LHC Performance Workshop - Chamonix 2012

Hotel "Les Aiglons", Chamonix, France

February 6th-10th, 2012

Do we really need an upgrade of the collimation system for HL-LHC?

Stefano Redaelli and Ralph Assmann
for the Collimation Project team
Inputs: A. Bertarelli, S. Fartouhk, R. Losito, V. Parma, L. Rossi

Outline

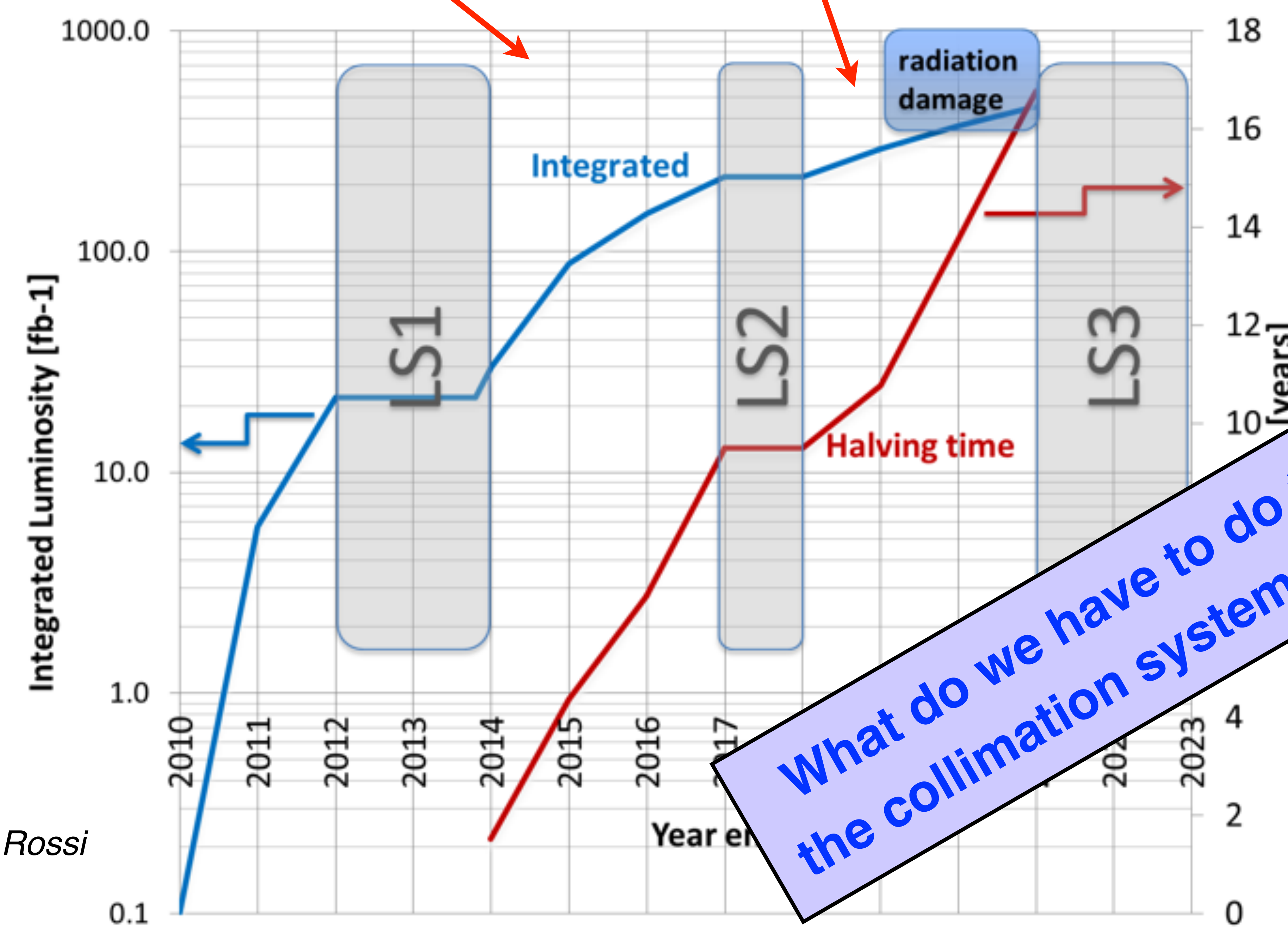
- ☑ Introduction
- ☑ LHC collimation until 2012
- ☑ Upgrade strategy
- ☑ Advanced concepts
- ☑ Conclusions

HL-LHC timeline

~ Nominal energy and Luminosity

Double the LHC luminosity

~ 3000 fb^{-1}!



What do we have to do to keep the collimation system on track?

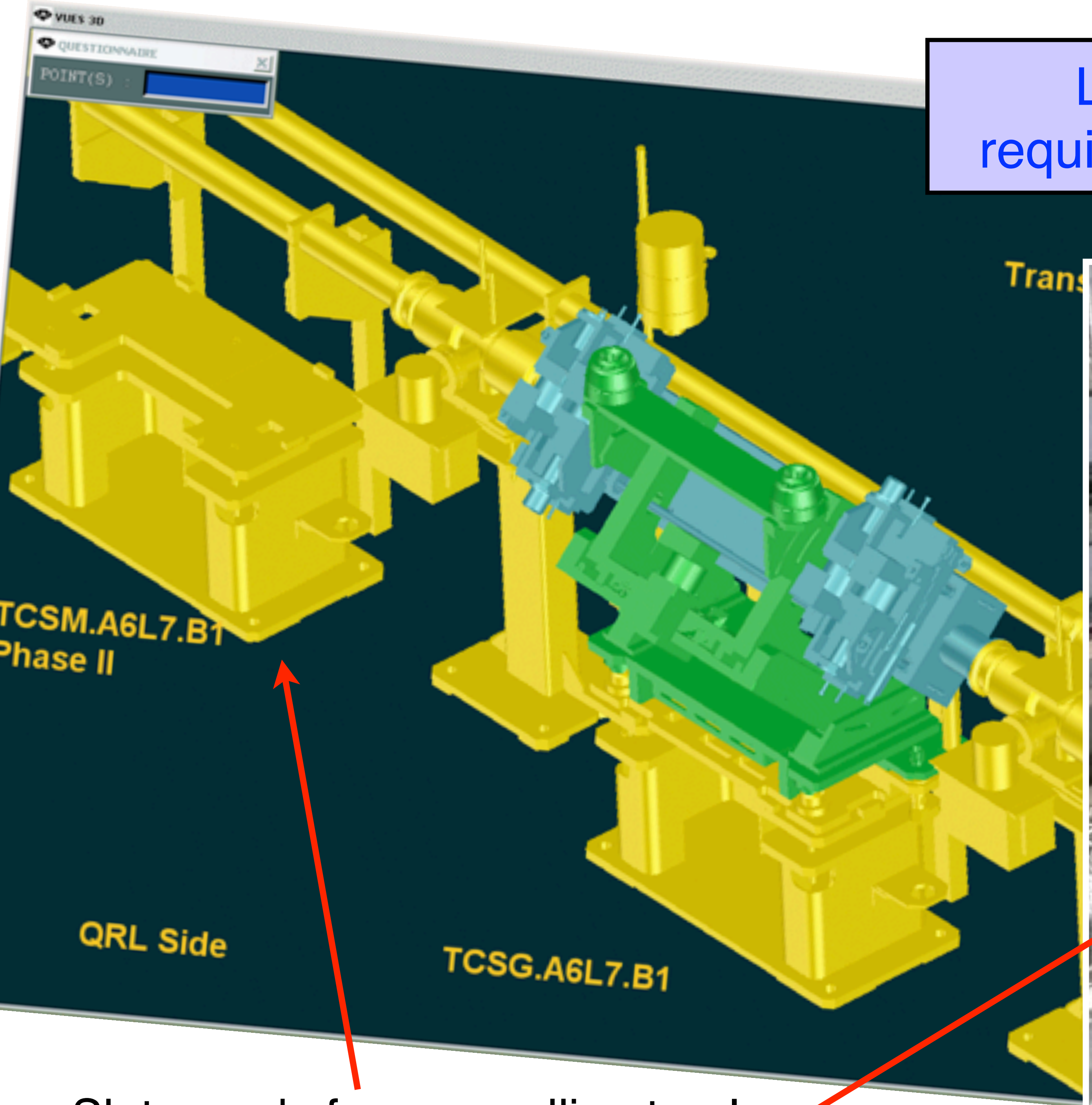
L. Rossi

Goals for collimation upgrades

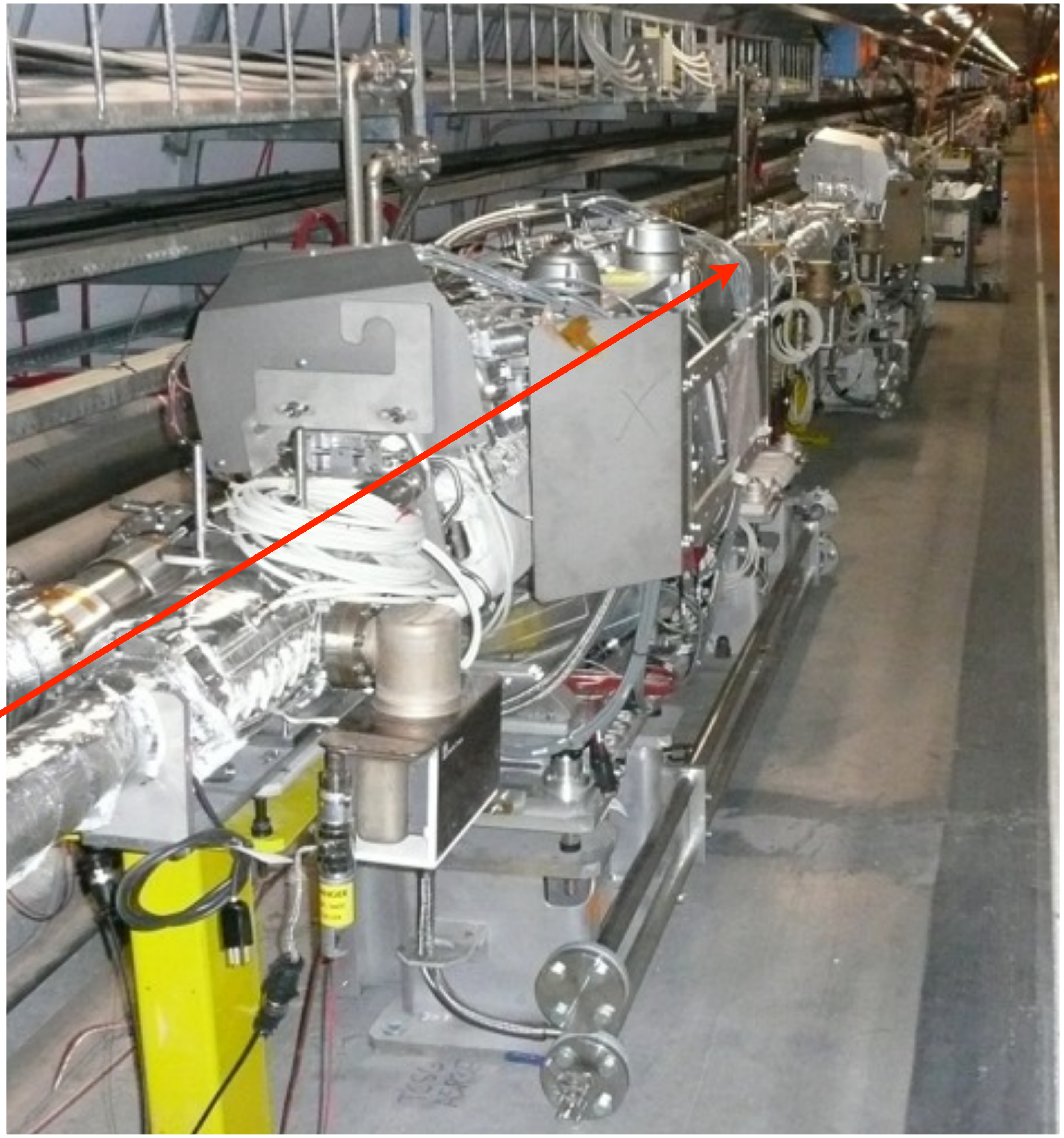
- Improve the **cleaning performance**
  - *System limitations: dispersion suppressors of cleaning (IR3/7) and experimental (IR1/2/5) regions*
- Improve **impedance** and **robustness**
  - *State-of-the-art new material for collimator jaws*
  - *Collimator aging: HW designed for 10 y lifetime (→backup slides)*
- **Operational** efficiency / machine protection aspects
  - *Faster collimator alignment, improved alignment accuracy*
  - *More flexibility for machine configurations (experimental regions)*
  - *Improved settings monitoring and machine protection*
- Achieve **remote handling** in high radiation environment
  - *Quick collimator replacement in hottest LHC locations*
- **New layouts** in experimental regions for **Hi-Lumi**
  - *Re-think IR1/5 collimation for new optics options/constraints*
- New injection / dump collimation → *discussed in previous talk*

The possibility to upgrade the system is built into the present layout: slots for new collimators, quick plug-in, ...

The layout is ready for upgrades!



Layout optimized for upgrade, by new requirements not covered by the existing slots



Slots ready for new collimators!
Can install and test new designs/ materials in IR3/7 without impact on the present system.
Installation in short tech. stops.

Outline

- Introduction
- **LHC collimation until 2012**
  - ***- Recap. of performance***
  - ***- Operational experience***
- Upgrade strategy
- Advanced concepts
- Conclusions

Layout of LHC collimation system

Two warm cleaning insertions, 3 collimation planes

- **IR3: Momentum cleaning**
  - **1 primary (H)**
  - **4 secondary (H)**
  - **4 shower abs. (H,V)**
- **IR7: Betatron cleaning**
  - **3 primary (H,V,S)**
  - **11 secondary (H,V,S)**
  - **5 shower abs. (H,V)**

Local cleaning at triplets

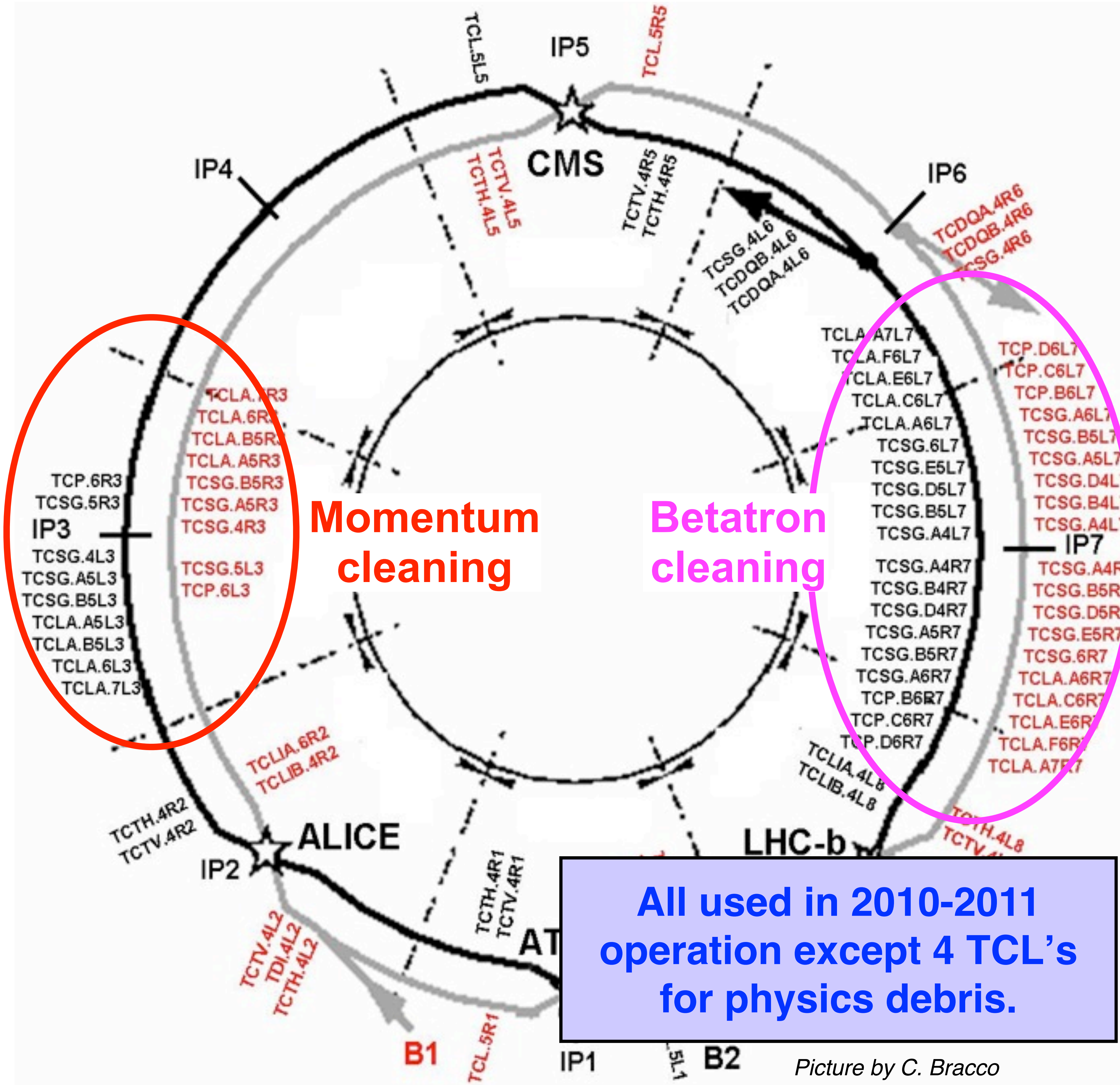
- **8 tertiary (2 per IP)**

Passive absorbers for warm magnets

Physics debris absorbers

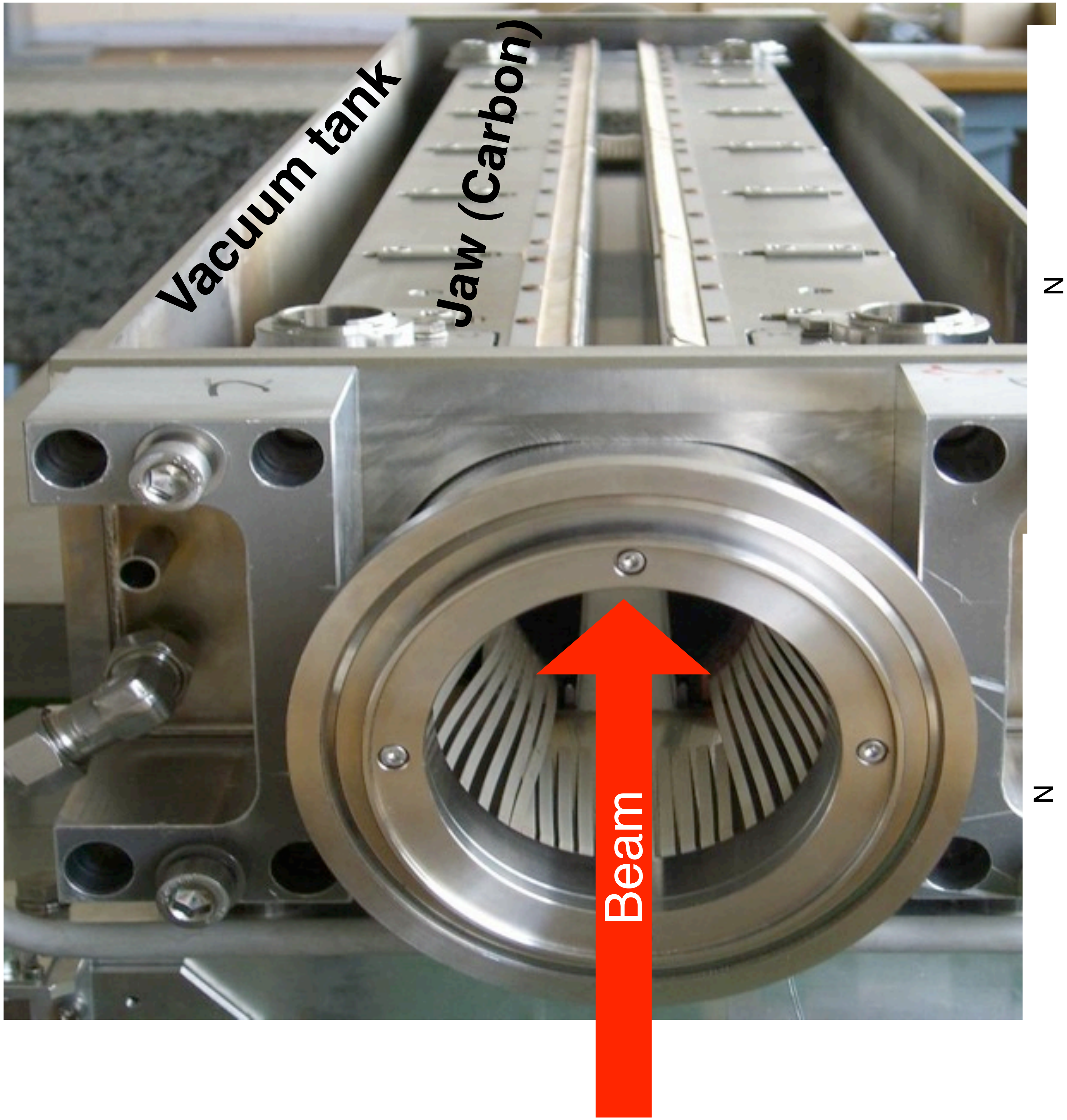
Transfer lines (13 collimators)
Injection and dump protection (10)

