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FCCee Injector Chain

T. Tydecks
on behalf of FCCee Injector and Optics Team

Thanks to:
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J. Wenninger, F. Zimmermann

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FCCee Injector Chain

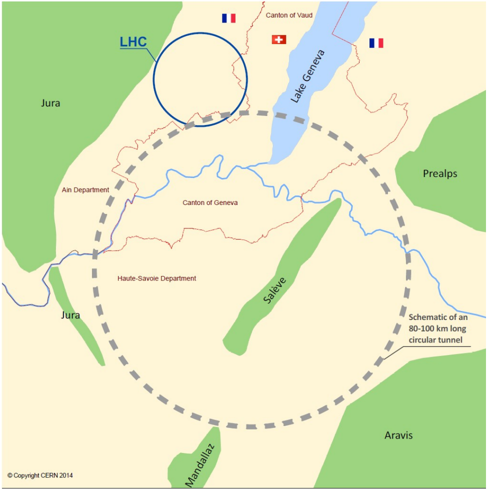
- LINAC
- Pre Booster Ring (SPS)
- Booster

Collider & Dynamic Aperture

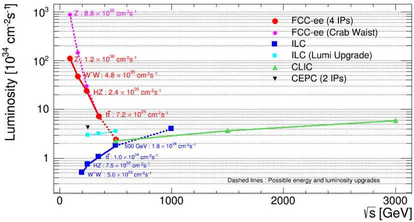
- Z Energy
- $t\bar{t}$ Energy

Swap Out Injection?

FCCee overview



- large circular collider with 100 km circumference
- beam energies of e^+e^- collider up to 175 GeV possible due to large bending angle
- same tunnel will host a *hh* collider afterwards with beam energies of 50 TeV



Pictures from http://tlep.web.cern.ch

Collider Requirements

	Z	W	H	$t\bar{t}$
Circumference / km		100		
Beam energy / GeV	45.6	80	120	175
Bunches / beam	70760	7280	826	64
Bunch population / 10^{11}	0.4	0.41	0.71	2.0
Hor. Emittance / nm rad	0.27	0.28	0.63	1.34
Ver. Emittance / pm rad	1	1	1.2	2.5
β_x^* / m	0.15	1	1	1
β_y^* / mm	1	2	2	2
$Q_{x/y}$	269.14/267.22	389.09/389.18		
Energy Loss / turn / GeV	0.04	0.34	1.72	7.8
SR power / beam / MW		50		

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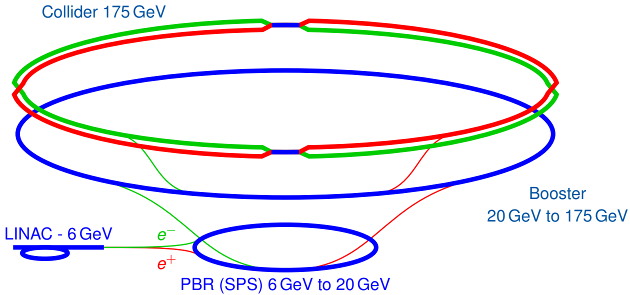
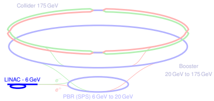
Injector Chain Overview

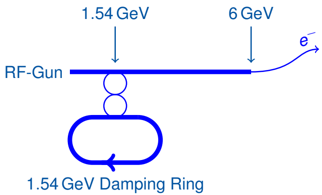


- LINAC: final beam energy 6 GeV
- PBR: ramp beam energy from 6 GeV to 20 GeV
- Booster: ramp beam energy from 20 GeV to 175 GeV
  $\rightarrow$ needs to be hosted in collider tunnel due to SR power

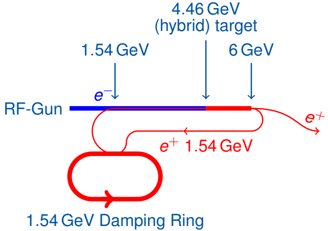
LINAC + Damping Ring (1)



Electrons:



Positrons:



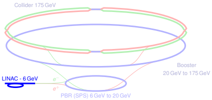
$\rightarrow$ delivering 2.55×10^{10} $e^{+/-}$ of 6 GeV beam energy @ 200 Hz

- positron production in hybrid target at 4.46 GeV,
- damping ring: $e^- \sim 25$ ms, $e^+ \sim 45$ ms
- hor. emittance at extraction: 0.7 nm rad

Freq.	E_i	E_f	Bunch Charge	Length	ε_i	ε_f
2.856 GHz	12 MeV	6 GeV	6.5 nC	257.3 m	0.35 µm/0.5 µm	0.7 nm/1.0 nm

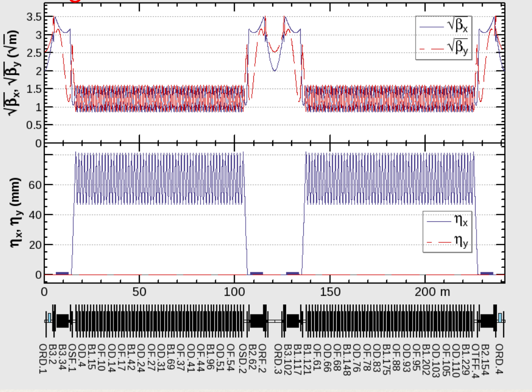
Courtesy S. Ogur

LINAC + Damping Ring (2)



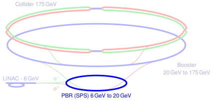
Damping ring: simple FODO lattice with two dispersion free straight sections and damping wigglers:

S. Ogur



Parameter	Value
tau_x	10.6 ms
tau_y	11.0 ms
tau_z	5.6 ms
natural emittance (x/y/z)	1.16 nm/- 1.46 μm
circumference	241.8 m
# of cells (FODO w/ sextupoles)	114
dipole field	0.66 T
no. of wigglers, field	4, 1.80 T

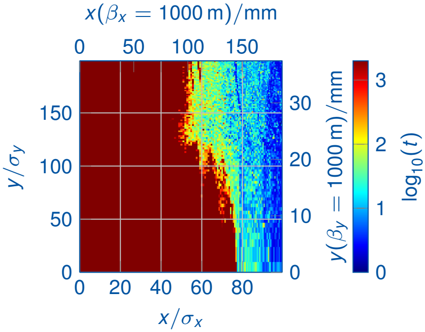
Pre Booster Ring (SPS)

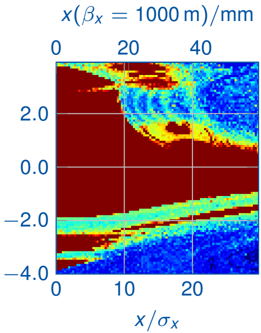


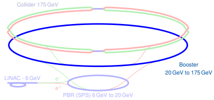
- planned to use SPS as a pre-booster ring $\leftrightarrow$ 6.9 km
- accumulation of beam from LINAC (multiple injections)
- ramping beam energy from 6 GeV to 20 GeV
- hor. emittance at extraction: 0.7 nm rad possible (with damping wigglers)
- cycle time: up to 18 s, ramp time to 20 GeV: 0.25 s
- dynamic aperture studied at the moment

Ö. Etisken

Booster Synchrotron







- large booster synchrotron hosted in same tunnel as collider

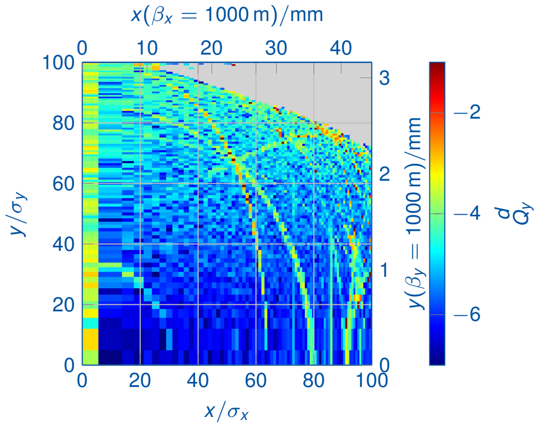
$\rightarrow$ similar arc lattice $\Rightarrow$ similar emittances

