Aperture and Collimation

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for the Collimation Team

CC08, BNL, US

RWA, CC08

Why Talk About Collimation?

- Collimation protects the machine aperture against damage and quenches.

- Any significant change in aperture must be revisited also from the collimation and machine protection view: possible impact on protection, loss distribution, activation, quench limitations, experimental background.

- A change in beam properties does also change the available aperture!

- Goal of this talk: **Give collimation input to the ongoing discussions for a possible crab cavity.**

- Note: MP and dump issues only mentioned as far as collimation is affected ➔ for additional input see presentations at LUMI06 by B. Goddard and R. Schmidt.
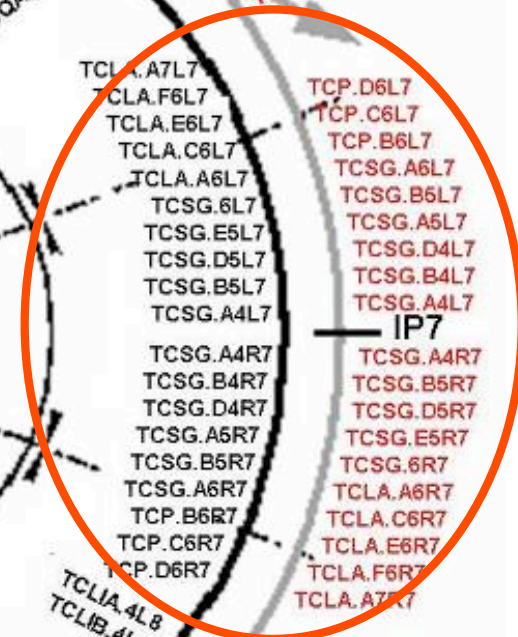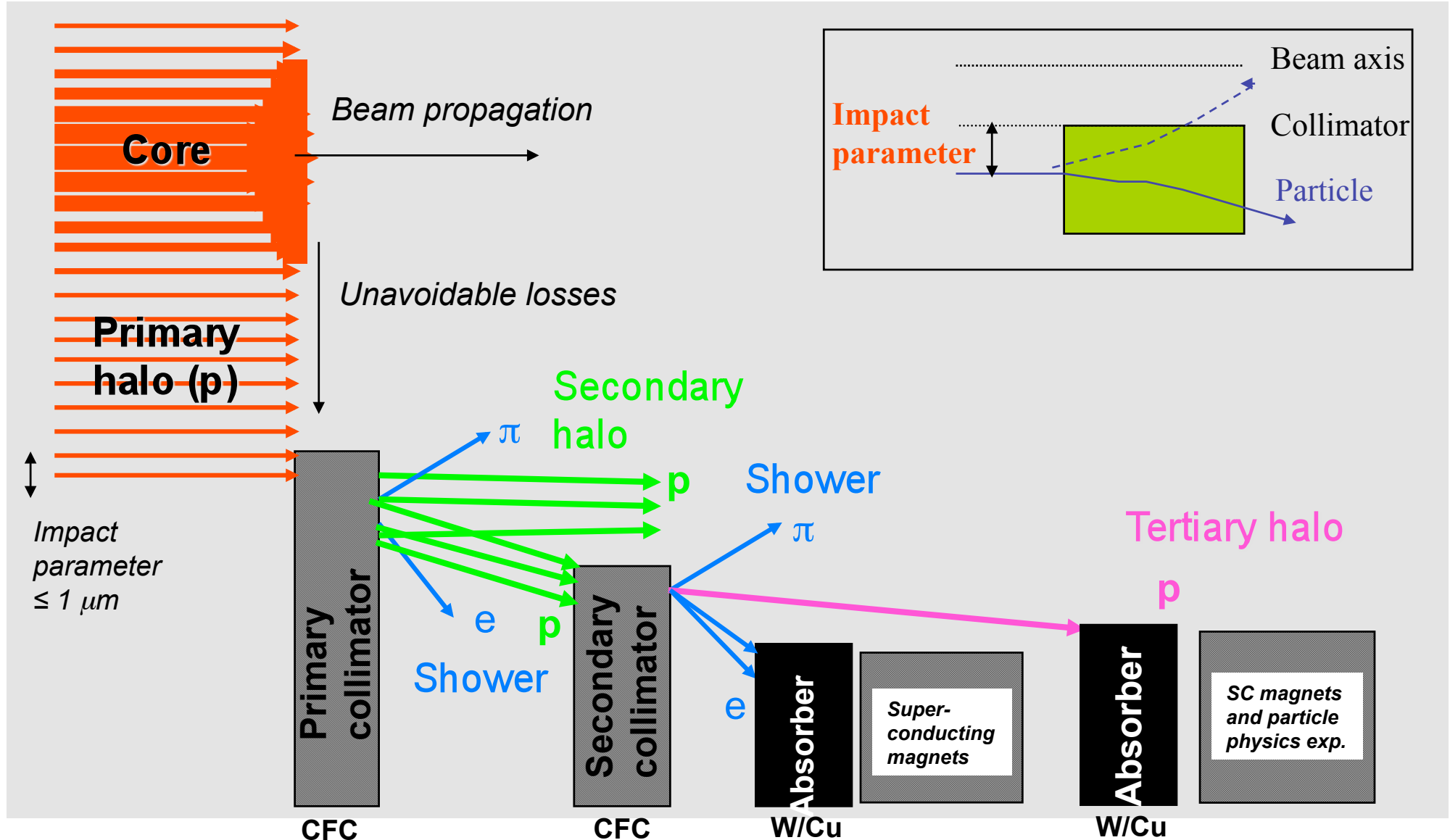
"Phase 1"
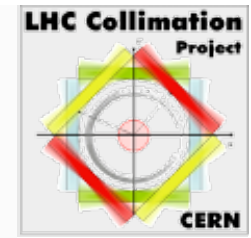
Momentum Cleaning
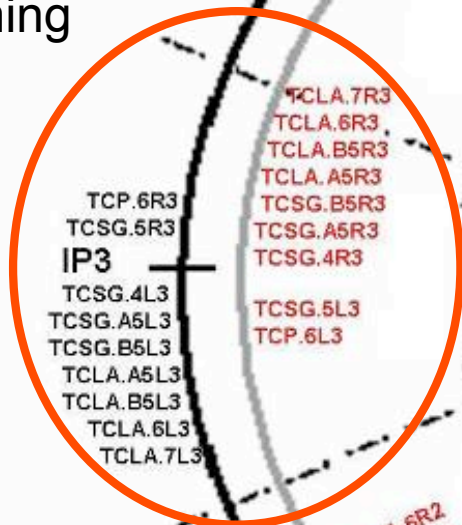
Betatron Cleaning

➔ Outcome of accelerator physics + energy deposition optimization

Multi-Stage Cleaning & Protection

Functional Description

- Two-stage cleaning (**robust CFC primary and secondary collimators**).

- Catching the cleaning-induced showers (**Cu/W collimators**).

- Protecting the warm magnets against heat and radiation (**passive absorbers**).

- Local cleaning and protection at triplets (**Cu/W collimators**).

- Catching the p-p induced showers (**Cu collimators**).

