The SPS as a Damping Ring Test Facility

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Test Facility for DR R&D

- Damping rings (DRs) target low emittances in all 3 dimensions for relatively high bunch charge
- Dominated by collective effects
- Technology of systems driven by design choices for reducing these effects
- Experimental program was set-up to test most challenging systems
- Ideal future scenario: use existing ring as test facility (TF) for DR R&D, for testing components and interdependencies in similar beam conditions
- Existing or future light source storage rings would be ideal for these tests
- Obvious drawback the beam time availability for experiments
- **Unconventional approach**: use SPS as DR TF

PARAMETER	2 GHz	1 GHz
Energy [GeV]	2.86	
Circumference [m]	427.5	
Bunch population [10^9]	4.1	
Wiggler field [T]	2.5	
Wiggler length [m]	2.0	
Wiggler period [cm]	5	
Damping times [ms]	(2.0,2.0,1.0)	
Momentum compaction [10^{-4}]	1.3	
Energy loss/turn [MeV]	4.0	
Repetition rate [Hz]	50	
number of bunches/train	312	156
number of trains	1	2
Horizontal normalized emittance [nm.rad]	472	456
Vertical normalized emittance [nm.rad]	4.8	4.8
Energy spread [%]	0.1	0.1
Bunch length [mm]	1.6	1.8
Longitudinal normalized emittance [keV.m]	5.3	6.0
RF voltage [MV]	4.5	5.1
Bunch spacing [ns]	0.5	1
RF acceptance [%]	1.0	2.4

SPS

Evans and Schmidt, 1988

A	B	F	G	H	I
VARIABLES		***WITH WIGGLER***		Intrabeam scattering	
ETA	0.0018	brho	13.3424	ep	0.001637
VOLTS(V)	4.00E+07	wiggler deflection	0.00356	A	3.9E-06
Q VALUE	27	Bending radius	14.04463	k	0.005958
MOMENTUM COMPAC	0.0018	2*pi*rho^2	1239.369	a	0.003439
BETA (V/C)	1	F	0.005544	d	0.997034
ENERGY DPN JE	2	***Parameters With wiggler on***		lnc2a	8.492016
RADIAL DPN JX	1	Energy loss per turn	5.51E+06	Tx(sec)	1.37E+00
ENERGY(EV)	4.00E+09	Energy damping time	1.67E-02	Tz(sec)	1.23E+02
PARTICLES/BUNCH	5.00E+09	Horizontal damping time	3.34E-02		
HORIZONTAL BETA	40	Energy spread	9.11E-04		179.3655
VERTICAL BETA	40	Synchrotron Tune	0.168447		85.4419
HARMONIC NUMBER	10000	Bunch length sigma	1.07E-02		532.8773
BWIGGLER (TESLA)	0.95	Sigmasquared/beta	3.63E-10		27.19585
Pole Length	0.05	Normalised emittance	2.84E-06		179.3655
Total Wiggler Length	300	Norm long emit	7.64E-02		

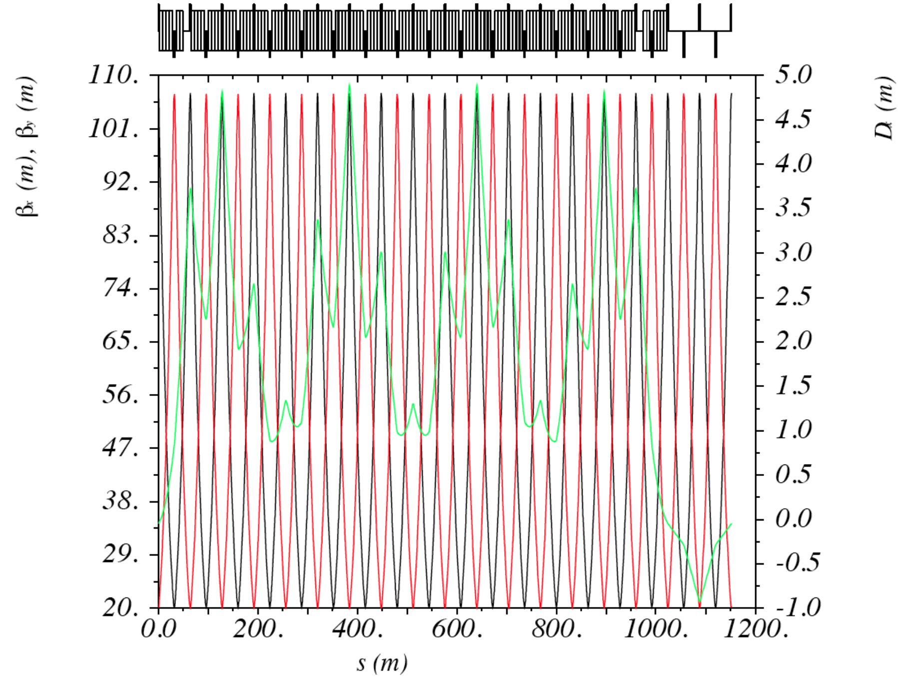
- Reviving old ideas, when SPS was running also as a LEP injector
- More recent ones, serving as e+ DR for LHeC

