Can an impedance be the source of the observed differences?

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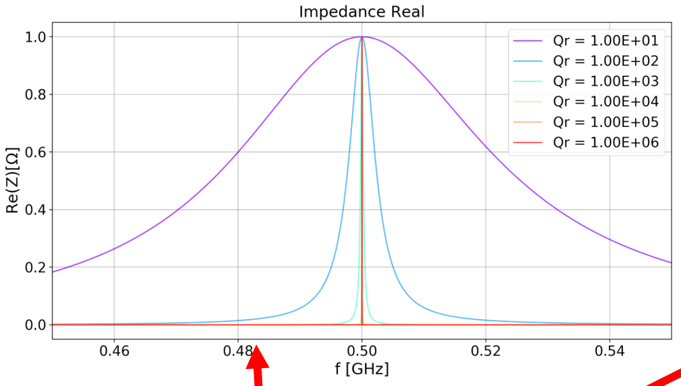
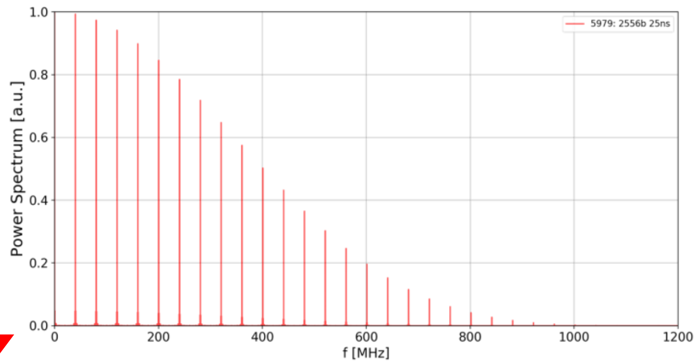
Agenda

- Context
- Rough scalings
- Broadband impedance
- Narrow band impedance
  - Comparison for 25 ns and 50 ns fill (5979 and 5980)
  - Including more fills
- Conclusion

Power Loss dependencies





For a given Impedance the Power loss is computed as:

$$P_{loss} = M^2 I_b^2 \sum_{p=-\infty}^{+\infty} Re[Z(pw_0)] |\Lambda(pw_0)|^2$$

M: Number of bunches
Z: Impedance
Λ^2: Normalized Power Spectrum
w_0: LHC revolution frequency
$I_b = N_b e f_0$: Beam current
N_b: Protons per bunch
$f_0 = \frac{w_0}{2\pi}$

Where it can be shown that [1]:

- $P_{loss} \sim M^2$ for narrow-band Impedance
- $P_{loss} \sim M$ for broad-band Impedance

So if the heat load is caused by an impedance, given 2 fills with the same shape of Λ we expect [2]:

- $\frac{P_{loss1}}{P_{loss2}} \approx \frac{M_1^2}{M_2^2}$ for narrow-band Impedance
- $\frac{P_{loss1}}{P_{loss2}} \approx \frac{M_1}{M_2}$ for broad-band Impedance

[1]:H. Lee M. Furman and B. Zotter. "Energy Loss of Bunched Beams in RF Cavities". In: (1986)
[2]:F. Giordano. "Impact of filling scheme on beam induced RF heating in CERN LHC and HL-LHC", Appendix A

New 25ns and 50ns fills

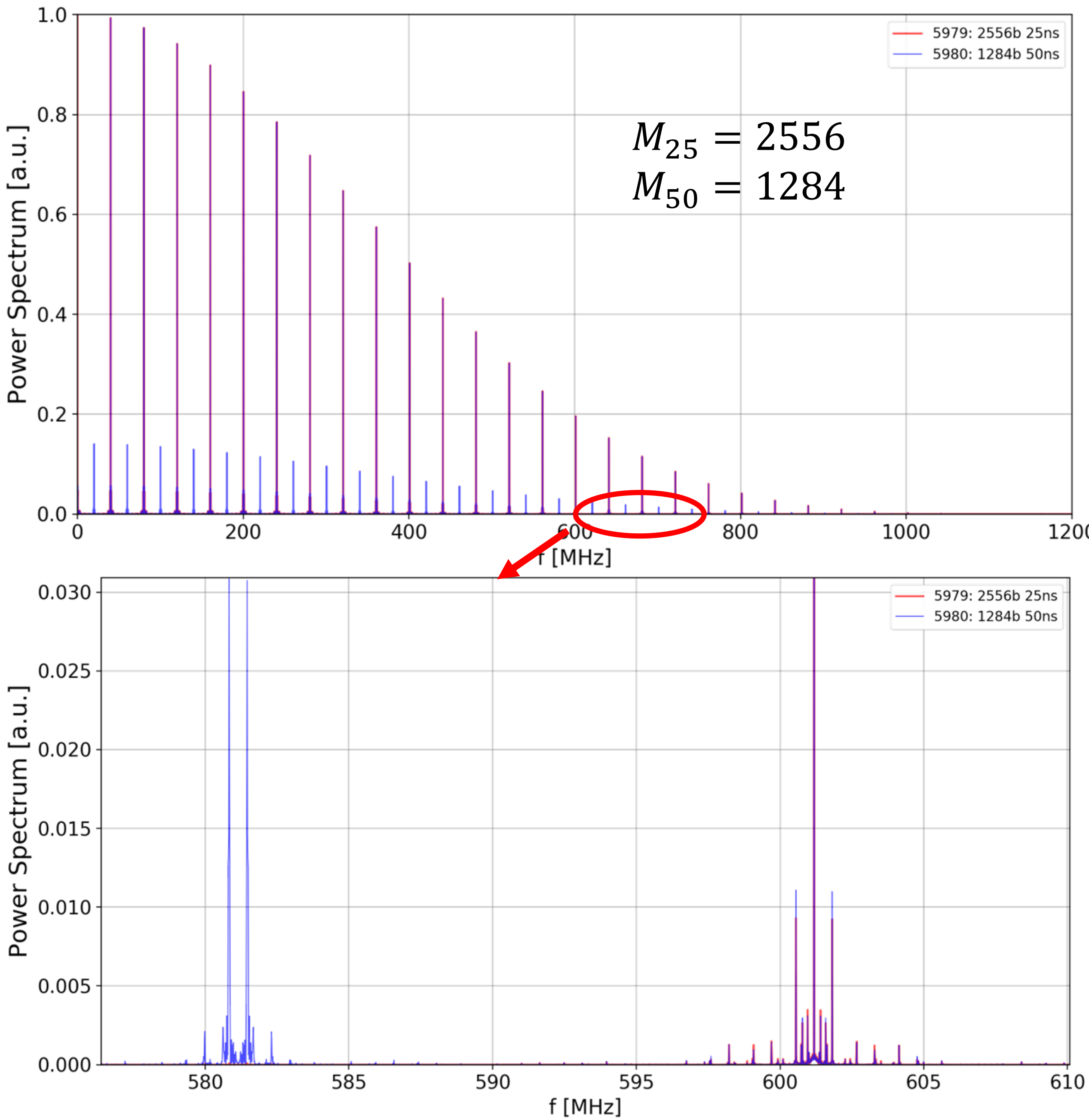
Both Spectra are normalized to better observe that around the pair main lines the **shapes are the same**

We can say that for all the pair main lines we have:

$$shape(\Lambda_{25}) \approx shape(\Lambda_{50})$$

We expect that

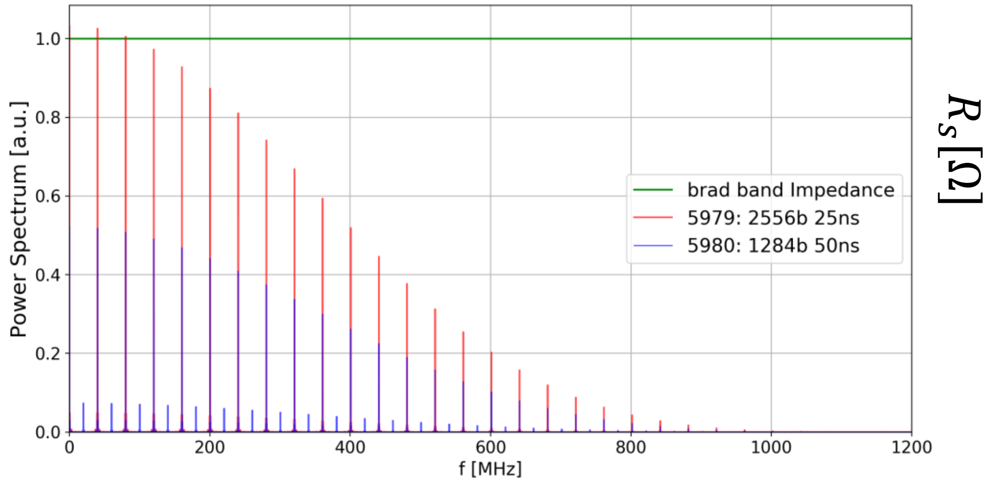
- $\frac{P_{loss25}}{P_{loss50}} \approx \frac{M_{25}^2}{M_{50}^2} \approx 3.96$ for narrow-band Impedance
- $\frac{P_{loss25}}{P_{loss50}} \approx \frac{M_{25}}{M_{50}} \approx 1.99$ for broad-band Impedance



Broad band Impedance

To benchmark the theory we have calculated the Ploss for the broad band case:

- $R_s = 1$ (doesn't count in the ratio)
- $Q_r = 0$



The ratio results to be:

$$\frac{P_{25}}{P_{50}} \approx 2.04$$

As expected.

