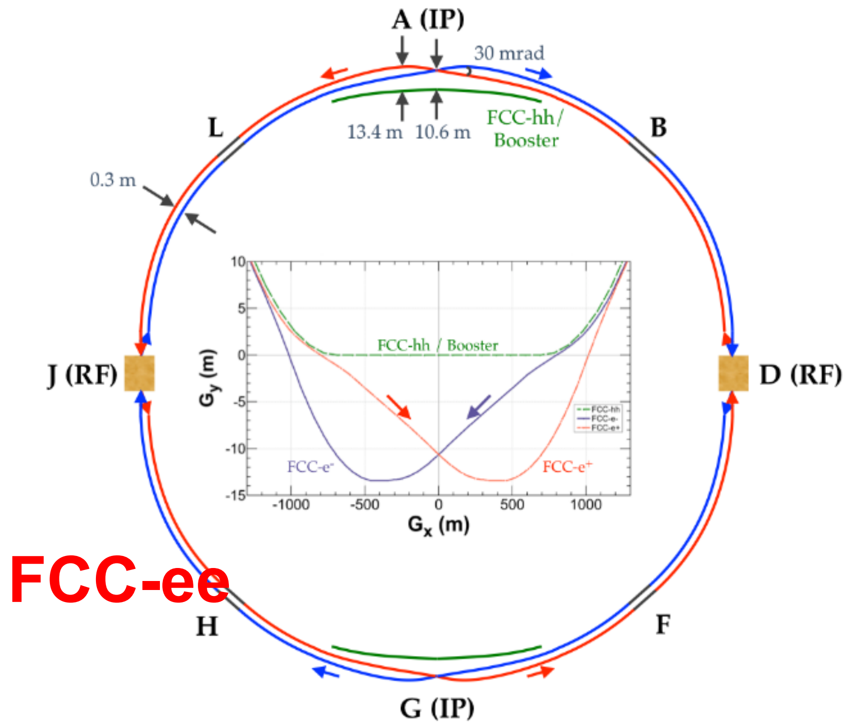
CHART Beam Dynamics Project: Code development plans

M. Benedikt, X. Buffat, F. Carlier, R. De Maria, W. Herr, G. Iadarola, K. Oide, T. Pieloni, L. Rivkin, F. Schmidt, D. Schulte, M. Seidel, S. White, F. Zimmermann

Future Circular Collider Innovation Study Kickoff Meeting, 9-13 Nov 2020

FCC-ee CDR study → collaboration of world experts



parameter	FCC-ee		
energy/beam [GeV]	**45**	**120**	**182.5**
bunches/beam	16640	328	48
beam current [mA]	1390	29	5.4
luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**230**	**8.5**	**1.5**
energy loss/turn [GeV]	0.036	1.72	9.2
total synchrotron power [MW]	100		
RF voltage [GV]	0.1	2.0	4+6.9
rms bunch length (SR,+BS) [mm]	3.5, 12	3.2, 5.3	2.0, 2.5
rms emittance $\varepsilon_{x,y}$ [nm, pm]	0.3, 1.0	0.6, 1.3	1.5, 2.9
longit. damping time [turns]	1273	70	20
crossing angle [mrad]	30	30	30
beam lifetime (rad.B+BS) [min]	68	12	12

