Pushing the limits ..

(crossing angle, aperture, β^*, ...)

W. Herr

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W. Herr

What (where) are the limits ?

(treated in this presentation ...)

- Mechanical aperture (β^*, crossing angle ...)
- Dynamic aperture (β^*, crossing angle ...)
- Considering:
  - → Head-on beam-beam
  - → Long range beam-beam
  - → With the target high luminosity

What (where) are the limits ?

We have for the luminosity (without correction factors):

$$\mathcal{L} \approx \frac{N_1 N_2 f n_b}{4\pi\sigma_x\sigma_y} \approx \frac{N^2 f n_b \gamma}{4\pi\epsilon_n\beta^*}$$

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$$\mathcal{L} \approx \frac{N_1 N_2 f n_b}{4\pi\sigma_x\sigma_y} \approx \frac{N^2 f n_b \gamma}{4\pi\epsilon_n\beta^*}$$

What is affected ?

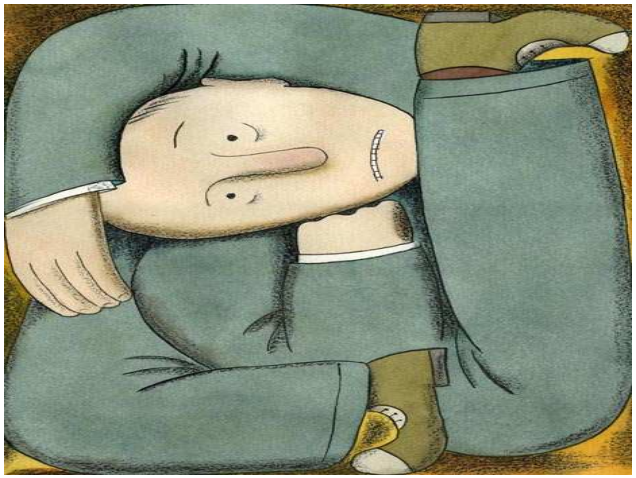
- γ → **beam size (aperture, separation)**
- β^* → **beam size (aperture, separation, long range beam-beam effect)**
- ϵ_n → **beam size (aperture, separation, beam-beam effect)**
- $N_1 N_2$ → **beam-beam effect, tune shift**
- $f n_b$ → **filling schemes, required crossing angle α, beam-beam effect**

What is desirable ?

	$\mathcal{L}$	beam-beam	aperture
β^*	small	large	large
ϵ_n	small	small/large	small
γ	large	large	large
α	small	large	small
n_b	large	small	large/small

- and flexible for the experiments (polarity, levelling ...)

Pushing the limits ..



(crossing angle, aperture, β^*, ...)

W. Herr

The known and the unknown

- Head-on beam-beam not yet a limit → keep intensity high and emittance small (see my talk in Evian)
- Should try to establish a limit early ..
- Long range not significant in 2010
- Long range plus head-on remains to be studied
- PACMAN effects significant, keep them small

Limiting factors

- β^*, determines the required crossing angle and available aperture
- Crossing angle, determines the separation:
  - Crossing angle in IP1/IP5
  - Crossing angle in IP2/IP8 (with spectrometers)
  - Polarity of spectrometer magnet in IP8
- Separation relevant for strength of long range beam-beam effects

What should be the beam-beam separation ?

- **Not much experience with significant long range effects**
- **More bunches and possibly smaller separation (for smaller β^*)**
- **Should stay on the safe side**
- **Key parameter for head-on and long range:**

  small emittance ϵ_n

What is safe ?

- No significant problem with 12σ separation between beams
- For more bunches we have larger number of encounters
- Assume that 12σ separation is comfortable

→ Defines the parameter space

Reminder: beam separation and tune shift

- **Normalized beam separation:**

$$d_{sep} = \sqrt{\frac{\alpha^2 \cdot \beta^* \cdot \gamma}{\epsilon_n}}$$

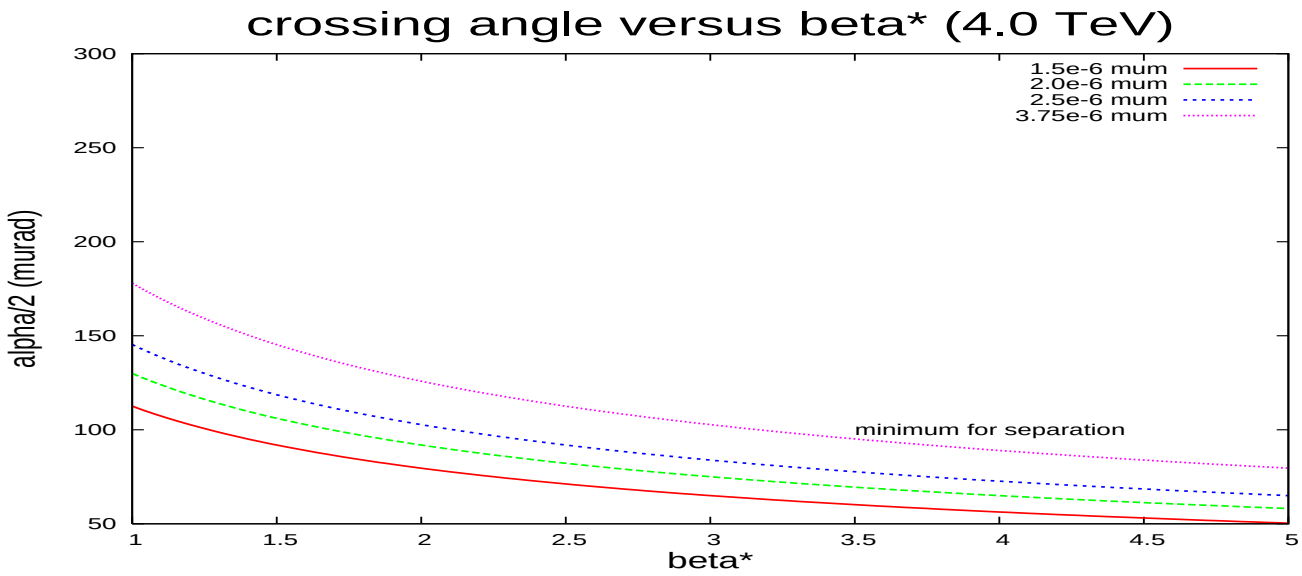
- **Long range tune shift:**

$$\Delta Q_{lr} \propto \frac{N}{d_{sep}^2} = \frac{N \cdot \epsilon_n}{\alpha^2 \cdot \beta^* \cdot \gamma}$$

Issues IP1/IP5

- **Given the required separation, bunch spacing and aperture:**
  - **Maximum crossing angle**
  - **Minimum β^***
  - **Sign of crossing angle only important for IP5 (unless physics requirements prefer a sign in IP1)**
- **Define scenario which works for 75 ns and 50 ns spacing**

