HL-LHC Parameter and Layout Committee
September 24th, 2015
CERN, Geneva, CH

Collimation Roadmap: Upgrades, Consolidation and Options

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on behalf of WP5

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Introduction: HL-LHC challenges

- ☑ Increased beam stored energy: 362MJ → 700MJ at 7 TeV

  Collimation cleaning, quench limits, tail population issues.

- ☑ Larger bunch intensity (lb=2.3x10^{11}p) in smaller emittance (2.5 μm)

  Collimation impedance and robustness.

- ☑ Larger p-p luminosity (1.0 x 10^{34}cm^{-2}s^{-1} → 7.5 x 10^{34}cm^{-2}s^{-1})

  New IR layouts and collimation of collision products.

- ☑ Much smaller β^* in the collision points (55 cm → 15 cm)

  Cleaning and protection of new triplets, physics background, new designs.

- ☑ Operational efficiency is a must for HL-LHC!

  High precision and reliability in harsh radiation environments.

- ☑ Upgraded ion performance (6 x 10^{27}cm^{-2}s^{-1}, i.e. 6 x nominal)

HL upgrade addresses most IRs, but some **50-70 collimators** are not necessarily planned for upgrades ⇒

Need strong synergy between HL and CONS project.

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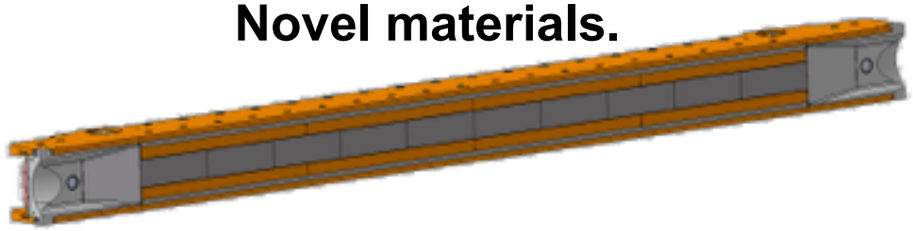
Baseline upgrades

IR1+IR5, per beam:

- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks

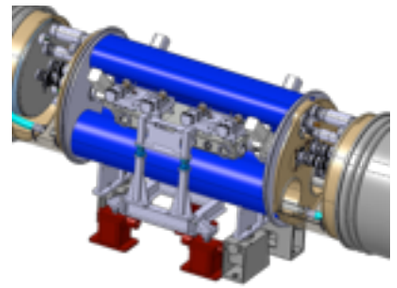
Completely new layouts

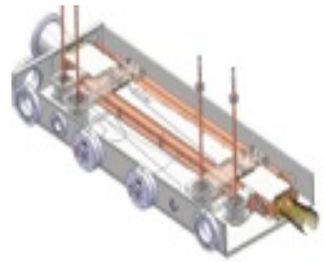
Novel materials.

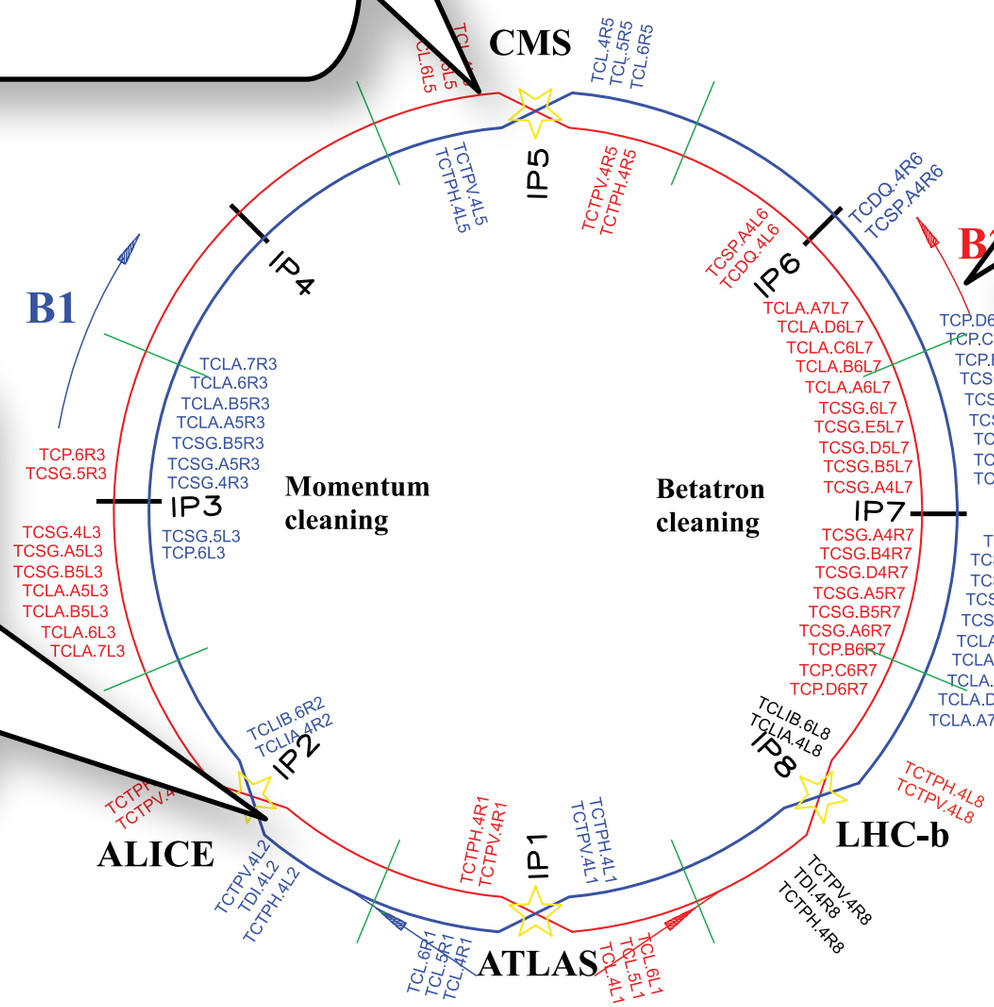


Final decision on installation to be taken based on Run 2 experience

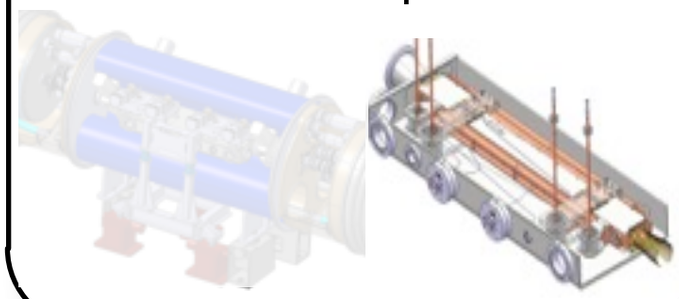
Cleaning: DS coll. + 11T dipoles, 2 units per beam





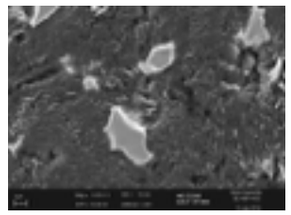


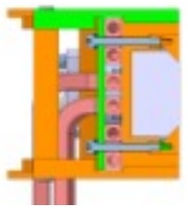
Ion physics debris:
DS coll. + 11T dipoles

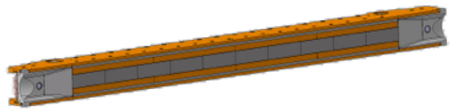


Advanced materials:

- Better TCT robustness
- Better impedance in IR7







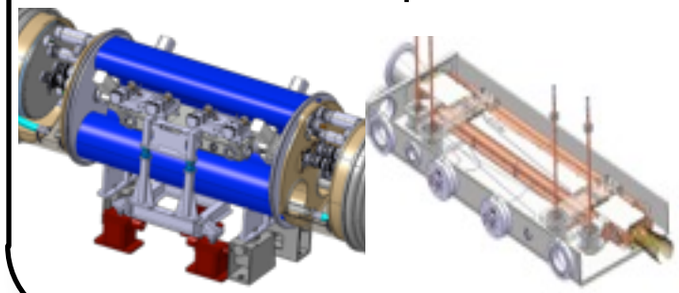
Project upgrade structure

- **HL-WP5 Collimation Project**
  - **Interaction regions cleaning**
    - Incoming
      - Robust tertiary collimators
    - Outgoing
      - Physics debris collimators
      - Physics debris fixed masks
  - **Dispersion suppressor (DS) collimation**
    - DS collimators
      - Δp/p cleaning
    - DS collimators
      - ALICE: ions
      - β* cleaning
      - ATLAS/CMS: p+ions
  - **Halo cleaning (β* & Δp/p)**
    - Crystal collimation
    - Hollow e-lens
    - β* cleaning: low impedance secondaries
    - Δp/p cleaning: low impedance secondaries
  - **Present system**
    - β* & Δp/p cleaning: Primary collimators
    - β* & Δp/p cleaning: Secondary collimators
    - β* & Δp/p cleaning: Shower absorbers
    - β* & Δp/p cleaning: Passive absorbers
    - Secondary collimator in the dump region
    - Tertiary collimators around the experiments

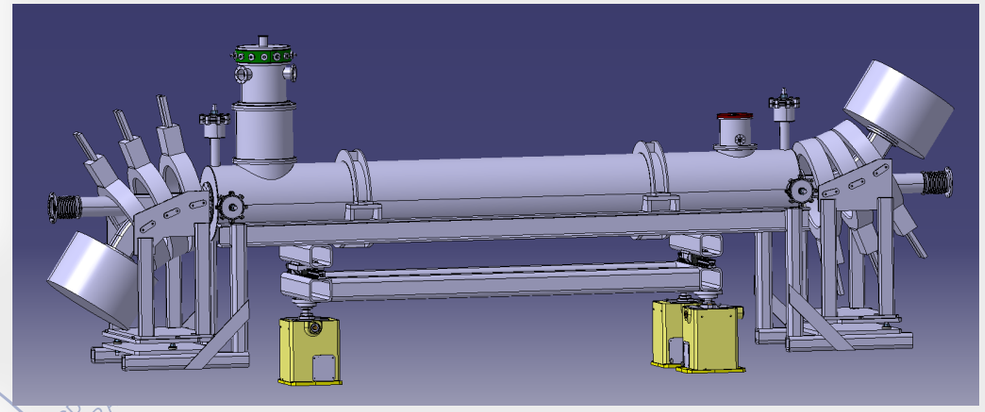
- HL baseline
- Present collimation
- Upgrade options

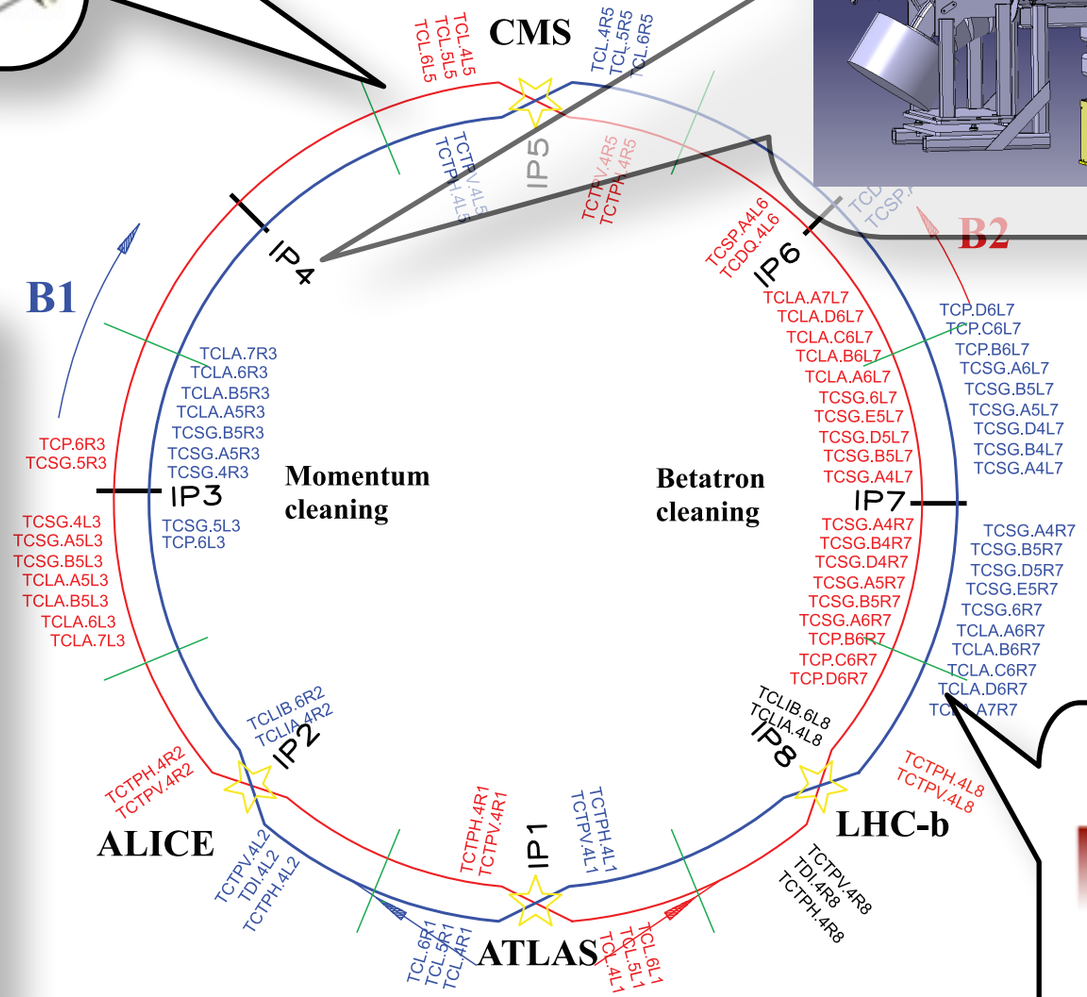
Non-baseline upgrades

ATLAS/CMS physics debris:
DS coll. + 11T dipoles



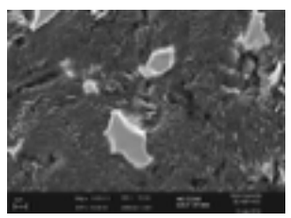
Hollow e-lenses for cleaning

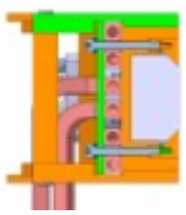


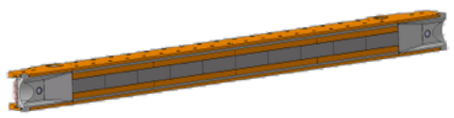


Subject of the collimation talk tomorrow.

