First Measurements of the Longitudinal Bunch Profile at SLAC using Coherent Smith-Purcell Radiation at 28GeV

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Motivation

Introduction to Coherent Smith-Purcell Radiation

Experimental

Results

Motivation

Longitudinal beam diagnostic tools are an essential part of colliders and FELs.

Beam-beam effects!

A bunch can "sense" the e-m field of its opposing bunch.

Leads to **deflection, beamsstrahlung, <u>luminosity losses</u>**!

→ Decreases chance of seeing new physics!

Beam-beam effects depend on the <u>longitudinal bunch profile and bunch length.</u>

... amongst other factors ...

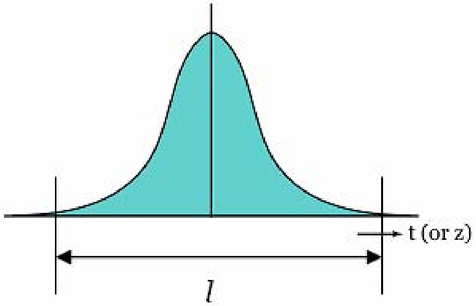
Knowing the longitudinal profile can be used to improve your luminosity/brightness.

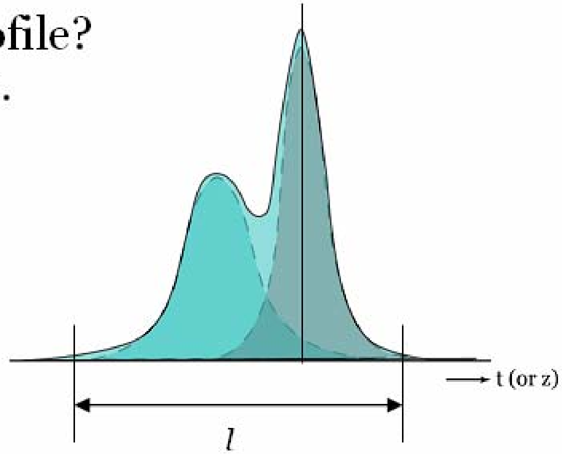
<u>New</u> diagnostics are required for future high energy accelerators such as the ILC.

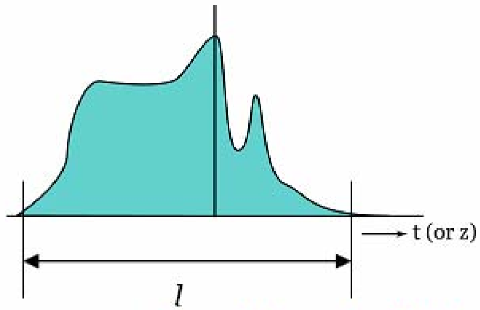
First Smith-Purcell experiment in the multi-GeV regime!

The Longitudinal Bunch Profile

What **is** the longitudinal profile?
Also called **time** profile.







...same bunch length, different profiles!

New Methods

- ✓ Resolve bunch length
- ✓ Resolve bunch profile
- ✓ Non-intercepting (i.e. must not destroy/alter the beam)
- ✓ Single-shot (i.e. can determine profile with one pass of the bunch)
- ✓ Passive
- ✓ Inexpensive

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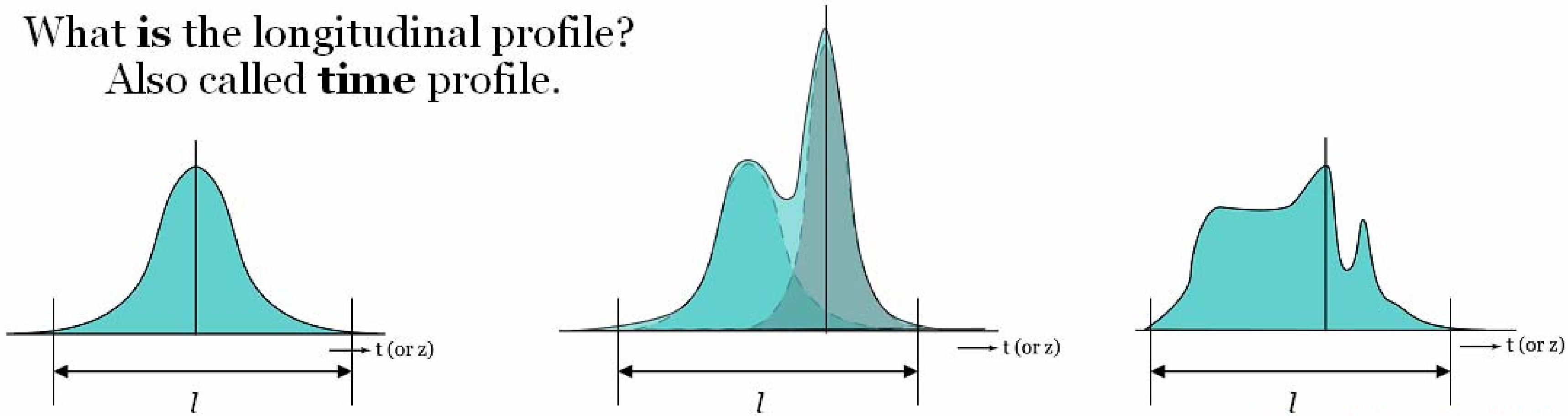

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Smith-Purcell

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✓ Resolve bunch profile

✓ Non-intercepting
(i.e. must not destroy/alter the beam)

✓ Single-shot
(i.e. can determine profile with one pass of the bunch)

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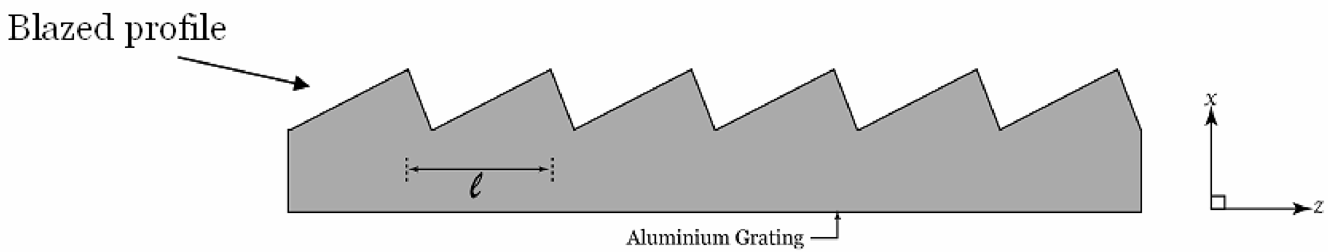
What is Smith-Purcell Radiation?

Belongs to a wider family of radiative processes that includes transition and diffraction radiation.

1. Start with a blazed, metallic, grating of period l.



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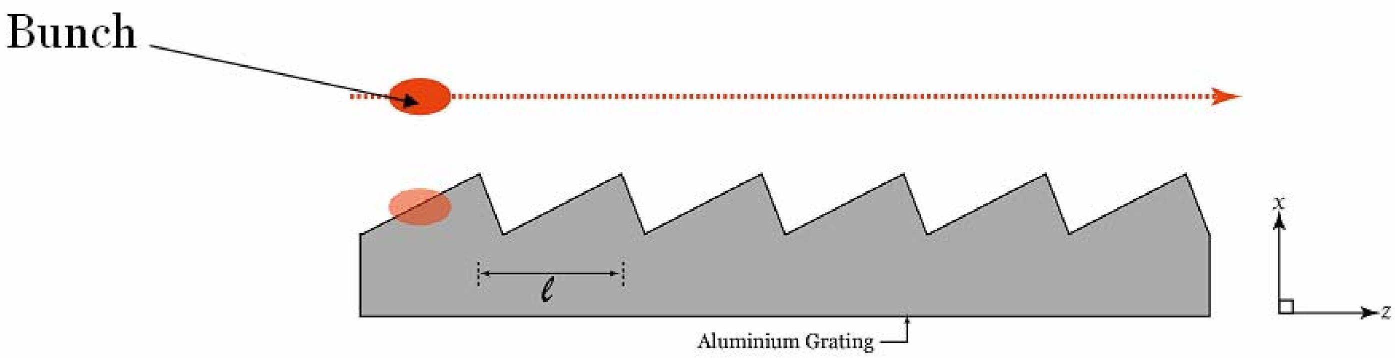

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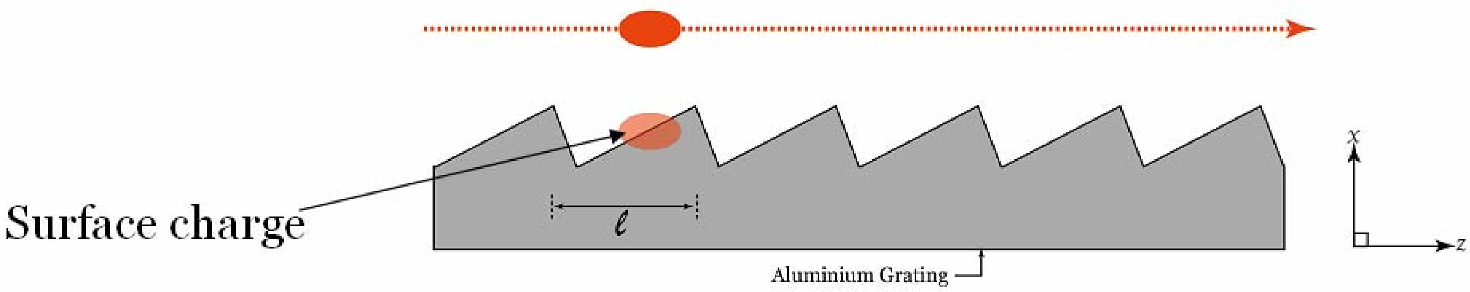

