

The Infrared Undulator Project at FLASH

Characteristics of the undulator

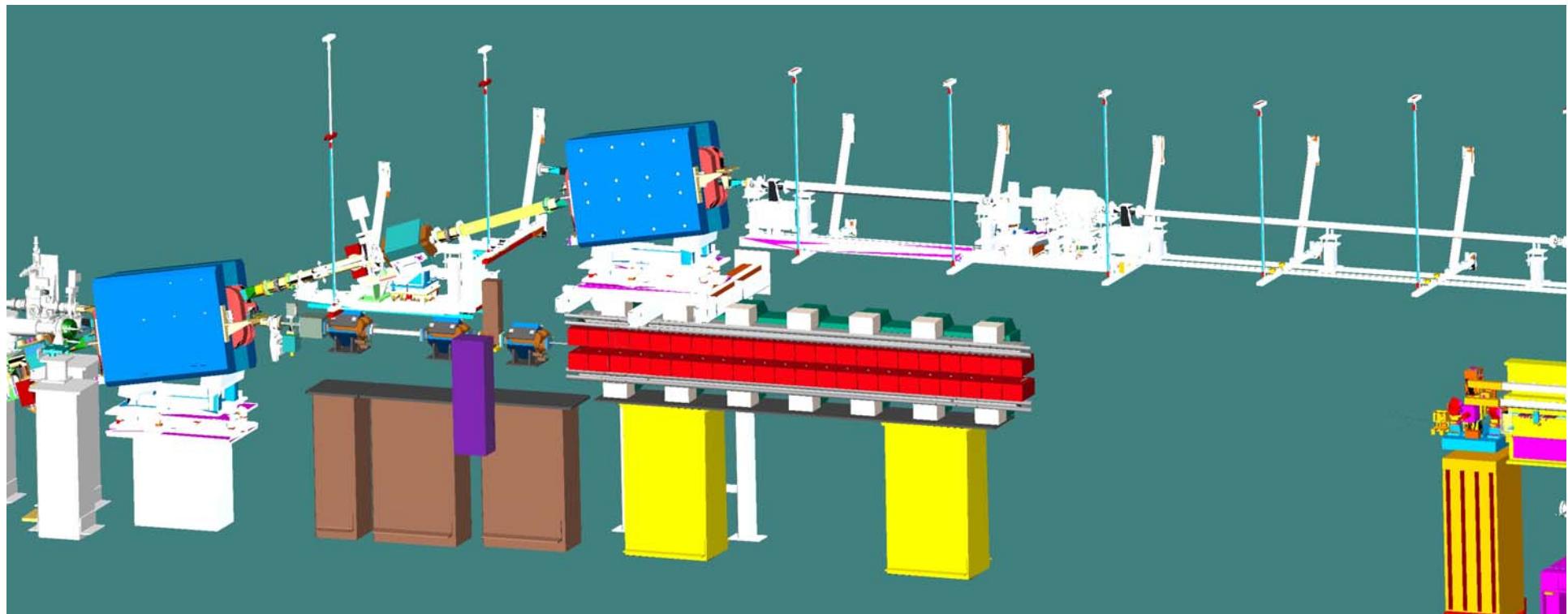
Shutdown installations of undulator and
modifications of EXP area

FLASH seminar, 13 Feb 2007

Oliver Grimm

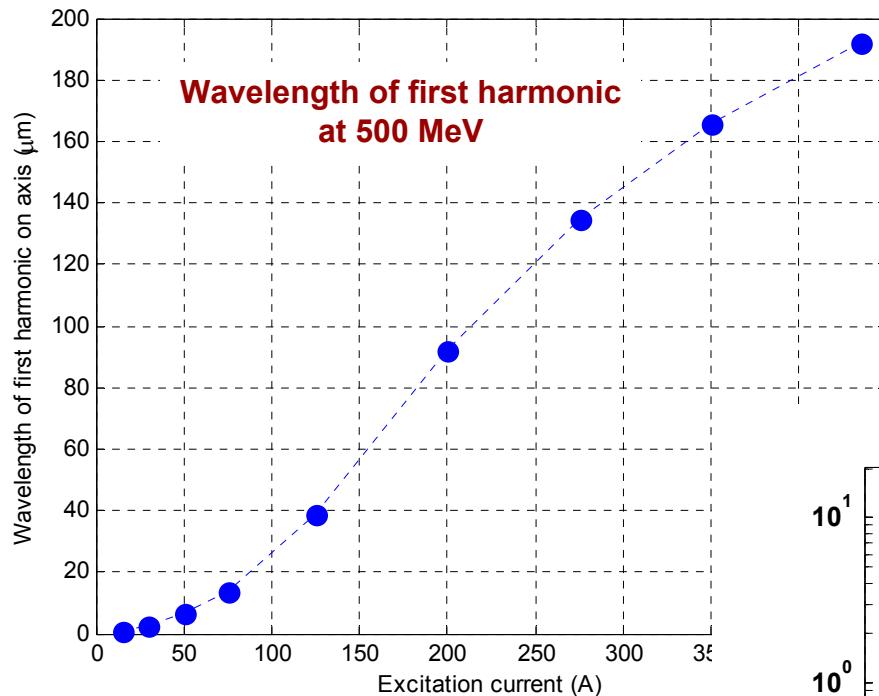
...which is?

- Electromagnetic undulator
- Generates radiation **(1-200) μm** (at 500 MeV)
- Infrared radiation source, pump/probe experiments
- Beam diagnostics



Gap	40 mm	K-value	3 – 44
Period length	400 mm	Weight	4.5 t
Number of periods	9	Max. total power	87 kW

