# *Corrector Orbit Dipoles (CODs) Analysis*

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# *Trip of orbit corrector magnets and effects on the beam*

# *Outline*

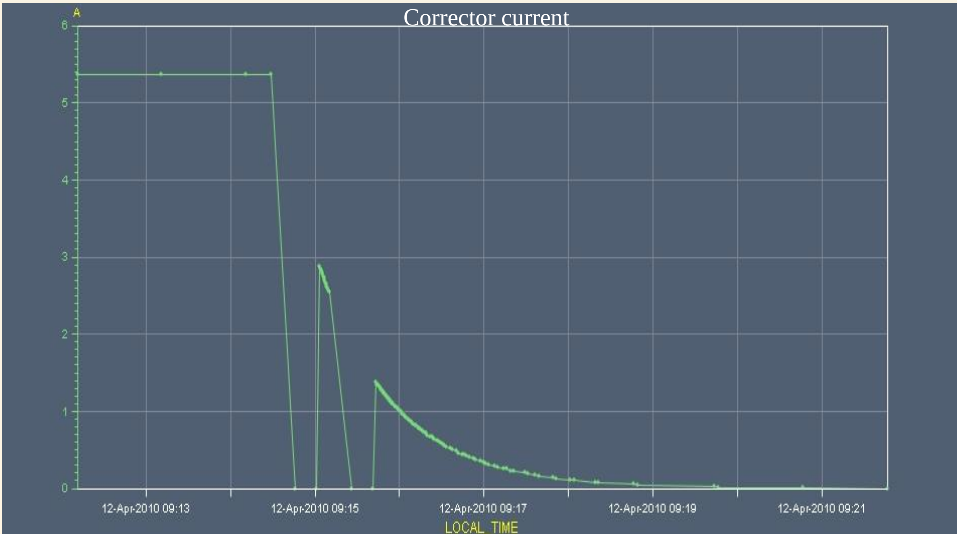
- Checked two cases where a corrector tripped
  1) MCBV.12L4.B1 at fill: #1034
  2) MCBV.17L1.B1 at fill: #1035

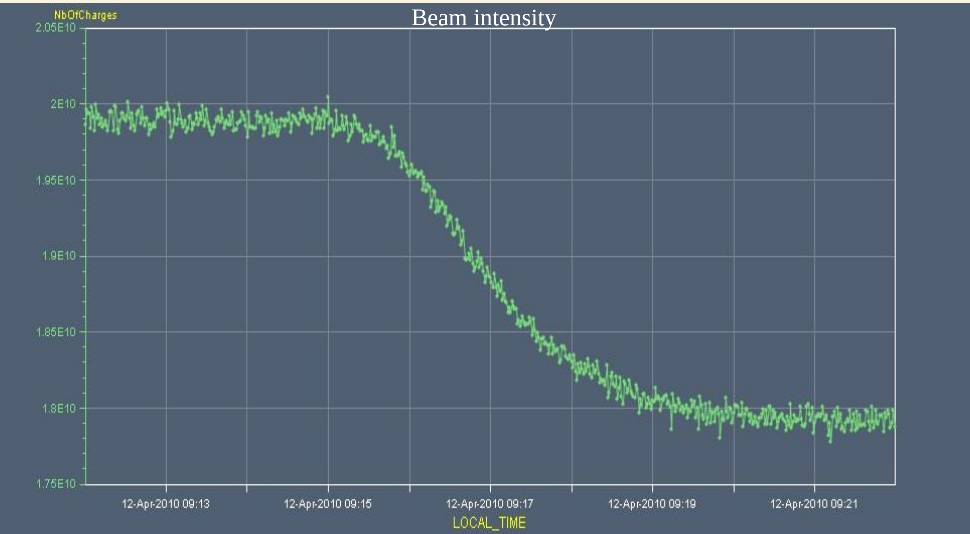
- We have looked at the current of the correctors, calculated the resulting kick and estimated the losses that such a kick produces using a simple model.

•60A superconducting
•Time constant: 55s (indicated 99s /130s)
•Nominal magnetic field: 2.93T
•Length: 0.647m
•Operating temperature: 1.9K

# *Corrector MCBV.12L4.B1*

- Time and date of event: 12/4 at 9:14
- Operating current : 5.37A
- Magnet kick: 16.6 μrad
- Intensity falls 10% - losses indicated by the BLMs in point 7.

