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FCC_ee Injector Complex
WP04: Transfer lines and Damping Ring

FUTURE CIRCULAR COLLIDER

FCC_ee injector: Positron damping ring design status

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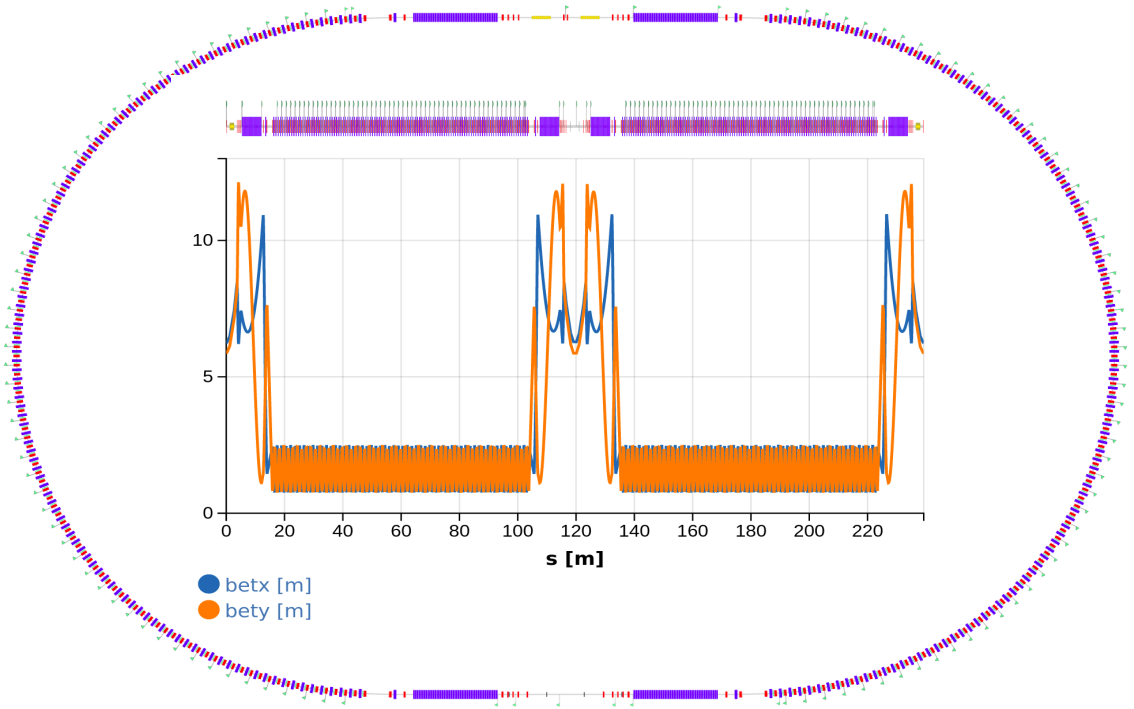
Outline

- DR optics
- Longitudinal acceptance
- Dynamical aperture
- Injetion/extraction timing scheme
- Conclusions

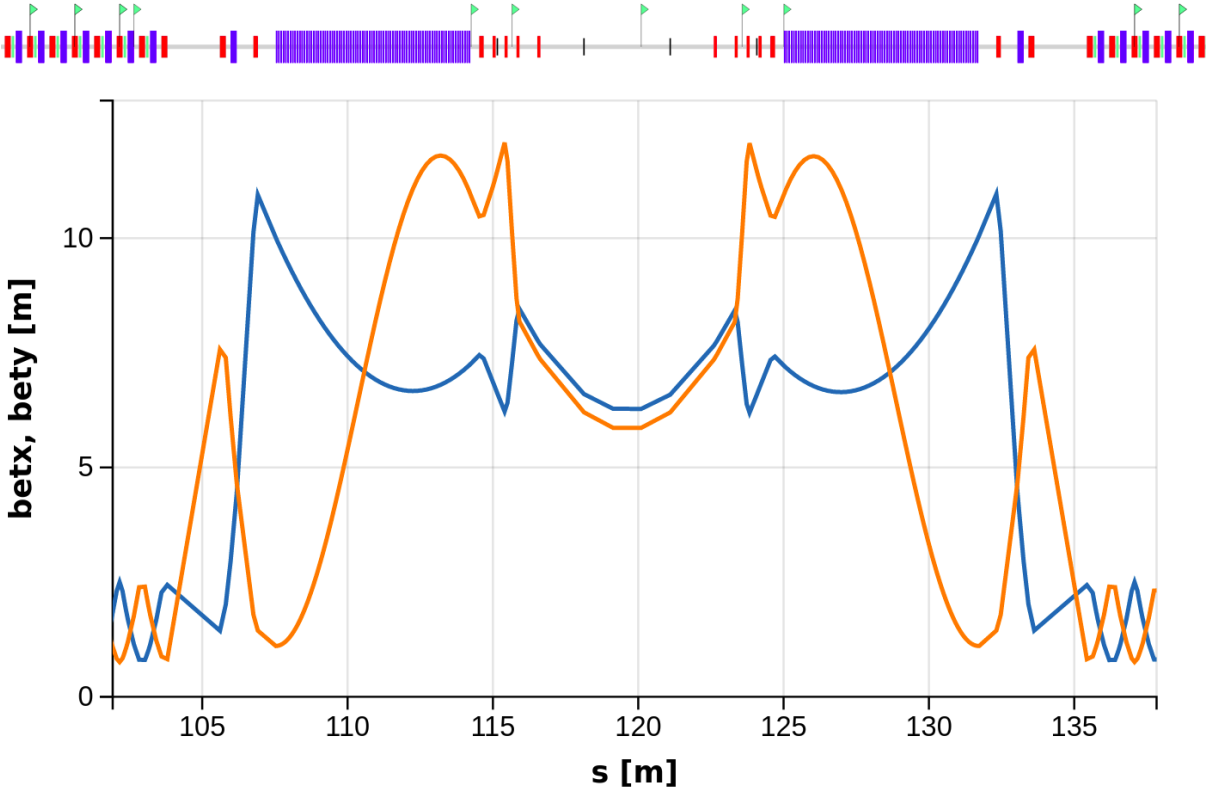
Damping ring layout



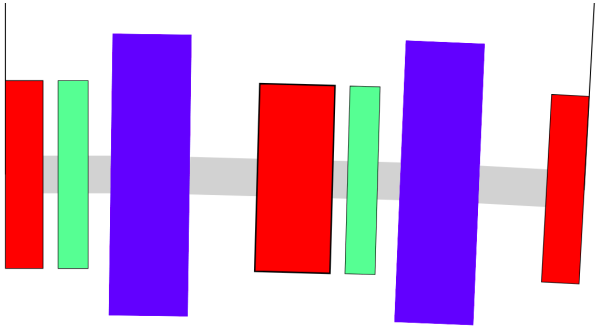
Parameter	FCC_ee DR
Circumference	**239.2 m**
Harmonic number	**319**
Eq. Emittance (x/y/z)	**1.01 nm/ - / 1.46 μm**
Dipole length, Field	**0.21 m, 0.66 T**
Wiggler #,Lenght, Field	**4, 6.64 m, 1.8 T**
Cavity #, Lenght, Voltage	**2, 1.5 m, 4 MV**
Bunch stored #, charge	**18 , 4.0 nC**
Damping Time (x/y/z)	**10.8 / 10.8 / 5.4 ms**
Store Time	**42.5 ms**
Energy loss per turn	**0.227 MV**
SR Power Loss (WGL)	**15.7 kW**

Following the FCC-ee injector review report reccomandations, the reference design for the DR is the one initially provided by K. Oide and S. Ogur in 2019. Newest design suited for multibunch operation have been abandoned.

