LHC Collimation Quench Test MD

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Acknowledgments to the FLUKA team, ADT team, BLM team

rMPP meeting

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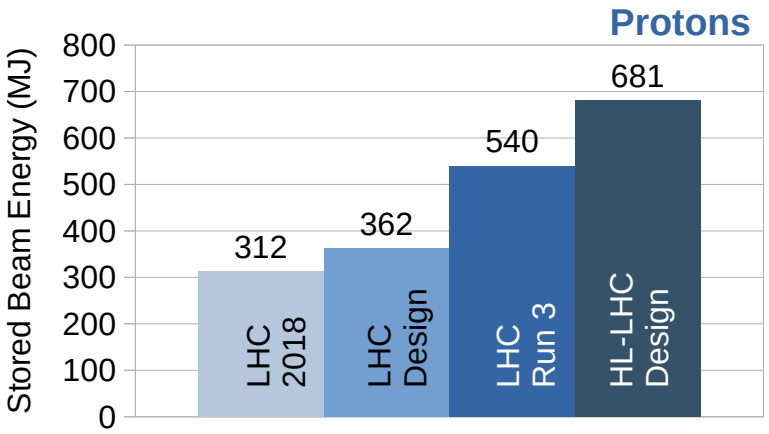
Introduction

- Tiny fraction of protons on collimators ultimately lost in IR7 DS magnets
- **Quench limit** of IR7 DS magnets **may limit HL-LHC intensity** reach
- Not well understood: previous tests could not reach quench
- **Key hardware upgrades** initially foreseen **might not be available**
  - 11T dipole availability for HL-LHC is uncertain
- **Need to understand quench limit** in operational conditions
- Proposal for **LHC collimation quench test** with protons (ID 7224)

Collimation quench risk in HL-LHC



Machine	Duration (s)	Min. beam lifetime (s)	Stored beam energy (MJ)	Beam loss power (kW)
LHC	10	720	362	**503**
HL-LHC	10	720	681	**946**

Specification Unchanged!

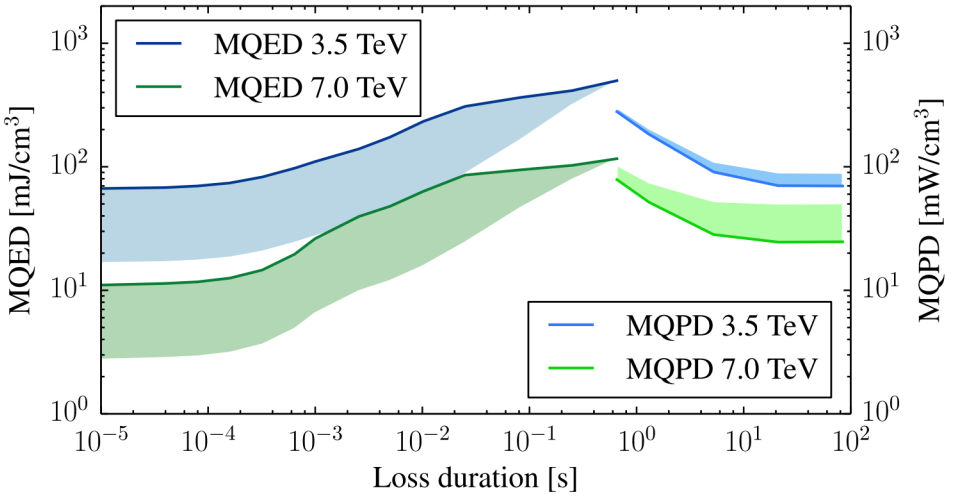
- **HL-LHC: collimation system must sustain ~1MW of power loss over 10s**
- **New DS collimators (TCLD) foreseen in LS2 but deferred** after reliable operation at 7TeV could not be demonstrated in cold testing of 11T dipoles
- Are we risking to quench the DS magnets in HL-LHC if we can't install TCLDs?

Collimation quench risk in HL-LHC

Quench limit

- Is not straightforward to measure or estimate
- Latest estimate (2019): for 7 TeV with losses of ~1s duration: **20-30mW/cm³**

B. Auchmann et al. PRSTAB 18. 061002



Year	Machine	Simulated coil power deposition (mW/cm³)
2019	HL-LHC	21
2021	HL-LHC	15

2021 simulation with new collimator materials

Expected DS MB peak power deposition

- Complex simulation chain: particle tracking in SixTrack used as input for detailed power deposition studies in FLUKA

With uncertainties: very tight margin for HL-LHC upgrade! Quench test needed!

