Overview of FCCee Injector Complex

John Seeman,
SLAC
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FCCee Injection Design Team

Electron source simulations, LINAC design: D. Nikiforov (BINP), A. Barnyakov (BINP), T. Bondarenko, A. Levichev (BINP), S. Polozov (MEPhI)

Pre-injector design (LINAC, DR , BTL): S. Ogur (Boğaziçi Un. & CERN), K. Furukawa (KEK), N. Iida (KEK), F. Miyahara (KEK), K. Oide (KEK), F. Zimmermann (CERN).

Pre-Booster ring design: Ö. Etişken (Ankara Un.), Y. Papaphilippou (CERN)

Injection/extraction: M. Aiba (PSI), A. Saa Hernandez (CERN)

Positron production: I. Chaikovska (LAL), A. Apyan (Yerevan Phy. Ins.), R. Chehab (LAL), P. Martyshkin (BINP), L. Rinolfi (CERN).

Booster ring design: B. Harer (CERN), B. Holzer (CERN), T. Tydecks (CERN)

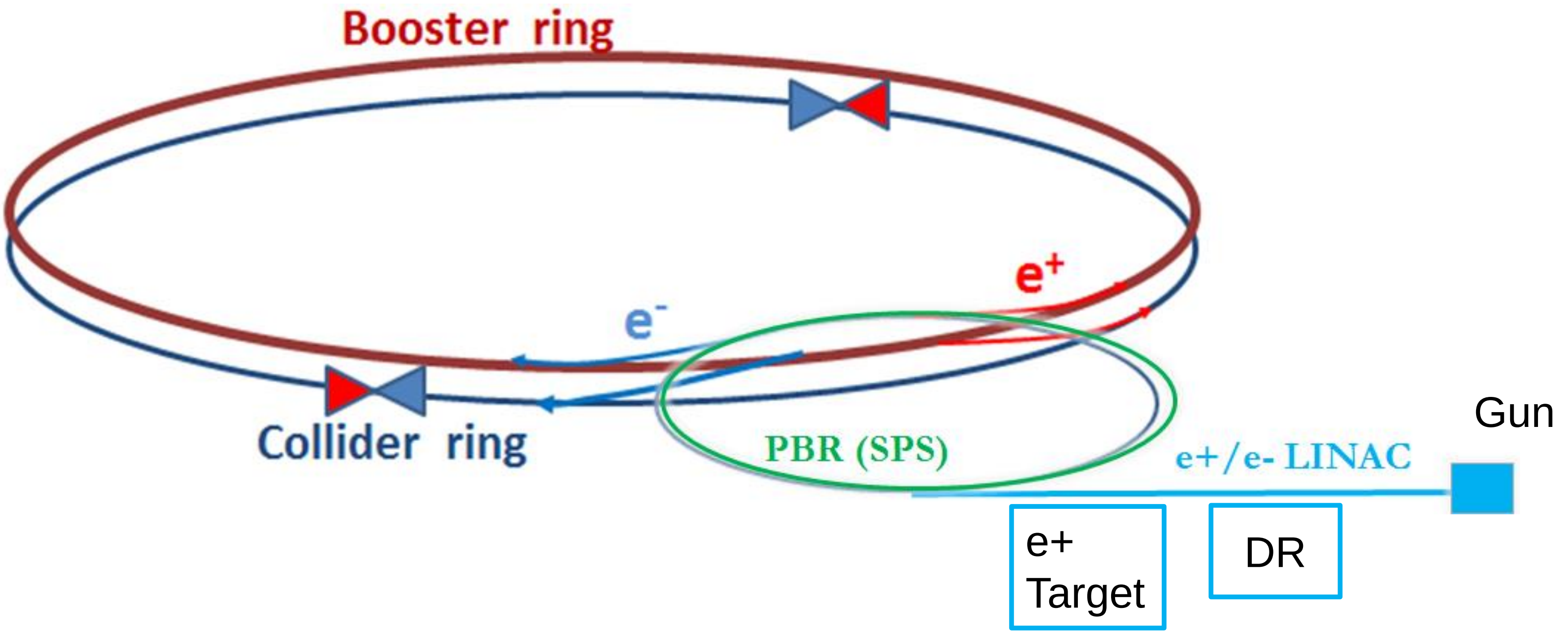
Polarization: I. Koop (BINP)

Injector parameters: K. Oide (KEK), Y. Papaphilippou (CERN) J. Seeman (SLAC), F. Zimmermann (CERN)

Topics

- Injection Requirements
- Gun Options
- Positron Systems
- Linac and Damping Ring
- Pre-booster Ring
- Booster Ring
- Injection into the Collider

Injector overview



FCCee Injector Complex

Injector complex is comprised of:

- e+/e- LINAC and Damping Ring (to ~6 GeV)
- Pre-Booster Ring - PBR (from ~6 to ~20 GeV) (SPS?)
- Booster ring (from ~20 to full FCCee energy ~45 to 175 GeV per beam)
- [Proposal for extra ring with wigglers for rapid radiative polarization (@ ~1-2 GeV)]

Injected beam parameters required:

Beam energy = 45 to 175 GeV

Energy stability < 0.3 %

Charge per injected bunch ~ 0.2 to 20 x 10^{10}

Charge stability < 2%

Bunch length < 2 mm

Energy spread rms < 0.3 %

Emittance (x,y) ~ 1.5 nm-rad

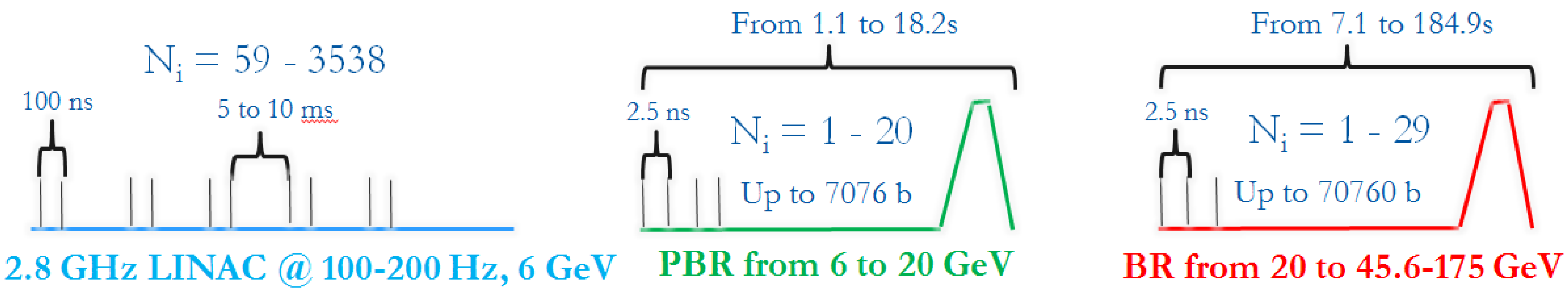
FCCee Collider Parameters (K. Oide, F. Zimmermann …)

