Possibilities in the FCC-ee pre-injector complex

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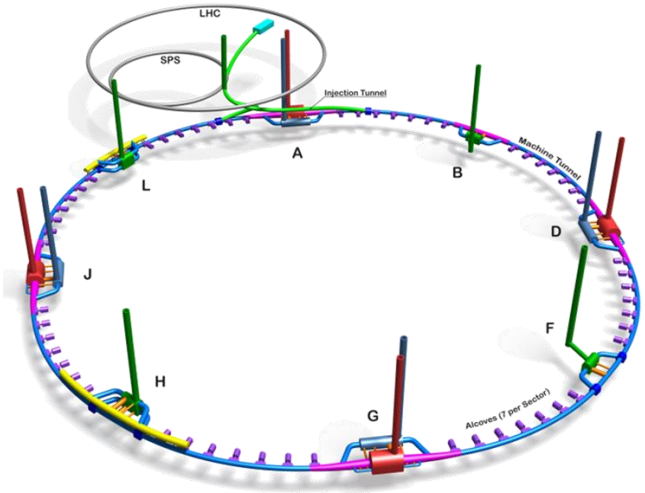
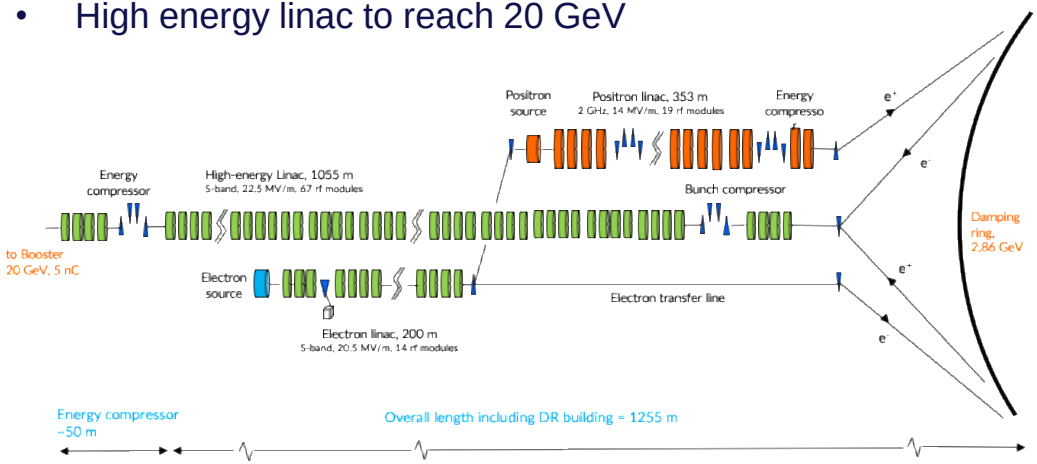
FCC-ee complex

FCC-ee tunnel
- collider with 4 experiments
- full energy booster for top-up operation

