“new” ideas

- pile-up leveling versus luminosity
    leveling schemes
- reminder - satellite bunches
- extremely flat collisions – flat beams?

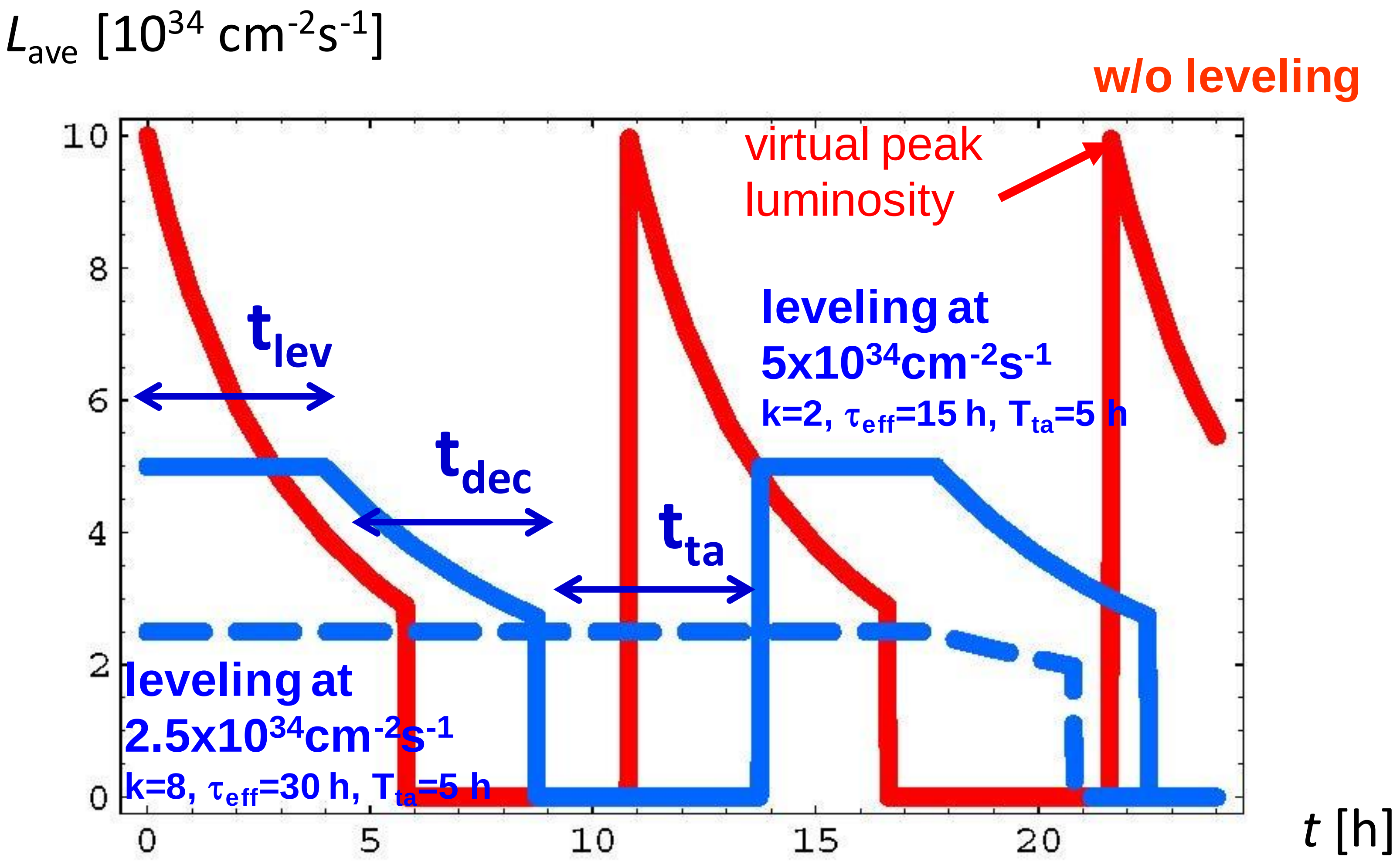
Frank Zimmermann

HL-LHC/LIU Joint Workshop
30 March 2012

example HL-LHC parameters

parameter	symbol	**nom.**	nom.*	**25 ns, crab, lrc**	**50 ns, crab, lrc**
protons per bunch	N_b [10^{11}]	**1.15**	1.7	**1.73**	**3.46**
bunch spacing	Δt [ns]	**25**	50	**25**	**50**
beam current	I [A]	**0.58**	0.43	**0.875**	**0.875**
75rms bunch length	σ_z [cm]	**7.55**	7.55	**7.55**	**7.55**
beta* at IP1&5	$\beta*$ [m]	**0.55**	0.55	**0.15**	**0.15**
full crossing angle	θ_c [μrad]	**285**	285	**425**	**425**
normalized emittance	$\gamma\varepsilon$ [μm]	**3.75**	3.75	**2.8**	**2.8**
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	**0.65**	0.65	**2.13**	**2.13**
tune shift	ΔQ_{tot}	**0.009**	0.0136	**0.006-0.011**	**0.012-0.020**
potential pk luminosity	L [10^{34} cm^{-2}s^{-1}]	**1**	1.1	**10**	**20**
actual (leveled) pk luminosity	L_{lev} [10^{34} cm^{-2}s^{-1}]	**1**	1.1	**5**	**5 (2.5)**
events per #ing		**19**	40	**95**	**190 (95)**
effective lifetime	τ_{eff} [h]	**44.9**	30	**13.5**	**13.5 (27.0)**
level time / run time	$t_{level,run}$ [h]	**15.2**	12.2	**3.9 / 8.7**	**6.7 / 10.3 (17.0)**
e-c heat SEY=1.2	P [W/m]	**0.2**	0.1	**0.4**	**0.3**
SR+IC heat 4.6-20 K	P_{SR+IC} [W/m]	**0.32**	0.30	**0.58**	**0.91**
IBS ε rise time (*z*, *x*)	$\tau_{IBS,z/x}$ [h]	**58, 104**	39, 70	**71, 60**	**36, 30**
annual luminosity	L_{int}[fb^{-1}]	**57**	58	**259**	**317 (204)**

luminosity leveling at the HL-LHC



key equations

effective beam lifetime

for given luminosity τ_{eff} scales with total beam current

$$\frac{dN_{tot}}{dt} = -\frac{N_{tot}}{\tau_{eff}} = -n_{IP}\sigma L_{lev}$$

(σ=100 mb)

