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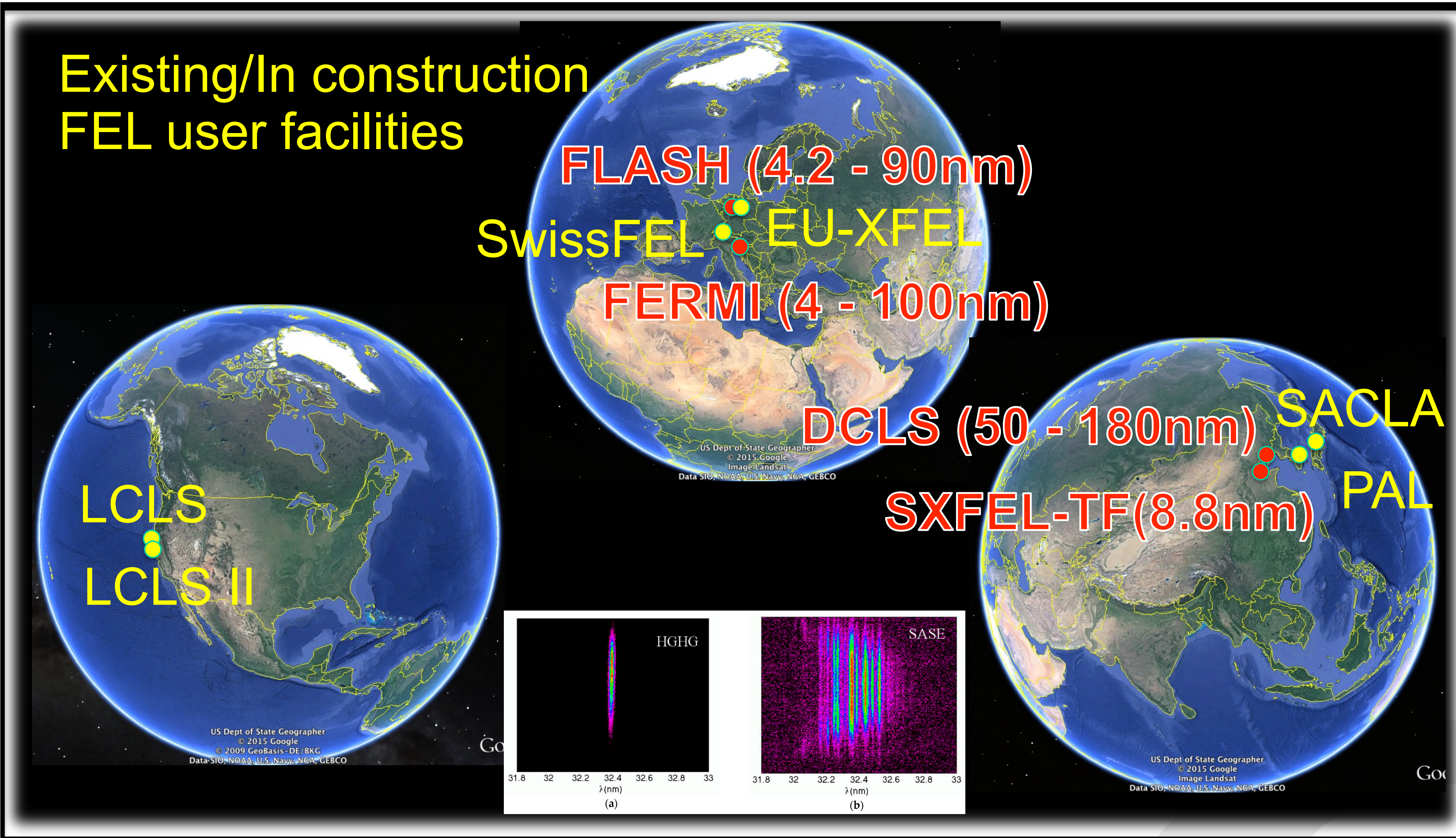
Photon beam transport and diagnostics systems at an EUV FEL facility: general considerations, and specific challenges, solutions and developments at the FERMI seeded FEL

Marco Zangrando
On behalf of the FERMI team

www.elettra.eu

FEL USER FACILITIES

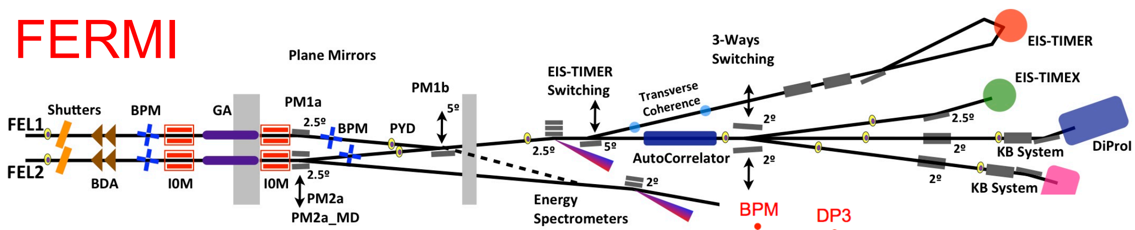
Existing and in construction



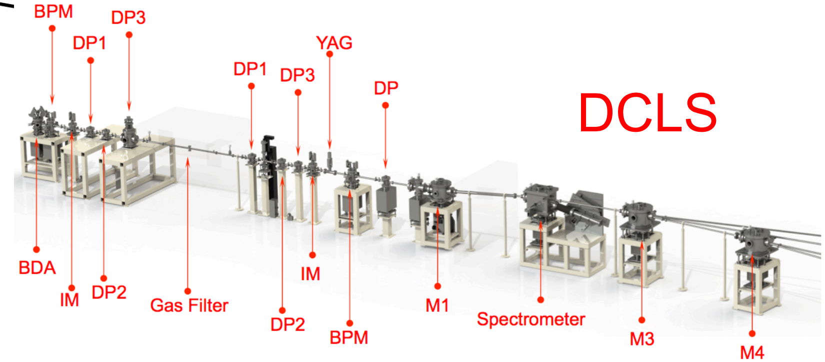
Marco Zangrando – marco.zangrando@elettra.eu

PH. TRANSPORT AND DIAGNOSTICS
General considerations

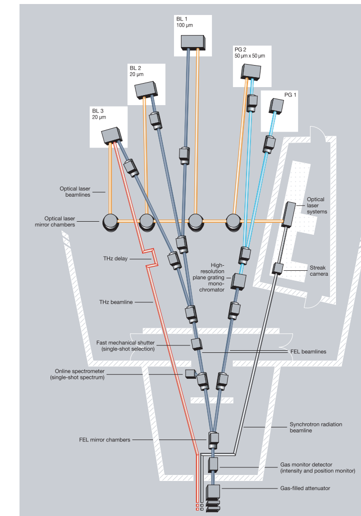
FERMI



DCLS



FLASH



- EUV/SXR tunable sources → **Reflective elements** (mirrors and gratings), in **grazing incidence**, with **single-layered optical coating**, in **UHV** (10^{-9}-10^{-10} mbar)
- Distance from source + unfocused until the endstations + divergence → **"big" mirrors** (tens of cm)
- **Quality of optics**: good but not necessarily as good as XFELs' ones (100's-nrad slope errors; 1-3 Å roughness)
- **One experiment per time** (possible exceptions by wavefront splitting or serial endstations)
- **Online and transparent diagnostics** → gas-based and/or grating-based
- Parameters to determine:
  intensity, **spectrum**, **position**, **mode**, **spot size**, **wavefront**, **polarization**, **pulse length**, **arrival time**
- Intensity/spectral content manipulation → gas and solid state **filtering**
- Focal spot manipulation sometimes necessary → **active optics** systems
- Transmission optimization → **mirror coating** selection

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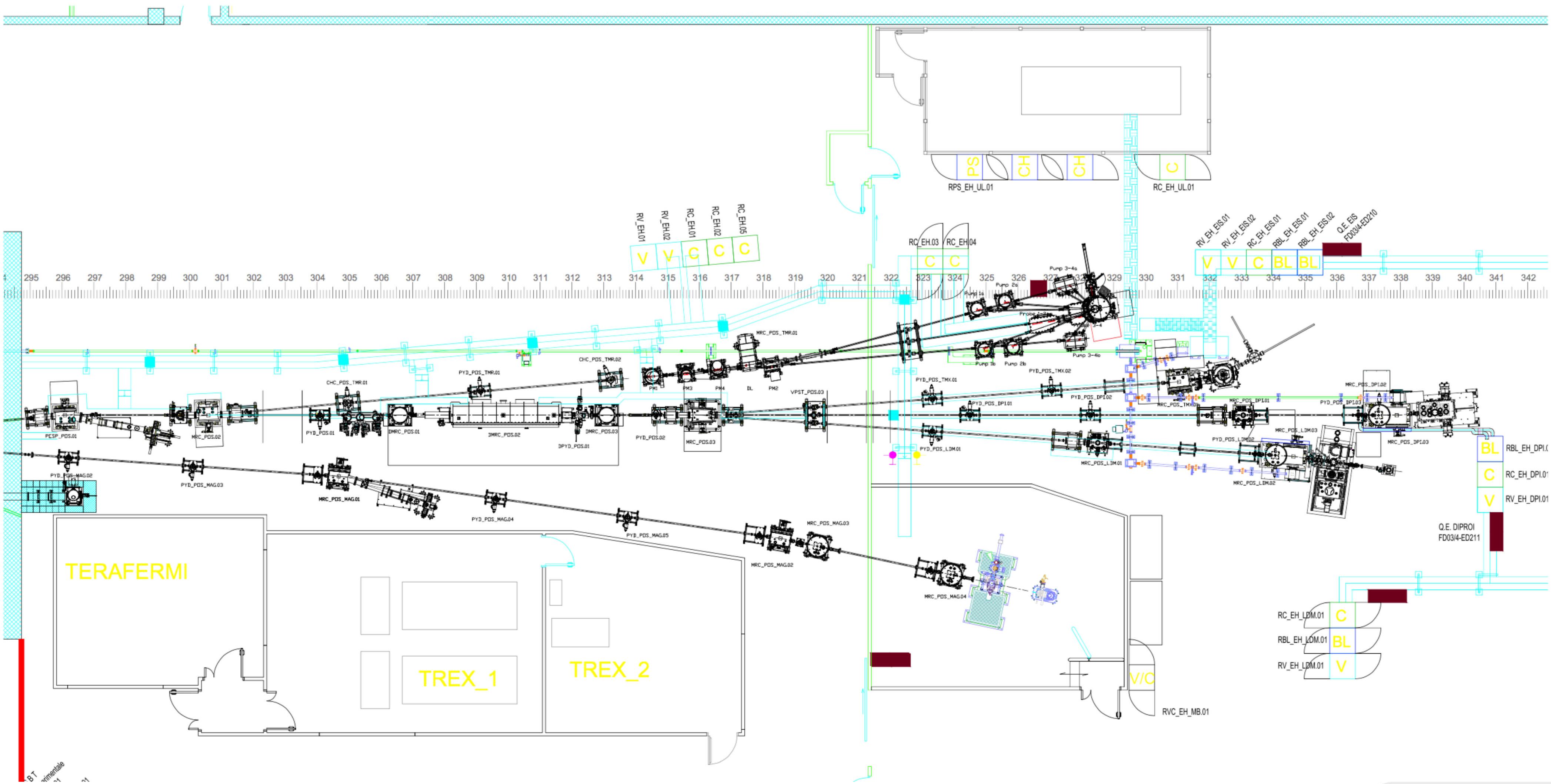
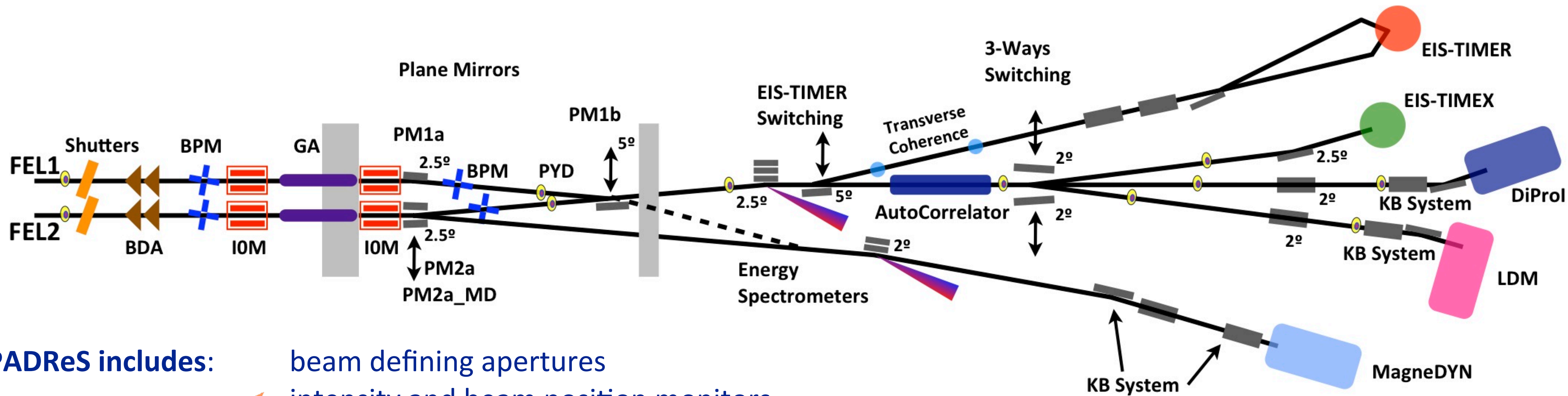
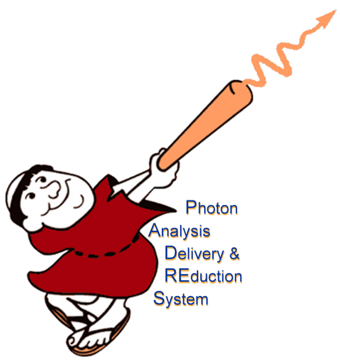
FERMI
The experimental hall



FERMI
Photon transport system PADReS



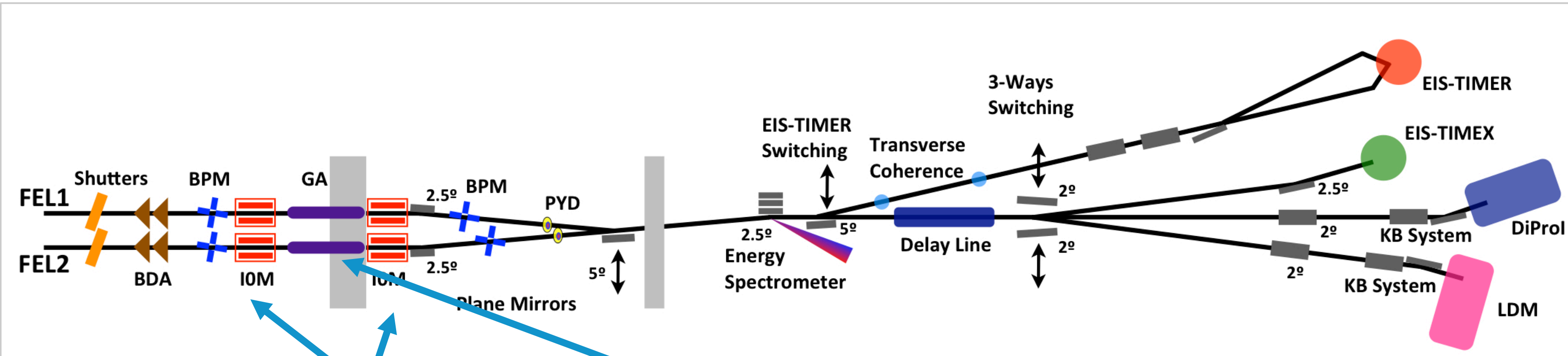
PADReS includes:



- beam defining apertures
- intensity and beam position monitors
- YAG screens and photodiodes
- intensity reducer
- energy spectrometer
- transverse coherence measurement
- split and delay line
- filters
- refocusing systems

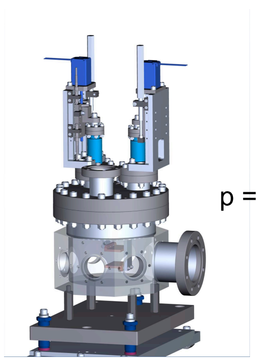
FERMI experience:
At the beginning (from CDR to first user Runs) the diagnostics had been "confined" to initial part of the transport. Run after Run it became clear that some **diagnostics** (e.g., intensity monitors) should be **replicated and installed all along the transport**

INTENSITY
Gas-based I_0 monitors and absorbers

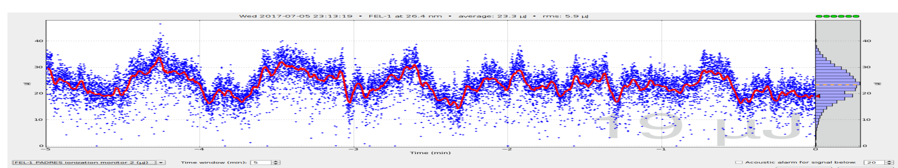


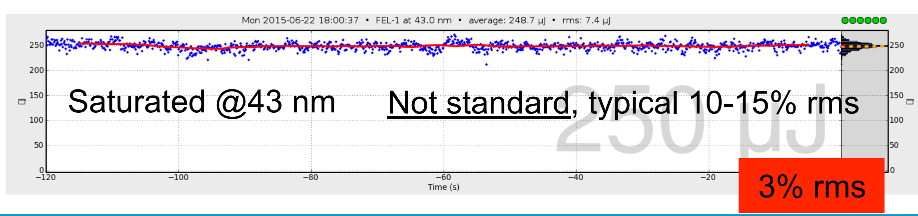
Intensity monitors:
Measures the number of photons of each pulse
(~3% precision, 1% reproducibility)
Online and shot-to-shot
Transparent

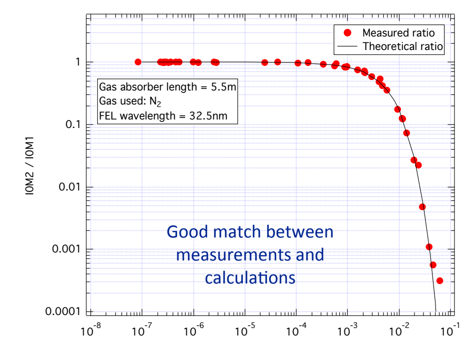
Gas absorber:
Need to align the beam w/out destroying the sample + intensity-dependent studies
Max attenuation at all λ: 10^{-4}
Preservation of coherence, spectrum, statistics, etc.



p = 2 · 10^{-5} mbar







FERMI experience:
I0Ms should be **diversified** (gas-based, grating-based, mirror photo-current, operating on residual vacuum) and **distributed** along the transport (especially before the endstations)

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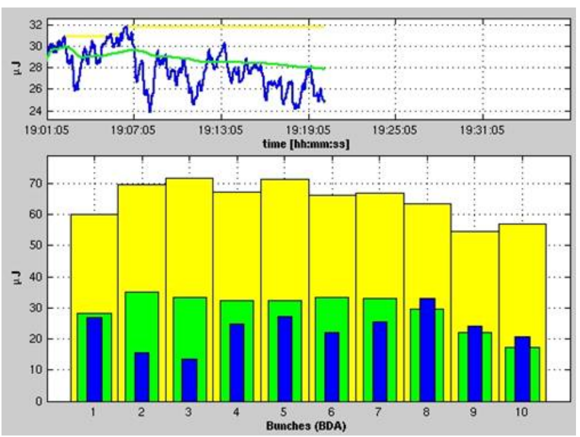
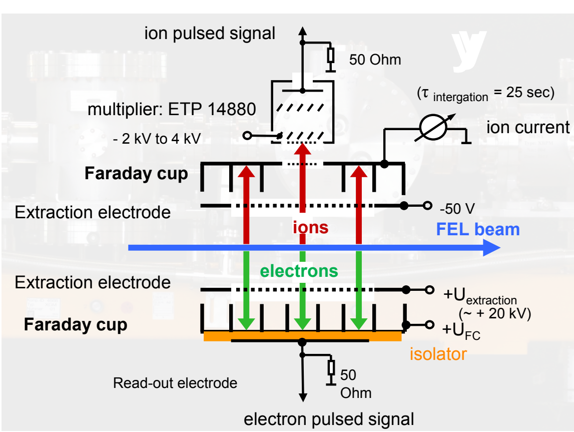
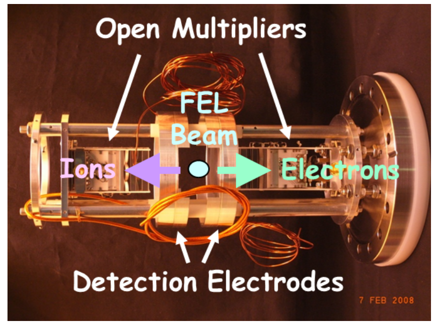
INTENSITY: GMD → XGMD
FLASH, FLASH2, EuXFEL, PSI

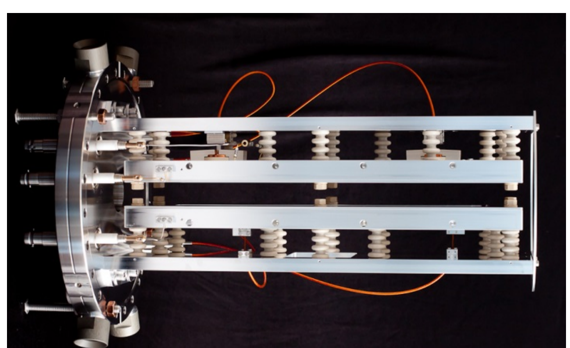
1st generation GMD (FLASH1)



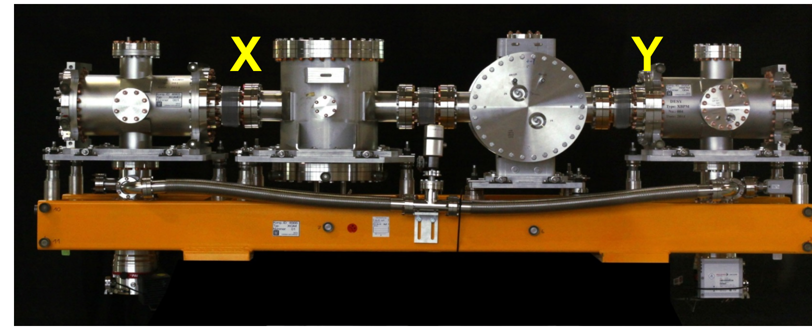


Advanced GMD (round-robin)





3rd generation GMD (XFEL, FLASH2)

