Dynamic Beam Control for Low-Energy Photo-Electrons

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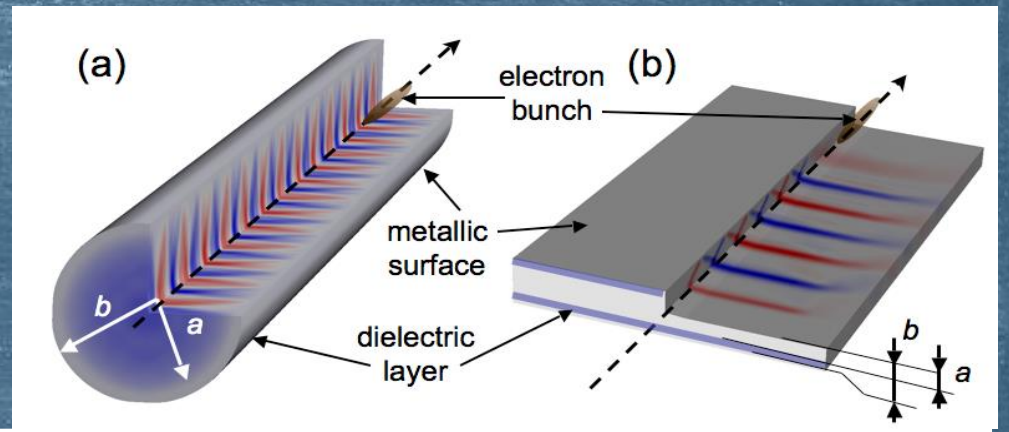
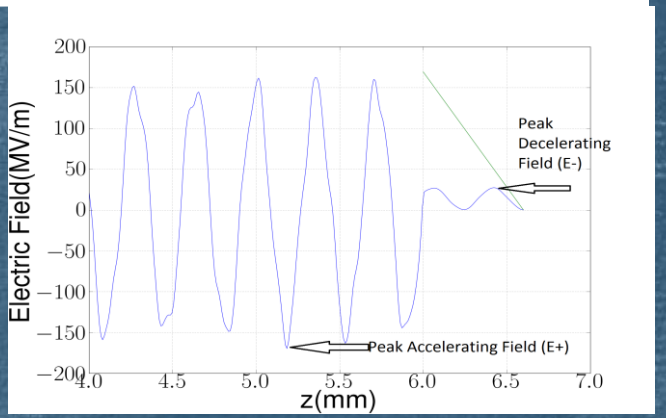
Fermilab's New Perspectives

Dielectric-Lined Waveguides (DLW) for Acceleration

- Beam driven acceleration (Voss-Weiland '82)
  - Drive bunch generates wakefield
    - 1D Green's function W(a, b, ε)
    - Longitudinal current (efficiency, amplitude)
    - High energy → Static wake
    - Shorter bunches → Larger field
- Advantage/Disadvantage
  - Orders of magnitude cheaper than RF/SRF
  - Fields limited by drive beam quality (fitting)
  - Gradients +GV/m compared to ~30 MV/m (SRF) (CLIC go for 100 MV/m)



