Status of the ANKA Short Bunch Operation

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Outline

- Operation with short bunches
  - ➜ Beam energies
  - ➜ SCU14
- Beam studies
  - ➜ Systematics of bunch length measurements with a Michelson interferometer
- Radiation characteristics
  - ➜ Polarisation
  - ➜ Development of bursts
- Summary & Perspectives

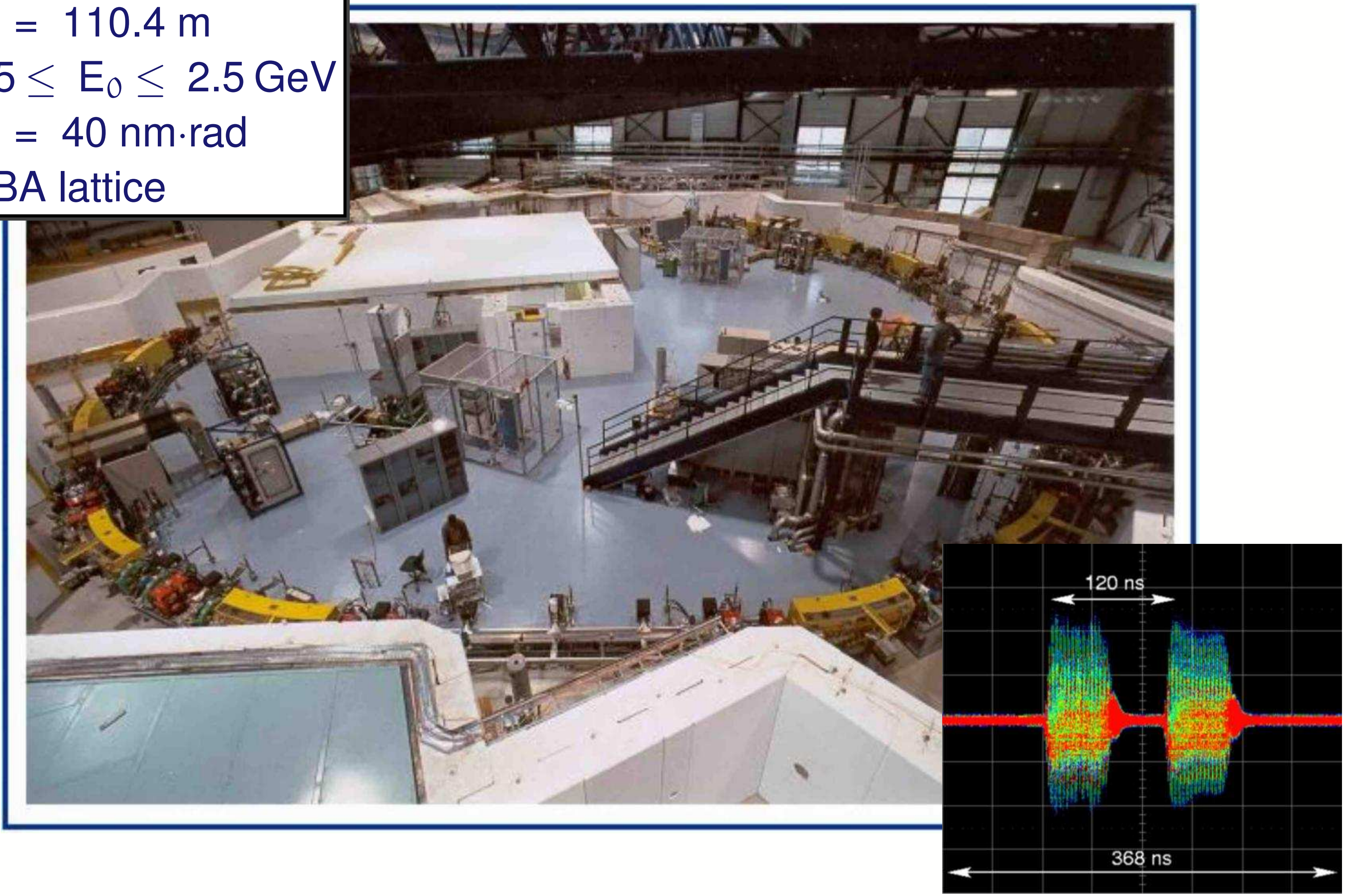
Research Centre Karlsruhe

Research & development in various fields:

- environmental analysis
- medicine/bio technology
- material science
- microsystem technology
- (astro) particle physics
- IT science
- nano technology
- ...

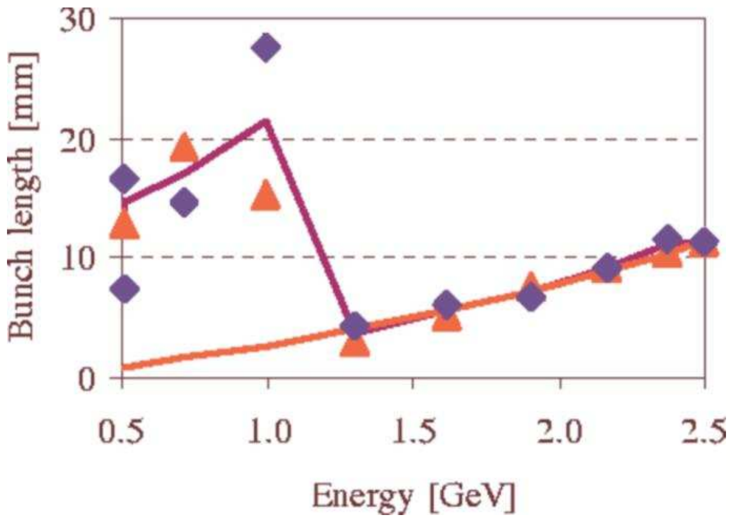
The ANKA Storage Ring

- ✔ C = 110.4 m
- ✔ $0.5 \leq E_0 \leq 2.5$ GeV
- ✔ ε_x = 40 nm·rad
- ✔ DBA lattice



