Overview of Beam Instrumentation developments for the pre-TDR phase

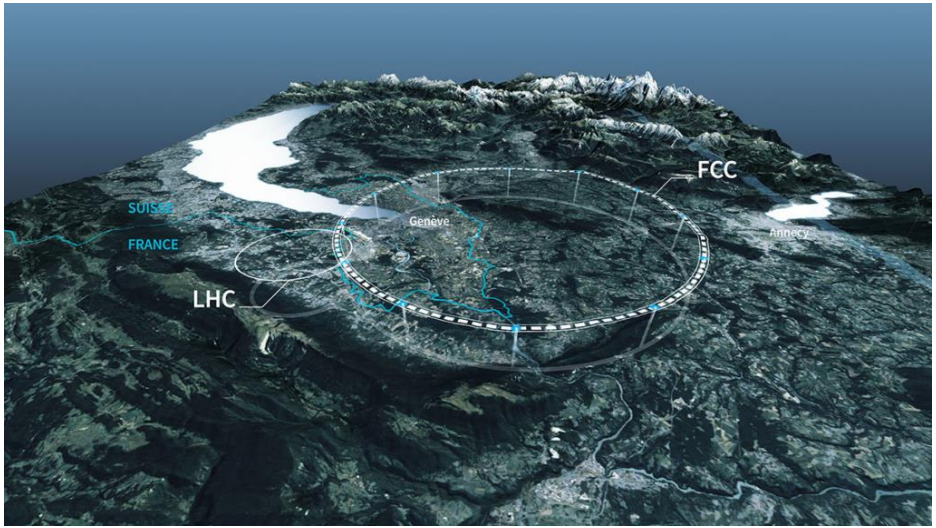
T. Lefevre on behalf of the FCC BI team

A tribute to our colleague and friend Stefano

He will forever remain in our hearts and memories, and his legacy will continue to inspire us and, through us, future generations.

Outline

- **FCC-ee Beam instrumentation in a nutshell**
  - ***Recent achievements***
- **Pre-TDR objectives**
- **Conclusion and perspectives**



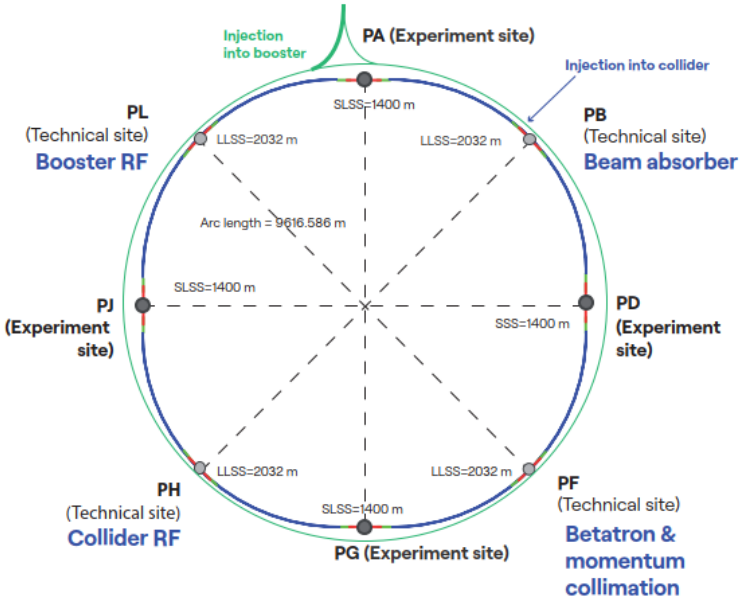
FCC-ee beam instrumentation team

- **Larger & larger collaboration**

- **BI Meetings: https://indico.cern.ch/category/8560/**
  - ***Weekly CERN Internal meeting***
  - ***Monthly catch-up meetings with External collaborators***
    - Next on FCC injector in June

FCC-ee from a BI perspective

parameter (4 IPs, $t_{rev} = 304\ \mu s$)	value
circumference [km]	90.7
SR power per beam [MW]	50
min./max. beam energy [GeV]	45.6 / 182.5
max./min. beam current [mA]	1294 / 5.1
max./min. # of bunches/beam	11200 / 64
min. H geometric emittance [nm]	0.71
min. V geometric emittance [pm]	1.42
min. rms bunch length SR / BS [mm]	1.95 / 14.45



