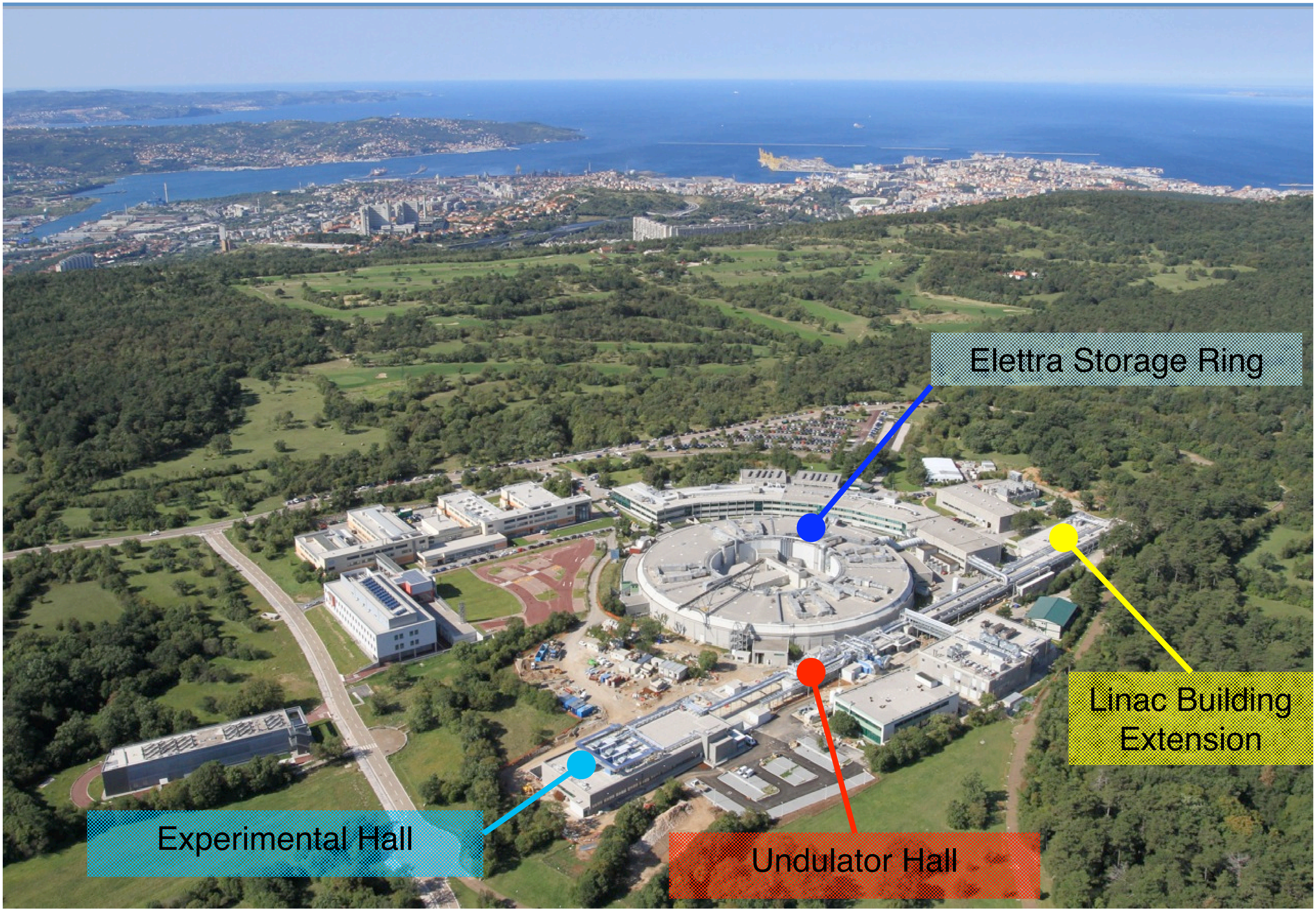
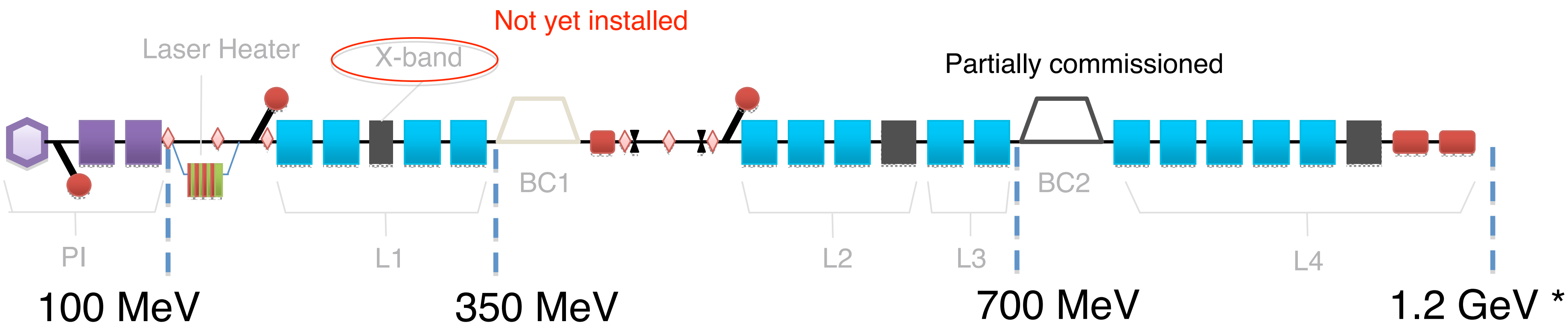
First results on the photon beam properties of the seeded FERMI@Elettra FEL1

Fulvio Parmigiani
on behalf of the FERMI@Elettra project

Overview of Elettra and FERMI



LINAC Layout

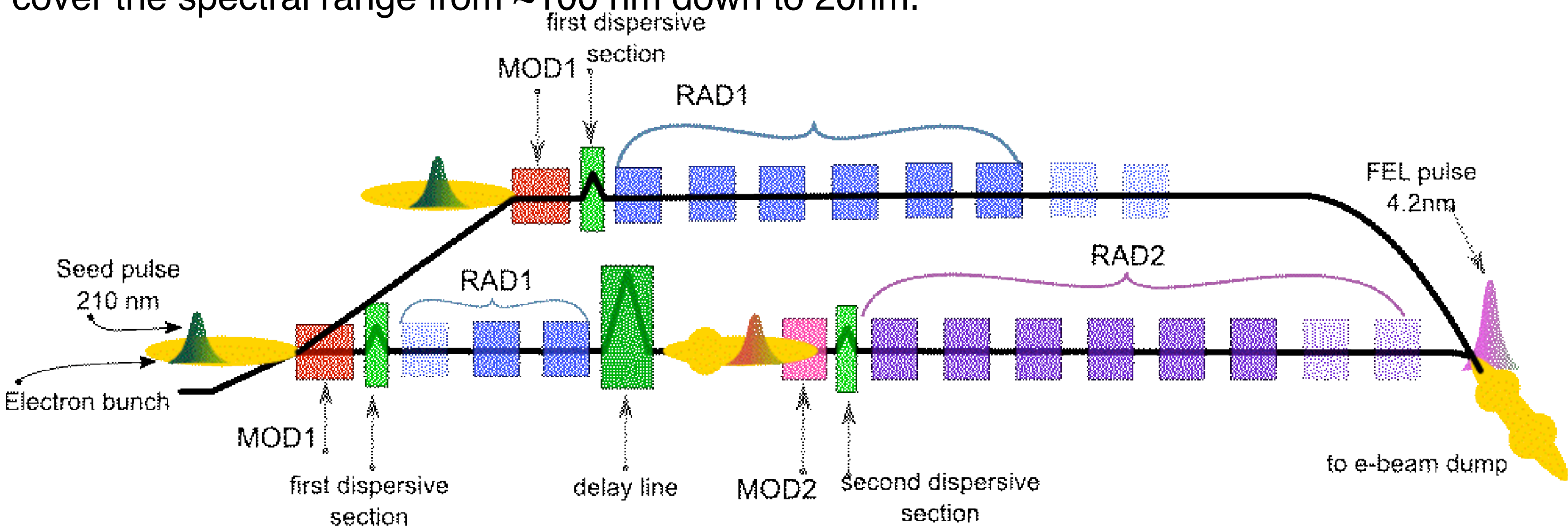


- ❑ Optimized a **450pC - 5ps flat top bunch** at the photo-injector ($\gamma\varepsilon_n$=0.9 μm)
- ❑ Some test on the Laser Heater but it will be optimized for FEL 2 operation
- ❑ X-band cavity has not yet been installed
- ❑ Beam compressed @BC1 by about **a factor 5** (BC2 not used up to now)
- ❑ Nominal energy @ linac end: **1.2GeV** (reached 1.35GeV)

FEL-1 and FEL-2

Two FELs will cover different spectral regions.

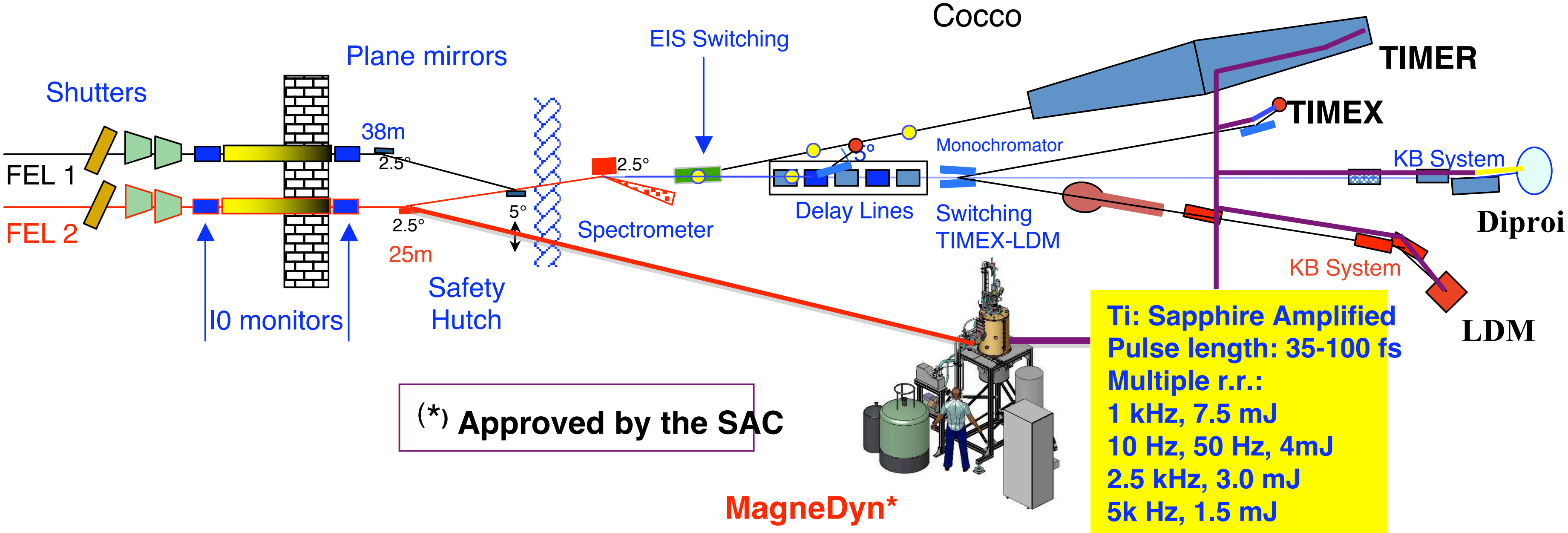
FEL-1, based on a single stage high gain harmonic generations scheme initialized by a UV laser will cover the spectral range from ~100 nm down to 20nm.



FEL-2, in order to be able to reach the wavelength range from 20 to ~4 nm starting from a seed laser in the UV, will be based on a double cascade of high gain harmonic generation. The nominal layout will use a magnetic electron delay line in order to improve the FEL performance by using the fresh bunch technique. Other FEL configurations are also possible.