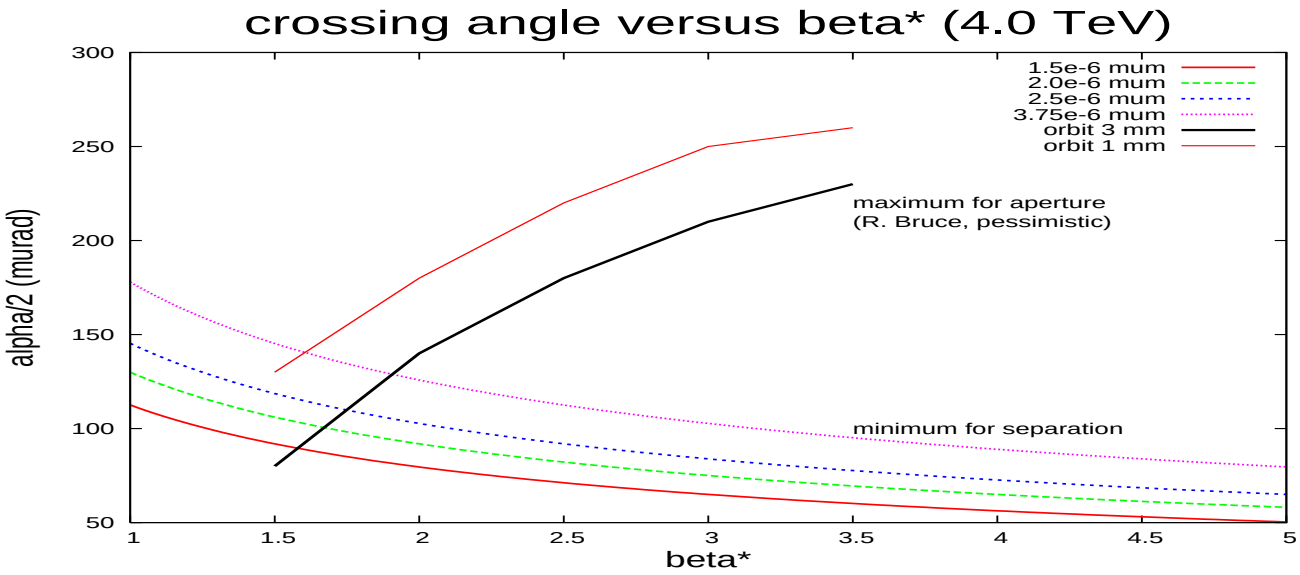
Required crossing angle - 12 sigma



➡ **Choice depends on emittance**

$$\alpha = \sqrt{\frac{d_{sep}^2 \cdot \epsilon_n}{\beta^* \cdot \gamma}} \qquad d_{sep} = 12$$

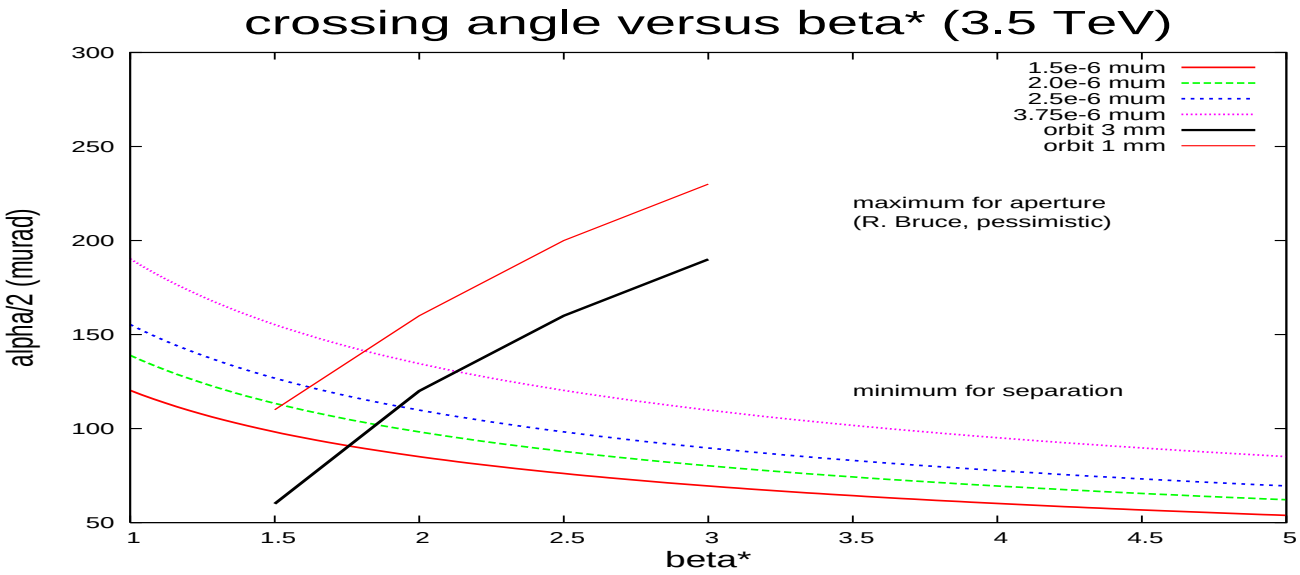
Required crossing angle - 12 sigma



- **Choice depends on emittance**
- **E = 4.0 TeV**

$$\alpha = \sqrt{\frac{d_{sep}^2 \cdot \epsilon_n}{\beta^* \cdot \gamma}} \qquad d_{sep} = 12$$

Required crossing angle - 12 sigma



- **Choice depends on emittance**
- **E = 3.5 TeV**

$$\alpha = \sqrt{\frac{d_{sep}^2 \cdot \epsilon_n}{\beta^* \cdot \gamma}} \qquad d_{sep} = 12$$

Recommendations/proposal IP1/5

ϵ_n **Energy**	β^* **(3.5 TeV)**	β^* **(4.0 TeV)**	α **(3.5 TeV)**	α **(4.0 TeV)**
1.5 μm	**1.4 m**	**1.4 m**	**$\pm$ 120 μrad**	**$\pm$ 120 μrad**
2.0 μm	**1.5 m**	**1.4 m**	**$\pm$ 120 μrad**	**$\pm$ 120 μrad**
2.5 μm	**1.6 m**	**1.5 m**	**$\pm$ 120 μrad**	**$\pm$ 120 μrad**
3.75 μm	**1.8 m**	**1.6 m**	**$\pm$ 140 μrad**	**$\pm$ 140 μrad**

- **O.K. for 50 ns and 75 ns**

Recommendations/proposal IP1/5

- **From necessary separation and available aperture:**
  - **Assuming $\epsilon_n \leq$ 2.5 μm**
  - **$\beta^* =$ 1.6 m, half crossing angle 120 μrad (140 μrad ?)**
  - **O.K. for 3.5 TeV, 4.0 TeV and 50/75 ns spacing**
- **What about emittance growth during fill ?**
  - **We have some margin ..**
  - **Not caused by (present) long range**
  - **Optimized working point would help (tune scan !)**

Issues IP2

- **Assume $\beta^* = 10$m**
- **Beams separated to adjust luminosity**
- **Polarity change of spectrometer:**
  - **In vertical plane → external angle follows (i.e. changes sign)**
  - **Requires two setups for the external angle**
- **Relative sign between external angle and spectrometer angle ?**

Issues IP2

- **Assuming full field (?) → ± 140 μrad !**
- **For same sign (as in LHC Design Report):**
  - **External angle 80 μrad**
  - **Net angle increases → $\approx \pm$ 220 μrad**
- **For opposite sign (not desirable):**
  - **Must avoid additional crossings**
  - **External angle 220 μrad**
  - **Net angle decreases → $\approx \pm$ 80 μrad**

