Beam lifetime in collision - LHC experience

G. Iadarola

Many thanks to:
G. Arduini, H. Bartosik, I. Efthymiopoulos, E. Metral, N. Karastathis,
S. Kostogluou, Y. Papaphilippou, K. Paraschou, G. Rumolo

Analysis based on **ABP python toolbox:**

- LHCLossesAnalysis, G. Iadarola et al.
- pytimber, R. De Maria et al.
- LHCMeasurementTools, scrubbing and lumi teams
- LHCFillingPatterns, G. Iadarola et al.
- CALS2Pandas, G. Sterbini, A. Poyet et. al.

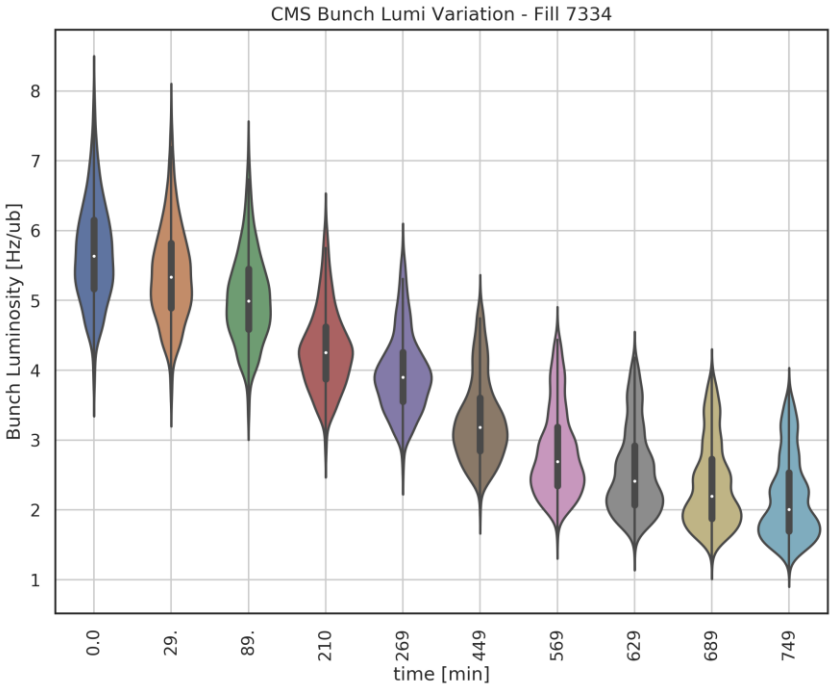
Outline

- **Introduction**
- **Analysis of a typical fill from 2018**
  - Burn-off corrected losses
  - Comparison against burn-off loss rate
  - Accumulated losses and comparison against transverse emittances
- **Additional information from tests and MD**
  - A 25 h fill
  - Test fill with constant crossing angle
  - Situation in 2017 (25 ns)
  - Situation in 2017 (8b+4e)
  - Are we dominated by e-cloud in the arcs or in the IRs?
  - MD fill with one circulating beam
  - MD fill with large ATS telescope
- **Summary and outlook for HL-LHC**

Introduction

During the last LHC Run in 2018 **slow losses were observed during collisions**, with significant **differences among the circulating bunches**

→ Resulting in a **large spread in the bunch-by-bunch luminosity** (see talk by I. Efthymiopoulos at 150th HiLumi WP2 Meeting)



The following slides collect **observations** made with **different beam and machine configurations** aiming at:

- Identifying the **source of the losses**
- Get a some ideas on **how this effect will evolve in the HL-LHC era**

Integrating previous work on the topic, which is summarized in:

- *S. Kostoglou et al., "Luminosity, lifetime and modelling", Evian '19*
- *K. Paraschou et al. "Analysis on Bunch-by-Bunch Beam Losses at 6.5 TeV in the Large Hadron Collider ", IPAC19*

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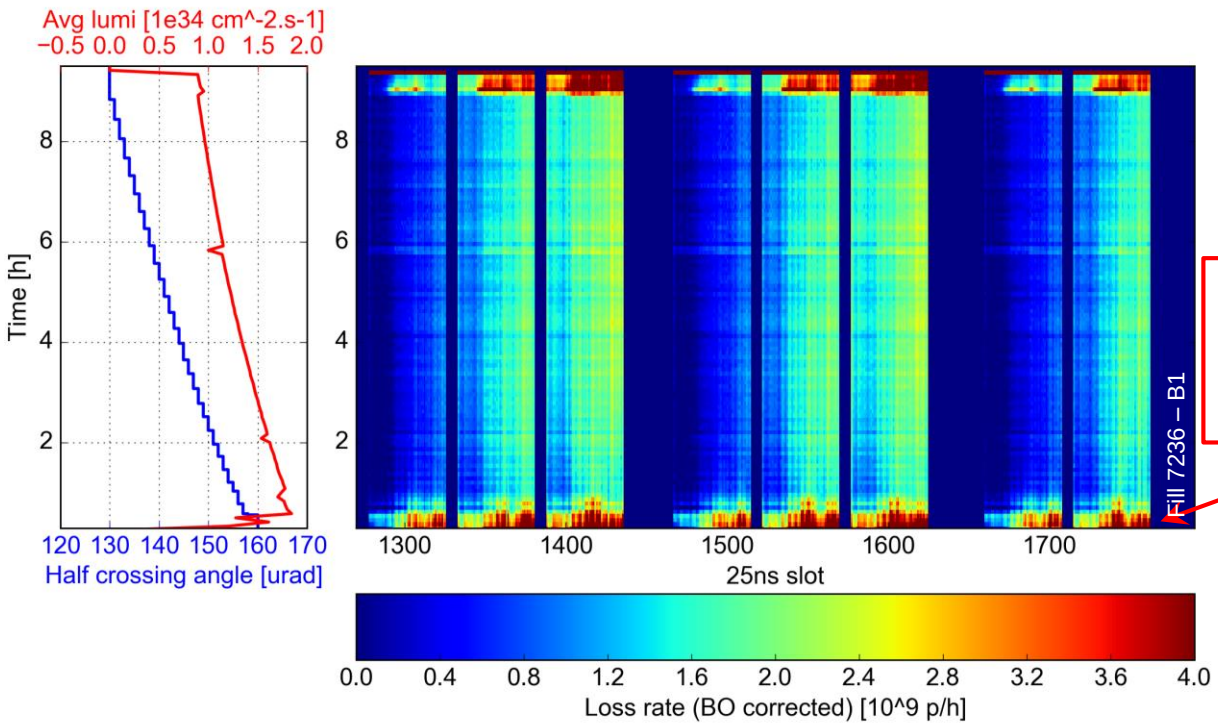
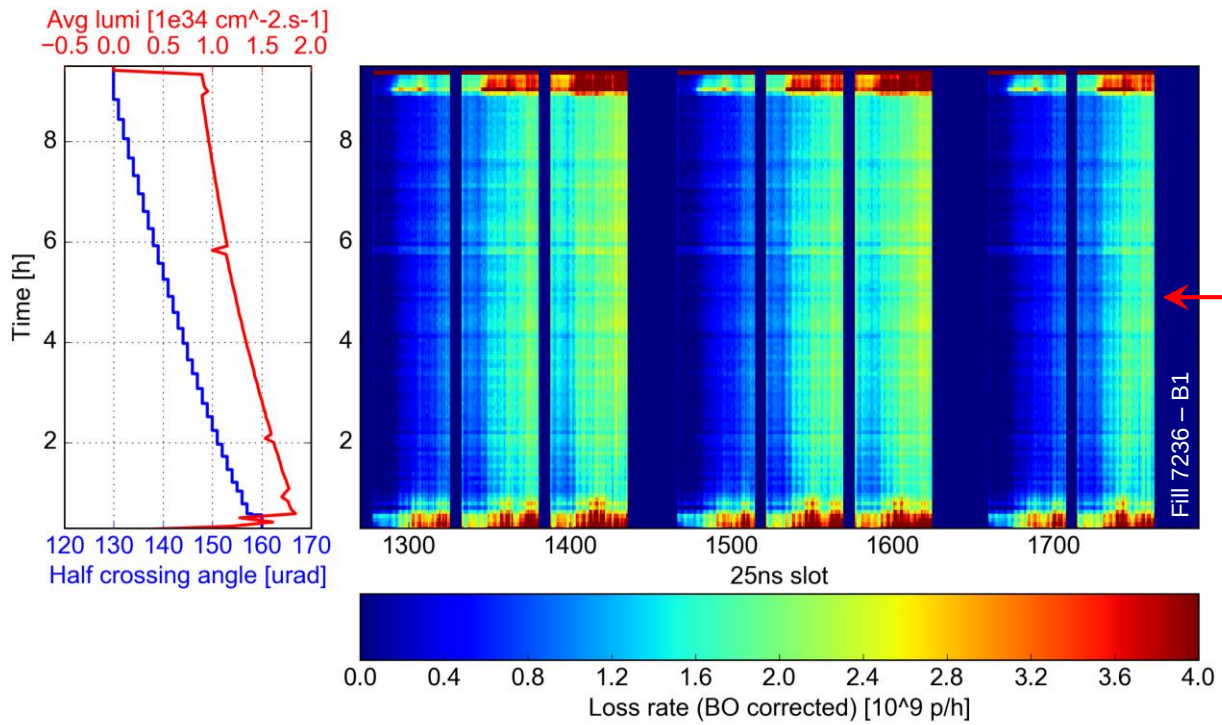


Larger losses right **after going in collisions**

- **BCMS beam**
  - 25 ns bunch spacing
  - Injections of 3x48 bunches
  - Bunch intensity: ~1.2 x 10^{11} p/bunch
  - Transverse emittances: ~2.0 μm
- **2556 bunches/beam**
- **β* = 30 cm** (reduced to 25 cm at the end of the fill)
- **Half crossing angle** reduced from **160 μrad to 130 μrad** gradually during the fill
- **L_{peak} = 1.9 10^{34} Hz/cm^2**

A typical fill from 2018



Continuous losses during collisions with **crossing angle anti-levelling**

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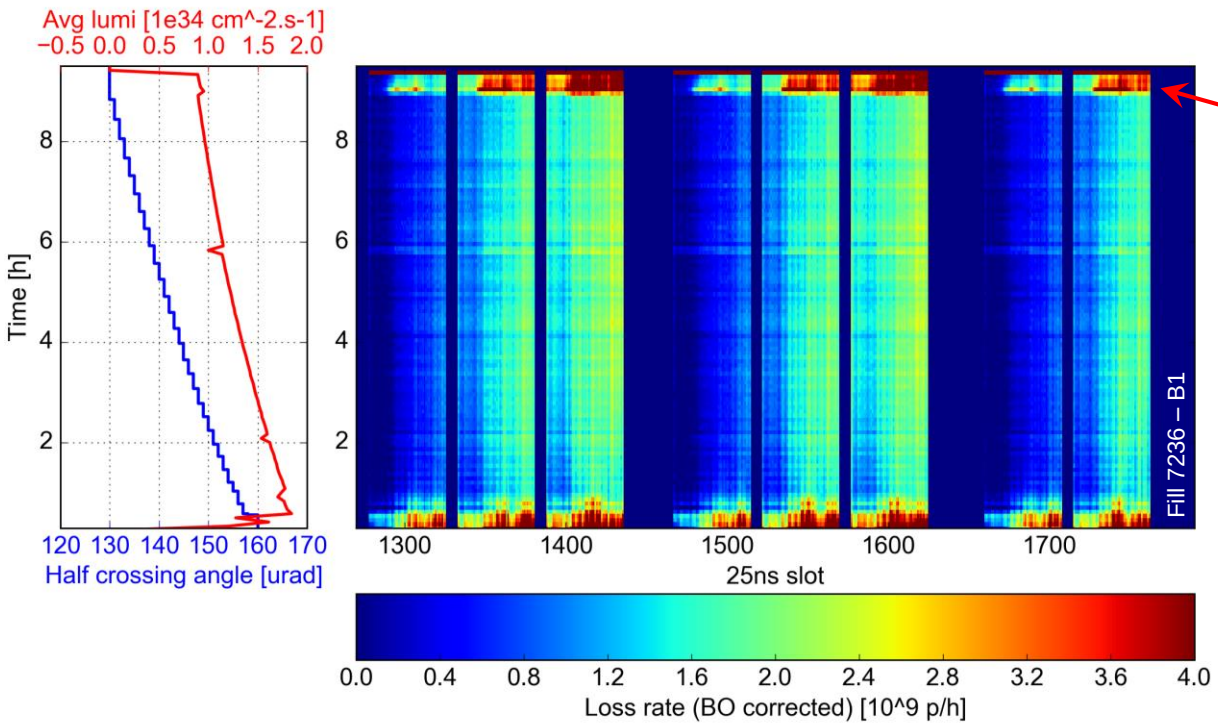

Further **increase when reducing β***

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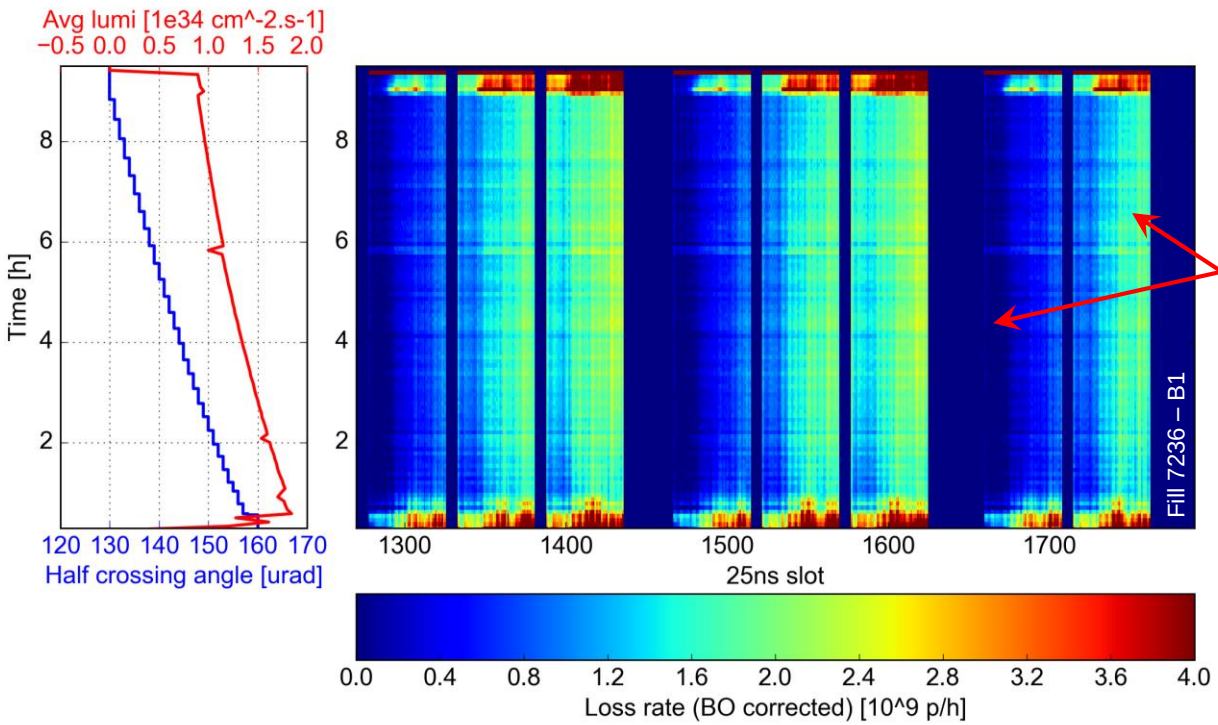

Significant **differences along the bunch trains**

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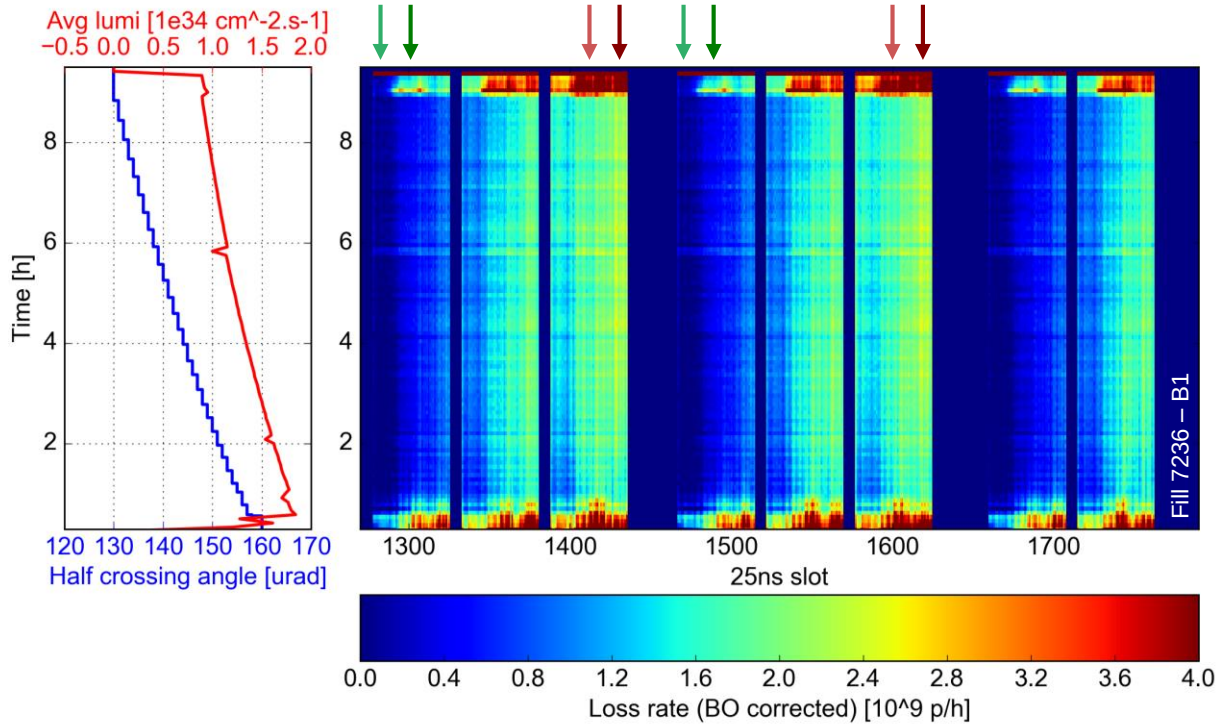
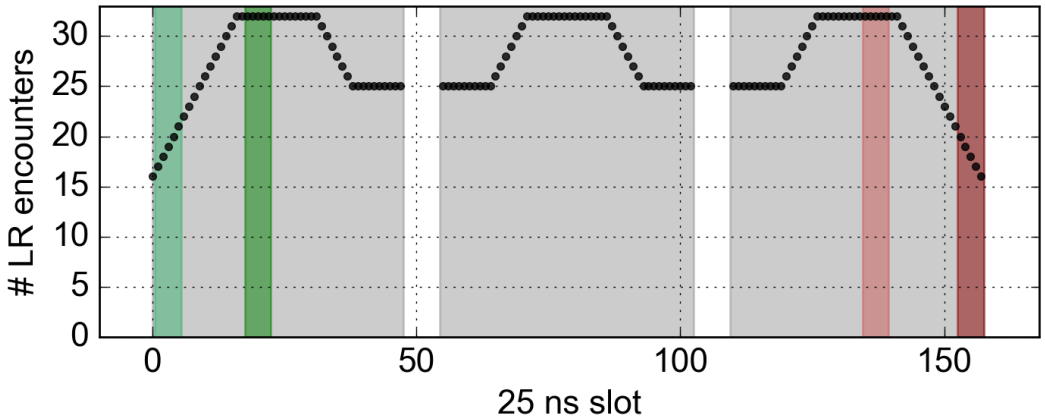


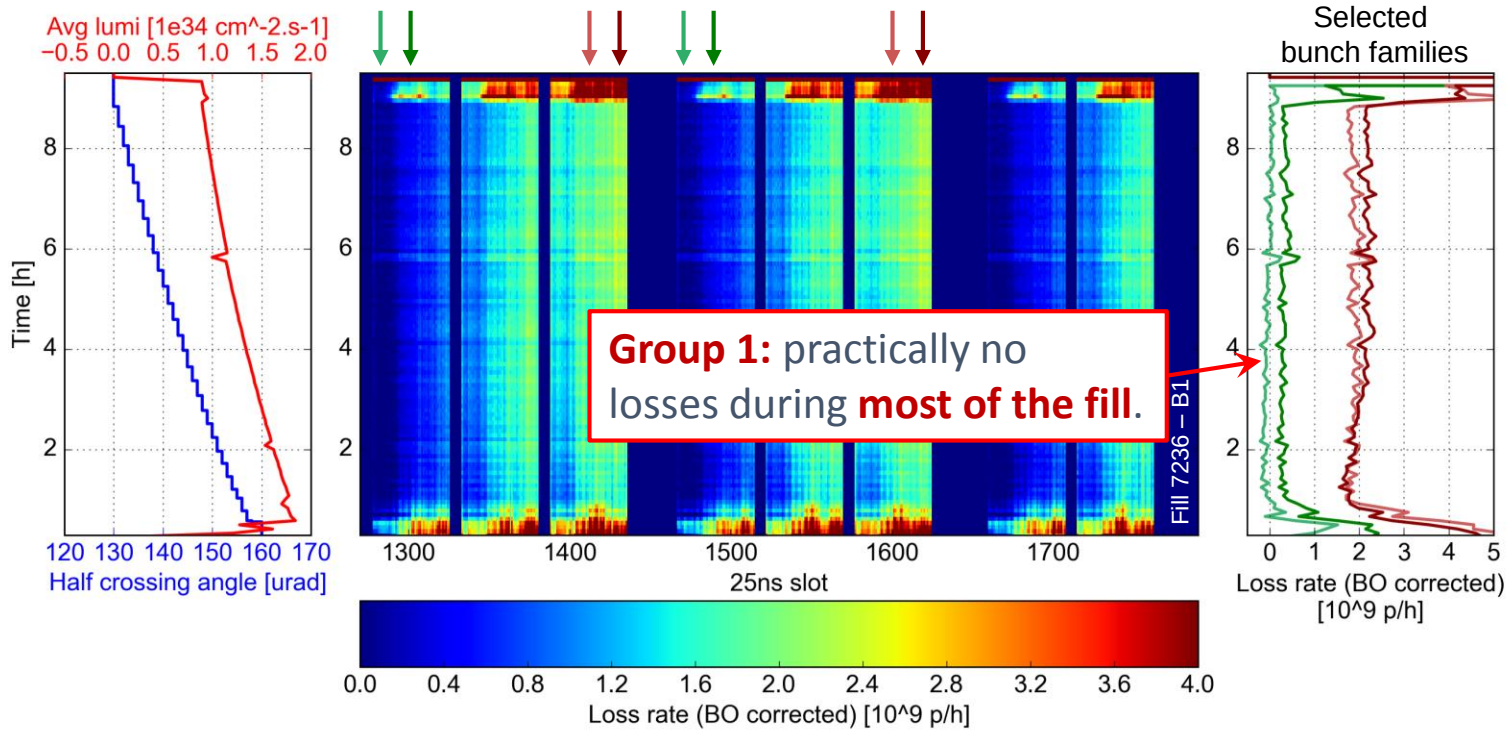
For more quantitative comparisons we select **four groups of bunches**:



	e-cloud	N. LR-BB
Group 1	weak	reduced
Group 2	weak	full
Group 3	strong	full
Group 4	strong	reduced

All trains of 3x48b within the beam are considered to evaluate the losses

A typical fill from 2018



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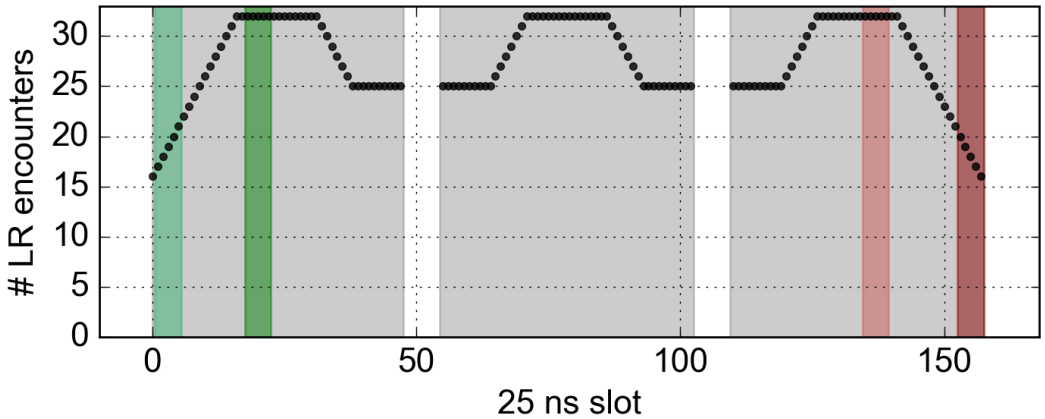

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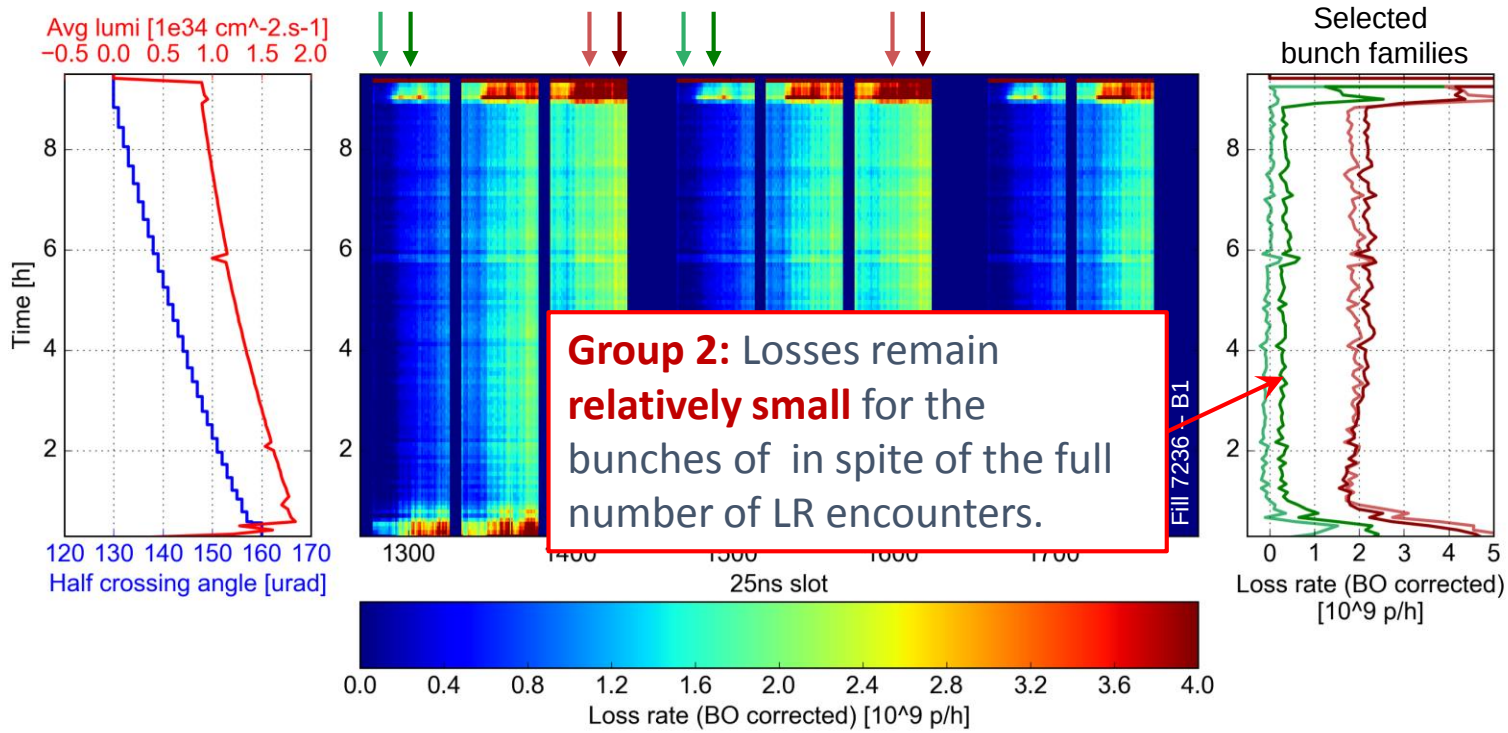
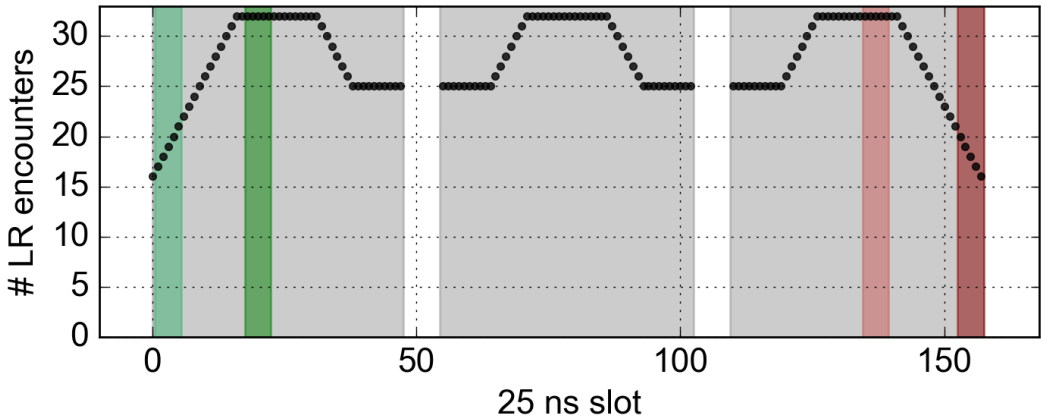


Group 2: Losses remain **relatively small** for the bunches of in spite of the full number of LR encounters.

For more quantitative comparisons we select **four groups of bunches**:



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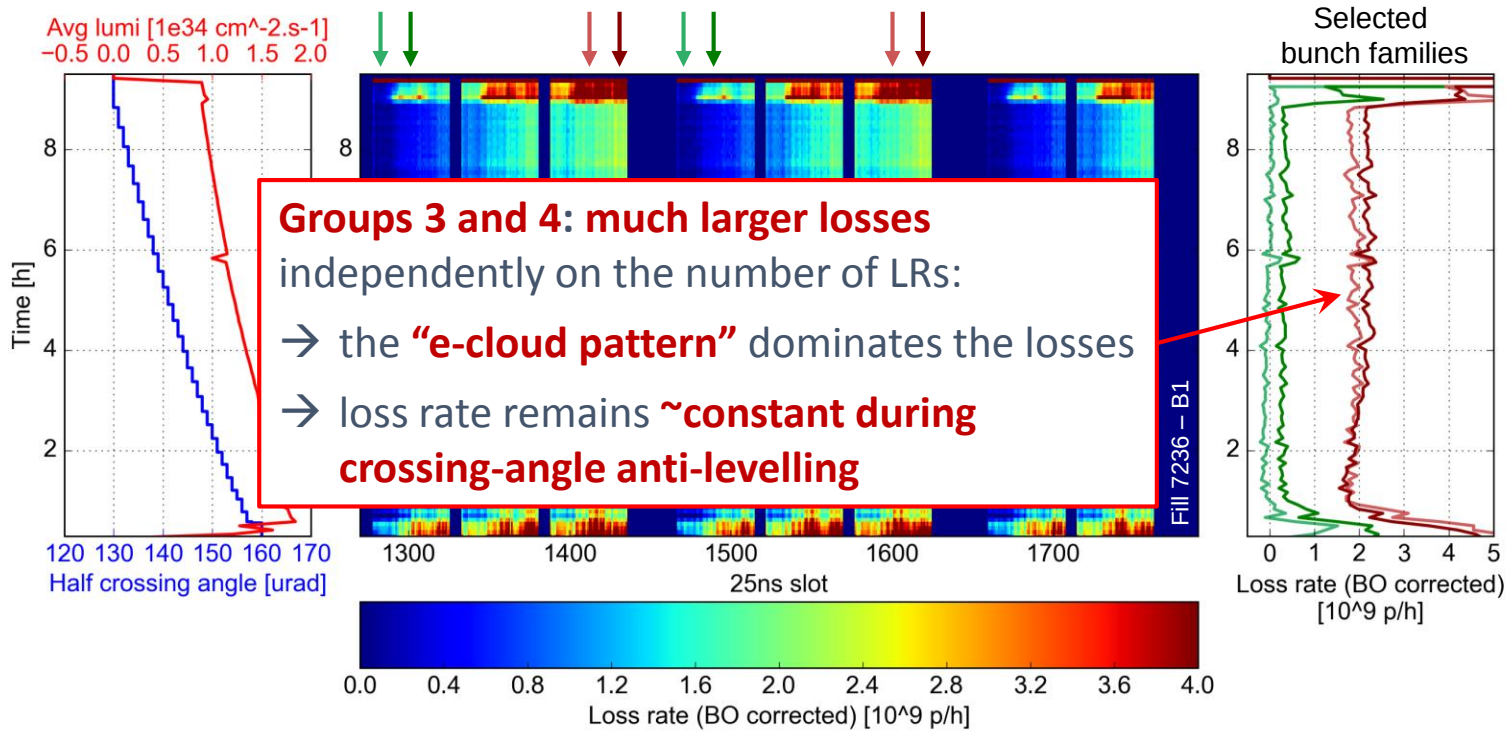
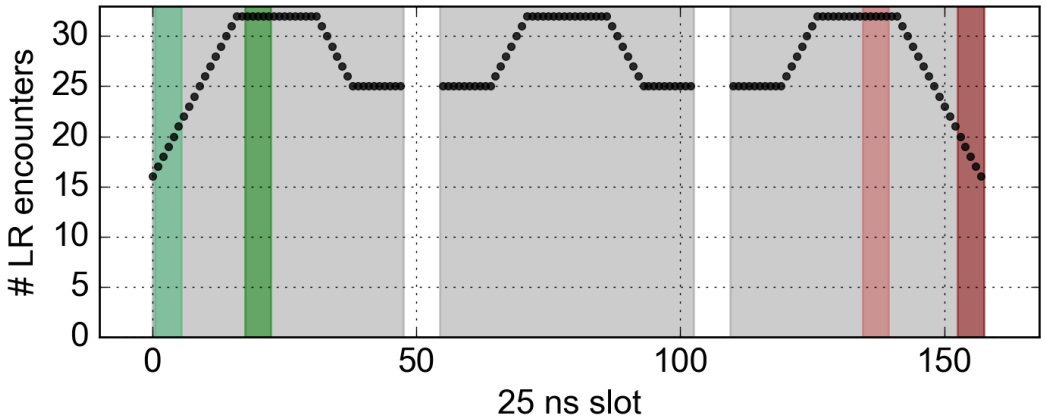


Groups 3 and 4: much larger losses independently on the number of LRs:

→ the **"e-cloud pattern"** dominates the losses

→ loss rate remains **~constant during crossing-angle anti-levelling**

For more quantitative comparisons we select **four groups of bunches**:



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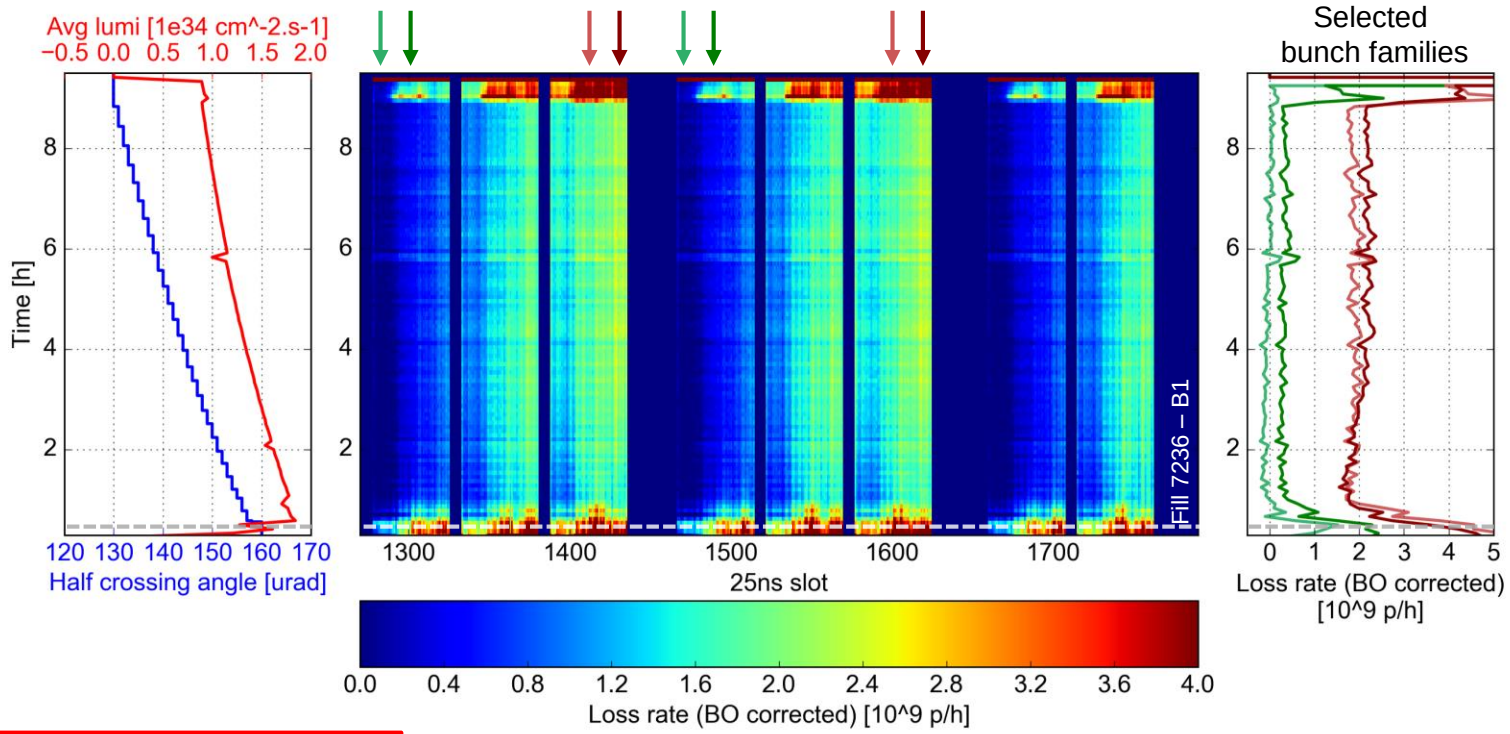
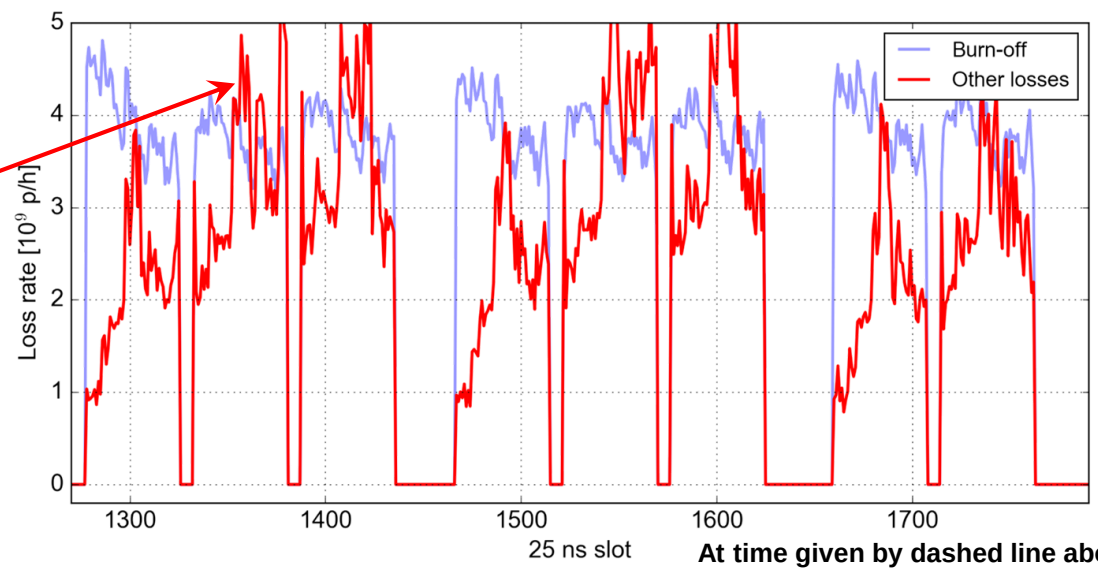


