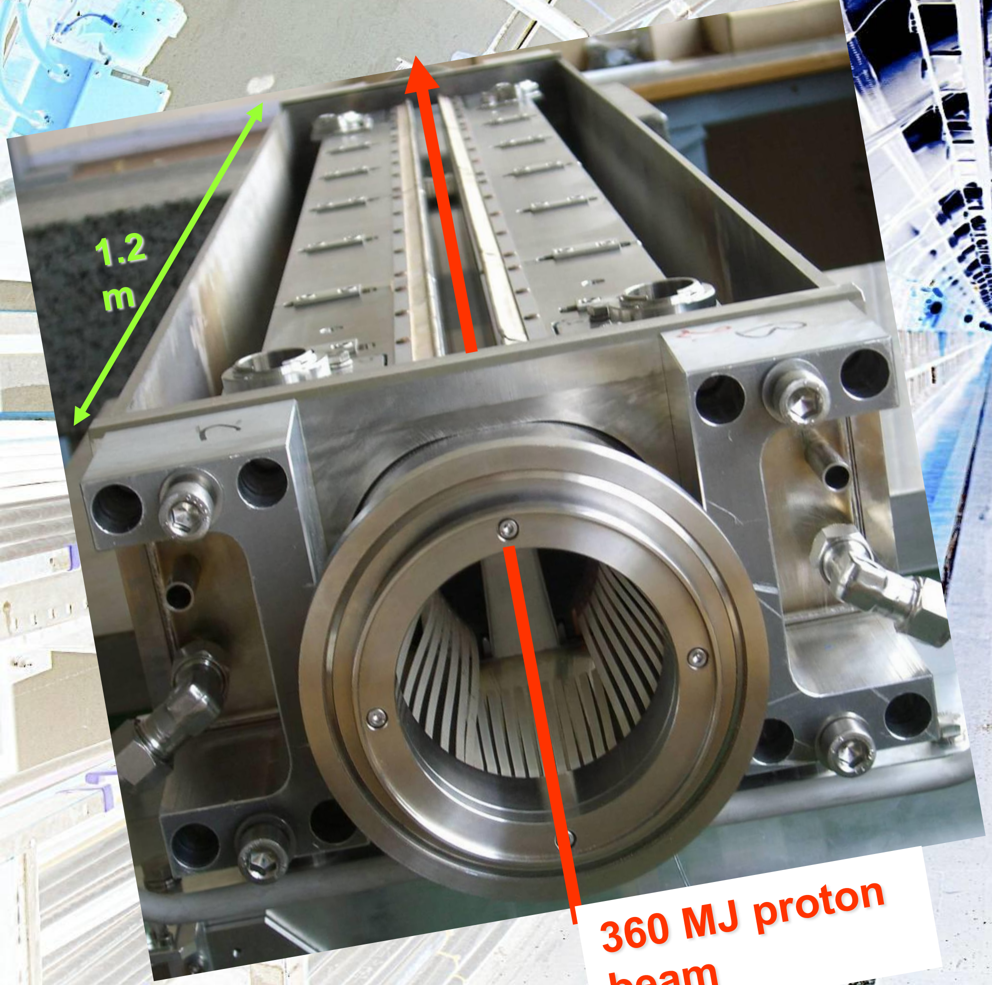
Summary of the Collimation Upgrade Plans



R. Assmann, CERN/BE

1/28/2010

for the Collimation Project

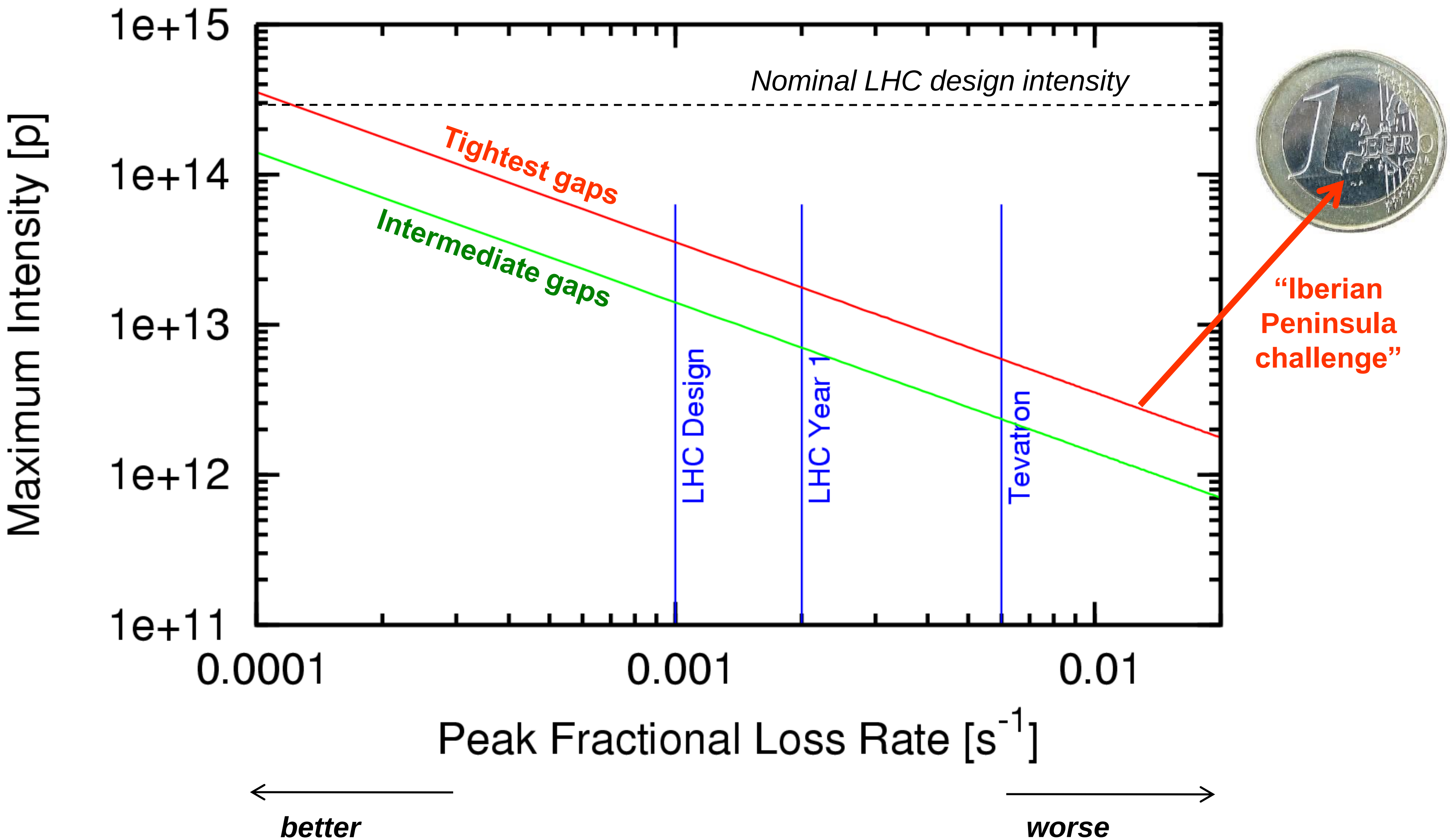
Chamonix 2010

What is Collimation Phase 1?

- It is the presently installed LHC collimation system (different to the triplet where phase 0 is installed).
- At optimum locations 100 movable collimators (TCP, TCSG, TCTVA, TCTVB, TCTH, TCLA, TCLP, TCL, TCDI, TCLIA, TCLIB), each with 2 jaws, tank rotated in x-y plane to best angle. Additional absorbers (TCAPA, TCAPB, TCAPC, TCLIM).
- Each collimator is a precision device with micron control of jaws, 3D hardware calibration and precision monitoring (triple redundancy).
- Implements complex 4-stage, 4D cleaning (x, y, skew, off-momentum phase space). Implements control of radiation distribution. System is the outcome of theoretical and numerical optimization.
- Two phases agreed in 2003: Phase 1 provides optimum robustness but ideal performance limited to ~40% of nominal intensity, less with imperfections. Phase 2 is prepared to maximum and allows nominal and ultimate intensities!

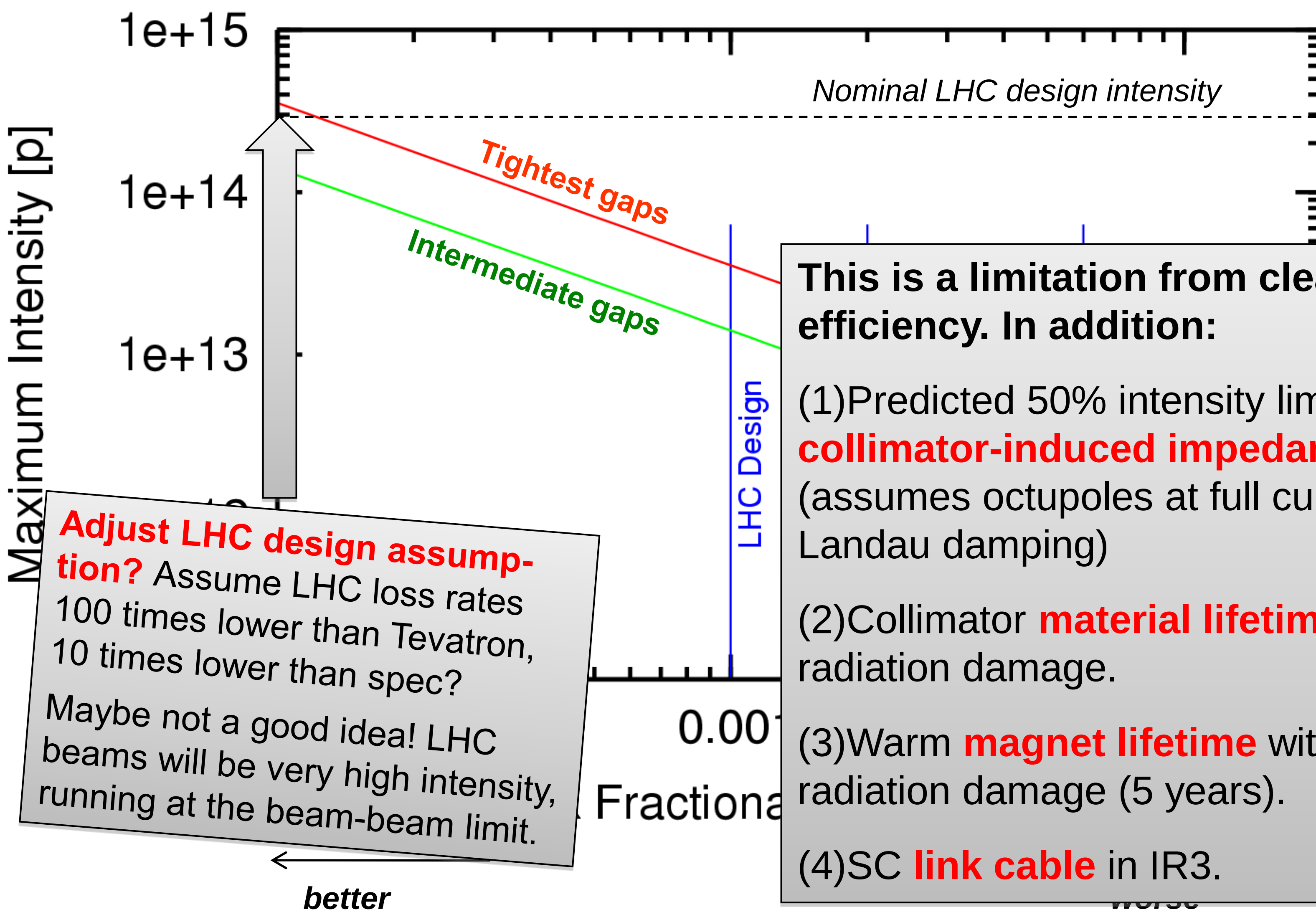
Phase 1 Intensity Limit vs Loss Rate at 7 TeV

Loss map simulations and LHC design values



Phase 1 Intensity Limit vs Loss Rate at 7 TeV

Loss map simulations and LHC design values



Adjust LHC design assumption? Assume LHC loss rates 100 times lower than Tevatron, 10 times lower than spec?

Maybe not a good idea! LHC beams will be very high intensity, running at the beam-beam limit.

This is a limitation from cleaning efficiency. In addition:

(1)Predicted 50% intensity limit from **collimator-induced impedance** (assumes octupoles at full current for Landau damping)

(2)Collimator **material lifetime** with radiation damage.

(3)Warm **magnet lifetime** with radiation damage (5 years).

(4)SC **link cable** in IR3.

