Multi-frequency Harmonic Cavity System at MAX IV

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On behalf of

Pedro F. Tavares, Lars Malmgren, Francis Cullinan, Mikael Eriksson, Miriam Brosi, Aleksander Mitrovic, Robert Nilsson, Robin Svärd …

iFAST Low Emittance Rings workshop 13th – 16th of February 2024

Outline

- ❑Introduction
- ❑Implementation calculations for the MAX IV case
- ❑Time plan
- ❑Summary

Introduction

LEP/70-25

ISR-RF-TH/PB/AH/PBW/ps

12th December 1977

A higher harmonic cavity to increase the bunch length in LEP-70

P. Bramham, A. Hofmann, P.B. Wilson

2. Theory

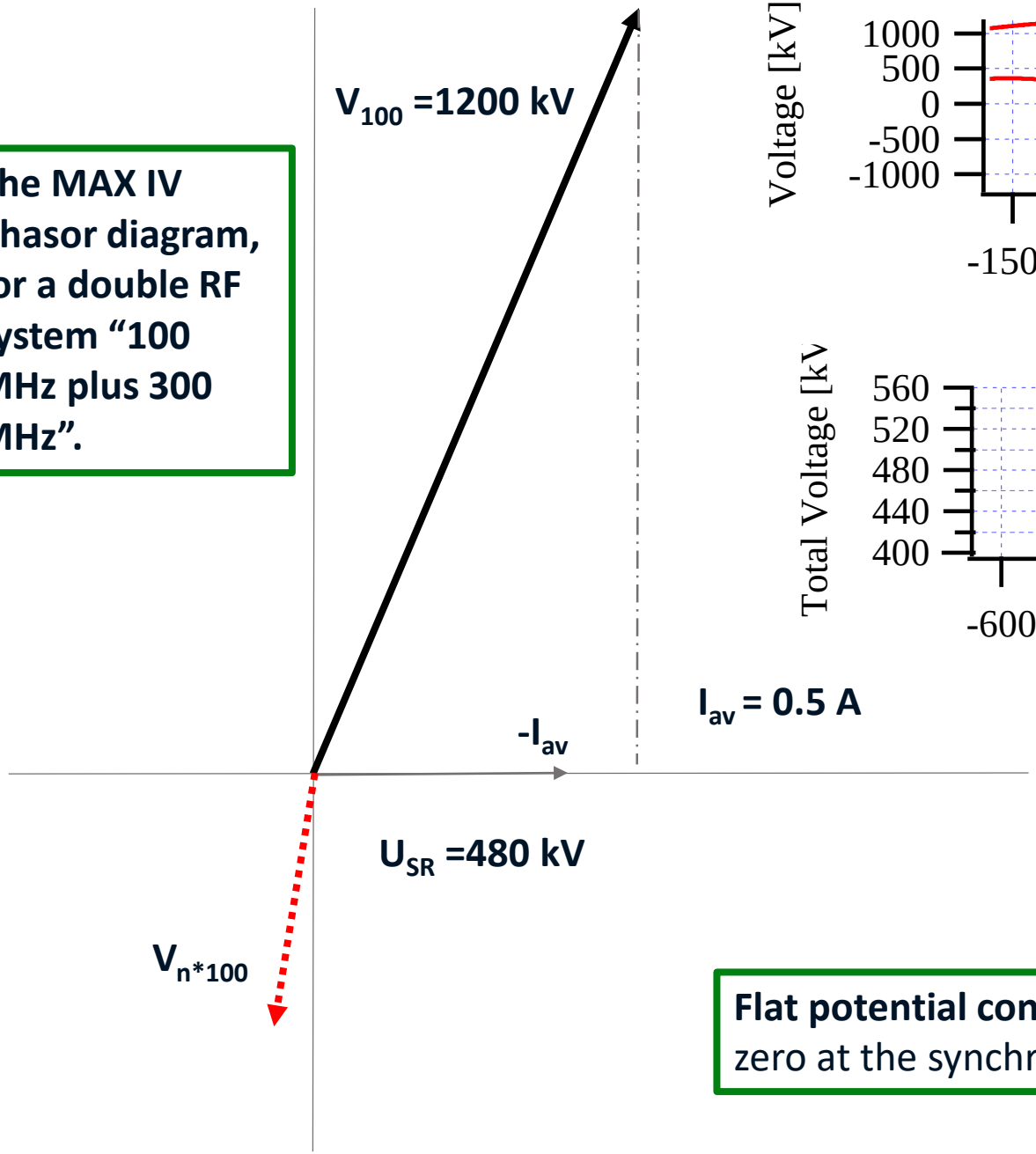
We assume a main RF system with amplitude V_o, frequency ω_{RF} and synchronous phase angle Φ_s and in addition a higher frequency system with amplitude $V_n = k\,V_o$, frequency $n\cdot\omega_{RF}$ and synchronous phase angle Φ_n (measured with respect to Φ_{RF}). The meaning of these parameters is illustrated in Fig. 1. Using Φ for the phase angle measured from the operating point

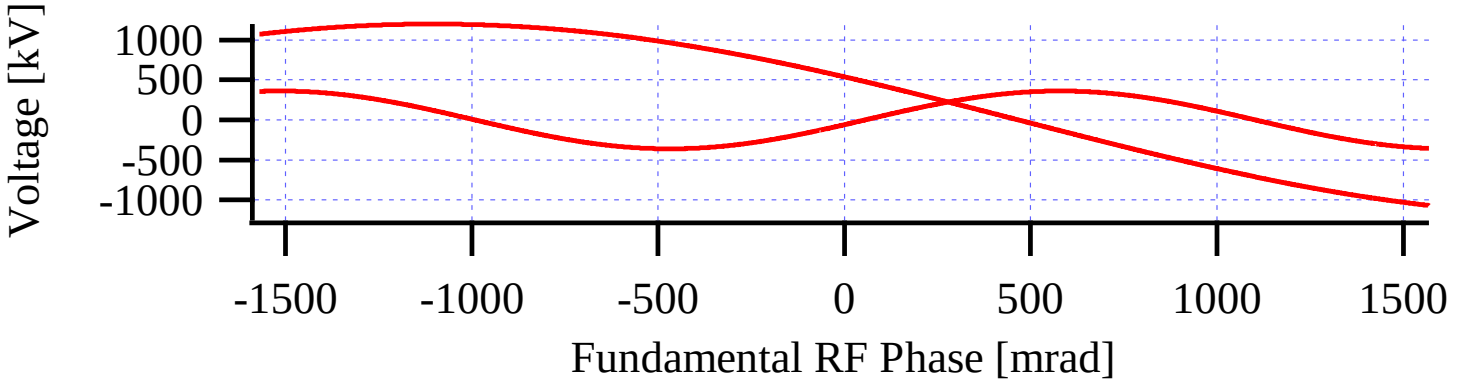
$$\Phi = \Phi_{RF} - \Phi_s = \omega_{RF} t - \Phi_s$$

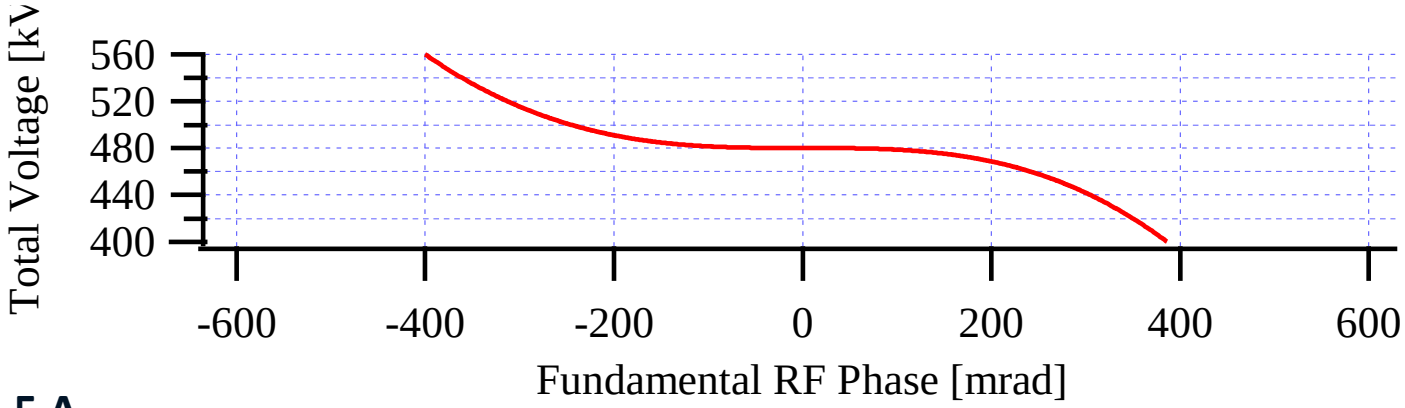
we get for the voltage $V(\Phi)$ seen by the particles in the beam

$$V(\Phi) = V_0 \left[\sin(\Phi + \Phi_s) + k \sin(n(\Phi + \Phi_n))\right] \qquad (1)$$

The MAX IV phasor diagram, for a double RF system “100 MHz plus 300 MHz”.