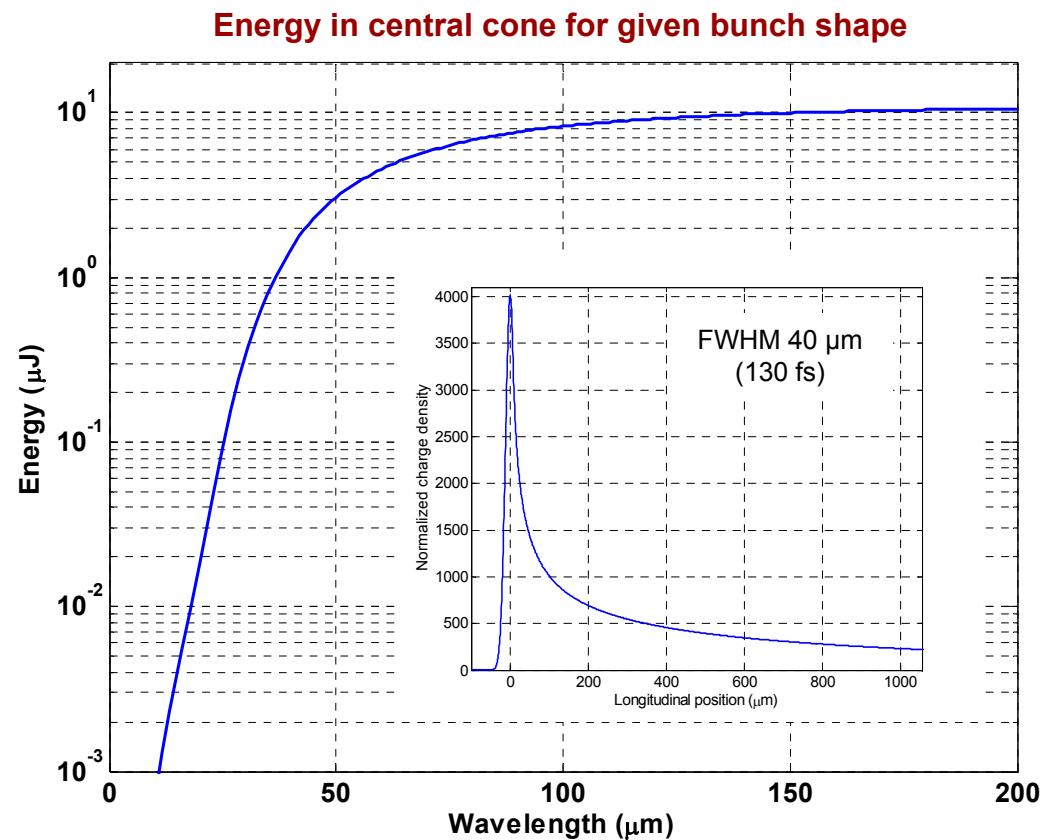
Source characteristics



Energy per pulse at 100 μm
similar to total energy from TR

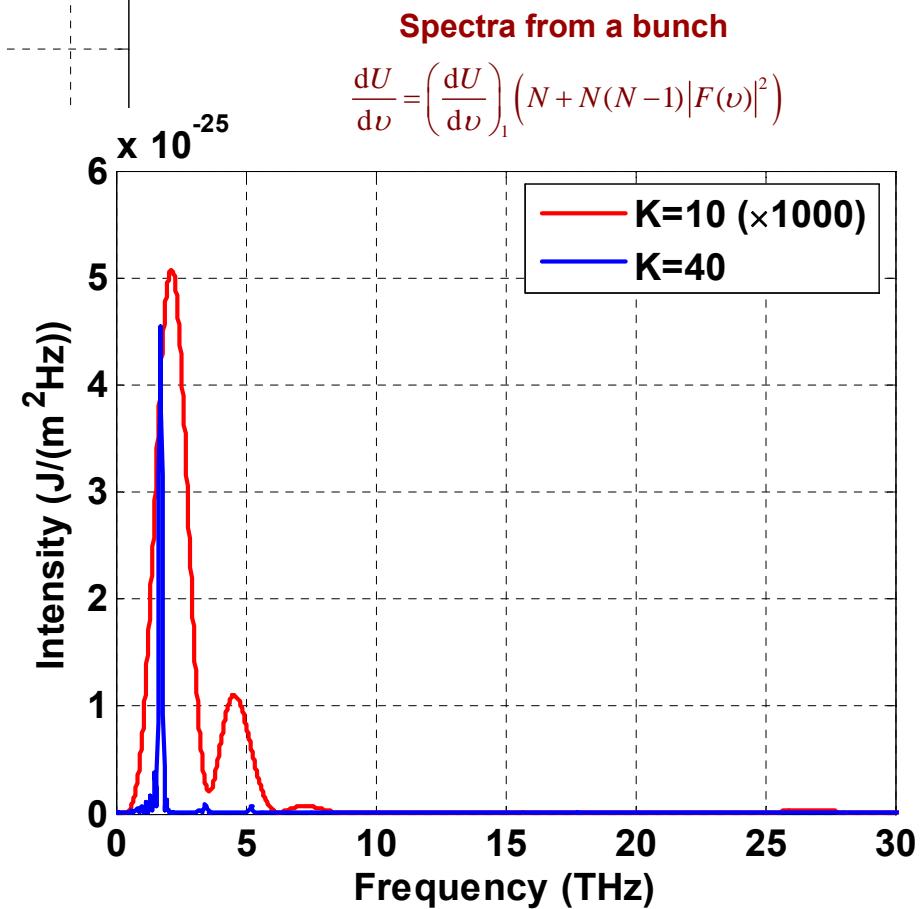
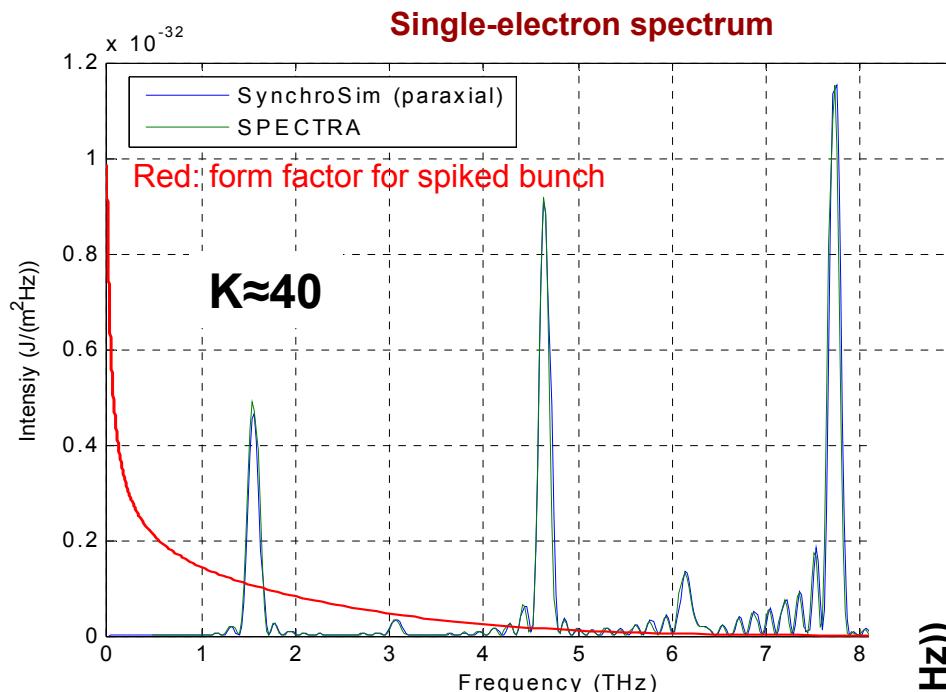
→ but within 10% bandwidth

