LHCb External V Crossing Angle

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B. Holzer, and the LHCb dipole

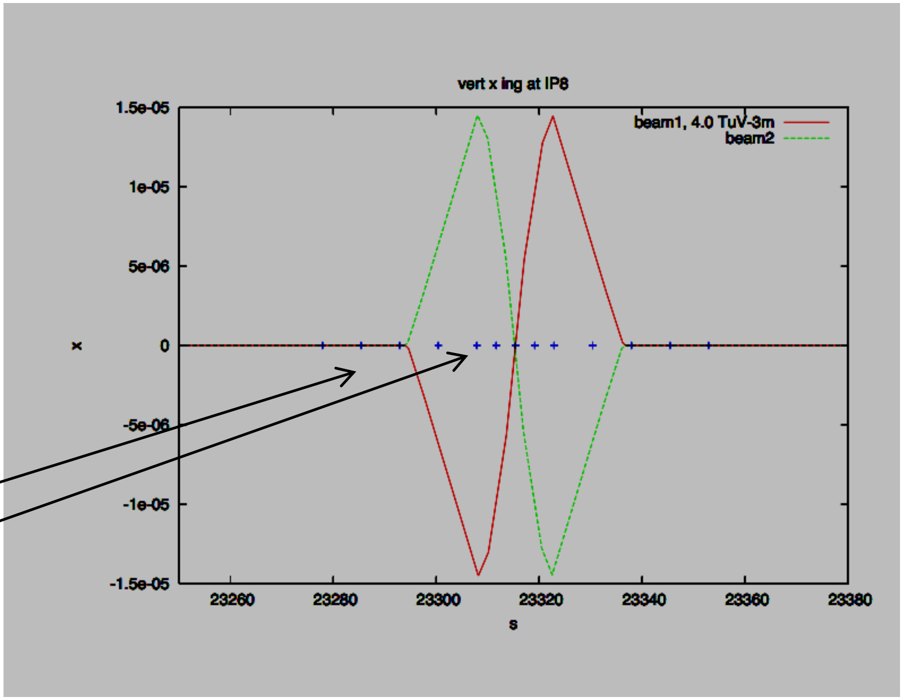
vertical crossing angle at IP8

"Doch furchtbar wird die Himmelskraft,
Wenn sie der Fessel sich entrafft,
Einhertritt auf der eignen Spur
Die freie Tochter der Natur.

Wehe, wenn sie losgelassen ...!!"

LHC-B Magnet & Compensator:

crossing angle at 4 TeV = +/- 236 μrad



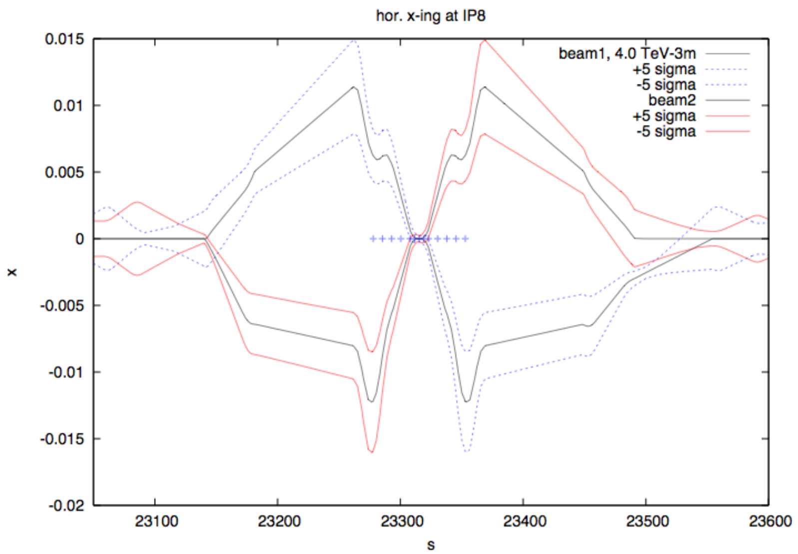
parasitic encounters for 50 ns
... and 25ns

By adding an external crossing angle bump we have to avoid parasitic encounters for both LHC-B polaristies.

Nota bene: LHC-B bump is compensated (i.e. closed) at +/- 21m, before the triplet.

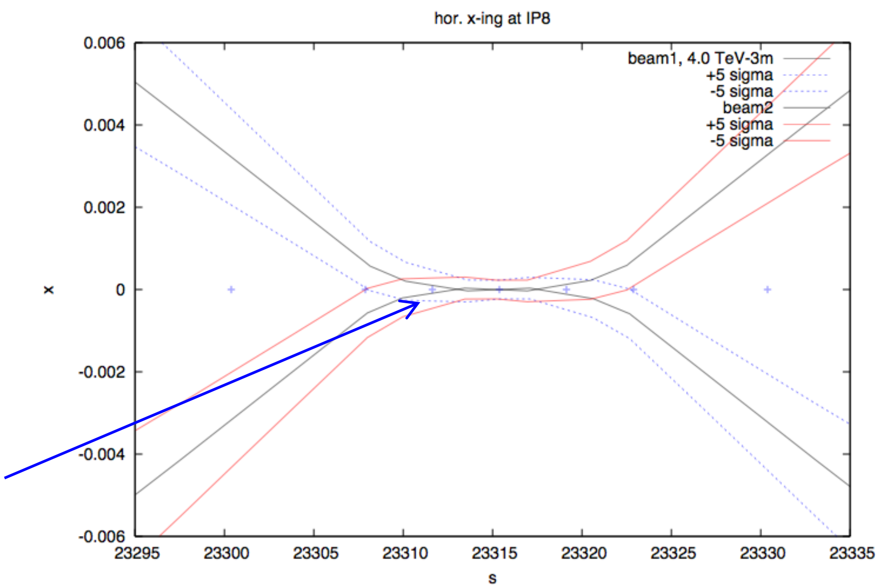
The problem: LHC_B at "wrong polarity"

Present Solution: the orbit effect (in hor. plane) has to be compensated by a strong external horizontal crossing angle bump.



"external bump" created to compensate the LHC-B effect θ = +/- 250 µrad

nota bene: LHC_B = +/- 236 µrad

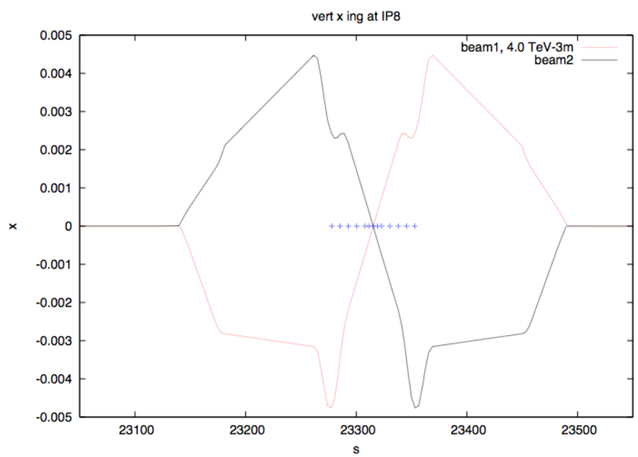


"external bump" zoomed in:

first paras. encounter at 25 ns

Proposed new Solution:
vertical external crossing angle bump:

crossing angle at 4 TeV: LHC_B = +/- 236 μrad
vert. angle = +/- 90 μrad



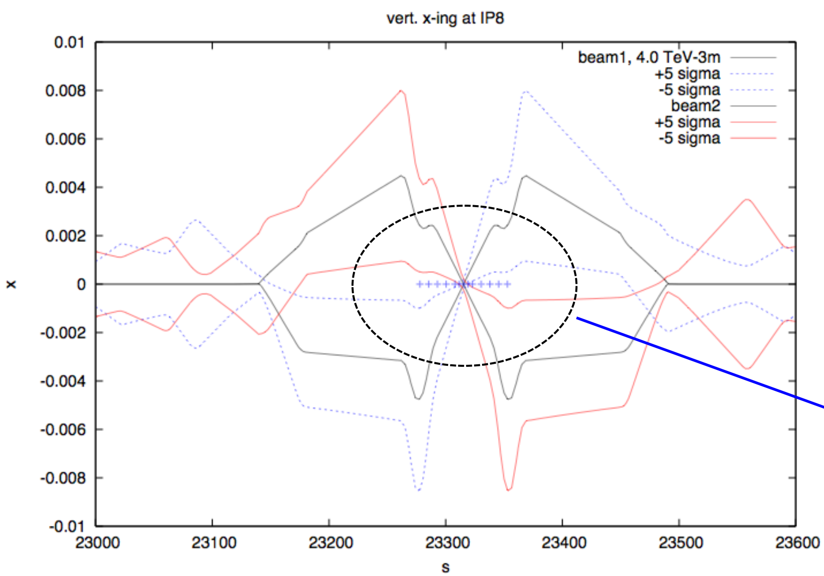
coils: acbcvs5.l8b1, acbyvs4.l8b1, acbyvs4.r8b1 acbyvs5.r8b1 — and it works ... in principle

