PAUL SCHERRER INSTITUT

PSI

FUTURE CIRCULAR COLLIDER

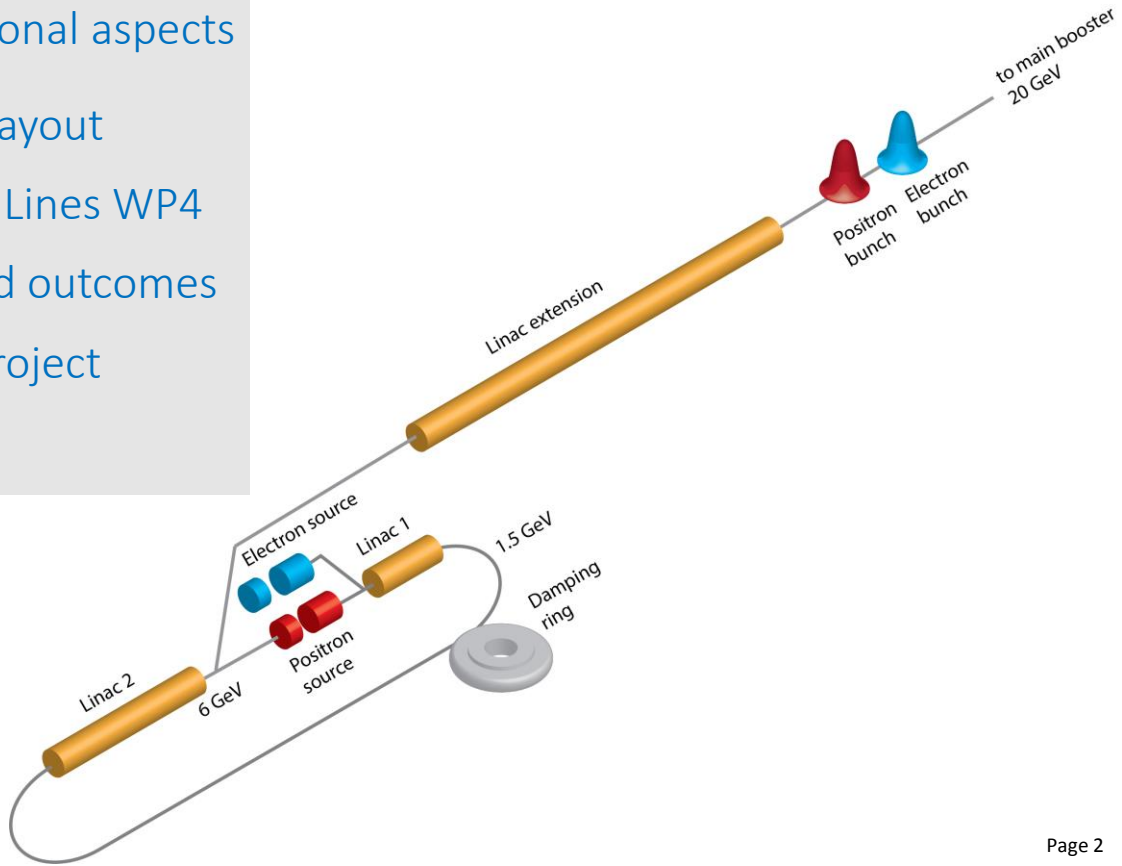
Paolo Craievich (PSI) on behalf of the FCCee Injector design study team

Overview and layout

FCC-ee Week, 30 June 2021

Outline

- Introduction and organizational aspects
- From CDR layout to a new layout
- Damping Ring and Transfer Lines WP4
- Injector review meeting and outcomes
- PSI positron source (PPS) project
- Conclusion