Narrow Band case

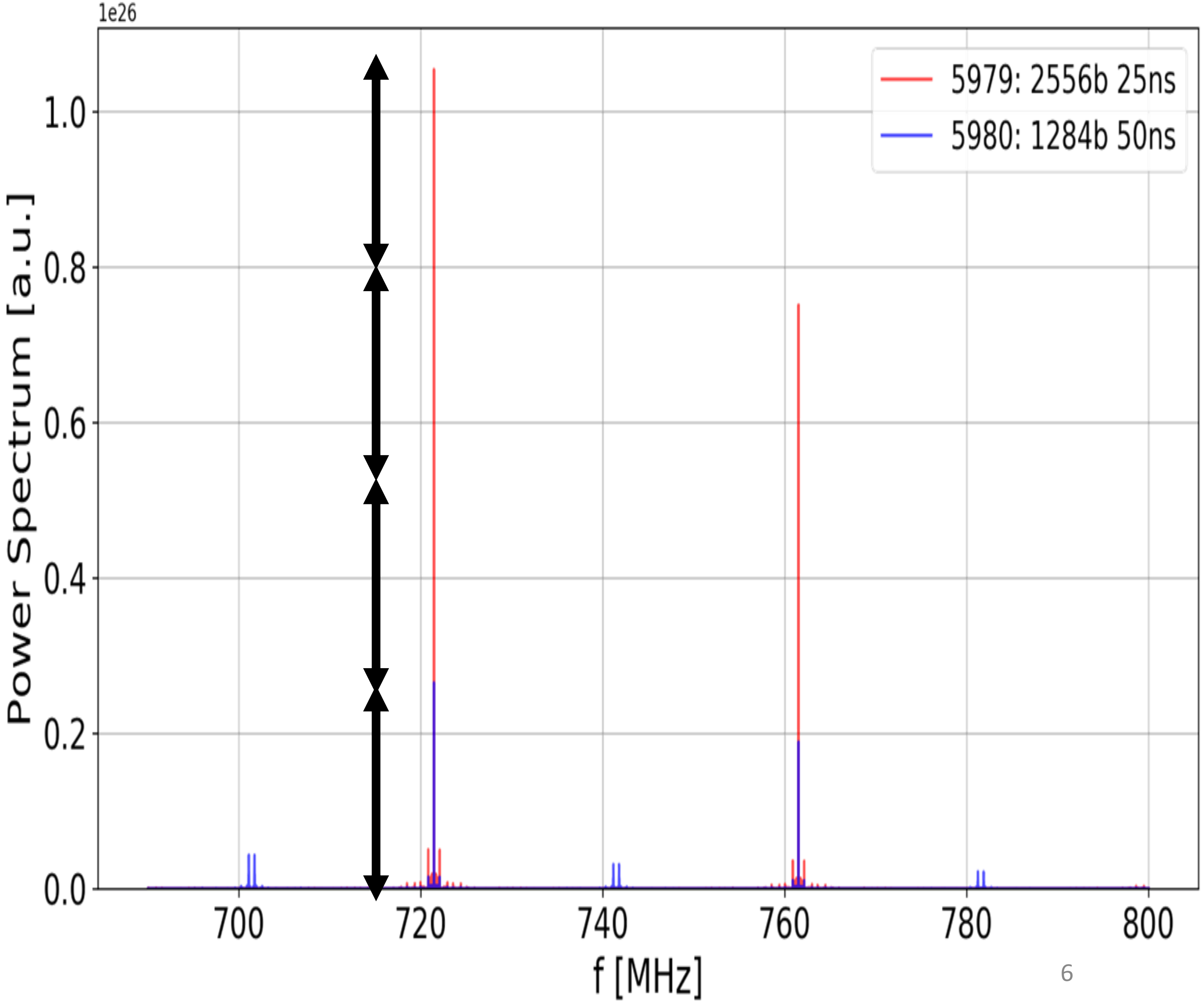
The Power Loss formula can also be written as:

$$P_{loss} = I_b^2 \sum_{p=-\infty}^{+\infty} Re[Z(pw_0)]|\Lambda^*(pw_0)|^2$$

Where Λ^* is the **not normalized** spectrum.
Here is more easy to observe that for a narrow band Impedance (1 term in the sum) we get:

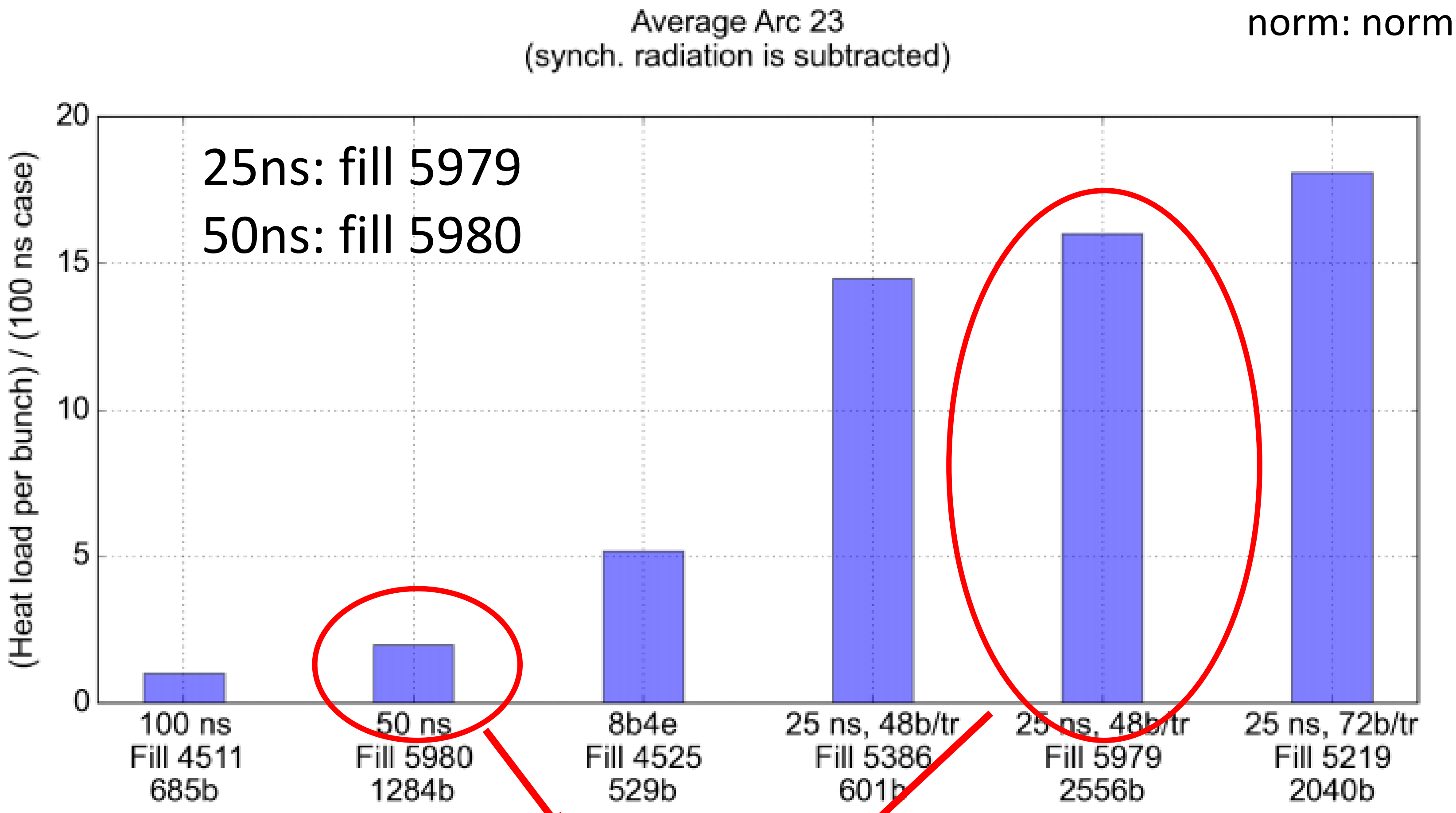
$$\frac{P_{loss25}}{P_{loss50}} \approx \frac{|\Lambda^*_{25}|^2}{|\Lambda^*_{50}|^2} \approx 4$$

As expected.



Cryogenic measurements on sector 23 (TE-CRG and G. Iadarola)

norm: normalized to the number of bunches



The ratio between the heat loads of the 50ns and 25ns **not normalized on M** should be between **2** and **4** if it's caused by an Impedance.

$$\frac{P_{loss25}(norm)}{P_{loss50}(norm)} \approx 8$$

Factor 2 between the number of bunches

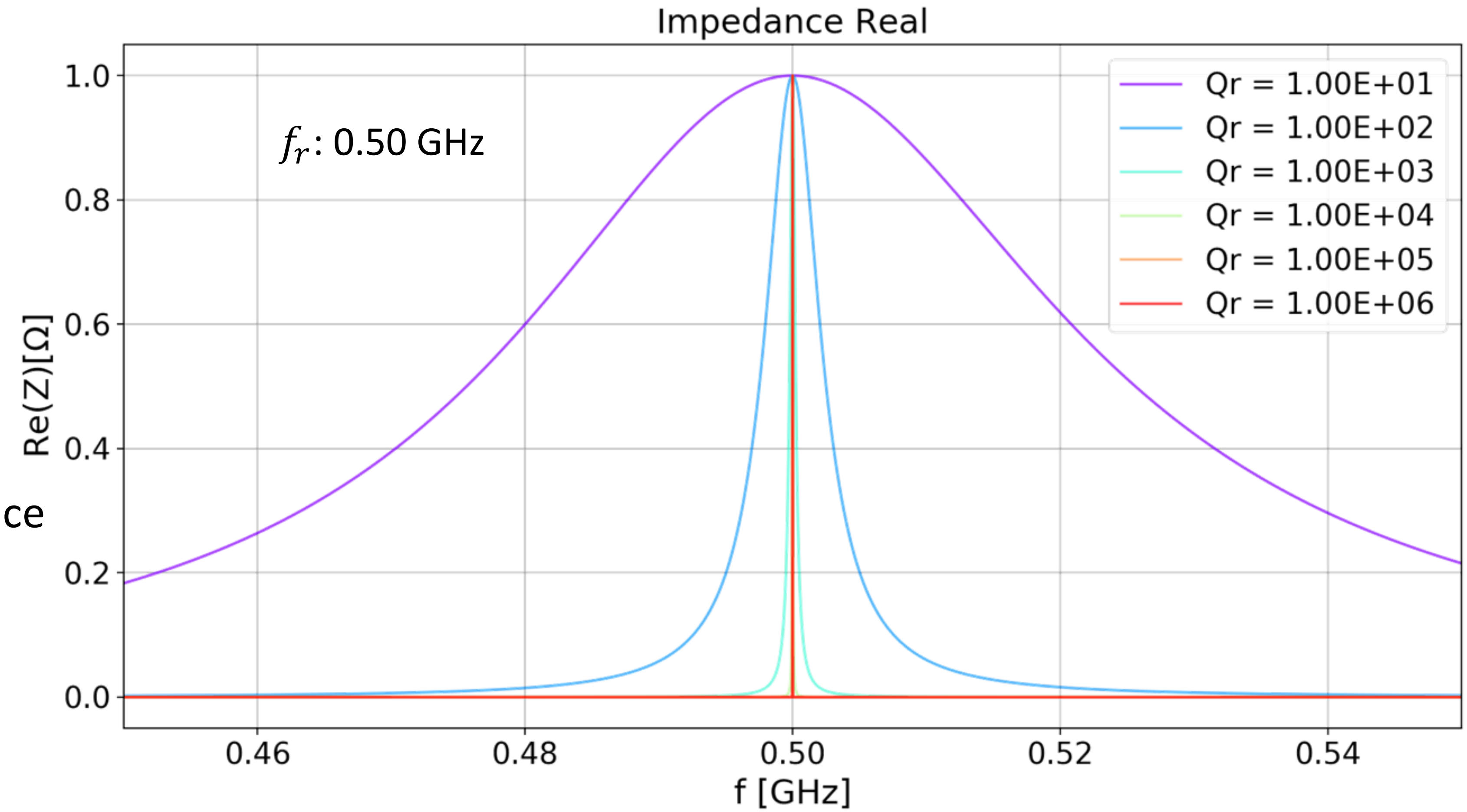
$$\frac{P_{loss25}(not\ norm)}{P_{loss50}(not\ norm)} \approx 16$$

