FCC-ee injector complex

SY – FCC workshop, 4 October 2024

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on behalf of FCC Injector collaboration

FUTURE CIRCULAR COLLIDER Innovation Study

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

PSI

CHART Swiss Accelerator Research and Technology

http://cern.ch/fcc

CERN

photo: J. Wenninger

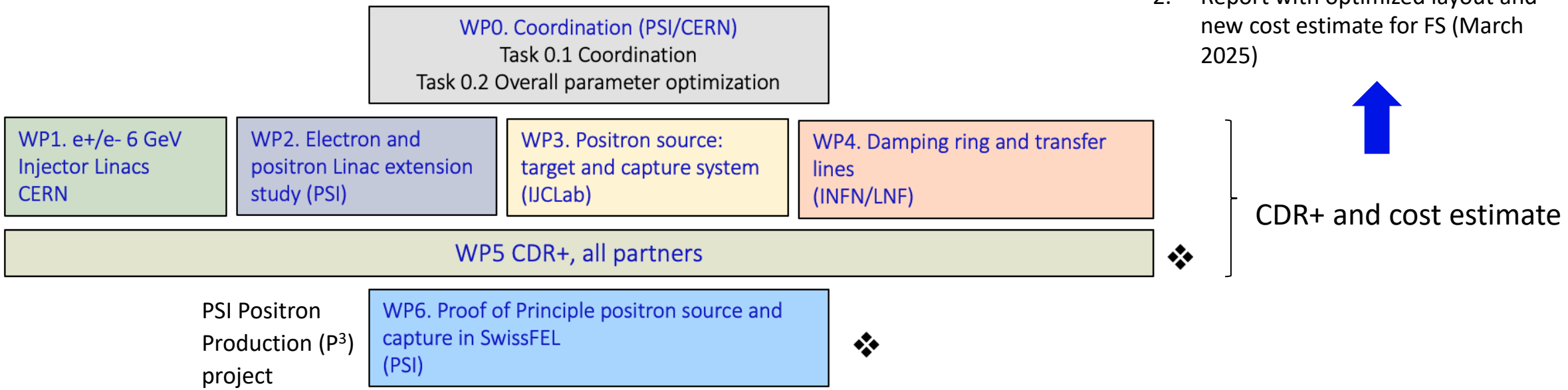
FCC-ee injector study

- Status of machine design, technical design and siting of the pre-injector complex
- News on “delivery model” and assumed timeline
- Collaboration needs, work plan, synergies, organization of the work
- Required interfaces between CERN groups and institutes responsible for in-kind contributions; how is CERN involved in the design? how to define of standards (e.g. for controls)? equipment ownership/maintenance during operation?

FCC-ee injector study and P-cubed project 2020-2024…

- CHART proposal is a collaboration between PSI and CERN with external partners, CNRS-IJCLab (Orsay), INFN-LNF (Frascati)
- other collaborators and/or observers:
  - KEK is also interested in the P^3 project (strong support from them)
  - INFN-Ferrara – radiation from crystal (possible future activity for p-cubed)
- we started in summer 2021 due to Covid, delay in budget setting, and long hiring process.