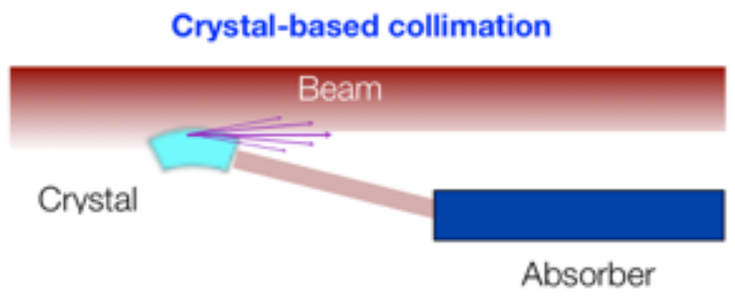
Advanced materials in IR3:
low-impedance secondaries







Advanced materials more robust tertiary collimators in low-luminosity points 2 / 8.

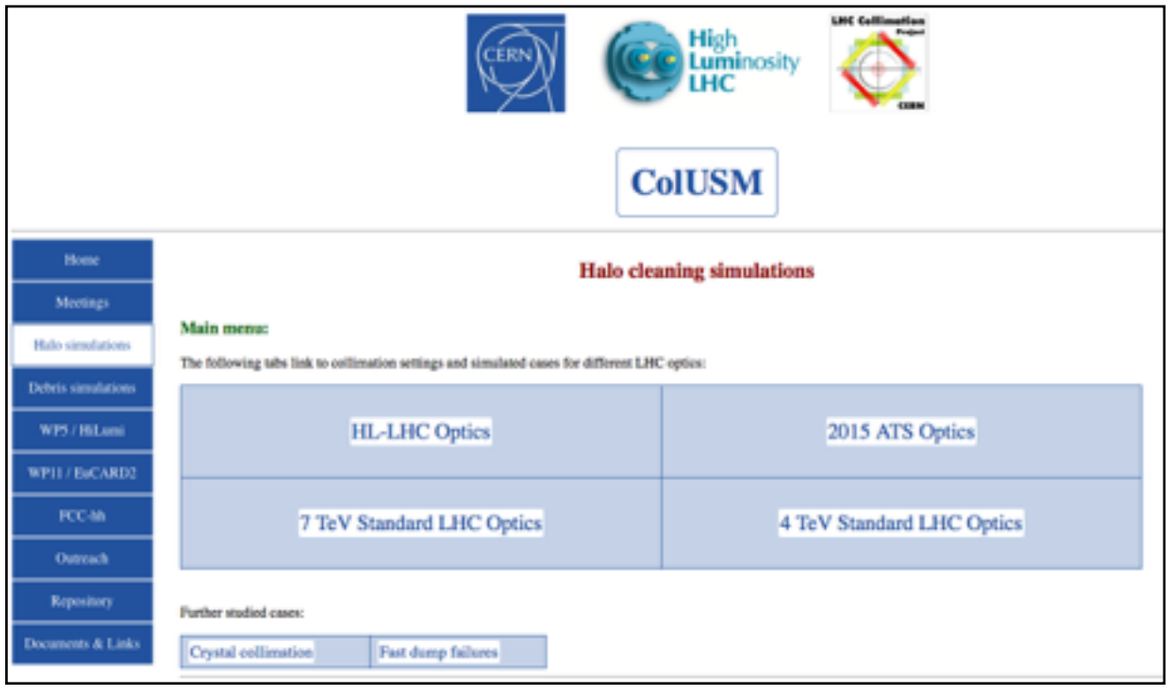


Recap.: Collimation baseline settings

Collimators	IR	Setting $[\sigma]$ for $\varepsilon = 3.5$ μm	Setting $[\sigma]$ for $\varepsilon = 2.5$ μm
TCP.	7	5.7	6.7
TCSG.	7	7.7	9.1
TCLA.	7	10	11.8
TCLD.	7	10	11.8
TCP.	3	15	17.7
TCSG.	3	18	21.3
TCLA.	3	20	23.7
TCT.	1/5	10.9	12.9
TCT.	2/8	30	35.5
TCL.	1/5	12	14.2
TCSP.	6	8.5	10.1
TCDQ.	6	9	10.6

R. Bruce, D. Mirarchi

https://lhc-collimation-upgrade-spec.web.cern.ch



Settings baseline stable since 2013

→ *"2 σ retraction" in IR7*

Consistently used for cleaning and impedance estimates

→ *Updated to include new TCT's and TCL's*

Now updated for ε=2.5µm, if accepted as new notation.

Similar tables can be produced for injection. Discussions on-going with WP2 and ion team.

Outline

- Introduction
- Baseline and options
- **Recent changes of baseline**
- DS collimation and 11 T dipoles
- Collimation Consolidation
- Conclusions

Changes of baseline - March 2015

Three main baseline changes proposed and presented to the C&S review. Items now as ‘options’:

1) TCLD collimators and 11 T dipoles in IR1/5

Keep in baseline IR2 (ion collision debris) and IR7 (betatron cleaning)

2) Low-impedance collimators in the momentum cleaning

Keep in the baseline all secondary collimators in IR7

3) New, more robust tertiary collimators in IR2/8

Keep in the baseline, obviously, collimators for new IR1/5 layouts

Also presented at a HL-TC in March

Update on related studies

1) TCLD collimators and 11T dipoles in IR1/5

IR1/5 for ions: now more convincing simulations that we can cure losses from collisions with bumps and no collimator (John, Anton).

Protons: losses down to DS seem ok (WP10).

Still pending: final energy deposition for v1.2 and multi-turn studies

2) Low-impedance collimators in the momentum cleaning

Quantified IR3 contribution to ~15%. See below (1 slide on that).

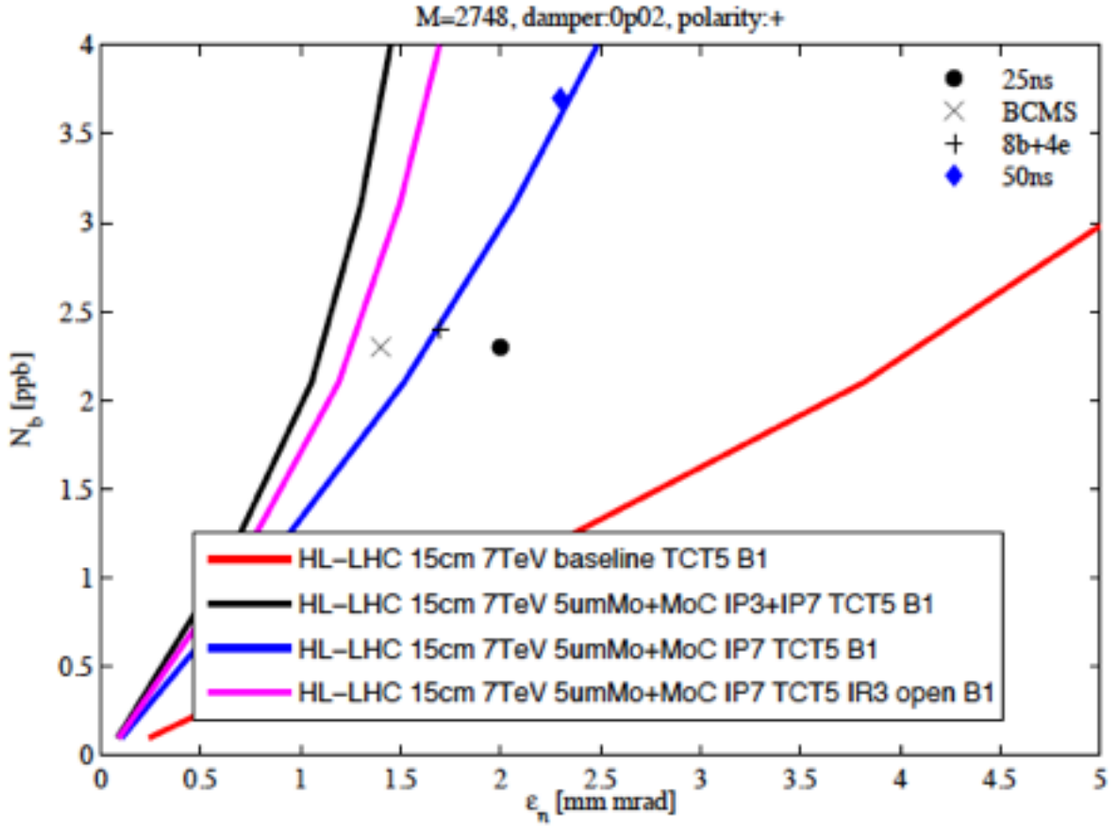
3) New, more robust tertiary collimators in IR2/8