Losses observed at the **beginning of collisions** are rather large

→ LR-BB pattern can be identified

→ Loss rate comparable to burn-off

→ This is a transient effect disappearing within the first hour



At time given by dashed line above

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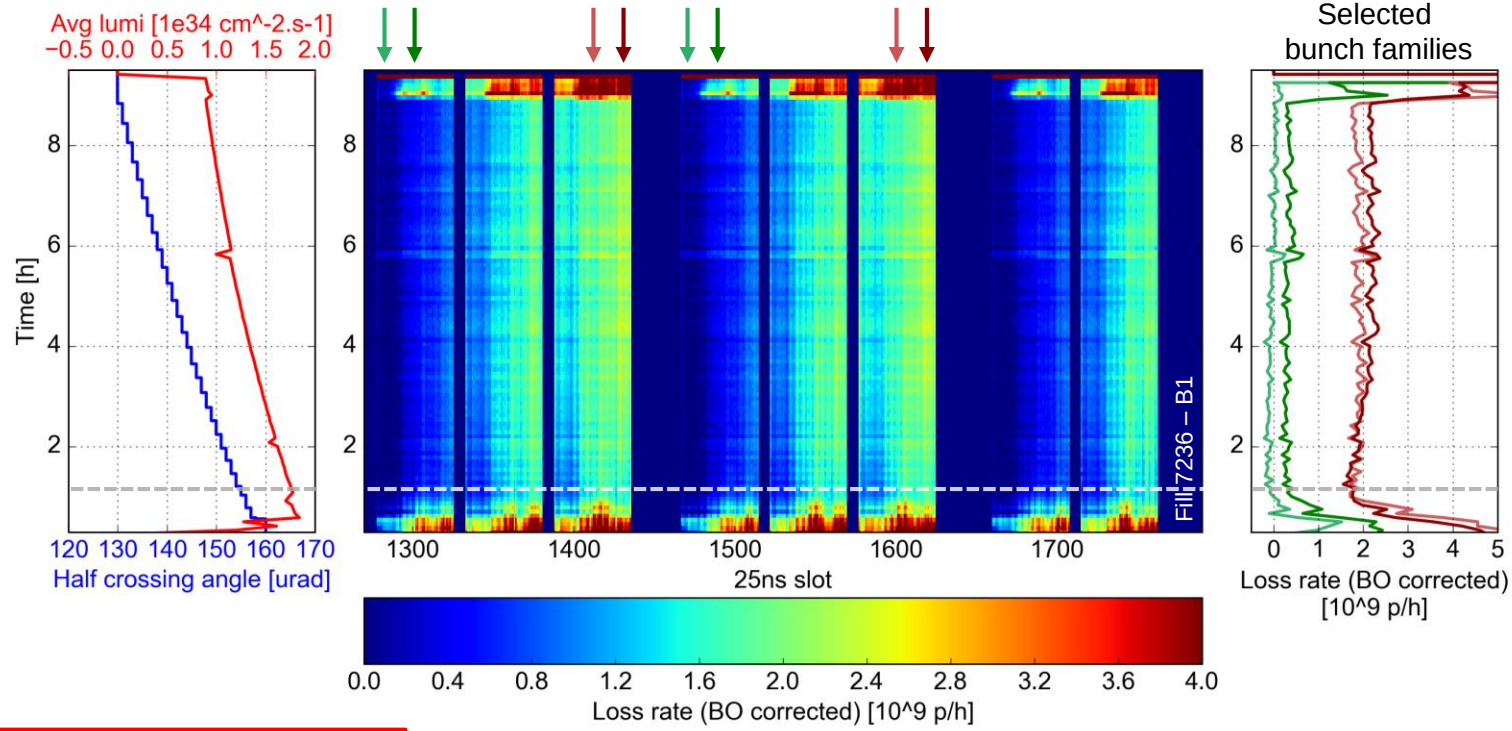
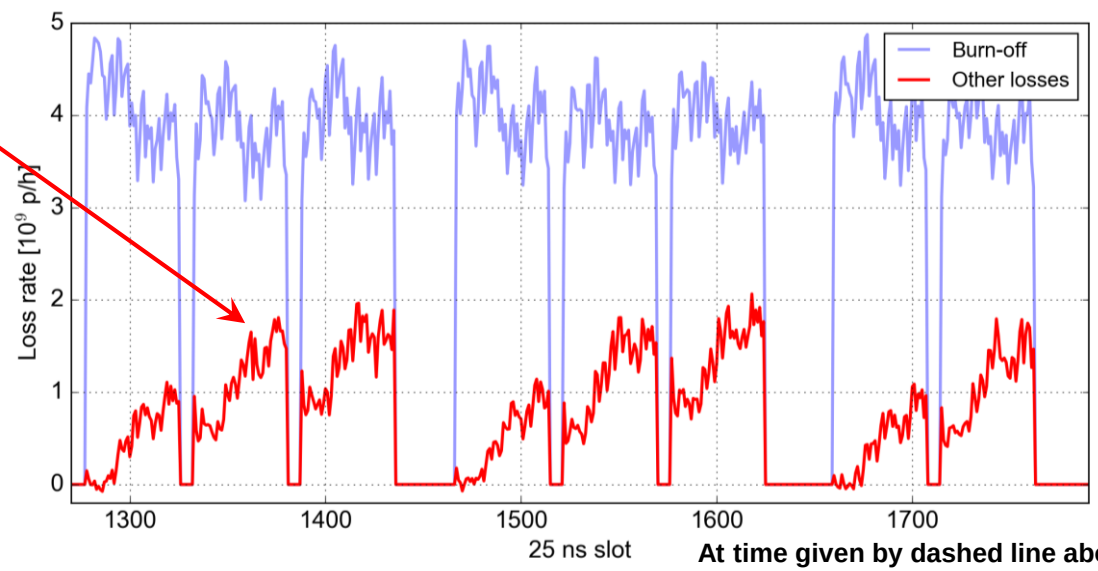


After the initial transient:

→ **LR-BB pattern** becomes practically invisible

→ **Loss rate smaller than burn-off** but still **not negligible**



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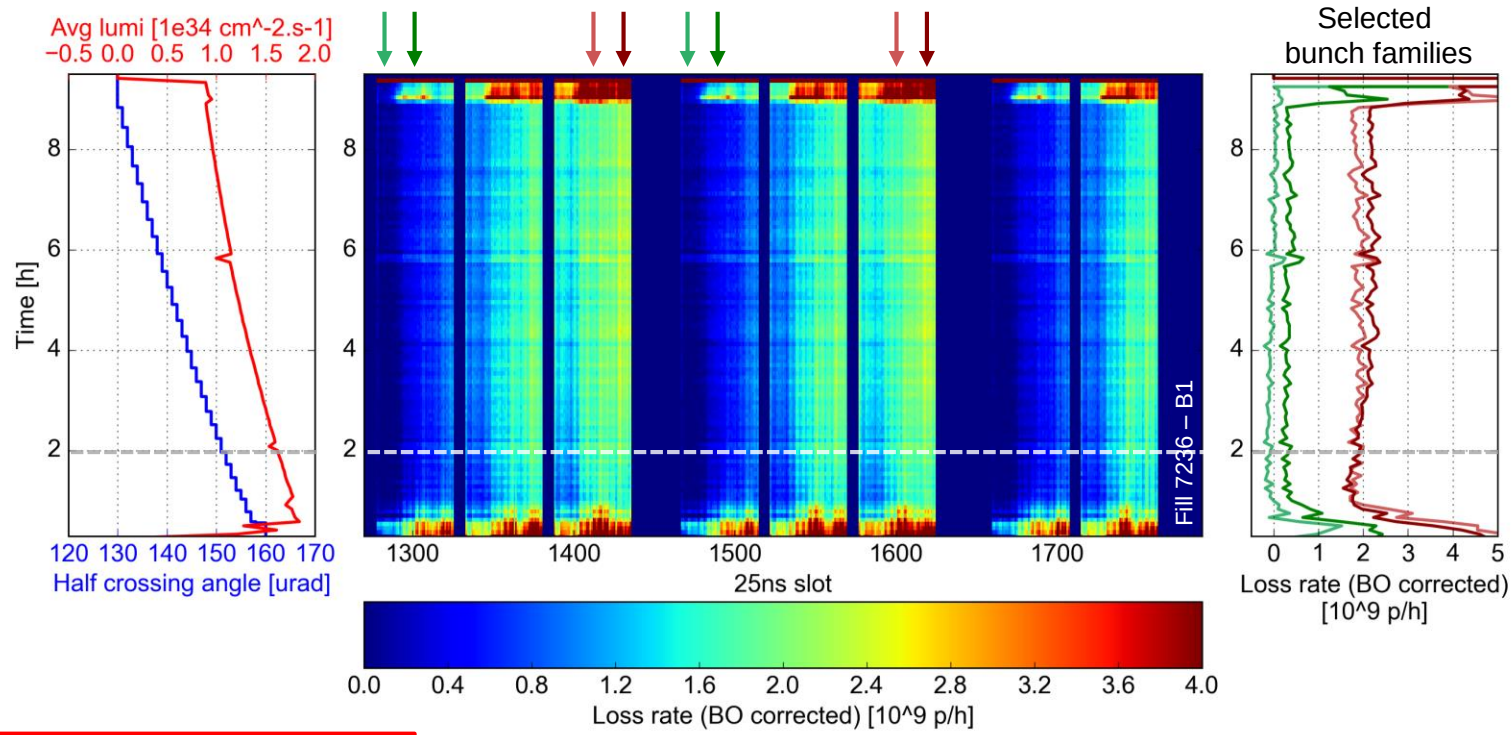
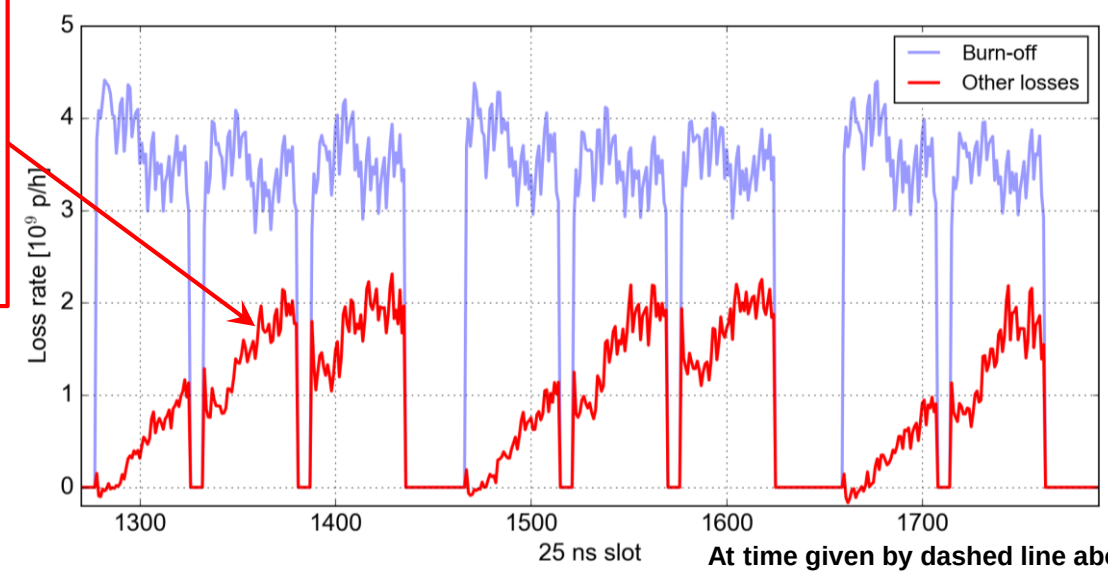


During the cross. angle anti-levelling:

→ **loss rate stays roughly constant** during the fill

→ becomes **comparable to the burn-off as the luminosity decreases**



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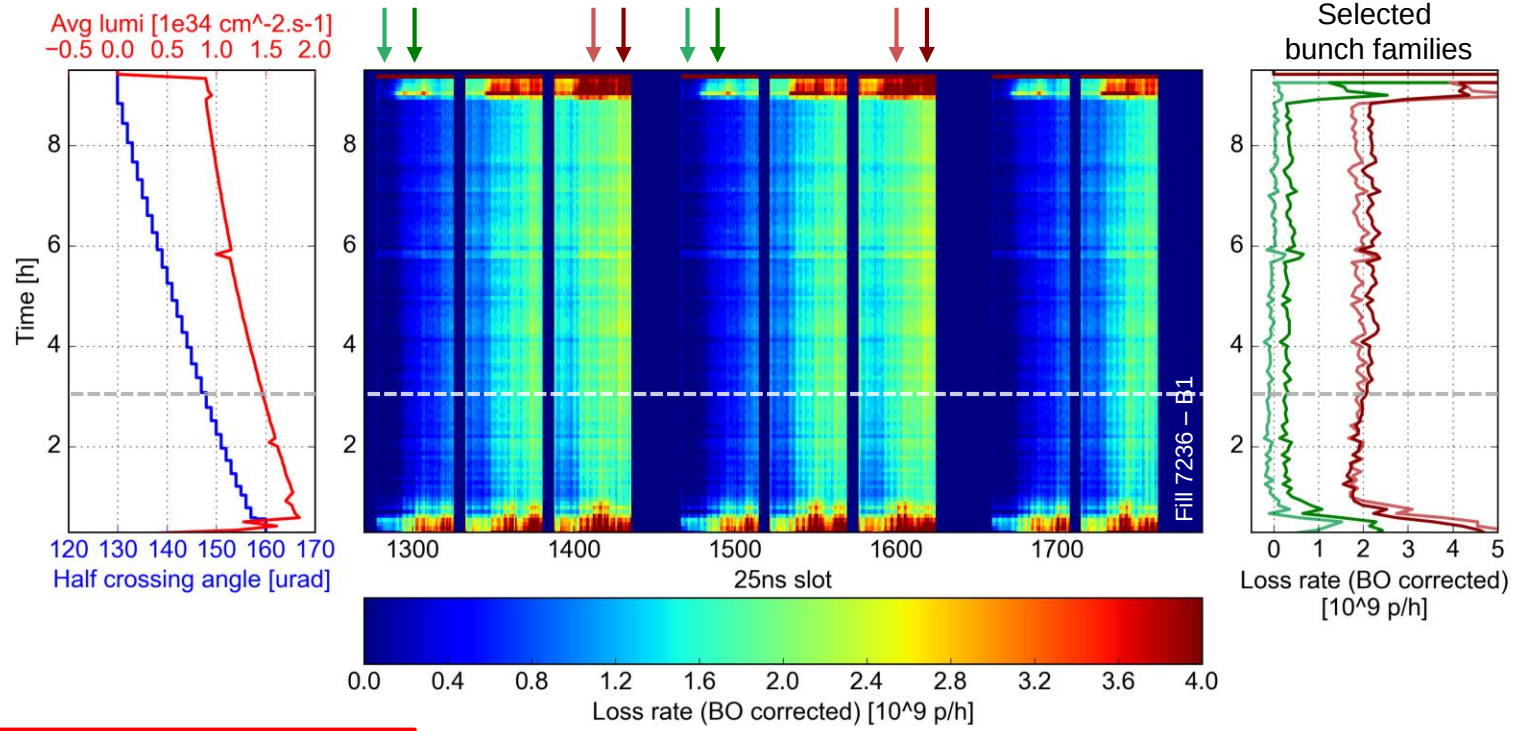

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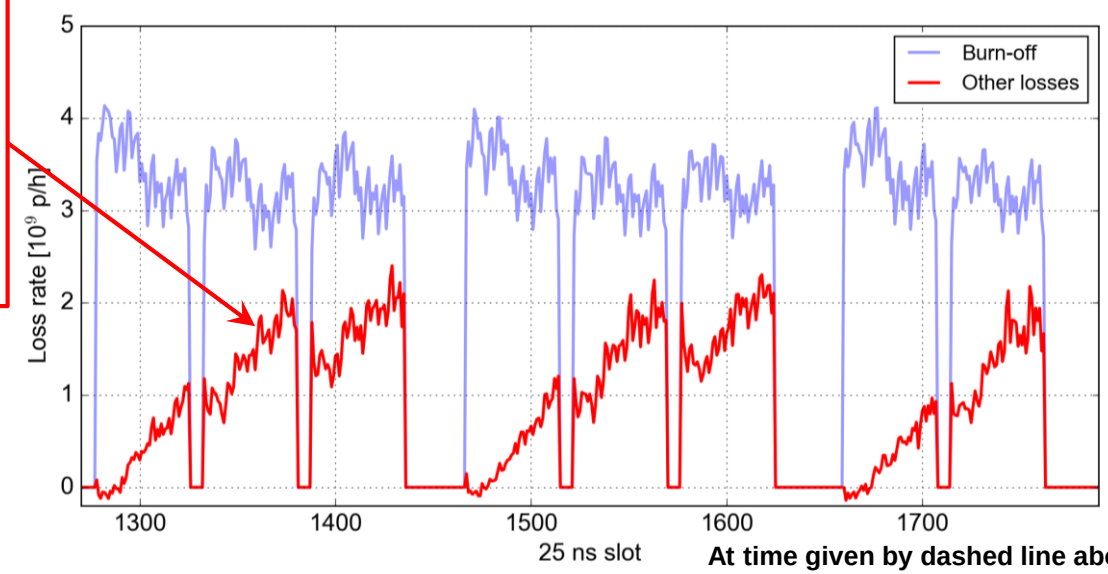

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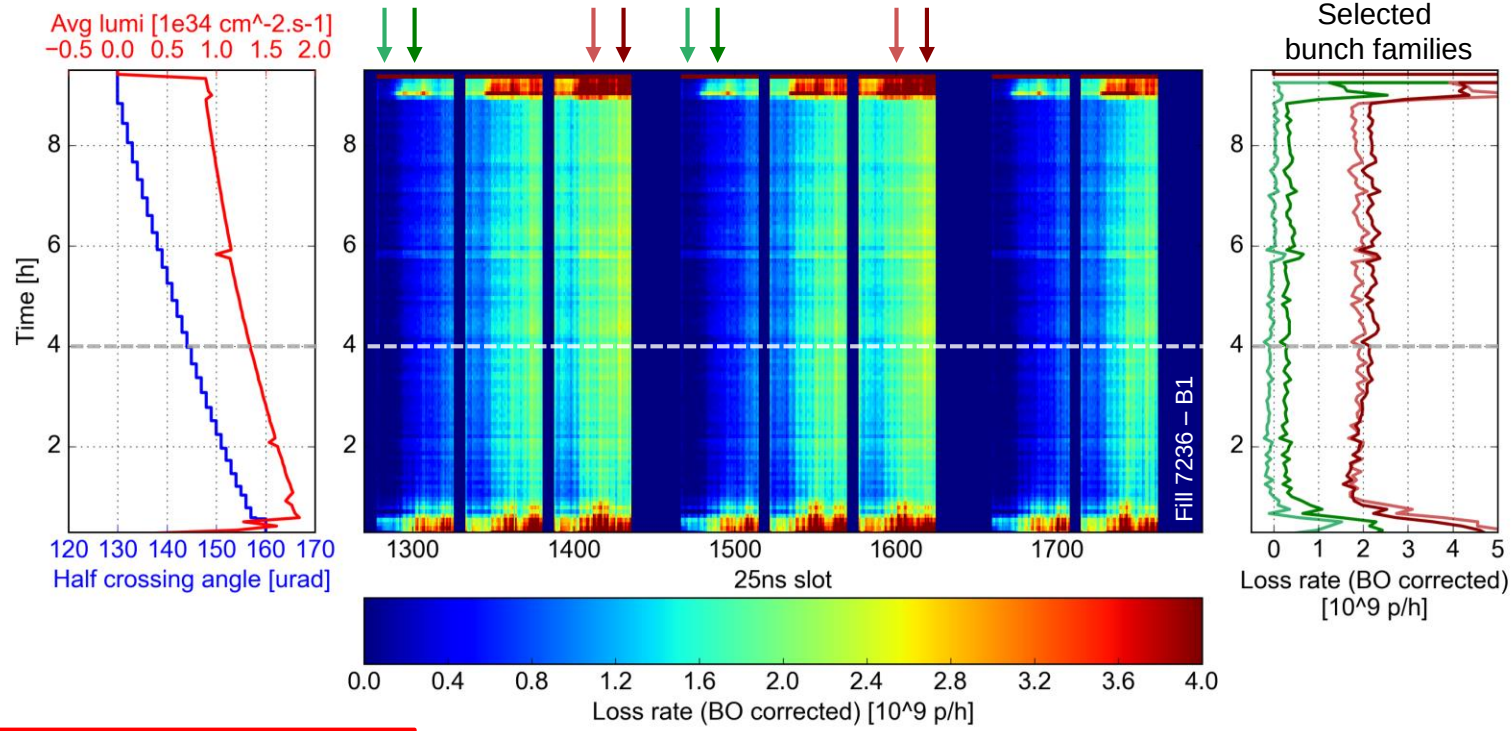

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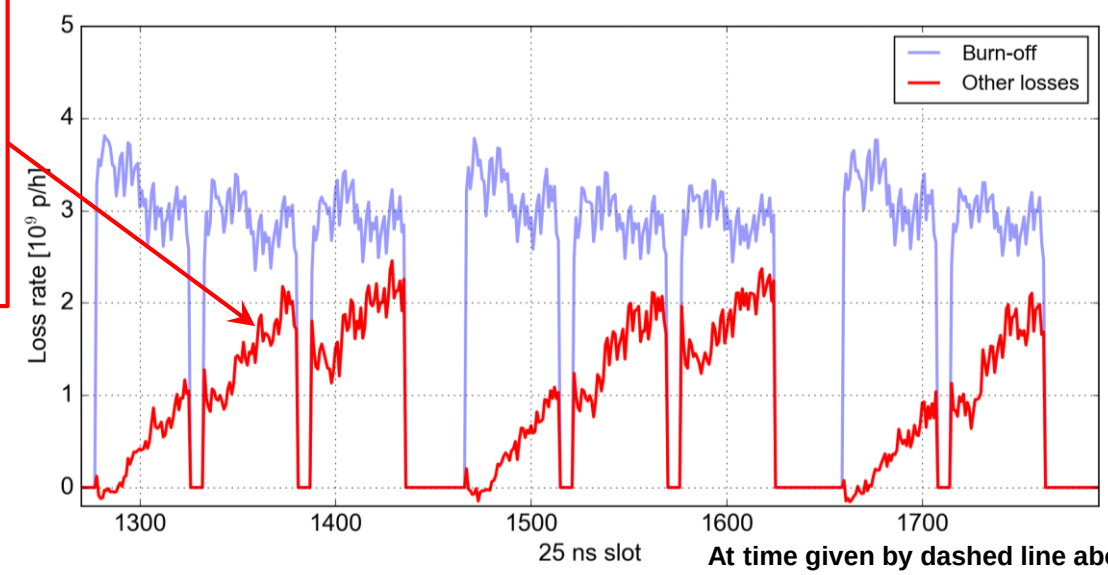

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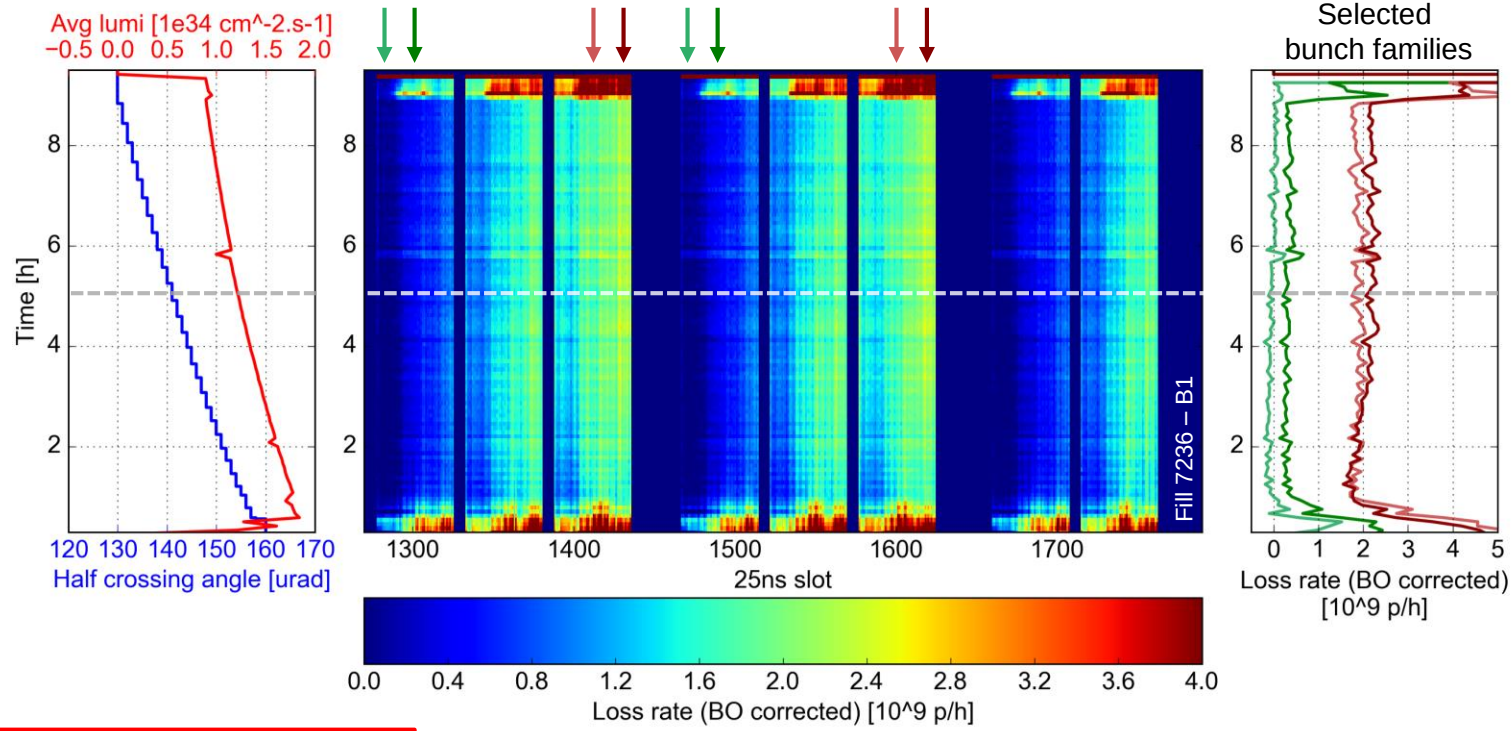

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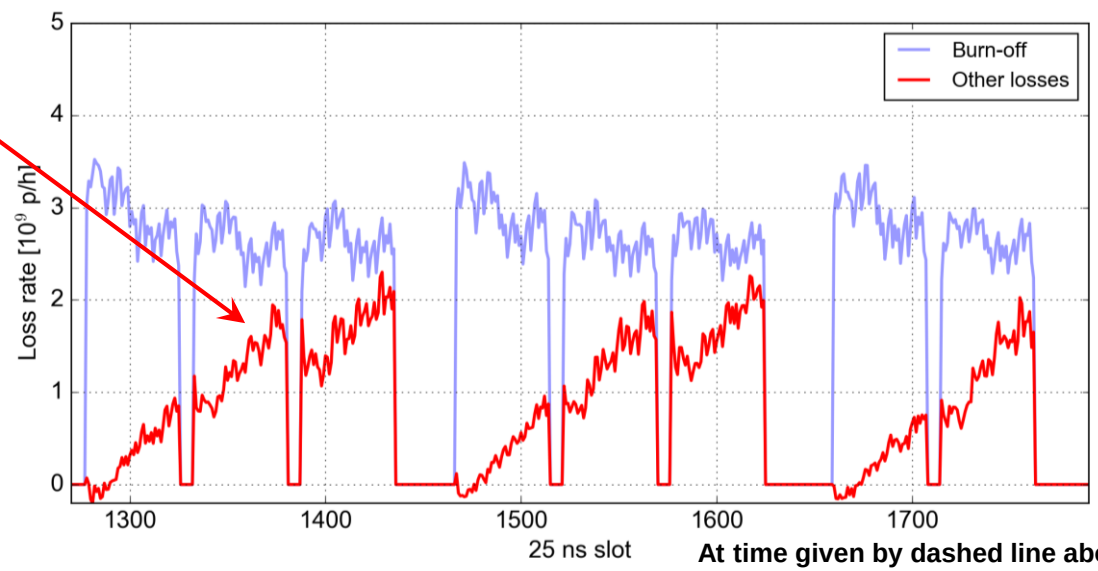

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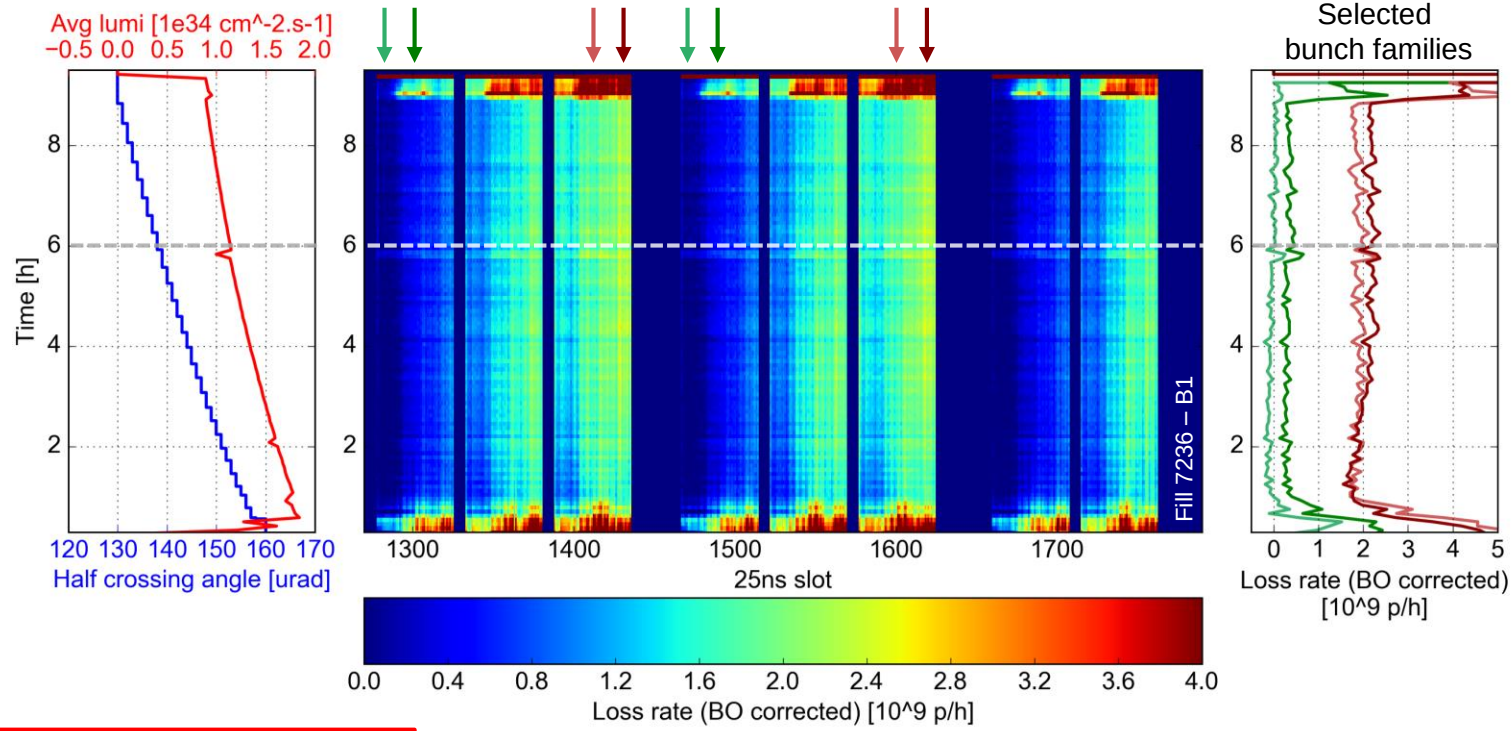

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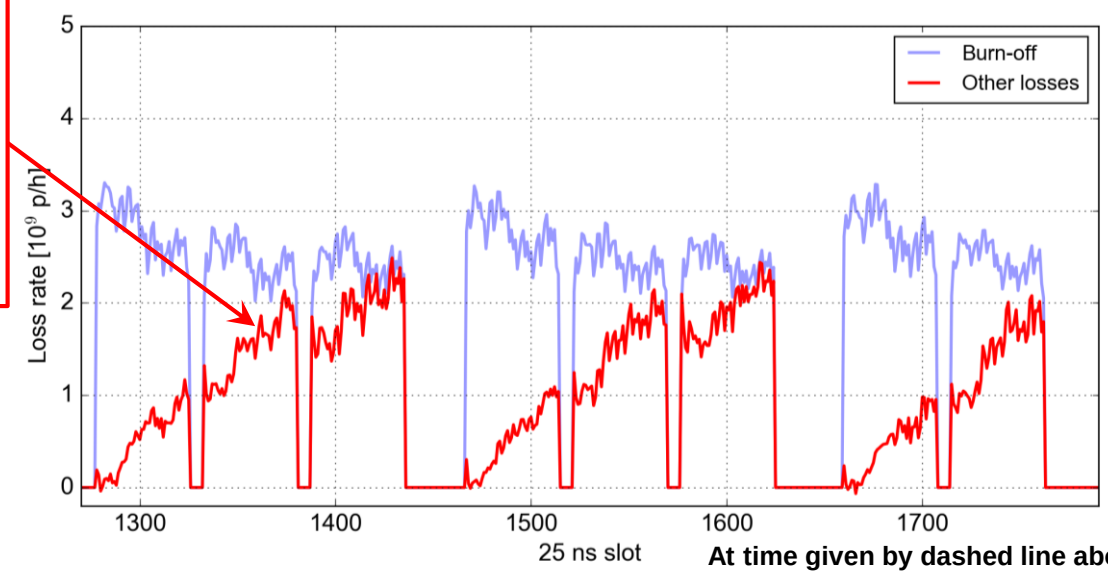

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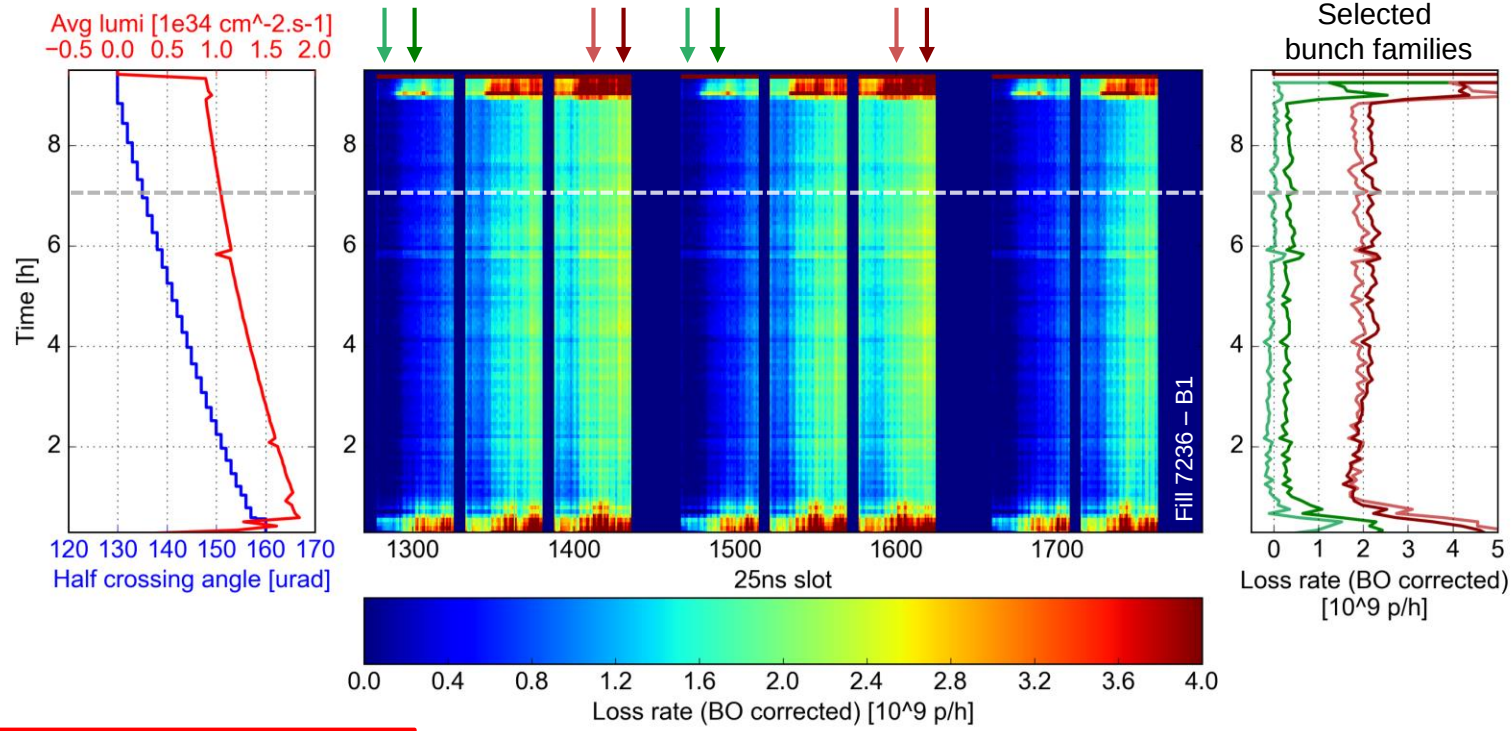

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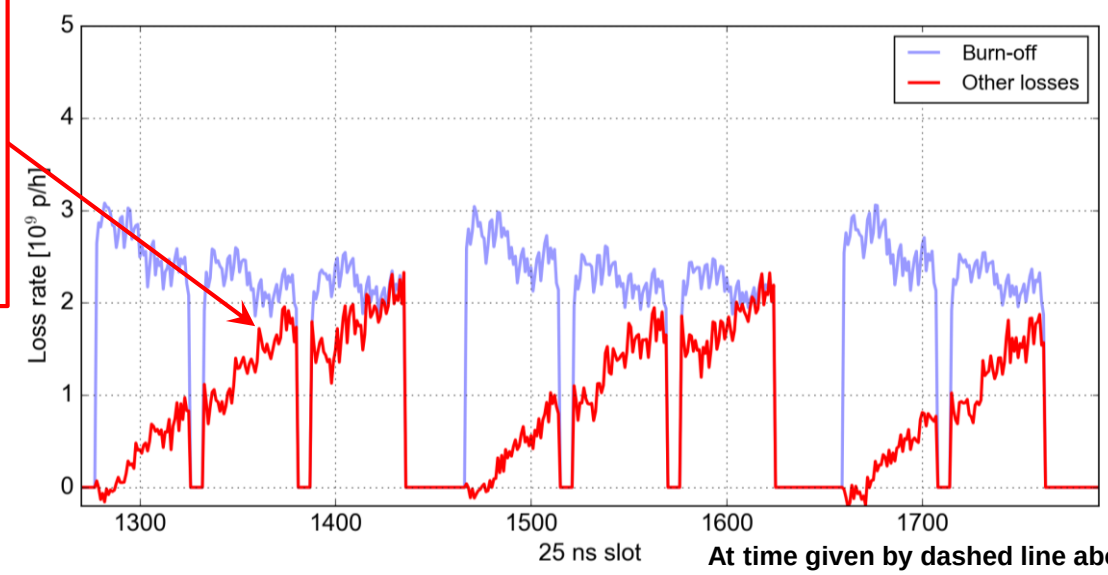

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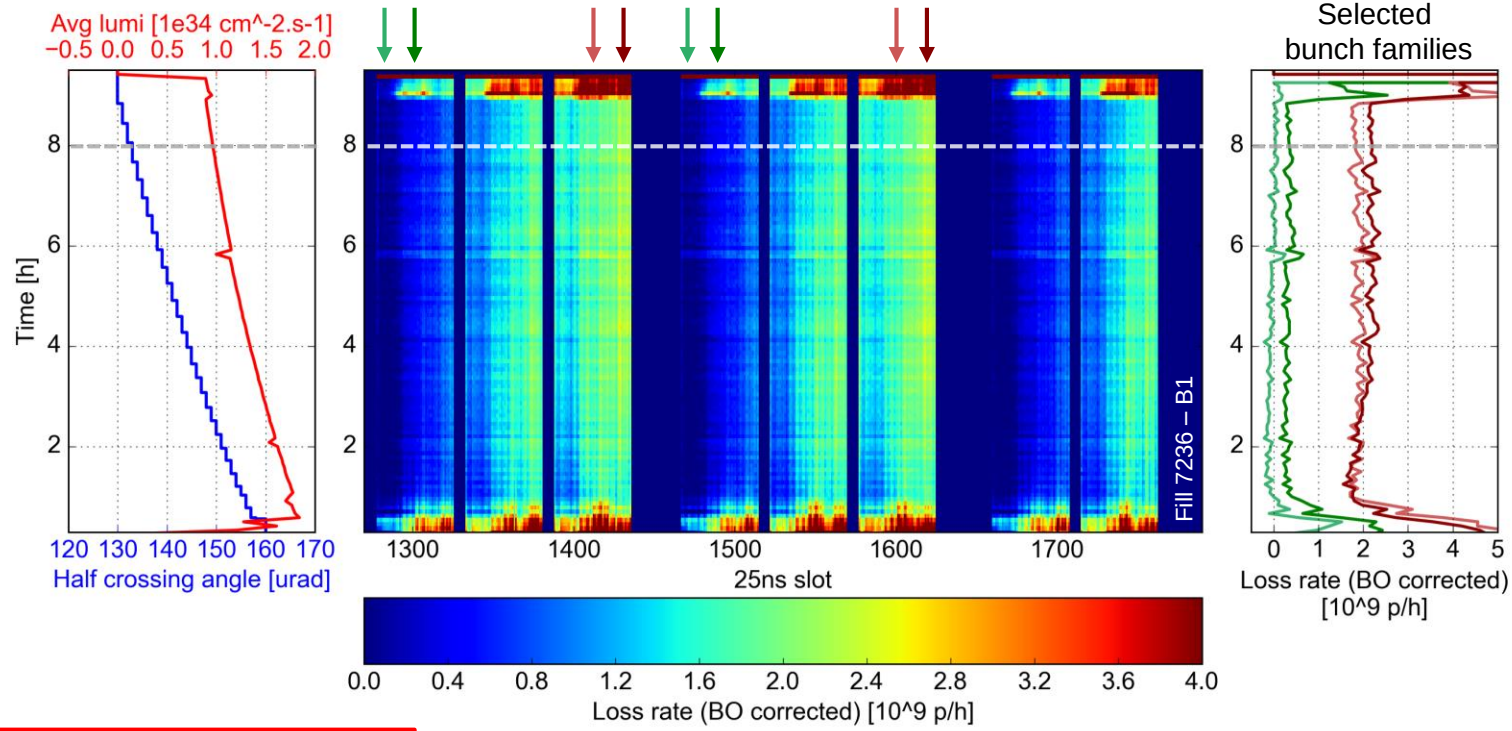

