Aperture measurements in LHC Run 3 Commissioning

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On behalf of the LHC Collimation Team

Joint LNO/NDC section meeting

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Introduction

- Machine Aperture defines clearance for circulating beams
- **Aperture must be protected** by the collimation system

At injection:

Aperture measurements for clearance to inject high intensity beams

At collision:

Measured aperture of inner triplets at experimental IRs defines β^* reach

Beam based aperture measurements:

Crucial part of the LHC commissioning and early detection of issues in beam tests!

Aperture measurement techniques

Global

- Collimator scan method
- Beam based alignment (BBA)
- AC Dipole excitation (Tested in 2017 MD)

Delivers

- The smallest normalized aperture in the machine
- The location at which the normalized aperture is smallest (bottleneck)

Local

- Local orbit bump method

Delivers the geometrical aperture at a dedicated location of interest in 2D

Collimator scan method

Measurement

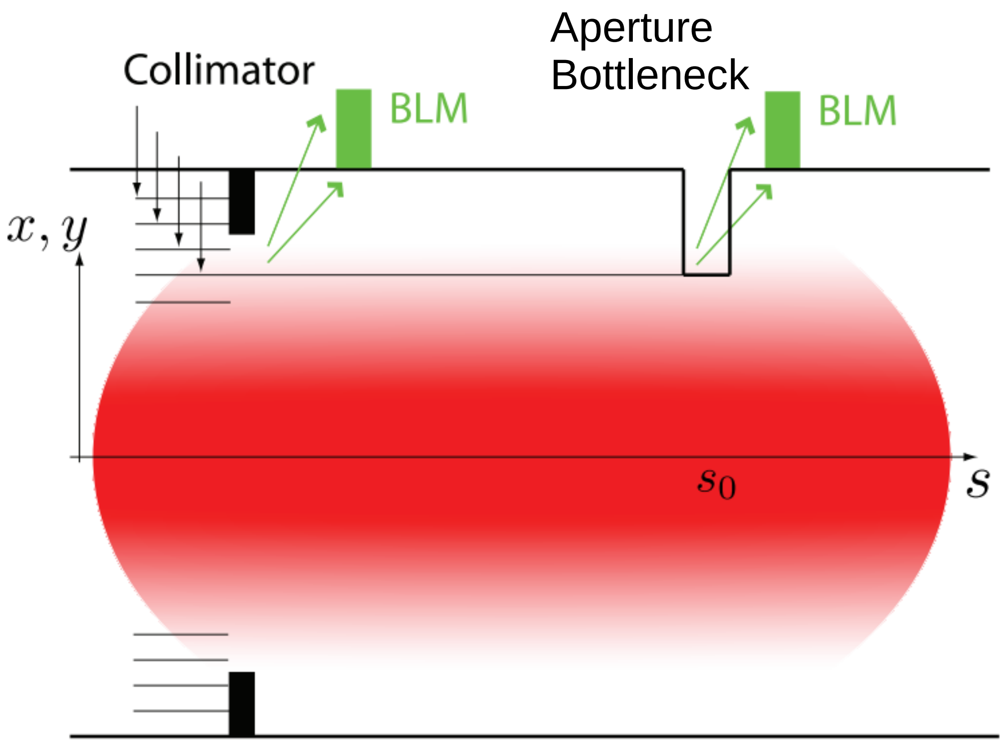
Step 1: Start with primary collimator at nominal gap

Step 2: Excite bunch with the transverse damper

Step 3: Retract TCP by a given step size

Step 4: Excite again with the transverse damper

Step 5: Repeat step 3 + 4



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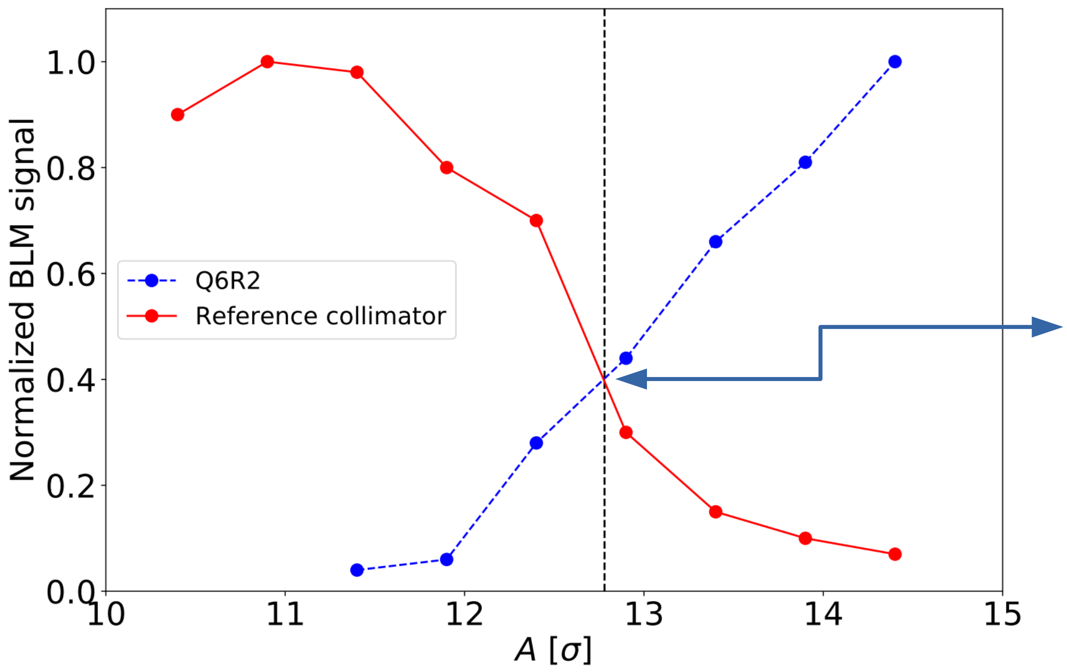
Collimator scan method