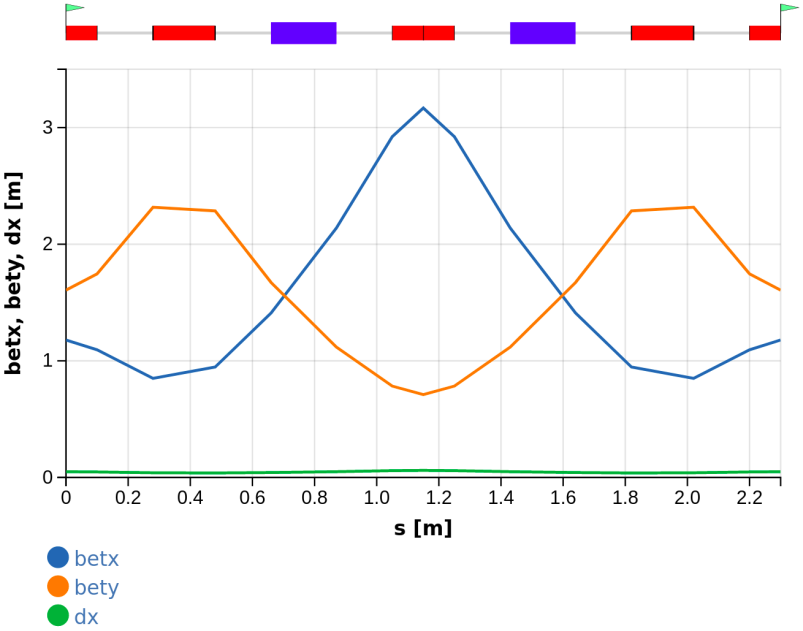
DR optics details



DR DBA Cell

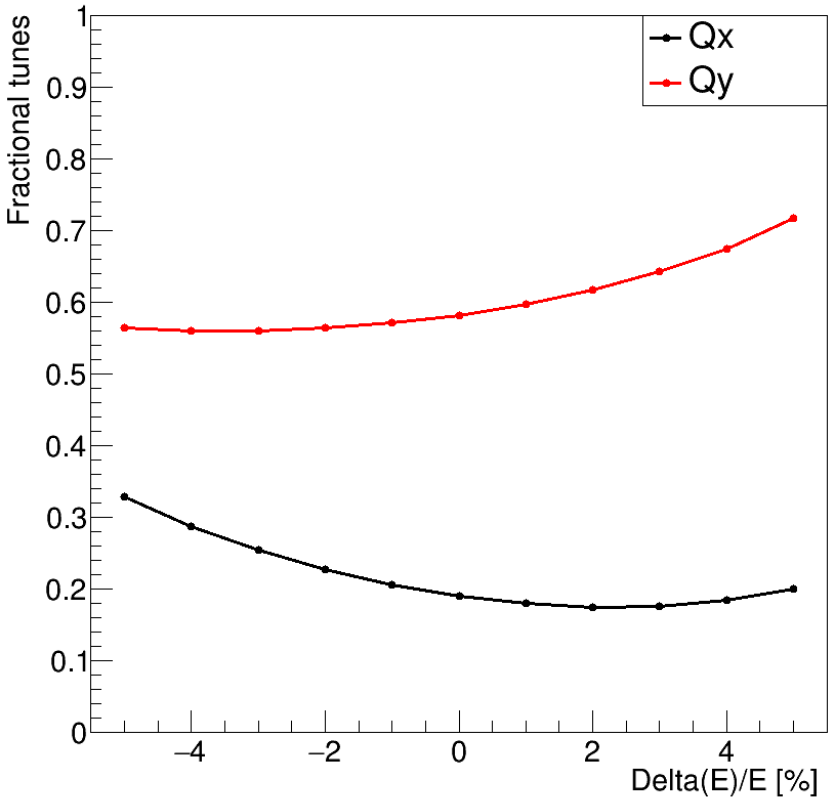


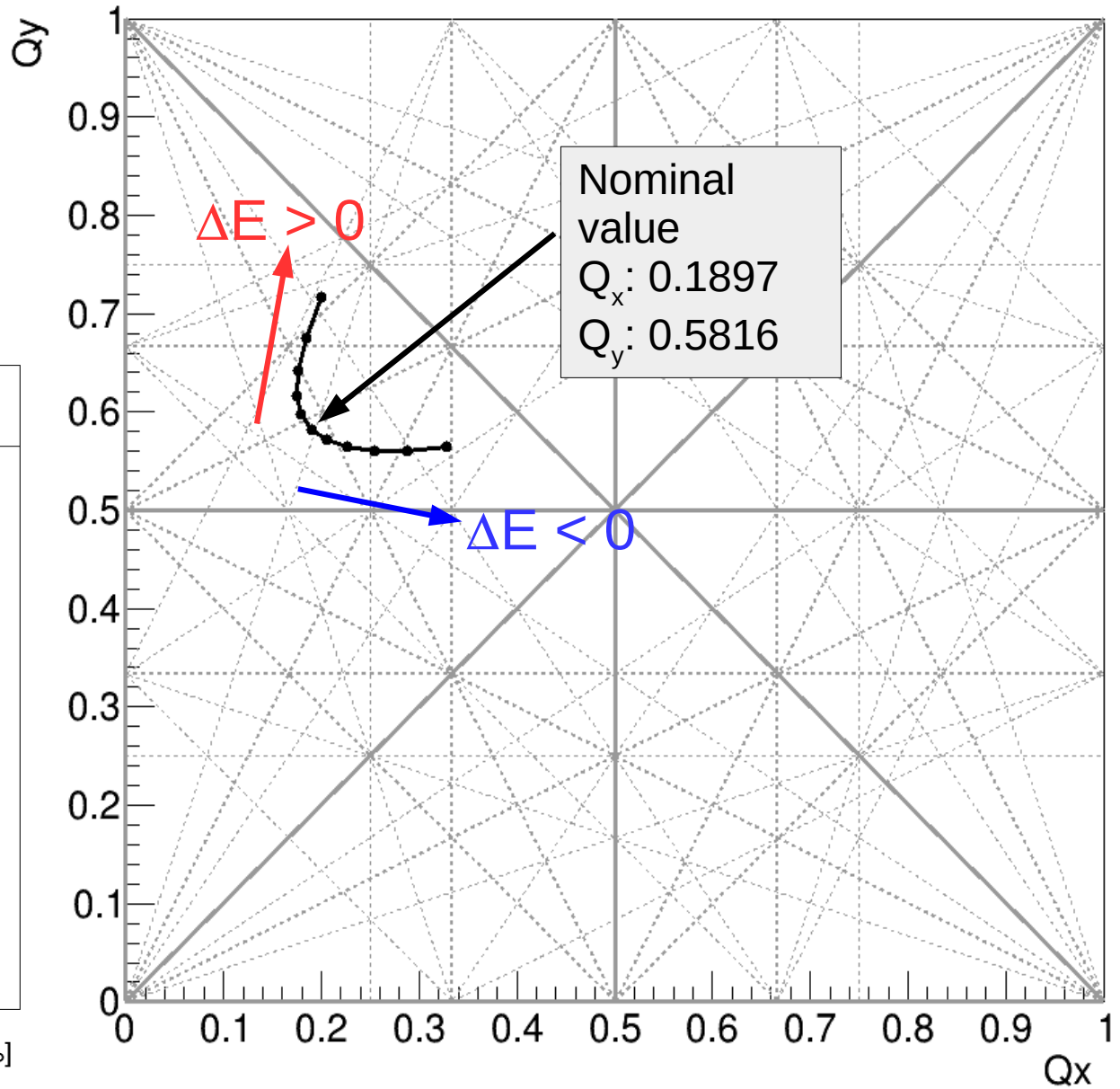
Straight section details.
Two of the four wigglers are shown.
Straight sections are designed to host RF cavities and Injection/Extraction equipments.



