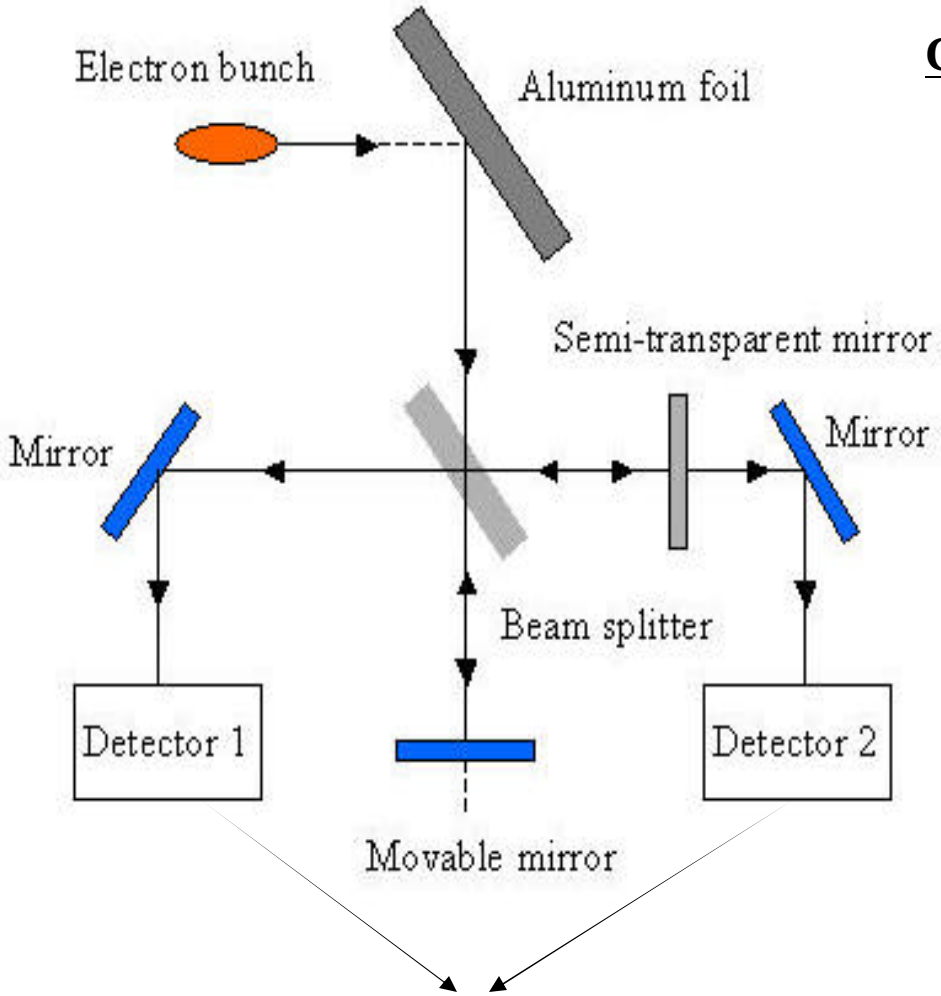
OTR Interferometry

Daniel Mihalcea

Northern Illinois University

Michelson Interferometer



Measure I_1 and I_2

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

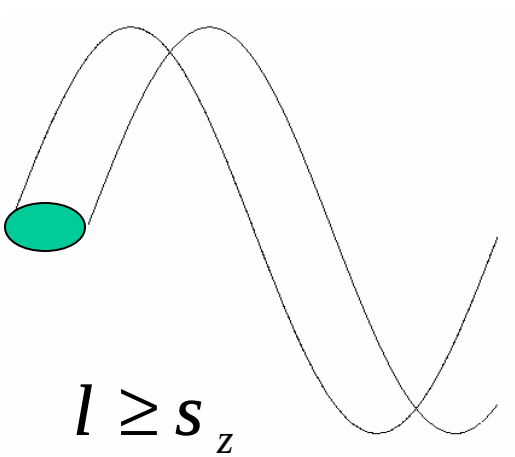
$$I_{total}(w) \approx N I_e(w)\left[1+(N-1)\,f(w)\right]$$