Request for budgets sent to CONS

To be revised if LHCb is also upgraded as part of HL-LHC

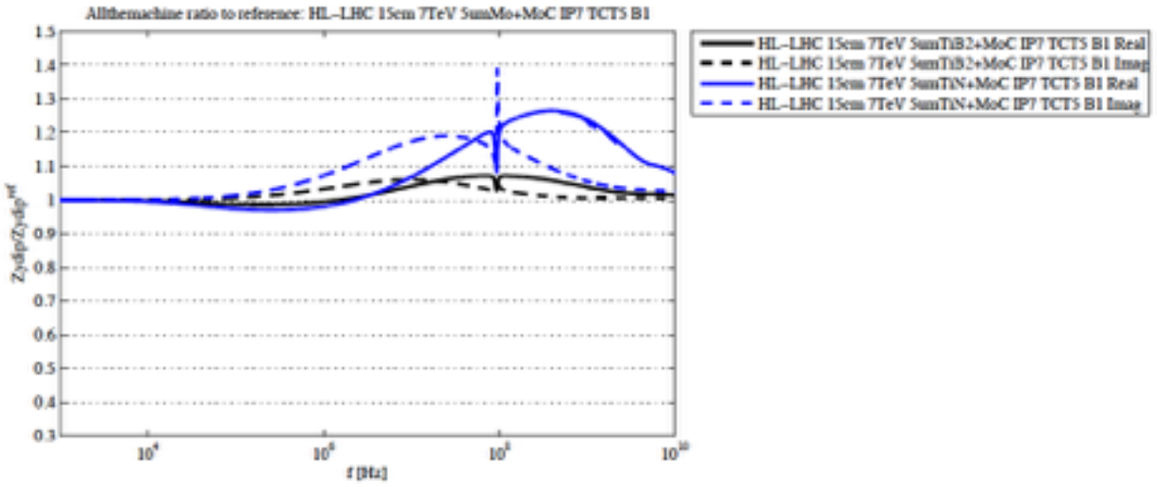
My conclusion is that at this stage, we are **taking reasonable risks** by considering these items as non-baseline

Latest impedance news



New materials other the Mo (σ_c = 18.7 MS/m) for coating on MoC have been recently proposed:

- TiN: (σ_c = 2.5 MS/m)
- TiB2 (σ_c = 11.1 MS/m)



→ 5 μm of TiN coating 30% less effective than Mo coating
→ 5 μm of TiB2 coating 10% less effective than Mo coating

N. Biancacci for the impedance team

→ Without replacing IR3 TCSG's:

Total impedance reduced to 55% instead than to 40%.

This seems acceptable. It might be recuperated by relaxing settings

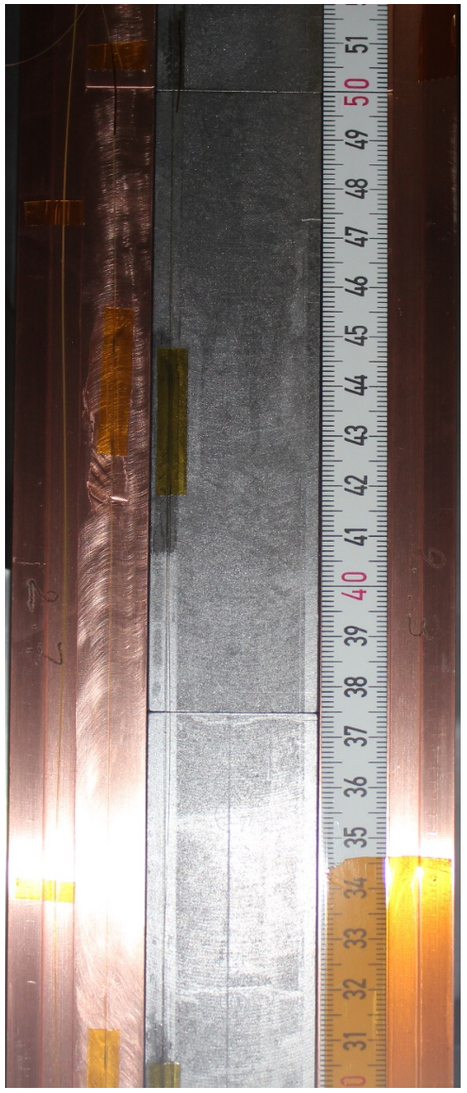
To be confirmed by radio-protection: it would change loss sharing

MDs at the LHC ongoing. Other mitigation methods being studied.

→ **High priority for IR7**: Studying alternative coating materials then pure Mo (not robust enough). So, it is important not to give up all margins.

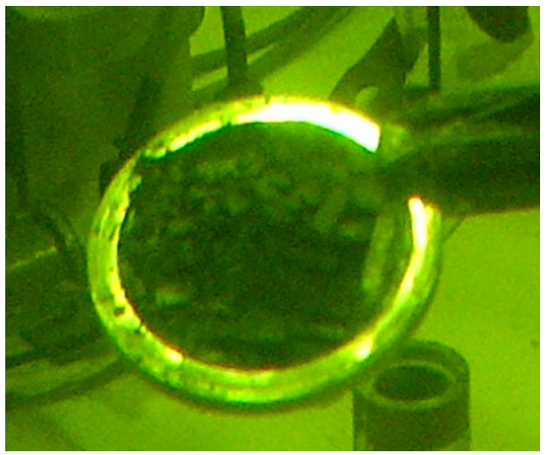
Note on new materials - MoGR

Two main regimes for tests with beam: fast failures (thermo-mechanical robustness) and high radiation doses (long times).



A. Bertarelli

Excellent results at HRM: full MoGR jaw survived 288b of 1.3x1011p with σ=350μm (density beyond LIU)



State of Mo-GR after 1.1 10^{21} p/cm^2 FLUENCE

N. Simos at US-LARP meeting

Very high doses at BNL: some MoGR samples broke!

Launching another set of measurements with latest MoGR grades and more optimised beam parameters.

