Coherent Radiation Spectrum Measurements at LUCX facility & LUCX - THz Program: Overview and Prospects

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On behalf of QB group and
LUCX THz collaboration

ERL beam dynamics group meeting

28 January 2014

Outline

- General motivation(s)
- THz project overview
  - LUCX activity, LUCX Projects Overview, THz program
- LUCX Laser system (briefly)
- LUCX 2012 upgrade
  - LUCX operation modes, e-beam optics
  - Vacuum system, 5D manipulator
- Measurement setup and DAQ THz spectrometer for LUCX
  - Michelson Interferometer
  - Detector
  - Motion system
  - Beam Splitter
  - Experiment at LUCX facility
  - Signal Study
  - Investigation of detector linearity
  - Autocorrelation measurement and spectrum reconstruction
- Schedule &Conclusion & future plans

General motivation

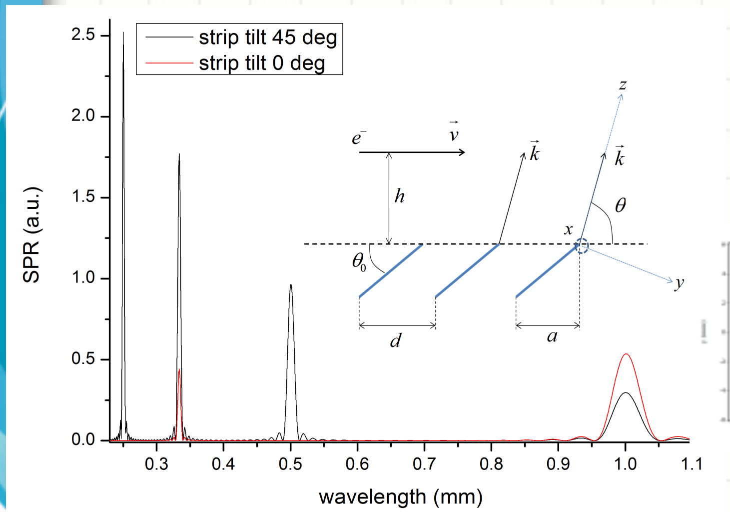
- Construction of a stable and tunable laser system for RF gun development and THz radiation sources tests based on modern technology.
- Build a broad collaborative network among leading institutions worldwide.
- Develop state-of-the-art tunable coherent THz radiation sources on the basis of a compact (preferably table-top) accelerator.

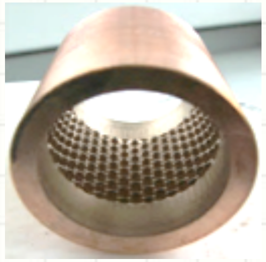
JAI John Adams Institute for Accelerator Science

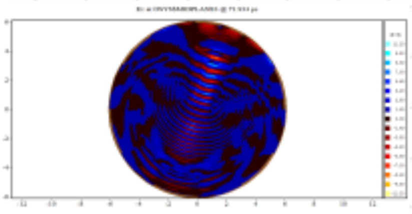
University of Strathclyde Glasgow

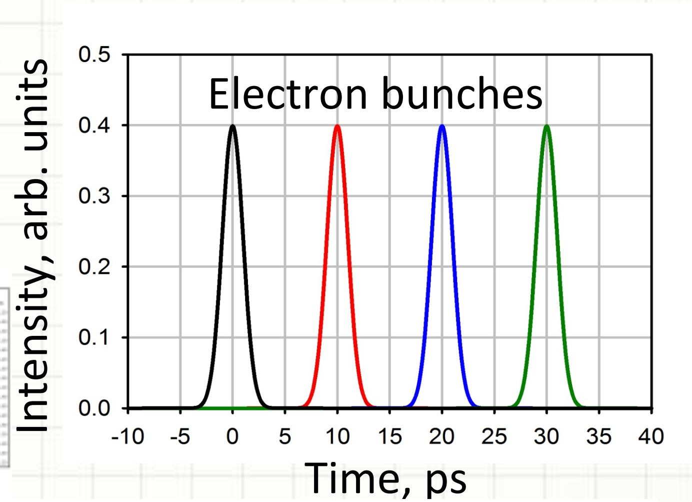
UNIVERSITY OF OXFORD

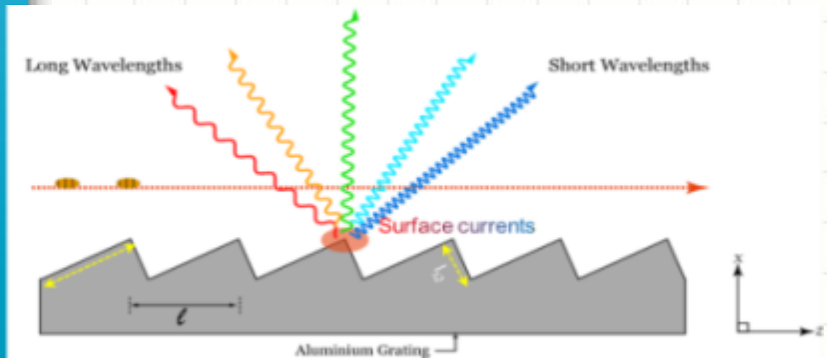
General motivation







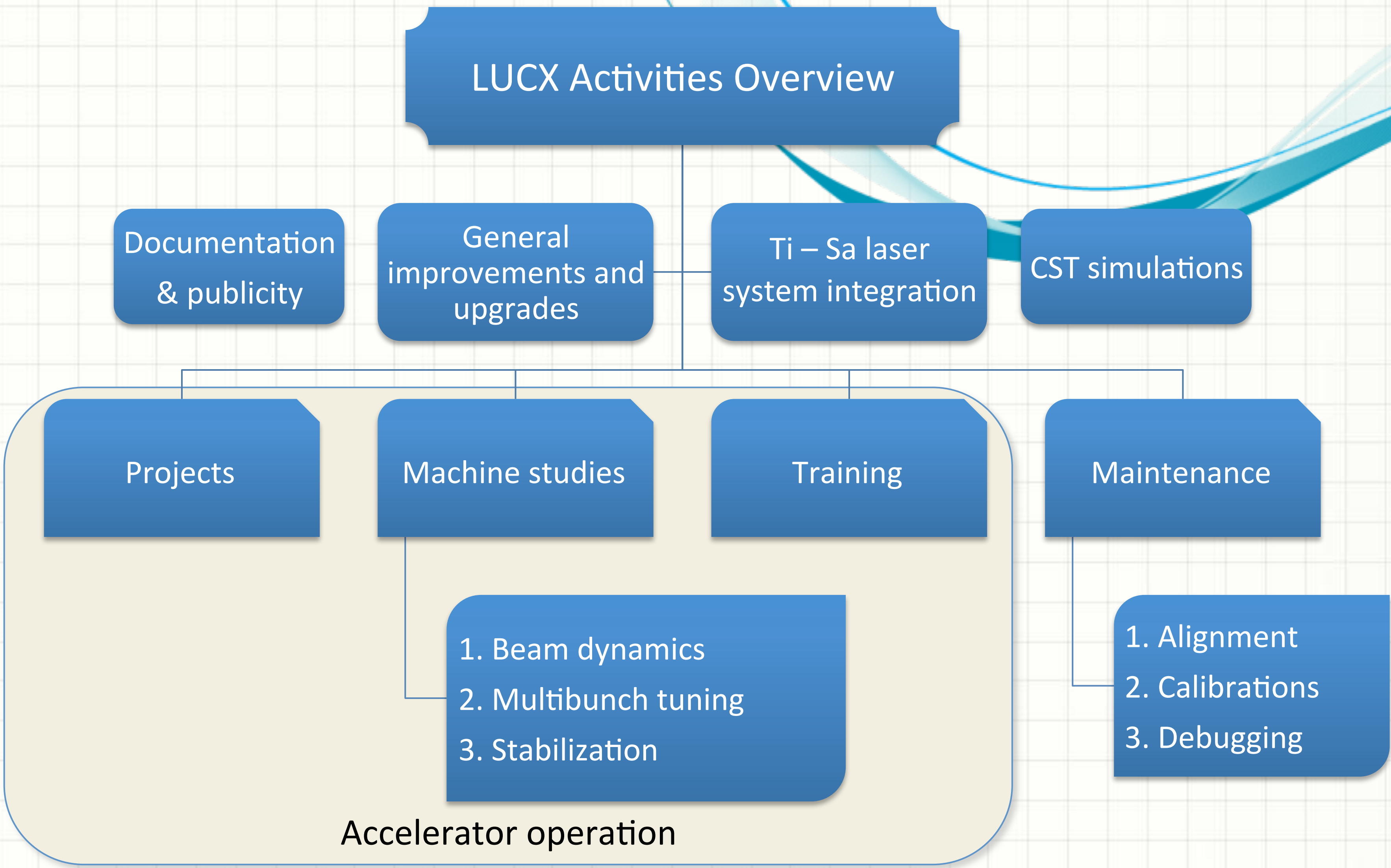


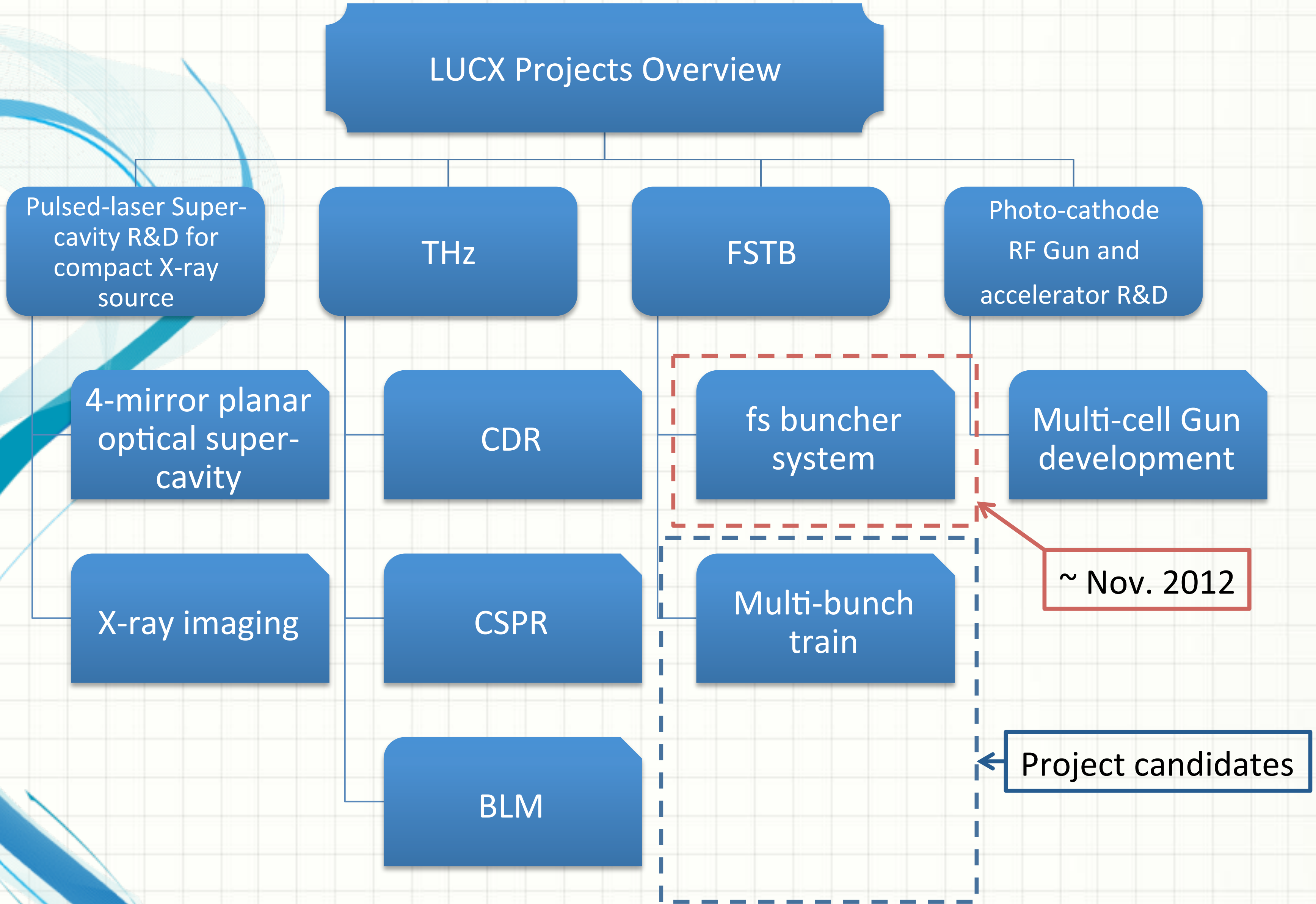


$$\frac{d^2W^s_{tot}}{d\omega d\Omega} = \frac{d^2W_{sing}}{d\omega d\Omega} N_e(1+(N_e-1)|f_l(\omega)|^2)$$

$$\Downarrow$$

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


LUCX Activities Overview
Documentation & publicity
General improvements and upgrades
Ti – Sa laser system integration
CST simulations
Projects
Machine studies
Training
Maintenance
1. Beam dynamics
2. Multibunch tuning
3. Stabilization
1. Alignment
2. Calibrations
3. Debugging
Accelerator operation