FERMI beamlines-end-stations and pump-laser

Information and graphics provided by D. Cocco



LASER SYSTEM: ordered
LASER HUTCH: under tender
LASER beam transport to the end-stations in progress

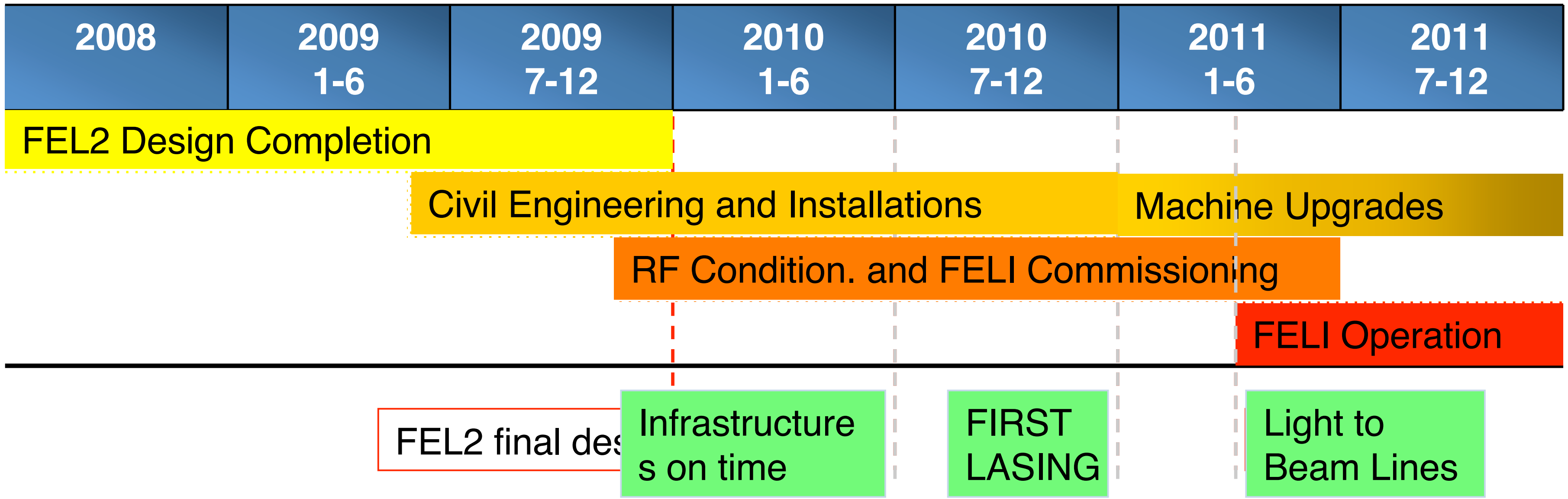
Human resources for the experimental hall (beside beam-line scientists) :

- **Experimental hall coordinator**
- **LASER responsible for the pump-probe experiments**

SCIENCE CASE

- **Low Density Matter** (*coord. C. Callegari*):
  - structure of nano-clusters ………………………………………….brightness
  - ionization dynamics ……………………narrow bw, circular polarization
  - magnetism in nano-particles ………………………….circular polarization
  - catalysis in nano-materials ………………………………………….λ-tunability
- **Elastic and Inelastic Scattering** (*coord. C. Masciovecchio*):
  - Transient Grating Spectroscopy (collective dynamics at the nano-scale) ………………………………….bw Fourier Tansform Limit
  - Pump & Probe Spectroscopy (meta-stable states of matter) ………………………………………brightness, λ-tunability
- **Diffraction and Projection Imaging** (*coord. M. Kiskinova*): Single-shot & Resonant Transverse Coherent Diffraction Imaging
  - morfology and internal structure at the nm scale ………………………….brightness
  - chemical and magnetic imaging

DESIGN GOALS & ACHIEVEMENTS



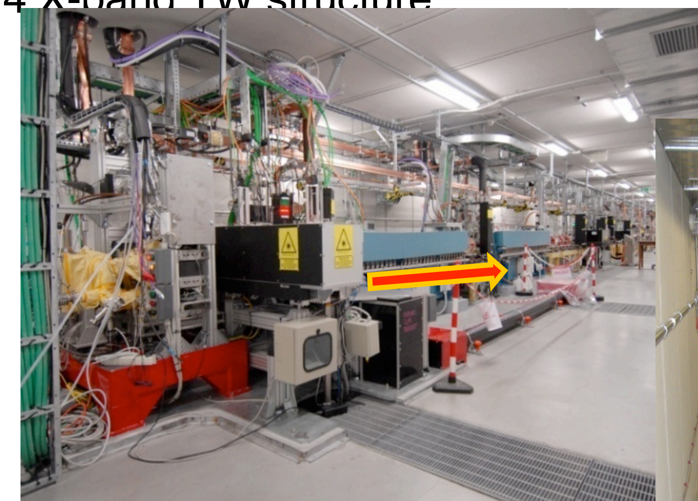
	Parameter	FEL1	FEL2	Units
γ	Output Wavelength (fund.)	100 – **20**	20 – 4	nm
	Peak Power	**1** – 5	> 0.3	GW
	Repetition Rate	**10**	50	Hz
e	Energy	**1.2**	1.5	GeV
	Peak Current (core)	**200** – 800	800	A
	Bunch Length (fhwm)	**0.7 – 1.2**	0.7	ps
	Slice Norm. Emittance	1.5 – **3.0**	1.0	mm mrad
	Slice Energy Spread	0.20	0.15	MeV

* **achieved**

LINAC

The existing 9-structures S-band Linac has been upgraded with:

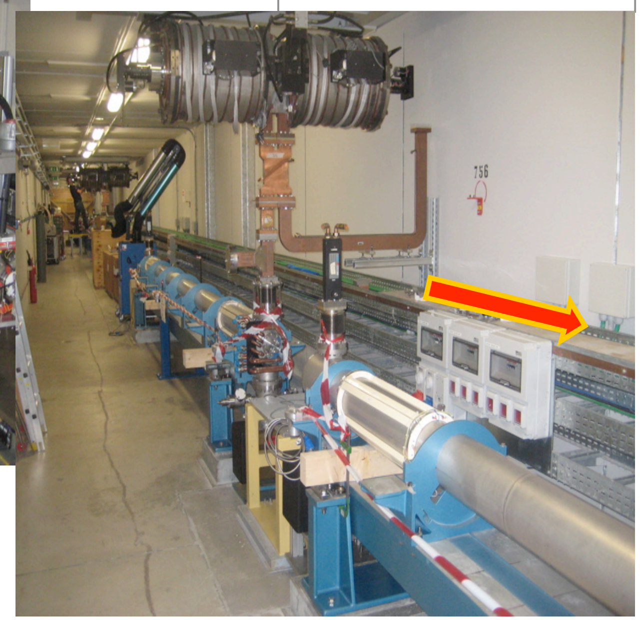
1. RF photo-cathode Gun (SLAC/BNL/UCLA) — ε_n = 1 μm measured at 400pC, 5 ps,100 MeV
2. 7 more CERN/LIL structures — 1.35 GeV routinely achieved
3. SLED optimization and phase-modulation — 27 MV/m reached for 1.5 GeV operation
4. X-band TW structure — *to be installed for linear time-compression*



PC Gun + Injector

CERN structures

“SLED” structures

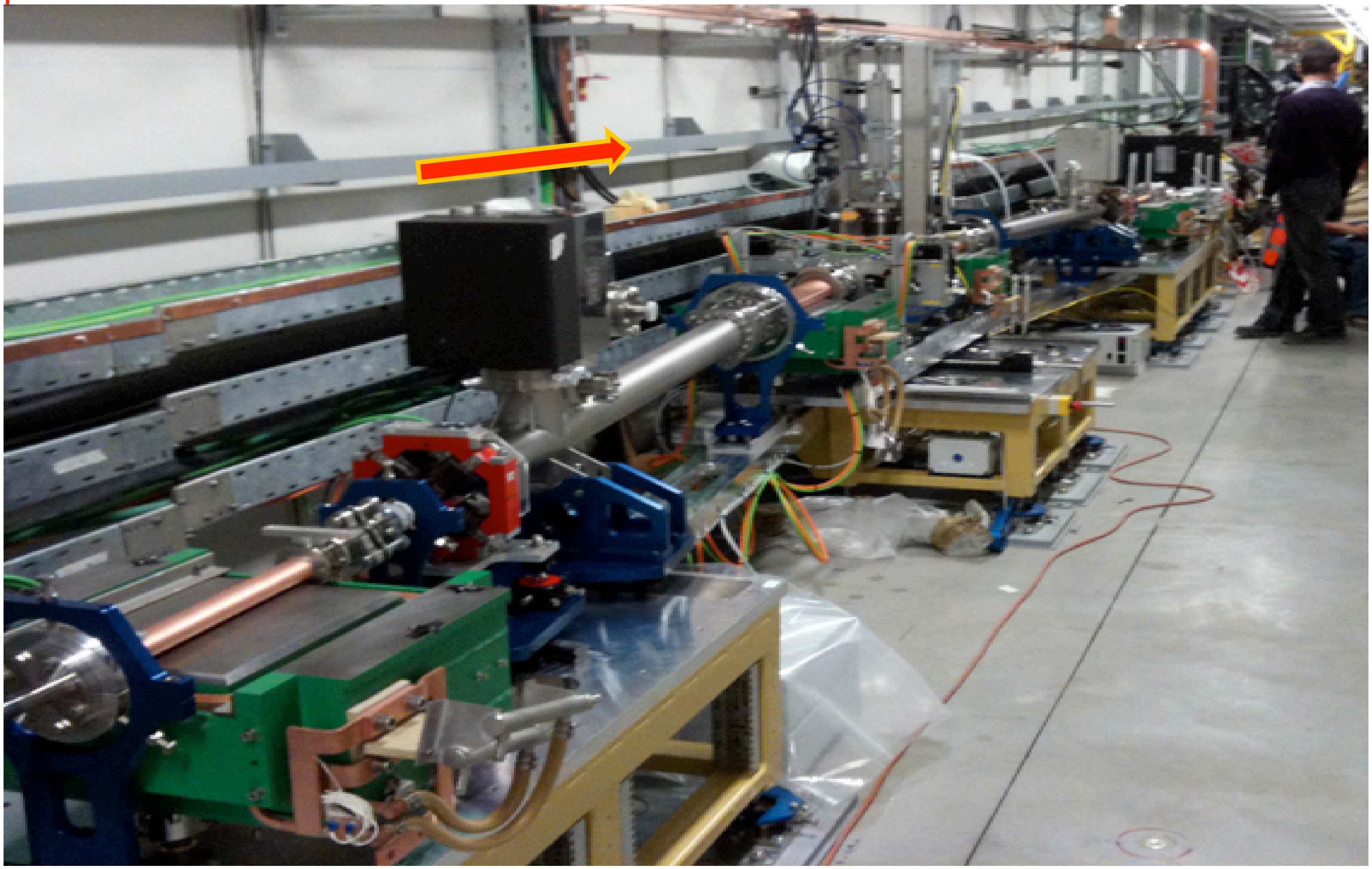


M. Trovo’ (Area Leader), M. Danailov, A. Fabris (Area Leader), P. Craievich

MAGNETIC COMPRESSOR

2 movable magnetic chicanes for one- or two-stage bunch length compression:

1.Developed *in house* on improved LCLS design CF ≤ 6 used for FEL operation



D. Zangrando (Area Leader), D. La Civita, D. Castronovo, G. Pangon

TRANSFER LINE

~30 m long high energy transfer line, switching FELI/FEL2. e-Beam diagnostics and collimation included.

It is followed by the undulators (~20 m) and the main dump line (~40 m).

“Spreader”

