HE-LHC with flat beams

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Flat beams

- Flat beams are being considered for the FCC-hh.
- They are an alternative to the use of crab-cavities, as they minimize the impact of colliding with crossing angle.
- Flattening the IP parameters ($\beta_x\uparrow$, $\beta_y\downarrow$) can offer some advantages:
  - Reduces the beam-beam parameter
  - Reduces the crossing angle (for the same beam-beam separation, Δ_{in})

$$\theta = \Delta_{in}\sqrt{\frac{\varepsilon}{\beta_x{}^*}}$$

Alternative to the use of crab-cavities

  - As the crossing angle is reduced:
    - The impact of not having crab cavities is lower
    - The radiation debris is less spread (less radiation in magnets)

Flat beams

- We should design the final focus to be compatible with a flat-beam solution.
- Need to take into account other aspects:
  - Dynamic aperture
  - Beam-beam: long range and head-on behave differently
  - Beam separation must be increased

J.L. Abelleira, 'FCC-hh Final-Focus for Flat-Beams: Parameters and Energy Deposition Studies'.

T. Pieloni et al, 'Beam-beam effects'.

T. Pieloni et al, 'Beam-beam effects', FCC week 2017

Flat beams

- We have explored a range of β* parameters, in order to get some idea of how integrated luminosity works
- Parameters for integrated luminosity:
  - T_p=3 h
  - Beam-beam parameter= 0.02
  - Damping time (hor): td=3.6 h
  - L_{int}~ 700-820 fb^{-1}/year (4.4-5.1 fb^{-1}/day)

Flat beams: integrated luminosity

- Integrated luminosity per day [fb-1]

L_{int} with Crab-cavities in parenthesis

betx* [m]

bety*[m]

	0.1	0.2	0.25	0.3	0.4	0.5	0.6
0.4					4.4 (5.2)		
0.3				4.6 (5.8)			
0.25			4.6 (6.2)				
0.2		4.7 (6.6)					
0.15	4.8 (7.2)						
0.1							
0.08							
0.05							

Beam-beam parameter>0.22

$L_0 > 30 \cdot 10^{34}$

$\theta = 10\sqrt{\varepsilon/\beta}$

Flat beams: integrated luminosity

- Integrated luminosity per day [fb-1]

L_{int} with Crab-cavities in parenthesis

betx* [m]

bety*[m]

Flat factor

	0.1	0.2	0.25	0.3	0.4	0.5	0.6
0.4					~~4.4 (5.2)~~		
0.3				4.6 (5.8)	4.7		
0.25			**4.6 (6.2)**		4.8		
0.2		4.7 ~~(6.6)~~	4.9		5.1		
0.15	(4.8) ~~(7.2)~~		5.2	5.3	5.4		
0.1		5.4	5.6	5.7	5.8	5.8	5.8
0.08					6.0		
0.0							

Beam-beam parameter>0.22

$L_0 > 30 \cdot 10^{34}$

Crossing angle, $\theta = 10\sqrt{\varepsilon/\beta}$

L_{int} loss compared to nominal: 7%

Flat beams: integrated luminosity

- Integrated luminosity per day [fb-1]

L_{int} with Crab-cavities in parenthesis

betx* [m]

bety*[m]

Flat factor

	0.1	0.2	0.25	0.3	0.4	0.5	0.6
0.4					~~4.4 (5.2)~~		
0.3				4.6 (5.8)	4.1		
0.25			**4.6 (6.2)**		4.3		
0.2		4.7 ~~(6.6)~~	4.9		4.5		
0.15	(4.8) ~~(7.2)~~		4.5	4.6	4.8		
0.1		4.7	4.9	5.0	5.2	5.3	5.4
0.08					5.4		
0.0							

