Longitudinal Halo from NEA and PEA Photocathodes

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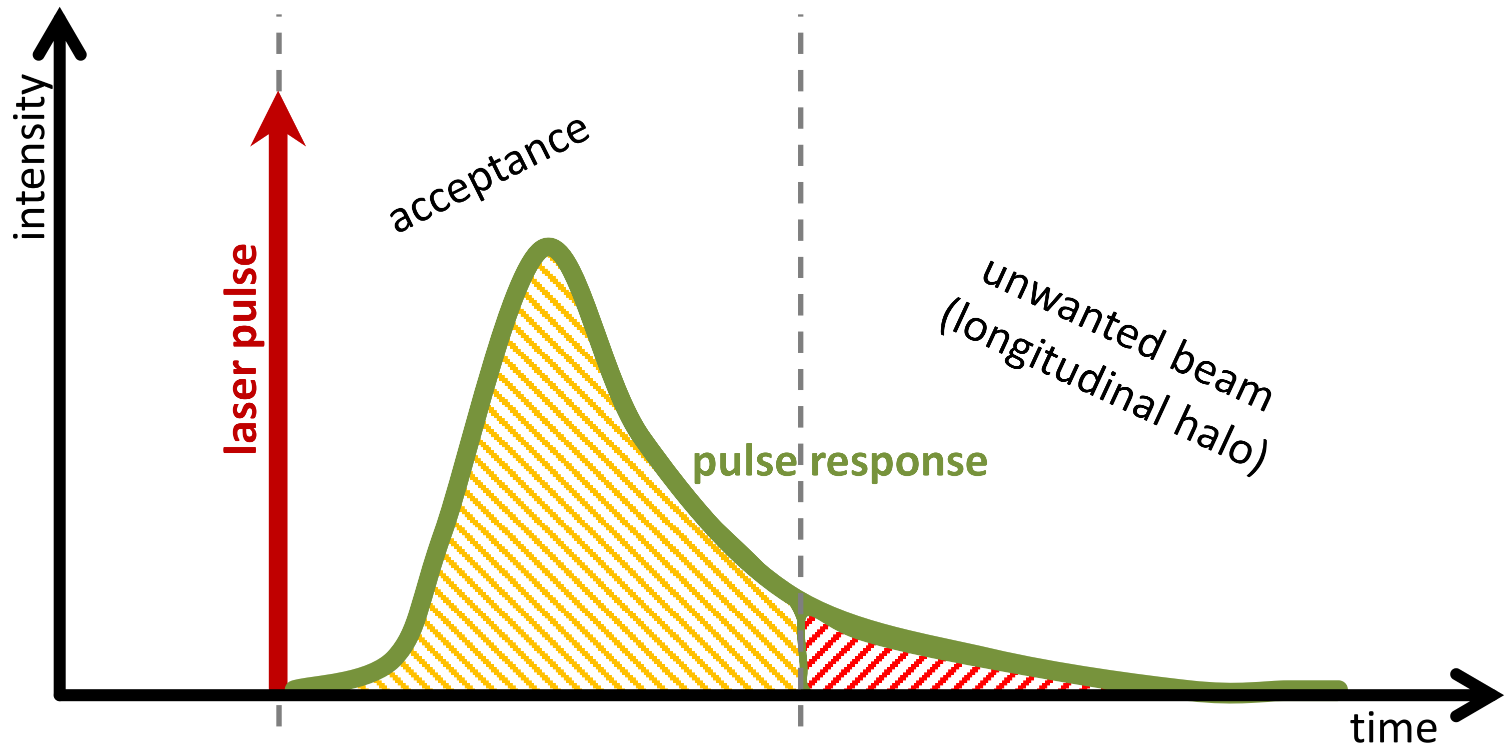
Motivation

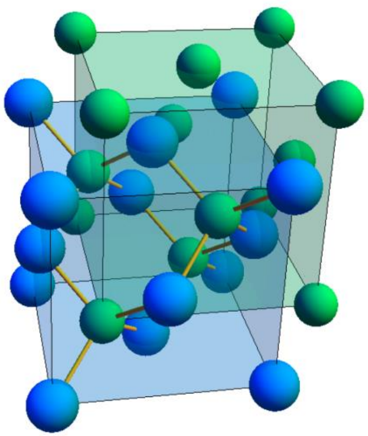


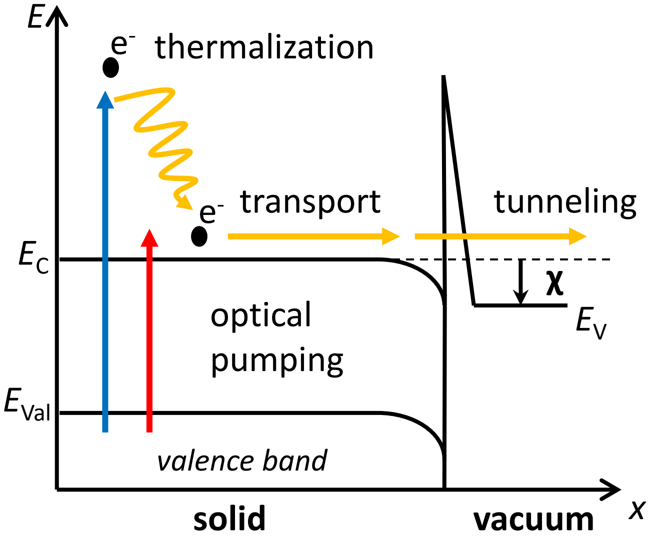
- Knowledge of shape, structure, and length of electron bunches out of a photoemission gun under different photo excitation conditions
- Beginning of the project as a collaboration between HZB, HZDR, JGU, MSU, and SPSPU
- Now collaboration between HZB, HZDR, DESY, University of Siegen, JGU, and the additional support through University of Rostock, University of Wuppertal, and TU Darmstadt

Outline

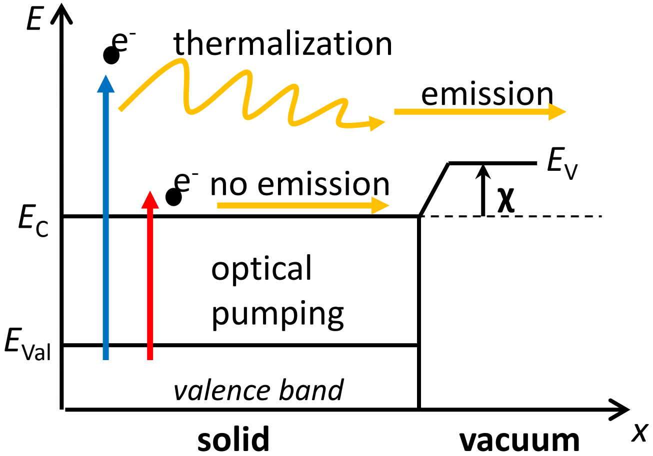
- Some fundamentals
  - Semiconducting photocathodes
  - Photoemission process
- Time response measurements
  - Experimental setup
  - Measuring principles
  - Measuring results
- Conclusion and Outlook

