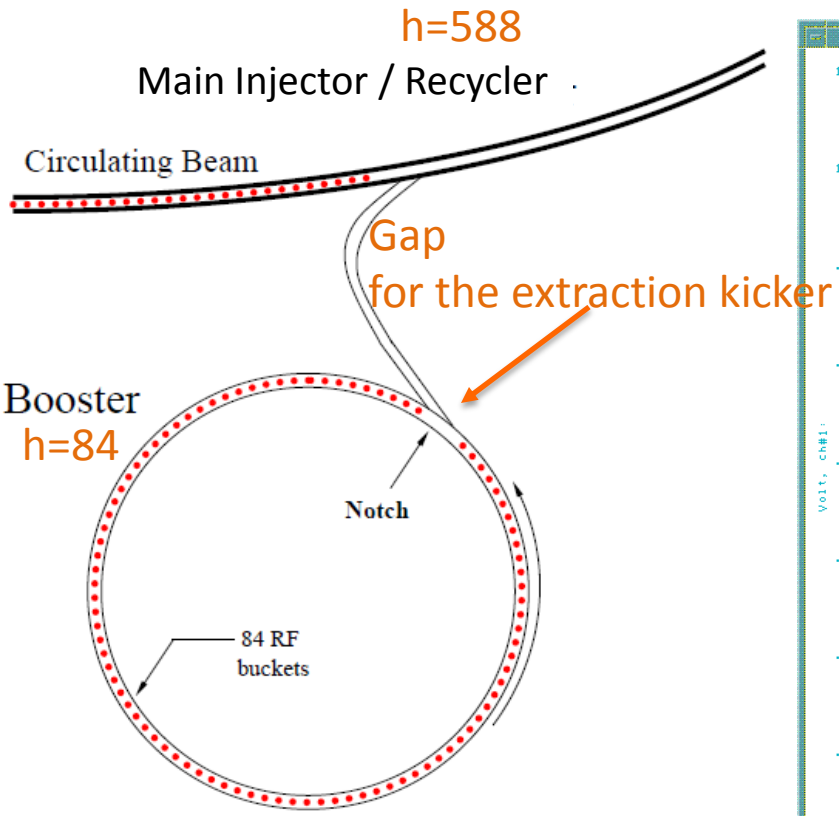
Booster Cogging

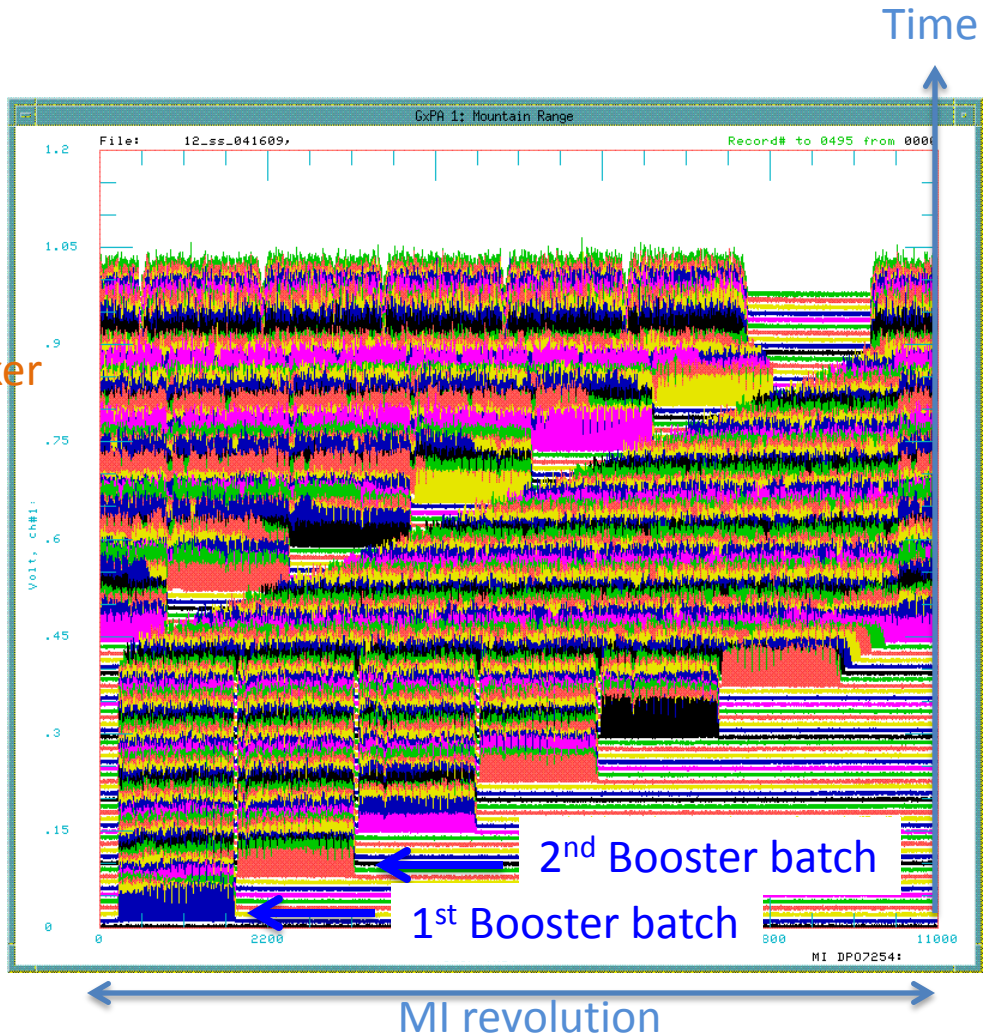
October 2, 2014

K. Seiya, S. Chaurize, C. Drennan, W. Pellico,
A. K. Triplett, A. Waller

Why do we need cogging?

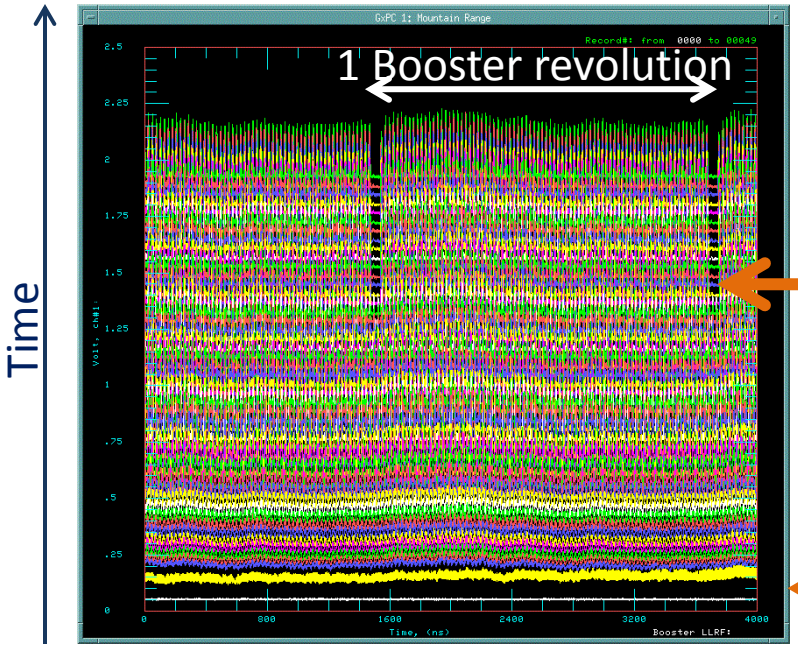


81 bunches + 3 empty buckets



Notch(extraction kicker gap) – Booster extraction kicker – MI/RR injection kicker

Beam at Booster Injection



Notch @ 700MeV

→ **81 bunches + 3 empty buckets**

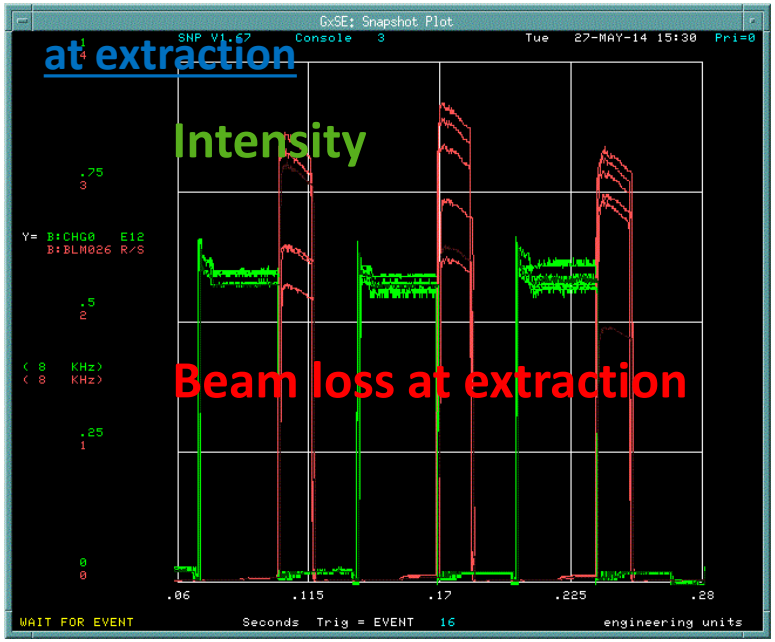
Adiabatic capture with 37MHz RF

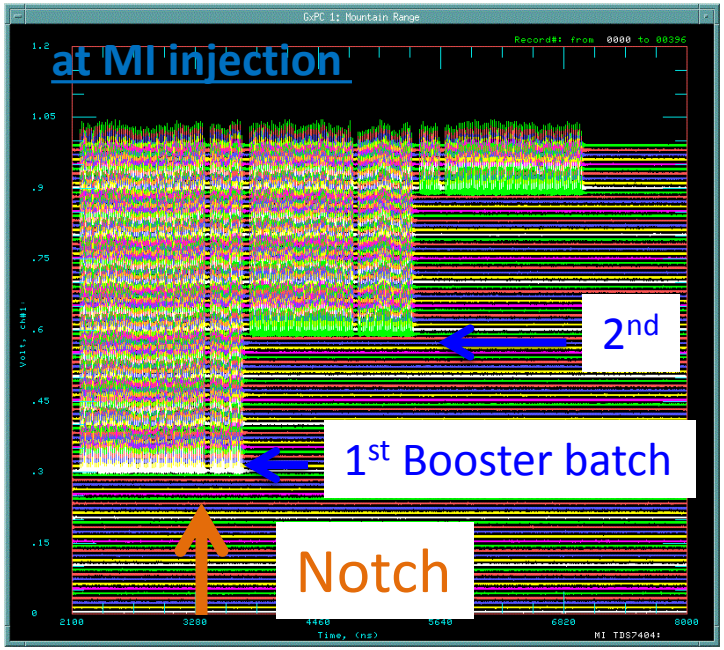
→ **84 bunches**

Injection from LINAC @ 400MeV

Beam w/o cogging

Lost 3 bunches every Booster extraction.





Present operational cogging (Radial cogging)

