Actuation and Alignment Challenges of LHC Collimators

M. Garlaschè

*on behalf of the **EN\MME collimation team***

1st PACMAN Workshop

CERN, Geneva, Switzerland – *2÷4 February, 2015*

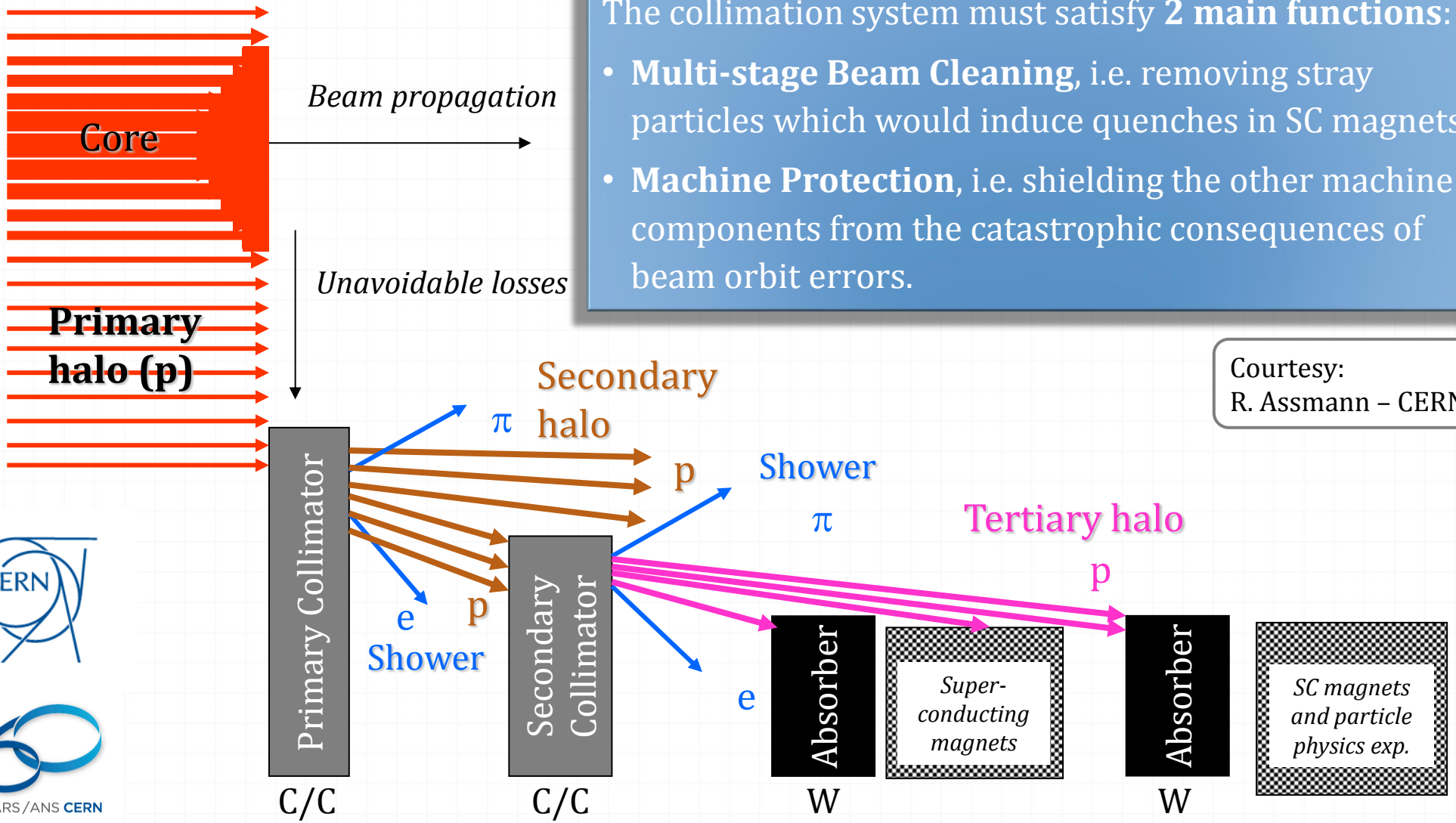
Outline

- LHC collimators
- Actuation system
- Beam-relative alignment
- Summary

What is a LHC collimator

The collimation system must satisfy **2 main functions**:

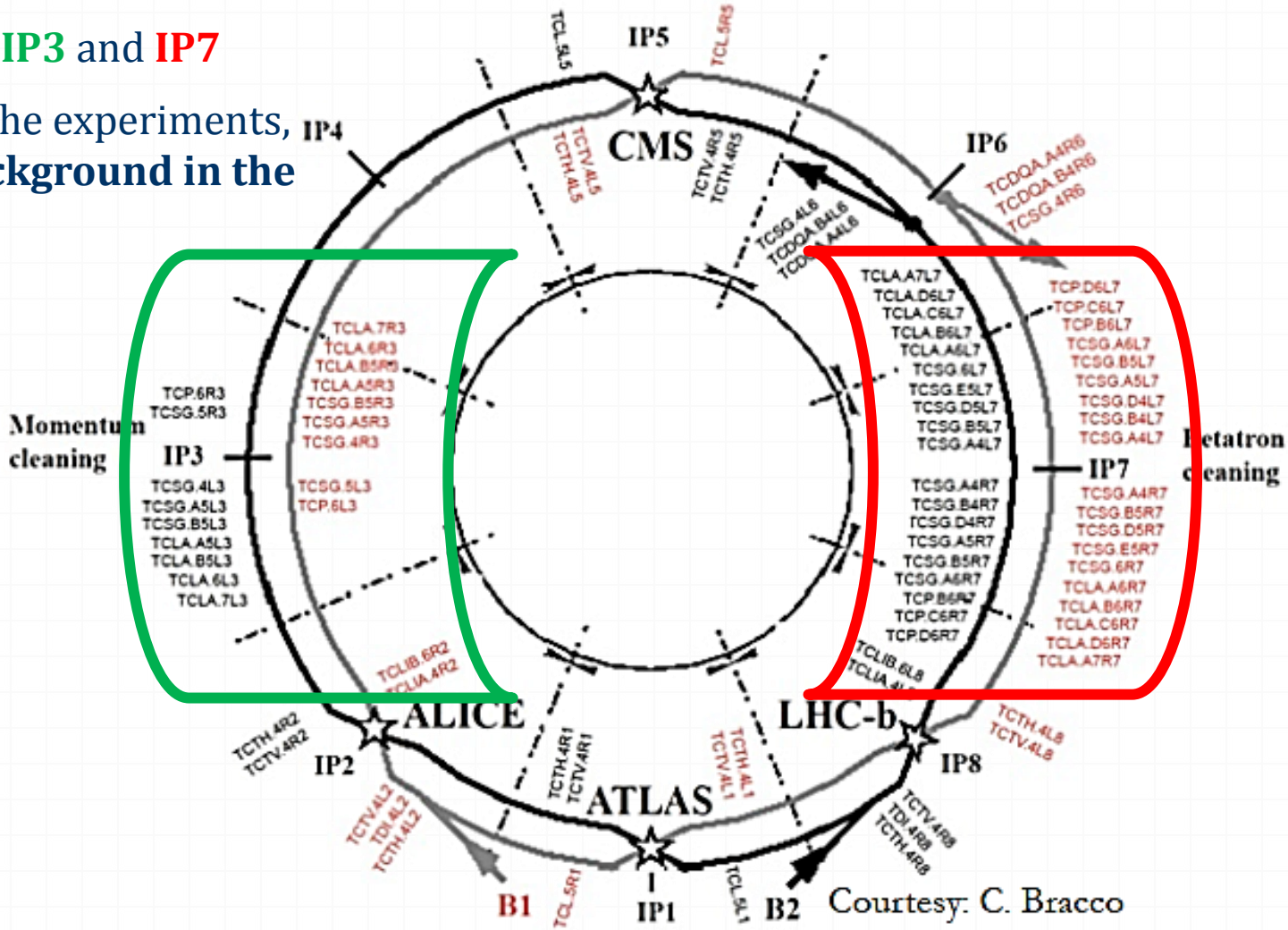
- **Multi-stage Beam Cleaning**, i.e. removing stray particles which would induce quenches in SC magnets.
- **Machine Protection**, i.e. shielding the other machine components from the catastrophic consequences of beam orbit errors.



