Polarization control experiences in single-pass seeded FELs

Carlo Spezzani on behalf of

the FERMI team & the storage-ring FEL group

Outline

Introduction

Storage Ring FEL test facility

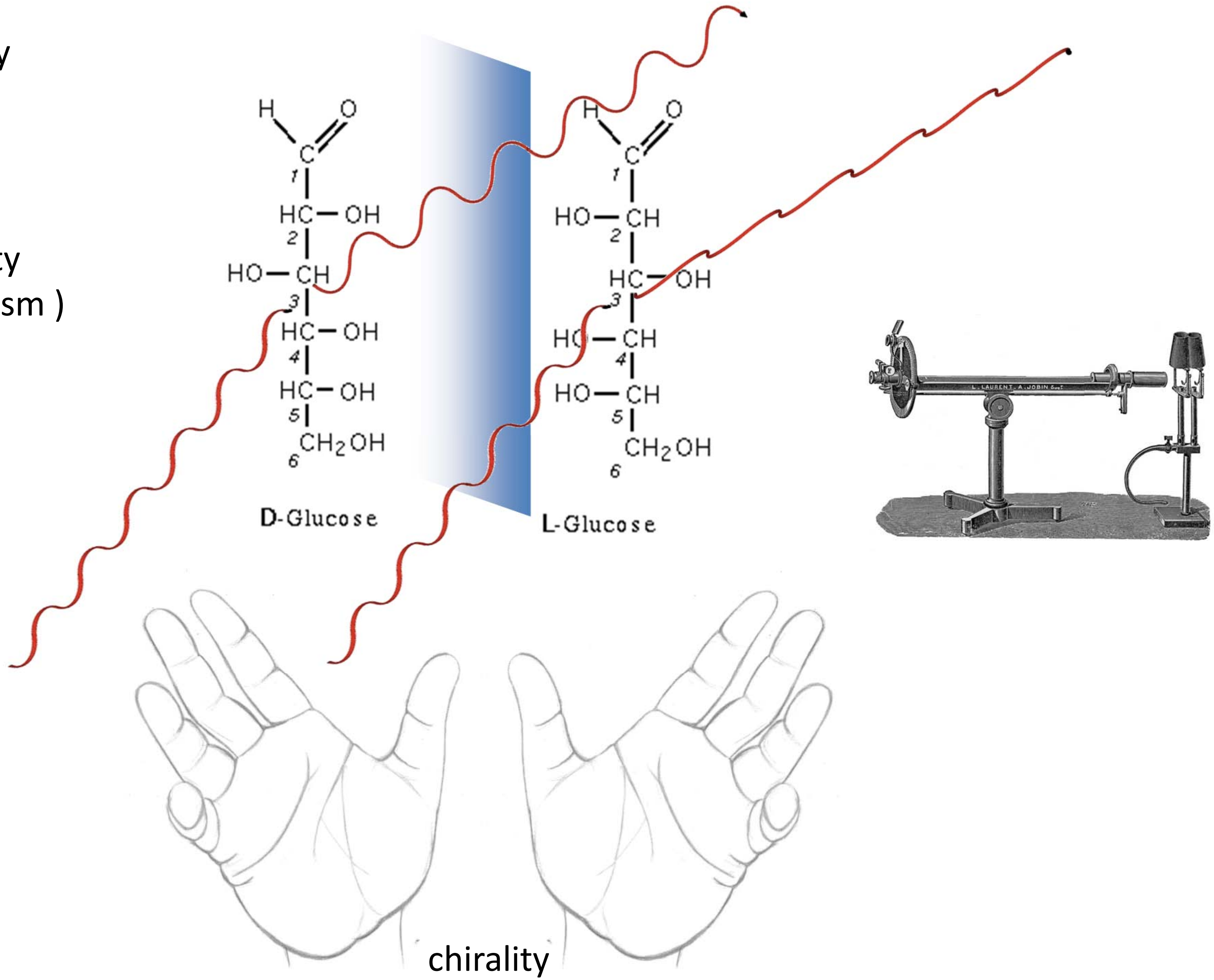
characterization of CHG emission from helical undulators

FERMI@Elettra FEL1

commissioning of the polarization tunability polarized light can be used to probe the local symmetry of a system

dissymmetry

optical activity
(circular dichroism)



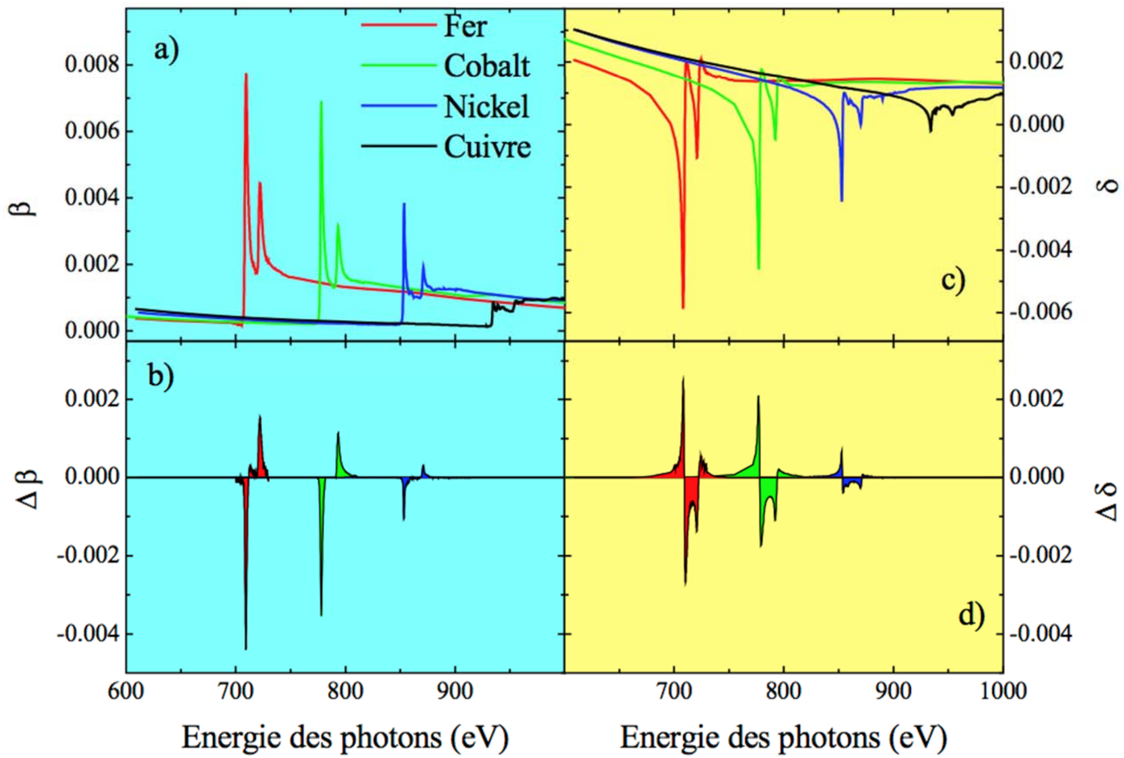
Polarized soft x-ray and magnetism

K. Namikawa *et al.*, J. Phys. Soc. Jpn. **54**, 4099 (1985).
D. Gibbs *et al.*, Phys.Rev. Lett. **61**, 1241 (1988).

$$f_{E1} = \frac{3}{8\pi}\lambda\Big\{\left(\hat{\mathbf{e}}^*_{sc}\cdot\hat{\mathbf{e}}_{in}\right)\left[F_{11}+F_{1-1}\right]+$$

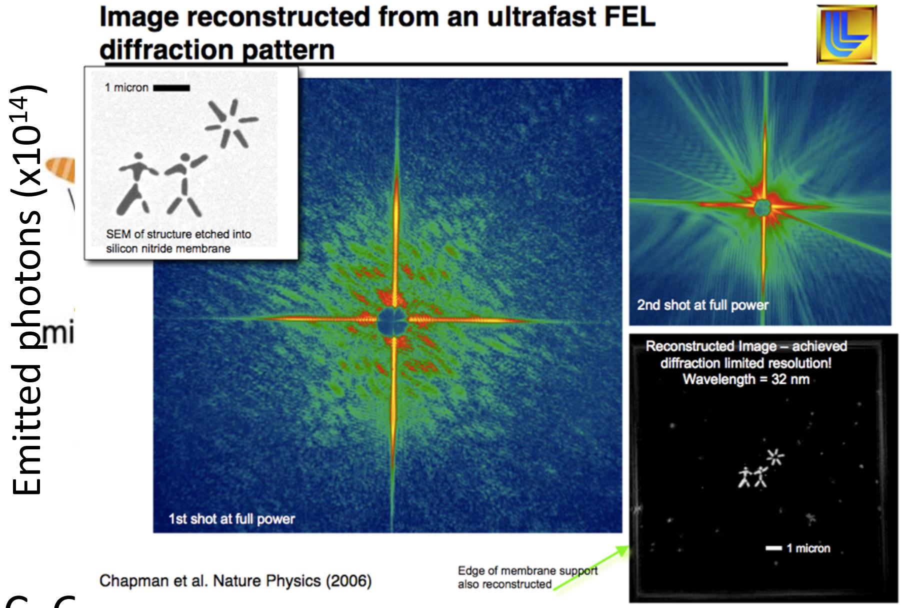
$$-i\left(\hat{\mathbf{e}}^*_{sc}\times\hat{\mathbf{e}}_{in}\right)\cdot\mathbf{m}\left[F_{11}-F_{1-1}\right]+$$

$$+\left(\hat{\mathbf{e}}^*_{sc}\cdot\mathbf{m}\right)\left(\hat{\mathbf{e}}_{in}\cdot\mathbf{m}\right)\left[2F_{10}-F_{11}-F_{1-1}\right]\Big\}.$$