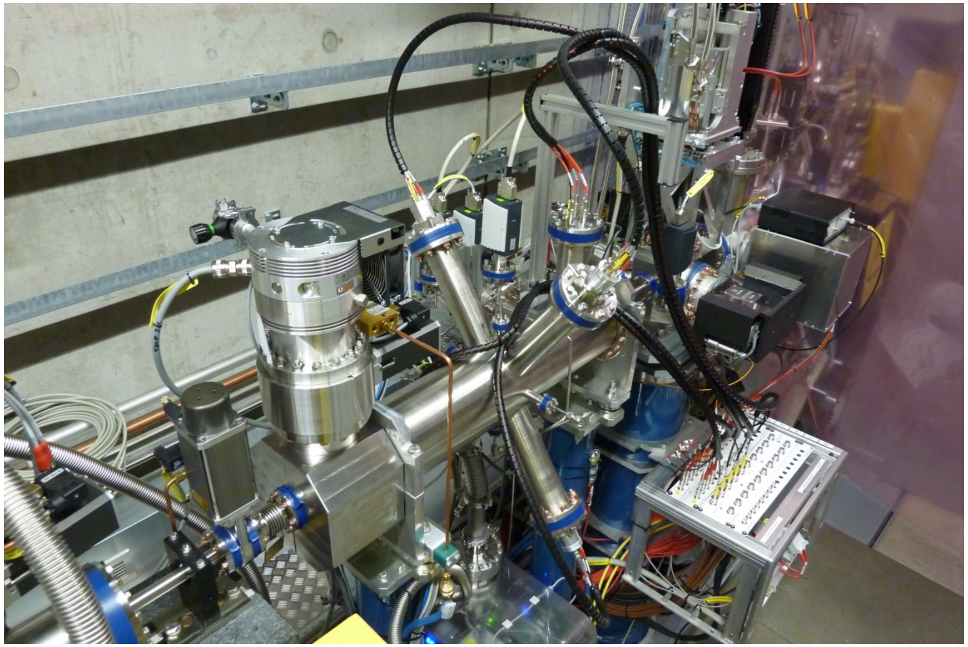


XGMD HAMP HAMP XGMD

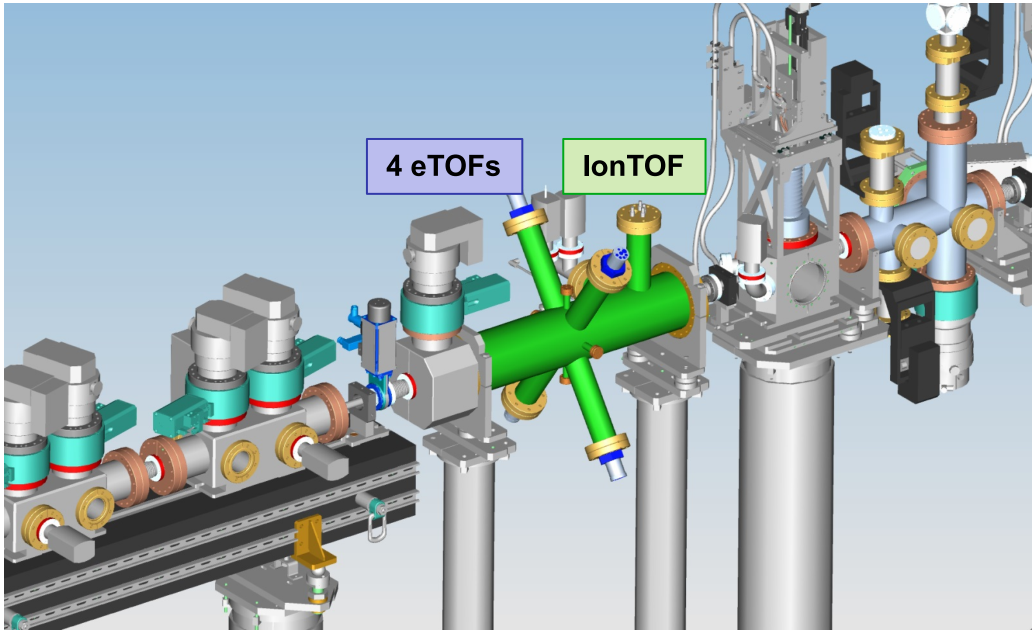
- New XGM design copes with enhanced demands of the XFEL wavelength range:
  - higher sensitivity (larger XGMD absorption length)
  - higher dynamic range (tunable HAMP stage voltages)
- Test runs gases at the Willy-Wien-Labor, PTB Berlin
- Measurement of absolute ionization cross sections of rare gases at the PTB beamline at BESSY

Courtesy of K. Tiedtke and E. Plönjes (DESY)

WAVELENGTH (AND BANDWIDTH)
FLASH2 OPIS



- 4 Electron time-of-flight spectrometers
  1 Ion time-of-flight spectrometer
- μ-metal chamber
- low target gas operation pressure:
  $p_{target} \approx 10^{-7}$ hPa



- Transmission: ~100%
- Signal recording by fast ADCs: Capable of operation with MHz repetition rate of the FLASH burst-mode
- Self-Calibration using Auger processes
- Accuracy better than 0.1nm

M.Braune et al., *J. Synchrotron Rad.* **23**, 10 (2016)

Courtesy of M. Braune (DESY)

WAVELENGTH (AND BANDWIDTH)
FLASH2 OPIS

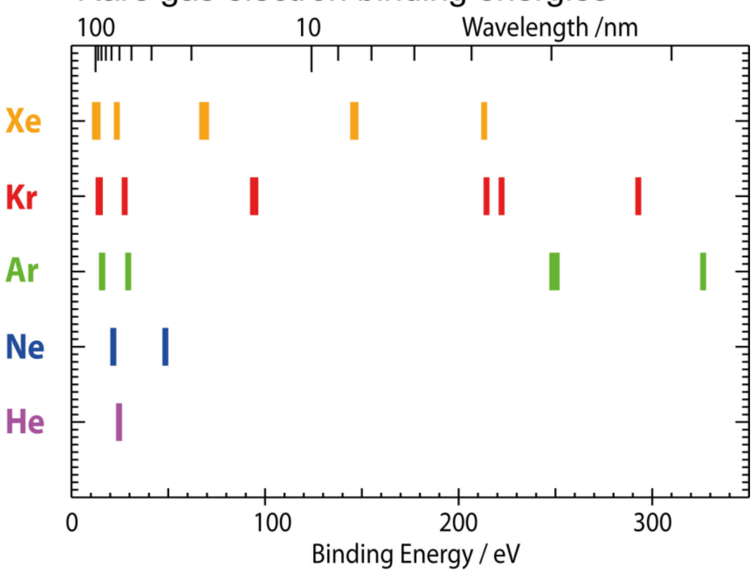
> Electrons

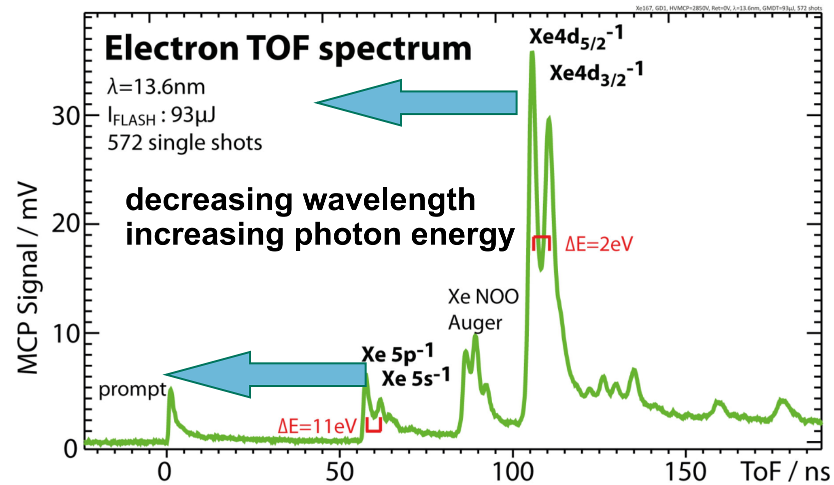
Determination of the kinetic energy of photoelectrons directly from the flight time

$$E_{FEL} = E_{kin} + E_{bind}\,,\quad \lambda_{FEL} = hc/E_{FEL}$$

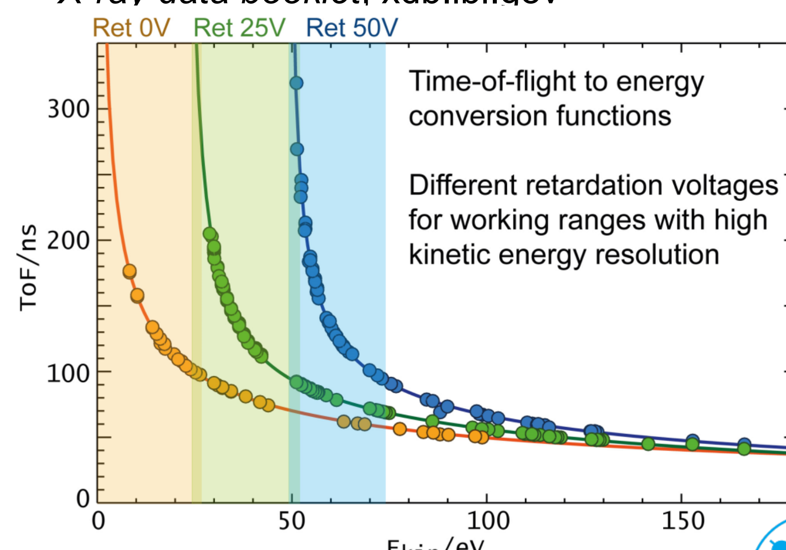
Various targets: rare gases
Binding energy: literature

Rare gas electron binding energies





X-ray data booklet, xdb.lbl.gov

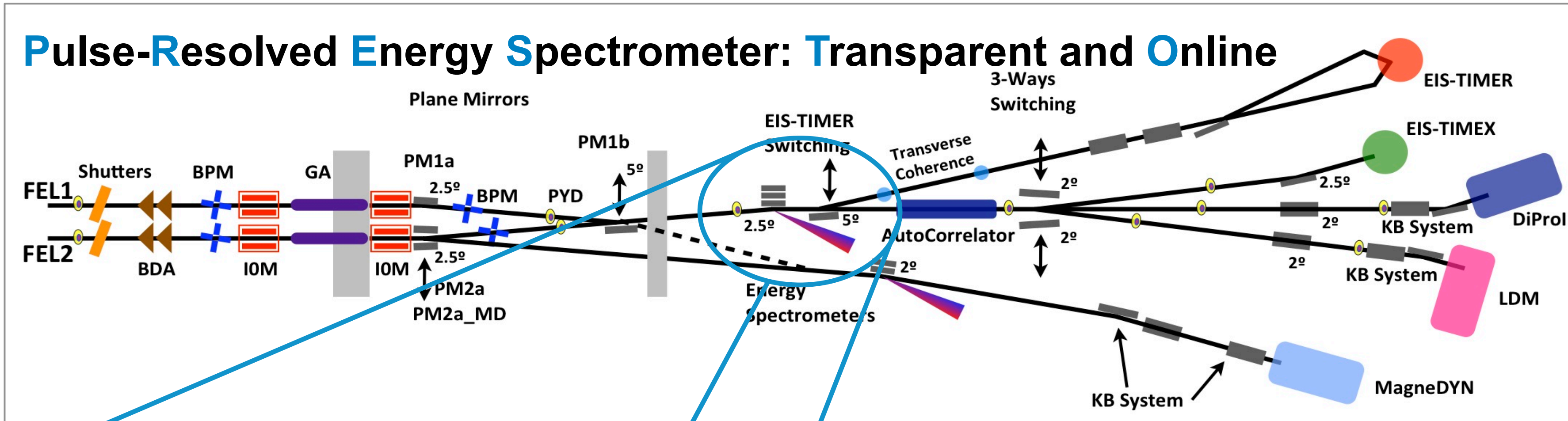


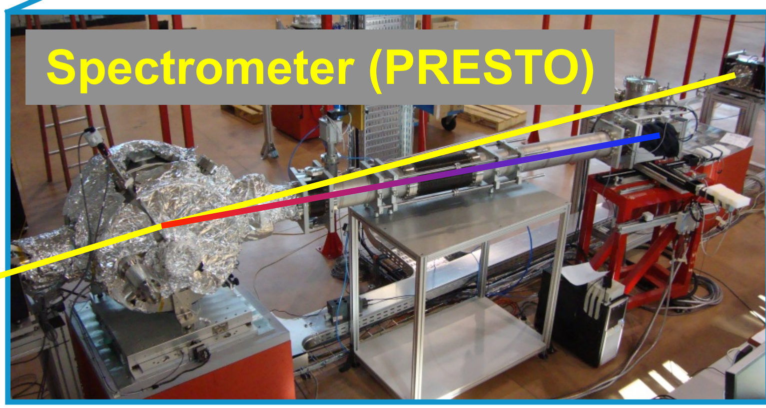
Advantages:
operational in the full FLASH wavelength range
measuring the complete wavelength range

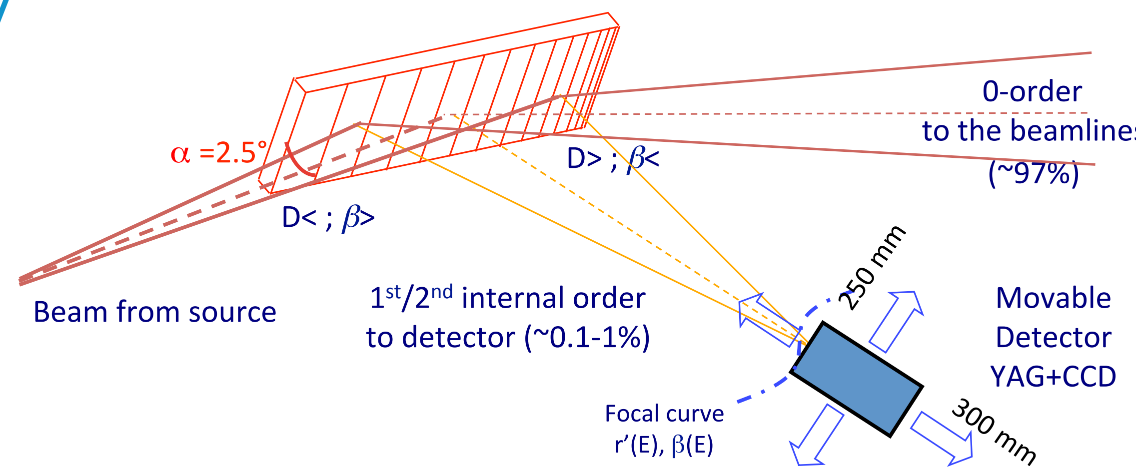
Possible error sources: external magnetic and electric fields
space charge

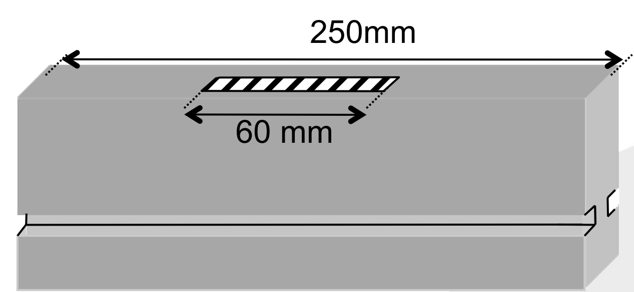
Courtesy of M. Braune (DESY)

SPECTRAL CONTENT
FERMI PRESTO (VLS-based)









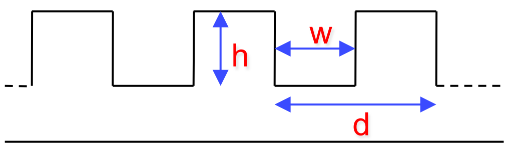
- **Online (non invasive)**
- Shot-to-Shot
- ~97% of FEL → beamlines
- 1% of FEL → YAG + triggered CCD
- Resolving Power ~15000 @32.5nm (2.5meV)
- Available information: **λ, BW, spectral content**
- **3 gratings** (Au, C and Ni coatings) – 2.5º-incidence

SPECTROMETER GRATINGS

Optical parameters

Requests:
Fused silica substrate
250x25mm^2 surface (240x17 active)
Laminar profile – Central 60mm ruled
Tang. Slope error rms <1μrad
Radius of curvature >30km

h = groove depth
w = groove width
d = groove spacing



	LE	HE	SHE
Wavelength (nm)	100 – 24	27 – 6.7	13 – 3.2
Slope error rms (μrad)	0.28	0.28	0.32
Radius (km)	22	31	43
D_0 (l/mm)	500	1800	**3750**
D_1 (l/mm^2)	0.35	1.26	2.68
D_2 (l/mm^3)	$1.7 \cdot 10^{-4}$	$6.3 \cdot 10^{-4}$	$1.4 \cdot 10^{-3}$
Groove height (nm)	12	4	8*
Groove ratio (w/d)	0.60	0.65	0.65**
Coating	Carbon	Gold	Nickel

HORIBA JOBIN YVON

*Requested: 6nm – Offered: 8nm – Actual: 9nm
**Requested: 0.8 – Offered: 0.65 – Actual: 0.65

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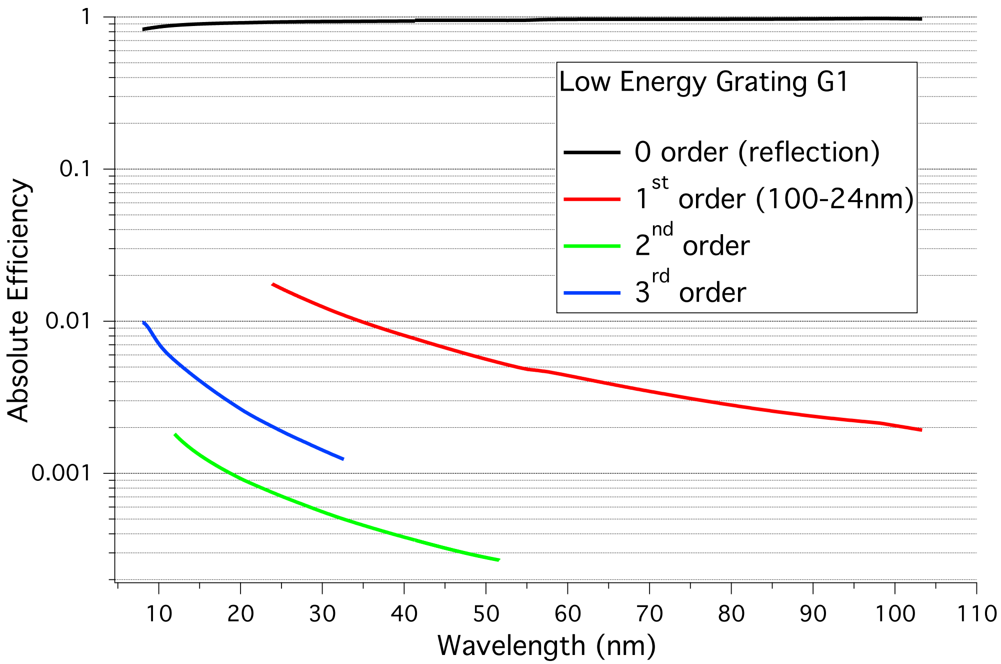
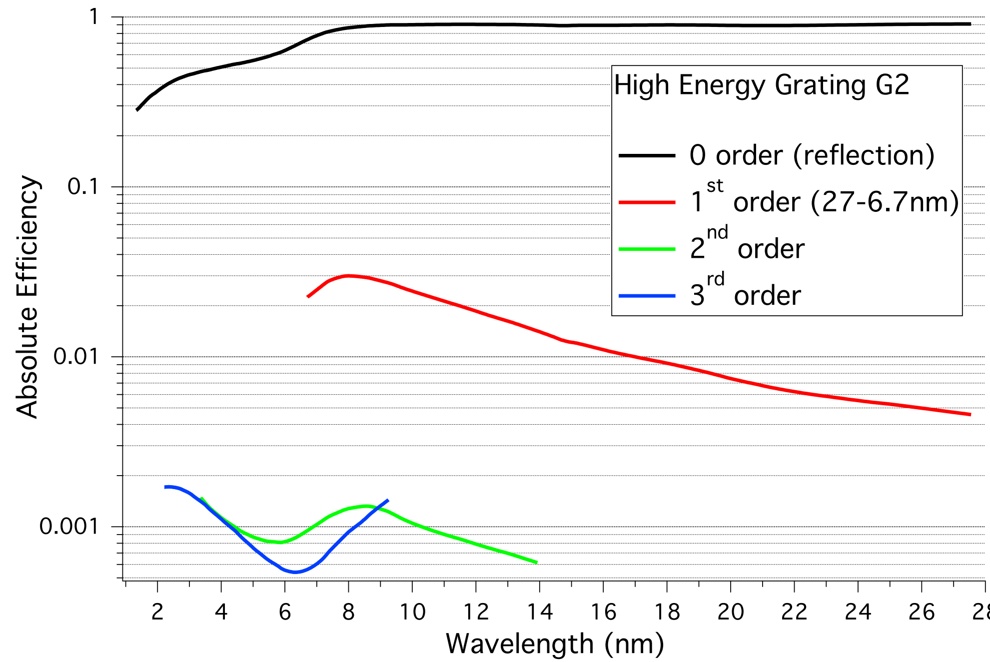
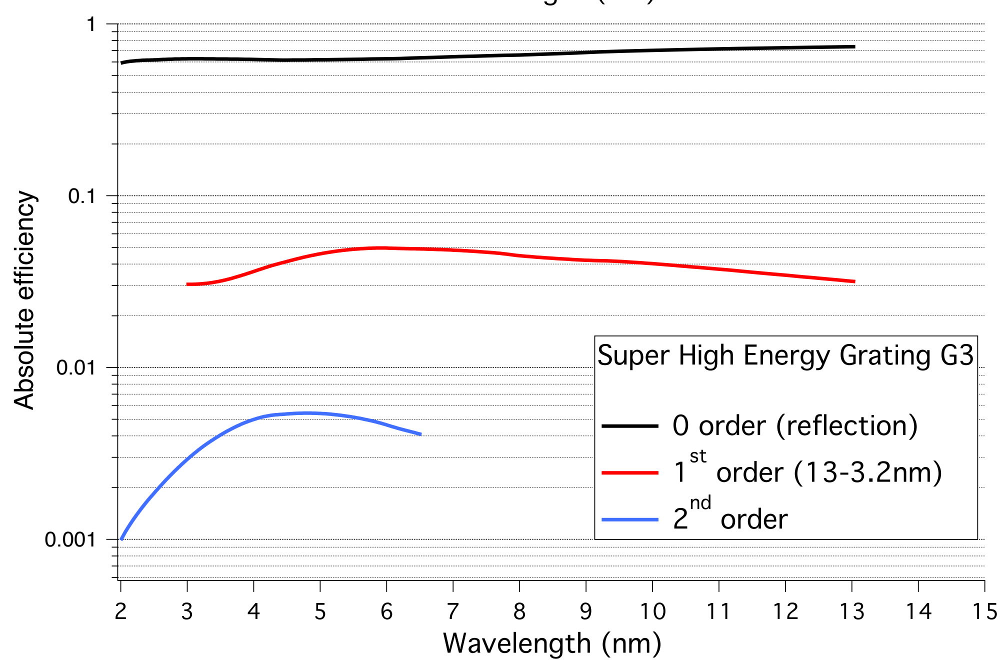
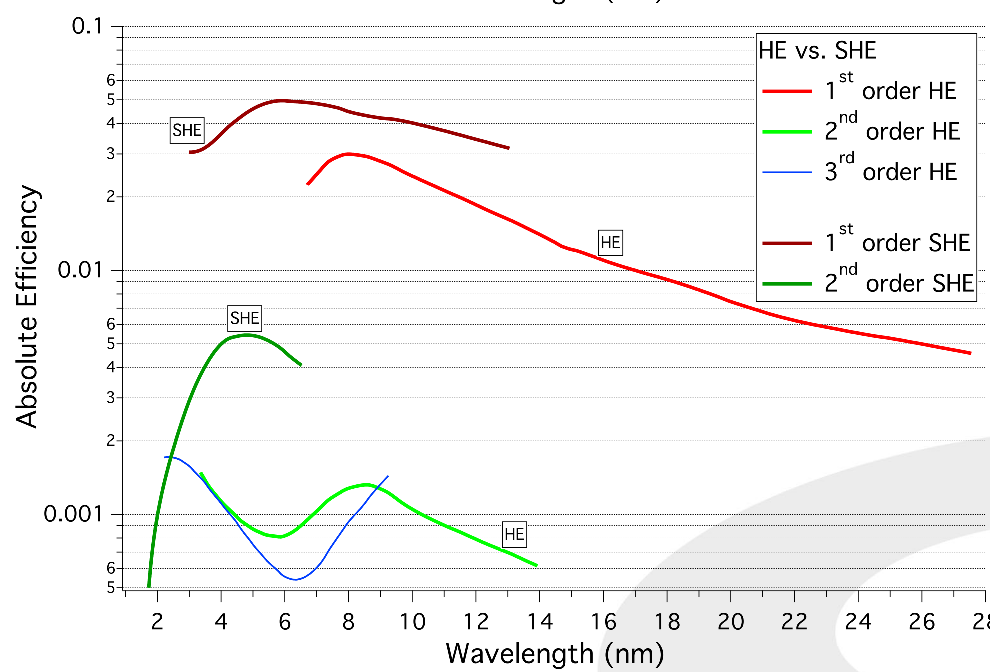
PRESTO GRATINGS