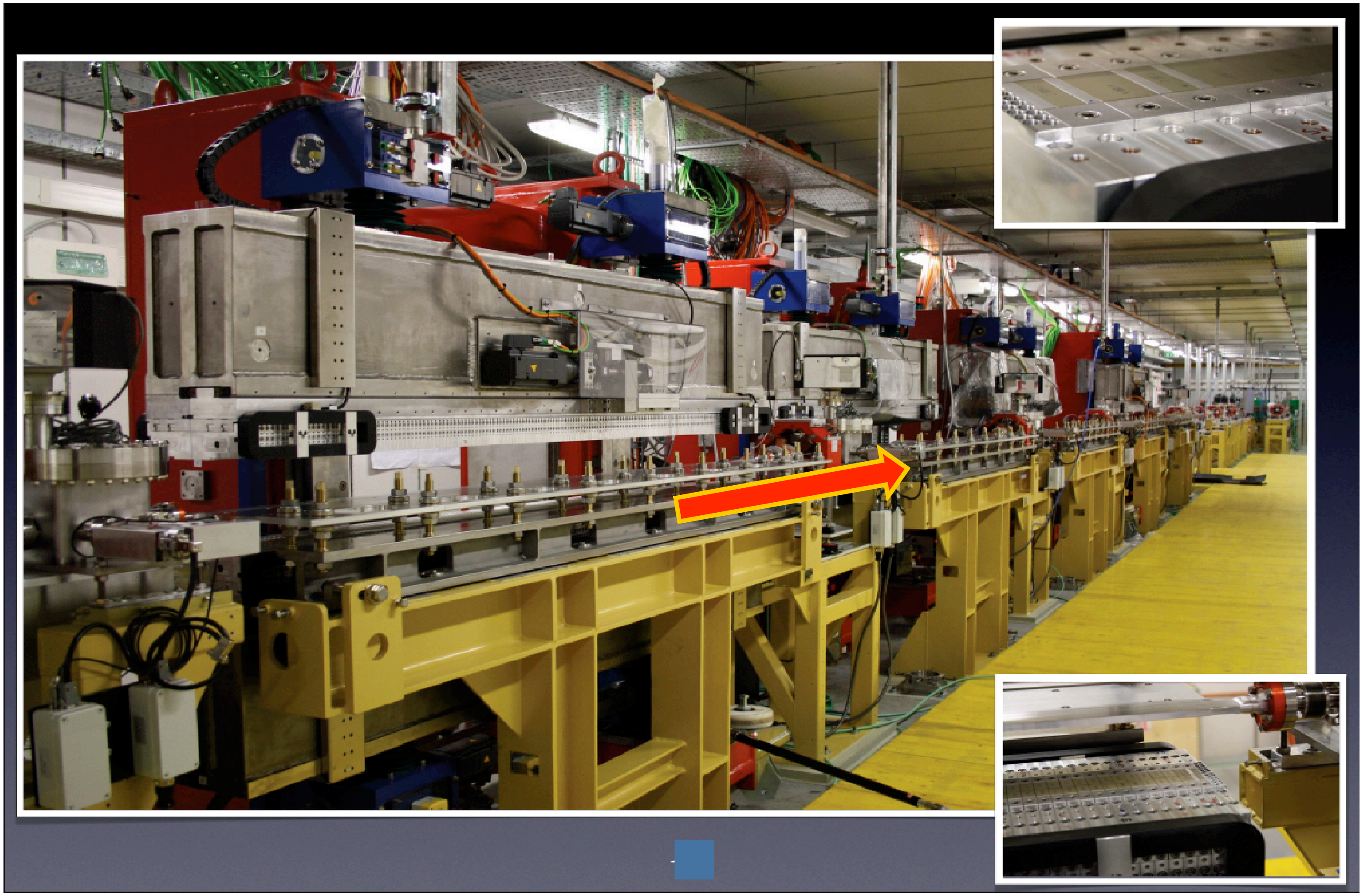
Main Beam Dump

E. Karantzoulis (Area Leader), S. Ferry, I. Cudin, M. Tudor, et al.

UNDULATOR
S

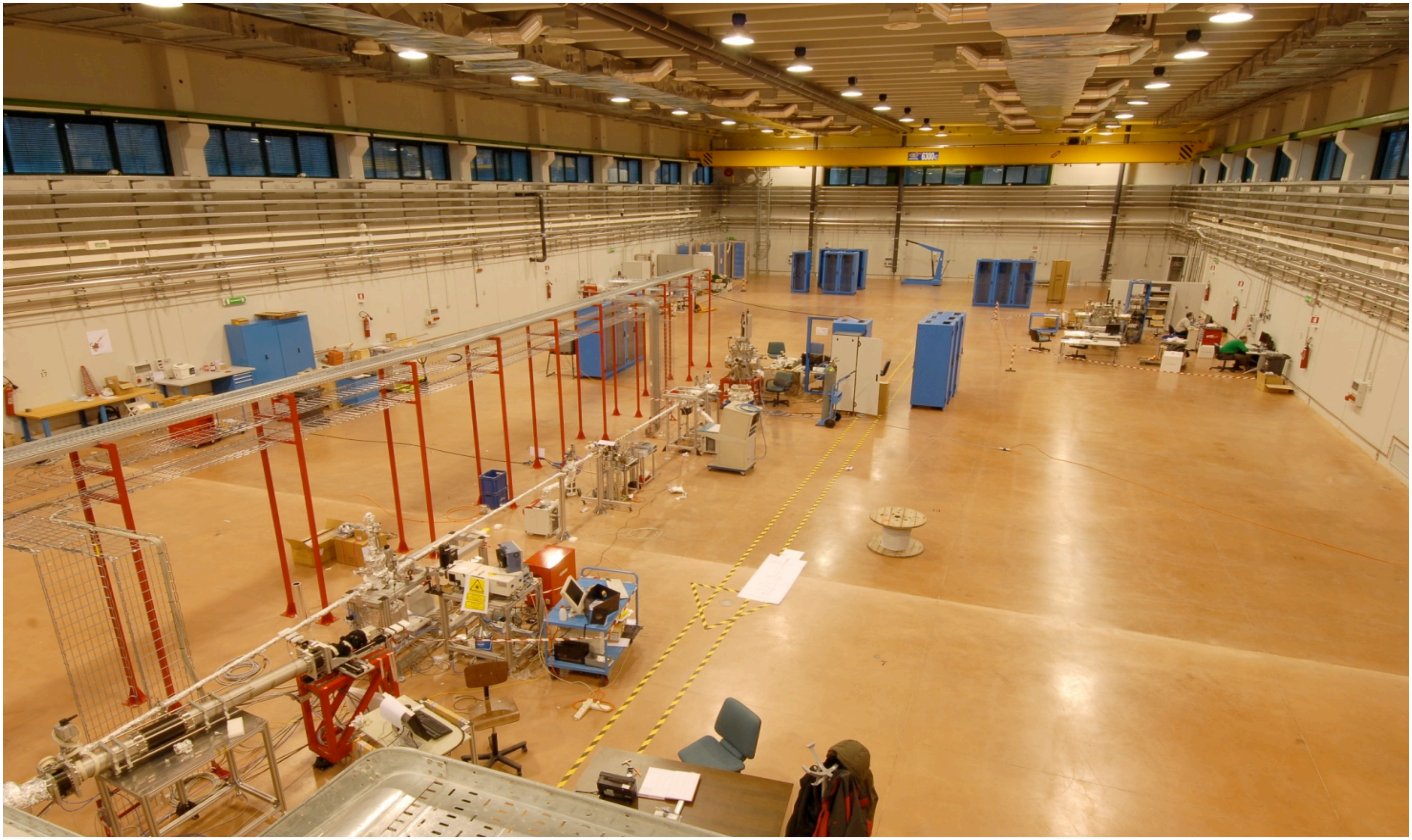
Variable gap, planar and APPLE-II type Insertion Devices design and manufacturing:

1.Developed *in house* (KYMA spin-off) variable polarization, λ-tuning provided to users



B. Diviacco (Area Leader), D. La Civita, M. Musardo

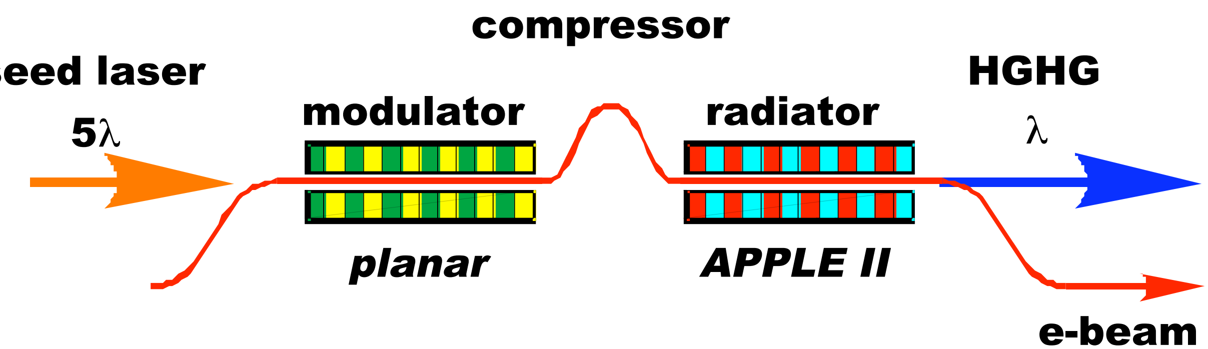
PHOTON TRANSPORT SYSTEM



D. Cocco (Area Leader), M. Zangrando, C. Svetina

FELs

- SASE
- SEEDED
- HGHG
- HHG
- NEW SCHEME



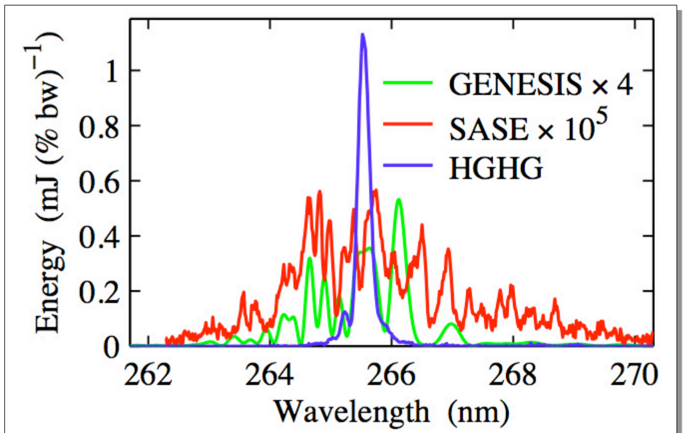
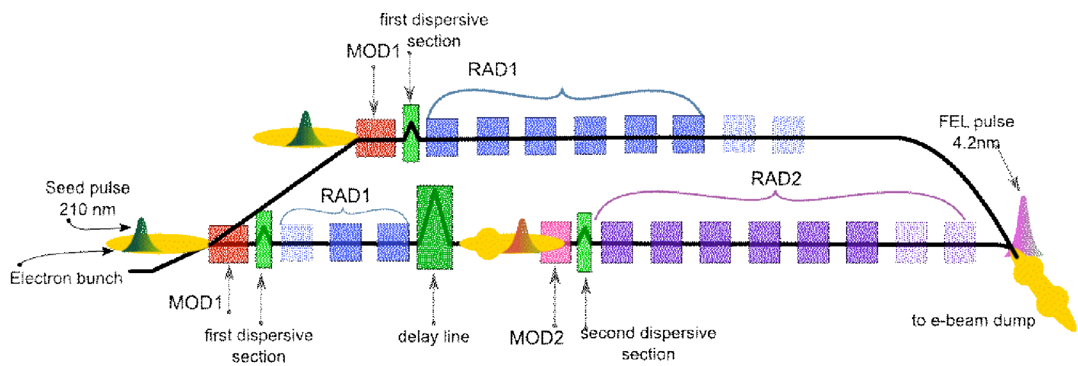


FIG. 4: Single shot HGHG spectrum for 30 MW seed (blue), single shot SASE spectrum measured by blocking the seed laser (red) and simulation the SASE spectrum after 20 m of NISUS structure (green). The average spacing between spikes in the SASE spectrum is used to estimate the pulse length.

Li-Hua Yu et al.
Phys. Rev. Lett. 91, 074801 (2003)