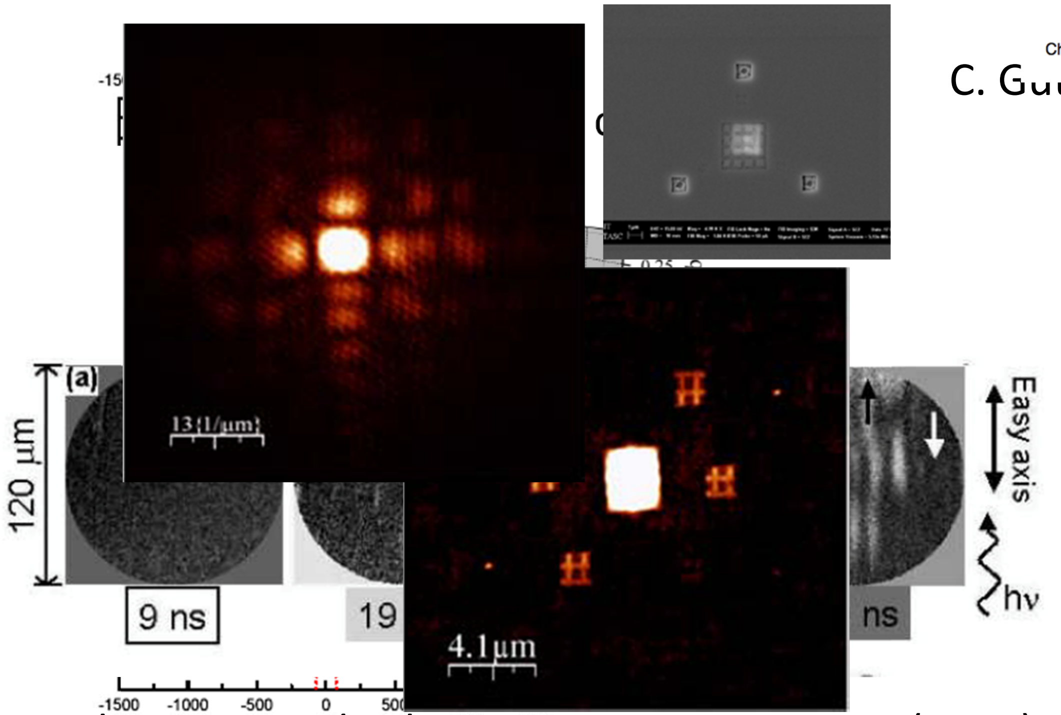


Synchrotron radiation

- ✓ Av. brightness
- ✓ Tunable ($h\nu$, polarization)
- ✓ partially coherent
- ✓ 10-100 ps time scale



C. Gutt *et al.*, Phys. Rev. B **81**, 100401 (R) (2010)



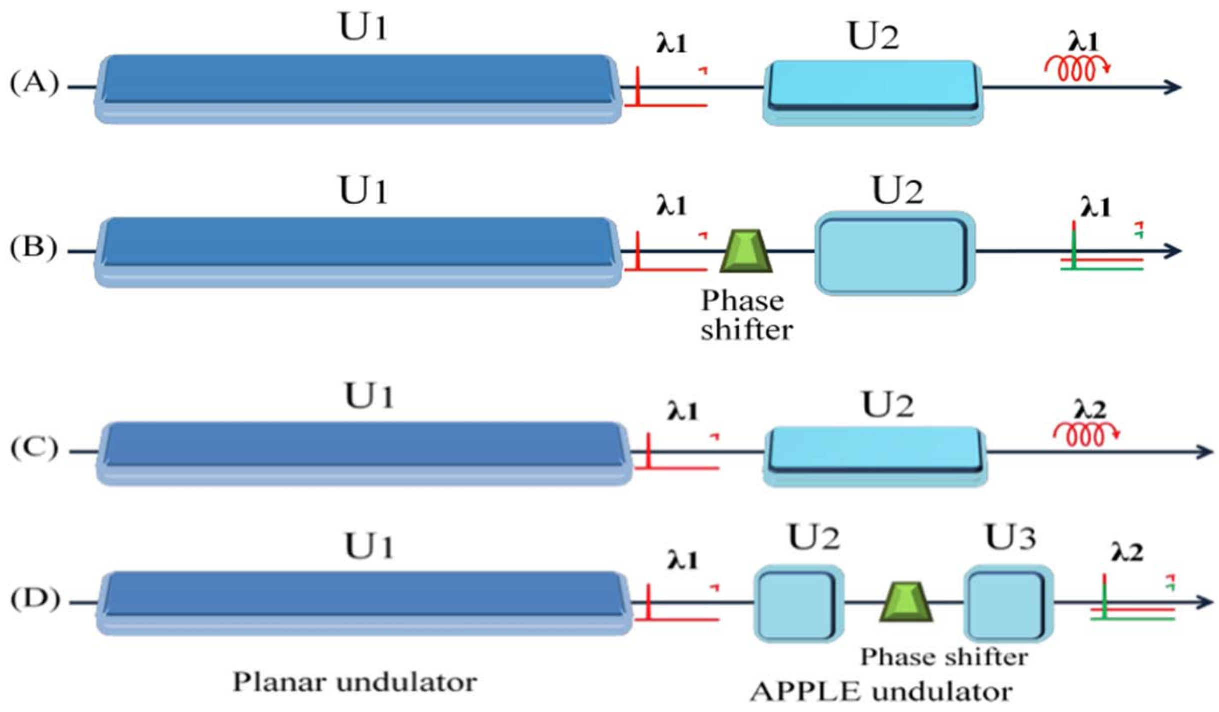
K. Fukumoto *et al.*, Phys. Rev. Lett. **96**, 097204 (2006)
Sacchi *et* al., Rev. Sci. Instrum. **78**, 043702 (2007)