Low-α_c Operation

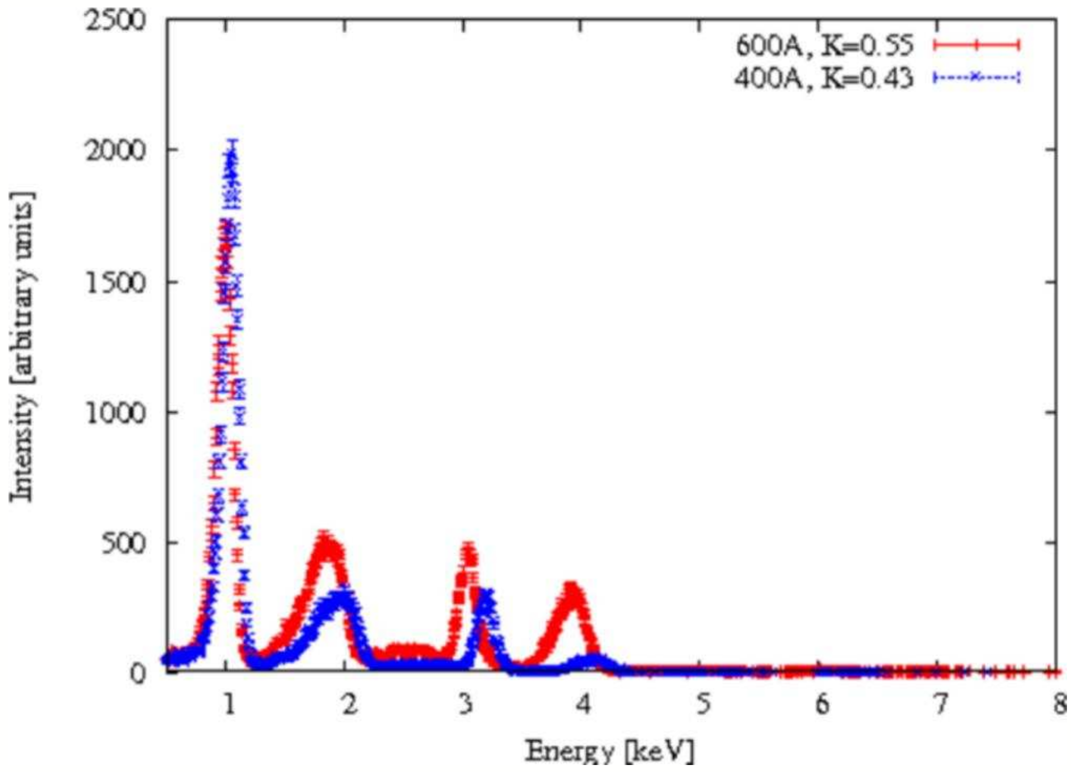
- Per year 12 days are dedicated short bunch operation for users as "special user operation".
- Typical beam energy in this mode is 1.3 GeV
  ➜ longitudinal instability due to one higher order cavity mode for $E_0 < 1$ GeV
- Low-α mode also operational at 1 GeV and 1.6 GeV on demand.
- In May 2007 a Helmholtz University Young Investigators Group dedicated to the study of the short bunch dynamics in storage rings has been founded.



F. Pérez et al., PAC03

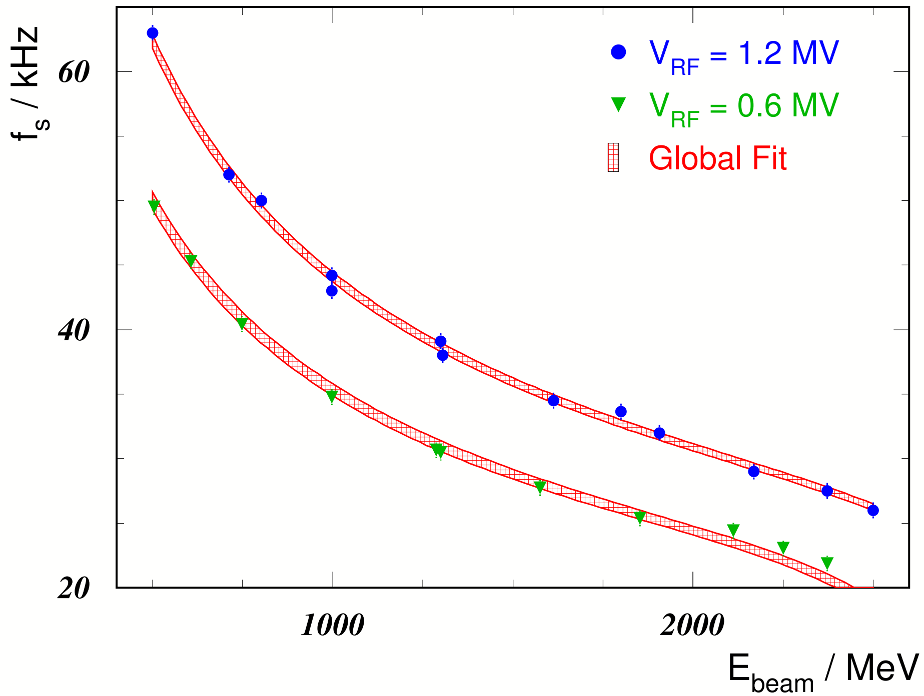
SCU14 and Short Bunches

- Short bunch operation for X-ray users at E_0 = 1.3 GeV
  - ➜ boost the photon energy with the SCU14
  - ➜ potential for time resolved experiments ($\sim 10^6$ integral photons/pulse)



A. Bernhard et al., "Performance of the First Superconducting Cold-Bore Undulator in an Electron Storage Ring, PRSTAB 2006