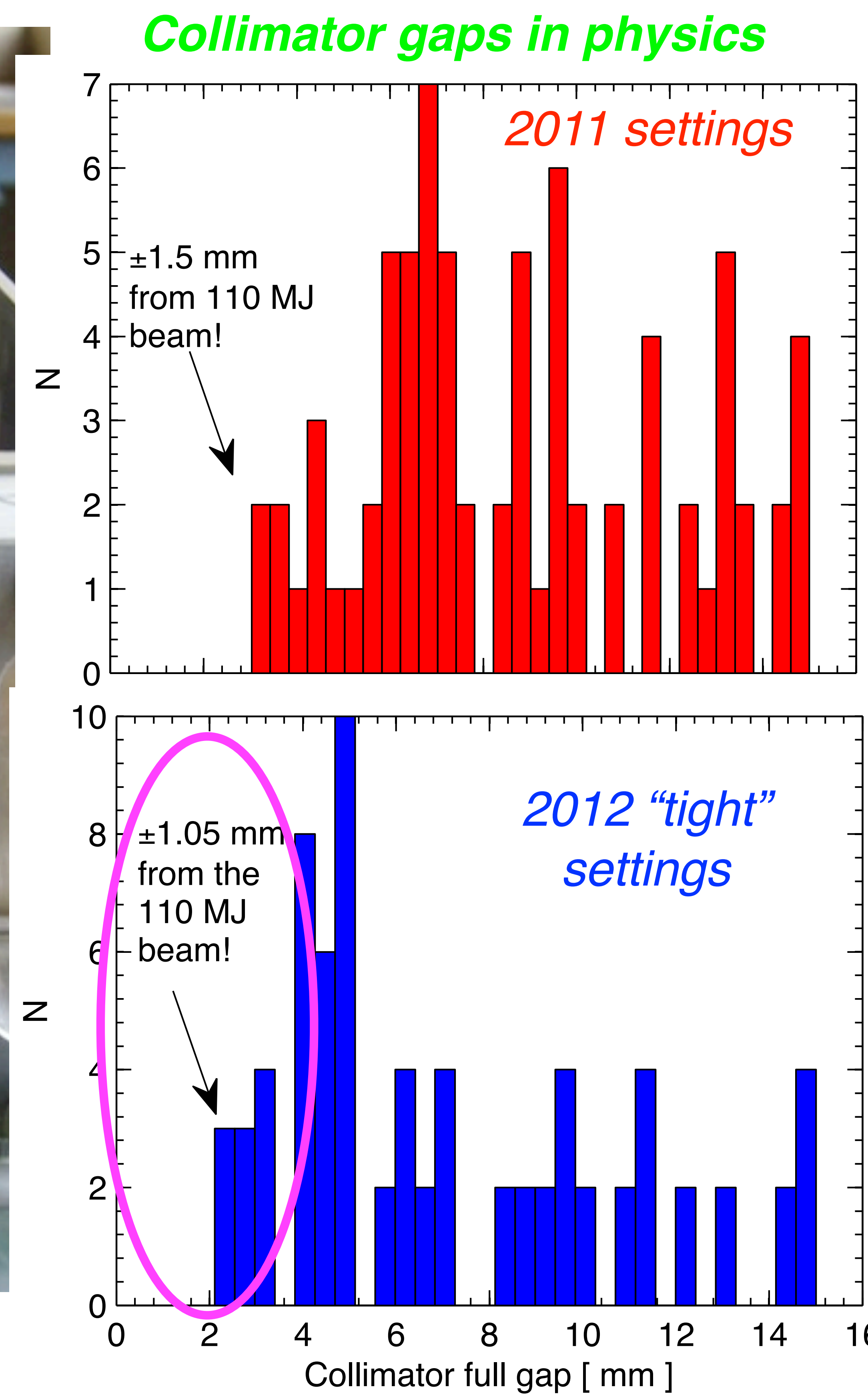
Total of 108 collimators (100 movable). Two jaws (4 motors) per collimator!



Picture by C. Bracco

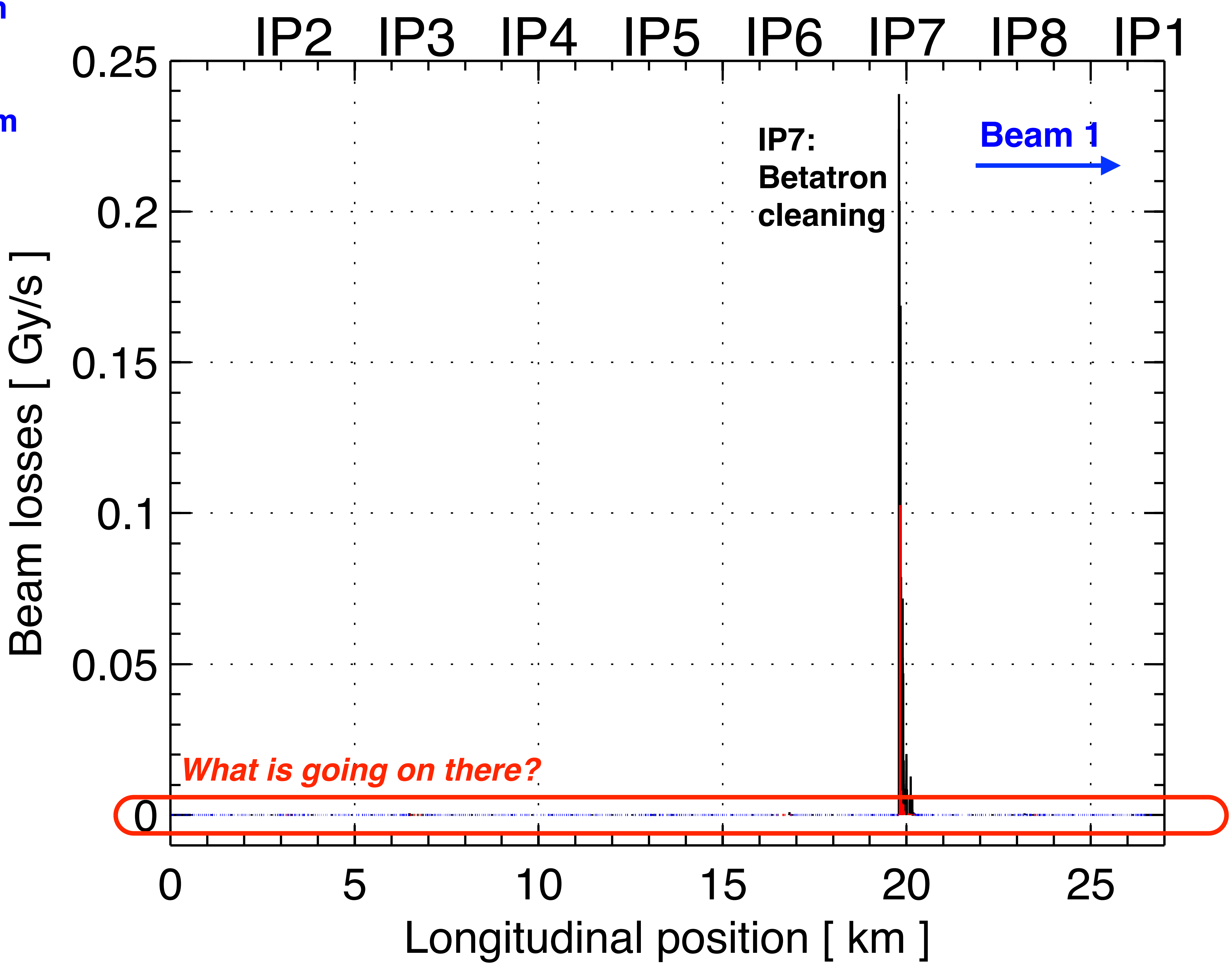
The LHC collimator





Collimation cleaning: 3.5 TeV, β^*=1.0m

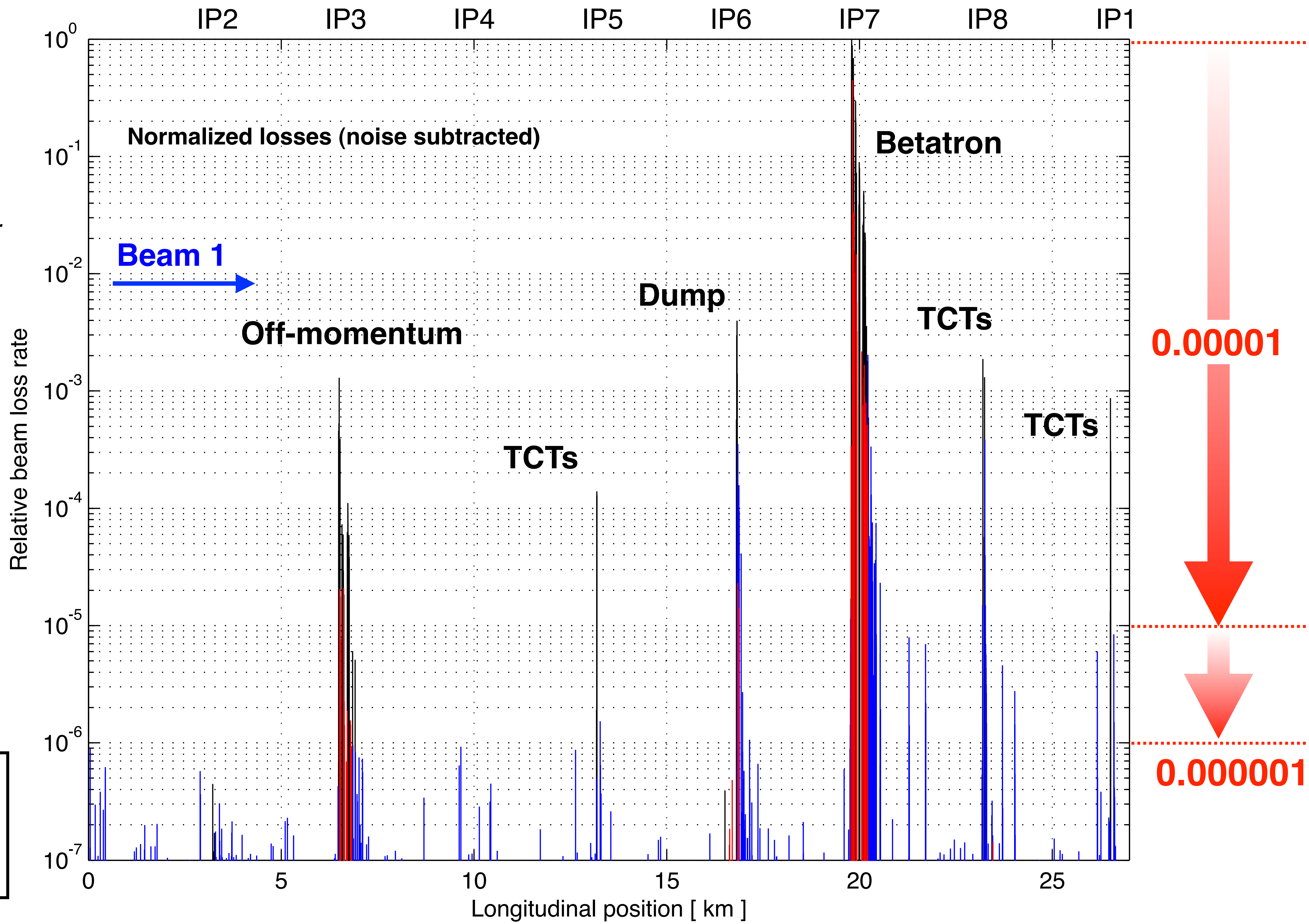
4000 beam loss monitors along 27 km during a loss map



Cleaning in 2011: 100 MJ, 3.5 TeV, β^*=1.0m

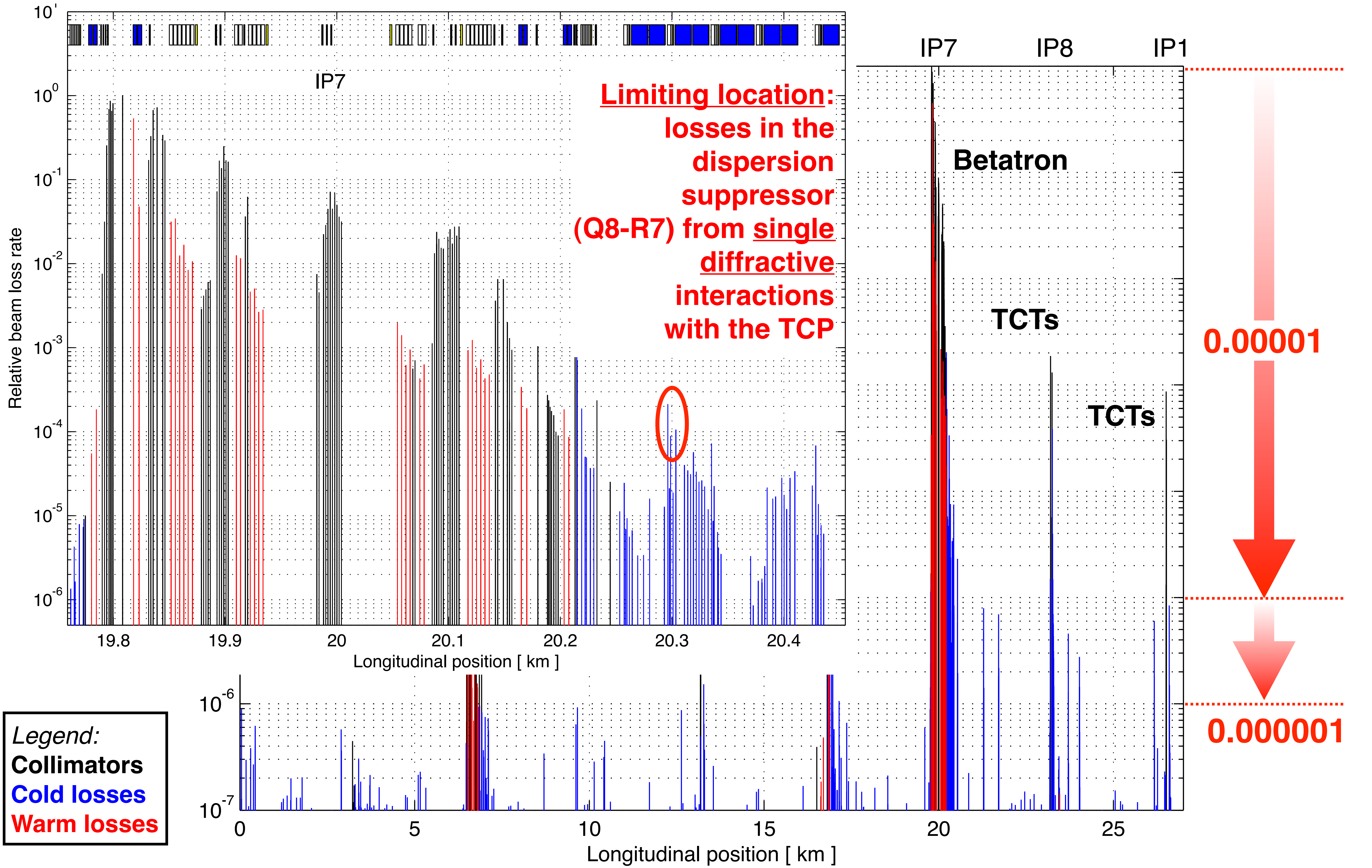
Higher loss rates: beam across the 3rd order resonance.

Repeated for ALL run configs.