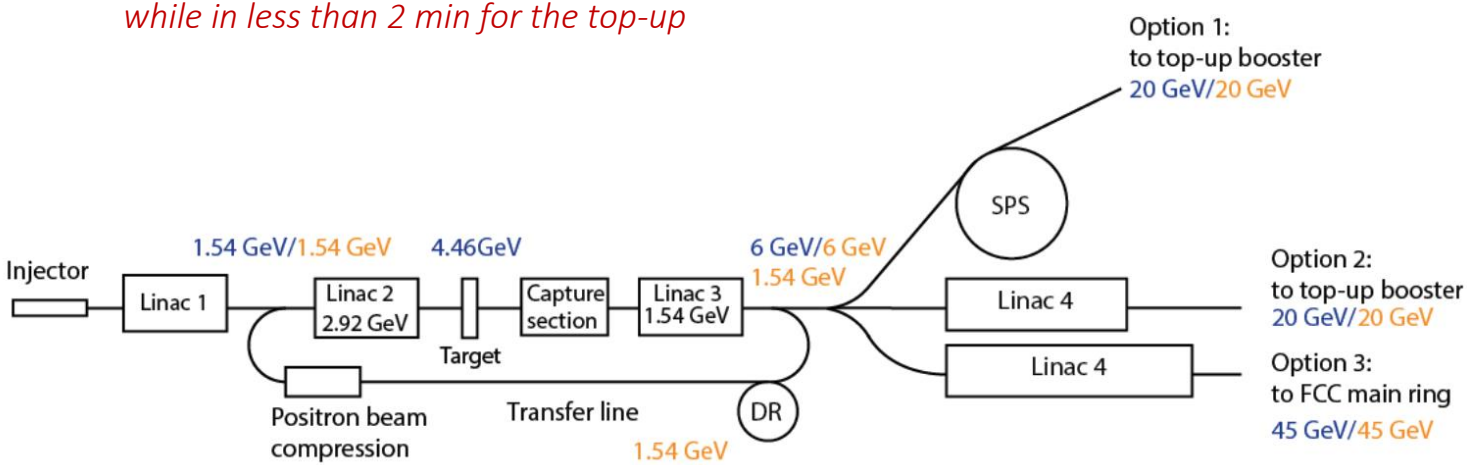
Introduction

- The Swiss Accelerator Research and Technology (CHART) council approved the proposal in June 2020 to finance the FCC-ee Injector update studies and a positron source demonstrator to be installed in PSI/SwissFEL
  - Collaboration between PSI and CERN with external partners IJCLab, INFN-LNF and BINP. Other laboratories are also involved KEK and CEA (booster ring)
  - Duration 4 years (from September 2020) + to be considered 1 year extension 😂
  - Goals:
    - *review of the actual CDR0/Injector and write a CDR+/Injector with cost estimate – deadline end 2023 → 2024*
    - PSI Positron source (PPS) experiment at SwissFEL – deadline end 2024 → 2025

From CDR layout to new layout

- The injector complex must provide beam for top up injection in the two collider rings supporting a beam lifetime of 40-70 min. Continuous top-up injection from the BR is also required. Goal is to maintain the collider beam lifetime limits within the ±3% current drop (±5% for the Z pole).
- It must also allow for a fairly rapid filling from zero (alternating bootstrapping injection), within at most half an hour
- Baseline described in the FCC-ee CDR considers a 6 GeV linac, with at most 2 bunches per pulse, with a spacing of 100 ns and with a repetition rate up to 200 Hz

→ *Status in CDR: The bunches are accumulated in the collider in less than 20 min, for the initial filling, while in less than 2 min for the top-up*



From CDR layout to new layout

New Approach

Alternative scenarios have meanwhile been proposed, considering three different aspects:

1. The number of bunches per linac pulse can be increased by an order of magnitude (2 → 25 up to 50), while the linac repetition rate is reduced (200 Hz → 100 Hz/50Hz) yielding an overall much faster filling time, but:
   - at the expense of a larger damping ring
   - more challenging (and more complex) e+ production requirements
   - *additional constraints on the linac, i.e. more challenging RF pulse compression or lower acceleration efficiency*
   - *less flexibility in bunch-by-bunch charge control required for top up operation (still under investigation)*

2. different layout allows some of the lower energy linacs to be separate from the main linac accelerating the bunches to the pre-booster or booster ring;

3. the pre-booster (SPS or new PB ring) could be replaced by an extension of the linac to 20 GeV to directly inject into the BR (already in CDR) or even 45 GeV to directly inject into the collider rings