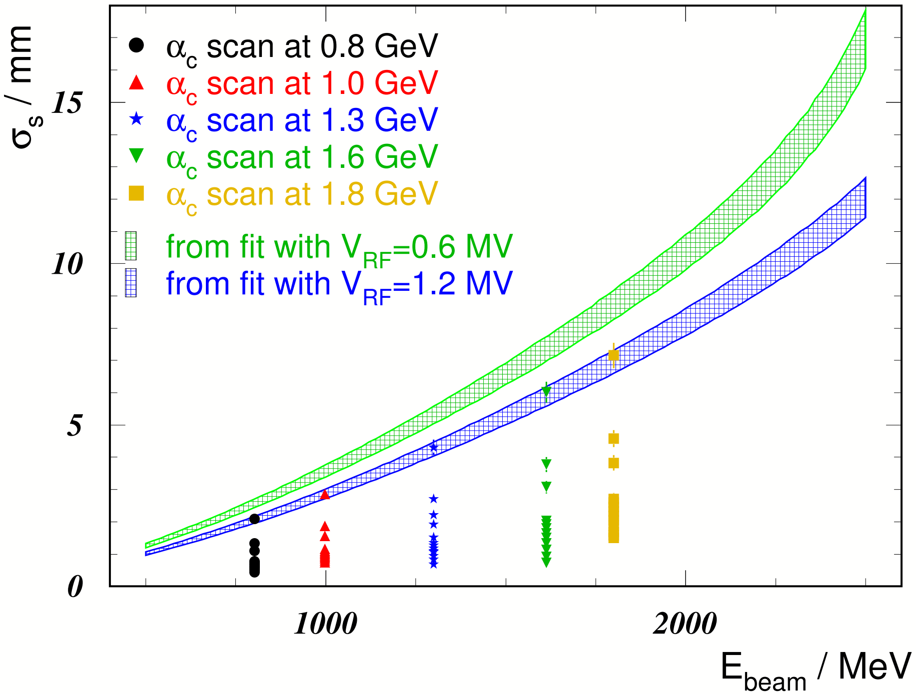
Bunch Length and Beam Energy



- The synchrotron tune is given by

$$Q_s^2 = \left(\frac{\alpha_c h}{2\pi E}\right) \sqrt{e^2\, V_{RF}^2 - U_0^2}$$

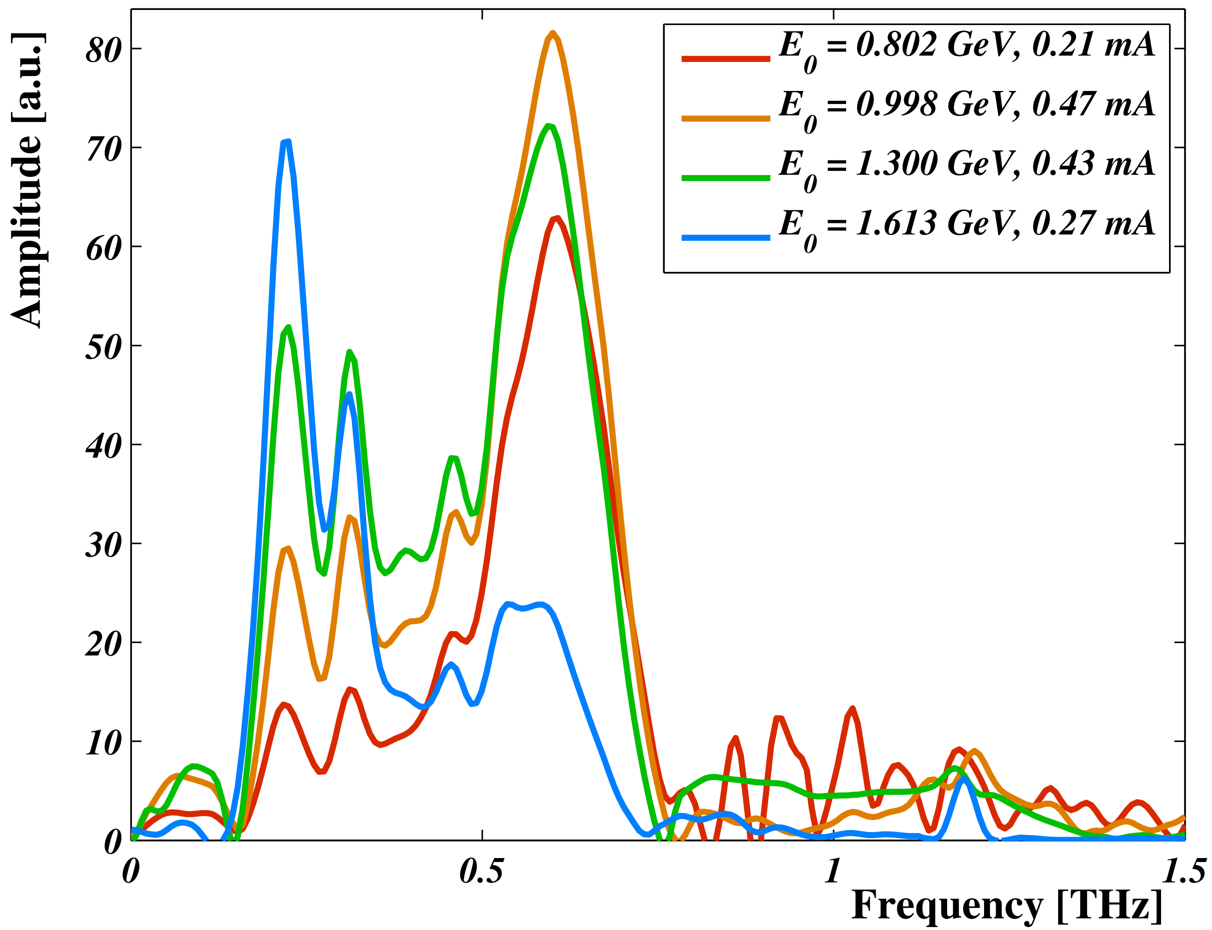
- A global fit yields an effective α_c:
  $\alpha_c = (6.6 \pm 0.1) \cdot 10^{-3}$
  RDP at 2.5 GeV: $(7.39 \pm 0.01) \cdot 10^{-3}$



- The bunch length scales $\propto (E_0)^{3/2}$
- Calculate σ_s from f_s with global α_c
- “Low-α_c squeeze” achieved for different beam energies

FIR-Spectrum & Beam Energy

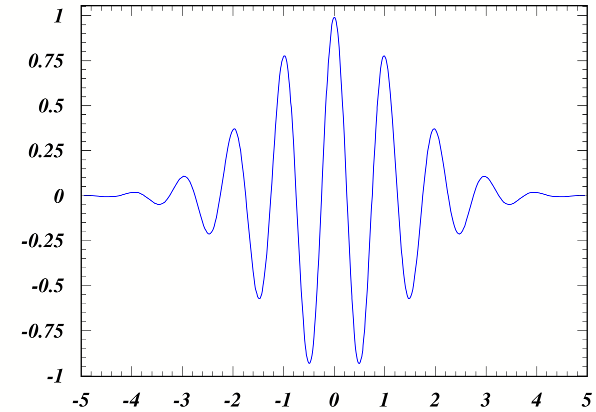
- FIR spectrum for different beam energies (measured with a Michelson interferometer)



- Observations
  - ➜ shift towards lower frequencies (longer bunches) with increasing E_0
  - ➜ suppression of low frequency content for shorter bunches
    $\Rrightarrow$ non-linearities of the detector?
- Observation of stable CSER also at 1.0 and 1.6 GeV.

Bunch Length from Interferograms

HELMHOLTZ GEMEINSCHAFT ANKA



- Simplified view: wave train of frequency ω emitted by charge distribution of RMS length σ:

$$A(t) = e^{-\left(\frac{1}{2}\frac{t^2}{\sigma^2} + i\omega t\right)}$$

- The pulse overlayed with itself shifted by a time Δ due to the Michelson interferometer is

$$A(t,\Delta) = e^{-\left(\frac{1}{2}\frac{t^2}{\sigma^2} + i\omega t\right)} + e^{-\left(\frac{1}{2}\frac{(t+\Delta)^2}{\sigma^2} + i\omega(t+\Delta)\right)}$$

- The time integrated intensity observed by the detector is therefore

$$\tilde{I}(\Delta) = \int I(\Delta)dt = \int |A(\Delta)|^2 dt \propto \cos(\omega\Delta)\, e^{-\frac{\Delta^2}{4\sigma^2}}$$