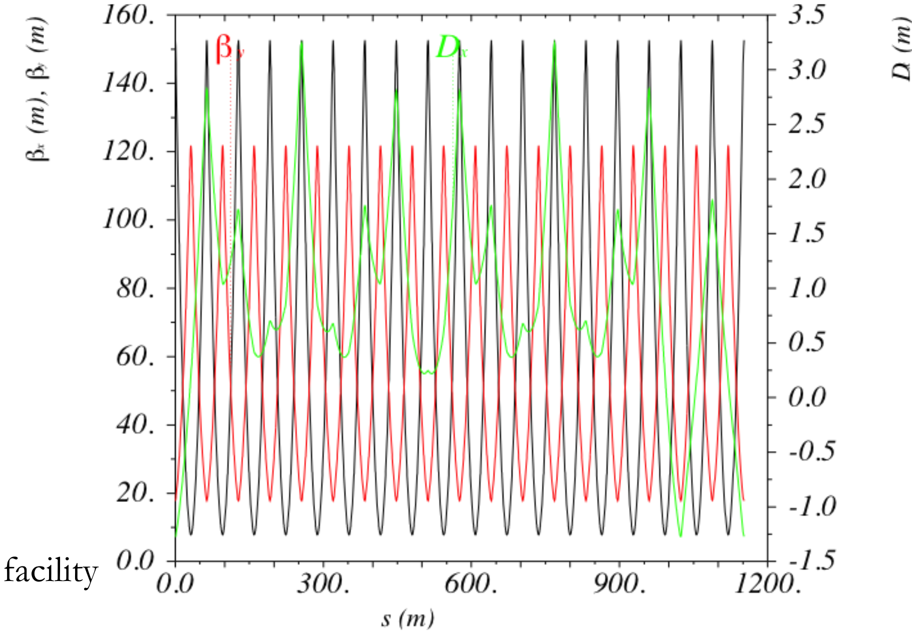
Papaphilippou 2011

Parameter [unit]	High Rep-rate	Low Rep-rate
Energy [GeV]	10	7
Bunch population [10^9]	1.6	1.6
Bunch spacing [ns]	2.5	2.5
Number of bunches/train	9221	9221
Repetition rate [Hz]	100	10
Damping times trans./long. [ms]	2/1	20/10
Energy loss/turn [MeV]	230	16
Horizontal norm. emittance [μm]	20	100
Optics detuning factor	80	80
Dipole field [T]	1.8	1.8
Dipole length [m]	0.5	0.5
Wiggler field [T]	1.9	-
Wiggler period [cm]	5	-
Total wiggler length [m]	800	-
Dipole length [m]	0.5	0.5
Longitudinal norm. emittances [keV.m]	10	10
Momentum compaction factor	10^{-6}	10^{-6}
RF voltage [MV]	300	35
rms energy spread [%]	0.20	0.17
rms bunch length [mm]	5.2	8.8
average power [MW]	23.6	3.6

SPS low emittance optics

- SPS is an all FODO cell lattice (6 sextants), with missing dipole
- Usually tuned to 90 deg. phase advance for fixed target beams (**Q26**) and since 2012 to 67.5 deg (**Q20**) for LHC beams
- Move horizontal phase advance to 135(3π/4) deg. (**Q40**)
- Normalized emittance with nominal optics @ 3.5GeV of 23.5μm drops to 9μm (1.3nm geometrical)
  - Mainly due to dispersion decrease
  - Almost the normalized emittance of ILC damping rings
- Damping times of 9s





Parameterisation

- Use classical formulas for horizontal equilibrium emittance, damping time, energy spread and bunch length, in presence of wigglers (CLIC DR prototype parameters)
- Assume SPS bending characteristics and placing of wigglers at lowest horizontal beta function location (~9-10m) and almost zero dispersion (close to defocusing quads of dispersion suppressor)

$$\epsilon_x = \frac{C_q \gamma^3}{12(1+F_w)J_x}\left(\frac{e_r \theta^3}{\sqrt{15}} + \frac{F_w {B_w}^3 {\lambda_w}^2}{\beta_{xw} 16 (B\rho)^3}\right)$$

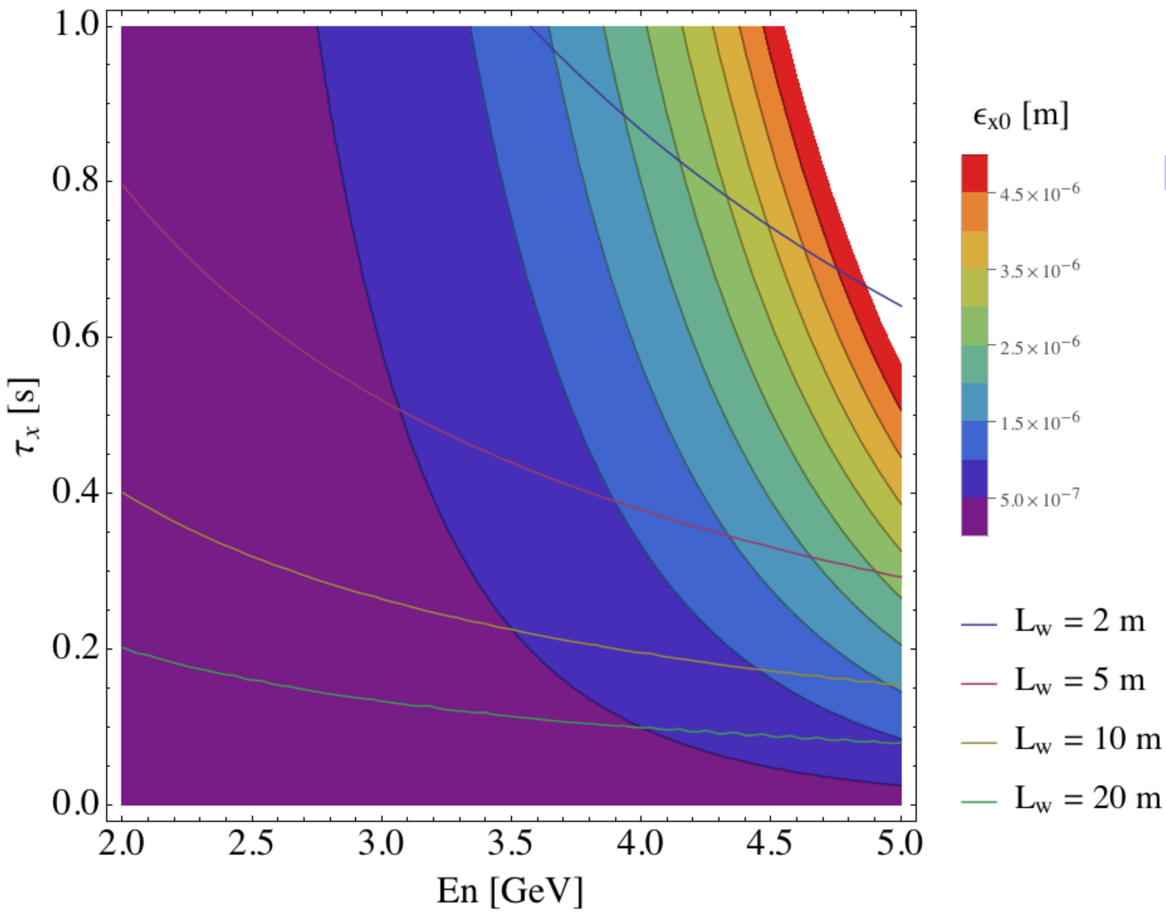
$$\tau_x = \frac{3E_0}{2\pi r_0 c}\frac{C}{B\gamma^2 (J_x + F_w)} \qquad F_w = \frac{L_w B_w^2}{4\pi B^2 \rho}$$

$$\sigma_p = \gamma \left(\frac{C_q (1+F_w \frac{B_w}{B})}{\rho(3-(1+F_w)J_x + 3F_w)}\right)^{1/2}$$

$$\sigma_s = \sigma_p C \left(\frac{\alpha_p E}{2\pi h (V^2 - {U_0}^2)^{1/2}}\right)^{1/2}$$