The Phase 2 Solution

April 2009 during the conceptual design review for phase II of LHC collimation. All talks and info available at:

http://indico.cern.ch/conferenceDisplay.py?confId=55195

You also find the report of the review committee:

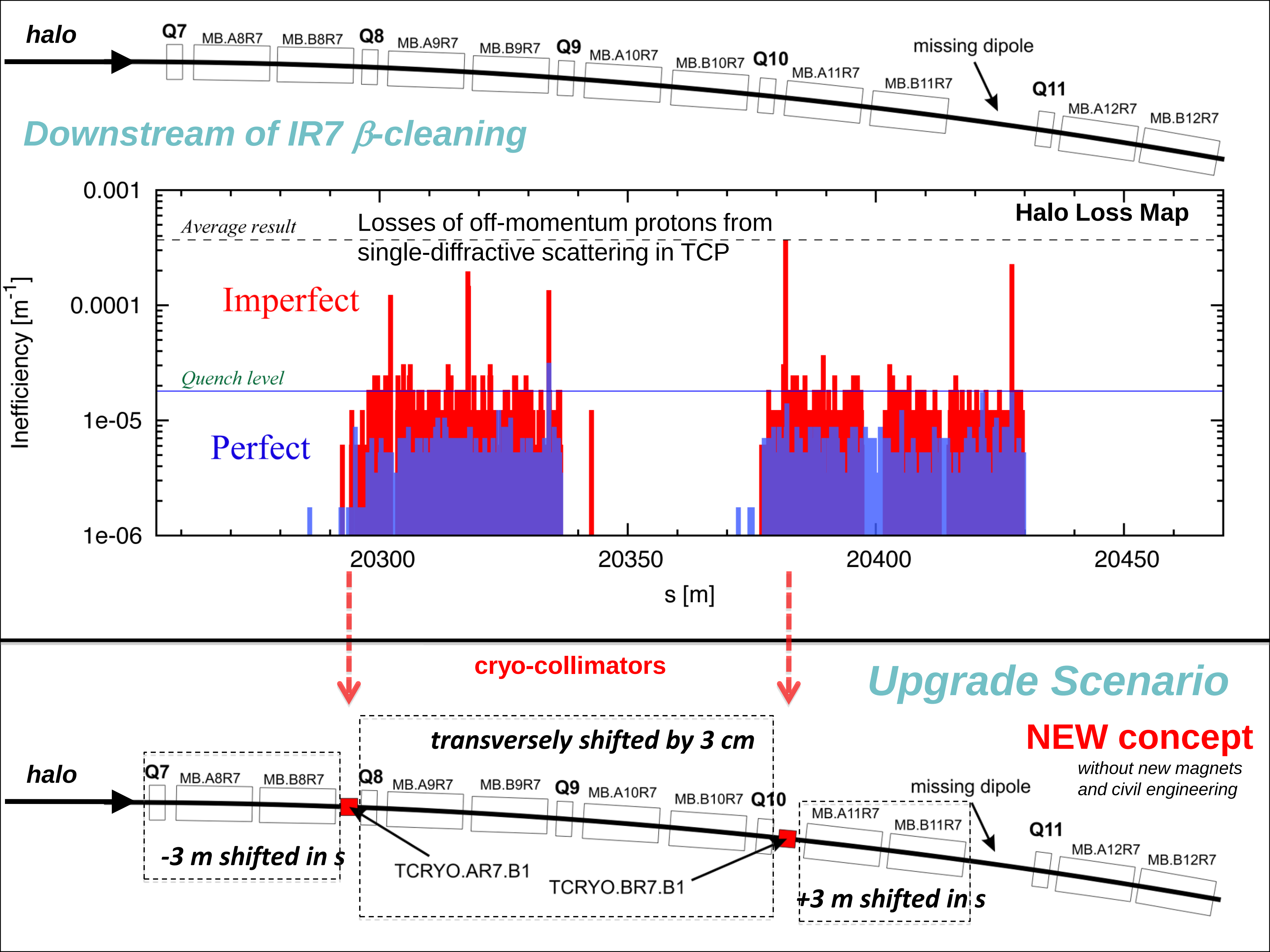
http://indico.cern.ch/getFile.py/access?resId=0&materialId=0&confId=55195

IR	Hardware	#	Justification	Construction	Infra-structure
1	TCLP installed	2	Interaction debris for **nominal luminosity**	OK	prepared
	TCTH, TCTVA moved	4	Phase 1 IR upgrade (if change in D2-D1 region)	OK	move
	TCT (new type?) installed	4	Phase 1 IR upgrade (reduced aperture in matching section)	new	new
2	TCTH installed	2	Improve **signal acceptance in ZDC**	new	new
	TCRYO installed	2	Remove limit on **ion luminosity**	new	new
3	TCSM installed	8	**Lower impedance (1/2), faster setup (h ➔ s), longer lifetime LSS3 (x 3)**	new	prepared
	Shift positions of 24 SC magnets by 3m, 3cm		Space for collimators at critical loss locations		
	TCRYO installed	4	**Better efficiency (x 15-90)** with collimators in SC dispersion suppressor	new	new
5	TCLP installed	2	Interaction debris for **nominal luminosity** (after removal of Roman Pots)	OK	prepared
	TCTH, TCTVA moved	4	Phase 1 IR upgrade (if change in D2-D1 region)	OK	move
	TCT (new type?) installed	4	Phase 1 IR upgrade (reduced aperture in matching section)	new	new
6	TCLA installed	2	**Reduce quench risk** after TCDQ	new	new
7	TCSM	22	**Lower impedance (1/2), faster setup (h ➔ s), longer lifetime (x 3), lower R2E UJ76 (1/6 – 1/2)**	new	prepared
	Shift positions of 24 SC magnets by 3m, 3cm		Space for collimators at critical loss locations		
	TCRYO installed	4	**Better efficiency (x 15-90)** with collimators in SC dispersion suppressor	new	new

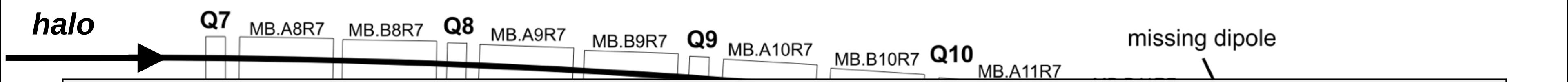
IR	Hardware	#	Justification	Construction	Infrastructure
1	TCLP installed	2	Interaction debris for **nominal luminosity**	OK	prepared
	TCTH, TCTVA moved	4	Phase 1 IR upgrade (if change in D2-D1 region)	OK	move
	TCT (new type?) installed	4	Phase 1 IR upgrade (reduced aperture in matching section)	new	new
2	TCTH installed	2	Improve **signal acceptan**		new
	TCRYO installed	2	P		new
3	TCSM				prepared
	Shift p magnet				
	TCRYO				new
5	TCLP ins				epared
	TCTH, TC		D1 region)	OK	move
	TCT (new		IR upgrade (reduced aperture in matching section)	new	new
6	TCLA installed	2	**Reduce quench risk** after TCDQ	new	new
7	TCSM	22	**Lower impedance (1/2), faster setup (h → s), longer lifetime (x 3), lower R2E (1/6 – 1/2)**	new	prepared
	Shift positions of 24 SC magnets by 3m, 3cm		Space for collimators at critical loss locations		
	TCRYO installed	4	**Better efficiency (x 15-90)** with collimators in SC dispersion suppressor	new	new

Total work (machine and experiment requests):

- 64 locations modified.
- 52 collimators + ~ 10 spares to be constructed.
- 22 new infrastructures.
- 8 infrastructures to be moved.
- 48 SC magnets to move in IR3 and IR7 (can be staged, 12 at a time).



halo
Q7
MB.A8R7
MB.B8R7
Q8
MB.A9R7
MB.B9R7
Q9
MB.A10R7
MB.B10R7
Q10
MB.A11R7
MB.B11R7
missing dipole
Q11
MB.A12R7
MB.B12R7
Downstream of IR7 β-cleaning
Halo Loss Map
Average result
Losses of off-momentum protons from single-diffractive scattering in TCP
Imperfect
Perfect
Quench level
Inefficiency [m^-1]
0.001
0.0001
1e-05
1e-06
20300
20350
20400
20450
s [m]
cryo-collimators
Upgrade Scenario
NEW concept
without new magnets and civil engineering
transversely shifted by 3 cm
halo
Q7
MB.A8R7
MB.B8R7
Q8
MB.A9R7
MB.B9R7
Q9
MB.A10R7
MB.B10R7
Q10
missing dipole
MB.A11R7
MB.B11R7
Q11
MB.A12R7
MB.B12R7
-3 m shifted in s
TCRYO.AR7.B1
TCRYO.BR7.B1
+3 m shifted in s



Solution catches off-momentum beam around any IR (any collisions generate off-momentum beam)! We had this solution for LEP2, FAIR will have it, …

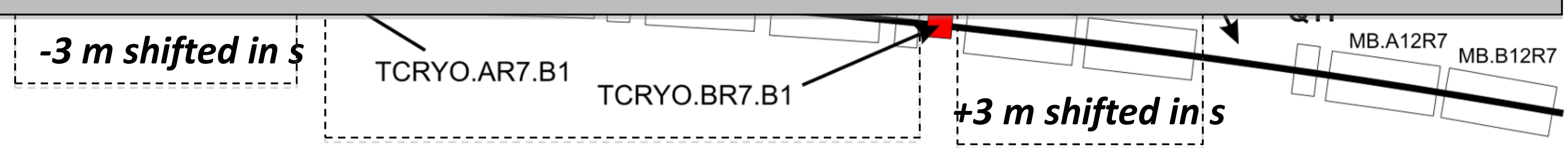
LHC implementation involves shifting 24 magnets per side of each IR. Also affects the connection cryostat obviously and possibly the DFBA.

We propose this solution for the cleaning insertions IR3 and IR7. We are lucky: Easiest to modify these 2 insertions.

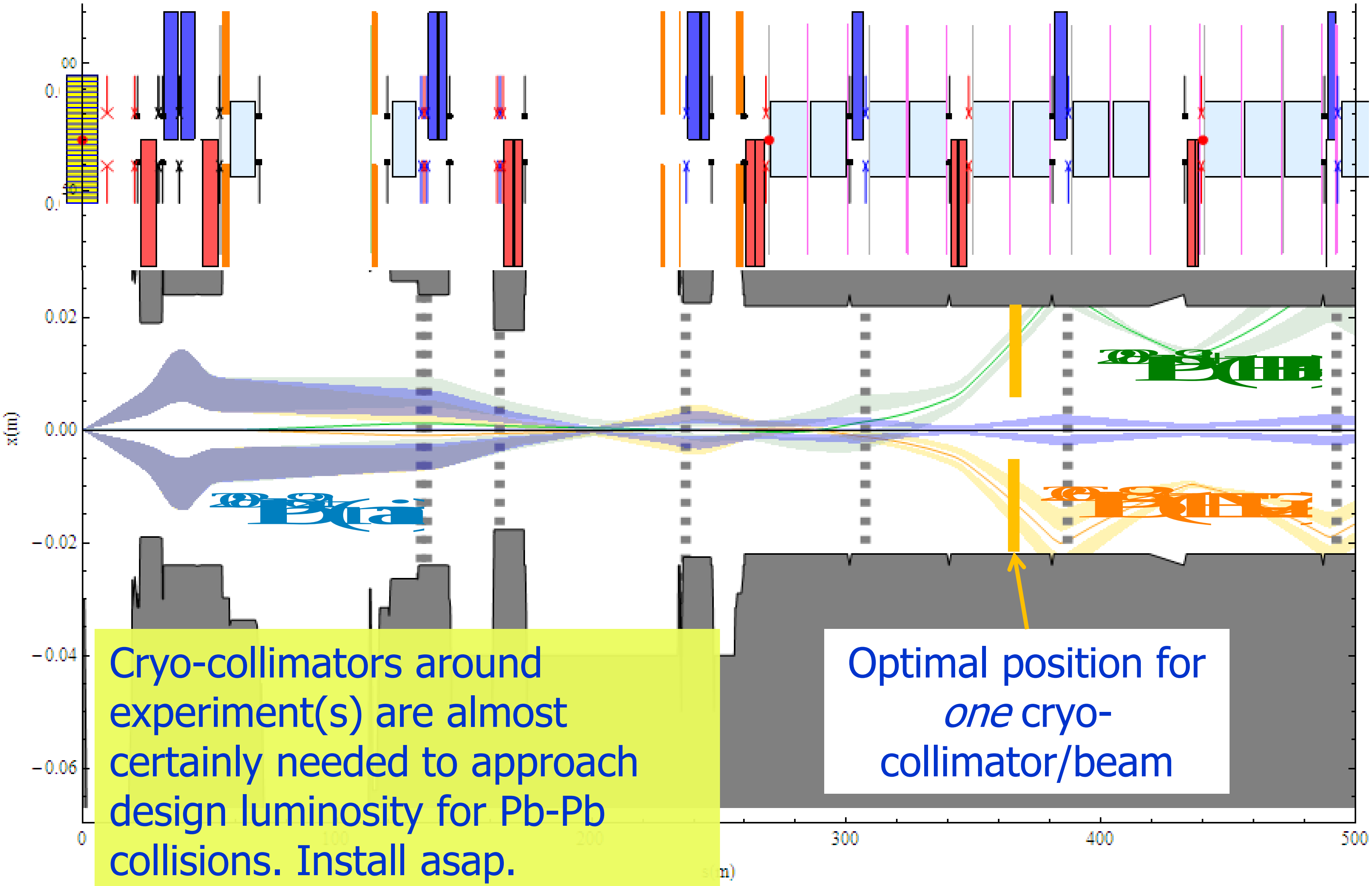
However, solution also solves IR2 ion luminosity limitation. Should be put there as well. *The installation of cryogenics collimator at P2 will be more complicated than for P3&7 because of the presence of individually powered quadrupoles at 6 kA instead of 600 A at 3&7 so the N line at 2 is not standard (same for all other points except 3&7 which are the easiest).*

No plans for IR1 and IR5, as existing collimation should be good for nominal and ultimate luminosities. However, might become needed at some point…

Collimation efficiency: **99.997% (phase 1) ➔ 99.99992% (phase 2)**



Main and secondary Pb beams from IP2



Cryo-collimators around experiment(s) are almost certainly needed to approach design luminosity for Pb-Pb collisions. Install asap.