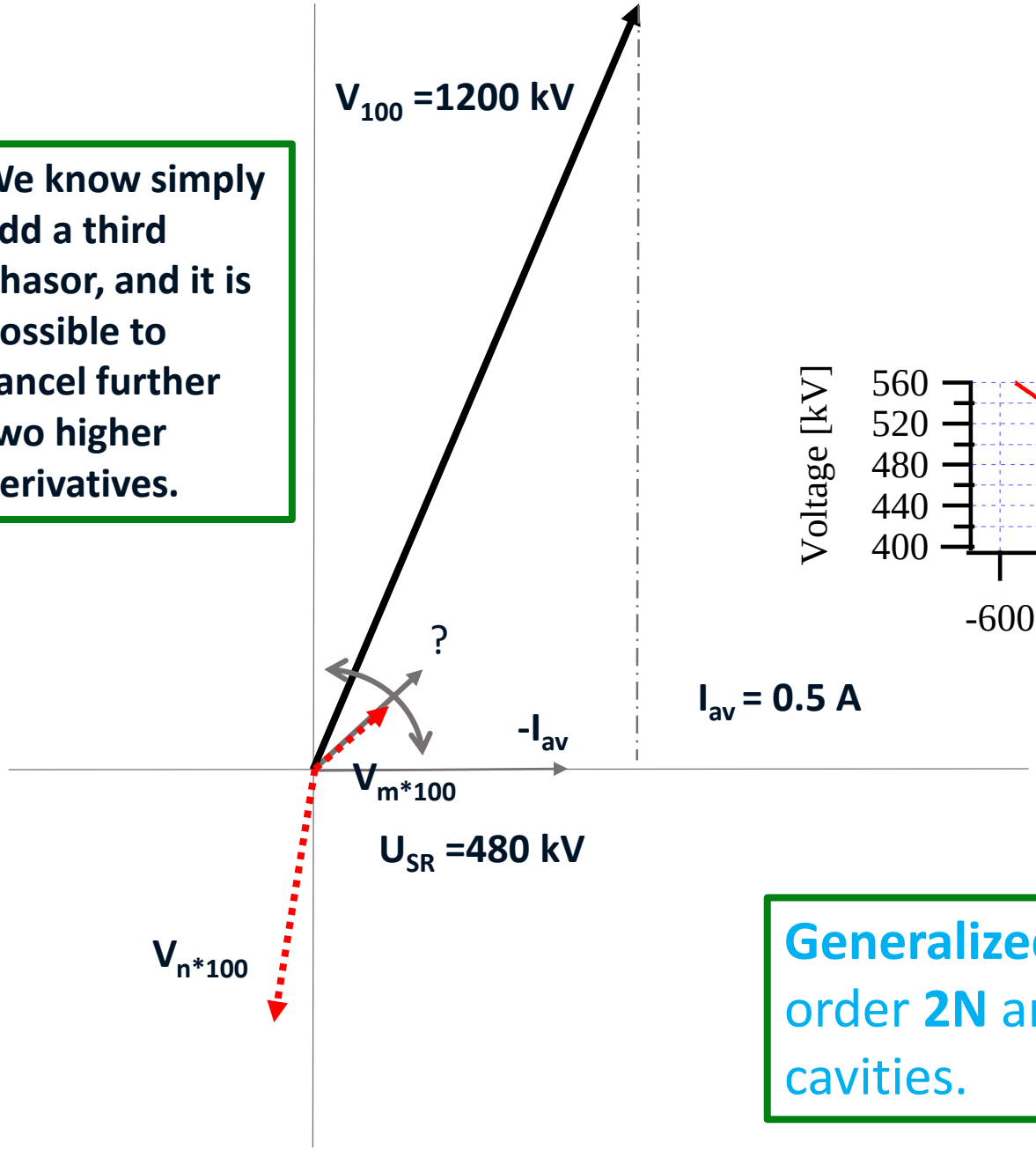


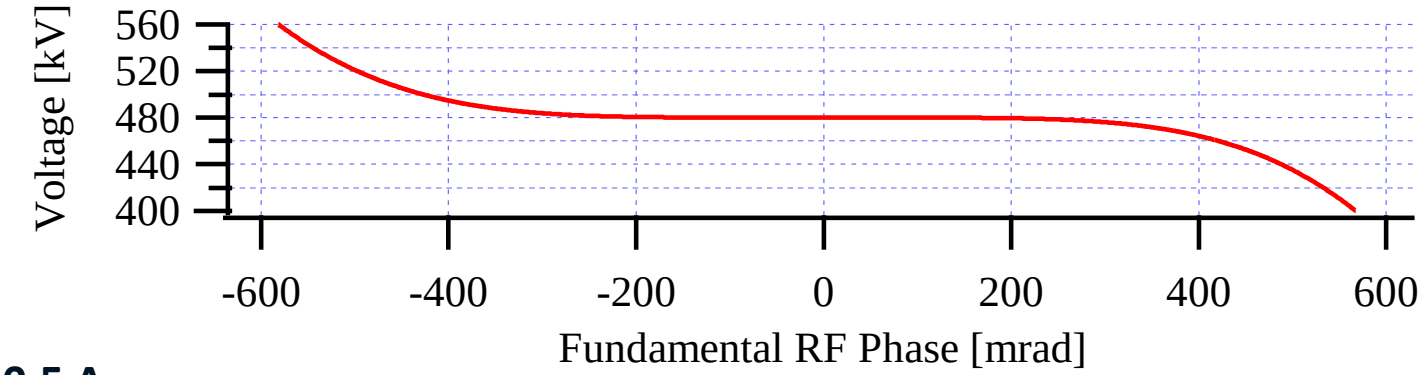




Flat potential conditions: First and second derivatives of the sum voltage, are zero at the synchronous phase. Can be achieved with **one** harmonic cavity.

We know simply add a third phasor, and it is possible to cancel further two higher derivatives.





Ultralong bunches for low emittance rings:

Generalized Flat Potential Conditions: Derivatives up to order **2N** are zero. Can be achieved with **N** harmonic cavities.

Triple RF system for reducing IBS and Touschek effects in MAX IV.