Magnetic Cogging

Cogging system and feedback

Beam Synchronization

Beam studies

Shutdown activities

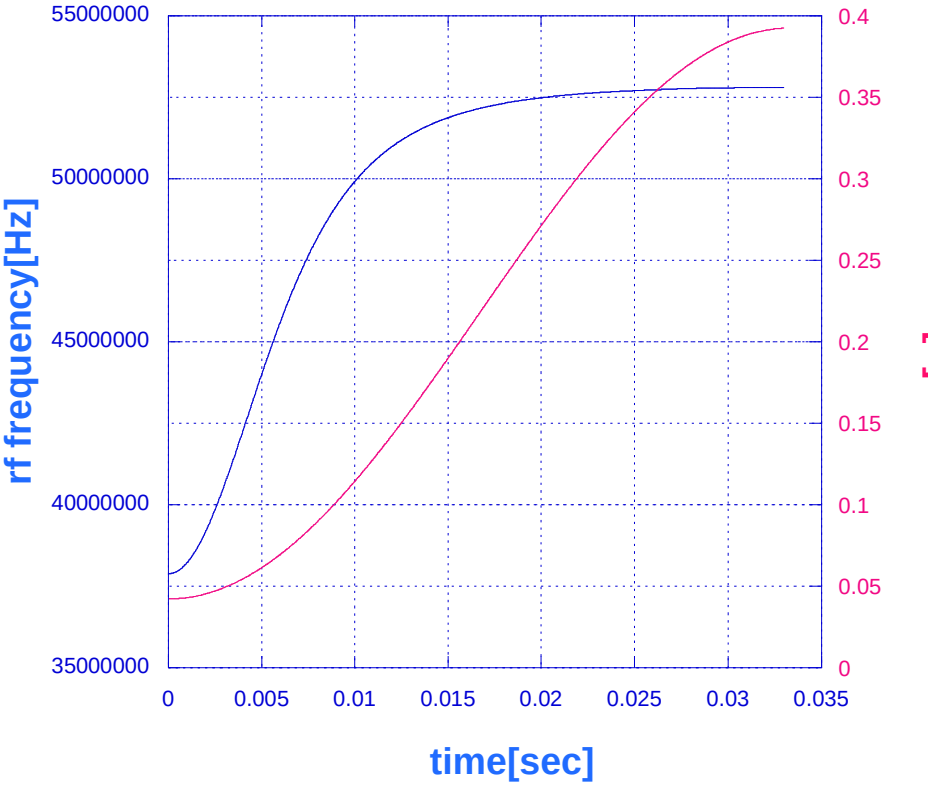
Plan

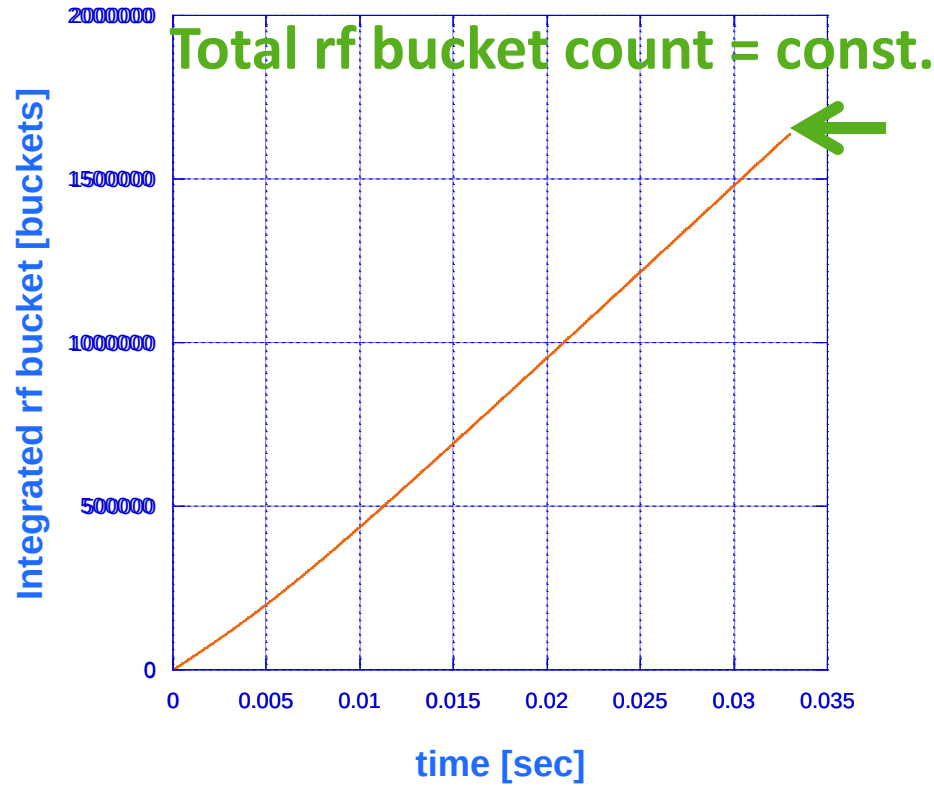
Total bucket counts during Booster cycle

Booster:

15 Hz resonant circuit

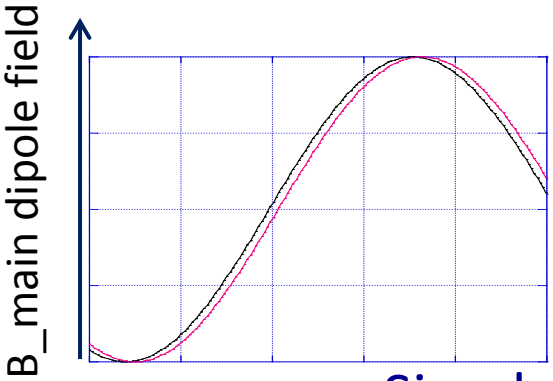
RF frequency: 37.7 – 52.8MHz





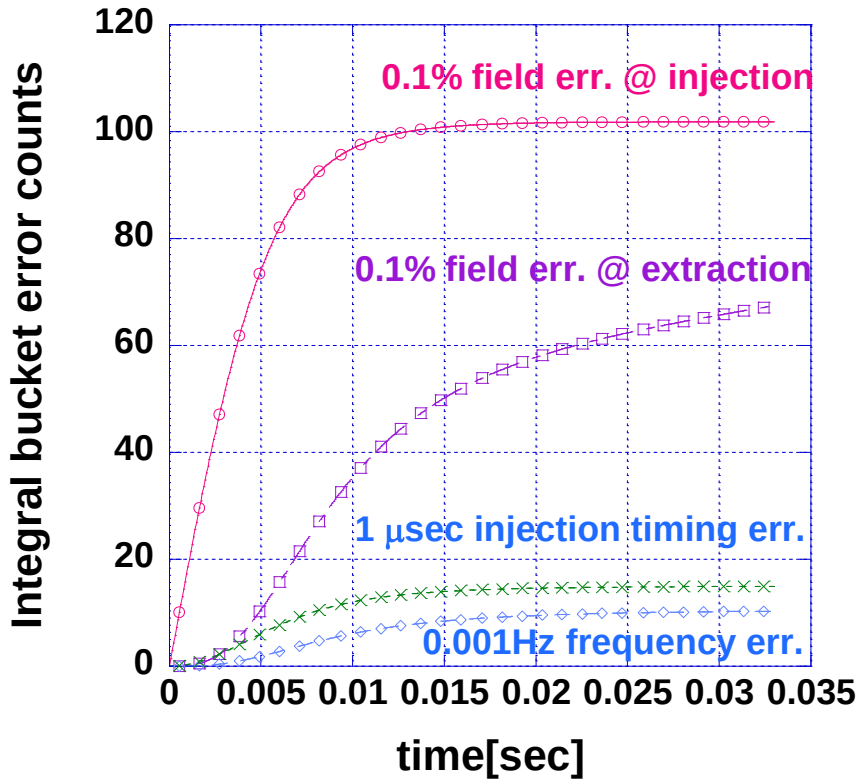
Total rf bucket count = const. -- Notch is at same position at extraction

Field error and integration of difference of rf counts

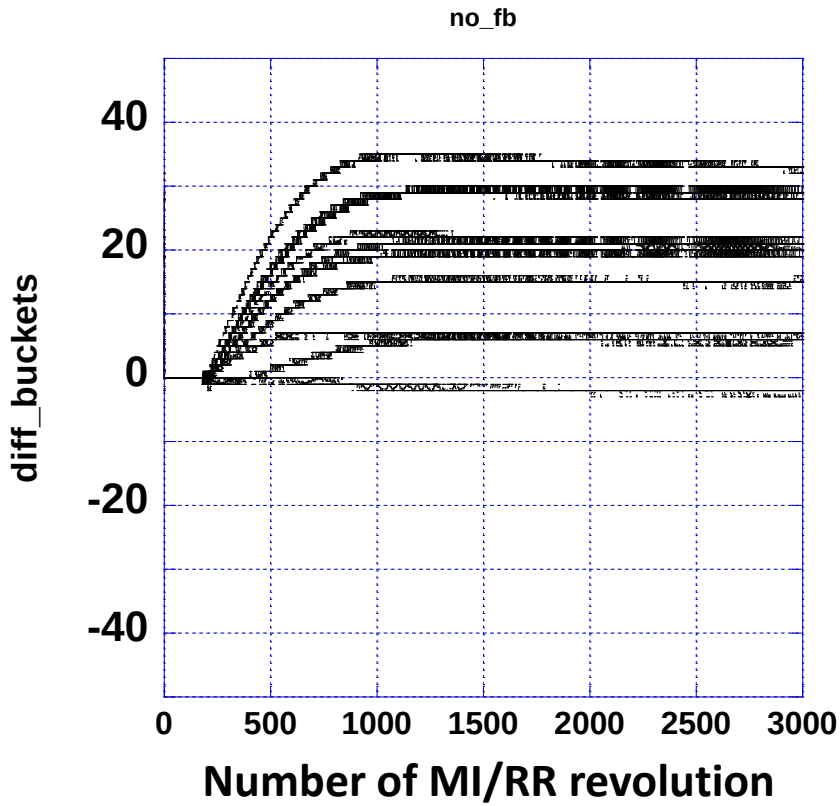


Booster: 15Hz resonant circuit synchrotron synchronized to the 60Hz power line.

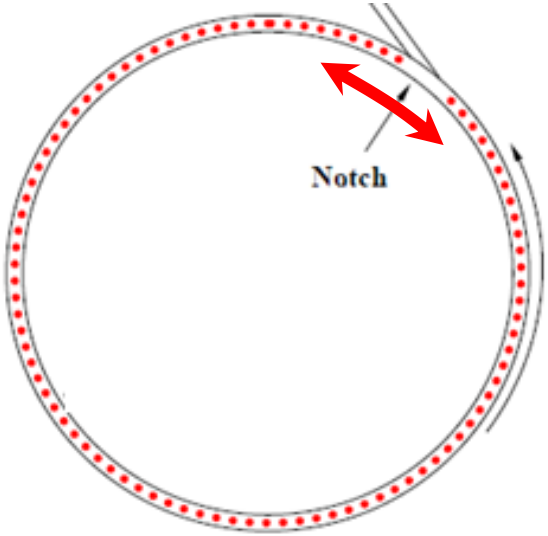
Simulation



Measurement

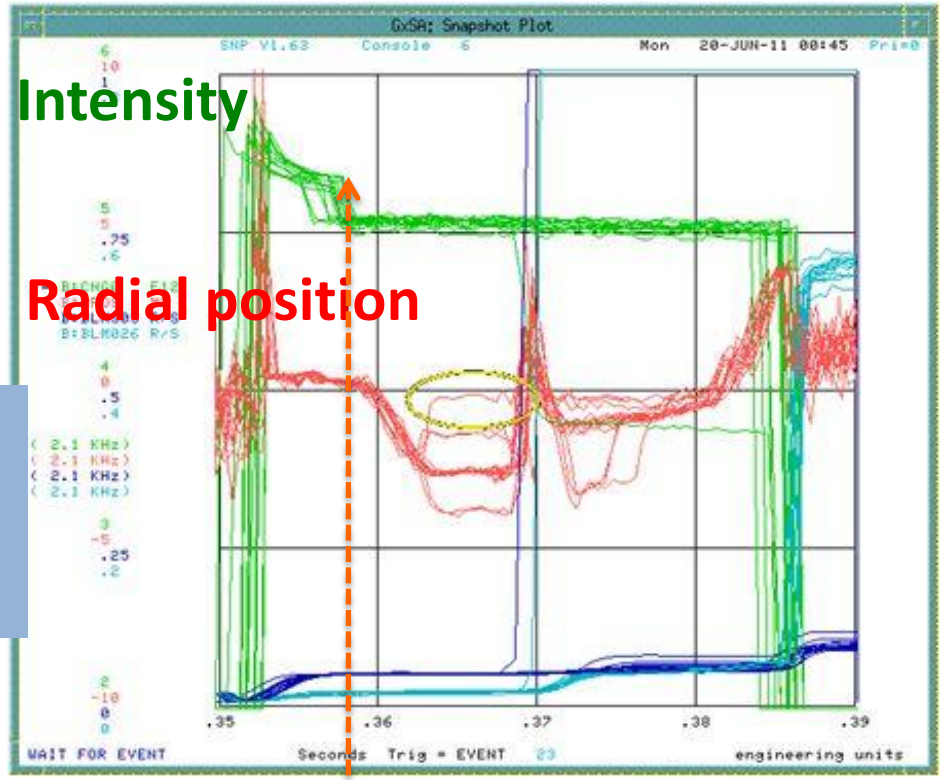


Revolution frequency control with Radial Cogging



$$\frac{\Delta f_{rev}}{f_{rev}} = \frac{1}{\gamma^2}\frac{\Delta P}{P} - \frac{\Delta L}{L}$$

Path length (radial position) of the beam



@ 700 MeV

Creates notch at 700MeV.

Moves orbit before/after transition.

