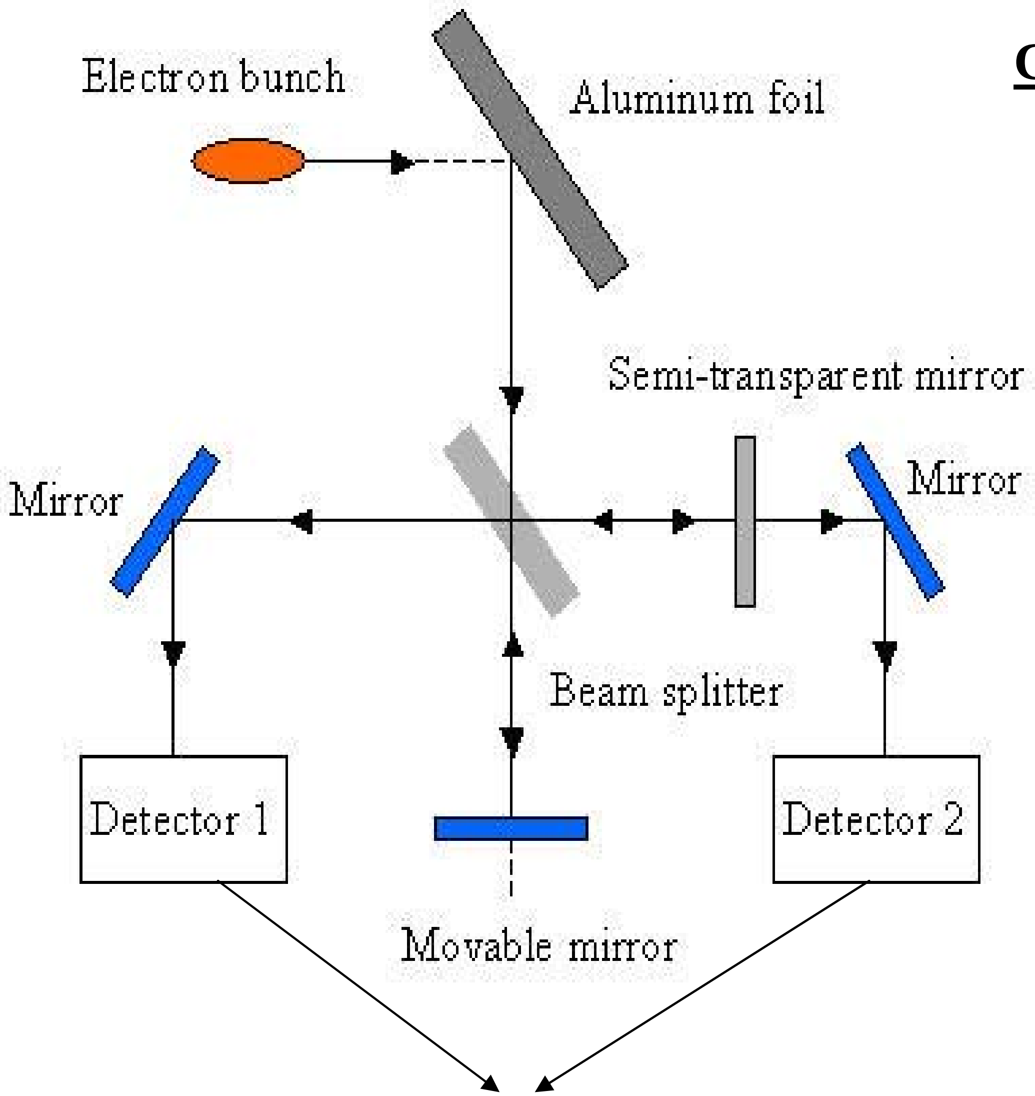
OTR Interferometry

Daniel Mihalcea

Northern Illinois University

Michelson Interferometer



Measure I_1 and I_2

<u>Goal</u>: measure longitudinal charge profile

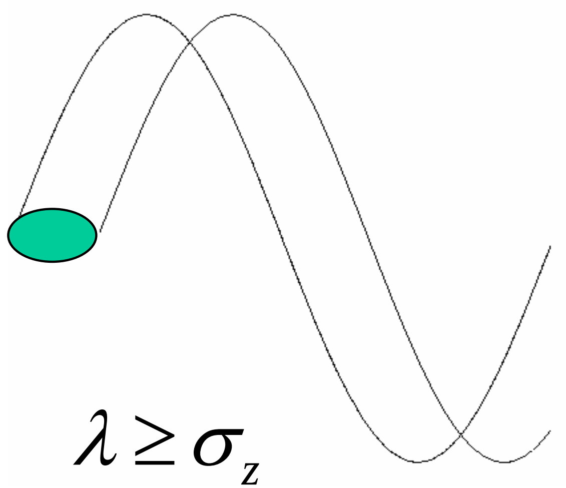
$$I_{total}(\omega) \approx N I_e(\omega)\left[1 + (N-1) f(\omega)\right]$$

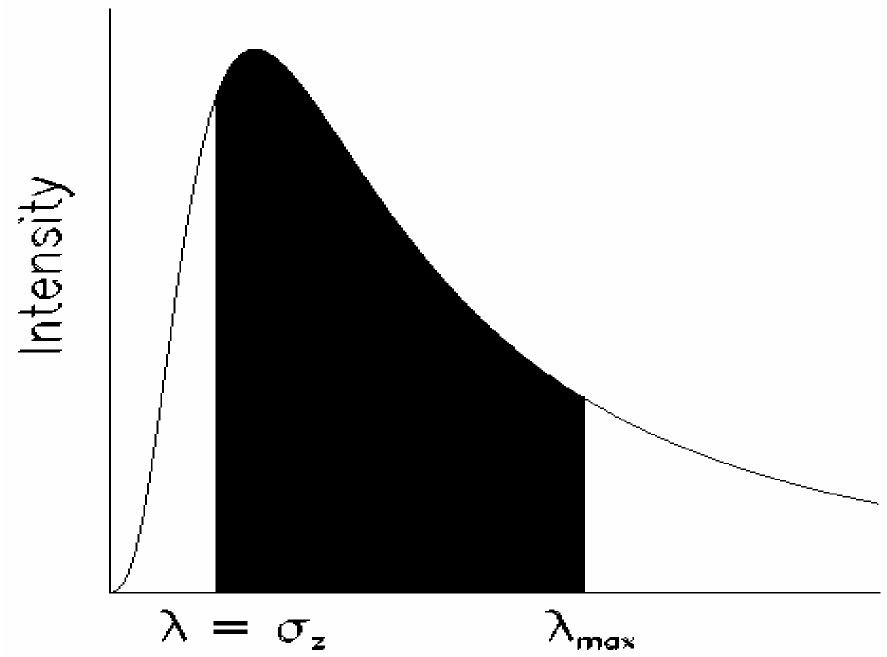