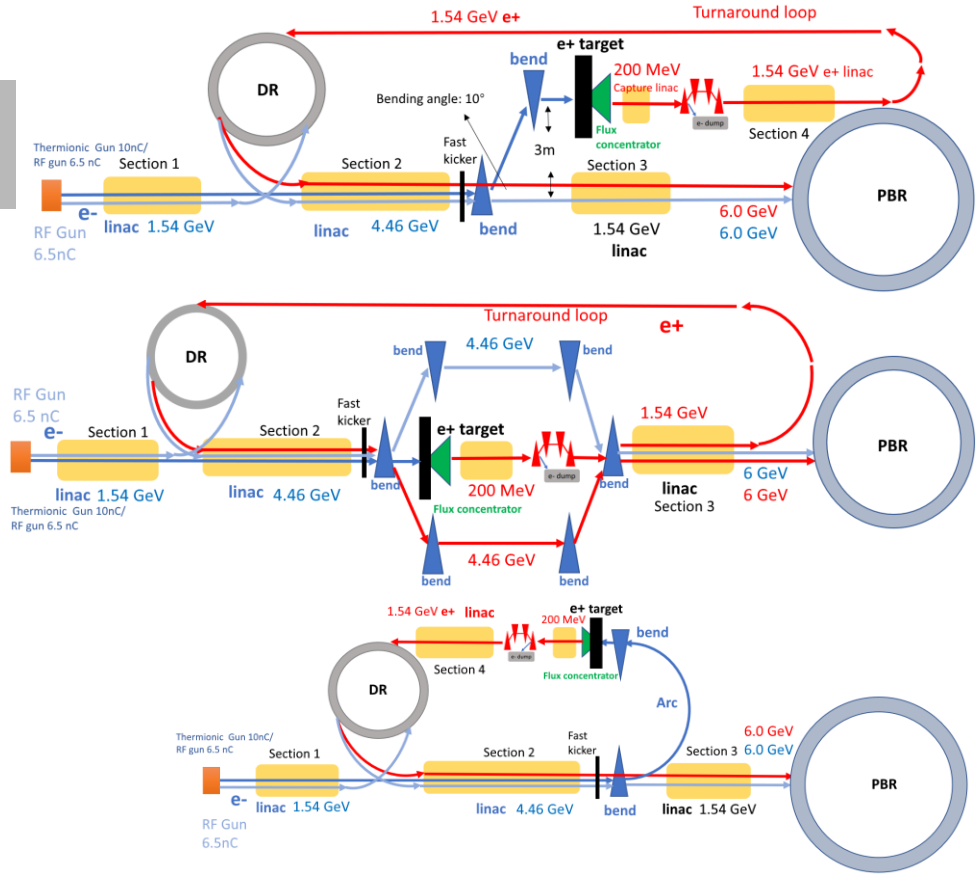
From CDR layout to new layout

Motivation and Figures of Merit

Injector complex provides beams with nominal parameters at the energy: E_{inj} = 6(20) GeV. This parameter is fixed by the rings: PBR(BR)	Figure of merit for CDR baseline
Cost: it is assumed that large part of the cost of the injector complex is in the linacs and it is proportional to the total energy gain in all linacs: **E_{tot}, the lower the better**	E_{tot} = 6(20) GeV E_{tot}/E_{inj} = 1
Positron production: Increasing energy of the driver beam on the positron target facilitates positron production and reduces required driver beam intensity (see next talk by Irina): **E_{db}, the higher the better**	E_{db} = 4.46 (4.46) GeV E_{db}/E_{inj} = 0.74 (0.22)
Additional arguments: ▪ Keep energy low in the arcs (cost): **E_{arc}, the lower the better** ▪ Avoid different energy in the same linac	E_{arc} = 1.54 GeV 1.54 and 6 GeV in L3

Outcome from WP0.2 meetings leading by A. Grudiev

Three different schemes – bypass options



Dogleg scheme

$E_{tot}/E_{inj} = 1.26$
$E_{db}/E_{inj} = 0.74$
$E_{arc} = 1.54$ GeV
No diff. energy