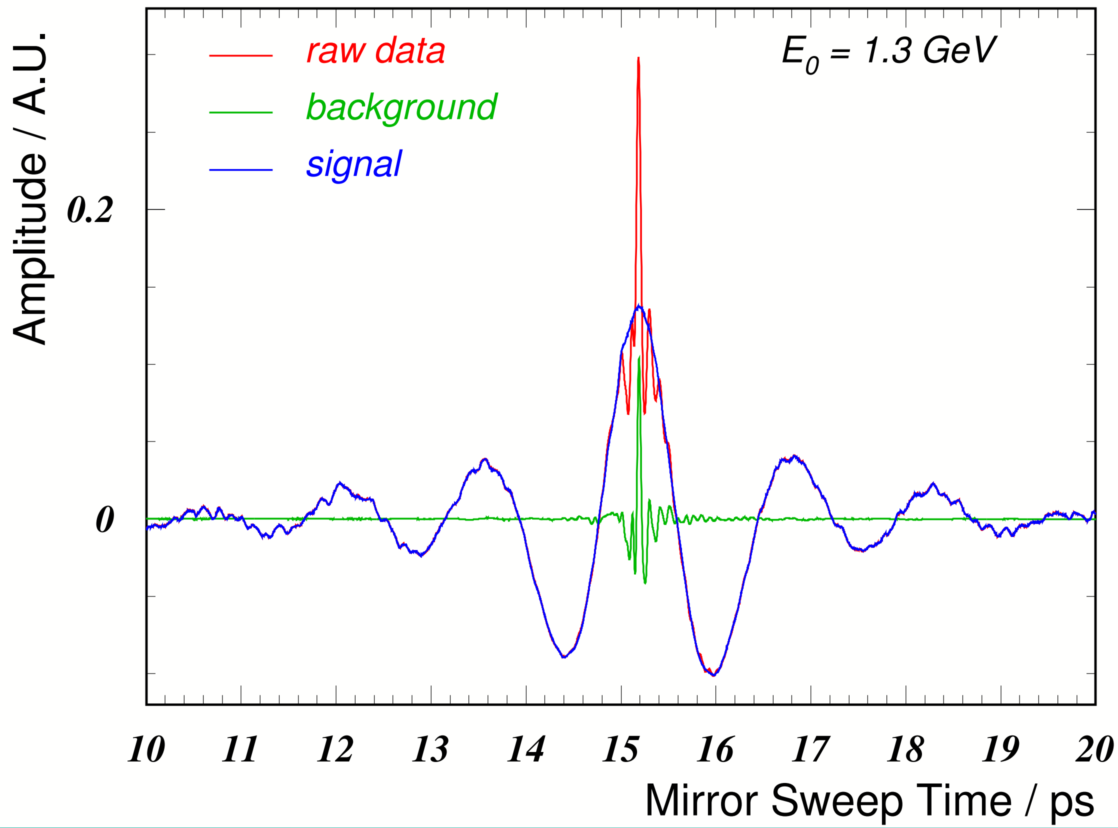
- Assumption: Since the shortest wave length emitted coherently is equal to full bunch length $\lambda_{\text{min}} = 2\sigma_w$, the max. frequency is $\omega_{\text{max}} = 2\pi c/\lambda_{\text{min}} = \pi c/\sigma_w$. It follows that

$$\tilde{I}(\Delta) \propto \cos(\omega_{\text{max}}\Delta)\, e^{-\frac{\Delta^2}{4\sigma^2}} = \cos\left(\frac{\pi}{\sigma}\Delta\right) e^{-\frac{\Delta^2}{4\sigma^2}}$$

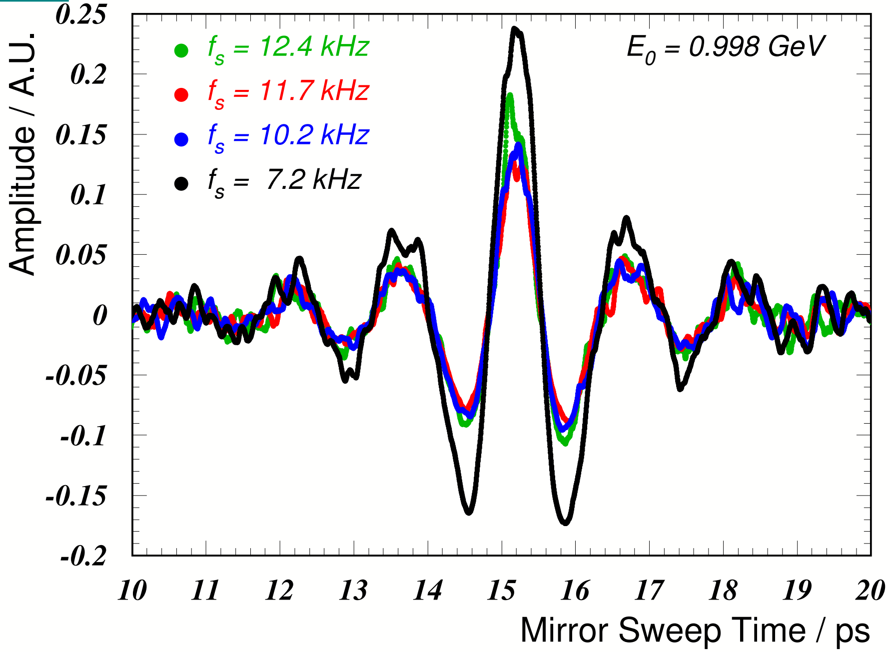
➜ Exponential doesn't change peak width: FWHM yields σ

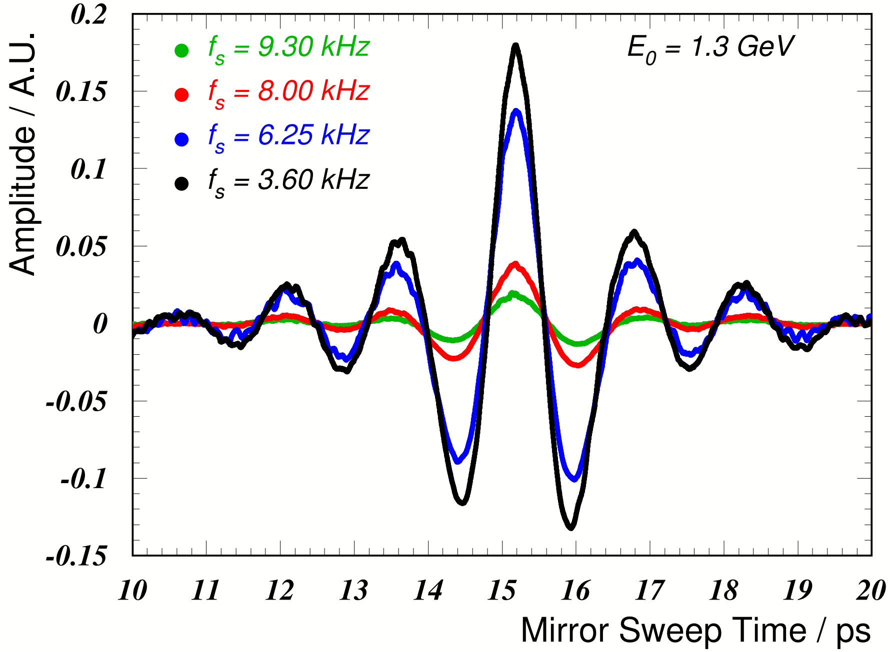
Background Subtraction

- The coherent signal in the interferogram is superimposed by the incoherent and the thermal contributions
  - ➜ The width of the central peak (i.e. the cos term) must be determined only after background subtraction
  - ➜ FWHM is very sensitive to noise ⇛ determine zero-crossings

