

# Commissioning of a 500 MHz Cavity for Bunch Lengthening using Two Higher RF Harmonics

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F. Cullinan, Å. Andersson, M. B. Alves,  
R. Lindvall, A. Mitrovic, R. Svärd, P. F. Tavares.

# Outline

- MAX IV 3 GeV ring and Triple-RF System
- Low-level RF
- Installation and Parking
- First beam measurements
- Next steps



# MAX IV 3 GeV Ring

Parameter	Value
RF frequency (MHz)	100
Landau-cavity (LC) harmonic	3
Shunt impedance per LC ( $M\Omega$ )	2.75
HC quality factor	20800
Delivery beam current (mA)	400
RF voltage (MV)	1.0
Natural RMS bunch duration (ps)	40.4
...with ideal HC lengthening (ps)	199
Harmonic number	176
Number of main (landau) cavities	5 (2)





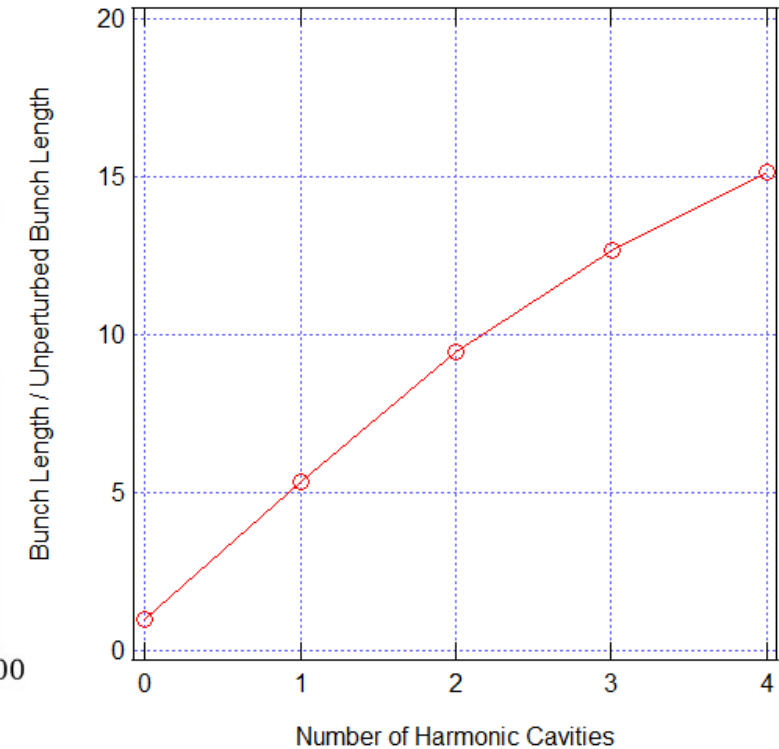
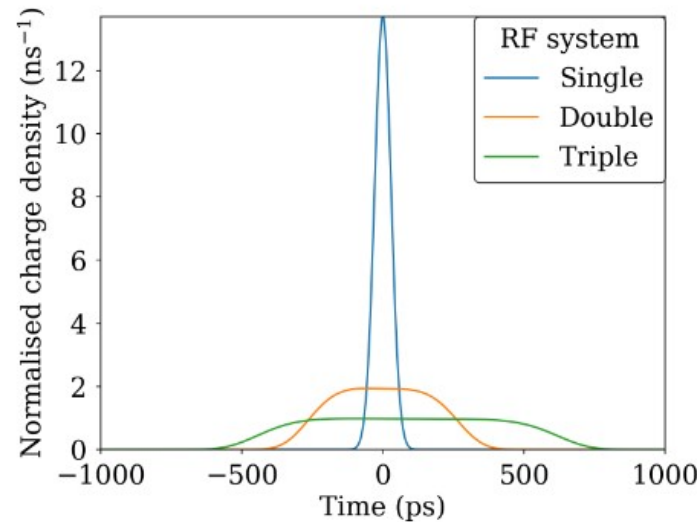
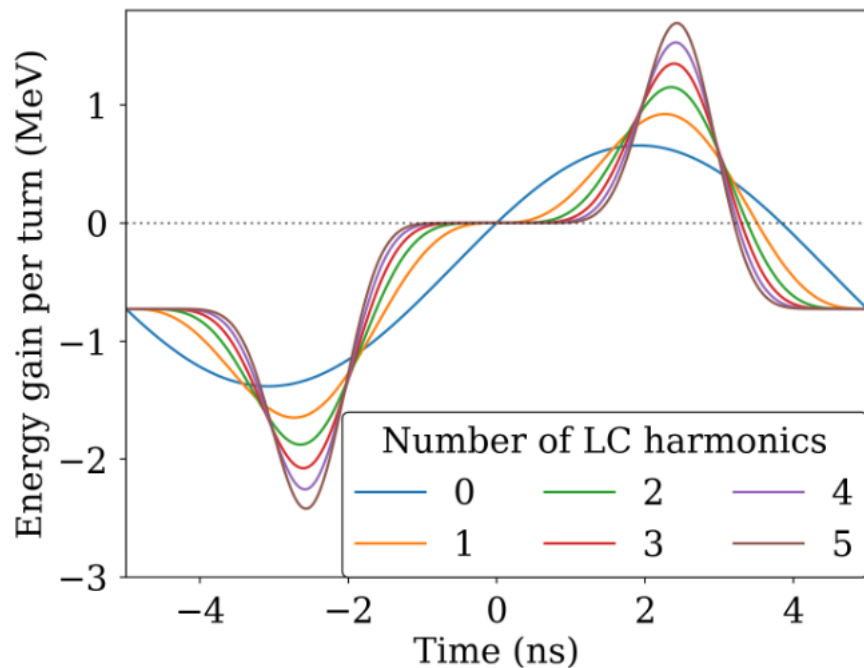
# The Triple RF system at hand in MAX IV:



# Ultralong bunches for low emittance rings:

Slide by Åke Andersson

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



F. Cullinan, P. Tavares, Å. Andersson, L. Malmgren, “Harmonic Cavity Parameters for Flat Potential to Arbitrary Order” MAX IV Internal Note 20240410

Plots: Curtesy of F. Cullinan & P. F. Tavares



# Installation/Commissioning plan

- Installation Summer SD 2025.
- **Phase#1**: find a proper **passive** parking position, without significant influence on bunch length.
- **Phase#2**: use it **passively**, in combination with 100 MHz cavities as an *alternative bunch lengthening system* while 300 MHz cavities are parked.
- **Phase#3**: explore **active** operation together with both 100 MHz and 300 MHz cavities. Need of ~ **1-5 kW** generator power.