- $CsO:GaAs$
  - Single crystalline structure
  - Negative electron affinity (NEA)





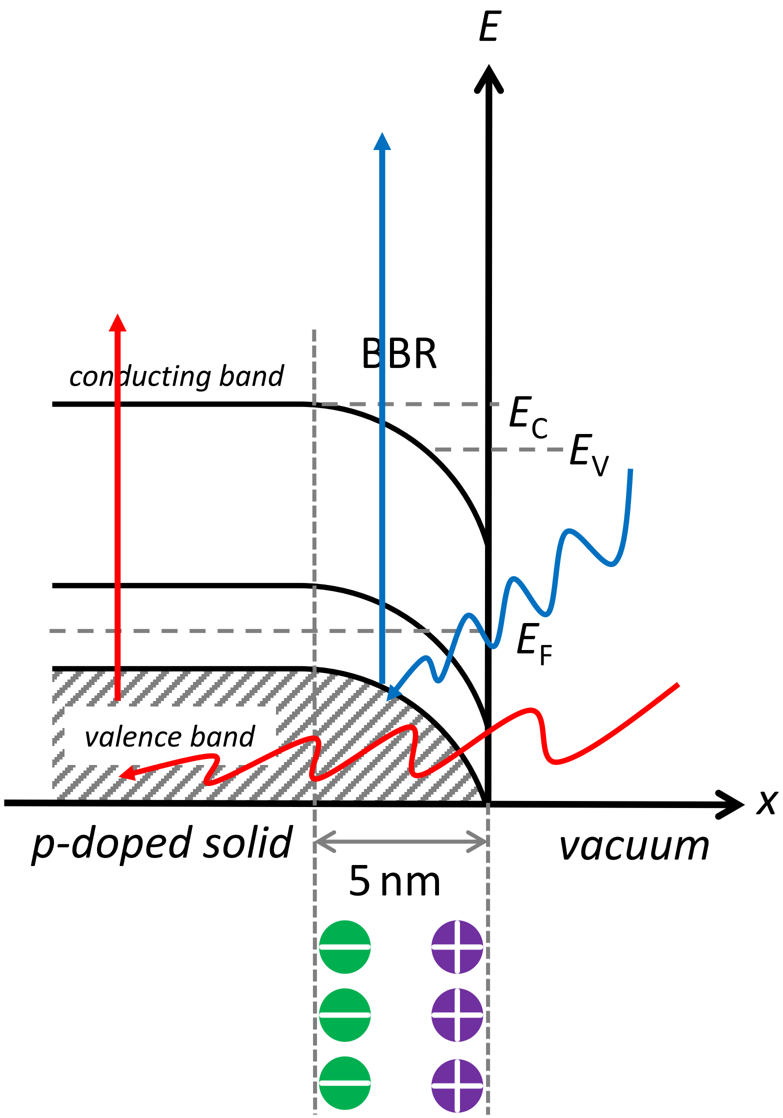
- K_2CsSb
  - Multi crystalline structure
  - Positive electron affinity (PEA)



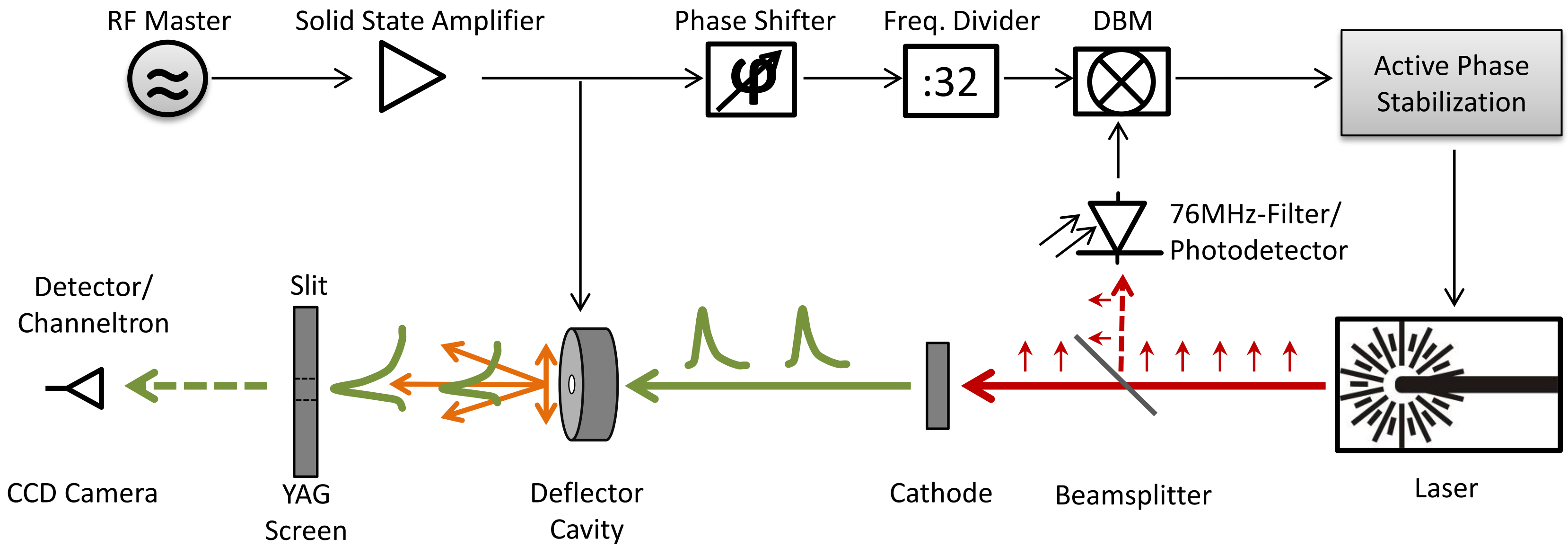
CsO:GaAs – Influences of the Photon Energy

- Penetration depth
  - ca. 1250 nm @ 800 nm (E_γ = 1.55 eV)
  - ca. 15 nm @ 400 nm (E_γ = 3.10 eV)
- Band bending region (BBR) causes an electric field
  - Electrons near the surface get accelerated

Parameter	Value
band gap (at 300 K)	1.42 eV
absorption coefficient 800 nm	$0.8\ \mu m^{-1}$
absorption coefficient 400 nm	$67.1\ \mu m^{-1}$
diffusion constant	$20\ cm^2 s^{-1}$
doping level	$2.8 \pm 1.2 \times 10^{19}\ cm^{-3}$
layer thickness	$10\ \mu m$