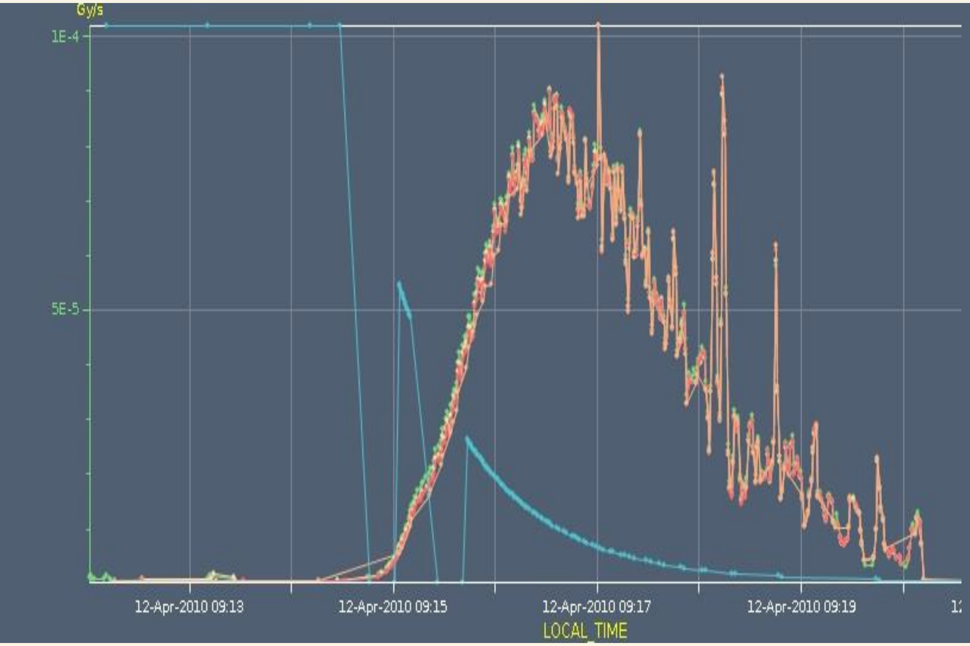


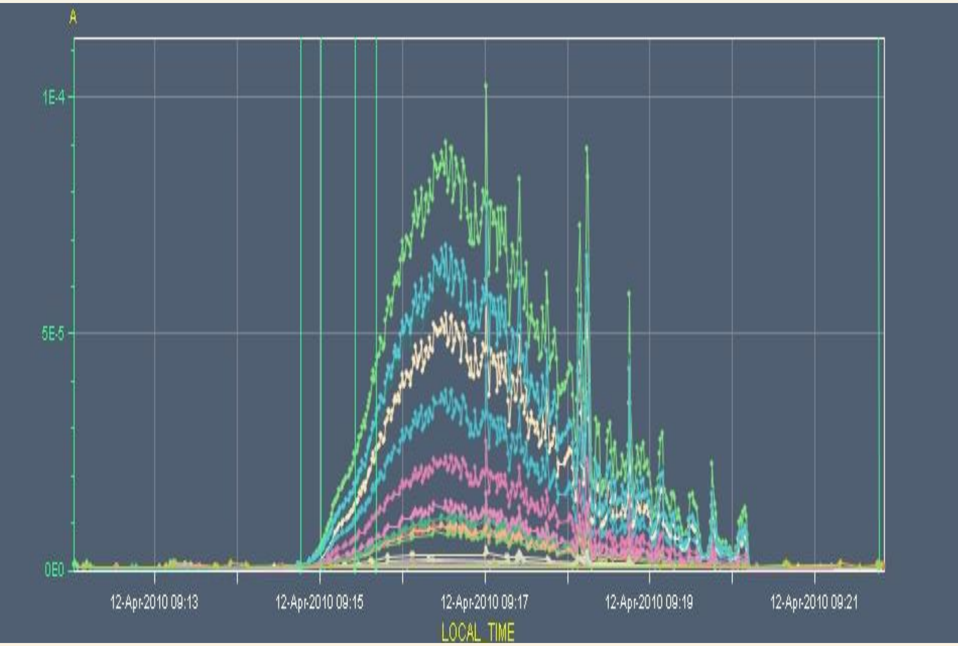



# *Data during loss*

Corrector current with scaled BLM signals (first losses observed at 3.5A)