Tune diagram

Tune variation as a function of energy for the nominal lattice





Energy Acceptance at injection for e^+ beam

$$\left(\frac{\Delta E}{E_s}\right) = \pm\beta\sqrt{\frac{eV}{\pi h \alpha_c E_s}\mathcal{R}(\varphi_s)}$$

$$\mathcal{R}(\varphi_s) = \lfloor 2\cos\varphi_s + (2\varphi_s - \pi)\sin\varphi_s \rfloor$$

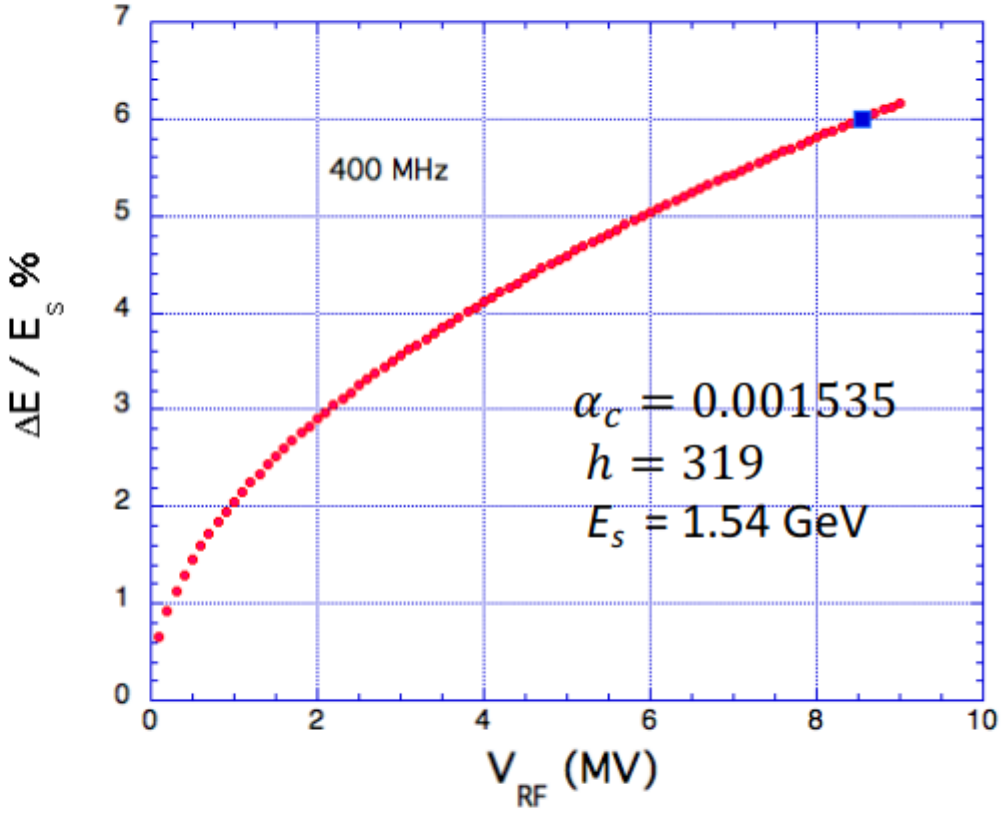
If an energy acceptance of the order of

$$\left(\frac{\Delta E}{E_s}\right) \sim 6\ \%$$

is requested in injection

V_{RF} = 8.53 MV

SC RF cavities working at 400 MHz and providing at last 4 MV are considered.



Minimum RF cavity voltage request to compensate the energy lost per turn is E_{LT} = 0.225 MV

DR Beam Dynamics Parameters

Relying on DR parameters:

E_s = 1.54 GeV

L = 239.2628817 m

$\alpha_c = 0.001535$

$\boldsymbol{h = 319}$

	V= 8MV	V= 6MV	V= 4MV	V= 2MV
U_0 [KeV]	227.1			
DE/E_s	$0.71 \cdot 10^{-3}$			
Ω_s [KHz]	25.313	21.918	17.888	12.618
T_0 [μsec]	0.79801			
ω_0 [s^{-1} rad]	$7.87\ 10^6$			
ν_s	0.003215	0.00278	0.002272	0.0016
L_{bunch}[m]	**0.00207**	0.00239	0.00293	0.00415
φ_s [rad]	0.0283967	0.0378663	0.0568164	0.113817
$(E - E_s)$ [GeV]	0.124	0.107	0.0862	0.058
$\Delta\varphi$ [unit of π]	1.8	1.7769	1.7269	1.6016
L_{bucket}[m]	0.6788	0.6664	0.6476	0.6006

Short bunch length can be an issue for:

- lifetime,
- injection must be carefully tuned,
- impedance and bunch lengthening must be evaluated,
- Beam coupling with RF system
- CSR,
- IBS,
- beam instability impact

