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Quadratic autocorrelation and photocurrent saturation study in two-photon QWIPs

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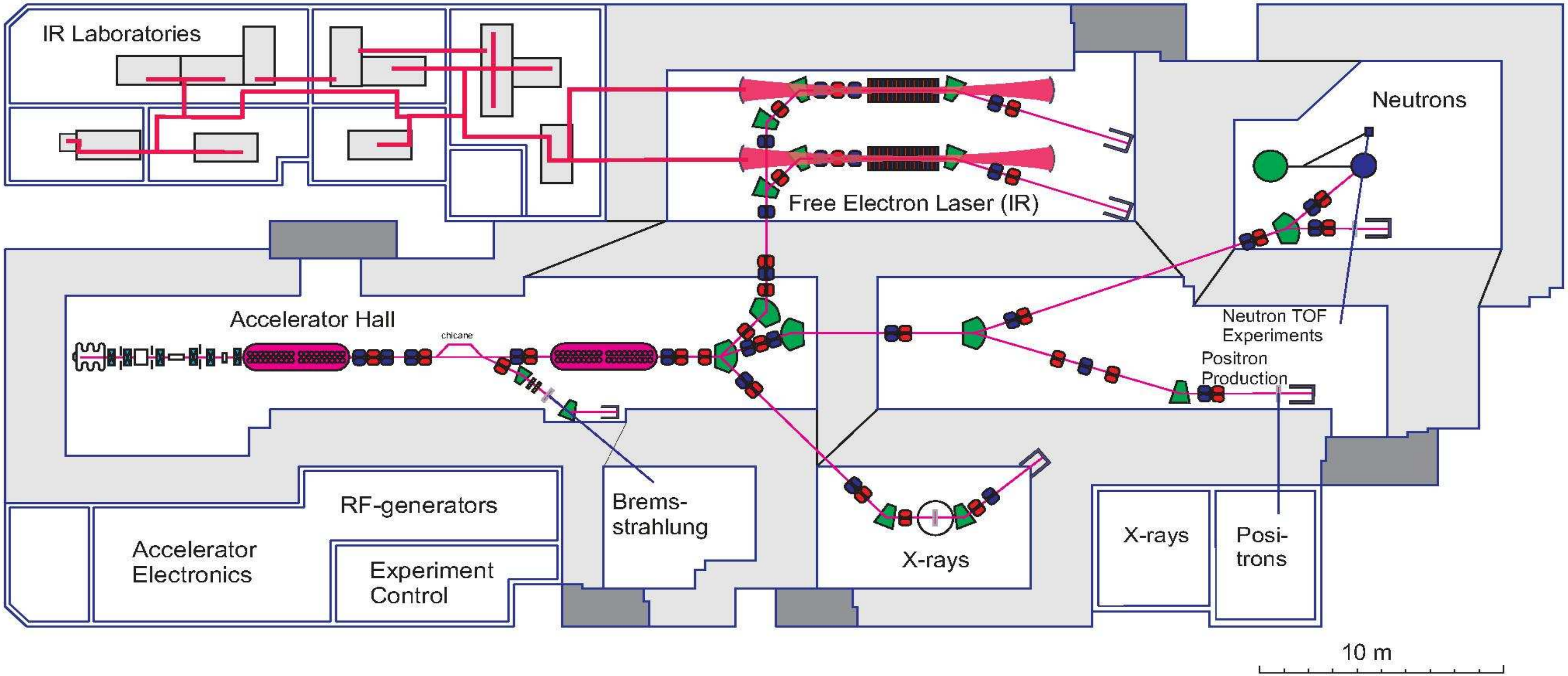
Outline

- Introduction
  - Free-electron laser (FEL) at ELBE
  - Two-photon QWIP
- Interferometric autocorrelation of FEL pulses
- Saturation of two-photon QWIP
- Room-temperature operation ?
- Conclusion