FELs

- ✓ Pk. brightness
- ✓ Partially tunable
- ✓ coherent
- ✓ 10-100 fs time scale

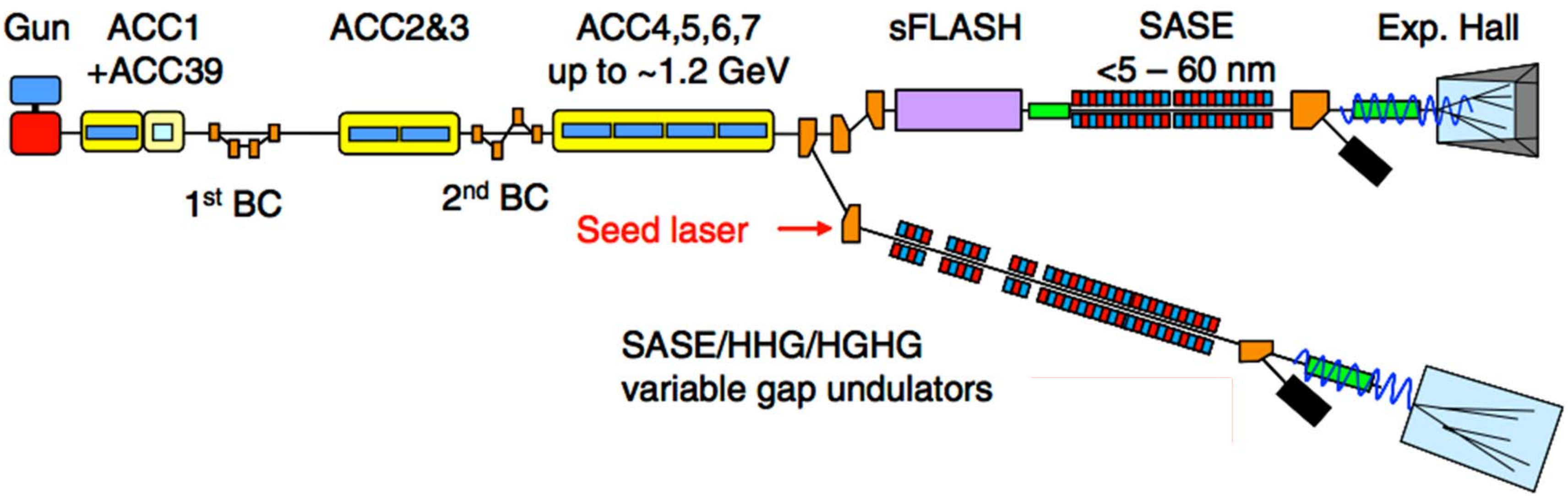
… toward variable polarization FELs

LCLS II



from LCLS II CDR

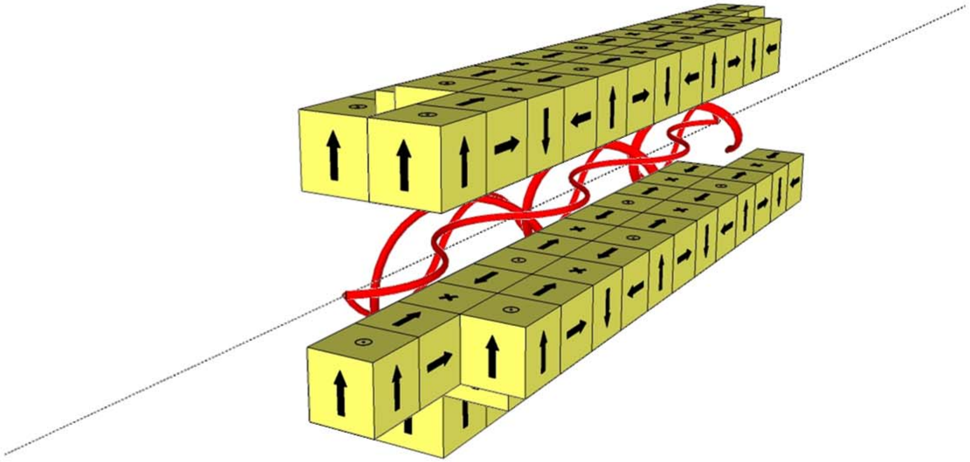
FLASH II

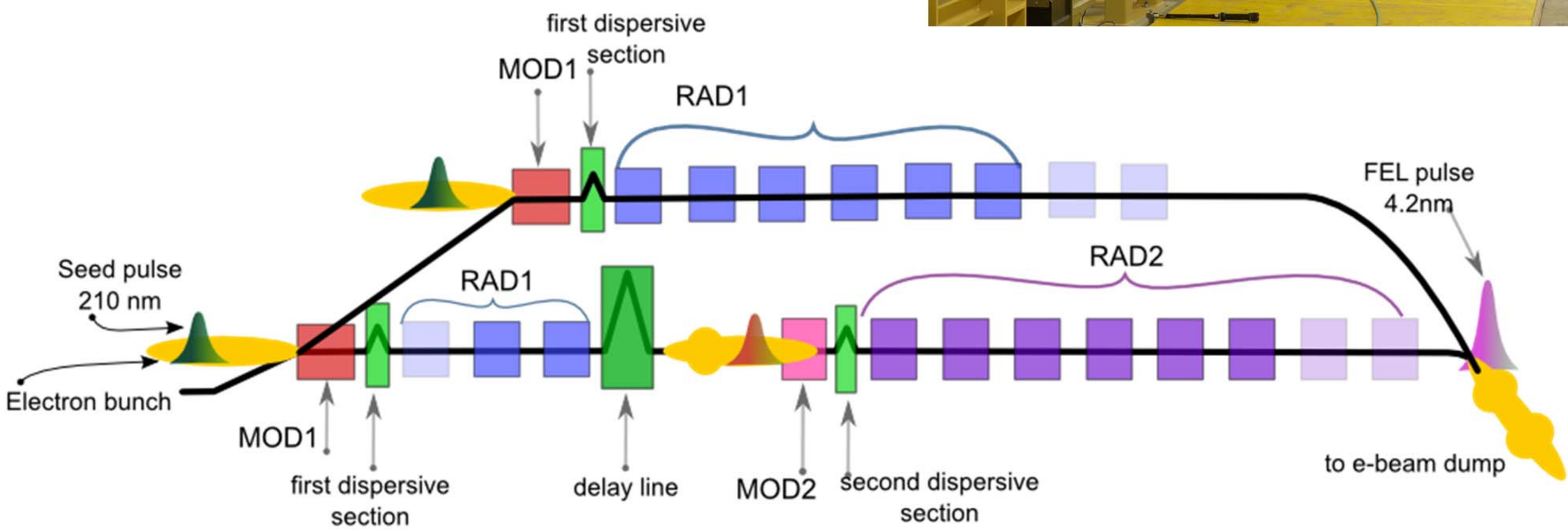


J. Feldhaus, J. Phys. B: At. Mol. Opt. Phys. **43,** 194002 **(2010)**

FERMI@Elettra FELs

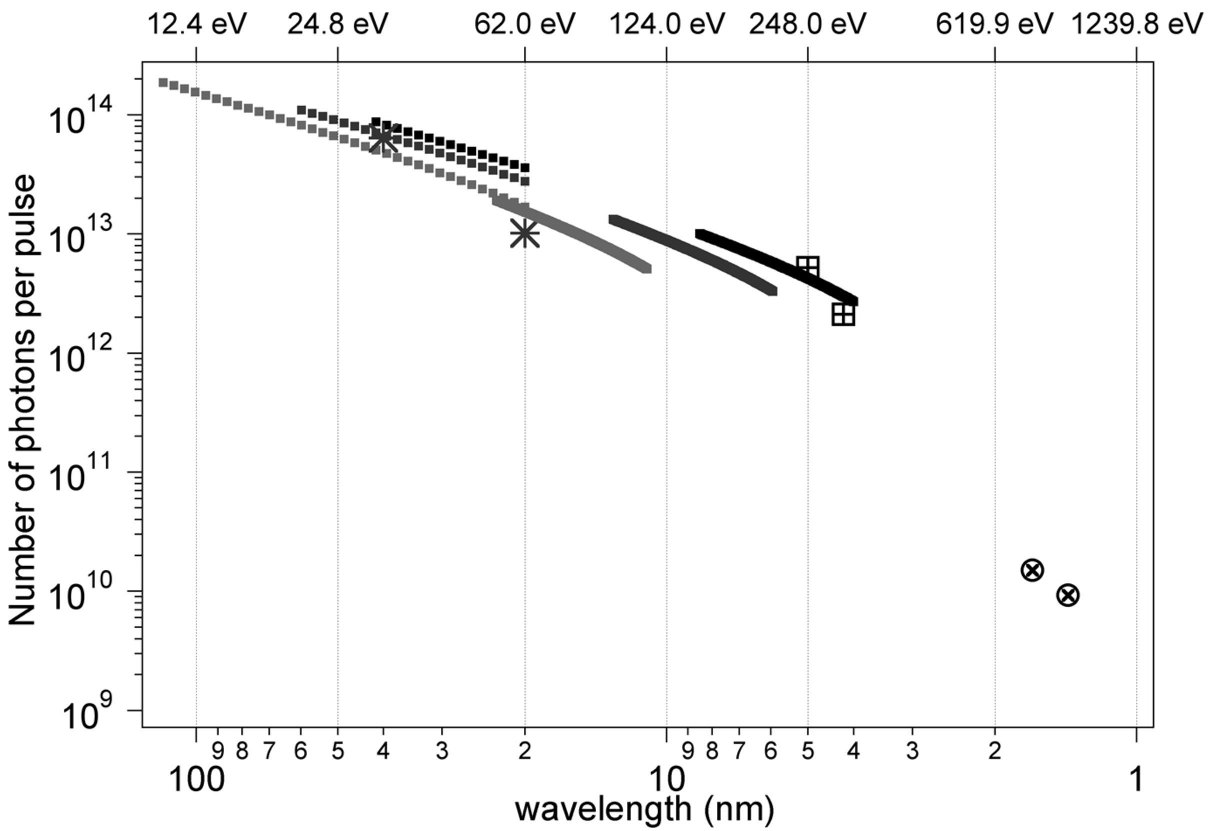
- based on APPLE undulators developped by KYMA





Motivation of the study

FERMI@ELETTRA - FEL2 goal: HGHG at 4 nm
NHG at the 3rd harmonic (1.3 nm = 930 eV) could allow to cover the photon energy range of $L_{2,3}$ edges of transition metal, opening the science case to ultrafast magnetization dynamics (XMCD - XMRS)

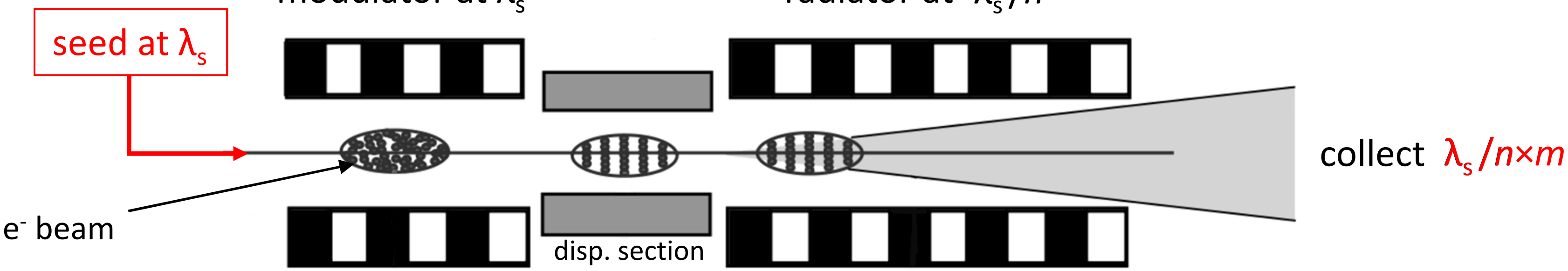


E Allaria, *et al.*, N J Phys, **12** 075002 (2010)

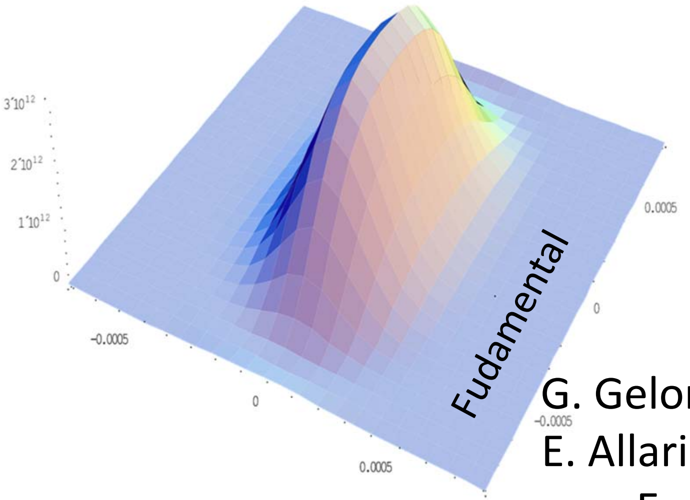
Out-of-axis harmonic emission

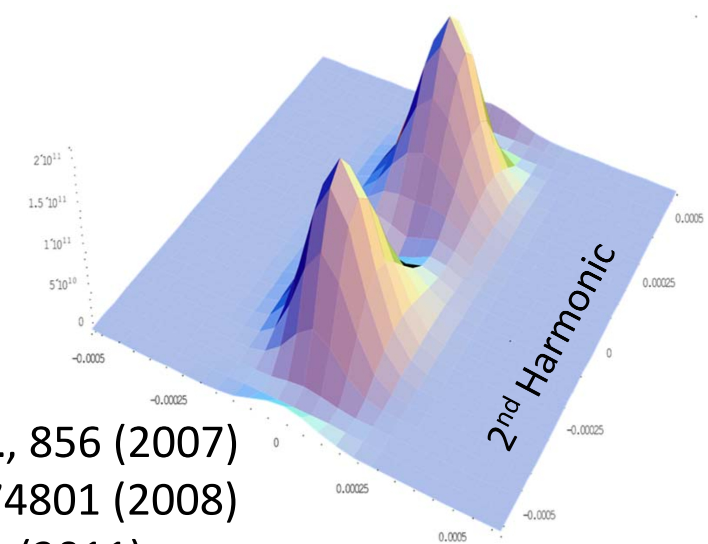
The "NHG" configuration

The "CHG" configuration



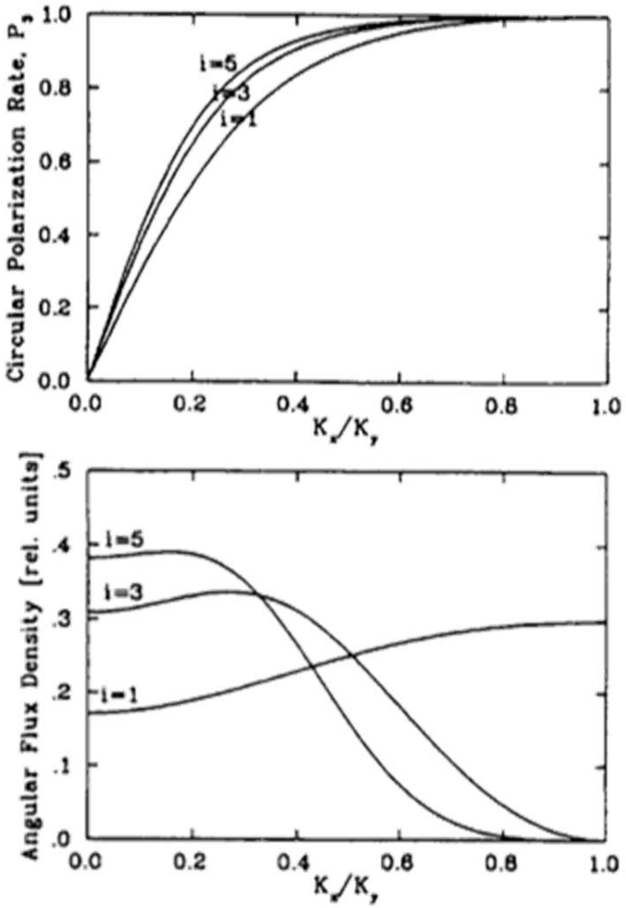
Angular distribution
for circularly
polarized emission

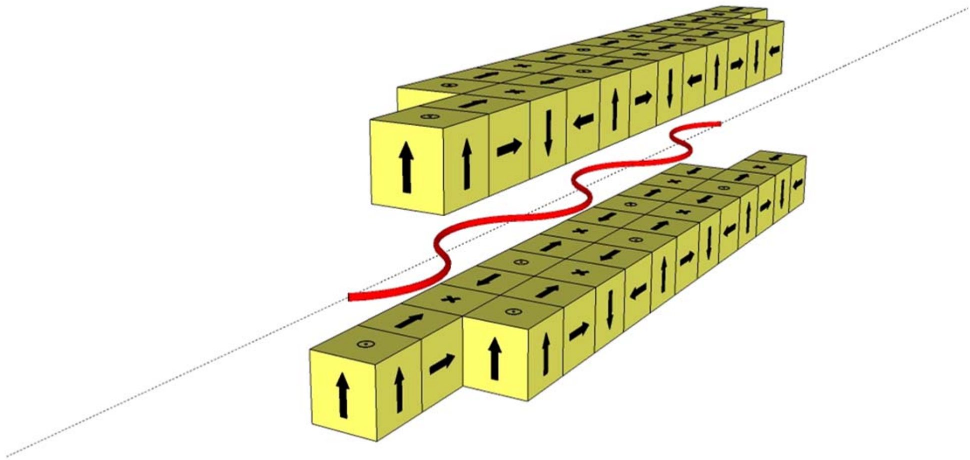




G. Geloni *et al.*, NIM A, **581**, 856 (2007)
E. Allaria *et al.*, PRL **100,** 174801 (2008)
E. Allaria, *et al.*, NIM A (2011)