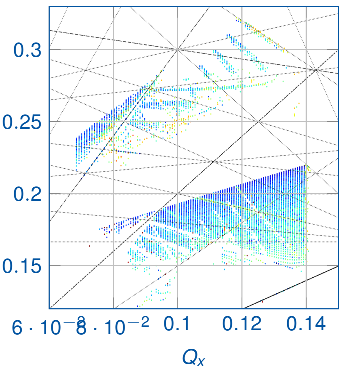
- due to missing IP's, large DA and momentum acceptance
- maximum repetition rate estimated as 0.1 Hz

→ see talk from B. Härer on "FCCee Booster Lattice Design"

Outline

Z - DA - no rad., no imperf.

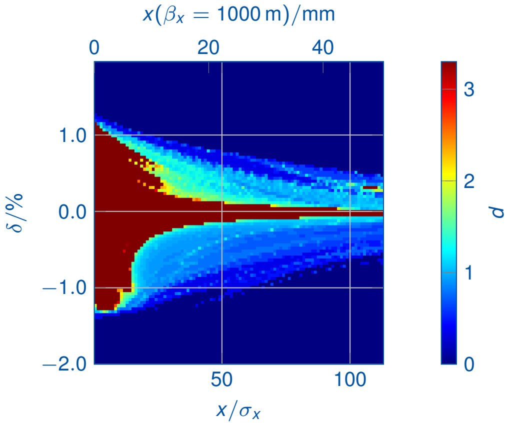




- $d = \log_{10}\left[\sqrt{\left(\nu_x^{(1)} - \nu_x^{(2)}\right)^2 + \left(\nu_y^{(1)} - \nu_y^{(2)}\right)^2}\right]$ using NAFF[1]

(1) Y. Papaphilippou, *Detecting Chaos in Particle Accelerators through Frequency Map Analysis Method*, Chaos 24 (2014) 024412, 2014

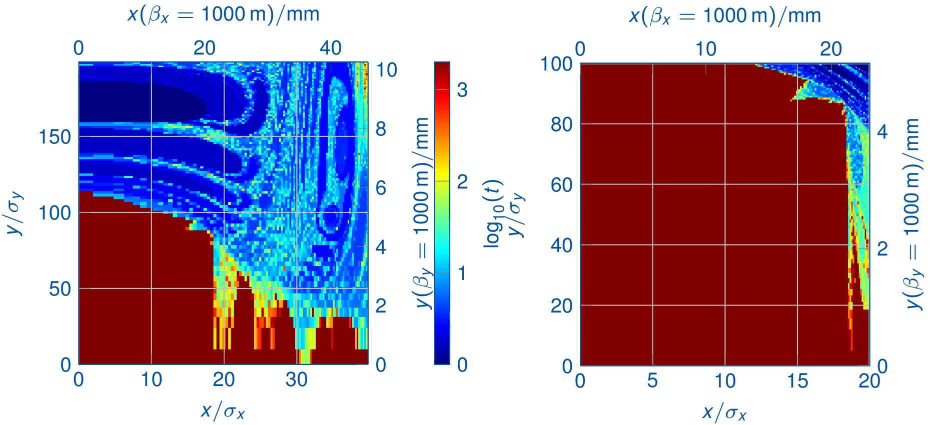
Z - MA - no rad., no imperf.



