First Lasing of the IR FEL at the Fritz-Haber-Institut, Berlin

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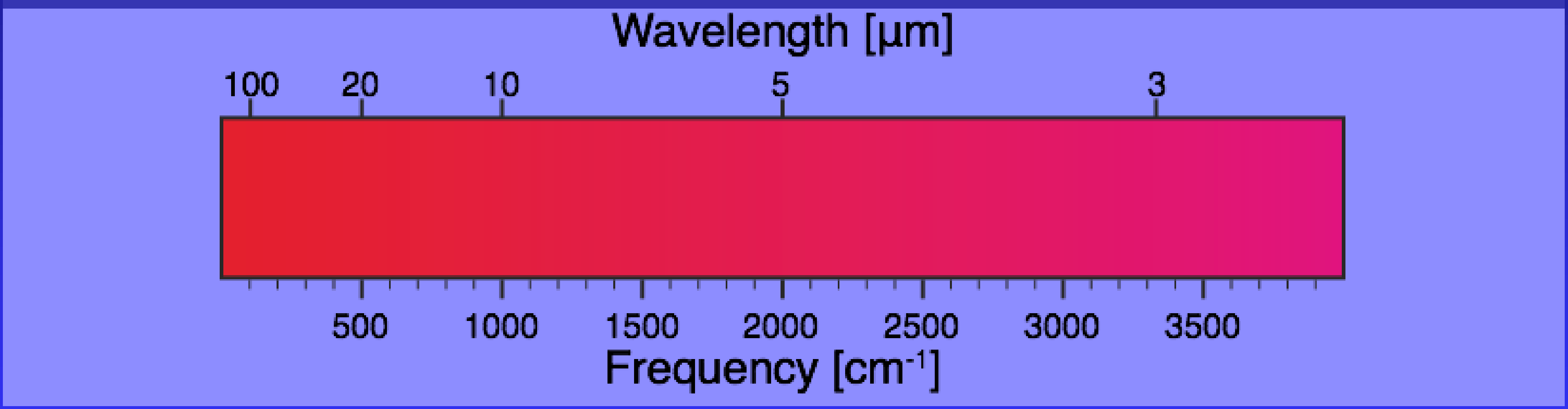
Fritz-Haber-Institut, Berlin

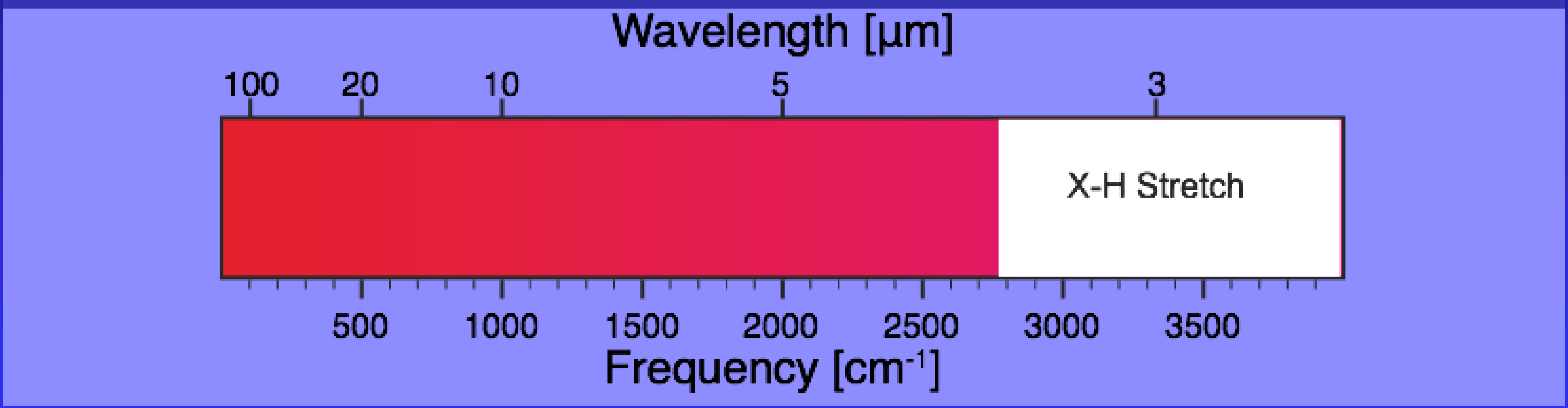
Outline

1. Motivation, applications of FHI FEL
   → molecular and cluster spectroscopy
2. Design and specs of the FHI FEL
3. Results from „First Lasing“

Interaction of molecules with IR light



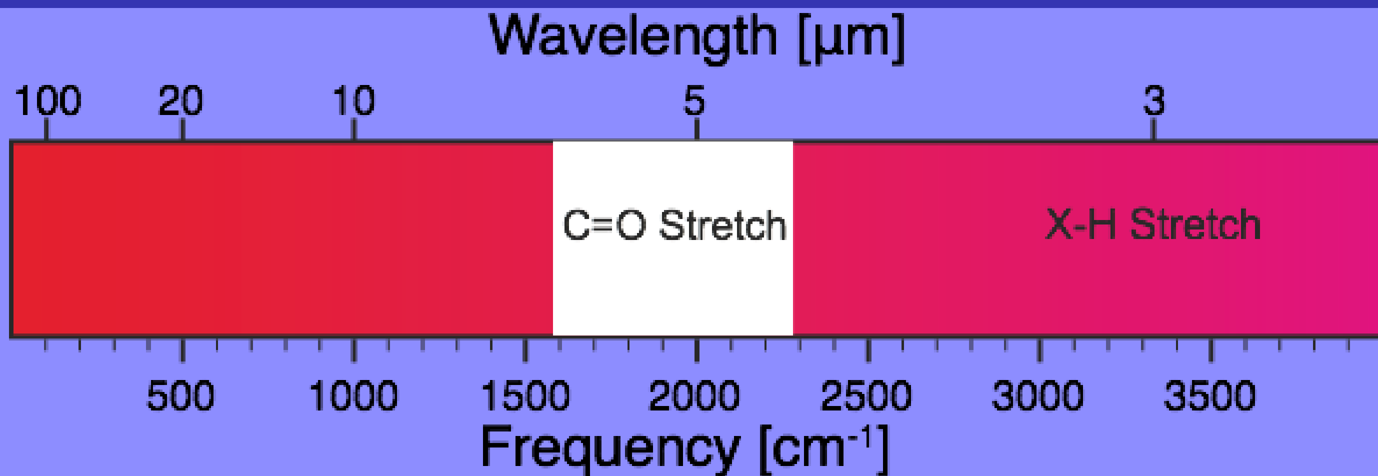
Interaction of molecules with IR light



X-H Stretch:
H-bonding
conformation of small biomolecules

Interaction of molecules with IR light

C=O Stretch:
“Amide I” in biomolecules
C=O on surfaces



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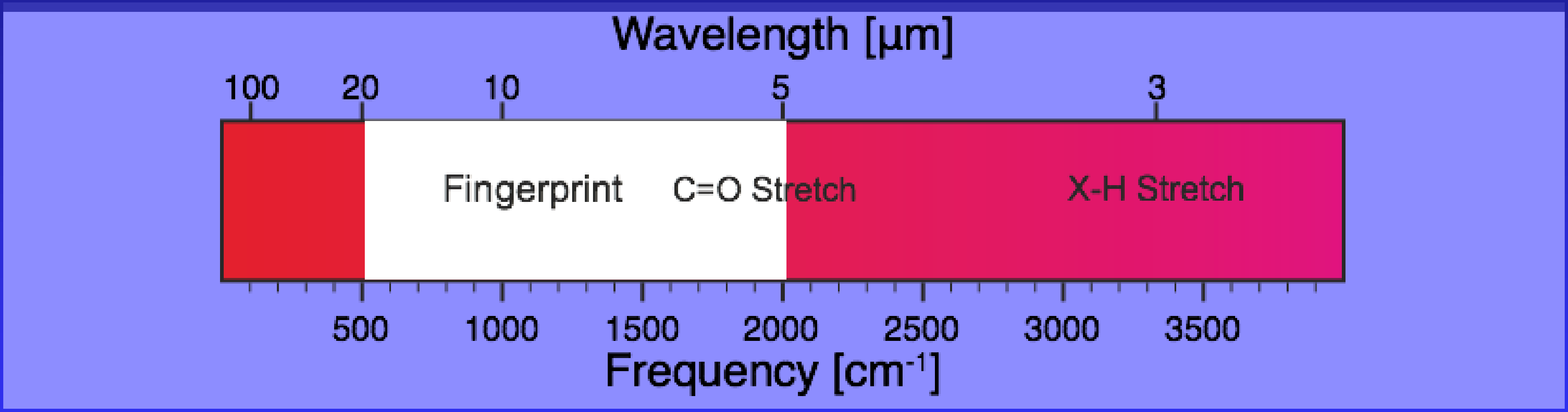

Fingerprint:
skeletal motion in molecules

X-H Stretch:
H-bonding
conformation of small biomolecules

Interaction of molecules with IR light

“Far IR”:
large amplitude motion / folding
metal-metal stretch
van der Waals modes
adsorbate modes on surfaces

C=O Stretch:
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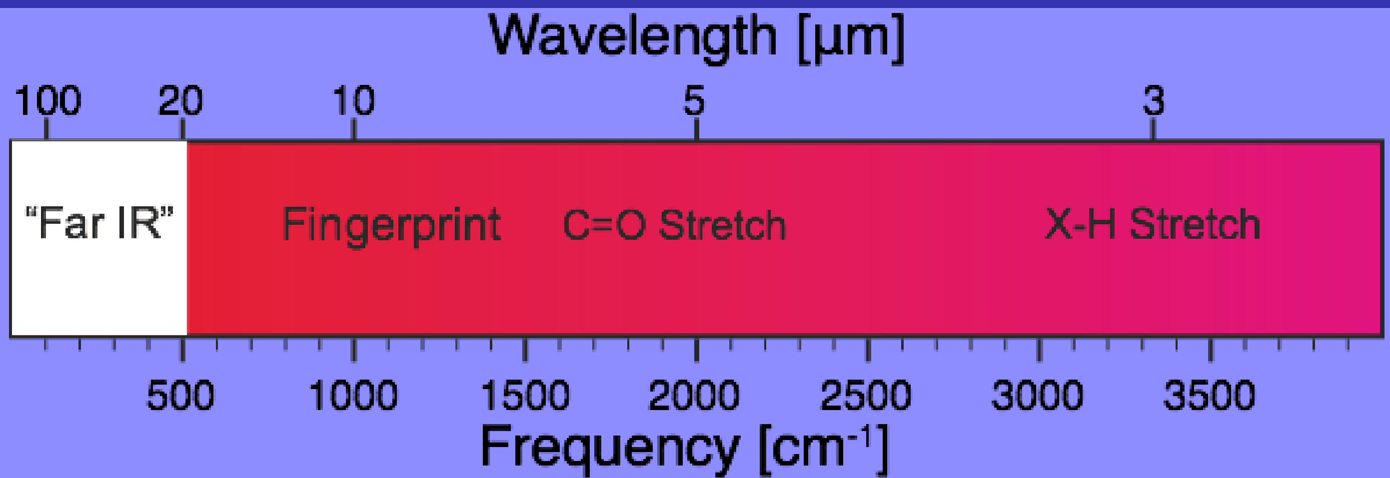

