KEK: LUCX - THz Program: Overview and Prospects

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Indo-Japan school on Advanced Accelerators of Ions and Electrons

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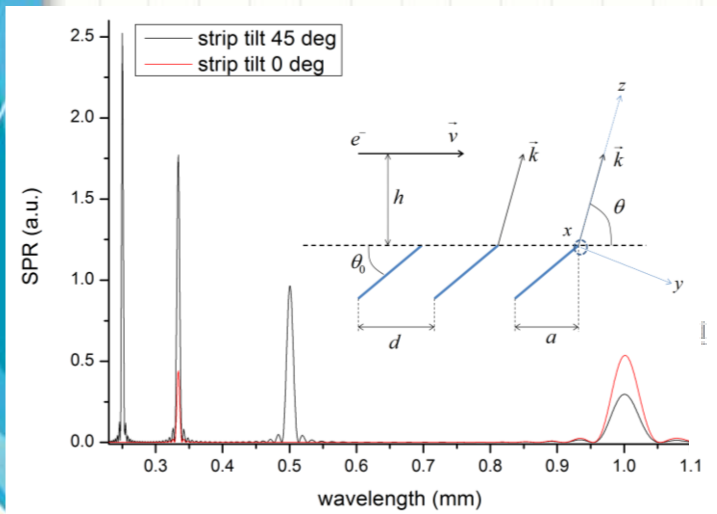
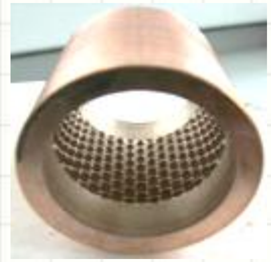
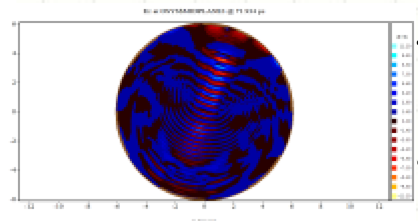
Outline

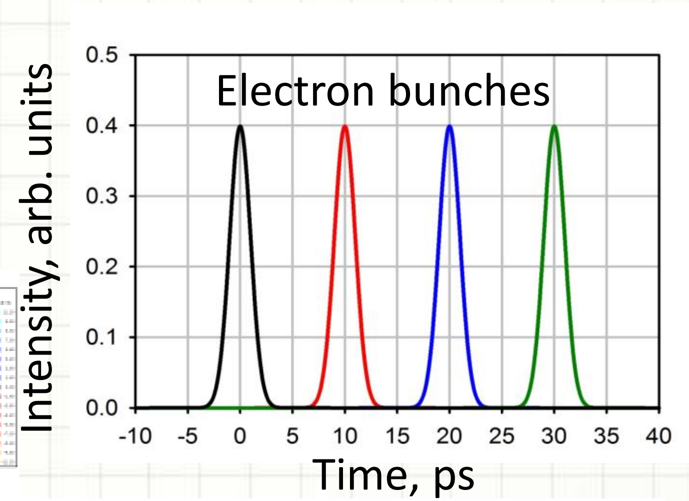
- LUCX THz general
  - General motivation(s)
  - THz project overview
  - LUCX activity, LUCX Projects Overview, THz program
- FSTB: Sub-TW, Ti:Sa Laser system
- Laser Transport Line (LTL)
- fs electron beam: generation, measurement and control
- LUCX THz: measurement setup, DAQ & Soft
- Conclusion, Plans, Schedule

General motivation





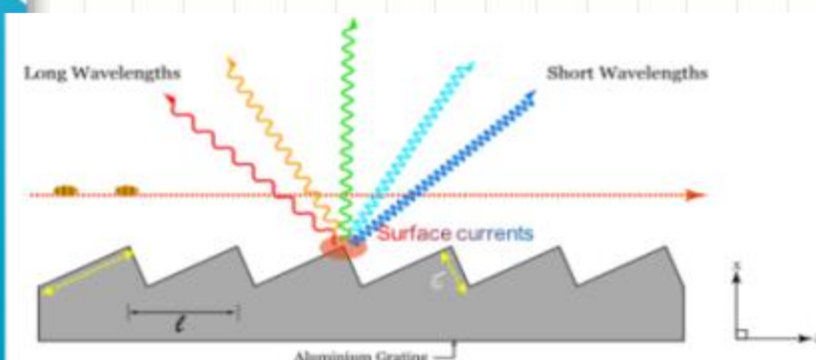




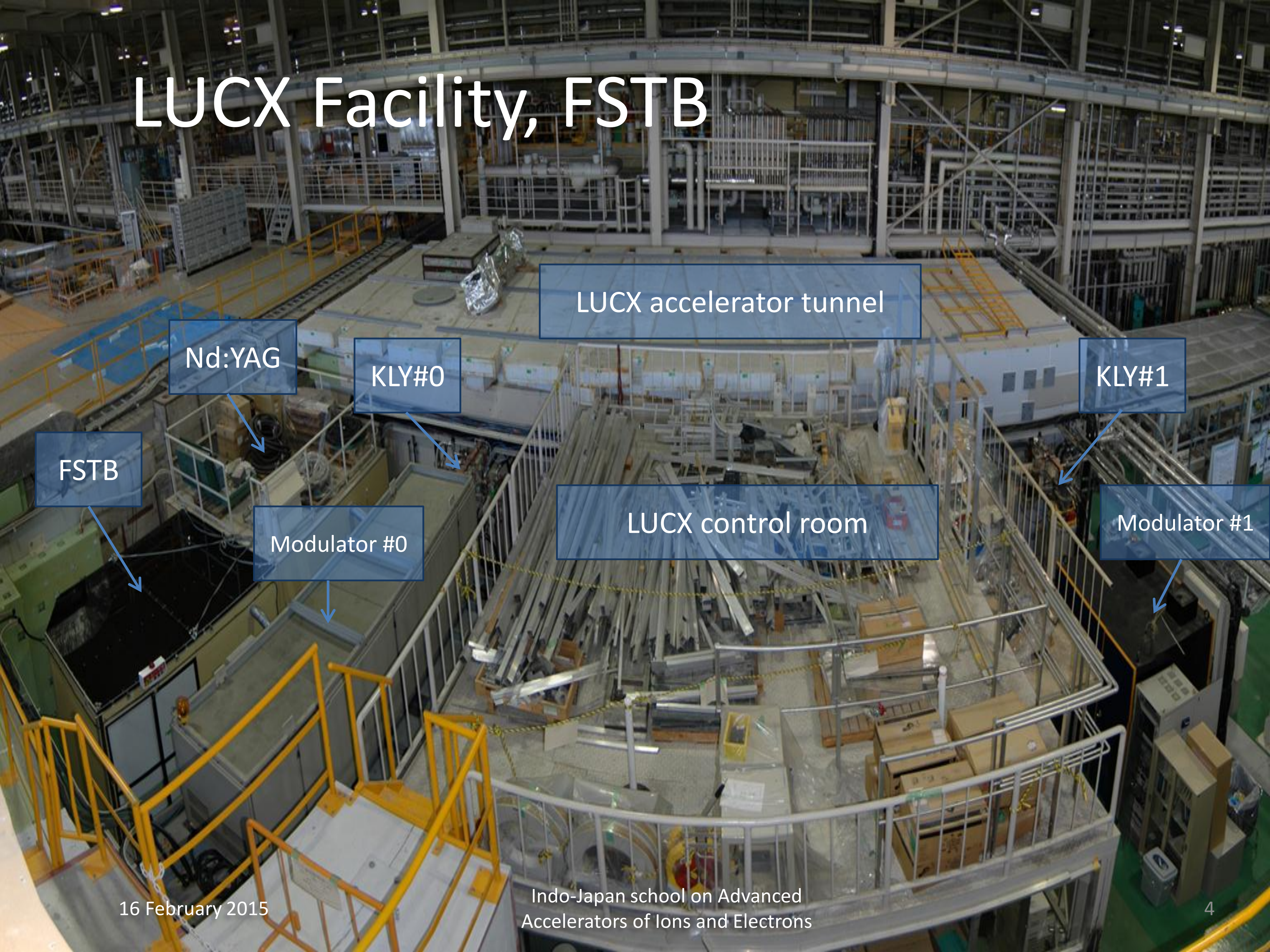
$$\frac{d^2W_{tot}^s}{d\omega d\Omega} = \frac{d^2W_{sing}}{d\omega d\Omega} N_e(1+(N_e-1)\,|\,f_l(\omega)\,|^2)$$

$$\Downarrow$$

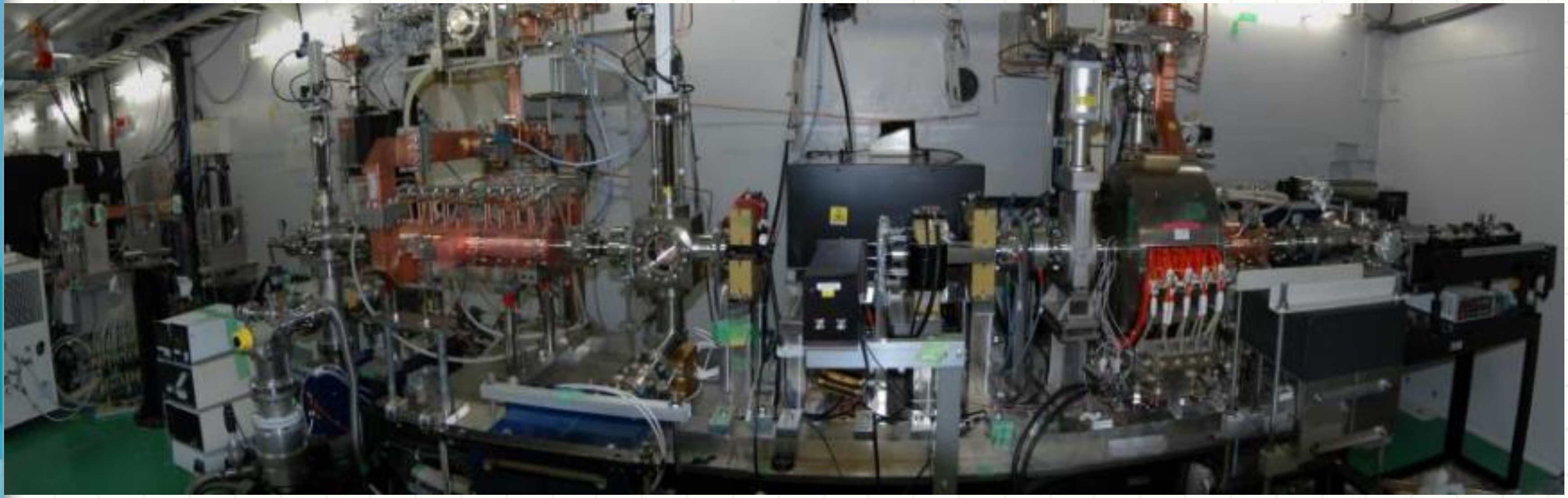
$$\frac{d^2W_{tot}^s}{d\omega d\Omega} = \frac{d^2W_{sing}}{d\omega d\Omega} N_e\left(1+(N_e-1)\frac{\sin^2[\frac{N_b\omega\lambda_{RF}}{2\beta c}]}{\sin^2[\frac{\omega\lambda_{RF}}{2\beta c}]}\,|\,f_l(\omega)\,|^2\right)$$



LUCX Facility, FSTB



LUCX beamline and operation modes



“Femtosecond mode”
- Ti:Sa laser
- e-bunch rms length ~100fs
- e-bunch charge < 100pC
- Single bunch train, Micro-bunching 4-16
- Rep. rate 10 Hz
- Experiments: THz program

“Picosecond mode”
- Q-switch Nd:YAG laser
- e-bunch rms length ~10ps
- e-bunch charge < 0.5 nC
- Multi-bunch train 2- few 10^3
- Rep. rate 12.5 Hz
- Experiments: Compton, CDR