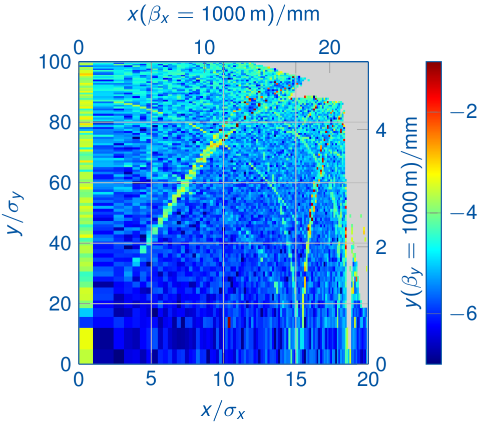
- large on-energy DA
- momentum acceptance rather small
- no errors included yet

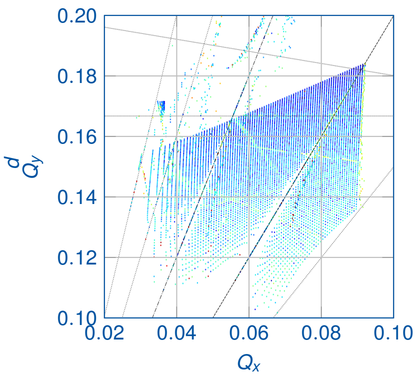
$\rightarrow$ DA likely to shrink significantly

$t\bar{t}$ - DA - no rad., no imperf.



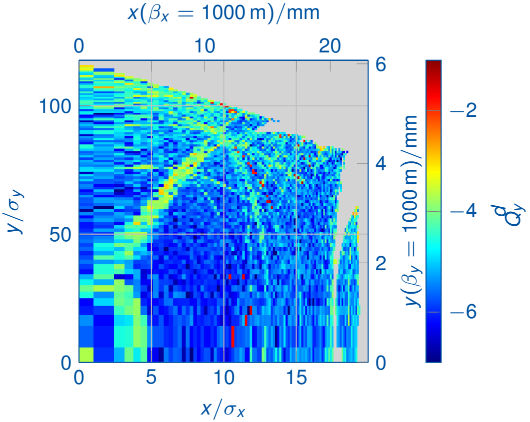
$t\bar{t}$ - DA - no rad., no imperf.

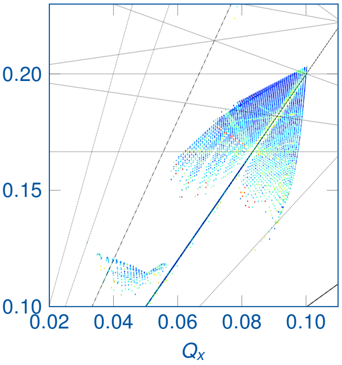




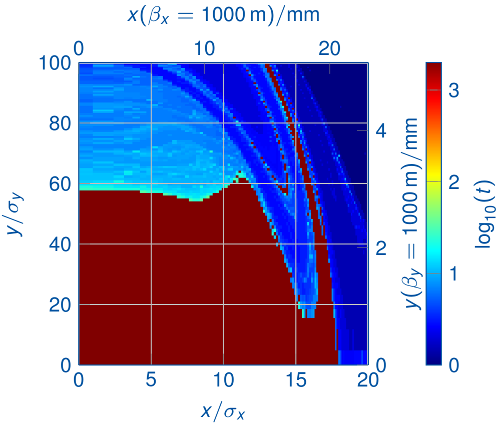
$t\bar{t}$ - DA - no rad., small imperf.

misalignment errors: $\sigma_{x/y/s} = 5\,\mu\text{m}$, $\sigma_{\phi,\theta,\psi} = 5\,\mu\text{rad}$