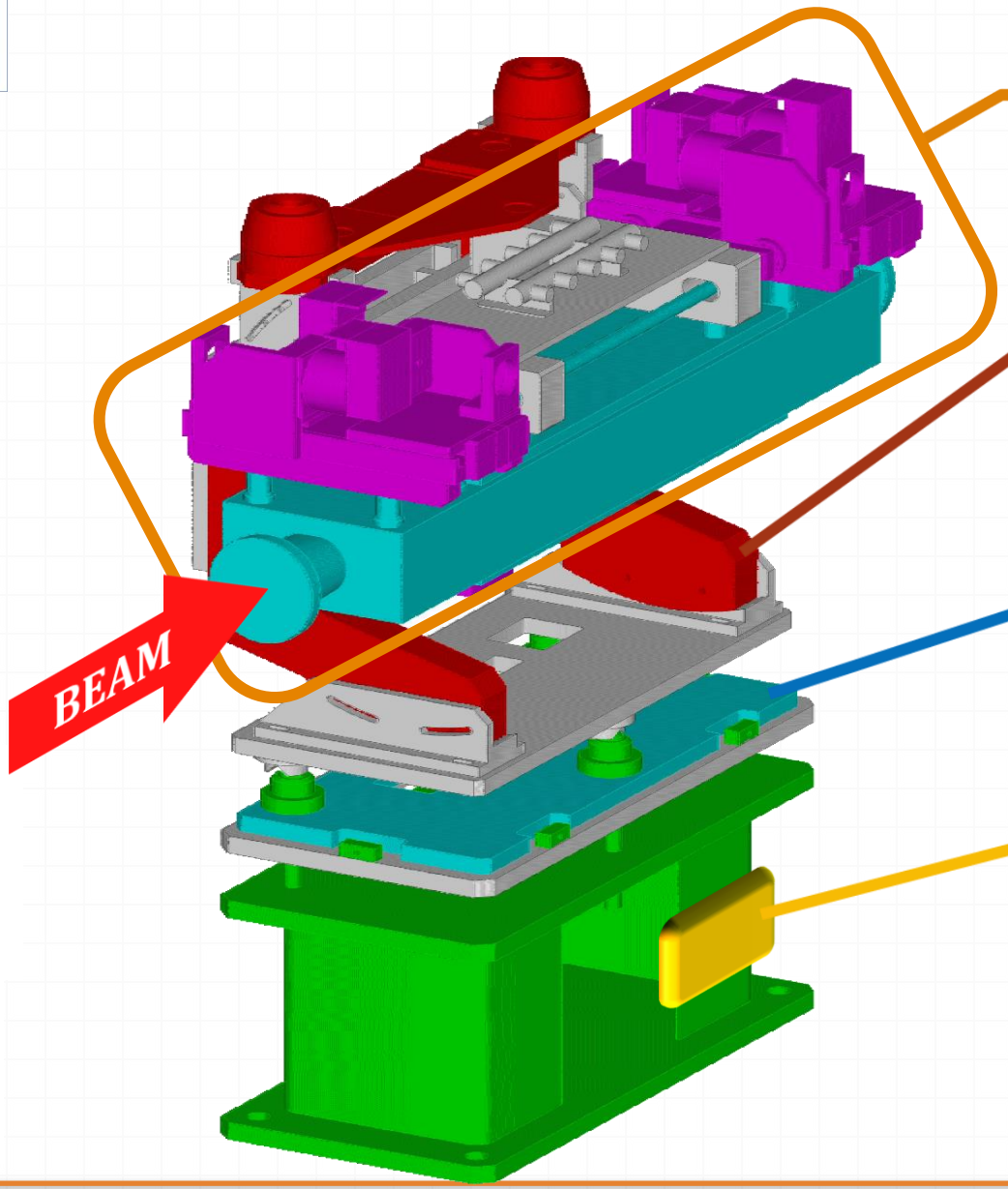
Courtesy:
R. Assmann – CERN

Collimators in the LHC

- **~100 collimators** in the LHC
- Mostly positioned at **IP3** and **IP7**
- Also present before the experiments, to **reduce signal background in the detectors**