BLM signals in IP7 (maximum losses at: 0.56A)

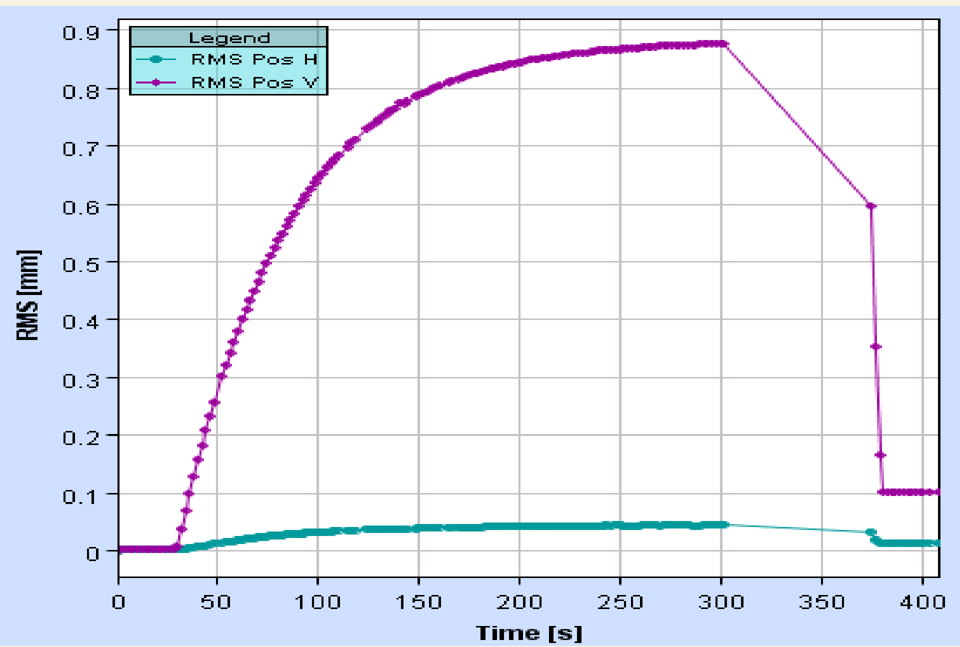


# Data during loss

Temperature around IP7 remains unchanged

Vertical orbit RMS increases to 0.9mm

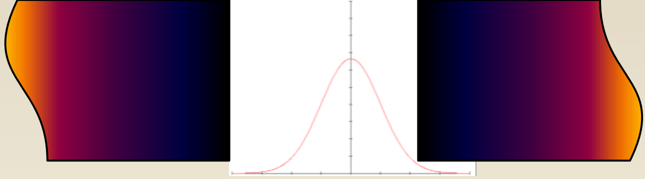
# *Beam at collimators*

- Calculated emittance from wire scanning: $\varepsilon = e^*/(\beta\gamma) = 3.18E\text{-}10$m (1.5h before event)