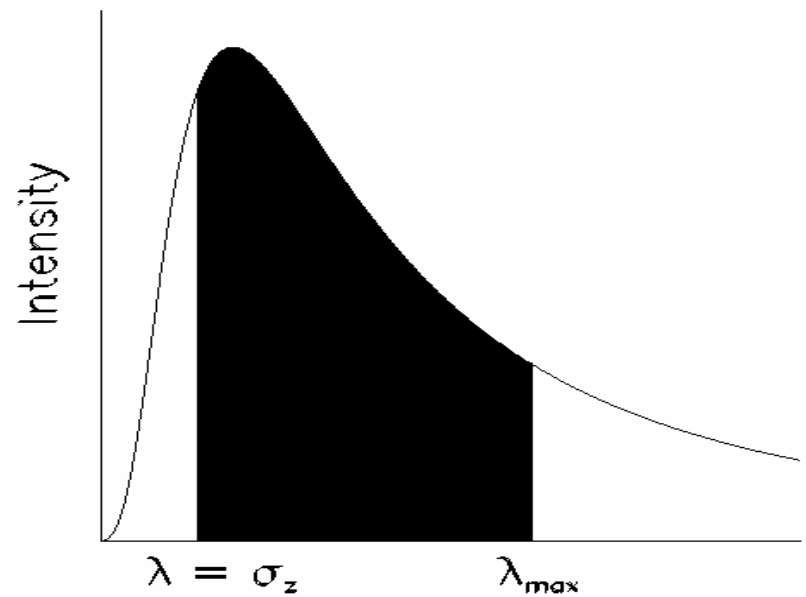
$$f(w) = \left| \int_{-\infty}^{+\infty} r(z)\, e^{iwz/c}\, dz \right|^2$$

<u>Beam requirements:</u>

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

Coherence condition



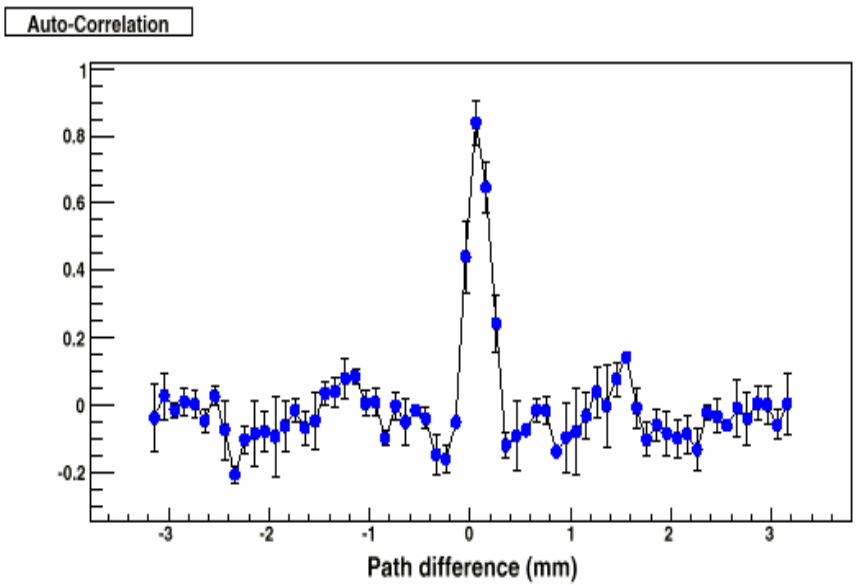


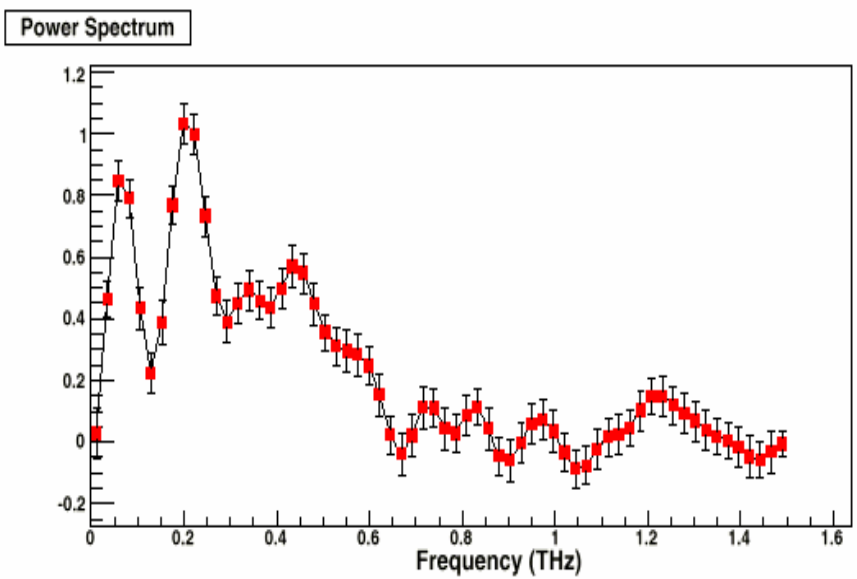
$$f(w) = \left| \int_{-\infty}^{+\infty} r(z) e^{iwz/c} dz \right|^2$$