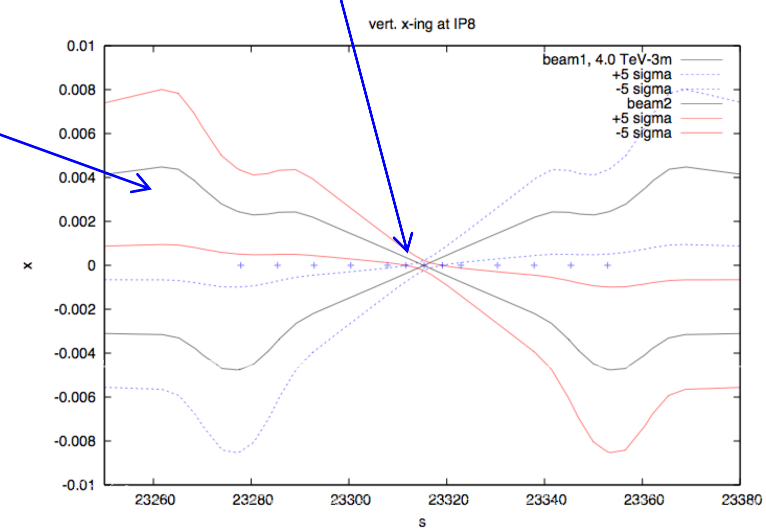
Problem ?? Aperture in the triplet according to beam screen orientation

Operational procedure is tricky

Proposed new Solution:
vertical external crossing angle bump:

crossing angle required at 4 TeV for sufficient separation at the 1st paras. encounter (25ns !!) = +/- 100 µrad





plot refers to 3 µm and +/- 5 σ beam envelope
for operation we will use:
ε=2.5µm, +/- 90 µrad

Operational Procedure

Injection & Ramp as today

450 GeV: vert separation Δy = +/- 2.0mm
hor. crossing angle: x' = +/- 2.1mrad (LHCb) + 170 μrad (ext)

4 TeV: vert separation Δy = +/- 650 μm
x' = +/- 236 μrad (LHCb) + 250 μrad (ext)

Squeeze at all IP's (.... why ... ?)

After the Squeeze find a combination of crossing angle - and separation - bumps
to collapse the beam separation without premature collisions in one or the or the plane

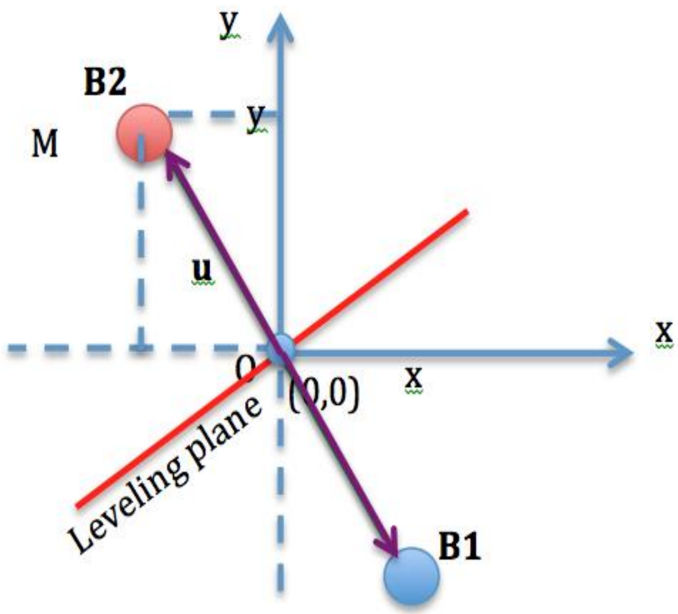
and maneuver the beams into the "diagonal" leveling plane without hitting an encounter !!!

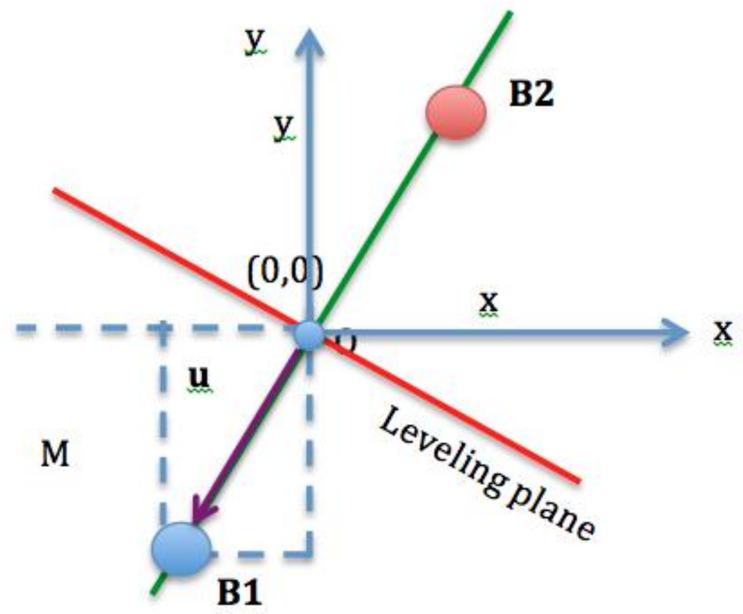
Proposed Solution:

- Eliminate the External H crossing angle
- Introduce an External V crossing angle

$$\hat{\boldsymbol{u}} = -\frac{(\sin\alpha y\mathbf{i} - \sin\alpha x\mathbf{j})}{\sqrt{\sin^2\alpha y + \sin^2\alpha x}}\ for\ \alpha_x = -236\ \mu rad$$

$$\hat{\boldsymbol{u}} = -\frac{(\sin\alpha y\mathbf{i} + \sin\alpha x\mathbf{j})}{\sqrt{\sin^2\alpha y + \sin^2\alpha x}}\ for\ \alpha_x = +236\ \mu rad$$





GOALS:

1. Determine if different tertiary collimators (TCT) settings are needed as a function of the LHCb polarity;
2. Identify a method that satisfies the following requirements:
   1. No head-on collisions are built up during the process;
   2. The beam separation at the 50 ns encounters is ≥12σ in at least one of the planes or in the tilted plane.
   3. The beam separation at the 25 ns encounters is ≥12σ in at least one of the planes or in the tilted plane.

Note:

α_{ext}^{H} = 250 μrad → 0

α_{ext}^{V} = 0 → 100 μrad

ε_n = 3.5 μm rad

Conclusions

1. No dependence on the TCT settings as a function of the LHCb dipole polarity is observed.
2. During the collapsing of the external horizontal crossing angle and the building up of the vertical crossing angle, the TCTs will have to follow the beams accordingly.
3. At the end of the process due to the effect of the LHCb dipole polarity, there is a $< 1\sigma$ beam position difference for each polarity which would have to be absorbed within the same collimators settings.

4. The methods analyzed satisfy the requirement of not having head-on collisions (provided the polarity of the vertical crossing angle is properly chosen; in this study B1: 100 μrad & B2: -100 μrad)