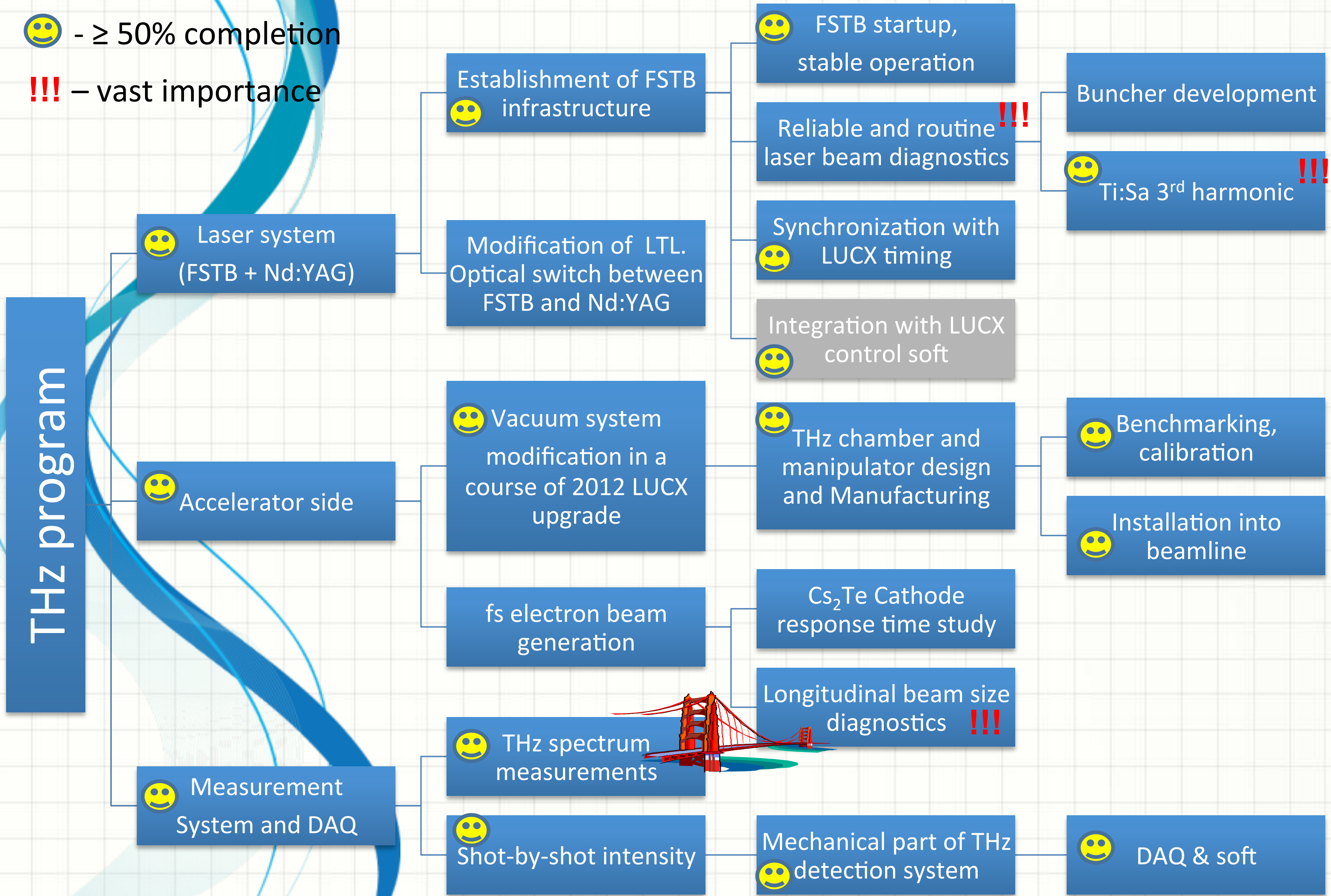

LUCX Projects Overview
Pulsed-laser Super-cavity R&D for compact X-ray source
THz
FSTB
Photo-cathode RF Gun and accelerator R&D
4-mirror planar optical super-cavity
X-ray imaging
CDR
CSPR
BLM
fs buncher system
Multi-bunch train
Multi-cell Gun development
~ Nov. 2012
Project candidates

THz program key points

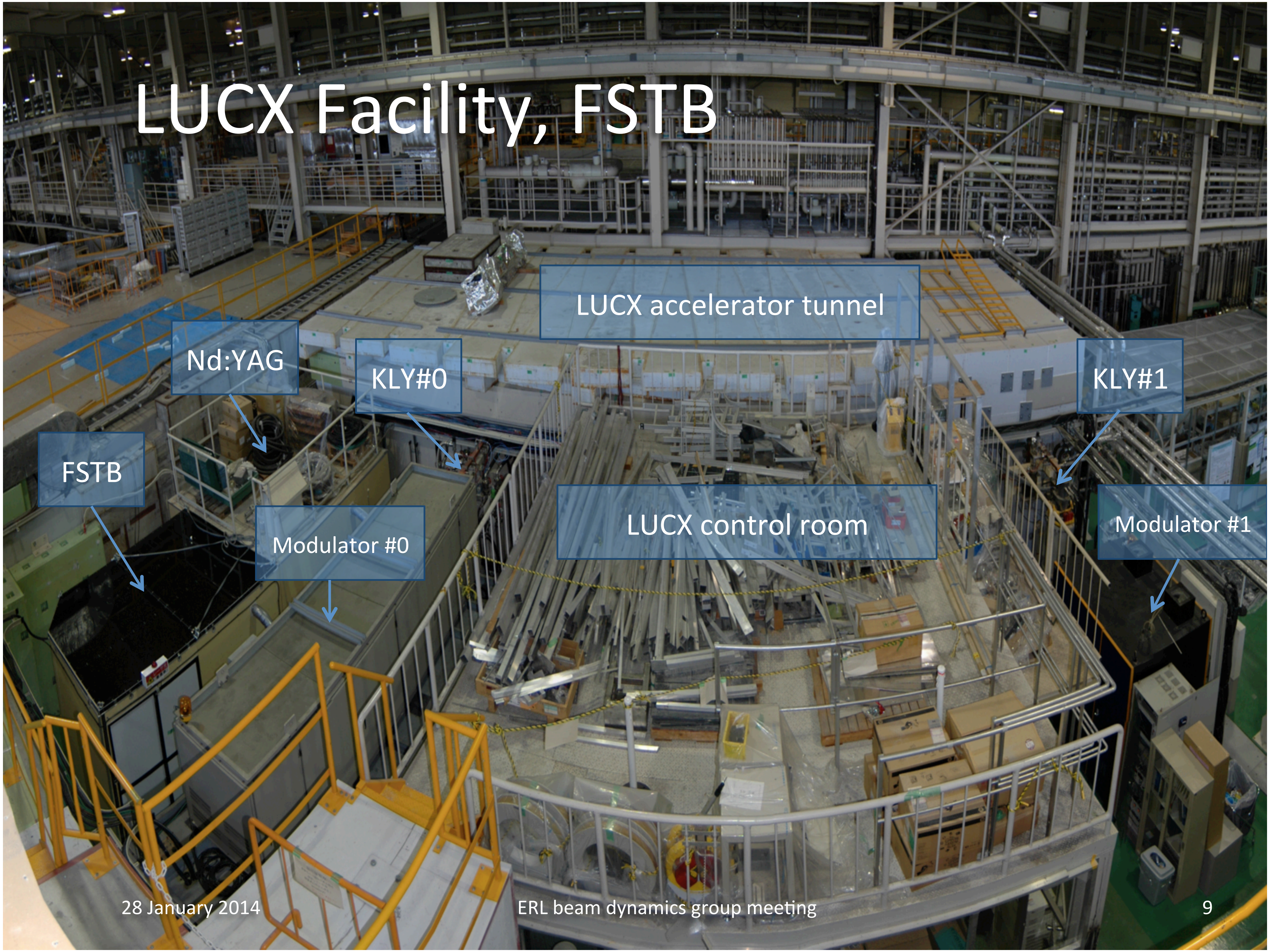
- **Laser system**
  - Stable operation and diagnostics
  - Generation of Ti:Sa 3rd harmonic (265nm) fs laser beam
  - Pointing, energy, mode stability @ 265nm
  - Micro-bunching
- **Accelerator**
  - Generation of fs electron beam
  - Ability to measure longitudinal beam profile
  - Vacuum chamber with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