$$f(\omega) = \left| \int_{-\infty}^{+\infty} \rho(z) e^{i\omega z / c} dz \right|^2$$

<u>Beam requirements:</u>

- Q = 1nC
- Good laser and rf stability.
- Sub-picosecond bunch length.
- Adjustable pulse stucture.

Coherence condition





$$f(\omega) = \left| \int_{-\infty}^{+\infty} \rho(z) e^{i\omega z/c} dz \right|^2$$

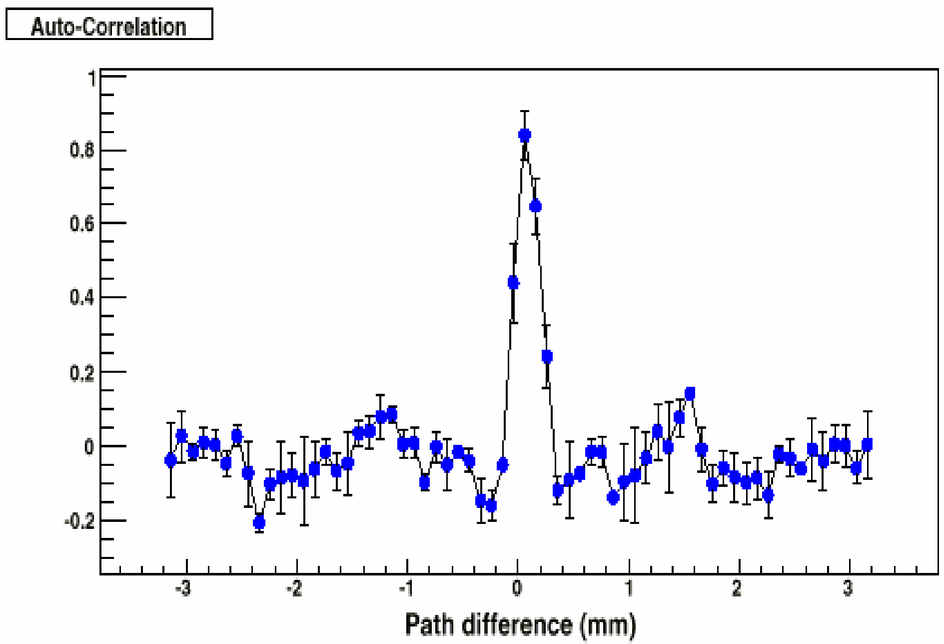
Detector sensitivity ➡ $\lambda_{\max} \approx 3mm$