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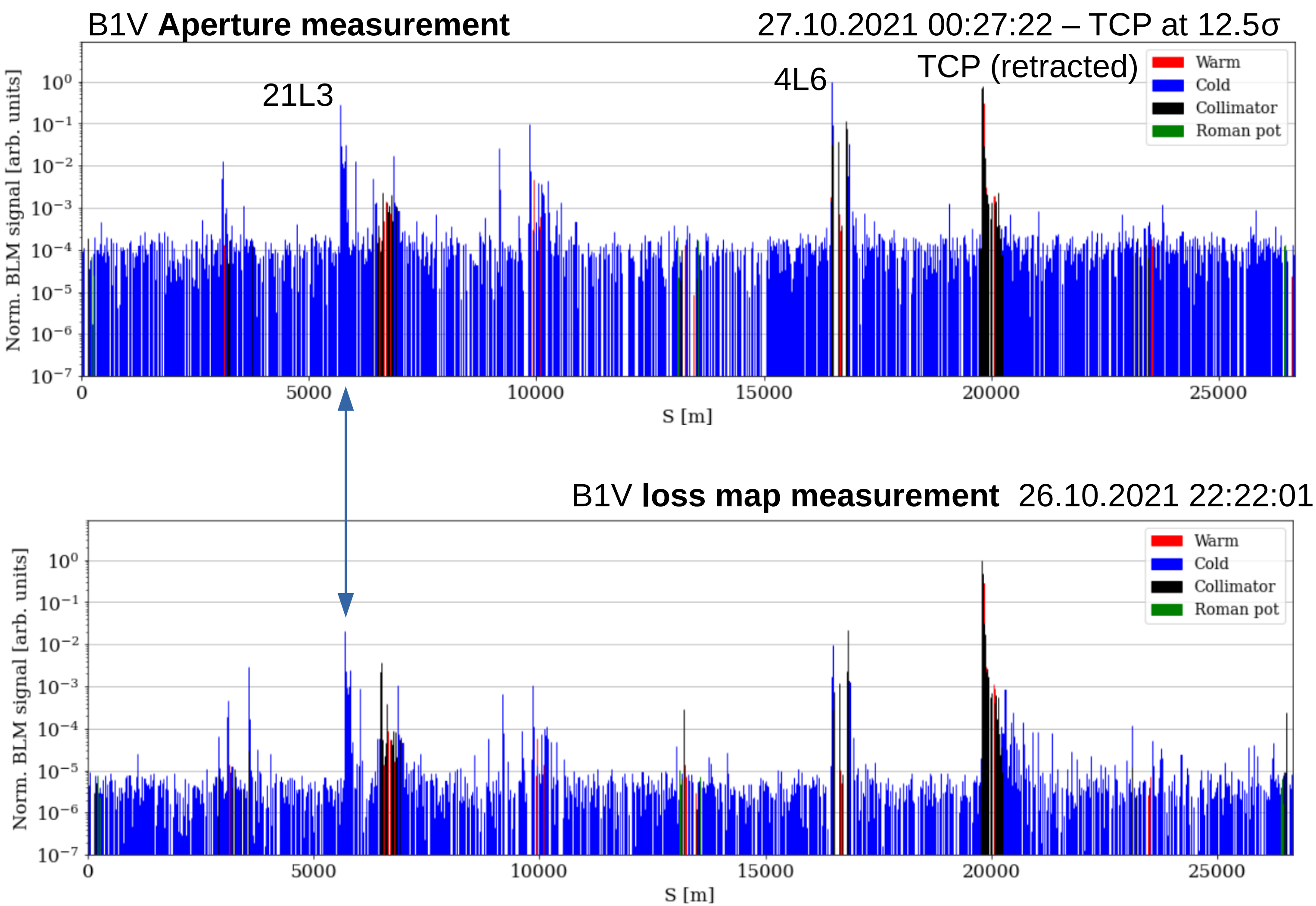
Analysis

Step 1: Normalize peak BLM signal at each excitation for reference collimator and location of aperture bottleneck

Step 2: Plot normalized BLM signals as function of collimator gap at excitation

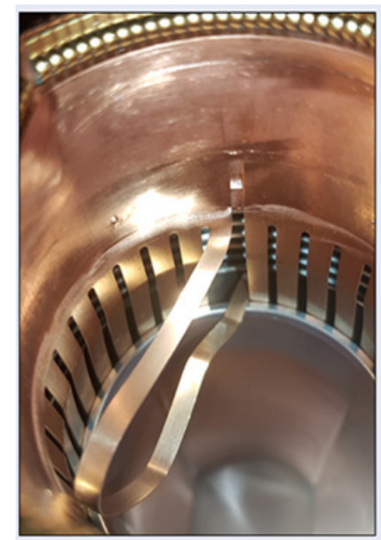
Step 3: Global aperture is amplitude where interpolated collimator and bottleneck BLM signals are identical

2021 – Discovery of the RF finger



21L3 was not the highest loss peak!

But: strange behaviour in BBA observed.