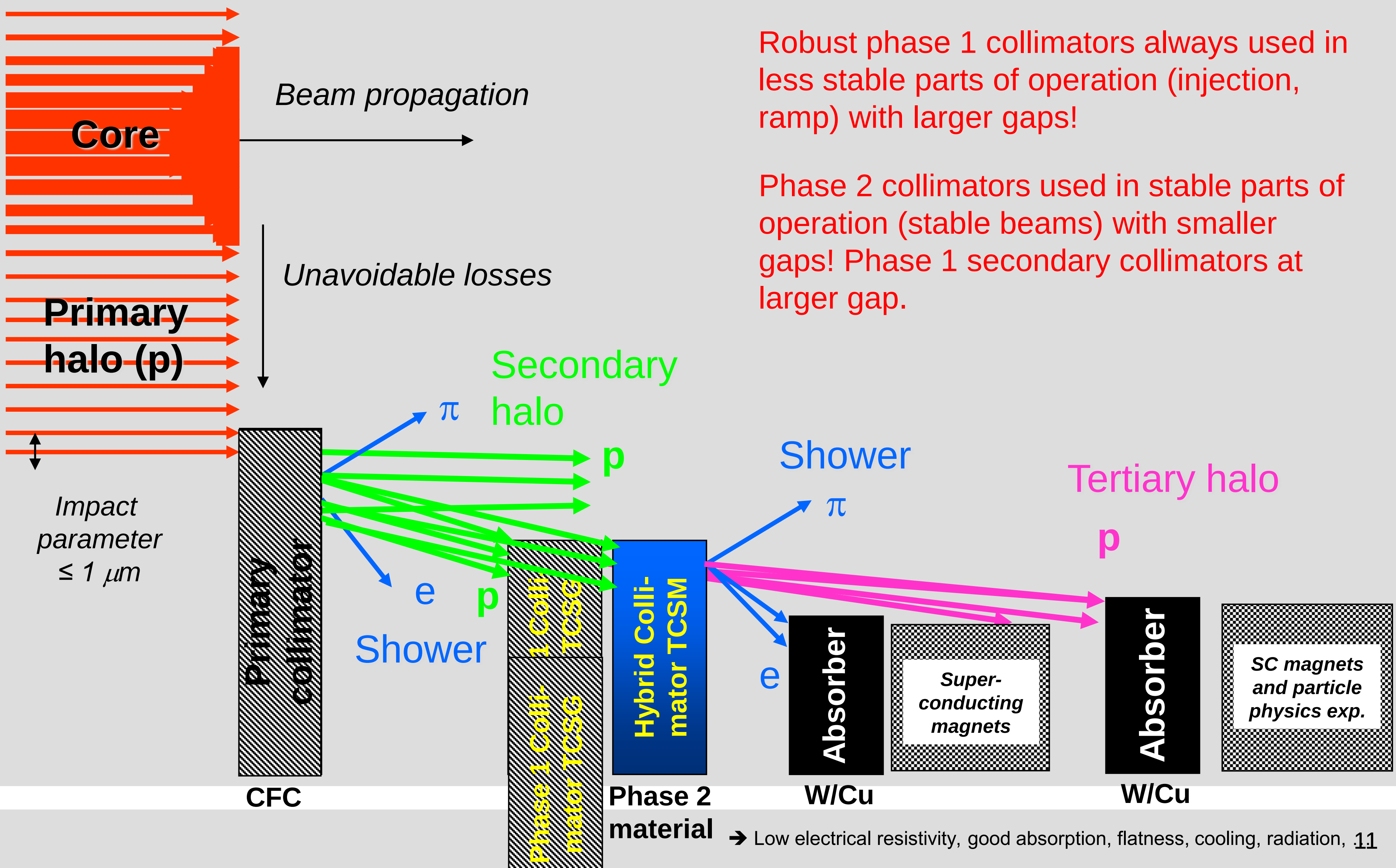
Optimal position for *one* cryo-collimator/beam

John Jowett

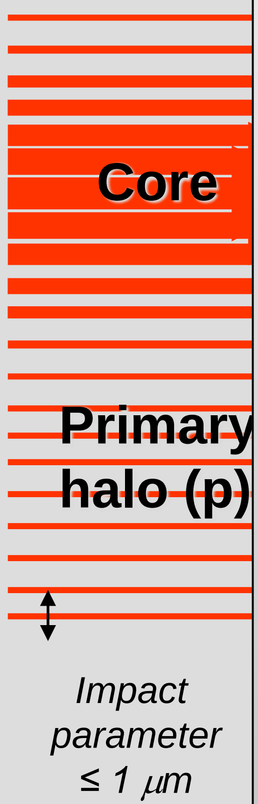
LHC Phase 2 Cleaning & Protection

Robust phase 1 collimators always used in less stable parts of operation (injection, ramp) with larger gaps!

Phase 2 collimators used in stable parts of operation (stable beams) with smaller gaps! Phase 1 secondary collimators at larger gap.



➔ Low electrical resistivity, good absorption, flatness, cooling, radiation, ...



Benefits

(1) Lower impedance (1/2).

(2) Have faster and more accurate collimator setup (hours ➔ seconds).

(3) Higher operational efficiency with fewer special calibration fills (BPM-based collimator setup).

(4) Longer collimator lifetime for phase 1 (distribute radiation load on more devices).

(5) Longer magnet lifetime in LSS3&7 (x 3).

(6) Lower radiation to electronics possible in IR7 for UJ76 (1/6 for beam 1, 1/2 for beam 2).

(7) Hardware could be used to do betatron cleaning in IR3, if intensity would be limited by radiation to electronics in IR7 (see 2007 memo): ~ *100 times lower radiation to electronics in IR3 for the same beam loss.*

Drawbacks

(1) Higher local radiation with high Z mat (dose to cables x2).

s used in
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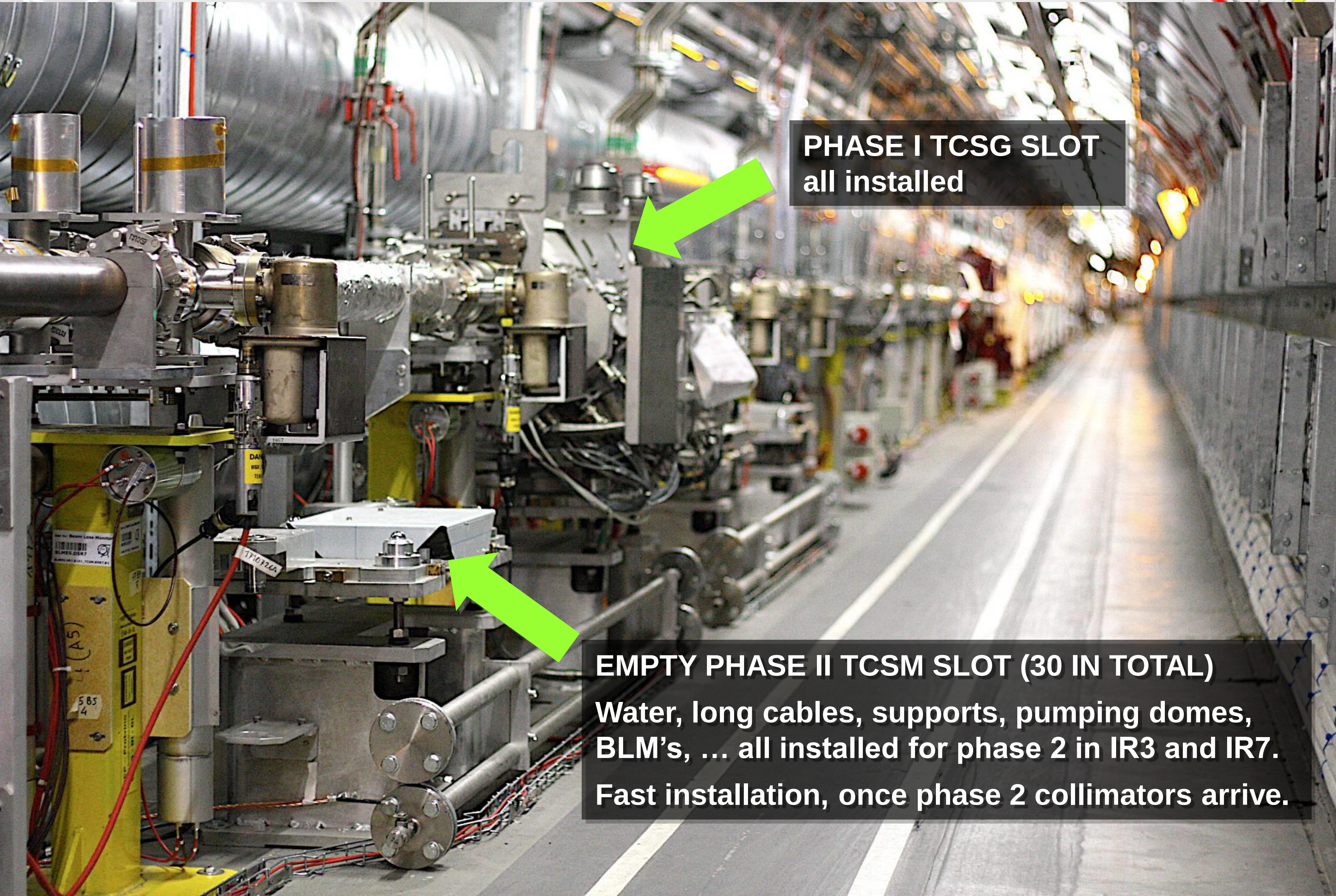
alo

SC magnets and particle physics exp.

CFC | Phase 1 | Phase 2 material | W/Cu | W/Cu

➔ Low electrical resistivity, good absorption, flatness, cooling, radiation,

Phase II TCSG Slots Ready in Tunnel

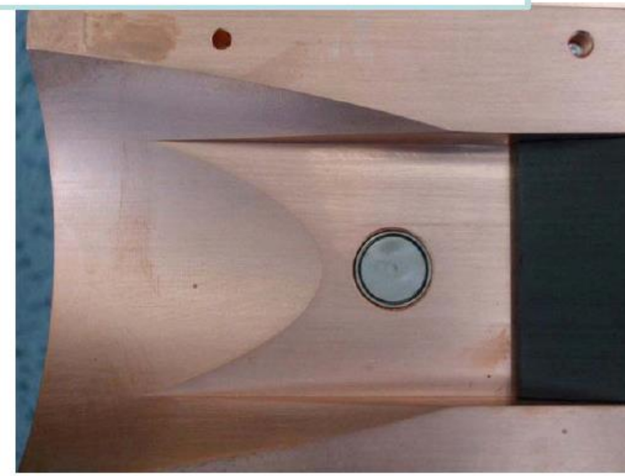


Installation of 1st Phase II Collimator

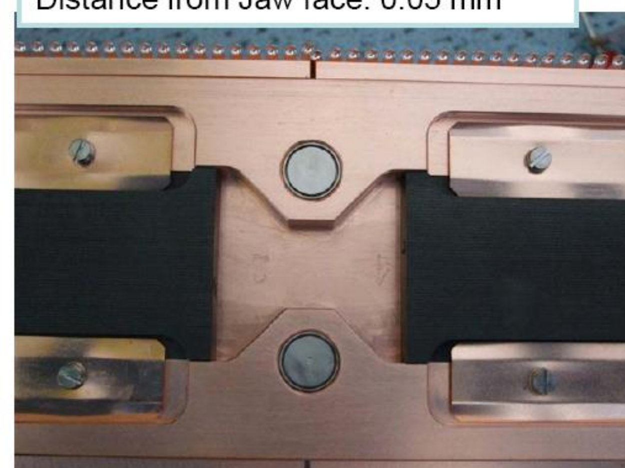
(CERN type, BPM's in jaws, into SPS for beam tests)

January 8, 2010

Button 1 at upstream port on D side
Distance from Jaw face: 10 mm

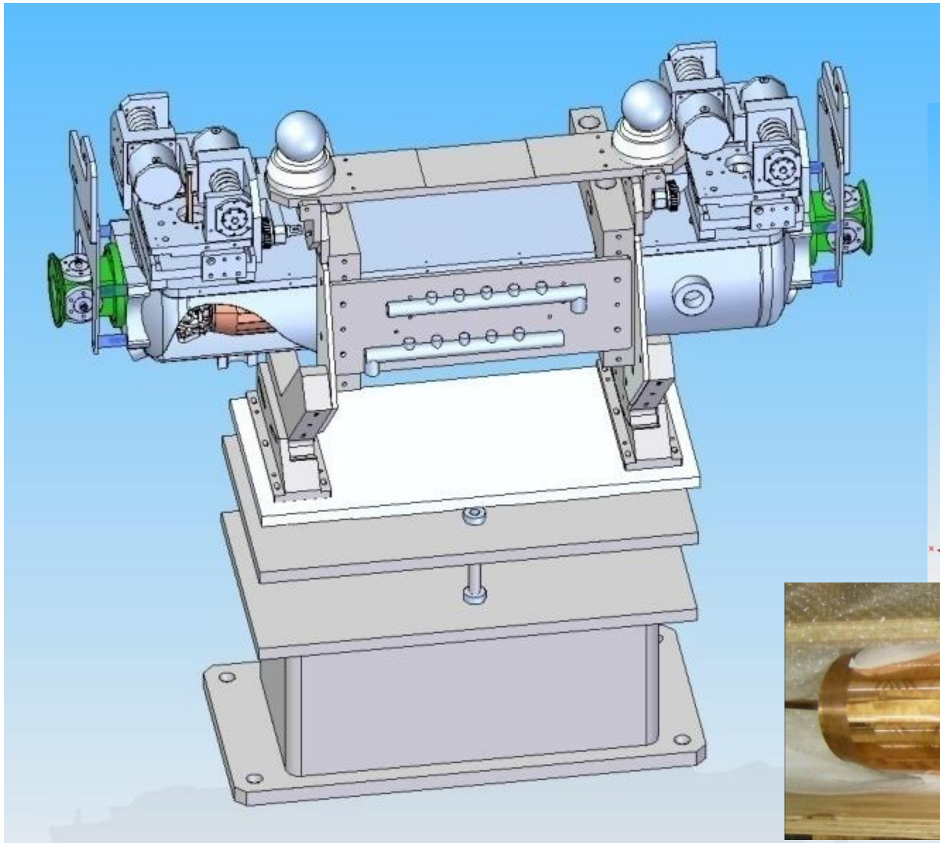


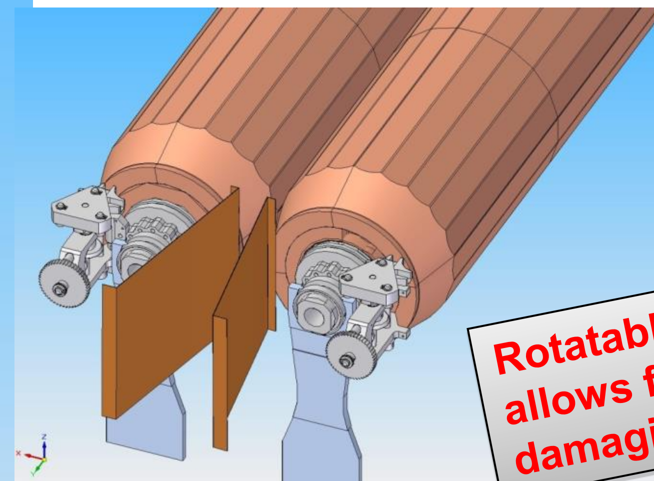
Button 10 at center of jaw on DB side
Distance from Jaw face: 0.05 mm



US Work on Phase II Design

(LARP funded, SLAC linear collider design to LHC)





Rotatable high Z jaw allows for multiple damaging beam hits!

First prototype to be delivered from SLAC to CERN in August 2010. Installation into SPS in 2010/11 shutdown. Beam tests in 2011.