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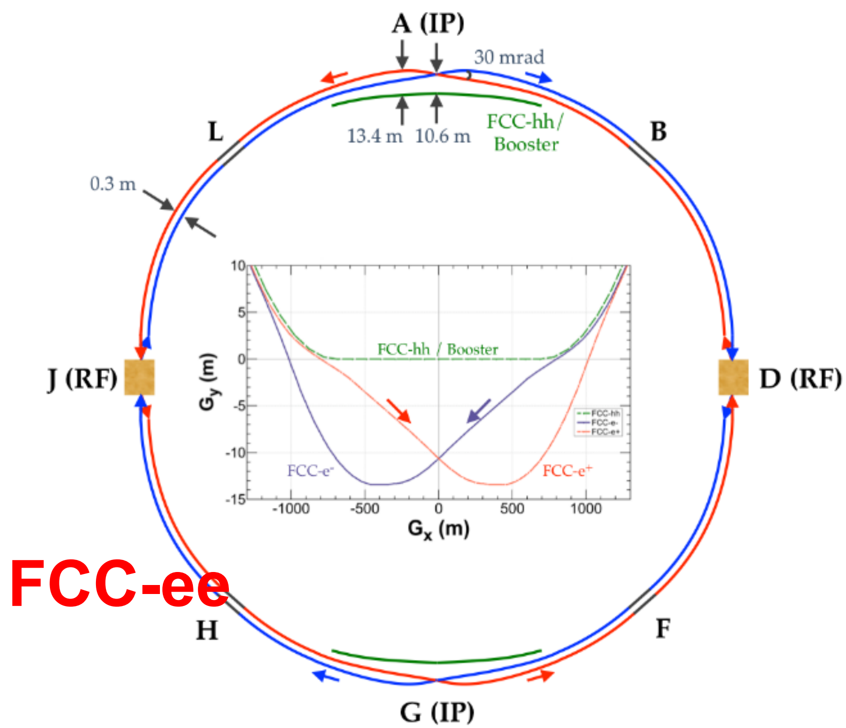

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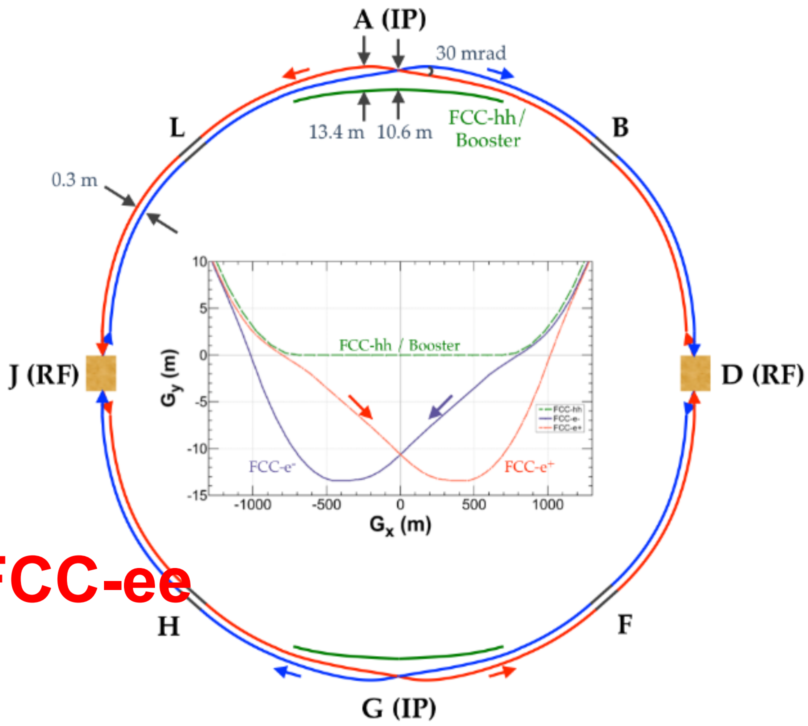
Challenging Physics Program → 3 machines to study and model