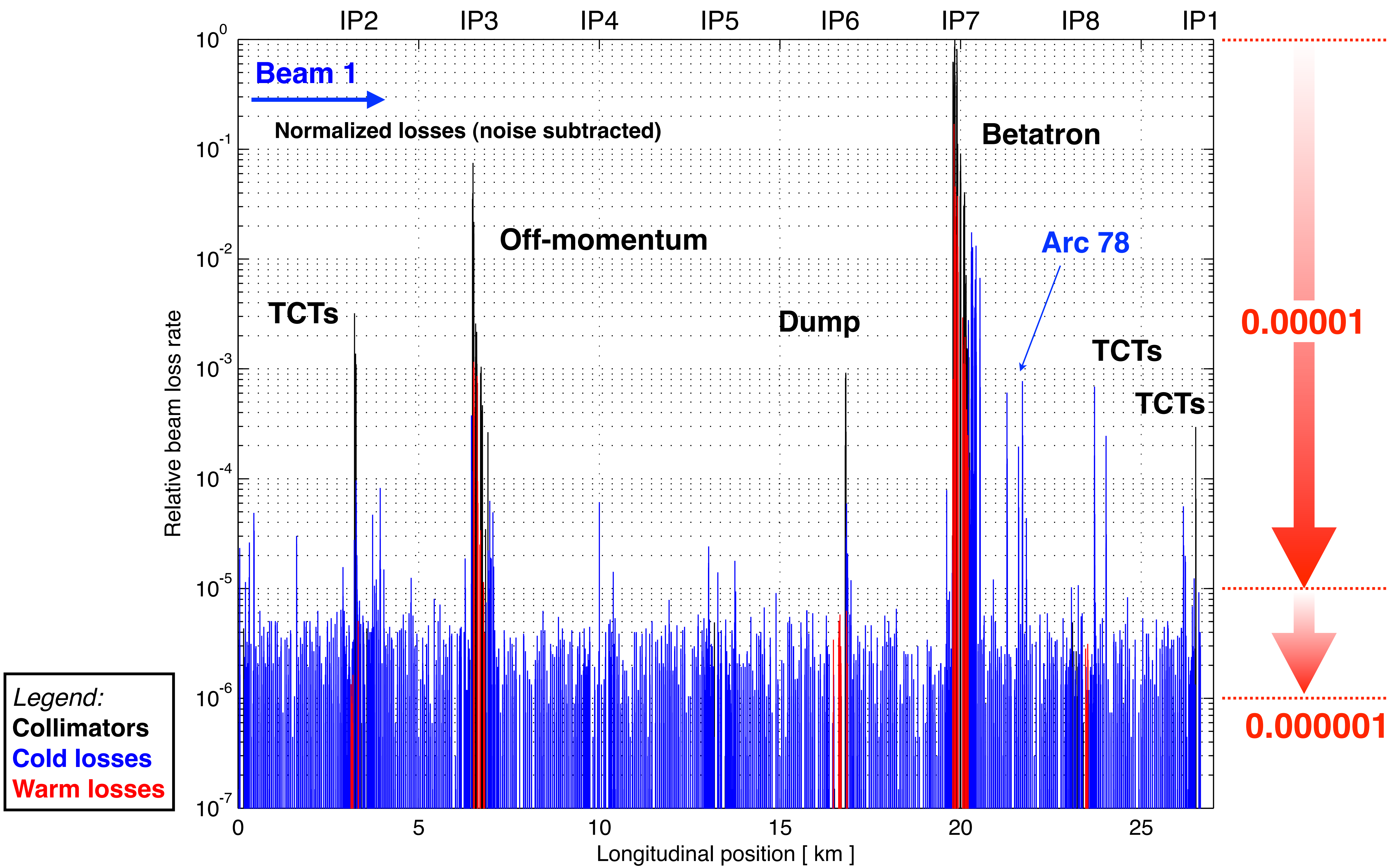


Legend:
Collimators
Cold losses
Warm losses

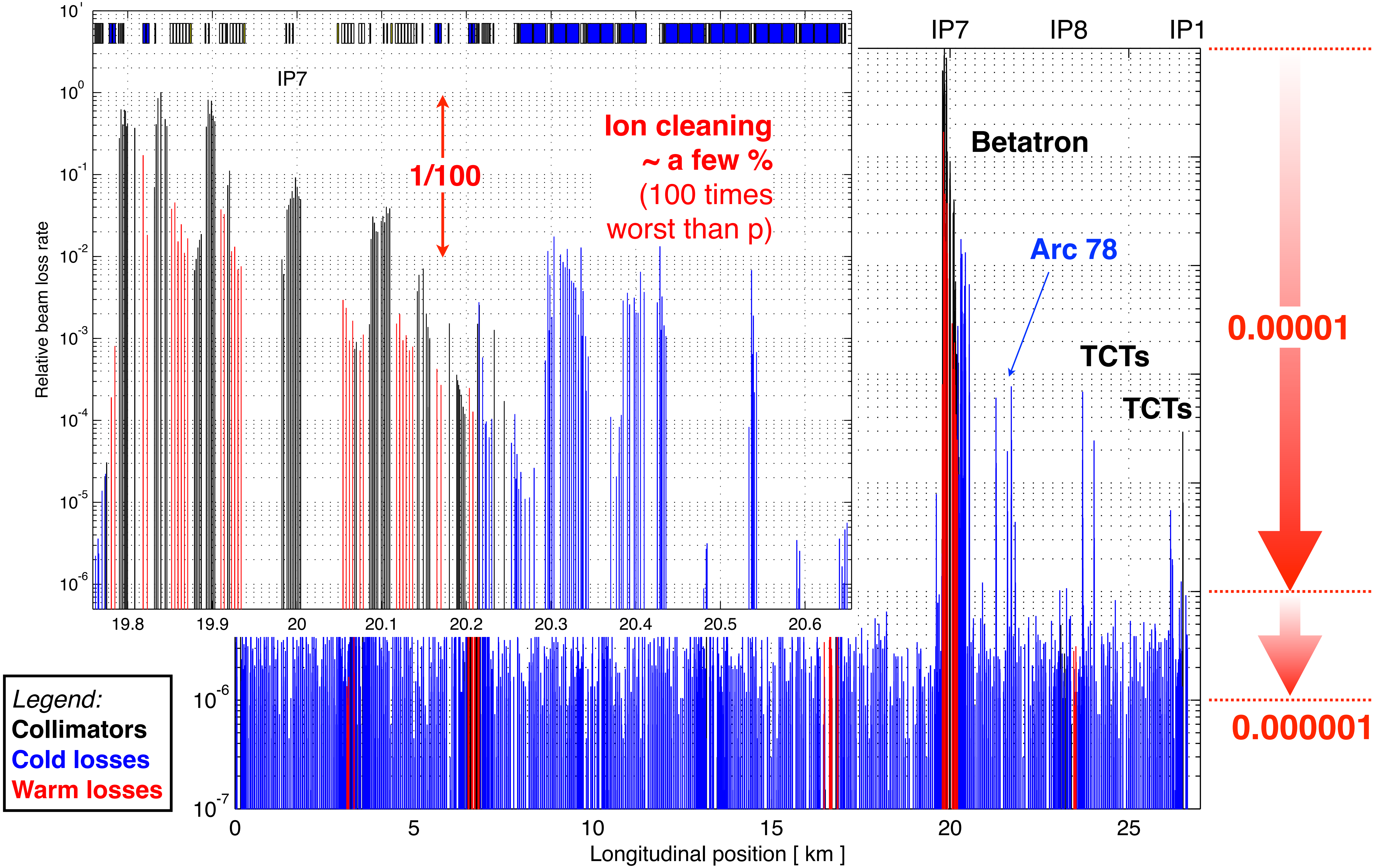
Cleaning in 2011: 100 MJ, 3.5 TeV, β^*=1.0m



Betatron losses for ions



Betatron losses for ions



Intensity reach from betatron cleaning

Performance reach of the system: not just collimation cleaning!

Minimum (assumed) beam lifetime

Quench limit of SC magnets

LHC total intensity reach from collimation:
(→R.Assmann, R.Bruce talks)

$$N_{\mathrm{tot}} = \frac{\tau R_q}{\tilde{\eta}_c}$$

Collimation cleaning at limiting cold location

7 TeV performance estimate based on ACHIEVED loss rates at 3.5 TeV
(500 kW for protons, 27 kW for ions)
→

Protons: > 4 x nominal
Ions: 5-25 x nominal
Ions (L debris) *closer to limit!*

Caveats/assumptions:

- So far, we did NOT quench → Figures for R_q are **conservative**
- It is assumed that the **lifetime** will be the **same** at **larger E and smaller β***
- The losses were achieved only during **short times ≤ 1 s**
- There are uncertainties on **quench limit** and **cleaning** performance at **larger E**

Intensity reach from betatron cleaning

Performance reach of the system: not just collimation cleaning!

Minimum (assumed) beam lifetime

Quench limit of SC magn

LHC total intensity reach from collimation:
(→R.Assmann, R.Bruce talks)

N_{tot}

ation

It is **crucial** to continue **investigations** on **quench limits** and to **monitor** the other relevant **parameters** in **2012**!

7 TeV performance estimate based on ACHIEVED loss rates at 3.5 TeV *(500 kW for protons, 27 kW for ions)* →

Protons: > 4 x nominal
Ions: 5-25 x nominal
Ions (L debris) *closer to limit!*

Caveats/assumptions:

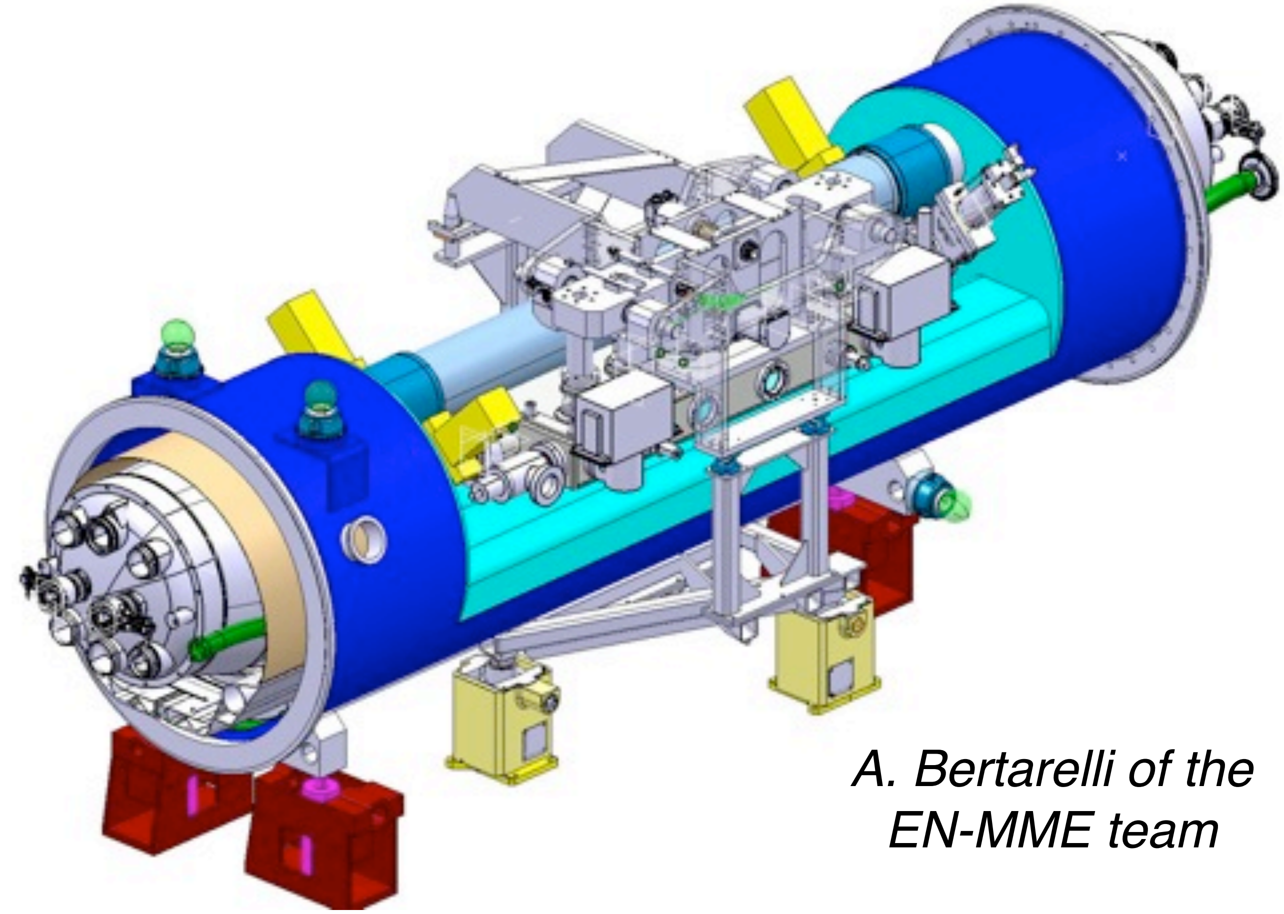
- So far, we did NOT quench → Figures for R_q are **conservative**
- It is assumed that the **lifetime** will be the **same** at **larger E and smaller β***
- The losses were achieved only during **short times ≤ 1 s**
- There are uncertainties on **quench limit** and **cleaning** performance at **larger E**

IR3 collimation upgrade

(Presented at Chamonix 2011)

(1) Catch local losses in the dispersion suppressor (DS): two DS collimators per beam

- Layout change of the DS: moving dipoles to create space;
- New design of warm collimators.

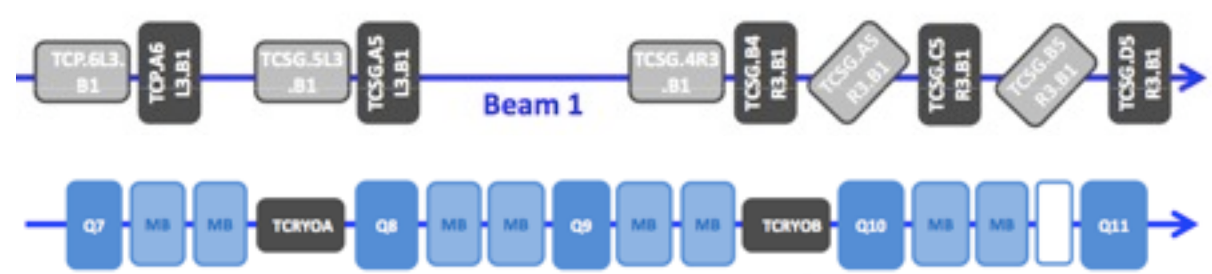


A. Bertarelli of the EN-MME team

(2) Combine momentum/betatron cleaning in IP3 by adding 5 vertical collimators per beam

- Standard technology of Phase I.
- Essentially using existing slots.
- New production chain for building the missing collimators.

New IP3 schematic layout (by A. Rossi)



Details: Review of DS work, July 2010:
http://indico.cern.ch/conferenceDisplay.py?confId=100156

IR3 collimation upgrade

(Presented at Chamonix 2011)

(1) Catch lo… losses in the disper… …ressor (DS): two D… …er beam

- La… …ving dipoles…
- …design o…

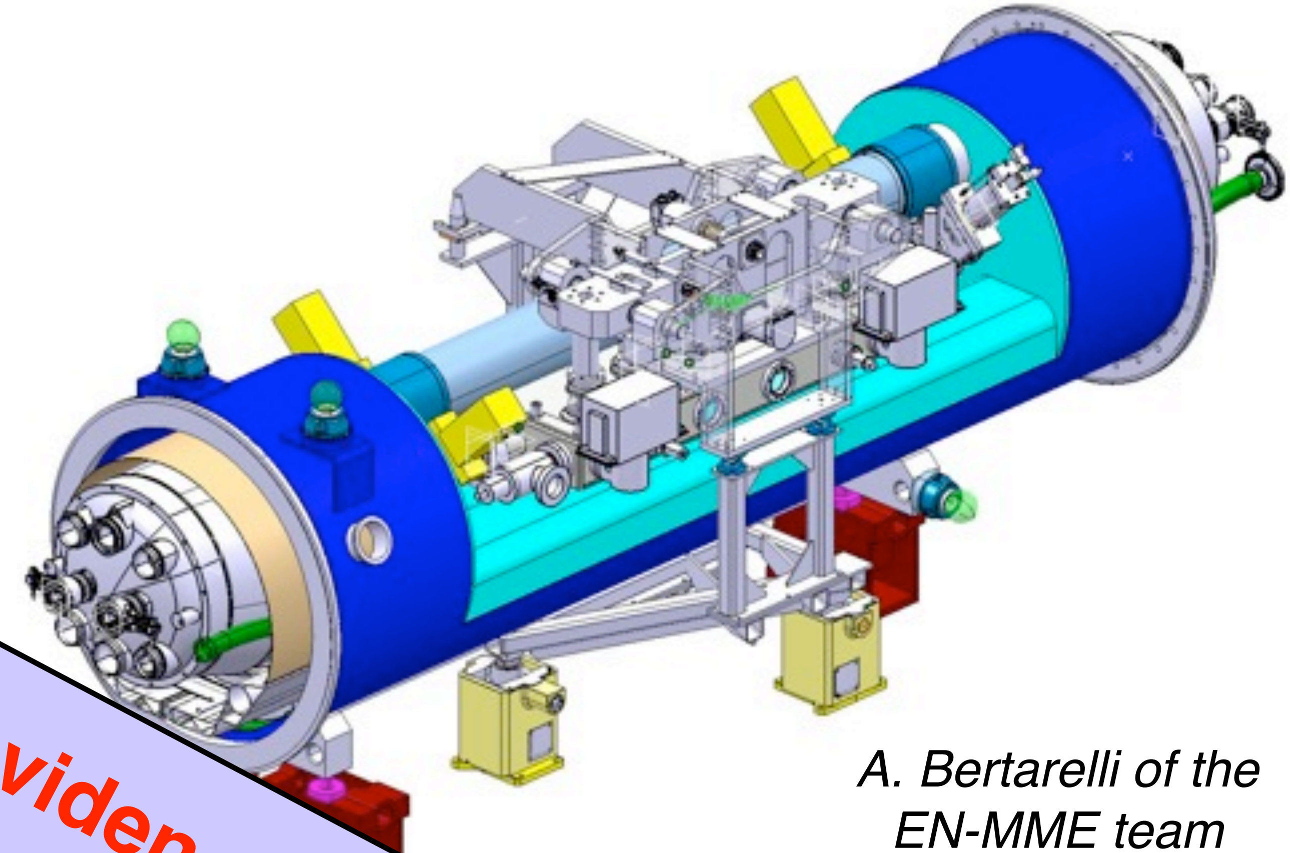
(2) … /betat… clea… …5 vertical c…

- Standard techn…
- Essentially using ex…
- New production chain fo… the missing collimators.

Postponed until there is evidence that the cleaning performance is compatible with ultimate LHC intensity!

Important work on warm "cold collimator" not lost → this advanced concept is now under study in association to the the 11 T dipole

https://indico.cern.ch/conferenceDisplay.py?confId=155408#2011-10-05



A. Bertarelli of the EN-MME team

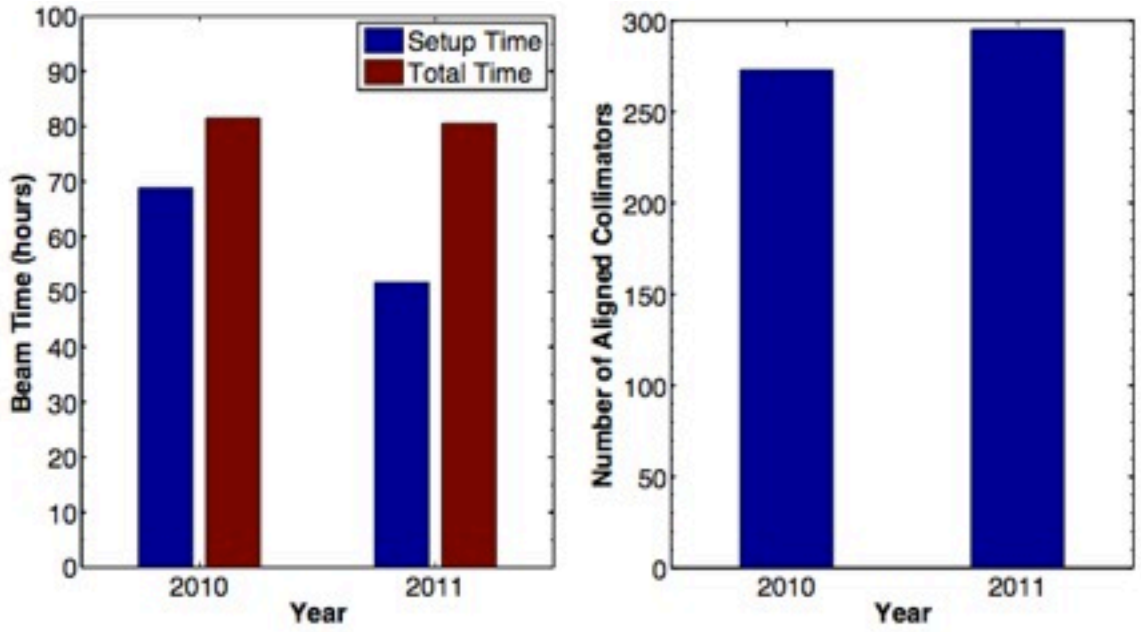
…matic layout (by A. Rossi)

Details: Review of DS w…
http://indico.cern.ch/conferenceDis… …onfId=100156

2010-2011 operational experience

- Good news from OP experience:
  - The beam lifetime at 3.5 TeV is good!
  - The alignment was only needed once!
  - No indication of problems from collimator **impedance** *(N. Mounet, Evian2011)*.