Design		2017			
Circumference	[km]	97.750			
Arc quadrupole scheme		**twin aperture**			
Bend. radius of arc dipole	[km]	10.747			
Number of IPs / ring		2			
Crossing angle at IP	[mrad]	30			
Solenoid field at IP	[T]	±2			
ℓ^*	[m]	2.2			
Local chrom. correction		y-plane with crab-sext. effect			
RF frequency	[MHz]	400			
Total SR power	[MW]	100			
Beam energy	[GeV]	45.6	80	120	175
SR energy loss/turn	[GeV]	0.036	0.34	1.72	7.80
Long. damping time	[ms]	414	76.8	22.9	7.49
Current/beam	[mA]	1390	147	29.0	6.4
Bunches/ring		70760	7280 (4540)	826 (614)	64 (50)
Particles/bunch	[10^{10}]	4.0	4.1 (6.6)	7.1 (9.6)	20.4 (26.0)
Arc cell		60°/60°	90°/90°		
Mom. compaction α_p	[10^{-6}]	**14.79**	7.31		
Horizontal tune ν_x		269.14	389.08		
Vertical tune ν_y		267.22	389.18		
Arc sext. families		208	292		
Horizontal emittance ε_x	[nm]	**0.267**	0.28	0.63	1.34
$\varepsilon_y/\varepsilon_x$ at collision	[%]	0.38	0.36	0.2	0.2
β_x^*	[m]	**0.15**	1 (0.5)		
β_y^*	[mm]	1	2 (1)		
Energy spread by SR	[%]	0.038	0.066	0.099	0.147
Energy spread SR+BS	[%]	0.073	0.072 (0.091)	0.106 (0.122)	0.193 (0.212)
RF Voltage	[MV]	**255**	696	2620	9500
Bunch length by SR	[mm]	2.1	2.1	2.0	2.4
Bunch length SR+BS	[mm]	4.1	2.3 (2.9)	2.2 (2.5)	2.9 (3.5)
Synchrotron tune ν_z		−0.0413	−0.0340	−0.0499	−0.0684
RF bucket height	[%]	3.8	3.7	2.2	10.3
Luminosity/IP	[10^{34}/cm^{2}s]	**137**	16.4 (30.0)	4.6 (8.0)	1.35 (2.09)

Injector Parameters (New Baseline) (Y. Papaphilippou)

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

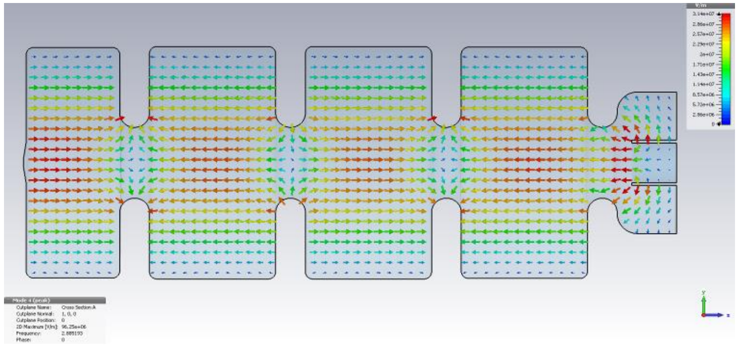
Injection Cycles (Y. Papaphilippau)



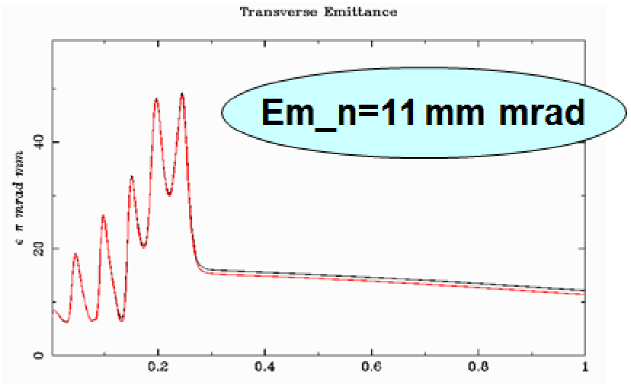
- Linac 1 or 2 bunches per pulse at 100-200 Hz.
- Electron bunch population = 2.66×10^{10} (can go up to $\sim 6 \times 10^{10}$ max for e+ production)
- Two bunches per pulse spaced by ~100 ns (can be increase up to 3-4 bunches)
- Required number of e+ (accepted) in the pre-booster (perhaps SPS) 2.66×10^{10}
- Required number of e+ in collider bunch: 4.25×10^{10}
- Assume 80% injection efficiency for each transfer.

Electron Gun Studies

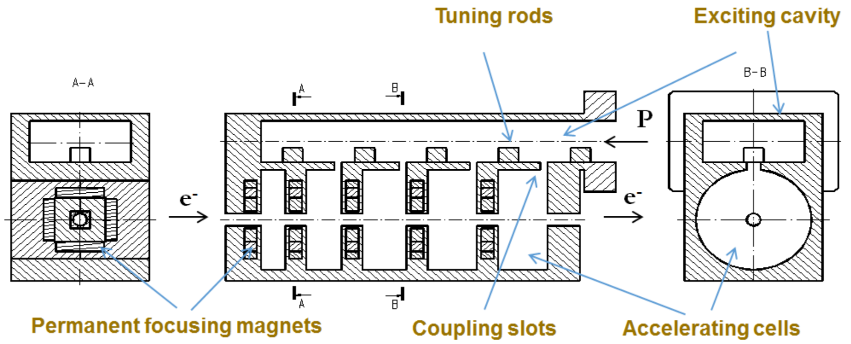
Courtesy: A.M. Barnyakov, D.A. Nikiforov, A.E. Levichev (BINP)



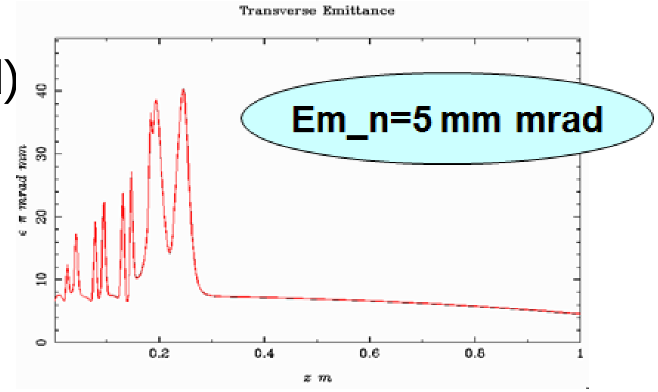
Old (traditional) gun design



RF gun based on the parallel coupled accelerating structure



New (proposed) gun design



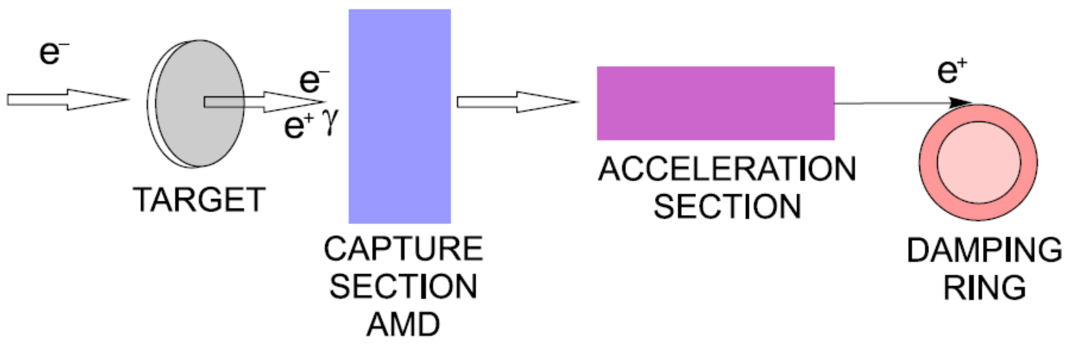
Positron Source (I. Chaikovska …)

