LHC Collimation Project
CERN

Chromatic phase space cuts from collimation

Ralph Assmann, Chiara Bracco

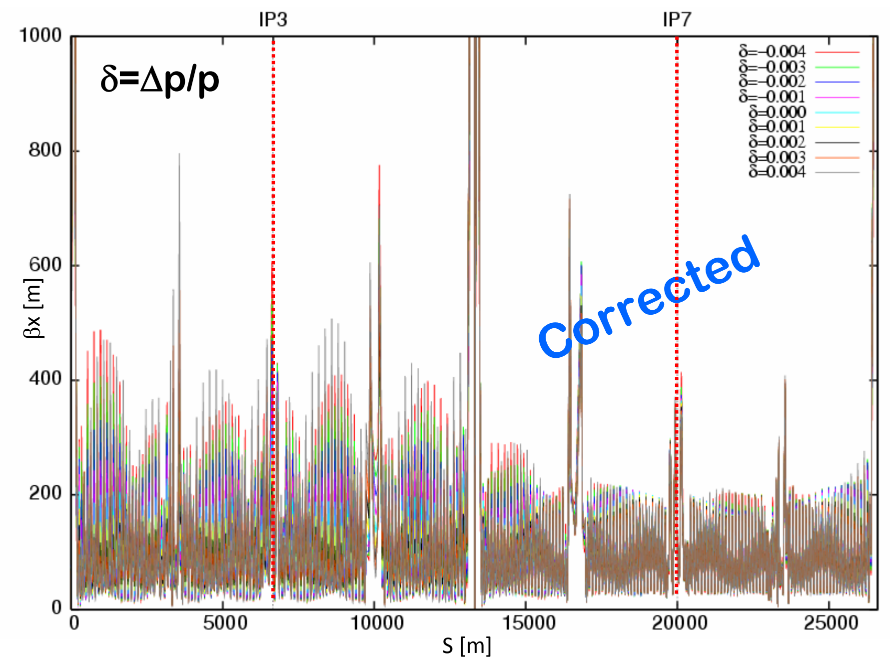
Outline

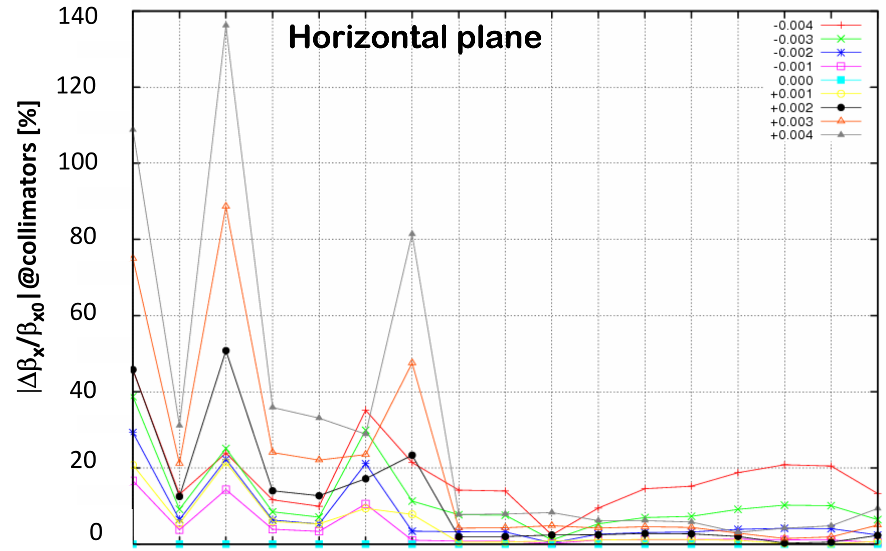
- Nominal 7TeV lowbeta optics:
  - beta beat in the first half of the ring (IP1→IP5)
  - beta beat in the second half of the ring (IP5→IP1)
- Beta beat and collimation: definition of the effective betatron amplitude cut and allowed phase space
- IP1→IP5 case: cleaning and retraction (extensively)
- IP5→IP1 case: cleaning and retraction (results)
- TCT and IR7 collimators at nominal+3σ setting
- Upgrade optics
- Conclusions
- All the studies refer to Beam1, Beam2 case is equivalent

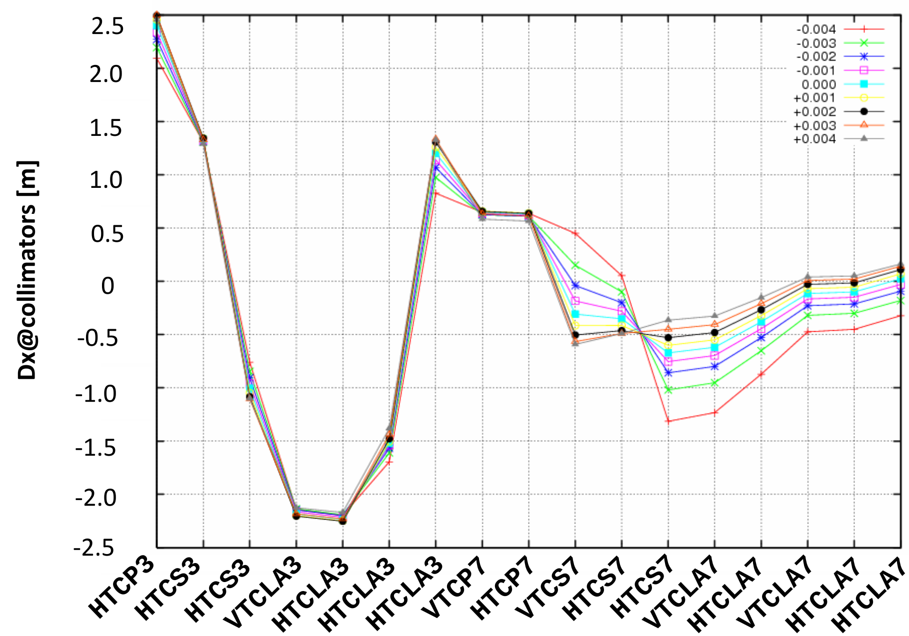
Off momentum beta beat IP1→IP5

Nominal 7 TeV Lowbeta Optics:
All crossings ON
All separations OFF

```
system, "ln -s /afs/cern.ch/eng/lhc/optics/V6.501 dn";
call,   file="dn/magic_phases15.thin.b1.str";
                 .
                 .
                 .
TWISS, DELTAP=0.004
```







Off momentum beta beat IP5→IP1

Nominal 7 TeV Lowbeta Optics:
All crossings ON
All separations OFF

```
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TWISS, DELTAP=0.004
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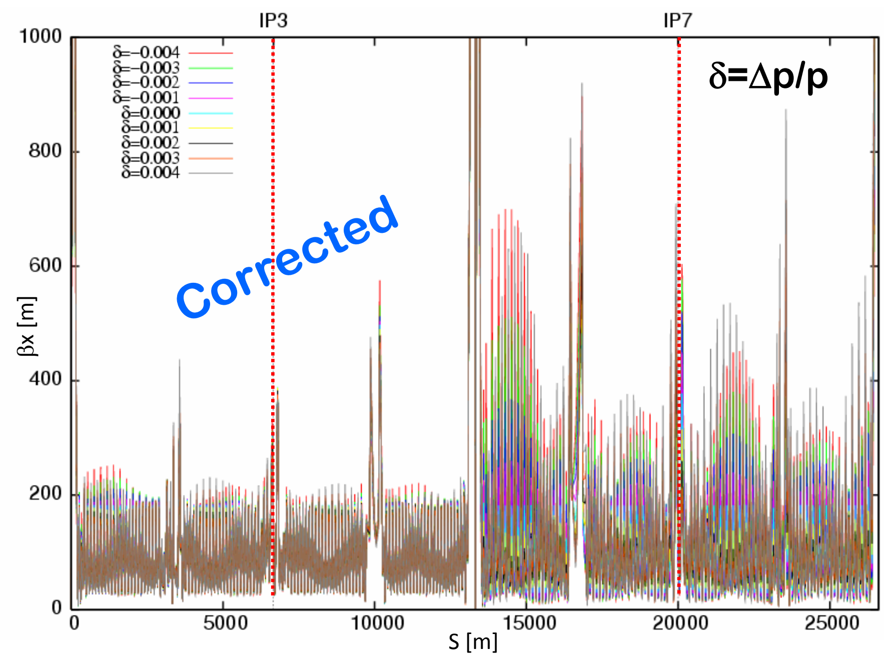

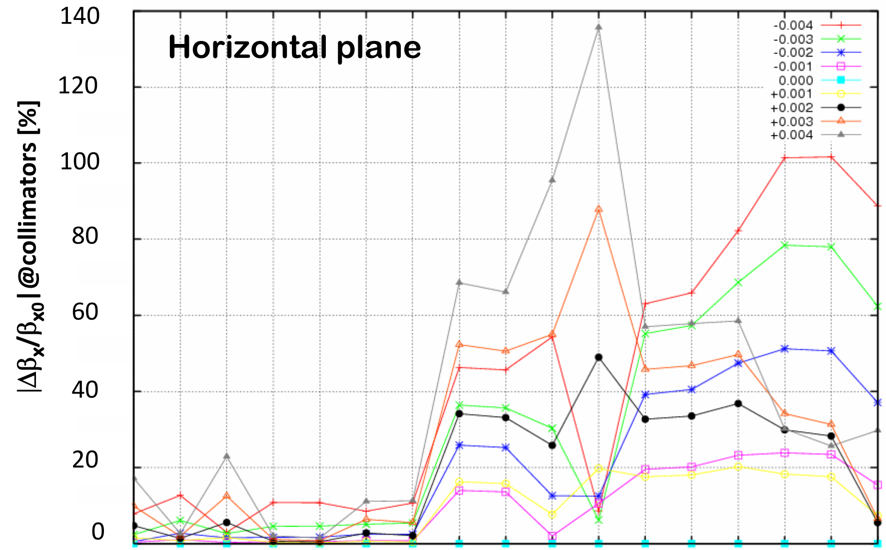

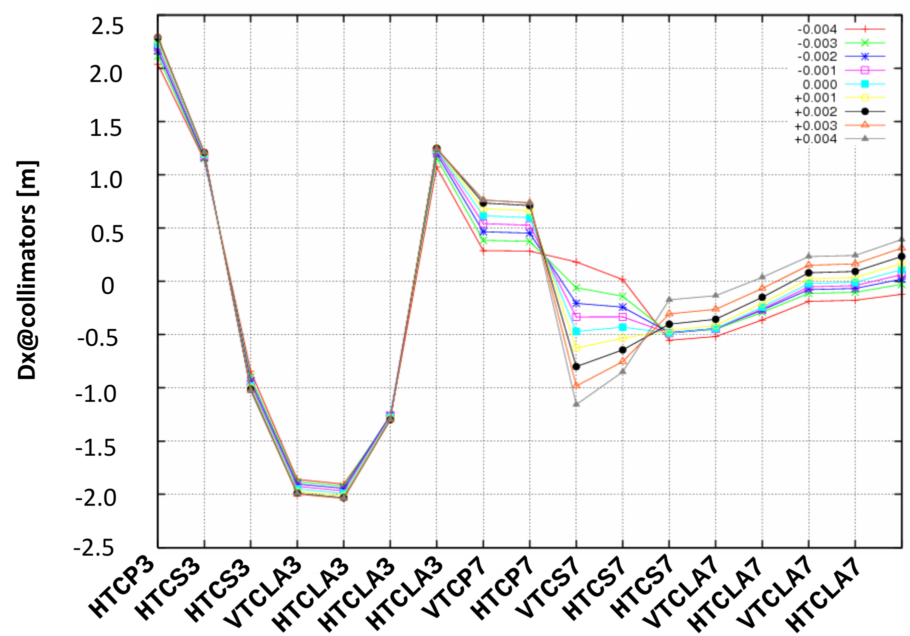

Off momentum beta beat IP5→IP1

Nominal 7 TeV Lowbeta Optics:
All crossings ON
All separations OFF

```
system, "ln -s /afs/cern.ch/eng/lhc/optics/V6.501 dn";
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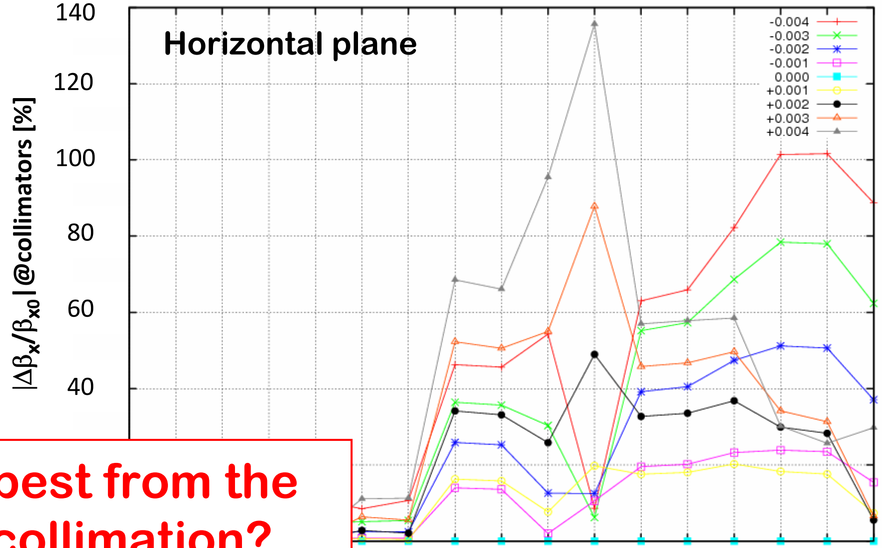
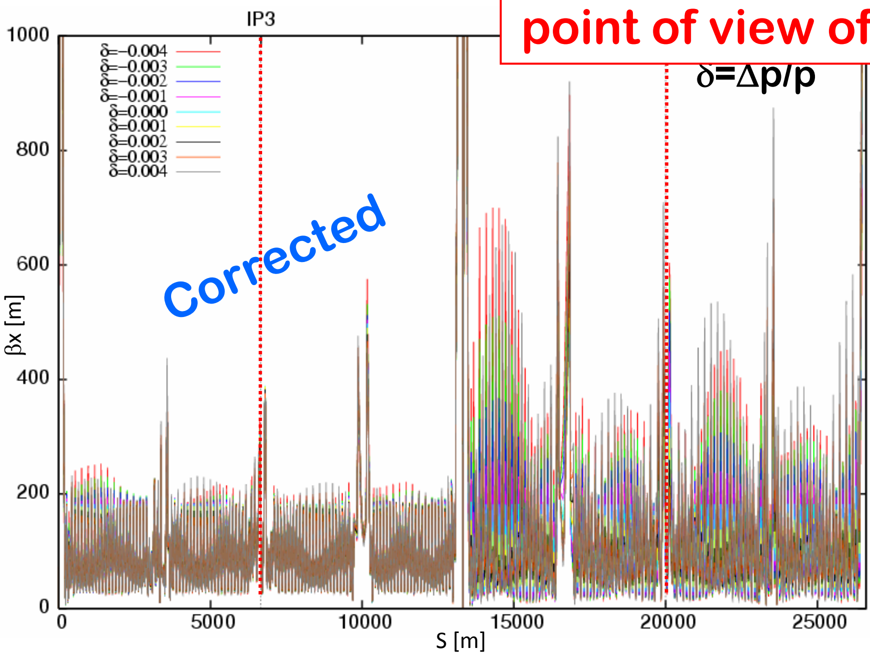
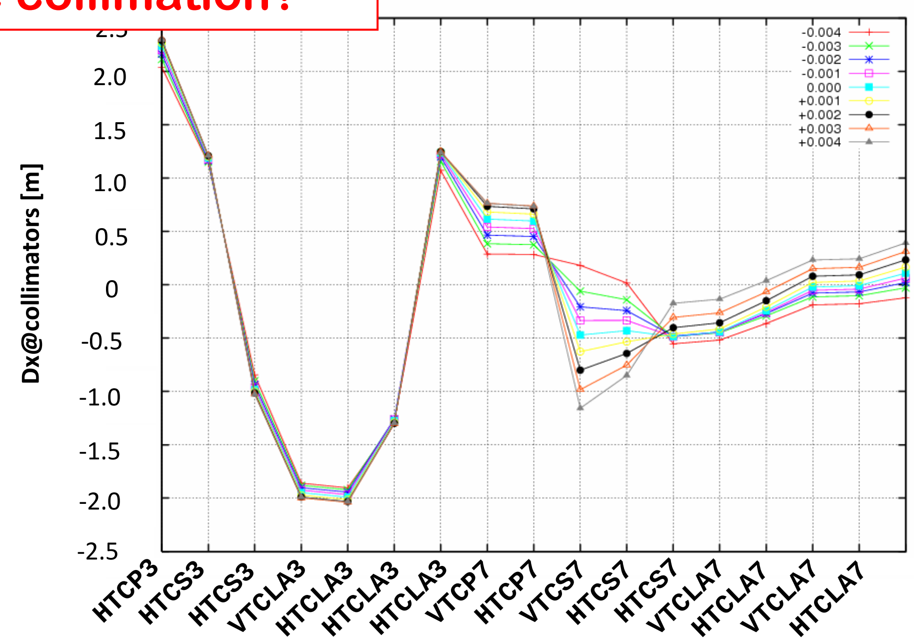
                .