Magnetic Cogging using 48 new dipole corrector magnets

$$\frac{\Delta f_{rev}}{f_{rev}} = \frac{1}{\gamma^2}\frac{\Delta P}{P} - \frac{\Delta L}{L}$$

Fixed with RPOS feedback

$$= \frac{1}{\gamma^2}\frac{\Delta B}{B}$$

Changed by dipole corrector
Dipole corrector: 0.009[T-m] @ 24.4[A]

$$\frac{\Delta B \ell_{max}}{B \times 2\pi\rho} = \frac{0.009[T \cdot m] \times 48 \times 10[A]/24.4[A]}{0.042[T] \times 2\pi \times 75.75[m]}$$

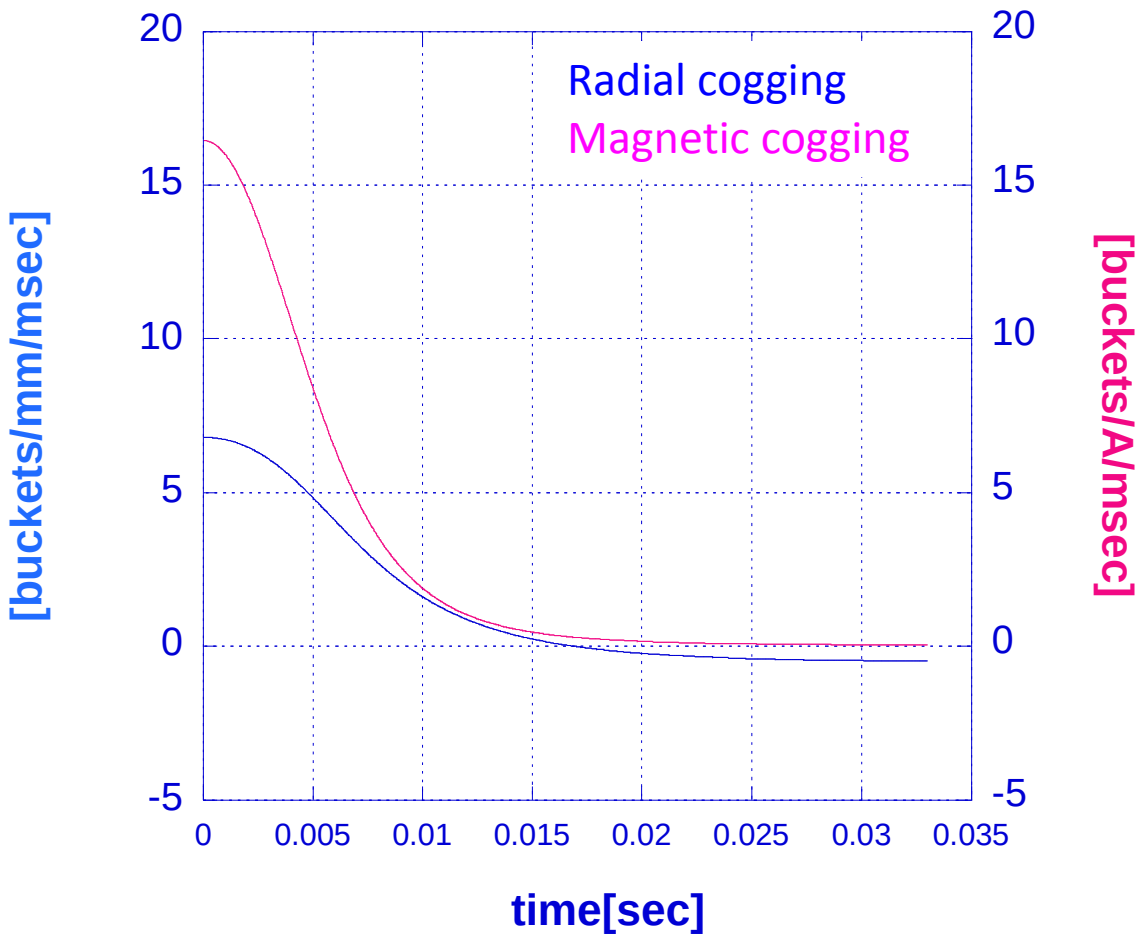
$$= \mathbf{0.0088}$$ (Assuming 10[A] change)

B field error ~1% can be compensated.

Keeps beam on central orbit and save aperture.

Creates notch anytime after injection(even LINAC notch)
→ reduce beam power loss by 40%.

Δf_{rev} with Radial Cogging and Magnetic Cogging



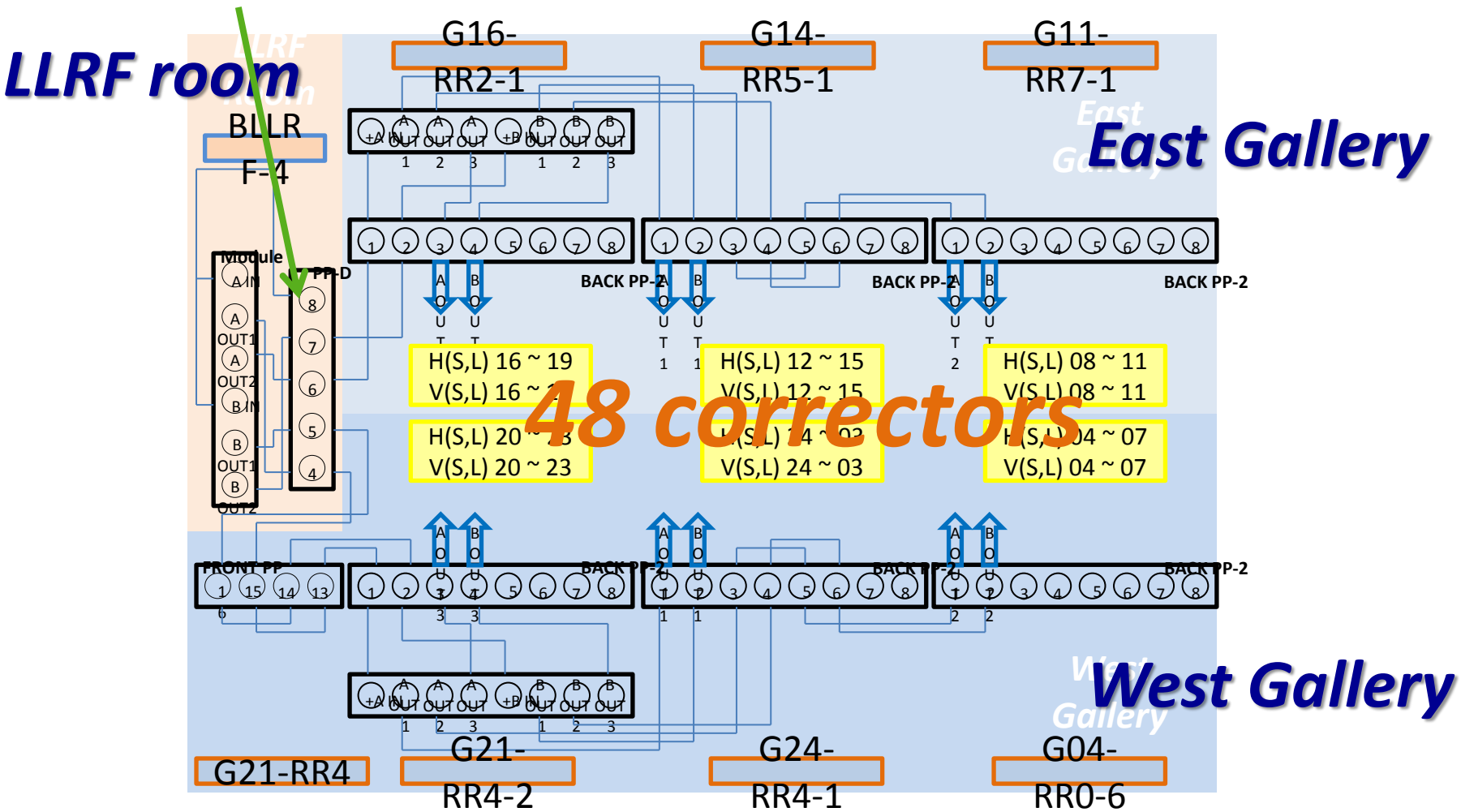
Effective early in the cycle.

Corrector current : +/- 40A

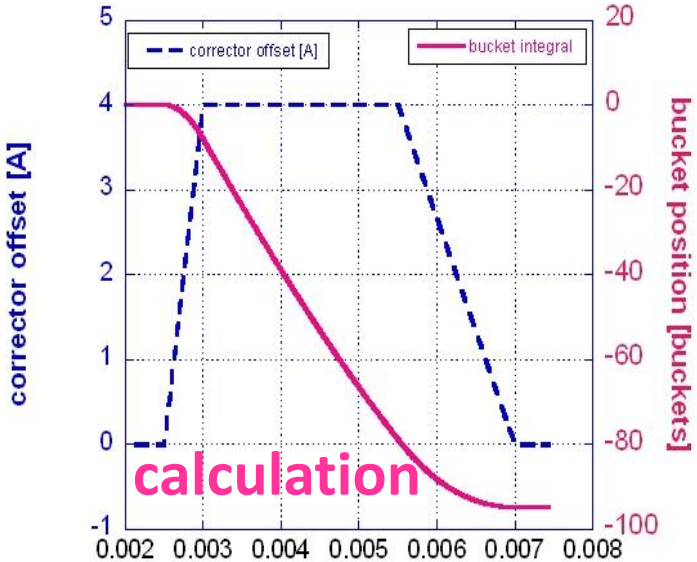
Adding ~+/- 2-3 [A] offset for cogging should not be problem.

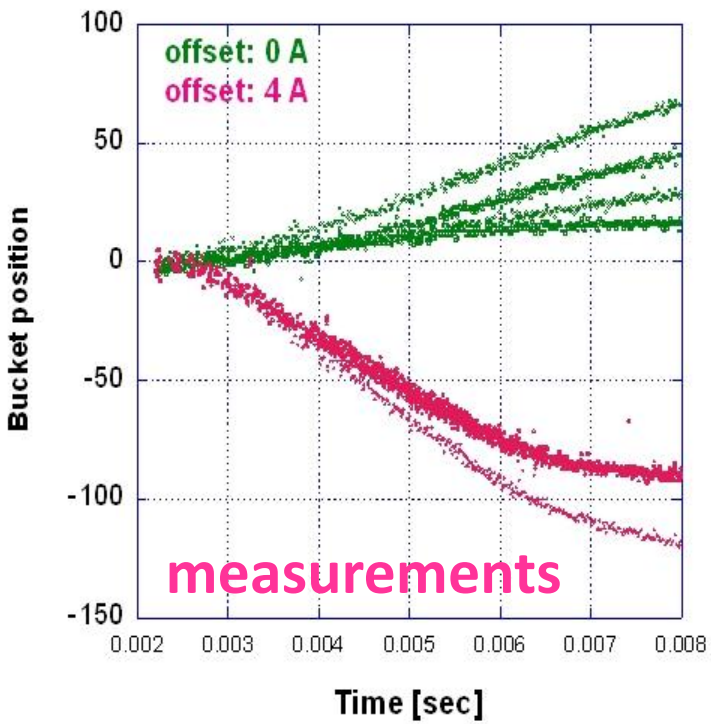
Cables to 48 correctors from LLRF room (K. Triplett, D. Dick)