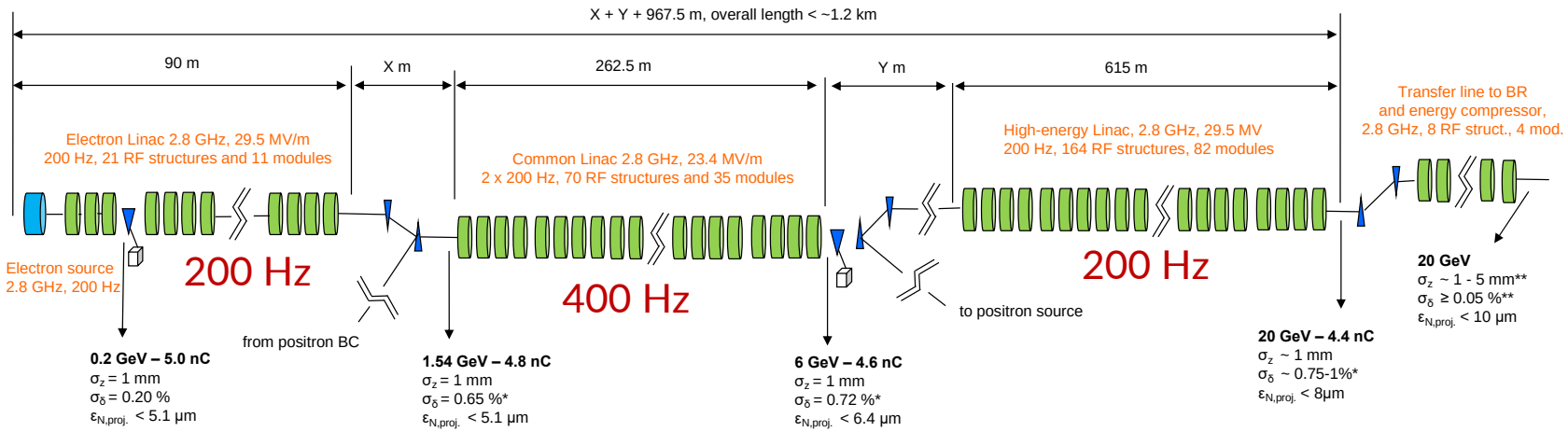
Work Breakdown Structure and deliverables:

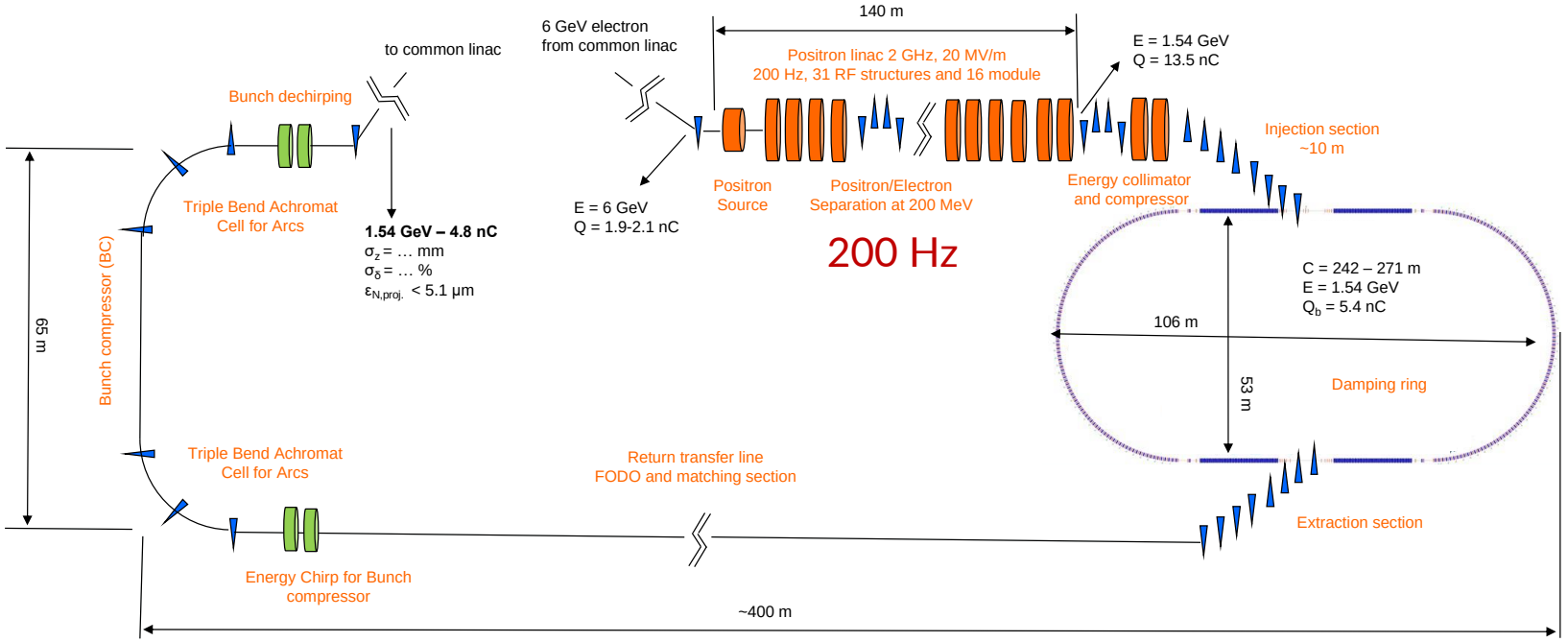


1. Report with cost estimate for FS MTR (Oct 2023)
2. Report with optimized layout and new cost estimate for FS (March 2025)

