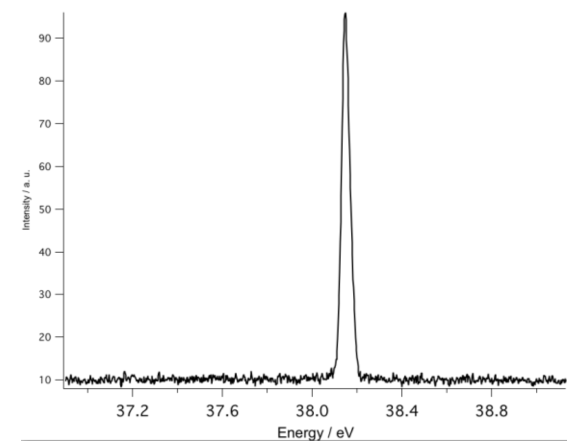
FWHM~29meV



FWHM~33meV



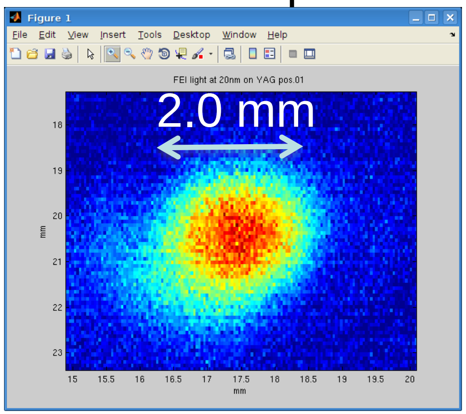
FWHM~44meV



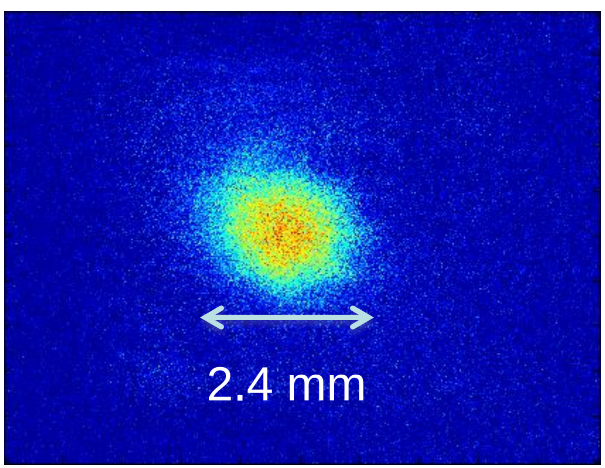
* Single shot spectrum

REF: M. Zangrando, C. Svetina

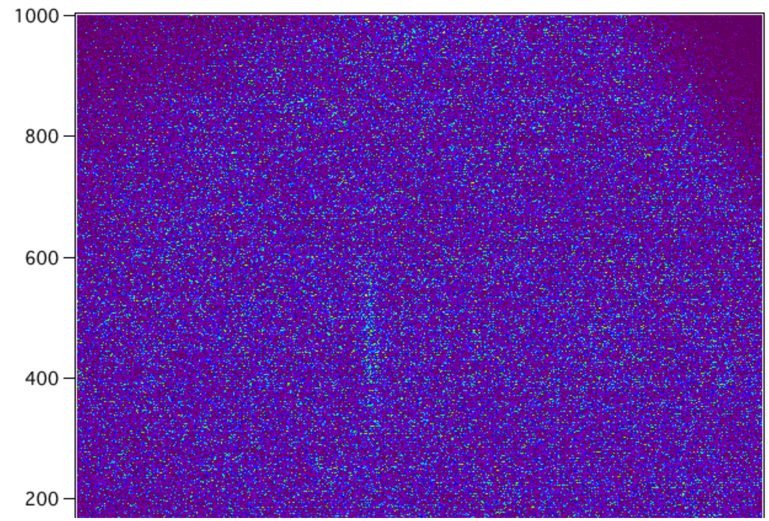
FEL spot on the YAG ~47m far from the source point

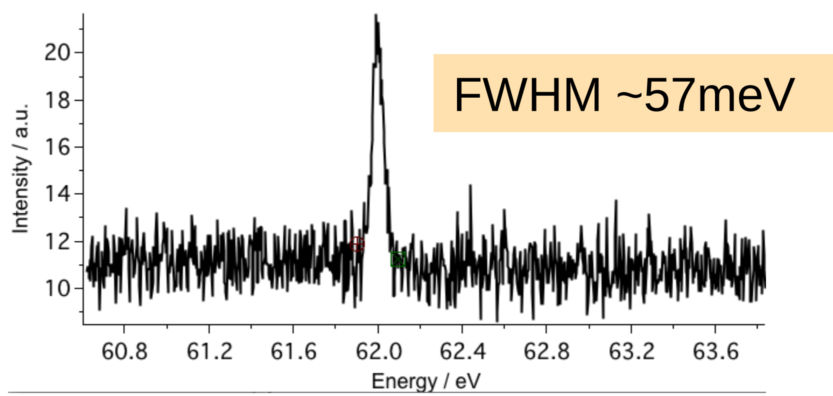


FEL spot on the YAG ~54m far from the source point (divergence ~ 0.05mrad)