Separatrix

W* - *Φ representation, canonical coordinates

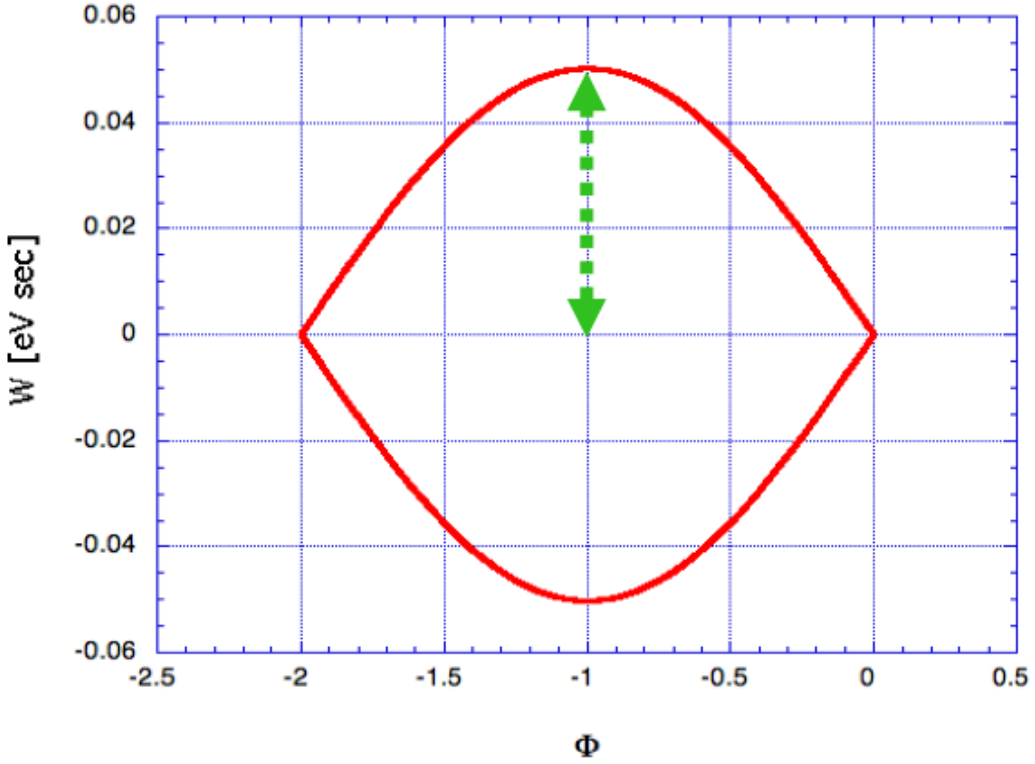
$$\frac{1}{\Omega_s}\frac{d\varphi}{dt} = \frac{2\pi c}{L}\sqrt{\frac{2\pi h^3 \eta_{tr}}{E_s eV\cos\varphi_s}}W$$

$$W_{bh} = \frac{L}{\pi hc}\sqrt{\frac{eVE_s}{2\pi h\eta_{tr}}}$$

$$A_{bk} = 2\int_0^{2\pi} W\, d\varphi = 8\, W_{bh}$$

The area of the bucket is an adiabatic invariant, ***longitudinal acceptance***
Bunch area is ***longitudinal emittance***

$\varepsilon_t = 4\pi\,\sigma_E\,\sigma_t$ ***[eV sec]***

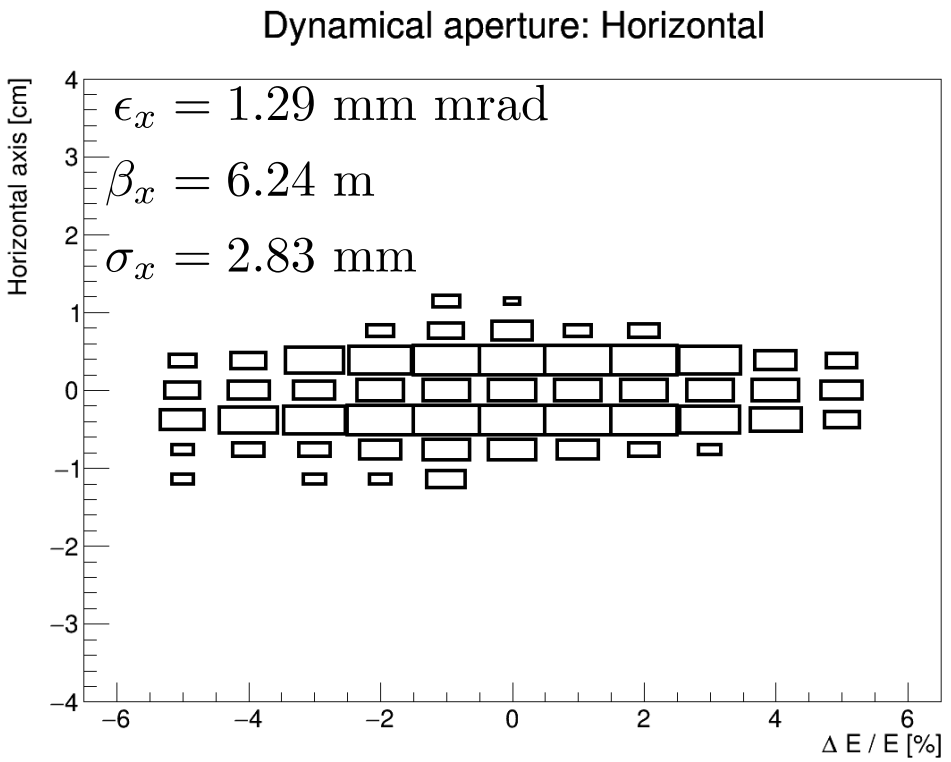


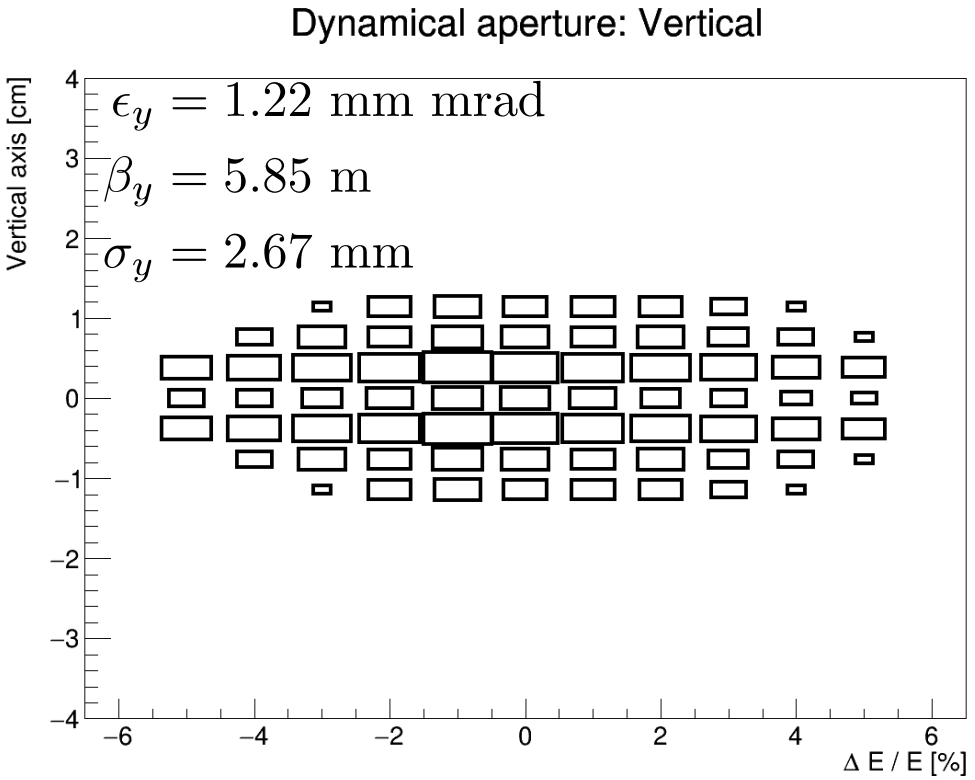
Assuming:

$\alpha_c = 0.001535$
$h = 319$
V = 8 MV
E_s = 1.54 GeV

W_{bh} = 0.0501813 (eV sec)
A_{bk} = 0.401451 (eV sec rad)

DR dynamical aperture



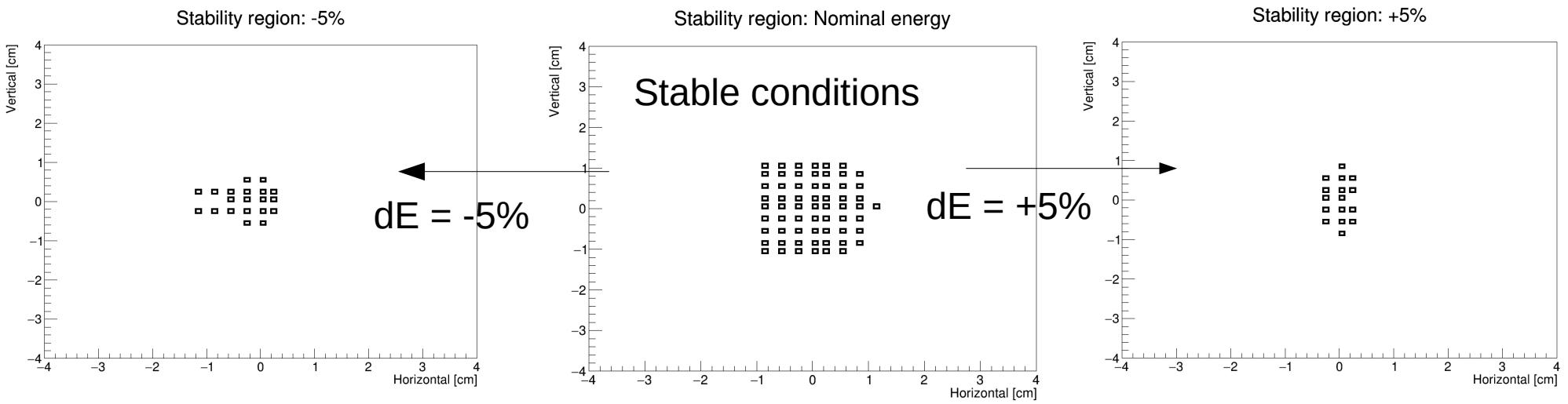


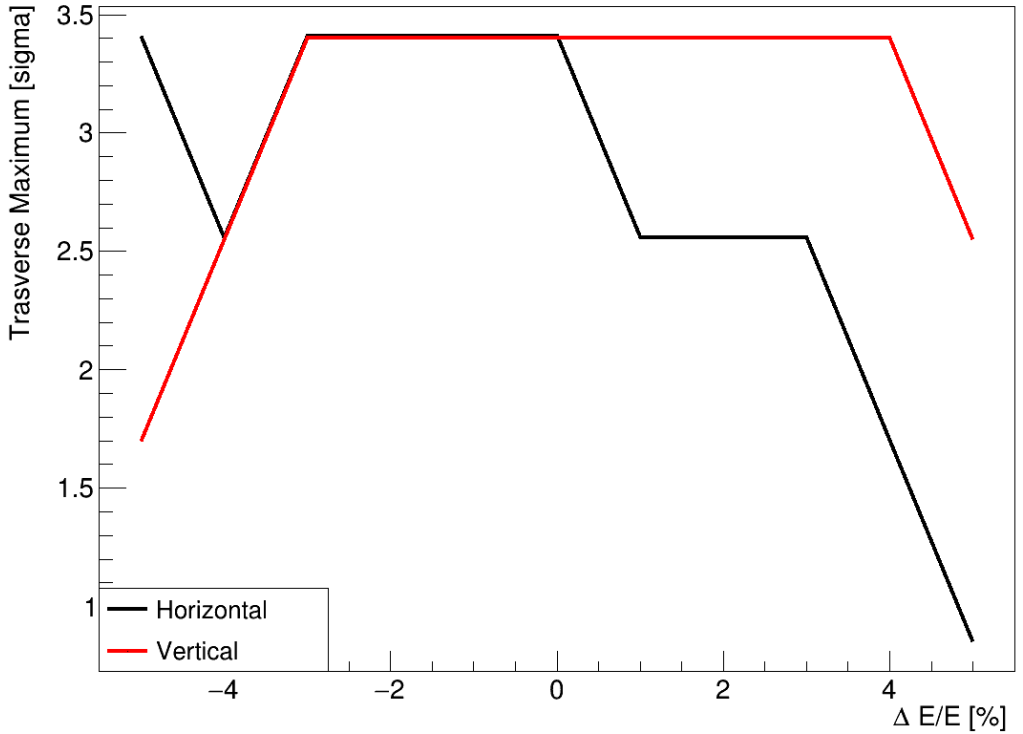
Tracking has been performed with PTC (MAD-X interface)
One damping time tracked

The phase space have been sampled up to 4x4 cm^2 in the transverse plane.
Only pure on-axis particles have been simulated (x'/y'=0)
Energy deviation from nominal is ± 5%

A relevant impact on the injected beam is observed

DR dynamical aperture





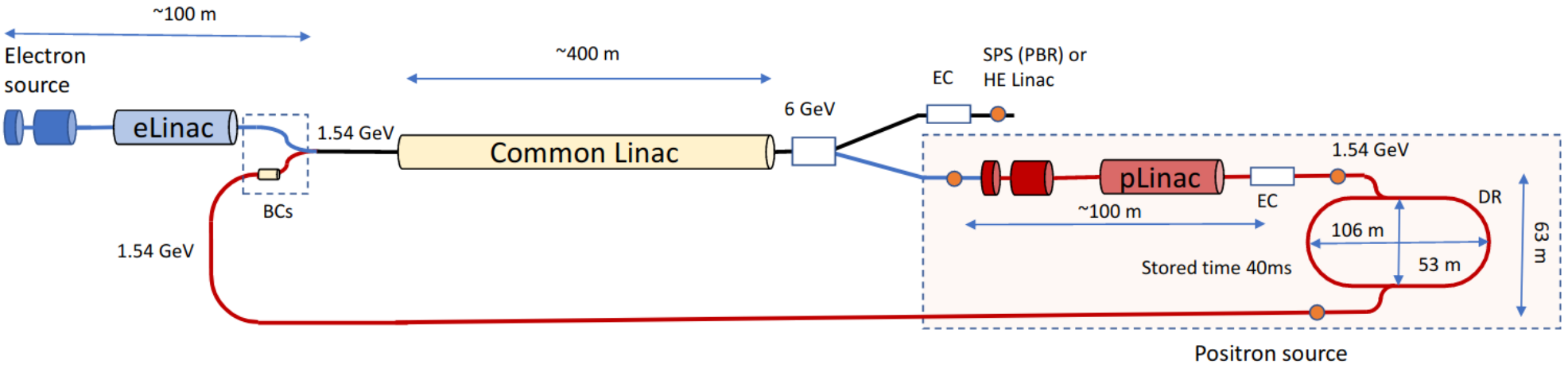
Injected beam widths:

σ_x = 2.83 mm

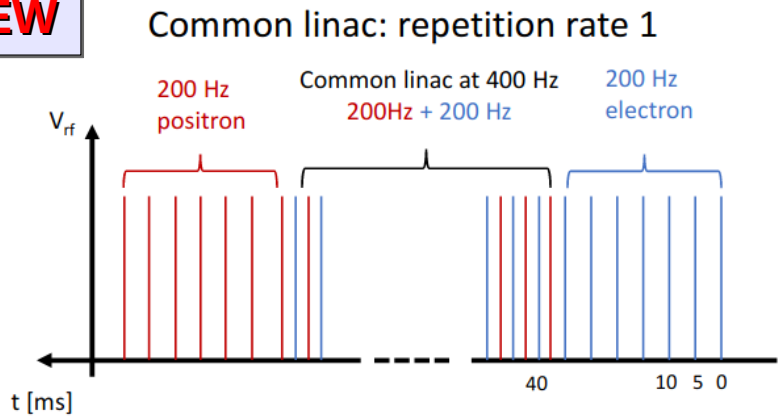
σ_y = 2.67 mm

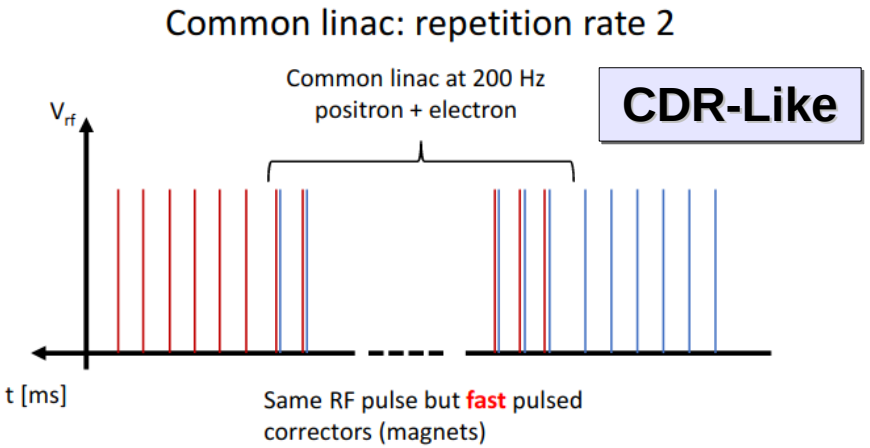
Resulting dynamical aperture between 3.5 and 1.5 sigma for ΔE/E ±5% .

Injector current general layout



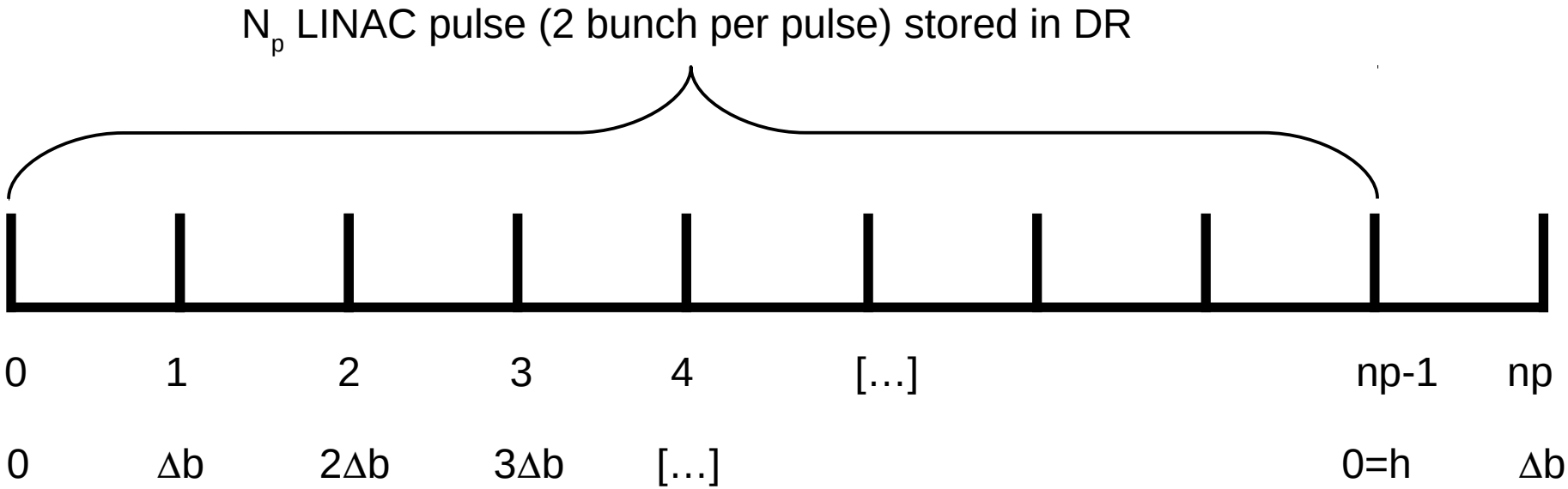
NEW





New baseline for FCC_ee Injector complex is under evaluation.
In the current scheme two low energy linac's are used for electron and positron and only the high energy linac is common.
DR should allow to damp the beam and delay extraction to allow single species operations for the coommon linac.