                .
                .
TWISS, DELTAP=0.004
```



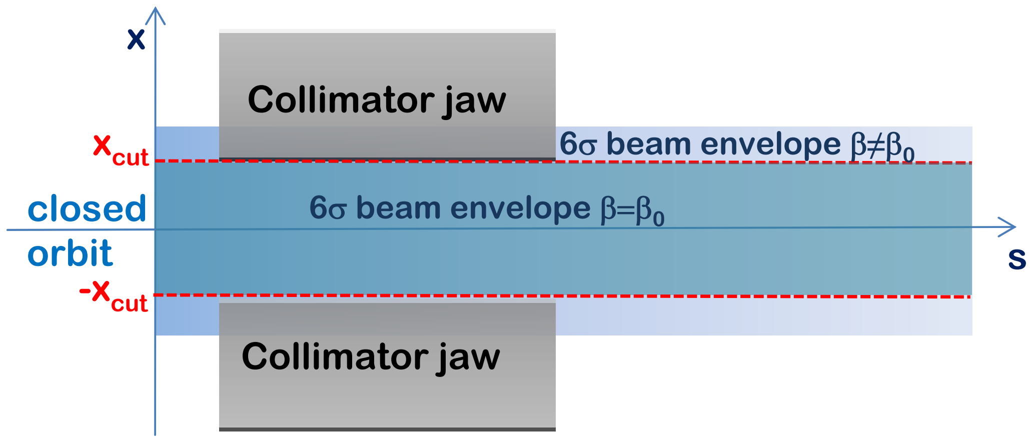
Which optics is the best from the point of view of the collimation?





Amplitude cut

How does the off momentum beta beat influence the collimation system setting?



The collimator jaws are always centered respect to the closed orbit.
The jaws "cut" all the particles oscillating with an amplitude $A_x \geq |x_{cut}|$ (horizontal plane).
x_{cut} ≡ half gap[mm] is calculated for $\delta=0$ and **fixed** (our nominal setting)!

A_x is determined by the sum of two contributions :

- Betatron oscillation amplitude: $n\sqrt{\varepsilon_x \beta_x(\delta)}$

- Dispersion function: $D_x(\delta)\cdot\delta$

Same considerations are valid for the vertical plane (y_{cut}, A_y, β_y, D_y)

Effective betatron amplitude cut

For the nominal collimation setting, the effective betatron amplitude cut at each collimator ($n_{\beta_x cut}(i_{coll})$)changes as function of δ, β_x and D_x!!

We can express the cut in the phase space $x_{cut}(i_{coll}, \delta)$ as:

$$x_{cut}(i_{coll}) = n_{\beta_x cut}(i_{coll}, \delta)\sqrt{\varepsilon_x \beta_x (i_{coll}, \delta)} + D_x(i_{coll}, \delta)\delta$$

From which we can then explicitly derive $n_{\beta_x cut}(i_{coll})$ as:

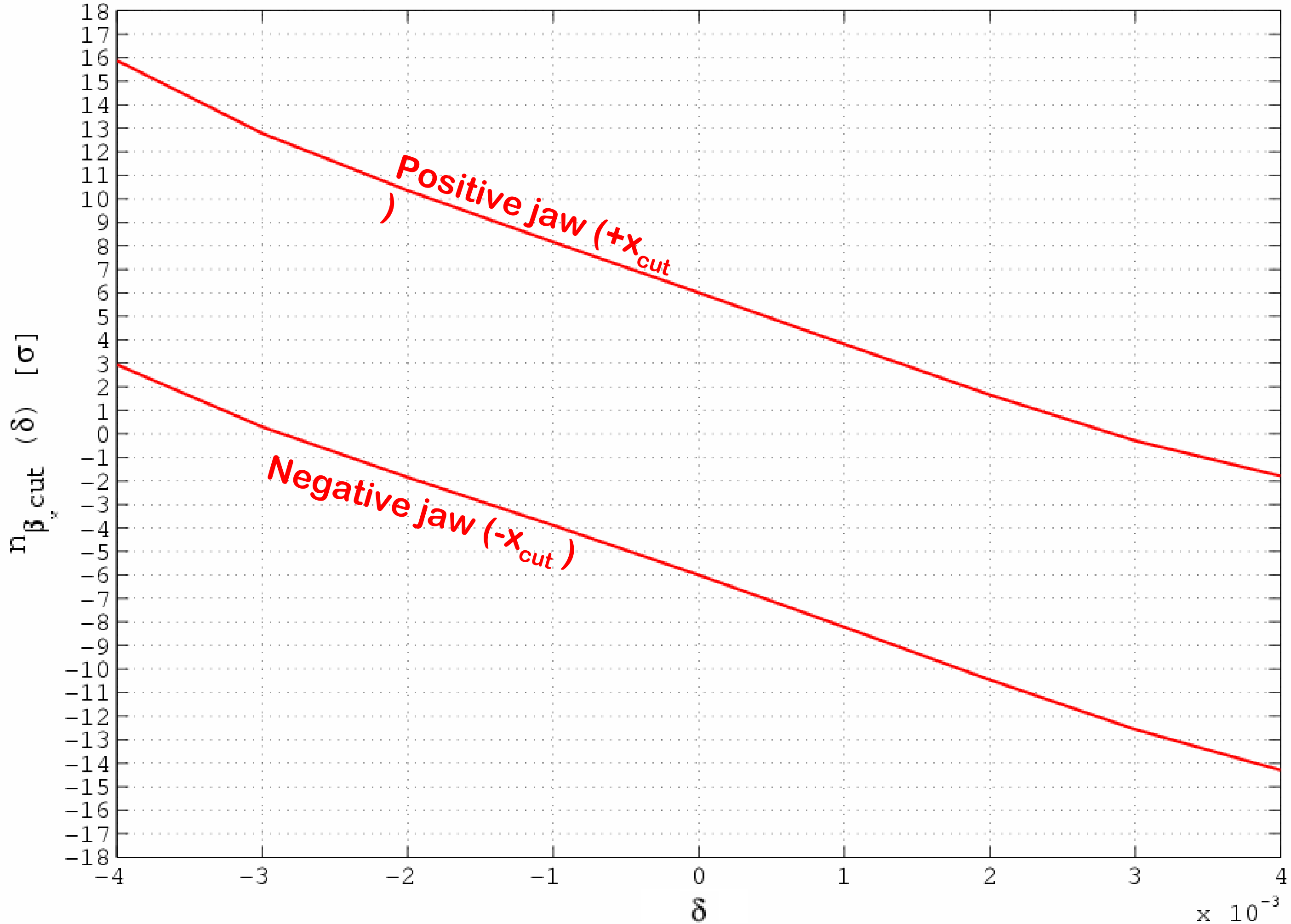
$$n_{\beta_x cut}(i_{coll}, \delta) = \frac{\pm x_{cut}(i_{coll}) - D_x(i_{coll}, \delta)\delta}{\sqrt{\varepsilon_x \beta_x (i_{coll}, \delta)}}$$

positive and negative x jaws

Plot $n_{\beta_x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

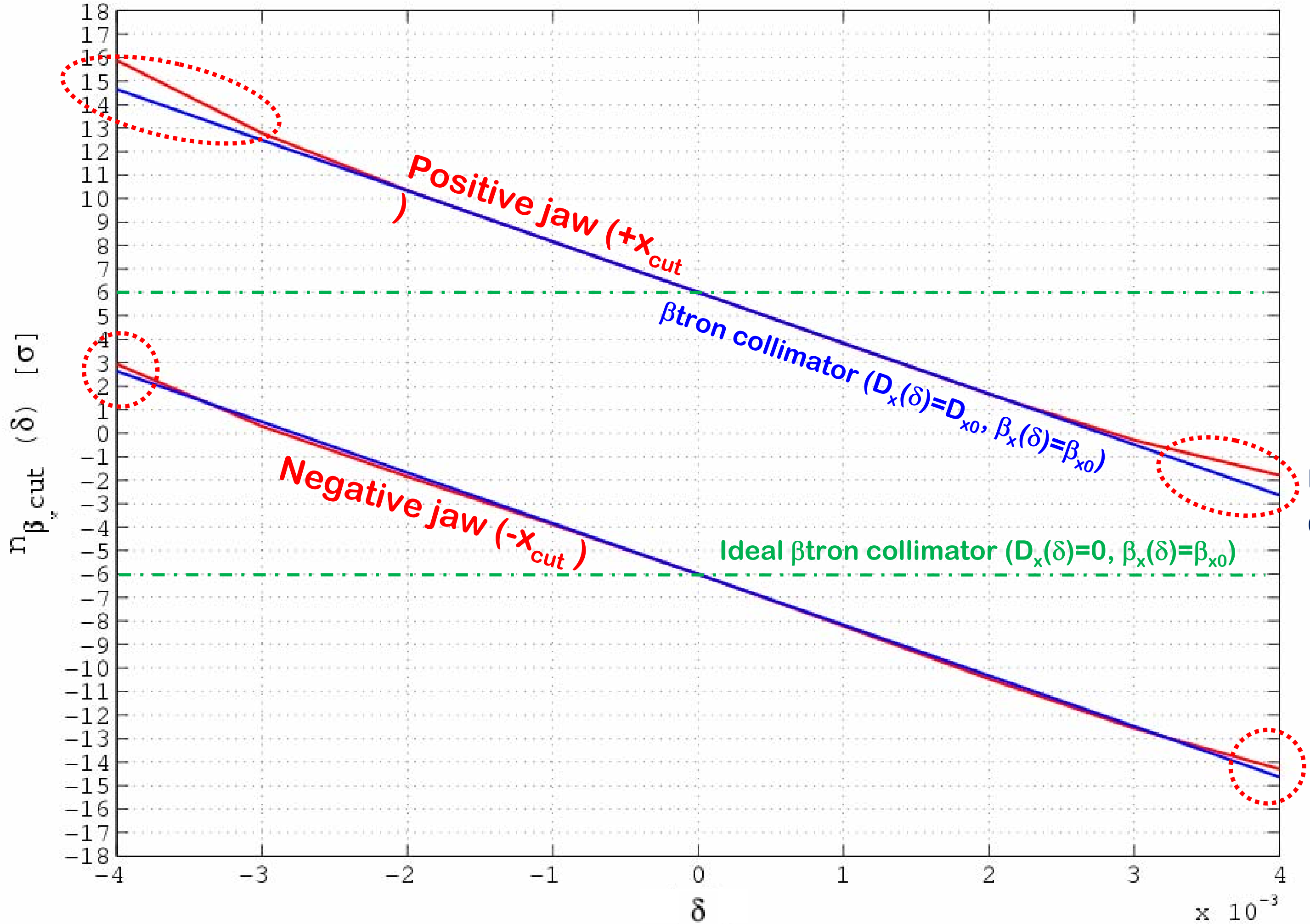
(Horizontal primary betatron collimator, beta beat IP1→IP5)



Plot $n_{\beta_x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

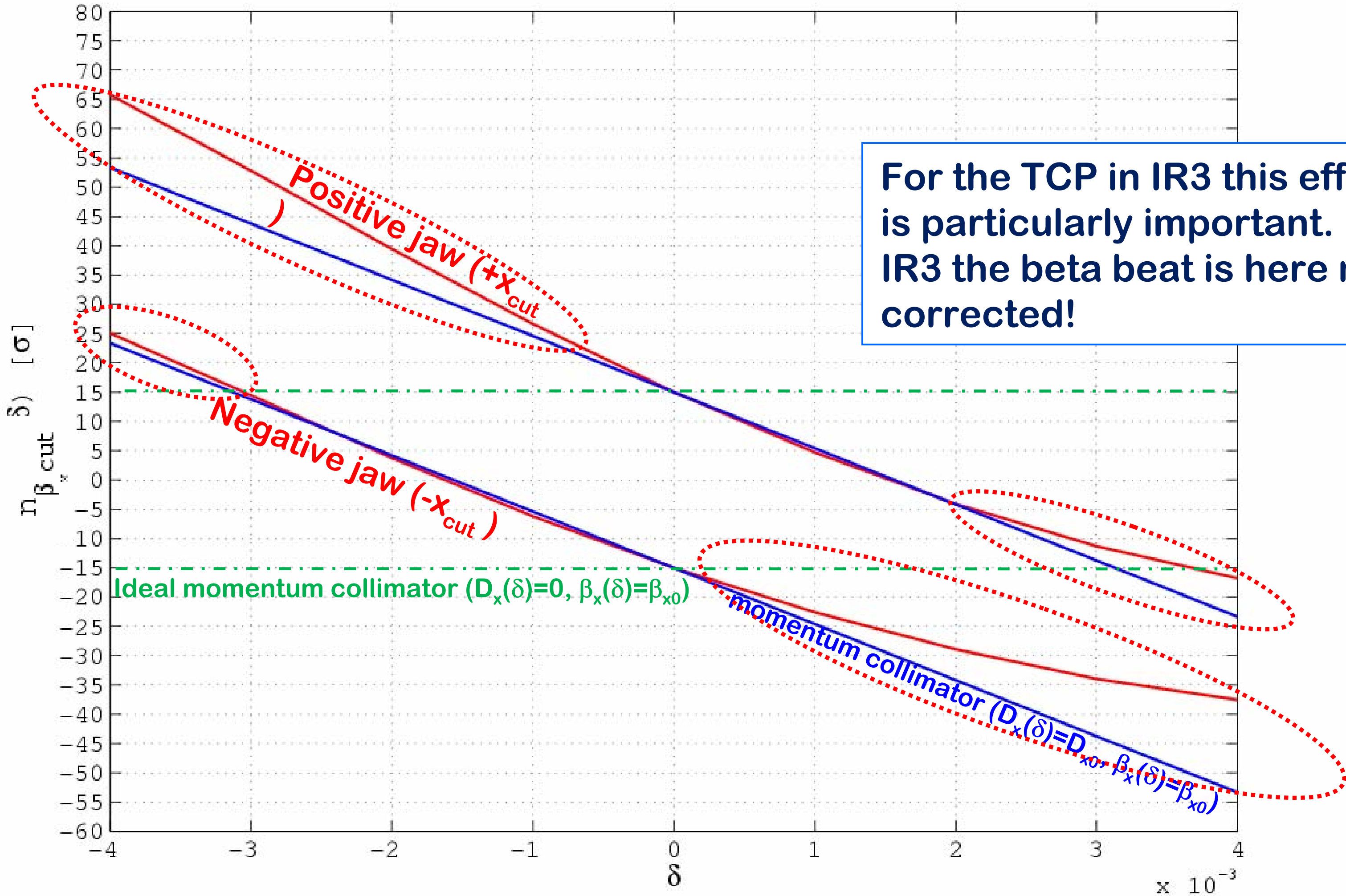
(Horizontal primary betatron collimator, beta beat IP1→IP5)



Effect of off momentum $\beta+D_x$ dependance.