Previous quench tests

Year	Species	Energy (TeV)	Test type	Max. power load at TCP (kW)	DS power density* (mW/cm^3)	Quench achieved?
2011	**Protons**	**3.5**	**Collimation**	**510**	**-**	**No**
2013	**Protons**	**4.0**	**Collimation**	**1050**	**-**	**No**
2015	**Protons**	**6.5**	**Collimation**	**585**	**23**	**No**
2015	Pb ions	6.37Z	Collimation	13.7	25-30	Yes
2015	Pb ions	6.37Z	BFPP	-	20	Yes

*) simulated with FLUKA

Click for references

- No quench achieved so far in proton collimation quench test
- With higher magnet currents at 6.8 TeV better chances of quenching

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Requirements

Goal: Induce high losses at collimation system to quench DS MB magnet

Loss duration and level

- Target level **1MW for 10s** : ramp losses from 0 to 1MW in ~5s
- Corresponds to HL-LHC specification at 7 TeV, but quench test at 6.8 TeV (quench limit slightly higher)

Optics & Beam

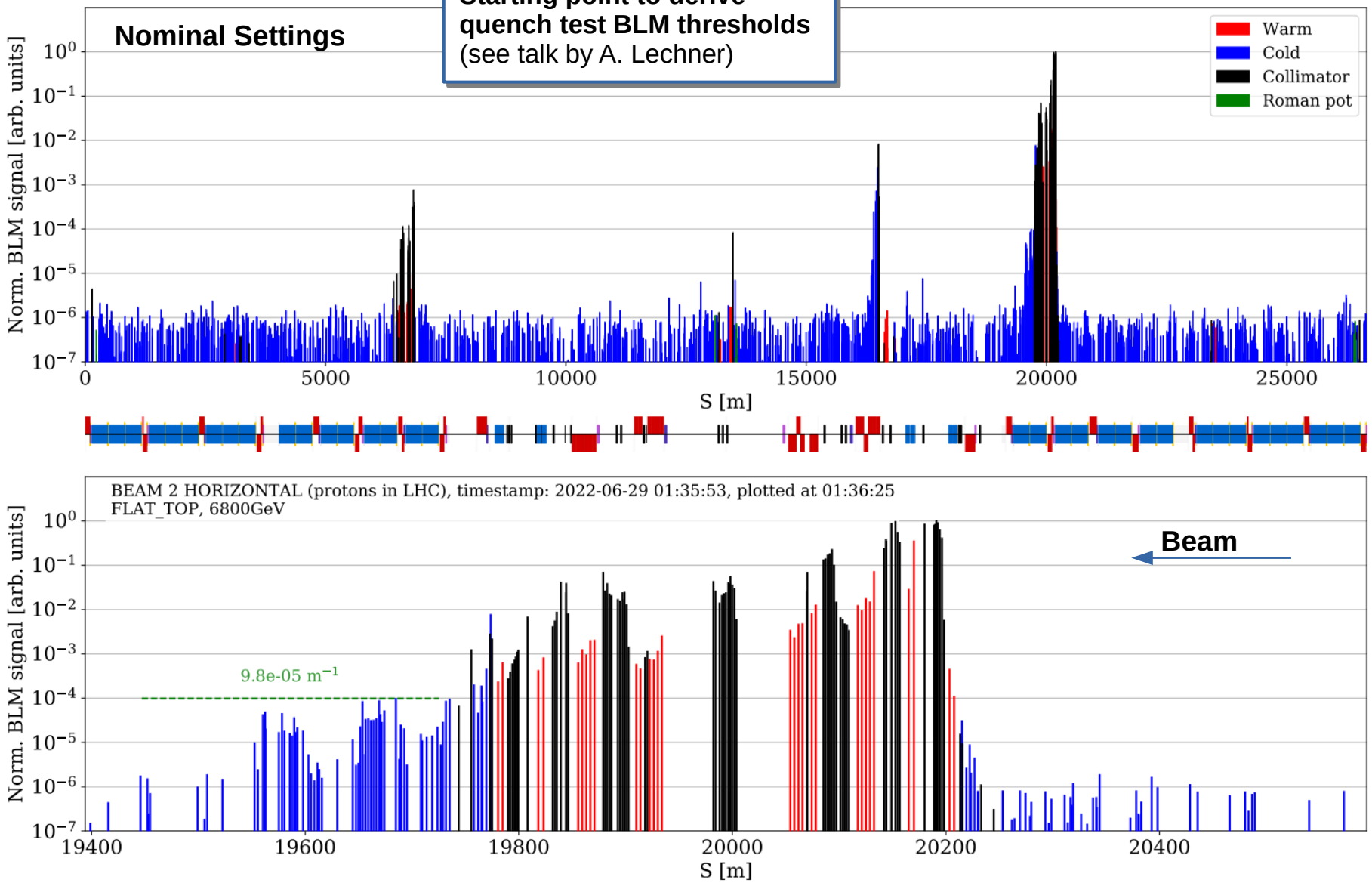
- Top energy (6.8TeV) at flat top (1.33m)
- Beam 2 horizontal plane: also used in past experiments
- Number of bunches: 144 or 192