Neither a narrow nor a broad-band Impedance can explain this ratio

Resonator model Impedance: more general case of 1 mode

$$Z(f) = \frac{R_s}{1 + jQ_r(\frac{f}{f_r} - \frac{f_r}{f})}$$

Q_r: tune the width of the impedance
f_r: tune the position in frequency



What we already know about this Impedance

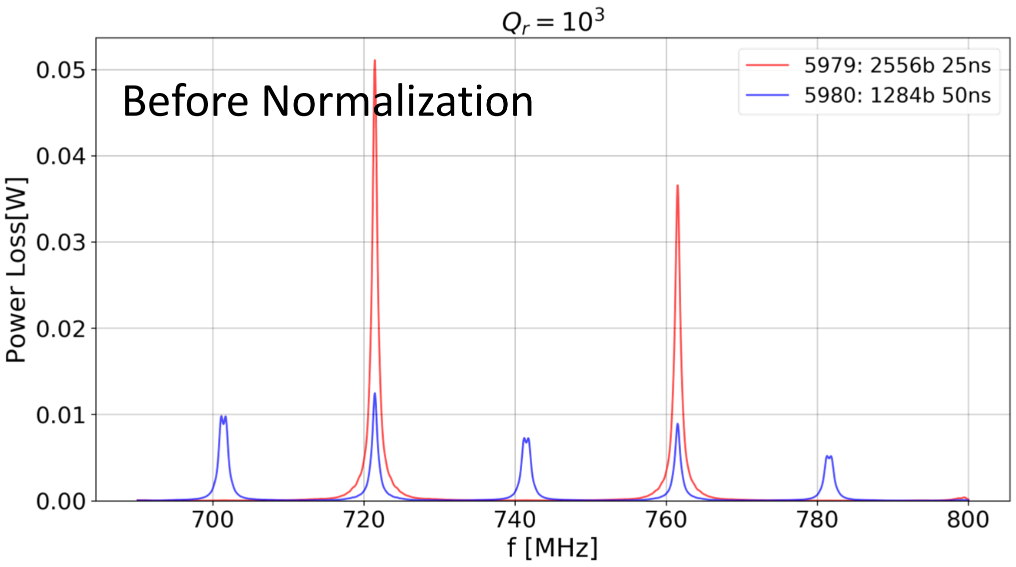
If this impedance exists, it should have [3]:

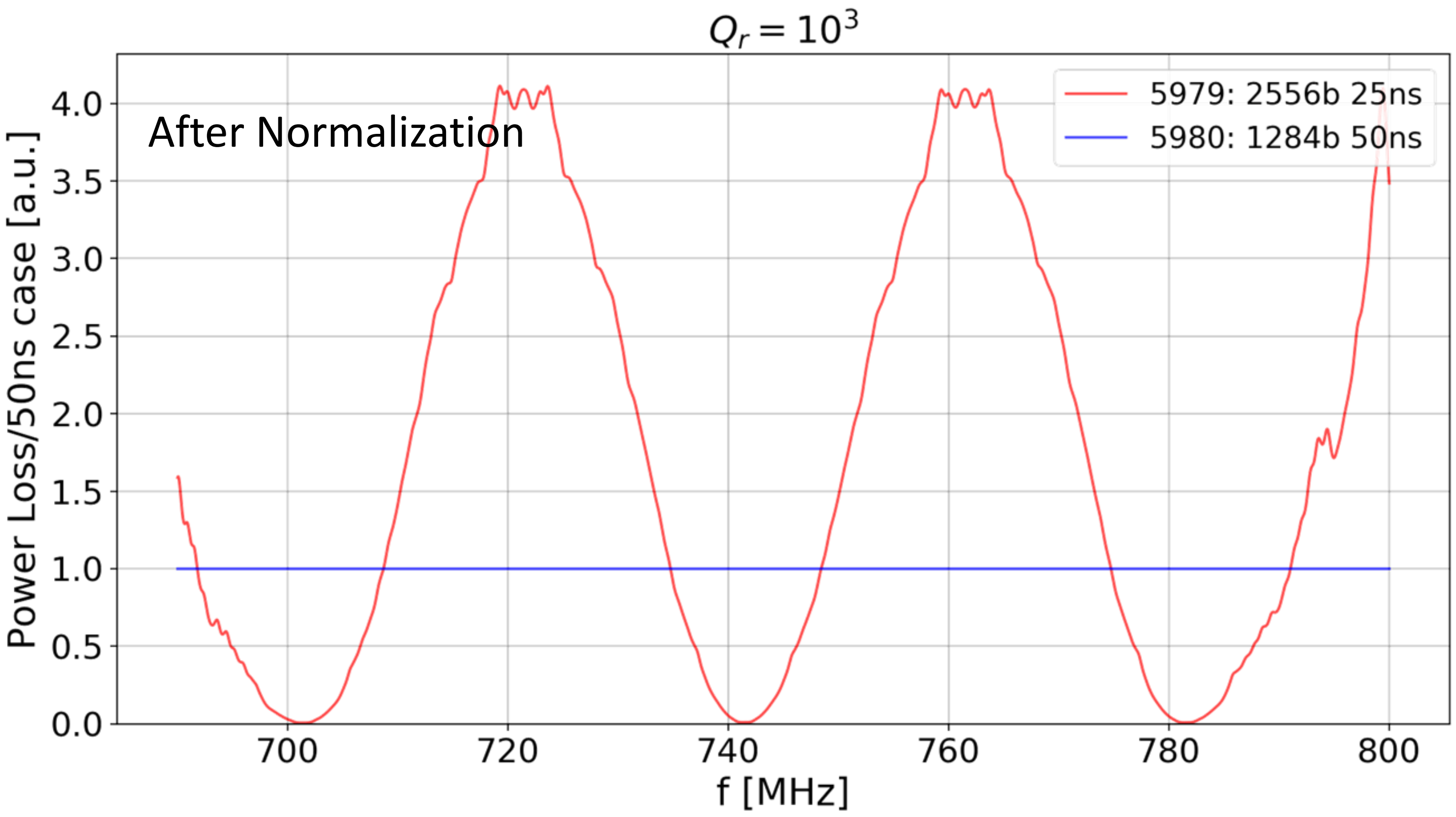
- $10^3 < Q_r < \ 10^4$
- $700MHz < f_r < 780MHz$

With those information we can compute the Power Loss for each one of these Q_r as function of $f_r$in order to find an Impedance that matches the heat load given by the measurements.

[3] B.Salvant: Expected impedance of a PIM non-conformity

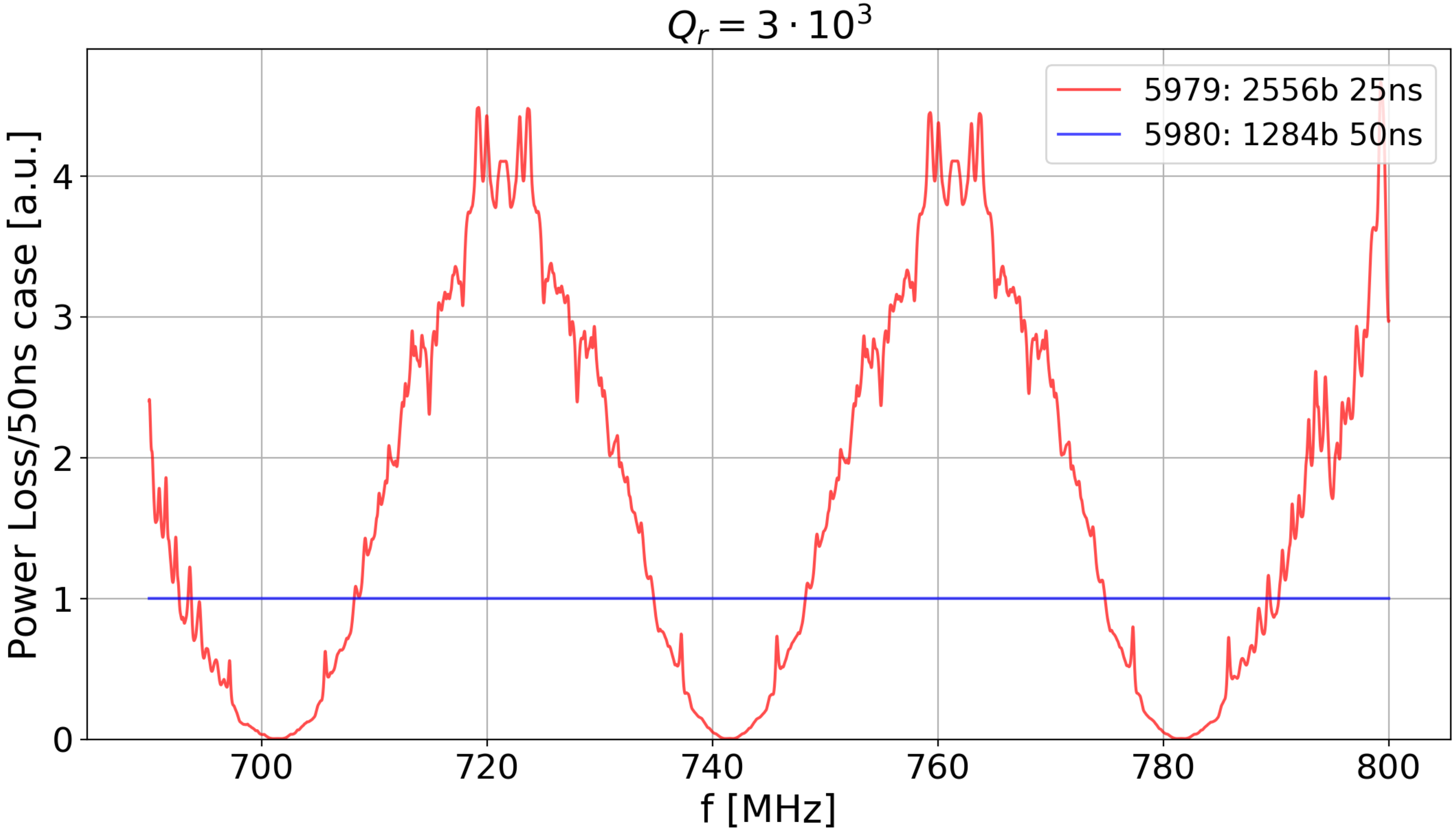
Normalizing each P_{loss} to the 50 ns case (lowest heating)