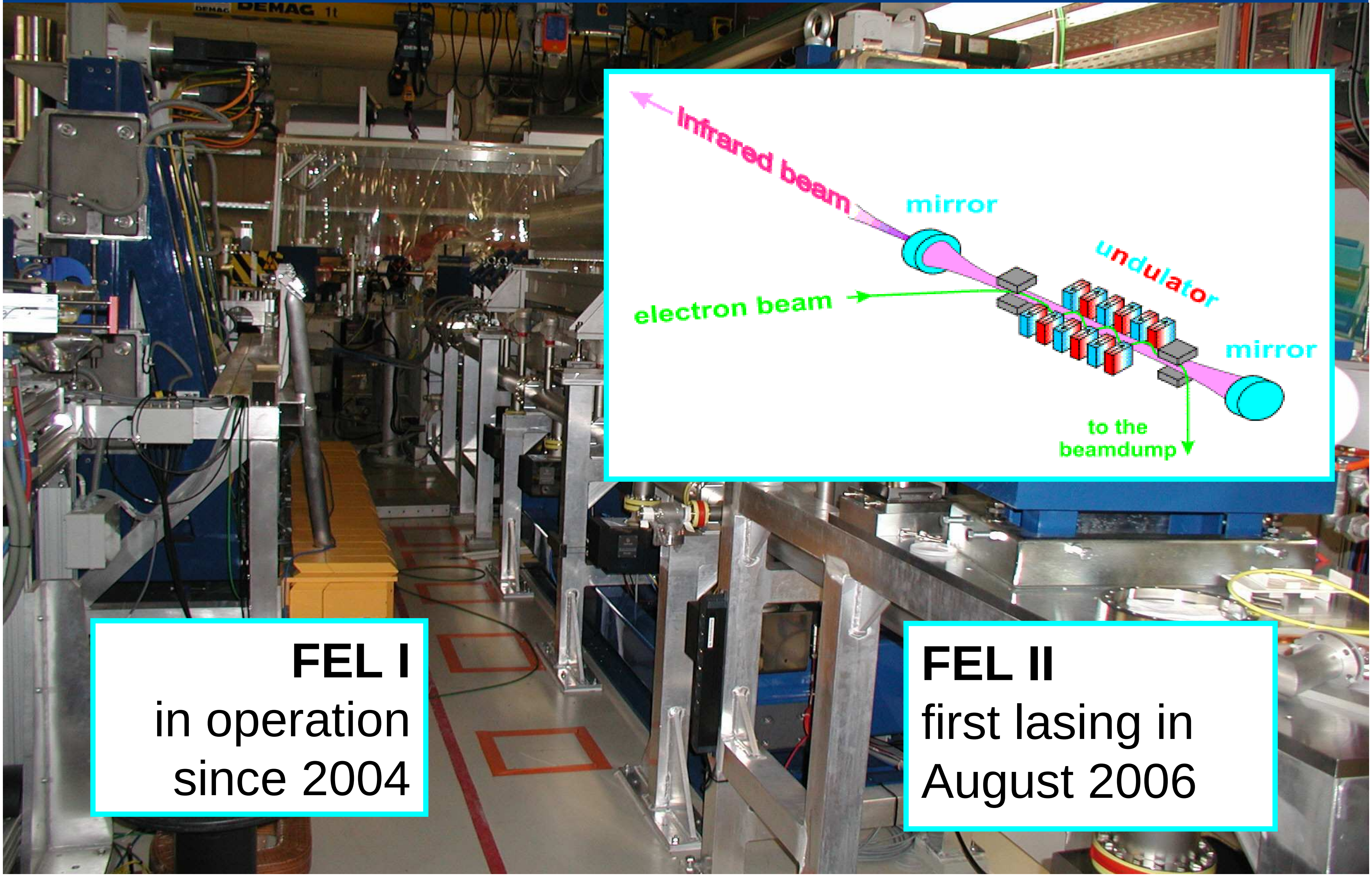
ELBE in Dresden

ELBE: Electron Linac with high Brilliance and low Emittance

FELBE = FEL @ ELBE



Free-Electron-Laser

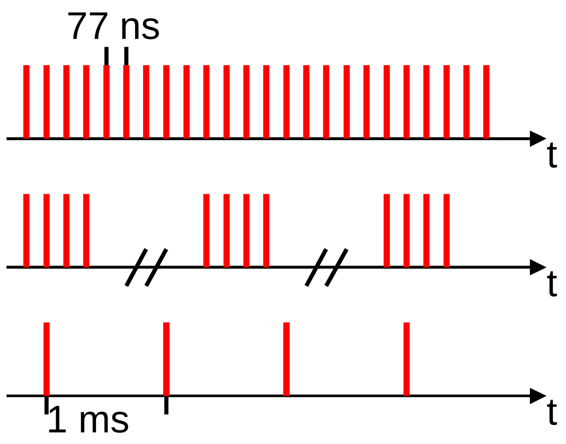


FEL I
in operation
since 2004

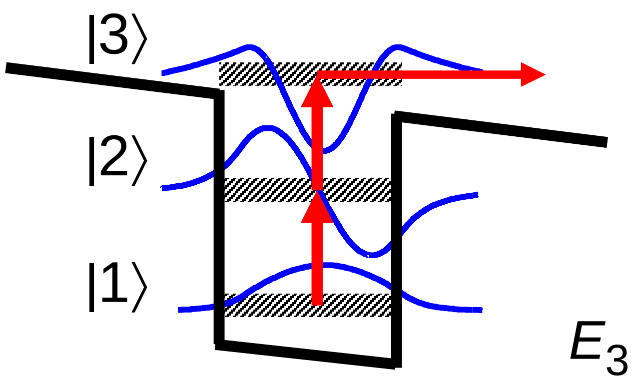
FEL II
first lasing in
August 2006

- **Wavelength range** λ = 4 – 200 µm
  (FEL I & II) ⇒ **1.5 – 80 THz**
- **Pulse width** 0.5 - 30 ps depending on λ
- **Pulse energy** 0.1 - 3 µJ 10 kW – 1 MW peak power
- **Spectral width** $\Delta\lambda/\lambda$ = 0.4 – 1.6 %

- Pulse structure
  - micro pulse („cw“) 13 MHz
  - macro pulse 100 µs – cw (1Hz – 25 Hz)
  - pulse picking 1 kHz



