Operational Considerations for Laser Control of the FCC Bunch Intensity

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Abstract

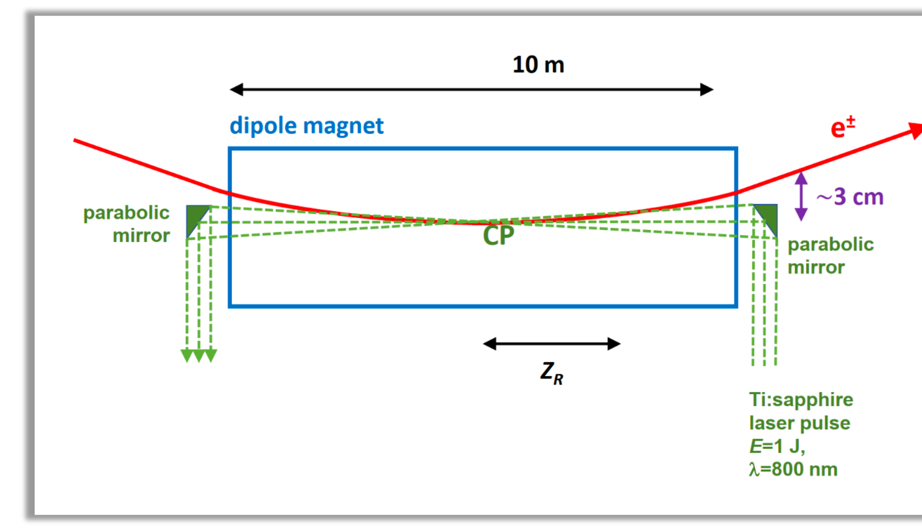
The charge imbalance between colliding bunches in the FCC-ee ring must be less than 3-5% in order to avoid the beamstrahlung-induced flip-flop instability [1]. The charge of the colliding bunches is leveled through top-up injection, but this is a slow process. Laser Compton back scattering (CBS) has been proposed as a mechanism to quickly level the charge of colliding bunches between top-ups [2]. This scheme has been shown to be effective through simulations of the Compton interaction and turn-by-turn modeling of the FCC [3]. In this work, we seek opportunities to improve performance and reliability of the CBS system. We explore strategies for reducing the required energy in the laser pulse by reducing the pulse spot size. To prevent radiation damage to the laser optics, we introduce a finite angle of incidence between the laser and e+/e- beams. We study the interplay between angle of incidence and laser pulse length in this scenario. We investigate novel concepts, such as using short pulse lasers for quenched photon emission in the strong-field regime [4,5]. Finally, we discuss opportunities for experimental tests using the E320 infrastructure at FACET-II.

Bunch Intensity Control Concept

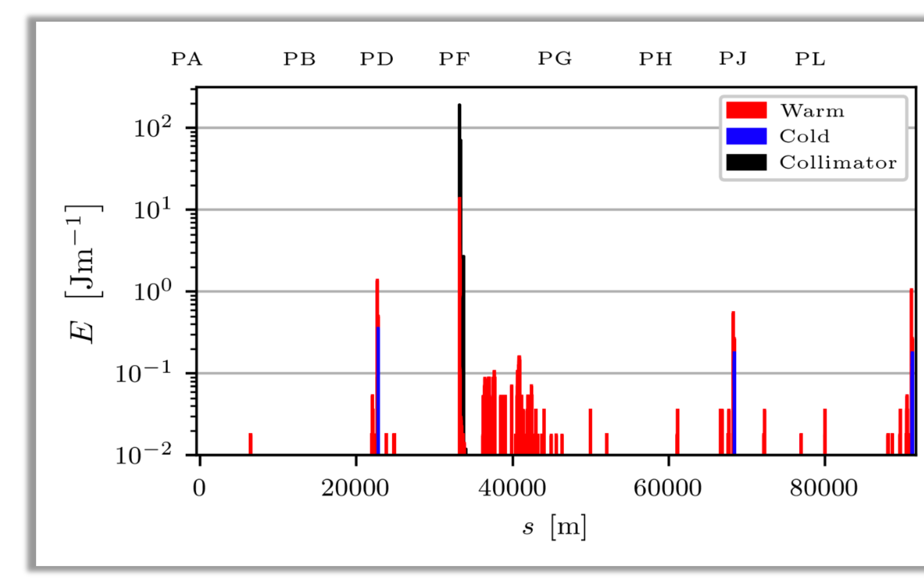
Concept: Use laser Compton back scattering (CBS) to control the intensity of colliding bunches in the FCC ring.