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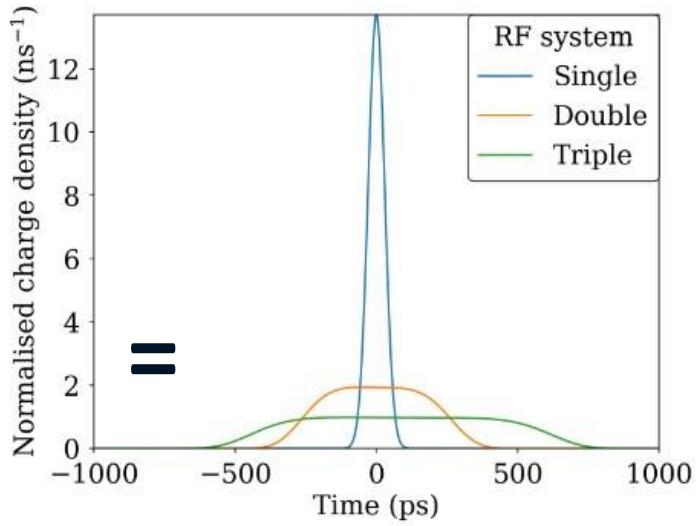
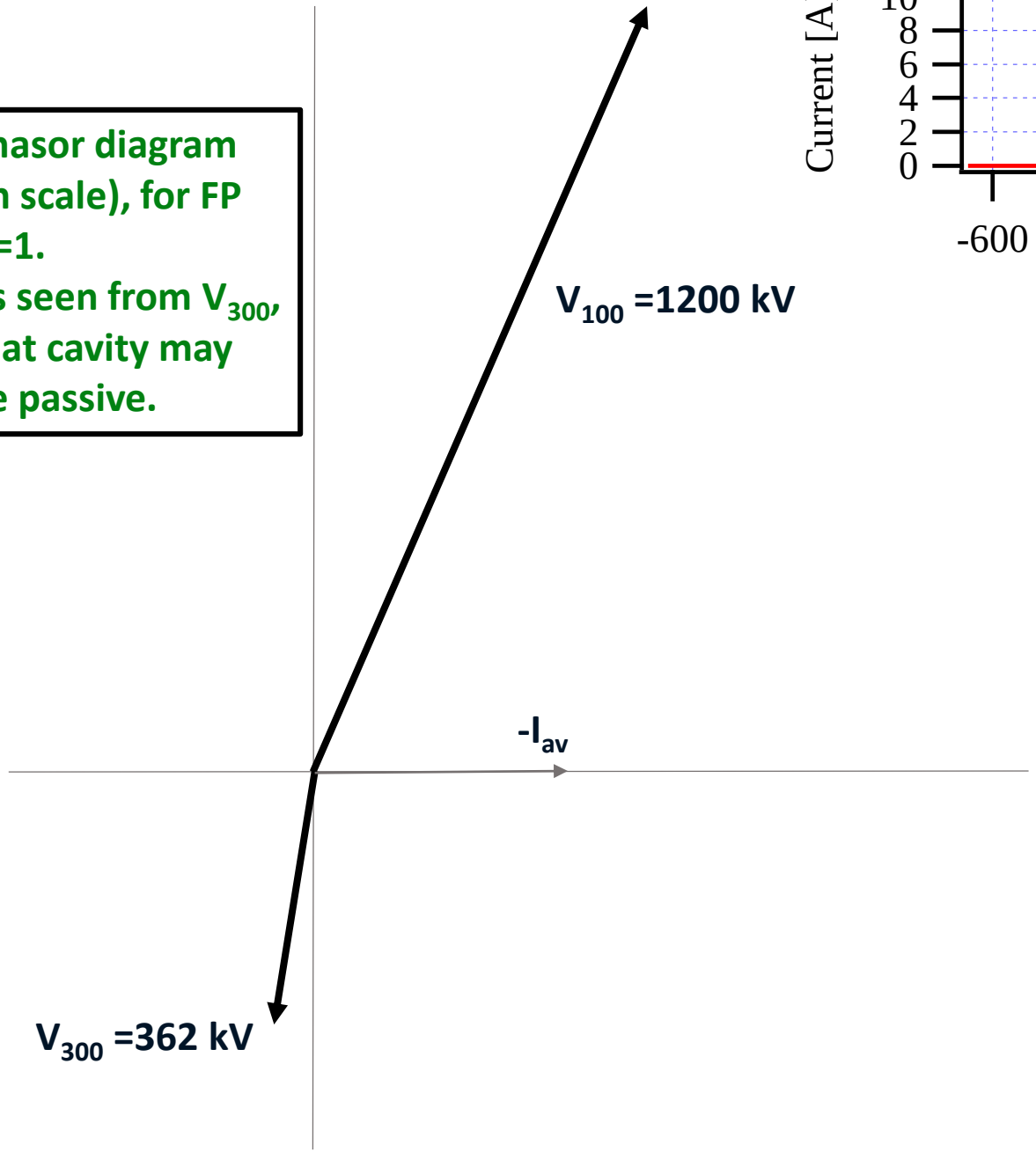
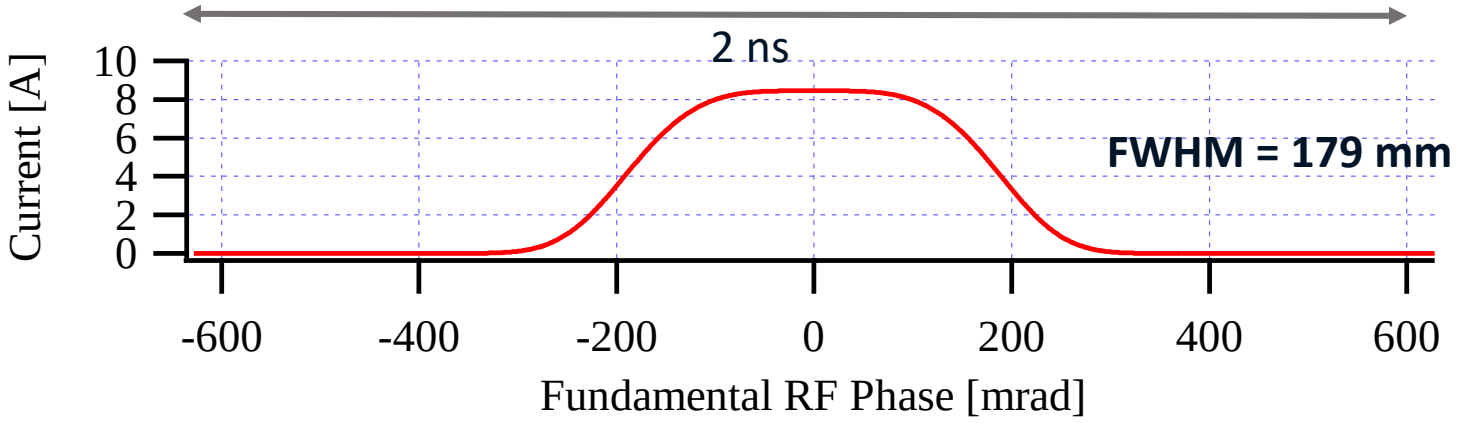
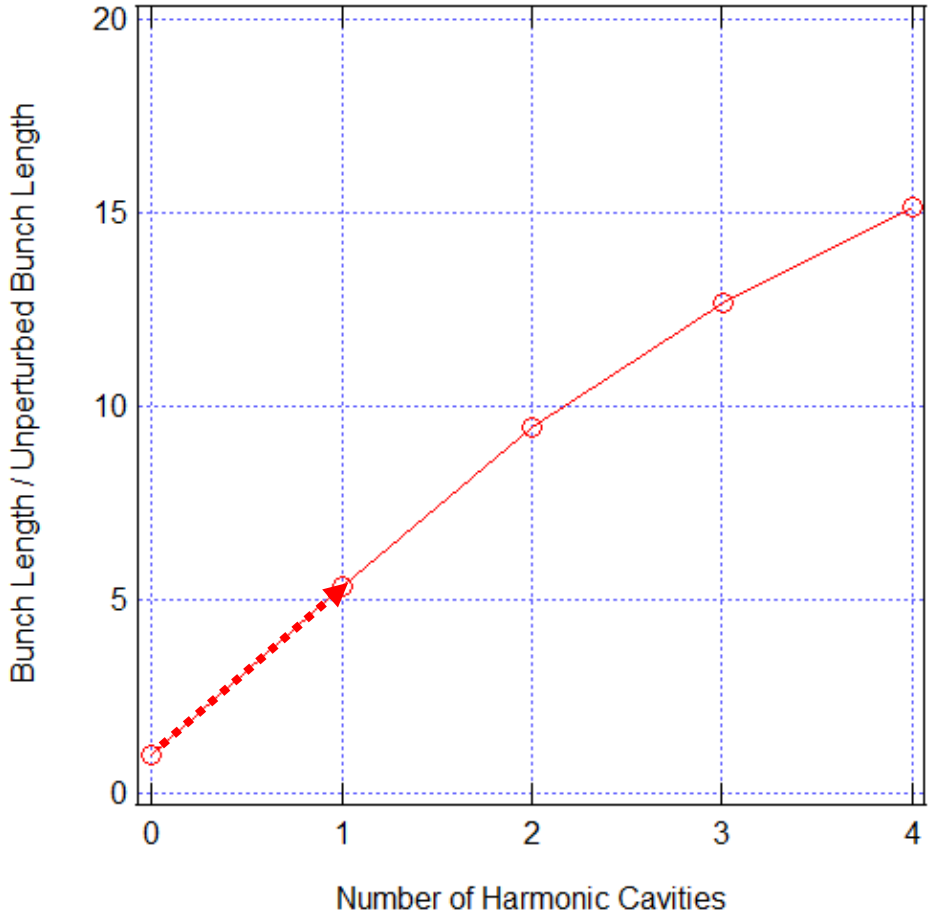