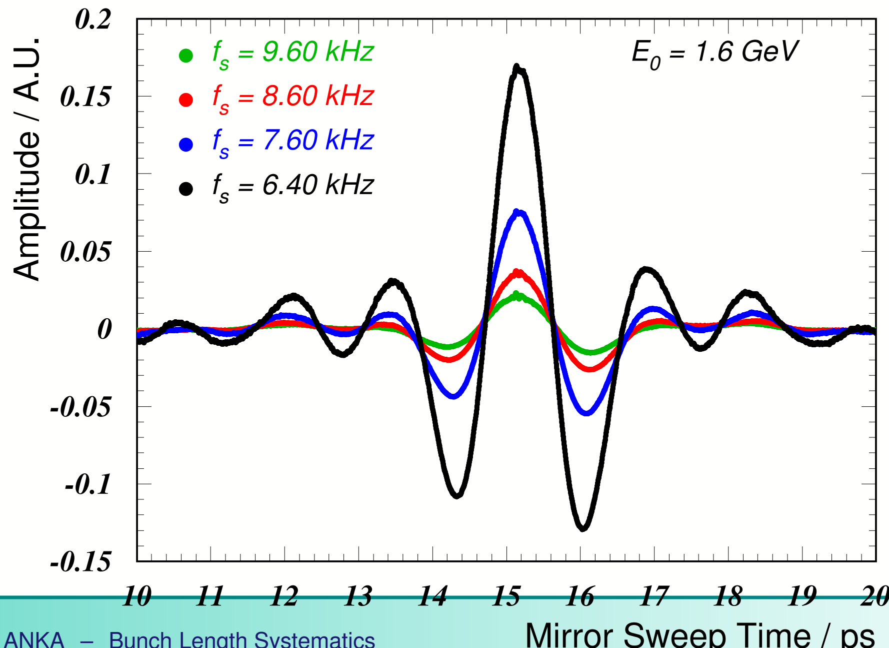


Interferograms and Energy

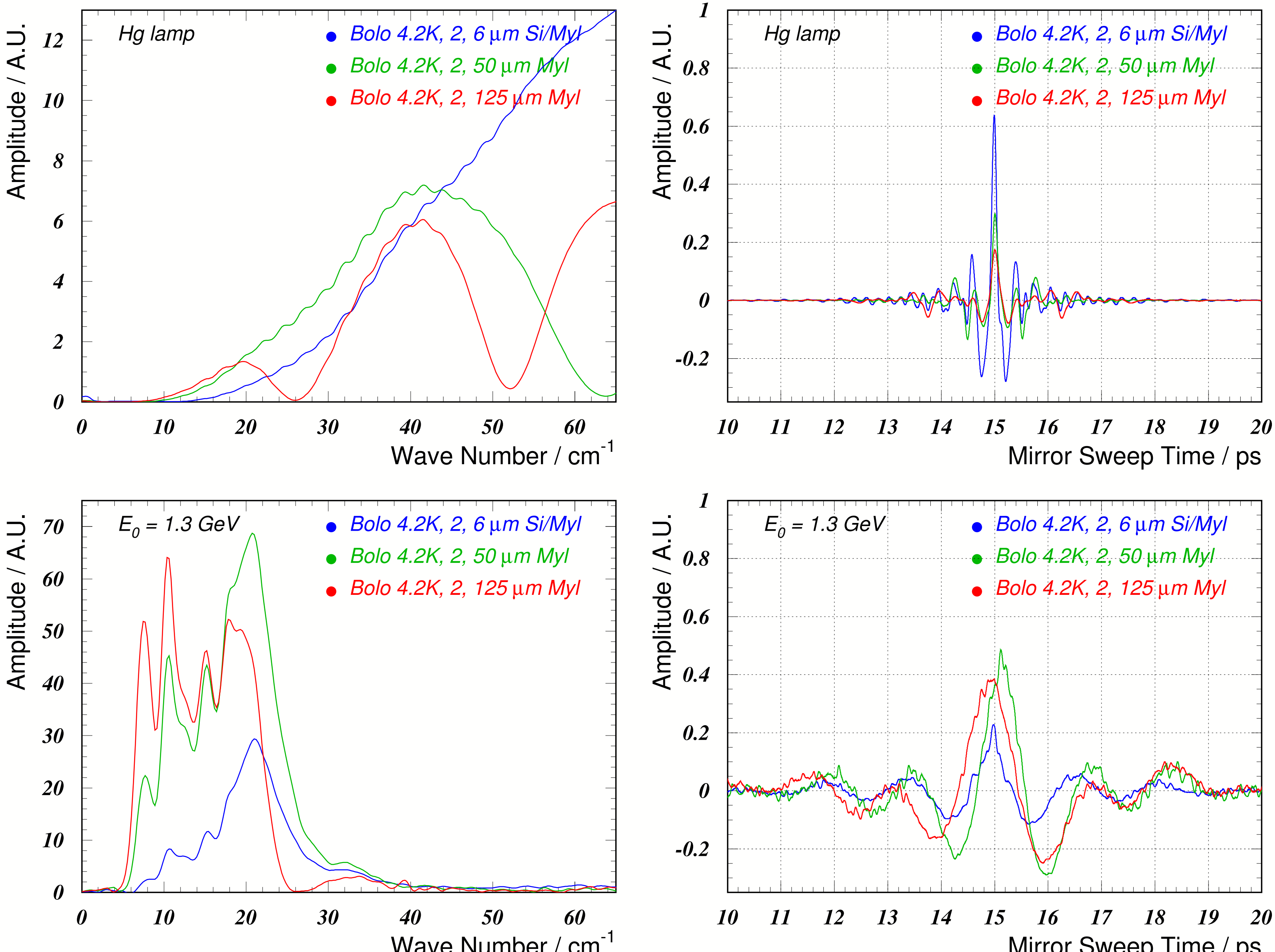




- Background subtracted data for different beam energies and "squeeze states":
  - ➜ the higher the energy, the lower the noise
  - ➜ cavity mode?