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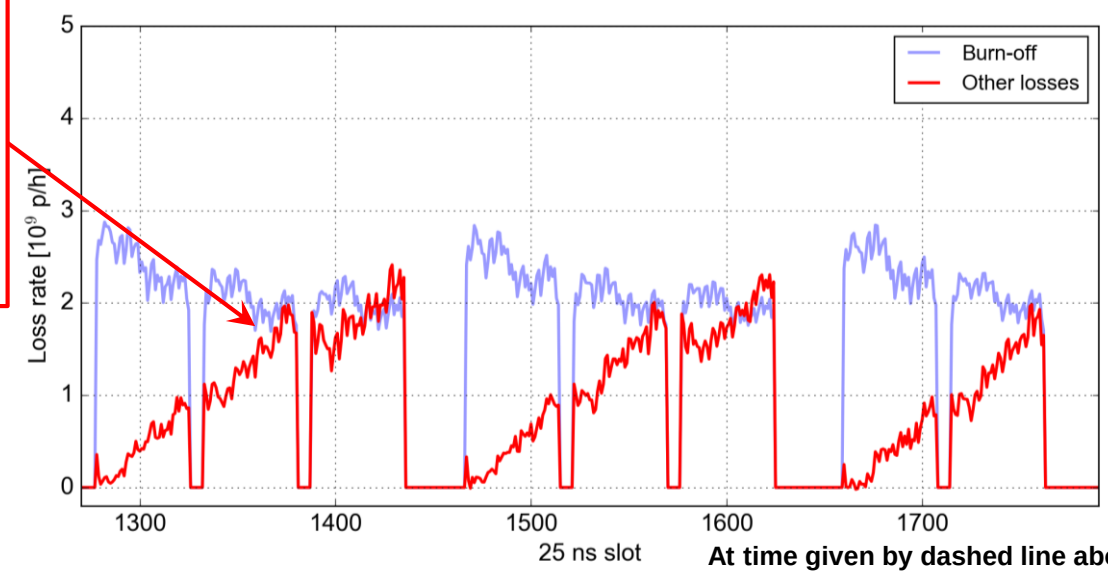

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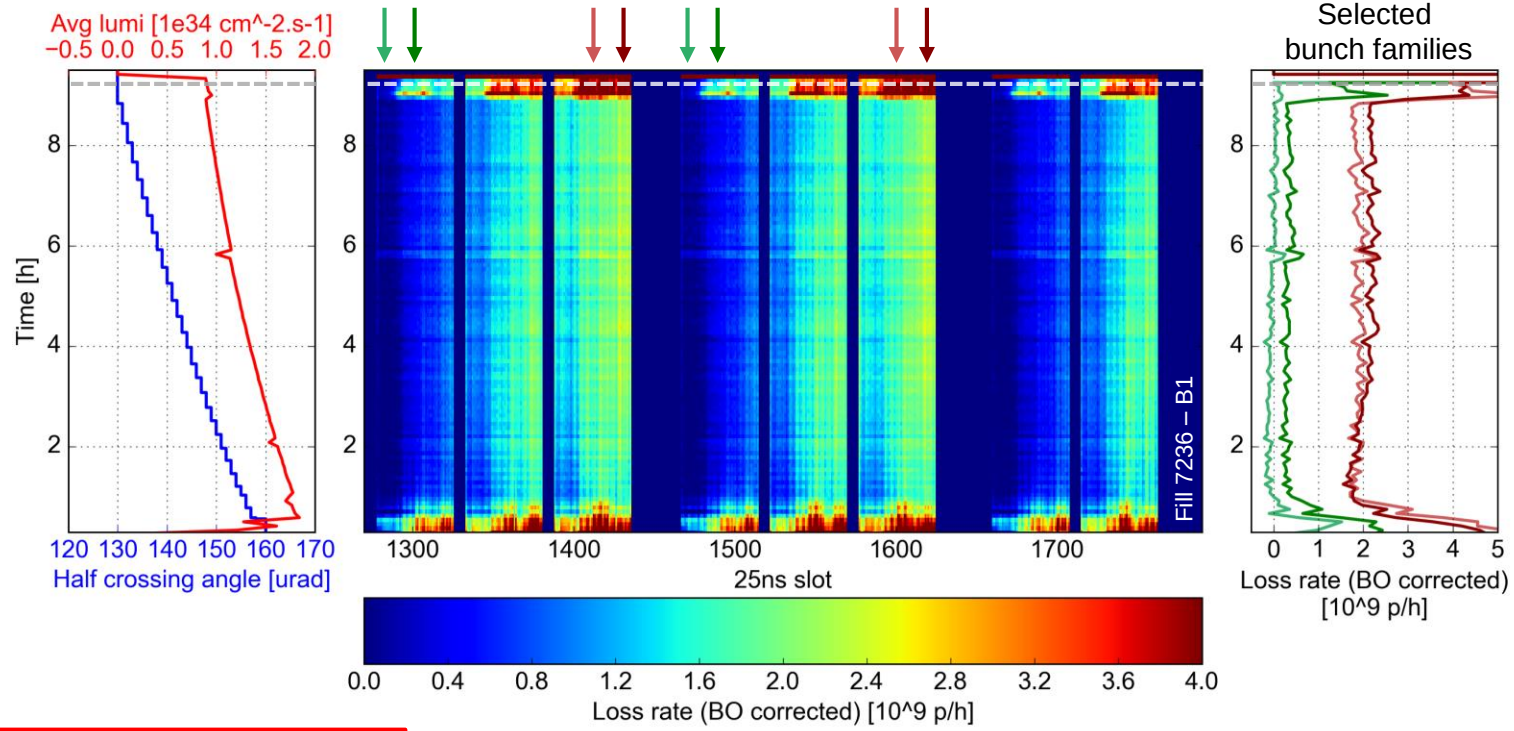
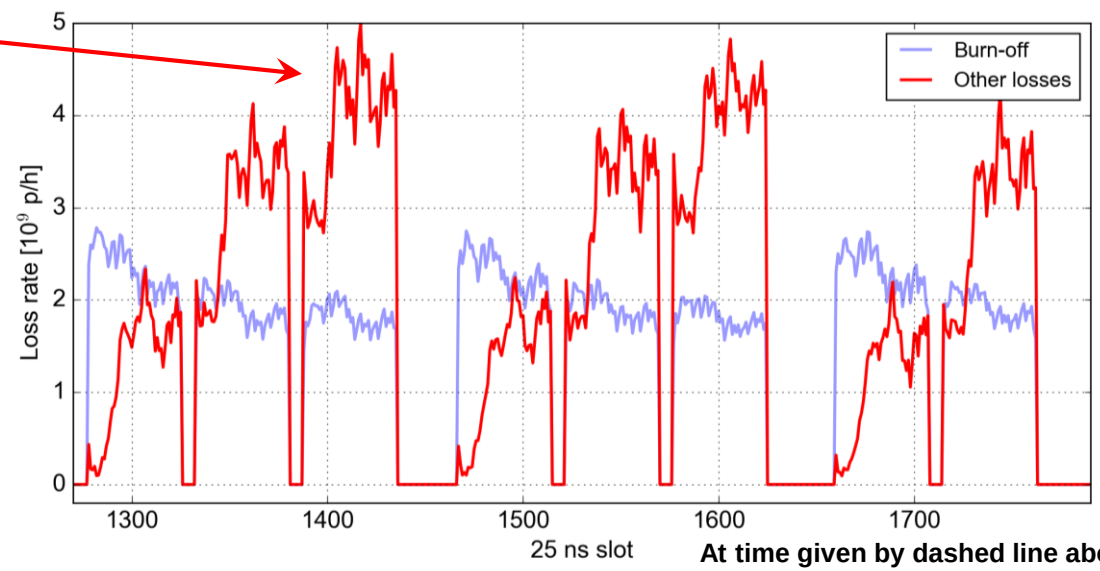


Losses **increase significantly when β* is reduced**



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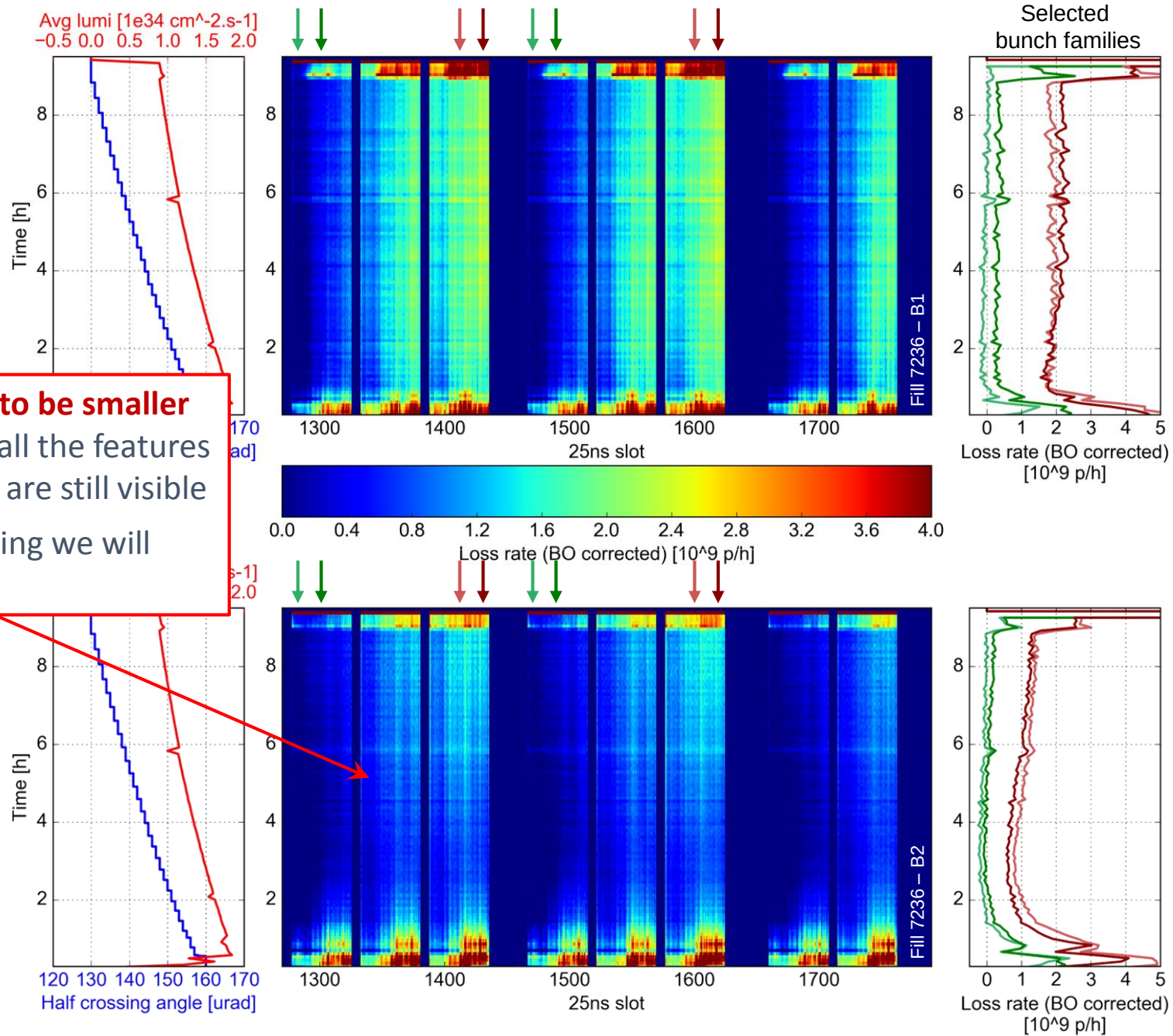
A typical fill from 2018

Beam 1

Beam 2



Loss rates tend to be smaller for beam 2 but all the features discussed so far are still visible

→ In the following we will focus on B1

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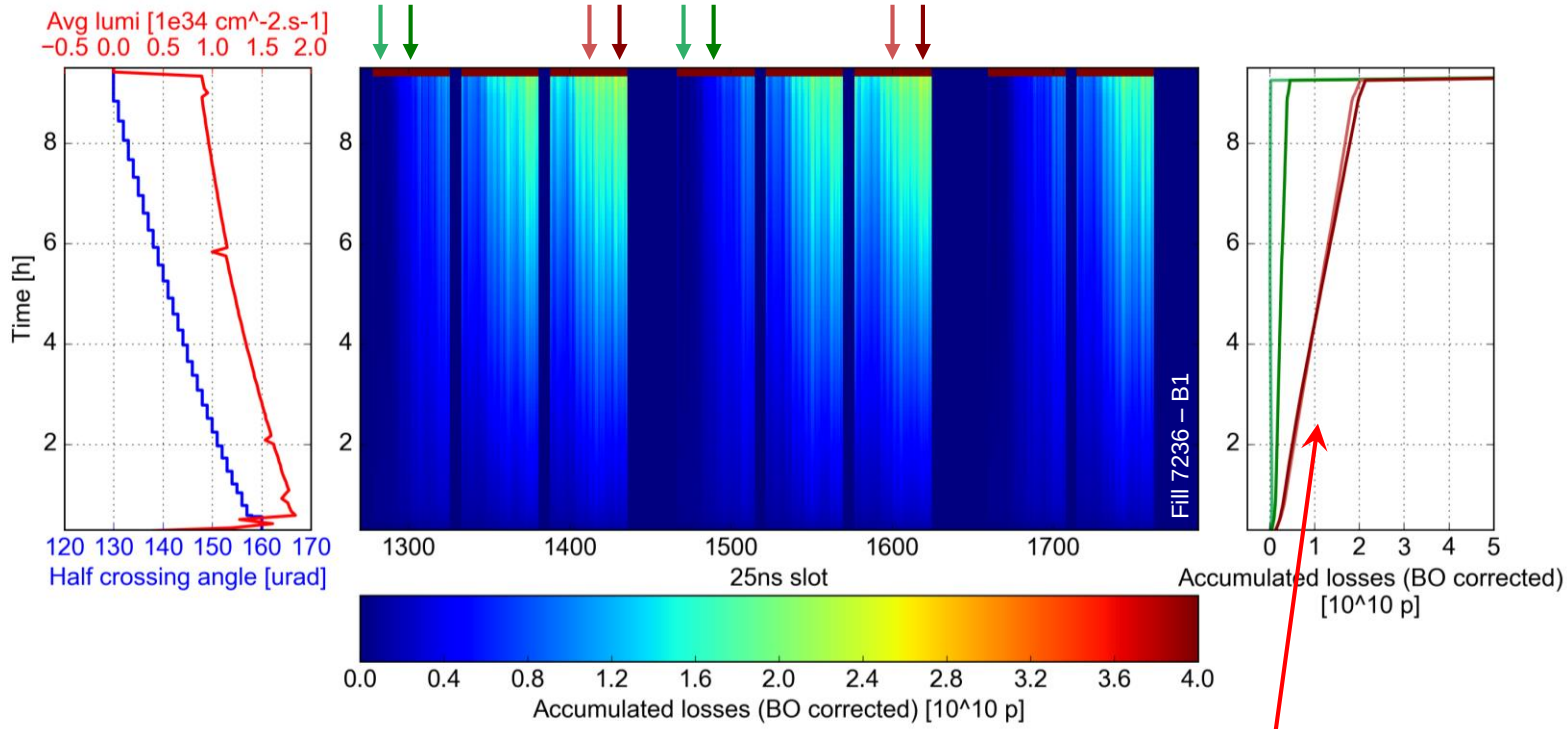
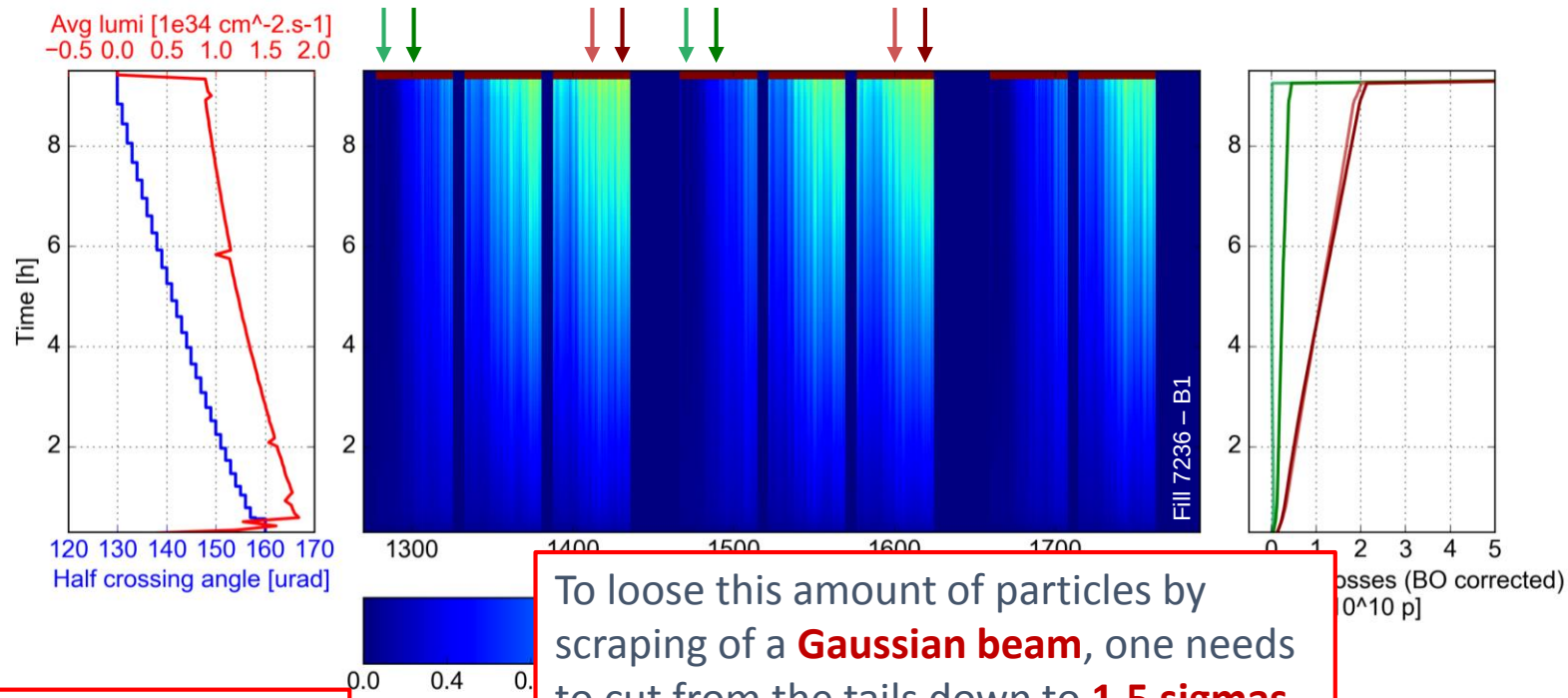
Accumulated losses



As the loss rate is ~constant, the **accumulated losses are practically linear with time**

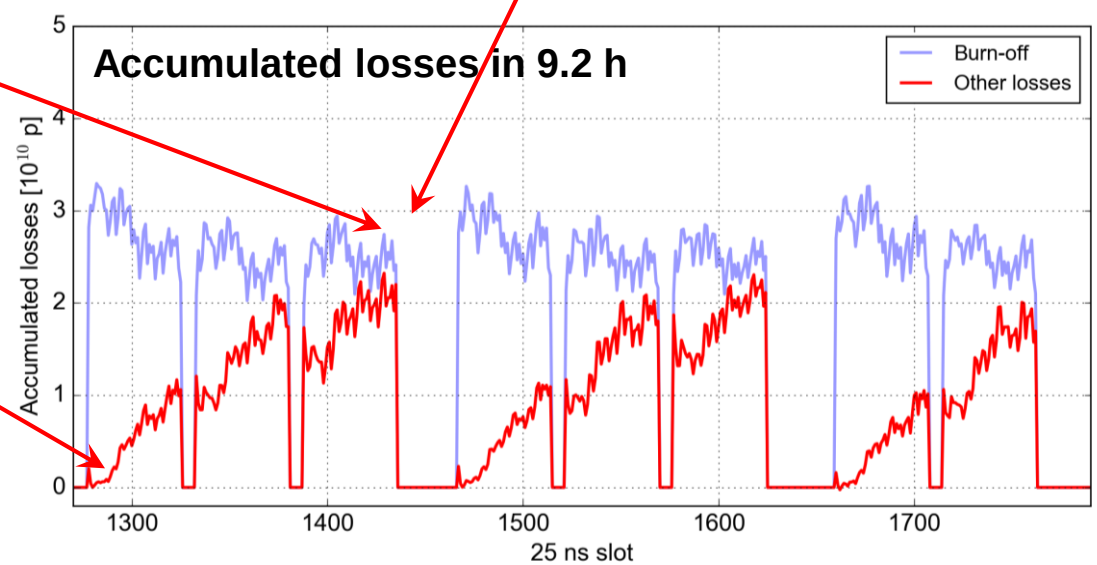
Accumulated losses



To loose this amount of particles by scraping of a **Gaussian beam**, one needs to cut from the tails down to **1.5 sigmas**

Total losses on the trailing bunches amount to **~20% of the initial intensity**, i.e. the same amount lost due to burn-off

Even over a 9h fill, **losses on the first bunches of the train are practically not measurable**

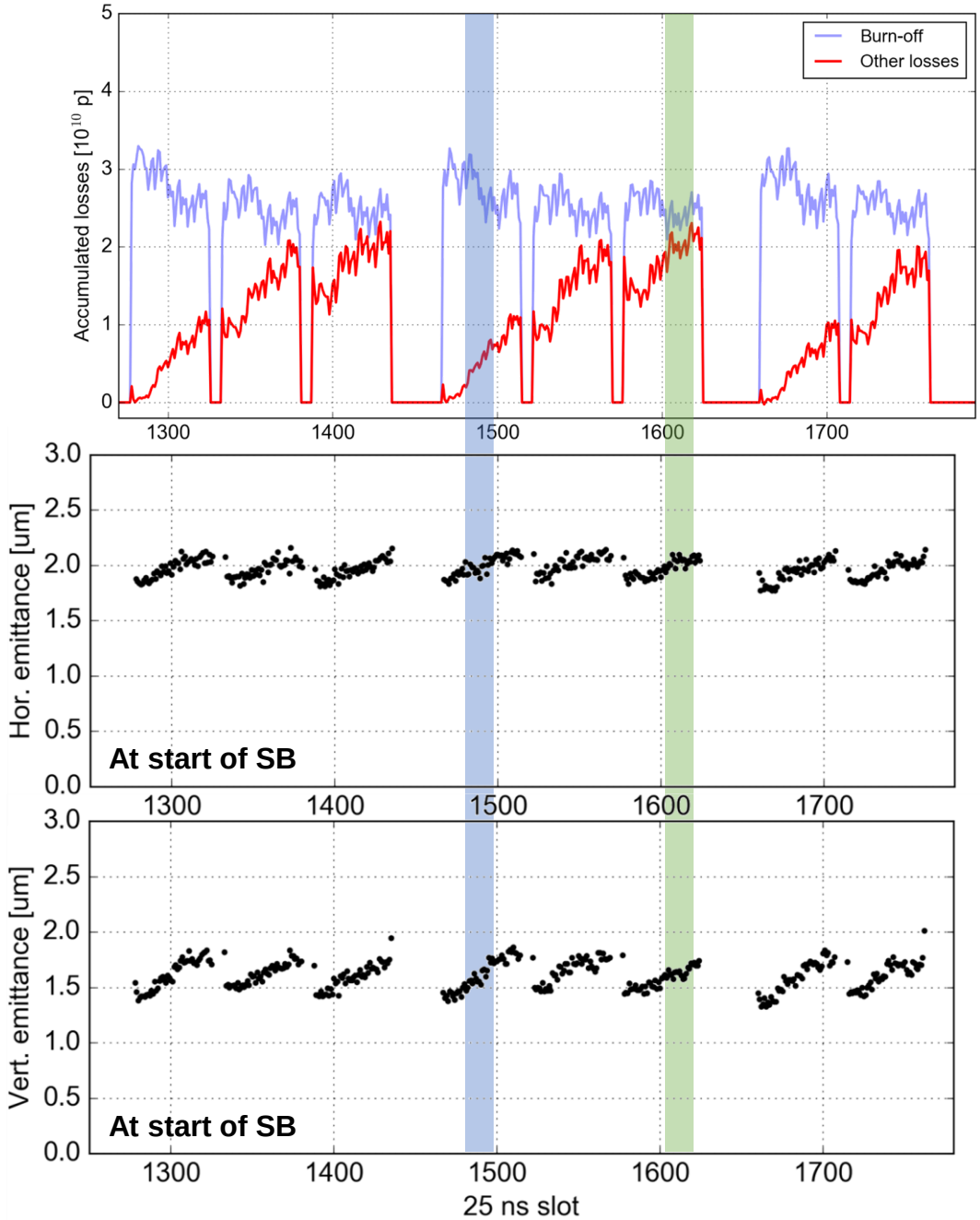


Comparison against initial emittances

Are the different beam losses caused by **different transverse size at start of collisions**?

→ **From BSRT measurements it seems that it is not the case**

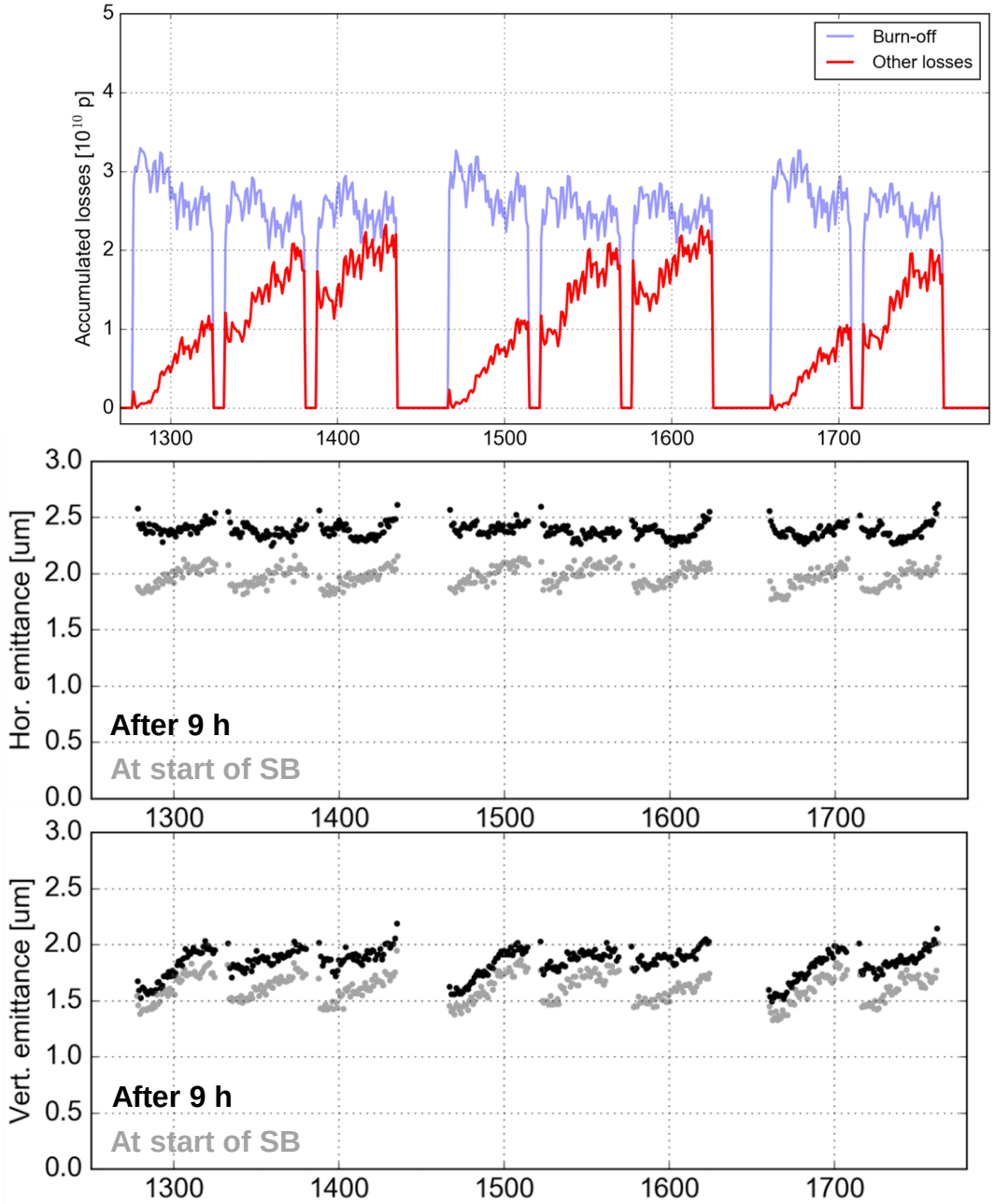
→ **Bunches with very similar initial size show significantly different losses**



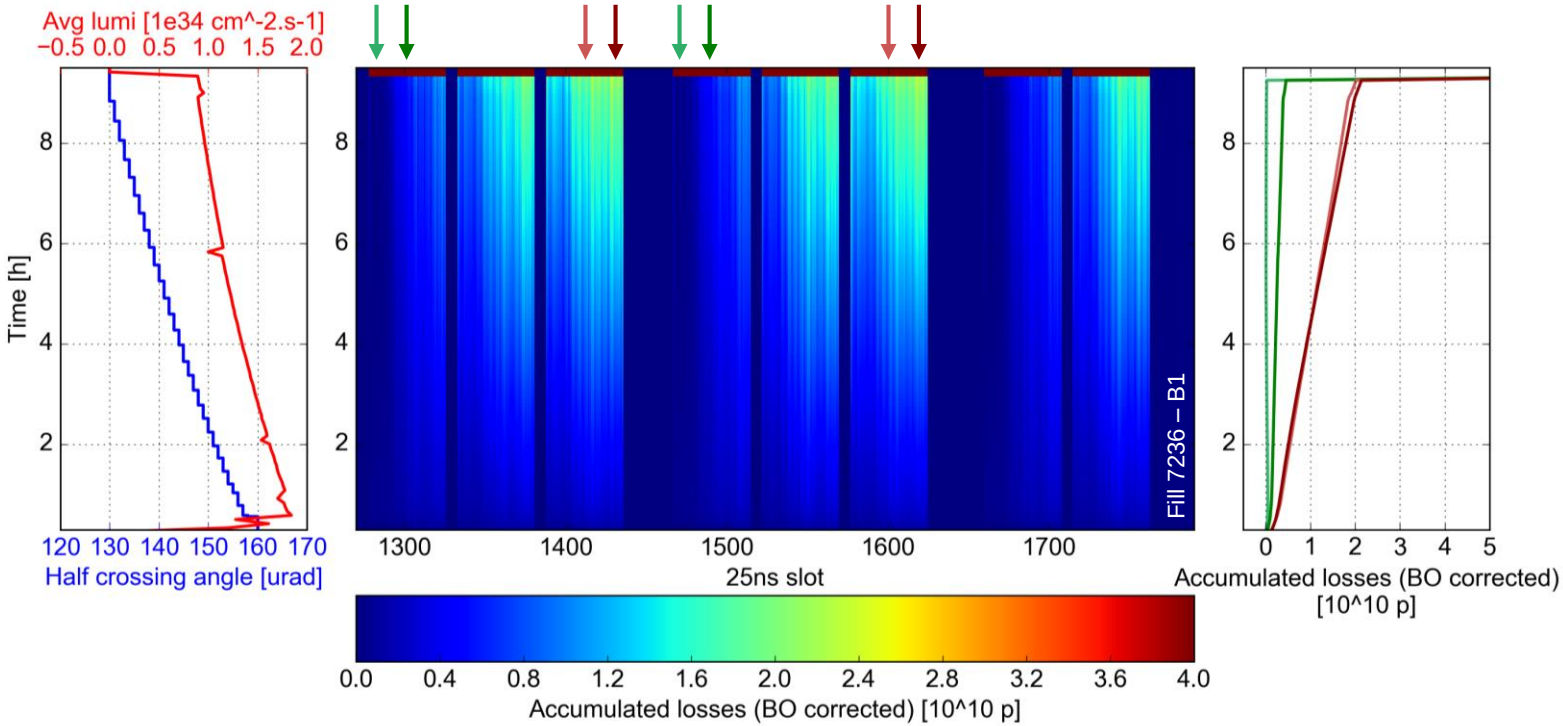
Comparison against emittance evolution in Stable Beams

Is there a **correlation with emittance-growth in stable-beams**?

- **Emittance growth in Stable Beams is modest** (~0.5 μm in 9 hours)
- There is **no evident correlation with the bunch-by-bunch loss pattern**



Summary of the main observations



- Losses are **stronger at the tail of the bunch trains**
- **Over a 9h fill**, losses amount to about **20% of the initial intensity on the most affected bunches**
- Time structure **looks like a constant spill more than a scraping** (loss mechanism does not depend strongly on the bunch charge)
- There is **no correlation with initial bunch-by bunch emittance**
- There is **no correlation with the number of BB LR encounters**

  → **e-cloud acting on the bunches during the Stable Beams phase** appears to be a key element in the underlying loss mechanism

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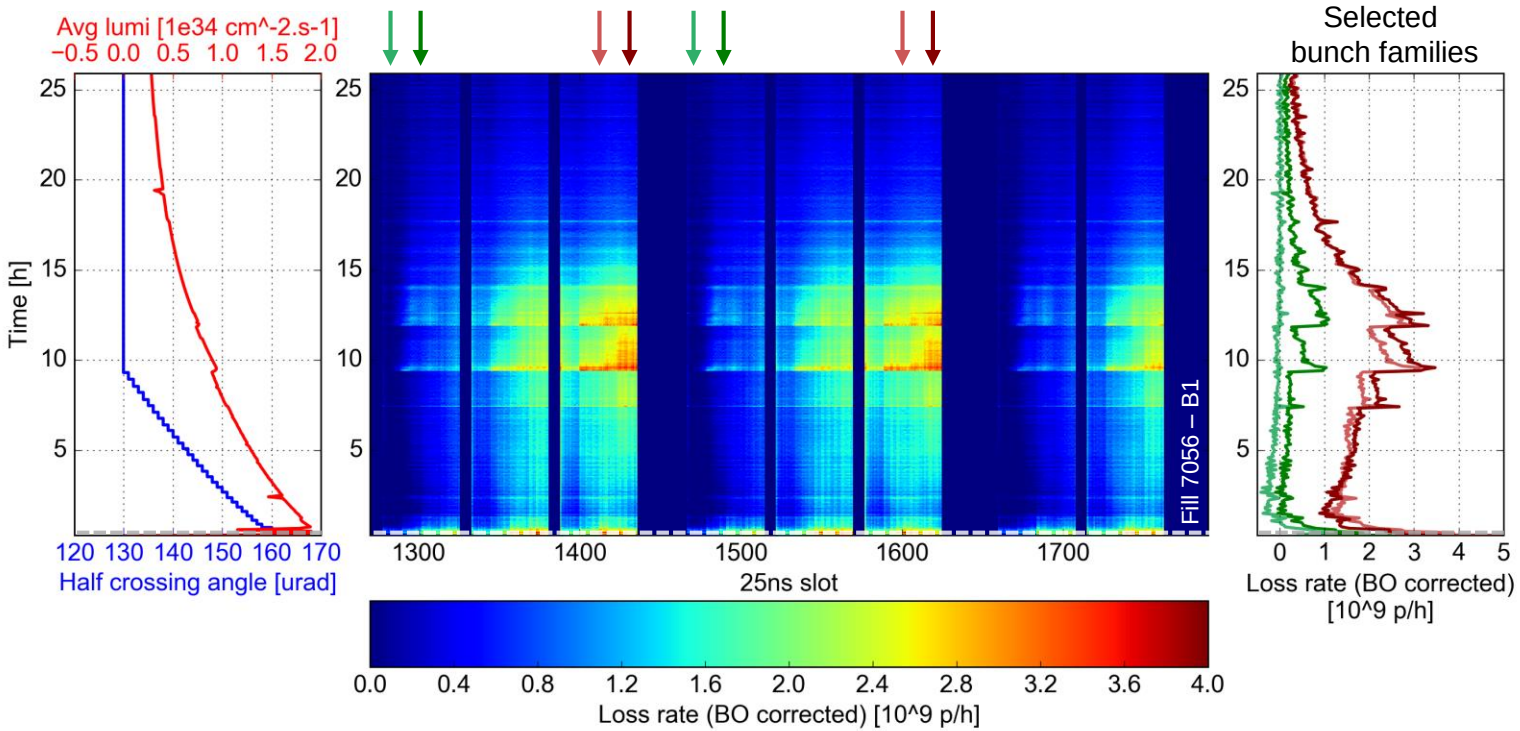
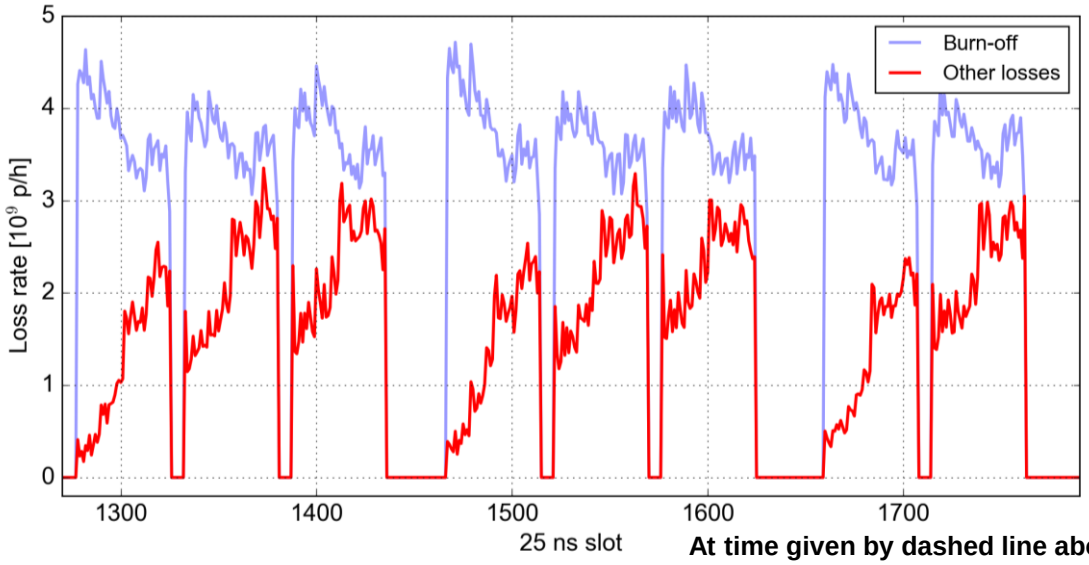
Very long 2018 fill (7056)



- Same features as observed before for the first part of the fill



At time given by dashed line above

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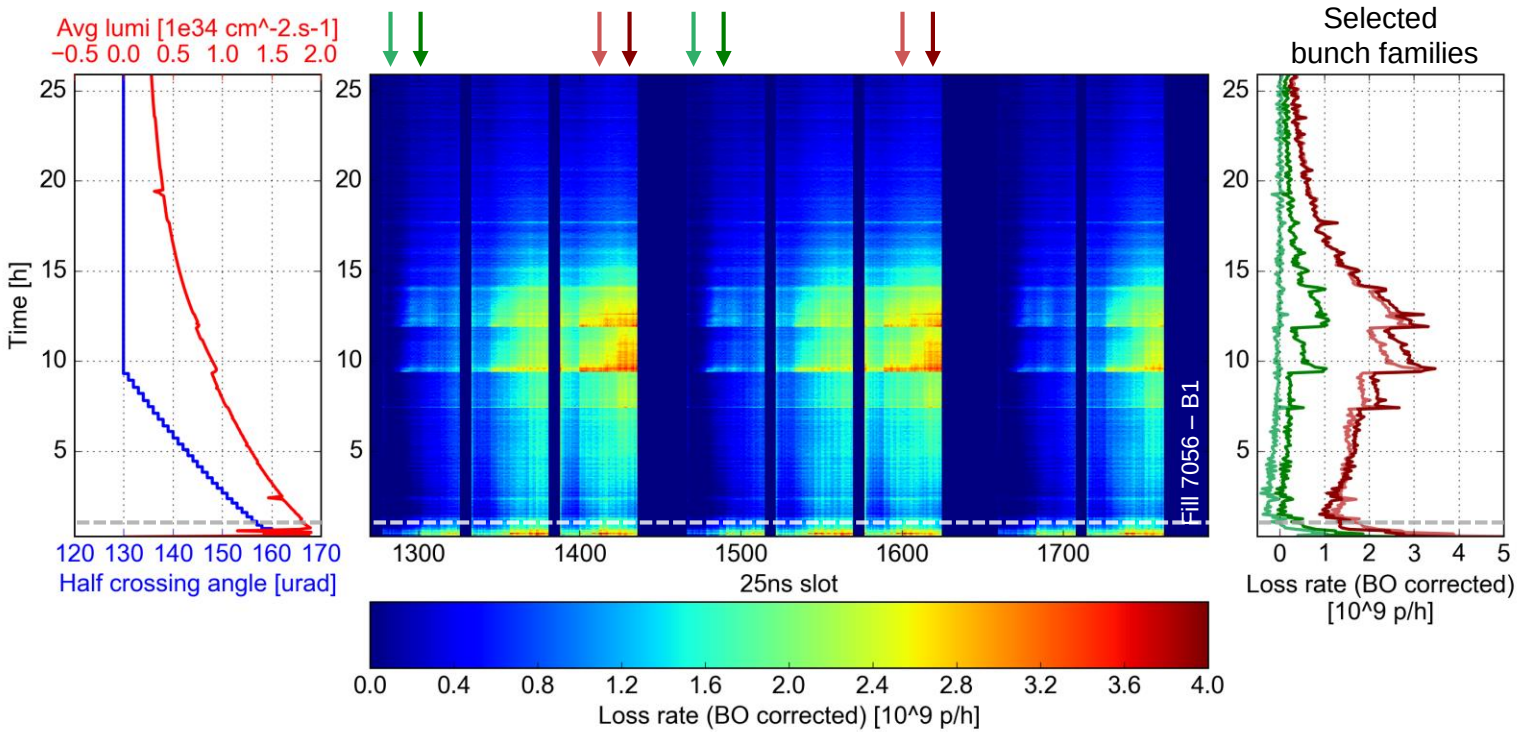