511 MeV, 1nC



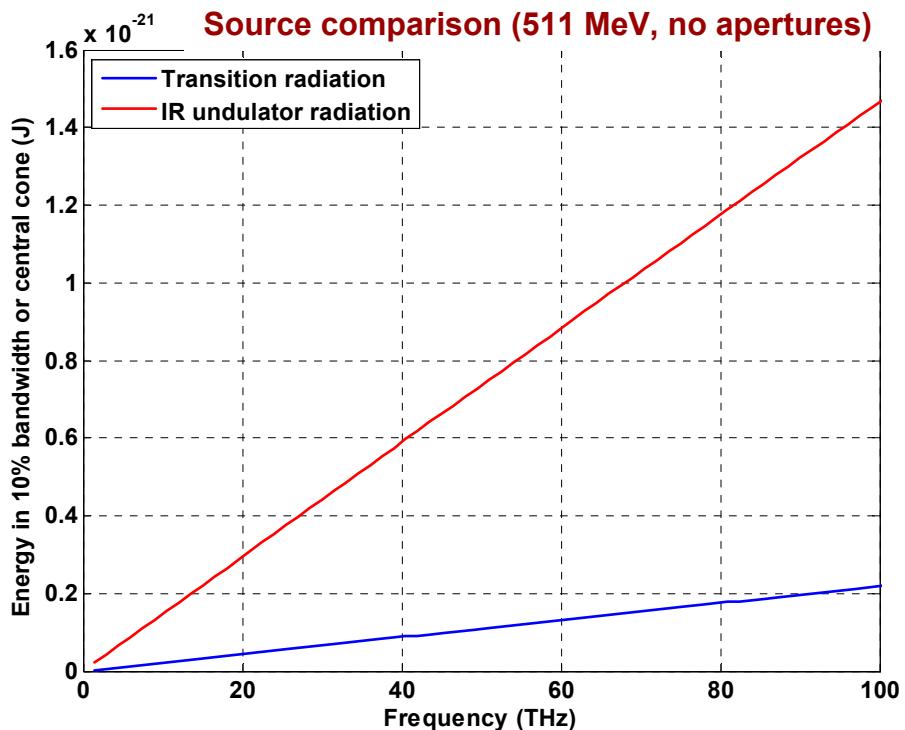
Emission spectra

10 m behind undulator centre on-axis

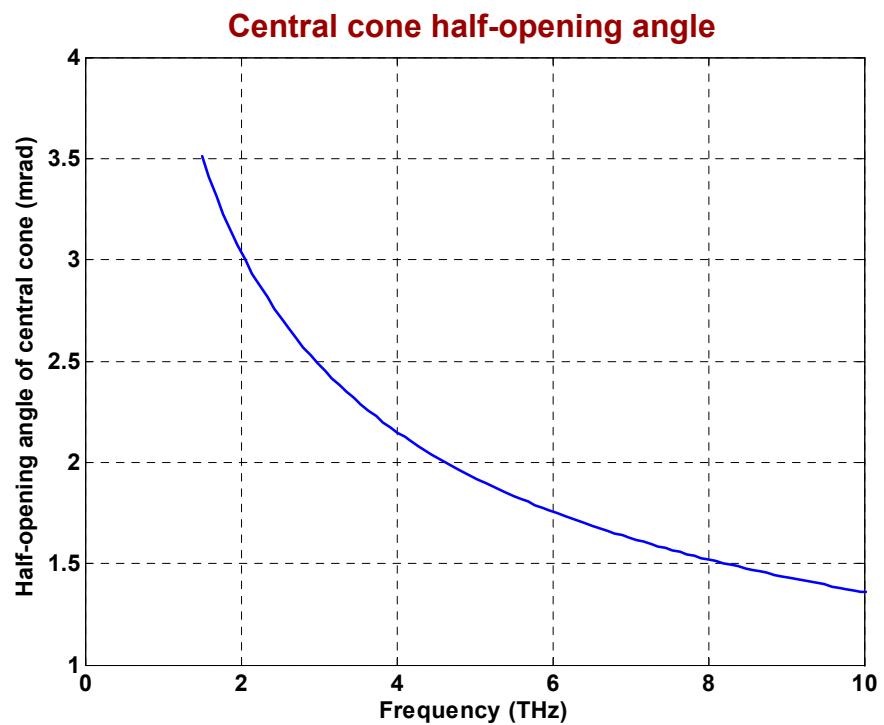
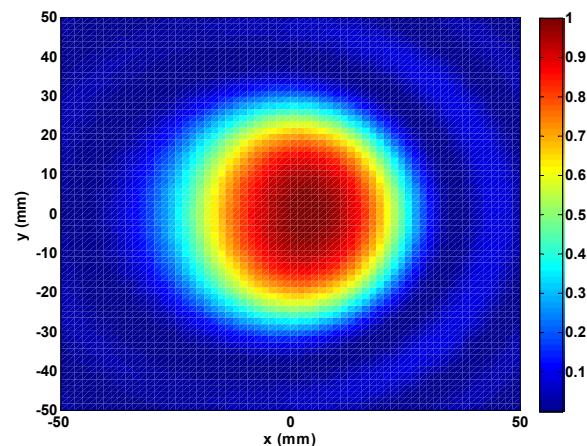


If form factor at high frequencies small,
need to use high-pass filters to measure
first-harmonic contribution (e.g. KRS-5).

Source comparison

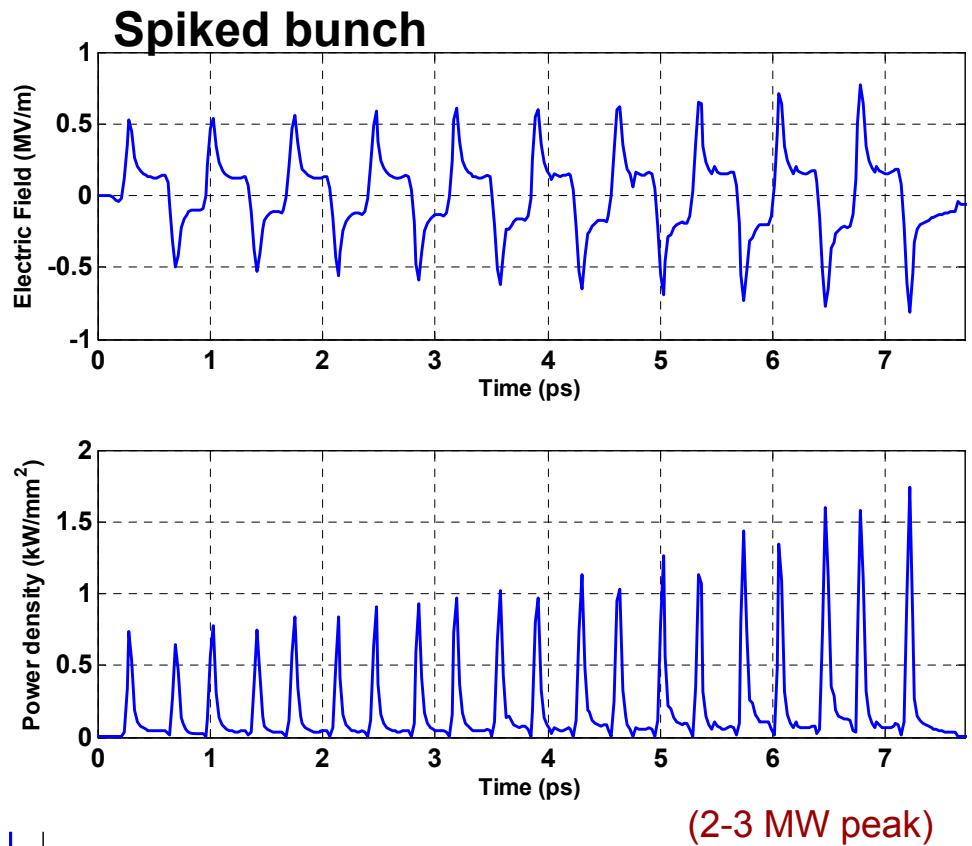
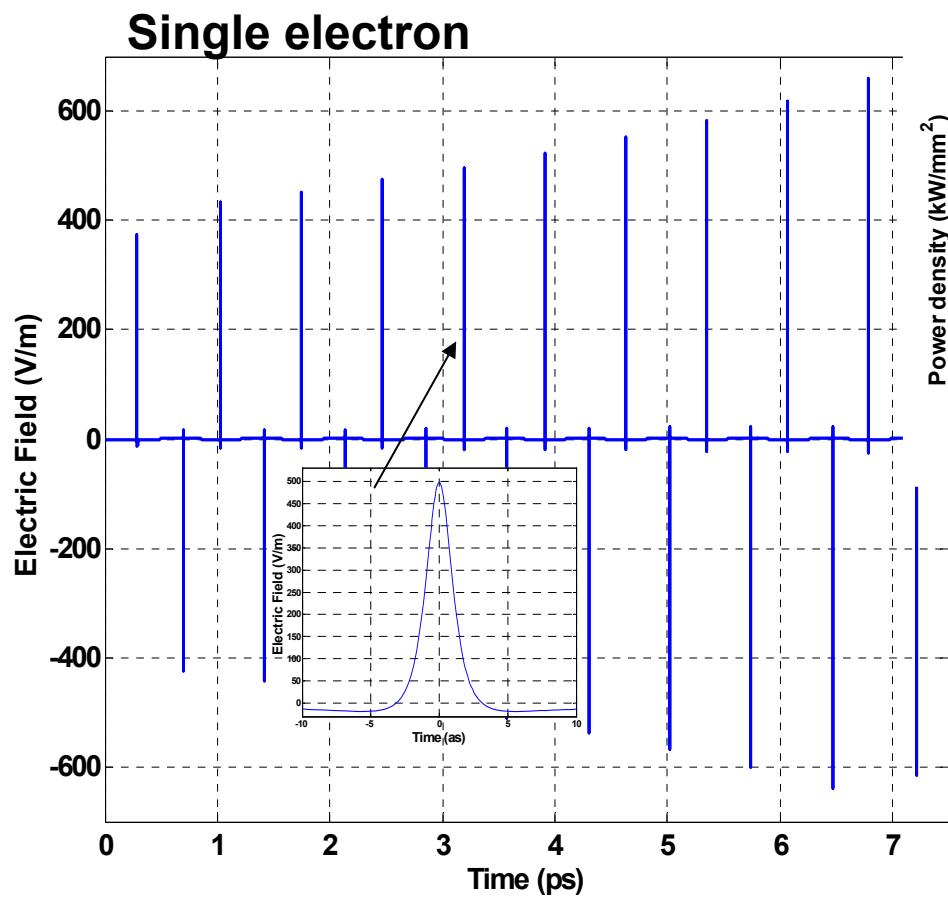