Plot: Curtesy of F. Cullinan

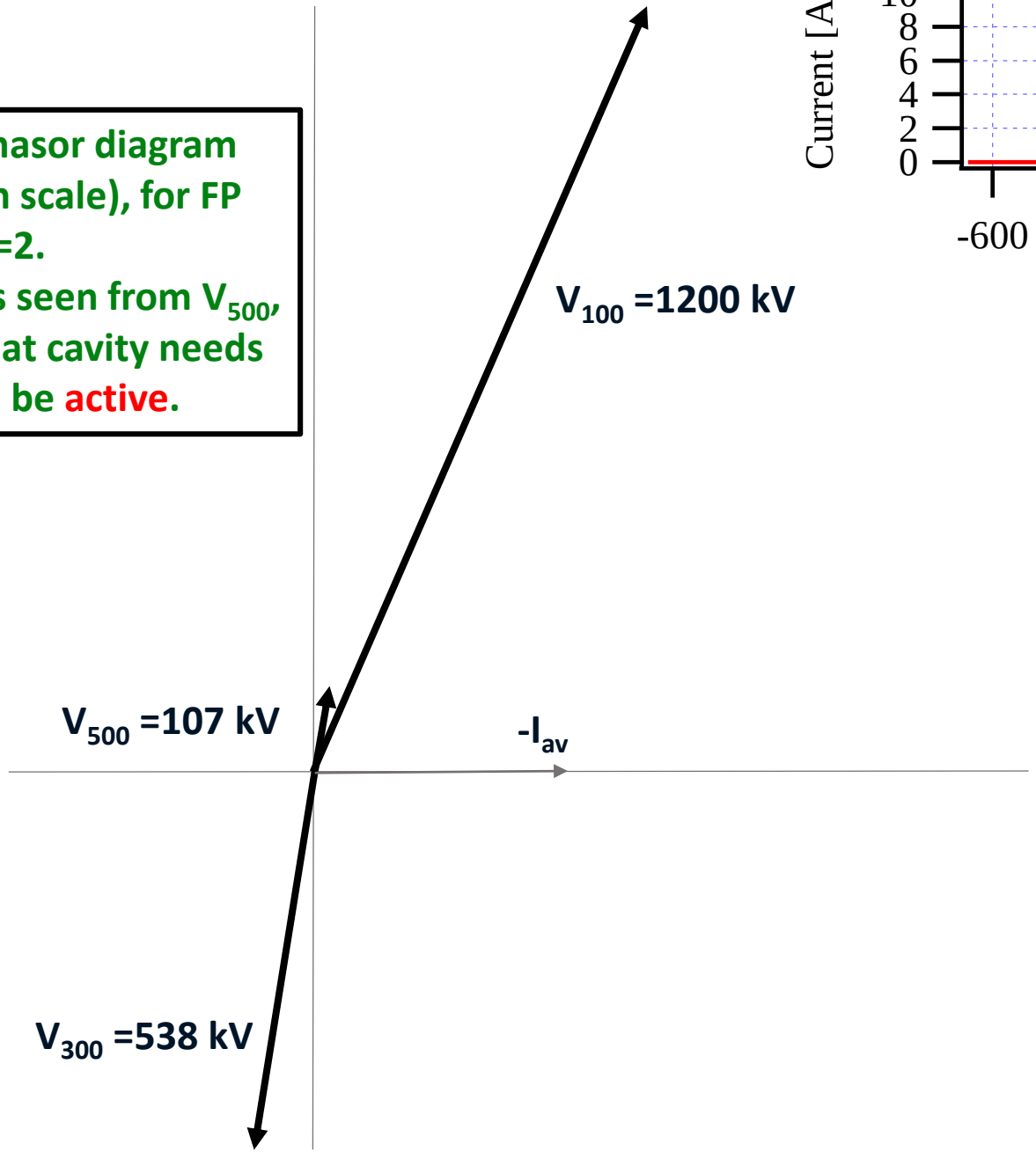
Phasor diagram (in scale), for FP N=1.
As seen from V_{300}, that cavity may be passive.

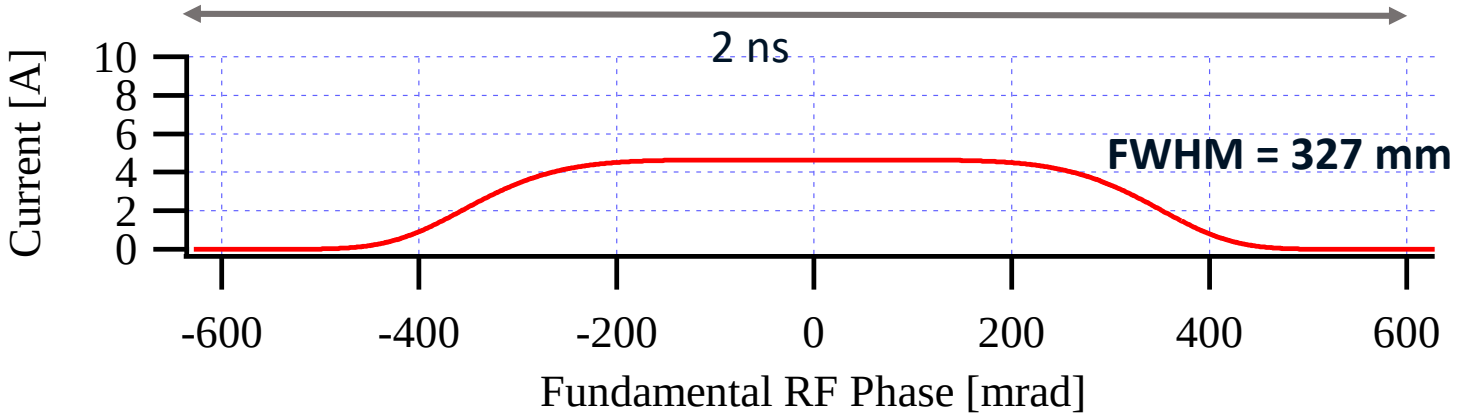


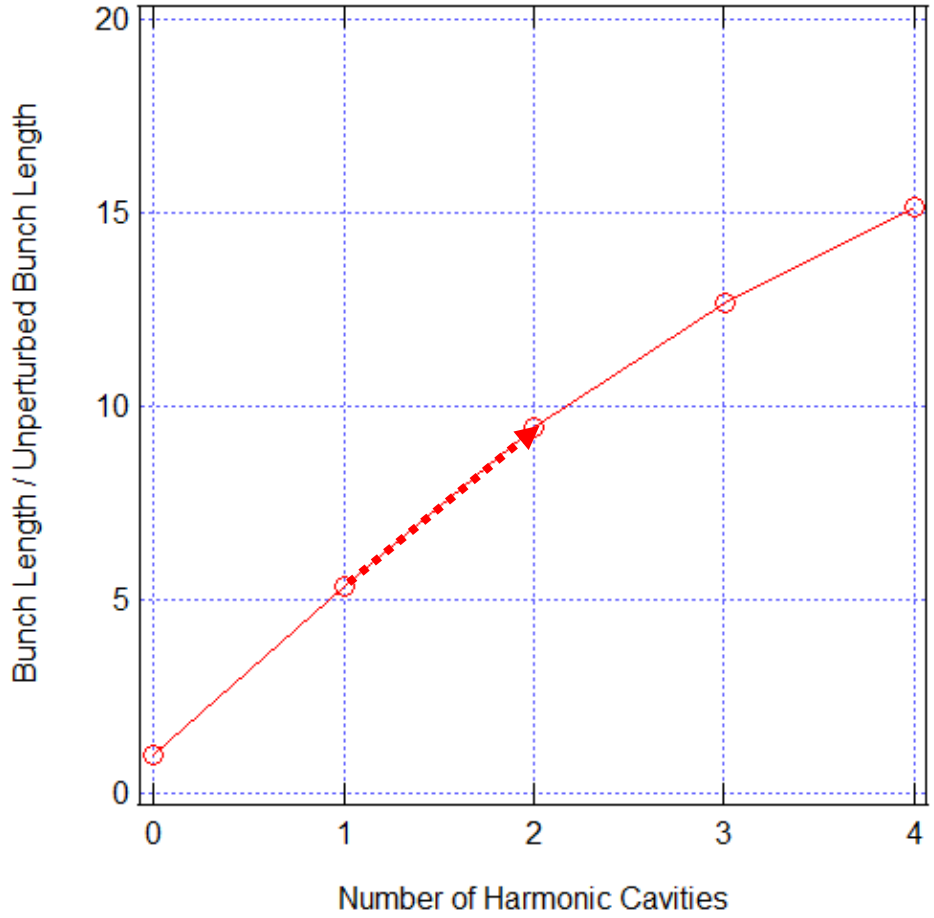




Phasor diagram (in scale), for FP N=2.
As seen from V_{500}, that cavity needs to be active.