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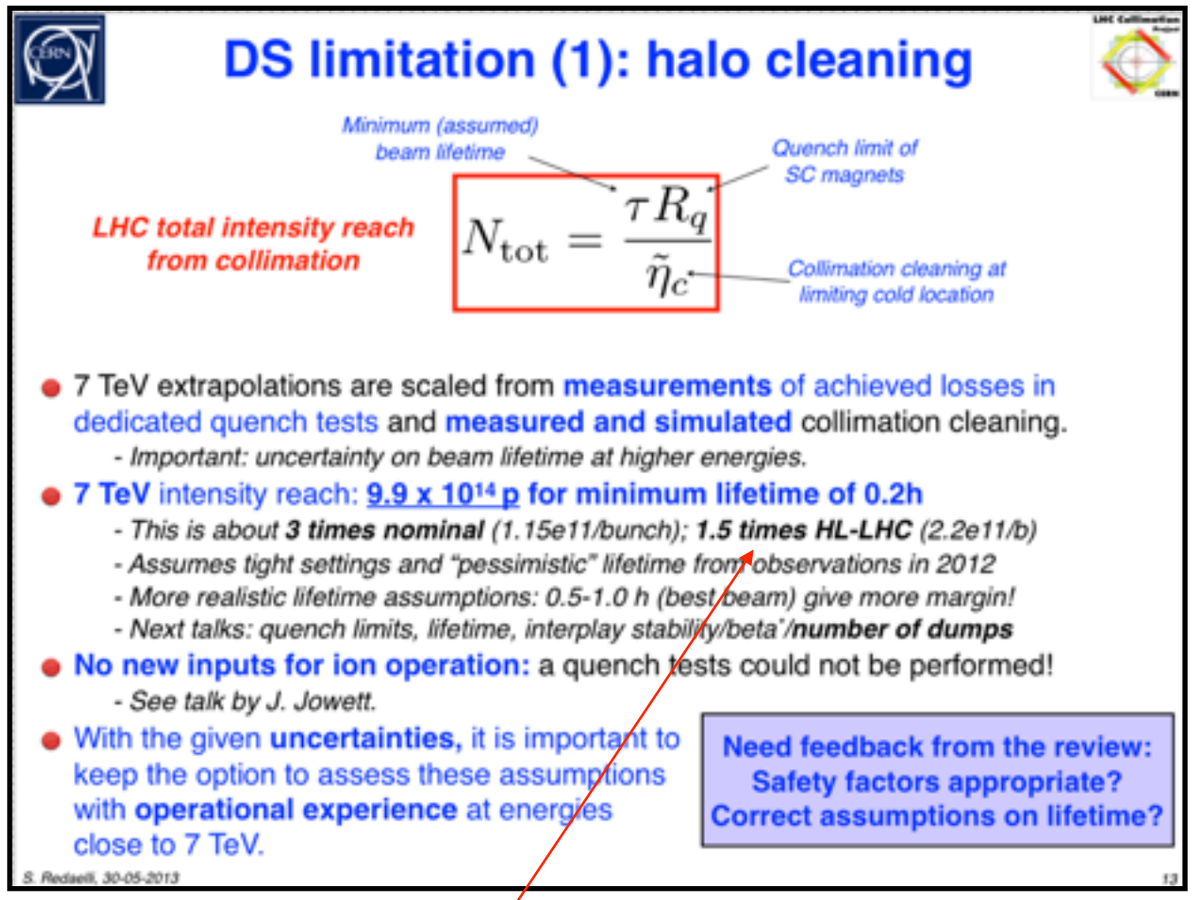
Recap. on 11T needs for collimation



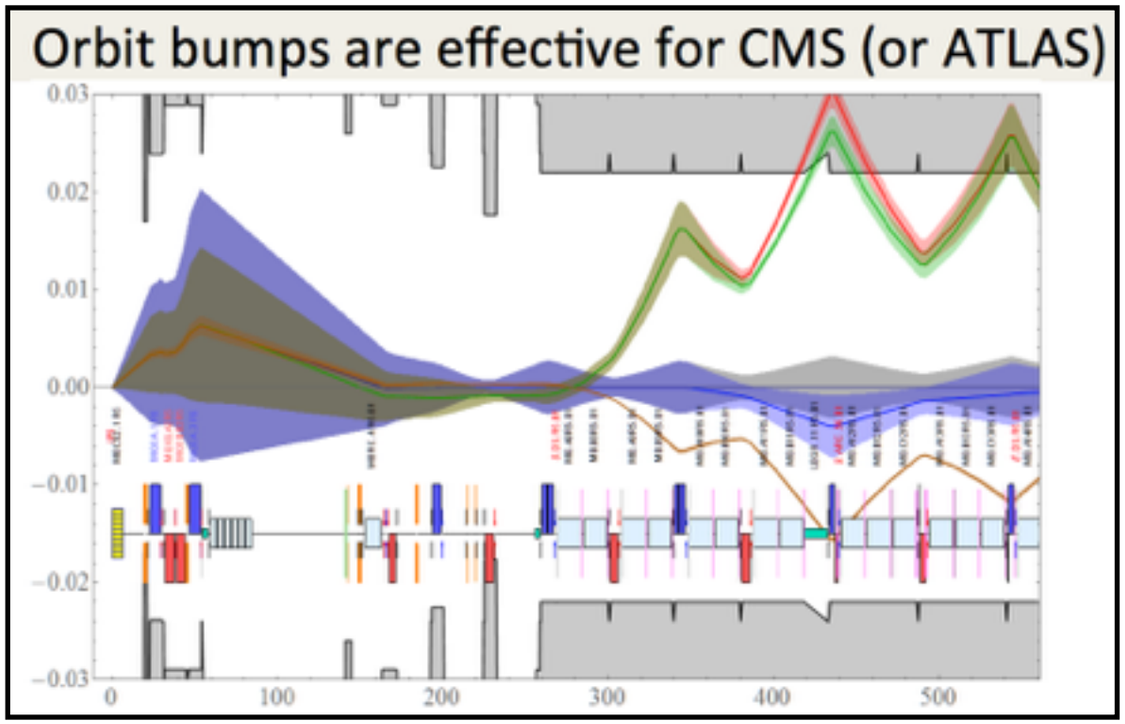
*"Gained" another **factor 2** from later analysis of quench tests: margin ~3 for HL*