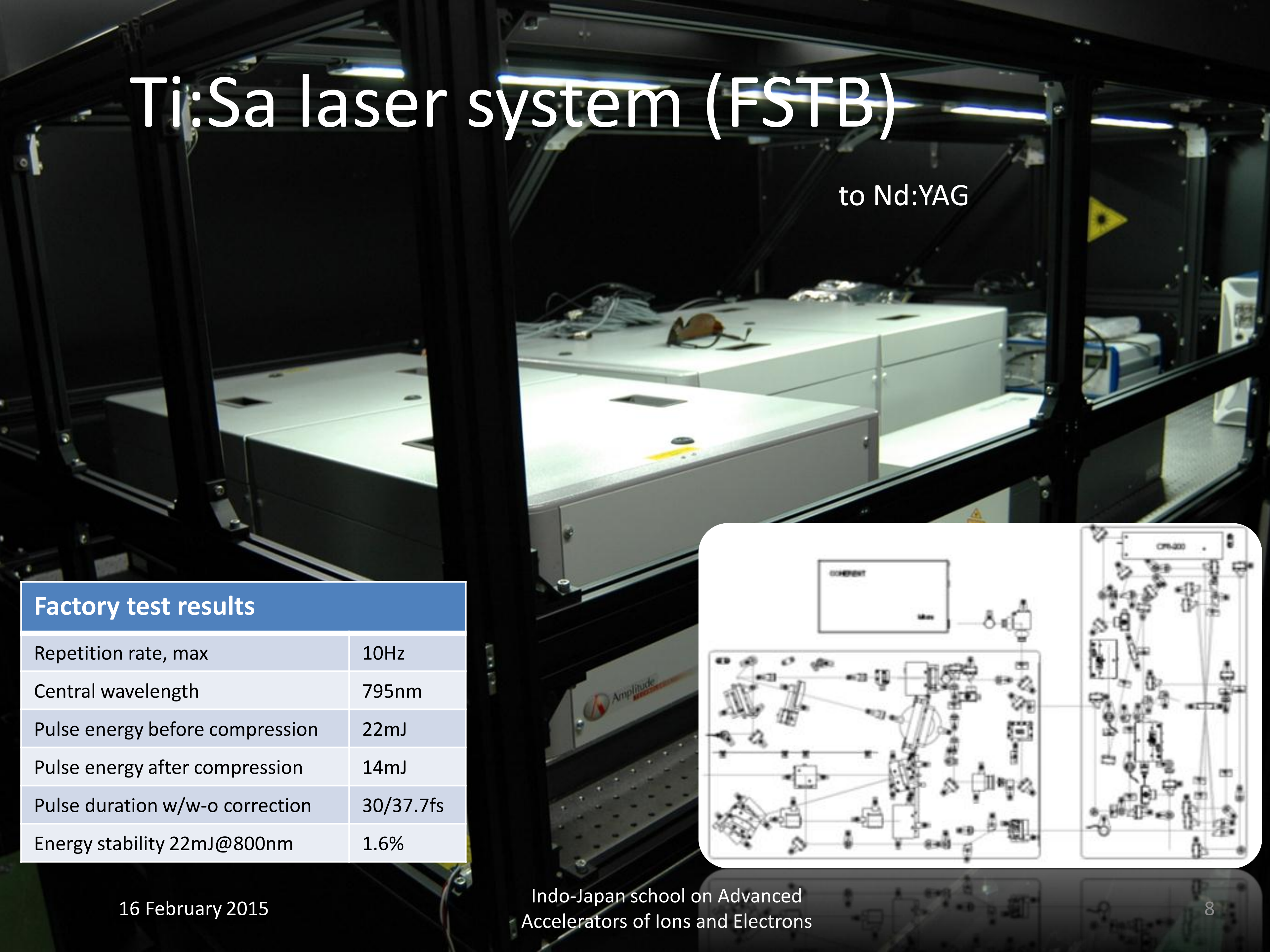
THz program key points

- **Laser system**
  - Stable operation and diagnostics
  - Generation of Ti:Sa 3rd harmonic (265nm) fs laser beam
  - Pointing, energy, mode stability @ 265nm
  - Micro-bunching
- **Accelerator**
  - Generation of fs, comb electron beam
  - Ability to measure longitudinal beam profile
  - Vacuum chamber with multi-axis manipulator system
  - Machine stability
- **THz Measurement system**
  - Reliable measurements of THz radiation spectrum and angular distribution.
  - Radiation intensity, Pulse duration, Shot-to-shot and Long-term stabilities.

FSTB: Sub-TW, Ti:Sa Laser system & Laser Transport Line (LTL)

Amplitude
TECHNOLOGIES
Nothing but ultrafast.

Ti:Sa laser system (FSTB)



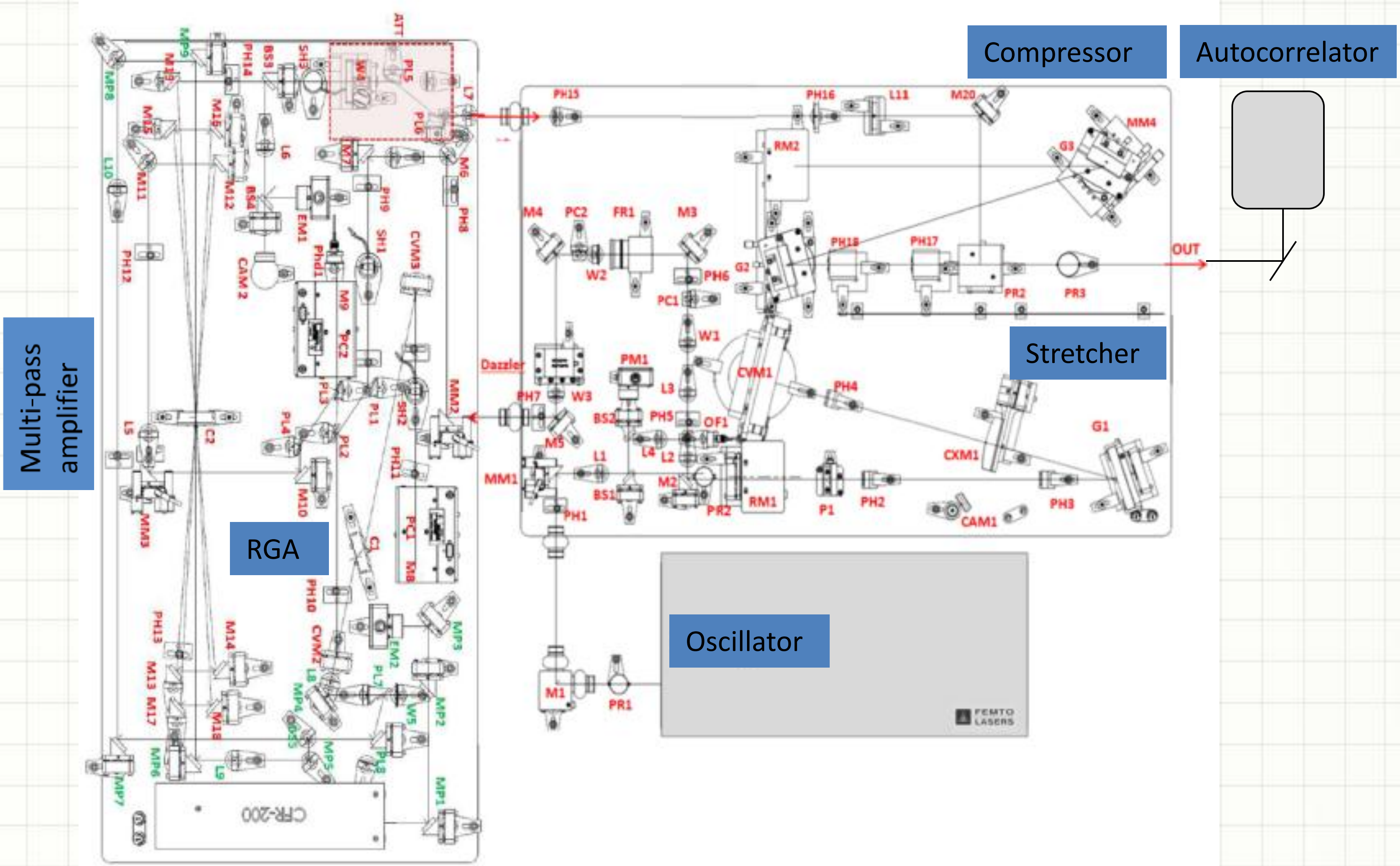
to Nd:YAG

Factory test results	
Repetition rate, max	10Hz
Central wavelength	795nm
Pulse energy before compression	22mJ
Pulse energy after compression	14mJ
Pulse duration w/w-o correction	30/37.7fs
Energy stability 22mJ@800nm	1.6%

FSTB: General approach

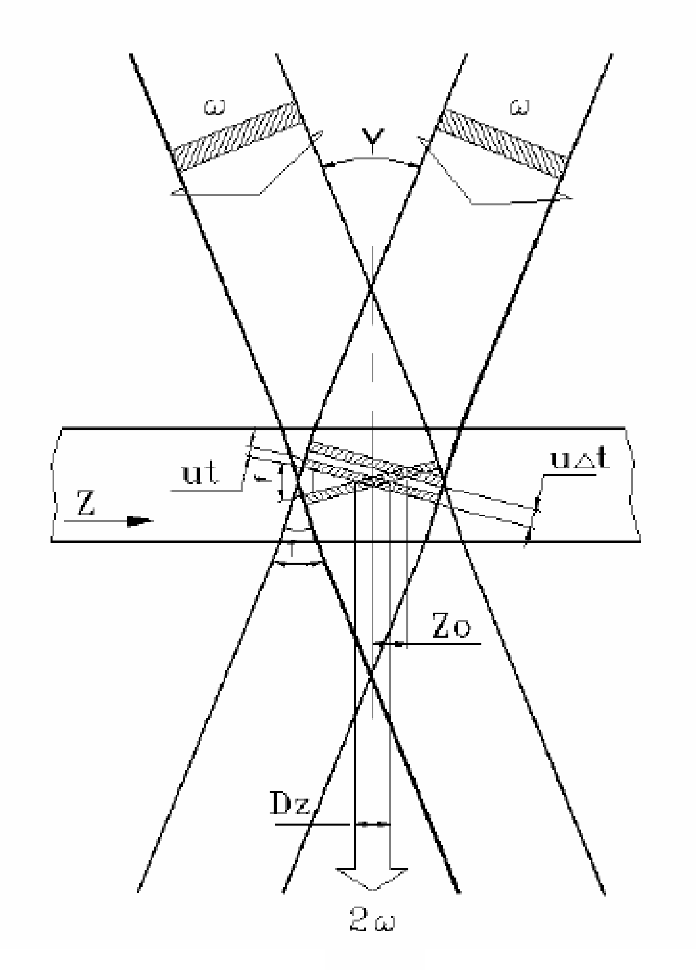
- Integrated laser system with wide tuning ranges:
  - Number of microbunches
  - Microbunch spacing
  - Duration(s), Intensity, position, size.
- On-line monitoring and control
- Feedback (Accelerator <-> Laser) (yet to be tested)
- Long term stability
- In-house expertise

Laser system: general layout



Laser system: fs Single Shot autocorrelator

The method based on the registration of cross distribution of Second Harmonic (SH) energy produced in nonlinear crystal under non-collinear interaction of two beams with determined aperture is used.



Cross size of SH beam:

$$D_z = \frac{tc}{sin\frac{\varphi}{2}}$$

t – pulse duration, φ – the angle between the combined beams in the crystal, c– light velocity of the base frequency in the crystal.

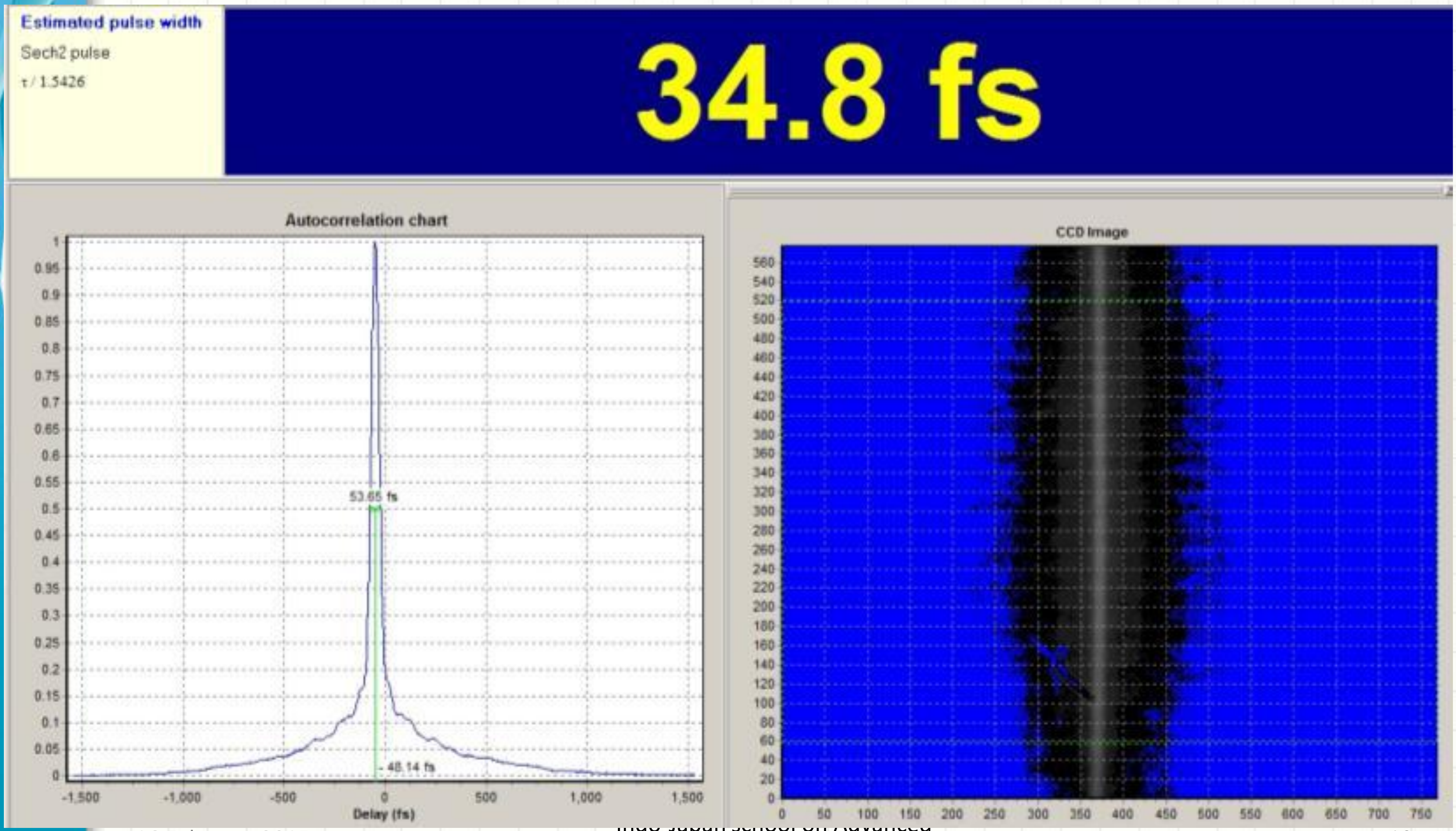
Time delay Δt causes the SH cross distribution to shift by an amount of Z_0:

$$Z_0 = \frac{\Delta tc}{2sin\frac{\varphi}{2}}$$

From the above expressions the pulse duration:

$$t = \frac{D_z \Delta t}{Z_0}$$

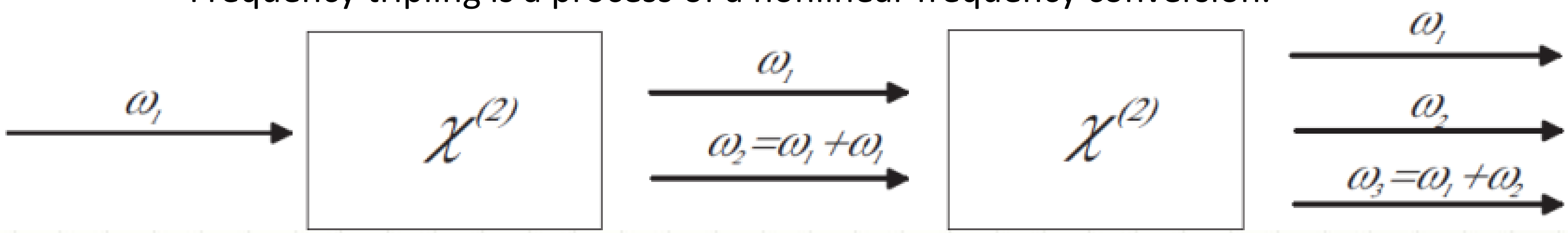
Laser system: fs Single Shot Autocorrelator



Laser pulse splitting and THG

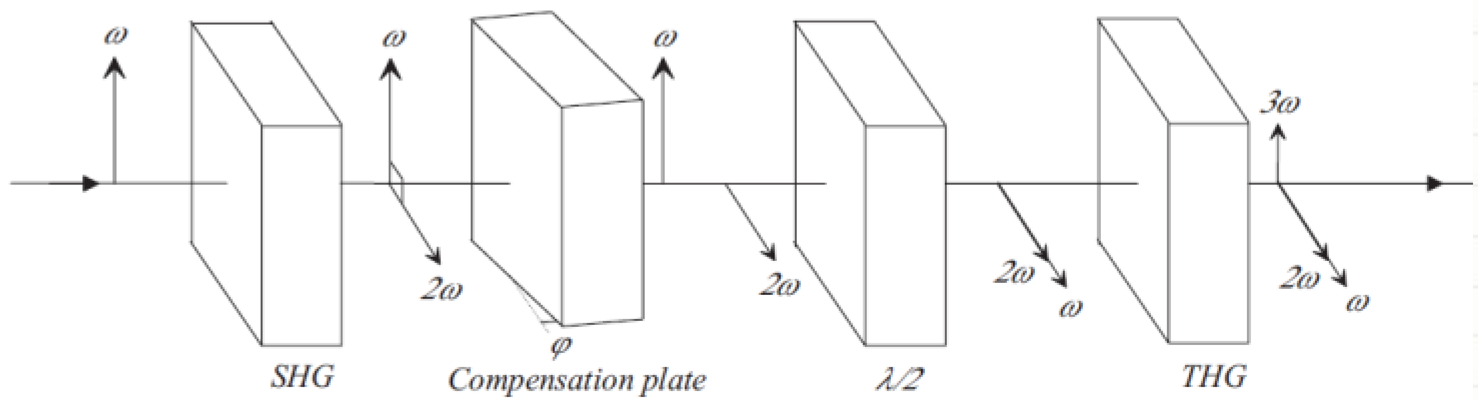
THG: Improvement of the current (collinear) scheme

Frequency tripling is a process of a nonlinear frequency conversion.



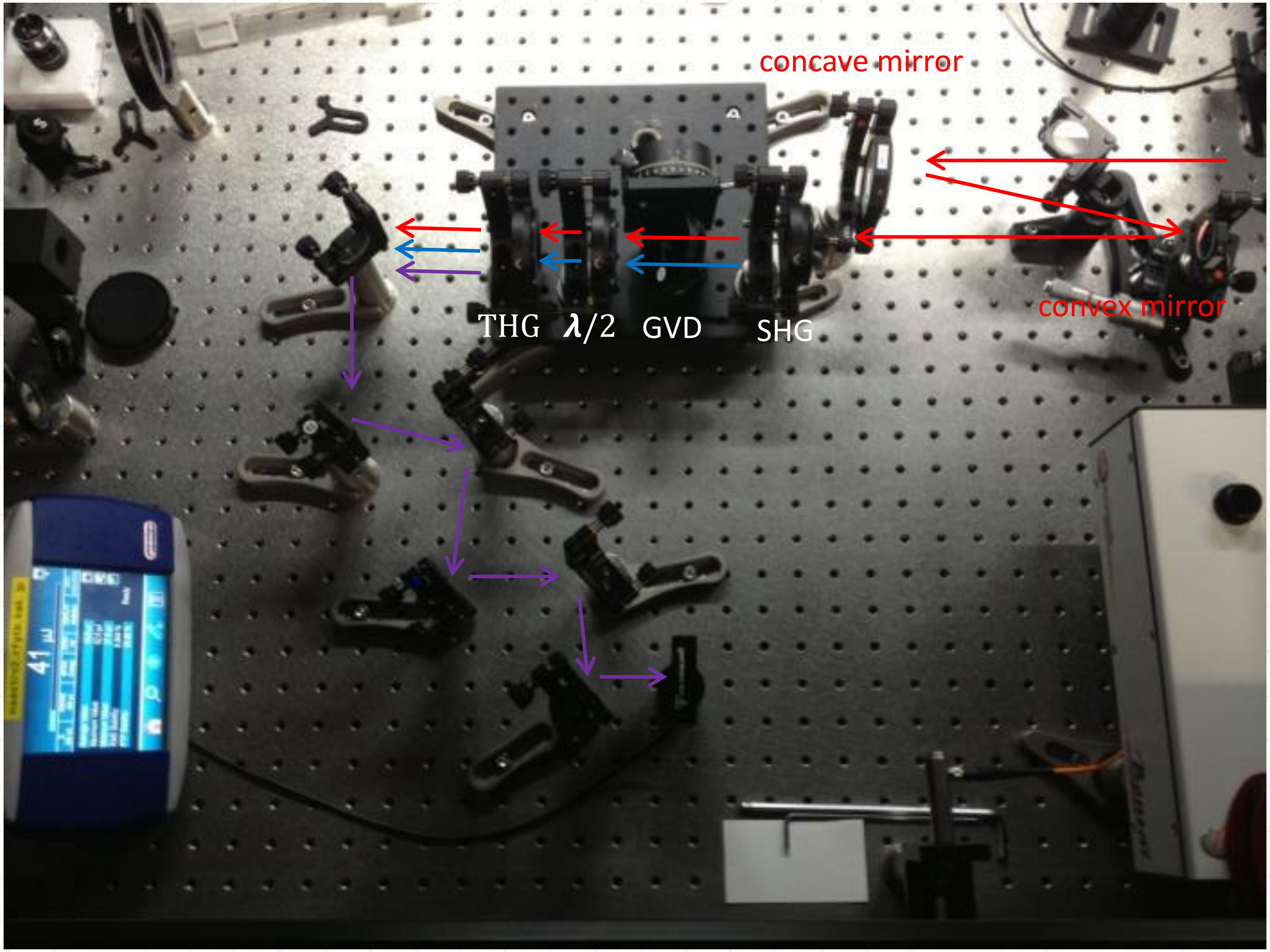
frequency doubler

sum frequency mixer



SHG	Compensation plate	$\lambda/2$	THG
BBO, Type1	Calcite	Achromatic Half-wave plate	BBO, Type1
θ = 29.2deg	ψ= 45deg		θ = 44.3deg
ψ~ 90deg		ψ~ 90deg	ψ~ 90deg
L= 0.2mm	L= 1.7mm	L= 2mm	L= 0.05mm

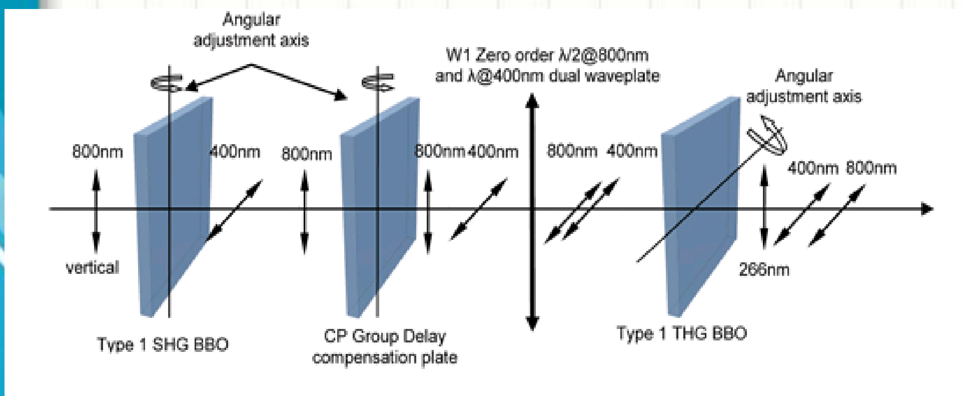
THG (setup)



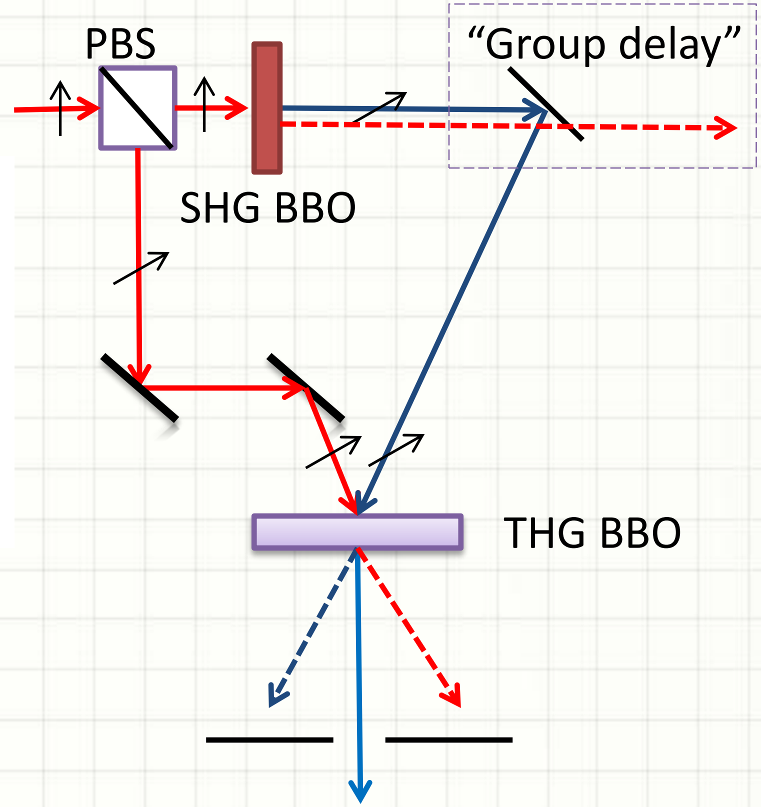
THG: Possible improvement

- Collinear scheme
  - Replace Calcite plate with BBO: θ = 70.0deg, ψ~ 90deg, L= 4mm according to H. Enqvist, Lund Reports on Atomic Physics, LRAP-330, Lund, October 2004
  - Better matching and focusing optimization.
- Non-collinear scheme
  - More complicated alignment.
  - Lower energy conversion threshold.