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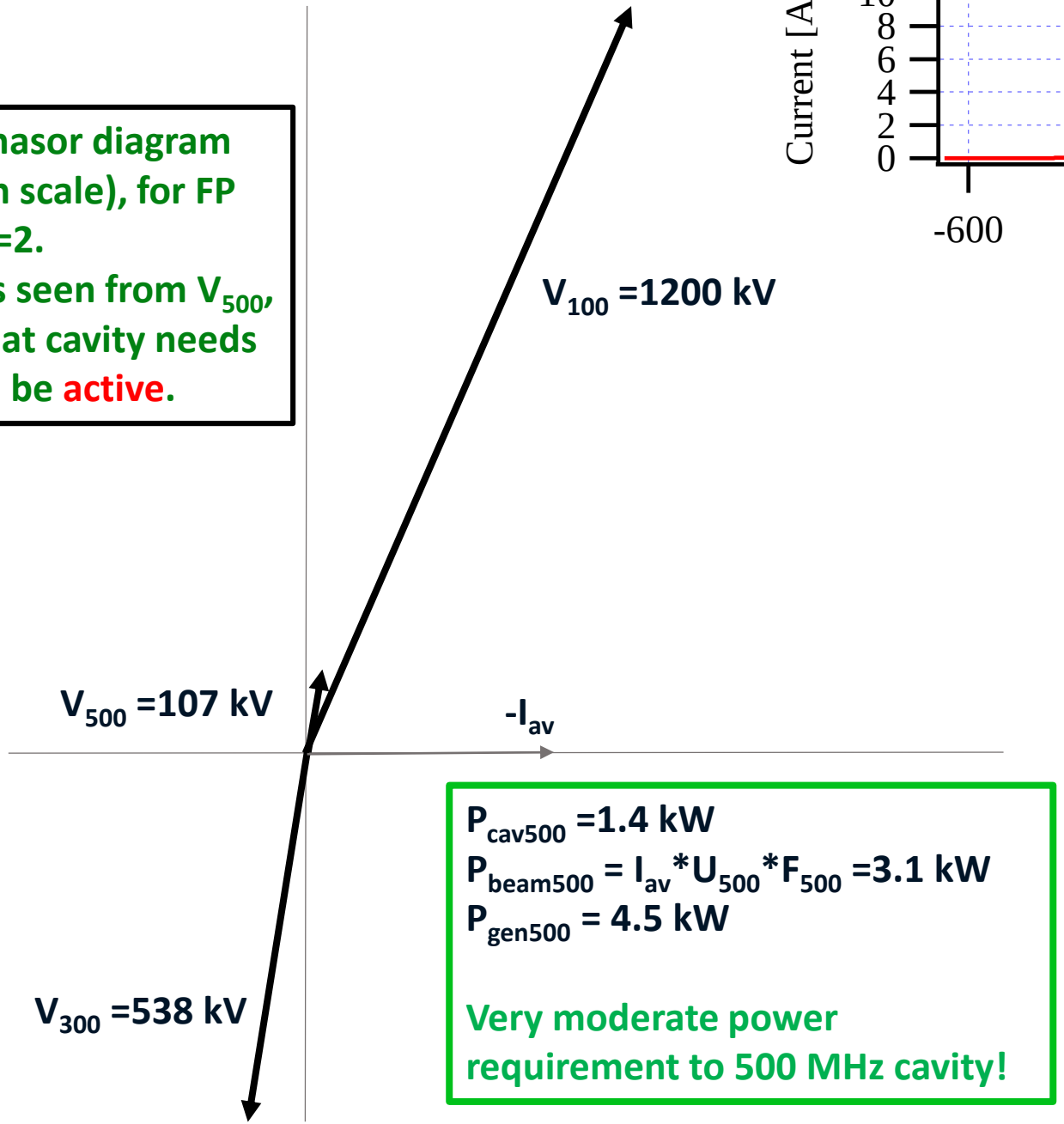
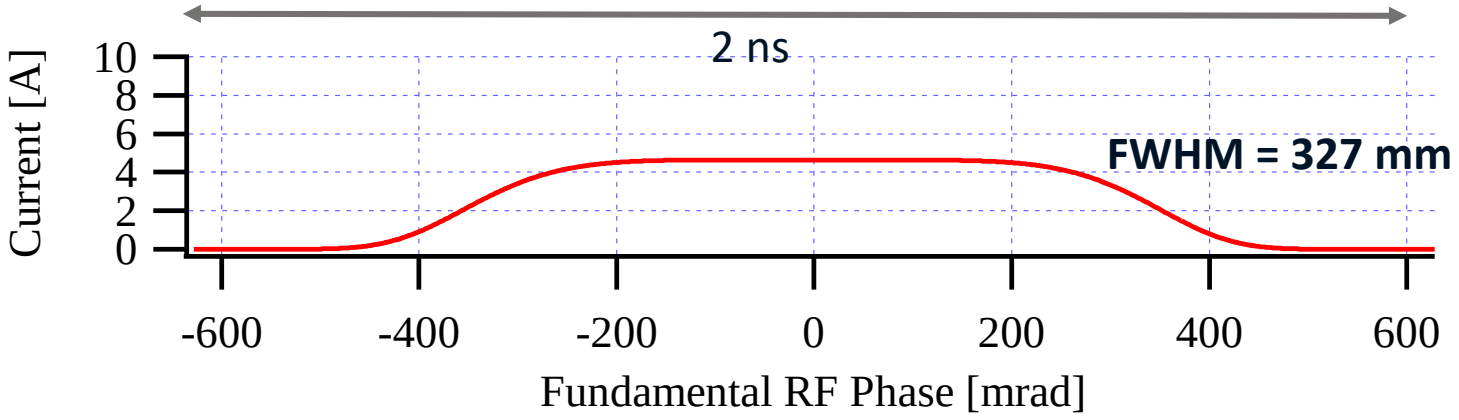
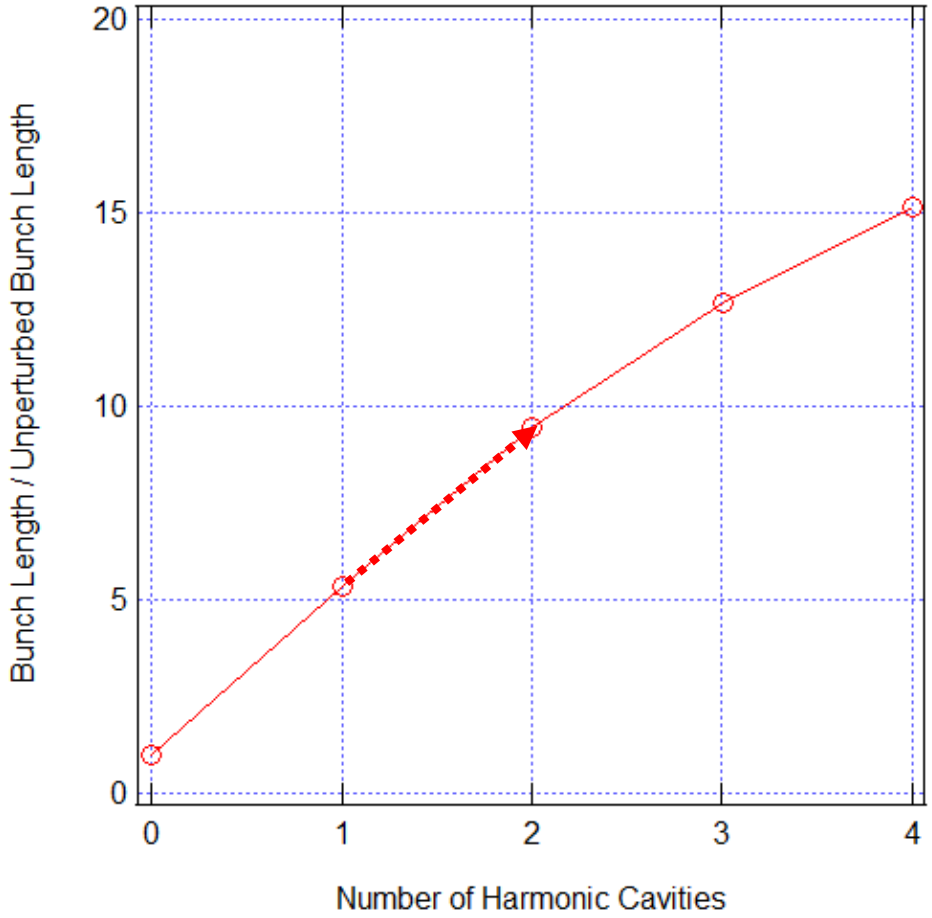
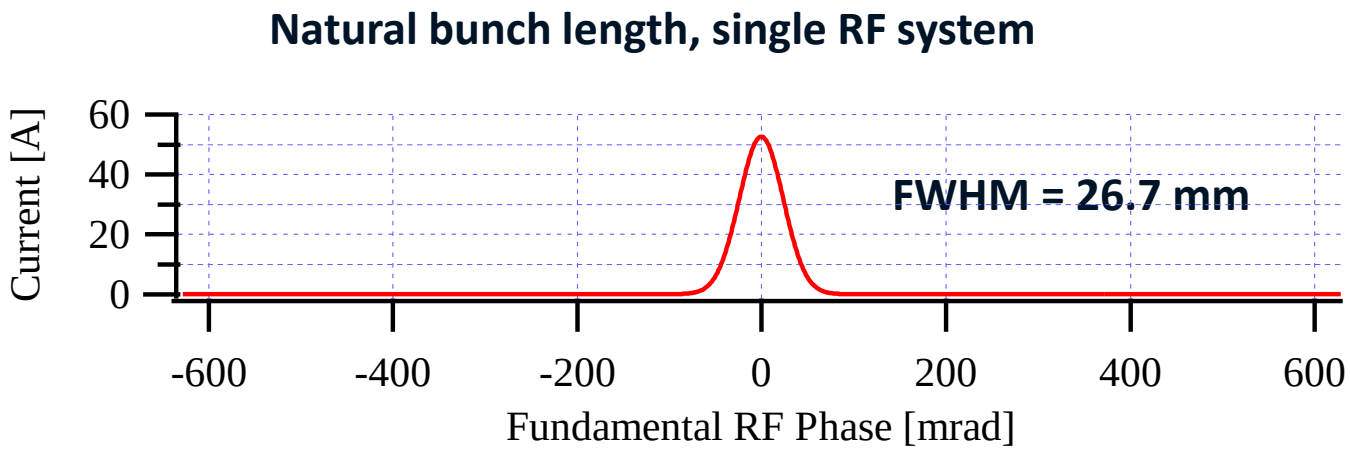


P_{cav500} =1.4 kW
$P_{beam500} = I_{av} * U_{500} * F_{500}$ =3.1 kW
P_{gen500} = 4.5 kW

Very moderate power requirement to 500 MHz cavity!