Collimator settings

- Start conservatively with nominal settings (IR7 **5σ/6.5σ/10σ**)
- If no quench achieved: relaxed settings (IR7 at **5σ/8.5σ/10σ**) to increase DS losses per kW of TCP power loss

Qualification loss map B2H

Starting point to derive quench test BLM thresholds
(see talk by A. Lechner)



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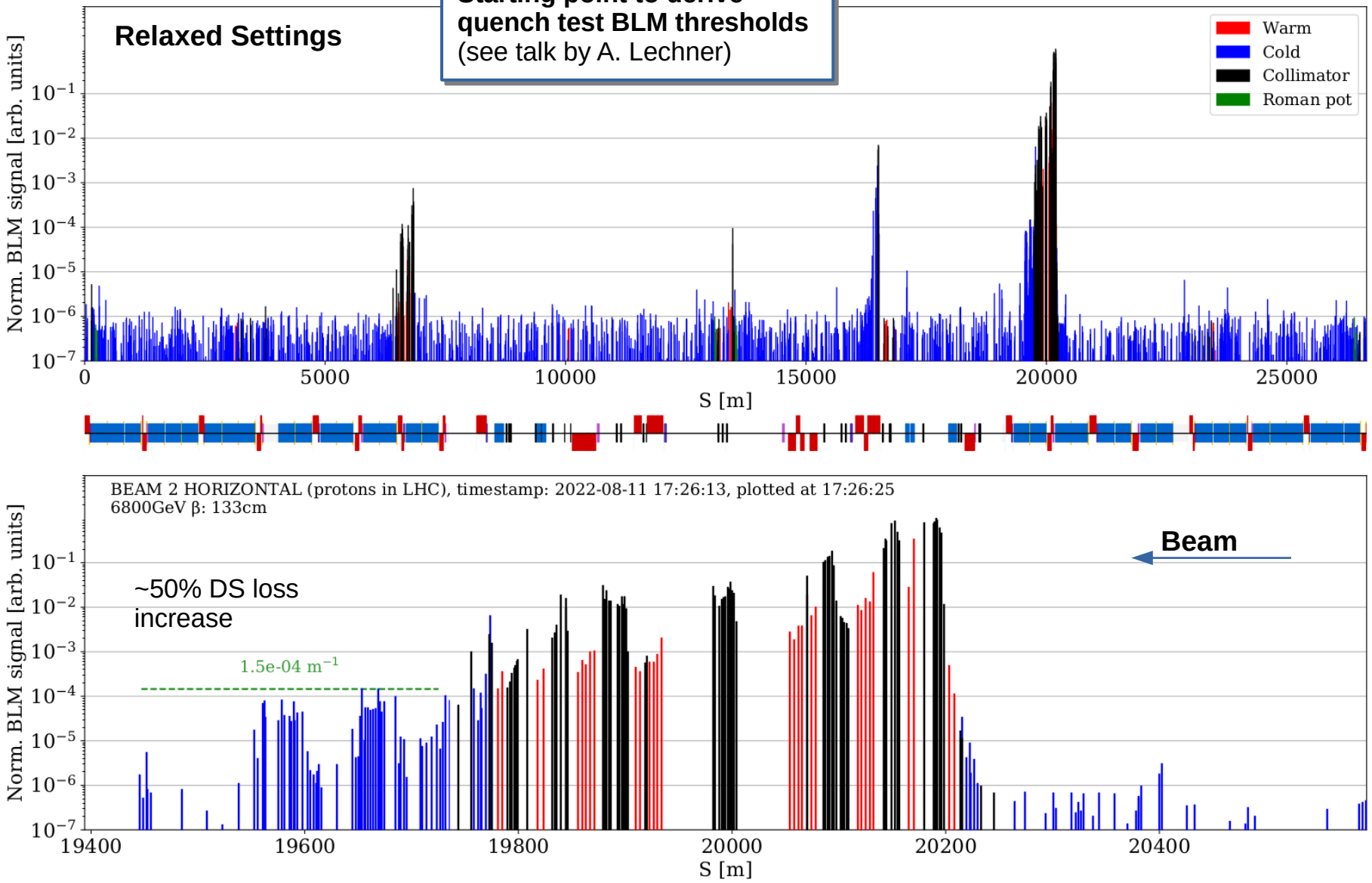
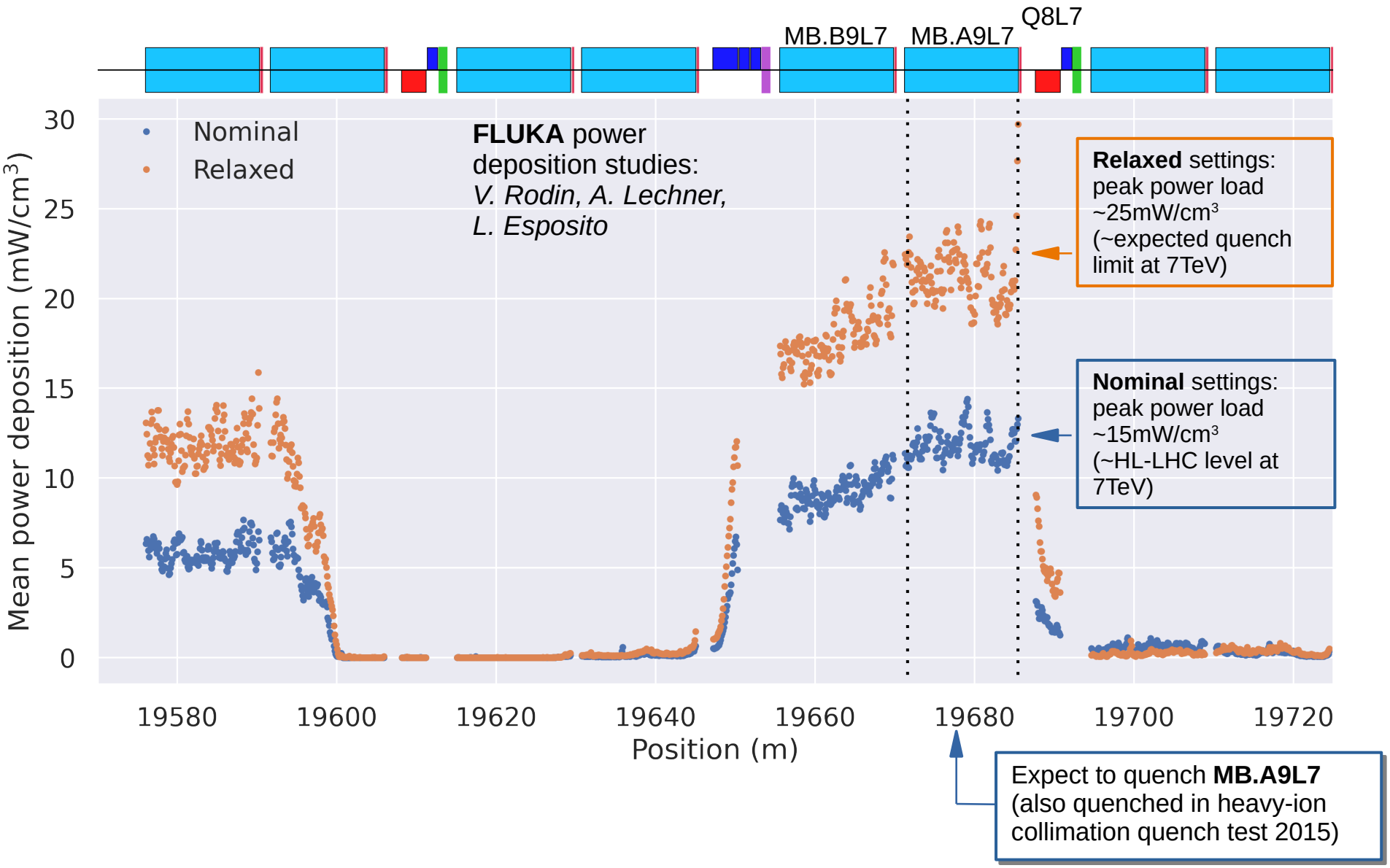


