Effect of WP, chromaticity, orbit correction on FB losses

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SPS OP Crew

SPS injection losses review – 30 November 2017

Outline

- The goal is to **maximize transmission** at injection (and throughout the cycle) and to maintain the **best possible beam quality** (brightness).
- In the transverse plane, there are a couple of **parameters that effect both transmission and beam quality** evolution. These can be categorized into:
  - Orbit → losses from aperture limitations
  - Working point → losses from interaction with resonances – incoherent effects
  - Chromaticity → losses from tune spreads and beam quality degradation from instabilities – incoherent and coherent effects
- Ultimately, **all effects are linked** and the goal is to find **the best settings** forming the ideal compromise in obtaining the maximum transmission in combination with the best possible beam quality.

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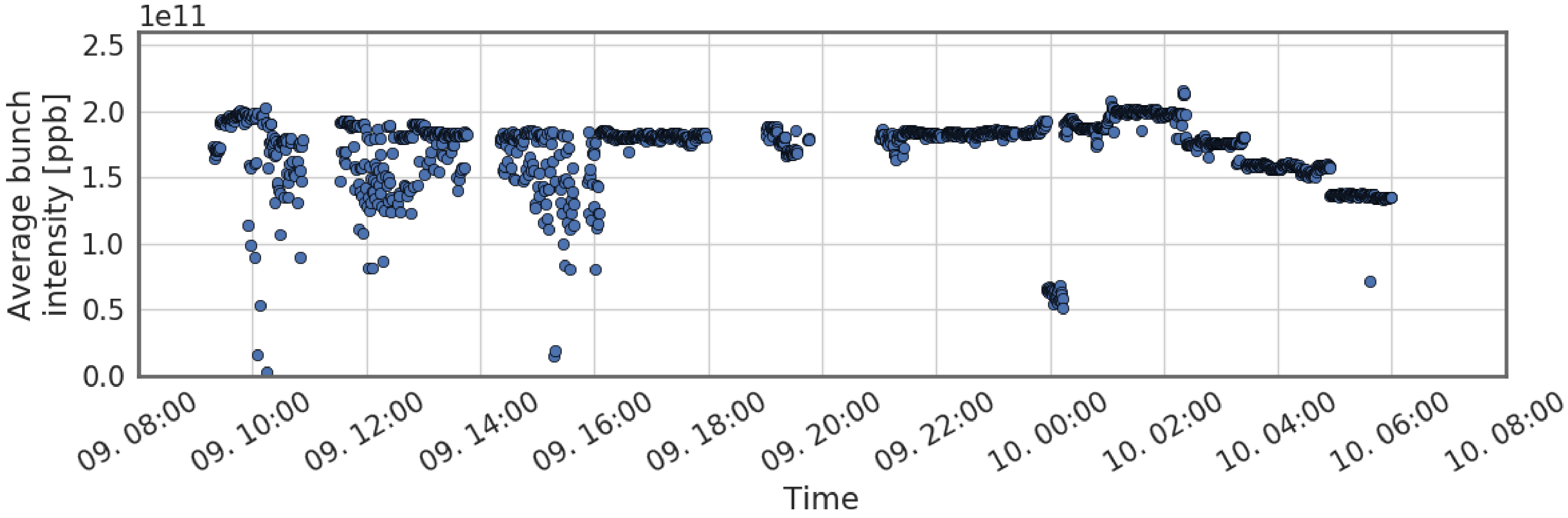
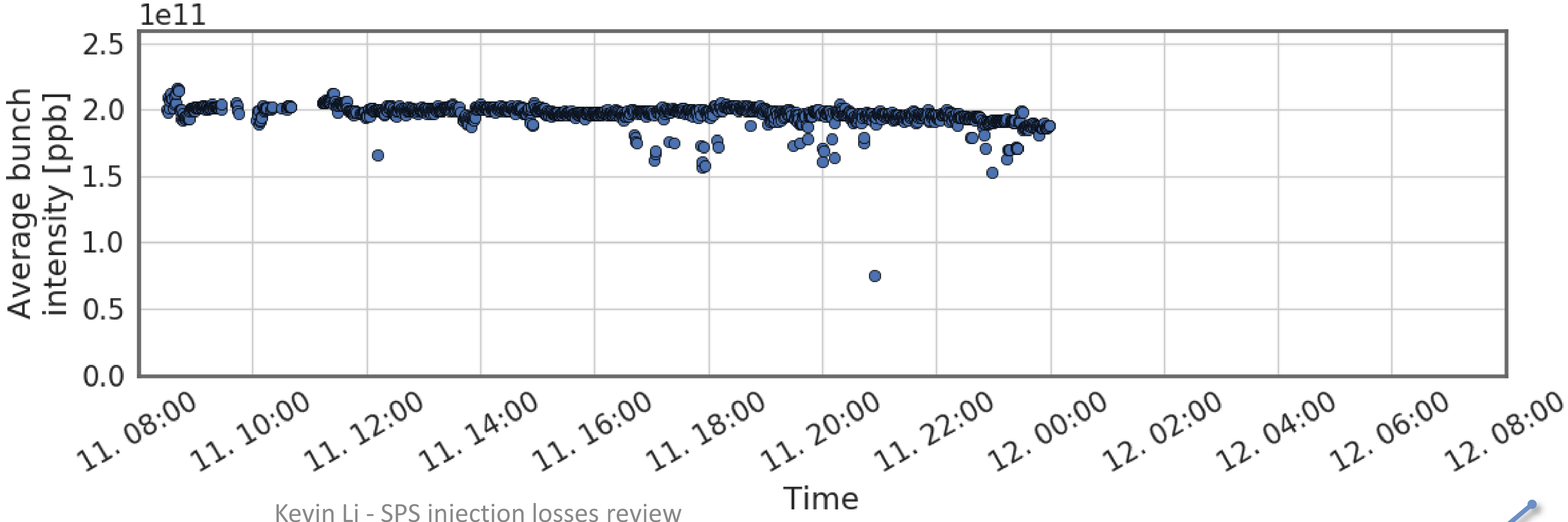
BCT overview

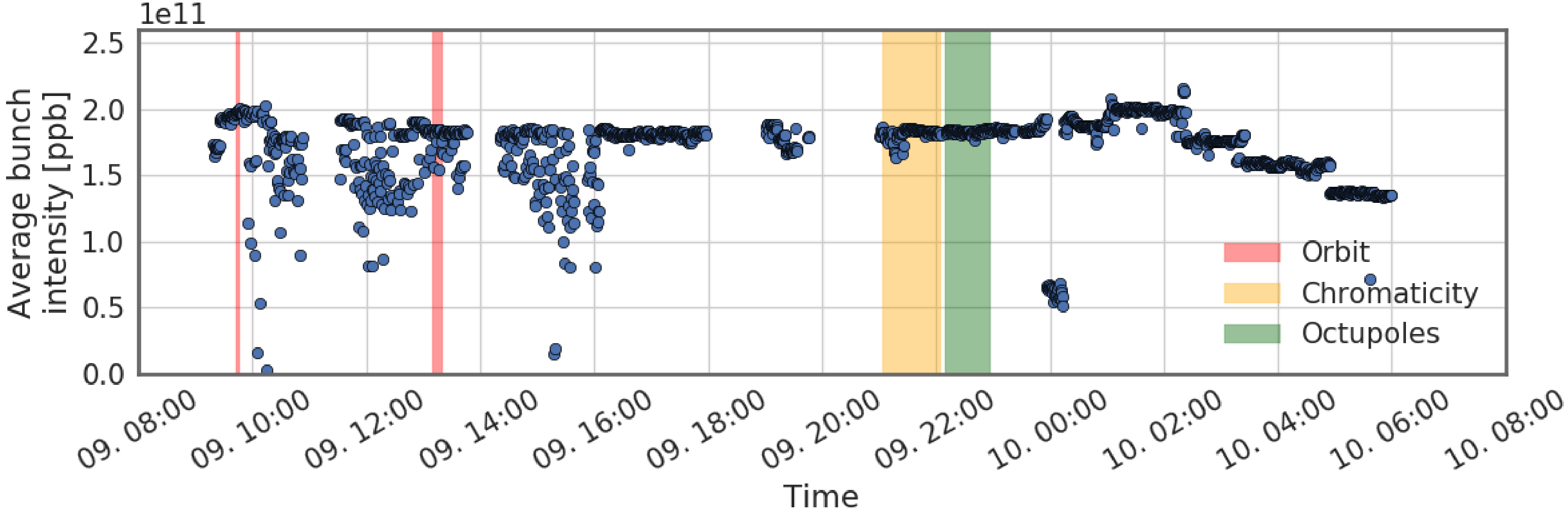
- Injection of 72 bunch batches (standard 25 ns) and 48 bunch batches (BCMS) with up to 2e11 ppb
- Nominal longitudinal parameters (0.35 eVs) from the PS

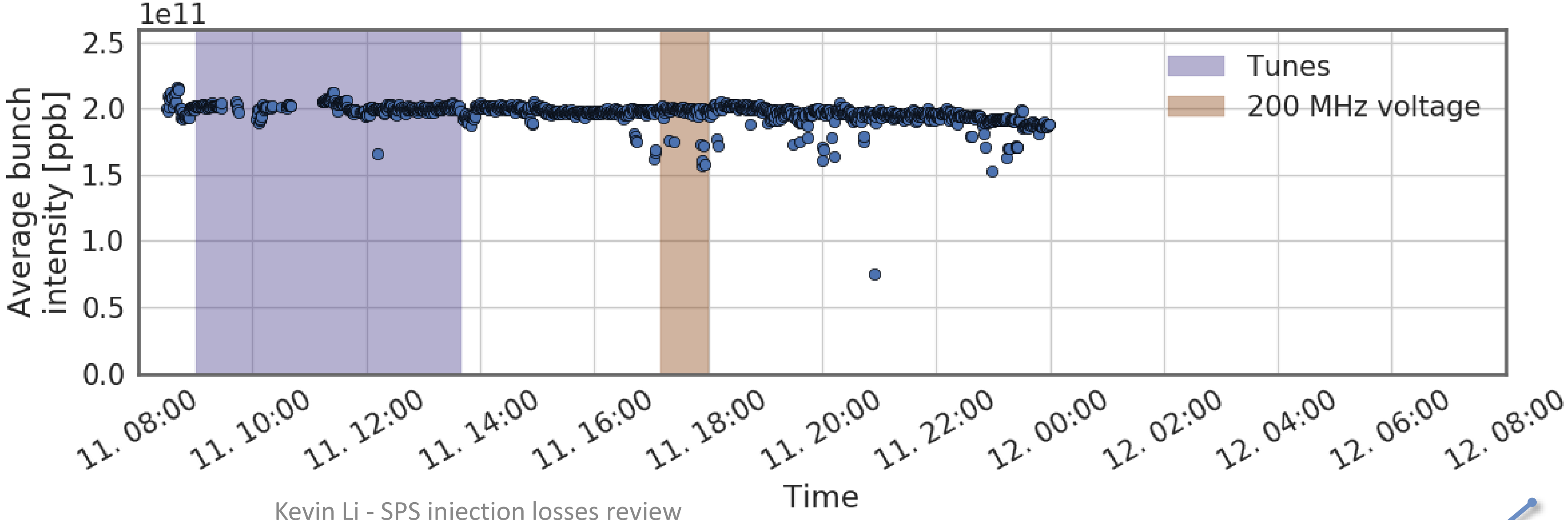




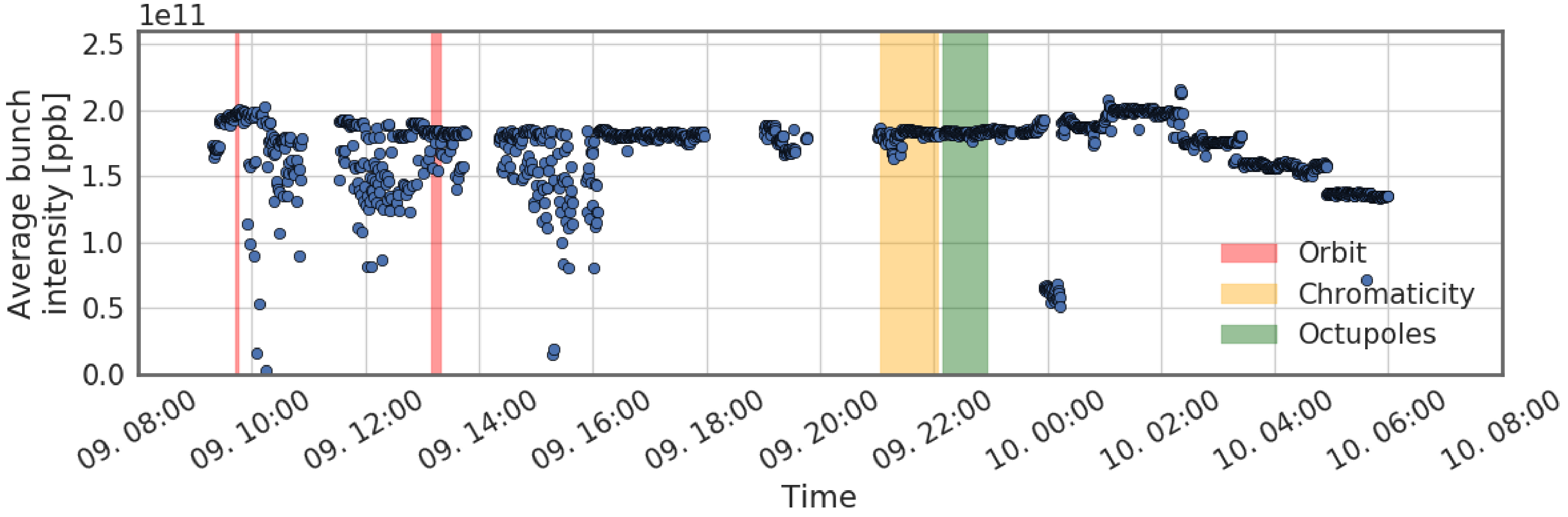
BCT overview

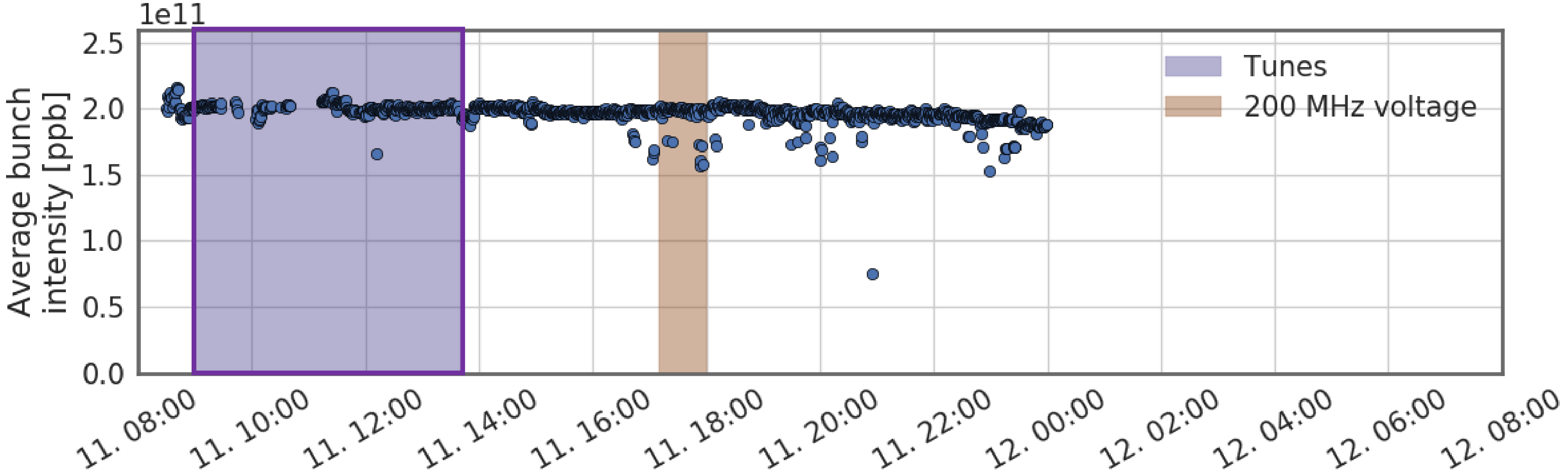
- Injection of 72 bunch batches (standard 25 ns) and 48 bunch batches (BCMS) with up to 2e11 ppb
- Nominal longitudinal parameters (0.35 eVs) from the PS
- Orbit optimization together with studies of incoherent and coherent effects on beam lifetime and beam quality





Spotlight – incoherent effects and WP optimization





- Investigation of losses as a function of tunes for potential working point optimization for high intensity beams.
- BCMS beam – 1 x 48 bunches

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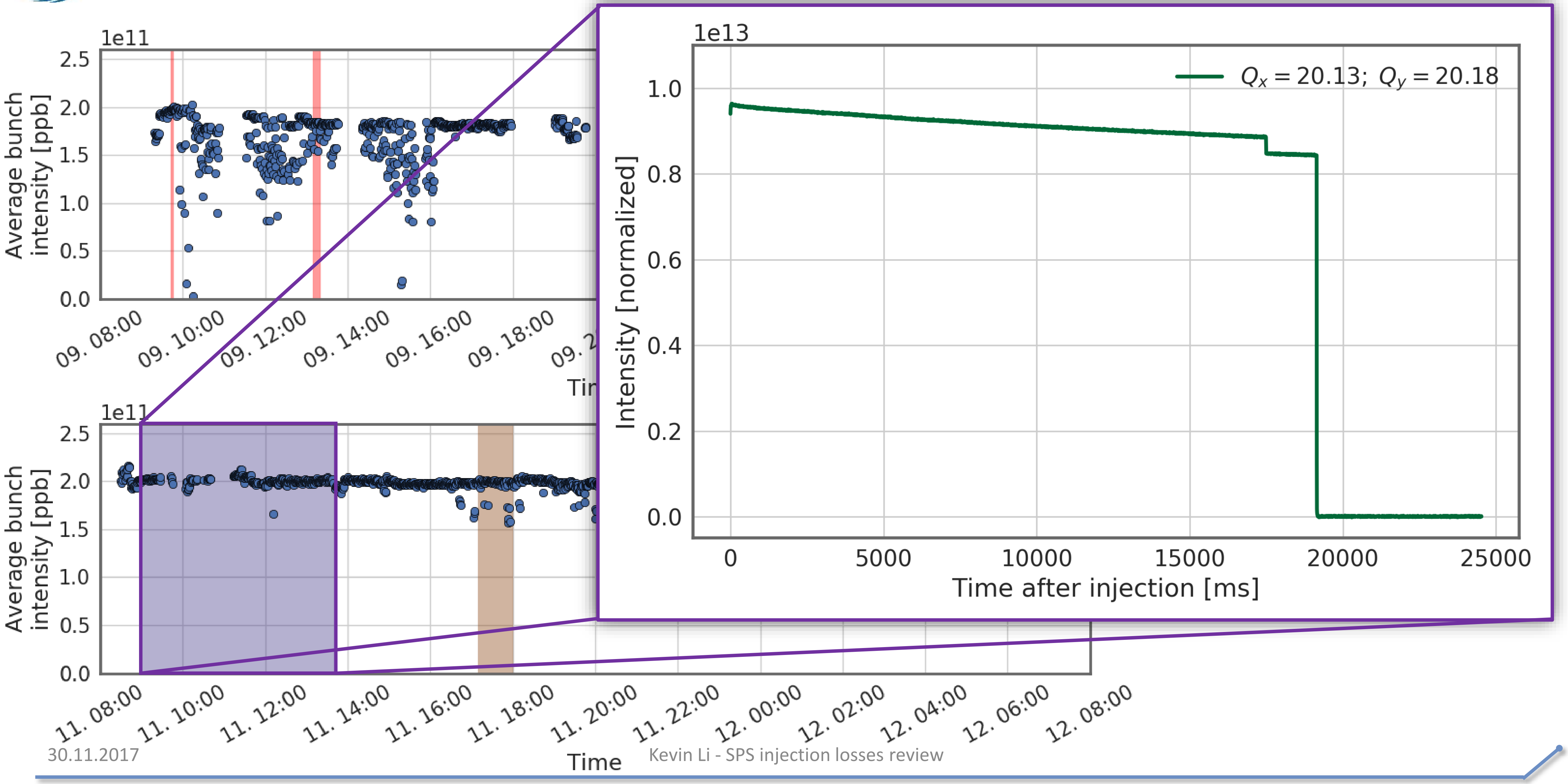

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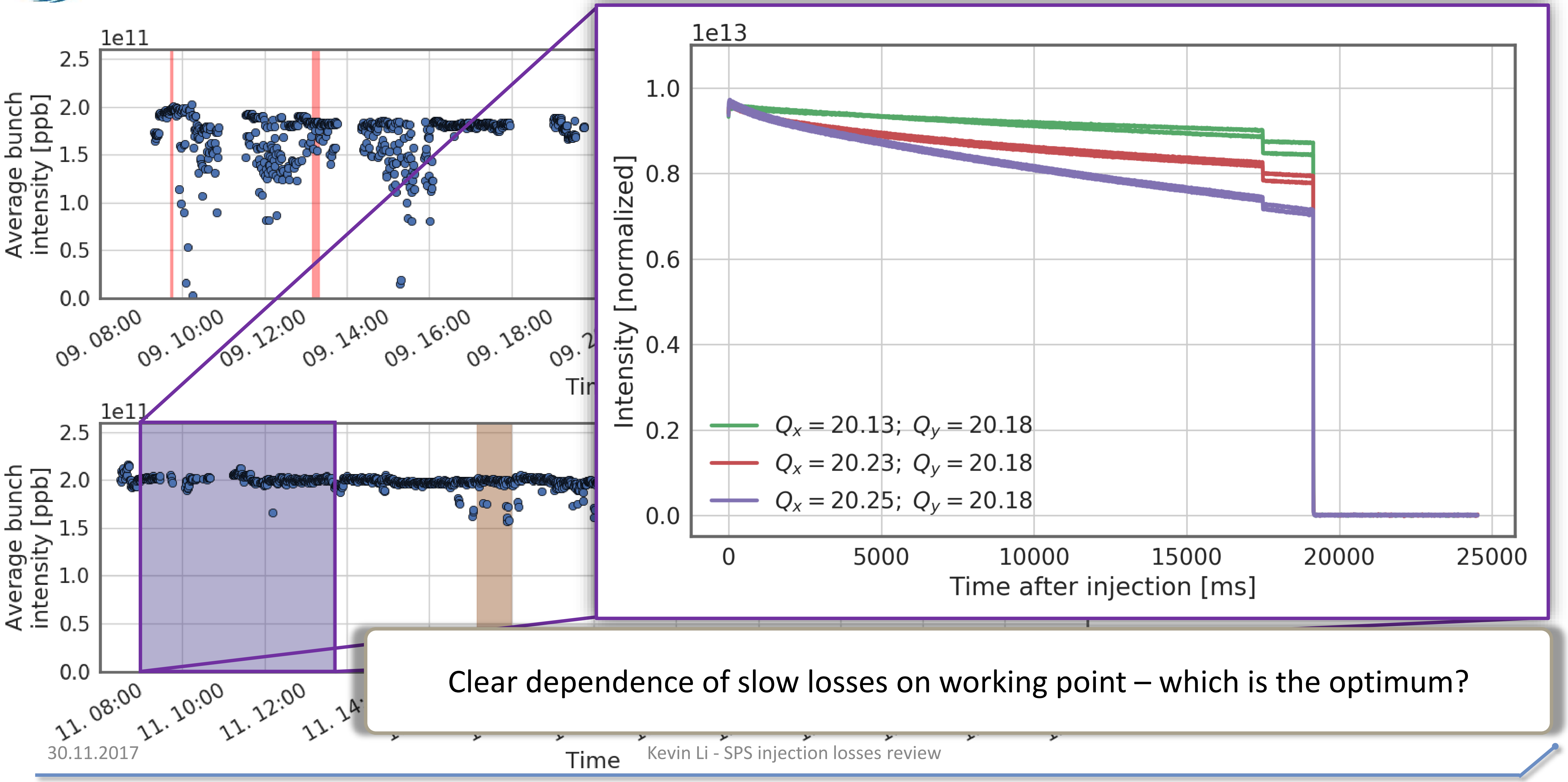
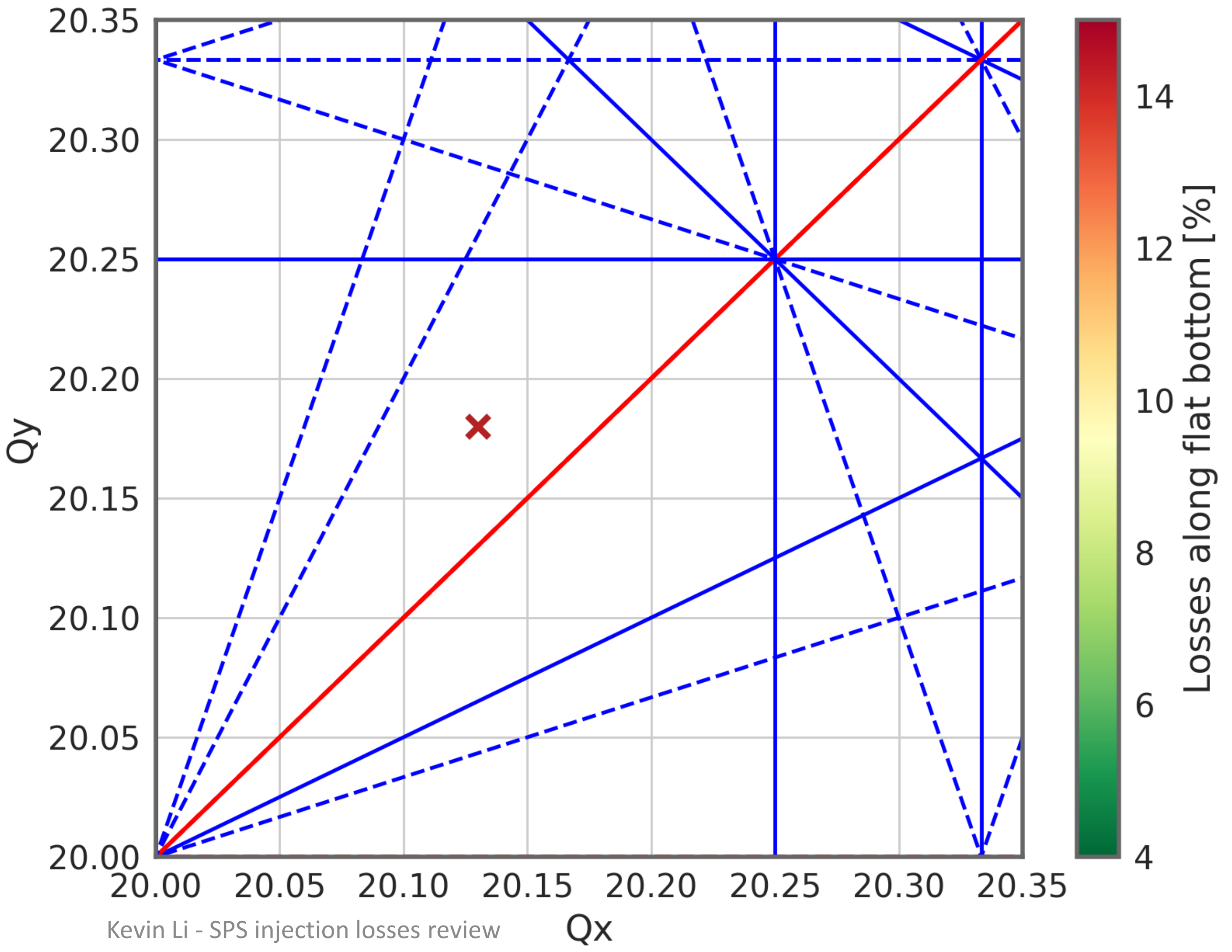


Clear dependence of slow losses on working point – which is the optimum?