Efficiencies



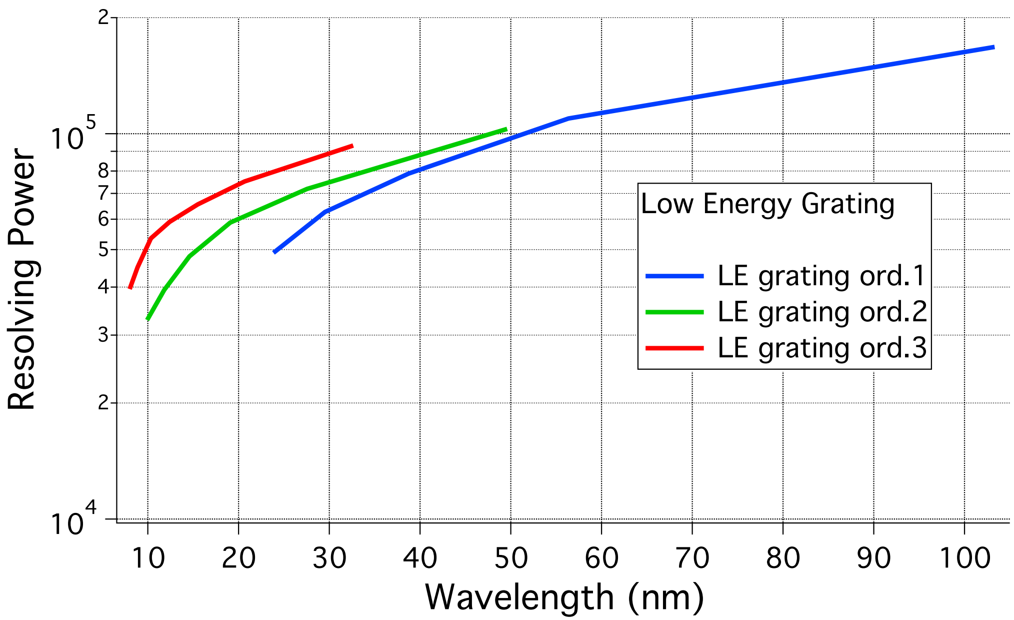


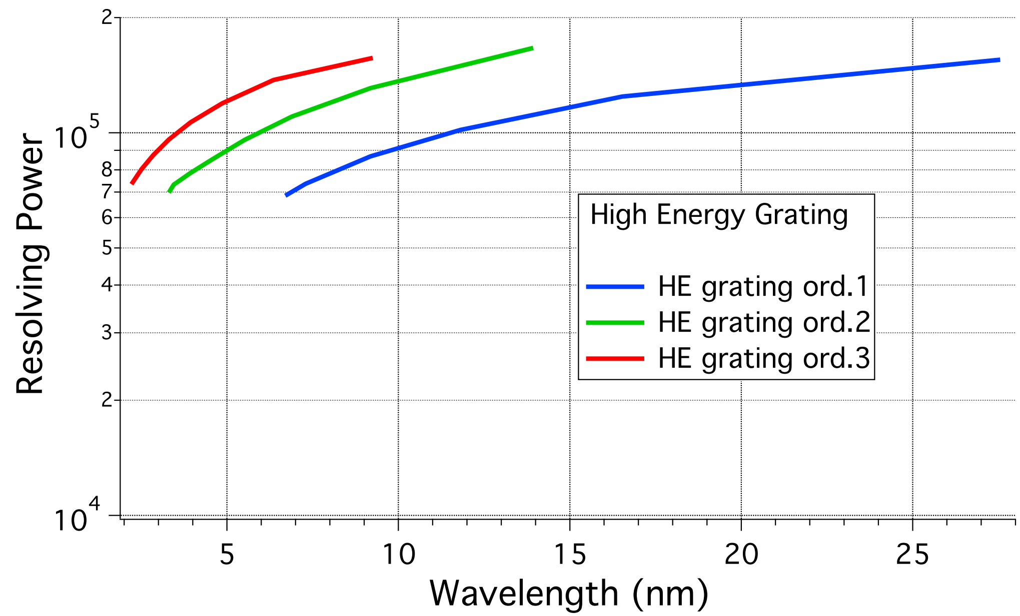


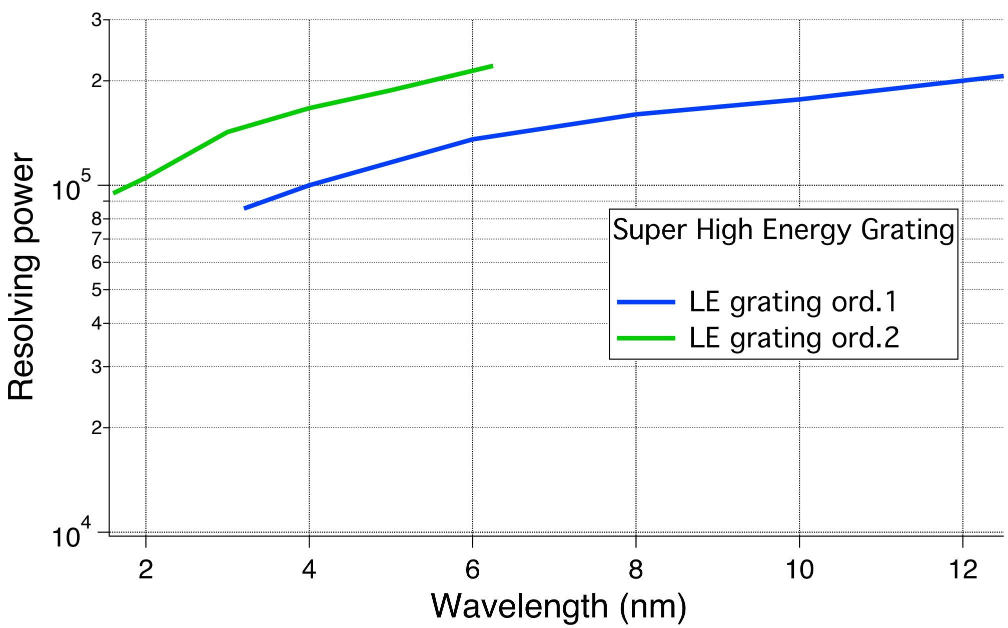


PRESTO GRATINGS

Resolving powers





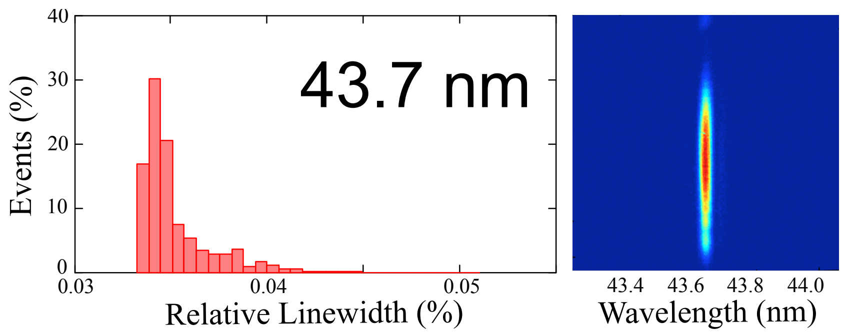


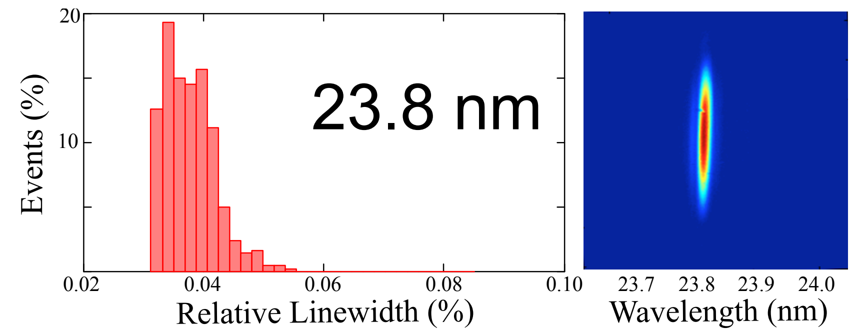
Resolving power to be scaled depending on the detection system

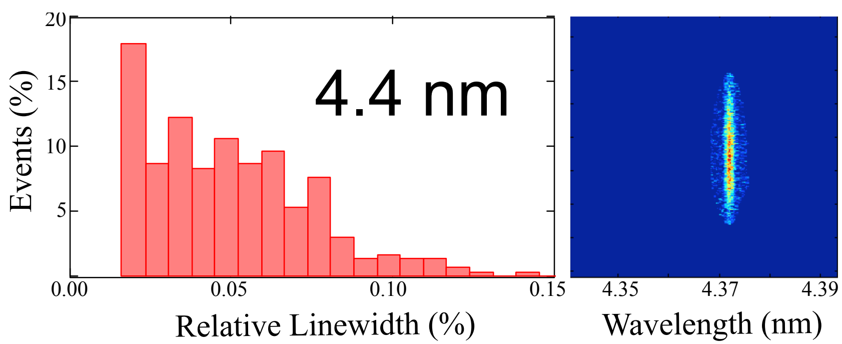
PRESTO currently uses a Ce:YAG in vacuum coupled to a visible light CCD camera → **Res.Power ~ 20.000**

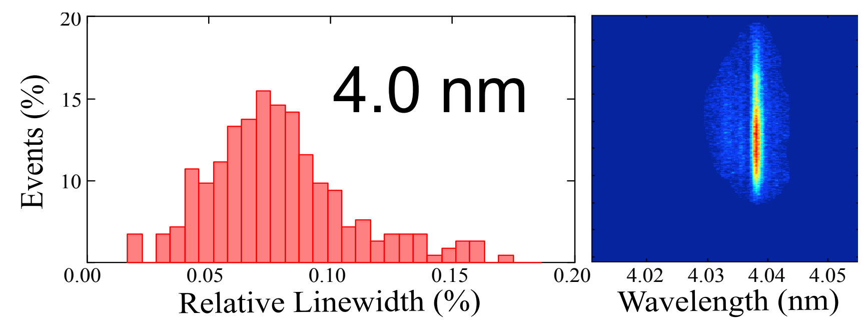
SPECTRAL CONTENT
FERMI PRESTO (VLS-based)

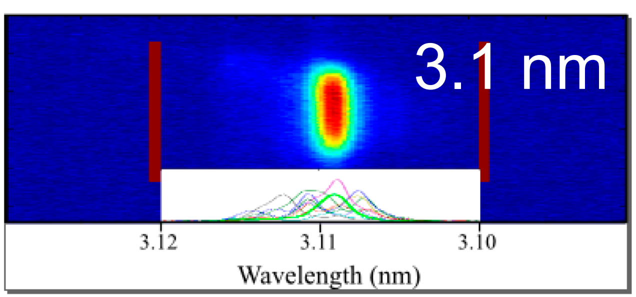
Single shot **spectra** measured down to **4 nm** (even at 3.2nm); **narrow linewidth** with an **energy** per pulse at shorter wavelengths larger than **10 μJ**.



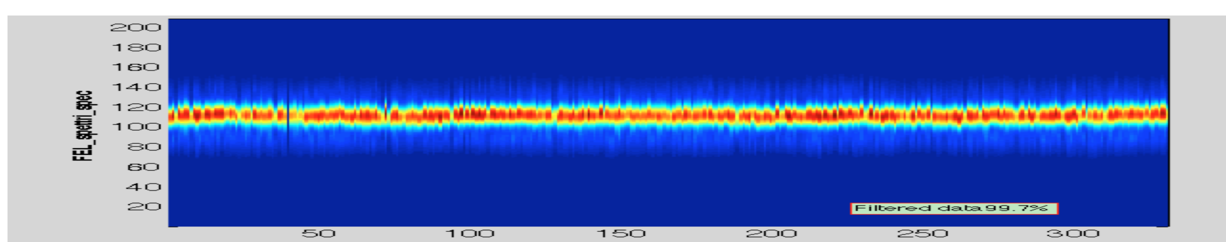








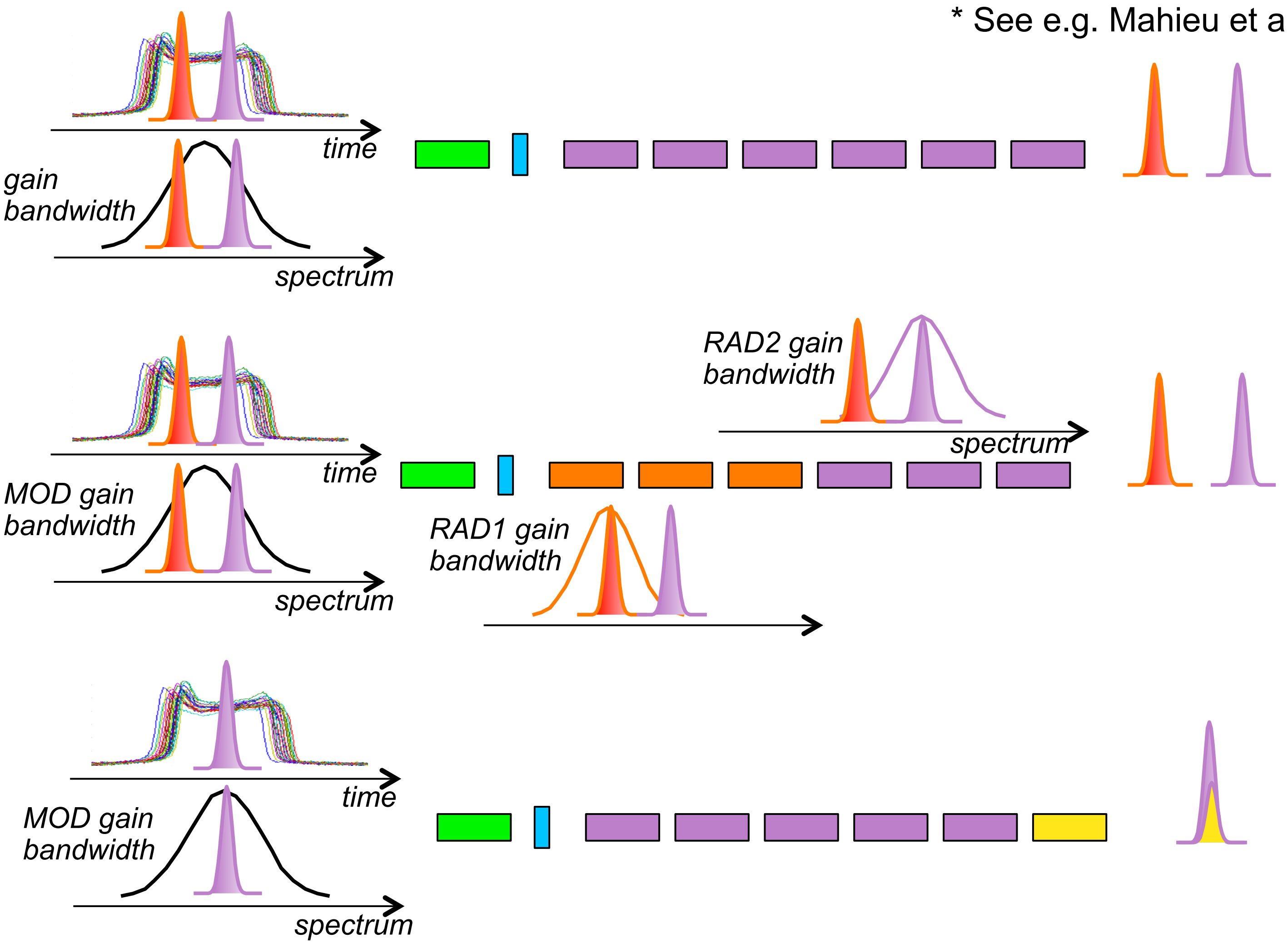
- **Gaussian with both wavelength and bandwidth stability.**



TWO COLOR – TWO PULSES
Seeded FEL options

Multiple pulses can be generated by **double pulse seeding** in different ways, depending on the requirements on the output radiation. Temporal **separation between 25-300 and 700-800 fs**. Shorter separations are accessible via FEL pulse splitting*. Larger separations require the split & delay line.

* See e.g. Mahieu et al. Optics Express 21, 22728 (2013)



Spectral separation 0.4-0.7% (Capotondi)

Spectral separation 2-3% or much larger if the two radiators are tuned at different harmonics (Sacchi)

Two (almost) temporally superimposed pulses at harmonic wavelengths of the seed. The two pulses are correlated in phase and the phase can be controlled with the phase shifter (Prince)

Courtesy of Luca Giannessi

TWO COLOR – TWO PULSES

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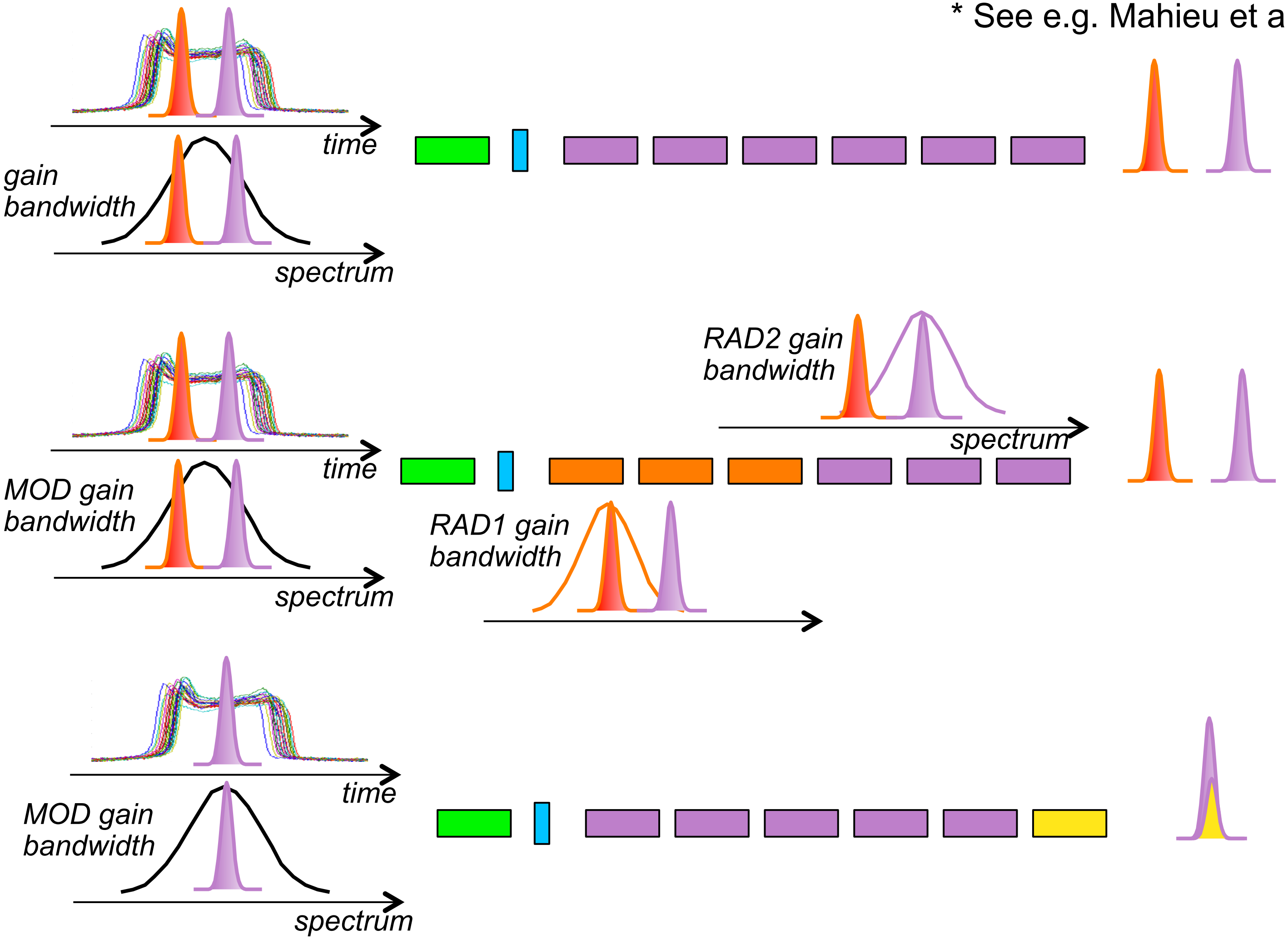