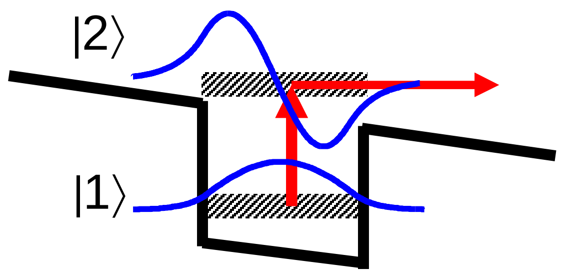
Resonant two-photon QWIP



$$E_3 - E_2 = E_2 - E_1$$

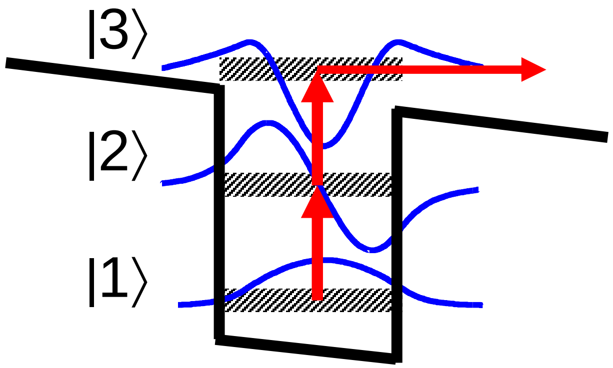
- **photocurrent ∝ (power density) ²**
  stronger signal if two pulses overlap in time
- **role of intermediate state**
  resonantly enhanced two-photon absorption
  incoherent (sequential) absorption

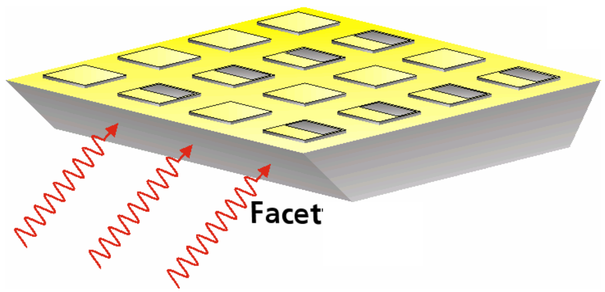
Standard QWIP



- **photocurrent ∝ power density**

H. Schneider *et al.*, Opt. Lett. **30**, 287 (2005).





	λ = 10 µm-design	λ = 8 µm-design
QWs	GaAs	$In_{0.10}Ga_{0.90}As$
Barriers	$Al_{0.33}Ga_{0.67}As$	$Al_{0.38}Ga_{0.62}As$
QW width	7.6 nm	6.8 nm
Barrier width	46 nm	
Doping	$4*10^{11}cm^{-2}$ (Si)	
Periods	20	

- growth by MBE
- processing into $(120µm)^2$ and $(240µm)^2$ mesas
- light coupling via 45° facets

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Two-photon photocurrent

Optical excitation with cw-CO_2 laser

- huge two-photon absorption coefficient

  $\beta = 1.3 \cdot 10^7$ cm/GW

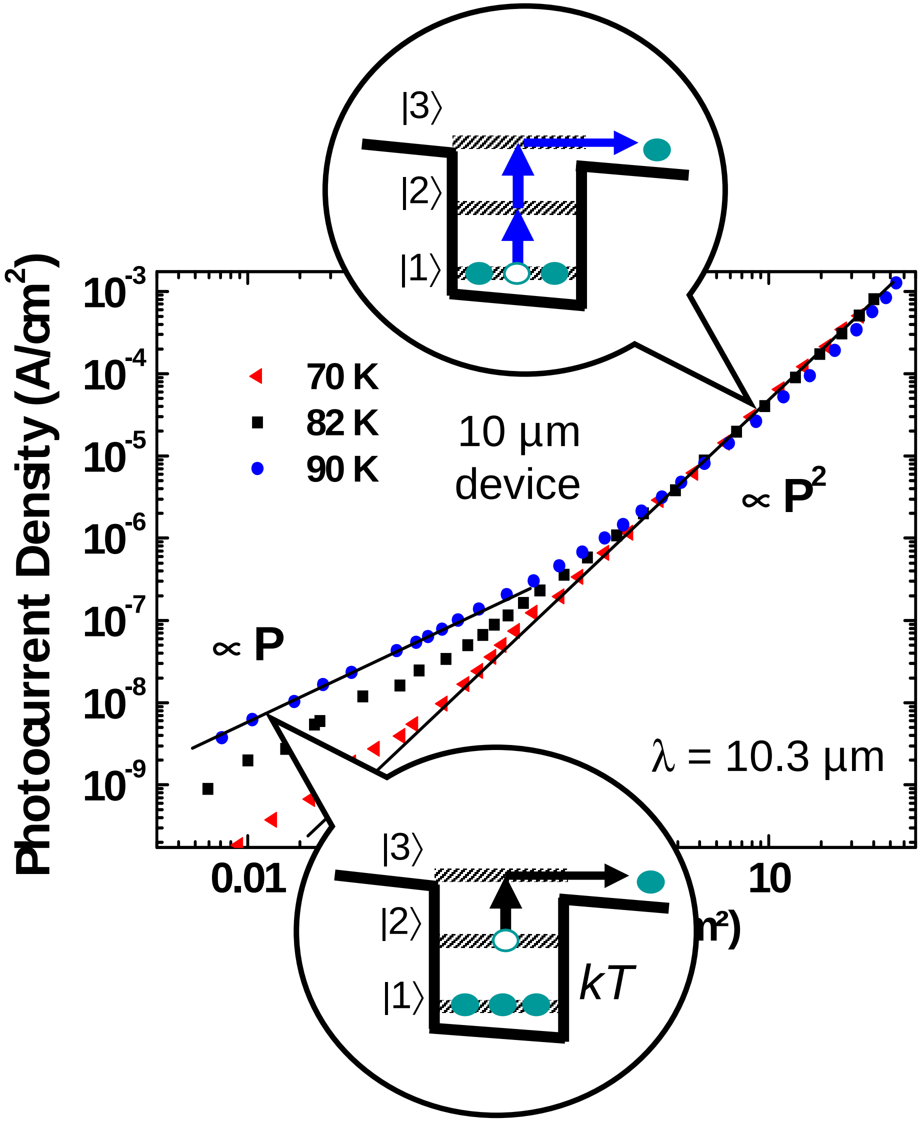
- $P > 0.1$ W/cm²: $I_{ph} \sim P^2$
- $P < 0.1$ W/cm²: $I_{ph} \sim P$