Time to build 5 collimators: 1 year. If decision in 2012 then available in 2013…

Should We Not Wait?

We always proposed to wait for first beam experience, to verify the many complicated choices and decisions we took. Therefore phase 2 project at moment only R&D project.

We could have been overlooking something and this could change the requirements for phase 2!

Now we have beam experience!

Lessons from Collimator Operation for Phase 2 Collimation

- Collimators were designed to be highly reliable for avoiding accesses in highly radioactive areas. High priority in collimation project.
- Experience: Not a single tunnel access required during 2009 beam run. Only one access to electronics gallery. Very reliable performance…
- Verified excellent reproducibility of collimator settings (< 30 μm).
- Hardware mechanical design, motorization, electronic and controls choices fully confirmed: due to excellent work in EN/MME, EN/STI, BE/OP, BE/CO, …
- No need for actions on the phase 1 collimator design. Can focus on phase 2 collimators.
- Collimation efficiency was measured with 2009 beam: ➔

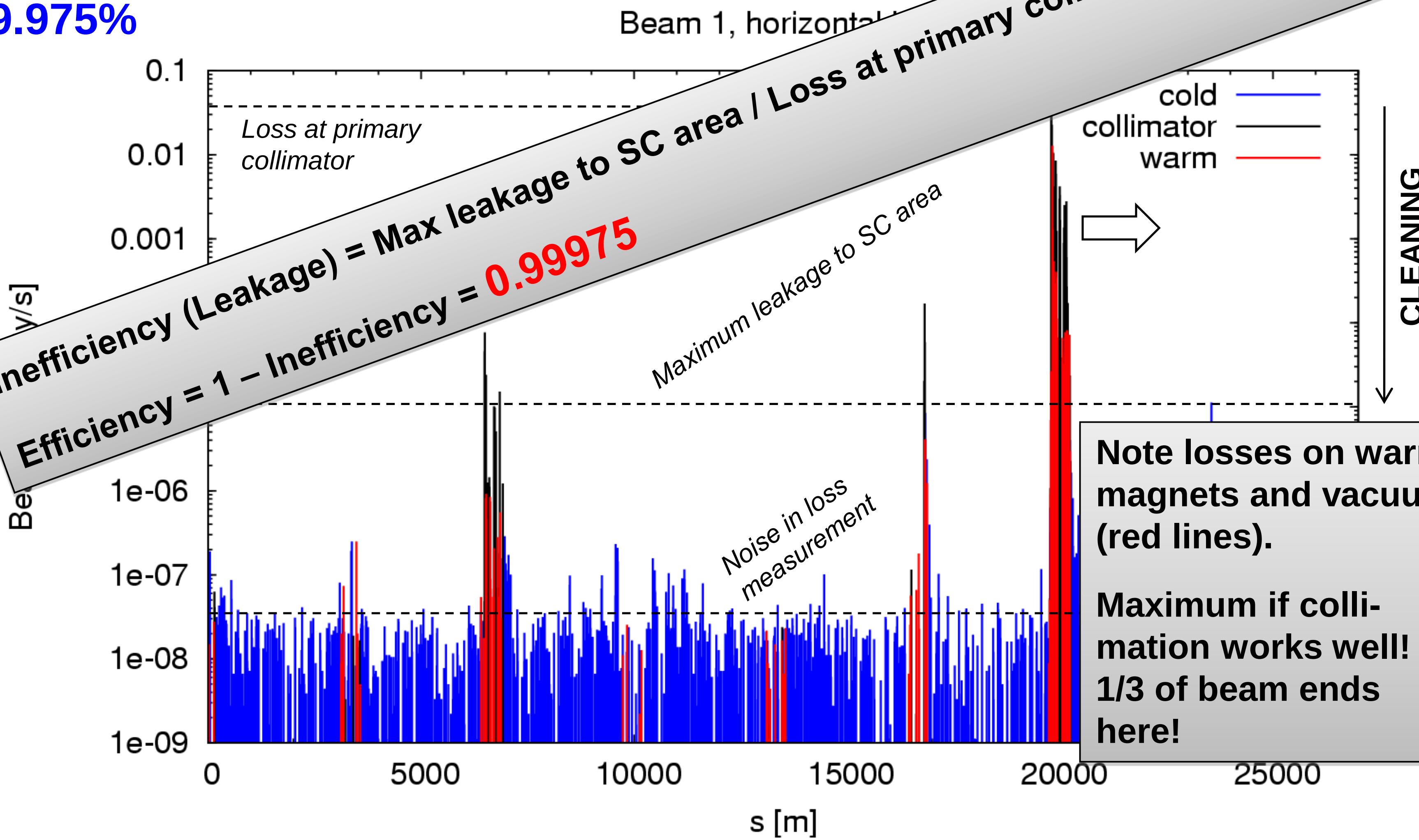
Phase 1 Cleaning Measurement

Beam 1 – Horizontal (Q_x crossing of 1/3 resonance)

99.975%

Inefficiency (Leakage) = Max leakage to SC area / Loss at primary collimator = 2.5e-4

Efficiency = 1 – Inefficiency = 0.99975



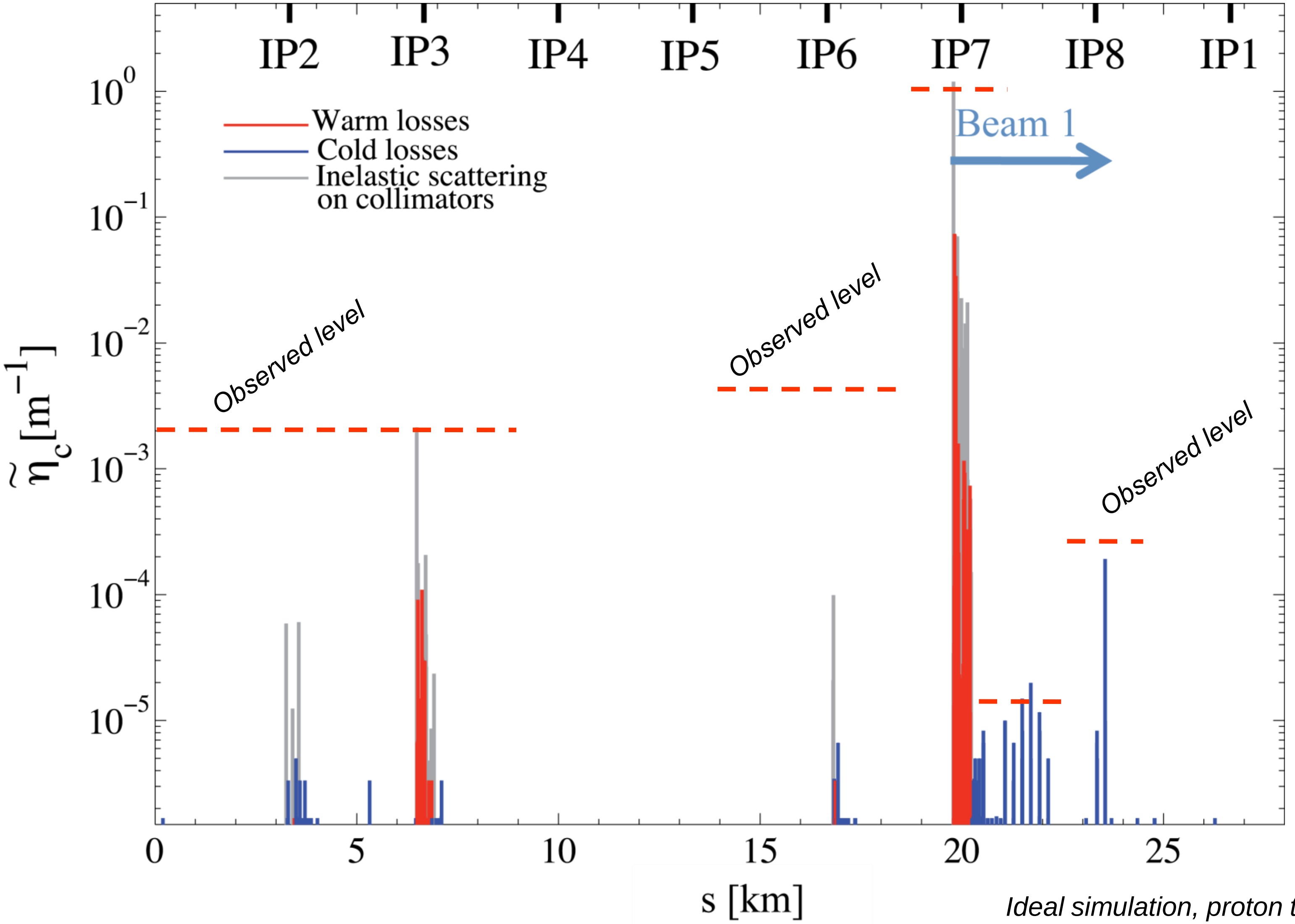
Note losses on warm magnets and vacuum (red lines).

Maximum if collimation works well! ~ 1/3 of beam ends here!

Measured 6 days after beam-based setup of collimators – no retuning…

Simulation

(PhD C. Bracco 2008, p. 74)

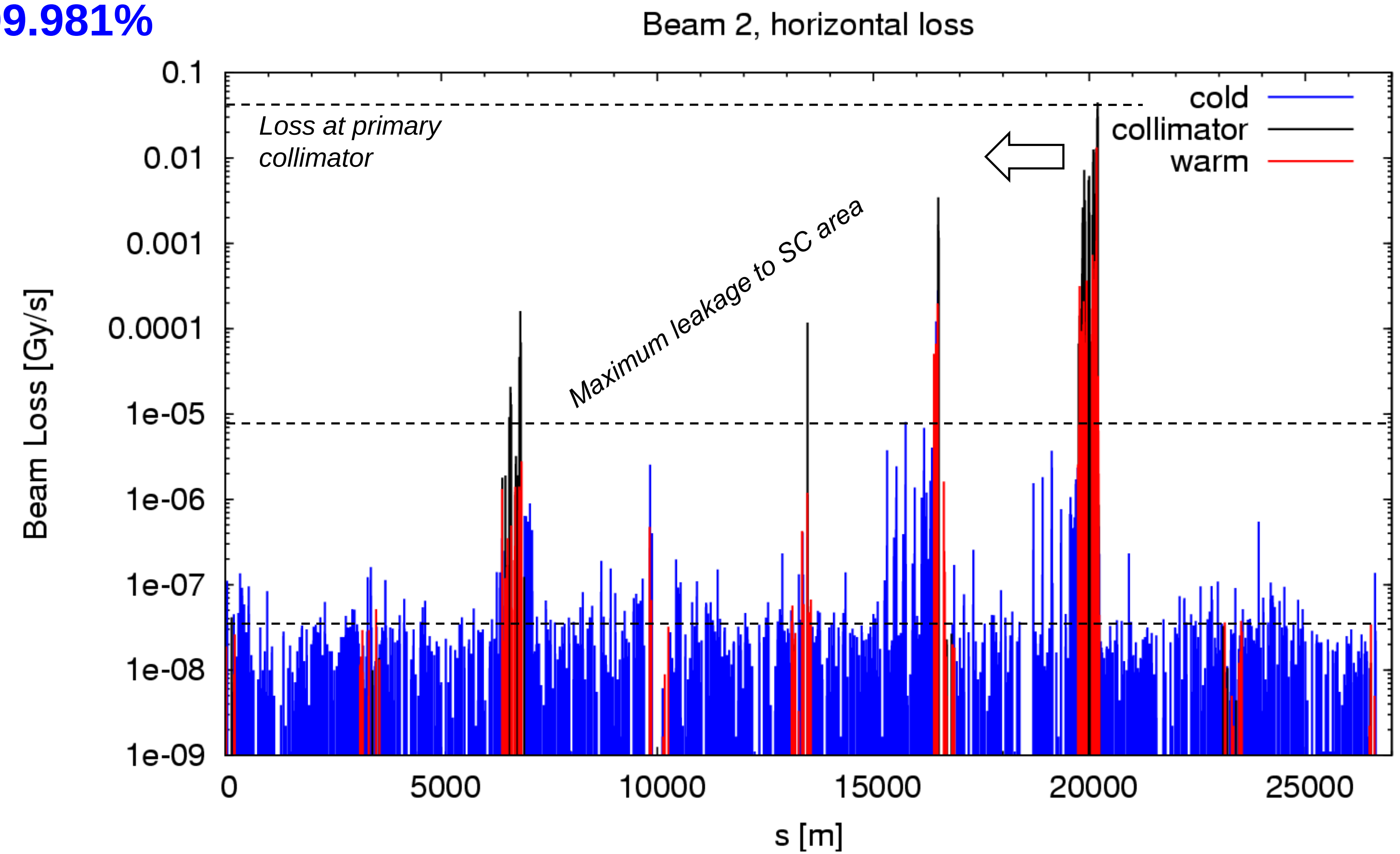


Ideal simulation, proton tracking, no showers

Phase 1 Cleaning Measurement

Beam 2 – Horizontal (Q_x crossing of 1/3 resonance)

