THz Coherent Transition Radiation at *TeraFERMI*:

First Characterization of THz Radiation and Electron Beam Dynamics

S. Di Mitri, *Elettra Sincrotrone Trieste*

on behalf of:

A. Perucchi, L. Capasso, P. Di Pietro, F. Giorgianni, S. Lupi, E. Roussel, C. Svetina, M. Veronese, E. Allaria, L. Badano, S. Bassanese, M. Bossi, B. Diviacco, M. Ferianis, E. Ferrari, G. Gaio, D. Gauthier, F. Gelmetti, L. Giannessi, S. Grulja, M. Milloch, G. Penco, M. Trovò, C. Serpico.

THz Sources @ Elettra Sincrotrone Trieste

FERMI FEL User Facility

- HGHG FEL (driven by external laser)
- User facility: alternate FEL1 / FEL2
- $\leq 300\ \mu J$, $\Delta t \leq 150$ fs fwhm, $\Delta\lambda/\lambda \approx 3\times10^{-4}$

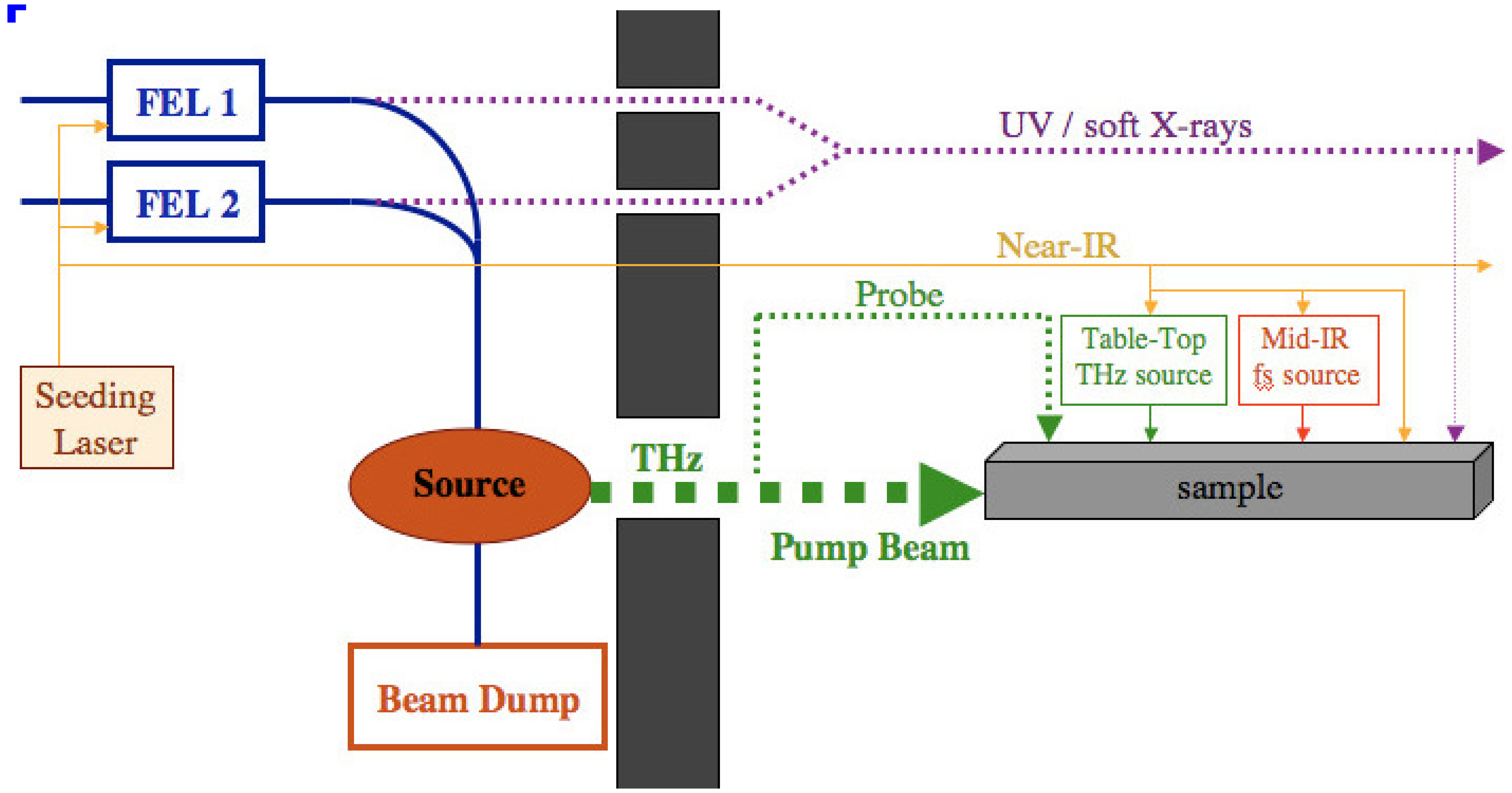
- High brightness e-beam from photo-injector
- S-band single pulse accelerator
- 700 pC, 600 A, 600 fs fwhm

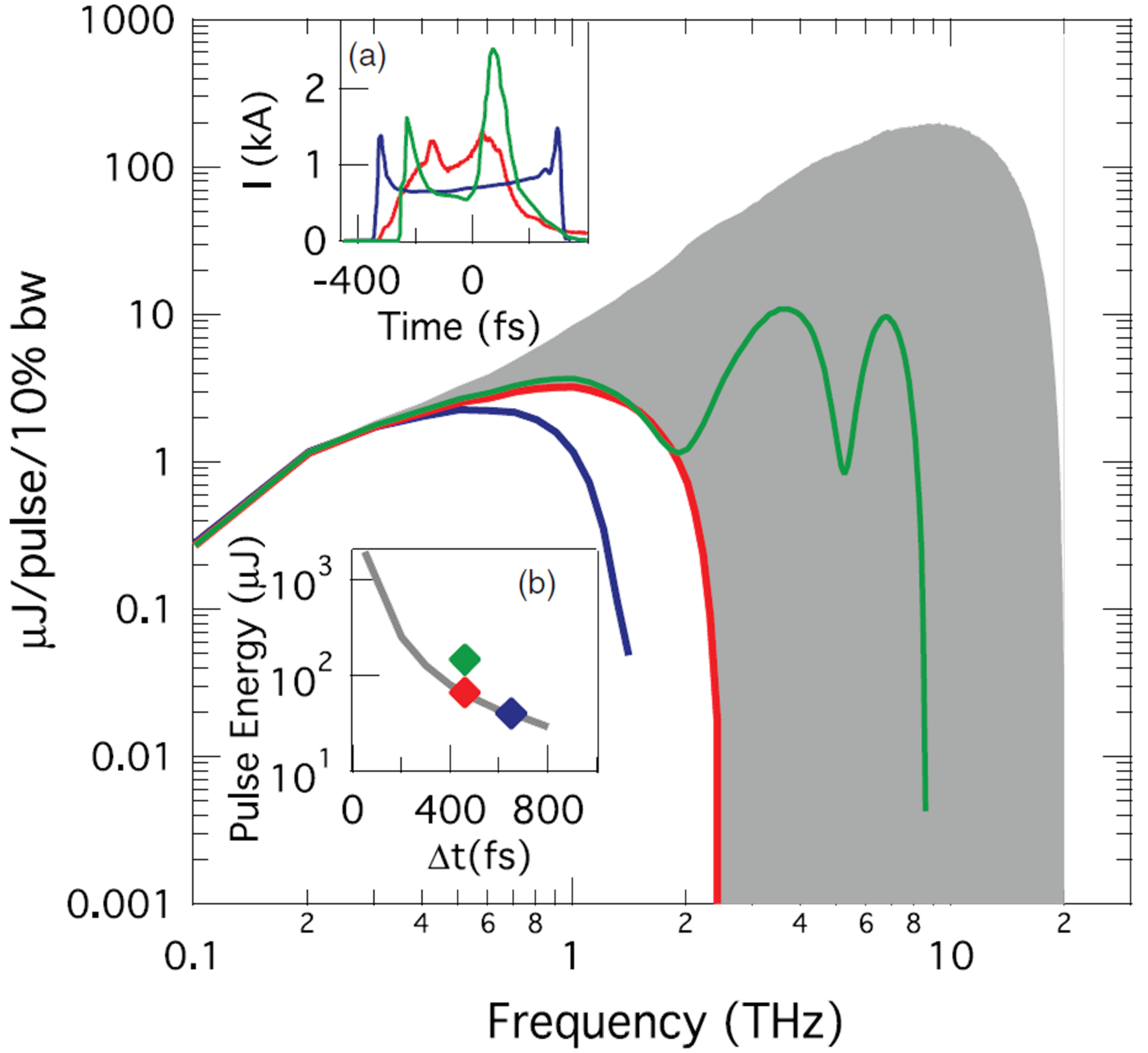
- **Exploiting the already existing FERMI LINAC:** reduced construction and operation costs
- **Parasitic THz emission:** will not affect FEL beamtime, while THz light is always available

TeraFERMI Specs.

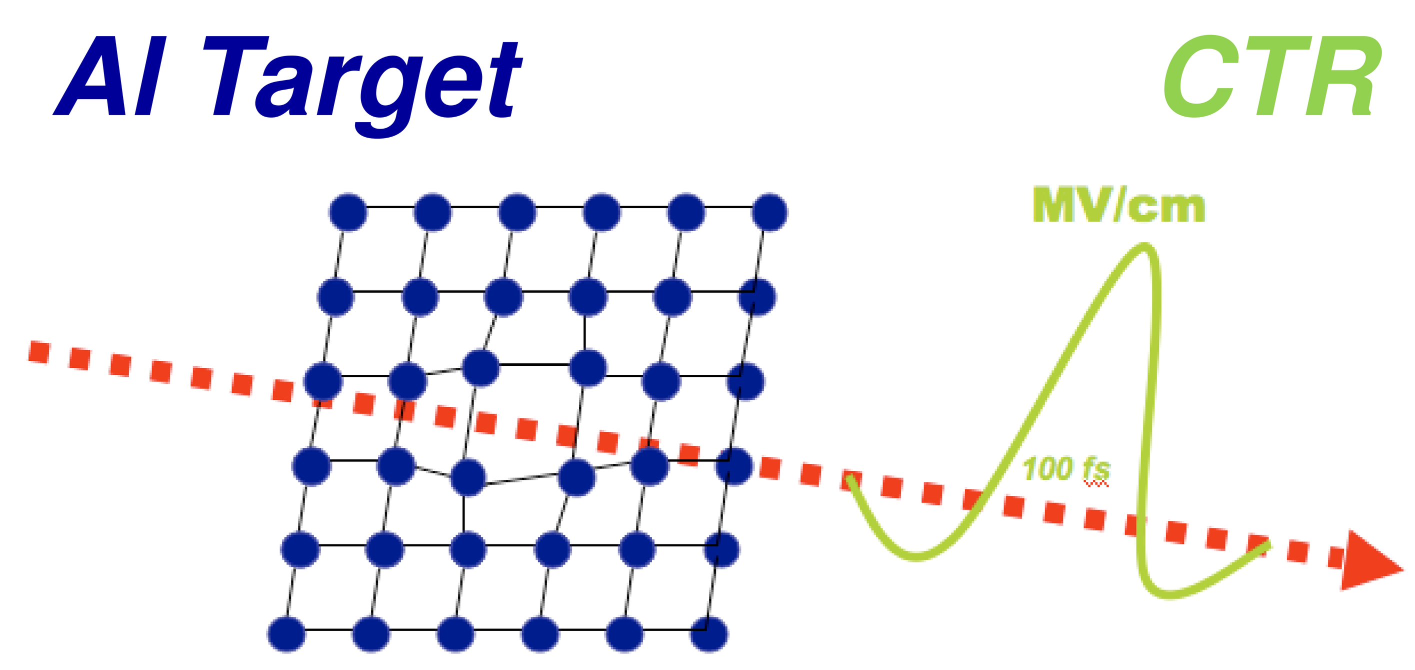
Coherent Transition Radiation occurs when relativistic electrons cross the boundary between two media of different dielectric constant:

- ***ultra-short, high-power, broadband THz pulses*** from short e-bunches and ***100 fs-electron structures.***





Wavelength Range	**0.3 mm - 20 μm (0.1 – 15 THz)**
THz Pulse Energy	**50 μJ – 1 mJ**
Peak Field	**> MV/cm**
e-Beam Operation	**1.0 - 1.5 GeV (FEL1 / FEL2) 10 - 50 Hz**



Simone Di Mitri – simone.dimitri@elettra.eu

Target Chamber

3-D Rendering

YAG screen for e-beam position

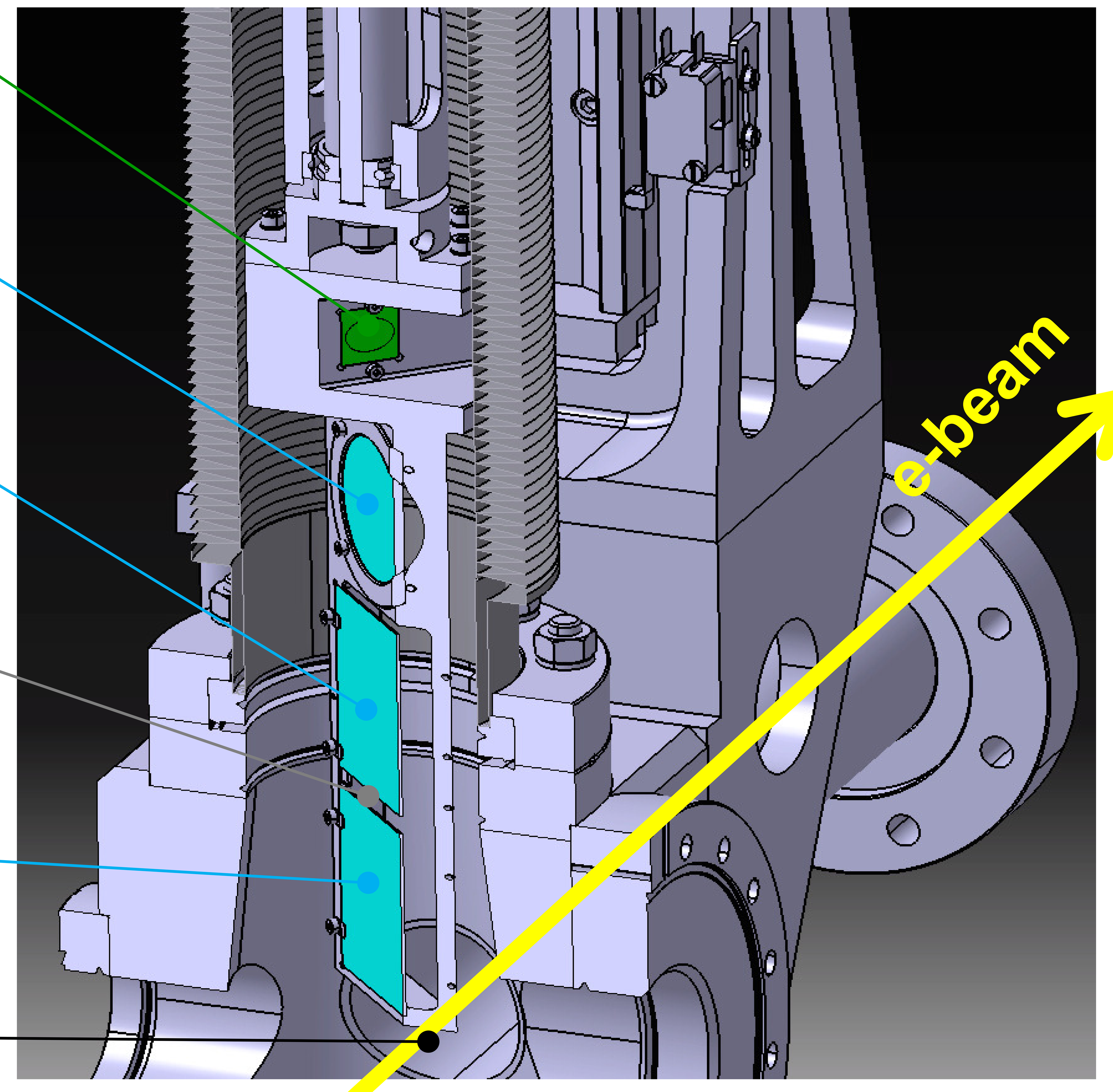
Free standing CTR source 40 mm ⃠,1 μm Al foil

