FCC-WG, 12.12.2014

High luminosity experiment with FCC injector

(what is possible ?)

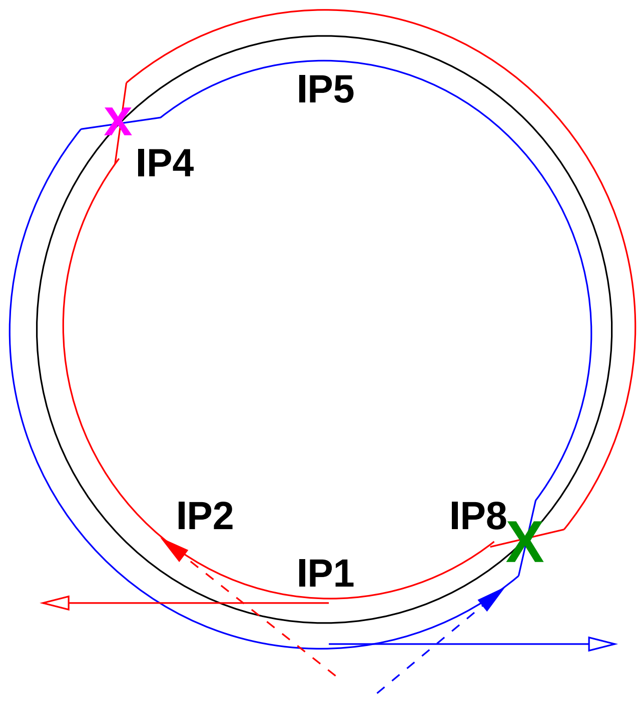
Assumption: re-use of LHC

Previously discussed - no experiment

Minimal invasive, still two crossings needed:

- **IP1: extraction, both beams (no more crossing)**
- **IP2: injection (no more crossing)**
- **IP3 and IP7 : collimation**
- **IP4: RF (+ crossing)**
- **IP5: standard optics (no more crossing)**
- **IP6: beam dump**
- **IP8: injection (+ crossing)**

Assumed layout:



- Solutions for the IPs available

Including high luminosity collisions:

- **High luminosity experiment**

  $\mathcal{L} \xrightarrow{\text{desired}} \mathbf{1.0 \cdot 10^{35}\ cm^{-2}\ s^{-1}}$

  needs low β^*, no more regular (FODO) lattice

- **Assumption: E = 3.3 TeV (other energies maybe difficult to operate together with injector, t.b.d.)**

- **With previously assumed layout: possible only in IP8**

Low β^* in IP 8

- **Implies: injection together with low β !**
- **Constraints on phases and geometry in the IR !**
- **Likely to limit minimum $\beta^* \geq$ 0.4 m (optimistic)**
- **Beam parameters (assume HL-LHC values):**

  N_b = **2.2** $\cdot$ **10**^{11}**,** ϵ_n **= 2.5** μ**m**

- **Maximum** $\mathcal{L} \xrightarrow{\text{maximum}}$ **0.4** $\cdot$ **10**^{35} **cm**$^{-2}$ **s**$^{-1}$

Fortunately ...

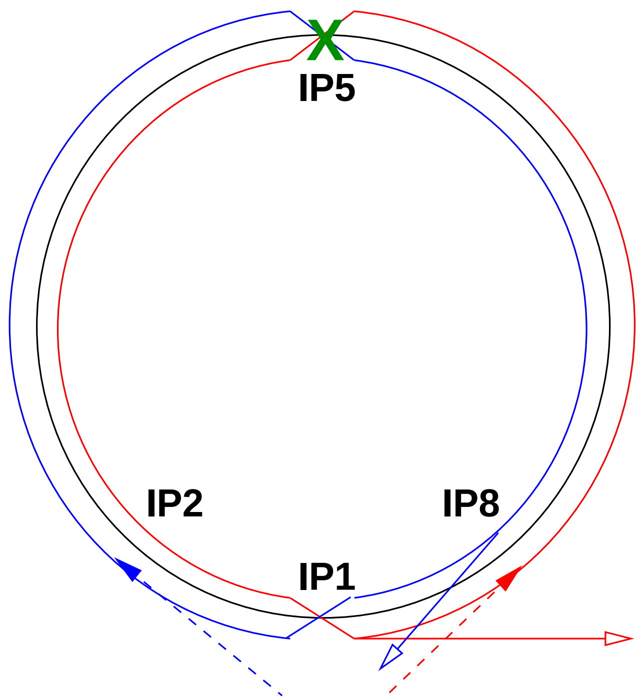
- **Proposed geometry for FCC-hh requires also extraction (at least one beam) in IP8**
- **Would imply: low β, crab crossing, injection, extraction in IP8 !**
- **Very impractical (aka impossible)**