$$I = RP + SP^2$$

R, S responsivities

- linear contribution due to thermal occupation of state |2⟩

  → **limited operation temperature for quadratic detection**



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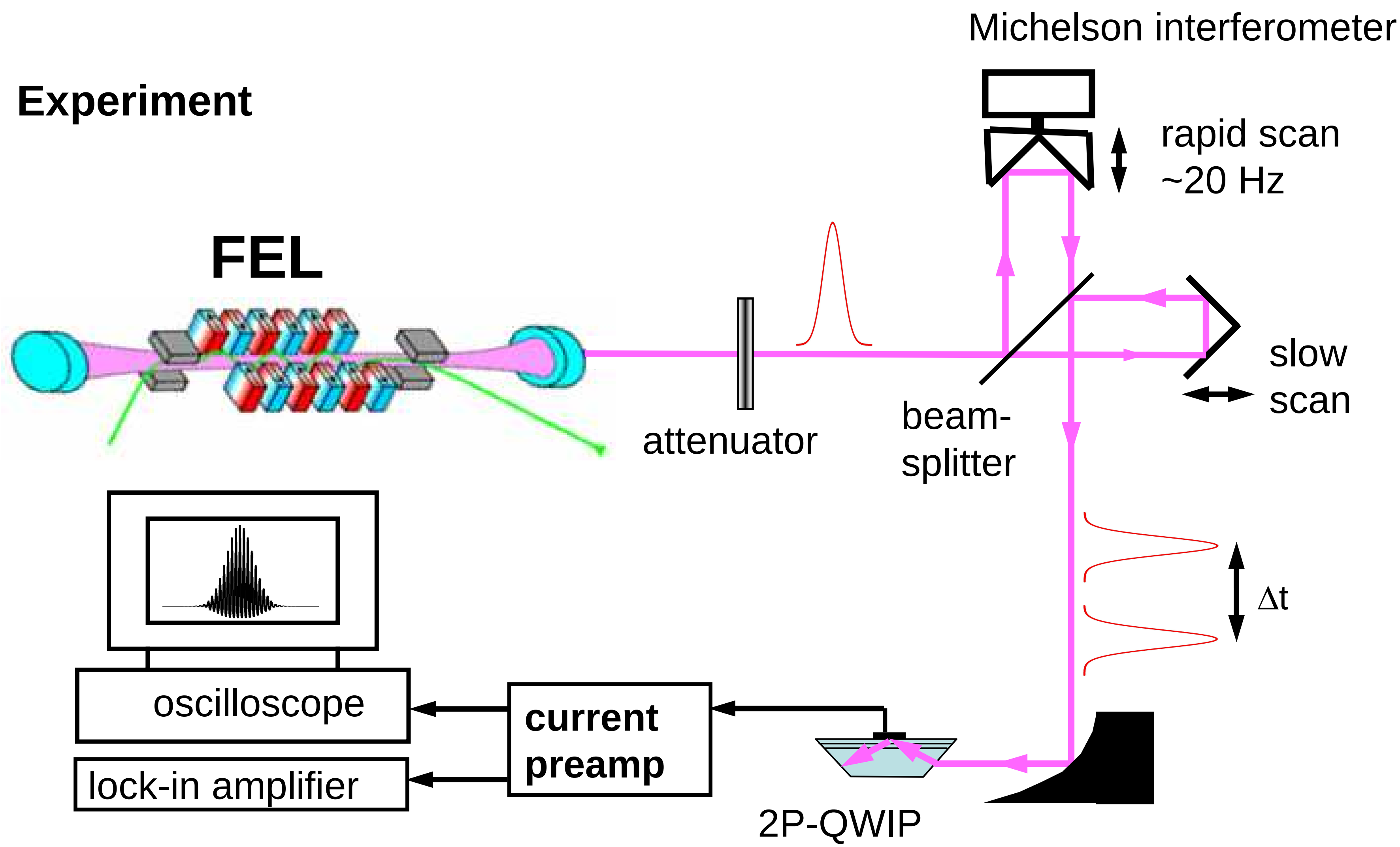
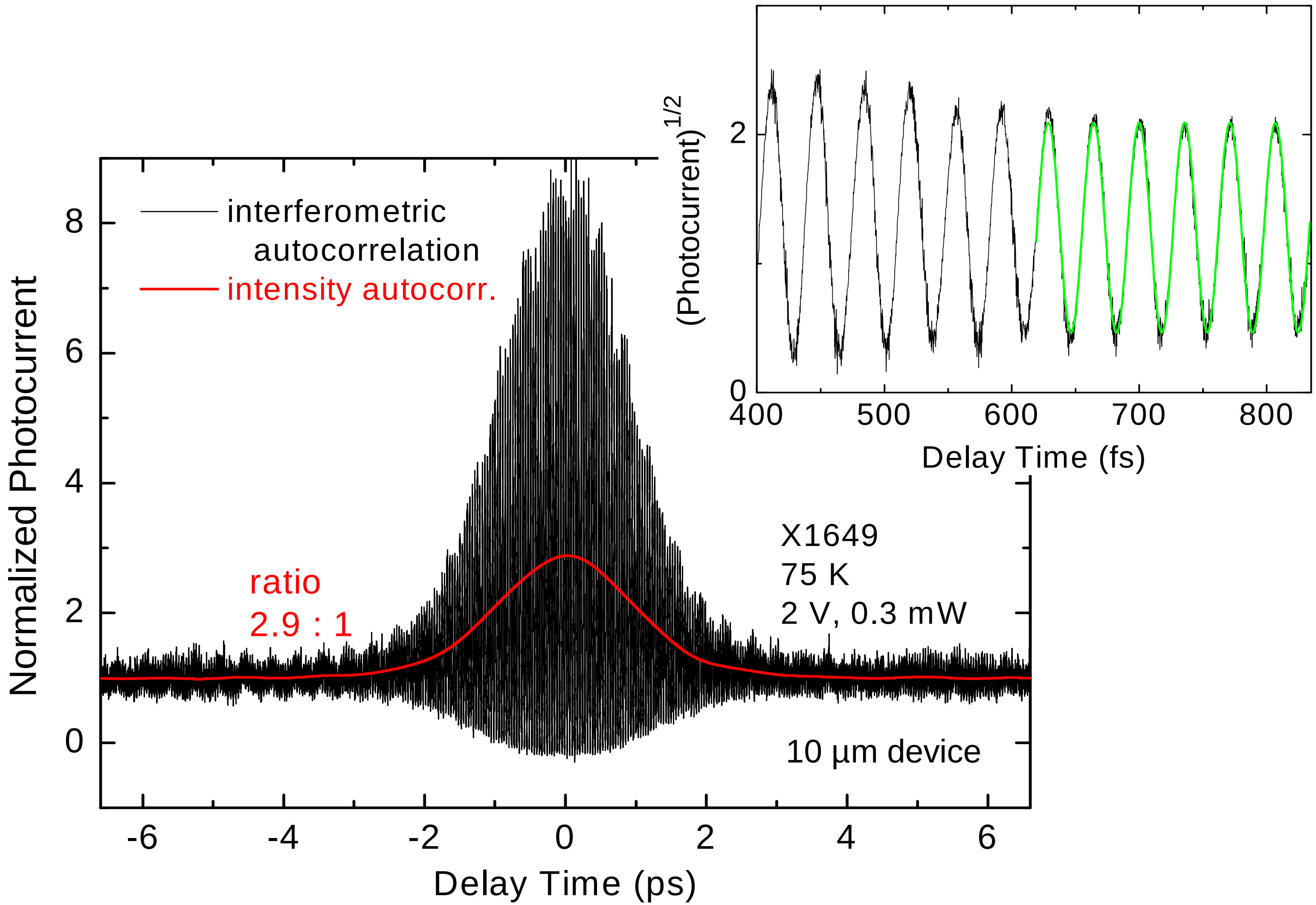