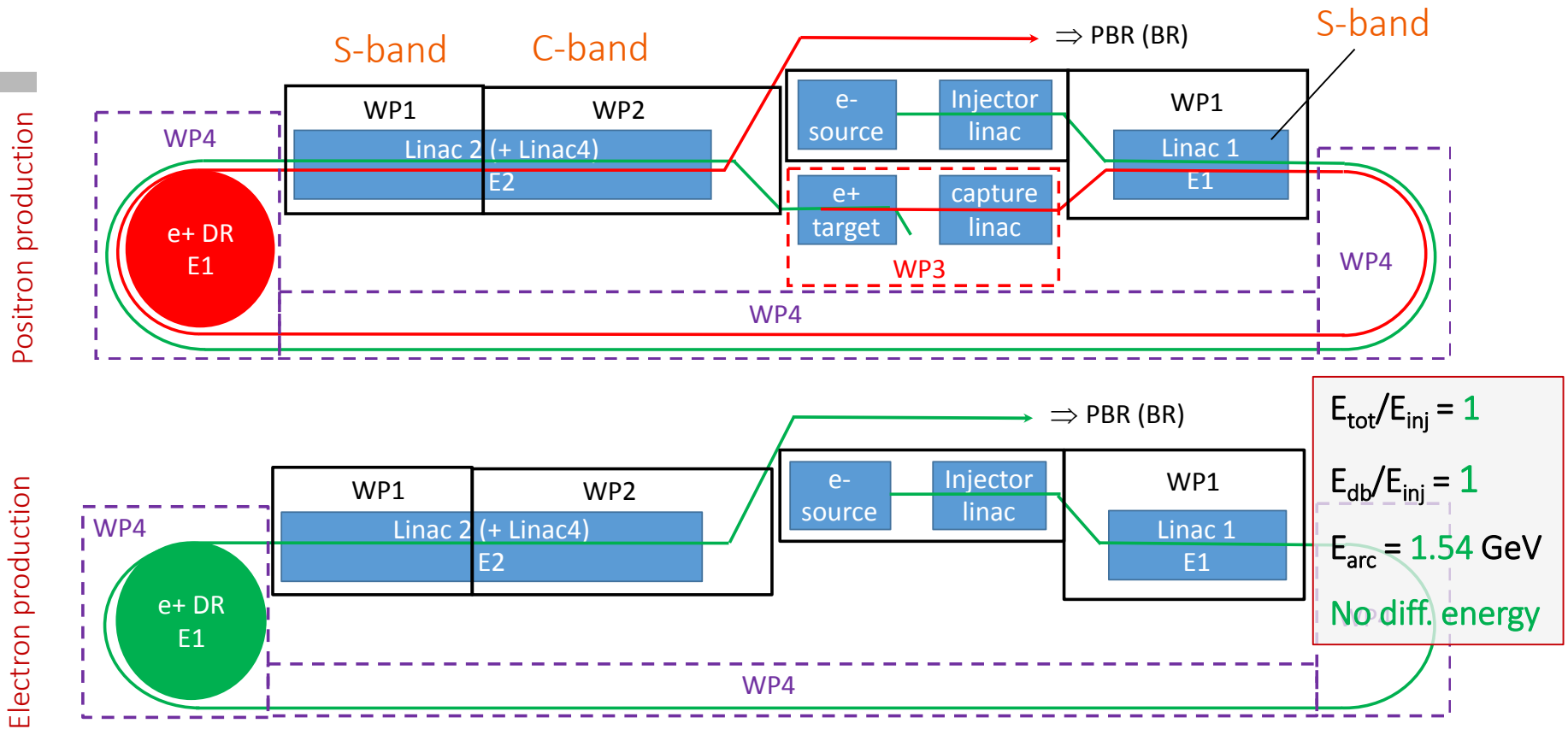
Chicane scheme

$E_{tot}/E_{inj} = 1$
$E_{db}/E_{inj} = 0.74$
$E_{arc} = 1.54$ GeV
1.54 and 6 GeV in L3

Arc scheme

$E_{tot}/E_{inj} = 1.26$
$E_{db}/E_{inj} = 0.74$
$E_{arc} = 4.46$ GeV
No diff. energy

Final proposal of the layout: 6(20) GeV

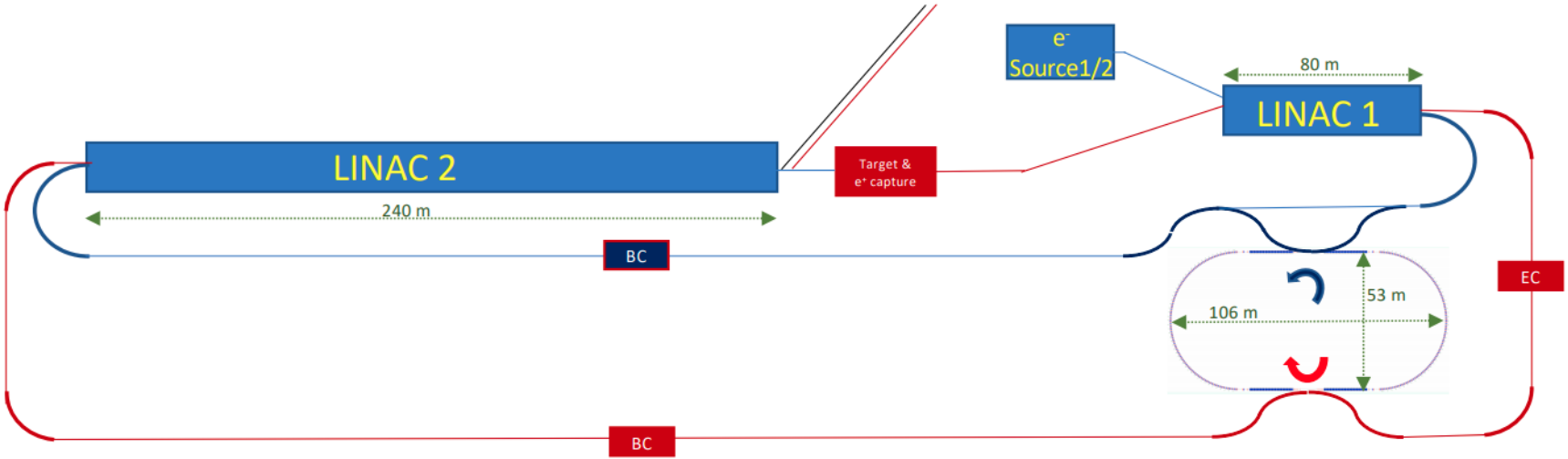


Outcome from WP0.2 meetings leading by A. Grudiev

Damping Ring and Transfer Lines WP4

Catia Milardi, Oscar Blanco, Antonio De Santis (INFN-LNF)