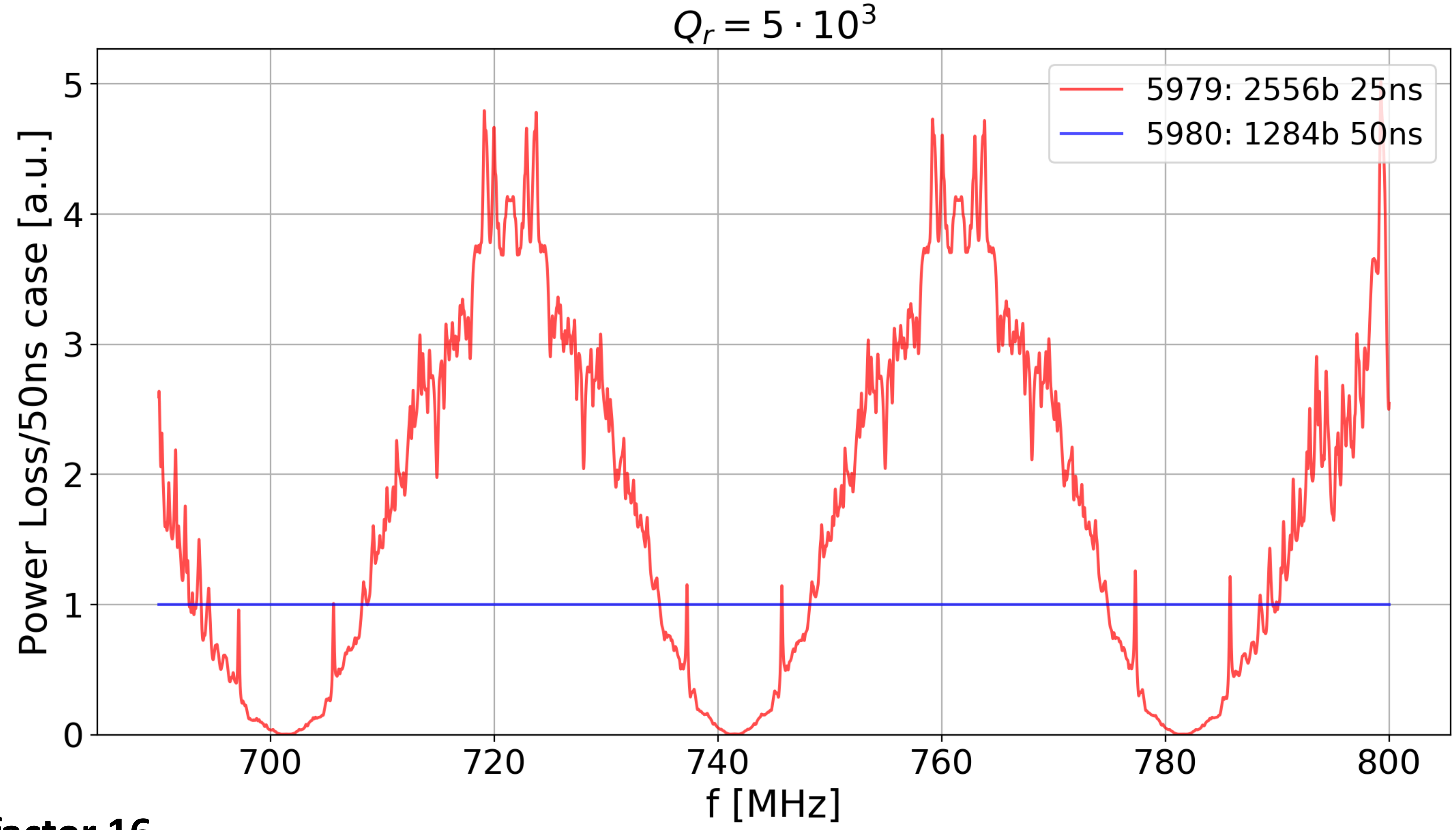
Far from factor 16.

Increasing Q_r [1/4]



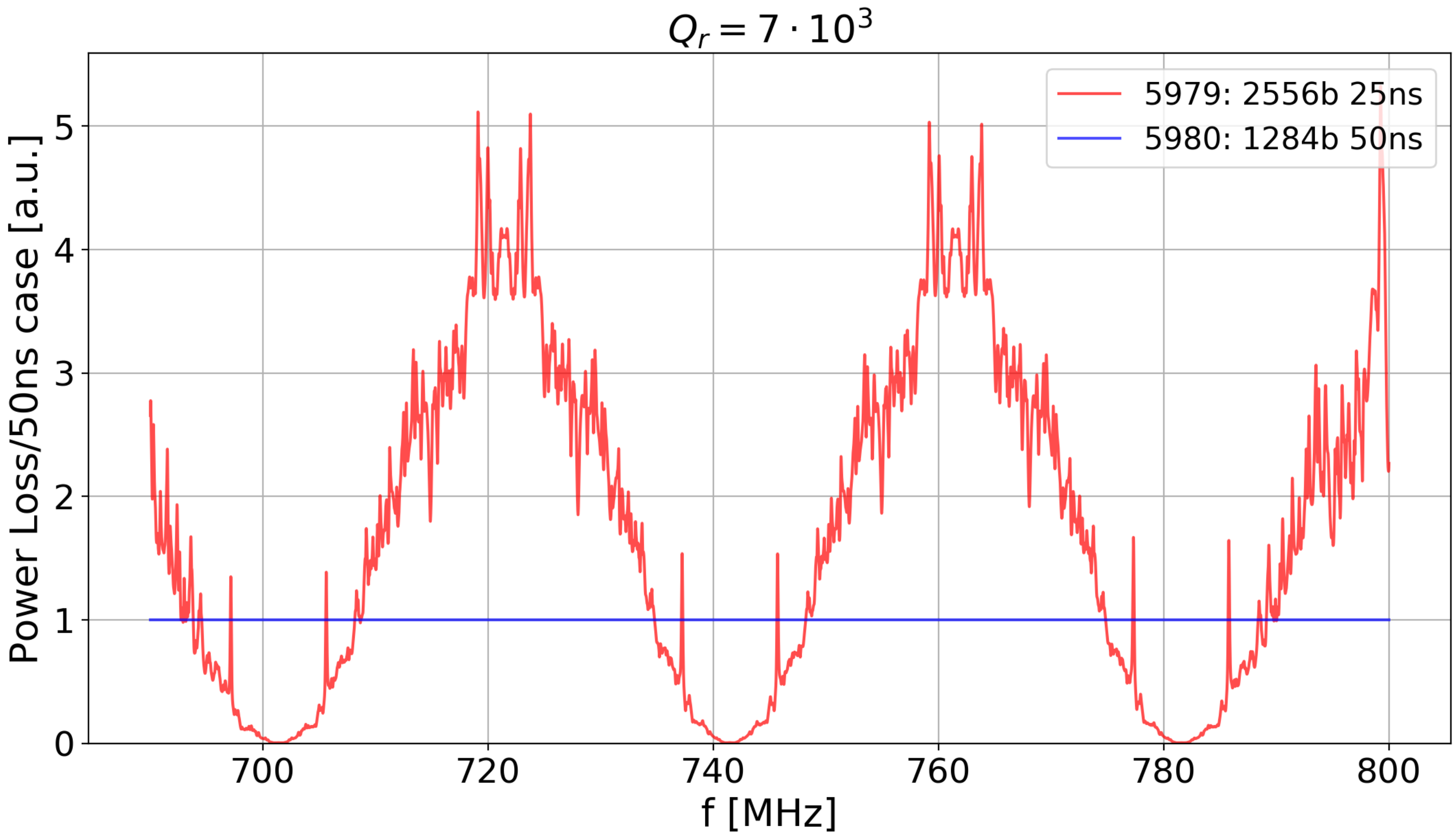
Far from factor 16.

Increasing Q_r [2/4]



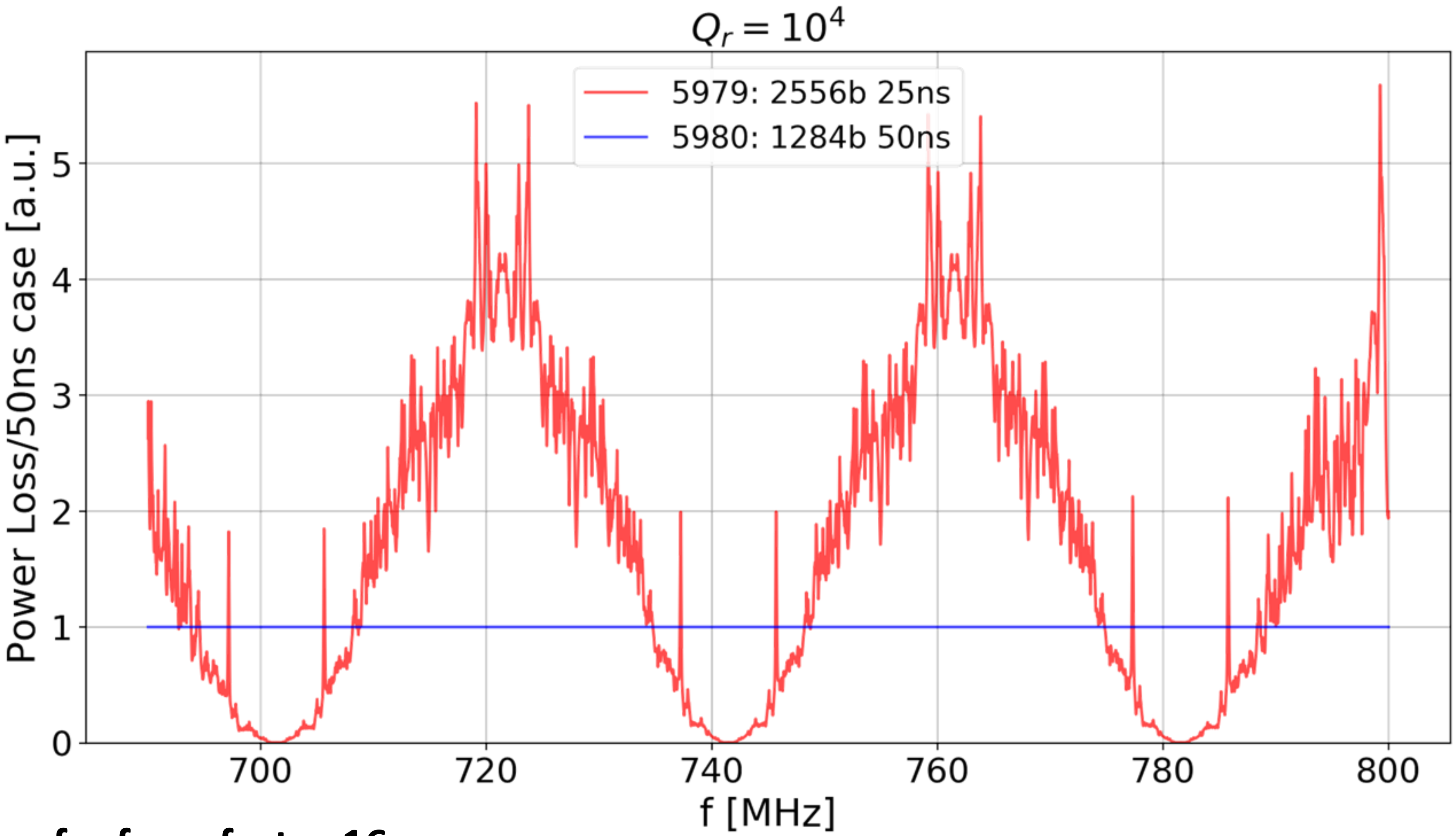
Far from factor 16.