Lengthening ratios:

At FP	RMS-lengthening	FWHM-lengthening
1 HC frequency	5.0	6.7
2 HC frequencies	8.7	12.2

Coming back to the introduction paper:

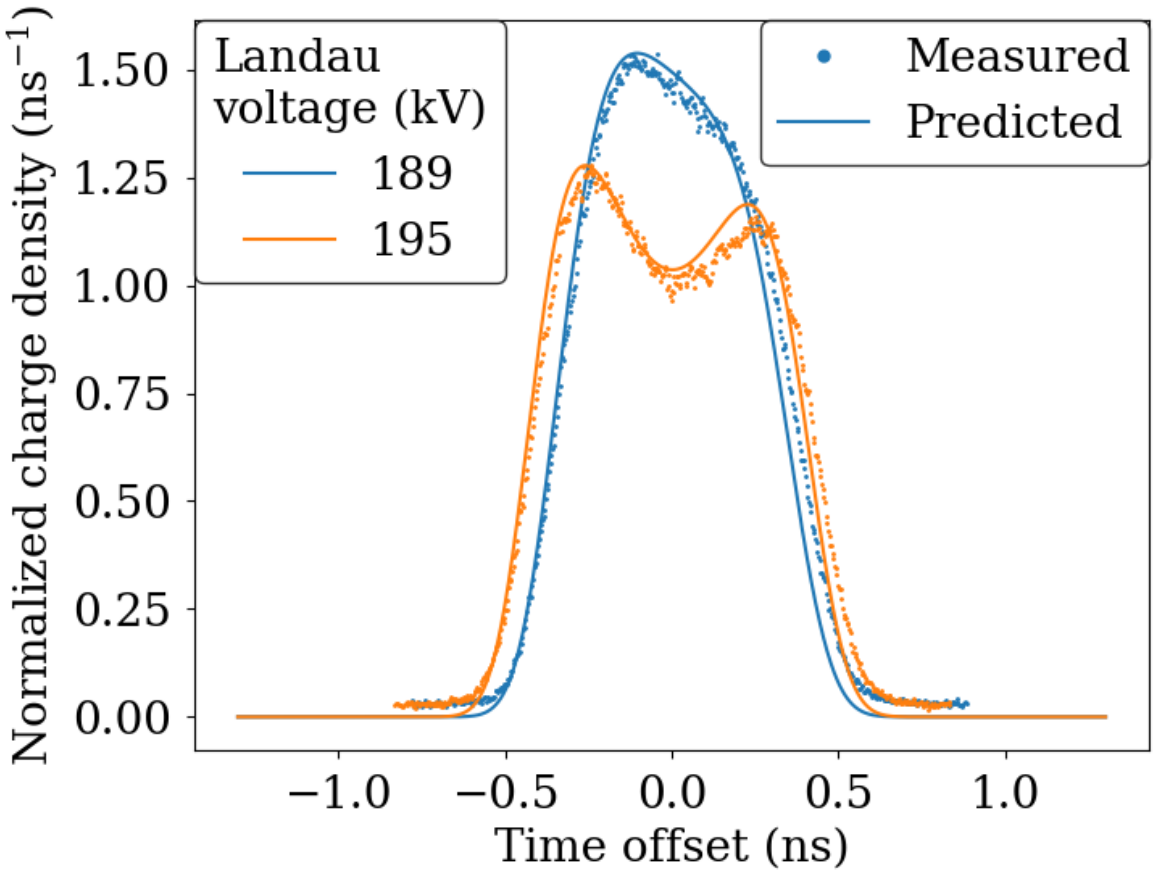
To obtain a large increase of the bunch length we make the slope of the RF wave form zero at the bunch

$$\frac{dV}{d\bar{\Phi}}(0) = V_0 \left[\cos \bar{\Phi}_s + nk \cos(n\bar{\Phi}_n)\right] = 0 \qquad (3)$$

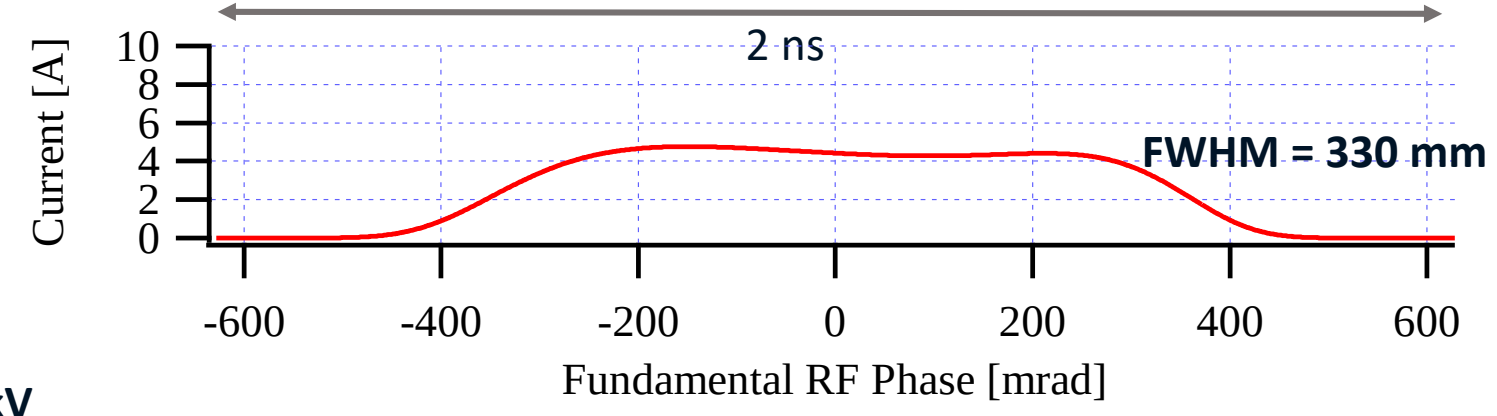
Furthermore we would like to avoid the wave form having a maximum or minimum at the bunch. This could form a small bucket inside the normal bucket. Although this would probably do no harm regarding the operation of the cavity, it makes the analysis more complicated. To avoid this we demand

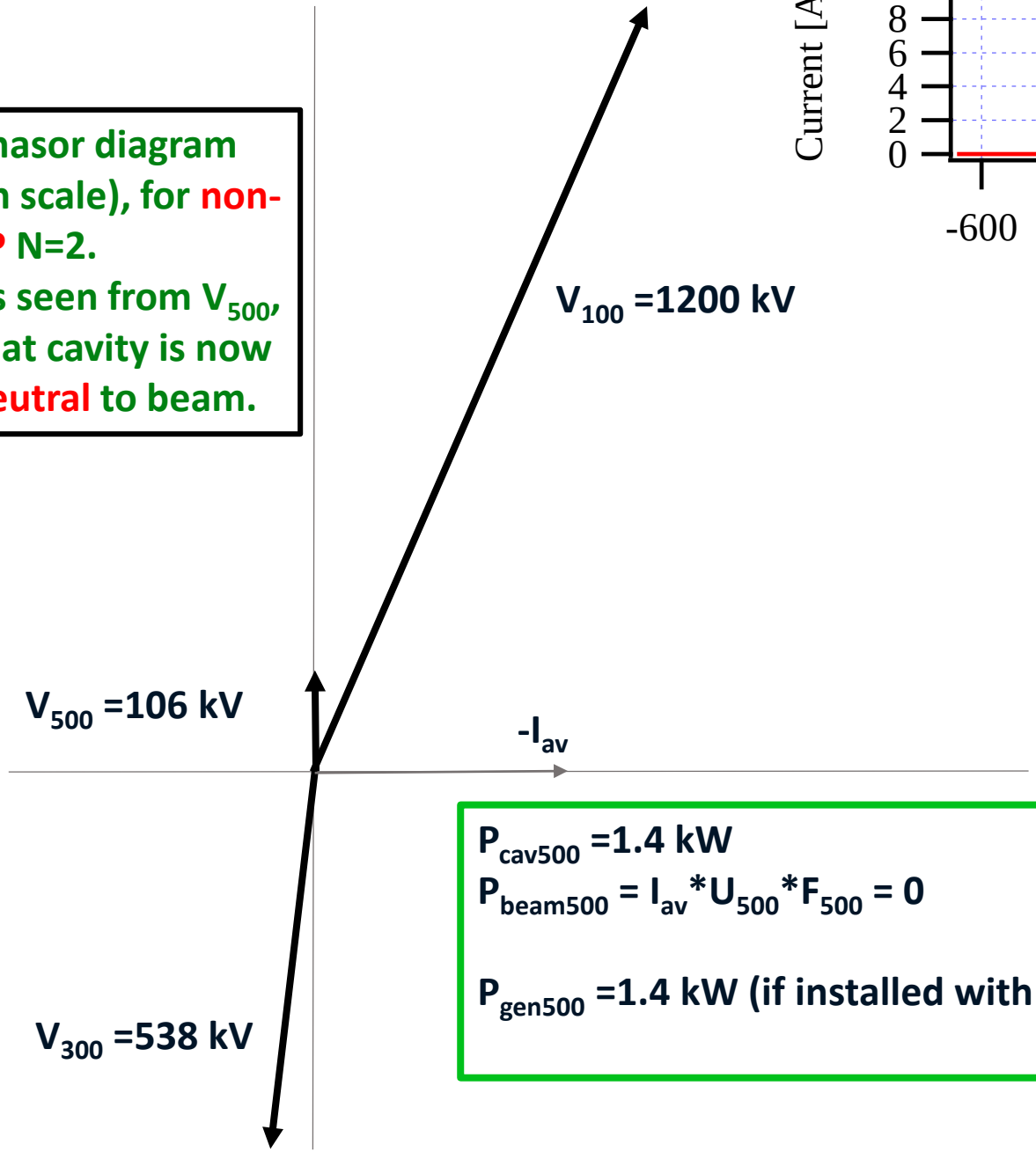
$$\frac{d^2V}{d\bar{\Phi}^2}(0) = - V_0 \left[\sin \bar{\Phi}_s + n^2 k \sin(n\bar{\Phi}_n)\right] = 0$$