Impact of working point on flat bottom losses

- The working point is typically set to about:
  - Qx = 20.13
  - Qy = 20.18

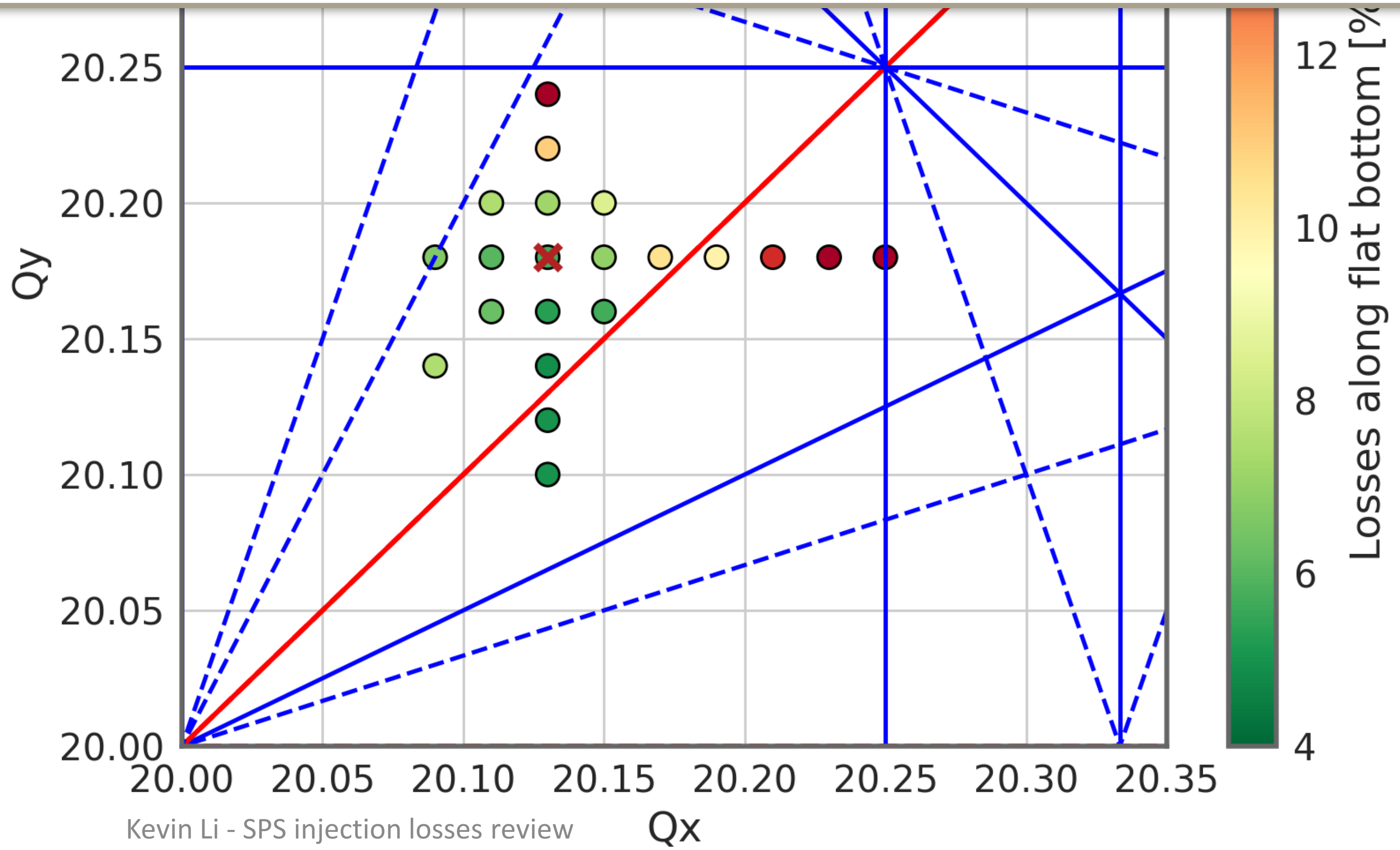


Impact of working point on flat bottom losses

The typical working point at (0.13, 0.18) **is already well optimized** in terms of losses – there is not much to gain in a WP optimization.

With the impact seen from chromaticity (later) we will nevertheless try gain a **qualitative insight in the loss mechanism**…

- In this study we try to optimize the coherent tune in terms of losses
- It turns out that **the usual working point is already very close to an optimum** – losses can be higher for other working points (in particular when increasing the tunes…)



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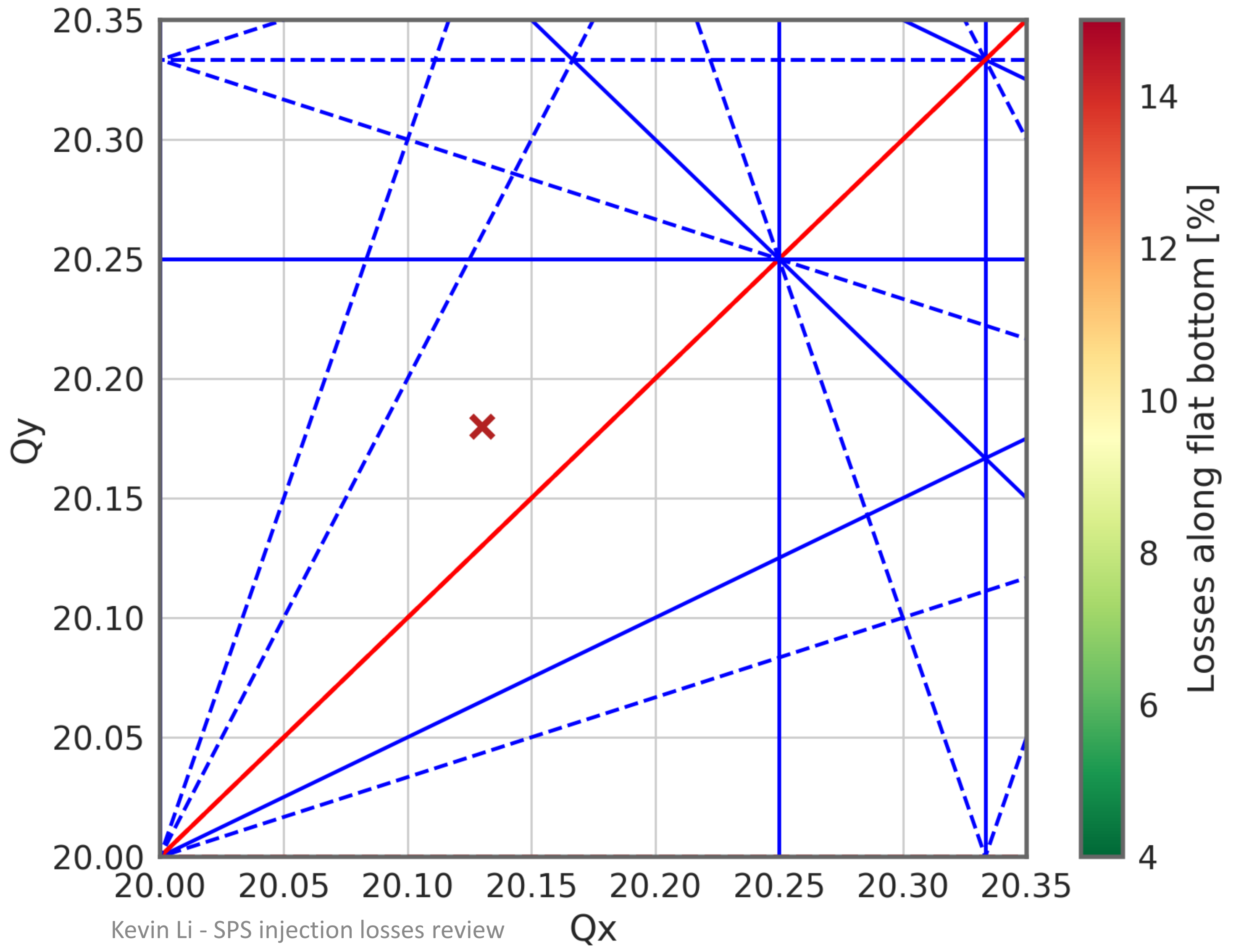


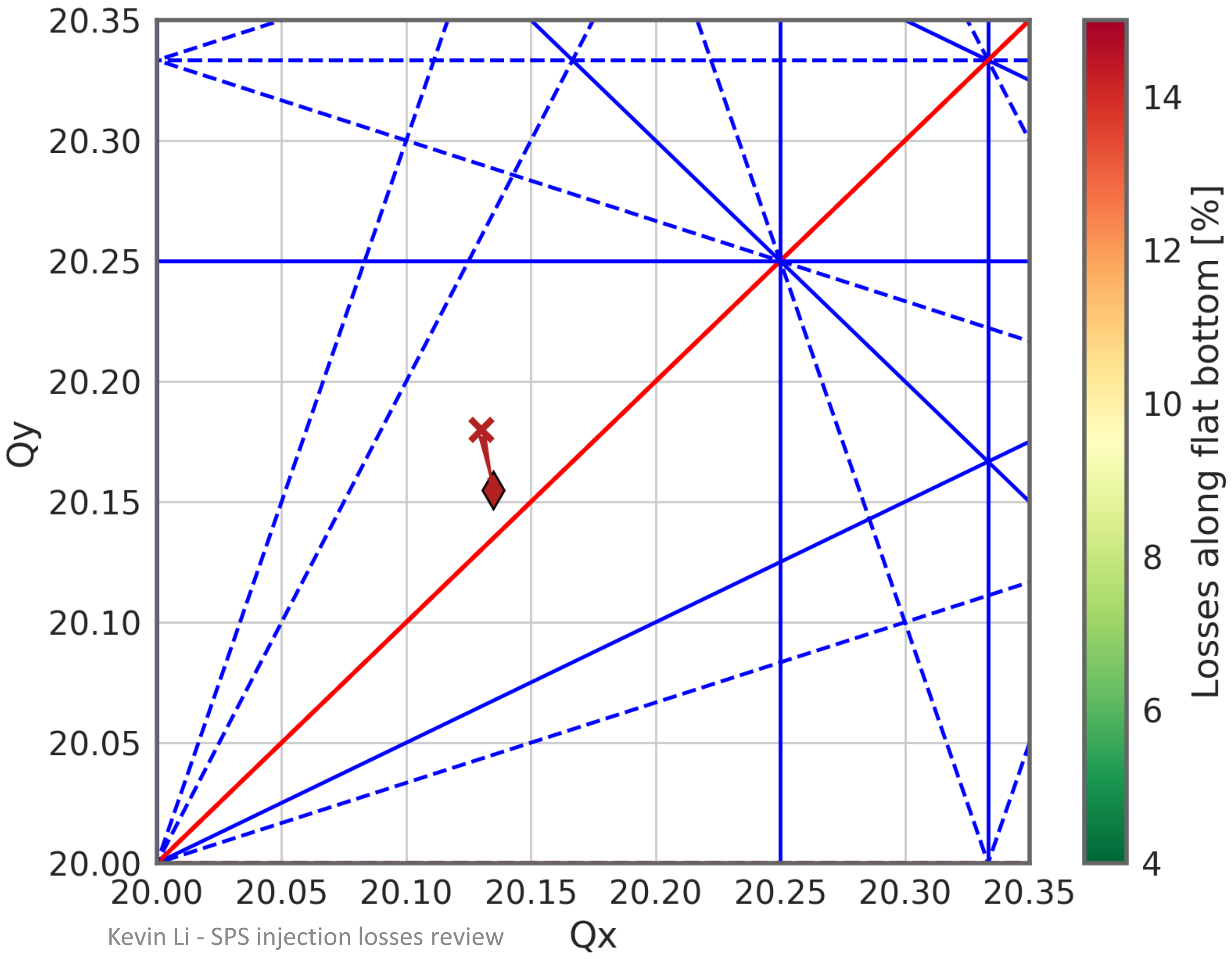
Impact of working point – qualitative analysis

- The working point is typically set to about:
  - Qx = 20.13
  - Qy = 20.18
- Impedance effects lead to a coherent tune shift. The measured coherent tune is the manifestation of the coherent ensemble motion.

In a qualitative view we **focus on large off-momentum/uncaptured** particles

We neglect incoherent tune shifts from quadrupolar wakes and space charge

This will be a **recurring view** and we will see later why this makes sense



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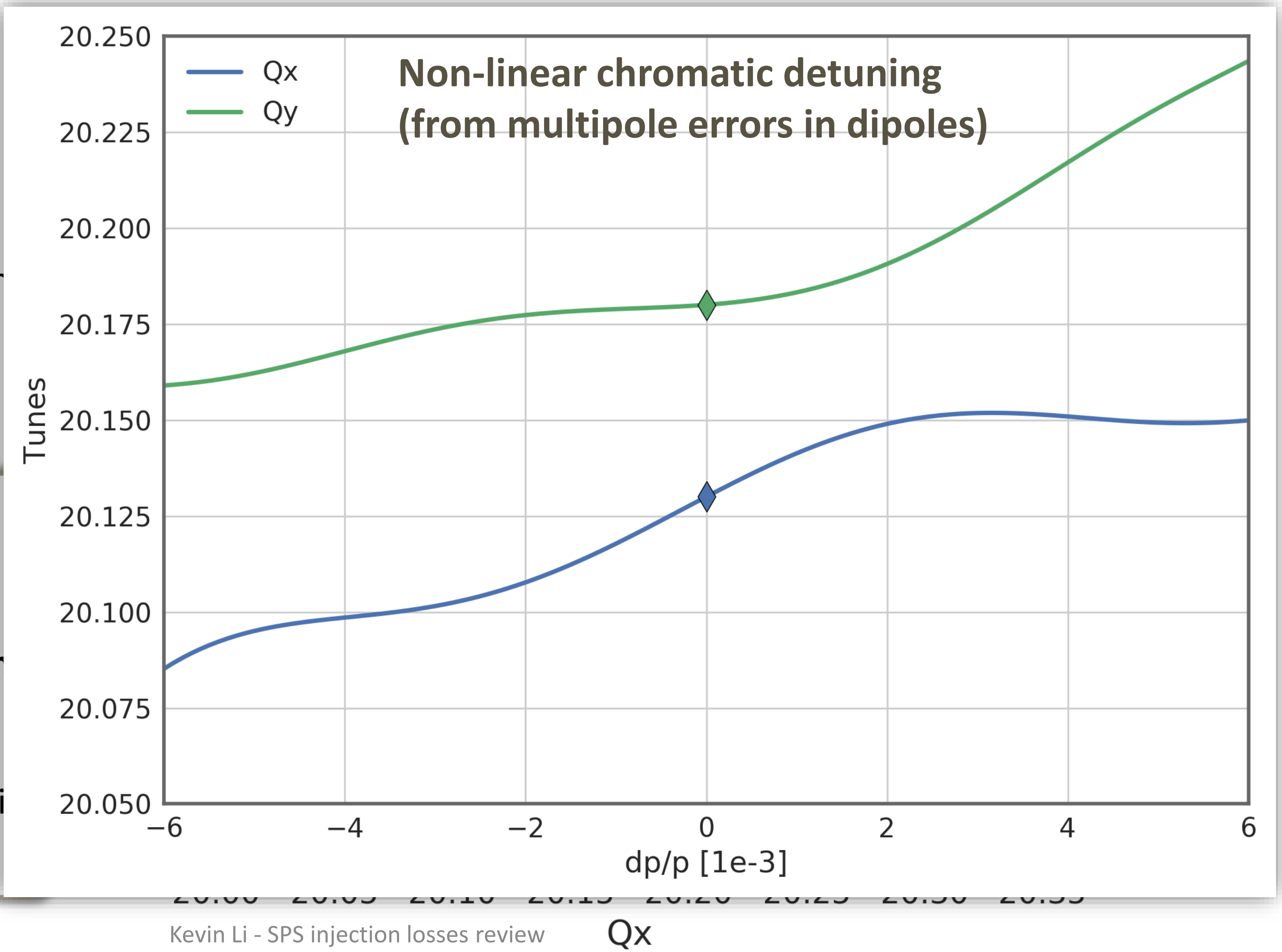
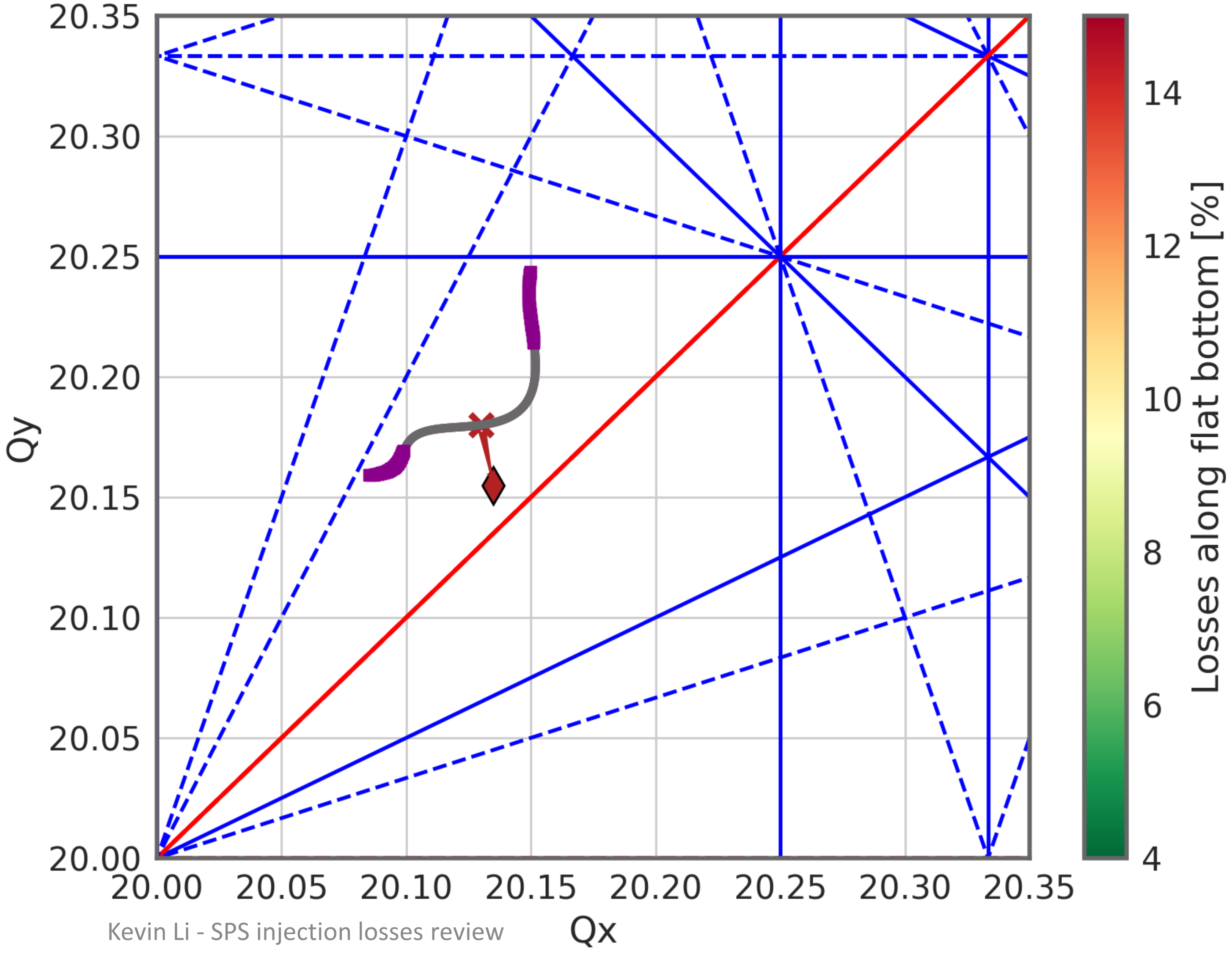


Impact of working point on flat bottom losses

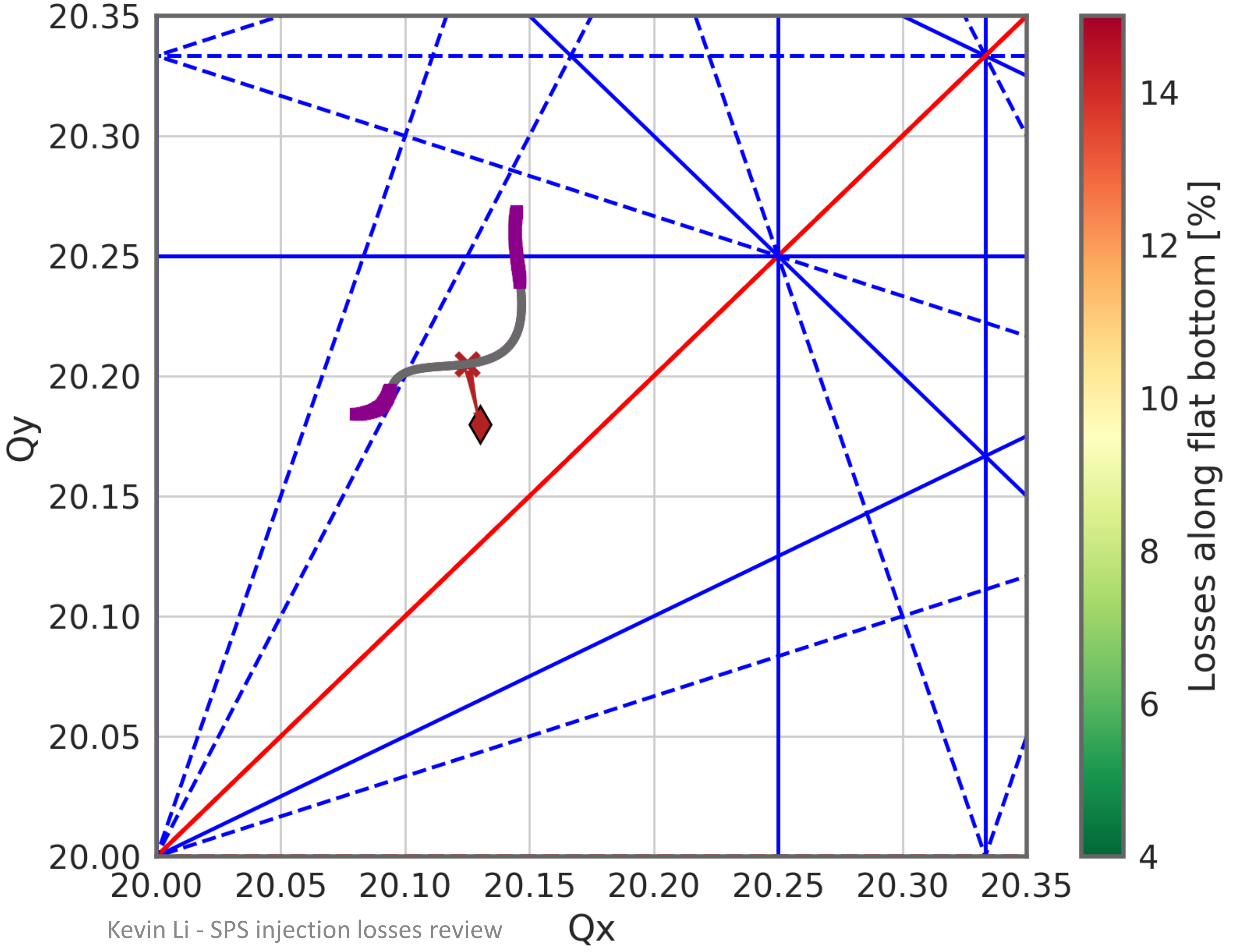
- The working point is typically set to about:
  - Qx = 20.13
  - Qy = 20.18
- Impedance effects lead to a coherent tune shift. The measured coherent tune is the manifestation of the coherent ensemble motion.
- Single particle (or incoherent) motion takes place still **around the bare machine tune**
- The **tune footprint** is generated by off-momentum particles in combination with chromaticity (gray: up to RF bucket height – magenta: up to momentum aperture)



Impact of working point on flat bottom losses

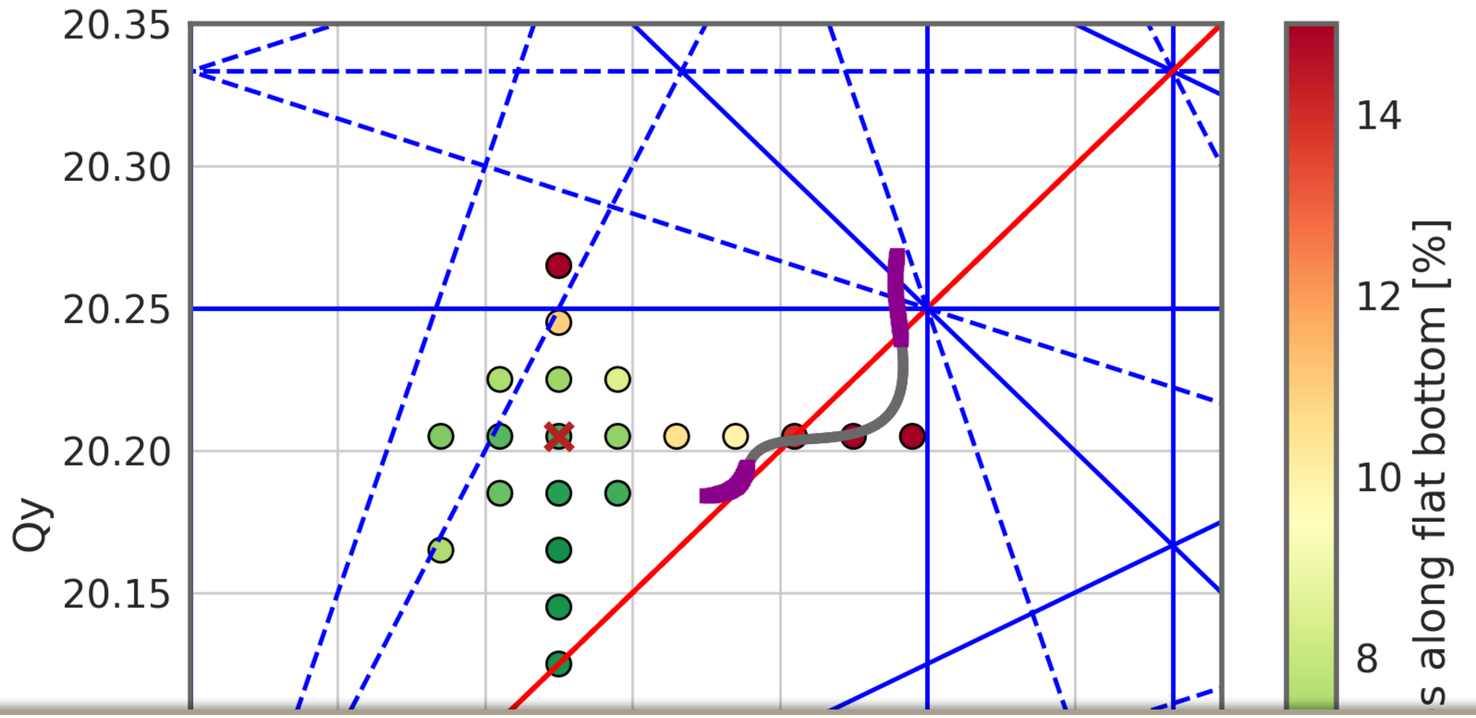
- The **tune correction of the SPS** shifts the measured coherent tune back to the set working point. This is required for the transverse damper to work correctly.