Increasing Q_r [3/4]



Far from factor 16.

Increasing Q_r [4/4]



We are always far from factor 16.
It's very improbable that is an Impedance the source of the heat load.

To be more convinced …

We can try to reproduce the the measurements plot with an Impedance.

But how can we choose $R_s, Q_r\ and\ f_r$?

We have to calculate all the P_{loss} with all the possible $Q_r\ and\ f_r$(R_s disappear with the normalization).

Then we look at all the plots (one for each value of Q_r)where the P_{loss} is plotted as function of f_r and we check if there is a frequency where all the fill are matching the measurements.

Comparing with the cryogenic measurements

How is the P_{loss} normalized ?**In the same way of the measurements!**

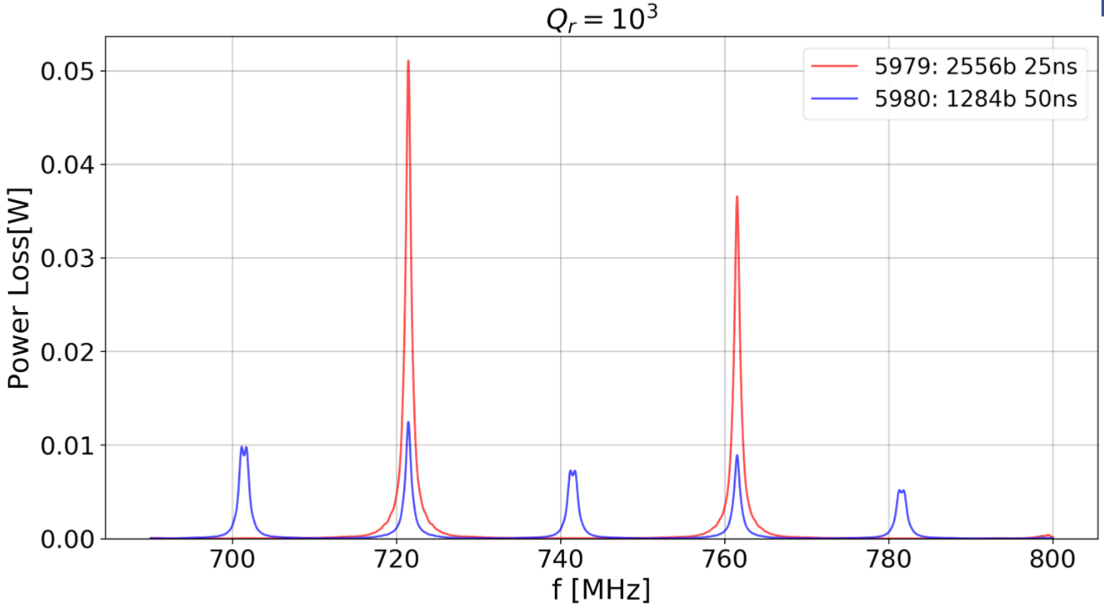
Once we get the $P_{loss}(f_r)$, to compare it with the measurements we have done the following operation:

- 1)Normalize each P_{loss} to the number of bunches (M)
- 2)Normalize each P_{loss} to the 100 ns case (lowest heating)
- 3)Normalize all the result to the factor obtained from the measurements: so the closer we get to 1, the more we are matching the measurements

Because the impedance **is not a function of the filling scheme**, we have looked for the frequencies where the Power Losses computed **for each filling scheme** were closer to 1.

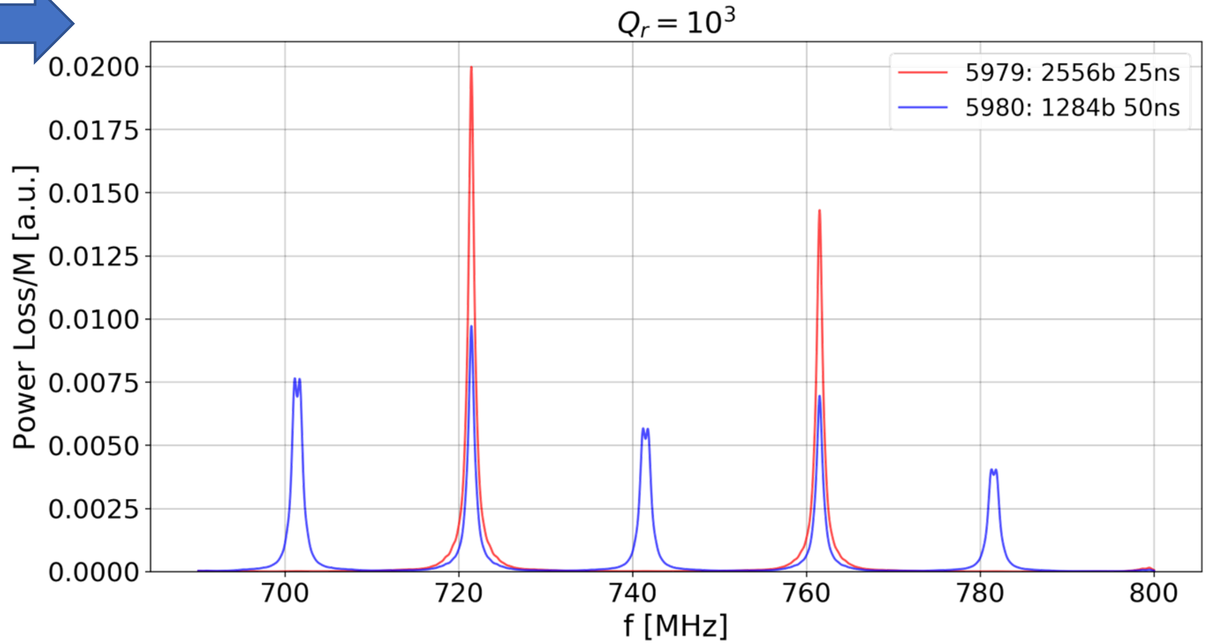
1)Normalize each P_{loss} to the number of bunches(M)

