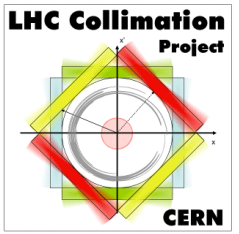

LHC aperture and ULO restrictions: are they a possible limitation in 2016?

D. Mirarchi, R. Bruce, M. Giovannozzi, P. Hermes,
S. Redaelli, B. Salvachua, G. Valentino, J. Wenninger

Special thanks to BE-OP for the support during measurements,
and to BE-ABP for internal discussions

Evian, 15th December 2015

Introduction

- Available **machine aperture crucial** parameter for the **LHC operations**:
  - At **450 GeV**: historical concerns on **tight aperture** design in superconductive magnets
  - At **6.5 TeV**: **reach in β^*** strongly connected with triplet aperture
- Precise knowledge of available aperture crucial to **push machine performance**
- Adequate **protection of bottleneck** has to be ensured at any time by the collimation system

Margins on collimation hierarchy rescaled to ensure the best cleaning and machine protection performances (see Roderik's talk on Thursday)

Thus:

- ✓ **Aperture measurements** performed every year during machine **commissioning (and MD)**
- ✓ Significant **UFO activity** in cell **15R8** triggered various studies that revealed the presence of an **unexpected restriction**: **U**nidentified **L**ying **O**bject

Outline

- **ULO:**
  - ✓ **ULO evolution in 2015**
  - ✓ **Where are we now?**
  - ✓ **How can we deal with it in 2016?**
  - ✓ **UFO at the ULO feature, activity and monitoring**
- **Overview of 2015 aperture:**
  - ✓ **450 GeV**
  - ✓ **Proton physics: 80cm and 40cm β^***
  - ✓ **Ions configuration**
- **Conclusions**

Outline

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  - ✓ **Ions configuration**
- **Conclusions**

Motivations

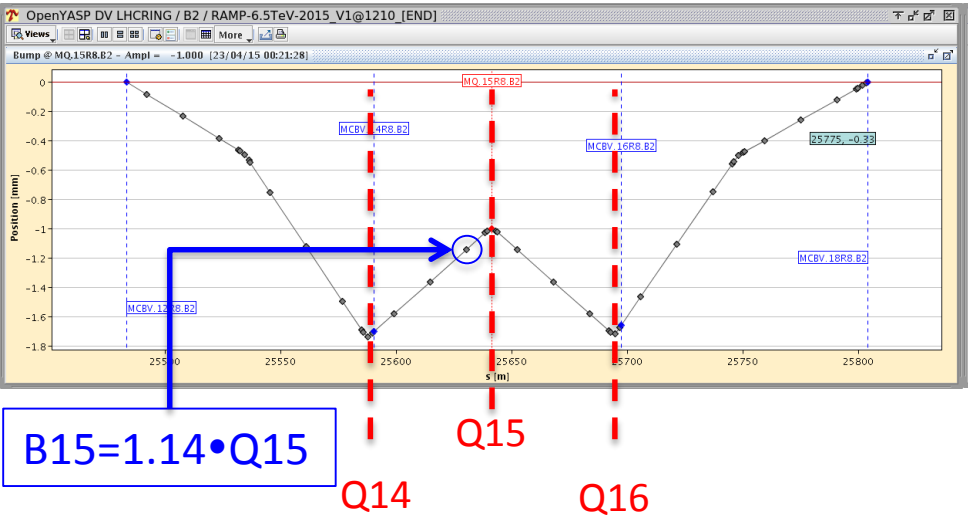
- ✓ **Significant UFO activity in cell 15R8** during machine commissioning (14 dump, 3 quench)
  - Energy dep. studies indicated **vertex of hadronic showers in MB.15R8.B2** (A. Lechner)

- ✓ Several **scans of local aperture** performed (12 between April and May)
  - Revealed presence of an **U**nidentified **L**ying **O**bject

- ✓ **Investigations** on beam loss at the ULO location rely on three **main observables**:
  - Dedicated **local aperture measurements**
  - Analysis of **UFOs at the ULO** location
  - **Parasitic monitoring** of beam losses during standard cycles

Measurement procedure

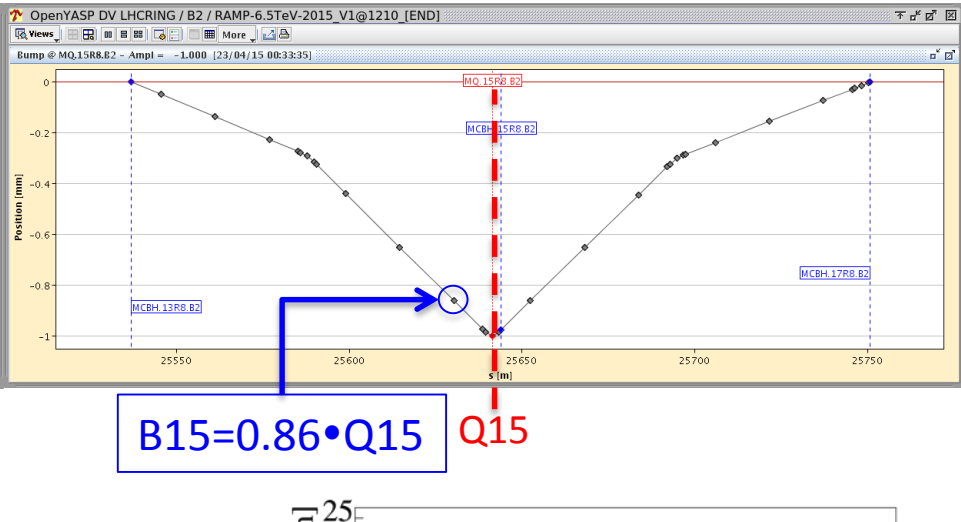
4 correctors bump in V plane



B15=1.14•Q15

Q14 Q15 Q16

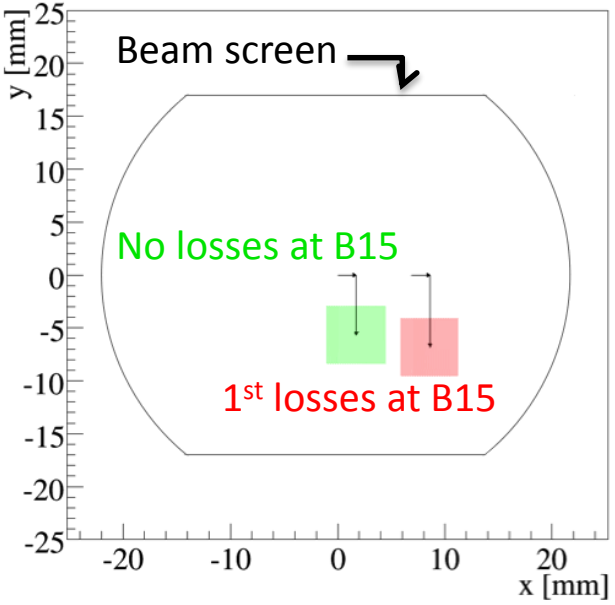
3 correctors bump in H plane



B15=0.86•Q15 Q15

Main measurement features:

- **Beam shaped with IR7-TCPs**: 4σ in V and 2σ in H
- **Local aperture probed** systematically:
  - Steps of **0.5mm at 450 GeV** and **0.2mm at 6.5 TeV**
- **Max bump** excursion:
  - in **H** ~ **±14mm** (losses on Q15)
  - in **V** ~ **±8mm** (losses on Q14 and Q16)

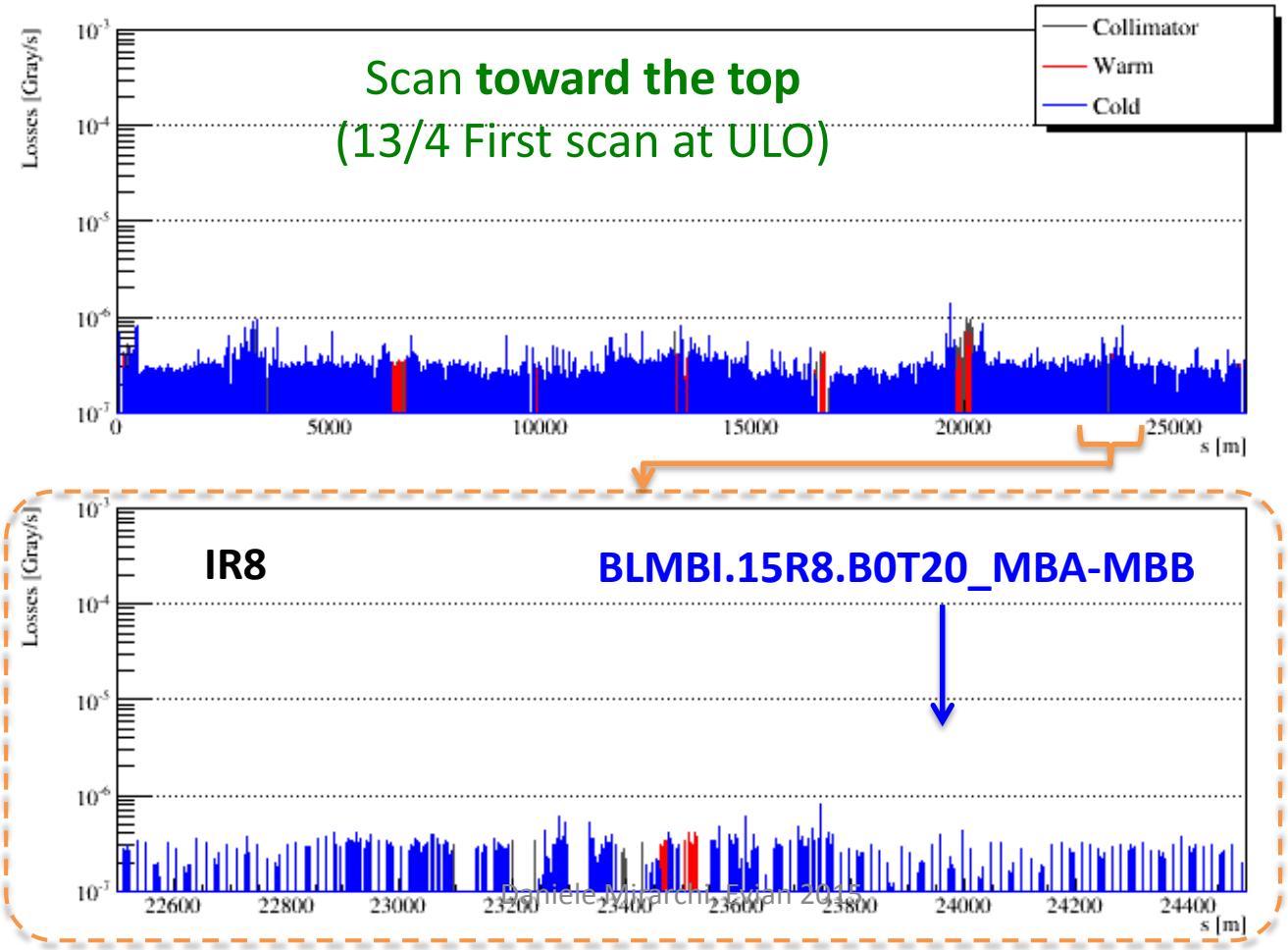


Local aperture scan

- **Was it there** from the beginning of RunII?