**Transverse intensity profile at 7.7 THz/39 μ m
(10 m behind undulator centre, horizontal polarization)**



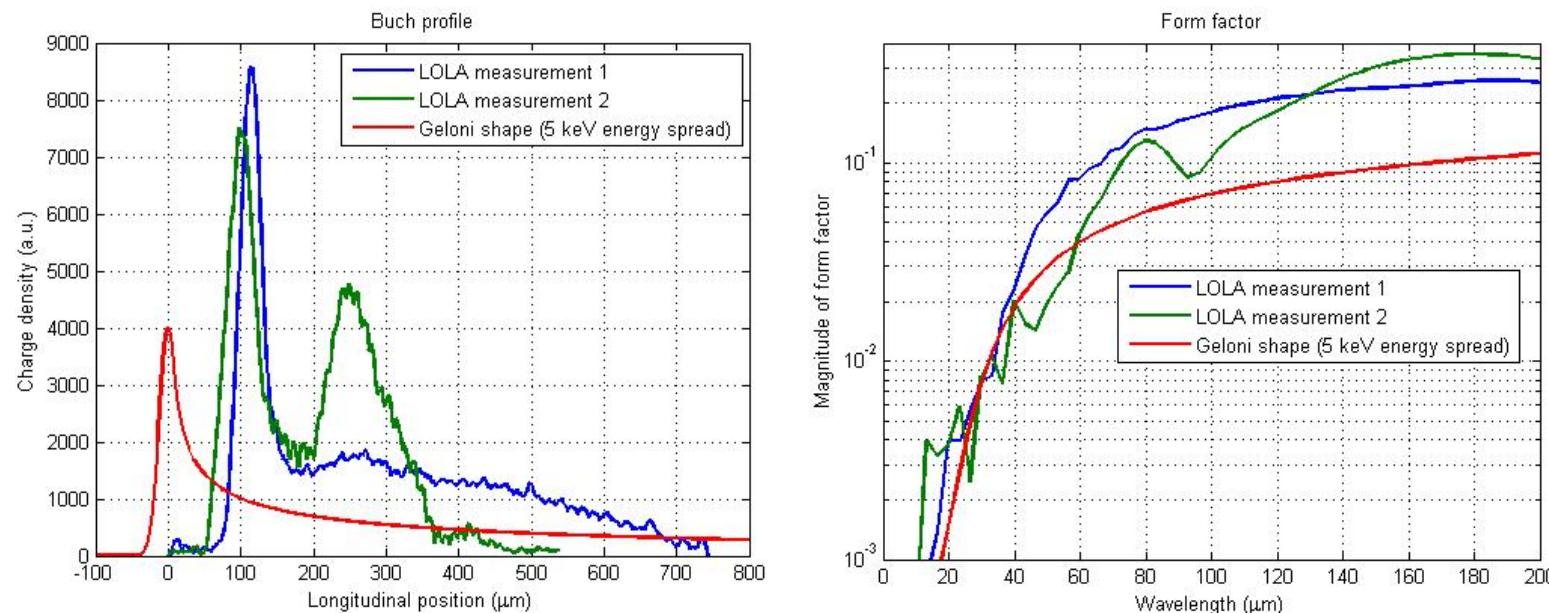
Time-domain signal at maximum excitation

10 m from undulator centre, on axis

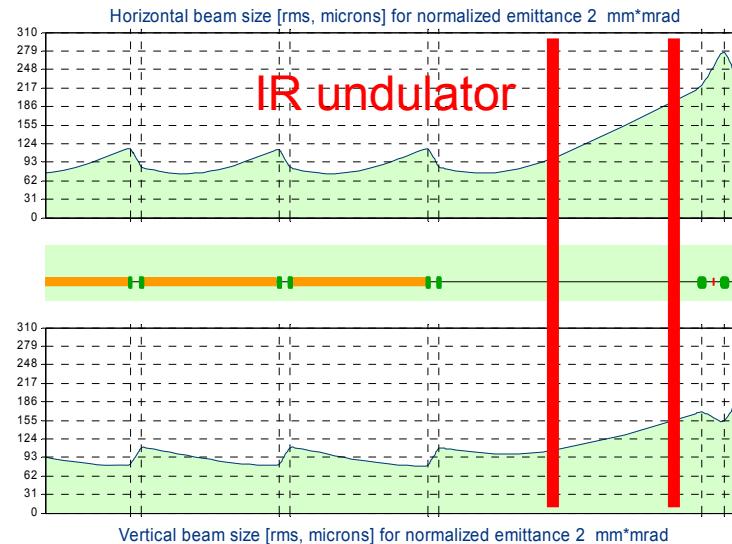
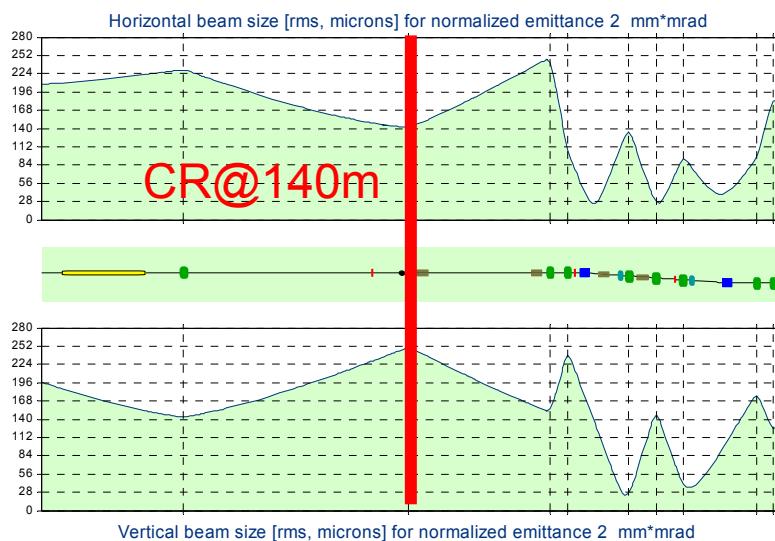