Collimator: General Layout



Collimator assembly

Adjustable stand

- Orientation
- Fine positioning

Quick Plug-in

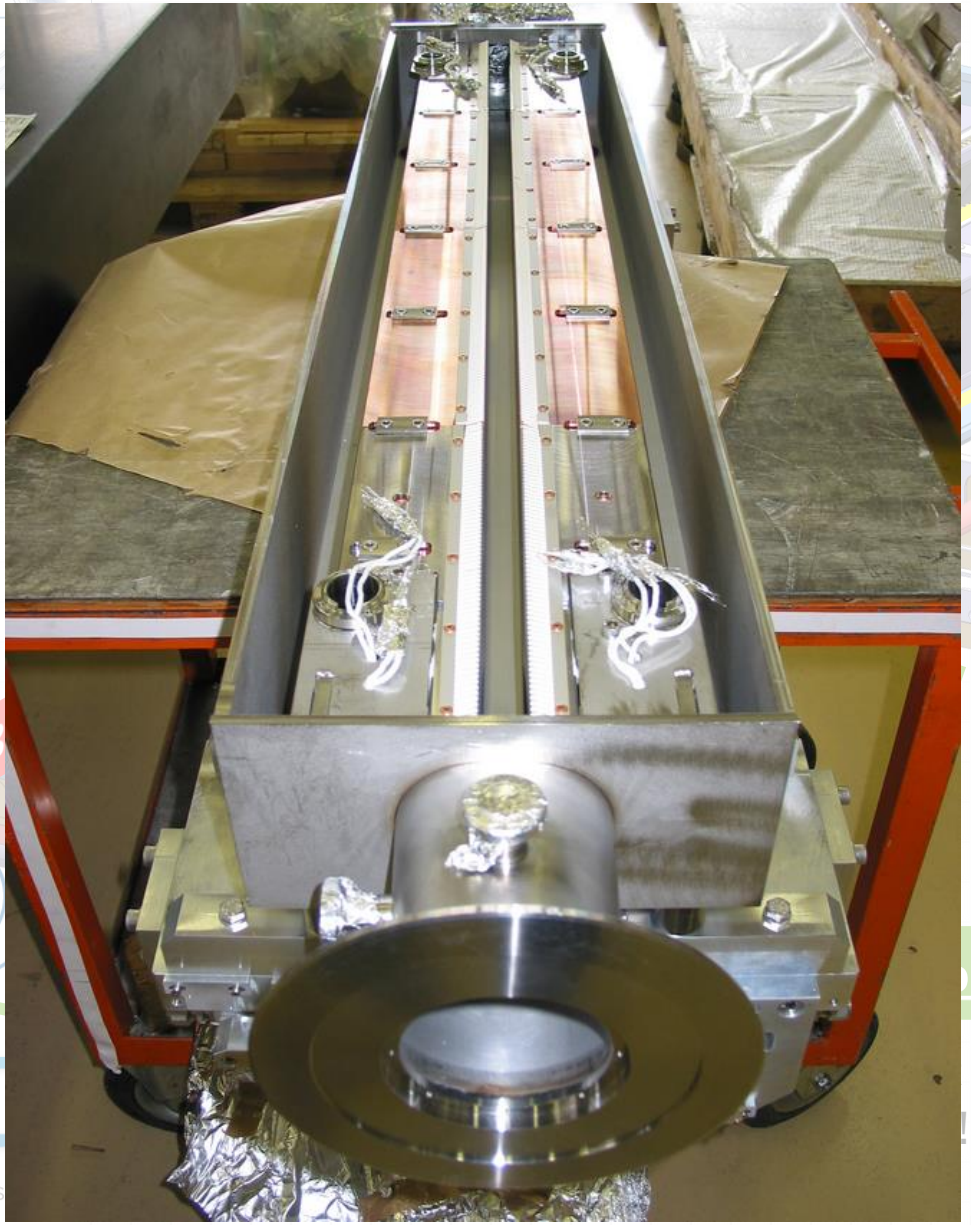
... High levels of radiation...

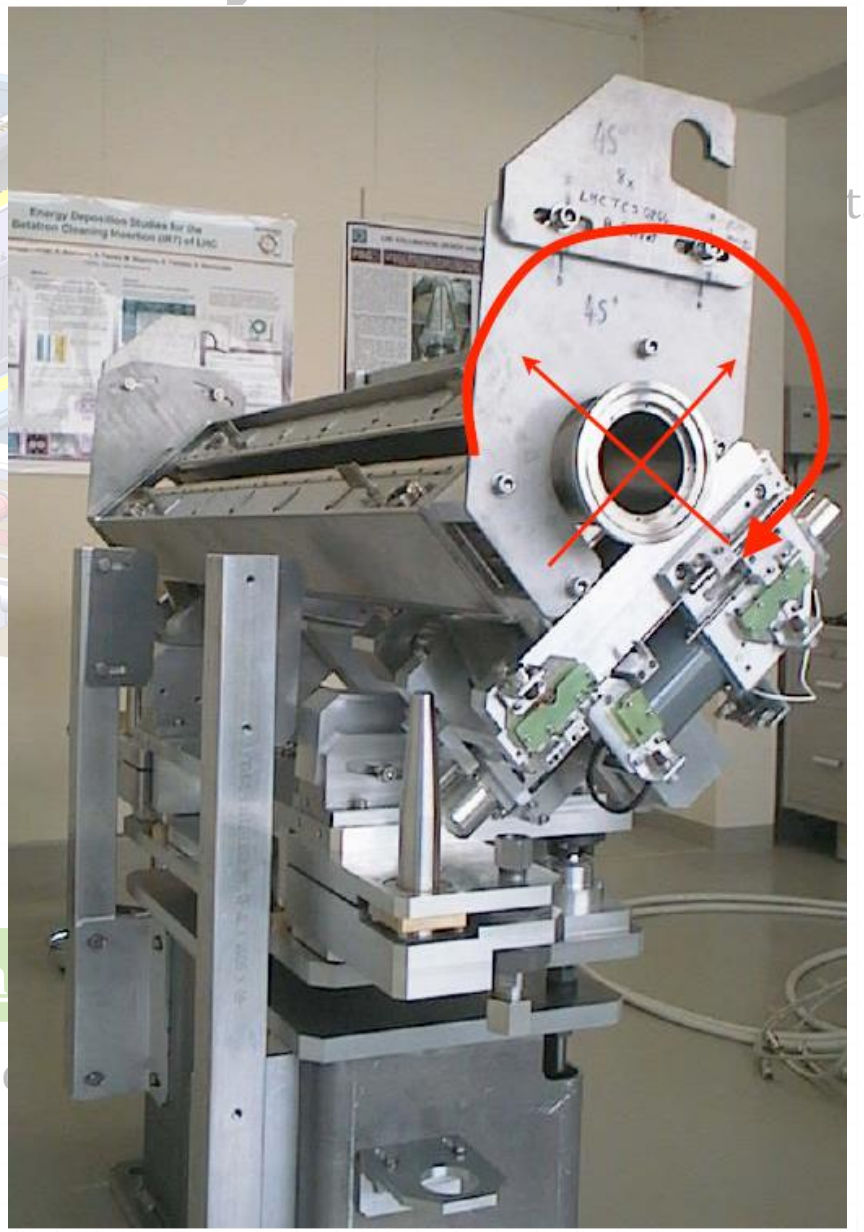
Beam Loss Monitor (BLM)