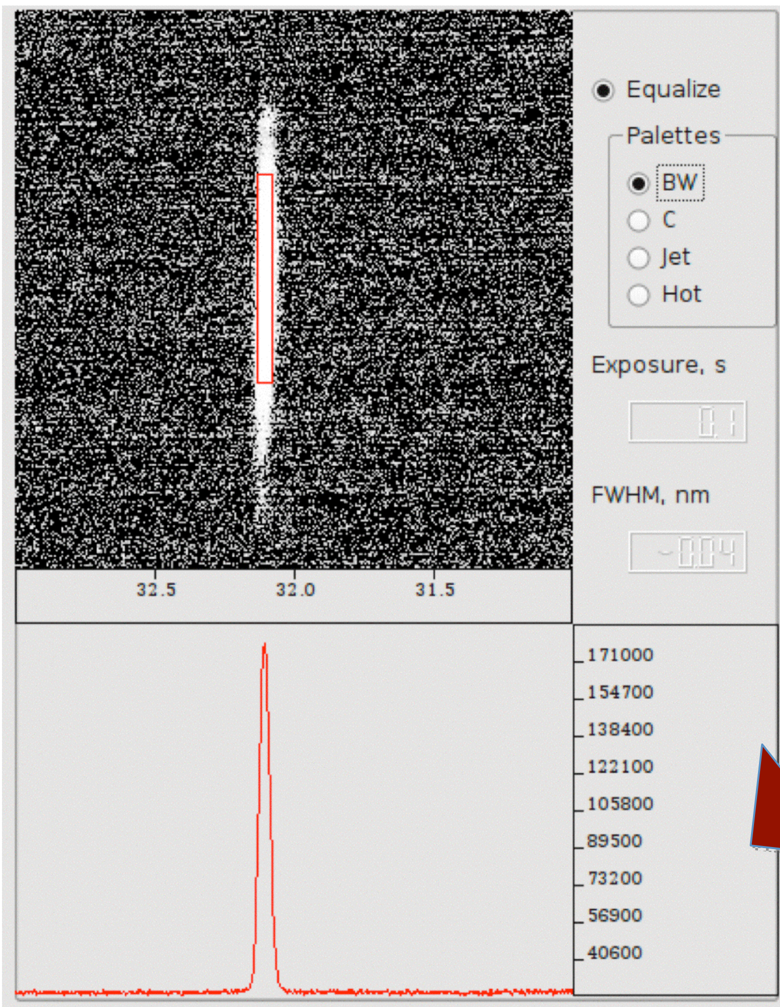


FERMI@Elettra

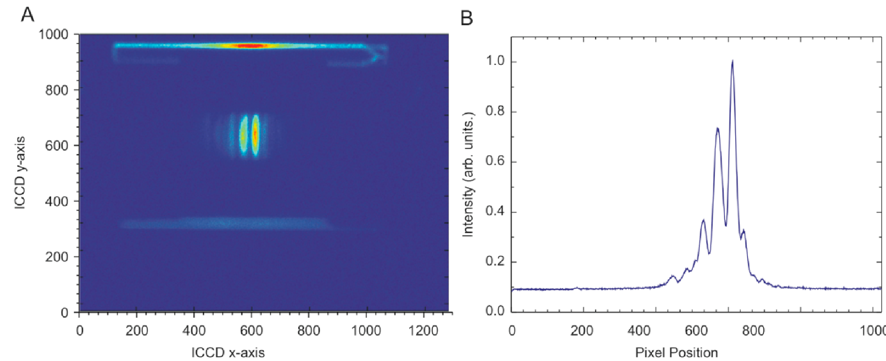
SASE AND SEEDED

First direct comparison between SASE AND SEEDED in the EUV-Soft X-ray region

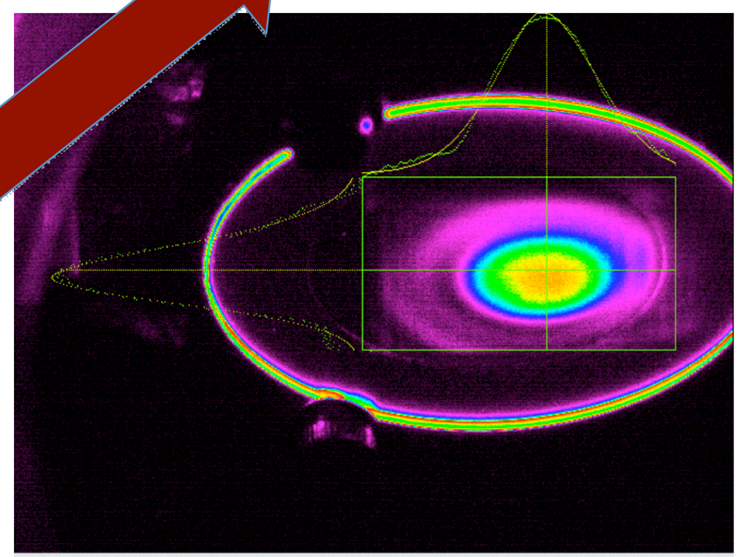
FERMI seeded FEL at 32. 2 nm



D. Cocco, C. Svetina, M. Zangrando W. Fawley and E. Allaria

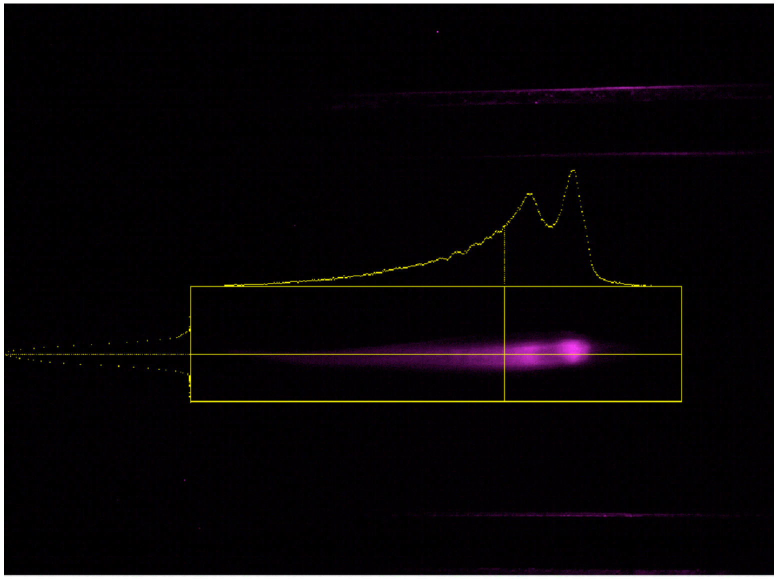


First results from the online variable line spacing grating spectrometer at FLASH, G. Brenner et al. NIMA 2010



W. Fawley, B. Mahieu, E. Allaria

SEEDING AND BANDWIDTH

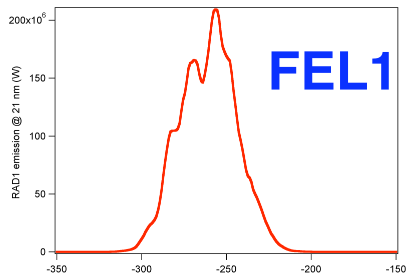


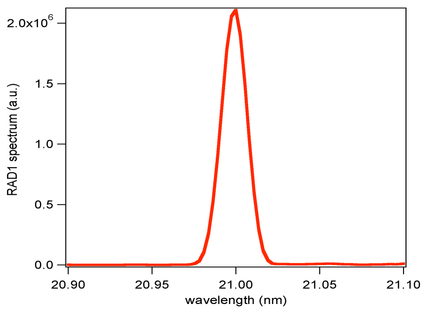
Typical used seed laser parameters have been:
Pulse length ~150fs FWHM with a measured bandwidth at 260nm of 0.8nm (15meV)

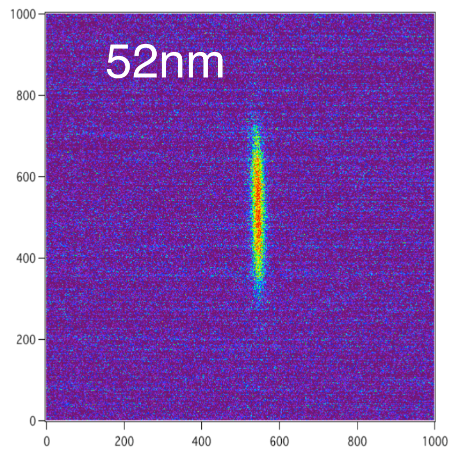
λ nm	Number of photons	E μJ	ΔE_{FWHM} meV	$\Delta E_{FWHM}/E$
52.5	>10[13(*)]	>40	30	$1.3*10^{-3}$
43.3	>10[13(*)]	>45	35	$1.2*10^{-3}$
32.5	>10[13 (*)]	>55	45	$1.2*10^{-3}$
20	$4*10^{12}$	40	50 100 shots	$8*10^{-4}$ 100 shots