Buckled RF finger found in 21L3
Source: CERN Courrier

Measurement time and setup

4/24/2022	3					Sunday
	M	4	COL		Coarse collimator setup & global injection aperture	
	M	4	COL		Coarse collimator setup & global injection aperture/ NL optics	
	A	4	OMC		Optics at injection (NL)	
	A	4	OMC/OP		Optics at injection (NL) / 6.5 TeV ramp of ballistic optics, dumped, IT L2 quench	
	N	4	OP		Cryo recovery IT L2 quench	
	N	4	OP		Inject and dump sequence, BPM quality checks	

- First preliminary measurements done 24/04/2022 (morning)
- Flat machine without crossing or separation bump
- Global aperture: Applied collimator scan method
- Link to LHC Logbook

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Results

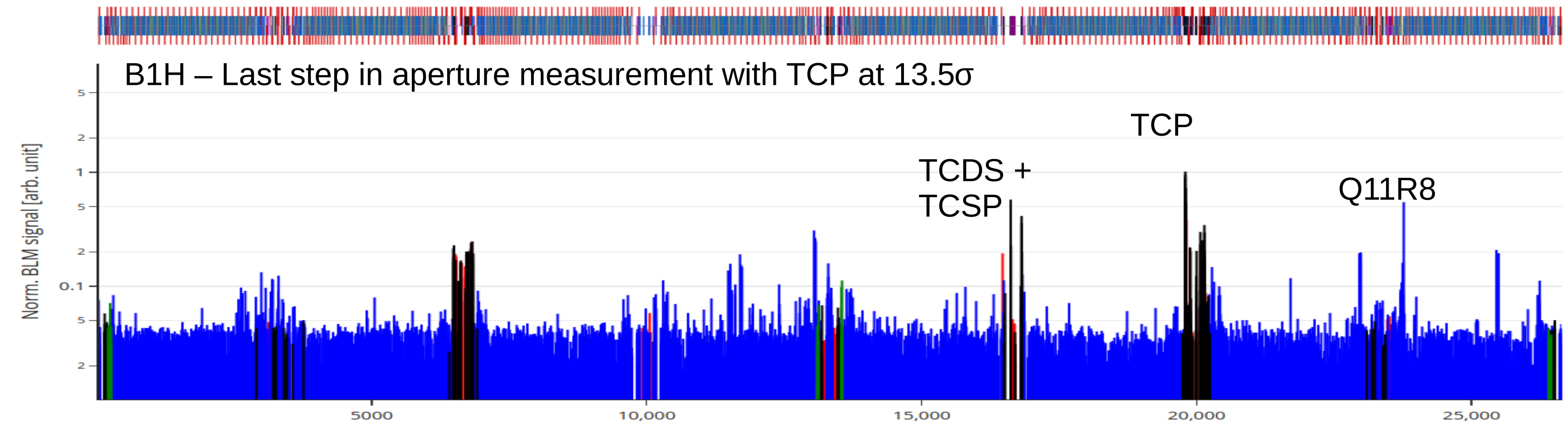
- Except B1V: global aperture bottleneck not found with collimator scan
- Next measurements: fully retract TCPs and cross-validate with beam based alignment (BBA) method (at which amplitude was the halo scraped?)
- TCP alignment issue B2H: impact on aperture?

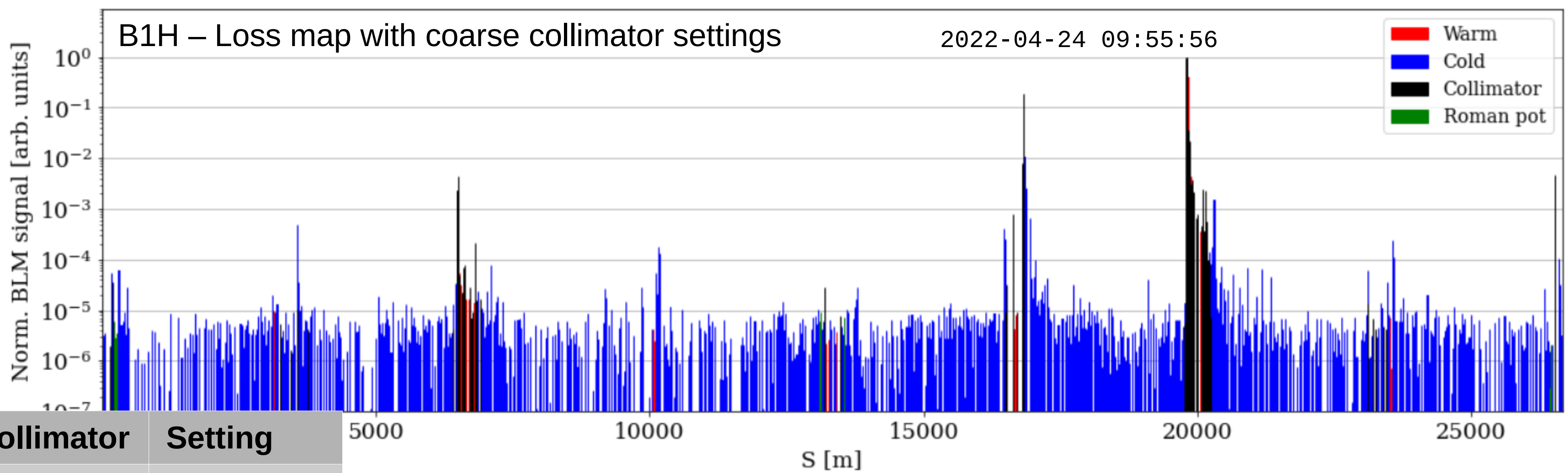
	2022		2018	
Plane	**Aperture (σ)**	**Bottleneck**	**Aperture (σ)**	**Bottleneck**
B1H	>13	Not found	13.3 – 13.8	Q4R6
B1V	12.5-13.0	Q4L6	12.2 – 12.7	Q4L6
B2H	> 13	~Warm IR6	13.0 – 13.5	Q4L6/Q6L8
B2V	> 13	~Q4R6	12.5 – 13.0	Q4R6