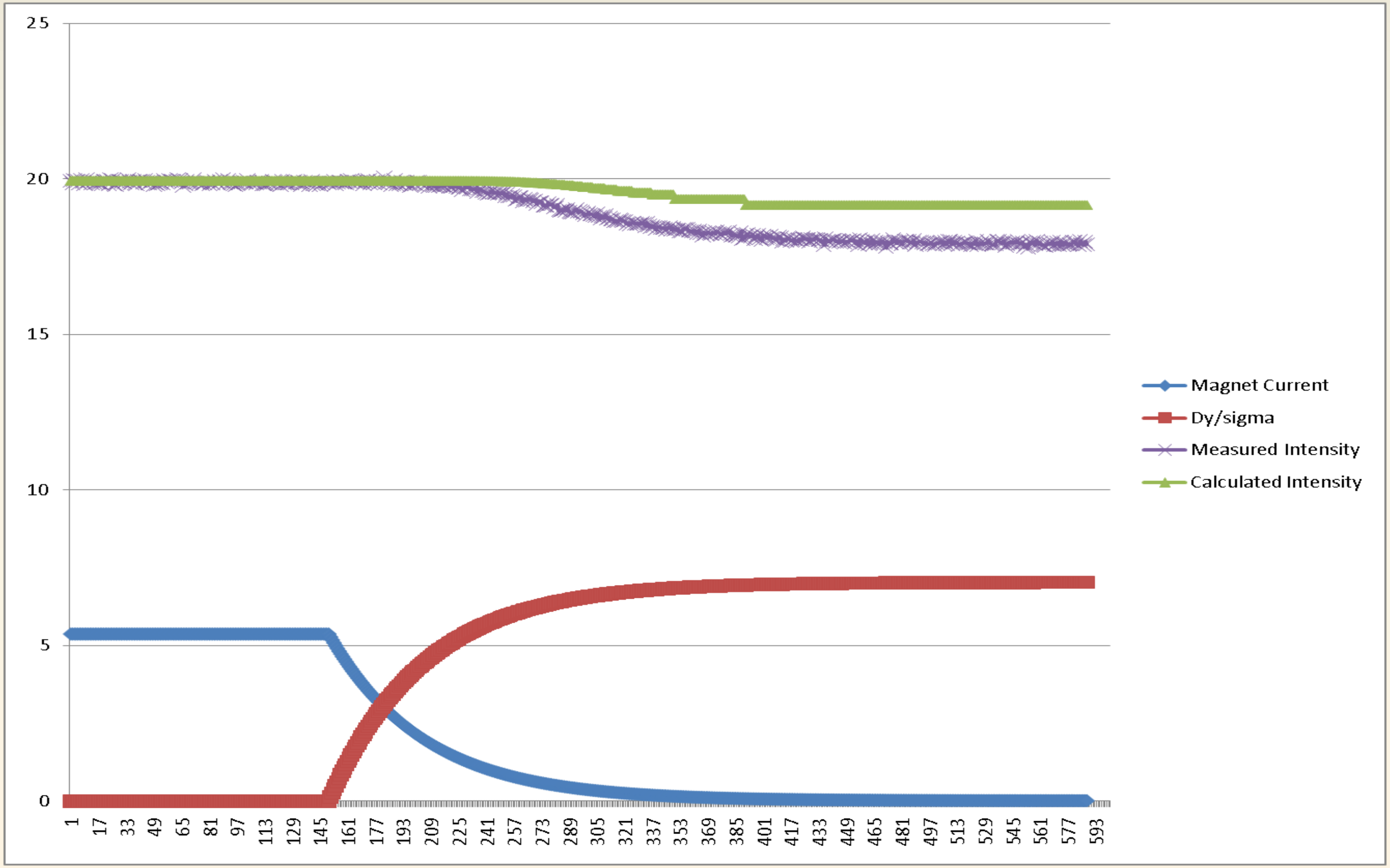
- Optics set to collision

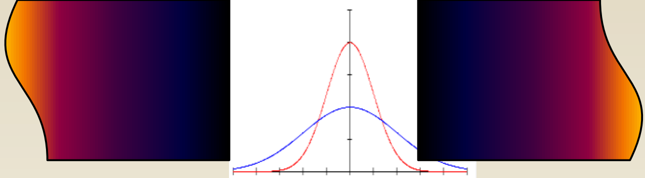
| | TCP.D6L7.B1 | TCSG.D4L7.B1 |
|---|---|---|
| **cos() factor** | 0.9 | 0.5 |
| **Dy (mm)** | 1.1 | 0.6 |
| **Dy (sigma)** | **7.0** | 3.7 |
| **Collimator half gap (sigma)** | 9.8 | 14.6 |

$$\Delta x_{co}(s) = \frac{\sqrt{\beta(s)}}{2\sin\pi Q}\sum_i \theta_i \sqrt{\beta(s_i)}\cos\left(\Psi(s) - \Psi(s_i) + \pi Q\right)$$