Ti:Sa 3rd harmonic generation

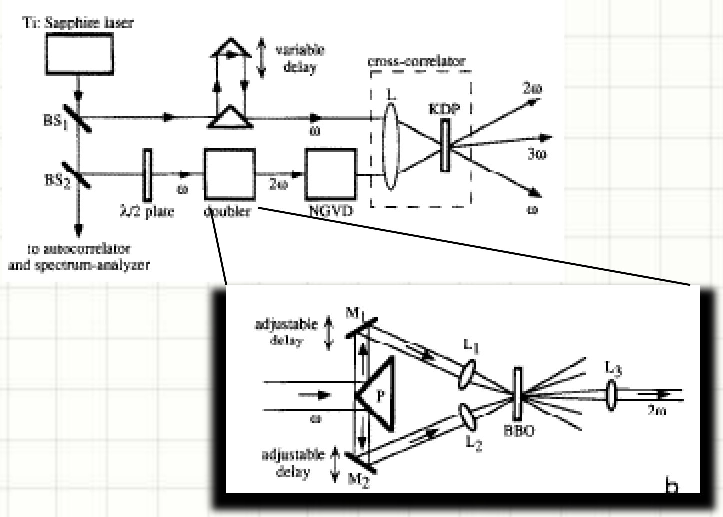


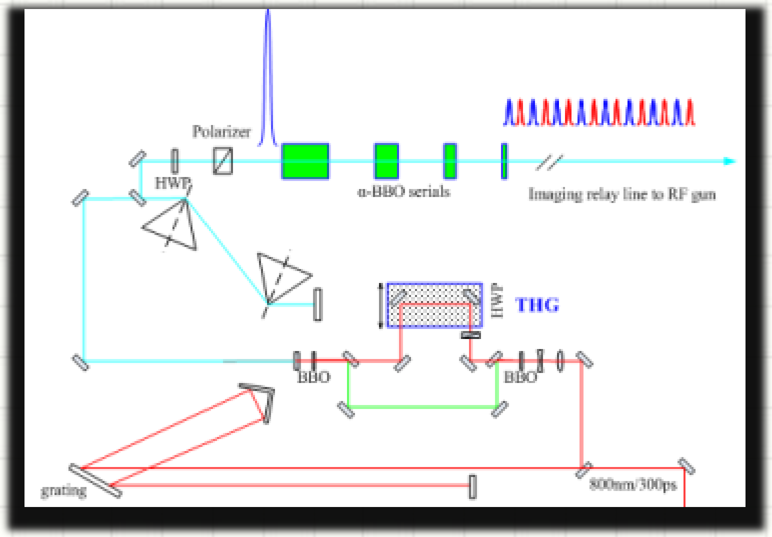
AT (also used at KEKB linac)



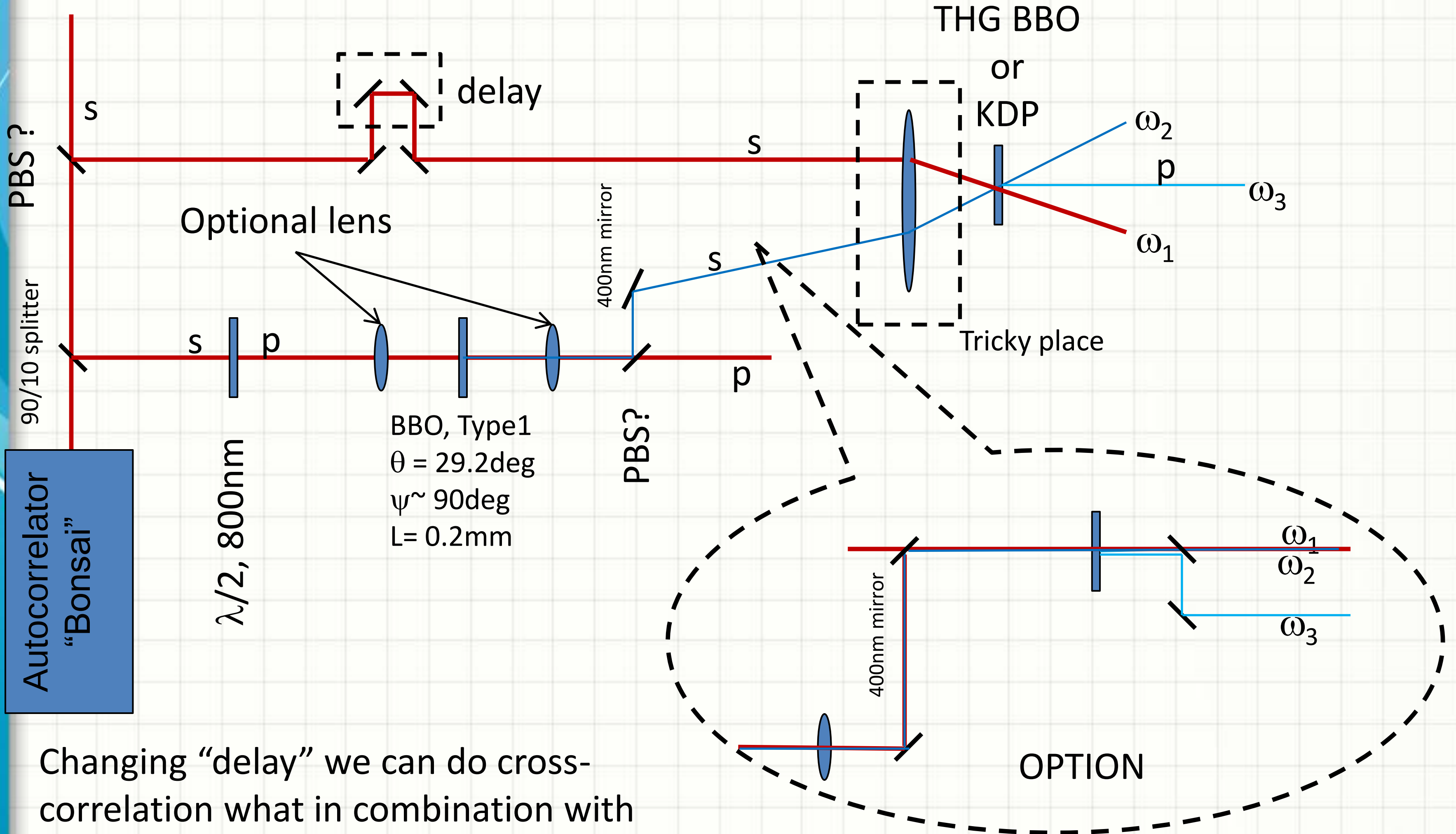
Non-collinear scheme

- C. Radzewicz, Optics communications 117 (1995) 295-302.
- Lixin YAN, Preliminary Experiments on Ultrashort Bunch Train Production by UV Pulse Stacking, Tsinghua University



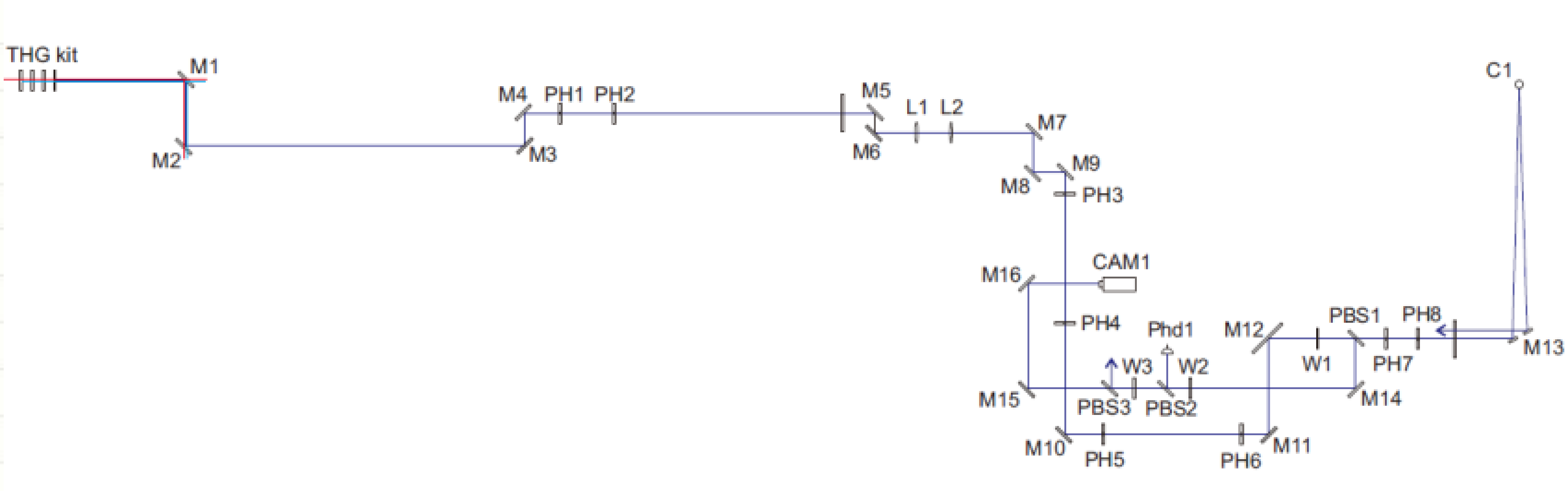


Non-collinear scheme



Changing "delay" we can do cross-correlation what in combination with Autocorrelator can give ω_2 pulse duration

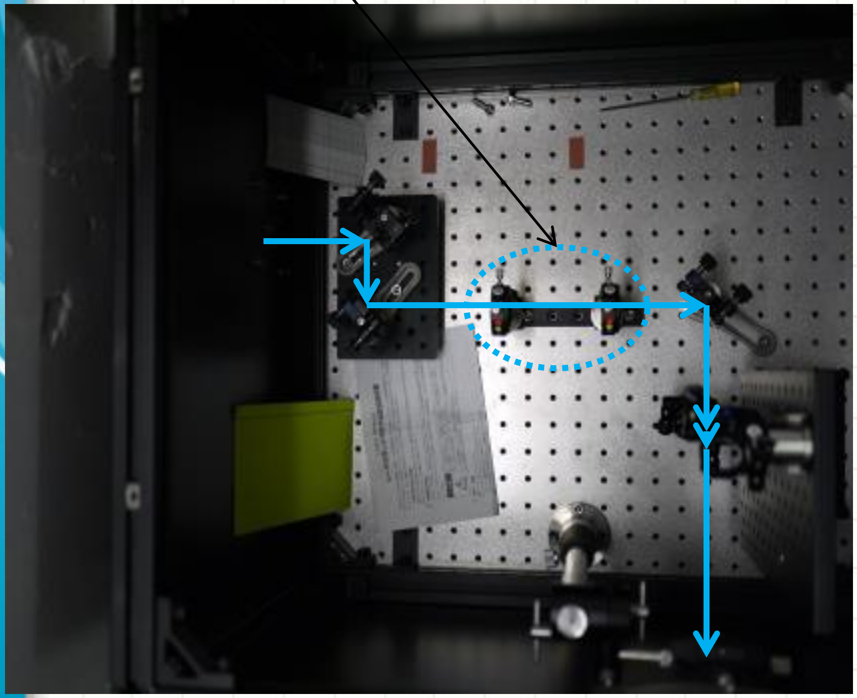
LUCX LTL



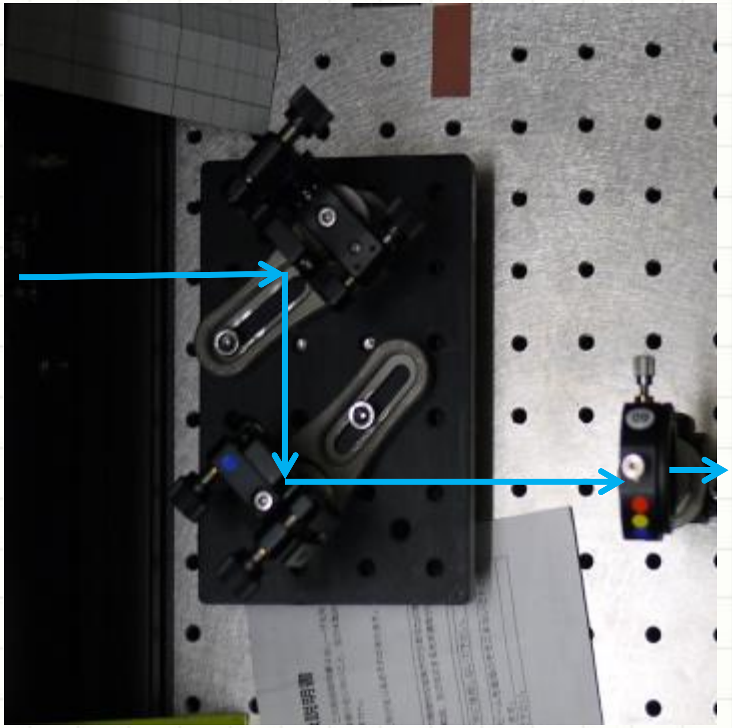
THG kit
M1
M2
M3
M4
PH1
PH2
M5
M6
L1
L2
M7
M8
M9
PH3
C1
CAM1
M16
PH4
Phd1
M12
PBS1
PH8
W3
W2
W1
PH7
M13
M15
PBS3
PBS2
M14
M10
PH5
PH6
M11