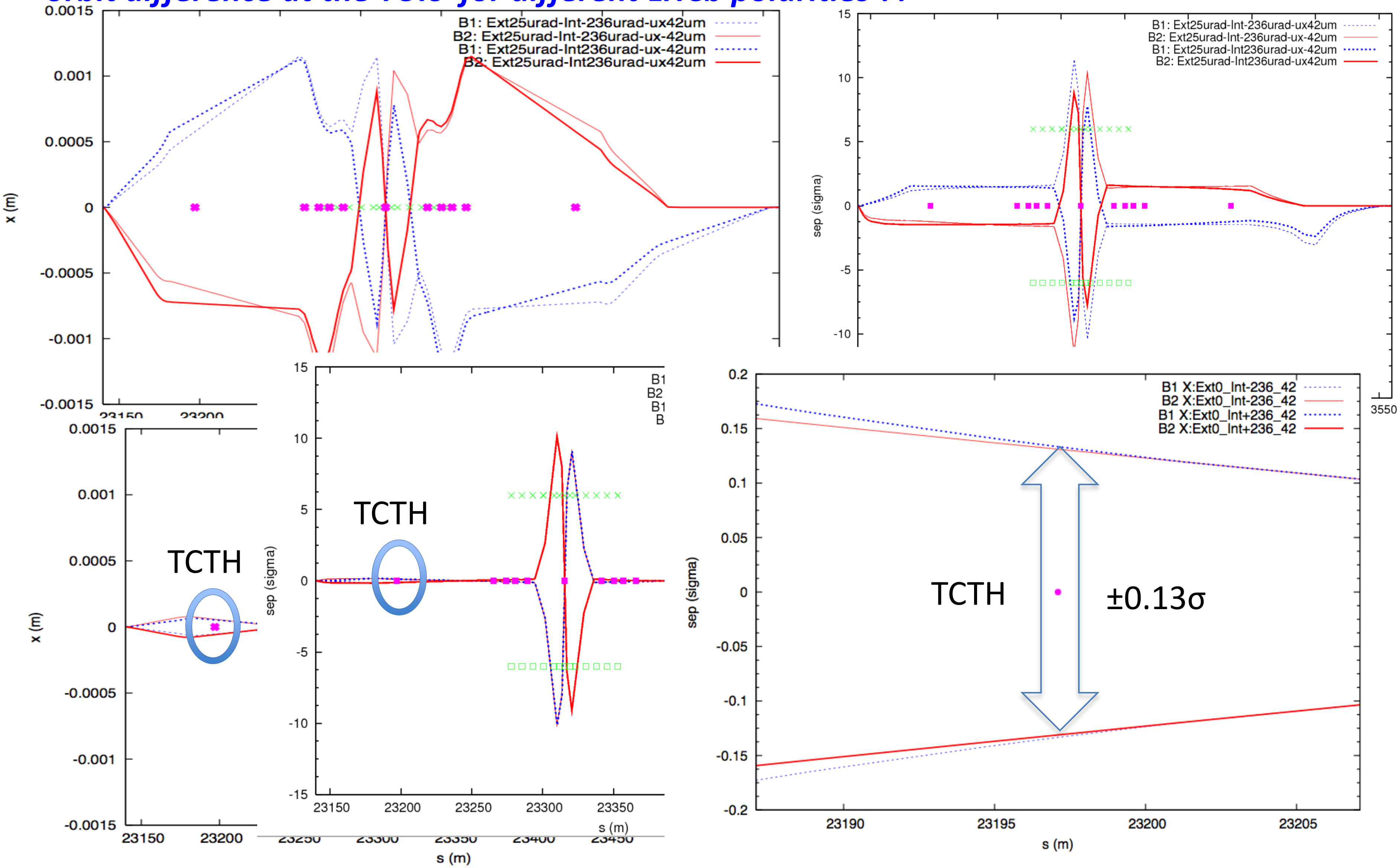
5. For small vertical separation of the beams, it can be guaranteed that the smallest beam separation at the first 50 ns encounter is never lower than $10\ \sigma$.

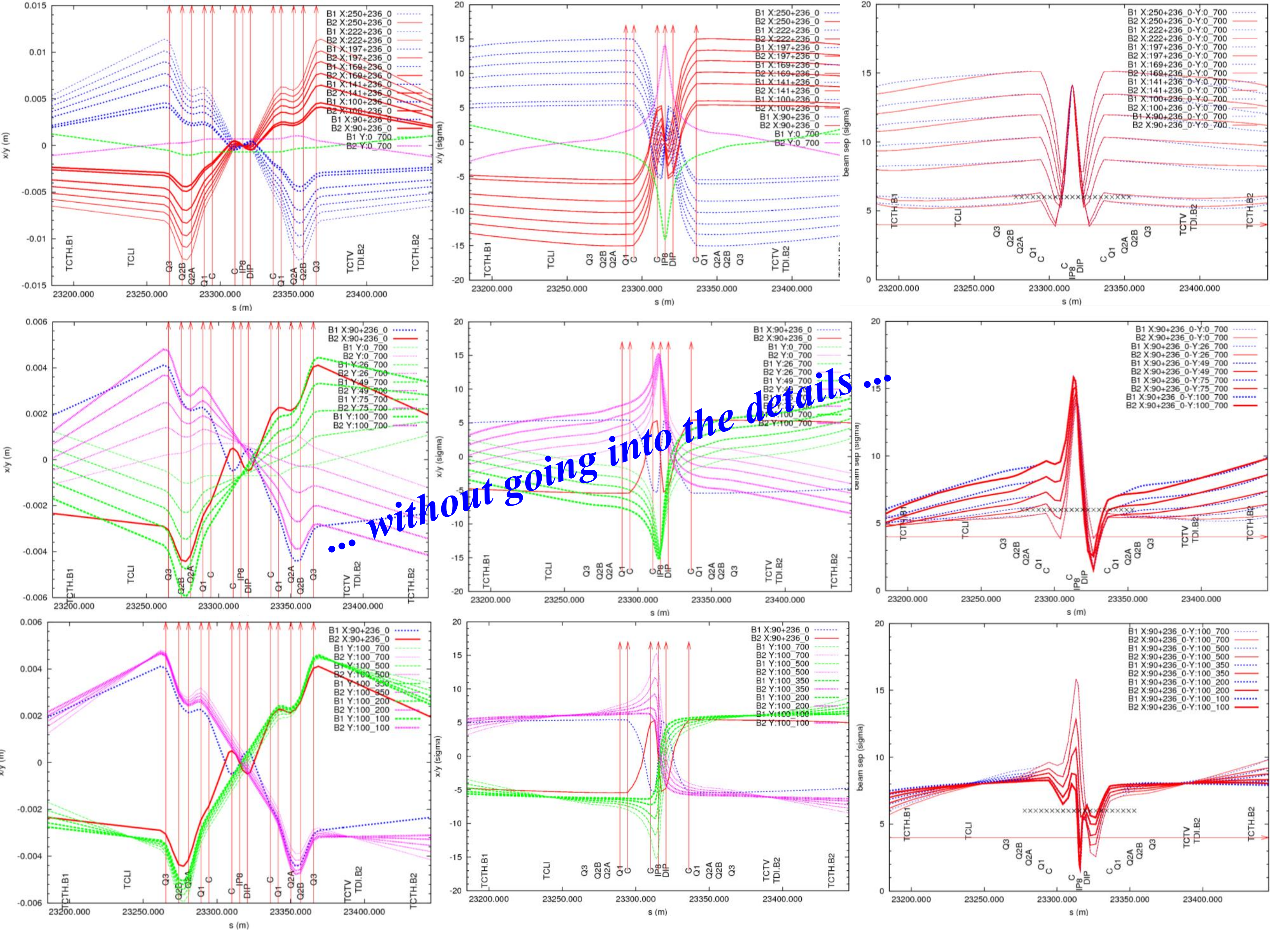
6. Only methods were the Vertical crossing angle is built first, guarantee a separation $\geq 8\sigma$ during the whole process EVEN FOR 25 ns.