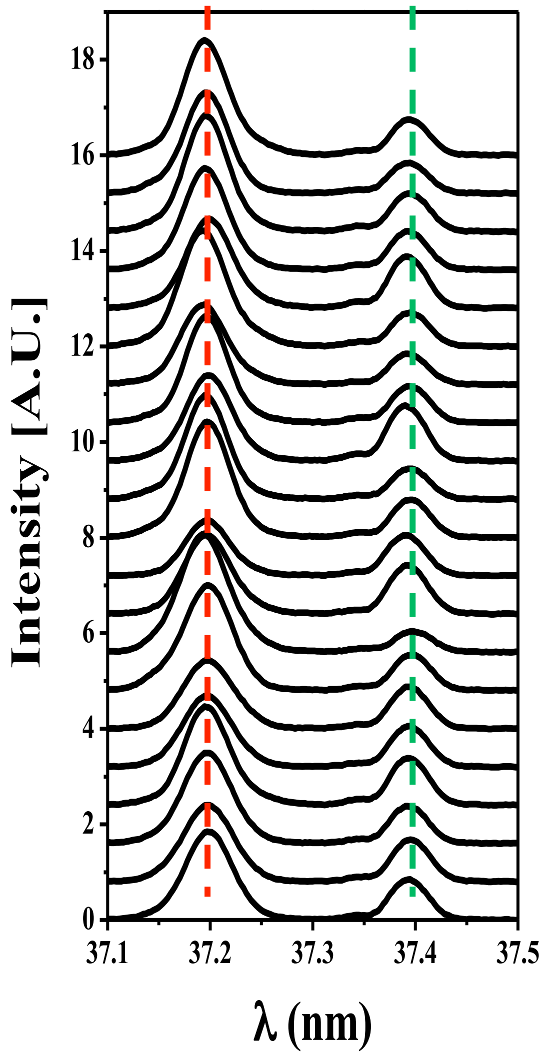

Courtesy of Luca Giannessi

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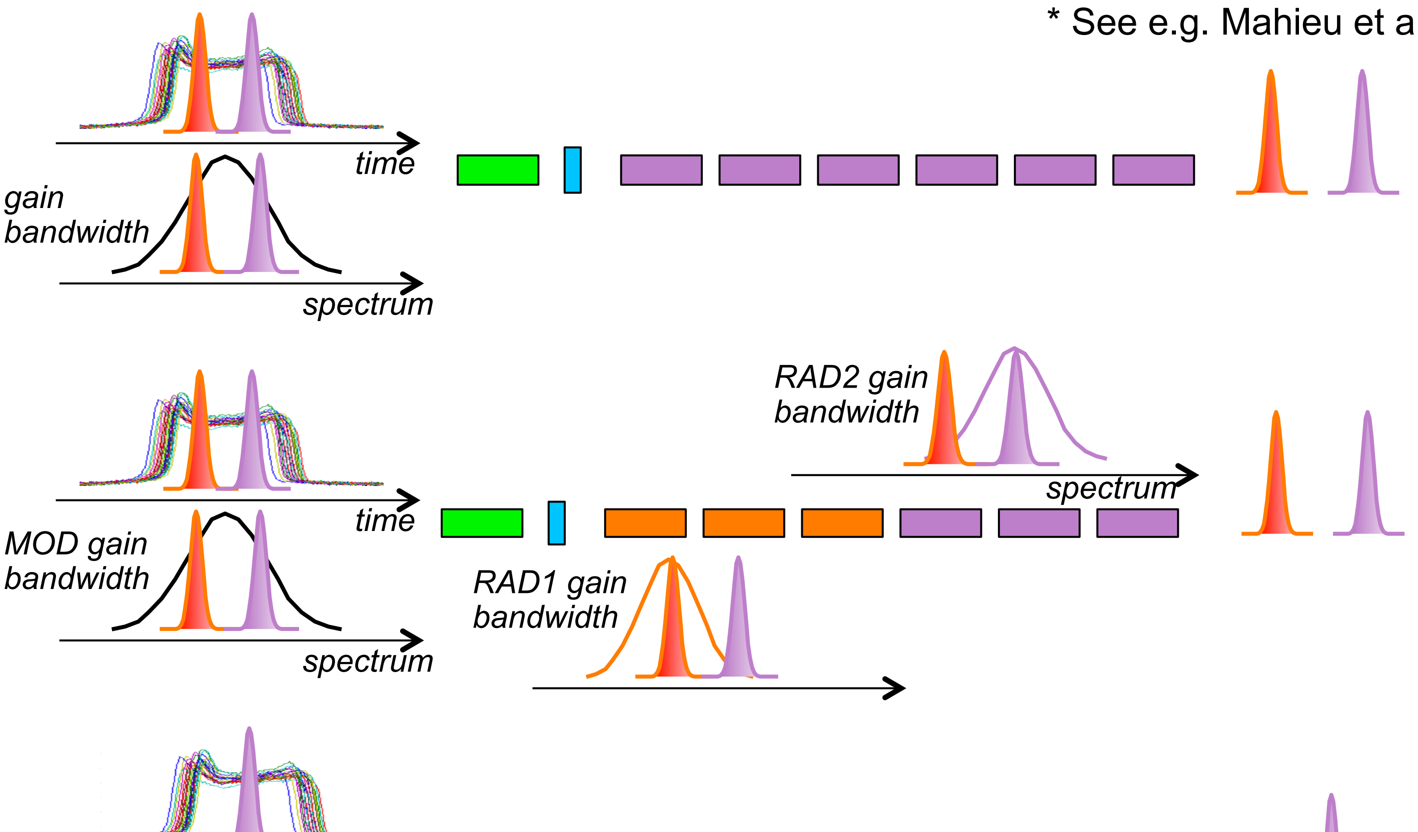
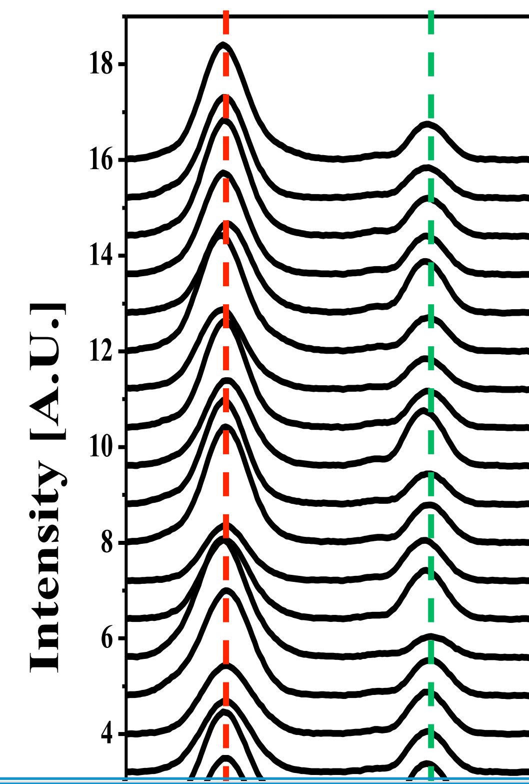
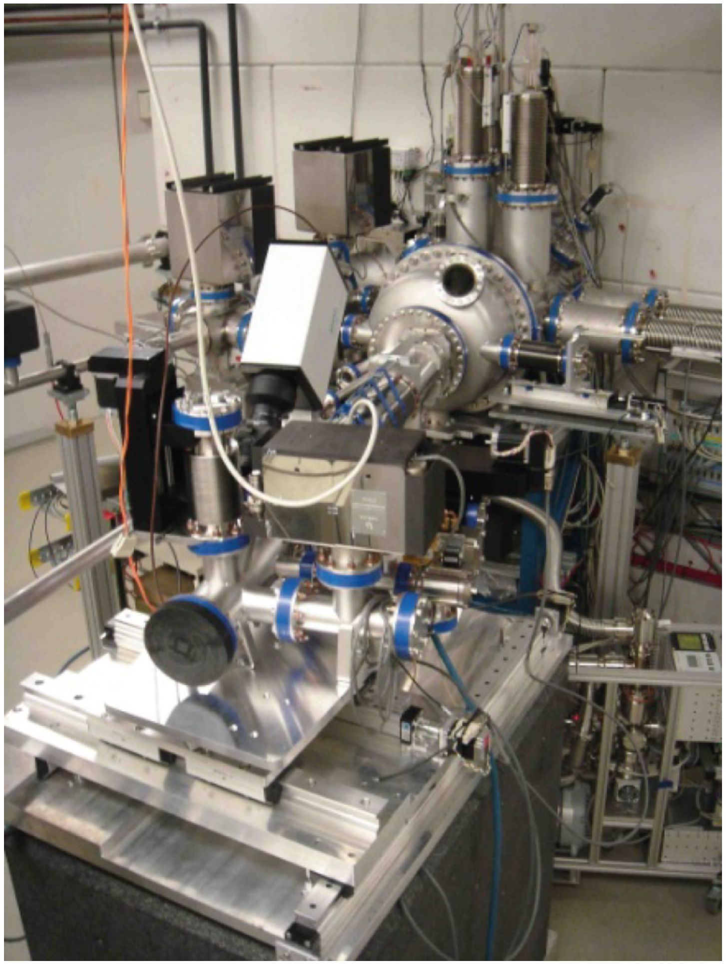




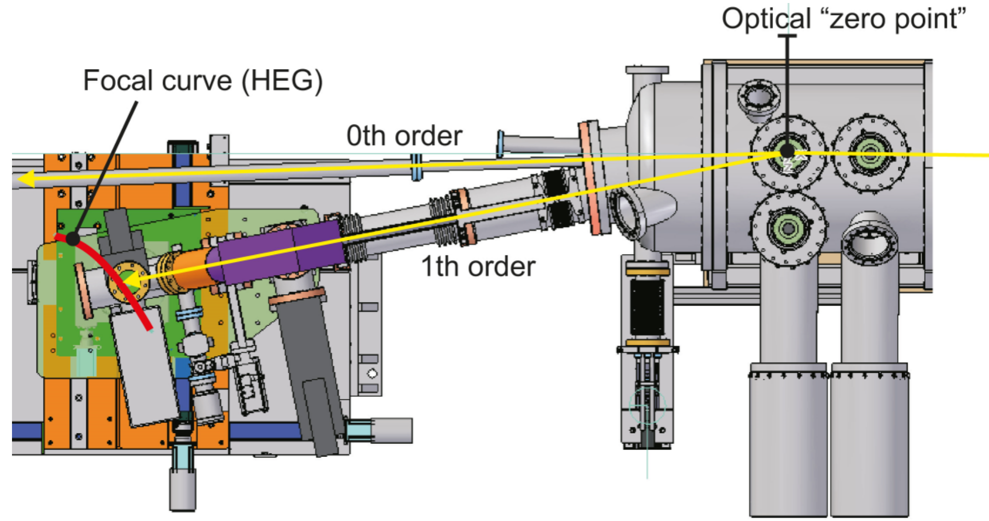
FERMI experience:
The energy spectrometer should operate in single-shot mode (→ **efficient grating and detectors**) and should be able to operate in **two/multi color acquisition mode** to measure fundamental/higher harmonics, 2-color double pulses, and FEL double-stage photons

SPECTRAL CONTENT
FLASH VLS Grating Spectrometer



Permanent installation in the beam distribution area

G. Brenner et al., NIM A 635, S99-S103 (2011)



Grazing incidence design (2° incidence angle)
High and low energy VLS gratings (900 / 300 l/mm)
Spectral range: 5.4 - 60 nm
Resolution ≈ 1500@25nm (design value >5000)

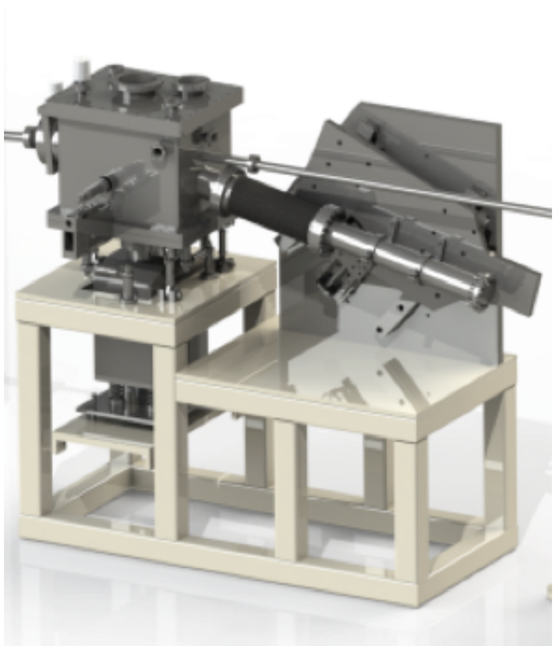
Additional plane mirror (Ni and C coatings)
Mirror-mode:
Full intensity to the experimental hall

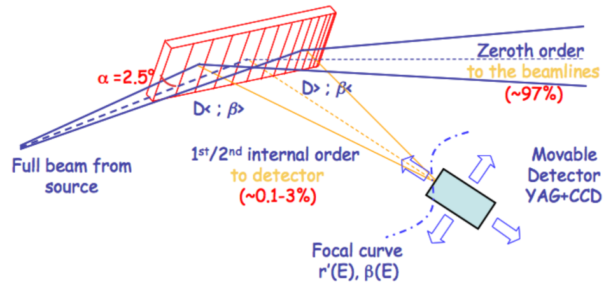
Spectrometer-mode:
0^{th} order: high transmission to exp. hall
1^{st} order: 1–10% of intensity for spectral analysis

DESY

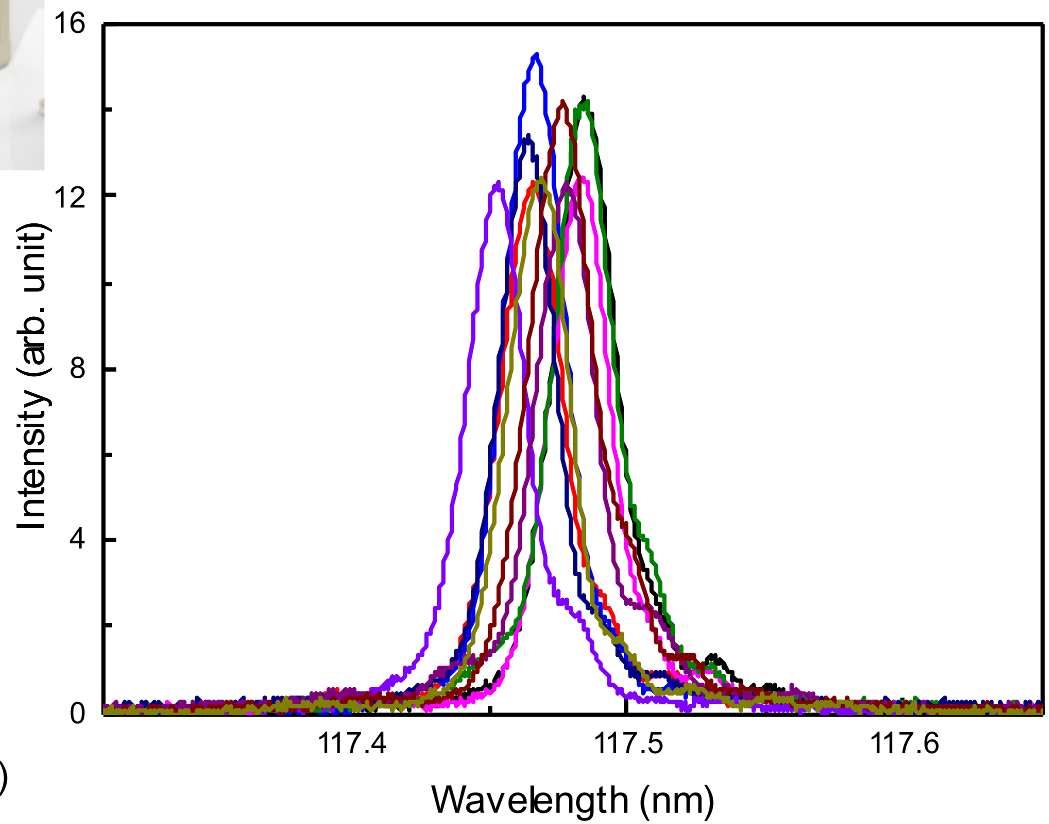
Courtesy of G. Brenner (DESY)

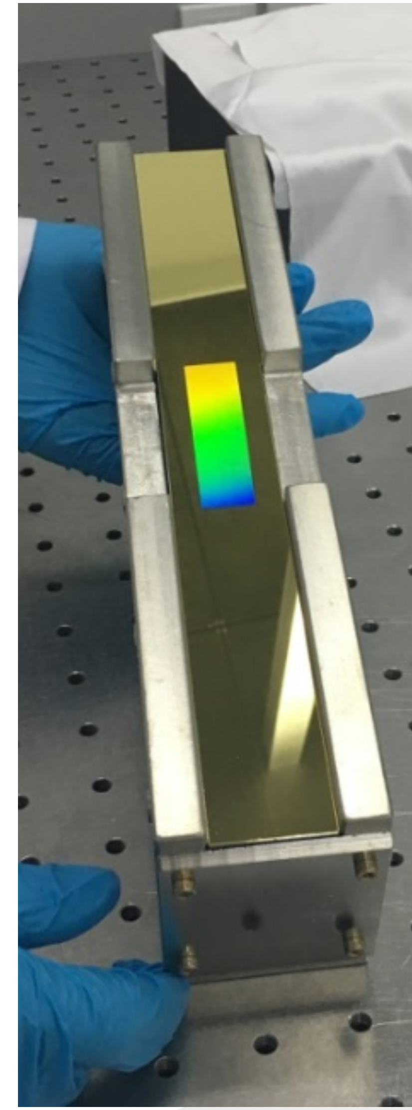
SPECTRAL CONTENT
Dalian DCLS Diagnostics





- **The resolution of spectrometer is designed as high as 14000.**

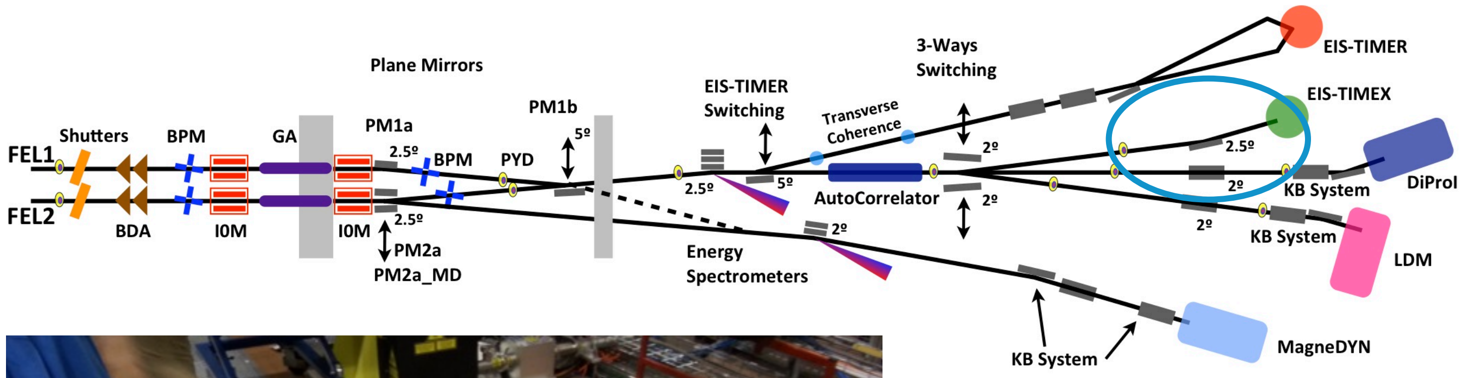




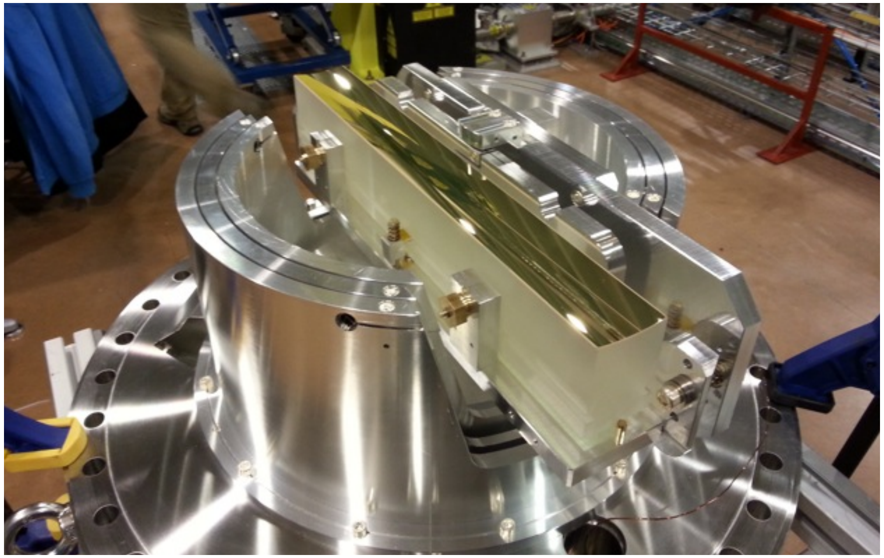
Courtesy of W. Zhang (DCLS)

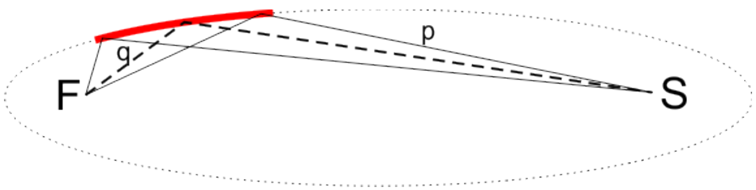
PHOTON BEAM FOCUSING

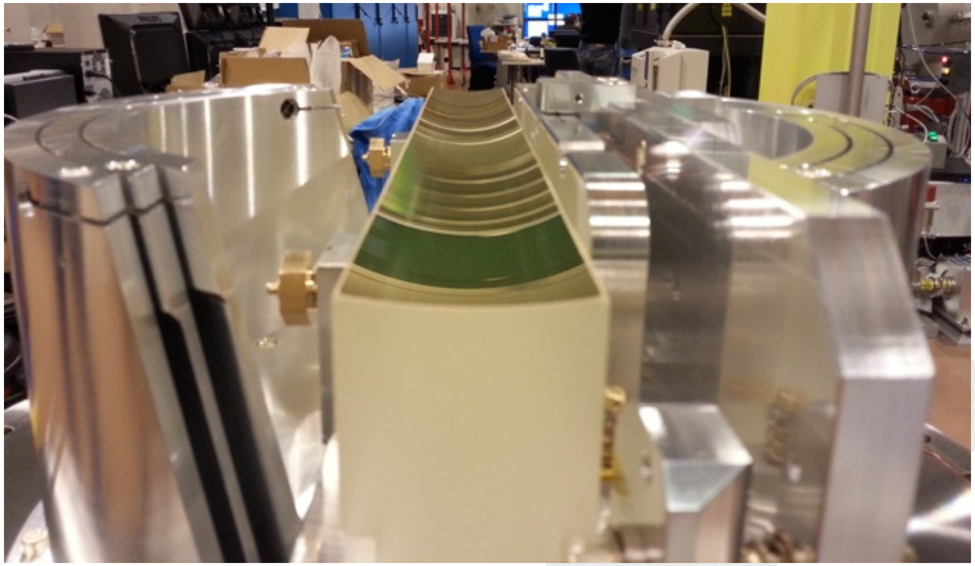
Bulk Ellipsoidal Mirror



Entrance arm: 84.85 m
Focal length: 1.4 m
Incidence angle: 2.5°



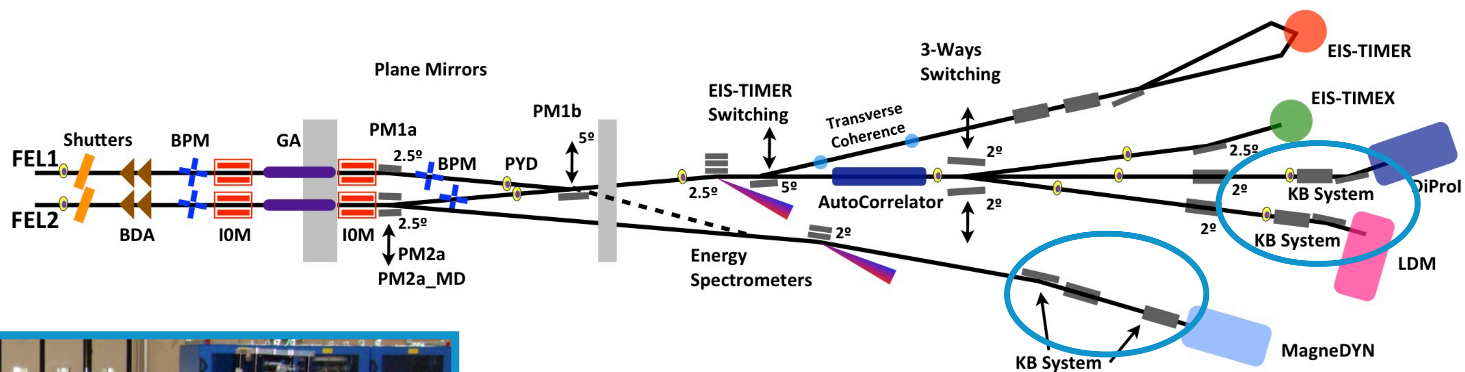


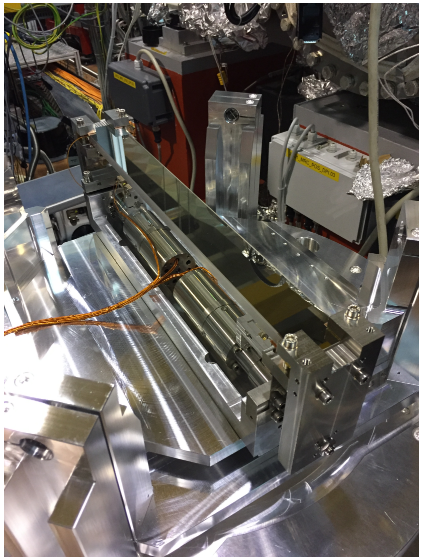


- **Single** ellipsoidal mirror (Hor. Deflecting)
- Optimized for FEL-2 (but focuses FEL-1 as well)
- Out-of-focus needed for FEL-external laser overlapping