Injector Layout

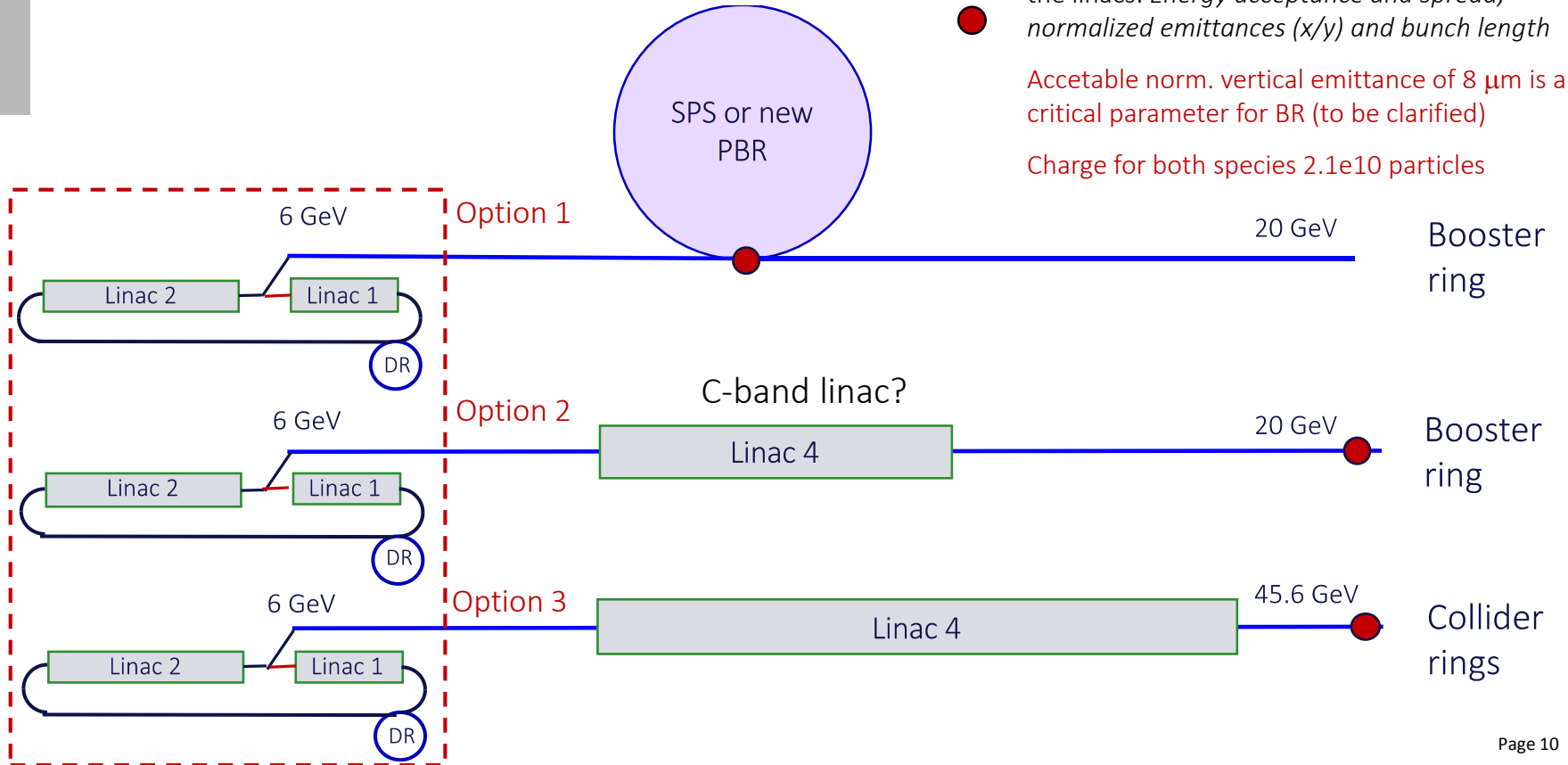


Three more options for injection into booster ring

Main beam parameters to be considered for the linacs: *Energy acceptance and spread, normalized emittances (x/y) and bunch length*

Accetable norm. vertical emittance of 8 μm is a critical parameter for BR (to be clarified)

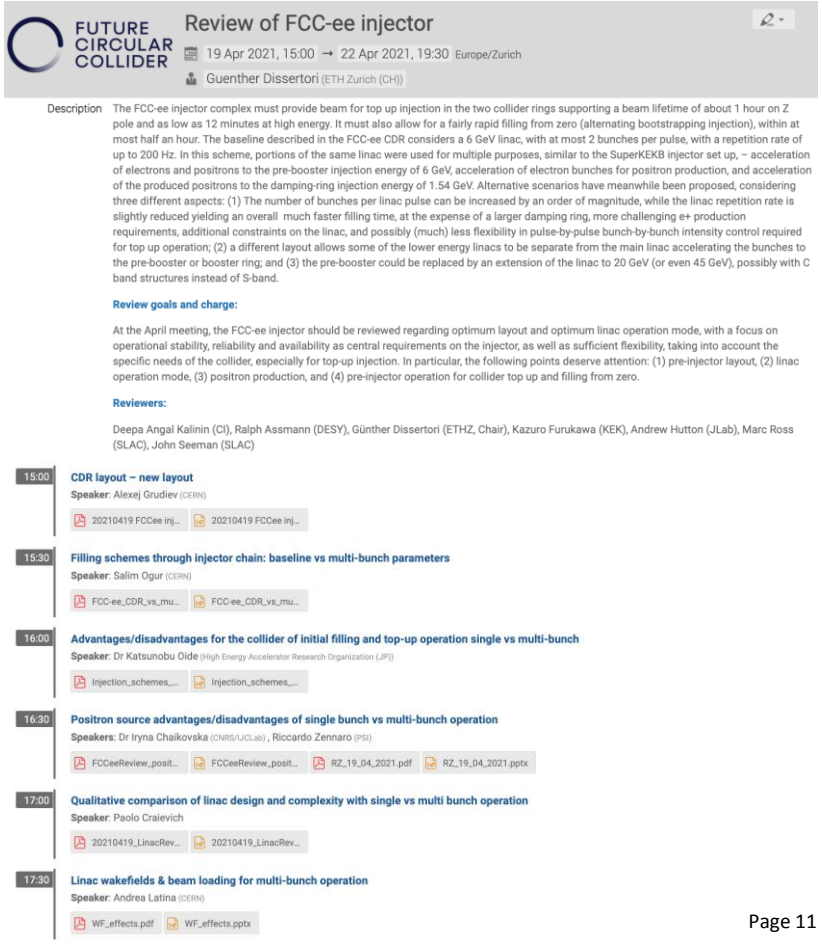
Charge for both species 2.1e10 particles



FCC-ee Injector Review Meeting

- We had a review on 19th of April 2021, reviewers from several international laboratories
- A detailed report from reviewers ready with comments and recommendations
- Here few important outcomes and remarks
- General requirements (seen from the collider, F. Zimmermann):
  - we would like to have a factor of 2 margin with respect to the maximum requirements in the case of 4 IPs, and for all modes of operation. This should be defining the minimum necessary performance of the injector.

