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Commissioning of the LHC collimation system

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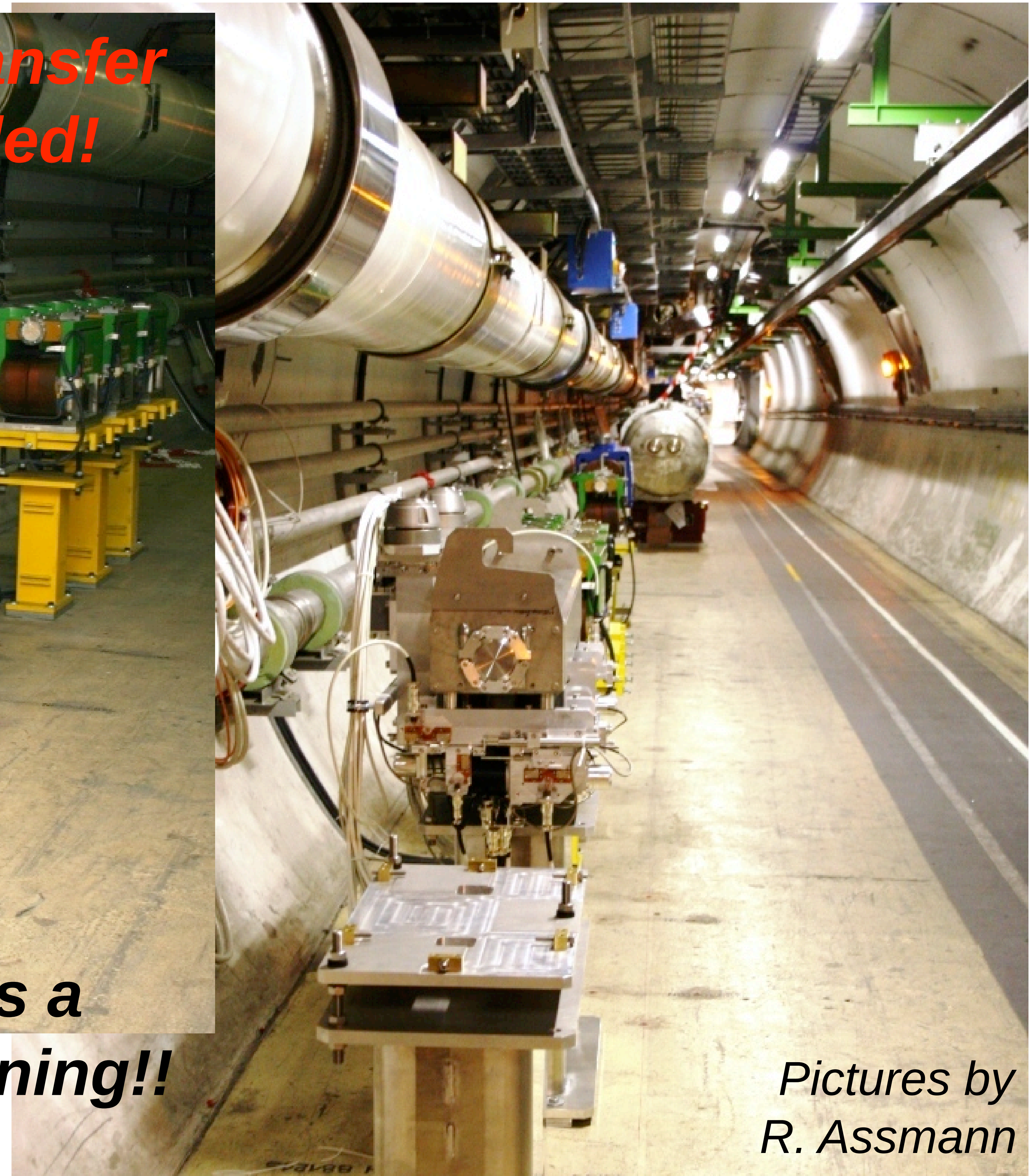
Outline

- Introduction
- Collimation commissioning plan
- Performance of reduced systems
- Collimator setup at the SPS
- Conclusions

Good news from CERN!

May 31st: First two transfer line collimators installed!



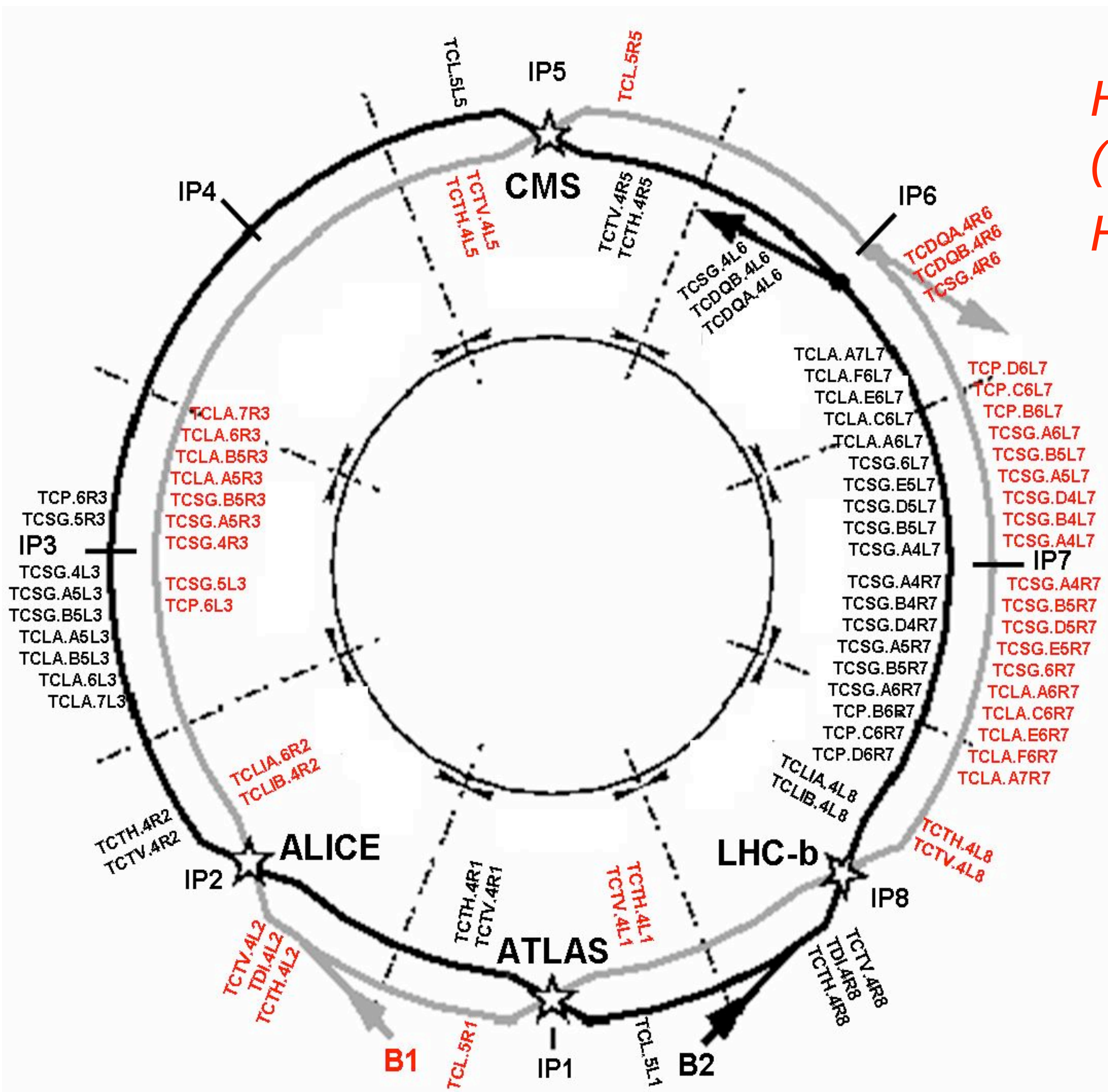
First milestone towards a successful commissioning!!