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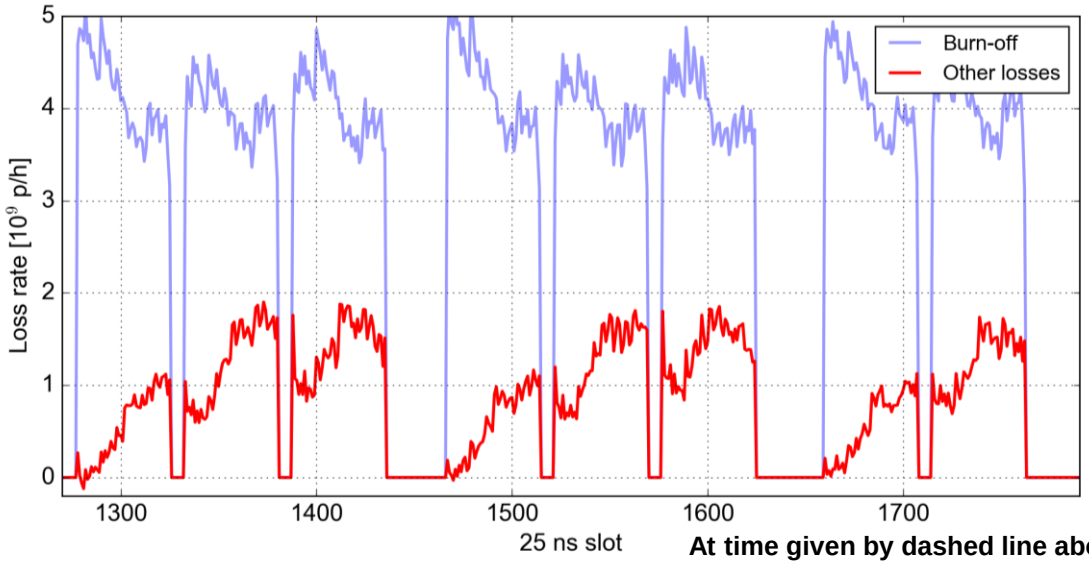

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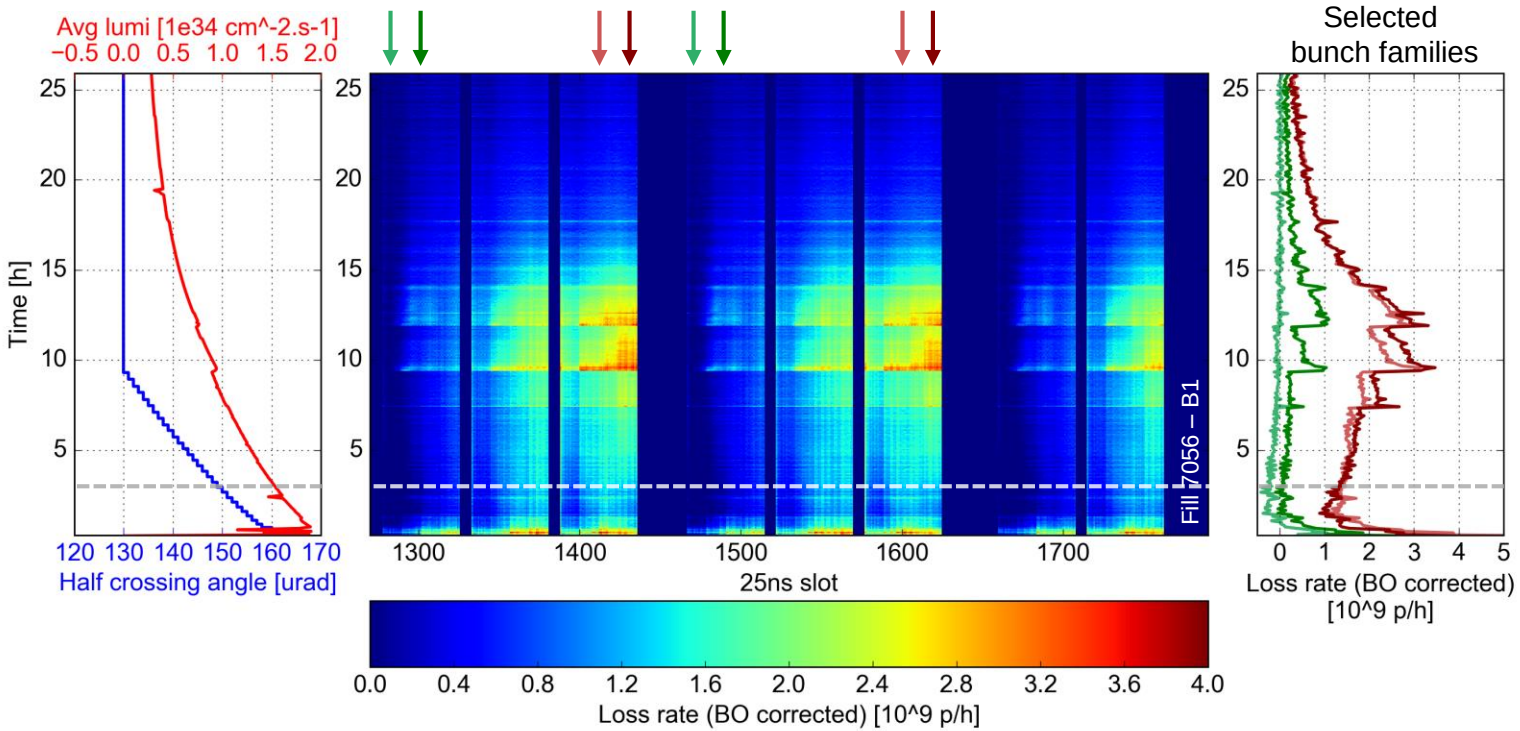

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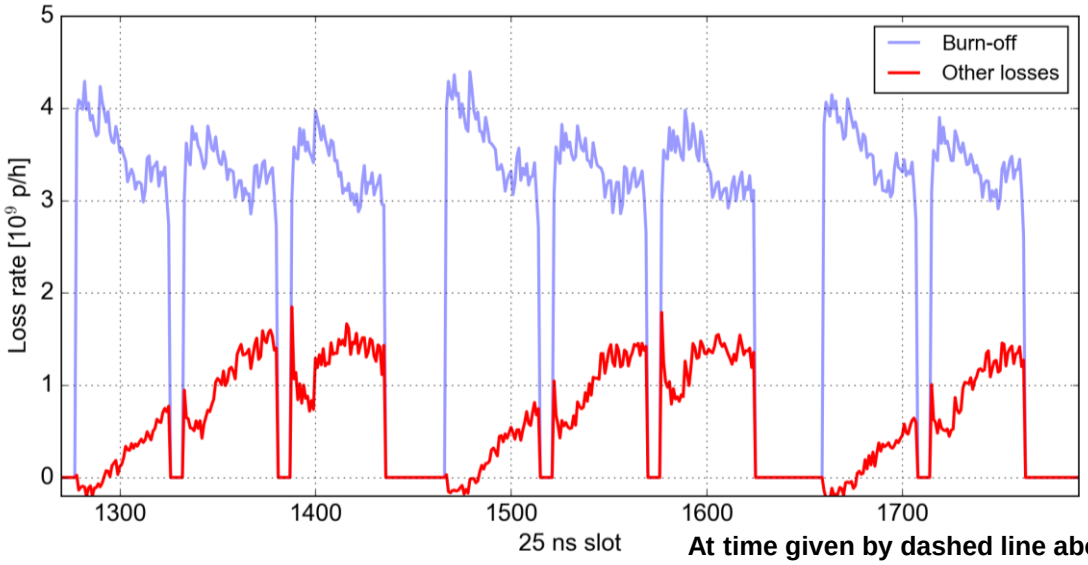

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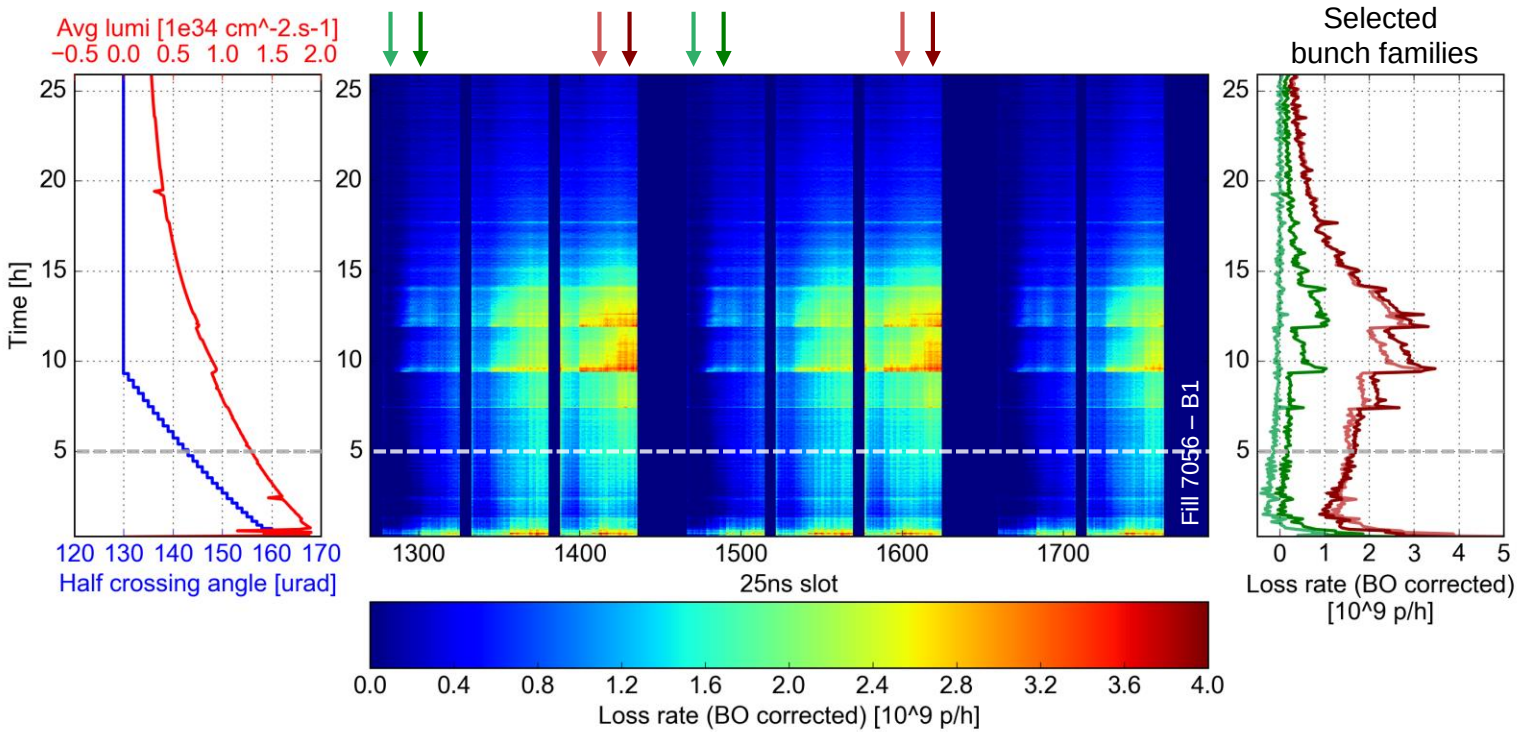

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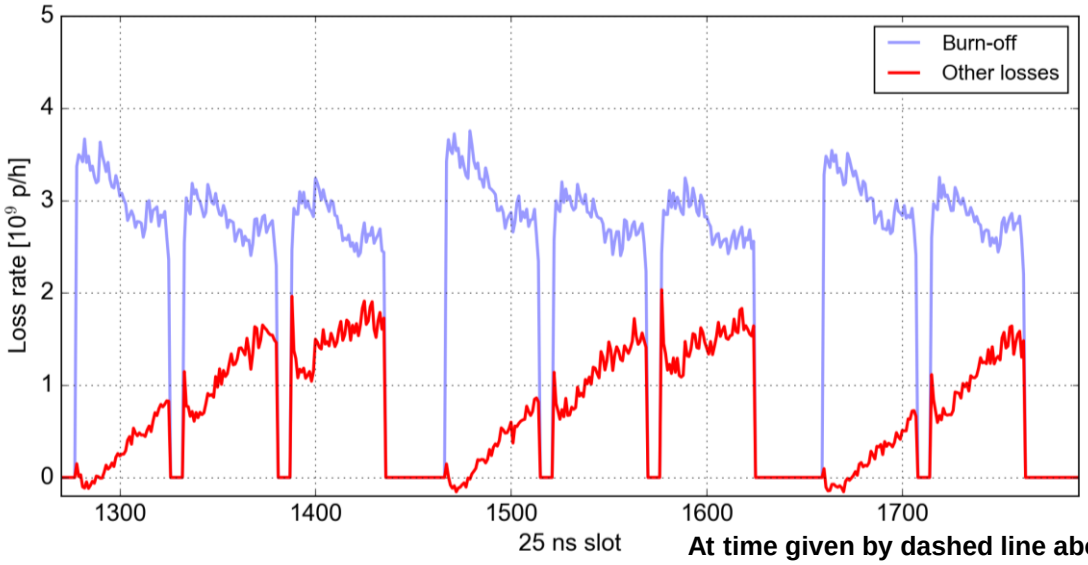

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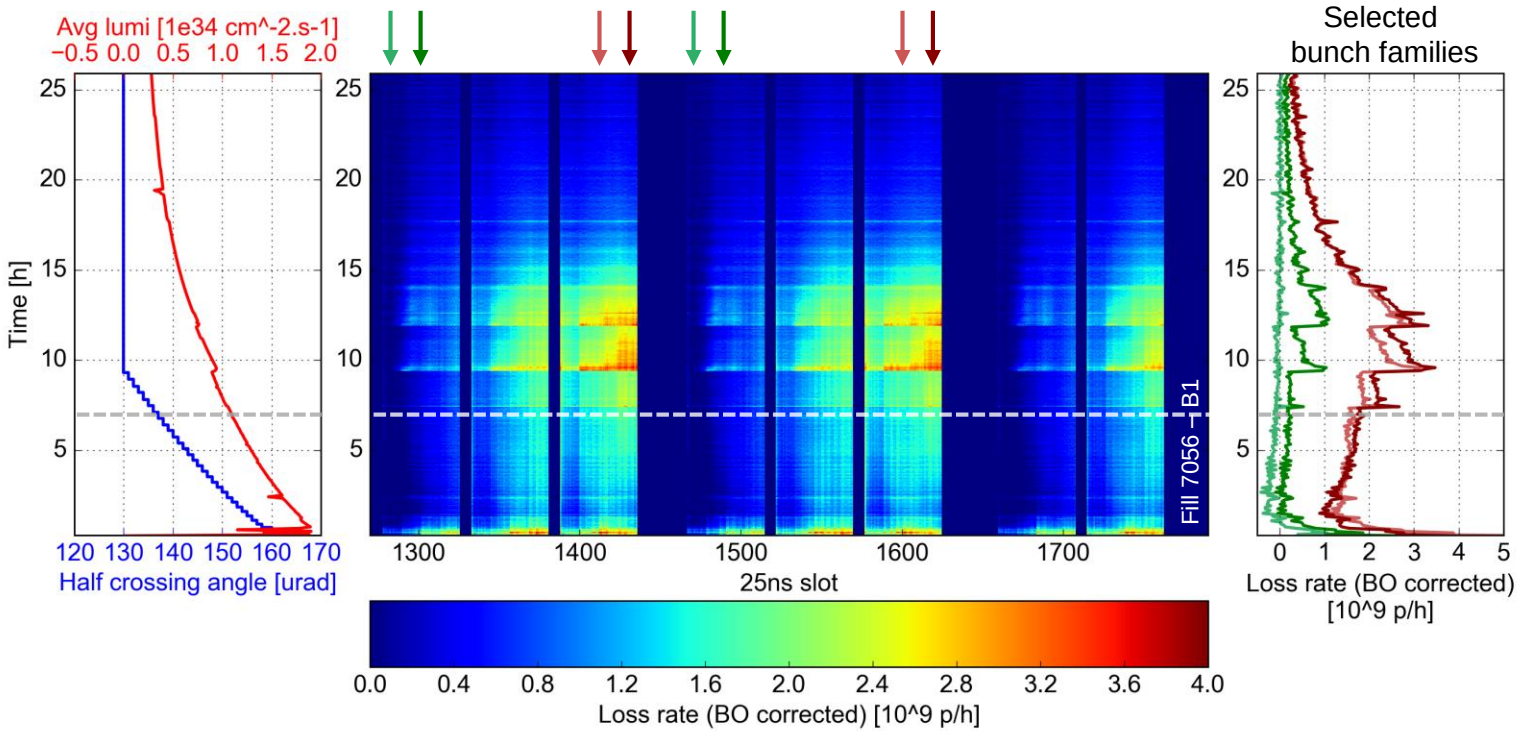

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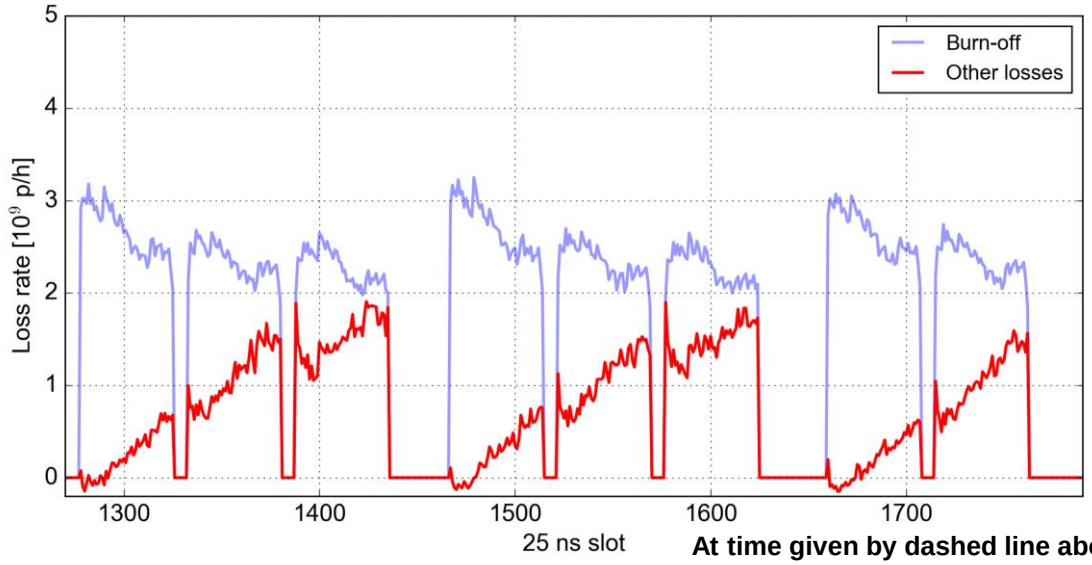

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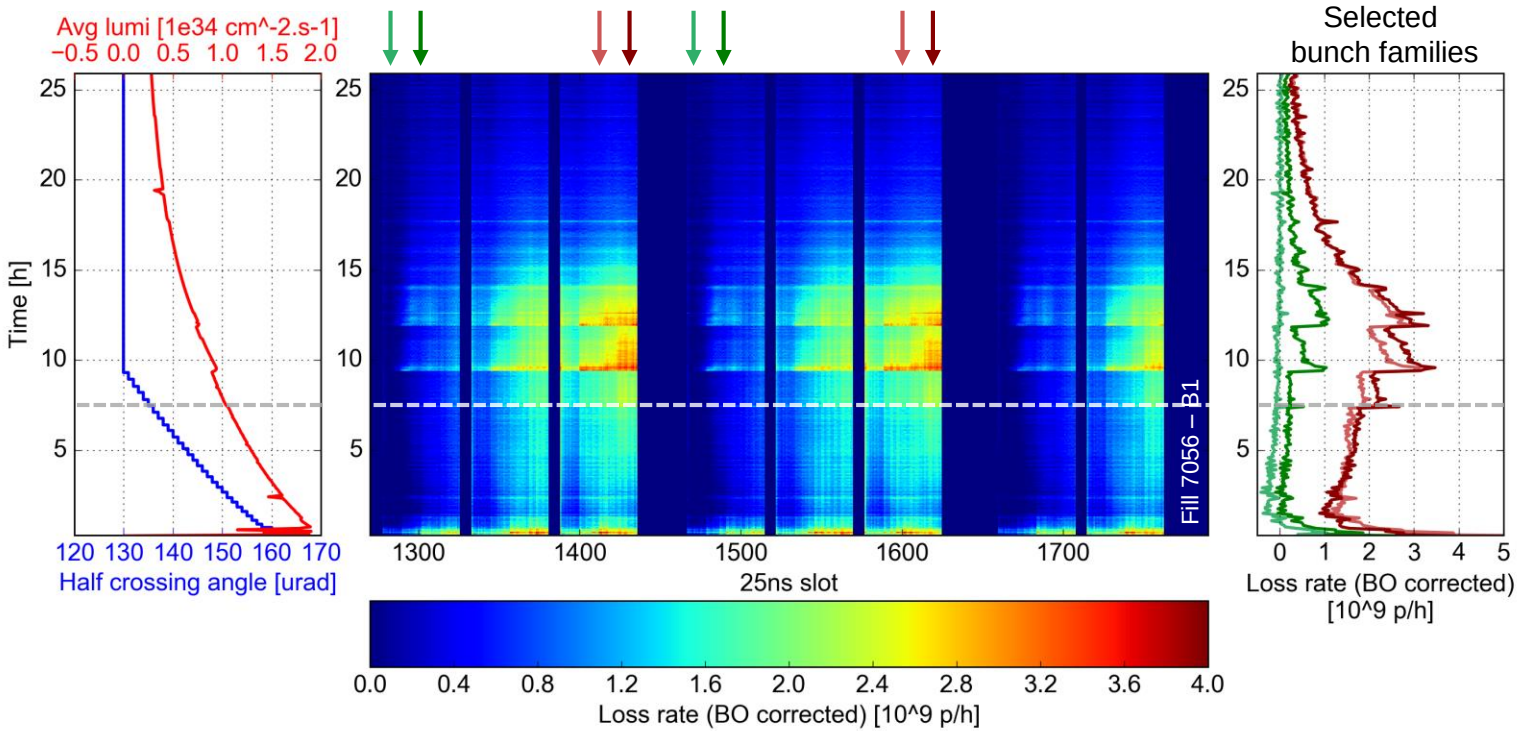

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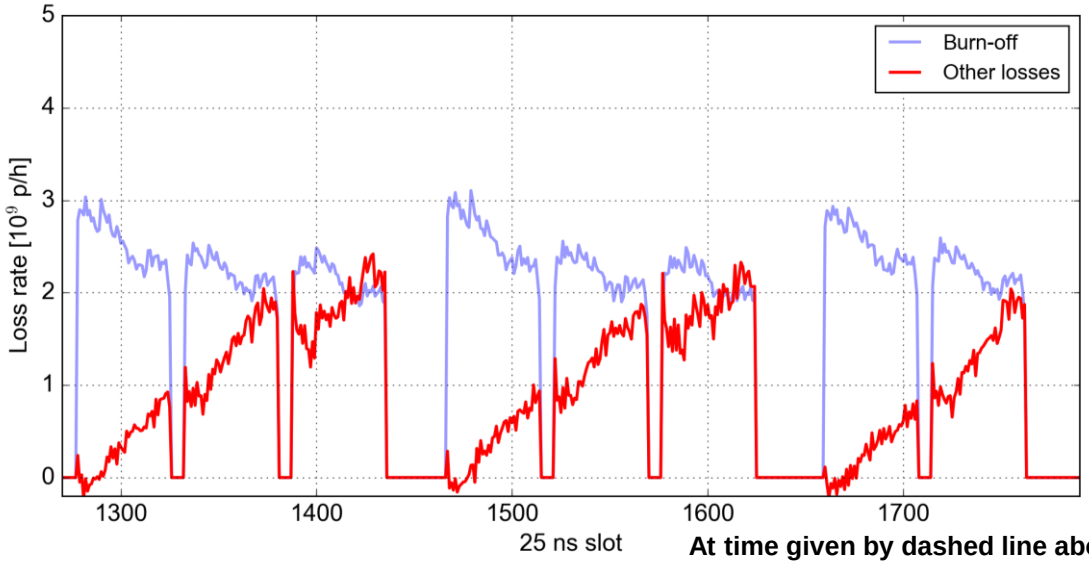

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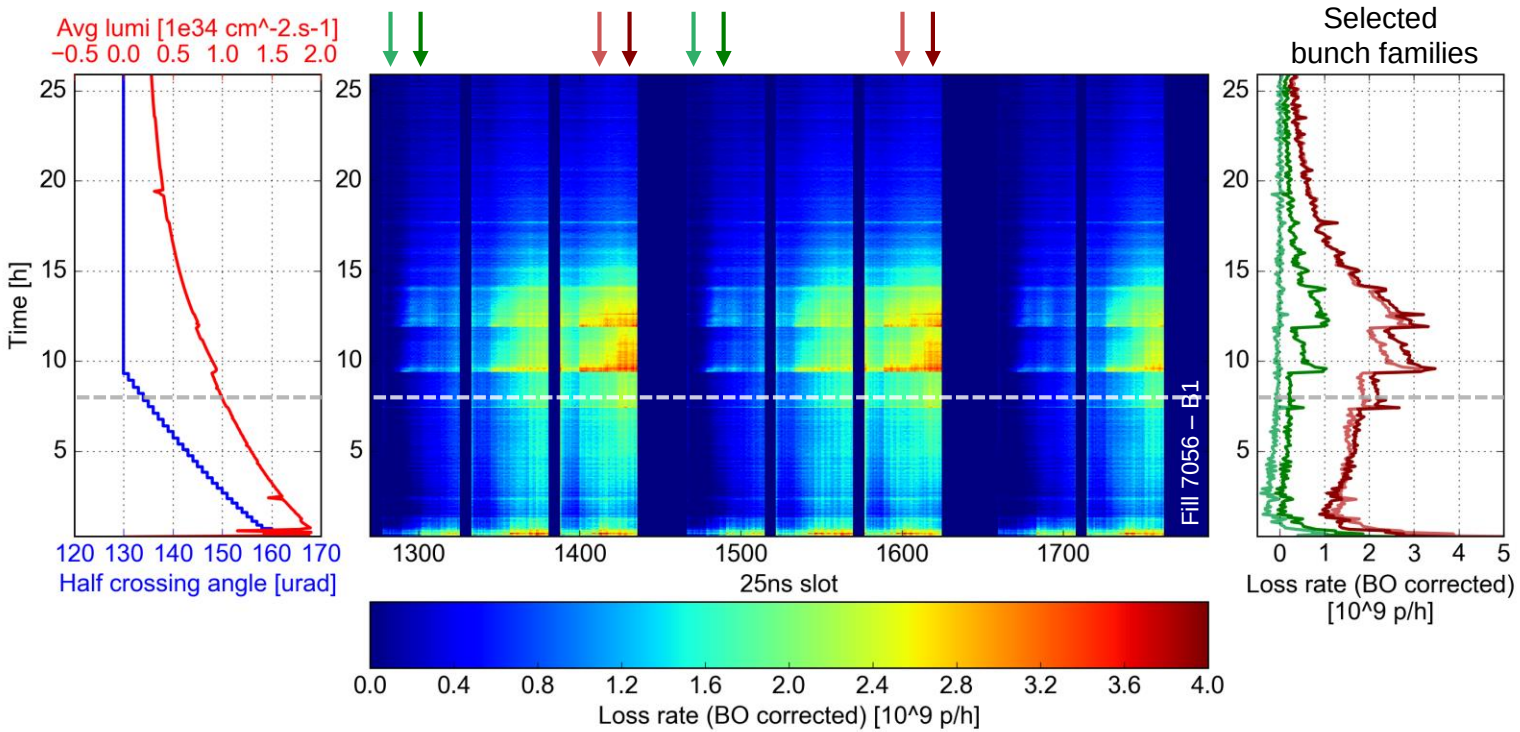

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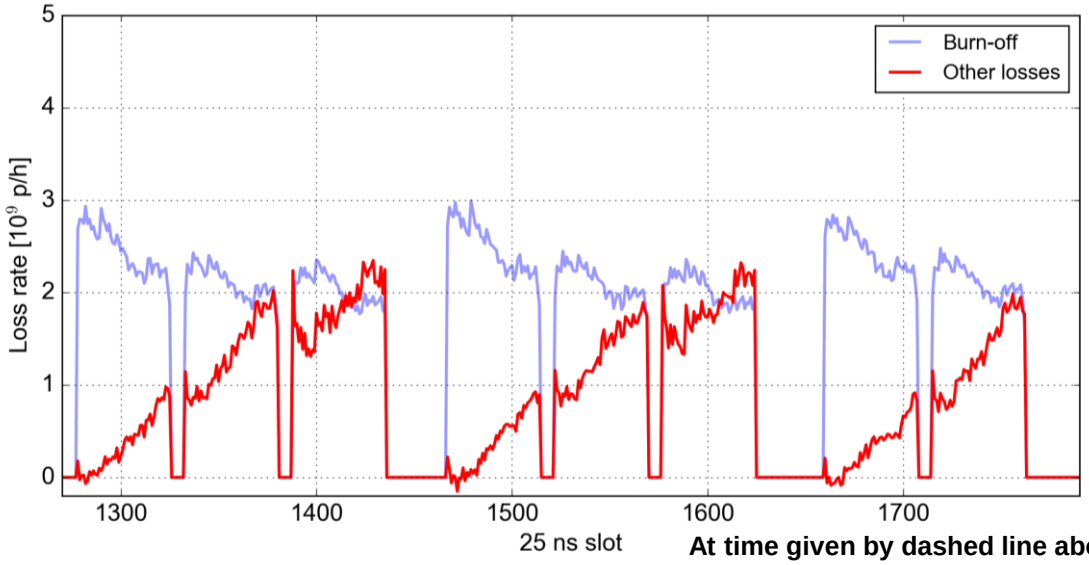

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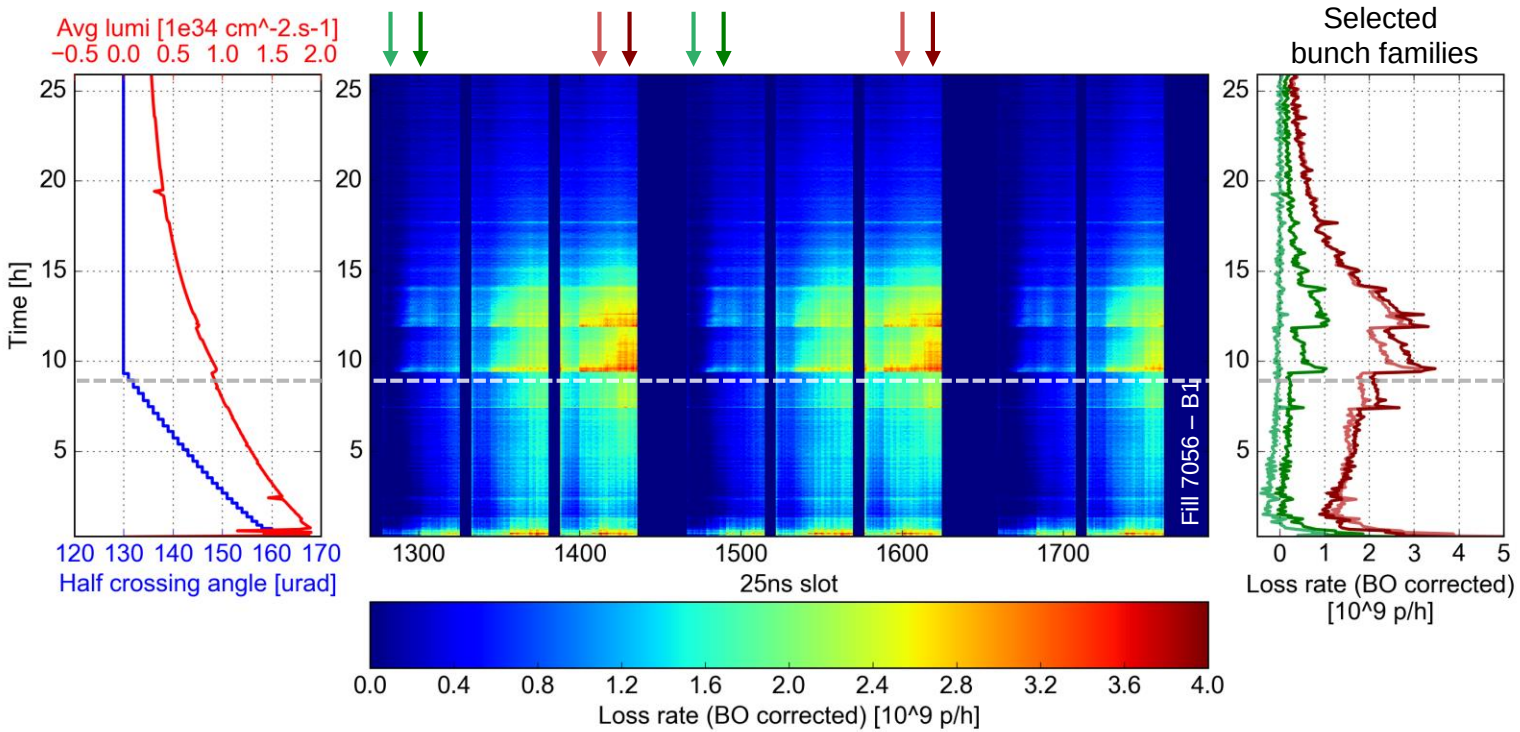

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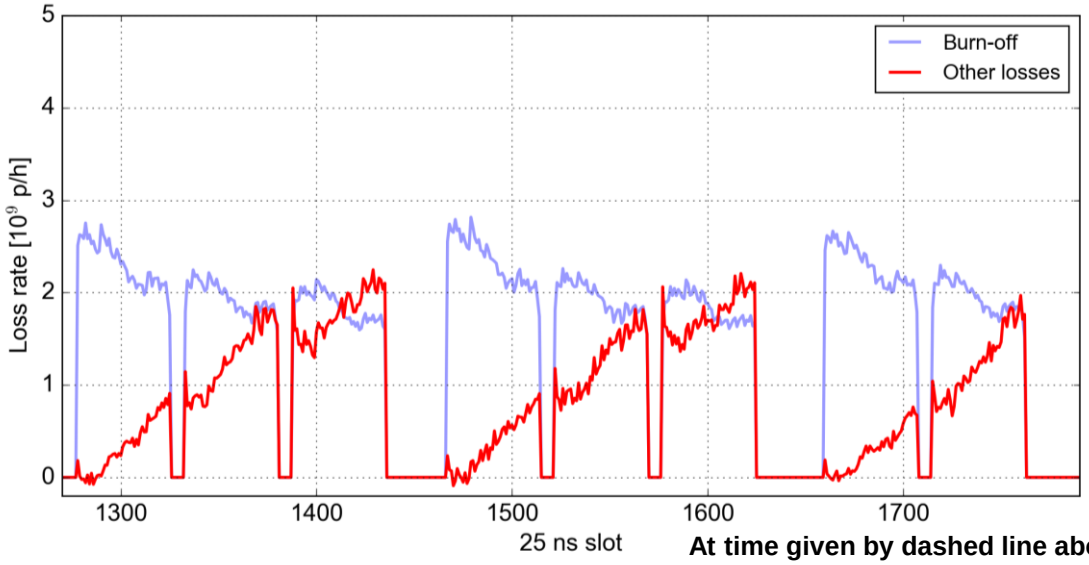

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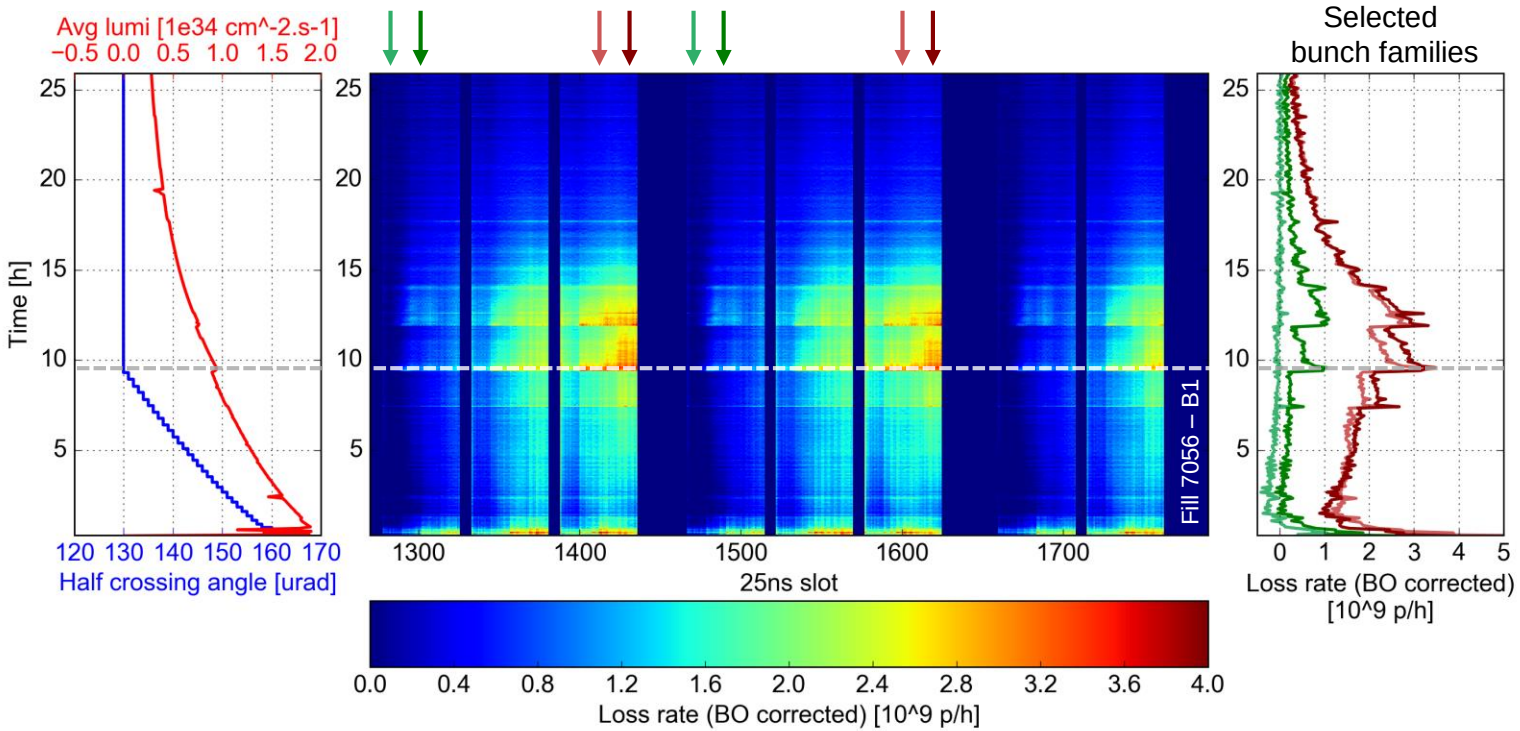
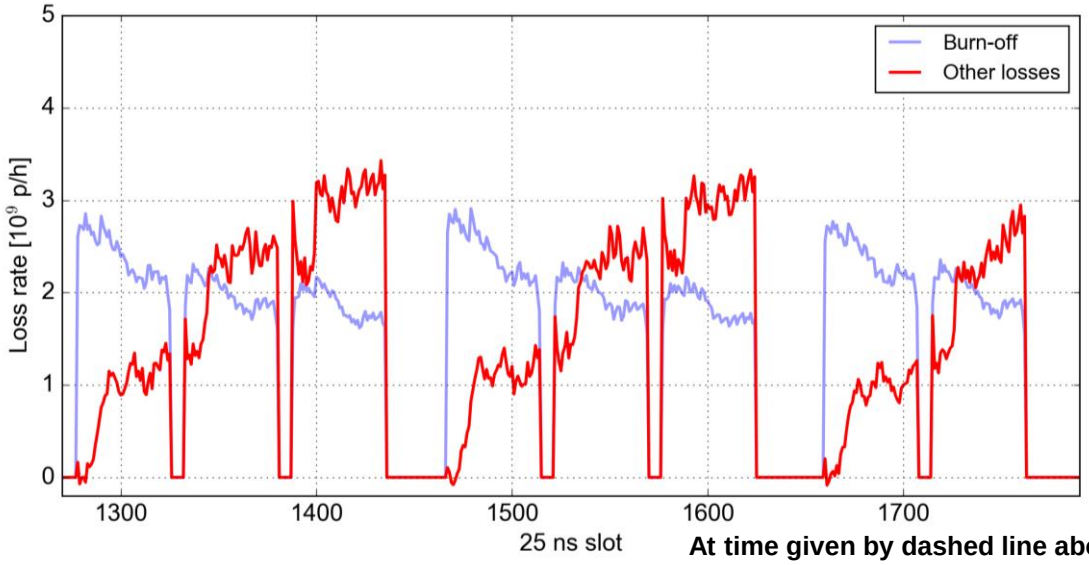