Plot $n_{\beta_x cut}(i_{coll})$ vs δ

An other example: TCP.6L3.B1
(Horizontal primary momentum cleaning collimator, beta beat IP1→IP5)

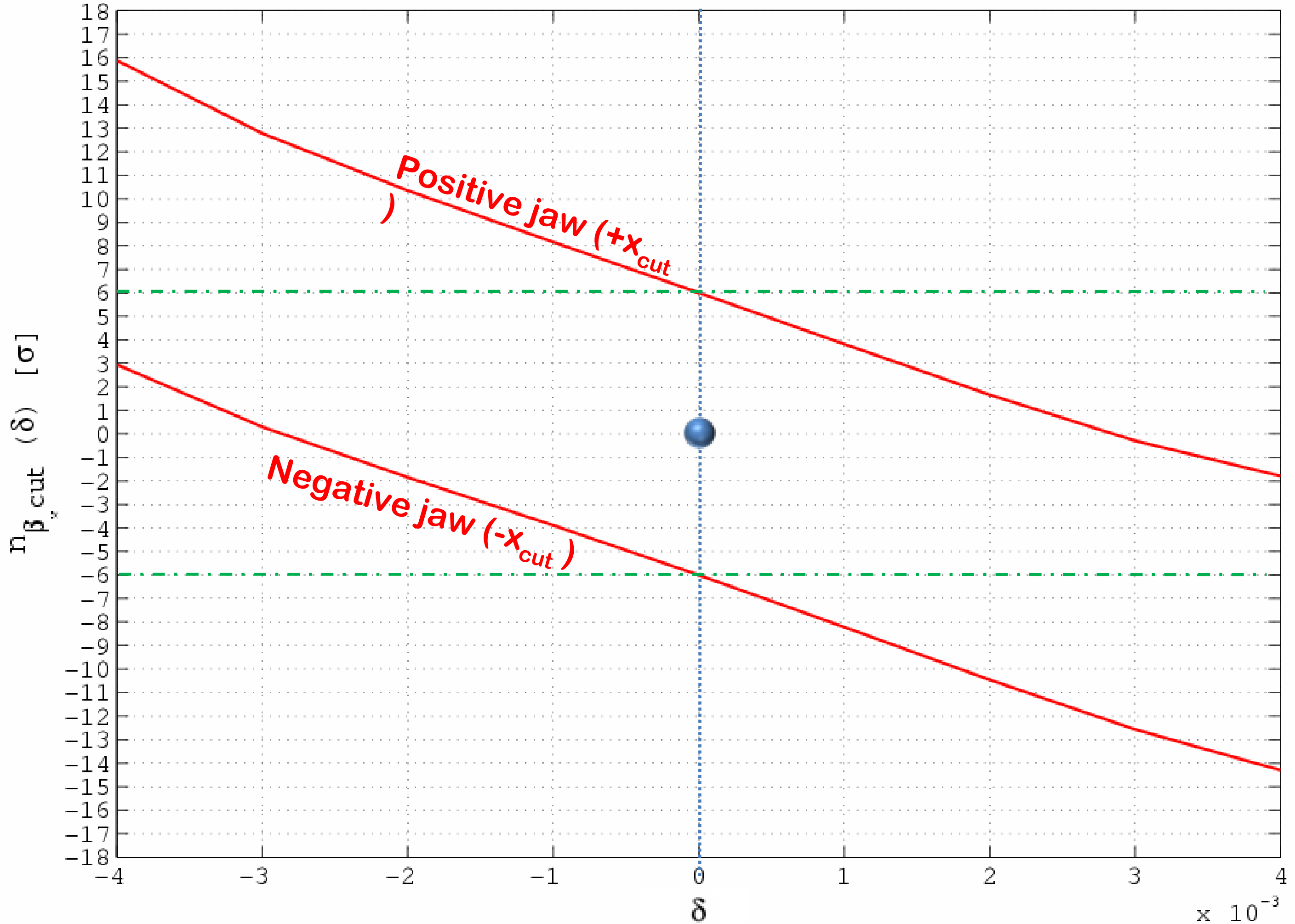


For the TCP in IR3 this effect is particularly important. In IR3 the beta beat is here not corrected!

Plot $n_{\beta x cut}(i_{coll})$ vs δ

Going back to: TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)

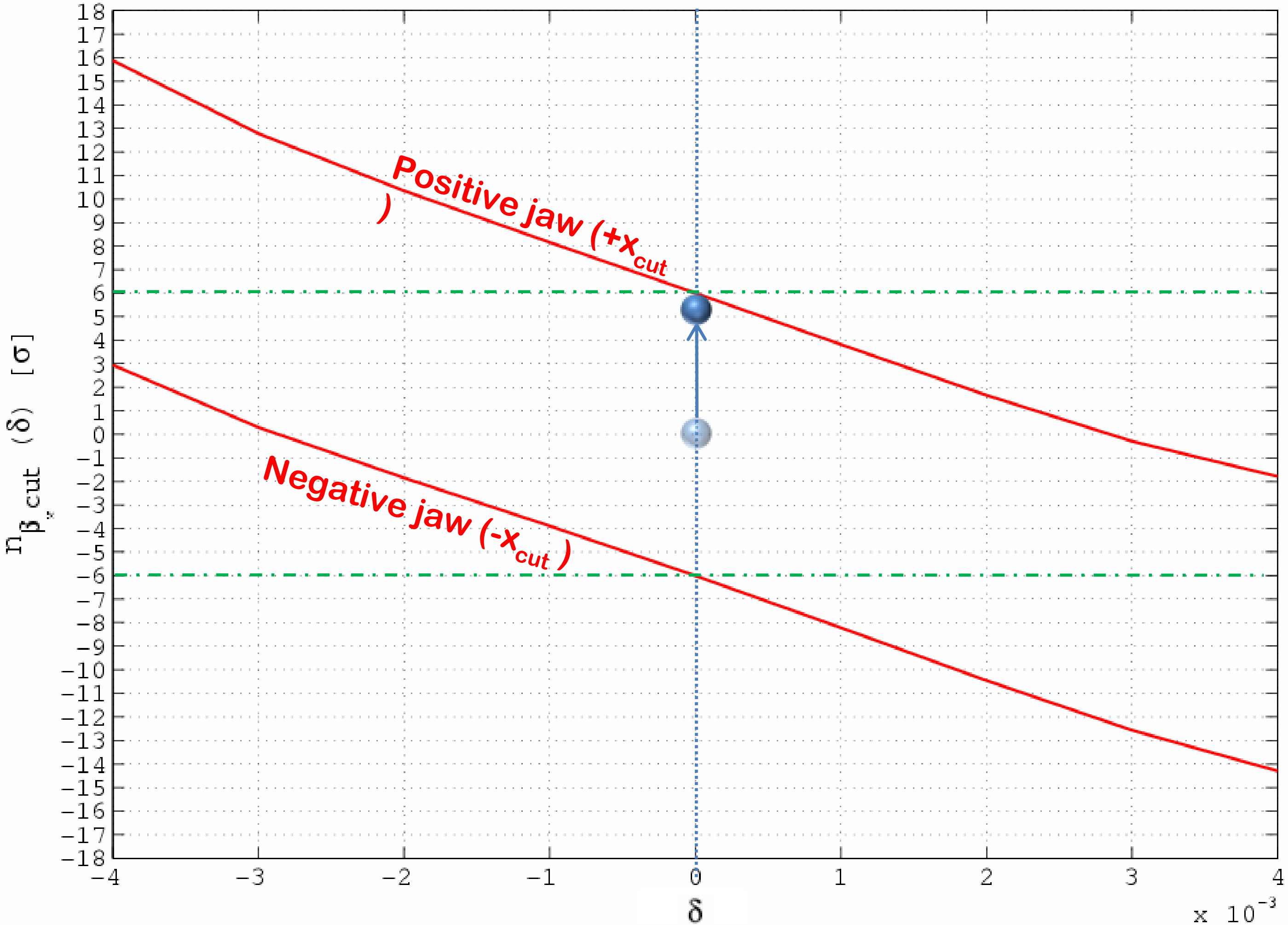


Let's consider the pure betatron motion of a particle with δ=0.

Plot $n_{\beta x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1➔IP5)

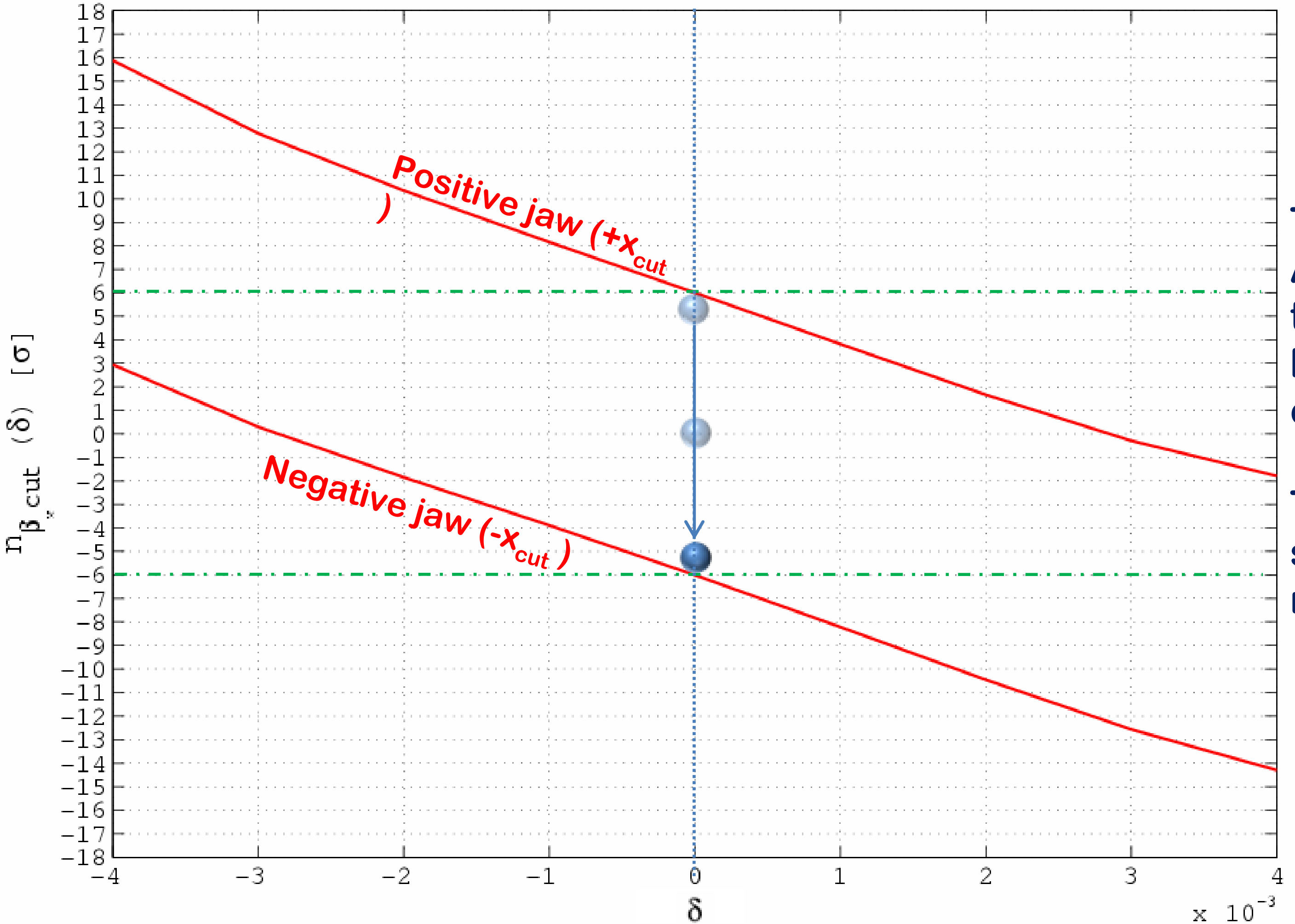


The particles with $A_x < |x_{cut}|$ are free to oscillate without being cut by the collimator jaws

Plot $n_{\beta x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)



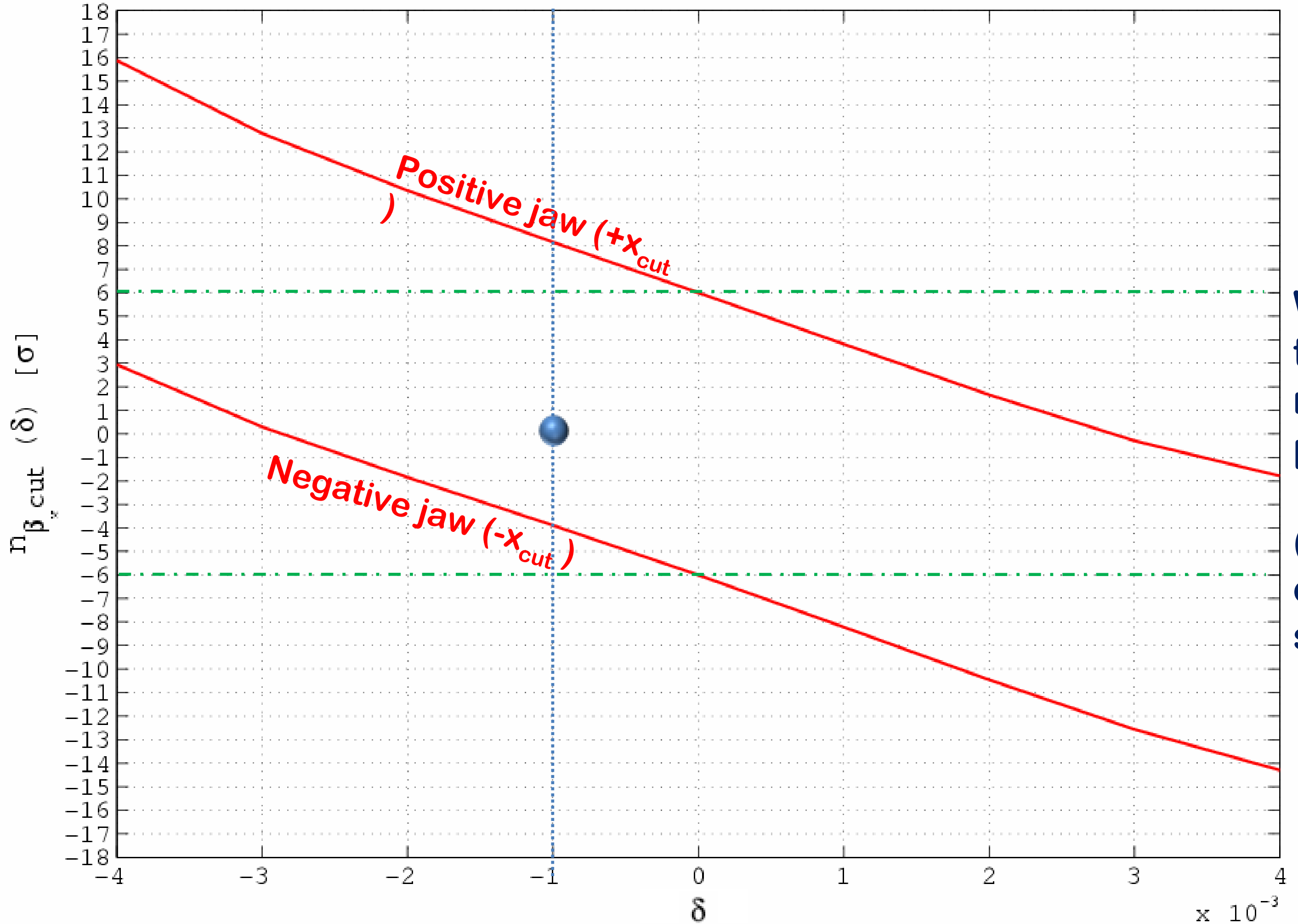
The particles with $A_x < |x_{cut}|$ are free to oscillate without being cut by the collimator jaws.