Before



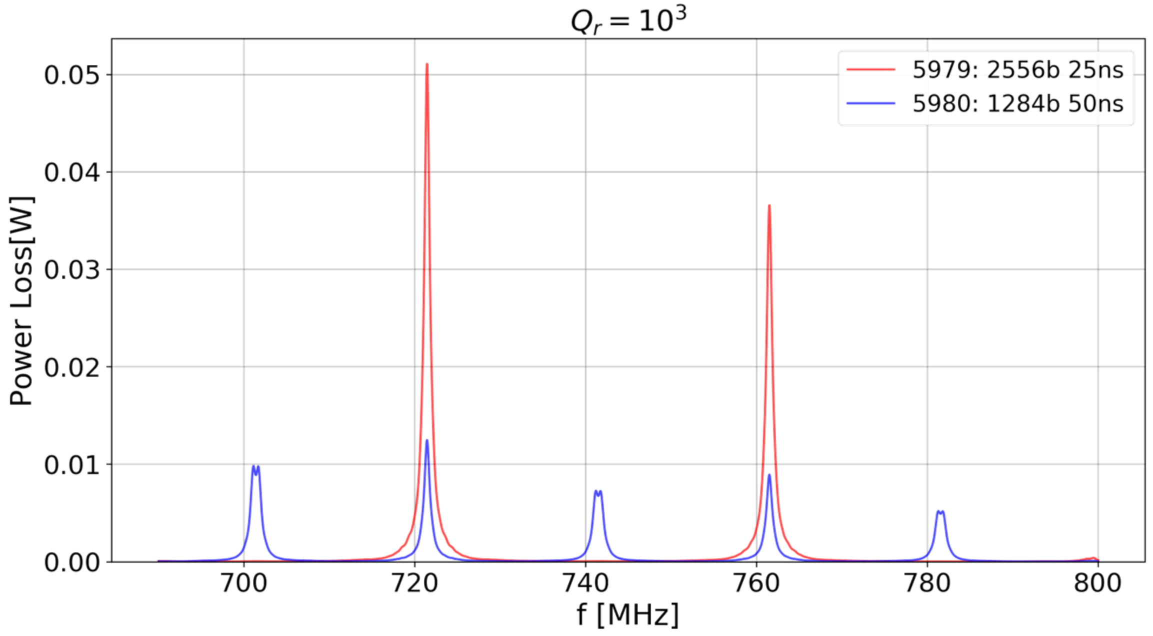
$\frac{1}{M}$

After

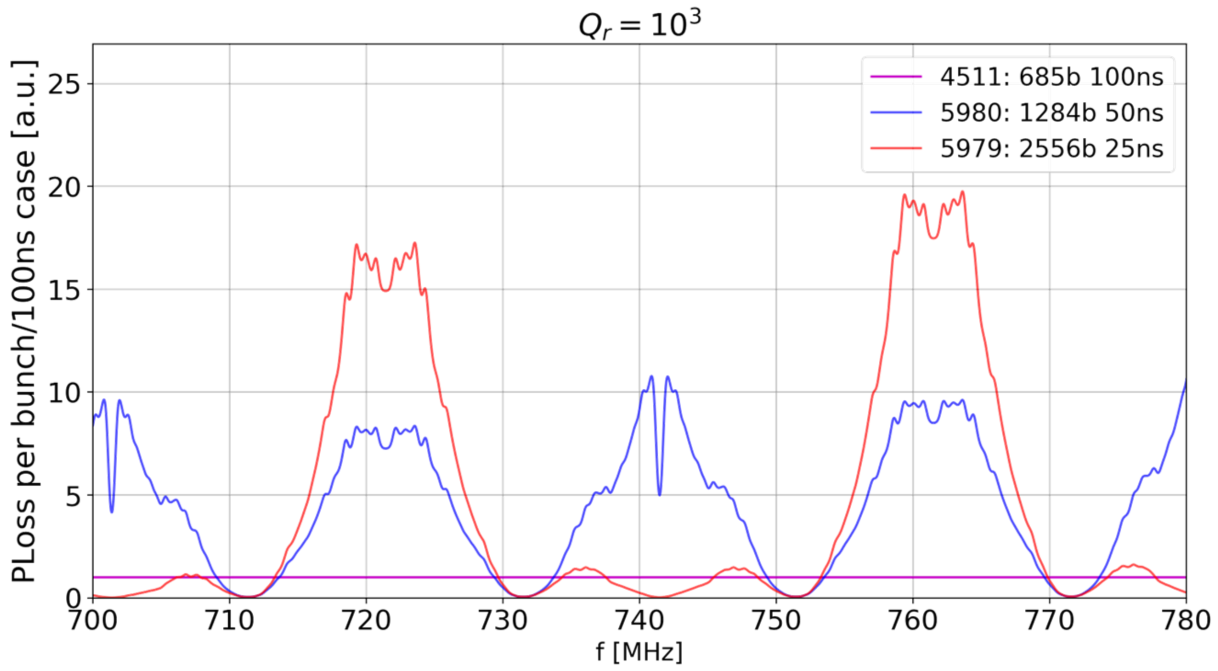


2)Normalize each P_{loss} to the 100 ns case (lowest heating)