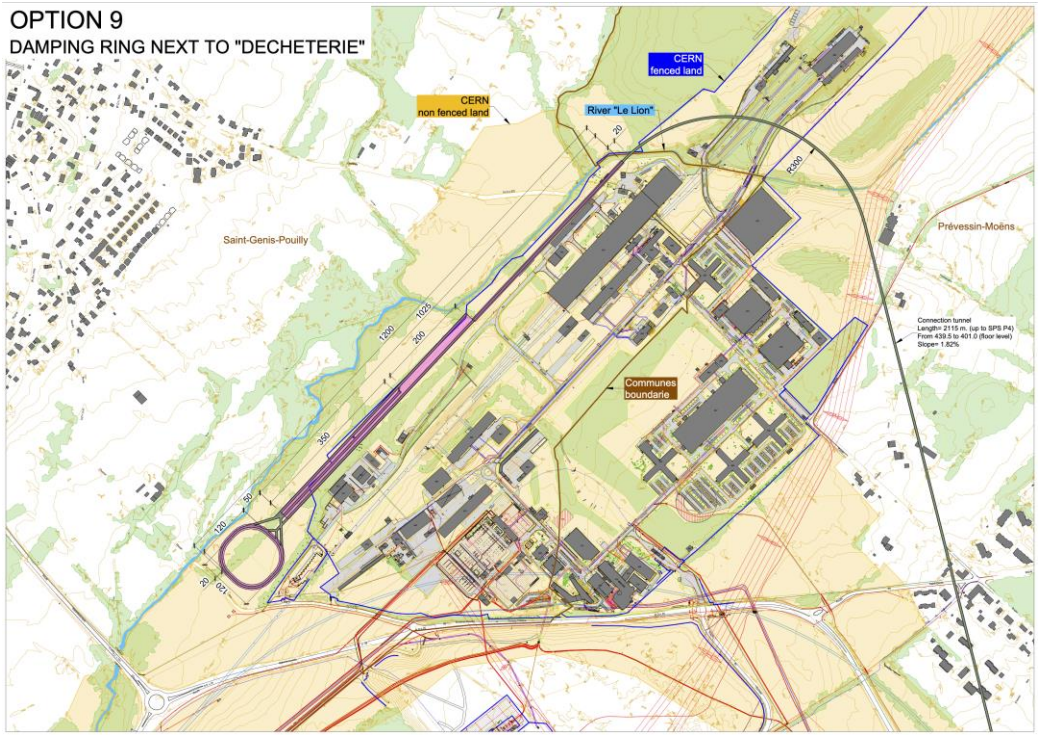


Injector complex up to 20 GeV (booster injection energy)
- Electron linac up to 2.86 GeV
- Positron target at 2.86 GeV and positron linac to reach again 2.86 GeV
- Damping ring for both e+ and e- at 2.86 GeV
- High energy linac to reach 20 GeV



Siting of injector complex

- Injector complex on the Prevessin site with damping ring next to the “dechetterie”
- High energy linac next to North Area and Beam Dump Facility
- Earlier proposal: connection tunnel (2.1 km) to reach BA4 of the SPS, for transfer to the booster



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Siting of injector complex

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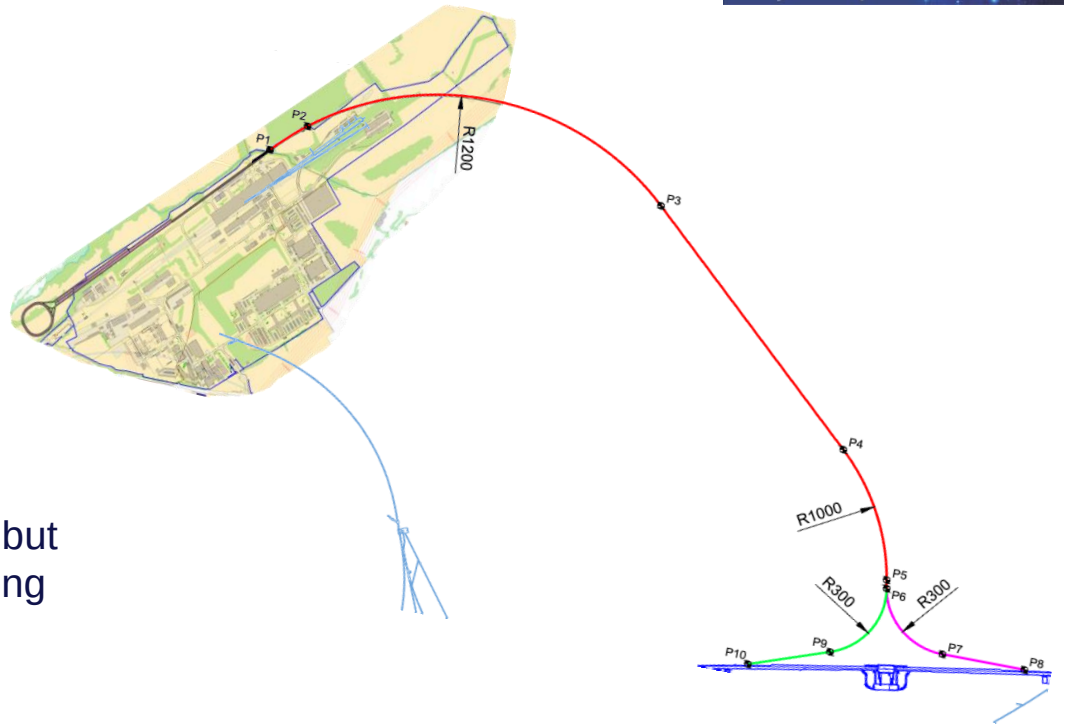
- High energy linac next to North Area and Beam Dump Facility
- ~~Earlier proposal: connection tunnel (2.1 km) to reach BA4 of the SPS, for transfer to the booster~~
- Latest proposal not going through SPS but towards PA of FCC-ee booster with a long section of common e^+/e^- transport lines