Pictures by R. Assmann

Introduction

*Initial LHC operation: **Phase I collimation system***

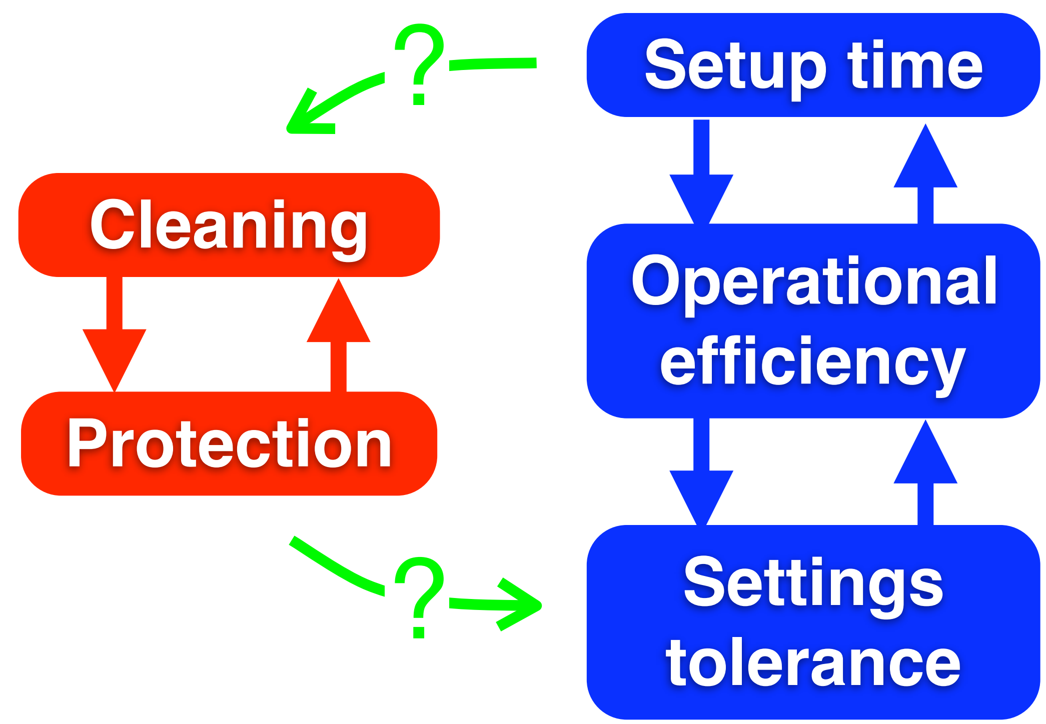
- ➟ *88 ring collimators + 13 in transfer lines (500 degrees of freedom!)*
- ➟ *Critical role for the machine protection*
- ➟ *Coherent settings required for element around the ring*



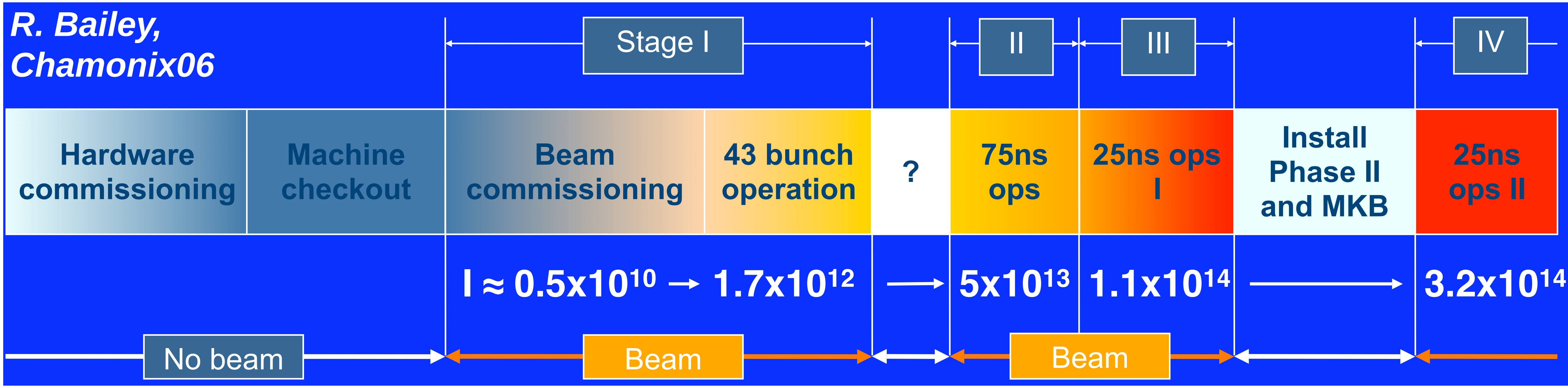
How do we commission this powerful (complex) system?

How do we adjust collimators w.r. to beams?

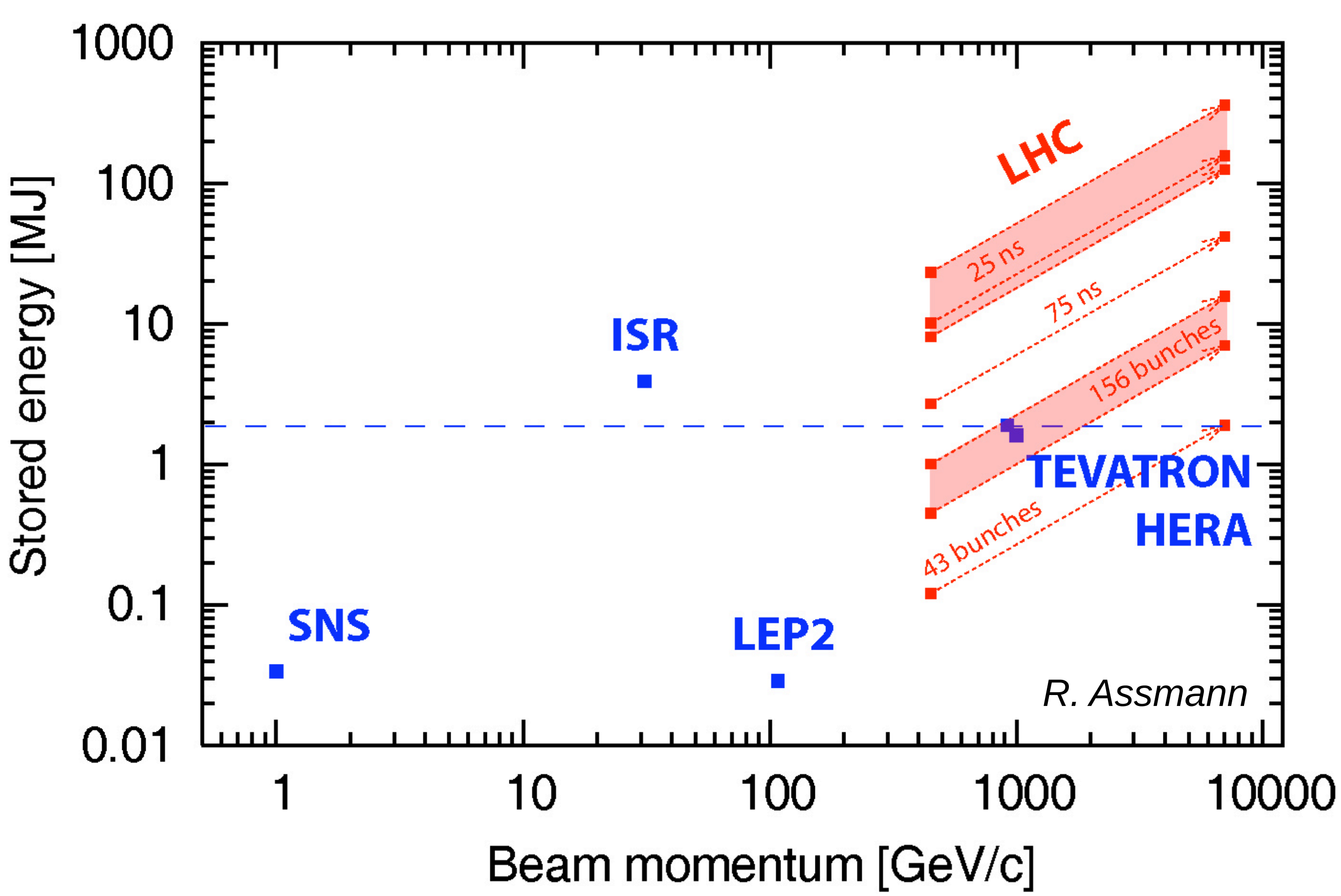
<u>Initially</u>: Trade-off between performance and operational efficiency!