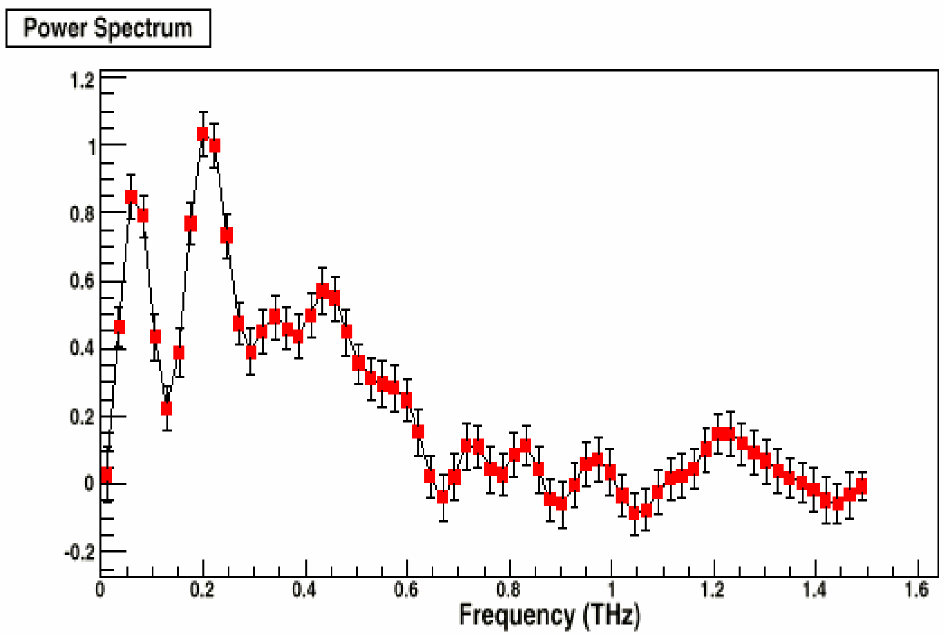
Acceptable resolution:

$$\sigma_z \leq 0.3\,mm$$

⇨ **Need bunch compression**

Auto-correlation function





- **Beam conditions: Q = 1nC, E = 14 MeV, maximum compression.**
- **About 40 degrees from 9-cell on-crest phase.**

$$S(\tau) \equiv \frac{I_1}{I_2} \propto \int E(t)E(t+\tau)dt$$

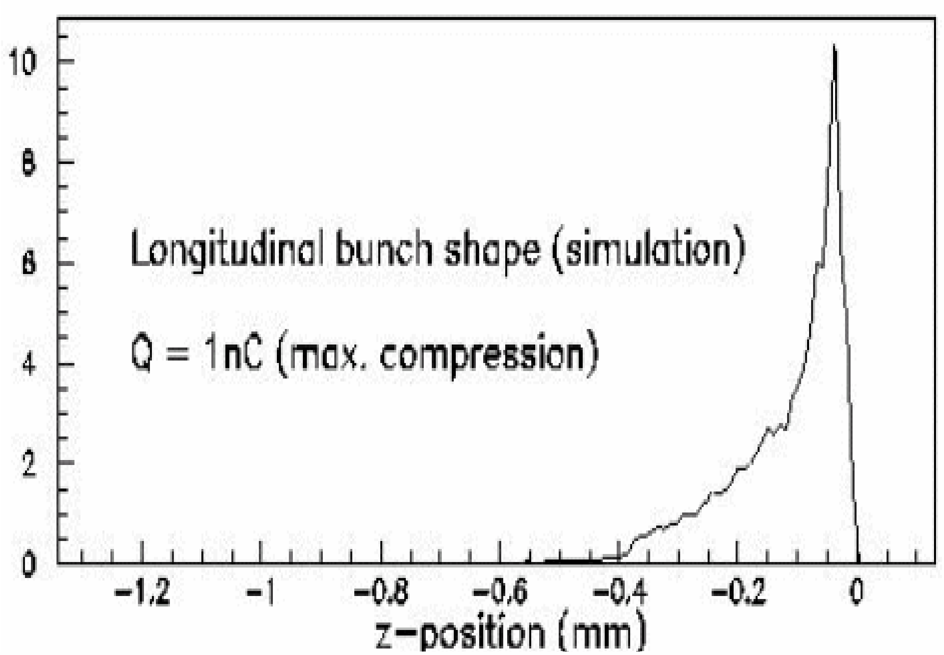
Measured power spectrum is affected by:

- **Diffraction at low frequencies.**
- **Absorption in quartz window, beam splitters, mirrors.**

Need to know apparatus response function!

$$I(\omega) \equiv |\tilde{E}(\omega)|^2 \propto \mathrm{Re}\int S(\tau)e^{i\omega\tau}\, d\tau$$

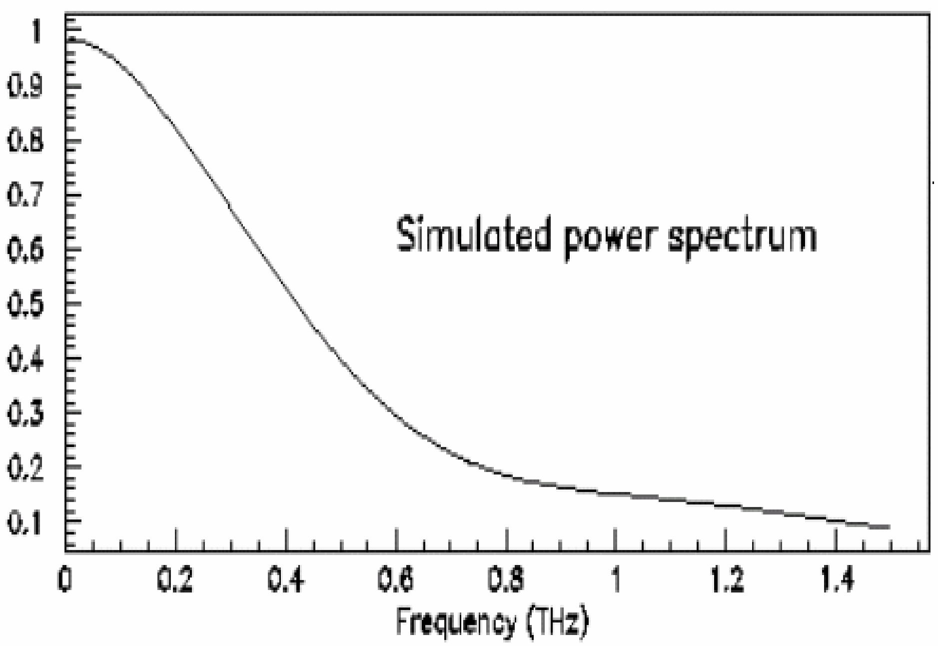
Response function

