Measurement of Very Short Electron Storage Ring Bunches using a Streak Camera at the Resolution Limit

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Cyrille Thomas

What is a streak camera?

Resolution: some definition and aspects

Calibration of the streak camera

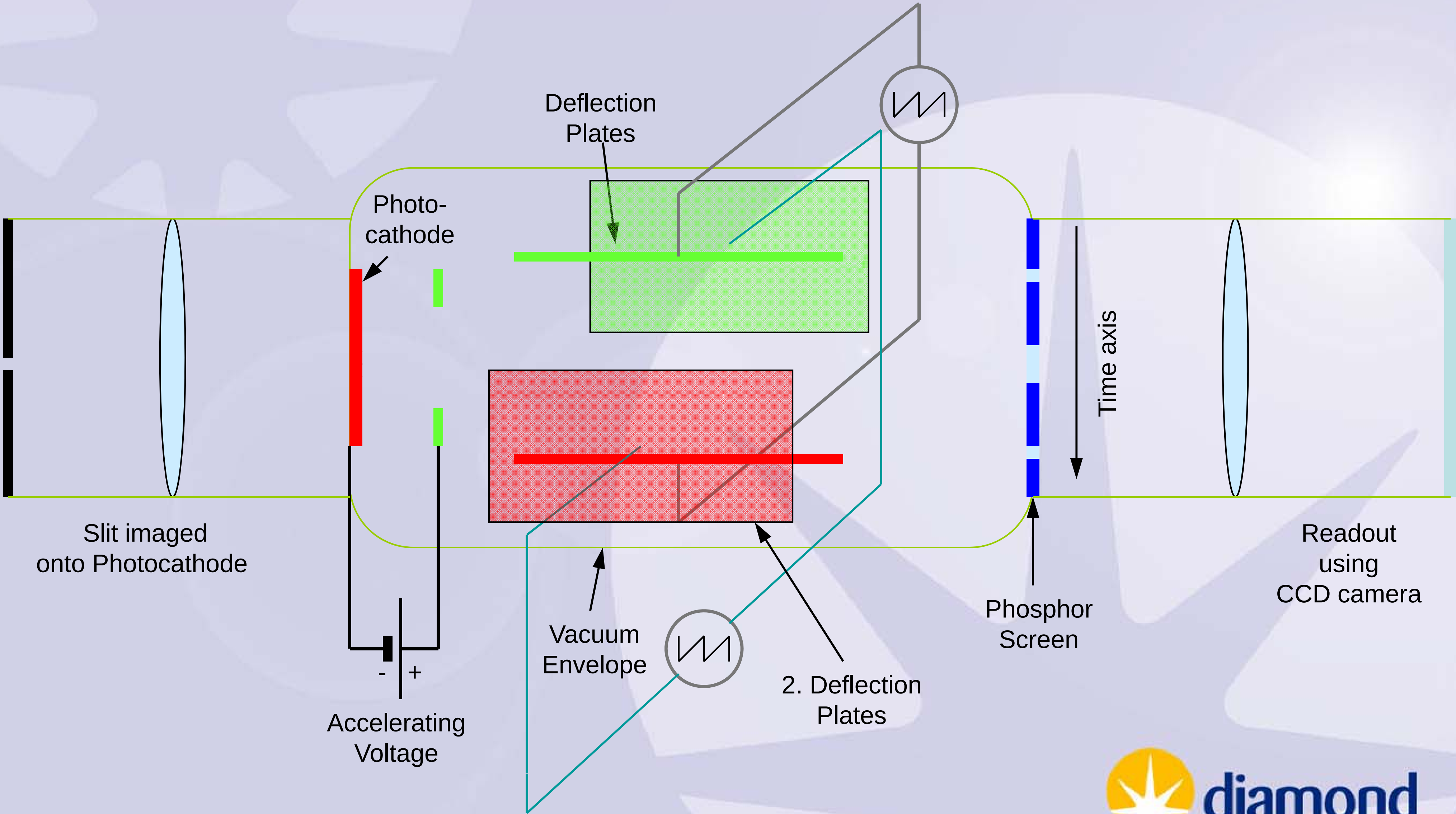
Streak camera resolution (1)

Time resolved spectra

Streak camera resolution (2)

Measurement performed at diamond

What is a streak camera?



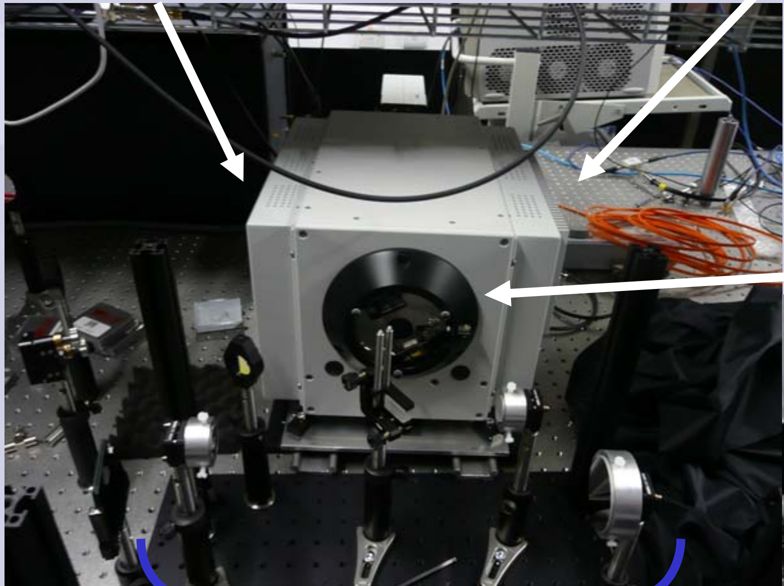
Streak camera at diamond

Slow sweep unit

Triggered ramp voltage

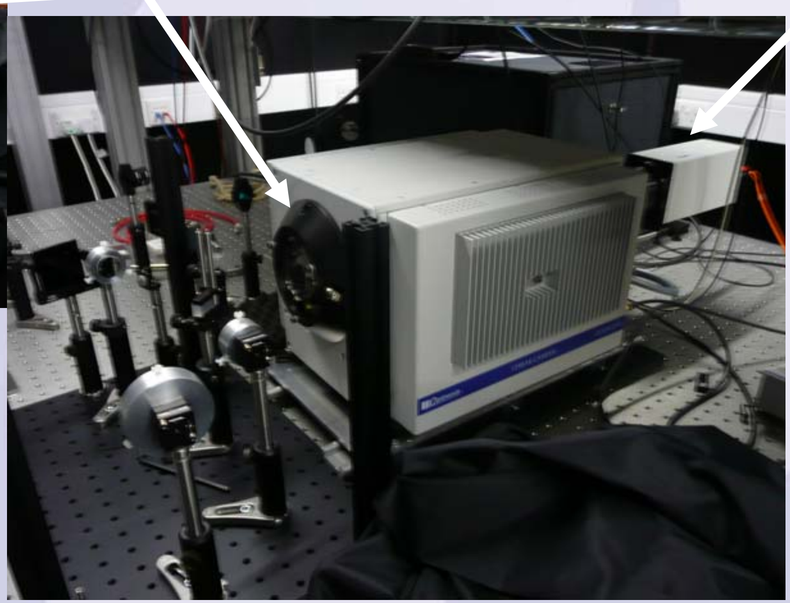
Synchroscan sweep unit

Resonant oscillator synchronous
with storage ring RF cavity



Photocathode

PCO camera



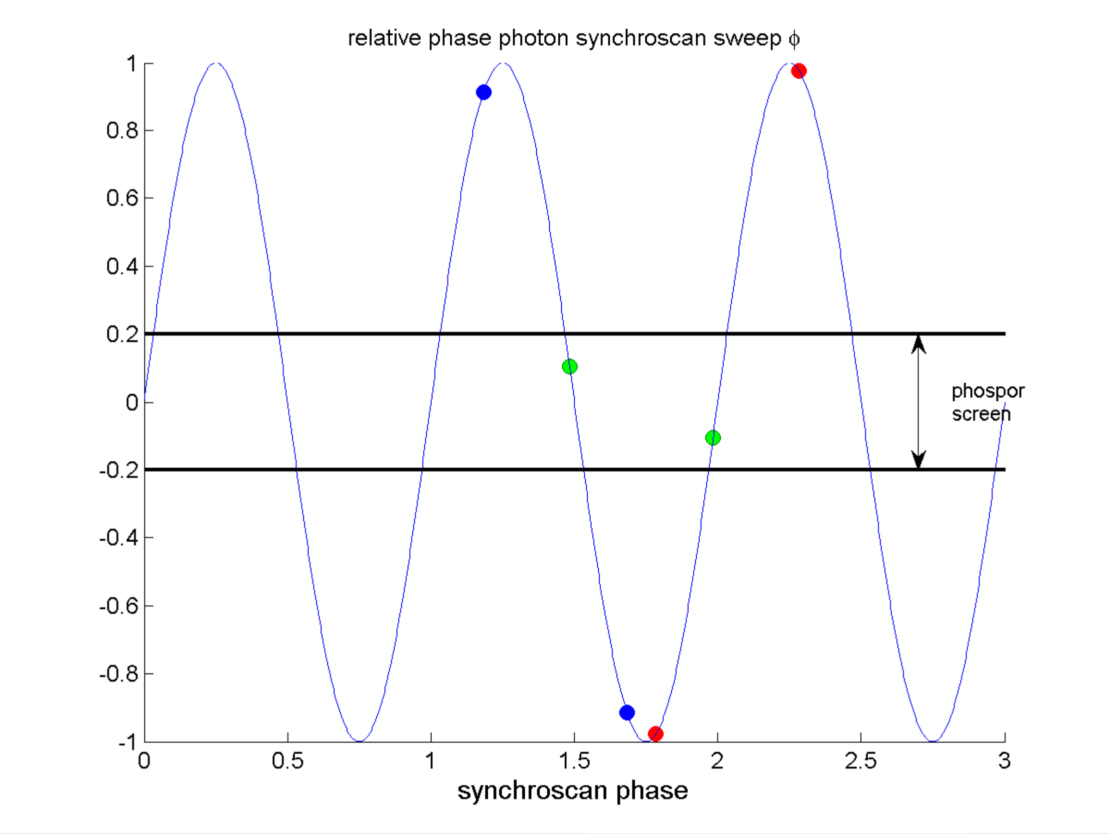
New Front Optics all reflective
(Diamond design)