☺ - ≥ 50% completion

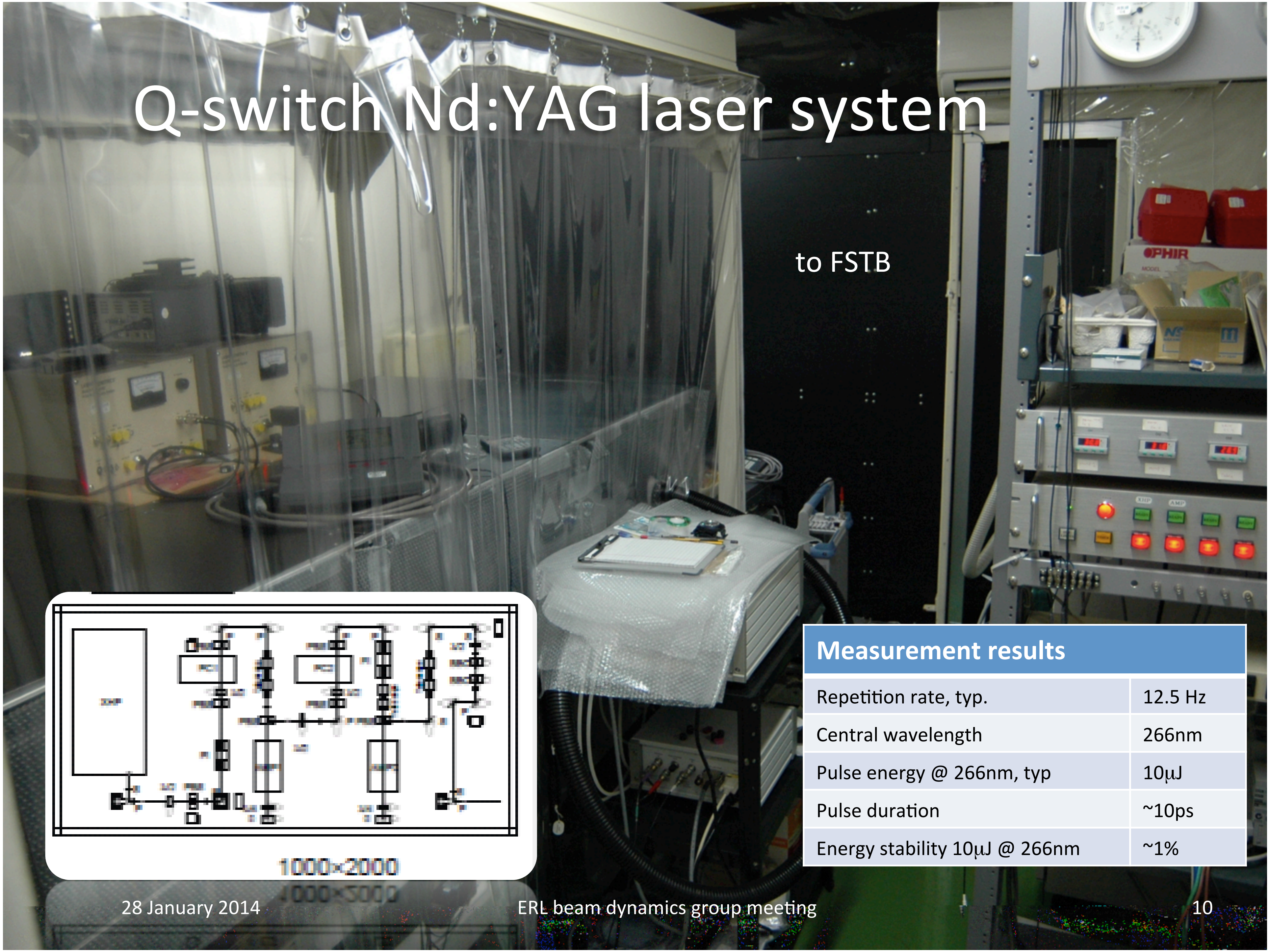
!!! – vast importance



LUCX Facility, FSTB



Q-switch Nd:YAG laser system

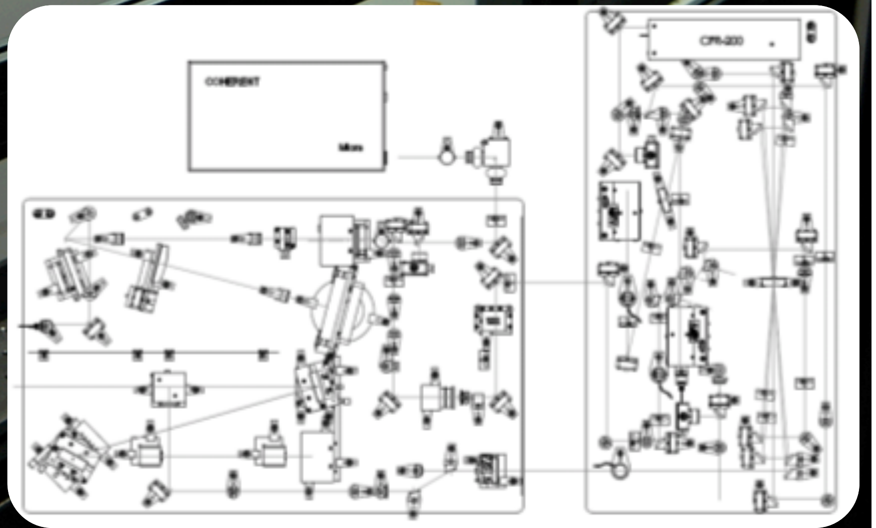


Measurement results	
Repetition rate, typ.	12.5 Hz
Central wavelength	266nm
Pulse energy @ 266nm, typ	10μJ
Pulse duration	~10ps
Energy stability 10μJ @ 266nm	~1%

Ti:Sa laser system (FSTB)

to Nd:YAG

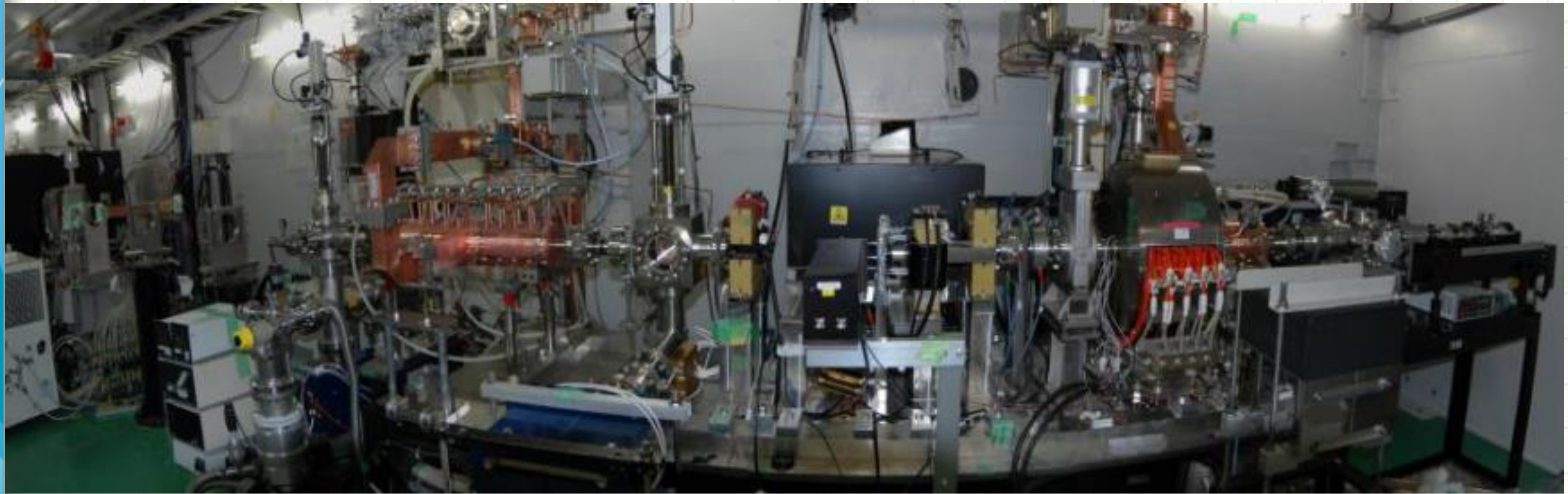
Factory test results	
Repetition rate, max	10Hz
Central wavelength	795nm
Pulse energy before compression	22mJ
Pulse energy after compression	14mJ
Pulse duration w/w-o correction	30/37.7fs
Energy stability 22mJ@800nm	1.6%



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)
- Long term stability
- In-house expertise

LUCX beamline and operation modes



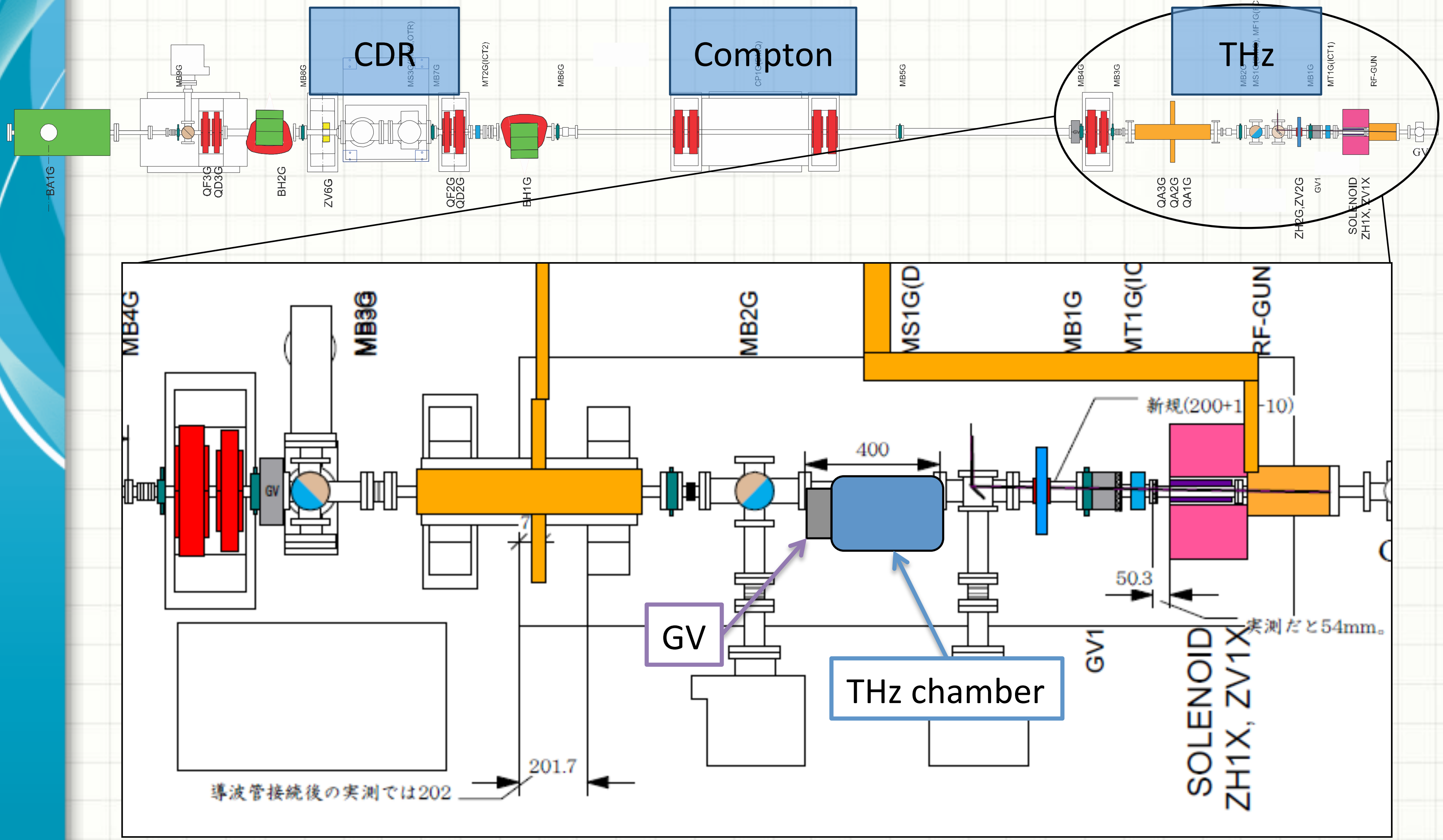
"Femtosecond mode"