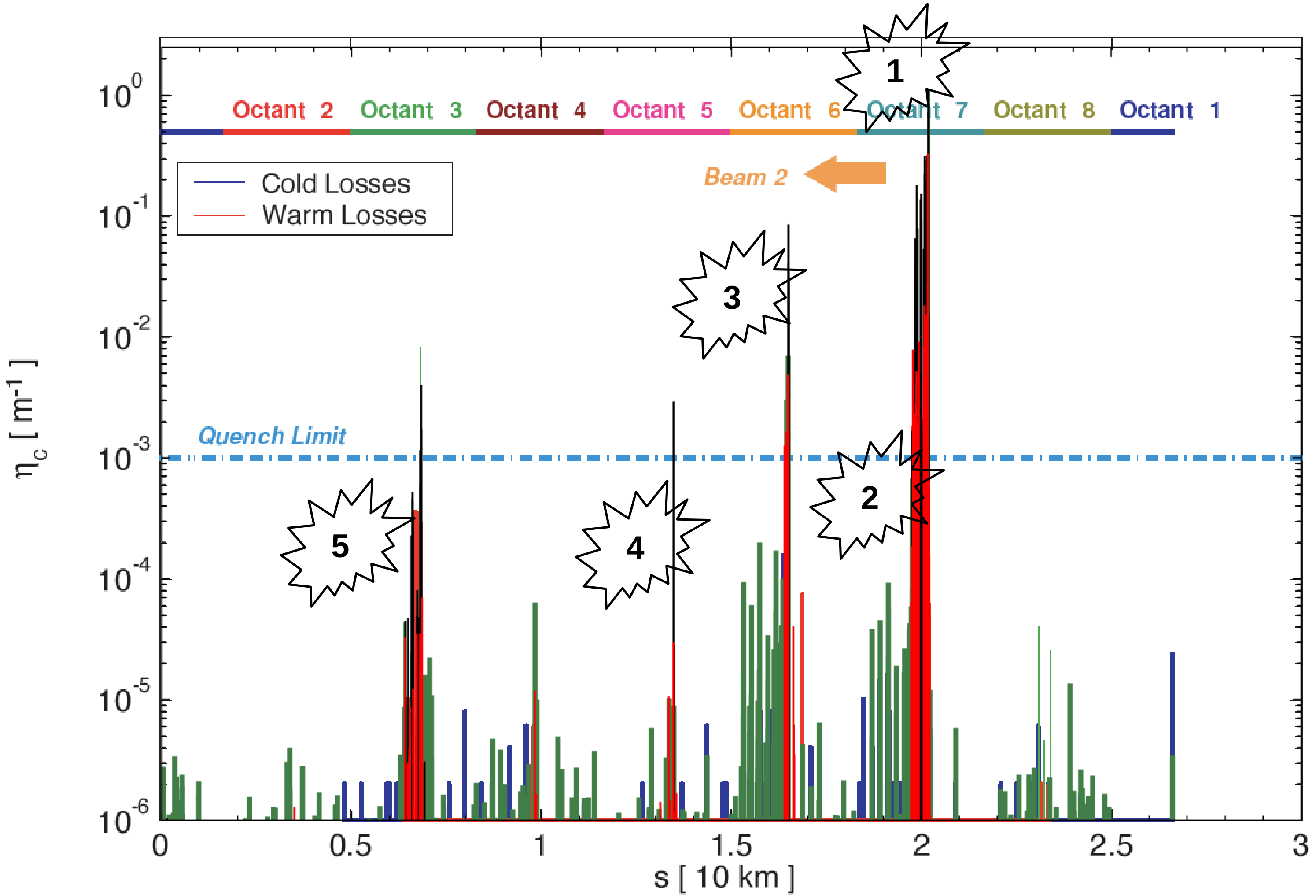
99.981%



Measured 6 days after beam-based setup of collimators – no retuning…

Simulation vs Measurement

(Data 2009 - PhD G. Robert-Demolaize 2006, p. 114)



Notes:

(1) As expected, additional losses from showers behind primary collimators.

(2) 3x higher than simulated losses in LSS7L SC magnets.

(3) 50x higher than simulated TCDQ losses ➔ setup.

(4) Additional loss on TCT in IR5: simulations at 450 GeV had TCT out.

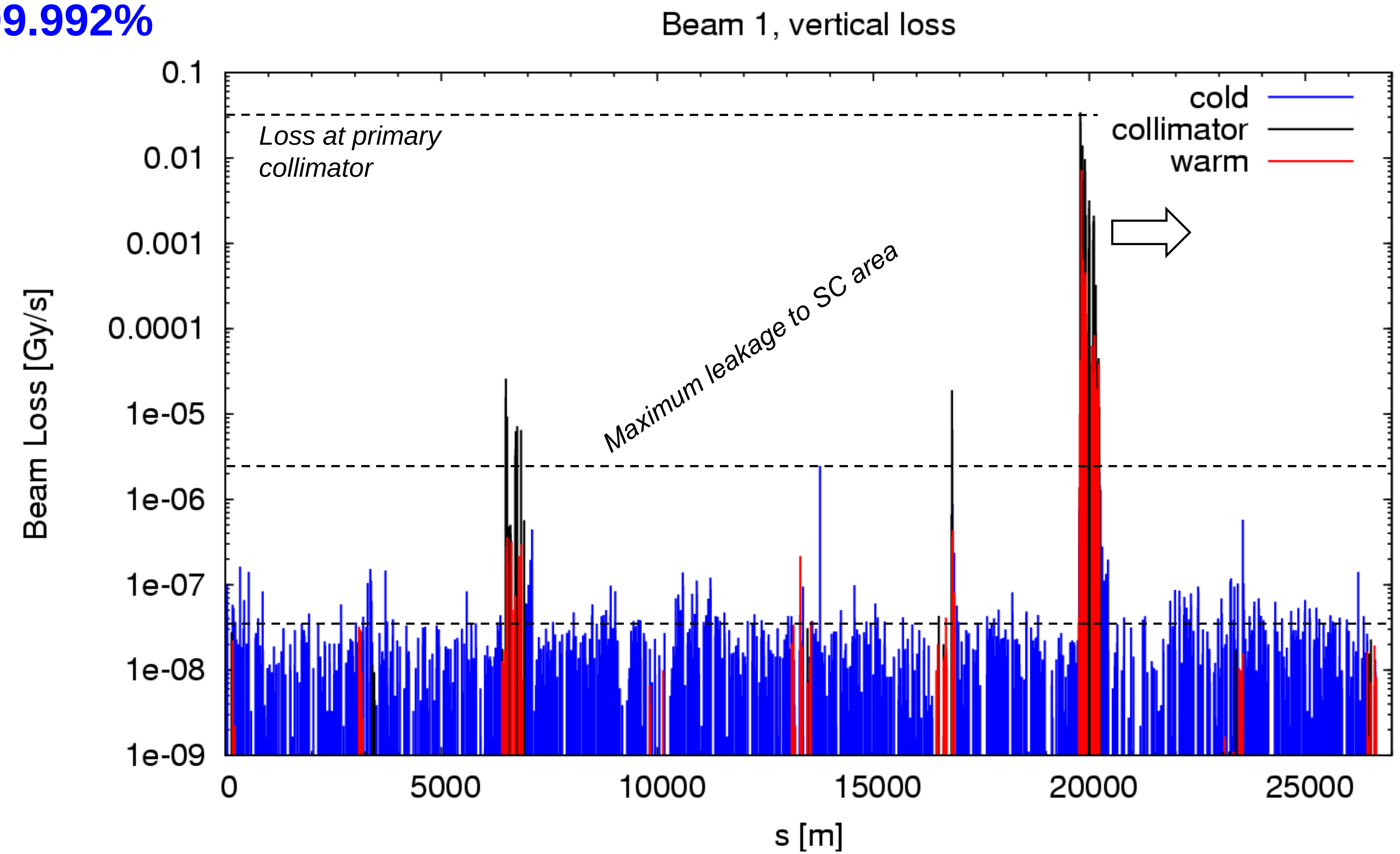
(5) As expected losses in IR3 ➔ correct simulation of energy loss in IR7 collimators.

Simulation with worst case design orbit error, proton tracking, no showers

Phase 1 Cleaning Measurement

Beam 1 – Vertical (Q_y crossing of 1/3 resonance)

99.992%

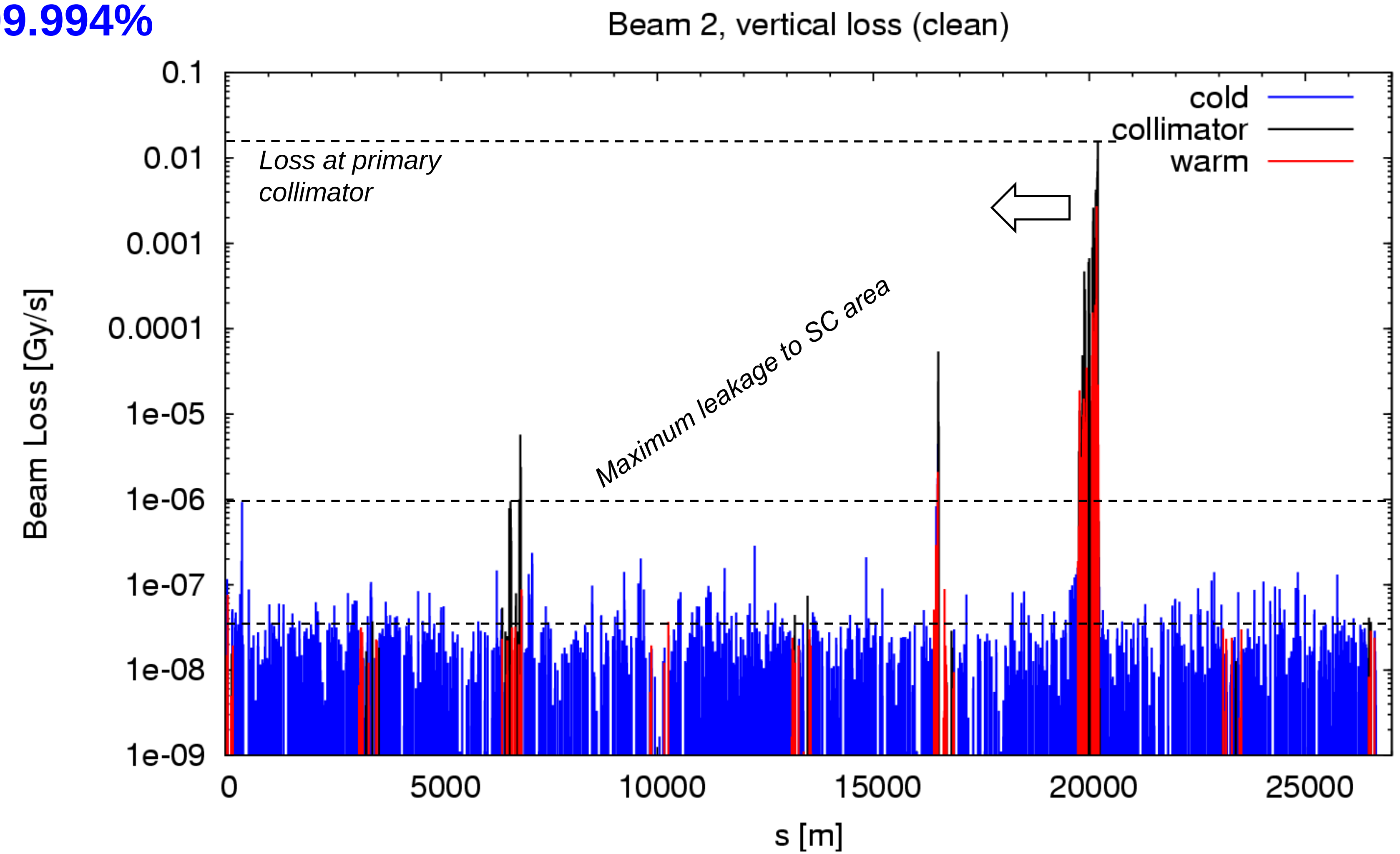


Measured 6 days after beam-based setup of collimators – no retuning…

Phase 1 Cleaning Measurement

Beam 2 – Vertical (Q_y crossing of 1/3 resonance)

99.994%

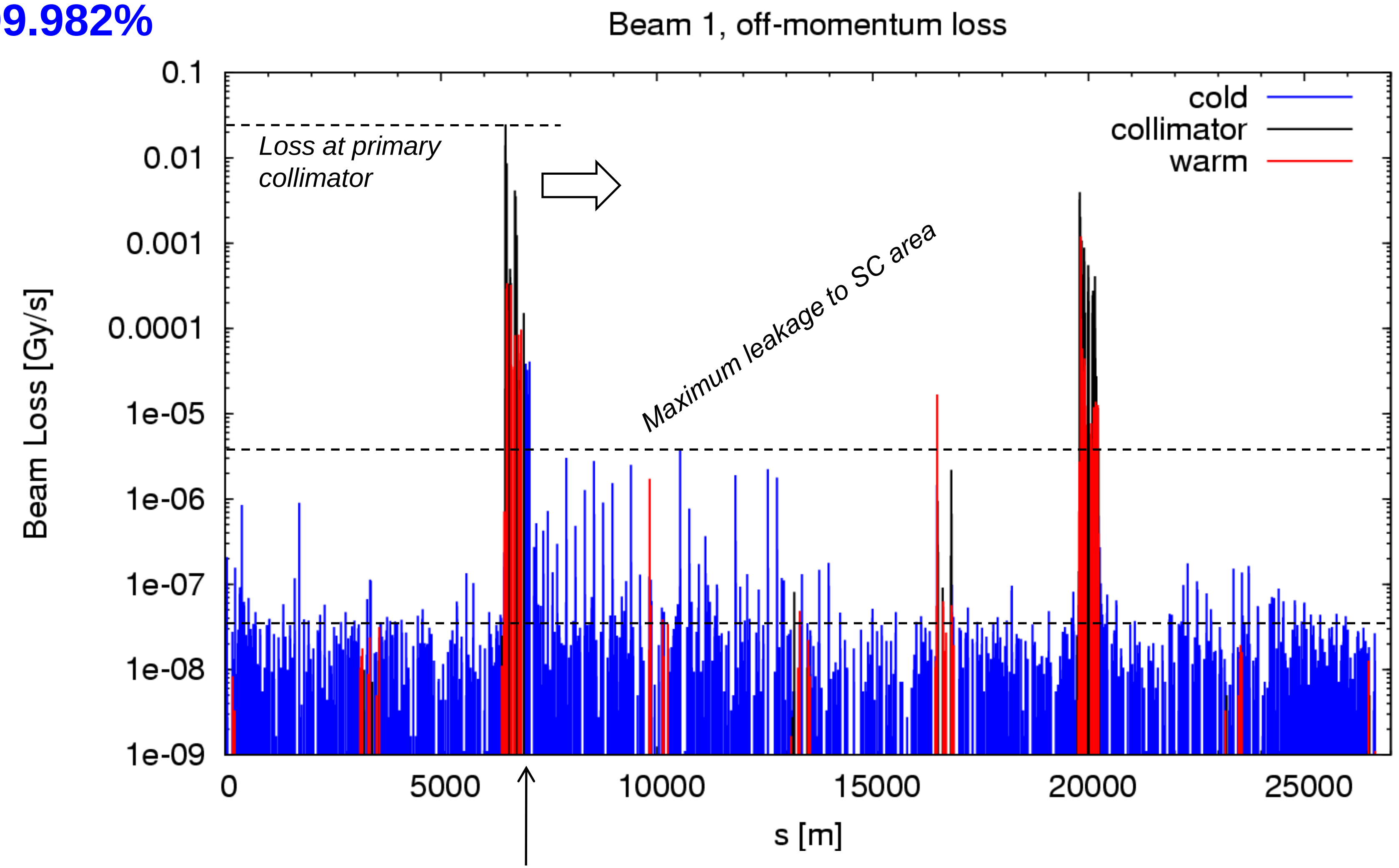


Measured 6 days after beam-based setup of collimators – no retuning…

Phase 1 Cleaning Measurement

Beam 1 – Off-Momentum (RF frequency change)