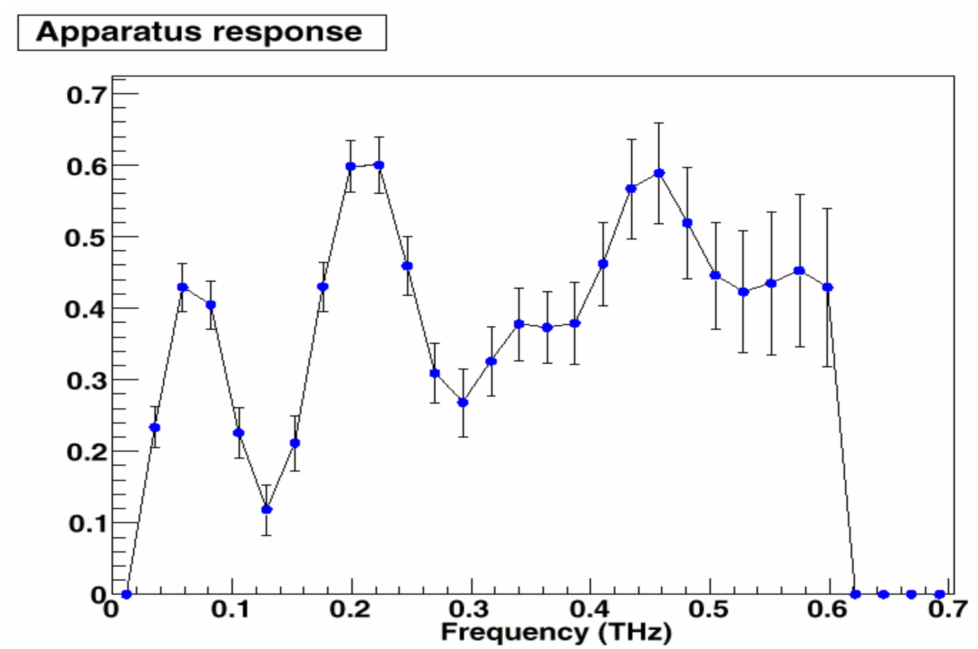


Parmela simulations:

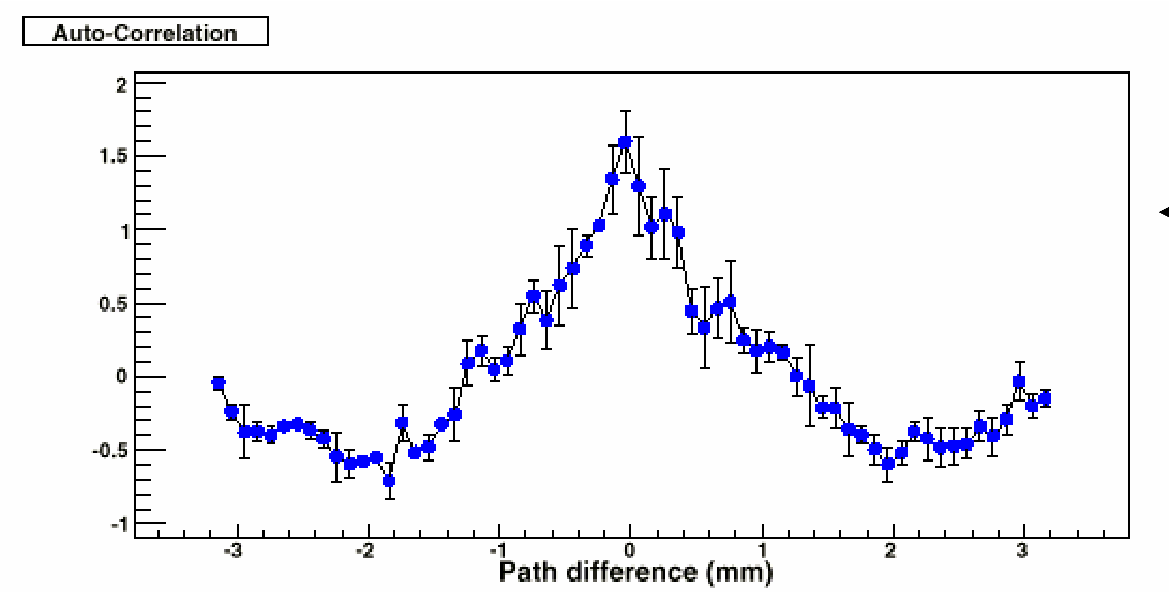
- Space charge forces ignored inside dipoles.
- Fringe fields ignored.
- Number of particles: 20,000.

$$\textbf{Response function} = \frac{\textbf{Measured power spectrum}}{\textbf{Simulated power spectrum}}$$