- Consequently, **the bare machine tune changes and the footprints are shifted**…



Impact of working point on flat bottom losses

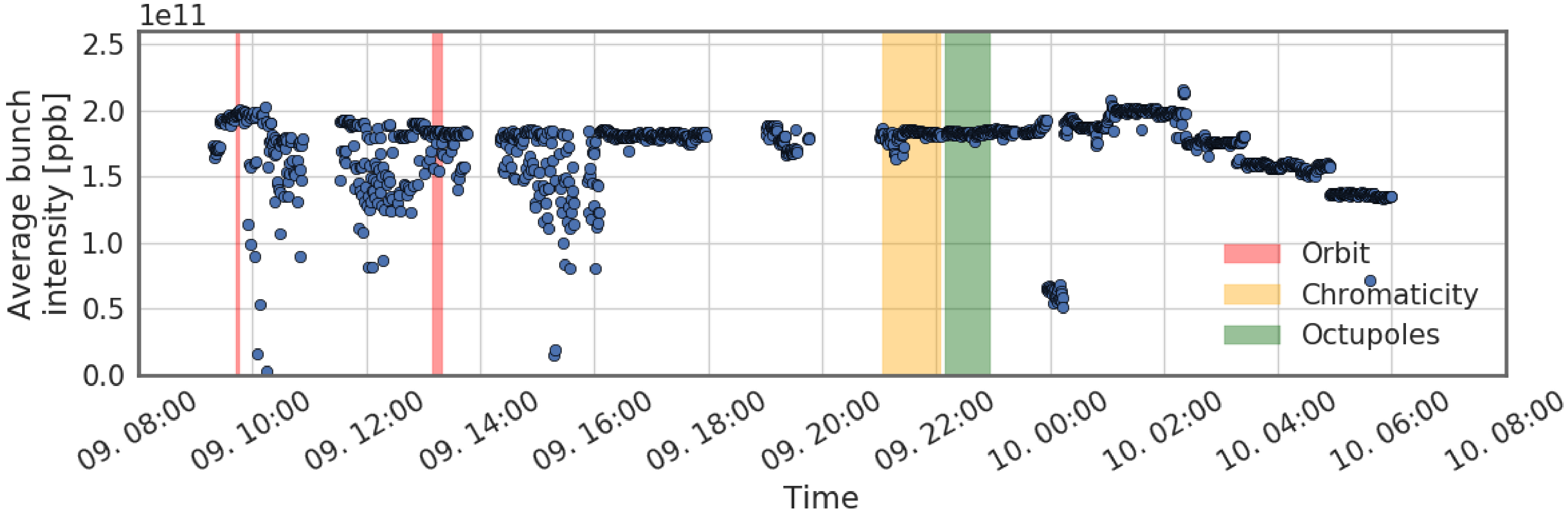
- Losses are generated by **single particles crossing resonances**
- In the measurements shown, large **off-momentum particles can cross several resonances** leading to enhanced losses
- **Which resonances are the detrimental ones taking into account the coherent and incoherent tune shifts is still under study**

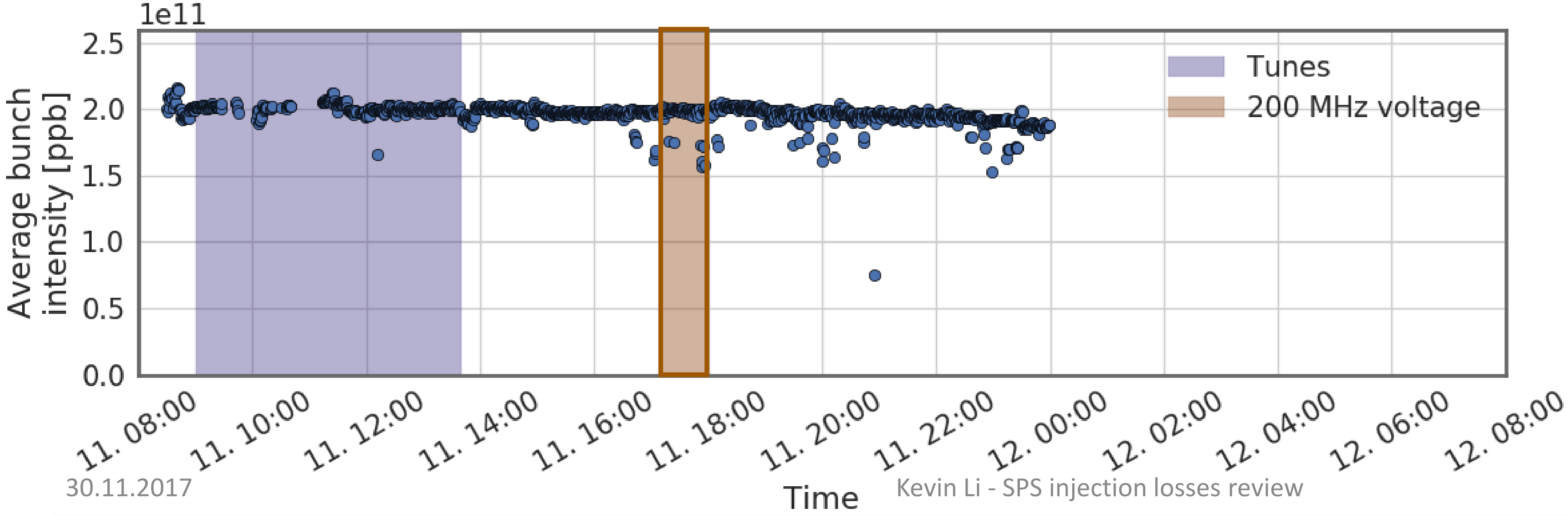


The observed loss pattern correlates well with the footprint traced out by off-momentum particles. Hence, these are a likely contributors to losses (especially, also, when moving the working point).

This footprint will change sensitively with chromaticity. We therefore **expect to see an impact of chromaticity** on the beam lifetime – this should **originate from large off-momentum particles**.

Spotlight – voltage scan and connection to losses





- Investigation of losses as a function of 200 MHz voltage for high intensity beams.
- BCMS beam – 1 x 48 bunches

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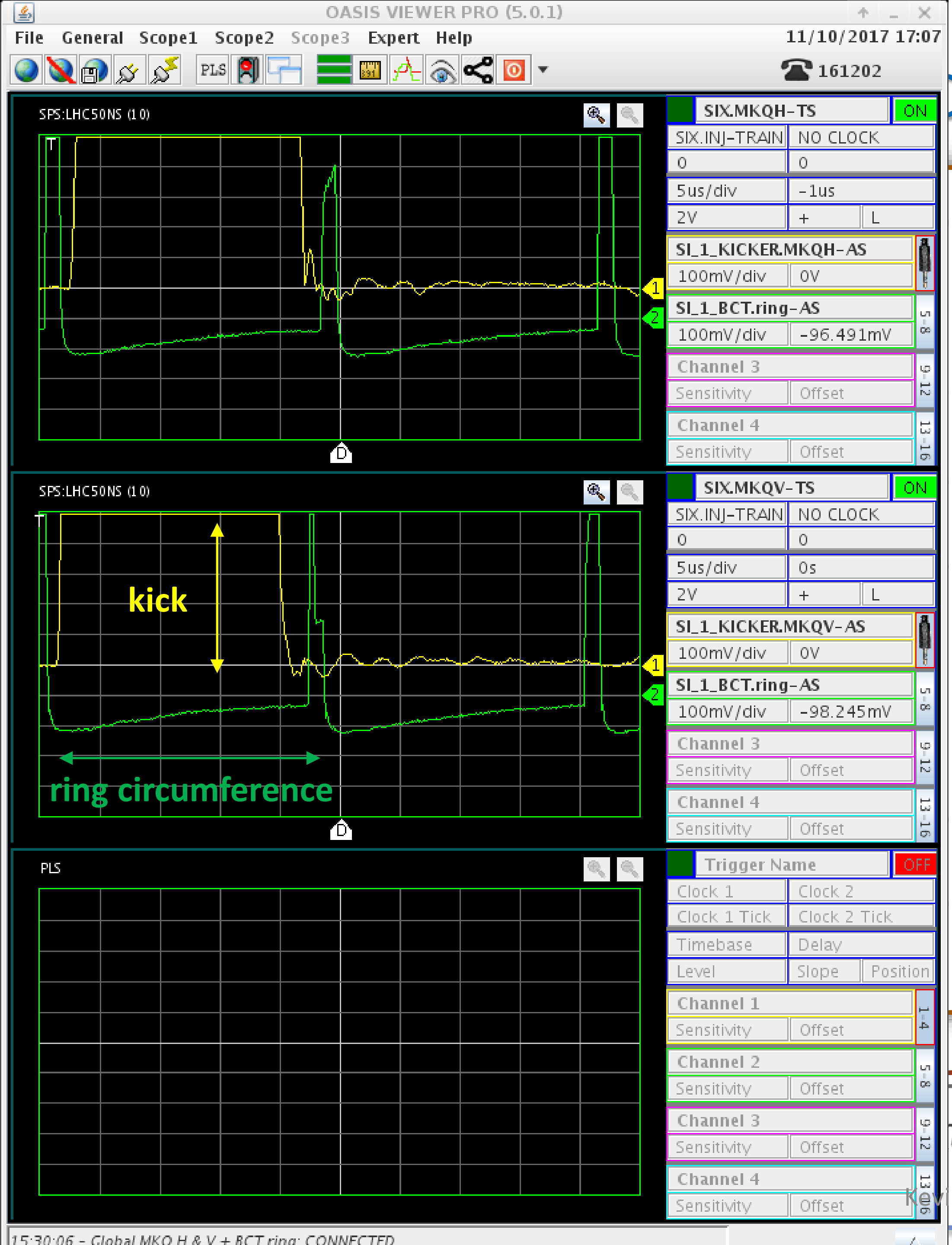

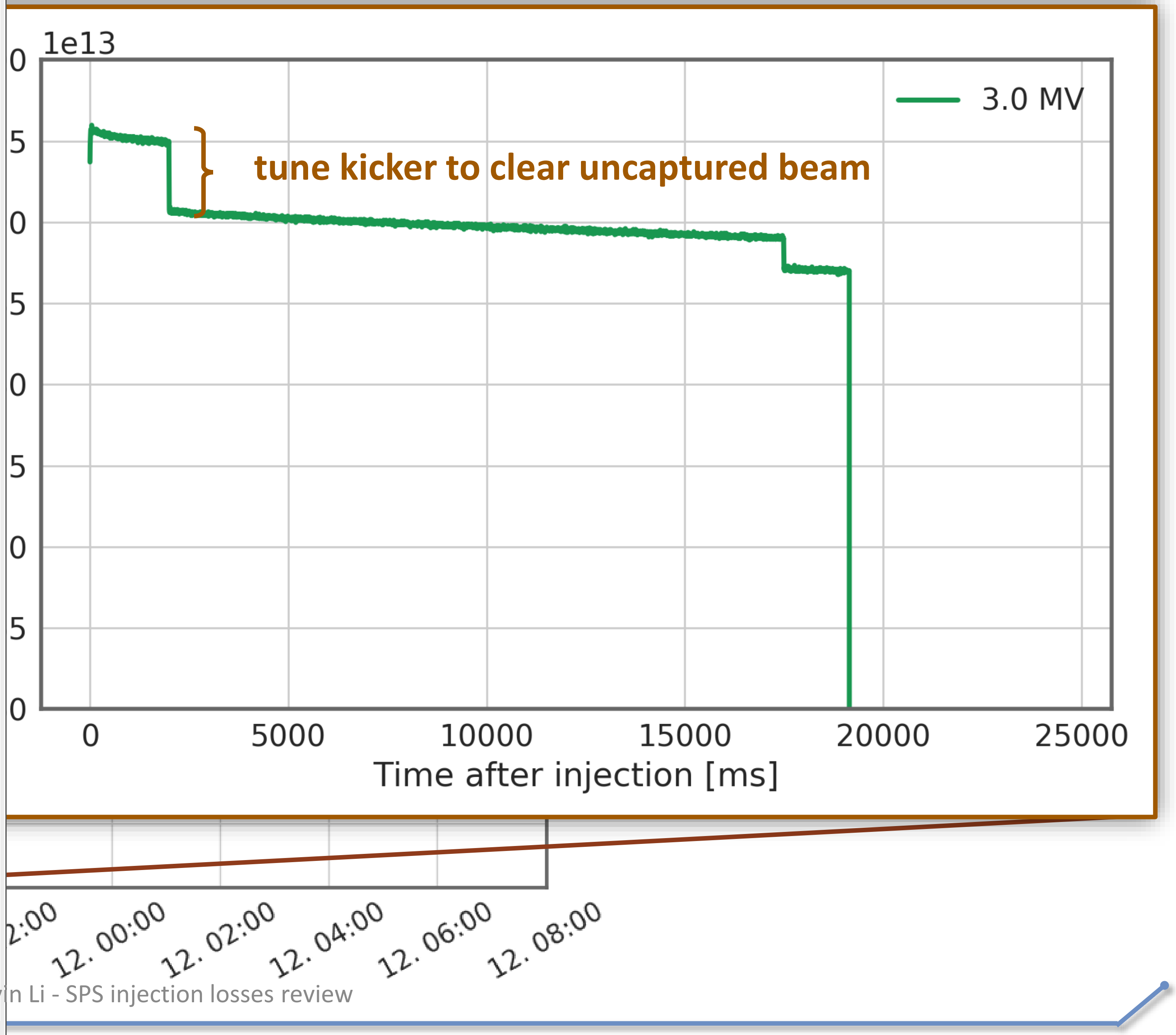

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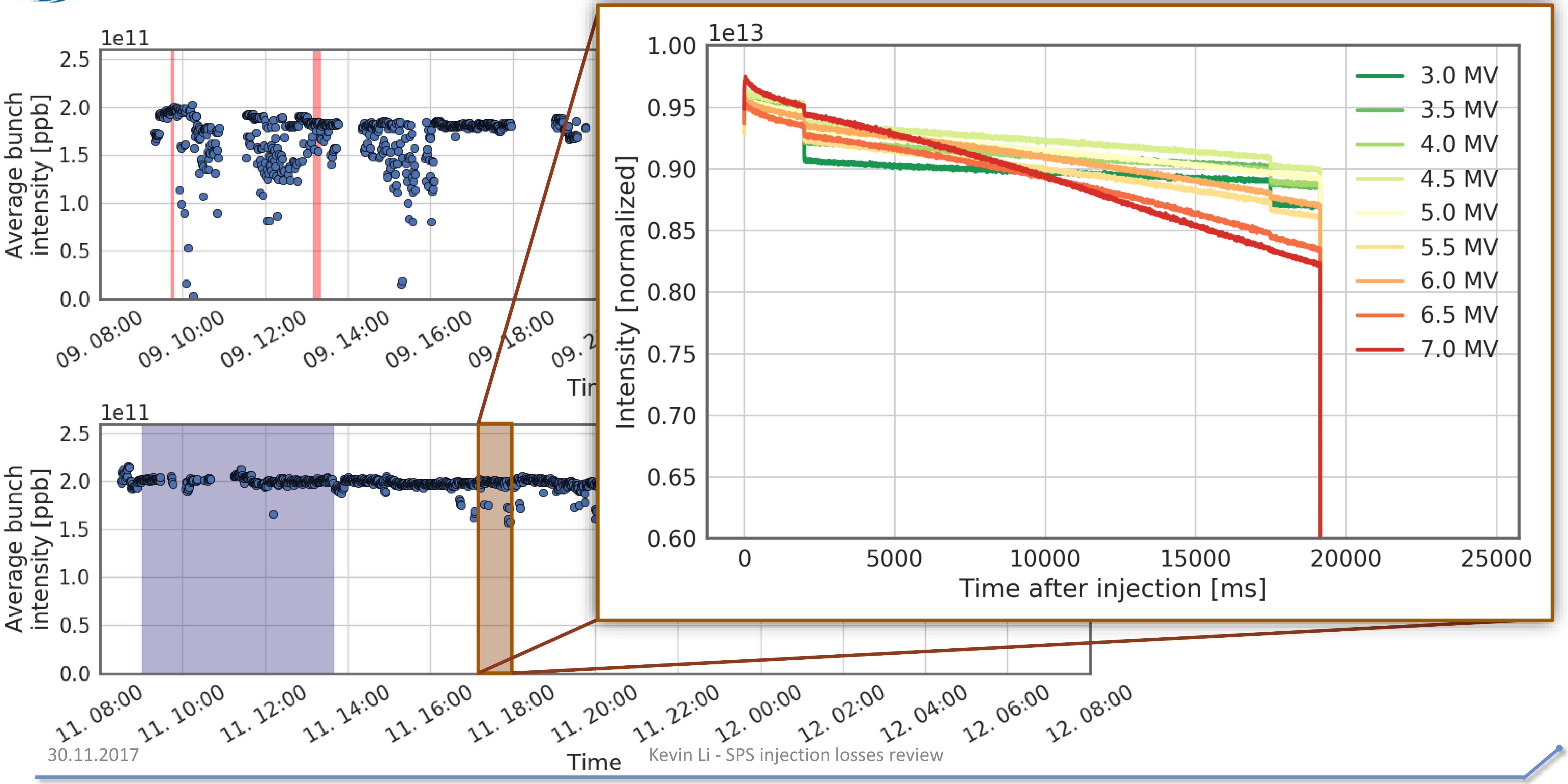
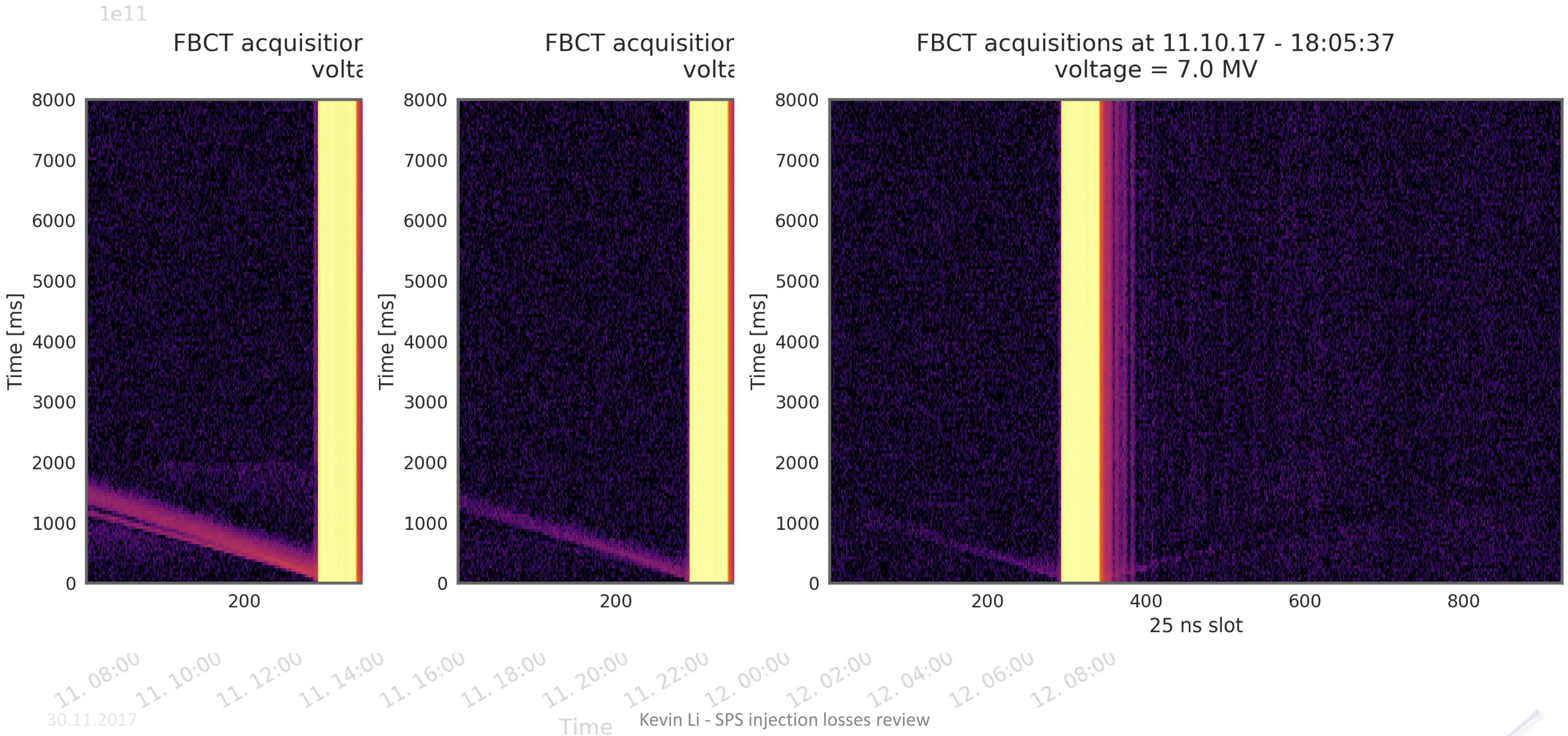