Expected peak power load



FLUKA Simulations

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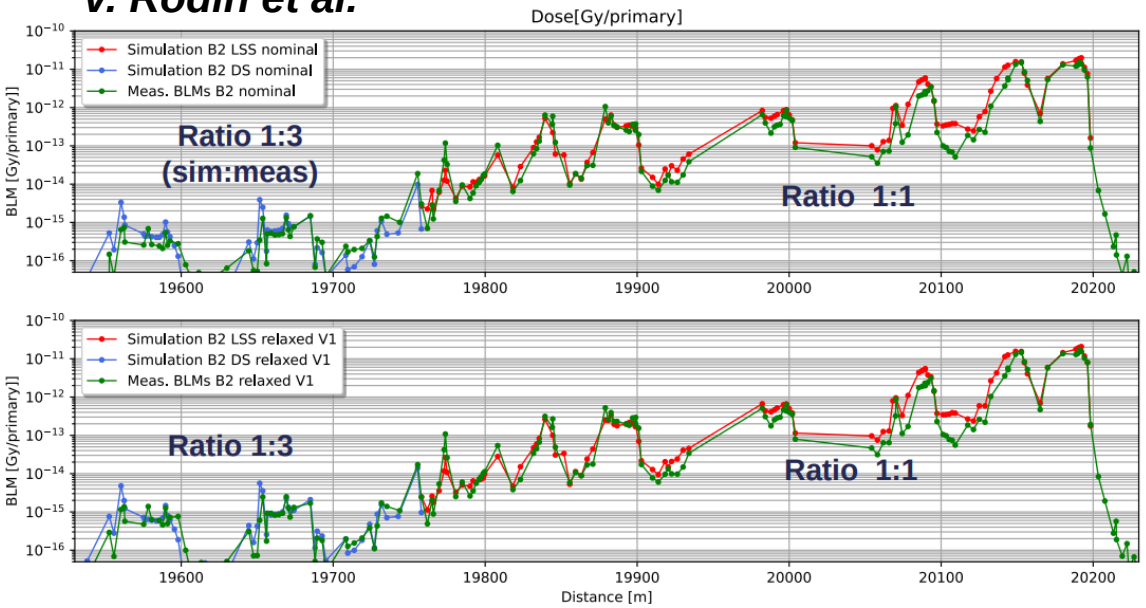

- **Both nominal and relaxed settings well understood in simulations and measurements**
- Excellent agreement between SixTrack/FLUKA simulations and measured qualification loss maps

V. Rodin et al.

- **Collimator power deposition not critical** (nominal settings studied as worst case)
- TCSPM coating exposure less than HL-LHC design scenario

Simulation study	TCPPM.C6, J1/J2 (full), kW	TCP.B6 J1/J2 (full), kW	TCSG.A6 J1/J2 (full), kW	TCSPM J1/J2 (full), kW	TCSPM Mo coating PPDD, W/cm^3
A. Waets 2020, B1, (HL-LHC baseline)	4.25/4.13 (23.5) MoGr	10.12/10.08 (42.5) CFC	5.8/5.27 (28.1) CFC	5.03/3.75 (19) MoGr B5	175 B5
V. Rodin 2022, B2, (LHC today, depicted)	4.5/4.07 (23.6) MoGr	10.33/10.03 (42.52) CFC	5.53/5.09 (26.65) CFC	1.95/1.92 (8.03) MoGr D4	72 D4

More details in LHC Collimation Working Group #269

Contents

MD Time Plan

- **Preparation:** BLM thresholds adjustment, activate 100Hz BLM and FBCT logging
- **First Ramp**: **ADT setup, calibration and testing**
  - 4 - 6 INDIV + 4 × 48 bunches*
  - First quench attempt with nominal collimator settings
    → allows check + fine-tuning BLM thresholds + ADT profile
- **Second Ramp**: **Quench attempt(s) with nominal collimator settings**
  - 4 - 6 INDIV + 2 × (4 × 48) bunches*
  - FLUKA simulations: expect ~15mW/cm^3 (~ expected HL-LHC level at 7TeV)
- **Third Ramp**: **Quench attempt(s) with relaxed collimator settings**
  - 4 - 6 INDIV + 2 × (4 × 48) bunches*
  - FLUKA simulations: expect ~25mW/cm3 (~ expected quench limit at 7TeV)