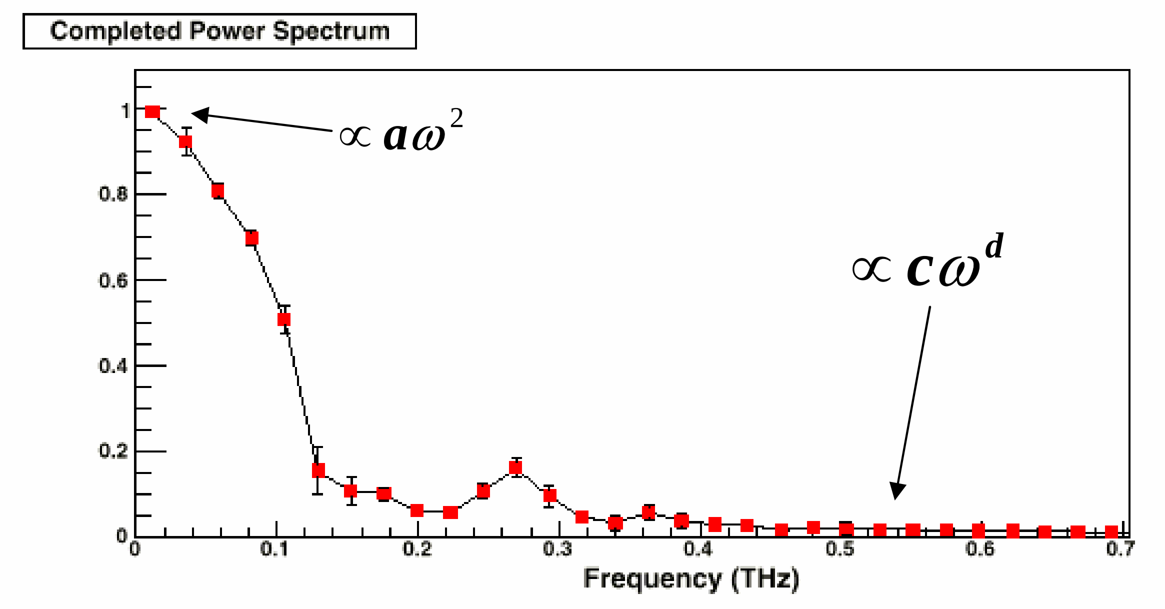




Completed spectra



Q = 3nC at moderate compression



Power spectrum completion:

◆ Multiply experimental power spectrum with response function.

◆ Complete power spectrum at low and high frequencies by using asymptotic expressions.

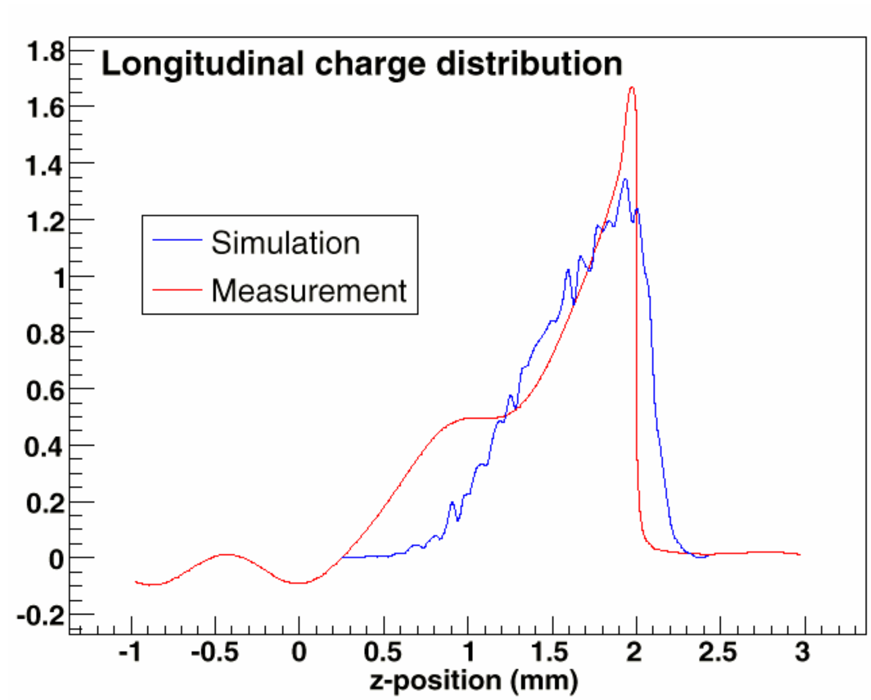
◆ Use least square method to fit for the unknown parameters.