FCC-ee CDR study: “software” wise



FCC-ee

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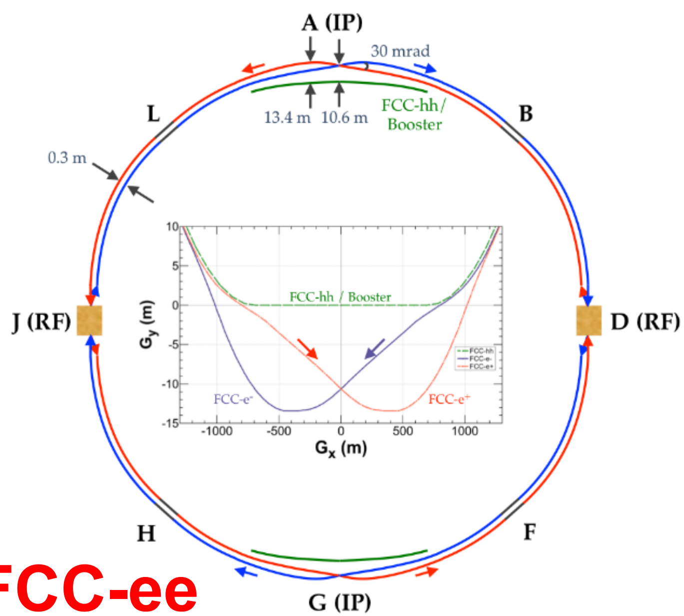

FCC-ee

Lattice design:

(synchrotron radiation, Quantum excitation, lattice elements, tapering, solenoids…)

- SAD (K. Oide KEKB)
- MADX (L. Van Riesen-Haupt, T. Persson LEP/LHC)

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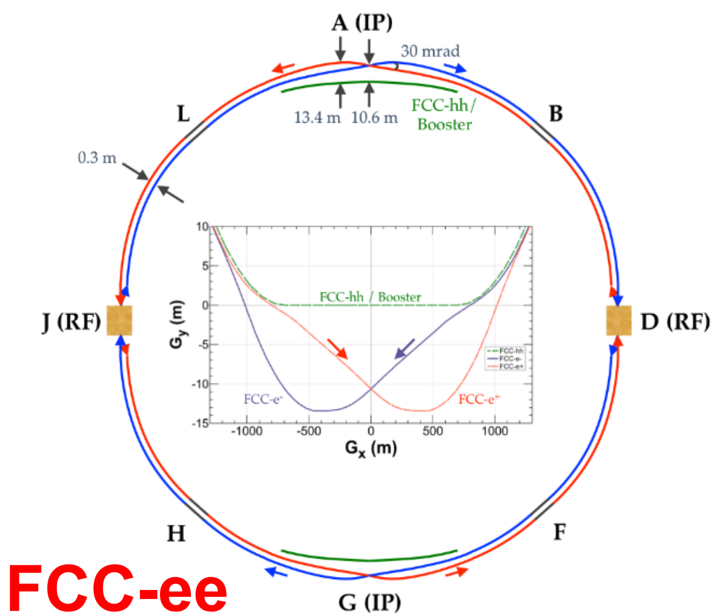

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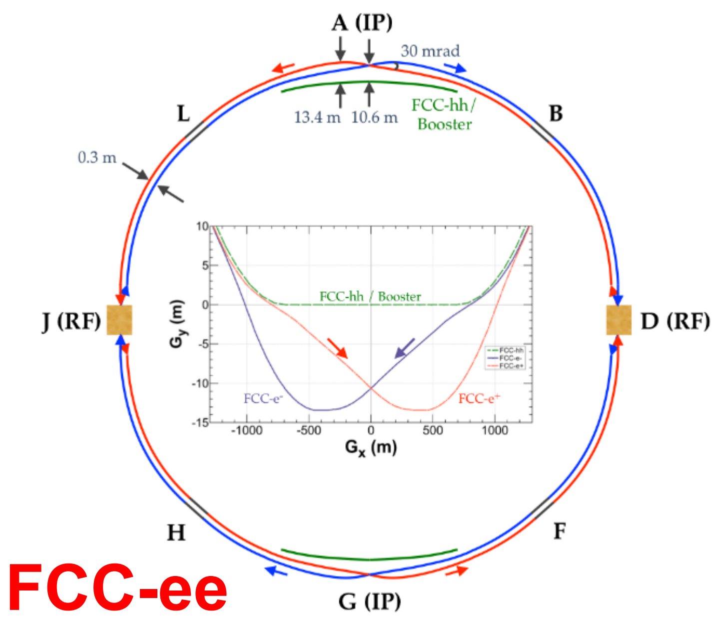
Collective effects:

(Beam-beam, beamstrahlung, impedance, ion instabilities)

- Lifetrack (D. Schatilov)
- Beam-beam model (K. Ohmi KEKB)
- GuineaPIG (D. Schulte CLIC)
- PyHead-tail (L. Mether, E. Belli LHC)
- Impedance models (M. Migliorati)

FCC-ee CDR study: "software" wise



Background studies MDI WG:

- SAD + scattering
- MDISim (MADX + Geant4 H. Burkhardt, M. Luckhof, M. Boscolo)
- MAD-X + scattering

Polarization

- Polarization and spin tracking (E. Gianfelice)

…maybe many more with all the analysis tools that come with them!

Existing codes I

Each code is developed to answer a physics question and for a specific machine

→ Designed and Optimized for these purposes

Difficult to be optimal for all possible cases and physics problems.

For FCC-ee a “**global model” does not exist yet** to answer the open questions for the CDR++.

- represents a big challenge for existing codes since so different
- It is needed to study the interplay of several effects as in real machines

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A global Model should be developed to demonstrate the feasibility of a FCC-ee collider with all ingredients in!

Existing codes II

- **Variety of Languages:**
  - Fortran, C, C++, MATLAB, Python, ROOT, MPI OpenMP, …
- **Different Technologies involved:**
  - Parallelization → high performance clusters
  - Distributed CPU → BOINC systems
  - Accelerated GPUs → GPU clusters
- **Different levels of documentation**: sometimes none
- **People:**
  - Experts: developed physics model and have clear knowledge of code
  - Users: develop the analysis tools and use the models
    - → very little knowledge of the physics model, difficult to extend or study interplay of effects
  - New comers: have to learn and be efficient to contribute to models
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Software needs to be maintainable, modern and user friendly to allow new comers to learn fast, use it and contribute efficiently!

Challenges for the CDR++

- Multiple IPs with multiple bunches self consistent 6D beam-beam + Beamstrahlung + Crabbed Waist + Solenoid
- Lattice description with tilted solenoids and overlapping multiple fields coupled to Beam-beam effects
- Local energy and tapering technique
- 8D tracking capabilities for possible extension for spin tracking studies
- Particle loss description in arcs and at IRs for protection set-up, background studies and lifetime estimations with coupling to radiation transport calculations
- Top-up injection scheme with collisions on
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Complex questions still to be addressed!

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How can we support the FCC-ee collaboration and contribute to the design of the next FCC?

Develop a Modern, Collaborative and Extendable Beam Dynamics Software tool to design the FCC-ee

Swiss Accelerator Research and Technology

CHART Swiss Institute for Accelerator Research and Technology

Approved project: partners EPFL-LPAP and CERN period 2020-2024

Develop a modular and extendable software framework for FCC-ee design and simulation work. In a first phase new functionality includes a multi-turn multiple interaction point model of a Future Circular Lepton Collider (FCC-ee) including a full lattice description, beam-beam modules, beamstrahlung, radiative Bhabha scattering and strong damping for beam lifetime and particle losses studies. Lattice and collective effects should be modeled in a self-consistent approach. The project aims at studying the luminosity reach and background tolerances with cross talk between the interaction points together with possible mitigating technics. Intensity limitations driven by beam stability constrains is the goal of the studies. A newly self consistent simulation tool to design high energy lepton colliders will be delivered together with an operational scenario for the FCC-ee option.

Resources: 1 Post-doc (4y) + 2 PHD students (3y)

Main goals

→ Step by step building up a global beam dynamics simulation model for the FCC-ee

→ Study and propose possible scenarios to reach/extend the colliders physics goals

→ Define a general frame-work and allow for extensions

→ Be general enough to serve a larger community (e.g. muon studies, Light sources)

→ Make it easy for users and new comers to master the complexity of the physics problems to study and propose new ideas

→ Define code development good practice and documentation

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How?