... but:



(a) Setup time and total time (b) Aligned collimators

G. Valentino et al., Evian2011

- Large losses in experimental regions
- Collimation setup is **time-consuming**
- The **operation flexibility** in the IRs affected by collimation (VdM scans, spectrometer polarity, β* levelling, ...)
- The ***β**** **reach** is determined by collimation/machine protection constraints: retraction between beam dump and horizontal TCTs *(R. Bruce's talk)* which are not robust
- Radiation aspects affected already the operation (trips/accesses around IRs)
- Only passive monitoring of performance by unfrequent loss maps (~4weeks)

Outline

- Introduction
- LHC collimation until 2012
- **Upgrade strategy**
  - ***- Plans for LS1/2/3***
  - ***- Selected examples***
- Advanced concepts
- Conclusions

Upgrade strategy (I)

- **Shutdowns 2010-11 and 2011-12** *(See talk at Chamonix 2011)*
  - New IR2 layout for improved ALICE data taking
  - Software for faster and more robust collimator alignment
  - Improved protection strategy (β^* limits)
  - Improved controls HW: OP efficiency against downtimes from radiation

- **LS1 (LHC energy to nominal)**
  - **BPM-integrated design** in experimental and dump regions (16 tertiary and 2 secondary) → **Faster** alignment in the IP's, **smaller β^***, improved **machine protection.**
  - New IP8 layout (to allow installation of TCTs with BPMs)
  - Considering **new passive absorbers in IP3** (longer lifetime of warm magnets)
  - Replacement of electronics components to improve redundancy
  - Update the **air duct** in the cleaning insertion

Upgrade strategy (II)

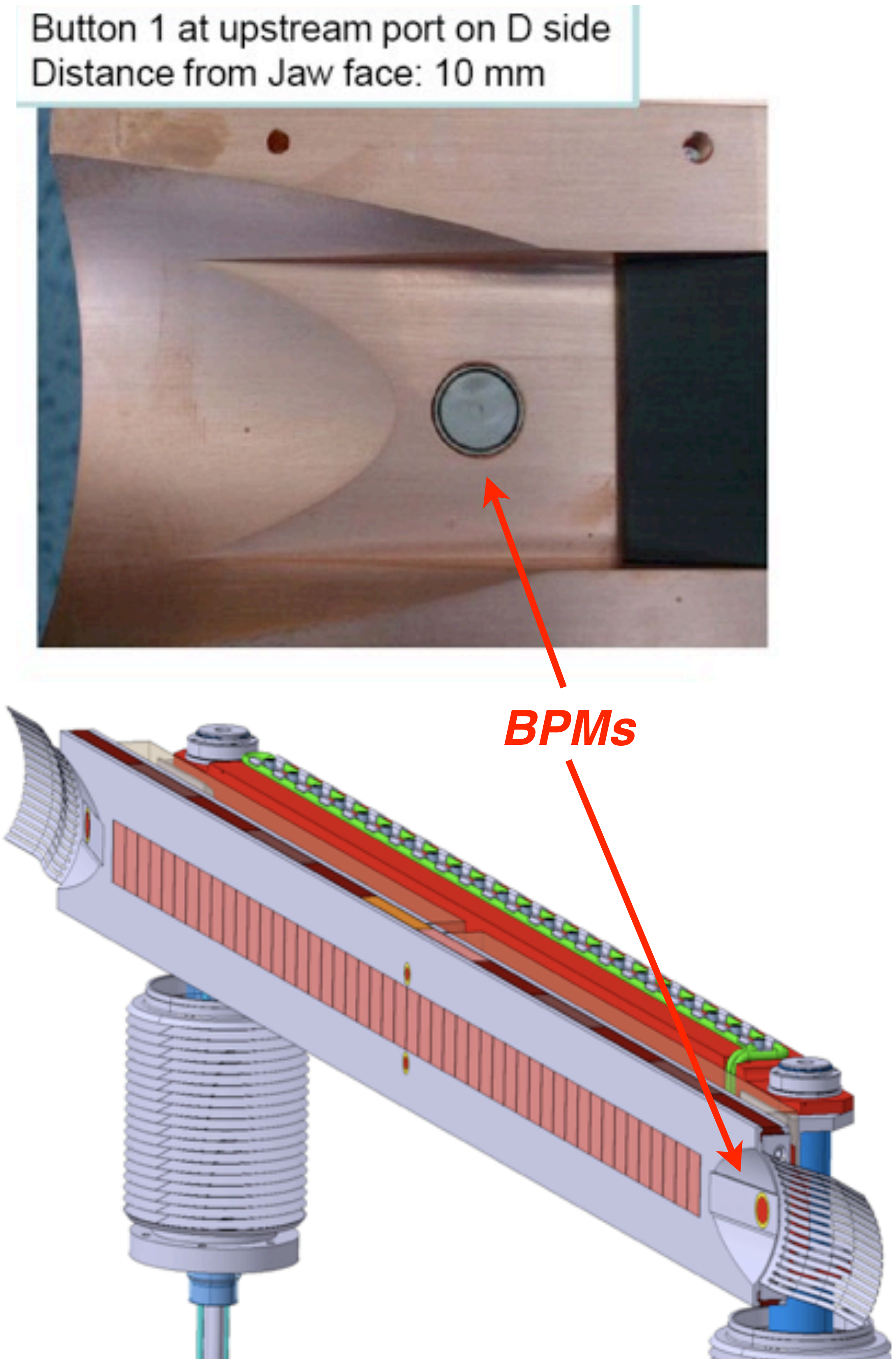
LS2 (double LHC luminosity)

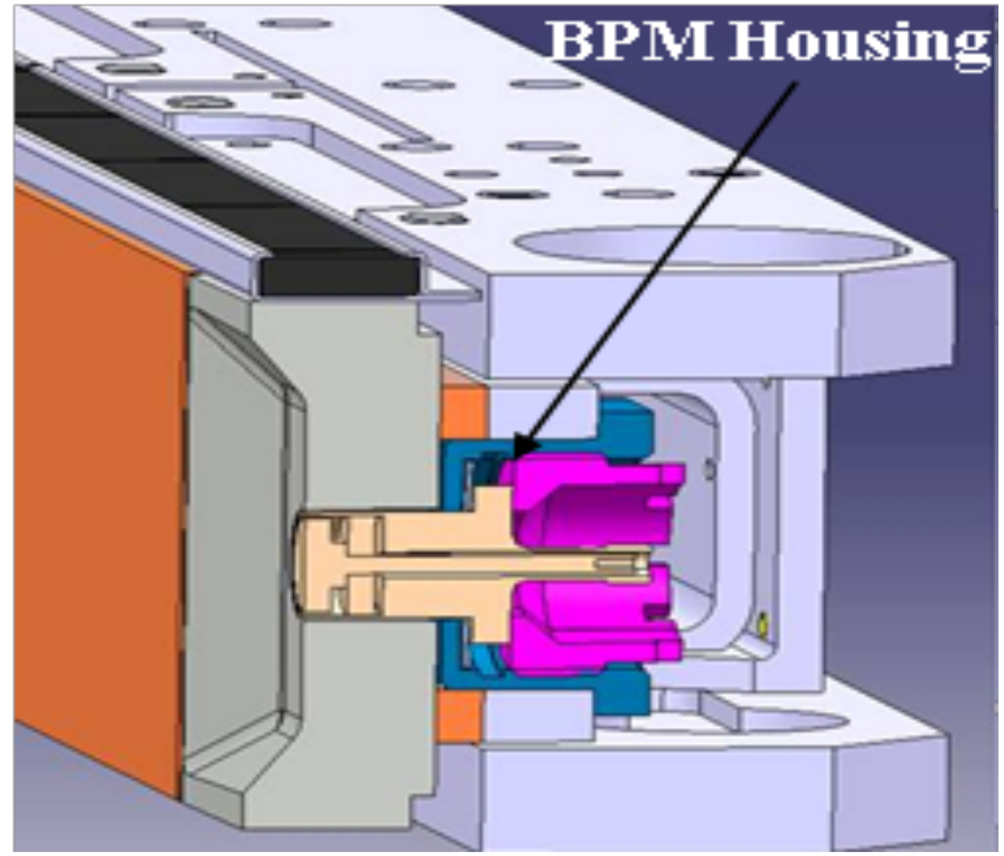
- Possible first upgrade of experimental regions: **DS collimators**
- Additional collimators equipped with **BPMs** (faster alignment, better protection)
- **Improved design** and **new materials** (less impedance, more robustness)
- Investigate collimator HW **aging** / lifetime
- Remote handling (partly)

LS3 (Hi-Lumi LHC)

- Re-design of **collimator layout** in the experiments regions
  (DS collimators + additional local protection for ATS optics)
- Complete **DS collimation** in all the required IRs (also IR3/7 if needed)
- New collimator materials to **replace collimators** that have aged. BPM design.
- Fully remote handling in radiation environment
- New concepts for improved cleaning (crystal, hollow e-lens) - if needed

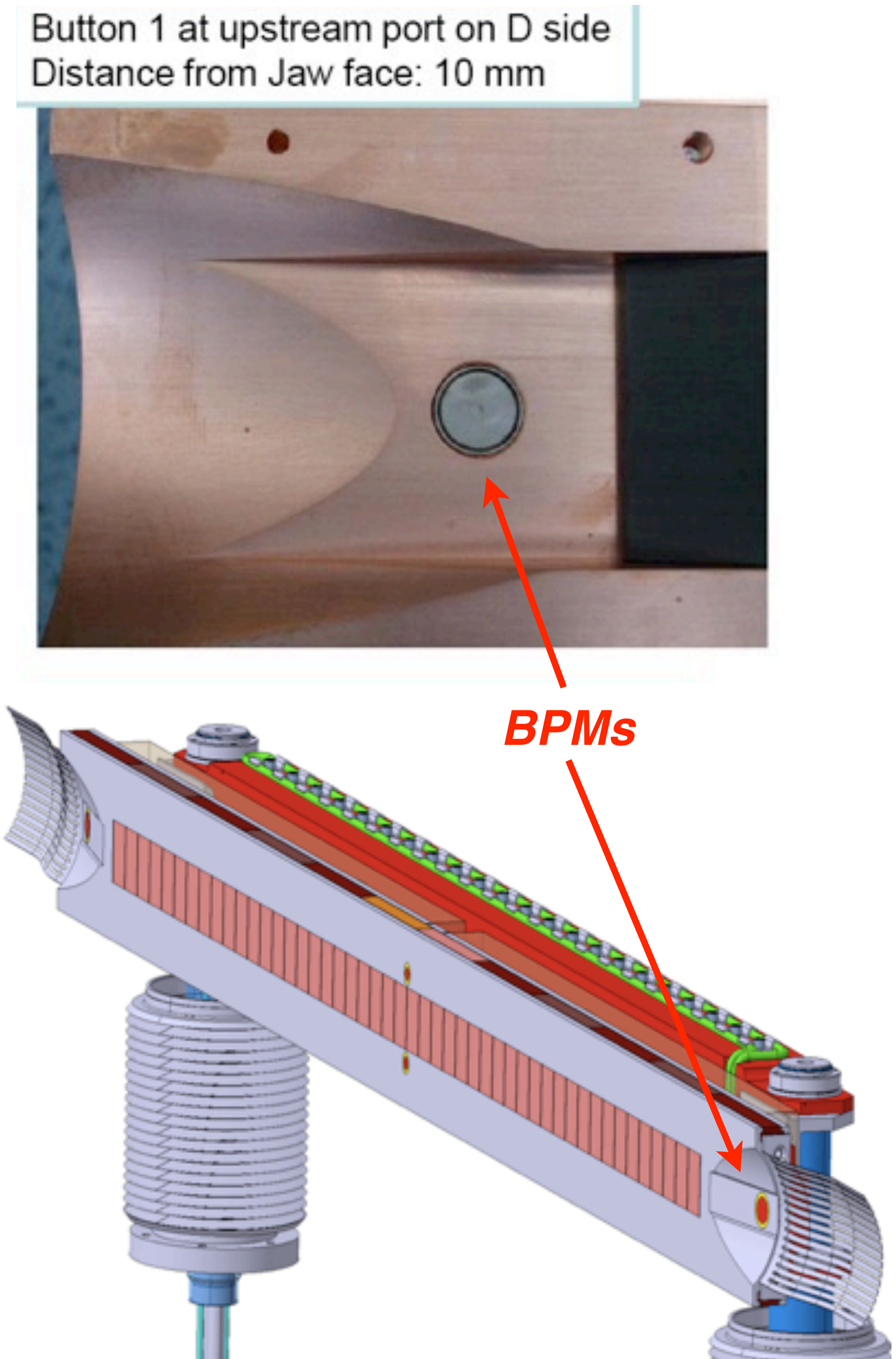
BPM-integrated design



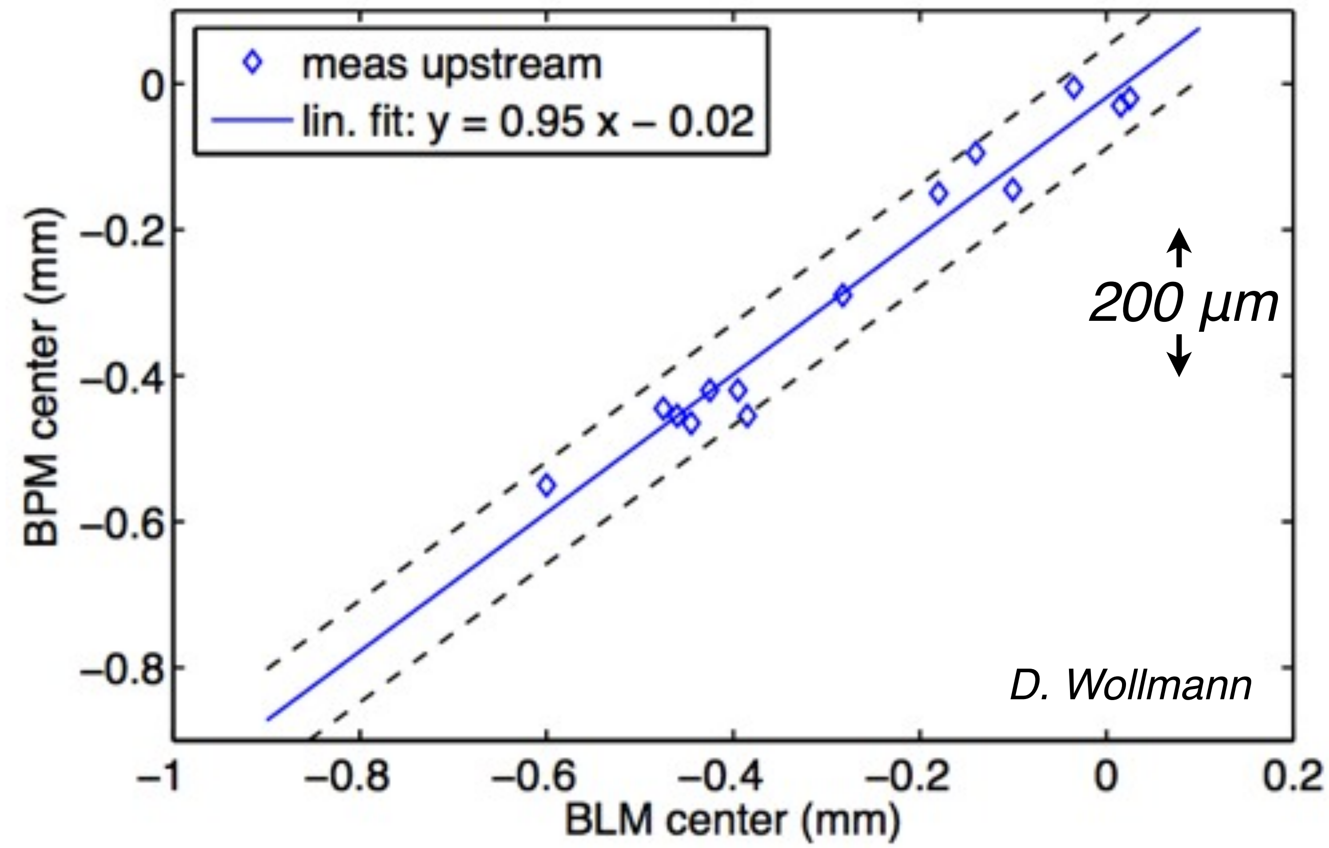


- BPM bottoms integrated in the collimator jaws to measure the **local beam position**.
- We will replace all 16 tertiary collimators in LS1!
- Reduce setup time from 15-20 min to tens s; Continuous monitoring during standard OP → Improved **machine protection** and **β^* reach**
- Proof of principle: SPS beam tests in 2010-11
- Promising on single pass → **use in TI2/TI8**?

BPM-integrated design



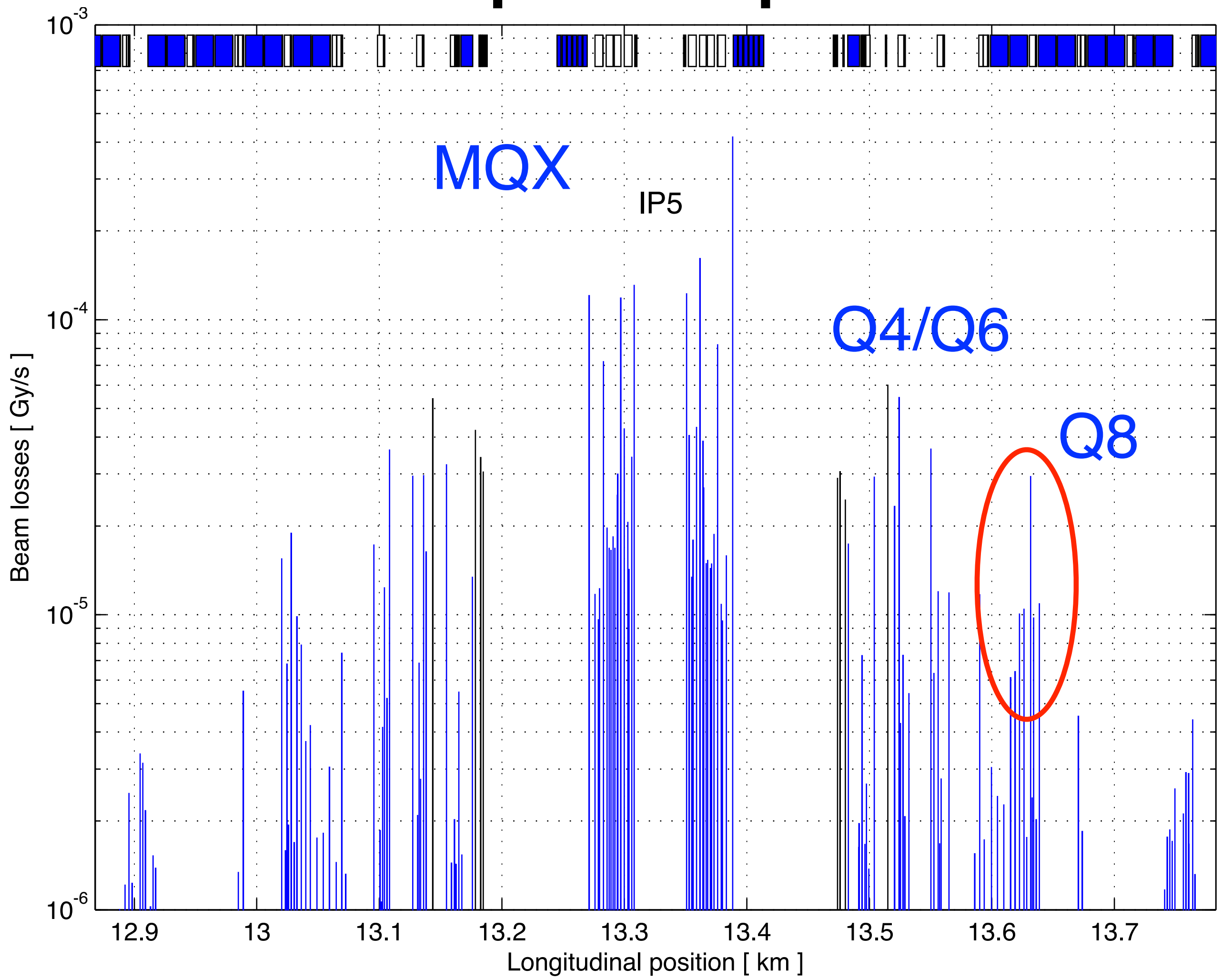
Present (10-15min/coll) to BPM (**~ten sec**)



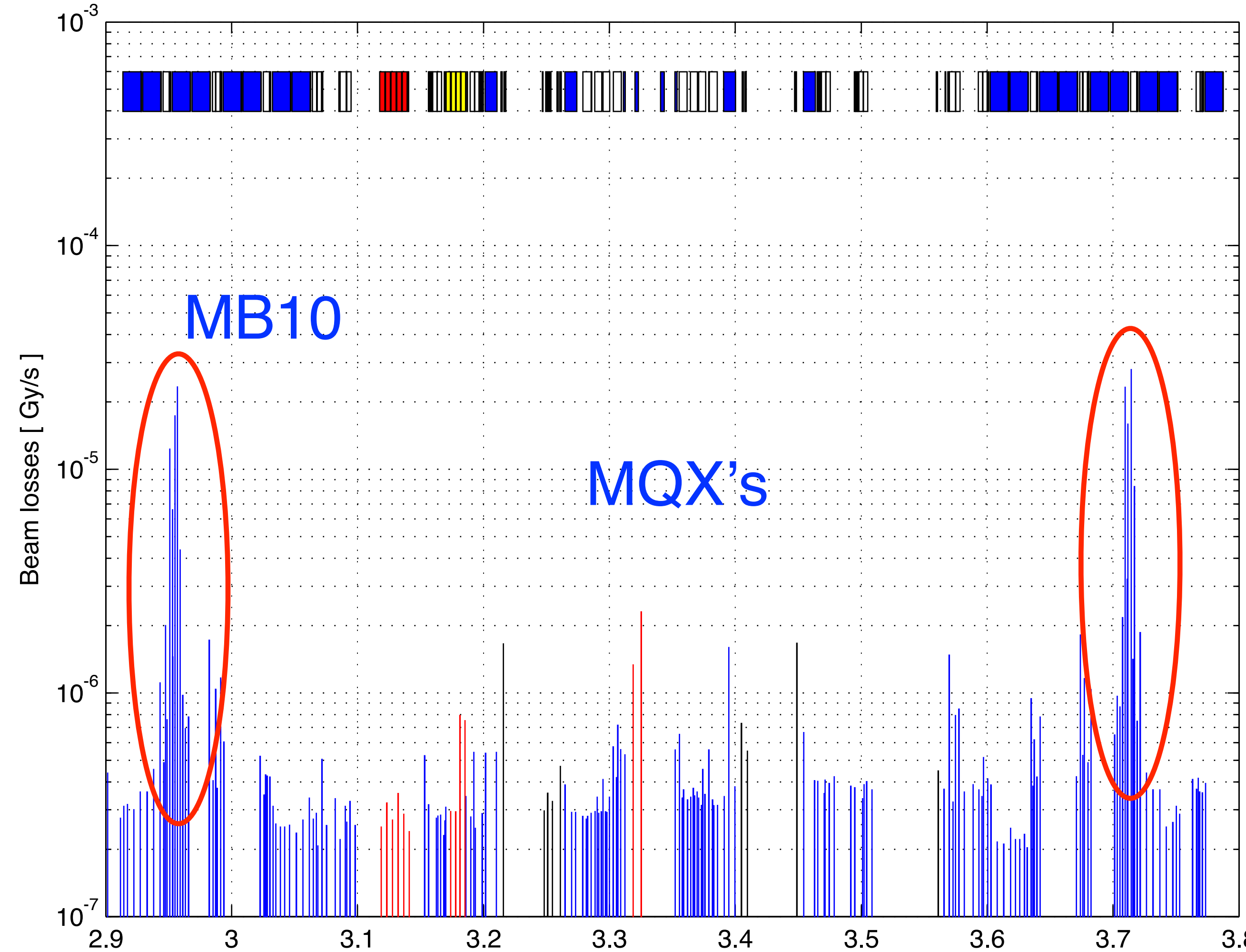
- BPM bottoms integrated in the collimator jaws to measure the **local beam position**.
- We will replace all 16 tertiary collimators in LS1!
- Reduce setup time from 15-20 min to tens s; Continuous monitoring during standard OP → Improved **machine protection** and **β^* reach**
- Proof of principle: SPS beam tests in 2010-11
- Promising on single pass → **use in TI2/TI8**?

