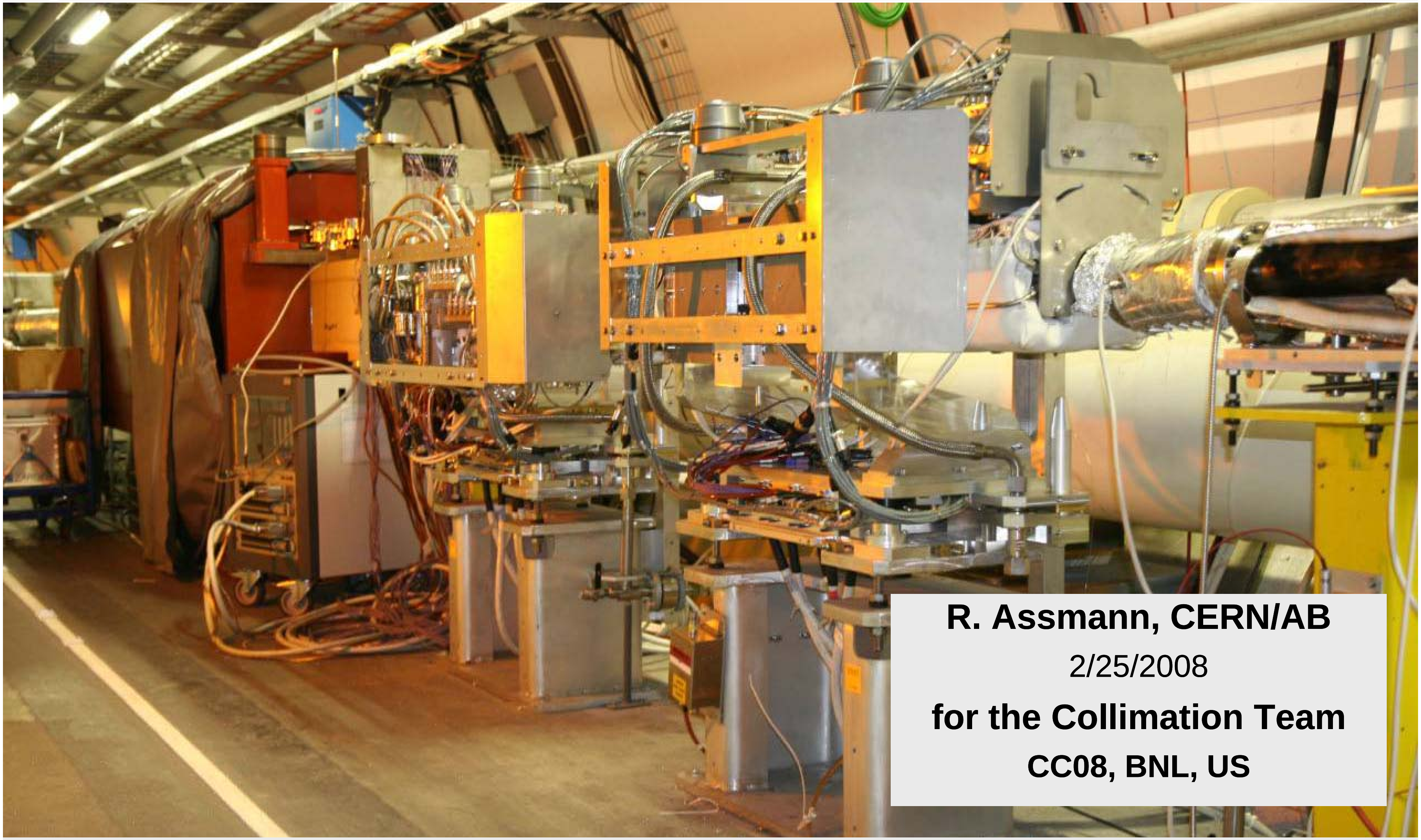
Aperture and Collimation



R. Assmann, CERN/AB

2/25/2008

for the Collimation Team

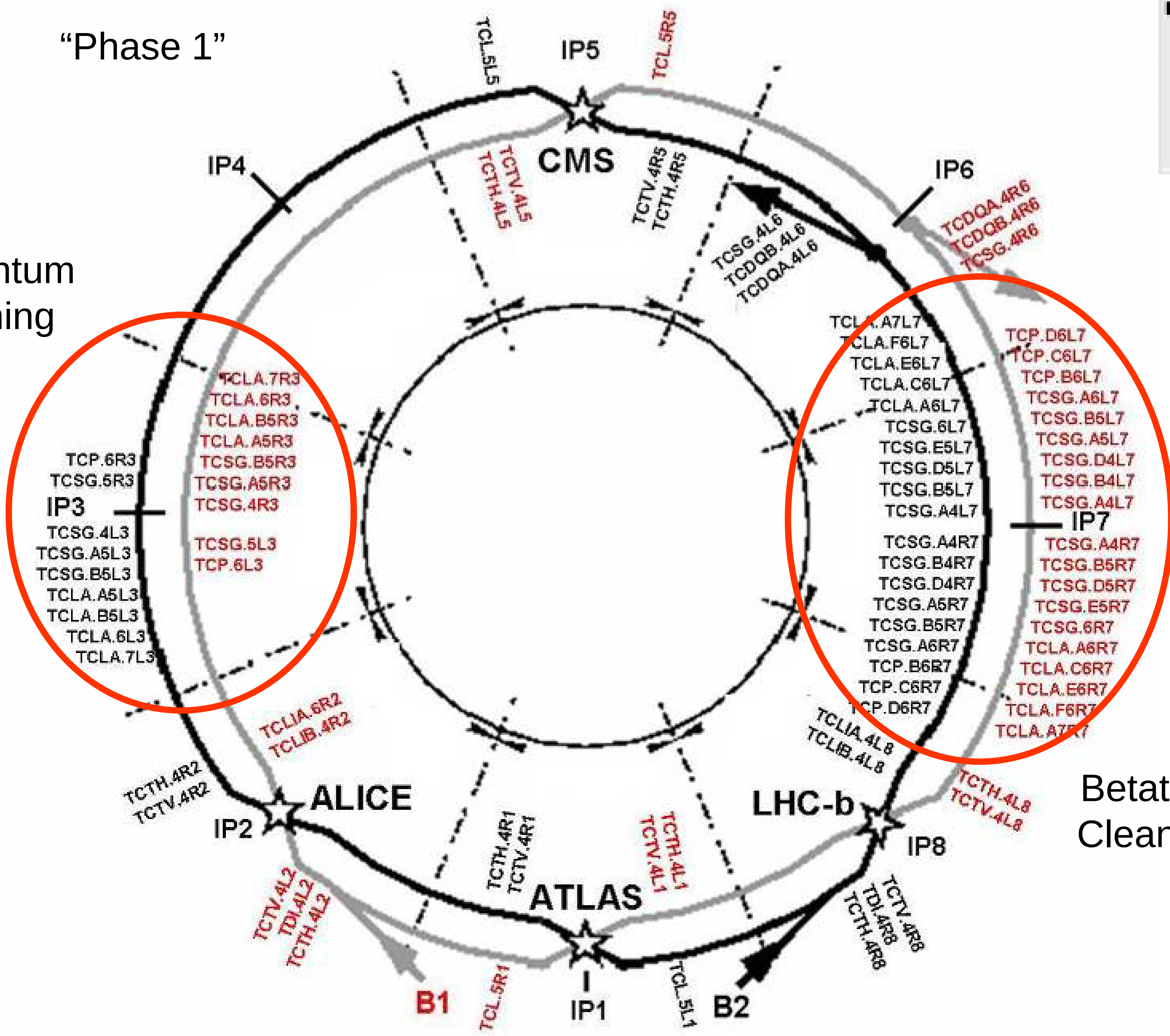
CC08, BNL, US

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”