LUCX LTL, Box#1

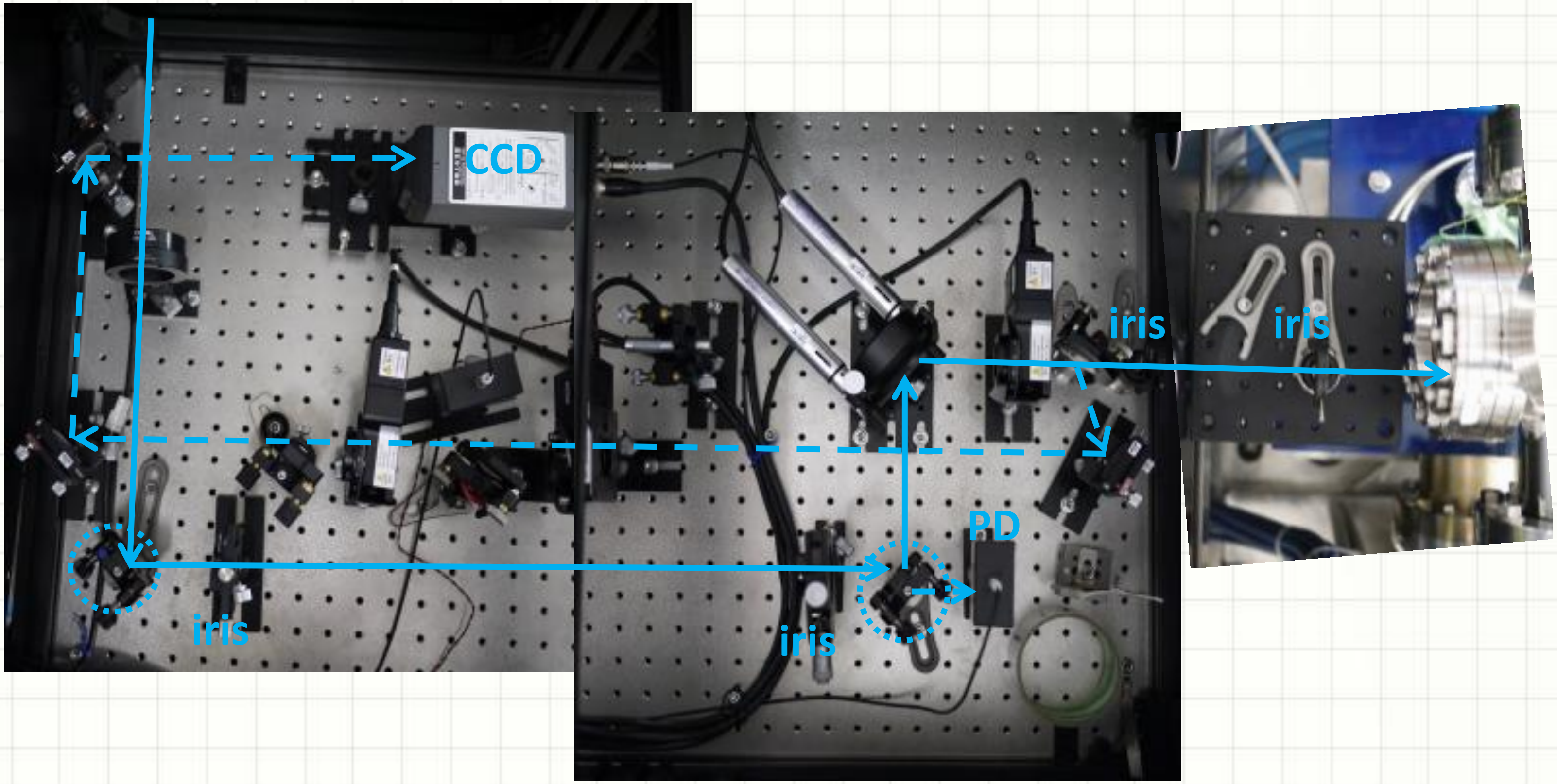
UV telescope



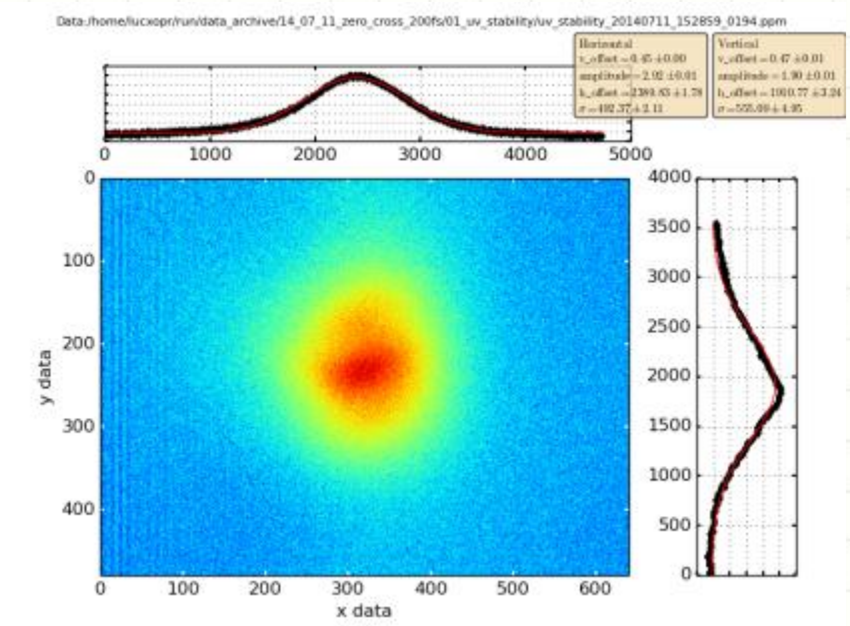
Replaceable platform

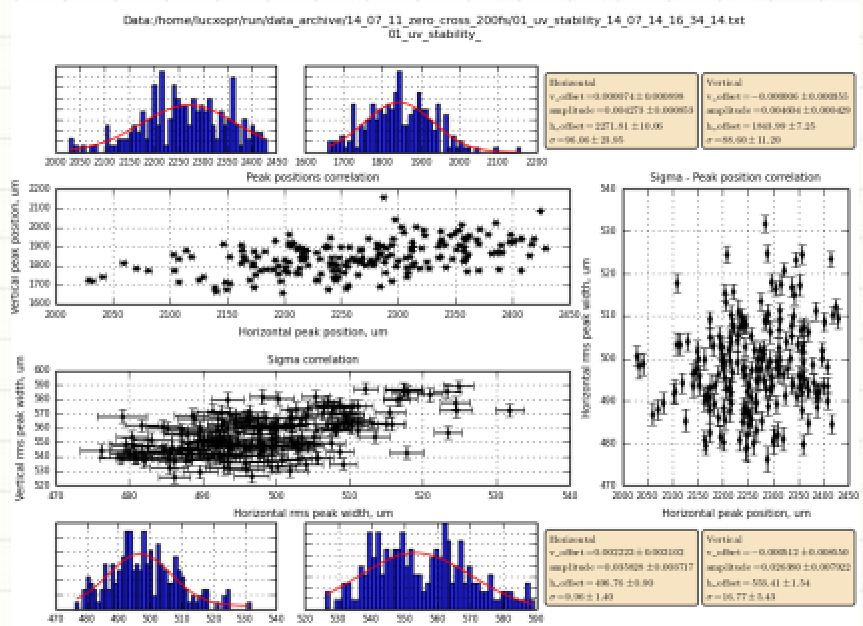


LUCX LTL, Box#2



FSTB & LTL measurements





Performance

Performance	Measured	Specified
Repetition rate	10 Hz	10 Hz
Central wavelength	805 nm	795 – 815 nm
Pulse energy before compression	22 mJ	> 20 mJ
Pulse energy after compression	16 mJ	> 12 mJ
Pulse duration without dazzler: with dazzler:	 39 fs 37 fs	 < 40 fs < 30 fs
Energy stability 22 mJ at 800 nm	1.4 %	< 2 %
Contrast ns	1x	< 1x

FSTB: 2/4 – micro bunch mode

Location

- After THG (UV, fs, spot)
- After compressor (FH, fs, spot, energy)
- After main amp.(FH, ps, energy)
- After pre-amp.(FH, ps)

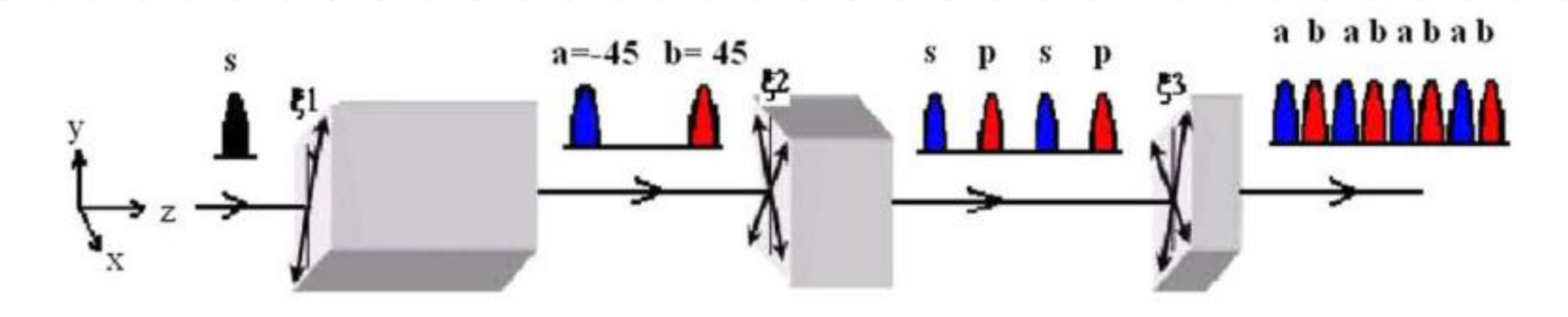
Type

- Crystals
  - no bunch separation control.
  - no easy number of bunches control.
- Interferometer
  - more difficult to tune

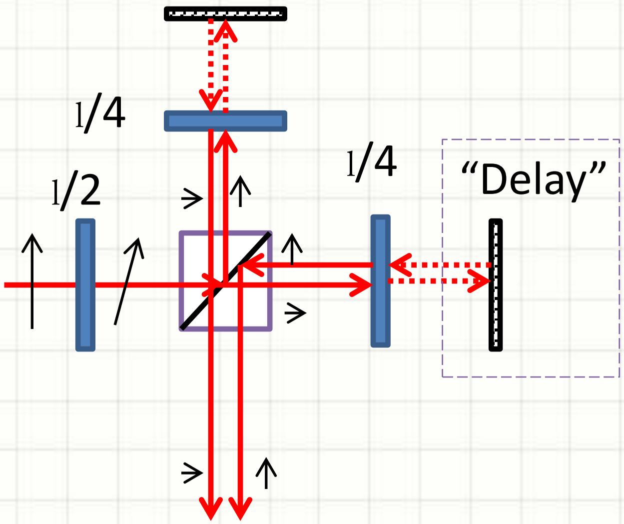
Handling

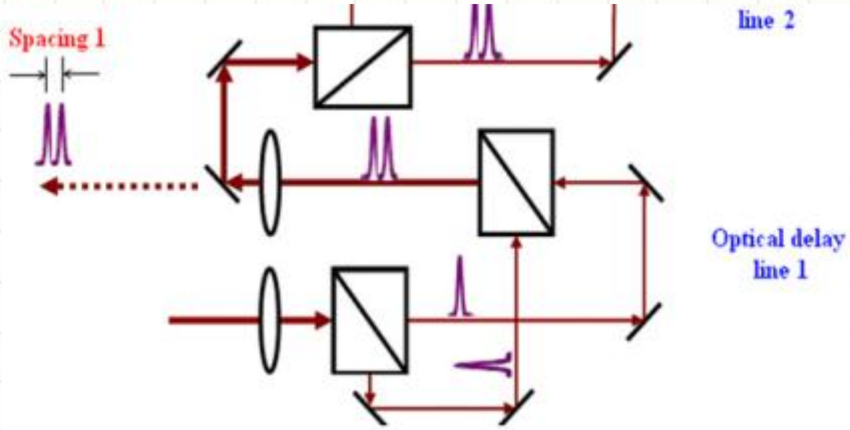
- Tuning
- Motorization possibility
- Compact design
- Same polarizations
- Low losses