- Significant **increase when reducing β***



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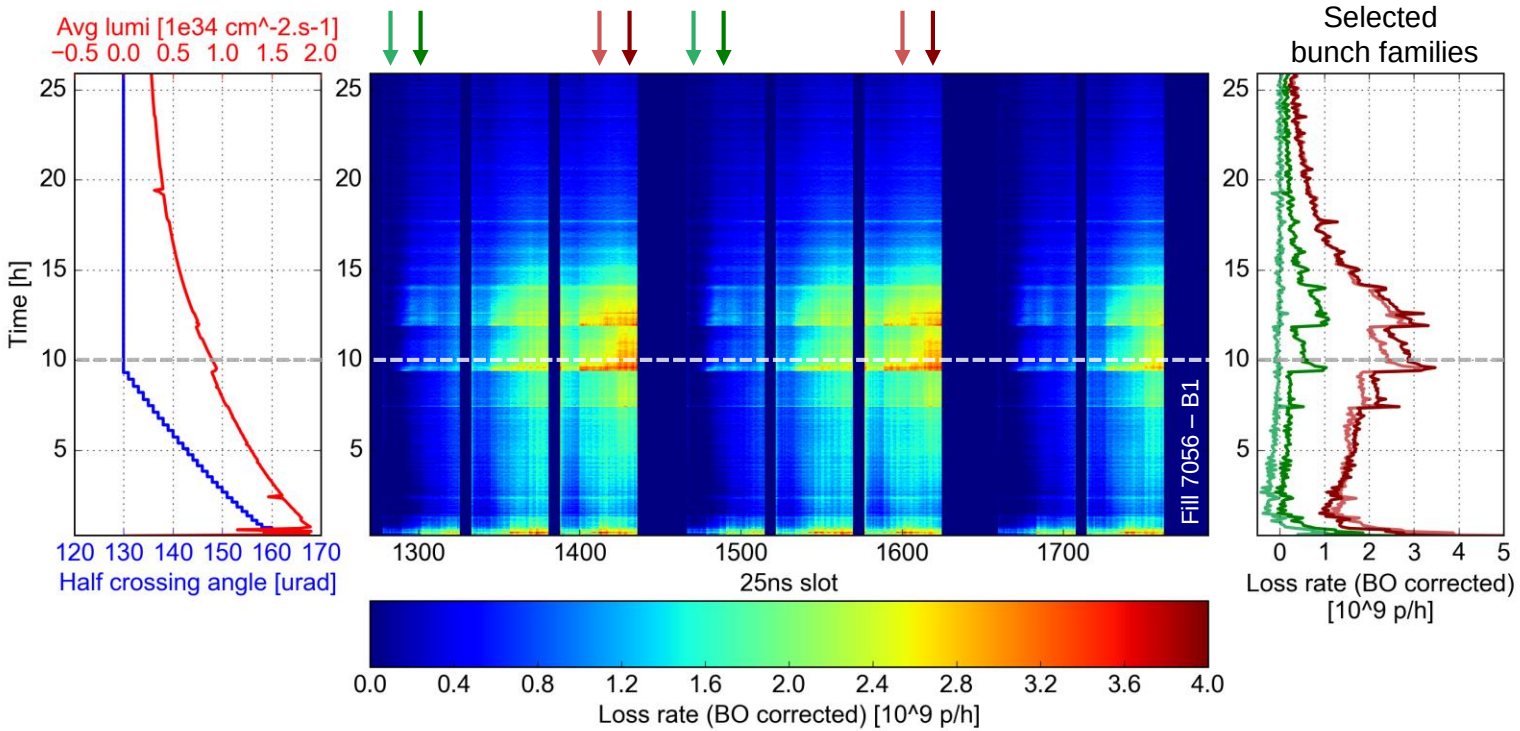

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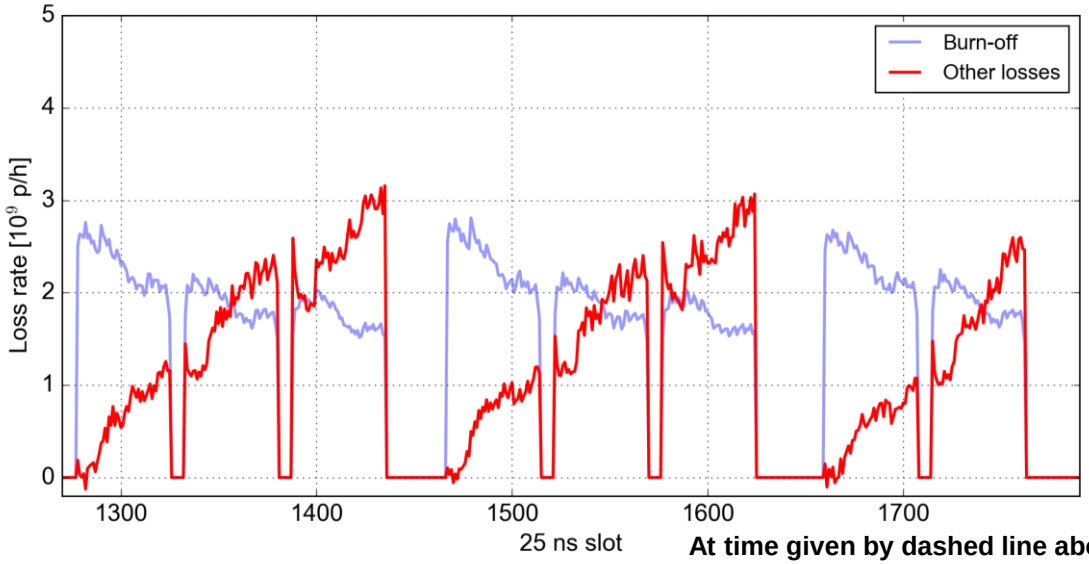

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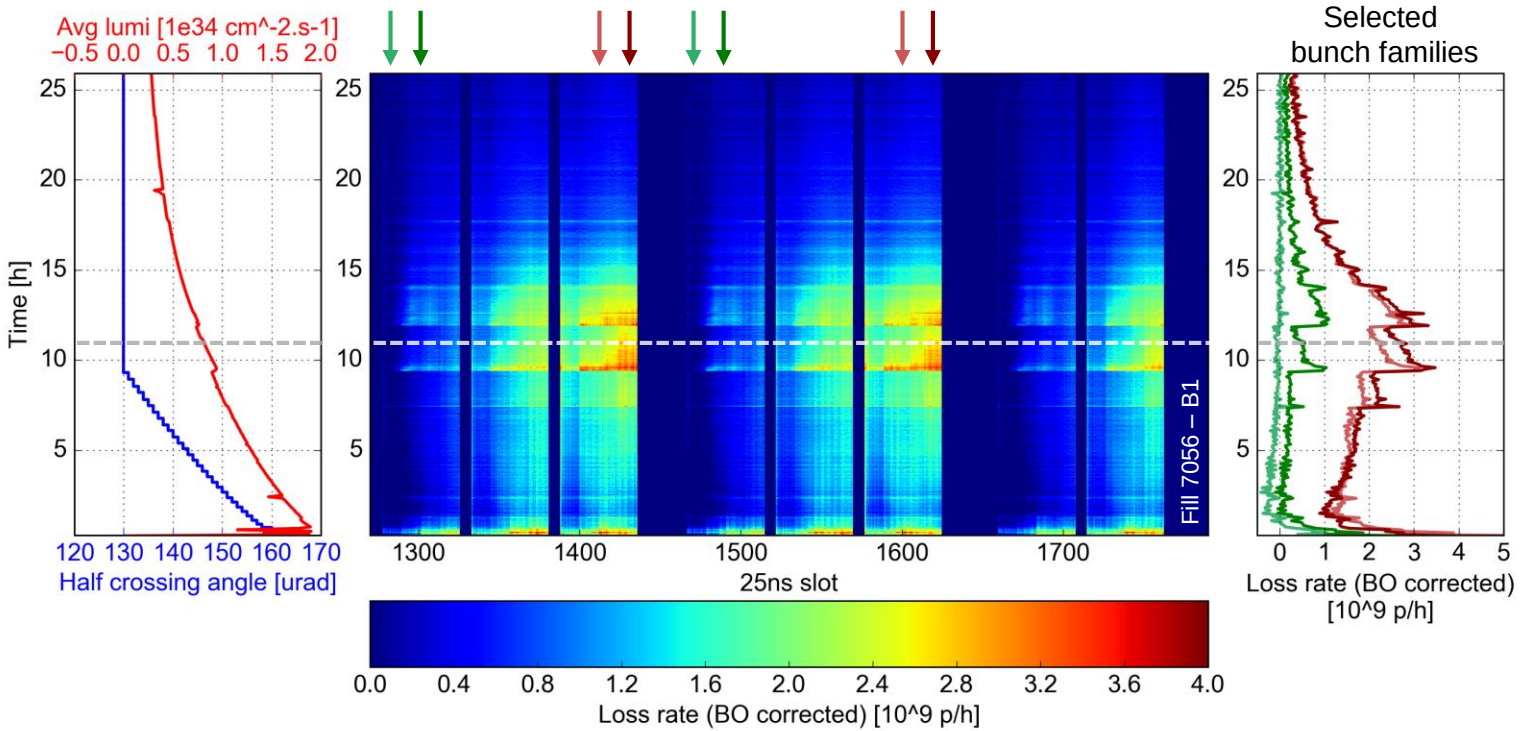

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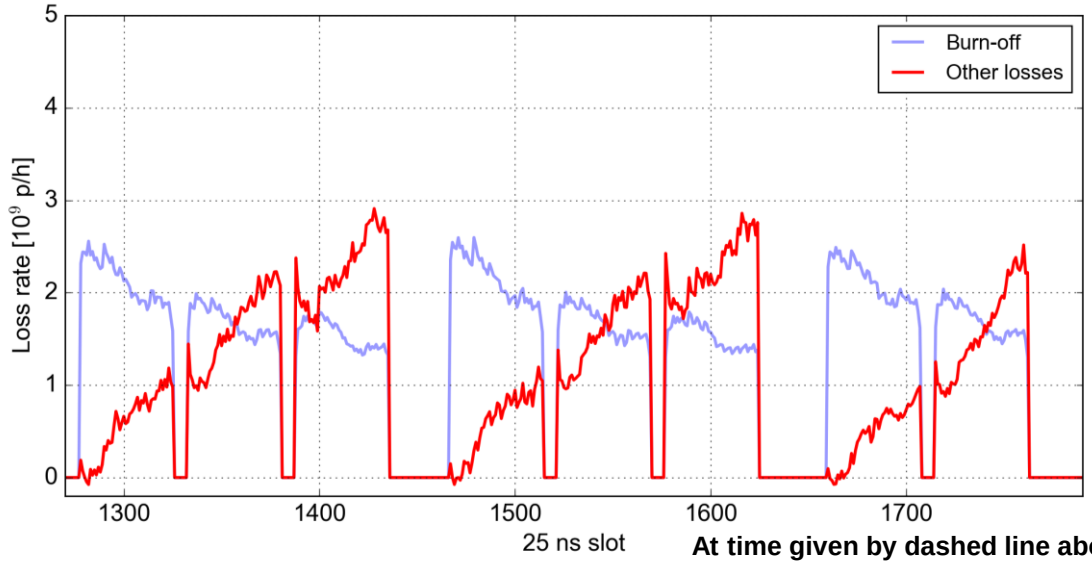

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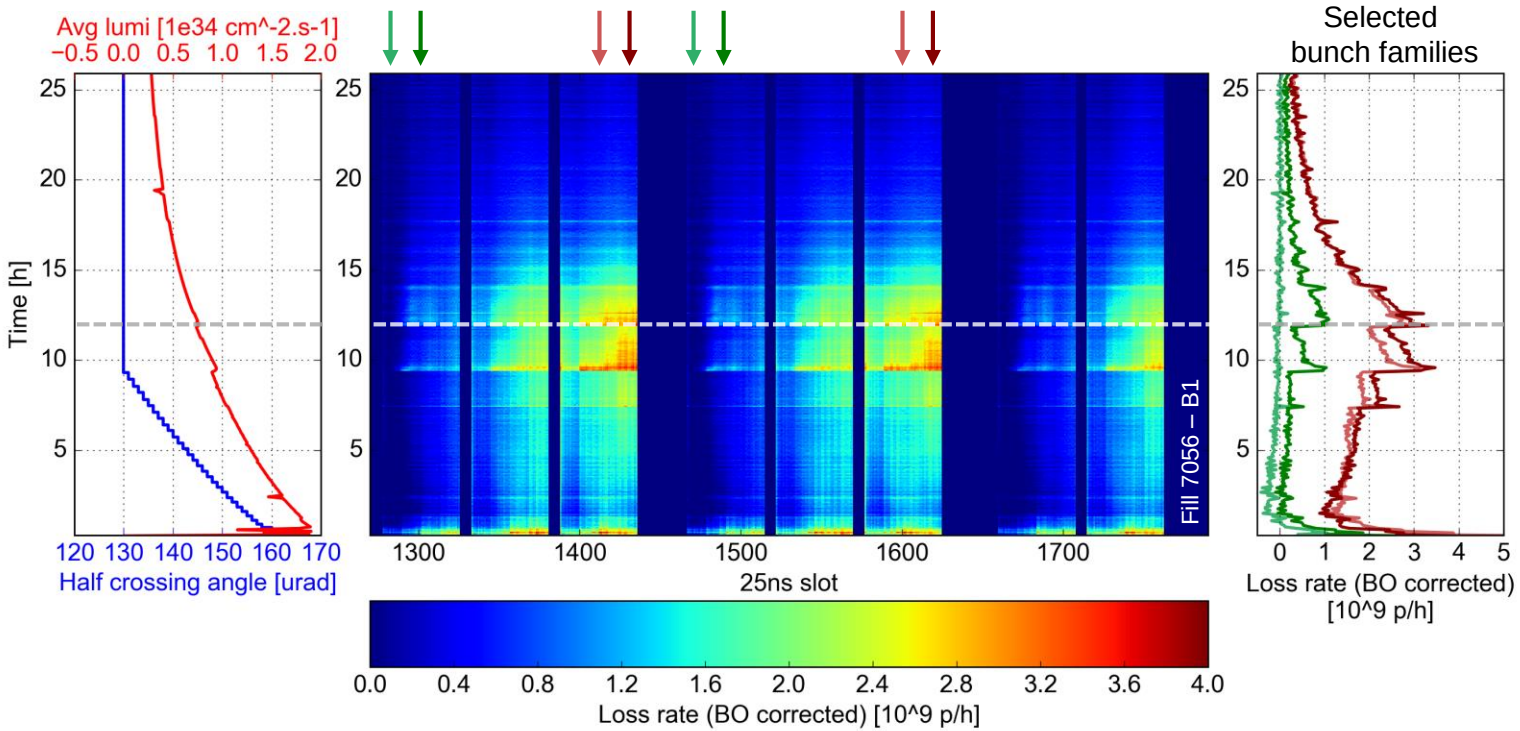

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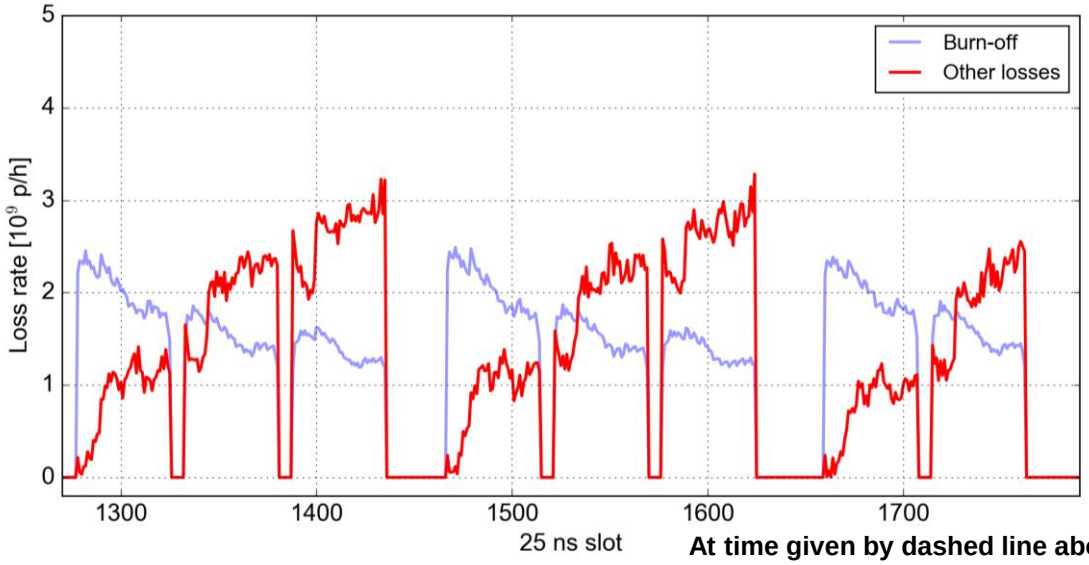

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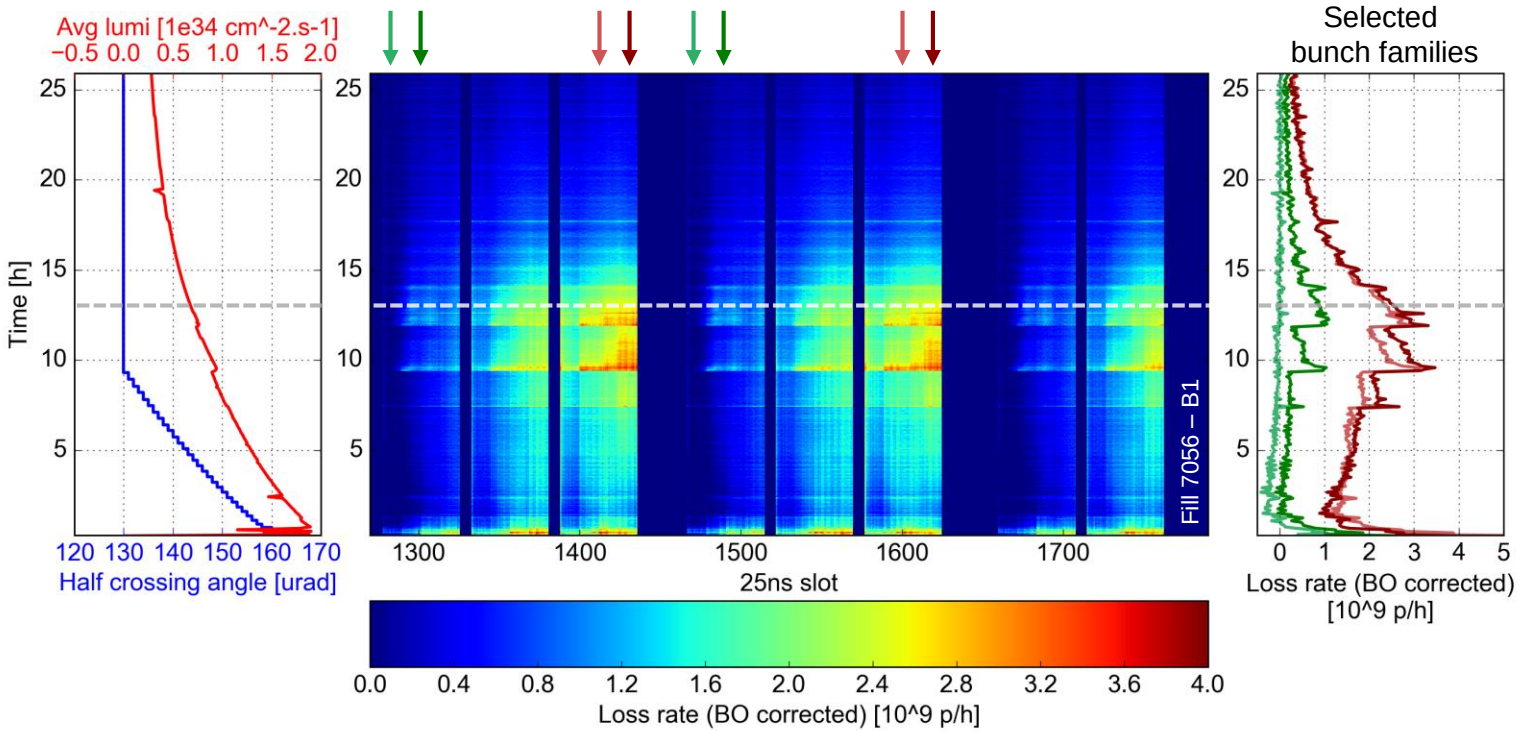

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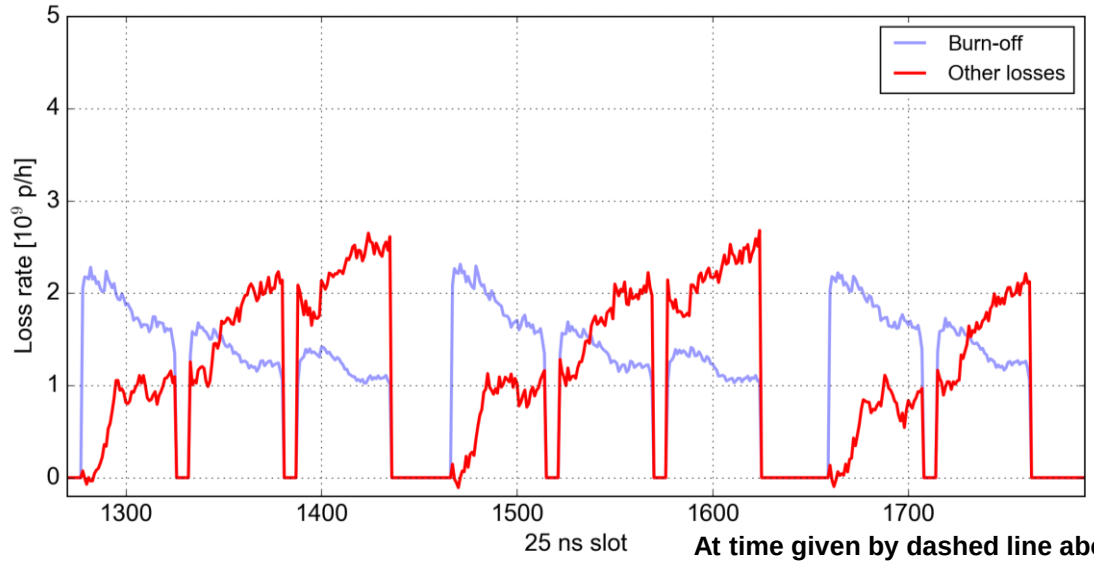

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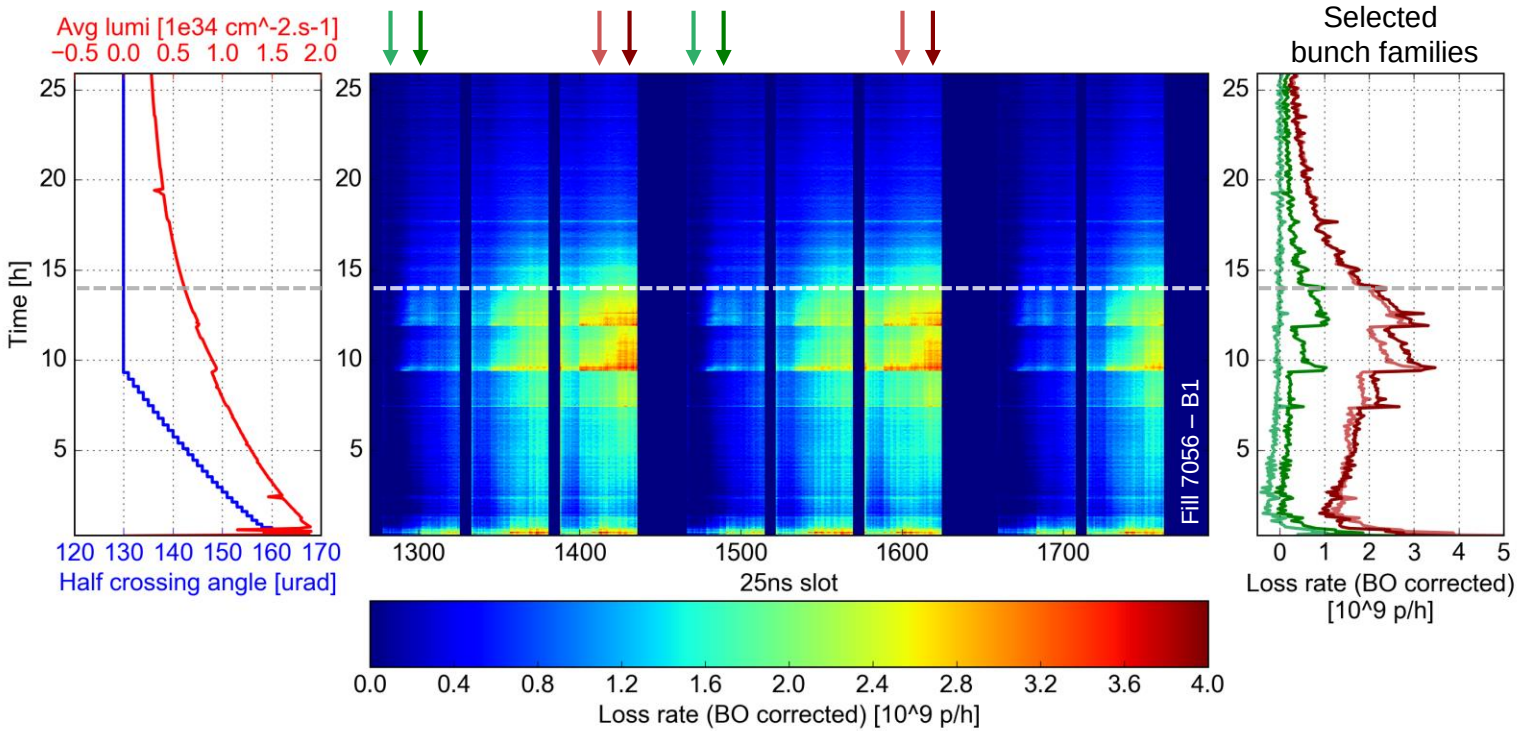
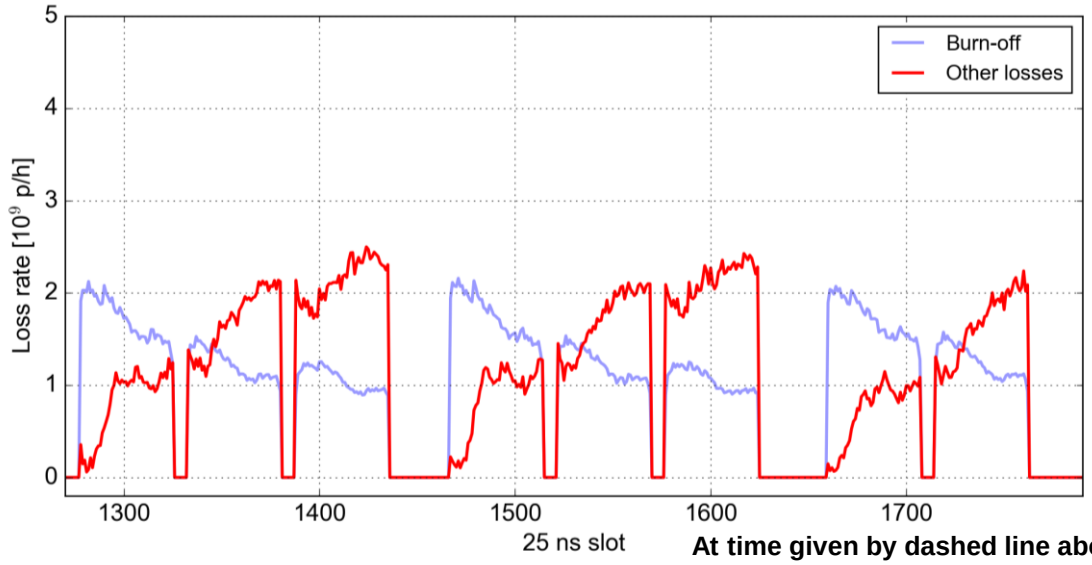


- Loss rates **decay in the last part with constant crossing angle and β***



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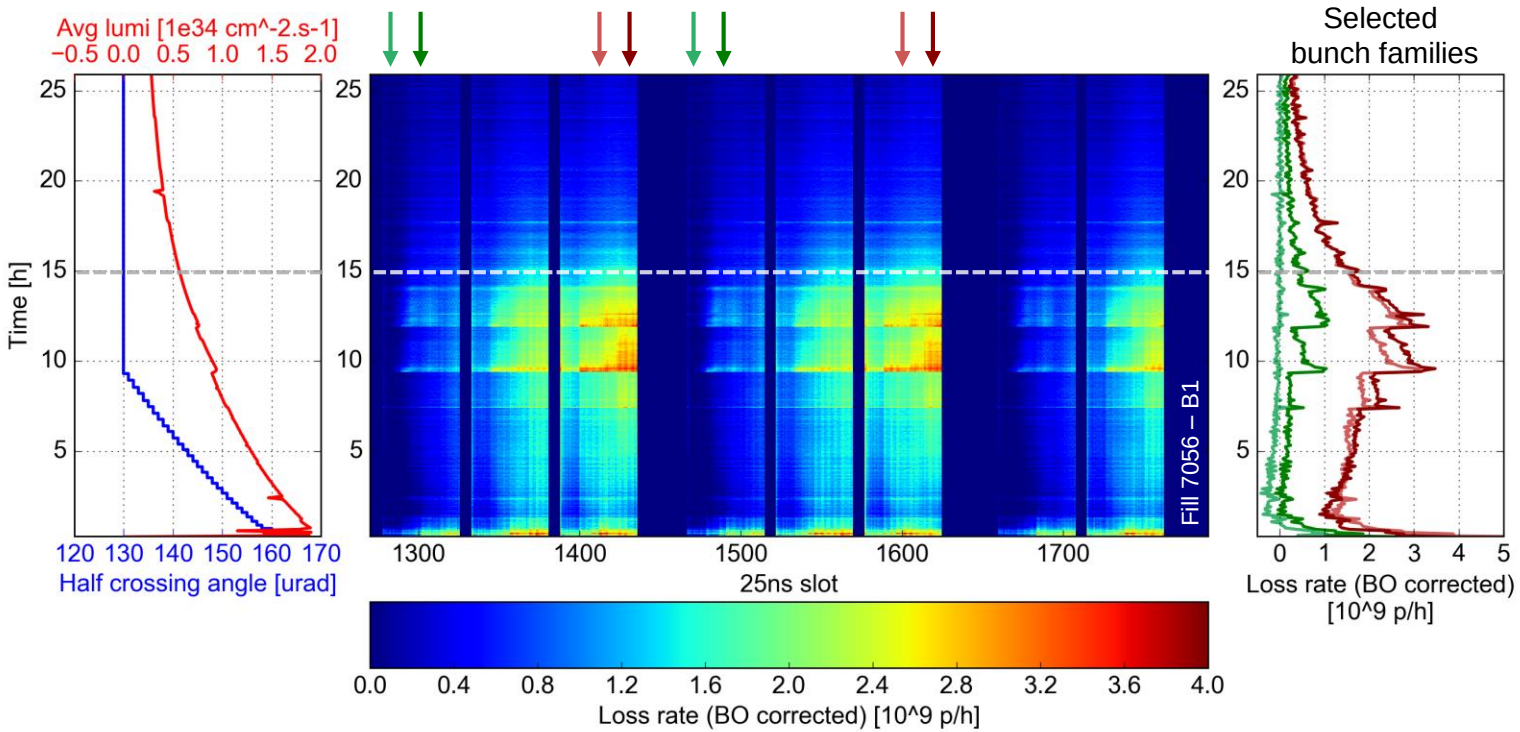

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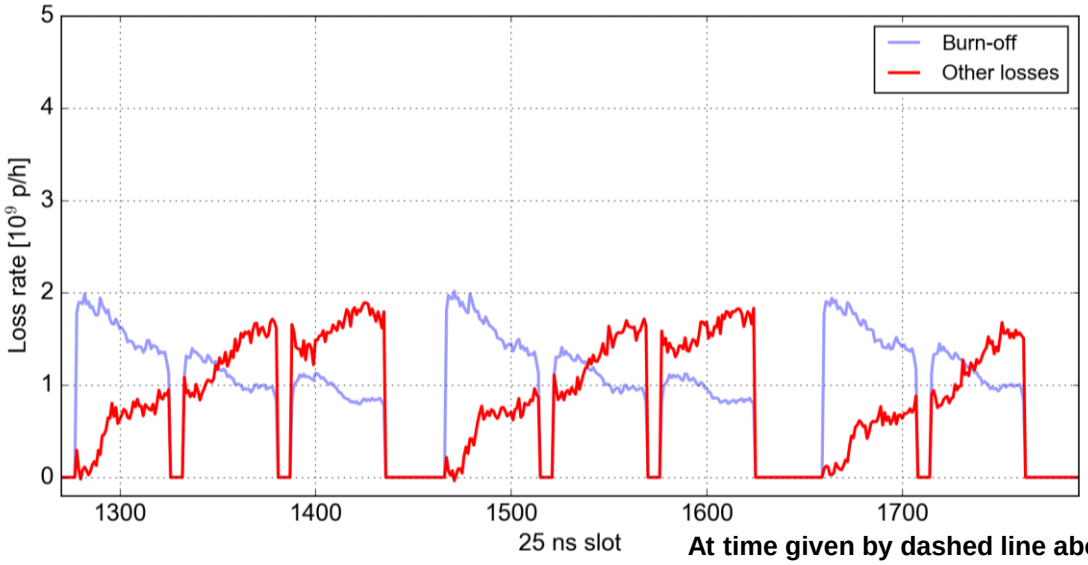

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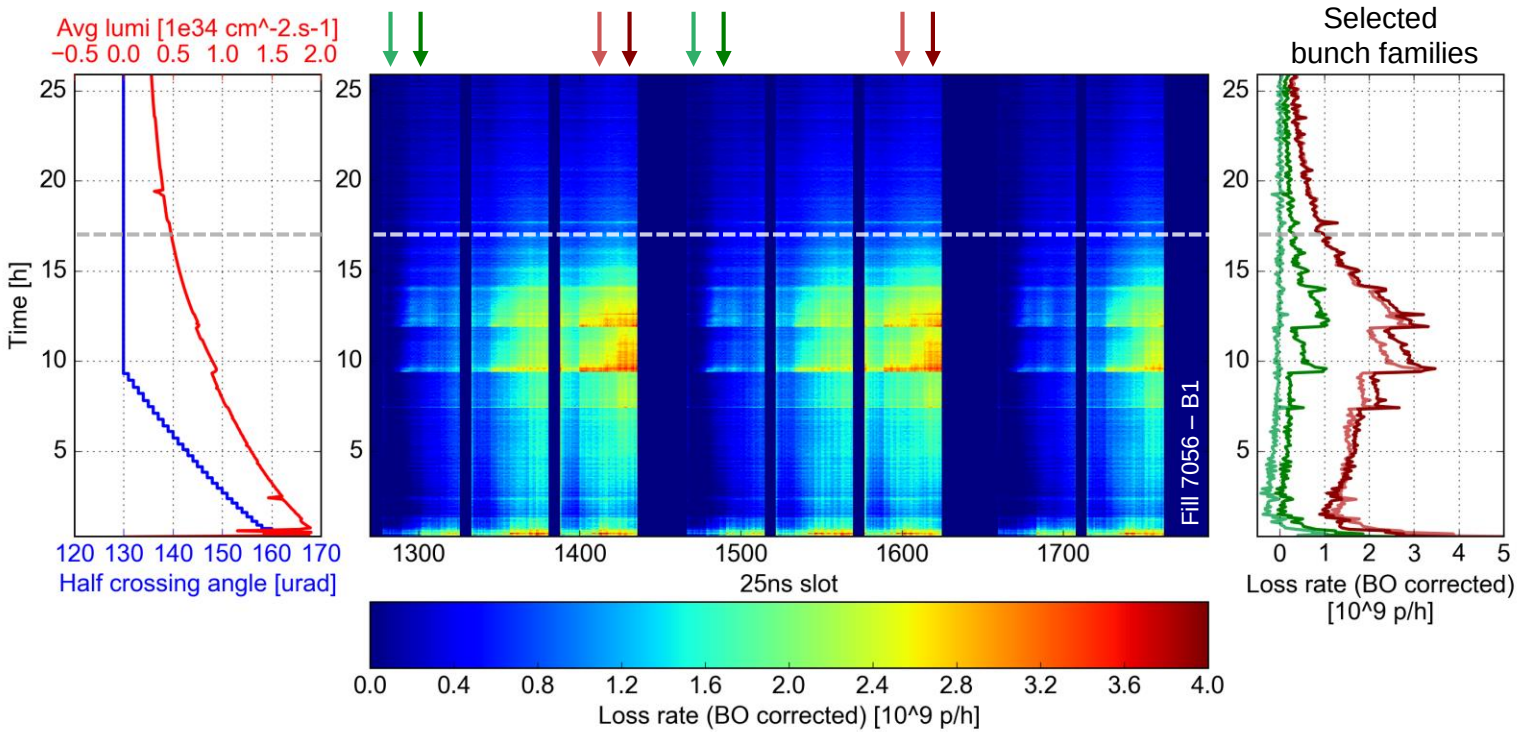

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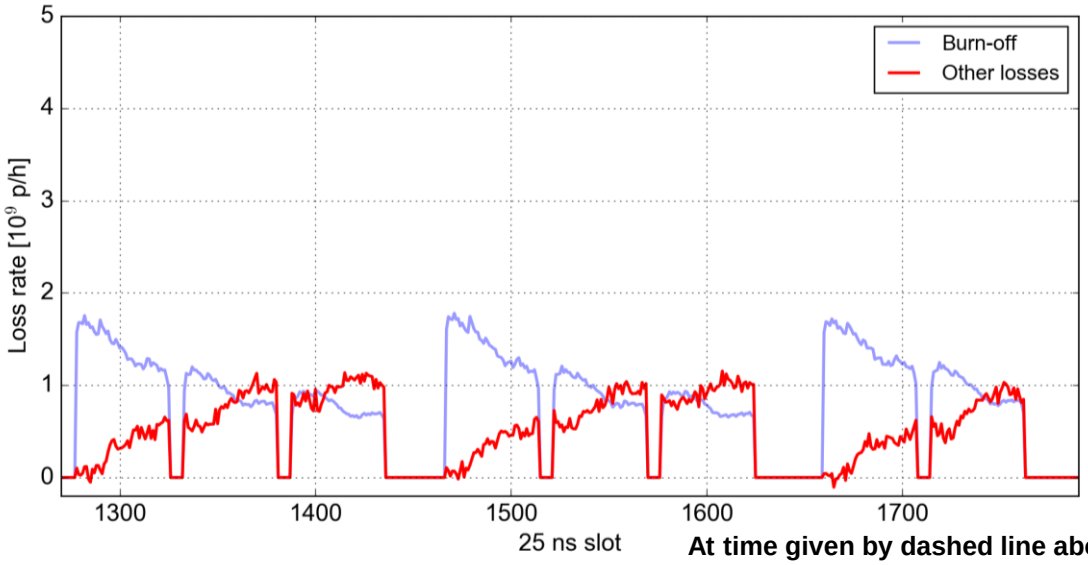