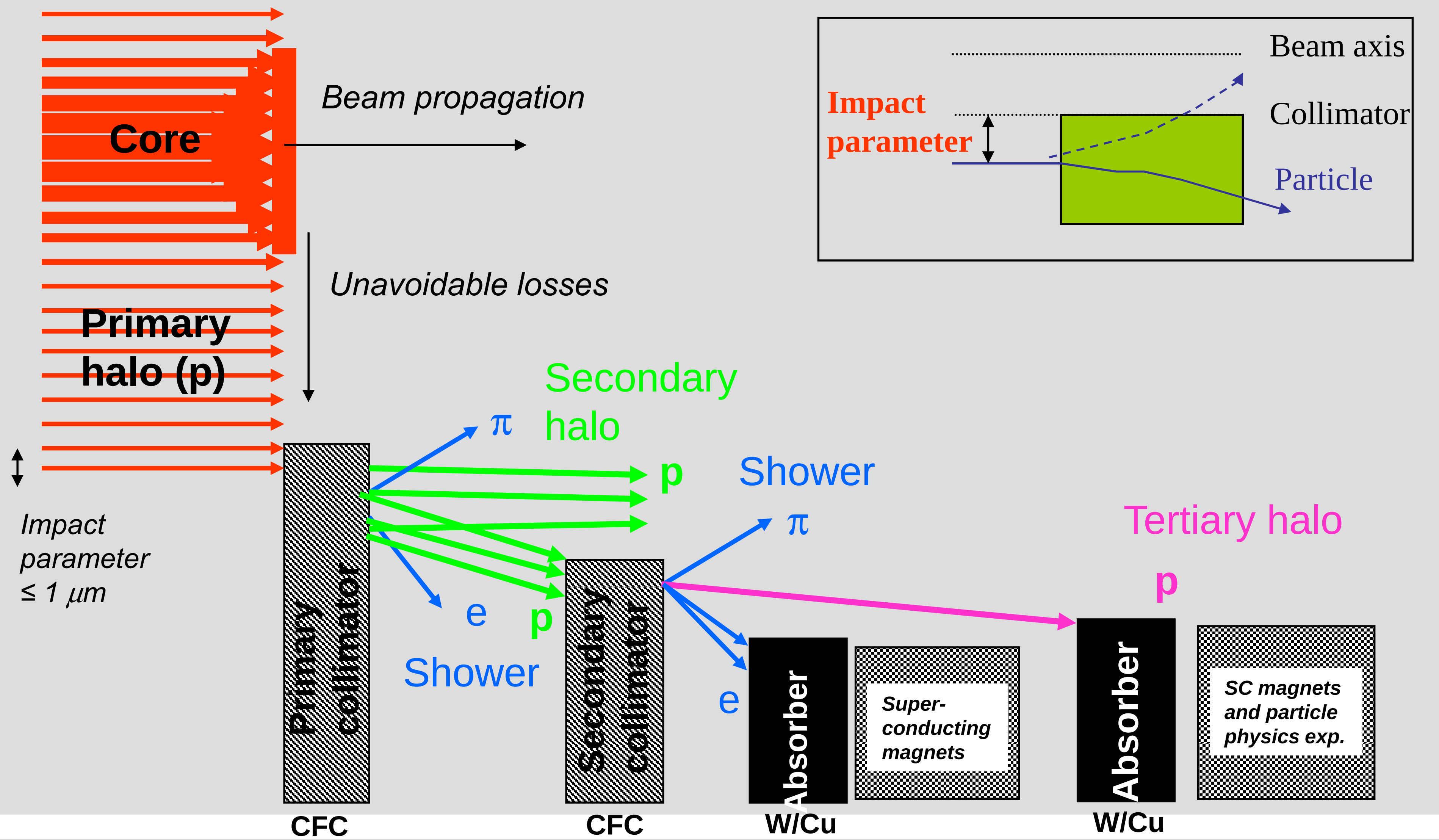
Momentum Cleaning



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 — a_{ring}

➔ *tight LHC aperture*

Protection devices must protect ring aperture — $a_{prot} < a_{ring}$

➔ *protect against injected beam; take into account accuracies*

Secondary collimators tighter than protection — $a_{sec} < a_{prot}$

➔ *avoid too much secondary halo hitting protection devices*

Primary collimators tighter than secondary — $a_{prim} < a_{sec}$

➔ *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!