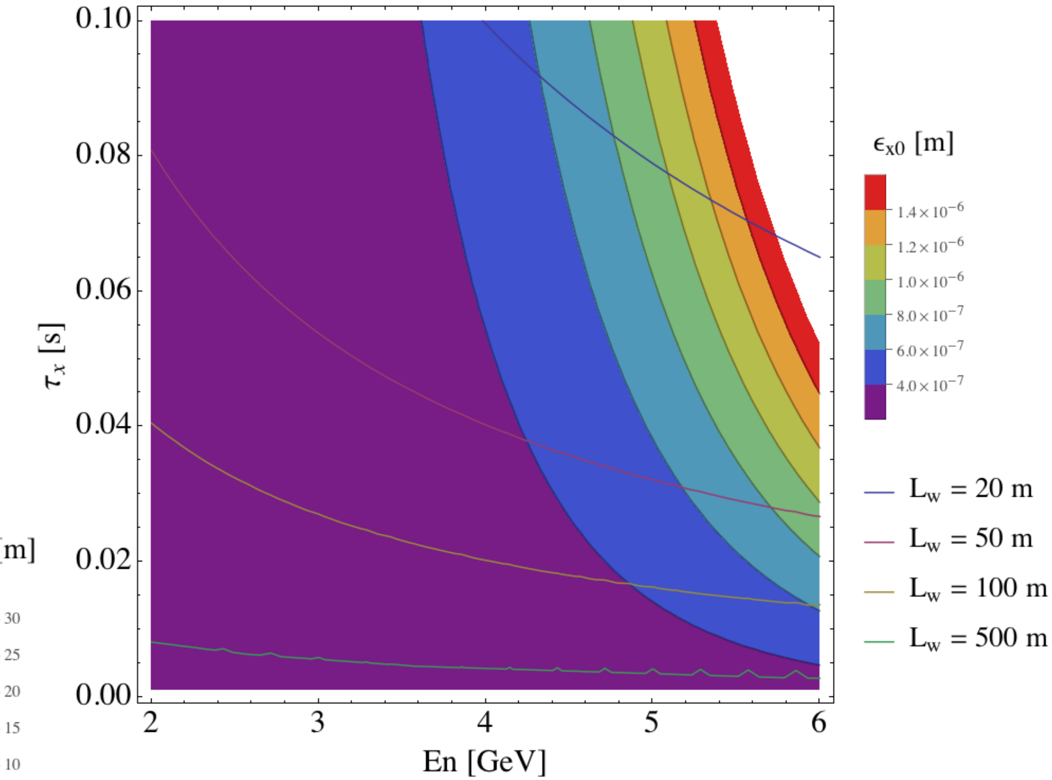
Emittance

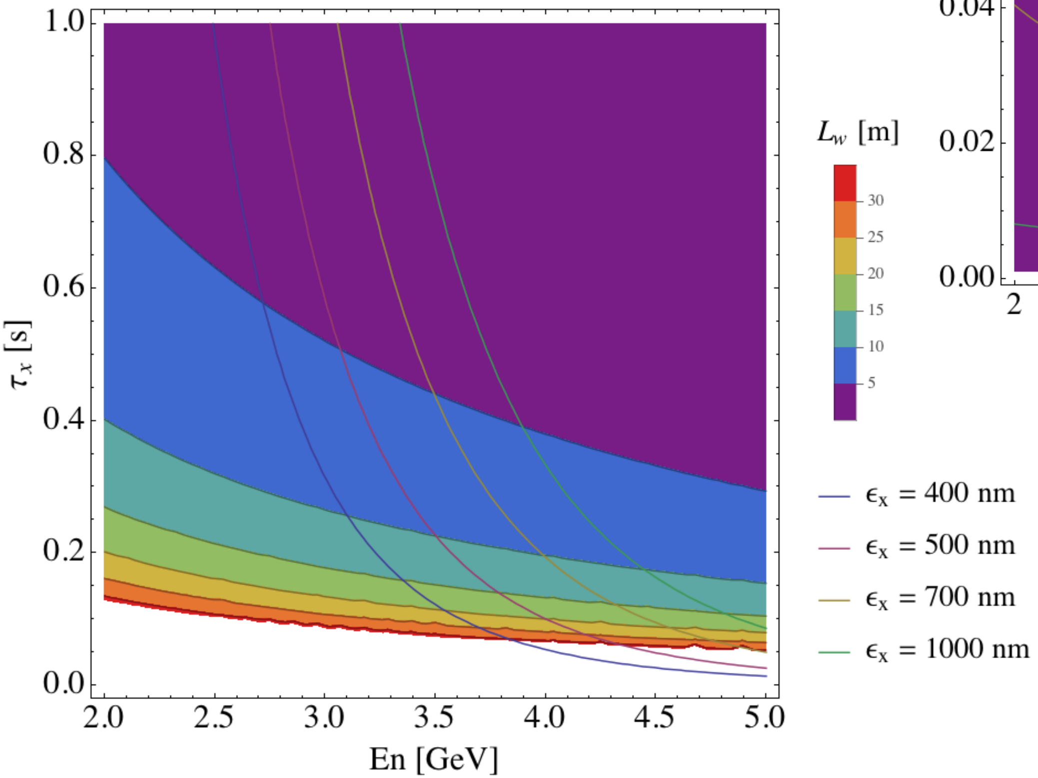
- Energy and damping time can be parameterised with equilibrium emittance, for different wiggler lengths
- Ultra-low emittance achieved in energy range of 2 to 5GeV



- For reaching emittances below the CLIC target (500nm), a few meters of damping wigglers should be used