$$\tau_{eff} = \frac{N_{tot}}{n_{IP}\sigma L_{lev}}$$

maximum leveling time

$\hat{L} = kL_{lev}$ virtual peak luminosity

$$t_{lev} = \tau_{eff}\left(1-\frac{1}{\sqrt{k}}\right)$$

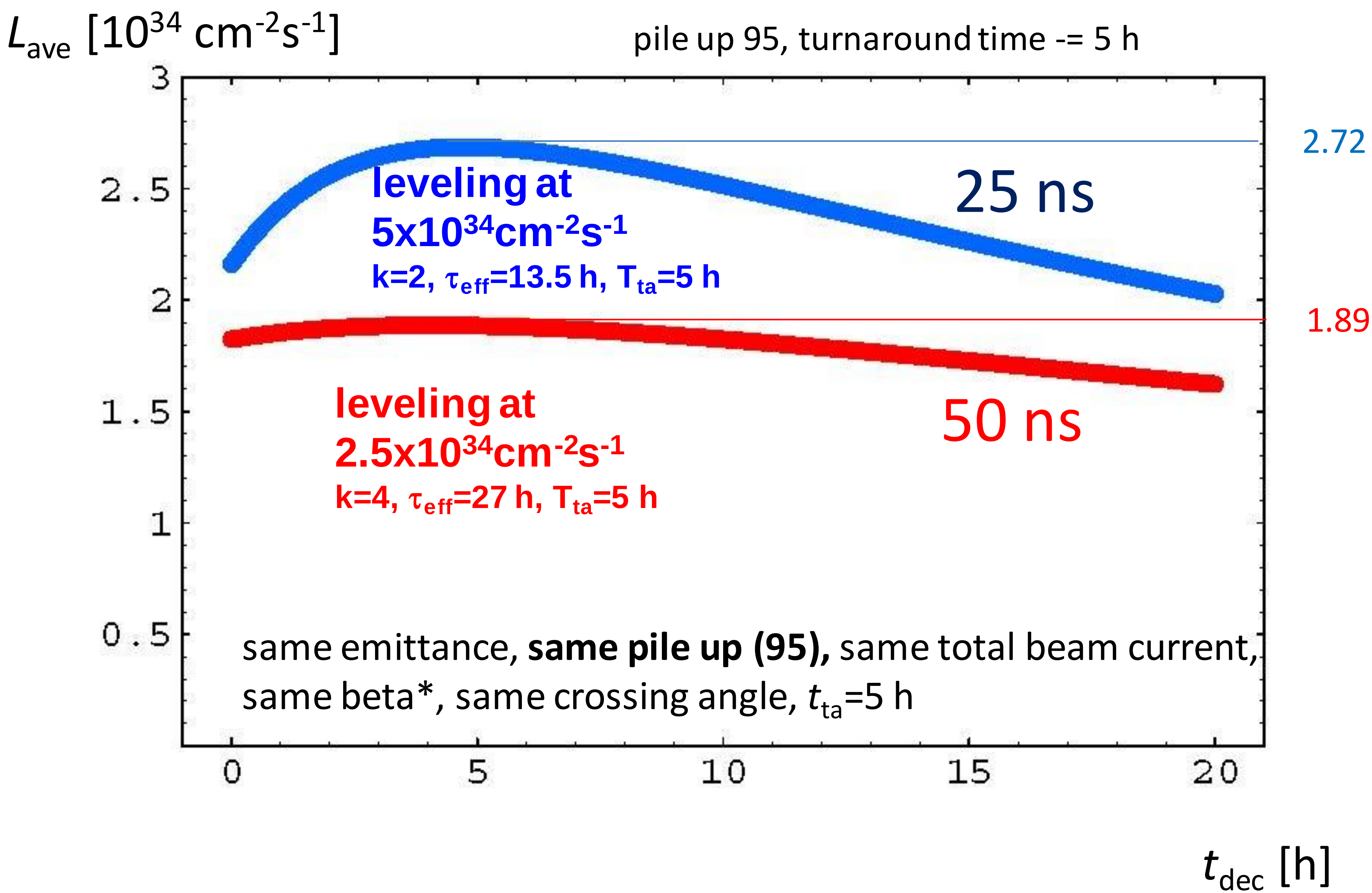
optimum "decay time" after leveling

$$t_{dec} = \tau_{eff}\frac{1}{2-\frac{1}{\sqrt{k}}}\left(-1+\frac{1}{\sqrt{k}}+\sqrt{\left(1-\frac{1}{\sqrt{k}}\right)^2+\left(2-\frac{1}{\sqrt{k}}\right)\frac{t_{ta}}{\tau_{eff}}}\right)$$