Starting point: Staged LHC commissioning



What are the implications on the LHC collimation?



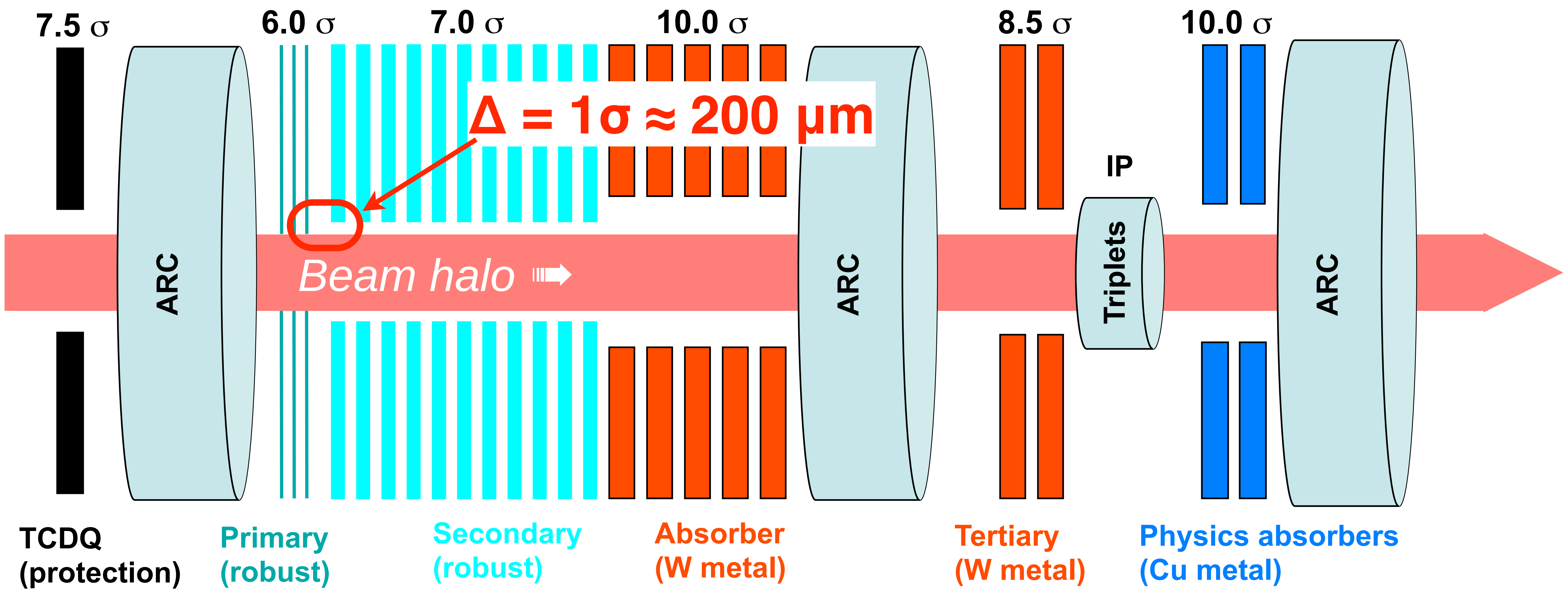
No easy startup!

- *43-on-43 ≈ Tevatron and HERA*
- *Pilot at 7 TeV above damage limit*

*However, collimation commissioning can profit from the **staged intensity!***

- *Can we find "reduced" collimation systems that ensure the required cleaning at each intensity stage??*

Nominal collimation settings at 7 TeV

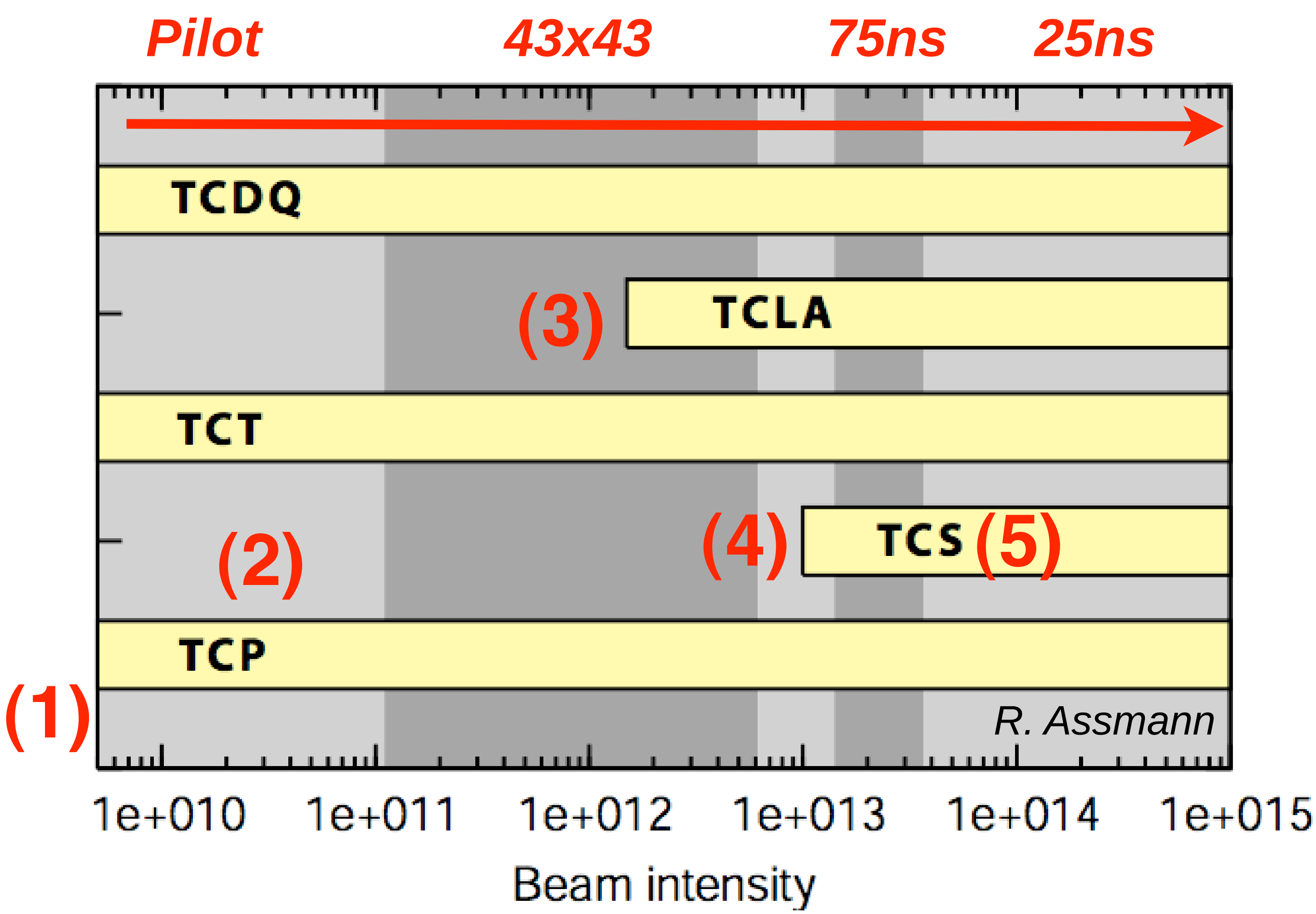


- Here: focus on **7 TeV operation** *(See also talk TUAZ03 for more details)*
- Aperture bottleneck: only super-conducting triplets is the IP's (±8.5 σ)
- Nominal settings: $\mathbf{A_{TCP} = 6.0\ \sigma}$ / $\mathbf{A_{TCS} = 7.0\ \sigma}$ / $\mathbf{A_{TCT} = 8.5\ \sigma}$ + $\mathbf{A_{ABS} = 10.0\ \sigma}$
- Protection (TCDQ): $\mathbf{A_{PROT} = 7.5\ \sigma}$ [must also protect the TCT's!]
- *Assumptions on expected cold aperture not discussed here (orbit, optics, ...)*

Staging the LHC collimation system

Staged intensity ⇔ Adapt collimator number and settings!