Beam-beam parameter>0.22

$L_0>30\cdot10^{34}$

Crossing angle

$\theta=15\sqrt{\varepsilon/\beta}$ for flat beams

L_{int} loss compared to nominal: 13 %

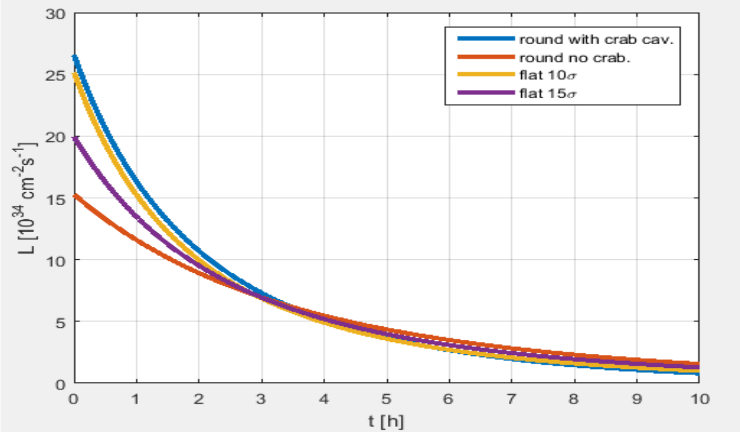
L_{int} loss compared to nominal: 20 %

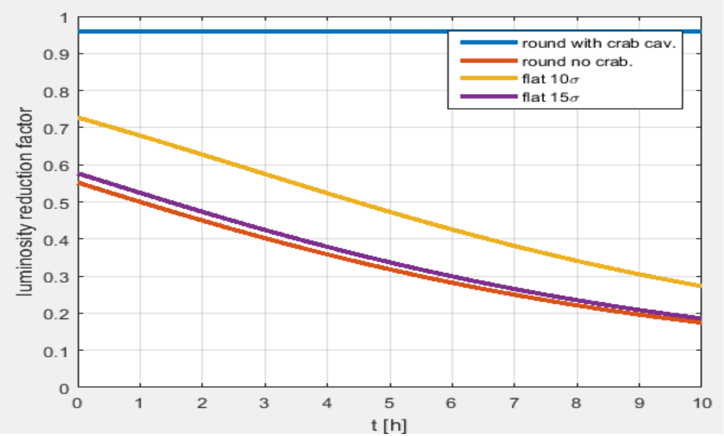
Flat beams

		nominal	flat
Particles per bunch	N [10^{11}]	2.2	
Normalized emittance	ε_N [μm]	2.5	
Number of bunches	nb	2808	
Bunch length	σ_l [cm]	7.55	
IP beta, function, hor	β_x* [m]	**0.25**	**0.4**
IP beta function, ver	β_y* [m]	**0.25**	**0.1**
Full crossing angle	ϴ [μrad]	260	208/312
Beam-beam separation	Δ_{in} [σ]	9.9	10/15
Crab-cavities		Yes	No
Piwinski angle	Φ	1.5	0.94/1.41
Event Pile up		760	730/585
Geom. Luminosity reduction factor	S	0.96	0.72/0.58
Total Beam-beam parameter, initial	ξ_0 [10^{-3}]	20	16/11
Initial luminosity	L_0 [10^{34} $cm^{-2}s^{-1}$]	26	25/20
Integrated luminosity (T_p=3h)	L_{int} [fb^{-1}/day]	6.2*	5.8/5.2