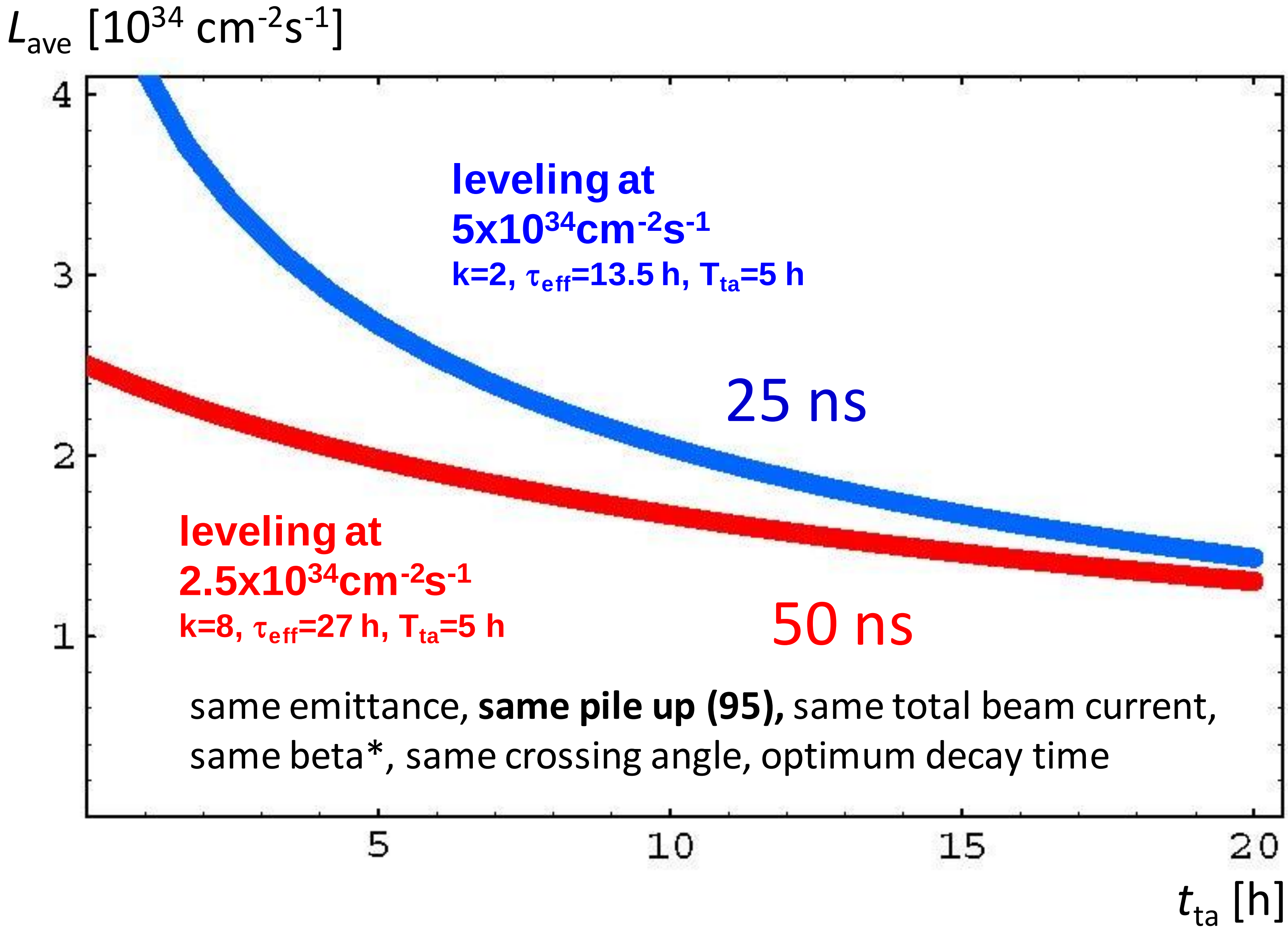
optimum total luminosity

$$L_{ave} = L_{lev}\frac{\left(1-\frac{1}{\sqrt{k}}\right)\tau_{eff}+\frac{t_{dec}\tau_{eff}}{t_{dec}+\tau_{eff}}}{t_{dec}+\left(1-\frac{1}{\sqrt{k}}\right)\tau_{eff}+t_{ta}}$$