➤ **Revised crossing scheme**

Modified layout

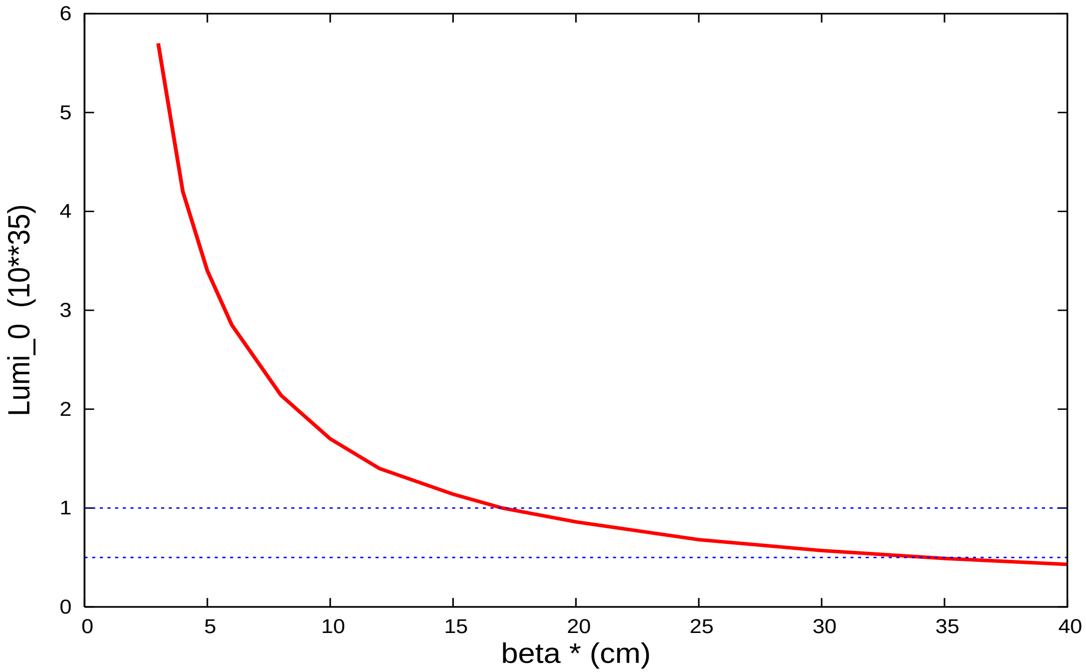
- IPs 3, 4, 6, 7 not changed
- No crossing in IP8: injection and extraction !
- No crossing in IP2: injection
- Crossing in IP1 (together with 1 extraction)
- Crossing and low β experiment in IP5 (easier, nothing else)

Layout of LHC



(non-intersecting version)

Luminosity performance - required β^*



- **Assumptions E=3.3 TeV,** $N_b = \mathbf{2.2 \cdot 10^{11}}$**,** $\epsilon_n = \mathbf{2.5}\ \mu\mathbf{m}$
- **For** $\mathcal{L} \approx 0.5\ 10^{35}$**:** $\beta^* \approx$ **0.40 m (conservative, achieved)**
- **For** $\mathcal{L} \geq 1.0\ 10^{35}$**:** $\beta^* \leq$ **0.18 m (<u>in theory !</u>)**

Reminder:

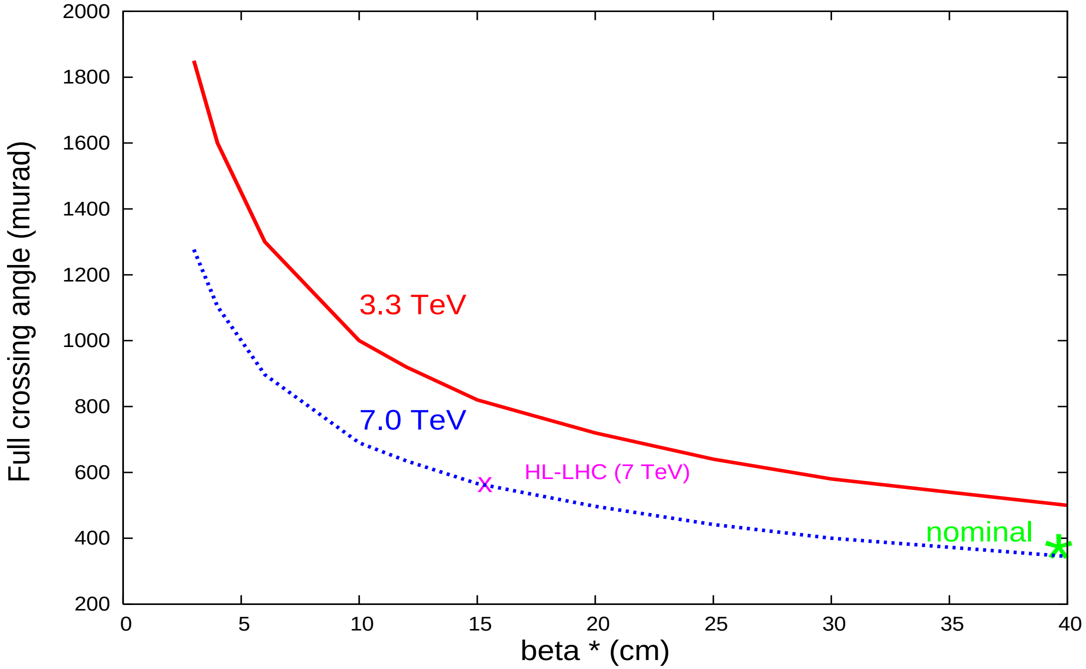
Long range beam-beam requires crossing angle α

normalized separation in drift space (for small enough β^***):**

$$d_{sep} = \alpha \cdot \frac{\sqrt{\beta^* \cdot \gamma}}{\sqrt{\epsilon_n}}$$

- ➡ **typically requires:** $d_{sep} \approx$ **12** σ **(LHC, HL-LHC, 4 IPs)**
- ➡ **low** β^* **requires larger crossing angle** α
- ➡ **lower energy** γ **a disadvantage**