Time Response Measurements Principles



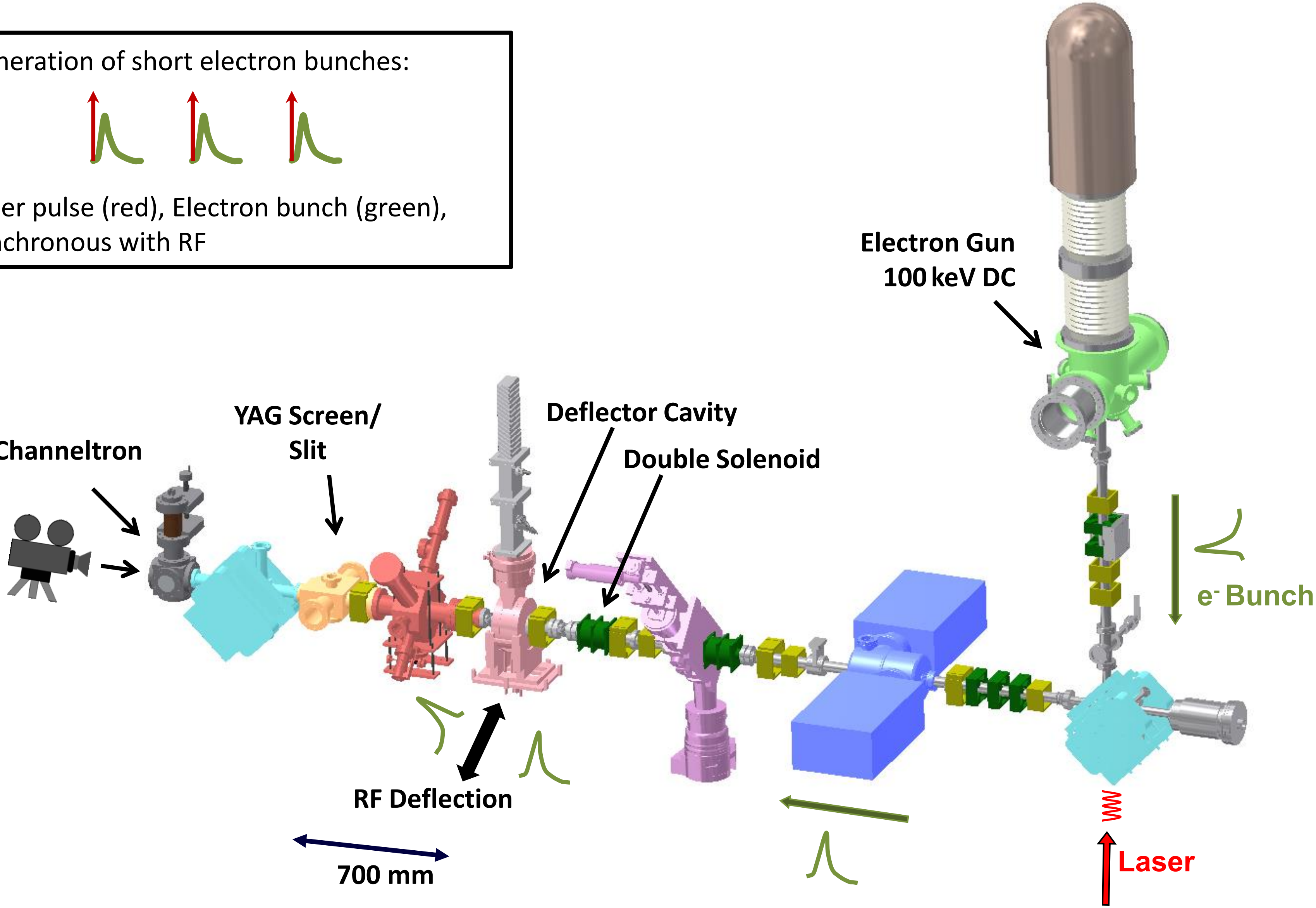
- Conversion of the longitudinal profile into transverse profile by TM_{110} RF Deflector Cavity
- Electron bunches must be emitted synchronously to RF Master

→ Longitudinal profile directly visible on the screen (intensity) or can be sampled by a Channeltron Detector

Time Response Measurements
Experimental Setup at PKAT

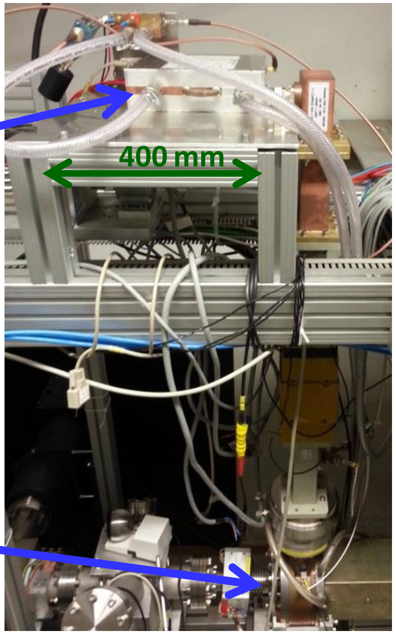
Generation of short electron bunches:

Laser pulse (red), Electron bunch (green), synchronous with RF



Time Response Measurements
Some Technical Details

- RF system:
  - 2.45 GHz master oscillator
  - 2.45 GHz solid state amplifier (developed in house)
  - $P_{max} = 322$ W
  - Electronic phaseshifter with 400° range (developed in house)
  - TM_{110} deflector cavity

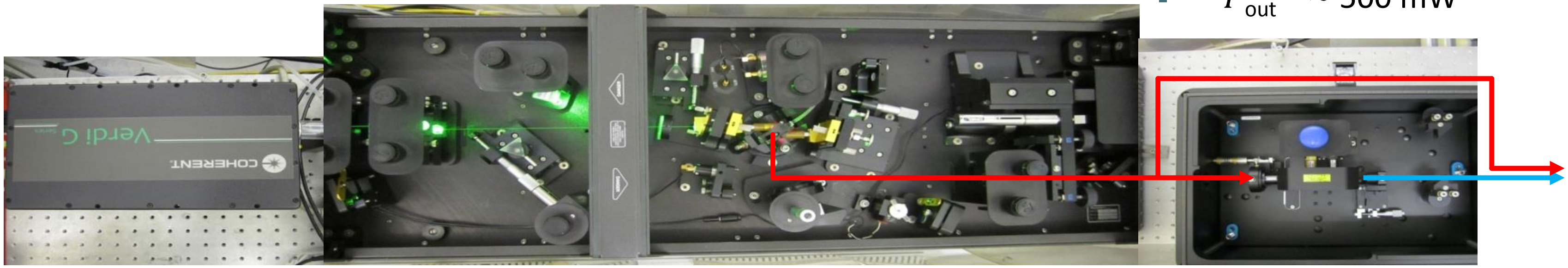


- Laser system:

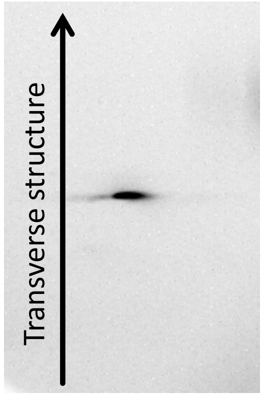
Verdi 10G
- Pump laser
- $\lambda_{laser} = 532$ nm
- $P_{out} \sim 10$ W (CW)

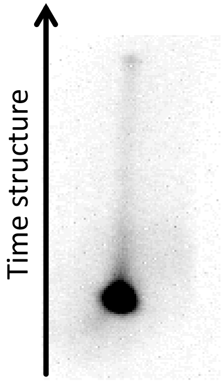
Modelocked Ti:Sapphire Laser (MIRA 900)
- Pulsed (~150 fs) or CW
- $\lambda_{laser} = 755 - 800$ nm tunable
- Repetition rate 76MHz (32^{nd} subharmonic of master)
- $P_{out} \sim 1.6$ W at $\lambda_{laser} = 800$ nm pulsed

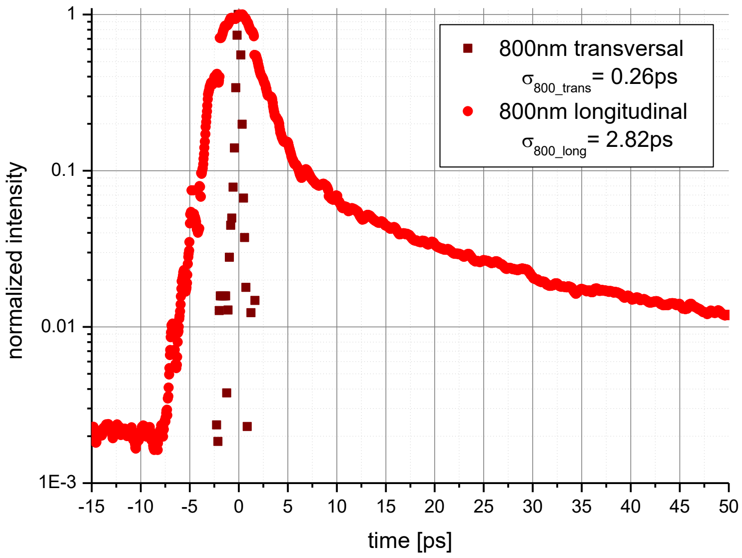
HarmoniXX SHG
- Frequency doubler (Second Harmonic Generation)
- $\lambda_{laser} = 400$ nm
- $P_{out} \sim 500$ mW



Time Response Measurements
Measurements with CsO:GaAs



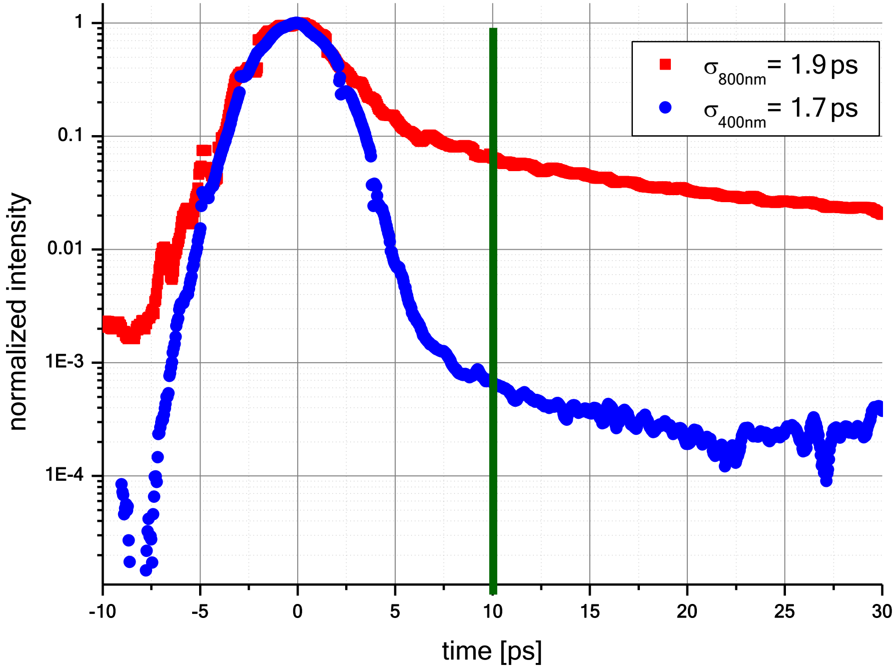




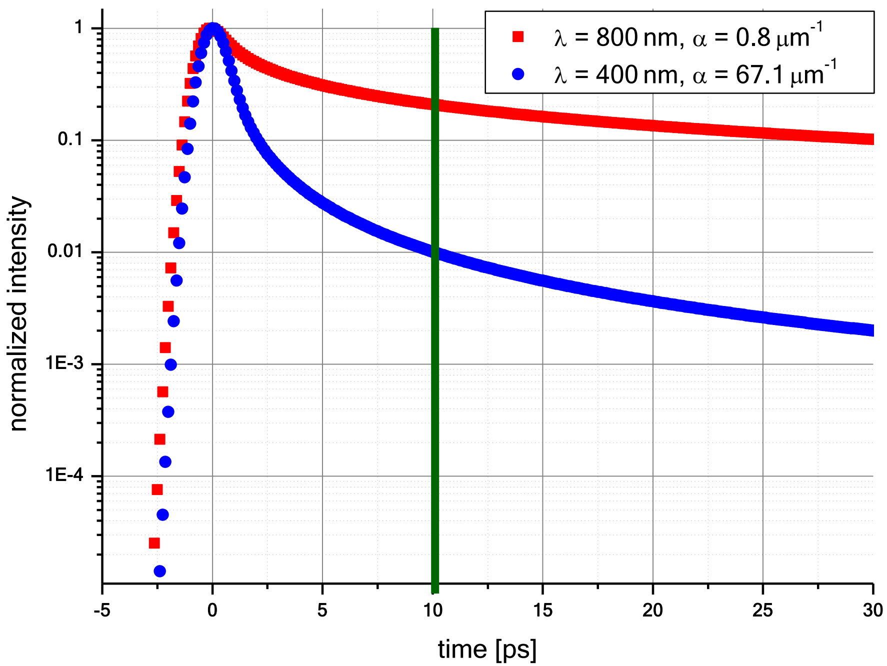
- Beam profile YAG-screen
- CW-beam (integrated over 25 x 10^6 bunches)
- Bunch charge < 0.01 fC
- Intensity distribution equals the convolution of
  - the transverse beam profile of deflection plane and the time response
  - time of flight effects because of energy distribution within the bunch
  - laser pulse length
  - laser spot size