1. Software frame work
2. Lattice 8D tracking module
3. Complete Beam-beam module

Resources and organization:

Core-Team:

EPFL: F. Carlier, W. Herr, T. Pieloni, L. Rivkin (CHART/PSI), M. Seidel (PSI)

CERN: M. Benedikt, X. Buffat, R. De Maria, G. Iadarola, F. Schmidt, D. Schulte, F. Zimmermann

KEKB: K. Oide

ESRF: S. White

2 PhD students tbd from February 2021

Experts: invited on a topic bases

Meetings: every 2-3 weeks

Reporting: at the FCC-ee Design Meetings on Fridays

1. Simulation Software Framework I

Support the FCC-ee community and guide the software developments/ extensions on a common platform :

- Modular
- Support physics studies and developments
- Collaborative approach
- Interphase between used and well established software packages
- Use as much as possible existing codes
  - Guarantee Benchmark and reproducibility of results

1. Simulation Software Framework II

- Fast and optimized to specific problem (i.e. explore new solutions to fasten computing time and modernize existing models)
- Use of modern technologies and algorithm is a priority
    - Parallel computing
    - GPU
    - Machine learning techniques, Artificial Intelligence
- Guarantee Maintainability
- Extendable to serve a broader purpose (e.g. collimation studies) and community (e.g. light sources)
- Continuous documentation
- Easy start-up tutorials and examples for new comers

2. Lattice tracking module

- 6D symplectic tracking for FCC-ee including solenoids, wigglers, optimize RF elements, synchrotron radiation, quantum excitation
- Lattice Tapering
- Explore new possibilities to speed up calculations without loosing details
- Lattice Multiple errors for realistic study
- Allow for 8D tracking for future extensions to spin tracking
- Define loss scenarios in the arcs and link to collimation tools

T. Persson,
R. Tomas
L. Van Riesen-Haupt
T. Charles
H. Burkhardt
E. Gianfelice

3. Beam-Beam module

- Beam-beam effects 6D self consistent
- Beamstrahlung
- Crabbed waist scheme
- Solenoids field
- Coupling to the arc optics in a self consistent manner
- Link to radiation transport calculations
- Define optimal scenario for multiple IP collider with top up injection scheme for 3 machines configurations

D. Schatilov,
K. Ohmi
X.Buffat
H. Burkhardt
M. Luckhof
M. Boscolo

General strategy:

- Use what is available!
- Modernize wherever is possible and optimize computations using modern technology and methods
- Have a first basic software frame work available asap with simplified modules to get experience and feedback from collaborators
- Develop new parts and more complex modules
- Benchmark to existing models
- Allow for collaborative analysis toolkits
- Address physics questions and provide inputs to the CDR++

Preliminary Plan:

2020

- **Review of** existing Codes/Models with definition of needs goals

2021

- Define **technical choices** for the **Software frame work** general structure
- **Select models** to be imported or modernized
- **First SF** with simplified modules available

2022

- Development and integration of **new lattice and Beam-Beam modules**
- **Simulation campaign** for multi IP studies
- Define functionalities for **Analysis tools**
- **Explore** new ways to speed up calculations and optimize

2023

- Include in the Software Frame work **other available modules**
- Simulation campaign for **combined effects**

2024

- Full Documentation available and **CDR++ contribution**

Summary

- Several tools exist to study different effects for the FCC-ee collider
- A global model that can be used to address the open questions does not exist yet
- CHART project aims to serve the collaboration to build such back-bone model and to use it for the design of the FCC-ee

Summary

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- A global model that can be used to address the open questions does not exist yet
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- Looking forward to start this challenging project together: learning from experts and helping where needed to modernize codes, make use of front-end technologies and…

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Address the open challenges to design the next generation lepton collider FCC-ee!

THANK YOU!

Questions?