- 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

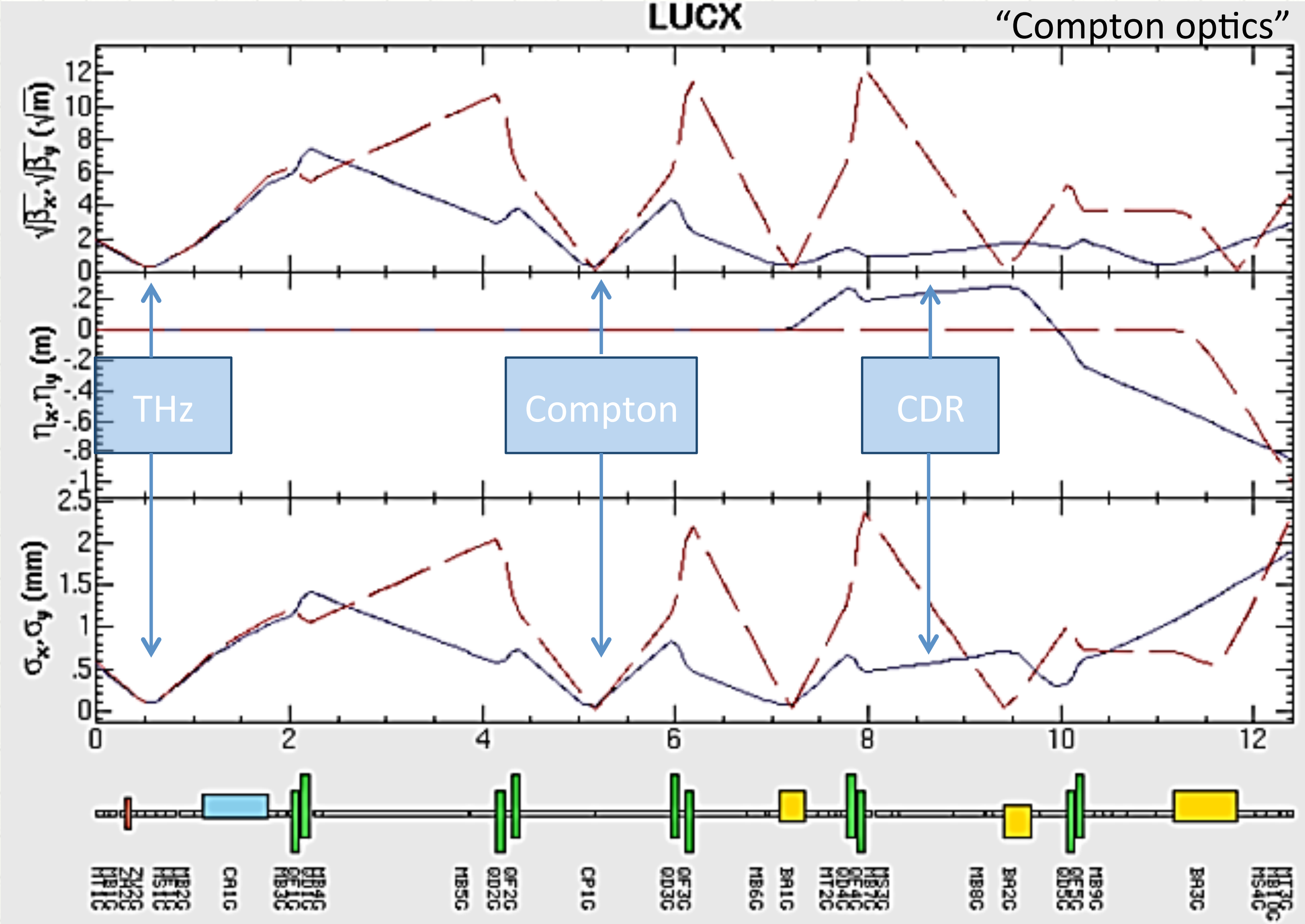
"Picosecond mode"

- 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

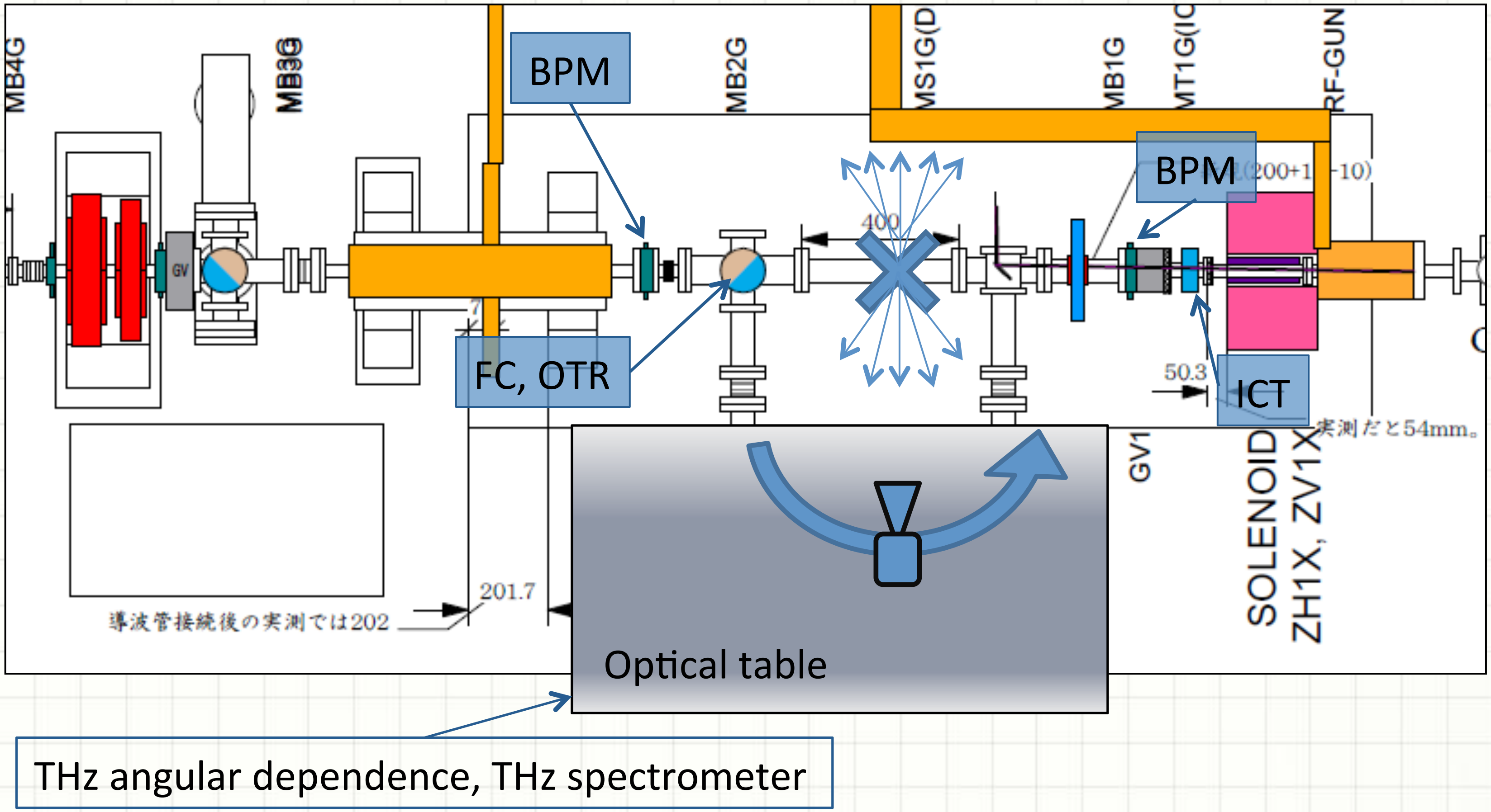
LUCX “2012 upgrade”