CDR+ and cost estimate

Baseline layout presented at MTR (2 bunches/rf pulse)



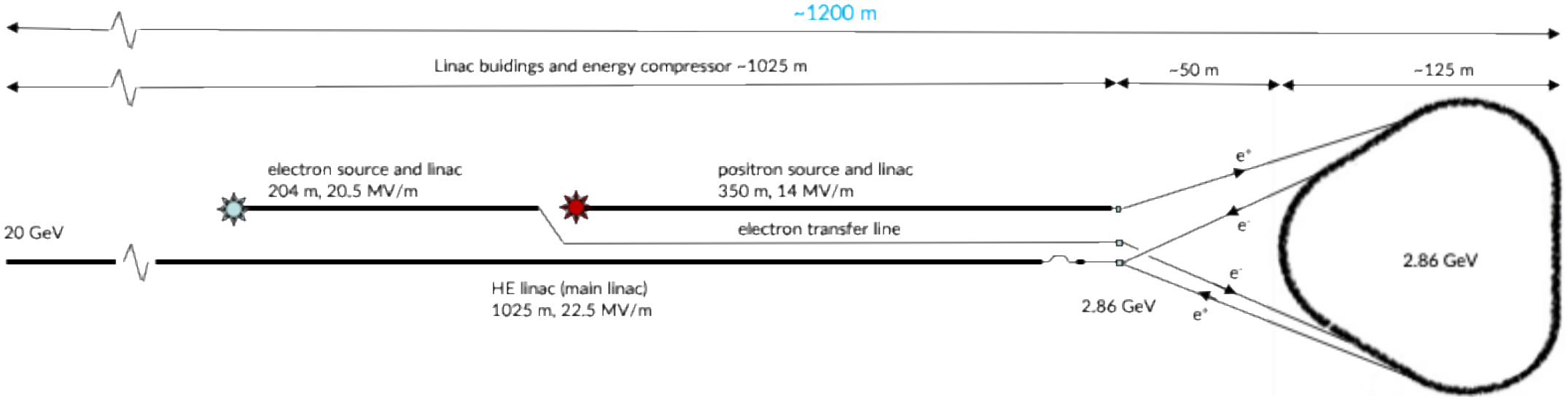


MTR recommendations:

- **Optimize linac design in term of cost and power!**
- **Overall power consumption 43.5 MW is too high**. Reduction of at least factor 2 or more is necessary
- **High average and peak power** (relatively high gradient for S-band) **operation reliability** has been questioned.
- SPS vs HE linac: keep only the HE-linac option for FS