No TCT settings dependence with LHCb polarity

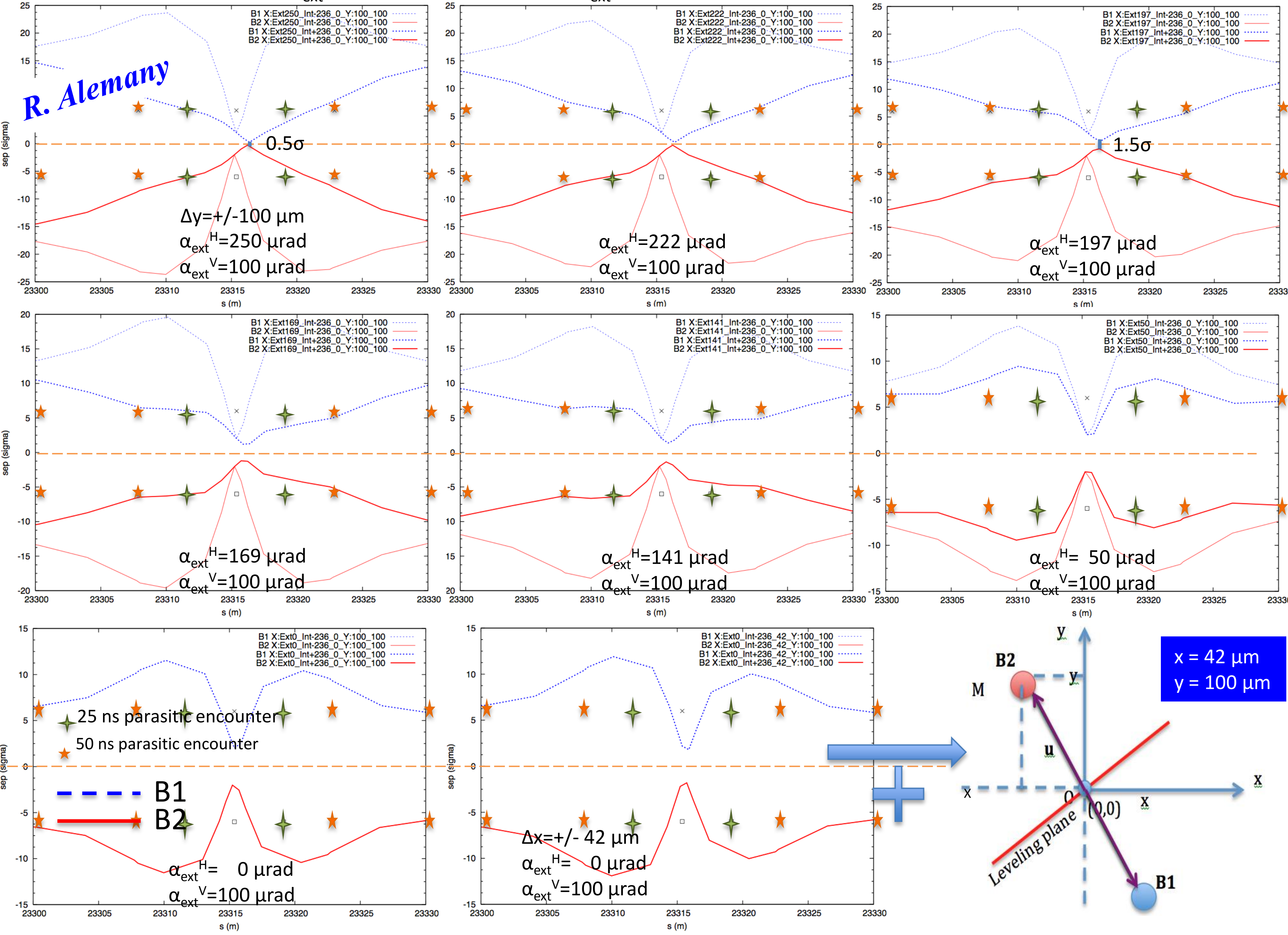
collapsing the external hor bump ->

orbit difference at the TCTs for different LHCb polarities ??




... without going into the details ...
x/y (m)
x/y (sigma)
beam sep (sigma)
s (m)
B1 X:250+236_0
B2 X:250+236_0
B1 X:90+236_0
B2 X:90+236_0
B1 Y:0_700
B2 Y:0_700
B1 Y:100_700
B2 Y:100_700
B1 X:90+236_0-Y:100_700
B2 X:90+236_0-Y:100_700
TCTH.B1
TCLI
Q3
Q2B
Q2A
Q1
C
IP8
DIP
TCTV
TDI.B2
TCTH.B2

METHOD 4: 1. Built $\alpha_{ext}^{V} \rightarrow$ 100 μrad; 2. collapse $\alpha_{ext}^{H} \rightarrow$ 0 μrad; 3. move the beams to the leveling direction



First step at flat top : decreasing vertical separation **Δy = 2*650 → 2*100 µm**

Separation in IR8 in terms of σ, for ε = 3.5 µm.rad

At IP8:
Δx = 0
α_x = 220 µrad
α_y = 0 µrad

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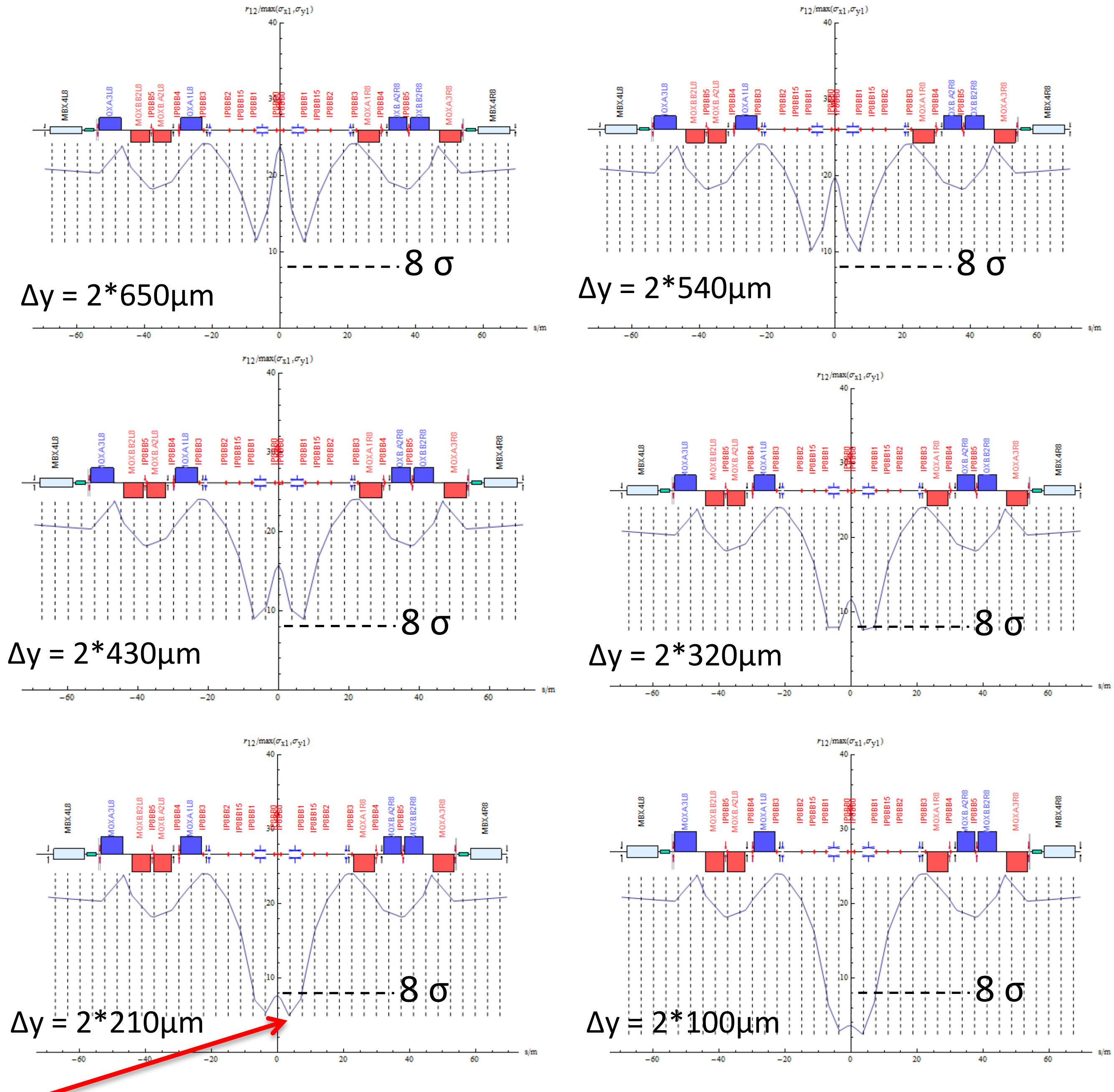