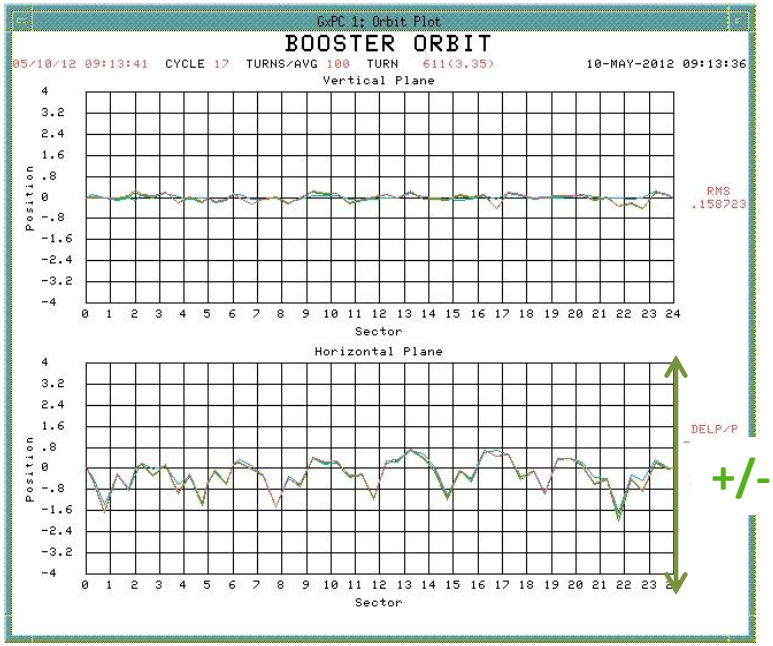
Corrector offset signal



Bucket slippage measurement with corrector offset







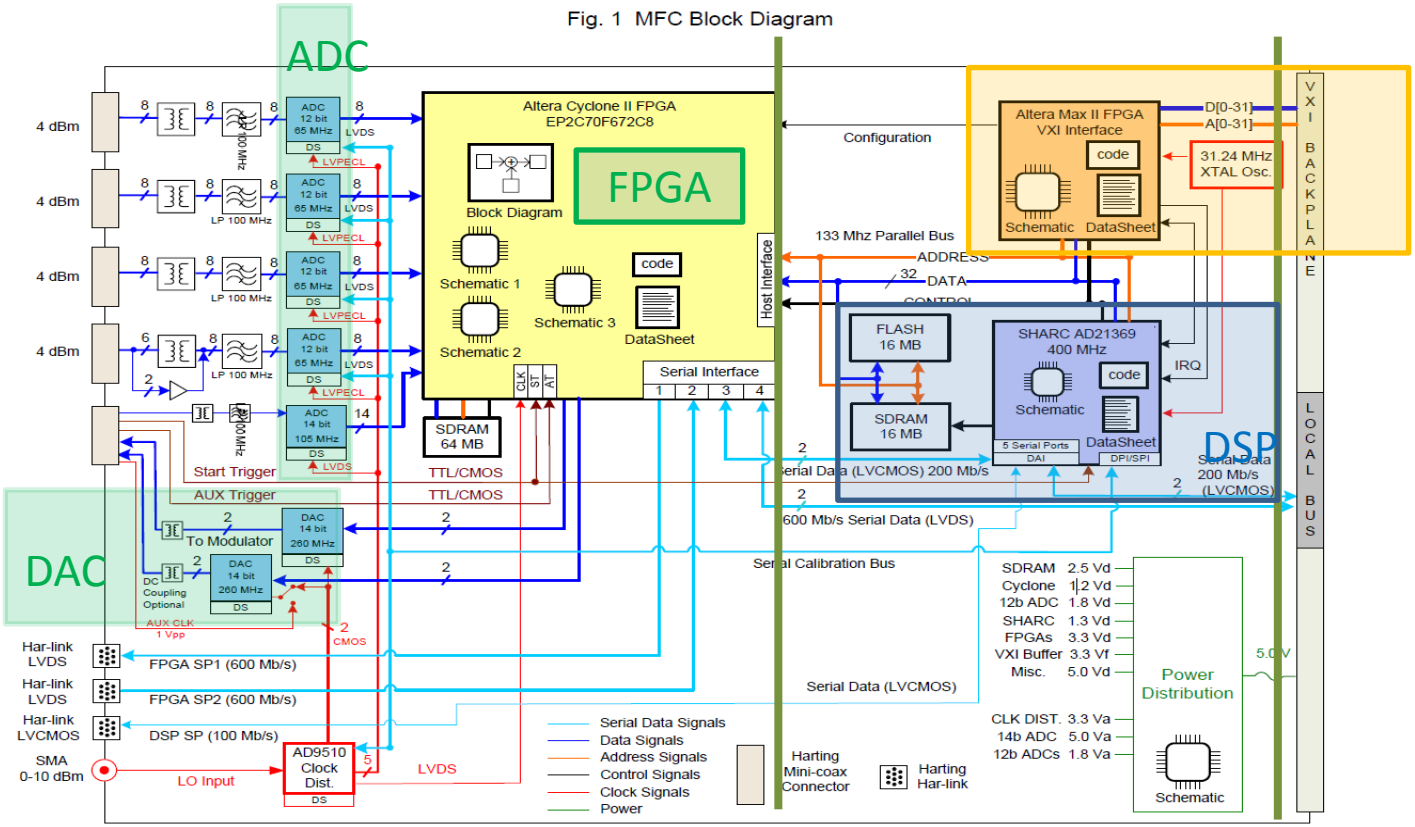
$$\int \Delta\text{buckets}\, dt = \mathbf{95}\ \boldsymbol{buckets}$$

Orbit change ~ +/- 1mm

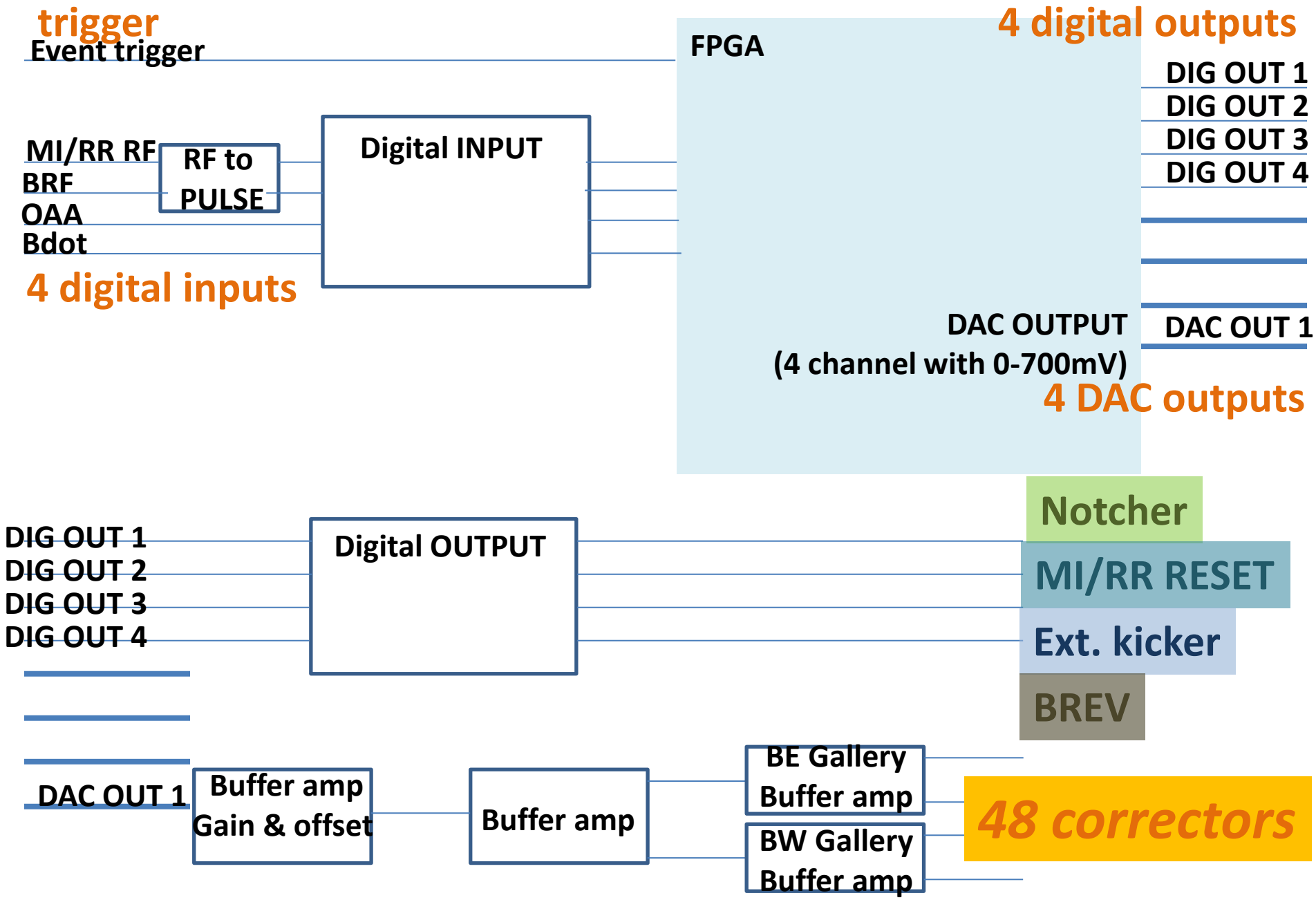
Programmable VXI controller module

Multichannel Field Control (MFC) module (AD/LLRF)

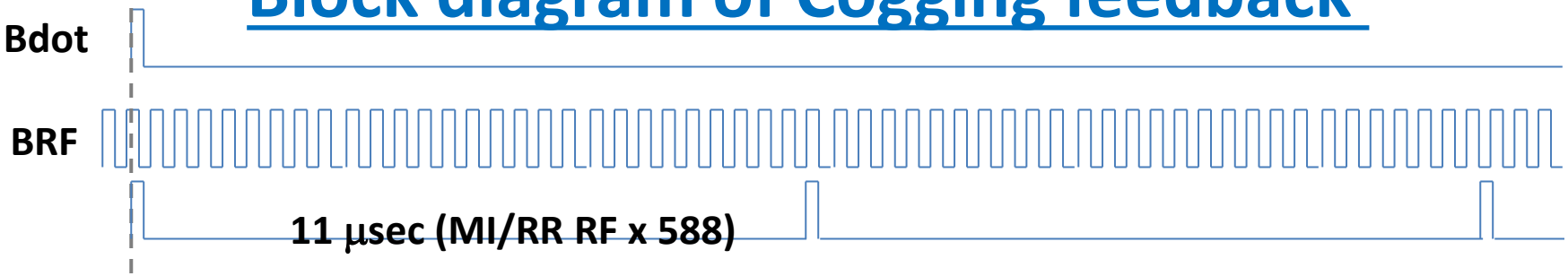
TCLK decoder on FPAG (AD/Control)

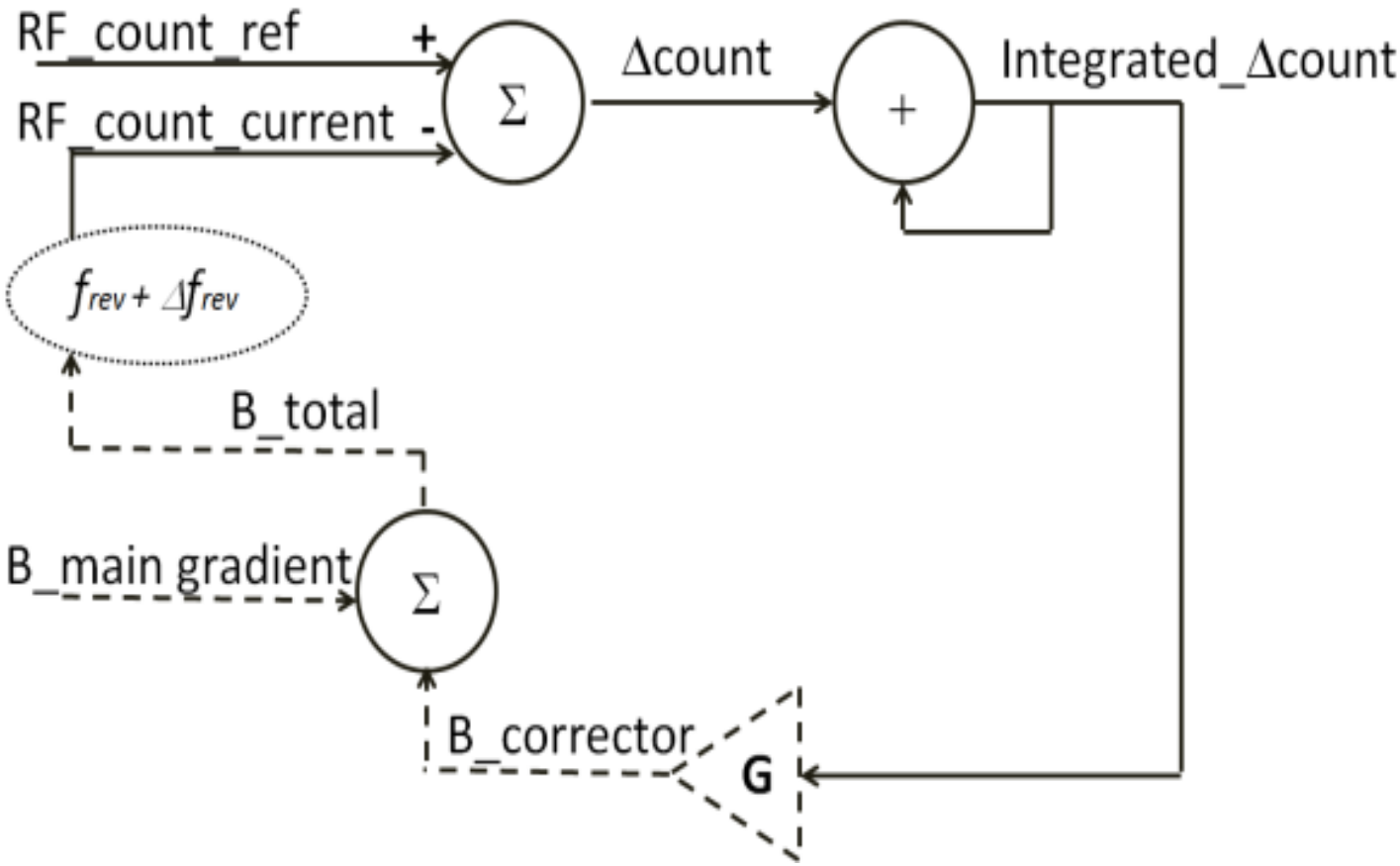


Cogging system layout



Block diagram of Cogging feedback



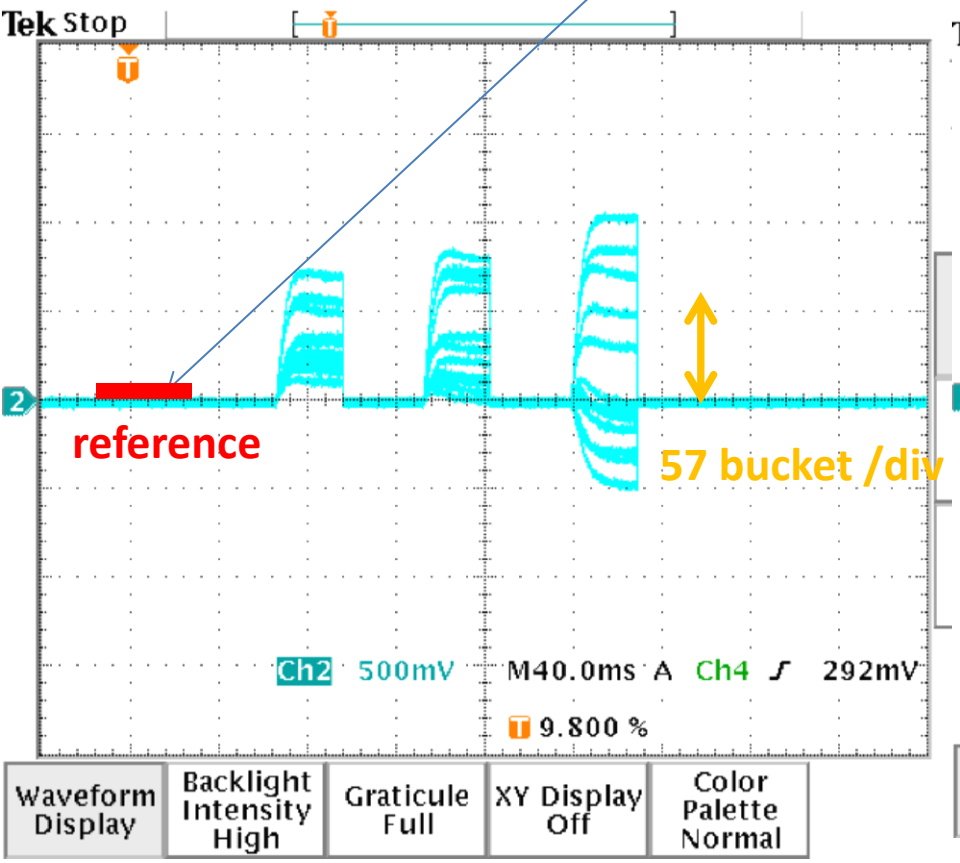


Integrated diff. bucket count has to be '0' at the end of cycle.