Overall length: 1480mm

Tank width: 260mm

Collimator: Main Subsystems



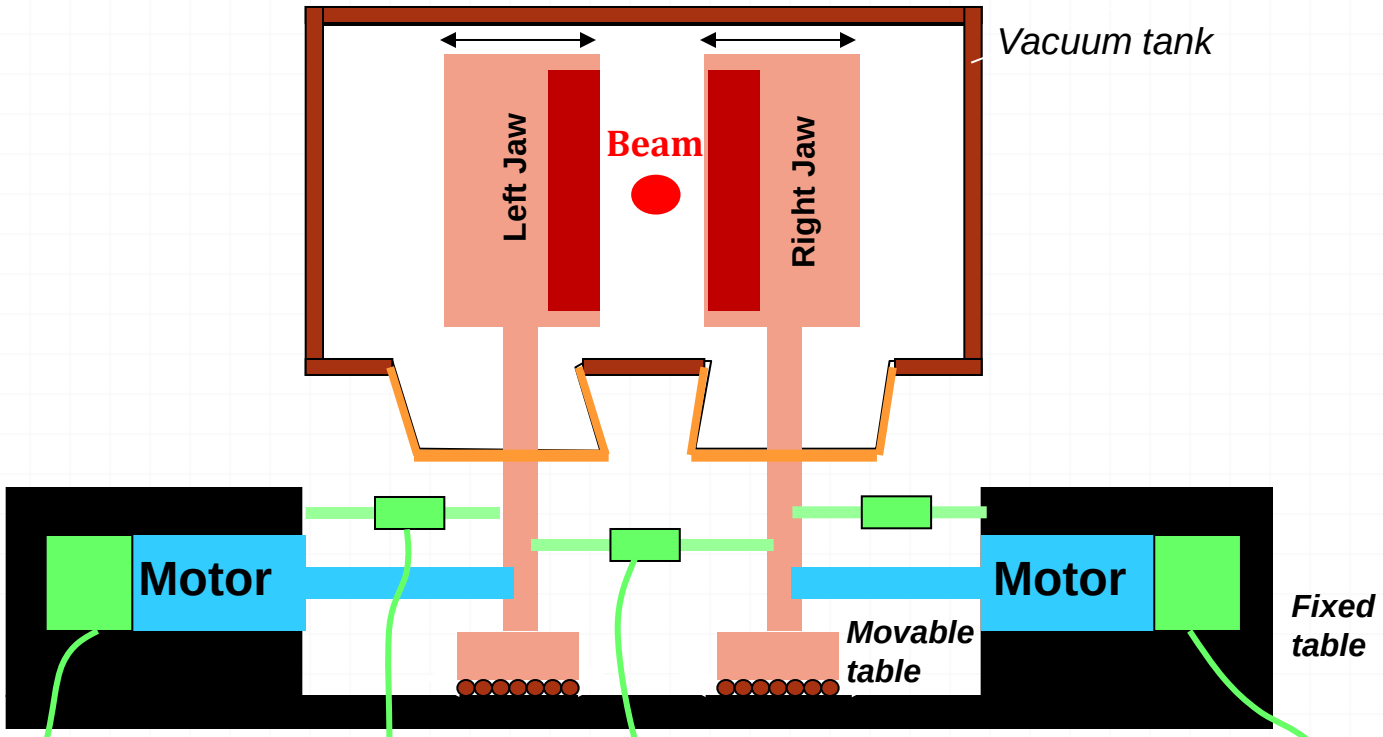


Outline

- LHC collimators
- Actuation system
- Beam-based alignment
- Summary

Actuation system

Frontal cross Section



Vertical movement (5^{th} axis) +/- 10mm

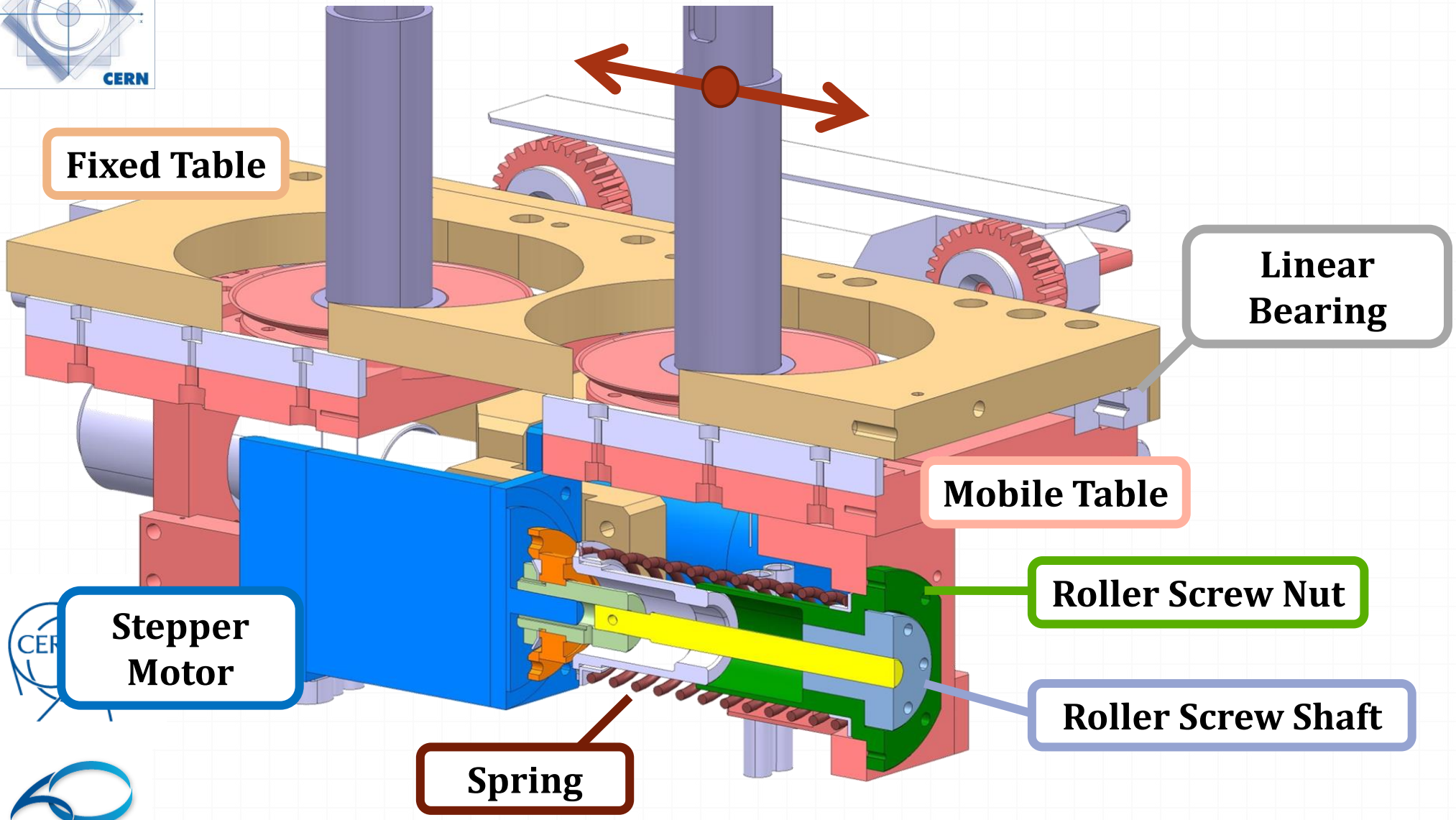
(1 motor, 2 switches, 1 LVDT)