- Intercepting mis-injected beam (**TCDI, TDI, TCLI**).

- Intercepting dumped beam (**TCDQ, TCS.TCDQ**).

- Scraping and halo diagnostics (**primary collimators and thin scrapers**).

Setting Strategy for Collimation and Protection Elements

- Clear requirements for settings:

LHC ring aperture sets scale $\qquad\qquad\qquad\qquad$ a_{ring}
  ➔ *tight LHC aperture*

Protection devices must protect ring aperture $\qquad$ $a_{prot} < a_{ring}$
  ➔ *protect against injected beam; take into account accuracies*

Secondary collimators tighter than protection $\qquad$ $a_{sec} < a_{prot}$
  ➔ *avoid too much secondary halo hitting protection devices*

Primary collimators tighter than secondary $\qquad$ $a_{prim} < a_{sec}$
  ➔ *primary collimators define the aperture bottleneck in the LHC for cleaning of circulating beam!*

- These conditions should always be fulfilled:

Not allowed to use protection devices (or warm aperture limits) as a single-stage cleaning system!
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ *R. Assmann, Chamonix 2005*

Collimator Settings @ 7 TeV

a_{abs} = ~ 20.0 σ Active absorbers in IR3

a_{sec3} = 18.0 σ Secondary collimators IR3 (H)

a_{prim3} = 15.0 σ Primary collimators IR3 (H)

a_{abs} = ~ 10.0 σ Active absorbers in and IR7

$\mathbf{a_{ring}}$ = **8.4** σ **Triplet cold aperture**

a_{prot} = **8.3** σ TCT protection and cleaning at triplet

a_{prot} ≥ **7.5** σ TCDQ (H) protection element

a_{sec} = **7.0** σ Secondary collimators IR7

a_{prim} = **6.0** σ Primary collimators IR7

Note: 1 σ @ 7 TeV   ~   200 μm
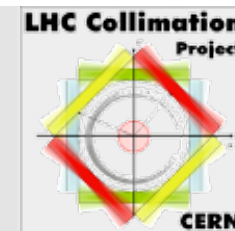
Risks and Dangers

- Active absorbers and tertiary collimators can be damaged:

  - Active absorbers and tertiary collimators use very sensitive tungsten jaws shall never be hit by primary or secondary beam halo.

  - Margin for active absorbers is **2.5 σ** to local dump protection.

  - Margin for tertiary collimators is is **0.8 σ** to local dump protection.

  - Damage can be non-local: water leak into vacuum.

- Machine can be damaged if protection not fully at right settings:

  - Machine aperture (warm and cold) must always be in shadow of collimators.

- Cleaning can be compromised:

  - Secondary collimators shall never be hit by primary beam halo.

  - Margin for secondary collimators is **1.0 σ** to primary collimator.

IR1 Tertiary Collimators

RWA, CC08
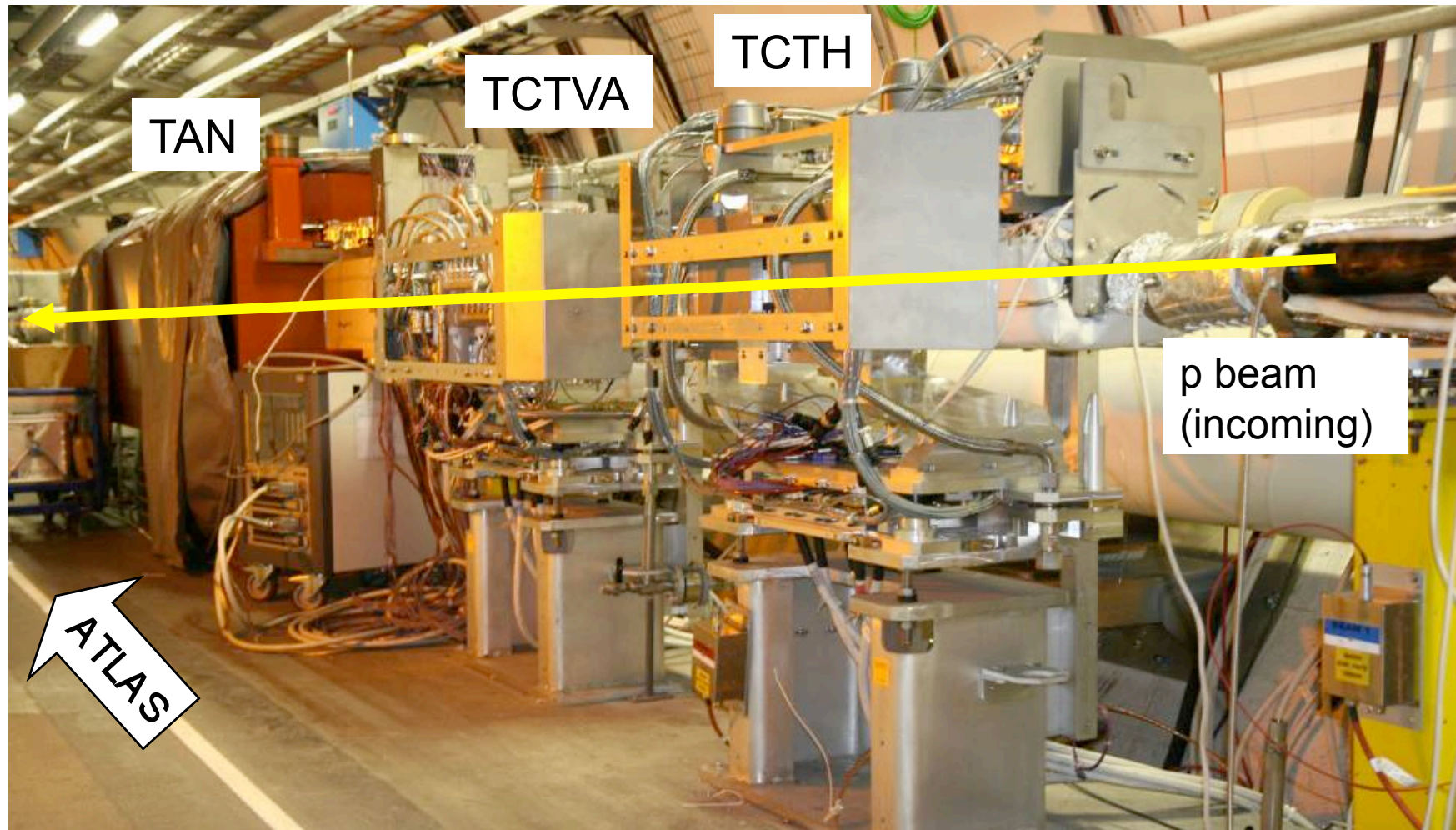
7 TeV Collimator Settings for Various Intensities

| Intensity	β^* [m]	n_1 [σ]	n_2 [σ]	n_a [σ]	n_3 [σ]	n_{tcdq} [σ]	
5.0×10^9	2.00	10.0	-	-	17.0	13.5	
1.5×10^{12}	2.00	6.0	-	10.0	17.0	8.0	*Tightest margin:*
3.0×10^{12}	2.00	6.0	9.5	10.0	17.0	8.0	*2.0 σ*
1.0×10^{13}	2.00	6.0	8.0	10.0	17.0	8.0	
1.3×10^{14}	2.00	6.0	7.0	10.0	17.0	8.0	
5.0×10^{14}	2.00	6.0	7.0	10.0	17.0	8.0	
5.0×10^9	0.55	6.0	-	-	8.3	7.5	*Tightest margin:*
1.5×10^{12}	0.55	6.0	-	10.0	8.3	7.5	*0.8 σ*
3.0×10^{12}	0.55	6.0	8.0	10.0	8.3	7.5	
1.0×10^{13}	0.55	6.0	7.0	10.0	8.3	7.5	
1.3×10^{14}	0.55	6.0	7.0	10.0	8.3	7.5	
5.0×10^{14}	0.55	6.0	7.0	10.0	8.3	7.5	**This we call retraction!!**