Wiggler Length

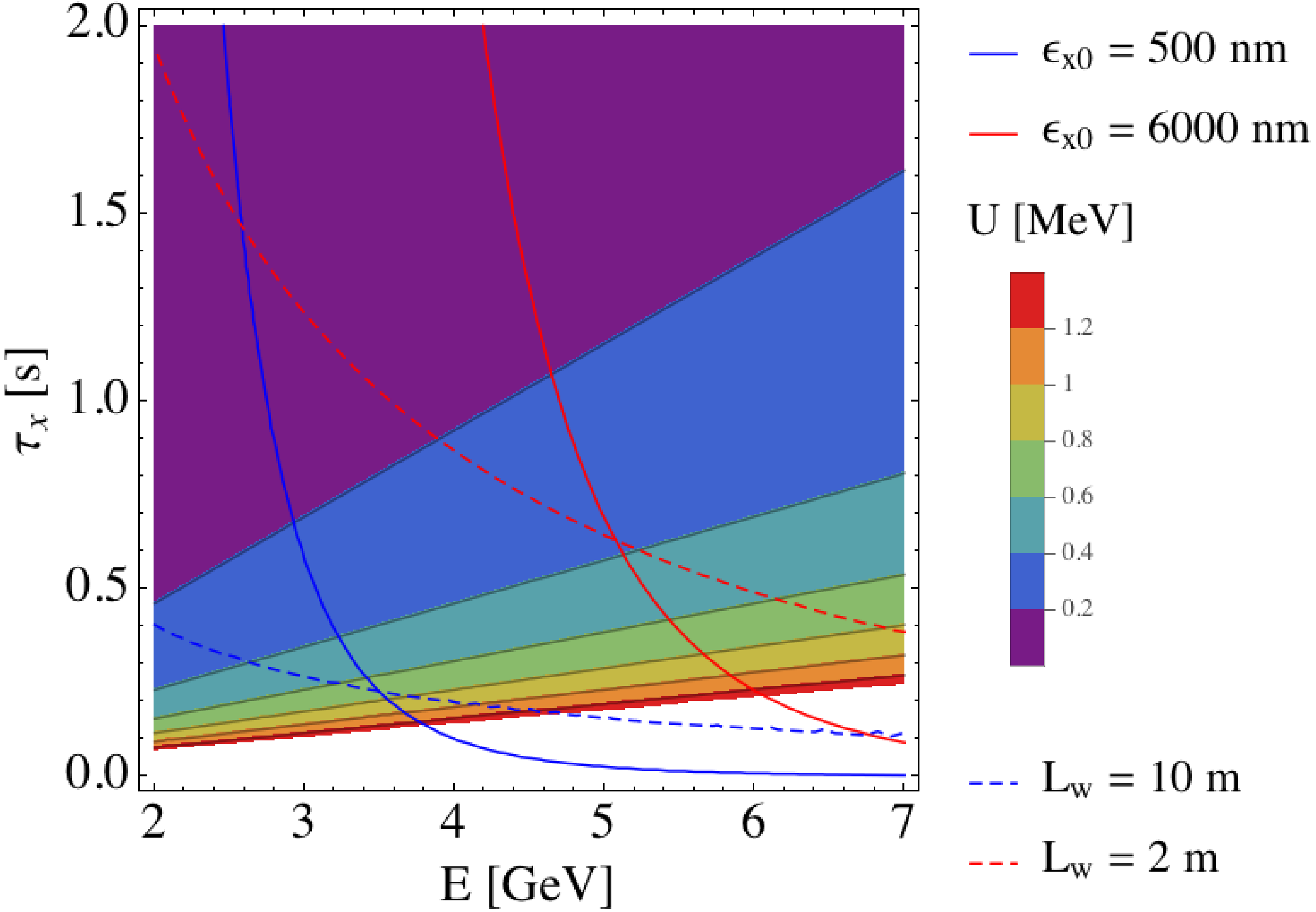




- It is only possible to reach ultra-low equilibrium emittance and very fast damping time, when a large number of wigglers is included

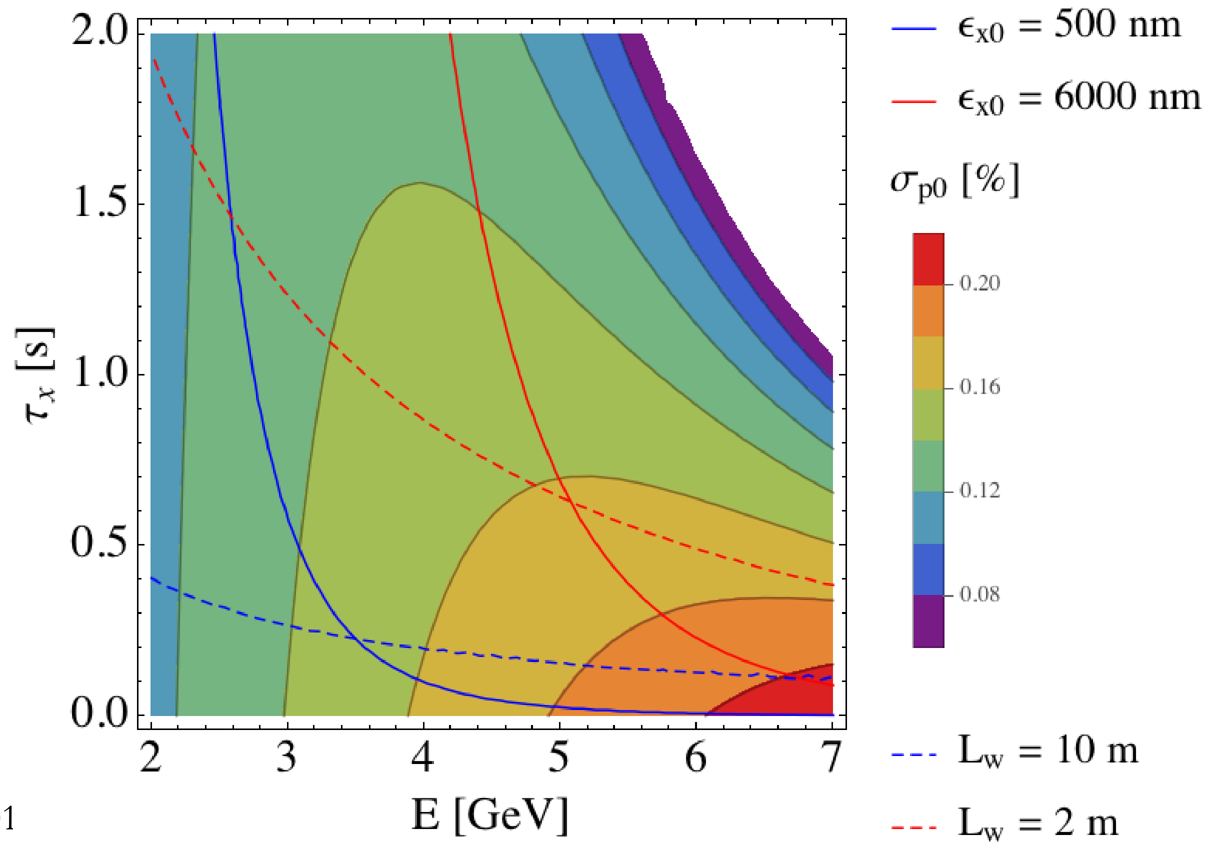
Energy loss per turn

- Energy loss per turn proportional to energy and inversely proportional to damping time
- In particular for 3.5GeV and 10m wigglers, ~0.7MeV, i.e. enough RF voltage available (~7MV)
- Note that for SPS during the LEP era, extra cavities were installed providing 30MV