50x50 mm² CTR source 1 μm Al on Si

Variable gap (1-5 mm) CDR source

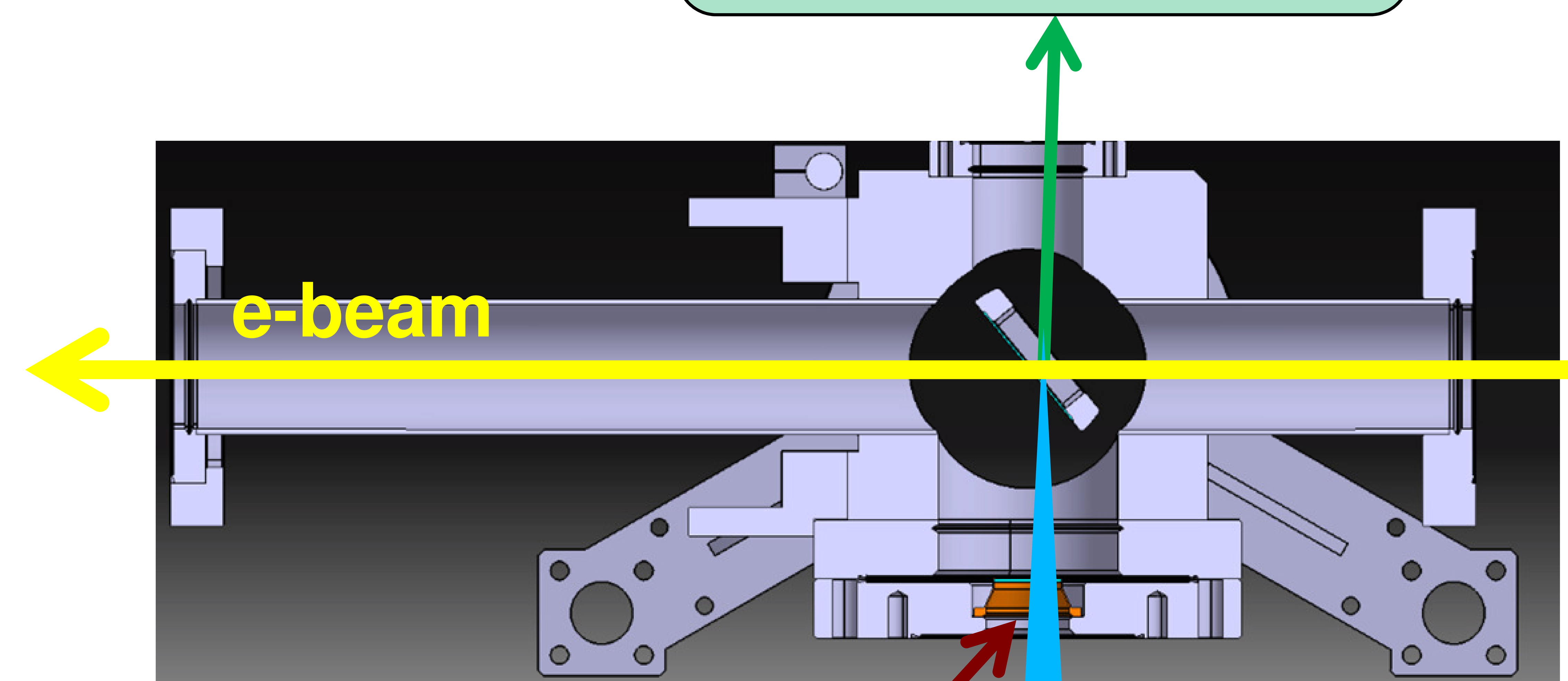
50x50 mm² CTR source 1 μm Al on Si

e-Beam Pipe



Top View

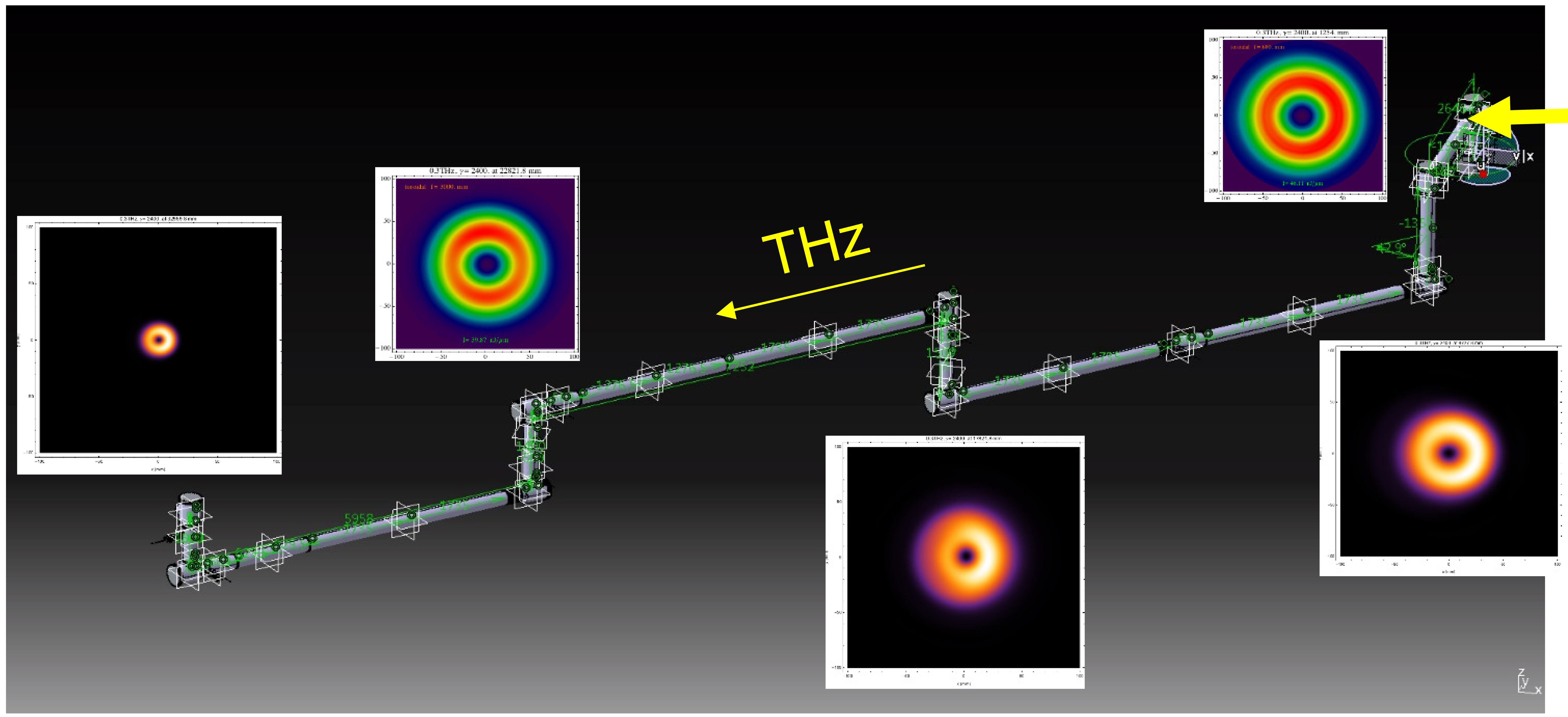
YAG fluorescence to CCD

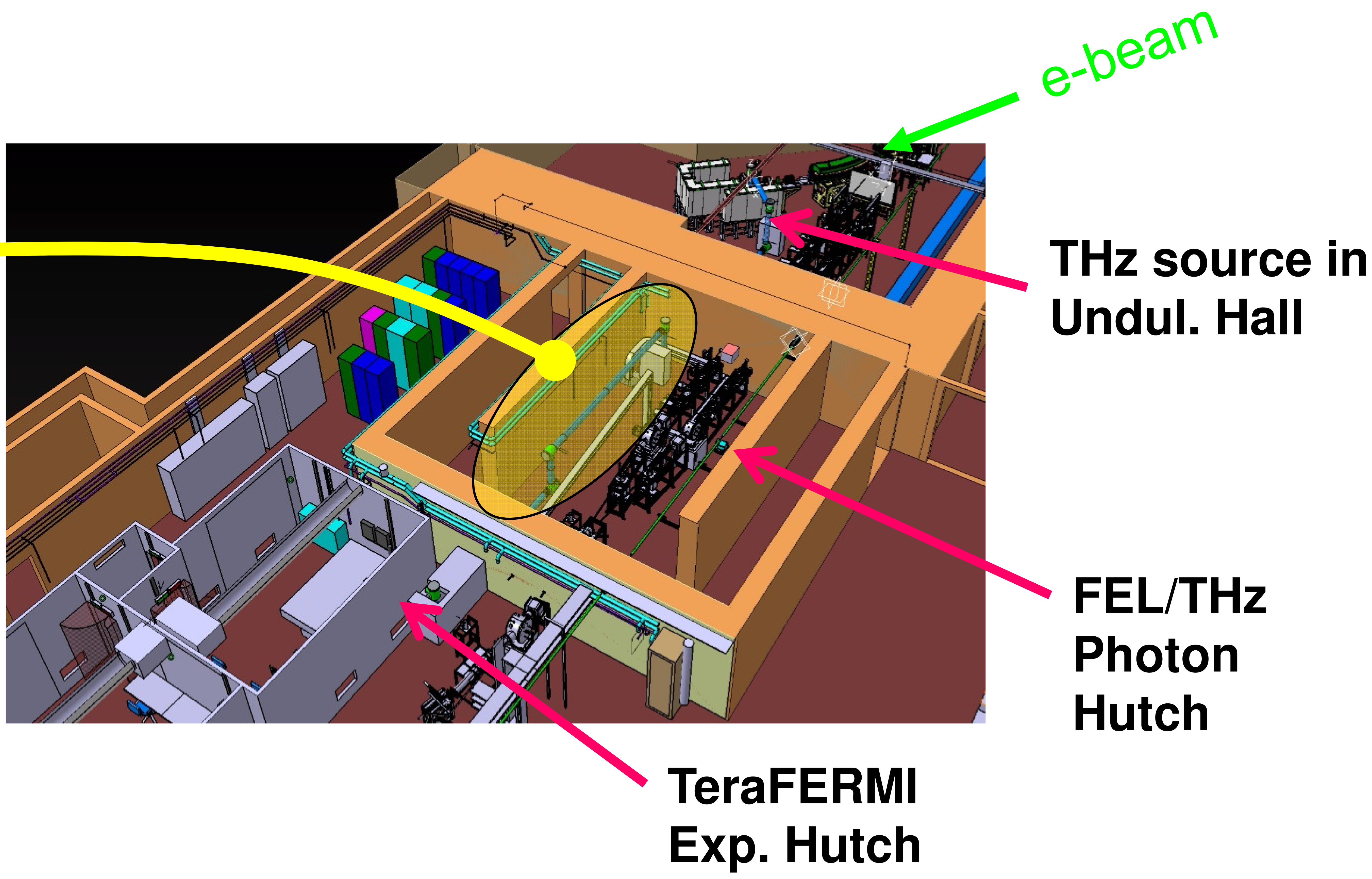


Diamond Window
Clear aperture: 20mm
Central thickness: 600 μm.
Wedge: 0.5°

THz (250 mrad ang. accept.)

THz Transport Line

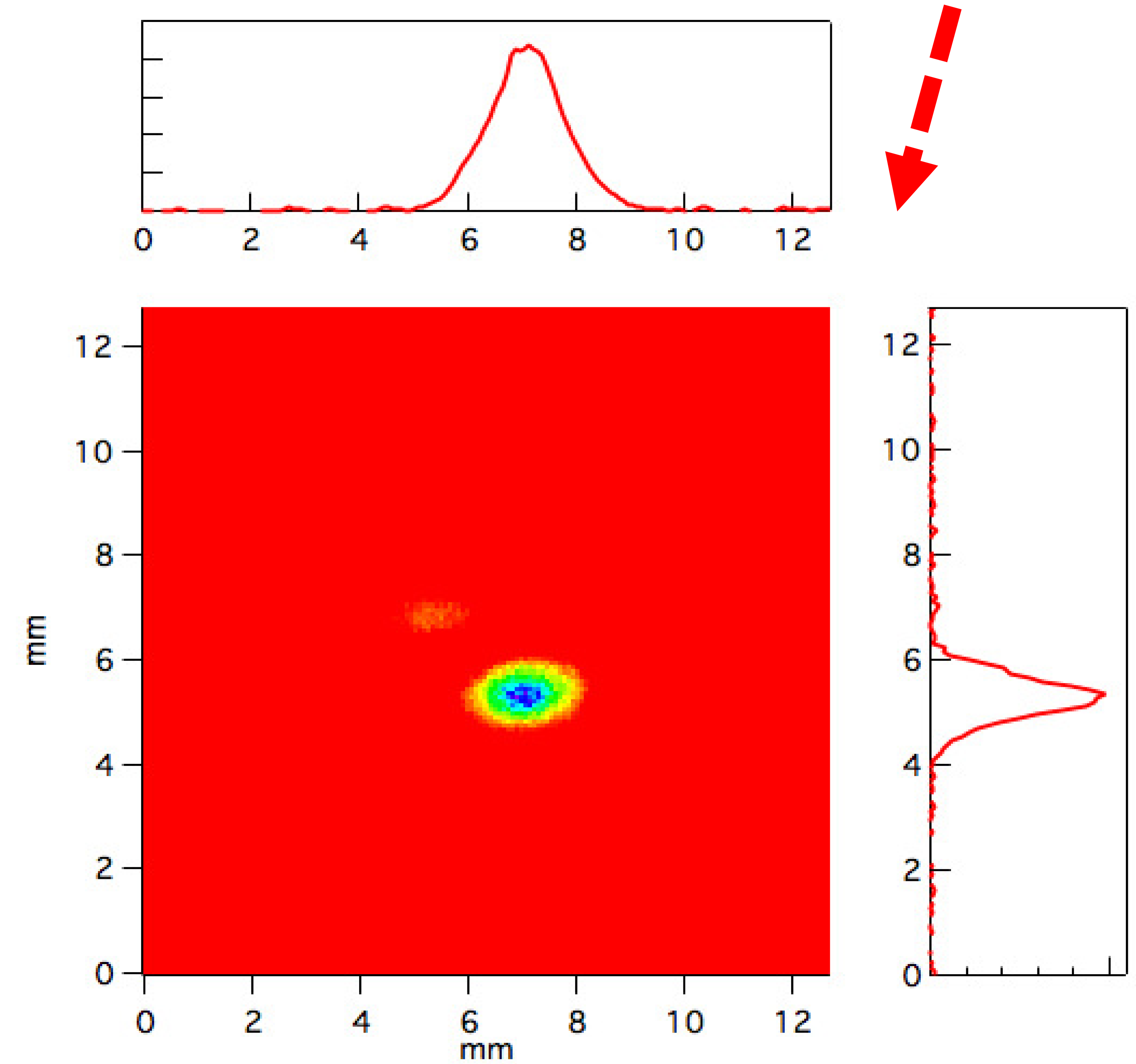




- 30 mm spot size at exit window in EH, @ 0.3 THz.

- 6 Focusing Toroidal, 4 Planar Mirrors
- 10 Screens for OTR visualization and pre-alignment
- 1 Screen for THz beam visualization
- Low Vacuum (<0.1 mbar)

Pulse Energy Measurement & Focusing



- **1-1.5 mm FWHM** spot size at sample position (all frequencies)
- For **10 μJ/pulse**, that gives **~MV/cm**