Without bumps With bumps

LHC Logbook

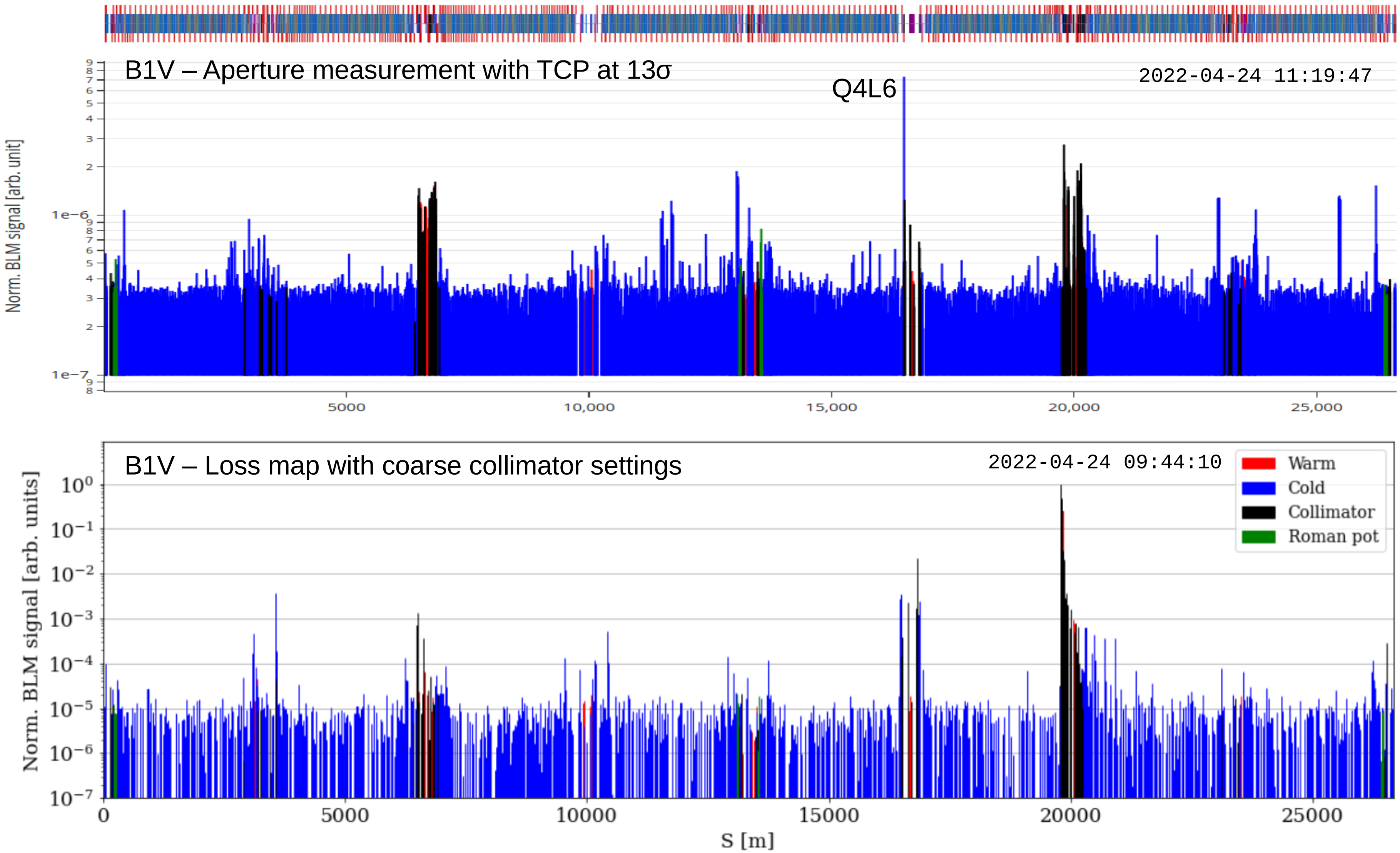
Results – B1H





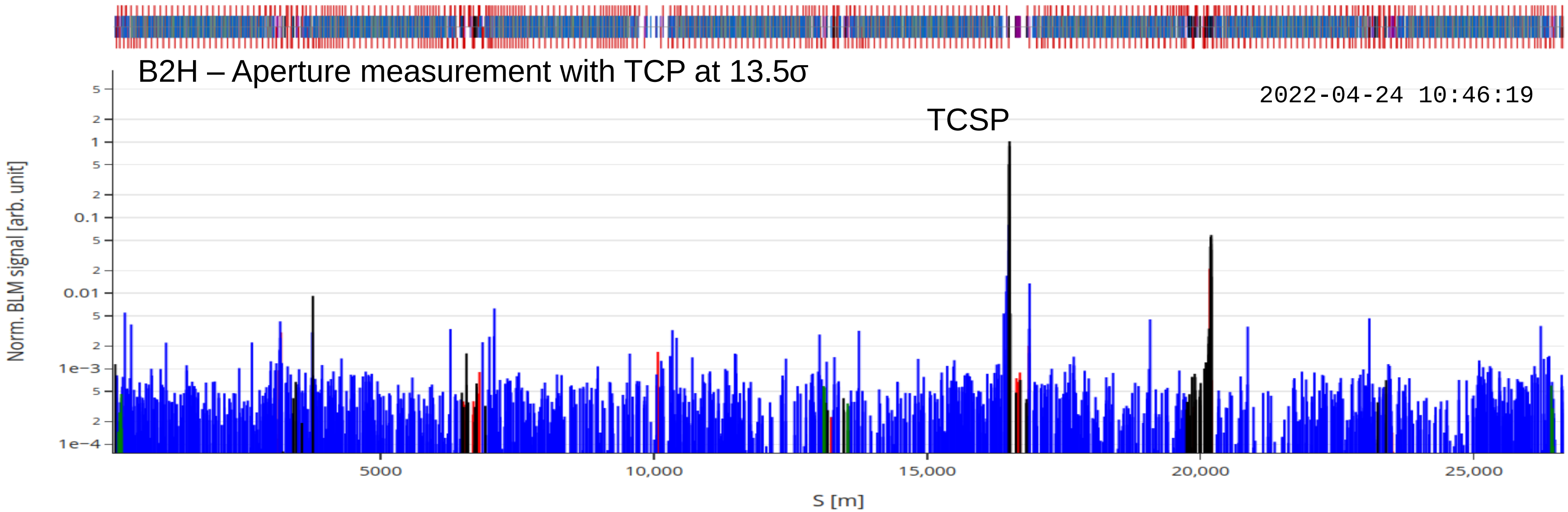
Collimator	Setting
TCP3	12 σ
TCP7	8 σ
TCSP6	10 σ
TCT	15mm