Michelson interferometer
Experiment
rapid scan
~20 Hz
FEL
slow
scan
attenuator
beam-
splitter
Δt
oscilloscope
current
preamp
lock-in amplifier
2P-QWIP

- ratio
  8:1 (interfer.)
  3:1 (intensity)

- 2.3 ps FWHM
  → 1.6 ps
  pulsewidth

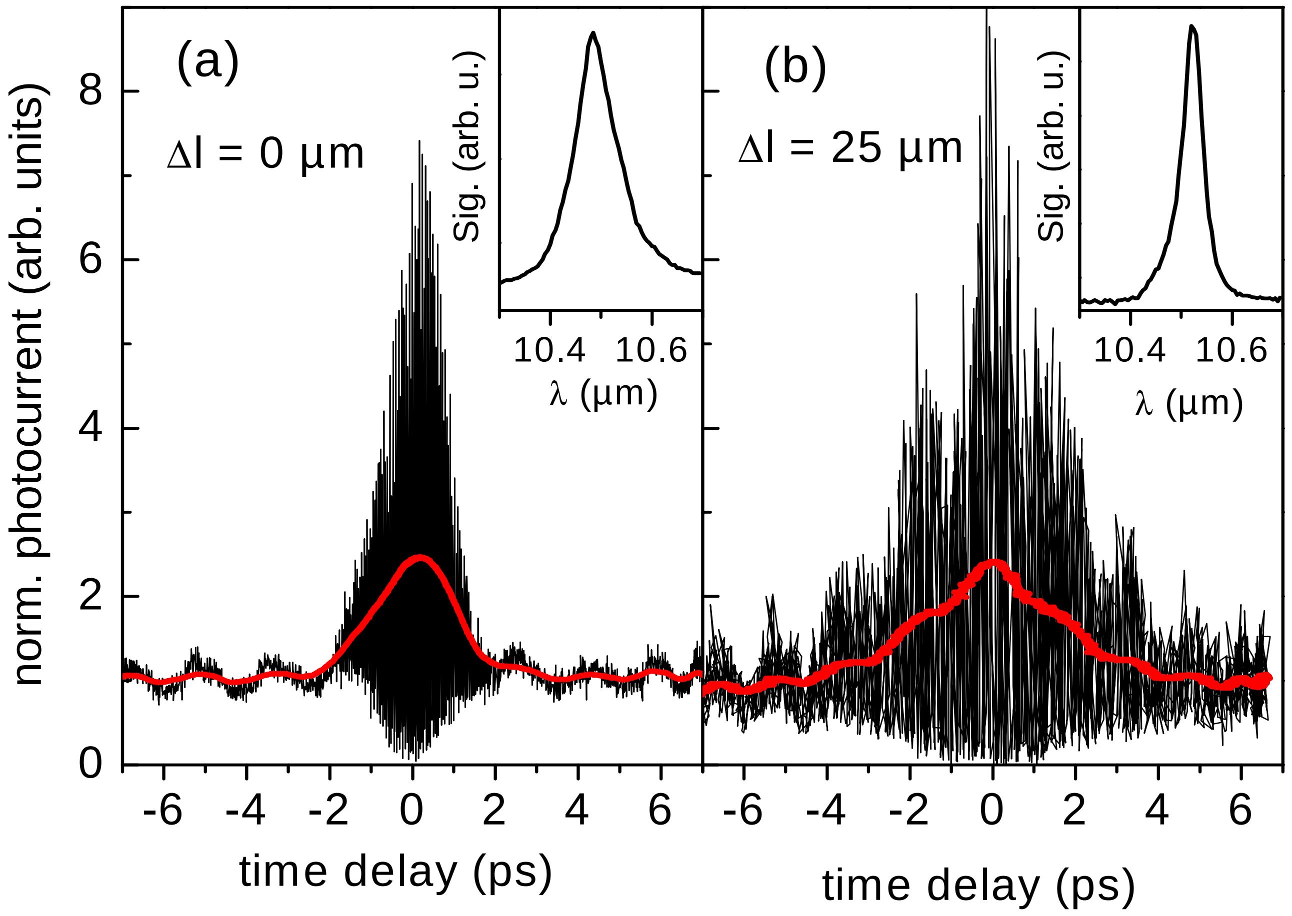
- square root
  of PC has
  sinusoidal
  fringes



Appl. Phys. Lett. **89**, 133508 (2006)

- changing FEL cavity length
  → variation of