Tsinghua University system



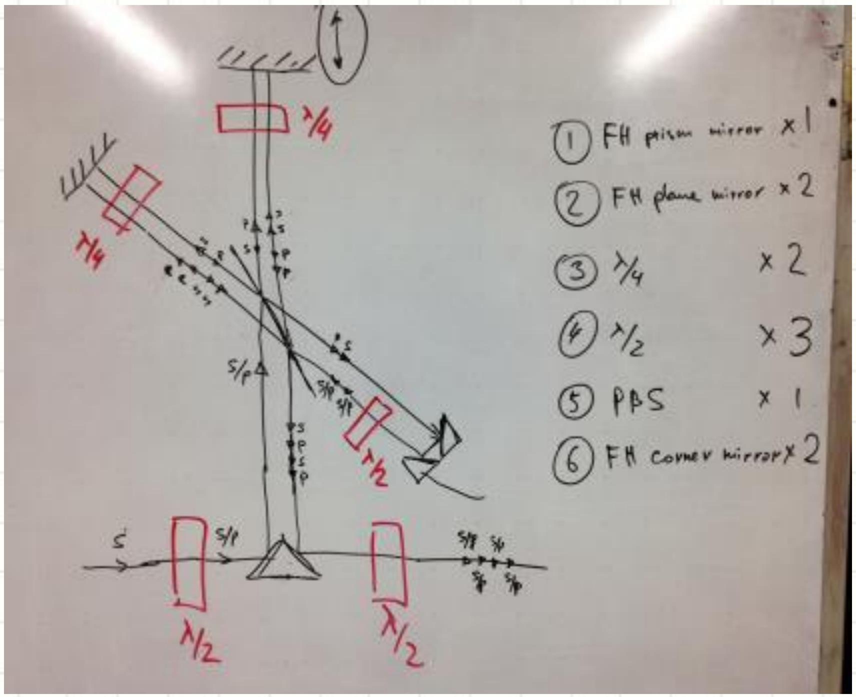
Pulse stacker



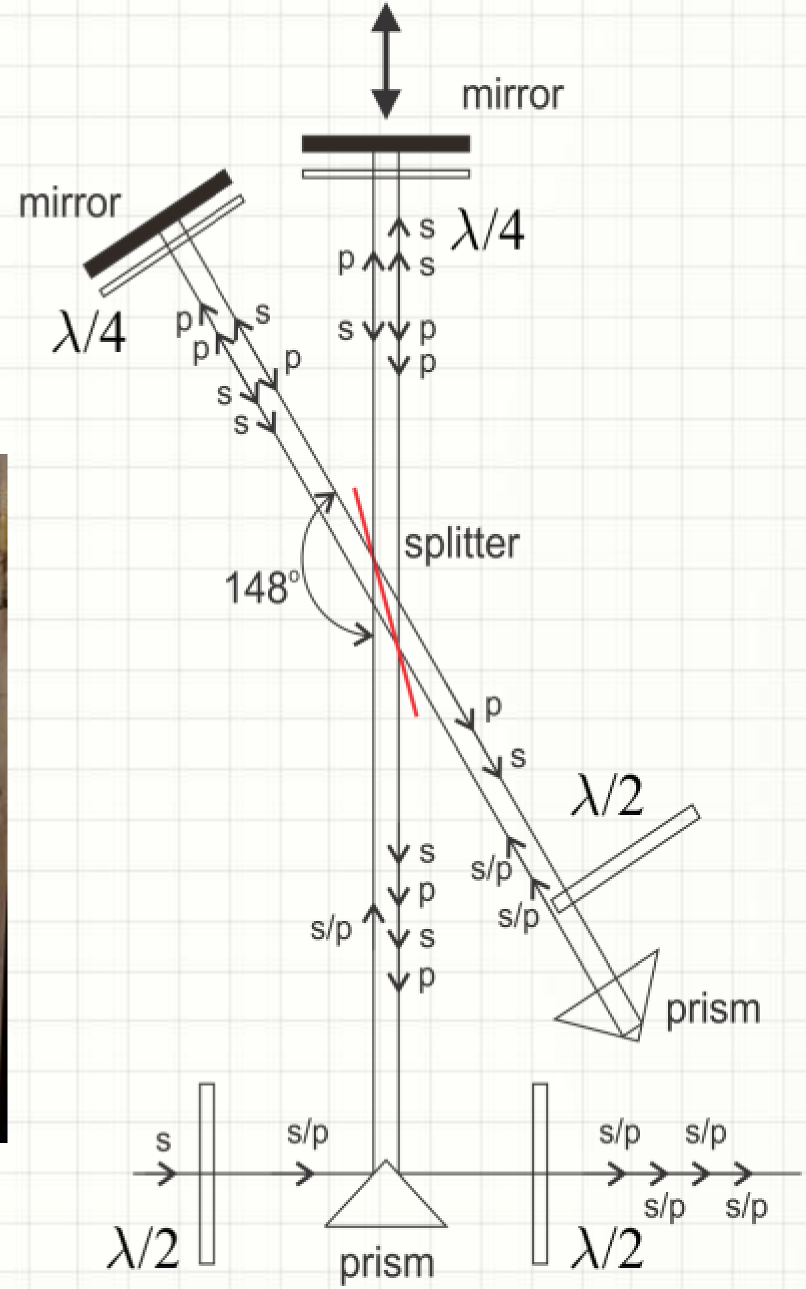


- Both approaches gives alternative polarizations within train, what is a problem if buncher will be placed before 3rd harmonic generator.
- What is Cs_2Te light polarization response?
- Points to check: stability, pulse duration broadening.

Buncher

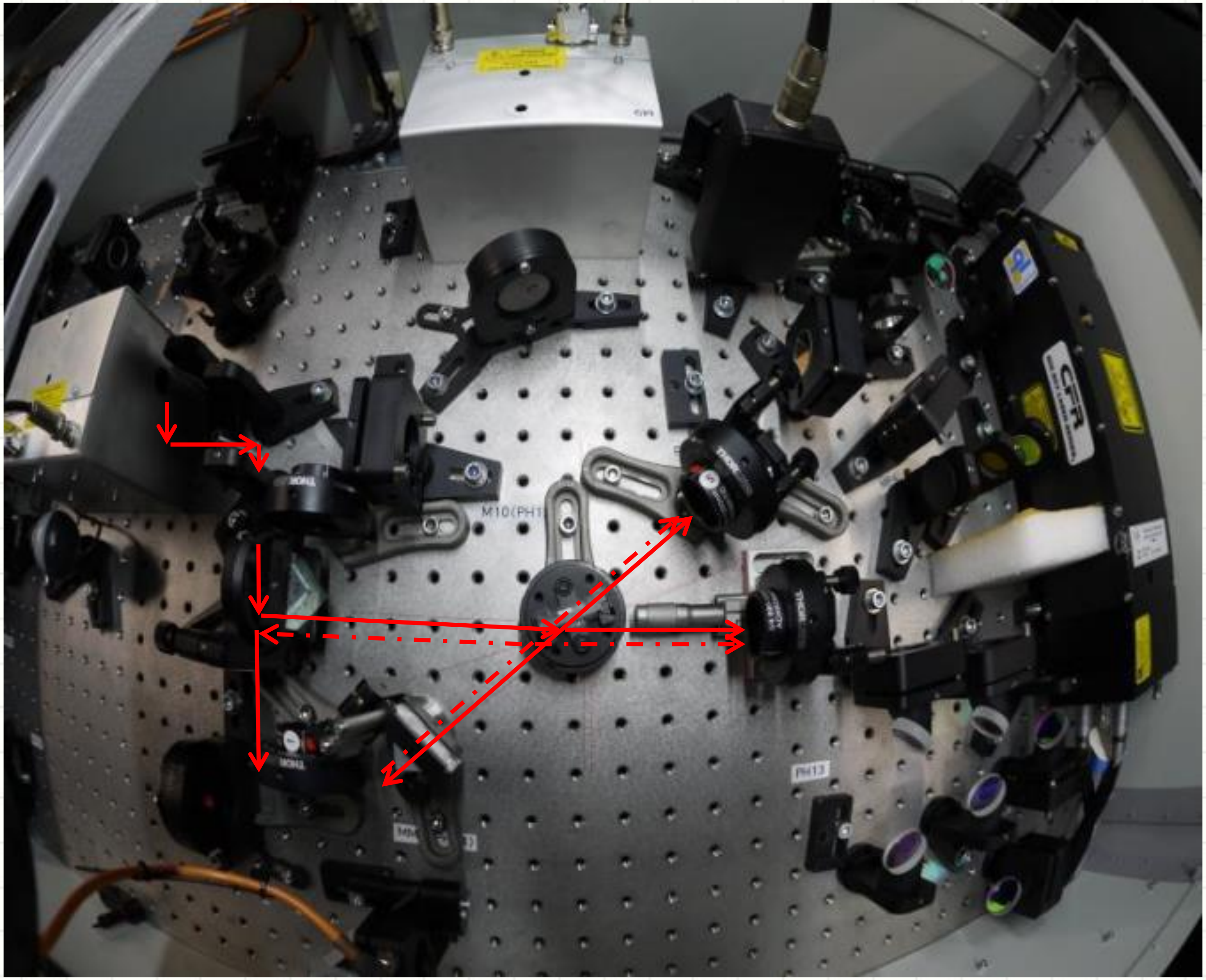


λ/4
λ/4
λ/2
λ/2
λ/2
① FH prism mirror ×1
② FH plane mirror ×2
③ λ/4 ×2
④ λ/2 ×3
⑤ PBS ×1
⑥ FH corner mirror ×2



mirror
mirror
λ/4
λ/4
splitter
148°
λ/2
prism
λ/2
prism
λ/2
s
s/p
s/p
s/p
s/p
s/p

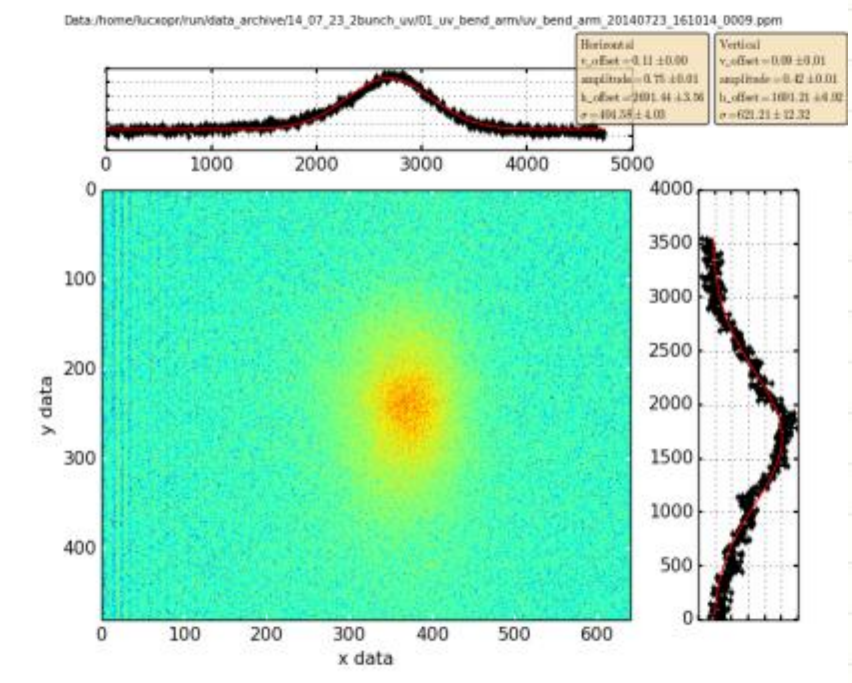
Buncher



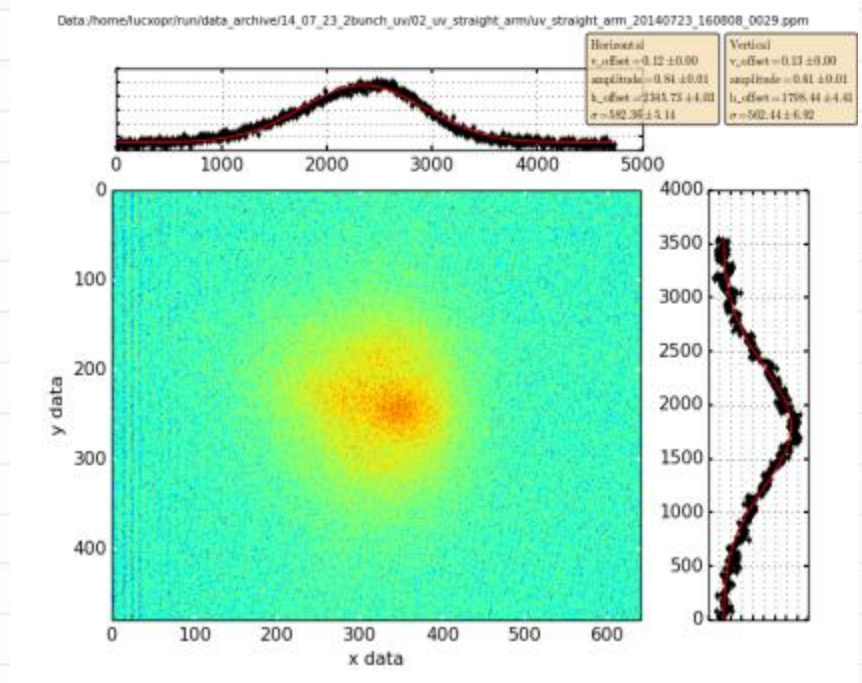
“Buncher” performance tests

~ 0.85 uJ each

“bend arm”



“straight arm”