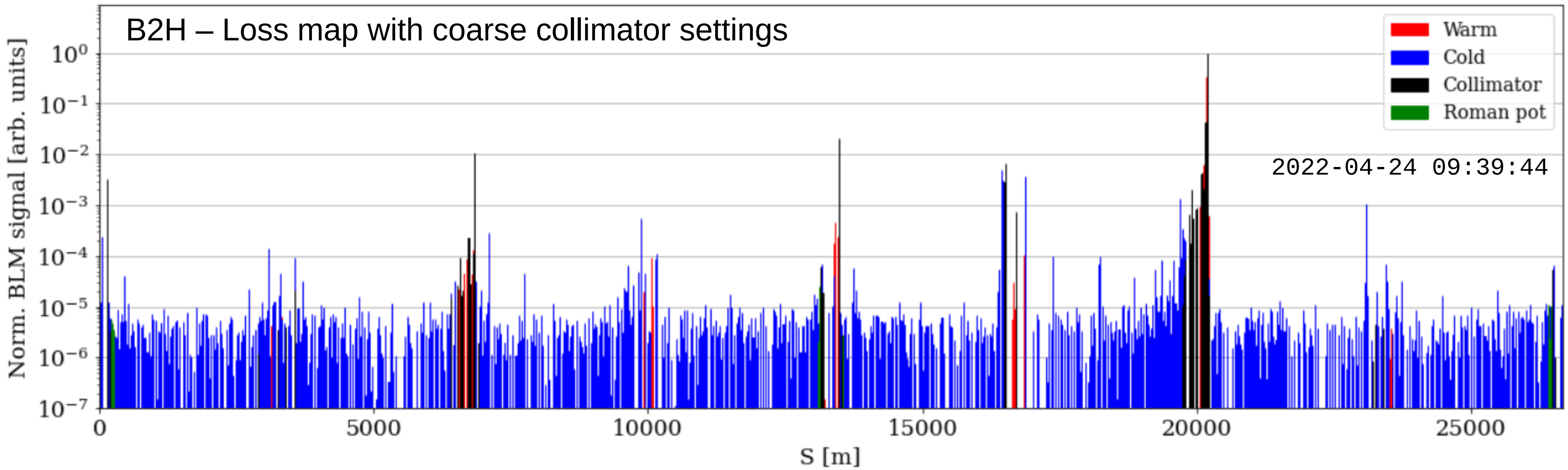
Results – B1V



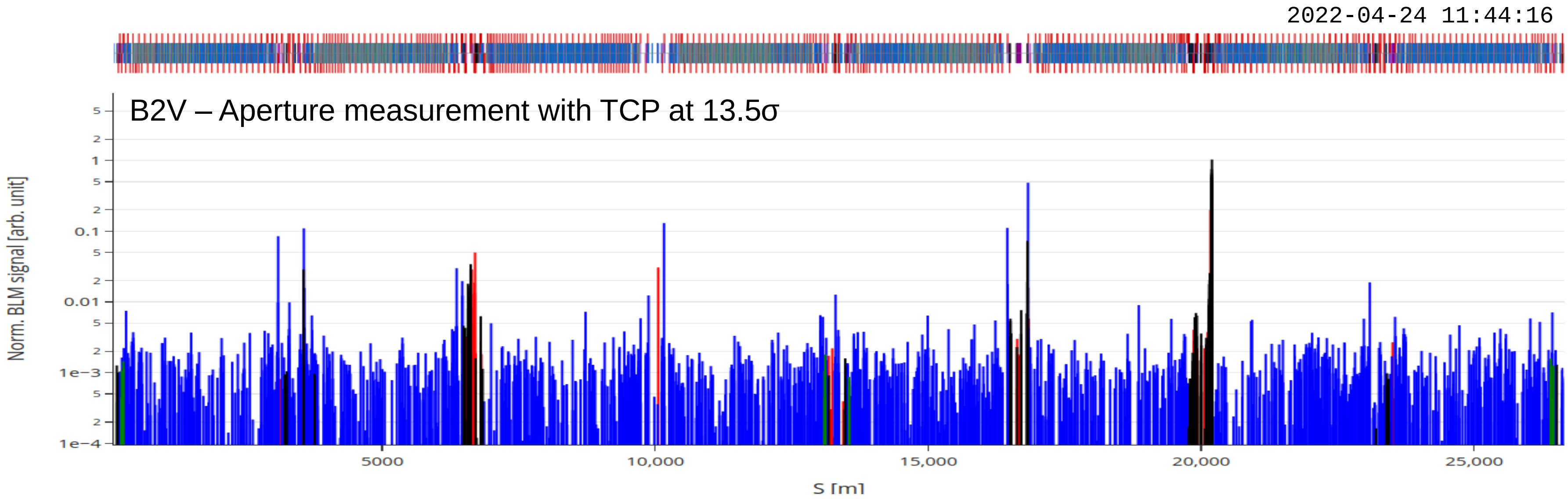
B1V – Aperture measurement with TCP at 13σ
2022-04-24 11:19:47
Q4L6
Norm. BLM signal [arb. unit]
1e−6
1e−7
5000
10,000
15,000
20,000
25,000
B1V – Loss map with coarse collimator settings
2022-04-24 09:44:10
Warm
Cold
Collimator
Roman pot
Norm. BLM signal [arb. units]
S [m]