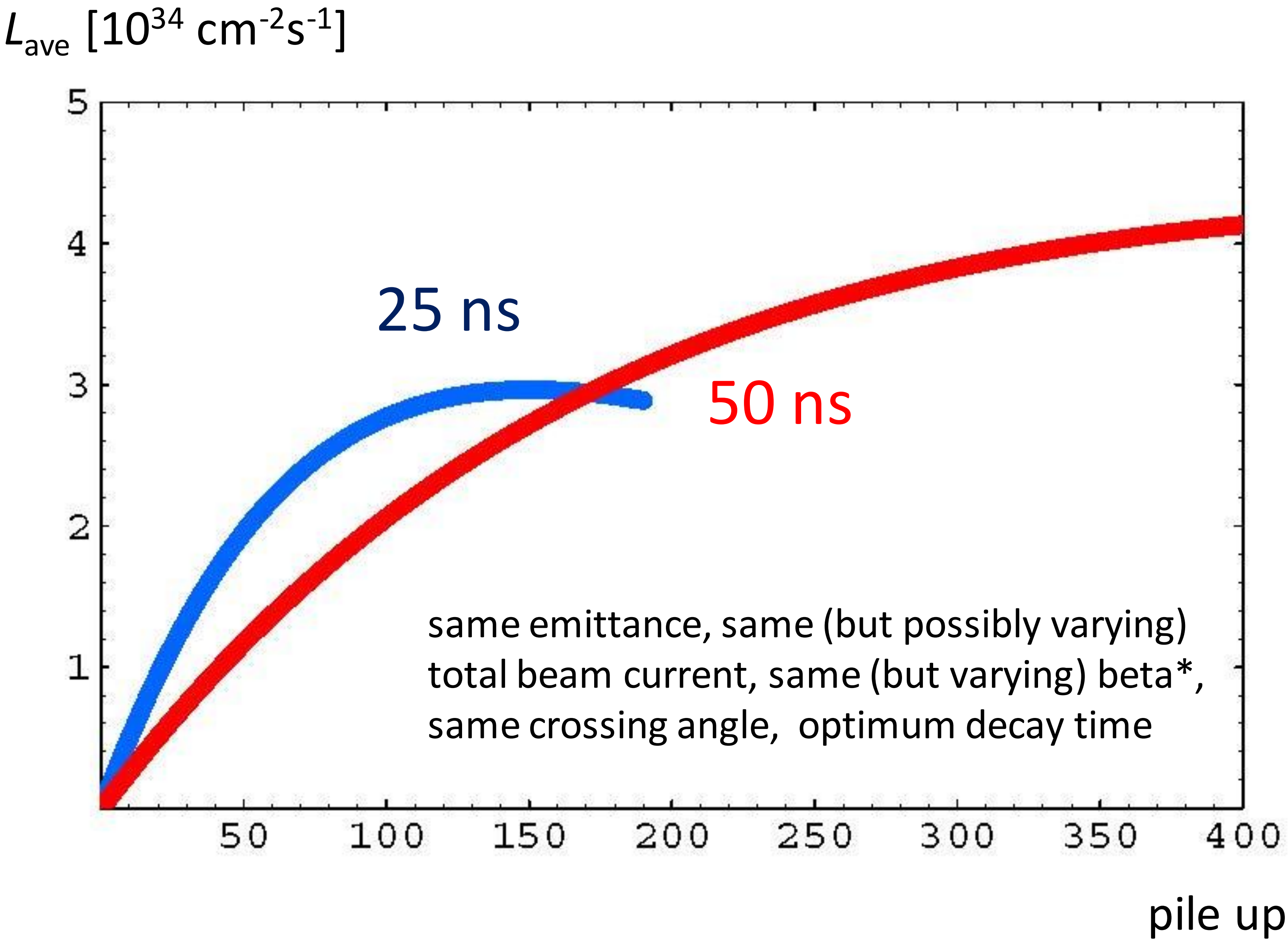
average luminosity vs. t_{dec}



average luminosity vs. t_{ta}

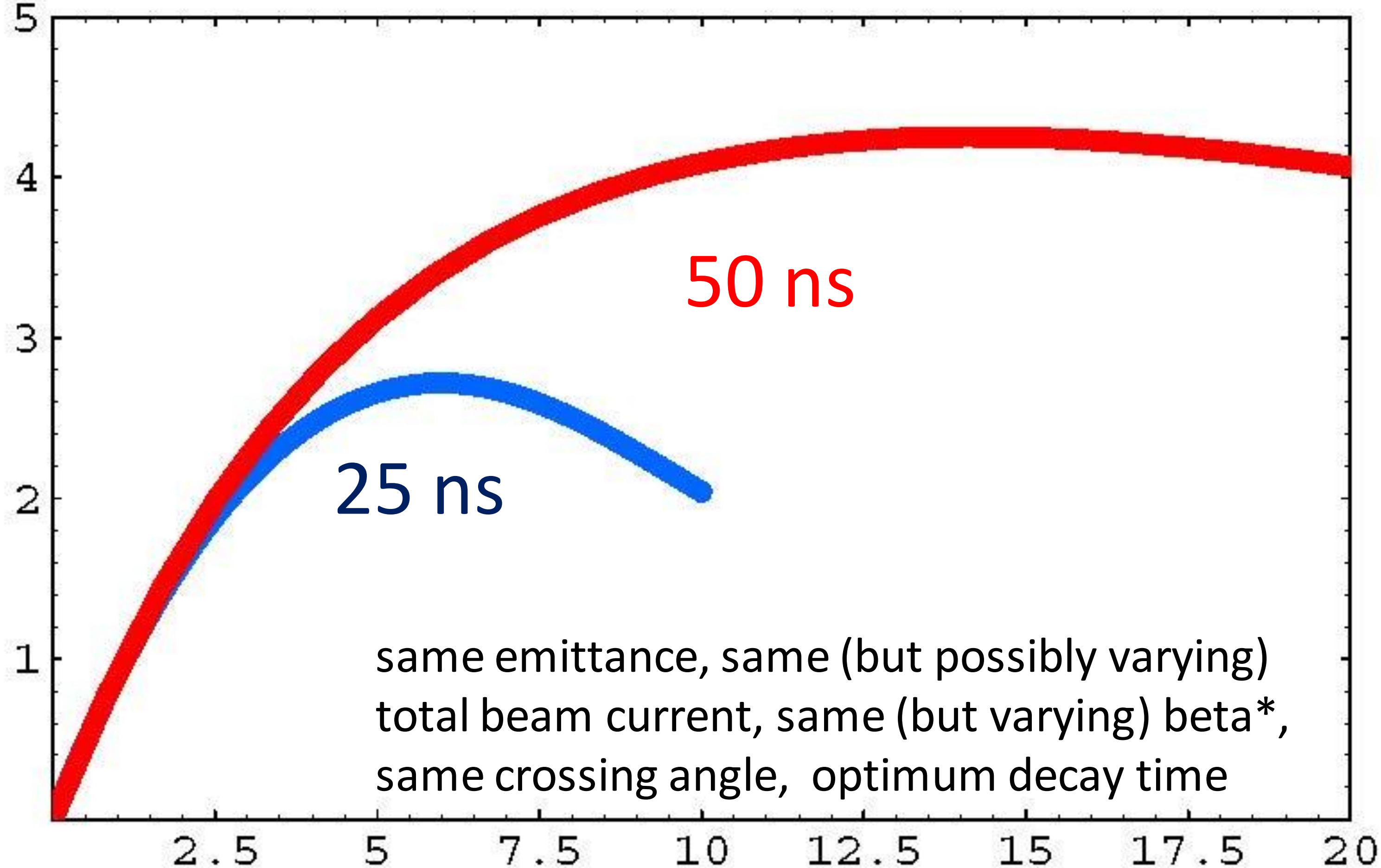


average luminosity vs. pile up



average vs. leveled luminosity

L_{ave} [10^{34} $cm^{-2}s^{-1}$]



L_{lev} [10^{34} $cm^{-2}s^{-1}$]

performance with leveling

for equal emittances & equal total beam current