R. Assmann, Chamonix 2005

Collimator Settings @ 7 TeV

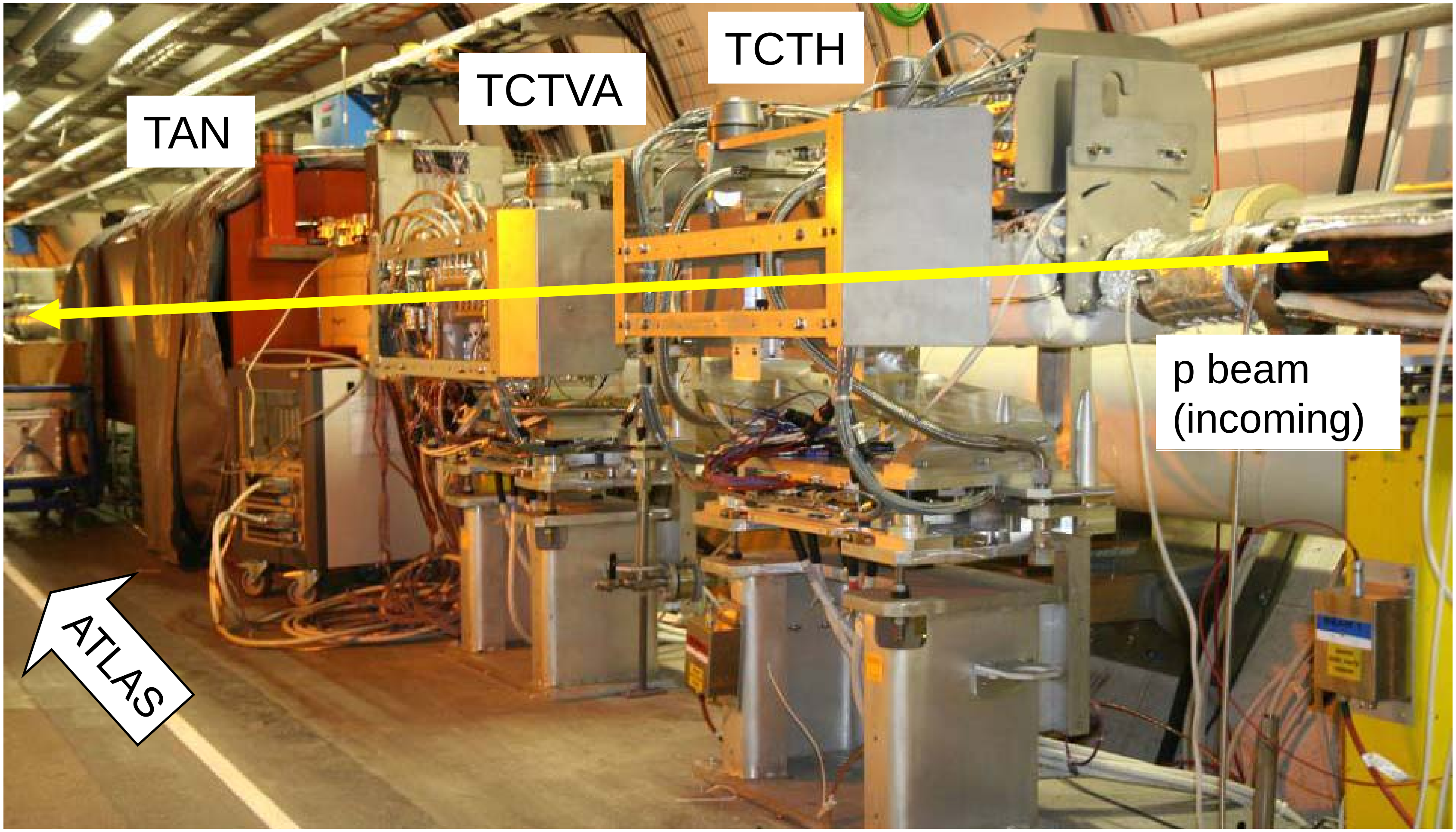
a_{abs}	=	~ 20.0 σ	Active absorbers in IR3
a_{sec3}	=	18.0 σ	Secondary collimators IR3 (H)
a_{prim3}	=	15.0 σ	Primary collimators IR3 (H)
a_{abs}	=	~ 10.0 σ	Active absorbers in and IR7
a_{ring}	**=**	**8.4 σ**	**Triplet cold aperture**
a_{prot}	=	**8.3 σ**	TCT protection and cleaning at triplet
a_{prot}	≥	**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



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
3.0×10^{12}	2.00	6.0	9.5	10.0	17.0	8.0
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
1.5×10^{12}	0.55	6.0	-	10.0	8.3	7.5
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

Tightest margin: 2.0 σ

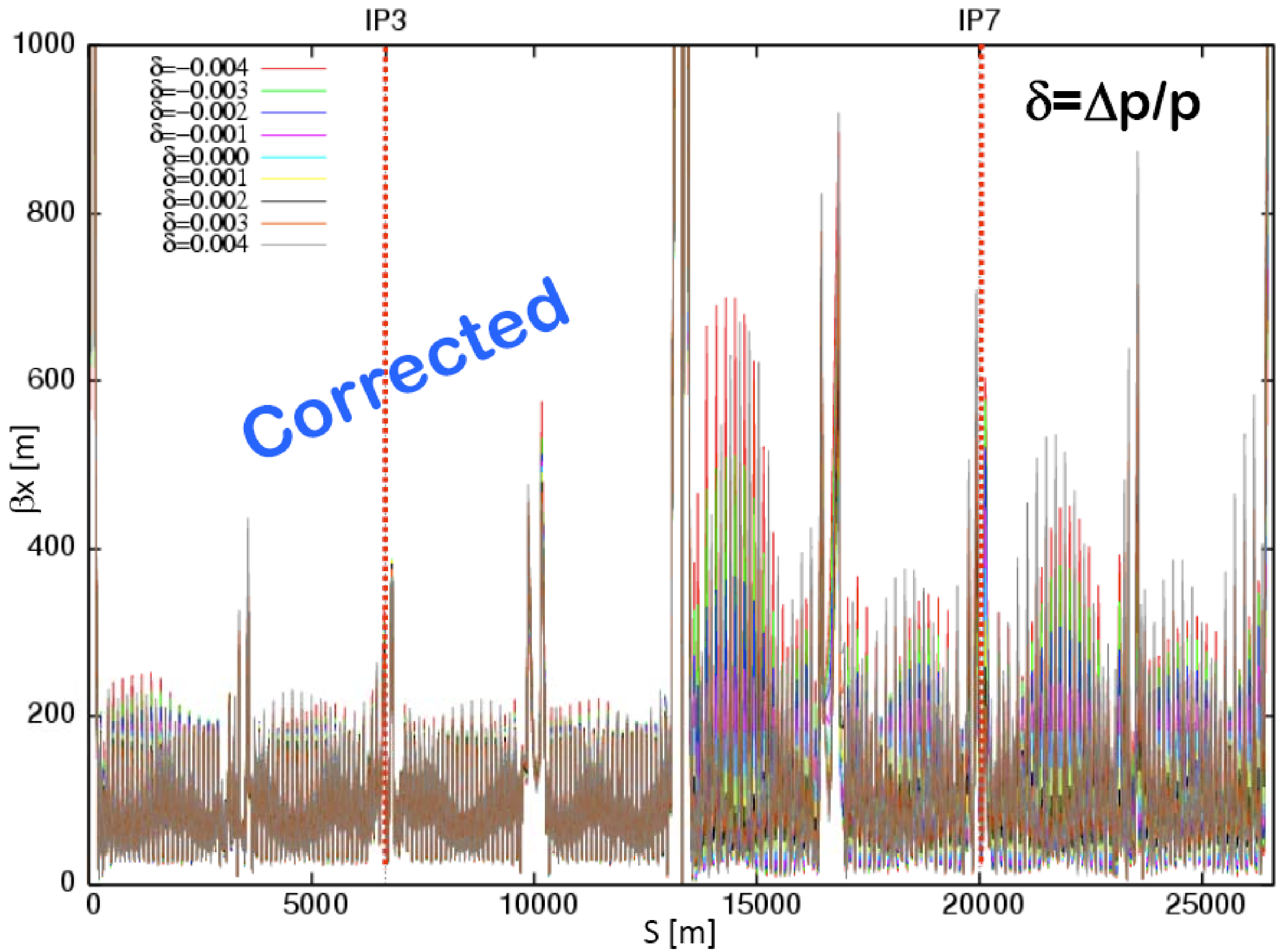
Tightest margin: 0.8 σ

This we call retraction!!