PHOTON BEAM FOCUSING

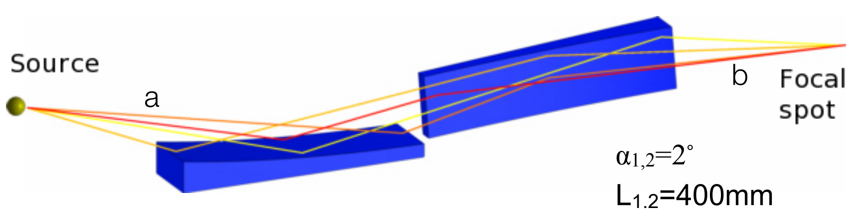
Active Optics Systems





Kirkpatrick-Baez Active Optical Systems (KAOS):

- Active plane mirrors in Kirkpatrick-Baez configuration
- Focus **different sources** (FEL-1 and FEL-2) in **selectable positions**
- Decouple H from V focusing
- Adjustable to optimize focusing
- Adapt spot for FEL-external laser **overlapping**
- Optimize focal spot in **external user endstations**



$a_{1,2}$ = 98754 - 99354 mm $b_{1,2}$ = 1750 - 1200 mm

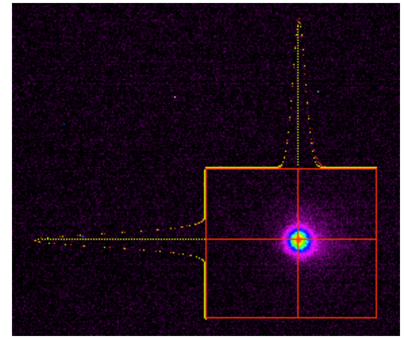
Entrance arm: ~100 m
Focal length: 1.2-1.75 m
Incidence angle: 2°

- Best focusing → **λ-dependent** (~2x3 – 8x8 μm^2)
- **Defocusing** possible: from best focus to ~1x1 mm^2)

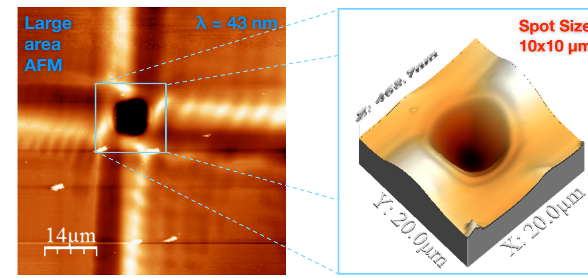
→ Need for suitable diagnostics

SPOT SIZES DETERMINATION
Different techniques

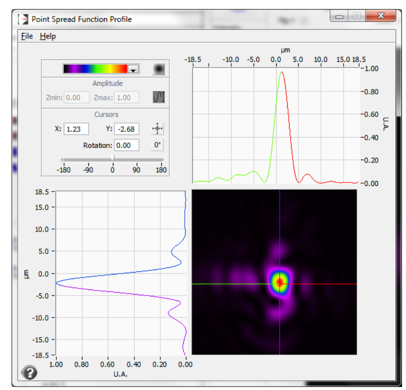
Scintillator-based (e.g. Ce:YAG)
- Invasive
- May suffer from saturation effects
- Scintillator gets damaged in focus
- No single-shot information (generally)
- Quick and cheap

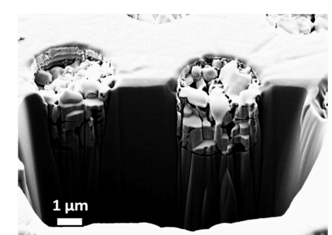


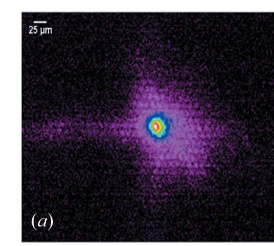
PMMA and Si indentation
- Invasive
- Single shot information
- Deadly time-consuming (not fit for beamtimes)



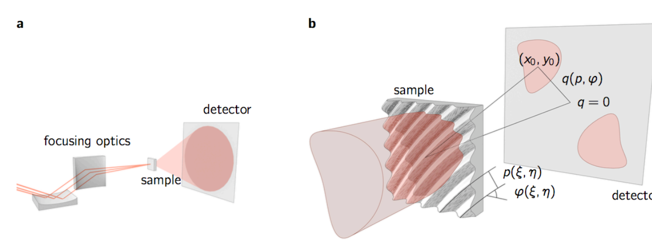
Wavefront sensor
- Almost non invasive (intensity issues)
- Single shot information
- Online
- Quantitative information about focusing



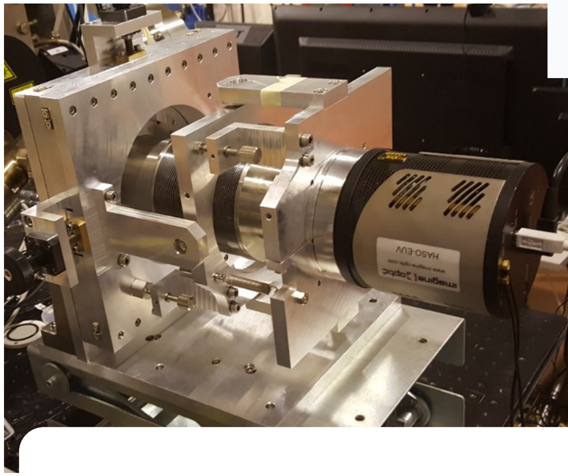




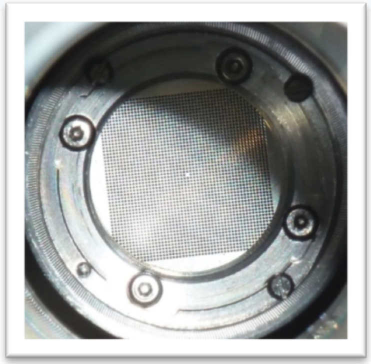
Other techniques
- Pixelated P array
  (ref. A. Matruglio et al., J. Synchrotron Rad. (2016). 23, 29-34)
- VLS grating based spot reconstruction
  (ref. M.Schneider, et al., arXiv:1705.03814)
- …

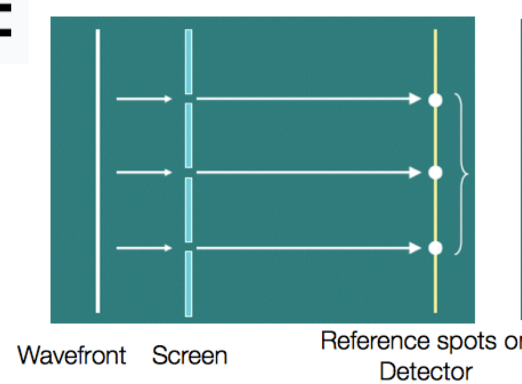


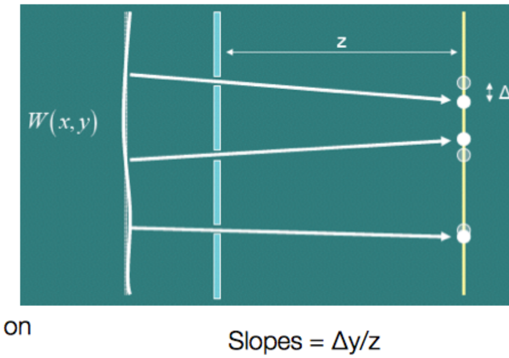
SPOT SIZES DETERMINATION
Wavefront sensor

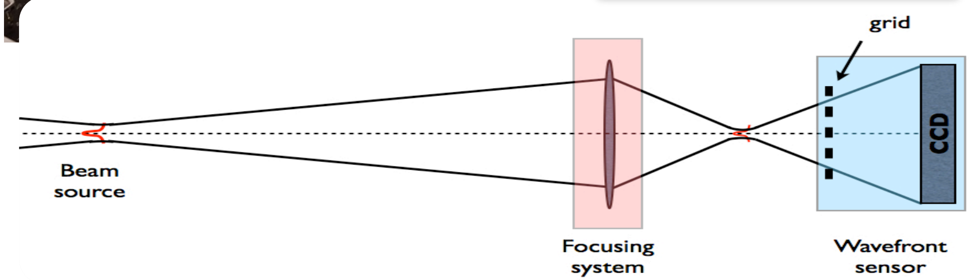


imagine optic



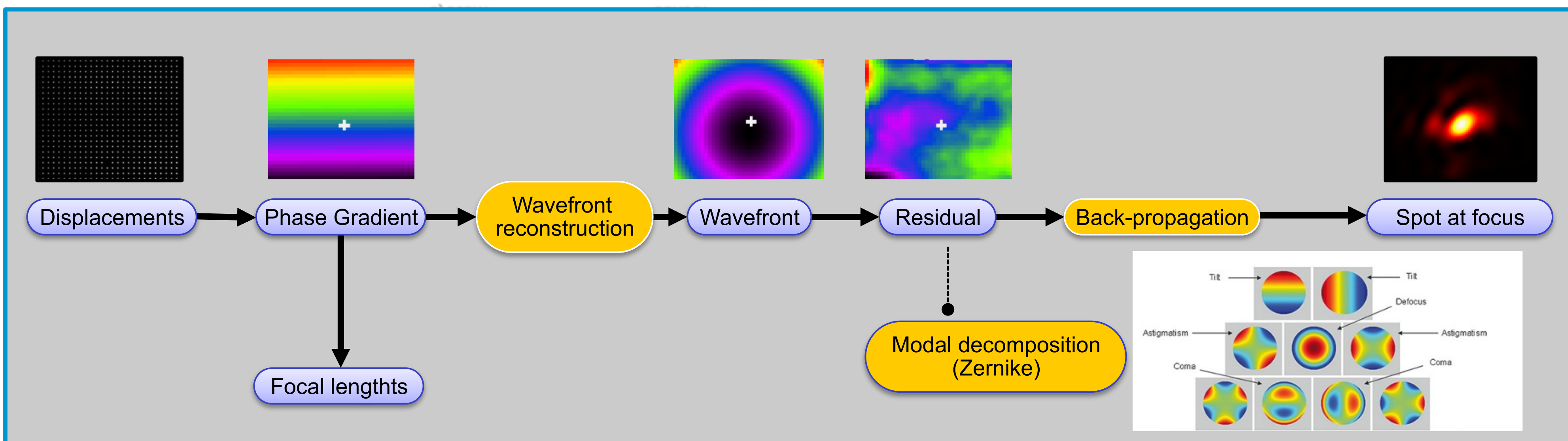






SPECS

- 72 x 72 grid (13 x 13) mm^2
- Pitch=180μm, Pinhole diameter: 60μm
- Wavelength range: 4-40nm
- Accuracy ~λ/10
- Squared pinholes !

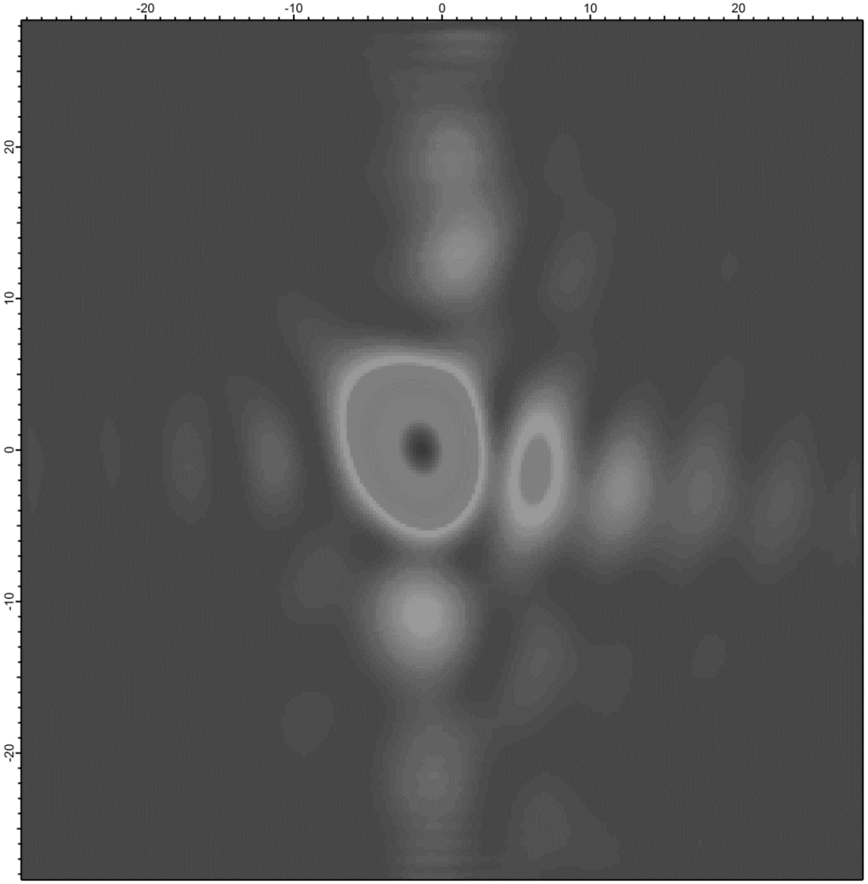


Elettra Sincrotrone Trieste

iom Istituto Officina dei Materiali

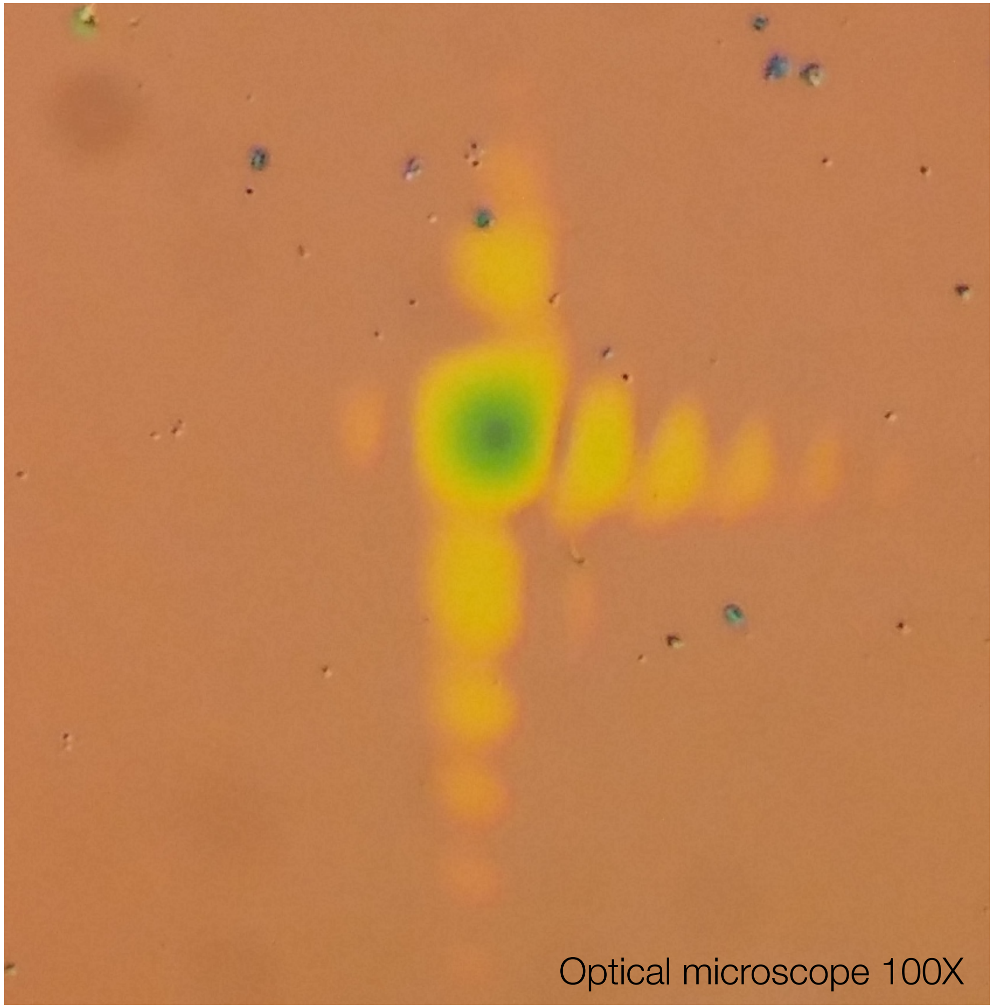
SPOT DETERMINATION
WFS vs. PMMA

Reconstruction from Hartmann WFS data



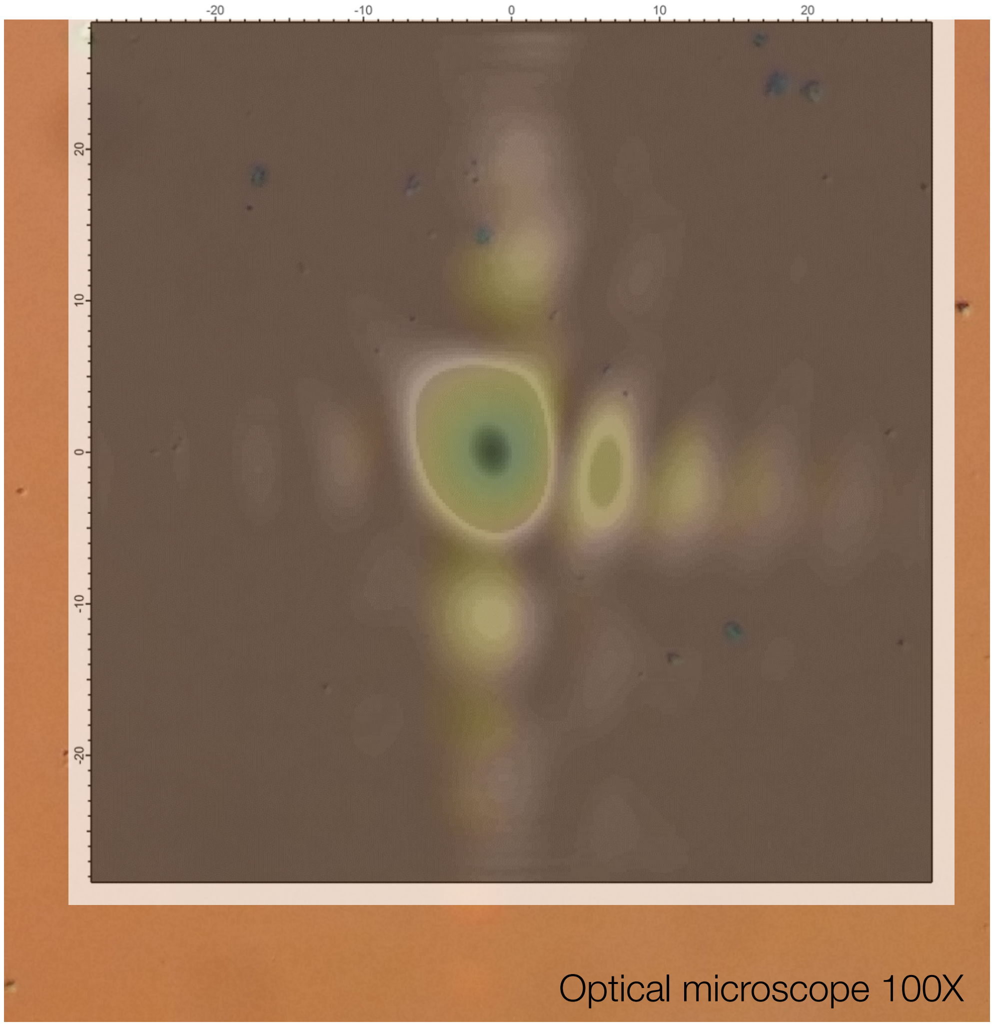
WFS reconstruction at 32nm: FWHM = 5.7x6.5 μm^2

PMMA ablation imprint



SPOT DETERMINATION
WFS vs. PMMA

PMMA ablation imprint

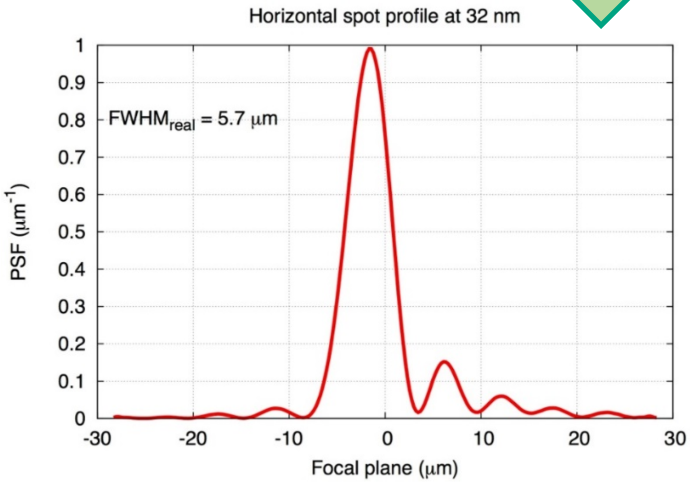


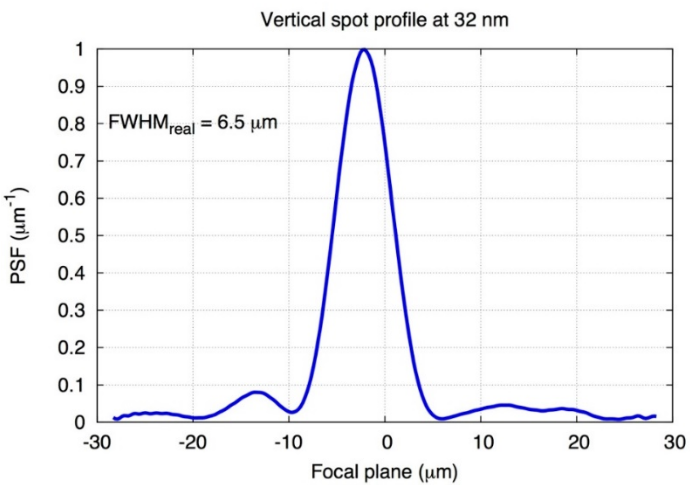
Good agreement between in-house reconstruction and PMMA