At MAX IV we are indeed often operating outside the FP condition:



Phasor diagram (in scale), for non-FP N=2.
As seen from V_{500}, that cavity is now neutral to beam.

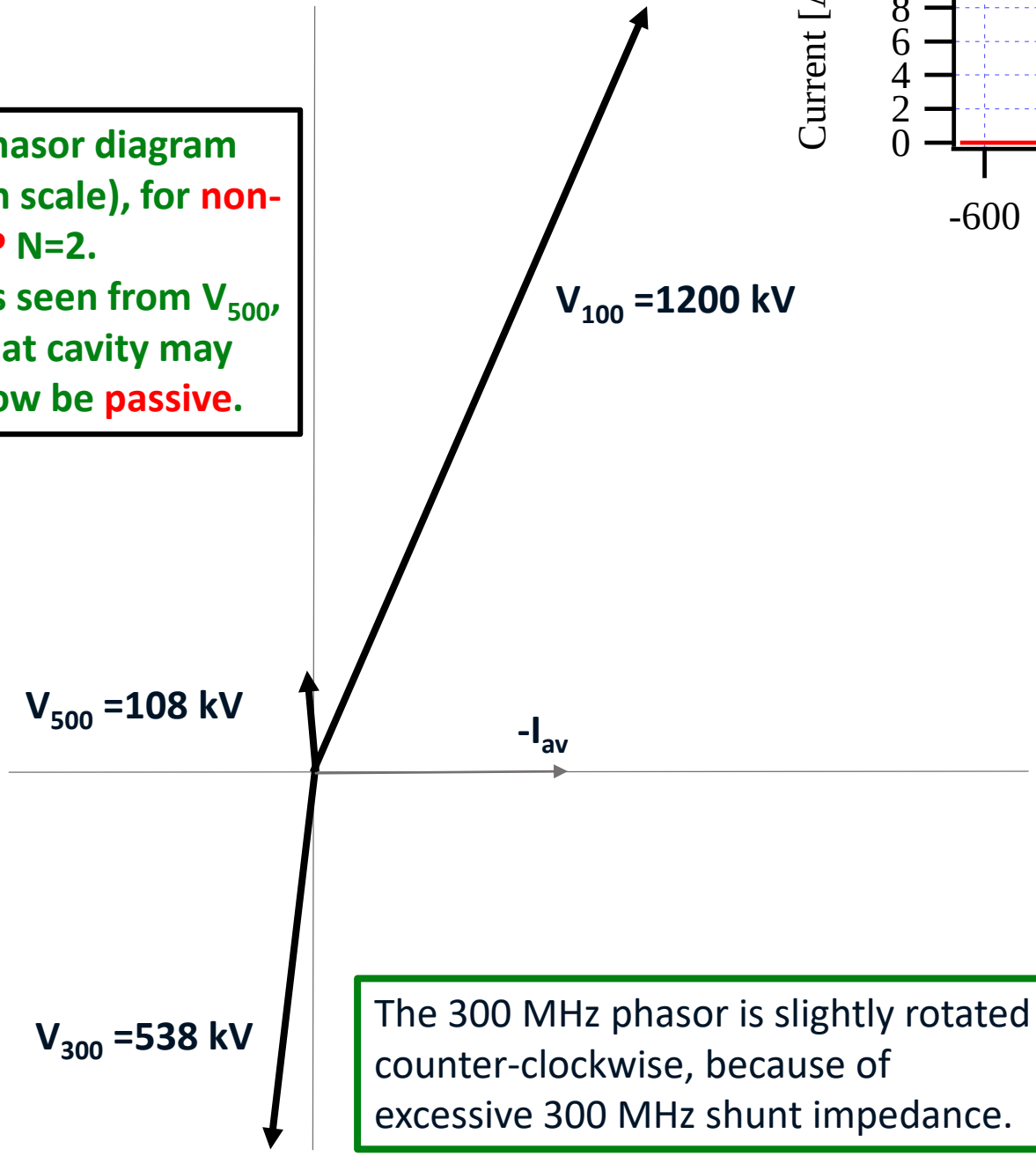




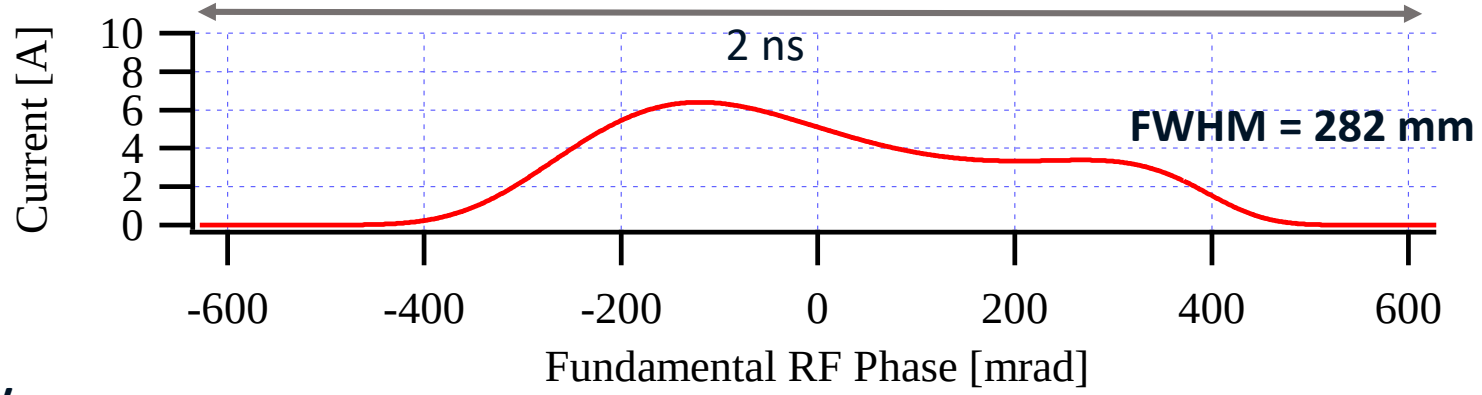
P_{cav500} =1.4 kW
$P_{beam500} = I_{av} * U_{500} * F_{500} = 0$

P_{gen500} =1.4 kW (if installed with beta=1)

Phasor diagram (in scale), for non-FP N=2.
As seen from V_{500}, that cavity may now be passive.



The 300 MHz phasor is slightly rotated counter-clockwise, because of excessive 300 MHz shunt impedance.



