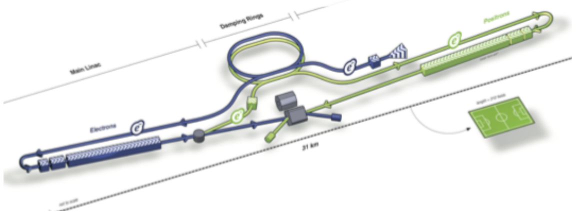
Developing new technologies for next-generation research facilities

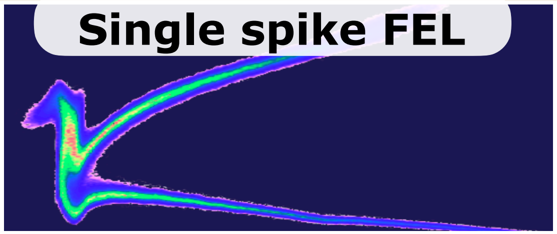
Future HEP collider



Alternative beamstrahlung mitigation strategy based on short, round beams: 100x reduction in beam power and thus costs $\sigma_z \sim 1\ \mu m @ 1\ TeV$

R. Blankenbecler, S. Drell, PRD 36, 277 (1987)

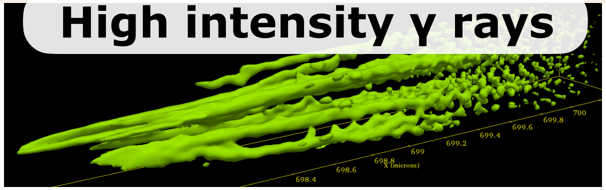
Single spike FEL



X-ray pulse has single spike when radiation emitted by the electrons in beam tail, travels to beam head in time shorter than few gain times $\sigma_z \sim 0.1\ \mu m @ 10\ GeV$

R. Bonifacio et al. PRL 73, 70 (1994)

High intensity γ rays

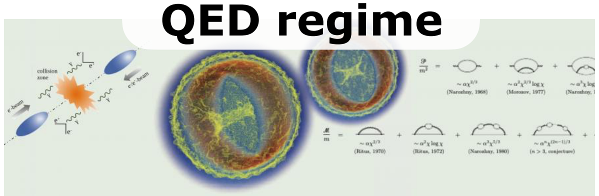


- Counter-streaming beam and plasma electrons result in instability and form self-generated beam filaments and strong EM fields.
- Convert joule-level electron-beam energy into gamma-rays via plasma instabilities

$\sigma_z \sim 0.5\ \mu m @ 10\ GeV$

A. Benedetti et al. Nature Photon. 12, 319 (2018)

Fully non-perturbative QED regime



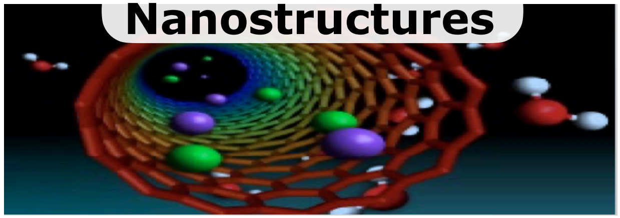
- Beam-beam collisions of short bunches can create the largest EM fields in the universe
- Access the regime where dynamical mass generation becomes dominant over the Higgs mechanism $\sigma_z \sim 0.1\ \mu m @ 100\ GeV$

V. Yakimenko, et.al. PRL 122, 190404 (2019)

Beam Physics Advancement

- Disruptive progress in accelerator technology is required in order to advance high energy physics
- Ultra-short, high-intensity beams promise to facilitate seminal research opportunities far beyond HEP
- The benefit of these opportunities outweigh the greater uncertainties associated with handling beams with such extreme parameters

TV/m in Crystals and Nanostructures



Acceleration in plasmas created from crystals and nanostructures facilitate extreme gradients, continuous focusing – the properties needed for producing high-quality, high-energy beams

