HEP GARD: Accelerator Physics Needs for Future e^+e^- and e^-h Colliders

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HEP GARD Abstract for Future Collider Studies

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Title: Accelerator Physics Needs for Future e+e- and e-h Colliders

Abstract: There are several new and future e+e- and e-hadron colliders that are in commissioning or being proposed that require substantial new accelerator physics studies. The ring lattices need low emittance optics and often precise spin manipulation and control. The future collision point beta-functions are 1 mm or below requiring two rings, large crossing angles, and precision collision feedbacks. These colliders have interaction regions with crab crossing or crab-waists. The beam collisions need extended beam-beam calculations and simulations to optimize the expected luminosity. The beam backgrounds in the detectors have the potential to be quite high because of the high beam currents and large IR-quadrupole beta functions. These high beam currents and top-up injection require excellent injectors, high power RF systems, tolerant beam abort systems, complex vacuum chambers with significant HOM damping, and bunch-gap RF transient compensation schemes. The hadron rings will need powerful emittance damping at both low and high beam energies. The workshop talk will illuminate these needs and possibilities.

GARD Workshop: Collider Studies (involves all WGs)

- Workshop #1 (LBNL, Dec. 9-10, 2019):
  - (WG1) Single-particle dynamics, including nonlinearities, and spin dynamics.
  - (WG2) High-brightness beam generation (including polarized beams), transport, manipulation and cooling.
  - (WG3) Mitigation and control of collective phenomena: instabilities, space charge, beam-beam, beam-ion effects, wakefields, and coherent synchrotron radiation.
  - (WG4) Connections to other GARD roadmaps (cross-cutting WG1-3)

P5 Recommendations for Frontier Colliders (April 2014)

Science Drivers (2 of 4):

- Use the Higgs boson as a new tool for discovery
- Explore the unknown: new particles, interactions, and physical principles

Recommendations: (3 of 22)

- Recommendation 4: Maintain a program of projects of all scales, from the largest international projects to mid- and small-scale projects.
- Recommendation 10: Continue LHC collaboration, LHC (HL-LHC) upgrades of the accelerator and both experiments (ATLAS/CMS).
- Recommendation 11: Engage in modest and appropriate levels of ILC accelerator and detector design..

P5 Accelerator Subcommittee Recommendations (April 2015) for Frontier Colliders (9 of 15)

- R2: Beam simulations
- R5a: Next generation pp collider
- R5b: High field magnet R&D
- R6: SRF for 1 TeV
- R7: PWFA
- R8: LWFA
- R9: Advanced concepts for multi-TeV collider
- R11: High power RF sources and high gradients
- R13: NC RF for multi-TeV

Accelerator Grand Challenges for Future Collider Studies (1)

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Accelerator Grand Challenge #1 (beam intensity):

- High bunch charges (now 15 nC→ 30 nC)
  - e cloud, resistive wall, compression, bunched cooling
- High beam currents (now 2 A → ~4 A)
  - Efficient injection, top-up, HOMs,
- Multi-bunches (now 1500 →2500)

  Feedbacks (L+T), RF gap transients, instabilities
- Higher Order Modes (8x worse)
  - Beam instabilities, vacuum heating, mode damping, IP heating

Accelerator Grand Challenges for Future Collider Studies (2)

Accelerator Grand Challenge #2 (beam quality):

- Collide with low x/y emittances (now nm → pm)
- Collide with low β_y^* (3 mm → 0.3 mm)
- High beam-beam parameters (now ξ_y = 0.1 → 0.2)
- Beam tail generation (low lifetimes ~30 min → higher)
- Low beam tail generation (high backgrounds → lower)

Accelerator Grand Challenges for Future Collider Studies(3)

Accelerator Grand Challenge #3 (beam control):

- Touschek lifetime maximization (better optical lattices)
- Beam-beam lifetime (top-up injection stronger)
- IP collision alignment control (dither feedback, b-b deflection)
- Background reduction (collimation, steering, coupling, masking)
- Multi-bunch instability control (faster feedback, gap transients)
- Crabbed bunch beam dynamics (phase and amplitude control, bunch lengths [σ_z ~10% λ_{rf}])
- Crab cavities at the IP (massive crab cavity installations (now 1 to ~20)
- Spin manipulation at IP (Figure-8, Siberian snakes, high energy spin rotators, injection charge/spin exchange, spin resonance reduction)
- Rapid energy changes (e.g. Z, Higgs, Top)

Accelerator Grand Challenges for Future Collider Studies (4)

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Accelerator Grand Challenge #4 (beam prediction):