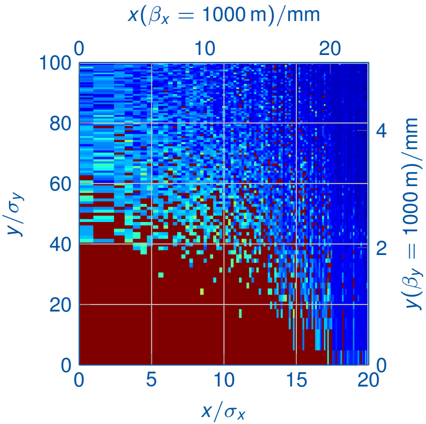




$t\bar{t}$ - DA - radiation



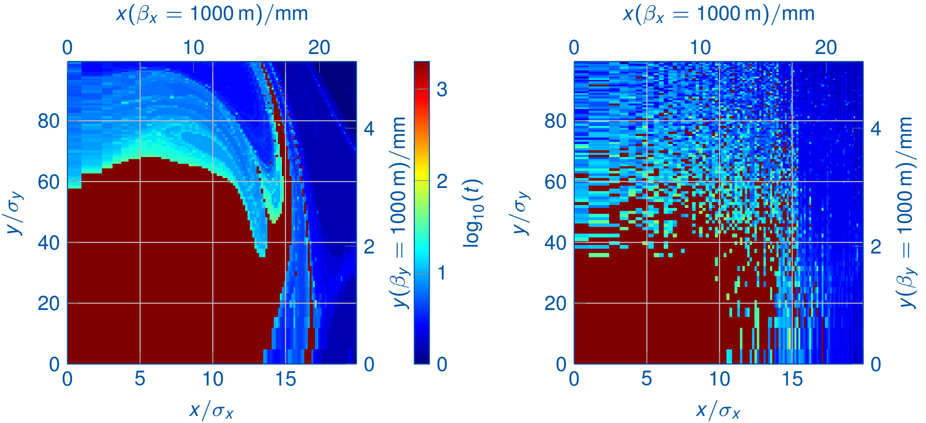
- only radiation damping



- radiation damping & quantum excitation

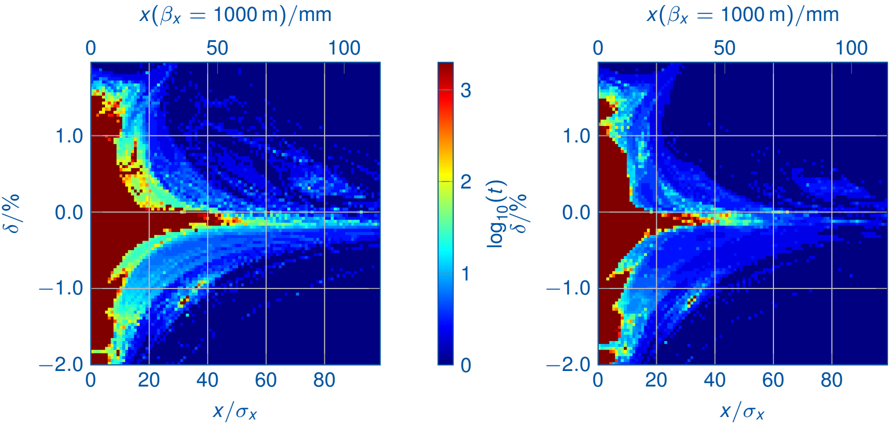
$t\bar{t}$ - DA - rad., small imperf.

Misalignment errors: $\sigma_{x/y/s} = 5\,\mu\text{m}$, $\sigma_{\phi,\theta,\psi} = 5\,\mu\text{rad}$



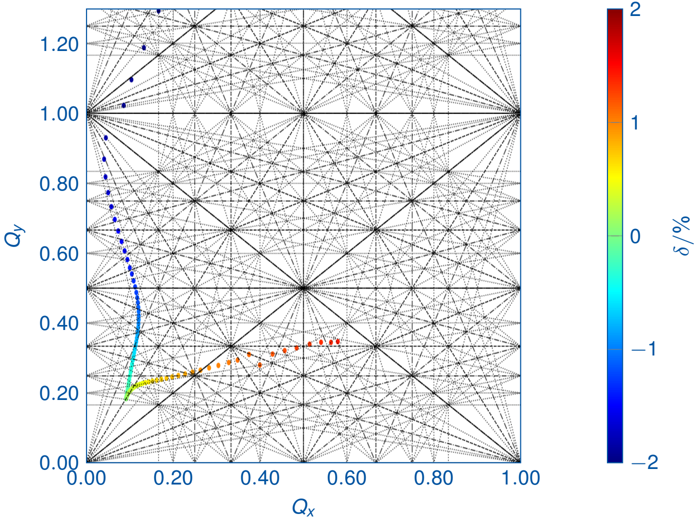
- only radiation damping
- radiation damping & quantum excitation

$t\bar{t}$ - MA - no radiation (1)