$\sigma_z \sim 0.3\ \mu m @ 10\ GeV$

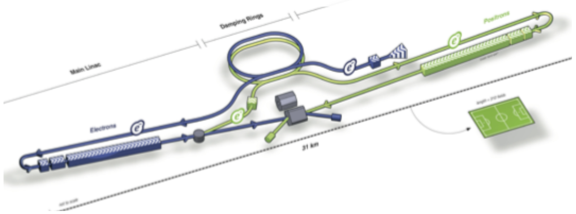
T. Tajima, et.al. PRL 59,1440 (1987)

Ultra-Short Bunches to Enable Qualitatively New Physics

Developing new technologies for next-generation research facilities

SLAC

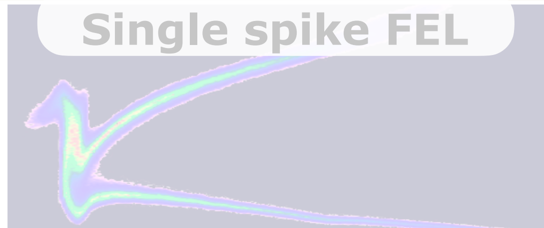
Future HEP collider



Alternative beamstrahlung mitigation strategy based on short, round beams: 100x reduction in beam power and thus costs $\sigma_z \sim 1\ \mu m @ 1\ TeV$

R. Blankenbecler, S. Drell, PRD 36, 277 (1987)

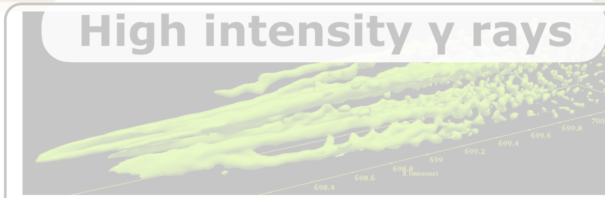
Single spike FEL



X-ray pulse has single spike when radiation emitted by the electrons in beam tail, travels to beam head in time shorter than few gain times $\sigma_z \sim 0.1\ \mu m @ 10\ GeV$

R. Bonifacio et al. PRL 73, 70 (1994)

High intensity γ rays

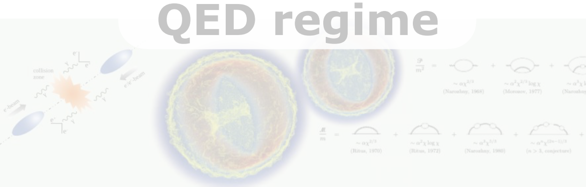


- Counter-streaming beam and plasma electrons result in instability and form self-generated beam filaments and strong EM fields.
- Convert joule-level electron-beam energy into gamma-rays via plasma instabilities

$\sigma_z \sim 0.5\ \mu m @ 10\ GeV$

A. Benedetti et al. Nature Photon. 12, 319 (2018)

Fully non-perturbative QED regime



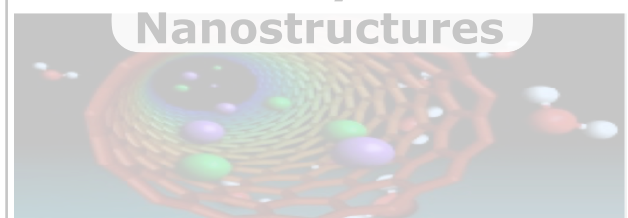
- Beam-beam collisions of short bunches can create the largest EM fields in the universe
- Access the regime where dynamical mass generation becomes dominant over the Higgs mechanism $\sigma_z \sim 0.1\ \mu m @ 100\ GeV$

V. Yakimenko, et.al. PRL 122, 190404 (2019)

Beam Physics Advancement

- Disruptive progress in accelerator technology is required in order to advance high energy physics
- Ultra-short, high-intensity beams promise to facilitate seminal research opportunities far beyond HEP
- The benefit of these opportunities outweigh the greater uncertainties associated with handling beams with such extreme parameters

TV/m in Crystals and Nanostructures



Acceleration in plasmas created from crystals and nanostructures facilitate extreme gradients, continuous focusing – the properties needed for producing high-quality, high-energy beams