→ The two-bunch operation meets this requirement (talk by K. Oide during the review meeting)



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Review of FCC-ee injector

19 Apr 2021, 15:00 → 22 Apr 2021, 19:30 Europe/Zurich

Guenther Dissertori (ETH Zurich (CH))

Description The FCC-ee injector complex must provide beam for top up injection in the two collider rings supporting a beam lifetime of about 1 hour on Z pole and as low as 12 minutes at high energy. It must also allow for a fairly rapid filling from zero (alternating bootstrapping injection), within at most half an hour. The baseline described in the FCC-ee CDR considers a 6 GeV linac, with at most 2 bunches per pulse, with a repetition rate of up to 200 Hz. In this scheme, portions of the same linac were used for multiple purposes, similar to the SuperKEKB injector set up, – acceleration of electrons and positrons to the pre-booster injection energy of 6 GeV, acceleration of electron bunches for positron production, and acceleration of the produced positrons to the damping-ring injection energy of 1.54 GeV. Alternative scenarios have meanwhile been proposed, considering three different aspects: (1) The number of bunches per linac pulse can be increased by an order of magnitude, while the linac repetition rate is slightly reduced yielding an overall much faster filling time, at the expense of a larger damping ring, more challenging e+ production requirements, additional constraints on the linac, and possibly (much) less flexibility in pulse-by-pulse bunch-by-bunch intensity control required for top up operation; (2) a different layout allows some of the lower energy linacs to be separate from the main linac accelerating the bunches to the pre-booster or booster ring; and (3) the pre-booster could be replaced by an extension of the linac to 20 GeV (or even 45 GeV), possibly with C band structures instead of S-band.

Review goals and charge:

At the April meeting, the FCC-ee injector should be reviewed regarding optimum layout and optimum linac operation mode, with a focus on operational stability, reliability and availability as central requirements on the injector, as well as sufficient flexibility, taking into account the specific needs of the collider, especially for top-up injection. In particular, the following points deserve attention: (1) pre-injector layout, (2) linac operation mode, (3) positron production, and (4) pre-injector operation for collider top up and filling from zero.

Reviewers:

Deepa Angal Kalinin (CI), Ralph Assmann (DESY), Günther Dissertori (ETHZ, Chair), Kazuro Furukawa (KEK), Andrew Hutton (JLab), Marc Ross (SLAC), John Seeman (SLAC)

15:00 **CDR layout – new layout**
Speaker: Alexej Grudiev (CERN)
20210419 FCCee inj... 20210419 FCCee inj...

15:30 **Filling schemes through injector chain: baseline vs multi-bunch parameters**
Speaker: Salim Ogur (CERN)
FCC-ee_CDR_vs_mu... FCC-ee_CDR_vs_mu...

16:00 **Advantages/disadvantages for the collider of initial filling and top-up operation single vs multi-bunch**
Speaker: Dr Katsunobu Oide (High Energy Accelerator Research Organization (JP))
Injection_schemes_... Injection_schemes_...

16:30 **Positron source advantages/disadvantages of single bunch vs multi-bunch operation**
Speakers: Dr Iryna Chaikovska (CNRS/LJCLab) , Riccardo Zennaro (PSI)
FCCeeReview_posit... FCCeeReview_posit... RZ_19_04_2021.pdf RZ_19_04_2021.pptx

17:00 **Qualitative comparison of linac design and complexity with single vs multi bunch operation**
Speaker: Paolo Craievich
20210419_LinacRev... 20210419_LinacRev...

17:30 **Linac wakefields & beam loading for multi-bunch operation**
Speaker: Andrea Latina (CERN)
WF_effects.pdf WF_effects.pptx