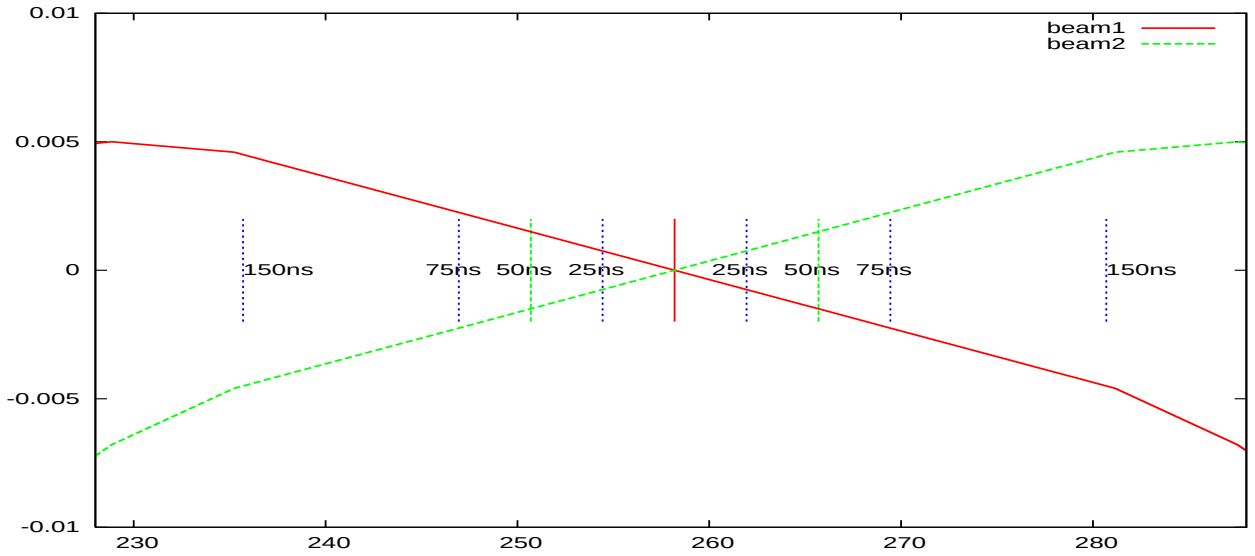
Issues IP8

- **Assumption: always full field in physics**
- **Given the required separation, bunch spacing and aperture:**
  - **What should be the spectrometer polarity and required crossing angle ?**
  - **Under which condition(s) can the spectrometer polarity be switched ?**
  - **Minimum β^* for polarity switch ?**
- **Luminosity levelling**
- **What about injection ?**

Crossing scheme in IP8

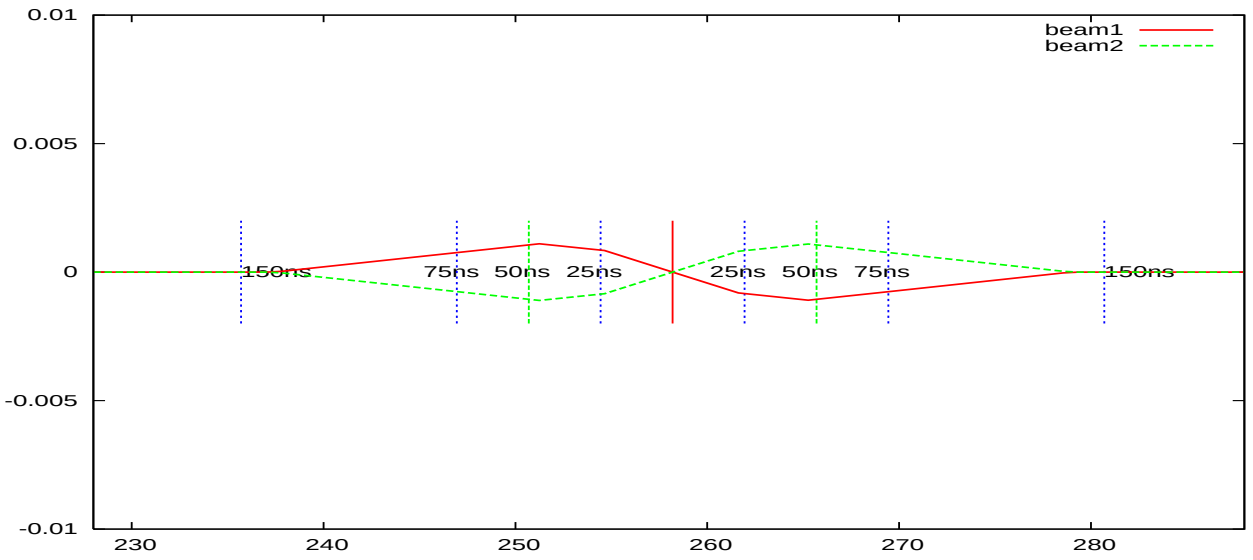
- **We said: we want 12 σ separation**
  - **Question: where ?**
  - **Answer: at the encounters !**
  - **In IP1/5 this is trivial - in IP8 it is not !**

REMINDER - LHCb



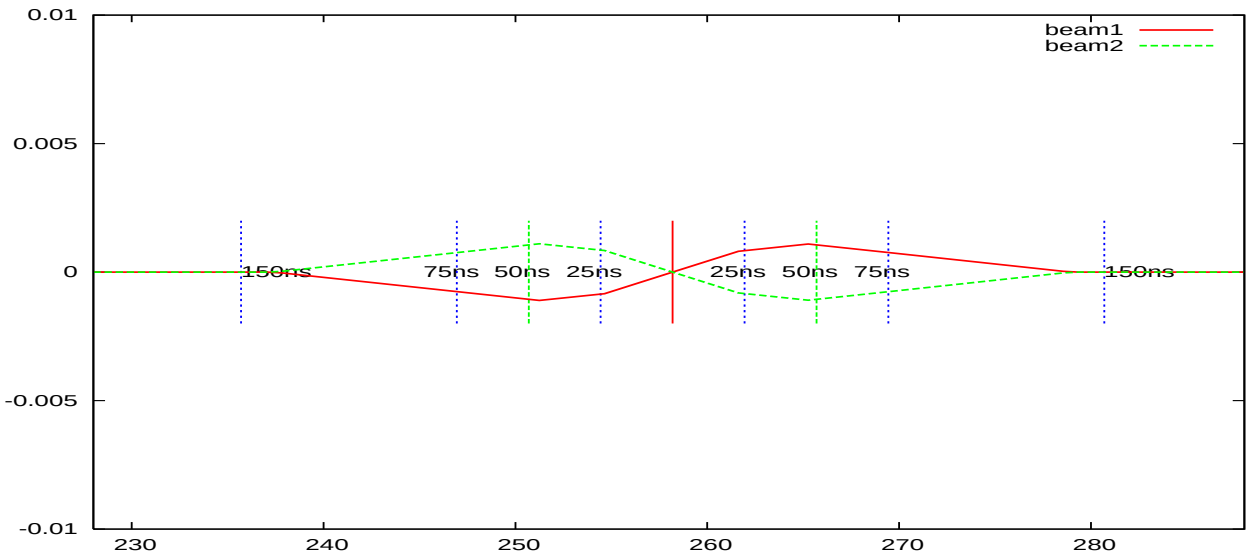
- **External crossing angle in IP8 (no spectrometer)**
- **Only one polarity possible (beam 1 angle negative) ...**
- **Only one setup required if angle large enough for both polarities**

LHCb



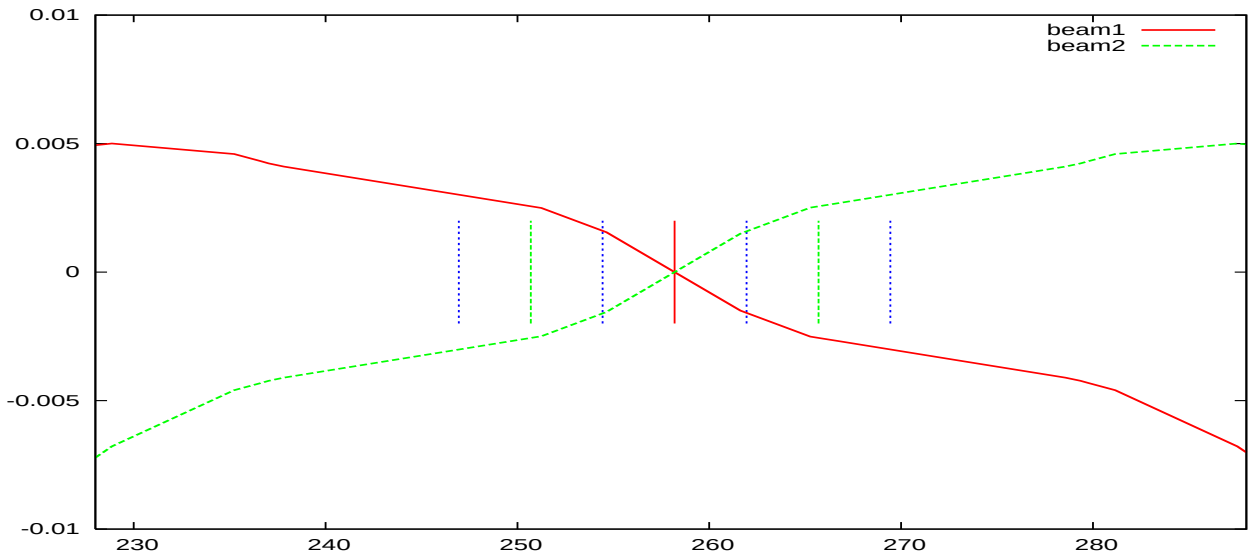
- **Crossing angle by spectrometer (no external angle)**
- **Spectrometer ”good” polarity (beam 1 angle negative)**
- **For 150 ns: outside bump, polarity has no effect**