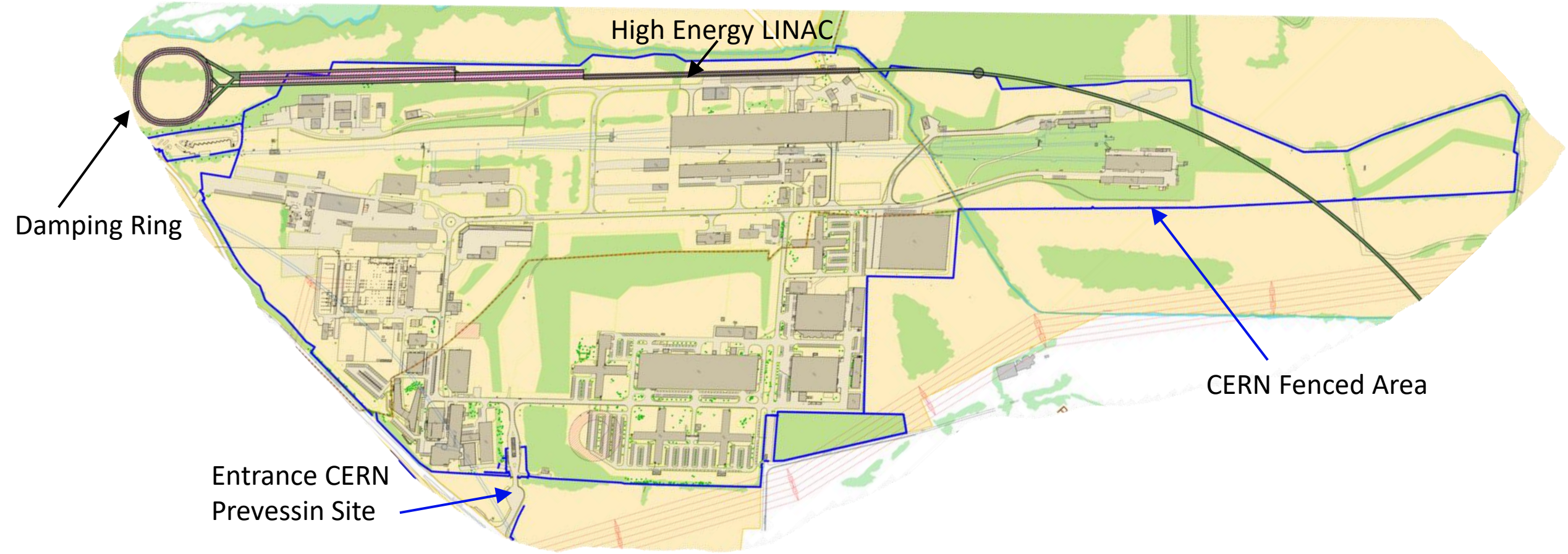
Optimized injector concept and parameters

- **Mid-term review recommendations to reduce gradients and repetition rate → new linac optimization in terms of cost and power density**
  - Overall power consumption (for linacs) is reduced by **more than a factor 3** by means of:
    - new accelerating structures with higher shunt impedance;
    - lower gradient (29.5 MV/m → 22.5/20.5 MV/m);
    - lower repetition rate (200/400 Hz → 100 Hz).
  - Rep. rate of **100 Hz with 4 bunches** per rf pulse, beam loading compensation and long range wakefield suppression;
  - Total length of the injector complex is longer, but operation will be more reliable;
  - New layout: **Damping Ring at higher energy 2.86 GeV**, no common linac (would require doubling repetition rate).



Optimised injector implementation at Prevessin site

- Better integration with existing CERN Prevessin Site and strongly reduced visible impact from outside.
- Ideal connection to existing experimental halls.
- Good conditions for construction (see next slide).
- CERN dedicated land, small part outside fenced area but with same urbanistic classification as enclosed Prevessin Site (UAcern)



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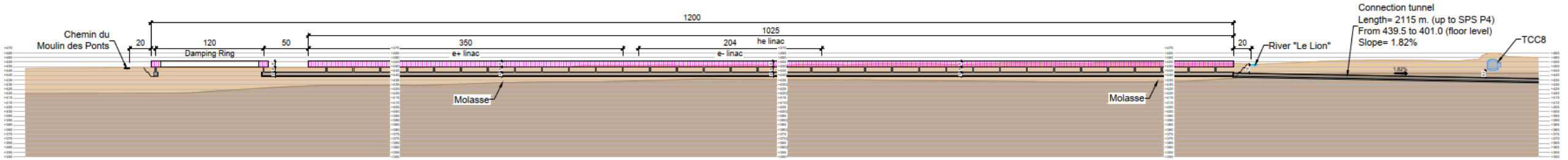
Injector construction concept

OPTION 9

DAMPING RING NEXT TO "DECHETERIE"