Conventional e+ source

Primary e- beam

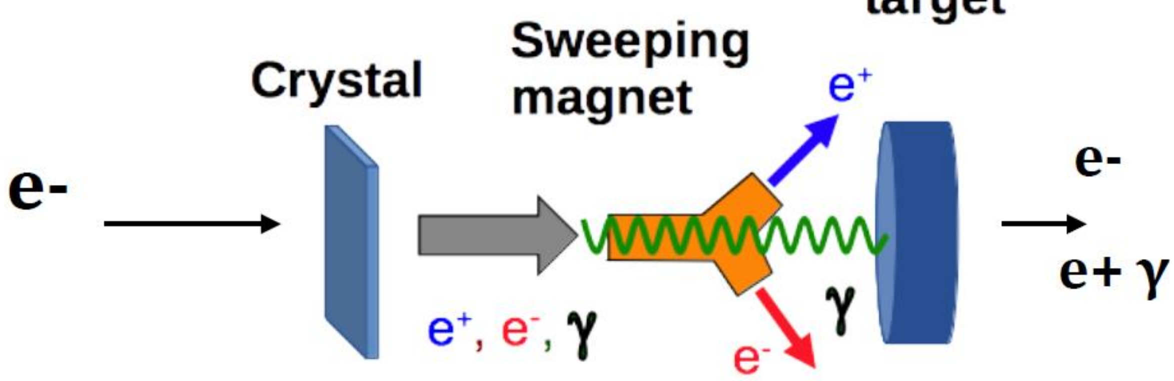
4.46 GeV

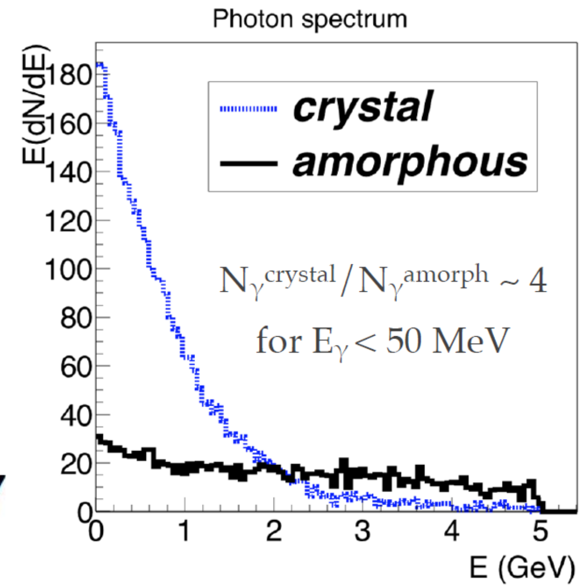
4.1×10^{10} e⁻/bunch ~ 6.5 nC
up to 10 nC



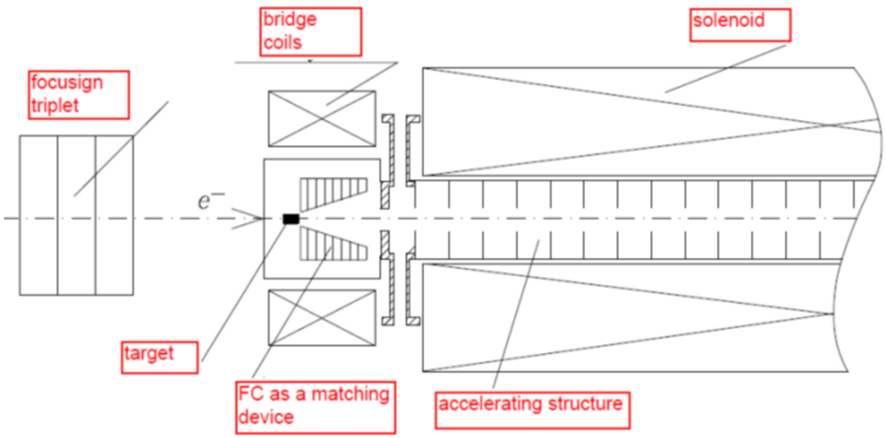
Hybrid e+ target

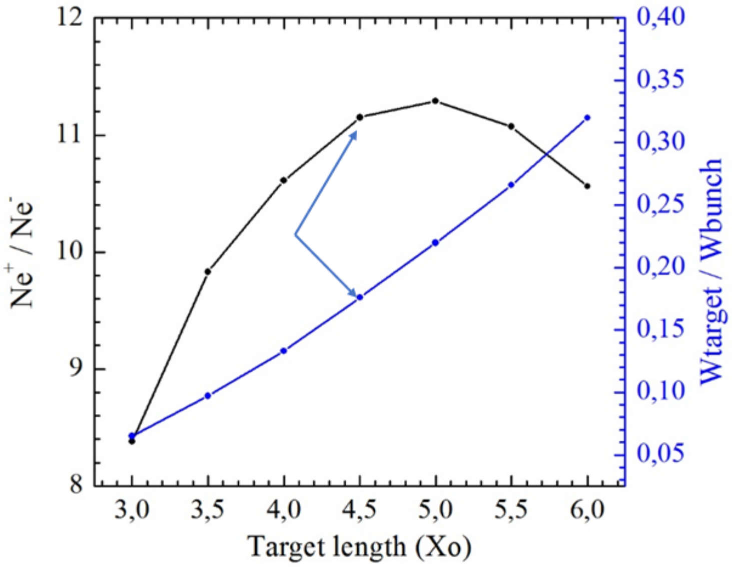
Compact or Granular target

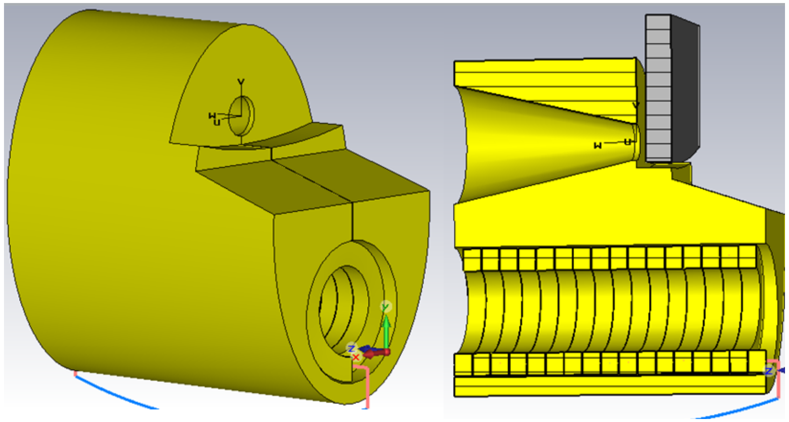




Positron Collection and Capture (P. Martyshkin, …) (BINP)