Challenges:

- The Compton cross section is small, which implies laser pulse energy.
- The Compton gamma cone is scattered in the direction of the laser optics.
- Modeling and understanding losses in the ring. Is this scheme compatible with ring optics and collimation systems.

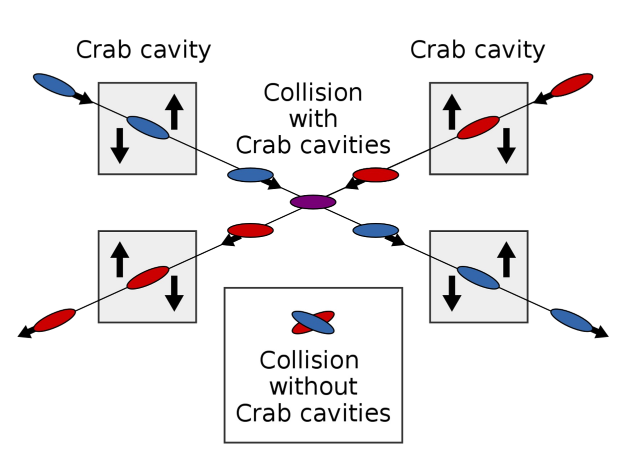


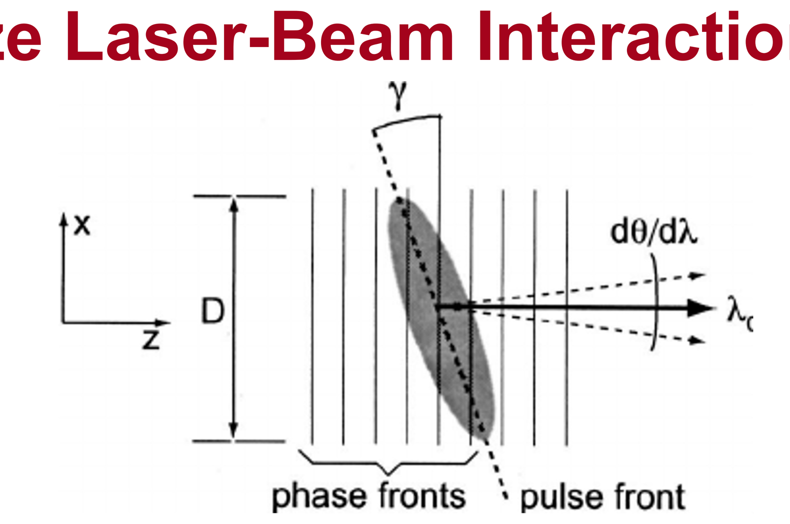
Concept for CBS with interaction inside a dipole from Ref [2].



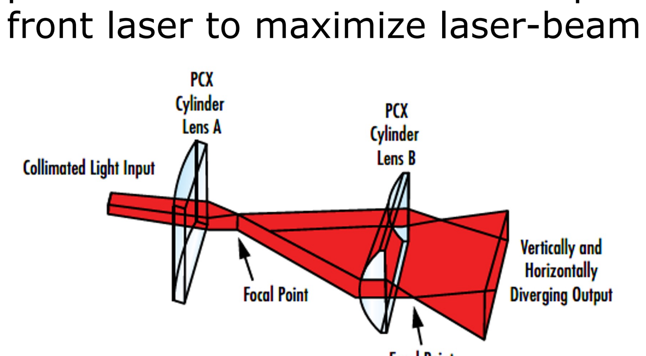
Modeled losses in the ring from Ref [3].