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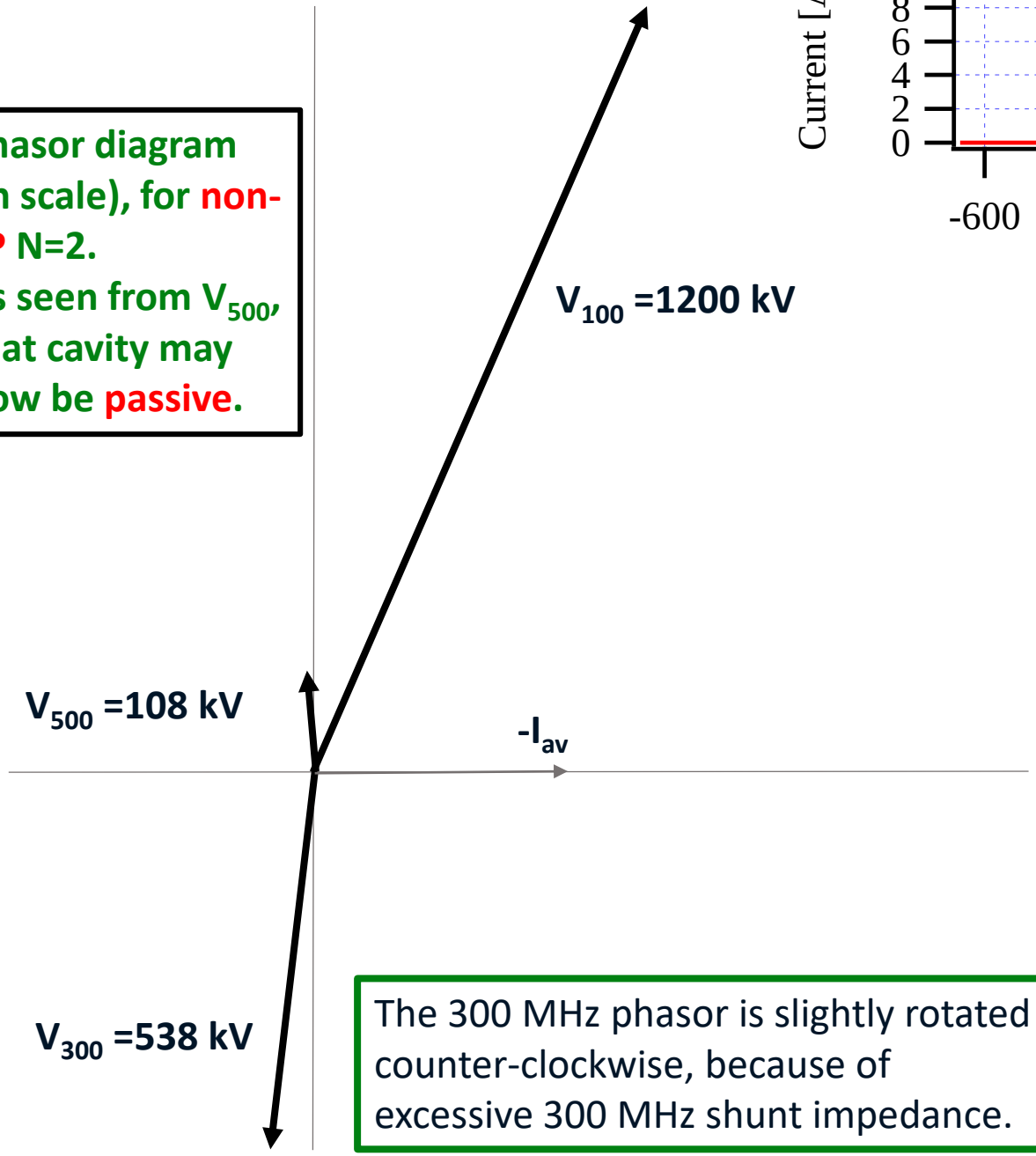

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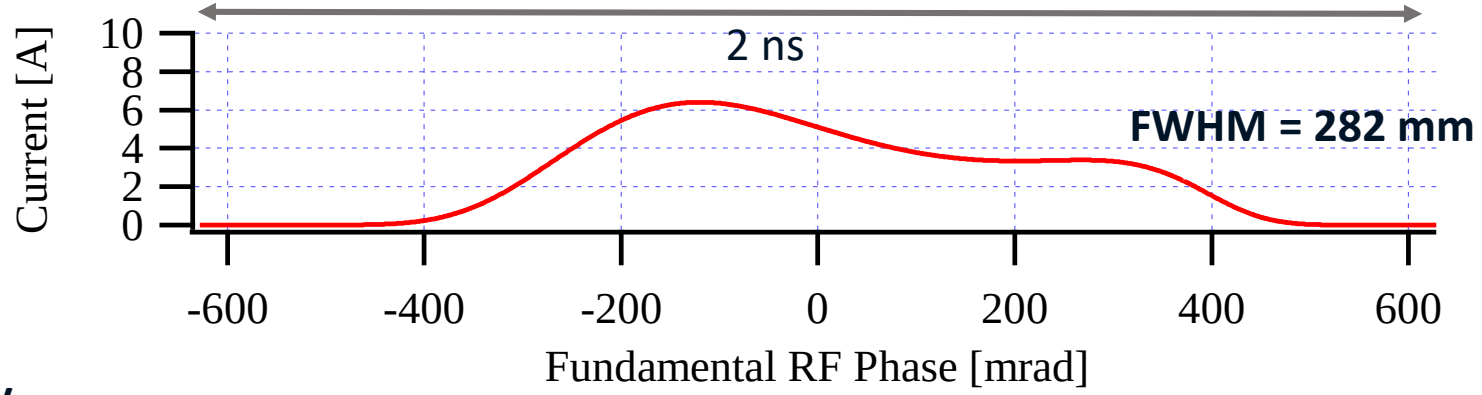


- **Self-consistent solutions for N=2 passive HC exists.**
- **We will explore such schemes during the first half year after installation.**

Time plan:

- Installation Summer 2024
- **First** goal is to use it **passively**, extracting **~ 10 kW** from the beam, in comb. with 100 MHz cavities.
- **Secondly**, explore **passive** operation together with both 100 MHz and 300 MHz cavities (while waiting for our 500 MHz generator).
- **Thirdly**, drive it **actively** with **~ 5 kW** generator power, in beginning 2025.

Summary

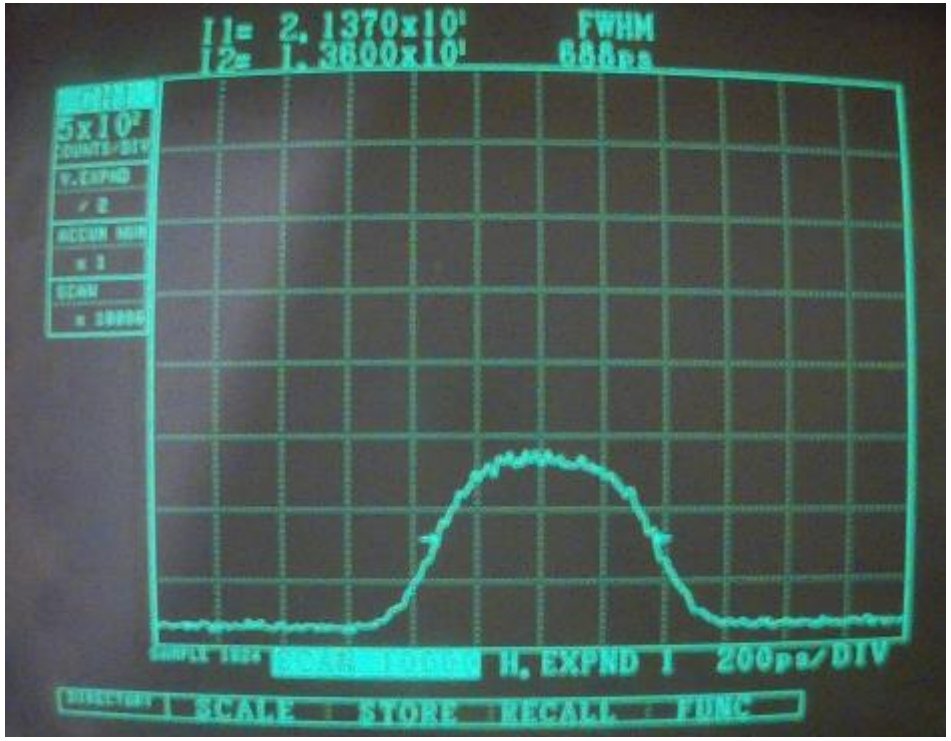
- A double-frequency harmonic system is being implemented in MAX IV 3 GeV ring, by installing a 5th harmonic cavity.
- Power requirements for reaching near Flat Potential conditions are very modest.
- We anticipate IBS and Touschek scattering to be reduced.

At FP	RMS-lengthening	FWHM-lengthening
1 HC frequency	5.0	6.7
2 HC frequencies	8.7	12.2

Many thanks to all people involved!!

Backup slides

Flat Potential conditions in MAX IV



Very close to **ideal Flat Potential** case.
Data at 40 mA.

Phasor diagram (in scale), for FP N=2.
As seen from V_{500}, that cavity needs to be active.