Possible parameters - (full) crossing angle



- **Required crossing angle for 12 σ separation:**

β^* **=0.40 m** ➡ $\alpha \approx$ **500 μrad**

β^* **=0.15 m** ➡ $\alpha \approx$ **860 μrad**

Reminder:

Crossing angle reduces the luminosity:

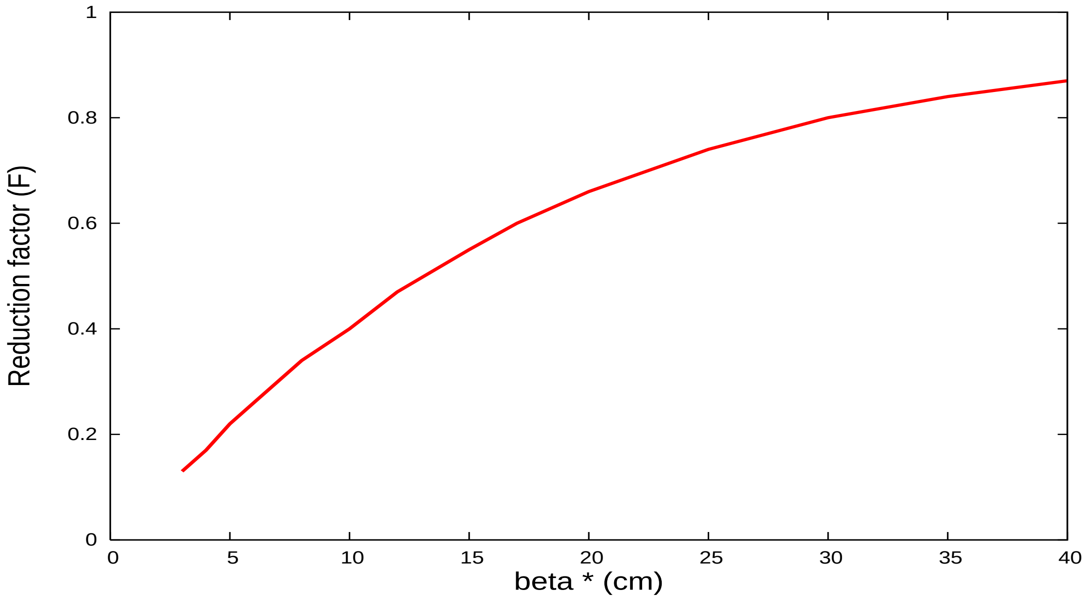
$$L/L_0 \;=\; F \;=\; 1/\sqrt{1 \;+\; \left(\frac{\alpha \cdot \sigma_z}{2\sigma^*}\right)^2}$$

➡ **assume round beams (σ^* in crossing plane)**

➡ σ_z **r.m.s. bunch length**

➡ **large angle, long bunches and small β^* reduce luminosity (so does small ϵ)**

Possible parameters



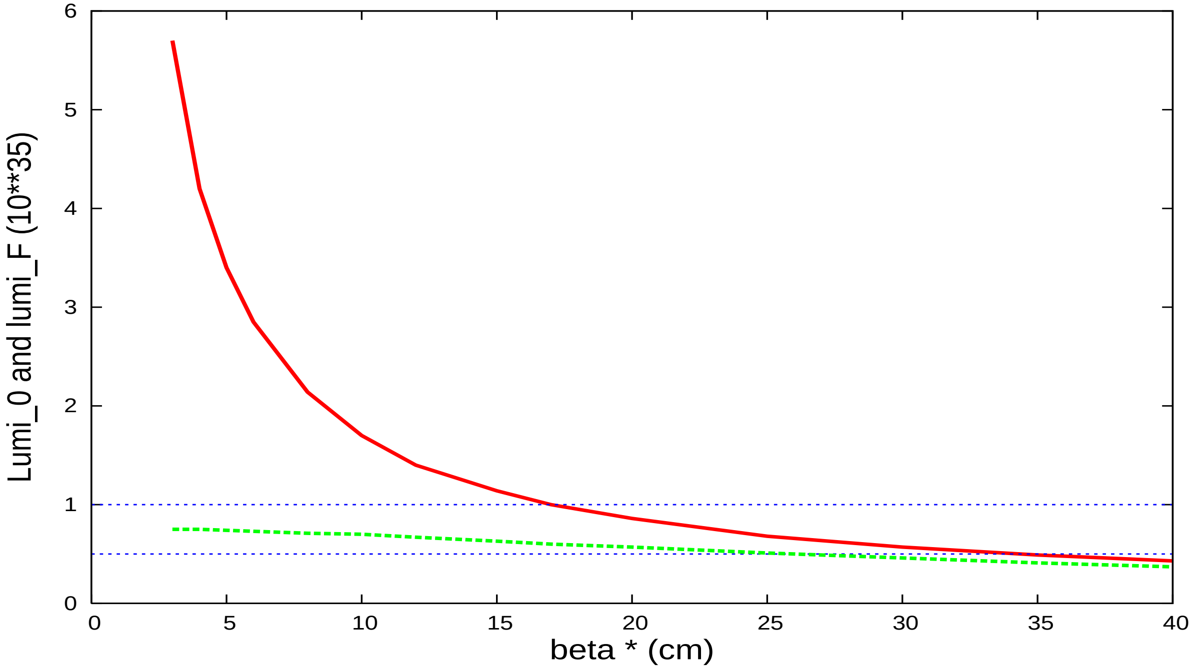
- **Reduction factor due to crossing angle**