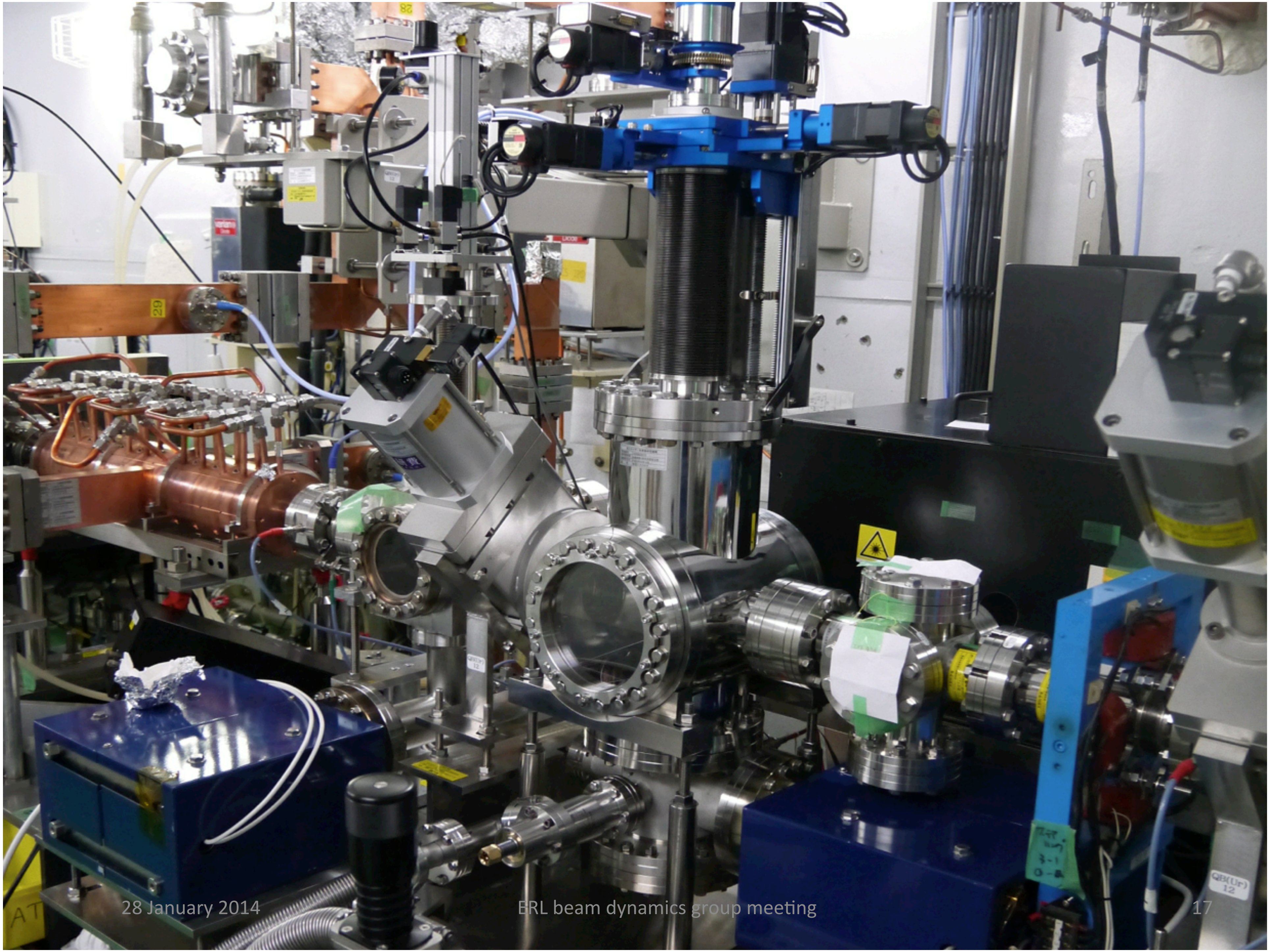


LUCX “2012 upgrade”, e-optics



Measurement setup and DAQ





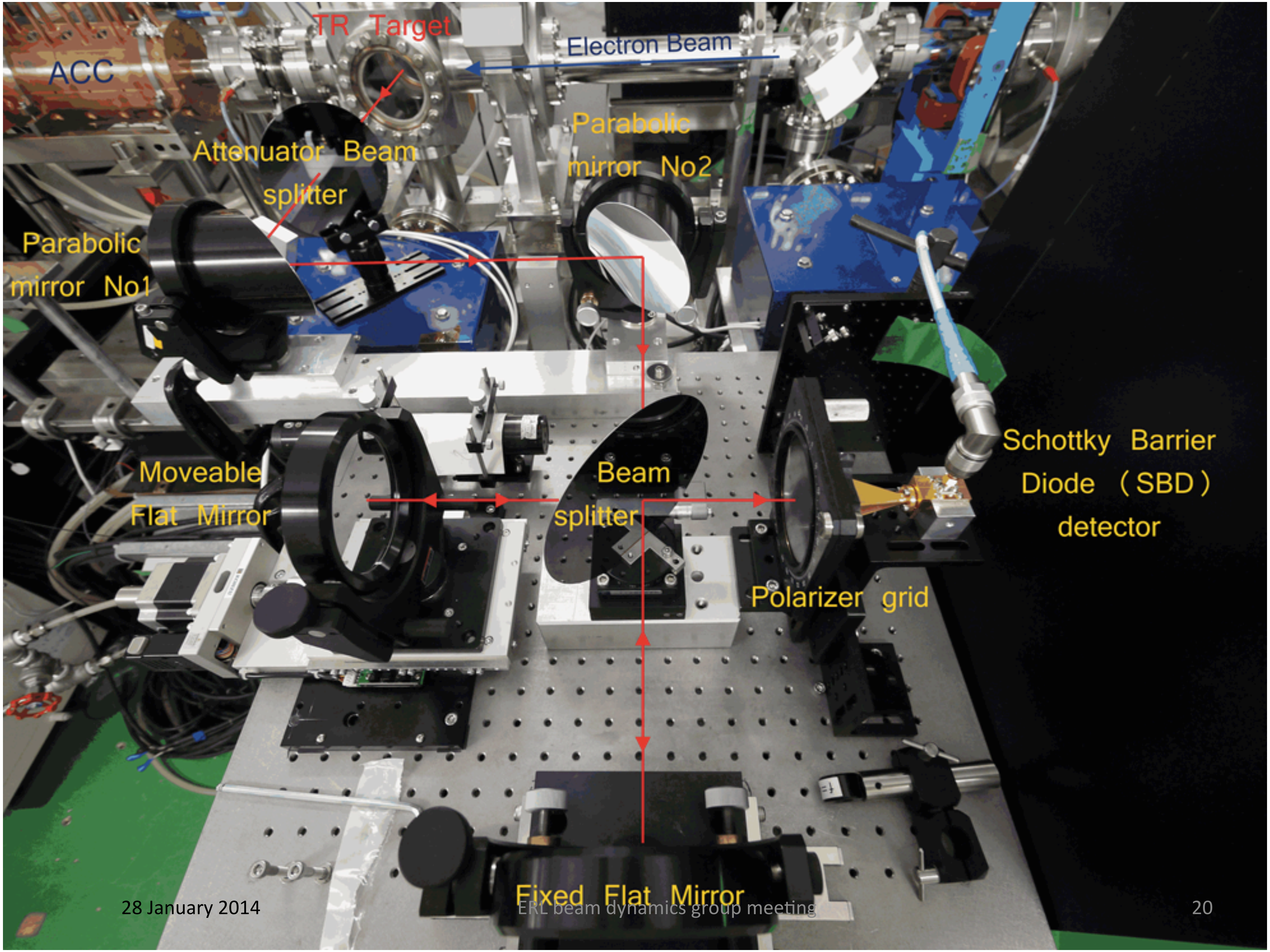
Bunch length measurements

- Direct time-of-flight measurements
  - Streak camera (Profile reconstruction, Single Shot, Expensive, Space-charge limited)
  - Deflecting cavity (Same as above)
  - Cavity-BPM (preliminary) (RMS relative length change, Calibration?)
- Electro-optical methods
  - Profile reconstruction, Single shot
  - http://www-library.desy.de/preparch/desy/thesis/desy-thesis-11-017.pdf
- Methods based on coherent spectrum
  - Spectral measurements
    - Longer wavelengths
    - Lack of broadband detectors
    - Care is needed (absolute calibrations, linearity, spectral responce)
  - Bunch profile reconstruction
    - Complicated mathematics
    - Dependence on radiation generation mechanism

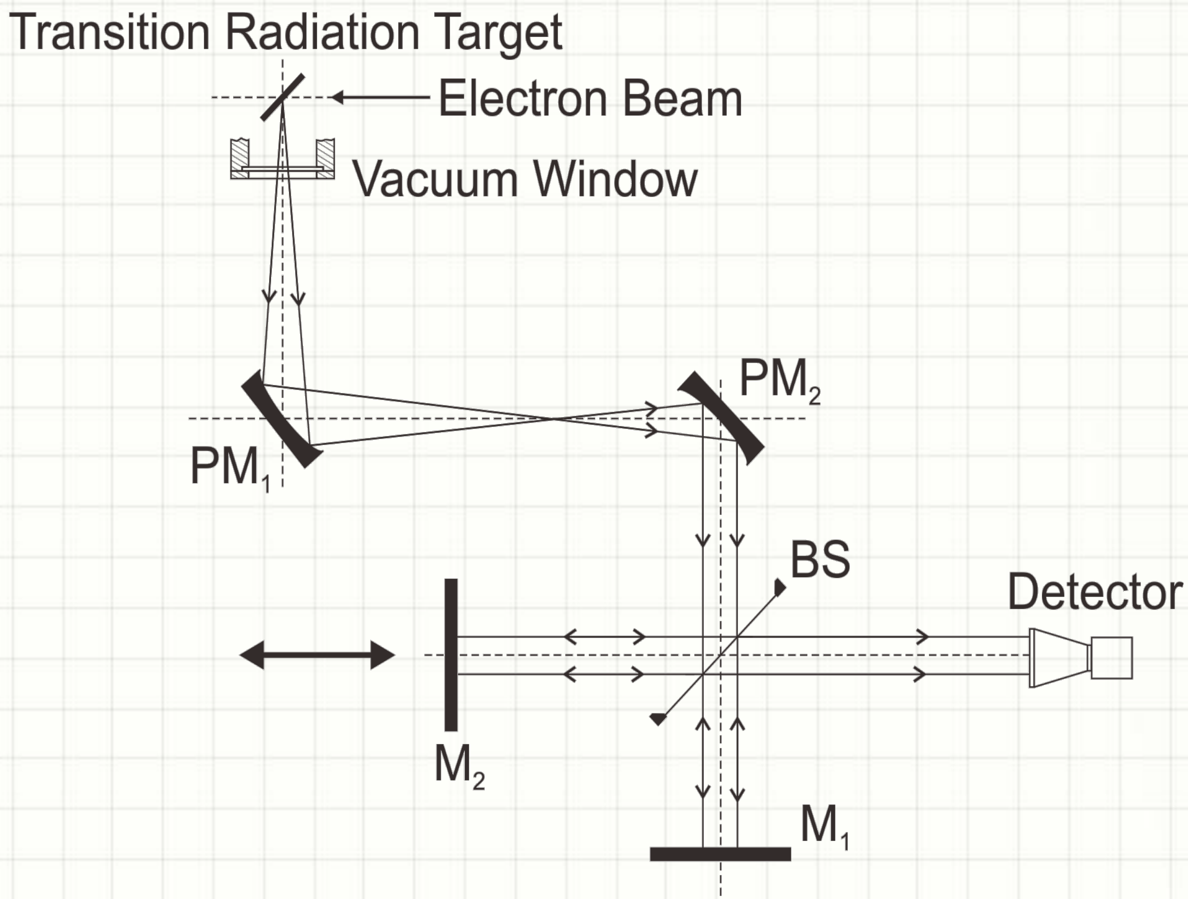
Terahertz Spectrometer for LUCX

(The terahertz spectral range roughly extends from 100 GHz to 10 THz)

- KEK LUCX THz program (http://www-atf.kek.jp/thz/) calls for construction of the Terahertz Spectrometer for systematic and robust measurements.
- Spectral and spatial THz radiation measurements are crucial for THz sources development.
- The coherent radiation spectrum information can be used for longitudinal beam size diagnostic and may be used for bunch profile reconstruction (for example Kramers-Kronig analysis).

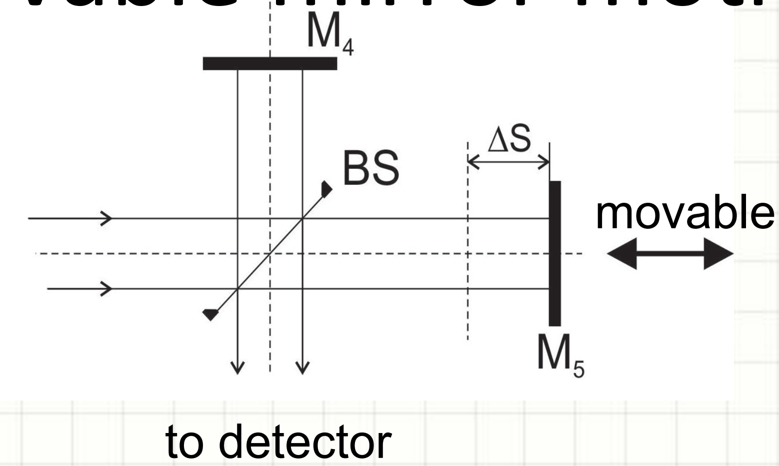

TR Target
ACC
Electron Beam
Attenuator
Beam splitter
Parabolic mirror No2
Parabolic mirror No1
Moveable Flat Mirror
Beam splitter
Schottky Barrier Diode （SBD） detector
Polarizer grid
Fixed Flat Mirror

Michelson Interferometer



Layout of Michelson Interferometer

Movable mirror motion accuracy

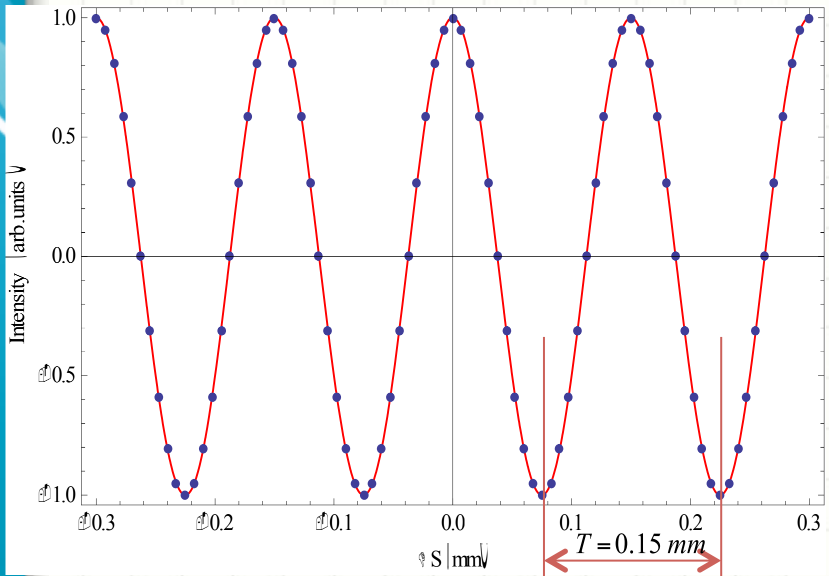


Michelson Interferometer

$$I_{total} = I(1+\cos[\frac{4\pi \cdot \Delta s}{\lambda}])$$

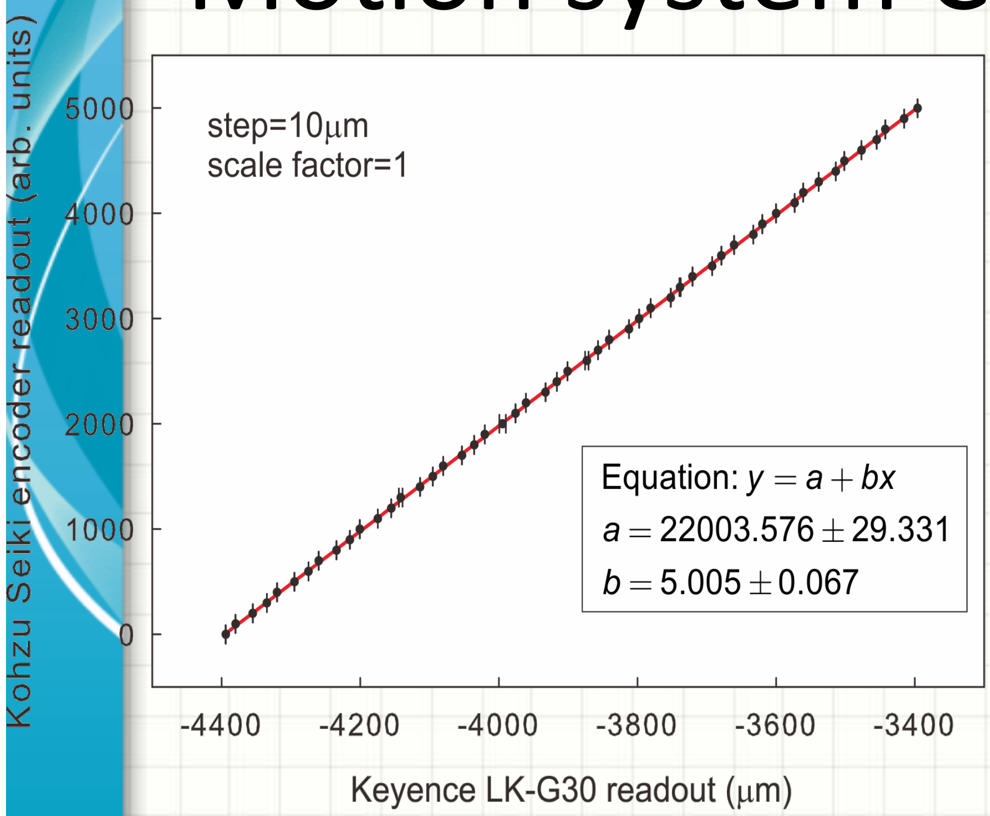
$$T = \frac{2 \cdot \Delta S}{\lambda}$$ - period of cosines;