Courtesy R. Losito (EN/STI)

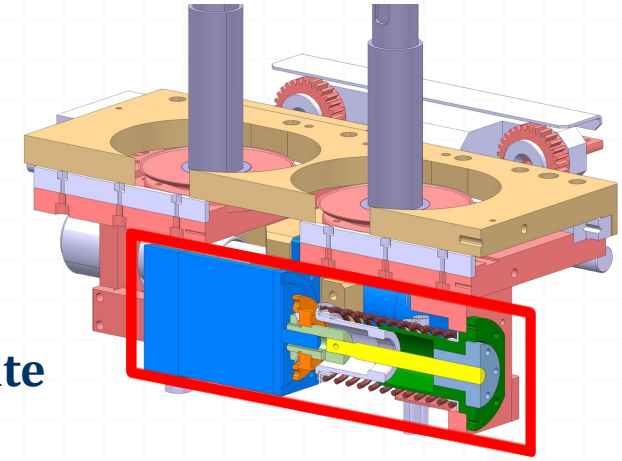
Actuation System: Functional Requirements

Requirements	
Jaw stroke	+30/-5 mm
Jaws auto-retraction	Yes
Motors per jaw	2
Stepper Motor min. Pull-in Torque	2.5 Nm
Stepper motor max Detent Torque	60 mNm
Tolerance on expected actuator position	**± 25 µm**
Repeatability on actuator position	**± 10 µm**
Minimum required lifetime	**20000 cycles over 20 years**
Component radiation hardness (cumulated)	**10 MGy**

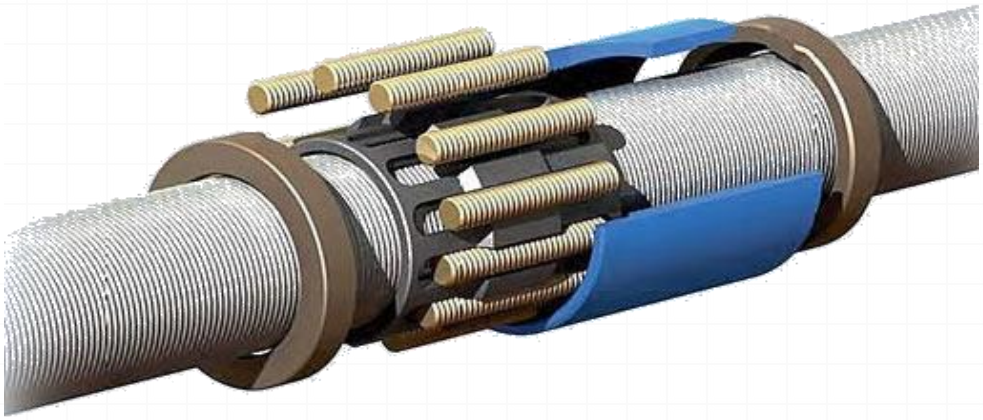
Actuation System... a closer look...



From Circular to Linear Motion



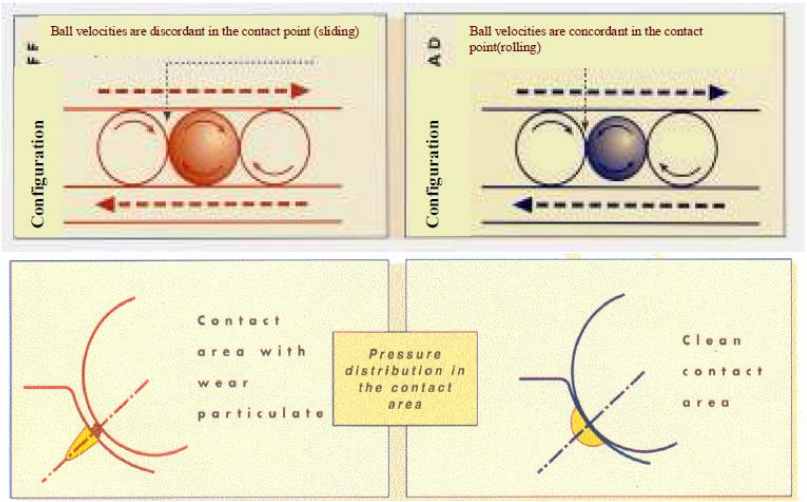
- High resolution **Stepper-motor**:
  - 400 (sub)steps/turn
- **Recirculation Roller Screw:**
  - Stainless steel (AISI420) components with **graphite coating of shaft** plus **radiation hard grease**
  - High precision (**<6 µm** on total screw travel)
  - Lead 2 mm/rev. → ***5 µm*** *jaw displacement per each motor step*



Next Step: Ball Screws

- End of 2013, an **increase** of demanded **torque** in some of the motors was detected
- This was due to the **evaporation of roller screw liquid lubricant**, which caused an increased in friction
- **Regular maintenance impossible** due to high radiation levels!

Alternate Architecture
(lower contact stress due to absence of wear particulate)