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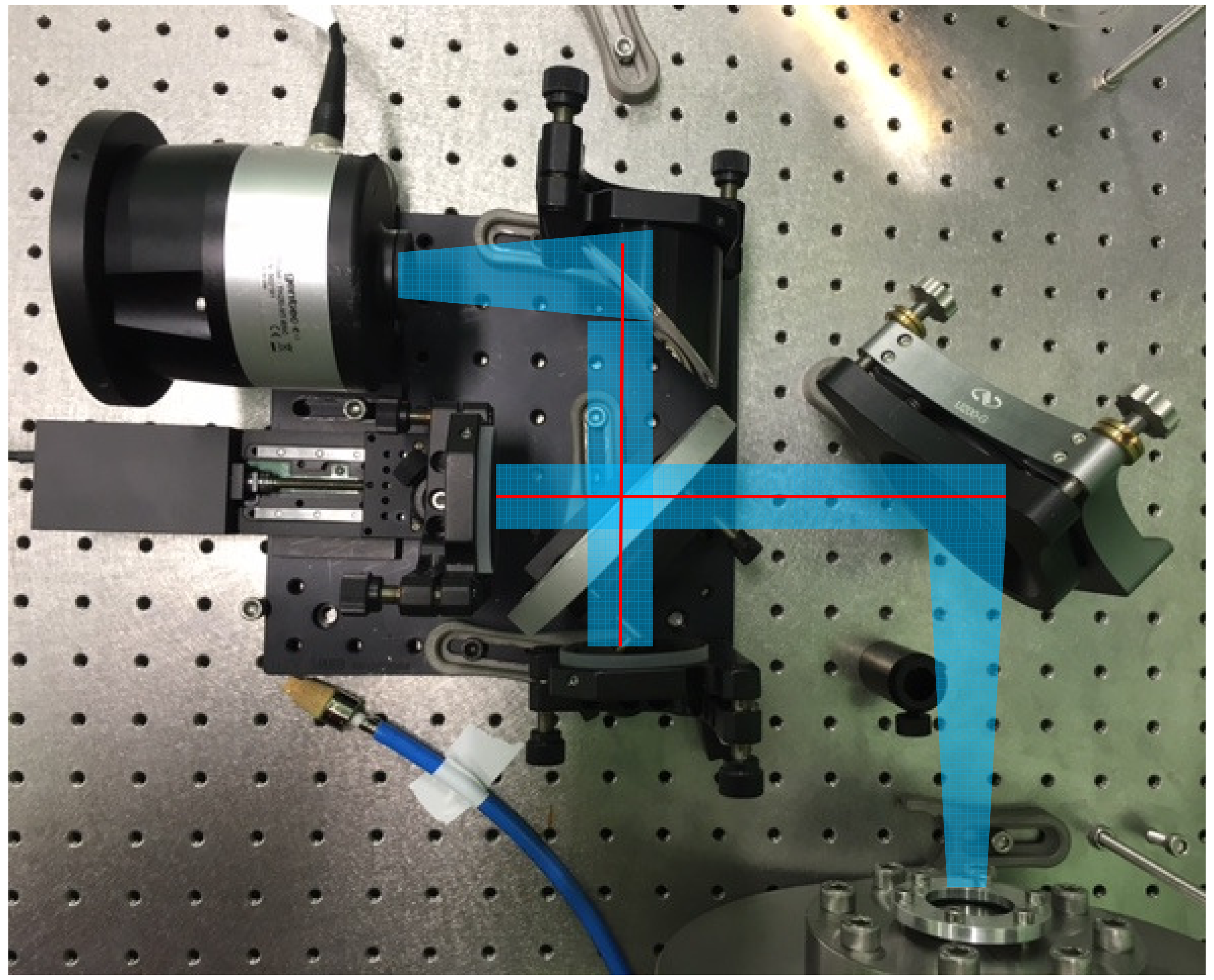
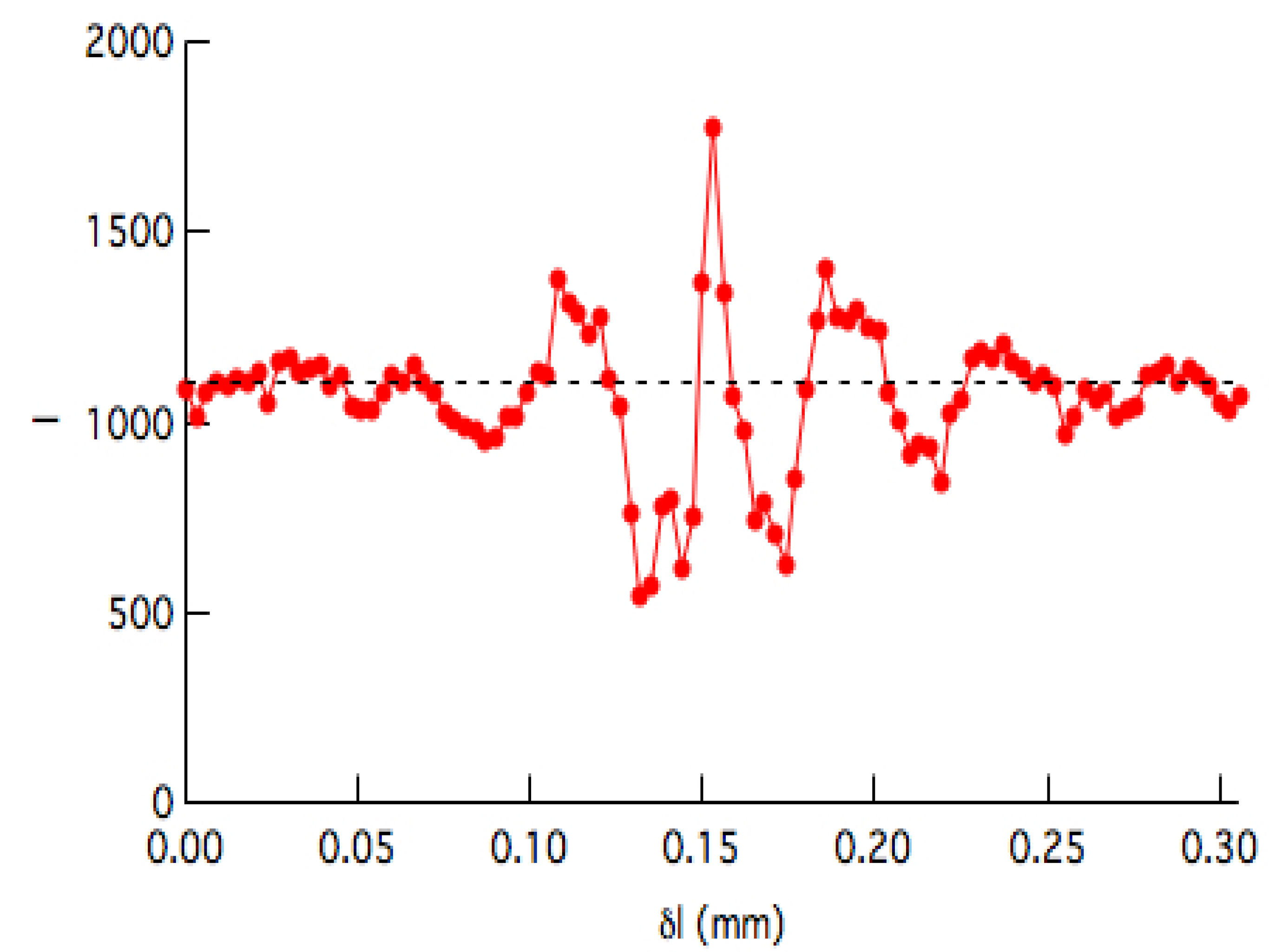
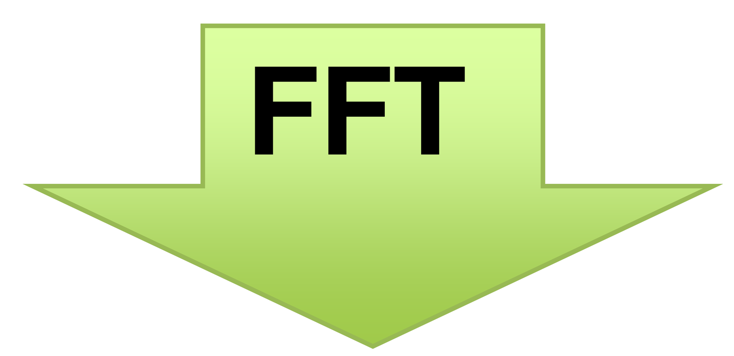
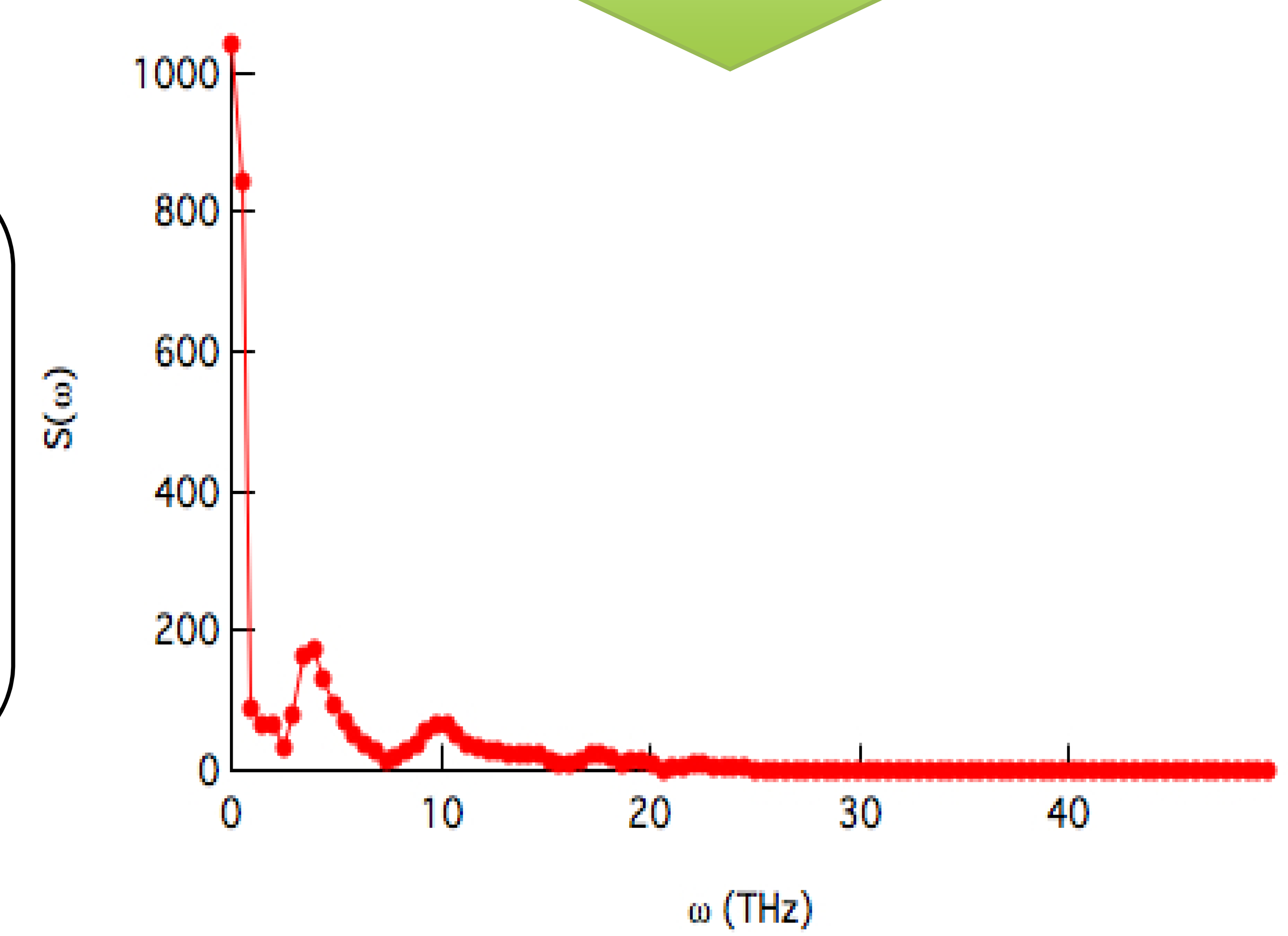
Spectrum Measurement