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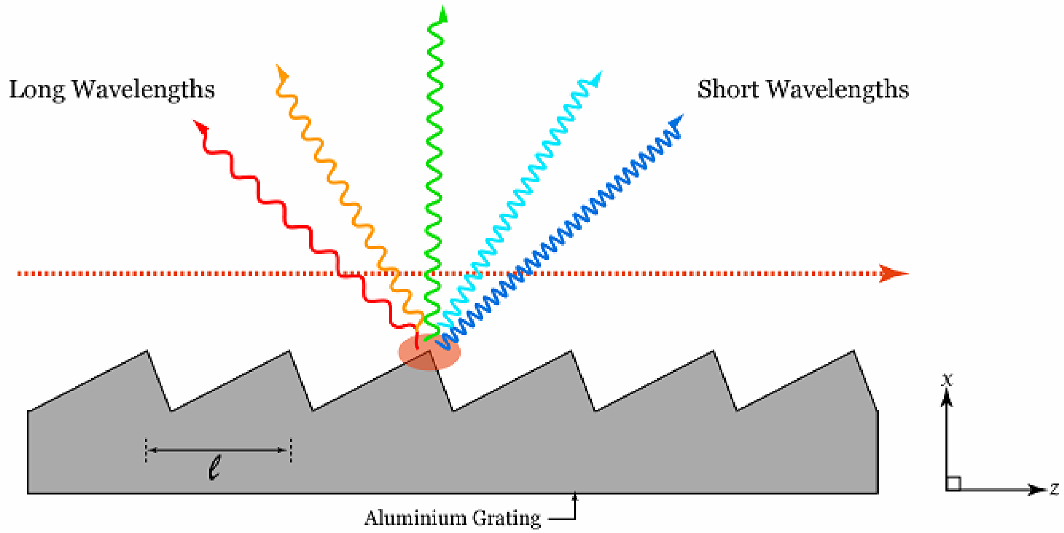
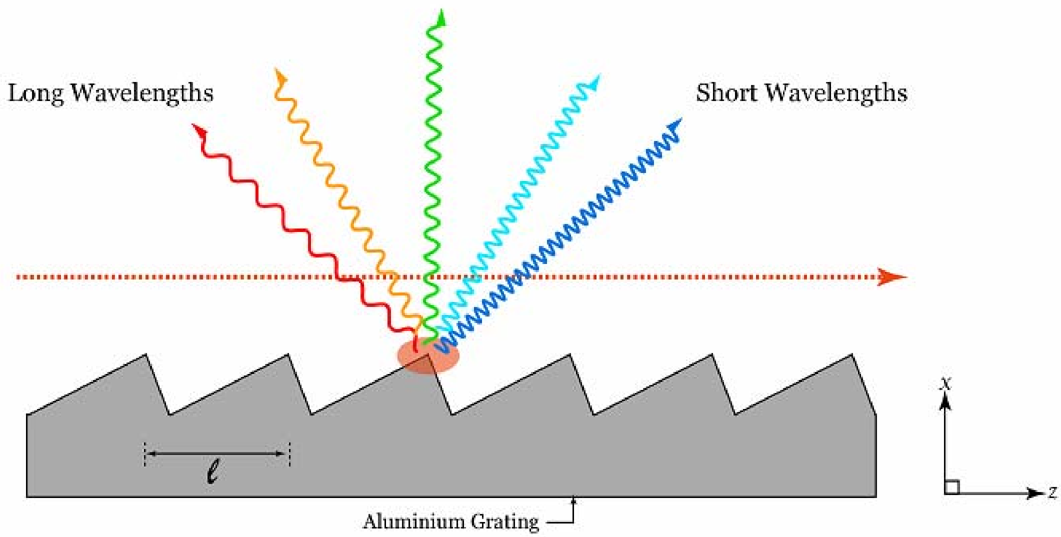
4. Accelerated charges emit radiation.



What is Smith-Purcell Radiation?



Smith-Purcell radiation is created, with wavelengths distributed according to:

$$\lambda = \frac{\ell}{n}\left(\frac{1}{\beta} - \cos\theta\right)$$

Wavelength depends upon grating period.
We observe in the **far infrared**.

can → choose

Coherent regime: When bunch length is shorter than, or equal to, emitted wavelengths.

Increases emitted intensity $\propto N_e^{\,2}$

Benefits

Wavelengths are emitted over a **large angular spread.**
Different SP wavelength at each observation angle!

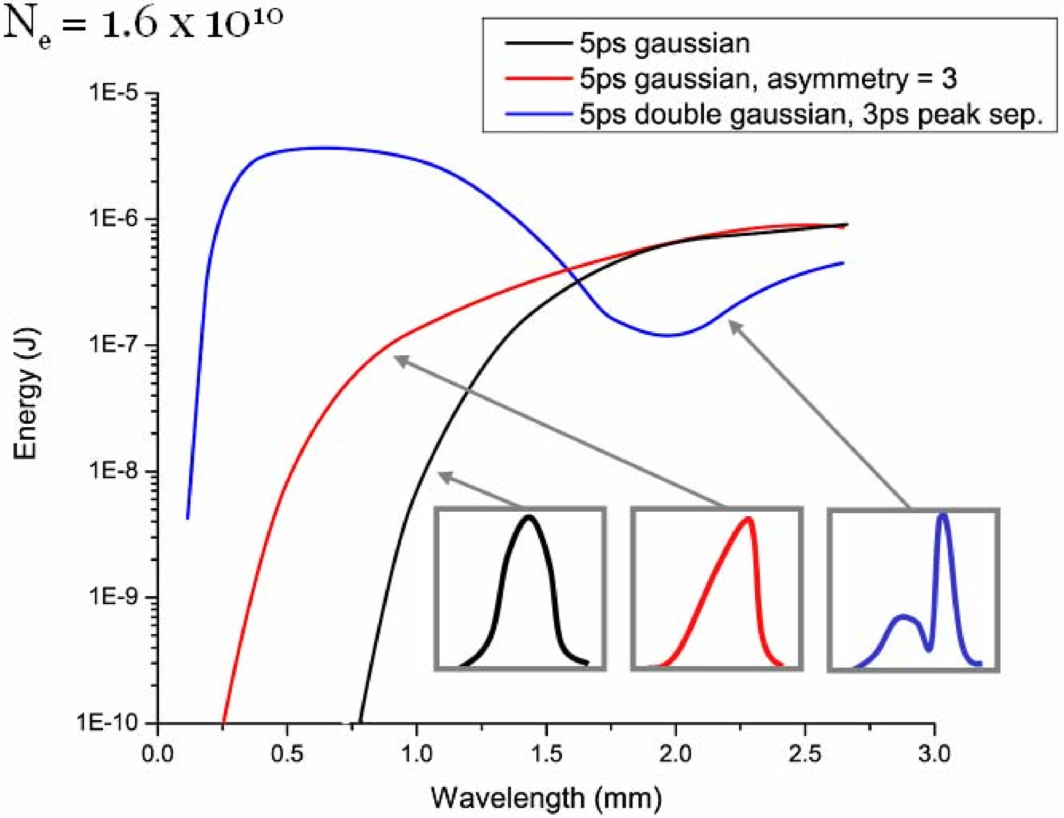
Different bunch profiles = different radiation distributions. Measuring emitted energy relates back to bunch profile.

Can measure multiple angles at once for a single-shot measurement.

Disadvantages:
Measure energy
↳ Lose phase information.

Solution:
Recover phase information with **Kramers-Kronig** technique.

$N_e = 1.6 \times 10^{10}$



Simulation of different profiles, as would be seen experimentally

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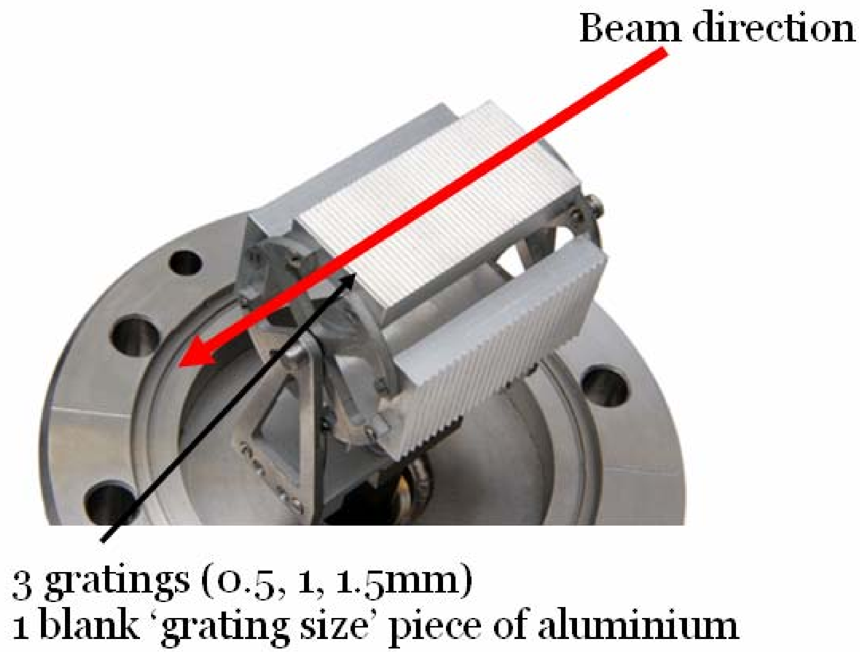
Detecting SP Radiation in the Far-Infrared