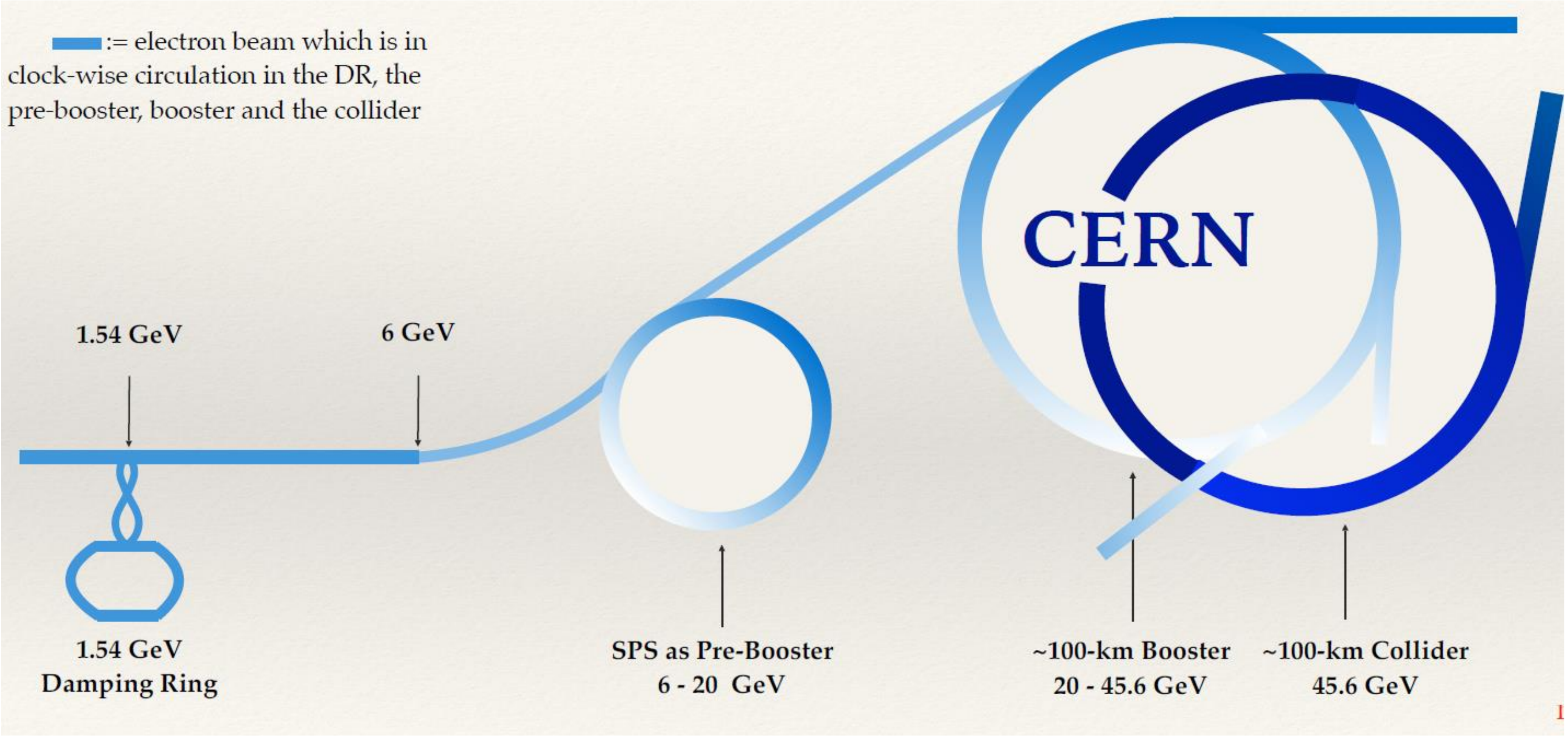




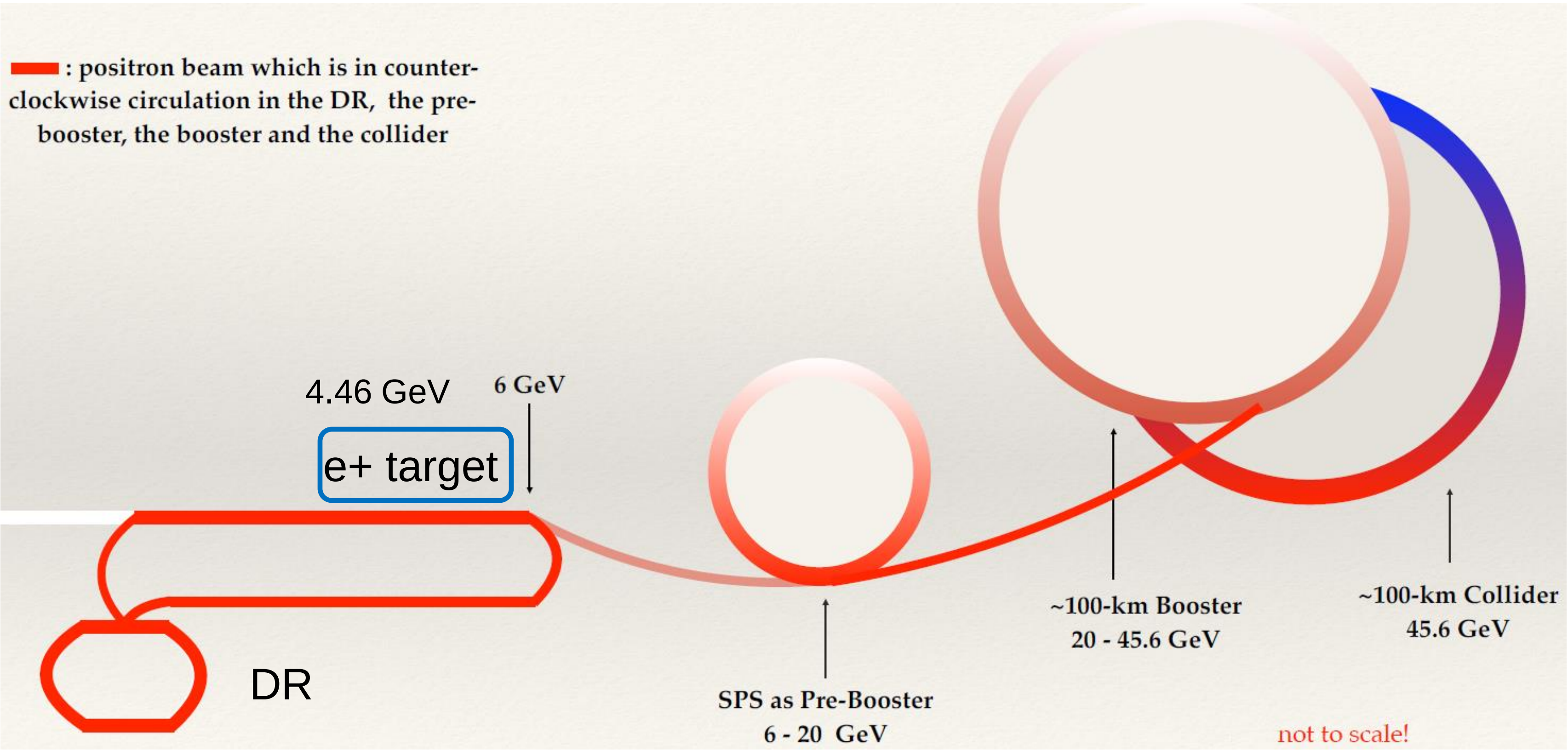
	FC field 7.5 Tesla solenoid field 0.5 Tesla	FC field 7.5 Tesla solenoid field 0.7 Tesla
Positron yield Ne^+/Ne^-	0.7 x channel transmission	0.92 x channel transmission
Emittance, μm	8.5	10.5