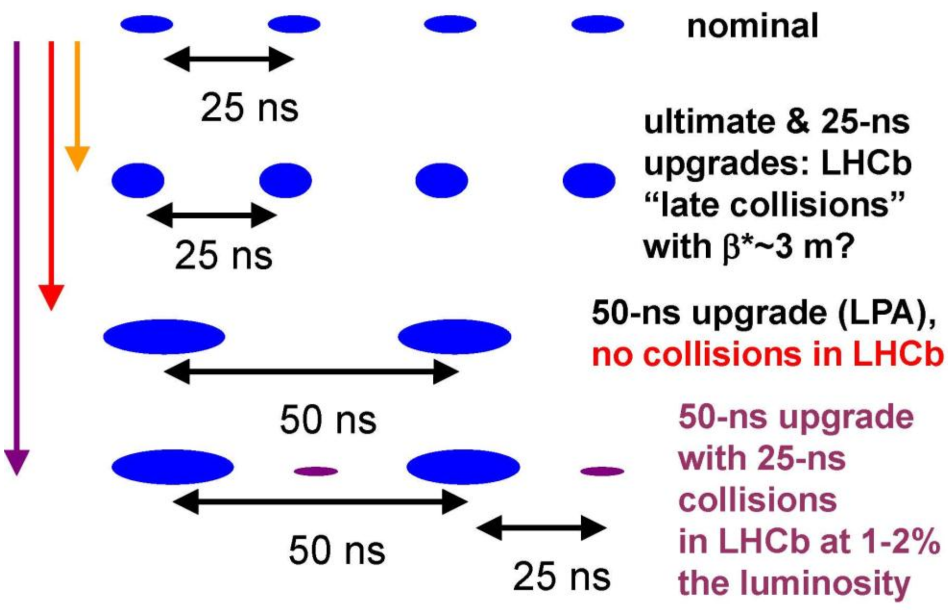
25 ns gives 20-50% more integrated luminosity than 50 ns for equal pile up below ~150

25 ns and 50 ns yield equal integrated luminosity for the same pile up of ~175

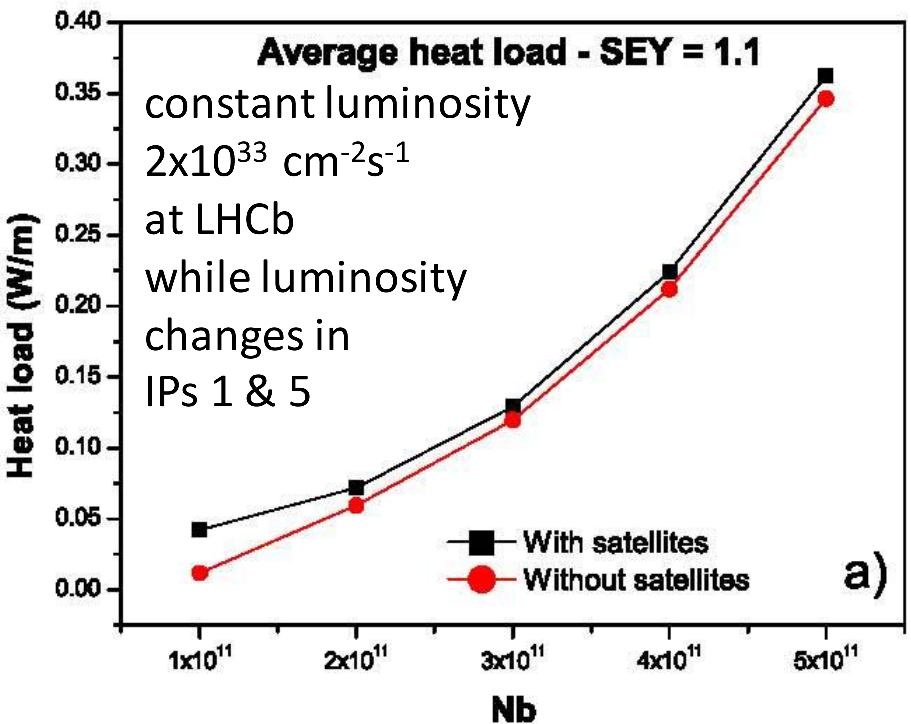
50 ns delivers 20-50% more integrated luminosity than 25 ns at higher pile up