Losses in experimental regions

IP5: proton operation



IP2: Ion operation



- **Continuous** losses in the dispersion suppressors of experimental regions during physics production
- Different loss locations for proton and ion beams in different IRs
- Local radiation caused by losses affected already the LHC operation!
- Can be cured satisfactorily only by local collimators in the DS

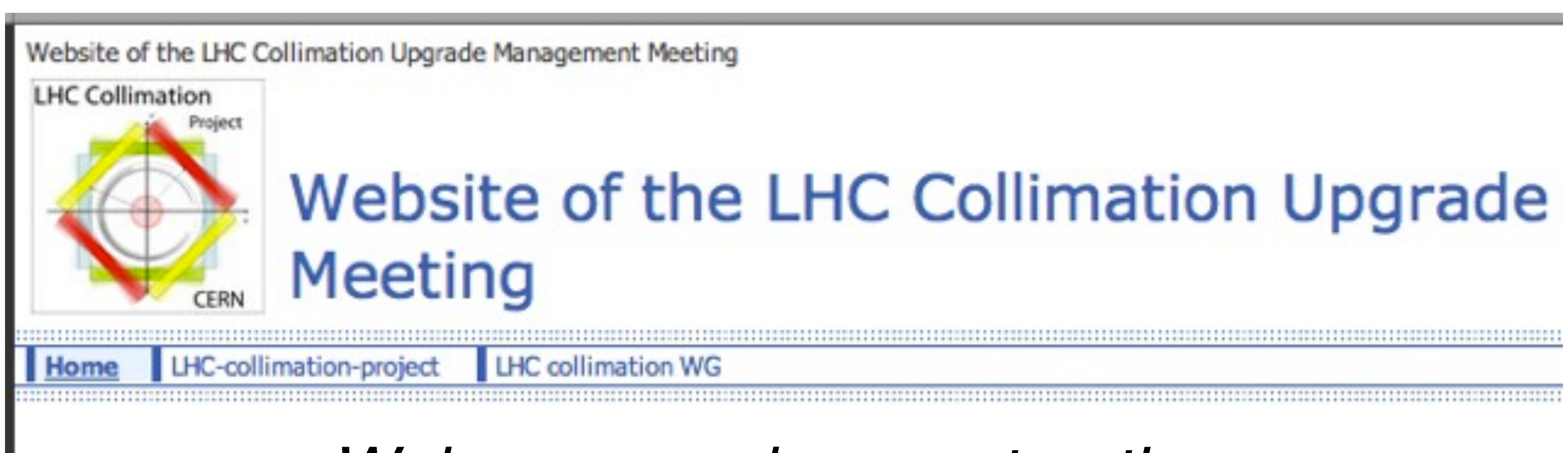
Collimation Upgrade Specs meeting

The studies for new collimation in the DSs are followed up by the ColUSM (**Collimator Upgrade Specification meeting**).

Meetings started in Jan. 2012 (2 so far).

Priorities:

1. Define layout for new collimation in the DS's of IR1/2/5 in LS2 (p + Pb)
2. Provide inputs to magnet builders for detailed engineering design
3. Address compatibility with future optics layout (ATS)
4. Full design of new collimation layouts in IRs for LS3
(feasibility of LR wire integrated in TCT, compatibility with crab cavities, ...)

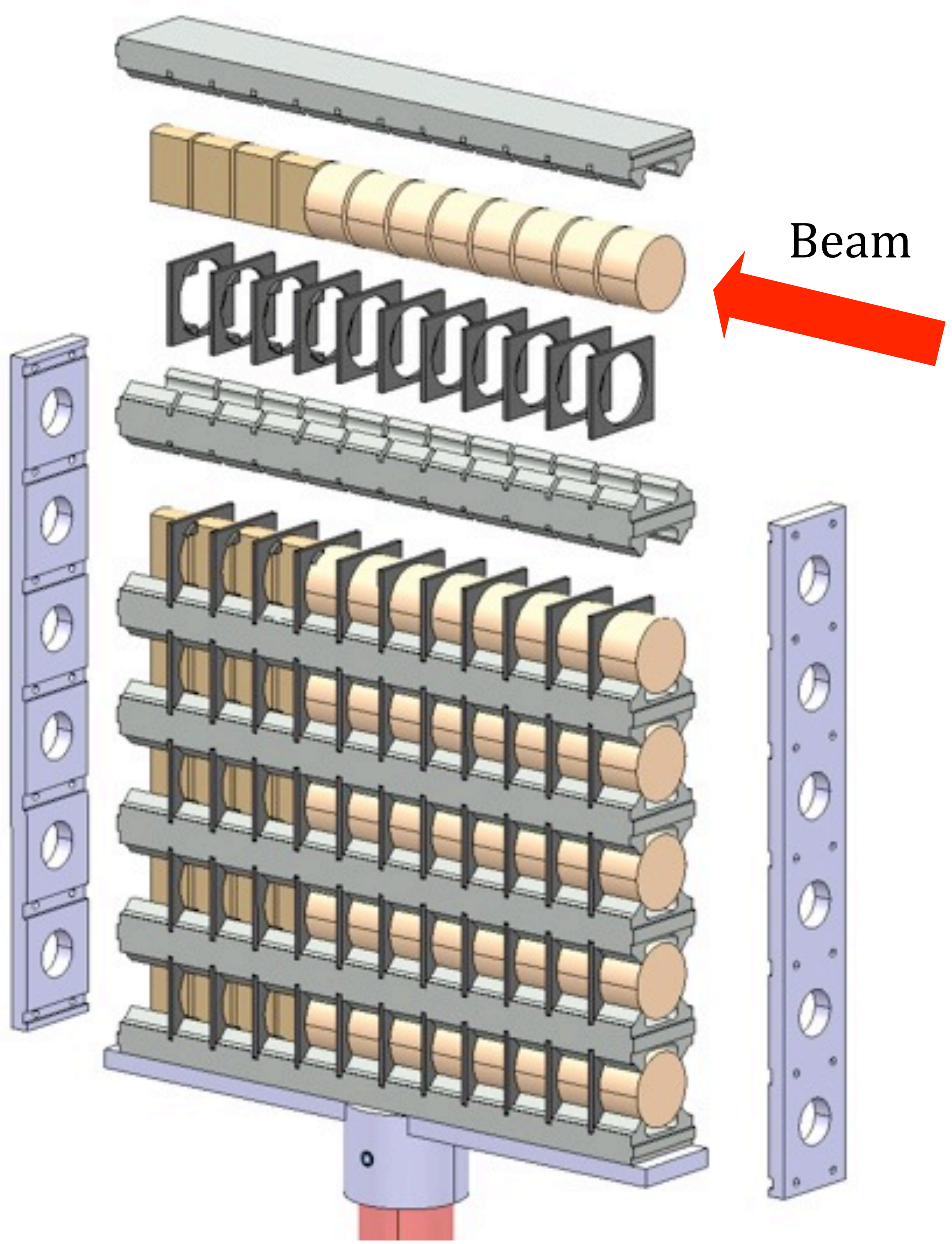


Web page under construction.

Working together with the FLUKA (F. Cerutti) and magnet (M. Karpinnen) teams and Cold Collimator Feasibility Study (CCFS) (V. Parma)
Participation of external collaborators (WP5 of Hi-Lumi).

R&D on collimator materials

- Chasing **“dream” material** for collimator jaw: improved robustness and small impedance!
  Ex.: replace secondary collimators in IR3/7; Robust tertiary collimators?
- **HiRadMat beam tests** scheduled for 2012
- After evaluation of the beam tests, we will decide about possible production of new collimators for the installation in LS2
- Note that HiRadMat tests also cover special “**consumable**” collimator prototype produced by **SLAC** within US-LARP collaboration.

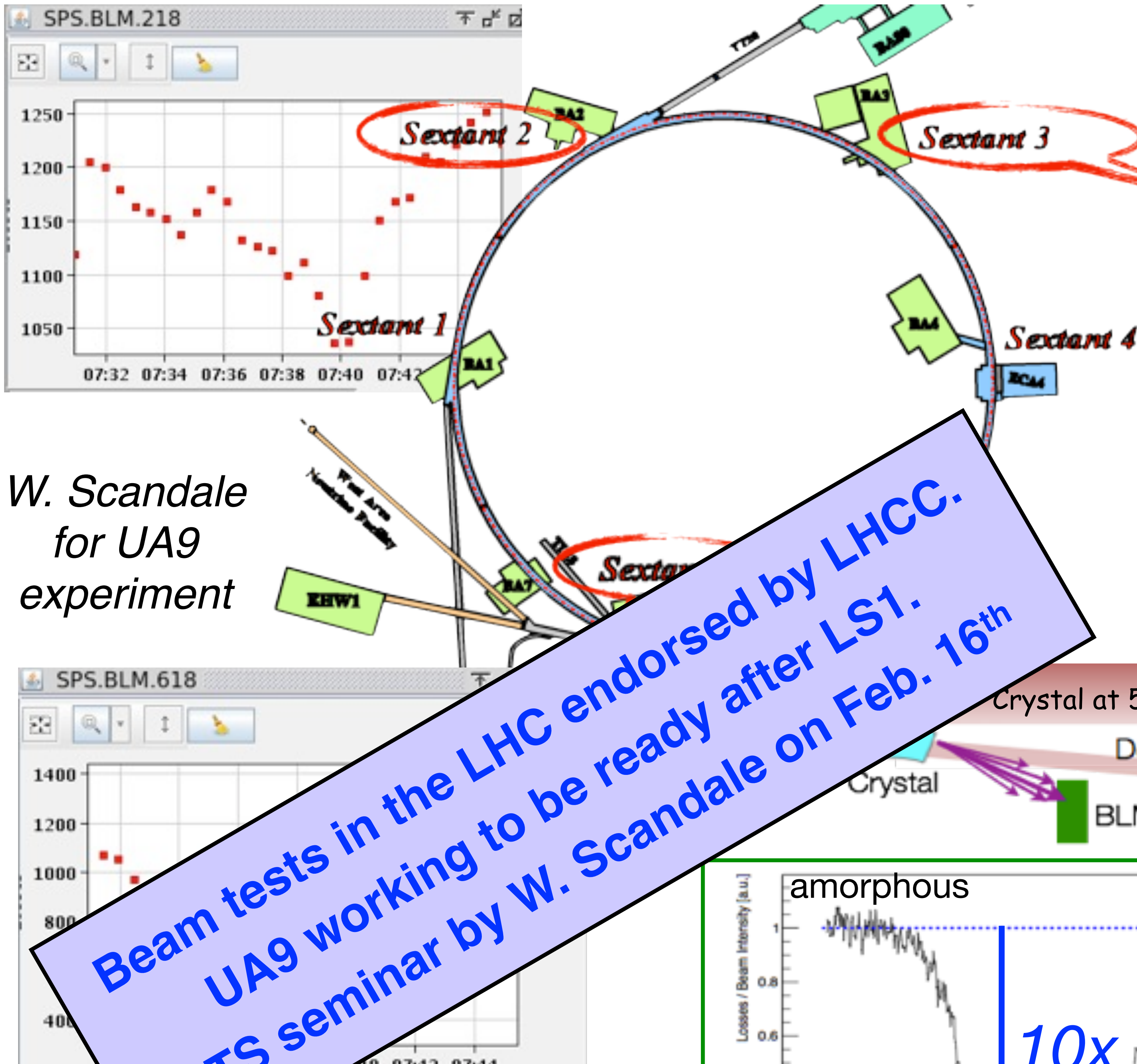


Courtesy of
A. Bertarelli

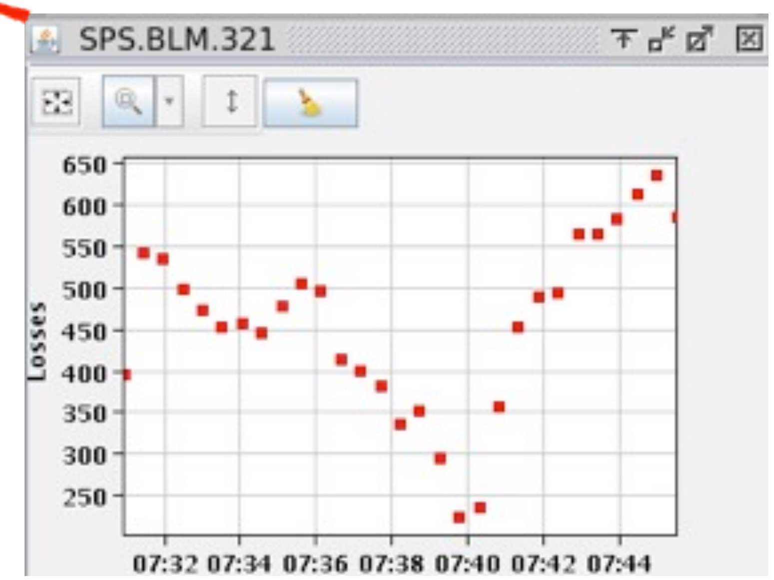
Outline

- ☑ Introduction
- ☑ LHC collimation until 2012
- ☑ Upgrade strategy
- ☑ **Advanced collimation concepts**
  - ***- Crystal collimation***
  - ***- Hollow electron beams***
- ☑ Conclusions

Crystal collimation

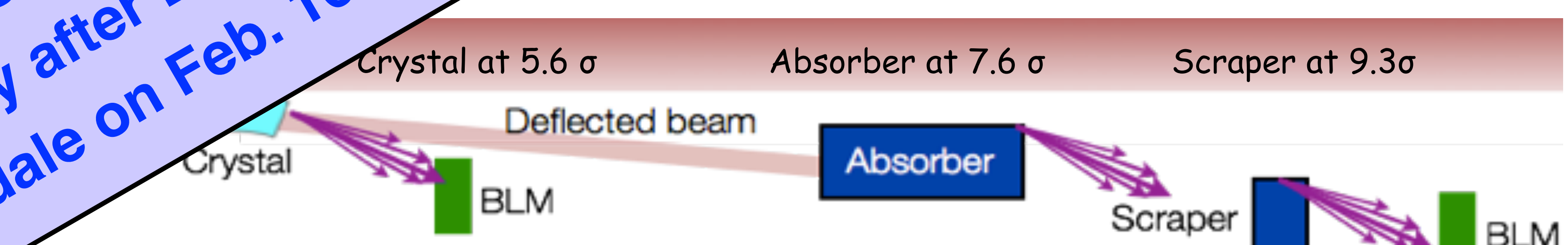


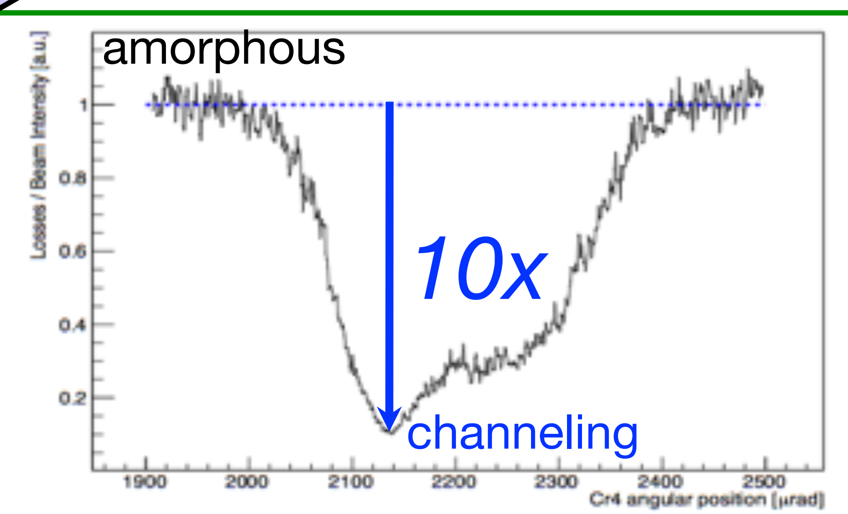
<u>loss reduction at the collimation insertion reproduced in all the sextants</u>



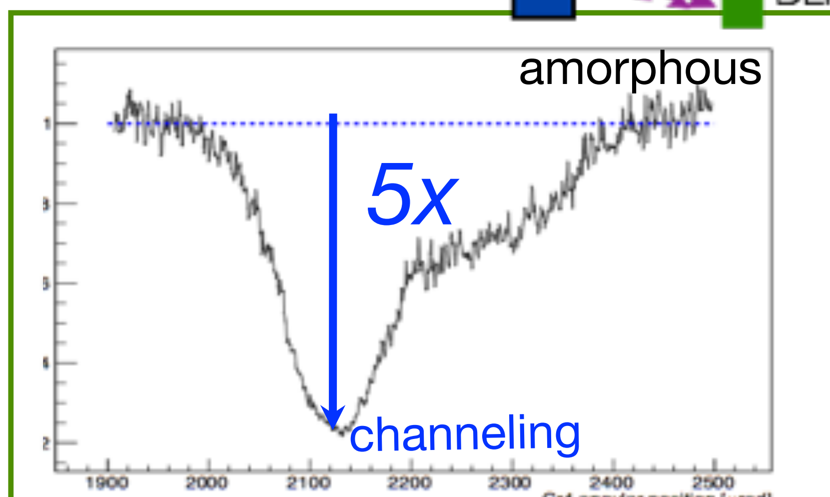
W. Scandale for UA9 experiment

Beam tests in the LHC endorsed by LHCC.
UA9 working to be ready after LS1.
ATS seminar by W. Scandale on Feb. 16th