# Hardware Installation

- 10 kW SS amplifier @ 500 MHz
- Cavity RF conditioning spring 2025
- Cavity installed summer 2025
- Transfer line connected ( $\beta=1.2$ )



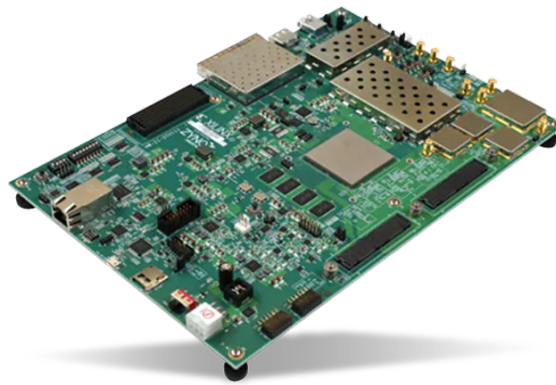


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# LLRF



- Moving from Nutaq to Xilinx RFSoc platform
- LLRF system can handle all SR cavities (100, 300 & 500MHz)
- Amp./phase PID loops for active operation
- Frequency loop on forward-cavity phase shift (active case) or cavity voltage (passive case)

Basic attributes   Expert attributes

### Controller state-machine

LimitState	<input type="text" value="4"/>	<input type="text" value="4"/>
AmpRefMin	<input type="text" value="49.99"/>	<input type="text" value="50.00"/> mV
PhRefMin	<input type="text" value="-79.99"/>	<input type="text" value="-80.00"/> deg
PidLimMin	<input type="text" value="174.99"/>	<input type="text" value="175.00"/> mV
PidLim	<input type="text" value="360.00"/>	<input type="text" value="360.00"/> mV
LoopsSel	<input type="radio"/>	
AmpTxMin	<input type="text" value="6.99"/>	<input type="text" value="7.00"/> mV

