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SwissFEL Instrument ESB – Femtosecond Pump-Probe Diffraction and Scattering

8th Hard X-ray FEL Collaboration Meeting

Oct 24-26 2016, Pohang

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Laser timing and jitter diagnostics tools for SwissFEL experimental stations

8th Hard X-ray FEL Collaboration Meeting

Oct 24-26 2016, Pohang

ESB Instrument: Team

Team (ESB Endstation)

G. Ingold: BL Scientist / FEMTO group leader
P. Beaud: Senior Scientist
H. Lemke: BL Scientist
A. Oggenfuss: Technician
J. Rittmann: Postdoctoral Researcher

P. Böhler: Mech. Design/Engineering (PSI AMI)
A. Keller: Mech. Design/Engineering (PSI AMI)
Y. Deng: Laser Scientist (SwissFEL Laser Group)
T. Zamofing: Software (PSI Controls Group)

In collaboration (ESB Instrument):

SwissFEL Management
R. Abela
B. Patterson
L. Patthey

Laser Group
Ch. Erny
Ch. Hauri
M. Divall

X-ray Diagnostics
P. Juranic
J. Rehanek

Detectors
A. Mozzanica
B. Schmidt

DAQ
L. Sala

Mech. Engineering
P. Wiegand

X-ray Optics Group
U. Flechsig
R. Follath

Synchronization
S. Hunziker

Instrument Development: Motivation

Femtosecond pump-probe diffraction and scattering in condensed matter

Special topic:

Time resolved dynamics in complex materials with (strongly) correlated electrons

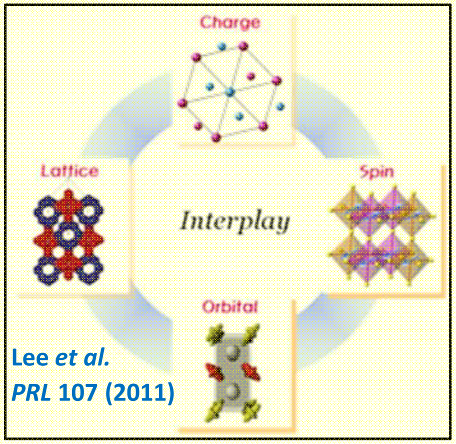
- Selective excitation and probing of low energy electronic, magnetic and structural dynamics

- Photo-induced (non-thermal) phase transitions away from equilibrium:
  Coupling and ordering dynamics, light induced symmetry breaking, photo-induced metastable (hidden) states, …

- Correlations & fluctuations in non-equilibrium systems

- Coupling, control & switching in multiferroic systems

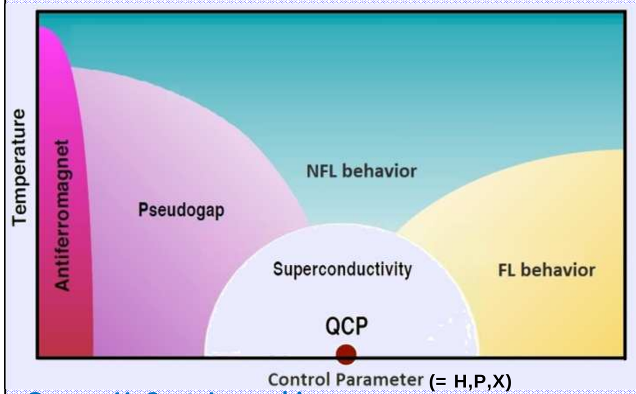
Motivation: Complex Solids with (strongly) correlated electrons



Lee *et al.*
PRL 107 (2011)

- **Coupling**: charge, orbital, spin & lattice

  Electronic and magnetic intreractions which are coupled to the atomic motions through electron-lattice interactions.
  → complex materials: CMR, MIT, High-Tc, CDW, Mott systems, …
  → functional materials: multiferroic, magnetis,, MSMA, …
  →**Flexible pump & probe beams (energy, polariz., time)**

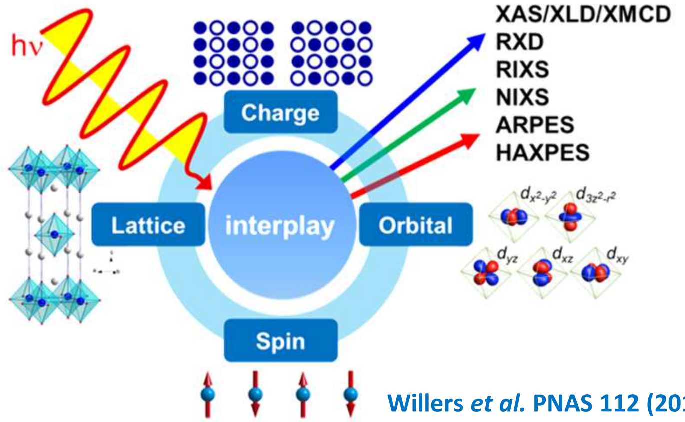


Gamza, U. Cent. Lancashire

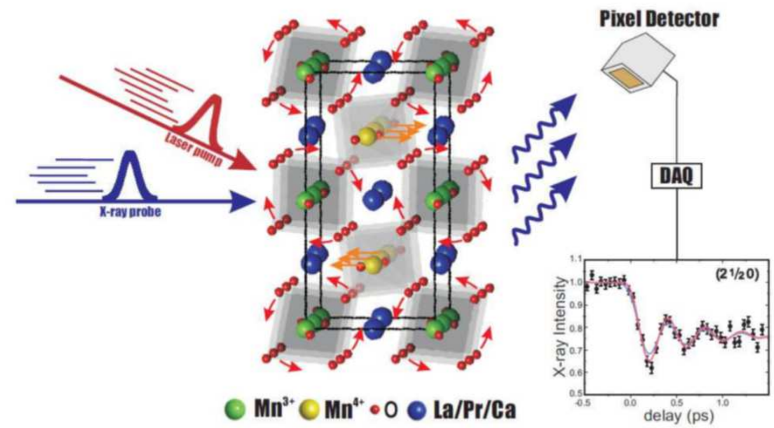
- **Phases:** complex phase diagram due to coupling

  New electronic and magnetic phases emerge with competing ground states, which are sensitive to changes of external conditions (T, H, P, doping x)
  → ***sample environment***