*) 4×48 bunches if < 1.4e11 p/b

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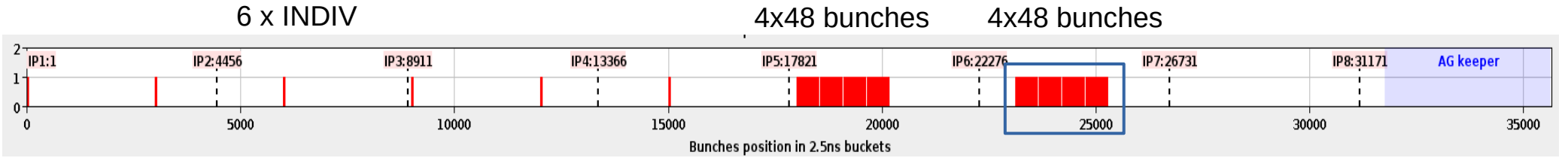
Filling pattern

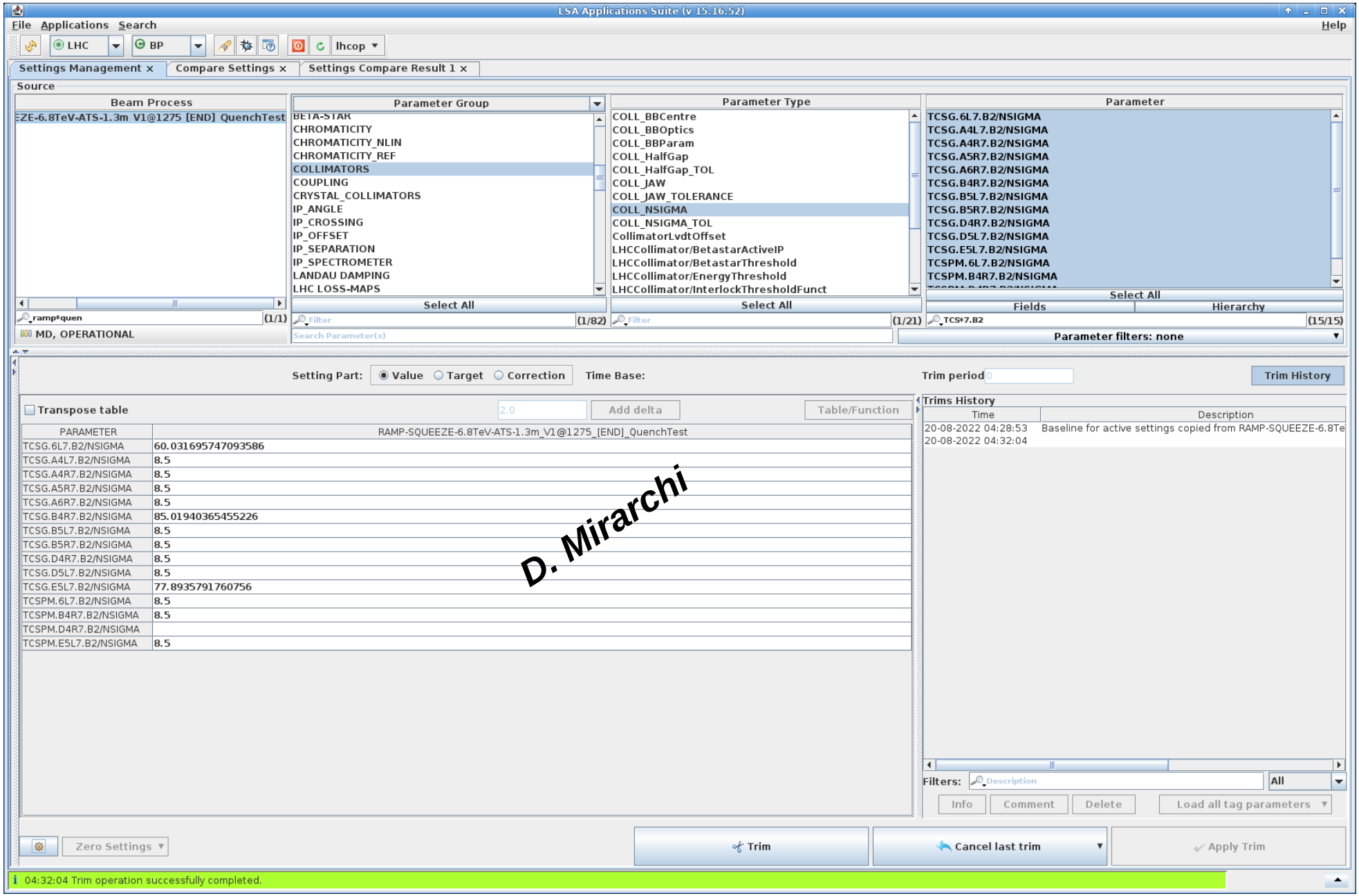
- Require 1MW: blow up several bunch trains simultaneously
- Proposal: **4x48 bunches* per quench attempt** + some nominal bunches to test ADT with increased window before excitation of bunch trains
- Stored energy in 4x48 bunches with 1.2x10^{11} intensity: ~22MJ
- Filling pattern *Quench_test_2022* prepared by D. Mirarchi :