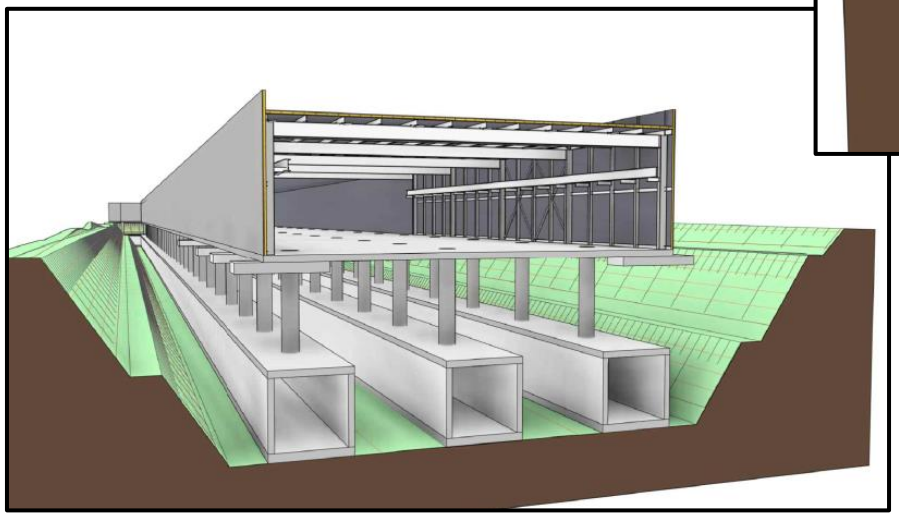


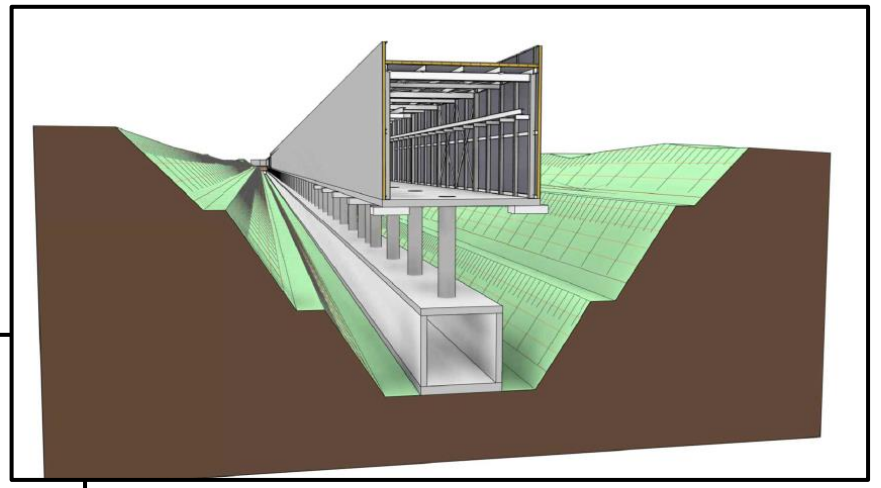
LONGITUDINAL PROFILE

Longitudinal Section

- Less than 5m elevation change over the 1200 m of terrain provides **ideal conditions for "cut and cover technique"**
- Most efficient and cheapest way of building shallow underground construction
- Excavated material largely re-used as backfill above the tunnel
- Accounts also for radio-protection requirements

HE LINAC Line +
Electron and Positron Lines





HE LINAC Line

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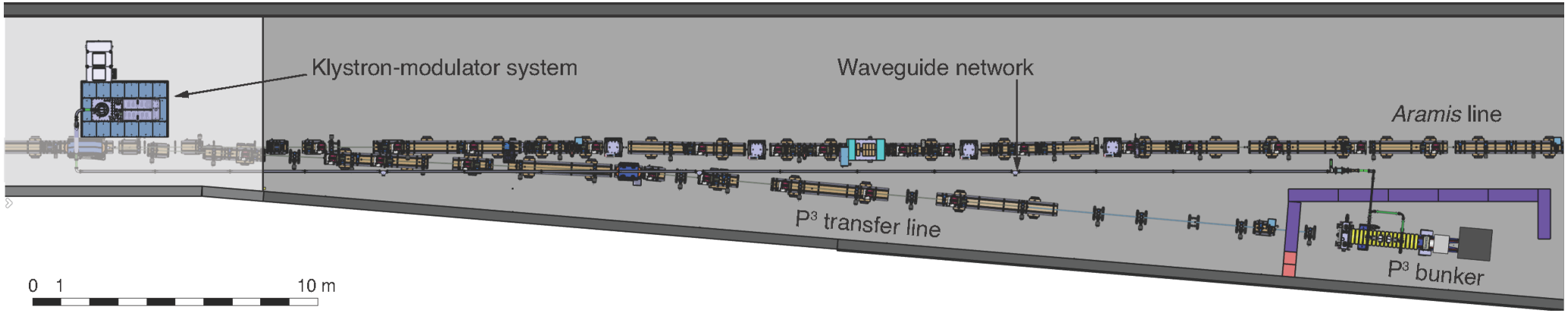
Important topics towards feasibility study report