SPOT DETERMINATION
WFS vs. PMMA vs. WISE

Focal spot simulations from metrology

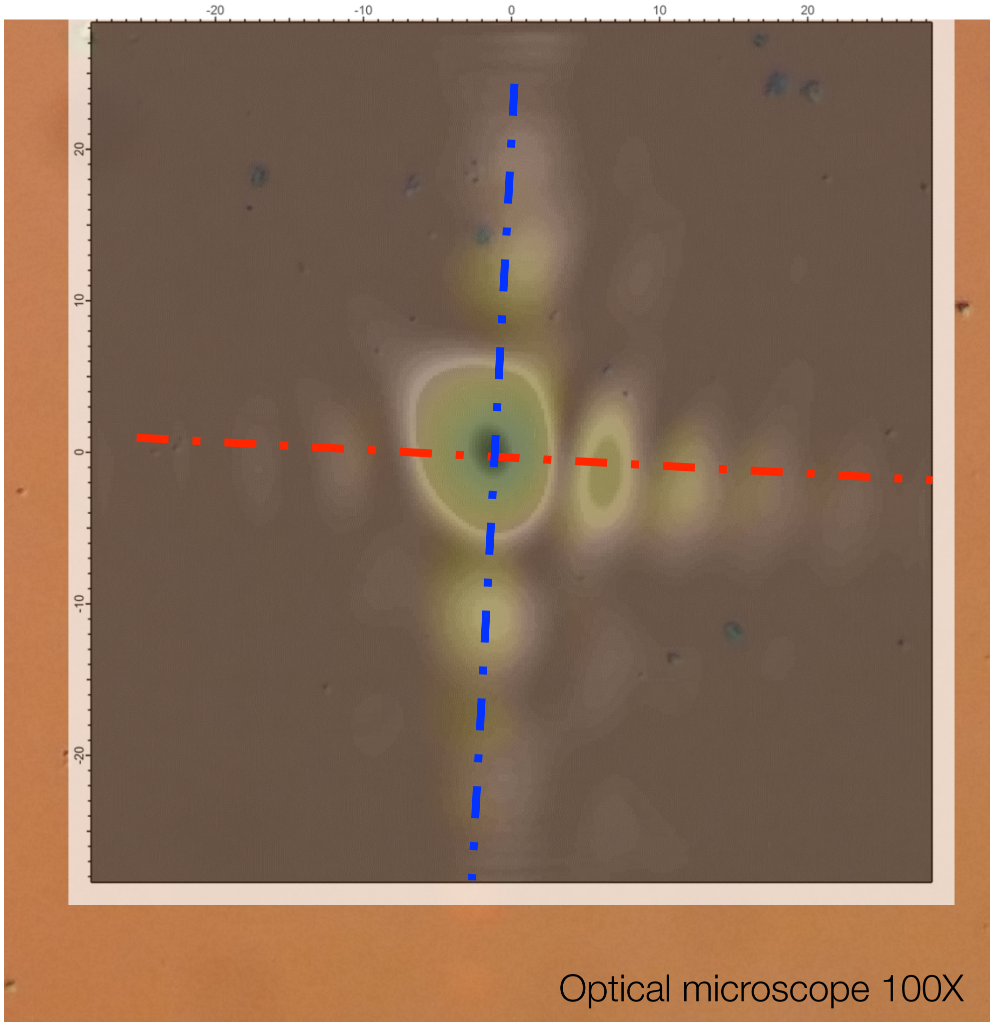
Profilometry at best curvature (LTP) → Simulations





(1) L. Raimondi, D. Spiga, SPIE Proc., 8147 (2011)
(2) L. Raimondi et al., NIM A, 710, 131 (2013)

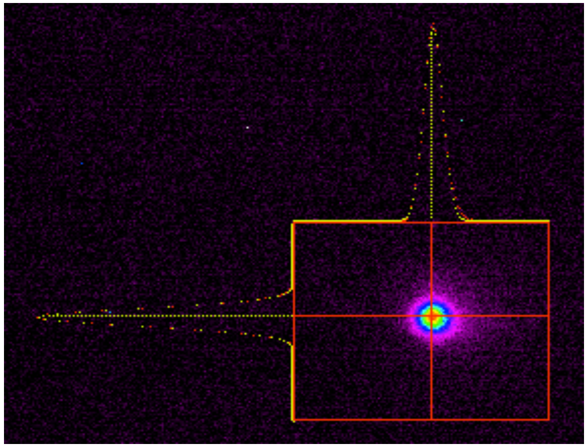
PMMA ablation imprint



Good agreement between in-house reconstruction, PMMA, simulations

FOCUSING

Further/Latest results

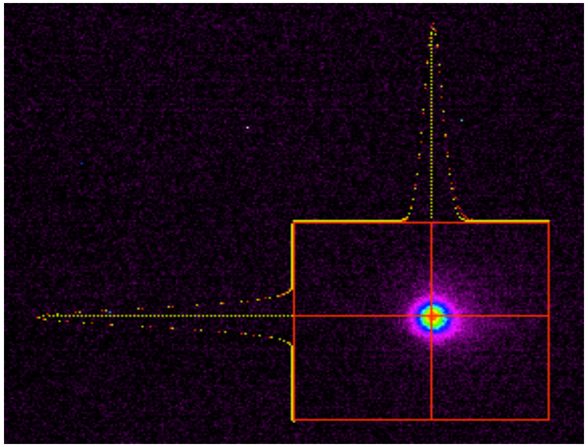


Focal spot of the **ellipsoidal mirror** (10x10μm^2 FWHM) with FEL-1

Best focus routinely achieved with the ellipsoidal mirror on FEL-1 (even though the mirror is optimized for FEL-2 (shorter entrance arm wrt FEL-1)

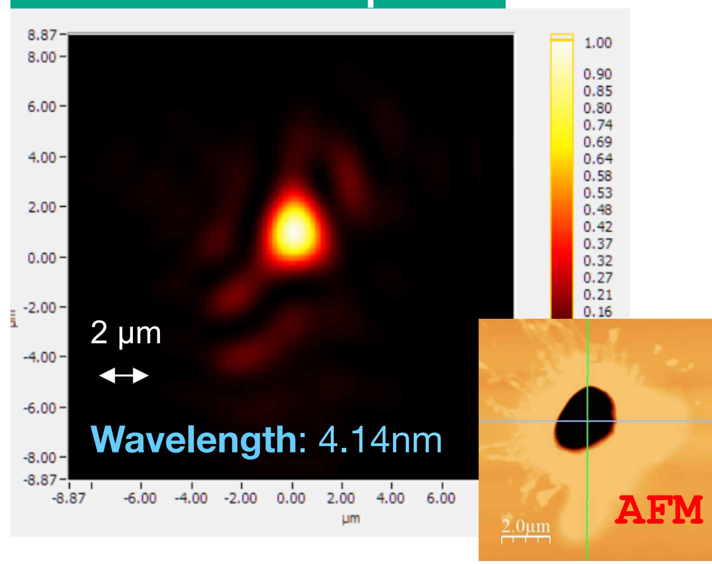
FOCUSING

Further/Latest results



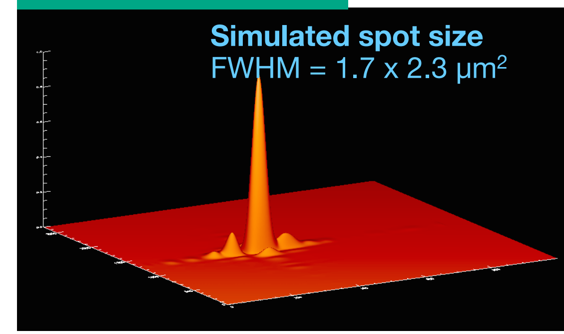
Focal spot of the **ellipsoidal mirror** (10x10μm^2 FWHM) with FEL-1

WFS best-spot

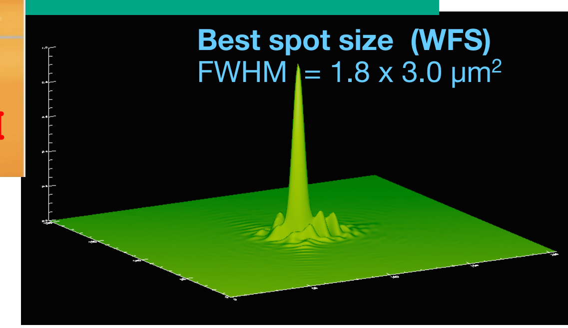


Focal spot sizes as low as **1.8µm** (FWHM) with FEL-2 (~4 nm)

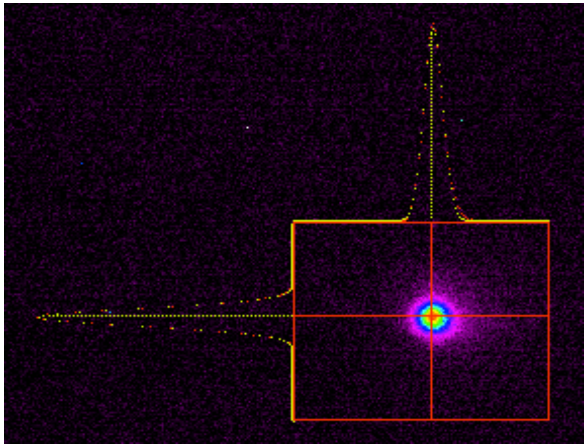
Simulated spot



Measured spot (best)

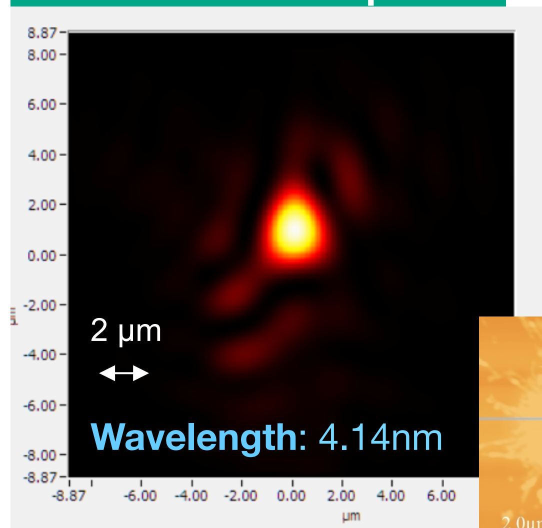


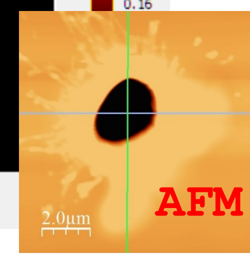
FOCUSING
Further/Latest results



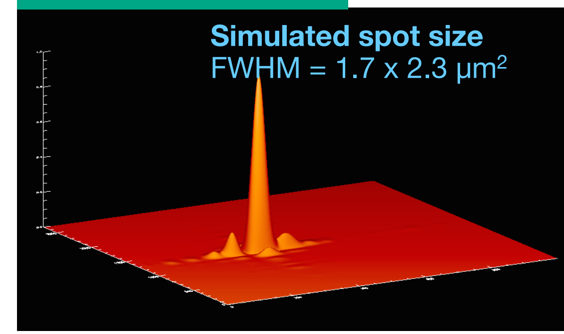
Focal spot of the **ellipsoidal mirror** (10x10μm² FWHM)

WFS best-spot

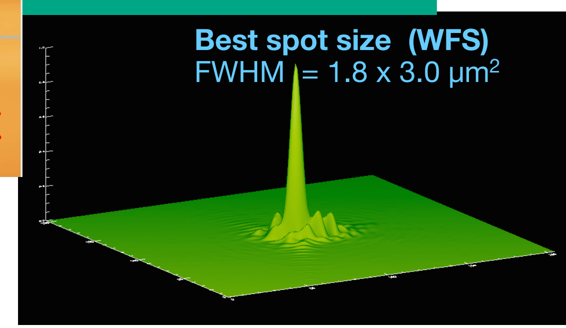




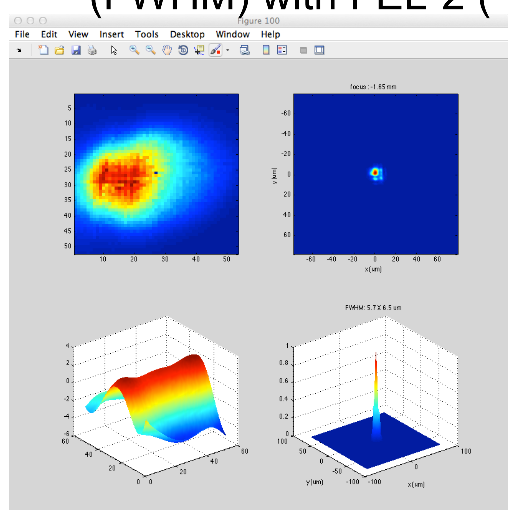
Simulated spot



Measured spot (best)



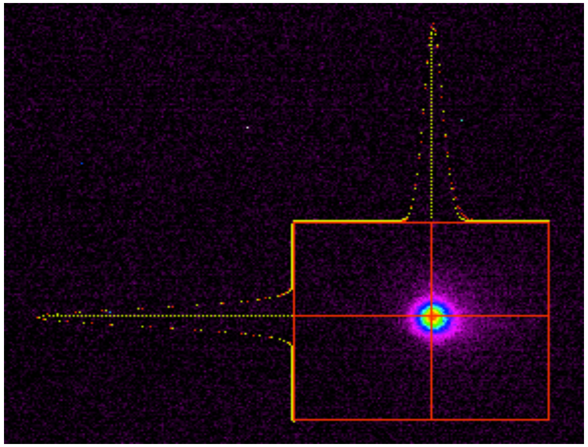
Focal spot sizes as low as **1.8μm** (FWHM) with FEL-2 (~4 nm)



Installation of a KAOS at FLASH2 (March 2017)
After very little time → 5.7x6.5μm²
(close to target value and obtained with not optimized FEL)

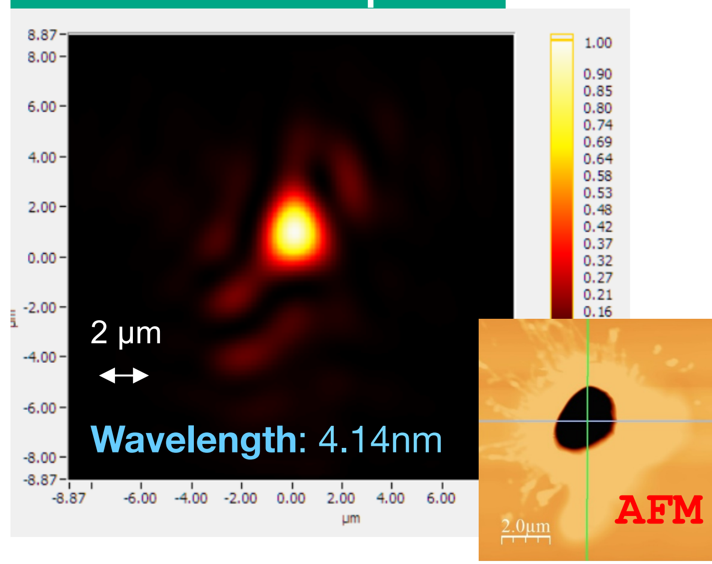
FOCUSING

Further/Latest results



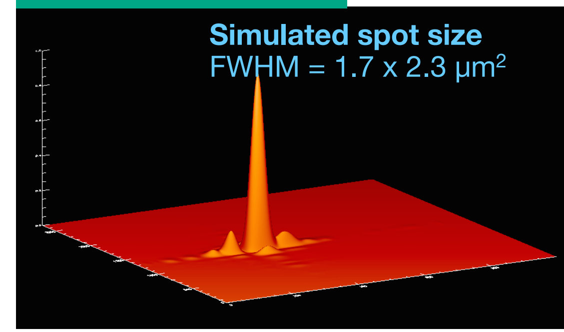
Focal spot of the **ellipsoidal mirror** (10x10μm² FWHM)

WFS best-spot

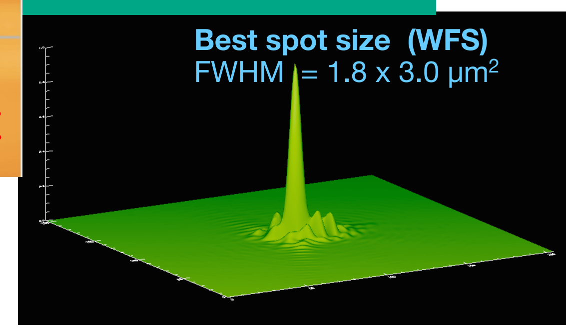


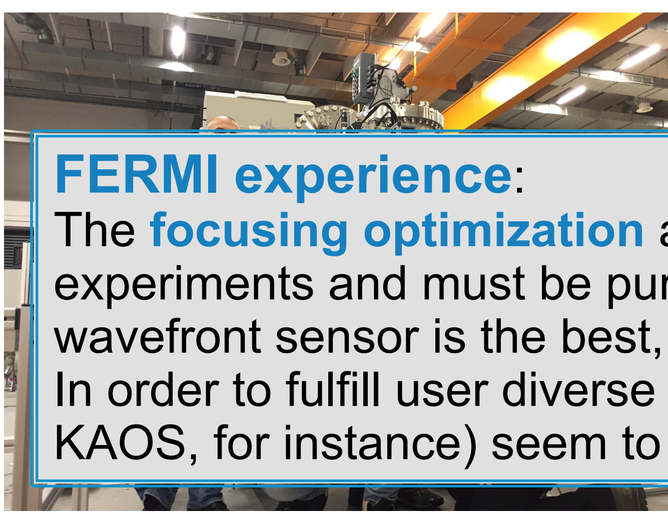
Focal spot sizes as low as **1.8μm** (FWHM) with FEL-2 (~4 nm)

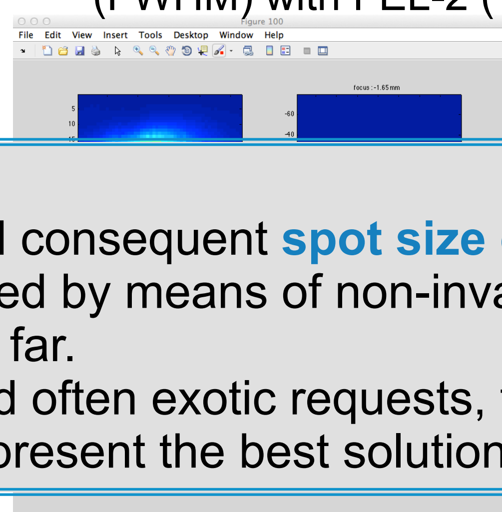
Simulated spot



Measured spot (best)





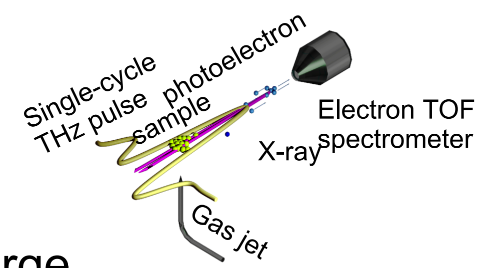


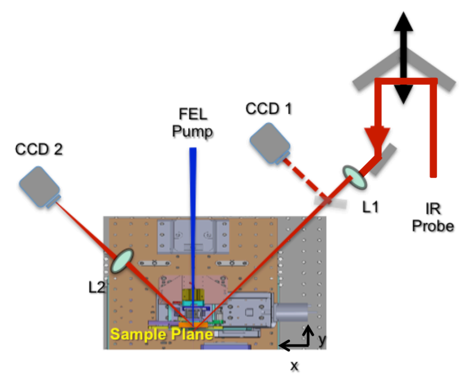
FERMI experience:
The **focusing optimization** and consequent **spot size characterization** is fundamental for experiments and must be pursued by means of non-invasive and online diagnostics → the wavefront sensor is the best, so far.
In order to fulfill user diverse and often exotic requests, the **active optics systems** (like KAOS, for instance) seem to represent the best solution.

PULSE LENGTH / ARRIVAL TIME

Different techniques

In experiments where dynamic processes are expected to occur during FEL exposure the **FEL pulse profile** must be measured with femtosecond accuracy on a single-shot basis. Moreover, determination of **time-arrival** is mandatory for proper synchronization in pump-probe experiments.



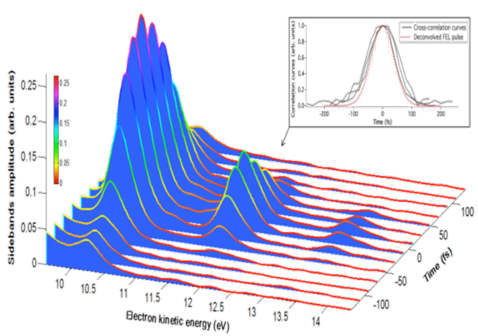


- THz streaking

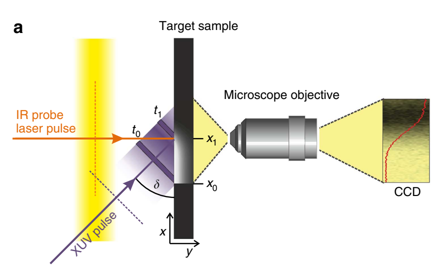
  Good if jitter is not too large

- Transmission/reflectivity spatial and spectral encoding

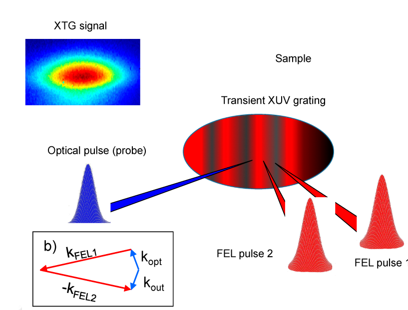
  Information only about arrival time



- Sidebands in electronic spectra



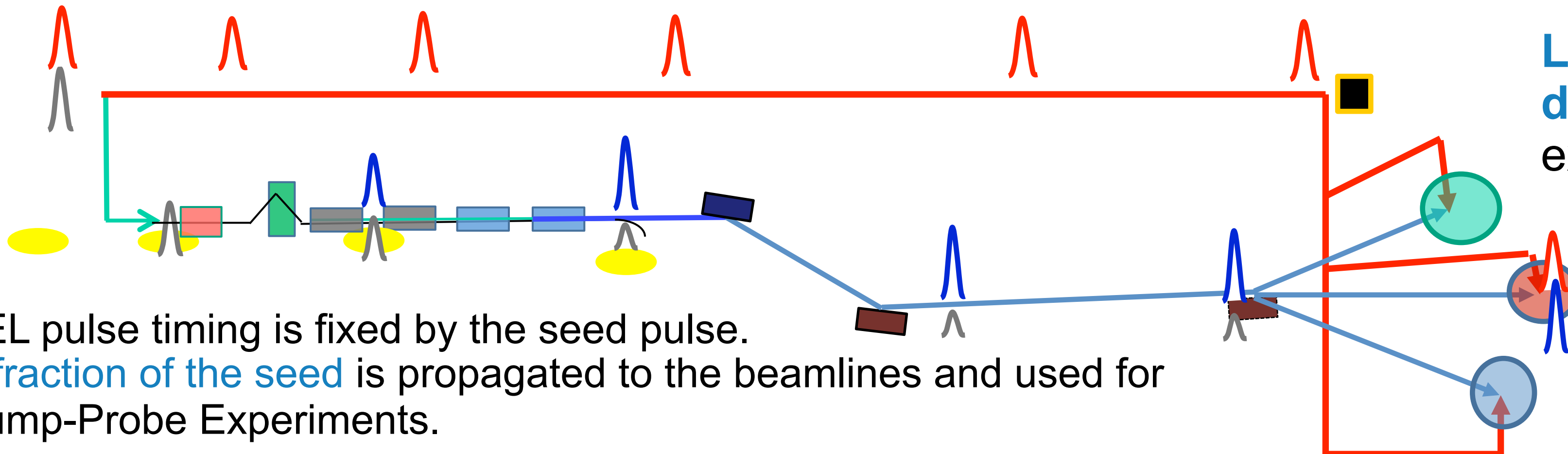
- Plasma gating



- Transient Grating-based measurements (see F. Bencivenga tomorrow)

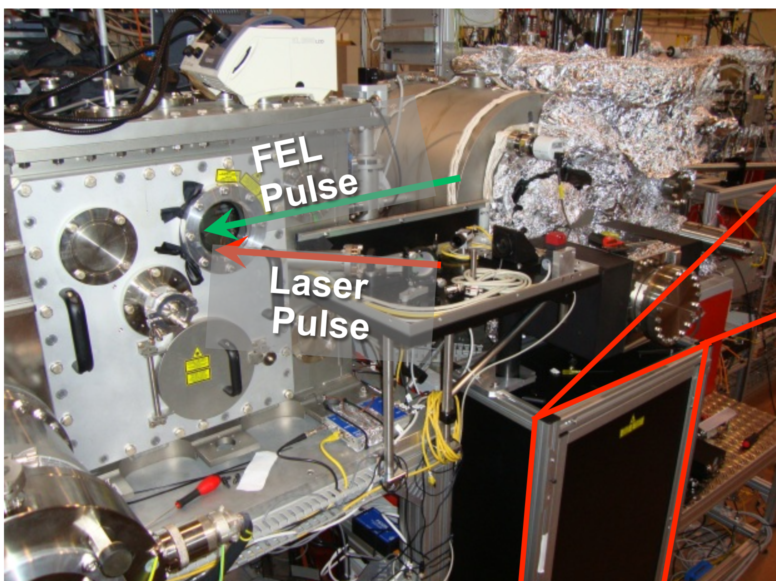
ARRIVAL TIME / SYNCHRONIZATION

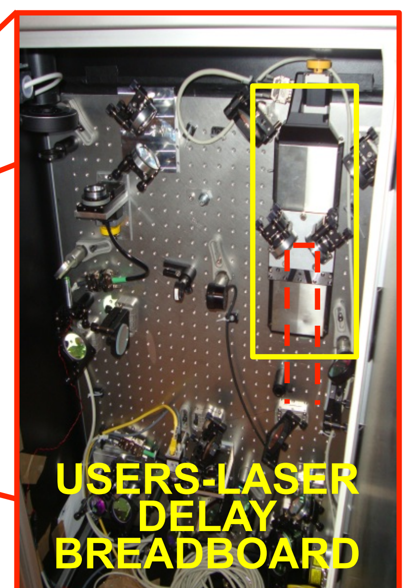
TR Si_3N_4 reflectivity



Large timing jitter/ drift reduction expected.