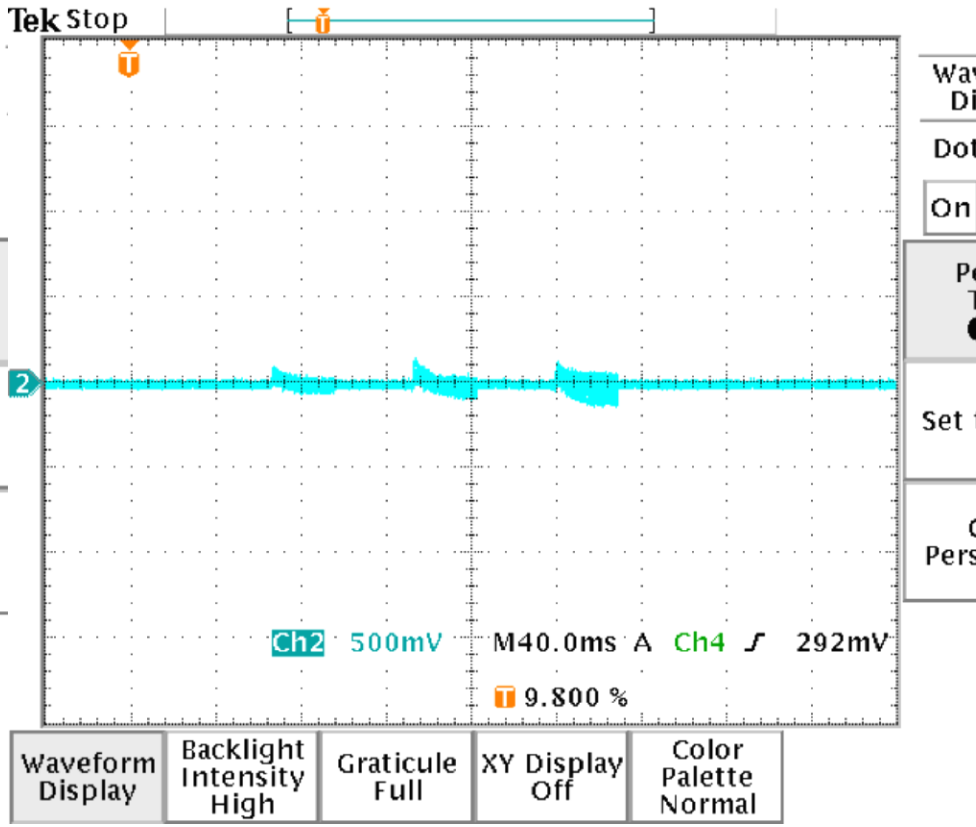
Beam study on $17(1)

$12 $17 $17 $17 $17

w/o dipole corrector

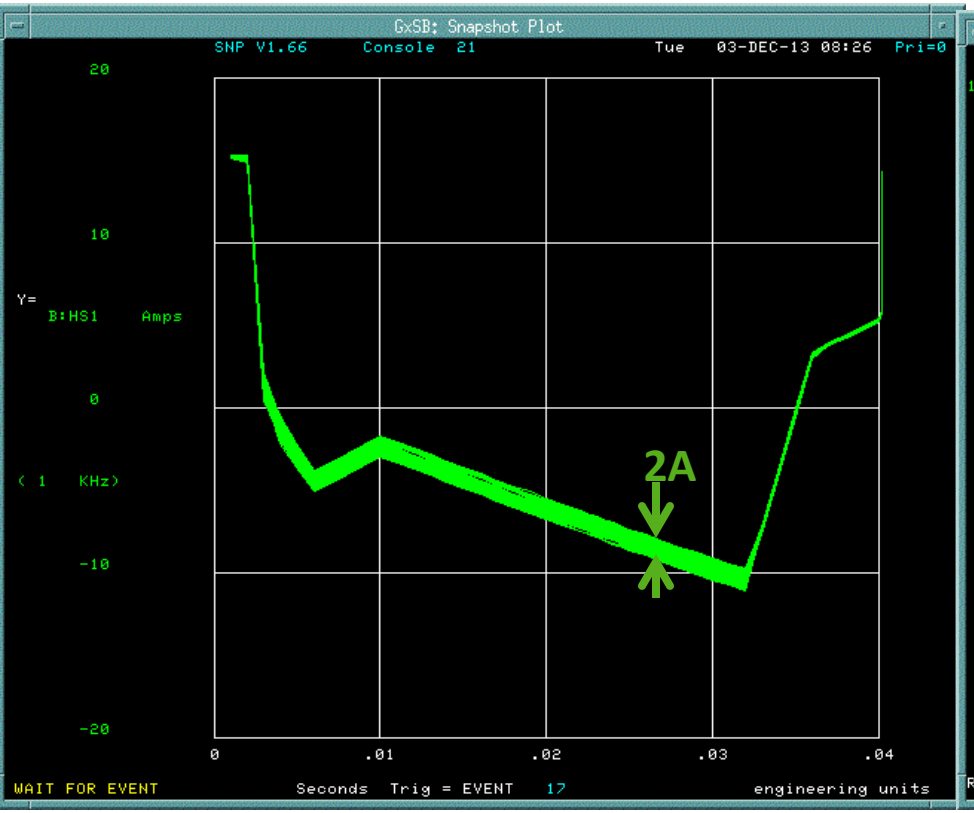


with

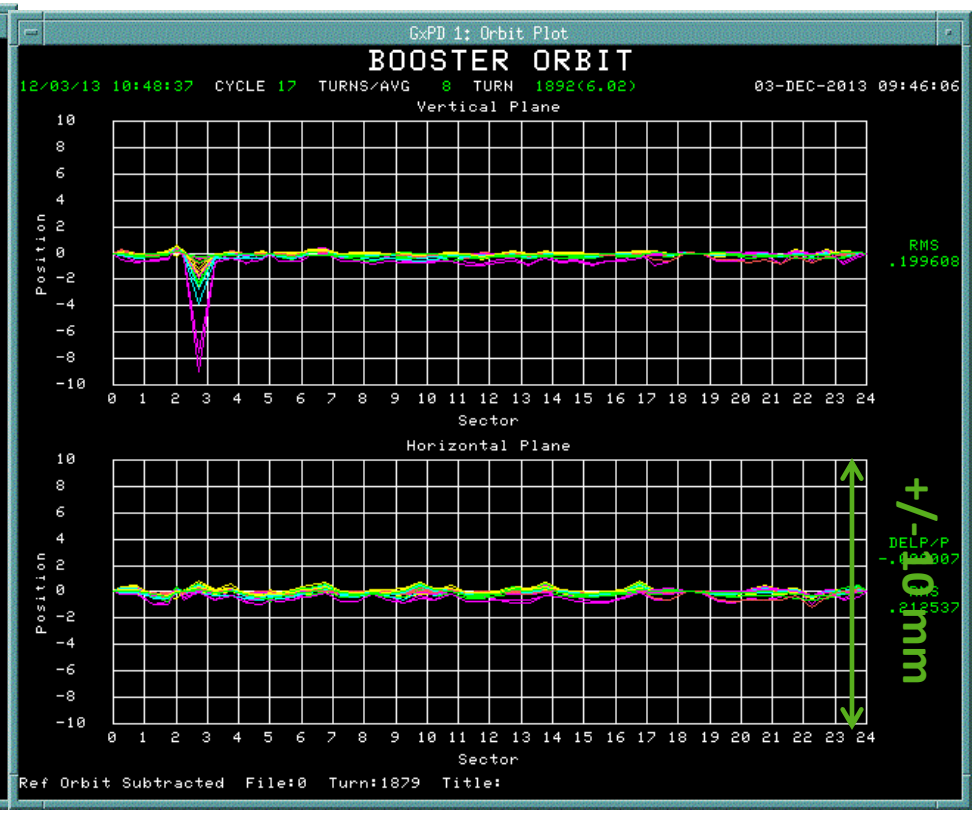


Beam study on $17(2)