Uncaptured beam seen with the FBCT



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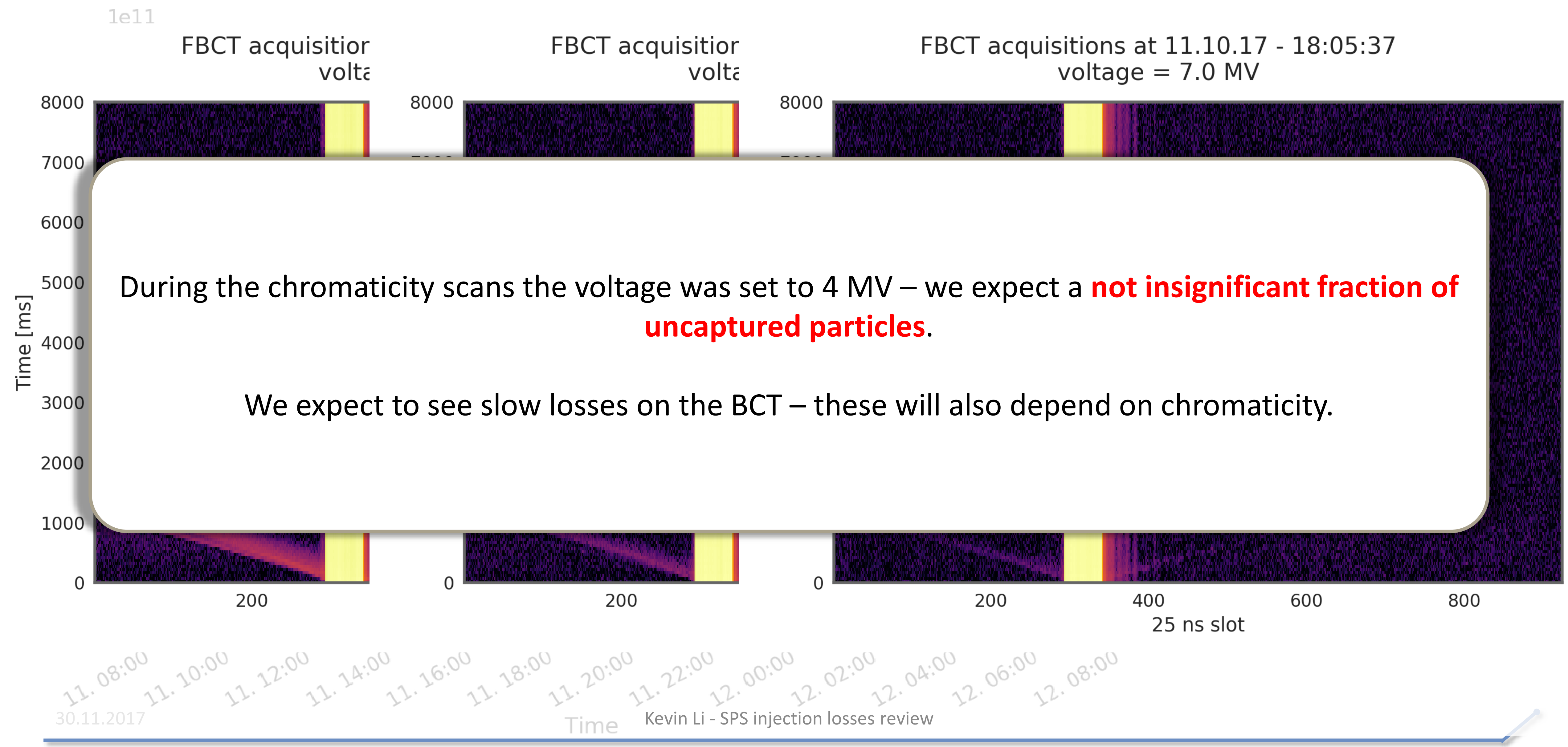
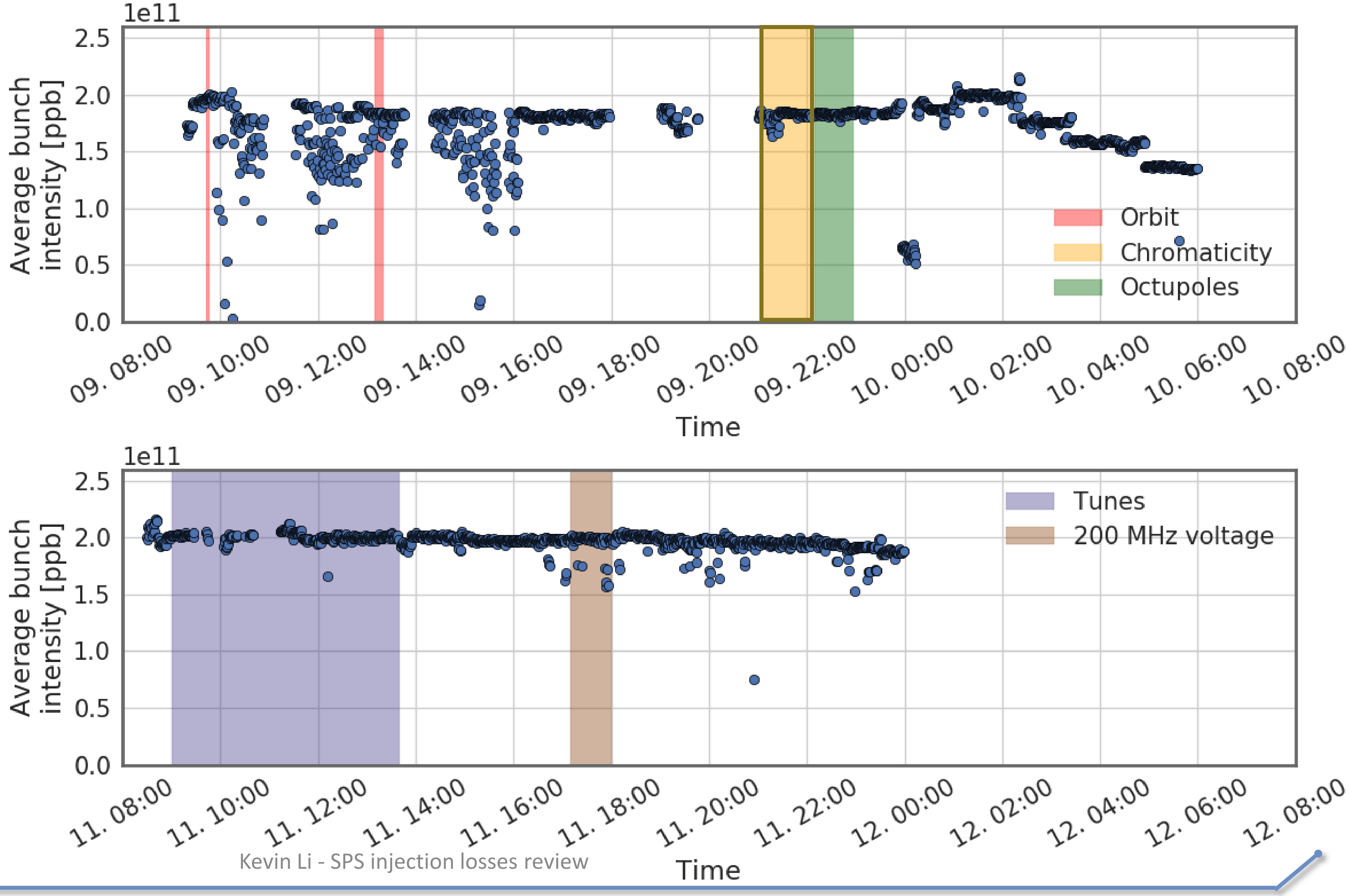


During the chromaticity scans the voltage was set to 4 MV – we expect a **not insignificant fraction of uncaptured particles**.

We expect to see slow losses on the BCT – these will also depend on chromaticity.

Spotlight – coherent effects and incoherent losses

- Investigation beam stability and incoherent losses as a function of chromaticity for high intensity beams.
- BCMS beam – 4 x 48 bunches



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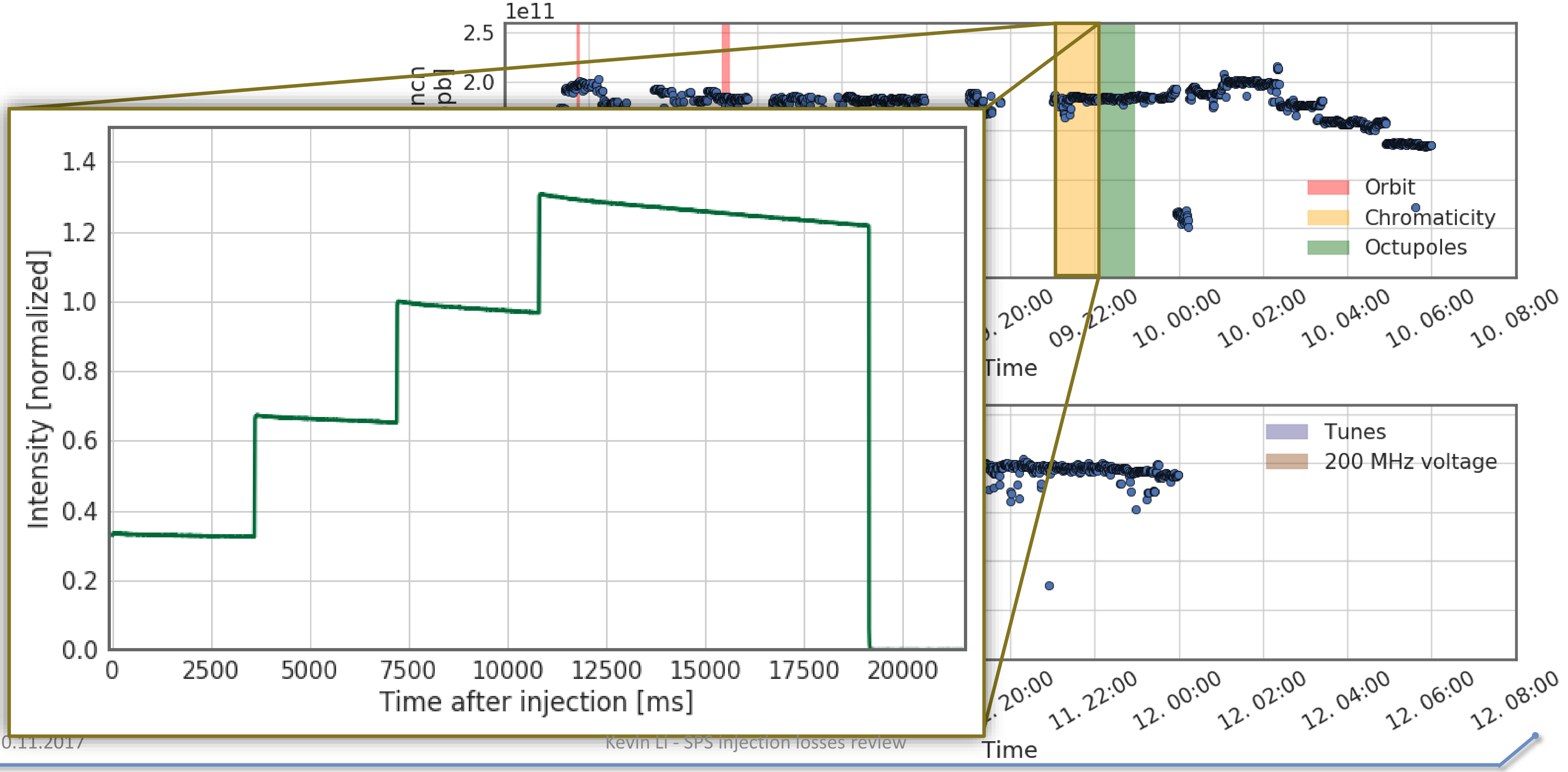

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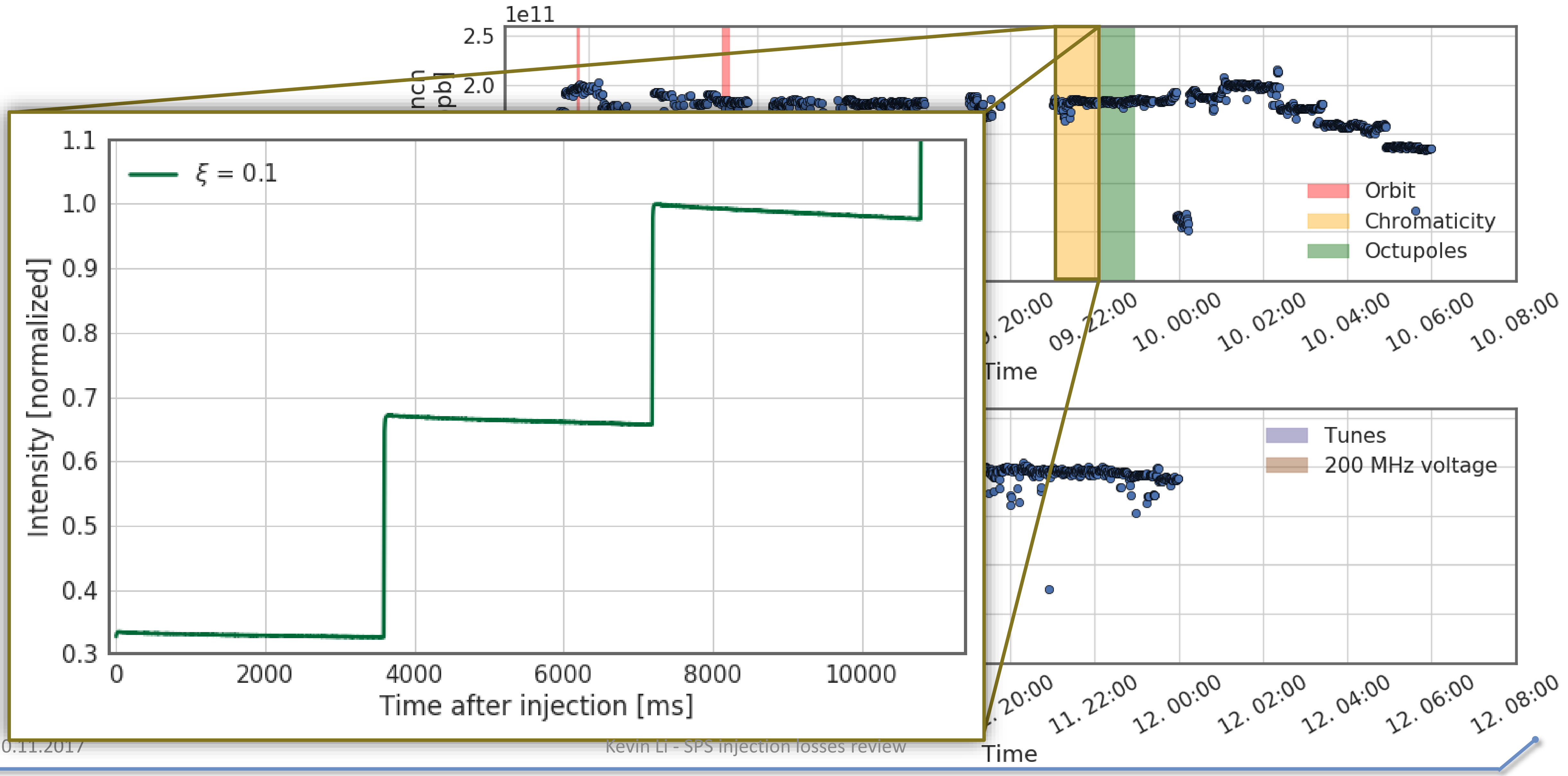

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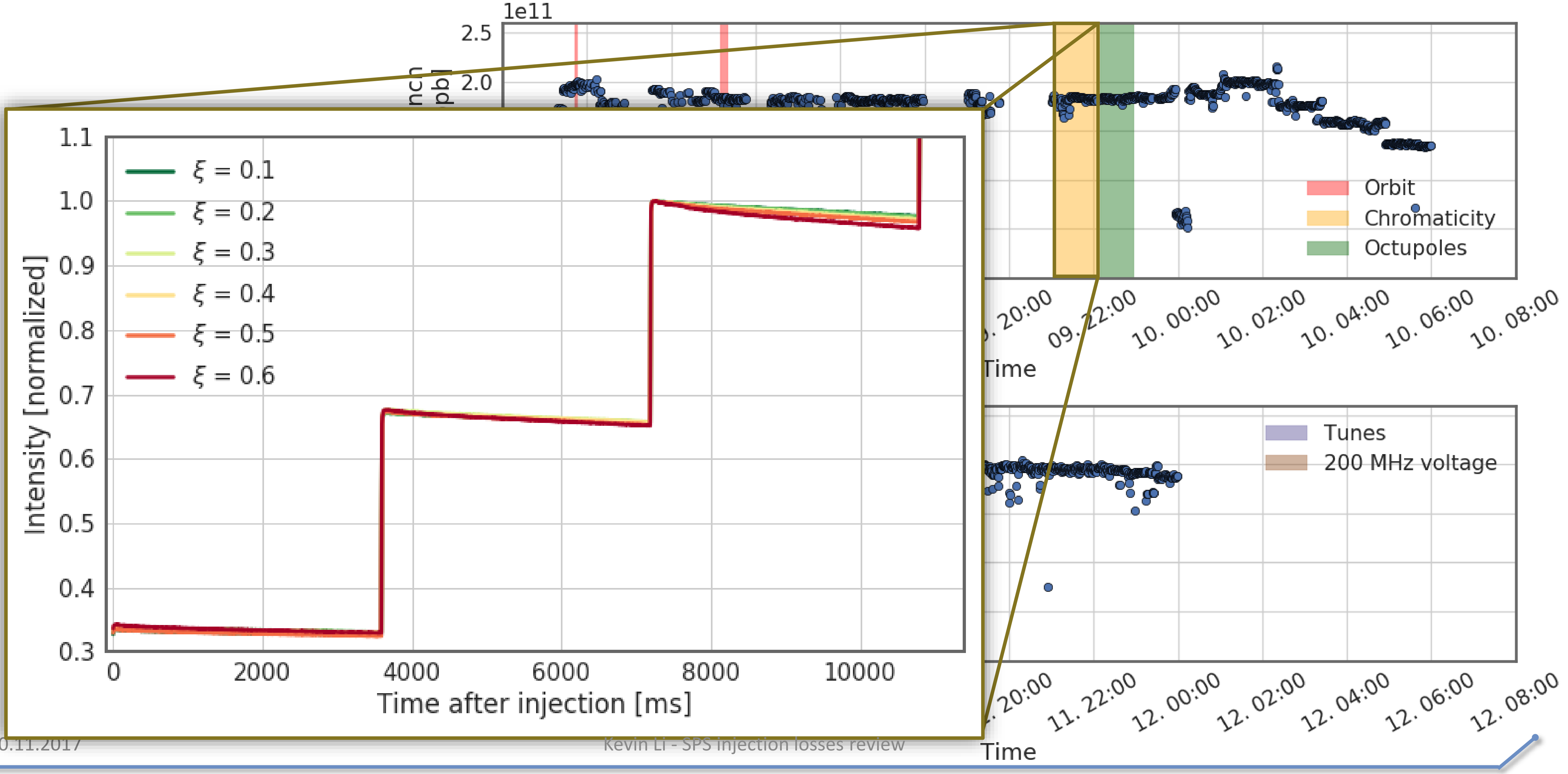
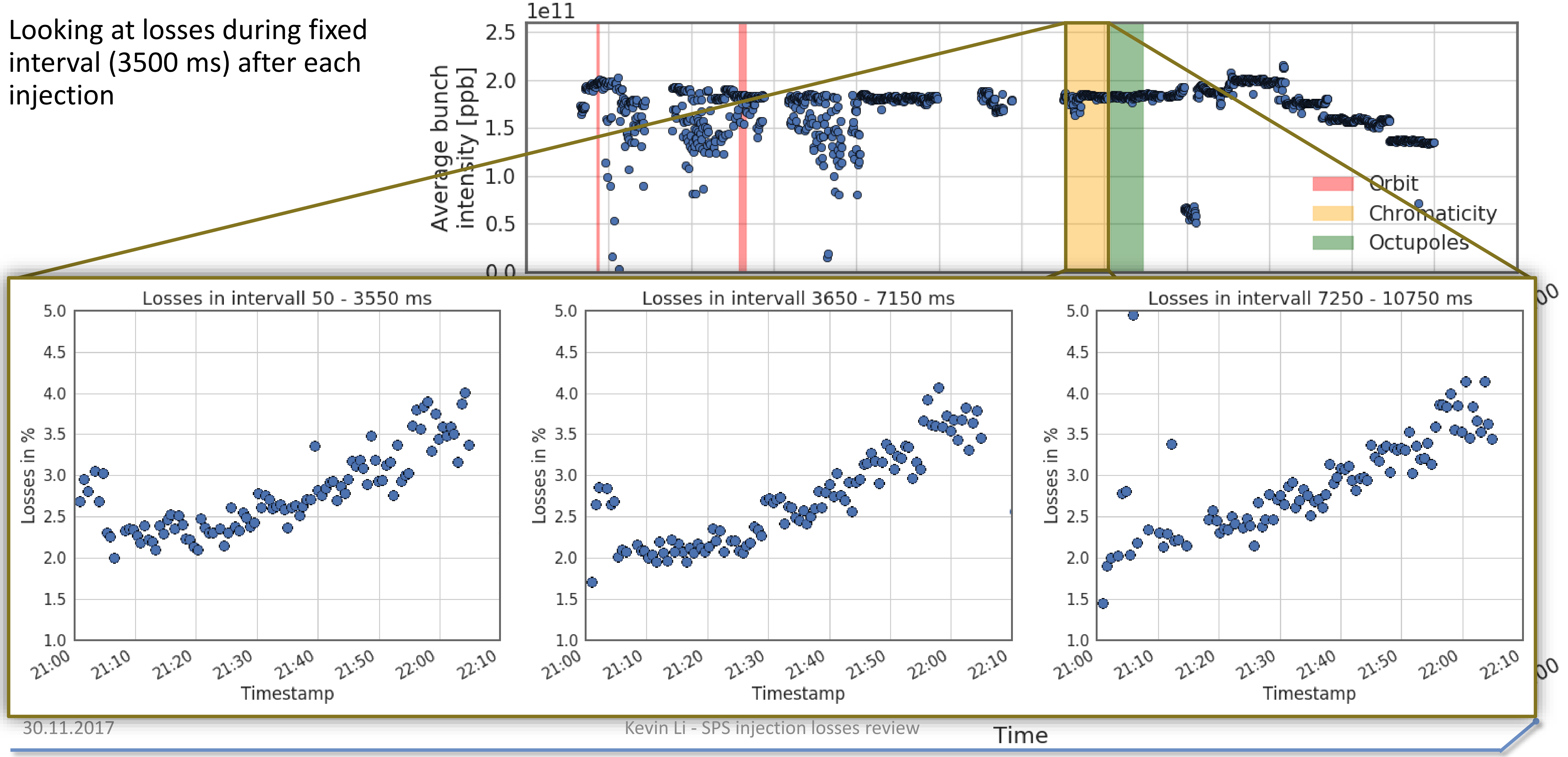


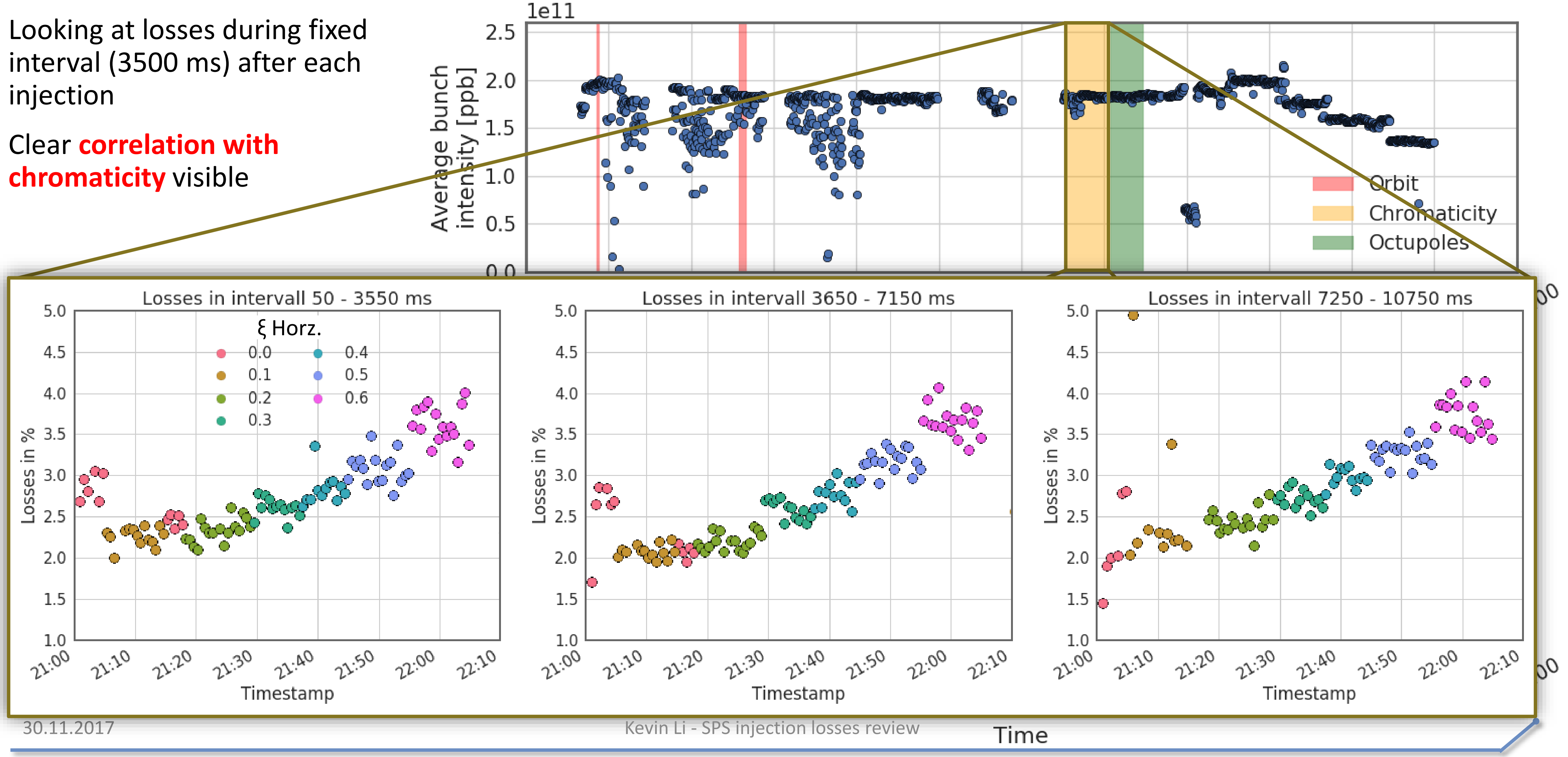
Spotlight – coherent effects and incoherent losses