Pump / Probe - Selective Excitation



Willers *et al.* PNAS 112 (2015)



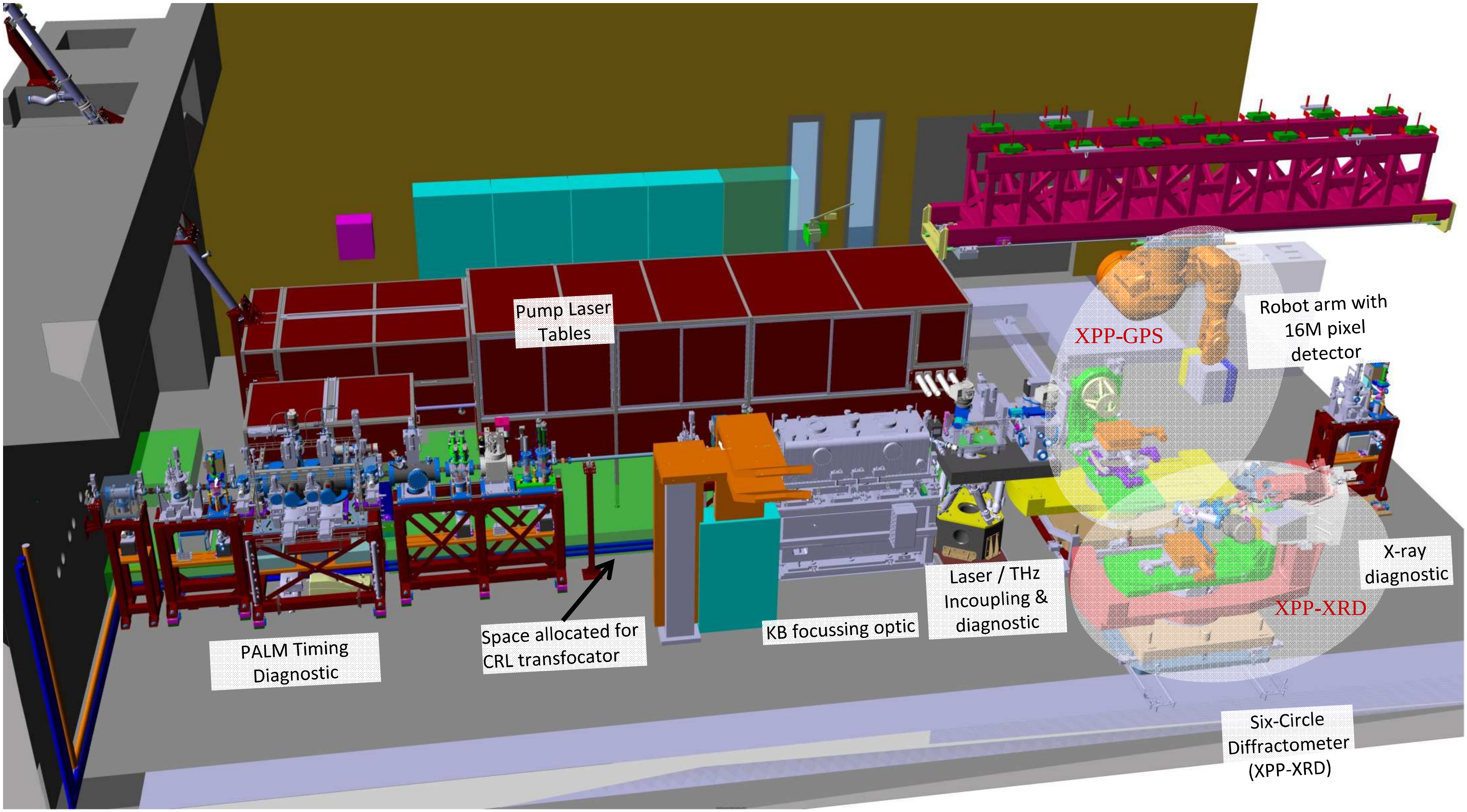
New: Excitation & probing of response with photons:

- real space & real time techniques (atomic & femtosecond resolution)
- Photon-in / photon-out pump-probe methods (stroboscopic)
- Selectivity: tunable wavelength / flexible polarization / fs pulses / E-, H-field

→ tr XRD: long range atomic order
→ tr RXRD: long range order, charge, orbital & spin
→ tr DS: elastic, short range correlations, reciprocal space
→ tr RIXS: inelastic, short range correlations, reciprocal space

ESB Overview & General Purpose Station

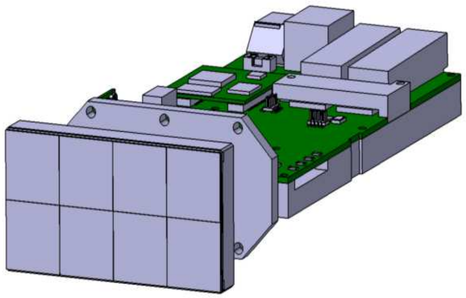
XPP-GPS: Heavy load goniometer & robot detector arm & 16M pixel detector