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

Acceptable resolution: $\boxed{s_z \leq 0.3mm}$ ⇨ **Need bunch compression**

Auto-correlation function





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

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

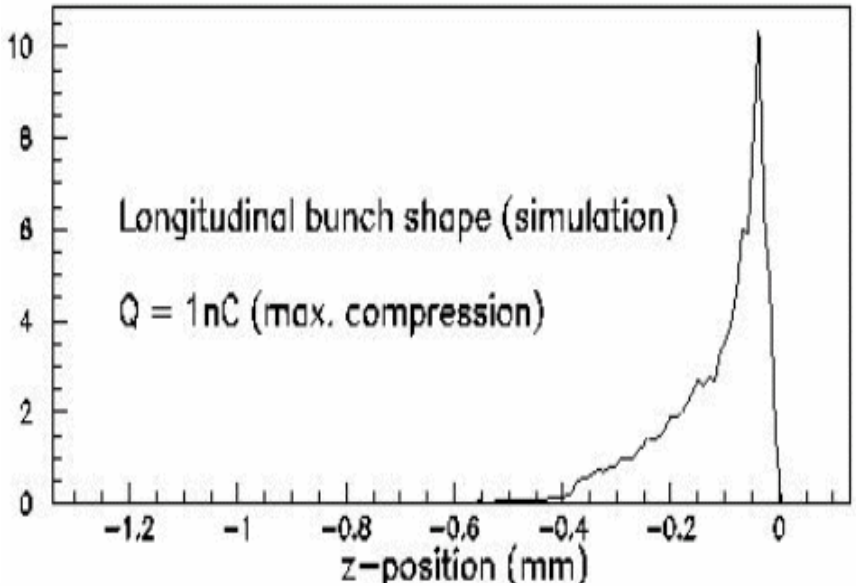
Measured power spectrum is affected by:

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

Need to know apparatus response function!

$$\boldsymbol{I}(w) \equiv |\tilde{\boldsymbol{E}}(w)|^2 \propto \mathrm{Re}\int \boldsymbol{S}(t)\boldsymbol{e}^{iwt}\,\boldsymbol{d}t$$