$$E(z) = \sum_n \int_{-\infty}^{z} I(z-\tilde{z}) W_n(\tilde{z}) d\tilde{z}$$



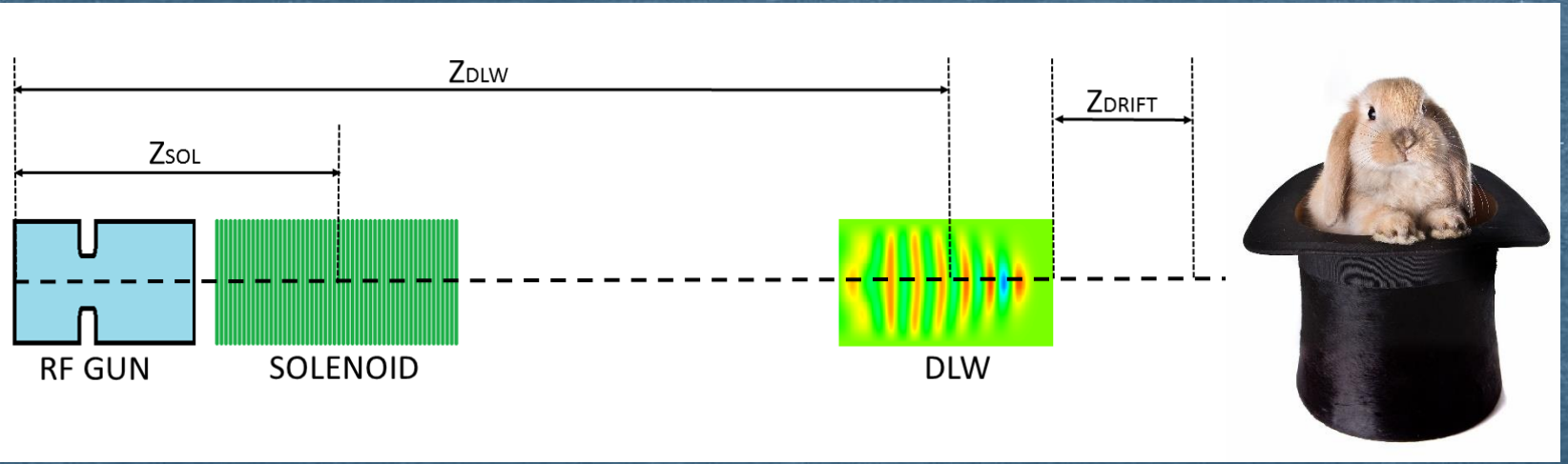
Static vs Dynamic Beams

Recall $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ $E = \gamma(\mathbf{u}) m_0 c^2$

- Ultra relativistic regime (static/frozen beams)
  - Very small velocity change for energy change
- Low energy (< 10 MeV) (dynamic)
  - Energy modulations → Density modulations?
  - Can we do something exciting?