Corrector current



Orbit difference

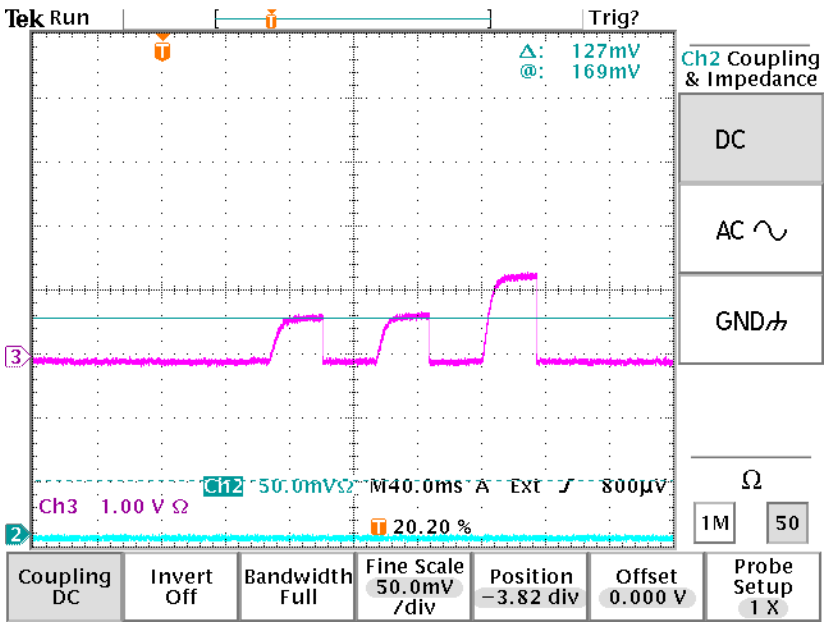


Corrector current : +/- 1A

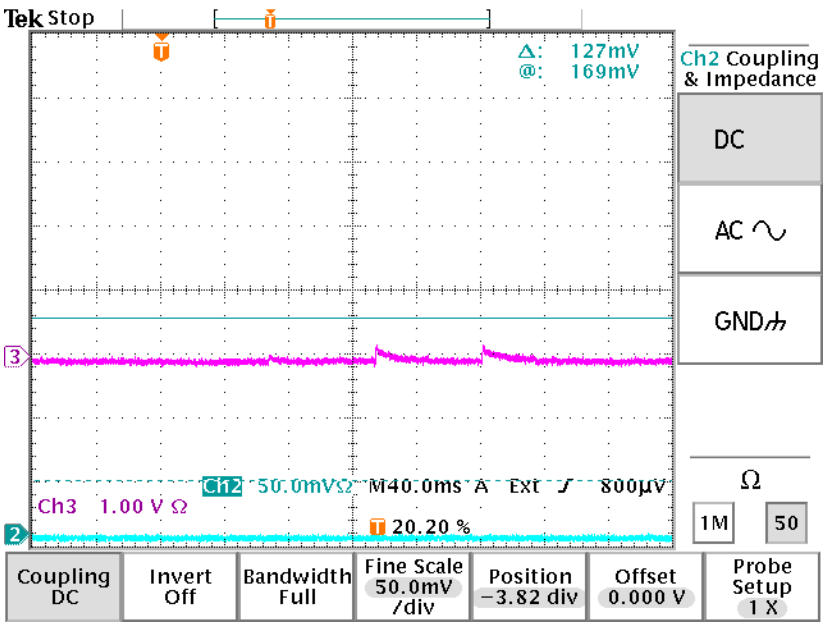
Orbit change < 1mm

Optimization of the cogging feedback gain

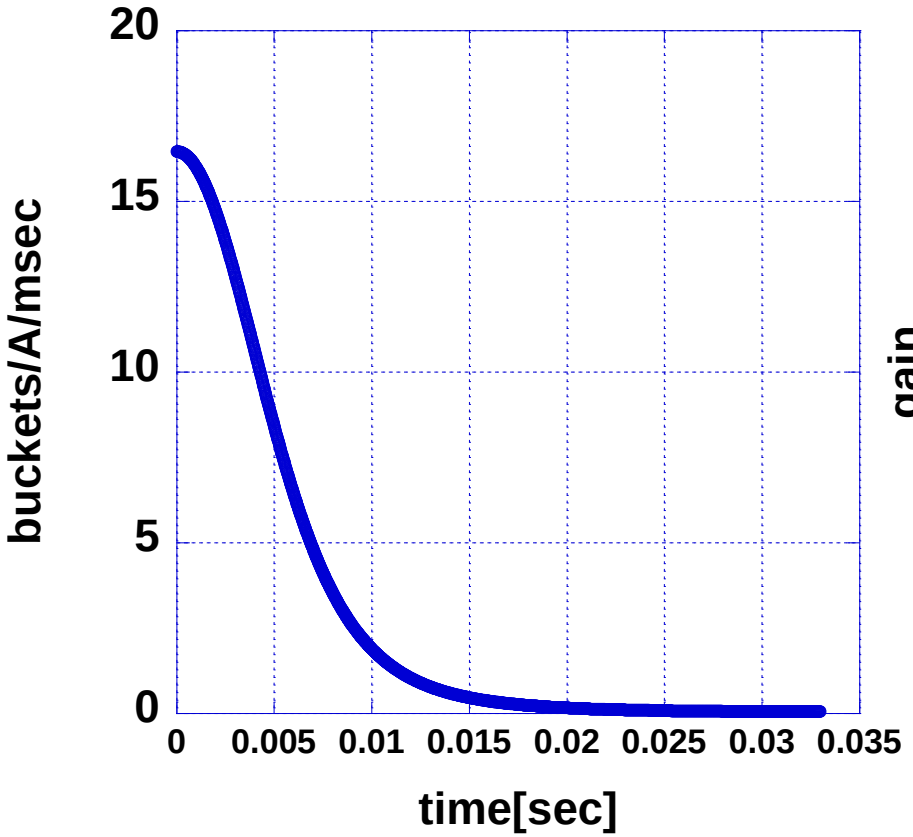
without feedback

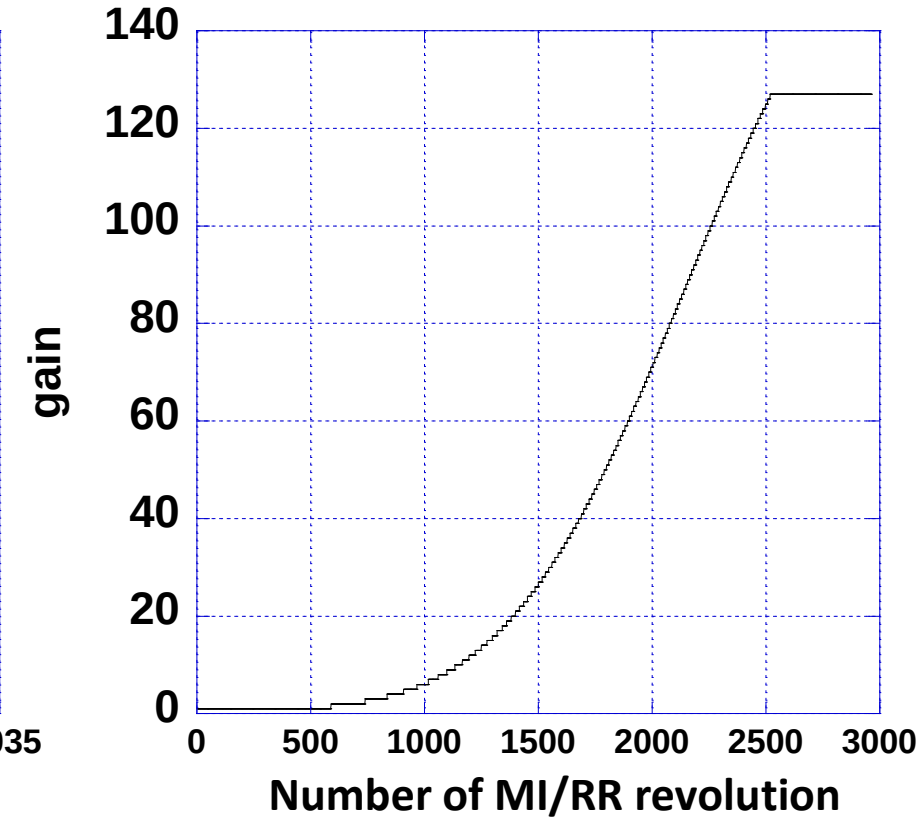


with feedback

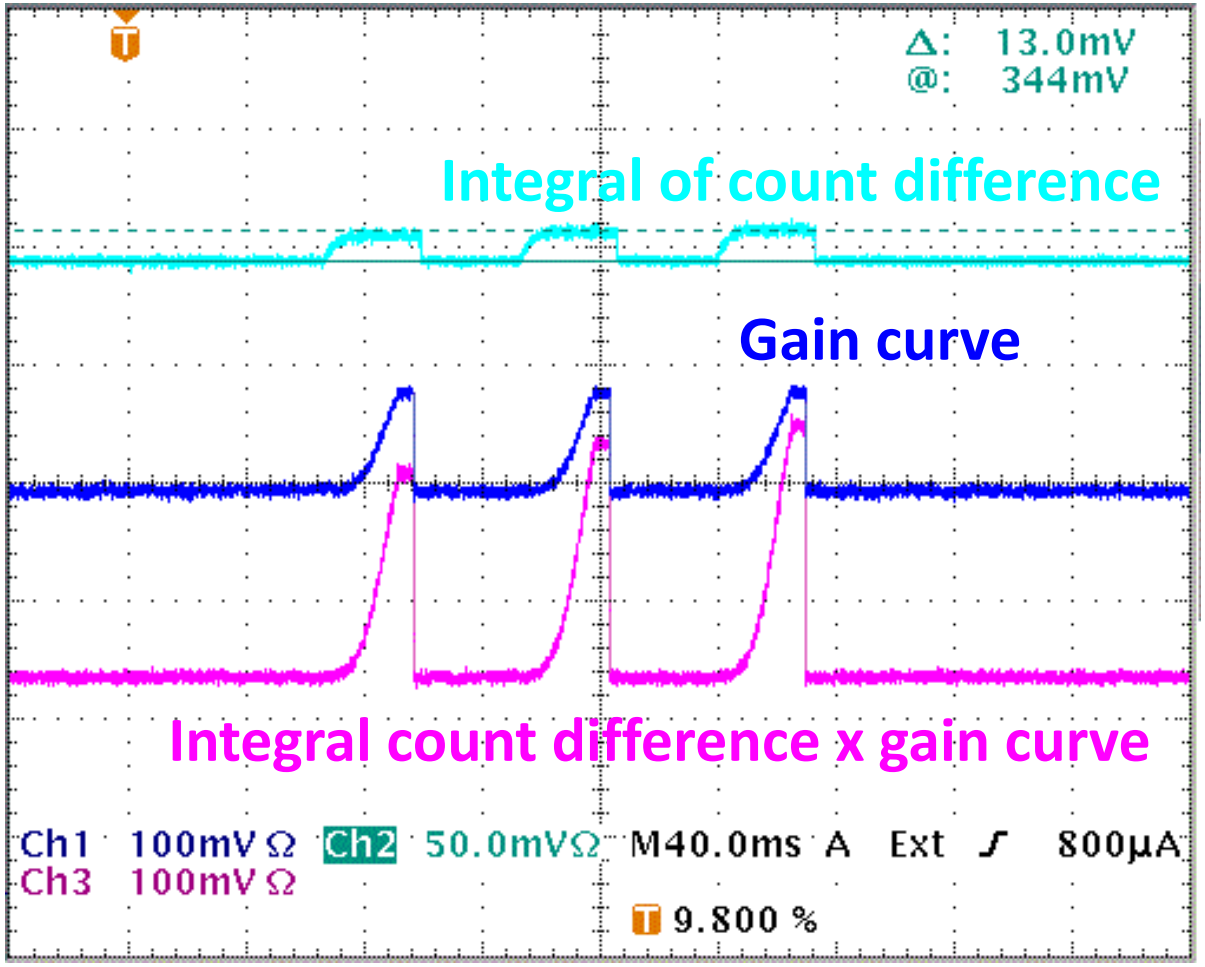


Bucket slippage with dipole correctors and gain curve





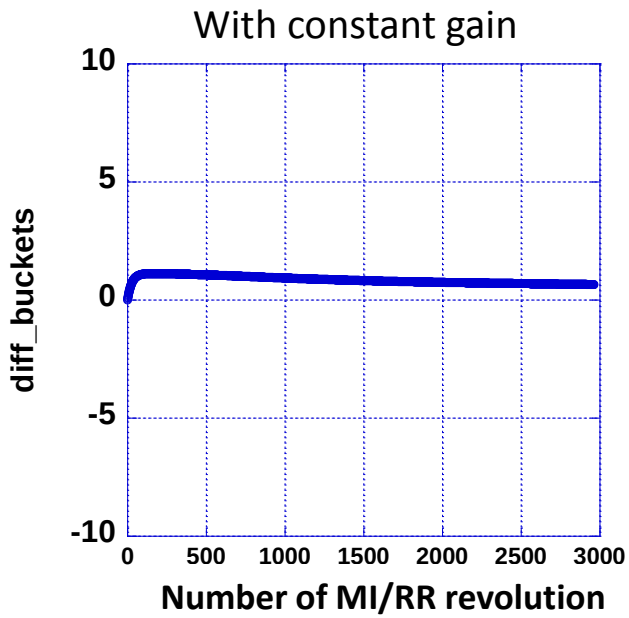
Inputs for the feedback with a gain curve

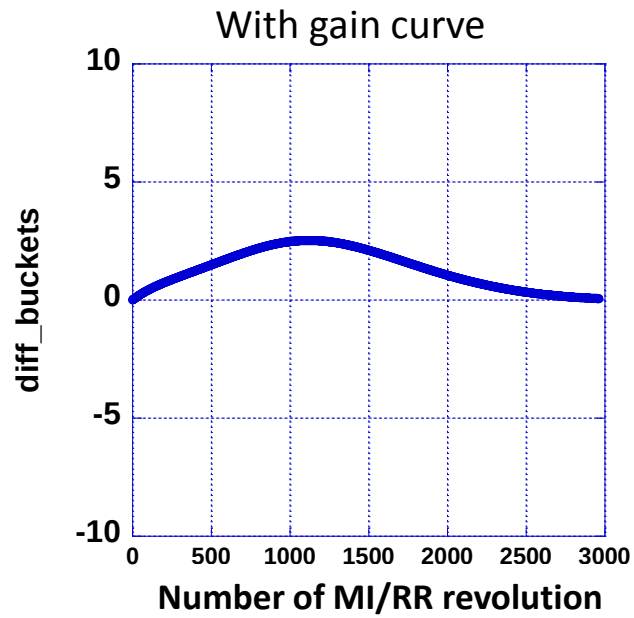


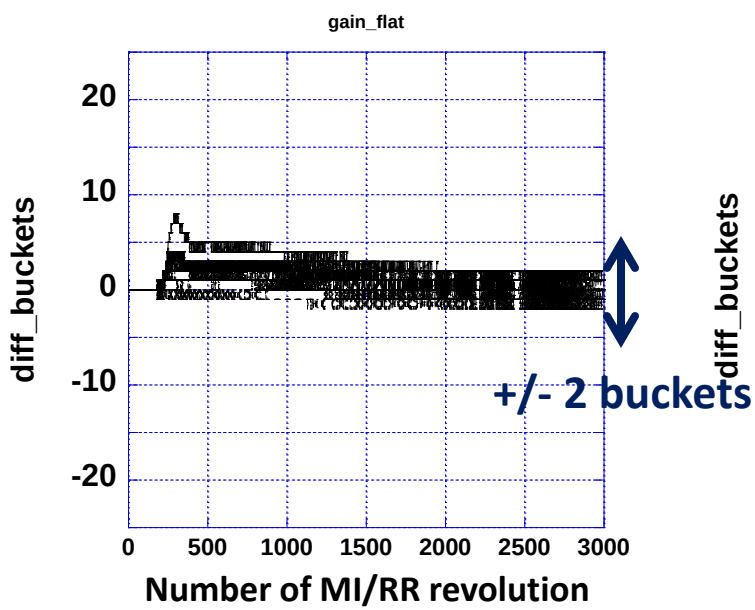
Cogging feedback with constant gain and gain curve

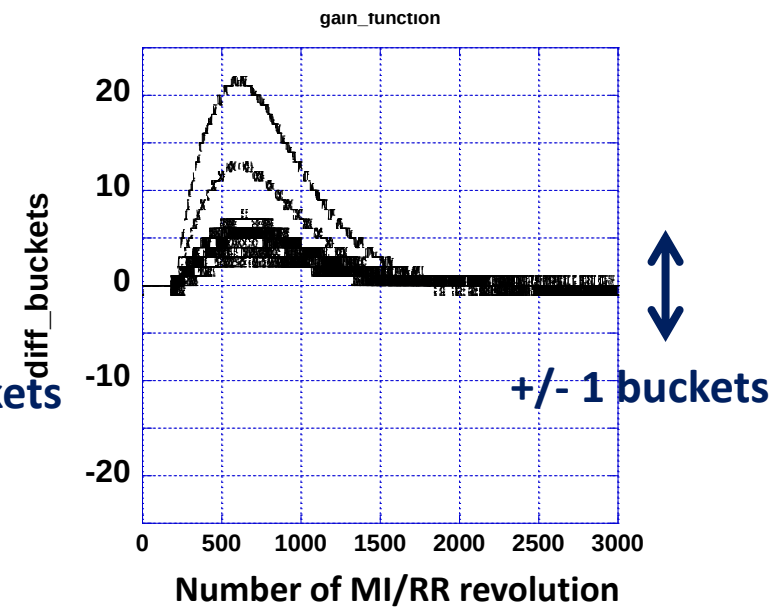
Simulation

Measurement (x 10)