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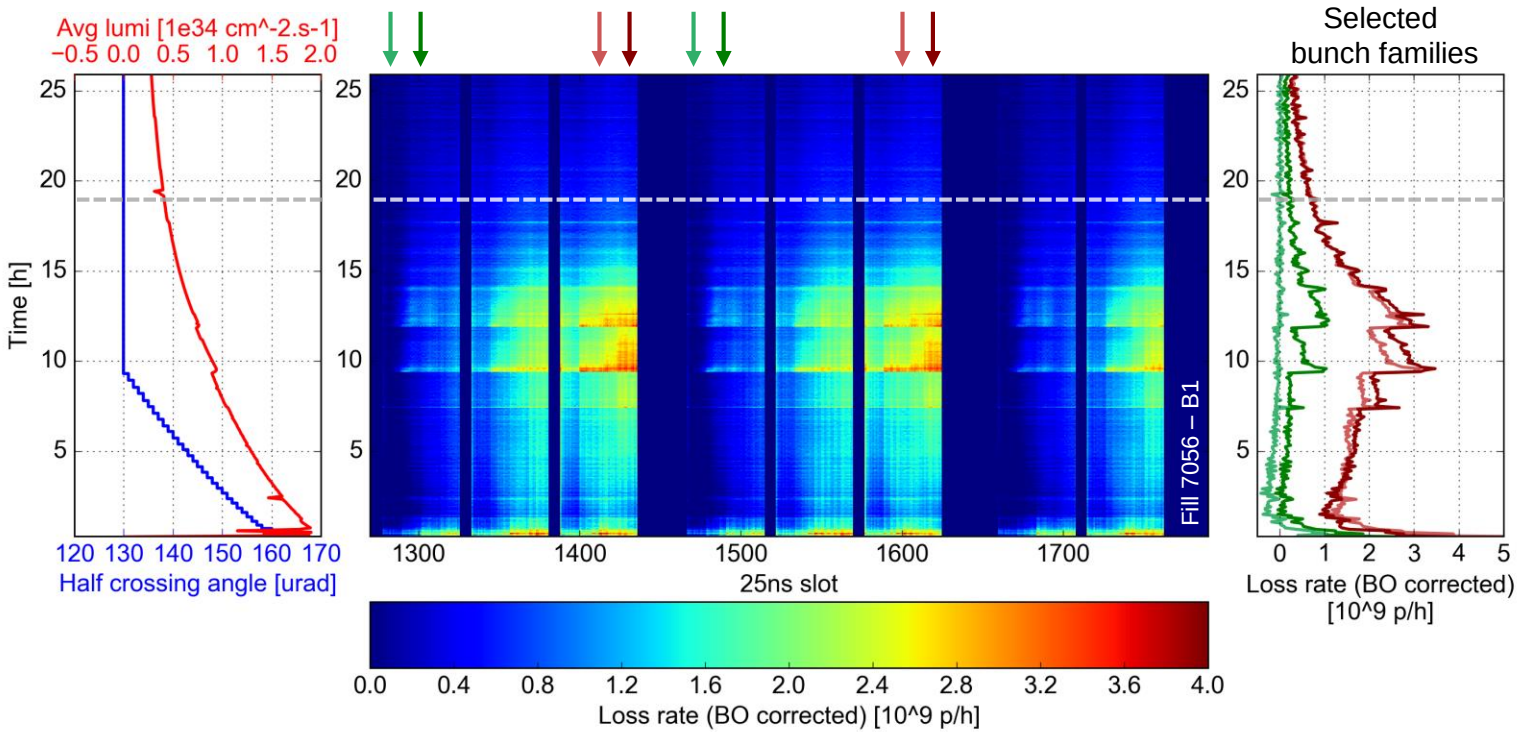

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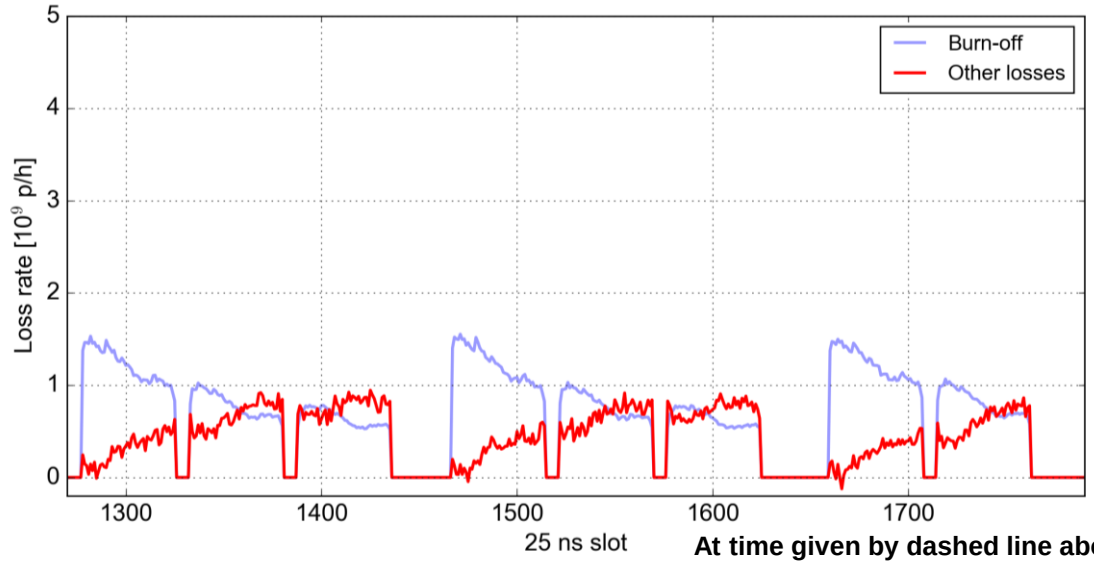

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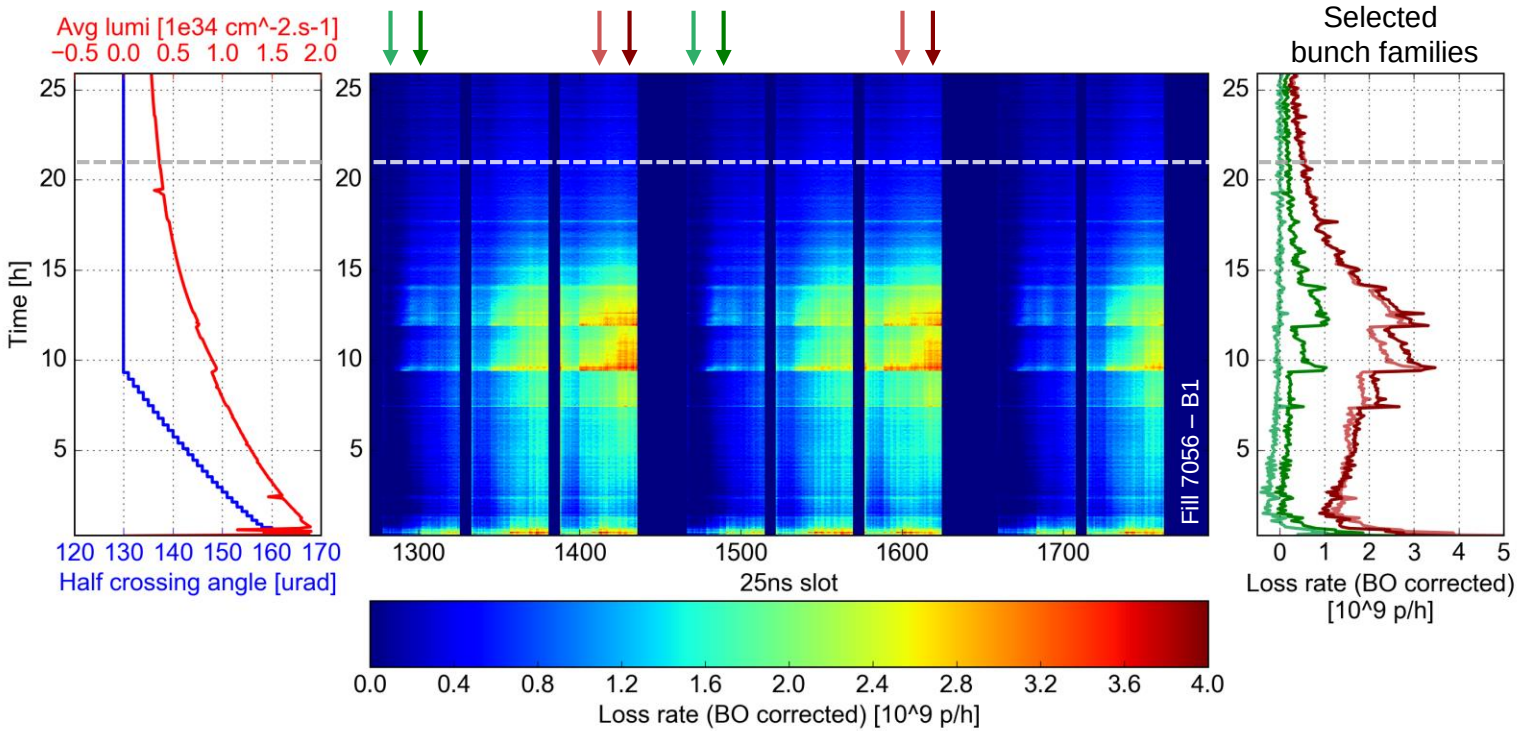

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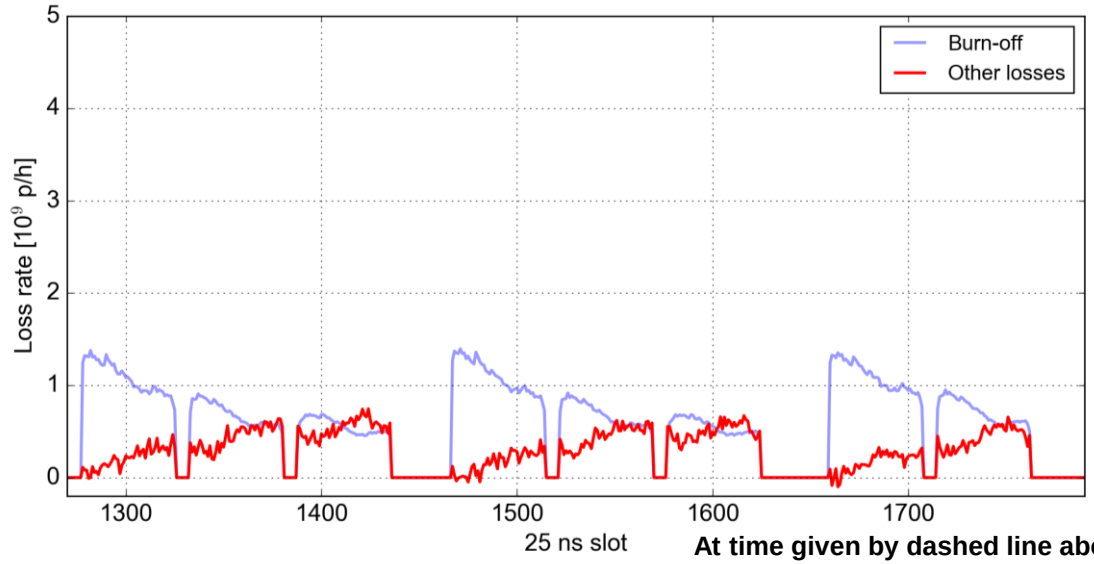

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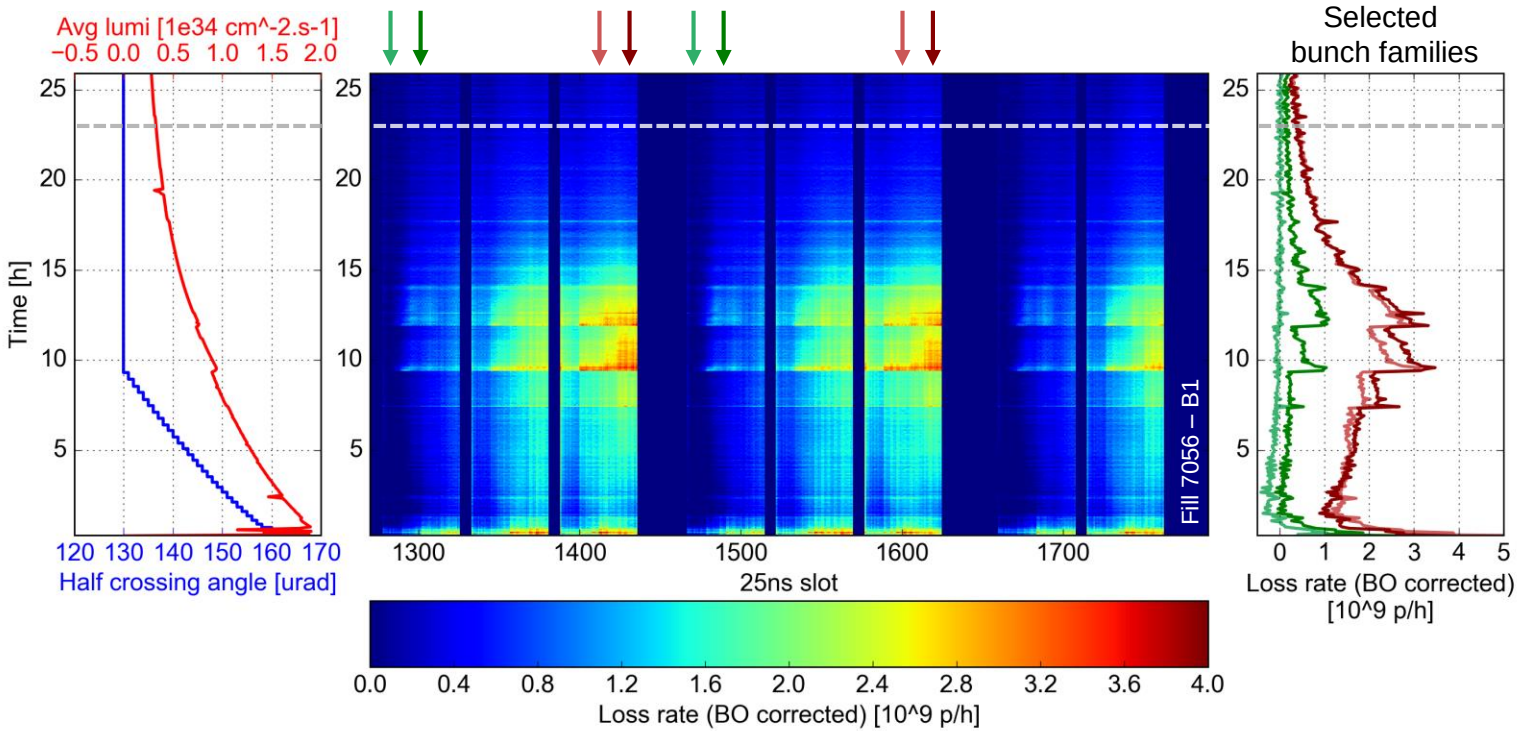

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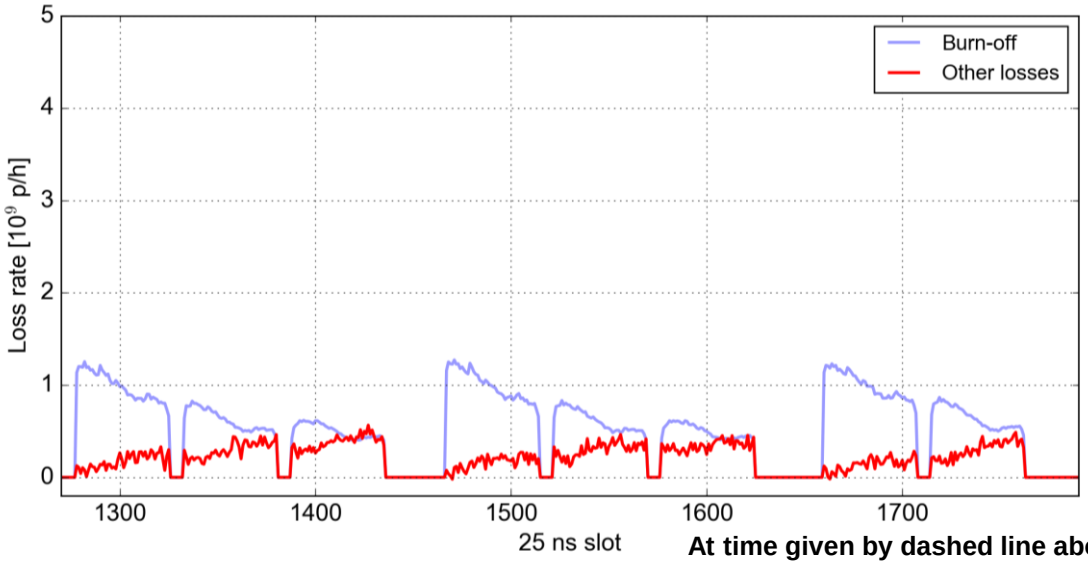

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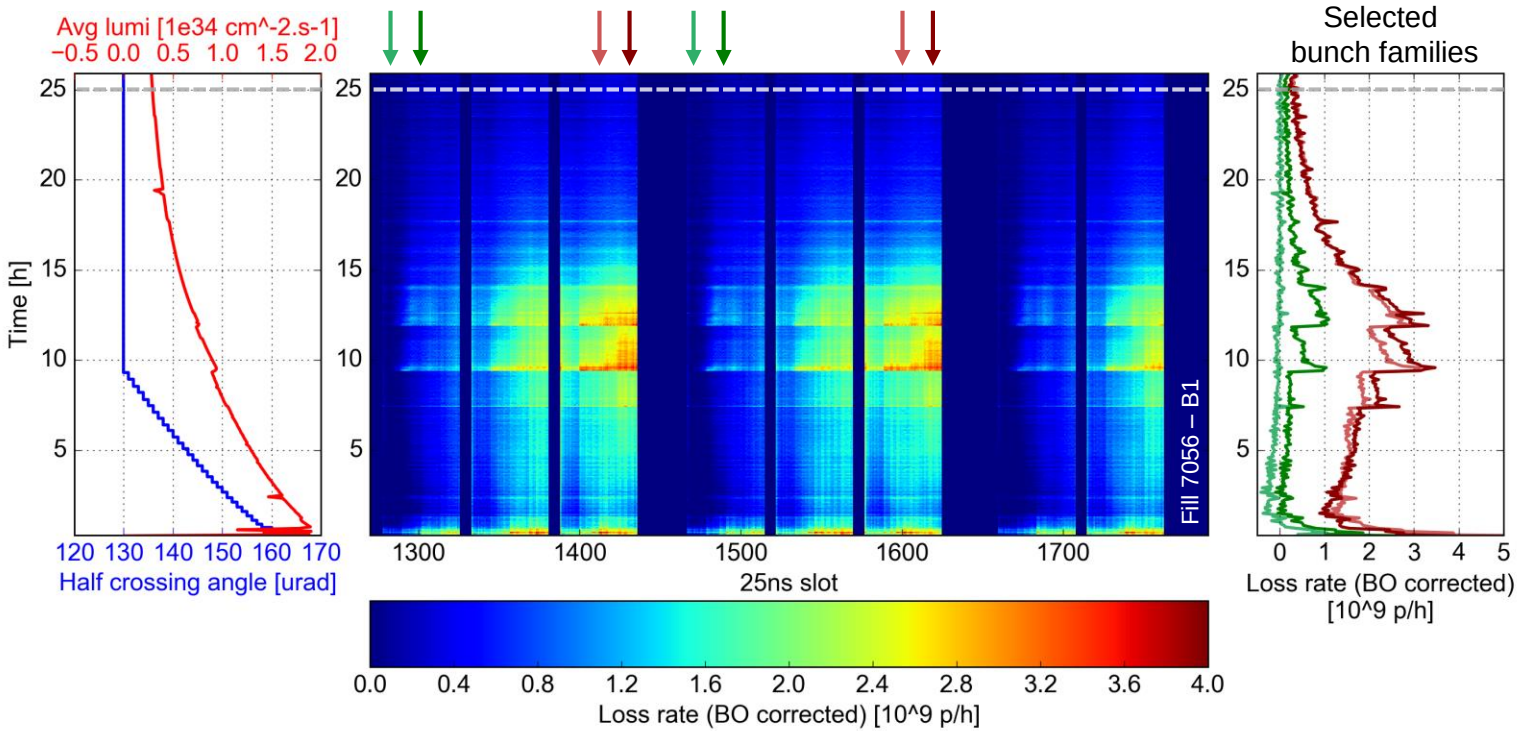

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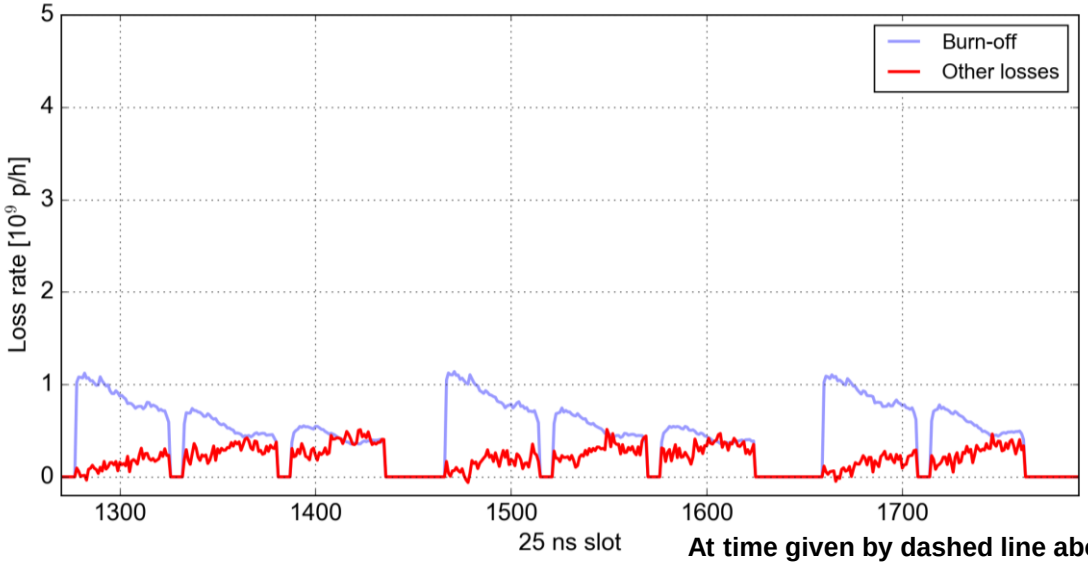

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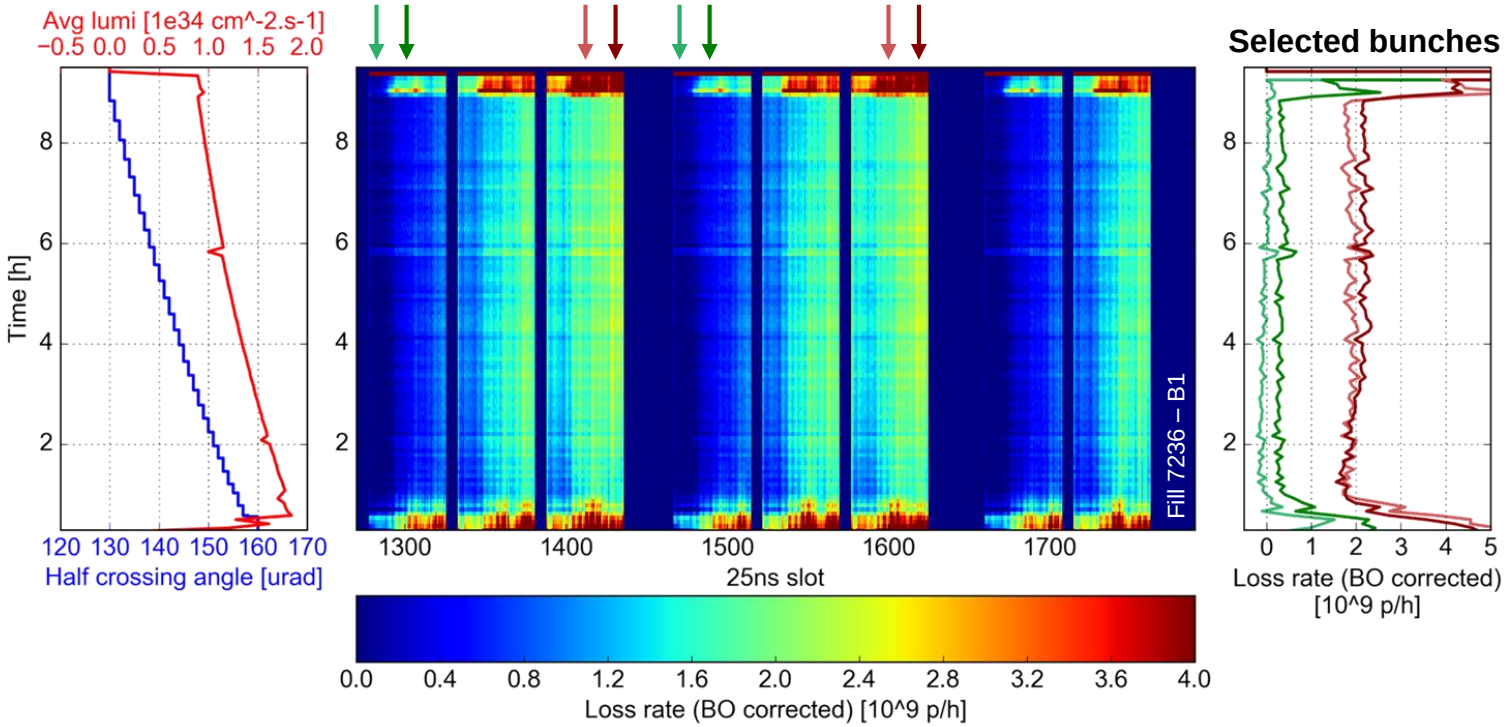
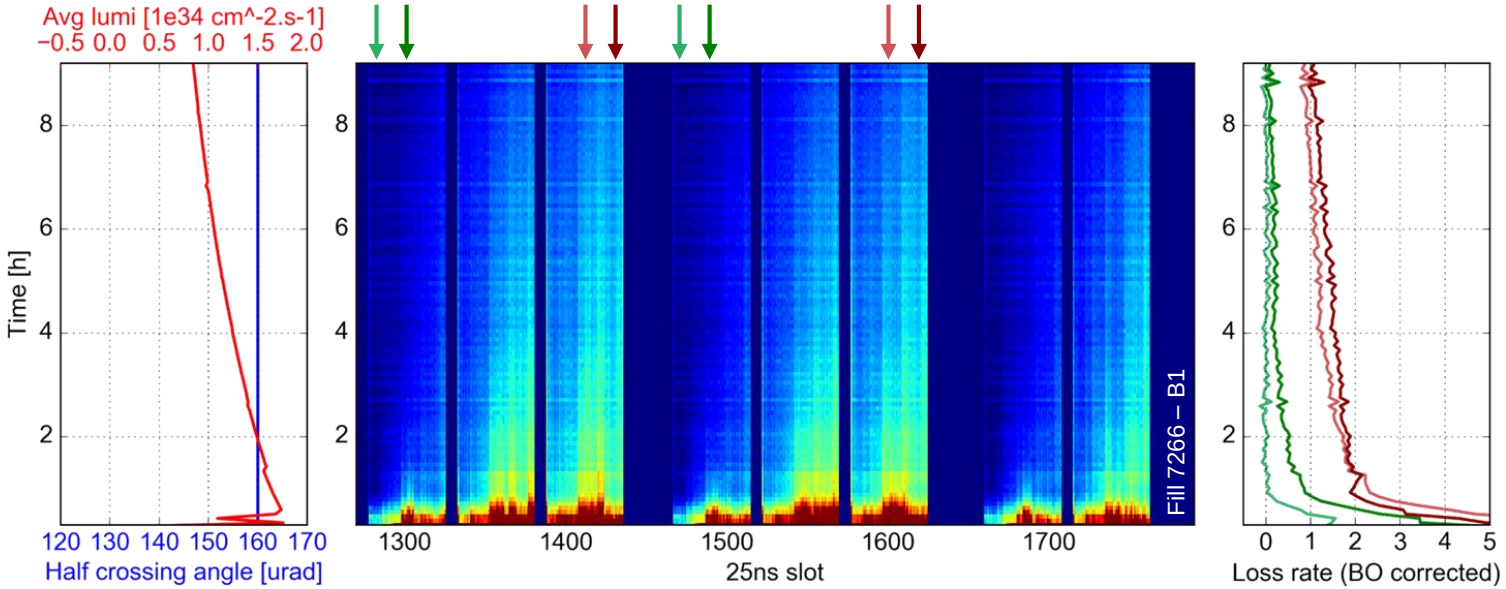
Test fill with constant crossing angle

Crossing angle anti-levelling



Constant crossing angle



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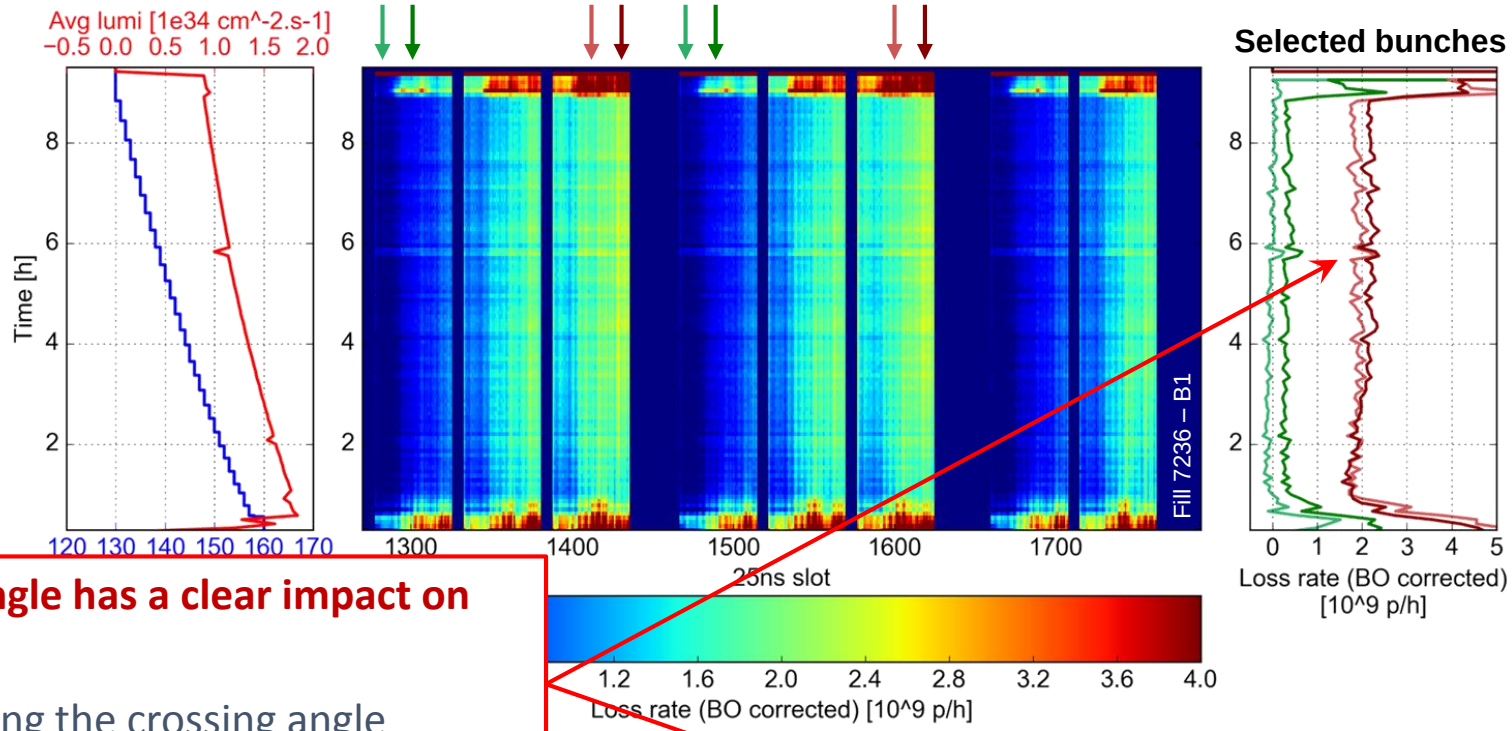
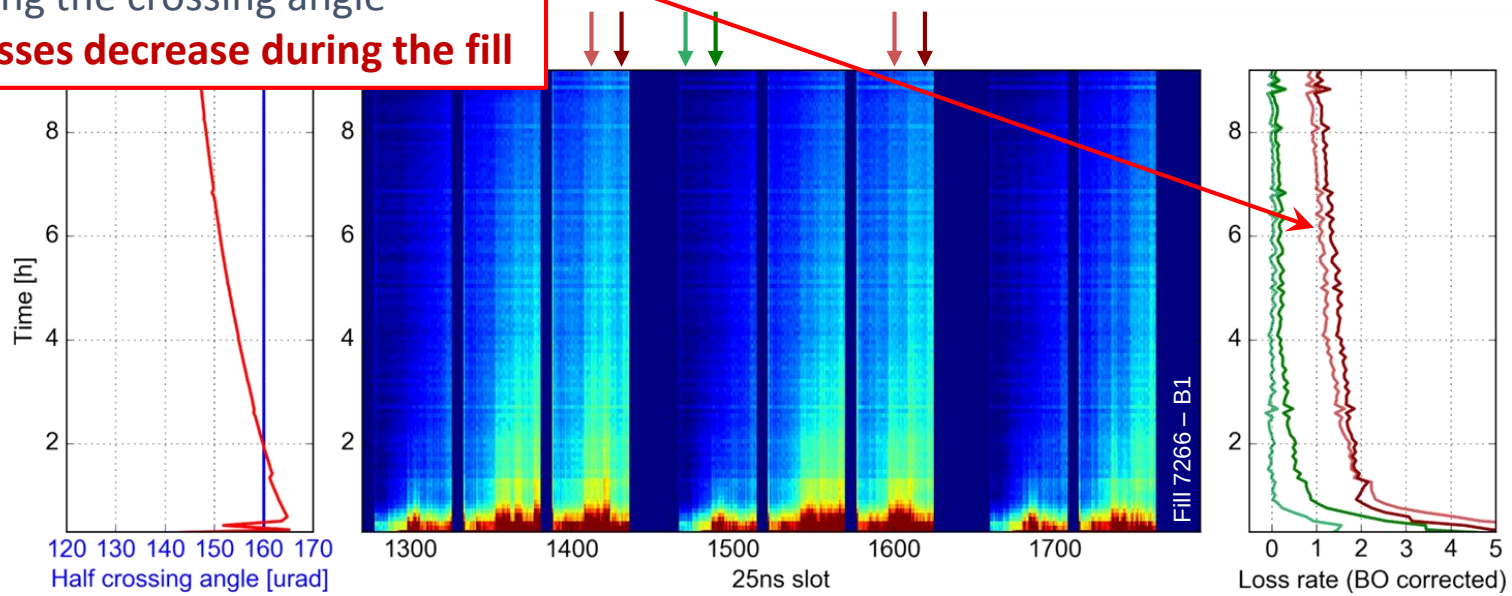
Crossing angle anti-levelling



The **crossing angle has a clear impact on the losses**:

- When keeping the crossing angle constant, **losses decrease during the fill**

Constant crossing angle



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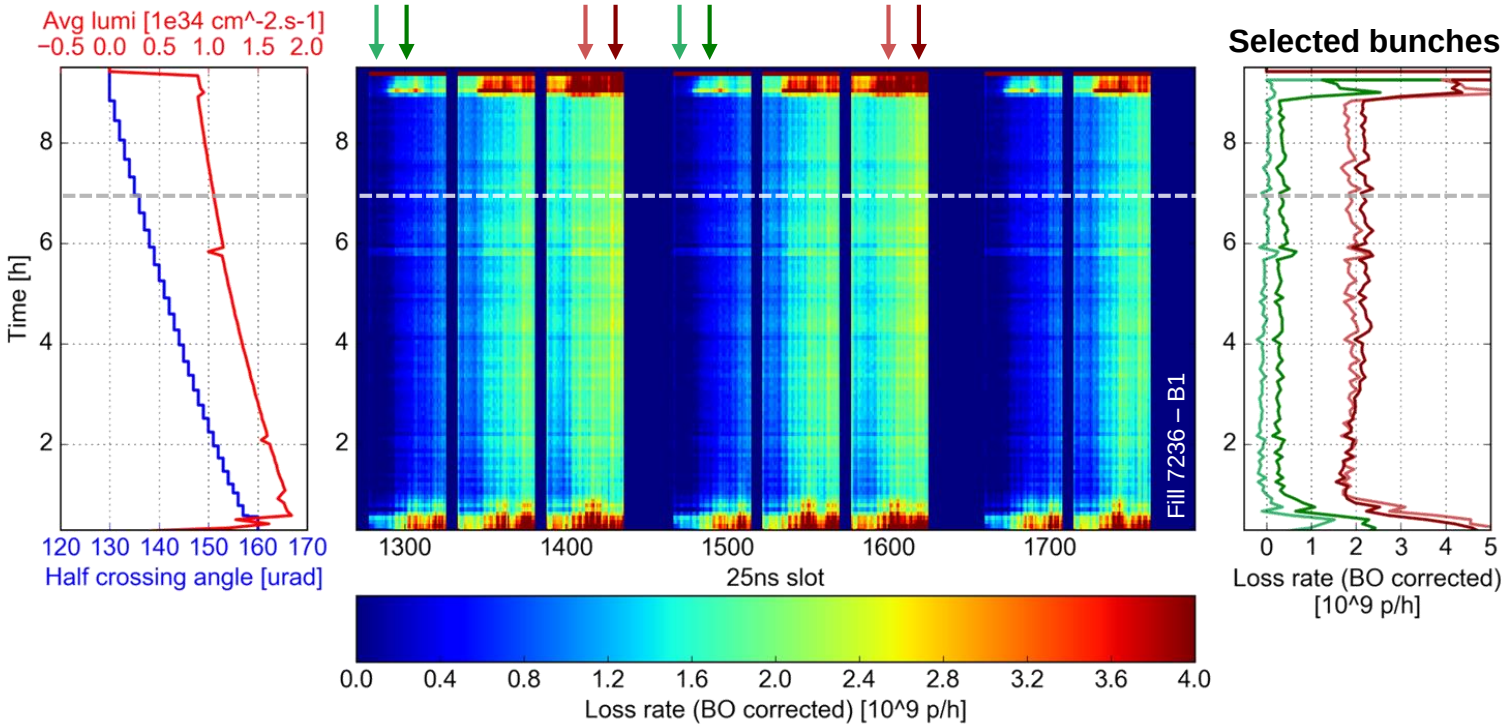
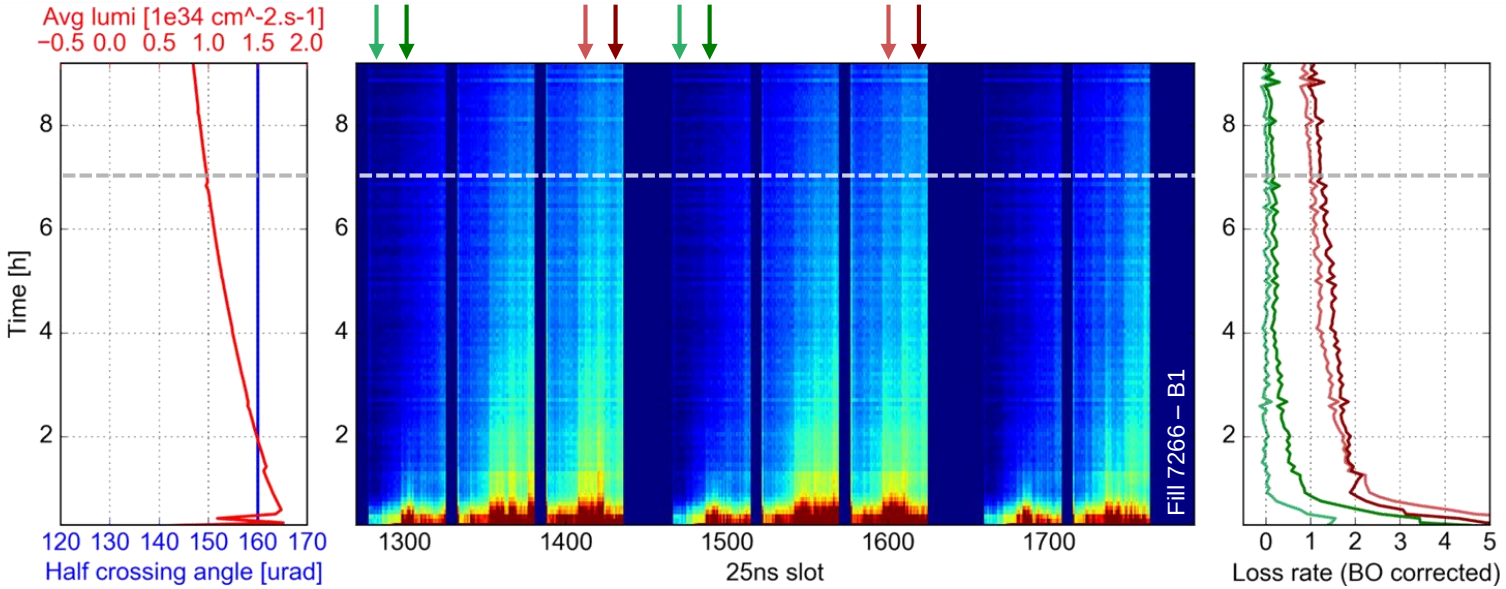
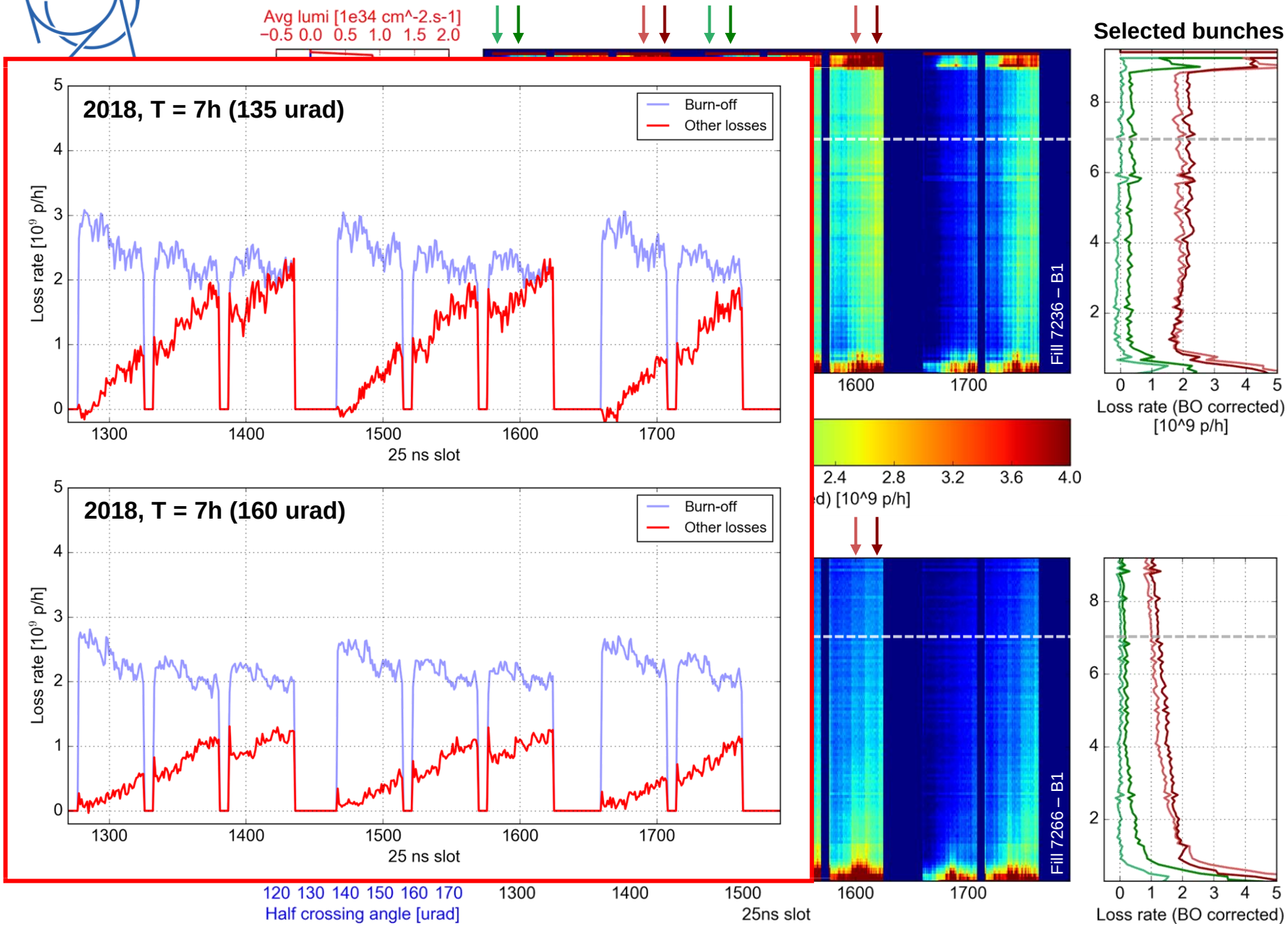