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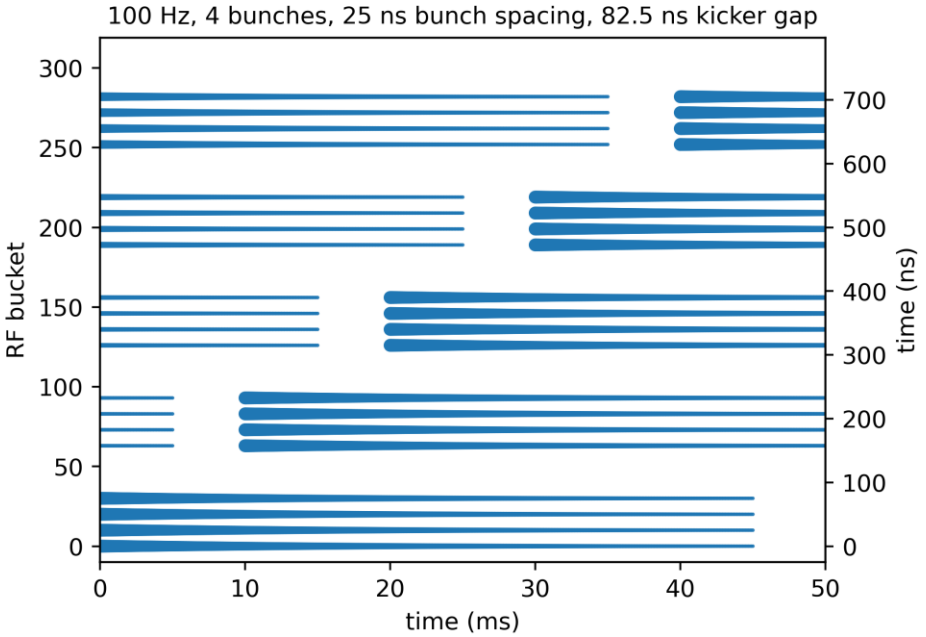
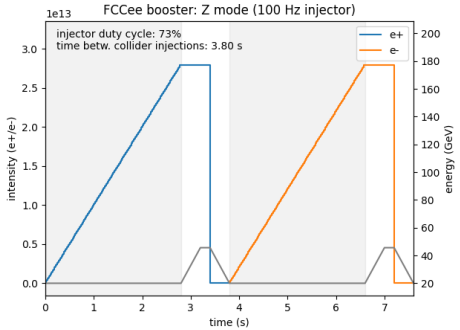
Damping ring filling scheme

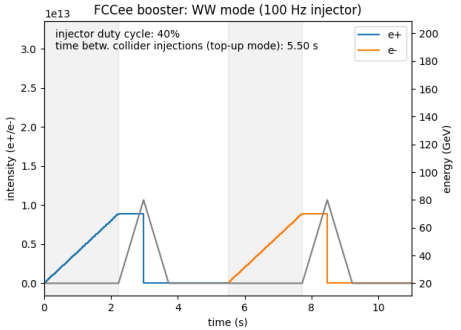
- Continuous re-filling scheme
  - Staggered injection at 100 Hz
  - 4 bunches with 25 ns bunch spacing per injection
  - Storage for ~42.5 ms (4x transverse damping times)
  - Staggered extraction
- Once the booster is filled with the required number of $e^+(e^-)$ bunches, the injector switches to $e^-(e^+)$ operation