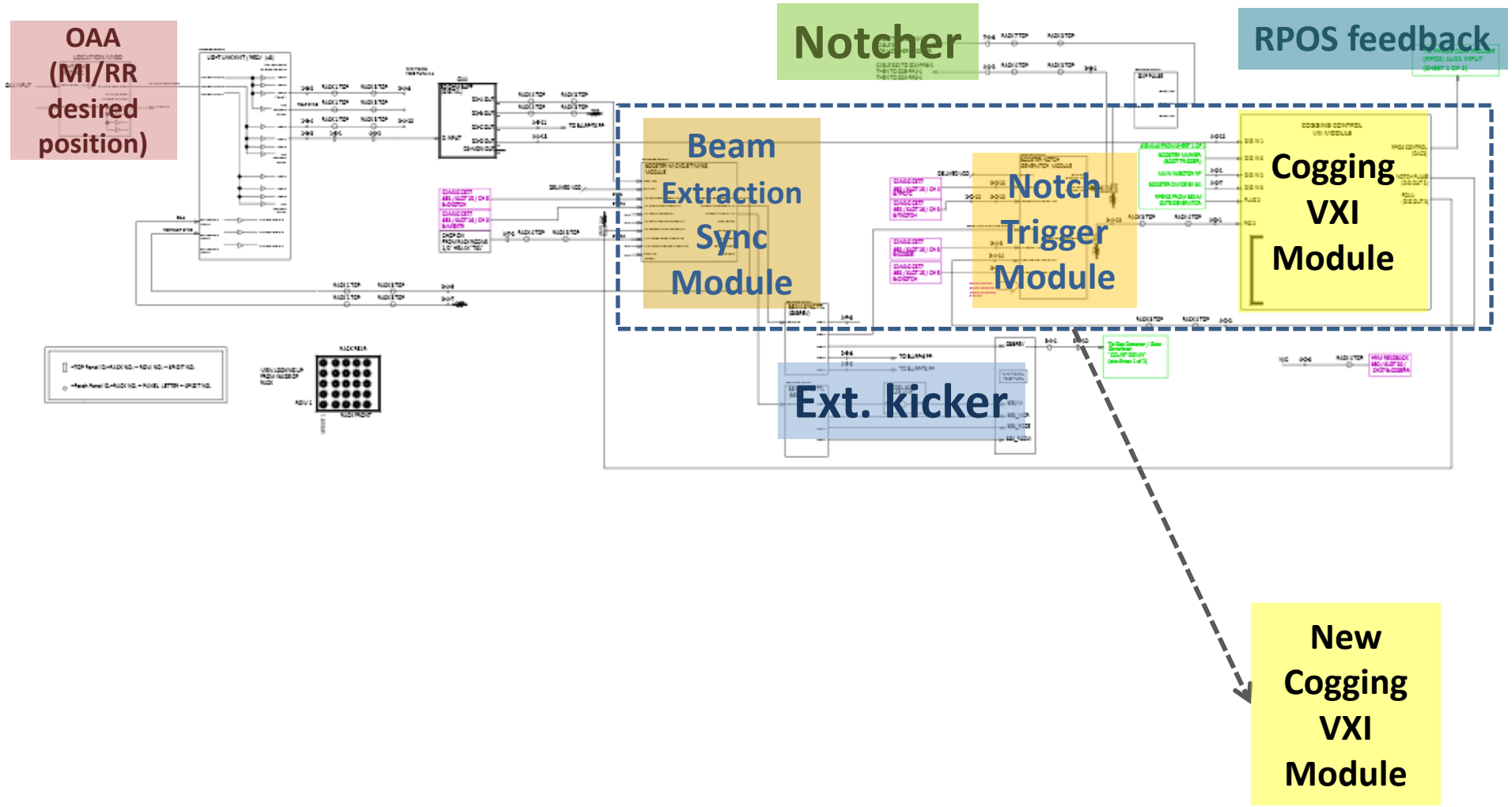






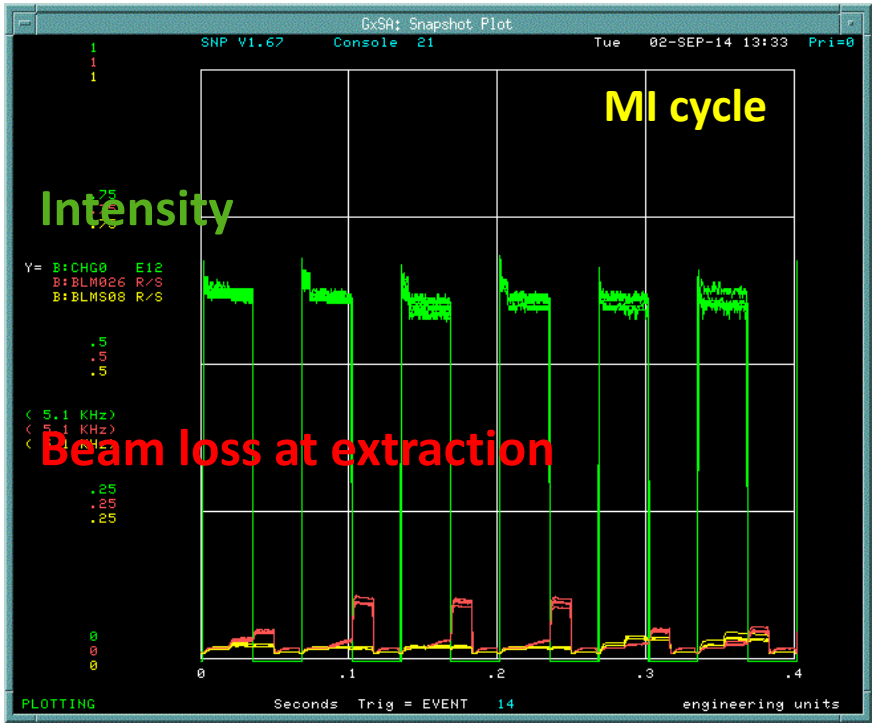


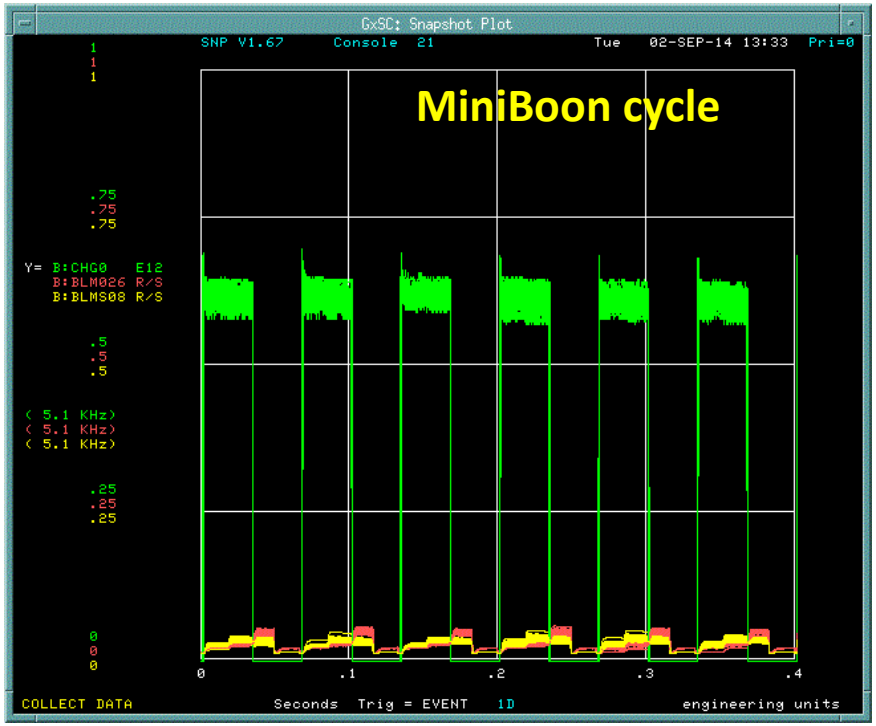
Beam Extraction Sync Block Diagram



Notch(extraction kicker gap) – Booster extraction kicker – MI/RR injection kicker

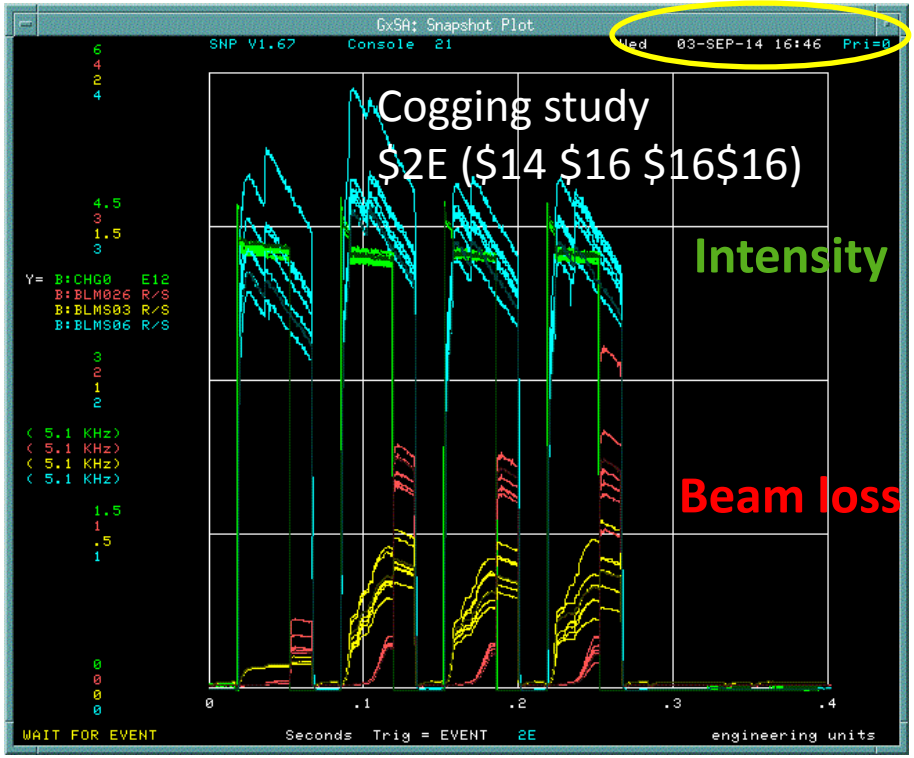
Beam Extraction Sync with New VXI board

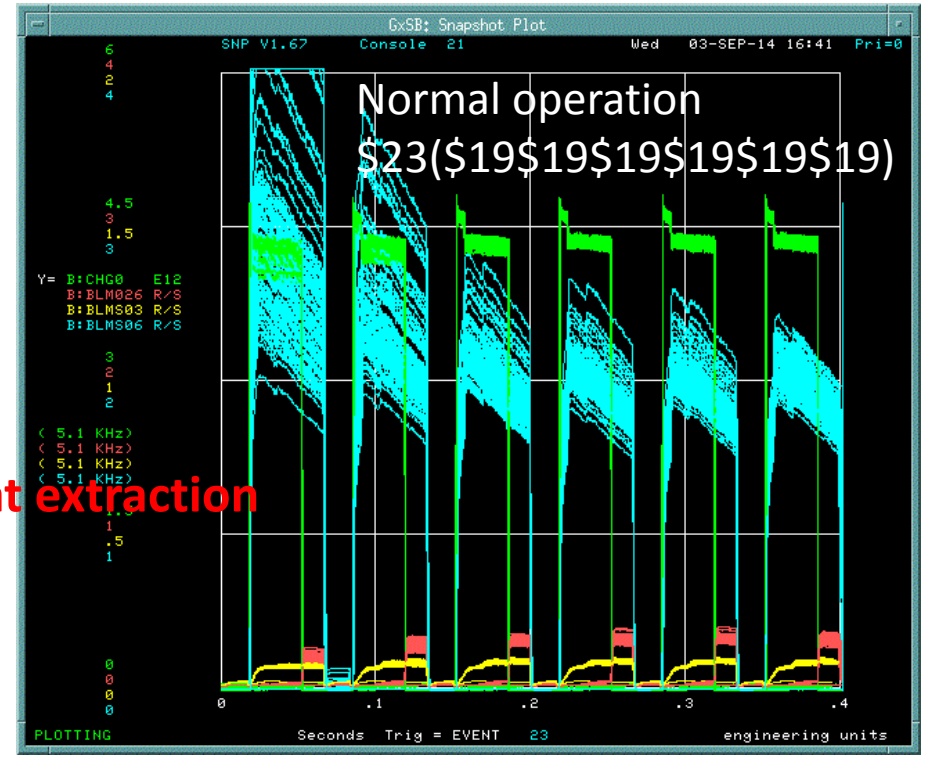




Beam Extraction Sync and MI/RR RESET worked on MI and MB cycles.