### Loops

AmpLoopsEnable ☒

OpenLoopGain

AmpRampRate

AmpKp

AmpKi

AmpKd

AmpTunedRange   mV

PhLoopsEnable ☒

PhRampRate

PhKp

PhKi

PhKd

PhTunedRange   deg

### FIM

AmpMoMin   mV

AmpFwLoadHigh   mV

AmpRvCircHigh   mV

AmpRvCavHigh   mV

DelayIntlk   ns

MpsinNo ☒

MpsOutNo ☒

DisMoIntlk ☒

DisFwLoadIntlk ☒

DisRvCircIntlk ☒

DisRvCavIntlk ☒

DisMpsIntlk ☒

DisArcIntlk ☒

DisVacuumIntlk ☒

DisCavEndSwIntlk ☒

DisLanEndSwIntlk ☒

DisExtIntlk ☒

### Fields

CavPhOffset   deg

TxPhOffset   deg

AvgSel

### Cavity tuning

Active cav   Passive cav

CavTuningPhOffset   deg

CavPhMarginHigh   deg

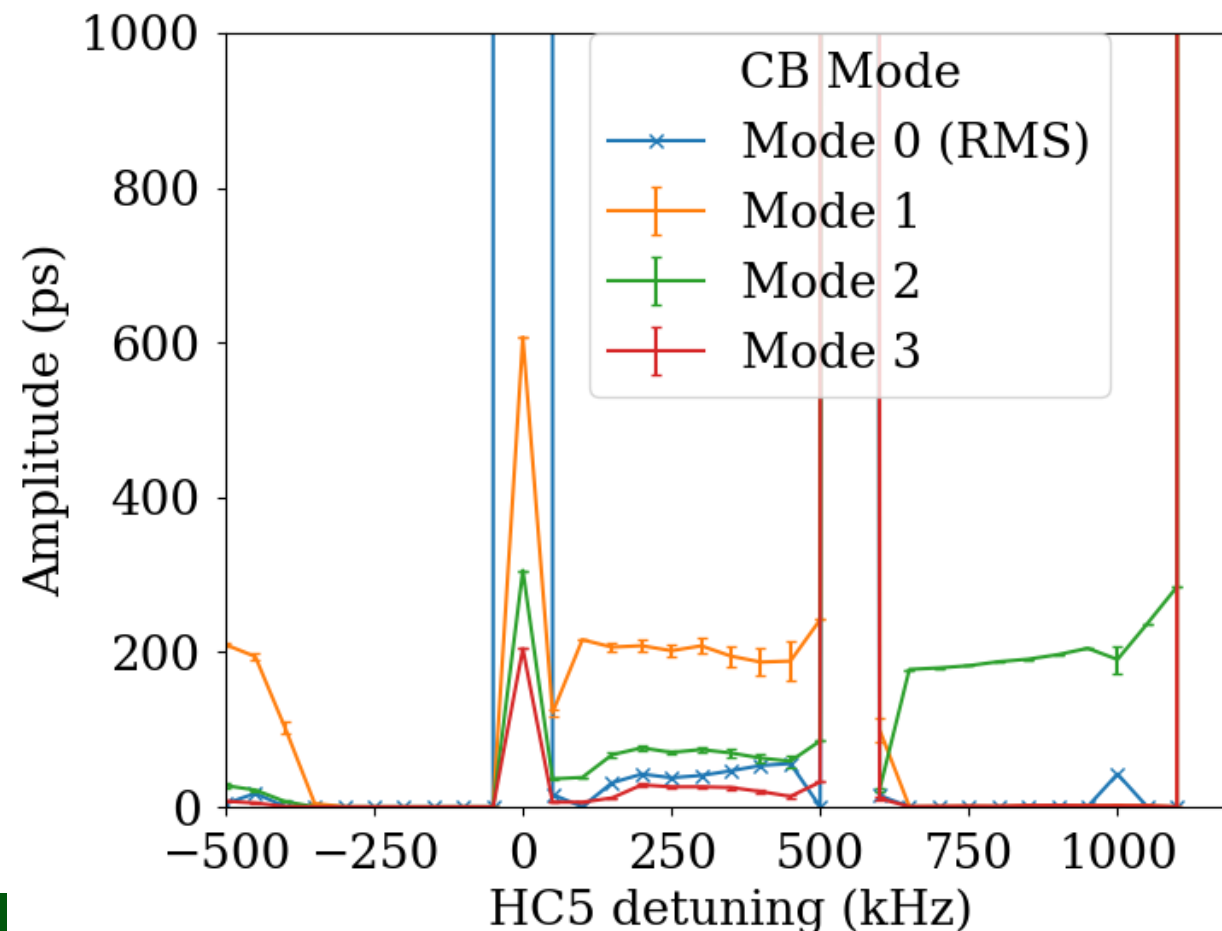
CavPhMarginLow   deg

CavClkPerPulse

CavTuningDirAuto ☒

# Phase #1 - Parking Candidates

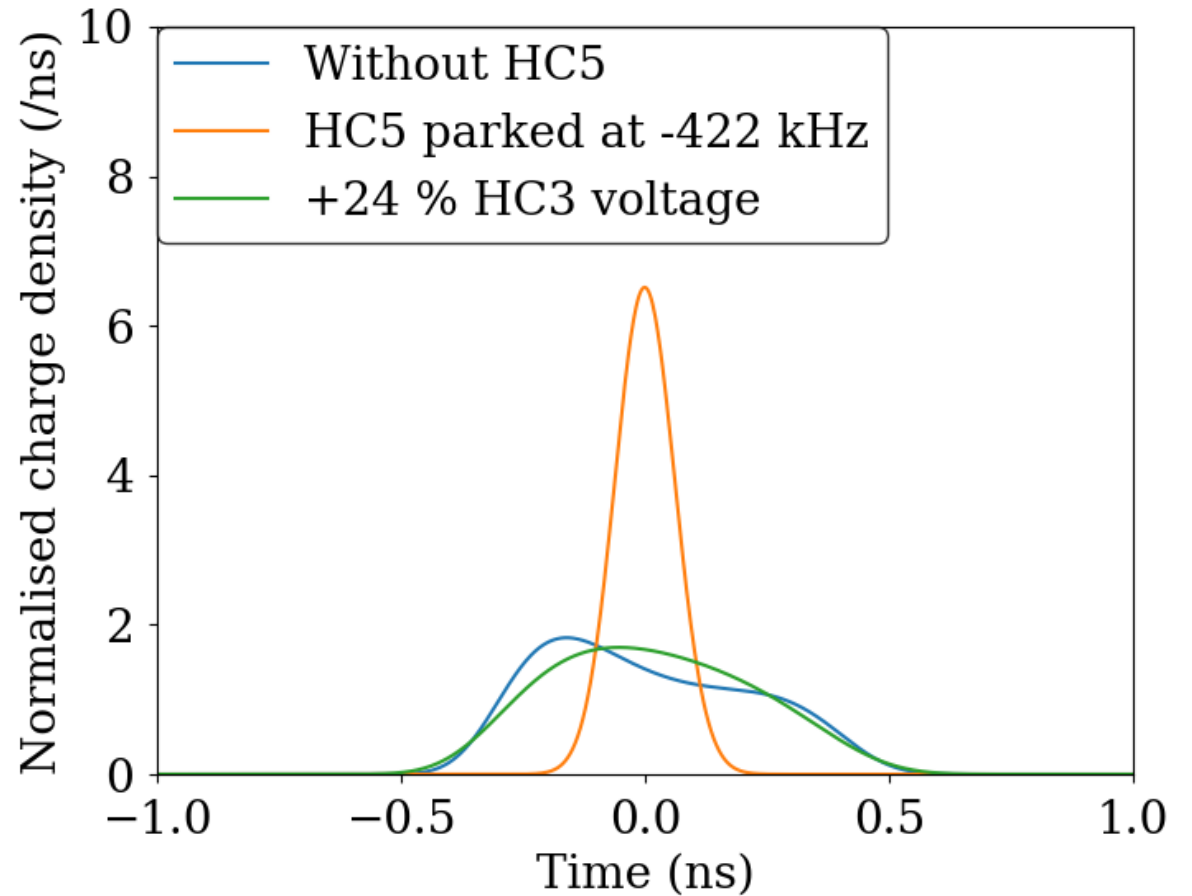
- 400 mA
- Beta=1
- HC3 detuning=+91 kHz