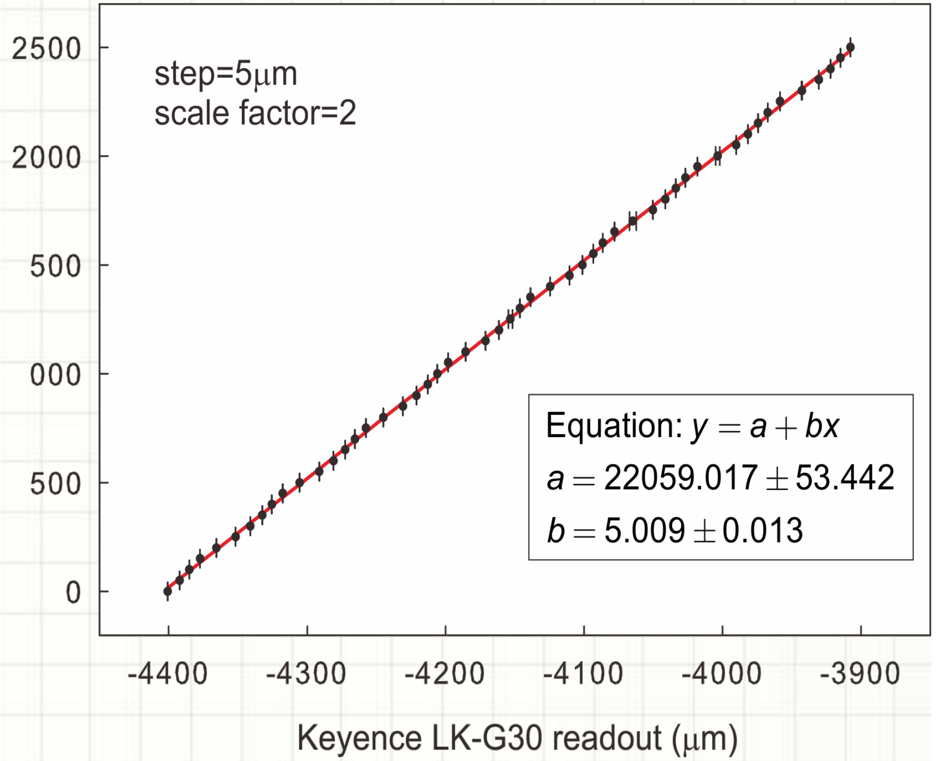
for $\nu = 1\,\text{THz} \Rightarrow \lambda = 0.3$ mm



For good approximation ~20 experimental data point per autocorrelation period will be needed, so for ν=1THz the mirror M_5 should be moved with the step of 7.5μm.

Motion system Calibration





The error of measurements is equal to about several tens of nanometers
The smallest mechanical resolution achieved at the test bench is 200 nm.

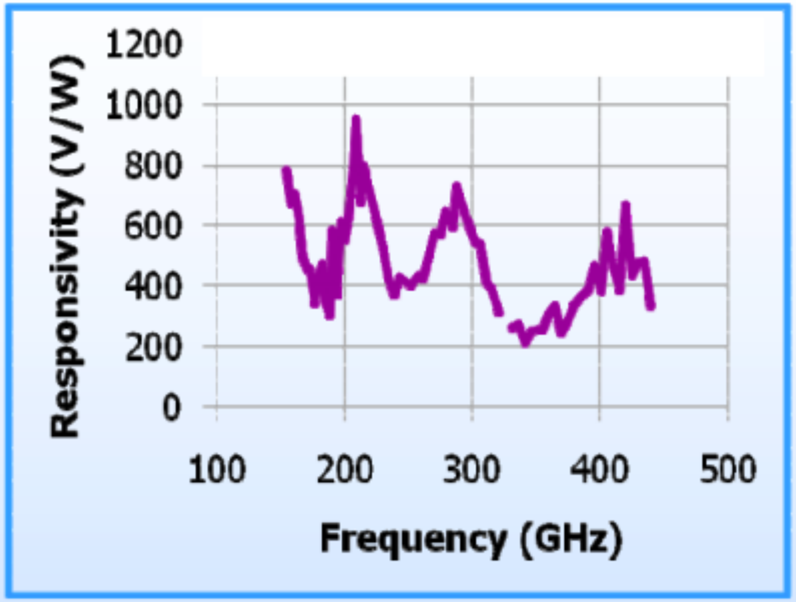
Detectors

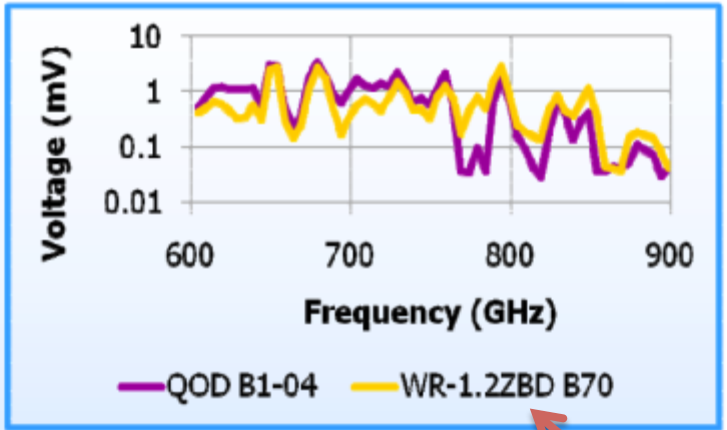
Detector	Parameter	Value
Schottky Barrier Diode Detector	Frequency Range	60-90 GHz
	Wavelength Range	3.33-5 mm
	Response Time	~ 250 ps
	Antenna Gain	24 dB
	Input Aperture	30×23 mm
	Video Sensitivity	20 mV/mW
Schottky Diode Quasi-Optical Detector	Frequency Range	100-1000 GHz
	Wavelength Range	3-0.3 mm
	Response Time	Sub-ns
	Antenna directivity	25-35 dB
	Video Sensitivity	500 V/W

Quasi-Optical Broadband Detector

Virginia Diodes, Inc.

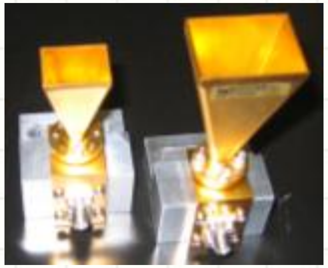
- Frequency Range 100- 1000 GHz
- Responsivity 500 V/W typical
- Antenna directivity 25-35 dB nom
- Sub-ns response time
- …but calibration done for CW



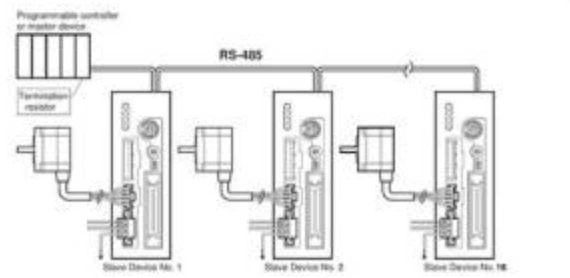


another THz detector

Measurement setup and DAQ



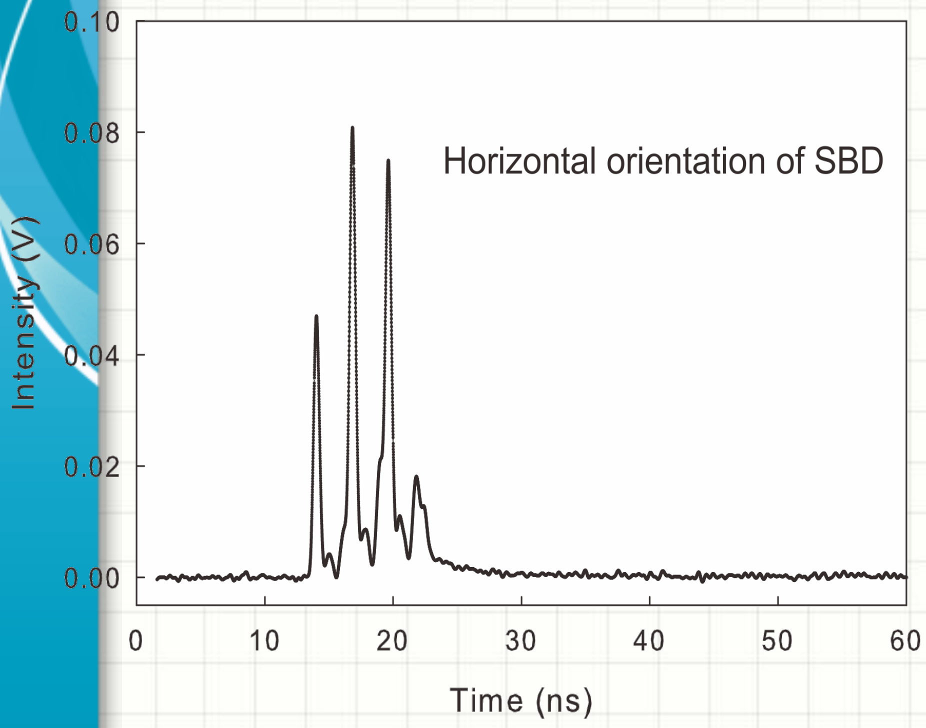
- Detectors
  - SBD 60 – 90 GHz
  - SBD 90 – 140 GHz
  - Gamma detector
  - Quasi-Optical Detector Frequency Range 0.1-1 THz
- DAQ
  - Oscilloscope 1GHz, 5GS/s
  - Fast digitizer ?
- Motorization
  - Similar to CDR (Oriental motors + controllers)
  - Raspberry Pi
- Soft
  - Qt GUI, EPICS, python scripts
  - Data format