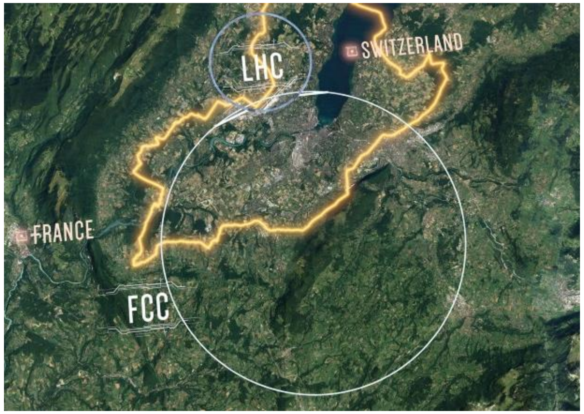
Beam-beam parameters (best tunes, tuning knobs)

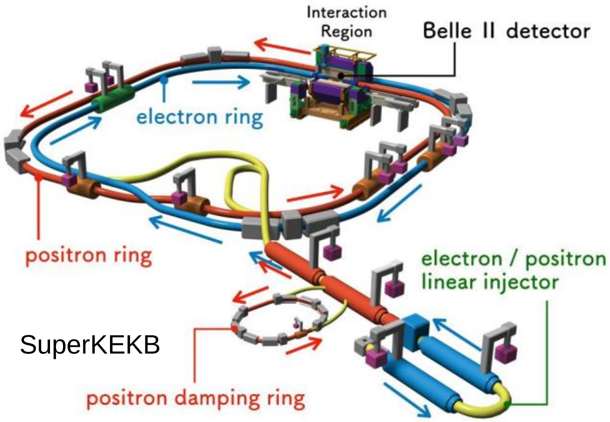
Beam-beam blow-up simulations (tail tracking, masking)

Machine detector-backgrounds (best detector characteristics, IP chamber dimensions and shapes)

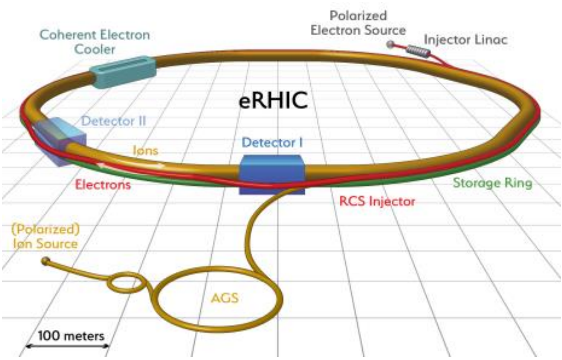
Beam spin lifetime (best manipulation and injection)

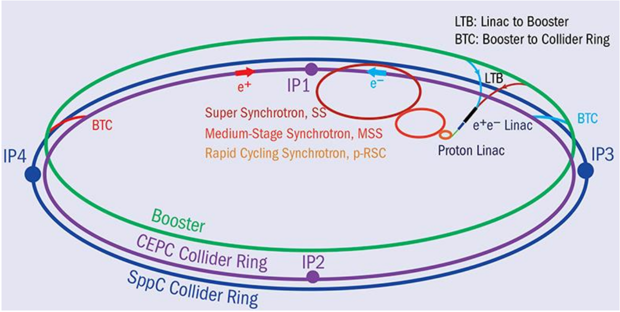
Present and future collider examples:

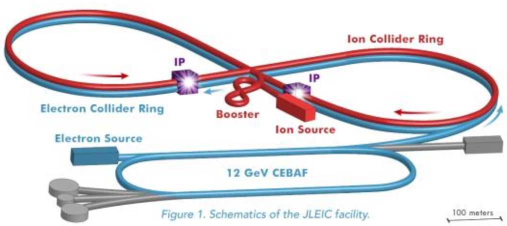




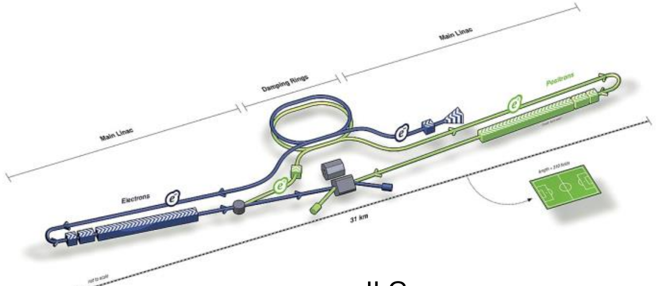
SuperKEKB



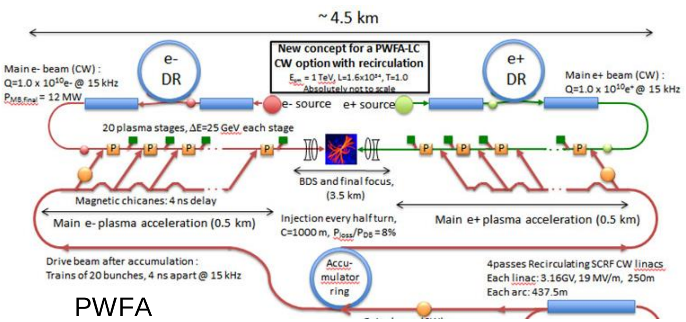




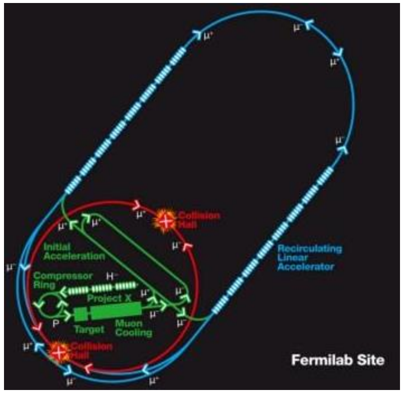
JLEIC



ILC

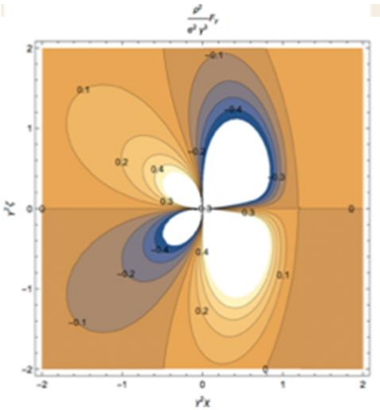


PWFA

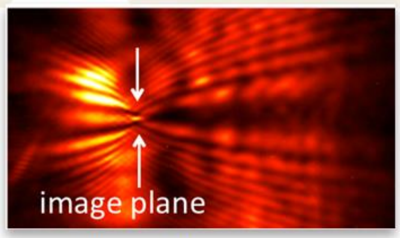


Muon

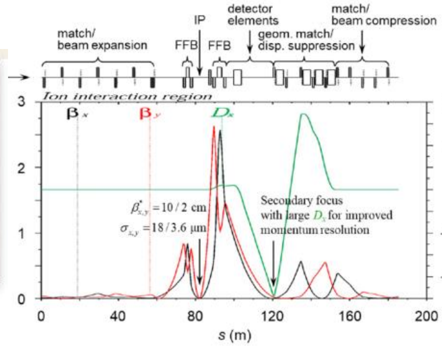
Present and future collider study examples:



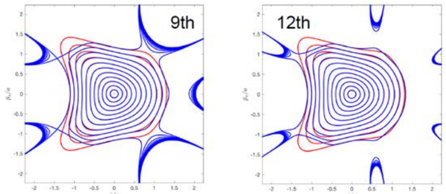
Vertical CSR field



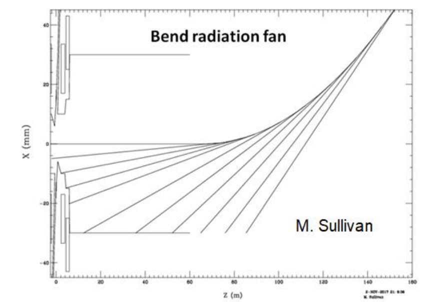
Plasma Wake Image



JLEIC IR

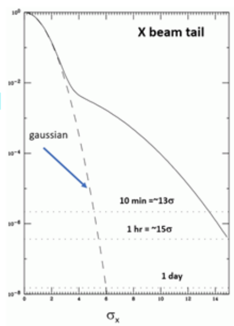


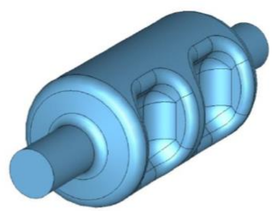
Yunhai Cai, SLAC, Beam Dynamics Workshop, IHEP Beijing



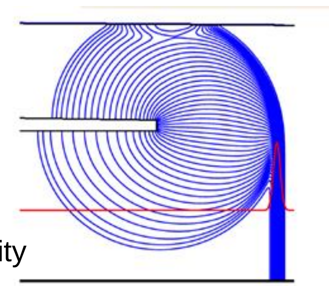
IP background studies

EIC beam tail background studies

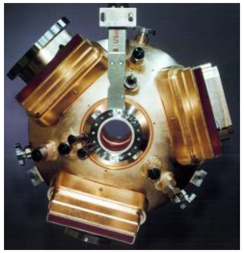




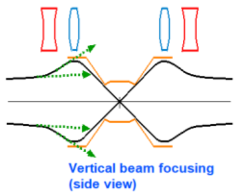
JLEIC SC Crab Cavity



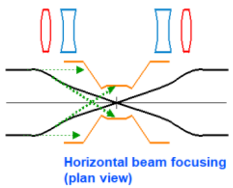
IR bunch HOM simulations and heating estimations