Optronis streak camera

diamond

Synchroscan at f_{RF} /2

- odd and even buckets separated by half synchroscan phase

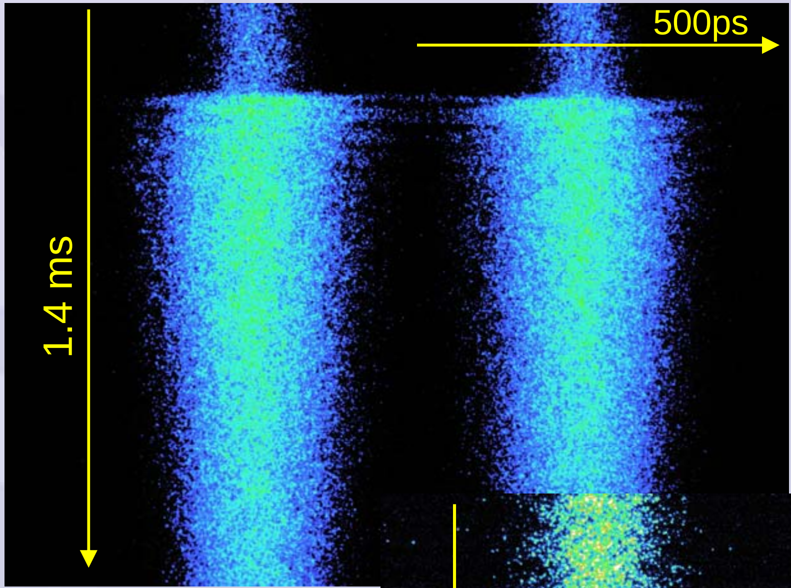


Relative phase RF-synchroscan ϕ_1

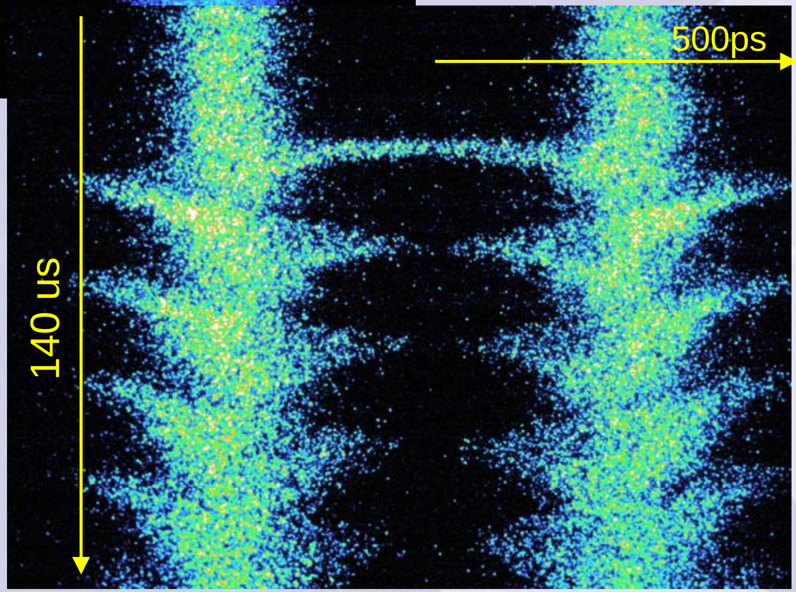
Relative phase RF-synchroscan ϕ_2

Relative phase RF-synchroscan ϕ_3

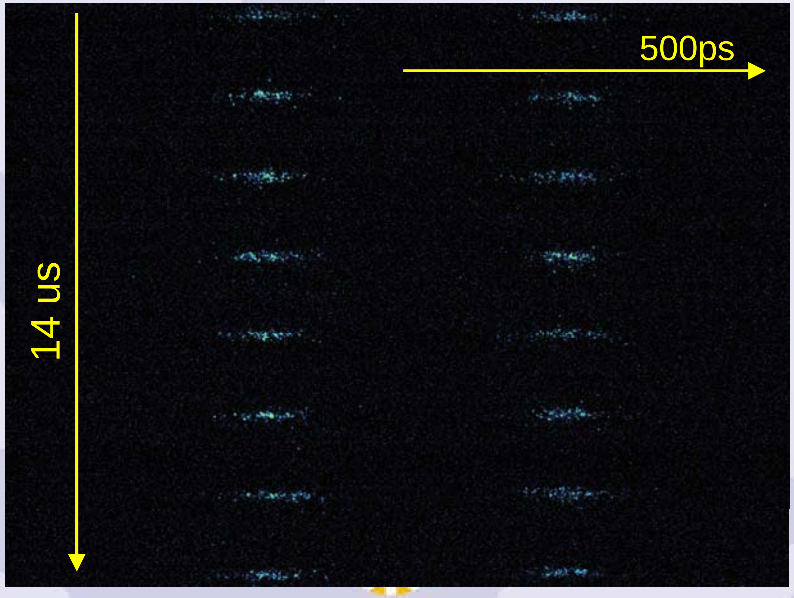
Streak camera images of the Diamond electron bunches