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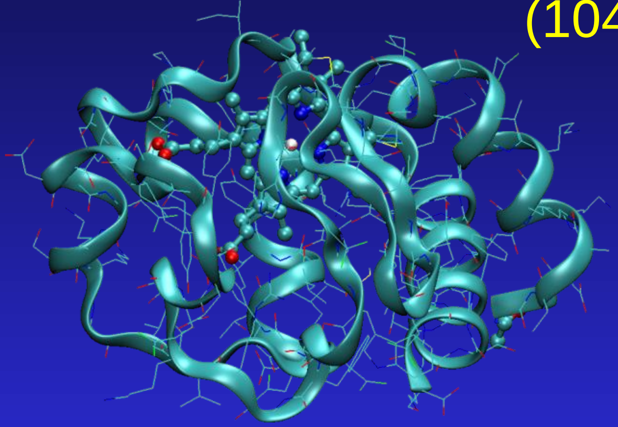
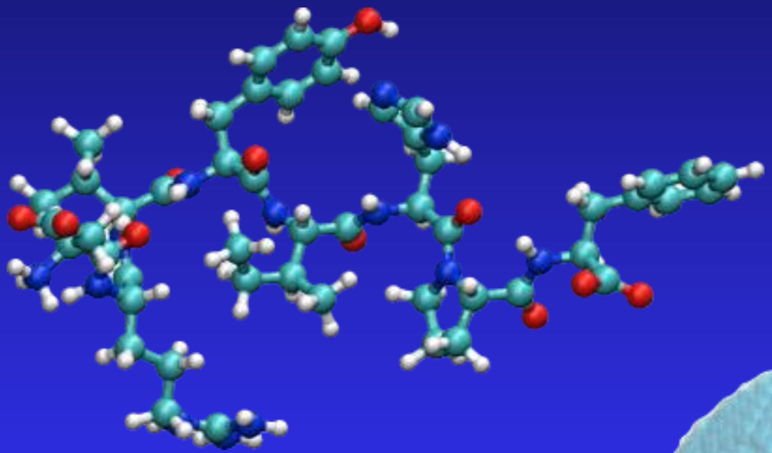
Planned applications of FHI FEL: 1st example

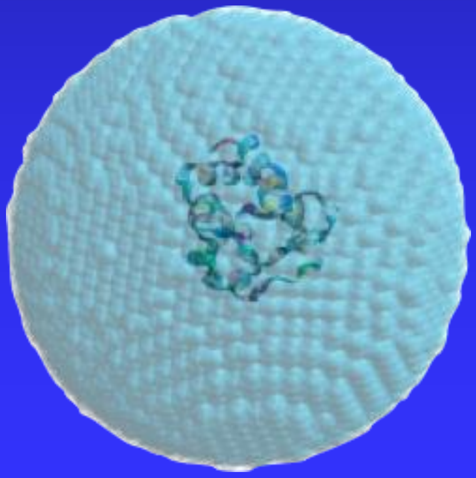
Spectroscopy of biomolecules embedded in liquid helium nano-droplets



Cytochrome C
(104 amino acids)



Angiotensin II
(8 amino acids)



He nano droplet:

- $10^4 - 10^6$ He atoms
- superfluid, T = 0.38 K
- Weak interaction with dopant molecules
- Optically transparent from deep UV to far IR

Gert von Helden et al., Fritz-Haber-Institut

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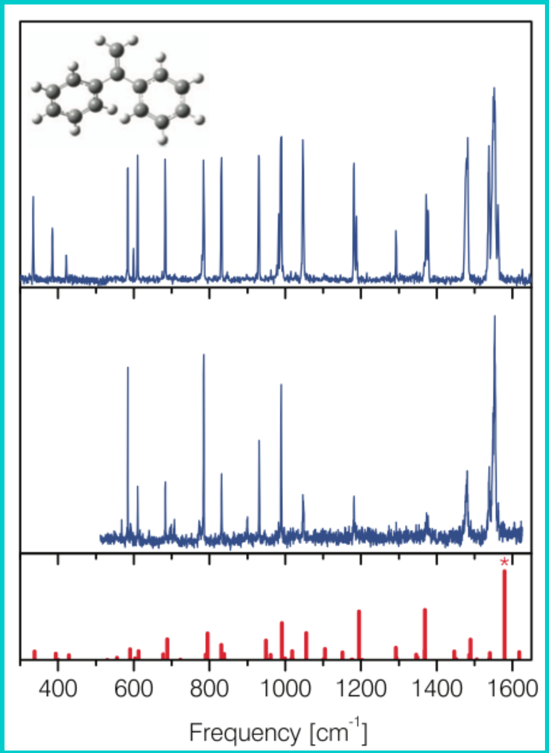
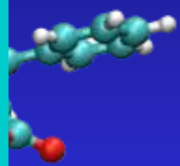
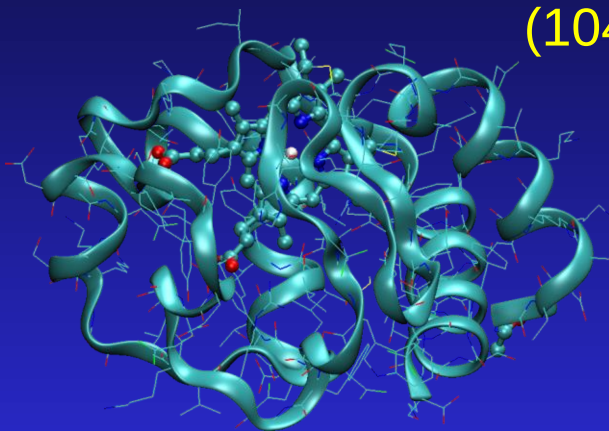
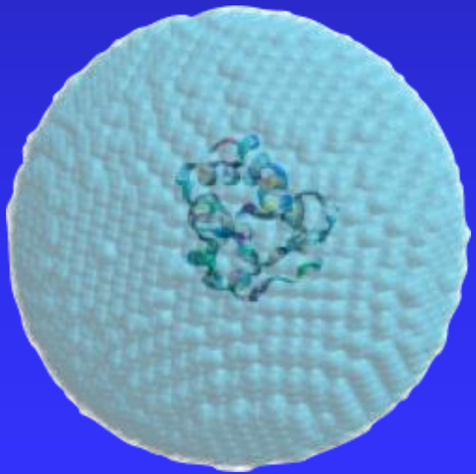


M. Drabbels et al.
J.Chem.Phys., **136**, 044305 (2012)







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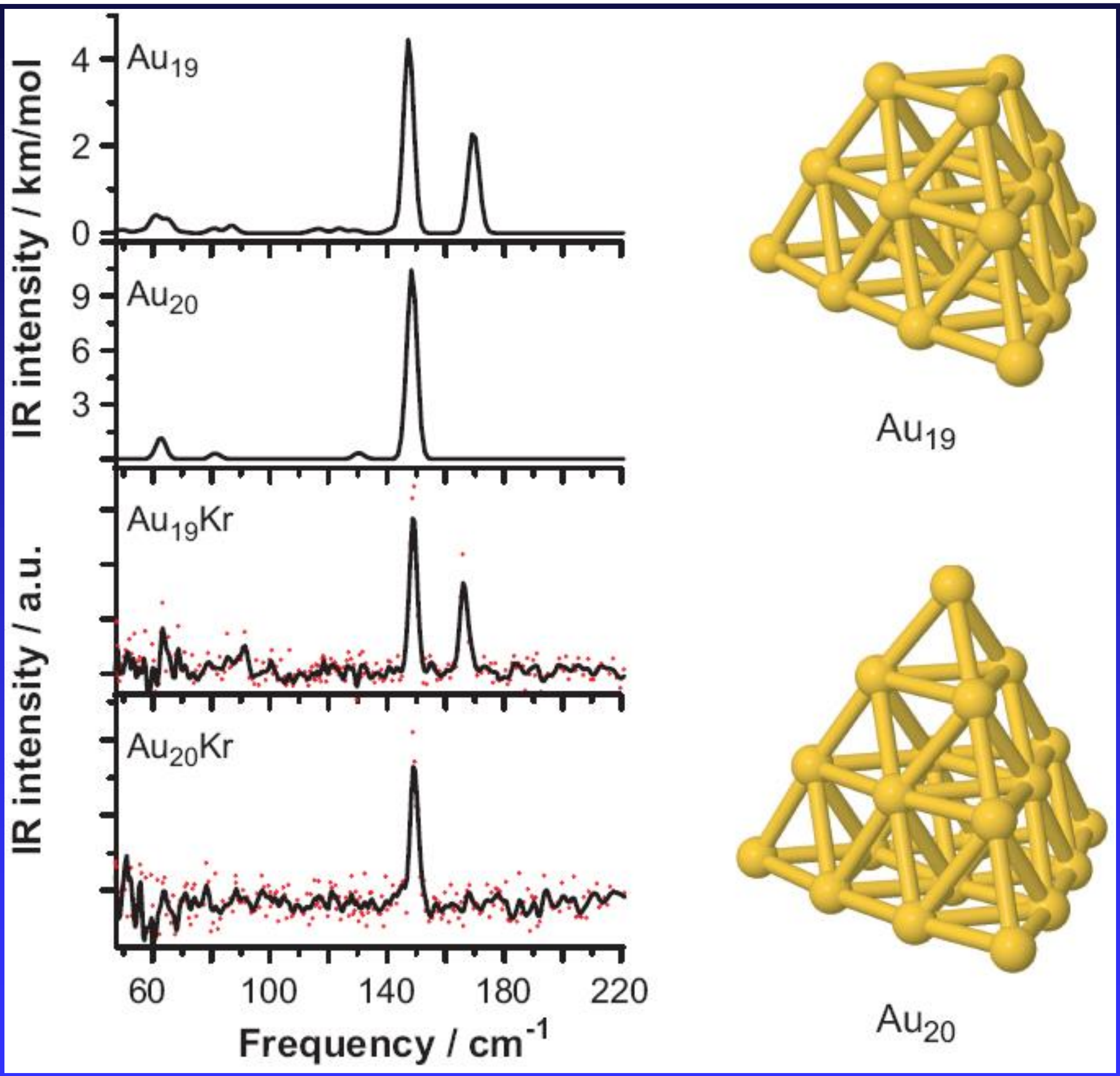
Planned applications of FHI FEL: 2nd example