  $\beta^* = \mathbf{0.40\ m}$: $L/L_0 = \mathbf{0.88}$

  $\beta^* = \mathbf{0.15\ m}$: $L/L_0 = \mathbf{0.53}$ **!**

➡ **Requires crab crossing scheme (not yet demonstrated)**

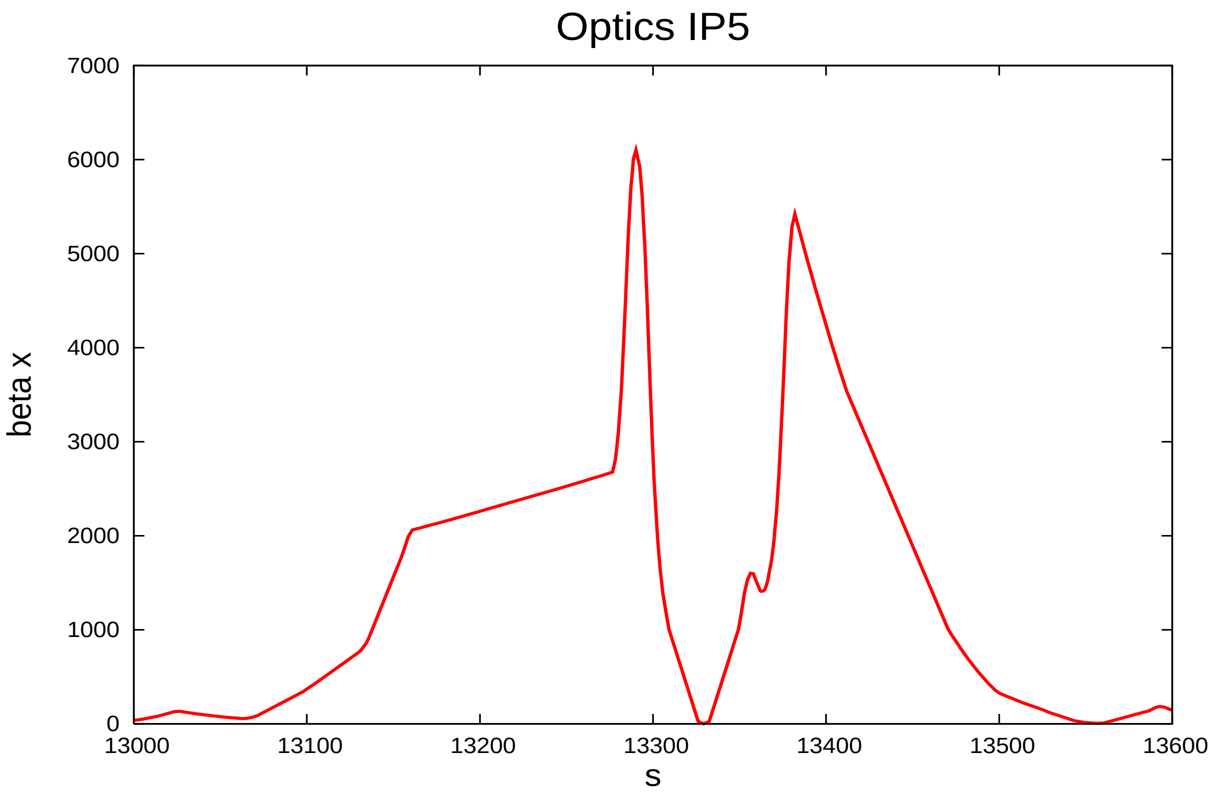
with/without crab crossing schemes



- Luminosity with and without reduction factor
- Below β^* $\approx$ 0.3 m, practically no gain