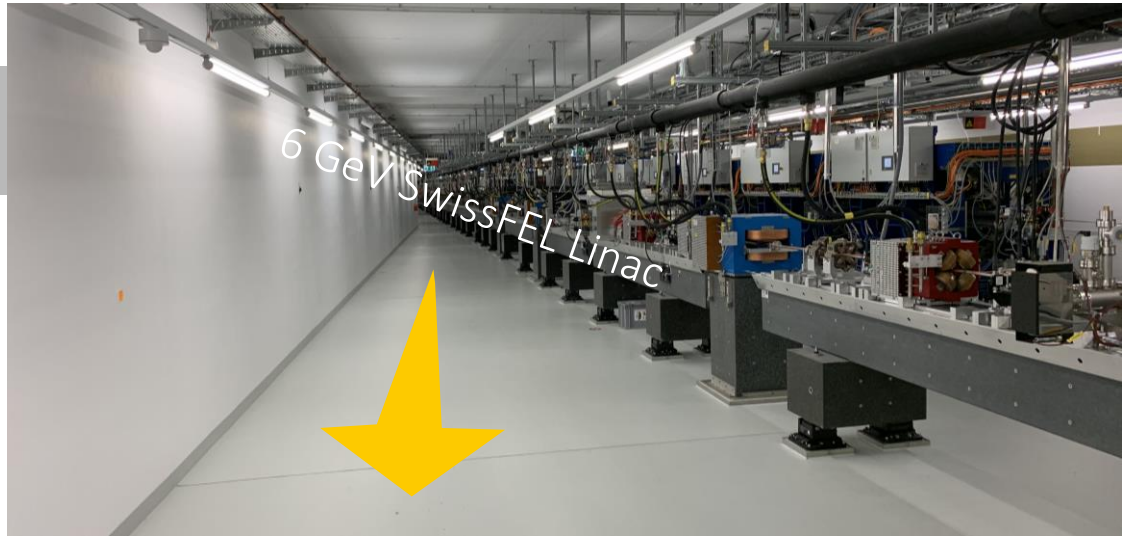
Guidelines for the future studies

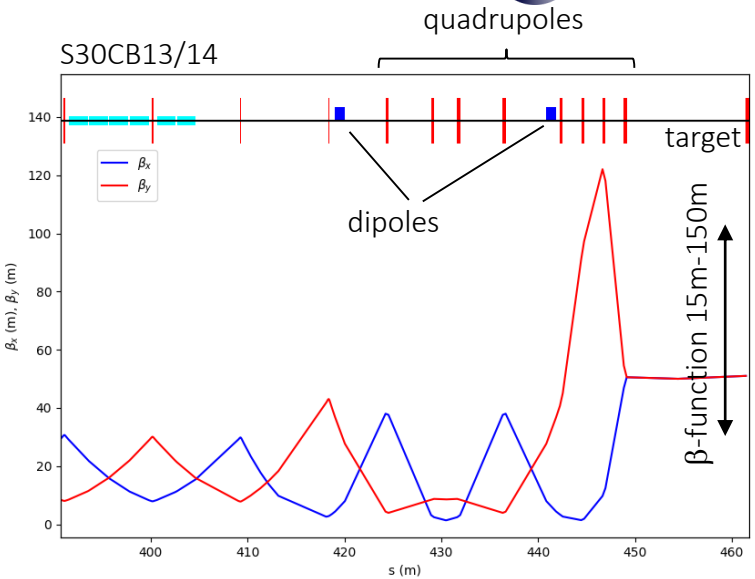
Extracted from the review report

1. adopt new layout for 6 GeV with only one energy in each linac & e+ production at 6 GeV
2. linac RF frequency should be chosen to be an appropriate multiple of the FCC-ee collider RF frequency to make potential future injection operation much easier to perform
3. check the acceptance of the booster ring in terms of emittance because this parameter will greatly influence the injector itself, i.e. RF guns and damping ring
4. carry out start-to-end simulations for the new baseline layout
5. rough relative cost comparison for new and old layout (probably only marginal differences)
6. concentrate on 2 bunch per pulse conservative scheme as recommended by review, with e+ target inspired by SLC's
7. study of 6-to-20 GeV linac, including rough cost estimate; e+ source performance at e- energy of 20 GeV
8. consolidation and confirmation of e+ yields expected at 6 and 20 GeV
9. preparation of PSI e+ experiment based on a target compatible with FCC 2-bunch operation