+ injectors and positron source

FCC-ee from a BI perspective

parameter (4 IPs, $t_{rev} = 304\ \mu s$)	value
circumference [km]	90.7

Large size

- >300kms of beam lines to equip with instruments
- Large distance imposes optical fibre transmission between beam line equipment and DAQ

Latest numbers from the final FS report

Instrument	Main tunnel	Injector + TLs	Total
Position	8855	862	9717
Losses	26544	200	26744
Intensity	15	15	30
Transverse profile	21	35	56
Longitudinal profile	6	14	20
Beamstrahlung monitors	8	0	8
Polarimeter	2	0	2

Numbers to be confirmed

New – *Beam loss monitoring system being studied in Arcs (covering both Main rings and Booster ring)*

FCC-ee from a BI perspective

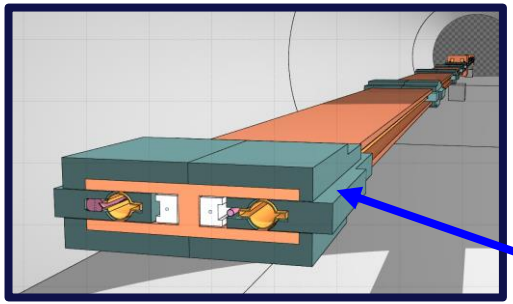
parameter (4 IPs, $t_{rev} = 304\ \mu s$)	value
SR power per beam [MW]	50

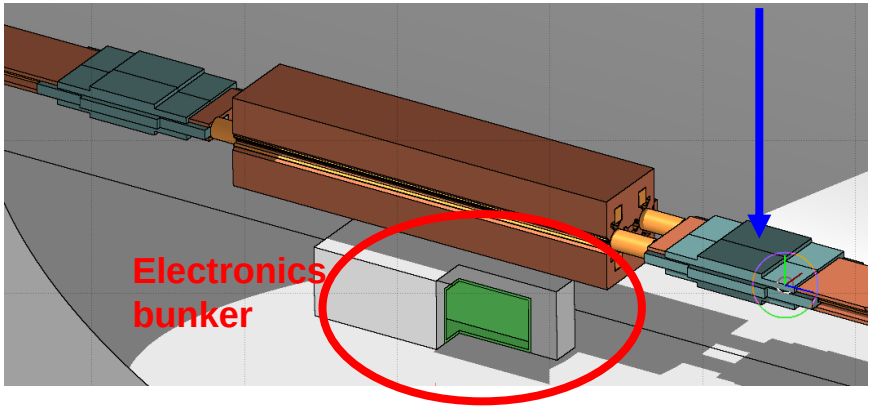
High Synchrotron radiation power in the arcs

- New SR shielding studied to bring the radiation level down to manageable levels (<10kGy/y)
- Add. Shielding for electronics sitting in the tunnel being studied as well (~ 10Gy/y)

FCC-ee Radiation and Shielding WG:
https://indico.cern.ch/category/17958/

Courtesy of A. Lechner et al.



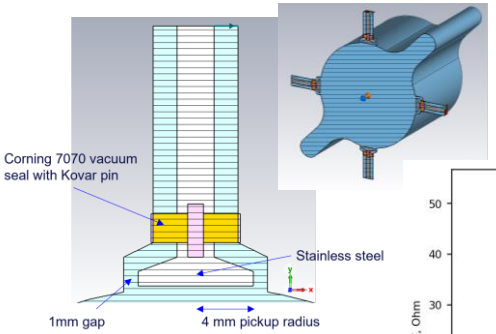


FCC-ee from a BI perspective

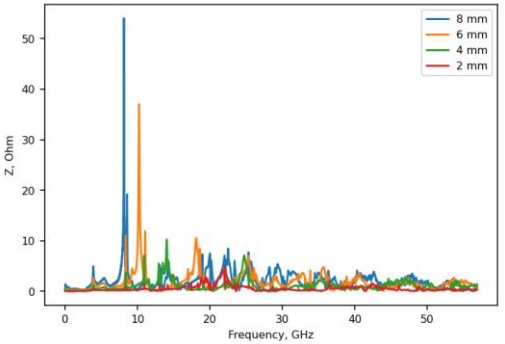
parameter (4 IPs, $t_{rev} = 304\ \mu s$)	value
min./max. beam energy [GeV]	**45.6** / 182.5
max./min. beam current [mA]	**1294** / 5.1
max./min. # of bunches/beam	**11200** / 64