- Looking at losses during fixed interval (3500 ms) after each injection



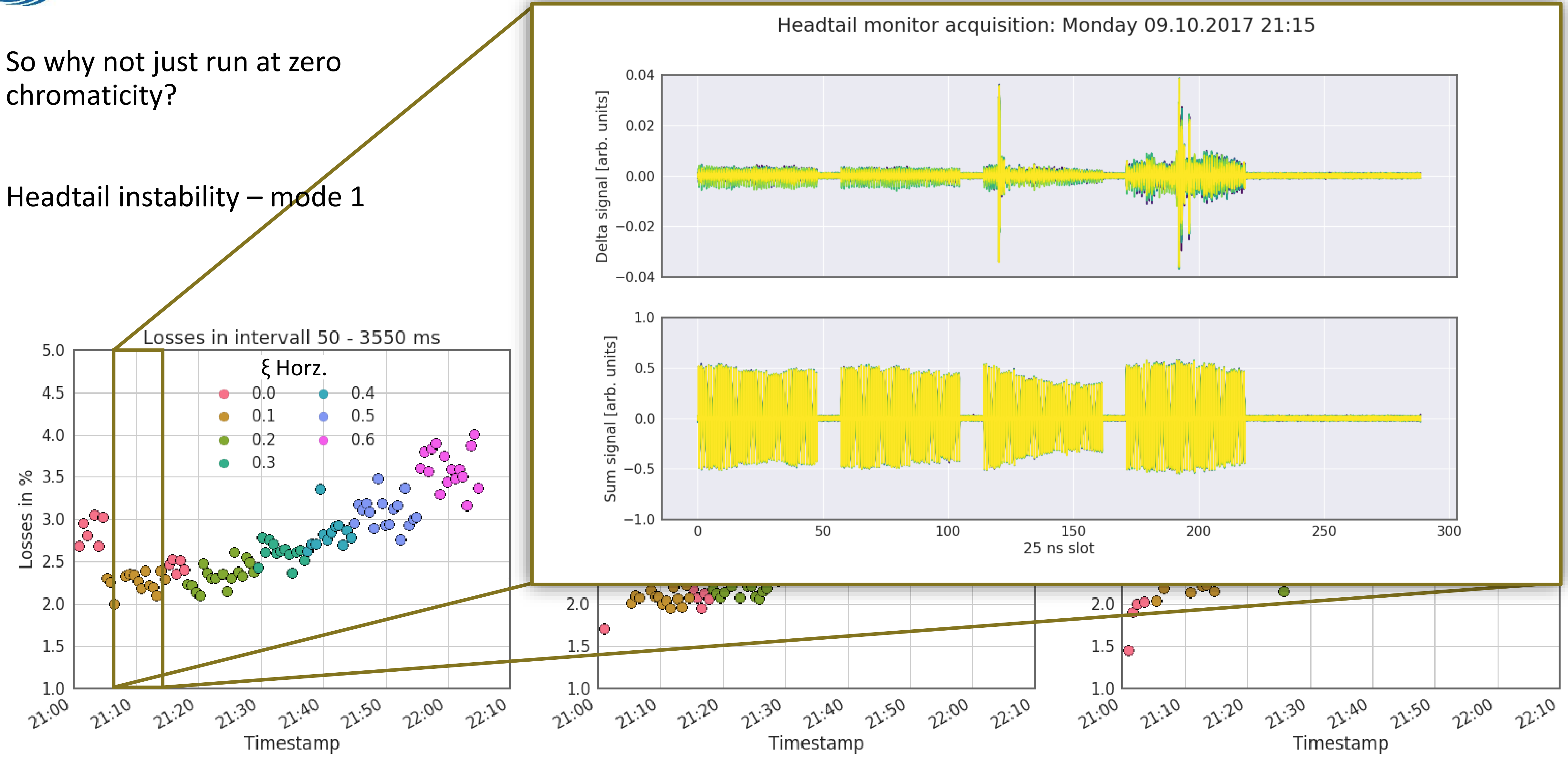
Spotlight – coherent effects and incoherent losses

- Looking at losses during fixed interval (3500 ms) after each injection
- Clear **correlation with chromaticity** visible



Horizontal instabilities and cure

- So why not just run at zero chromaticity?
- Headtail instability – mode 1



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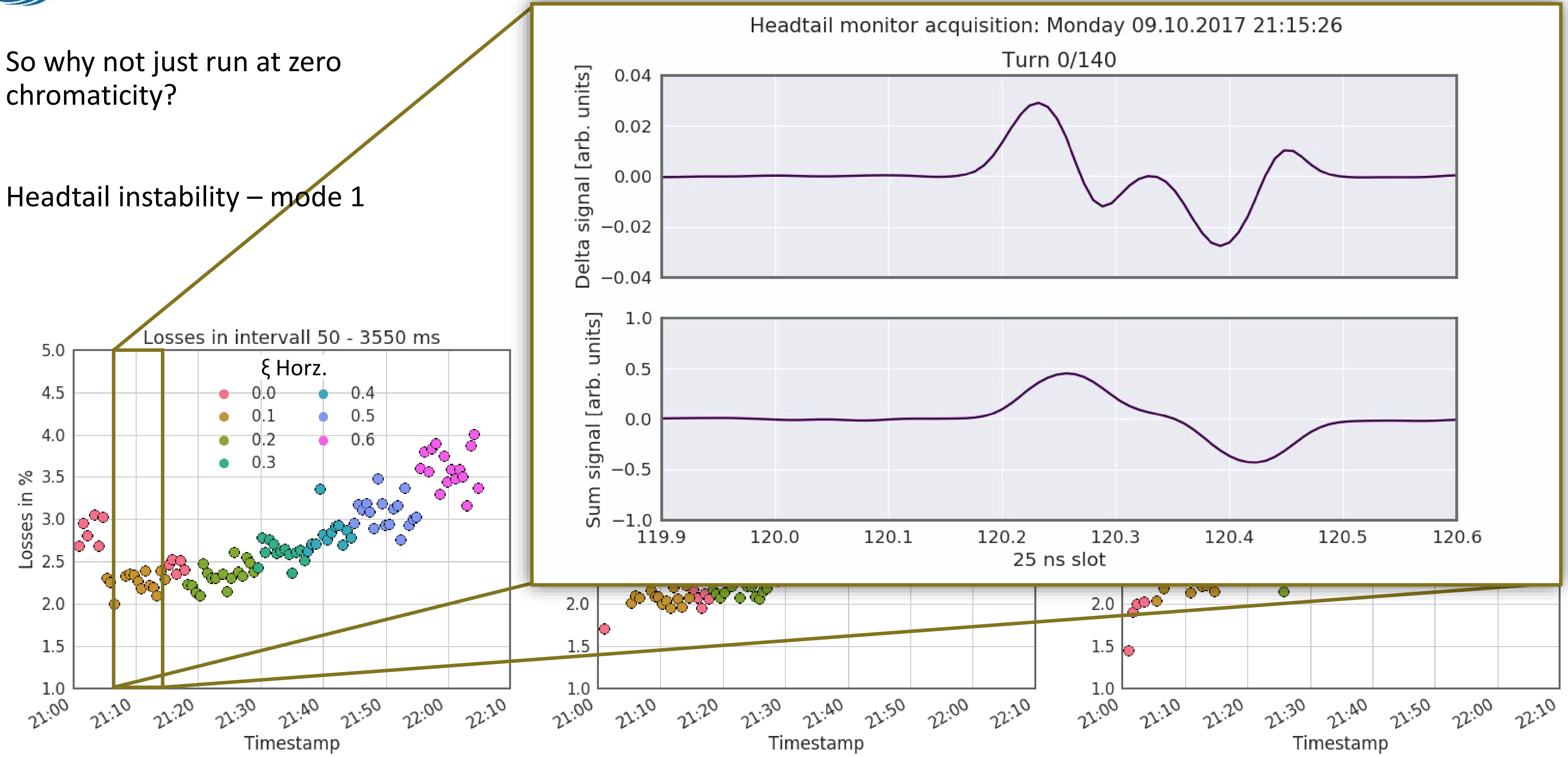
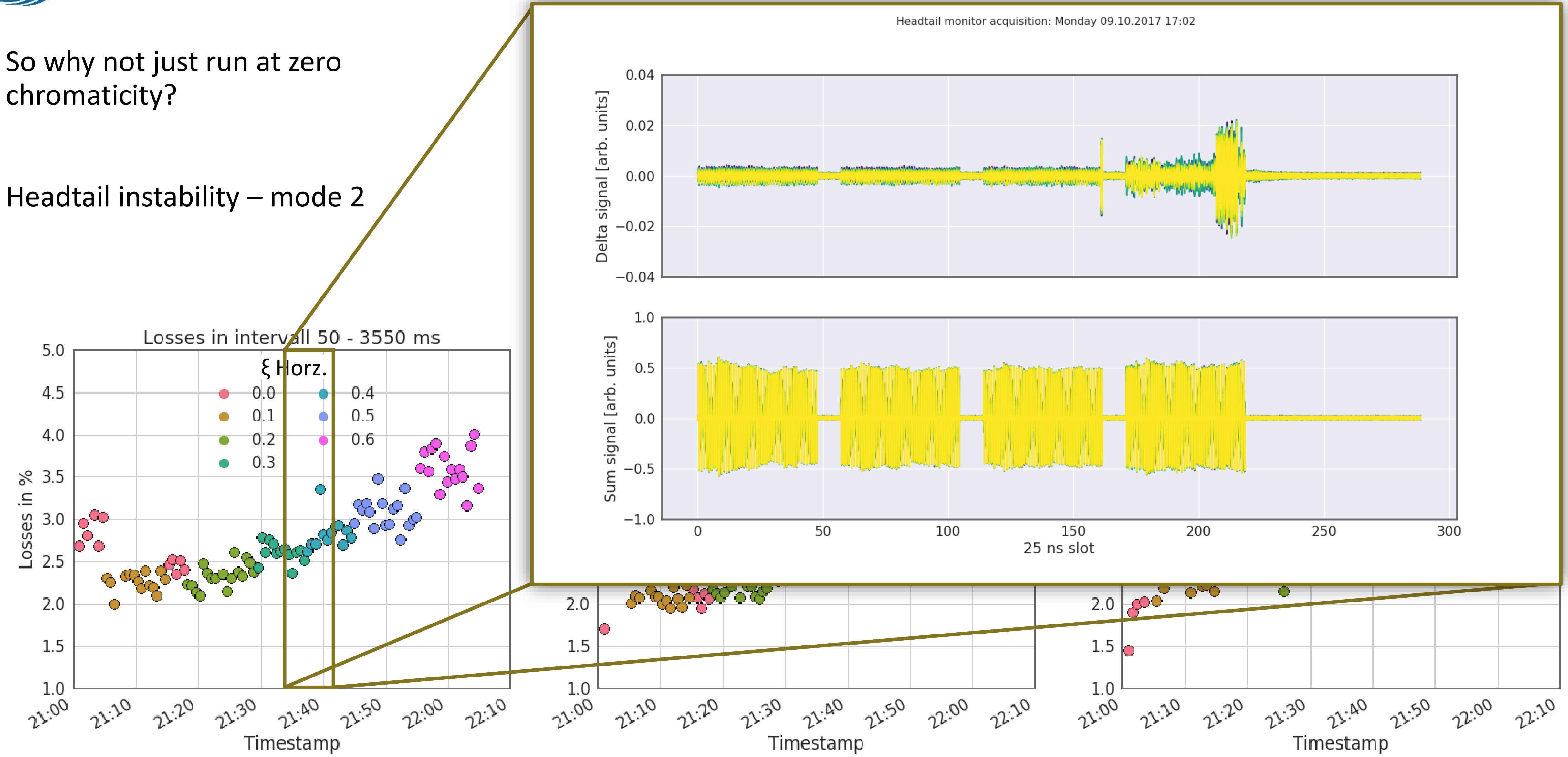


Horizontal instabilities and cure

- So why not just run at zero chromaticity?
- Headtail instability – mode 2



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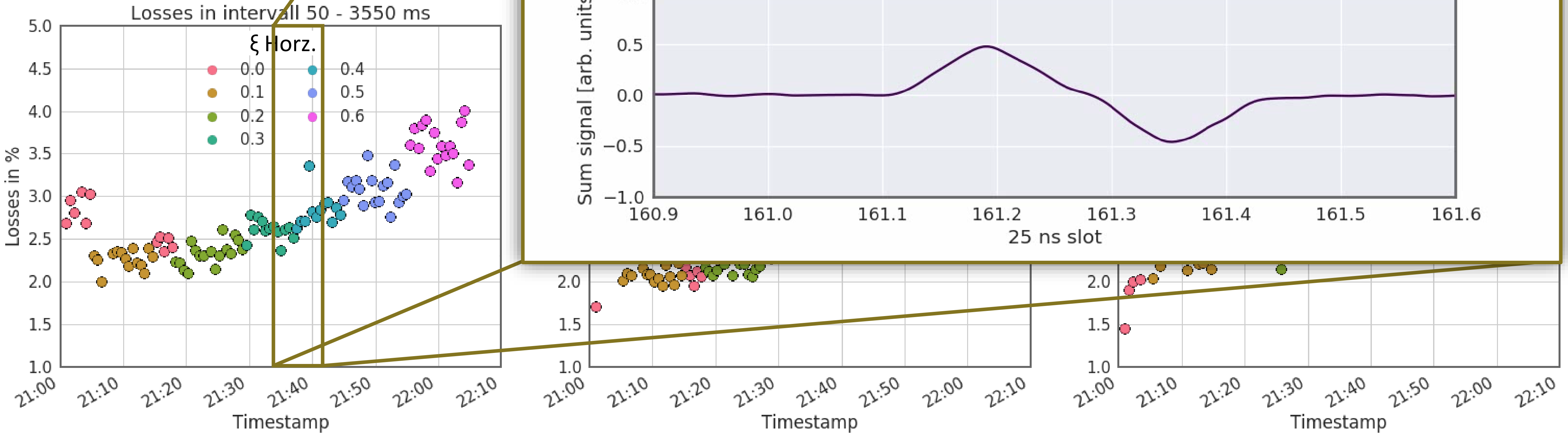
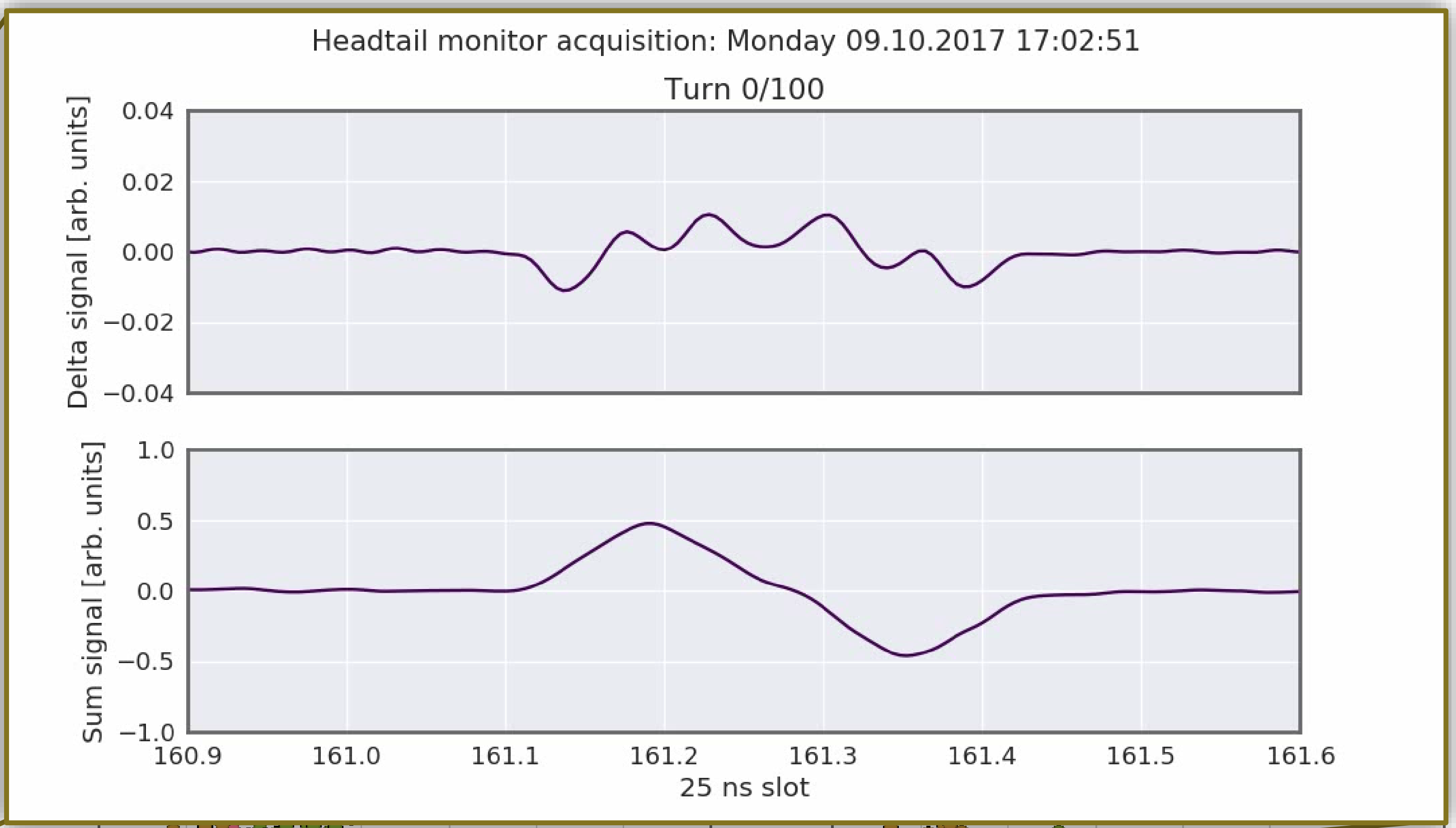
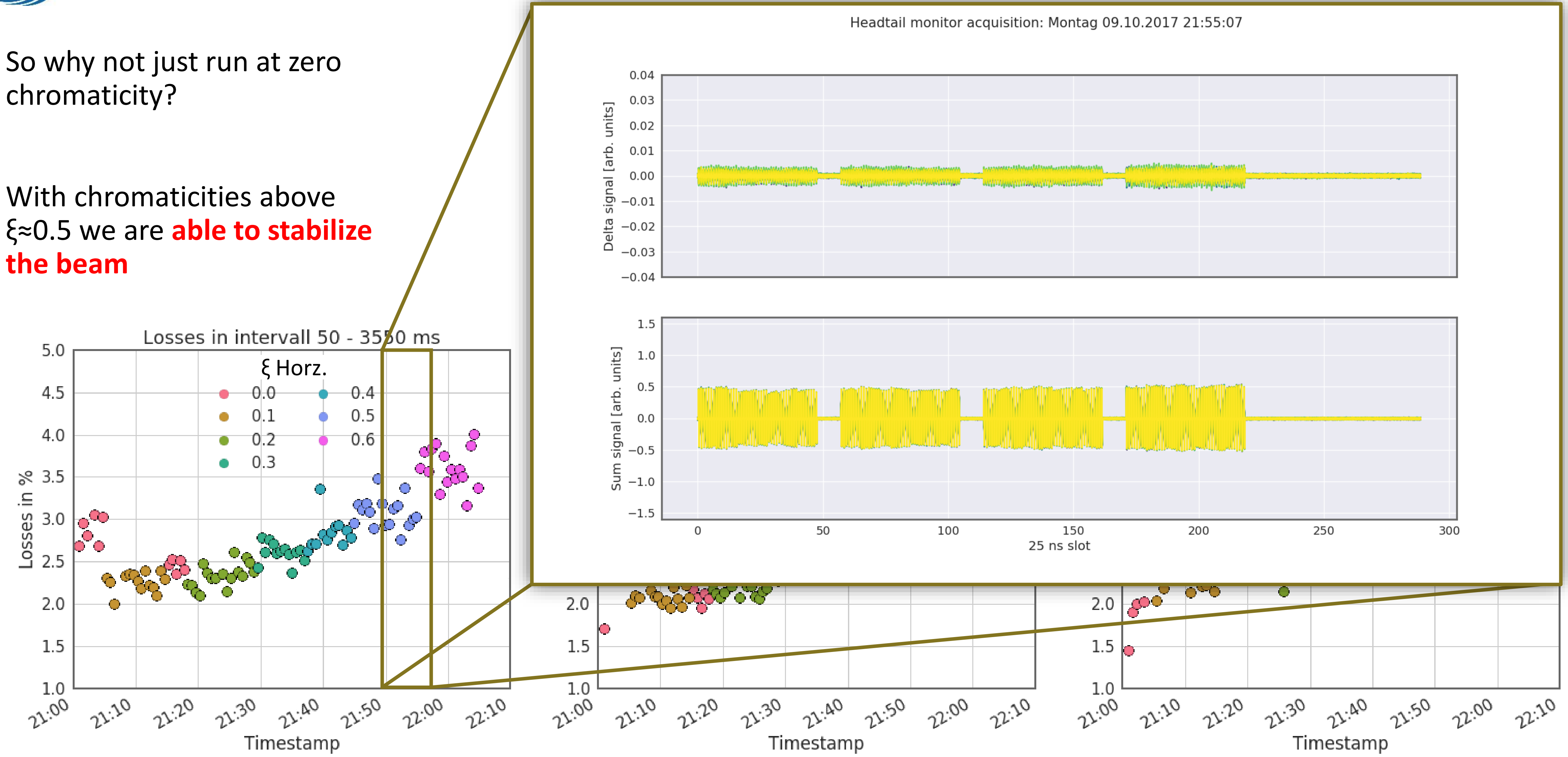




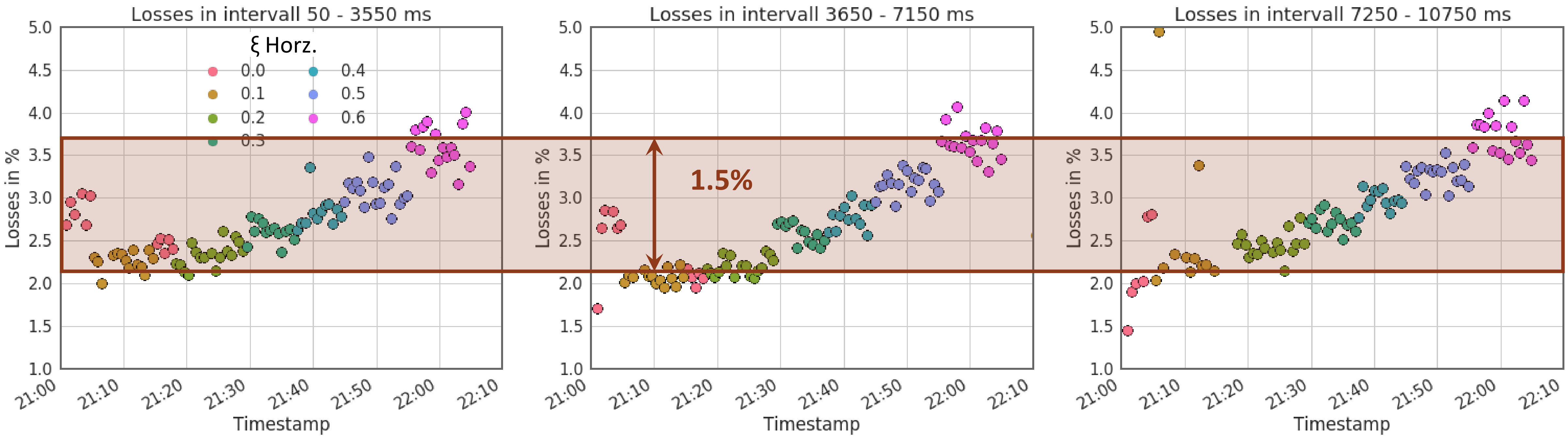
Horizontal instabilities and cure

- So why not just run at zero chromaticity?
- With chromaticities above ξ≈0.5 we are **able to stabilize the beam**



Impact of chromaticity on flat bottom losses

- Being able to run at low chromaticities, it **appears that losses can be reduced by about 40%** (1.5% absolute).
- Is this gain persistent?



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We expect to see slow losses on the BCT – these will also depend on chromaticity.

Uncaptured particles are less likely to get lost at low chromaticities – they will get lost, however, at the start of the ramp. **This may fake potential gains that can be achieved when moving towards low chromaticities.**

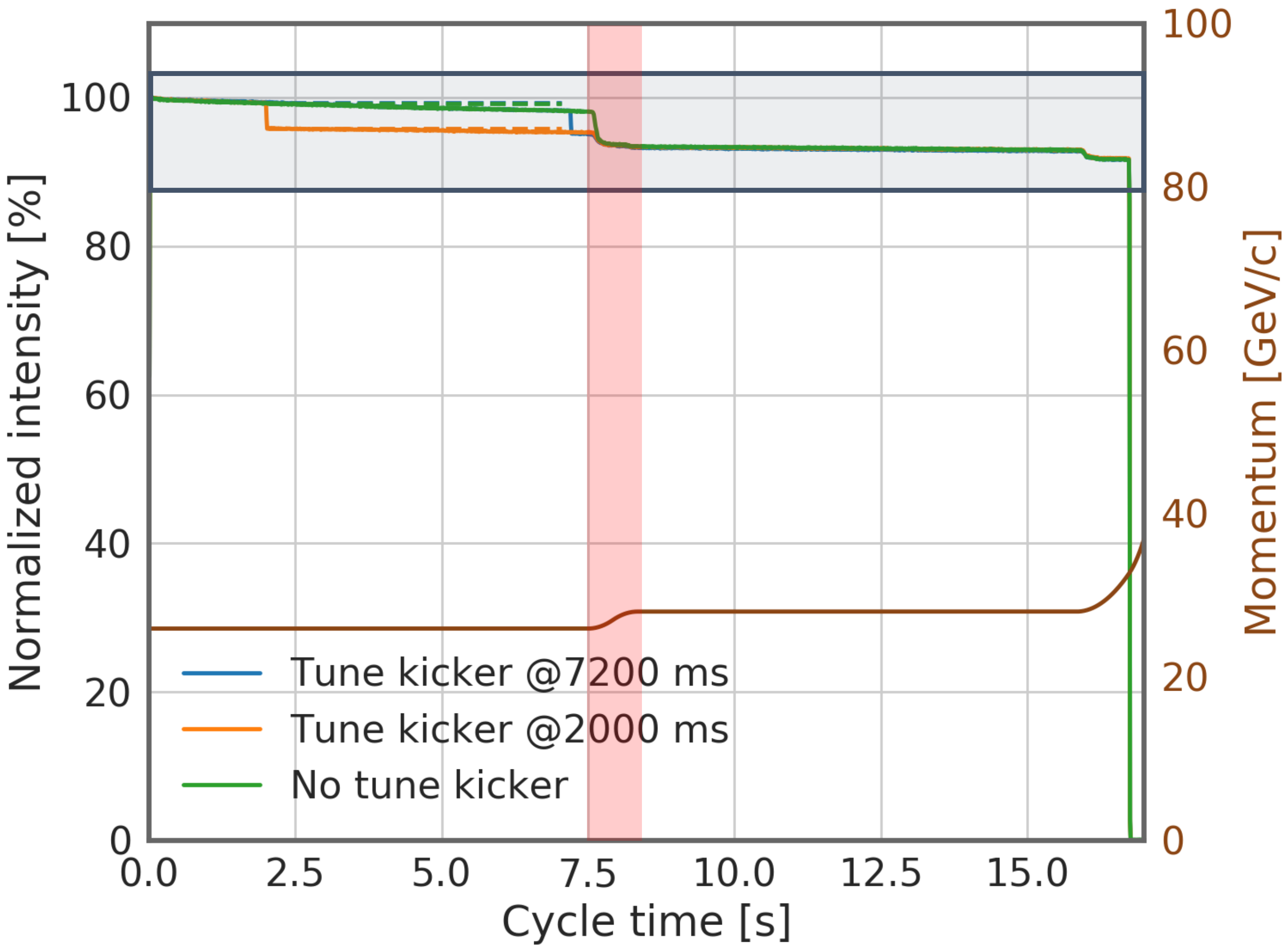
Losses in %

Timestamp Timestamp Timestamp

Measurements done in July 2016

- Experiment with a special cycle consisting of a small ramp from 26 GeV to 28 GeV to **simulate the start of ramp**.