Loss of horizontal retraction

- Set-up errors of collimators and transient changes of beam can be minimized but cannot be avoided fully:

  - Estimate: ~ 0.3 σ (60 μm)

- Off-momentum beat beat mixes up the 6D phase space and can corrupt collimation performance (e.g. loss of horizontal retraction for tertiary tungsten collimators):

  - Estimate for tertiary collimators (margin 0.8 σ): ~ 0.5 σ

  - Estimate for absorbers (margin 2.5 σ): ~ 1.5 σ

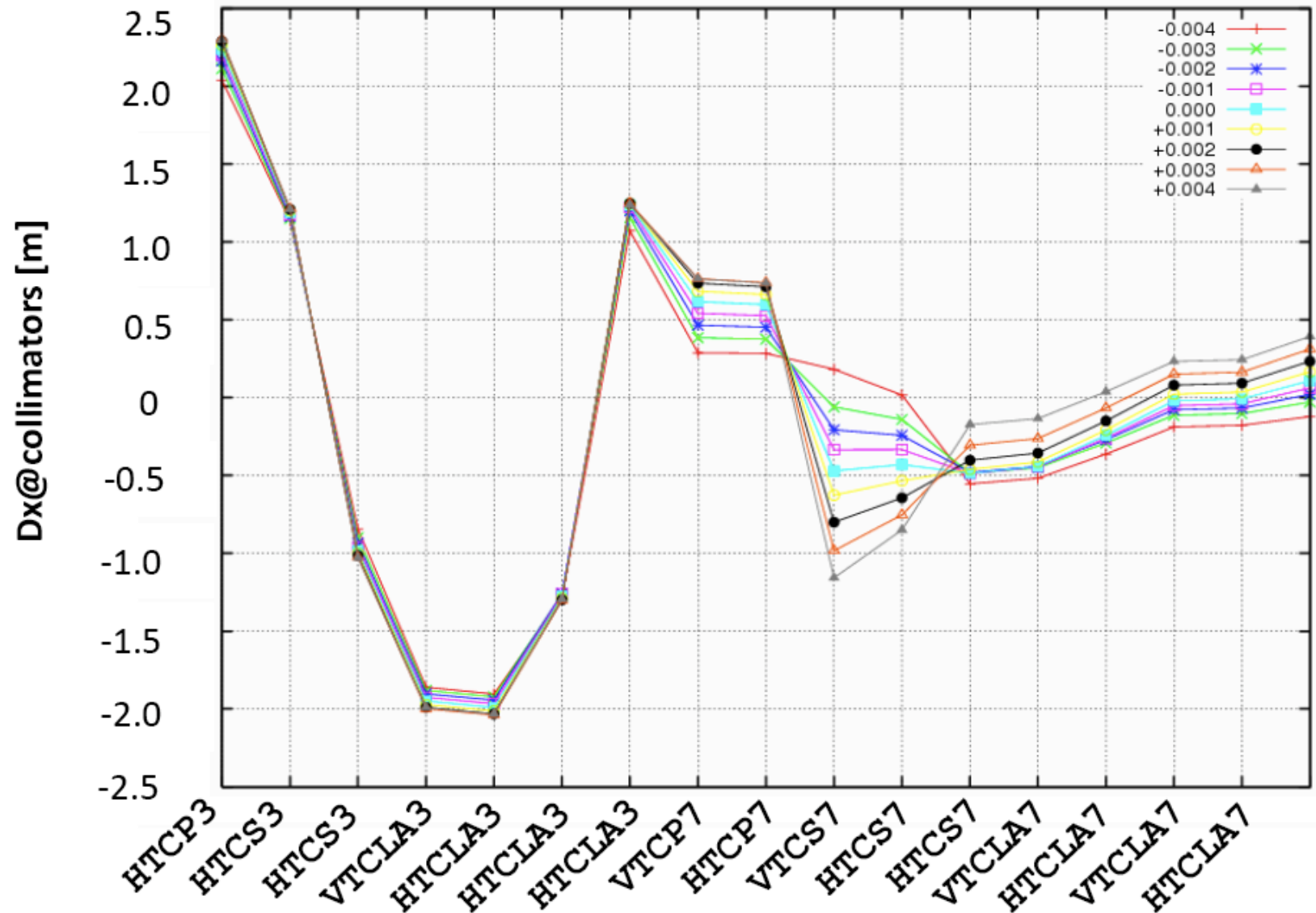- Already very tight for nominal situation…