Longitudinal bunch shape

$$f(\omega) = \left| \int_{-\infty}^{+\infty} \rho(z) e^{i\omega z/c} dz \right|^2 \quad \Rightarrow \boldsymbol{f}(\omega) \text{ contains no phase information}$$

$\propto$ power spectrum

3nC moderate compression

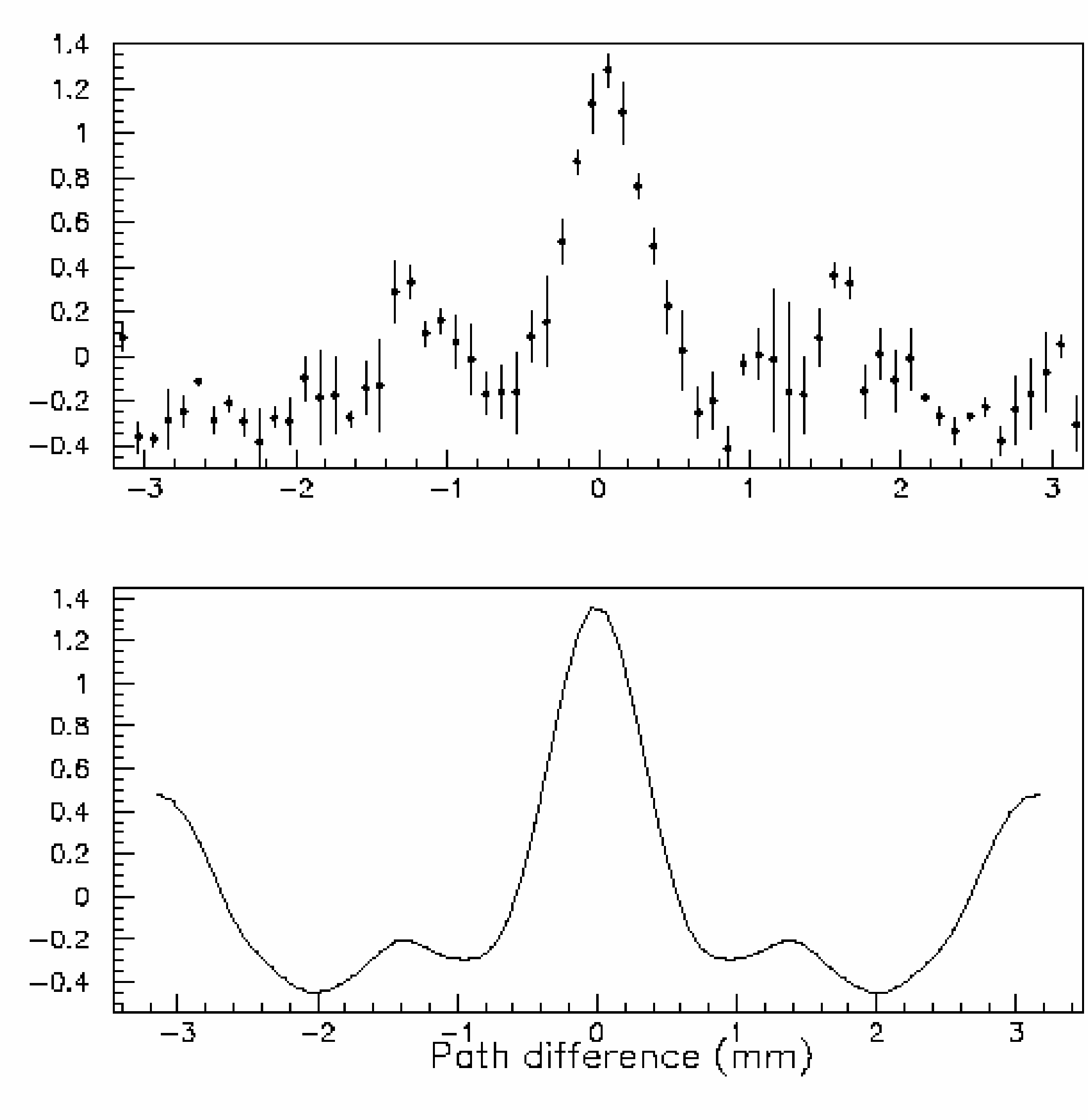


<u>**Kramers-Kröning method:**</u>

$$\psi(\omega) = -\frac{\omega}{\pi} \int_0^{\infty} \boldsymbol{dx} \frac{\ln[\boldsymbol{I}(\boldsymbol{x})/\boldsymbol{I}(\omega)]}{\boldsymbol{x}^2 - \omega^2}$$

$$\rho(\boldsymbol{z}) = \frac{1}{\pi \boldsymbol{c}} \int_0^{\infty} \sqrt{\boldsymbol{I}(\omega)} \cos[\psi(\omega) - \omega \boldsymbol{z}/\boldsymbol{c}] \boldsymbol{d}\omega$$

Complex longitudinal distributions



Beam preparation:

◆ 2 pulses separated by a known distance.