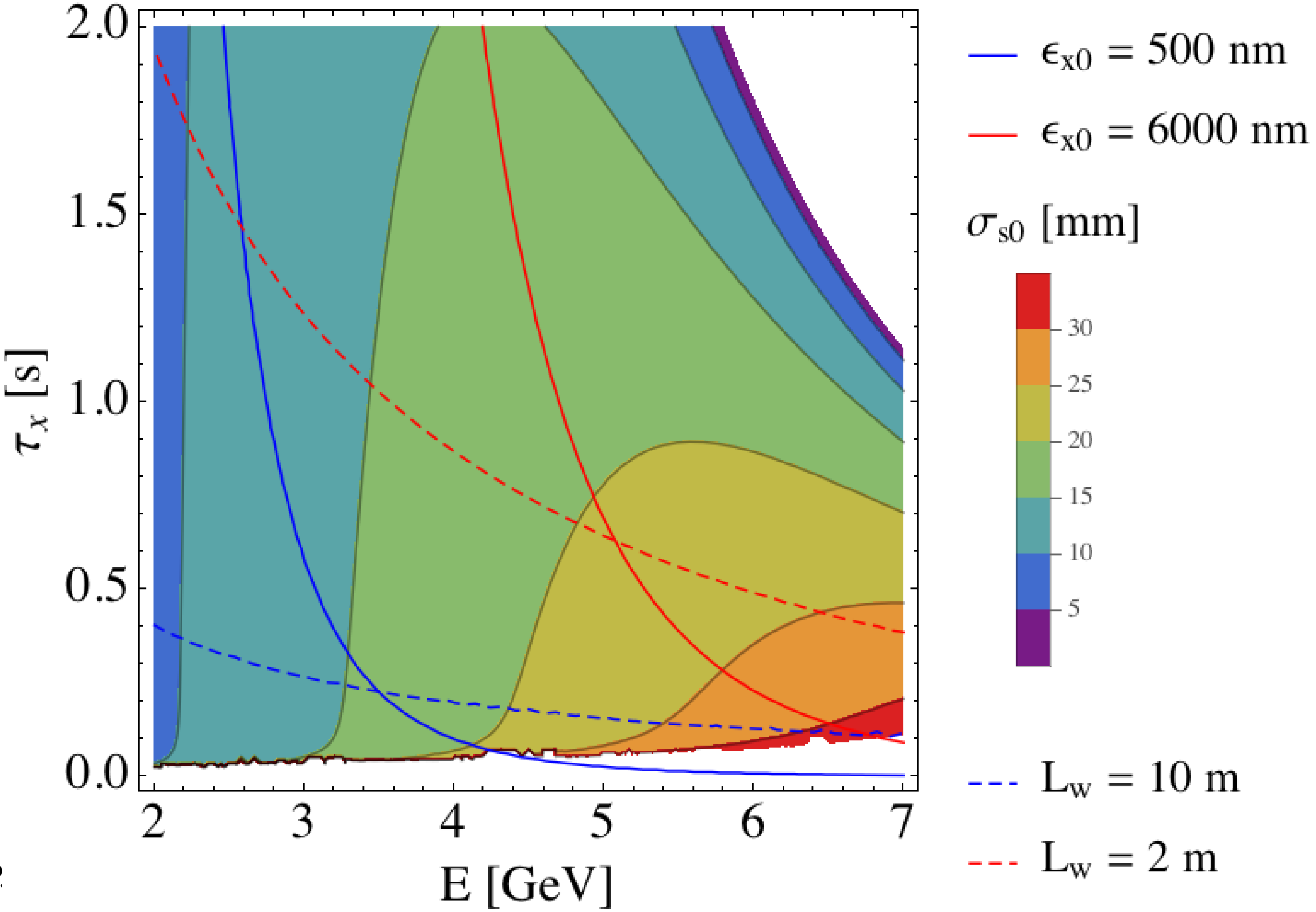
Energy spread

- Energy spread depends weakly on damping time for lower energies
- Higher energies show a rapid change with damping time
- Generally, values lie between 0.1 and 0.2%
- In particular for 3.5GeV, energy spread of ~0.15%