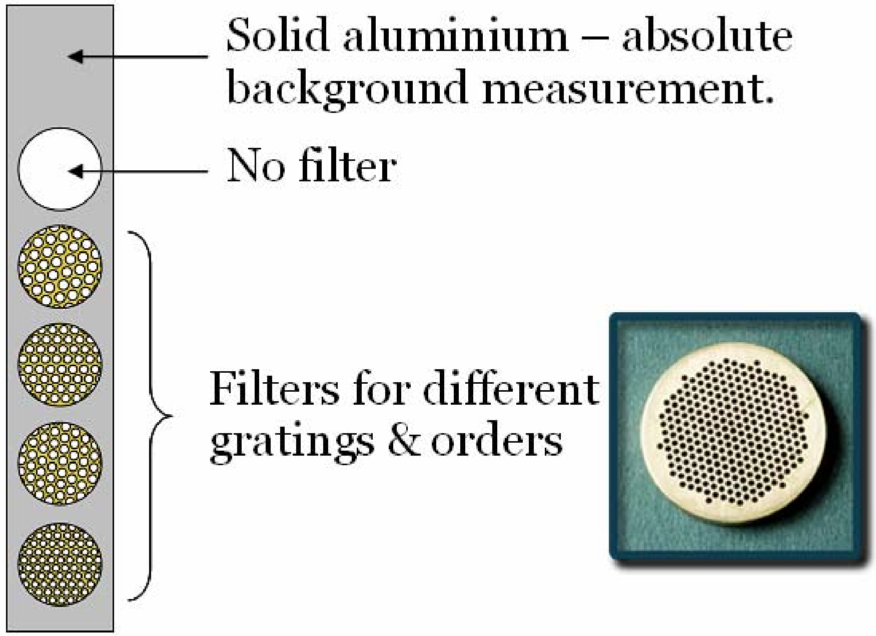
Presents a number of challenges:

1. Eliminating background radiation.

Selection of gratings, blank "grating", WAP filters...

SP signal = grating signal – blank signal





Detecting SP Radiation in the Far-Infrared

Presents a number of challenges:

1. Eliminating background radiation.

   Selection of gratings, blank "grating", WAP filters...

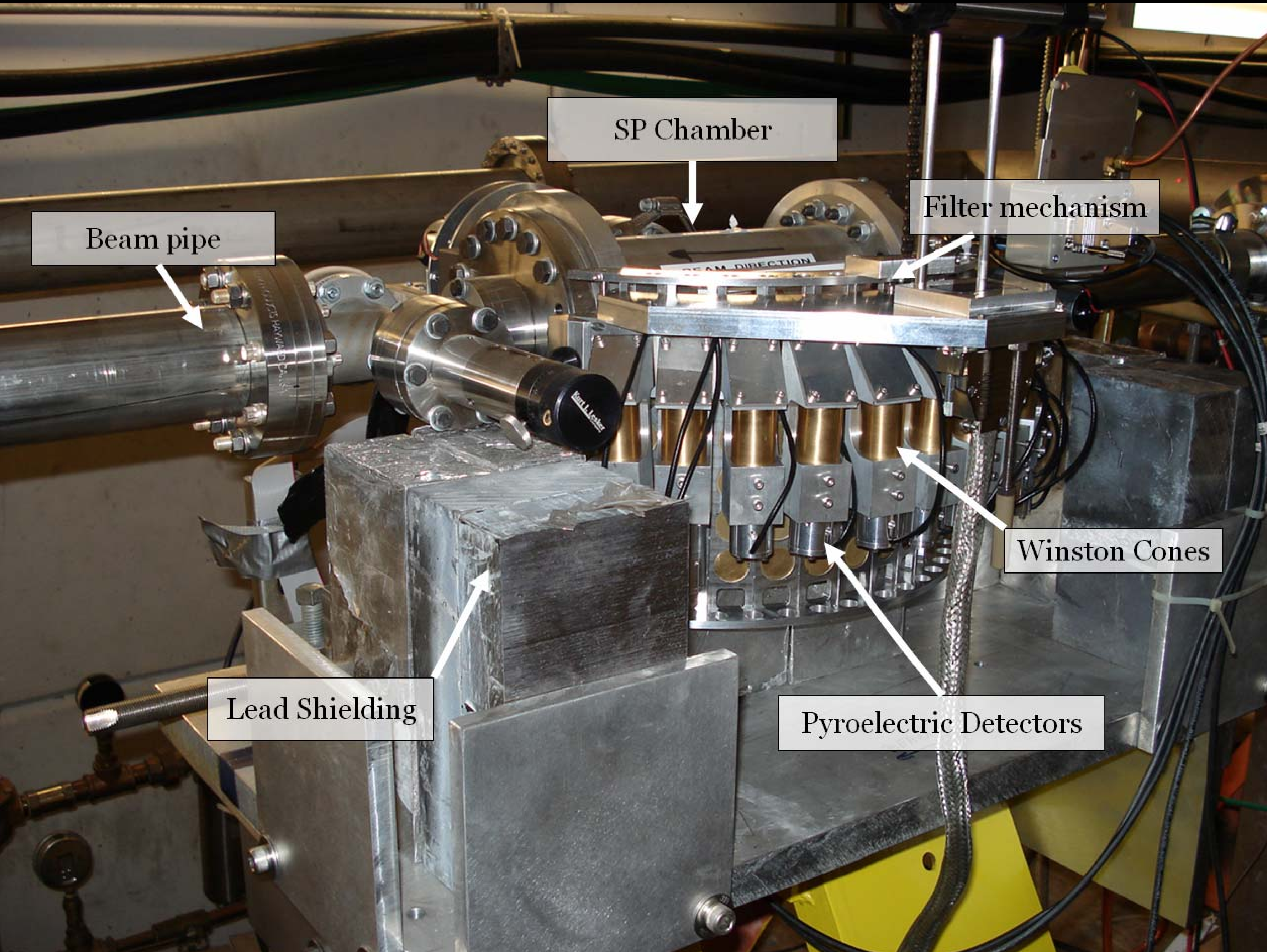
SP signal = grating signal – blank signal

2. Collecting sufficient optical power.

   Light concentrator (Winston Cone)

3. Collecting a wide range of wavelengths.

   Use 3 gratings, observe at 11 angles (40 – 140°) using room-temperature, pyroelectric, detectors.


SP Chamber
Beam pipe
Filter mechanism
Winston Cones
Lead Shielding
Pyroelectric Detectors

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Experimental

Coherent SP Radiation & SLAC

Experiment carried out in July 2007 at ESA, SLAC.
- E = 28GeV,
- 1e10 – 1.6e10 electrons,
- 10Hz beam.

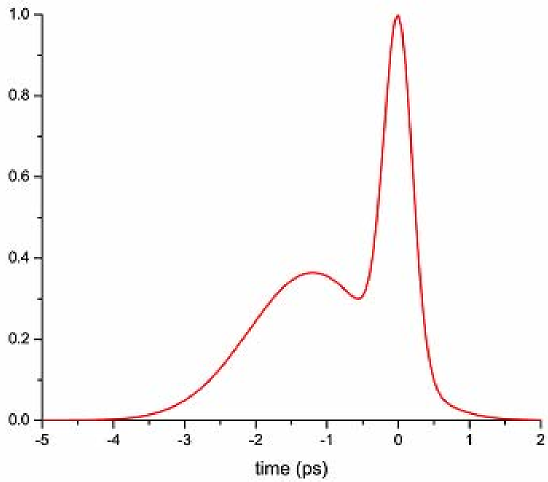
Each measurement lasts ~ 1 minute (~600 bunches).
- Complete set of measurements ~ 40 minutes.

Some processing of data is required:
- Correct for losses through filters
- Corrections due to detector calibration (difficult in the far-infrared!)
- + more…

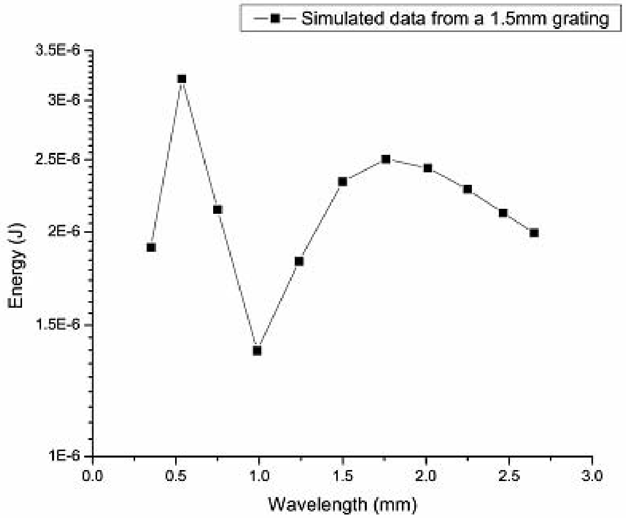
Then use Kramers-Kronig technique to recover bunch profile.