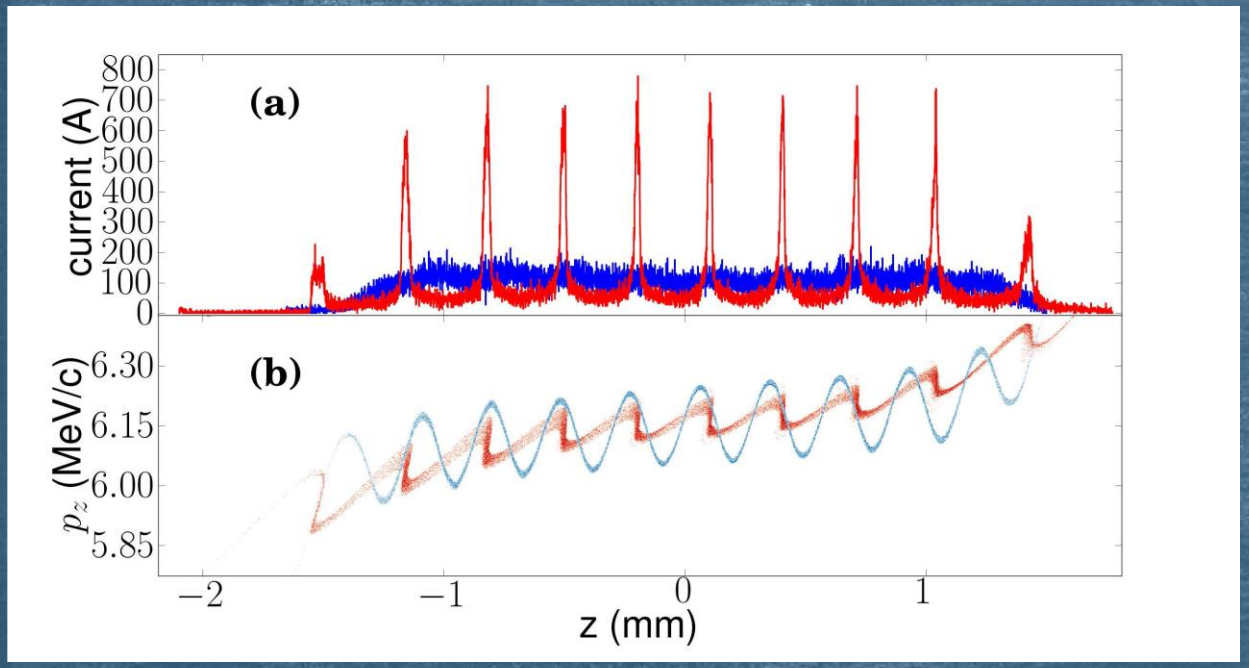
The Scheme

- Photo-Injector
  - RF-Gun – electrons from photo-emission (laser)
  - Lead to ~mm bunch lengths (nC ~ 100 A bunches)
  - 3-10+ MeV energy out of gun (L(1.3GHz - 35 MV/m) vs S(2.856 GHz – 120 MV/m), X…)
- Use solenoid to focus into DLW. Then drift…