The oscillation is symmetric around $n_{\beta x cut}=0$

Plot $n_{\beta_x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)



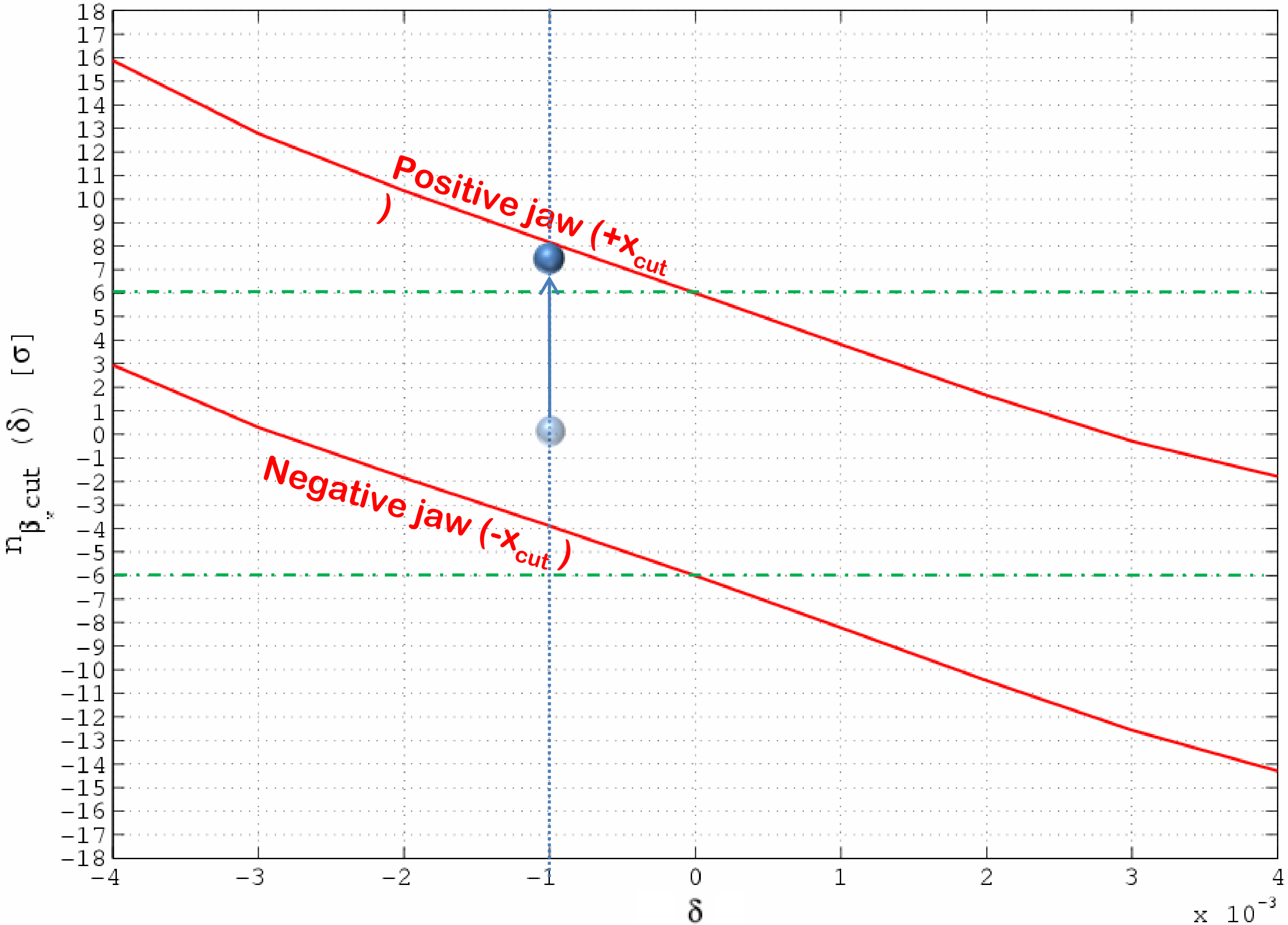
We now consider the pure betatron motion for a particle with $\delta>0$

(synchrotron oscillation much slower)

Plot $n_{\beta_x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)

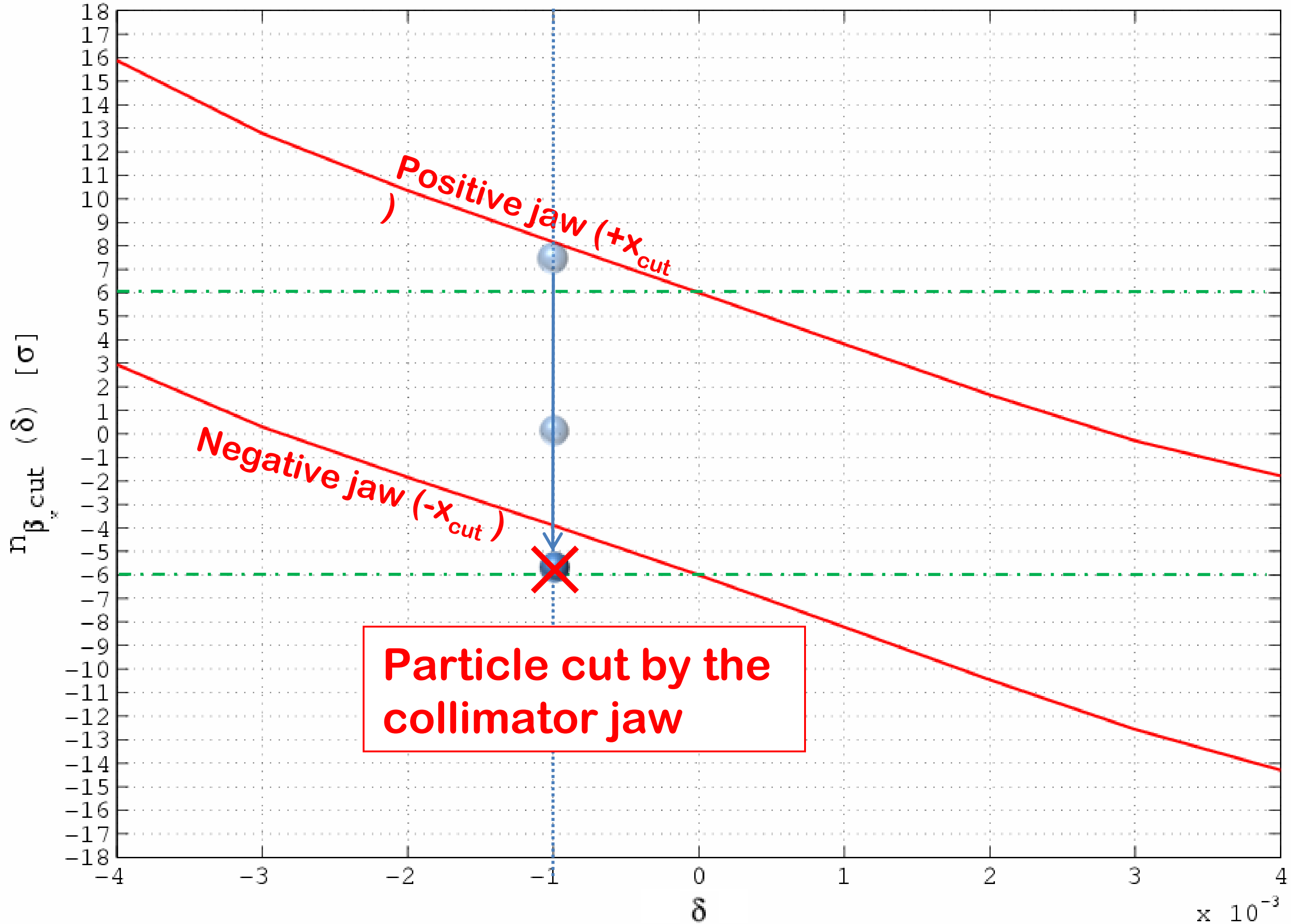


We now consider the pure betatron motion for a particle with $\delta>0$

Plot $n_{\beta_x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)



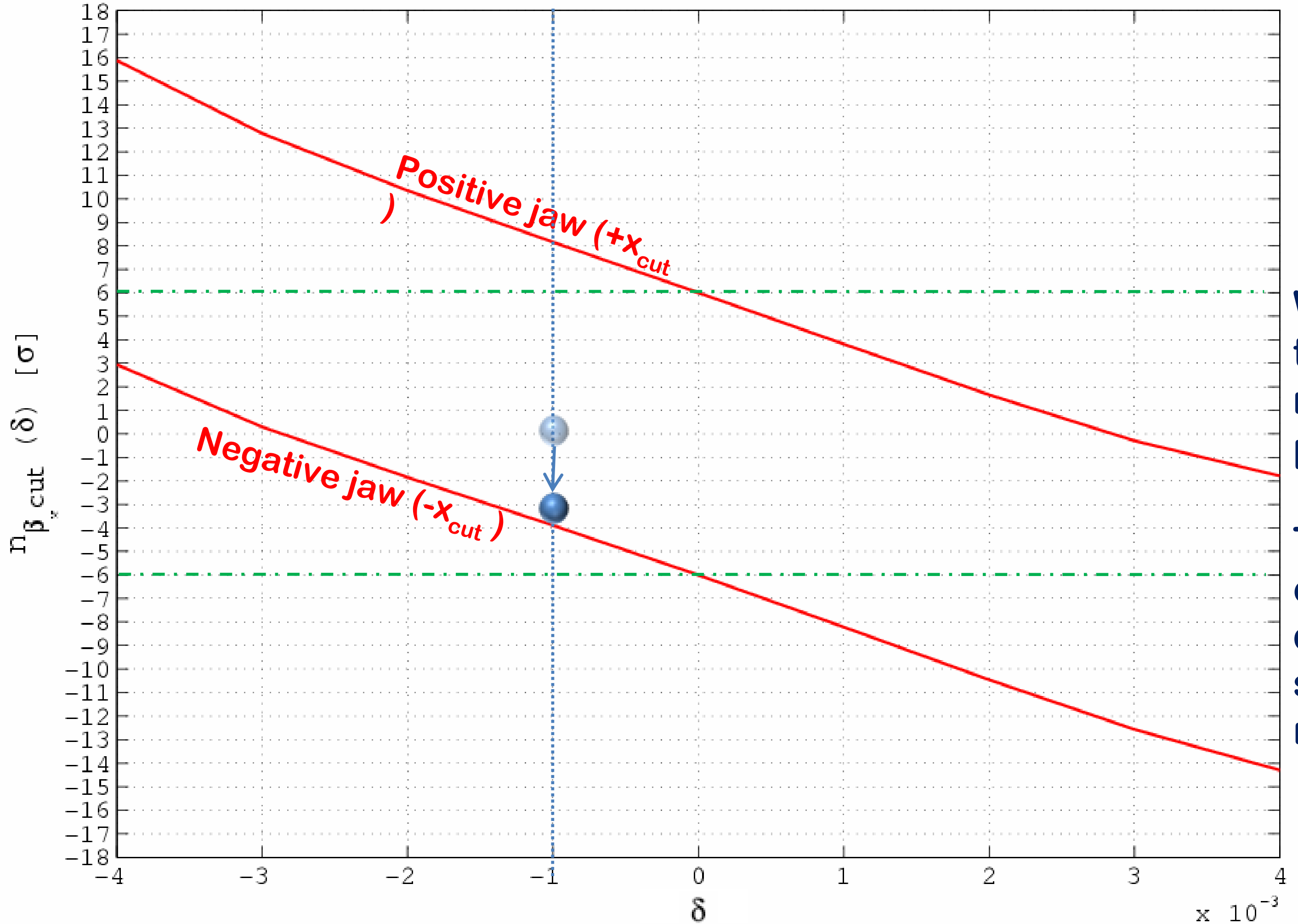
We now consider the pure betatron motion for a particle with $\delta>0$

The particle cannot move downwards symmetrically respect to $n_{\beta_x cut}=0$!