- Tune kicker programmed at 2000 ms and at 7200 ms to clean uncaptured beam



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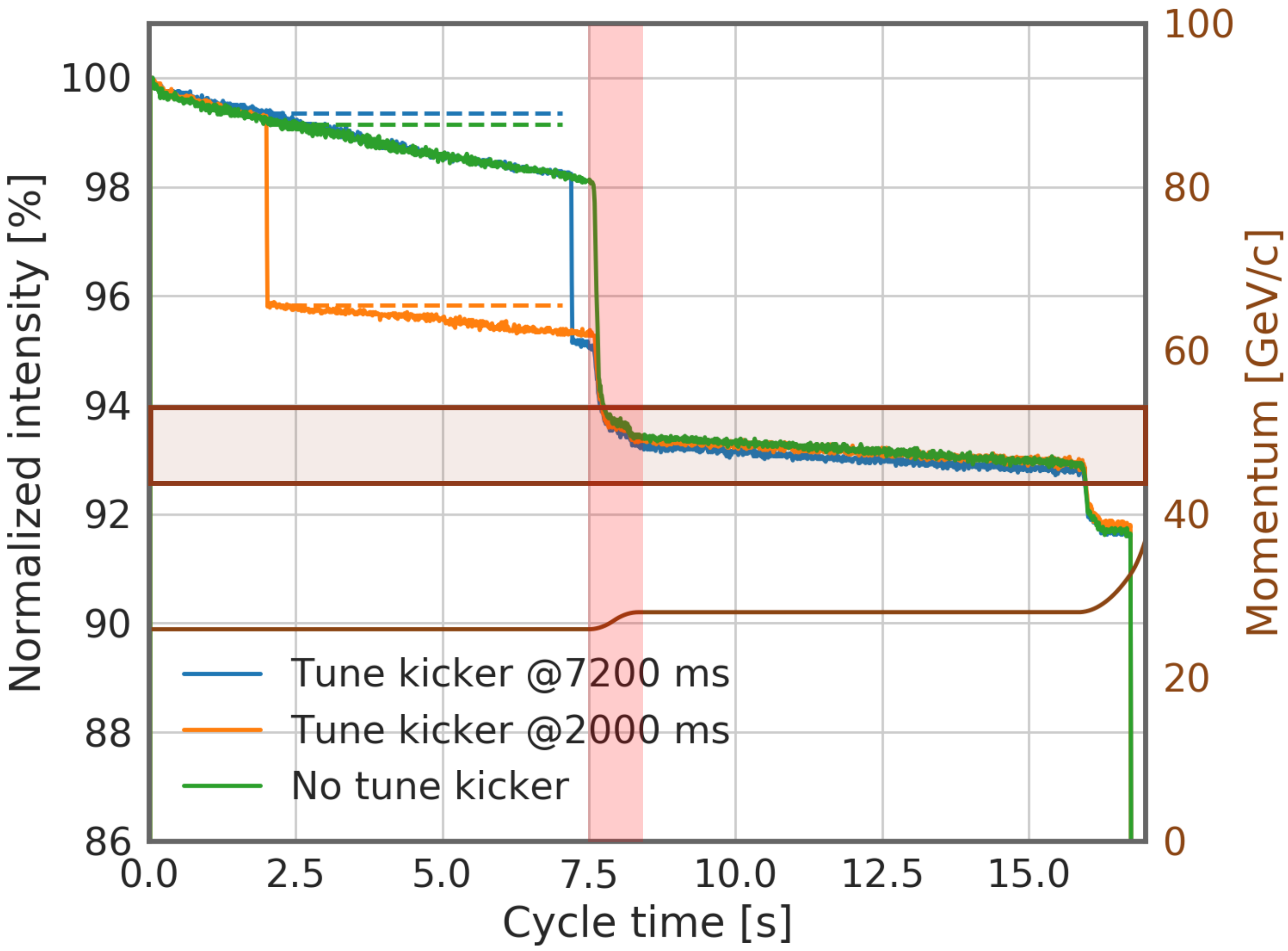
- After the start of the ramp, **all intensities ultimately reach the same value**

Particles removed or lost during the flat bottom are mainly large (longitudinal) amplitude particles which **are lost anyway at the beginning of the ramp** (non-adiabatic).



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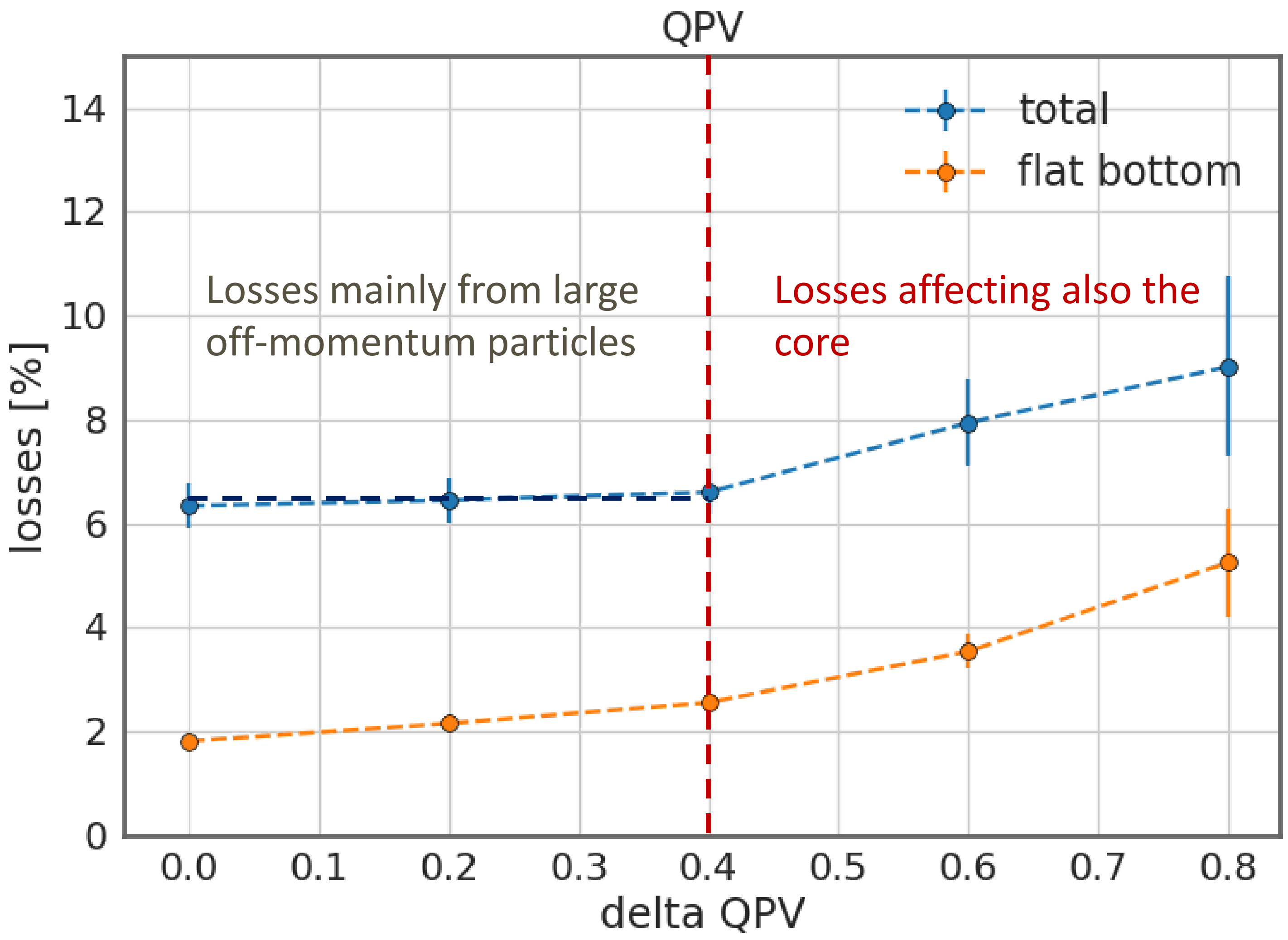
Limiting these losses during flat bottom might **not actually give a net improvement** after start of the ramp – as particle will be lost there in any case.



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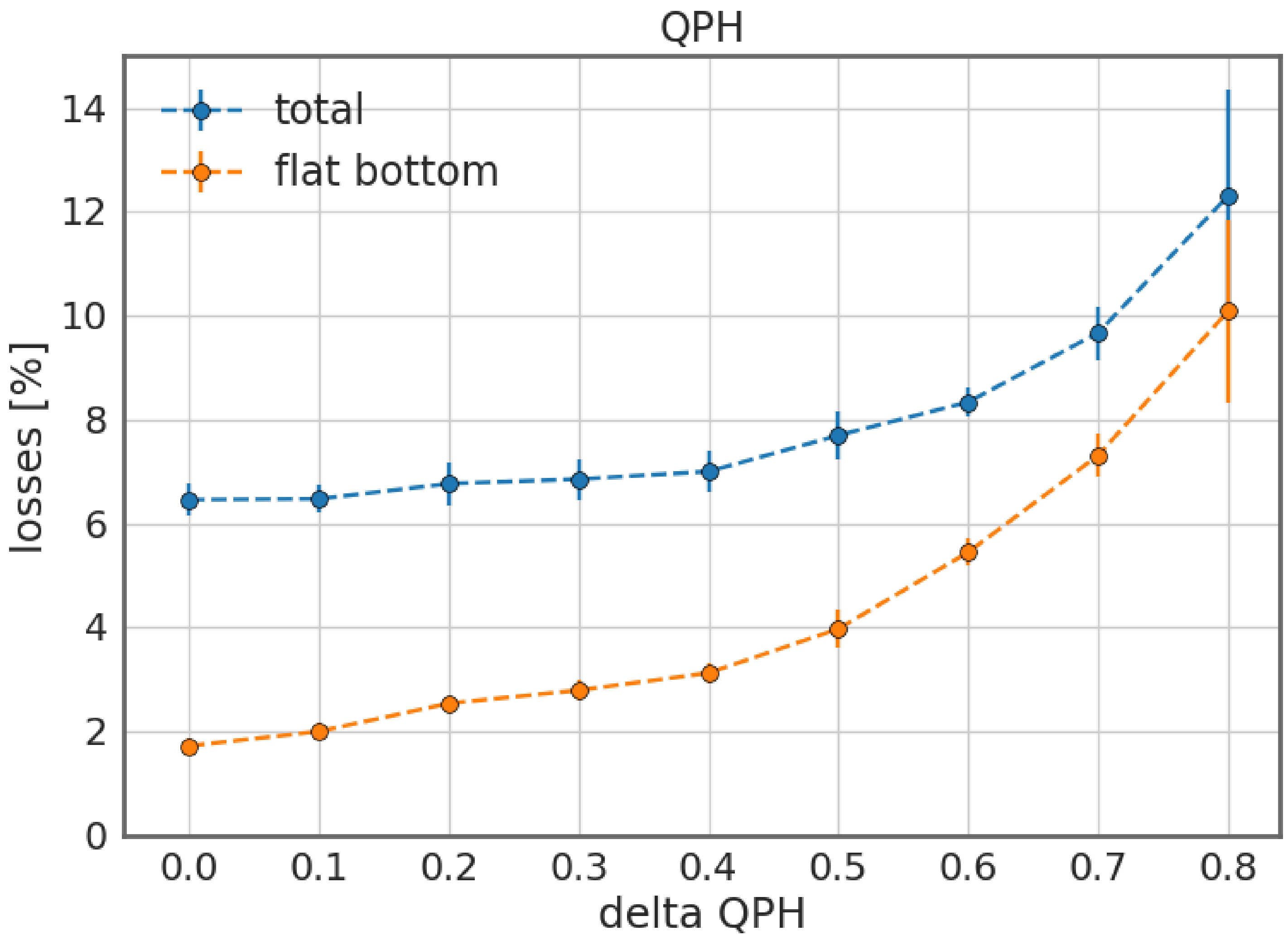

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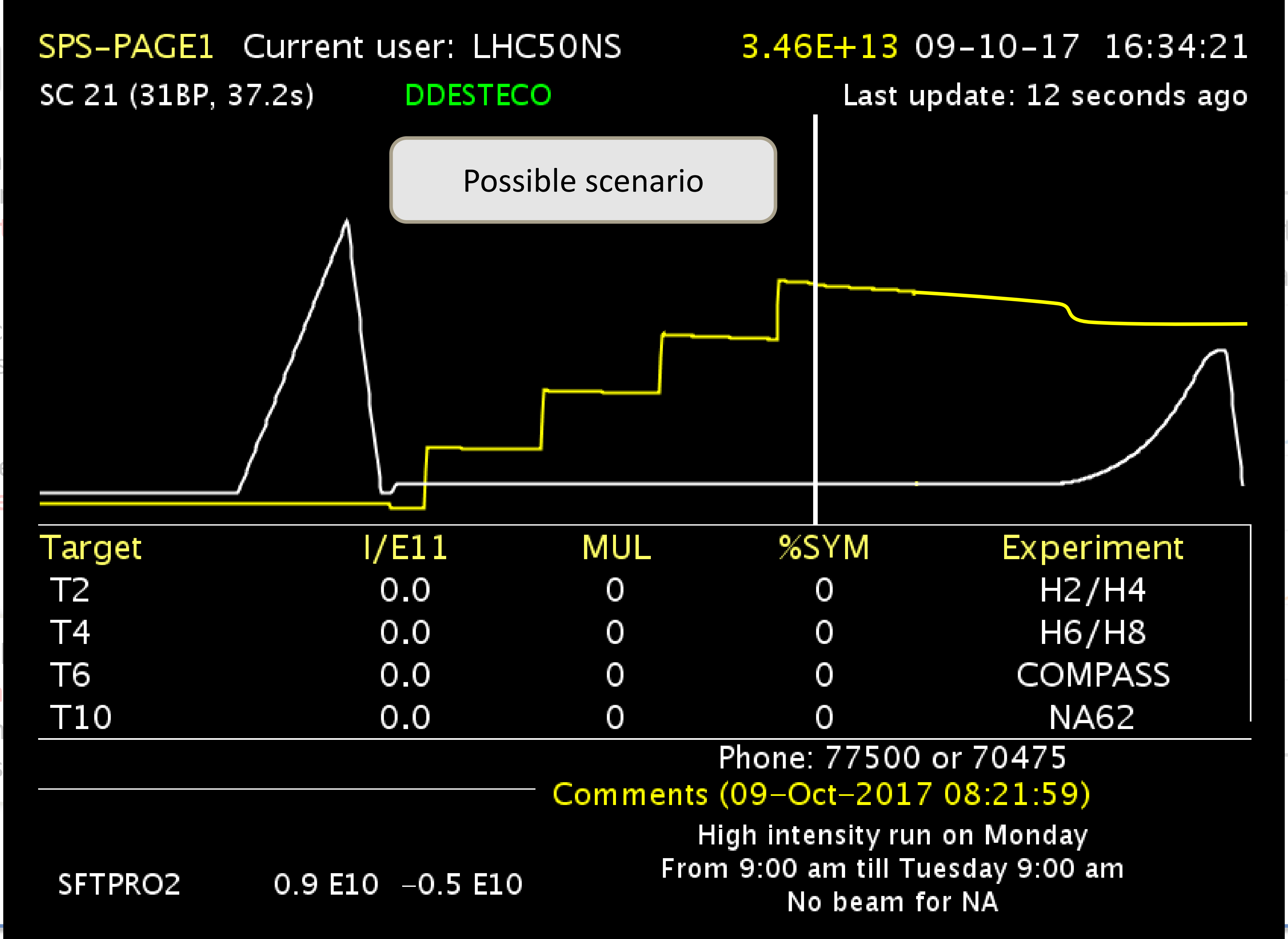

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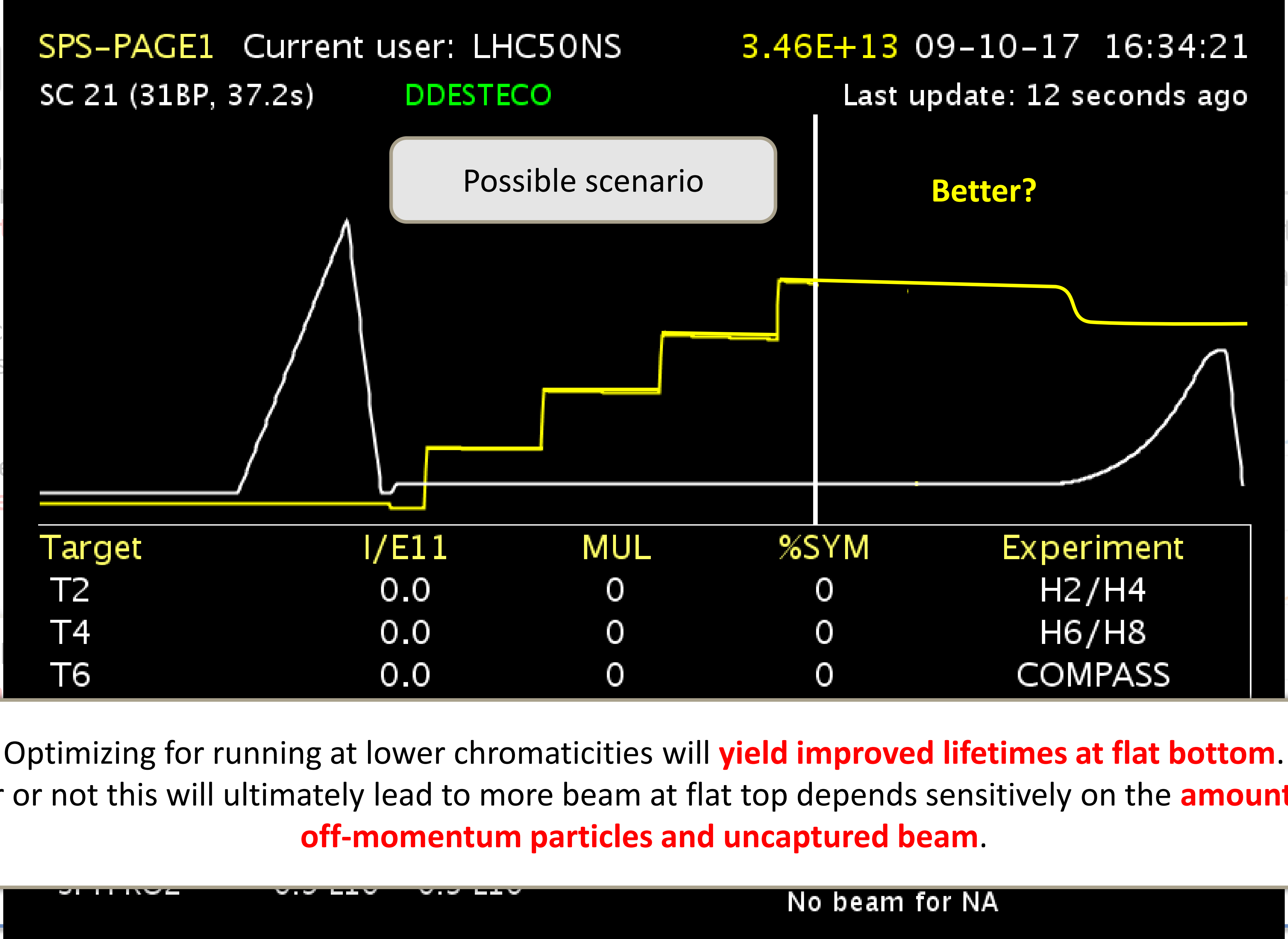
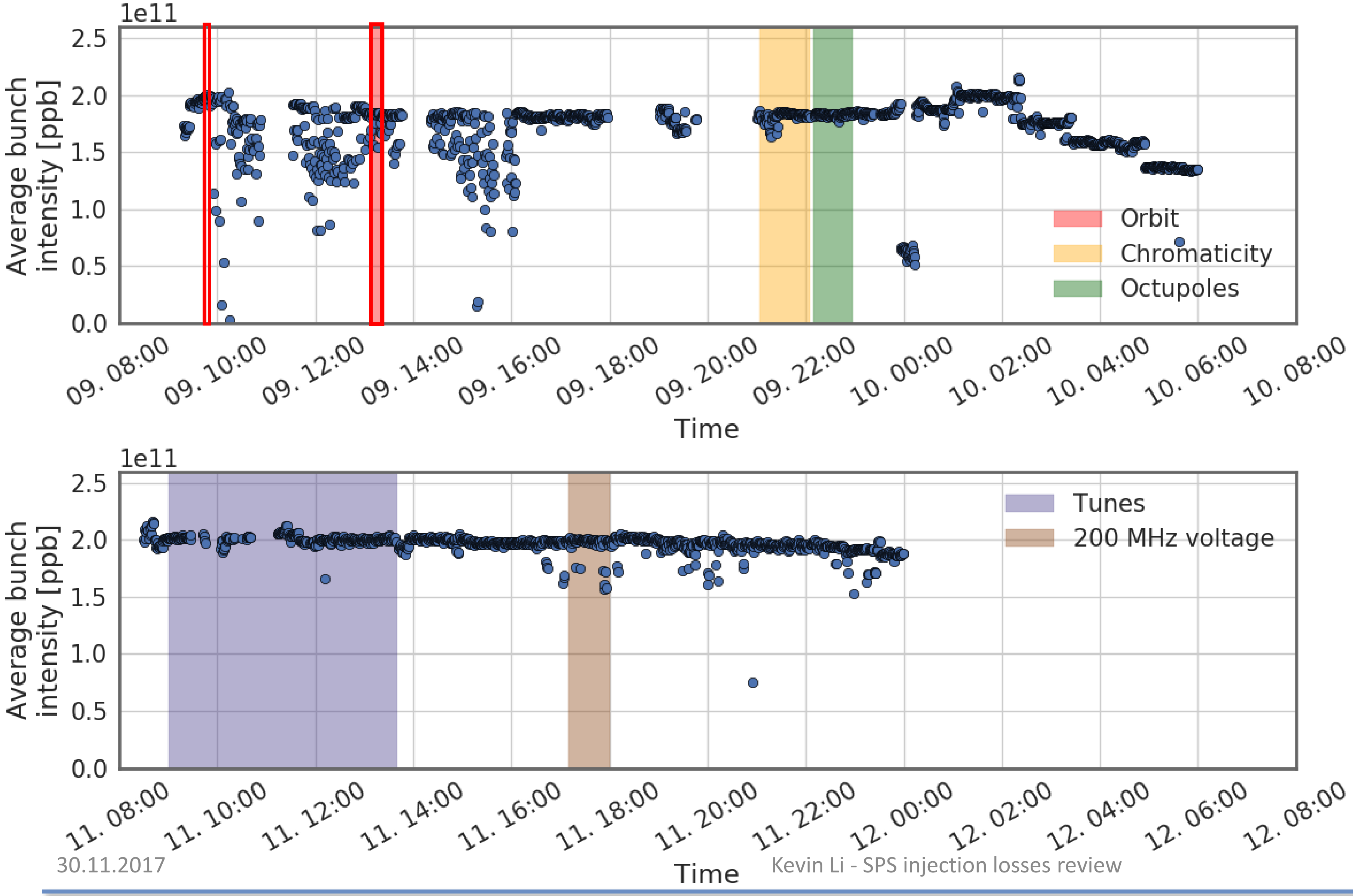


Optimizing for running at lower chromaticities will **yield improved lifetimes at flat bottom**.
Whether or not this will ultimately lead to more beam at flat top depends sensitively on the **amount of large off-momentum particles and uncaptured beam**.

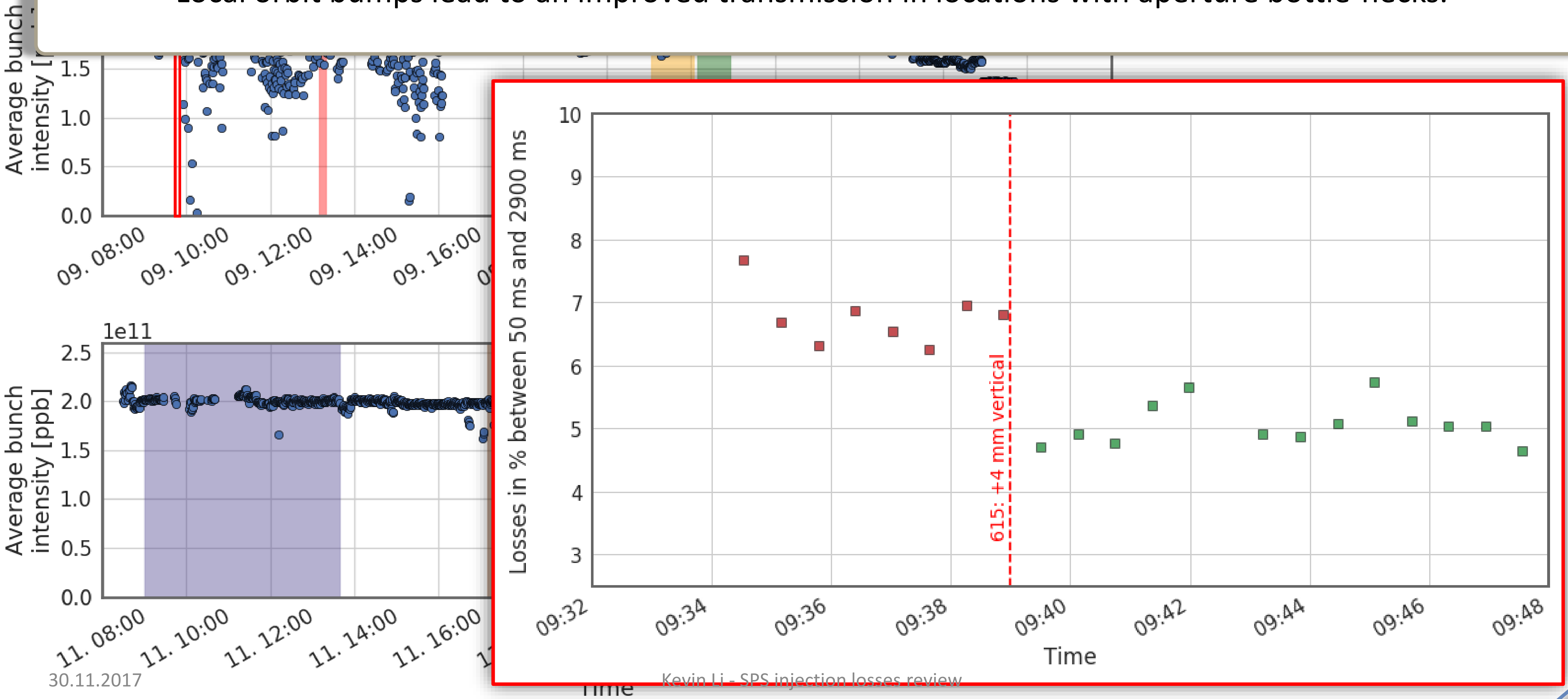
Spotlight – orbit optimization



- Orbit optimization by implementation of local bumps for high intensity beams.
- Standard 25 ns beam – 1 x 72 bunches

Spotlight – orbit optimization

Local orbit bumps lead to an improved transmission in locations with aperture bottle-necks.