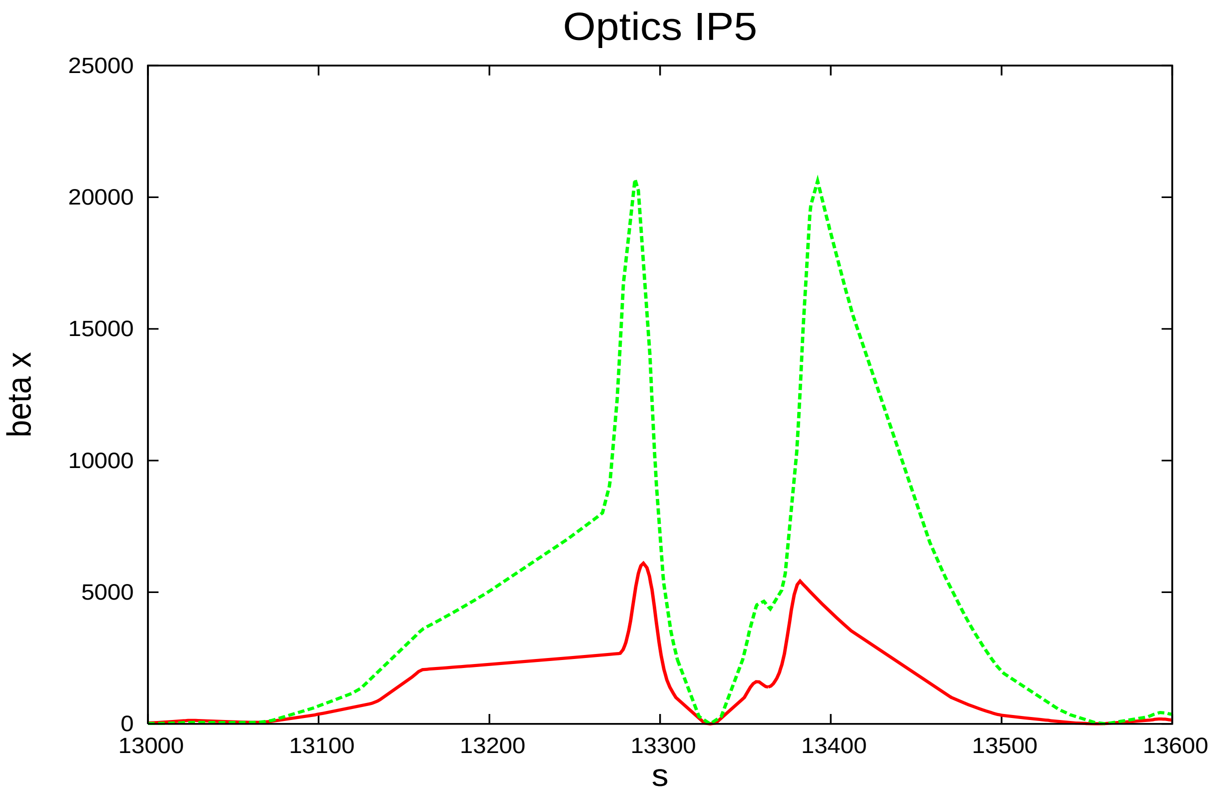
➡ Crab crossing required for $\mathcal{L} \geq 1.0 \cdot 10^{35}$ cm^{-2} s^{-1})

Conservative low β optics in IR5



- Standard L^*, round beams
- Crossing in IP5, $\beta^* = 0.40$ m, $\hat{\beta} \approx 6$ km

Low β optics in IR5



- **Comparison:** $\beta^* = 0.15$ **m versus** $\beta^* = 0.40$ **m**
- **Crossing in IP5,** $\beta^* = 0.15$ **m,** $\hat{\beta} \approx 20$ **km**

Crossing schemes - options

Vertical or horizontal ?

- **Vertical:**

  Some residual dispersion

  Rather flexible (sign and size)

- **Horizontal:**

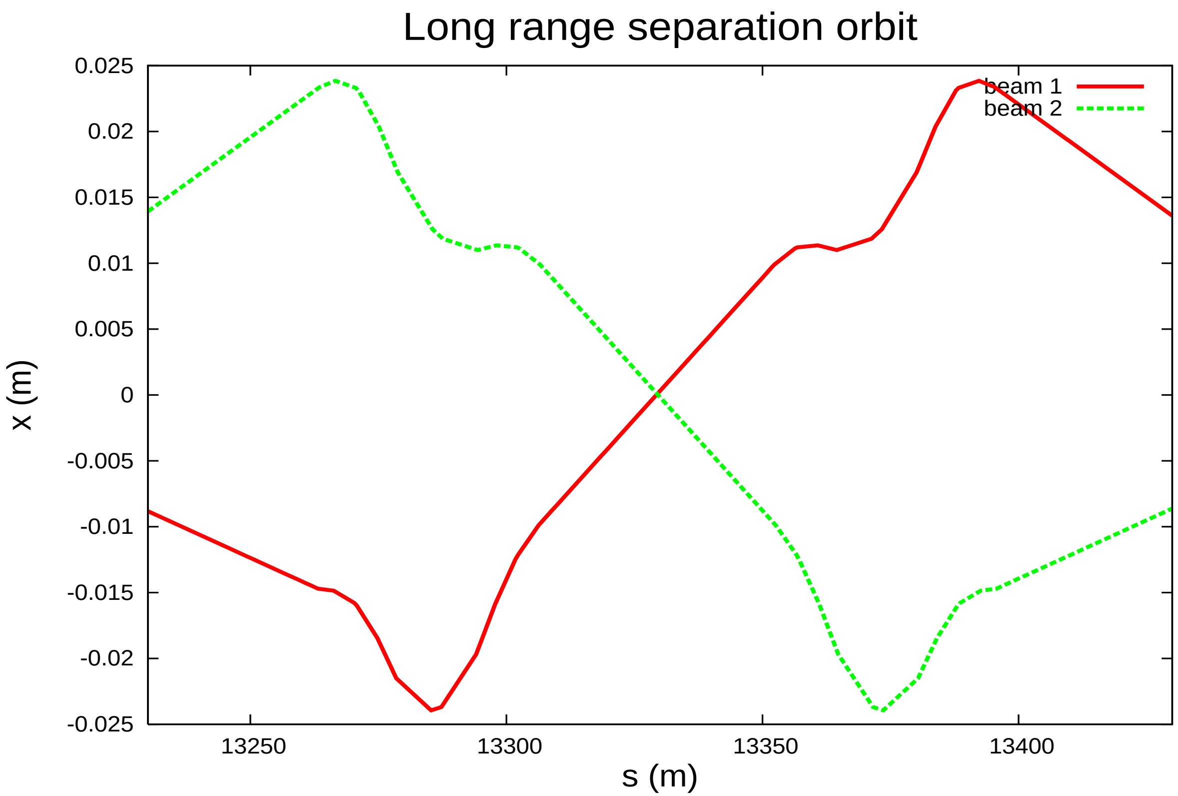
  No dispersion in vertical plane (is it important ?)