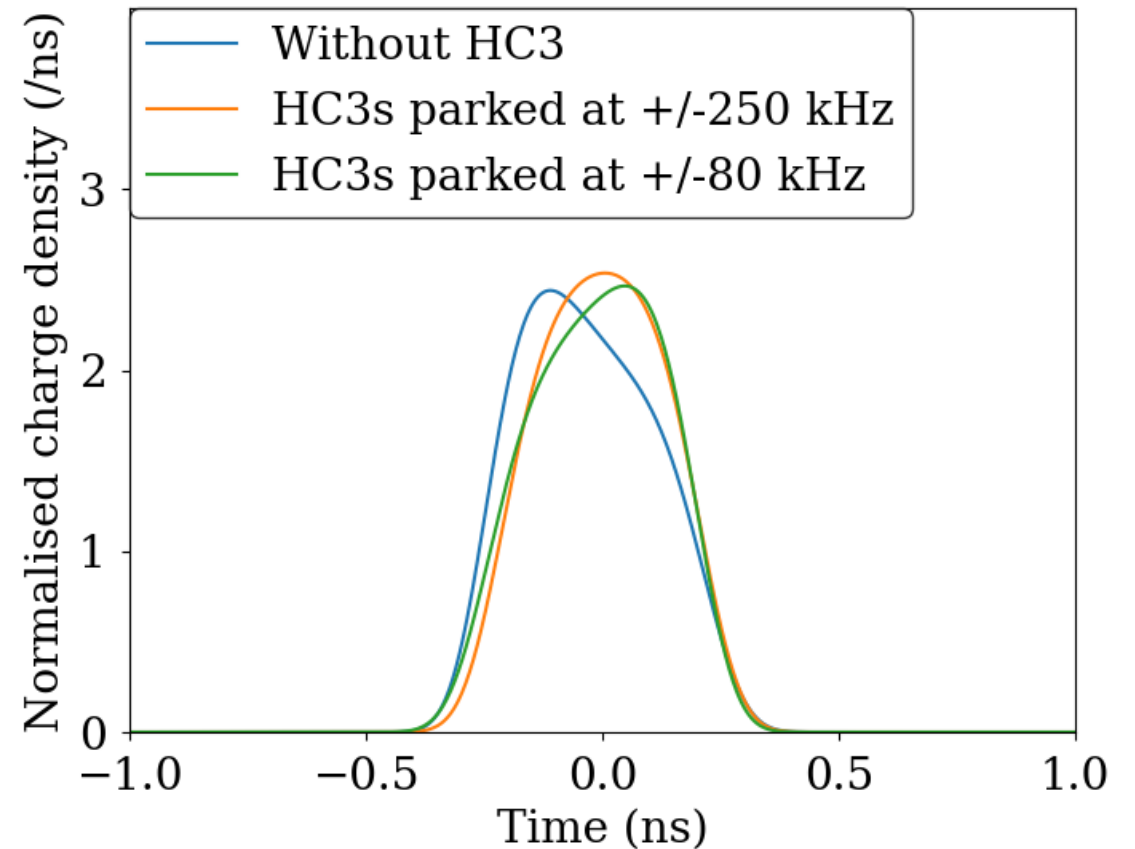
# Phase #1 - Parking Results

- Final parking position found
  - -422 kHz detuning
- Better parking with shorted transmission line
  - -450 kHz detuning
- HC3 fields increased by about 10 %



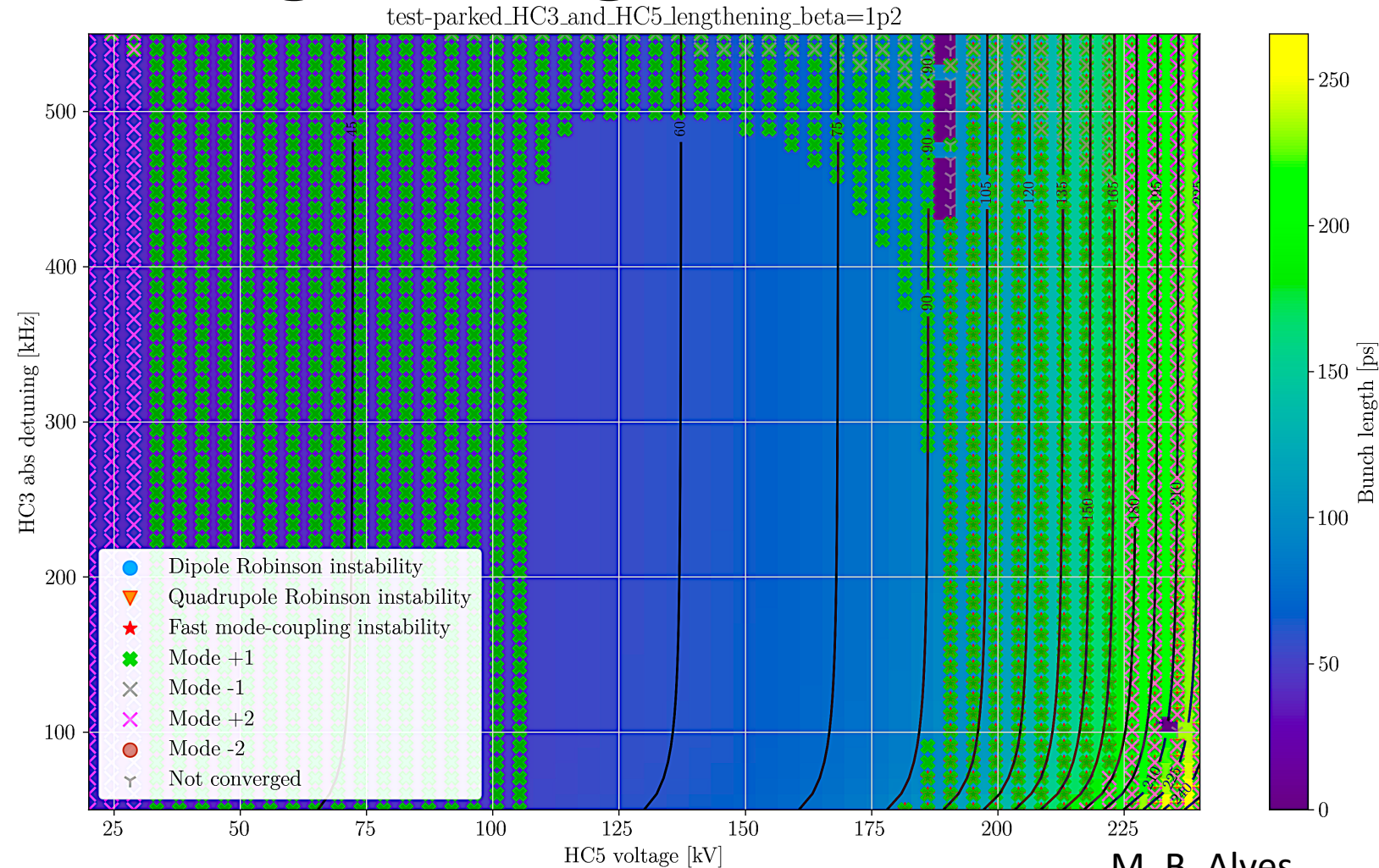
# Phase #2 - Lengthening with HC5

- Can park HC3s either side of 3rd RF harmonic
- Little degradation of lengthening