- New baseline **needs a new DR at 2.86 GeV** to be included in the FS report.
- **Working RF frequency**: presently we assume a multiple frequency of the main rings to keep flexibility but no power source on the market!
- **Positron linac:** new optimization to use S-band commercial frequency (presently 2 GHz).
- **Top-up operation:** Injector will run continuously, and the reliability and availability become important aspect for the new baseline (→ low-gradient injector!) – breakdown rate to be experimentally verified
  - What is the effect of short interruptions due to linac RF breakdowns on top-up operation?
- **Electron source:** top-up operation requires that the bunch-by-bunch charge will vary from 0 up to 5 nC, depending on the intensity balance in the collider rings – approach using a Digital Micromirror Device (MDM) in the laser system to be validated.
- **Polarized positron (and electron)** from the injector?

Status of PSI Positron Production experiment (P^3)

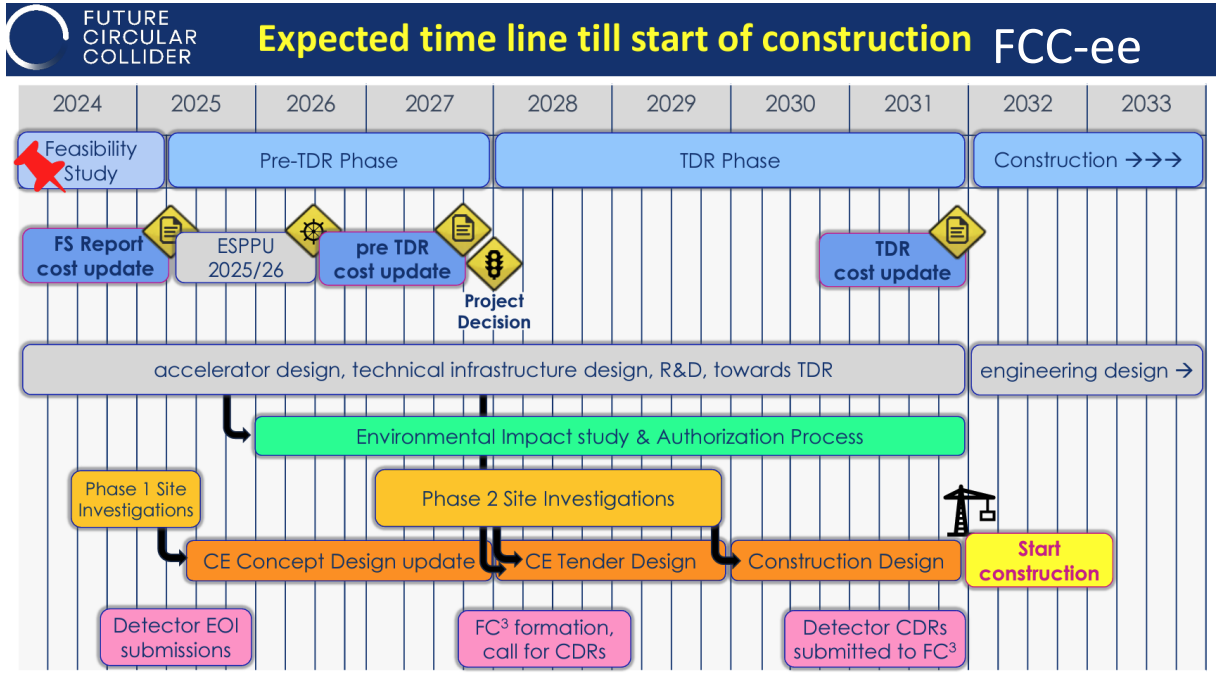
- The installation works at SwissFEL are progressing smoothly during the SwissFEL shutdowns (3 per year):
  - Parts of the dedicated extraction line and the HV klystron-modulator system accommodated in the tunnel.
  - **Procurement and assembly of most accelerator and diagnostics components is progressing on schedule.**
  - Operation of the HTS solenoid, which is probably the most critical component of the experiment, has been successfully demonstrated at PSI (up to 18 T).
  - Radiation tests on a dedicated HTS solenoid in the beamline of the PSI cyclotron is under discussion.
- The major part of the installation work is expected to conclude by end 2025, allowing to **start the operation with e+ in 2026.**