What's the minimum system that ensures the required cleaning vs. intensity?



- ➙ *Primary coll.(TCP) define the aperture*
- ➙ *Tertiary collimators (TCT) always protect the SC triplets*
- ➙ *TCDQ: protect against asynchronous firing of the beam dump*

They are needed with pilot at 7 TeV!

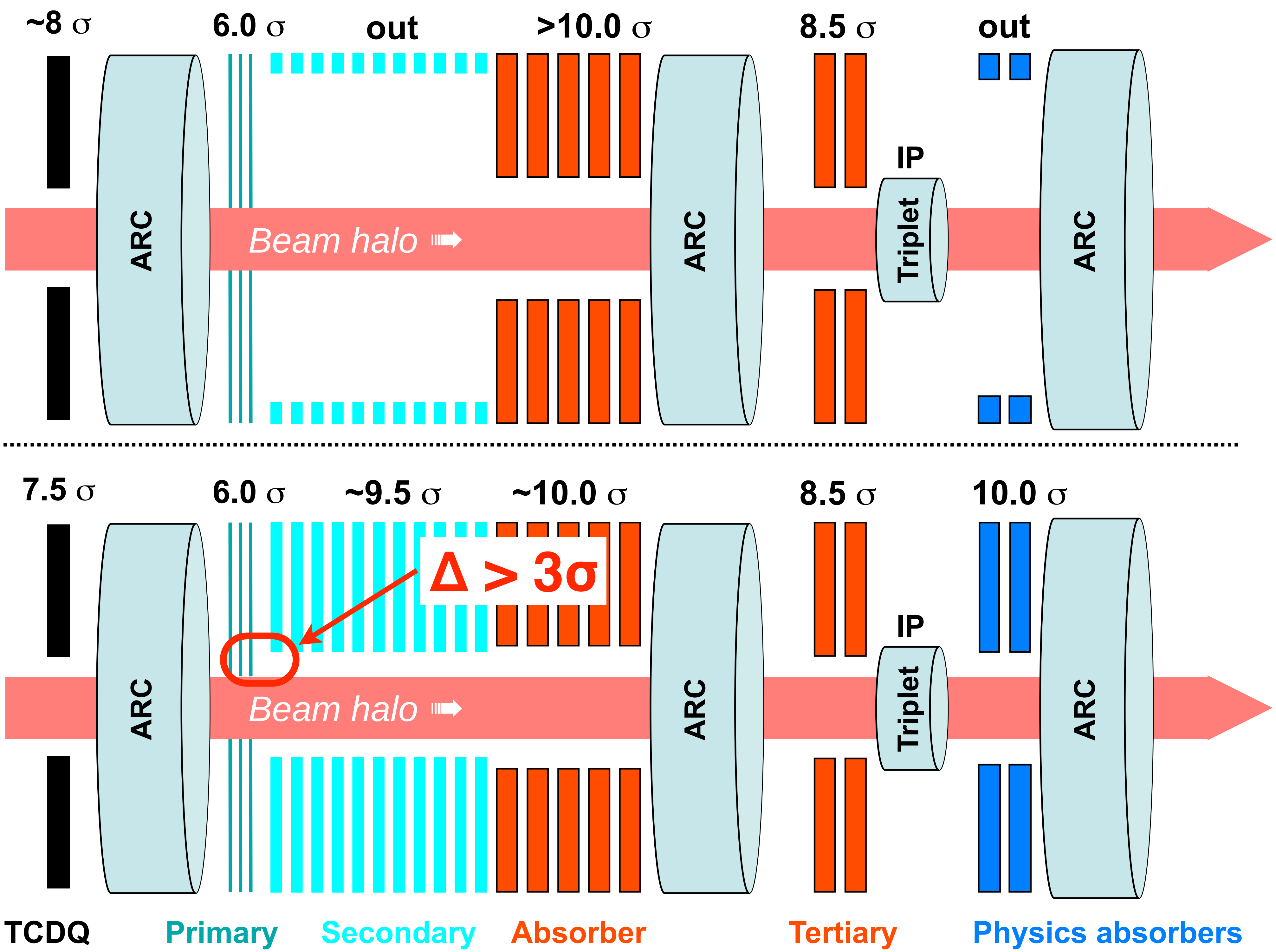
All collimators in place! We propose to adapt the number of the ones to be used

		N_{coll}
(1)	No collimators [$I_{max} \approx 5.6 \times 10^9$ p at 7 TeV] but protection	(14)
(2)	One-stage cleaning (TCP) + protection	14
(3)	One-stage + shower absorbers (TCLA) + protection	23
(4)	Relaxed two-stage (TCS) + shower absorbers + protection	38
(5)	Complete system at nominal settings [7 TeV]	38

Illustrative schemes of staged systems

(3) One-stage cleaning + shower absorbers + protection

(4) Relaxed two-stage cleaning + absorbers + protection



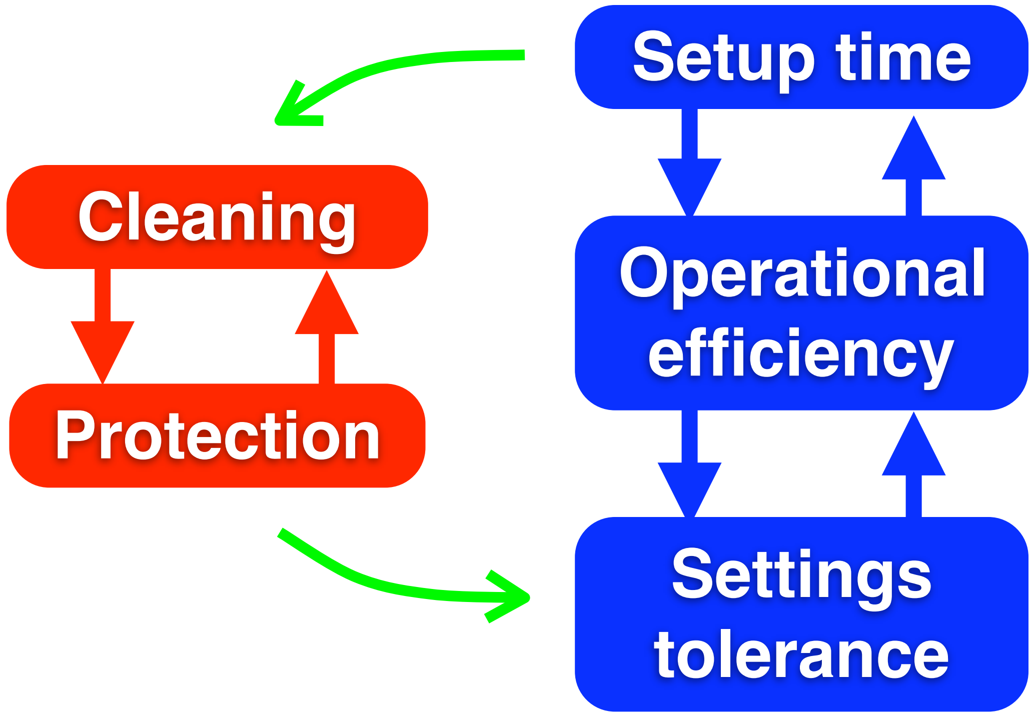
Nominal:	7.5σ	6.0σ	7.0σ	10σ	8.5σ	10σ

What do we gain with this staged approach?