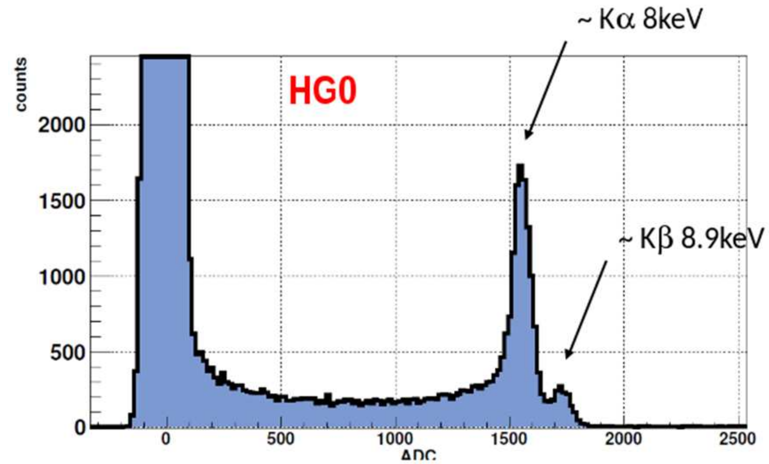


The JUNGFRAU pixel detector

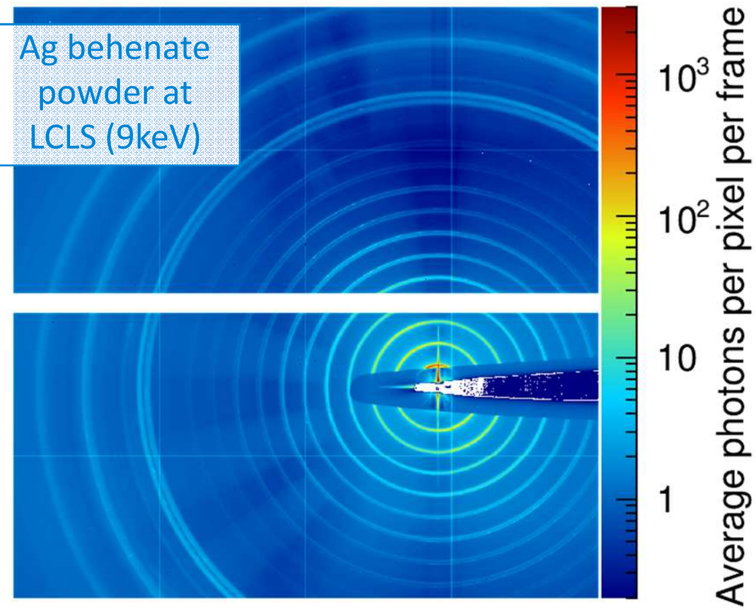
JUNGFRAU:

adJUstiNg Gain detector FoR the Aramis User s





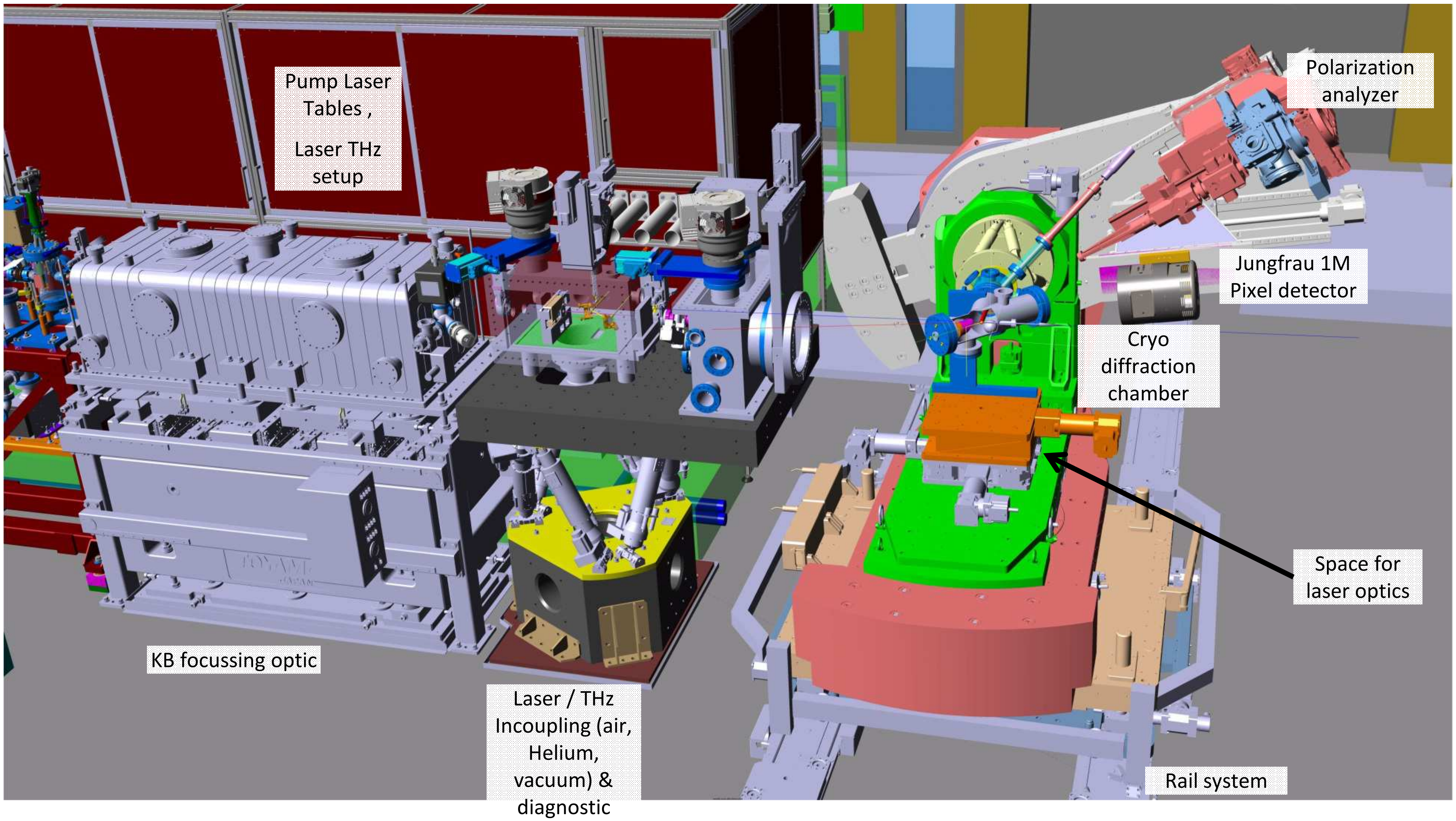
ASIC technology	UMC110nm
mudule pixel count	525k
mudule size	80x40 mm^2
sensor thickness	320-500 µm
pixel size	75x75 mm^2
dynamic range	up to 10^4 12keV photons
noise r.m.s.	50 e.n.c.
min Energy	1.5 keV
linearity	better than 1%
point spread function	1 pixel
dead time	<500ns
ext. power consumption	30 W /module
cooling	liquid @ e.g. 10^0C
readout time = 1 / frame rate	2.4kHz with 2x10GbE
rate capability @ syncrotron (with 10GbE)	10^4 x 2.4 10^3 = 2.4x10^7 photons per ch. per s