Time Response Measurements
Results at 400 nm and 800 nm with CsO:GaAs

Measurements



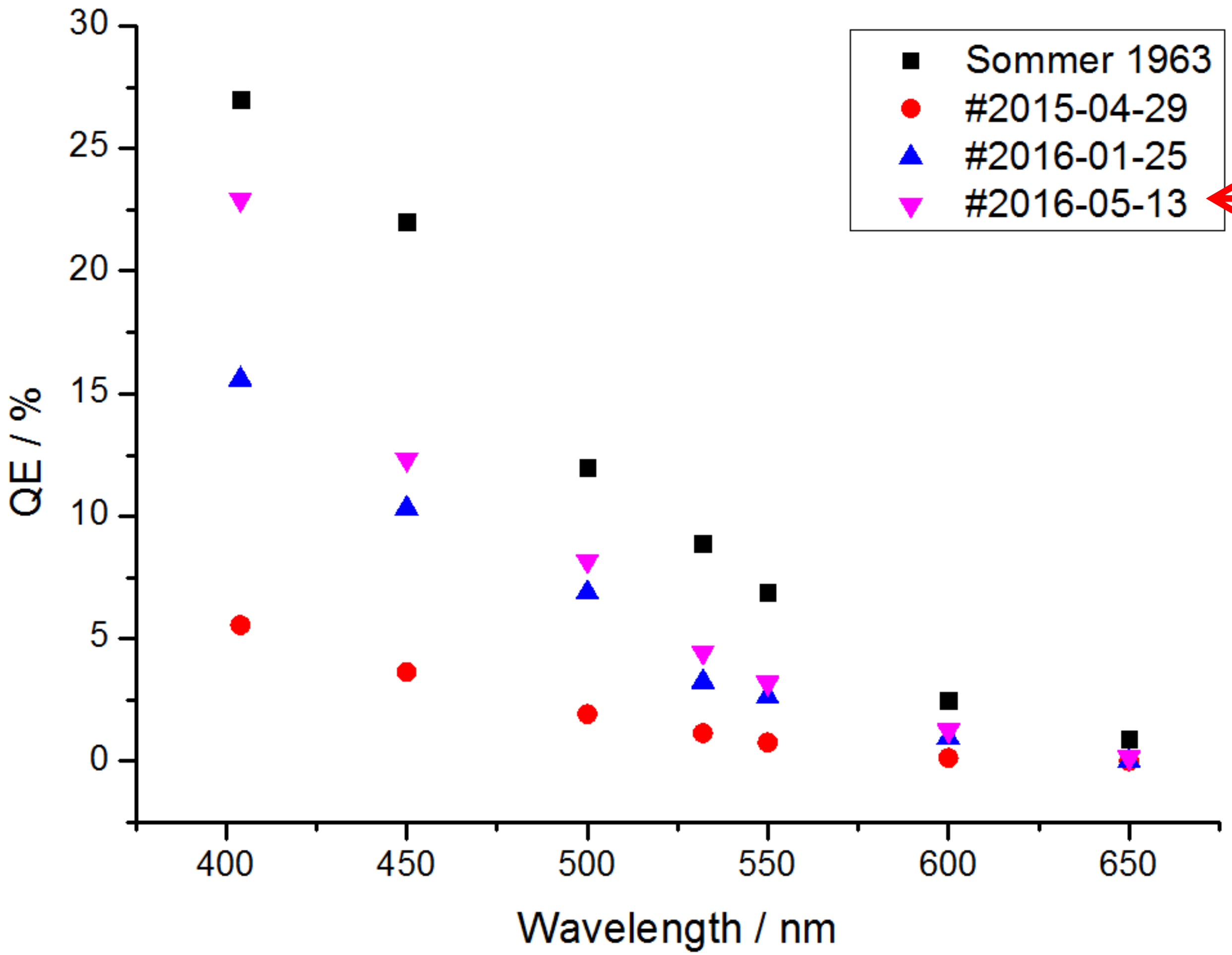
Simulations with the diffusion model



- After 10 ps the intensity at 400 nm is about 2 orders of magnitudes smaller.
- Quantum efficiency
  - QE_{800} = 0.05%
  - QE_{400} = 0.5%

- Simulation with a diffusion model
- Describes the pulse response only qualitatively not quantitatively
- The signals do not fall as fast as in the measurements
  - E.g. unknown doping level
  - Electrons at 400 nm do not follow a diffusion