Far IR spectroscopy of metal clusters

Neutral gold clusters, Au_{19} & Au_{20}



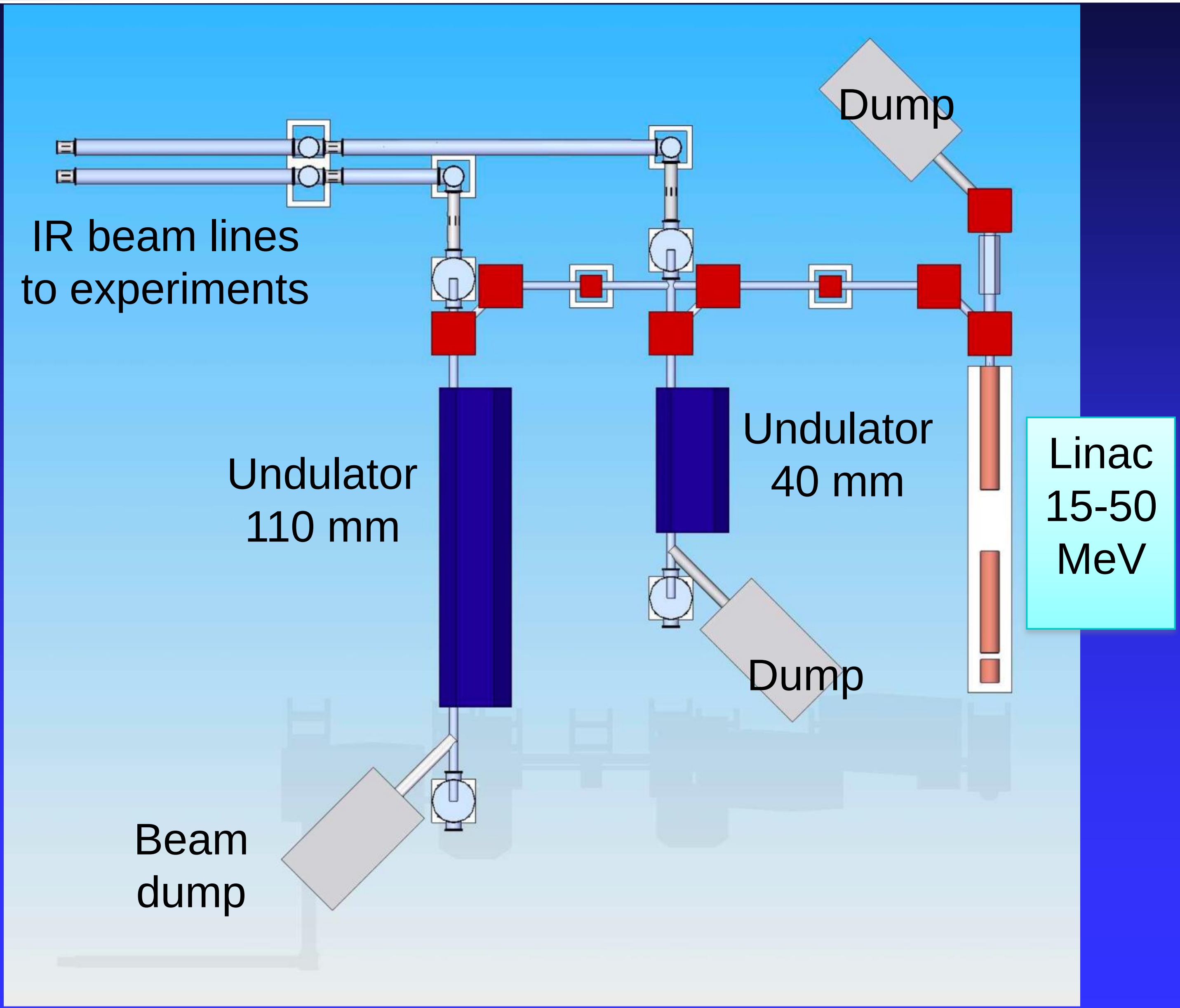
Gruene, Rayner, Redlich, van der Meer, Lyon, Meijer, Fielicke, Science 321, 674 (2008)

Schematic layout of FHI FEL

Light output

Mid-IR:
4 – 50 µm

Far-IR:
40 – 500 µm

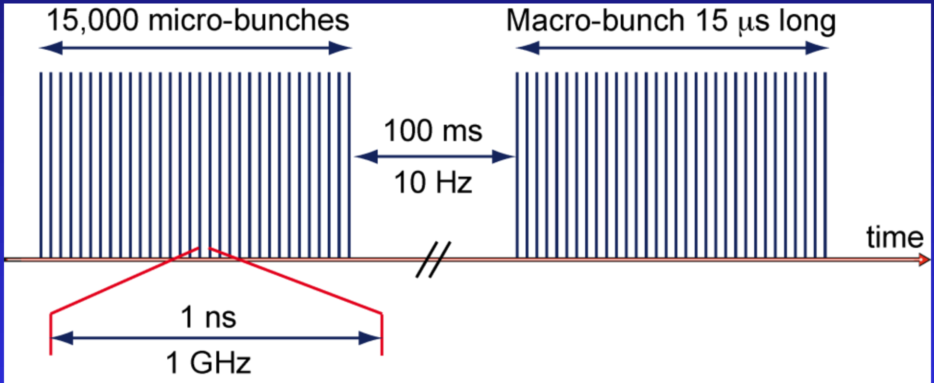


Linac specs summary

Normal-conducting S-band accelerator:

electron energy:	15 - 50 MeV
rf frequency:	3 GHz
bunch rep. rate:	1 GHz
bunch charge:	> 200 pC
bunch length:	1 - 5 ps
macro-bunch length:	15 μs
macro-bunch rep. rate:	10 Hz
energy spread:	< 50 keV
energy drift:	< 0.1% per hour
norm. transverse emittance:	20 π mm mrad
beam power:	up to a few kW

Macro-bunch temporal structure



Design and construction of linac and e-beamline:
Advanced Energy Systems, Inc., Medford, NY, USA

→Talk WEOC04 by Alan Todd

Specs of FHI FEL

Mid-IR:

installed and commissioned

IR wavelength:	~4 – ~50 μm
IR cavity length:	5.4 m
IR waveguide:	none

Undulator: planar hybrid, NdFeB

period:	40 mm
number of periods:	50
length:	2 m
rms-K:	0.5 – 1.6

Far-IR:

projected

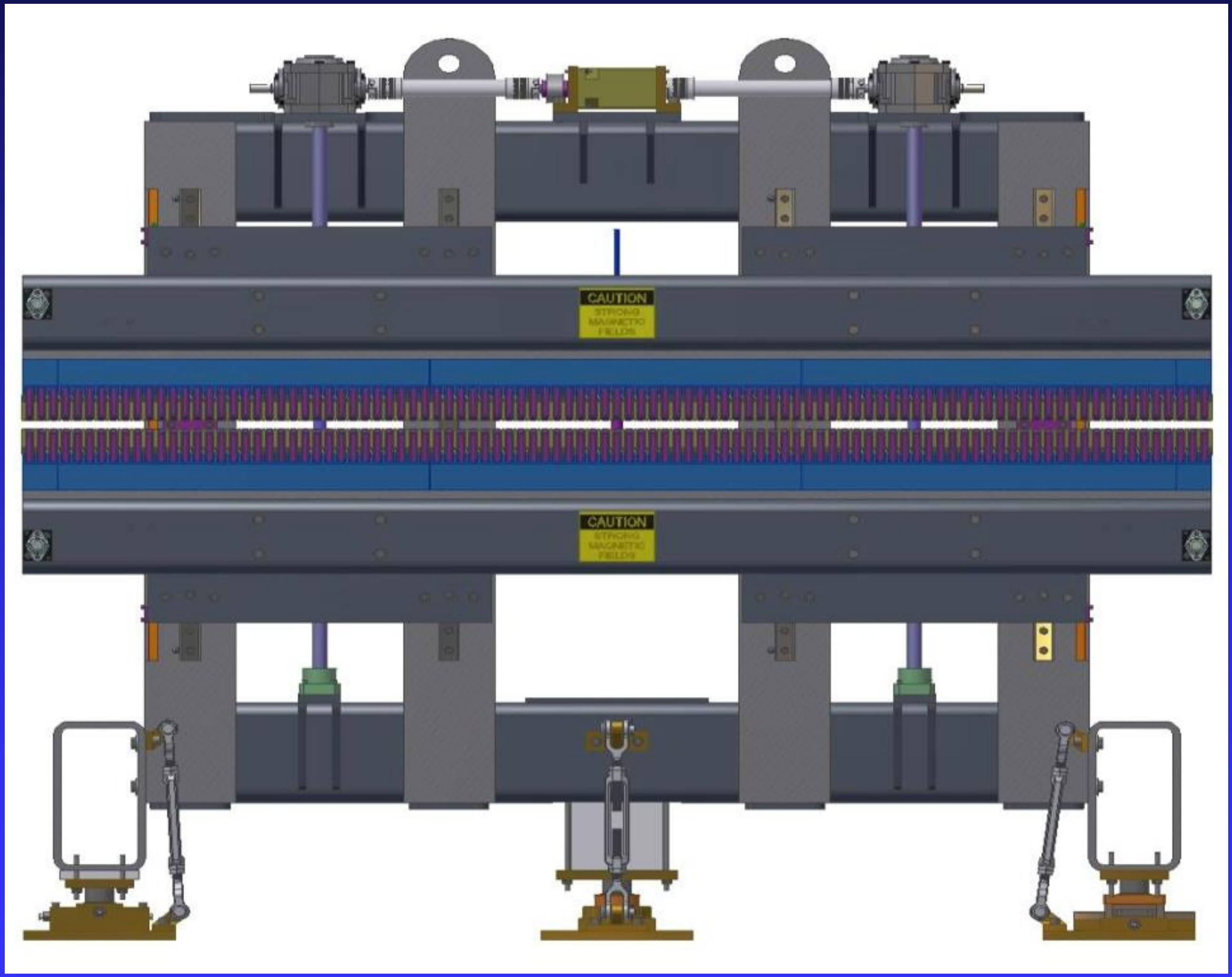
IR cavity length:	7.2 m
IR wavelength:	~30 – ~500 μm
IR waveguide:	1-dim. 10 mm height

Undulator: planar PPM or hybrid, SmCo or NdFeB

period:	110 mm
number of periods:	40
length:	4.4 m
rms-K:	1 – 3

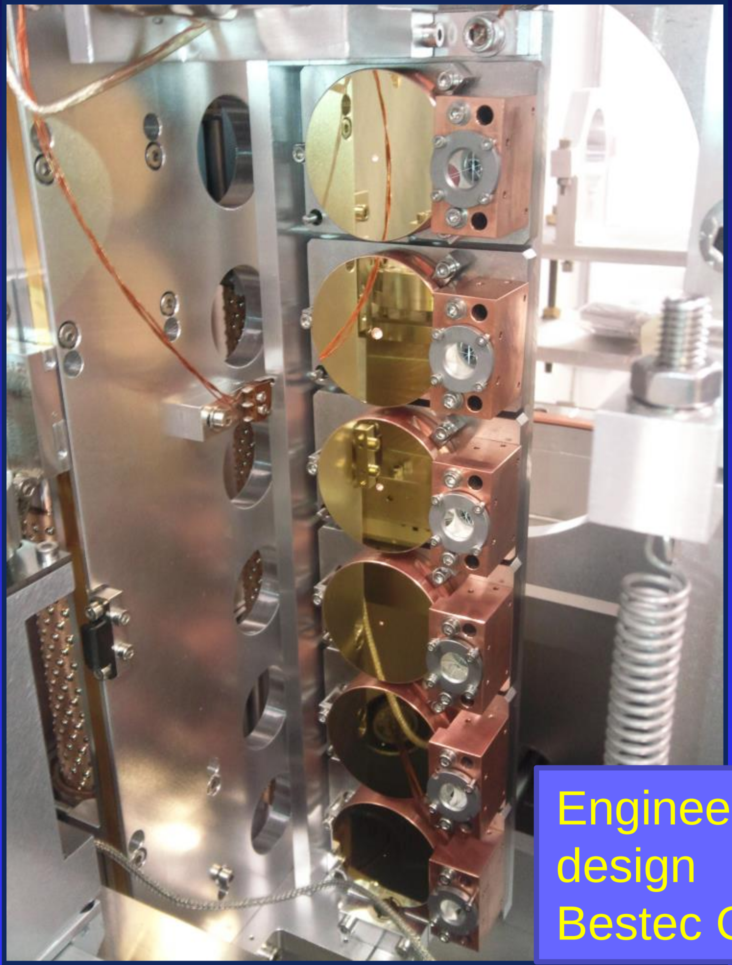
MIR Undulator

- Hybrid magnet NdFeB
- Radiation resistant
- Wedged poles
- Designed and built for FHI by STI Optronics, Steve Gottschalk
- See poster THPD13