Destructive study 2 days before shutdown (~1hr)





Ran $2E MI study cycle and $1D

Higher loss at extraction

Destructive study 1 days before shutdown(~1hr)

Ran $23 MI operational cycle and $1D

Continue studies after shutdown

Test system using MFC board

DAC output
0-700mV

↓

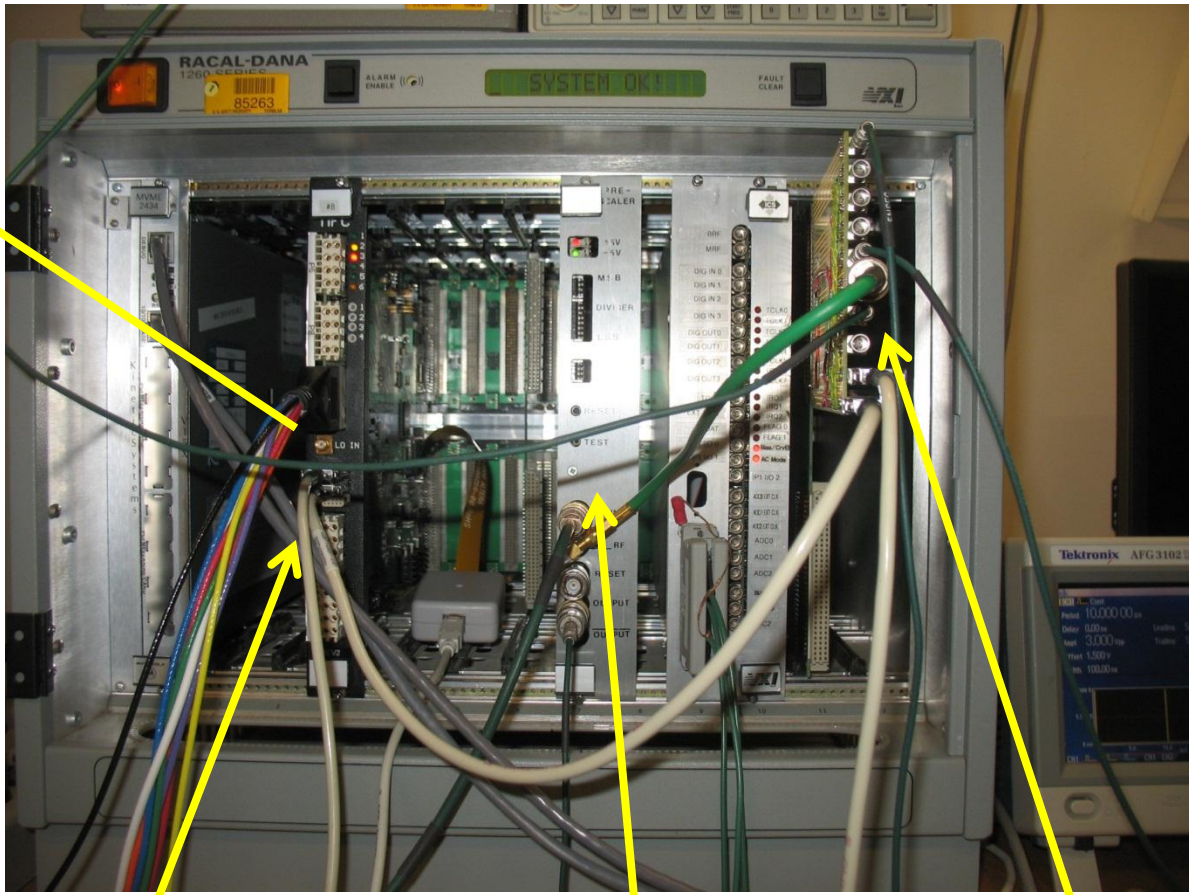
Buffer amp
offset

↓

Buffer amp
gain

↓

Corrector
offset



MFC

RF
To
pulse

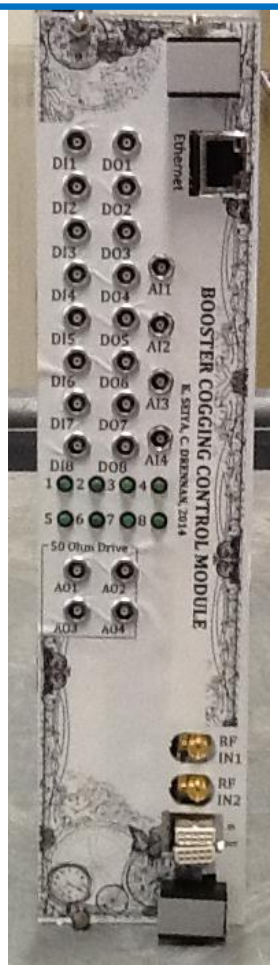
4 x Digital inputs
To
Harting connector

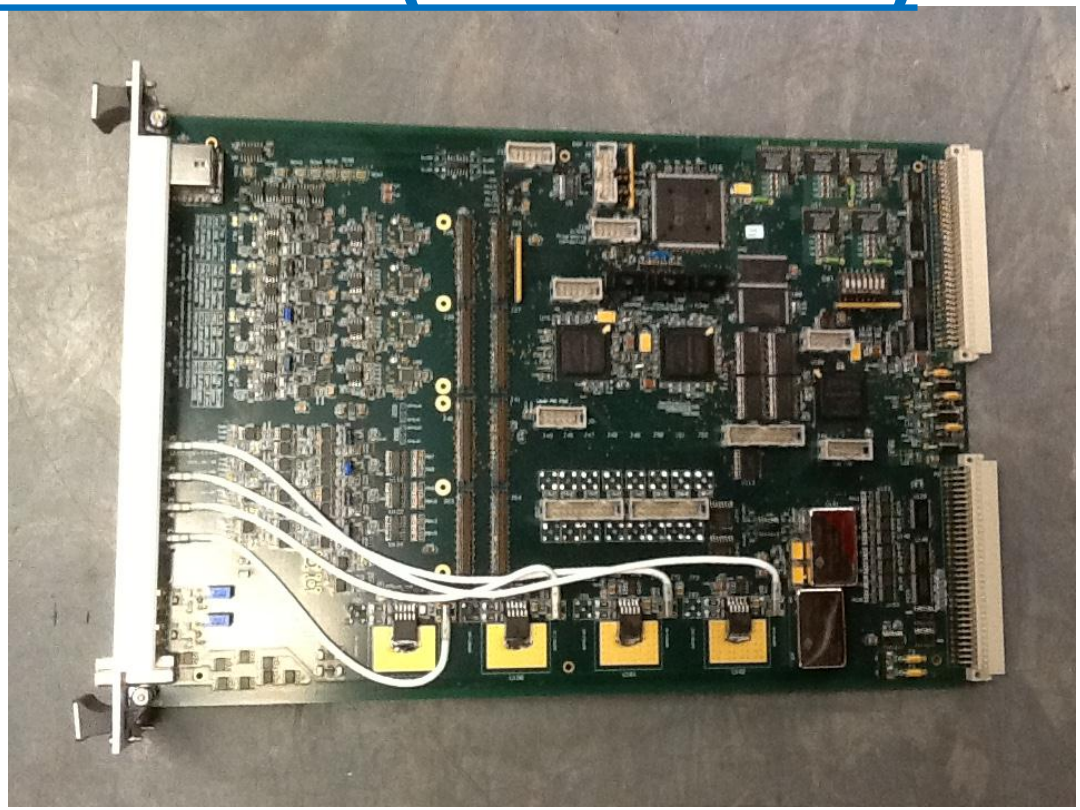
New Booster VXI board (C. Drennan)

8 x digital inputs
8 x digital outputs

4 x ADC inputs
4 x DAC outputs

2x RF inputs



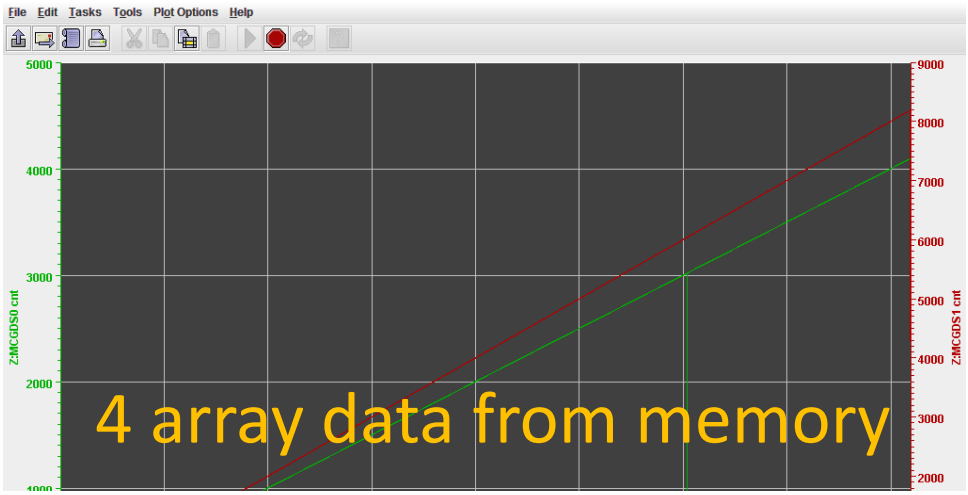


More digital outputs for diagnostics.

Add “beam gate signal” for the logic.

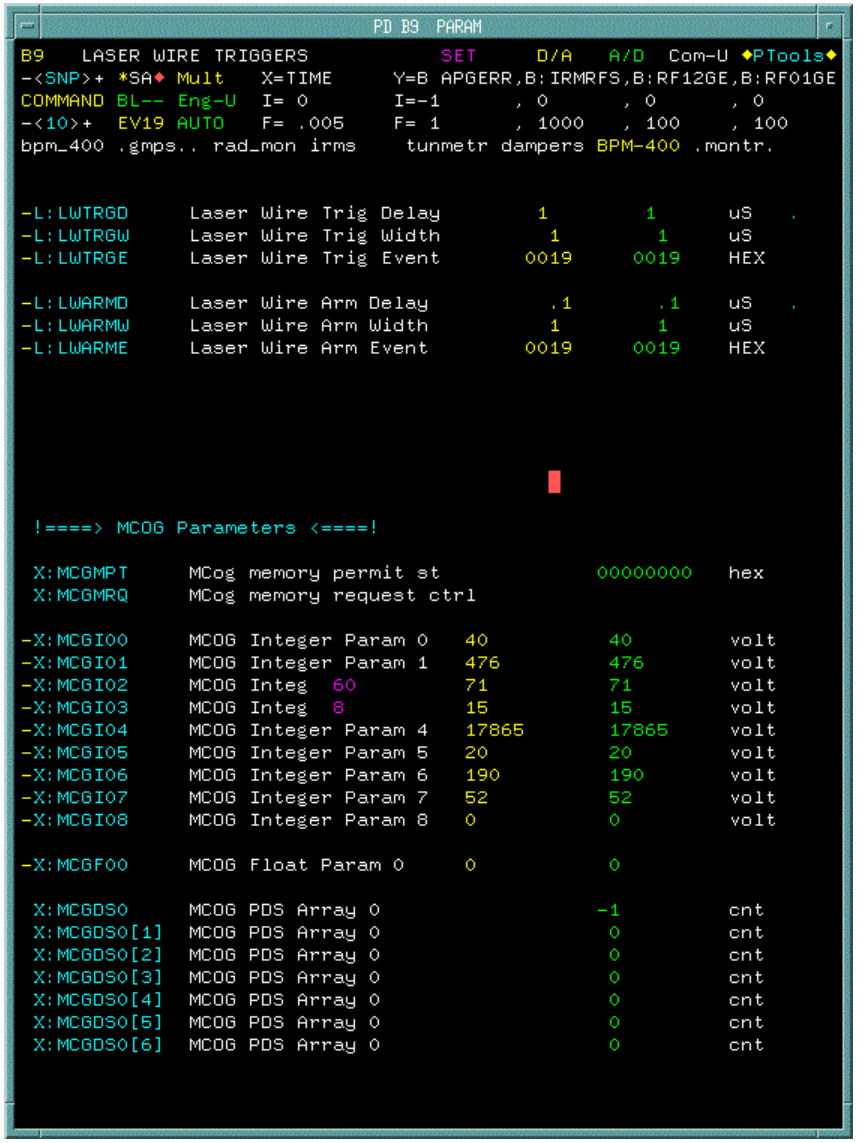
Replacement for the 15 years old present Booster VXI/DSP board as well as performs all functions of test system shown on last slide.

Parameters and plots on console (A. Waller)



File Edit Options

Array Index	Z:MCGDS0	Z:MCGDS1
0	0.0	1.0
1	1.0	3.0
2	2.0	5.0
3	3.0	7.0
4	4.0	9.0
5	5.0	11.0
6	6.0	13.0
7	7.0	15.0
8	8.0	17.0
9	9.0	19.0
10	10.0	21.0
11	11.0	23.0
12	12.0	25.0
13	13.0	27.0
14	14.0	29.0
15	15.0	31.0
16	16.0	33.0
17	17.0	35.0
18	18.0	37.0
19	19.0	39.0
20	20.0	41.0



During shutdown

FPGA code transfer from MFC to New VXI board

Improve resolution of the final bucket position
+/- 1 to +/- 0.5 buckets

Add more diagnostics and protection

Set Acnet parameters for operation

After shutdown

Beam study with high intensity on Booster study cycle

More destructive studies

Switch to Magnetic Cogging by December, 2014