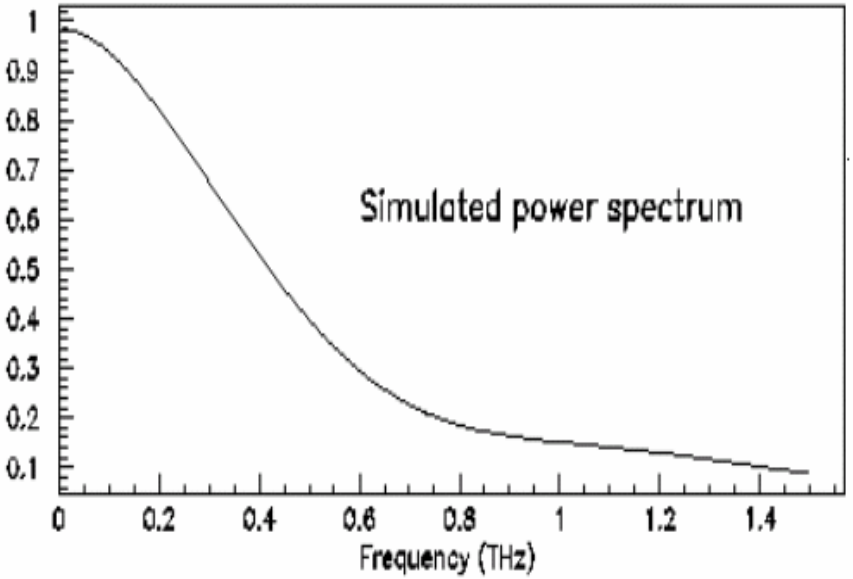
Response function

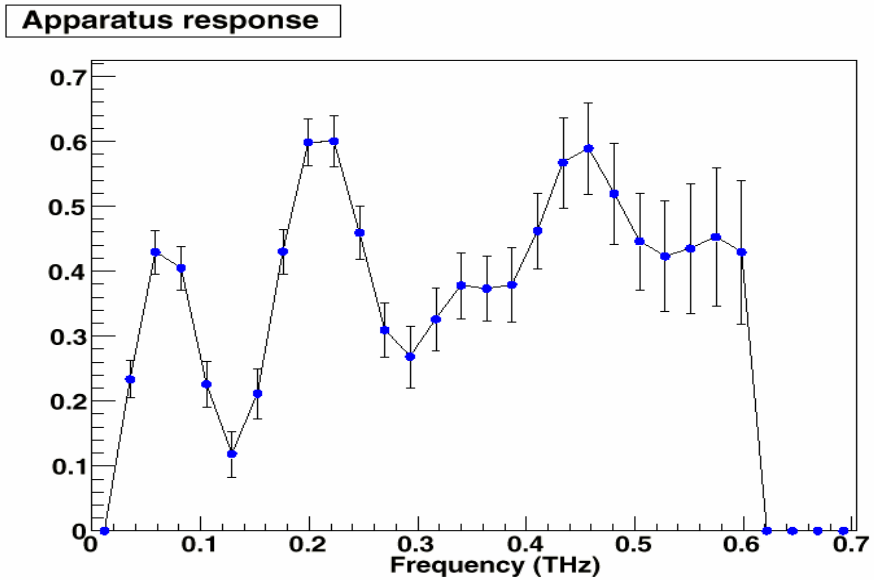


Parmela simulations:

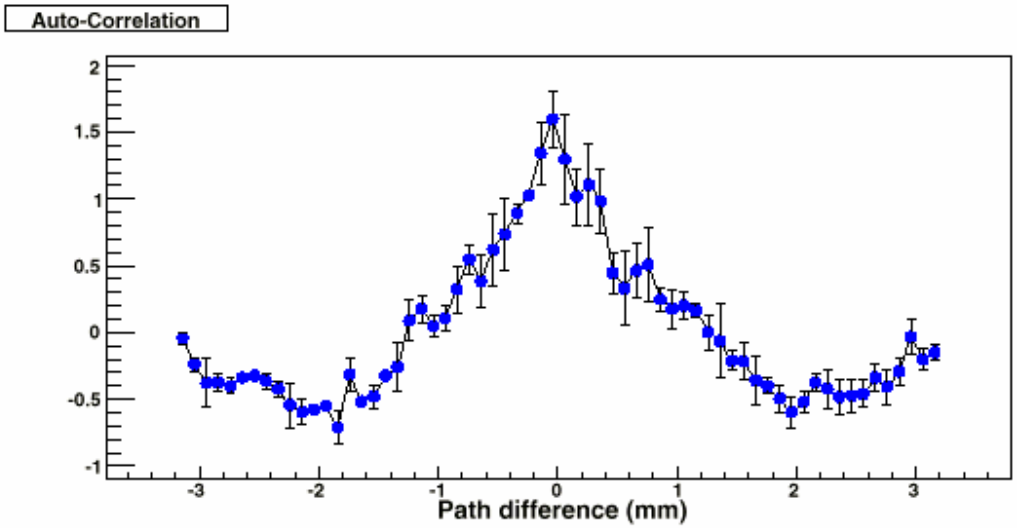
- Space charge forces ignored inside dipoles.
- Fringe fields ignored.
- Number of particles: 20,000.