A. Mozzanica, SLS Detectors Group, http://www.psi.ch/detectors

Diffraction Station

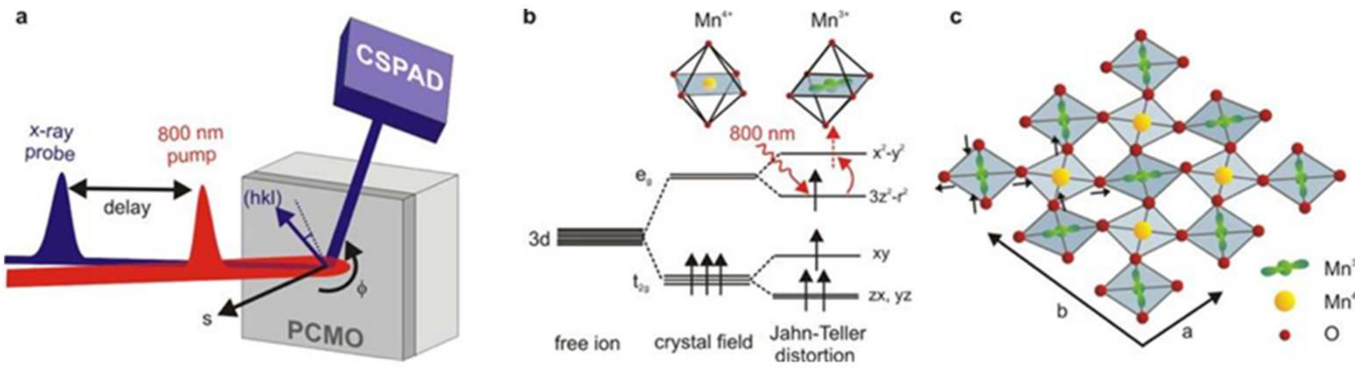
XPP-XRD: 6-circle (reconfigurable) diffractometer with dual detector arm

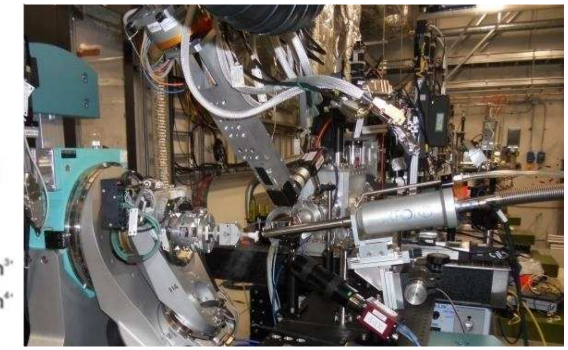


Science Case – Resonant Diffraction tr-(R)XRD

Hard X-ray Resonant tr-RXRD (XPP/LCLS)

XPP-instrument (5 x 12h, Feb 2013)

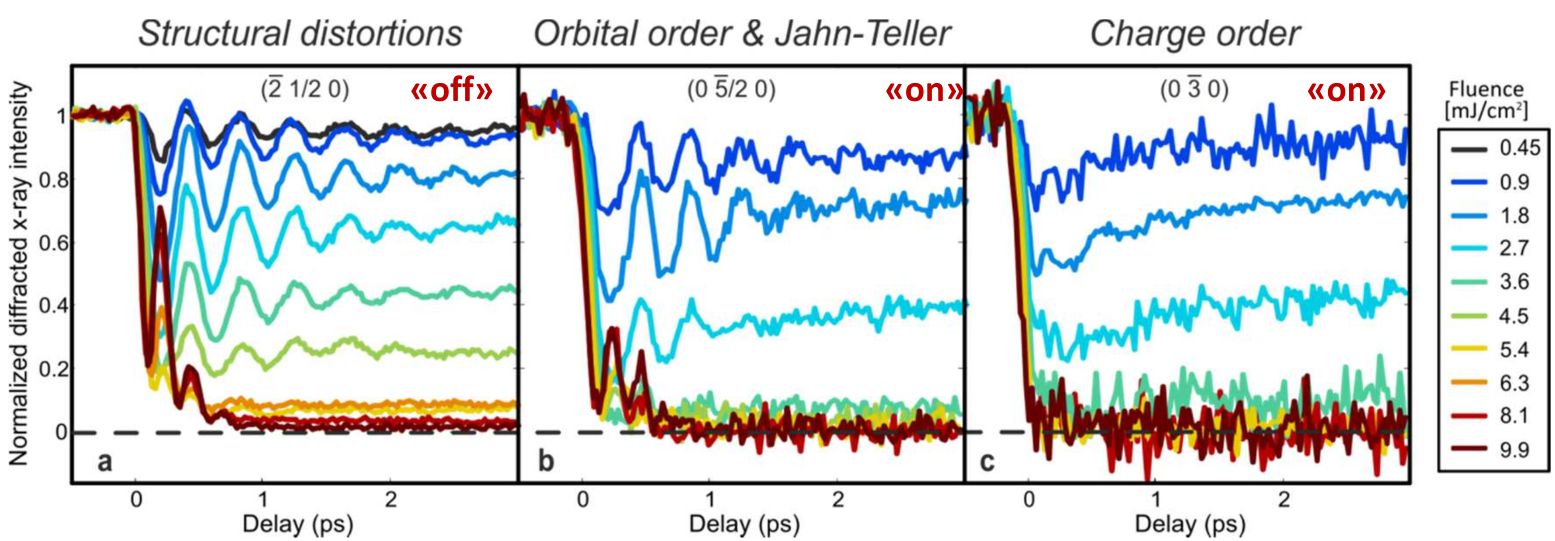




X-ray arrival time: Spectral encoding

Beaud et al., Nature Materials 13, 923–927 (2014)

tr-(R)XRD on Manganites PCMO (Close to Mn Absorption Edge 6.5 keV)