Before

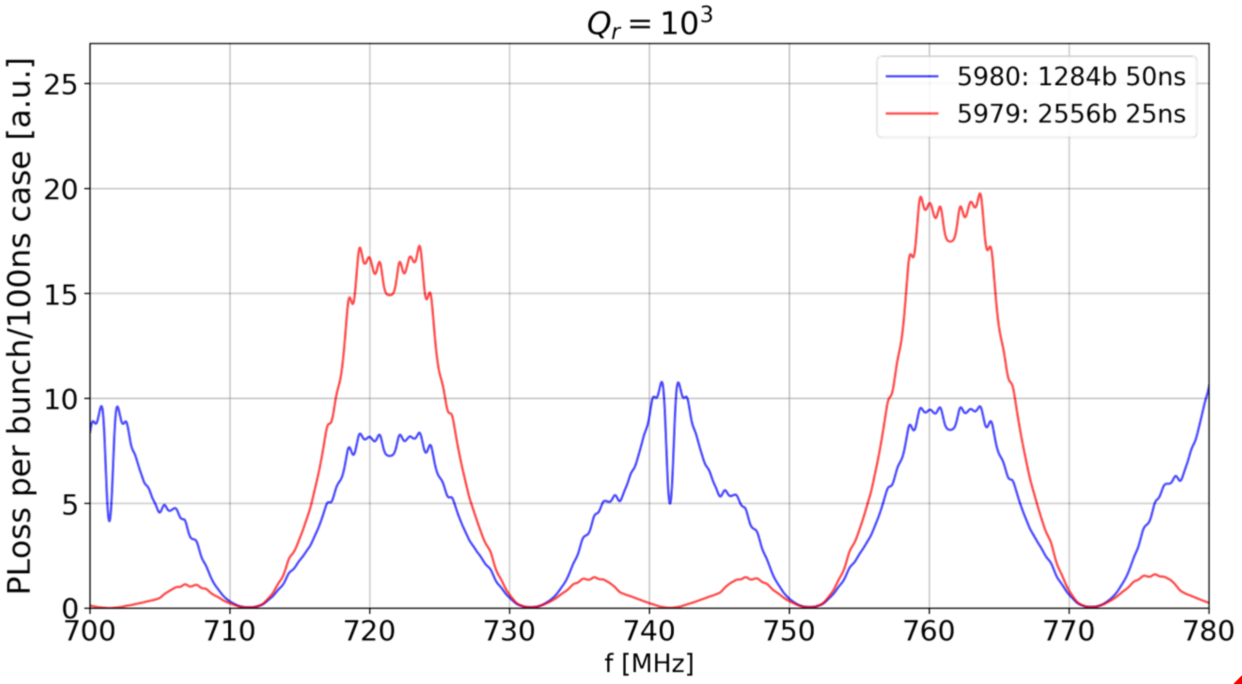


After

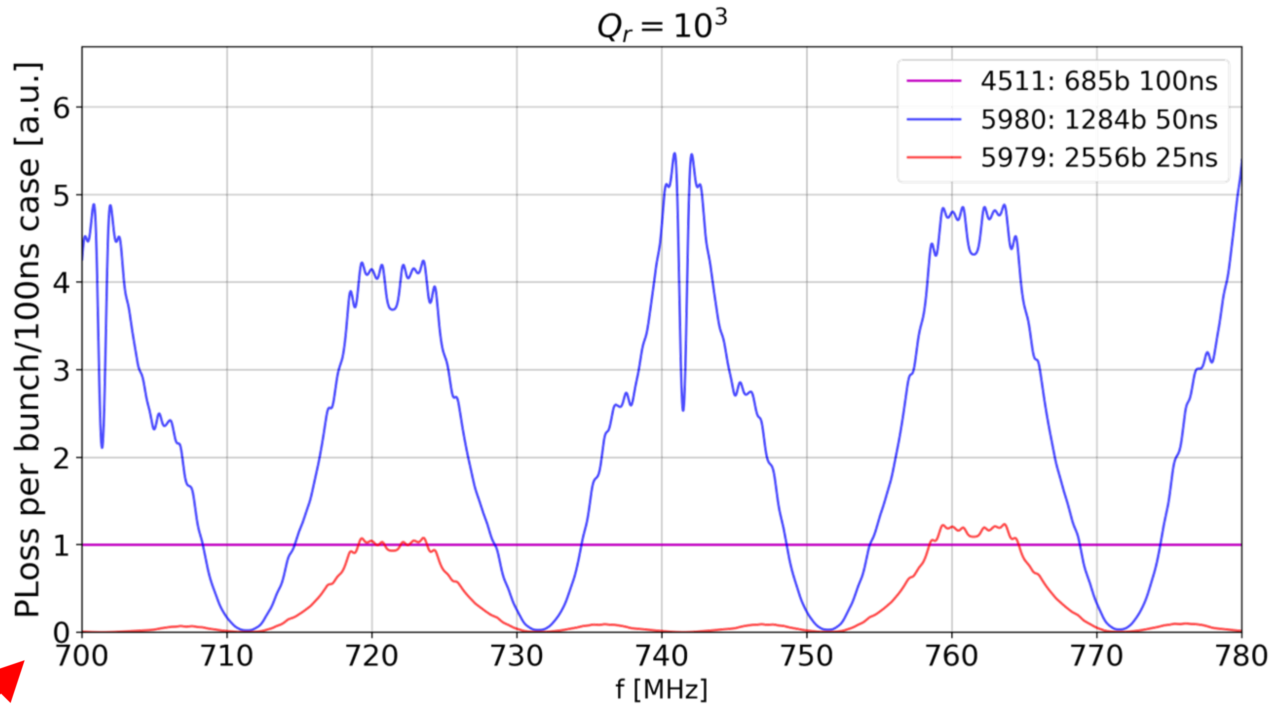


3)Normalize all the result to the factor obtained from the measurements

Before



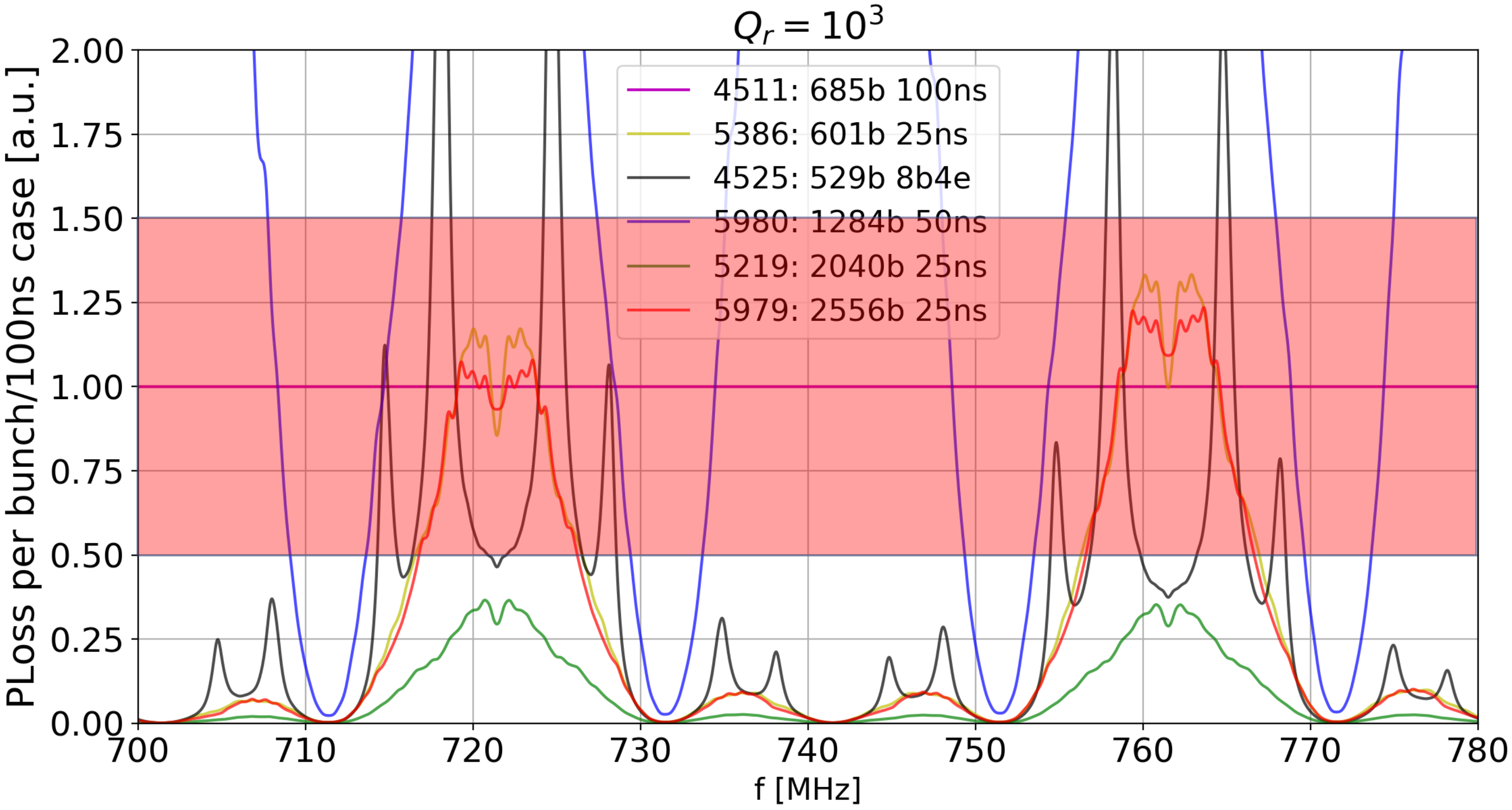
After



We look for a frequency where **all the curves** are closer to 1

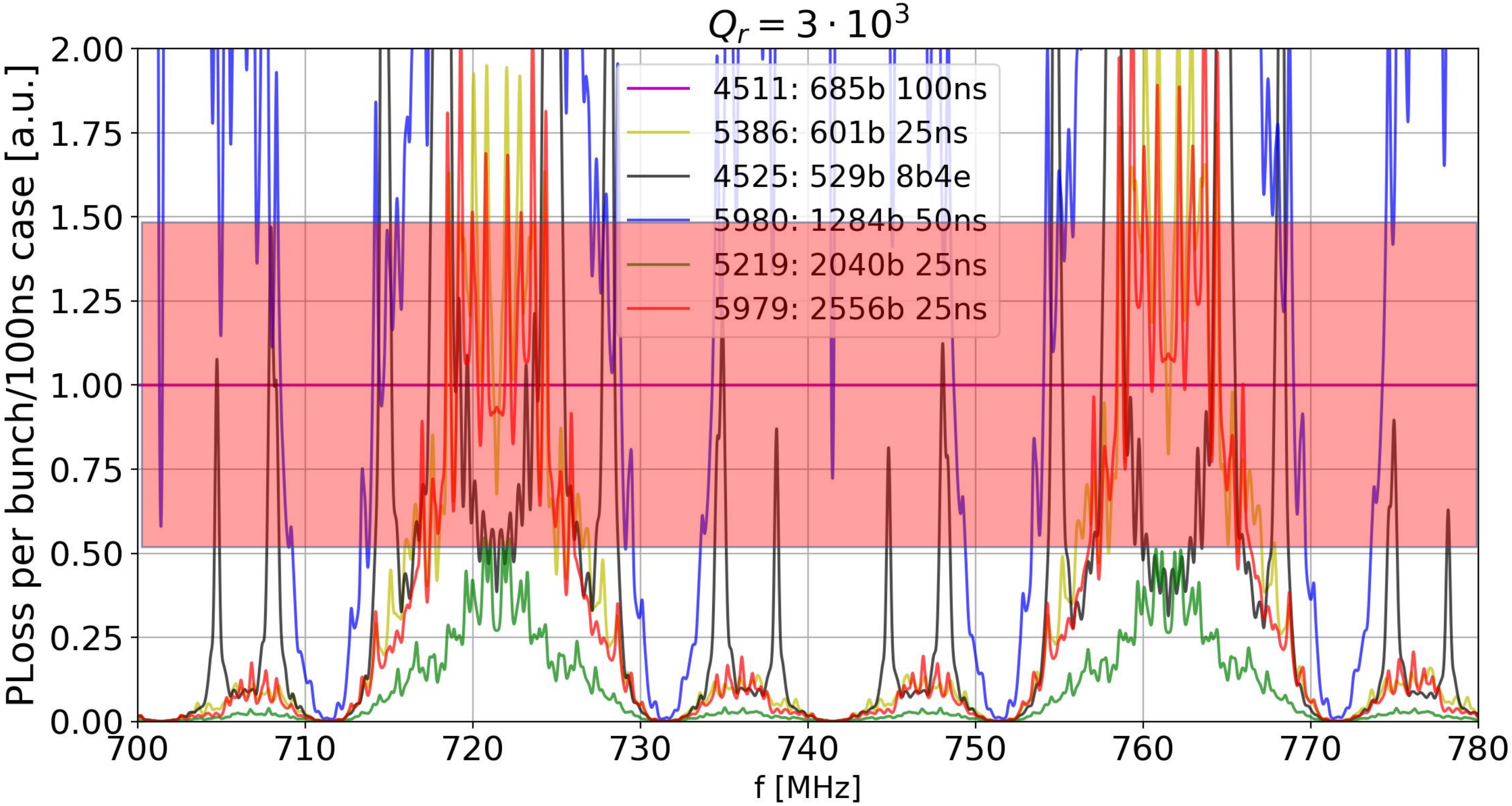
Taking in account all the fills studied we get: [1/5]

Q_r is increasing..



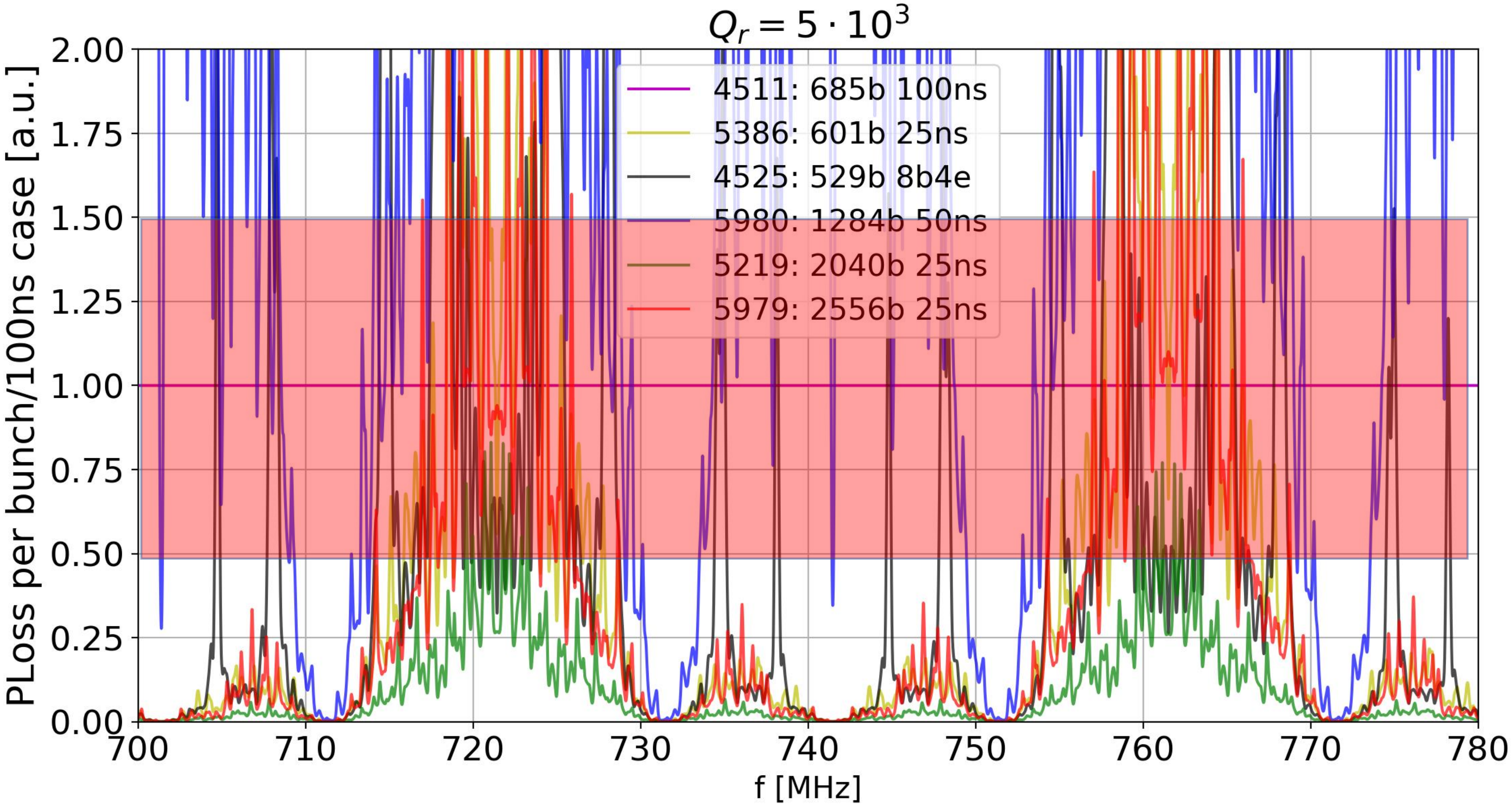
Taking in account all the fills studied we get: [2/5]

Q_r is increasing..



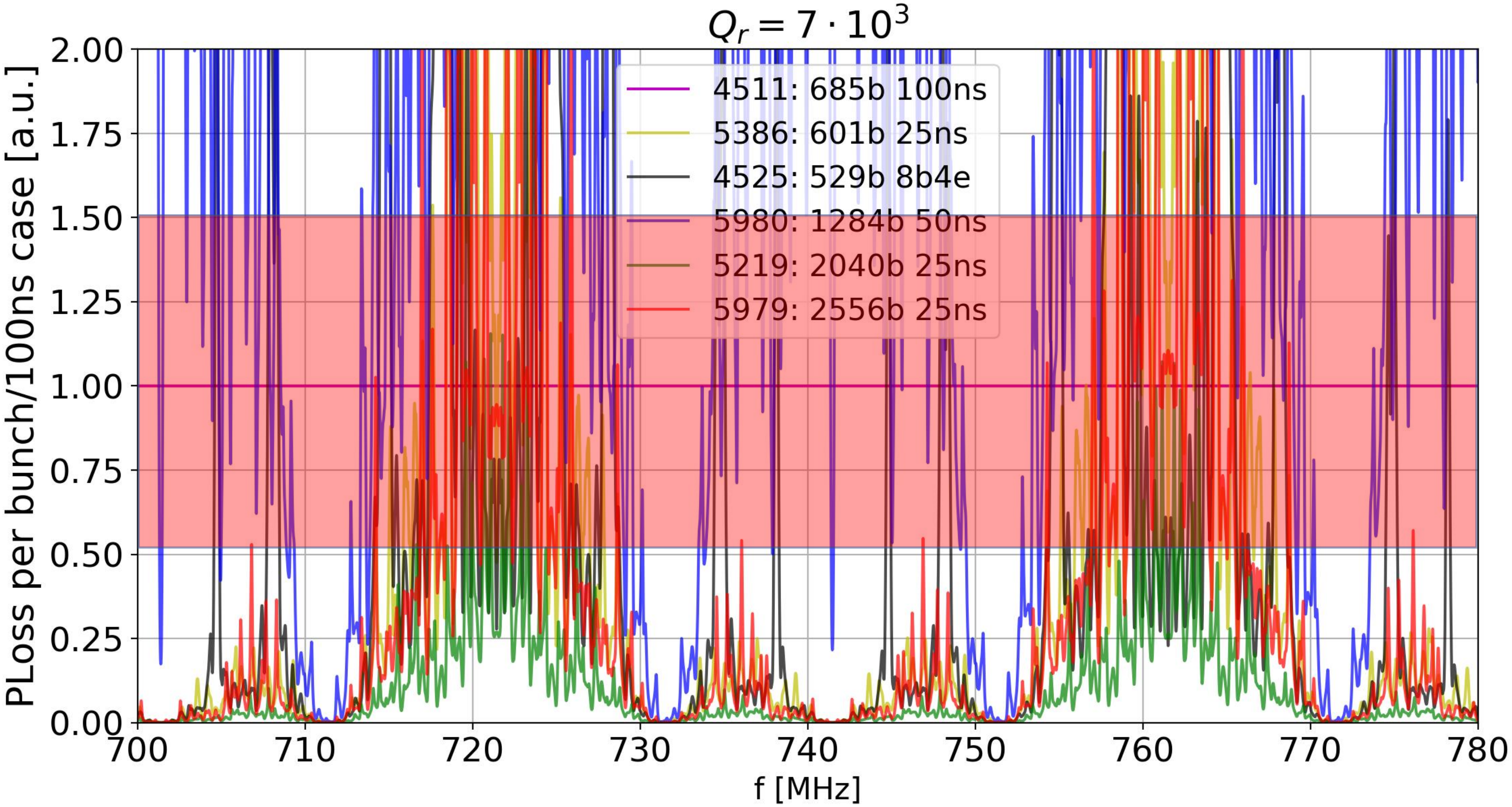
Taking in account all the fills studied we get: [3/5]