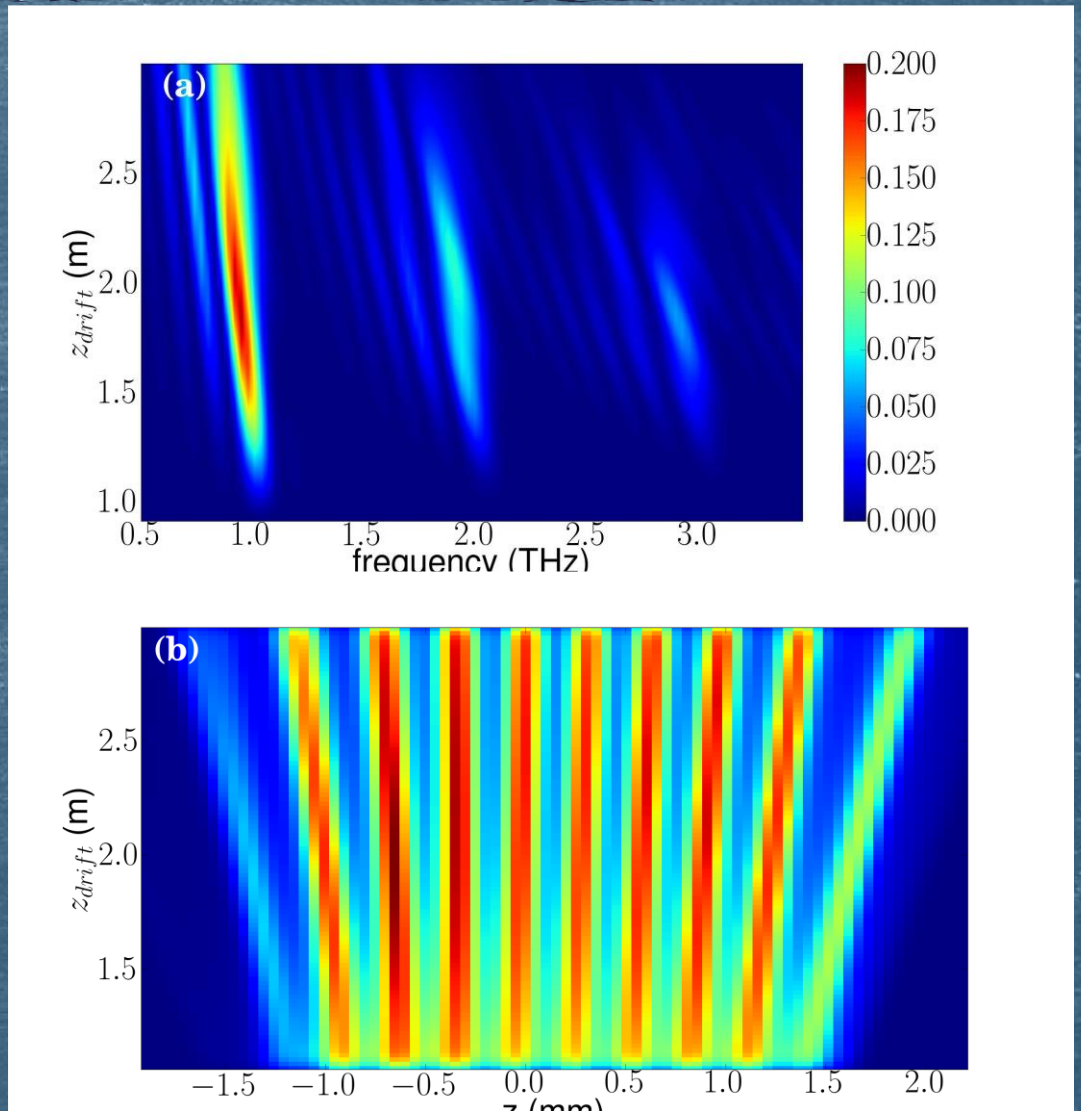


Ballistic bunching (1 THz)

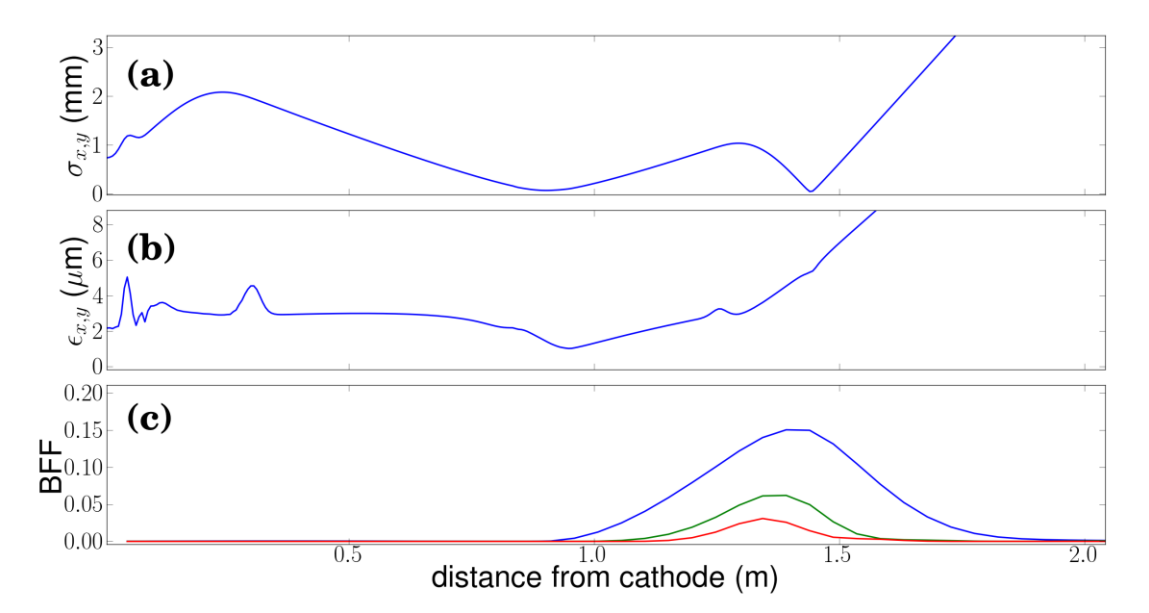
- S-Band example: (a, b, ε, L) = (350 um, 363 um, 5.7, 11 cm)



$$\widetilde{F}(\omega) = \frac{1}{N^2}\left(\left|\sum_i^N \cos\frac{\omega z_i}{c}\right|^2 + \left|\sum_i^N \sin\frac{\omega z_i}{c}\right|^2\right)$$