Mid-IR cavity

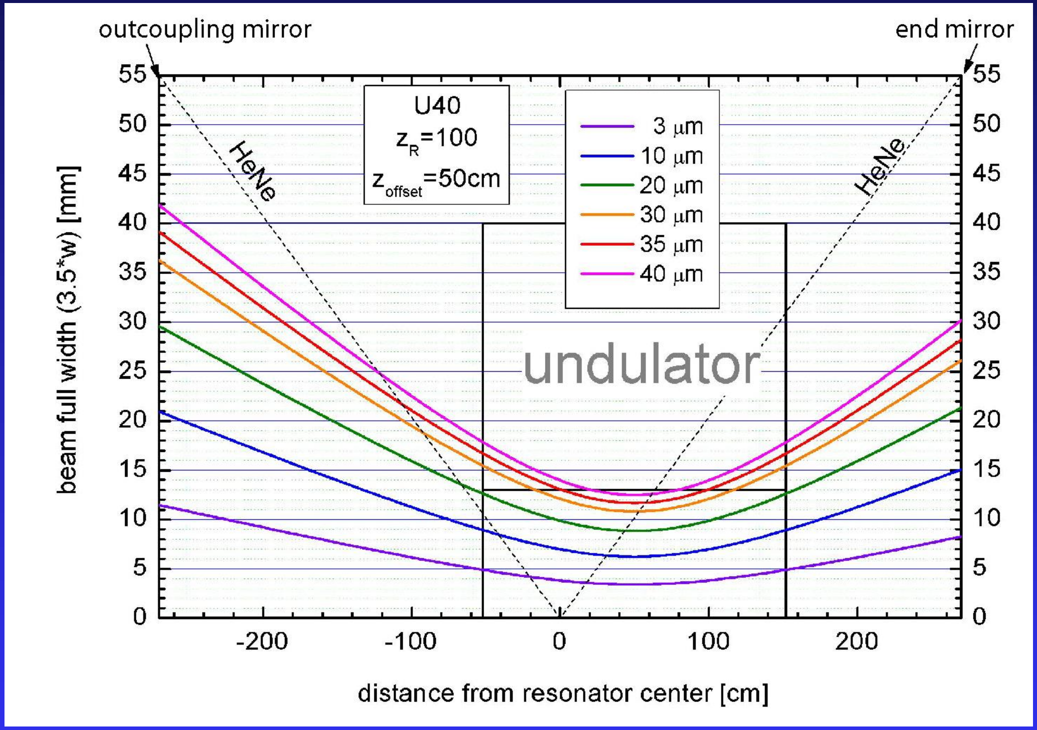
Out-coupling mirror



Engineering design
Bestec GmbH

Outcoupling hole diameters
0.75, 1.0, 1.5, 2.5, 3.5 mm

IR cavity modes



Cavity length 5.4 m
Concave cavity mirrors
→ 1.0 m Rayleigh length

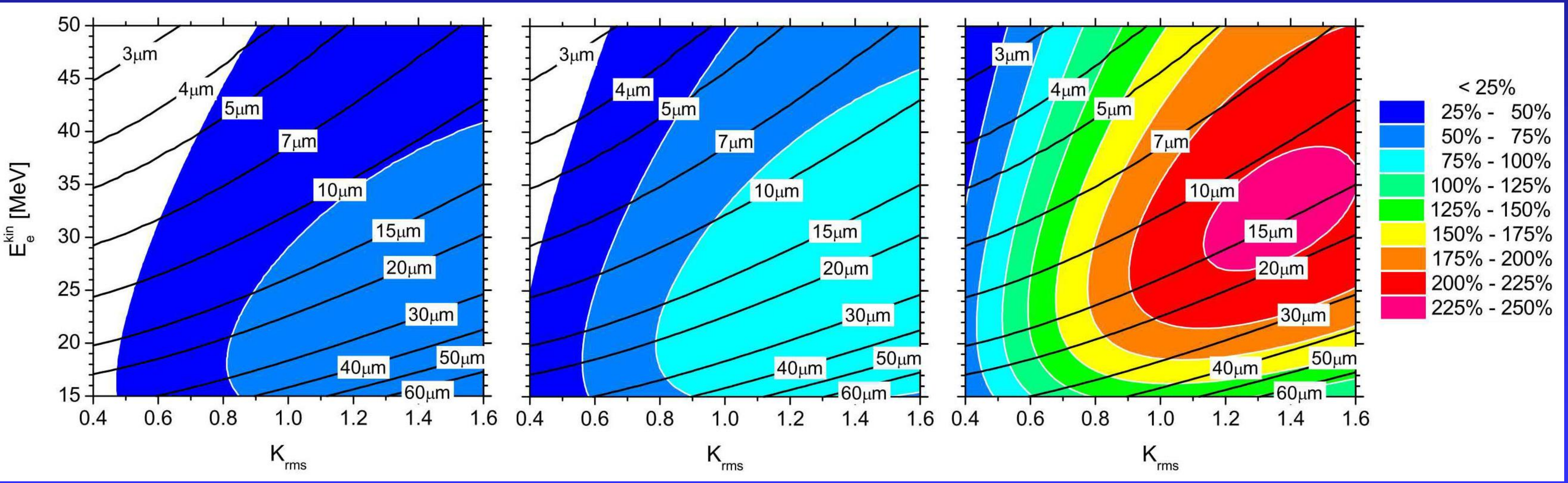
Calculated small-signal single-pass gain

<u>Assumptions:</u>

- 50 keV energy spread
- 200 pC bunch charge
- **20 π mm mrad norm. trans. emittance**

rms bunch length:

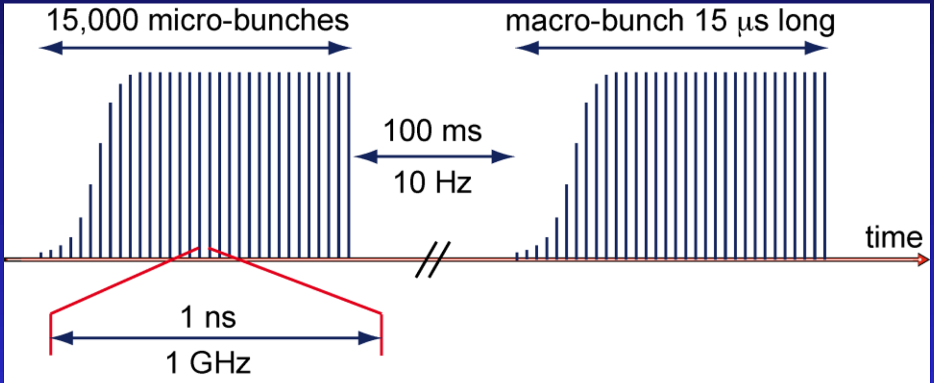
5 ps **3 ps** **1 ps**



→ Up to ~200% gain
→ Anticipated lasing wavelength range: 4 - 50 micron

Specs of FHI FEL

Time structure of IR output given by electrons: micro-pulses and macro-pulses



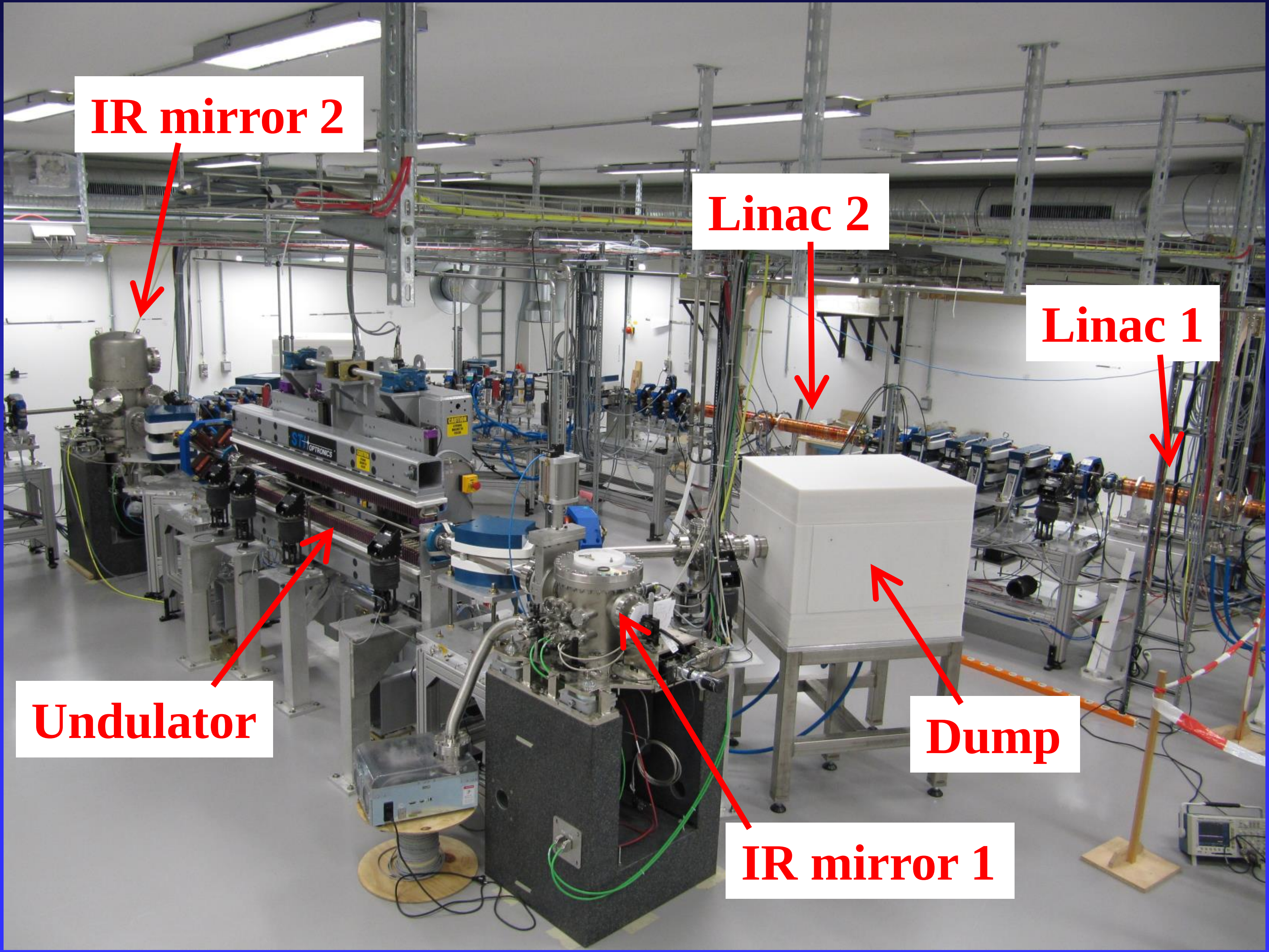
IR output:

- 10 Hz (max. 20 Hz) rep. rate
- 1 GHz and 1/n GHz micropulse rep. rate
- macro-pulse length > 10 μs
- ≈ 100 mJ / macro-pulse
- 10 – 20 μJ / micro-pulse

We expect:

- micro-pulse length 0.3 – 5 ps
- FT-limited bandwidth: 0.3 – 5% of central frequency