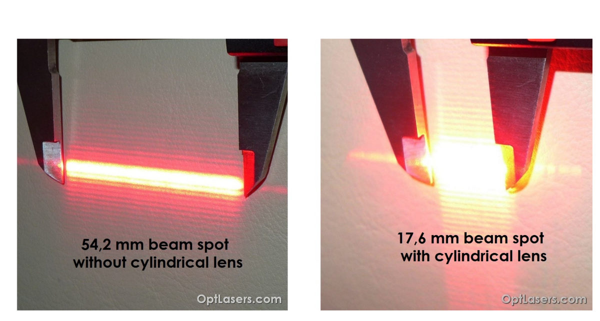
Schemes to Optimize Laser-Beam Interaction



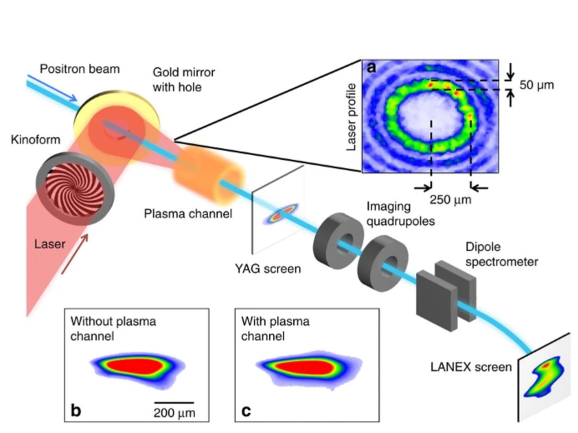


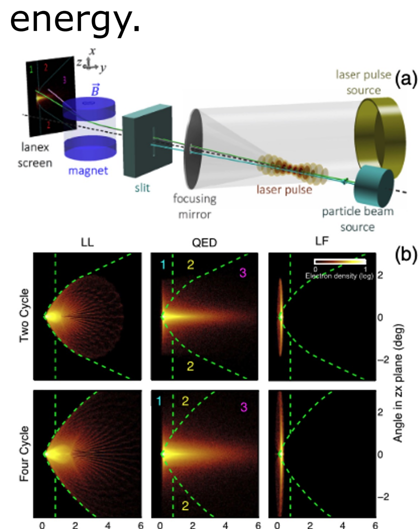
The crab cavity scheme is invoked to maximize overlap between electron and positron beams at the collision point. A similar concept involves a tilted phase-front laser to maximize laser-beam overlap for lasers propagating at an angle.





Cylindrical lens are used to redistribute light to match the aspect ration of the beam while minimizing the required laser pulse energy.





Hollow laser pulses [7] will be explored in the context of bunch collimation. Ultrashort pulses will be explored for low pulse energy, but high pulse intensity collimation studies.