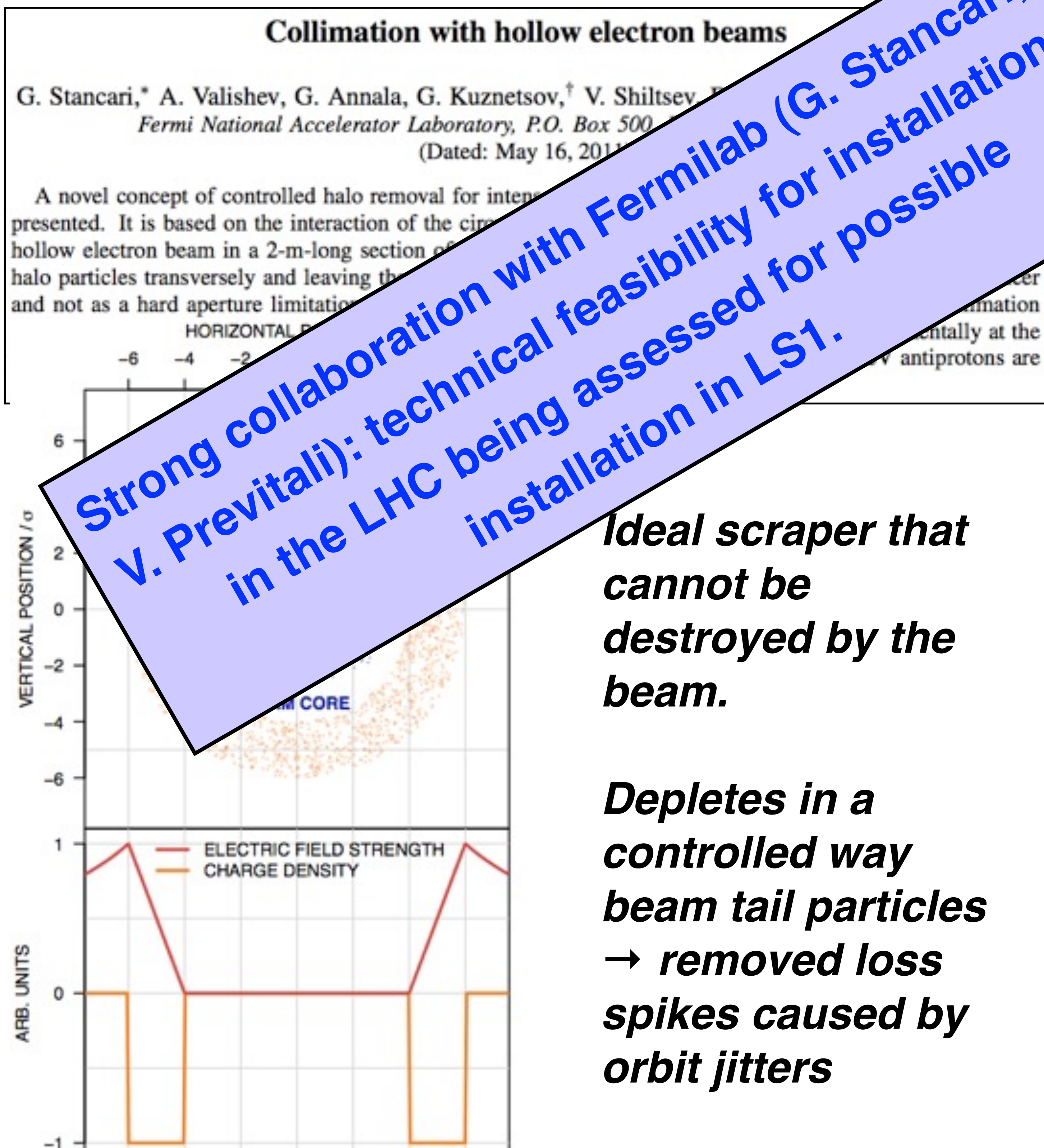
reduction of losses at the crystal collimator



... and ~ 130 m downstream (dispersive area)

Hollow e-lens

Paper submitted to Phy. Rev. Letter


Collimation with hollow electron beams

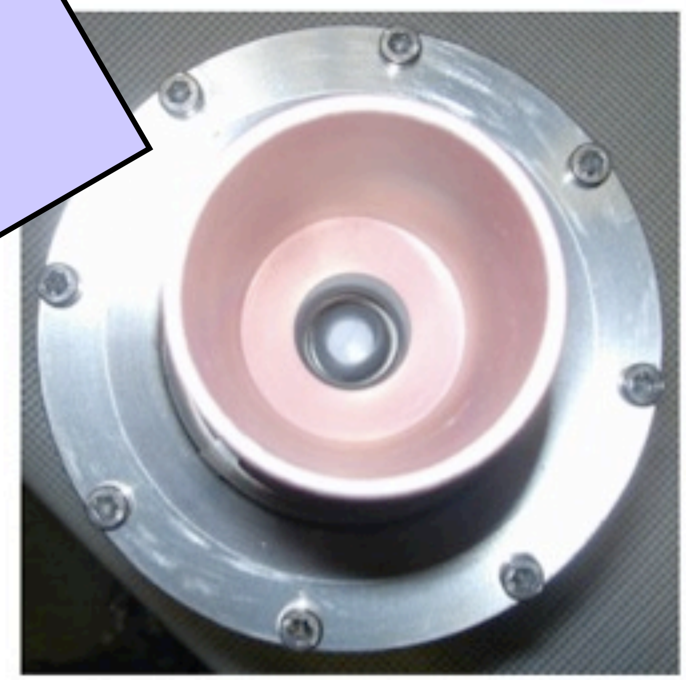
G. Stancari,* A. Valishev, G. Annala, G. Kuznetsov,† V. Shiltsev
Fermi National Accelerator Laboratory, P.O. Box 500
(Dated: May 16, 201

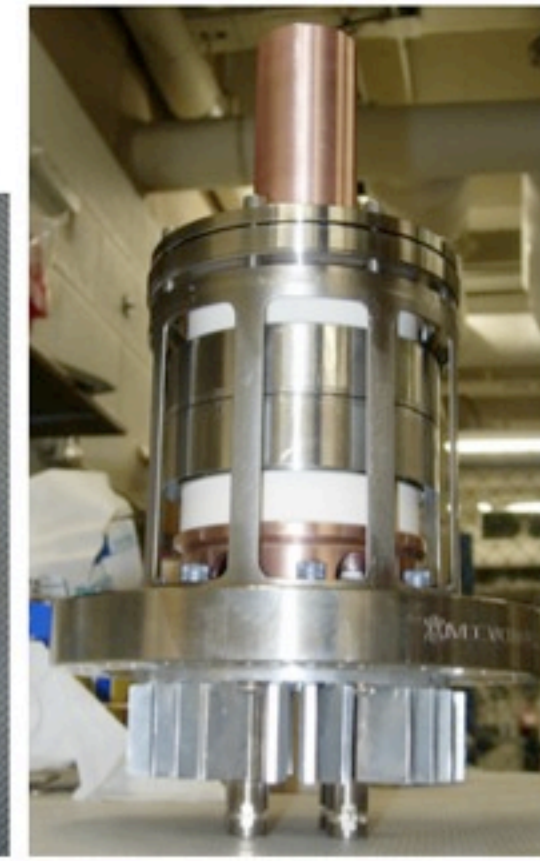
A novel concept of controlled halo removal for inten
presented. It is based on the interaction of the cir
hollow electron beam in a 2-m-long section of
halo particles transversely and leaving th
and not as a hard aperture limitatio

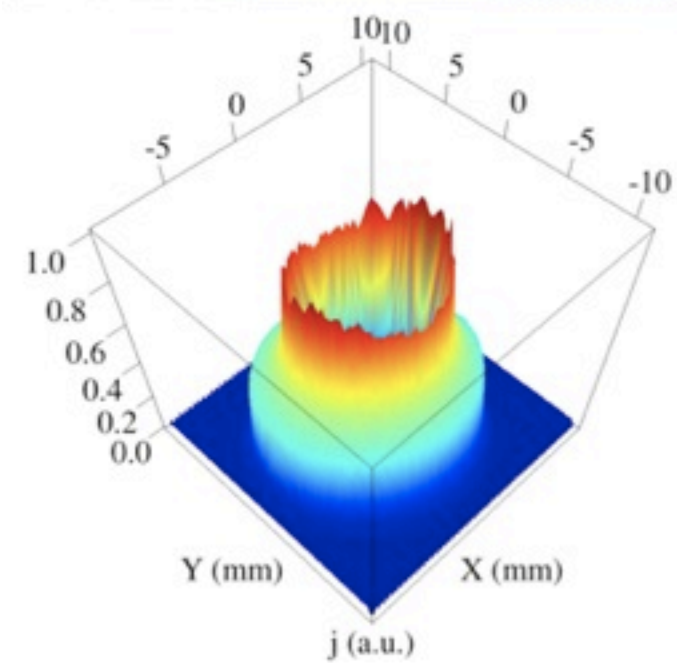
Strong collaboration with Fermilab (G. Stancari, V. Previtali): technical feasibility for installation in the LHC being assessed for possible installation in LS1.

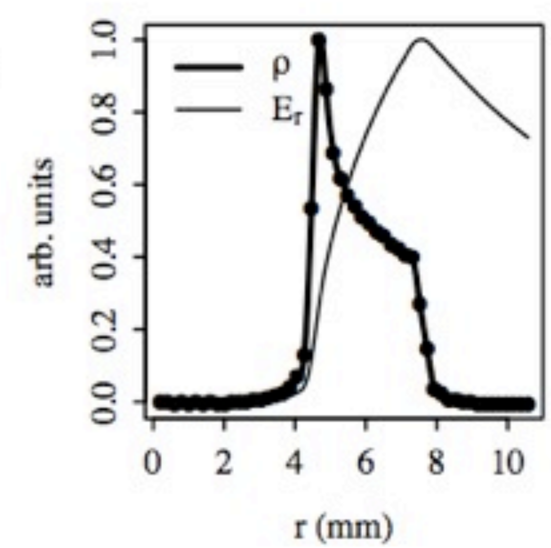
Ideal scraper that cannot be destroyed by the beam.

Depletes in a controlled way beam tail particles → removed loss spikes caused by orbit jitters









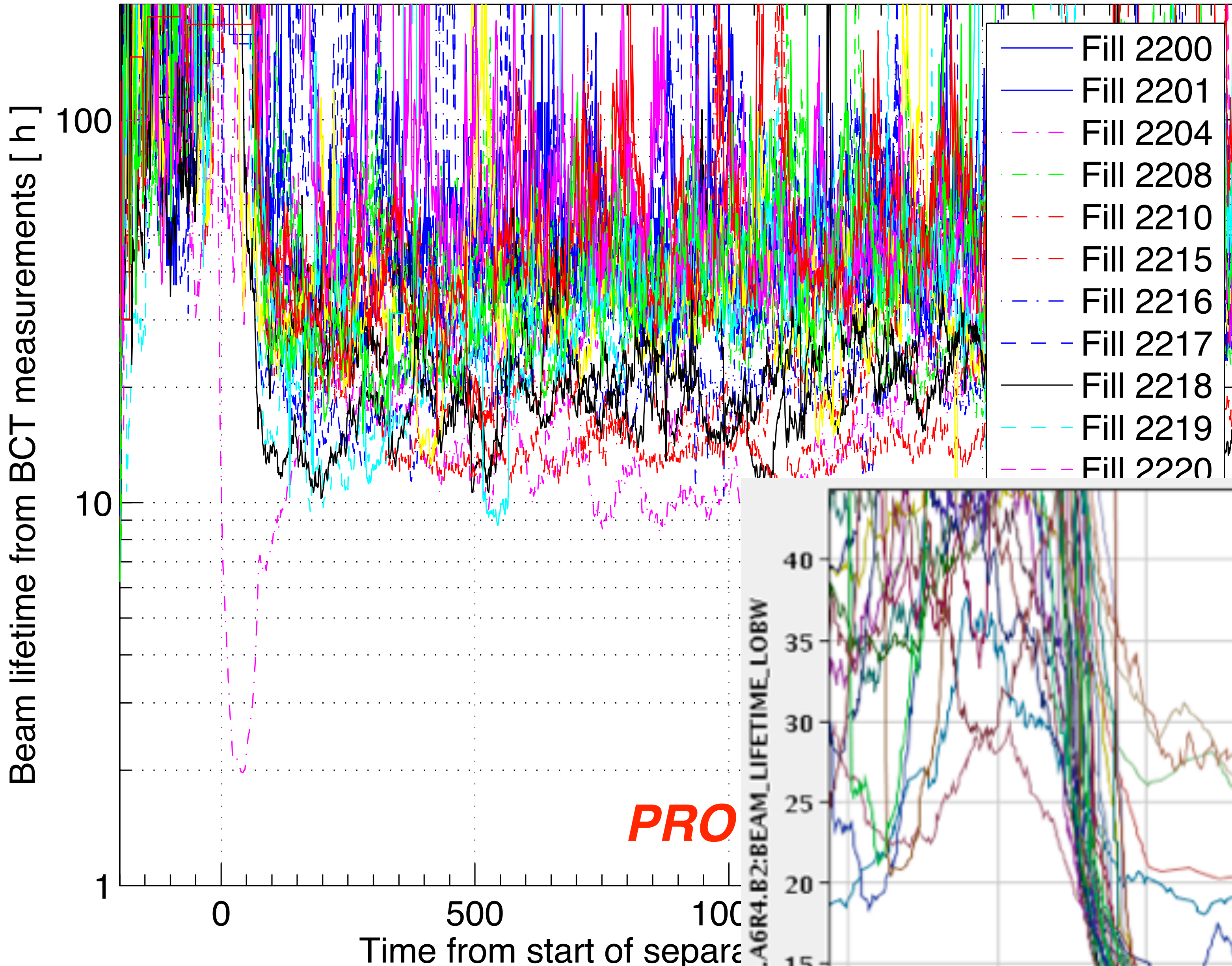
Courtesy of G. Stancari, Fermilab.

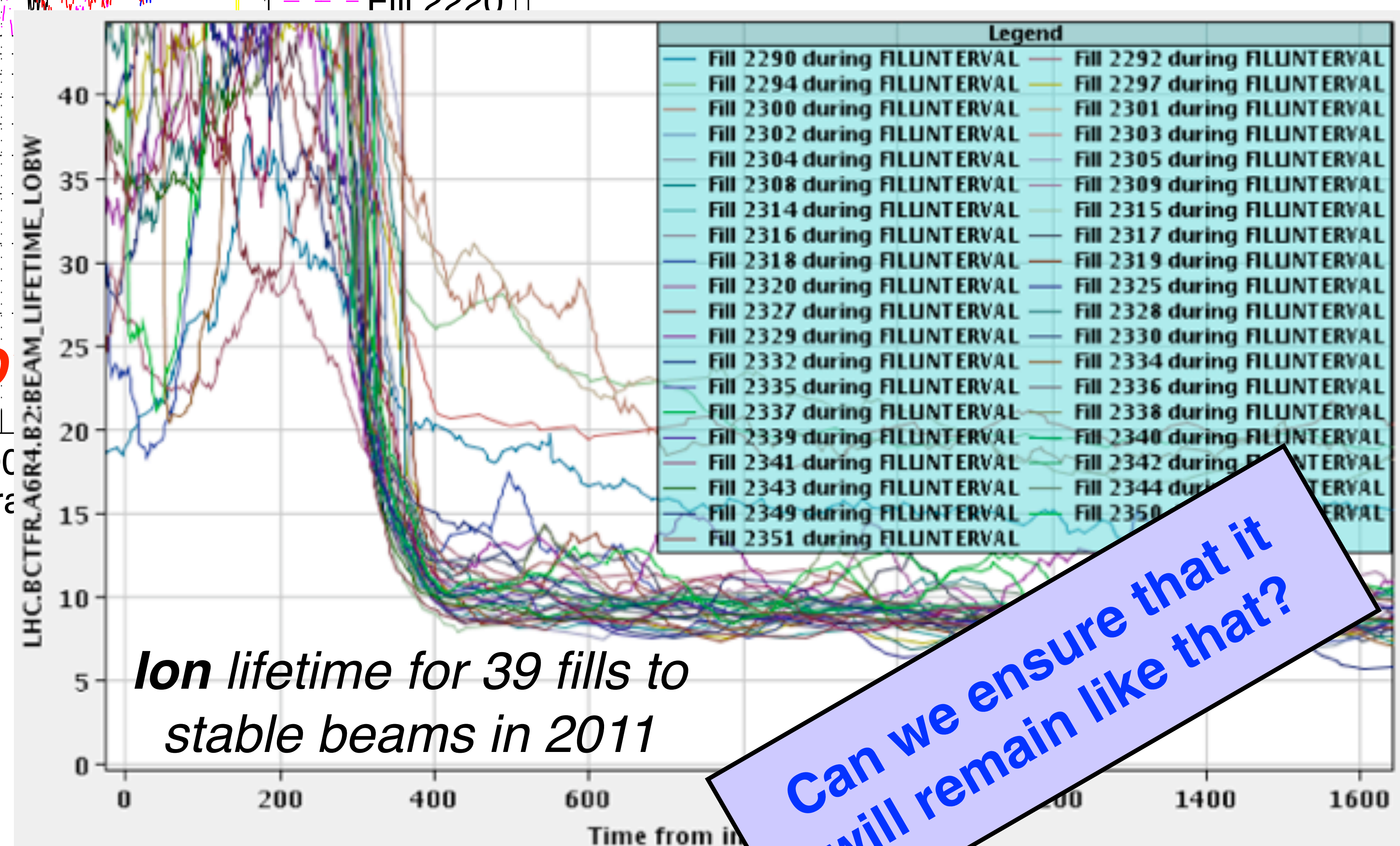
Conclusions

- The LHC machine and its **collimation system** work **well** (up to 110 MJ)
  - *- Full validation of all major collimator HW/SW design choices!*
  - *- Indication that IR3/7 cleaning is ok for ultimate LHC intensity*
  - *- Need continuous studies in 2012 to extrapolate at larger E and smaller β^**
  - *- Final verification only in 2015!*
- The LHC collimators will not last forever!
  - *- Pursuing R&D program on new materials to improve impedance and robustness*
  - *- Inputs expected at the end of 2012 after beam tests at HiRadMat*
  - *- Can profit of existing space reservation to add new collimators when/if needed*
- The LHC collimation cannot protect the **cold magnets** in the **DS's**.
  - *- Focus of present studies is moved to **experimental regions***
  - *- **Quench**: no obvious limitation for proton beams but ions might be closer to limit*
  - *- **Magnet lifetime** to be assessed carefully by magnet guys (implications on collimation system!)*
- **LS1**: collimators with **integrated BPMs** in experiment and dump regions
- We want to be ready with **a design of DS collimation** in IR1/2/5 for **LS2**
  - *- **11 T dipole** development is critical.*
- **New collimation** in the experimental regions to be worked out for **LS3**
  - *- We see no show stoppers for HL-LHC challenges*

Reserve slides

Beam lifetime in 2011 at 3.5 TeV



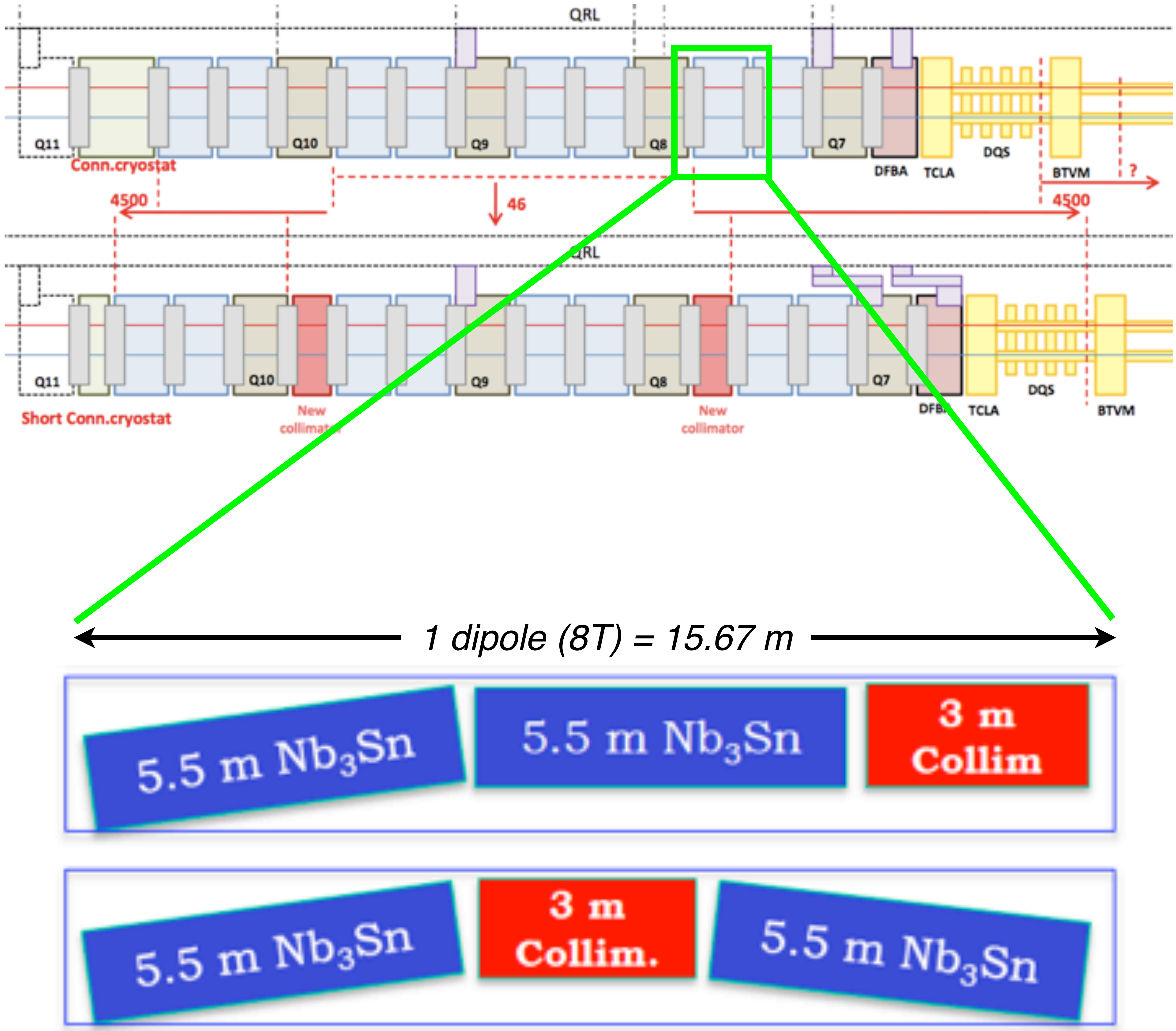


Can we ensure that it will remain like that?