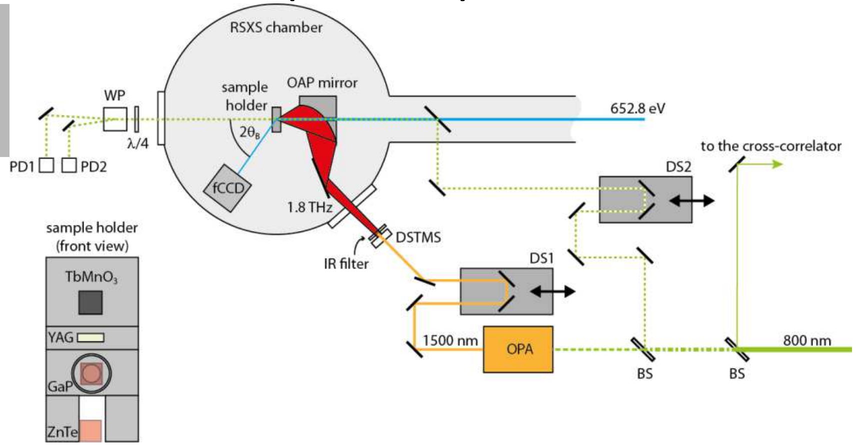


Future → SwissFEL ESB: Dedicated 6-Circle Diffractometer including Polarization Analyzer

Science Case: tr-(R)XRD & THz pumping

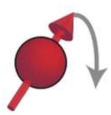
Resonant Diffraction & Collinear Pump-Probe

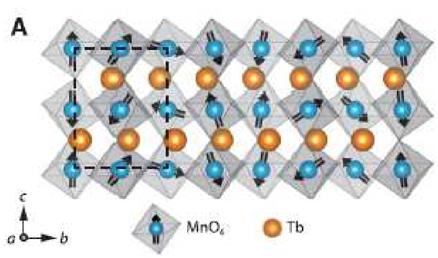
(LCLS – SXR)



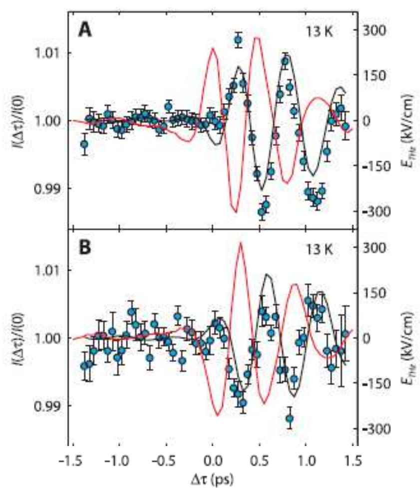
Magnetic Order:

Magnons





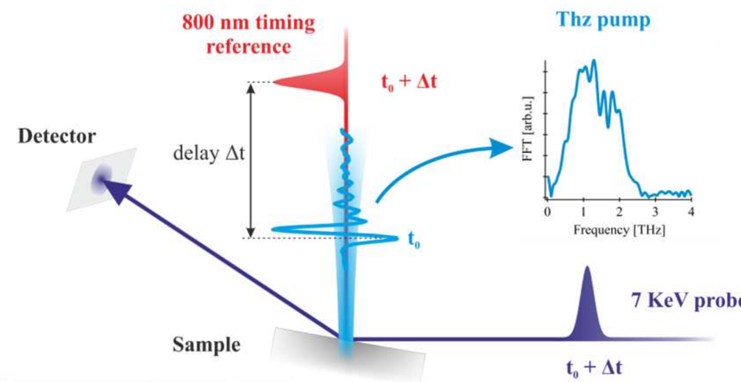
$TbMnO_3$

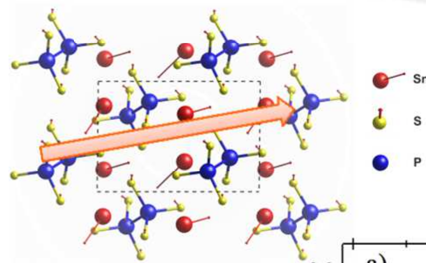


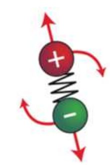
Kubacka et. al. Science 343, 1333 (2014)

Non-Resonant Diffraction & Non-Collinear Pump-Probe

(SLS – FEMTO)





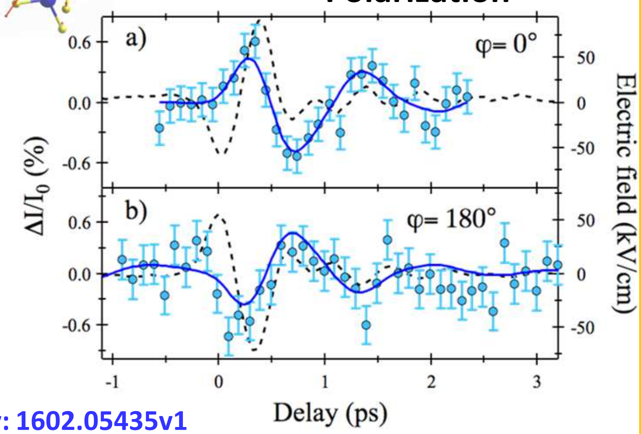


Structural Order:

Ferroelectric

Polarization

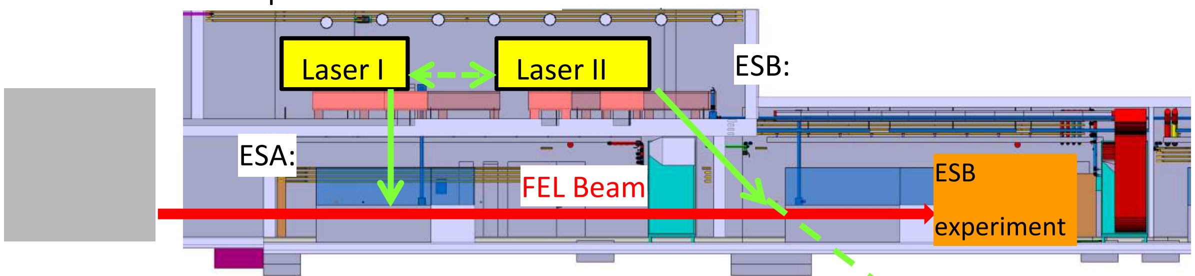
$Sn_2P_2S_6$



Grübel et. al. arXiv: 1602.05435v1

Femtosecond laser system - Pump beam

LHx Experimental laser room



Core laser system:

- Commercial Ti:Sa System
- > 20 mJ, < 30 fs @ 100 Hz
- **Laser 1, delivered**
- **Laser 2, ordered,** delivery **Q3 2016**

Laser installation in experimental station:

OPA (ordered, delivery Q1 2016):