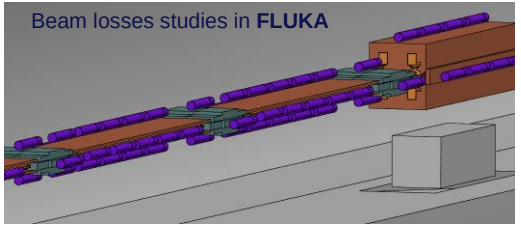
High beam current / number of bunches when running at Z pole

- Large impact on beam heating related issues
  - All beam monitor designs required to have ‘very’ low coupling impedance
  - Impact on stability and precision to be evaluated
- Study of machine protection system and beam loss monitoring system for FCC-ee launched recently



The impedance spectrum of different radii trapezoid buttons simulated in **CST**.



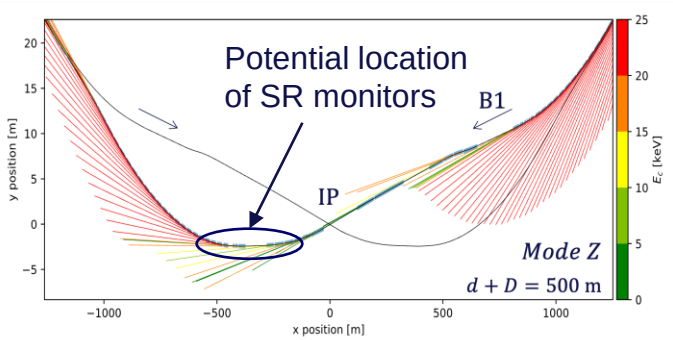


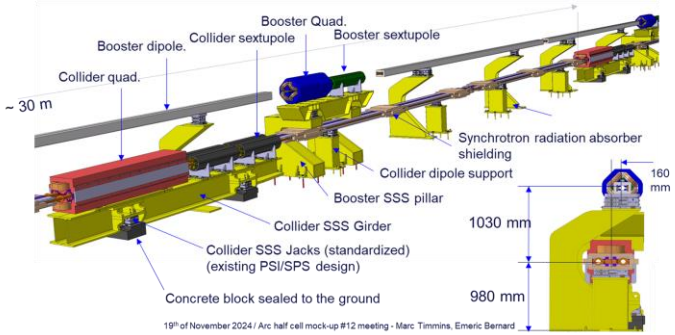
FCC-ee from a BI perspective

parameter (4 IPs, $t_{rev} = 304\ \mu s$)	value
min. H geometric emittance [nm]	0.71
min. V geometric emittance [pm]	1.42

Small emittance and small beam size at IP (34nm in V plane)

- Challenge in measuring beam profile and emittance *Sync. Radiation monitoring Studies on going.. Hard X-ray spectrum, long extraction lines, ..*
- Rely on **proper alignment of machine components** (BPM to Quad). Discuss and develop a strategy to study the performance of the arc cell alignment at ATDC https://indico.cern.ch/event/1516427/
  - need to converge on a baseline plan





Design of an arc cell - A. Piccini, M. Timmins

FCC-ee from a BI perspective

parameter (4 IPs, $t_{rev} = 304\ \mu s$)	value
min. rms bunch length SR / BS [mm]	5.6 / 12.7 @Z
min. rms bunch length SR / BS [mm]	1.81 / 2.17 @ Top

Beamstrahlung generated at IP, combined with top-up operation result in fast changing beam longitudinal bunch profiles