Channel Transmission ~<60%

Towards a Preliminary FCC-ee Injector Design for Electrons: s. Ogur (Bogazici U., CERN)

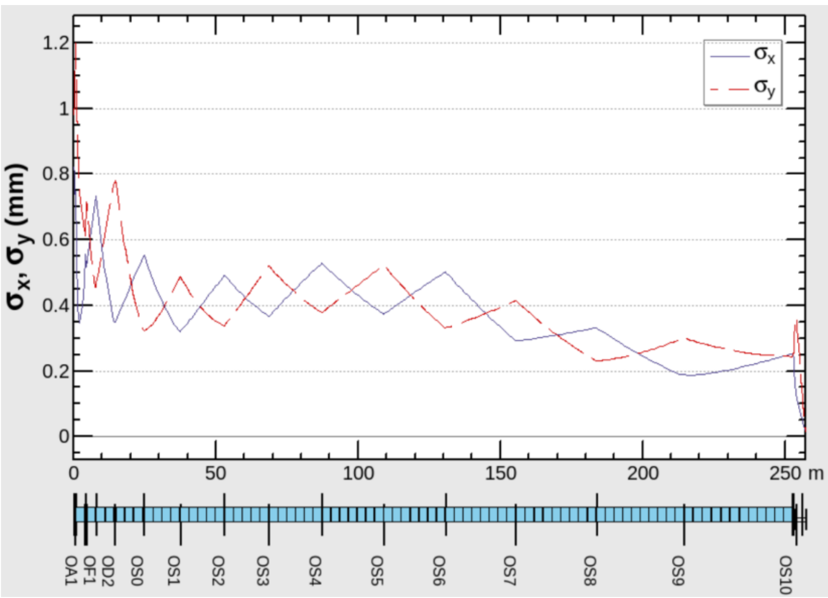


Towards Preliminary FCC-ee Injector Design for Positrons: S. Ogur (Bogazici U., CERN)

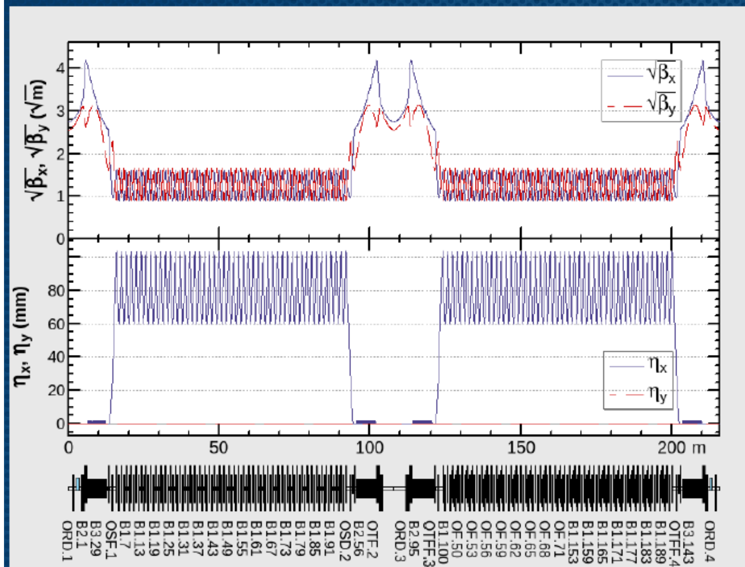


Linac and Damping Ring Optics and Transmission (S. Ogur)

Linac



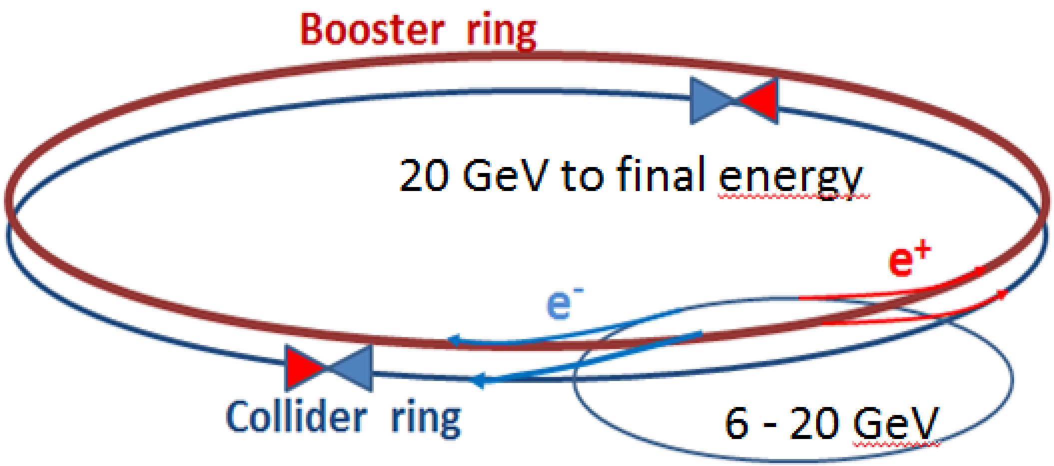
2 . Damping Ring - Optics



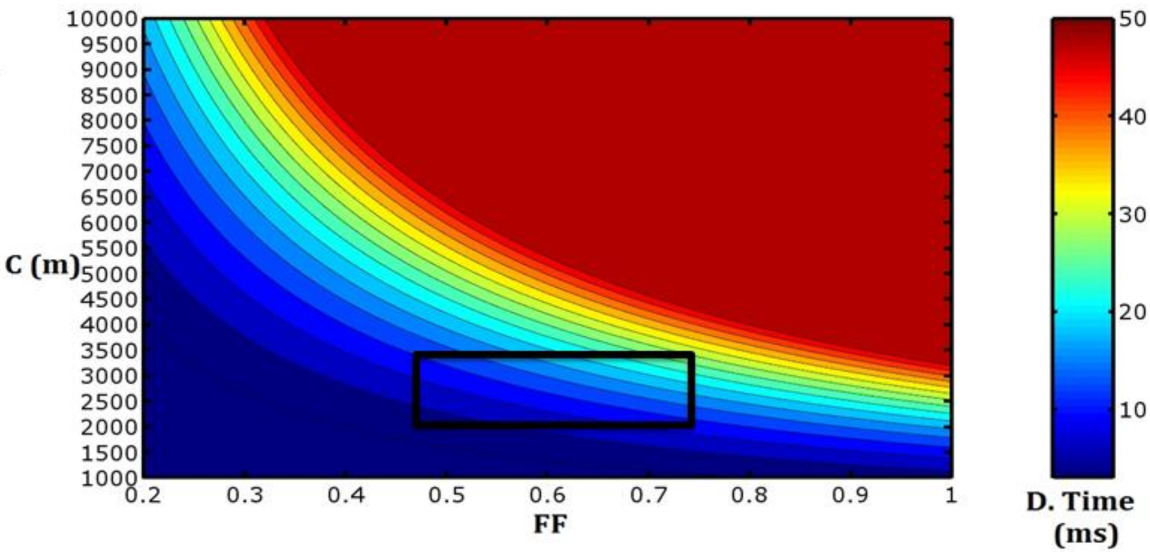
Parameter	Value
tau_x [millisecond]	11.0
tau_y [millisecond]	11.4
emit_x [nm]	1.3
emit_y	-
Circumference [m]	216
# of bends	192
Dipole Field [T]	0.67
Wiggler Field [T]	1.65
Cell_tune_x [rad]	0.193
Cell_tune_y [rad]	0.183

ko7.sad

Study of 20 GeV Pre-Booster (O. Etisken …)



- Linac
- Pre-booster design,
- Booster same tunnel with main ring,
- Collider ring.