Kramers-Kronig(KK) Demonstration

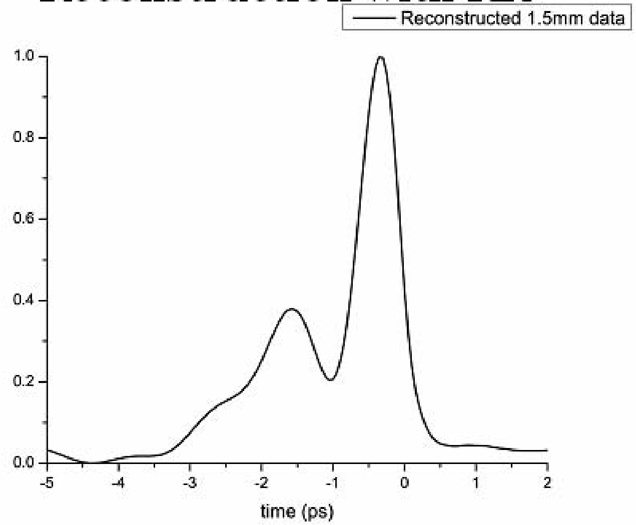
~3ps double Gaussian



Simulated data



Reconstruction with KK



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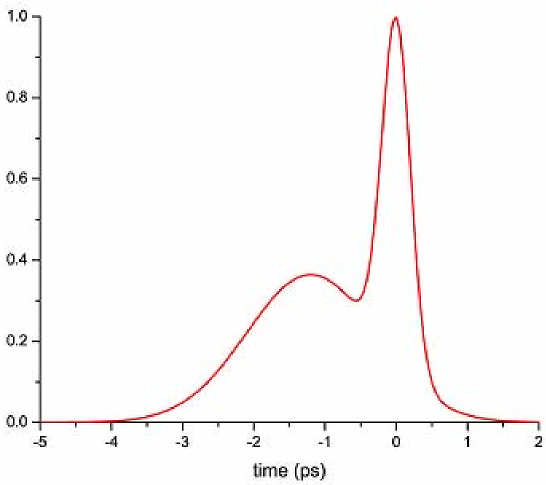

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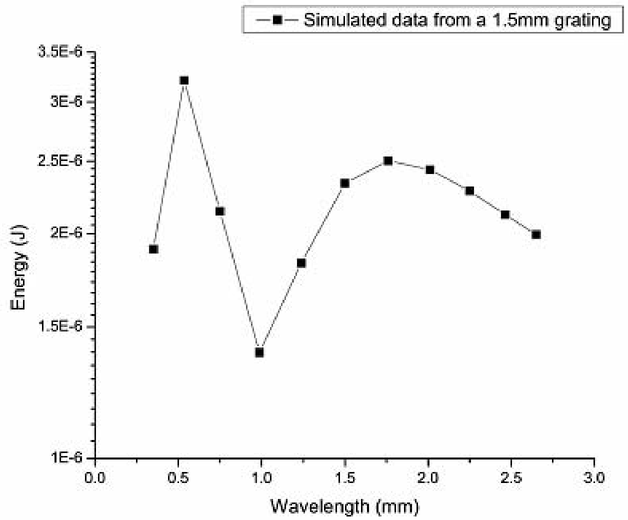

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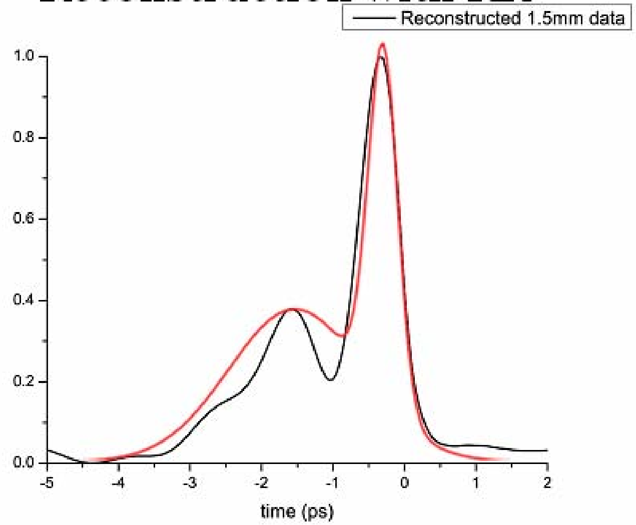

This is for **one** grating. More data points = better reconstruction!

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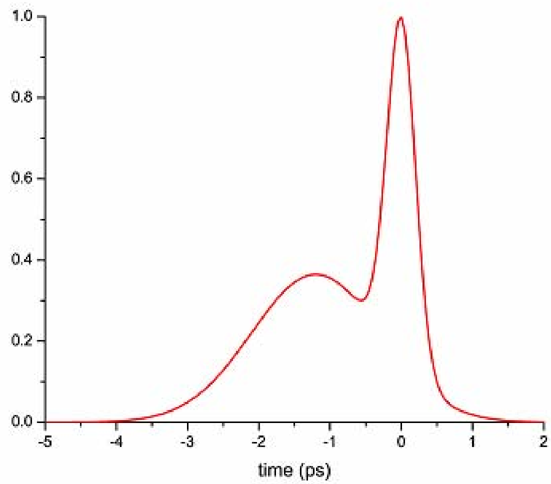

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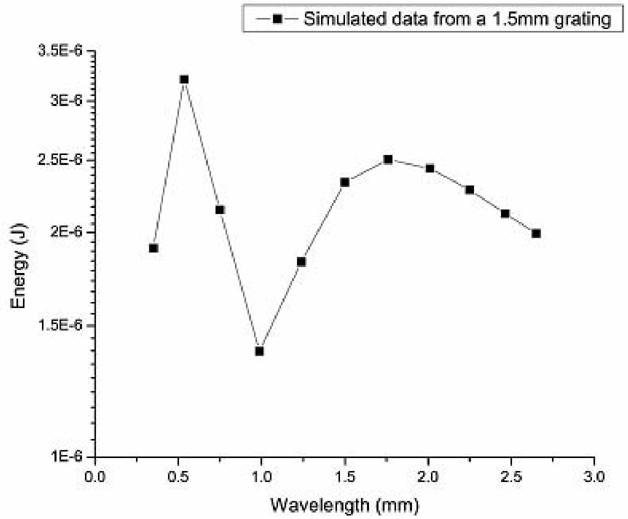

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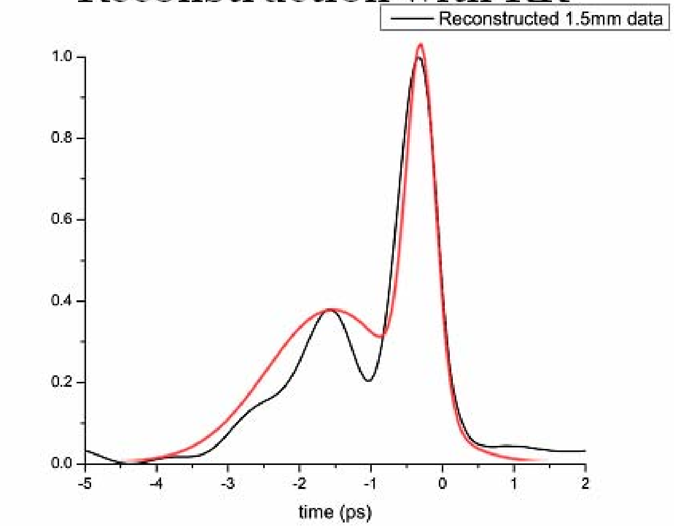

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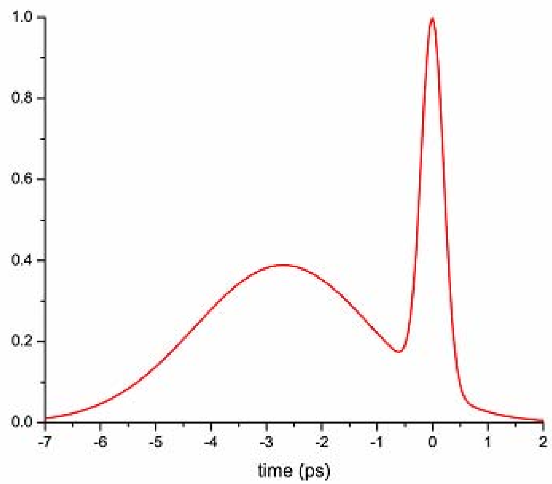
~6ps double Gaussian



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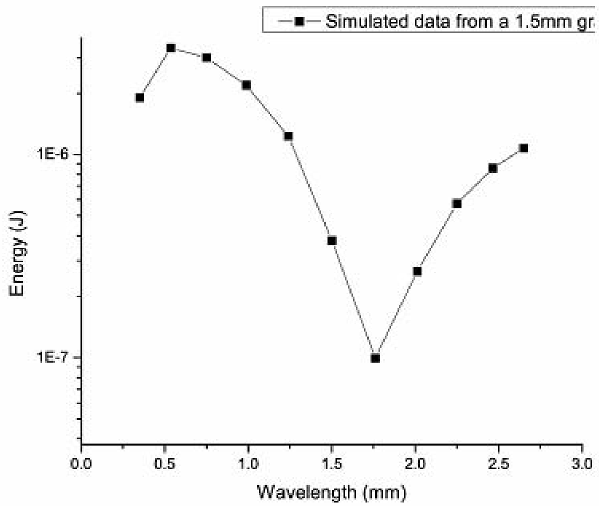

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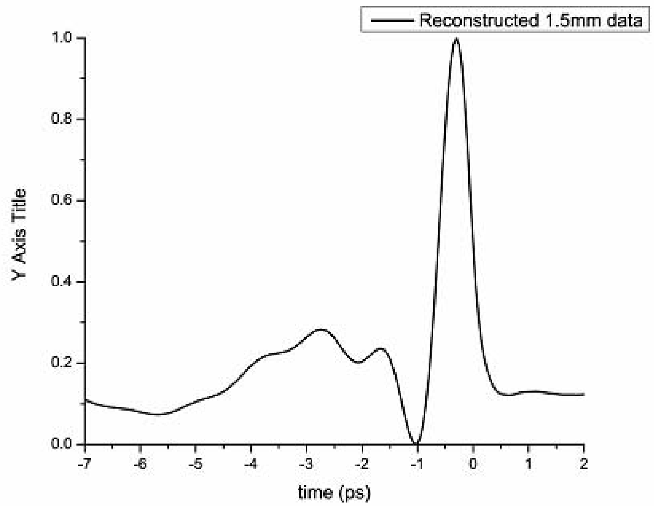