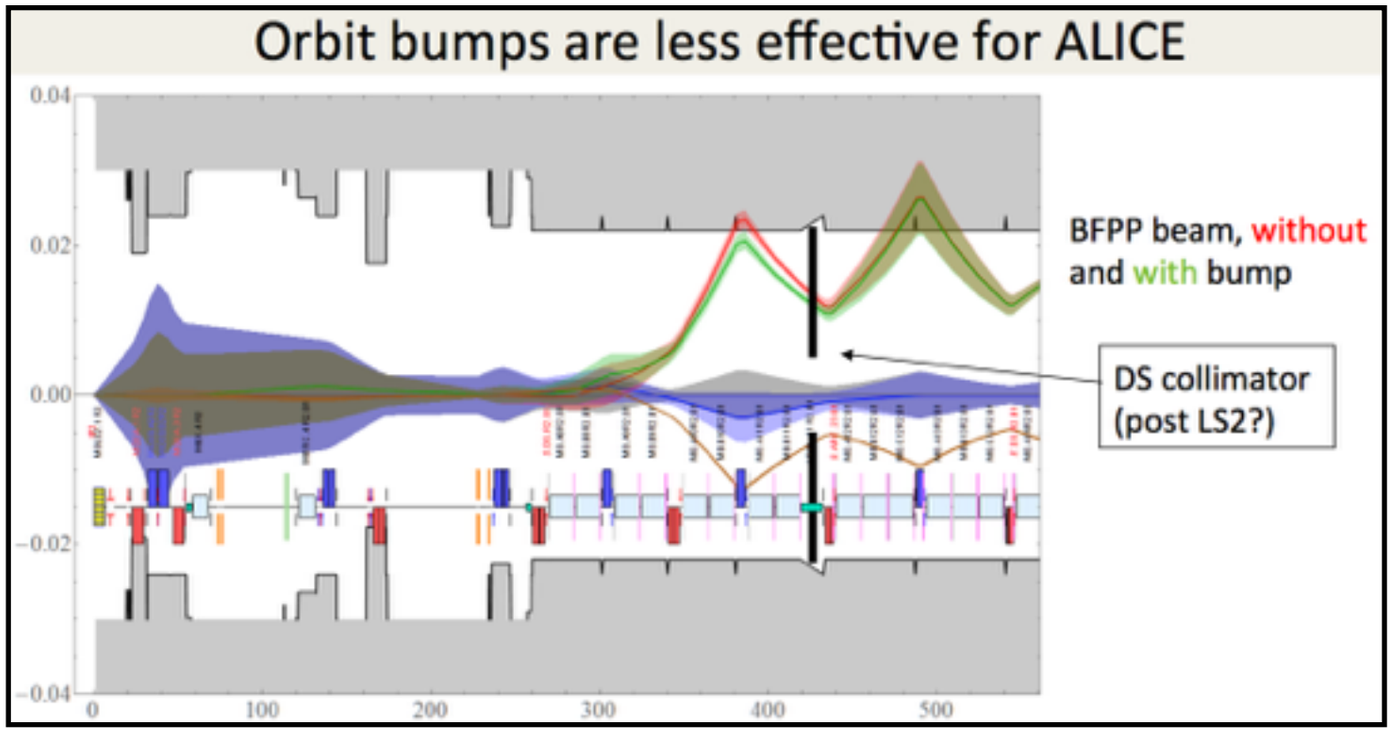
Review outcome/recommendations:

- Recommendation to continue with high priority the development of 11T dipoles
  → *Answer to main question, as in the previous review of the DS collimation this had been put in question (2011).*
- Acknowledged that final strategy should be finalized after adequate operational experience at higher energy
  → *Focus on a few units for LS2, define later final layouts*
- **Suggested to prepare units for IR2 for LS2, but also warned about important uncertainties for IR7**
- Acknowledged the choice of parameters for performance estimate (τ_b=0.2h) in line with the 2012 experience at small gaps and high loss rates
- Suggested to address problems of collimator impedance and loss spikes (hollow e-lens)
  → *Out of mandate, but clearly hot topics for collimation*

We did not yet accumulate conclusive evidence from Run II beam operation.
Small refinement of quench models, no change of conclusions.
New proton and ion simulations: more detailed studies
on **bumps** for IR2 and for IR1/5.

“Ion bumps”: IR2 vs IR1/5





Fundamental layout/optics differences between IR1/5 and IR2:

- Bumps in IR1/5 can move ion losses to connection cryostat with no risk of quenches → no need for collimator nor for 11T dipoles
- Bumps in IR2 can move the losses such that the first magnet is missed → we still need a collimator, but likely not the 11T dipoles

See later one slide on “Considerations”.

See recent talks by John and Anton at the LMC!

Where we were in 2013

		Until HL-LHC (before LS3) [$L=2.5\times10^{34}cm^{-2}s^{-1}$, $I_{tot}=3.2\times10^{14}p$]		**HL-LHC era** (after LS3) ($L=5\times10^{34}cm^{-2}s^{-1}$, $I_{tot}=6.2\times10^{14}p$)	
As presented at 2013 Review		Protons	Ions	Protons	Ions
IR7	Betatron cleaning	**Needed?**	**Needed?**	Needed? with or w/out ATS	Needed?
IR3	Momentum cleaning	Not needed	Not needed	Not needed	Not needed
IR1/5	ATLAS/CMS	Not needed	**Needed**	Needed? Updated layout	Needed?
IR2	ALICE	Not needed	**Needed**	Not needed	Needed?
IR8	LHCb	Not needed	Not operating	Not needed	Not operating

Where we are now

		Until HL-LHC (before LS3)		**HL-LHC era** (after LS3)	
		Protons	Ions	Protons	Ions
IR7	Betatron cleaning	**Not needed?**	**Not needed?**	Needed (?)	Needed (?)
IR3	Momentum cleaning	Not needed	Not needed	Not needed	Not needed
IR1/5	ATLAS/CMS	Not needed	**Not needed**	Not needed	Not needed
IR2	ALICE	Not needed	**Needed**	Not needed	**Needed**
IR8	LHCb	Not needed	Not operating	Not needed	Not operating

Implications of collimation changes on 11T dipole program:

→ we might remove the 4 units for IR2; relaxed schedule for LS2!

→ budget wise: reasonable to delay units

→ *technically: solution and prototypes ok, can have units by LS2*

Various considerations

It is crucial to demonstrate as soon as possible that the **new solutions** based on bumps work reliably in IR2 and IR1/5:

We still have important uncertainty on quench margins at 7 TeV.

Need perform quench tests with beam for proton and ion beams!

Bump technique for all IRs need to be demonstrated operationally.

Rather confident that there will be no issues, but…

Remark on bumps in IR1/5:
Bump technique tested in 2011 and presented at the 2013 review. Then, concluded then bumps were not fully reliable and the TCLD were expected to be needed. Now: we consider it as baseline based on simulations only.

Note on beam energy: more what if we are at 6.5 TeV until Run III!

Detailed energy deposition studies (Anton) indicated potential issues beyond quench limits (like loads to cryogenics). To be understood.

Various considerations

It is crucial to demonstrate as soon as possible that the **new solutions** based on bumps work reliably in IR2 and IR1/5:

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Note on beam energy: more what if we are at 6.5… Run III!

Detailed energy deposition studies (Anton) in… otential issues beyond quench limits (like loads to cryogenics)… be understood.

Propose to review all that at a dedicated review in 2016.

Status of TCLD design

60cm baseline agreed.

Final design for integration between 11T dipoles: ok

→ *decided "cold" solution for other beam*

Still possible to change material

→ *launched construction W prototype*

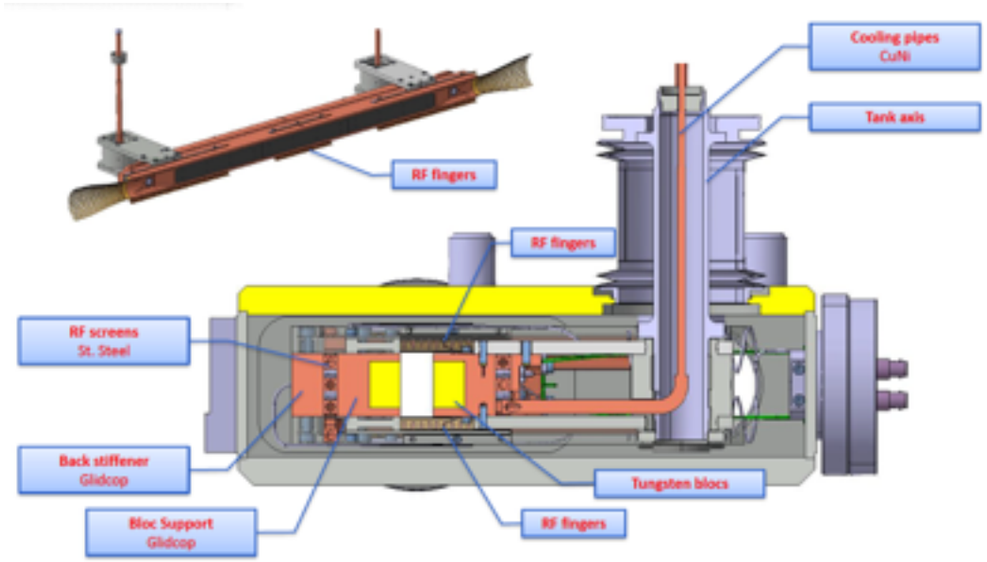
Preparing production of 2+1 units for LS2 (solution without 11T dip)