Time Response Measurements
Production of K_2CsSb Photocathodes

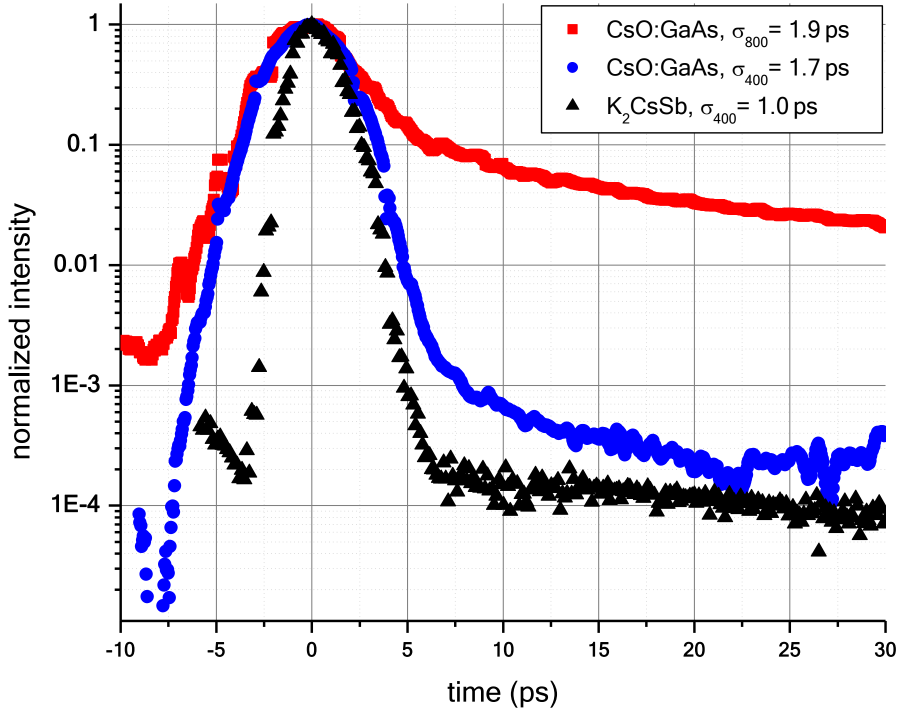


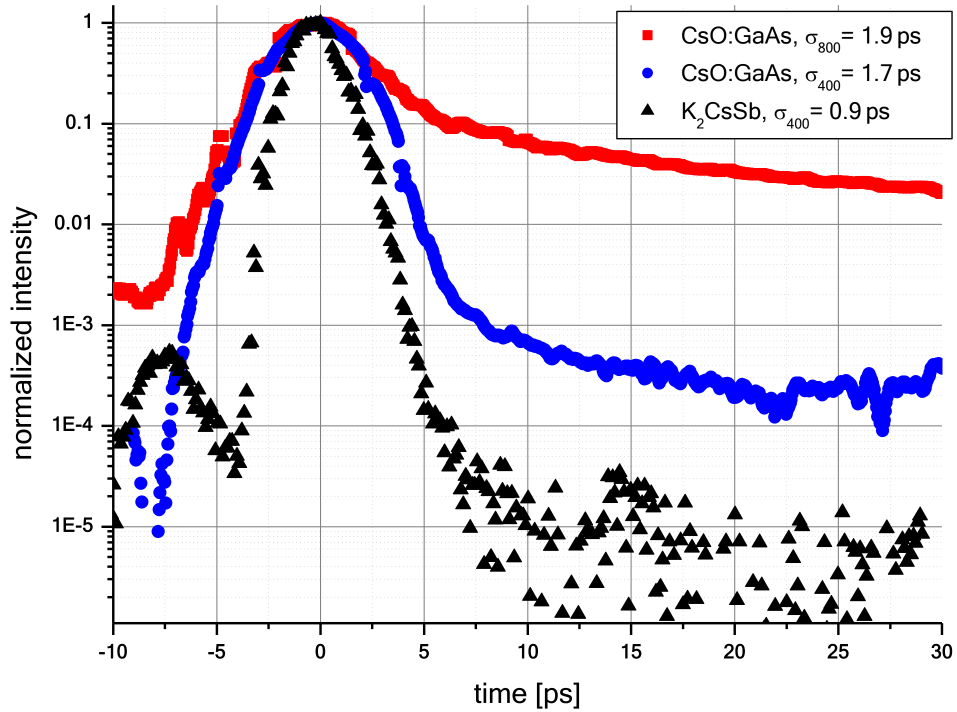
Used for measurements

Further information:
Poster
Victor Bechthold
MOPSPP004

Victor Bechthold, DPG spring meeting 2017, Dresden

Time Response Measurements
Comparison of CsO:GaAs and K_2CsSb



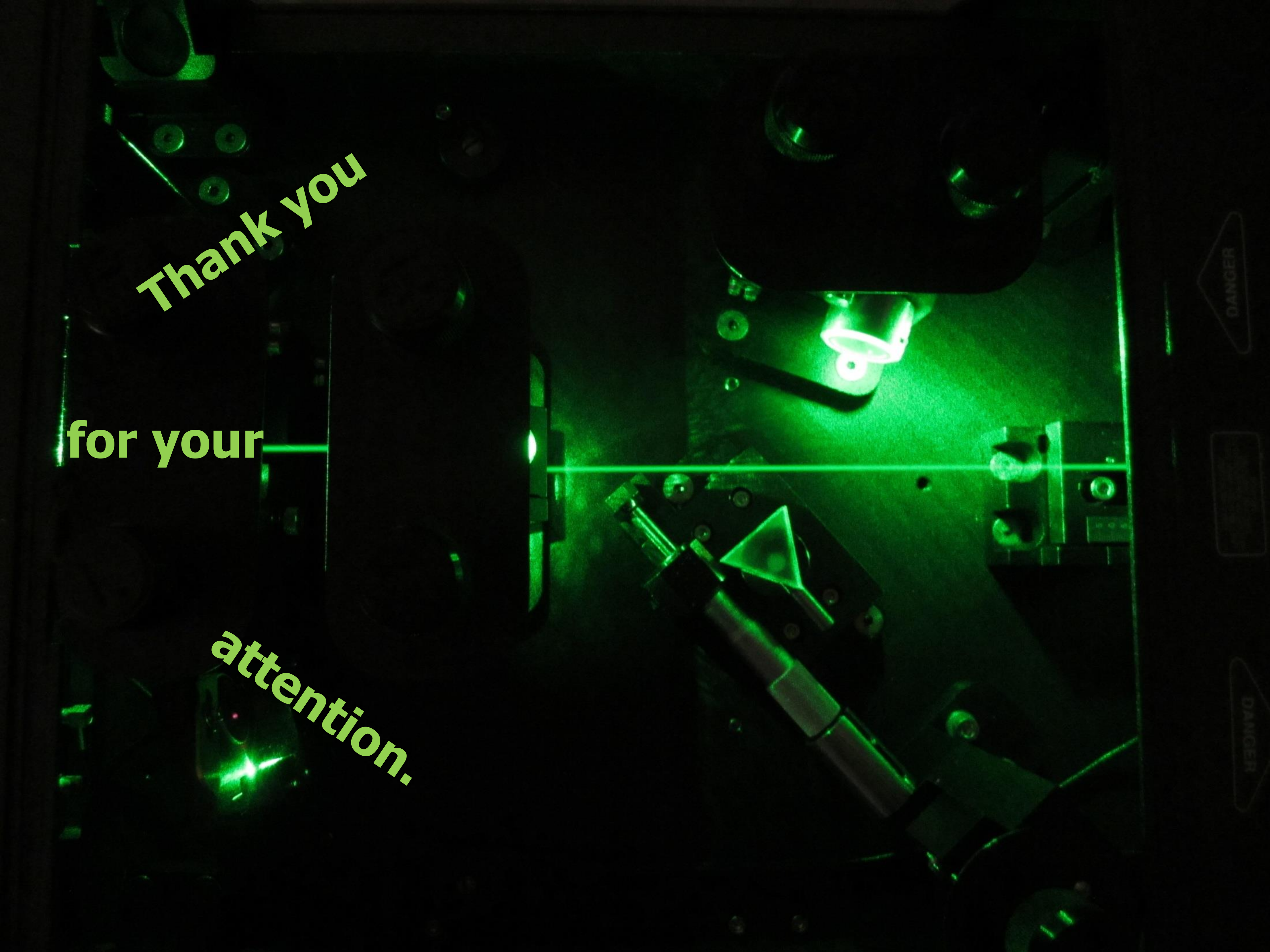


- Red and blue line: NEA
- Black line: PEA
  - Pulse response faster than NEA
  - Variation of the intensity in the tail: between a factor of 2 (left) and 10 (right)
  - QE = 1 %