Dashed lines correspond to 25ns encounters

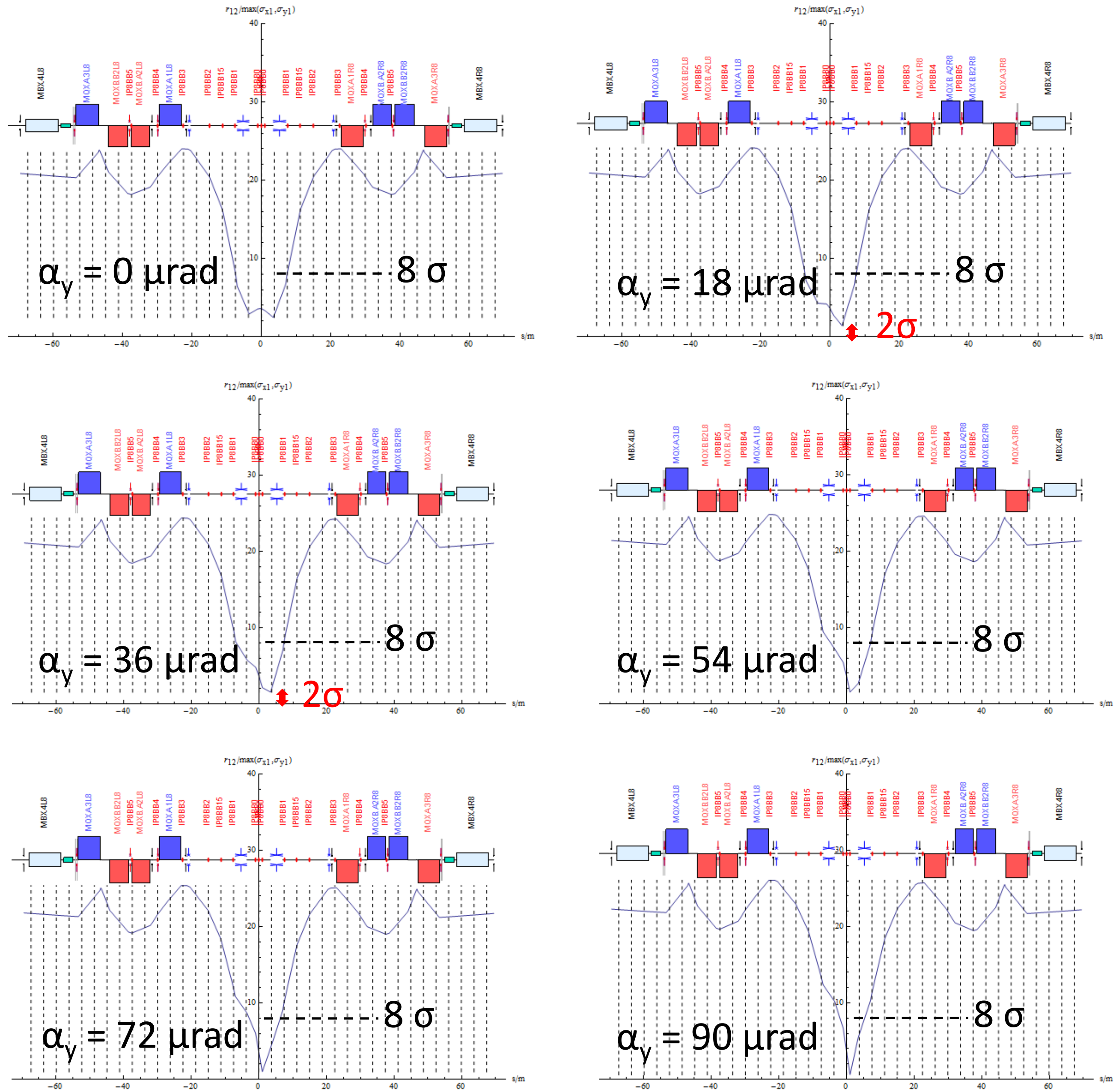
Second step at flat top : increasing vertical crossing angle **α_y = 0 → 90 µrad**

Separation in IR8 in terms of σ, for ε = 3.5 µm.rad

At IP8:
$\Delta x = 0$
$\Delta y = 2*100$ µm
$\alpha_x = 220$ µrad

R. Versteegen

Dashed lines correspond to 25ns encounters

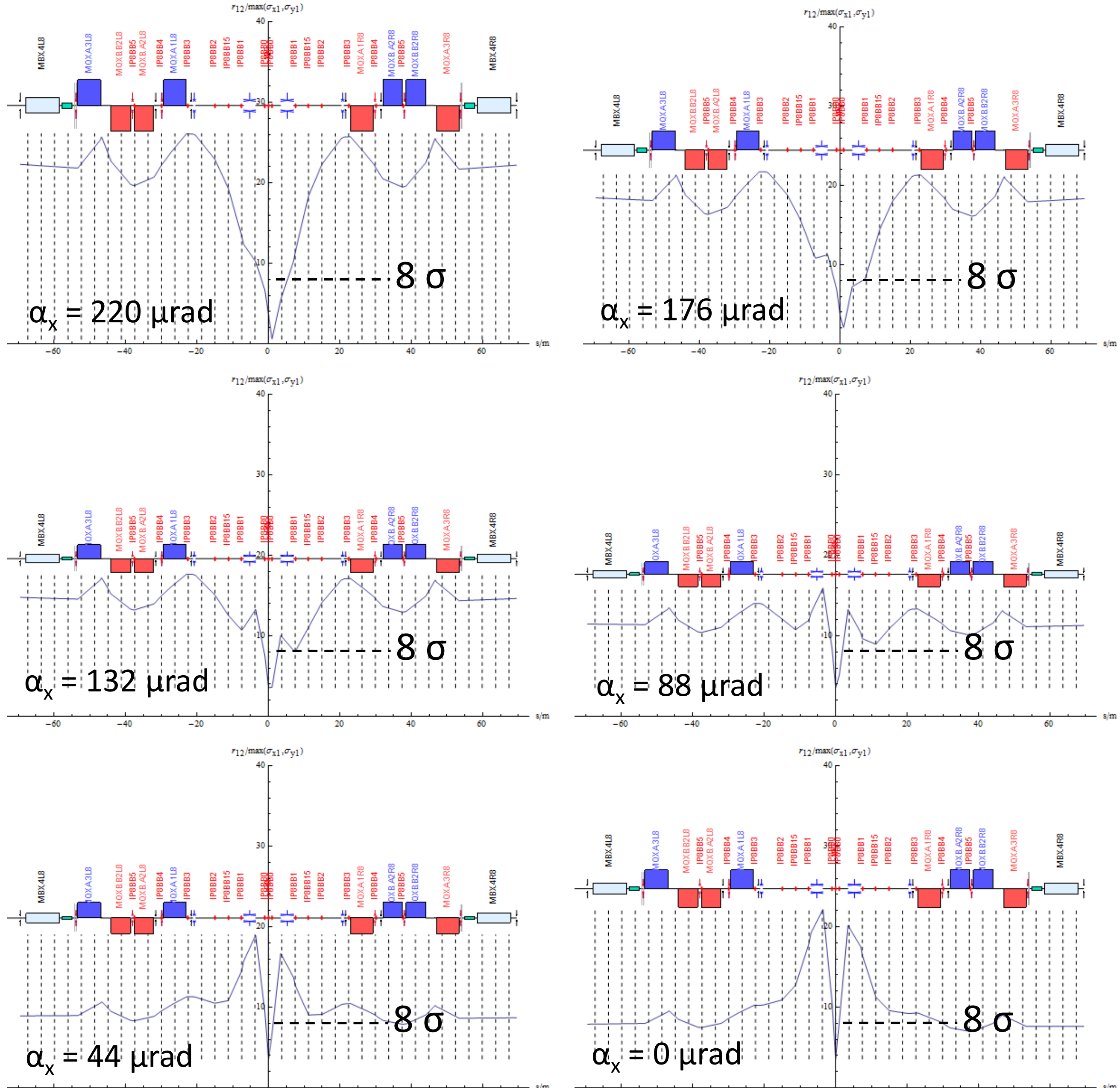


Third step : decreasing horizontal crossing angle **α_x = 220 → 0 μrad**

Separation in IR8 in terms of σ, for ε = 3.5 μm.rad

At IP8:
$\Delta x = 0$
$\Delta y = 2*100$ μm
$\alpha_y = 90$ μrad

R. Versteegen

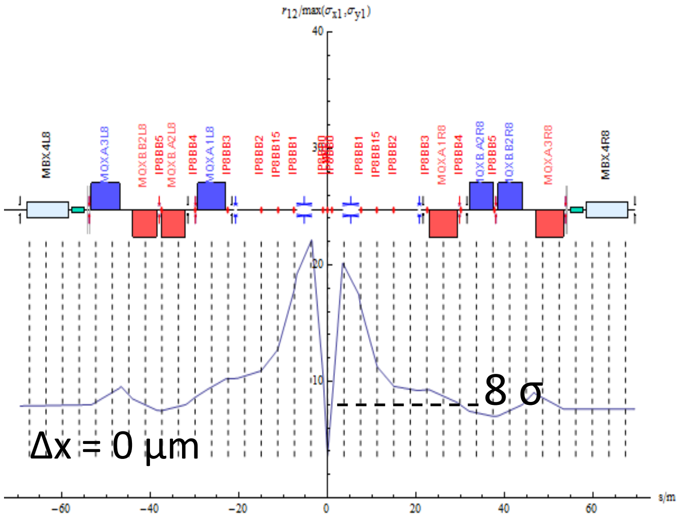


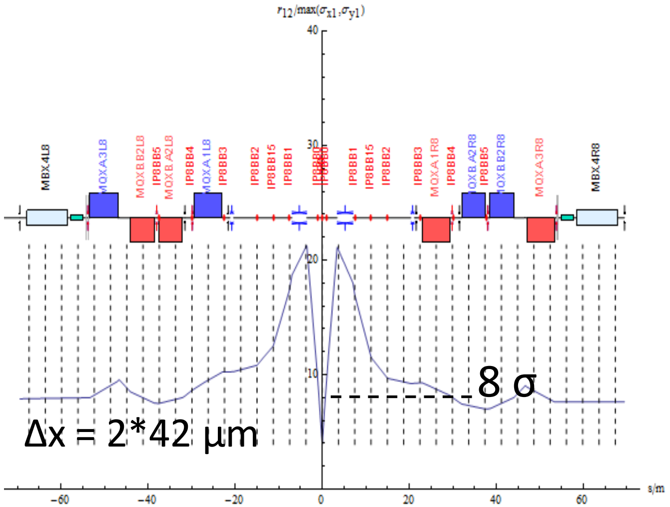
Dashed lines correspond to 25ns encounters