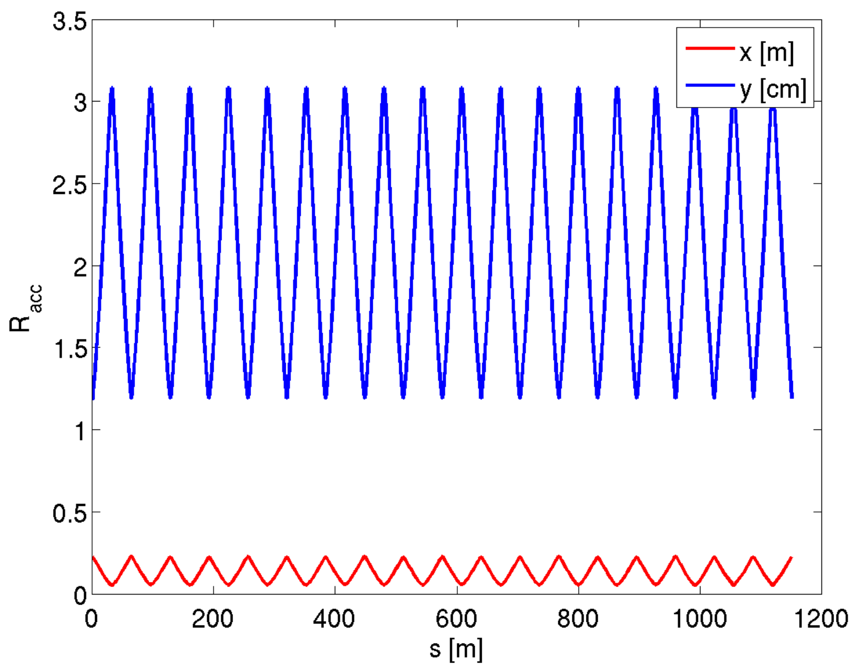
Bunch length

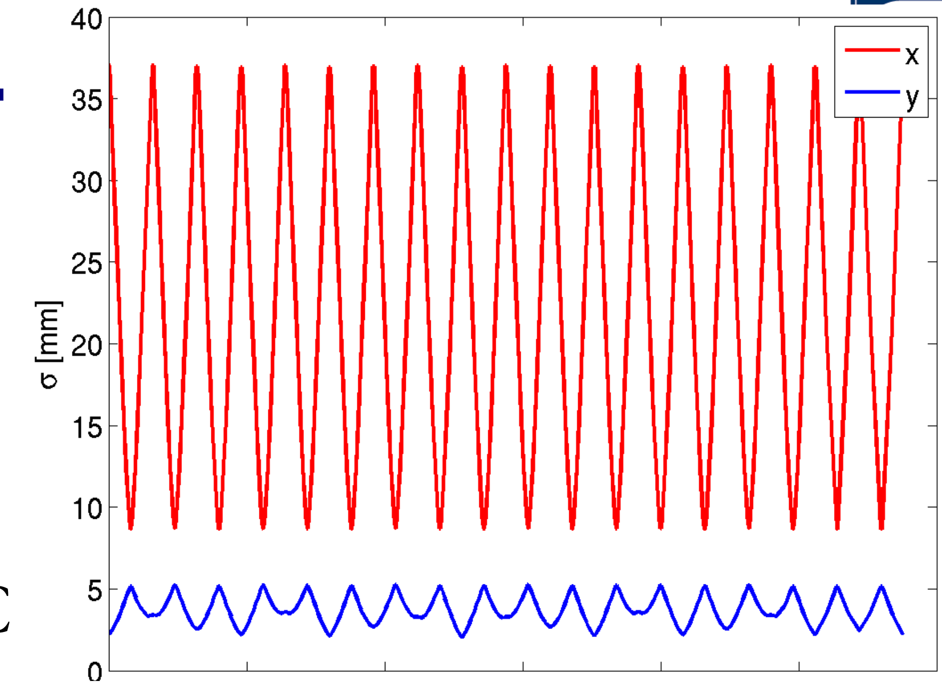
- Bunch length has very similar behaviour as energy spread for fixed voltage (5MV in this example)
- In particular for 3.5GeV, bunch length of 16mm

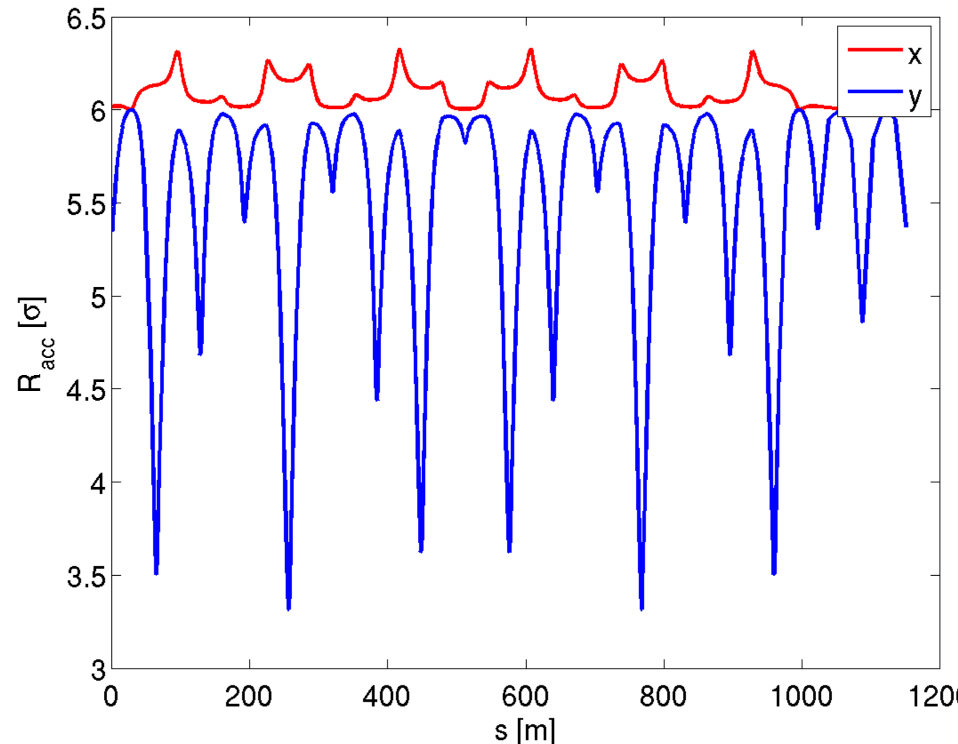


Geometrical Acceptance

- Assuming CLIC pre-damping ring beam parameters
- Wiggler gap needed of the order of 3 cm (1.3cm for CLIC prototype)