  pulse width
- in (a):
  → $\Delta t\, \Delta \nu = 0.51$
- Gaussian limit
  $\Delta t\, \Delta \nu = 0.44$

10µm device, 75 K, 2 V, 0.3 mW



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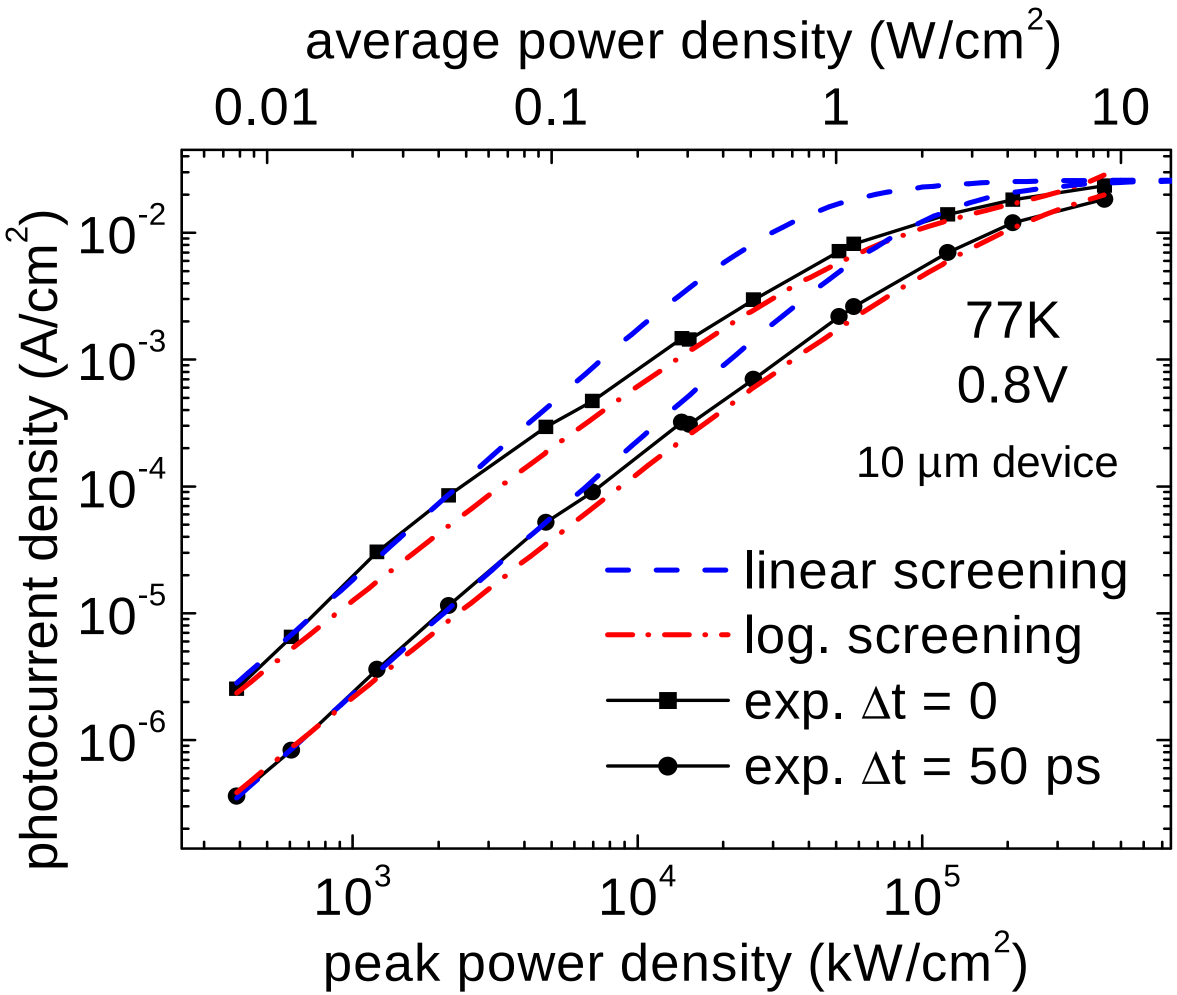
- quadratic behavior at low power
- saturation at
  ~100 kW/cm²
  ~1.3 kA/cm²
- different models for saturation tested
- distortion-free autocorrelation only at low power