PSI Positron Source (PPS) project

PSI Positron Source Project

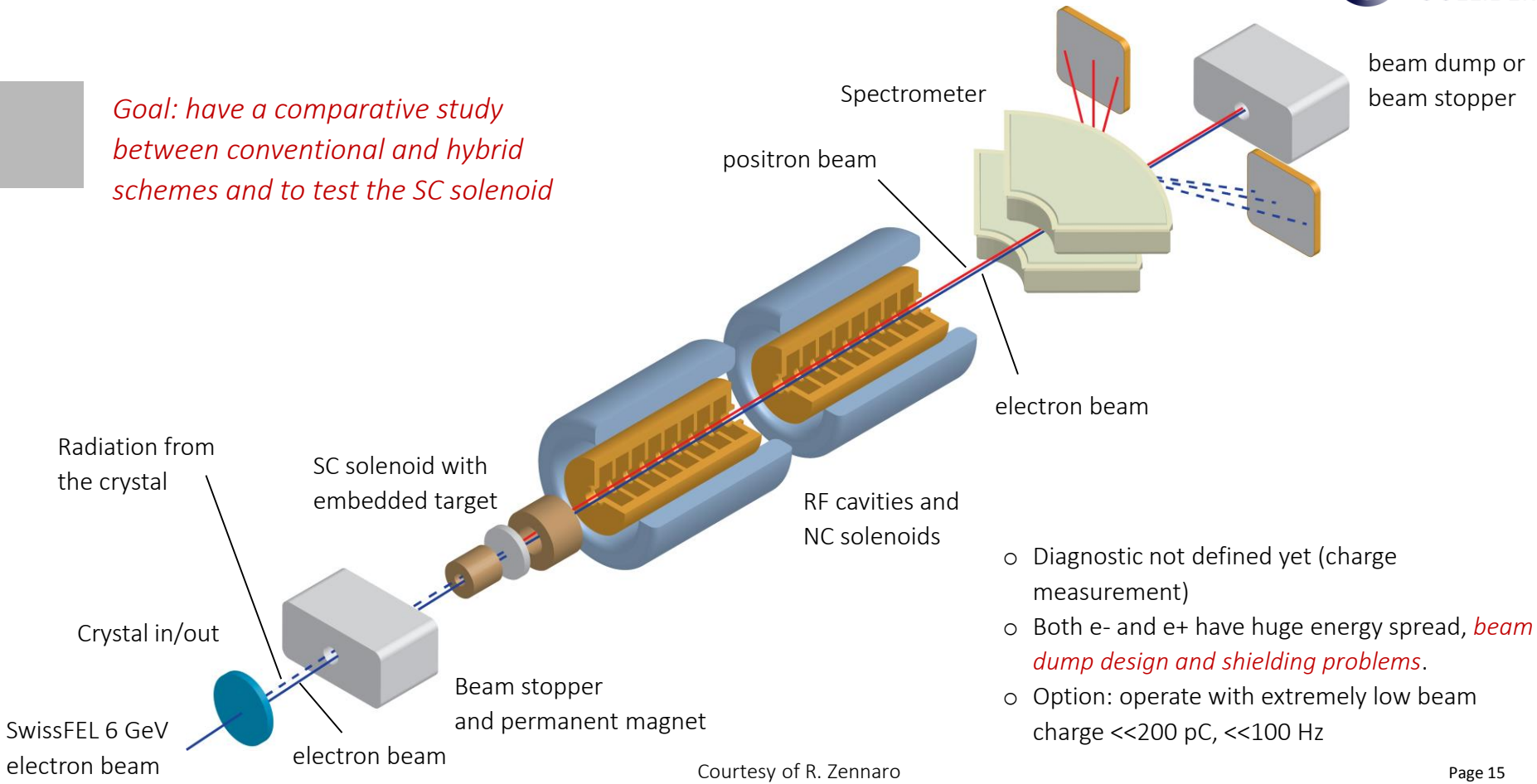




- Key point: Positron production and capture efficiency reduces the cost and complexity of the driver linac, the heat and radiation load of the converter system, and increases the operational margin
- Any progress with R&D on the target and capture systems will have a direct benefit for the injector chain
- Test bench at PSI/SwissFEL for the conventional and hybrid schemes using a SC solenoid, mainly for the positron yield (and maybe for the positron beam quality as well)

Experiment layout

Goal: have a comparative study between conventional and hybrid schemes and to test the SC solenoid



- Diagnostic not defined yet (charge measurement)
- Both e- and e+ have huge energy spread, *beam dump design and shielding problems*.
- Option: operate with extremely low beam charge <<200 pC, <<100 Hz

Courtesy of R. Zennaro

Conclusion

- Several alternative layouts have been discussed and compared to the CDR baseline layout from the CHART collaboration
- A new layout has been proposed which
  - facilitates positron production and reduces required intensity of the driver beam
  - avoids accelerating beams of two different energies in linacs
  - reduces number of linacs from 3(4) to 2(3)
  - increases the length of the transfer lines
- From review meeting: conservative approach, optimized layout
- Positron source experiment at SwissFEL
  - It won't be a 1-to-1 demonstrator for the FCC-ee positron source (lower charge and repetition rate)
  - But it will be a test bench for the conventional and hybrid schemes using a SC solenoid, mainly for the positron yield (and maybe for the positron beam quality as well)

Credits

The ideas/outcomes presented in this contribution has been carried out in the last months/year. An acknowledgment goes to all the colleagues who contribute to it: I hope, cited in a right way here and in the talk

R. Zennaro, J.-Y. Raguin, M. Pedrozzi, H. Braun, S. Sanfilippo, B. Auchmann, J. Kosse, S. Reiche, M. Duda – PSI

I. Chaikovska, S. Ogur, A. Faus-Golfe – IJCLab

A. Grudiev, S. Doebert, A. Latina, Y. Zhao, T. Brezina, H. Pommerenke, F. Zimmermann, M. Benedikt, S. Gilardoni, T. Gilles, A. Lechner, P. Hilser, – CERN

K. Oide, Y. Enomoto, K. Furukawa – KEK

P. Martyshkin – BINP

C. Milardi, O. Blanco, A, De Santis – INFN-LNF

L. Bandiera, M. Soldani, A. Sytov – INFN Ferrara

B. Dalena, A. Chance - CEA

Wir schaffen Wissen – heute für morgen

Thank you for the attention!

Any questions?

FCCIS: 'This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754.'

Strong support from Switzerland via CHART II program 2019 – 2024 for FCC-ee injector, HFM, beam optics developments, geology and geodesy activities.