Off-momentum beta beat

R. Assmann & C. Bracco
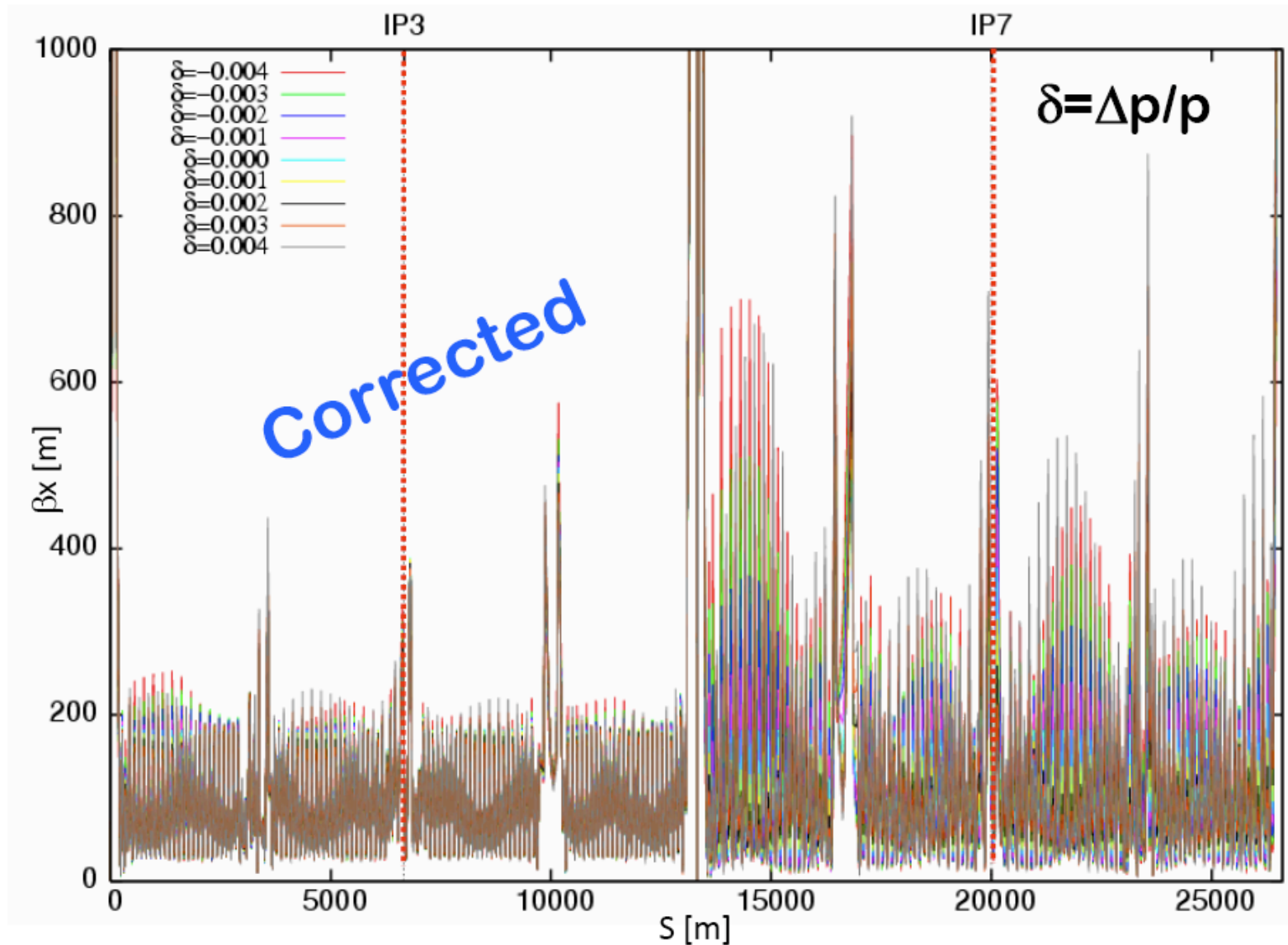
Beta change for various δ

R. Assmann & C. Bracco
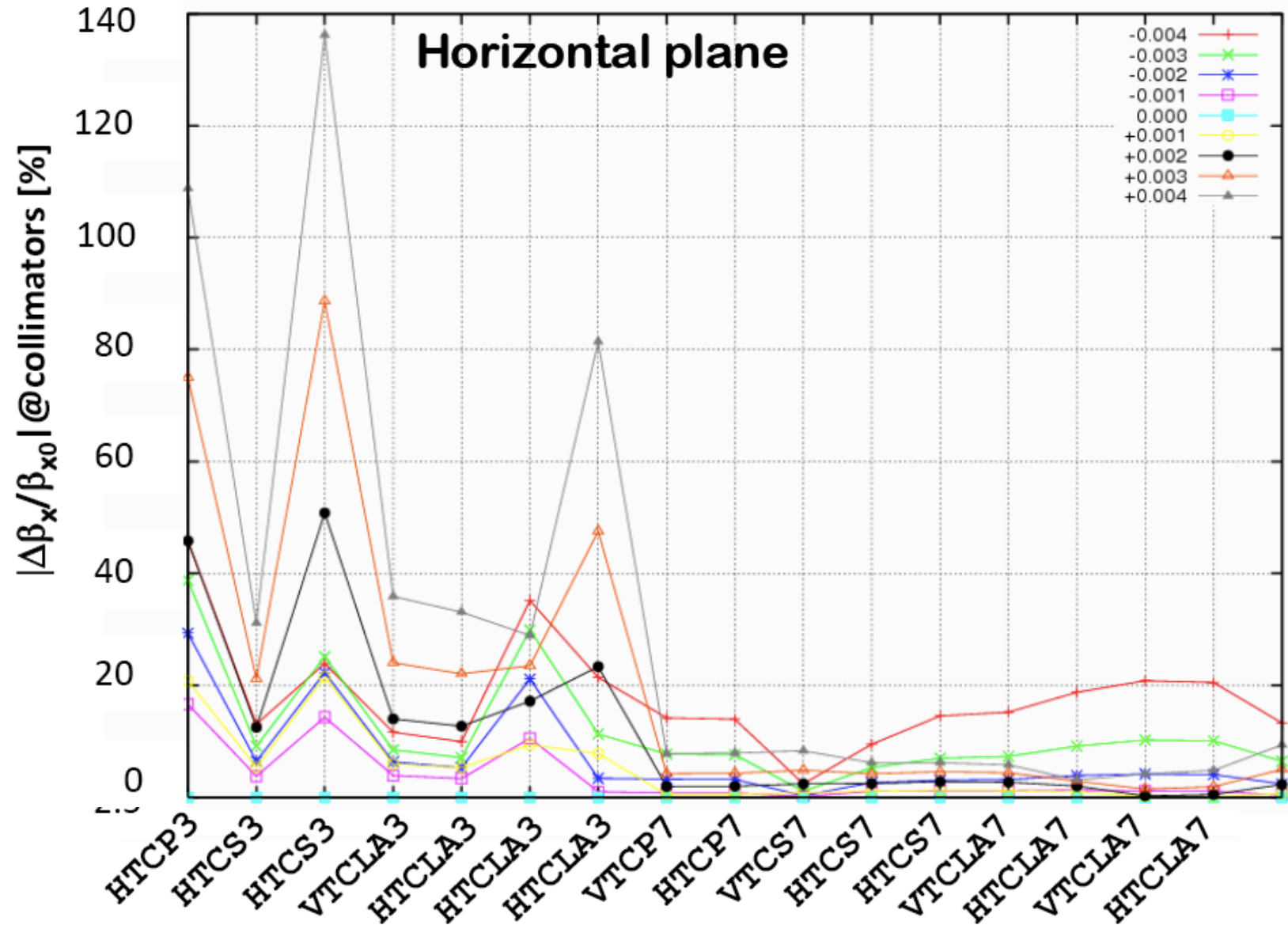
Dispersion change for various δ

R. Assmann & C. Bracco

Analytical estimates

Effective betatron amplitude cut

For the nominal collimation setting, the effective <u>betatron</u> 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:

$$\mathbf{x}_{cut}(i_{coll}) = n_{\beta_x cut}(i_{coll}, \delta)\sqrt{\varepsilon_x \beta_x(i_{coll}, \delta)} + \mathbf{D}_x(i_{coll}, \delta)\delta$$