*4.6 without crab cavities

Flat beams



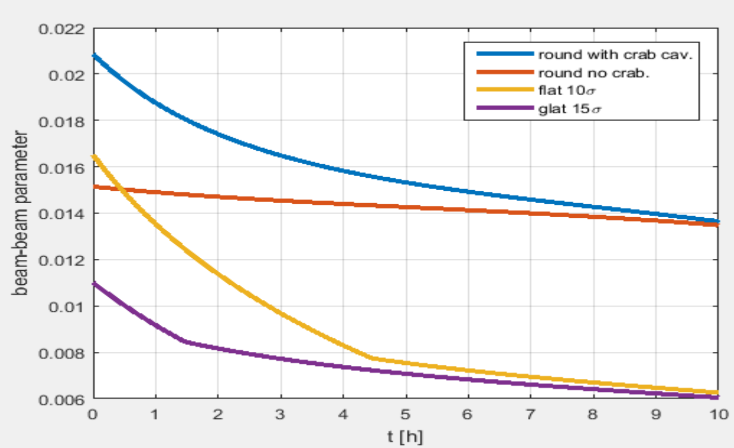


Round: $\xi_T = \xi_x + \xi_y$

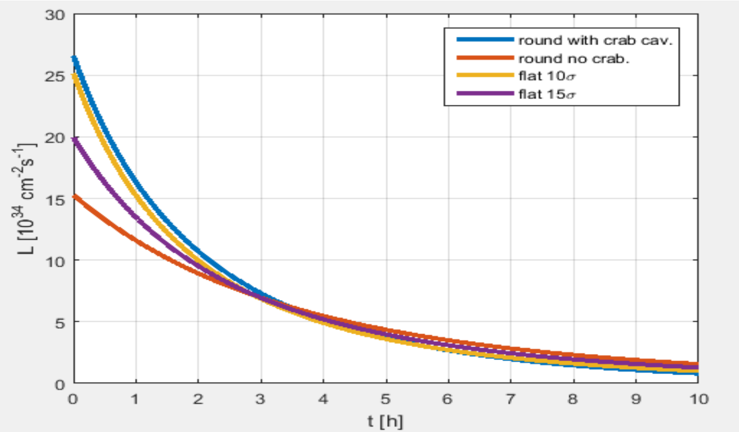
Flat:

$\xi_T = 2*\max(\xi_x,\xi_y)$

(no alternating crossing)

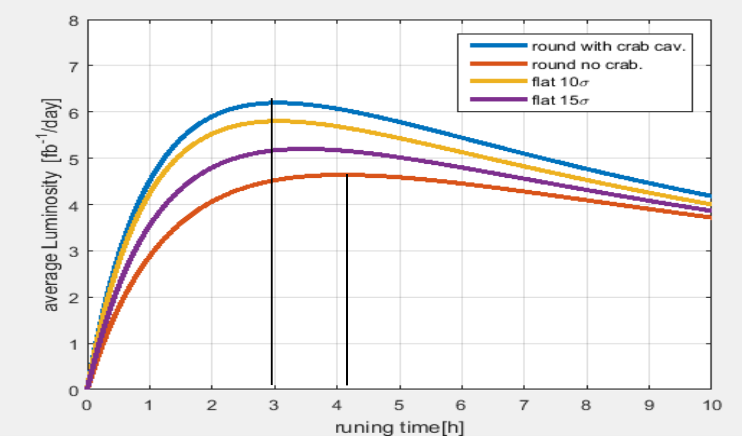


Flat beams



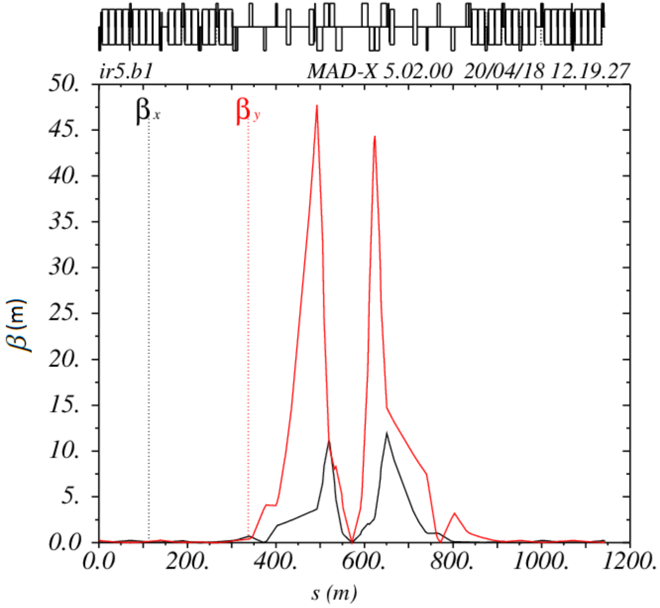
- Flat beams restore some of the luminosity lost with the crossing angle.
- This benefit is diluted if the beam-beam separation is increased.

- The performance of the flat-beam optics depends heavily on the beam-beam separation.