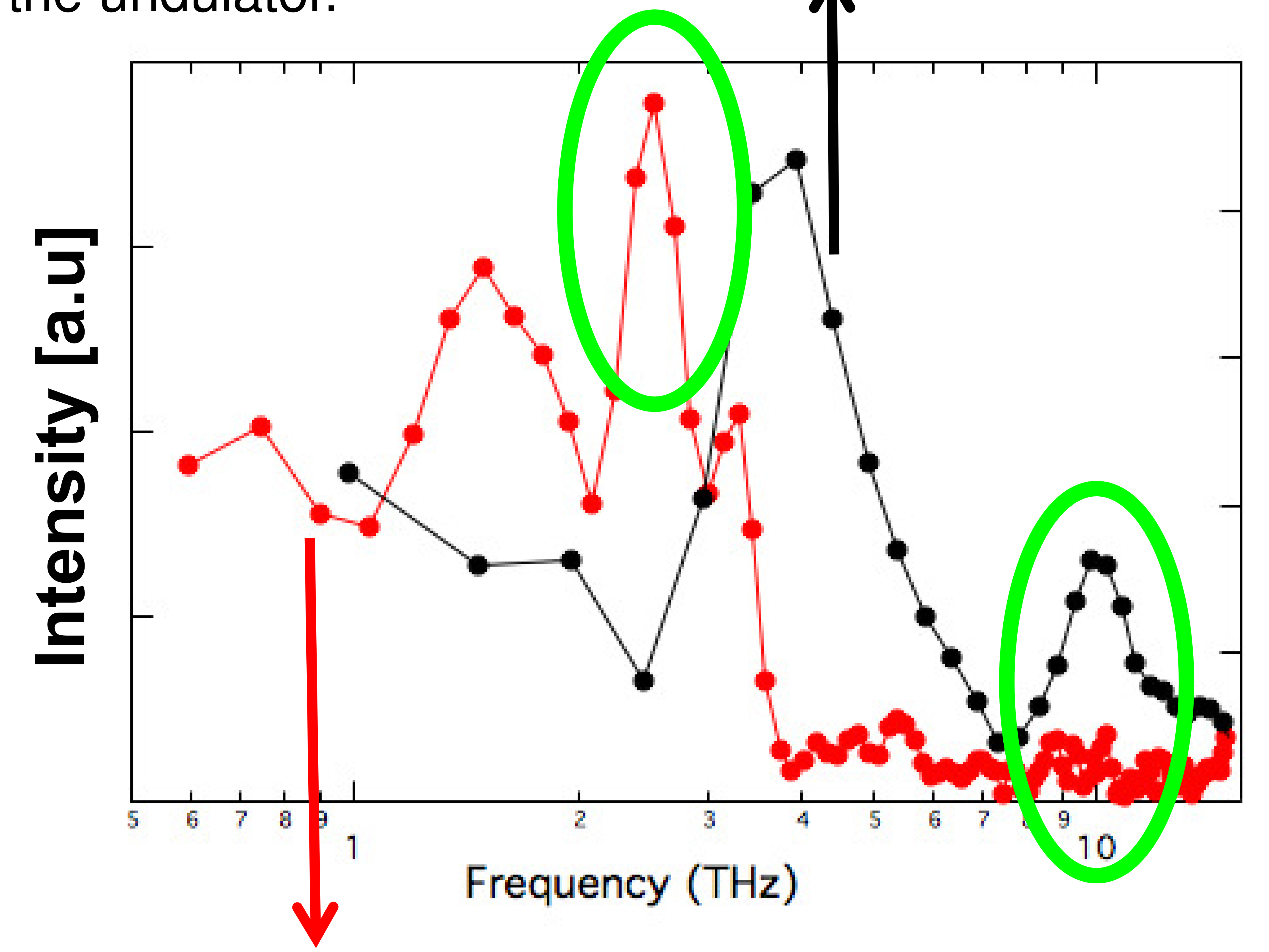
$\Delta L = 0.3$ mm → $\Delta\omega_{res} = 0.5$ THz
$\delta L = 3\ \mu m$ → N = 100 pts
30 averages for each point
1 Spectrum in ~ 5 minutes @ 10Hz







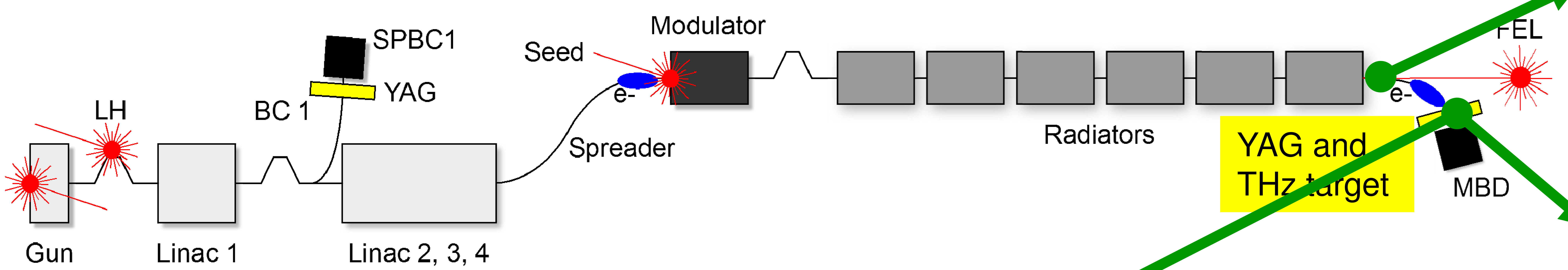
TeraFERMI commissioning shift (March 2016):
e-beam showing a current spike in the bunch head at the undulator.

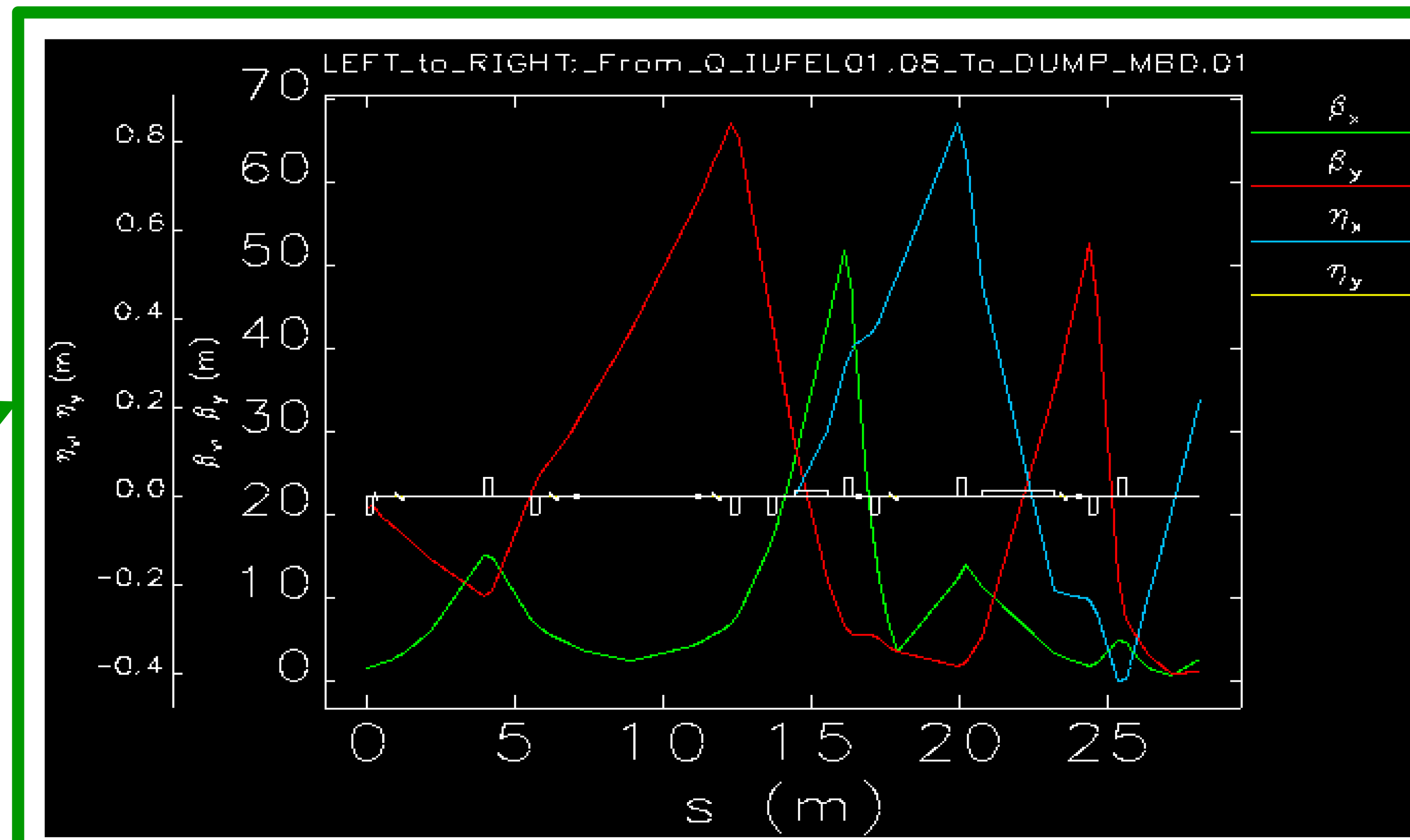


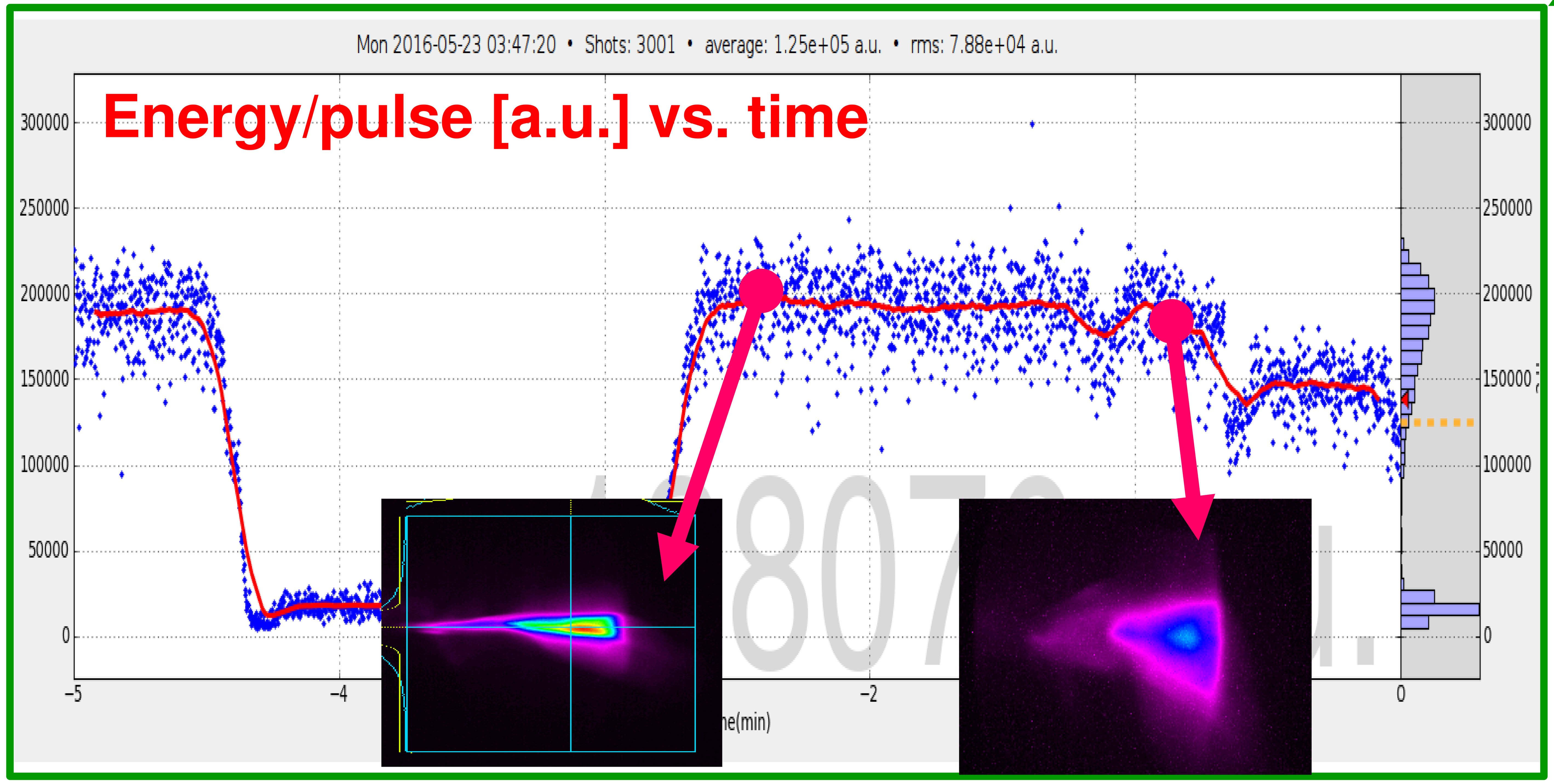
e-Beam optimized for FEL users, flat current profile at the undulator (April 2016).