On-axis spontaneous harmonic emission



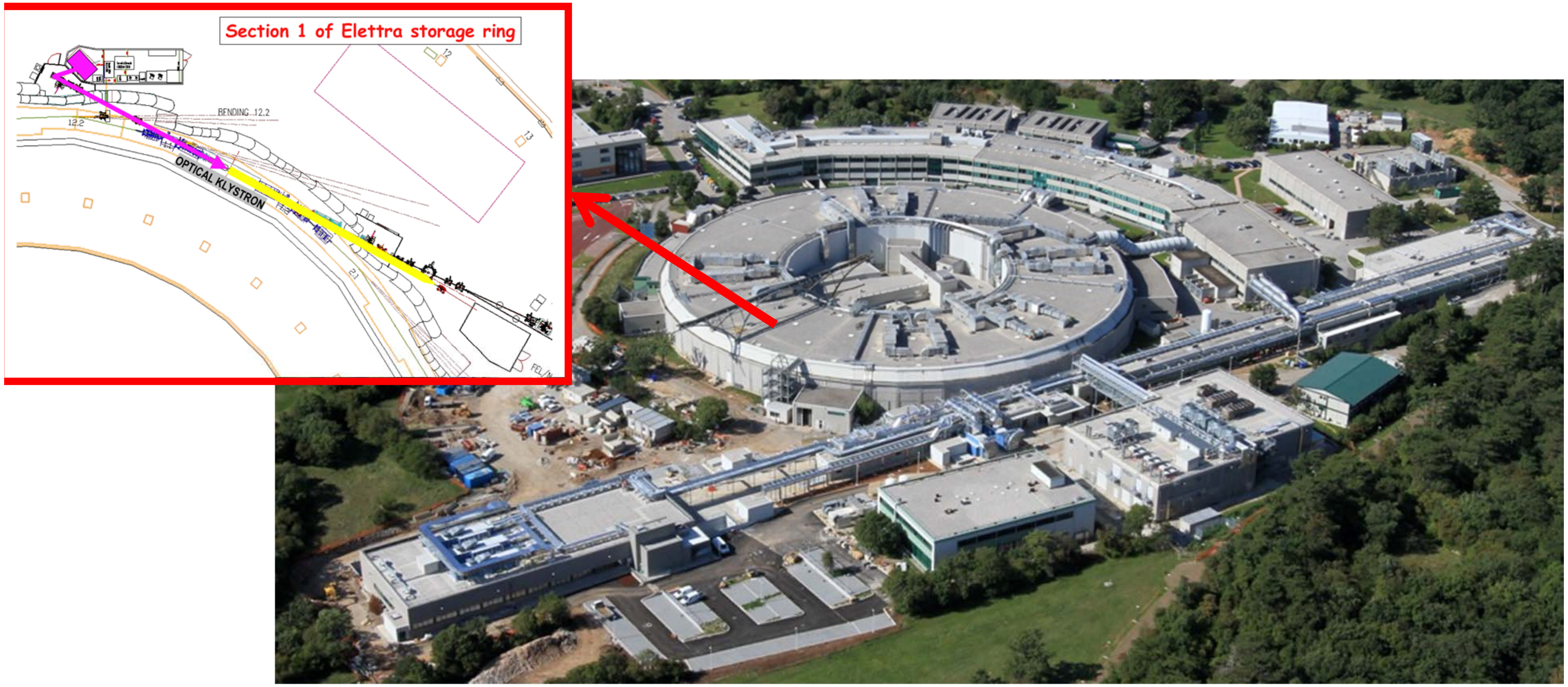


R.P. Walker, C.A.S. lecture (1996)

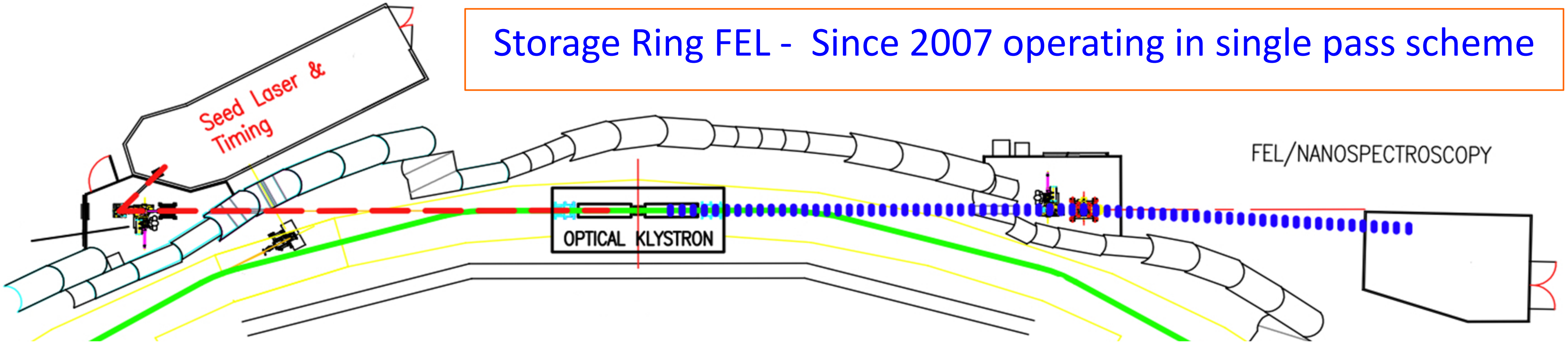
Variable polarization at Elettra

The Elettra Light Source Facility :

Elettra storage ring
storage ring FEL
FERMI@Elettra FEL



Storage Ring FEL - Since 2007 operating in single pass scheme



Back-end station

Seed laser

Ti:Sapphire
Regenerative amplifire

Er fiber laser
with SHG

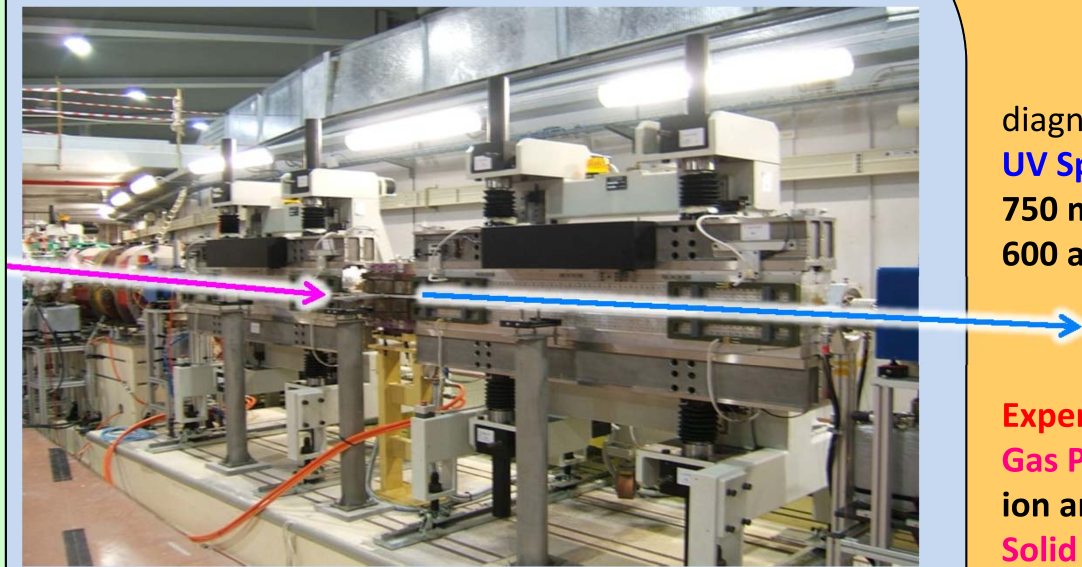
Rep rate: 1kHz

λ: 780, 390, 260 nm

Peak power: 1-20GW

Pulse length: 100 - 200fs

Machine



Elettra in single bunch mode

e^- energy: 0.75 – 1.8 GeV

Rep rate: 1.157 MHz

Peak current: 10-50 A

Pulse length: 30ps rms

Optical Klystron - Section 1

2 Apple Undulators

Variable polarization

Dispersive section

Electromagnetic

Front-end station

diagnostics:

UV Spectrometer

750 mm CCD & PMT

600 and 3600 l/mm

Experimental Stations

Gas Phase

ion and e^- TOF

Solid State

2 circles UHV reflectometer

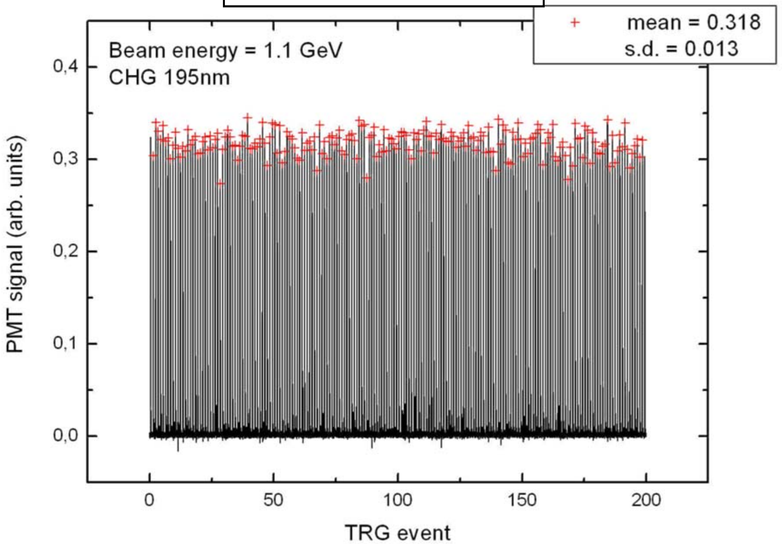
Storage-Ring FEL performance

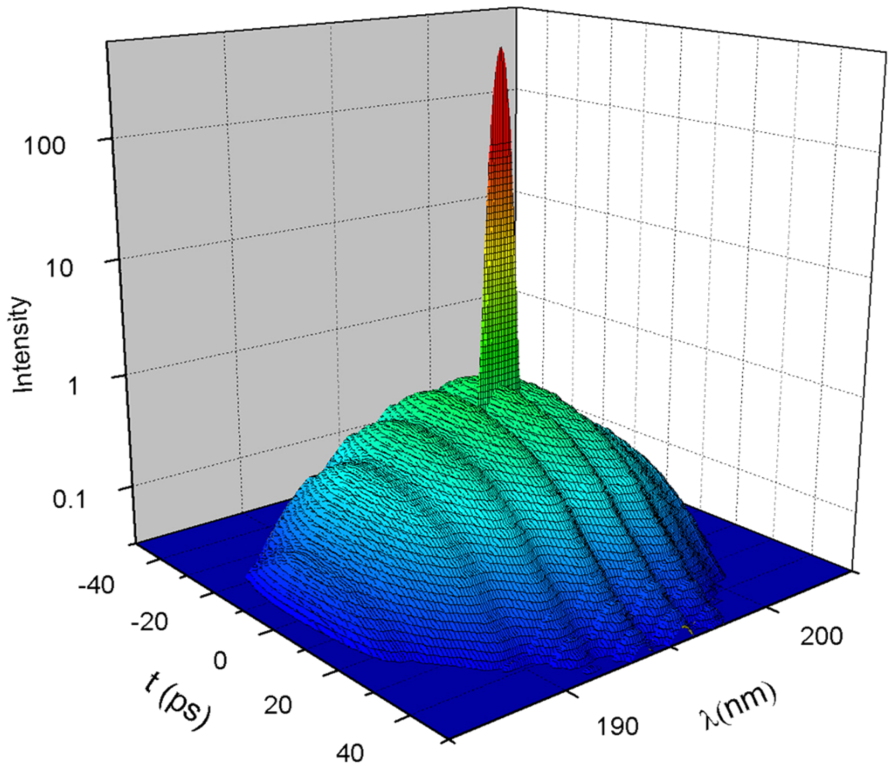
Seed (nm)	CHG (nm)	
λ	λ/2	λ/3
780	390	260
390	195	130
260	130	**87**

$10^9 \div 10^{10}$ ph/pulse
in 200 fs (~ 100KW)
rep. rate = **1KHz**

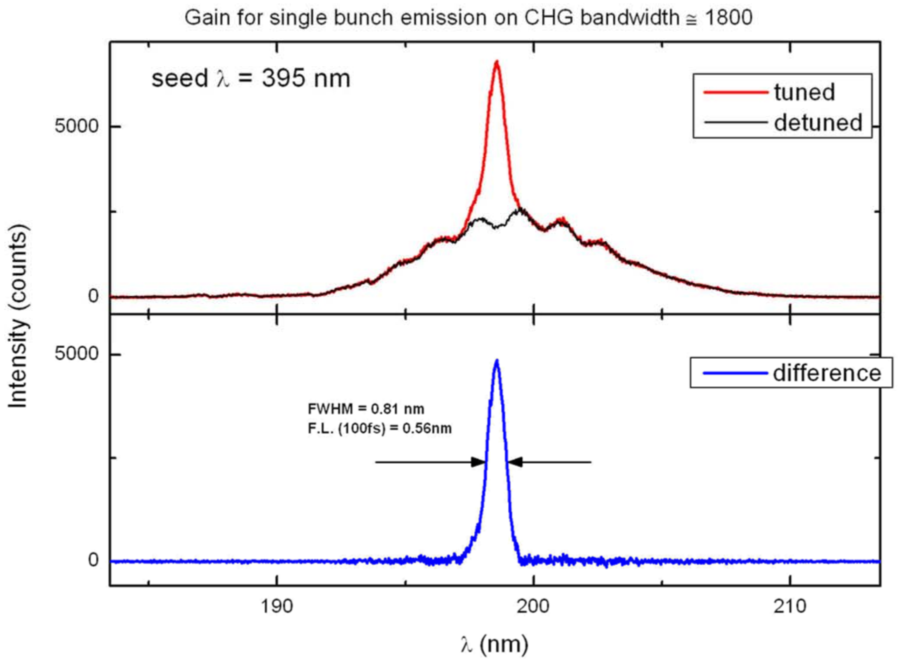
- Monochromatic
- Coherent
- Variable polarization

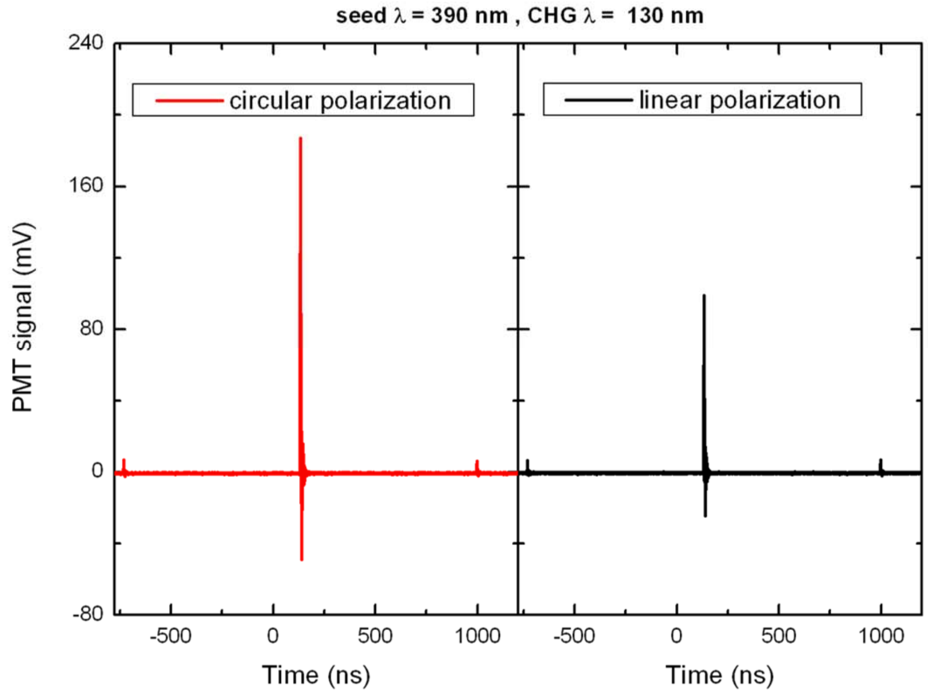
Stability ~ 5%





Storage-Ring FEL performance





Δλ = 1.4 Fourier limit - SB gain ~ 2000

Variable polarization

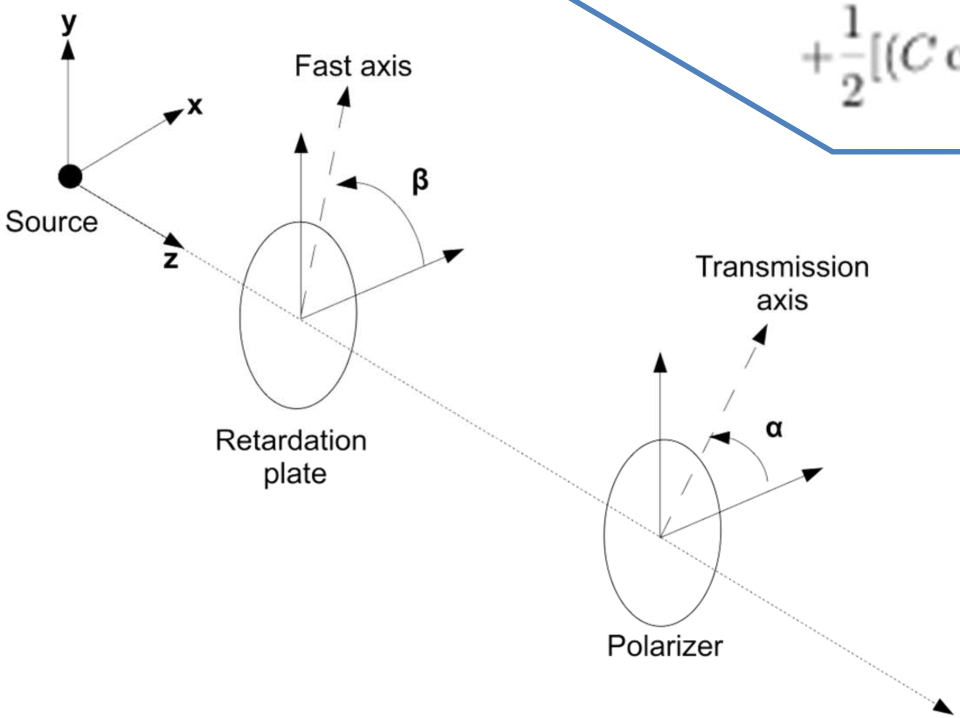
C. Spezzani *et al.,* Nucl. Instr. and Meth. A **596,** 451 (2008).