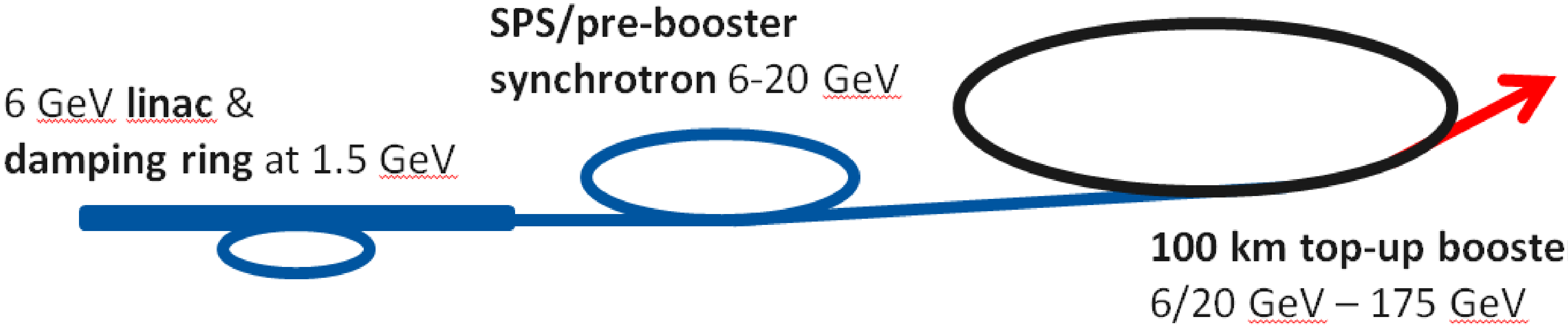


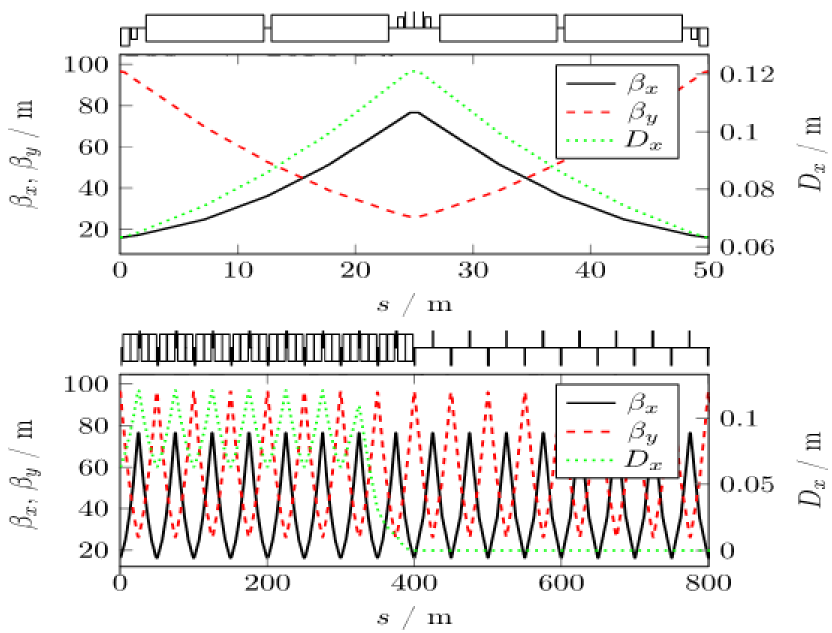
Dipole filling factor

Convenient ring circumference is 2 to 3 km with a damping time of 8 to 15 msec.

Circ of SPS = 6.9 km

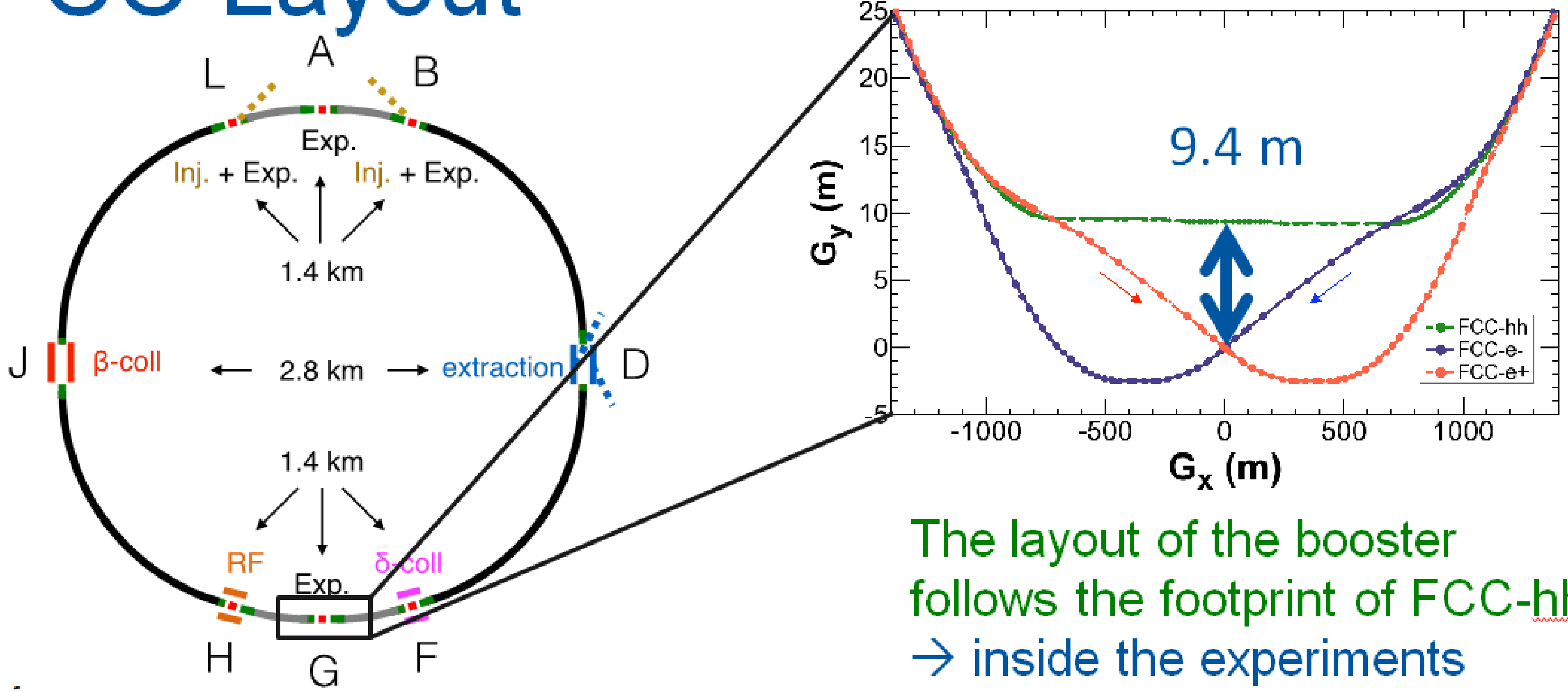
Booster Lattice Design (B. Haerer, …)