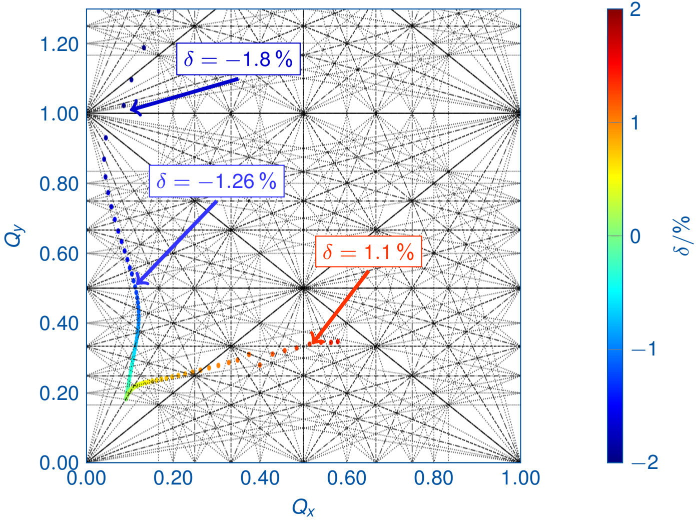


- no imperfections
- Misalignment errors: $\sigma_{x/y/s} = 5\,\mu\mathrm{m}$, $\sigma_{\phi,\theta,\psi} = 5\,\mu\mathrm{rad}$

$t\bar{t}$ - MA - no radiation (2)



$t\bar{t}$ - MA - no radiation (2)



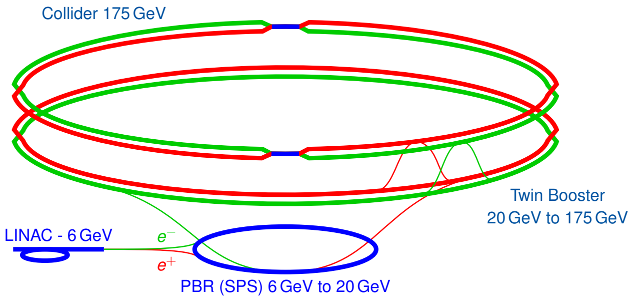
DA / MA summary

- machine without errors yields sufficient DA
- momentum aperture for $t\bar{t}$ large if half integer / integer crossing possible
- small errors reduce aperture significantly

$\Rightarrow$ more realistic misalignment amplitudes & field errors in combination with orbit correction to be studied

Outline

To Discuss: Alternative Swap Out Injection (1)

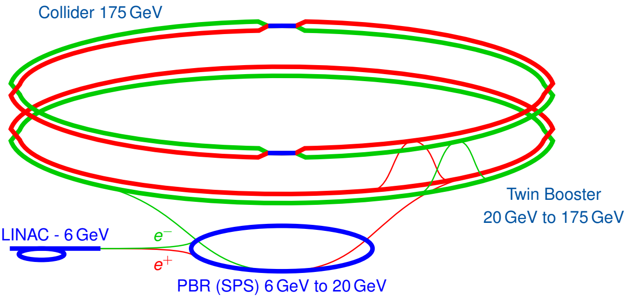


- in the case that DA reduces further:

→ build booster out of rampable replica of collider magnets

→ twin booster ring that continously ramps down degraded beams, refurbishes at flat bottom and brings fresh beams up to swap with collider beams

To Discuss: Alternative Swap Out Injection (2)



main advantages:

→ possibility for very small dynamic apertures

⇒ very little interference with experiments as little betatron / synchrotron oscillations from injected beam present

- in case of LHC: measured rms position jitter 0.27/0.13 $\sigma^*_{x/y}$

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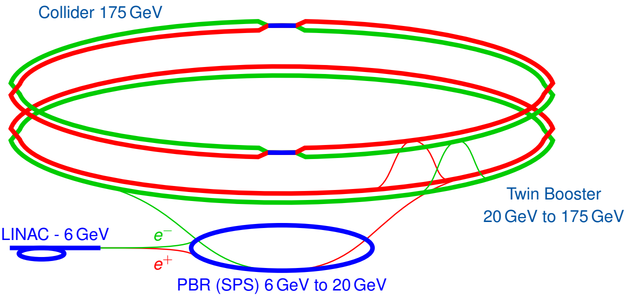
* Mertens et al., Beam commissioning of injection into the LHC, Proc. PAC09, 2009

To Discuss: Alternative Swap Out Injection (3)



main disadvantages:

- depending on bunch charge in booster: high rf-power consumption
- swaping large amount of power every couple of minutes might be an issue for machine protection
- etc... ?