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

$$\mathbf{n}_{\beta_x cut}(i_{coll}, \delta) = \frac{\pm \mathbf{x}_{cut}(i_{coll}) - \mathbf{D}_x(i_{coll}, \delta)\delta}{\sqrt{\varepsilon_x \beta_x(i_{coll}, \delta)}}$$

positive and negative x jaws

RWA, CC08
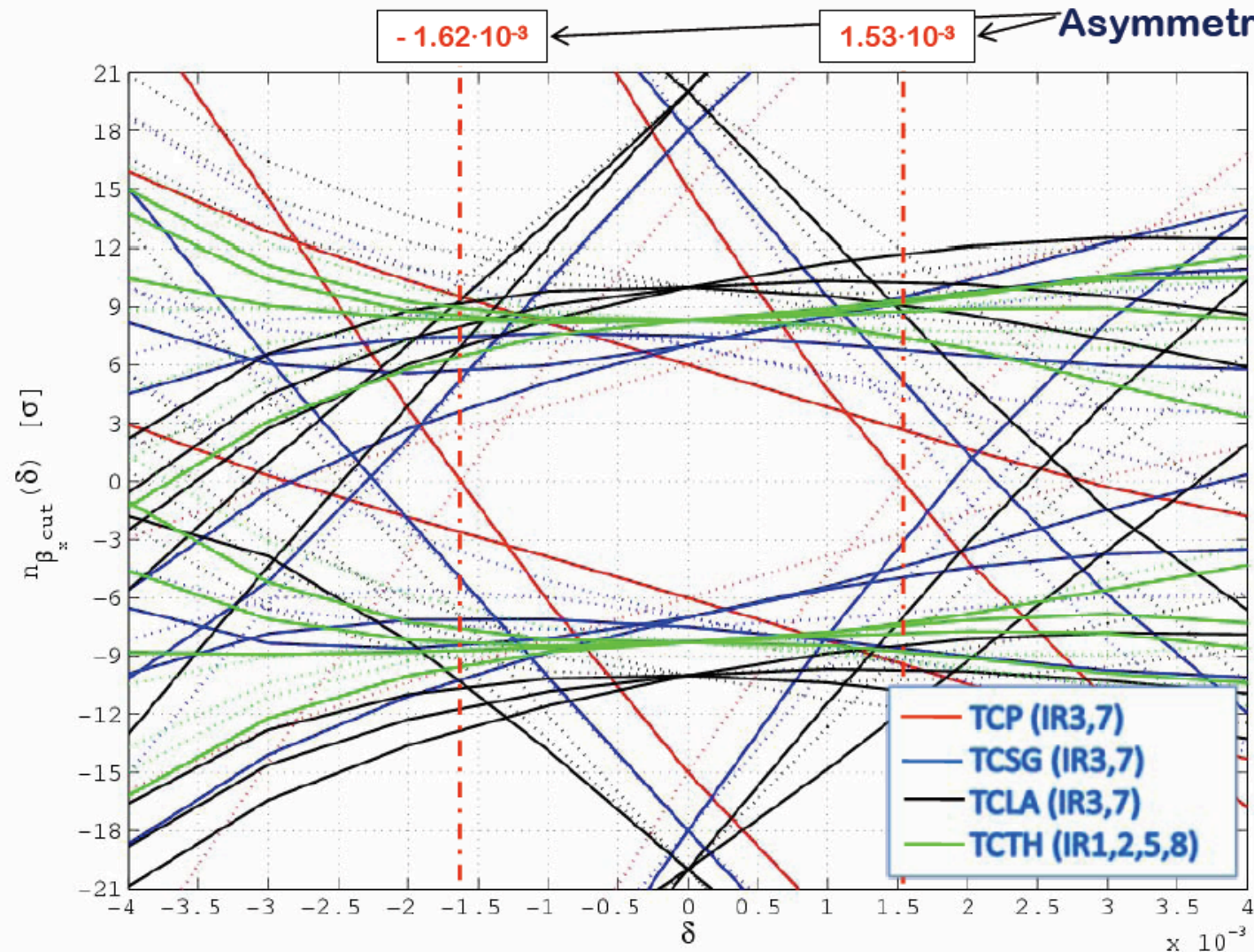
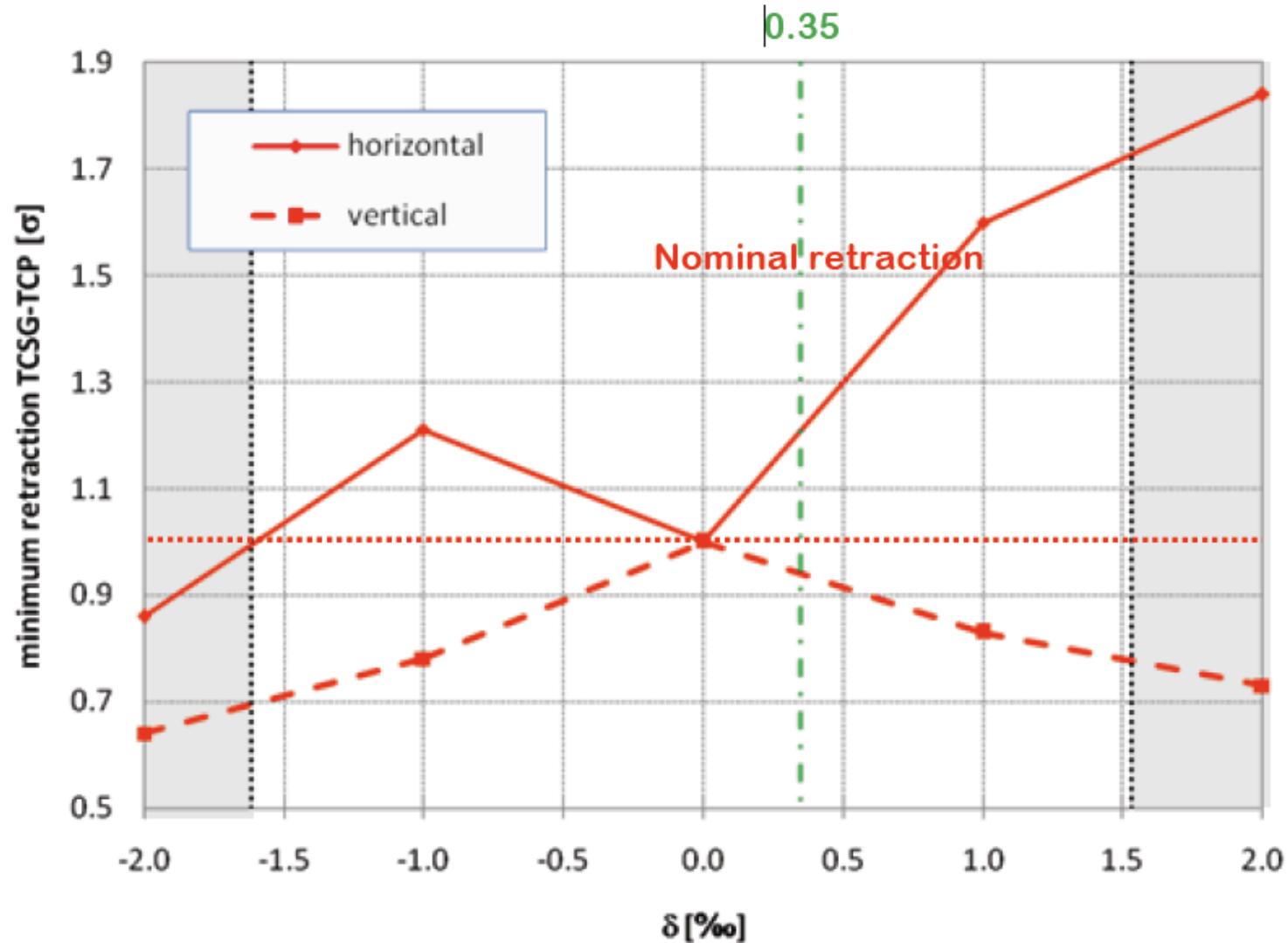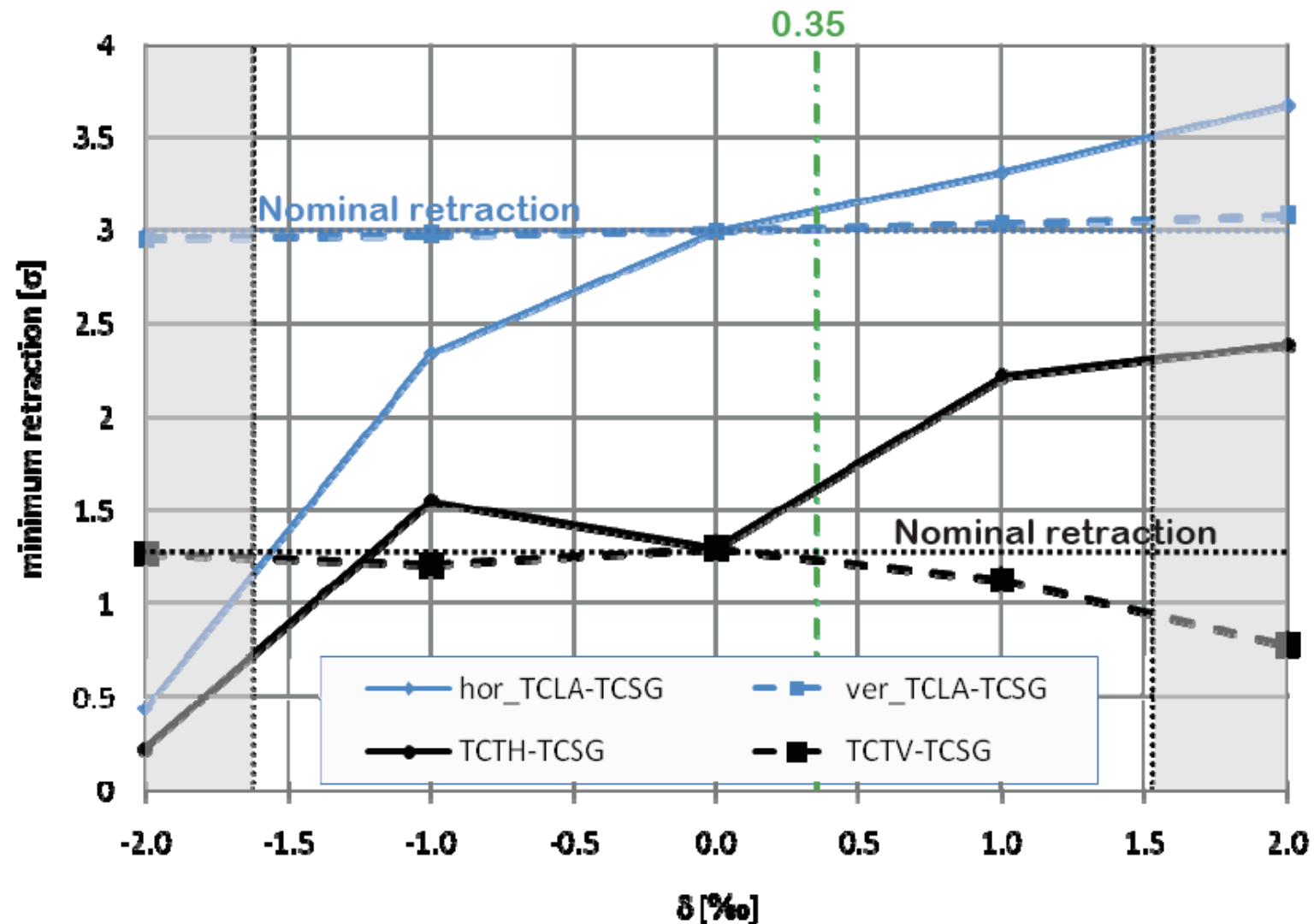**Each solid line represent one collimator jaw.**