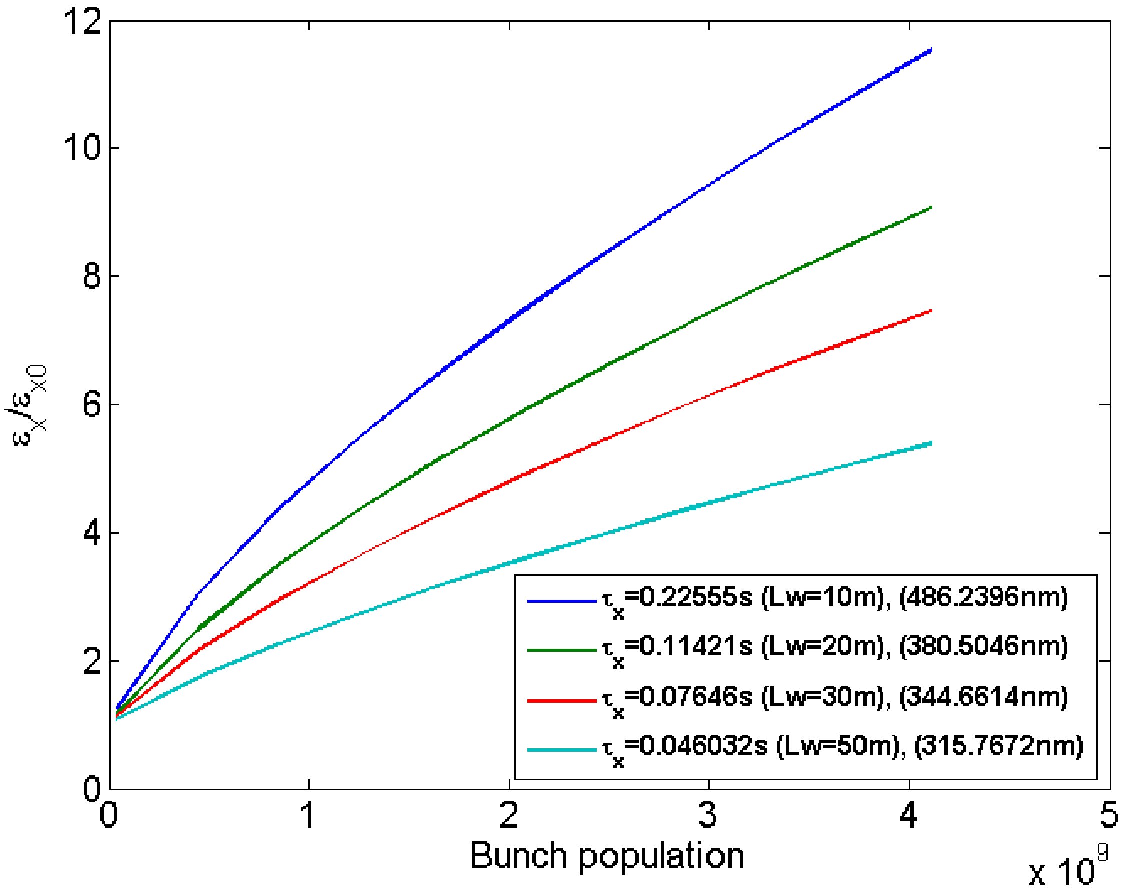






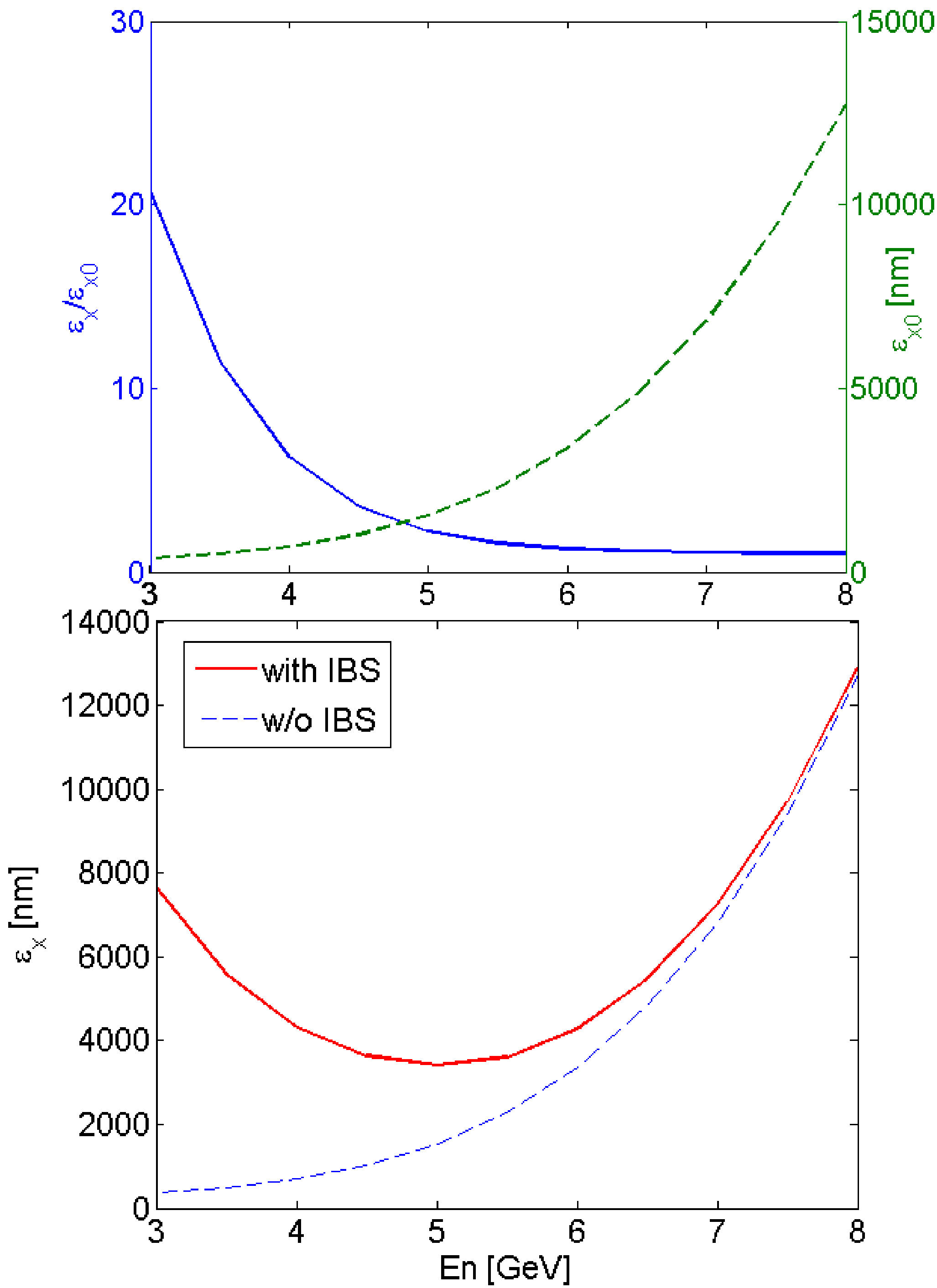
Intrabeam Scattering

- Scaling of the blow-up due to IBS in the horizontal plane with the bunch population, @ 3.5GeV for different total wiggler length (thus damping times and zero current emittance)