- Photocurrent $I = R(F)P + S(F)P^2$

  assume: gain ~ electric field *F*, thus *R* ~ *F* and *S* ~ *F*

- Linear screening (as a function of *I*): $F \sim 1 - I/I_{sat}$

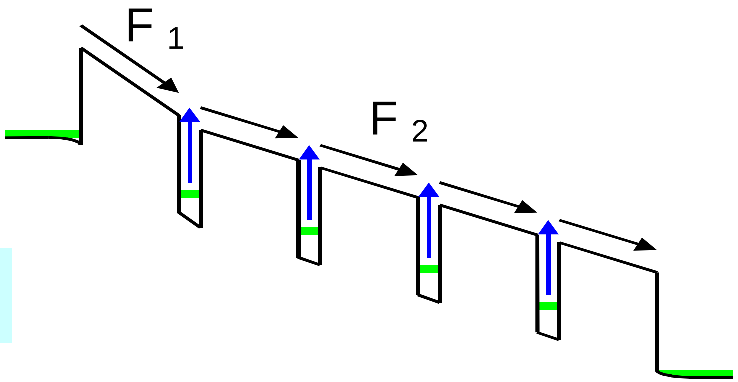
  → $I = (1 - I/I_{sat})(\tilde{R}P + \tilde{S}P^2)$

- Logarithmic screening

  only "thermal" current I_{th}, at 1st barrier

  assume $I_{th}(F_1) = I_0 \exp(\alpha F_1)$

  → $I = (\ln(I_{sat}) - \ln(I)) \cdot (\tilde{R}P + \tilde{S}P^2)$



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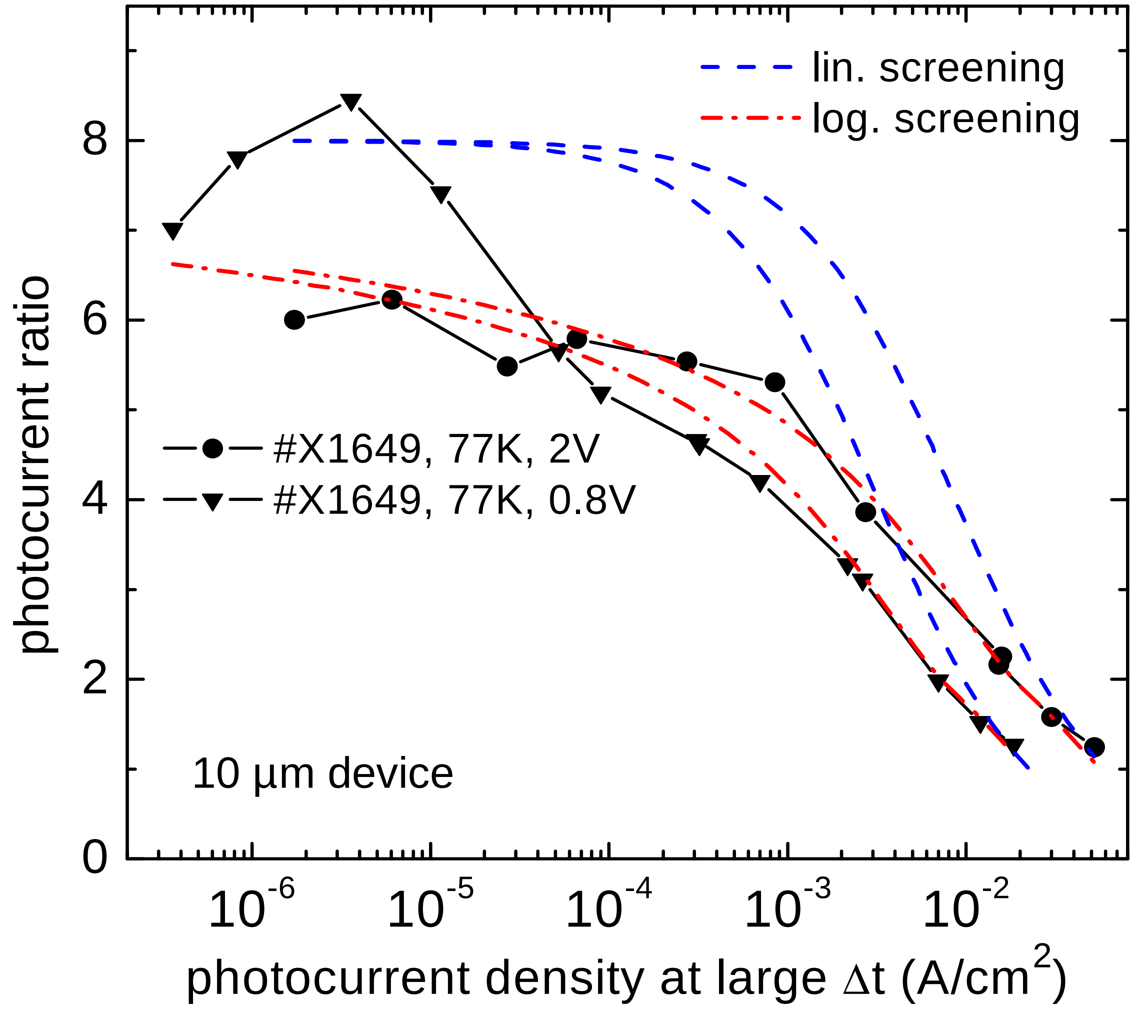
- better agreement for log. screening
- ratio is independent of *S* for *R* = 0
  → I_{sat} is the only fit parameter!