Dump magnet
Spike ≈100 fs later

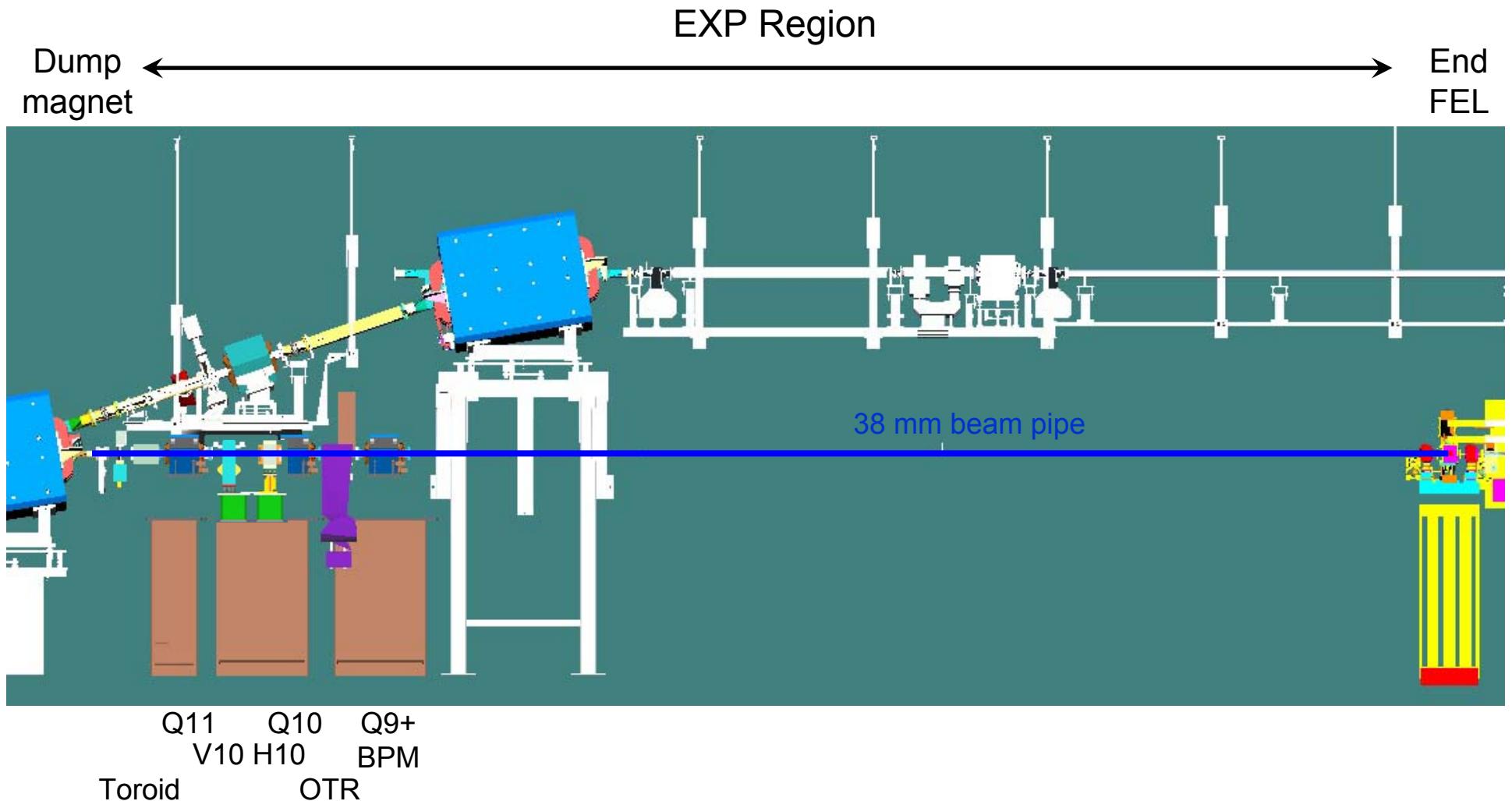
Measured and assumed bunch profiles



Beam sizes for Optics Option 2, V4, 500 MeV

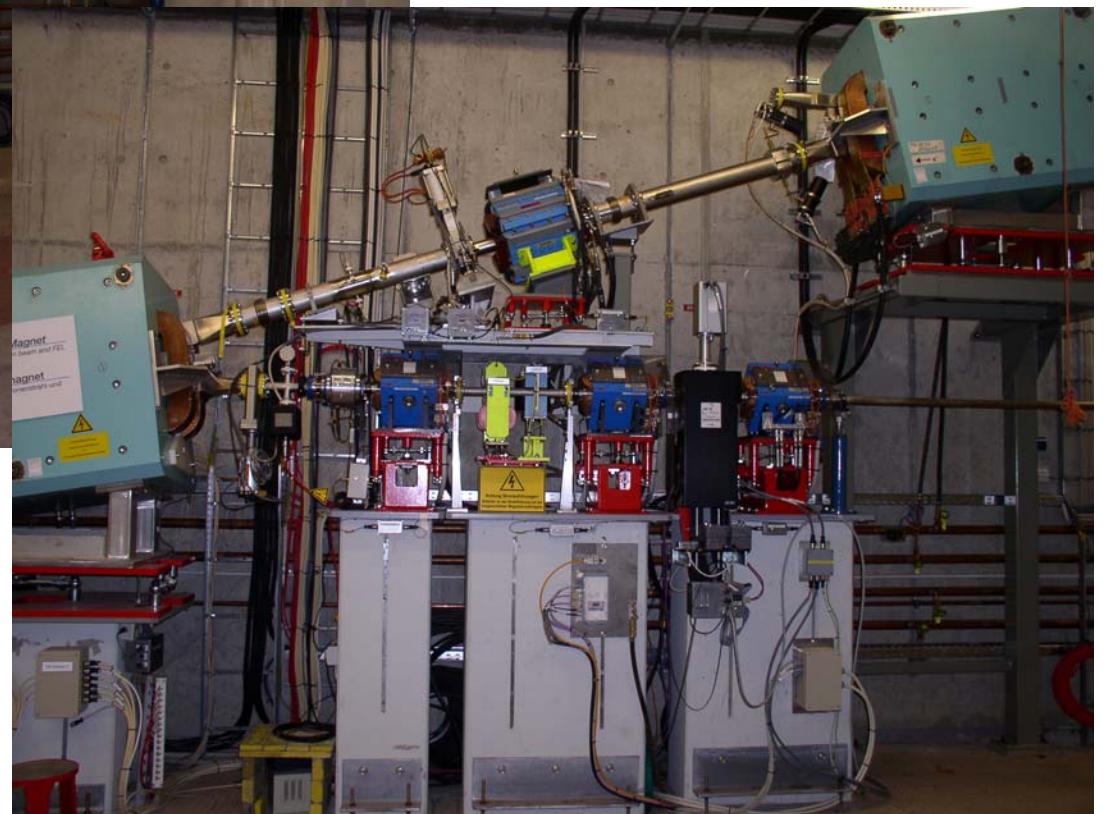


Current layout of EXP area

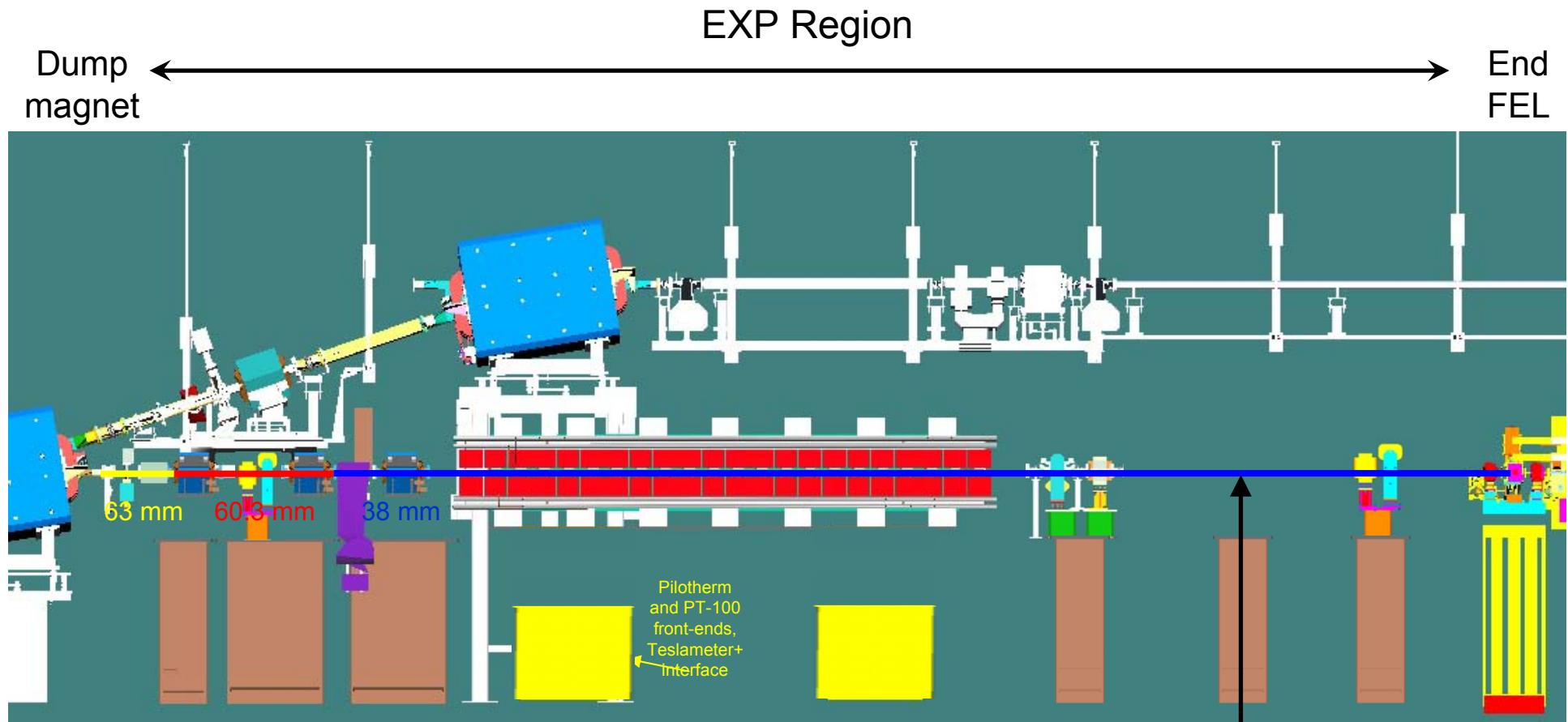


Steerer type TCA-40 (+/- 350 mA power supply)
Quad type TQA (+/- 120 A power supply)

View of EXP area



Planned redesign of EXP area



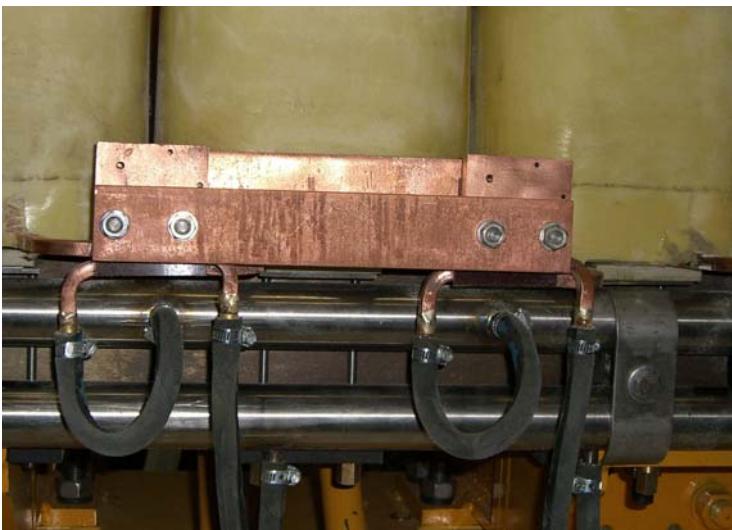
- Replace steerers by TCA-70 (from H10/V10ACC6)
- Replace TQA quads Q10 and Q11 by modified TQB
Gap 50 mm → 62 mm, same base, 48 mm longer
- Replace toroid by 63 mm type
- Replace pump and vacuum shutter by 63 mm types
- Add two beam loss monitors
- Move wire scanner scintillator/photomultiplier

IR Undulator
Steerer pair
TCA-70+BPM, TCA-40
3.5 A, new

Steerer pair
2x TCA-40, 3.5 A
from H10/V10EXP

Alignment laser
entry chamber

Photos of undulator at JINR