99.982%

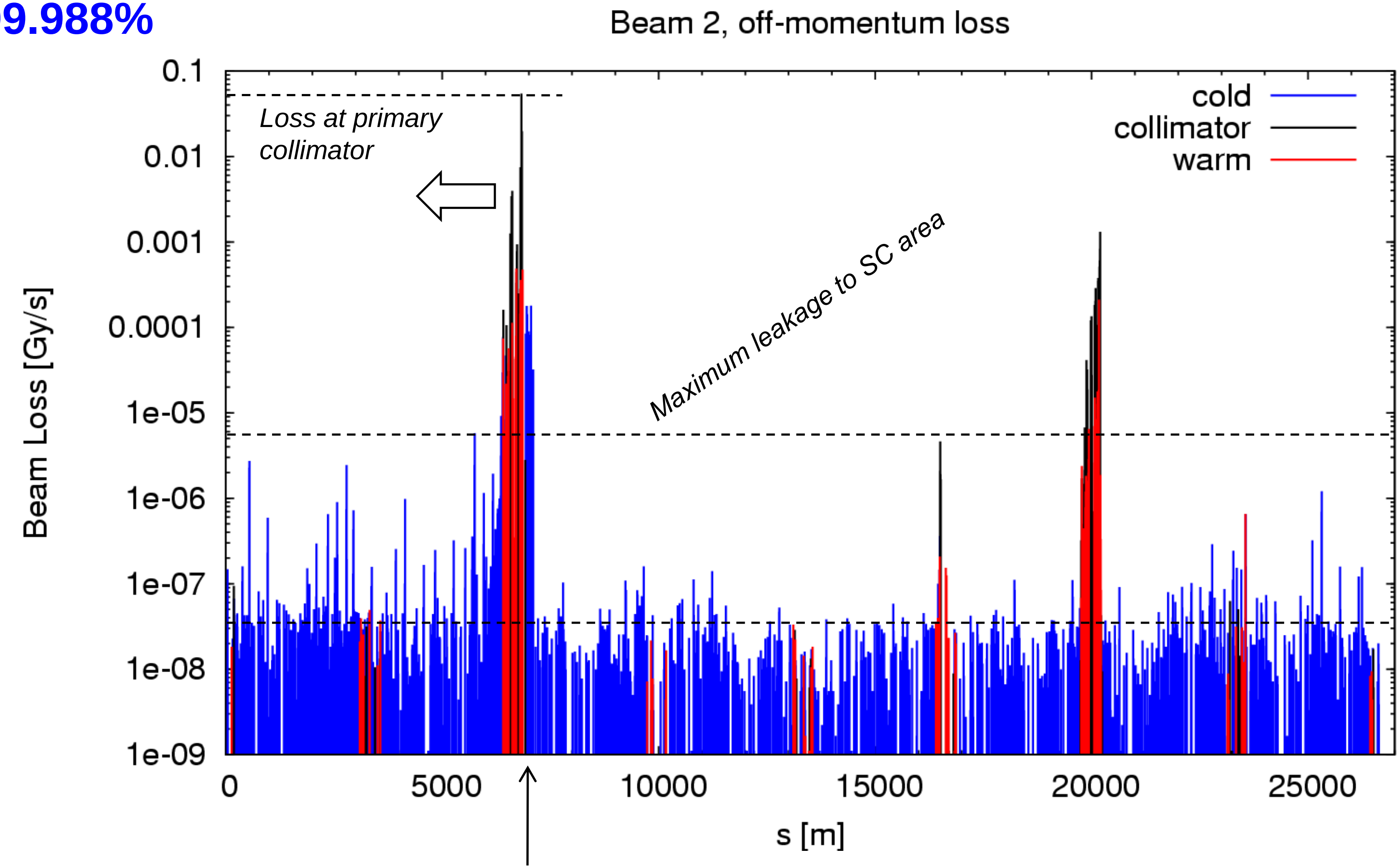


Note: We ignore Q11 losses at LSS3R: non physical signature and high BLM noise.

Phase 1 Cleaning Measurement

Beam 2 – Off-Momentum (RF frequency change)

99.988%



Note: We ignore Q11 losses at LSS3R: non physical signature and high BLM noise.

2009 Lesson for Phase 2 Collimation

- Measurements verify collimation design choices and proper system functioning (based on theoretical work in BE/ABP and EN/STI).
- Quantitative lessons can be drawn:
  - Efficiency at 450 GeV of about 99.98% for x betatron and momentum cleaning. Efficiency of about 99.993% for y betatron cleaning.
  - See expected 0.1% to 0.4% leakage from betatron to momentum cleaning: Collimators produce off-momentum halo. Reason for better vertical efficiency and proposed collimators in dispersion suppressors.
  - **See 1e-5 to 2e-4 leakage** (x and momentum halo) into SC areas downstream of cleaning insertions, depending on imperfections. Intensity reach estimates **assumed 1.2e-4 at 450 GeV**. Performance limitation for LHC at 7 TeV!
- Fully consistent (be aware of limits: no correction BLM response, shower contributions, longitudinal loss length, only 450 GeV).
- Proves predictive power of our simulations (CPU cluster and Grid)!

Optimal Strategy

Rely on 2009 measurements with LHC beam as sufficient to include collimator production as baseline activity (MTP, ATS management).

Waiting would delay readiness for improved collimation, while it is very unlikely that 2010 halo behaves different from 2009 halo.

Optimal to ensure in-time readiness for possible collimator needs:

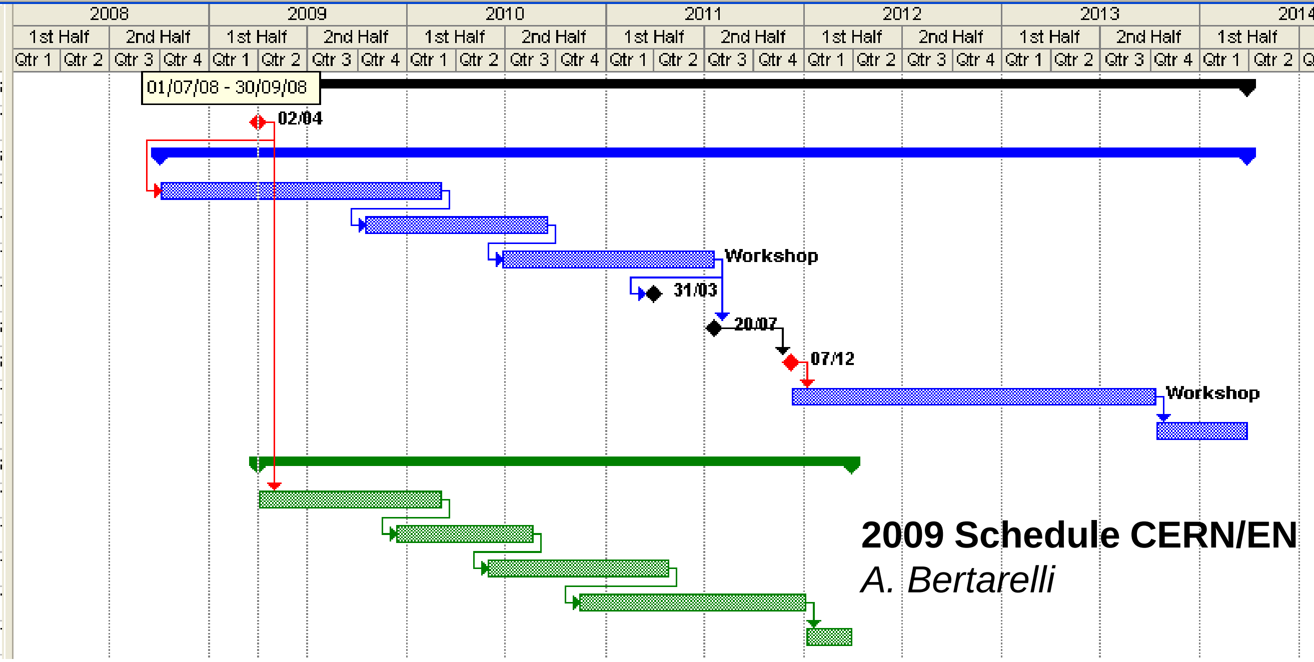
(1)Include phase 2 collimator construction into MTP and approve as baseline activity in 2010.

(2)Provide production resources from 2011, allowing proper preparation.

(3)Stop/rethink in Summer 2011 if there is a surprise. Otherwise start production and prepare hardware (better early than late).

(4)Install as needed and fitting with general LHC schedule…

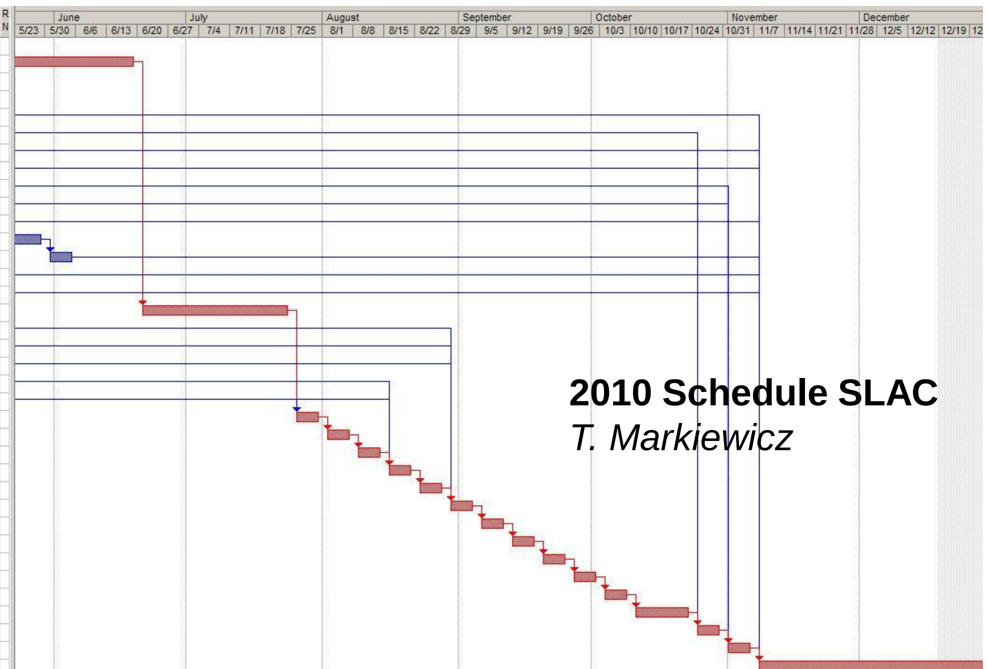
Task Name	Duration
Phasell Collimation	**1420 days?**
Conceptual Review	0 days
Phasell Collimators	**1420 days?**
Phasell - Engineering, & Pre-study	18 mons?
Phase II - Design, Drafting & Material	12 mons?
Phasell - Prototyping & Testing	14 mons
Phase II - Materials demostrators for H	0 days
Phase II - Prototype(s) Ready for HiRa	0 days
Phase II collimators - Construction	0 days
Phasell - Production& Quality control	24 mons
Phasell - Installation	6 mons
Cryogenic Collimators	**780 days?**
Tcryo - Engineering & Pre-study	12 mons
Tcryo - Design & Drafting	9 mons
Tcryo - Prototyping & Testing	12 mons?
Tcryo - Production	15 mons
Tcryo - Installation	3 mons