FEL pulse timing is fixed by the seed pulse.
A fraction of the seed is propagated to the beamlines and used for Pump-Probe Experiments.





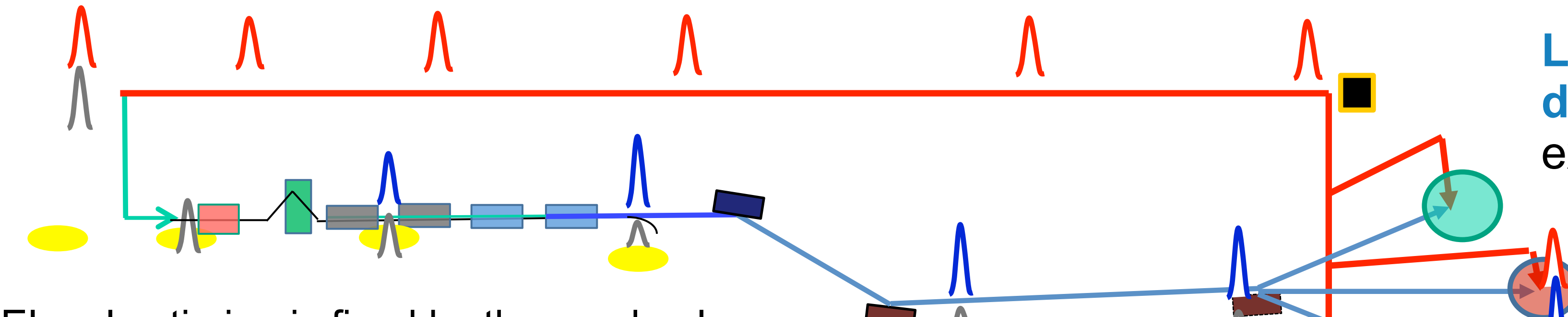
- Two pass optical delay line ±600ps
- Automatic attenuator plate and vertical horizontal polarizer
- Laser shot-by-shot Intensity monitor
- Pulse selector shutter

Since Feb-2013 DiProI end station equipped with external user laser

DiProI Team, PADReS team, Lasers team

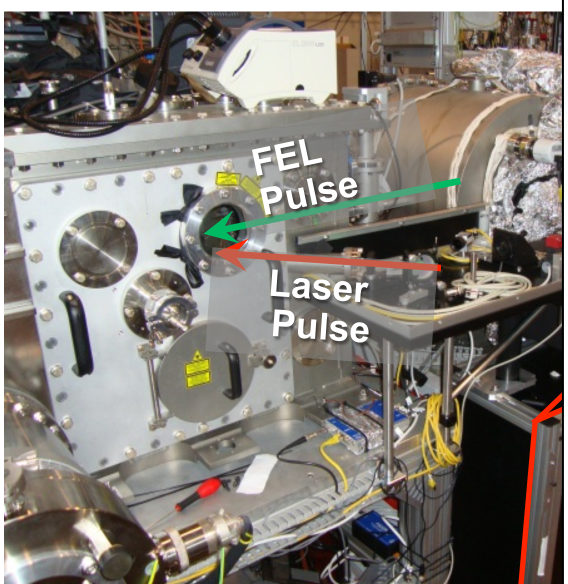
ARRIVAL TIME / SYNCHRONIZATION

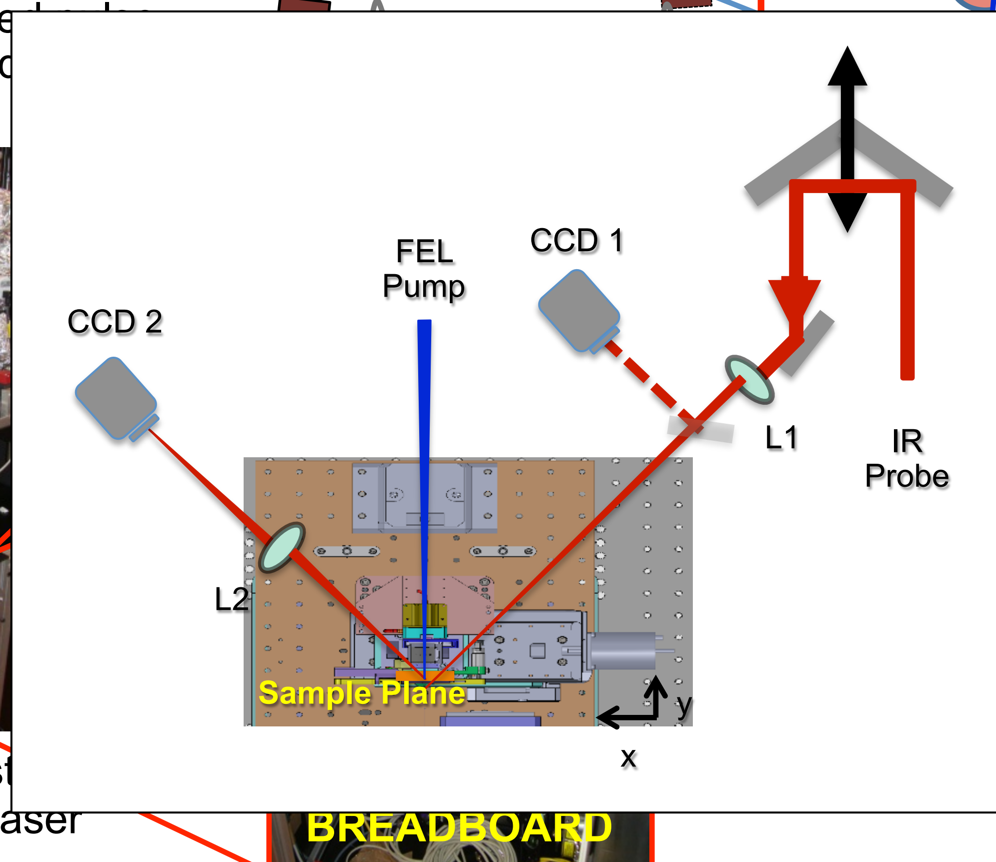
TR Si_3N_4 reflectivity



Large timing jitter/ drift reduction expected.

FEL pulse timing is fixed by the see
A fraction of the seed is propagatec
Pump-Probe Experiments.





cal delay line ±600ps

nuator plate and
ntal polarizer

shot Intensity

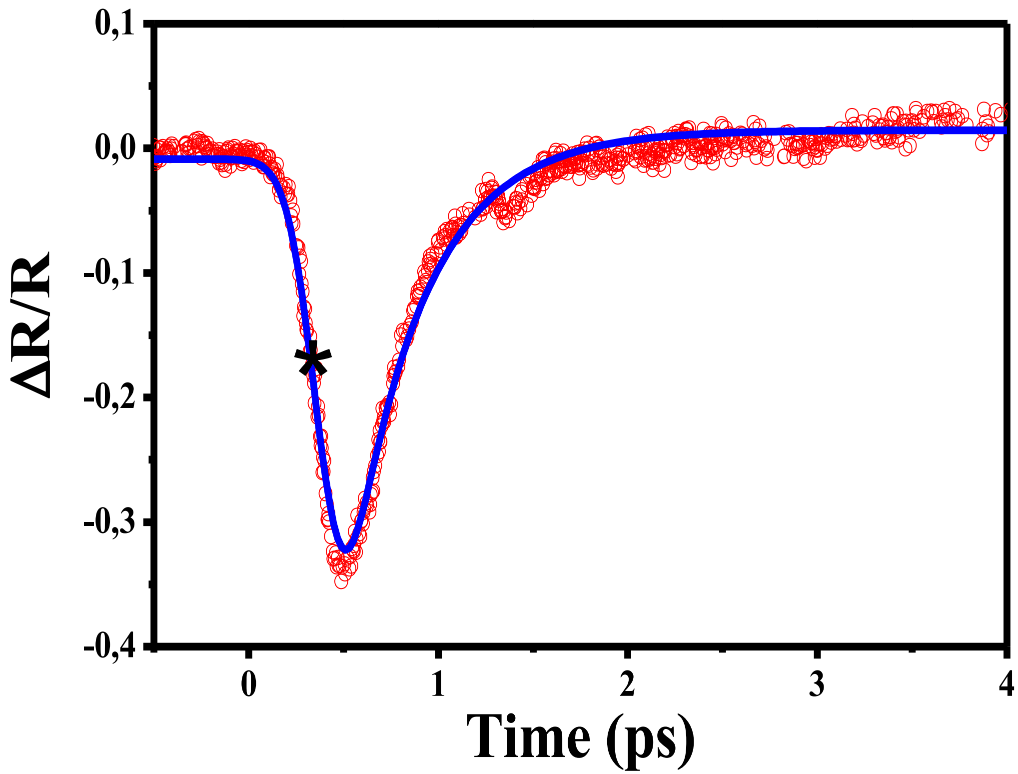
shutter

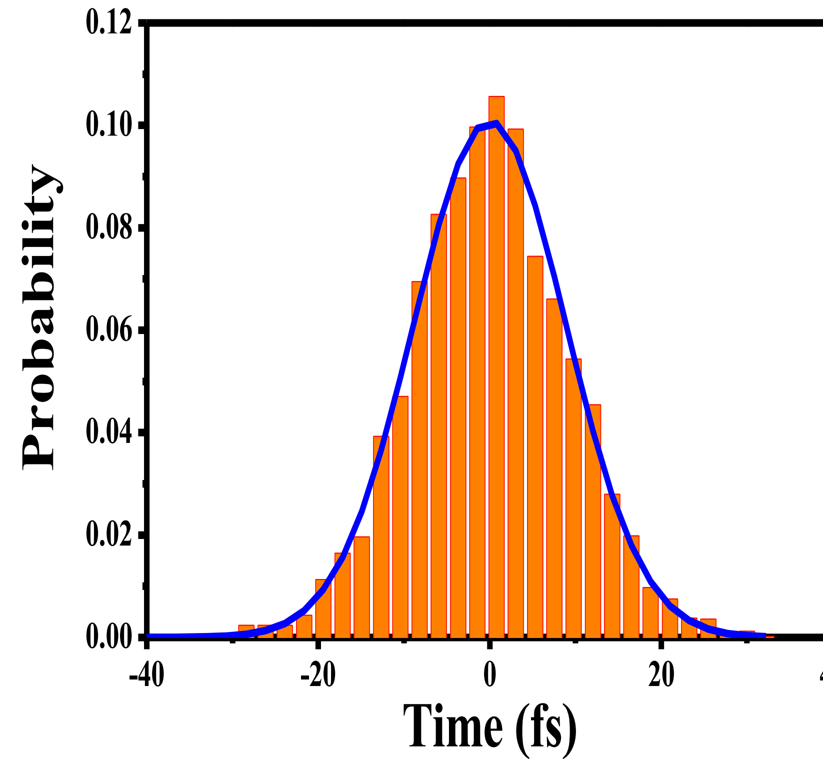
Since Feb-2013 DiProI end st
equipped with external user laser

DiProI Team, PADReS team, Lasers team

ARRIVAL TIME / SYNCHRONIZATION

TR Si_3N_4 reflectivity





M.Danailov, et al., Optics Express 22, 12869 (2014)

Arrival time jitter FEL-IR laser **< 6±2 fs (RMS)**→ 2μm over 100m-path length !!!
(Measured at the ½ drop point of the reflectivity curve)

Long term (~1 day) stability time zero between FEL and IR laser ~70 – 60 fs.

Recent result @DiProi: 2.2fs RMS jitter between a NOPA Pumped by the IR seed and FEL

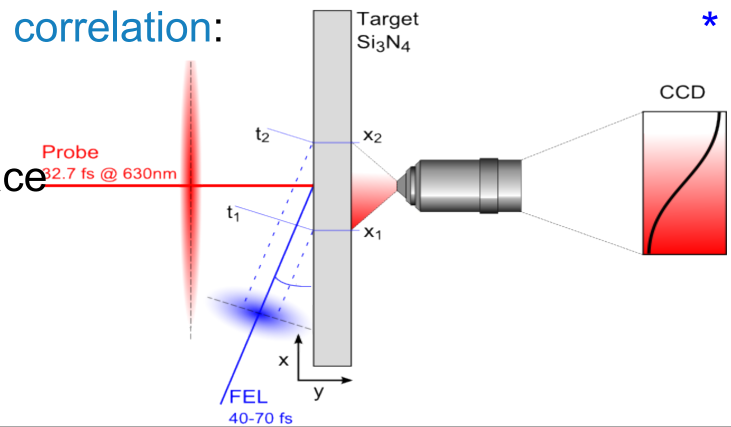
Marco Zangrando – marco.zangrando@elettra.eu

PULSE LENGTH
Cross-correlation measurements

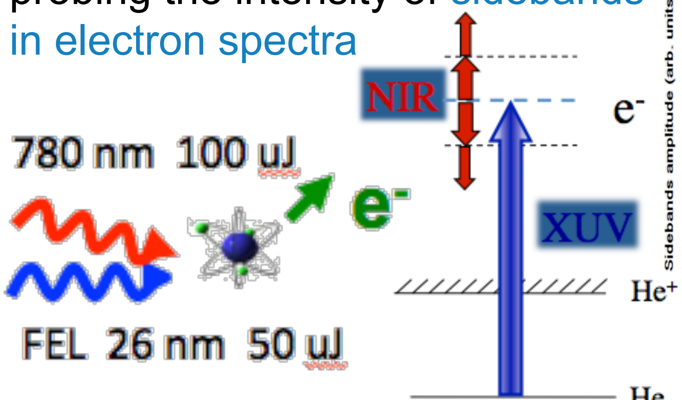
Two cross-correlation methods have been implemented and used for **measuring the FEL pulse length**.

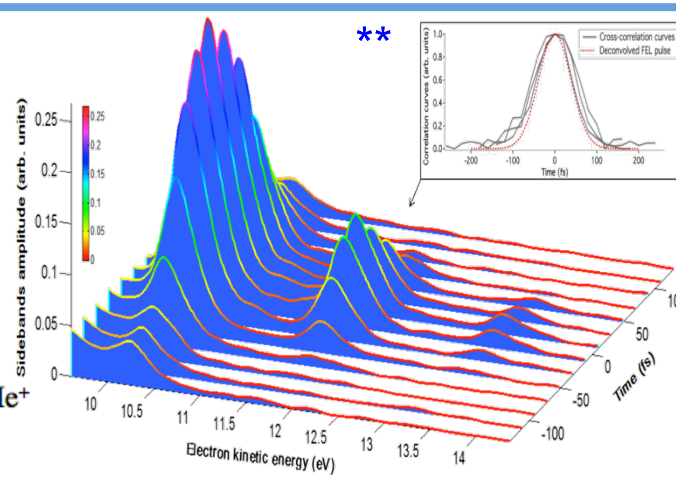
In both cases FEL pulse length has been studied as a function of seed laser parameters and FEL wavelength.

Solid state cross correlation: temporally & spatially encode FEL on the surface of a Si_3N_4 target probed with an ultrashort laser pulse



Cross correlation measurement probing the intensity of sidebands in electron spectra





λ_{seed} (nm)	λ_{FEL} (nm)	τ_{seed} (fs)	τ_{FEL} (fs)
257.8	25.78	140	61.5 ± 3
261.1	23.74	140	63 ± 4
261.1	20.08	140	74 ± 3
261.7	37.38	112.5	52 ± 8
261.7	26.17	112.5	53 ± 3
261.7	26.17	157.5	72 ± 6
261.7	18.69	112.5	42 ± 6

Expected FEL pulse shortening at higher harmonics (shorter wavelength) has been confirmed by measurements.

P. Finetti et al. Phys. Rev. X **7**, 021043 (2017)

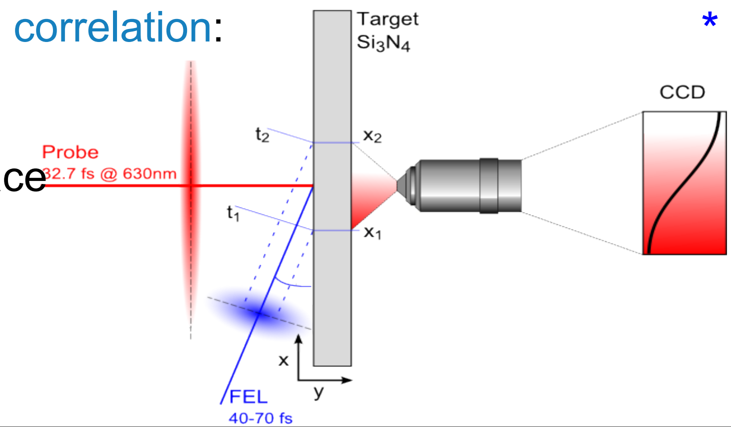
* In collaboration with F. Tavella team
** In collaboration with C. Callegari and LDM team

PULSE LENGTH
Cross-correlation measurements

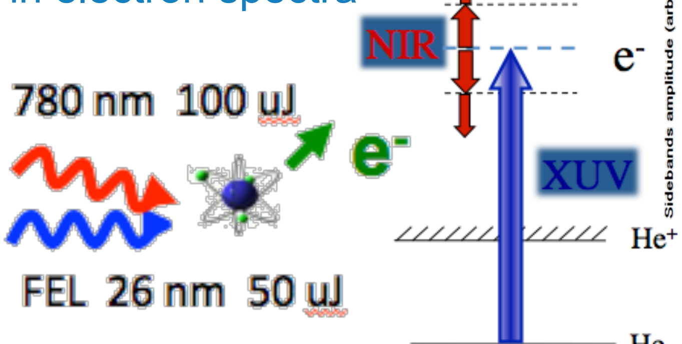
Two cross-correlation methods have been implemented and used for **measuring the FEL pulse length**.

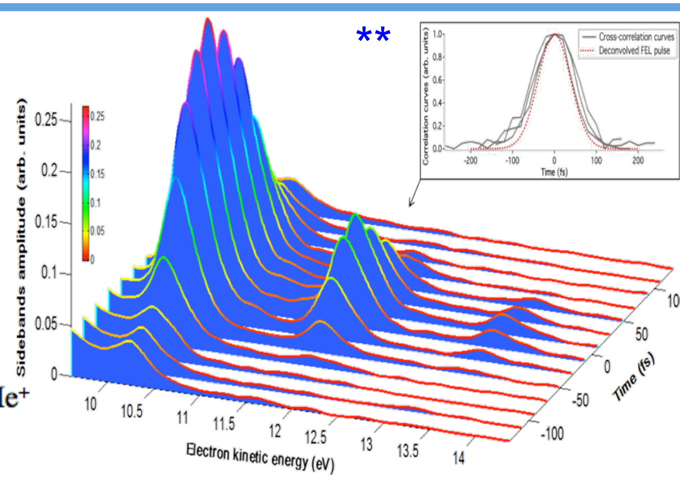
In both cases FEL pulse length has been studied as a function of seed laser parameters and FEL wavelength.

Solid state cross correlation: temporally & spatially encode FEL on the surface of a Si_3N_4 target probed with an ultrashort laser pulse



Cross correlation measurement probing the intensity of sidebands in electron spectra



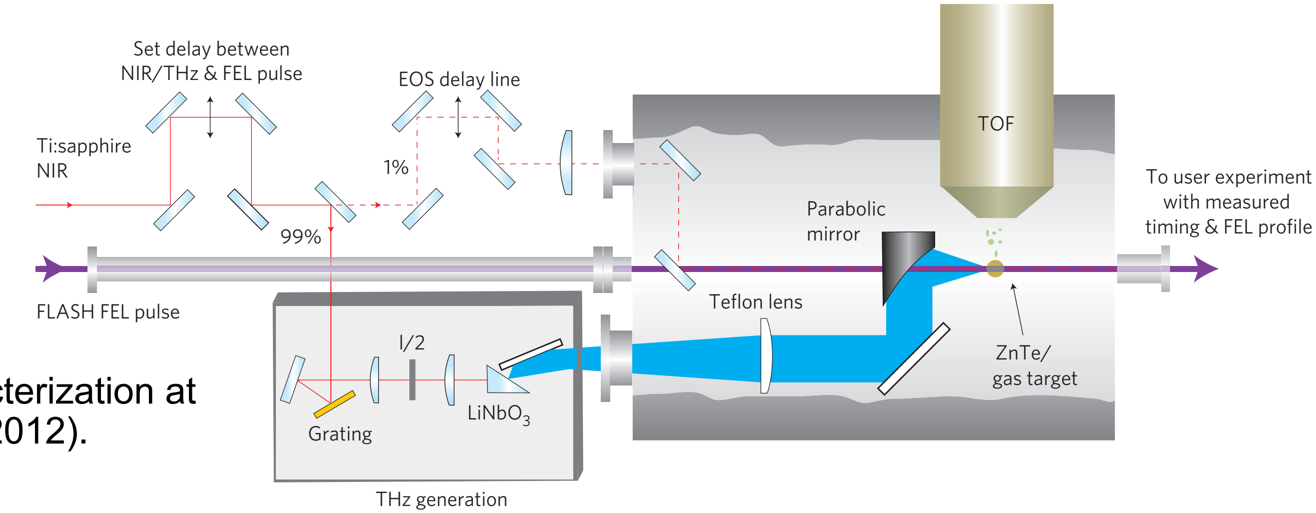


λ_{seed} (nm)	λ_{FEL} (nm)	τ_{seed} (fs)	τ_{FEL} (fs)
257.8	25.78	140	61.5 ± 3
261.1	23.74	140	63 ± 4
261.1	20.08	140	74 ± 3
261.7	37.38	112.5	52 ± 8
261.7	26.17	112.5	53 ± 3
261.7	26.17	157.5	72 ± 6
261.7	18.69	112.5	42 ± 6

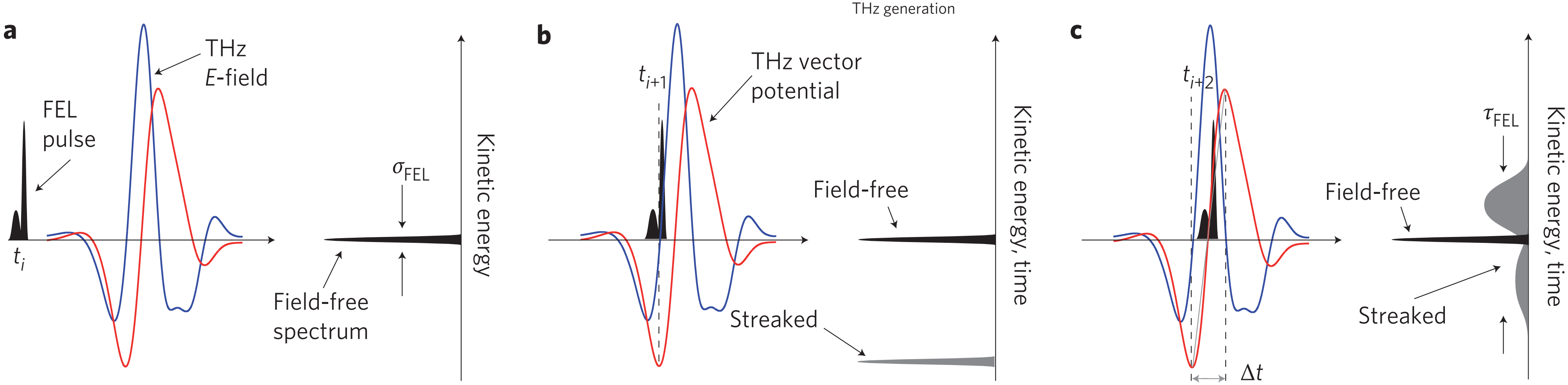
FERMI experience:
The pulse length/time profile/arrival time determination can still be seen as an **experiment on its own**. The cross correlation-based techniques cannot serve as online, non invasive diagnostics. A different scheme should be employed.