  Less flexible (sign fixed)

- **Still need crab crossing (not yet proven to work)**

- **Other options ?**

Low β orbit in IP5



- **Standard crossing angle, IP5, $\beta^* = 0.15$ m, $d_{sep} = 12\ \sigma$**
- **Requires: $\alpha \approx\ \pm$ 430 μrad**

Reduced L^*

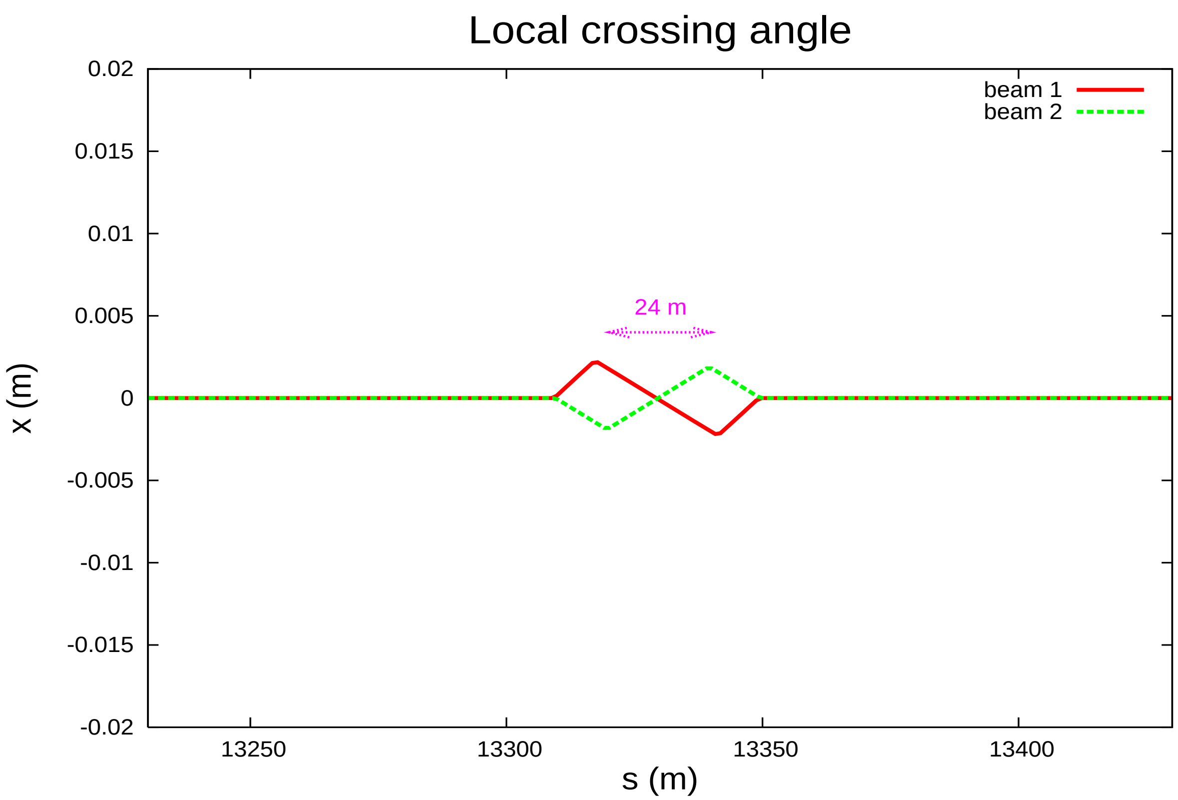
- **Effect of a smaller L^***
  - **Can be used to reduce $\hat{\beta}$**
  - **Or modified crossing scheme:**

➡ **Make an additional, local crossing angle**

  - **Would require dipole magnets in drift space (like LHCb)**
  - **With correct (bad) sign: "effective" crossing angle smaller**