2009 Schedule CERN/EN

A. Bertarelli

	Task Name	Duration	Start	Finish	Predecessors
1	Order OFE Copper for all 10 Mandrels	3 wks	Mon 3/1/10	Fri 3/19/10	
2	Order Glidcop for all 50 Jaw cylinders and 10 Hubs (incl extra ID material)	16 wks	Mon 3/1/10	Fri 6/18/10	
3	Order Cu-Ni Tubing	10 wks	Mon 3/1/10	Fri 5/7/10	
4	Order 20 Bellows	11 wks	Mon 3/1/10	Fri 5/14/10	
5	Order hardware and bearings	6 wks	Mon 3/1/10	Fri 4/9/10	
6	Fab tooling for welding and supporting Jaws during Assembly and shipment	5 wks	Mon 3/1/10	Fri 4/2/10	
7	Fab 20 RF Foils	3 wks	Mon 3/1/10	Fri 3/19/10	
8	Fab 10 BPM Housing Assy	5 wks	Mon 3/1/10	Fri 4/2/10	
9	Fab 20 Sets of Support Bearing Parts	5 wks	Mon 3/1/10	Fri 4/2/10	
10	Fab 20 RF Bearing Part Sets	5 wks	Mon 3/1/10	Fri 4/2/10	
11	Fab 5 Tank (duration is for 1)	3 wks	Mon 3/1/10	Fri 3/19/10	
12	Fab 5 Base Plate (duration is for 1)	2 wks	Mon 5/17/10	Fri 5/28/10	4
13	Weld 5 Base Plate and 20 Bellows (duration for 1 set)	1 wk	Mon 5/31/10	Fri 6/4/10	12
14	Fab 10 Sets of Rotator mechanism parts	10 wks	Mon 3/1/10	Fri 5/7/10	
15	Fab 20 Flex Supports	10 wks	Mon 3/1/10	Fri 5/7/10	
16	Fab 50 Jaw and 10 Hub Cores (duration is for 1 set of 5 Jaws and 1 Hub)	5 wks	Mon 6/21/10	Fri 7/23/10	2
17	Fab 20 Moly Half Shafts	8 wks	Mon 3/1/10	Fri 4/23/10	
18	Fab 10 Moly Gear	8 wks	Mon 3/1/10	Fri 4/23/10	
19	Fab 10 Moly Axle	8 wks	Mon 3/1/10	Fri 4/23/10	
20	Fab 20 Retainer Ring Sets for Shaft Braze Assy (duration is for 1 set)	1 wk	Mon 3/1/10	Fri 3/5/10	
21	Fab 10 Mandrel (duration is for 1)	1 wk	Mon 3/22/10	Fri 3/26/10	1
22	Fab 10 Glidcop Hub Preliminary Machining (duration is for 1)	1 wk	Mon 7/26/10	Fri 7/30/10	16,21
23	Plate 10 Hub OD surfaces (duration is for 1)	1 wk	Mon 8/2/10	Fri 8/6/10	22
24	Final Machine Hub OD surfaces to match Mandrel ID (duration is for 1)	1 wk	Mon 8/9/10	Fri 8/13/10	23
25	Braze 20 Half Shafts to 10 Hubs (duration is for 1)	1 wk	Mon 8/16/10	Fri 8/20/10	24,21,20
26	Wind 10 Mandrels with Tubing (duration is for 1)	1 wk	Mon 8/23/10	Fri 8/27/10	25
27	Braze 10 Shaft/Hub to Mandrel with Tubing, Axle and Gear (duration is for 1)	1 wk	Mon 8/30/10	Fri 9/3/10	26,17,18,19
28	Fab 10 Mandrel Final Machining (duration for 1)	1 wk	Mon 9/6/10	Fri 9/10/10	27
29	Fab 50 Jaw Preliminary Machining (duration is for sets of 5)	1 wk	Mon 9/13/10	Fri 9/17/10	28
30	Plate 50 Jaw Cylinders ID surfaces (duration is for sets of 5)	1 wk	Mon 9/20/10	Fri 9/24/10	29
31	Groove 50 Jaw Cylinder I.D. (duration is for sets of 5)	1 wk	Mon 9/27/10	Fri 10/1/10	30
32	Braze Jaws on 10 Collimator Jaw Mandrels (duration is for 1 mandrel)	1 wk	Mon 10/4/10	Fri 10/8/10	31
33	Fab Collimator Jaw Finish Machine 10 Collimator Jaws (duration is for 1)	2 wks	Mon 10/11/10	Fri 10/22/10	32
34	QA Finished Machining (duration is for 1)	1 wk	Mon 10/25/10	Fri 10/29/10	33,6
35	Fit Bearings for RF and Support Assemblies for each Jaw	1 wk	Mon 11/1/10	Fri 11/5/10	34,9,10
36	Assemble 5 each CollimatorAssemblies ,Weld, Bake-out and scan (duration is 3 weeks each 1)	15 wks	Mon 11/8/10	Fri 3/4/11	5,7,8,35,14,15,13,11



2010 Schedule SLAC

T. Markiewicz

Collimation Phase 2 Milestones

Year	**Milestone**
2009	*Conceptual design review April 2009. Solution supported.*
2010	Review of lessons with LHC beam. Completion of first phase 2 prototypes. First phase 2 beam tests. Estimates for MTP'10. Approval of construction as baseline.
2011	SPS and HiRadMat beam tests. Summer: Start phase 2 production (~2.5 years): industry, CERN, SLAC.
2012+x (x ≥ 0)	Modifications of dispersion suppressors (ideally when sector is already warm): 2 months (?) per IR* (➔ J.P. Tock, TE)
2012+x+1	Cryogenic collimation operational ➔ nominal intensity. Hollow e-beam lens for LHC scraping *(good FNAL progress)*…
2014/15	Phase II completed ➔ Ready for nominal & ultimate intensities (consistent with IT project goals).

*2 months per side of IR but some parallelism can be envisaged provided resources are available. Note: Perhaps better to have this NOT simultaneous to installation of new inner triplets because same expertise/competences/tooling/resources would be needed. For the same reason + extra complexity of P2 (see above), better perhaps to have P2 cryo collimators installed later. If I understand correctly, they could be less urgent/lower priority.

Conclusion

- Total: 64 locations modified, 52 collimators + 10 spares to be constructed, 22 new infrastructures, 8 infrastructures to be moved. Requests from various areas included (machine + experiments).
- Compare cost to investment for phase 1 & phase 2 infrastructure (CERN), phase 2 R&D (CERN, SLAC, EU): phase 2 construction is 1/3 addition.
- Some details (work, manpower, budget) to be clarified. E.g. IR1/5 TCT's part of IT project. Proposal by R. Ostojic to change this? Remote handling?
- In addition require longitudinal movement of 20 SC magnets by 3 m and lateral movement of 28 SC magnets by 3 cm. TE study ongoing for MTP.
- Performance gains are high (factor > 10) and certainly useful.
- Early start of interventions will minimize radiation to personnel.
- System will partially pay for itself due to increased lifetime of magnets and phase 1 collimators. *Otherwise: Advise to start soon rebuilding warm magnets for IR3 and IR7! With phase 1 we brought lifetime from 6 months to 5 years.*

7 September 2009

Collimation Phase 2 Project CERN

Project Leader (R. Assmann)

Project Engineer for tunnel & beamline activities (O. Aberle)

Project Engineer for coll. design, lab. tests, prototyping (A. Bertarelli)

LARP/SLAC Phase 2 Collimator Work
T. Markiewicz, SLAC

EuCARD collaboration for collimators & materials (FP7)
R. Assmann (CERN), J. Stadlmann (GSI)

Tunnel and beamline activities (below surface)

- **Install., mainte-nance, beam test support** — *O. Aberle (EN/STI)*
- **Controls, Operation** — *S. Redaelli (BE/OP)*
- **Remote tools** — *K. Kershaw (EN/HE)*
- **Changes to SC installa-tions** — *J.P. Tock (TE/MSC) .*

Coll. design, prototyping and production (above surface)

- **Mechanical engineering, lab tests, prototyping, production** — *A. Bertarelli (EN/MME)*
- **Final assembly on surface** — *O. Aberle (EN/STI)*
- **Electronics, sensors, actuation** — *A. Masi (EN/STI)*
- **Vacuum issues** — *M. Jimenez & V. Baglin (TE/VSC) .*

Performance studies, simulations and beam tests

- **Beam instru-mentation** — *B. Dehning (BE/BI)*
- **Energy deposition** — *A. Ferrari (EN/STI)*
- **Radiation aspects** — *S. Roesler (DG/SCR)*
- **Machine protection & beam tests** — *R. Schmidt (TE/MTE)*
- **Ion loss issues** — *J. Jowett (BE/ABP)*
- **Simula-tions, beam tests** — *R. Assmann (BE/ABP)*

participate in collaboration

Crystal Collimation Tests at SPS & Tevatron
UA9: W. Scandale
T980: N. Mokhov

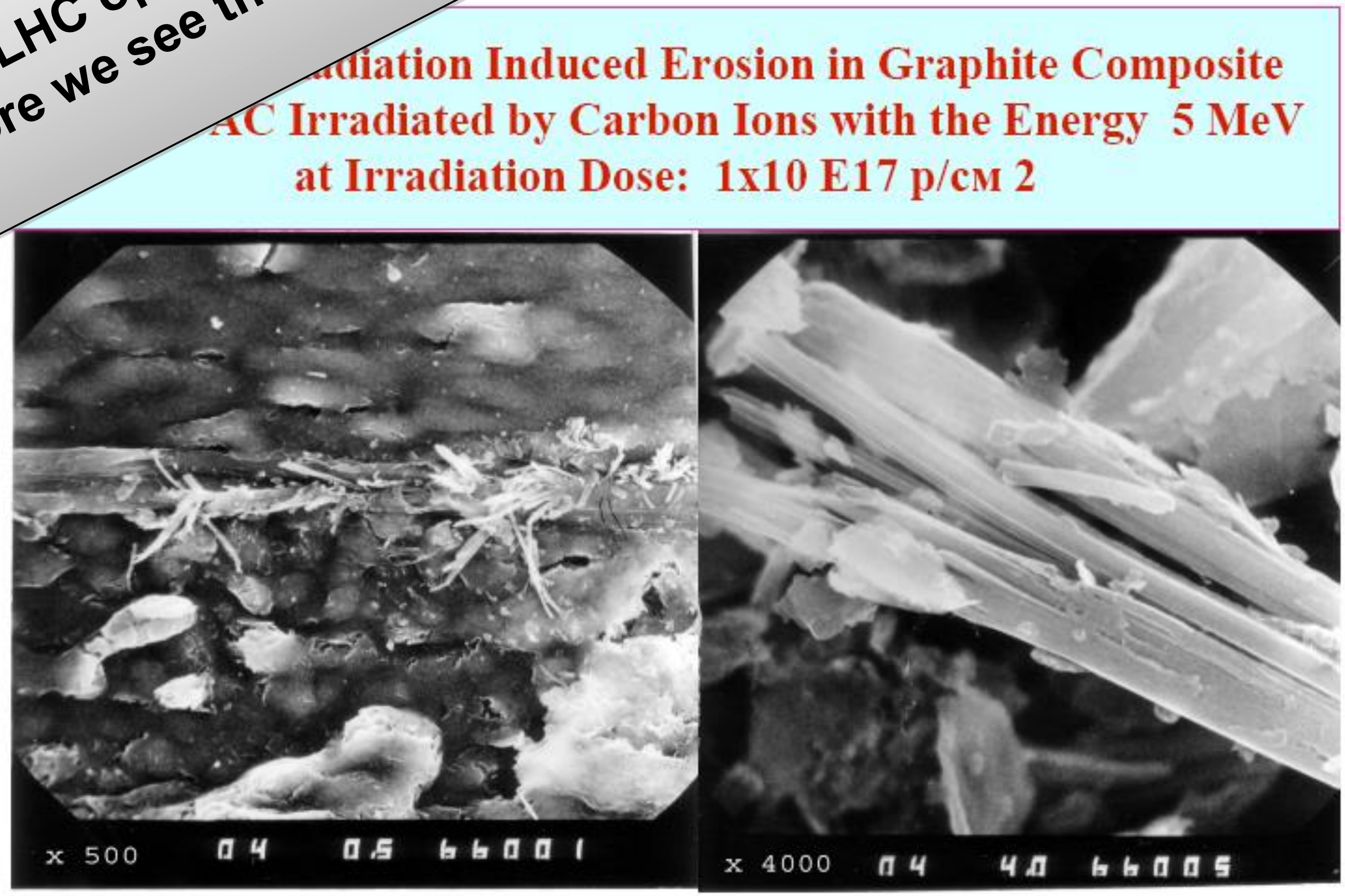
Note: Phase 1 collimation project still active until end of system commissioning. In practice integrated with Phase II!

Reserve Slides

Phase 1 Collimator Jaw after 1e17 p/cm^2

(Beam Test of our Material at Kurchatov, Russia)

We must realize: collimators are consumables of LHC operation! We must react before we see the problems…



Phase 2 Collimation Solution

Fastest Possible Readiness for Nominal Intensity

LHC Collimation Project CERN

- **Modified dispersion suppressors** in IR3/7. Design & build new cryostat for missing dipole.
- "**Cryo-collimators**" for modified dispersion suppressors to intercept off-momentum particles after end of straight section.

WP's A
No need for major testing, beam experience.

- **Advanced, low impedance materials or high Z** for phase 2 collimators.
- **Install 30 phase II secondary collimators**, with in-jaw pick-ups and various jaw materials.
- ***HiRadMat beam test facility*** *for beam verification of advanced designs, following conceptual design. Approved separate project.*

WP's B
Continue to be ready for 2013/14. Needs major testing and beam experience.

- **Hollow e-beam lens** for LHC scraping. Progress at Tevatron…

WP's C
R&D and beam testing required.

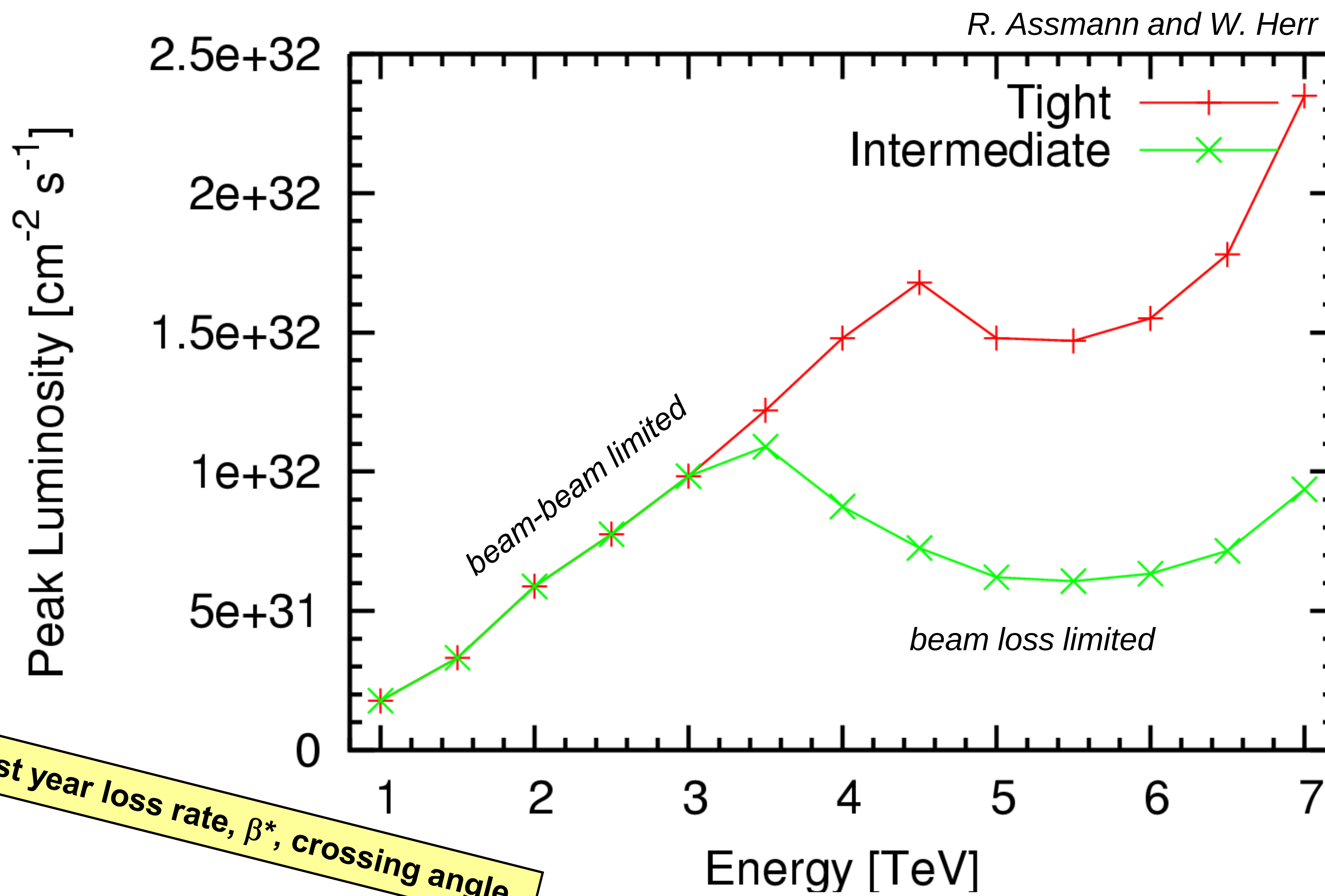
- Minor modifications of **collimation in experimental insertions**.