PULSE LENGTH / ARRIVAL TIME
Optical laser-driven THz streaking

Full temporal characterization using independent optical laser-driven single-cycle THz pulses for fs time-resolved photoelectron spectroscopy



Grguraš, I. *et al*. Ultrafast X-ray pulse characterization at free-electron lasers. *Nat. Phot.* 6, 852-857 (2012).



Transparent inline geometry

XUV – HXR

10 – 100 fs pulses

Using standard laser technology

Not requiring dedicated accelerator infrastructure

PULSE LENGTH / ARRIVAL TIME

Optical laser-driven THz streaking

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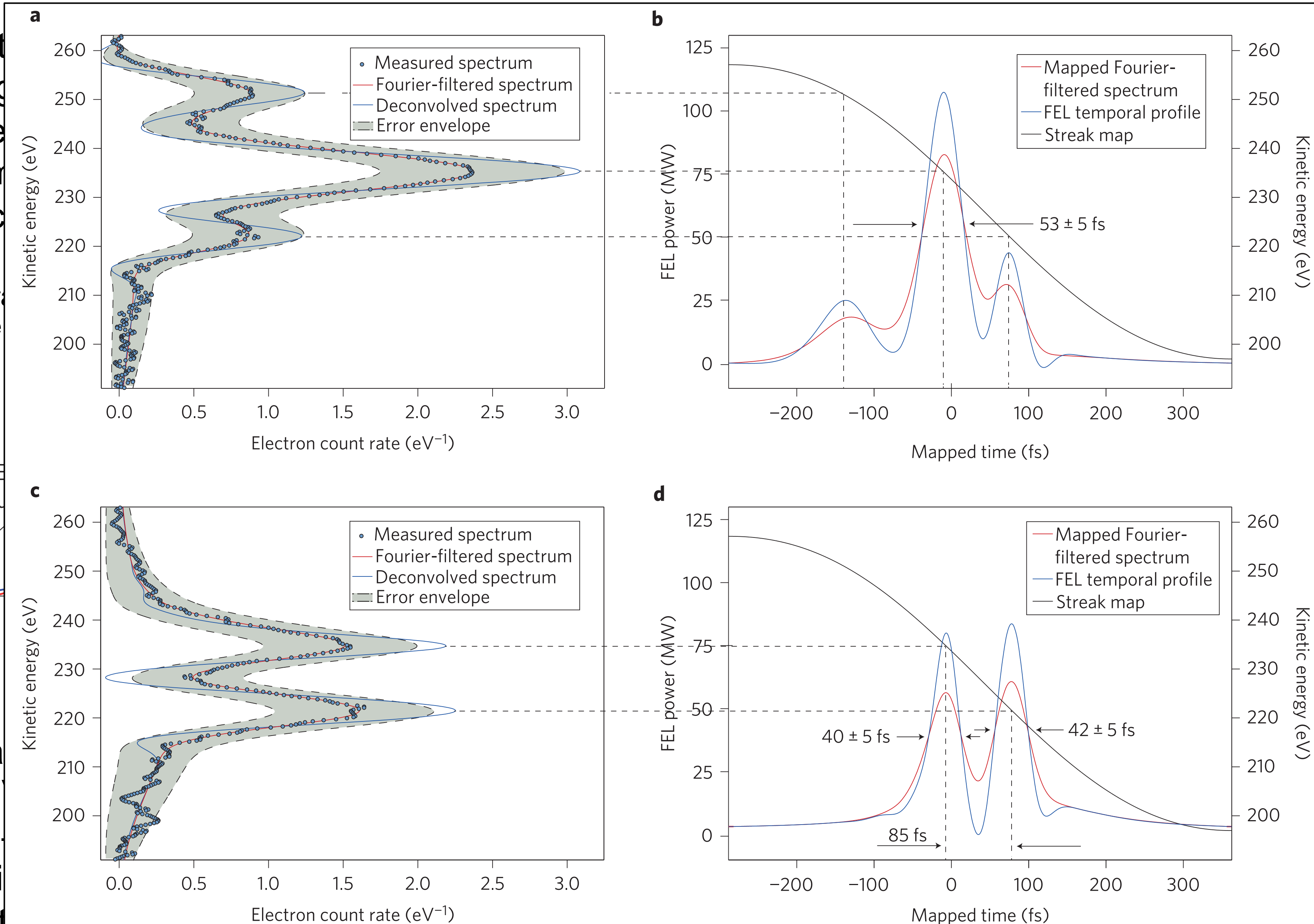

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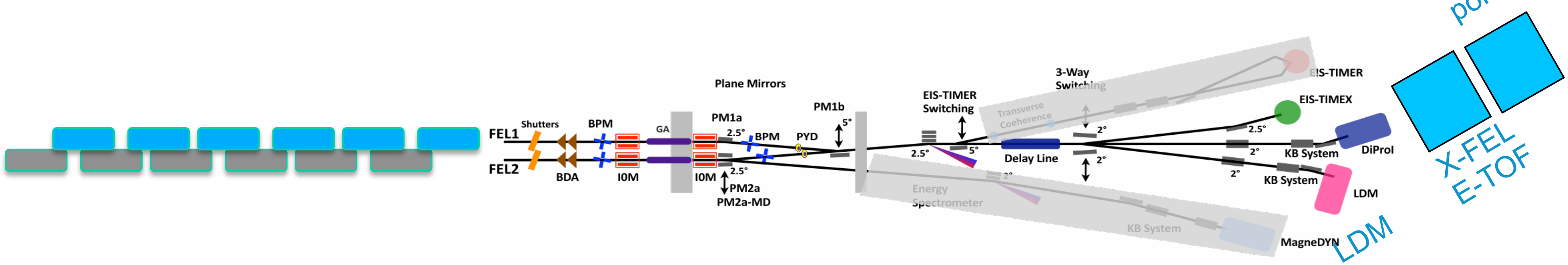
POLARIZATION MEASUREMENT
Motivation and setups

APPLE-II undulators in the final radiator ensure **polarization control**

Three different setups for characterization of the FERMI FEL polarization (coord. E.Allaria):
- LOA optical UV polarimeter.
- DESY electron spectrometer polarimeter.
- LDM X-UV He fluorescence polarimeter.



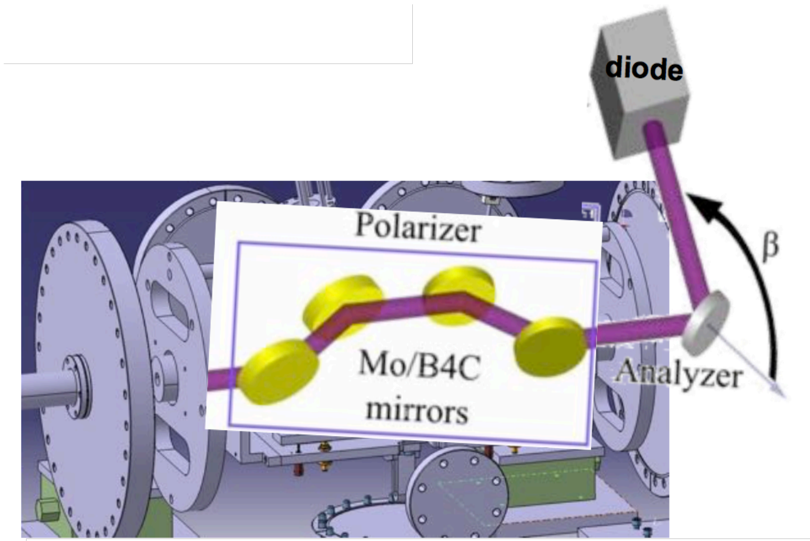
Characterization of the FEL polarization produced by APPLE-2 undulators at 32nm, 26nm, 43nm, 53nm
- Horizontal/Vertical polarization.
- Circular polarization.

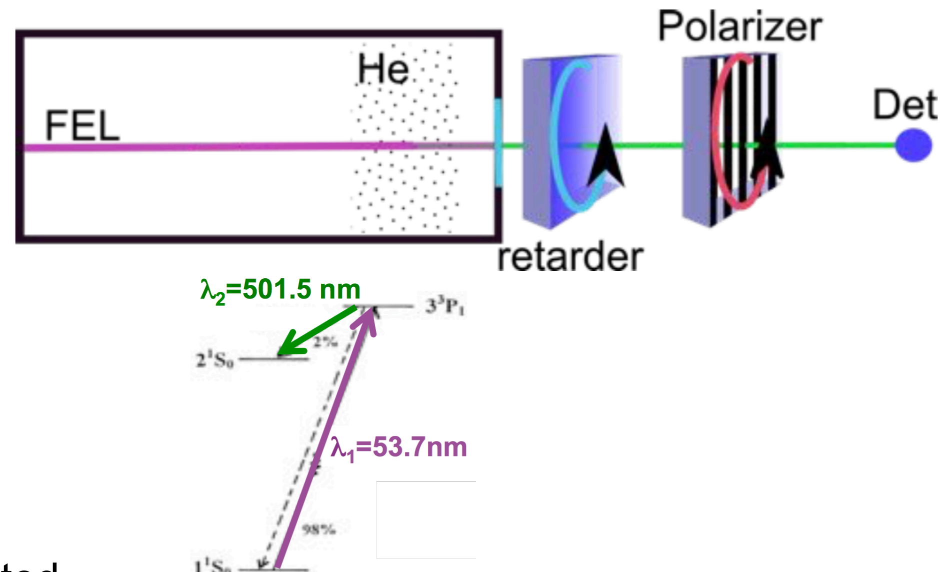
Studies of cross-polarized schemes to control the polarization
- Circular right and left for generating linear polarization.
- Linear vertical and horizontal for generating circular polarization.

DESY · European XFEL · Laboratoire d'optique appliquée UMR 7639 - Palaiseau - France · SLAC National Accelerator Laboratory

POLARIZATION MEASUREMENT

EUV and Visible light polarimeters





Optical polarimeter for EUV sources (LOA): 4 coated grazing incidence mirrors used as phase retarder for *s* and *p* field components and a 45° mirror used as a polarized.

Setup installed at FERMI: suitable for characterizing 26nm and 32nm with circular and vertical polarizations.

Proper fit of the measured detector signal as a function of the detector angle β → FEL polarization state

Measuring the polarization of **fluorescence light emitted in the visible range** following suitable X-UV excitations → FEL polarization state

Optical transitions selected:
He + λ_1→He1s(1)3p(1)→He1s(1)2s(1)+λ_2

Polarization measured in the visible with standard optical methods using a retarder (λ/4) and a polarizer. Acquisition are done by scanning the polarizer angle for various values of the retarder angle.

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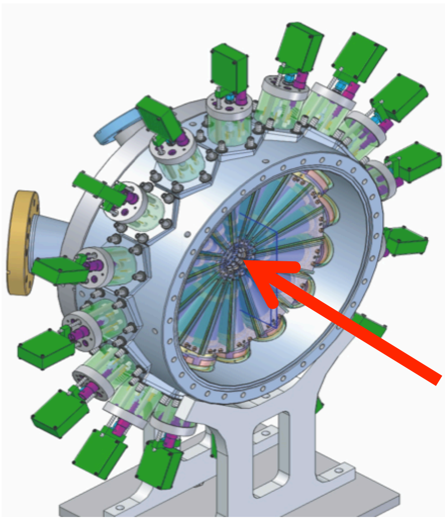
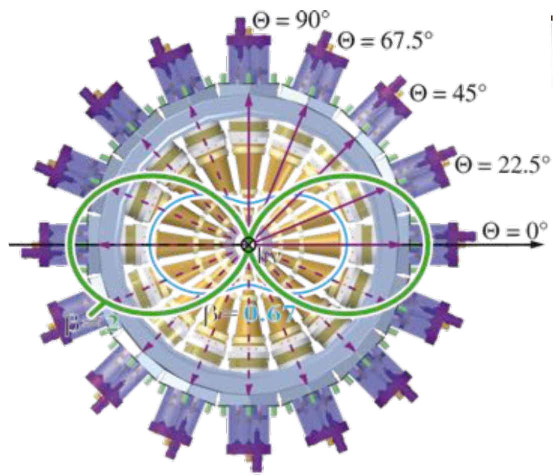
POLARIZATION MEASUREMENT

e-TOF polarimeter





A **single shot polarimeter** based on angle resolving electron spectrometer (J.Viefhaus' group at DESY)

Theory predicts specific electron distributions over the 16 detectors depending on the used gas and FEL polarization.

Diagnostics

- Versatile online beam diagnostics unit
- Used at PETRA III, FERMI, LCLS, …
- Feasible as a (X)FEL diagnostic
- Polarization characterization on a shot-to-shot

Detection scheme

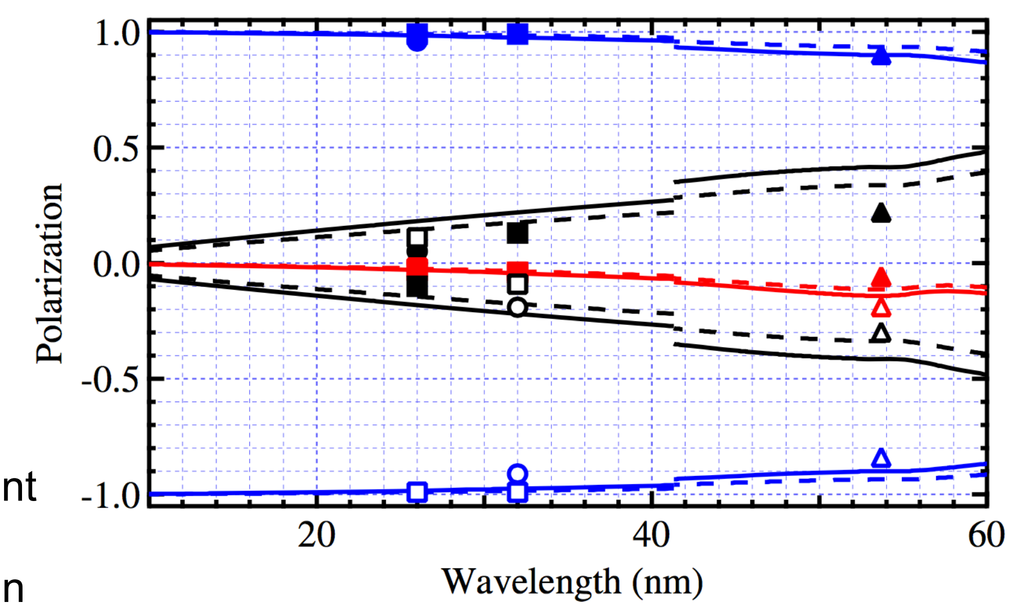
- Single-shot spectra → High detection efficiency ~4% of 4π
- Energy resolution → Resolution up to 10^{-3}
- Angular resolution → 16 spectrometers 22.5°
- Energy range → 0.02-25 keV (for European XFEL)

POLARIZATION MEASUREMENT
Results

DESY					
λ	**Polarization**	**S1**	**S2**	**S3**	**Pol**
26 nm	Vertical	-0.97	0.01	0.2	**0.97**
26 nm	Circ Right	-0.02	0.10	0.99	**0.99**
32 nm	Vertical	-0.91	-0.04	0.40	**0.97**
32 nm	Circ Right	-0.04	-0.13	0.99	**0.99**

LOA					
λ	**Polarization**	**S1**	**S2**	**S3**	**Pol**
26 nm	Vertical	-0.95	0	0.07	**0.95**
26 nm	Circular R	0	0.05	0.96	**0.96**
32 nm	Vertical	-0.96	0	0.06	**0.96**
32 nm	Circ Right	-0.05	-0.19	0.90	**0.92**

LDM					
λ	**Polarization**	**S1**	**S2**	**S3**	**Pol**
52 nm	Horizontal	0.92	0.11	0	**0.92**
52 nm	Circ Right	-0.07	0.21	0.89	**0.91**
52 nm	Circ Left	-0.20	-0.31	-0.85	**0.93**



Measurements of the degree of polarization with different polarimeters has shown a **good control of the polarization*** allowing switching from linear to circular in the whole spectral range of operation.

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POLARIZATION MEASUREMENT
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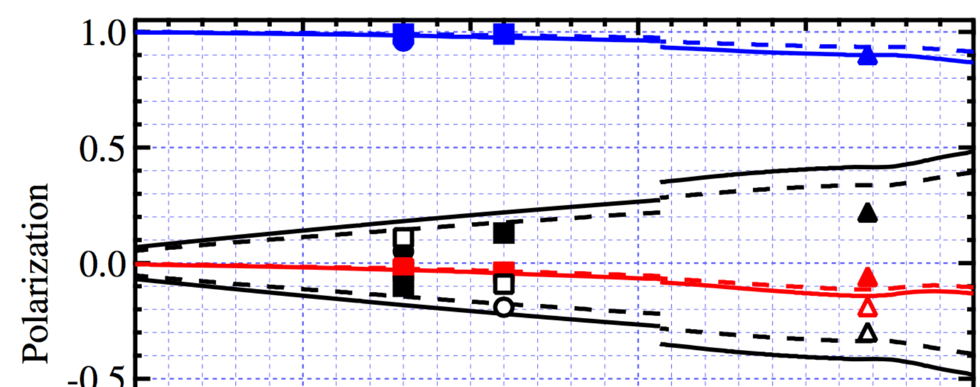

FERMI experience:
The polarization determination, similarly to the time-related quantities, requires a **dedicated experiment** or at least (as in the case of the cookie box) cannot always be compatible with normal user operation at a facility.

the whole spectral range of operation.

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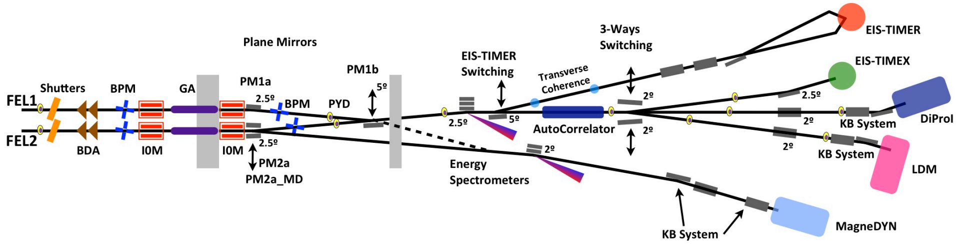
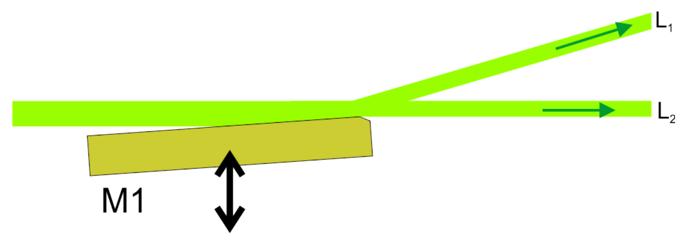
(MULTI) CONCLUSIONS
Possible future developments

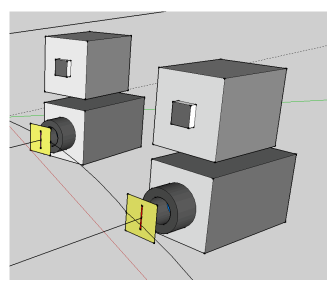
Photon diagnostics
multi-diagnostics along the transport:
intensity (different types), spectrum,
pulse length, time arrival, spot size, …

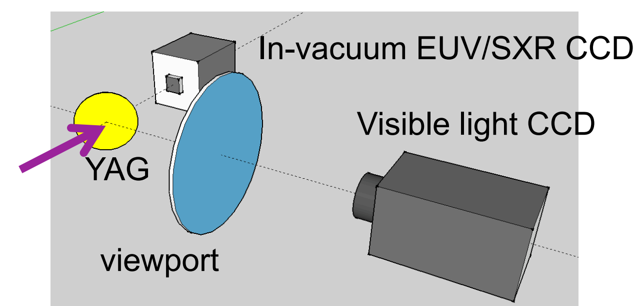


Endstations operation
multi-endstation
(WF splitting) → soon at FERMI

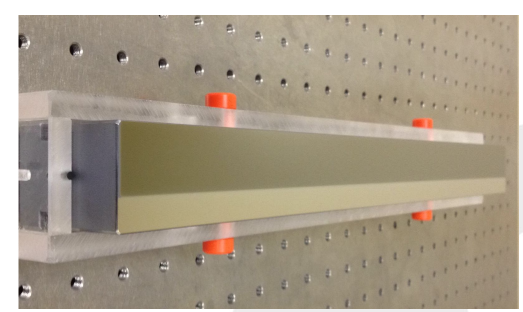


Energy spectrometer
- **multi-color** mode
(2 independent detection units)
- **multi-detectors**
(optimizing efficiency to λ) → soon at FERMI





Optics
multi-coatings/stripes (to optimize the reflectivity)
→ soon/already at FERMI
[particularly challenging for active optics systems]



THANK YOU

Allaria E., Bencivenga F., Callegari C., Capotondi F., Castronovo D., Cinquegrana P., Craievich P., Cudin I., Danailov M.B., De Monte R., Demidovich A., D'Auria G., Dal Forno M., De Ninno G., Di Mitri S., Diviacco B., Fabris A., Fabris R., Fava C., Fawley W.M., Ferianis M., Ferrari E., Finetti P., Froehlich L., Furlan Radivo P., Gaio G., Gauthier D., Gerusina S., Giannessi L., Gobessi R., Ivanov R., Kiskinova M., Kurdi G., Loda G., Lonza M., Mahne N., Mahieu B., Manfredda M., Masciovecchio C., Mazzucco E., Predonzani M., Principi E., Nikolov I., Parmigiani F., Penco G., Plekan O., Prince K.C., Raimondi L., Rossi F., Roussel E., Rumiz L., Serpico C., Sigalotti P., Scafuri C., Spampinati S., Spezzani C., Sturari L., Svandrlik M., Svetina C., Trovò M., Vascotto A., Veronese M., Visintini R., Zangrando D., and MANY MORE including users, collaborators, visitors, administrative people…