# Phase #2 - Passive Lengthening with HC5

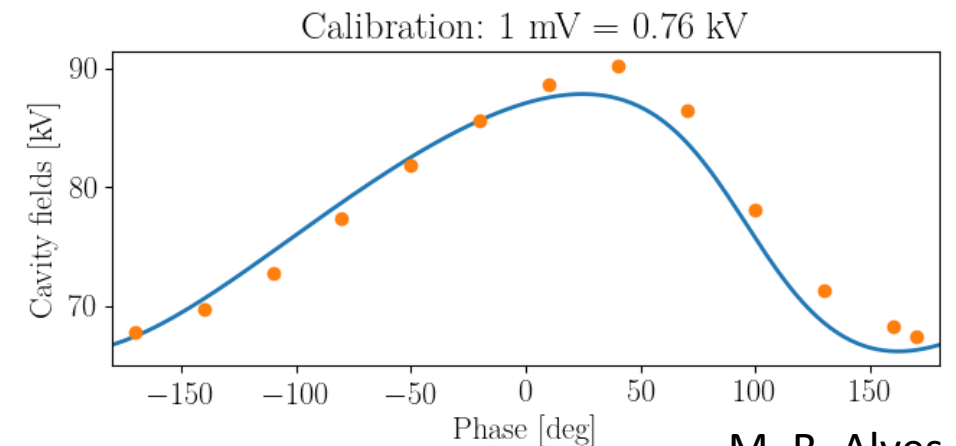
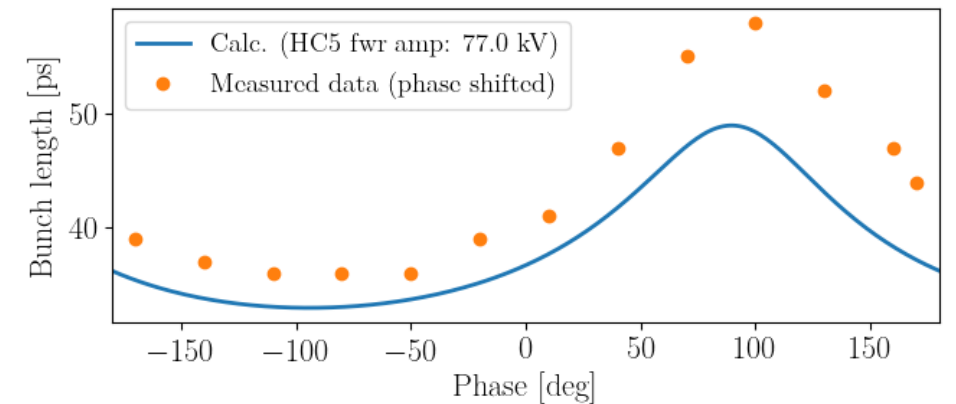
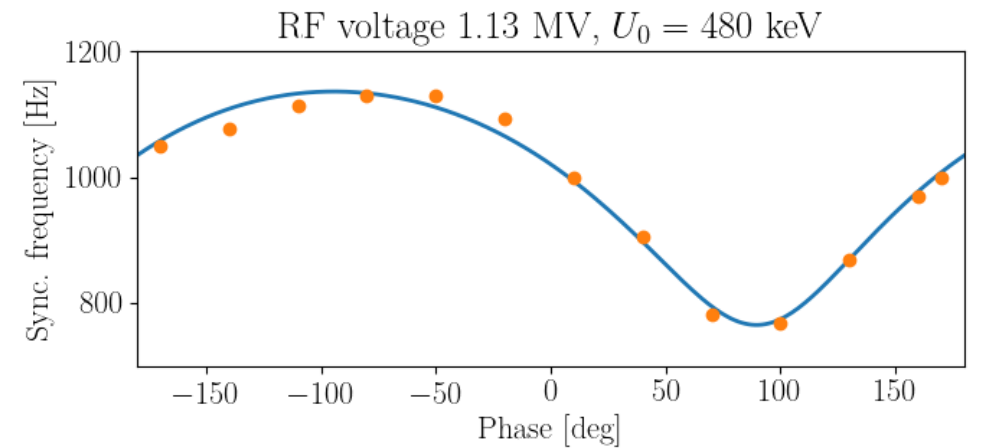
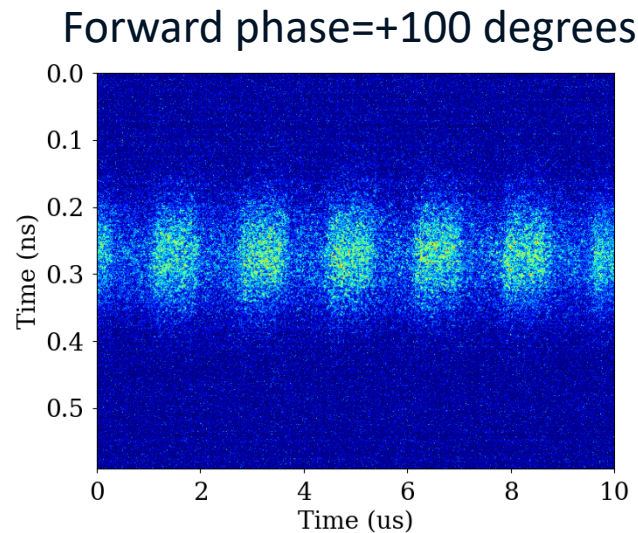
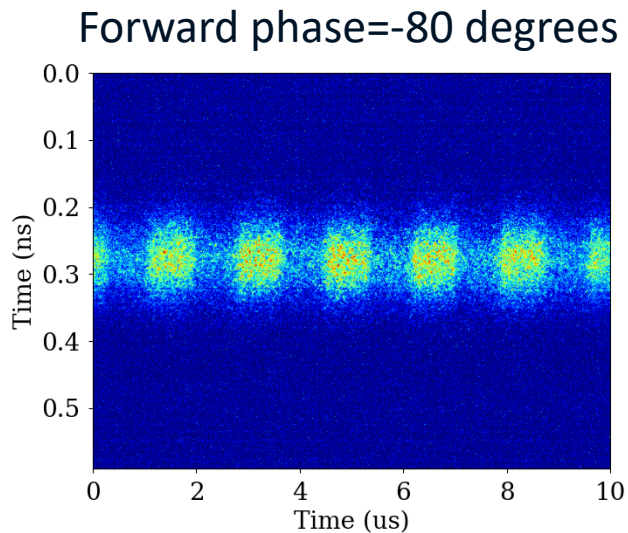
- 400 mA delivery candidate
- Small region of mode-1 stability