Each color represent one collimator family (legend)

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

Loss of retraction for secondary collimators

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Loss of retraction for tertiary collimators

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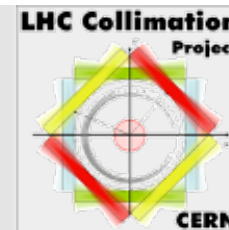# Loss of horizontal retraction

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- Off-momentum beat beat mixes up the 6D phase space and can corrupt collimation performance (e.g. loss of horizontal retraction for tertiary tungsten collimators):
  - Estimate for tertiary collimators (margin 0.8 σ):   ~ 0.5 σ
  - Estimate for absorbers (margin 2.5 σ):   ~ 1.5 σ

- Already very tight for nominal situation…

- **What is added by crab cavities?**

Preliminary analysis: closed orbit with global crab cavity

Yi-Peng Sun, Rogelio Tomas, Frank Zimmermann

Thanks to Rama Calaga

AB/ABP Group

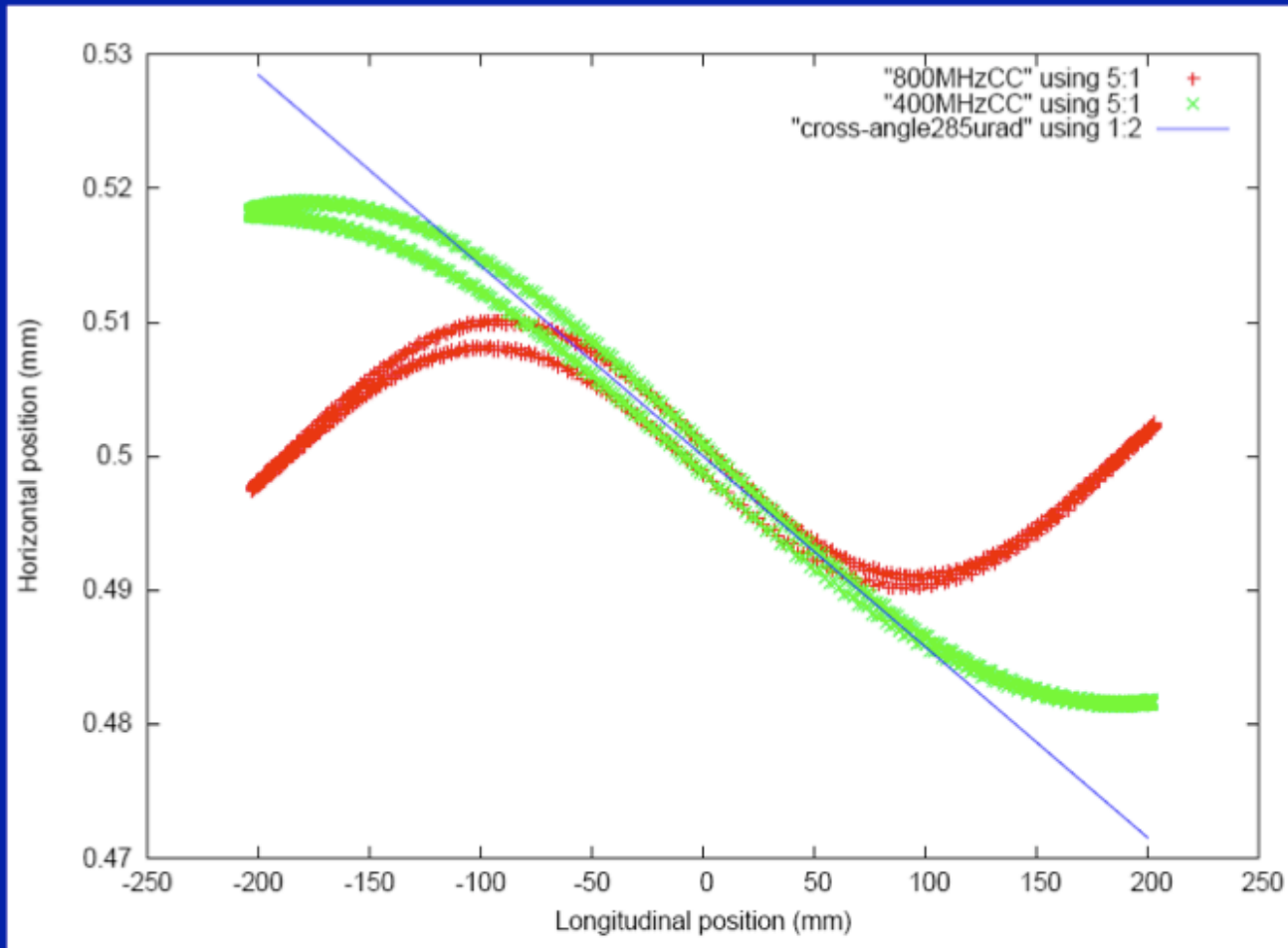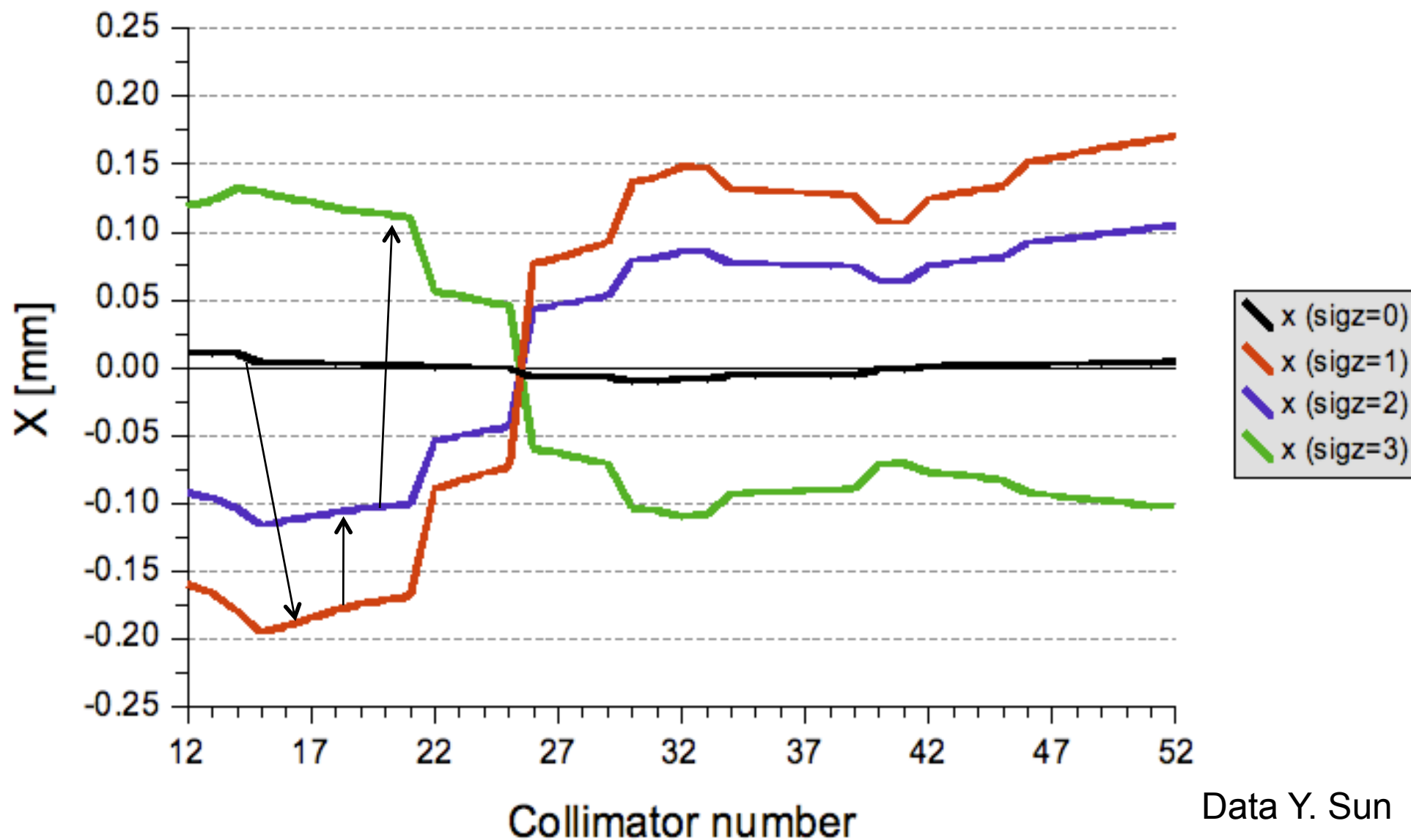European Organization for Nuclear Research (CERN)