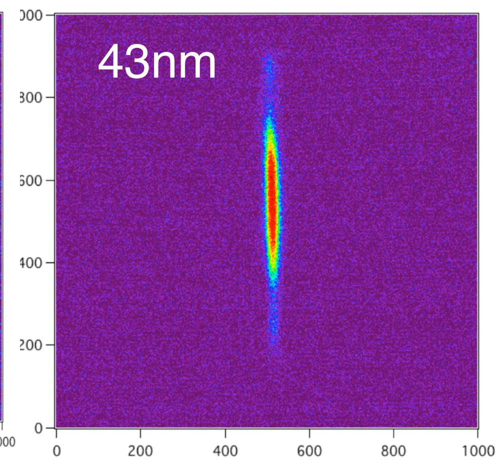
(*) calibration must be confirmed

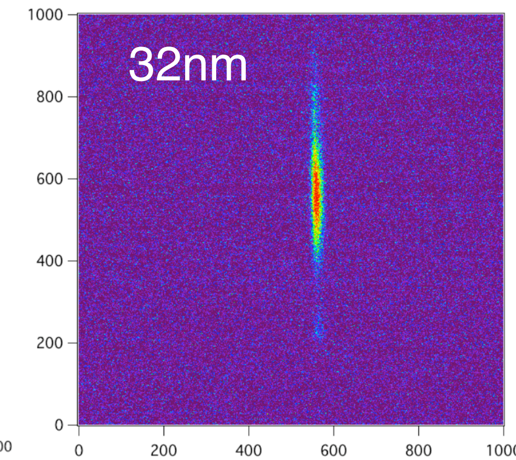
FERMI FEL1 and FEL2 seeded HGHG layout

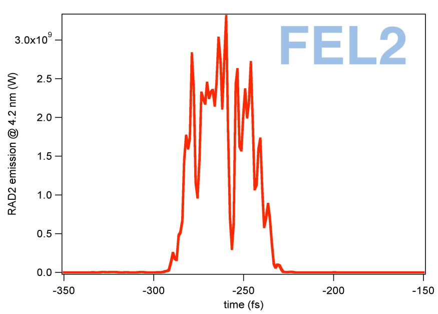


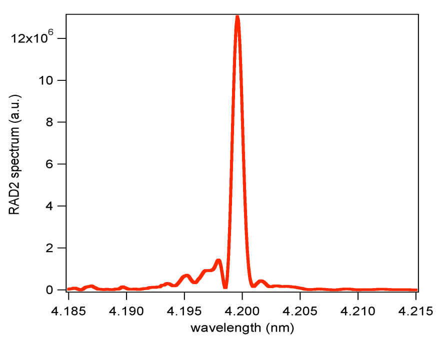




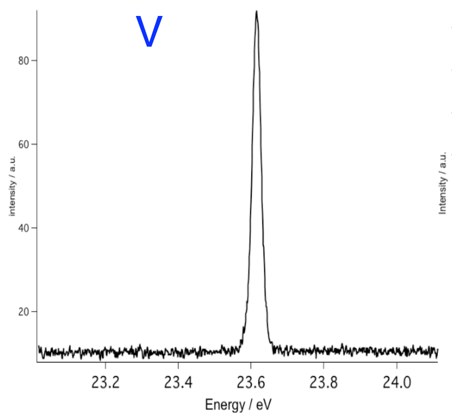




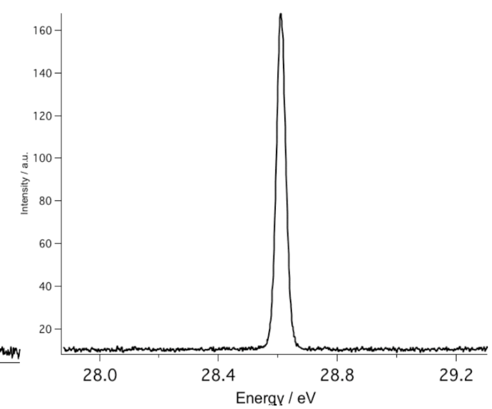




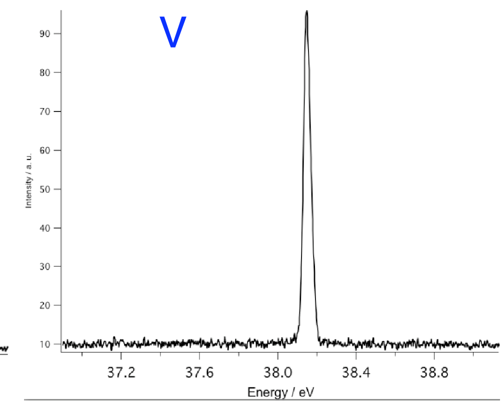
FWHM~29meV



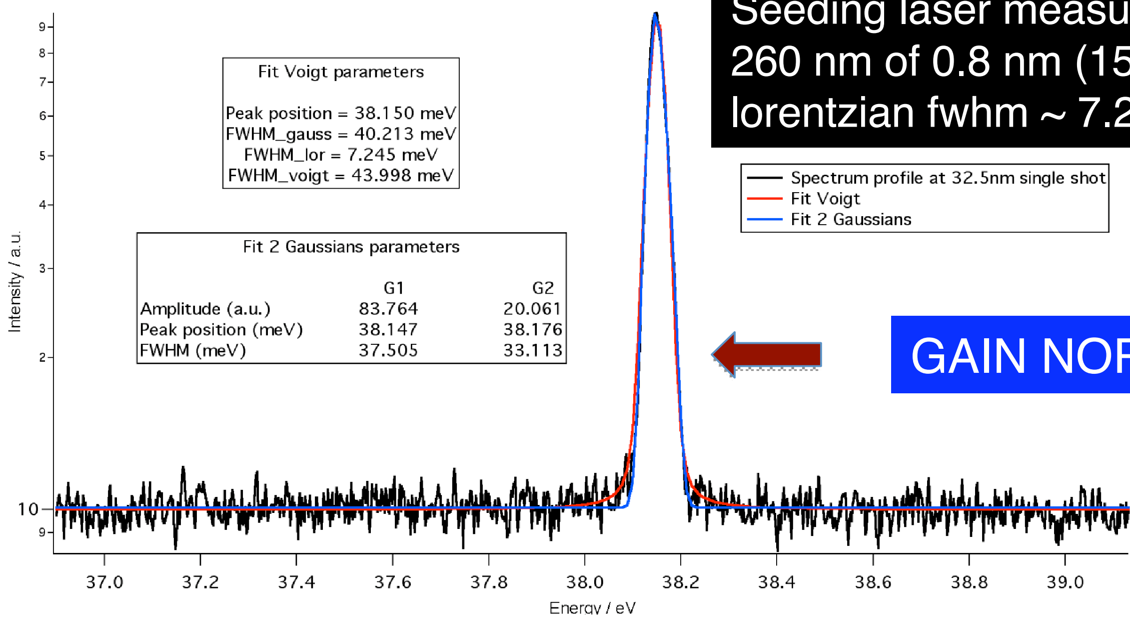
FWHM~33meV



FWHM~44meV



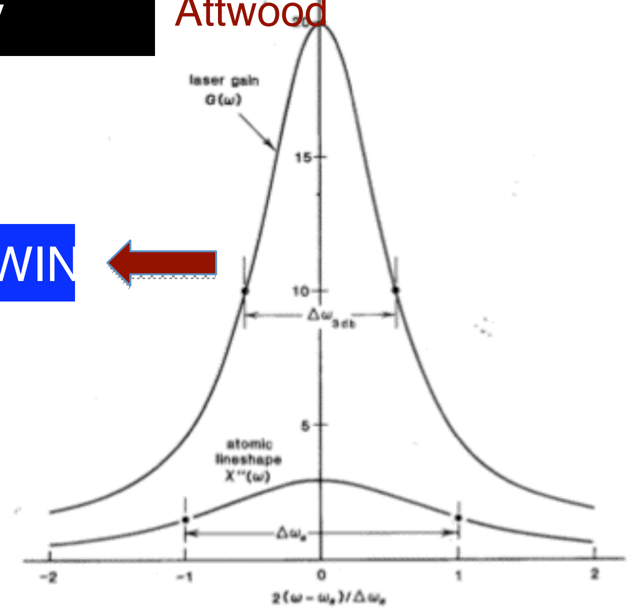
SPECTRAL LINE ANALYSIS

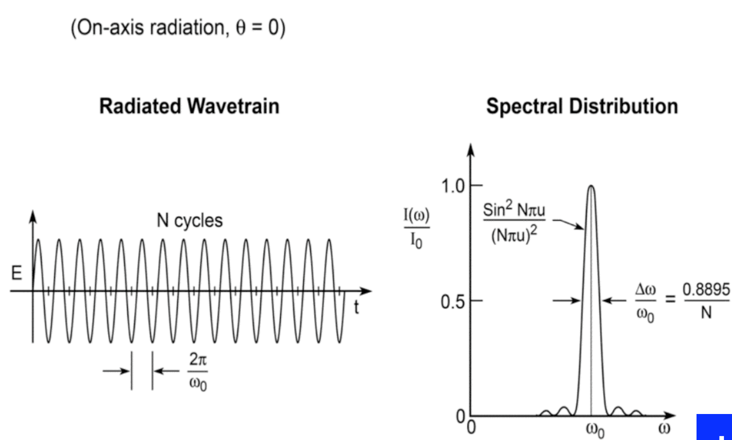


Seeding laser measured fwhm at 260 nm of 0.8 nm (15meV) vs lorentzian fwhm ~ 7.2 meV

After discussions with Max Zolotorev and Dave Attwood

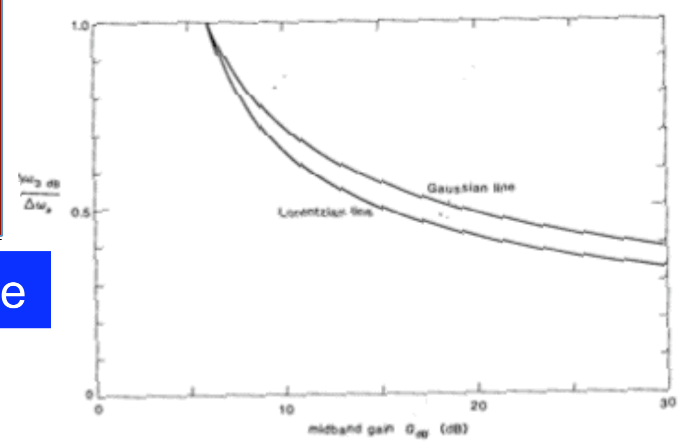
GAIN NORROWIN



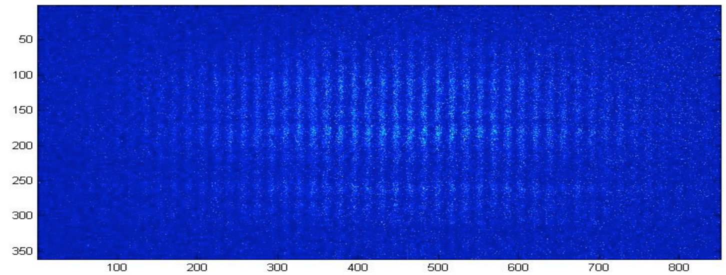


Exponentiall y amplified e.m. field

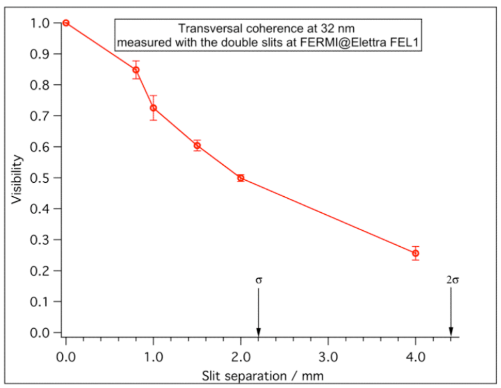
Lorentzian line shape



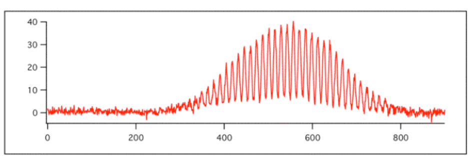
SASE AND SEEDED COHERENCE

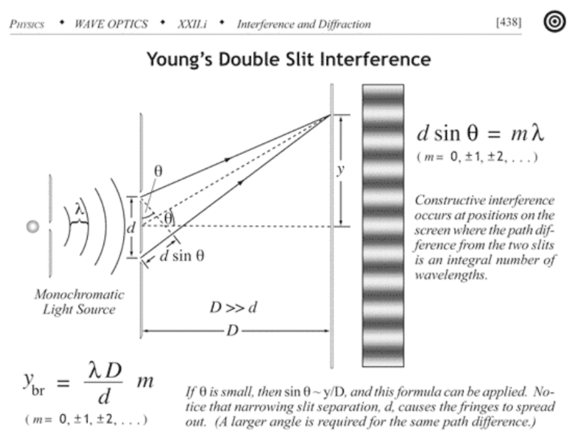


Visibility for a 32nm photon beam (FEL1) measured with the double slits system



Example of diffraction pattern obtained during the measurements (d=1mm w=40um)

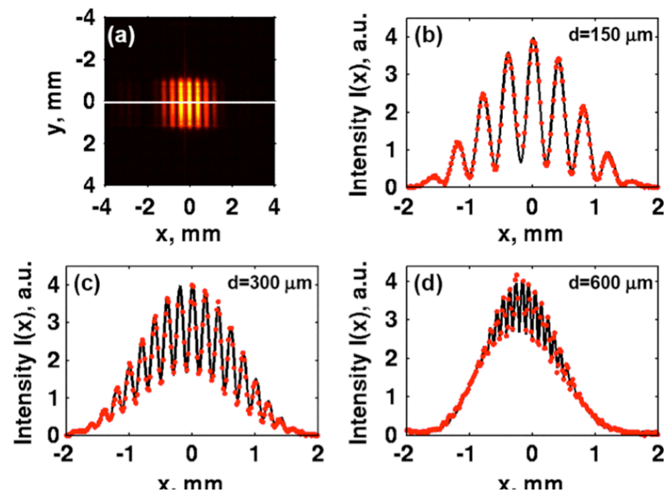


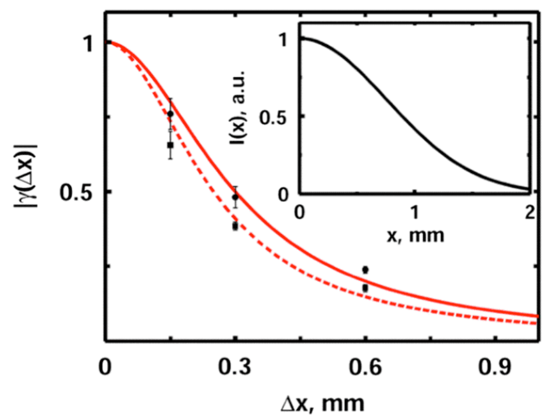


$$\Gamma(\mathbf{r}_1, \mathbf{r}_2, \tau) = \langle E(\mathbf{r}_1, t) E^*(\mathbf{r}_2, t + \tau)$$

$$I(P) = I_1(P) + I_2(P) + 2\sqrt{I_1(P) I_2(P)} |\gamma_{12}($$

$$\times \cos[\omega\tau - \alpha_{12}(\tau)],$$





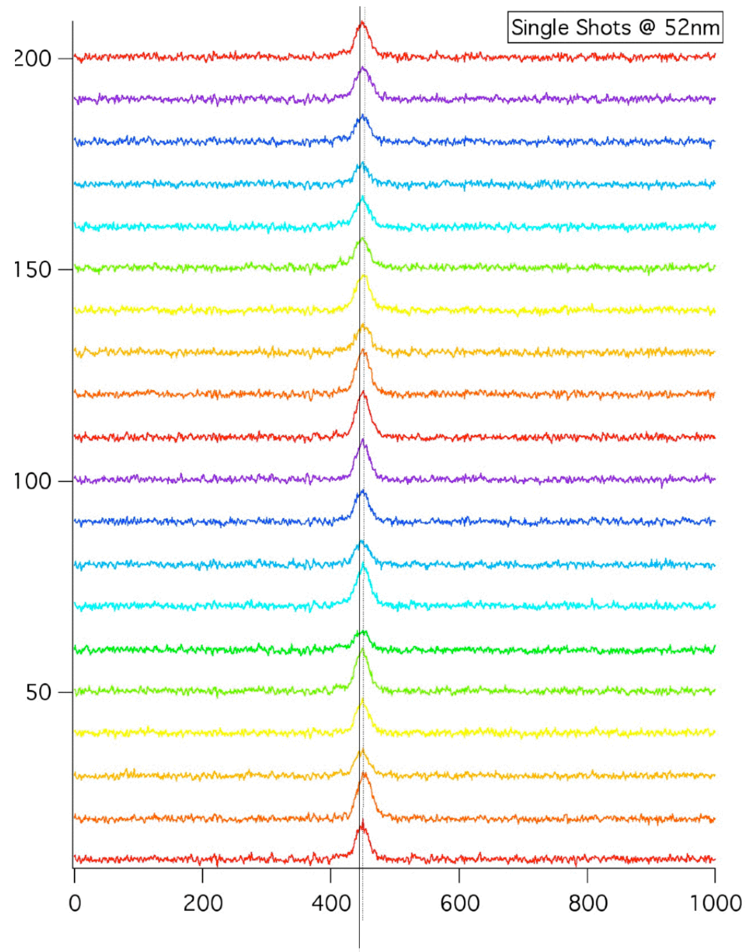
SASE FEL(FLASH)at a wavelength of 13.2 nm [seePRL 101,254801(2008)]

FERMI seeded FEL at 32 nm

D. Cocco, C. Svetina, M. Zangrando, C. Spezzani, E. Ferrari

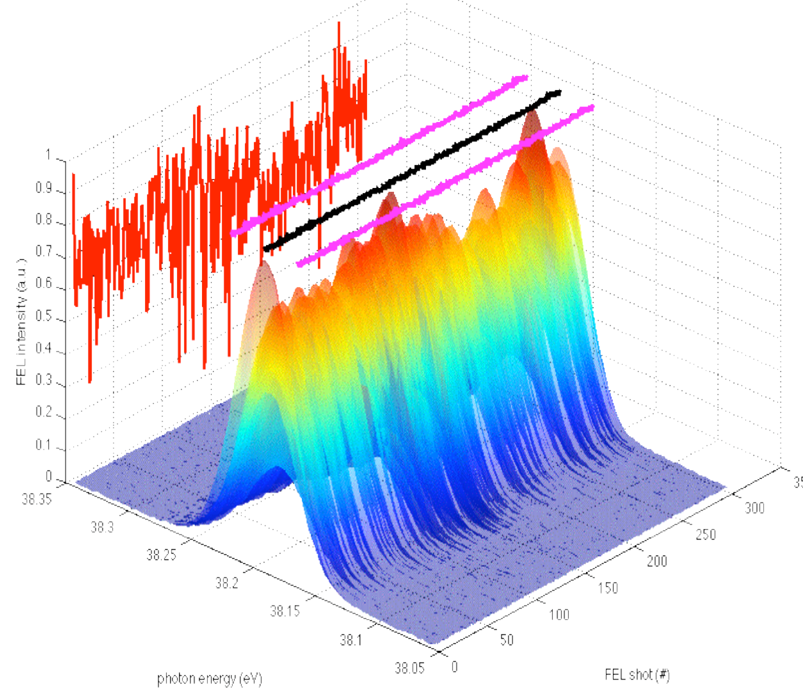
SASE AND SEEDED BANDWIDTH AND SPECTRAL STABILITY

In addition to the very narrow spectrum FERMI is characterized by a very good spectral stability. Both short and long terms measurements show that the spectral peak move less than 10^{-4}.