G. de Ninno *et al.*, Phys. Rev. Lett. **101**, 053902 (2008).

E. Allaria *et al.,* Opt. Express **19**, 10619 (2011).

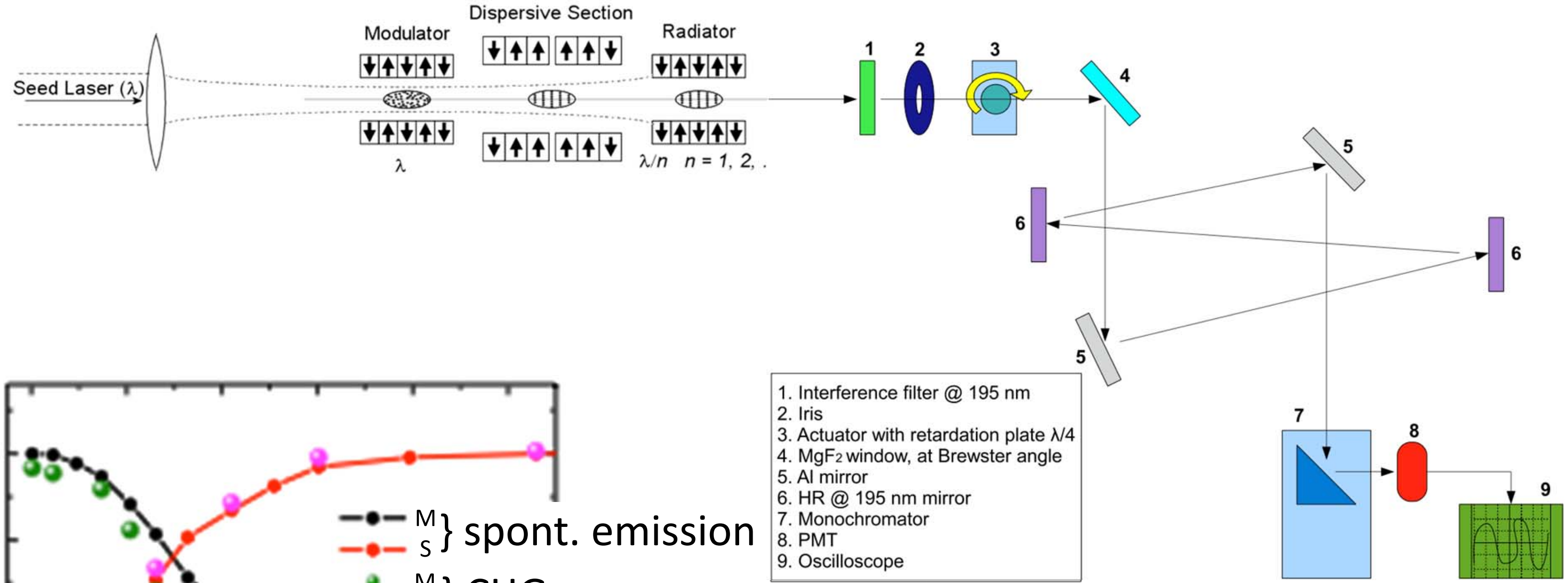
Measurement of the Stokes parameters

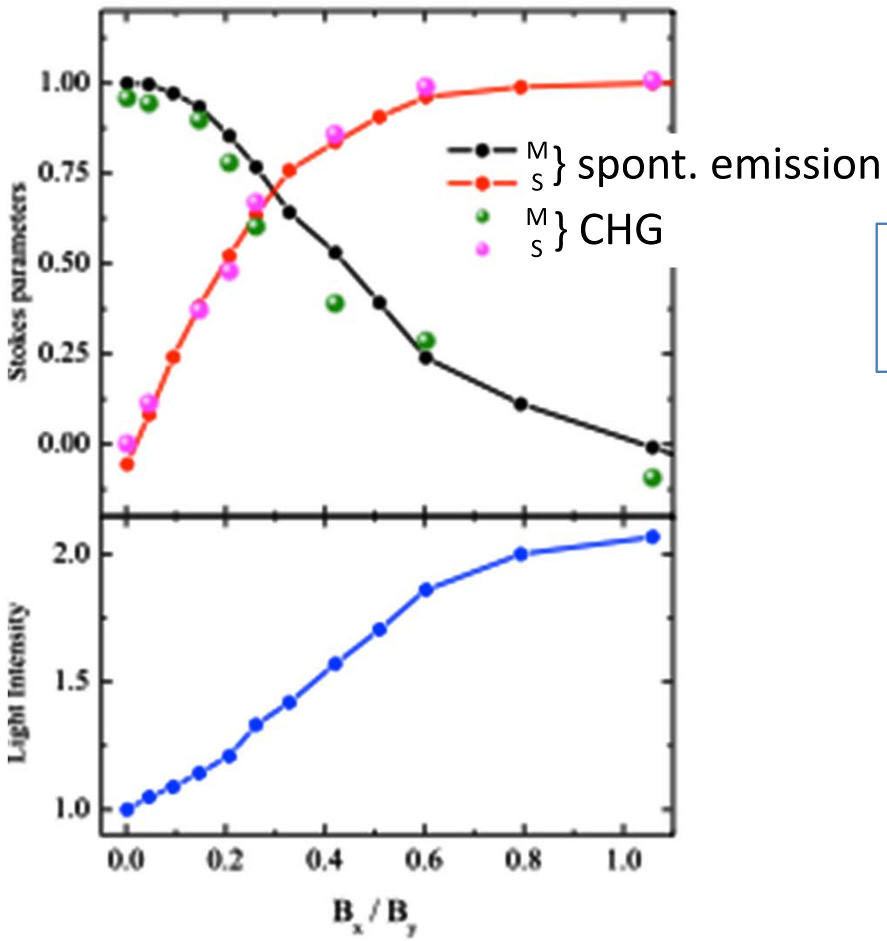
$$I_T(\alpha,\beta,\delta) = \frac{1}{2}I + (M\cos 2\beta + C\sin 2\beta)\cos 2(\alpha-\beta) +$$
$$+\frac{1}{2}[(C\cos 2\beta - M\sin 2\beta)\cos\delta + S\sin\delta]\sin 2(\alpha-\beta)$$



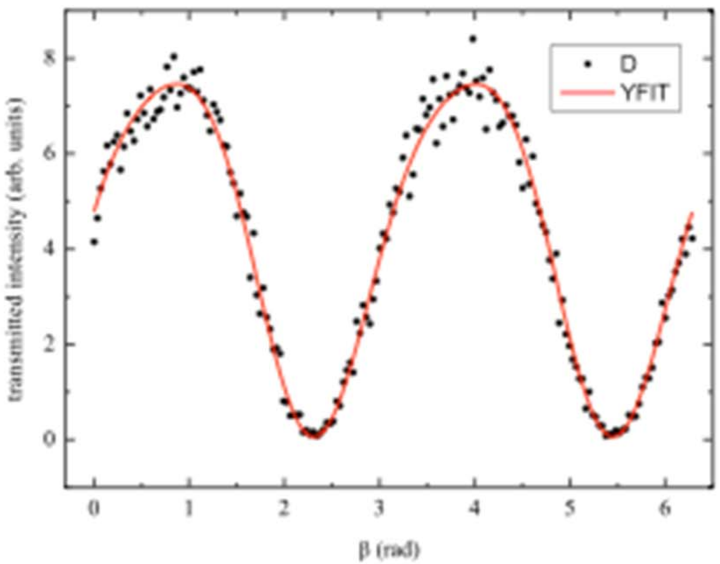
H. G. Berry et al.,
APPLIED OPTICS **16**, 3200 (1977)

$$I = \langle|E_x|^2\rangle + \langle|E_y|^2\rangle = I(0°) + I(90°)$$
$$M = \langle|E_x|^2\rangle - \langle|E_y|^2\rangle = I(0°) - I(90°)$$
$$C = \Re\langle E_x E_y\rangle = I(45°) - I(135°)$$
$$S = \Im\langle E_x E_y\rangle = I_{RHC} - I_{LHC}$$

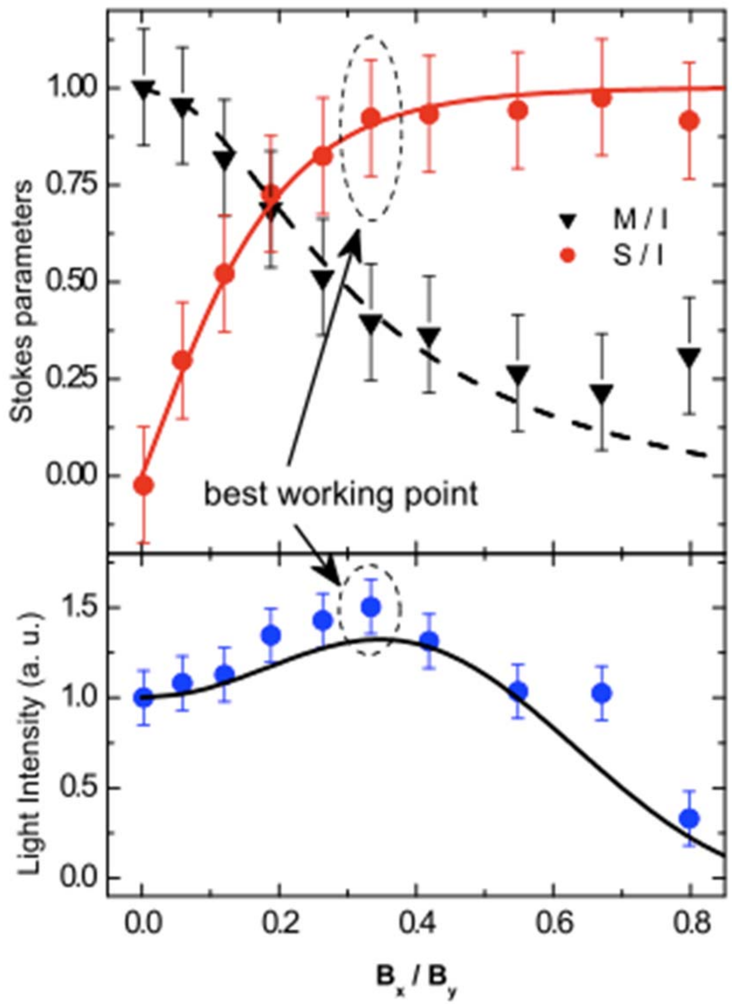




$$I_T(\alpha,\beta,\delta) = \frac{1}{2}I + (M\cos 2\beta + C\sin 2\beta)\cos 2(\alpha-\beta) + \\ + \frac{1}{2}[(C\cos 2\beta - M\sin 2\beta)\cos\delta + S\sin\delta]\sin 2(\alpha-\beta)$$



On-axis harmonic emission



NHG at the 3rd harmonic

- there is a tradeoff between intensity and circular polarization ratio

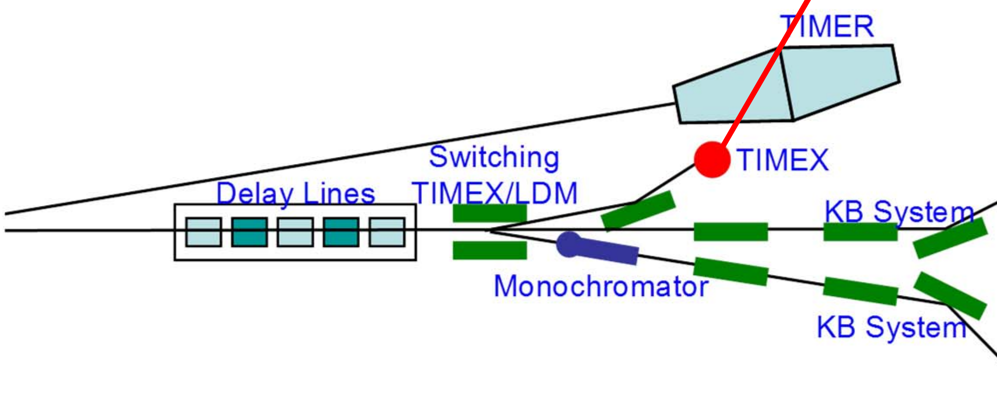
C. Spezzani *et al.*, PRL **107**, 084801 (2011)

Commissioning of variable polarization at FERMI

- **Science Case**

  (*coord. F. Parigiani)*

- **Elastic and Inelastic Scattering**
- (*coord. C. Masciovecchio*):
- Transient Grating Spectroscopy
- Pump & Probe Spectroscopy (including ultrafast magnetization dynamics)