  Initial though: **something frozen** on the top of the beam pipe **fallen due to warm up**

Answer: **YES**, *it was there on the bottom but seems grown after the first warm up*



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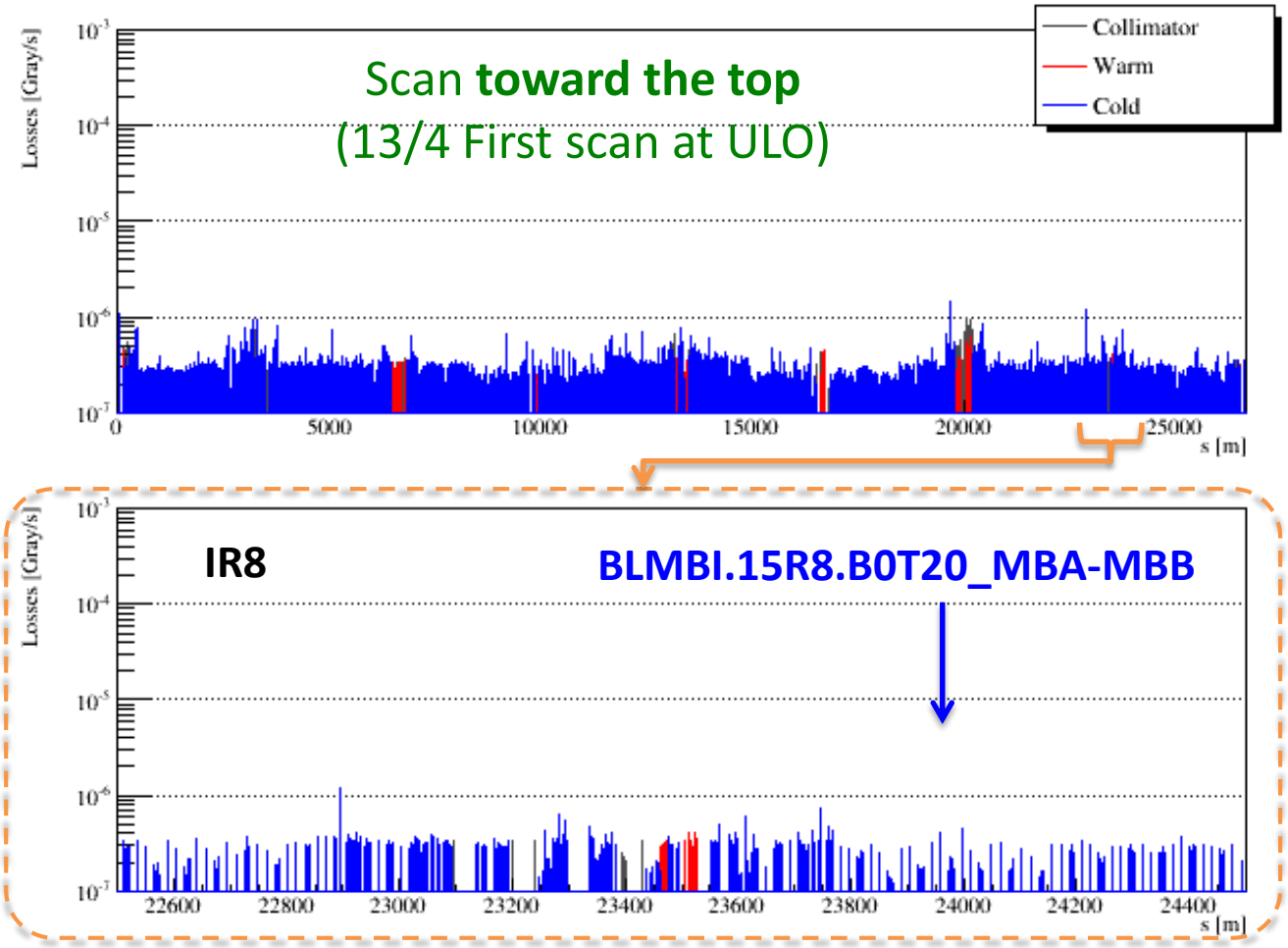

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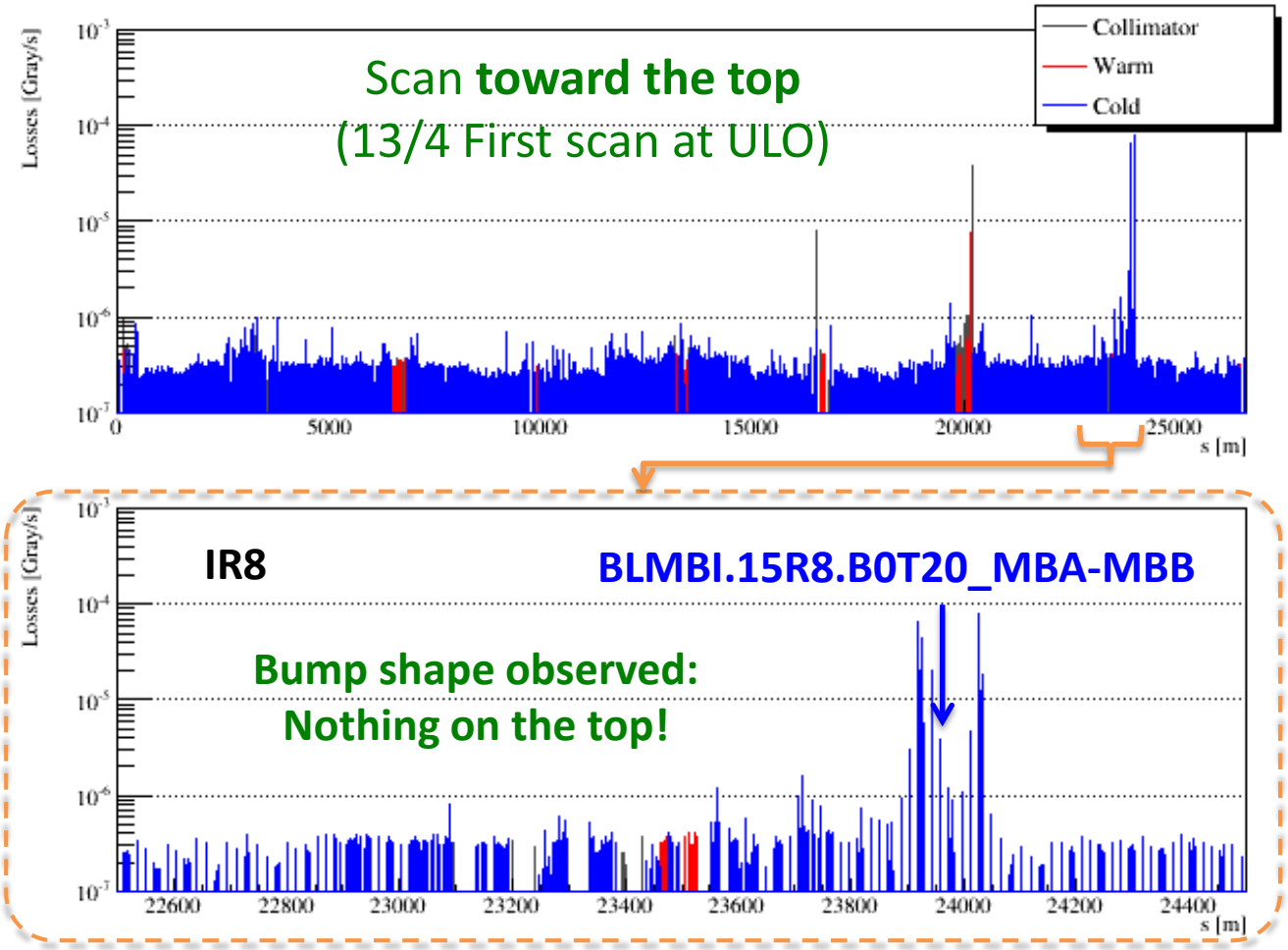

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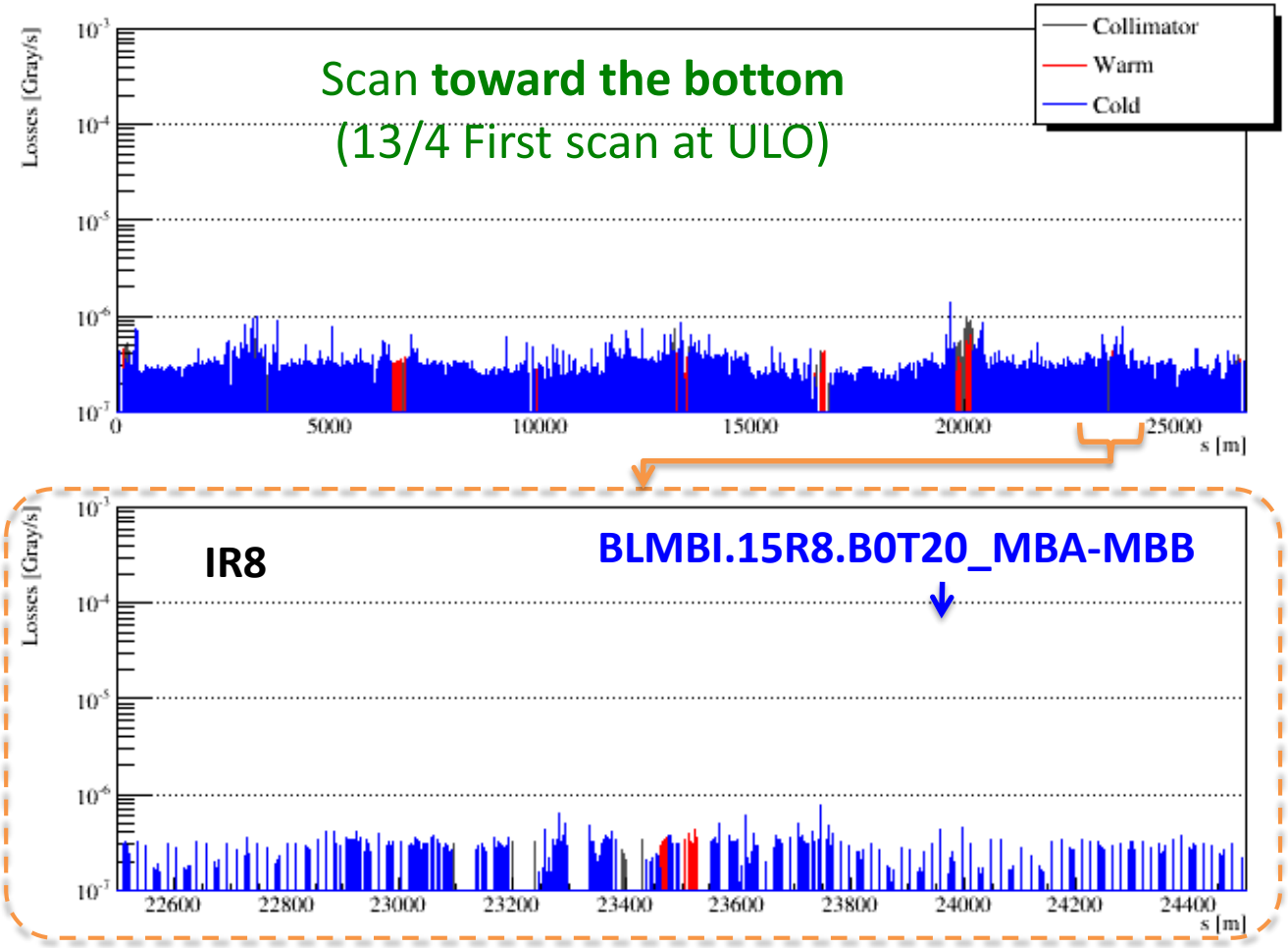