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

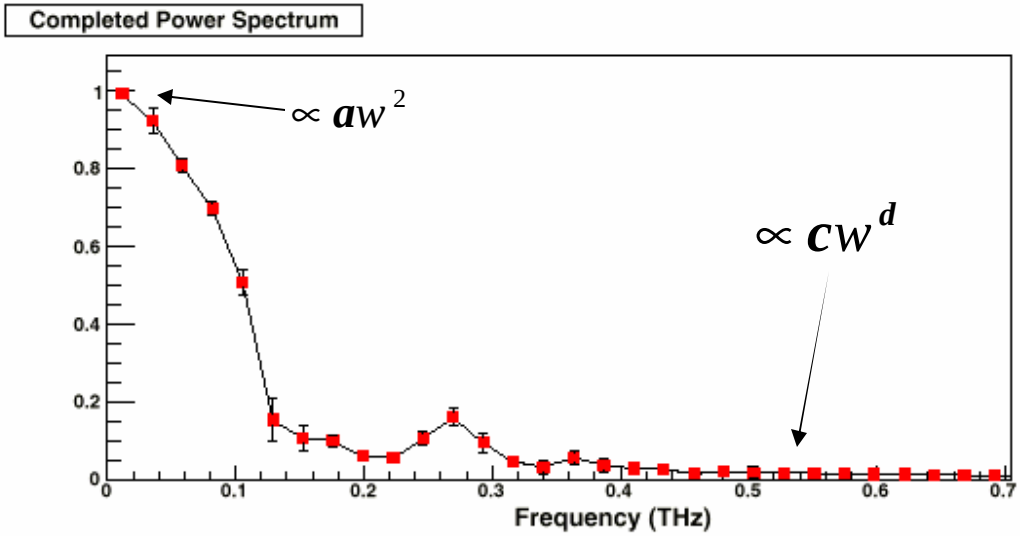




Completed spectra



Q = 3nC at moderate compression



<u>Power spectrum completion:</u>

- 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

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

$\downarrow$

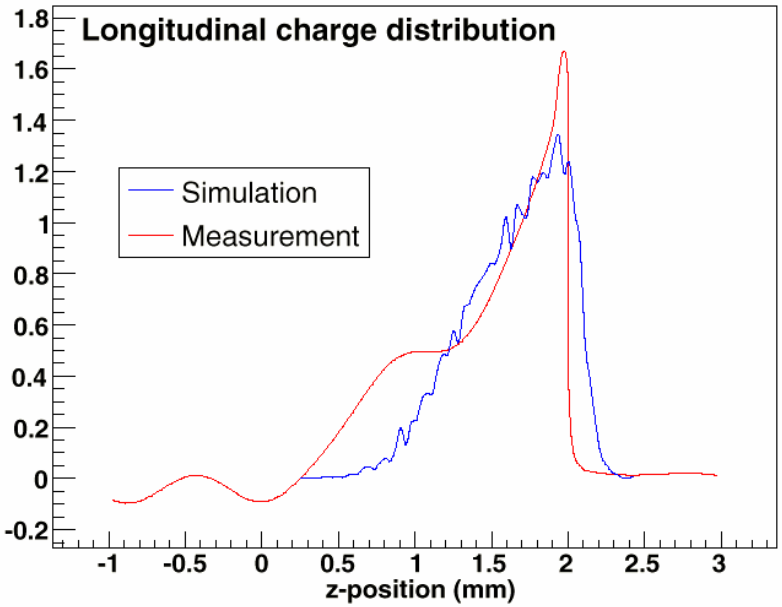
$\propto$ power spectrum

3nC moderate compression

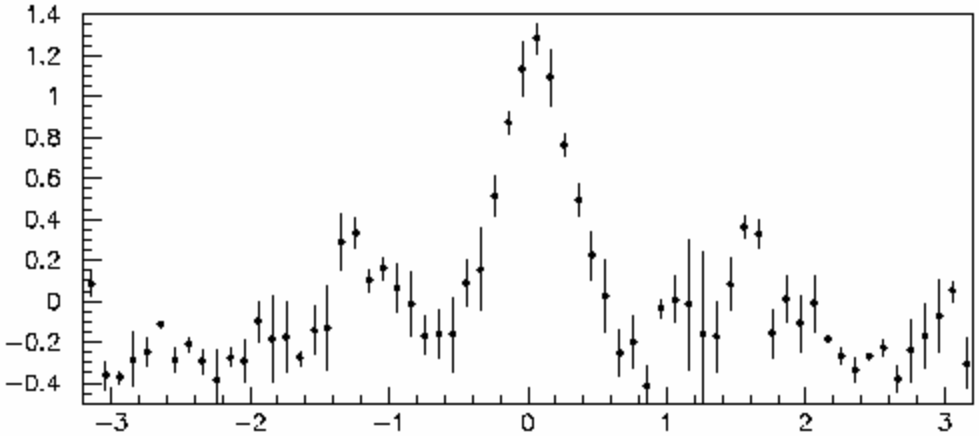
<u>Kramers-Kröning method:</u>

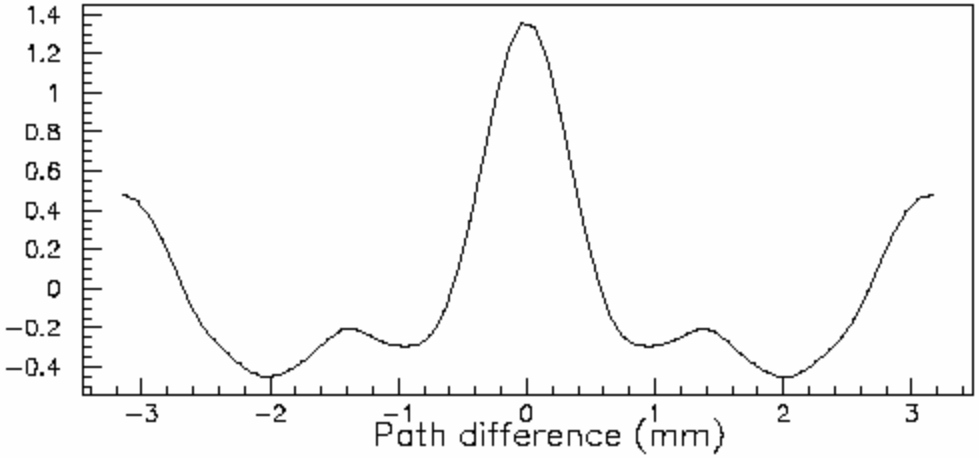