LHCb



- **Crossing angle by spectrometer (no external angle)**
- **Spectrometer "bad" polarity (beam 1 angle positive)**
- **For 150 ns: outside bump, polarity has no effect**

LHCb



→ **Spectrometer (good polarity) plus external angle**

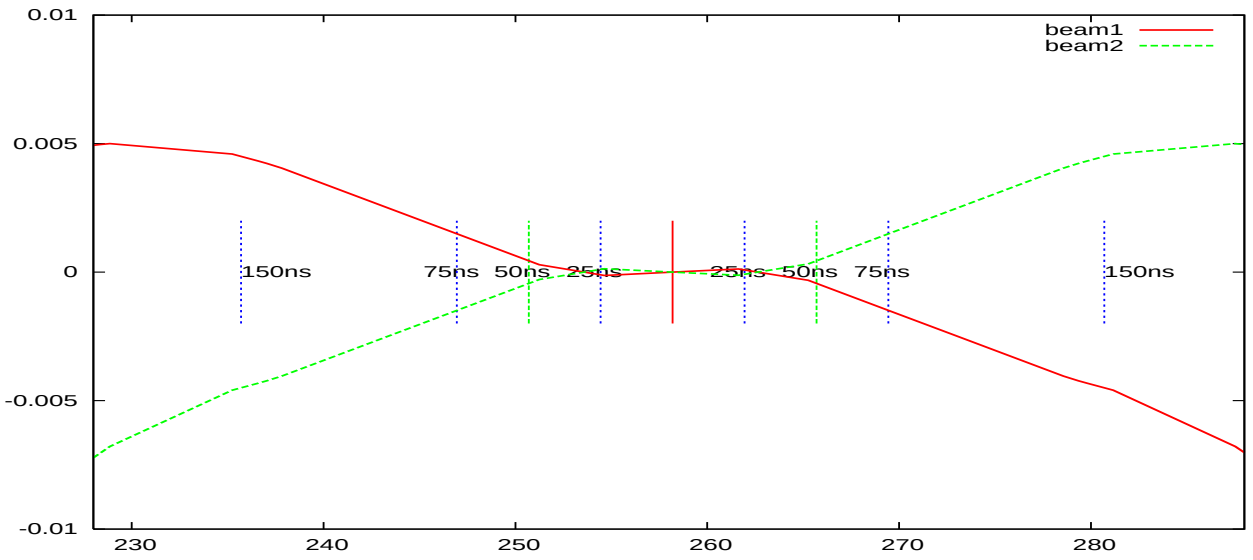
LHCb

- **For "good" polarity:**
  - **No interference with external angle (for any energy)**
  - **Works for any β^* (allowed by aperture)**
  - **Works for any bunch spacing**

LHCb

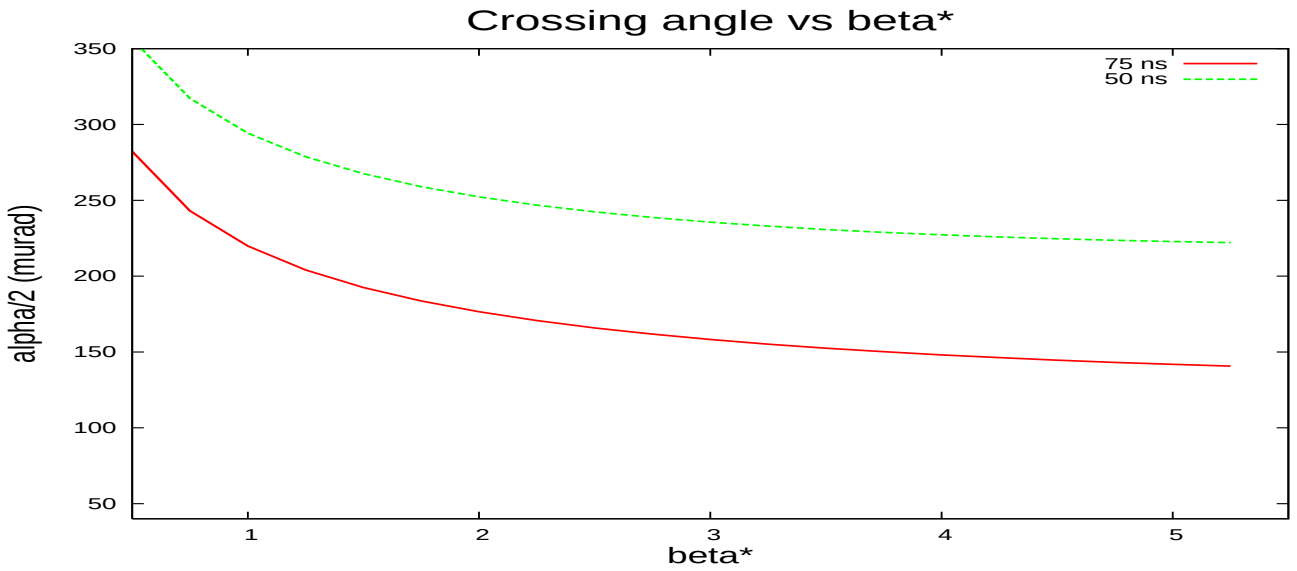
- **For "good" polarity:**
  - **No interference with external angle (for any energy)**
  - **Works for any β^* (allowed by aperture)**
  - **Works for any bunch spacing**

LHCb



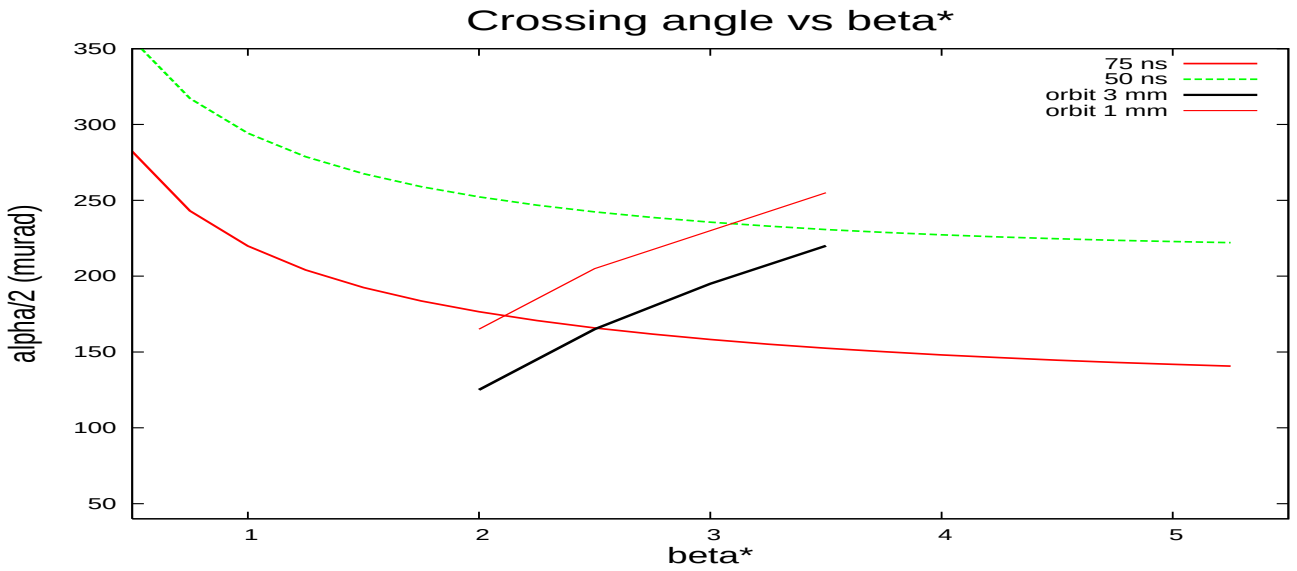
- **Spectrometer (bad polarity) plus external angle**
- **Spectrometer at full field for 3.5/4 TeV**
- **Encounter for 50 ns spacing strongly affected, o.k. for 75 ns**