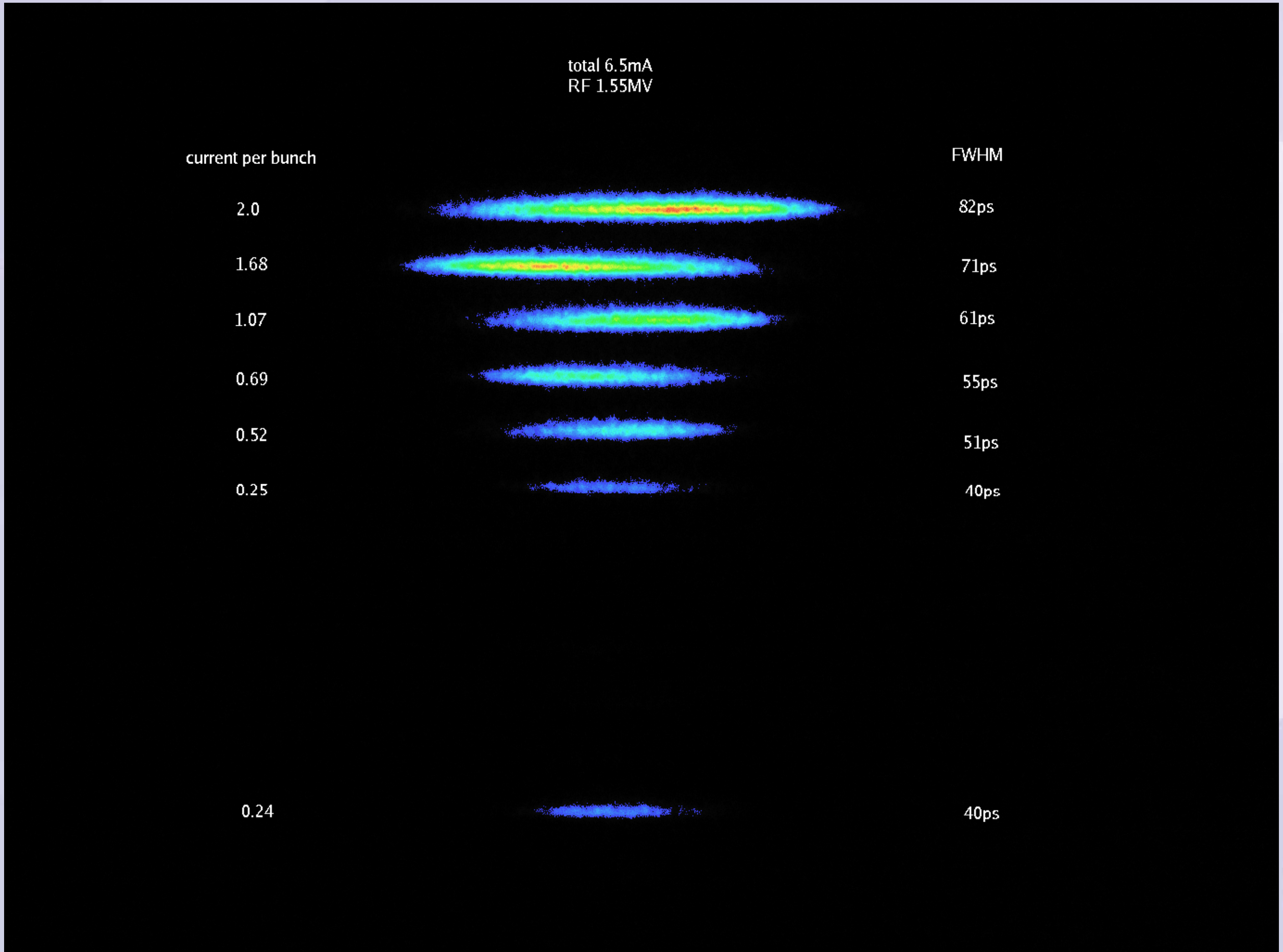
injection



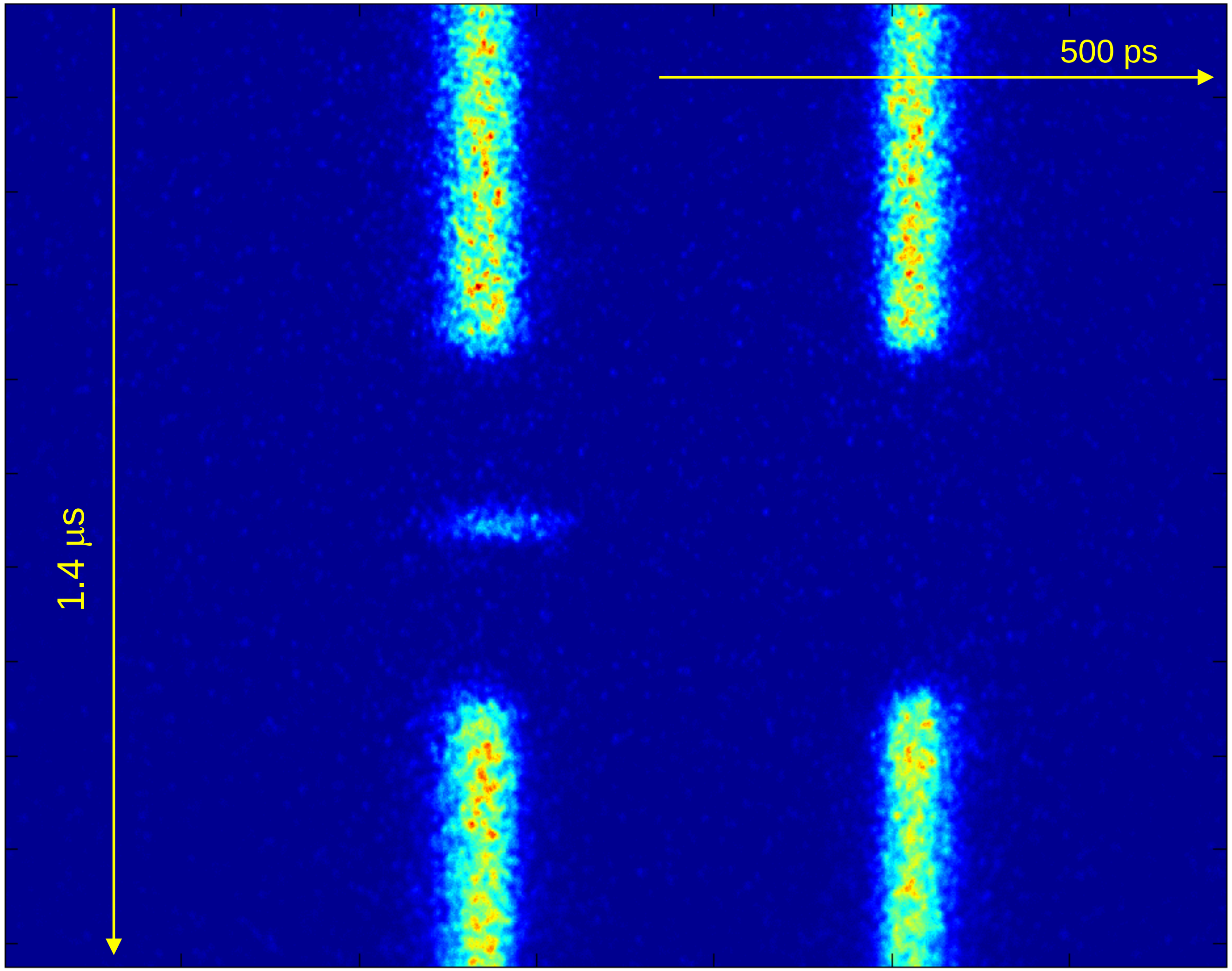
Two bunches



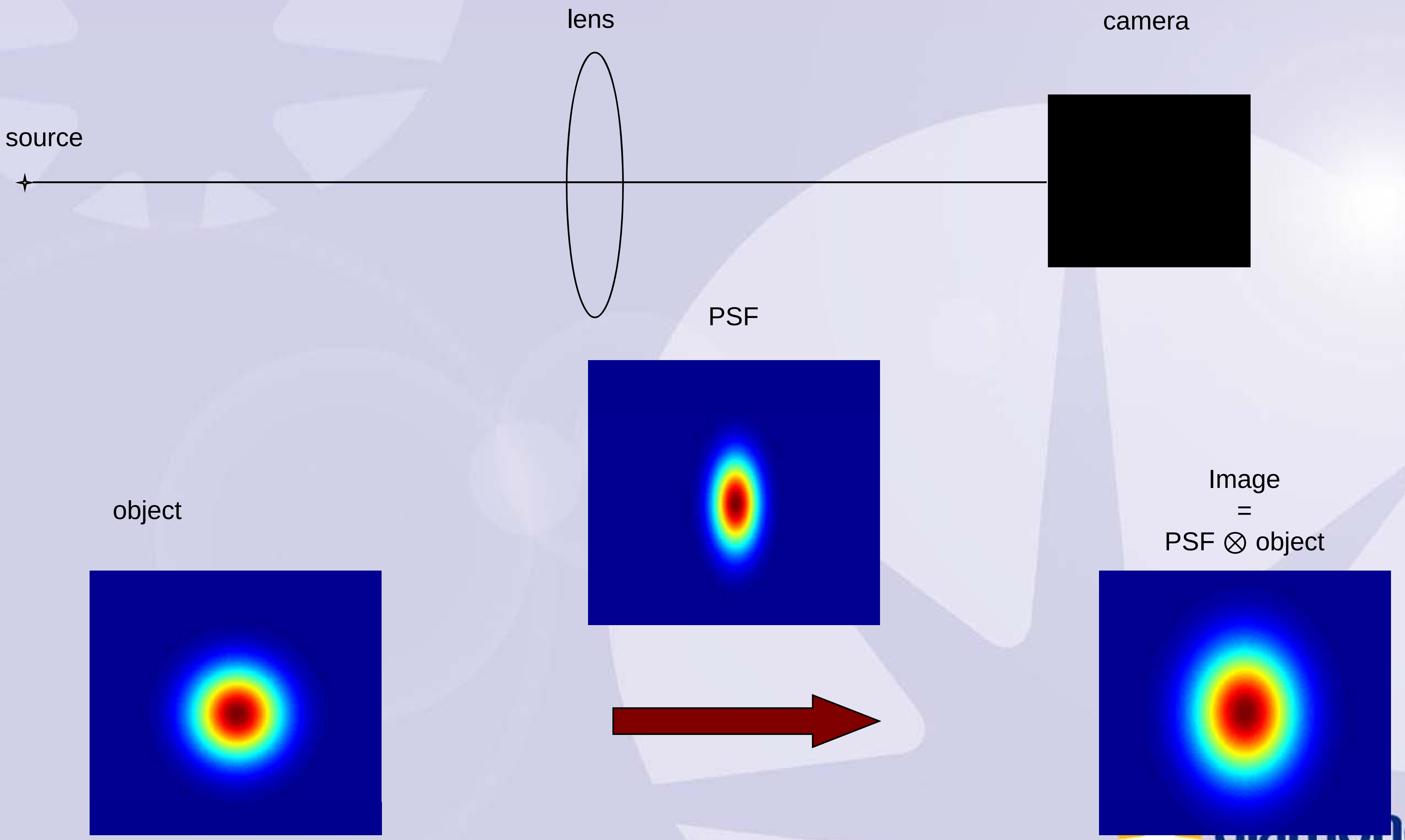
Single shot with 7 bunches filled with different charges



Hybrid fill: 600 bunches consecutive and one bunch with a higher charge in the gap



Resolution: some definition and aspects



Some definition of the resolution

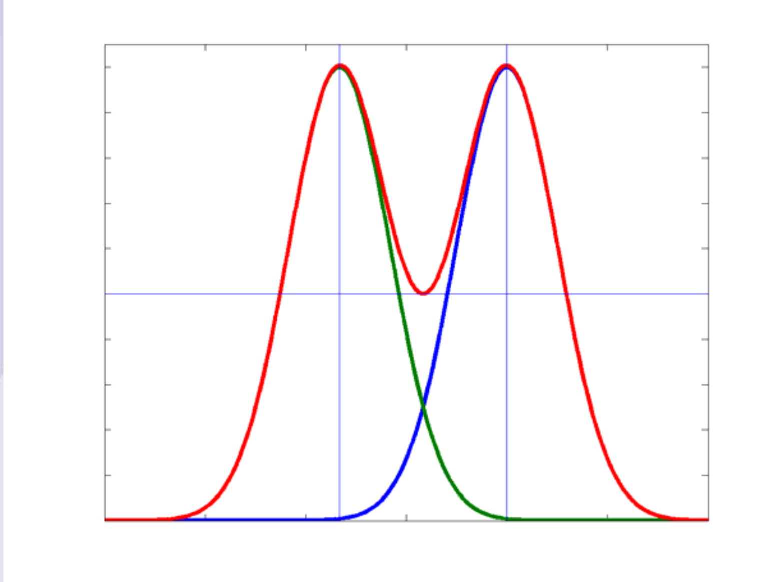
- Rayleigh Criterion:

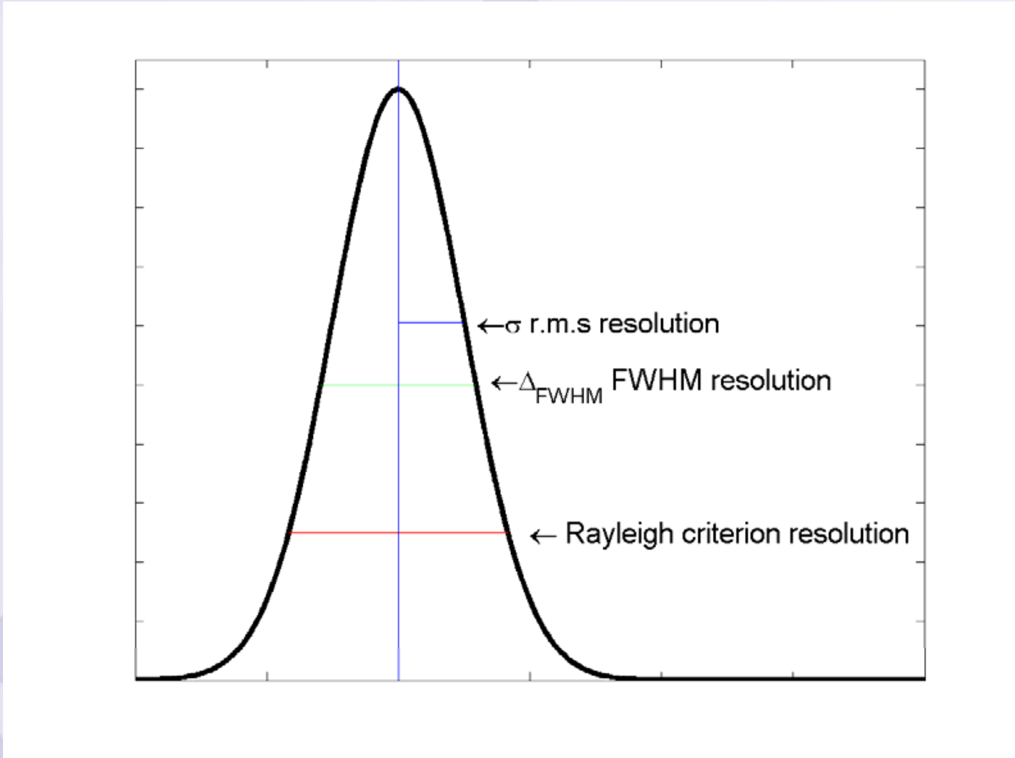
  separation power of two point sources

- r.m.s width of the PSF
- FWHM of the PSF
- Spatial frequency spectrum

  Fourier transform of the PSF

- …





For a PSF Gaussian:

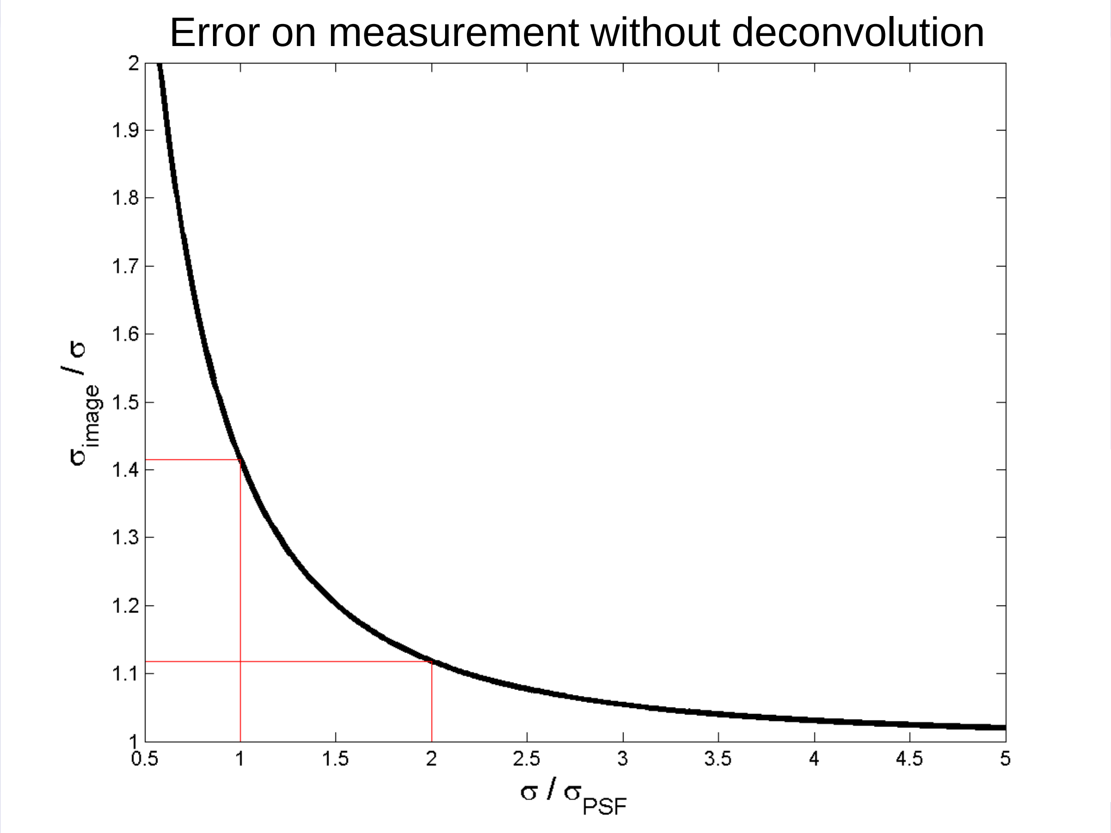
r.m.s width = σ

FWHM = 2.35 σ

Rayleigh Criterion = 3.33 σ

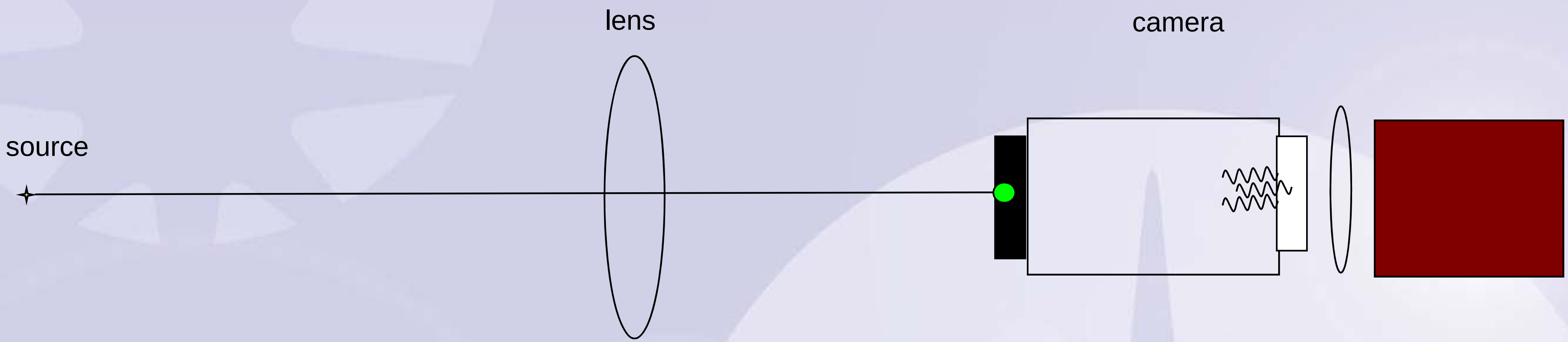
Convolution of Gaussian distribution:

$$G_0(\sigma) \otimes PSF(\sigma_{PSF}) = G_i(\sigma_i) \qquad \sigma_i = \sqrt{\sigma^2 + \sigma_{PSF}^2}$$



Deconvolution is essential for resolution limit measurement

PSF of the streak camera (1)

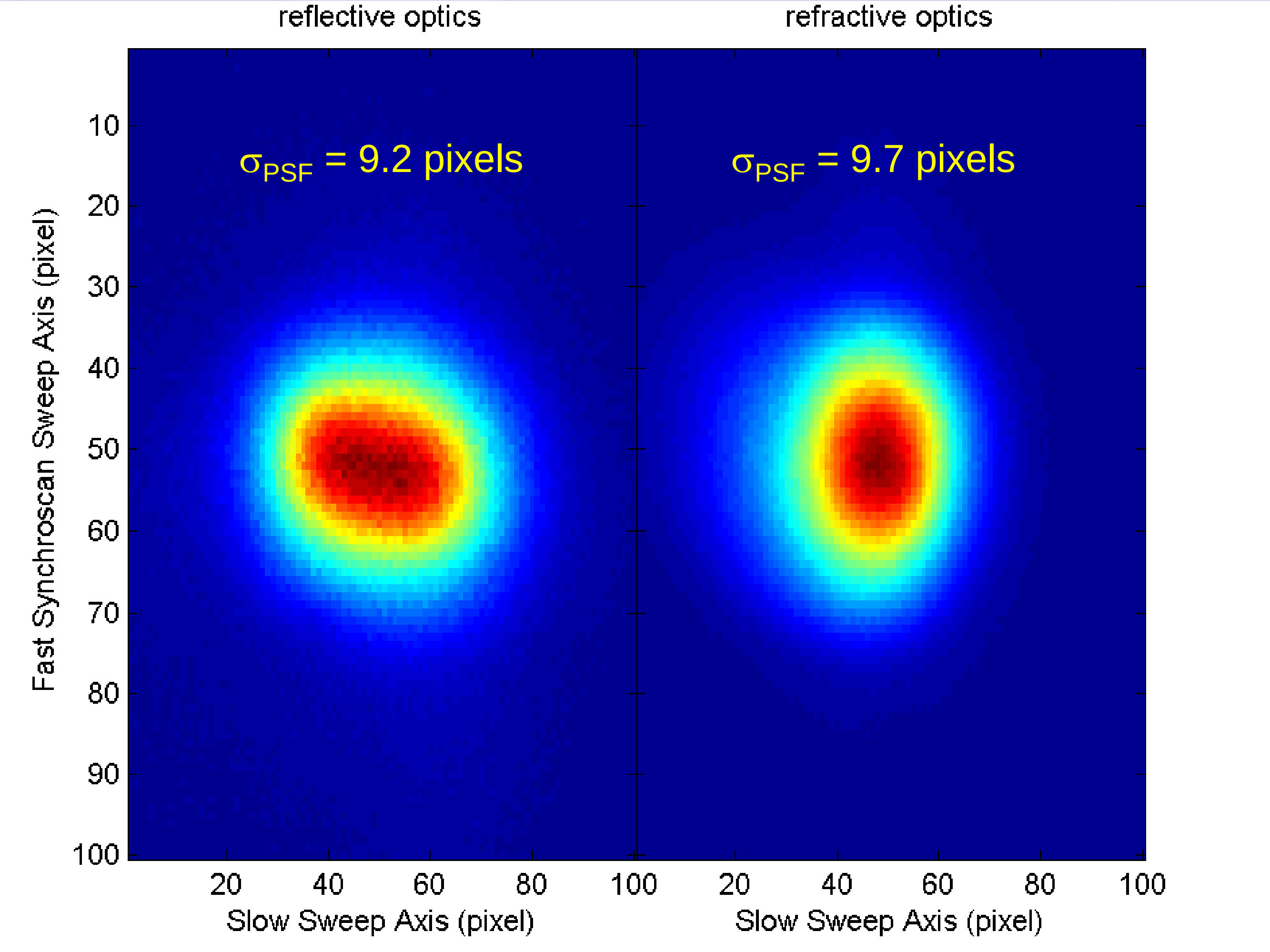


Convolution of :

- PSF focussing front optics ← photon beam properties and optics performance
- PSF electron on phosphor screen + MCP ← space charge effect
- PSF camera imaging phosphor screen

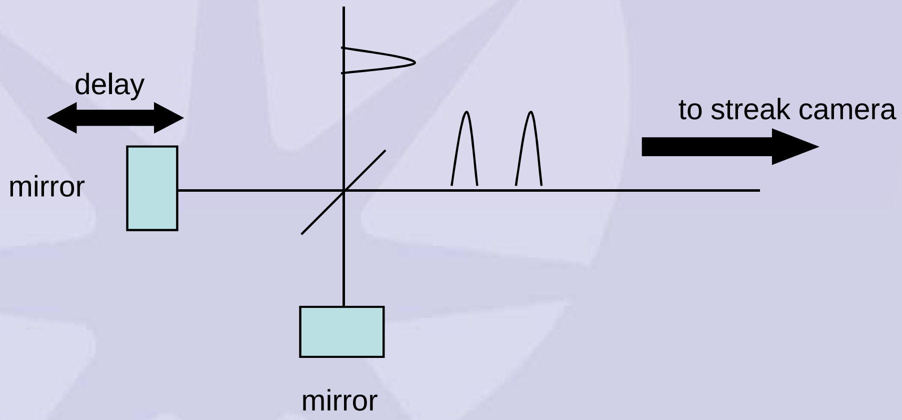
PSF of the streak camera (1)