Thz Signal vs. e-Transverse Profile

e-beam **optical parameters** are predicted starting from ***measured* initial parameters**, and ***actual* magnets setting**.

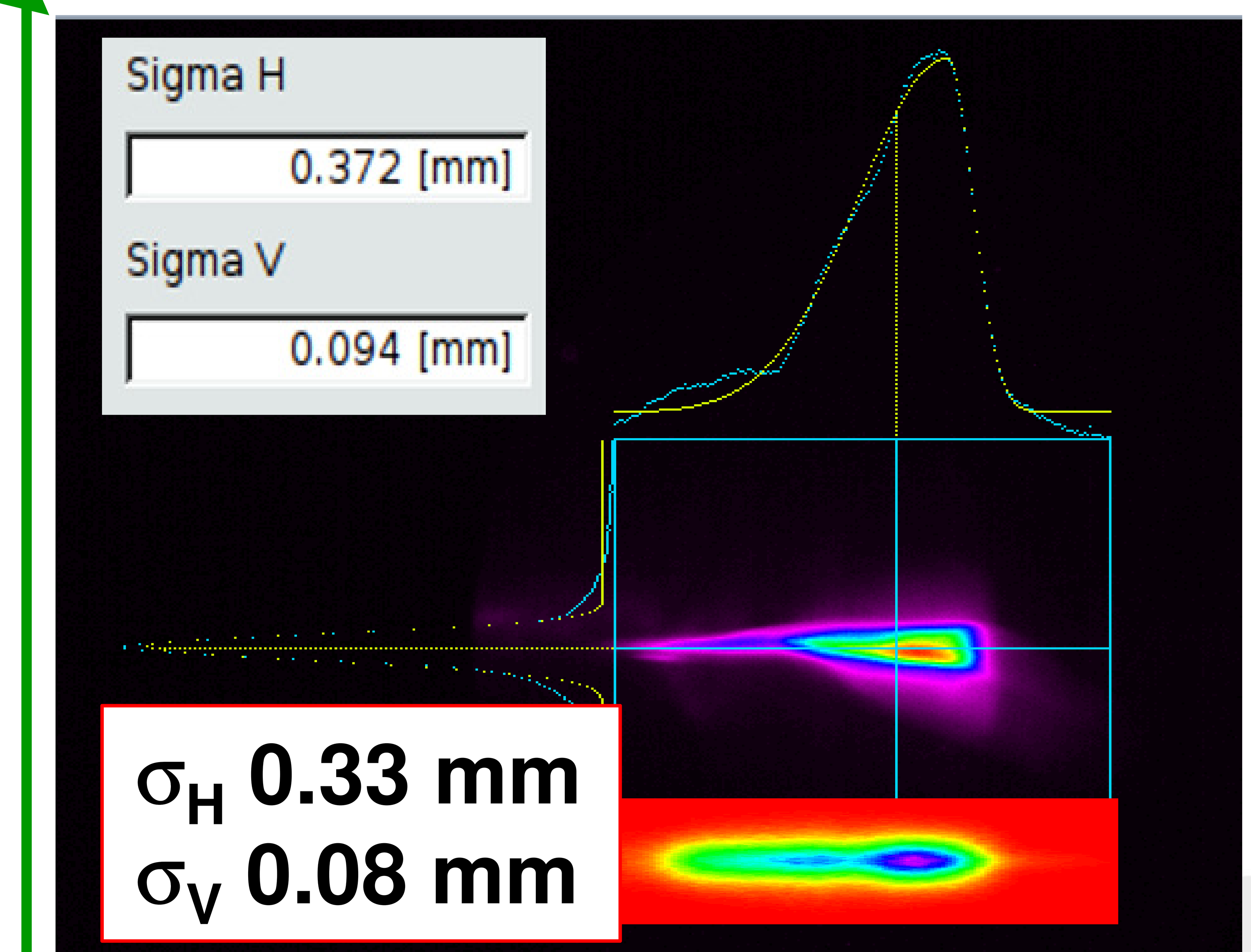






The THz energy/pulse decreases for:

- beam transverse sizes at the target $\geq$ **500 μm**
- beam lateral displacements at the target $\geq$ **1 mm**



e-beam **transverse spot** at the THz target is at **~100 μm level**

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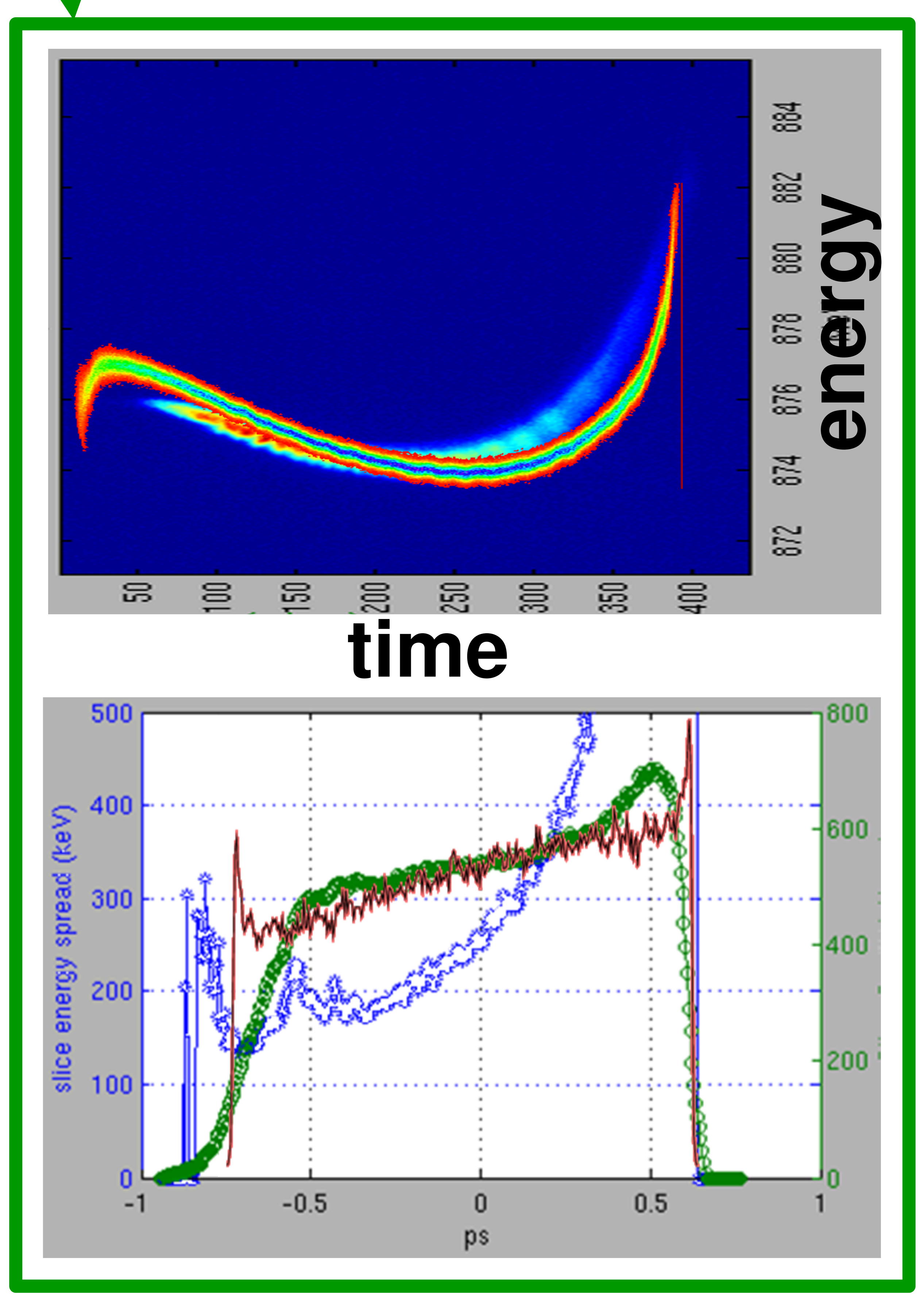
Thz Signal vs. e-Peak Current

- e-bunch length is compressed here by a factor ~10 nominally, possibly tuned in the range 5–15.
- Peak current increases accordingly.