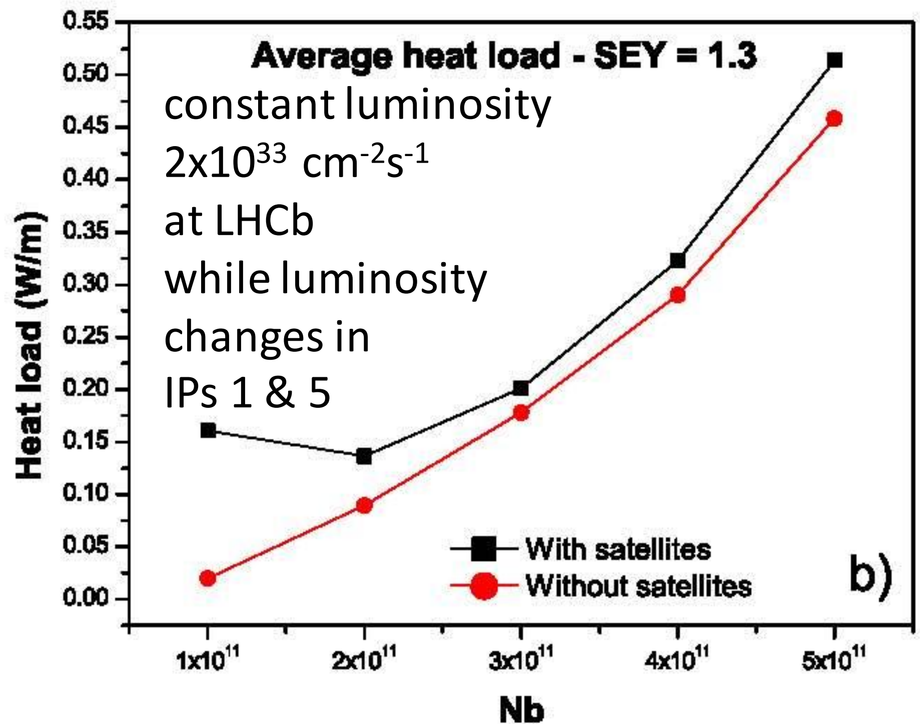
controlled satellites for 50 ns mode

e-cloud heat load almost unchanged by adding the satellites



H. Maury





LHC flat beams with $\beta^*_x >> \beta^*_y$

$\theta, mrad$	Φ	$1/\sqrt{1+\Phi^2}$	R	$L_0 R, 10^{34}$	ξ_x	ξ_y
1.0	1.8875	0.4682	0.2981	10.826	0.00792	0.00169
1.5	2.8312	0.3330	0.2417	8.7754	0.00406	0.00122
2.0	3.7749	0.2561	0.2019	7.3311	0.00242	0.00094
2.5	4.7187	0.2073	0.1728	6.2730	0.00159	0.00077
3.0	5.6624	0.1739	0.1506	5.4690	0.00113	0.00065

$$L = \frac{N^2 n_b f}{4\pi\sigma_x\sigma_y} \times R$$

$$R = \frac{L}{L_0} = \sqrt{\frac{2}{\pi}} a e^b K_0(b)$$

$$a = \frac{\beta_y^*}{\sqrt{2}\sigma_z}, \quad b = a^2\left(1+\Phi^2\right)$$

$$\Phi = \frac{\sigma_z \tan(\theta/2)}{\sigma_x}$$

$$\beta_x = 1.36m, \quad \beta_y = 1.36cm, \quad \varepsilon_n = 2.194\mu mrad$$

$$\sigma_x = 20\mu m, \quad \sigma_y = 2\mu m, \quad \sigma_z = 7.55cm$$

$$N = 3.4\times 10^{11}, \quad n_b = 1404, \quad \gamma = 7461$$

LHC crab waist requires $\sigma_x/\sigma_y \geq 10$
(M. Zobov, D. Shatilov, 2010);
→ separate doublets & large Θ_c

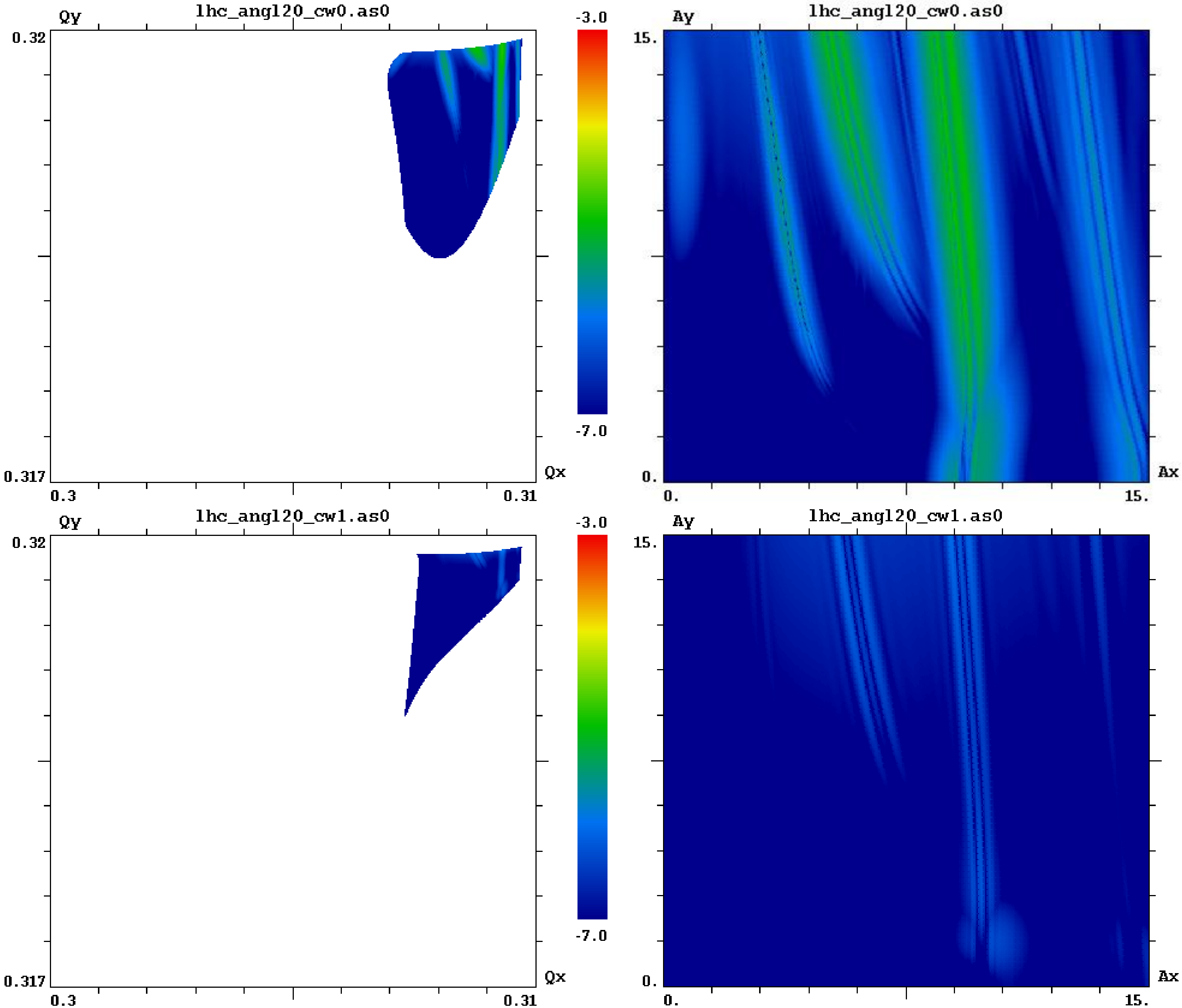
Jose Abelleira, Mikhail Zobov, Frank Zimmermann