Constant crossing angle



Test fill with constant crossing angle



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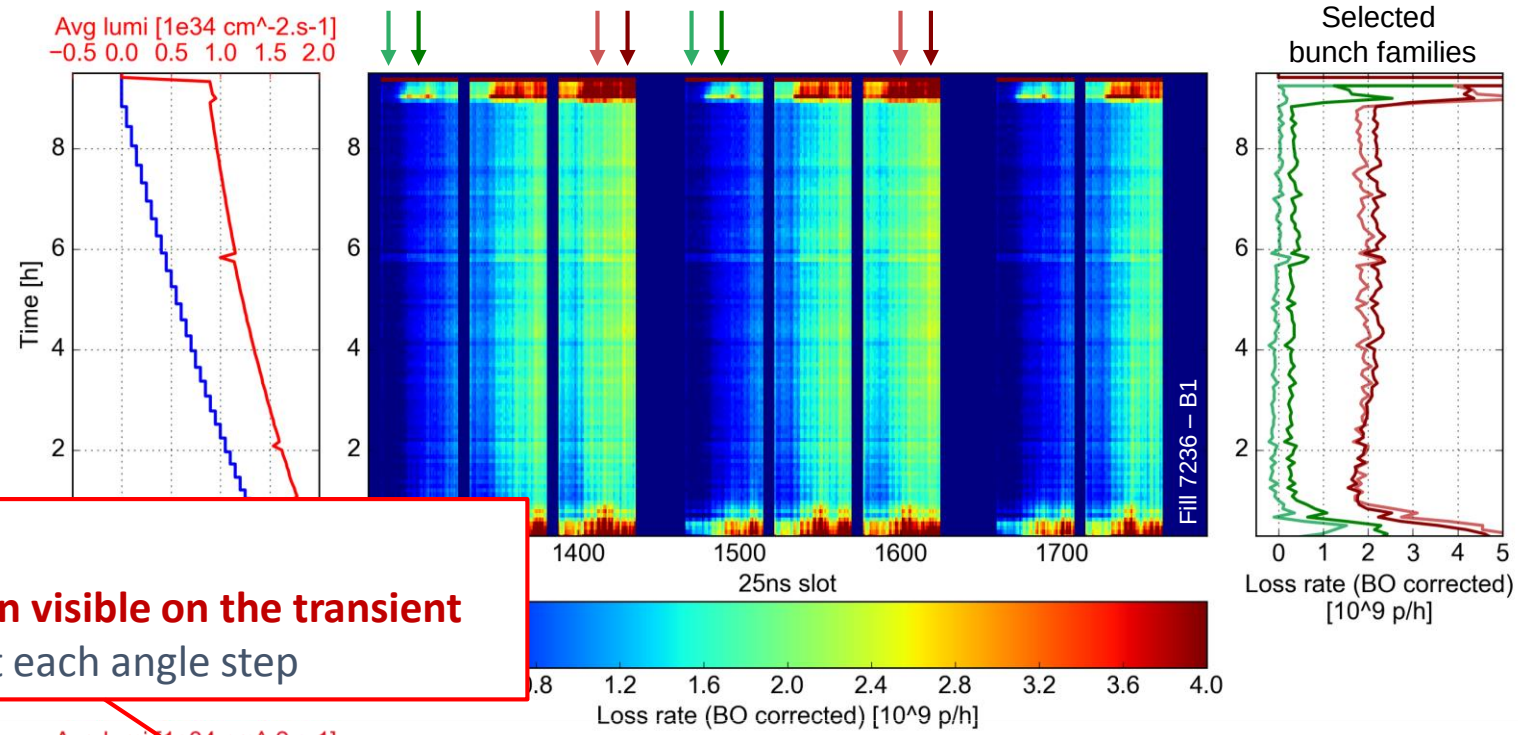
Situation in 2017 (25 ns)

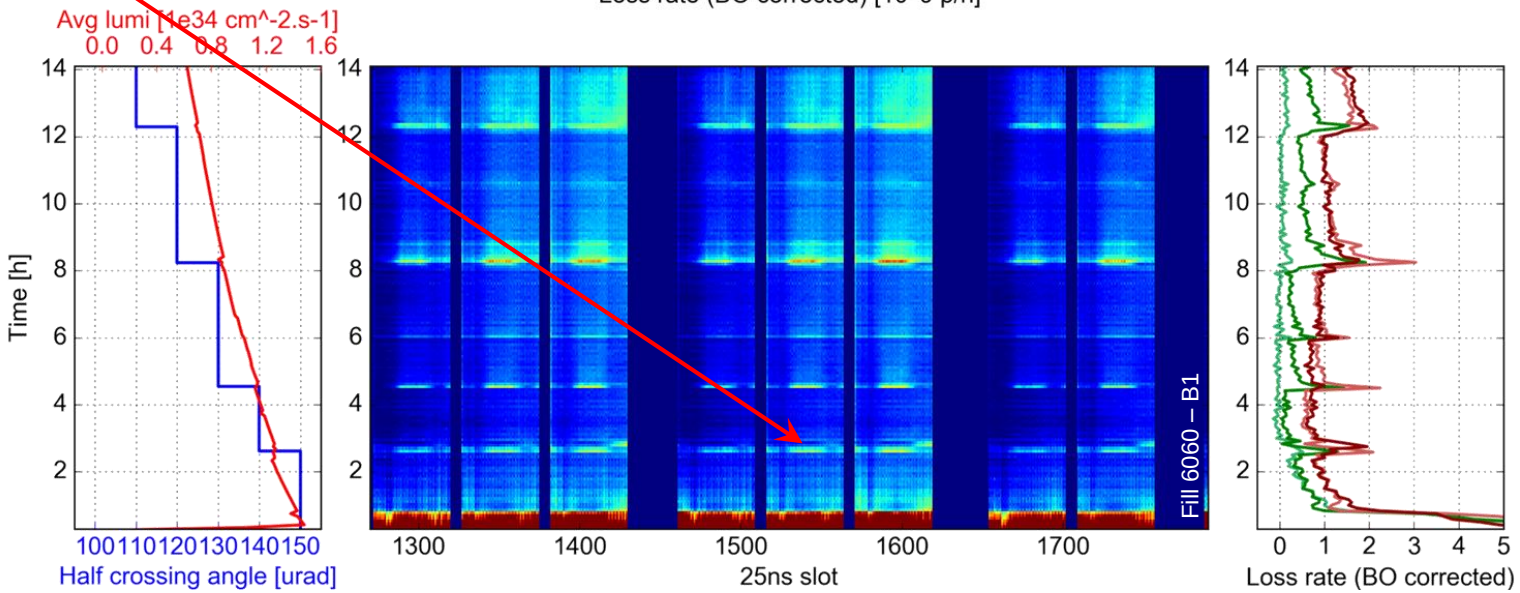
2018
$\beta^* = 30$ cm



In 2017:

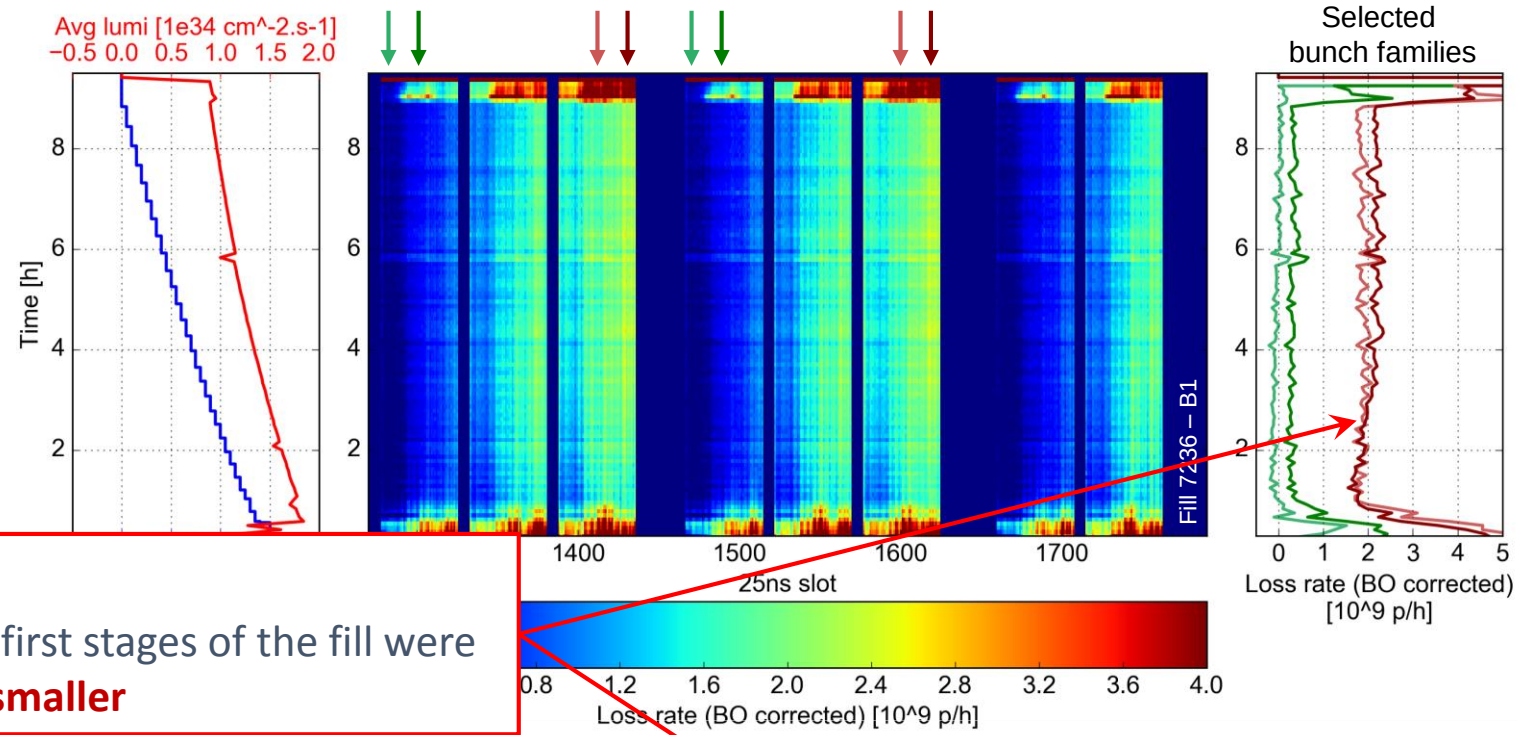
- **LR-BB pattern visible on the transient** happening at each angle step

2017
$\beta^* = 40$ cm
25 ns



Situation in 2017 (25 ns)

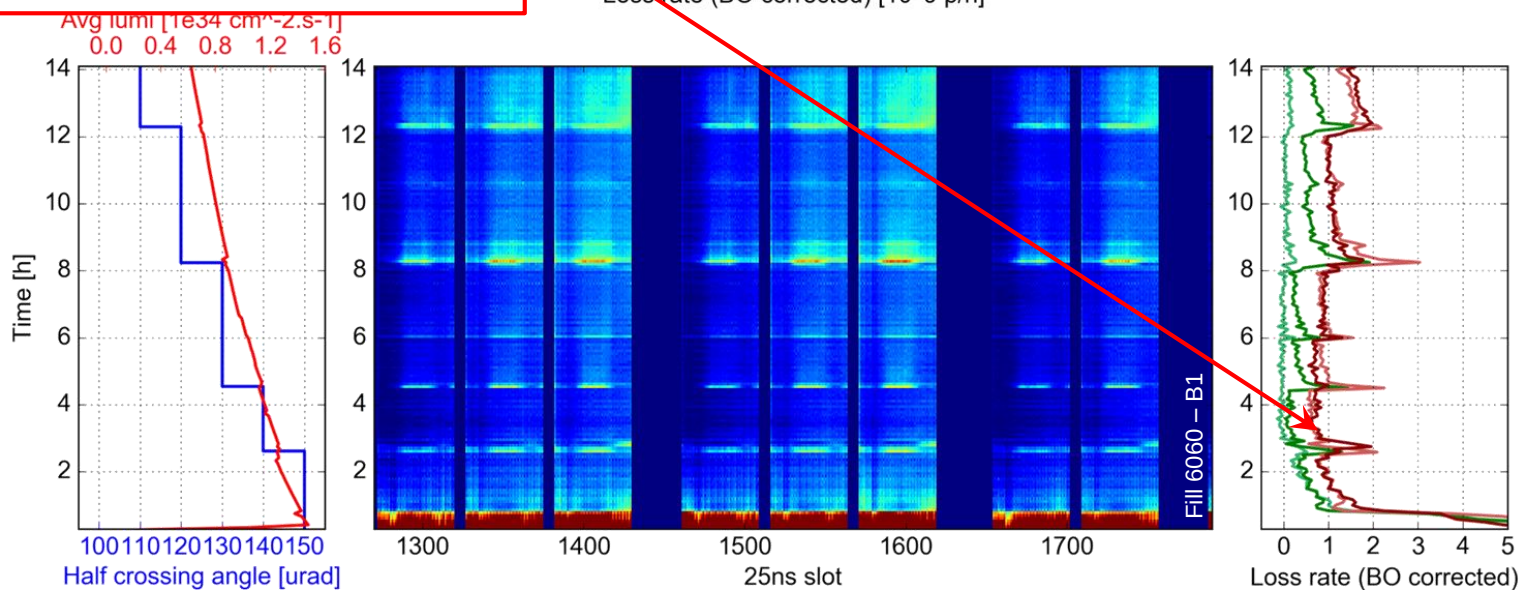
2018
$\beta^* = 30$ cm



In 2017:

- Losses at the first stages of the fill were **significantly smaller**

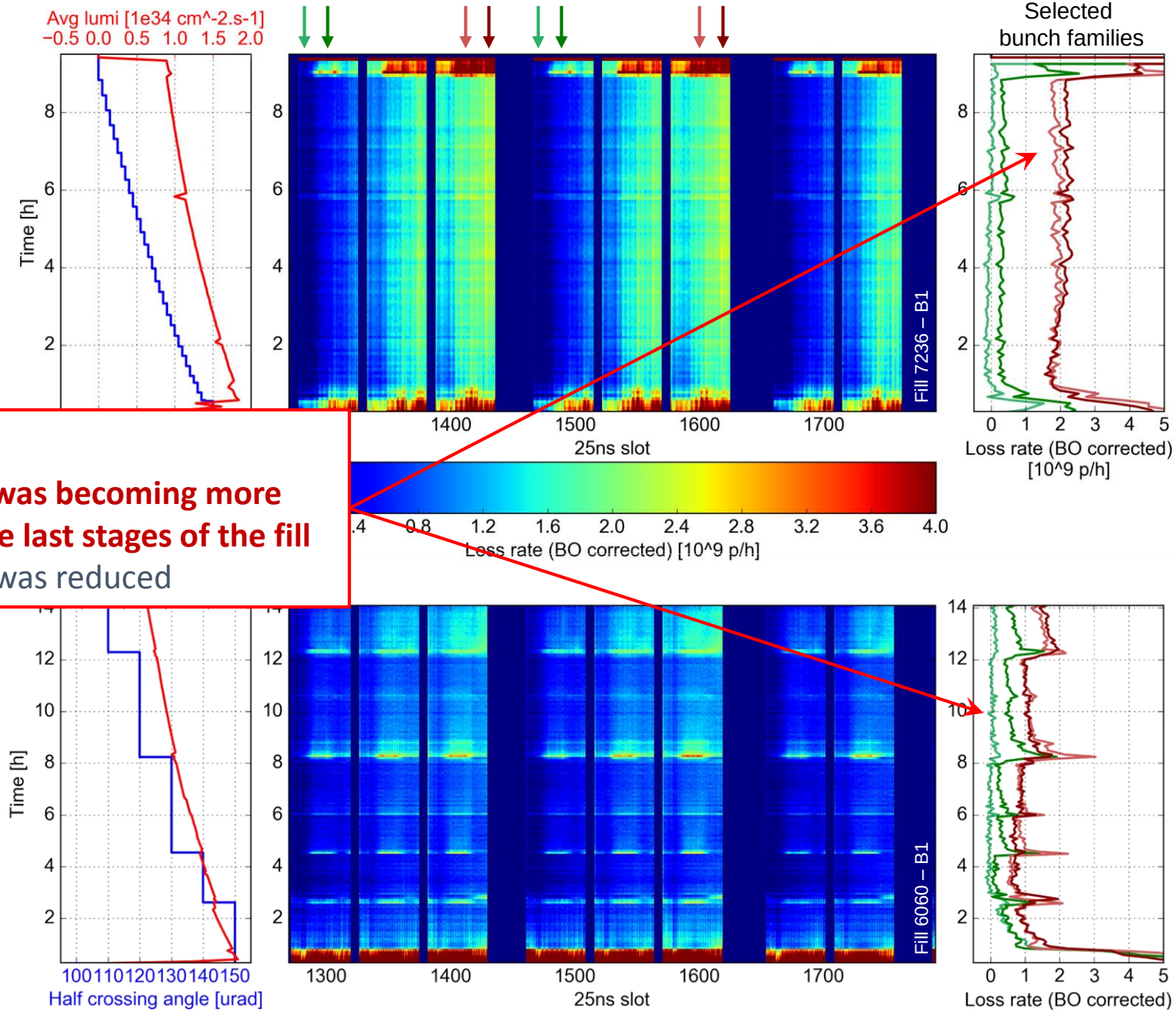
2017
$\beta^* = 40$ cm
25 ns



Situation in 2017 (25 ns)

2018
$\beta^* = 30$ cm

2017
$\beta^* = 40$ cm
25 ns

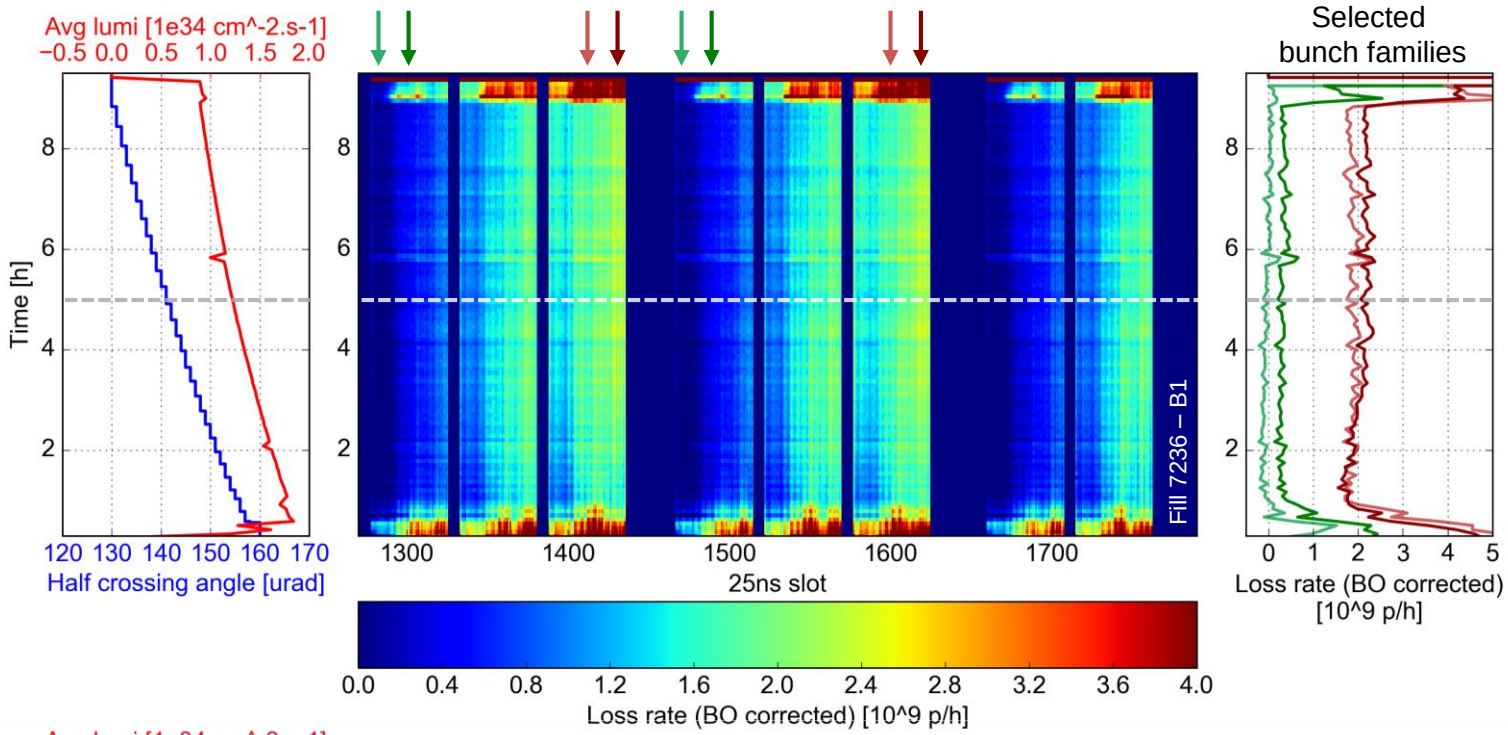


In 2017:

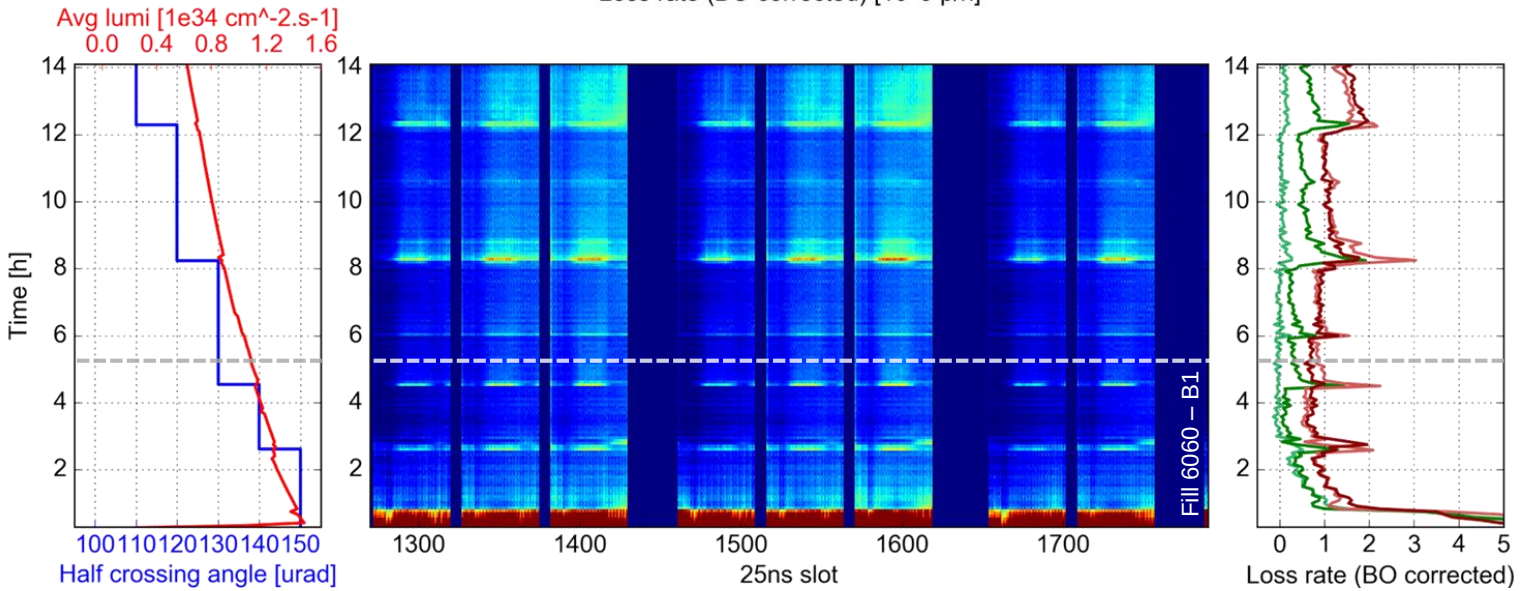
- The **pattern was becoming more evident in the last stages of the fill** as the angle was reduced

Situation in 2017 (25 ns)

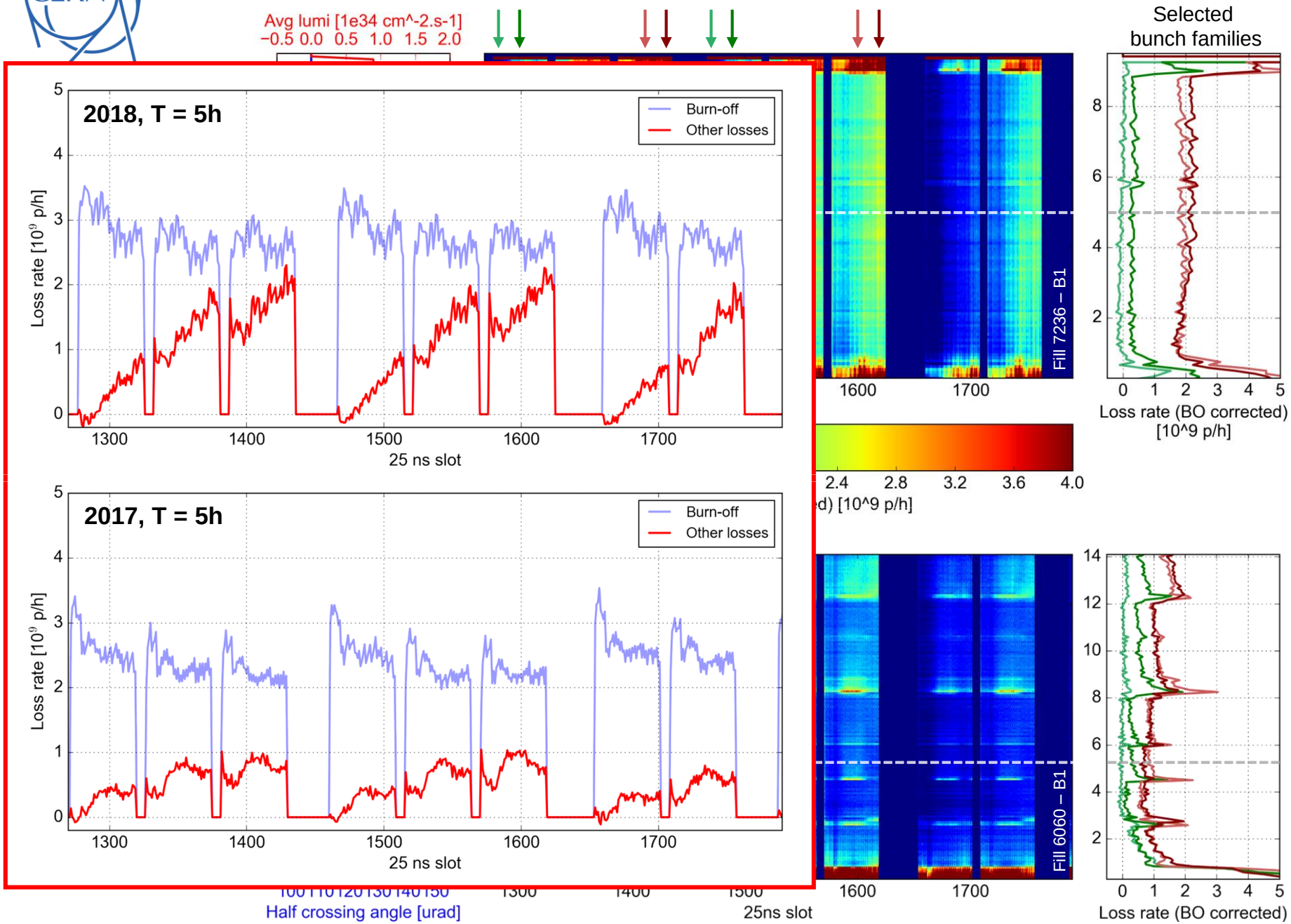
2018
$\beta^* = 30$ cm



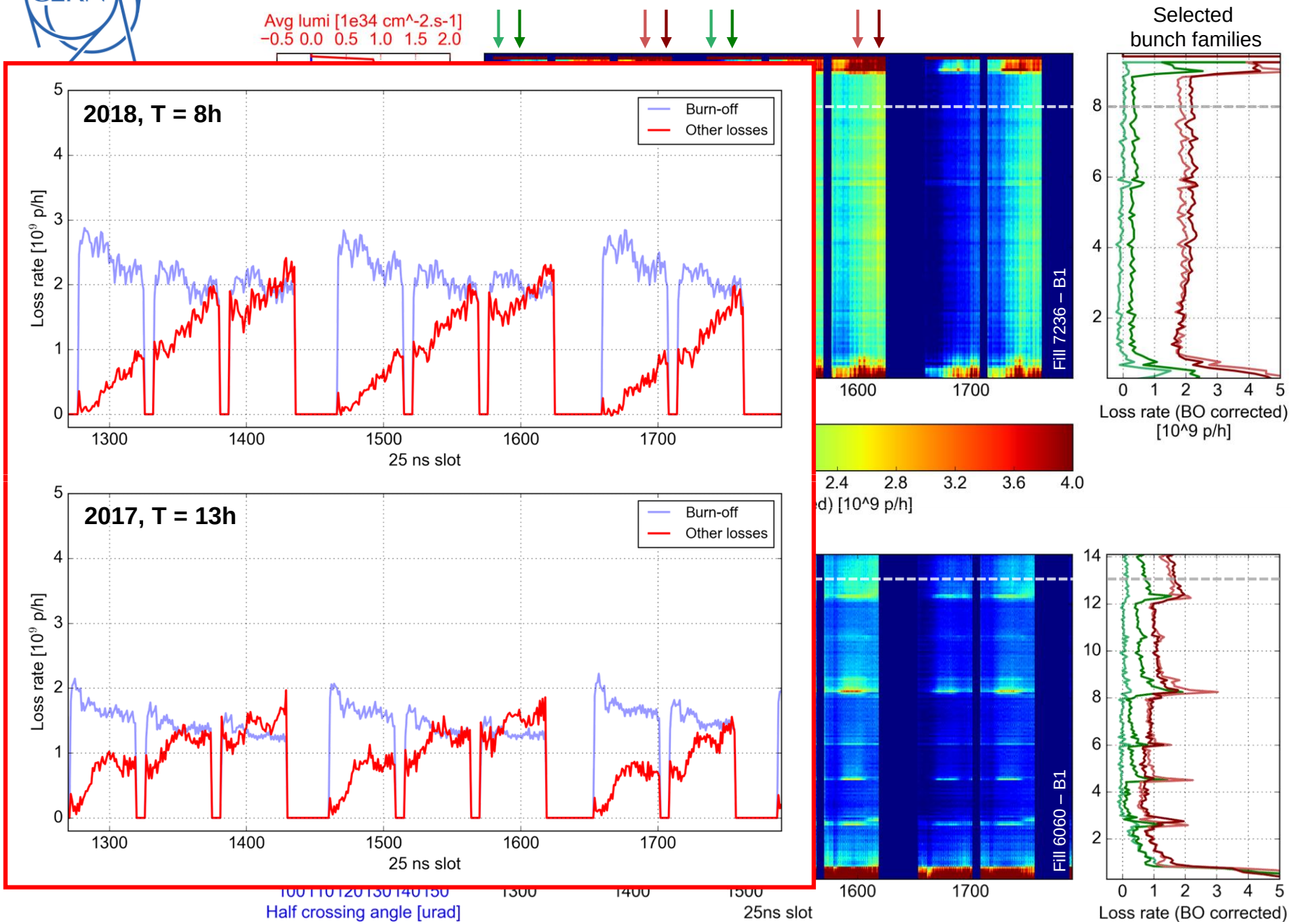
2017
$\beta^* = 40$ cm
25 ns



Situation in 2017 (25 ns)



Situation in 2017 (25 ns)



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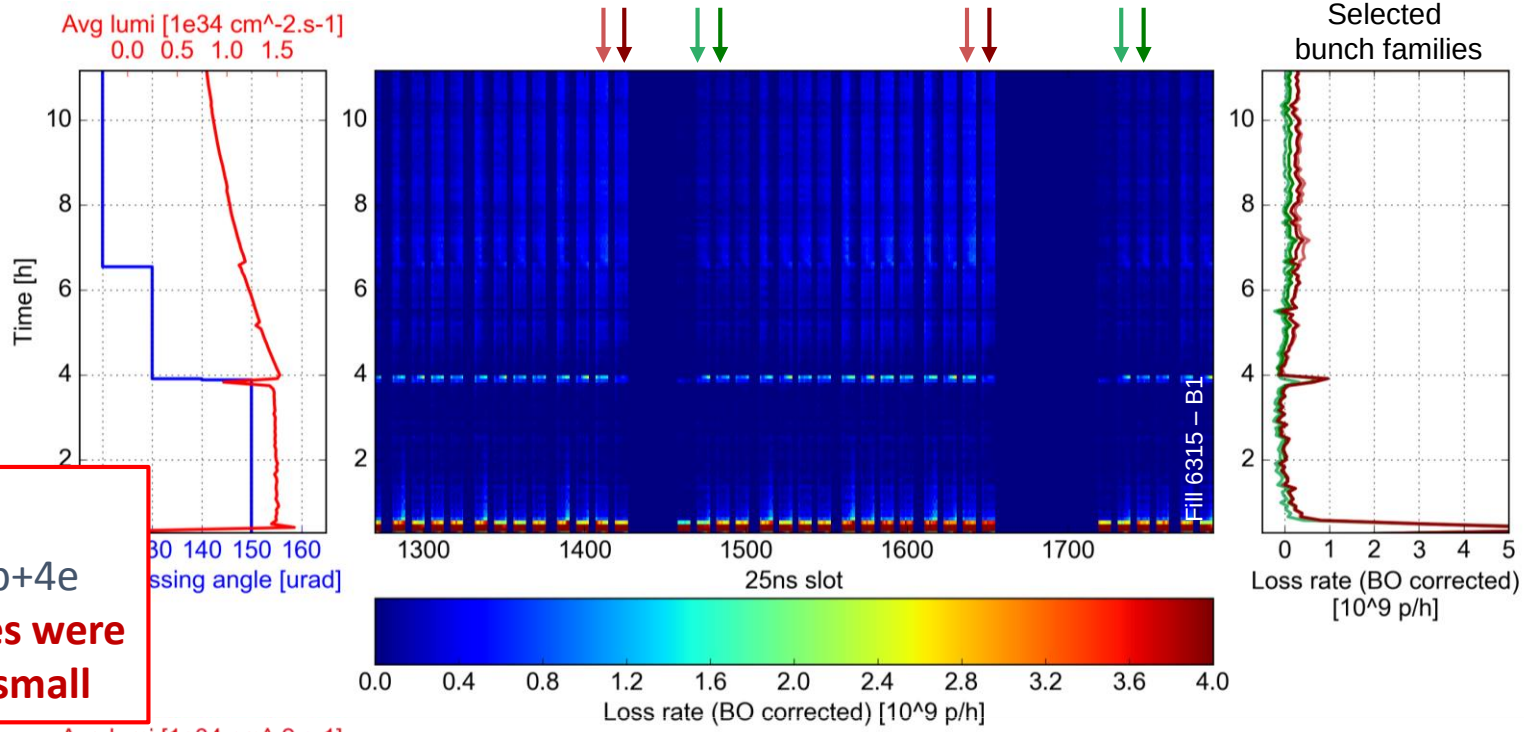
Situation in 2017 (8b+4e)