M. B. Alves

# Cold Beam Measurements

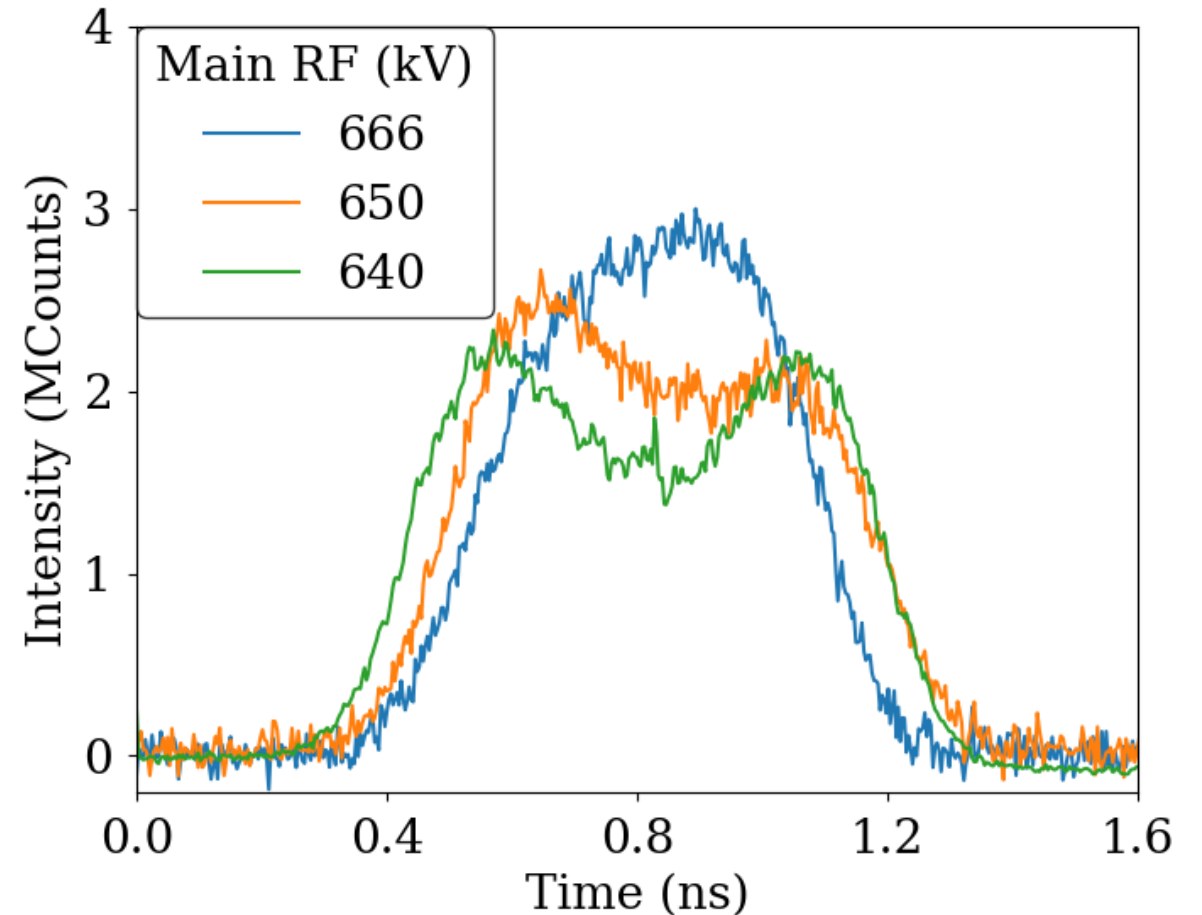
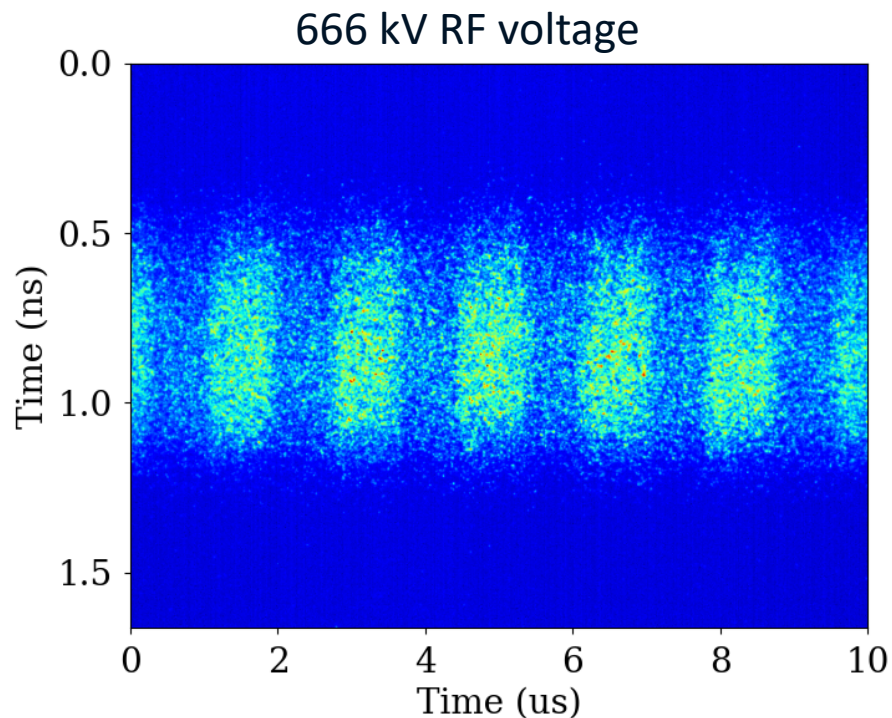
- First measurements of active operation impact on 3 mA beam
- 77 kV cavity voltage