E(GeV)	ε_x (nm rad)*	тau (s)*
6.0	0.001	368
20.0	0.012	9.94
45.5	0.194	0.84
175.0	0.959	0.02

FCC Layout



The layout of the booster follows the footprint of FCC-hh

→ inside the experiments

FCCee Booster to Collider Injection

Requirements and assumptions for top-up injection:

- Similar emittance in booster and collider (~1.3 nm @ 175 GeV)
- ~1.5 km injection straight section available in collider
- 5 sigma clearance for high injection efficiency
- (Limited) dynamic aperture: ~15 sigma for on-energy, 5 sigma up to +/- 2% off-energy
- Minimize septum width
  - Blade thickness of 5 mm (3 mm + mechanical margin)
  - Wire septum of 0.2 mm (~20 um + mechanical margin)

Collider Injection Phase Space with Traditional Stacking

Typical parameters:

β_x at injection septum (stored) = ~200m

β_x at injection septum (injection) = ~30m

$\varepsilon_{xstored}$ (stored) =9.4 nm

ε_{xinj} (injected) =50 nm

$\sigma_{xstored}$ at septum (stored) = 1.4 mm

σ_{xinj} at septum (injected) = 1.2 mm

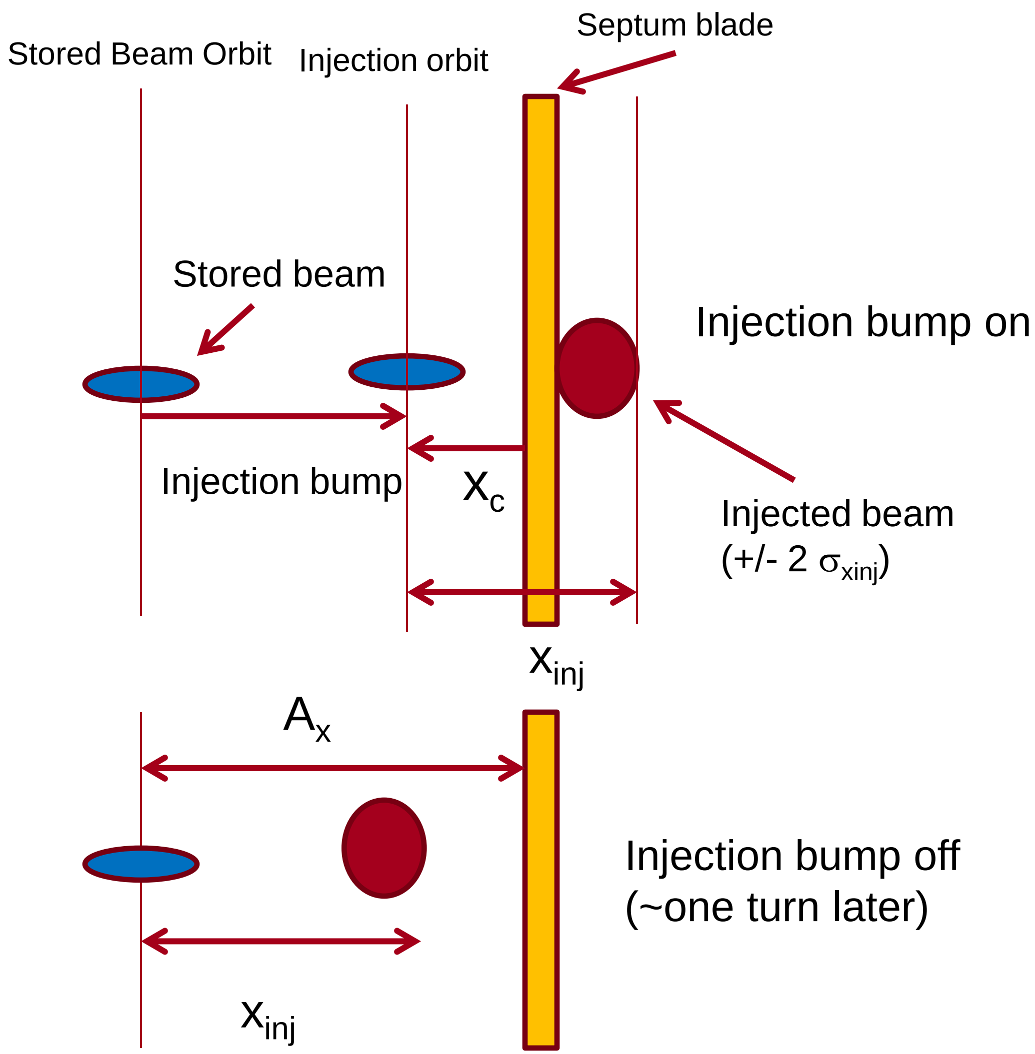
X_s = Septum blade thickness =~ 5 mm

X_c = septum clearance distance = ~$6\sigma_x$

Xinj < A_x

Xinj = 4Xσinj+X_s+Xc = ~18 mm

A_x = machine aperture > ~20 mm

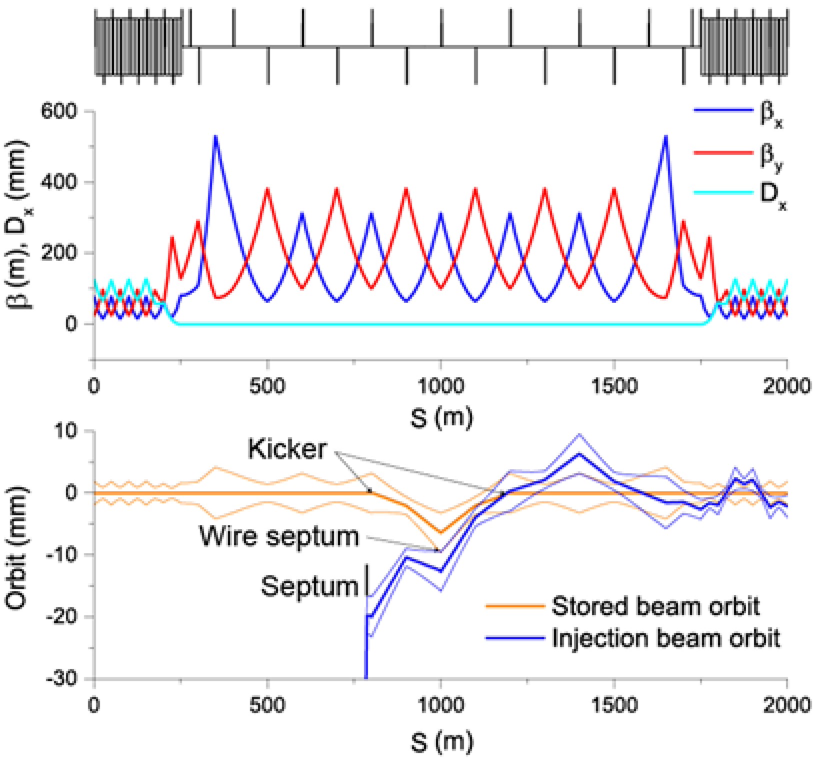


FCCee Booster to Collider Injection (M. Aiba …)