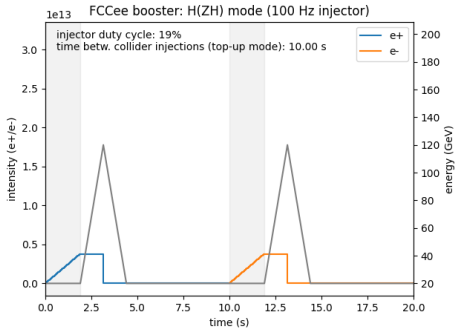


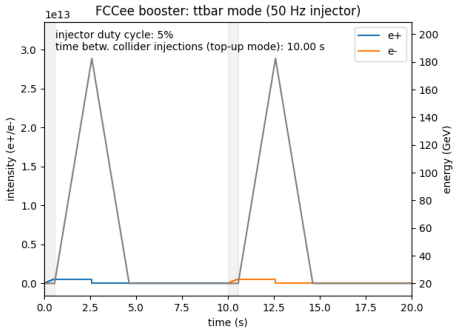
Booster filling cycles

- The required pre-injector **duty cycle for FCC-ee top-up** depends on operating mode
  - **73% for Z** (high number of bunches in collider)
  - **5% for ttbar** (few bunches with “long” acceleration in booster)
  - **Other modes are in between**
- **During the ramping of the booster, the pre-injectors could serve other users with e^+ or e^- beams**







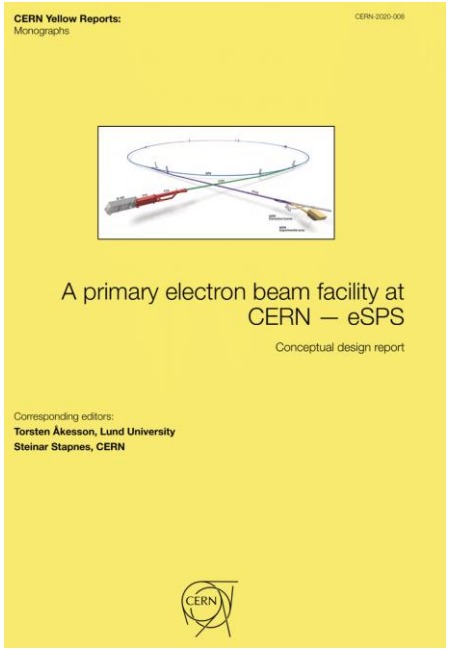


Beam parameters FCC-ee pre-injector

Running mode	FCC	PBC users	Unit
Beam energy at exit of injector	20	≤20	GeV
Maximum bunch charge	4	4	nC
Maximum bunch intensity	2.5	0.1-2.5	10^{10}
Number of bunches per pulse	2-4	1-4 (more?)	
Linac repetition rate	50-100	100	Hz
Normalized emittance (x, y) (rms)	≤20, 2	≤20, 2	mm mrad
Physical emittance (x, y)	≤0.5, 0.05	≤0.5, 0.05	nm rad
Bunch length (rms)	~4	1-4	mm
Energy spread (rms)	~0.1	0.1-0.75	%
Bunch spacing from injector	25	25-50	ns
Pre-injector duty cycle	5-73	27-95	%

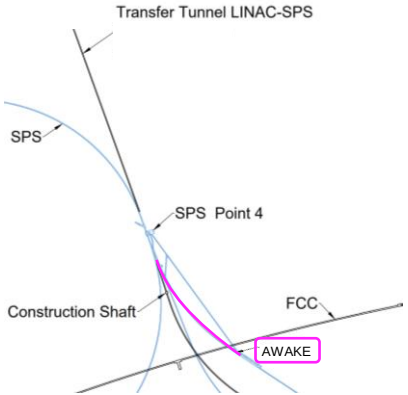
Other exploitation of FCC-ee injectors?