Presently: main reason for the good surprise on performance reach!

Why 11T dipoles can help

V. Parma



M. Karppinen

Radiation at the collimators

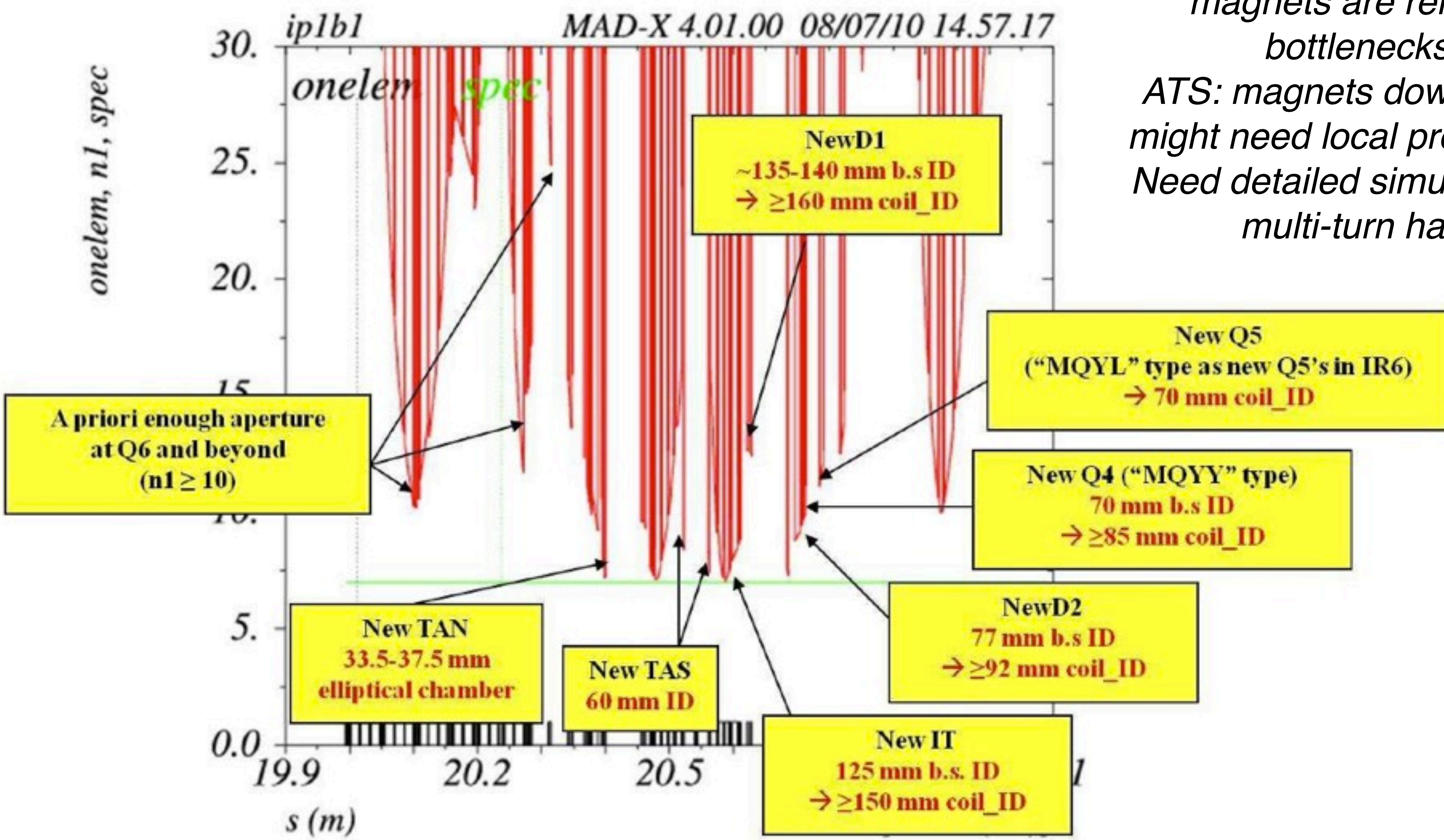
Doses in µSv/h

IR3-Right	January 2011		January 2012	
Element	Contact	Aisle	Contact	Aisle
TCP	13	0.3	88	6
TCAPA	24	0.7	360	8
TCSG.5	7.5	0.2	172	12
MQWA.C	9		176	5

IR7-Right	January 2011		January 2012	
Element	Contact	Aisle	Contact	Aisle
TCP.D6	10	1.2	376	6
TCP.C6	18	2.5	345	16
TCP.B6	31	3.1	560	40
TCAPA	70	3.0	860	35
TCAPB	13	1.2	203	13
TCSG.A6	8	1.5	450	28
TCAPC	65	2.5	840	16

Courtesy of S. Roesler for the RP team

IR aperture with ATS optics



Present optics: only triplet magnets are relevant bottlenecks.
ATS: magnets downstream might need local protections.
Need detailed simulations of multi-turn halo!

S. Fartoukh, Chamonix 2011

Effect of radiation on materials

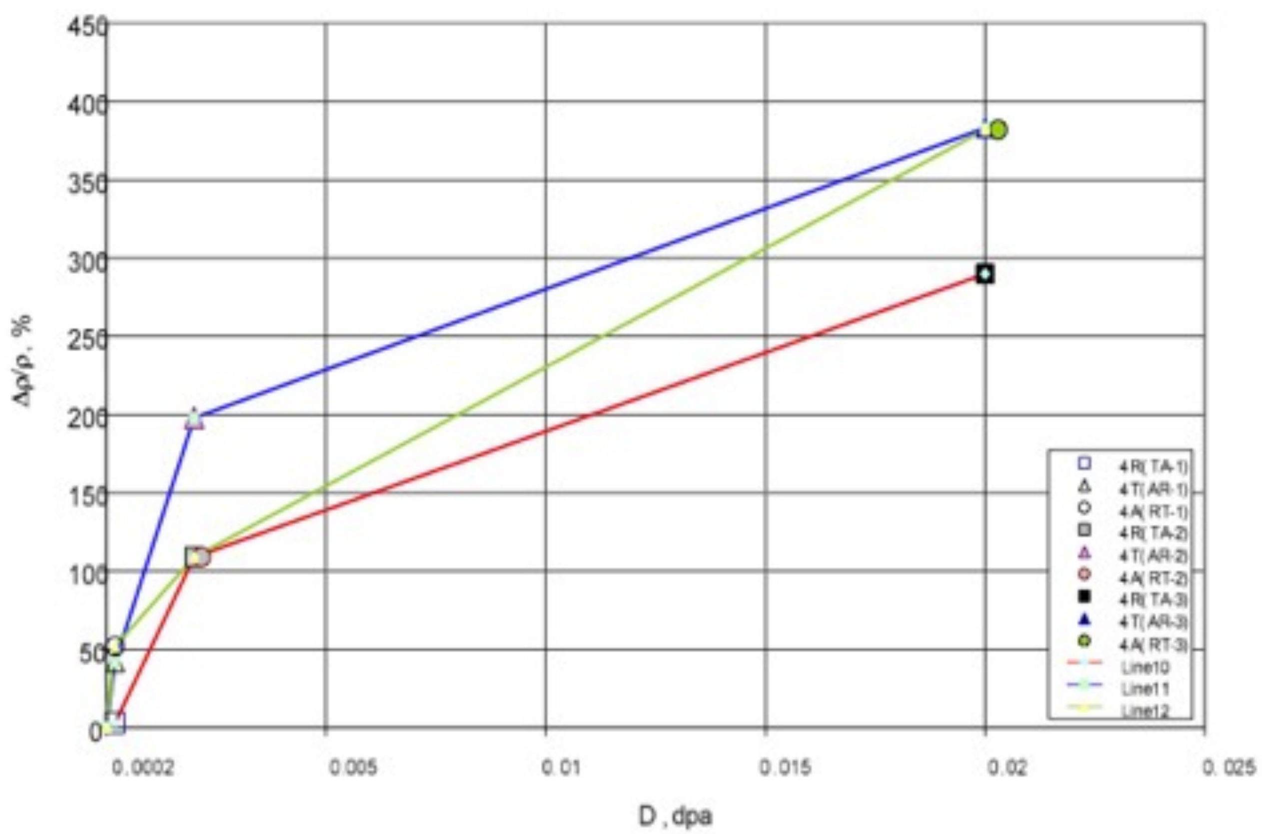


Fig. 50. The relative change in resistivity of samples for AC-150 material depending on the doses.

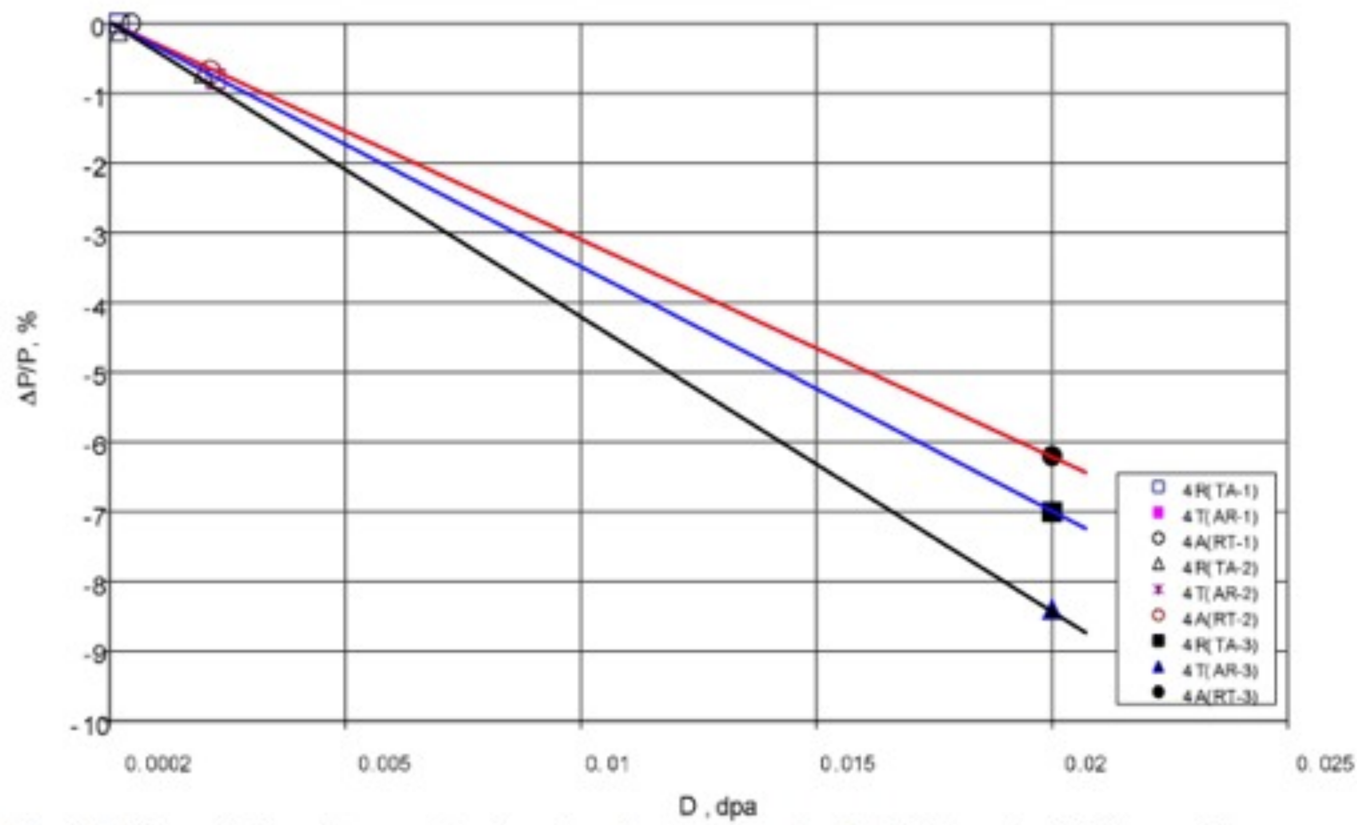
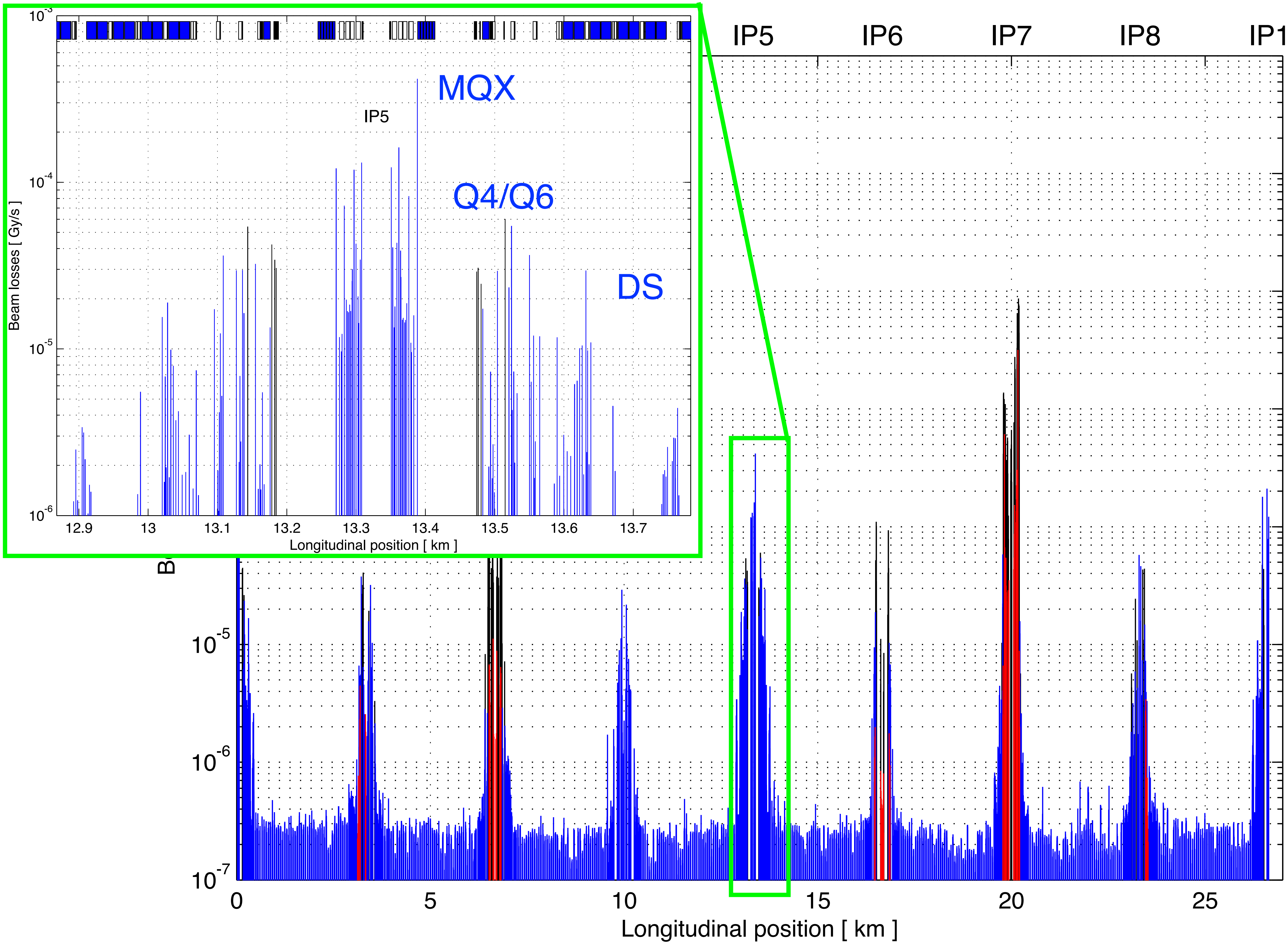


Fig.48. The relative change in density of samples for AC-150 material depending on the doses.