- requiring bunch by bunch, turn-by-turn measurements with ps/sub-ps resolution

+ Challenge of measuring ~ 400kW Beamstrahlung photons as luminosity monitors

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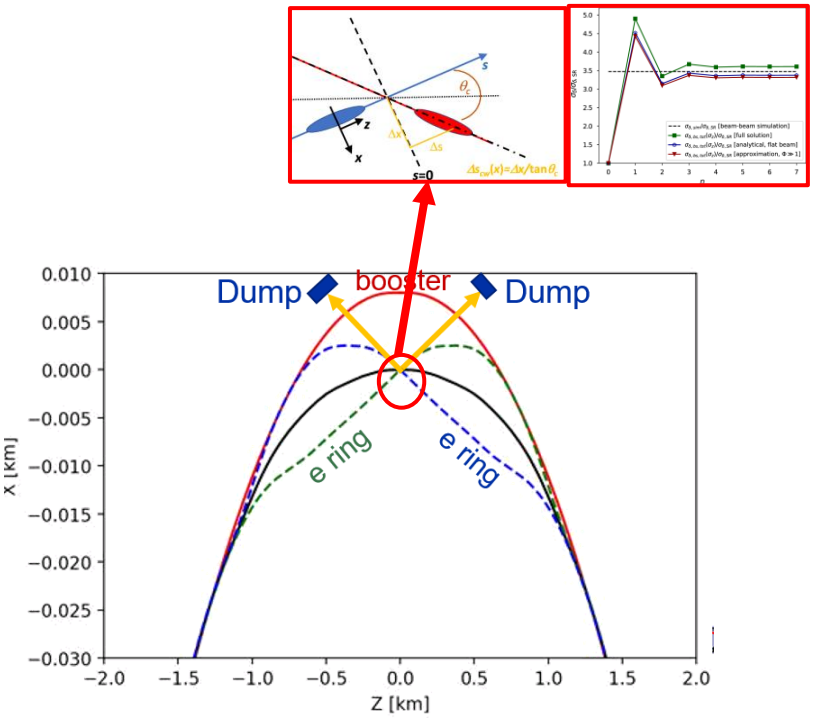


FCC-ee pre-TDR BI studies

- No show-stoppers but a considerable amount of work ahead of us
  - Current, Position, Losses, Trans. and long. Profiles, Polarisation, Luminosity

- With limited resources for pre-TDR phase, we focus on:
  - Devices related to machine protection

  - Devices requiring a substantial R&D phase with large impact on performance
    - Specific or unique design for FCC-ee
    - Challenging specifications requiring long prototyping and validation phases

  - Devices involving very large quantities with large impact on cost
    - ~ x5 more monitors than today at CERN
      - e.g. from 2000 to 9600 BPMs, from 5000 to 26000 BLMs
      - Standardisation, Cost optimisation and much larger production to handle (automatic inspection and acceptance tests using robot and AI)

Beam instrumentation workpackage

T_0 = 'ready for installation'

Beam Position and Loss Monitors

Years:	T_0-15				T_0-10				T_0-5				T_0-1
R&D													
Design + prototyping													
Industrialization + pre-series													
Series prod. + testing													

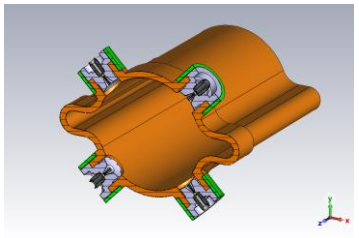
Trans. & long. Profiles, Polarisation and Luminosity (incl. Beamstrahlung) monitors

Years:	T_0-15				T_0-10				T_0-5				T_0-1
R&D													
Design + prototyping													
Industrialization + pre-series													
Series prod. + testing													

Beam Current Monitors

Years:	T_0-15				T_0-10				T_0-5				T_0-1
R&D													
Design + prototyping													
Industrialization + pre-series													
Series prod. + testing													

Beam instrumentation pre-TDR goals



Beam Position Monitoring system

- Design and prototype of a low impedance pick-up for FCC-ee Main rings
  - CST simulations for pick up optimisation
  - Heat load simulations and implication on BPM stability and need for water-cooling system
  - BPM integration in the machine layout including alignment tolerances to be done together with EN-MME, TE-MSC, TE-VSC and BE-GM in a dedicated test-stand
  - Pick-up prototyping and validation by laboratory and beam tests (CLEAR *and Solaris*) – to be done in collaboration with TE-VSC for optimised manufacturing techniques