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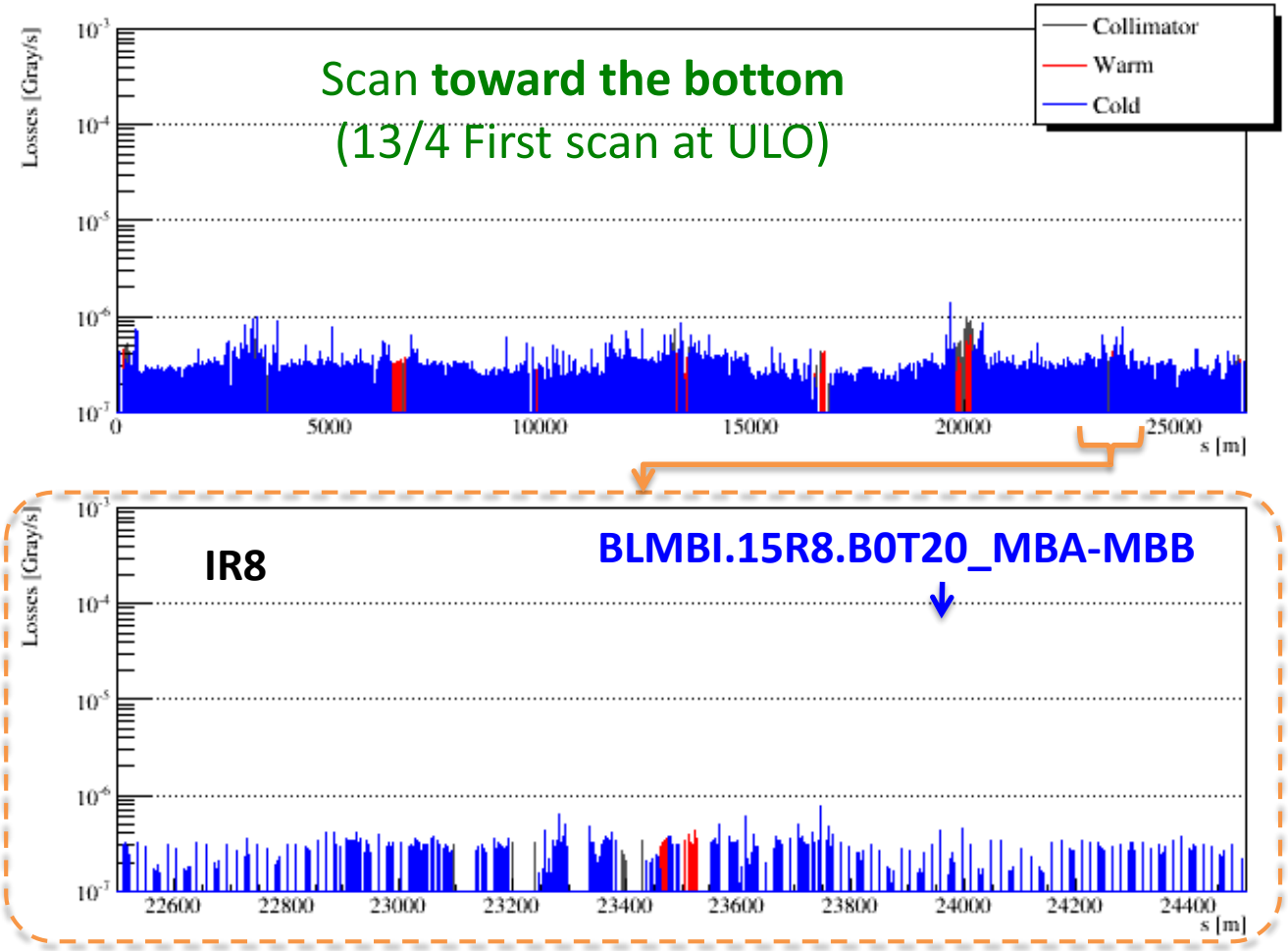

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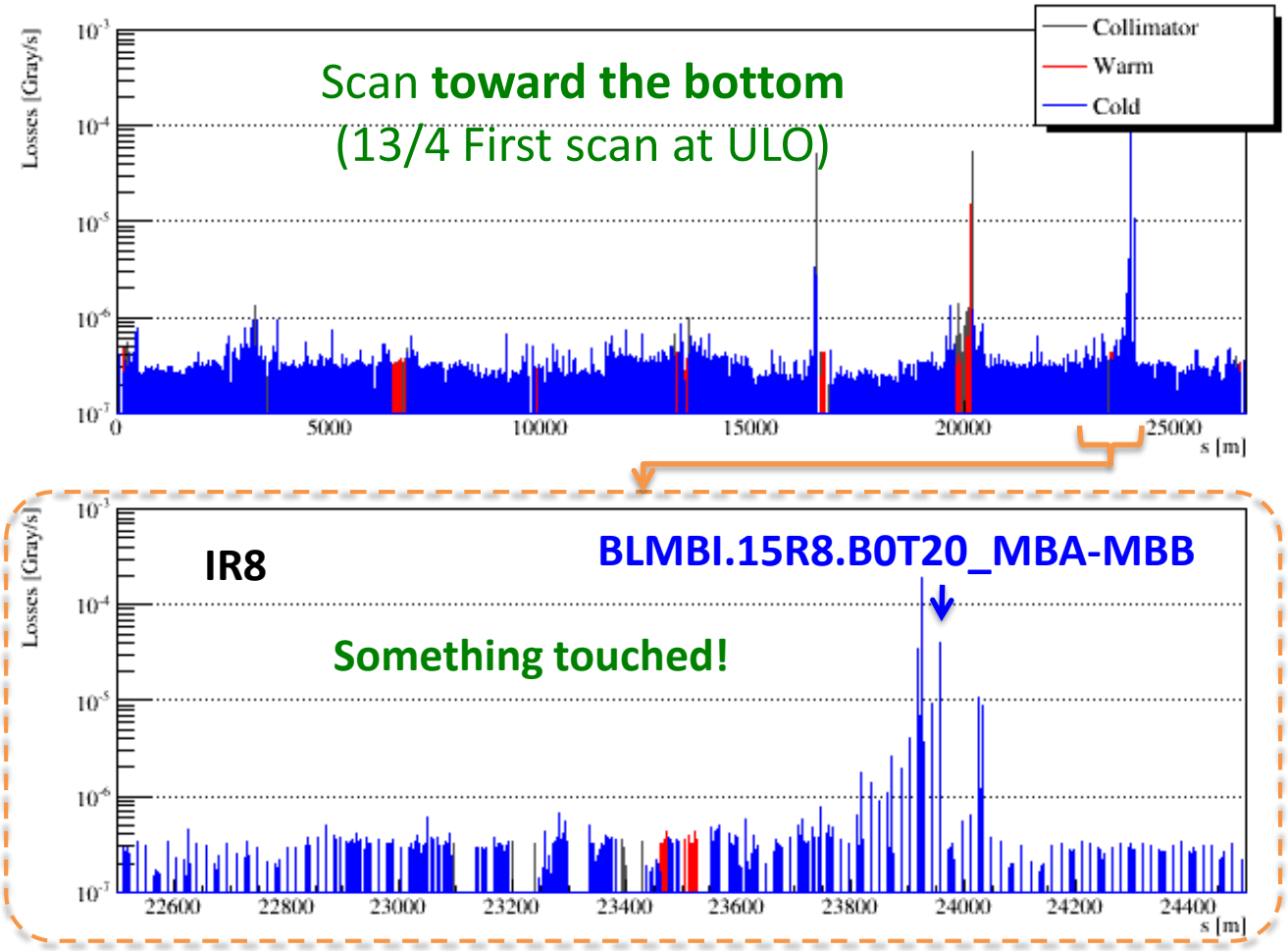

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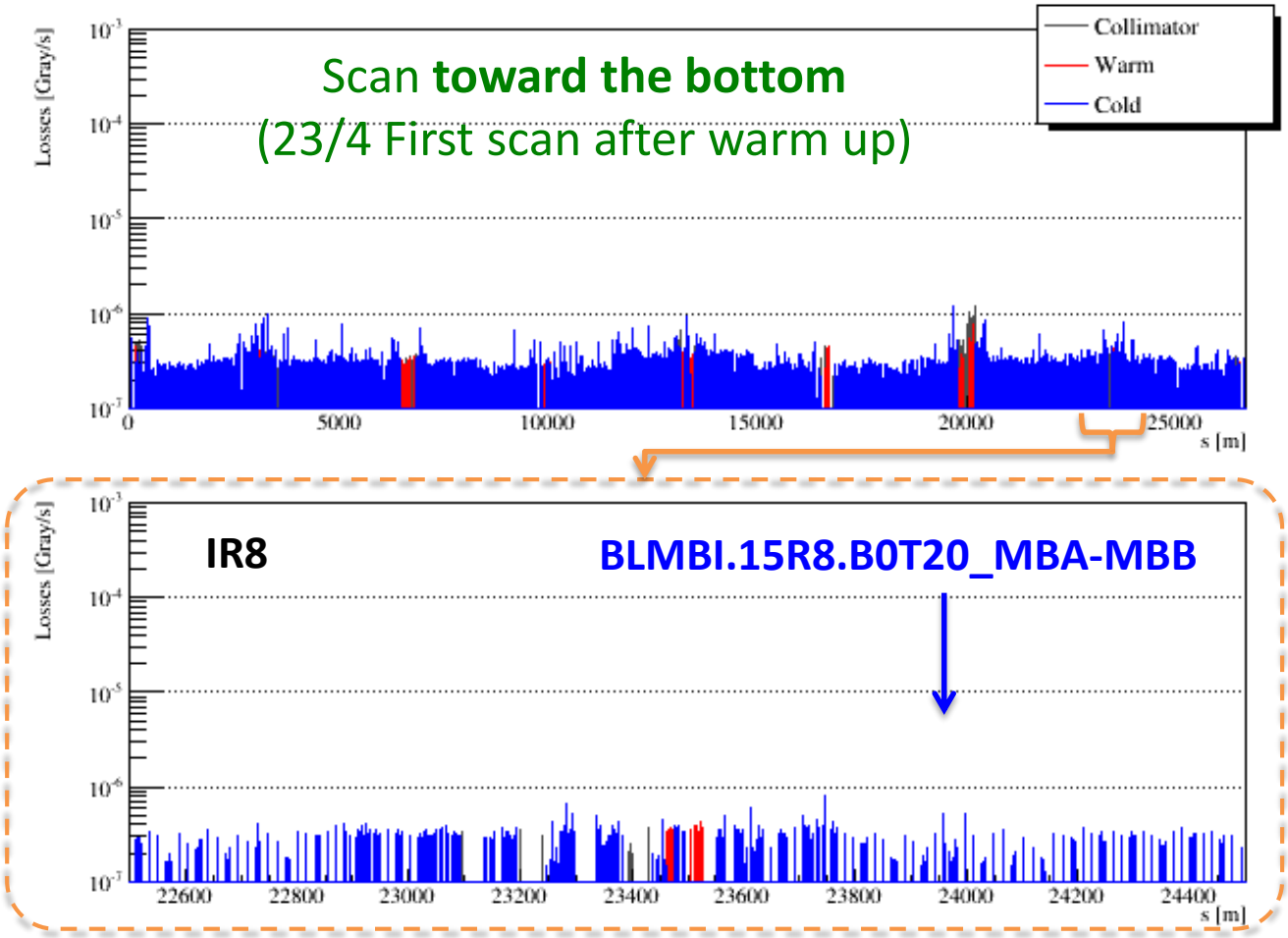