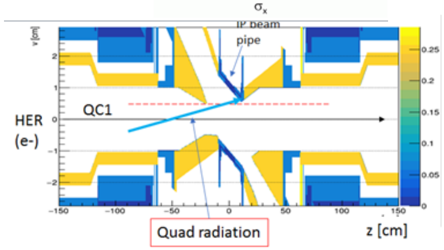


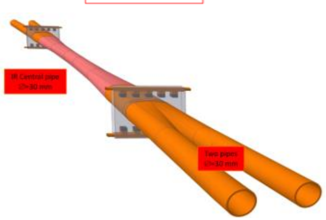
NC RF cavities

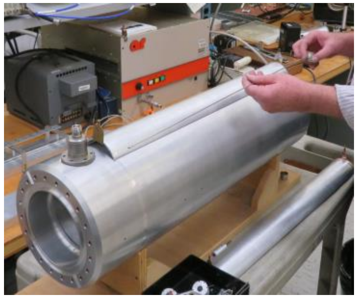


SKEKB dither feedback coils

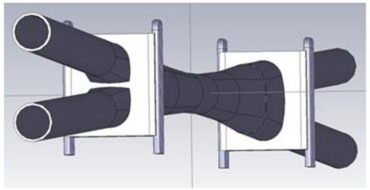




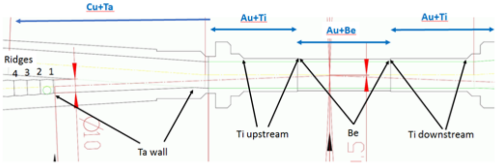




Transverse Kickers



FCCee IR HOM Model



Belle-2 IR background layout and studies

HEP mission:

- How is your proposed research related to the HEP-specific missions?
  - Intensity frontier: High Luminosity colliders (SuperKEKB, FCCee, CEPC)
  - Energy frontier: Hadron colliders (LHC-HL/HE, FCChh, SPPC)
  - Energy frontier: Lepton colliders (ILC, NC/SC TeV Linear Collider)
  - Colliders and accelerators beyond Standard Model (ALL)

- “Blue-sky” with high-impact and relevance to HEP:
  - PWFA, LWFA, Muons, Gamma-gamma, High field

Synergies for collider studies

- HEP:
  - CERN: LHC, LHC-HL, LHC HE, LeHC, FCCee, FCCeh, FCChh, DRs
  - China: BEPC, Tau-Charm, CEPC, SPPC, DRs
  - Japan: SuperKEKB, ILC, DRs
  - Russia: VEPP-2000, Tau-Charm
  - Muon colliders
- NP: eRHIC (BNL), JEIEC (TFNAF)
- BES: New high beam-current low-emittance photon sources

Road Map for Colliders

- Operating now: SuperKEKB, LHC, BEPC, VEPP-2000, RHIC
- Operation in 10 years (start building now or in a few years): LHC-HL, ILC (250), CEPC, eRHIC, JLEIC
- Operation in 20 years (start building in 10 years): LHC-HE, FCCee, SPPC, ILC (1 TeV), PWFA (Higgs), LWFA (Higgs), Muons
- Operation in 30 years (start building in 20 years): FCC-hh, SC/NC Linear Collider (2 TeV), PWFA (2 TeV), LWFA (2 TeV)

Accelerator Collider Efforts and Collaborations

- BNL: eRHIC, ILC, CEPC
- FNAL: LHC-HL, LHC-HE, ILC, muons
- LBNL: LWFA collider, ILC
- SLAC: eRHIC, JLEIC, SuperKEKB, ILC, LHC-HE, FCCee, CEPC, PWFA colliders
- US Universities: eRHIC, JLEIC, PWFA, LWFA, ILC
- China: BEPC, Tau-Charm, CEPC, SPPC
- Japan: SuperKEKB, ILC
- Russia: VEP2000, Tau-Charm

- →Facilities needed in the future: The world community needs a steady progression of future colliders to push the state of the art for higher energy and higher luminosity.

Summary: HEP GARD Accelerator Collider Studies

- Many R&D studies to do for future colliders → must continue.
- Need to concentrate on the future best technology options and best physics options as present-day colliders progress.
- Must be an international effort.
- United States needs to be ready for the next (local) big collider project after LBNF/Dune is finished in about ten years.