References

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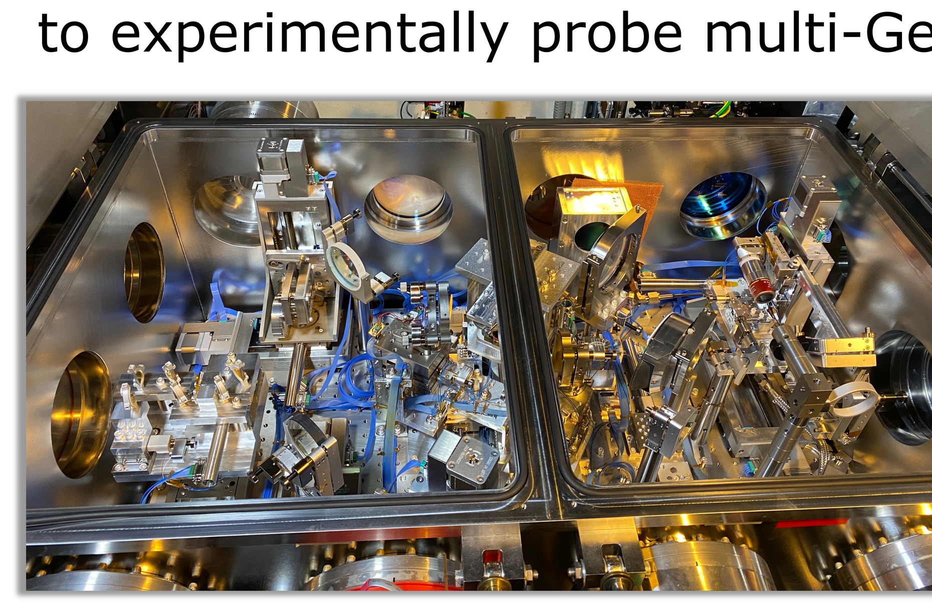
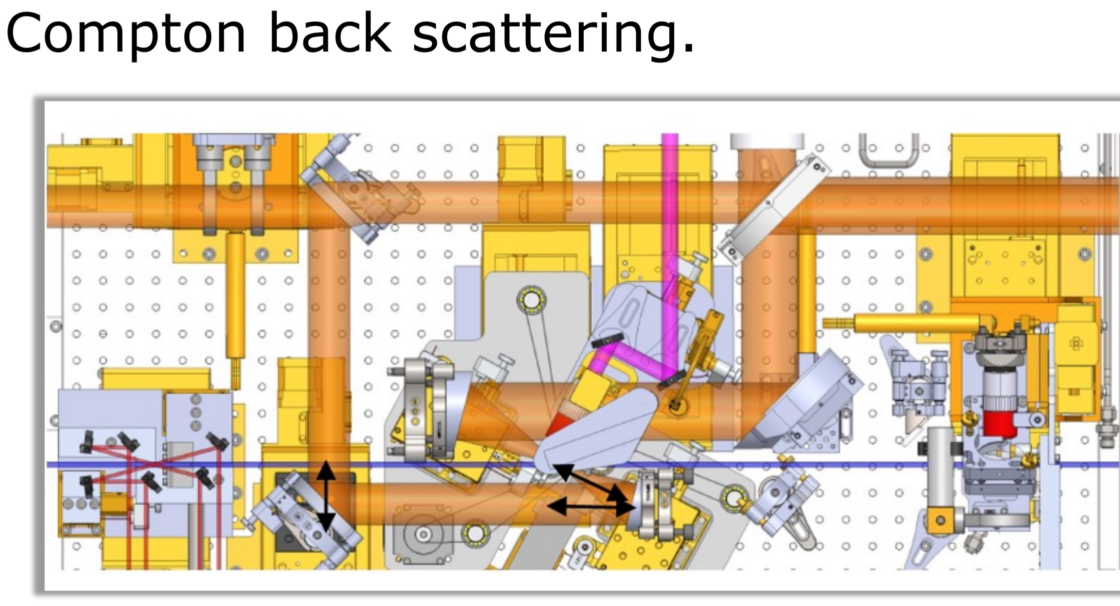
Experiments at FACET-II

FACET-II delivers high peak current electron bunches at 10 GeV energy. FACET-II also delivers high intensity laser pulses to the experimental interaction region. This is one of few facilities world-wide with the capability to experimentally probe multi-GeV Compton back scattering.





The E320 experiment at FACET-II collides 10 GeV electron beams with multi-TW laser pulses to probe strong field QED effects. The geometry of the interaction region can be modified to simulate the FCC CBS IR.

Simulation Validation

Table 3. Features of traditional beam-beam codes (GUINEA-PIG, CAIN) and first-principles electromagnetic PIC codes (WarpX, OSIRIS). Physics processes that are currently missing from WarpX and OSIRIS are in the process of being implemented.

Physics Process	GUINEA-PIG	CAIN	WarpX	OSIRIS
Quantum Synch.	✓	✓	✓	✓
Bethe-Heitler	✓	✓	×	✓
Linear Breit-Wheeler	✓	✓	×	×
Landau-Lifshitz	✓	✓	×	×
Coherent Pair Production	✓	✓	✓	✓
Trident Cascade	✓	×	×	×
Hadronic Production + Minijets	✓	×	×	×
Electron-Laser Interaction	×	✓	✓	✓

Under development

The WarpX code will be evaluated against the CAIN and GUINEA-PIG codes [6], as well as experiments at FACET-II, to evaluate the fidelity of the CBS modeling.