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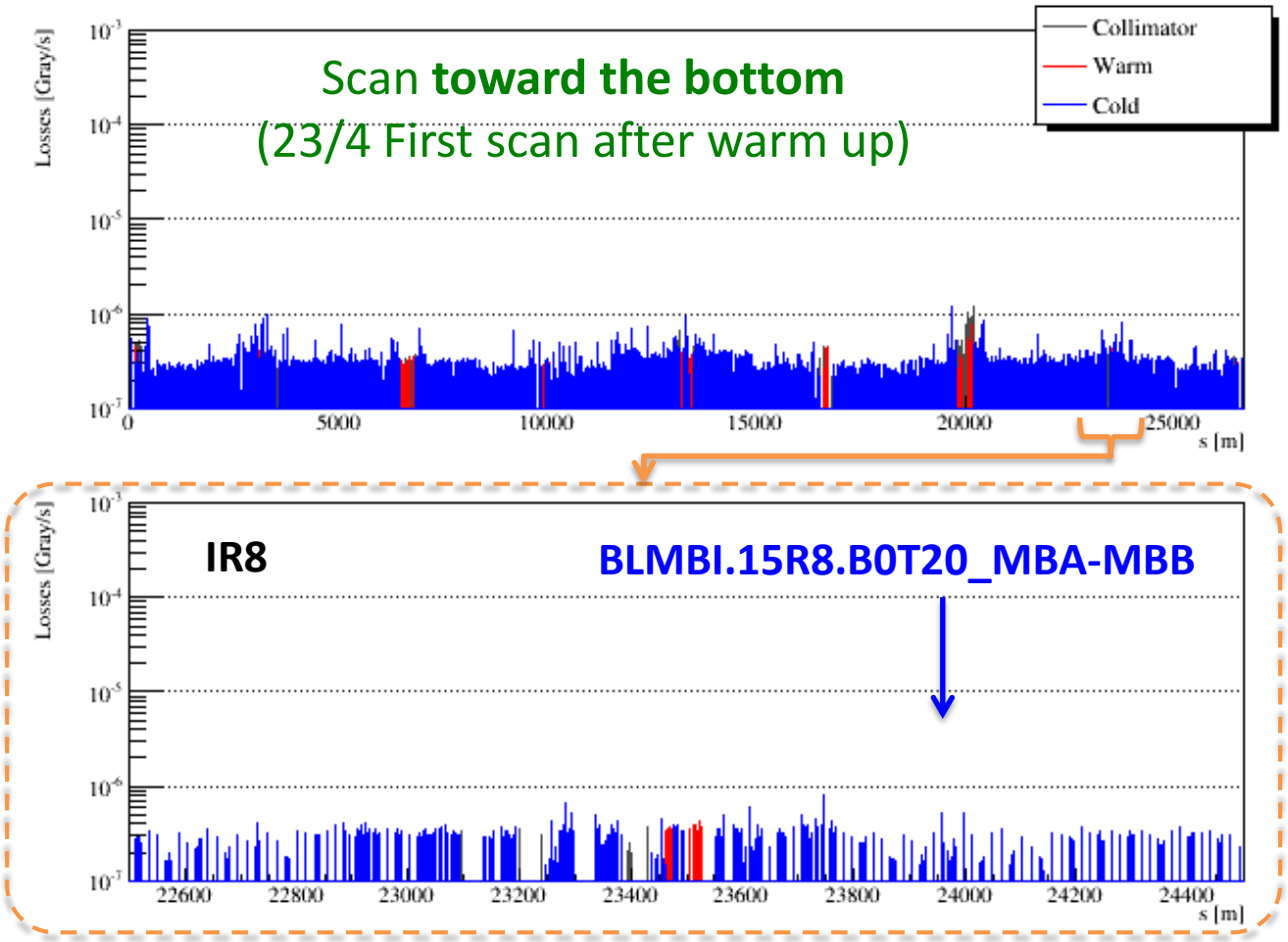

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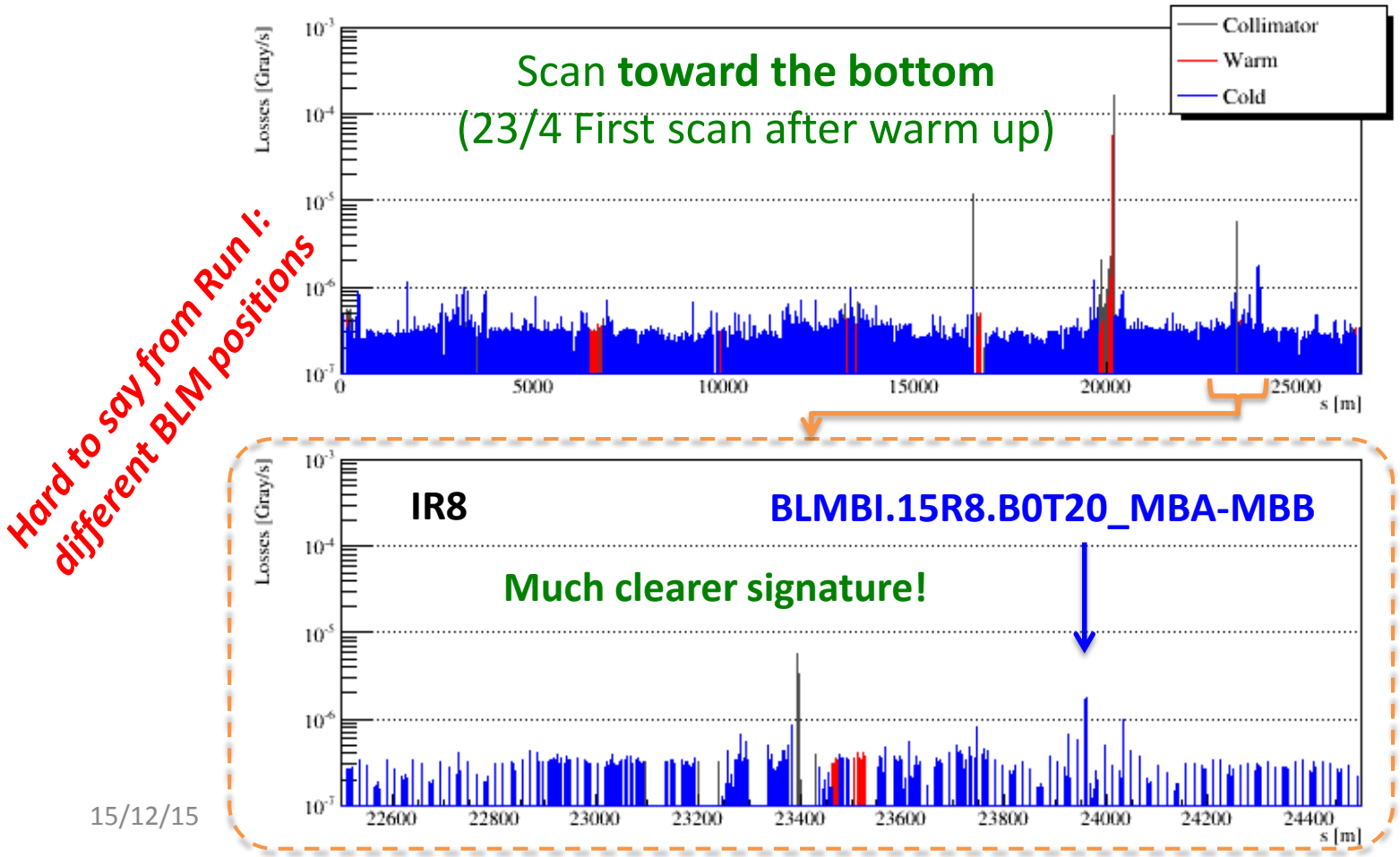
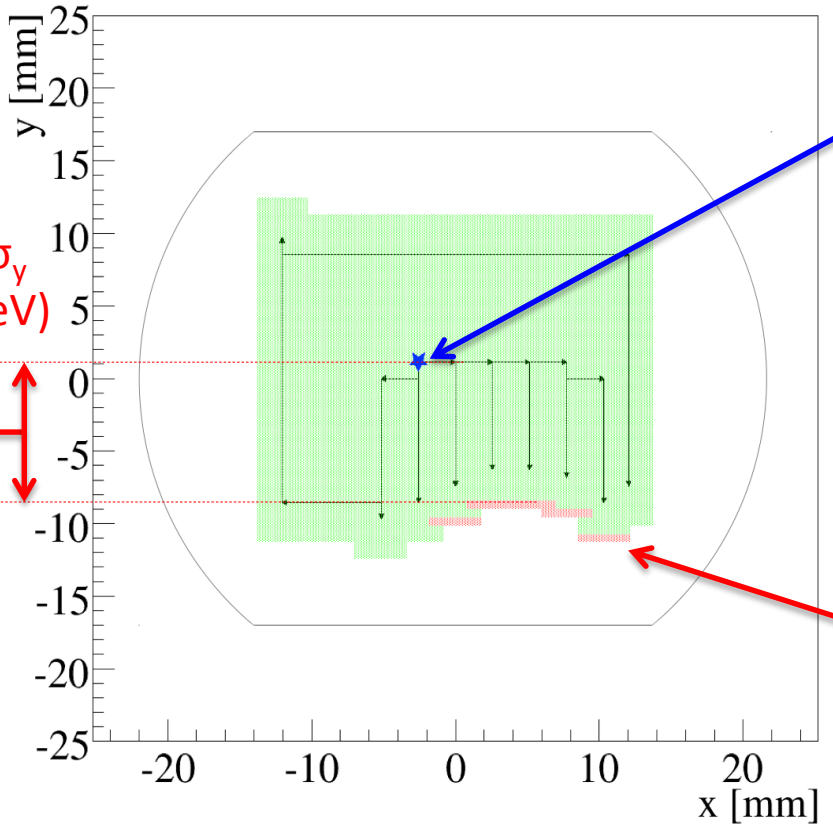


ULO restriction in May 2015

Vertical restriction **not constant**: typically 13-14 σ at injection, but in a few cases less than 8 σ

Horizontal position of ULO **stable**: *deployed local orbit bumps*



~13-14 σ_y (@ 450 GeV)

Fixed bump of:
H = -3mm
V = +1mm

Edge of the object

No obvious limitations in operations (losses, collimation cleaning) **after bumps** were deployed