Timing: DR Injection



$$\Delta_b = INT[h/N_p]$$

$$\mathrm{T}_{gun} = iT_1 + \Delta_b T_{RF}(i\%np)$$

Gun has been phased with DR RF so that the "first" gun pulse arrives at the DR in the #bkt=0

$$\Delta T_{DR} = (N_p - 1)T_1 \geq m\tau_{x/y} \qquad \text{Store time}$$

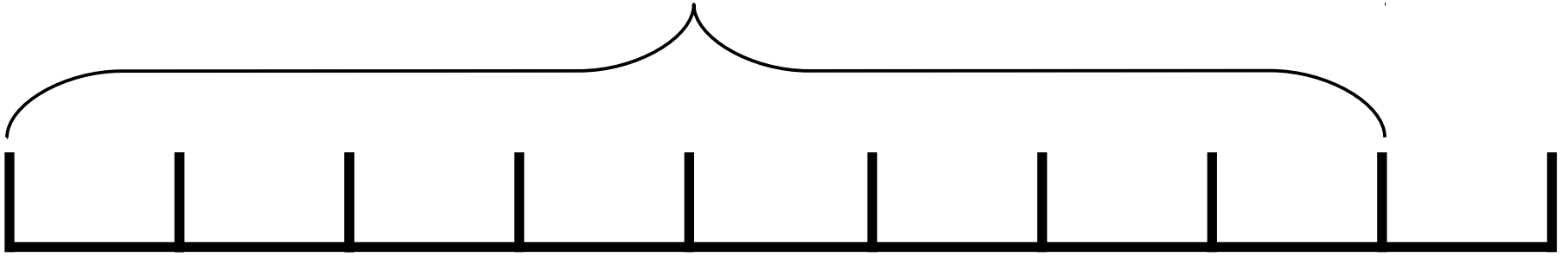
To store for at least 4 damping times

$$\mathrm{N}_p \geq 9 \qquad \Rightarrow \qquad \Delta_b \leq 35$$

$$\mathrm{h}\%\mathrm{N}_p \neq 0 \Rightarrow \Delta_b \equiv \Delta_b(i)$$

With Δ_b = 35 the last filled bucket is the 281st 38 bucket before the 319th

Timing: DR Extraction



#pls	0	1	2	3	4	[…]	np-1	np
#bkt	0	Δb	2Δb	3Δb	[…]		0=h	Δb
#ext	-	-	-	[…]		0	1	

$$\mathrm{T}_{EXT} = \boxed{T_{gun} + \Delta T_{DR}} + \boxed{T_S/2} + \boxed{T_2 - \Delta T_{12}}$$

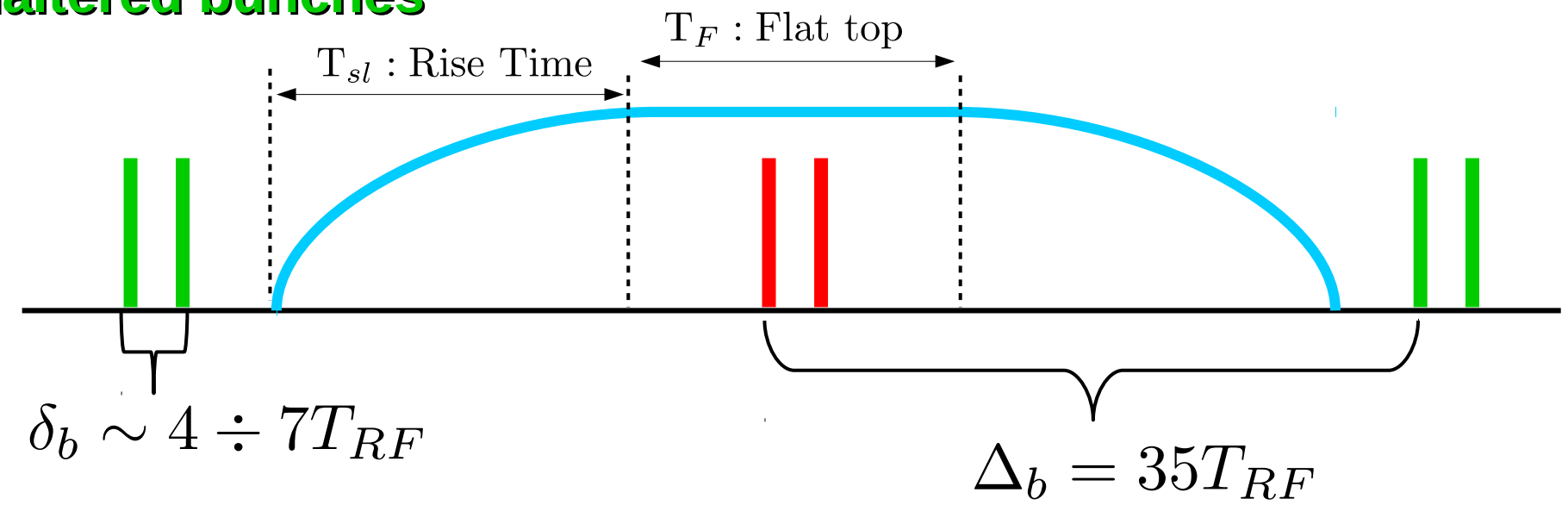
Arrival + Storage time

Half turn to reach the extraction section

Phasing with “empty” L2 pulses.
Δ_{12} accounts for propagation time from DR to L2
Time is measured in T_S units

Timing: Extraction kickers details

Unaltered bunches



Kicked bunches

Time differences between the two bunches of the same pulse (10-15 ns) and between different pulses stored (87.5 ns) has the following implications on kickers pulses:

$$T_{sl} \leq 70 \text{ ns} \qquad T_F > 17.5 \text{ ns}$$

Reasonable values could be: T_{sl} = 50 ns and T_F = 20 ns

Summary/Conclusions

DR Longitudinal acceptance

- RF requirements to allow largest energy acceptance have been evaluated. Assuming SC RF cavity, two cells are needed.
- Large energy acceptance imply short bunch length. Potential issue

DR Dynamical aperture:

- Tracking has been performed with PTC
- The maximal aperture is 3.5 sigma of the injected beam
- Refinement needed to properly evaluate the transverse acceptance (charge reduction)