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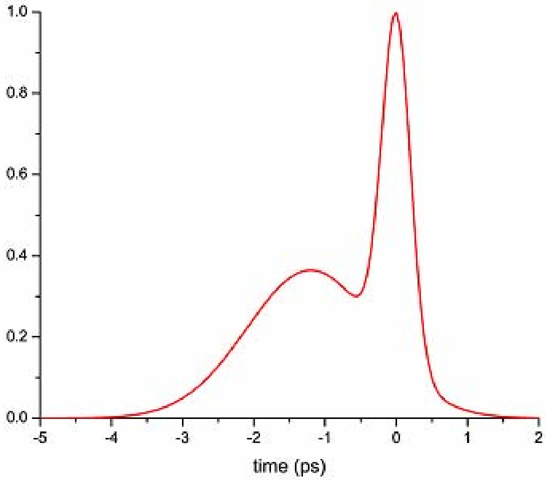

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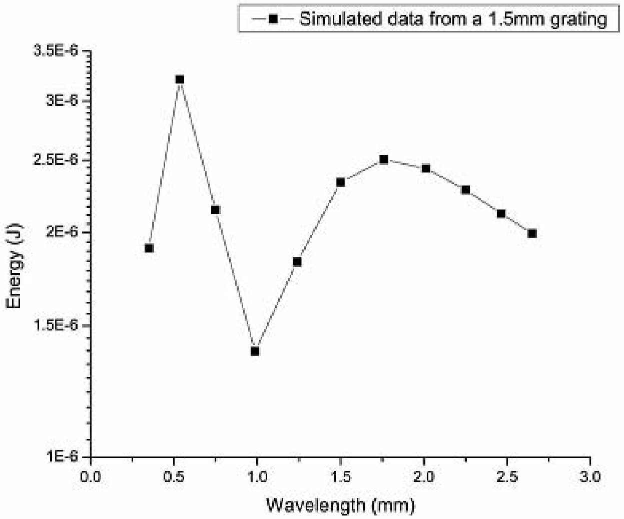

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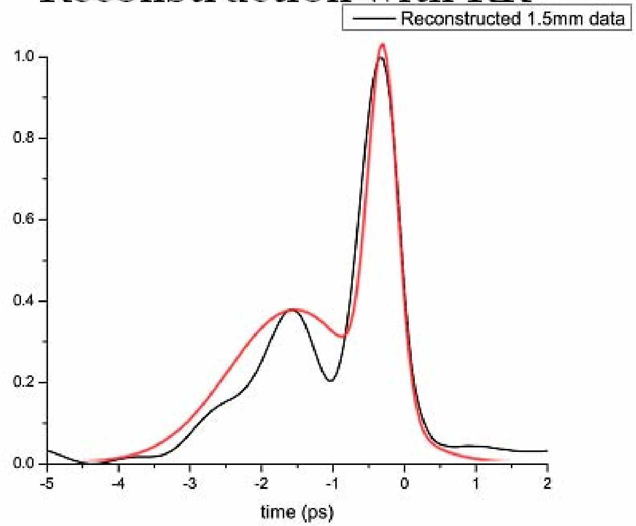

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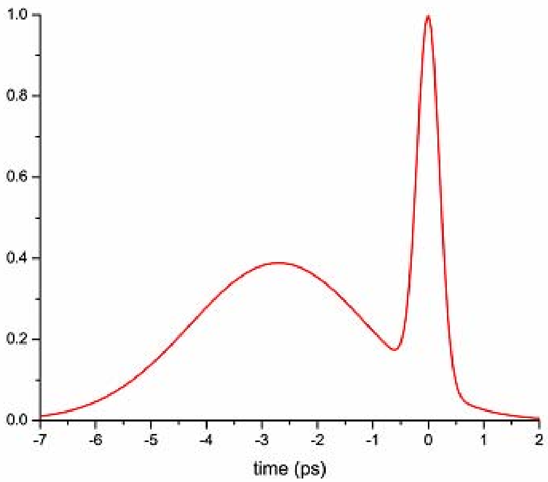

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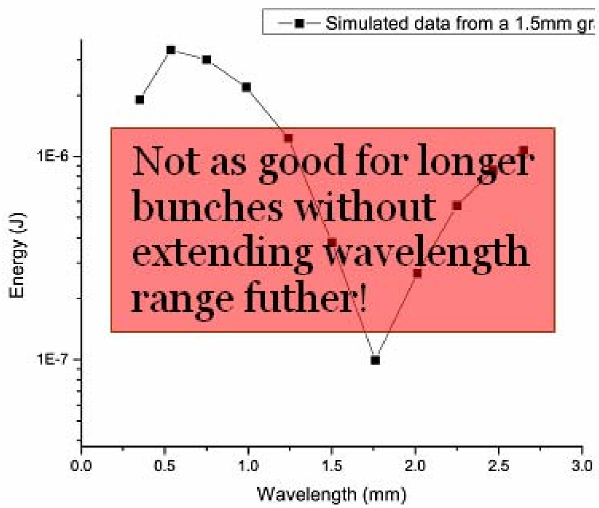

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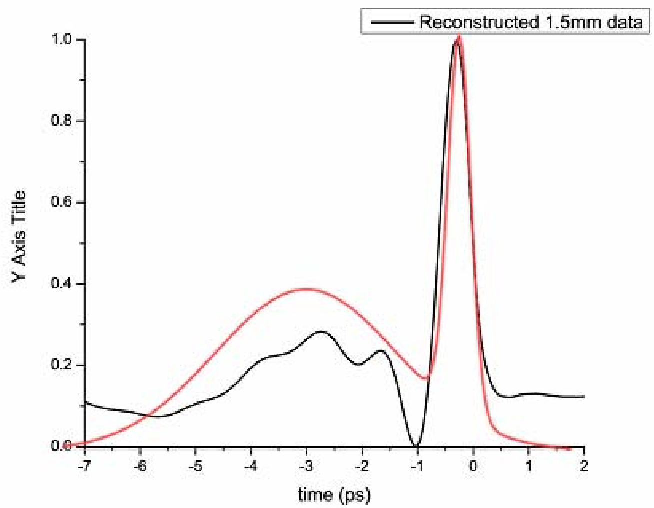
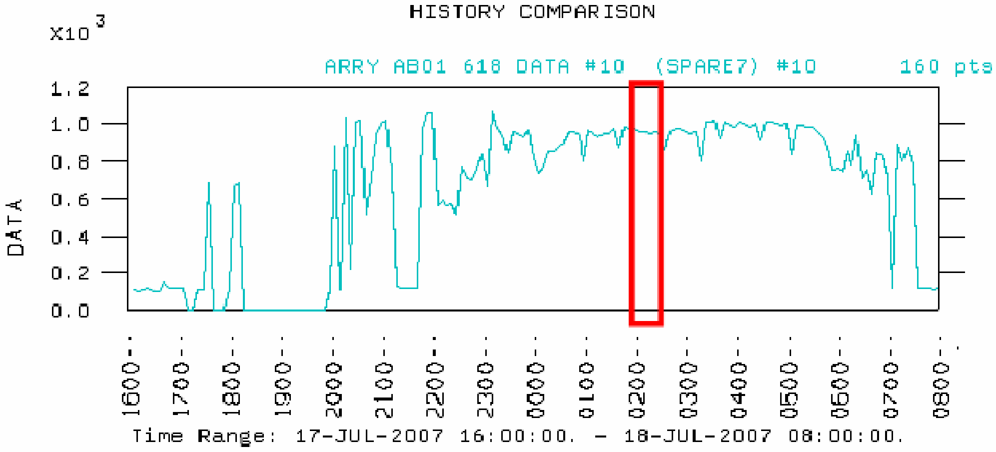


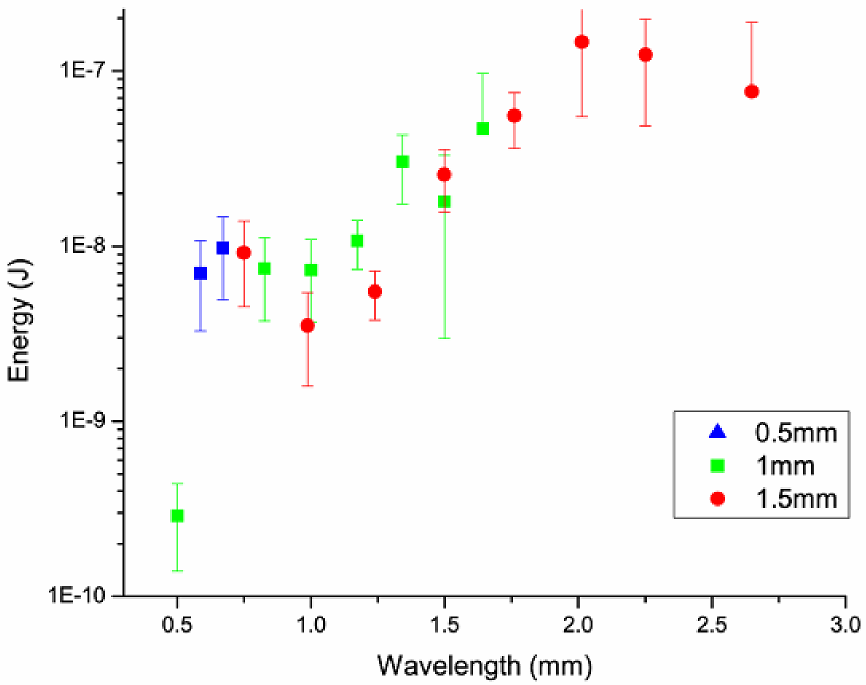
18/07/07: 02:05 – 02:30

100GHz diode in ESA gives **independent** indication of current bunch length.