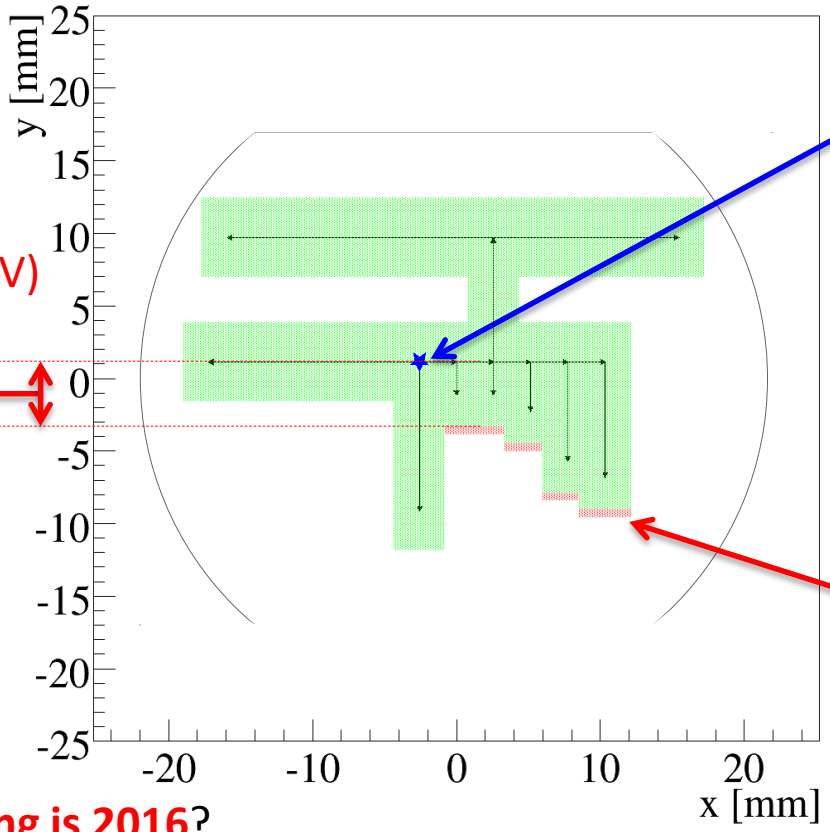
Checked correlations with: intensity, energy, present and previous machine mode

No clear correlation found!

ULO restriction now?

- Local aperture **scan repeated** with protons **(15/11)** and lead beams **(10/12)**

  ↳ Consistent results obtained: *vertical dimension increased*



~5-6 σ_y (@ 450 GeV)

Fixed bump of:
H = -3mm
V = +1mm

Edge of the object

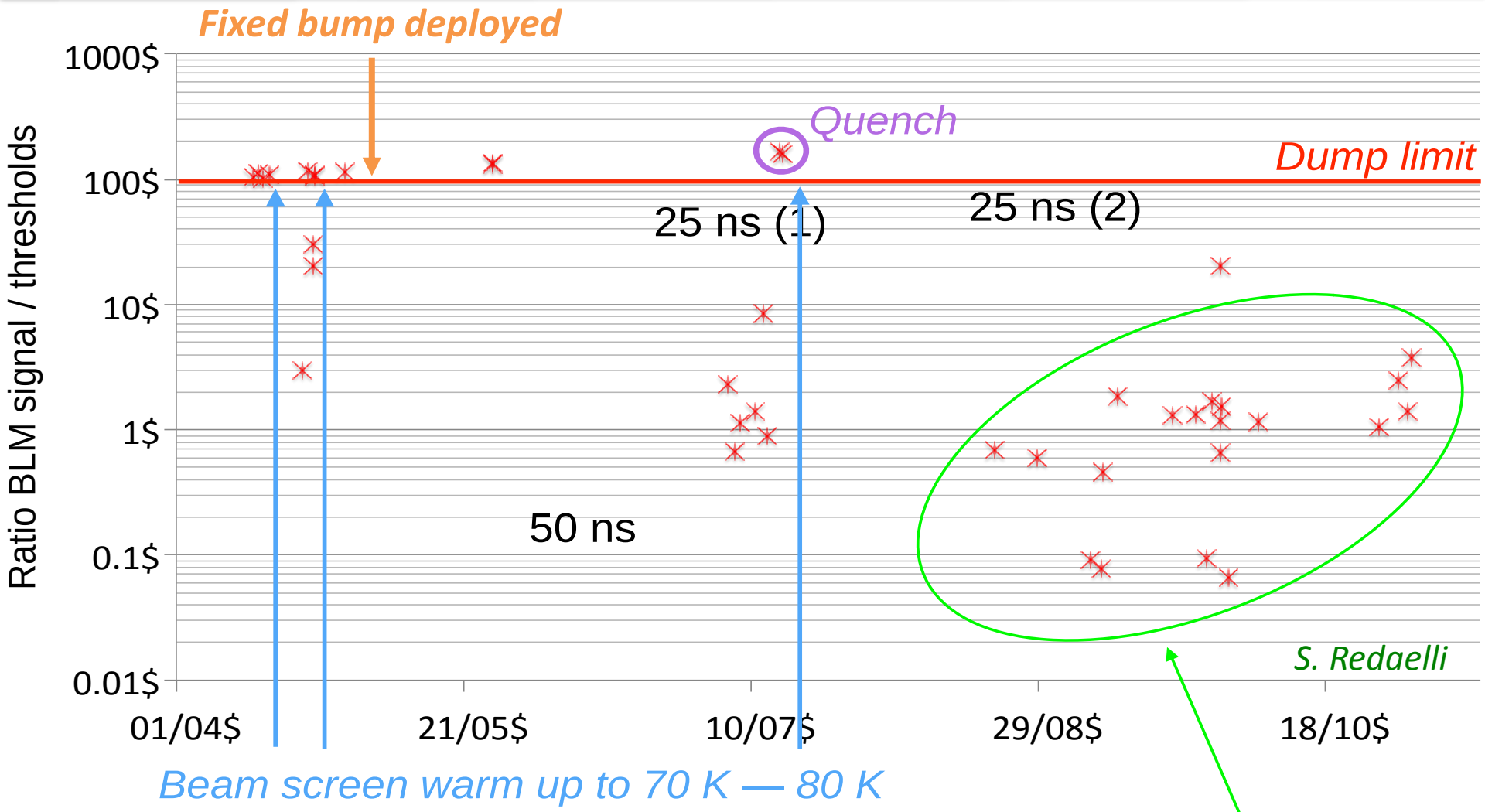
- What if it keep **growing is 2016**?

  ↳ ✓ **Still room** to have at least **10σ** in both planes (@ 450 GeV)

  ✓ Possible best **new bump** to be decided based on **actual situation**

Maximum shifts:
H = -6mm
V = +3.5mm

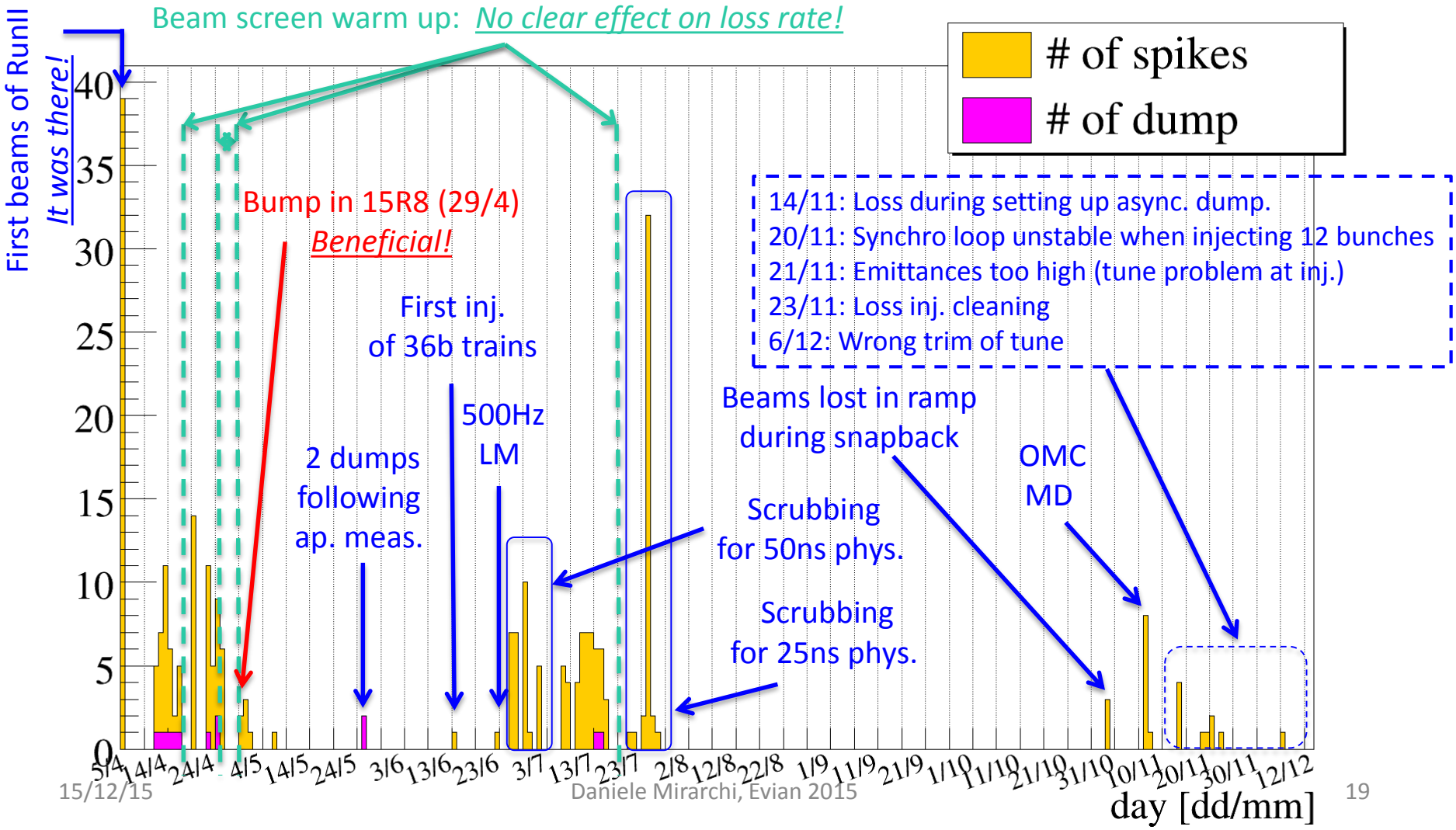
UFO at the ULO



Parasitic monitoring of beam losses

- Clear **loss spikes** (i.e. exp. decay and peak > 1e-6 Gy/s) looking at **1.3s BLM running sum**