D. Cocco, C. Svetina, M. Zangrando

Reported data refer to an electron beam of 350 pC at 1.24 GeV compressed about a factor 3. The 6 radiators are tuned at 32.5 nm.



FEL photon energy	~ 38.19eV
Photon energy fluctuations	= 1.1meV (RMS)
FEL bandwidth	= 22.5meV (RMS)
	= $5.9e^{-4}$ (RMS)
FEL bandwidth fluctuations	= 3% (RMS)

E. Allaria, W. Fawley

FERMI, measured photon flux

December 2010 (*250pC*):
Compressed e-beam 43nm with photodiode: ~6 nJ;~$1*10^9$
Compressed e-beam 43nm with spectrometer: ~3 nJ;~$5*10^8$
Compressed e-beam down to 17 nm: clear evidence of coherent signal

March 2011 (*250pC*):
Uncompressed e-beam 65 nm with the DESY gas detector: ~0.3μJ, ~$1*10^{11}$, ~2MW
Compressed e-beam 65 nm with the calibrated FERMI gas detector: ~3 μJ , ~$1*10^{12}$, ~20MW

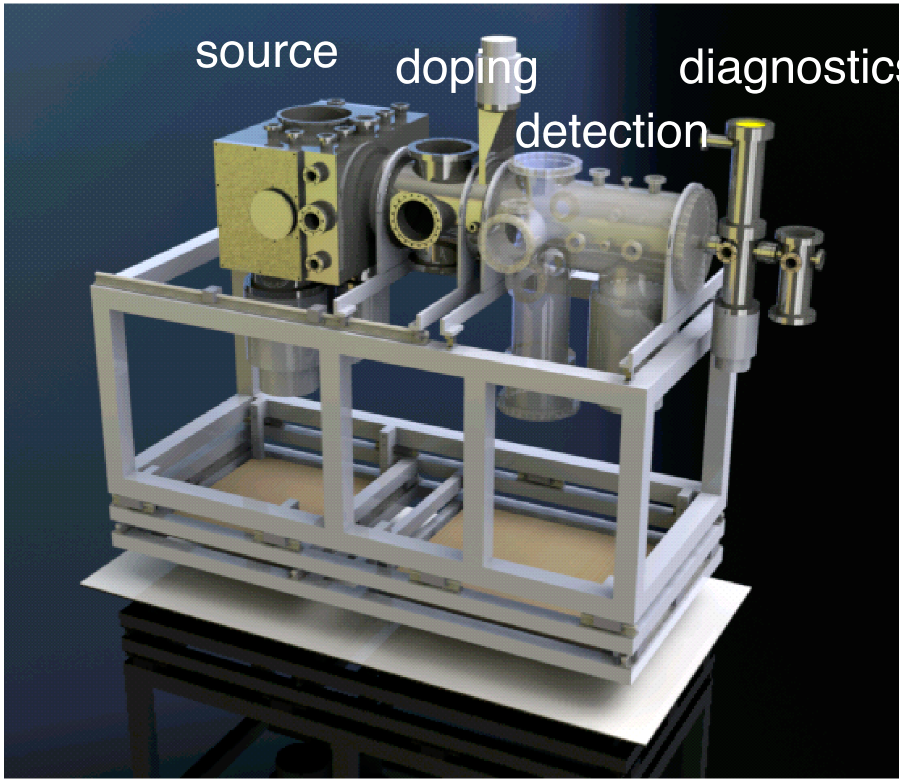
April 2011 (*350pC*):
Compressed e-beam 65 nm with spectrometer (average): ~2 μJ, ~$6*10^{11}$, ~12MW
Compressed e-beam 43 nm with spectrometer (average): ~5 μJ, ~$1*10^{12}$, ~30MW
Down to ~24 nm ~0.3 μJ, ~$4*10^{10}$, ~2MW

***Experimental stations**:*
Timex 65 nm with Al filter (March 25th): ~135nJ (peak), 70-80nJ (average).
LDM 65 and 52 nm: estimated from PADReS measurements

June-July 2011:
350pC-450pC
Compressed e-beam 52nm with calibrated* photodiode: ~30μJ, >$1*10^{13}$ [VERY PRELIMINARY]
Compressed e-beam 43nm with calibrated* photodiode: ~45μJ, >$1*10^{13}$ [VERY PRELIMINARY]
Compressed e-beam 32.5nm with calibrated* photodiode: ~100μJ, >$1*10^{13}$ [VERY PRELIMINARY]
Compressed e-beam 20nm with calibrated* photodiode: ~40μJ, ~$1*10^{12}$ [VERY PRELIMINARY]

FERMI CT: E. Allaria, M. Trovo',P. Craievich,S. Di Mitri, G. Penco *** Photododie calibration to be confirmed**

LDM end-station

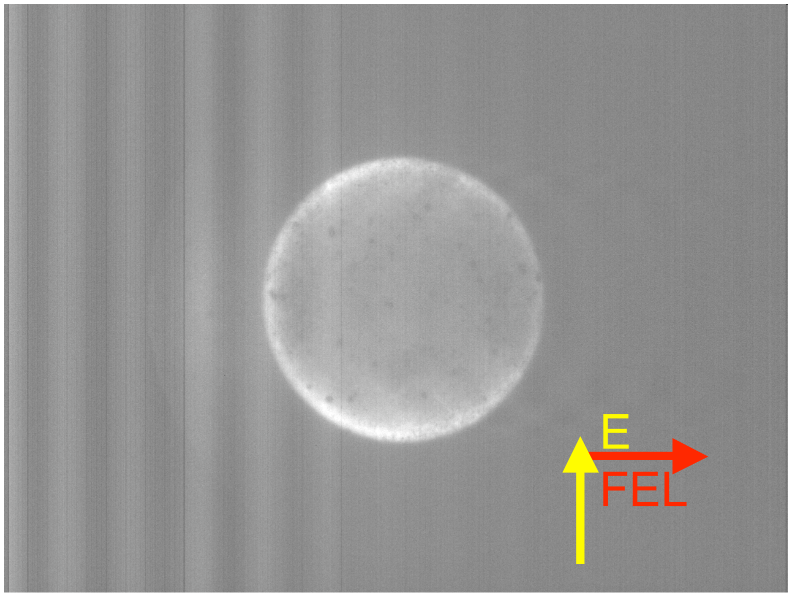


- FRAME CONSTRUCTION COMPLETED
- SOURCE CHAMBER COMPLETED
- DOPING CHAMBER COMPLETED
- DIAGNOSTIC CHAMBER COMPLETED
- DETECTION CHAMBER BEING FINALIZED

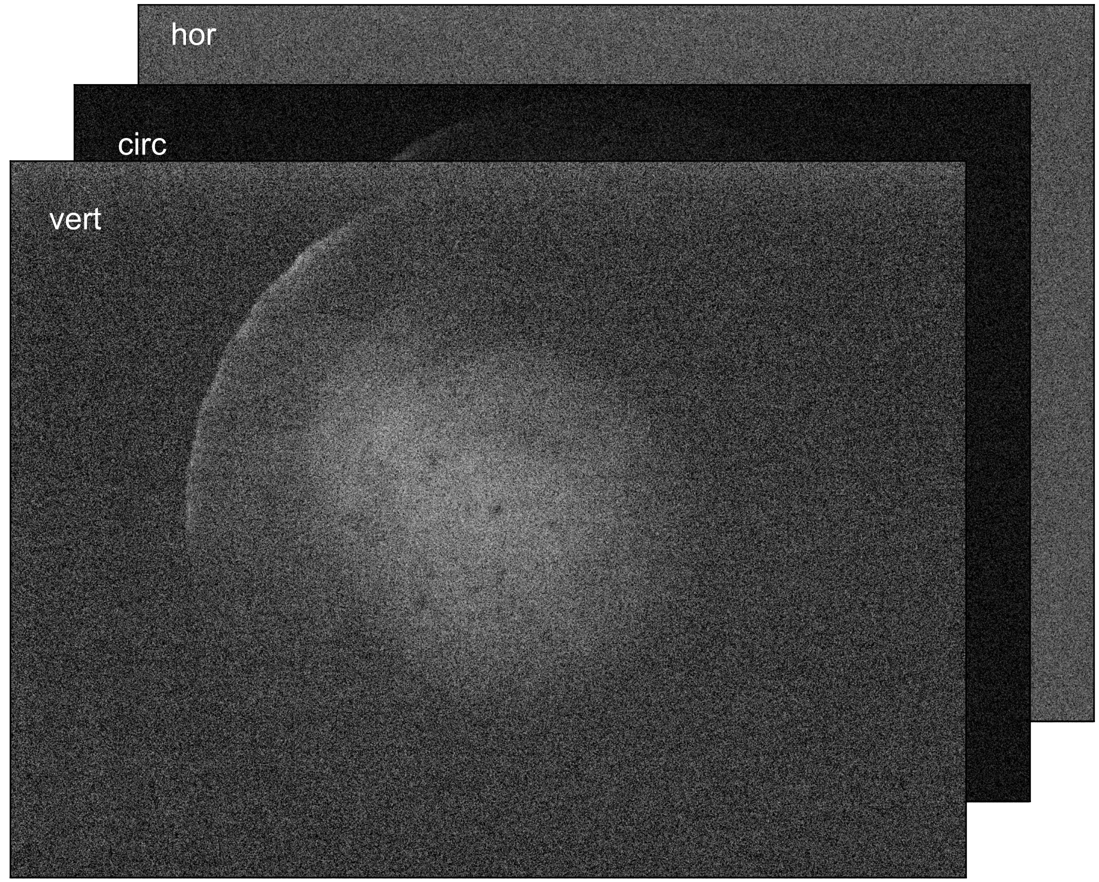
C. Callegari and LDM TEAM

LDM First experiments

First FERMI polarization data:
He photoeletcron spectra
(averaged)
hν=43 nm

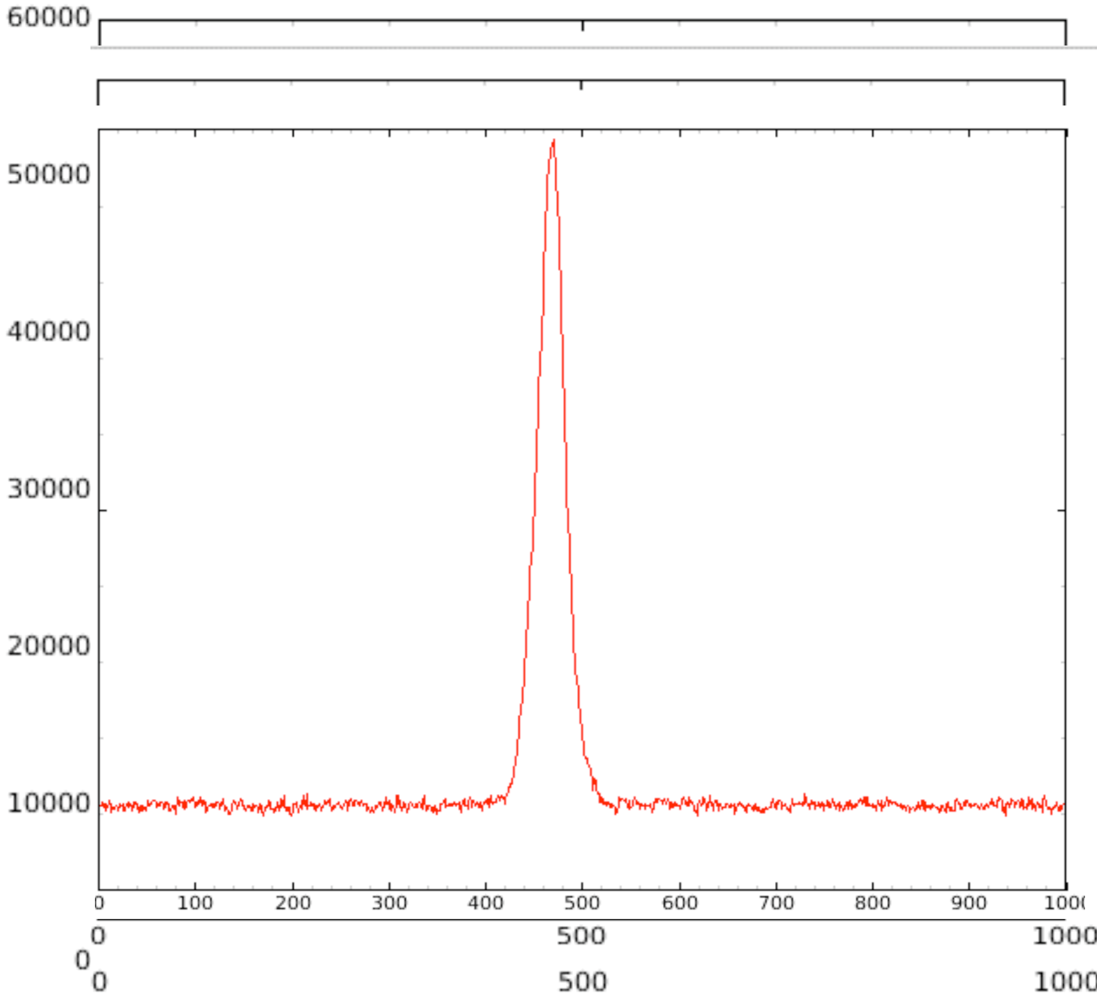


First FERMI spectrum:
Ar photoeletcron spectrum
hν=65 nm, horizontal polarization



INSTITUTIONS:
Sincrotrone Trieste; Technical University Berlin (TUB); University of Freiburg (UF); University of Milan; University of Rome
*EXP HALL: Michele Alagia (CNR-IOM), Paola Bolognesi (CNR-IMIP), Carlo Callegari, Marcello Coreno (CNR-IMIP), Monica de Simone (CNR-IOM), Michele Devetta (UniMI), Vitaly Feyer, Raphael Katzky (UF), Antti Kivimaki (CNR-IOM), Victor Lyamayev (UF), Patrick O'Keeffe (CNR-IMIP), Yevheniy Ovcharenko (TUB), Kevin Prince, Robert Richter, Rudi Sergo, Stefano Stranges (UniRM).
*CONTROL ROOM: Carlo Spezzani.