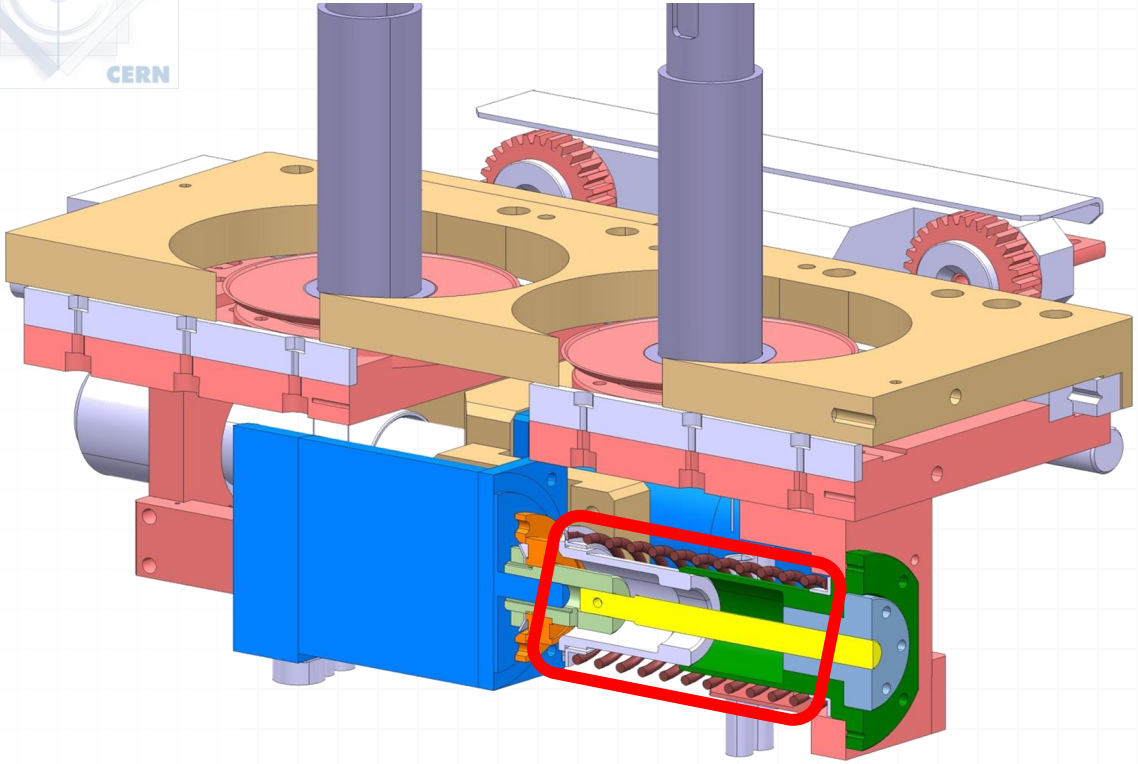
Dry screws

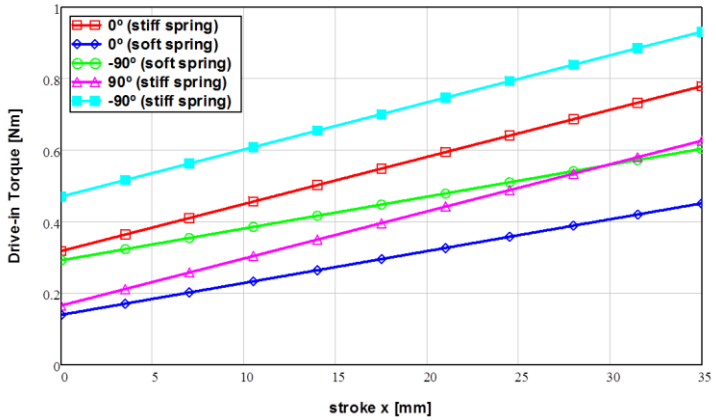
Courtesy O. Aberle (EN/STI)

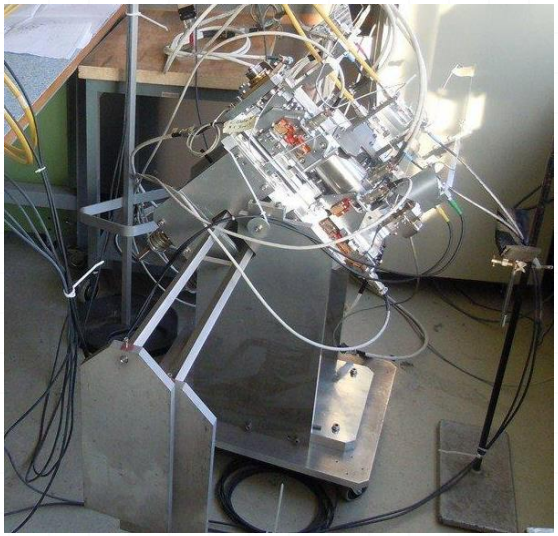
Dust and debris in the end cap and the housing

- Alternative solution under testing: hybrid **stainless steel/ceramic ball screws**
- **Low friction & wear** between the rolling elements, **no need of lubrication**
- **Radiation-hard!**

Minimizing Play…



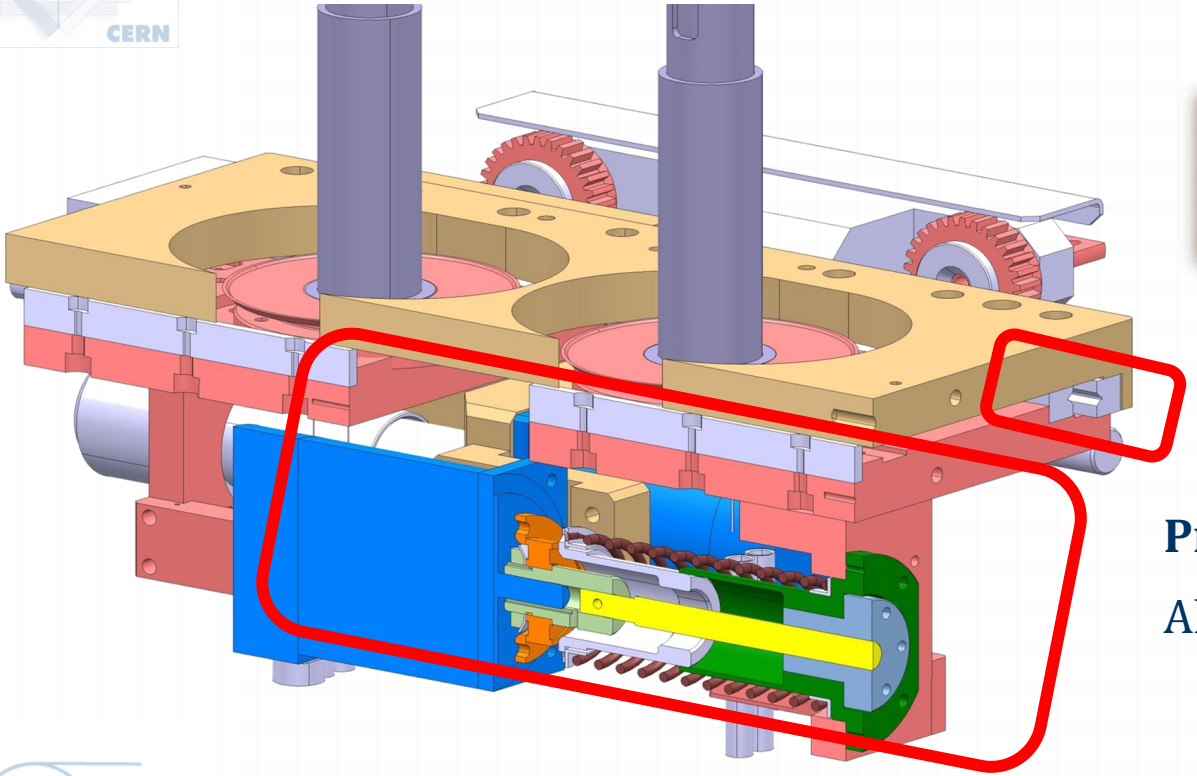




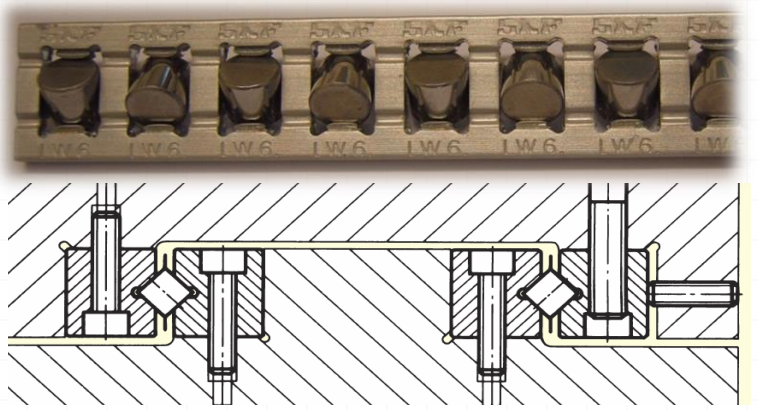
Preloaded spring, in order to:

- **Recover** screw mechanical **gaps**
- Move the **jaws away from** the **beam axis** in case of short-circuit
- The torque of **each movable table is qualified with a dedicated test bench**

Minimizing Play...