Conclusion and Outlook

- Conclusion
  - Pulse response measurements with CsO:GaAs photocathodes at 800 nm and 400 nm
  - Lower contribution to unwanted beam at 400 nm due to higher concentration to electrons at the surface
  - Pulse response measurements with K_2CsSb photocathodes at 400 nm
  - Pulse response of K_2CsSb is faster than CsO:GaAs, and lower contribution to unwanted beam even to CsO:GaAs
  - Actually, the measurements with K_2CsSb show the lowest limit of our time resolution with $\sigma = 0.9$ ps

- Outlook
  - Analysis of the different types of jitter during the measurements
  - Time resolved measurements with other types of GaAs photocathodes (thin layers)
  - Investigations in the differences of the tail intensities of K_2CsSb


Thank you
for your
attention.
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Time Response Measurements
Limits of the Resolution

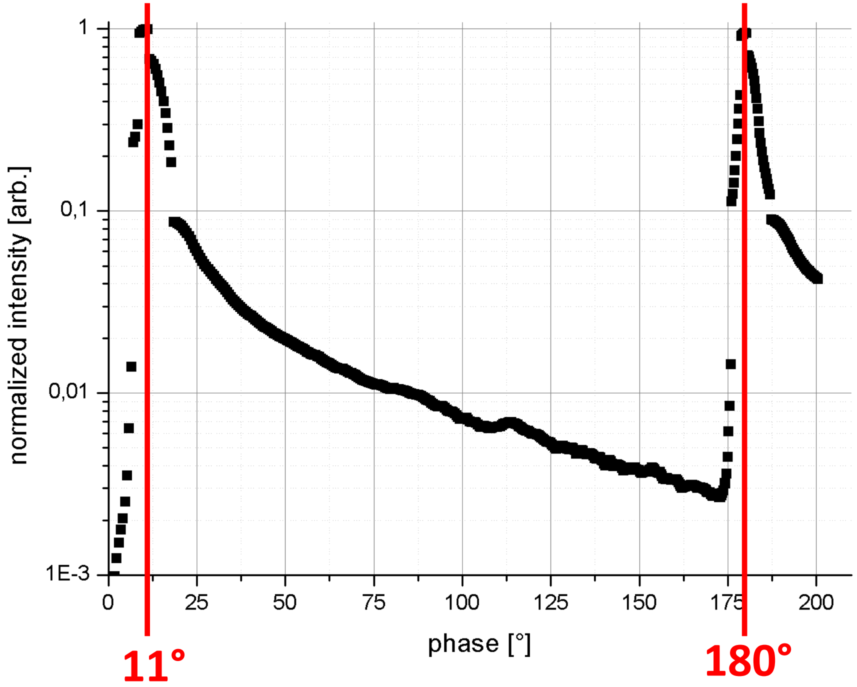
- Different effects
  - Real transverse spot size only by the emittance
  - High voltage power supply: jitter
  - Beam spot: jitter
  - RF phase: jitter
  - Laser bunch length: jitter
  - Electrons: different starting energies
  - Electrons: different transverse momenta
  - Channeltron: hum of the mains
  - Water cooling: drifts

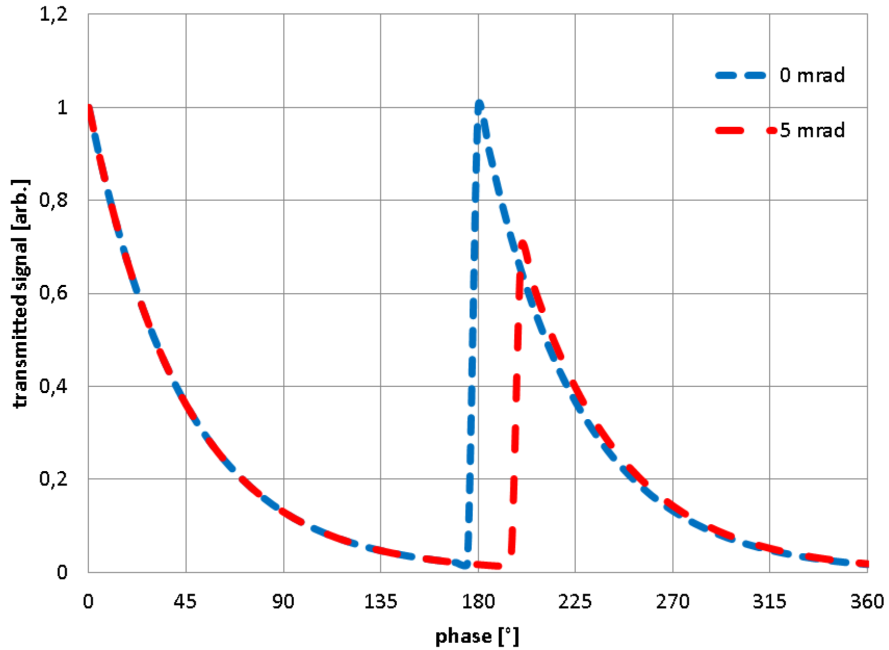
- Limits by the Experimental Setup
  - Phase Stability (Jitter and Drift of the RF Cavity)
    - Jitter (fast) mainly due to the Laser Systems
    - Drifts (slow) by thermal effects
    - → τ_{jitter} depends on measurement time
  - Finite transversal size of the electron bunch
    - "Deflection speed" on the screen ~400µm/ps at minimum transversal size of ~190µm

      → $\tau_{\text{Beam}} \approx 1\text{ps}$
    - Size of Laser spot on Cathode affects bunch size (Emittance)

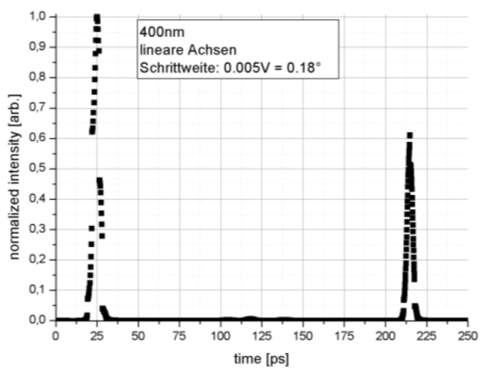
      → $\sqrt{\varepsilon_{\text{Beam}}} \propto d_{\text{Beam}}$ → $\varepsilon_{\text{Beam}} \propto d_{\text{Laser}}$ → $d_{\text{Beam}} \propto \sqrt{d_{\text{Laser}}} \leftrightarrow \sqrt{\tau_{\text{Laser}}}$
  - → $\tau_{\text{App.}} = \sqrt{\tau_{\text{jitter}}^2(t) + \tau_{\text{Beam}}^2 + \tau_{\text{Laser}}^2 + \tau_{\text{x}}^2}$
- Physical Limits (beam transport)
  - Longitudinal dispersion caused by distribution of kinetic energy at emission
  - → $\tau_{\text{phys}} = \frac{\sqrt{2mE_{\text{NEA}}}}{eF}$