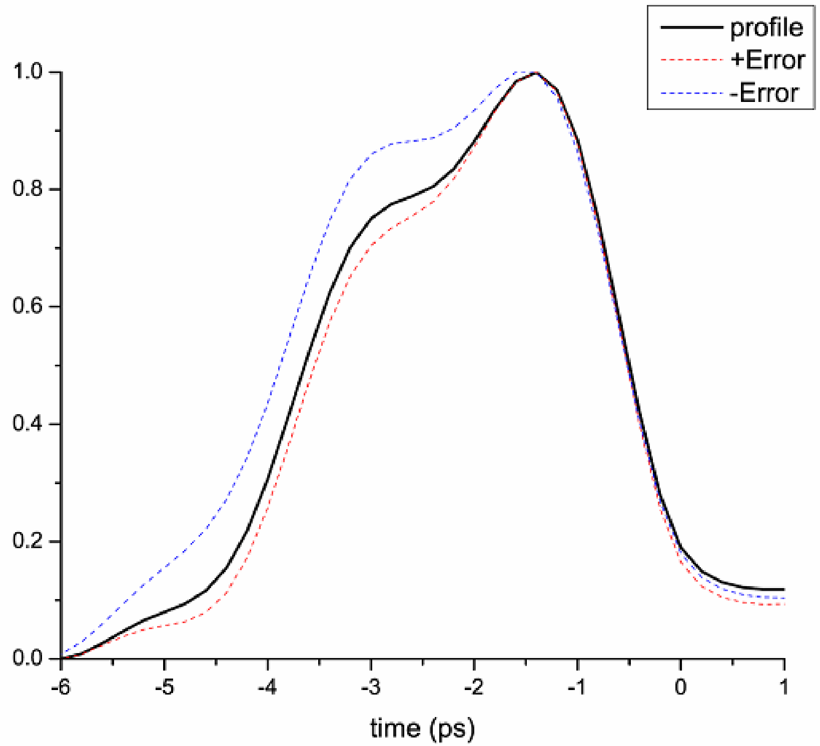


Higher diode reading = shorter bunch

Measured data:



Reconstructed bunch:



18/07/07: 06:25 – 06:58

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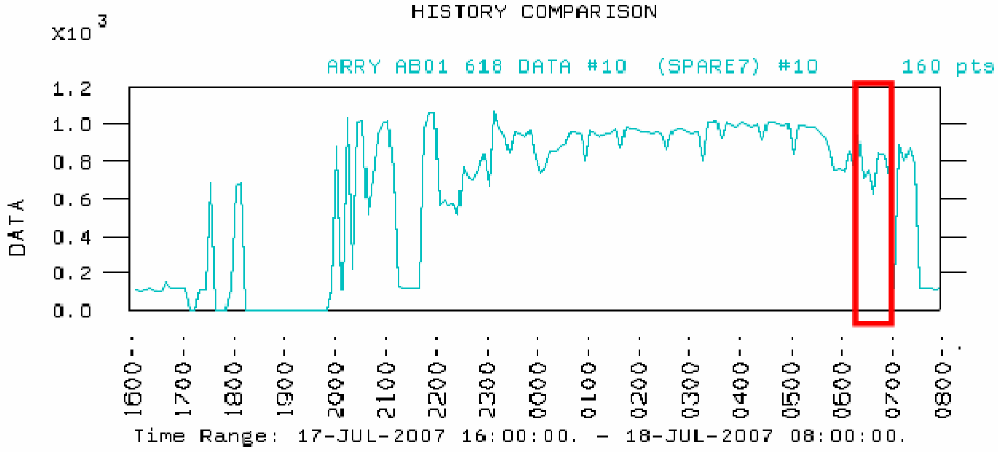

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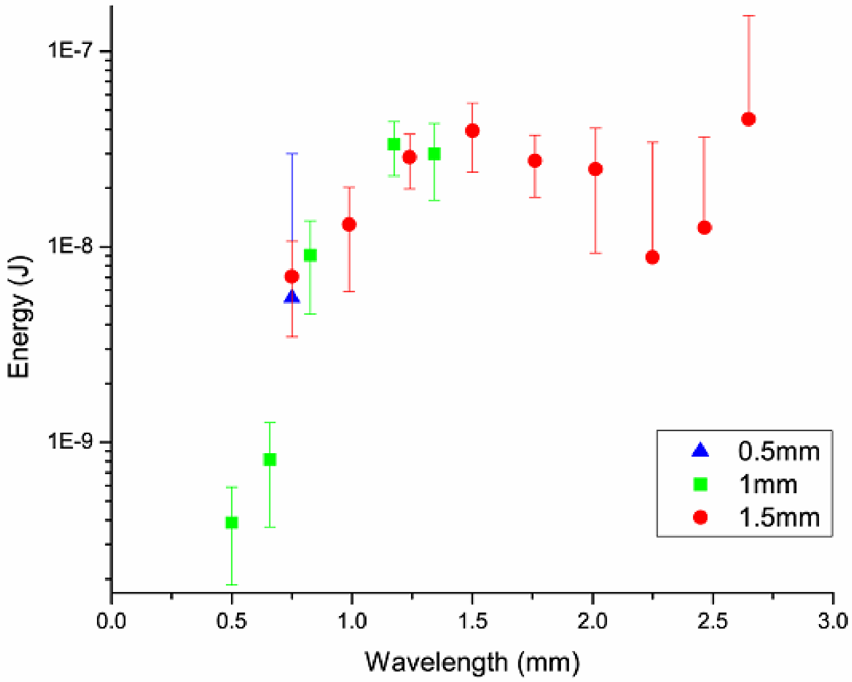

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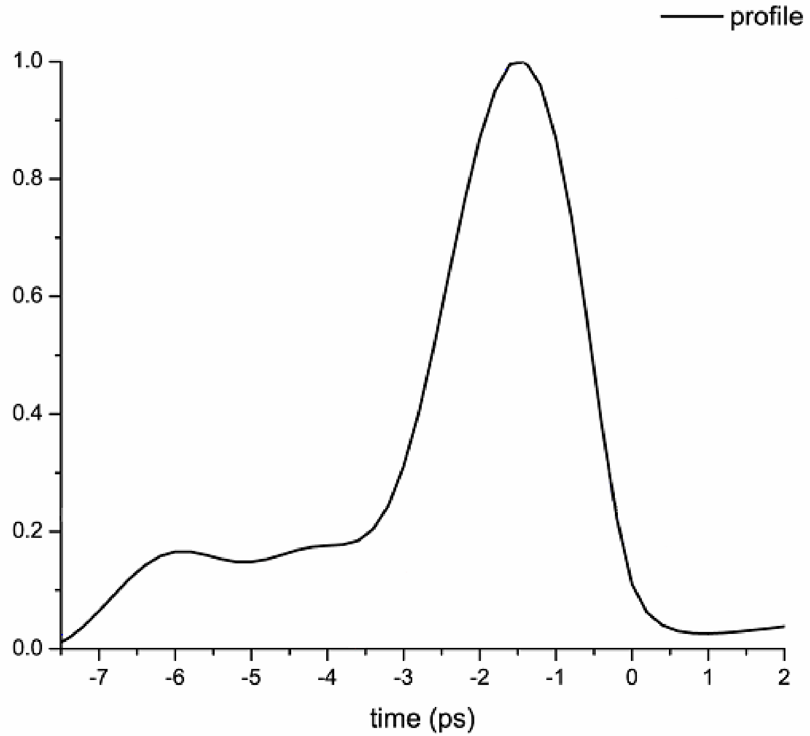
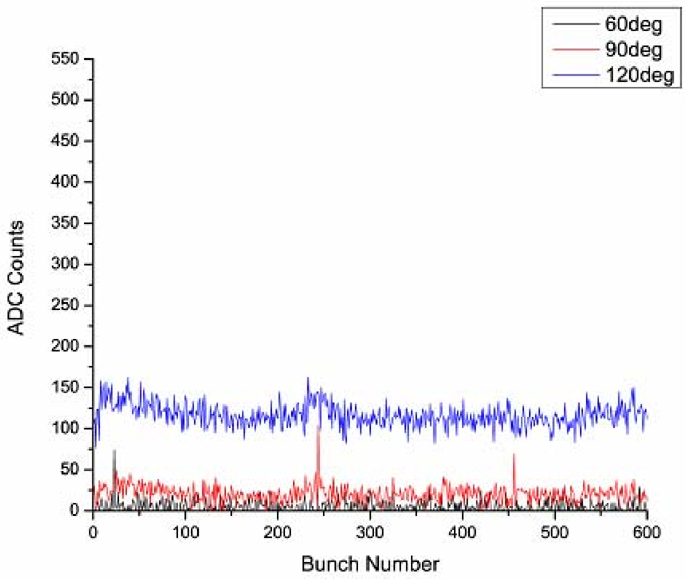


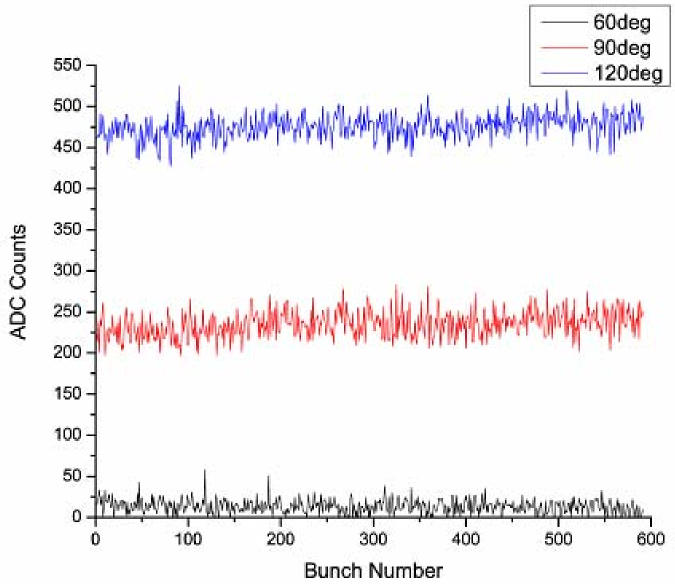
Bunch Profile Changes

In addition, bunch profile changes can be observed whilst taking data!