Required crossing angle - 12 sigma



- **Require $\approx$ 12 σ separation at 50/75 ns encounter**
- **For emittance assume $\epsilon_n = 2$ μm**

Required crossing angle - 12 sigma



- **Require $\approx$ 12 σ separation at 50/75 ns encounter**
- **For emittance assume $\epsilon_n = 2$ μm**

Recommendations/proposal IP8

- **For good polarity:**
  - **No real restriction, o.k. for 50 ns and 75 ns**
- **For bad polarity (ϵ_n = 2 μm, = 2.50 μm, = 3.75 μm):**
  - **o.k. for 50 ns and β^* $\geq$ 3 (3.2) (3.6) m,**
    $\alpha = \mp$ 235 (250) (270) μrad
  - **o.k. for 75 ns and β^* $\geq$ 2 (2.2) (2.5) m,**
    $\alpha = \mp$ 160 (170) (210) μrad

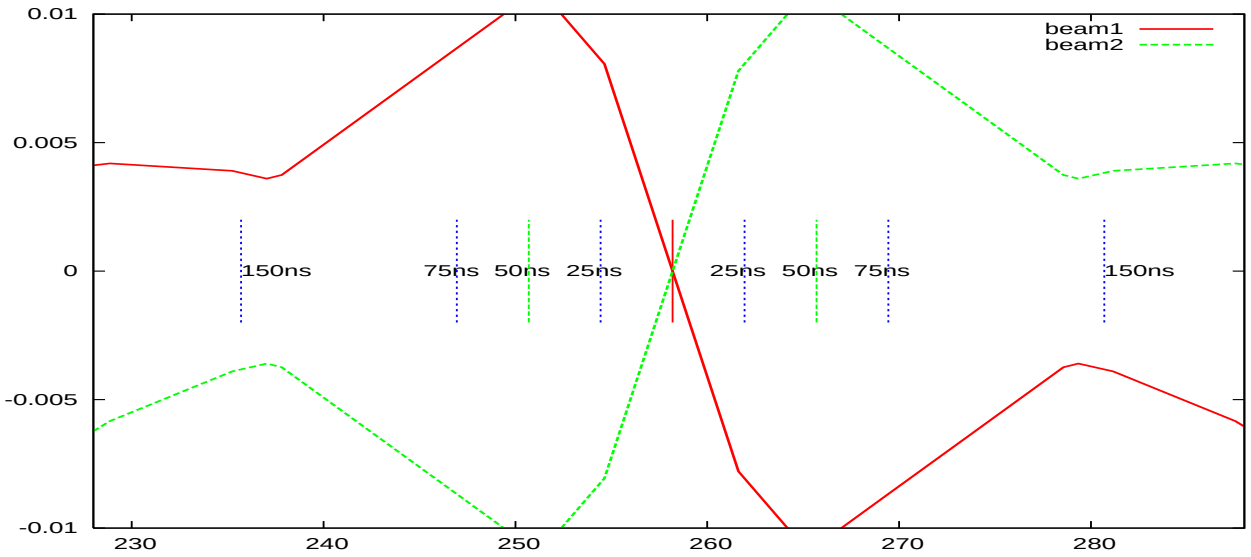
→ **With ϵ_n = 2.5 μm: β^* $\geq$ 3 m, $\alpha = \mp$ 250 μrad**

o.k. for 50 ns and 75 ns

What about injection ?

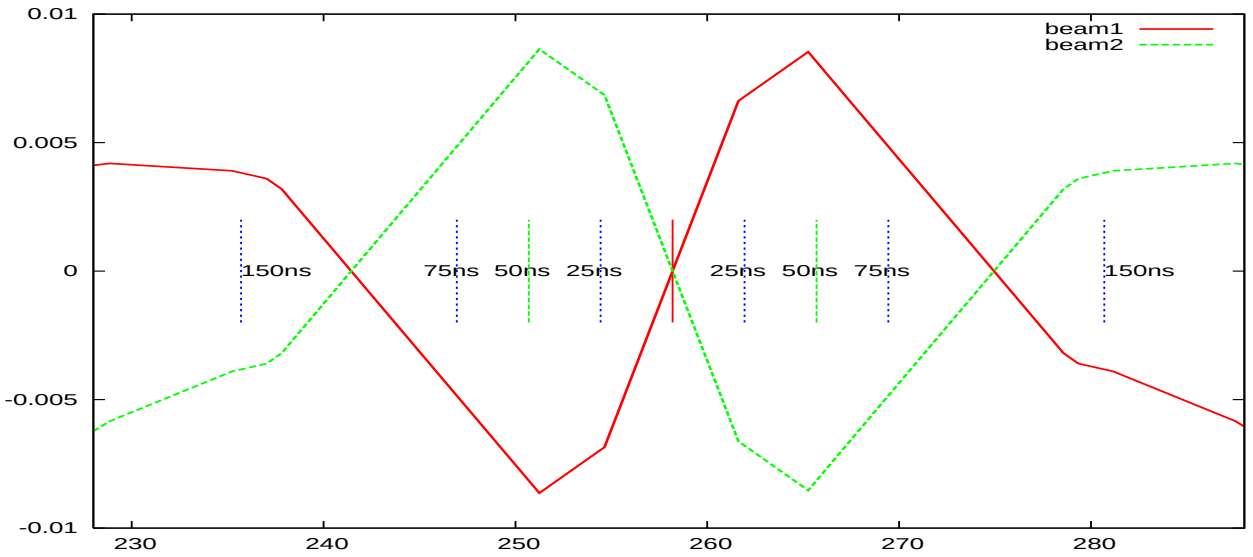
- **Standard crossing angle $\mp$ 170 μrad**
- **Standard separation bump $\pm$ 2 mm**
- **Polarity of spectrometer must be the same as in physics**
- **Can the spectrometer be at full value at injection energy ?**