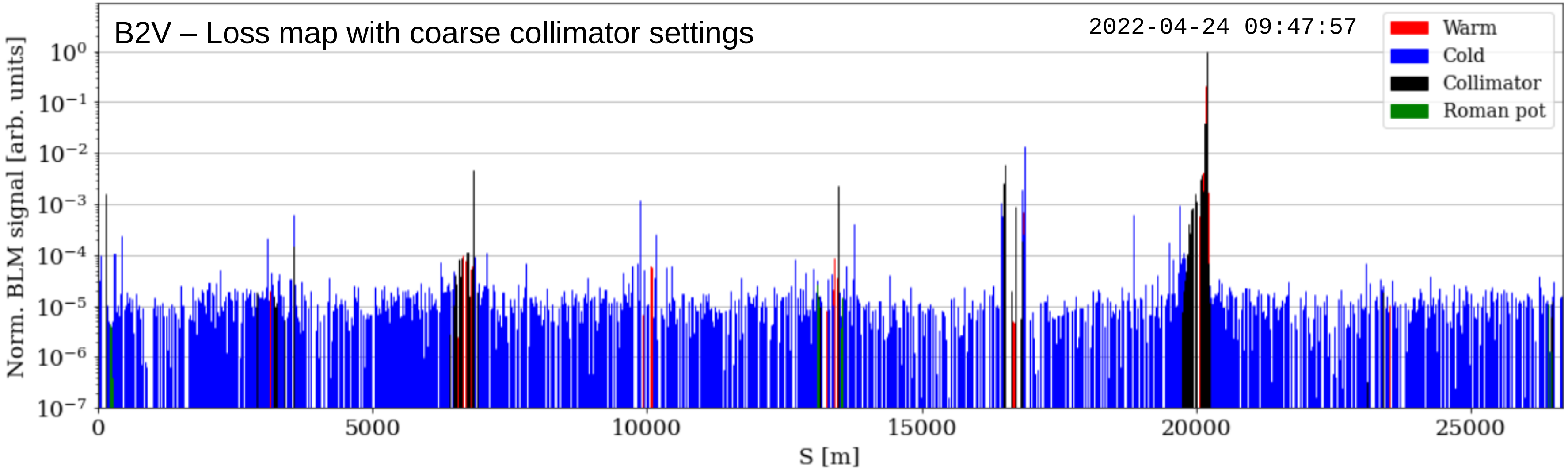
Results – B2H


B2H – Aperture measurement with TCP at 13.5σ
2022-04-24 10:46:19
TCSP
Norm. BLM signal [arb. unit]
S [m]


B2H – Loss map with coarse collimator settings
Warm
Cold
Collimator
Roman pot
2022-04-24 09:39:44
Norm. BLM signal [arb. units]
S [m]

Results – B2V


2022-04-24 11:44:16
B2V – Aperture measurement with TCP at 13.5σ
Norm. BLM signal [arb. unit]
S [m]


B2V – Loss map with coarse collimator settings
2022-04-24 09:47:57
Warm
Cold
Collimator
Roman pot
Norm. BLM signal [arb. units]
S [m]

Summary

- First preliminary aperture measurements at injection (flat machine)
- Good aperture measured – no obvious show stoppers identified
- Collimator scans should be analysed together with measured loss maps + BBA method

Outlook Run3 Commissioning

- Verify results with BBA method (future: perform at the end of each collimator scan measurement)
- Repeat injection measurements with established reference orbit + optics: defines clearance for high intensity
- Global + local measurements with squeezed beams at top energy: defines β* - reach

LHC Logbook

Previous measurements

Table 4. Summary of the measured global aperture bottlenecks per beam and plane at injection energy. The aperture measurements are expressed by the reference collimator half-gap before and after exposing the bottleneck. All values are given in units of beam size σ, for ϵ_n =3.5 μm. The bottleneck location is also indicated for each beam and plane and the beam-based aperture measurement method used.

	E [TeV]	**Method**	**B1H**	**B1V**	**B2H**	**B2V**
2010	0.450	Tune resonance blow-up +coll. scan	12.5-13.0 (Q6R2)	13.5-14.0 (Q4L6)	14.0-14.5 (Q5R6)	13.0-13.5 (Q4R6)
2011	0.450	Tune resonance blow-up +coll. scan	12.0-12.5 (Q6R2)	13.0-13.5 (Q4L2)	12.5-13.0 (Q5R6)	13.1-13.6 (Q4R6)
2012	0.450	Controlled white noise emittance blow-up+coll. scan	11.5-12.0 (Q6R2)	12.0-12.5 (Q4L6)	12.5-13.0 (Q5R6)	12.5-13.0 (Q4R6)
2015	0.450	Controlled white noise emittance blow-up+coll. scan	11.6-12.1 (MBRC.4R8)	12.1-12.6 (Q6L4)	12.5-13.0 (Q6L6)	12.0-12.5 (Q4R6)
2016	0.450	Controlled white noise emittance blow-up+coll. scan	12.5-13.0 (MBRC.4R8)	12.0-12.5 (Q6L4)	12.5-13.0 (TCDQM.4L6)	12.5-13.0 (Q4R6)
2017	0.450	Controlled white noise emittance blow-up+coll scan	13.1-13.6 (Q6R2)	12.2-12.7 (Q4L6)	13.2-13.7 (Q6L8)	12.8-13.3 (Q4R6)
2018	0.450	Controlled white noise emittance blow-up+coll scan	13.3-13.8 (Q4R6)	12.2-12.7 (Q4L6)	13-13.5 (Q4L6 & Q6L8)	12.5-13.0 (Q4R6)