- FCC-ee injector beams could be used for a **CLEAR-like facility** (including also the damping ring):
  - **R&D for accelerator components and beam diagnostics for FCC-ee** or the injector itself (in particular if injector goes online ahead of FCC-ee and/or is built in stages)
  - **Irradiation facility** (e.g. for testing electronics components)
  - **Medical research**
  - **Use synchrotron light from damping ring at 2.86 GeV** to test coatings, photon desorption but also other low emittance rings beam dynamics and technology (BT elements, RF, wigglers, instrumentation,…) for FCC-ee and beyond
  - **Plasma wakefield acceleration test facilities** (electron driven, but maybe even in combination with proton driven plasma, see next slide)



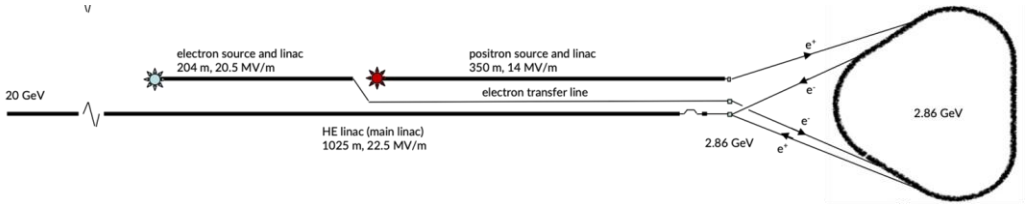
e^+/e^- beams interesting for AWAKE !

- The previous layout of the FCC-ee injectors passes through SPS BA4, i.e. the SPS extraction point of protons for the plasma wakefield acceleration experiment AWAKE
- Keeping SPS operation with protons, there would be a unique opportunity to perform **proton driven plasma wakefield acceleration of 20 GeV electrons and *positrons***
  - Lepton beam parameters fit extremely well for wakefield experiments
  - Unique possibility of positron acceleration (currently no experiments worldwide)
- With the two-bunches setup, also electron driven plasma wakefield acceleration experiments can be performed
  - 1st electron beam is the drive beam, 2nd one is the witness beam
- Proton beam line, experimental facility as well as lepton injection area and tunnel to the experiment exists
  - Would require transfer line for e+/e- in TT40/41 tunnel (+transfer to the SPS if latest layout proposal is retained)



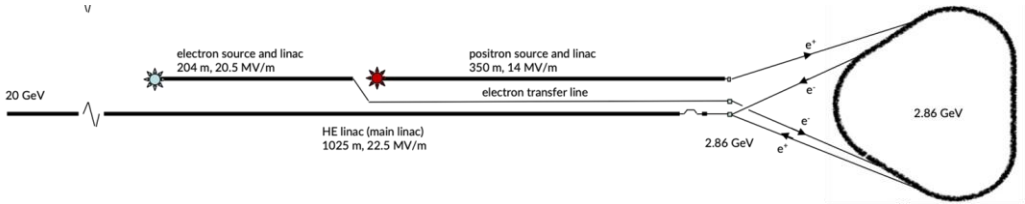
Positrons for dark matter searches

- Request from physics (P. Crivelli): **“Continuous” stream of “single” positron bunches, spaced by few ns at 20 GeV**
- **Option I: 20 GeV**
  - Use dark current of photo-cathode to produce continuous low intensity electron beam and convert to positrons on the target (2.86 GeV)
  - Linac **repetition of 100 Hz with pulse length of only 75 ns (linac design for FCC-ee)**
  - Use Damping Ring as transfer line to get the beam into the high energy Linac
  - Common frequency of electron and positron Linacs is 400 MHz → **2.5 ns bunch spacing, 31 bunches**
  - Possibility to change to 3 GHz for electron and high energy Linac, common frequency of 1 Ghz → 1 ns bunch spacing, with 76 bunches



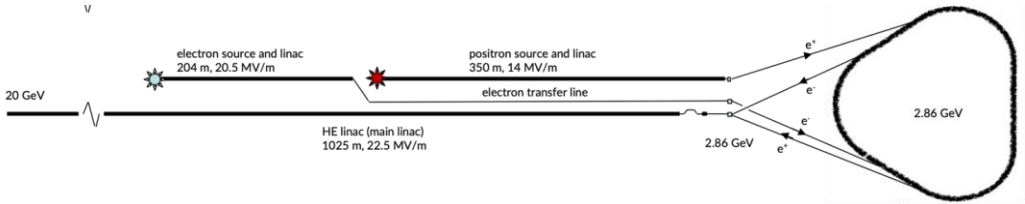
Positrons for dark matter searches

- Request from physics (P. Crivelli): **“Continuous” stream of “single” positron bunches, spaced by few ns at 20 GeV**
- **Option II: intermediate energy (e.g. 11.8 GeV)**
  - Fill the damping ring with low intensity bunches and perform **slow extraction towards high energy linac** – details to be worked out
  - Pulse high energy linac at **100 Hz with longer pulses at the expense of the final energy**
    - **e.g. 3 us pulse length could allow for 11.8 GeV, resulting in 1200 bunches each pulse – higher energies with shorter pulses are also possible, to be studied in more detail**