- 1100 nm - < 15’000 nm
  ca. 1 mJ - ca. 10 µJ
  ca. 40 fs - < 100 fs

THz[3]:

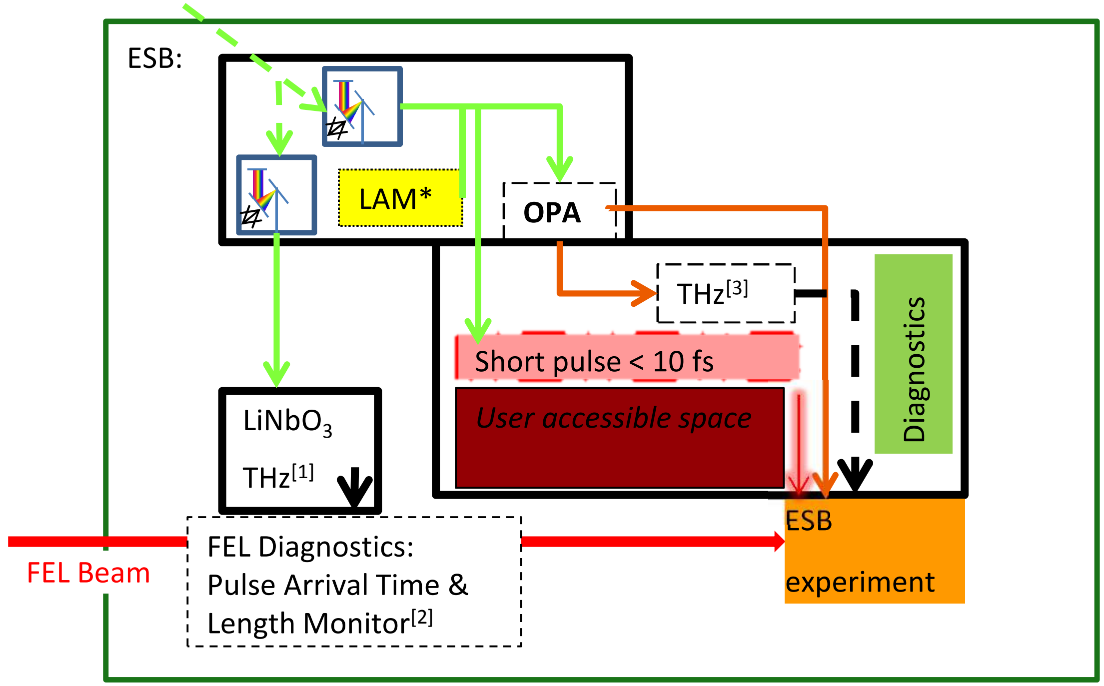
- 1 – 10 THz
  > 1 MV/cm, ca. 10 µJ
  single cycle

Short pulse[4]:

- < 10 fs @ 800 nm
  ca. 500 µJ

Pulse diagnostics

User accessible space ca. 1m^2



[1]: Hebling et al. Appl. Phys. B, 78, 593, 2004
[2]: Juranic et al. JINST 9, P03006, 2014
[3]: Ruchert et al. PRL 110, 123902, 2013
[4]: Nisoli et al. Appl. Phys. Lett. 68, 2763, 1996

*: Laser Arrival Time Monitor

(courtesy Ch. Erny, Laser Group)

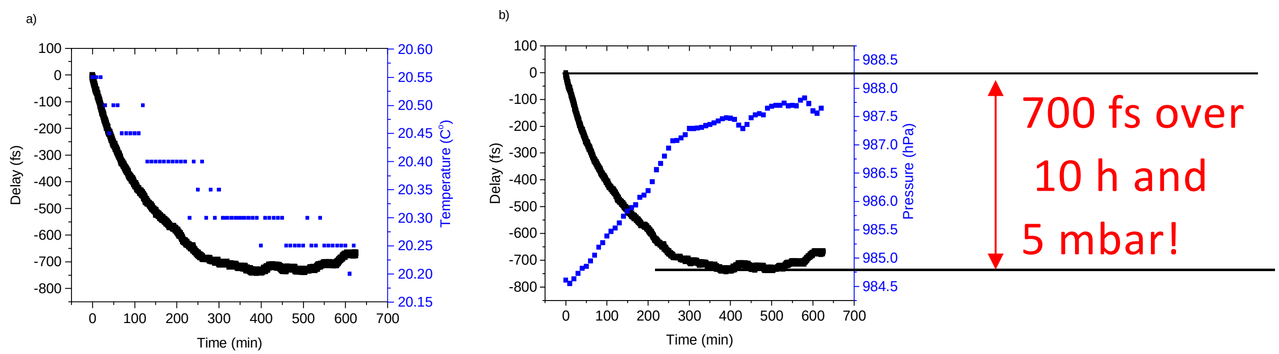
Why does SwissFEL need a LAM ?

Because we want excellent time resolution at SwissFEL!

- For pump probe Experiments: $\Delta t = \sqrt{\Delta t_{\text{laser}}^2 + \Delta t_{\text{XUV}}^2 + \Delta t_{\text{jitter}}^2}$.

Ultimate goal: Arrival-time stability between x-ray pulses and pump-probe laser pulses to be fraction of pulse duration

- Limitation: **Environmental changes** have **large impact** on the arrival time of the experimental laser in the Endstation:

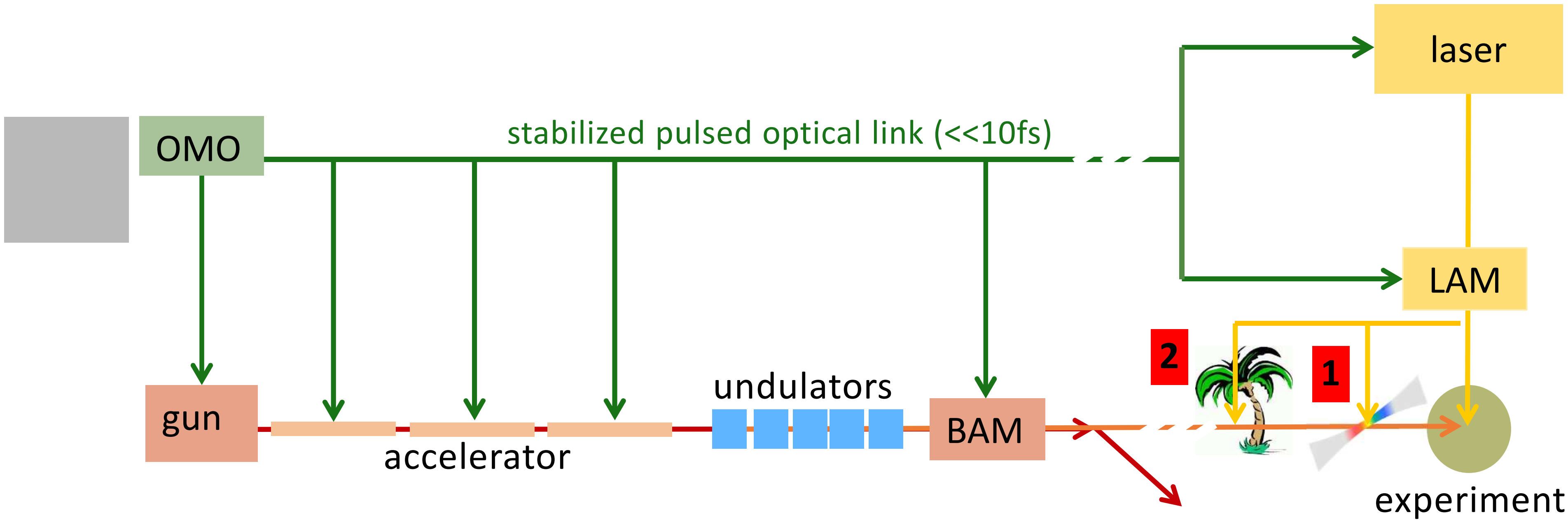


- With a LAM:
  - Drifts controlled within measurement window of PALM & PSEN -> can be optimized for highest time resolution
  - Increased long term stability of laser system -> consistent data taking over long FEL runs.
  - Excellent timing control of SwissFEL up to the last meters -> longterm goal of 20 fs r.m.s between laser and x-ray is possible.

***M. Csatari Divall**, et al. , Optics Express, vol. 23, num. 23, p. 29929, 2015.*

DOI: 10.1364/OE.23.029929

Synchronization and beam arrival measurements



BAM **B**unch **A**rrival-Time **M**onitor < 10 fs

V. Arsov Proc. FEL'14, Basel, Switzerland (2014), 933, THP085.

LAM **L**aser **A**rrival-Time **M**onitor < 3 fs (couple of hours)

M. Divall et al. Opt. Expr. 29930 (2015)

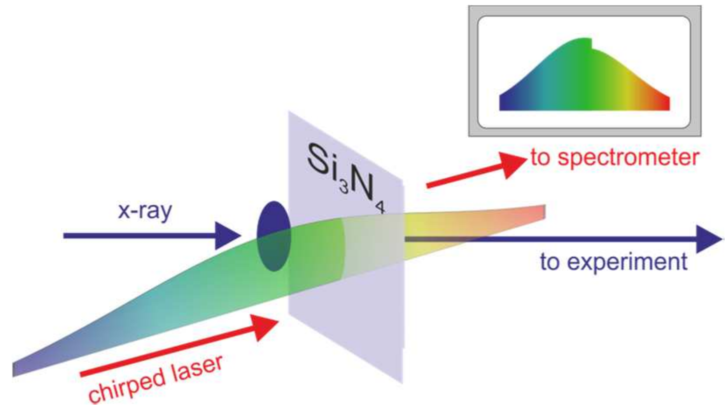
Combination BAM/LAM: < 50 FWHM (due to additional jitter in photon beam)

+ laser/x-ray arrival time jitter measurements at experimental station:

1 **Spectral encoding time tool**

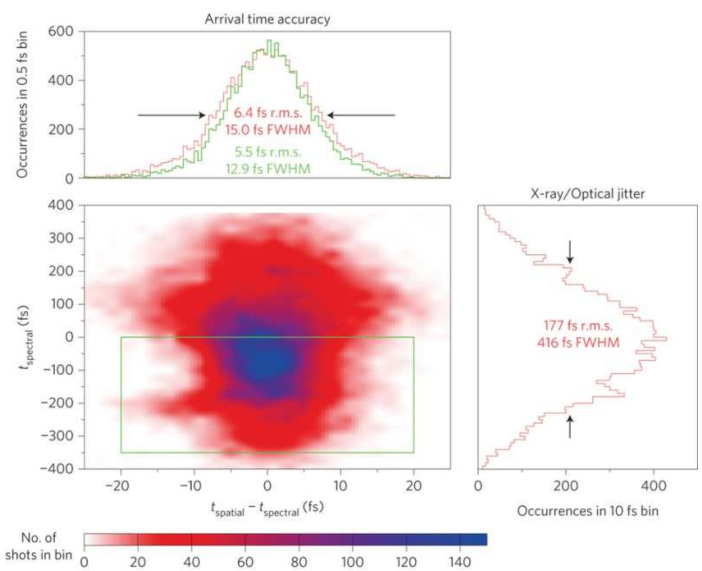
2 **PALM: Photon Arrival and Length Monitor**

Spectral (spatial) encoding timing tool



- X-Ray pump optical probe
- Collinear configuration
- Time window controlled by probe chirp

Beye et al. (2012), Applied Physics Letters, 100(12), 121108.
Krupin et al. (2012), Optics express, 20(10), 11396-406.
Schorb et al.(2012), Applied Physics Letters, 100(12), 121107.
Bionta et al. (2011), Optics express, 19(22), 21855-65.
Harmand et al. (2013) Nature Photonics, 7(3), 215-218.