Advantages of the staged commissioning

- ☑ Machine protection not compromised
- ☑ Required cleaning vs. beam intensity achieved
- ☑ Next intensity stages not compromised (all hardware in place)!
- ☑ Understand better the machine when full system and precise setup will be required!
- ☑ Reduced number of elements
- ☑ Relaxed setting tolerances

→ Optimize the setup time!



What's the beam intensity that we can achieve in each scenario?

Experience will tell, but we can try to predict what we will get!

Expected cleaning performance

		TCP	TCS	TCLA	TCT	TCDQ
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

Larger β operation* (first six rows)

Nominal β operation* (last six rows)

"Educated" guesses of the expected performance

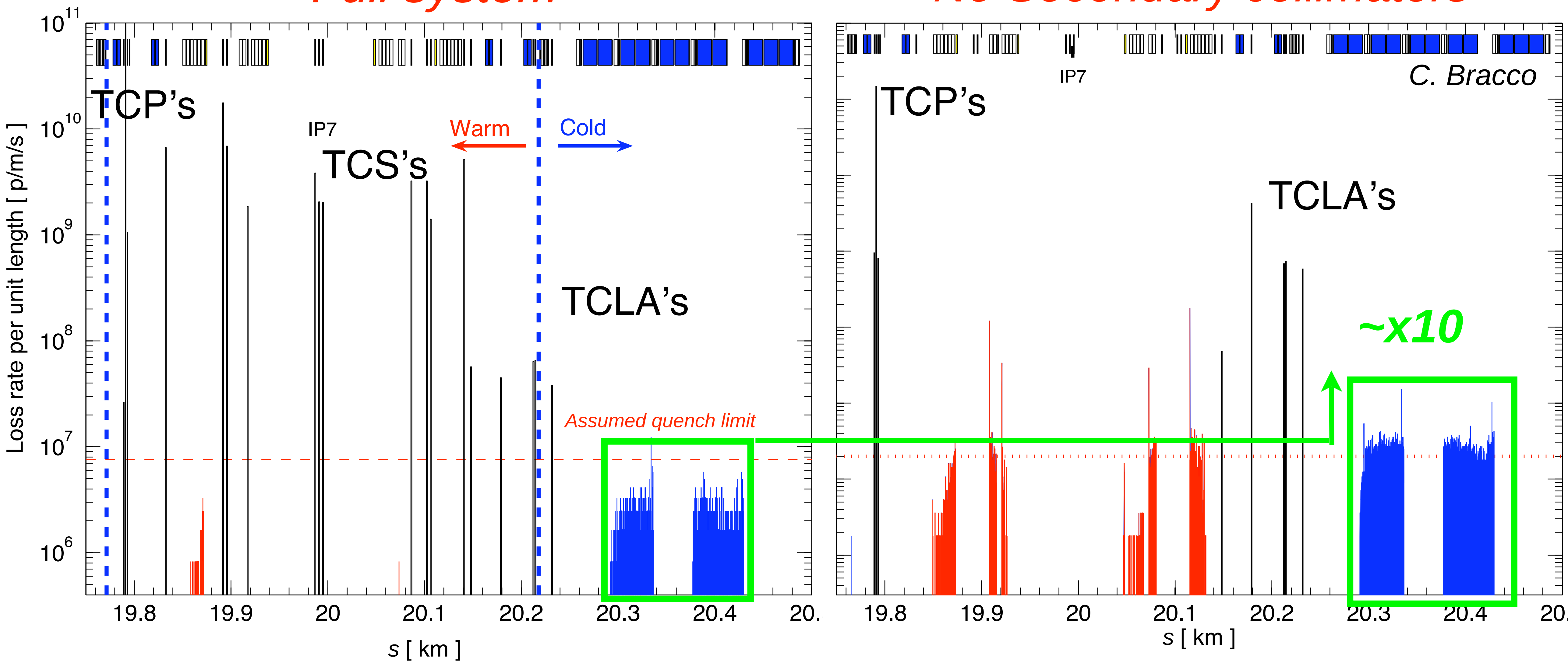
43-on-43 operation (row 1.5×10^{12}, 0.55 m)

R. Assmann et al., Chamonix 2006

Work ongoing: simulate in detail these operational scenarios and assess the cleaning performance.

Performance of the reduced system

Full system | *No Secondary collimators*



Power in the SC magnets

Magnet	Full system P_{dep}^{peak} [mW/cm^3]	Minimal system P_{dep}^{peak} [mW/cm^3]
Q6 (MQTL)	0.22	1.34
Q11	1.55	9.94
MB9	0.55	4.05

x7 (Q6 (MQTL) row)

Preliminary results from M. Santana

One-stage cleaning + shower absorbers is **~10 times above** the quench limit
⇒ allow physics with 43 on 43 operation!

Detailed studies ongoing for other scenarios.

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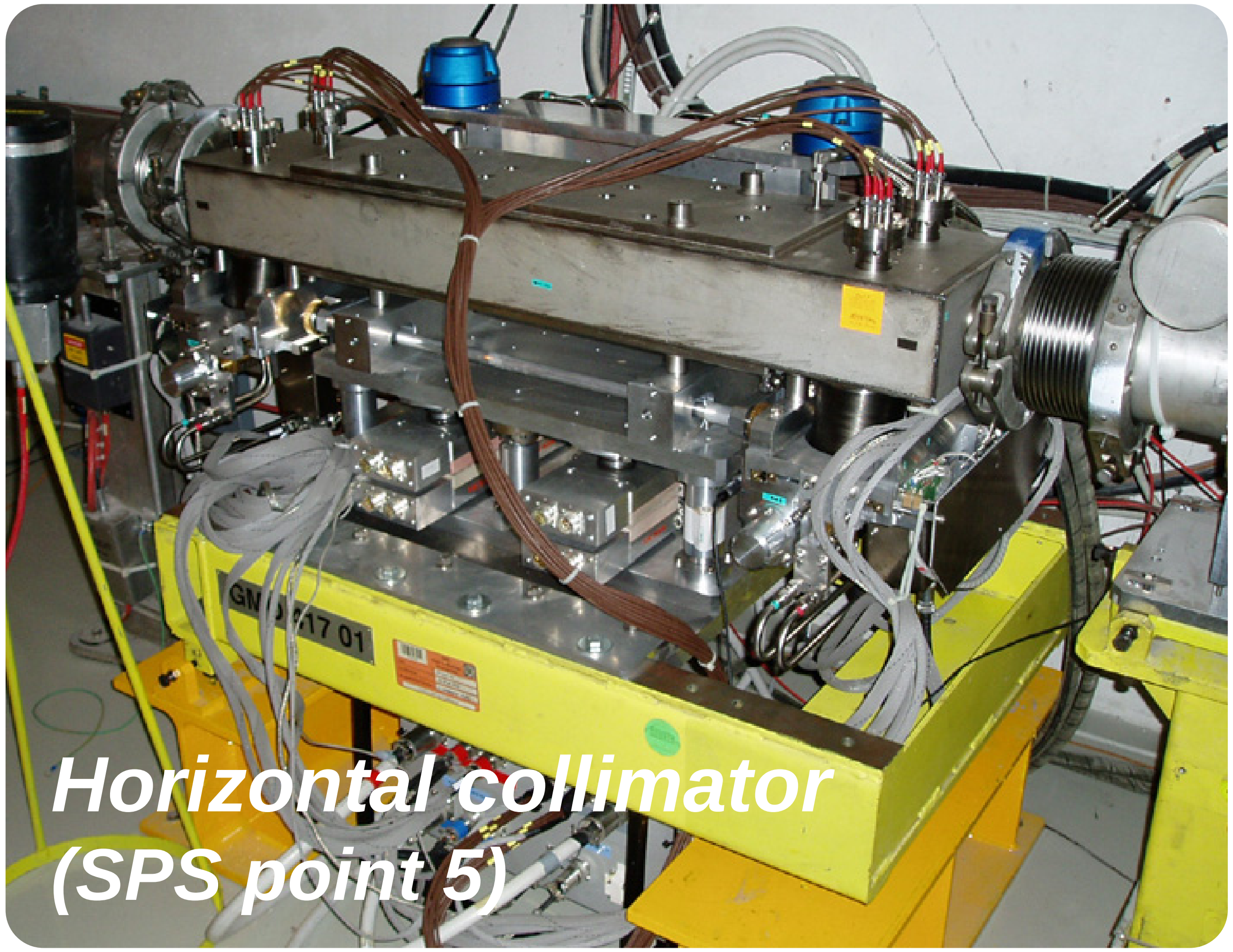
The collimator test with beam at the SPS