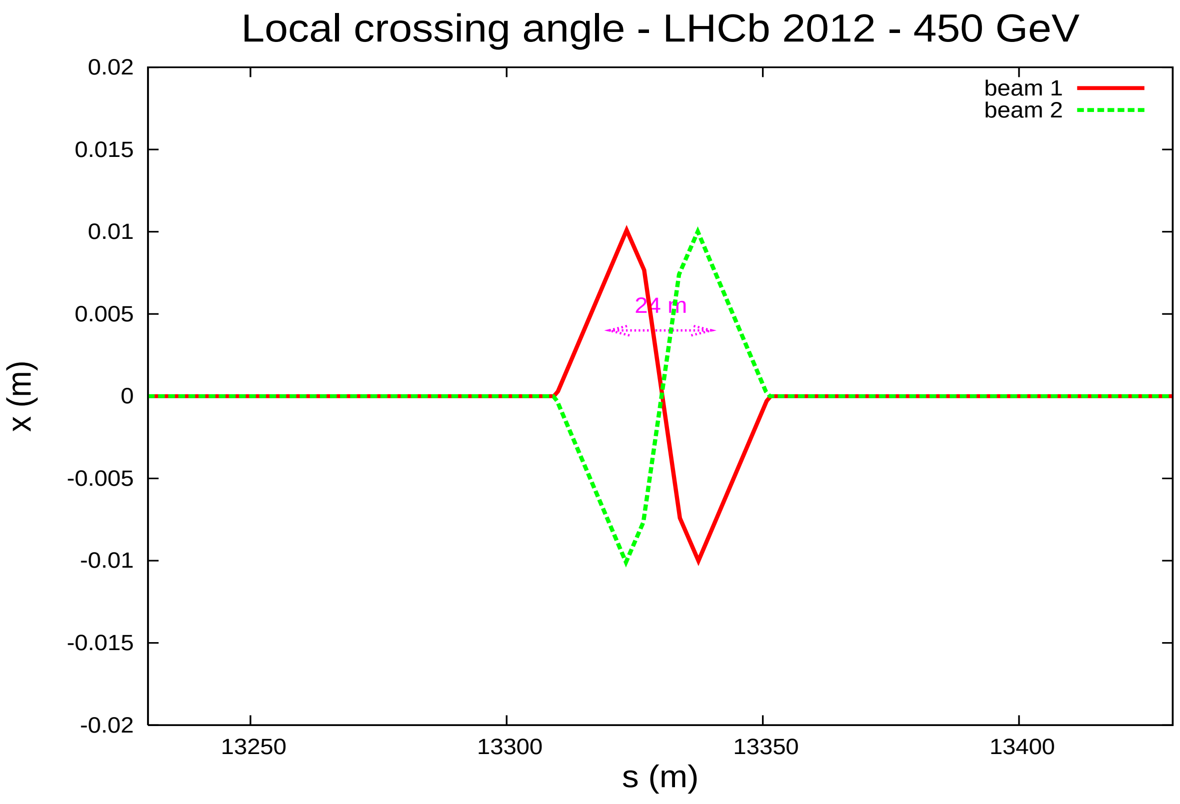
➡ **Reduced geometric loss factor**

Low β orbit in IP5



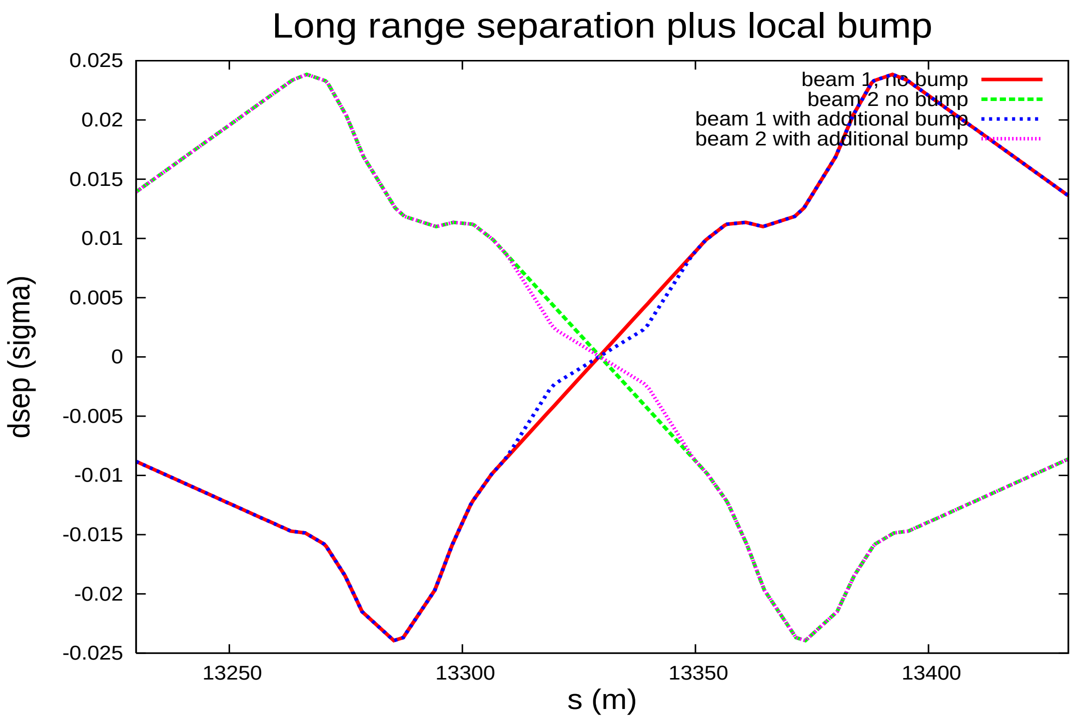
- **Closed (short) bump around IP5**
- $L^* = \pm$ **24 m,** $L^*_{exp} = \pm$ **12 m**