SLAC

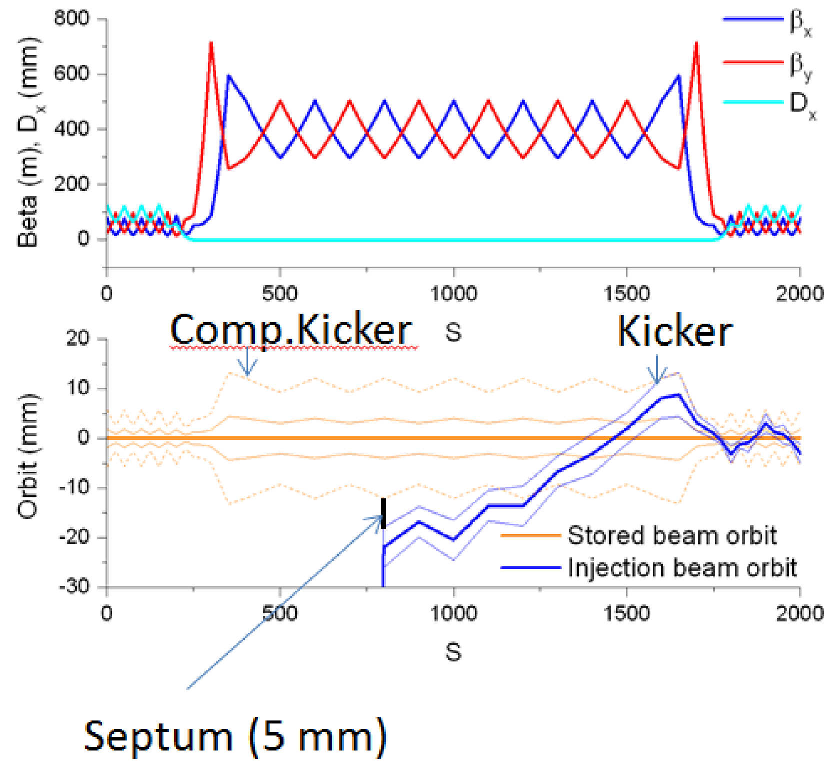
Traditional stacking

Optics and orbits for on-energy injection with wire septum

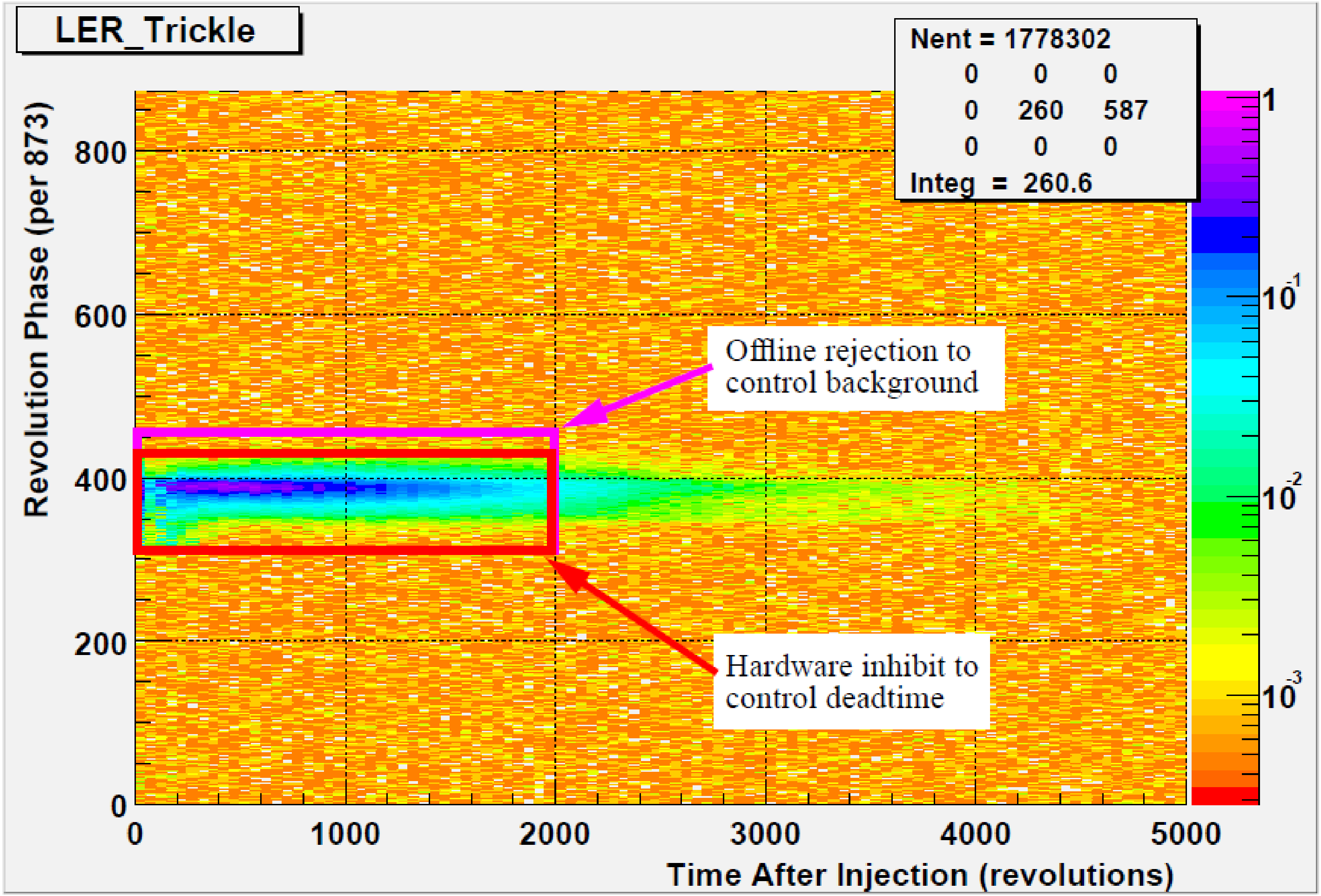


Alternative Multipole Kicker

Optics and orbits for on-energy injection with multipole kicker and compensation kicker



Detectors need to plan for masking of injection pulses during top-up data recording (~10 msec)



BaBar LER trigger vetoes (~2008).

Other Booster Injection Options

The full energy booster, by itself, is a large and serious accelerator:

1) 98 km
2) 175 GeV
3) >10 GeV SC RF
4) 10% of collider ring current (~150 mA)
5) 70760 bunches

There may be other possibilities to acceleration to 175 GeV.

Make a small effort soon to investigate possibilities.

Future injection work

Many small details to work out.

Consider reducing early linac beta functions by adding quadrupoles.

Make layouts of linac transport lines.

Positron systems tests.

Find filling patterns that satisfy beam loading restrictions in the collider rings. (from Teytelman)

Investigate beam loading and, thus, allowed bunch patterns in injector booster.

Investigate booster possibilities.

Look at mismatched beta functions for the injected bunches into the collider to loosen septa blade requirements.

Conclusions: FCC-ee Injection

Working toward a base line for the draft CDR for Fall 2017.

Operation at the Z_0 is the most difficult for the injector chain for generated beam charge.

Operation at tt determines the booster cost.

As presented, the e+/e- production chain can produce the required bunch charges and injection rates for injection into the collider at all energies.

A 6 GeV linac should work for positron and electron production.

The design for a 1.54 GeV positron damping ring is well advanced.

Investigating a pre-booster (perhaps the SPS) to raise the beam energy from 6 to 20 GeV.

The booster design is advancing. The injection energy of 6 GeV may be too low, with a pre-booster 20 GeV is more manageable.