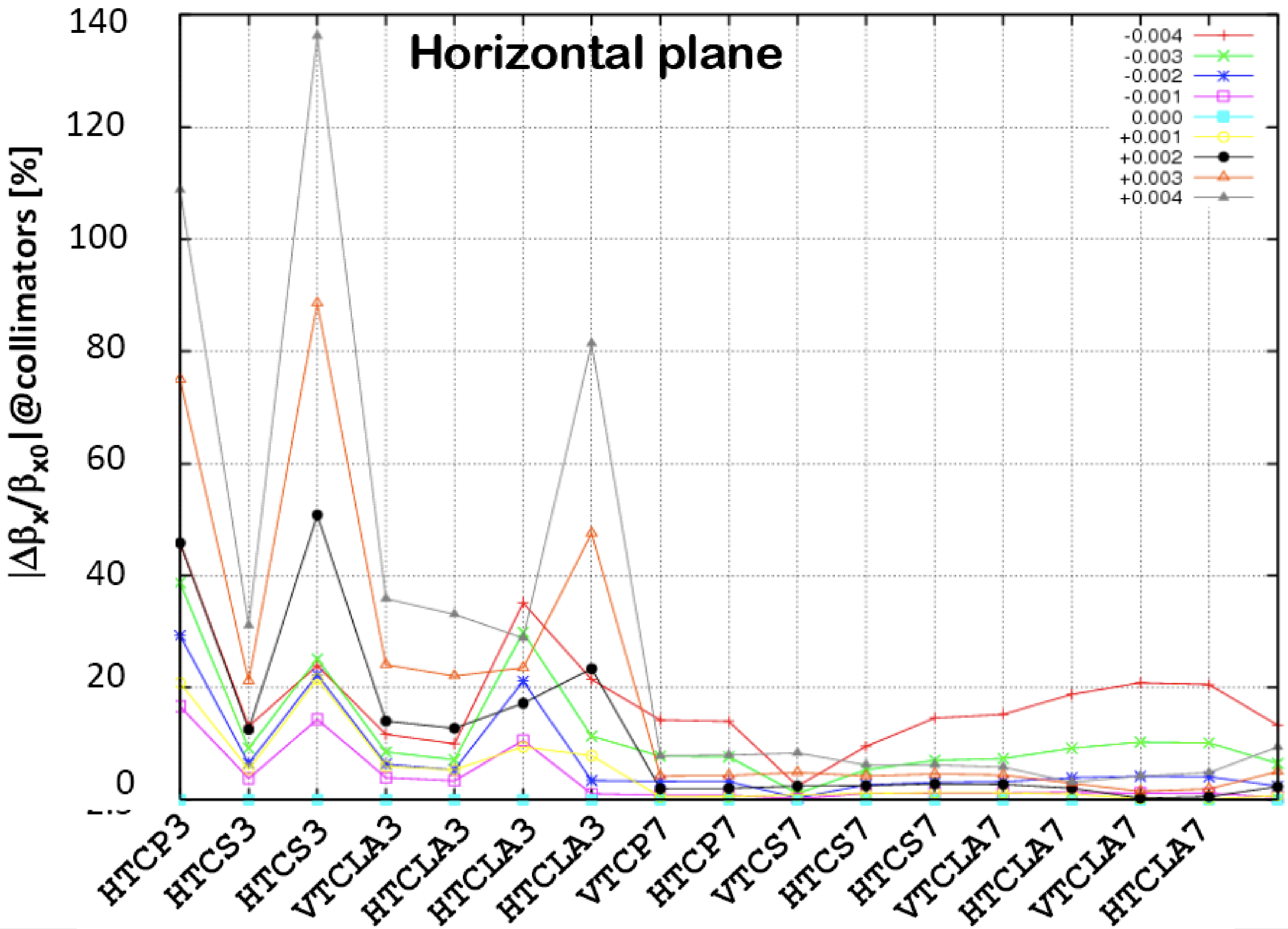
Loss of horizontal retraction

- 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…

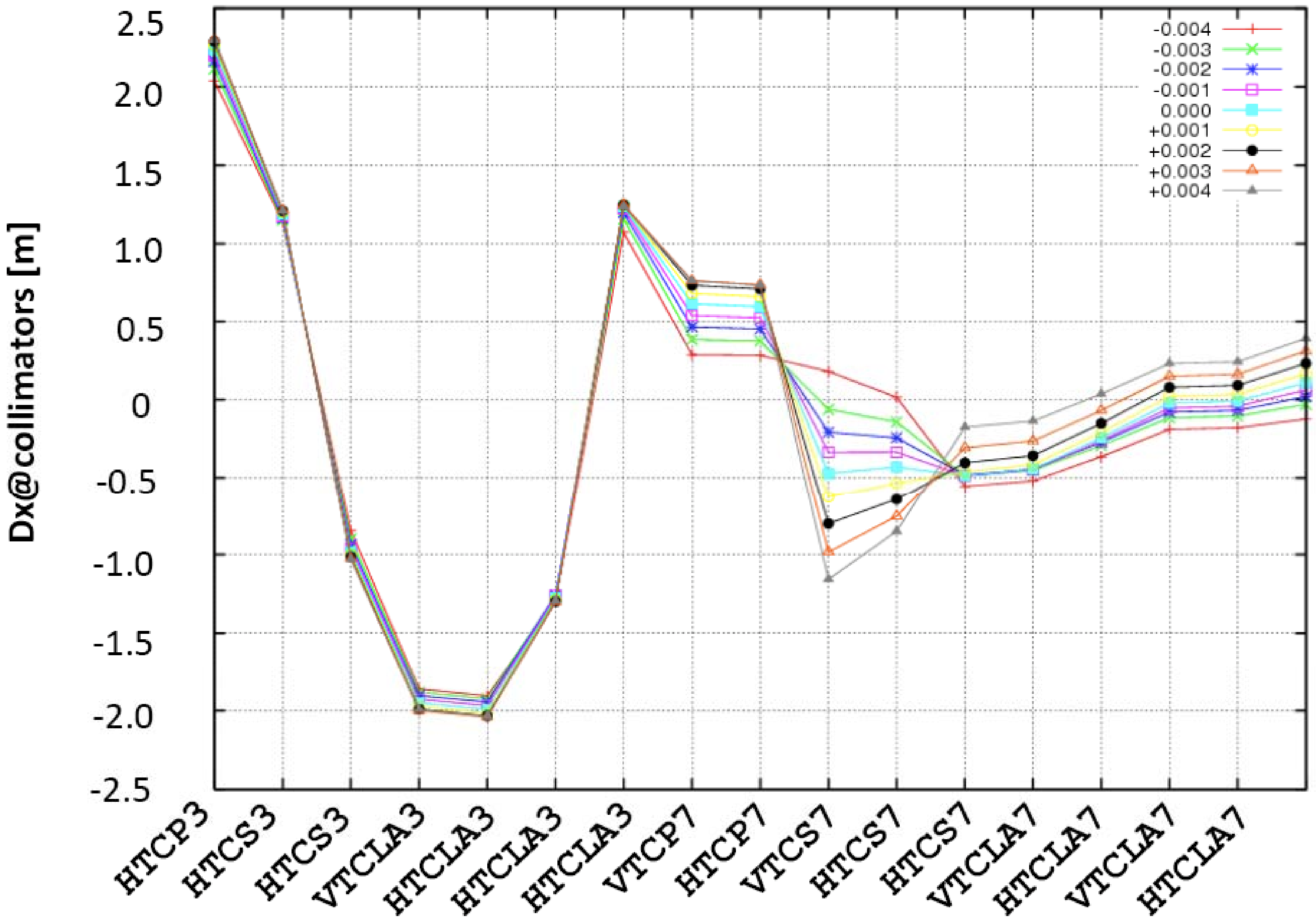
Off-momentum beta beat



Beta change for various δ



Dispersion change for various δ



Analytical estimates

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:

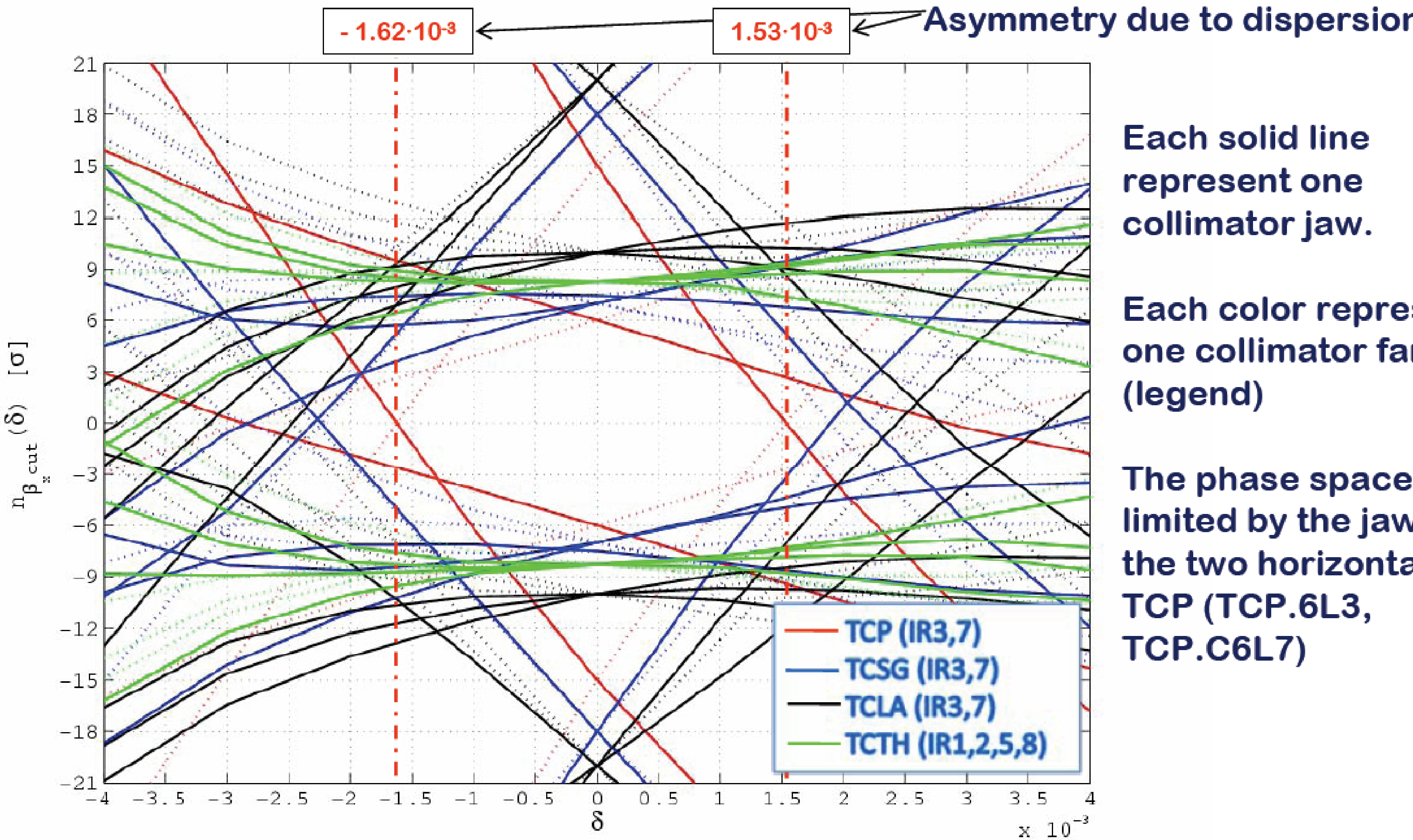
$$x_{cut}(i_{coll}) = n_{\beta_x cut}(i_{coll},\delta)\sqrt{\varepsilon_x \beta_x(i_{coll},\delta)} + D_x(i_{coll},\delta)\delta$$

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

Phase space cuts (δ – x)