Conclusions

- The operational working point is already close to an optimum.
- Off-momentum particles or uncaptured beam are prone to incoherent losses at flat-bottom.
- For high intensity (>1.8e11 p/b) the chromaticity needs to be high around 0.5 in the horizontal plane to avoid instabilities.
- Running at lower chromaticities will reduce flat-bottom losses but the ultimate gain will depend sensitively on the amount and distribution of off-momentum particles and uncaptured beam.
- Slightly improved transmission after orbit bumps in locations with aperture bottle-necks.

LHC Injectors Upgrade

- Transfer overview – losses overview; with studies, trims inside
- Orbit → aperture limitations, momentum acceptance etc. with reference to Verena’s talk
- WP → tune spread, bunch-by-bunch tune shifts with SC and Michele’s plots
- Chromaticity → impact on beam stability – lifetime plots, trims, also with octupoles; show second order chromaticity effects from octupoles, warn about large off-momentum particles and uncaptured beam, show examples from voltage scan with FBCT and potential no-gains from chroma improvement. Studies scanning chroma with kicking the uncaptured beam and ramping will help.
- Conclude with gains per effect, optimization/mitigation methods and lmitations/warnings.

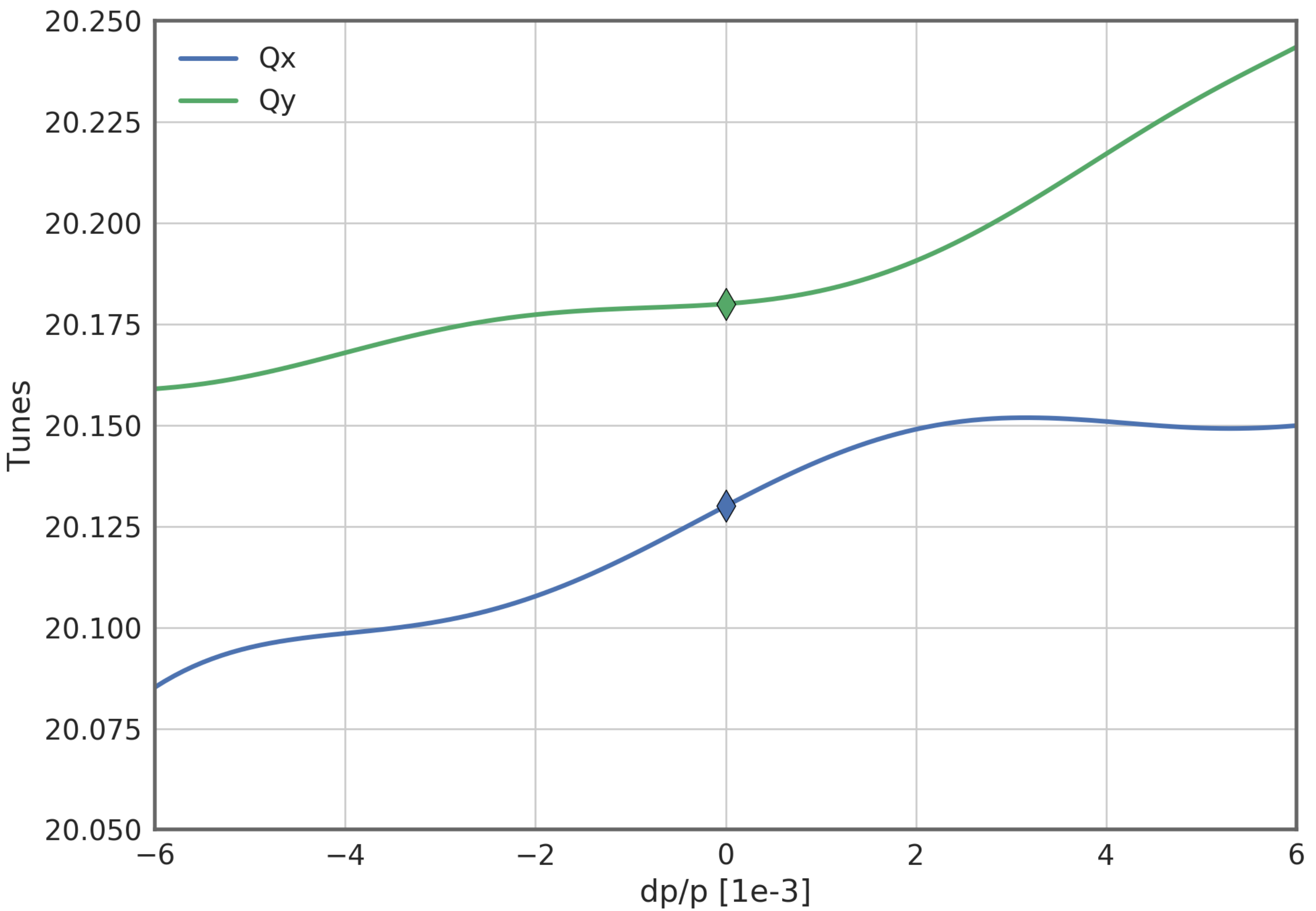
Chromaticity and non-linear model

- Chromaticity will lead to a detuning of individual off-momentum particles
- Due to the multipole errors in dipoles, the chromatic detuning is non-linear
- Measurement of the non-linear chromaticity allow to deduce the **tune footprint of these off-momentum/uncaptured particles (without other incoherent tune shift)**

In a qualitative view we **focus on large off-momentum/uncaptured** particles

We neglect incoherent tune shifts from quadrupolar wakes and space charge

This will be a **recurring view** and we will see later why this makes sense



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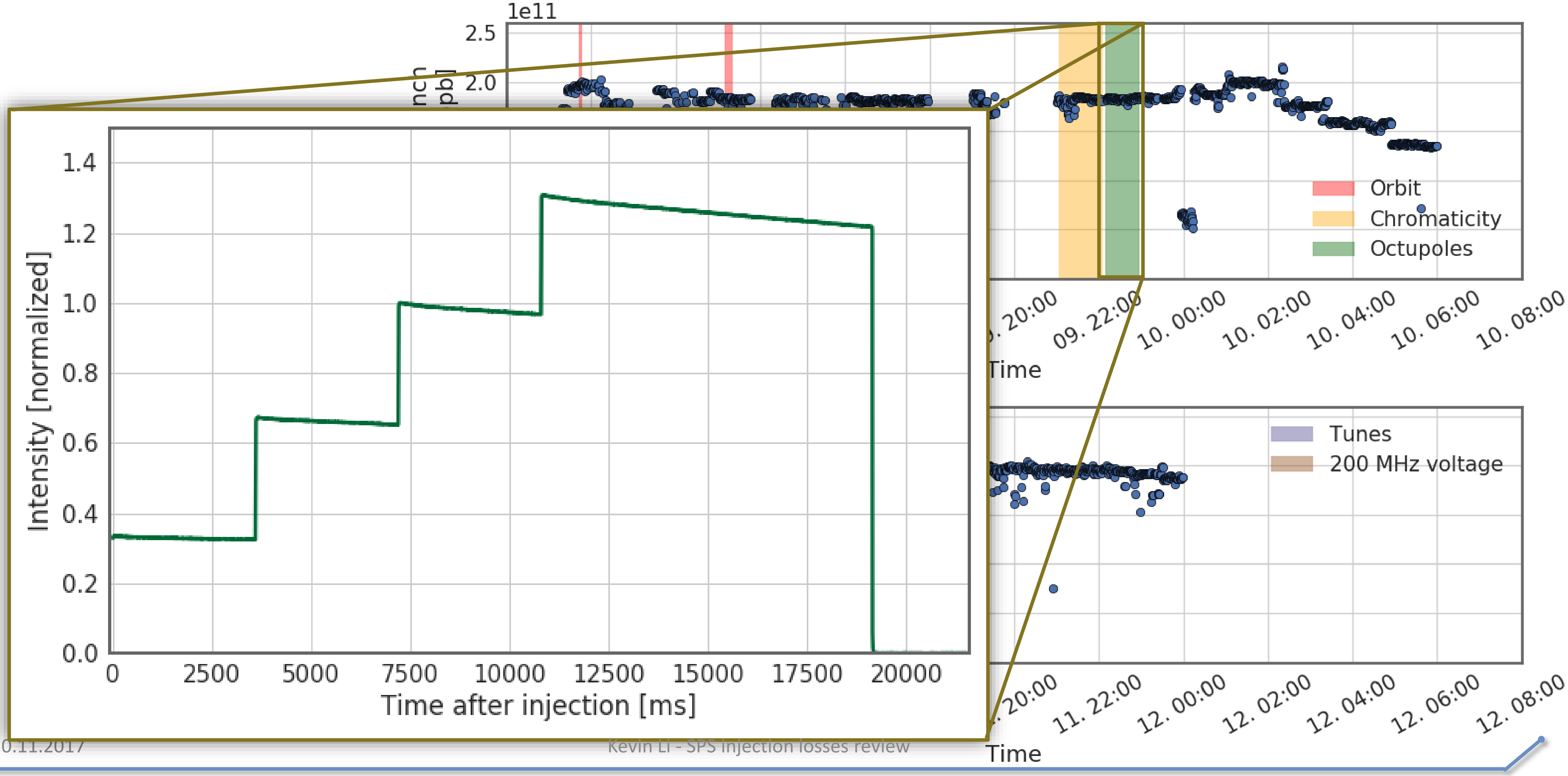

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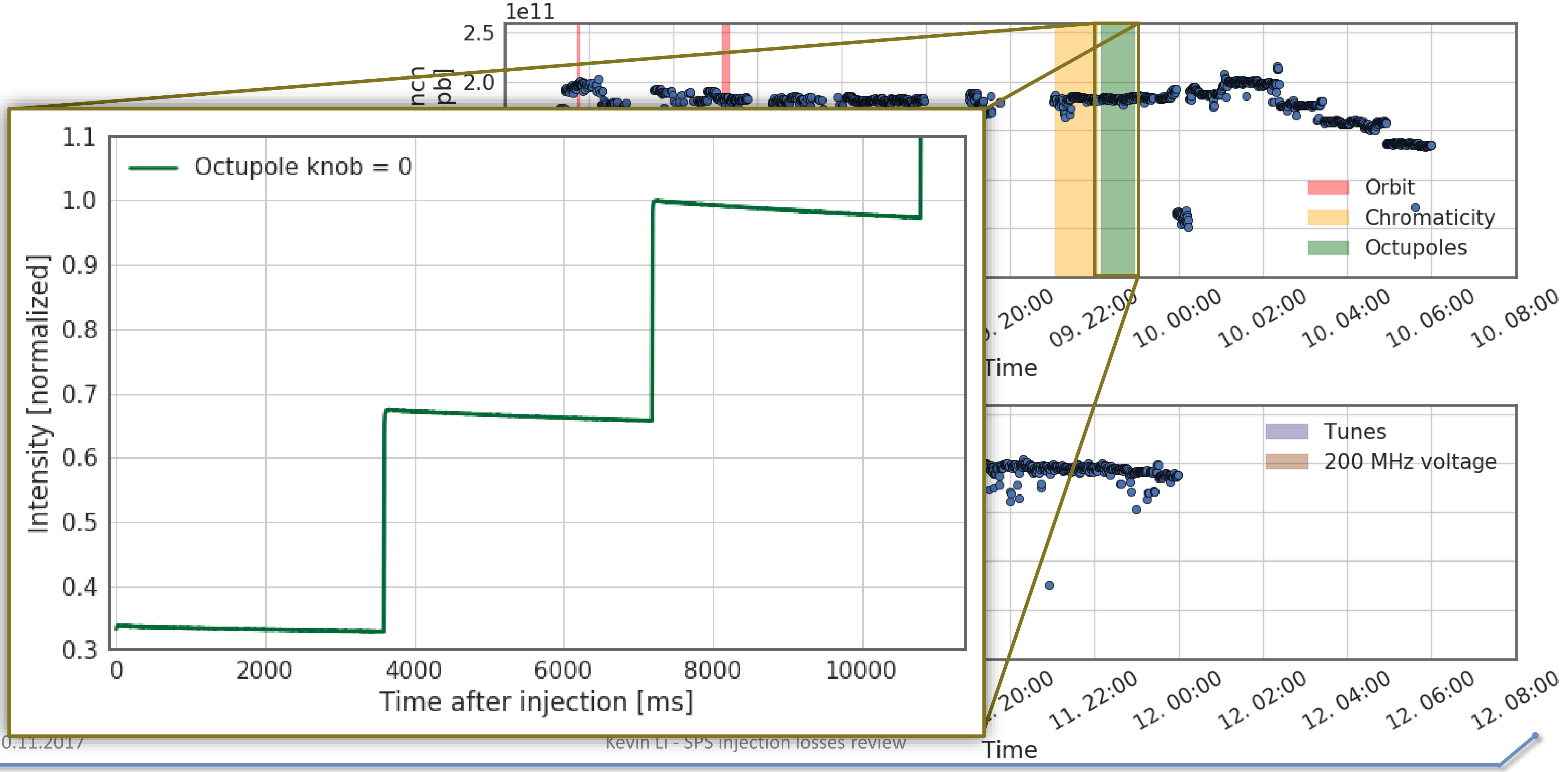
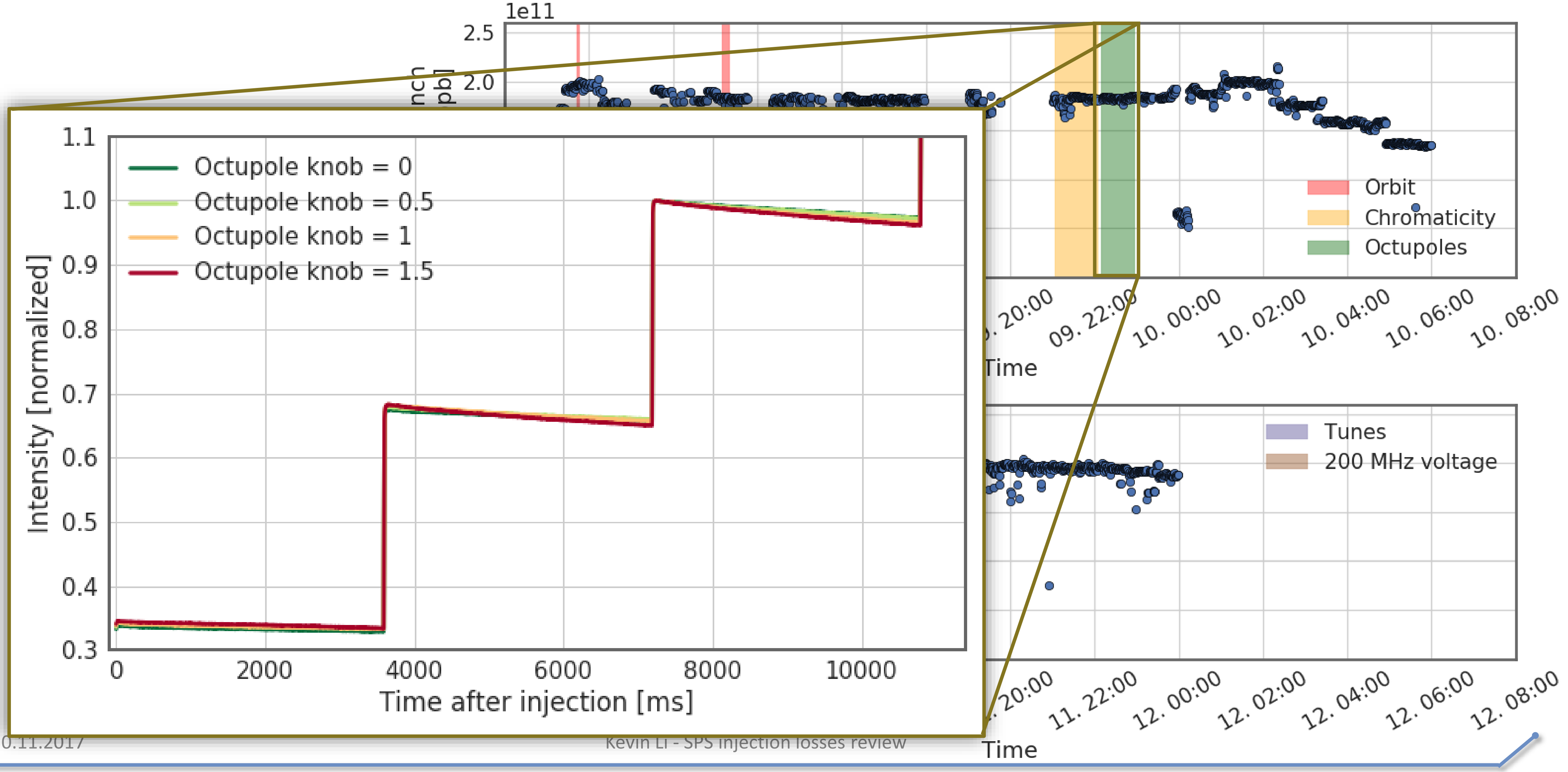
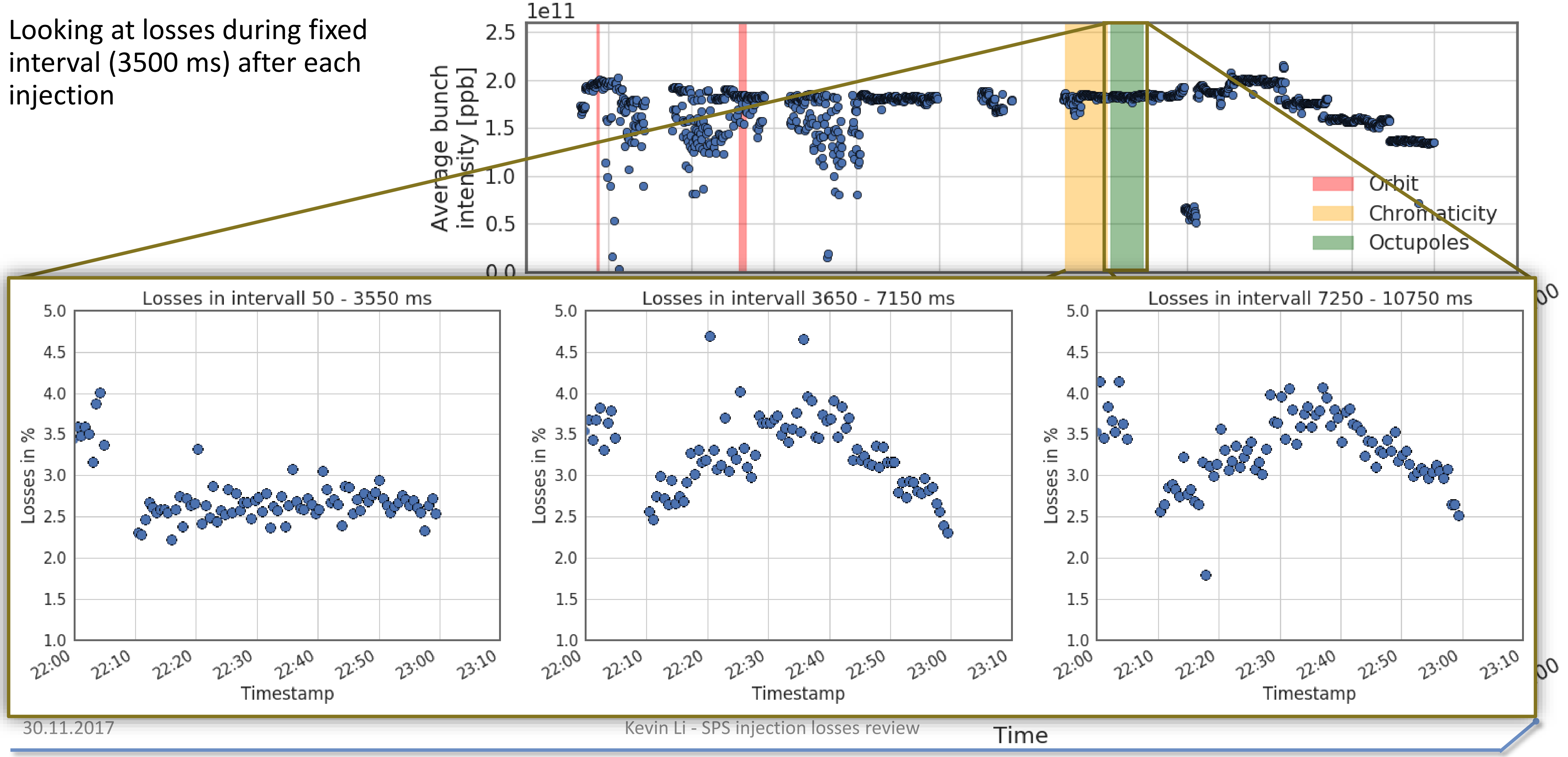


Spotlight – coherent effects and incoherent losses



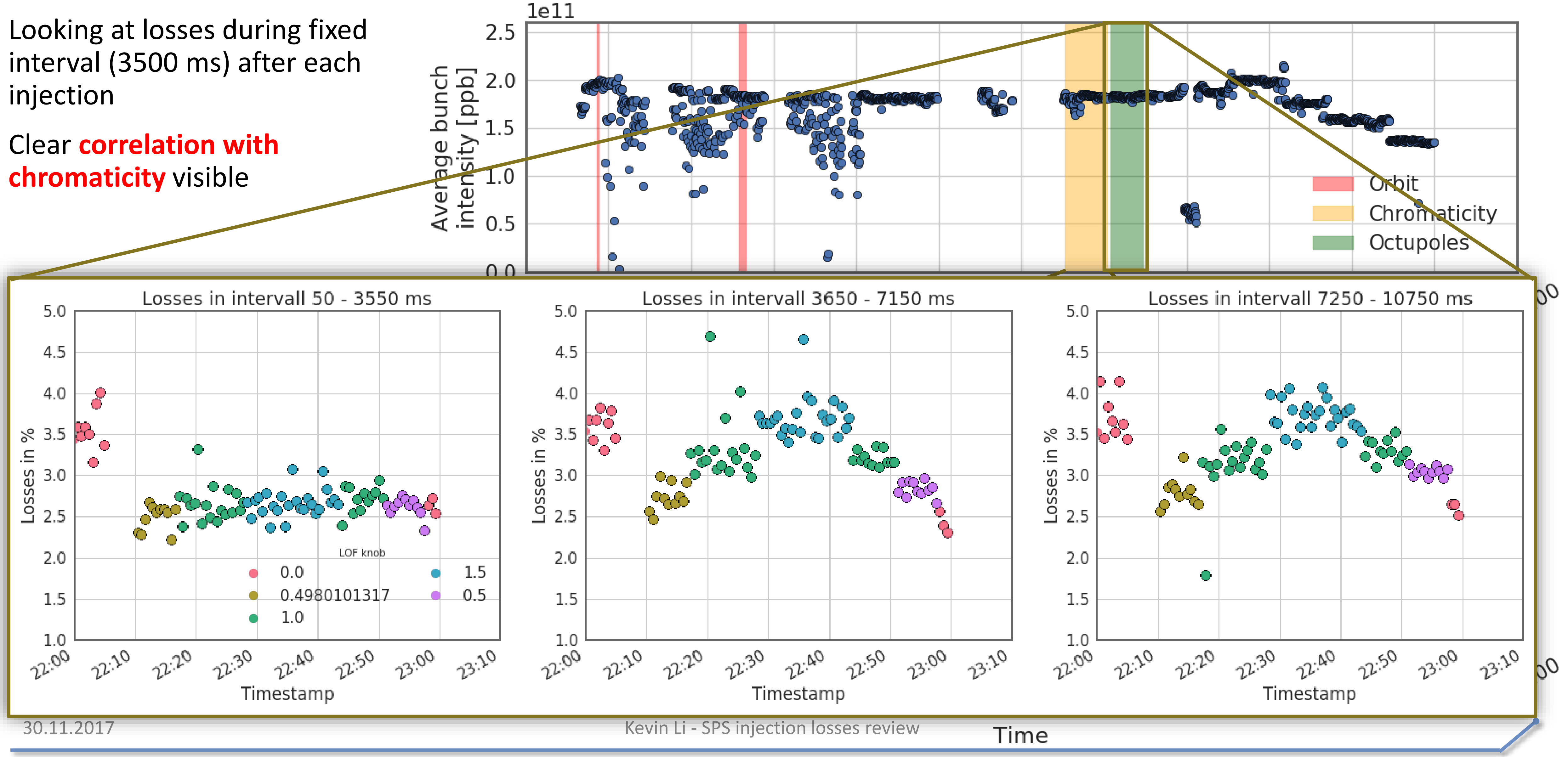
Spotlight – coherent effects and incoherent losses