REMINDER - LHCb



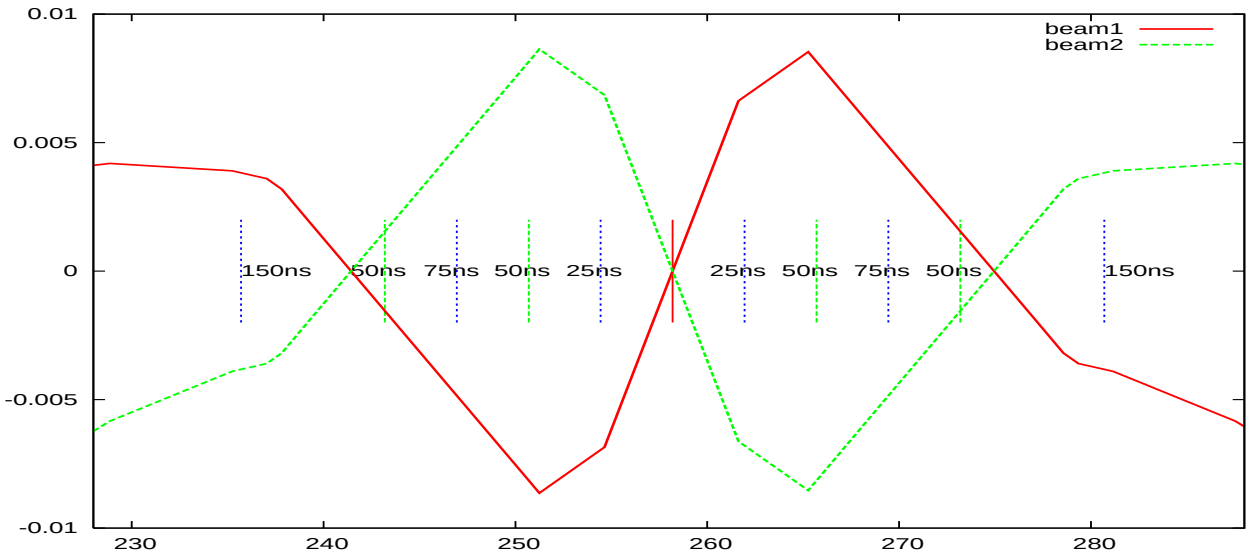
- **Full field, good polarity**

REMINDER - LHCb



- **Full field, bad polarity**
- **Looks like sufficient separation, but ...**

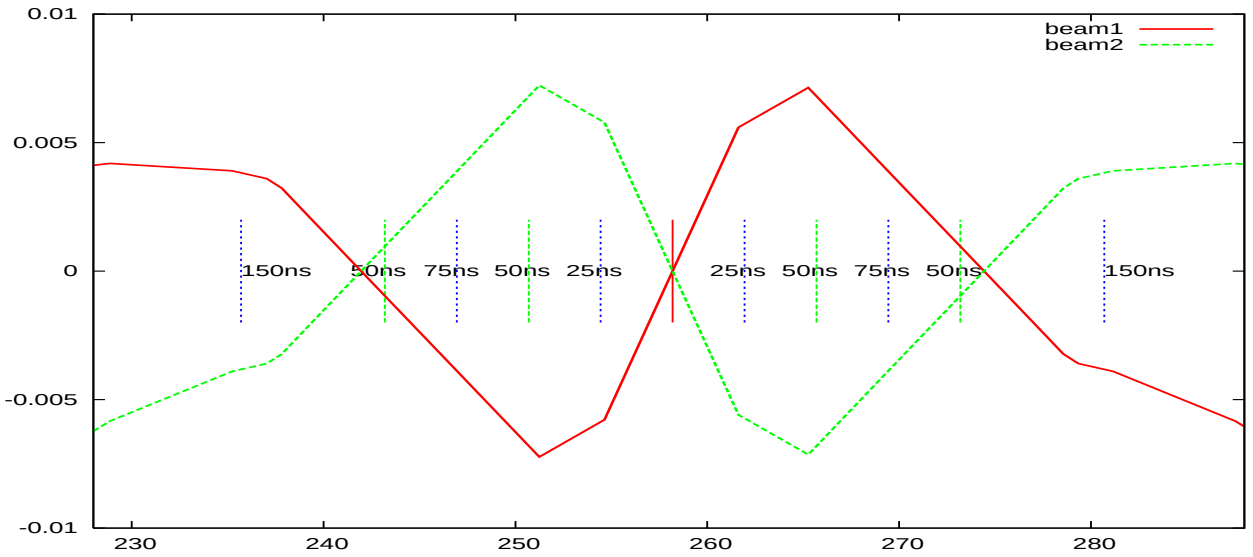
REMINDER - LHCb



External angle $\mp$ **170** μ**rad**

Spectrometer magnet at 100%

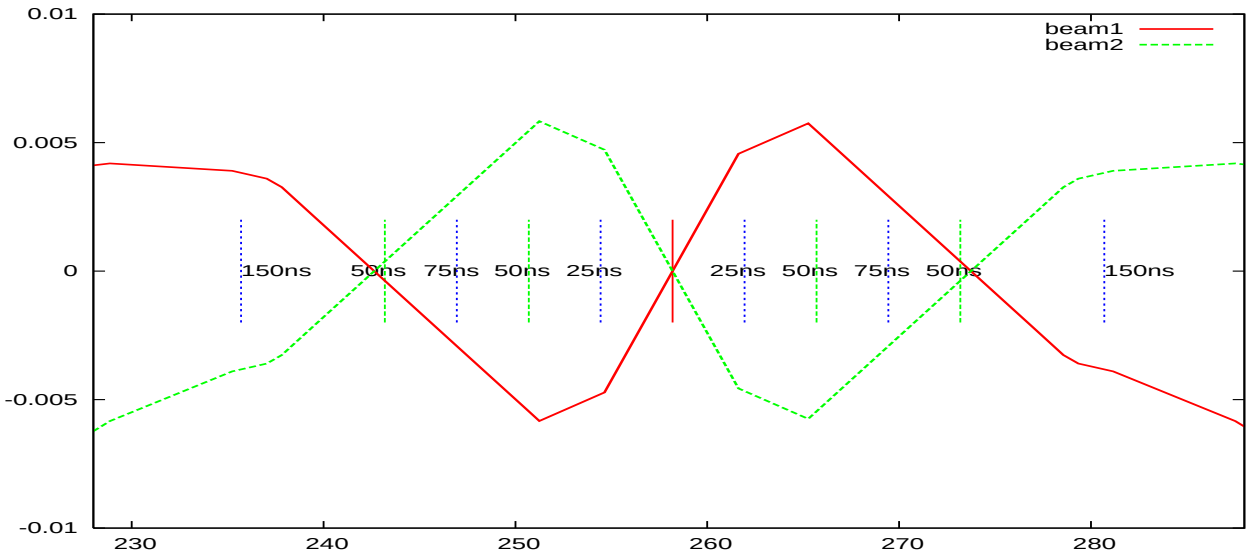
REMINDER - LHCb



External angle $\mp$ **170** μ**rad**

Spectrometer magnet at **86%**

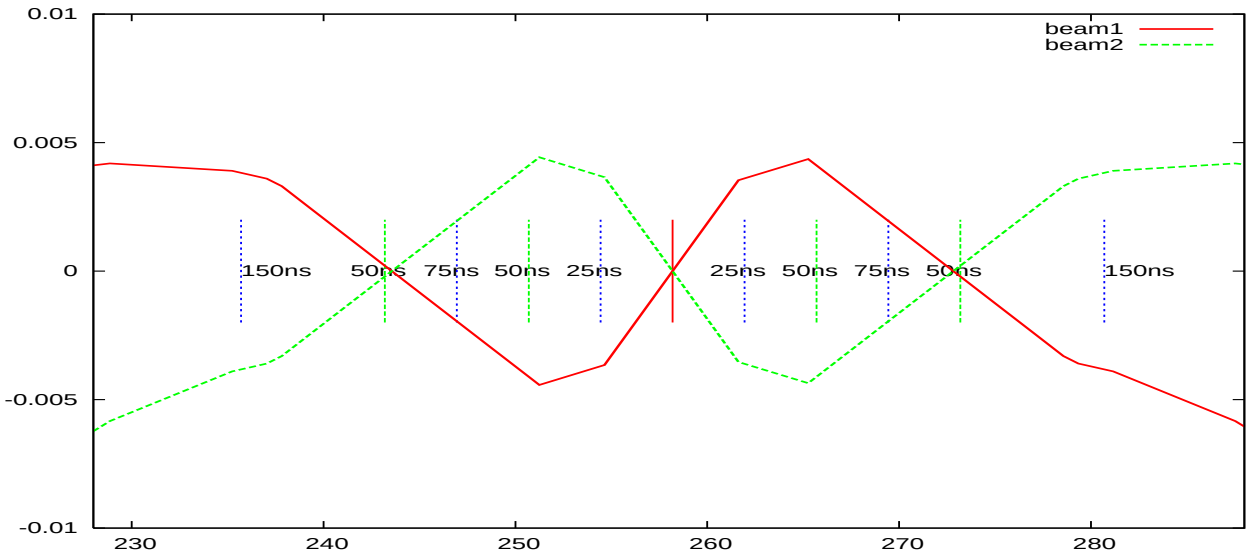
REMINDER - LHCb



External angle $\mp$ **170** μ**rad**

Spectrometer magnet at **71%**

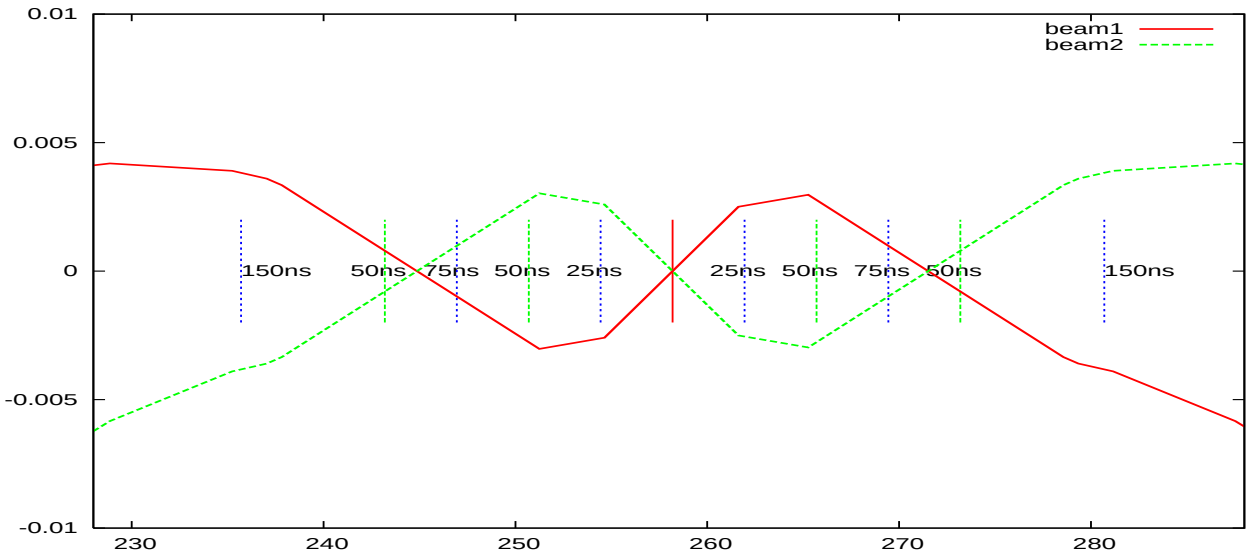
REMINDER - LHCb



External angle $\mp$ **170** μ**rad**

Spectrometer magnet at **57%**

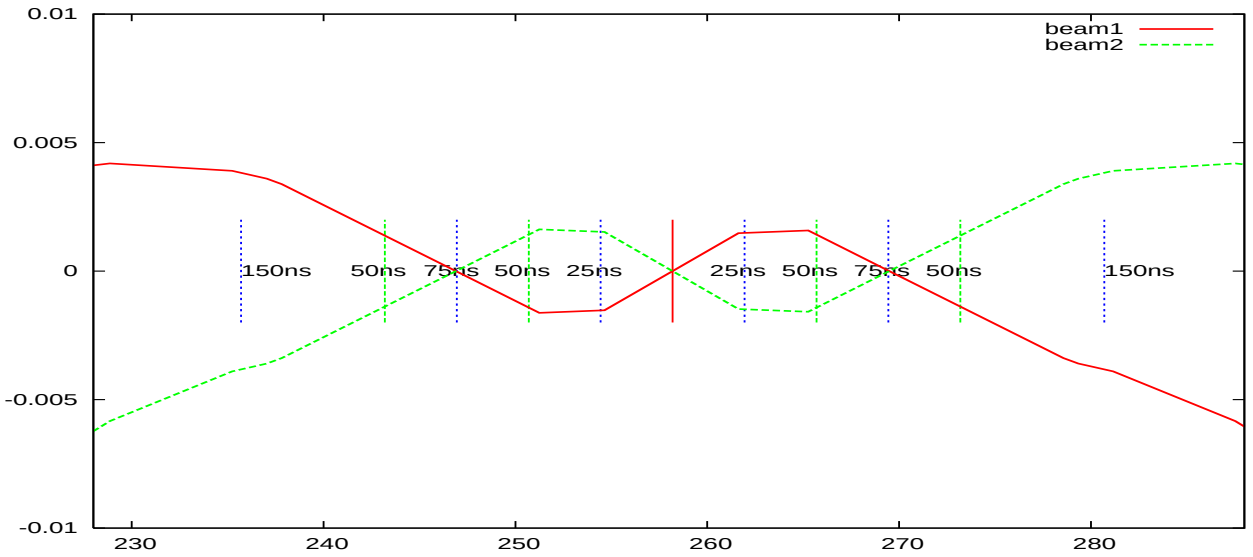
REMINDER - LHCb



External angle $\mp$ **170** μ**rad**

Spectrometer magnet at **43%**