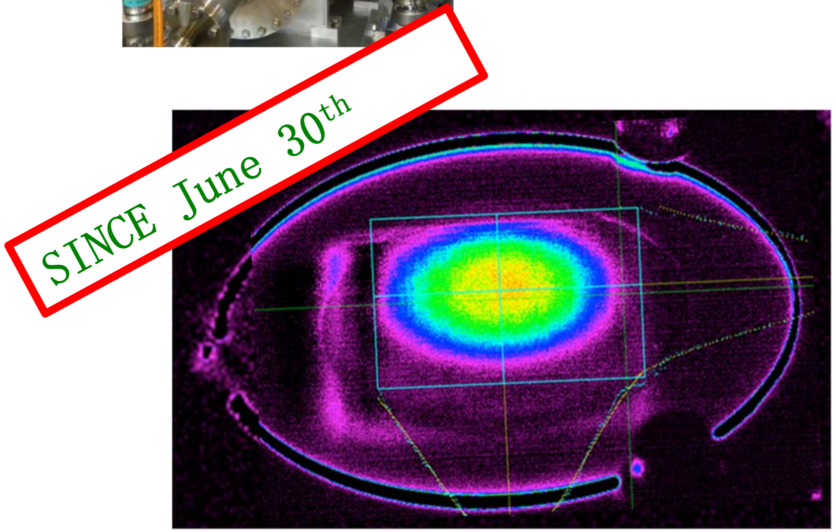


- **Diffraction and Projection Imaging**
- (*coord. M. Kiskinova*):
- morphology and internal structure at the nm scale
- chemical and magnetic imaging

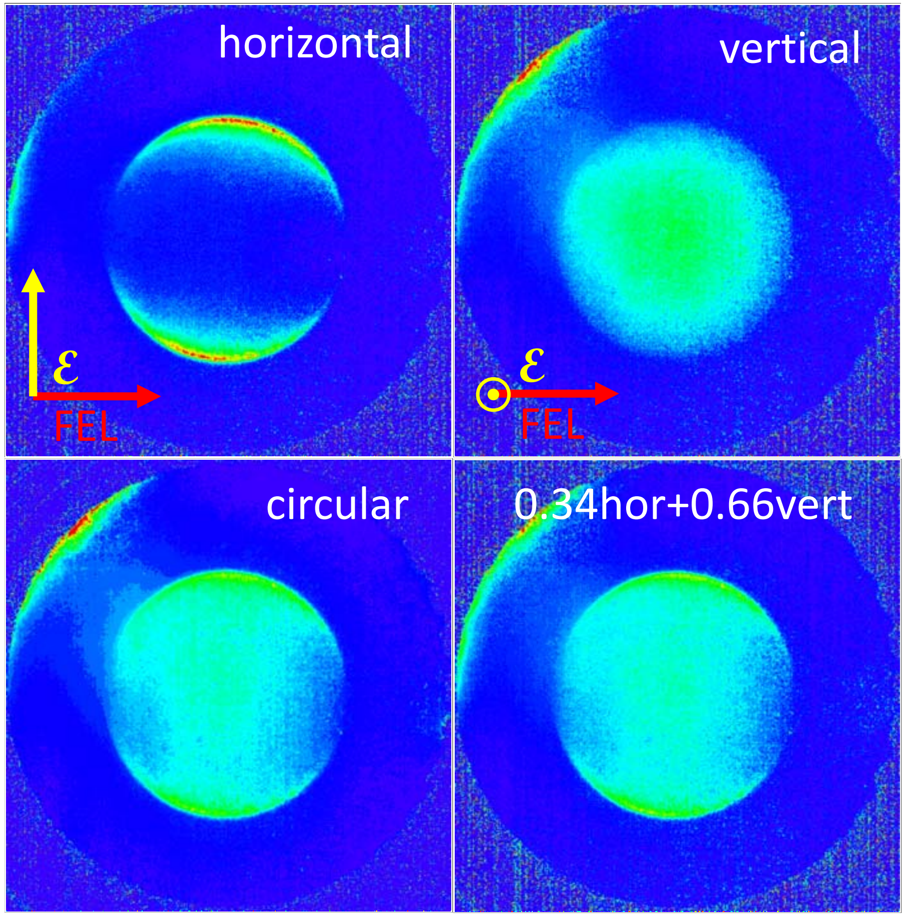
- **Low Density Matter**
- (*coord. C. Callegari*):
  - structure of nano-clusters
  - ionization dynamics
  - magnetism in nano-particles
  - catalysis in nano-materials

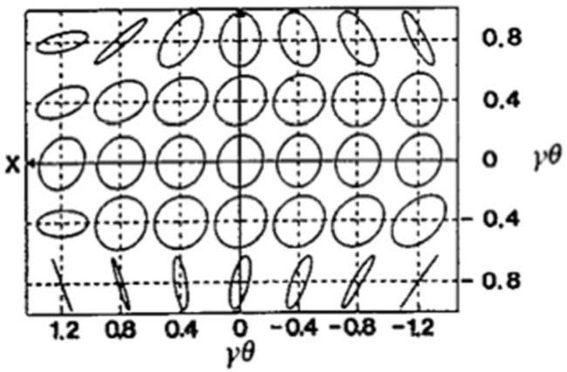
Polarization measurements at the LDM beam line during **RUN6**

The VMI provides energy and angle-resolved spectra, which can be related to the energy and angular momentum structure of the system under study.
For a simple atom (here He, λ_{FEL}= 43 nm), the spectra have been used to characterize the light produced by FEL1.



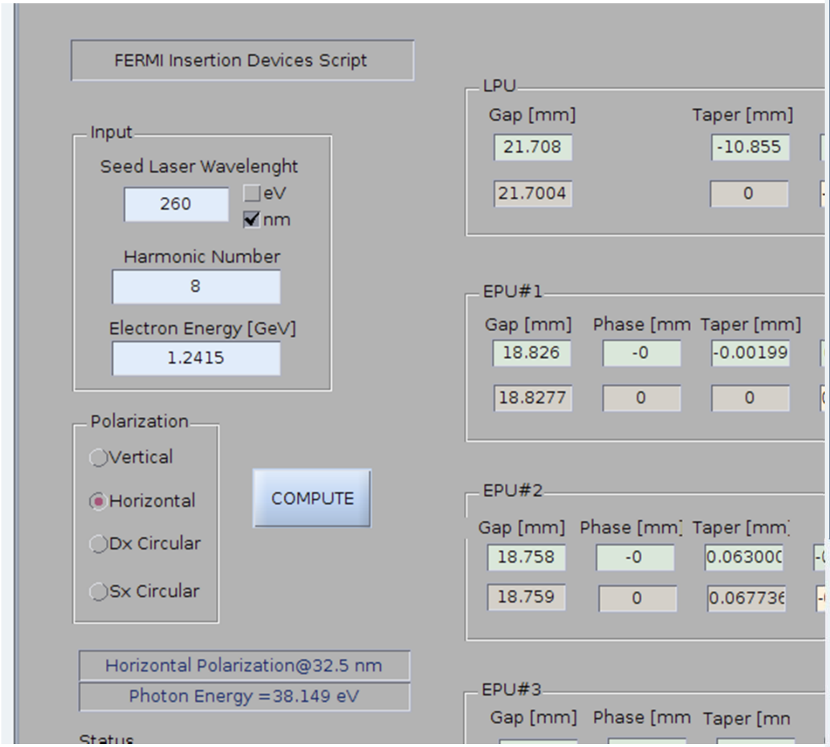
courtesy of the LDM - C. Callegari *at al.*