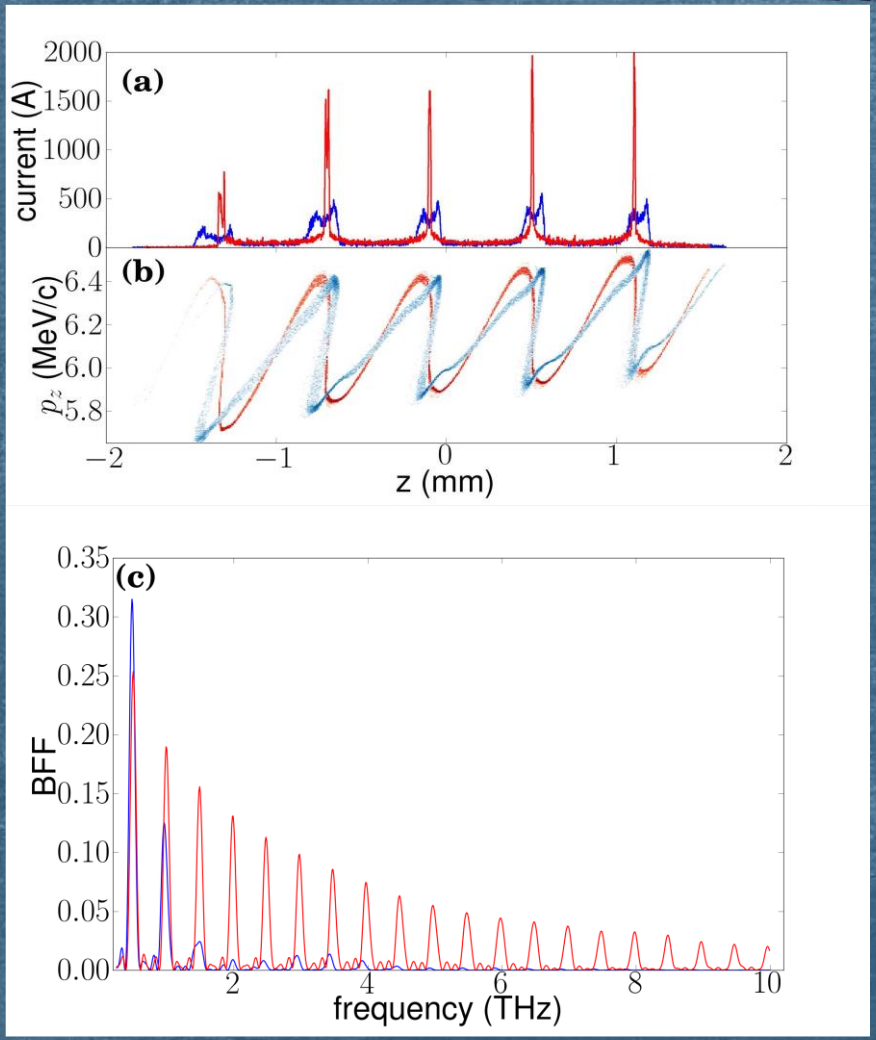


1THz Continued..