Goal of the test: Demonstrate the required functionalities of the LHC collimator prototype (mechanical movements, impedance, vacuum, …)

Low intensity test:	E_b = 270 GeV	$N_b \approx 1.1 \times 10^{11}$p	I_b = (1-16) x N_b
(TOTEM beam)	$\varepsilon_x \approx$ 1 μm	$\sigma_x \approx$ **0.4 mm**	
High intensity test:	E_b = 270 GeV	$N_b \approx 1.1 \times 10^{11}$p	I_b = 4 x 72 x N_b
(LHC beam)	$\varepsilon_x \approx$ 3.75 μm	$\sigma_x \approx$ **0.7 mm**	



Many tests performed
(mostly reported at PAC05):
*Mechanical functionality and basic control, **beam-based setup**, halo dynamics and beam shaping, systematics of BLM system, impedance and trapped modes, tune shift vs. collimator gap, vacuum, out-gassing, ...*

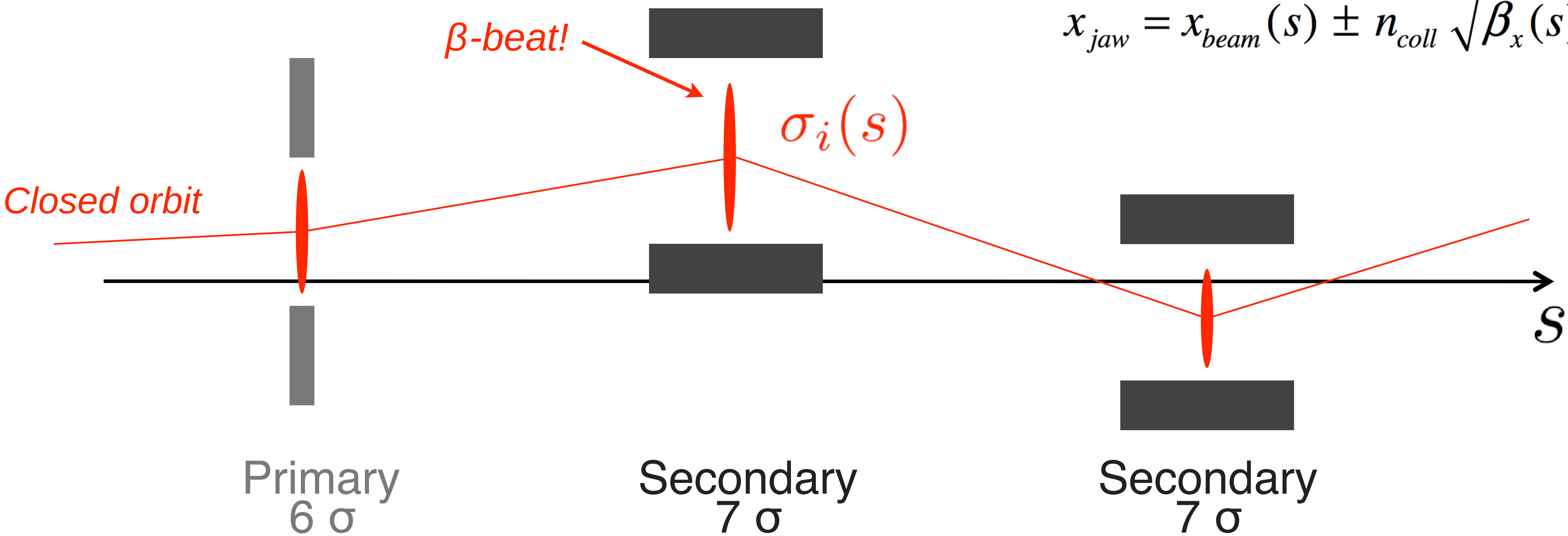
What do we want to setup collimators?

Normalized collimator settings must be converted to positions in [mm]:

- Center the two collimator jaws → Know the orbit!
- Adjust the gap to the correct setting → Know the beam size!

$x_{beam}(s)$, $y_{beam}(s)$, $\sigma_x(s)$, $\sigma_y(s)$ ⇒ **Normalized settings** ↕ **Gaps in millimetres**

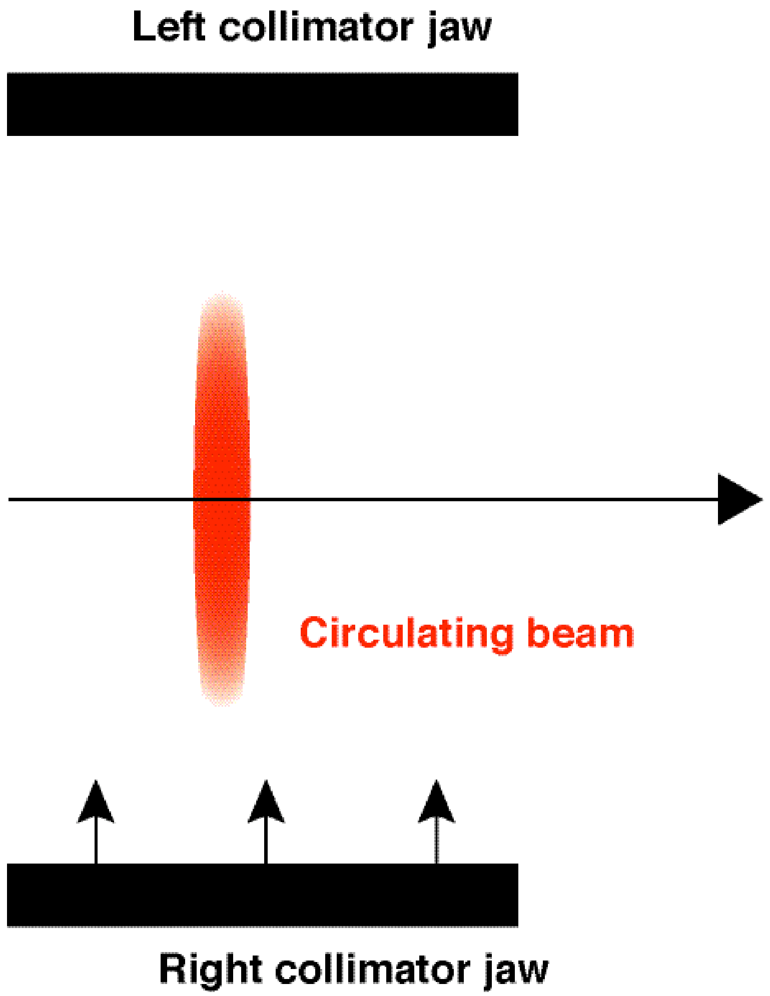
$$x_{jaw} = x_{beam}(s) \pm n_{coll} \sqrt{\beta_x(s)\ \varepsilon_x}$$