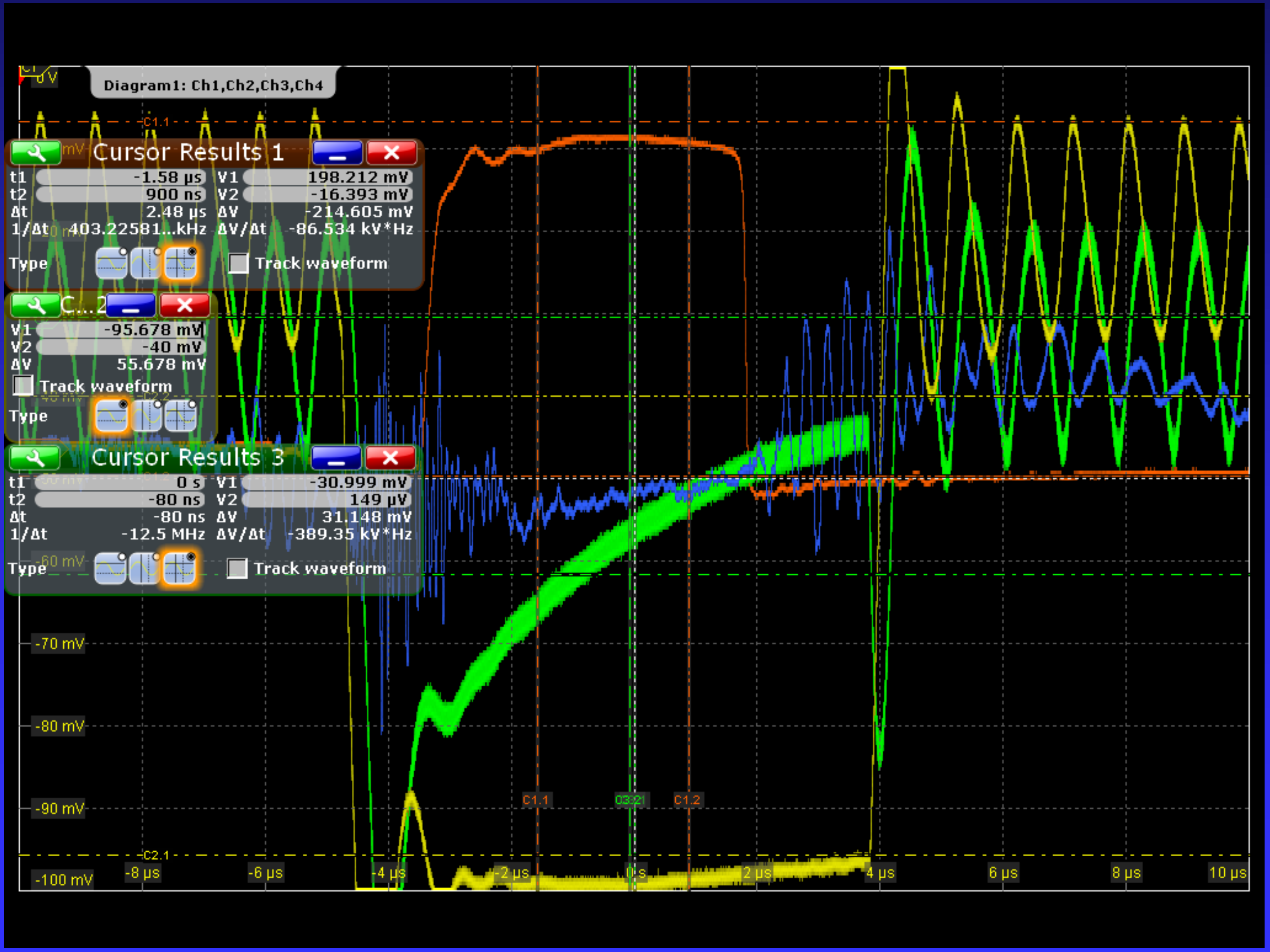
Photograph of FHI FEL



First Lasing 14.2.2012

Blue trace: IR detector signal,   Brown signal: electron bunch current

Cavity length L detuned; No lasing



E_{El} = 28 MeV

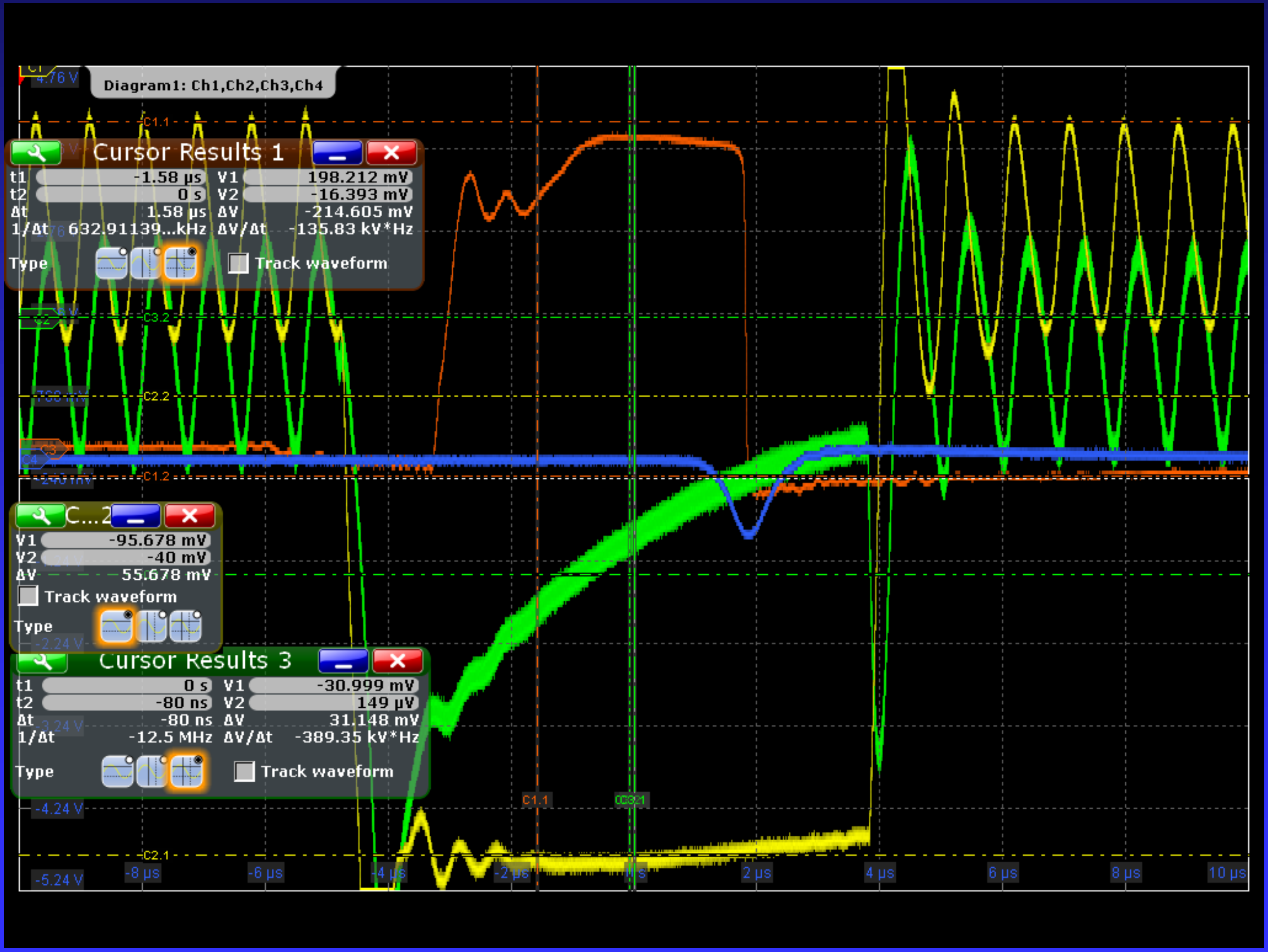
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal, Brown signal: electron bunch current

Cavity length L:

L=L_0



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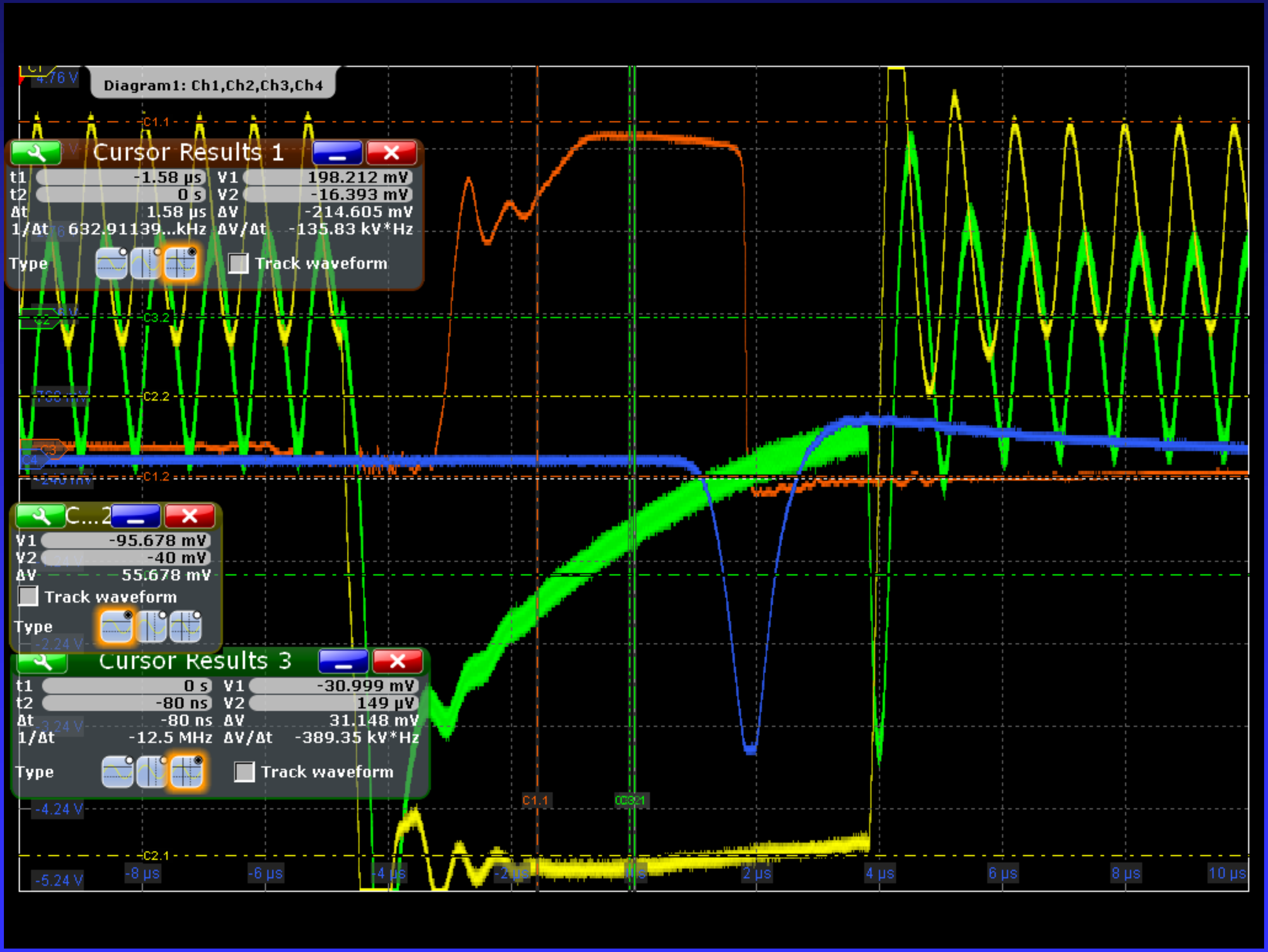
First Lasing 14.2.2012

Blue trace: IR detector signal,   Brown signal: electron bunch current

Cavity length L:

ΔL = 10 µm



E_{El} = 28 MeV

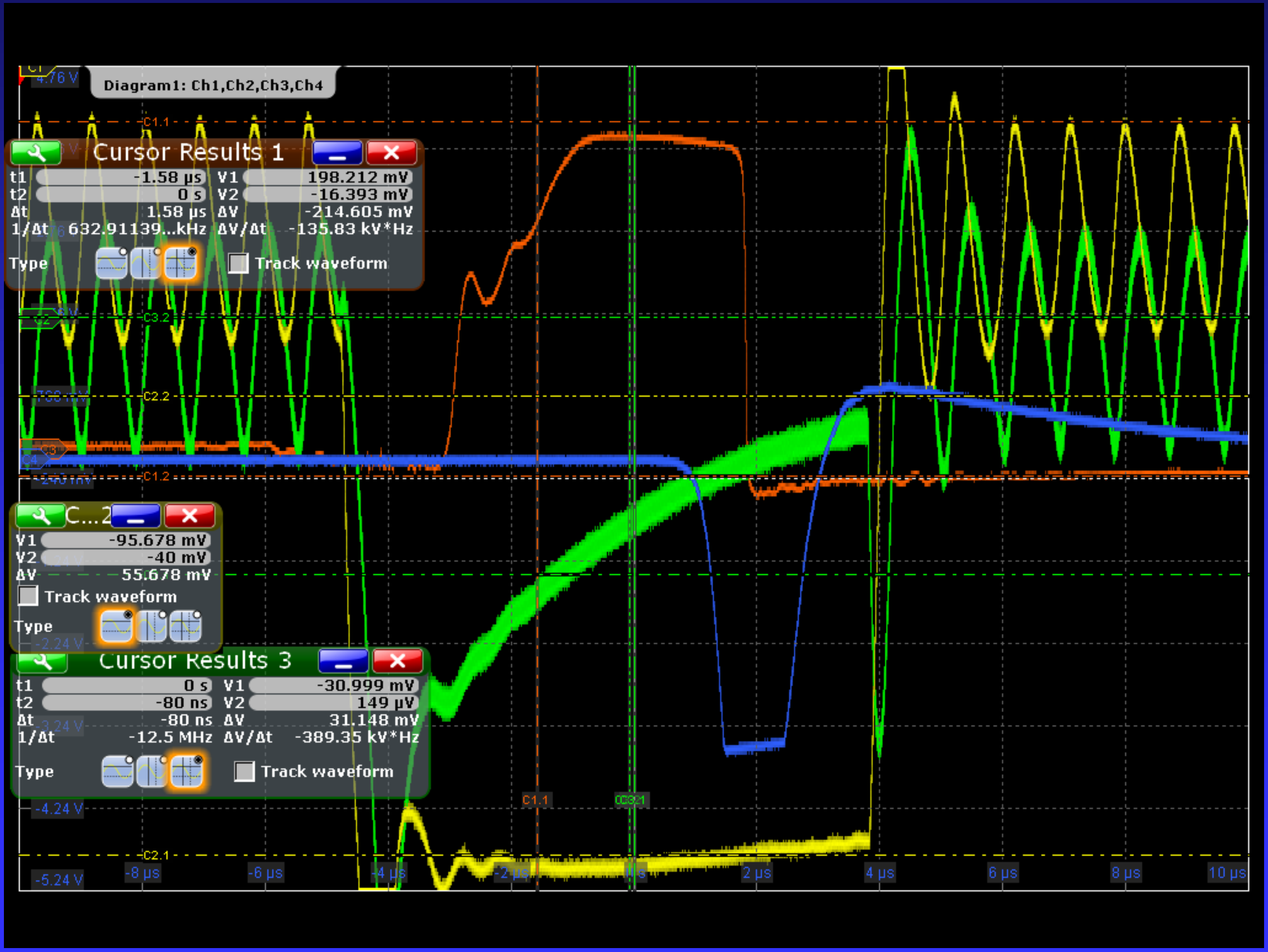
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal, Brown signal: electron bunch current

Cavity length L:

ΔL = 20 µm



E_{El} = 28 MeV

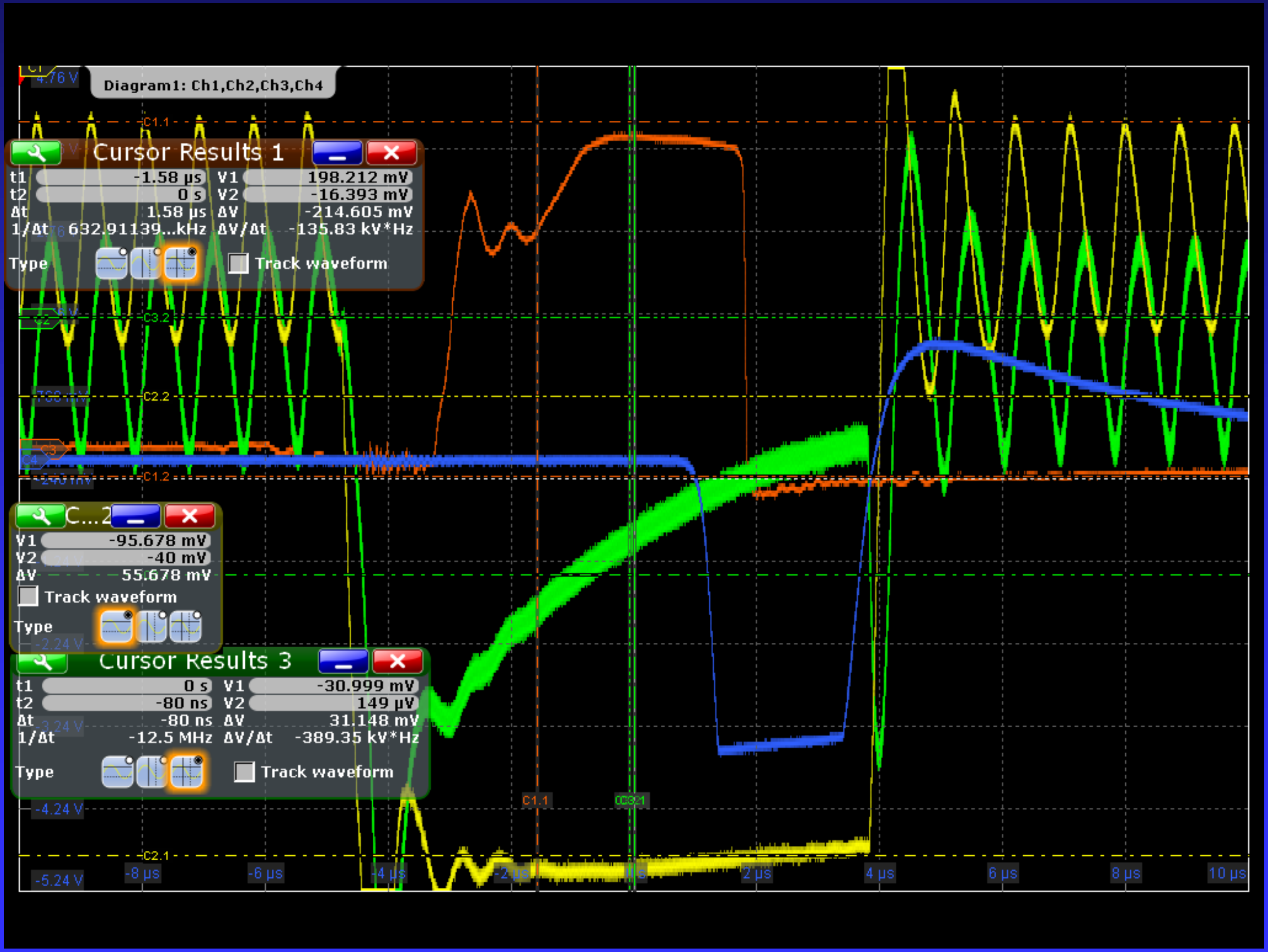
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal,   Brown signal: electron bunch current

Cavity length L:

ΔL = 30 µm



E_{El} = 28 MeV

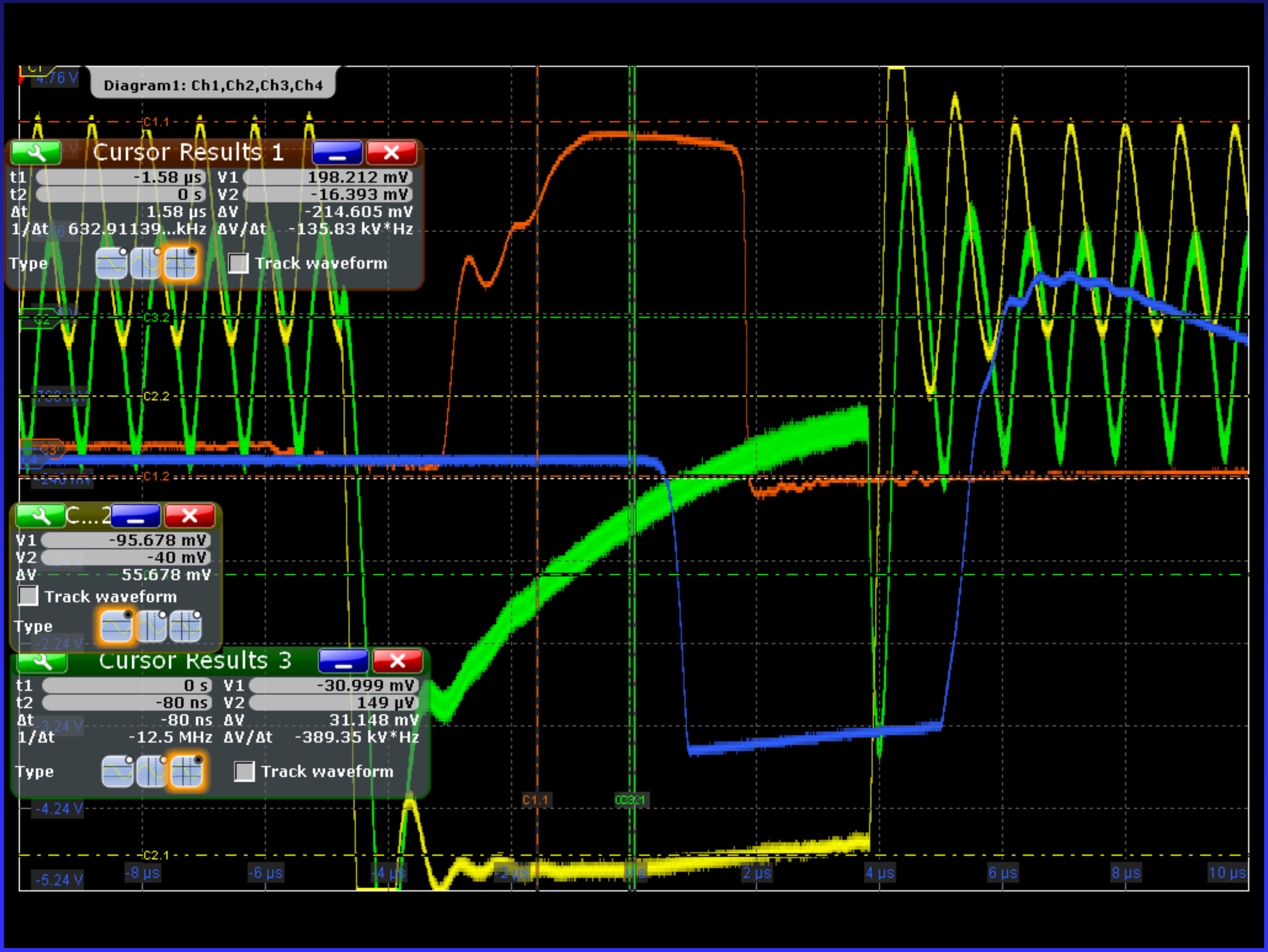
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal, Brown signal: electron bunch current

Cavity length L:

ΔL = 40 µm



E_{El} = 28 MeV

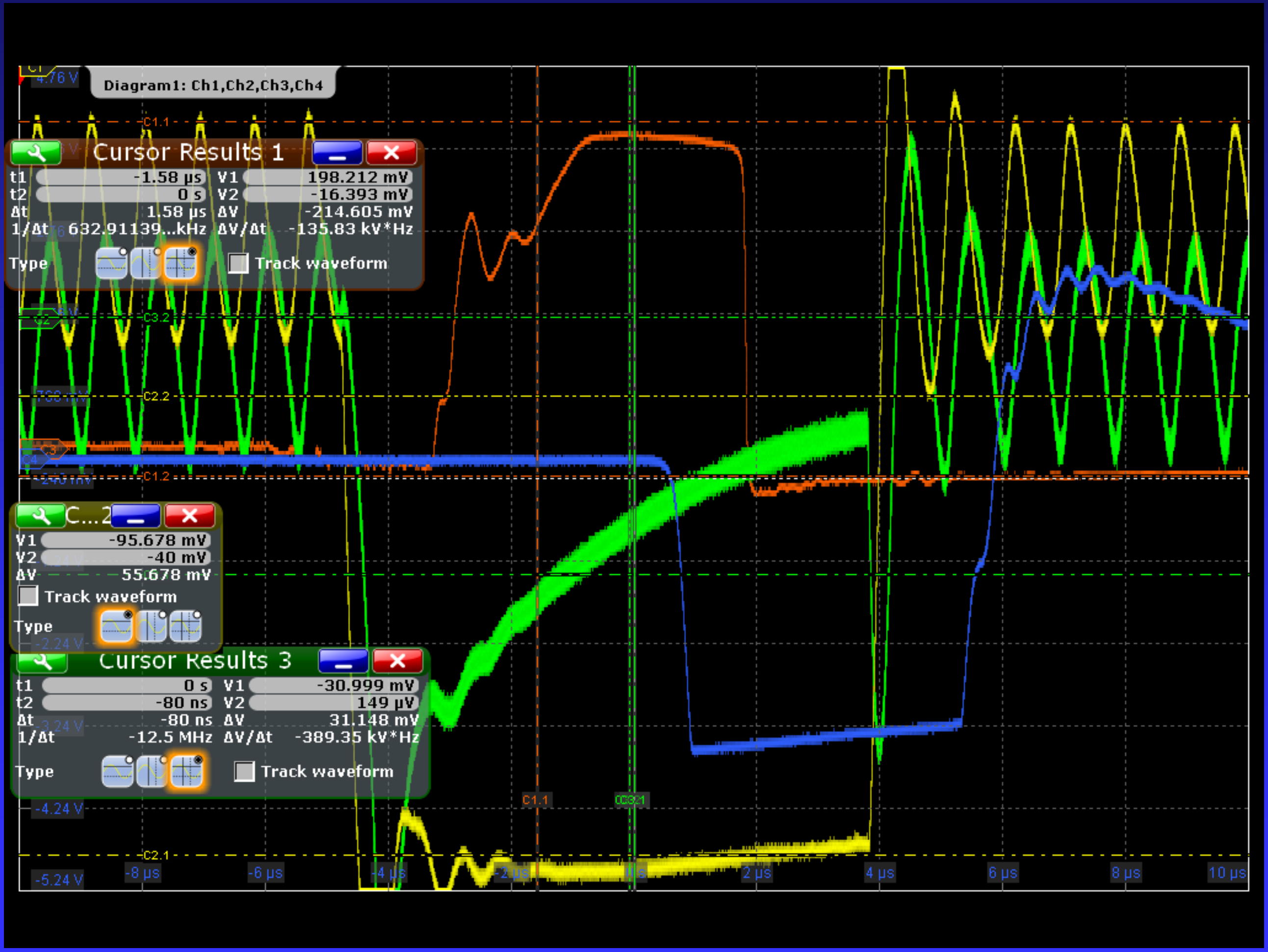
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal,   Brown signal: electron bunch current

Cavity length L:

ΔL = 50 µm



E_{El} = 28 MeV

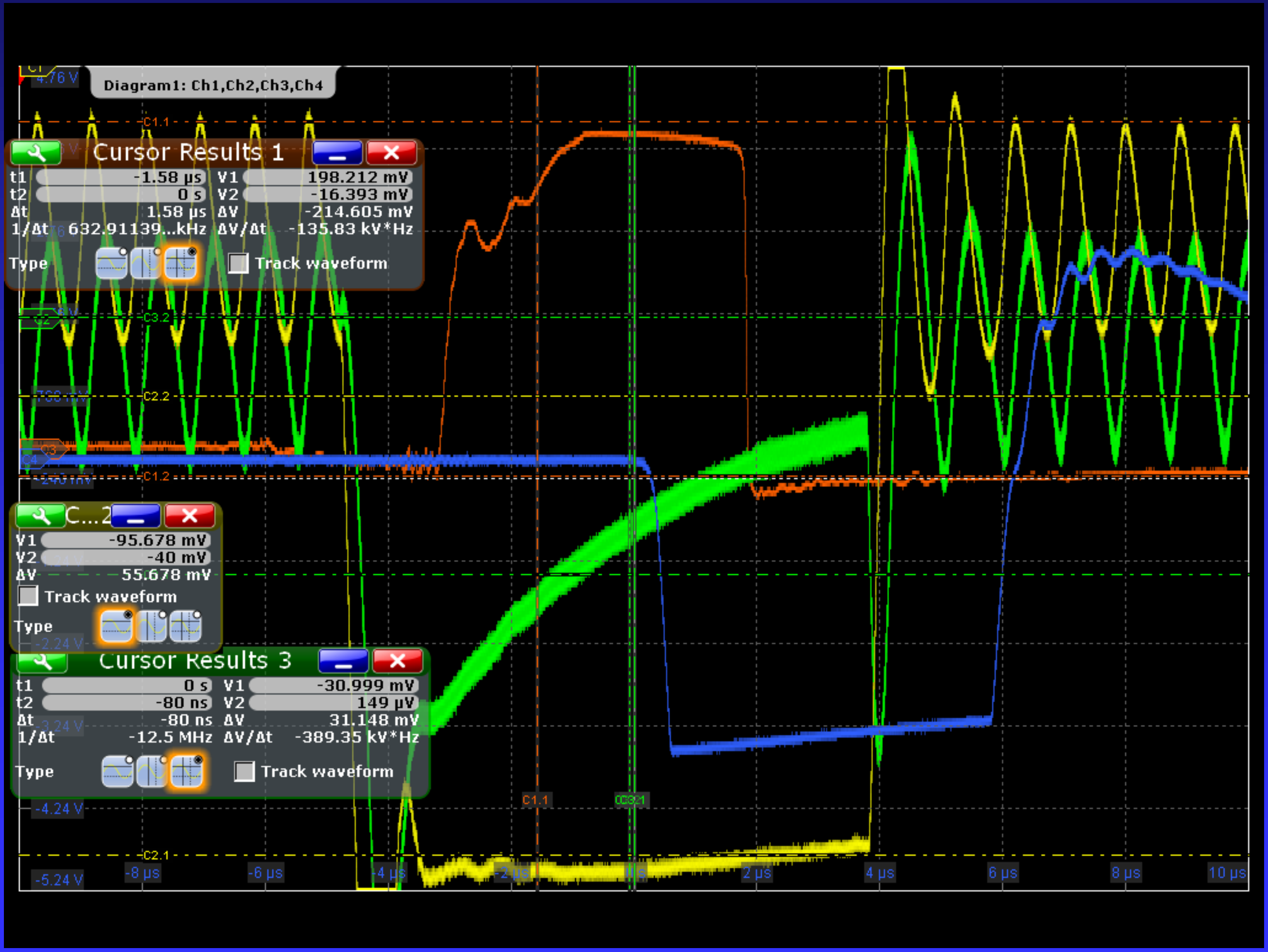
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal, Brown signal: electron bunch current

Cavity length L:

ΔL = 60 µm



E_{El} = 28 MeV

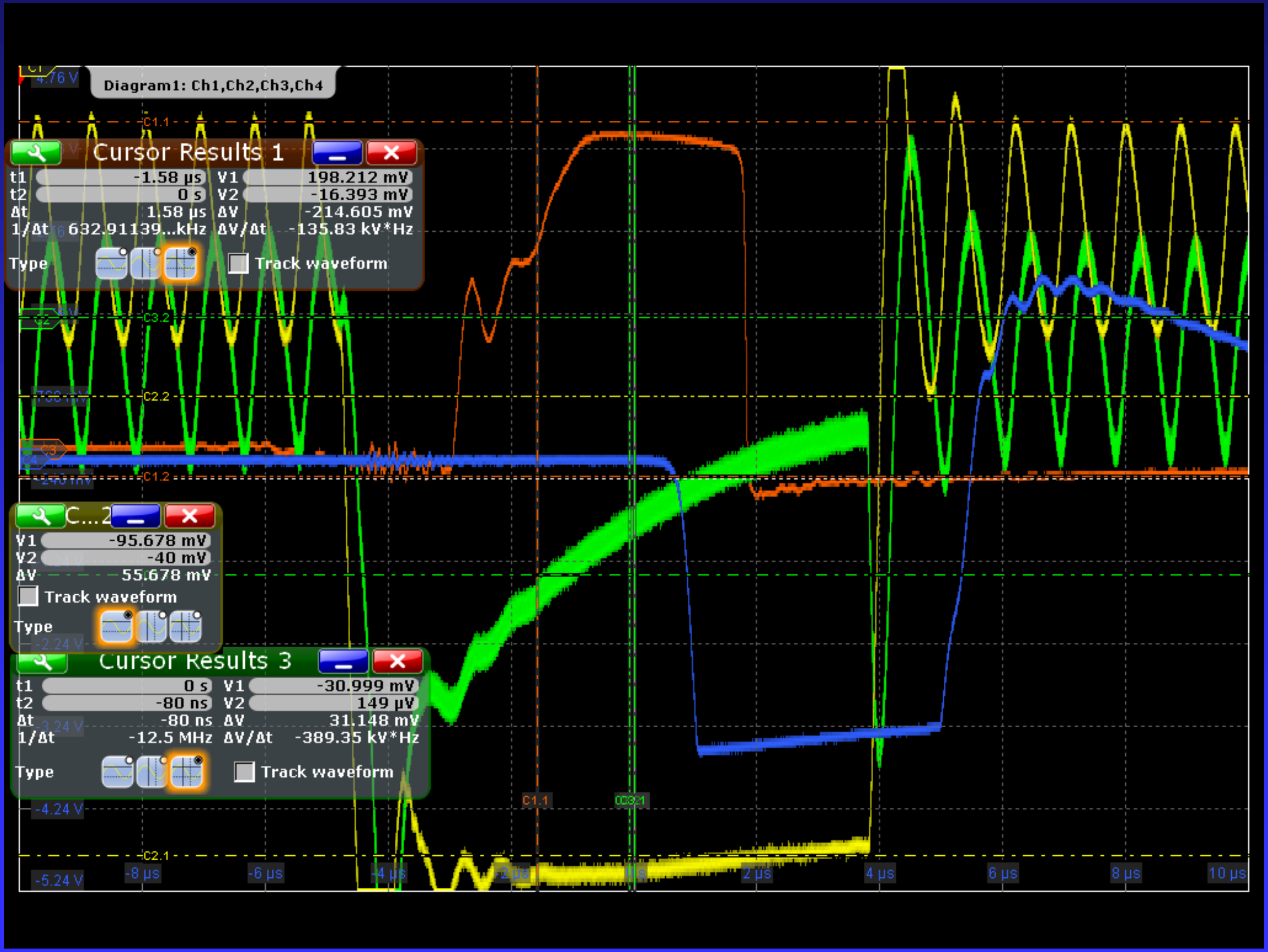
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal,   Brown signal: electron bunch current

Cavity length L:

ΔL = 70 µm



E_{El} = 28 MeV

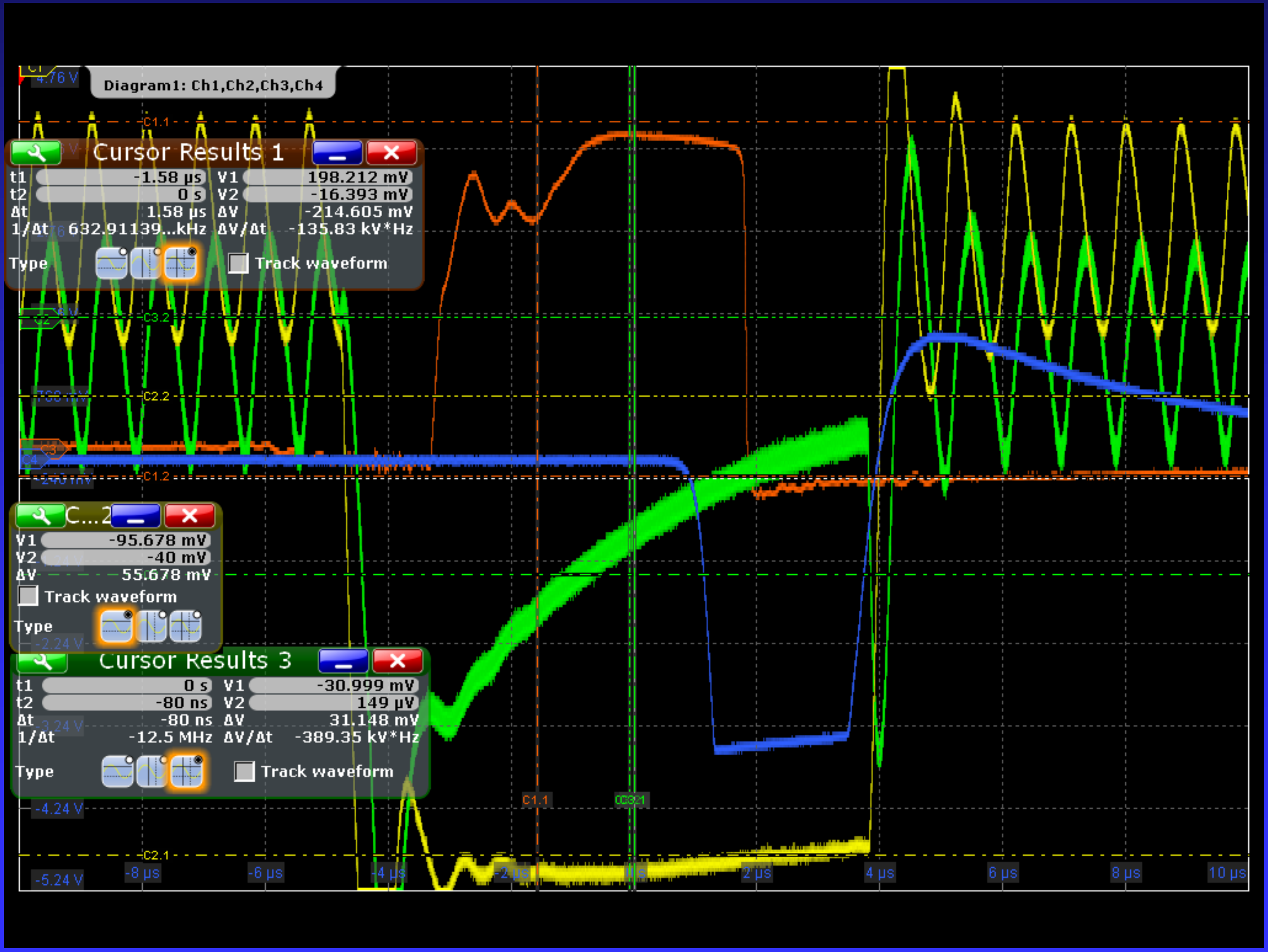
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal,   Brown signal: electron bunch current

Cavity length L:

ΔL = 80 µm



E_{El} = 28 MeV

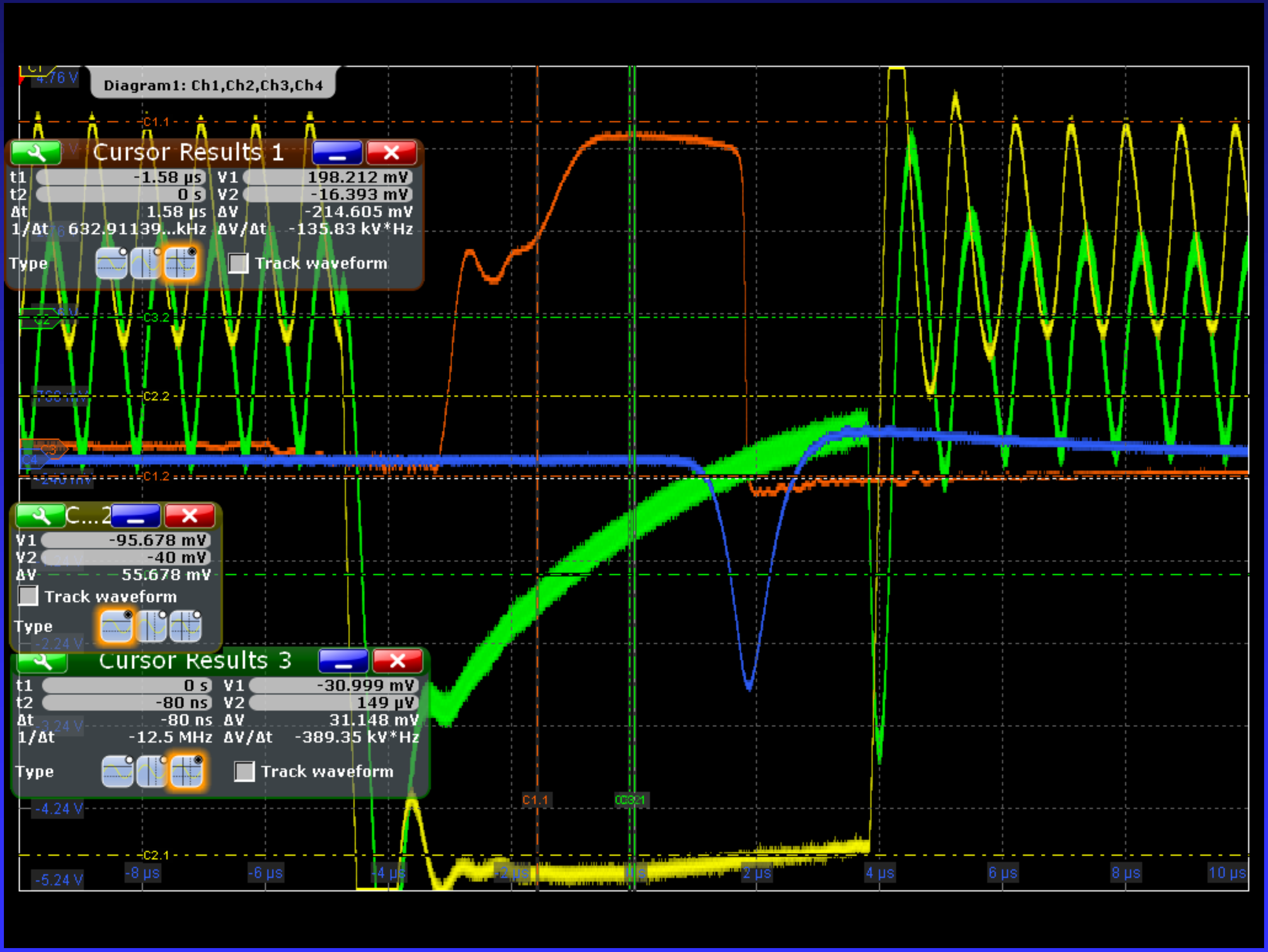
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal,   Brown signal: electron bunch current

Cavity length L:

ΔL = 90 µm



E_{El} = 28 MeV

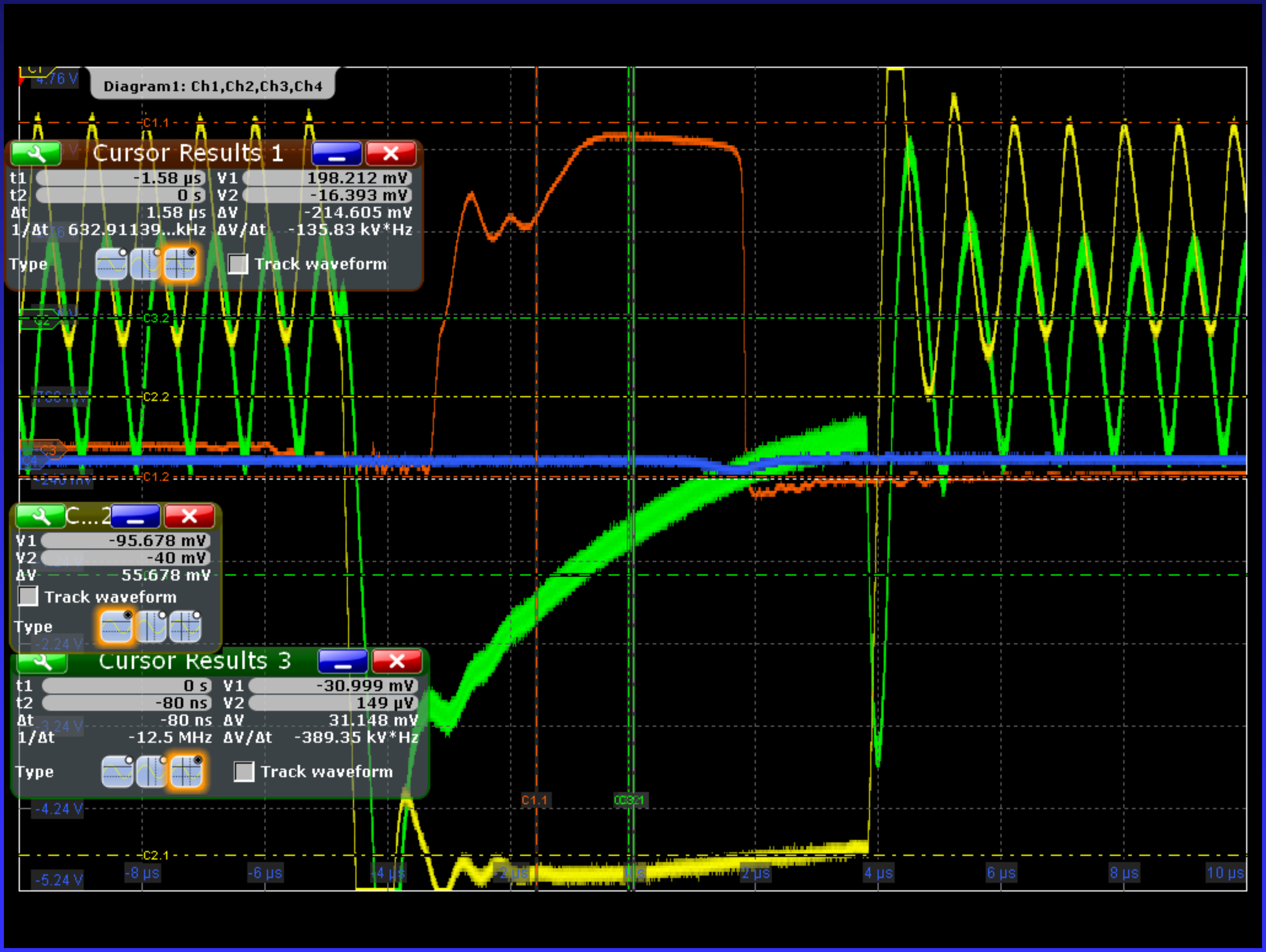
λ_{IR} = 16 µm

First Lasing 14.2.2012

Blue trace: IR detector signal,   Brown signal: electron bunch current

Cavity length L:

ΔL = 100 µm



E_{El} = 28 MeV

λ_{IR} = 16 µm

Acknowledgment

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