14 February 2008

Consider 800 MHz with Lower Voltage

Orbit Change from CC
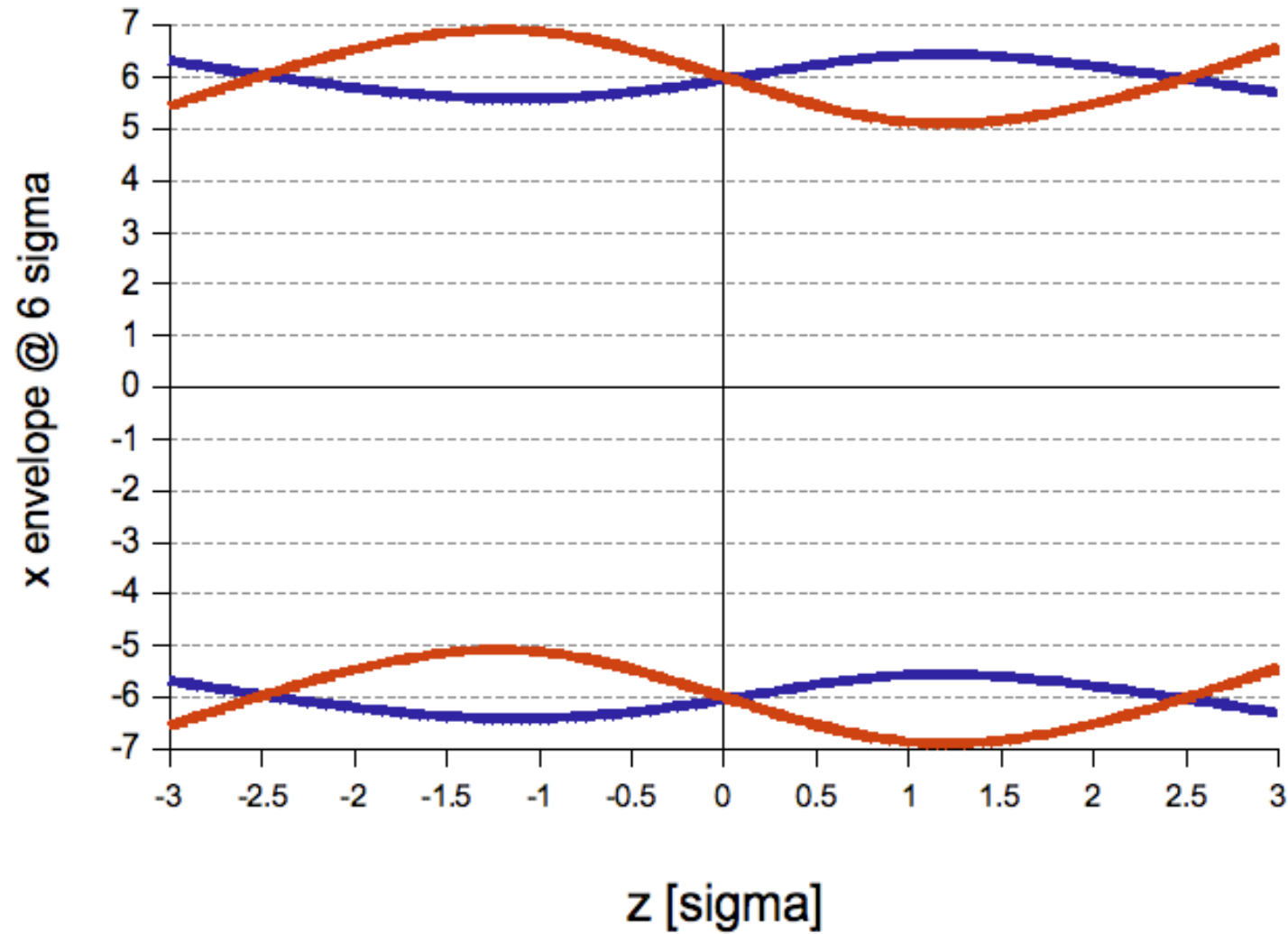

Data Y. Sun

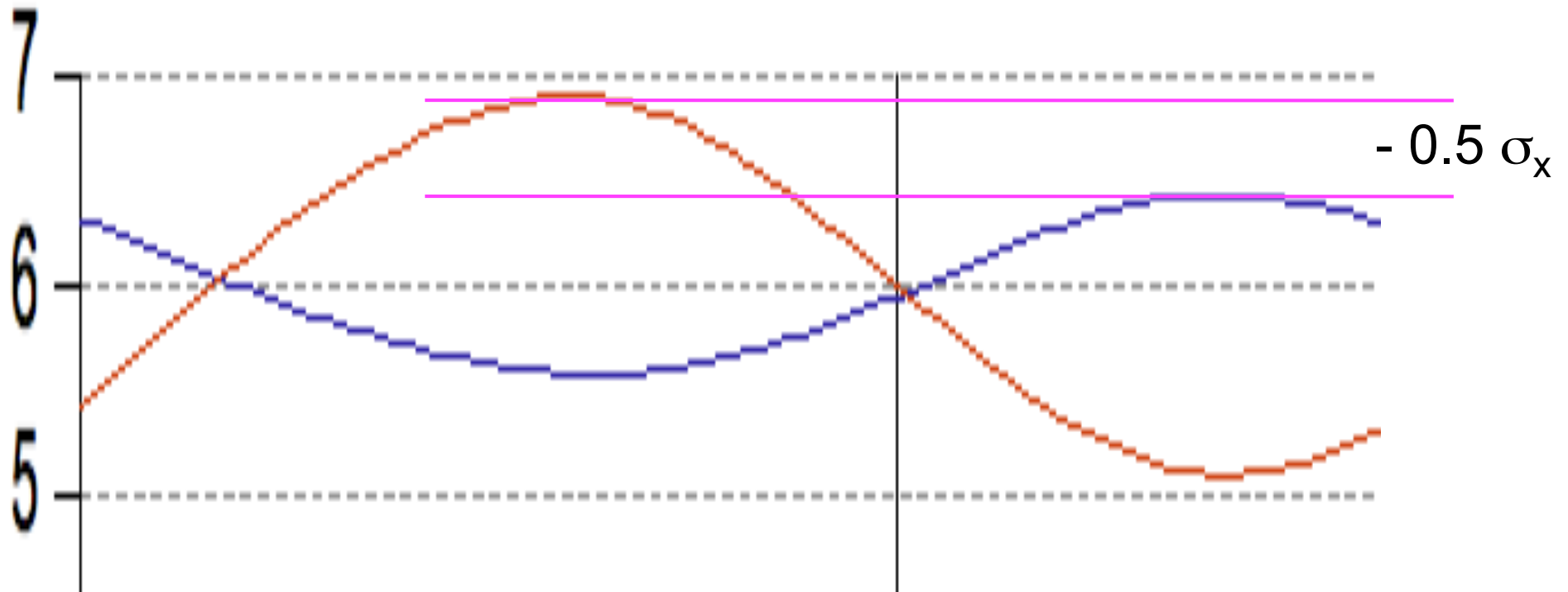# What does it mean?

$- 0.5 \; \sigma_x$

Details are still being analyzed!
Question: Shall we let LHC tune free ➔ worst case…

Loss of horizontal retraction

- Set-up errors of collimators and transient changes of beam can be minimized but cannot be avoided fully:

  - Estimate: $\sim 0.3\ \sigma$ (60 μm)

- Off-momentum beat beat mixes up the 6D phase space and can corrupt collimation performance (e.g. loss of horizontal retraction for tertiary tungsten collimators):

  - Estimate for tertiary collimators (margin 0.8 σ): $\sim 0.5\ \sigma$

  - Estimate for absorbers (margin 2.5 σ): $\sim 1.5\ \sigma$

- Global crab cavity further reduces horizontal retraction:

  - Estimate: ongoing, in the order of 0.5 σ

- Difficult situation…

Conclusion

- The LHC **collimators must sit very tight** on the beam to provide good passive protection and cleaning.

- As a consequence, the **6D phase space must be well defined**. Tolerances on relative settings (retraction) are critical.

- **Off-momentum beat is important** and is being addressed (S. Fartoukh). Larger off-momentum beta beat with upgrade optics.

- A **global crab cavity scheme will further complicate the situation**, probably to the point where collimation breaks down.

- **Tests with a global crab scheme can be performed** with a few nominal bunches (increase of specific luminosity).

- **Presently, little hope to improve integrated luminosity with global crab scheme.**

- Further work is ongoing and required. Interference local crab cavities and collimation in experimental insertions.

Acknowledgements

- C. Bracco, T. Weiler, S. Fartoukh, Y. Sun,
  R. Tomas, F. Zimmermann, R. Calaga