Plot $n_{\beta_x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)



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Plot $n_{\beta_x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

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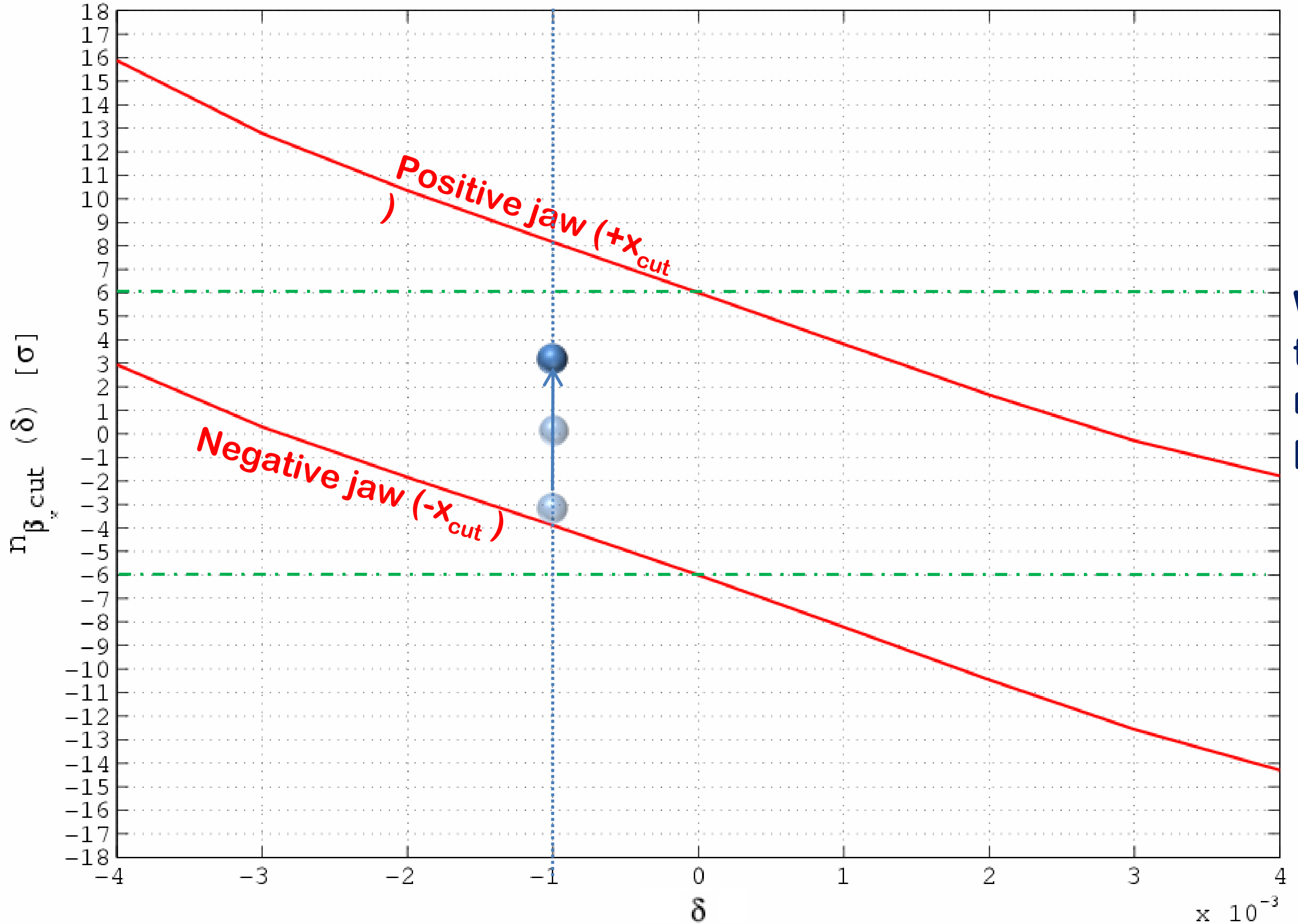
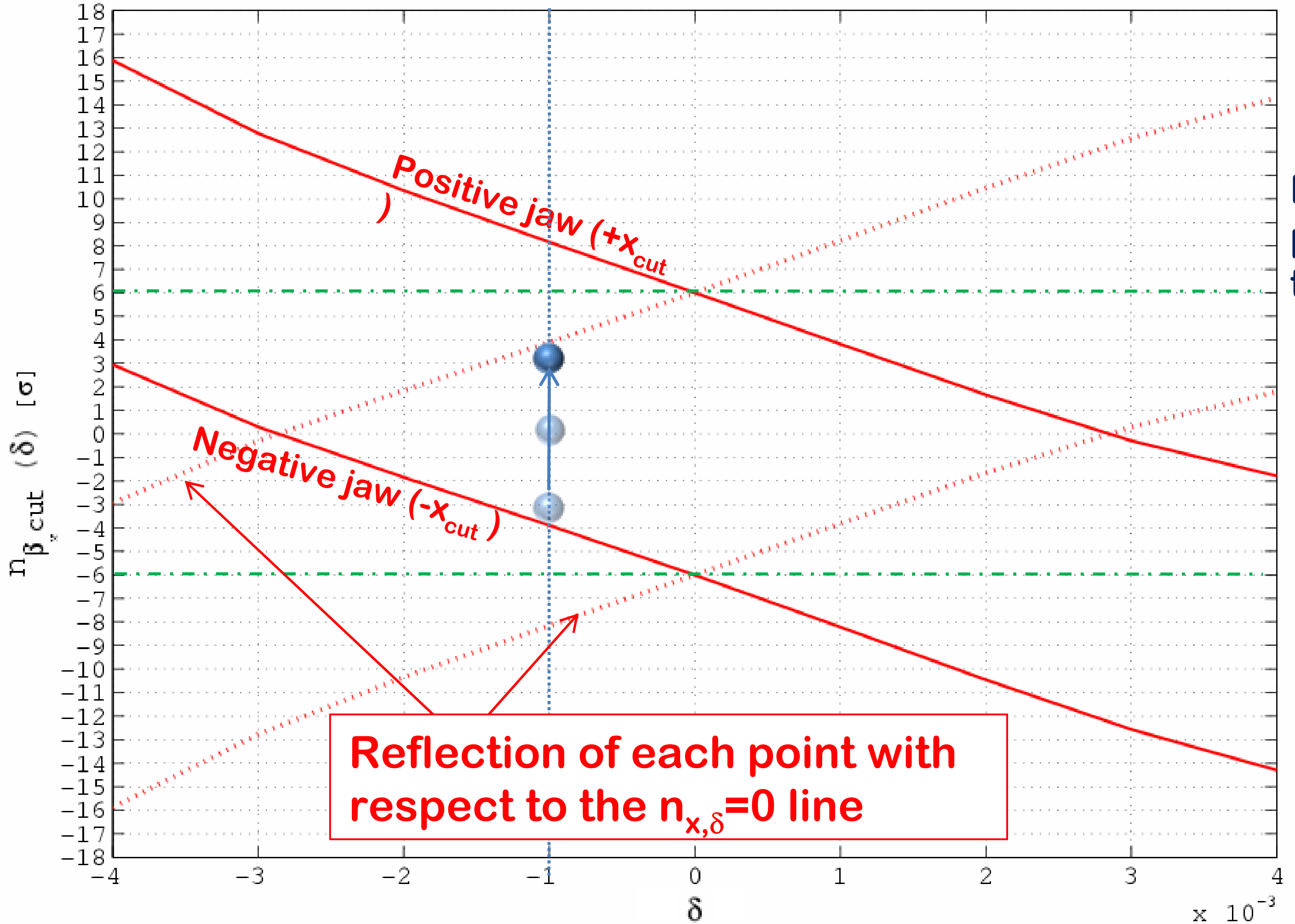


We now consider the pure betatron motion for a particle with δ>0

Plot $n_{\beta_x cut}(i_{coll})$ vs δ

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)

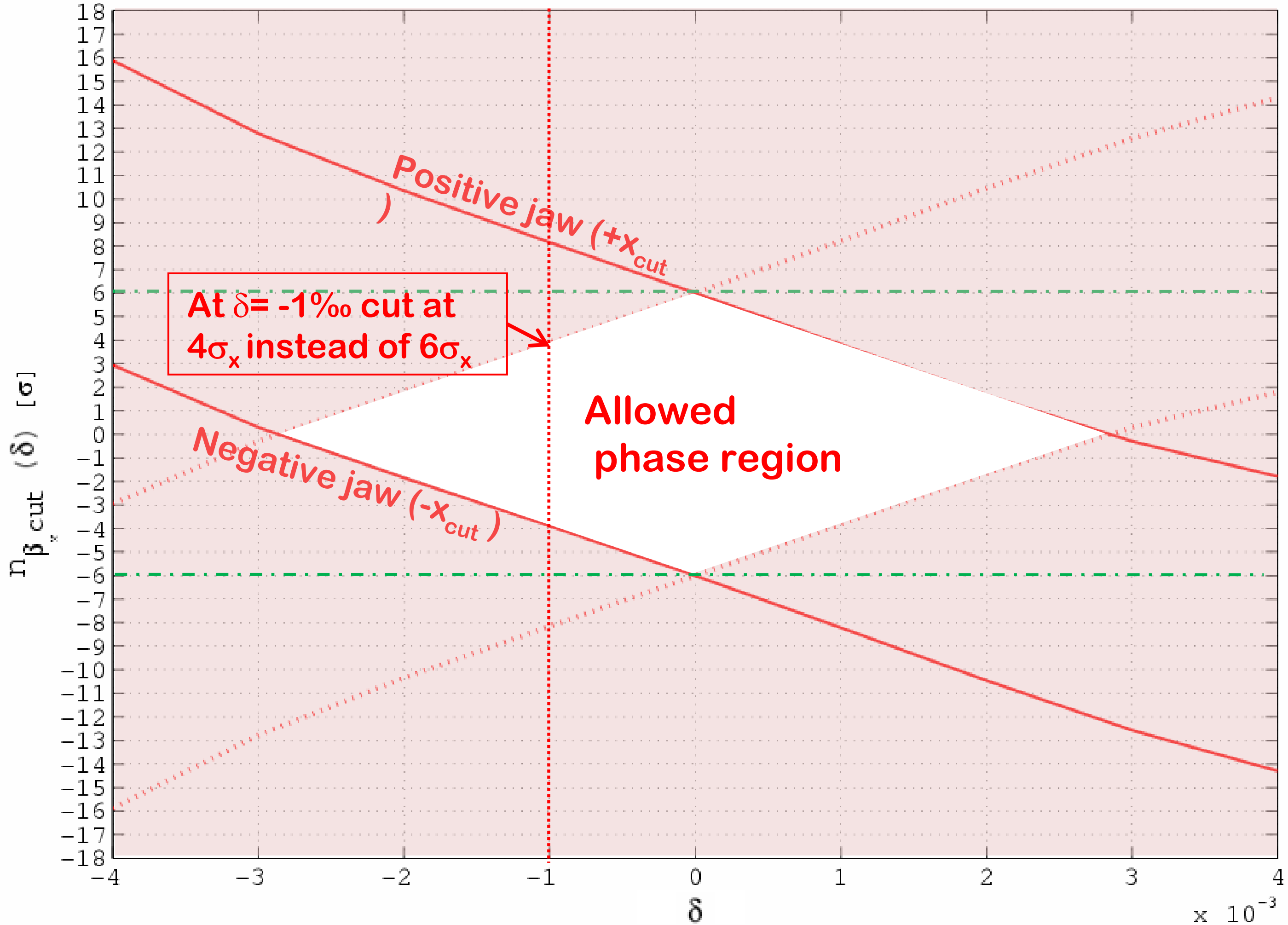


Reflecting each point with respect to the $n_{\beta x cut}$=0 line

Allowed phase space region

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)

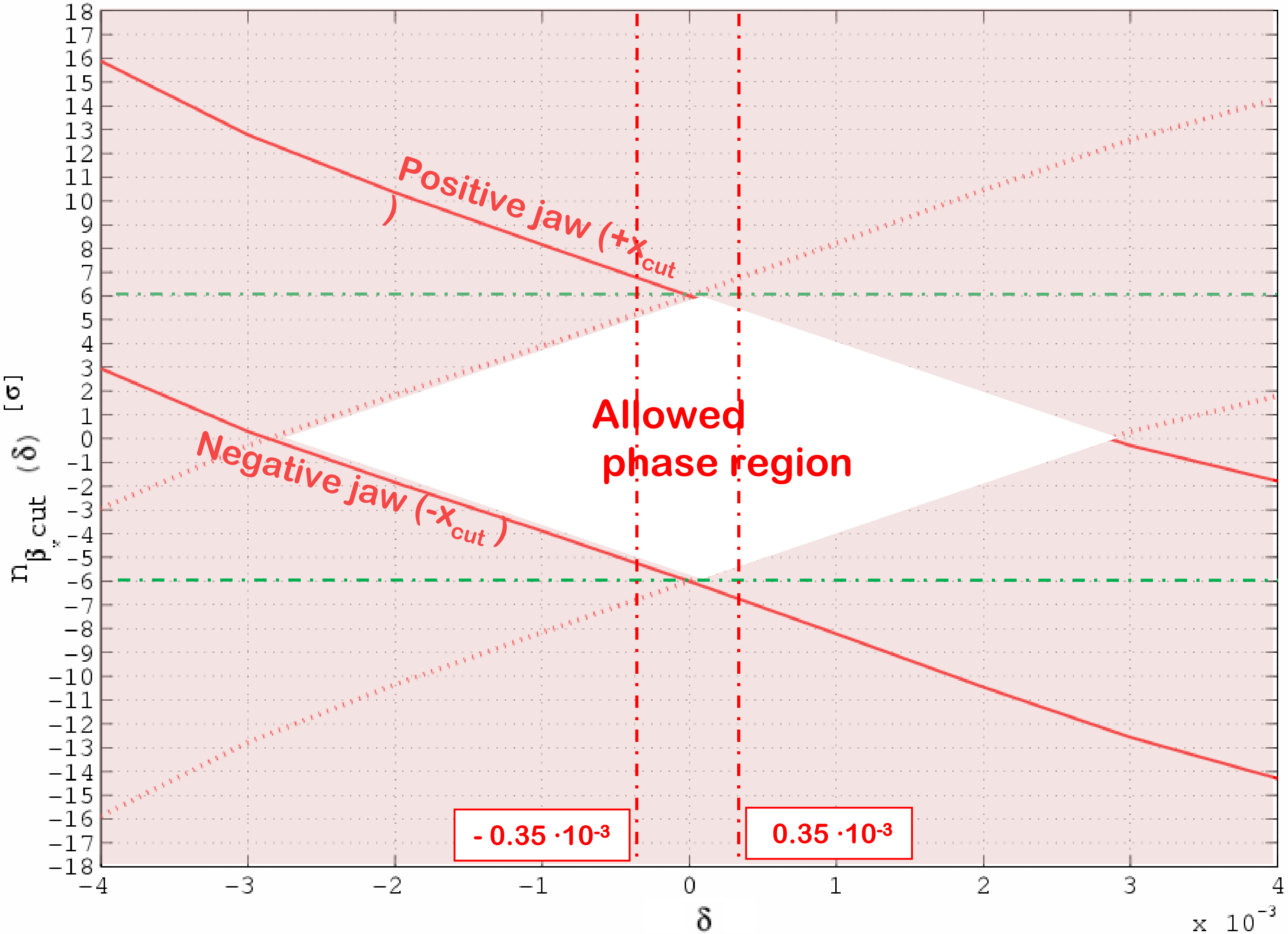


Reflecting each point with respect to the $n_{\beta x cut}$=0 line an "allowed phase space region" is defined. (single turn amplitude jumps of many σ_x are excluded)

Allowed phase space region

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)



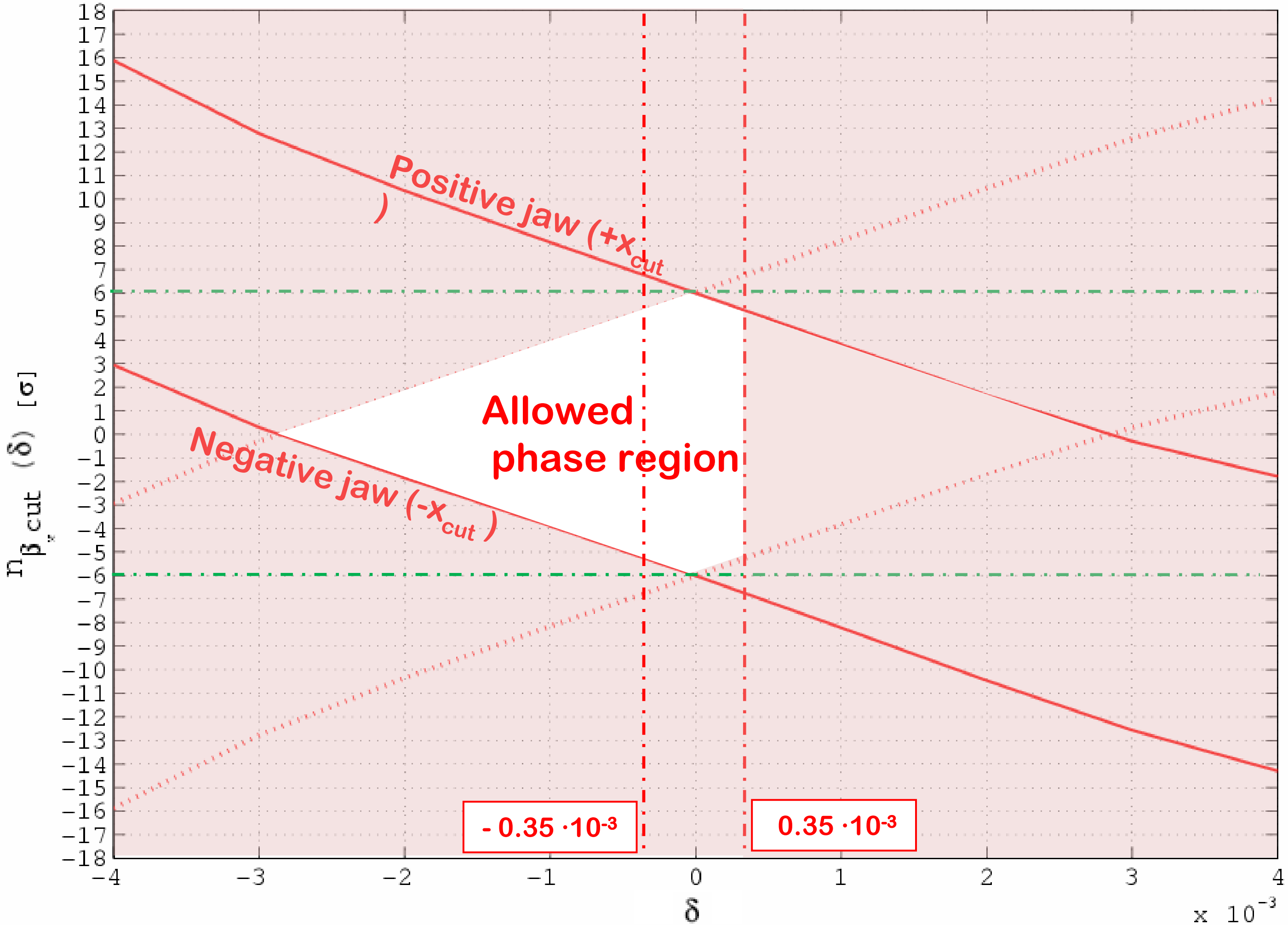
Momentum aperture in the ring: ±7·10^{-3} [δ] (mechanical aperture, tolerances, orbit, 3σ beam)

Half height of the bucket : ± 0.35 ·10^{-3}[δ] [E. Shaposhnikova, S. Fartoukh, B. Jeanneret "LHC abort gap filling by proton beam"; *LHC project report t 63*]

Allowed phase space region

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1➔IP5)



Momentum aperture in the ring: ±7·10^{-3} [δ] (mechanical aperture, tolerances, orbit, 3σ beam)

Half height of the bucket : ± 0.35 ·10^{-3}[δ]

Particles cannot have δ> +0.35 ·10^{-3}[δ].