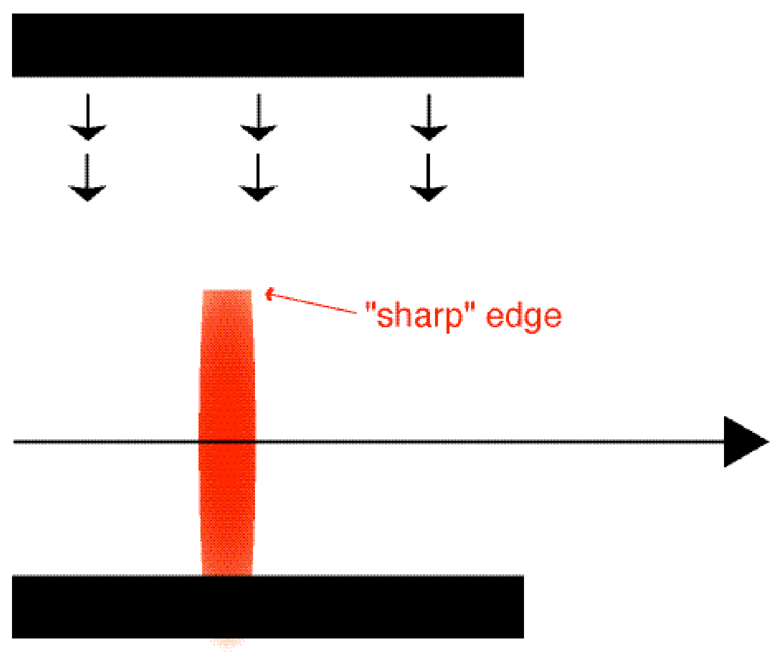
How do we center the collimator jaws

Beam-based alignment relies on dedicated sets of BLM's mounted at each collimator.

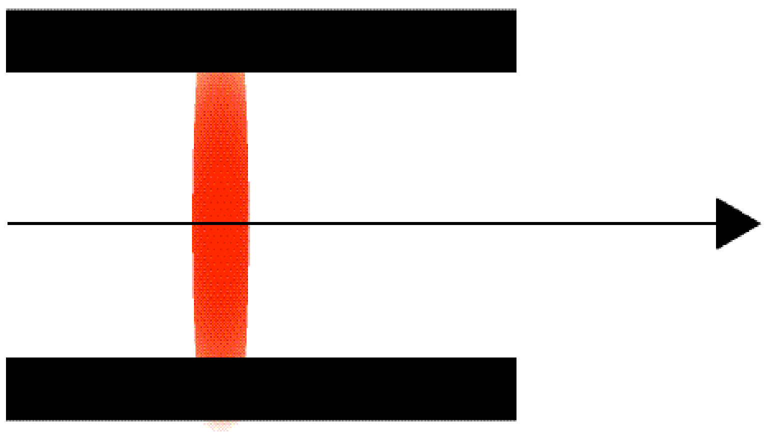
1. Move one jaw in



2. Scrape the beam (sharp edge)

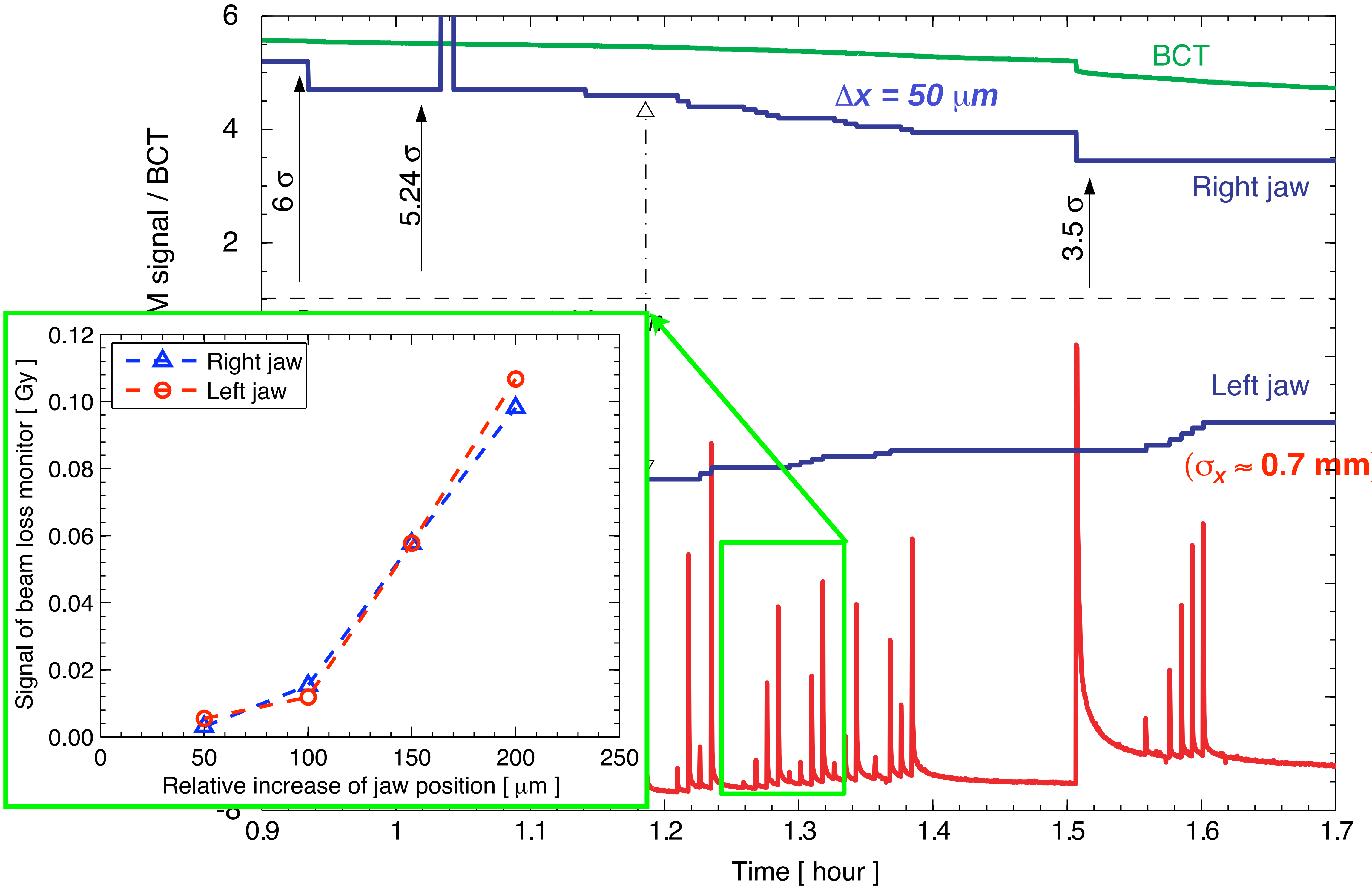


3. Move the other jaw until you see a signal on the BLM



- *Take profit from the the two-sided design!*
- *Alignment rely on the reading of downstream beam loss monitors*
- *The step size Δx sets the precision of the final alignment!*
- *Move one jaw corner at the time to adjust angles?*