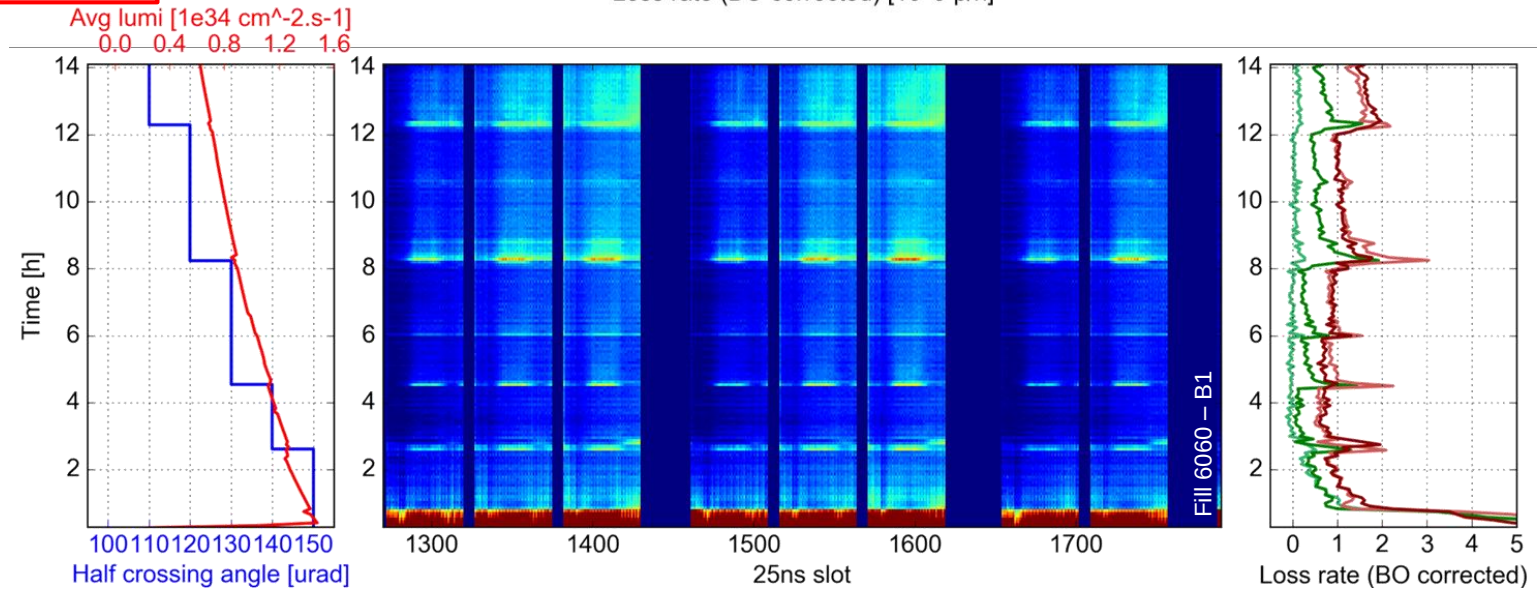
2017
$\beta^* = 30$ cm
8b+4e



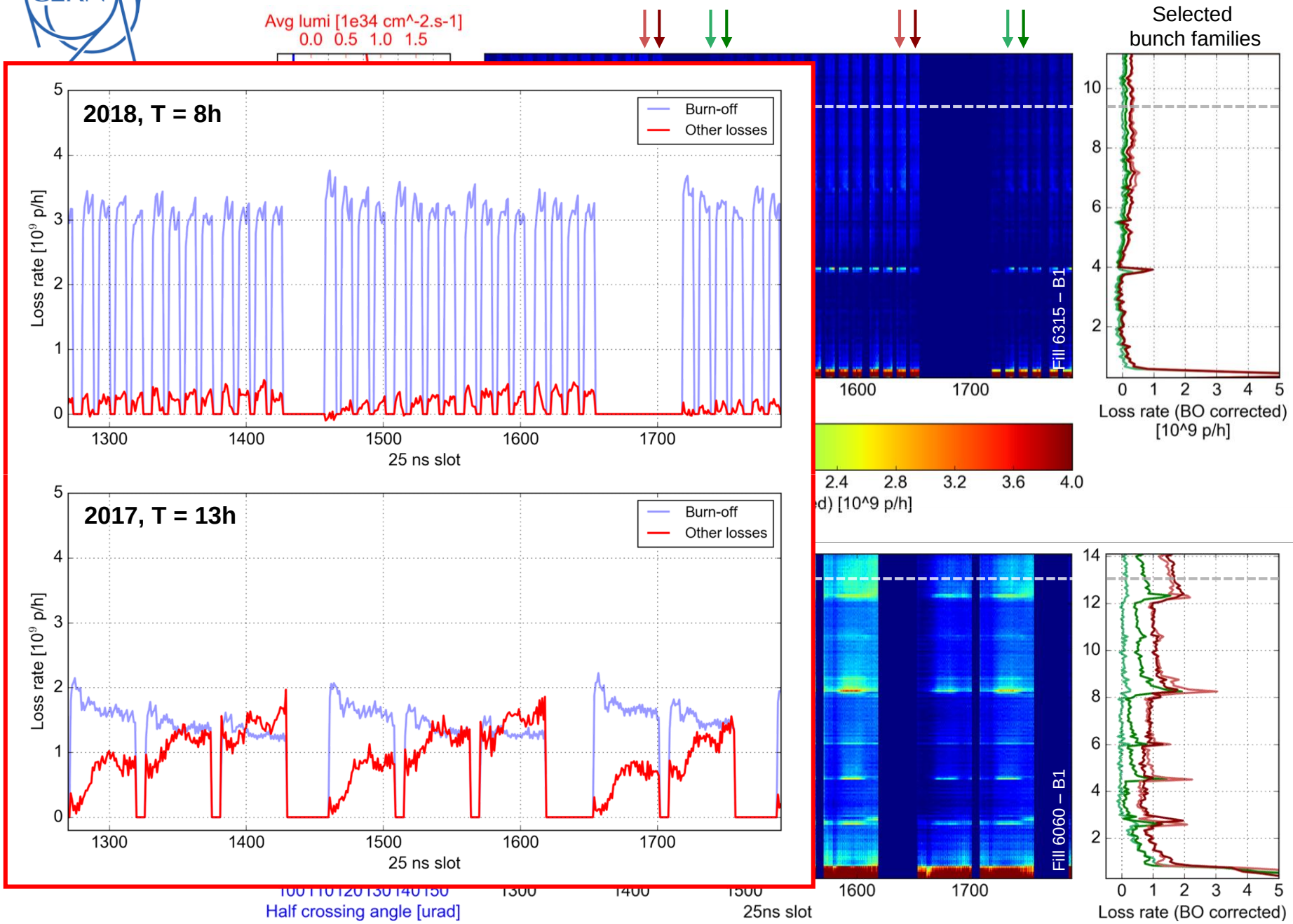
In 2017:

- With the 8b+4e **beam losses were extremely small**

2017
$\beta^* = 40$ cm
25 ns



Situation in 2017 (8b+4e)



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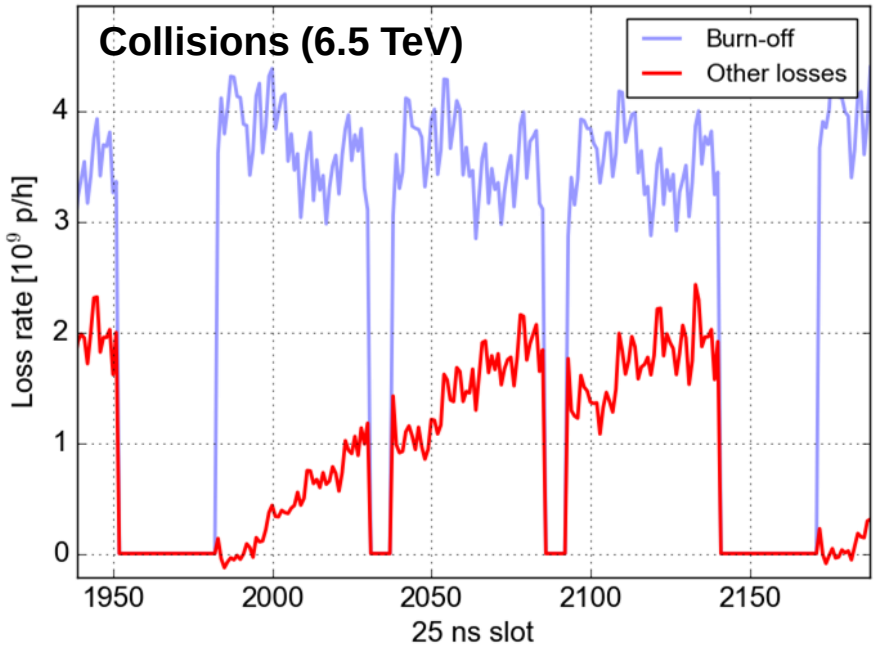
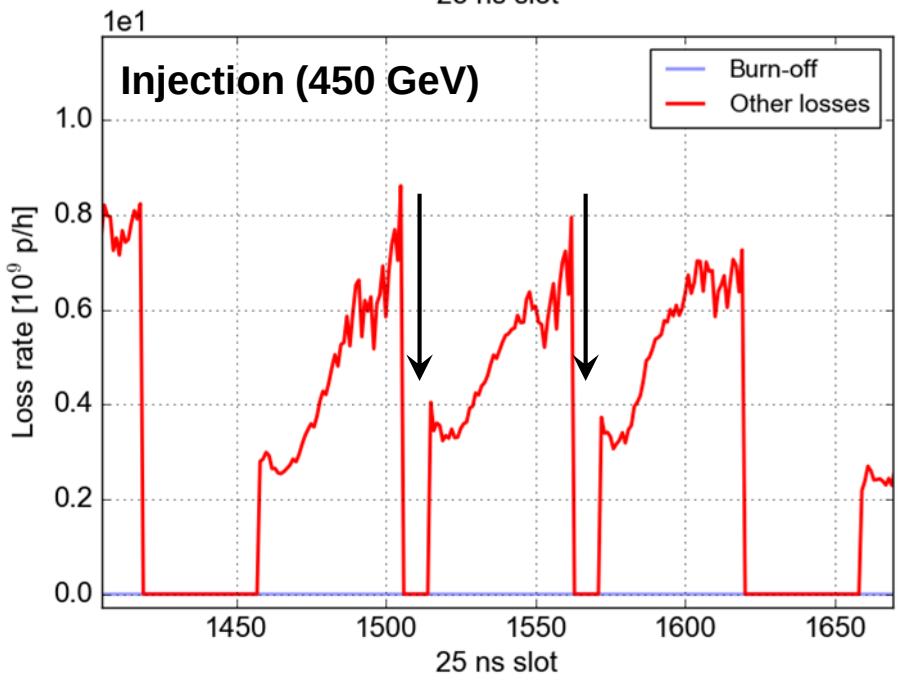
Are we dominated by e-cloud in the arcs or in the IRs?

The **loss pattern is different compared to what is observed from e-cloud effects in other conditions**:

- **200 ns gaps** between trains **do not reset** the buildup





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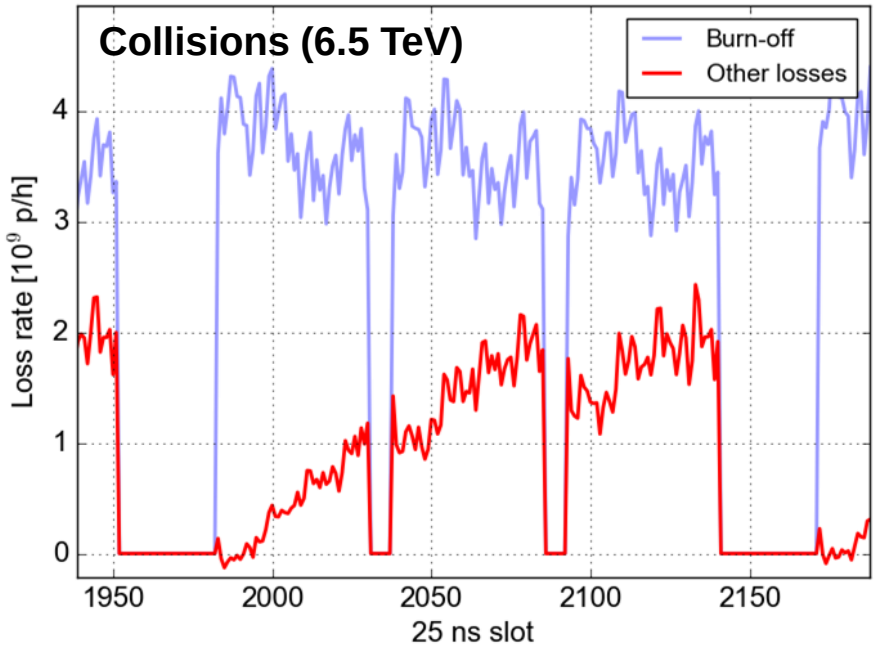
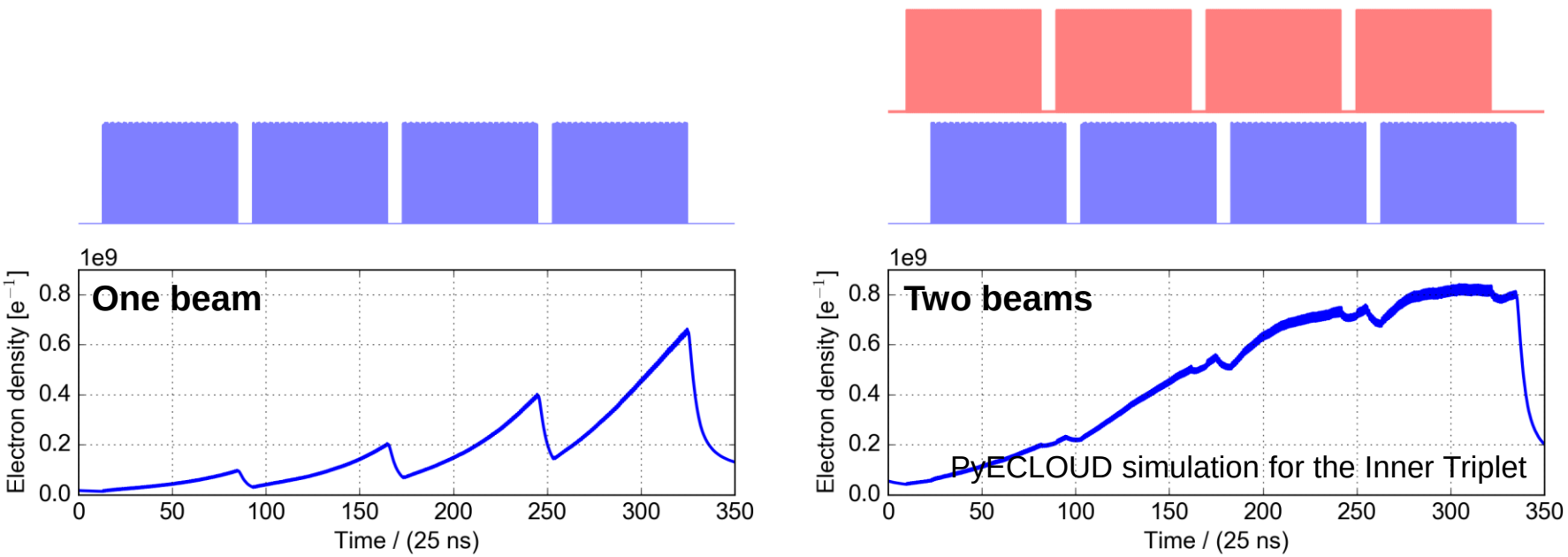
- Suggests that **losses in collisions are dominated by e-cloud in the Inner Triplets**





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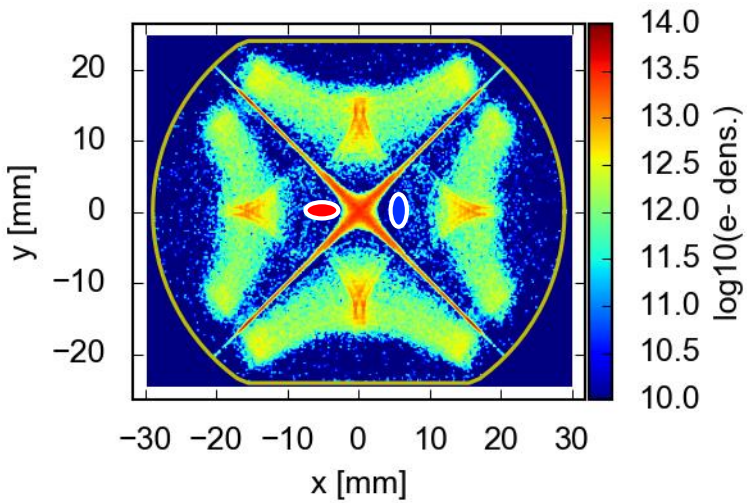
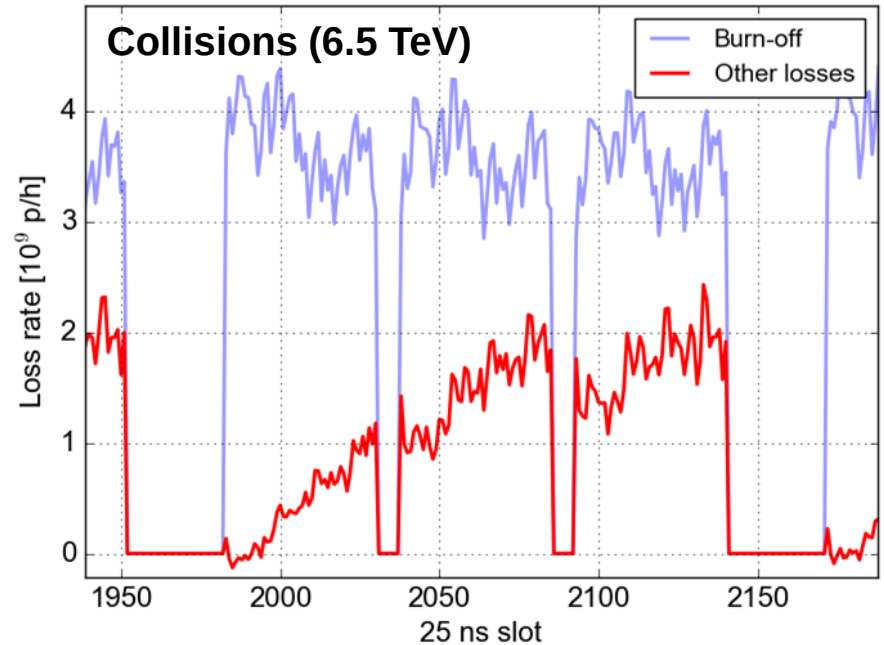
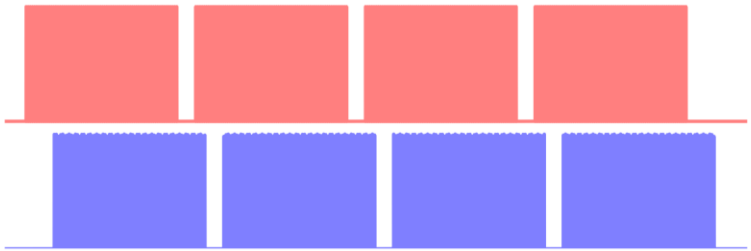
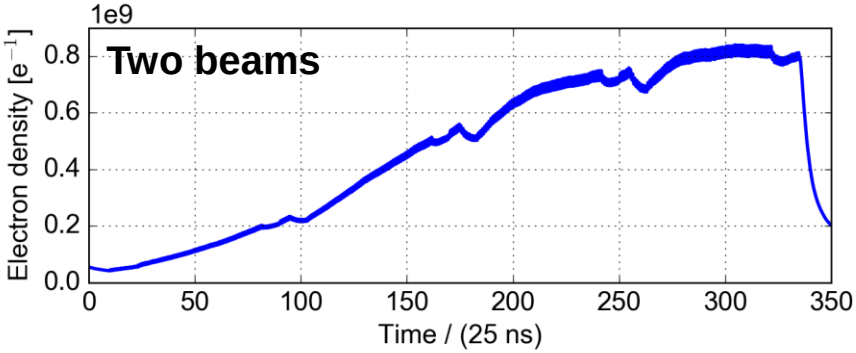
  → consistent with strong **sensitivity on β* and crossing angle**









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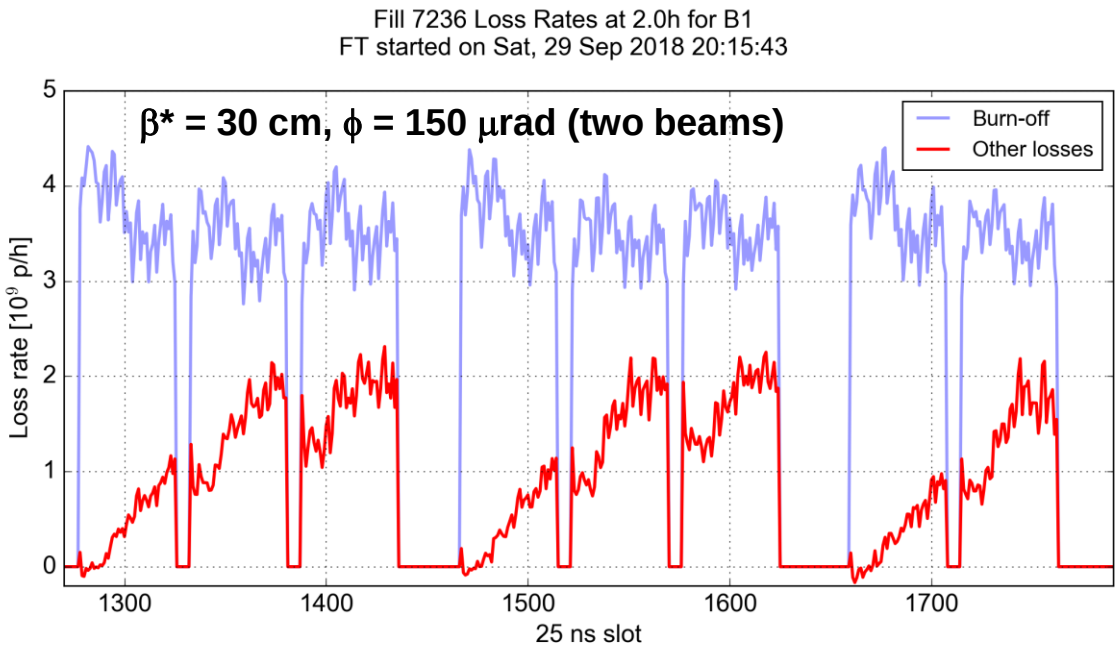
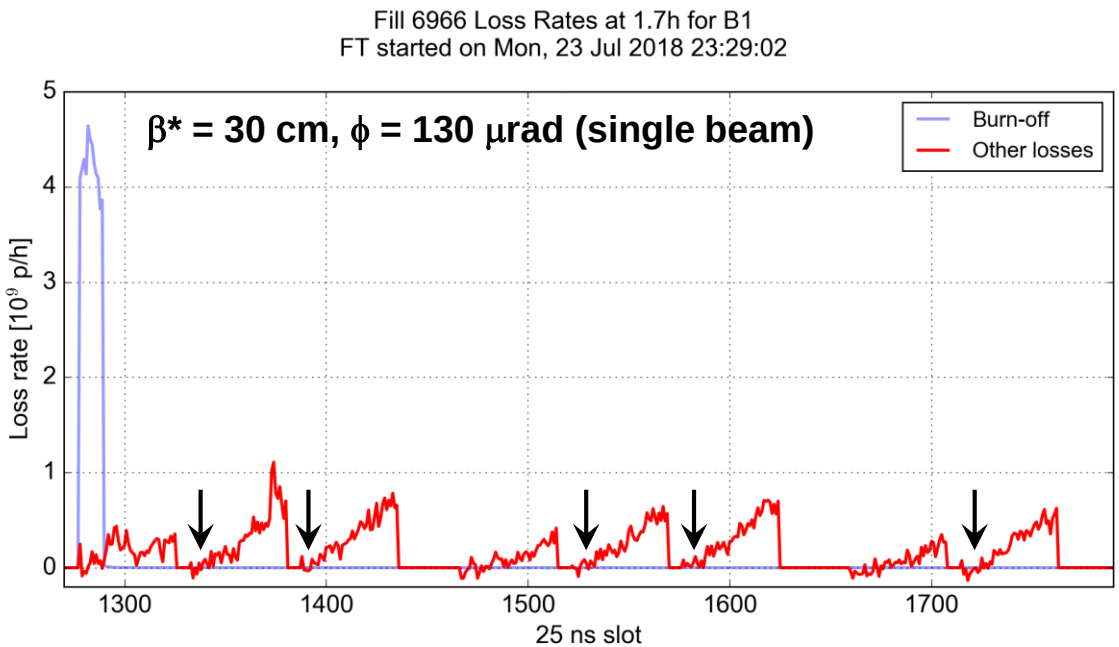
One circulating beam (6966, 25ns)

Losses with a **single beam in "collision configuration"** could be **measured during an MD** dedicated to heat-load characterization

- **Losses are found to be very small** compared the two-beam case (DA in the absence of beam-beam is much larger)
- As expected the **200 ns gaps reset the buildup**





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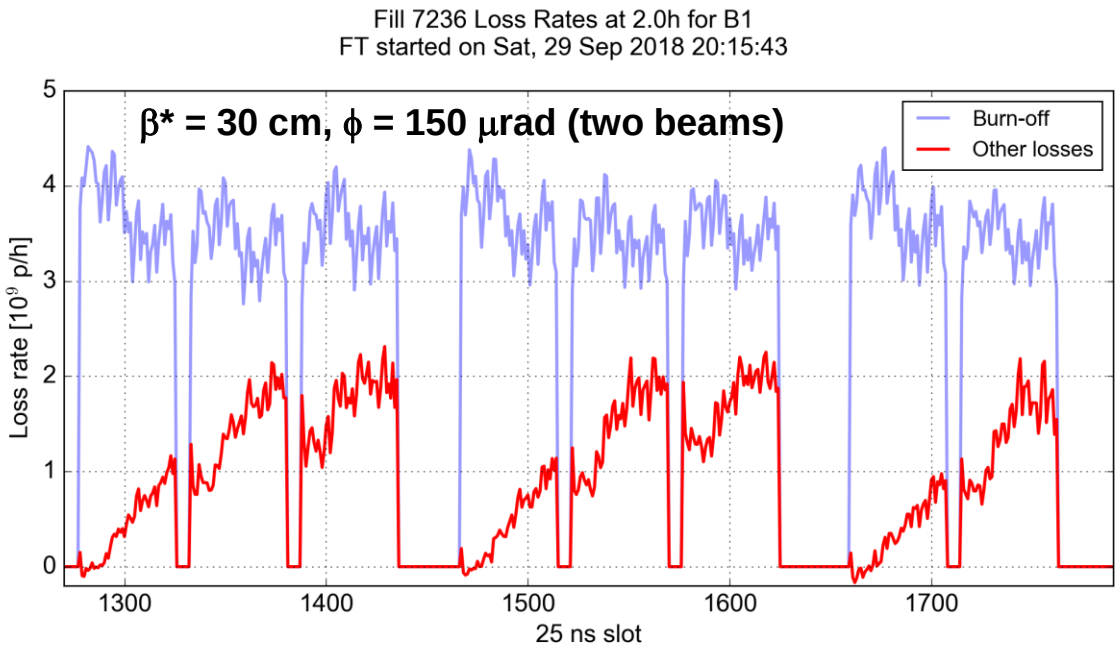

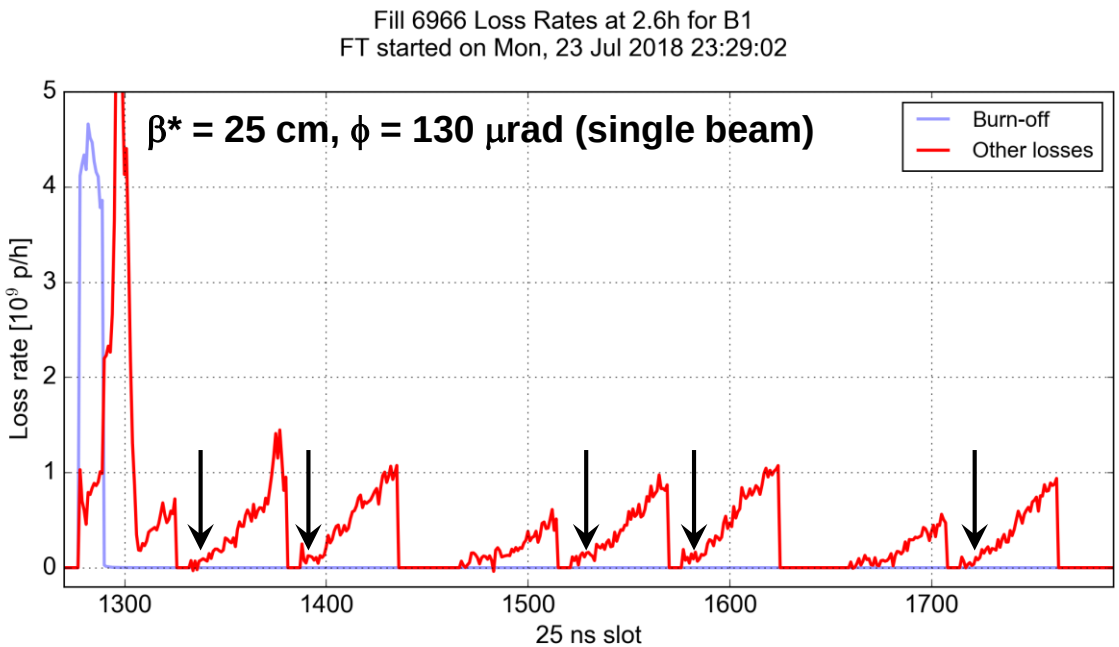

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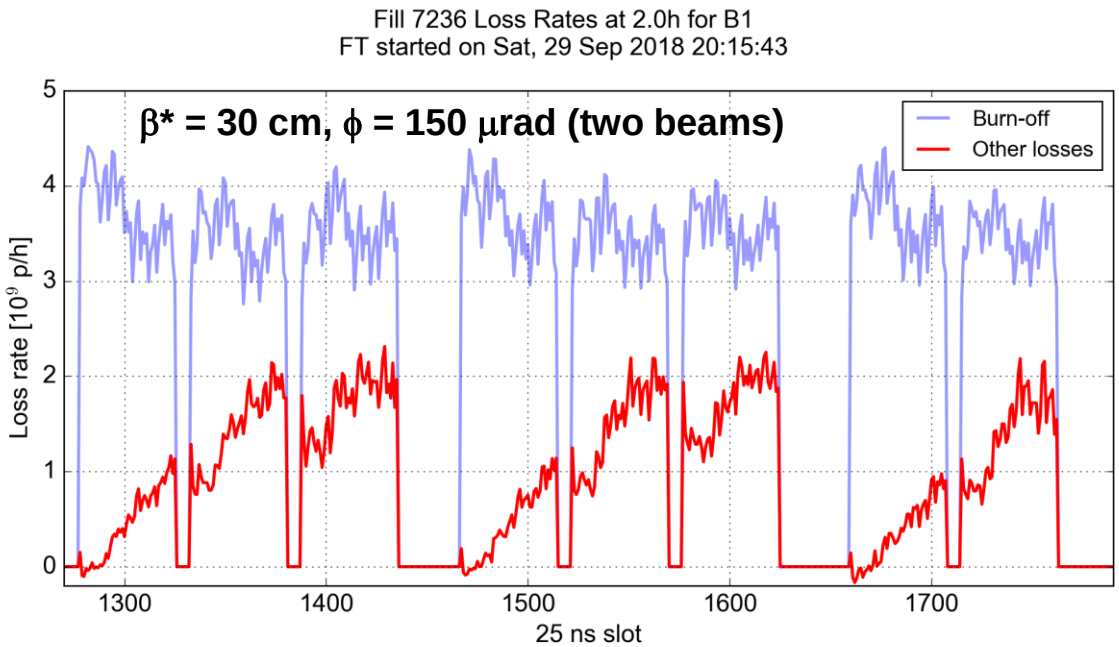
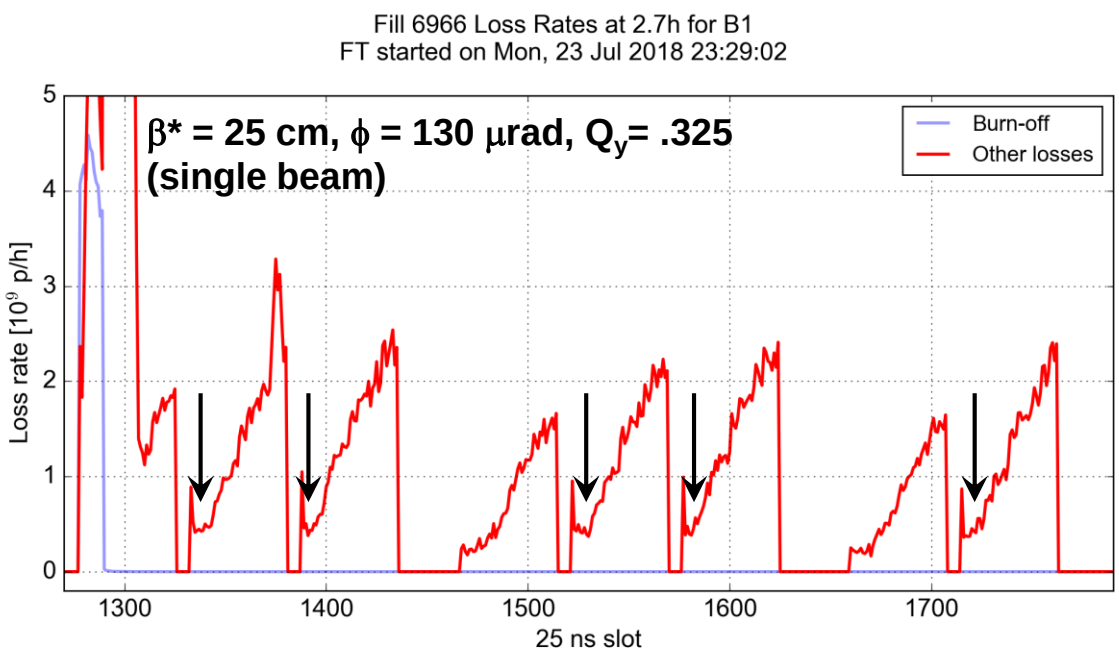
- **Losses are found to be very small** compared the two-beam case (DA in the absence of beam-beam is much larger)
- As expected the **200 ns gaps reset the buildup**
- Losses **become stronger when reducing β* and going to less optimized tunes**
  - Suggests that **effect of triplets is still present**





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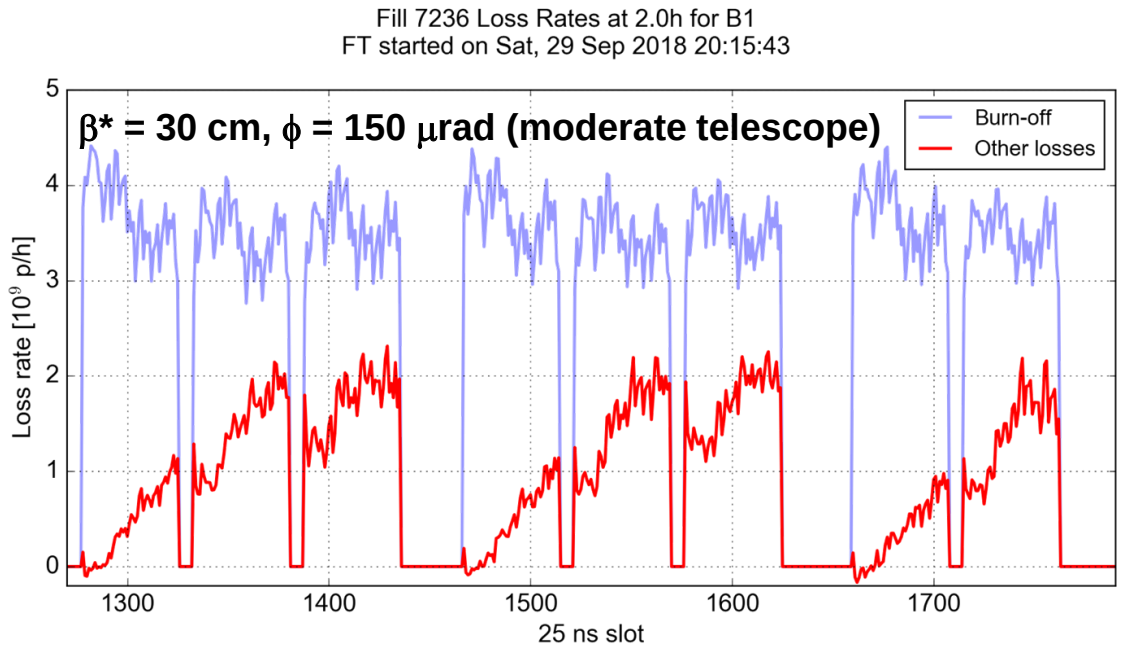
Large ATS telescope (25ns)

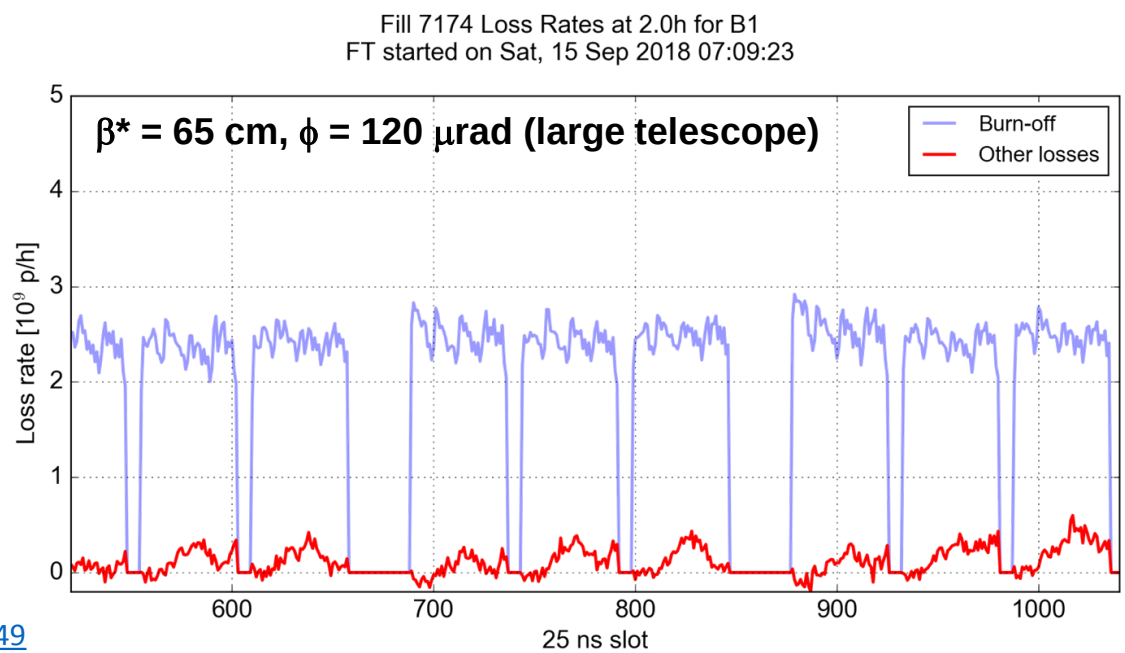
The fact that losses in collisions are driven by e-cloud in the IRs and not in the arcs is **confirmed by an MD performed with special optics**[1]:

- **Relatively large β*** → small beta function in the triplets
- **Similar beam-beam separation** compared to physics configuration
- **Large telescopic factor (~3)** → large in beta func. in four arcs



In these conditions **losses were found to be very small**

→ This configuration **is quite representative of the beginning of the HL-LHC fill**



[1] Talk by S. Fartoukh at LSWG 29/11/2018
https://indico.cern.ch/event/772189/contributions/3209049

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Summary of the observations

- During the last LHC Run in 2018 **slow losses were observed during collisions**, with significant **differences among the circulating bunches**
  - **Over a 9h fill**, losses amount to about **20% of the initial intensity** on the most affected bunches **(comparable to burn-off)**
  - There is **no correlation with the number of BB LR encounters**, instead losses **increase along the bunch trains**
  - Time structure **looks like a constant spill more than a scraping**
  - There is **no correlation with initial bunch-by bunch emittance**

→ **e-cloud acting on the bunches during the Stable Beams phase** appears to be a key element in the underlying loss mechanism

- The losses rate increases when reducing **crossing angle and β^***
- Losses are **very small with a single circulating beam** in "collision configuration"

- **Gaps of 200 ns do not reset the loss pattern**
  - → Suggests that the main driver is the **e-cloud in the Inner Triplet**
  - → **Consistent** with observation made in **MD with large telescopic factor**

Outlook for HL-LHC

- Observations suggest that the main source of the observed losses is the **e-cloud in the triplets**

  → In HL-LHC this **will be suppressed by the amourphous carbon coating**

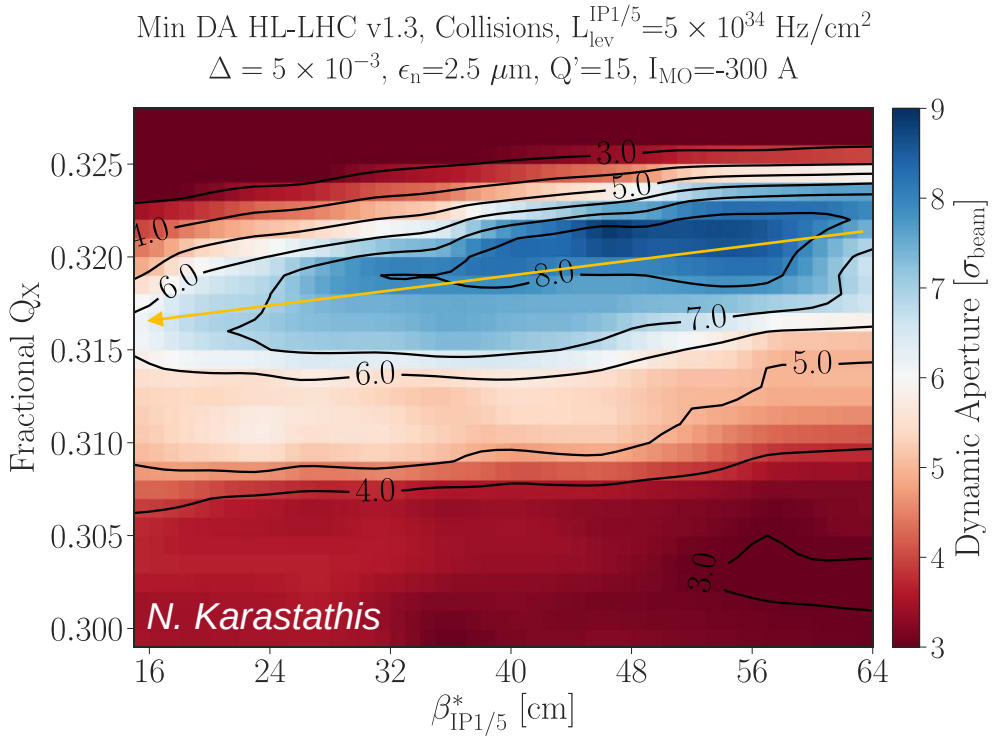
Moreover:

- The LHC configuration in **2018** was defined to **run at constant DA of about 5 sigmas** without e-cloud by slowly decreasing the crossing angle → **goal was to maximize the luminosity**
- In the **HL-LHC** during a large part of the **β* levelling** we will run with **much larger DA** (thanks to the relatively large beam-beam separation)

  → **Tests with constant crossing angle in 2018** showed that this **is clearly beneficial**

- In the HL-LHC era the **average burn-off loss rate will be ~5 times larger** (due to higher luminosity)

  → Additional losses from **e-cloud will have less impact on the total loss rate** and on the bunch-by-bunch luminosity decay



Thanks for your attention!