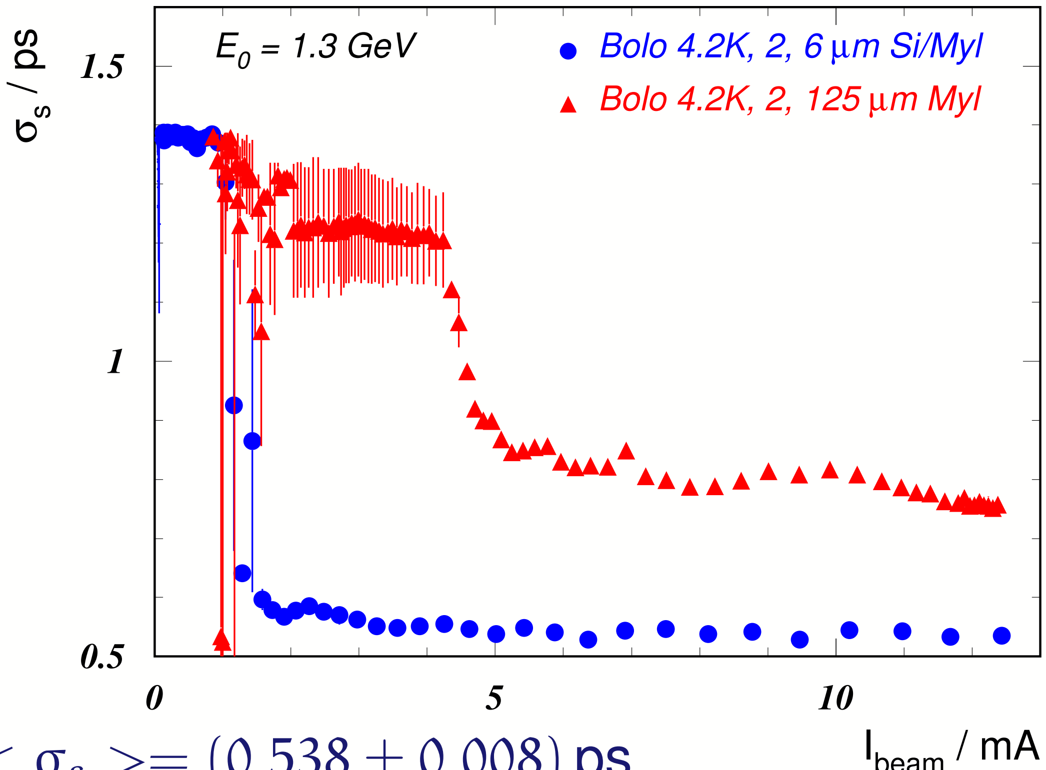


Beam Splitter Comparison



Bunch Length and Current I

- Conclusion from beam splitter comparison: thin splitters are more sensitive in the critical region of the spectrum
  - ➜ 6 μm Si/Mylar splitter expected to be more sensitive to small bunch length changes (e.g. due to beam current change) than 125 μm Mylar splitter



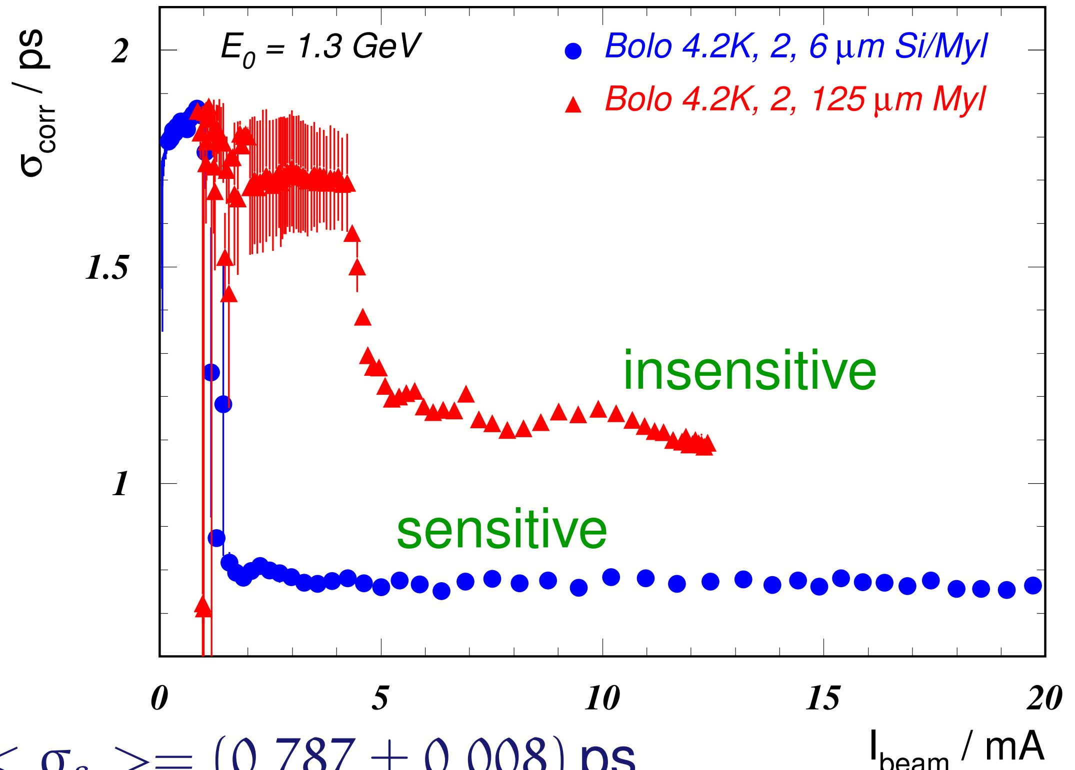
$$< \sigma_s > = (0.538 \pm 0.008)\ \text{ps}$$

Bunch Length and Current II

- Observation of coherent emission for

$$\frac{2\,\pi\,\sigma_{s,real}}{\sqrt{\ln N}} \lesssim \lambda_{observed} \qquad \text{or} \qquad \sigma_{s,real} \lesssim \frac{\sqrt{\ln N}}{\pi}\,\sigma_{s,observed}$$

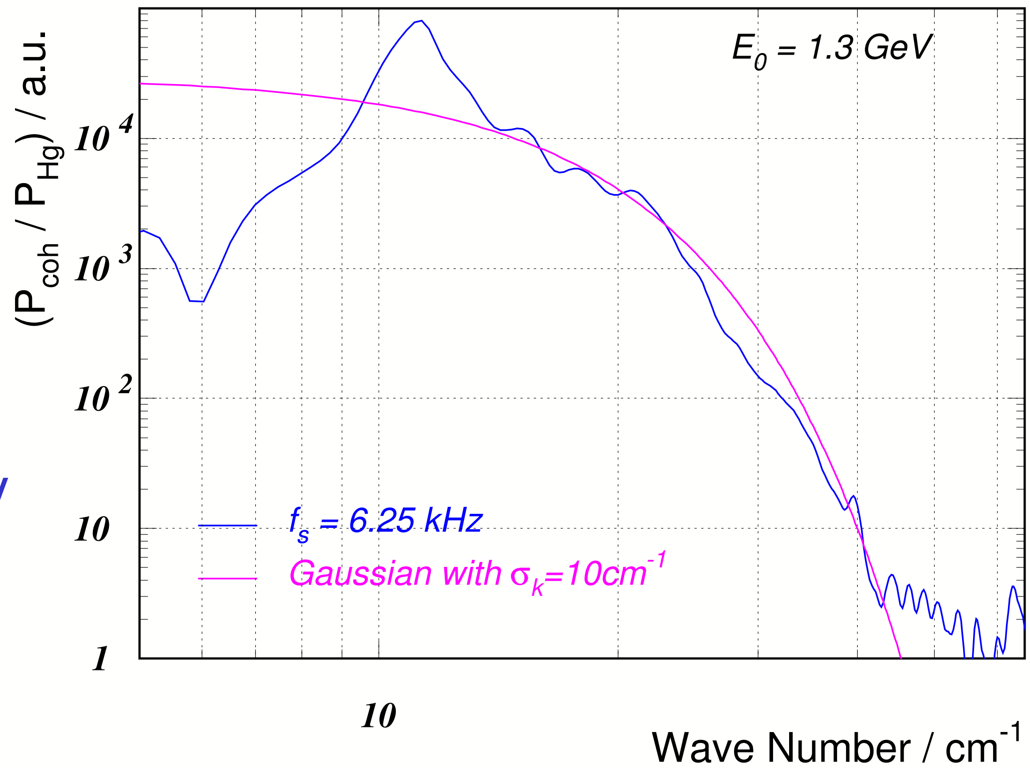
- Correct the σ derived from interferogram accordingly
  ➜ if the beam splitter is sensitive, the N dependence must vanish



$$<\sigma_s> = (0.787 \pm 0.008)\ \text{ps}$$

Bunch Length from Spectrum

- Determination of σ from normalised spectrum
- Ideally normalisation by incoherent spectrum
  - ➜ Problem: low intensity
  - ➜ Alternative: Normalise by spectrum of Hg lamp