Strip line BPM in steerer (H3/V3EXP)

BPM (34 mm TTF strip line)

- Measurement range **+/- 6 mm**
- Resolution about 10 μm
- Electronics in building 49

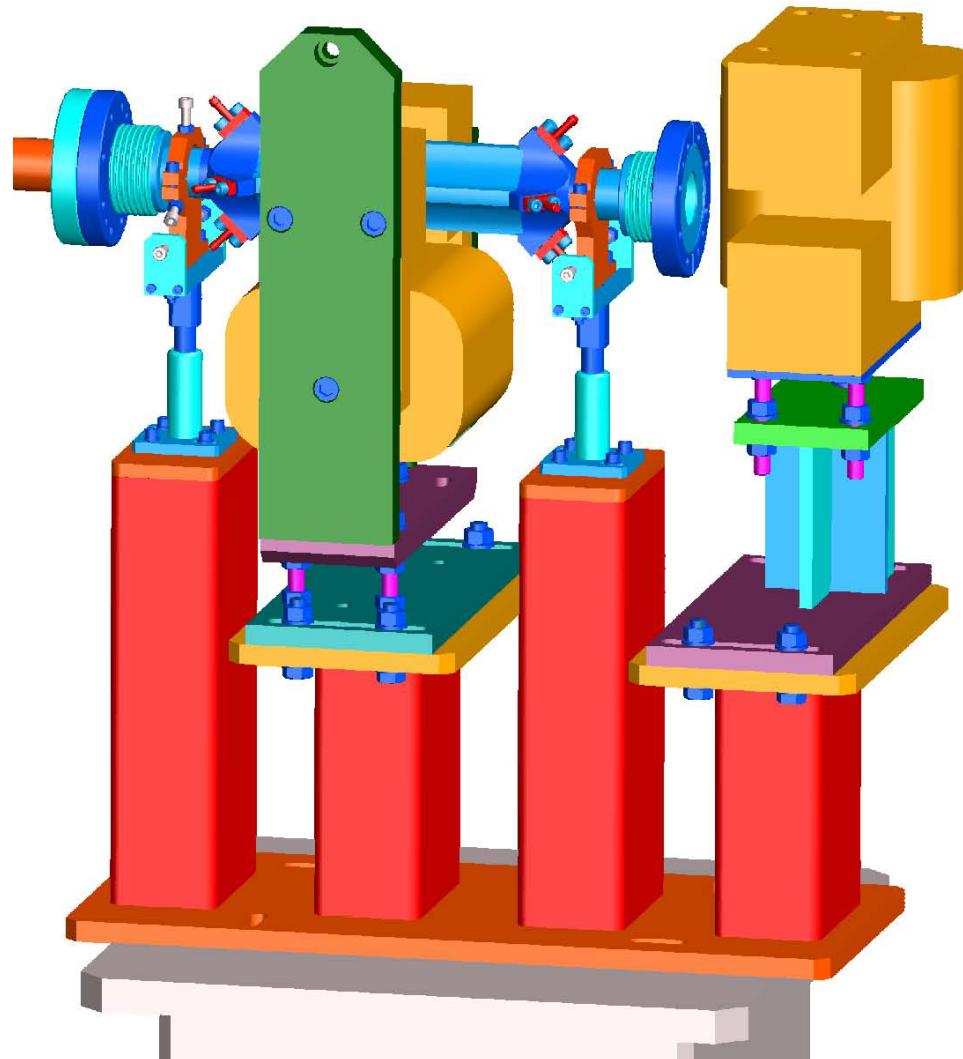
Steerer (TCA-40)

- 0.089 T/A
- Magnetic length 0.1 m
- Maximum current 3.5 A

→ Maximum field 310 mT

Maximum kick angle
 $e c l B/E \approx 10 \text{ mrad}$ (at 1 GeV)

(**+/-30 mm** over 3 m)



Power supplies

Undulator main power supply MK 506/4

- 500 A/260 V (can be grounded)
- Will be installed in extension to hall 3



Undulator corrector power supplies

- 2x 2 A/150 V (main coil correctors, can be grounded)
- 2x 10 A/20V (end coils 1+22)
- 2x 20 A/25 V (end coils 2+21, can be grounded)
- Installed in building 49 or power supply room



Other power supplies

- 4x 3.5 A for steerers
- 2x 290 A for Q10EXP/Q11EXP

- Foresee cable with higher current capability for Q9EXP?
- Change H10/V10EXP back to 3.5 A?