Measure ≡ Model



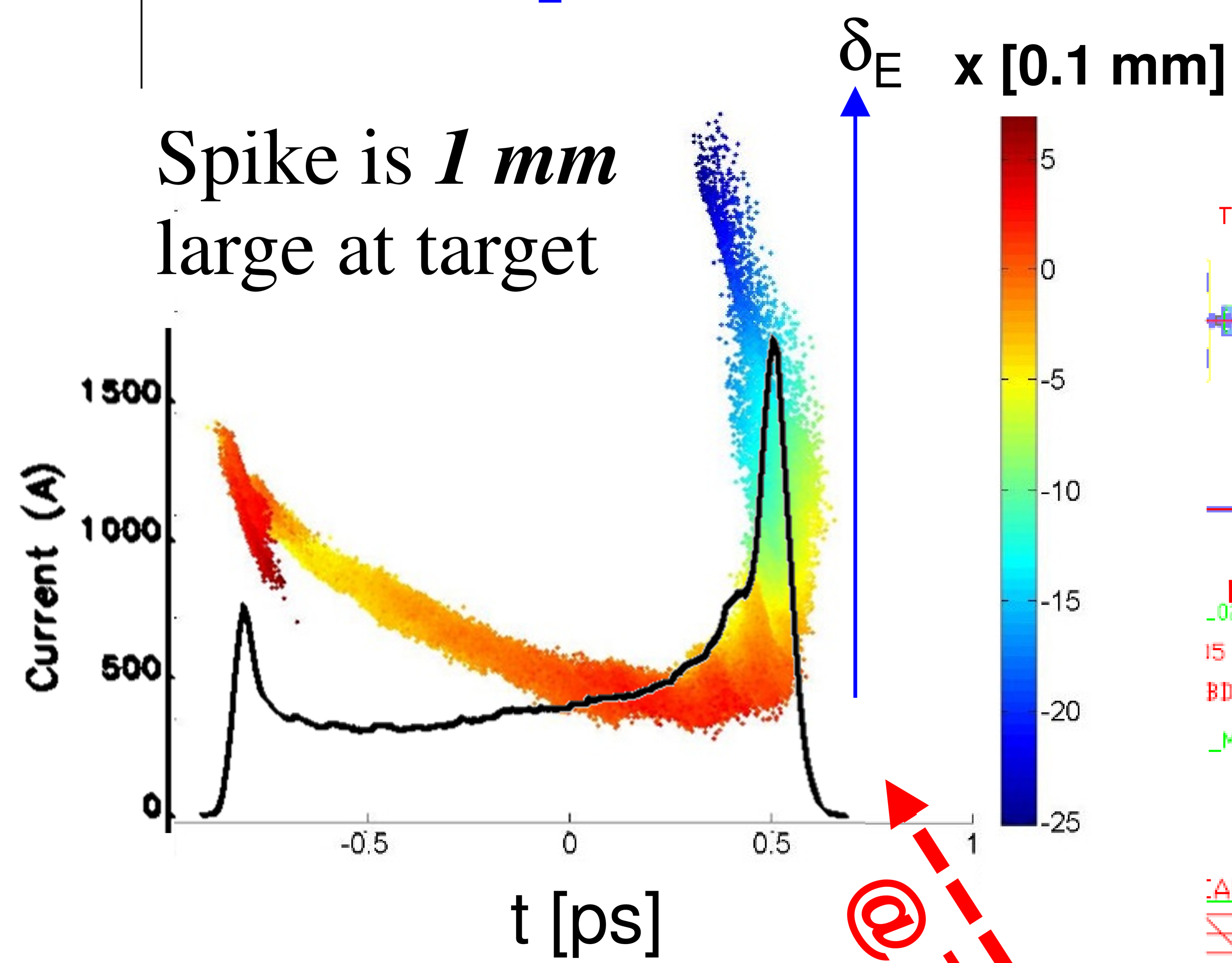
Measured Values

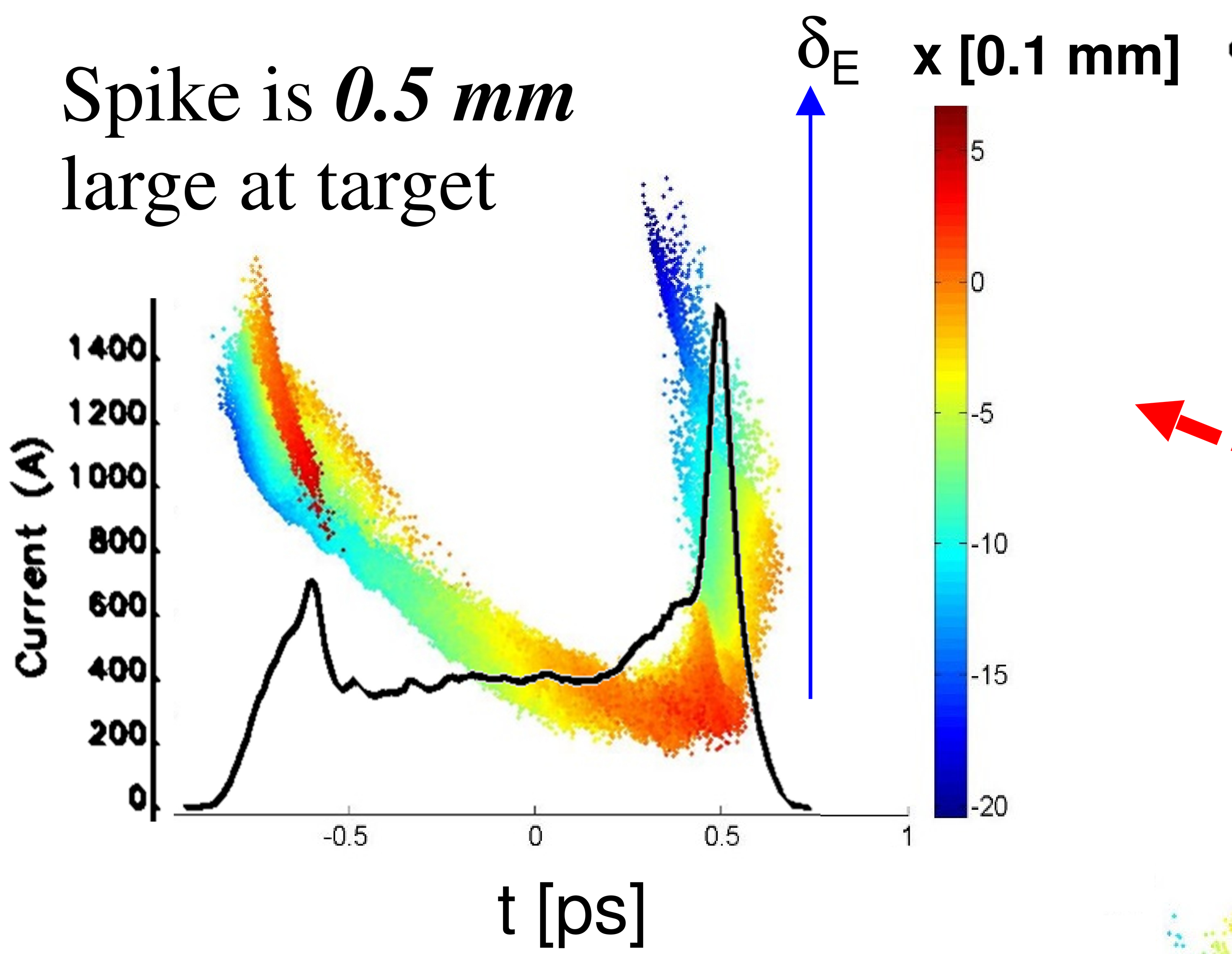
Peak Current at Undulator [A]	Compression Factor (Injector to Undulator)	THz Signal [a.u.]
500	7.1	1.0
590	8.4	2.0
730	10.4	1.5

❑ *THz pulse energy* is ***NOT*** *monotonic* with the *peak current at the undulator. Why ?!?*

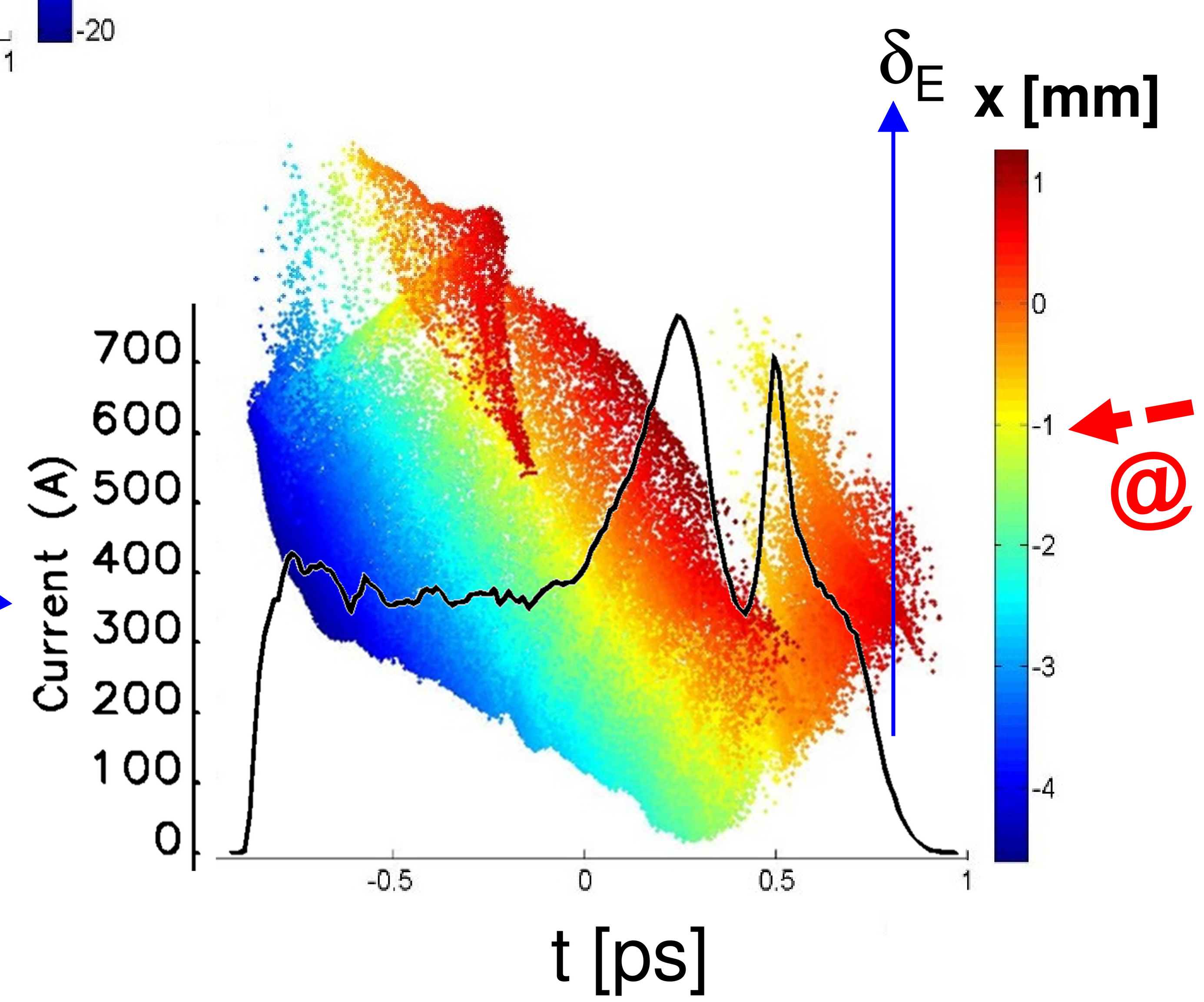
Coupled x-δ Dynamics

I-spike and its x-size at the target may explain a stronger THz signal.





Lower current & larger beam size may explain a weaker THz signal.