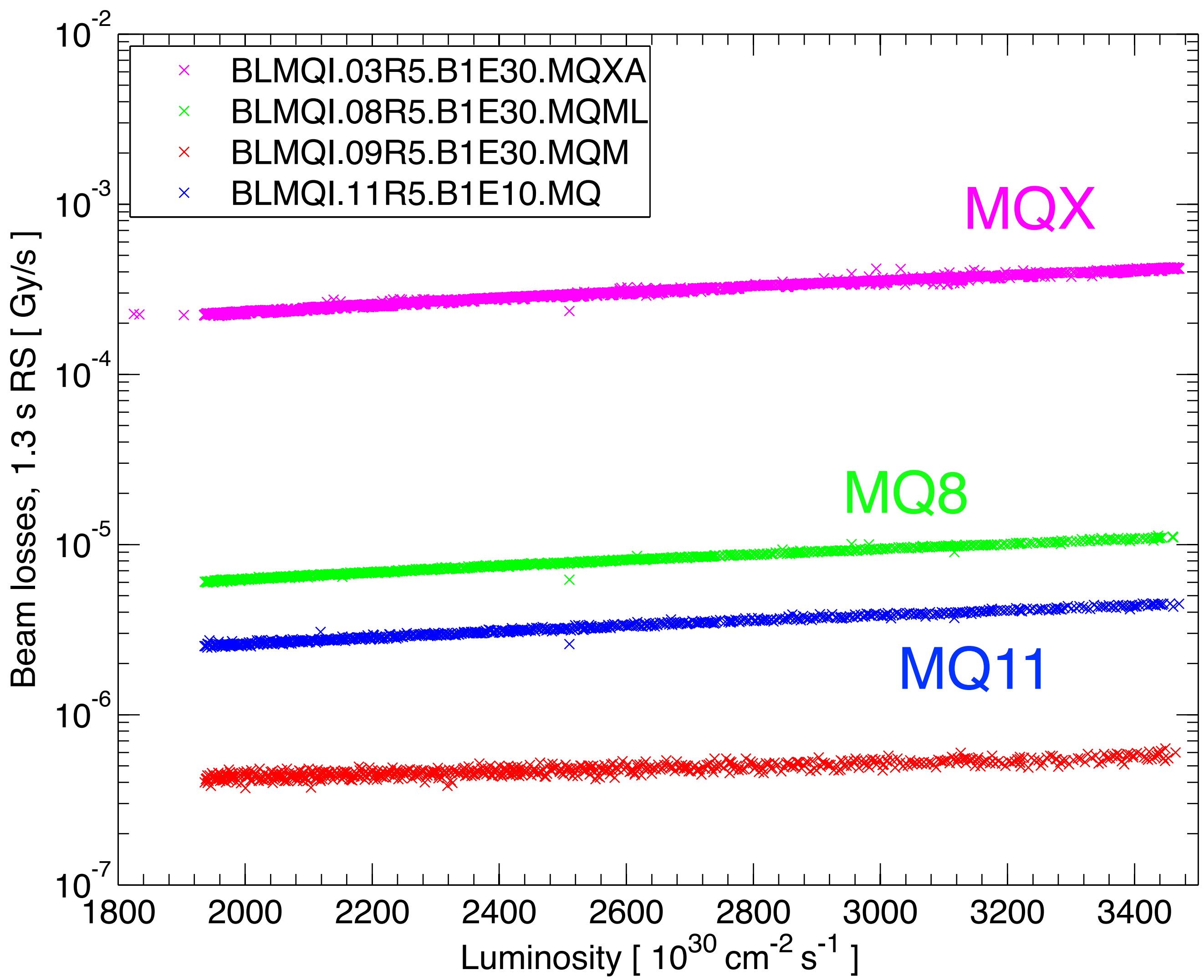
Samples of the Carbon material used for the collimator jaws were tested under radiation environment (10^{17}-10^{19} p /cm^2 of up to 30 MeV) at the Kurchatov institute (Courtesy of A. Ryazanov)

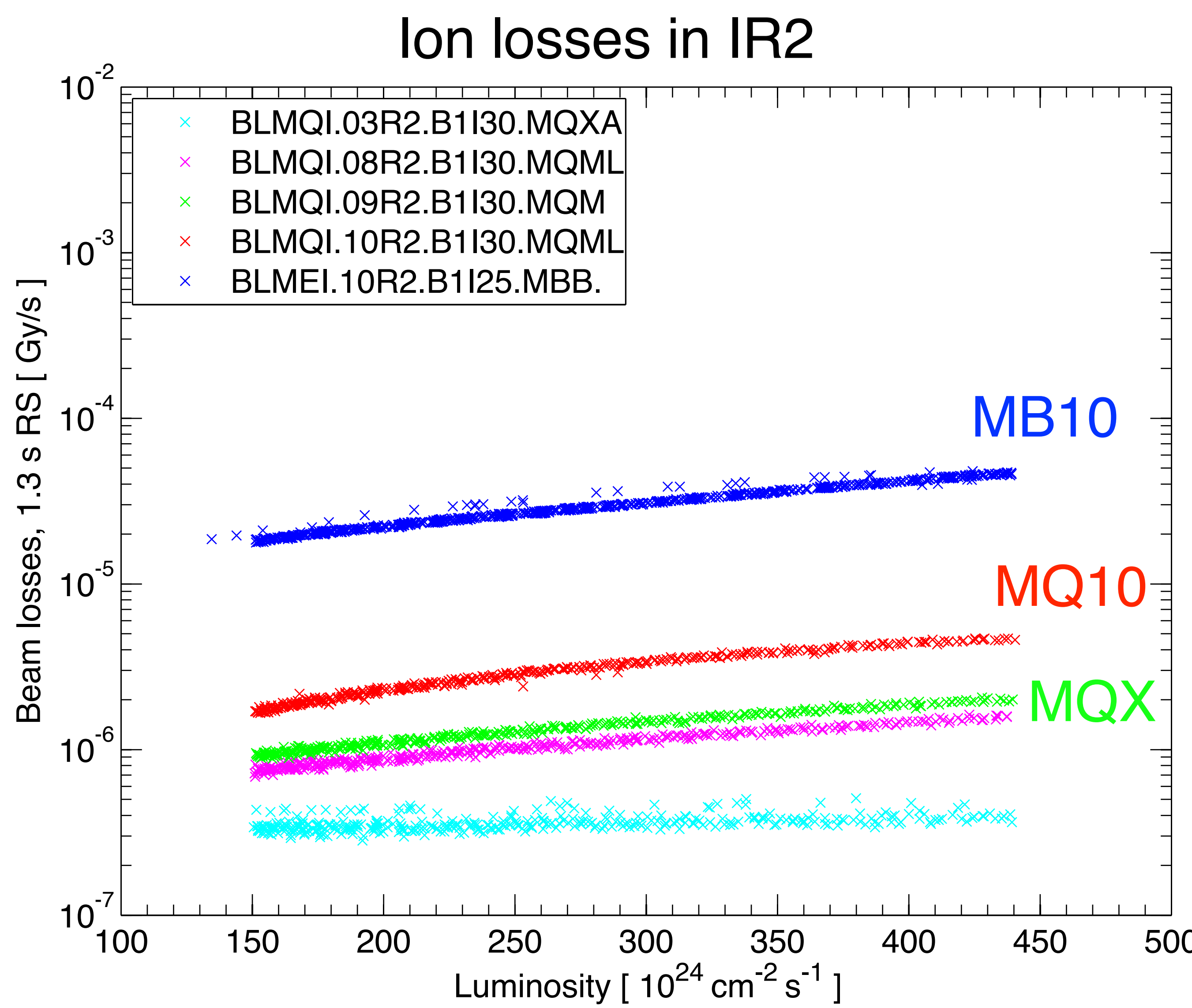
Material properties degrade in high-radiation environments. Examples: resistivity increased by more than 350%; thermal conductivity reduced by 70-80%

Ex: losses in the experimental regions



Losses in the DS of IR1/2/5



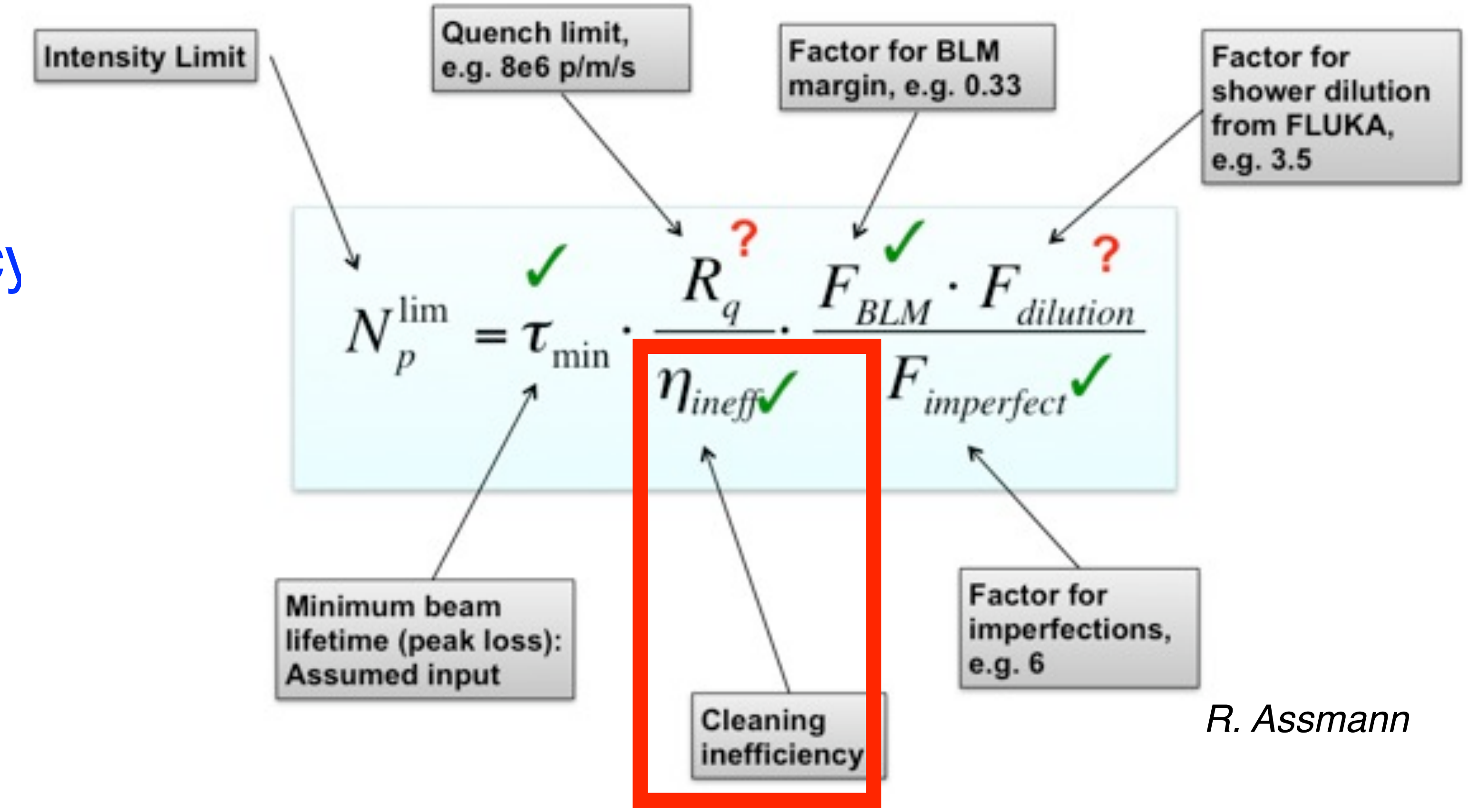


Large loss also for ions that affected operation already!
Issues: operational efficiency, radiation, magnet lifetime, ...

Design loss assumptions

Performance reach depends on:

- Collimation cleaning inefficiency
- Total beam intensity;
- Peak minimum lifetime;
- Quench limit of magnets;
- Loss dilution length.



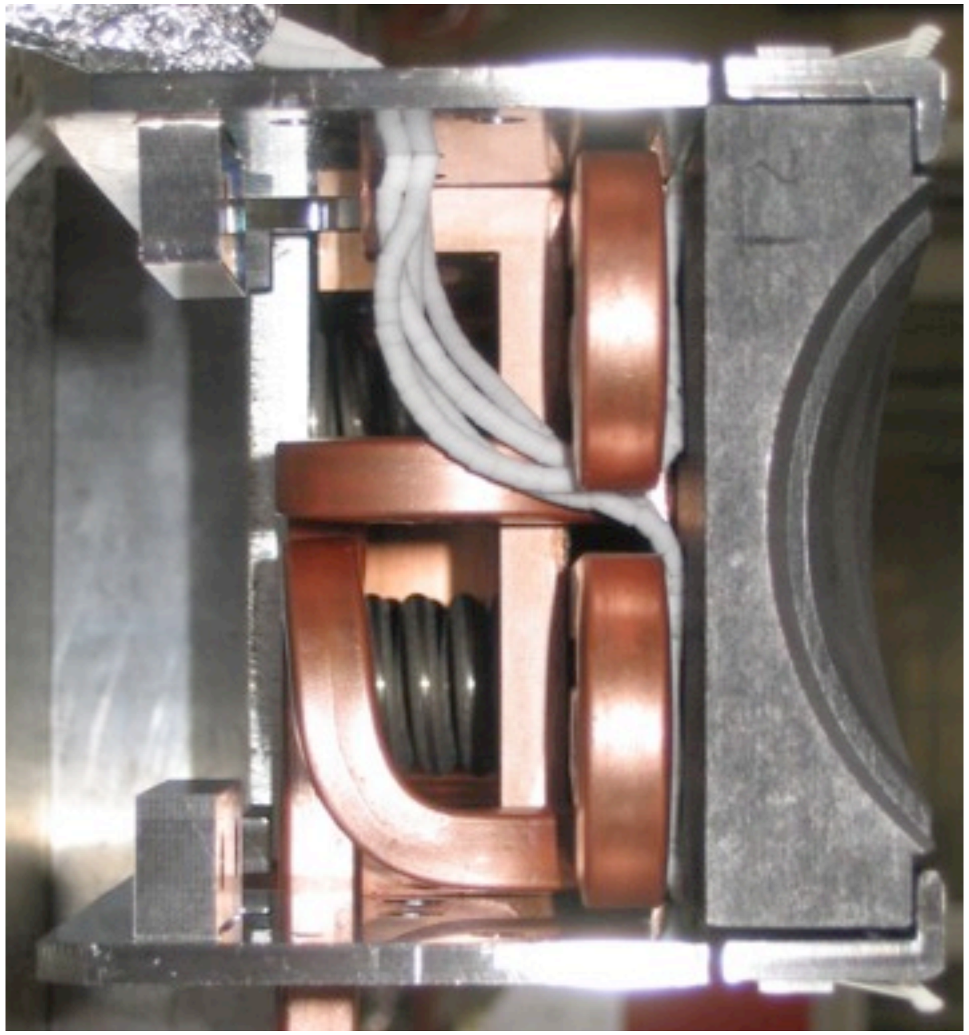
R. Assmann

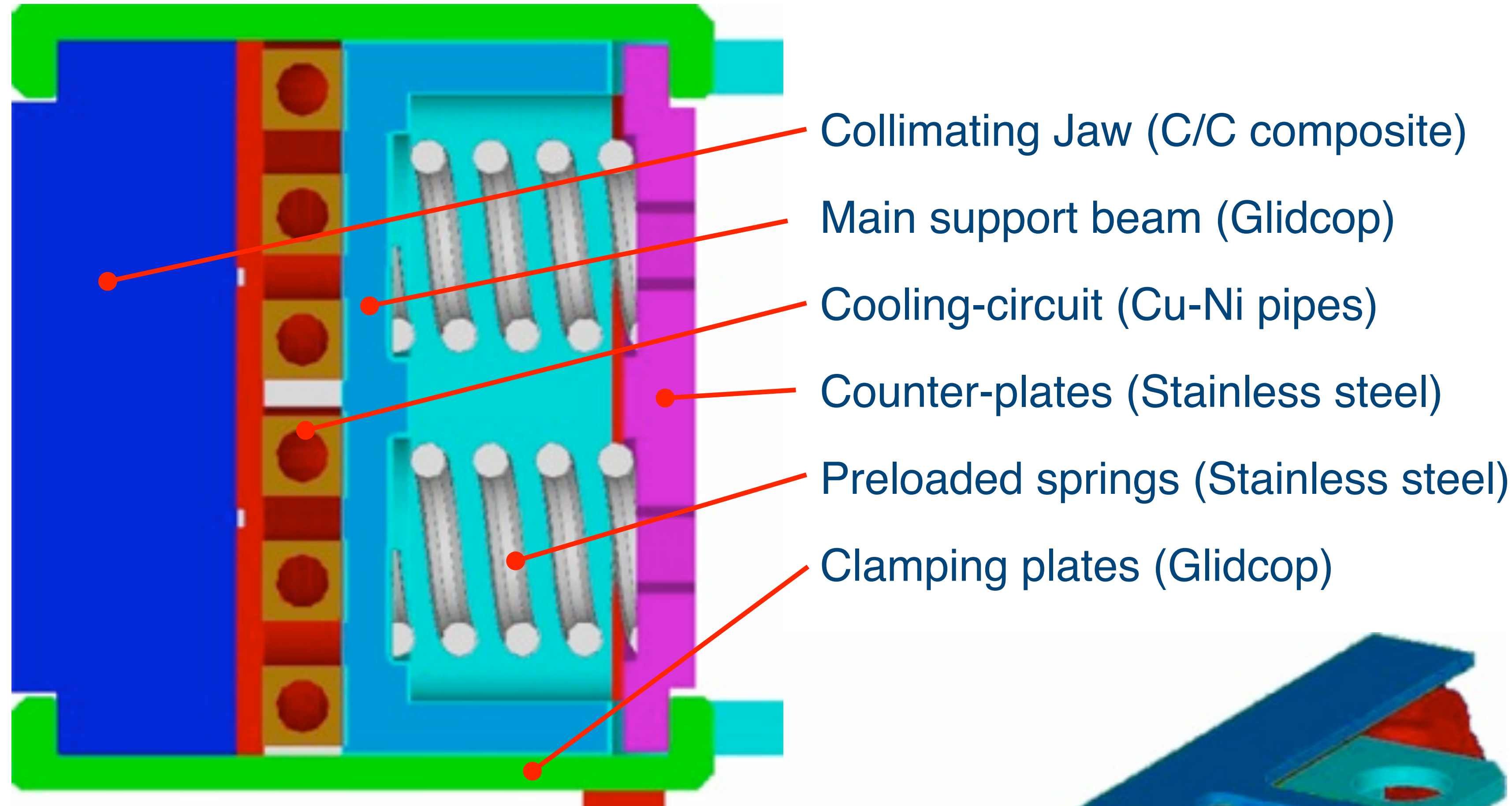
Our design specification:

Mode	T $[s]$	τ $[h]$	R_{loss} $[p/s]$	P_{loss} $[kW]$
Injection	cont.	1.0	0.8×10^{11}	6
	10	0.1	8.6×10^{11}	63
Ramp	≈ 1	0.006	1.5×10^{13}	1200
Collision	cont.	1.0	0.8×10^{11}	97
	10	0.2	4.3×10^{11}	487

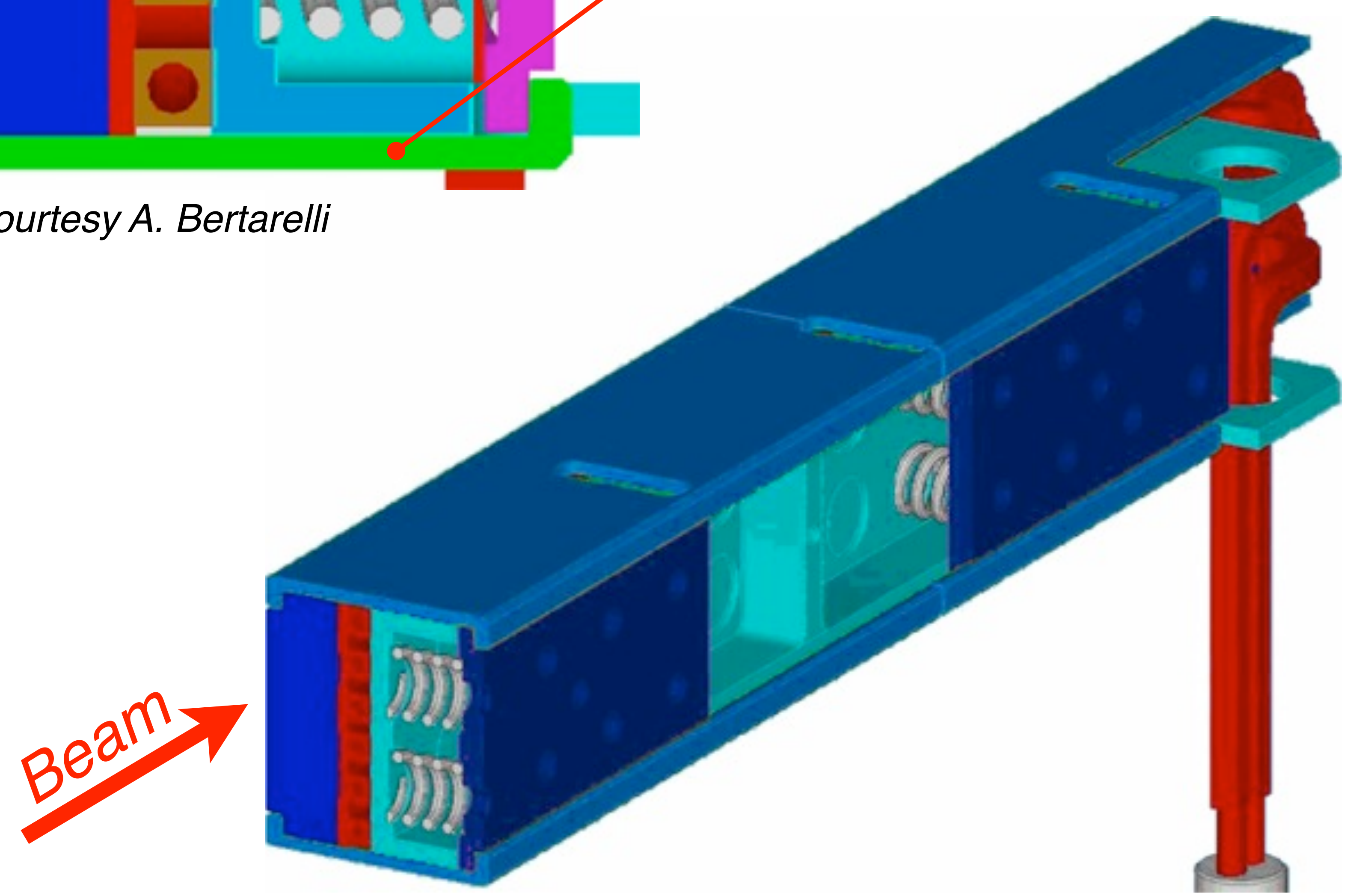
This figures are being revised based on the beam experience

The collimator jaw





Courtesy A. Bertarelli



"Sandwich" design with different layers minimizes the thermal deformations:

Steady (~5 kW) ➙ < 30 μm
Transient (~30 kW) ➙ ~ 110 μm