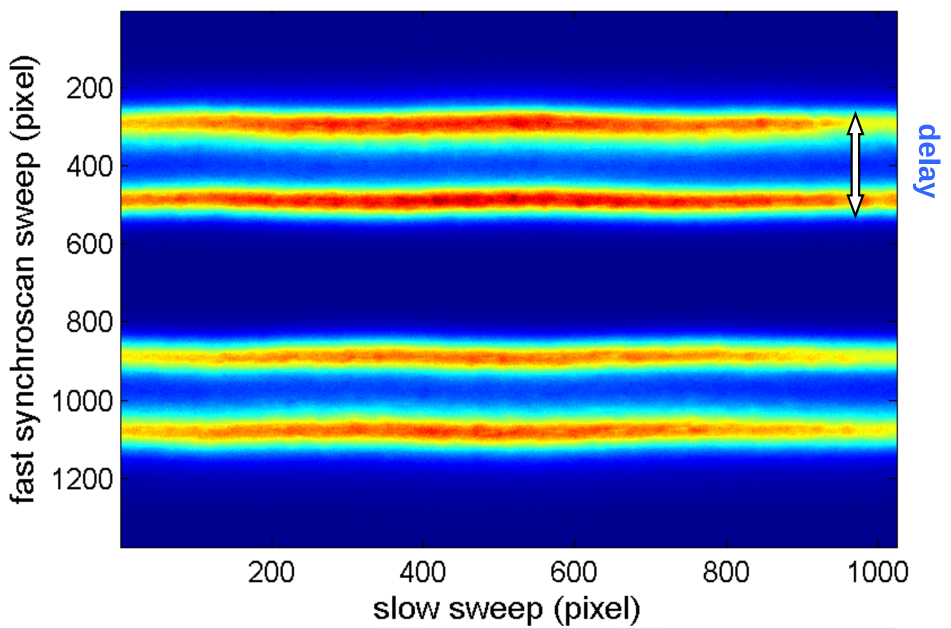
➢ image of a focussed beam on the photocathode with no sweep

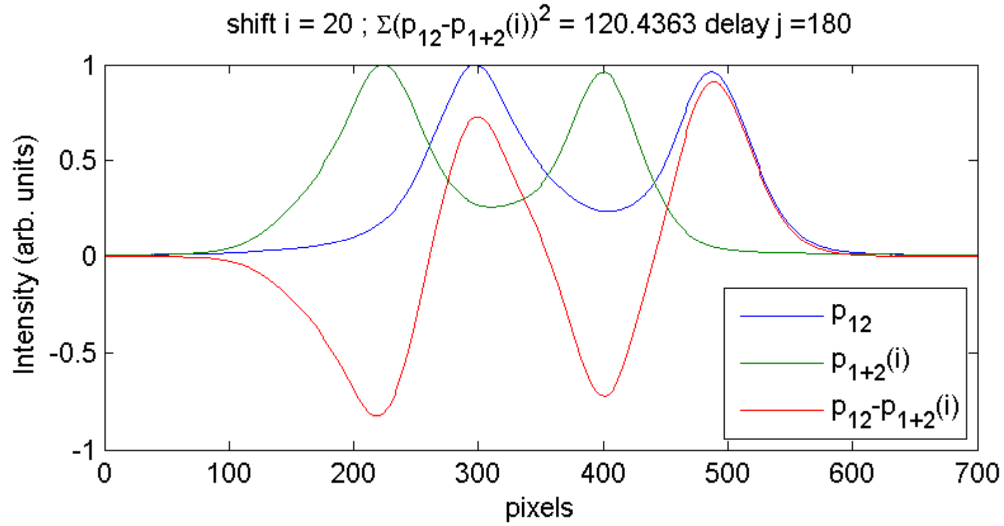


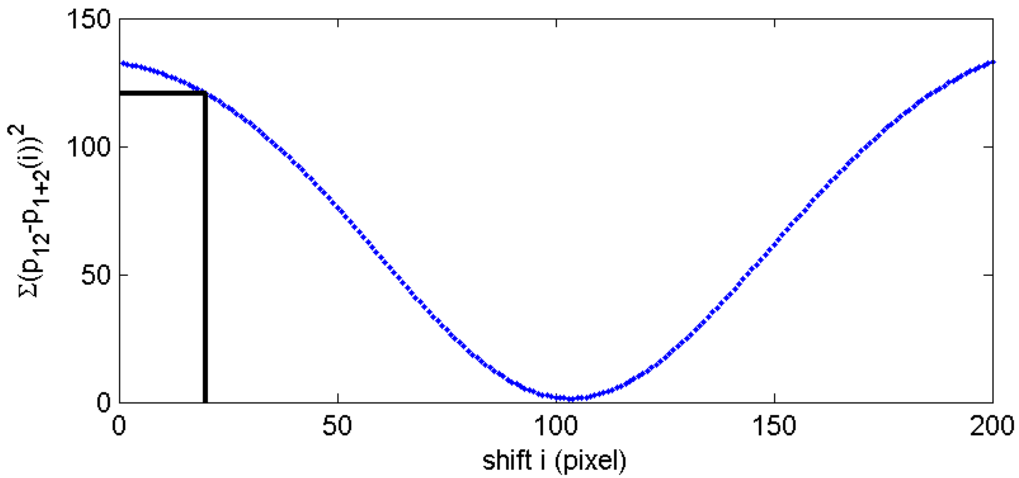
- White beam
- low intensity

Calibration of the fast synchroscan sweep









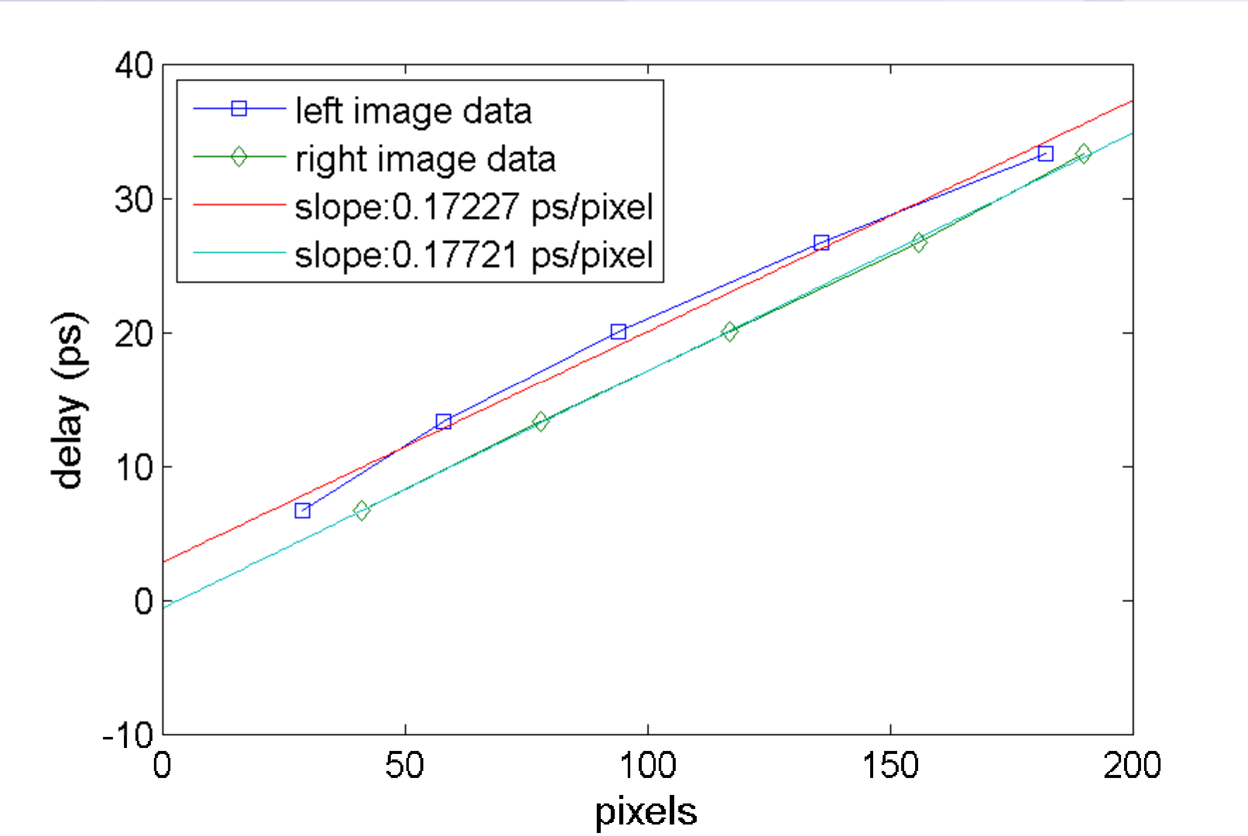
Streak camera image (Low Alpha mode)

Delay between pulses 10mm (33.33ps)