Typical signal over one minute (at 3 observation angles, 60, 90 and 120°):



Blank

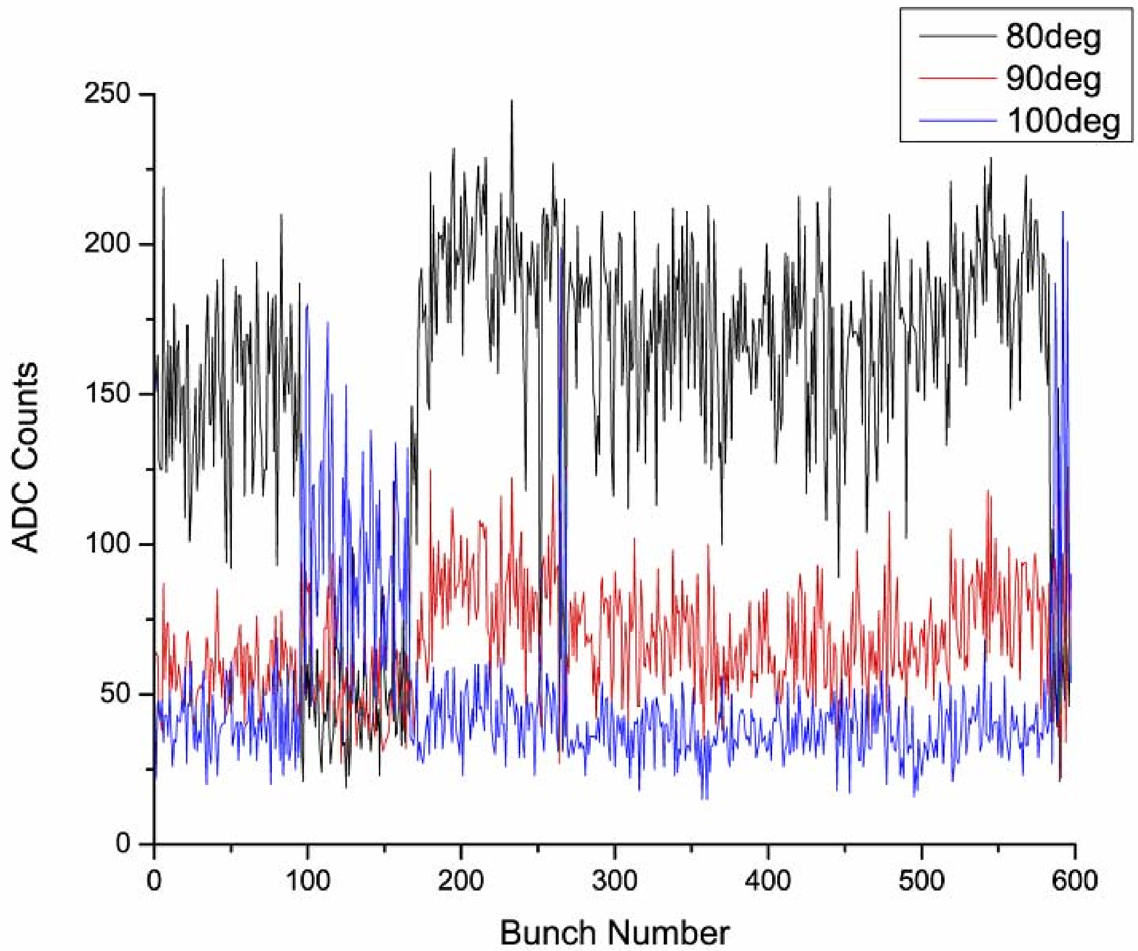


1.5mm grating

Bunch Profile Changes

80, 90 and 100° are the most sensitive to changes in bunch length & profile.

1.5mm grating



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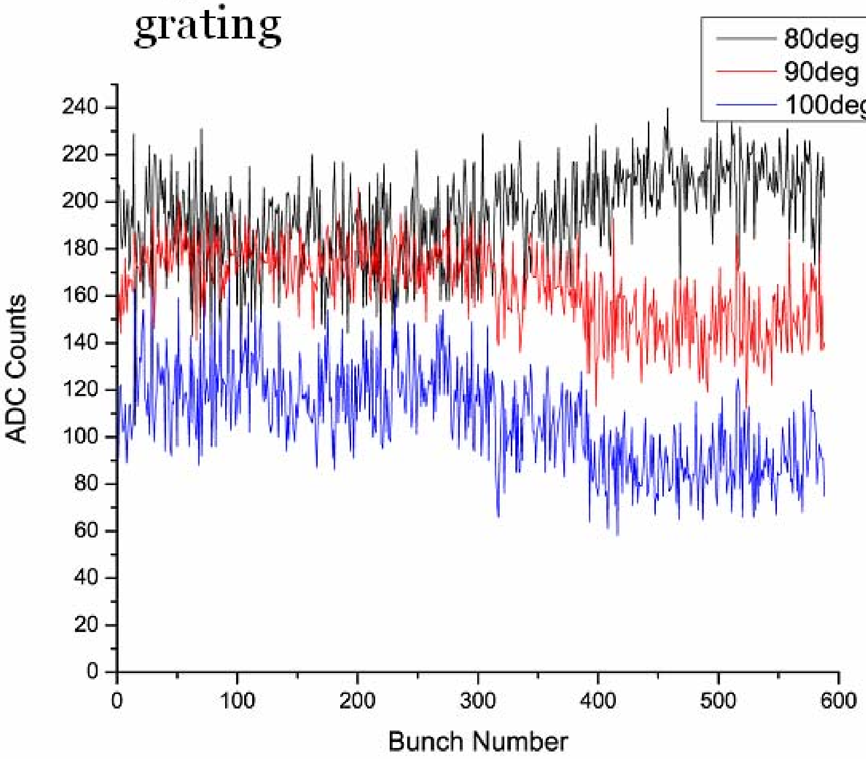
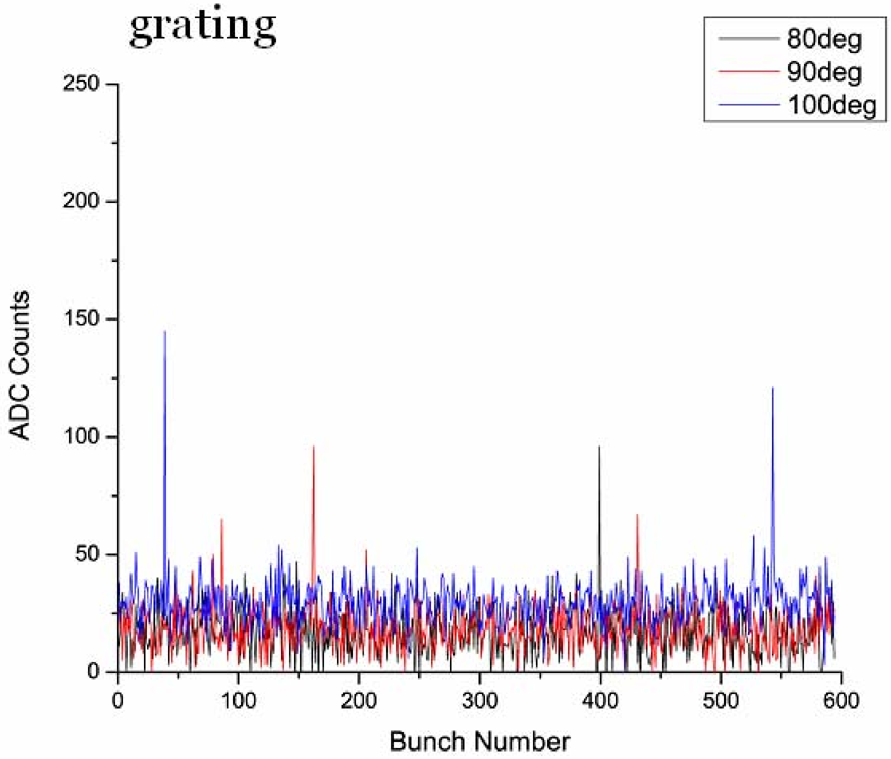


“blank” grating



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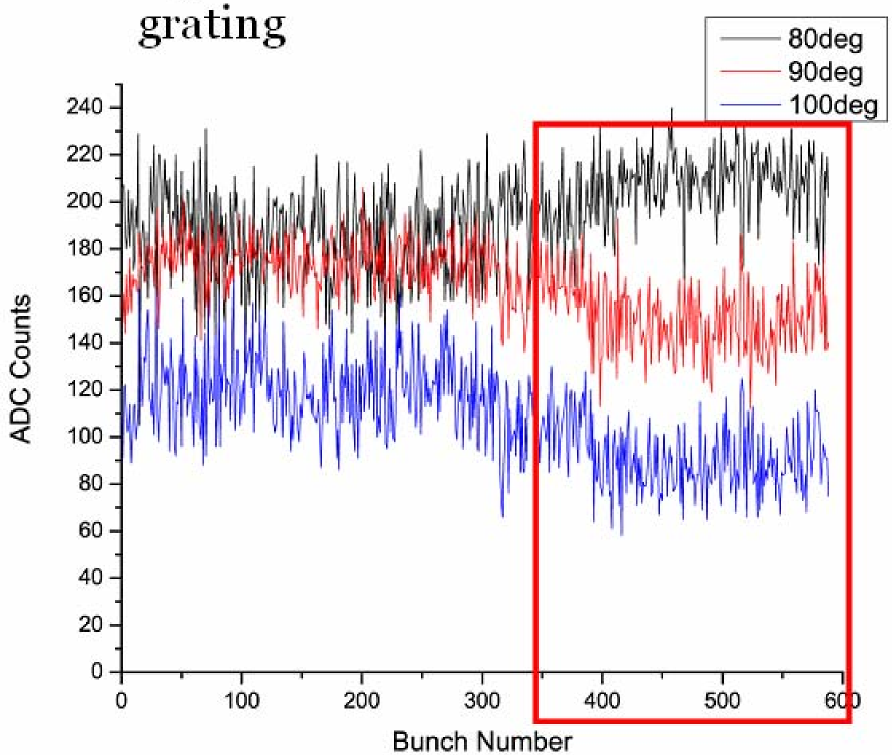