Plans for technical design of injector complex and beyond

- Strong support from Switzerland and PSI to continue CHART collaboration on FCC-ee injector towards technical design report.
- Presently preparing a proposal for CHART III phase with all partners that were already involved in the CHART II phase.
- Development of the realisation model for the injector included in the TDR work, to be available in 2027, before potential project decision.
- Partially also dependent on progress with funding model discussions, in-kind contributions, host-states, etc…

Time plan FCC-ee and FCC-ee Injector



FCC-ee Injector: Technical Design Report, 2025-2028:

- Following the completion of the Feasibility Study phase (March 2025), a preliminary technical design report (pre-TDR) will be produced by mid-2027.
- The objective of the pre-TDR is to provide detailed specifications for the accelerator and technical infrastructure requirements necessary for the initial phase of the civil engineering (CE) design.
- By the end of 2028, the final Technical Design Report (TDR) for both the accelerator and the technical infrastructure will have been completed.

Injector Project schedule (discussions ongoing)

- Start 2028 – end 2030 CE design and tendering (3 years)
- Start 2029 – end 2031 Accelerator engineering and technical infrastructure designs
- Start 2031 – end 2034 Civil construction (4 years)
- Start 2032 – end 2040 Component production (assuming similar production rates for RF structures as for SwissFEL)
- Start 2034 – end 2036 Technical infrastructure installation
- Start 2035 – end 2040 Component installation and testing
- Start 2042 beam commissioning

Organisation of FCC-ee Injector TDR phase

WP	Description	Lead	Collab.	2025	2026	2027	2028	Comments
0	Coordination and drafting of the TDR	PSI/CERN	All			1	1	Main parameter and technical choices, delivery model
1	Electron source	PSI	CERN				2	Demostrator for the top-up scheme. Need a test stand
2	Electron and positron linac	CERN	PSI/IJCLab				3	Protoypes and high power test of the RF structures for the linacs.
3	Positron source and capture system	IJCLab	PSI/CERN		4			Optmiziation based on the acceptance in DR, explore SC solenoids for capture system, commercial rf frequency
	3.1 P-cubed experiment	PSI	CERN /IJCLab		5			P-cubed experiment, implementation of the hybrid scheme, test with high power beam?
4	Damping ring, injection and extraction lines	INFN	PSI/CERN		6			Design of the DR at 2.86 GeV, drafting of the TDR with cost estimate. PSI can support this WP from 2025.
5	Civil Engineering (CE)	CERN	PSI					Start of the CE tender design
6	Infrastructures (including Radiation and machine protection systems)	CERN	PSI					Design of building infrastructure, personnel and machine safety issues.
7	Technical systems interfaces and integration in CERN environment	CERN	All					Operation concept for the whole complex including diagnostics, LLRF, powering….

Deliverable:

1 TDR ready

Milestones:

1 Pre-TDR (ready to start CE design)

2 Top-up scheme demostrated

3 BDRs defined for all prototypes.

4 Baseline for capture system defined

5 Positron source with conventinal target demostrated with lower power beam

6 Acceptance DR defined.

Conclusions

- The FCC-ee injector study for the feasibility study is advancing as planned, thanks to the very efficient CHART collaboration including also external partners.
- PSI positron production experiment well under way towards first positrons in 2026.
- Reports, documentation and cost estimate for the mid-term review were well received.
- The valuable recommendations from MTR led to a re-baselining of the injector concept coupled to a new implementation on the Prevessin site.
- Most challenging point for the completion of the feasibility study is the update for a new damping ring at 2.86 GeV.
- For the next phase towards a TDR there is strong support from Switzerland and PSI for a continuation and strengthening of the CHART collaboration.
- Program description is being prepared by the injector project team from PSI and CERN to have a full description with resource and cost estimates ready for implementation before end 2024.