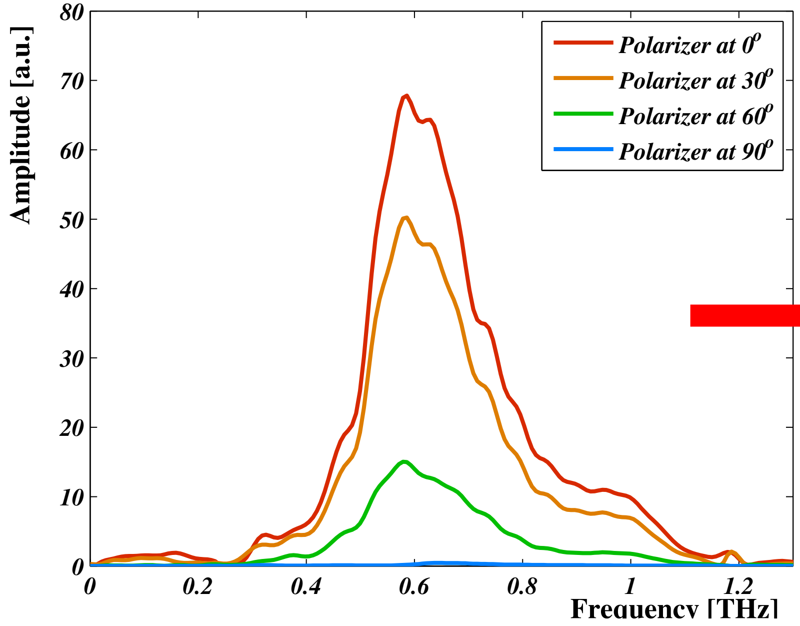


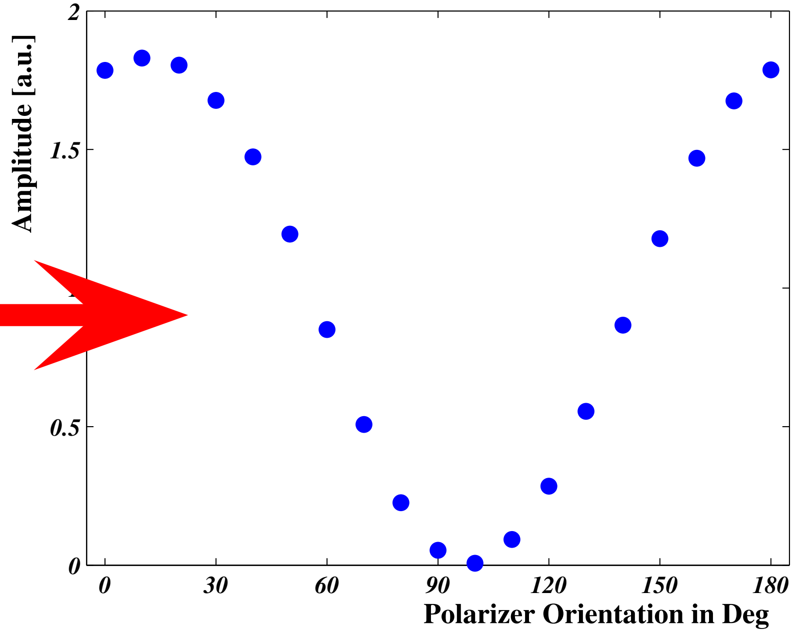
- The bunch length is related to the spectral bandwidth σ_k by (G. Wüstefeld, SBSR05):

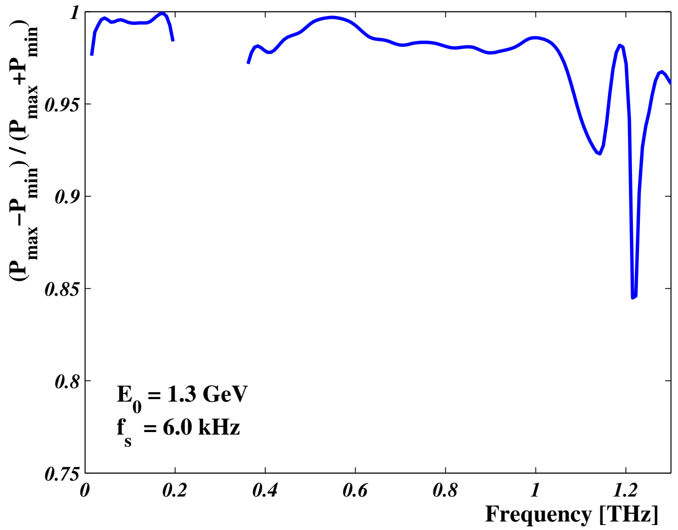
$$\sigma_s = \frac{1}{2\pi\sqrt{2}\,\sigma_k}$$

- The bunch length determined thus is 0.375 ps.