- Design a cost-efficient bunch-by-bunch and turn-by-turn data acquisition system
  - Identify proper technologies to be used (rad-tol vs rad-hard, ASIC, photonics,…)
  - Propose a system architecture including operation and maintenance considerations
  - *Prototyping and testing phase to be performed in a later stage*

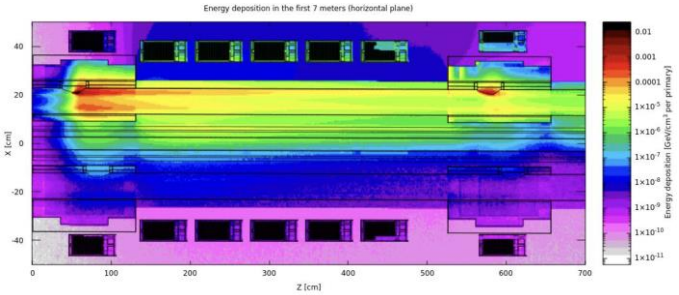
- *Would need final focus BPM specifications on resolution and accuracy asap – possibly a big challenge*

Poster by E. Howling on Thursday

Beam instrumentation pre-TDR goals

Beam Loss Monitoring system

- Collect the specifications of BLM system w.r.t. Machine protection and operation needs
  - Fast and slow losses
  - Dynamic range to be covered



- MC simulations to develop a BLM system capable of :
  - Identifying losses from main rings vs booster
  - Insensitive or weakly sensitive to Sync. Radiation

- Optimisation of the system architecture, choice of detector technology
  - Rely as well on on-going activities in the group
    - Bunch-by-bunch BLM using Diamond or Timepix technologies (with CERN EP-ESE)
    - Production of large number (x1000) of Ionisation chamber for HL/Consolidation
    - Optical BLM in long optical fibre (started with CLIC, now developed for NACONS)

- Validation and Tests (CLEAR), *possibly also following work at SuperKEKb*

Talk by B. Salvachua & Poster by F. Titz on Thursday

Beam instrumentation pre-TDR goals

Important considerations for very large BI systems (BPM and BLM)

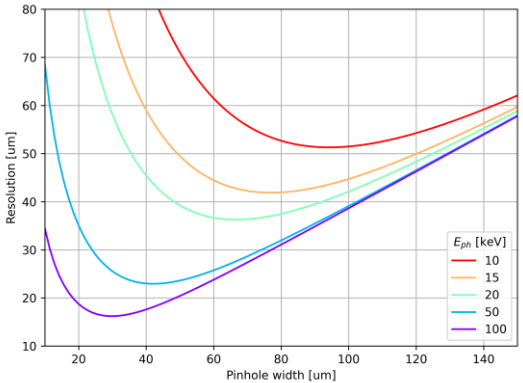
- Prepare for production of large systems
  - Look for standardization throughout the whole FCC-ee complex (injector, booster and main rings)
    - Avoid diversification of components to minimize the number of different designs, optimization of production cost but also ease maintenance later on
  - Identify key components (BI shopping list)
  - Look for industrial partners, Understand and Develop (if necessary) production capacity in industry
- Develop a model for cost / design / performance optimisation

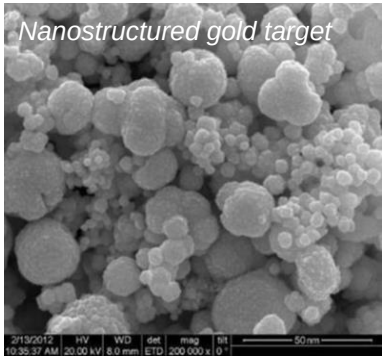
Beam instrumentation pre-TDR goals

Transverse profile monitoring system

- Design of a Beam Size monitoring system based on Synchrotron Radiation
  - Simulations of the SR source properties and of the SR extraction system, impacting on integration and on civil engineering
  - Design and tests of X-ray monitor systems using Pinhole camera or Interferometric methods
    - On-going tests at Alba and Uni. Milano
    - *More collaboration with KEK*