WP's D

Impact on Phase 2 Work

- Approach: Wait first beam experience before preparing construction!
- Measurements show that the complex 4 stage cleaning in x, y, skew, momentum planes works well and that efficiency limitations are as predicted.
- Shows that the defined collimation improvements (phase 2) address the important issues. No doubt that the proposed solutions will improve collimation performance by factor ≥15!
- I recommend to now prepare construction: will ensure availability of optimum cleaning efficiency and improved hardware lifetime.
- Will we need this efficiency? I think yes! Depends on beam stability and loss rates. 2009 losses were > specification but too early to conclude!
- In best case (excellent efficiency and low loss rates) we will never quench and collimation is no issue! Risk if not proceeding: Reduce intensity to run just below quench limit of magnets, collimation at the limit!

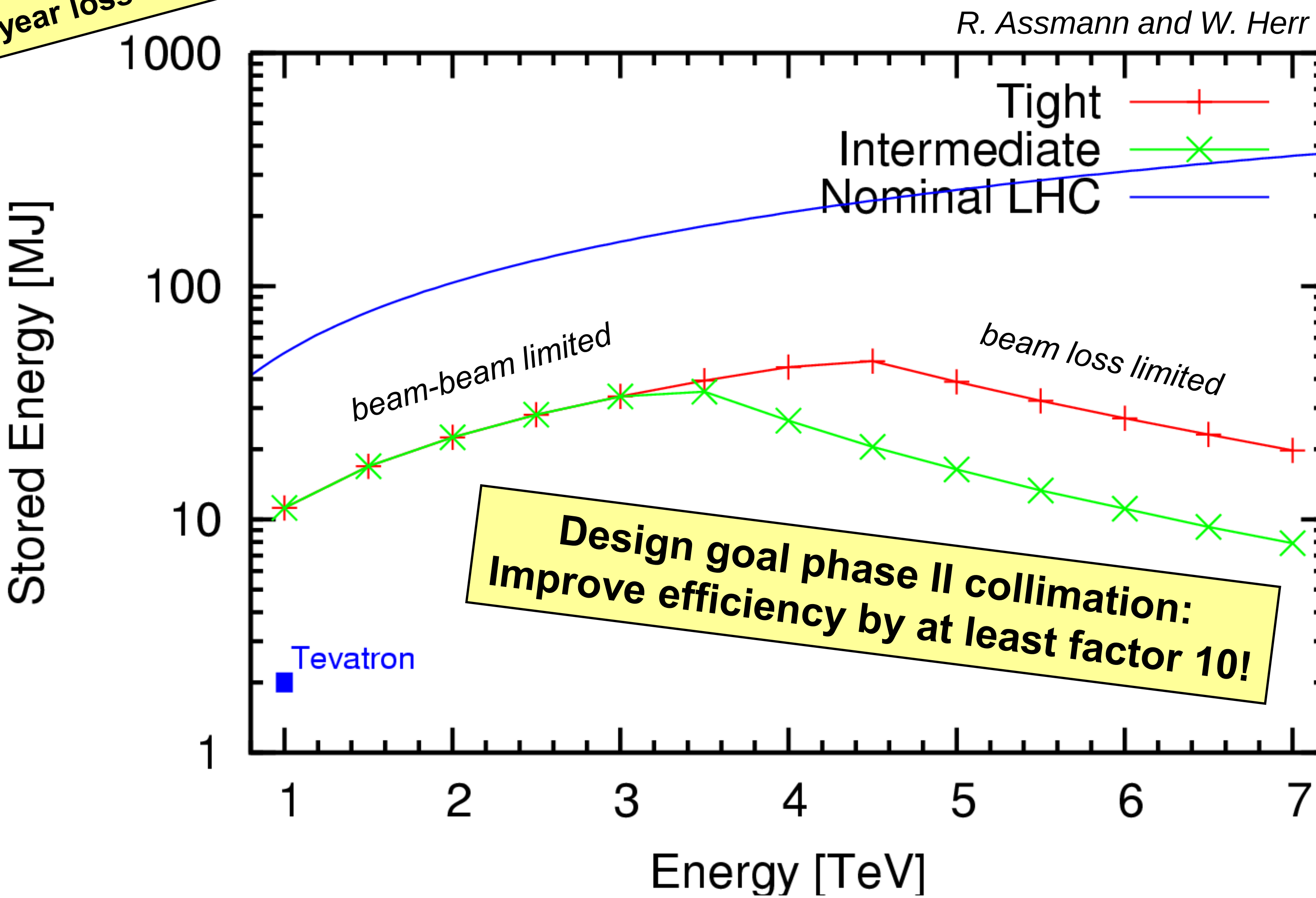
Limit Peak Instantaneous Luminosity



First year loss rate, β*, crossing angle.

Limit Stored Energy vs Beam Energy

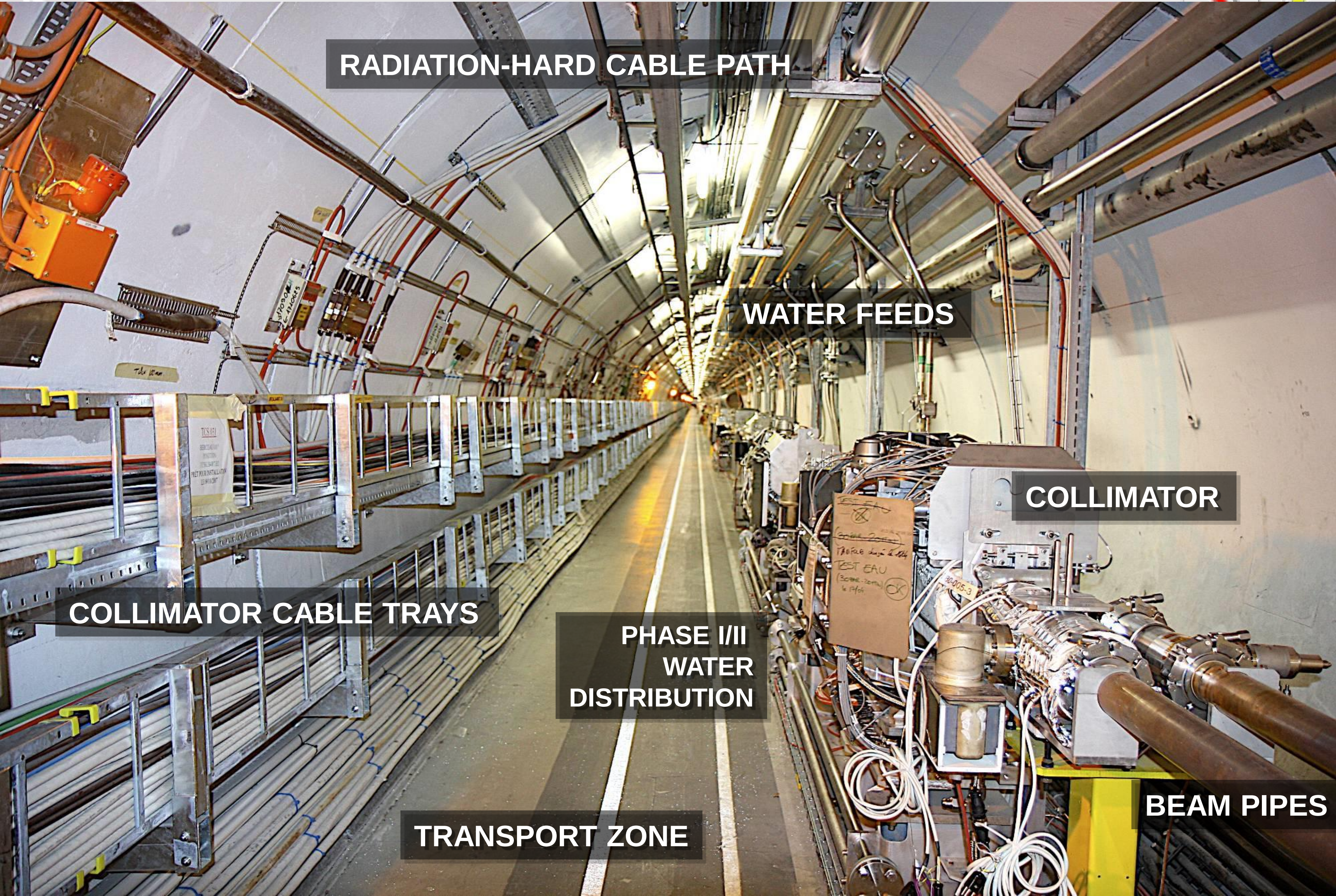
First year loss rate.



Design goal phase II collimation: Improve efficiency by at least factor 10!

Phase I in Tunnel (Radiation-Optimized)

LHC Collimation Project



Specifying Peak Loss of Stored Beam

Mode	Energy [TeV]	Duration [s]	Min. lifetime [h]	Power [kW]
Injection	0.45	cont	1.0	6
		10	0.1	60
Ramp	0.45-7.0	10	0.1-0.2	60-465
	0.45	≈ 1	0.006	1000
Top energy	7.0	cont	1.0	93
		10	0.2	465

Table for nominal intensity.
LHC Design Report.

Peak fractional loss of 0.1 % per second.

LHC design value: 10^{-3} /s

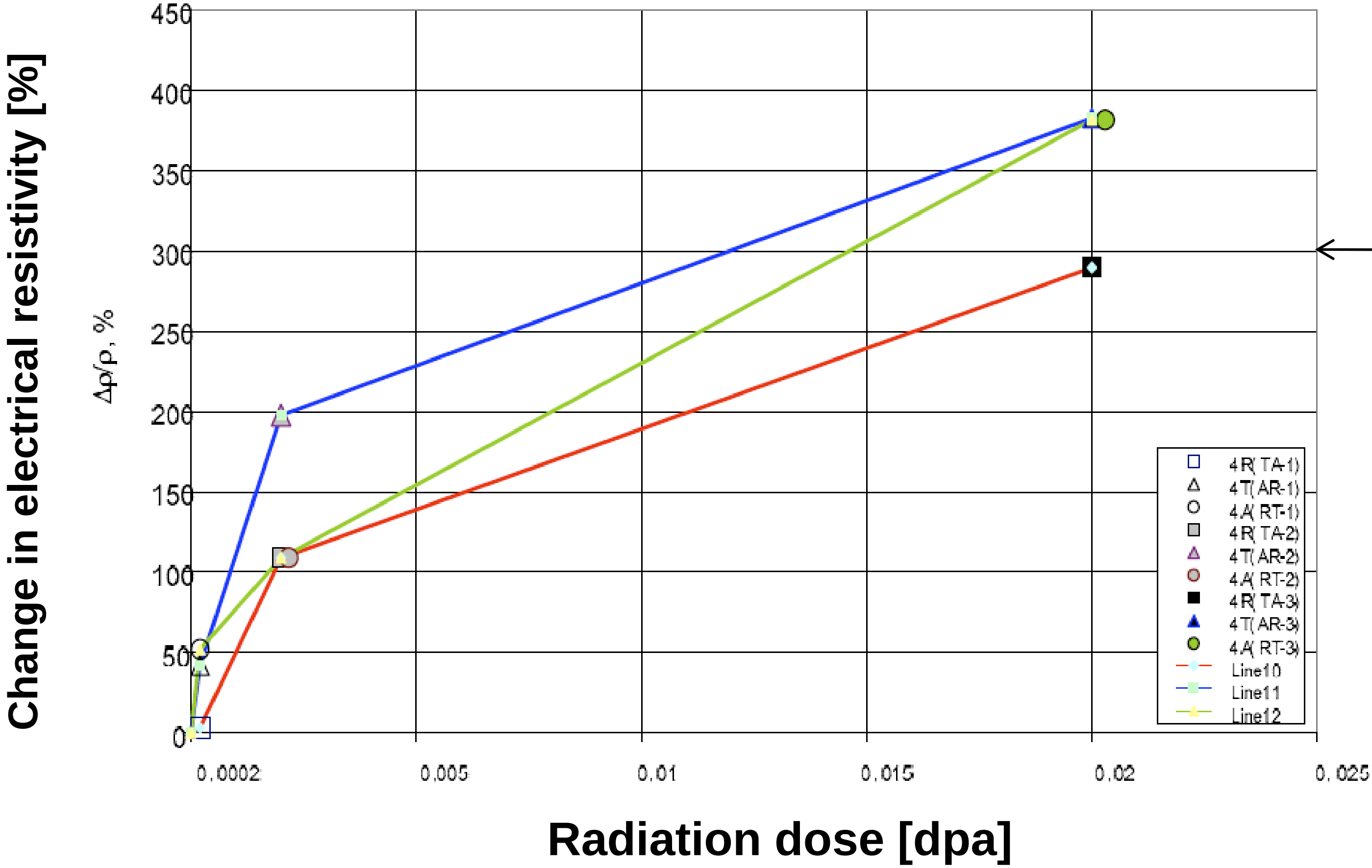
Tevatron 2009: $> 6 \times 10^{-3}$ /s

Reviewed by external review of LHC collimation project in June 2004.

Supported by HERA, RHIC, Tevatron experts.

Radiation Effect on Electrical Resistivity

(measured at Kurchatov Institute in Russia)



Four times electrical resisitivity:

higher impedance!

A. Ryazanov

Collimator properties will change with time ➔ many properties checked.

Beneficial to distribute radiation over phase I and phase II collimators!