Fourth step : increasing horizontal separation **Δx = 0 → 42 µm**

Separation in IR8 in terms of σ, for ε = 3.5 µm.rad

At IP8:
Δy = 2*100 µm
α_x = 0 µrad
α_y = 90 µrad





R. Versteegen

Dashed lines correspond to 25ns encounters

Conclusions

1. The procedure works if:
   1. We obtain a min of 10σ beam separation at the 50 ns encounters.
   2. Collimators accept an asymmetry of ~ 0.5 σ in the TCT settings w.r.t. beam position
2. Time estimate is 3 minutes ➔ although it fits in the 393 s from IP8 β^*=3 m to end of collision beam process (BP), there are some unknowns that push in the direction of decoupling this process completely from the squeeze to the end of the collision BP adding a ~2 minutes to the declaration of stable beams.
3. Vertical Crossing angle knob created in madx
4. LSA KNOBS under construction
5. Lumi-scan application being adapted
6. The best solution (to our knowledge) is "if aperture available at injection" ➔ do this at injection … UNDER STUDY

25ns problem.....

proposed operational procedure:

1.) $\Delta x =$ +/- 350 μm
2.) $\Delta y =$ 700μm -> 0 μm
3.) $\alpha_{ext}\, y =$ 0 -> 90 μrad
4.) $\alpha_{ext}\, x =$ 220 -> 0 μrad
5.) $\Delta x =$ +/- 42 μm, $\Delta y =$ +/- 100 μm

detailed plots will follow asap

minimum separation at the 1st 25ns encounter: +/- 3 σ
beam orbit depends on the LHCb polarity ($\Delta x = 2\sigma$)
-> TCTs ... ??

vert crossing at Injection

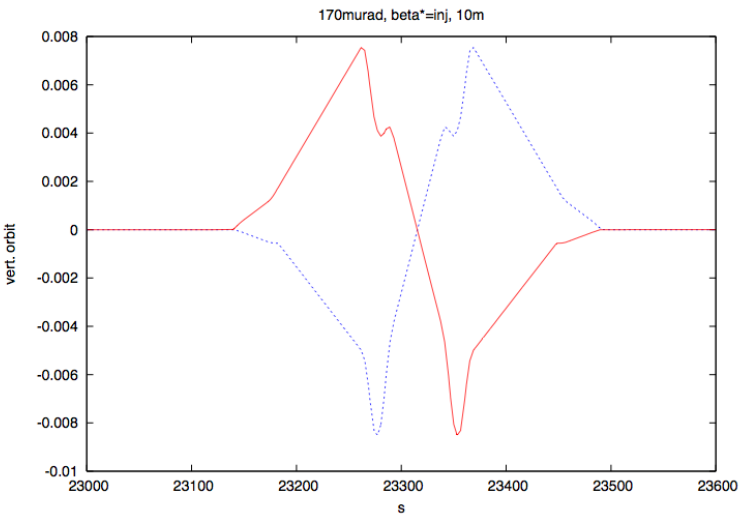
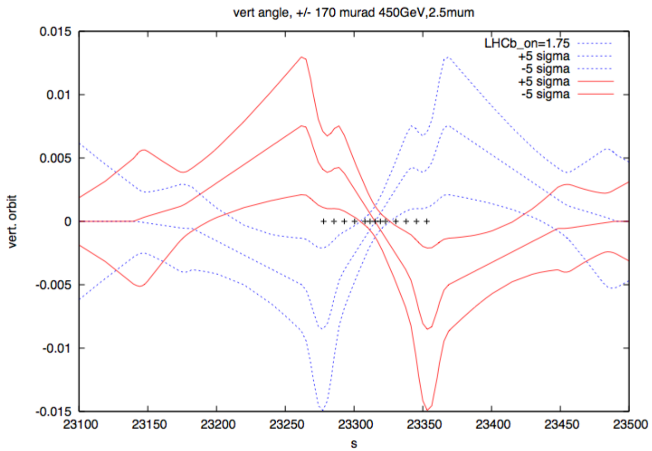


Fig1: new vertical bump for vertical crossing at LHC injection energy, 170 μrad using only the standard orbit correctors at Q4, Q5



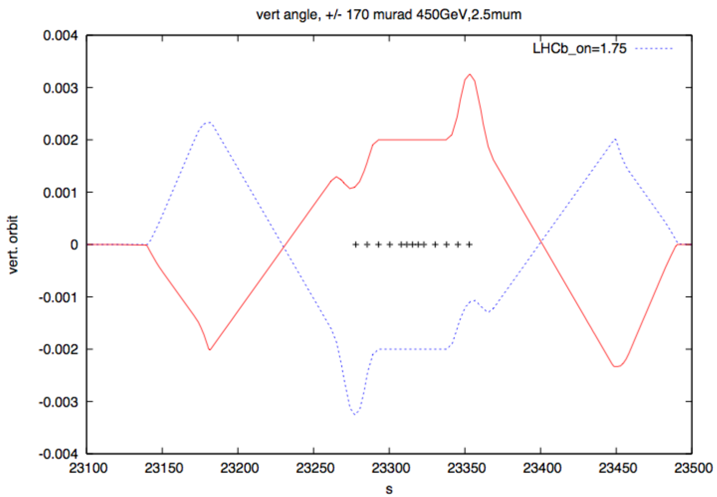
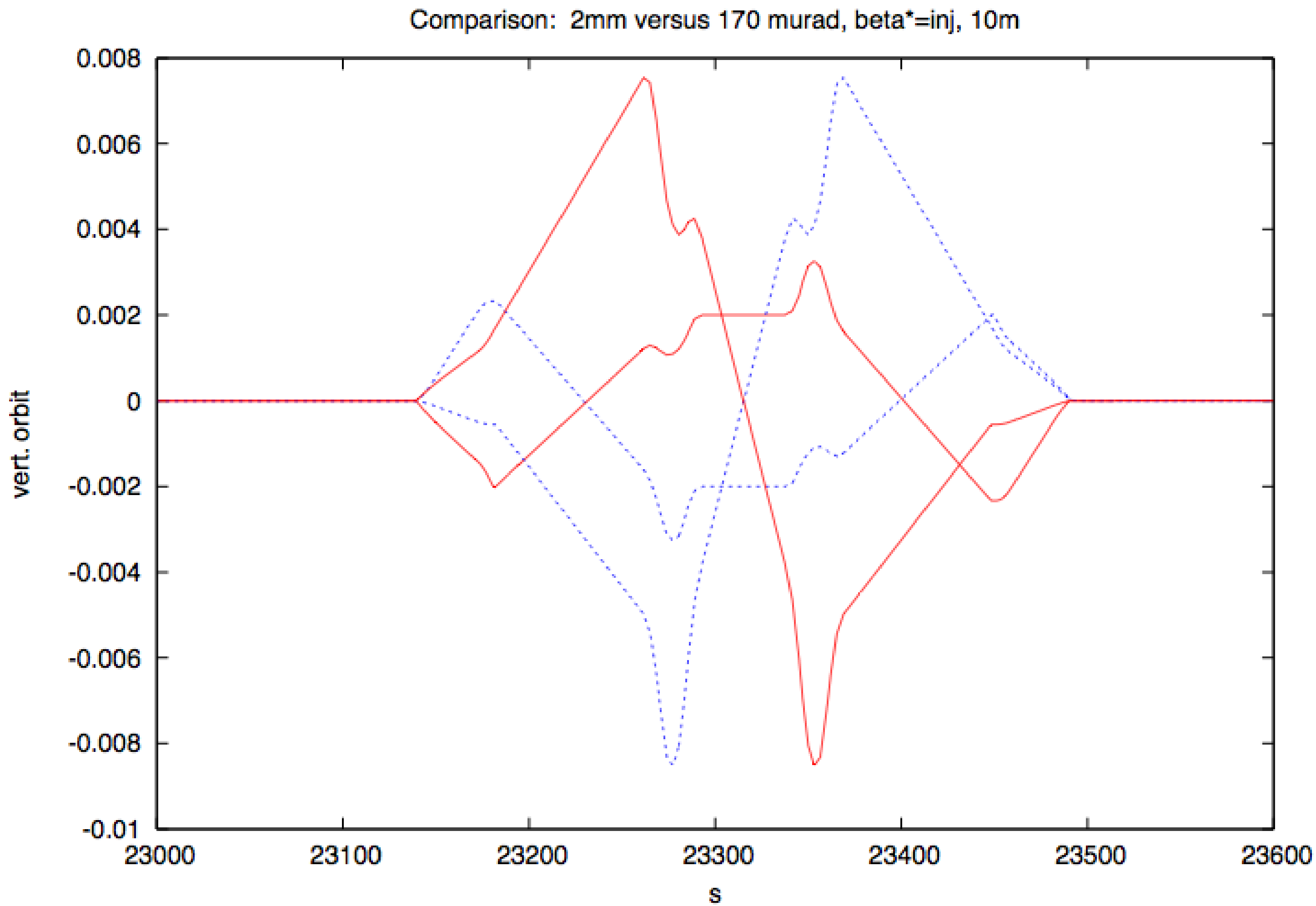