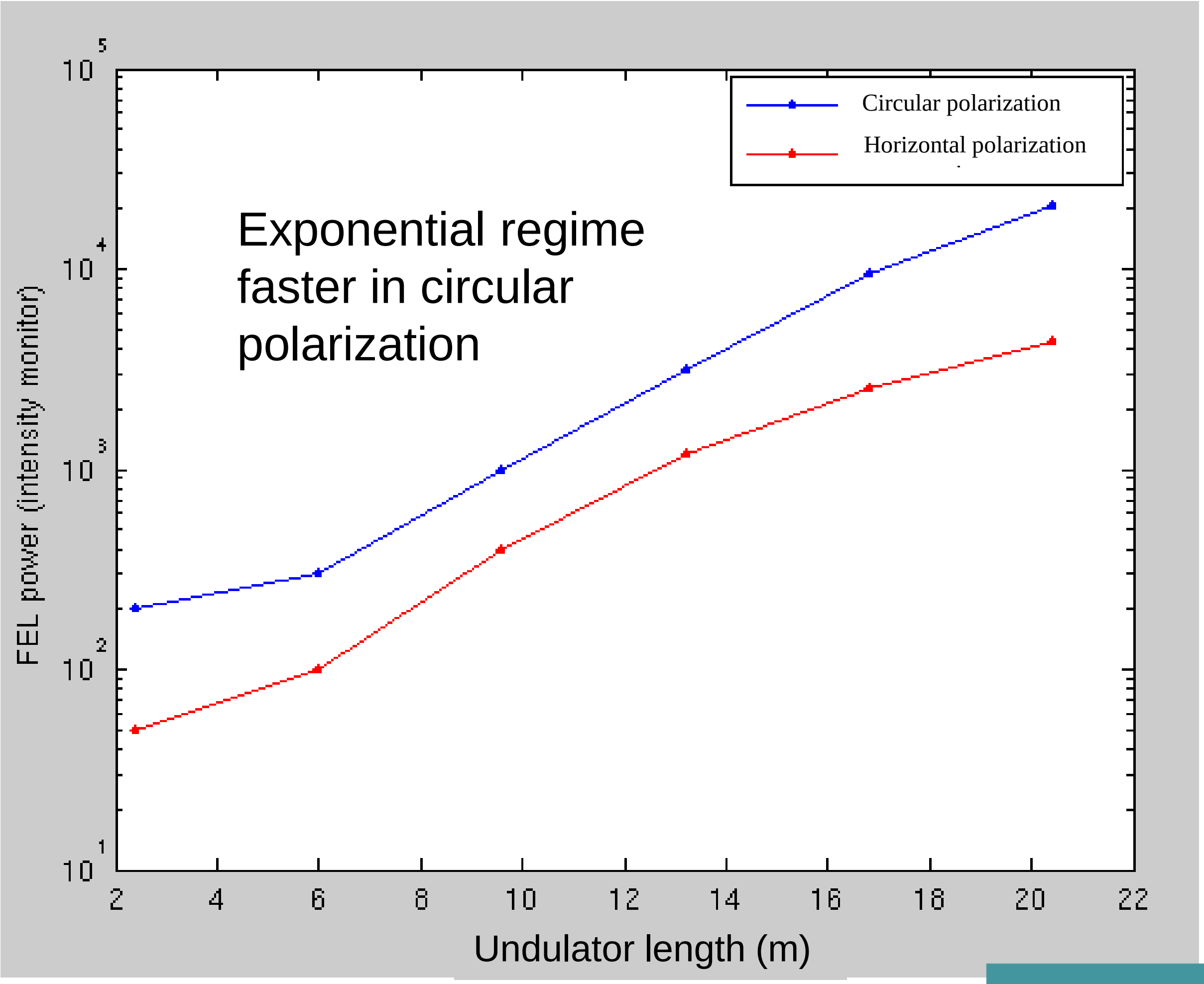
We used the 2nd order of diffraction of the spectrometer (transmission less than 10% wrt to the 1st order)





* Spectrum obtained integrating over 10s

FEL variable polarization



More details in
C. Spezzani talk **THOBI1**

Acknowledgments

The FERMI@Elettra lasing has been possible thanks to the whole **FERMI team** and **Sincrotrone Trieste staff**, the **consultants** and **guests** that contributed in the design, the construction and the commissioning of the machine in the past 6 years.

POSTERS:

- ✓ **MOPA03** **Polarization Control of FEL Non-linear Harmonic Generation Emission**
- ✓ **TUPA05:** **Polarization Tunability at FERMI@Elettra. First Tests and Perspectives**
- ✓ **TUPB25:** **Full Tunability of a High-harmonic Source from Near-UV to XUV**
- ✓ **TUPB29:** **Status of the FERMI@Elettra Project**
- ✓ **WEPA03:** **Commissioning of the FERMI@Elettra Multi-purpose Electron Beam Diagnostics Station in the First Magnetic Compressor Area**
- ✓ **WEPB23:** **Coherent Ultraviolet Transition Radiation for Seeded FEL Bunching Optimization**

TALKS:

- ✓ **TUOC4:** **Design and First Experience with the FERMI Seed Laser**
- ✓ **WEOBI1:** **FEL Commissioning at FERMI@Elettra**
- ✓ **THOBI1:** **Polarization Control Experiences in Single-pass Seeded FELs**
- ✓ **FROAI2:** **All-optical Femtosecond Timing Distribution for the Fermi@Elettra FEL**

Thank you

感謝