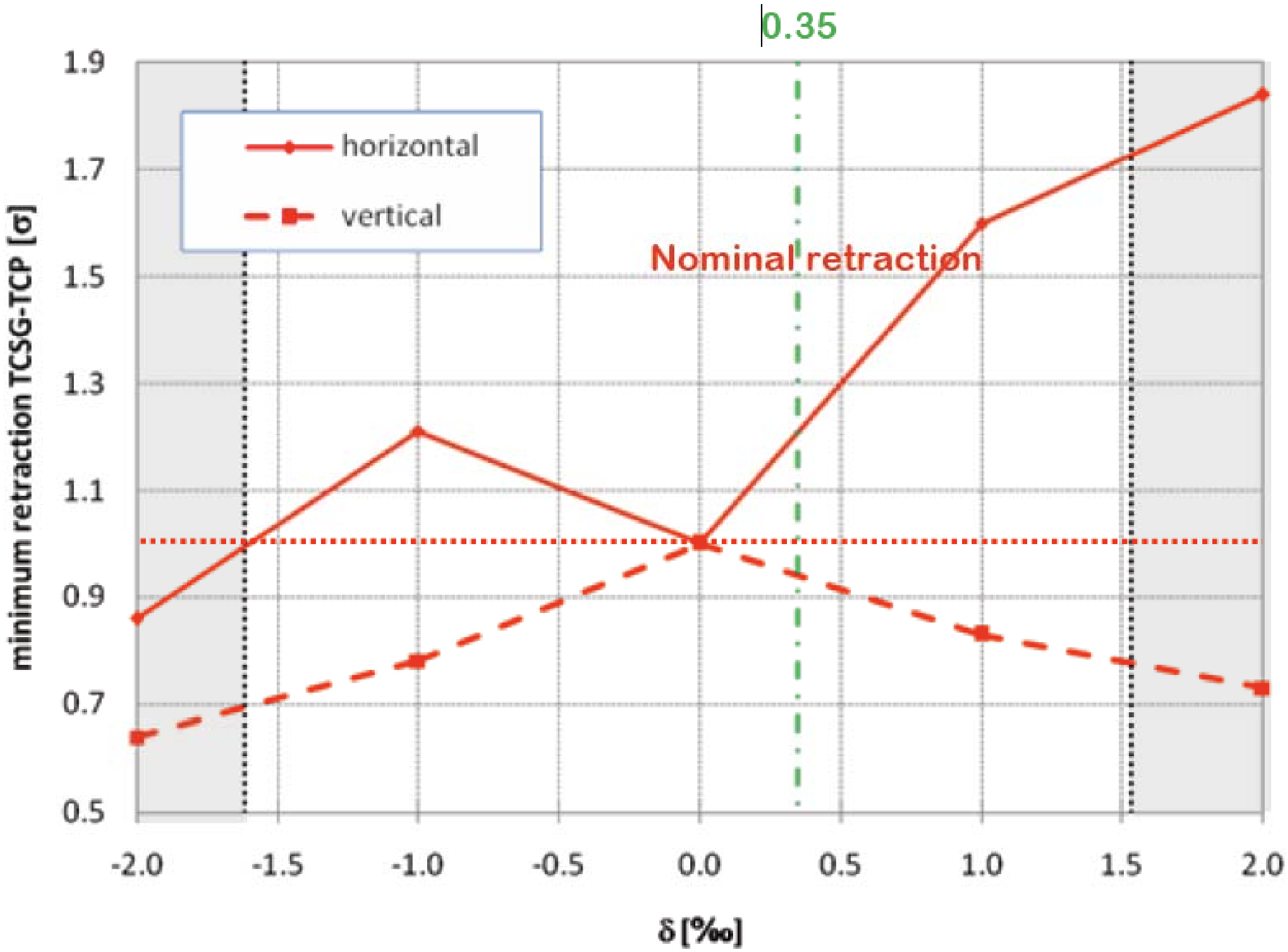


Each solid line represent one collimator jaw.

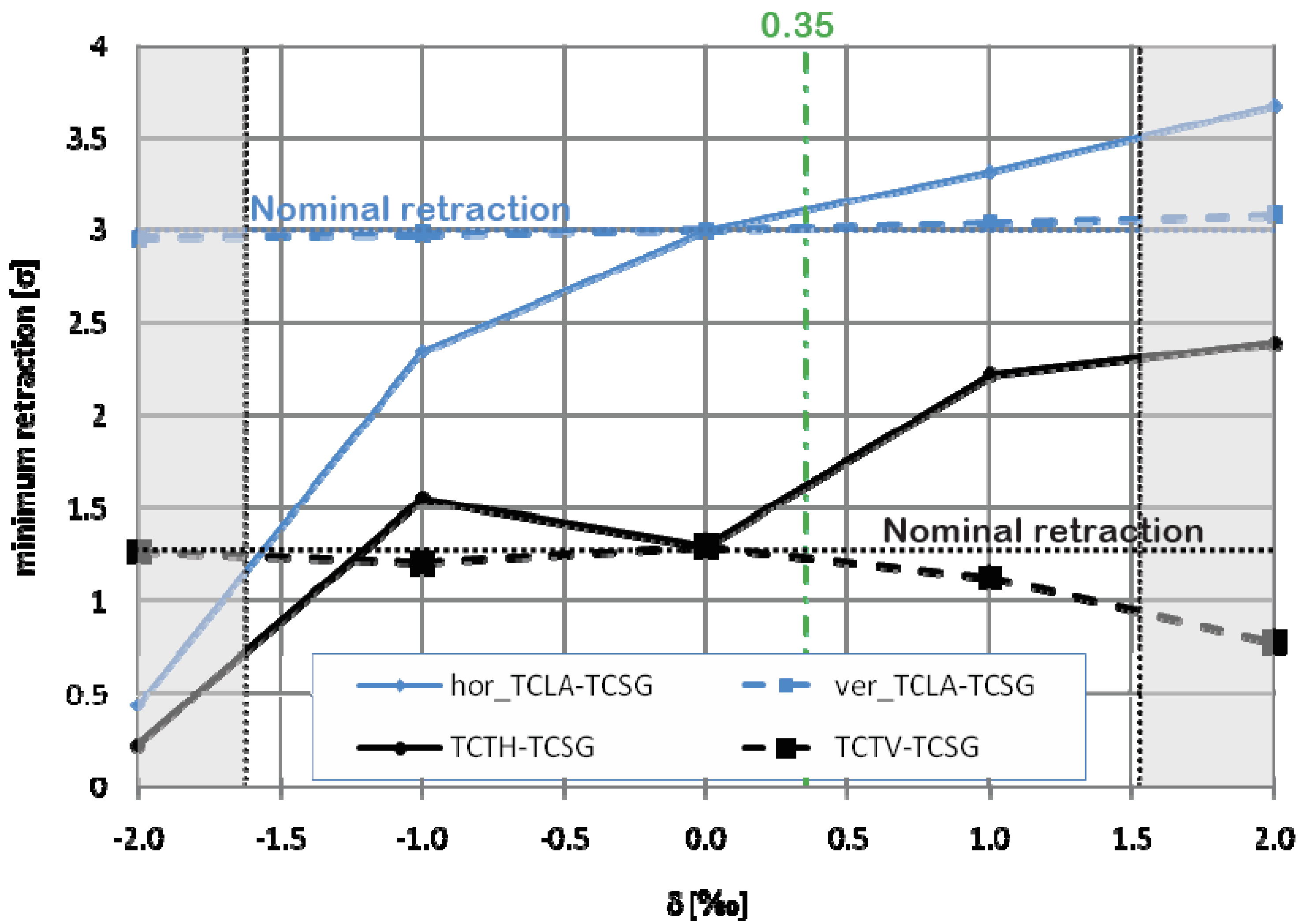
Each color represent one collimator family (legend)

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

Loss of retraction for secondary collimators



Loss of retraction for tertiary collimators



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  - Estimate for absorbers (margin 2.5 σ): ~ 1.5 σ
- Already very tight for nominal situation…
- **What is added by crab cavities?**