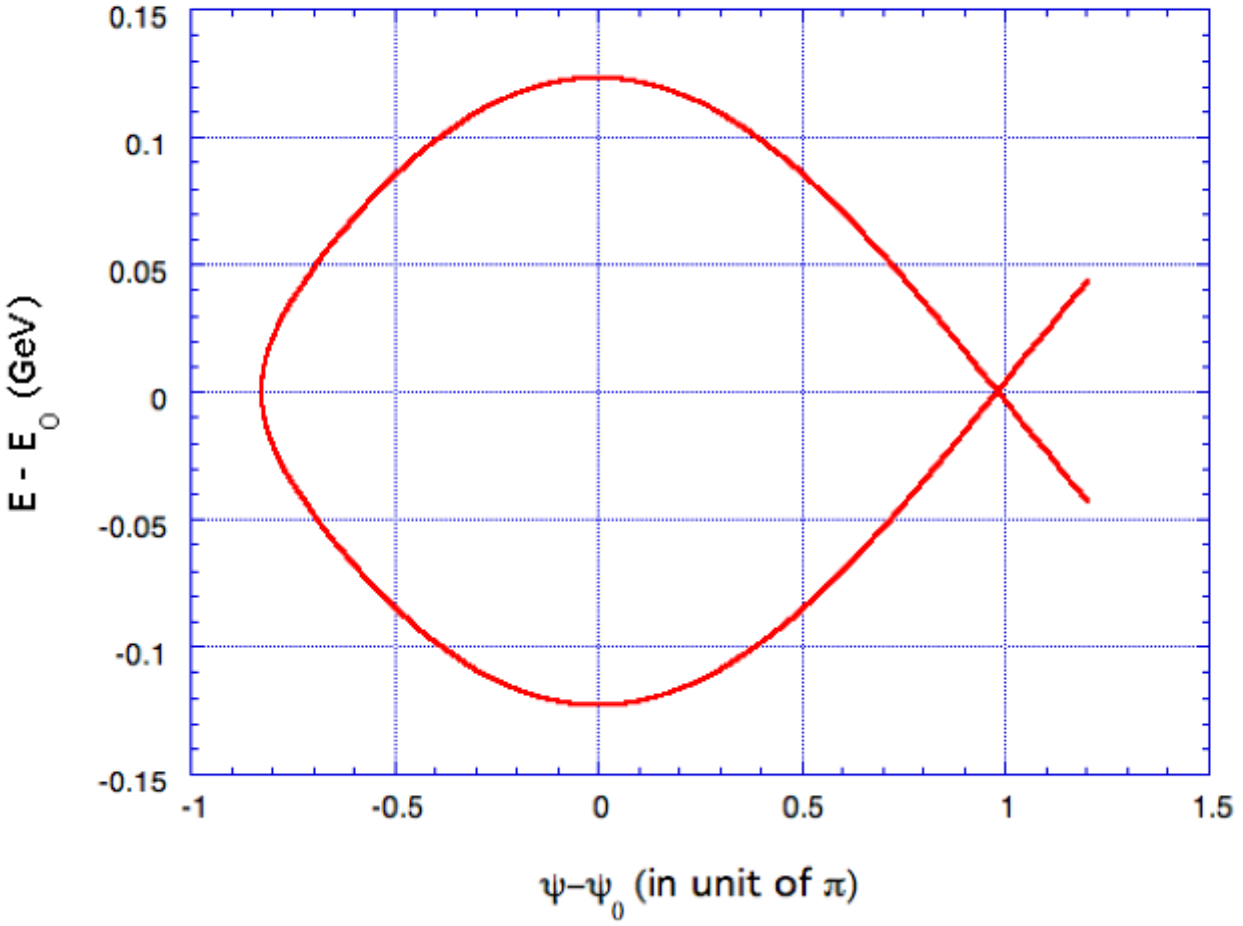
Timing:

- DR filling scheme allows to have extracted pulses after 42.5 ns.
- The scheme of L2 at 400 Hz Rep Rate is feasible
- Tunability of L1/L2 effective repetition rate is requested to be within 0.8 μs O(10^{-4})
- DR KCK's time requirement have been defined and seems not prohibitive

SPARES

Separatrix

ΔE - ΔΨ representation



$\alpha_c = 0.001535$

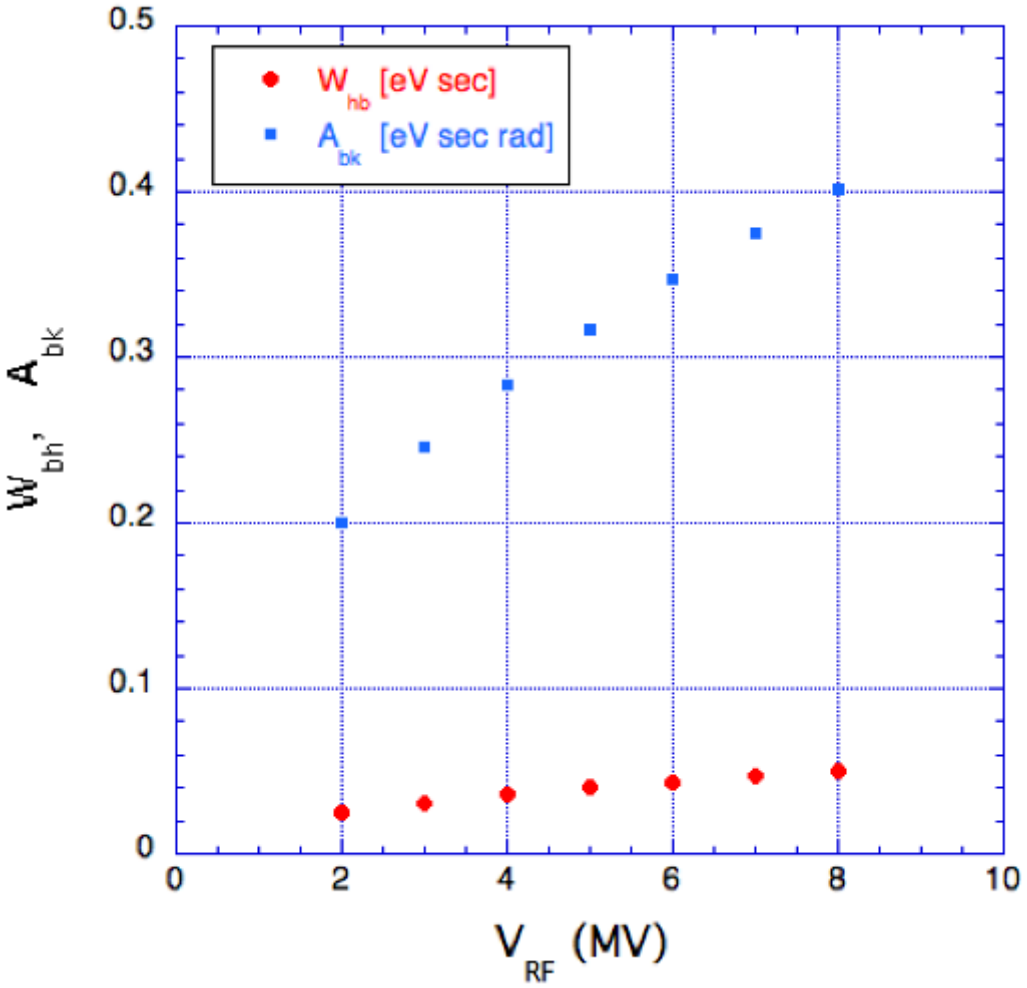
$h = 319$

V = 8 MV

E_s = 1.54 GeV

φ_s = 0.028 rad

Separatrix vs. VRF



Timing: Some definitions

$\mathrm{R}_1(T_1)$: Repetition rate (Period) L1: 200 Hz

$\mathrm{R}_2(T_2)$: Repetition rate (Period) L2: 400 Hz

$\mathrm{RF}(\mathrm{T}_{RF})$: DR Radio Frequency (RF Period): 400 Hz

ΔT_{ep} : Delay between Electron Gun an DR injection

T_S : DR Revolution period: ~ 0.8 μs

h: DR harmonic number: 319

N_p : Number of LINAC pulses stored (2 bunch each)

$\tau_{x/y}$: Damping time: $\sim$10.8 ms

The number of stored pulses depends on the time needed to damp the incoming positron beam.