Polarisation



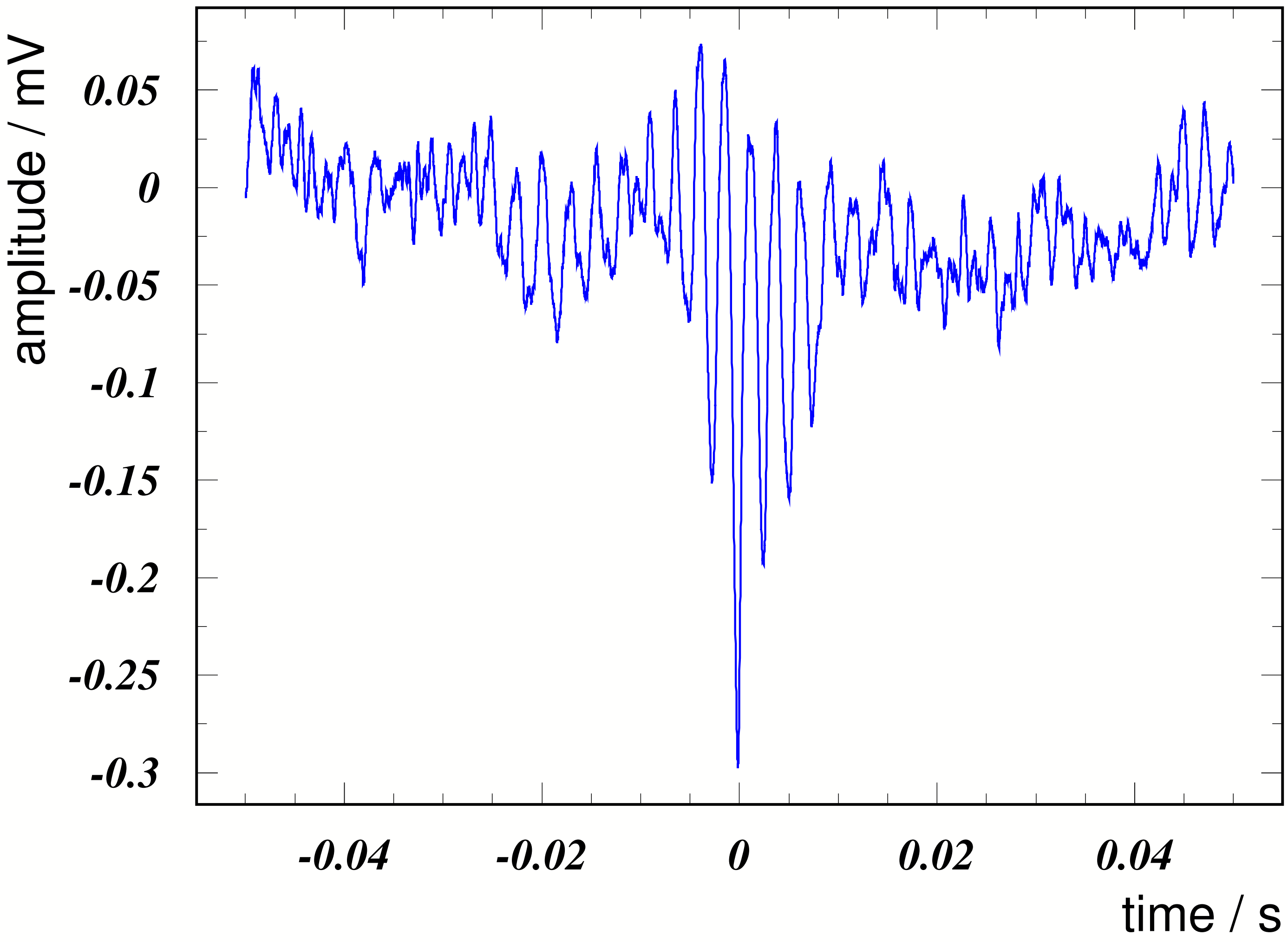




- Edge radiation in mid-IR shows radial polarisation
- For very low frequencies only a slice of the radiation in the orbit plane is visible

➜ measure mostly linear polarisation ✔

Bursting Emission

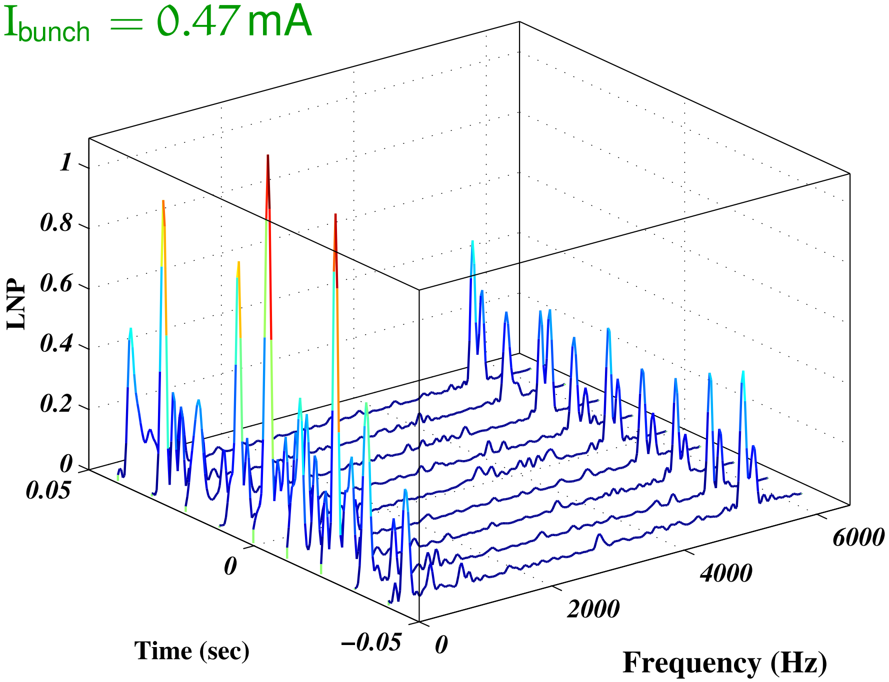


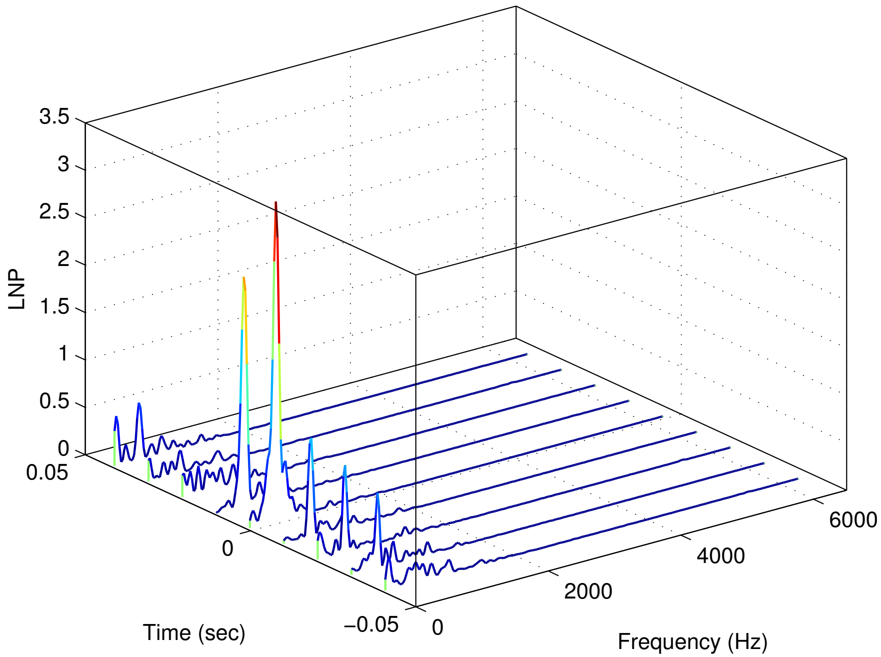
- Investigate the frequency content time slice by time slice

Zooming into a Burst

- Study of the change of the bolometer signal frequency contents during the build-up of a burst
  - ➜ signal around a burst is cut in slices that are analysed separately

$I_{bunch} = 0.47\,mA$





$I_{bunch} = 0.16\,mA$

- High current: double peak structure around f_s (σ_s oscillations?)
- Low current: f_s structure gone and max. of burst more pronounced

Perspectives

- Accelerator :
  - ➜ A dual sweep streak camera will be added to the ANKA diagnostics for direct bunch length measurements
  - ➜ A single bunch gun will replace the present diode gun for systematic studies of single bunch / multi-bunch differences
  - ➜ HEB to resolve revolution
- Experiments:
  - ➜ Time resolved measurements making use of the short X-ray pulses generated in the SCU14

Summary

- Regular low-α_c mode for special user operation at 1.3 GeV
- Potential for X-ray experiments using the SCU 14
- Beam studies:
  - ➜ Extensive and ongoing study of bunch length measurements systematics
  - ➜ Investigation of radiation properties
  - ➜ Further instrumentation will allow a closer look

Bunch Length from Spectrum