→ *prototype conform might be used as spare.*

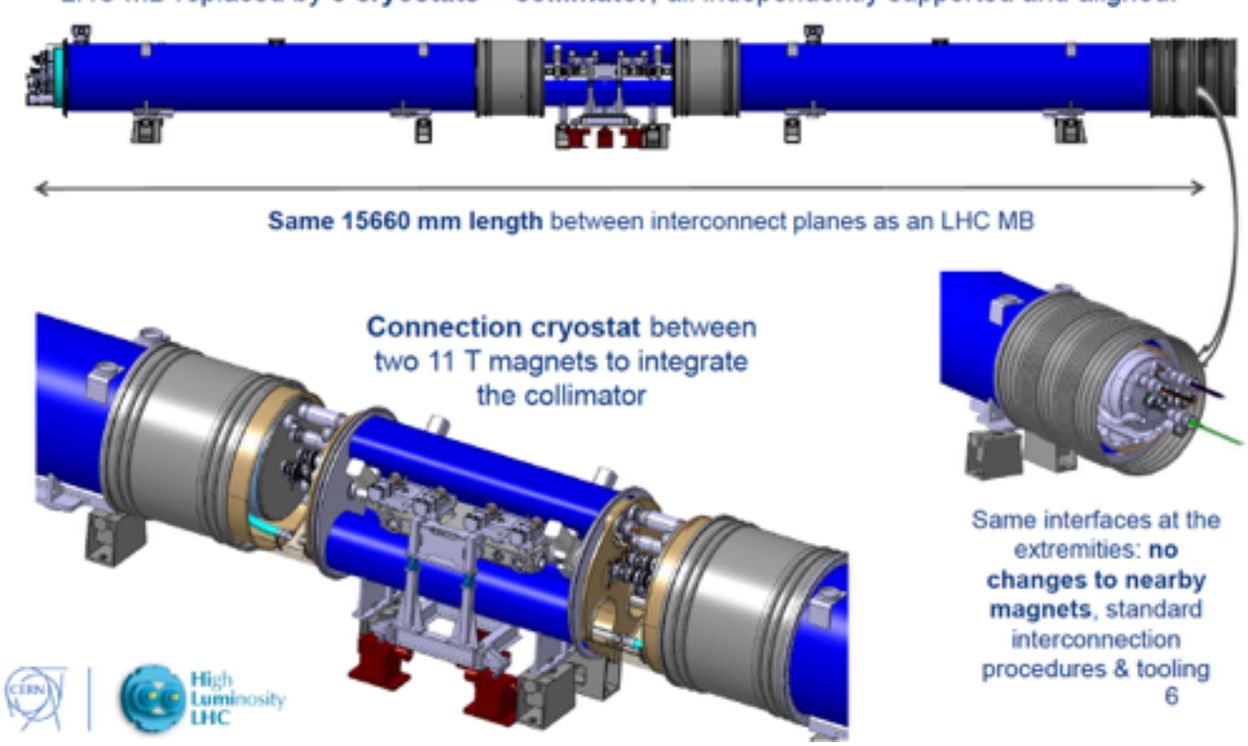
Need to work on the integration into the connection cryostat

→ *WP11 now busy, still ok if we launch that in 2016 as no obvious issues are expected.*

See detailed talks by Delio D. and Luca G. at last ColUSM, 18/09/2015



Current baseline



Status of TCLD design

60cm

Final

b

→ *dec*

Still p

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Prepa

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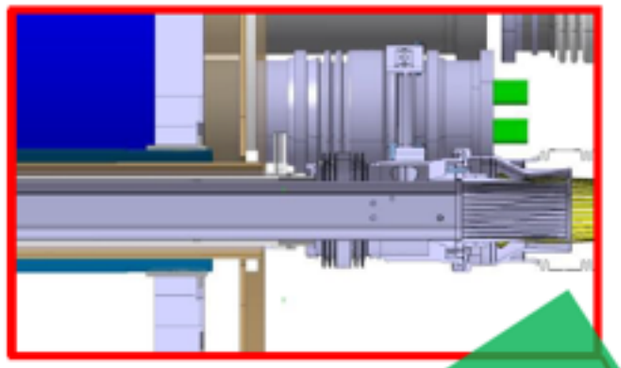
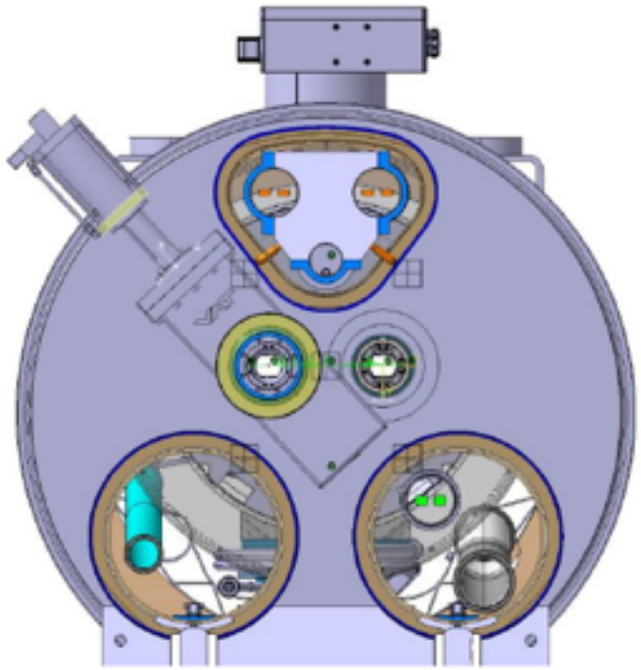
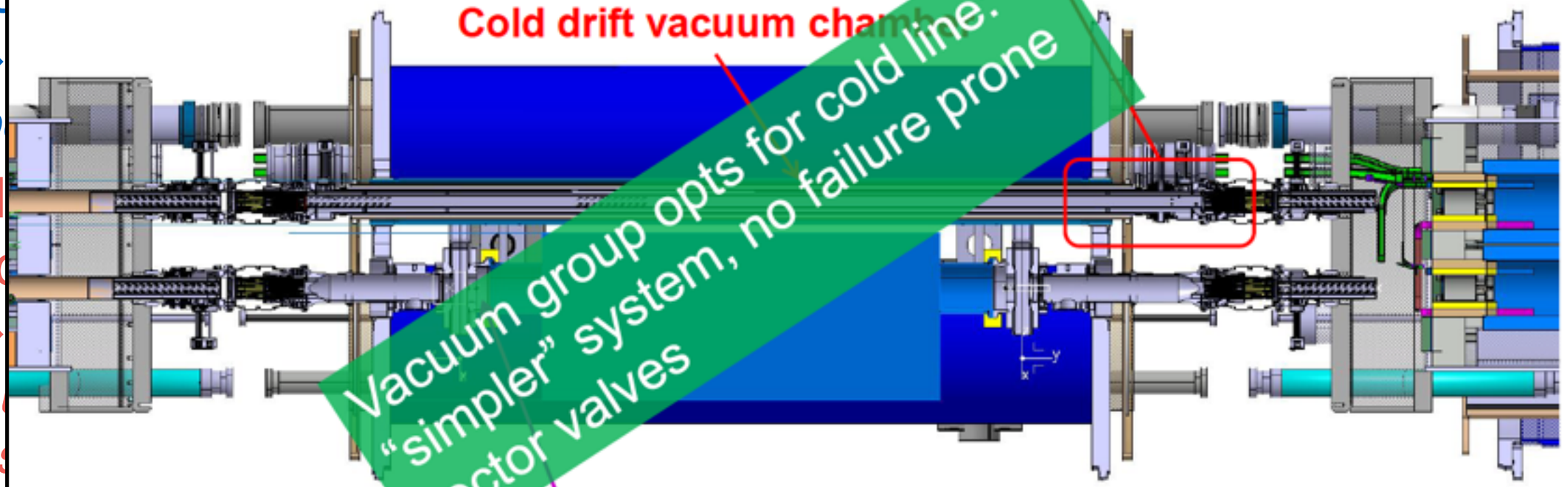
See de