Undulator power dissipation

Measurements at JINR

Electrical power **83 kW** (390 A/213 V)

Water temperature rise $(14\pm 1)^\circ\text{C}$ ($18^\circ\text{C} \rightarrow 32^\circ\text{C}$)

Water flow 66 l/min

→ Power carried by water **64 ± 5 kW**

Power dissipated into environment **19 kW**

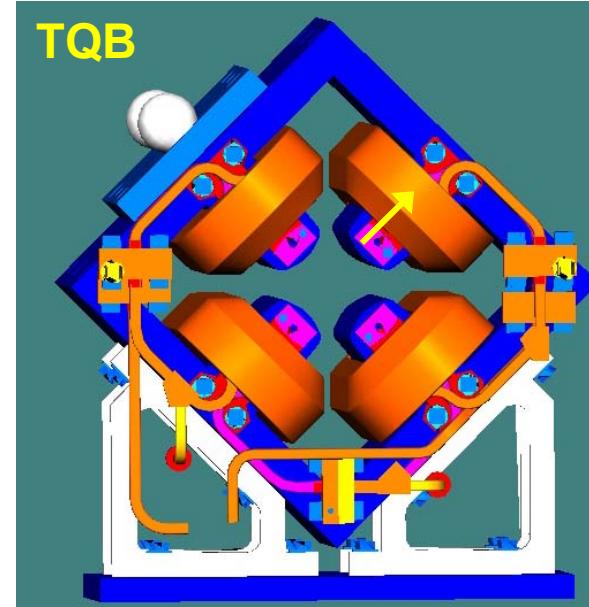
Temperature isolation expected to rise water temperature by about 2°C , reducing the dissipation by 10 kW.

Issues of increasing quad aperture

— Achievable gradients —

Maximum TQA strength for operation modes A and B
(long bunch trains, energy spread measurement at OTR 9DUMP)

$$k=4.0 \text{ m}^{-2} \rightarrow I_{\text{mag}} \sqrt{K} = 0.54 \text{ (N. Golubeva)}$$



Poles will be shortened on back side by 6 mm (ready March)

Current quads **TQA**: gap 40 mm, max 36 T/m (@298 A, $\Delta T=30^\circ\text{C}$), $I_{\text{mag}}=27 \text{ cm}$ (yoke 25 cm)

$$K_{\text{max}} = 6.7 \text{ m}^{-2} \text{ (@1.6 GeV)} \quad I_{\text{mag}} \sqrt{K_{\text{max}}} = 0.70 \text{ (Current p/s max 120 A -> } I_{\text{mag}} \sqrt{K_{\text{max}}} = 0.44)$$

Quads **TQB**: gap 50 mm, max 27 T/m (@347 A), $I_{\text{mag}}=33 \text{ cm}$ (yoke 30 cm)

$$K_{\text{max}} = 5.0 \text{ m}^{-2} \text{ (@1.6 GeV)} \quad I_{\text{mag}} \sqrt{K_{\text{max}}} = 0.74$$

Field quality $\Delta B/B \approx 10^{-4}$ at 20 mm radius

Quads **TQB** modified: gap 62 mm, max 26 T/m (@520 A, $\Delta T=41^\circ\text{C}$), $I_{\text{mag}}=33 \text{ cm}$ (yoke 30 cm)

$$K_{\text{max}} = 4.8 \text{ m}^{-2} \text{ (@1.6 GeV)} \quad I_{\text{mag}} \sqrt{K_{\text{max}}} = 0.72 \quad 290 \text{ A for } I_{\text{mag}} \sqrt{K} = 0.54$$

Field quality $\Delta B/B \approx 10^{-2}$ at 20 mm radius (Opera 2d calculation by A.Petrov)

Issues of increasing quad aperture

– Field quality –

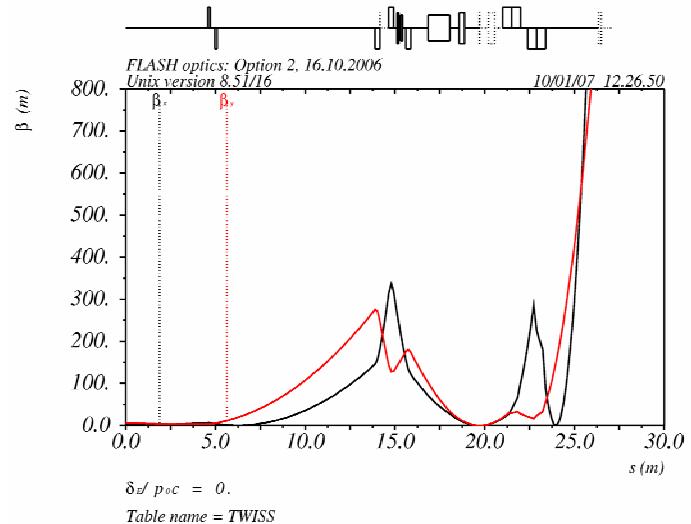
Beam sizes for spectroscopic mode B:

(no operation experience, theoretical values, 500 MeV, $\epsilon \approx 2 \mu\text{m}$)

Q10/Q11EXP ($z \approx 244 \text{ m}$, $\beta \approx 500 \text{ m}$) 1 mm

OTR9DUMP ($z \approx 249 \text{ m}$, $\beta = 0.1 \text{ m}$) 15 μm

Dispersion at OTR: 0.75 m → Resolution $\Delta p/p = 2 \times 10^{-5}$



Needed gradient for Q10/Q11EXP: 6.6 T/m ($k=4.0 \text{ m}^{-2}$, 500 MeV)

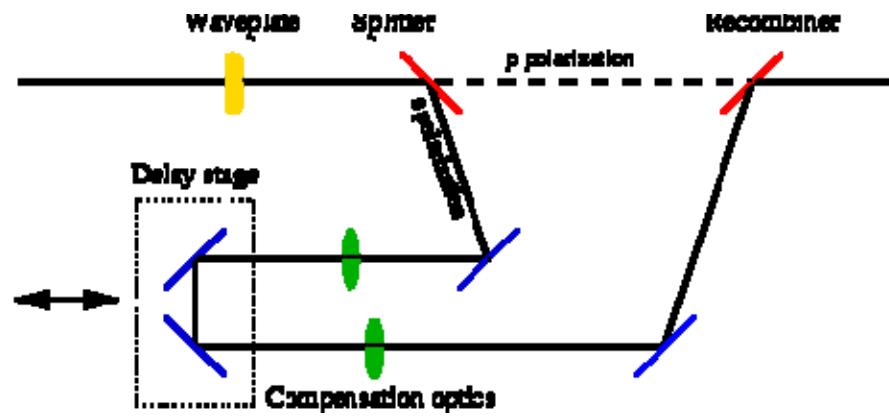
Radius	B at radius (for 21 T/m gradient)	$\Delta B/B$ (linear scaling)	ΔB	Kick (@ 500 MeV)	Offset (after 5 m)	Offset (if $\Delta B/B \times 100$, after 5 m)
1 mm	6.6 mT	5×10^{-6}	33 nT	5.3 nrad	27 nm	2.7 μm
5 mm	33 mT	2.5×10^{-5}	825 nT	133 nrad	675 nm	68 μm
20 mm	130 mT	10^{-4}	13 μT	2.1 μrad	10.5 μm	1 mm