Talk by M. Siano & Poster by D. Butti on Thursday



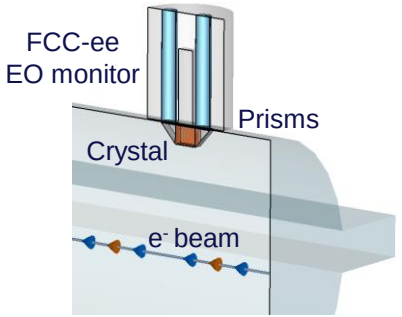


- *Alternative design of laser wire scanner (Compton scattering)*
  - *No specific design in pre-TDR*
  - *Performance and cost estimation based on the Compton polarimeter design*

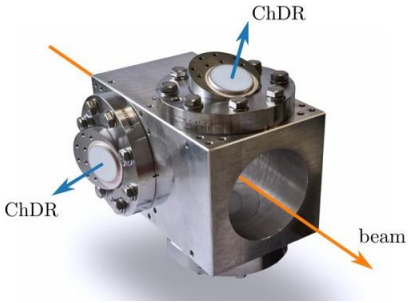
Beam instrumentation pre-TDR goals

Longitudinal profile monitoring system

- Design and prototype of a Bunch Length monitoring system based on Electro-Optical (EO) Spectral Decoding (KIT)
  - Design and prototyping of an in-vacuum, low impedance EO pick-up with appropriated resolution
  - Design of a bunch-by-bunch, turn-by-turn acquisition system with sub-picosecond time resolution



- Design and prototype of a Bunch Length monitoring system based on beam induced radiation (CERN)
  - Design of radiation source : Synchrotron radiation or Cherenkov Diffraction radiation
  - Testing of **incoherent Cherenkov Diffraction radiation** (KEK and IOTA)
  - Testing of **coherent radiation monitoring** at CLEAR

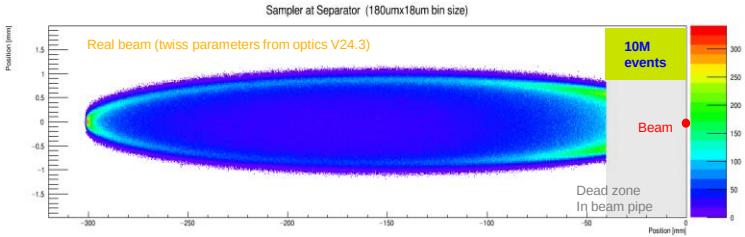


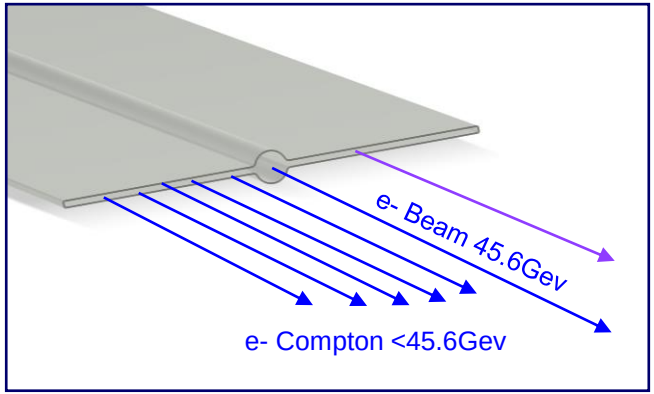
Next talk by K. Lasocha on latest news about bunch length monitoring developments
Talk by A. Schlögelhofer on fast digitiser scheme on Thursday