@ THz target

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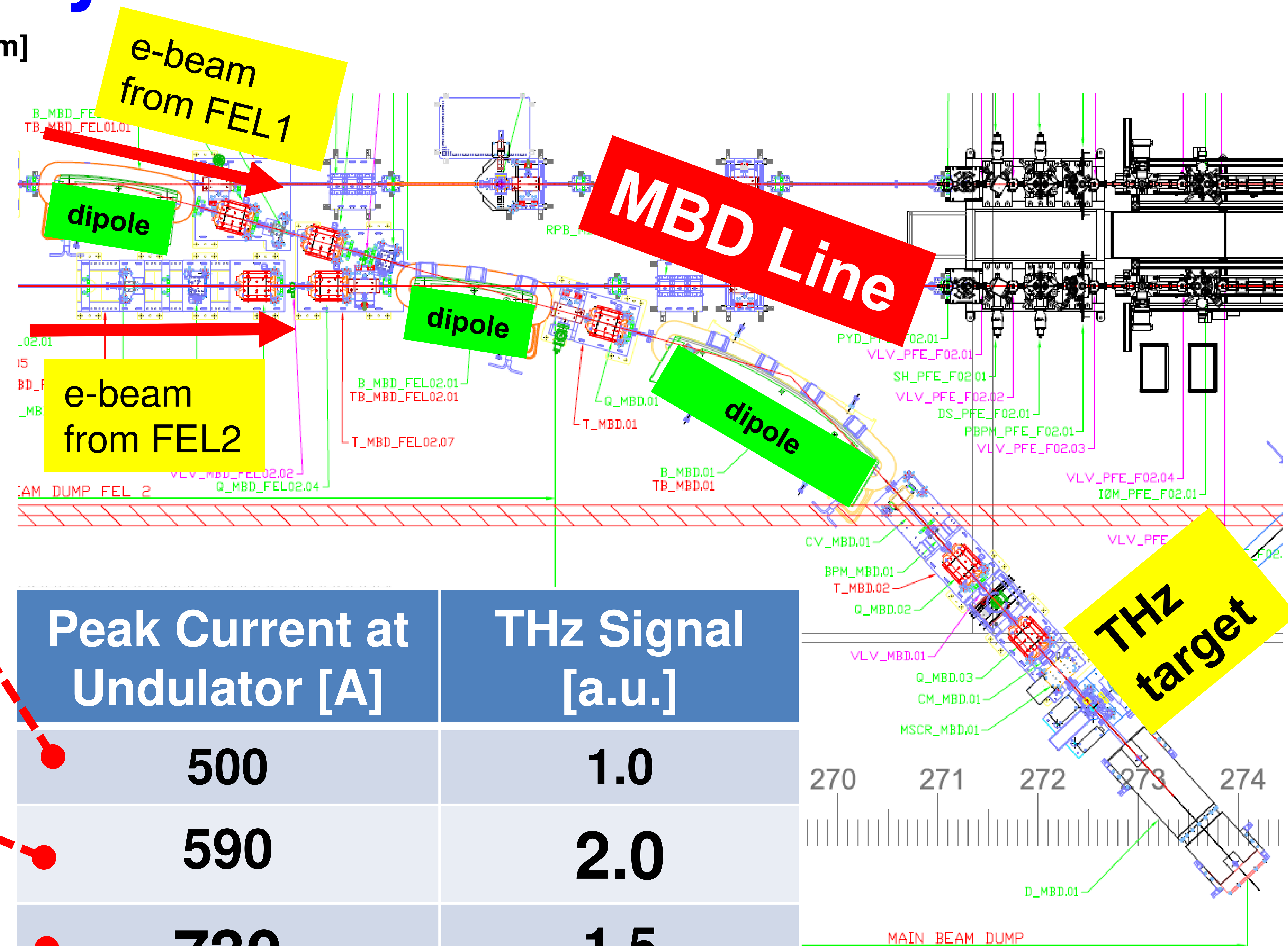

Peak Current at Undulator [A]	THz Signal [a.u.]
500	1.0
590	2.0
730	1.5

FEL adds some dynamics…more simulations are ongoing.

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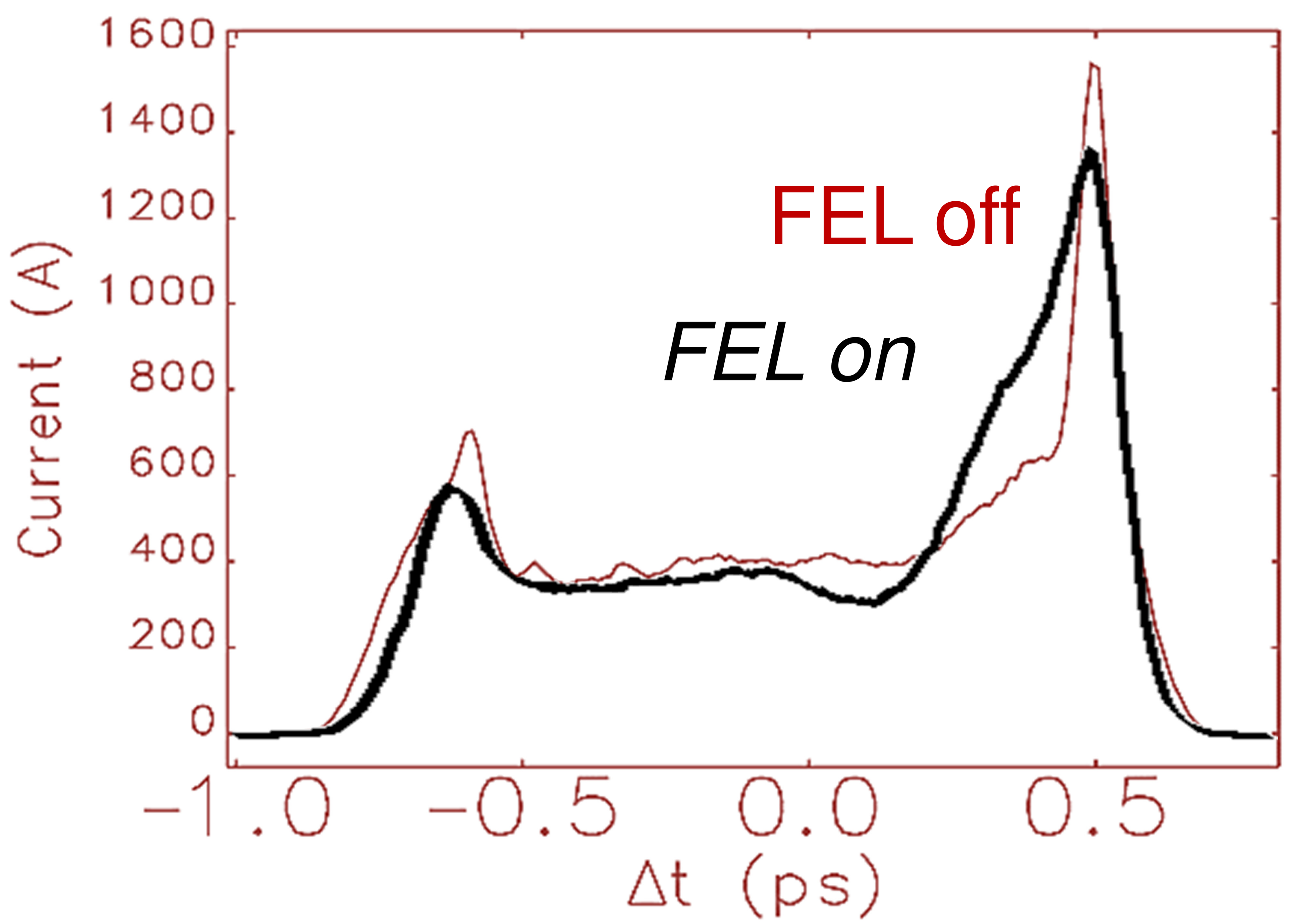
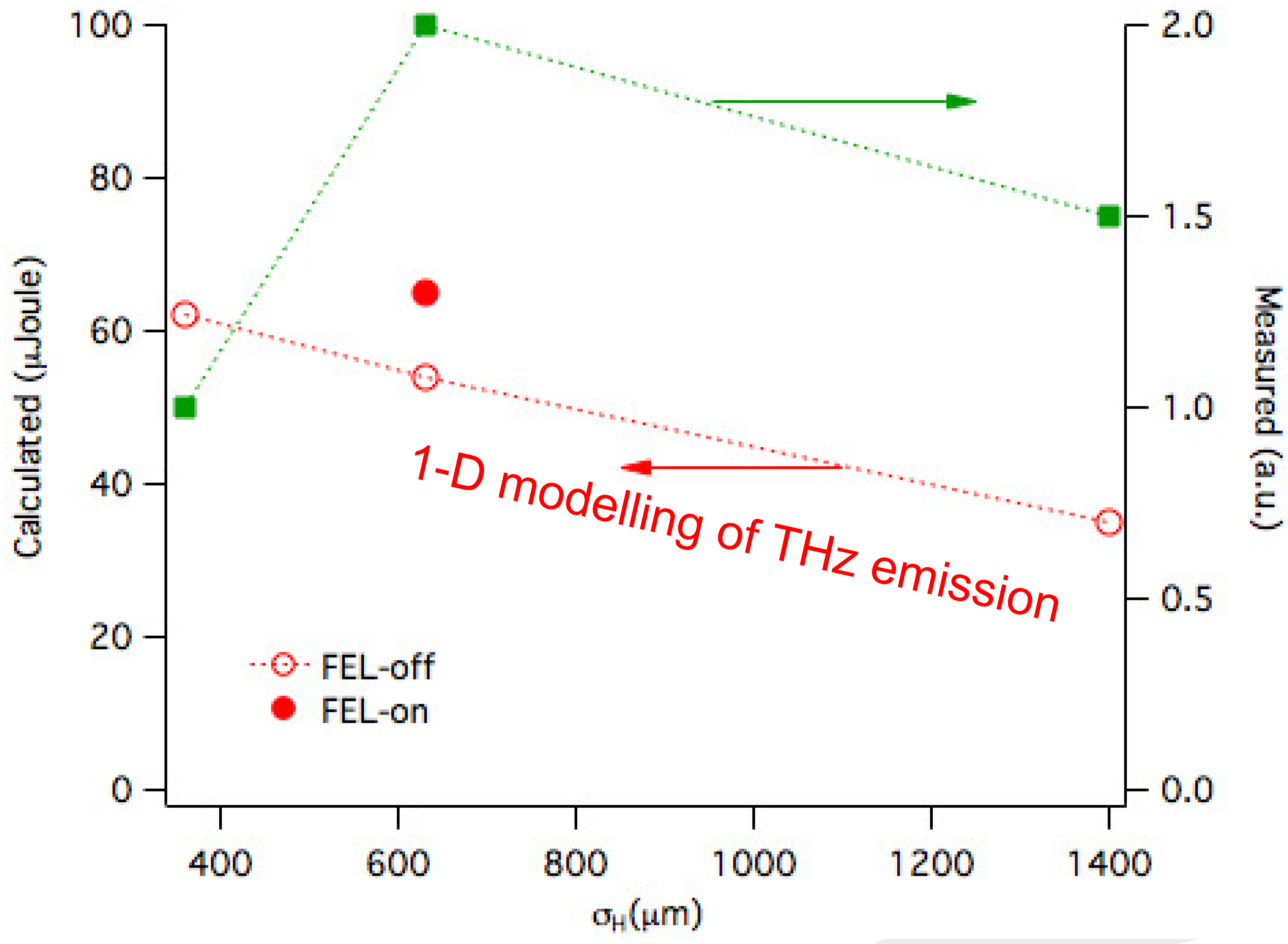
Effect of FEL

Lasing forces some electrons to move along the bunch, as the beam passes through the MBD line

Some enhancement of THz emission is observed, depending on the lasing efficiency and tuning of the beam transport to the THz target.





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Conclusions and Outlook

Achieved Results:

- More than **60 μJ/pulse @ source**
- Pulse energy of up to **25 μJ @ optical table**
- Spectral content up to **12 THz**
- Focal spot ~ 1-1.5 mm fwhm
- **> MV/cm** electric field in the lab

Lessons Learned:

- **Routine parasitic** operation to FEL ensures **10's μJ/pulse, up to 50 Hz**
- THz signal basically driven by current spikes
- Keep beam size smaller than 500 μm rms, both planes

Next Developments:

- Synchronizing an external laser source
- Electro-optic sampling (scanning/single shot)
- THz pump - NIR probe (780 and 1560 nm)
- THz pump – Faraday/Kerr rotation
- Extend probes to broader range
- Upgrade e-beam line for more flexible manipulation of bunch length, in standard FEL operation.

Pilot Experiments:

- Fluence-dependent THz transmission
- Self-synchronized THz pump/THz probe

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Thank You for Your Attention