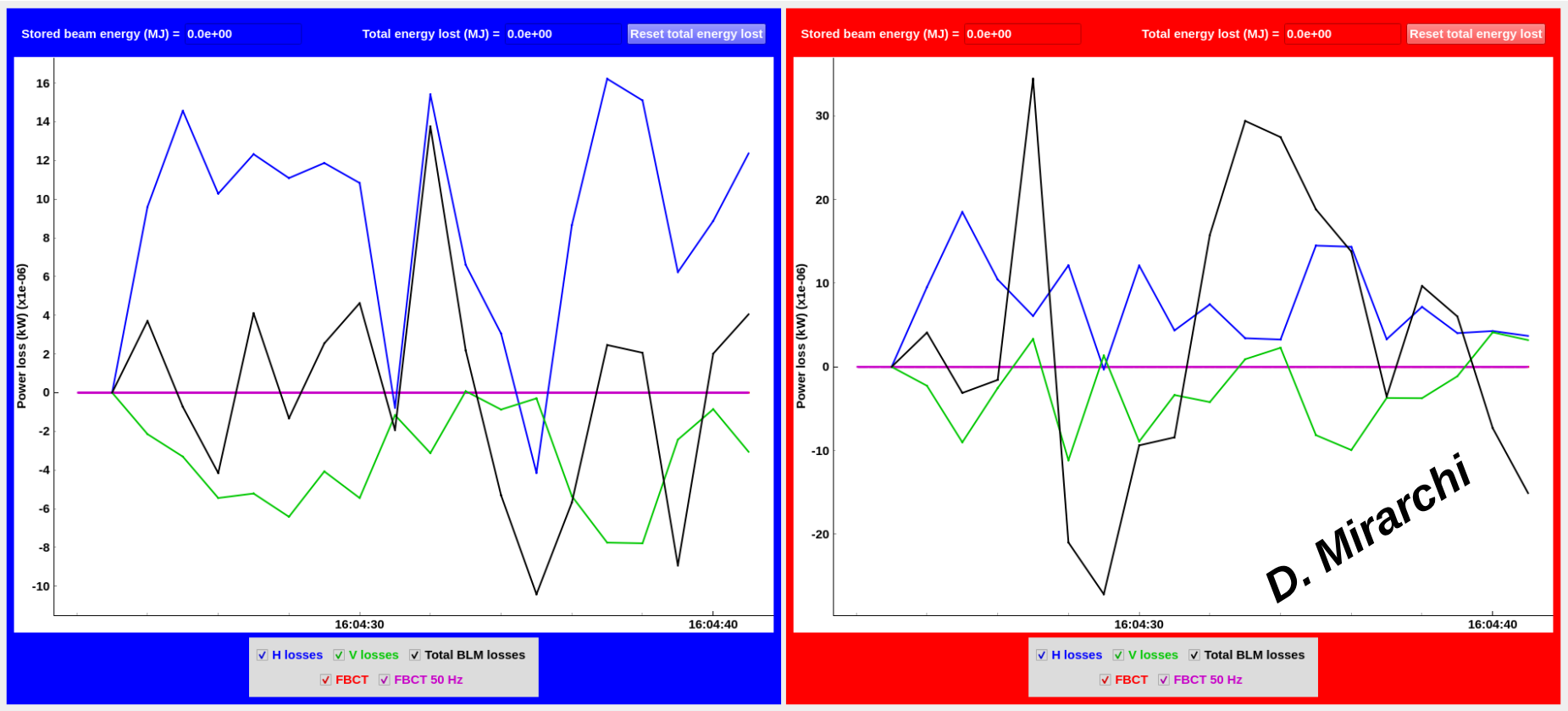
Optional (if no concerns from MP side) inject twice the bunch trains needed for one quench attempt