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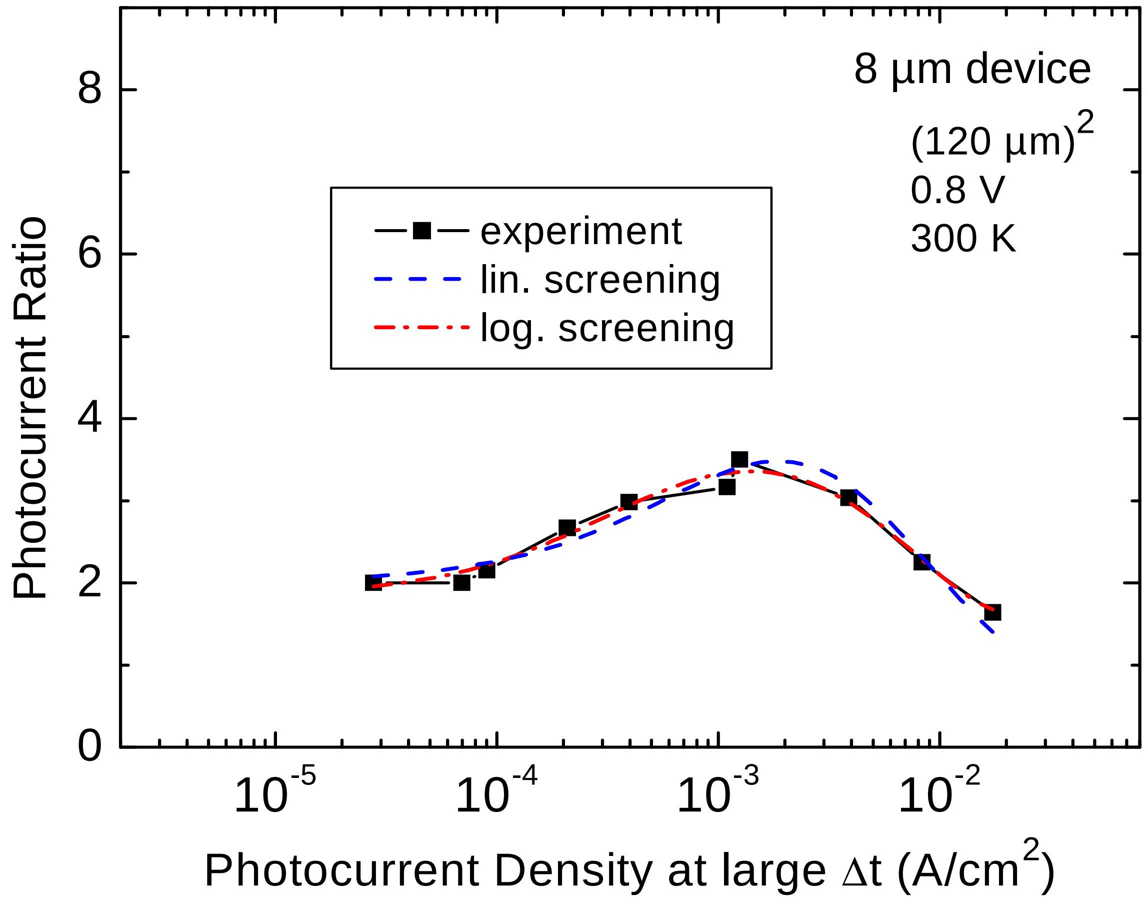
Measured ratio: 300 K



- saturation at high power
- ratio = 2 at low power
  → linear behavior
- max. achieved ratio ≈ 3.5

Temperature limit for quadratic detection increases with photon energy!

Conclusion

- two-photon QWIP is suitable for quadratic autocorrelation measurements of FEL pulses

- saturation of two-photon QWIP
  - induced by space charges inside the active region similar as for "standard" QWIP

- room-temperature operation
  - maximum operation temperature limited by linear contribution and photocurrent saturation

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