$\sigma_z \sim 0.3\ \mu m @ 10\ GeV$

T. Tajima, et.al. PRL 59,1440 (1987)

Ultra-Short Bunches to Enable Qualitatively New Physics

HEP collider with ultra short bunches and low beam power

Phil H. Bucksbaum, Gerald V. Dunne, Frederico Fiuza, Sebastian Meuren, Michael E. Peskin*, David A. Reis, Greger Torgrimsson, Glen White, and Vitaly Yakimenko*

SLAC

$$\mathscr{L} = \frac{P_b}{E_b}\frac{N}{4\pi\sigma_x\sigma_y}$$

Present designs for high energy colliders based on mitigating beamstrahlung with flat $\sigma_x \gg \sigma_y$ and elongated bunches:

$$n_\gamma \propto \left(\frac{\sigma_z}{\gamma}\right)^{1/3}\left(\frac{N}{\sigma_x+\sigma_y}\right)^{2/3}; \quad \mathscr{L} \propto \frac{n_\gamma^{2/3}}{\sqrt{\sigma_z}\sigma_y}\frac{\sigma_x/\sigma_y+1}{\sigma_x/\sigma_y}$$

Idea: Short bunches ->

beamstrahlung suppressed ->

round beams at IP ->

≳100x reduction in beam & wall power / backgrounds / activation / cost

Radiation Probability: $W \approx \alpha\chi_{av}^{2/3}\frac{\sigma_z/\gamma}{\lambda\!\!\!^{-}}$

Disruption Parameter: $D \approx \frac{2N\alpha\lambda\!\!\!^{-}_c\frac{\sigma_z}{\gamma}}{\sigma_r^2}$

$\sigma_z \sim 100\ nm@100\ GeV\ \&\ \sim 1\ \mu m@1\ TeV$

Can we compress bunches to sub-micron length and ~MA peak currents while mitigating CSR emittance growth?

- FACET-II S2E simulations (too be tested soon):

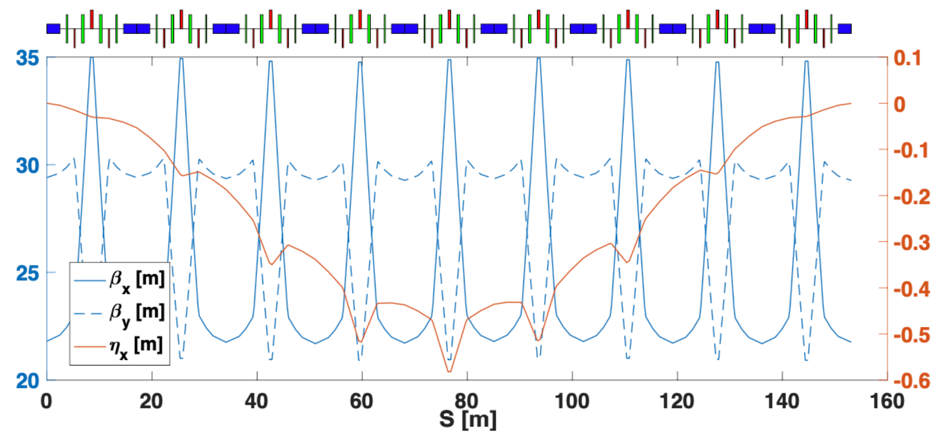
10GeV; $I_p \sim$ 300kA, $\sigma_z \sim$ 0.5μm, $\Delta\varepsilon_n \sim$ 3 -> 30μm

- FACET-III S2E simulations:

(150m compressor at 30 GeV)

$I_p \sim$ 300kA, $\sigma_z \sim$ 0.5μm, $\Delta\varepsilon_n \sim$ 0.5 -> <2.5μm

$I_p \sim$ 100kA, $\sigma_z \sim$ 1.5μm, $\Delta\varepsilon_n \sim$ 0.5 -> <1μm



- Short bunch and NpQED collider at 125GeV

6km compressor strawmen design