Linear Bearing



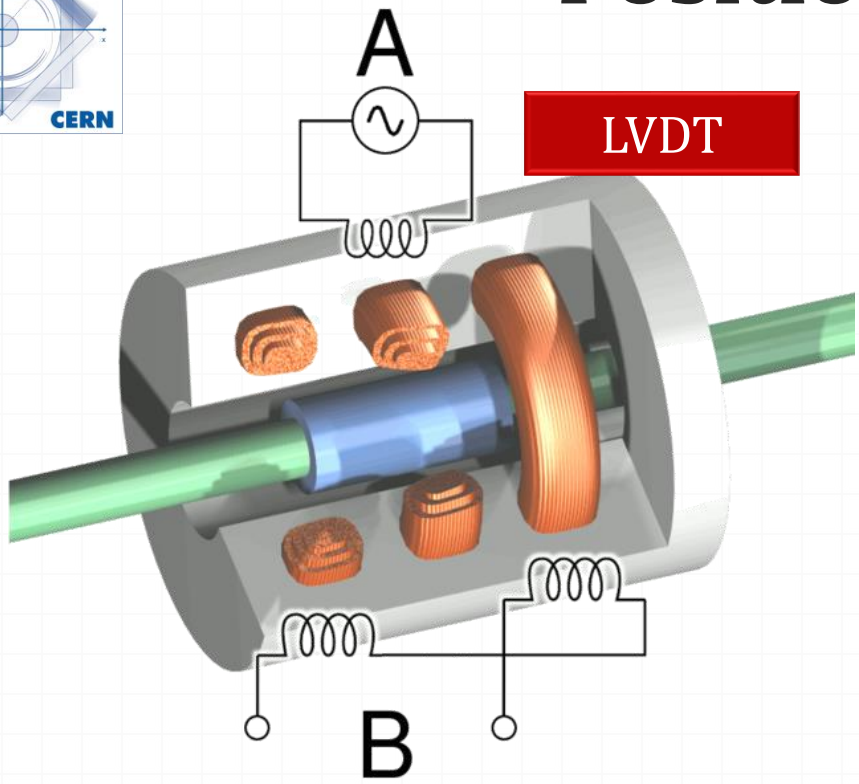
Preloaded crossed roller configuration

All-metal, corrosion resistant, for use in non-lubricated conditions

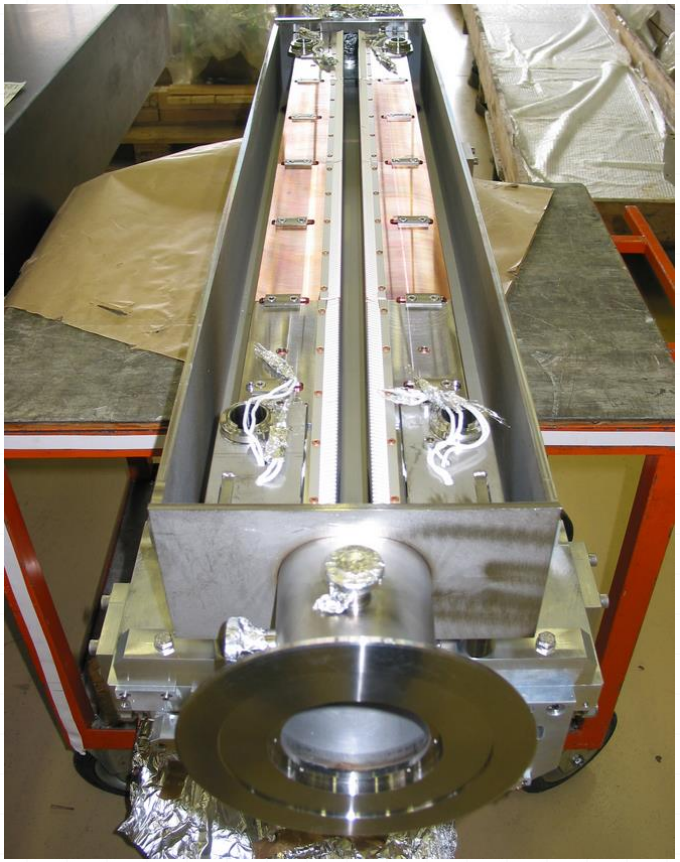
Iperstatic motor-screw **fitting**:

- Adds complexity to assembly procedure
- Eventual decoupling would allow for play