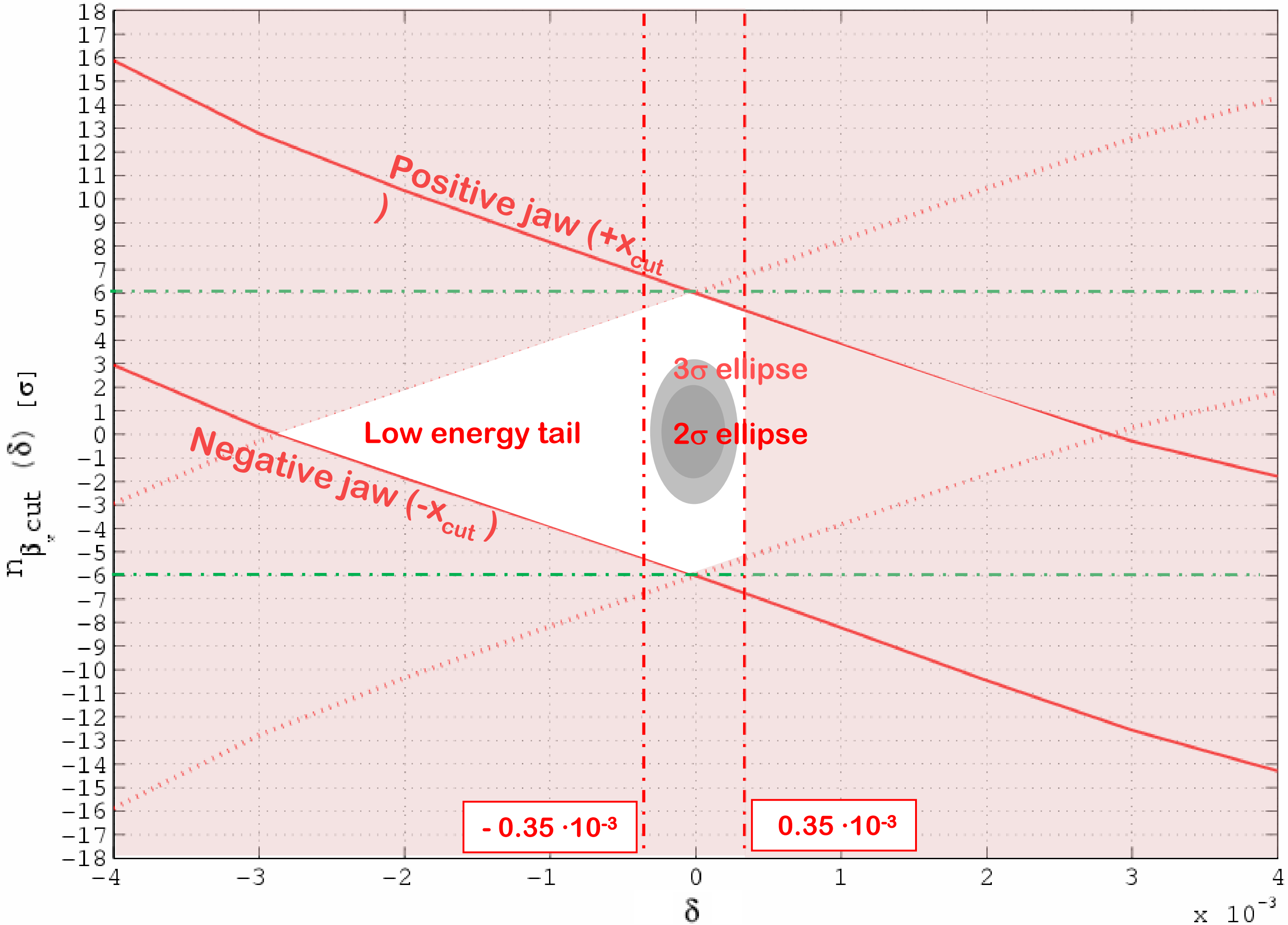
Particles can have a lower energy than the bucket due to:

- **Synchrotron radiation**
- **Impedance**

Allowed phase space region

TCP.C6L7.B1

(Horizontal primary betatron collimator, beta beat IP1→IP5)



Momentum aperture in the ring: ±7·10^{-3} [δ] (mechanical aperture, tolerances, orbit, 3σ beam)

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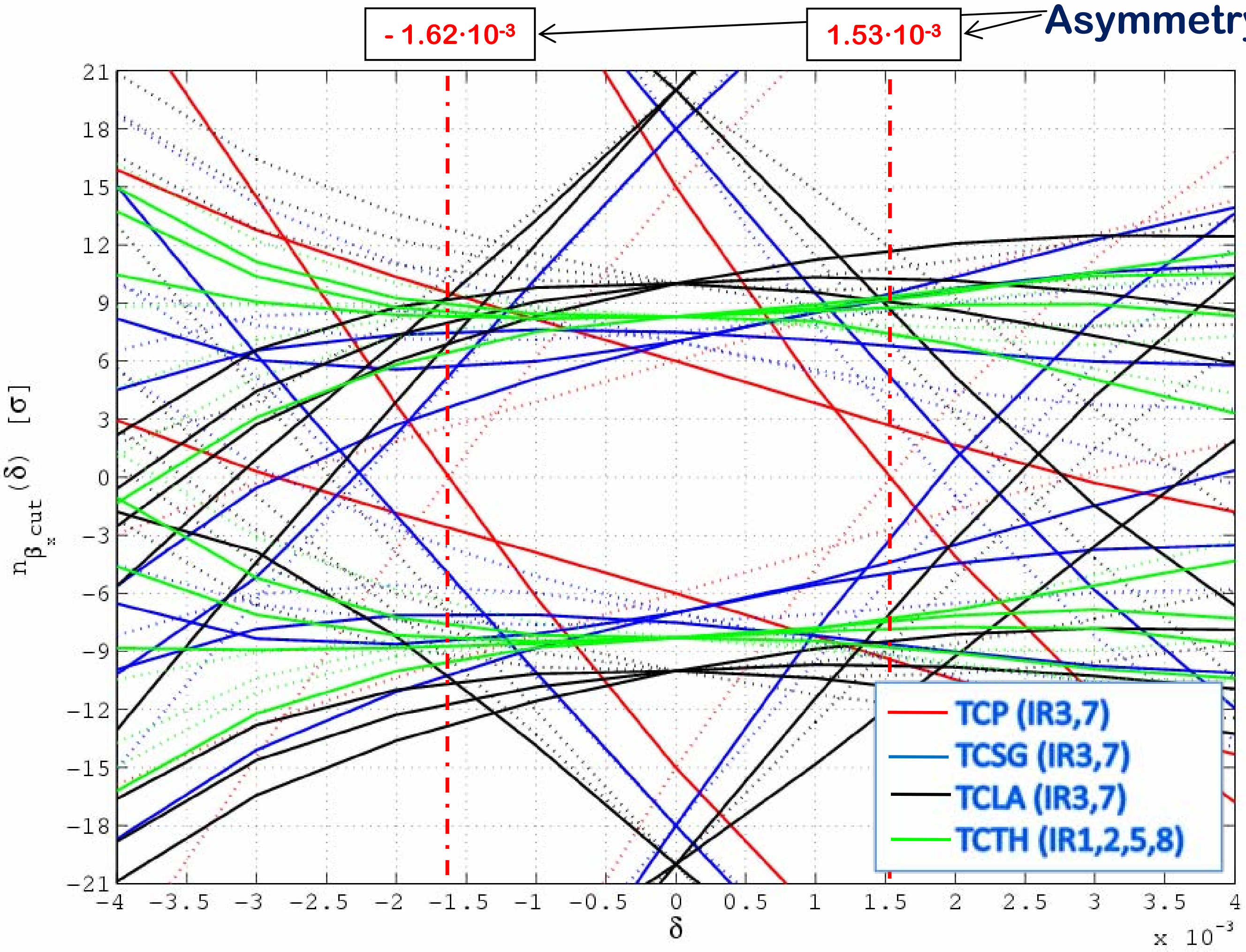
Particles cannot have δ> +0.35 ·10^{-3}[δ].

Particles can have a lower energy than the bucket due to:

- **Synchrotron radiation**
- **Impedance**

Off momentum Beta beat IP1→IP5

Overlapping all the horizontal collimators:



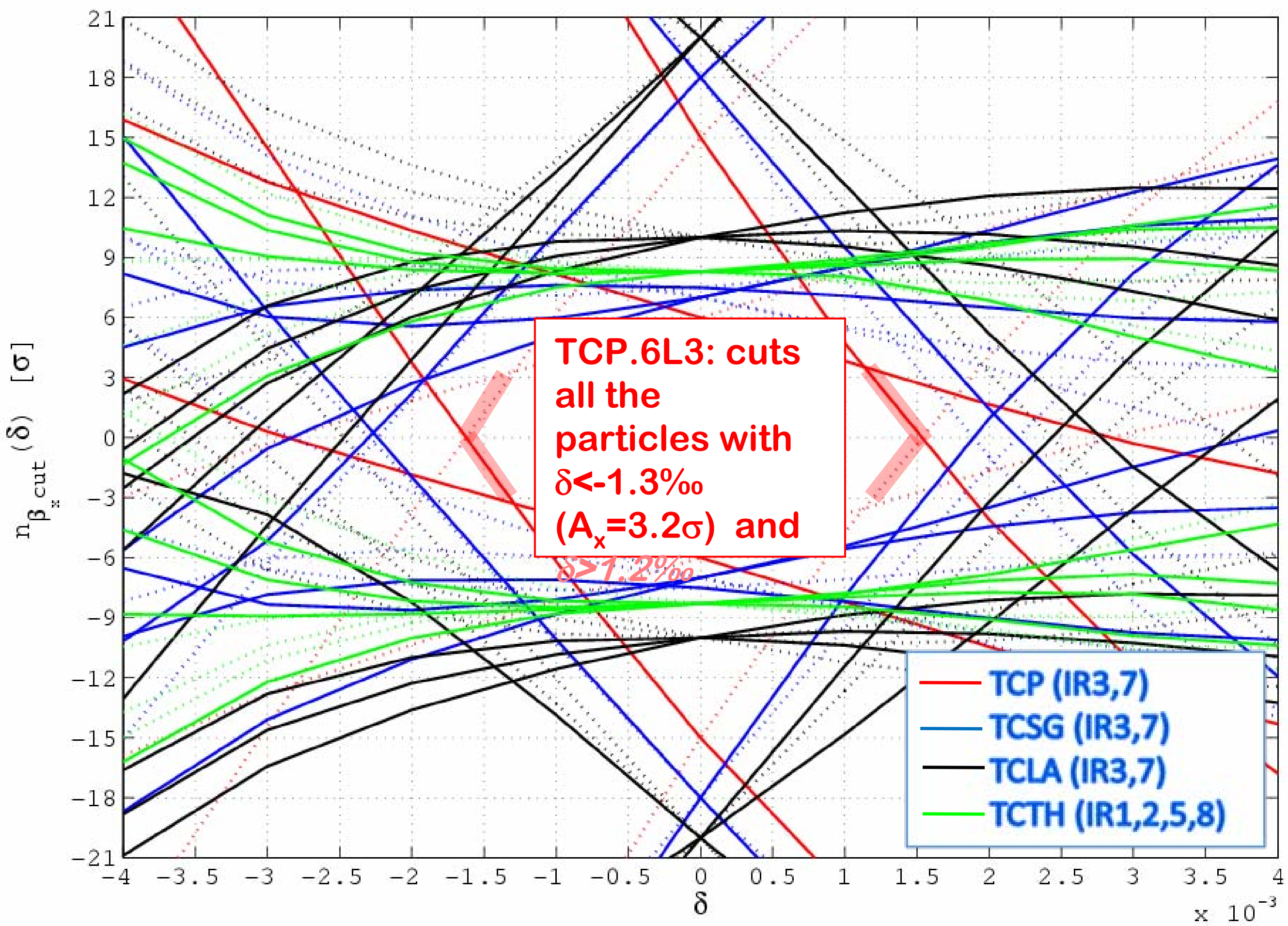
Each solid line represent one collimator jaw.