Time Response Measurements
Long Phaseshift





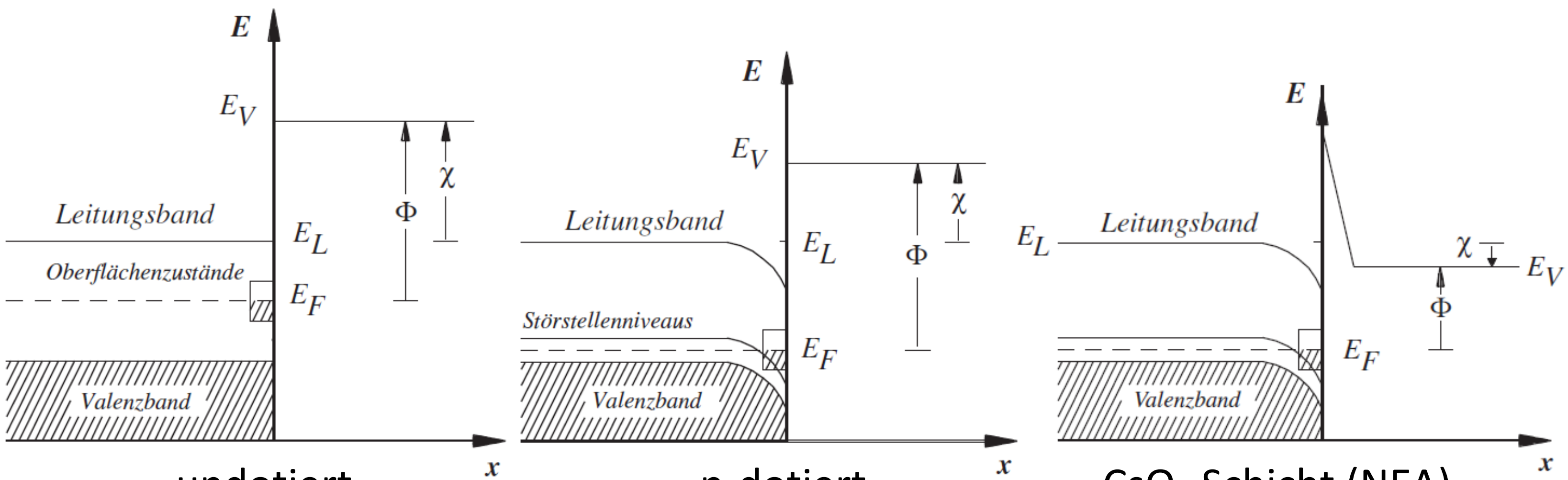
- Phase shift: 200°
- Pulse repeats after 169°



- Cavity simulation
  - E.g. a beam deviation of 5mrad through the cavity shows an additional phase shift and an intensity modulation.

Source: Kirsch, E.: Johannes Gutenberg Universität Mainz, Diplomarbeit, 2014

Semiconducting photocathode GaAs



undotiert p-dotiert CsO_2 Schicht (NEA)

Fundamentals
Photoemission from Semiconductors

- Absorption
  - Condition: $E_\gamma > E_{gap}$
  - Absorption coefficient:

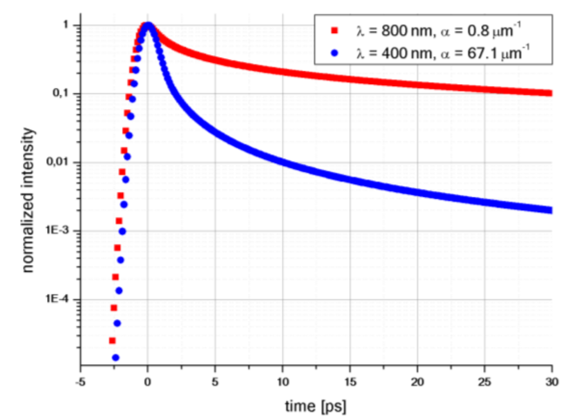
$$\alpha(E_\gamma) = \frac{\pi e^2 \hbar}{m^2 c n_r \epsilon} \frac{1}{E_\gamma} \frac{2}{3} |p_{CV}|^2 \rho_{CV}(E_\gamma)$$

- Diffusion model for GaAs-photocathodes
  - Electron motion only by diffusion, not by scattering:

$$D \frac{d^2}{dx^2} c(x,t) - \frac{d}{dt} c(x,t) = 0$$

And the solution

$$c(x,t) = \sum_{k=1}^{\infty} A_k \sin\left(\frac{k\pi x}{d}\right) e^{-\left(\frac{k\pi}{t}\right)^2 Dt}$$



  - Emitted current:

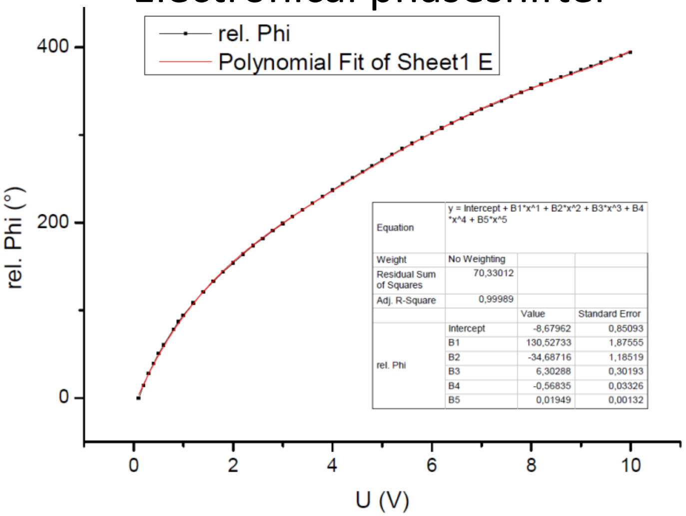
$$j(t) \propto \frac{d}{dx} c(0,t) \propto \sum_{k=1}^{\infty} A'_k e^{-\left(\frac{k\pi}{t}\right)^2 Dt}$$

with

$$A'_k = kA_k \qquad \text{und} \qquad A_k \propto \frac{k\pi\left[1-(-1)^k e^{-\alpha d}\right]}{(\alpha d)^2 + (k\pi)^2}$$

Time Response Measurements
Some Calibrations

Electronical phaseshifter



Equation	y = Intercept + B1*x^1 + B2*x^2 + B3*x^3 + B4 *x^4 + B5*x^5		
Weight	No Weighting		
Residual Sum of Squares	70,33012		
Adj. R-Square	0,99989		
		Value	Standard Error
rel. Phi	Intercept	-8,67962	0,85093
	B1	130,52733	1,87555
	B2	-34,68716	1,18519
	B3	6,30288	0,30193
	B4	-0,56835	0,03326
	B5	0,01949	0,00132

Source: Bechthold, V.: Johannes Gutenberg Universität Mainz, internal notes, 2016