FEL tuning



A small FEL tuning around 52nm has been achieved by changing the seed laser wavelength of 1 nm (0.4%).

Following the seed laser wavelength tuning the undulator resonance has been changed accordingly to maximize the FEL power.

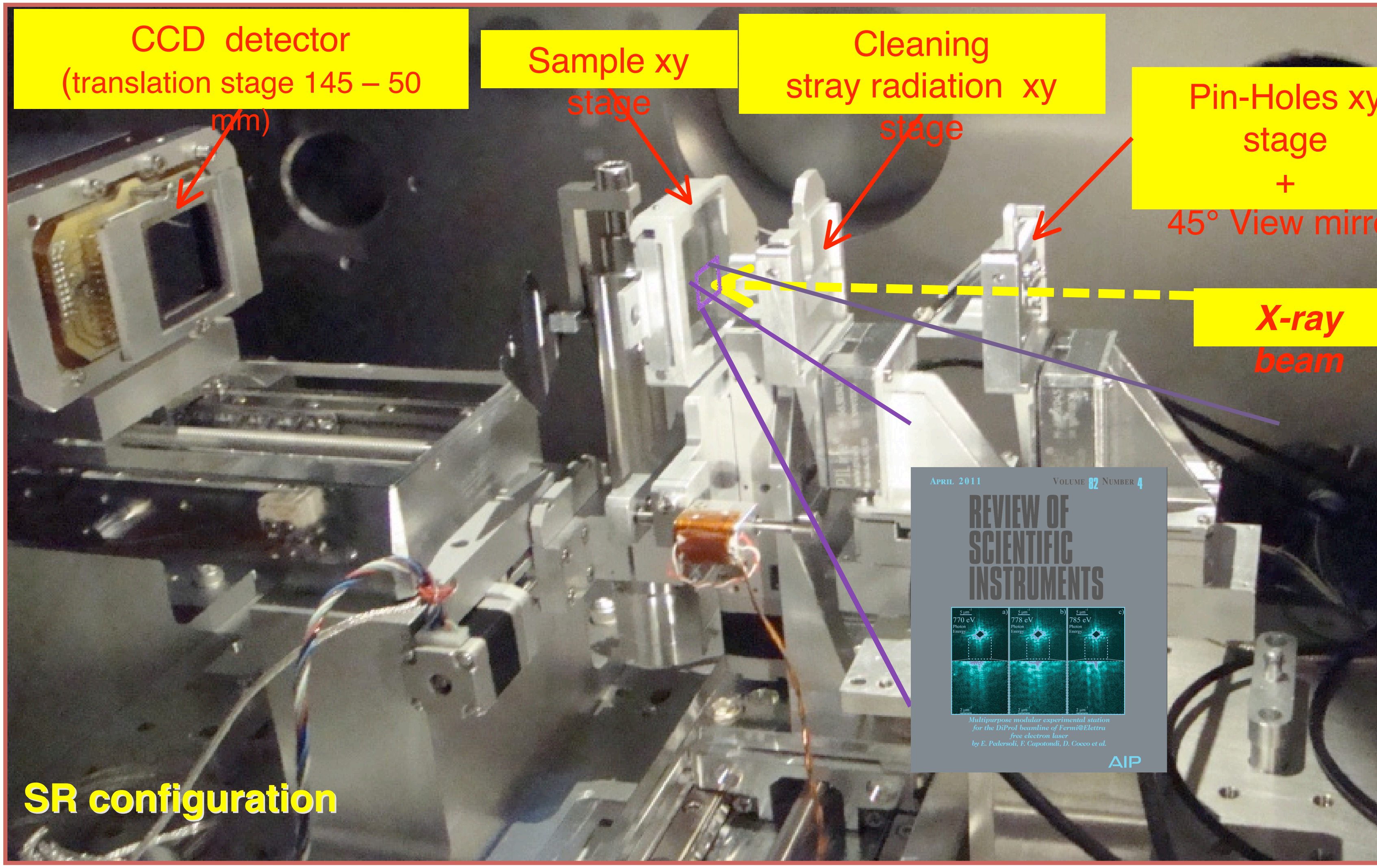
$\Delta\lambda_{seed}/\lambda_{seed}$ =0.4%, undulators gap tuning around 52 nm

→ **on-line tunable λ_{FEL}**

These data collected by: E. Allaria, B. Mahieu, W. Fawley, B. Diviacco, M. Musardo, L. Froehlich, C. Svetina, C. Spezzani, M. Danailov, S. Demidovich, C. Callegari, M. Zangrando

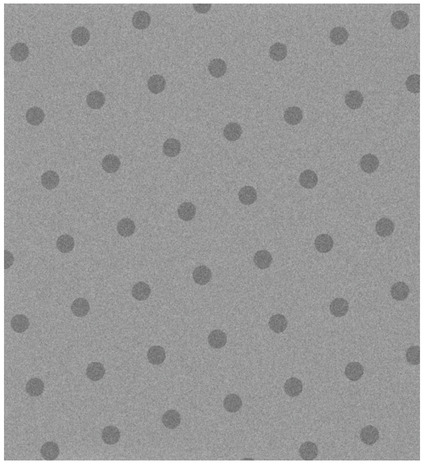
DiProI: test on Nanospectroscopy

Detector Configuration used at Nanospectroscopy is in direct detection mode as should be provided with proper detector for FERMI-2. ***Demonstrated feasibility of resonant magnetic imaging using circular polarisation .***

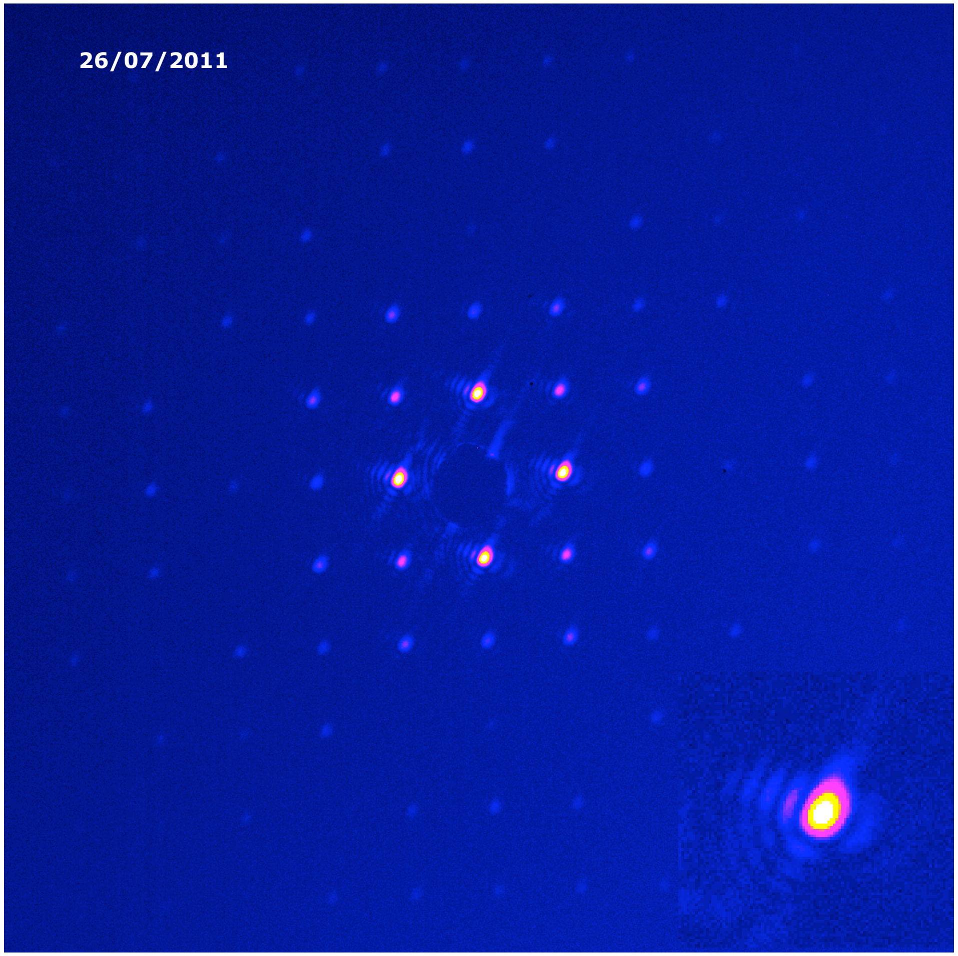


M. Kiskinova and and DiProI Team

First use of FEL light in experimental chambers



FEL radiation at 32.5 has been used to start with the activities on the DiProI experimental chamber.



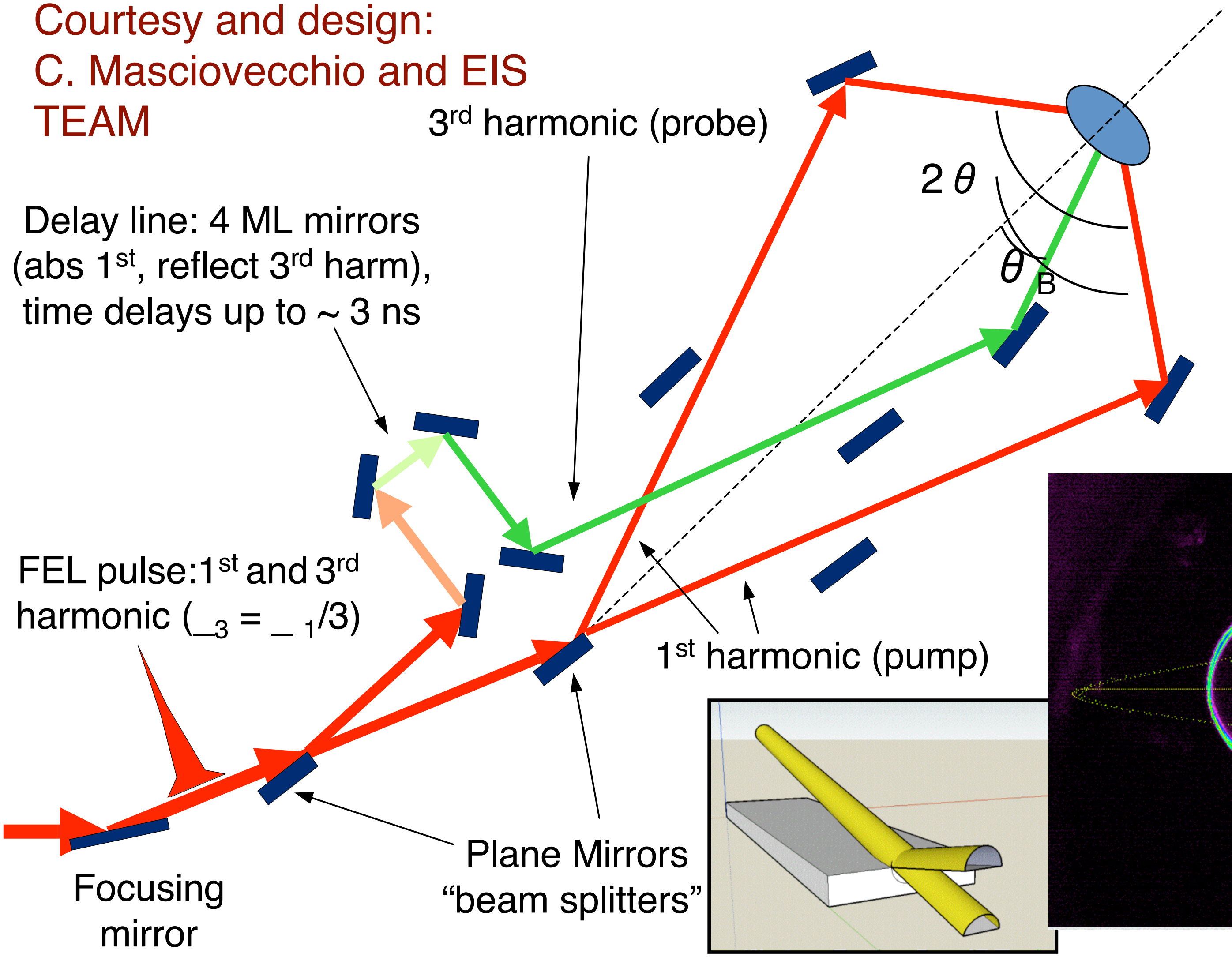
Due to an issue on the focusing mirror the small FEL spot has been produced by means of a 20 μm pin-hole from QuantiFoil. FEL signal has been also filtered by using two Al filters (400 and 800 nm respectively)

