OTR Interferometry

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Michelson Interferometer

**Goal:** measure longitudinal charge profile

\[ I_{total}(\omega) \approx N \bar{I}_e(\omega)[1 + (N-1)f(\omega)] \]

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

**Beam requirements:**
- Q = 1nC
- Good laser and rf stability.
- Sub-picosecond bunch length.
- Adjustable pulse structure.
Coherence condition

\[ \lambda \geq \sigma_z \]

\[
\begin{align*}
f(\omega) &= \left| \int_{-\infty}^{+\infty} \rho(z) e^{i\omega z/c} \, dz \right|^2
\end{align*}
\]

Detector sensitivity \( \lambda_{\text{max}} \approx 3\,\text{mm} \)

Acceptable resolution: \( \sigma_z \leq 0.3\,\text{mm} \) → Need bunch compression
Auto-correlation function

- Beam conditions: $Q = 1\text{nC}$, $E = 14\text{ MeV}$, 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!

$$I(\omega) \equiv |\widetilde{E}(\omega)|^2 \propto \text{Re} \int S(\tau)e^{i\omega \tau}\,d\tau$$
Response function

Parmela simulations:

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

Response function = \frac{\text{Measured power spectrum}}{\text{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

\[ f(\omega) = |\int_{-\infty}^{+\infty} \rho(z) e^{i\omega z / c} \, dz|^2 \Rightarrow f(\omega) \text{ contains no phase information} \]

\( \propto \) power spectrum

**Kramers-Kröning method:**

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

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

3nC moderate compression
Complex longitudinal distributions

**Beam preparation:**
- 2 pulses separated by a known distance.
- $Q = 1\text{nC}$ for each pulse.
- Determine the phase of maximum compression for each pulse ($\phi_1$ and $\phi_2$).
- Set 9-cell phase at $\frac{\phi_1 + \phi_2}{2}$.

**Simulation:**
- 2 pulses separated by 15 ps.
- Determine power spectrum.
- Correct power spectrum.
- Determine auto-correlation function.
Complex longitudinal distributions (2)

Peak separation significantly different.

Longitudinal charge from experimental auto-correlation

Longitudinal charge from Parmela simulation
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 N₂ (?):

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.