$$\text{Kick angle } \alpha = \frac{ec\Delta Bl}{E}$$

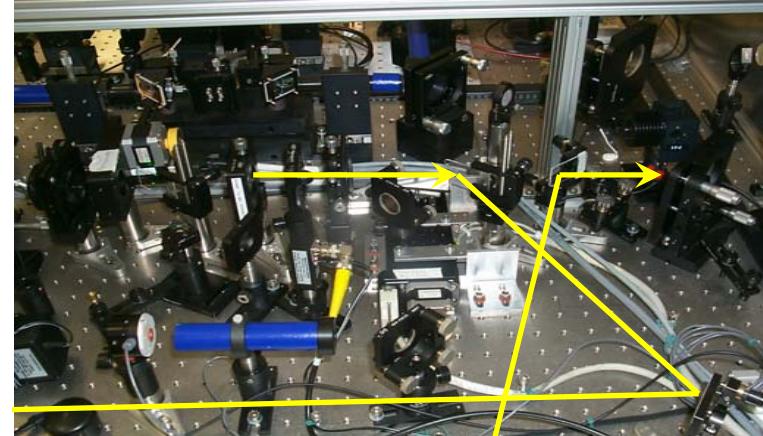
Time-line for undulator installation

Laser double pulse experiment

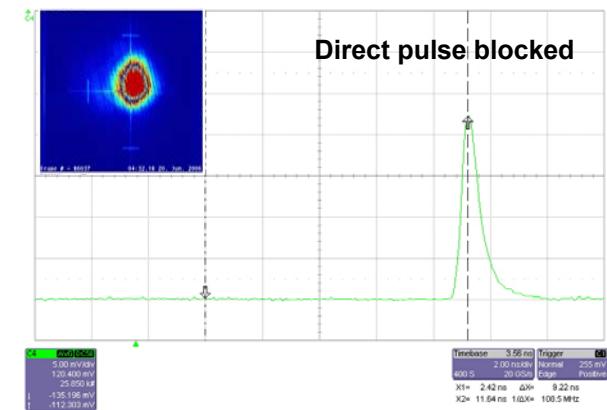
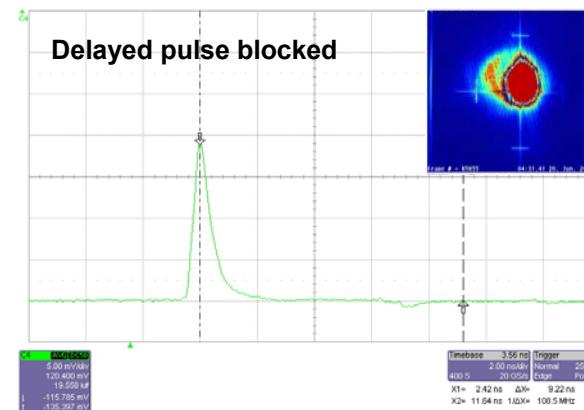
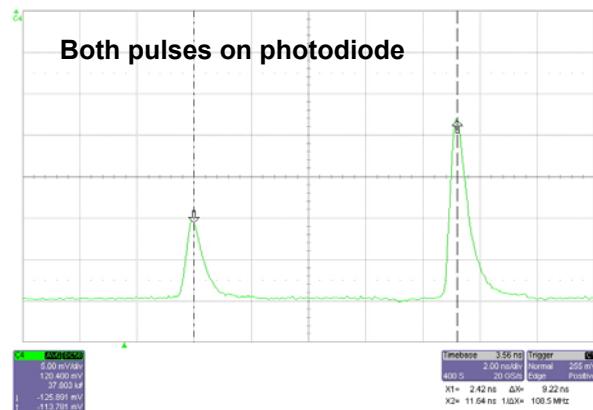
Demonstrate transport and lasing with double pulses ≈ 10 ns apart
One possible scheme for IR/VUV pump/probe experiments



- $\lambda/2$ plate to rotate polarization
 - Brewster-angle beam splitter and recombiner
- Arbitrary relative intensity of direct and delayed pulse
 - No lateral offset of direct beam



- Direct beam is alignment reference for delayed beam
- Two lenses to compensate additional path length of delayed beam



Magnetic measurements at DESY

as of 9 February 2007, items essential for installation in red

1. 1d Field map along undulator centre at 200 A and 390 A

Without thermal wrapping (to compare with JINR result prior to shipment), then with partial wrapping (to see influence of wrapping). Step 1 cm, keep undulator wrapped for all remaining measurements. **This is an essential check.**
If results differ significantly, need to keep partial-only wrapping also for tunnel installation.

2. Hysteresis/cycling check

Cycle undulator to 435 A, measure 1d field map (step 1 cm), cycle to 60 A, measure map, and repeat this procedure once.
All according to procedures prescribed by JINR. **This is an essential check.**

3. 3d field maps over good field region along undulator

Currents: 435 A (maximum), 215 A ($\approx 100 \mu\text{m}$), 140 A (50 μm), 60 A (10 μm), 42 A (5 μm),
17 A (1 μm), 8 A (0.5 μm), **undulator off ('Cycle to zero field' as prescribed by JINR)**.

All correctors set as prescribed by JINR. Grid $x=0, \pm 5 \text{ mm}, \pm 5 \text{ mm}$, $y=0, \pm 5 \text{ mm}$, $\Delta z=10 \text{ mm}$ over 5 m.

4. Horizontal field component along axis

Current 435 A and 215 A, longitudinal step 1 cm.

5. Field versus current from 0 to 435 A

Steps 1A, points 1,2,3,5,6,7,9,10, **points 5,6,7 essential**.

All correctors set as prescribed by JINR.

6. Temperature transients

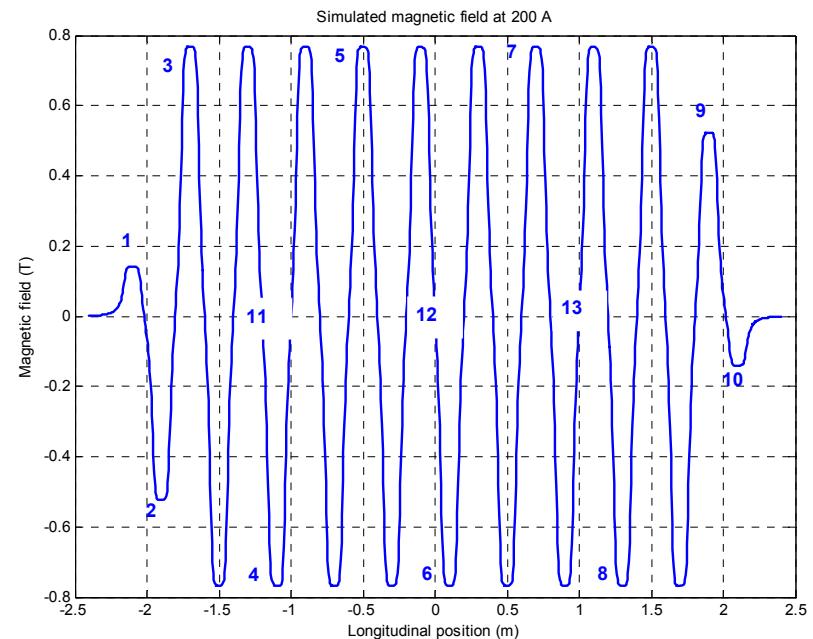
Field against time if excitation current changed from maximum to 10% (and vice versa). Points 2,**5,8,10**.

7. Longer-term monitoring of field stability

Points 1,4,7,12 on axis. Current 435 A, duration 1 day.

Cooling water temperature difference with and without temperature isolation expected to be only 2°C (F.-R. Ullrich).

Check pilotherm and temperature sensor functionality before wrapping undulator for temperature isolation.



That's it for part 1.

Next week:

The IR beamline
by
Michael Gensch