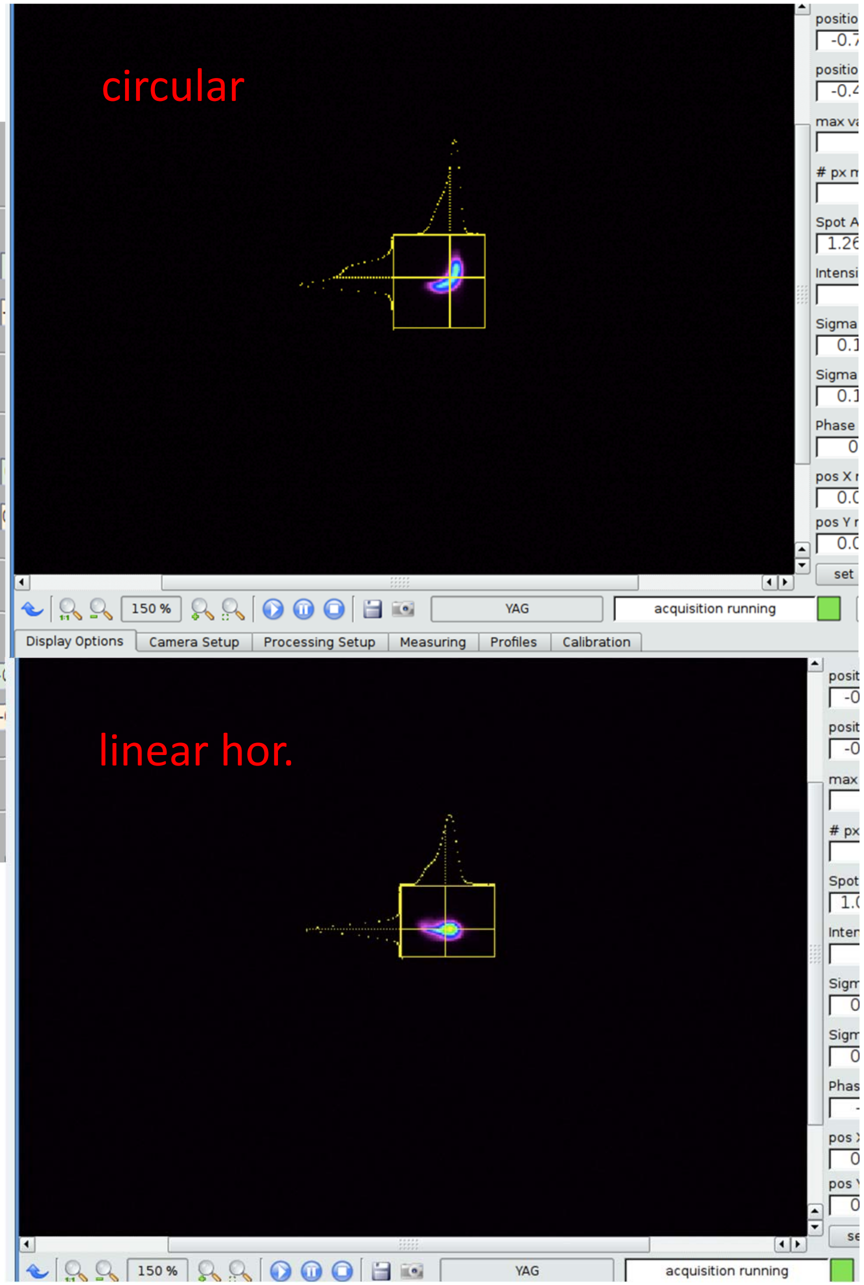




K. Yagi *et al.*, Rev. Sci. Instrum. **63**, 396 (1992)

polarization control





BUNGAP script
developped by M. Musardo

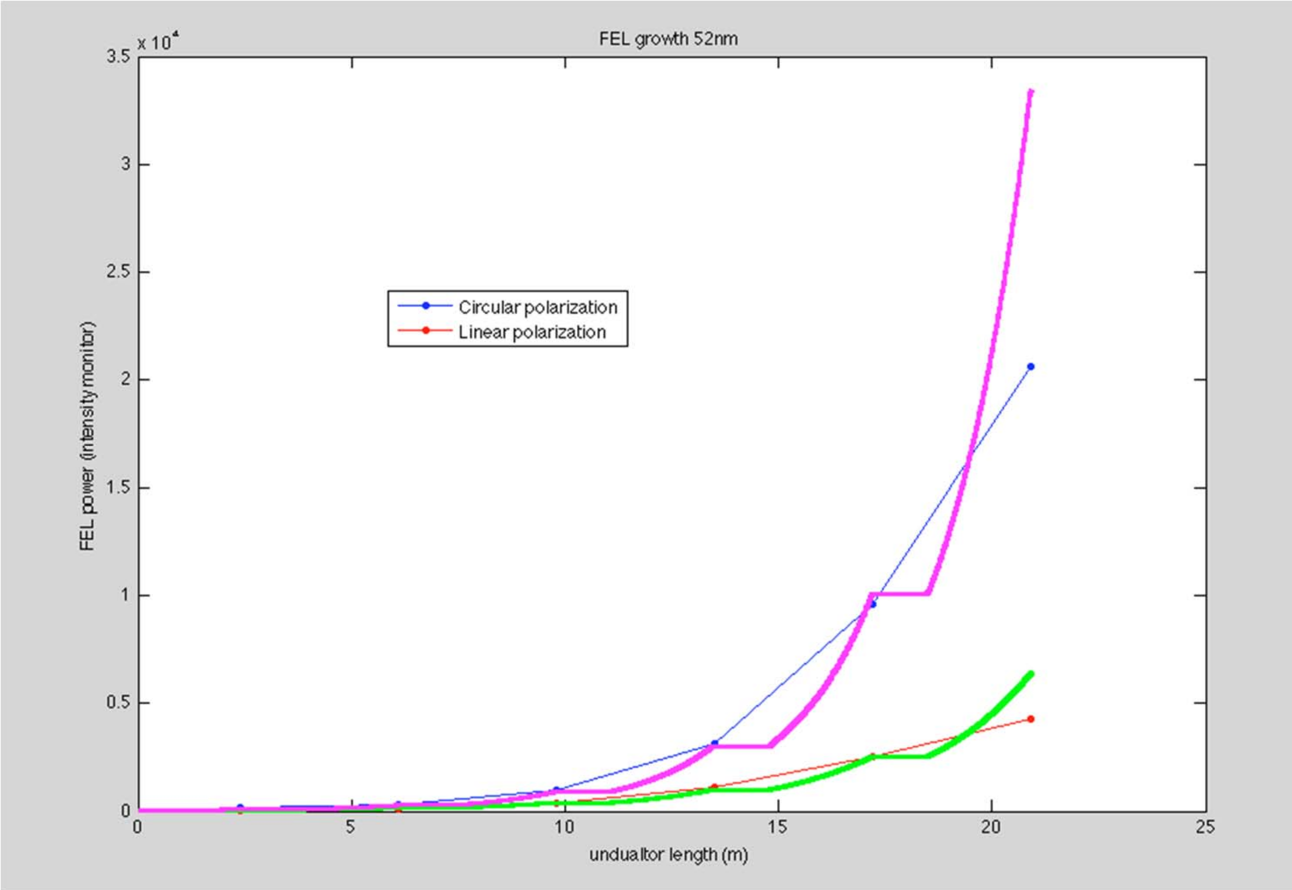
FEL exponential growth

RUN7

I = 300A
ΔE = 450 keV
ε = 2.7 mm × mrad

M. Xie →

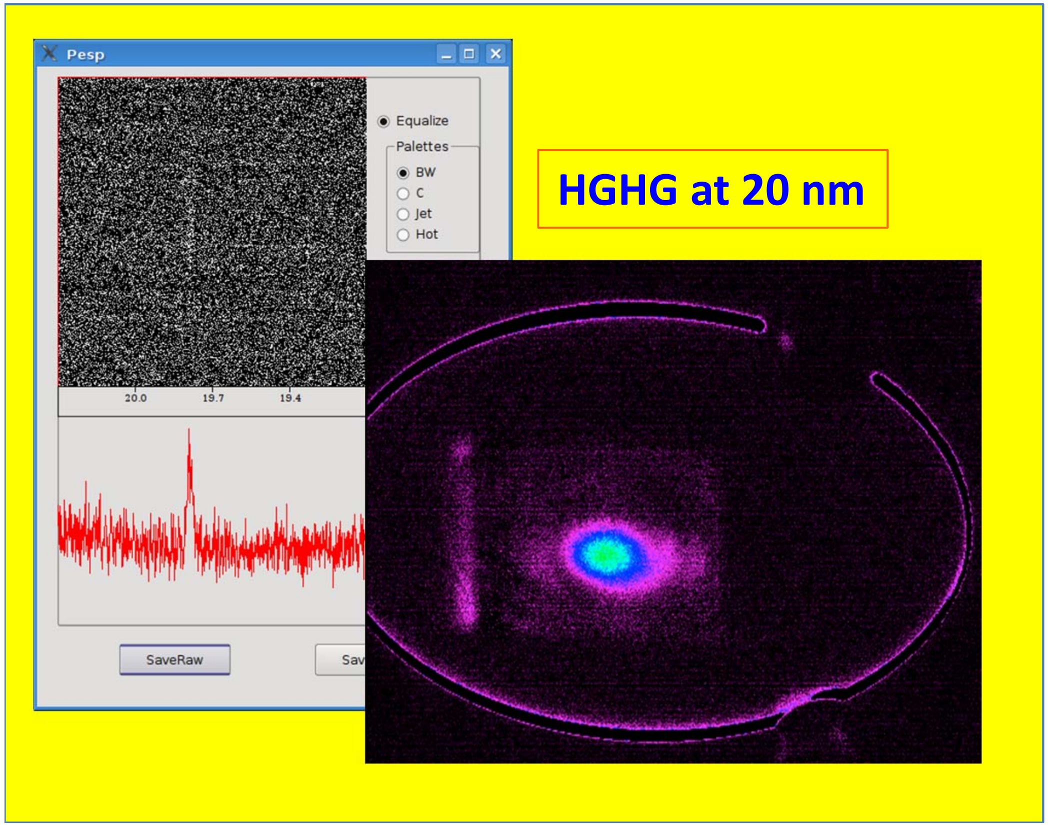
L_{g_planar} = 2.6 m
$L_{g\_circular}$ = 2.1 m



Perspectives

- characterization of the gaussian mode (at the LDM beamline)
- on-axis circular polarization at shorter wavelengths via NHG
- polarization dependent studies
  - FEL1 reached 20 nm (i.e. M edges of Fe, Co and Ni).

    → first coherent diffraction magnetic imaging experiment at the DiProI beamline



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)

Rev. Sci. Instrum. **82, 043711 (2011)**

Conclusions

I. Apple undulators work well also for FELs

II. we can obtain highly circularly polarized light ($S \approx 90$ %) from NHG on-axis

III. in circular polarization the emission is more intense and the gain length is reduced

SR-FEL Group

G.De Ninno, E.Allaria, M.Trovò, L.Romanzin, M.Coreno,
B. Diviacco, E. Ferrari, C.Spezzani, B. Mahieu

Theory

G. Geloni (European XFEL GmbH)

LDM

C. Callegari, F. Stienkemeier (University of Freiburg),
T. Möller (*Technische Universität Berlin*)

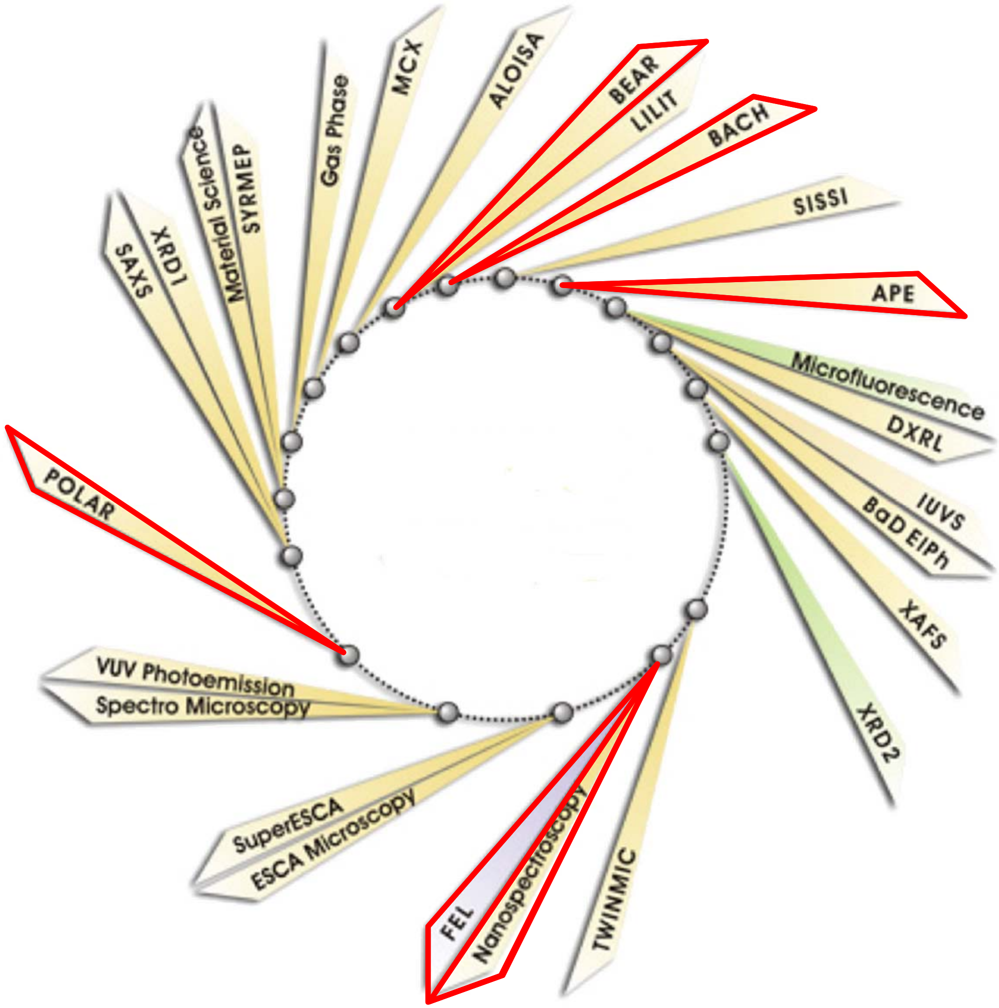
Fermi Commissioning Team

E. Allaria, P. Craevich, S. Di Mitri, G. Penco, M. Trovò

Fermi Team

Elettra storage ring

- 25 beamlines
- 5 (+1) beamlines using variable polaization
- 3 based on APPLE undulators



Insertion Devices Laboratory

Elliptical Undulators

six variable polarization undulators have been designed and constructed at ELETTRA