Reminder: spectrometer bump in LHCb



- **Compensator bump at injection energy**

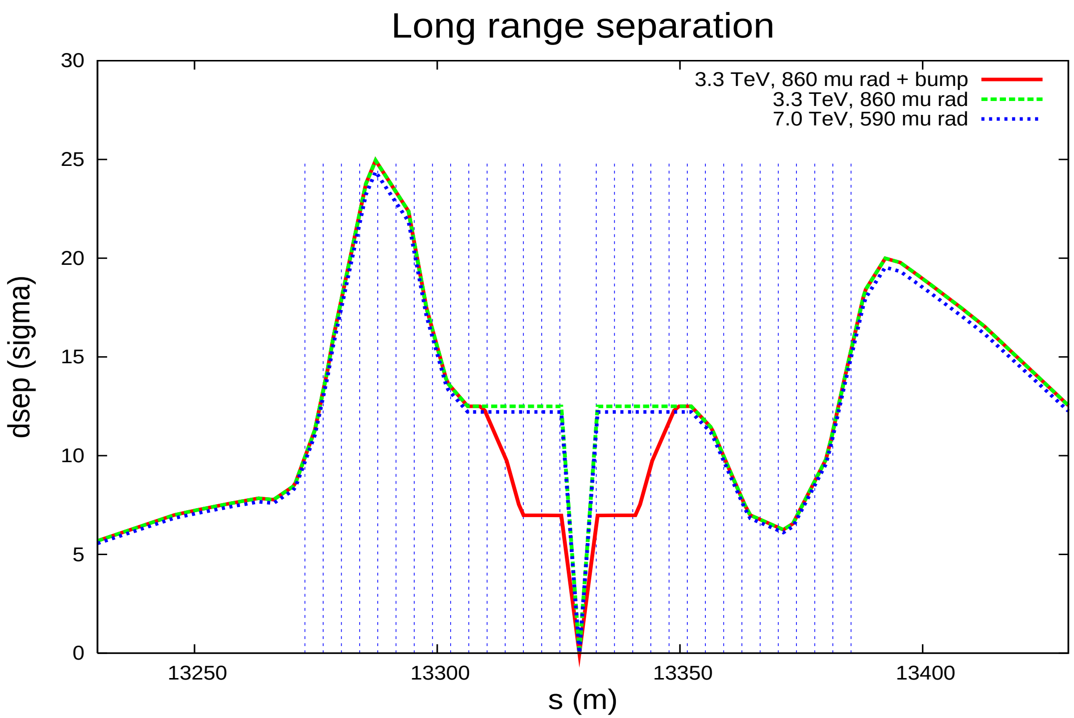
Low β orbit in IP5



- **Standard crossing angle plus bump, IP5**

➡ **decreased separation near IP, smaller "effective" angle**

Separation in IP5



- decreased separation near IP, smaller "effective" angle
- geometric loss much reduced ($\pm$ 240 μrad, $\approx$ 40% more)

Beam-beam effects

- **Assume HL-LHC parameters**
- **Beam-beam parameter: $\xi \approx$ 0.01 (achieved with more than one IP)**
- **Single IP, i.e. no compensation with alternating crossing, expect stronger PACMAN effects**
- **Overall long range effects smaller**
- **With bump: 6 of 30 LR encounters with 7 - 10 σ, all others at 12 σ**

Options (comparison with HL-LHC)

Possible luminosity performance:

E (TeV)	β^*	α (μrad)	L_0	L	L/L_0
7.0	0.15 m	$2\cdot$ 295	$2.4\cdot 10^{35}$	$1.3\cdot 10^{35}$	0.539
3.3	0.15 m	$2\cdot$ 430	$1.14\cdot 10^{35}$	$0.61\cdot 10^{35}$	0.539
3.3	0.15 m	$2\cdot$ (430 - 190)	$1.14\cdot 10^{35}$	$0.86\cdot 10^{35}$	0.755

- **Assumptions:**

  Single low β insertion

  $2.2\cdot 10^{35}$ per bunch, bunch spacing 25 ns

  ϵ = **2.5** μ**m**

  Round beams ($\beta^*_x = \beta^*_y$)

To sum up

Options:

- **For** $\mathcal{L} \geq 1.0\ 10^{35}$**:** β^* $\approx$ **0.15 m + crab crossing**
- **For** $\mathcal{L} \geq 0.5\ 10^{35}$**:** β^* $\approx$ **0.40 m (achieved ..)**
- **Without crab crossing** $\mathcal{L} \geq 1.0\ 10^{35}$ **is out of reach (see HL-LHC)**
- **For** β^* = **0.15 m + bump:** $\mathcal{L}$ $\approx$ $0.8 - 0.9 \cdot 10^{35}$
- **Simplest option: larger intensity per bunch** (N_b = $\mathbf{2.4 \cdot 10^{11}}$)