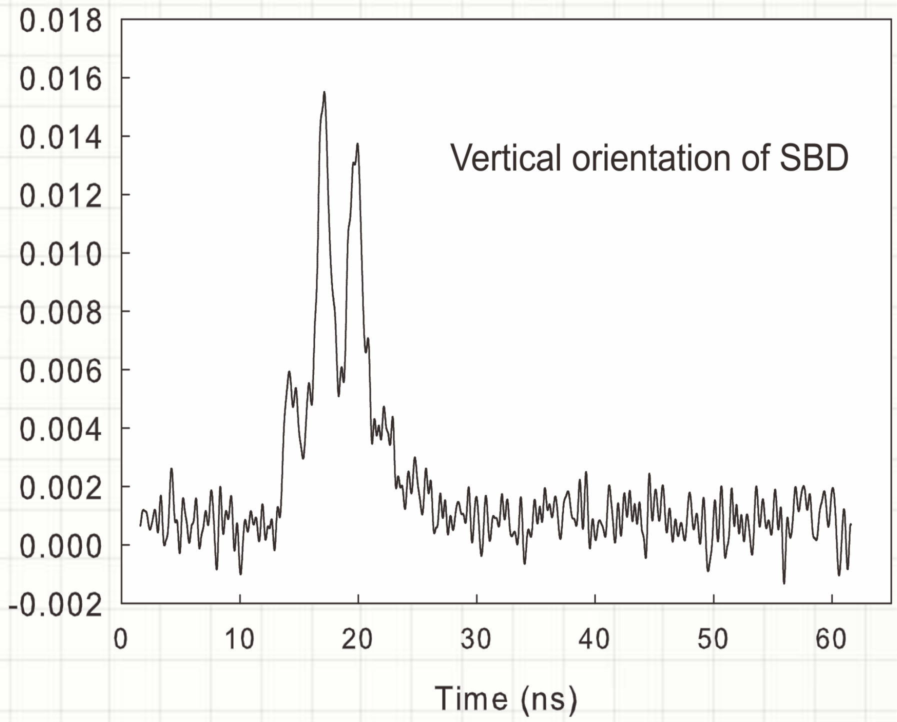


Experimental results

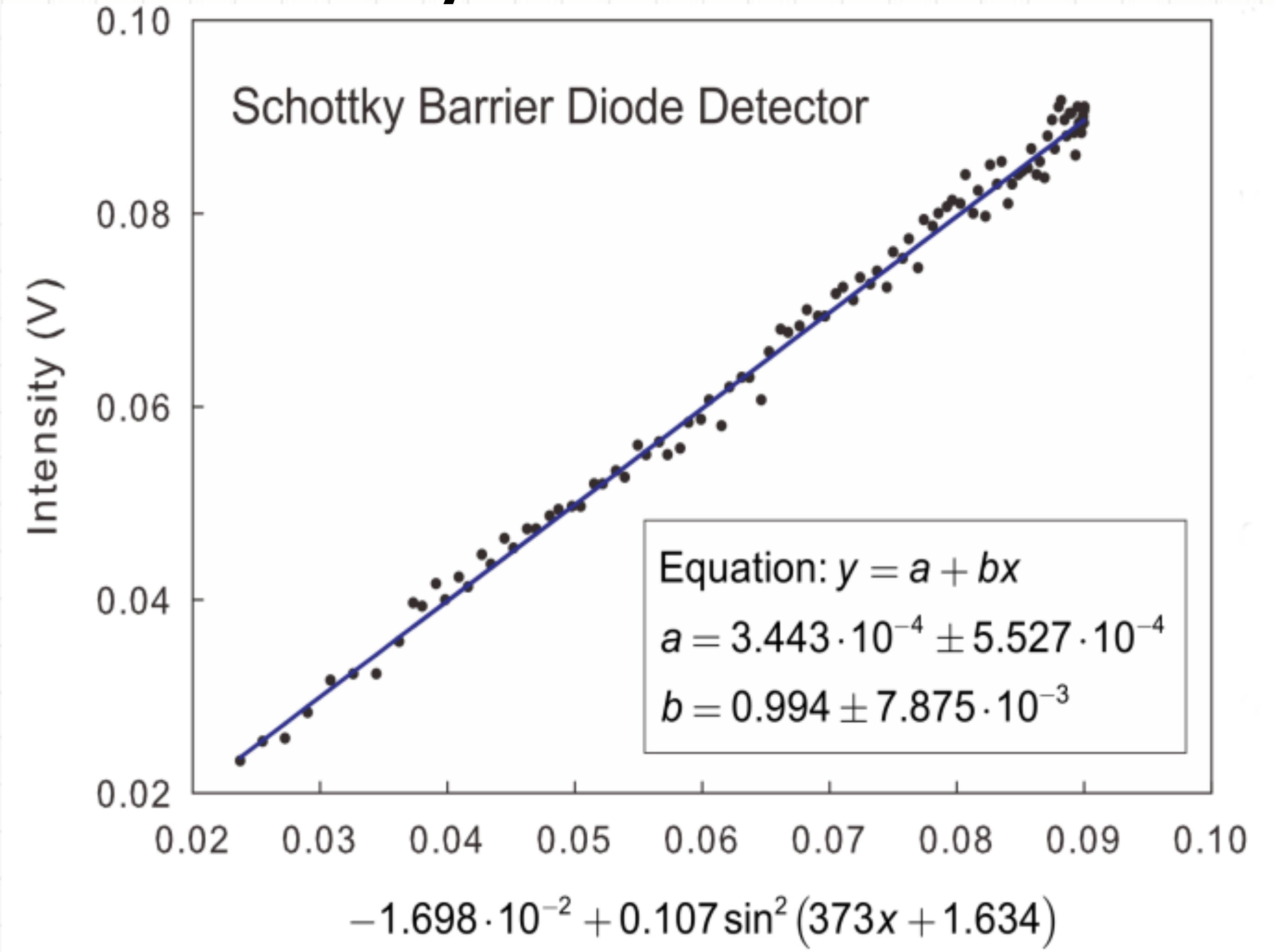
- Detectors Signal study
  - Schottky Barrier Diode Detector (SBD)
  - Quasi-Optical Broadband Detector (QOD)
- Detectors linearity measurements
- Spectrum measurements

SBD signal examples and polarization sensitivity

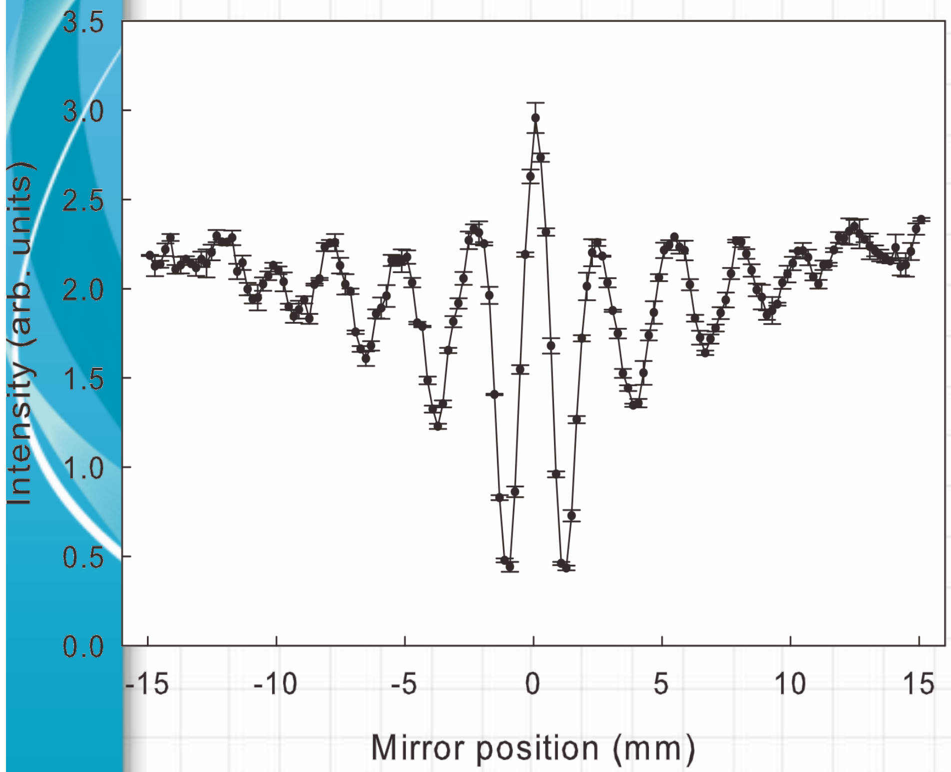


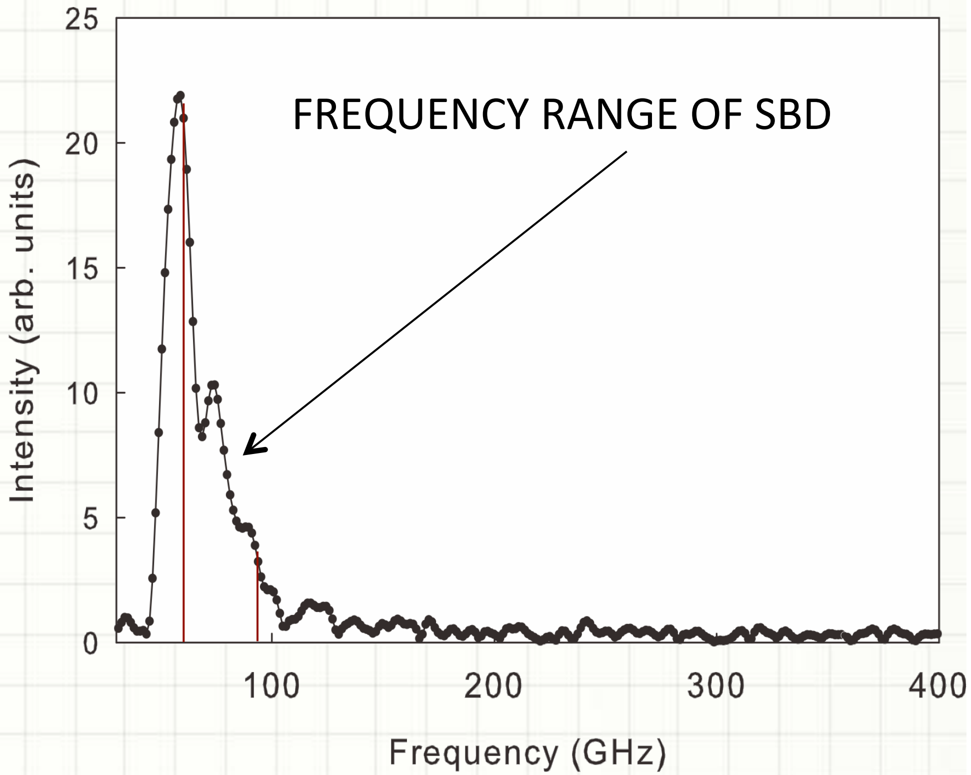


SBD linearity



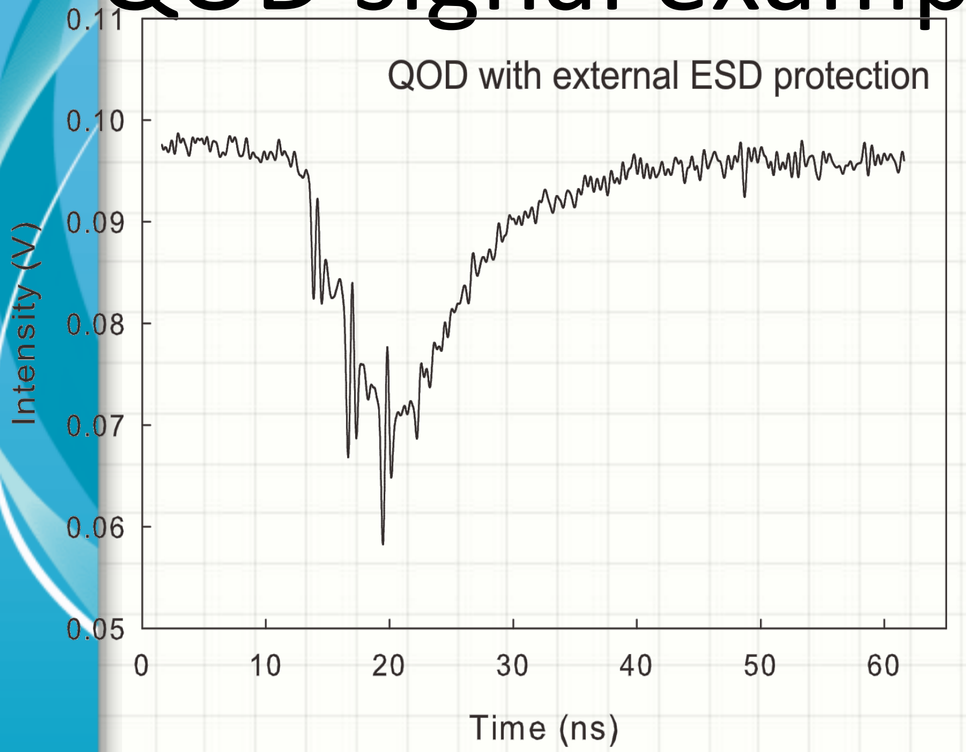
Autocorrelation dependence measured by SBD