Preliminary Discussions

Preliminary analysis: closed orbit with global crab cavity

Yi-Peng Sun, Rogelio Tomas, Frank Zimmermann

Thanks to Rama Calaga

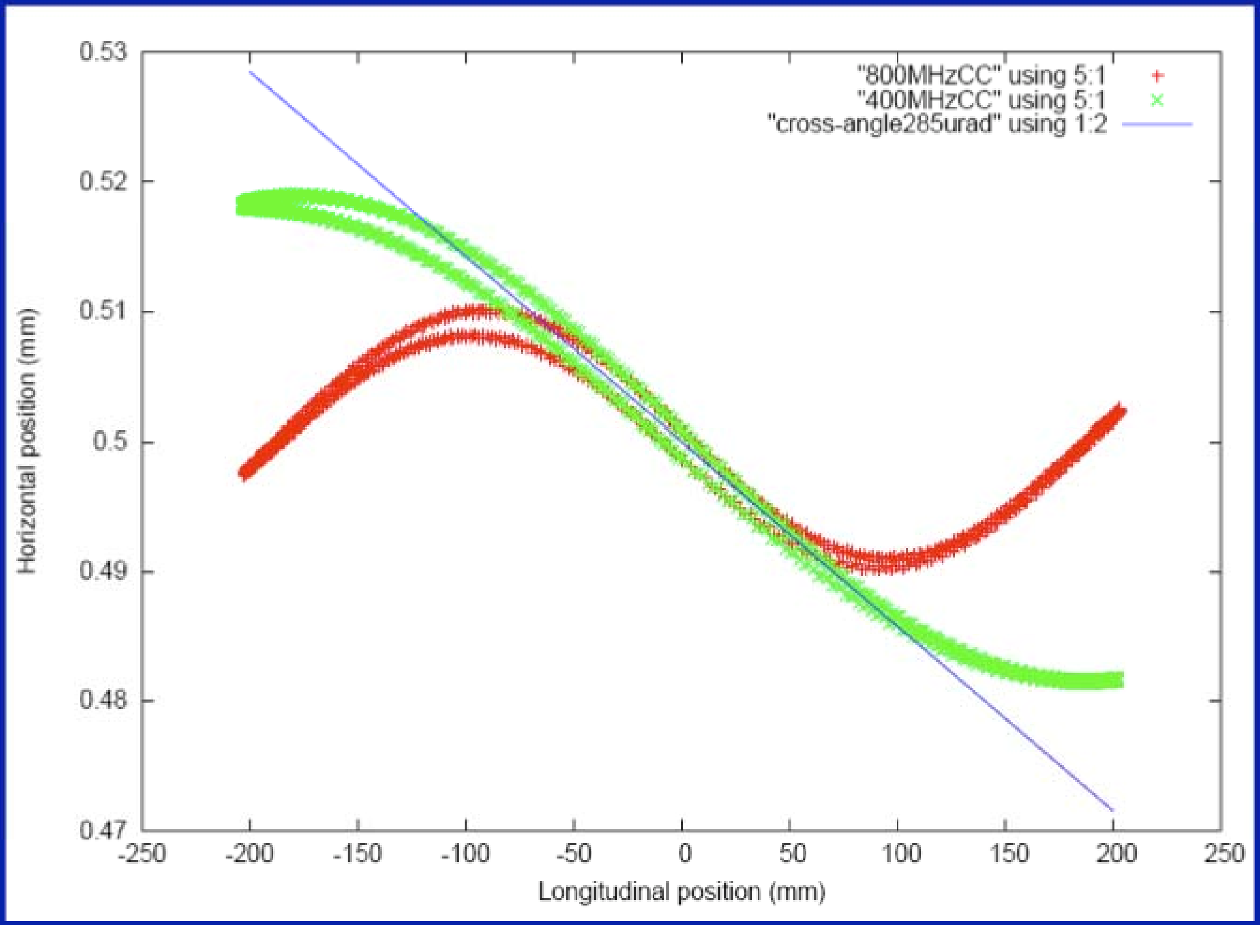
AB/ABP Group

European Organization for Nuclear Research (CERN)

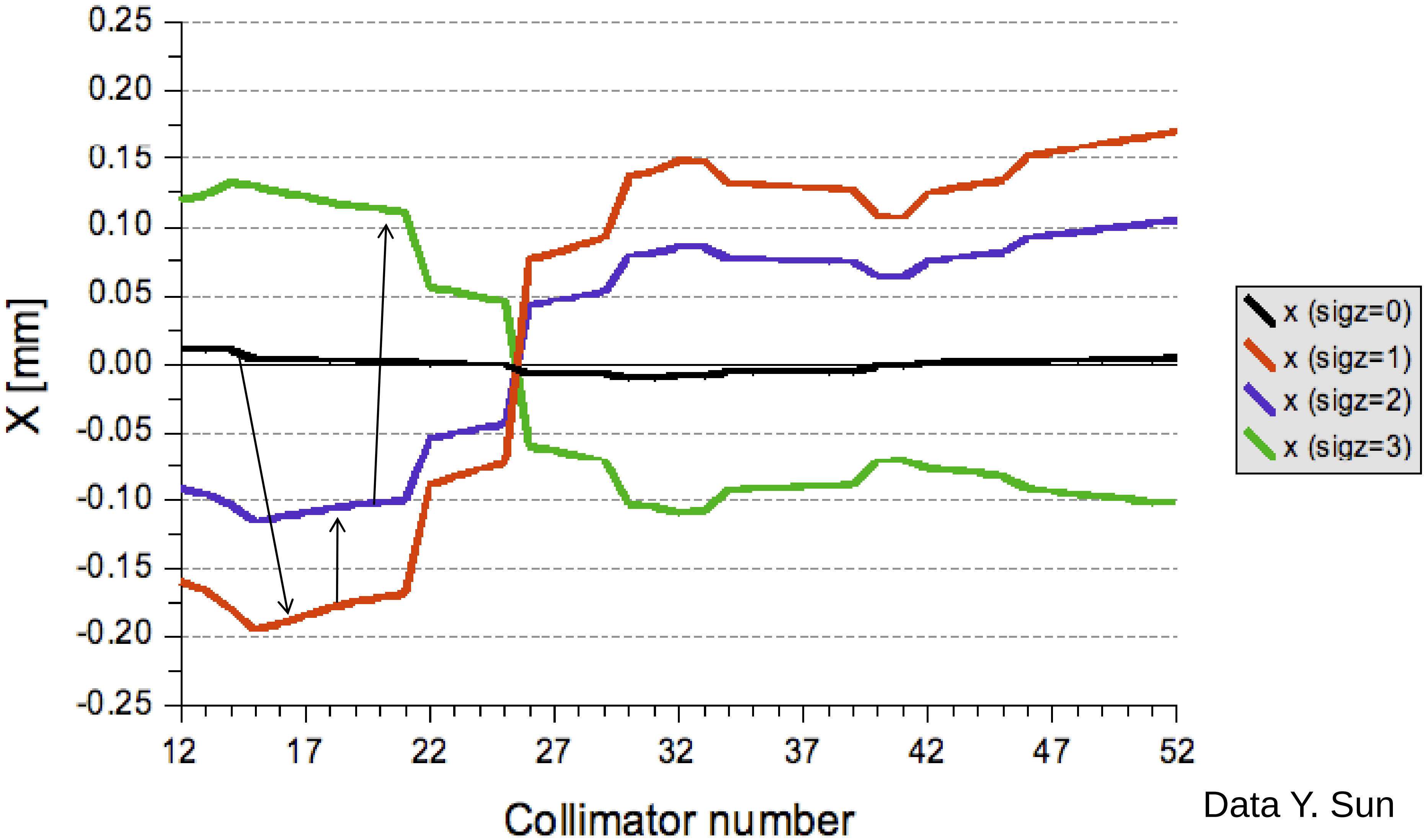
14 February 2008

Consider 800 MHz with Lower Voltage

Use 800 MHz CC (red one)