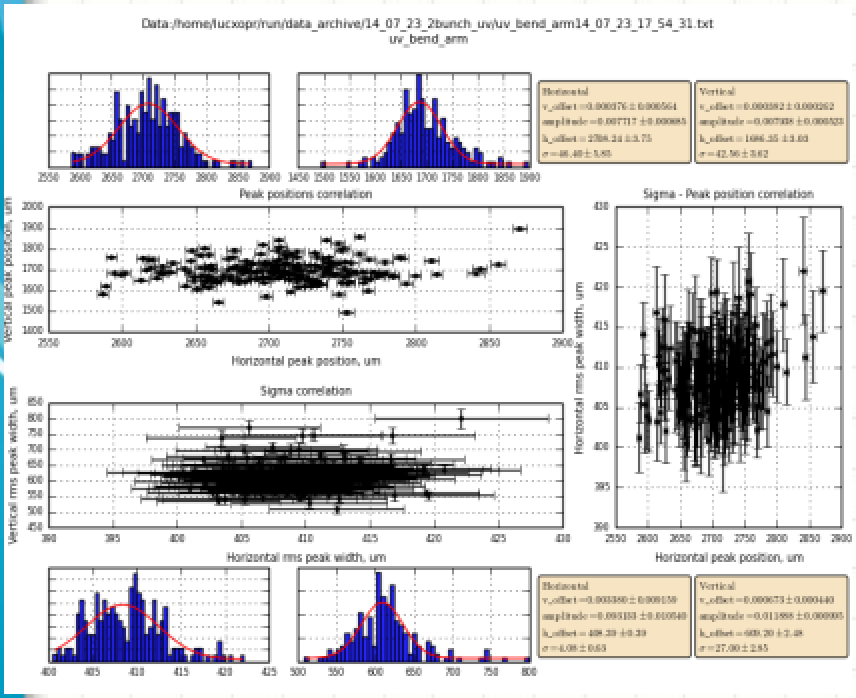
Performance tests

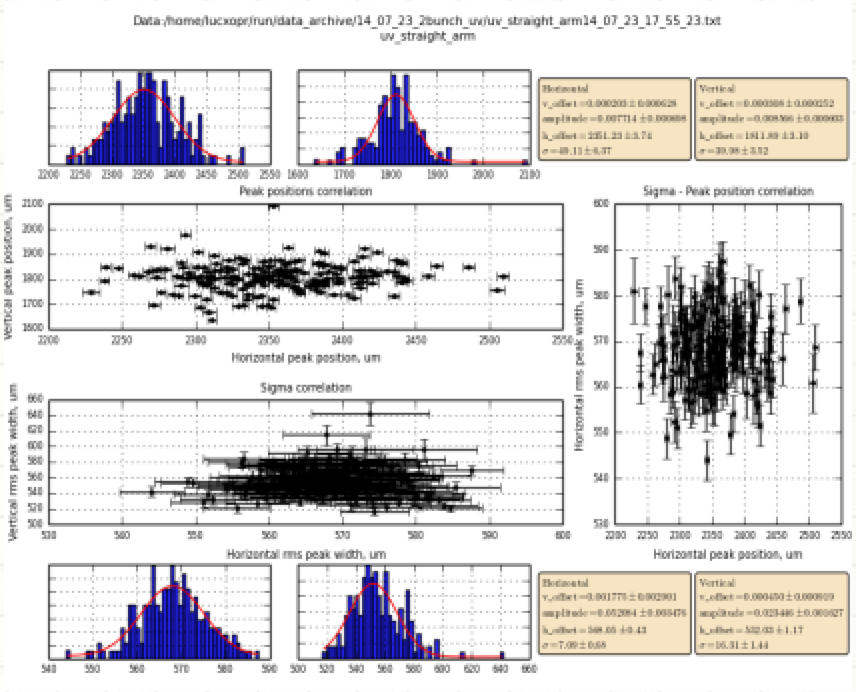
Hor. Offset rms ~ 350 um
Ver. Offset rms ~ 150 um

(jitter included)

“bend arm”

“straight arm”



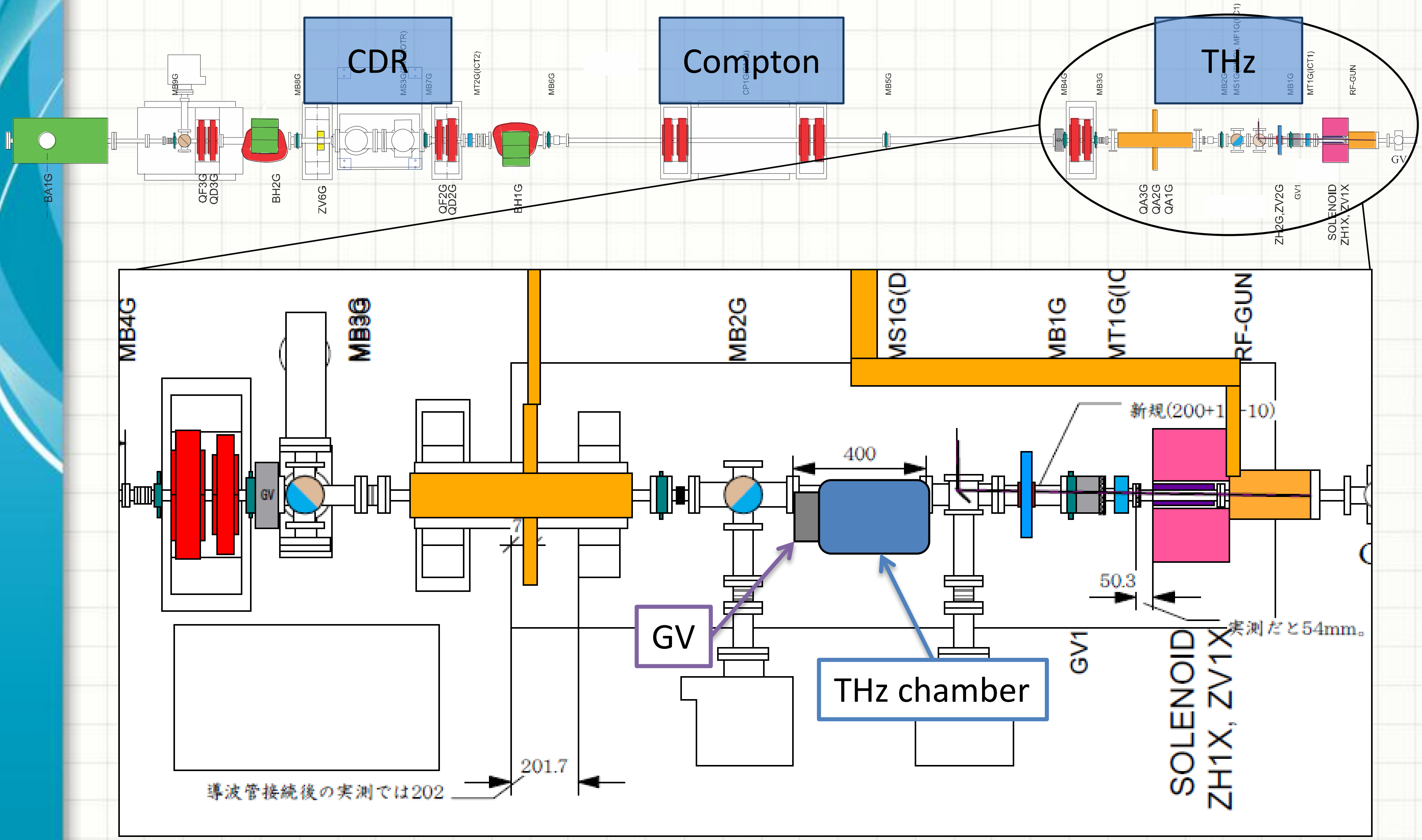


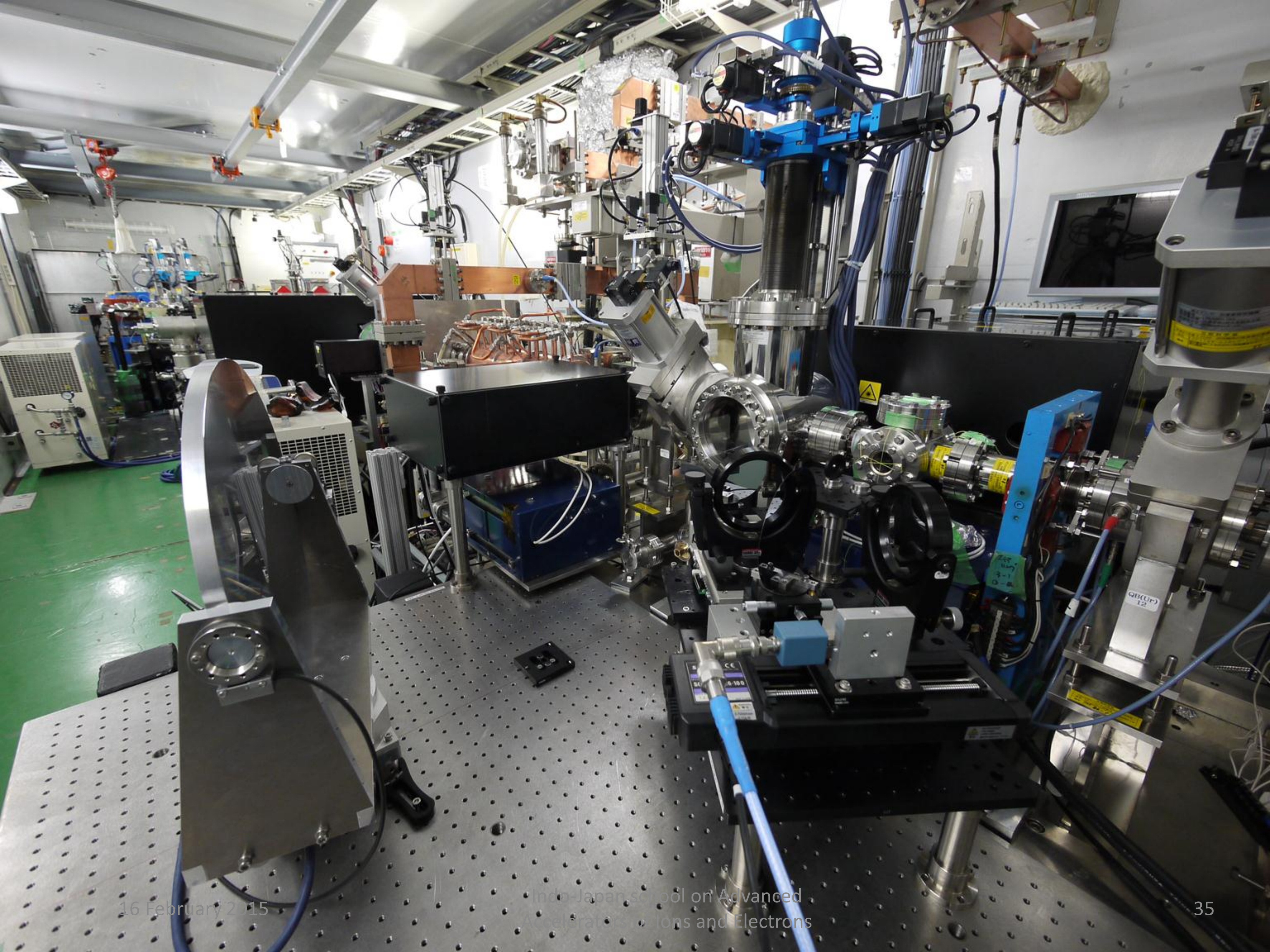
Limitations

- Now we have a trade between amplification (of each micro bunch) and path.
- Somewhat it is coming from not optimized design.
- The most important notice is that pulse durations appears to be different (due to path: angle-position difference through the compressor).
- In order to obtain similar energy for each bunch at the cathode we have misbalanced FH energies.
- **We are sure that if 4-, 8- and even 16- bunches are possible to make on this scheme.**