$$y(w) = -\frac{w}{p} \int_0^{\infty} \boldsymbol{dx} \frac{\ln[\boldsymbol{I}(\boldsymbol{x}) / \boldsymbol{I}(w)]}{\boldsymbol{x}^2 - w^2}$$

$$r(\boldsymbol{z}) = \frac{1}{p\boldsymbol{c}} \int_0^{\infty} \sqrt{\boldsymbol{I}(w)} \cos[y(w) - w\boldsymbol{z}/\boldsymbol{c}] \boldsymbol{d}w$$



Complex longitudinal distributions





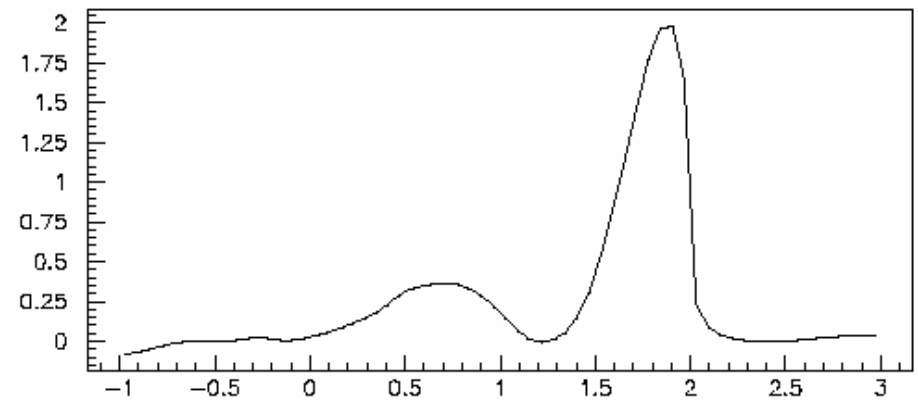
Beam preparation:

- 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 $\frac{j_1 + j_2}{2}$

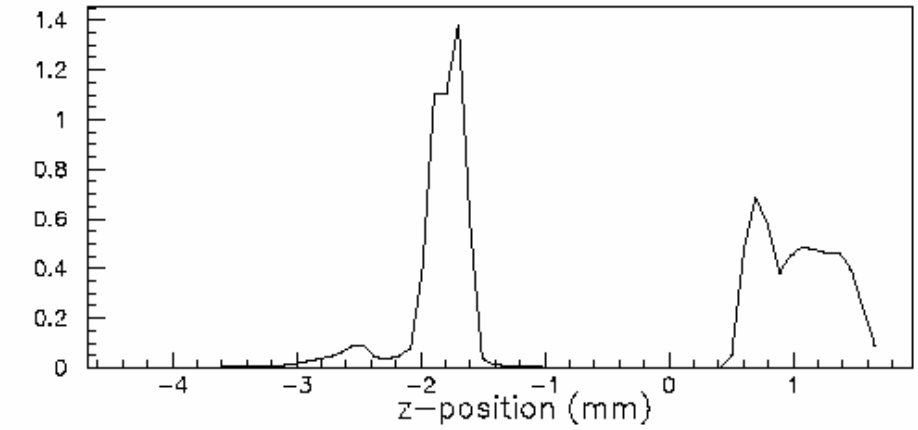
Simulation:

- 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.