Mikhail Zobov, Dmitry Shatilov

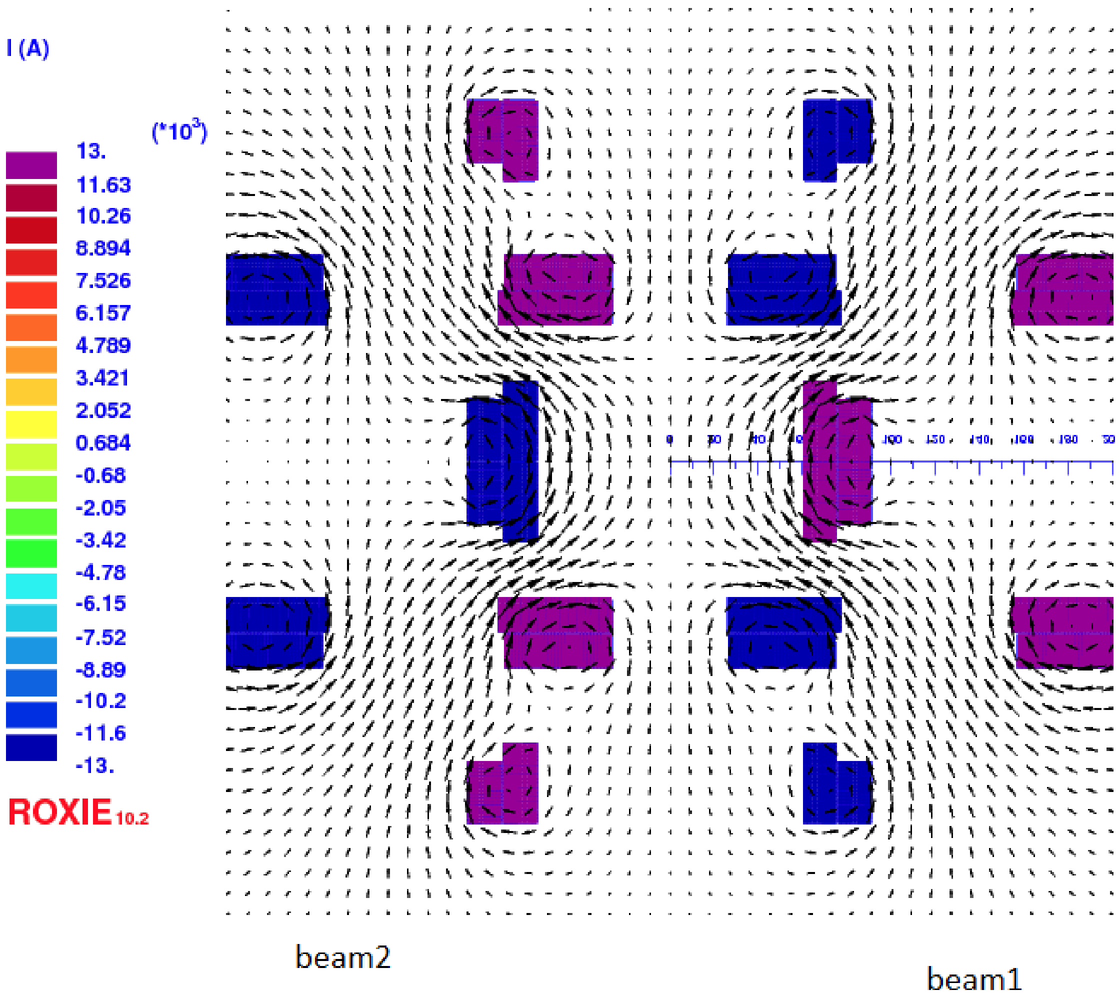
Angle = 2.0 mrad

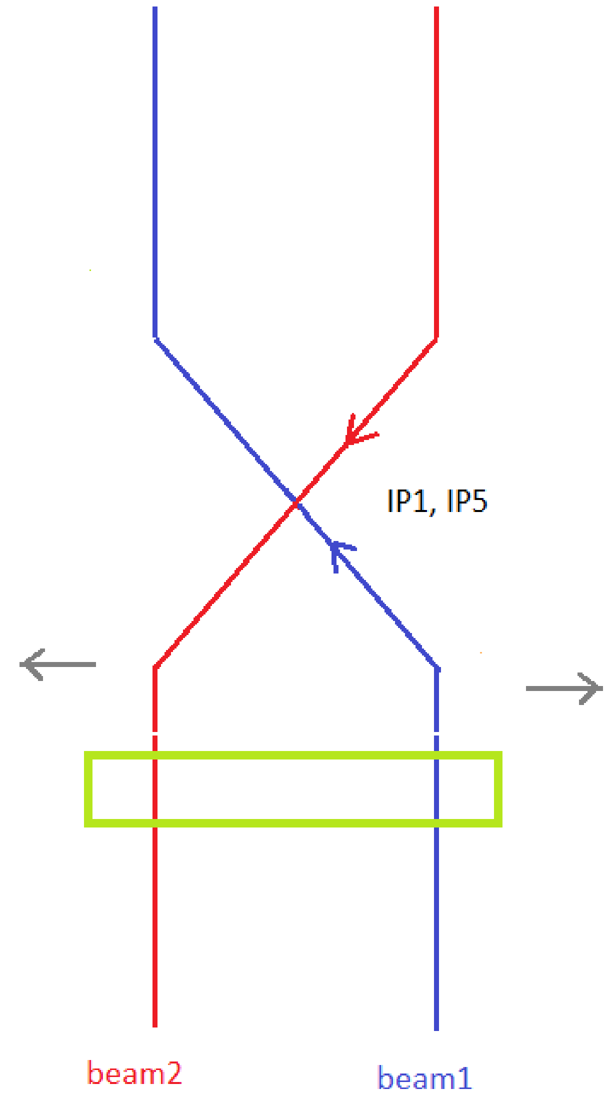
CW = 0

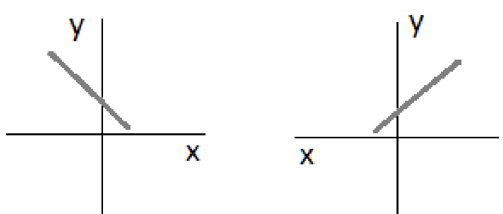
CW = 0.5



“double half” quadrupole







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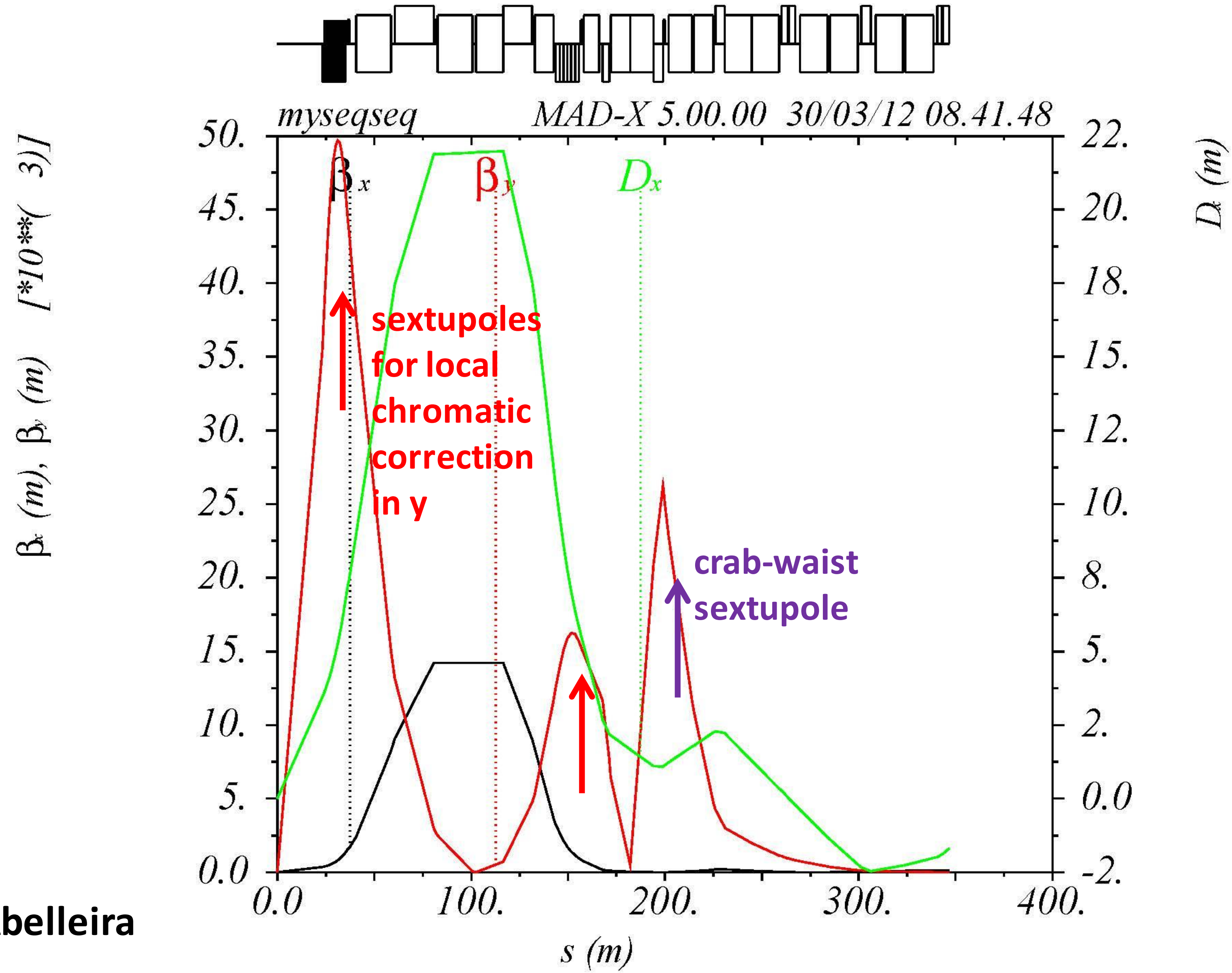
a flat-beam optics