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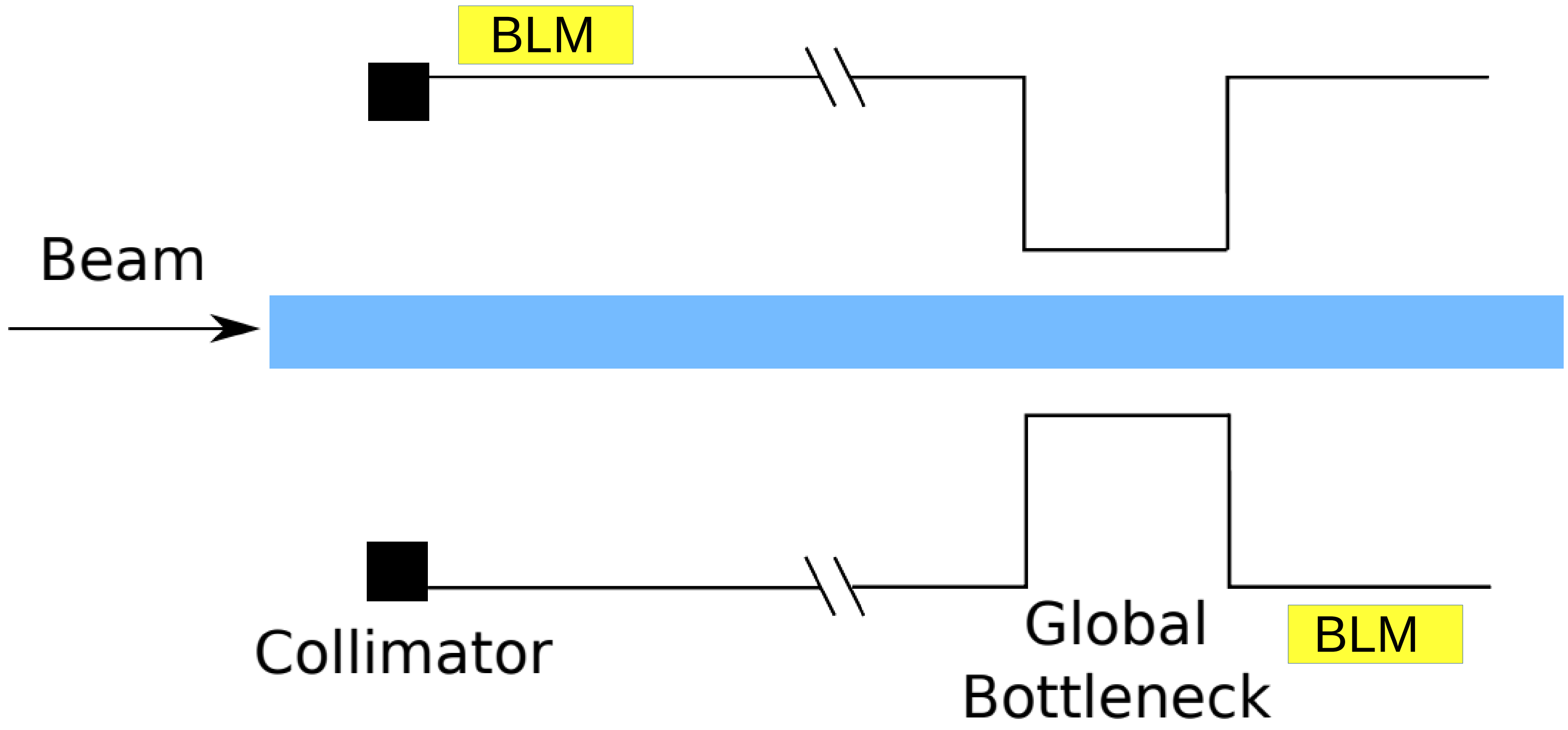
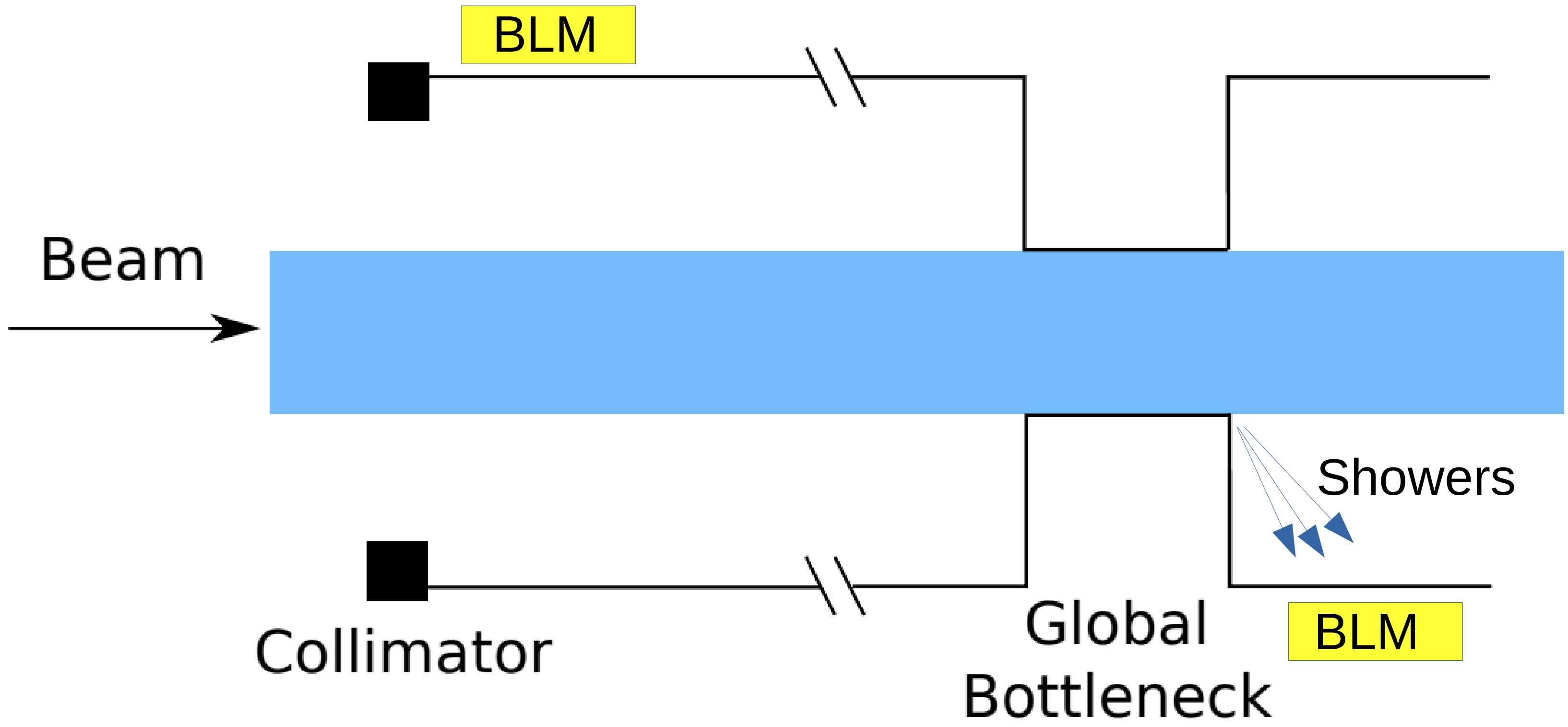
Beam-based alignment method