Each color represent one collimator family (legend)

The phase space is limited by the jaws of the two horizontal TCP (TCP.6L3, TCP.C6L7)

Off momentum Beta beat IP1→IP5

Overlapping all the horizontal collimators:



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Off momentum Beta beat IP1→IP5

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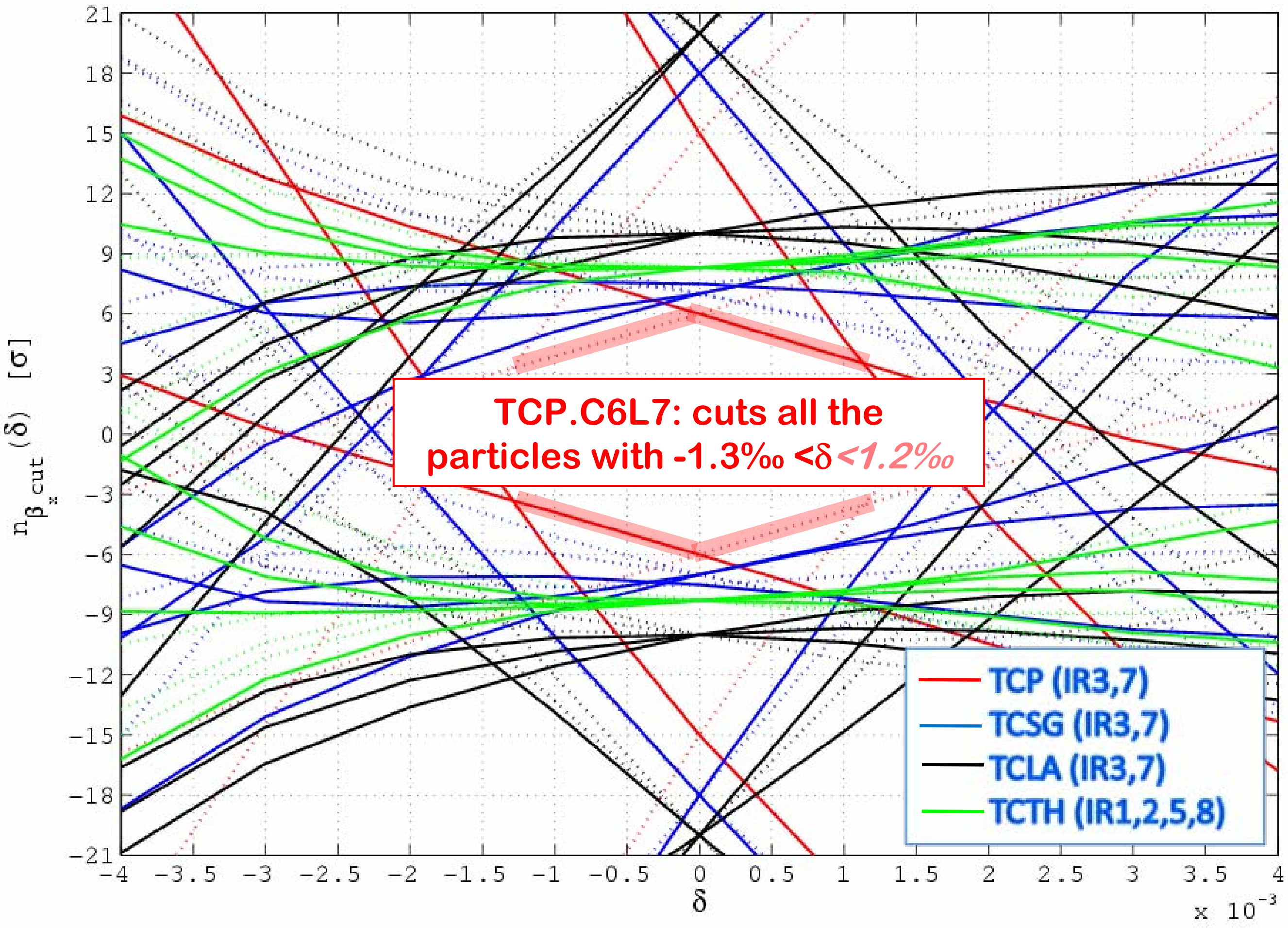
Overlapping all the horizontal collimators:



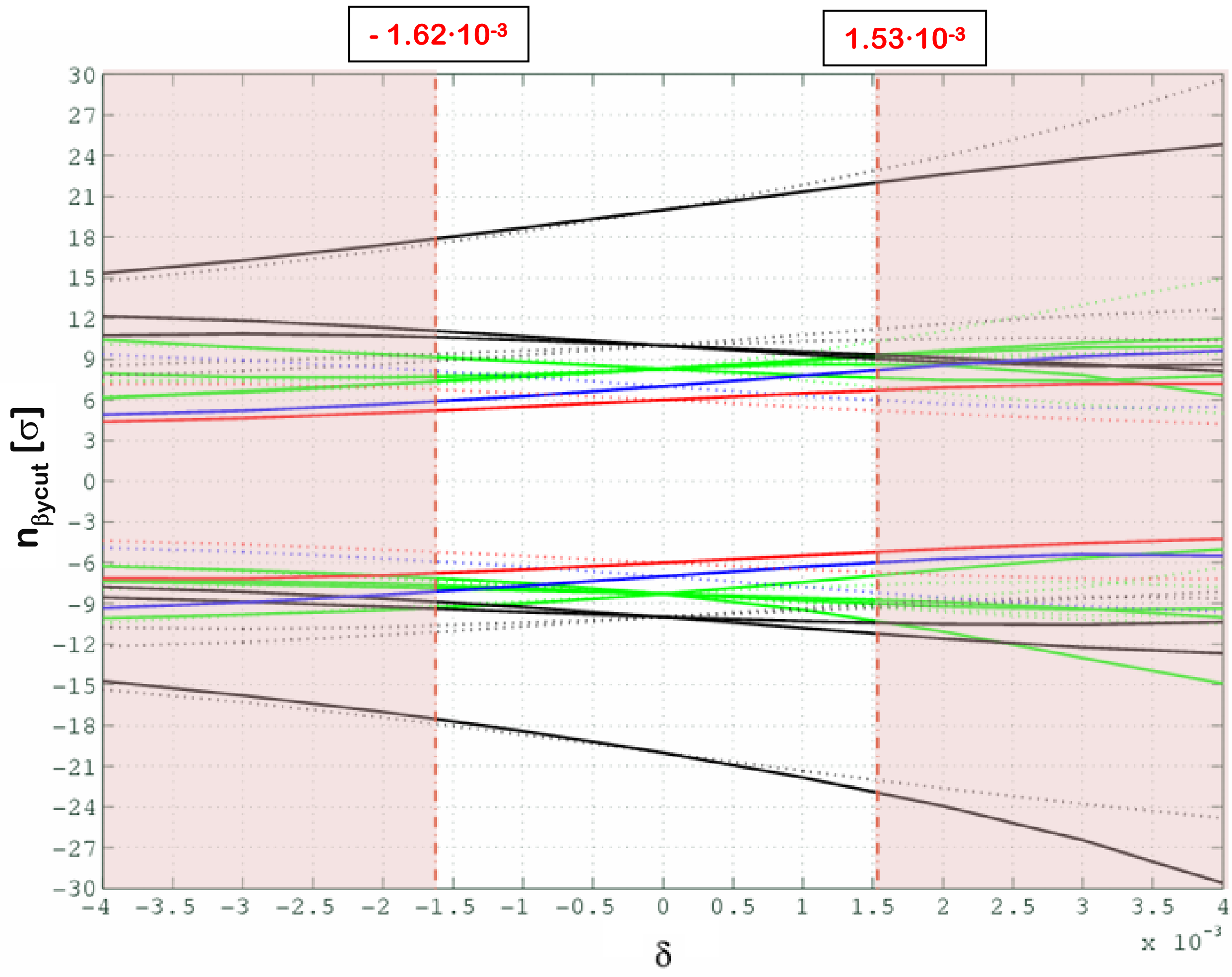
Each solid line represent one collimator jaw.

Each color represent one collimator family (legend)

The phase space is limited by the jaws of the two horizontal TCP (TCP.6L3, TCP.C6L7)

Off momentum Beta beat IP1→IP5

Overlapping all the vertical collimators:



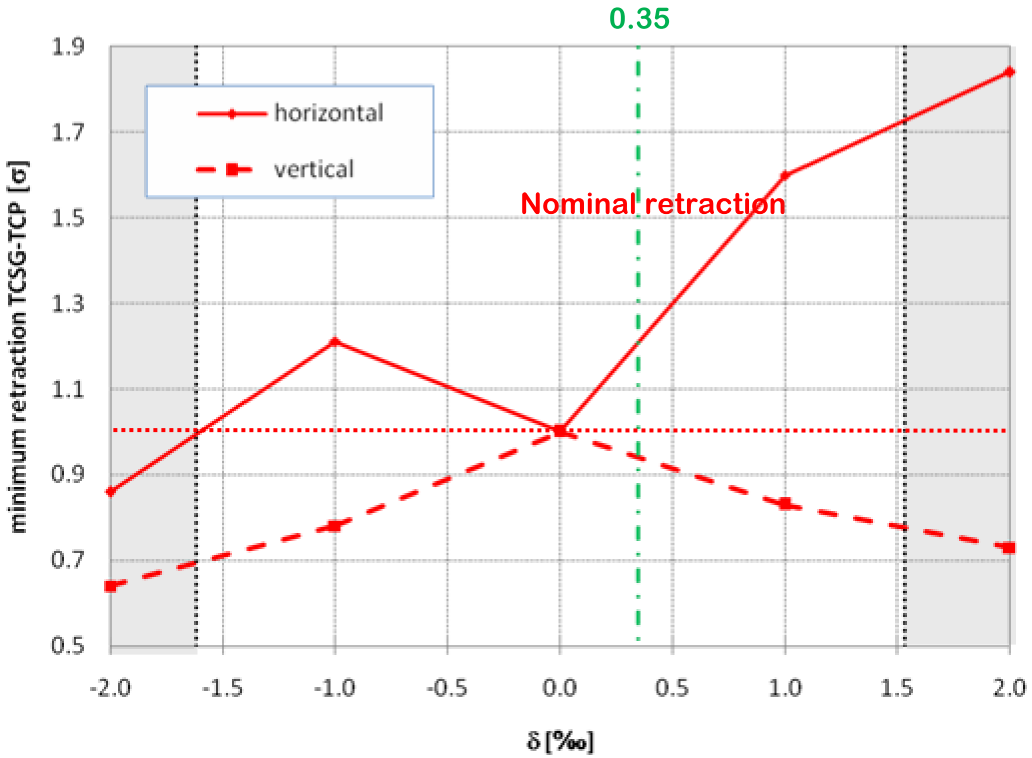
The limitation in δ comes from the horizontal plane.

At -1.5‰ the allowed phase space is reduced by 0.8σ

IR7 TCSG-TCP retraction [σ]

TCSG-TCP retraction: Half-gap$_{TCSG}$ [σ] - Half-gap$_{TCP}$ [σ]

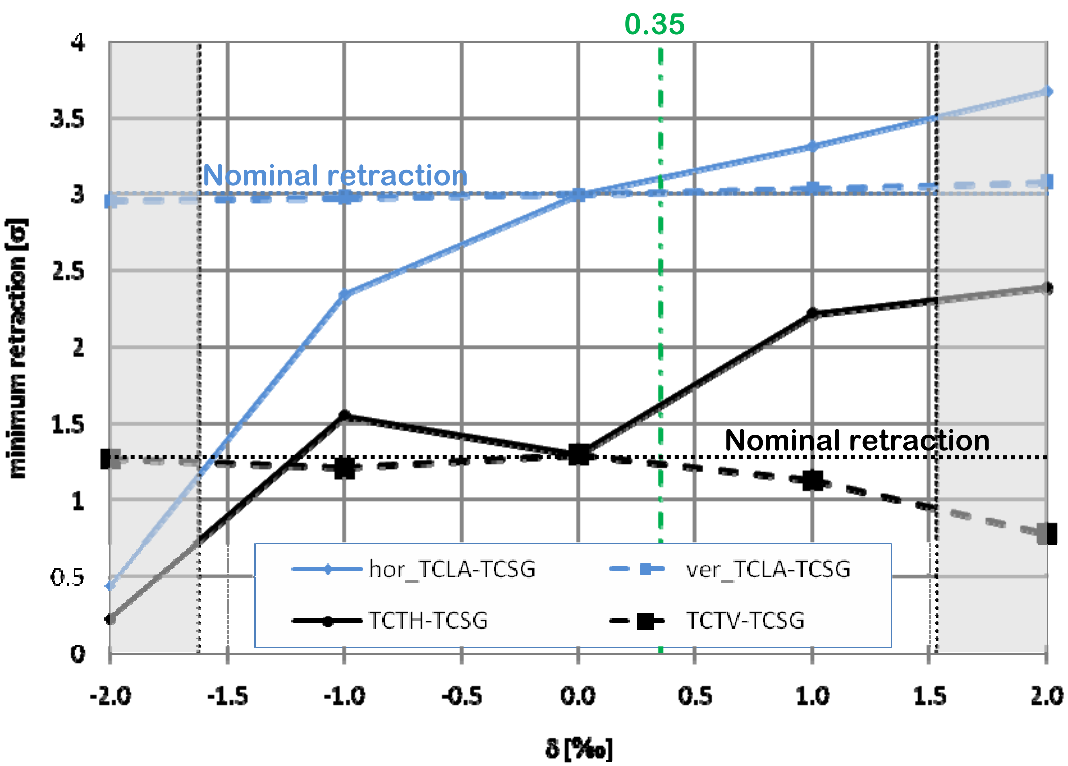
Nominal half-gap ($\beta=\beta_0$) in IR7: TCSG =7σ
TCP= 6σ



- **No retraction reduction** for the horizontal secondary collimators
- **0.3σ reduction** for vertical TCSG retraction → tighter tolerances in operation!