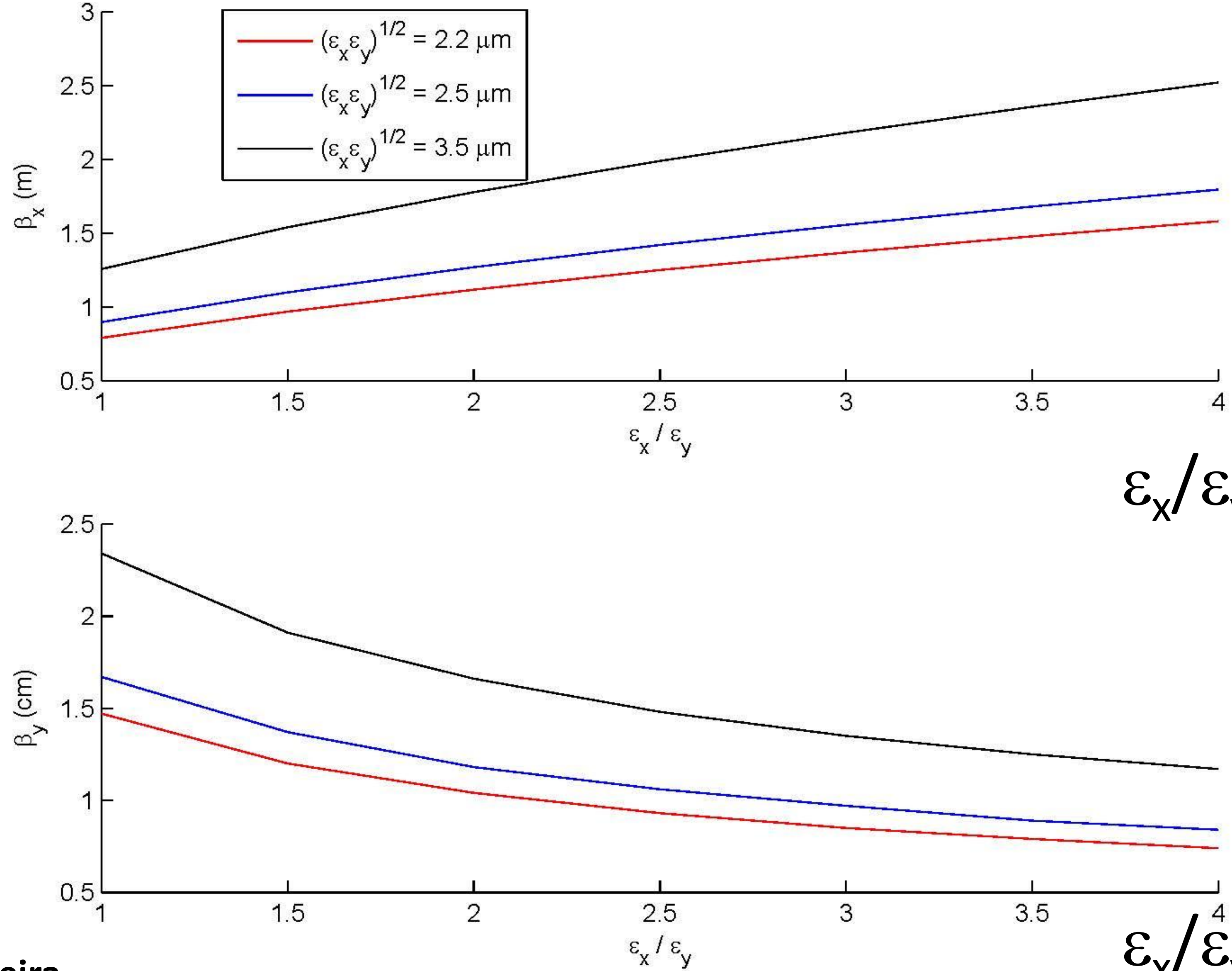


Jose Abelleira

even flatter beams, $\beta^*_x >> \beta^*_y$ & $\boldsymbol{\varepsilon_x > \varepsilon_y}$

β^*_x

β^*_y



$\varepsilon_x/\varepsilon_y$

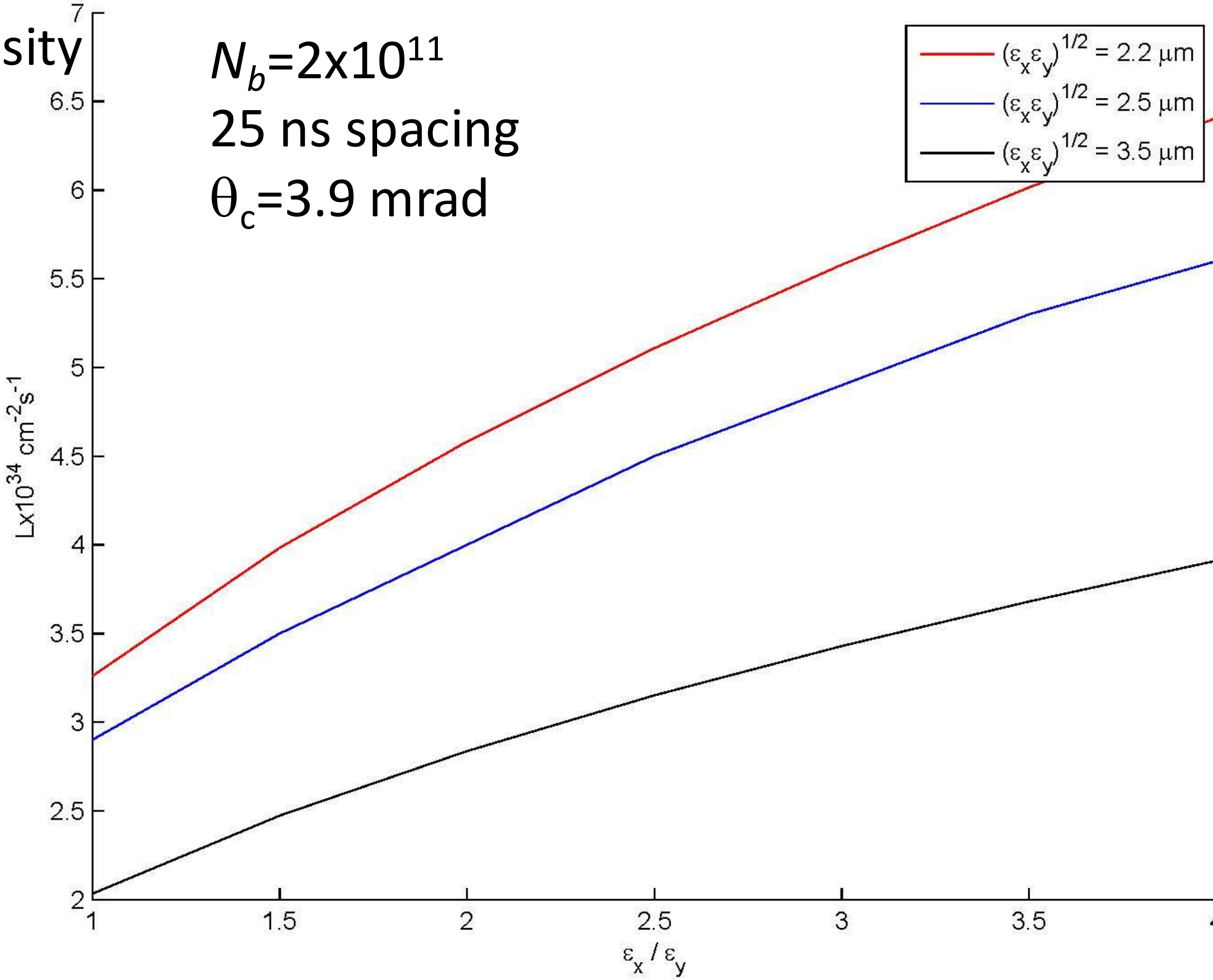
$\varepsilon_x/\varepsilon_y$

Jose Abelleira

extremely flat beams, $\beta^*_x >> \beta^*_y$ & $\varepsilon_x > \varepsilon_y$

peak luminosity

N_b=2x10[11]
25 ns spacing
θ_c=3.9 mrad



$\varepsilon_x/\varepsilon_y$

Jose Abelleira

conclusions

25-ns or 50-ns can deliver the same average luminosity or the same pile up at most 30-50% difference (for the same emittance and same total current); optimum choice depends on detectors and physics case

generating controlled satellites in the injectors should be kept in mind for all 50-ns scenarios

can the injectors deliver “flat” beams – and with which performance?