Flat beam optics

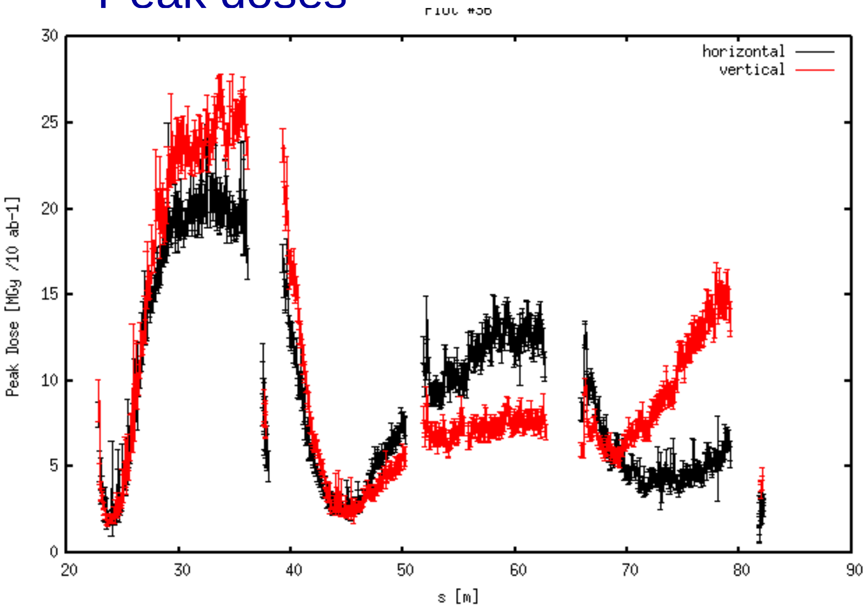
- Optics solution with the same triplet (betx*=0.4 m, bety*=0.1 m)



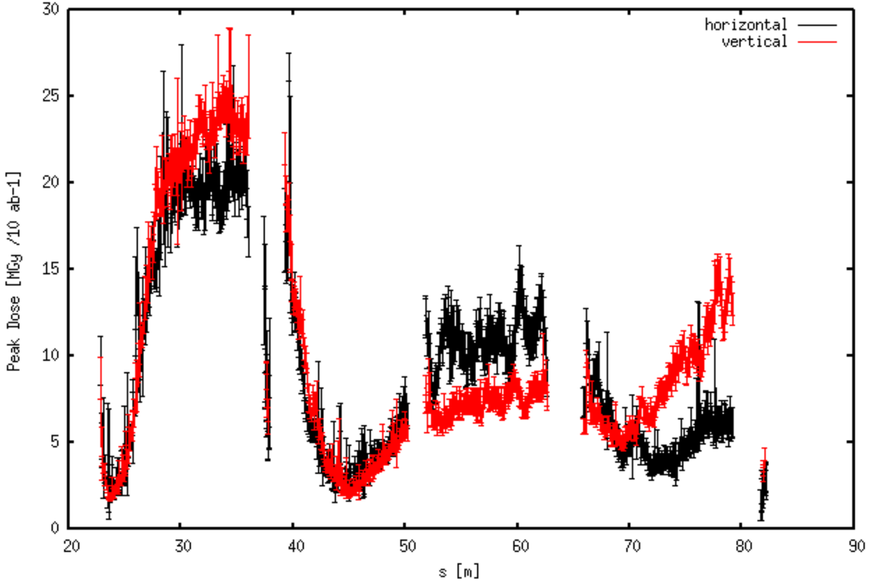
Leon Van-Riesen Haupt,
‘Experimental Interaction Region Optics for the High Energy LHC’ (Thursday)

Flat beams, energy deposition

- Peak doses



Round beam (ϴ=260 μrad)



Flat beam (ϴ=208 μrad)

Almost no effect with this shielding.

Conclusions

- Flat beams are an alternative to the use of crab-cavities.
- They restore some of the luminosity lost with the crossing angle.
- The larger horizontal beam size favours a shorter crossing angle (but minor impact in dose).
- An optimum flat-beam parameter choice is betx*=0.4 m, bety*=0.1 m.
- There is an optics solution with the same triplet.
- Beam separation: we need the exact requirement from beam-beam studies in order to asses the full performance for this option.
- In any case, it is clear that the only case for flat beams is as a back up solution fro the crab-cavities.

Thank you for your attention