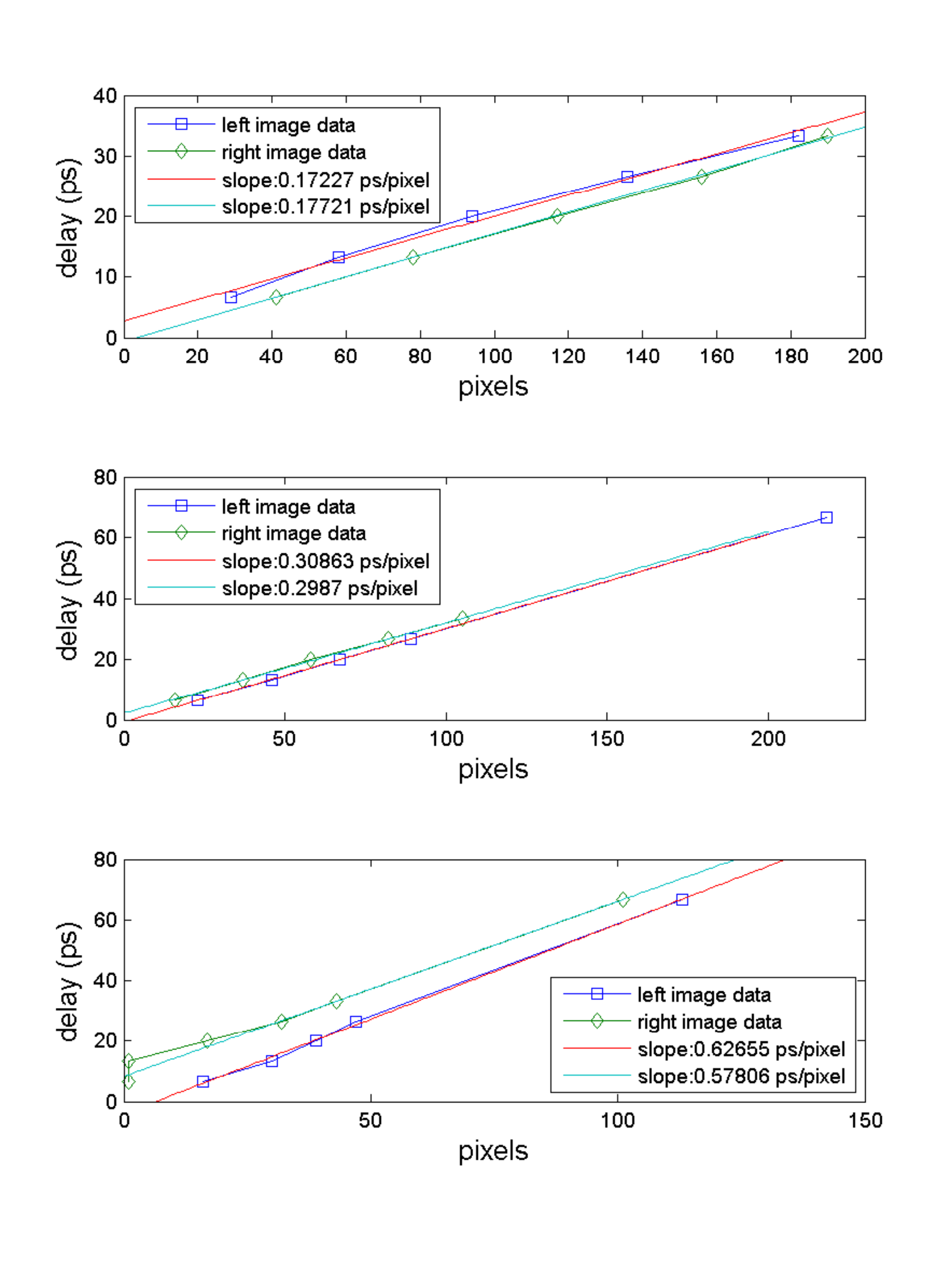
Moving the delay and measuring it in pixels gives the calibration of the synchroscan sweep

Advantage of the small bunch length: more accurate calibration

Previous calibration: 0.186 ps/pixel (performed with 20ps laser pulse)



diamond



Calibration with 20ps laser pulse

Scale 15ps/mm: 0.186 ps/pixel

Scale 25ps/mm: 0.313 ps/pixel

Scale 50ps/mm: 0.637 ps/pixel

Calibration with low alpha pulse

Scale 15ps/mm: 0.177 ps/pixel

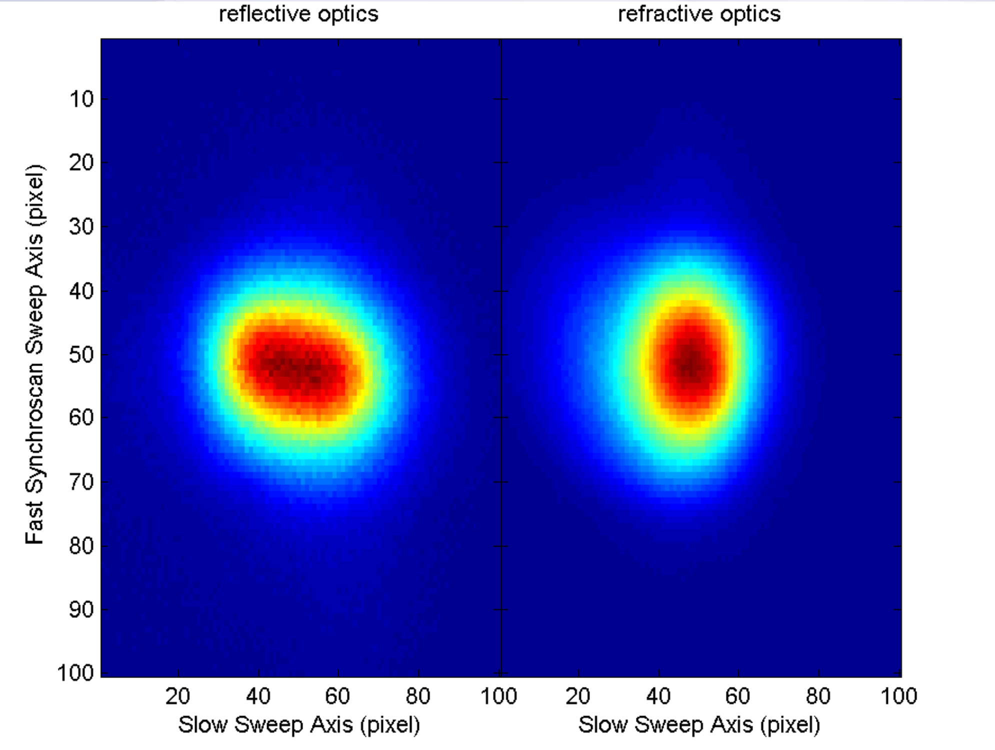
Scale 25ps/mm: 0.308 ps/pixel

Scale 50ps/mm: 0.626 ps/pixel

PSF of the streak camera (1)

- image of a focussed beam on the photocathode with no sweep

	Reflect. Optics	Refract. Optics
σ_{PSF} (pixel)	9.2	9.8
σ_{PSF} (ps) 15ps/mm	1.6	1.7
σ_{PSF} (ps) 25ps/mm	2.85	3.0
σ_{PSF} (ps) 50ps/mm	5.75	6.2



- White beam!

Chirp of a pulse

Light pulse

$\Delta\tau$
$\Delta\omega$

True representation of the bunch profile

Medium of length L

Light pulse

$\Delta\tau' > \Delta\tau$
$\Delta\omega$

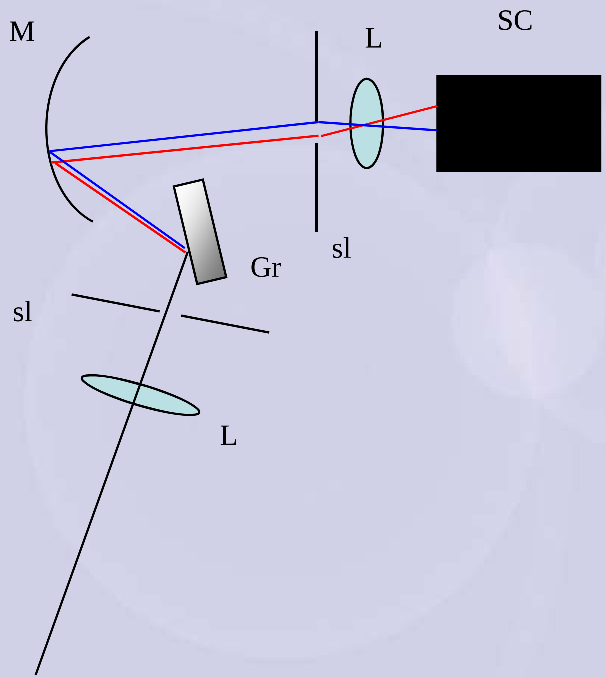
biased representation of the bunch profile

Attention: measurement with broad spectrum of SR can suffer from this!

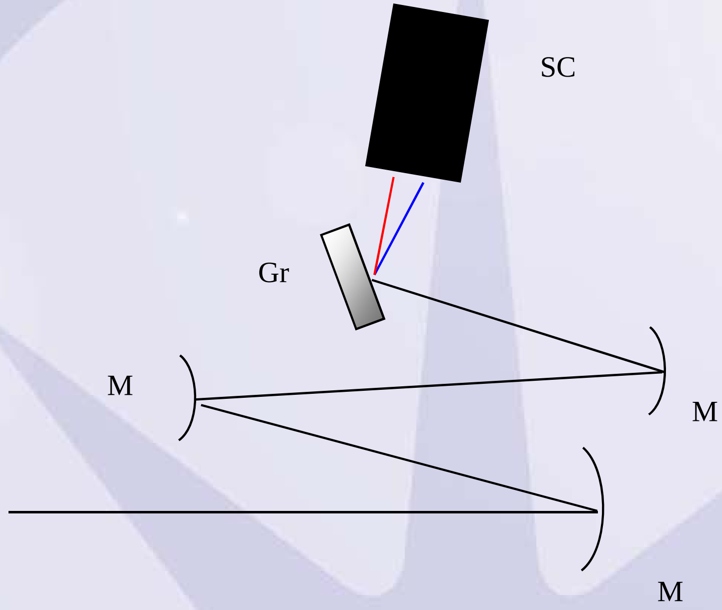
Time resolved spectra

- ➢Coupling front optics of the streak camera with grating
- ➢ Use only synchroscan sweep