Beam vacuum options (B)

- Interconnects become longer because of the beamscreens
- Very compact cold line because of the sector valve RF shielding







Transitions avoided because there are no sector valves on the other beam lines

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Outline

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- DS collimation and 11 T dipoles
- **Collimation Consolidation**
- Conclusions

Present collimation

- **Present system**
  - **β* & Δp/p cleaning: Primary collimators**
  - **β* & Δp/p cleaning: Secondary collimators**
  - **β* & Δp/p cleaning: Shower absorbers**
  - **β* & Δp/p cleaning: Passive absorbers**
  - **Secondary collimator in the dump region**
  - **Tertiary collimators around the experiments**

It is essential to ensure a high-performance collimation system for HL.

1. Topics requested from consolidation:

Replacement of primary collimators with BPM (TCPP)

Spares for TCSP collimators for point 6 with BPM

Recovery of collimator 5th axes for TCT's in IR1/5

Update of collimator control system

More robust tertiaries for lower beta* in Run II/III

Replacement of secondary collimators with BPM design

New TCTPM collimators for IR2/8

Passive absorbers in IR7 for MQW consolidation

2. Uncertainty if the existing collimators that will not be upgraded, are adequate for the LHC parameters:

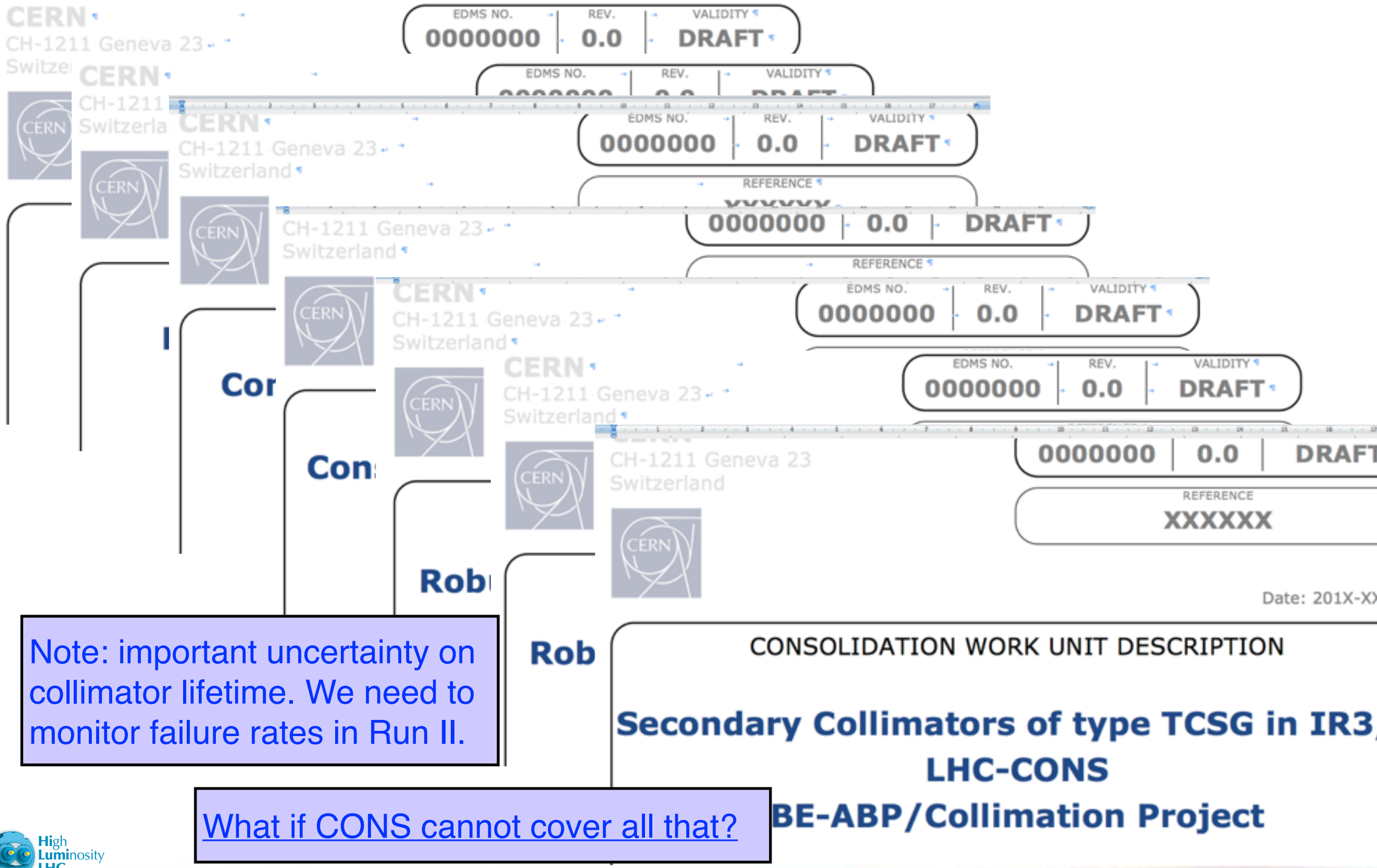
Injection and top energy failures with HL beams;

Radiation resistance (passive absorbers) in warm IR's;

Faster setup of several collimators in IR3/7.

We need more discussion between HL and CONS.

Collimation project requests to CONS



Note: important uncertainty on collimator lifetime. We need to monitor failure rates in Run II.

What if CONS cannot cover all that?

Conclusions

- **Reviewed main recent news on collimation upgrade baseline**
- **We have converged to a solid baseline**

  Recent changes brought up for the C&S review, now studies in more details
  Some uncertainties still applies, but associated risks seems acceptable
  Important: decisions can be reverted if needed !
  (re-baseline affect number of units, technology developed anyway!)
- **The TCLD collimators with 11T dipoles reviewed in details**

  No major changes for collimator units: 2 in IR2 + 4 in IR7
  Studied in detail a bump solution that removes 11T dipoles in IR2
  Usual caveats apply (in both directions!)
- **Positive recent results on new collimator materials but important uncertainties needs still more work**

  Radiation resistance of MoGR in question after BNL tests
  Coating solutions still being elaborated.
- **Important synergy with CONS to ensure a successful upgrade**