# Cold Beam Measurements

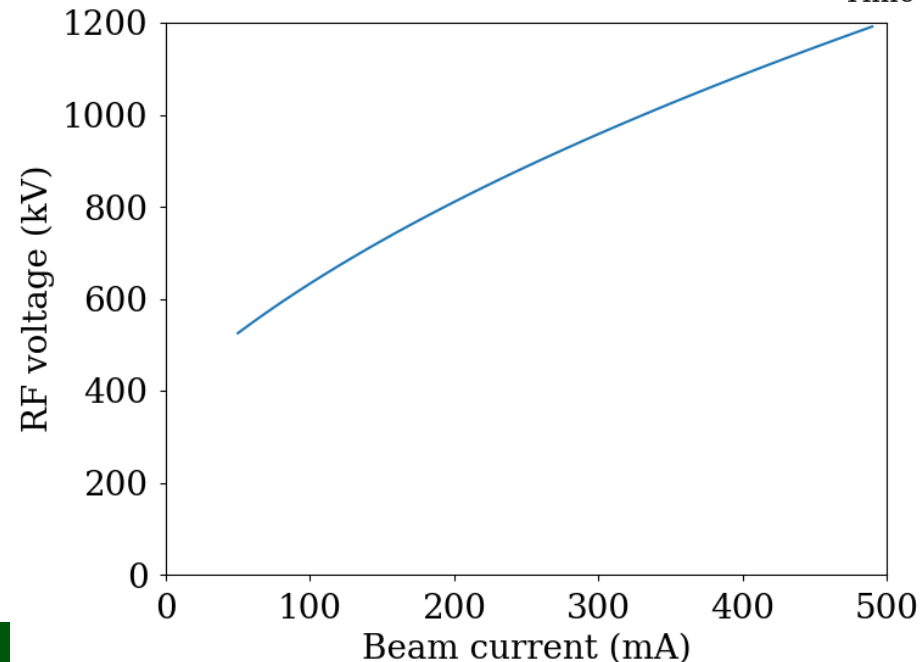
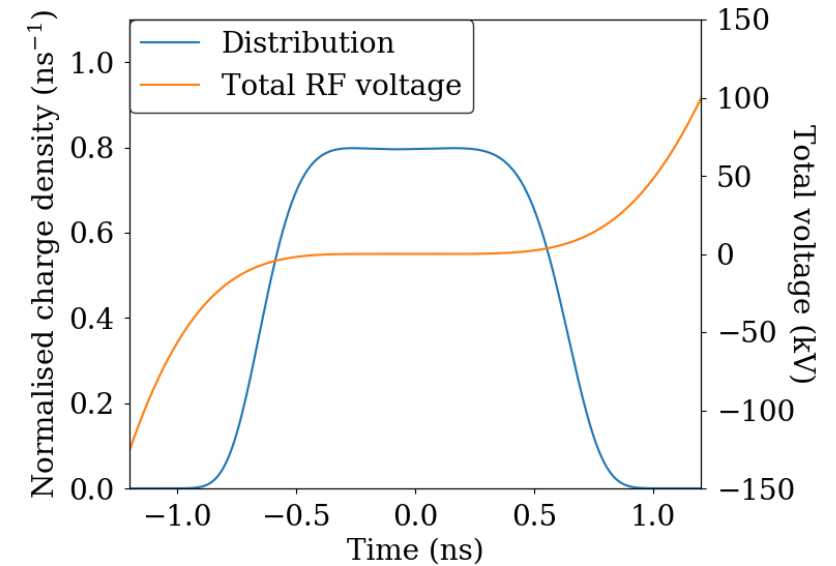
- Near (double-RF) flat-potential conditions arrived at empirically