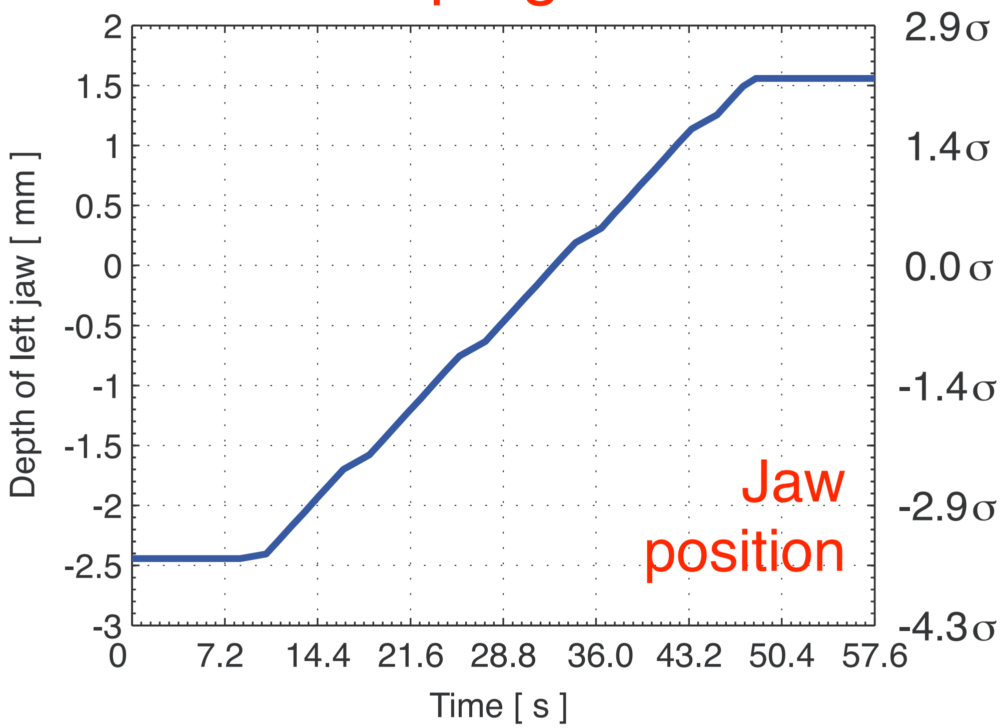
Beam-based centering of the collimator jaws

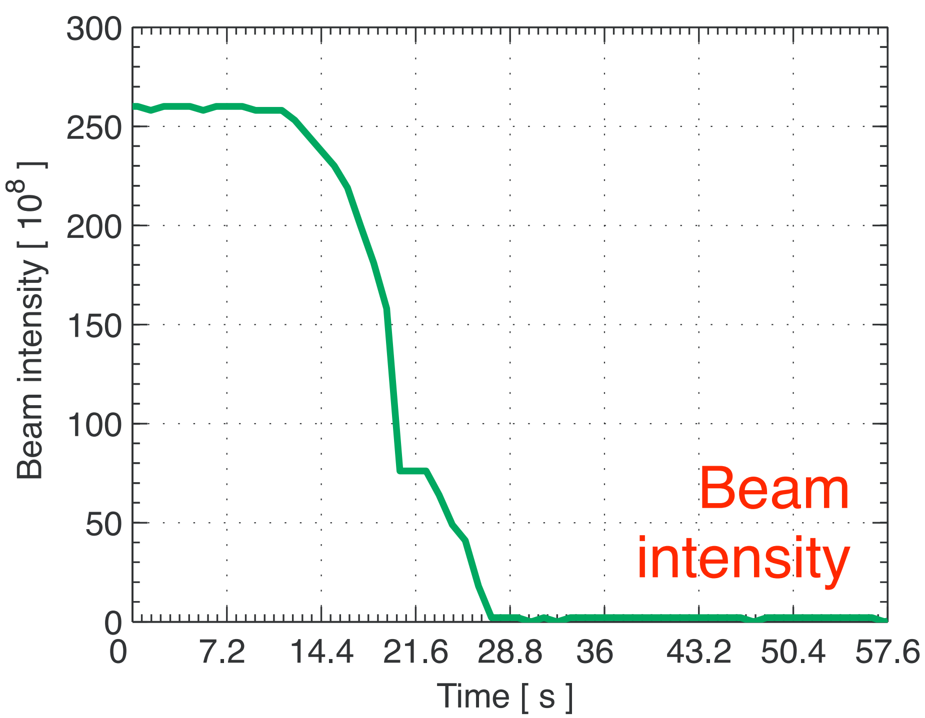


First centering with high-intensity beams: ≤ 1h. ***50 μm centering accuracy*** *demonstrated!*
Then, 10-15 minute (precision of 50 μm). Less time for less precise settings.
Setting of gap values relied on good optics model + emittance measurements.

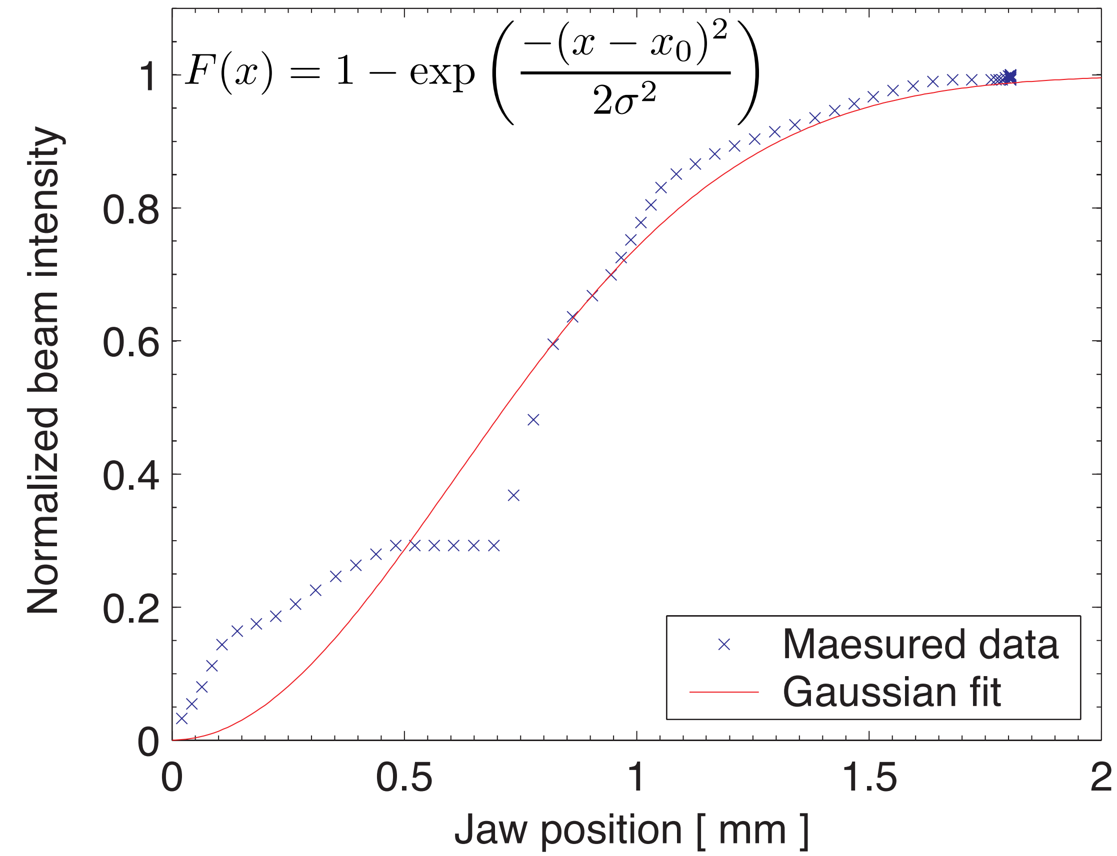
Local beam size at the collimator

Full beam scraping at the collimator





Example of SPS measurements



Expected beam size : σ = √βε = 700 μm

Fitted beam size : (665±52) μm

More studies this year at the SPS...

Method: **accurate** but **destructive** and **long**!

Repeat it at each collimator?

How scales from injection to 7 TeV?

However, can be a solution if the optics model is not good enough!

Conclusions

- Commissioning of the LHC collimation system discussed
- Reduced systems proposed for various LHC stages
  - ➞ Insure required cleaning versus beam intensity
  - ➞ Safety not compromised
  - ➞ Use a smaller number of collimators
  - ➞ Positioning tolerance relaxed
- Proposed scenarios are validated with detailed simulations
- Setup of collimator successfully achieved at the SPS
  - ➞ Centering to the 50 μm level routinely achieved
  - ➞ Methods to adjust the collimator gaps were worked out
- LHC issues (start the discussion?):
  - ➞ Infer 7 TeV settings from setup at 450 GeV
  - ➞ Relative retraction of many collimators at different places
  - ➞ What is the expected halo population of the LHC beams?
  - ➞ Precise setup of skew collimators