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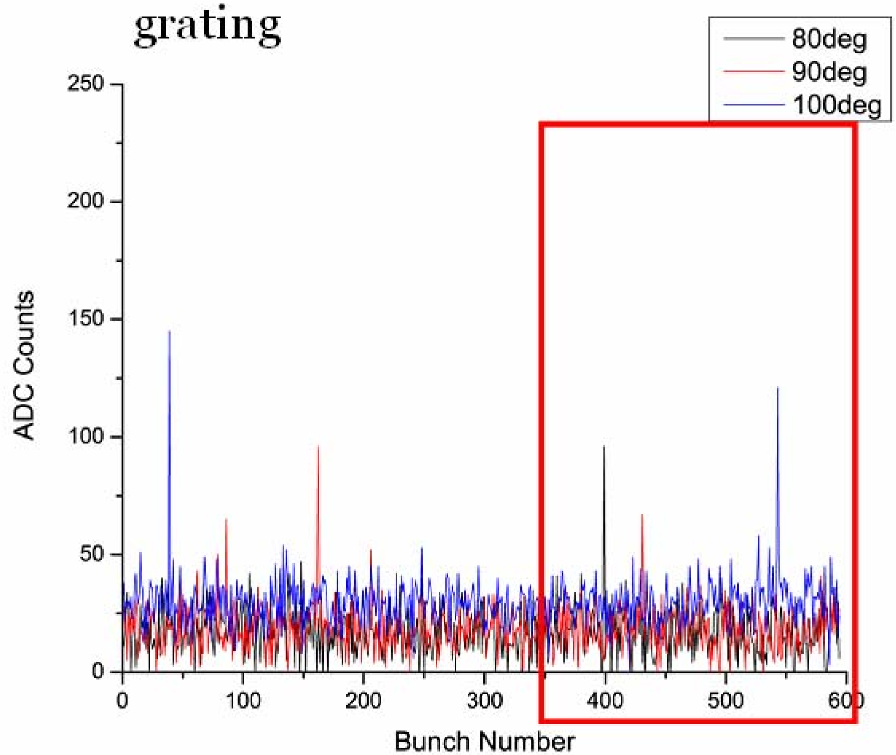


Change seen **with grating only!**

Summary

Bunch lengths have been observed within the range **<u>4 – 7ps.</u>**

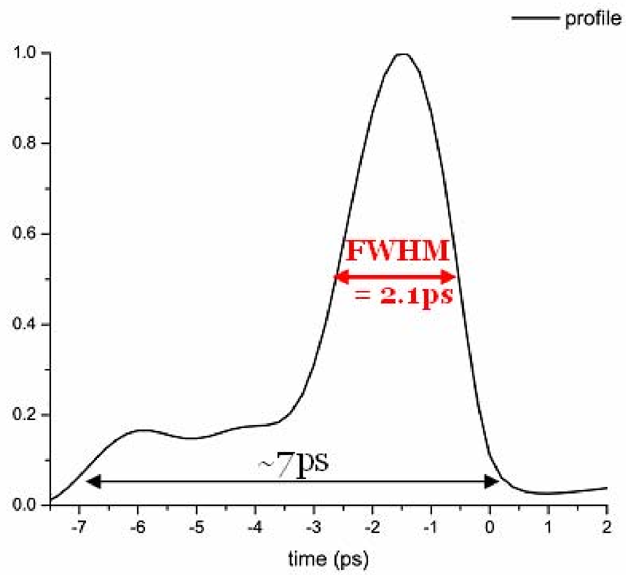
LOLA has also been used to predict the bunch length in ESA. However…

- Data taken in March 07
- Predicted bunch length in ESA based on measurements taken at end of linac.

Rough agreement.

- Direct comparison preferable
  - i.e. same place, same time.

Difficult to compare σ's, **but**:



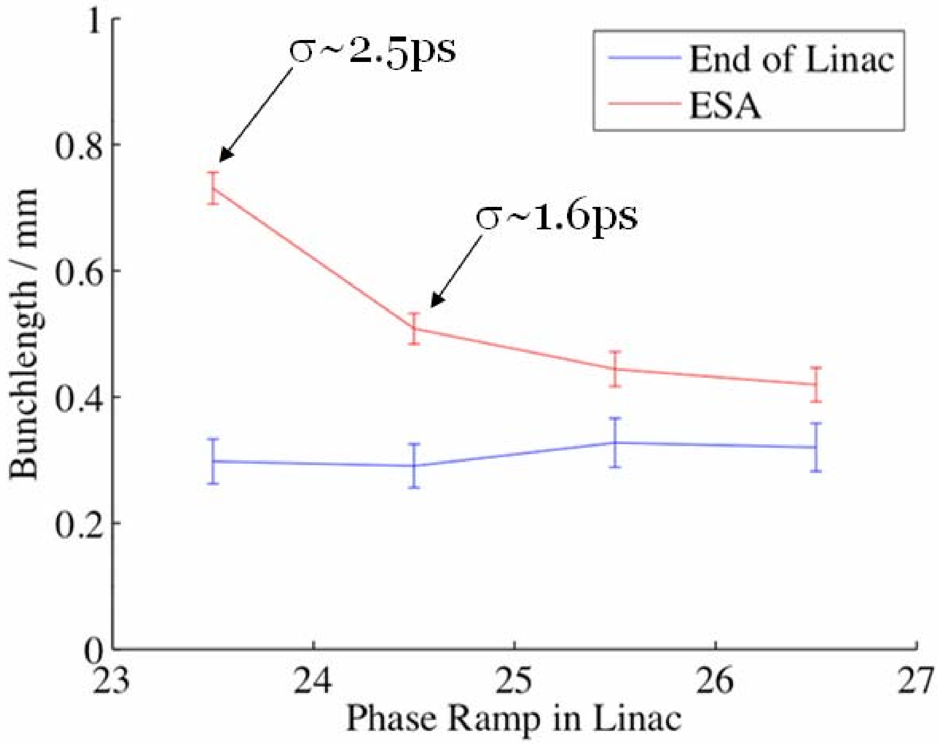
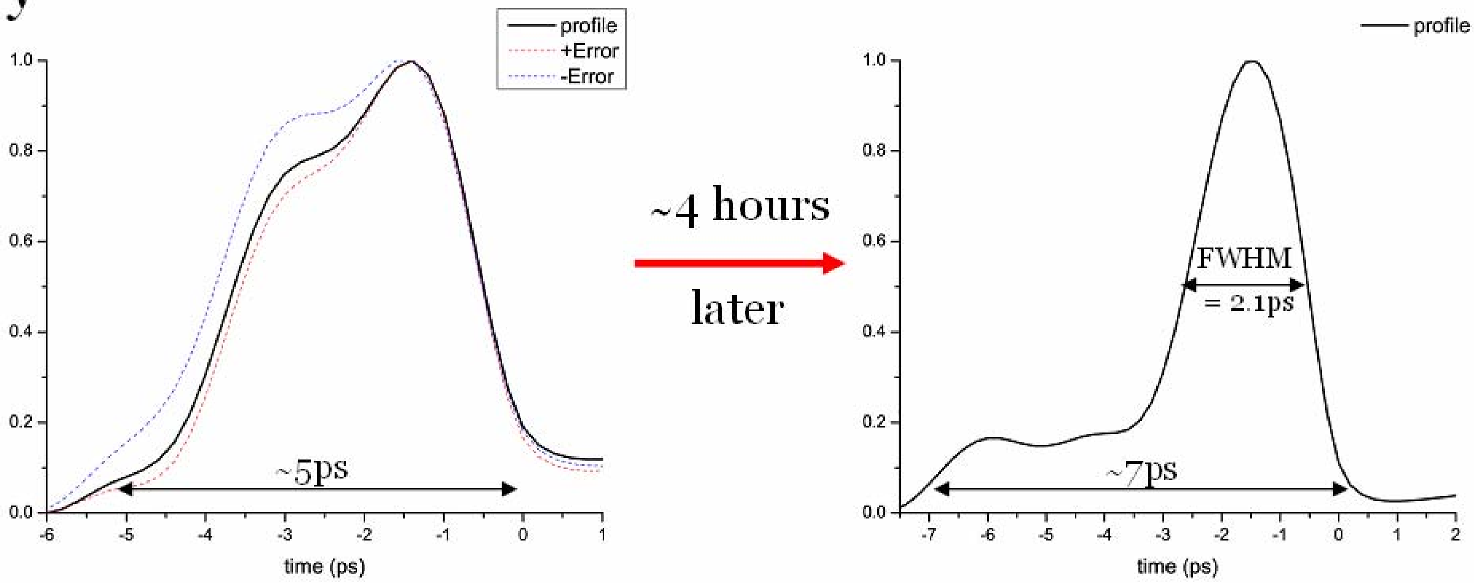


Figure from "Picosecond Bunch Length and Energy-Z Correlation Measurements at SLAC's A-line and End Station A", S. Molloy *et. al*.

Summary



Coherent Smith-Purcell radiation has been used to measure the longitudinal bunch profile at SLAC.

Bunch profile is <u>complex</u> and <u>not</u> Gaussian.
↳ Difficult to define σ of bunch.

Can see the profile clearly changing over time – even whilst taking data!