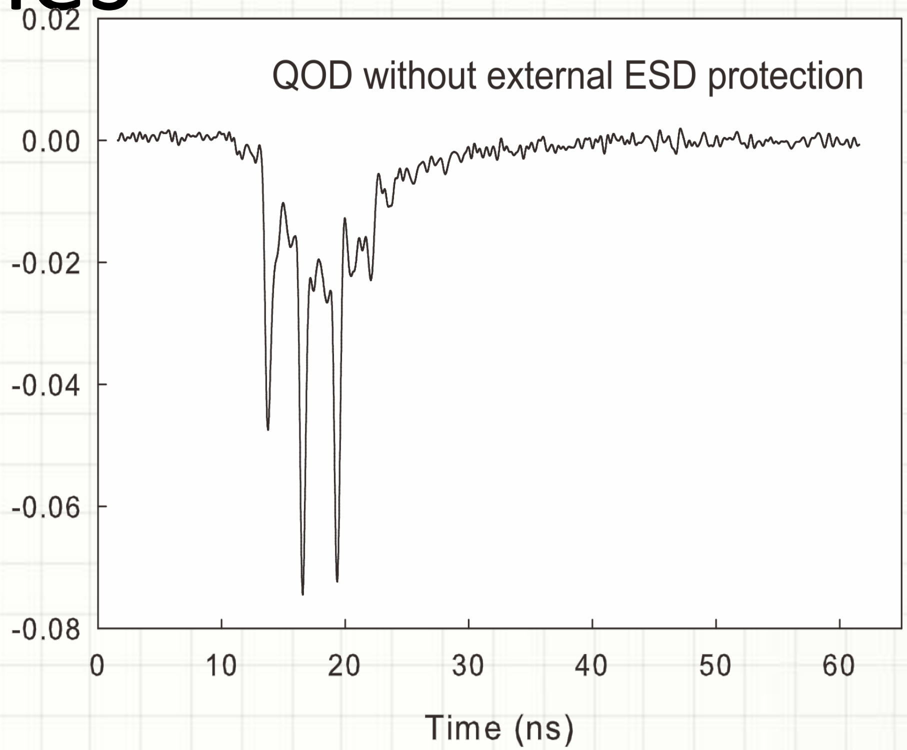




There is not enough information about real coherent radiation spectra.
Reconstructed spectra shows only SBD spectral response.
Most certainly we need better SBD calibration.

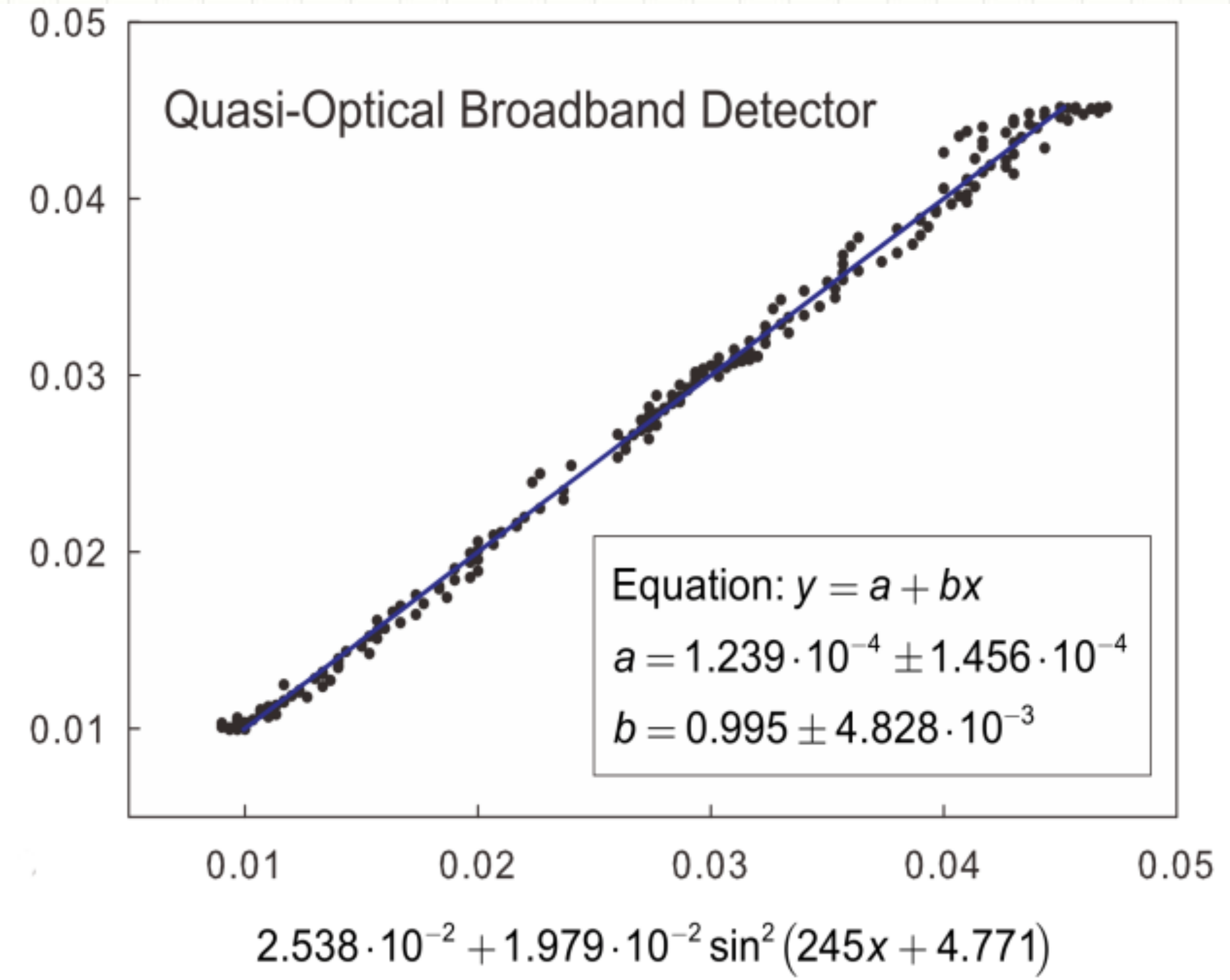
QOD signal examples



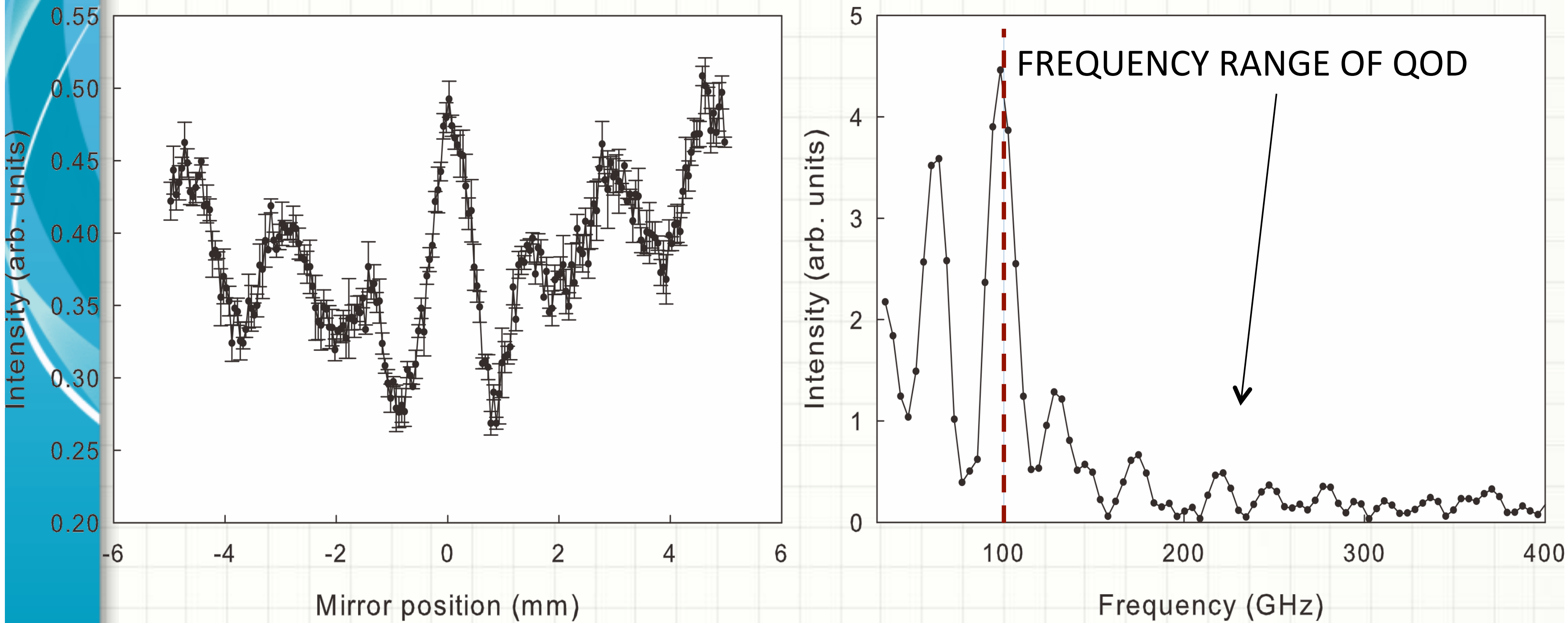


- The QOD detector connected to external RF line is susceptible to damaging electrostatic discharge (ESD) pulses from the peripherals. As shown from figure (right), the additional external protection device can decrease detector responsivity.
- The QOD signal measured without external ESD protection is shown at figure (left). The detector sensitive increases rapidly, nevertheless it was much lower than what we expected. Nevertheless the quality and intensity of THz QOD signal were enough for polarization and linearity tests.

QOD linearity



Autocorrelation dependence measured by QOD



Definitely much shorter bunch length is needed for using QOD detector more efficiently.

Schedule & Conclusion

- Work in every direction is ongoing
- FSTB
  - startup: from 22 August 2012
  - Full integration & THG by March 2014
- THz chamber & 5D manipulator
  - Installed December 2013
- LUCX diagnostics
  - BPMs, ICT, OTR – has to be checked
  - BLM – has to be developed
- Measurement setup and DAQ
  - QOD and SBD were checked
  - The Michelson interferometer was commissioned

Near Future plans

- Laser transport line modification (Feb. 2014)
- THz station final installation (Feb. 2014)
- fs e-beam generation (~ Mar. 2014)
  - Coherent radiation spectrum measurement
  - Bunch length reconstruction
  - Deflecting cavity ?
- Collaboration experiments
  - KEK (CSPR, CTR, etc) ~ Apr. 2014
  - Oxford (3D THz structures) ~ Sep. 2014

Resources

- THz program web:
  http://www-atf.kek.jp/thz/index.html
- LUCX wiki (documentation, e-log, etc.):
  http://atf.kek.jp/twiki/bin/view/LUCX/WebHome
- QB program web:
  http://kocbeam.kek.jp/
- E-mails
  - Aryshev Alexander : alar@post.kek.jp
  - Shevelev Mikhail : mishe@post.kek.jp