Q_r is increasing..



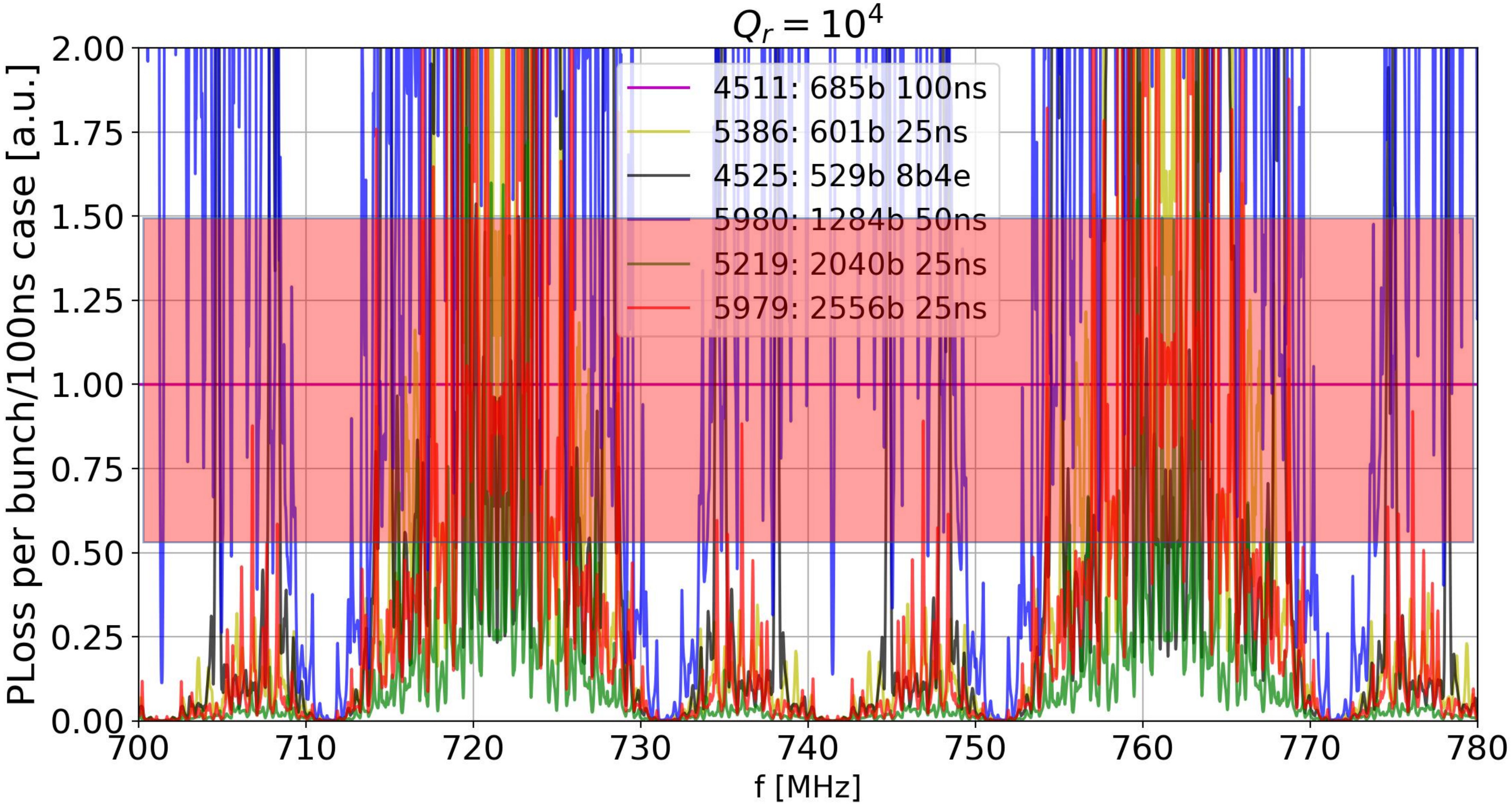
Taking in account all the fills studied we get: [4/5]

Q_r is increasing..



Taking in account all the fills studied we get: [5/5]

Q_r is increasing..



Is there any frequency that explain that heating?

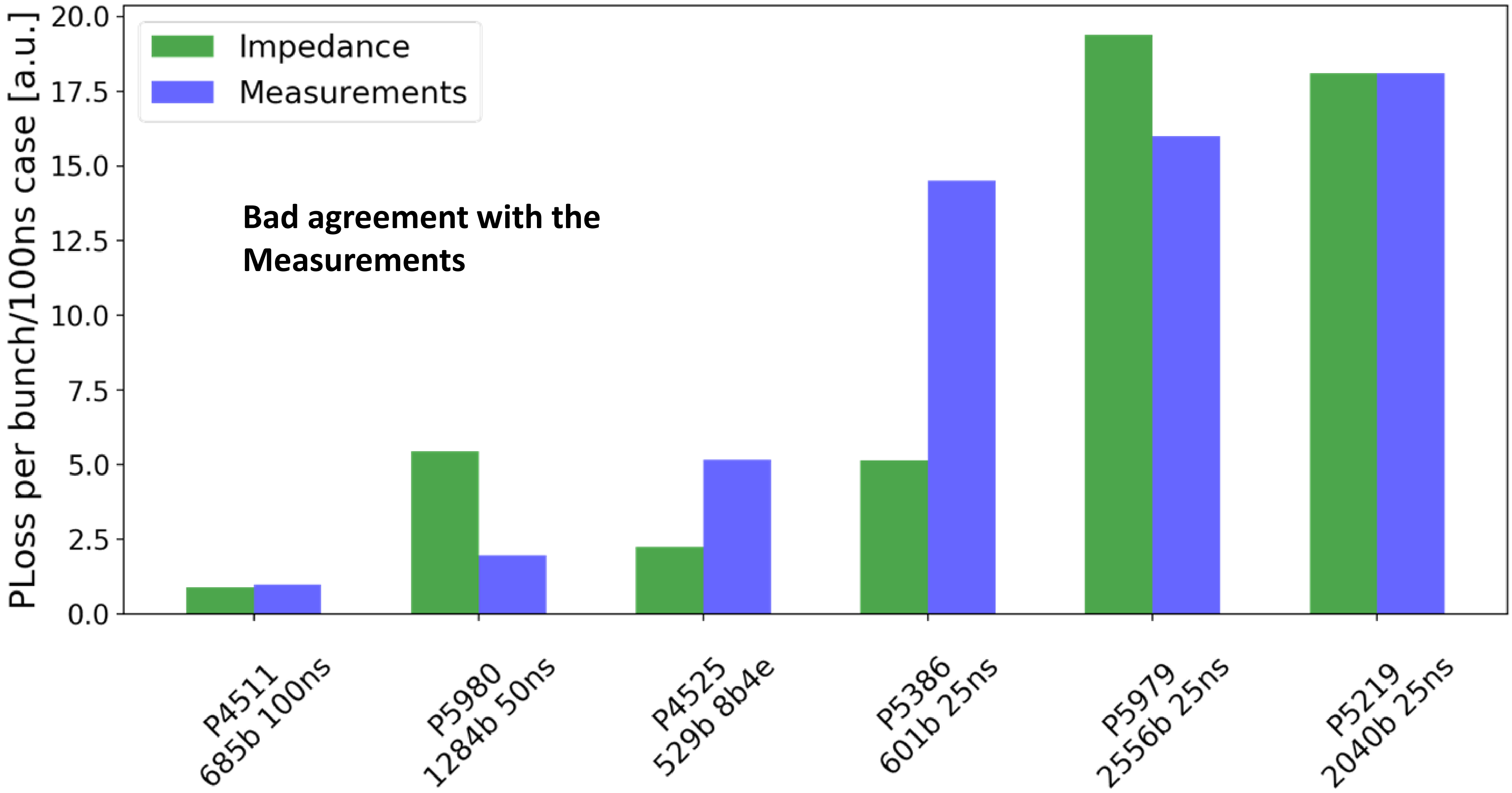
Being pessimistic on the measurement accuracy, we have looked with an algorithm to the frequencies where all the P_{loss} were within $\mp 50\%$ from 1 and we found **no one.**

If we extend the range to $\mp 65\%$ we found a frequency : 764.03MHz.
That frequency exist only for $Q_r = 10^4$.

Given this frequency we can check if we match the cryogenic measurements.

Measurements Comparison

-R_s $needed$: $9.4M\Omega$
-$f_r = 764.03MHz$
-$Q_r = 10^4$



Conclusions

- The ratio between the 25ns and the 50ns Ploss is too huge to be explained with an impedance.
- The only frequency that seems give us an impedance that get close to the measurements does not match all the measurements for all the fills.
- The Shunt Impedance needed for the only frequency found in order to match the heating is too huge to be reasonable.
- This Impedance should be the same for all the sectors → It is even more improbable that this impedance exist

Binomial Distribution formula

https://cernbox.cern.ch/index.php/s/6aGnq8rDMooBTDD