*Most of them **synchronised** with **injection or inj. cleaning***



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  - ✓ **450 GeV**
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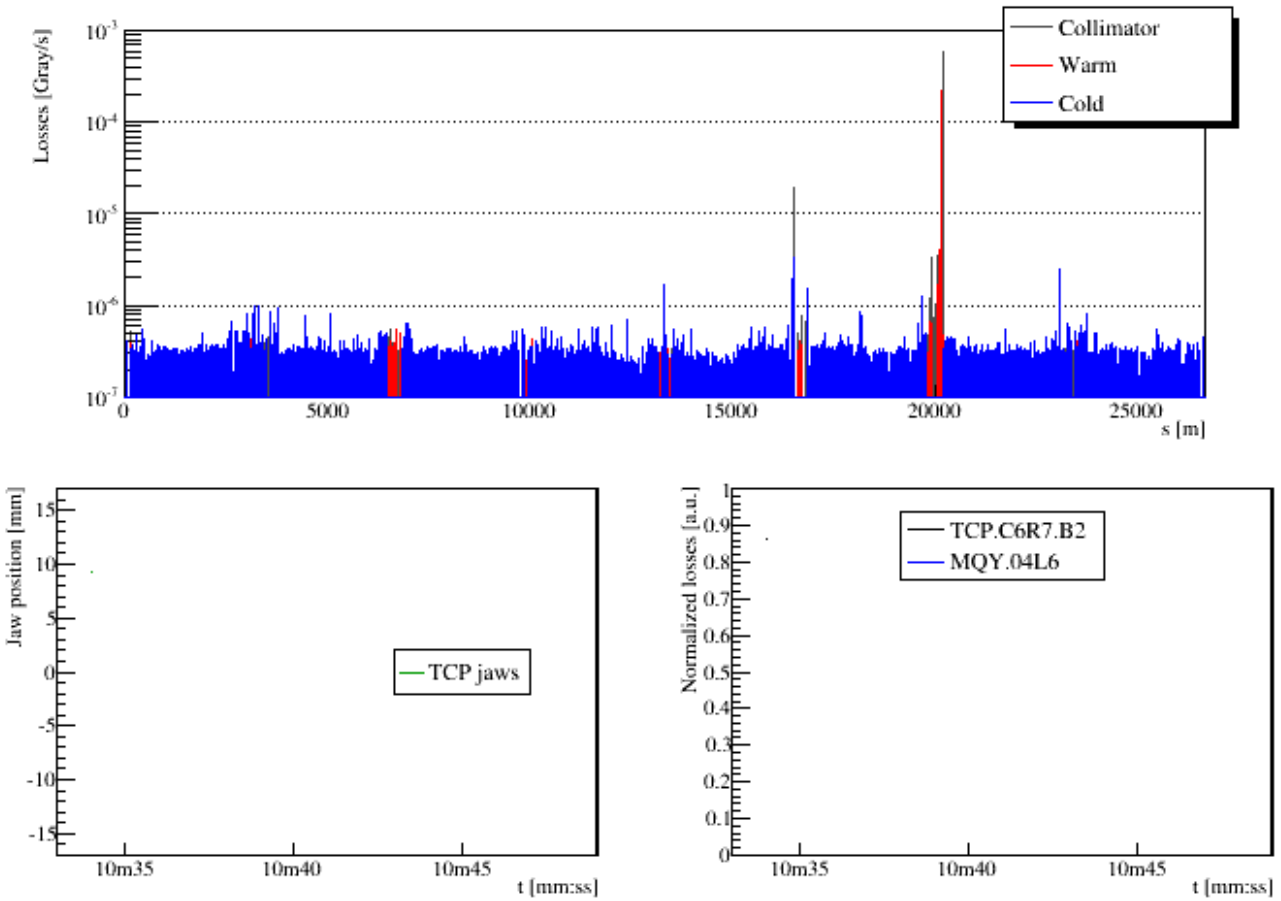
- Conclusions

Global aperture at 450 GeV

Global aperture measurements allows to **identify machine bottleneck**:

- Only **TCP in place and opened** in steps of 0.5σ
- Gentle **ADT blow up** at each step, **until losses on aperture** are observed



Example of continuous TCP scan and ADT blow up

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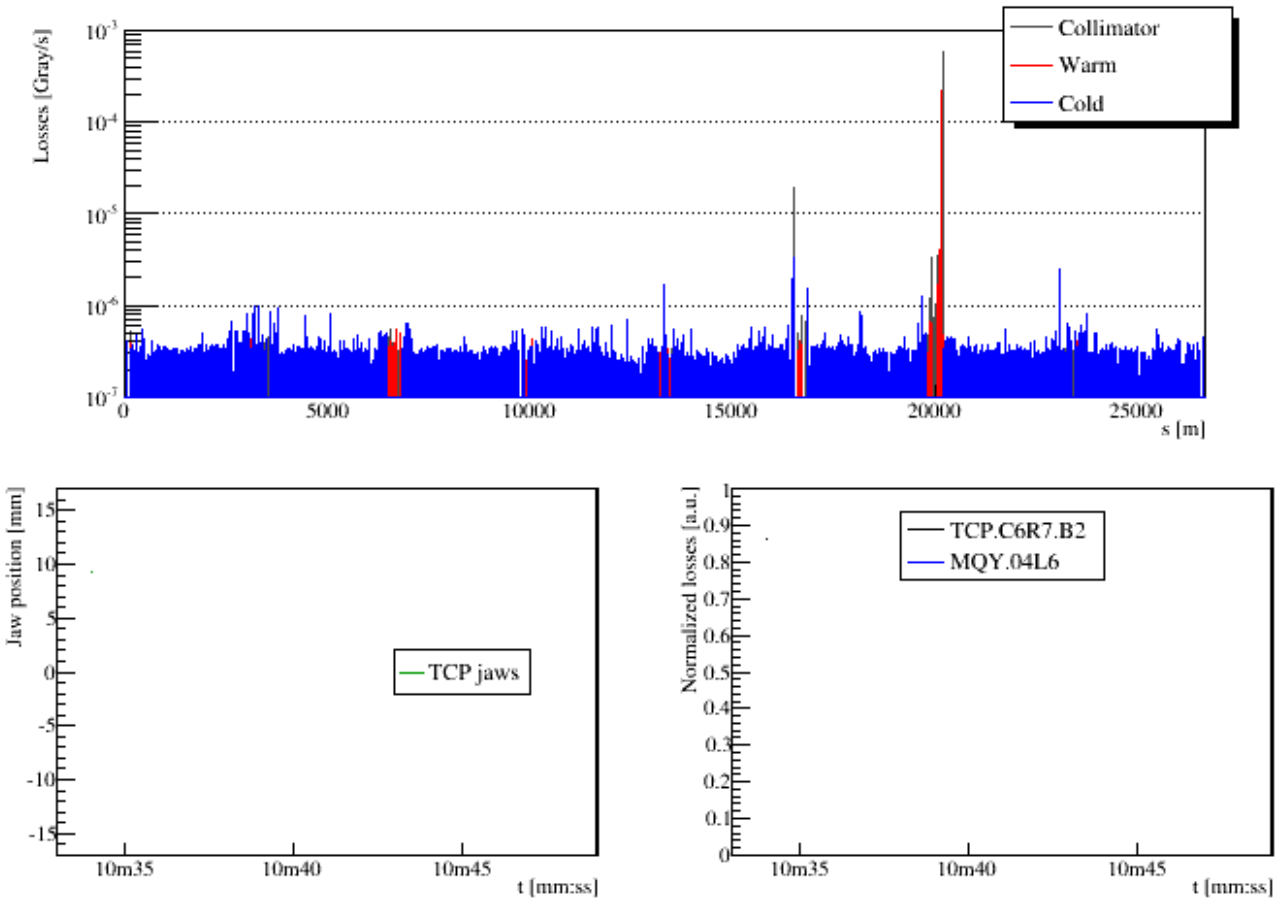
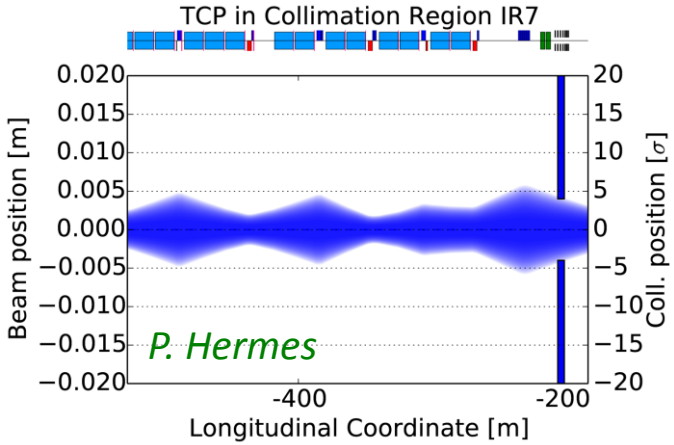


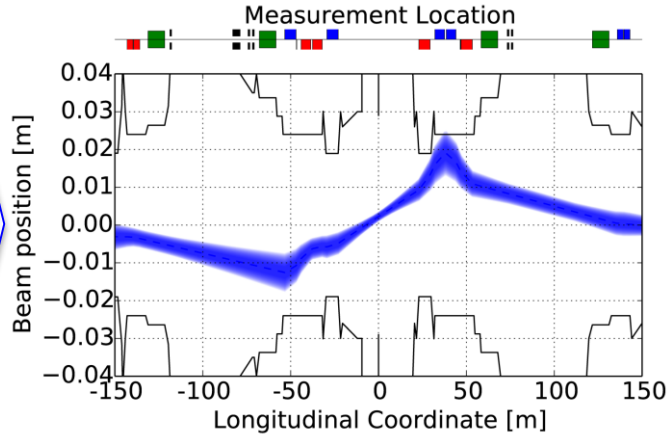
Example of continuous TCP scan and ADT blow up

Local aperture at 450 GeV

Local aperture measurements are performed **at bottleneck** found with global measurements:

- **Beam are shaped with TCPs** at 4σ and available aperture probed with **local bumps**

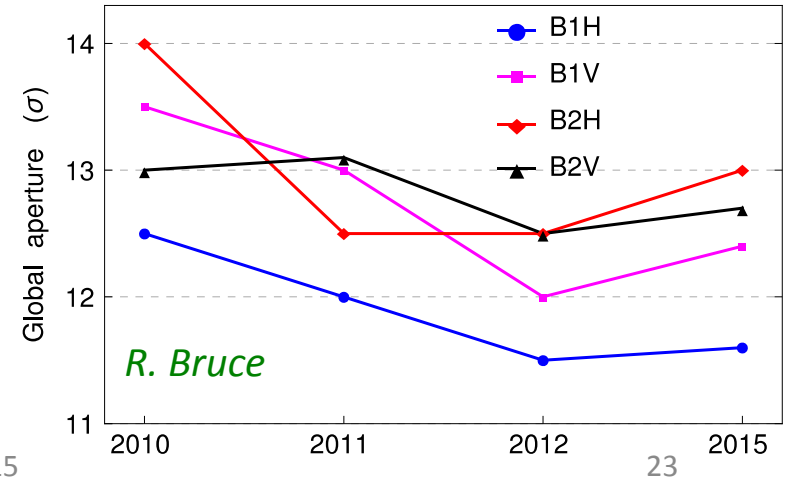




$$A_{\text{bottleneck}} = A_{\text{bump}} + 4\,\sigma$$

Summary of bottleneck combining smallest global and local aperture measurements:

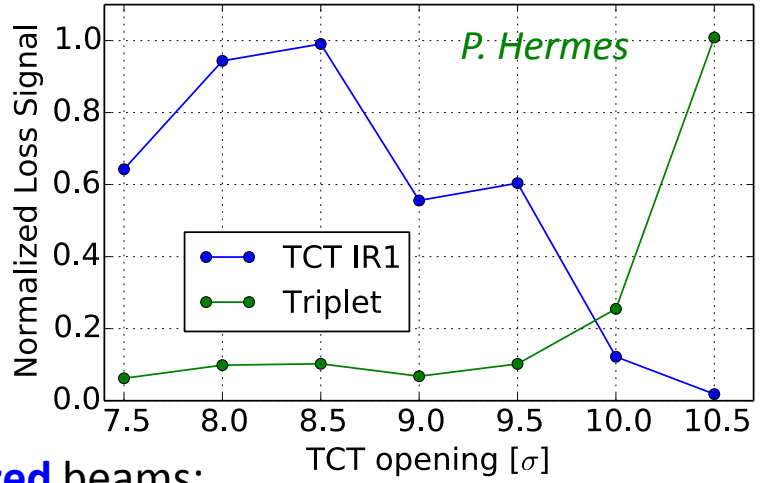
	2015		Run I	
	A [σ]	Element	*A* [σ]	Element
B1H	11.6	MBRC.4R8	11.5	Q6R2
B1V	12.4	Q6L4	12.0	Q4L6
B2H	13.0	Q4L6	12.5	Q5R6
B2V	12.7	Q4R6	12.5	Q4R6



MQX aperture at 6.5 TeV

- Measurements performed with **squeezed** and **colliding** beams, **80cm** and **40cm β*** , p and Pb

- Similar approach of global aperture at Injection:
  - Only **TCTs** in place and **opened in steps of 0.5σ**
  - Gentle **ADT blow up** at each step, until losses moved from TCT to MQX



Summary of triplets aperture measurements with **squeezed** beams:

	Protons		*Lead*
	β* = 80cm Xing = 145 µrad	**β* = 40cm Xing = 205 µrad**	**β* = 80cm Xing = 145 µrad**
B1H	16.7	11.0	>15.5
B1V	**15.7**	**9.5**	**14**
B2H	>18.7	10.0	>15.5
B2V	**15.7**	**9.5**	**14**

Good agreement with predictions: 15.9σ with 80cm β*, 9.5 with 40cm β* (R. Bruce, Chamonix '14)

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Conclusions

- **U**nidentified **L**ying **O**bject:
  - ✓ **Present since beginning of 2015** and maybe earlier (different BLM positions in RunI)
  - ✓ Although initial concerns (14 dump, 3 quench) it was **not a main limitation in 2015**
  - ✓ **Fixed bump** to "by-pass" the object **beneficial** on UFO rate and beam loss
  - ✓ **Hard to predict** situation in 2016: lack understanding the nature of the ULO
  - ✓ **Still room to increase fixed orbit bump** to get a least 10σ at 450 GeV in worst scenarios

Crucial to perform local scan during 2016 commissioning to set optimum orbit bump, plus periodic beam loss monitoring and ULO scans to avoid any limitation to LHC operations

- **Available machine aperture:**
  - ✓ At **450 GeV**: **11.5σ** for B1V
  - ✓ At **6.5 TeV**: **15.7σ** with 80cm β^*, **9.5σ** with 40cm β^*, for both beams in V
  - ✓ With **lead beams**: **14σ** for both beams in V

Required aperture measurements in 2016 commissioning to check bottleneck evolution and to avoid any limitation to LHC operations

Outline

BACKUP

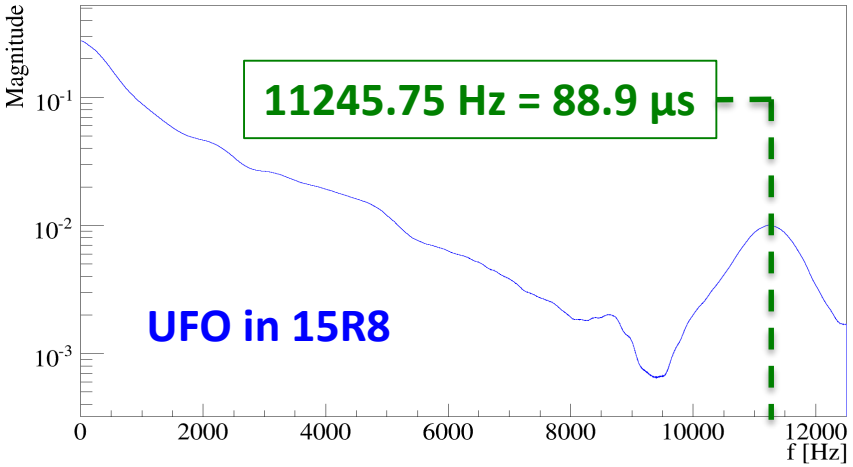
UFO at the ULO

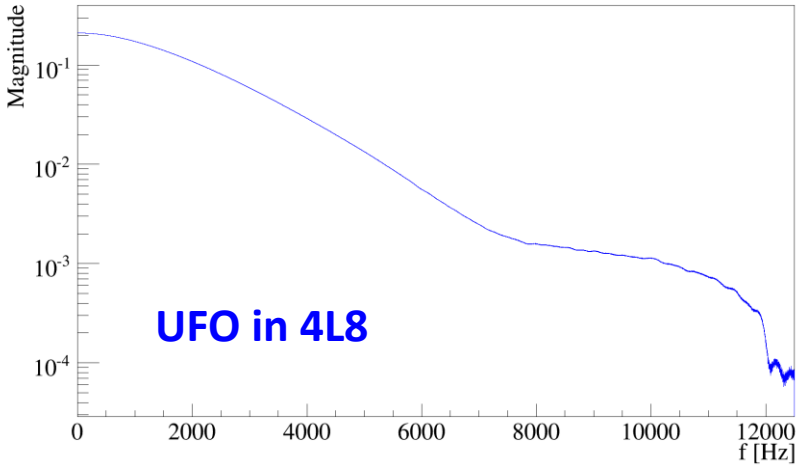
*Is there any particular **feature of UFOs in C15R8** w.r.t. UFOs in the rest of the ring?*

Comparative analysis between:

- ✓ All the dumps due to **UFOs at the ULO**, **UFOs** in the machine, and **programmed dump**

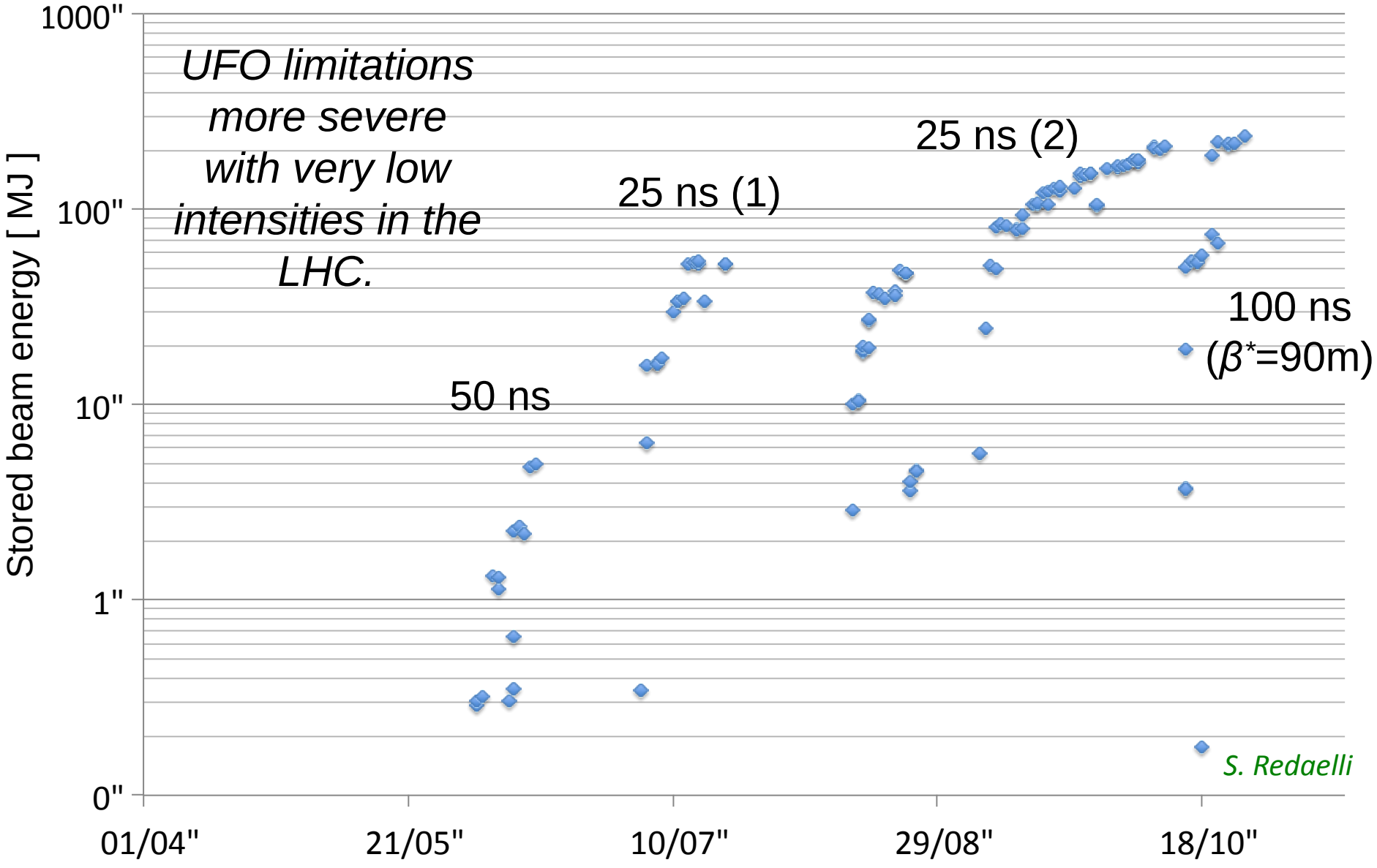
FFT of BLM that detected the UFO using **PM data**