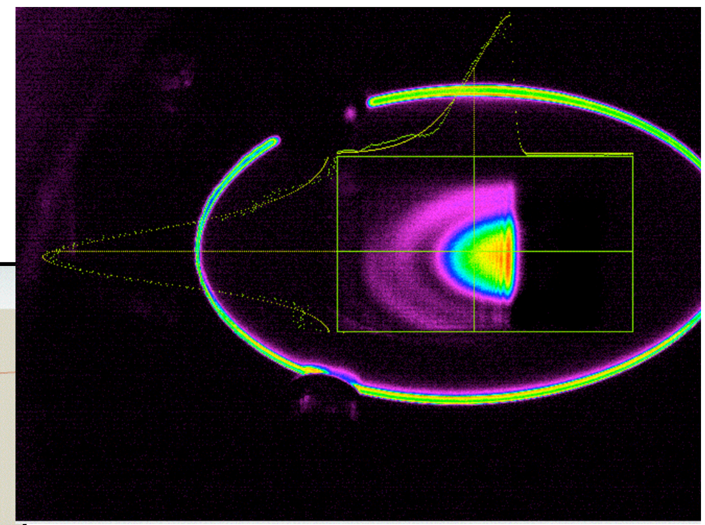
In these conditions it has been possible to record coherent scattering images from a periodic array by integrating the CCD signal over few minutes.

F. Capotondi, E. Pedersoli, R. Menk, M. Kiskinova and
H. Chapman et al. (CFEL-DESY), J. Hajdu et al. (Uppsala), M. Bogan et al. (SLAC), M. Pivovaroff, A. Nelson et al. (LLNL)
S. Spampinati, S. Bassanese, E. Allaria

TIMER: optical layout

Courtesy and design:
C. Masciovecchio and EIS
TEAM

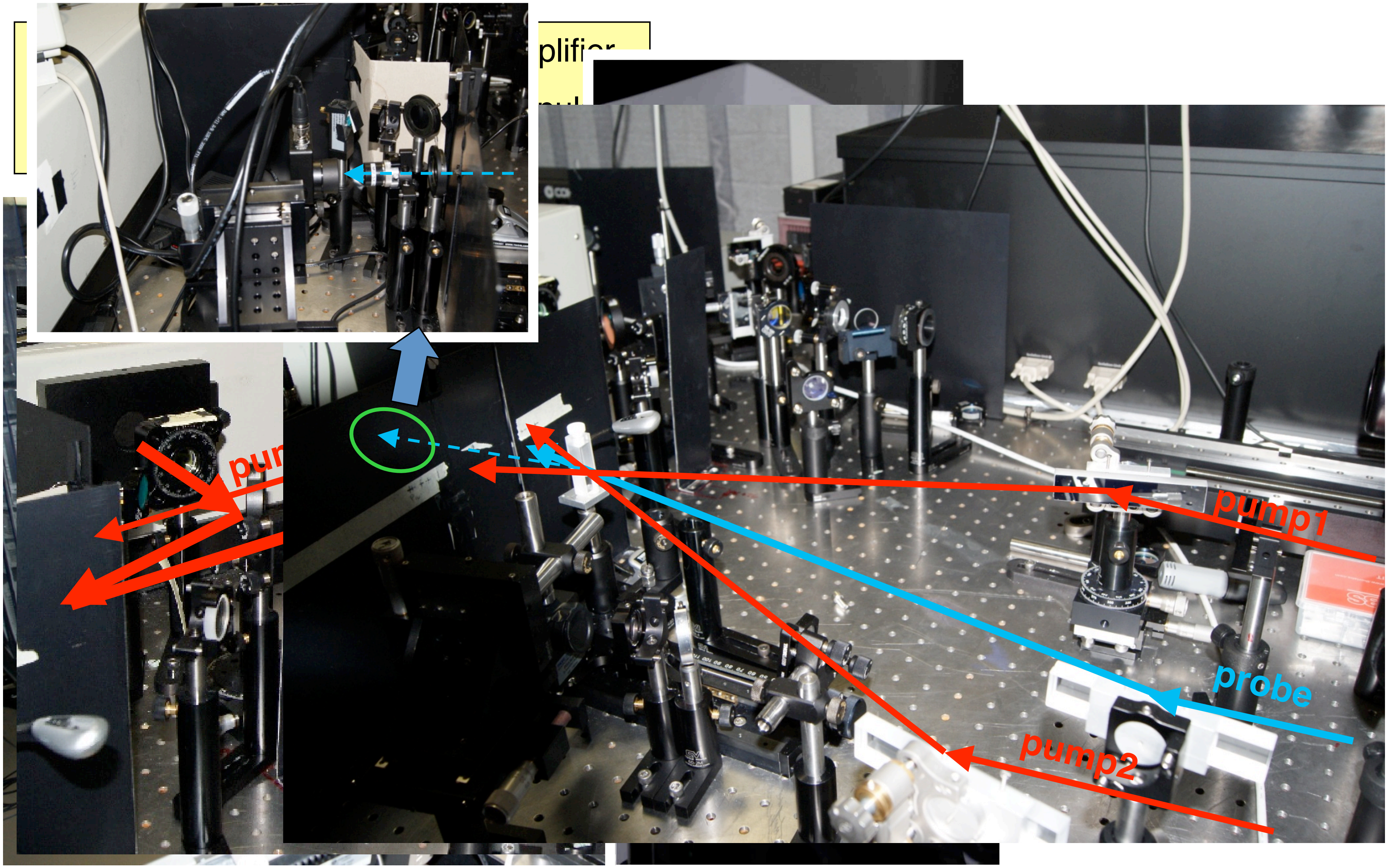




W Fawley

R. Cucini et al et al., NIMA (2011)

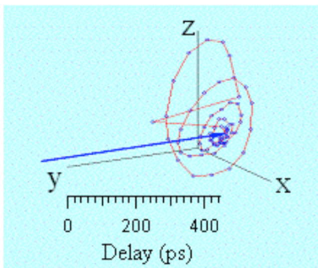
TIMER: proof of principle



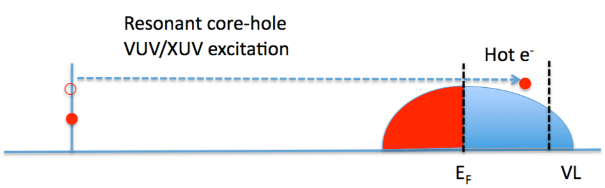
Magnedyn scientific proposals and cases

Ultrafast demagnetization

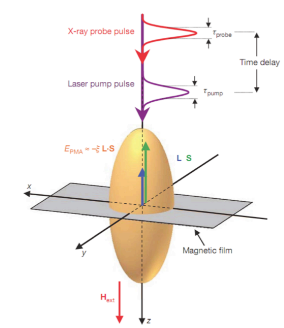
Ultrafast demagnetization after optical excitation



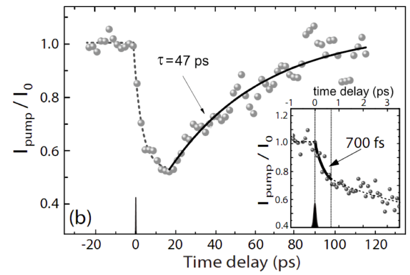
Ultrafast demagnetization after core hole excitation



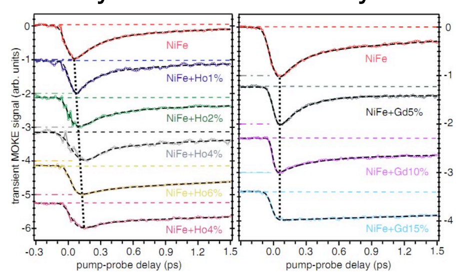
temporal evolution of the orbital moment anisotropy



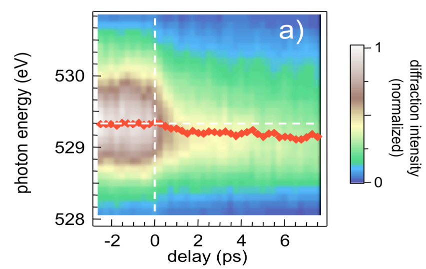
magnetization dynamics in complex materials



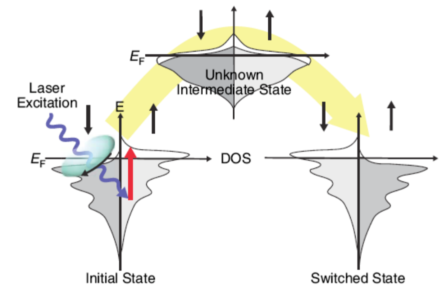
Magnetic dynamics in dilute systems.



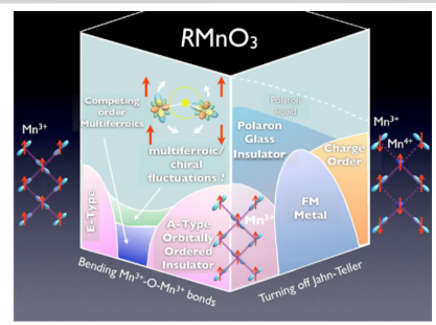
Transient phases in complex materials.



Phase Transitions in Advanced Magnetic Materials.



Single shot experiments And magnetic fluctuations



- The way to produce fully coherent X-ray radiation is paved. If also the second stage for the HGHG will be proved a new technology will be available.
- Tunability
- Variable polarization
- Full coherence
- High repetition rate

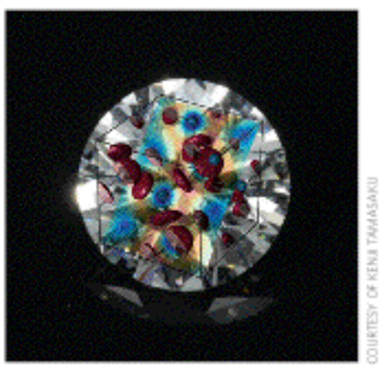
The future scenario

Coherent X-ray Optics

Quantum X-ray optics

Stroboscopic phase tomography

An extraordinary effort is needed to develop a suitable science program



XPDC imaging. Tamasaku *et al.*[4] use their parametric down-conversion-based technique to investigate the response of diamond to ultraviolet light at a resolution as small as 0.54 Å.

news & views

NONLINEAR X-RAY OPTICS

The next phase for X-rays

Phase information can be obtained from inelastically scattered X-rays by combining parametric down-conversion with tunable quantum interference. This is a step towards putting this nonlinear phenomenon to a practical use in the X-ray regime: investigating the optical response of chemical bonds at their electron-volt and subnanometre scales.

Bernhard Adams

NATURE PHYSICS | ADVANCE ONLINE PUBLICATION |

Published online: 17 July 2011
Corrected online: 28 July 2011

Future road map

FEL-1

FEL-1 optimization is expected to be concluded in 2011 and the users' program started in 2012

Two projects have been already founded for implementing HHG sources to be tested as a seed on FERMI in the 30 nm range and more long term below 10nm.

When FEL-2 become online FEL-1 could be temporary configured for HHG tests (*end 2012?*).

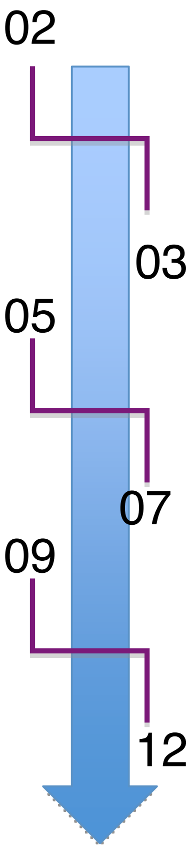
FEL-2

Prove HGHG with FEL2 (major goal in 2012)

FEL-2 has been already shown to be almost compatible to ECHO scheme. A possible temporary modification could be done in agreement with the users for testing ECHO at 50th

Conclusions

2010: **Possible photon beam characterization with the first FEL**
1 light



2011: **Commissioning of the beamline and end stations with FEL**
1

In house tests and experiments only. No external user

program.

RUN 6: Test and commissioning of some end-stations [(EIS)TIMEX, LDM in-house [not DiProi, TIMER and LDM main-station].

RUN 7:

Tests and commissioning and preliminary experiments with TIMEX, DiProI, LDM in-house on the respective beamlines. Variable polarization and limited photon energy tuning.

Possible
RUN 8-9: MagneDyn experiments.

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.