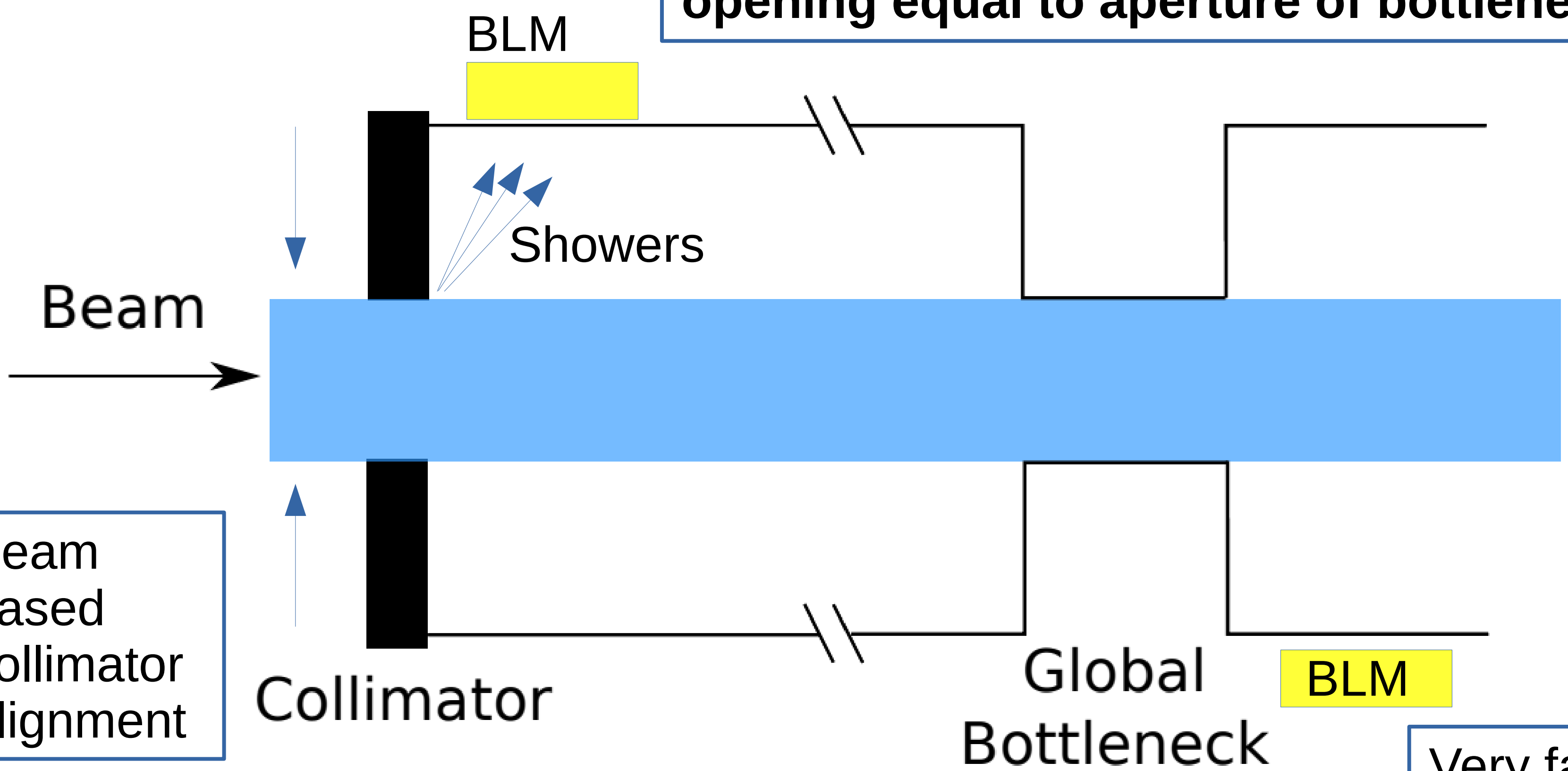


Beam-based alignment method



Beam-based alignment method

BLM signal spike when collimator opening equal to aperture of bottleneck



Beam based collimator alignment

Very fast method!

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