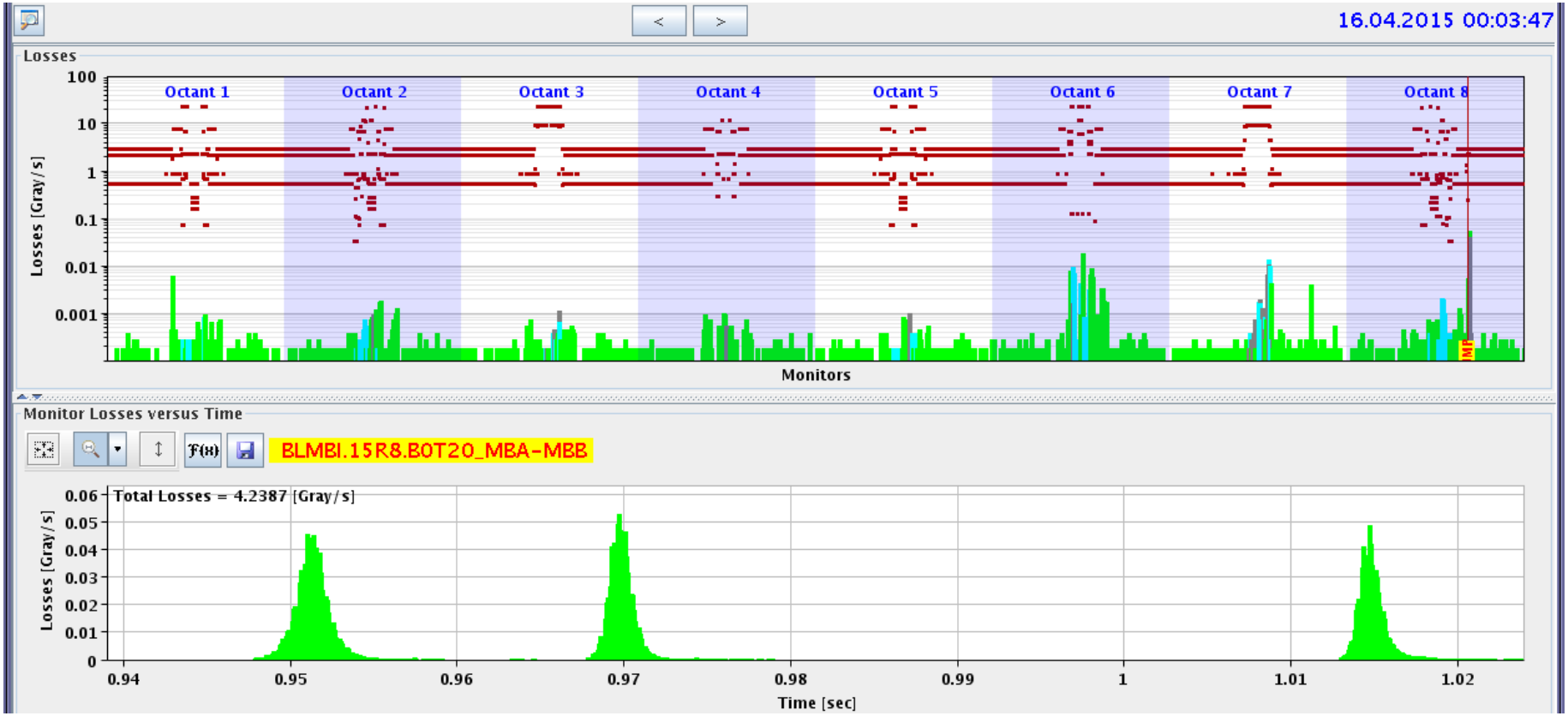


Characteristic FFT: UFOs in cell 15R8 generated by repeated passage of the beam on the ULO

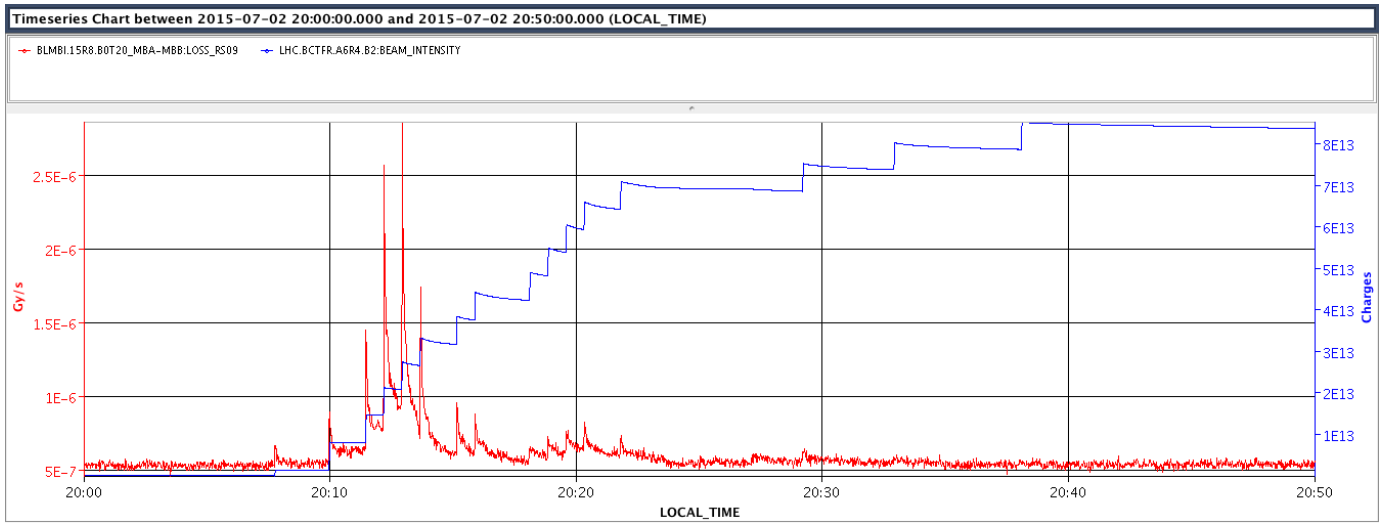
Stored energy in the machine

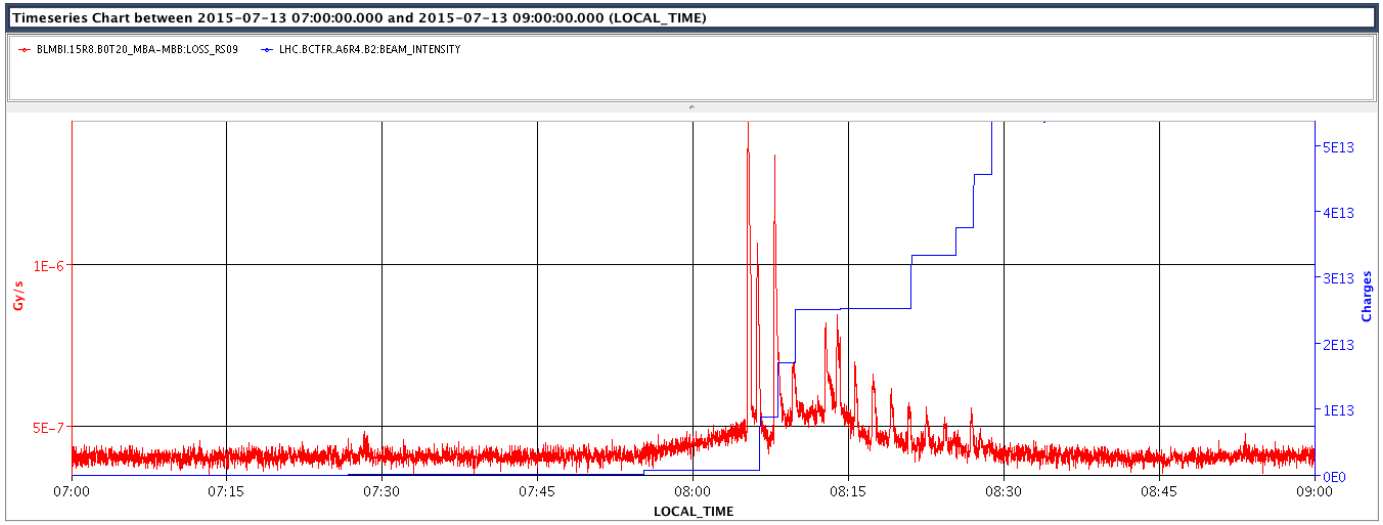


Example of multiple UFO at the ULO

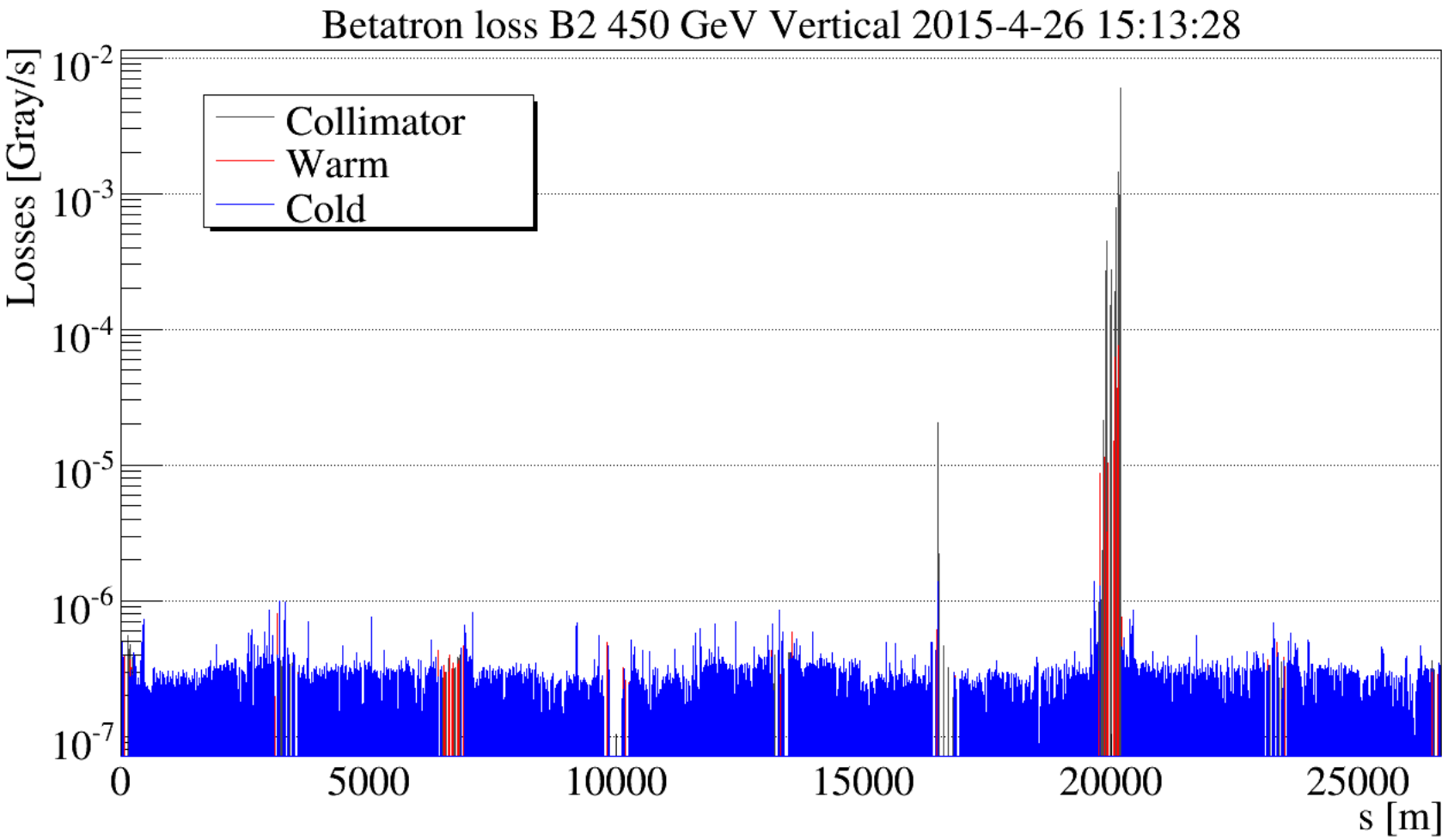


Beam loss at the ULO





Beam 2 loss maps



No obvious activity seen in C15R8

The most weird measurement…

Seems that we touched something with very small shift…but…