IR7 TCLA/TCTH-TCSG retraction [σ]

Nominal half-gap ($\beta=\beta_0$) in IR7: TCSG =7σ
TCLA =10σ
TCTH/V= 8.3σ

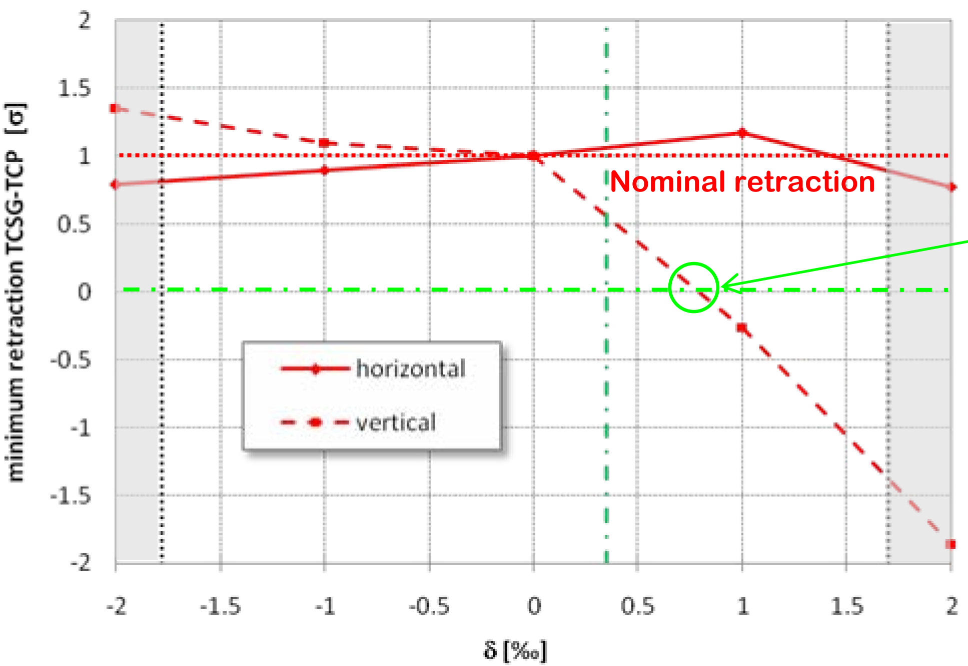


- Horizontal TCLA-TCSG:
  1.8σ reduction ➔ Worrisome!
- Horizontal TCTH-TCSG:
  0.5σ reduction

tighter tolerances!!

Off momentum Beta beat IP5→IP1

- TCP.6L3:cuts all the particles with $\delta < -1.3‰$ (A_x=4.1σ) , *$\delta > 1.4‰$ (A_x=2.2σ)*
- TCP.C6L7:cuts all the particles with $-1.3‰ < \delta$ *$< 1.4‰$*
- Primary collimators cut at: -1.8‰, 1.7 ‰
- Collimators retraction:



- **Retraction reduction down to 0.7σ** between horizontal TCP and TCSG
- **TCSG** becoming a **primary** in the **vertical** plane for $\delta \geq 0.8‰$

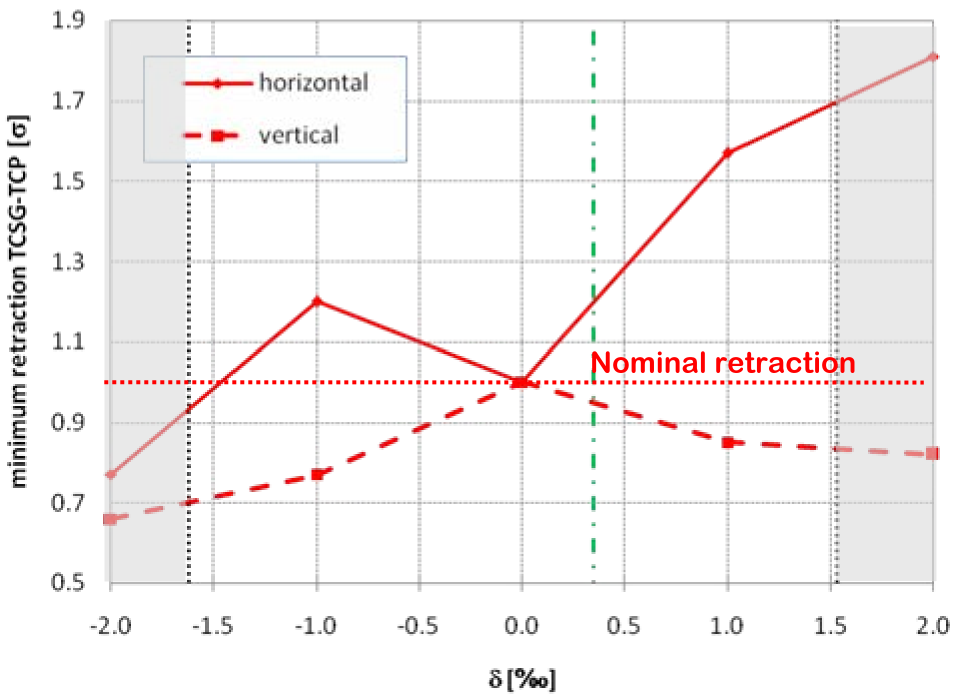
Worse than IP1→IP5 beta beat case from the collimation point of view!!

Decision: off momentum beta beat IP1→IP5

Off momentum Beta beat IP1→IP5

Collimator setting:

	TCP	TCSG	TCLA
IR3	15σ	18σ	20σ
IR7	9σ	10σ	13σ
	TCTH/V		
IR1/2/5/8	11.3σ		

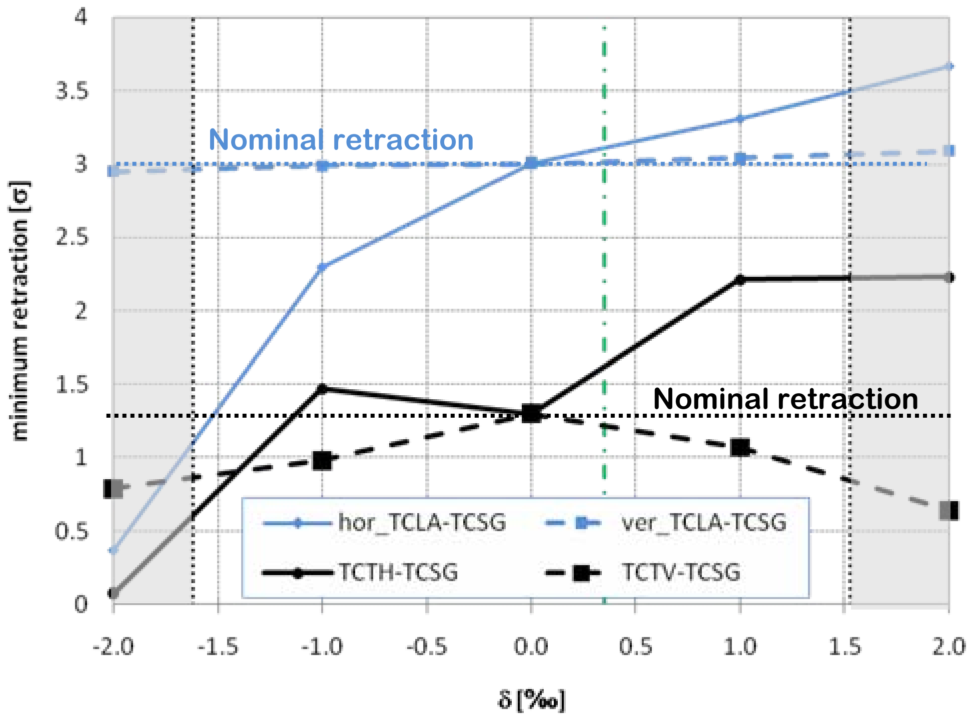


- 0.07σ retraction reduction for the horizontal TCSG
- 0.3σ retraction reduction for the vertical TCSG

Off momentum Beta beat IP1→IP5

Collimator setting:

	TCP	TCSG	TCLA
IR3	15σ	18σ	20σ
IR7	9σ	10σ	13σ
	TCTH/V		
IR1/2/5/8	11.3σ		



Respect to the nominal setting **retraction reduction** of:

- **0.6σ** for TCTH-TCSG
- **1.8σ** for horizontal TCLA-TCSG
- **0.5σ** for TCTV-TCSG

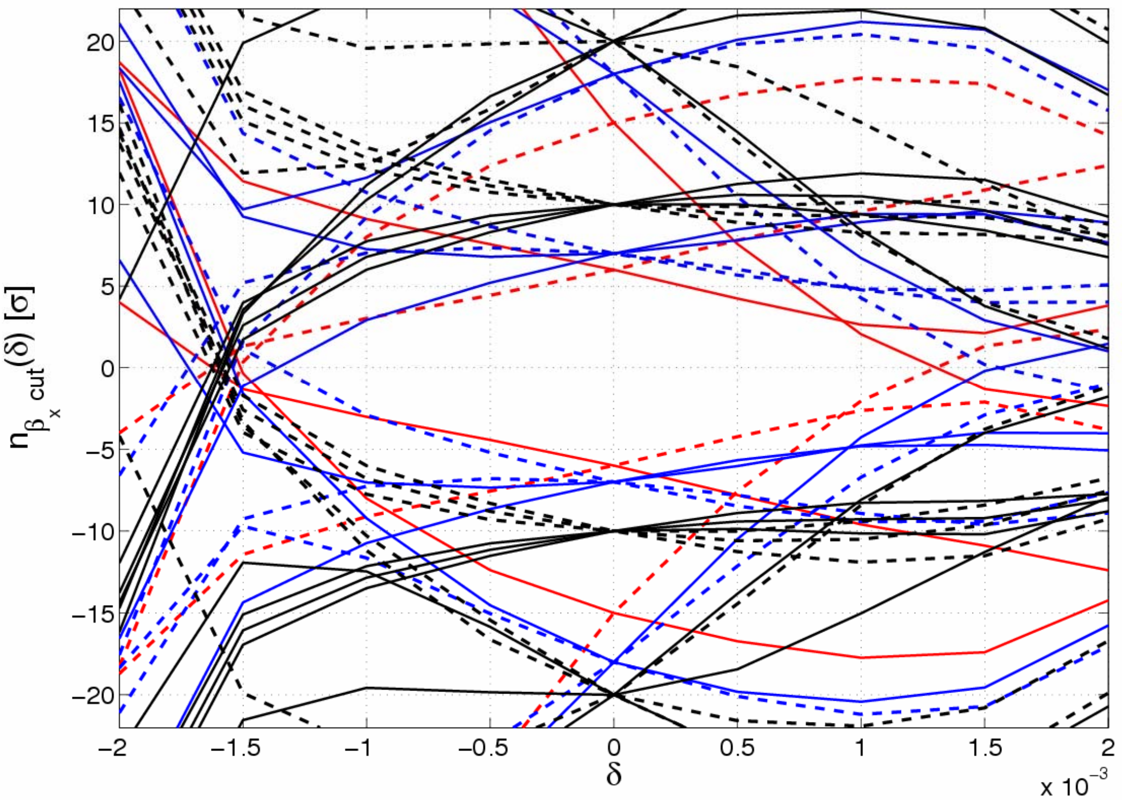
↓

Less stable operation

Upgrade optics Beta beat IP1→IP5

Collimator setting:

	TCP	TCSG	TCLA
IR3	15σ	18σ	20σ
IR7	6σ	7σ	10σ



- Lowbetamax optics
- Crossing ON
- Separation OFF

No stable solution for δ<-2 ‰ and δ>2 ‰

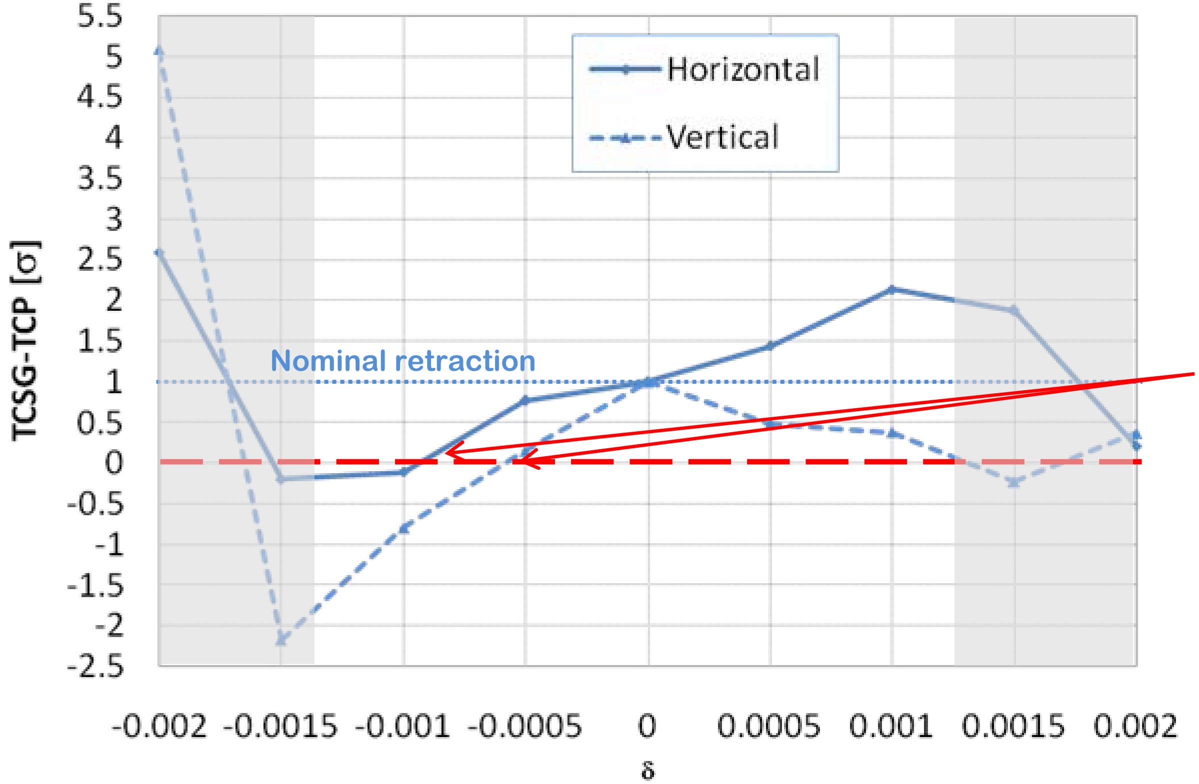
Primary collimators cut at: 1.3‰
IR7 secondary collimator cuts at -1.36 ‰

Upgrade optics Beta beat IP1→IP5

Collimator setting:

	TCP	TCSG	TCLA
IR3	15σ	18σ	20σ
IR7	6σ	7σ	10σ

Retraction:



Retraction loss for horizontal and vertical collimators for δ<0

Secondary collimators become primary!!

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Conclusion

- We considered collimation criteria for defining the best solution for beta beat correction: in the first or in the second half of the ring

- For the collimators set to one physical gap (calculated with δ=0) the effective cut in betatron amplitude changes as function of δ, β_x and D_x → formalism was derived to define the allowed phase space region

- IP1→IP5 beta beat optics is preferred (otherwise problems in the vertical retraction)

- The reduction in operational margin was evaluated for the nominal optics with IP1→IP5 beta beat: up to 60% of retraction lost with off momentum particles.
Extremely important result for commissioning: better understanding of possible collimator settings during commissioning (my PhD thesis)

- Even higher loss of operational margin when opening collimators.

- Will be worse for the upgrade optics with higher off momentum beta beat. Works on going!