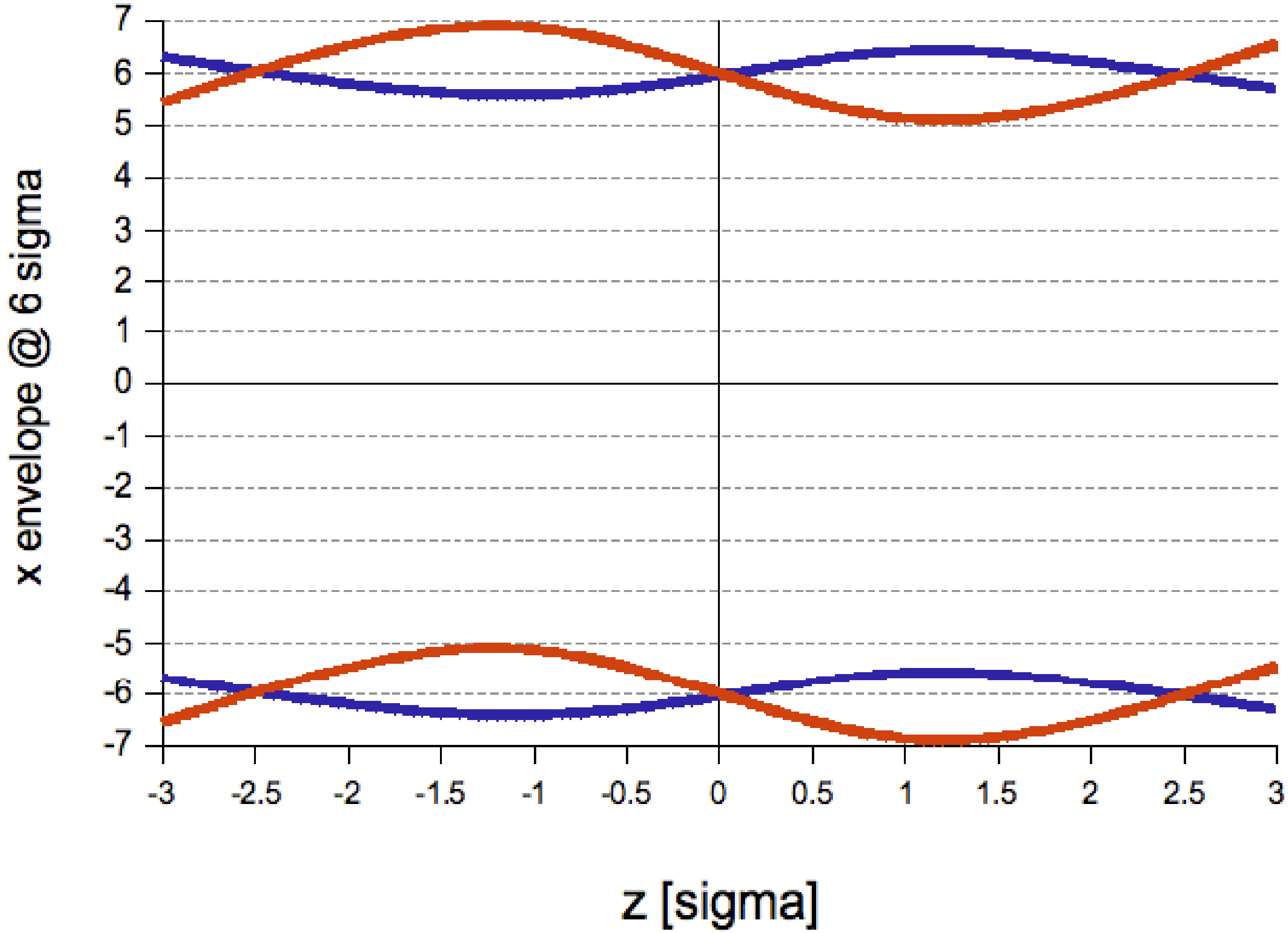


Orbit Change from CC

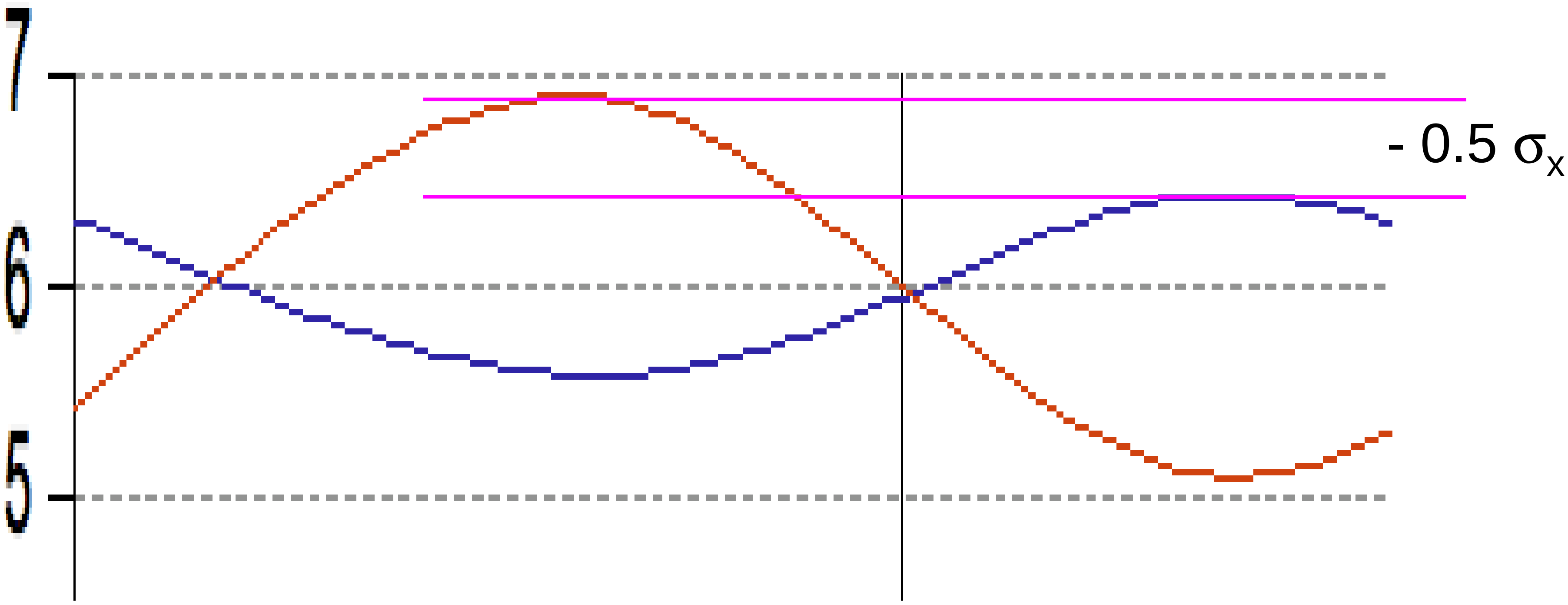


Data Y. Sun

What does it mean?



Loss of retraction…



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

Loss of horizontal retraction

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  - Estimate for tertiary collimators (margin 0.8 σ): ~ 0.5 σ
  - Estimate for absorbers (margin 2.5 σ): ~ 1.5 σ
- 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