With refractive front optics



With reflective front optics

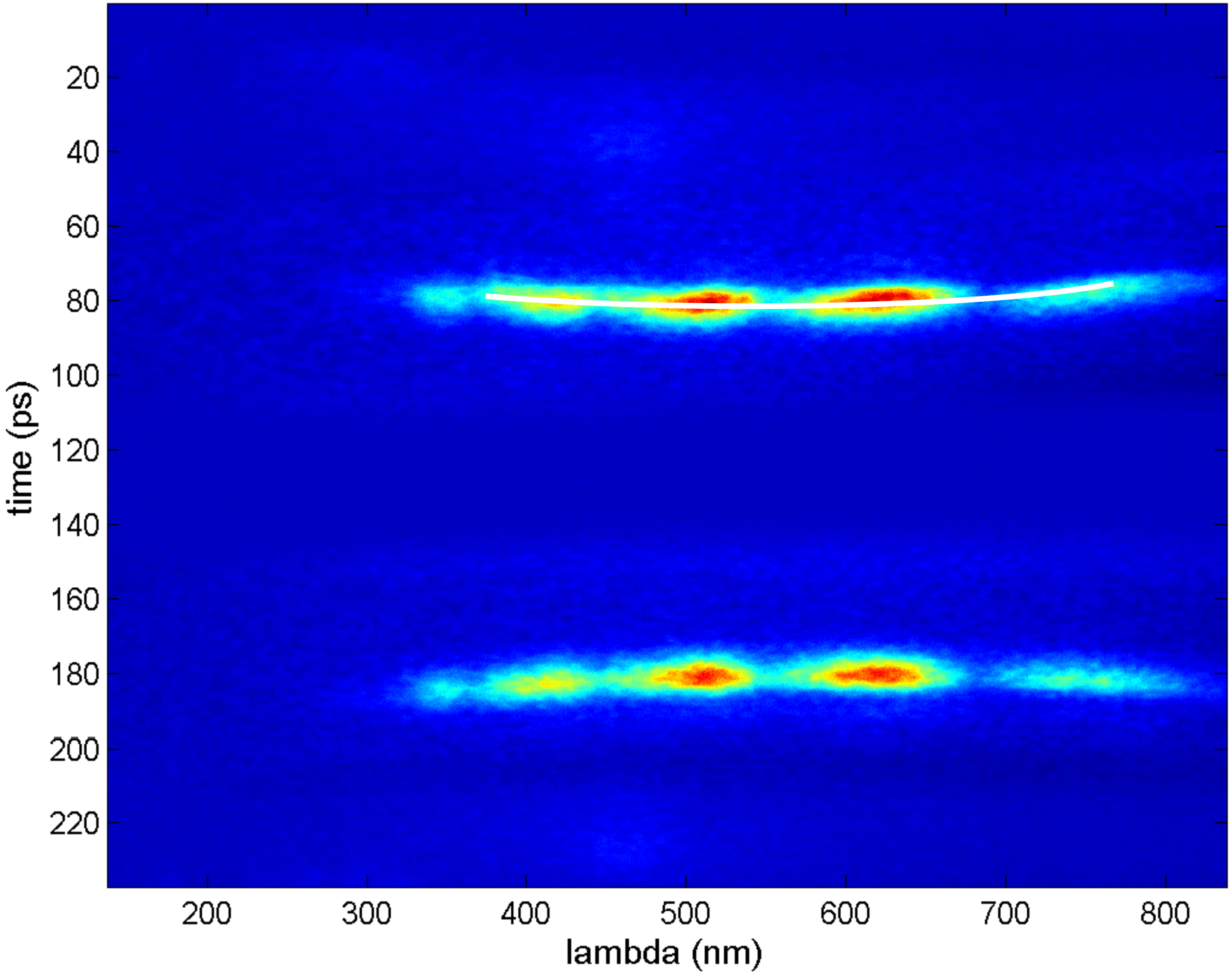


Gr: grating - L: lens - M: mirror - sl: slit - SC: streak camera

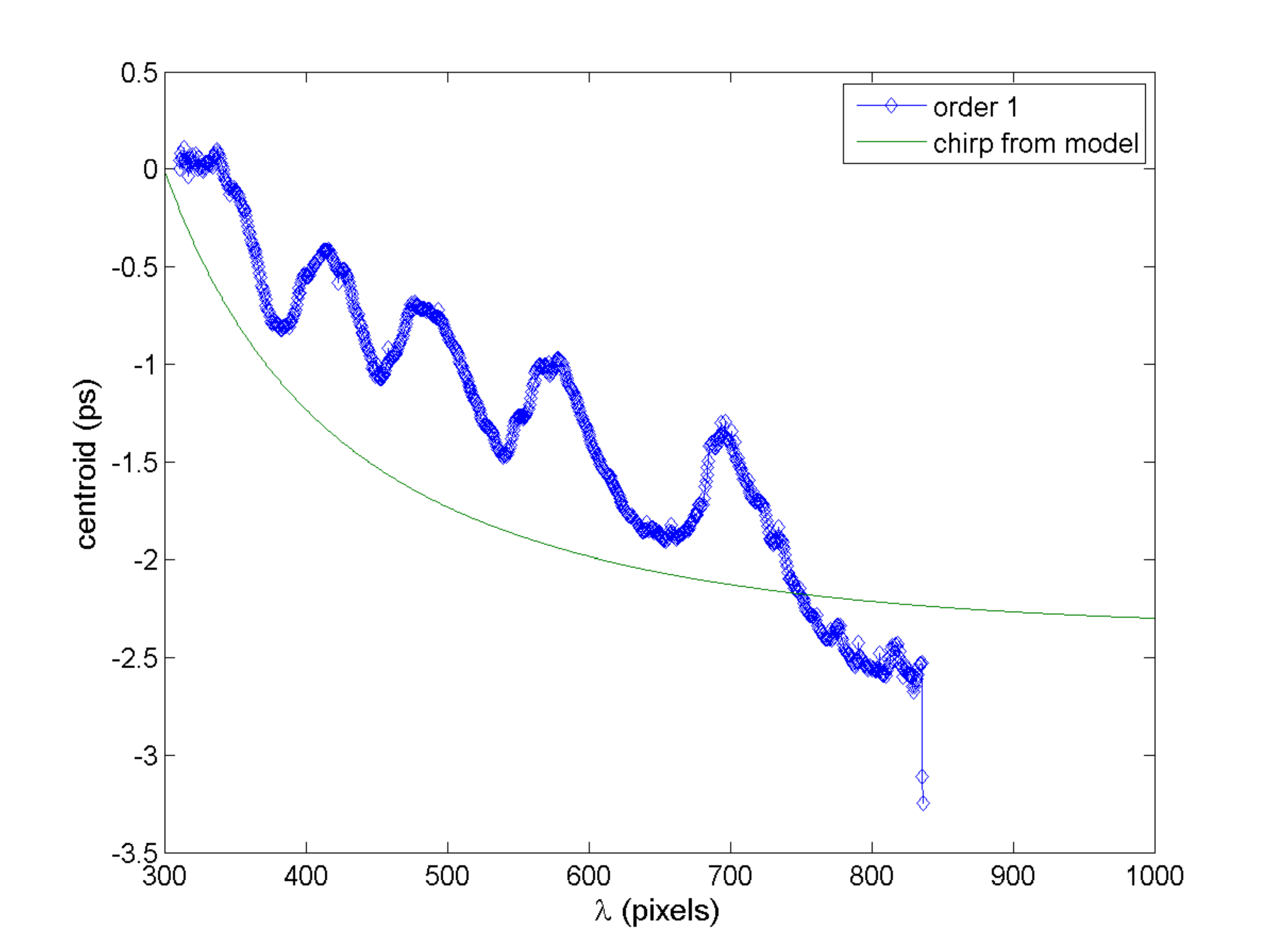
diamond

Time resolved spectrum – Low alpha mode – 0.04 mA / bunch

- New reflective front optics
- Colour glass filter 315nm – 750nm

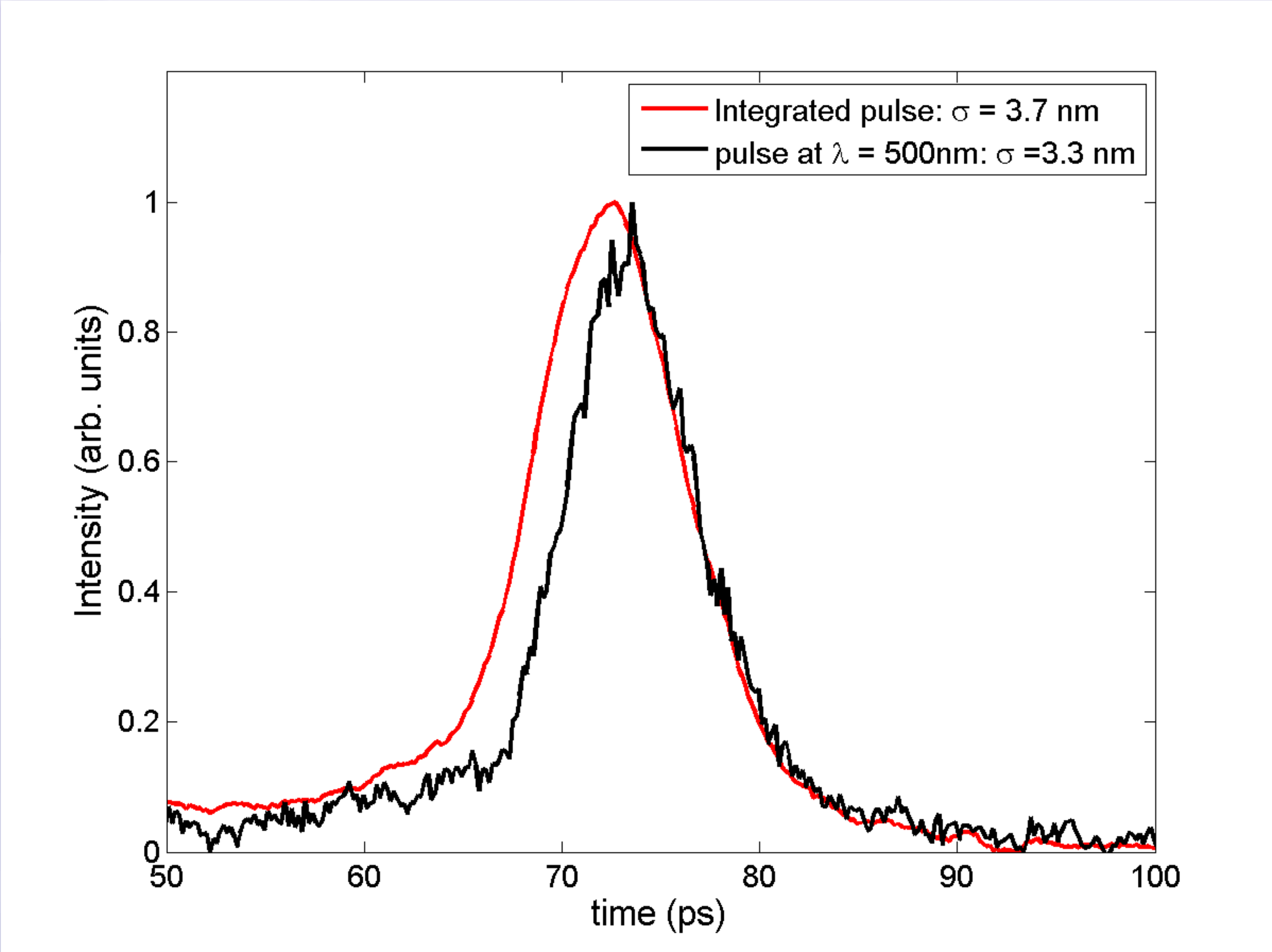


Centroid of the pulse spectrum: chirp



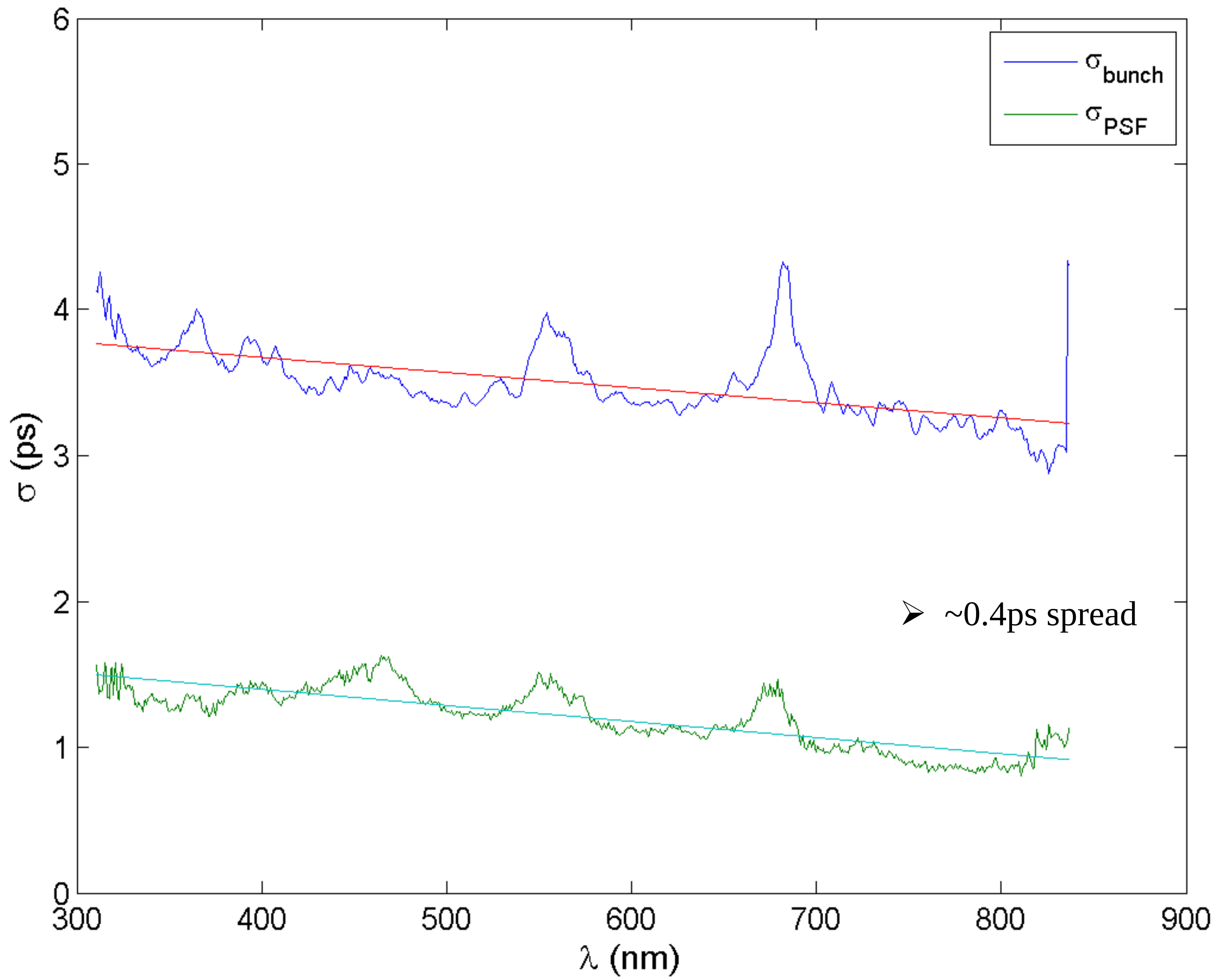
nond

Chirp: comparison between integrated spectrum pulse profile and profile at λ



$$\sigma_{chirp} = \sqrt{\sigma_{total}^2 - \sigma_{\lambda}^2} = 1.7\,ps$$

Pulse width vs. wavelength



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Streak camera resolution (2)

Static PSF

- measured with focussed beam and no sweep: 1.5ps (white beam)
  ~1ps red photons

Dynamic PSF

- function of the bandwidth and chirp of the measured pulse

Refractive Front Optics	Sapphire window 6.4mm + Nikkor 50mm + BK7 50mm Bandwidth 400-700nm	Pulse broadening 6 ps
Reflective Front Optics	Sapphire window 6.4mm Bandwidth 300-800nm	Pulse broadening 1.7 ps

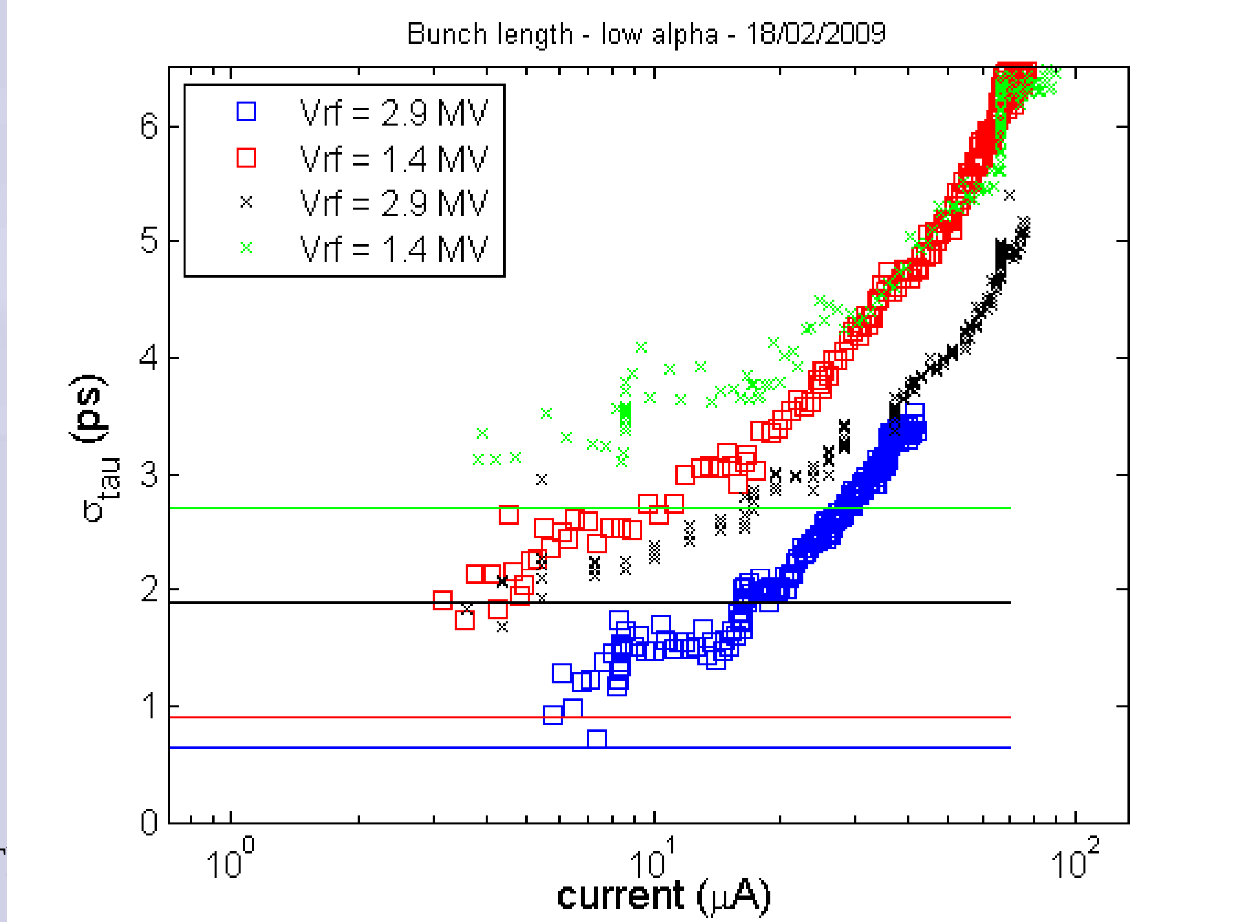
Measurement performed at diamond

- Measurement with bandpass filter 560+-10nm (no chirp)
- Refractive Front Optics (didn't have the new design in 2009)
- $\alpha = 5\ 10^{-6}$ (crosses)
- $\alpha = 10^{-6}$ (squares)
- lines: expected 'zero' current bunch length

'zero' current bunch length:

$$\sigma = \frac{\alpha}{\omega_s}\sigma_\varepsilon = C(V_{RF})\sqrt{\alpha}\ \sigma_\varepsilon$$

Nominal $\alpha = 1.7\ 10^{-4}$



Conclusion

- Short pulses from short electron bunches down to $\sigma = 1$ ps (r.m.s.) can be measured with a streak camera.
  - best condition for that measurement: repetitive stable pulses. Single shot measurement in single sweep might be very challenging, due possible space charge effect.

- Knowledge of the Static and Dynamic Point Spread Function of the camera is absolutely required so that deconvolution can be performed.

- Calibration of the streak camera in situ is also strongly recommended.

- Measurement of the dynamic PSF with very short pulses shows some intrinsic features of the streak camera:
  - Field linearity of the electrodes and the accelerating voltage.
  - Ballistic behaviour of the electrons initial energy, perhaps revealed by the slope of the pulse width vs. wavelength.