Fig 2: to get an estimate for the aperture need of the new vertical crossing angel bump I plot here our standard vertical separation bump: Δy=2.0mm at 450 GeV. Again only Q4, Q5 correctors are applied. Message: the aperture need for the new bump in Fig 1 is much higher than what we normally do in the vertical plane.

Fig3: Just for clarity: both bumps of Fig 1 and 2 in one plot.



To reduce the aperture need and to get a fair statement of what we can do to optimise the story I introduced the triplet corrector mcbxv1.
The strength is "fixed" and the crossing angle bump is closed with the usual Q4, Q5 correctors.
Following what has been done in the past and what is applied in IP2, where we have a quite similar situation I put the mcbxv1.l8 = 3.0e-5,
mcbxv1.r8=-3.0e-5.

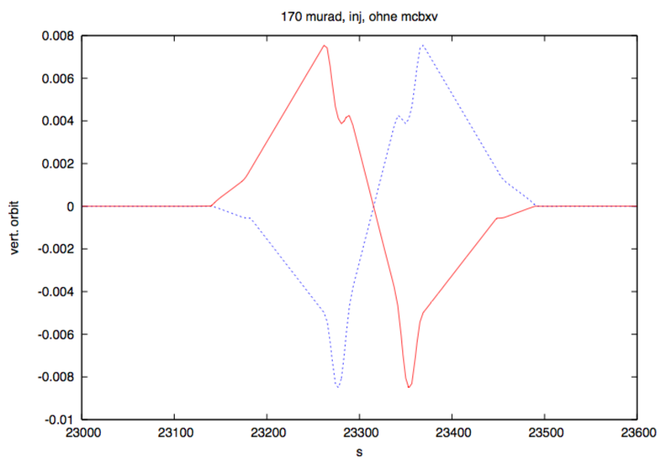


Fig4: vert crossing angle bump 170 μrad without triplet corrector

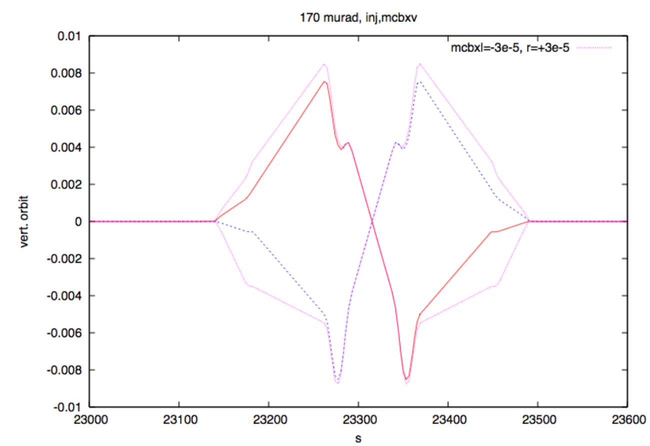
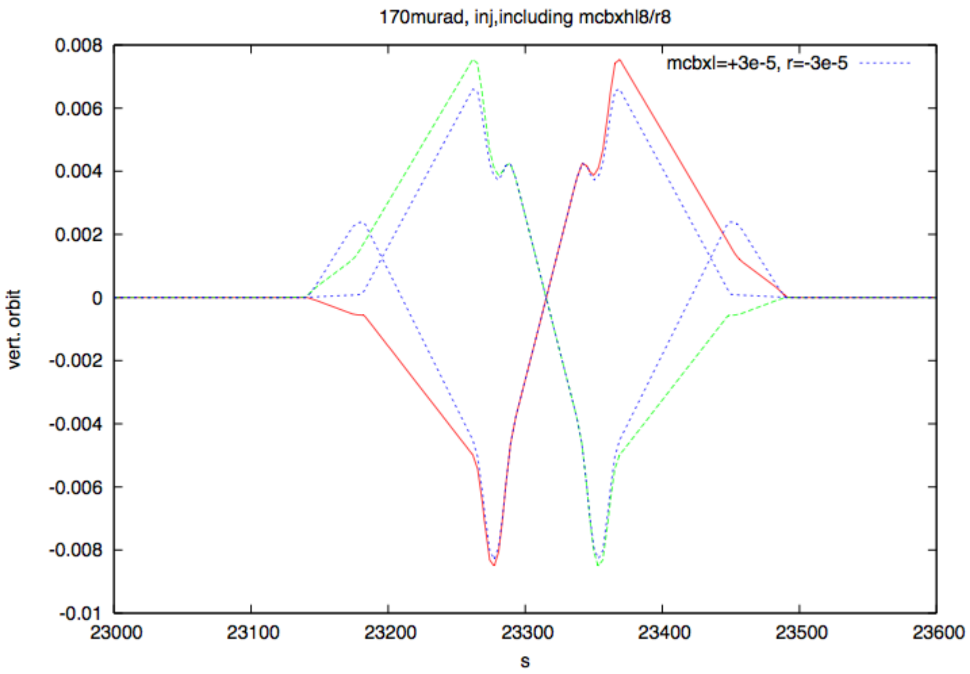


Fig5: vert crossing angle bump 170 μrad combined with the triplet corrector mcbxv1.l8=-3.0e-5, ~.r8 +3.0e-5
... well this is not what we should do as the triplet correctors counteract the bump.

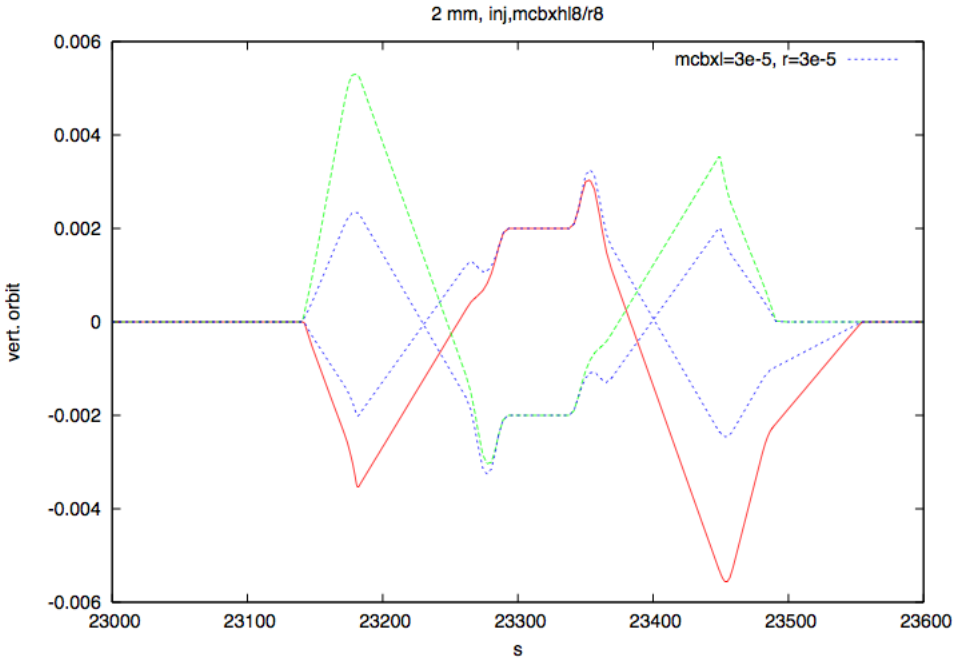
Fig6: vert crossing angle bump 170 μrad combined with the triplet corrector mcbxv1.l8=+3.0e-5, ~.r8 -3.0e-5. The blue lines show the bump including the triplet correctors. The aperture need is reduced. However the strength of the Q4, Q5 correctors is considerably increased. In the end aperture considerations will tell us where to go to.