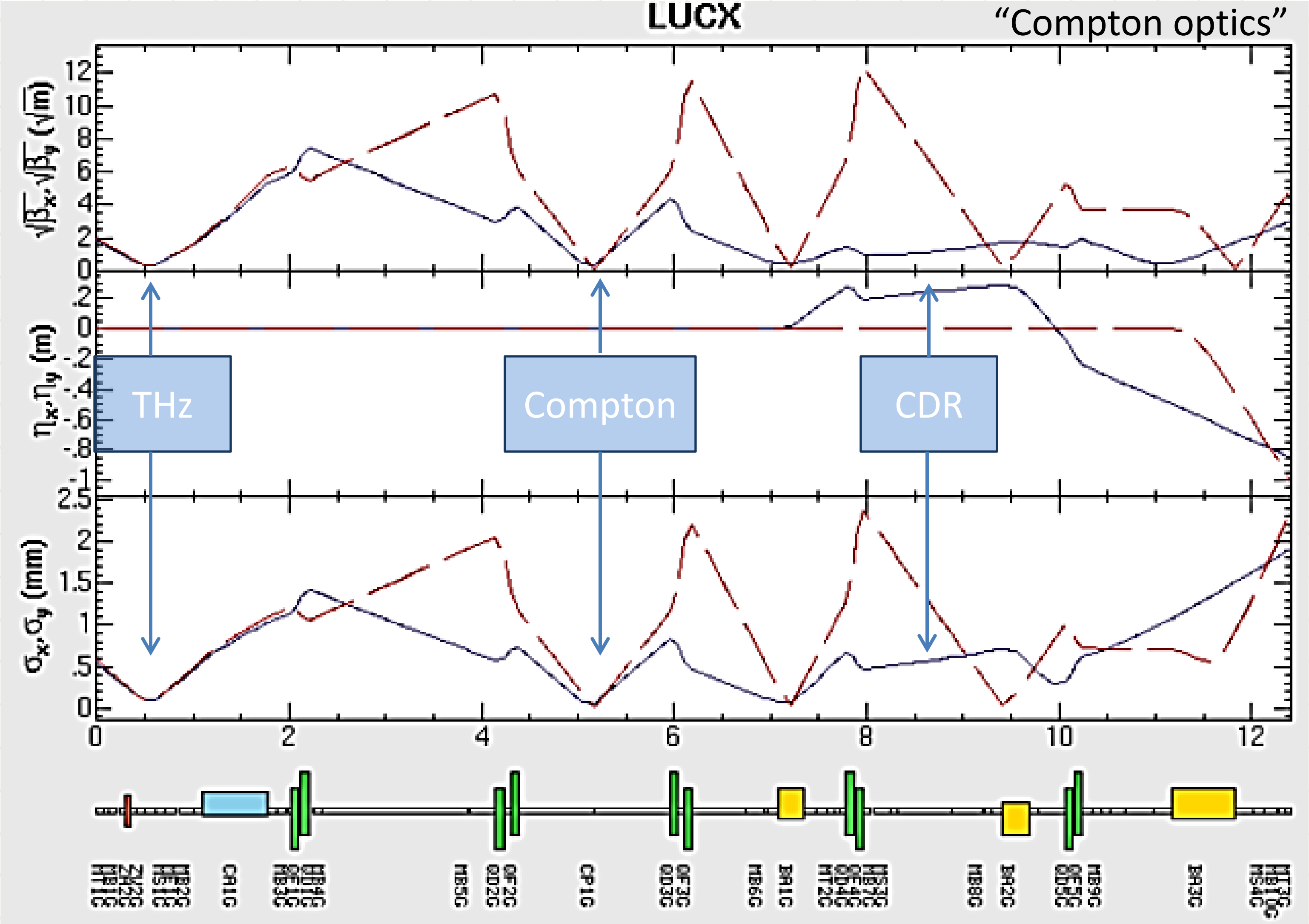
FS ELECTRON BEAM: GENERATION, MEASUREMENT AND CONTROL

LUCX beamline



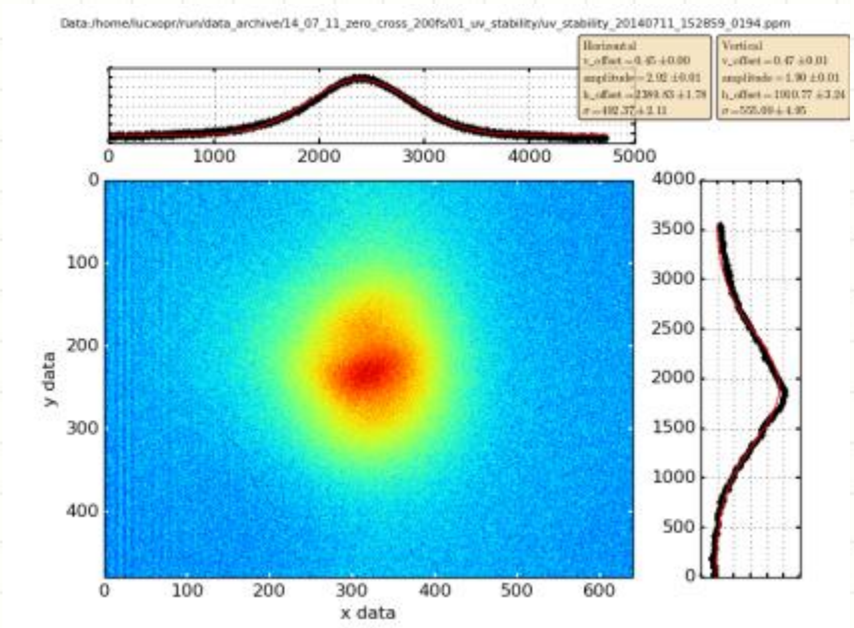

QB(Ur)
12

LUCX “2012 upgrade”, e-optics

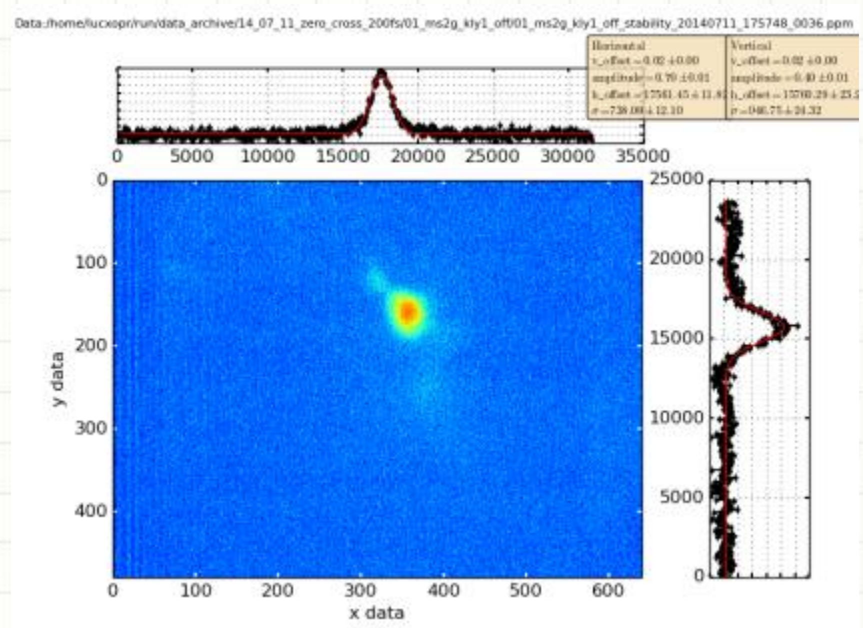


fs e-beam generation

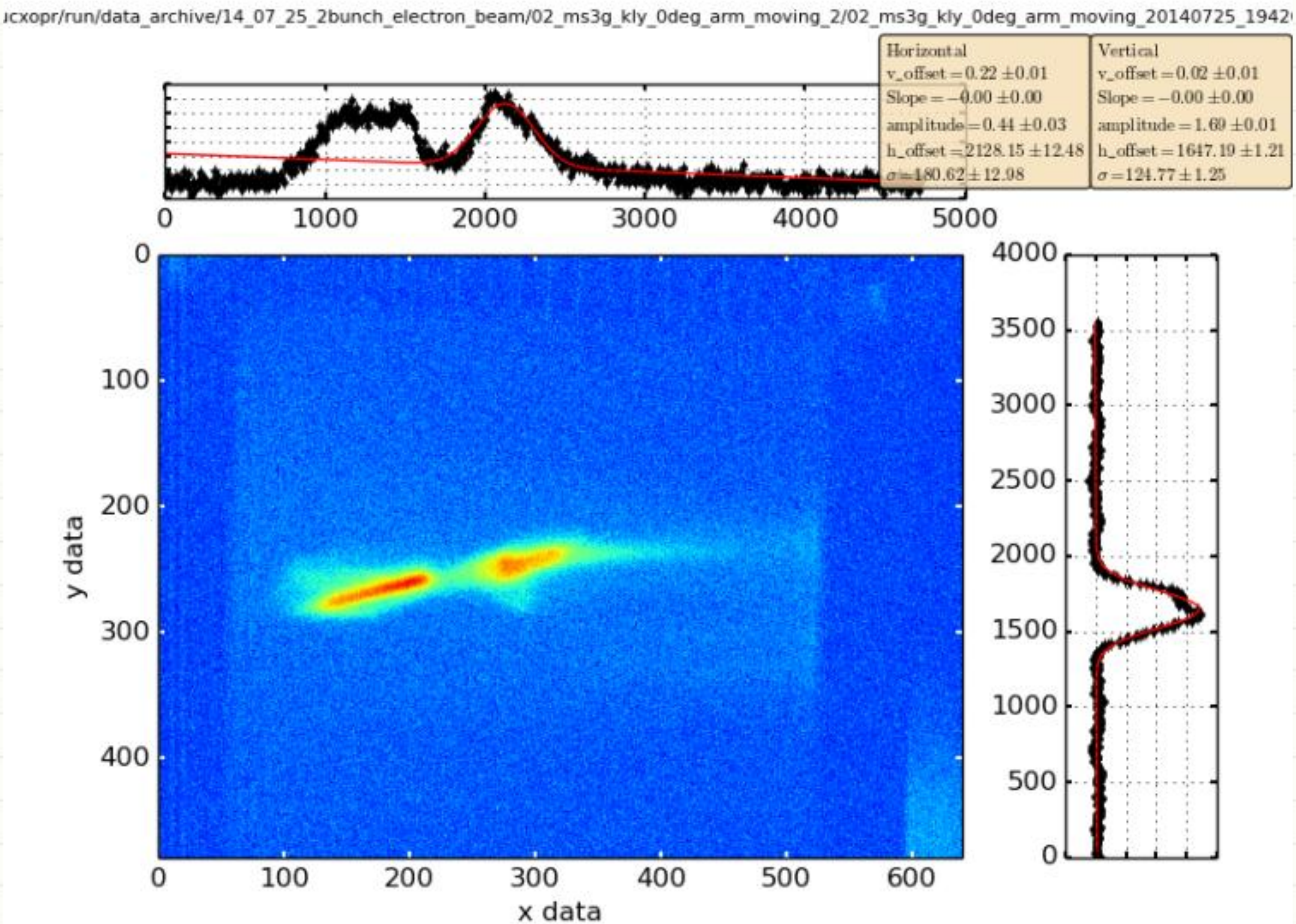
UV



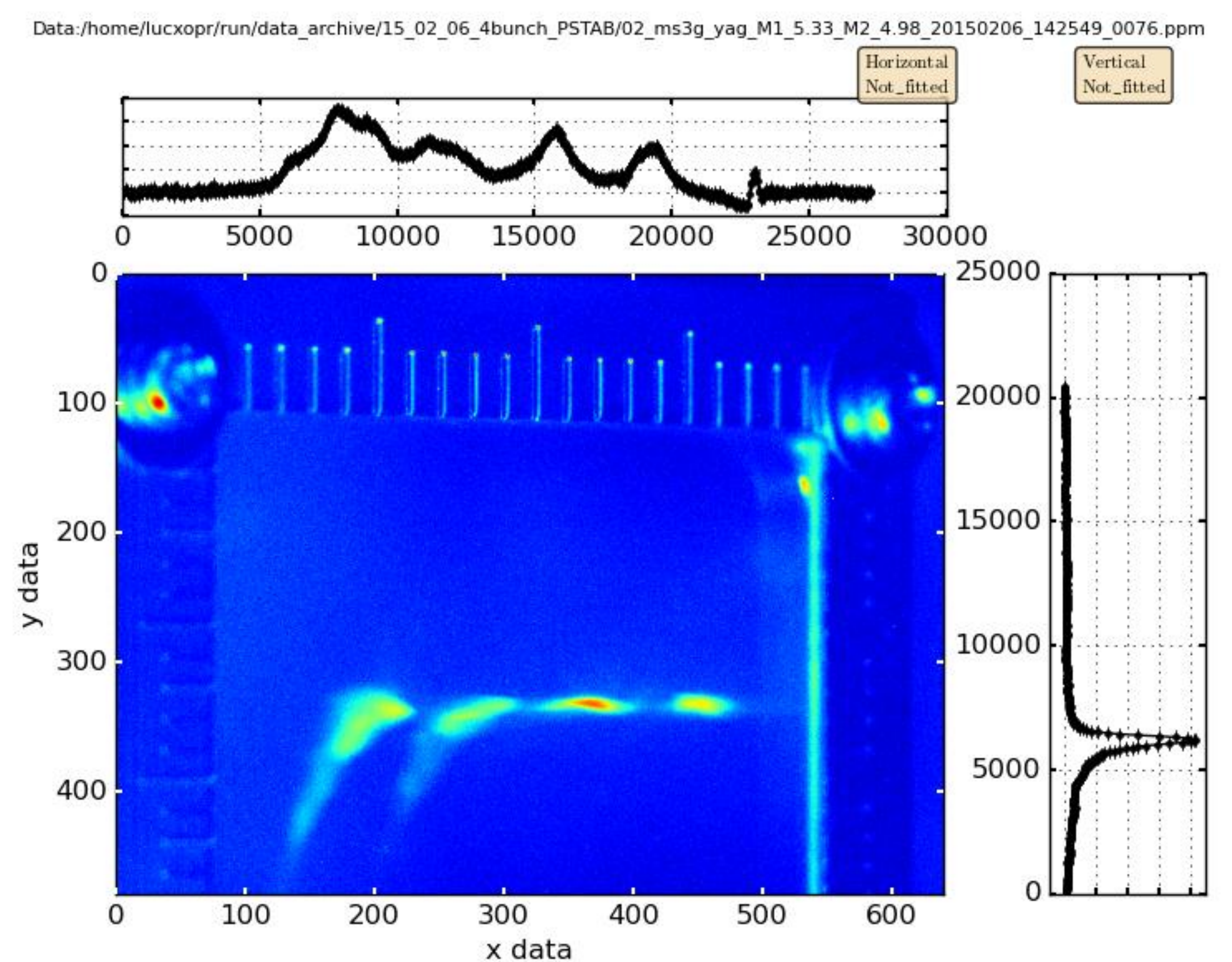
e-beam



Two micro-bunch mode



Four micro-bunch mode



fs e-beam: generation, measurement and control Conclusion & Plans

- e-beam
  - reliable beam generation with repeatable beam condition is achieved.
  - Beam tuning still needed (BBA, emittance compensation optimization, energy spread, bunch length).
  - Bunch length measurements through THz spectrum has to be done in nearest future.
- Laser system
  - “buncher” system is now under upgrade

CONCLUSION, PLANS, SCHEDULE

Schedule & Conclusion

- Work in every direction is ongoing
- FSTB
  - startup: from 22 August 2012
  - Minimum integration & THG from March 2014
  - Non-collinear THG
  - LTL remote diagnostics and control
  - Complete FSTB soft integration
- THz chamber & 5D manipulator
  - Installed December 2013
- LUCX diagnostics
  - BPMs, ICT, OTR – were checked
  - Beam tuning still needed (BBA, emittance compensation optimization, energy spread, bunch length).
  - Bunch length measurements through THz spectrum has to be done in nearest future.
  - Machine stability has to be improved
- Measurement setup, DAQ & Soft
  - QOD and SBD were checked
  - The Michelson interferometer was commissioned
  - Q.E. analysis soft
  - Beam jitter analysis soft

THANK YOU FOR YOUR ATTENTION