IFEL/Chicane Based Microbuncher at 800nm

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Motivation

The injector system will produce 50pC bunches with length ~1 ps. At laser wavelength of 800nm this corresponds to ~500 microbunches. This microbunching is interesting for:

- **E-163 Directly:**
  - Allow us to see a net acceleration from laser accelerator test structures

- **Long Term interest:**
  - Improved capture efficiency of electrons.
  - Gain experience producing, controlling, and diagnosing femtosecond scale electron bunches.
  - Short RF linac plus IFEL/chicane microbuncher may serve as an injector for a laser linac for HEP
• Standard RF linac produces low-charge, low emittance ps electron pulses
• IFEL: hybrid-Halbach magnetostatic array type planar undulator, 3 periods, with ~450 MW peak power laser at 800 nm inducing an energy modulation of ~0.15%.
• Chicane: 3 H-magnets, both permanent magnet and coils for fine tuning.

Drawing by C. Barnes.
Details: IFEL

• 1.8 cm period, 3 periods with ~1/2 width end magnets plus end plates.
• Magnets: NdFeB $B_r=1.25$ T, poles: Vanadium permendur
• Adjustable gap: 4-15 mm → $a_w\sim0.3-1$
  • To cover range in $\gamma$ or possible switch to 1.5µm laser
  • Set to 8mm for 60 MeV, 800nm

Other Numbers:

Width: 4 cm, magnet thickness: 5mm, pole thickness: 4mm

Total Dimensions including Support structure: ~9cmx12cmx12cm

![Undulator Field On-Axis](image1)

![Second Integral](image2)

- Residual translation ~16µm
- Design help from R. Carr of SSRL
Details: Chicane

Chicane strength set by

\[
\frac{\lambda}{2\pi} = \left(\frac{e}{\gamma m_e c}\right)^2 \left(\frac{\Delta \gamma}{\gamma}\right) \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} B(z')dz' \right) dz
\]

(comes from finding path length difference inside buncher due to IFEL induced modulation \( \Delta \gamma \))

For field strengths \(~0.4\) T gives chicane length of \(~12\) cm

Remaining dimensions:

Pole width: 40 mm  Gap: 7mm (fixed)

Magnets: NdFeB \( B_r = 1.25 \) T
  40x10.5x19(38)mm

Coils: 160 turns with 1.5 Amps max

Copper structure with water cooling to base plate (hardware will likely be inside vacuum).

Total dimensions: 16 x 9 x 18 cm
Emittance Growth & Focusing Effects

- Laser acceleration will require very low emittance: effect of bunching hardware should be considered
- Studied by particle tracking through full 3D fields (imported from Mafia). Inject initially cold beam with transverse spot size of 0.1 mm radius
- Focal lengths:
  - Undulator: $f_x > -300$, $f_y = 6.5$ m
  - Chicane: $f_x = -50$, $f_y = 3$ m
- Emittance growth
  - Undulator: $\Delta \varepsilon_x = 0.06$, $\Delta \varepsilon_y = 0.07$ mm-mrad
  - Chicane: $\Delta \varepsilon_x = 0.1$, $\Delta \varepsilon_y = 0.05$ mm-mrad

Note: Actual incoming emittance $\sim 1.25$ mm-mrad
Microbunching Simulation

Use 3D particle tracker code with full gaussian laser field

Assuming $E=60\text{MeV}$ with initial rms spread of $42\text{ KeV}$ and IFEL modulation of $60\text{ KeV}$.
Analytic result obtained in similar manner as bunching in klystrons. Actual microbunches are wider due to electron focusing & laser wavefront curvature. The first 2 corresponding bunch factors are $b_1=0.64$ and $b_2=0.3$ where the longitudinal density is given by

$$\rho = A \left( 1 + \sum_n b_n \cos(nk_L z) \right)$$
Beam Monitors Overlap

- In undulator: Monitor transverse laser/e-beam overlap with 2 YAG screens (upstream & downstream of undulator) viewed with common path long-distance microscope (2mm FOV, ~10μm res.)

- Timing overlap:
  - Gross: photodiode & time-of-flight. Resolution ~ 1 ns
  - Fine: Streak camera. Resolution limited by cherenkov radiator (multipath spread of pulse)
Bunching Performance Monitor (still under study)

- Based on coherent transition radiation from single foil
- For single foil CTR, have transverse term
  \[ \text{Intensity} \propto \exp \left( -\frac{2\pi^2 \sigma_r^2}{\lambda^2 \gamma^2} \right) \]

This would prevent use for E-163 since beam large compared to \( \lambda \gamma \).
Idea: selectively radiate transversely to eliminate destructive portion of output radiation

Measuring intensity at fundamental and first few harmonics should give bunching factors.

\[ \gamma \lambda_{ph} = \text{Or } \sim 100 \text{ microns} \]
Future Research (& discussion ideas)

- All-optical injectors for cheap, compact accelerator
- Will involve small charge (10mA peak current)
- Currently exploring open metal structures for tapering beta
  - (ideas for low phase velocity/tapered beta dielectric structures?)
- Sources ???:
  - Field emitting needle
  - Field/photo emission from backside illuminated thin foil
    (Kretschman geometry)

Structure: planar drift tube linac (similar to foxhole structure. Mikhailichenko AAC 1998 p547)

1D simulation of structure showing capture ~25% of charge
Closing Remarks

• Hardware awaiting commissioning at E-163 experimental area of NLCTA

• Will test IFEL interaction off-resonance with 30 MeV beam available at Stanford SCA
  – Gain experience in laser/e-beam overlap; diagnostics & control

• Still longer term: research all-optical injectors on a chip
  – Both structure & sources