Position Sensors



LVDT

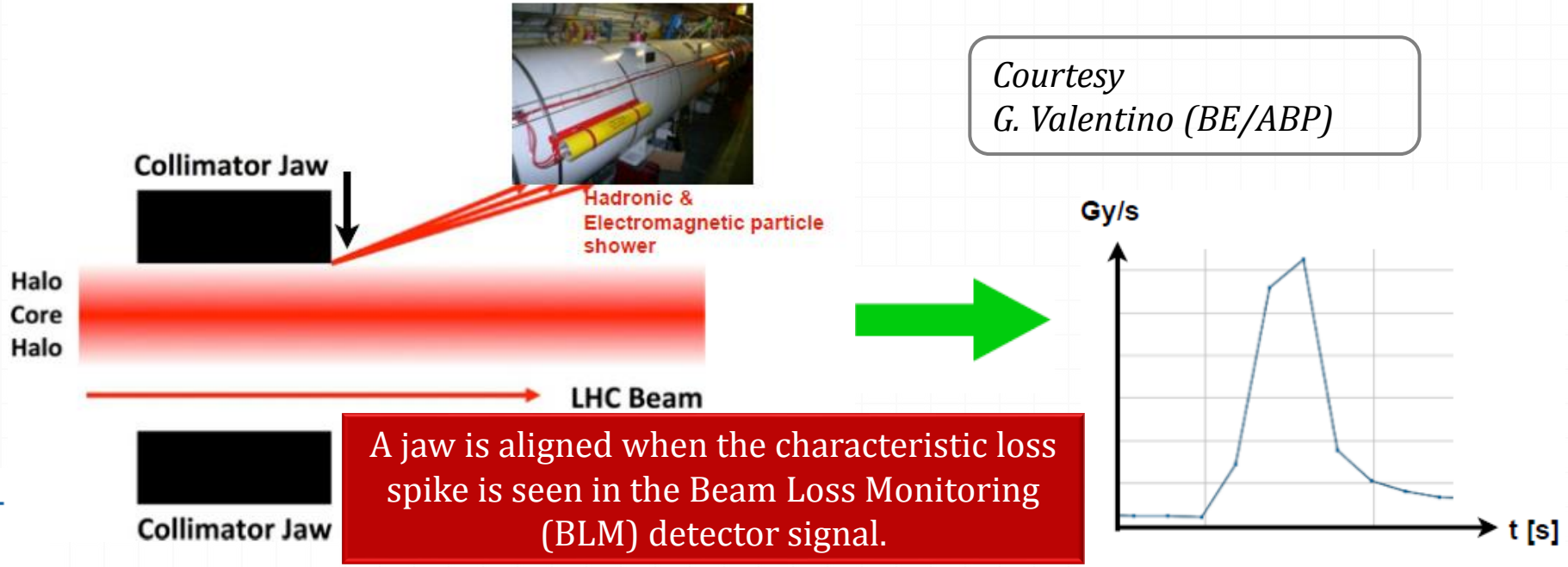


LVDT and Resolvers:

- Radiation hardness
- Lifetime: *infinite* since contactless (no mechanical stresses)
- 'Zeroing' performed at CERN metrology during last assembly steps

BLM-based alignment

- **How to align collimator jaws once installed in the tunnel?**
- First method **(indirect)**: use the signal coming from **Beam Loss Monitors (BLMs)**



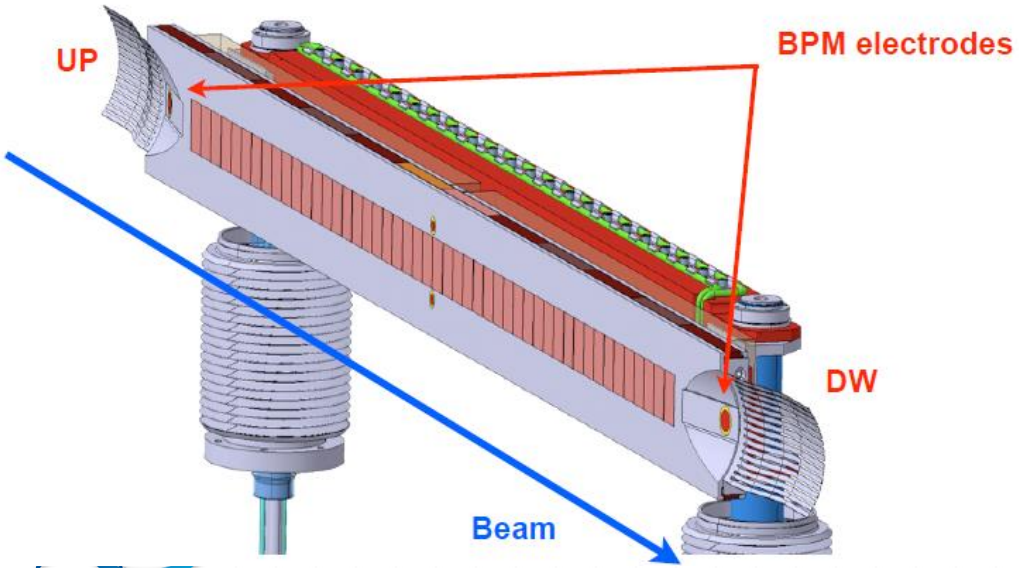
Courtesy
G. Valentino (BE/ABP)

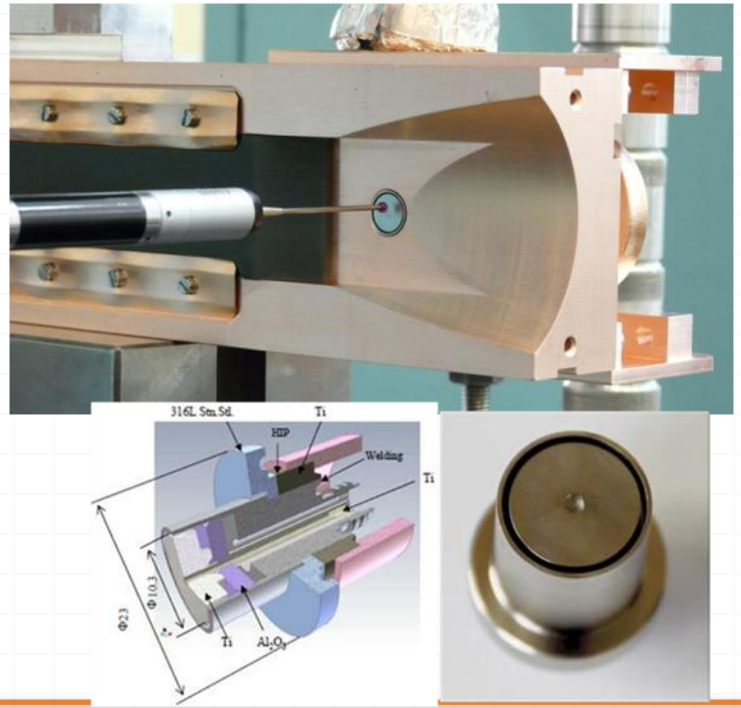
A jaw is aligned when the characteristic loss spike is seen in the Beam Loss Monitoring (BLM) detector signal.

- **Two main limitations** of the system:
  - **Time consuming** (tens of hours in the worst cases for manual alignment!)
  - **Beam instabilities** & other effects may **impair cleanness of signals**

BPM-based alignment

- In order to speed-up the alignment procedure, new collimators with embedded **Beam Position Monitors (BPMs)** have been installed in the LHC and will be operational starting from the 2015 run
- BPM alignment duration**: few tens of seconds!**
- The device performance has been **tested in the SPS** with a mock-up BPM-equipped collimator jaw
- BPMs provide a **direct measurement of the beam orbit** at the collimator locations





Summary

- **Collimators are key elements of the LHC**, providing beam cleaning and protection to the machine most delicate components, such as the magnets
- The collimator jaws actuation system has to guarantee **precision, reliability and robustness in a harsh environment** (radiation-induced degradation, corrosion, low or no accessibility/maintenance)
- *How do we obtain it?*

  Linear displacement given by **µm precise** stepper motor + roller screws
- *How do we guarantee it?*

  Preloaded elements and **minimized play.** Minimization of components degradation (corrosion, wear...)
- *How do we control it?*

  In operation, it is of paramount importance to **precisely determine the jaw position with respect to the particle beam**. Two methods are adopted:
  - **BLM-based alignment** (indirect, time consuming)
  - **BPM-base alignment** (direct, rapid, adopted on last-generation collimators)

Thank you for your attention!