- ➢ Makes the difference towards a successful experiment!
- ➢ Works well for pink beam, not so much for monochromatized beams

PALM - Photon Arrival and Length Monitor

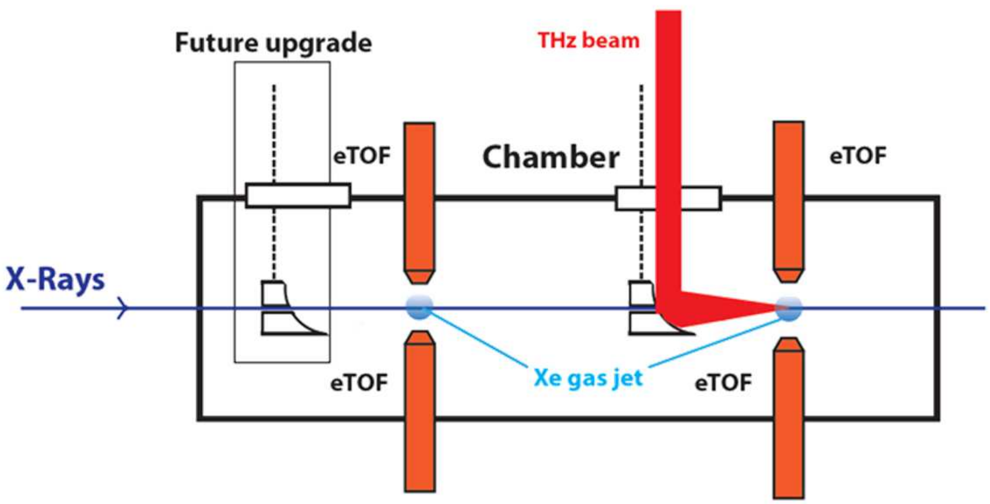
Purpose: Non-destructive measurement of photon beam pulse arrival relative to the experimental laser and photon beam pulse length.

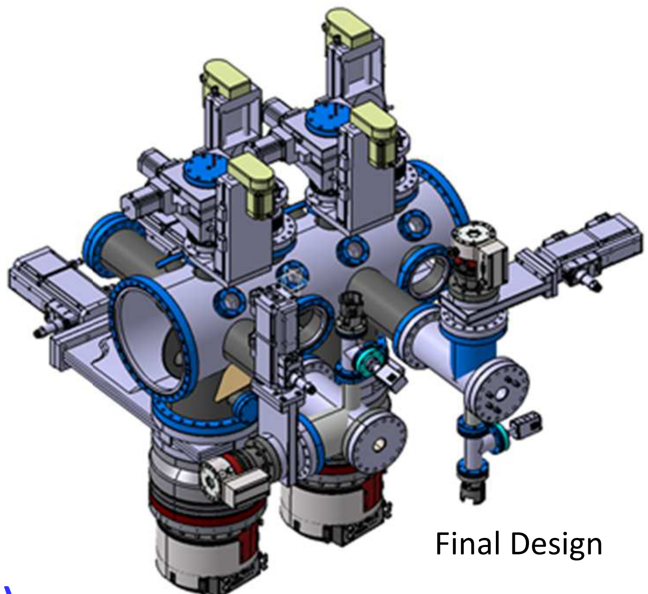
Requires: 2000 eV – 14500 eV, SASE mode.

Accuracy: 0.5-5 fs rms, depending on the wavelength and FEL and laser jitter.

Theory: A double-set of THz/IR streak cameras (PALM) will be used in conjunction with a spectral encoding setup (PSEN) to measure the arrival time and pulse length of the FEL beam relative to the experimental laser pulse.
Successful tests at SACLA with the prototype (2014 & 2016).

Schedule: All the devices (2 total) are in the process of being ordered. Expected full installation by end of 2016.





Final Design

(Courtesy Pavle Juranić)

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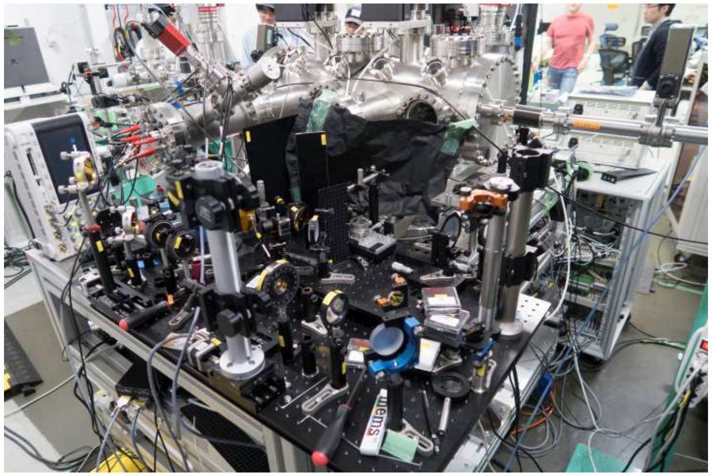
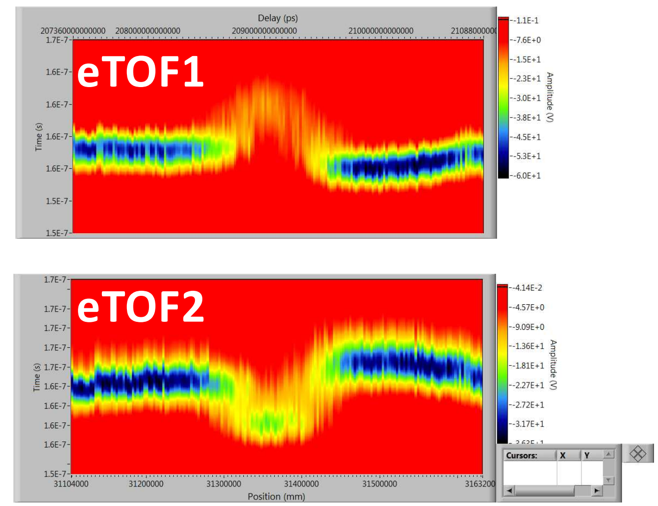
SACLA vs. PALM correlation plot



16-19 fs uncertainty between the SACLA timing tool and the PALM:

- 12-15 fs PALM accuracy
- 7 fs from the timing tool
- about 10 fs from the laser jitter between the two.

Arrival time comparison between two eTOFs



- Accuracy ~15 fs rms (single eTOF).
- Works with weaker e.g. monochromatized beams
- Works over large energy range 2- 12 keV

Summary:

- **ESB instrument will allow new types of experiments in condensed matter, starting late 2017/early 2018.**
- **Assembling and installation of major components is starting now.**
- **Foucs on pump-probe experiments: three timing-tool systems are developed and installed:**
  - **- Spectral encoding**
  - **- PALM**
  - **- BAM/LAM**