Positrons for dark matter searches

- Request from physics (P. Crivelli): **“Continuous” stream of “single” positron bunches, spaced by few ns at 20 GeV**
- **Option III: 2.86 GeV**
  - Fill the damping ring with low intensity bunches (detailed scheme of accumulation to be worked out) and perform **slow extraction at 2.86 GeV towards the experiment**
  - 400 MHz (RF cavity in Damping Ring) → **2.5 ns bunch spacing** and **pulses can be much longer** (order of ms long pulses to the experiment)



Positrons for dark matter searches

- Request from physics (P. Crivelli): **“Continuous” stream of “single” positron bunches, spaced by few ns at 20 GeV**
- **Option IV: slow extraction from FCCee booster at 20 GeV**
  - Inject 10 pulses (100 ms) and dilute all bunches around the booster circumference (RF off, debunch, re-bunch in 800 MHz buckets → **1.25 ns bunch spacing**) during another 100 ms → time required for debunching to be confirmed in more detailed studies
  - Slow extraction as long allowed in between booster cycles for FCC-ee top-up
  - Due to 800 MHz RF structure of the booster, can extract **8e+8 single positrons per second**
  - 50% (30%) of the booster duty cycle is available in H and ttbar (WW) → assume 40% (20%) resulting in **2.7e13 (1.3e13) single positrons / day in H and ttbar (WW), but not possible during Z-pole operation**
  - To be checked if beam can be transported back to CERN Prevessin site using the same transfer lines between booster and linac, or if experiment should be installed close to booster extraction

Positrons for dark matter searches

	Option I: 20 GeV e^+ (high energy linac)	Option II: 11.8 GeV e^+ (high energy linac)	Option III: 2.86 GeV e^+/e^- (slow extr. from DR)	Option IV: 20 GeV e^+/e^- (slow extr. from booster)
Bunch spacing	2.5 ns (or 1.0 ns)	2.5 ns	2.5 ns	1.25 ns
Pulse length	75 ns	3 us	100 ms	~ seconds
Number of “single positrons” per pulse	31 (76)	1200	40e+6	800e+6 (for a 1 s pulse)
Repetition rate	100 Hz	100 Hz	5 Hz	cycles in the booster
Duty cycle	25-90%	25-90%	25-90%	40% in H and ttbar (20% WW)
Energy	20 GeV	11.8 GeV	2.86 GeV	20 GeV
Pot / day	2e+8 (5e+8) (70% duty cycle)	7e+9 (70% duty cycle)	1e+13 (70% duty cycle)	2.7e+13 during H and ttbar (1.3e+13 during WW)
Required hardware		• extraction kickers with ~few us flat top • slow extr. (DR)	• injection kickers with ~few us flat top • slow extr. (DR)	• Slow extr. (booster)

Summary and conclusions

- The FCC-ee injector complex has potential to provide beams for other facilities
- The injector complex can provide
  - 4 e+ or e- bunches spaced by 25 ns (maybe longer if needed) with up to 2.5e10 particles per bunch (4 nC) at 20 GeV, normalized emittance <10 mm mrad and bunch length of ~ 1 mm
  - Only between 5% and 73% of the duty cycle is needed for top-up of FCC-ee, the rest would be available for other users / facilities
  - A typical other facility could use bursts of 4 bunches at 100 Hz for ~ seconds with the possibility to vary the bunch intensity accurately
  - A special mode of operation could be foreseen for dark matter searches using “single positron” bunches between 2.86 and 20 GeV – details to be studied if intensity interesting for physics
- This opens the possibility for new facilities (e.g. dark matter searches with positrons) and applications (e.g. plasma wakefield acceleration of electrons and positrons in proton or electron-driven plasma wakefield experiments)

Thanks for your attention!