◆ Q = 1nC for each pulse.

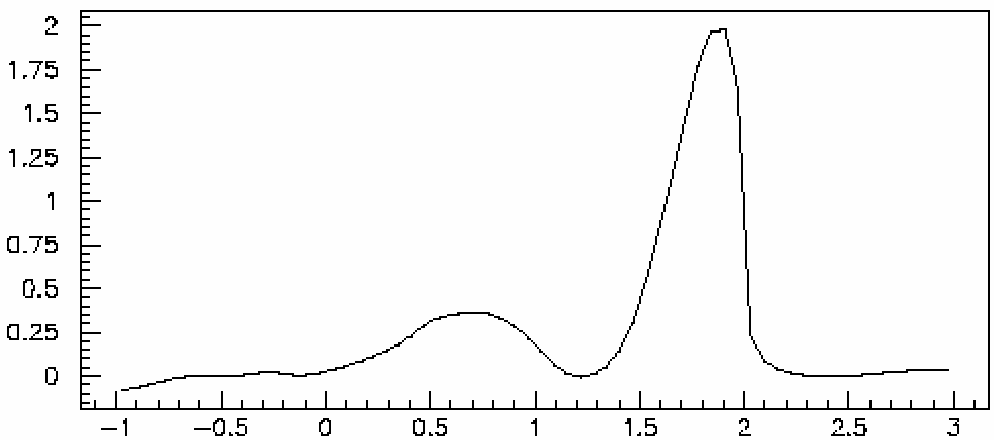
◆ Determine the phase of maximum compression for each pulse (φ_1 and φ_2).

◆ Set 9-cell phase at $\frac{\varphi_1 + \varphi_2}{2}$

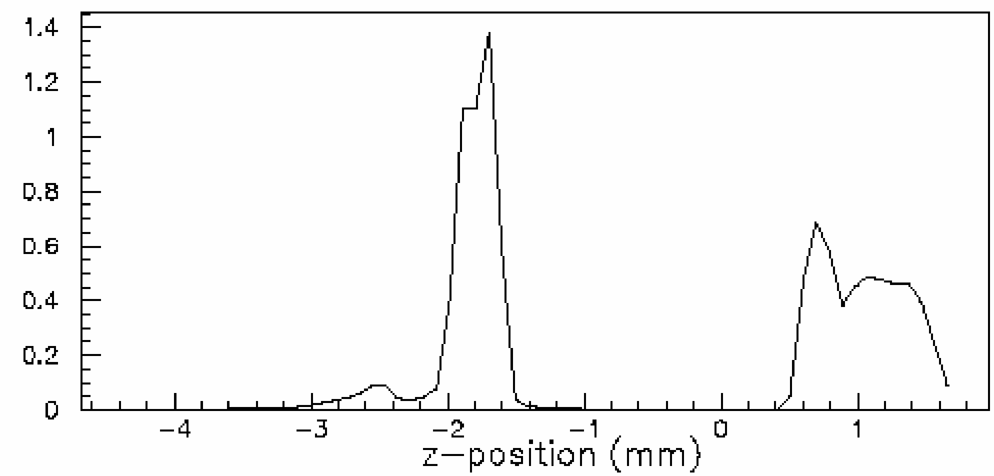
Simulation:

- 2 pulses separated by 15 ps.
- Determine power spectrum.
- Correct power spectrum.
- Determine auto-correlation function.

Complex longitudinal distributions (2)



Longitudinal charge from experimental auto-correlation



Longitudinal charge from Parmela simulation

Peak separation significantly different.

Plans for future work

Experimental:

- Determine apparatus response function more accurately.
- Diversify experimental conditions (bunch charge, pulse separation, radius).
- Estimate sources of errors (energy, current through chicane, beam radius).
- Purge interferometer with N_2 (?).

Simulations:

- ◆ Use ImpactT-T to model the beam (in addition to Parmela).
- ◆ Improve chicane model by including fringe fields.
- ◆ Estimate errors from spectrum completion procedure and other simulation inaccuracies.

Pending on results: publish a paper.