HORIZONTAL SEPARATION BUMP

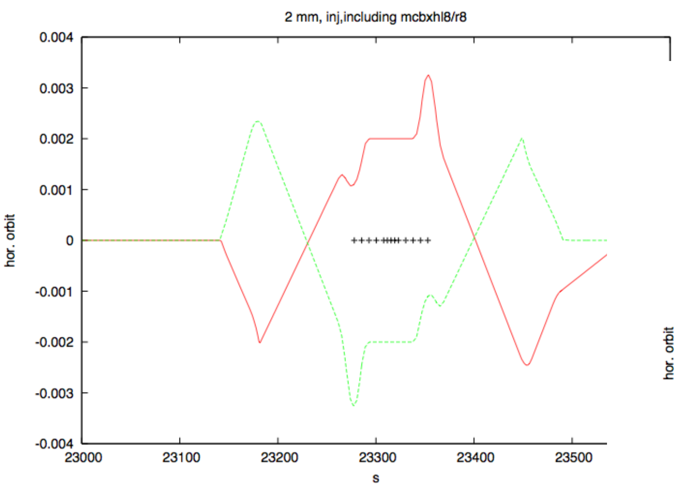
At LHC injection a vertical crossing angle bump will have to be combined with a horizontal separation bump to avoid parasitic (and head on) encounters. Basically a mirror symmetric situation to what we have at present just with the two planes exchanged.
To create this horizontal separation bump again the triplet correctors have been included to reduce the aperture need and (possibly) the strength of the Q4, Q5 correctors.

Fig7: hor. separation bump 2mm
mcbxh1.l8=+3.0e-5
mcbxh1.l8=+3.0e-5
The green & red curves show the bump without triplet corrector, the blue lines the bump including the supporting mcbxh.
A considerable aperture reduction is obtained, i.e. nearly a factor of two.

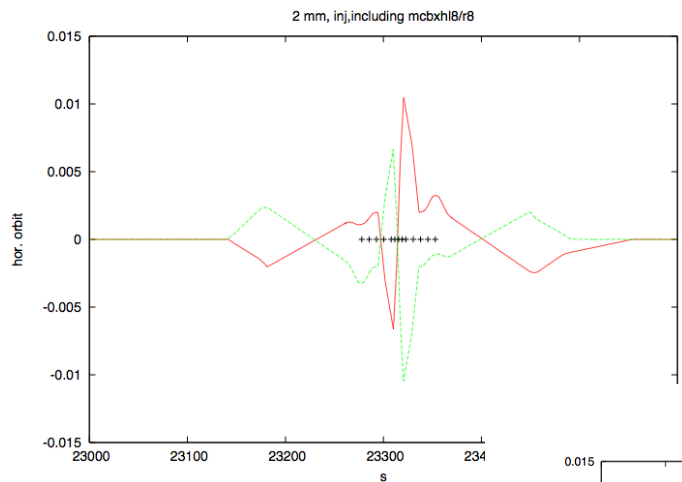


HORIZONTAL BUMP

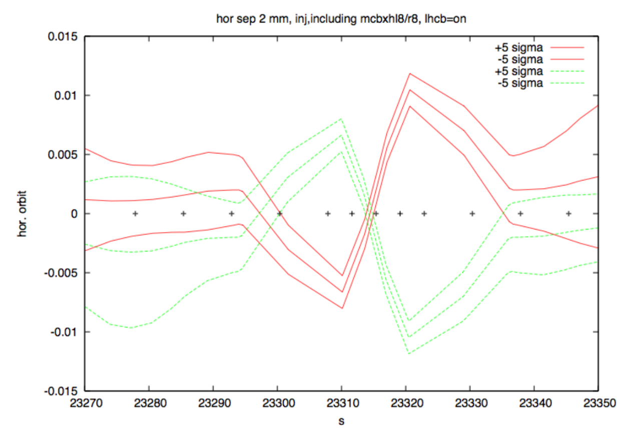
including the position of the paras. encounters



hor sep bump



hor sep bump plus LHC-B



hor sep bump plus LHC-B
zoomed in, +/- 5 σ

the external separation bump of 2 mm in combination with the LHCb dipole magnet allow a separation at the paras. encounters of > 10 σ

THE DETAILS

Applying the vert crossing at injection means ...

set-up of the crossing angle bump (“knobs”) for

injection optics,

10m flat top

and ... β^*=7.5m, 6.0m, 3.75m, 3.5m, 3.25m, 3.0m

Advantage:

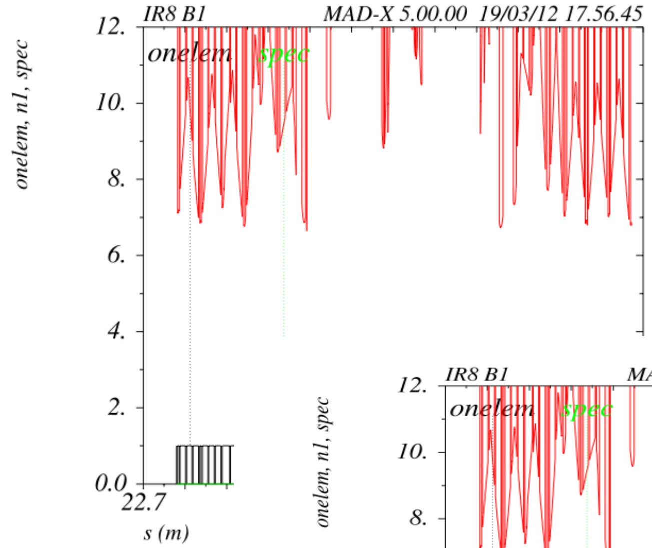
just collapse the separation bump to go into collision

Dis-Advantage:

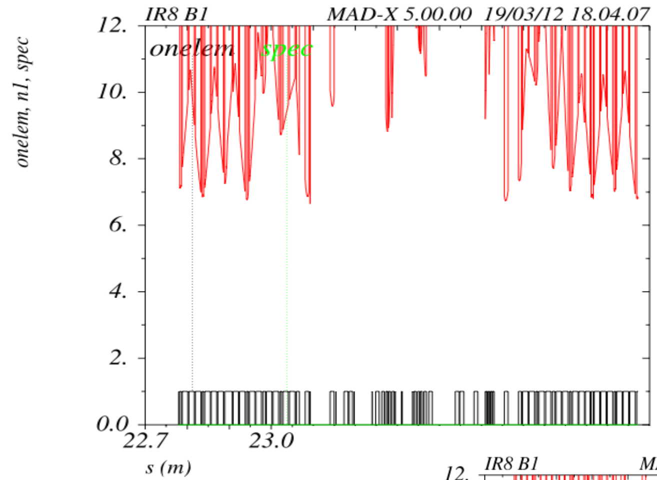
aperture need at injection

APERTURE at 450 GeV

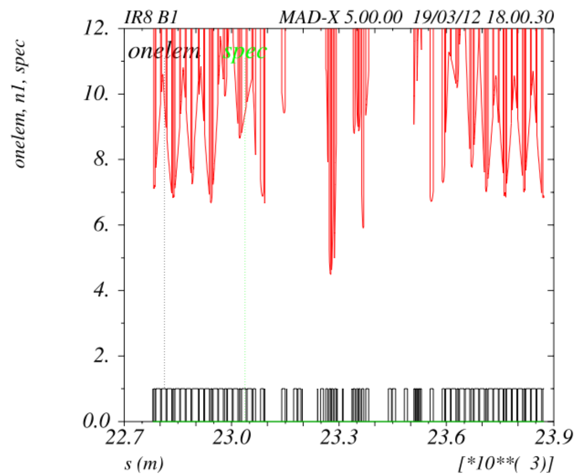
LHC Standard,
no angle, no sep, no LHCb



LHC Standard,
no angle, no sep, LHCb_on=15.55



LHCb_on=15.55
vert xangle = 170 murad
hor sep = 2mm



Resume:

1.) procedure at 4 TeV, 3m optics established
bumps calculated and included in the lhc data base

2.) leveling / separation bump calculated as a combination of 8 coils

3.) to be applied after squeeze in all IPs ($\Delta t \approx 2$ min) ... to be improved

4.) sufficient separation at the 50ns encounters
25ns case needs some more optimisation / check

5.) vertical crossing / horizontal separation at Injection is critical for the aperture & machine safety

6.) waiting for beam