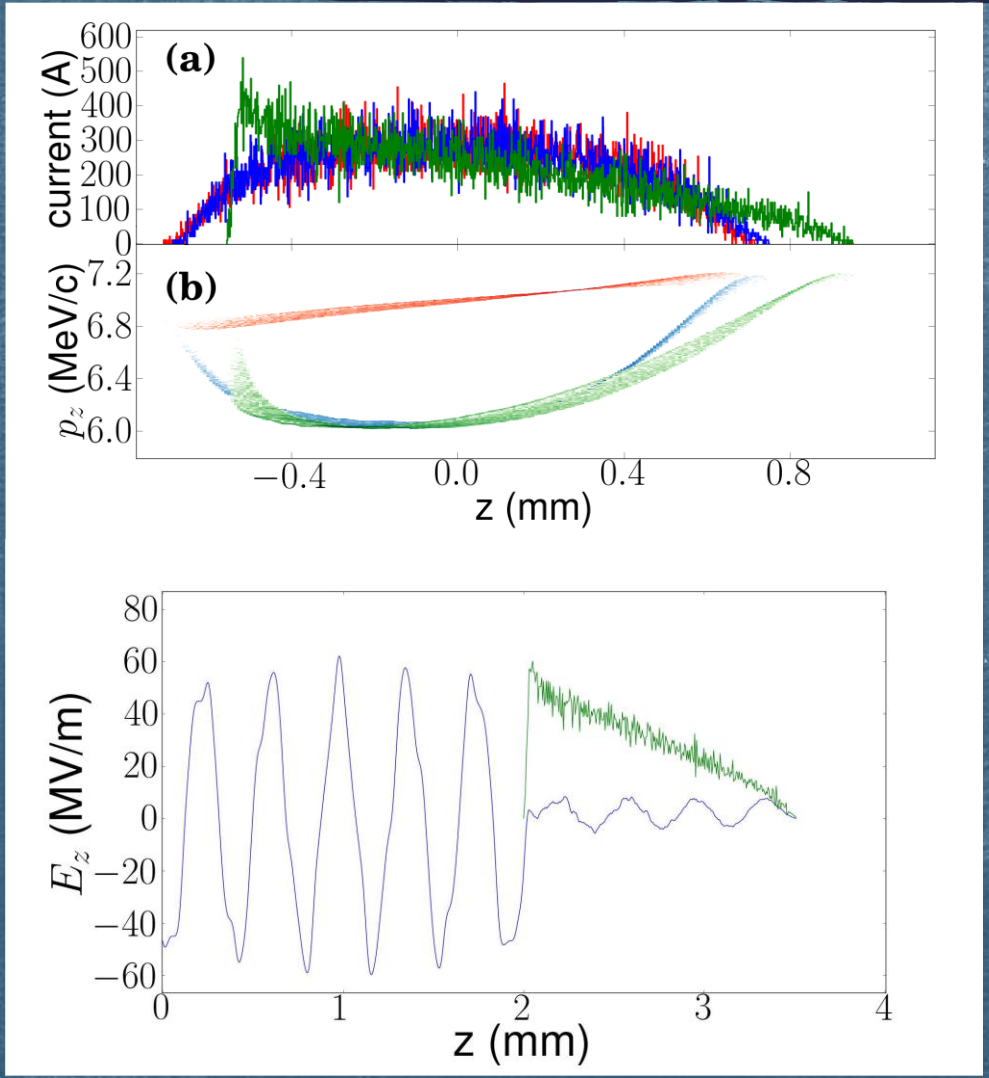
- Fitting into 11 cm structure OK (84 % transmission)
- DLW length change impact?
- Can we do better than BFF=0.2?
  - Initial LPS a problem
    - Solution 1: Longer bunch
    - Solution 2: Lower the frequency

500 GHz DLW – (350 um, 393 um, 5.7)



- Large harmonic content at maximum compression.
- Higher mode suppression by under/over compressing the bunches.

Longitudinal Shaping



- Larger wavelengths (λ~σ)
  - Bunch shaping
  - Passive bunching
  - De-chirper/Linearizer
- Ramped bunch for high transformer ratio acceleration.
  - Here for (165 um, 197 um, 5.7)
  - R = 7.3 (Theoretical max 9.3)

Conclusion

- Dynamical beam control with simple setup.
- Could be implemented in electron machines easily/affordably.
- Can generate micro-bunch train

- Thanks!

Questions & Discussion