Summary & Outlook

- FCCee injector chain as planned at the moment will be capable to deliver necessary beam intensities and properties for FCCee collider
- dynamic aperture of FCCee appears to be large enough in both transverse and longitudinal plane if no misalignments / field errors are present
- studies of misalignments and orbit corrections are on their way and shall be finalised for CDR next year
- if DA remains small, alternative injection schemes like swap out have to be taken into account

Thanks for your attention...

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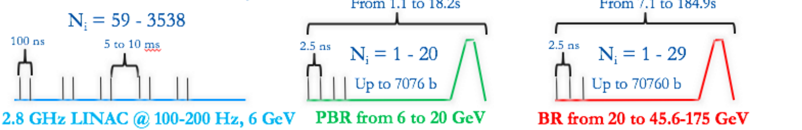
FCC-ee injector **baseline** scheme

- **Baseline** established based on SLC/SUPERKEKB-like linac (higher gradient)
  - Longer pulses with **1 or 2** bunches with repetition rate of **100-200 Hz, 2.8 GHz** RF
  - Maximum linac bunch intensity ~ **2.55×10^{10} particles** (both species).
  - Twice as much will be needed for e-beam for e+ production
  - Injected several times (from **64 to 3538**), @ **6 GeV** into of PBR (SPS or new ring) with 1 linac bunch to 1 ring bucket (**400 MHz** RF system), up to **7076** bunches
  - SPS ramp to **20 GeV** with **0.25 s** ramp rate and cycle length **below 18 s**
  - Transferred to main Booster (**1-20** SPS cycles), with **400 MHz** RF frequency, to a bunch structure required by the collider (from **64** to **70760** bunches)
  - Accelerated to the corresponding energy with ramp time from **1.5-3 s**, and total cycle length up to 185 s
  - Transferred to the collider by accumulating current for the full filling or single injection for top-up
  - **Interleaved** filling of e+/e-
  - Full filling below **20 min** for both species
  - Top-up target time, based on **5 %** of current drop due to corresponding lifetime, always achieved
  - **80 %** transfer efficiency



FCC-ee injector parameters (new)

Accelerator	FCCee-Z		FCCee-W		FCCee-H		FCCee-tt	
Energy [GeV]	45.6		80		120		175	
Type of filling	Full	Top-up	Full	Top-up	Full	Top-up	Full	Top-up
LINAC # bunches, with 2.8 GHz RF	2		1					
LINAC repetition rate [Hz]	200		100					
LINAC/SPS bunch population [10^{10}]	2.5	0.25	1.25	0.25	1.11	0.44	2.55	1.28
# of LINAC injections	244	3538	364		59		64	
SPS bunch spacing [ns]	2.5		40		390		360	
# SPS cycles	10		20		14		1	
SPS # of bunches	488	7076	364		59		64	
SPS cycle time [s]	1.72	18.19	4.14		1.09		1.14	
SPS duty factor	0.79	0.94	0.91		0.15	0.70	0.16	
BR # of bunches	4880	70760	7280		826	826	64	
BR cycle time [s]	20.2	184.9	88.8		21.3		7.1	
#of BR cycles	29	1	4	1	8	1	10	1
# of injections/collider bucket	2	1	4	1	8	1	10	1
Total number of bunches	70760		7280		826		64	
Filling time (both species) [sec]	1171.6	369.8	710.4	177.6	340.2	42.5	142.8	14.3
Injected bunch population [10^{10}]	4.0	0.2	4.0	0.2	7.1	0.35	20.4	0.10