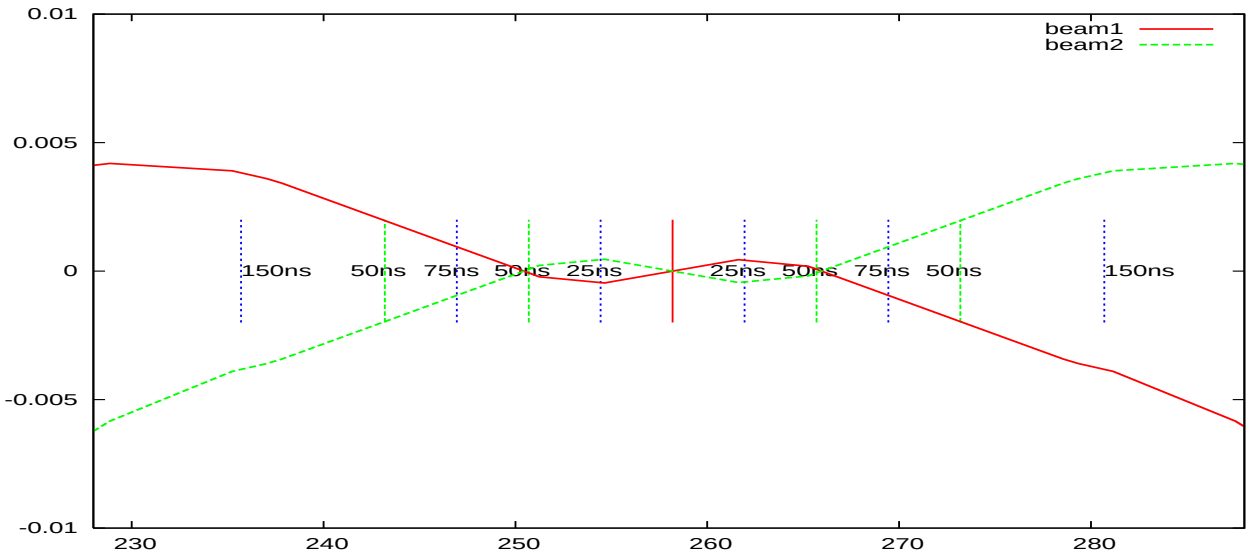
REMINDER - LHCb



External angle $\mp$ **170** μ**rad**

Spectrometer magnet at **28%**

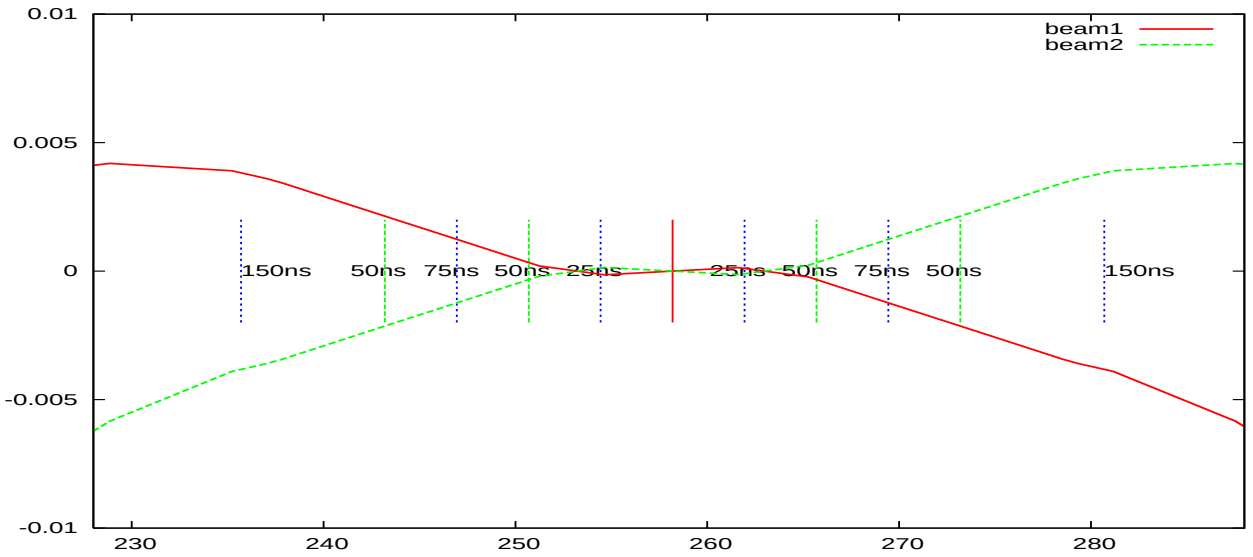
REMINDER - LHCb



External angle $\mp$ **170** μ**rad**

Spectrometer magnet at **14%**

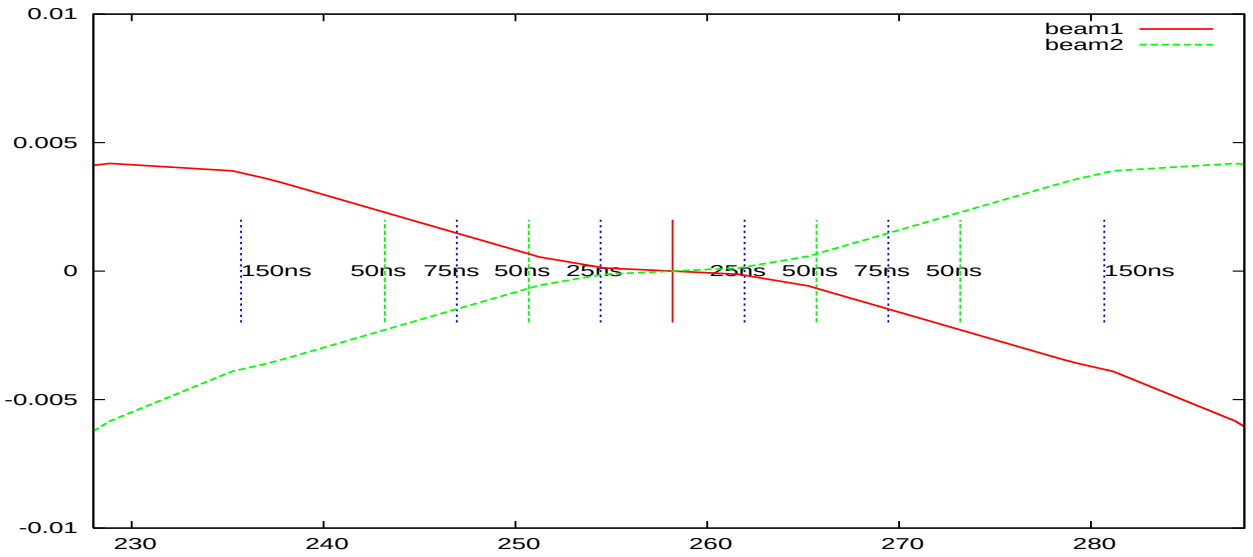
REMINDER - LHCb



External angle $\mp$ **170** μ**rad**

Spectrometer magnet at 10%

REMINDER - LHCb



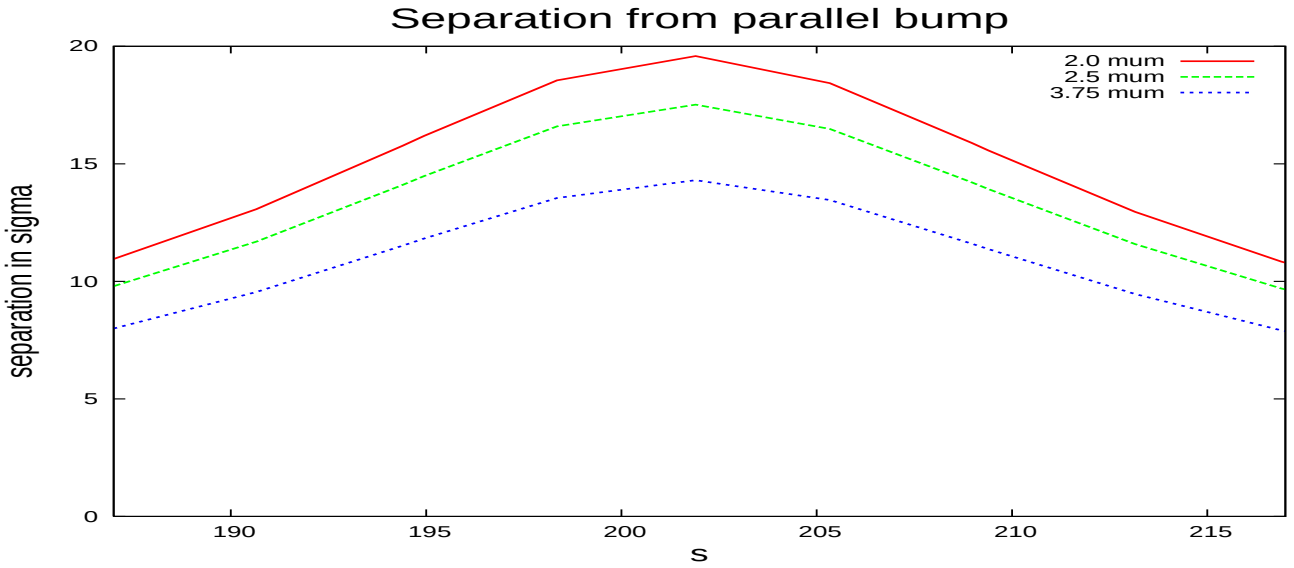
External angle $\mp$ **170** μ**rad**

Spectrometer magnet at **6.5%**

What about injection ?

- **To separate at all encounter at all times:**
  - **External angle very large (not possible)**
  - **Spectrometer at lower field ($\approx$ 10% nominal)**
  - **Parallel separation large enough for additional encounters ? (Remember: parallel separation originally to separate central collision)**

Separation from parallel bump



- **Separation from parallel bump only**
- **Parallel separation large enough (for small emittances, i.e. $\leq$ 2 - 2.5 μm)**
- **Could run with full field at injection**

Summary I

- **Small emittance important for overall performance:**
  - **Allows lower β^* with moderate crossing angle**
  - **Allows more flexibility for LHCb spectrometer**
  - **Allows full field (at all times and configurations) for LHCb spectrometer**
  - **Personal recommendation: rather give up on higher intensity and not on small emittance**

Summary II

- Should find the head-on beam-beam limit early, will tell us the good parameter range
  - Good working point needs to be established (tune scan)
  - Might change with significant long range contributions
- Luminosity levelling in LHCb must be tested