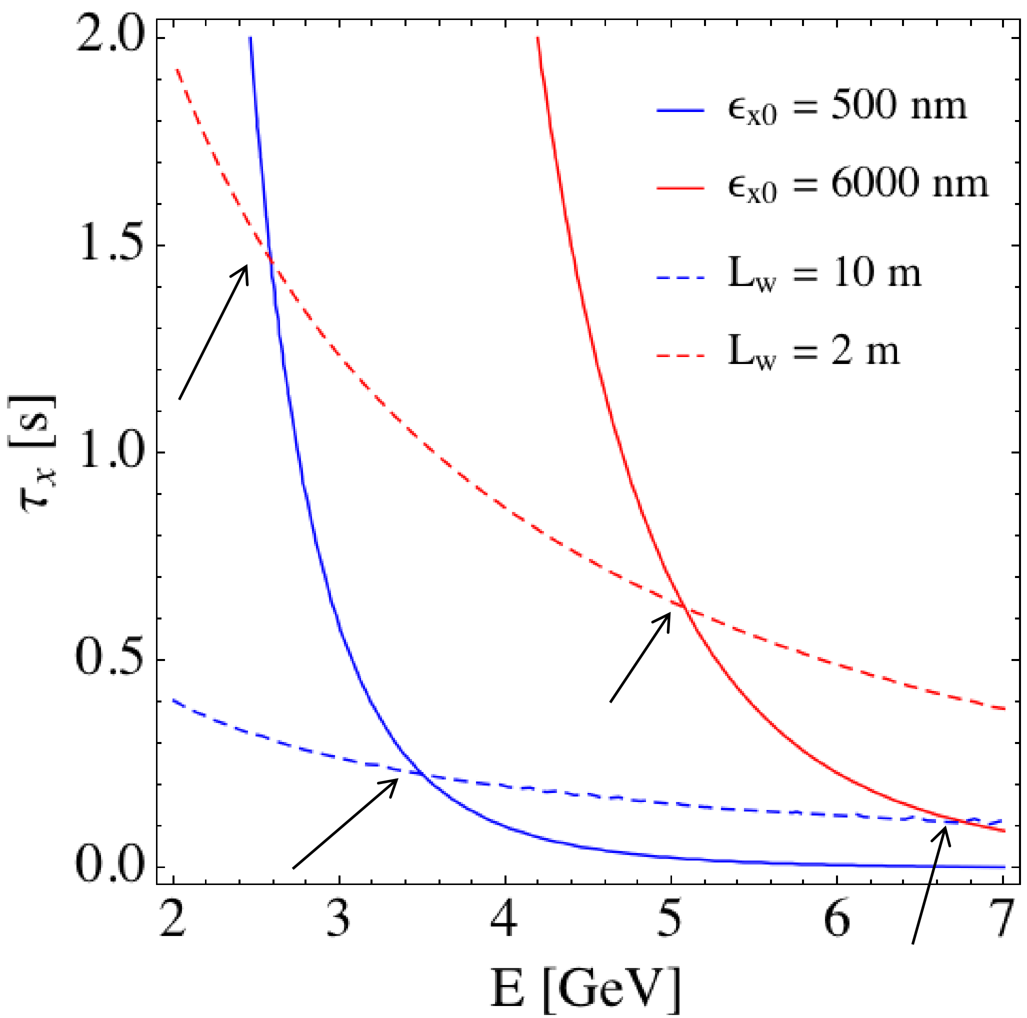
IBS

- Scaling of the IBS blow-up in the horizontal plane (blue) and the zero current horizontal emittance (green) with energy
  - For a total wiggler length of 10 m and for the CLIC bunch current Nb=4.07E9
- Minimum at around 5GeV but still a factor of 2 blow up



Parameter Choice

- Interesting parameters for one 2m-wiggler (CLIC prototype) or five (10m total length), crossing the CLIC and ILC target emittances, at 2.6, 3.5, 5 and 6.6 GeV

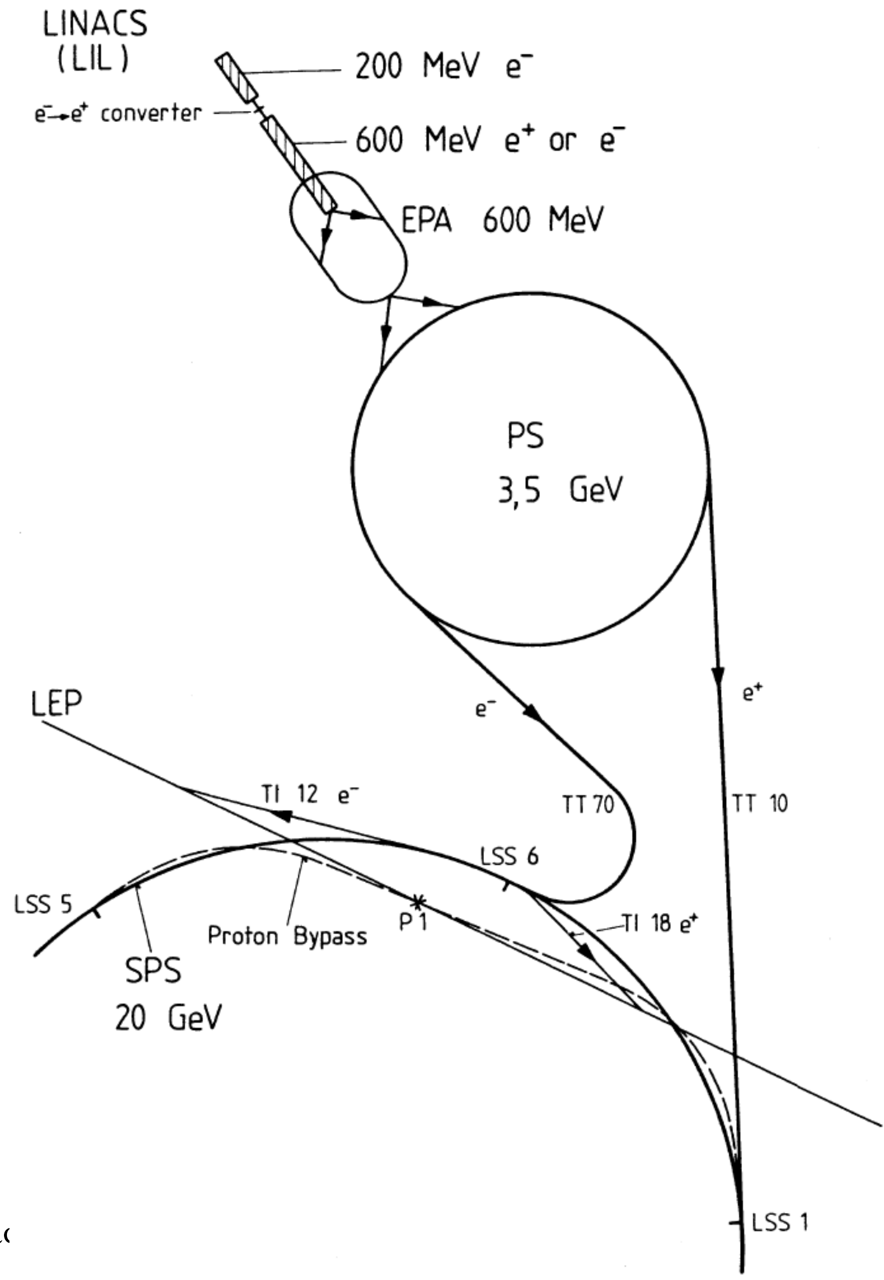


Tentative parameters

Parameter [Unit]	Lw=0 m	Lw=2 m	Lw=10 m	Lw=2 m	Lw=10 m
Energy [GeV]	3.5	2.6	3.5	5	6.8
Hor. Norm. emit. [nm]	8800	480		5600	
Damping time (x,y) [sec]	9	1.46	0.22	0.64	0.11
Bunch length [mm]	3.6	11.5	16.1	20.5	32.5
Energy spread [%]	0.011	0.13	0.15	0.16	0.20
Energy loss/turn [MeV]	0.02	0.08	0.72	0.36	2.8
Bunches/pulse	<=9221				
Bunch spacing [ns]	5				
Repetition rate [Hz]	0.83				

EP Injector complex

- Need to revive a "LEP-like" injector complex
- Pre-injector includes and e/p linac at a few hundreds MeV (LIL at LEP), and accumulator (EPA for LEP)
- It should be transferred through PS to SPS
- Transfer line for positrons exis (TT10) but for electrons (TT70) completely dismantled



Further studies

- Consideration for the injector complex (CTF3?)
- Parameters for the PS at different energies considered
- Transfer-line and injection/extraction elements
- Complete parameter set for SPS including collective effects and synchrotron radiation
- Test the new optics in the SPS with protons (2015)
- Establish synergies with different projects (LHeC, TLEP, AWAKE,…)

ELectron Positron Injector Design Study

ELPIDES