*) 3×48 bunches for 1.4e11 p/b or 4×48 bunches for 1.2e11 p/b

Collimator sequence ready



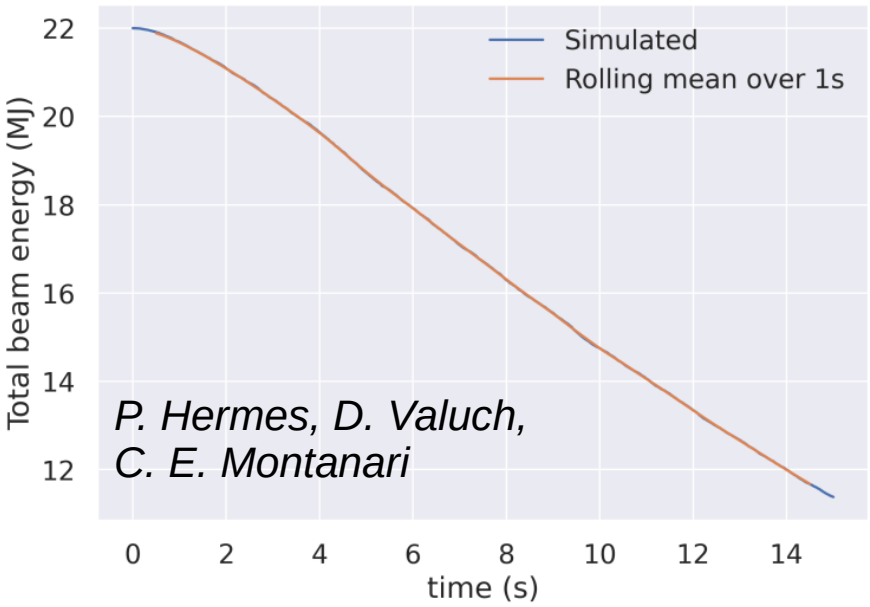
Power load monitoring



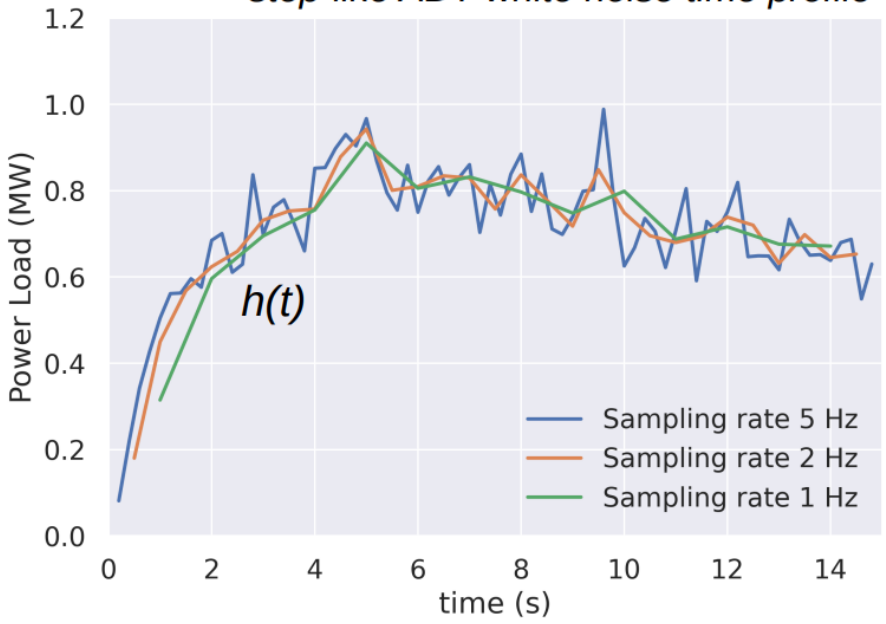
Preparatory ADT profile simulations

Derivative

Calculated from scaling initial stored beam energy with number of simulated macro-particles



Step response h(t) from step-like ADT white noise time profile



New tracking simulation approach with ADT excitation – maybe can save time in quench test (Quench test not relying on it)

Summary

Collimation quench test: crucial input for HL-LHC

Preparation completed for

- ✔ Choice of settings
- ✔ Energy deposition simulations: no showstoppers
- ✔ OP filling scheme
- ✔ OP functions for collimator movement (incl. Limits)
- ✔ OP power load monitoring tool

- BLM Threshold preparation status report by A. Lechner
- IR6 QPS symmetric thresholds: no change needed (MP3 feedback)

Round table