- Looking at losses during fixed interval (3500 ms) after each injection

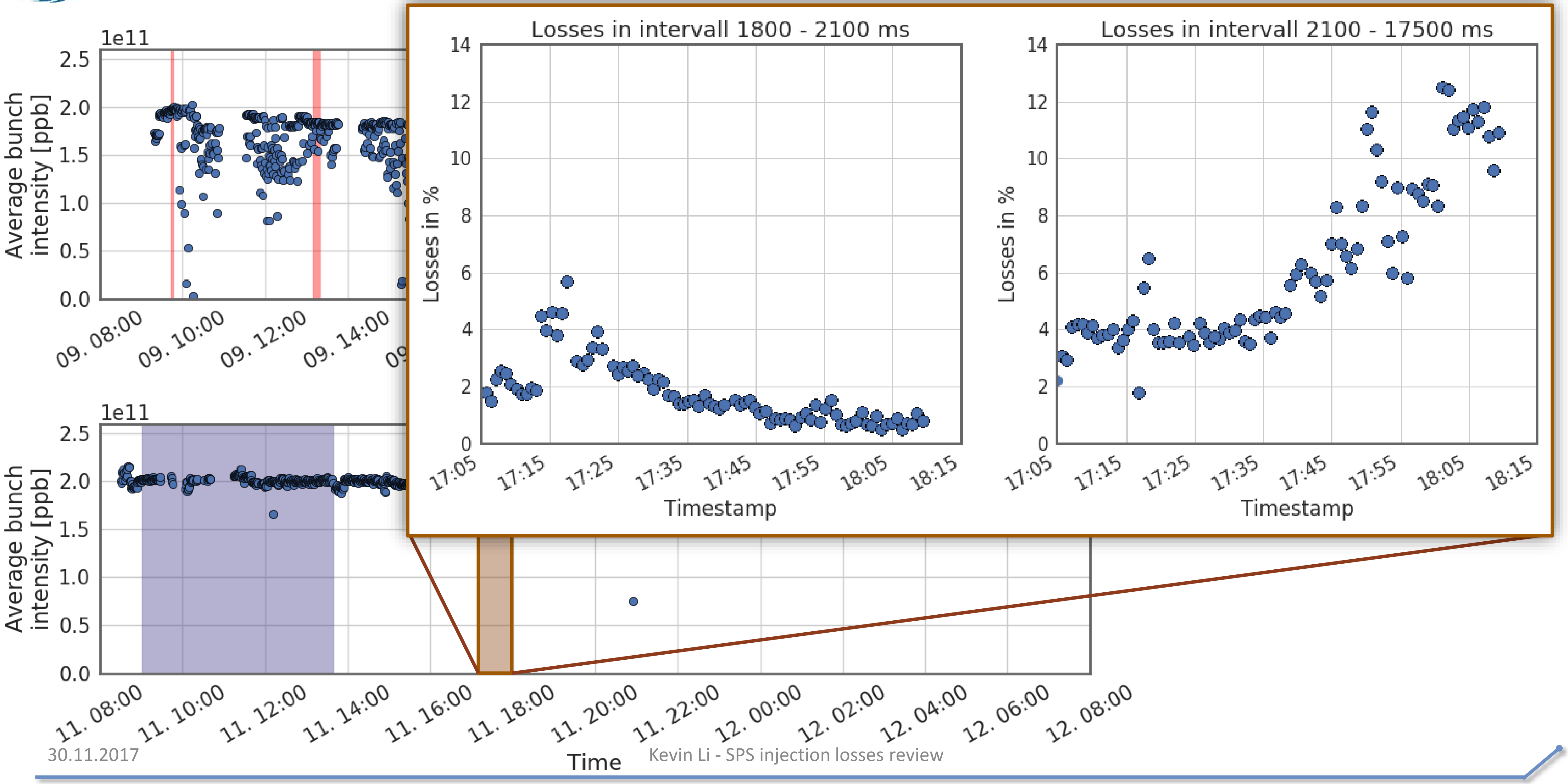


Spotlight – coherent effects and incoherent losses

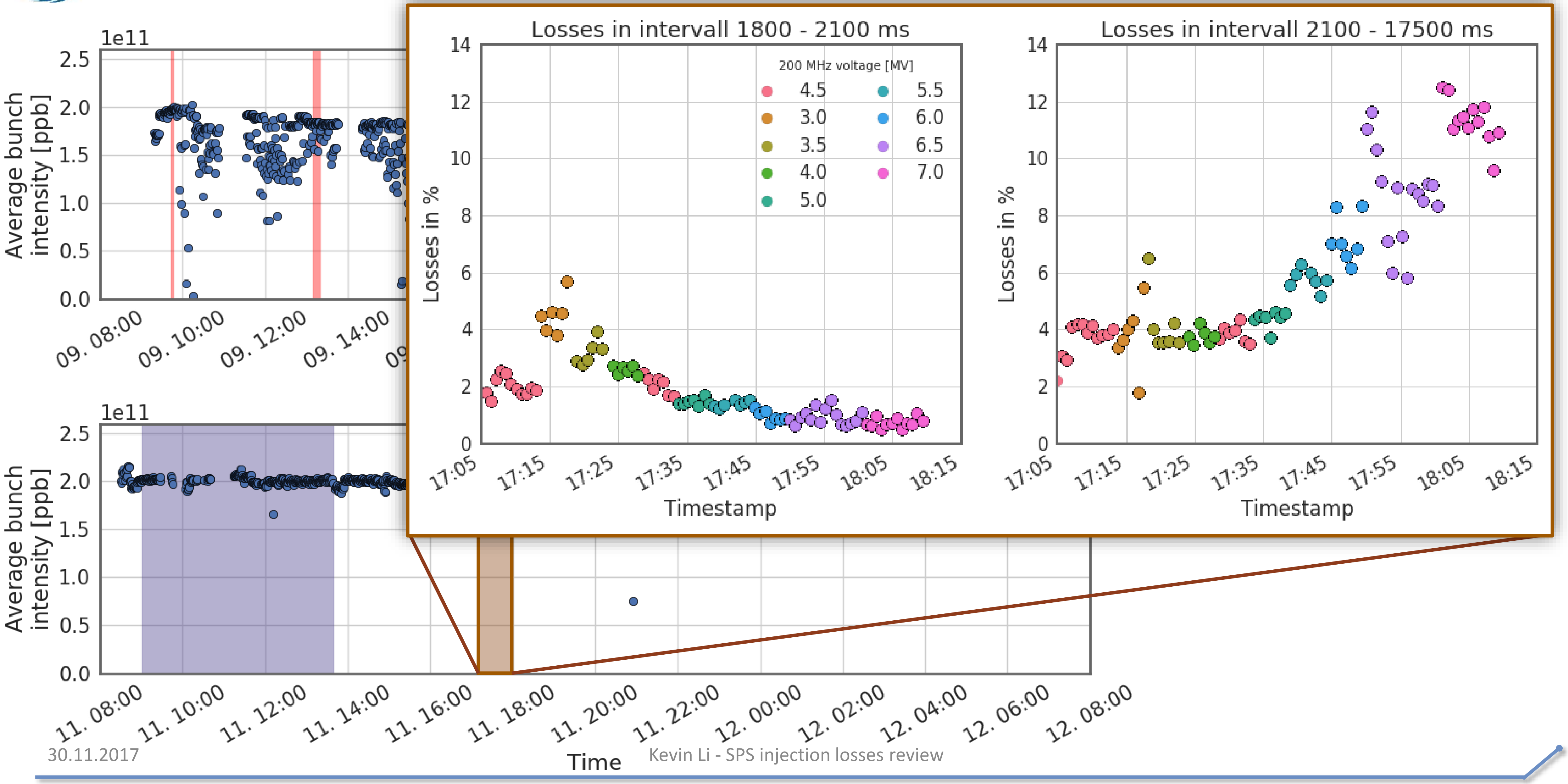
- Looking at losses during fixed interval (3500 ms) after each injection
- Clear **correlation with chromaticity** visible



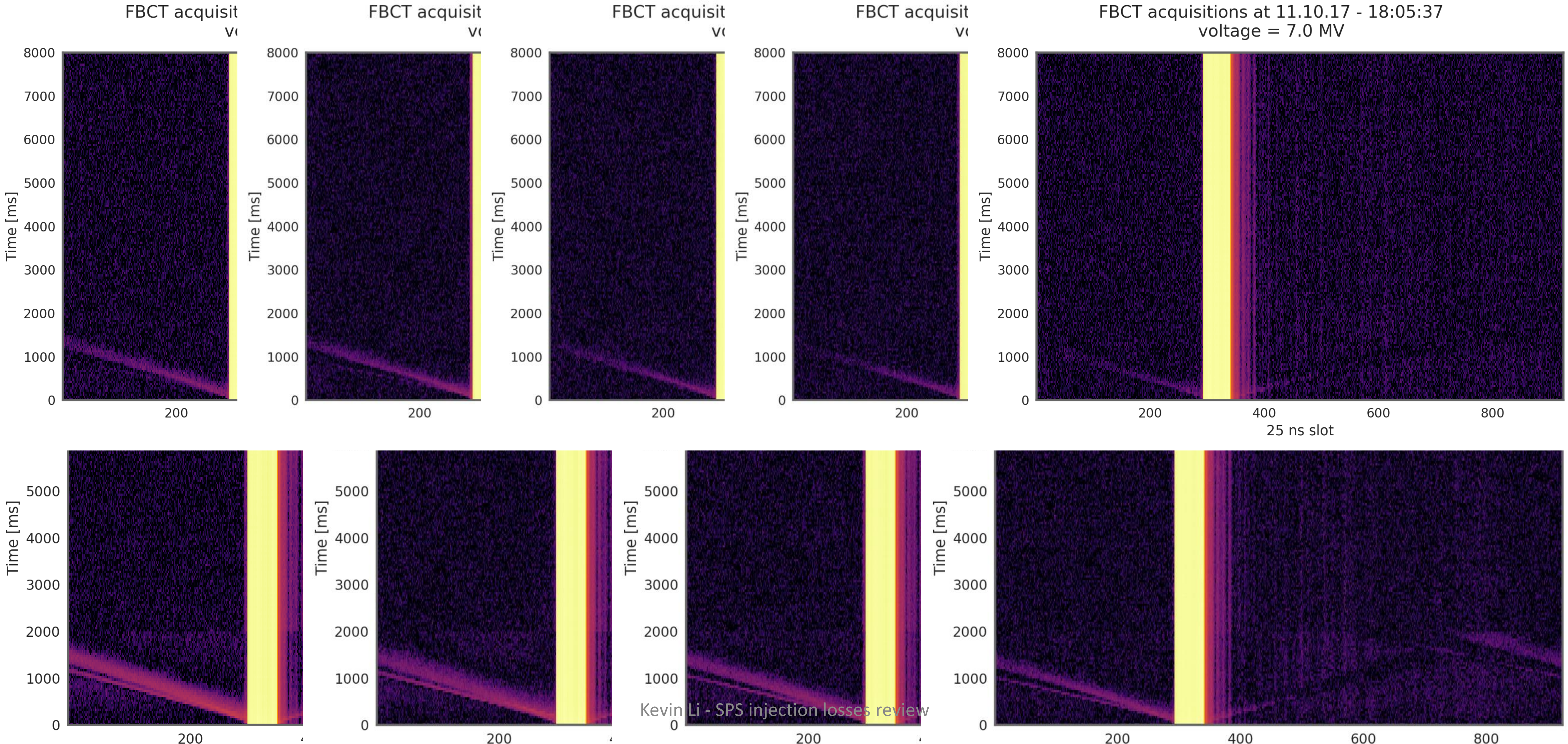
Focus voltage scan



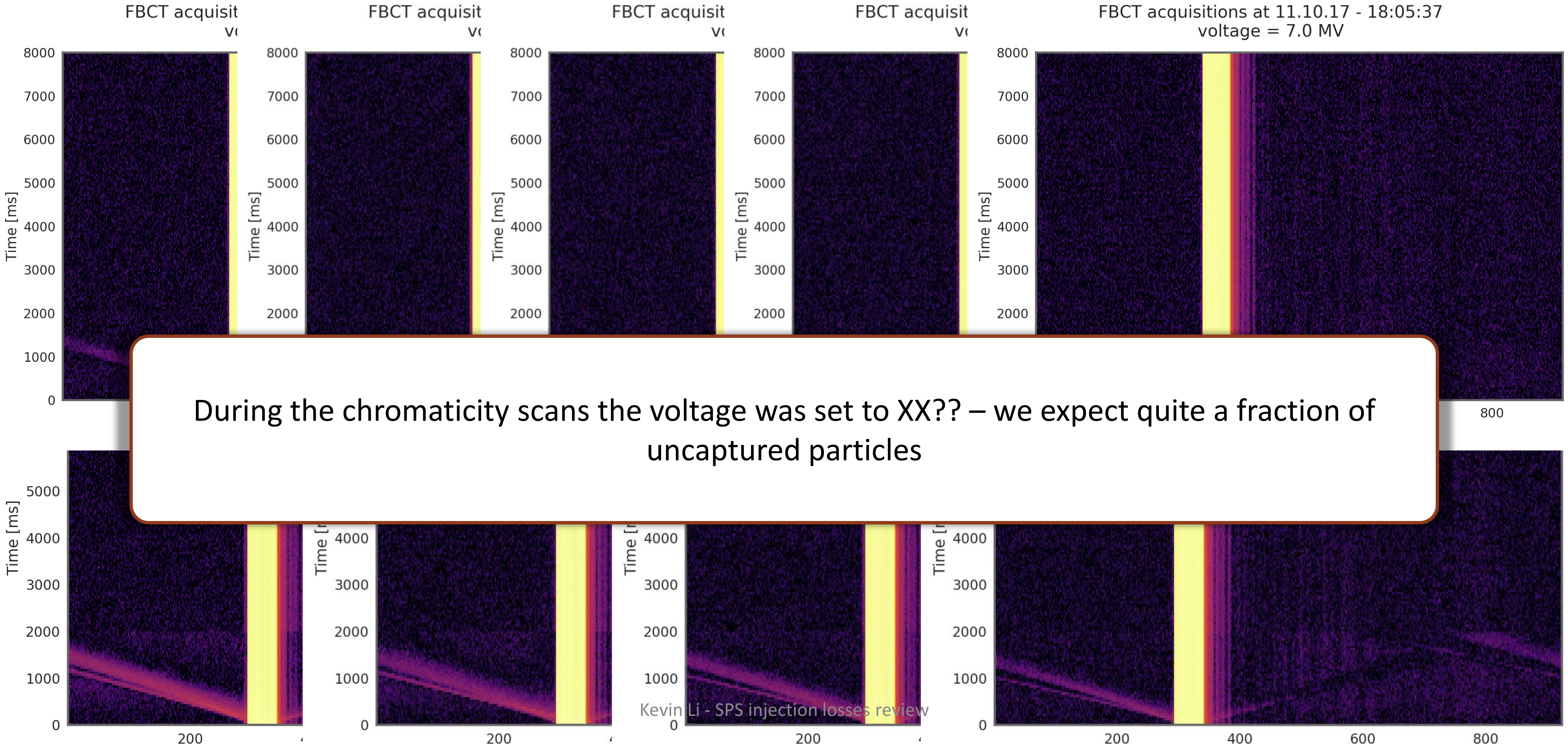
Focus voltage scan



Uncaptured beam seen with the FBCT

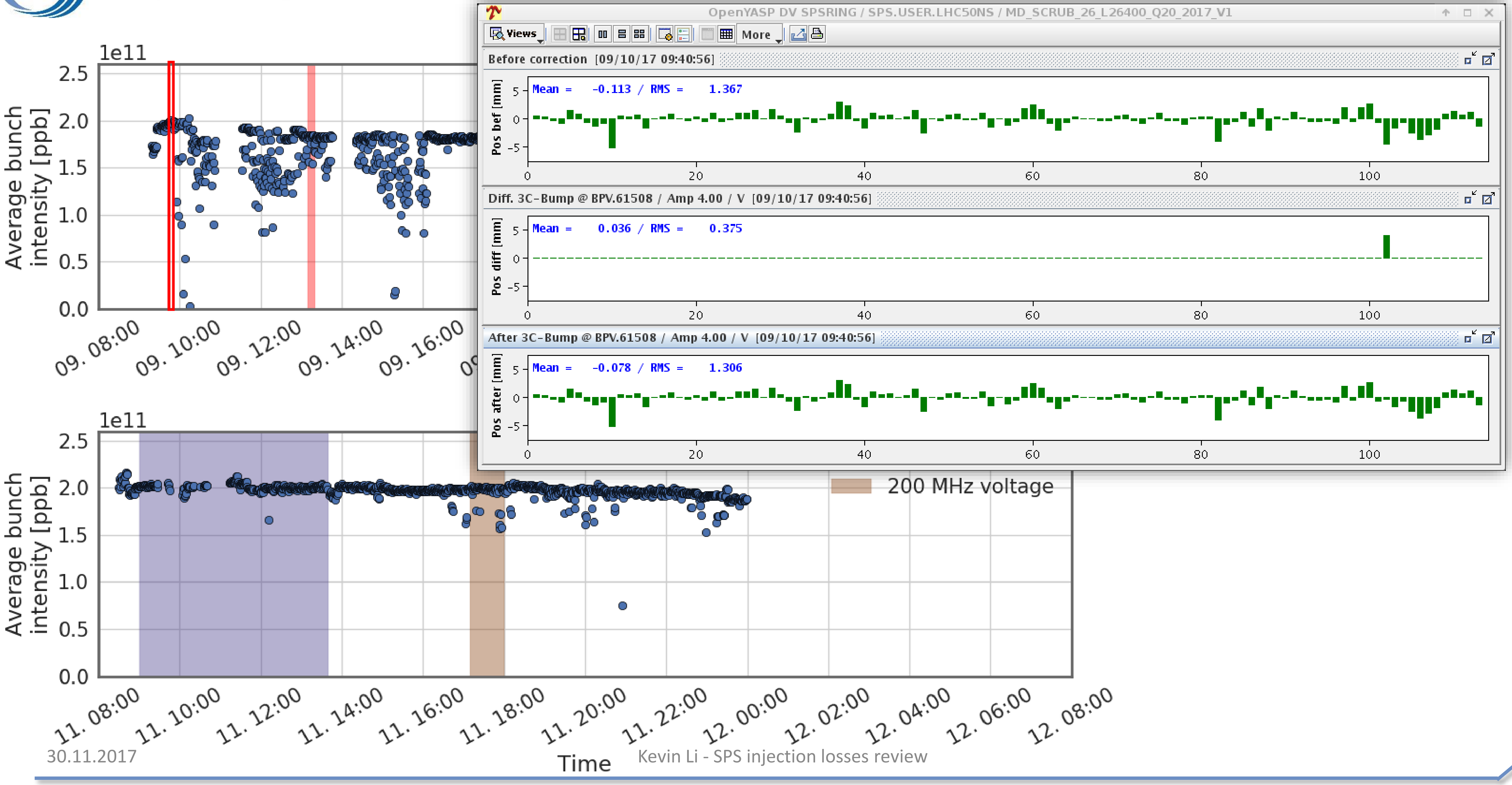


Uncaptured beam seen with the FBCT

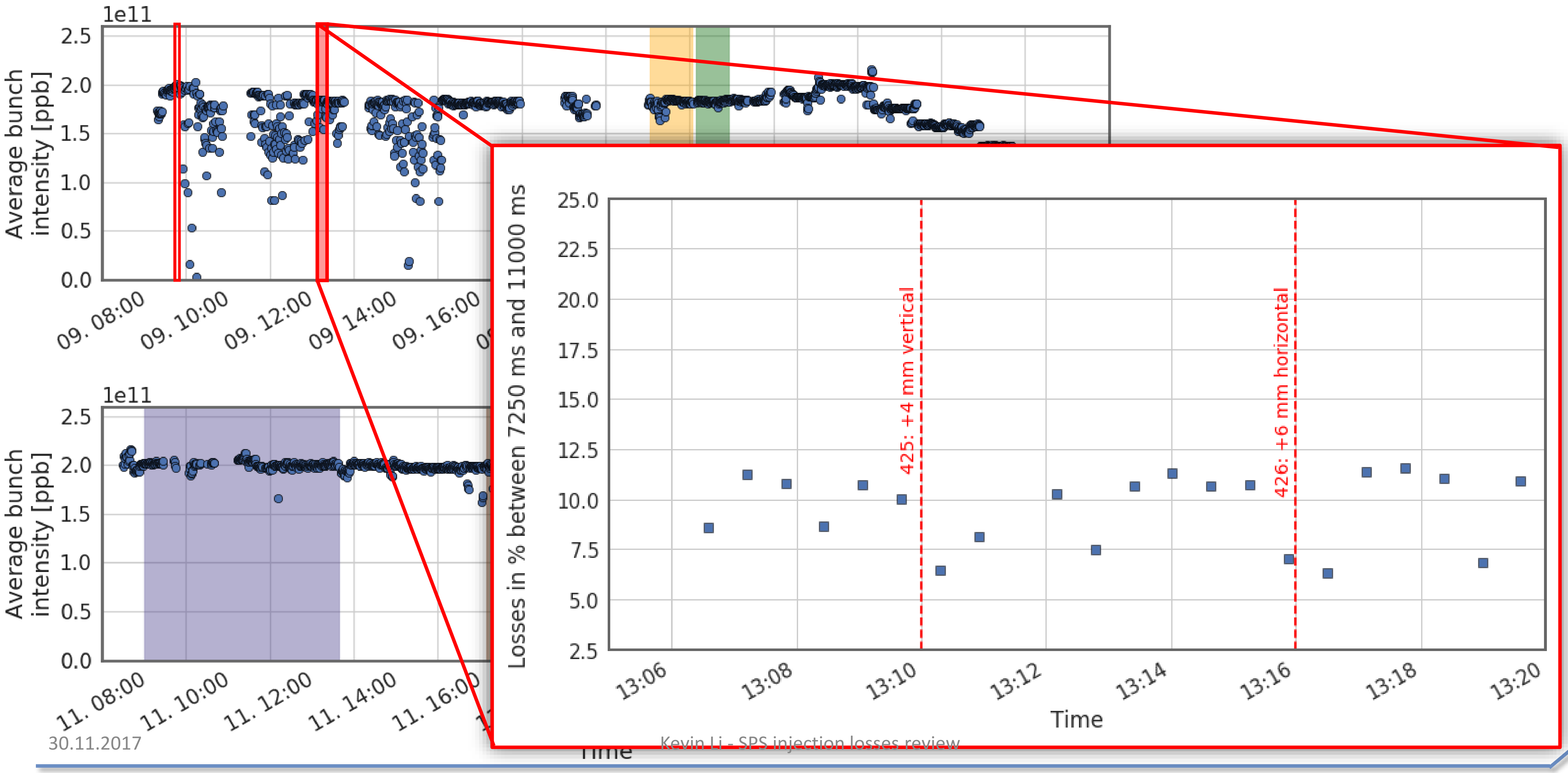


During the chromaticity scans the voltage was set to XX?? – we expect quite a fraction of uncaptured particles

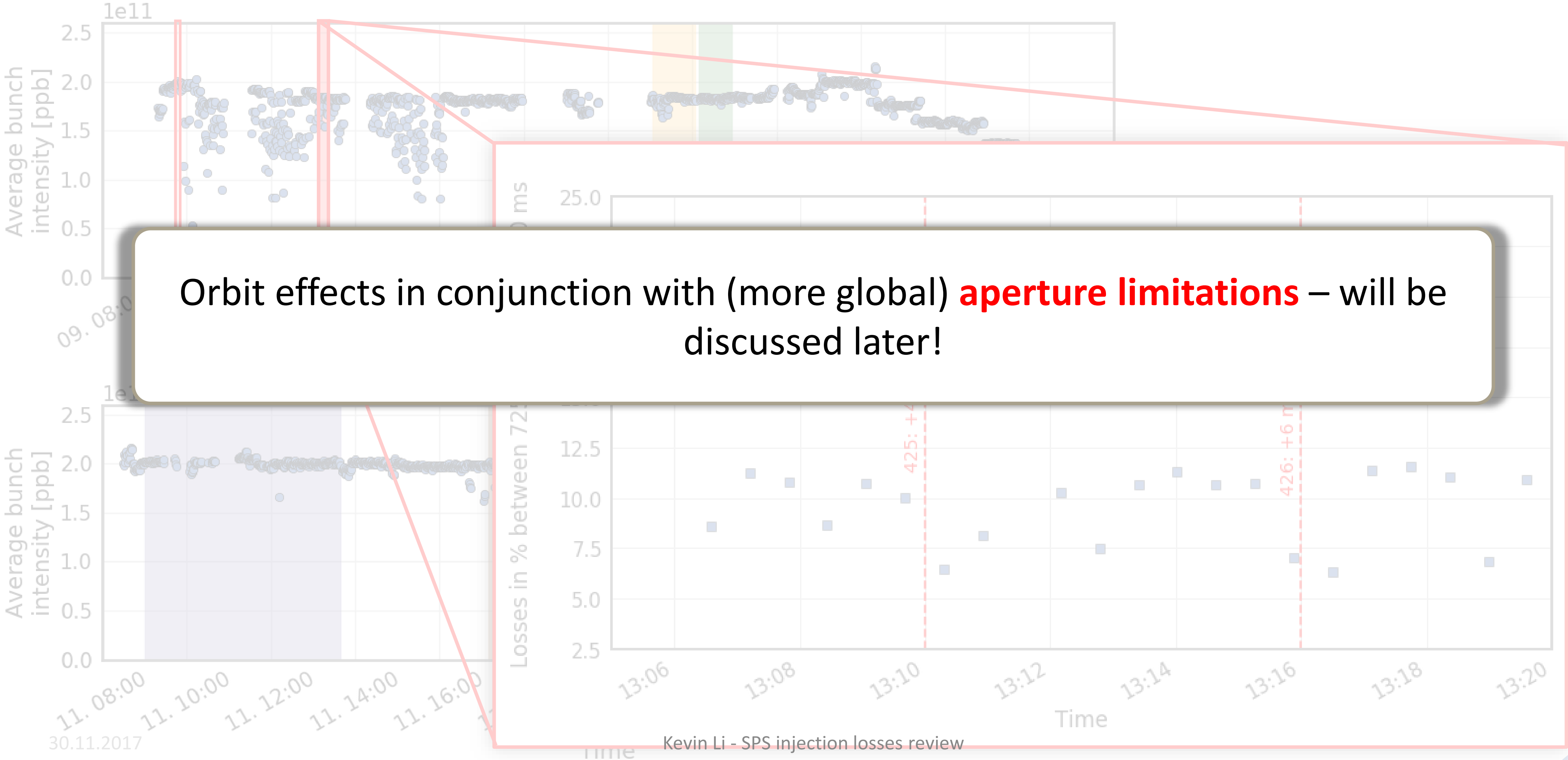
Spotlight – orbit optimization



Spotlight – orbit optimization



Spotlight – orbit optimization



Orbit effects in conjunction with (more global) **aperture limitations** – will be discussed later!