# Plan for Phase #3

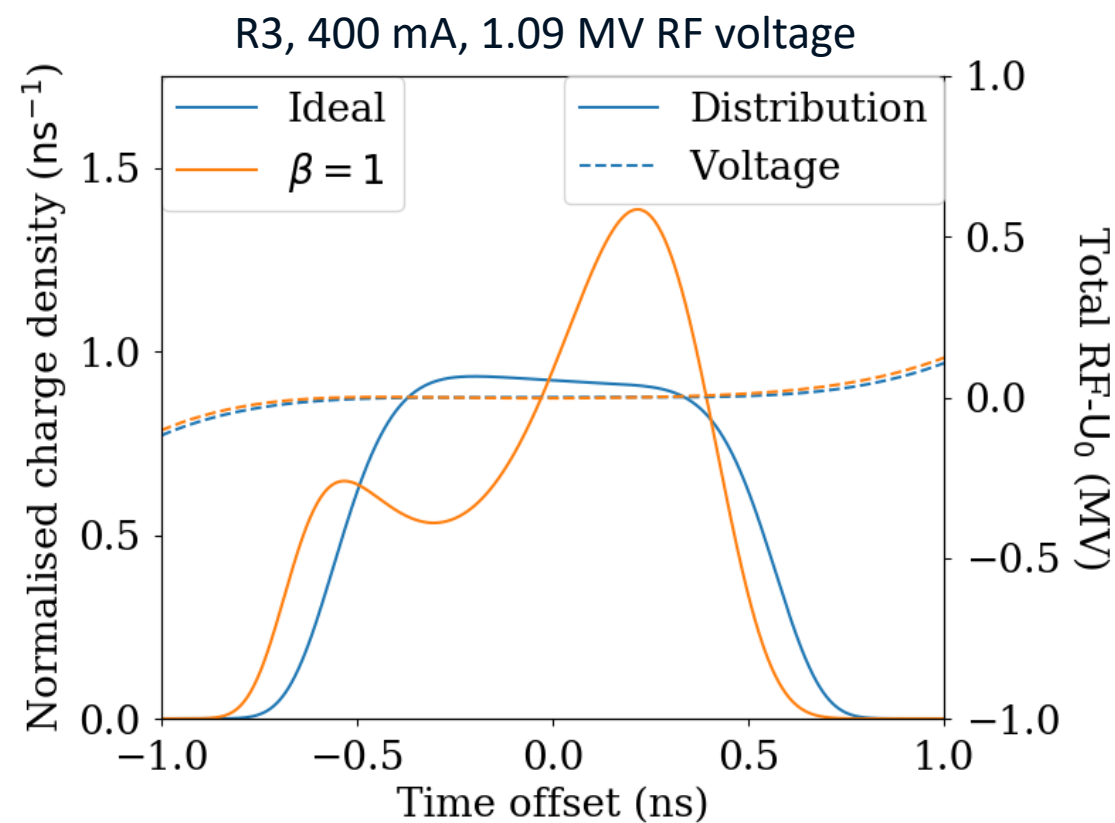
Increase current to engage HC3s

- Beam predicted to be stable at 100 mA
- Transmitter power enough for full range



# HC5 $\beta=1$

- HC5 phase adjusted to not exchange energy with the beam
- Voltage adjusted to maintain slope
- Lengthening maintained at cost of flat-top profile



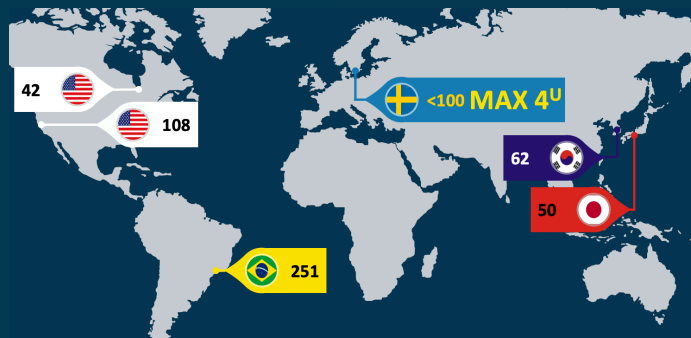
# Summary and Conclusions

- Complete 500 MHz active harmonic cavity system has been installed in MAX IV 3 GeV ring
- Commissioning underway
- Phase 1 (transparent parking) complete
- Phases 2 and 3 in progress
- Goal is to demonstrate factor-10 bunch lengthening



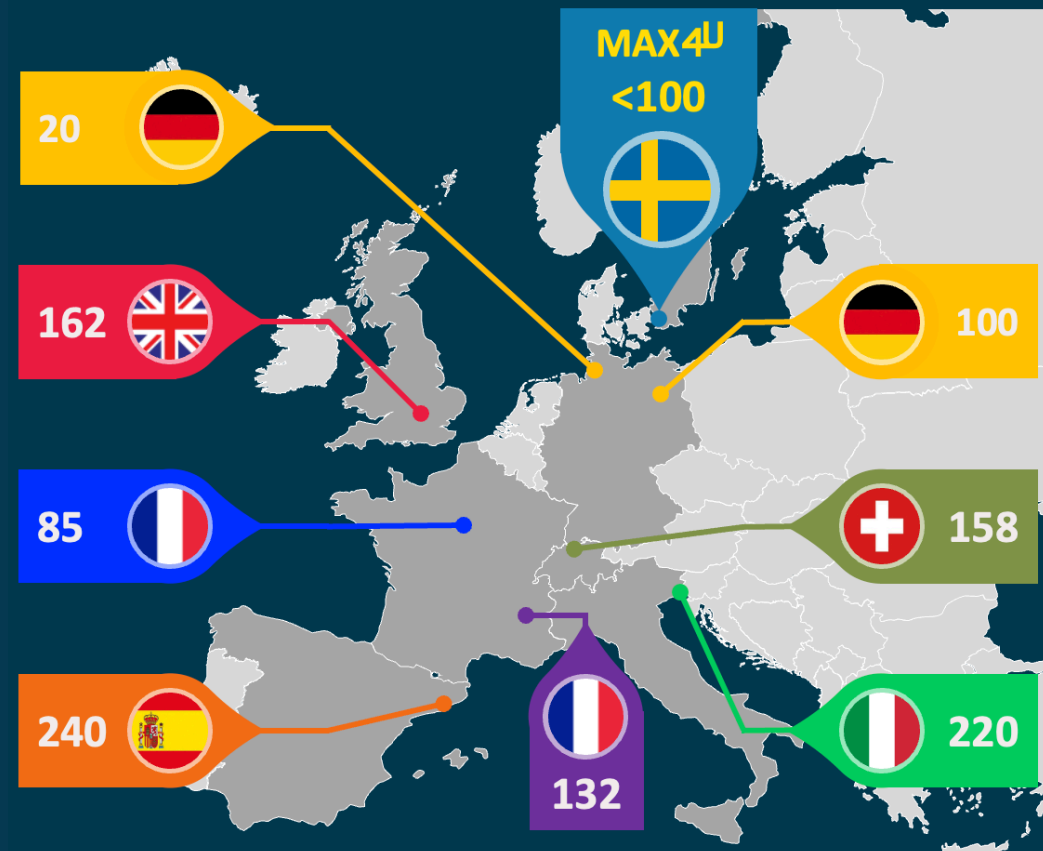


Securing leadership, excellence, resilience, and relevance  
of Swedish research with X-rays for the next decades



A "surgical" upgrade of our 3GeV ring  
from 328 to below 100 pm · rad

## Horizontal Emittance [pm·rad]



MAXIV

The logo for MAXIV is centered on a dark green background. The word "MAXIV" is rendered in a light gray, stylized, sans-serif font. A bright yellow swoosh, consisting of two curved lines, arches over the letters "A", "X", and "I", starting from the left and ending on the right.