Beam instrumentation pre-TDR goals

Polarimeter and Luminosity monitoring

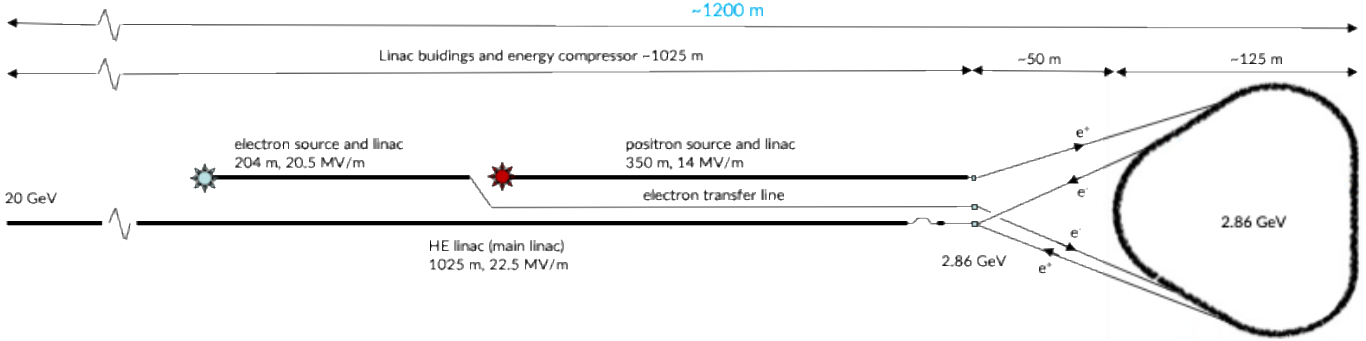
- System design using MC and beam tracking simulations
- Design of beam line elements including impedance studies (very specific design for both systems)
- Detector design (identifying most relevant technologies) and prototyping studies
- Integration studies to clarify the needs for underground space and laboratory
- Test and validation plans to be developed
  - possibly some involvements at SuperKEKb to gain experience
- 2 Ph.D students starting in the coming months

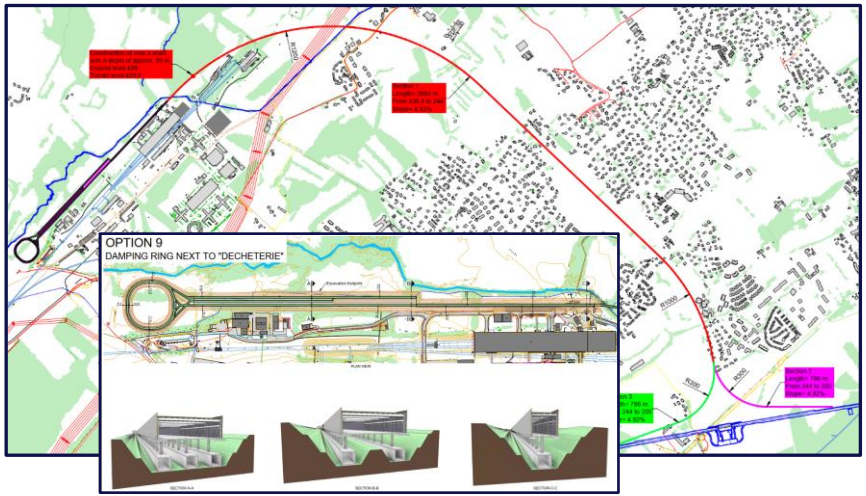




Talk by R. Kieffer on Compton polarimeter on Thursday

FCC-ee Injector TDR by 2028





In 2025, we need to discuss and confirm the instrumentation needs and specifications for the injector complex

Today there are no people to work on the injector TDR at CERN. We should see how to get this done

Including FCC-ee in the BI consolidation cycle

Consolidation cycle with electronics being changed ~ 20 years, less frequent for mechanics

<u>Opportunity and synergy with FCC work</u>

- HW systems for FCC-ee injector should be based on the technology we developed for LS4
- FCC-ee main ring equipments could potentially be aligned with consolidation work that would be required to keep the proton complex alive beyond HL era

Conclusions

- FCC BI study has progressed well and will progress even faster with new resources allocated in 2025
- Scientific challenges ahead of us are exciting and we rely on a motivated team of young scientists and an efficient international collaboration to address them
- Pre-TDR goals have been set and looks well achievable. FCC injector work should be defined with greater details in 2025
- Welcoming new collaborators anytime !
- Stay tuned for the BI talks and posters presented during the week

Thank you
for your attention.