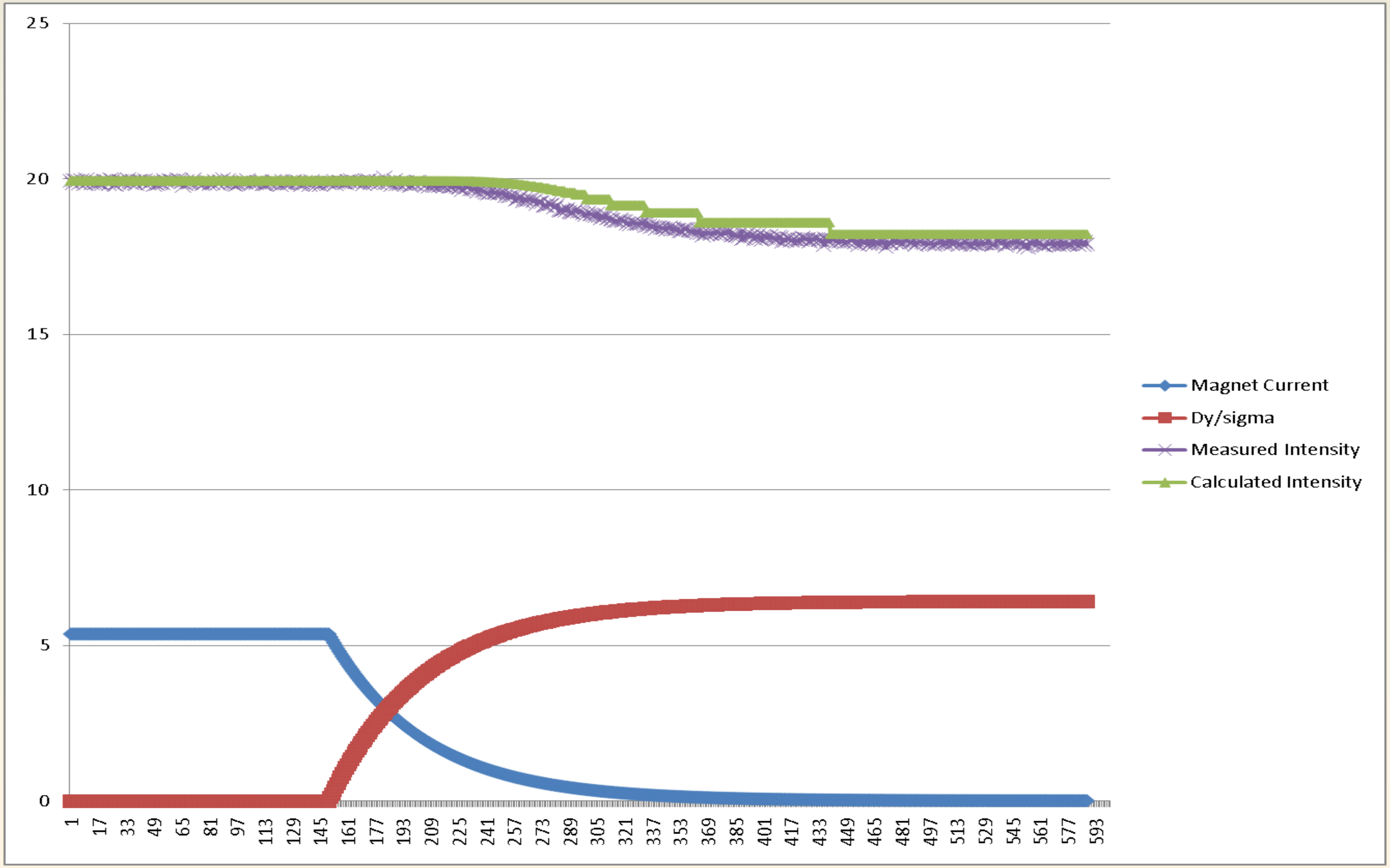


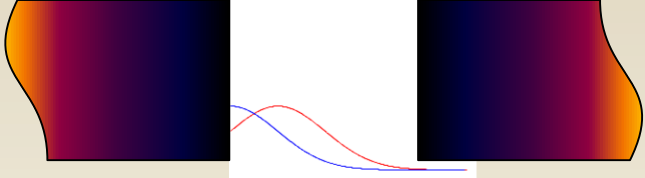
# *Event progression*



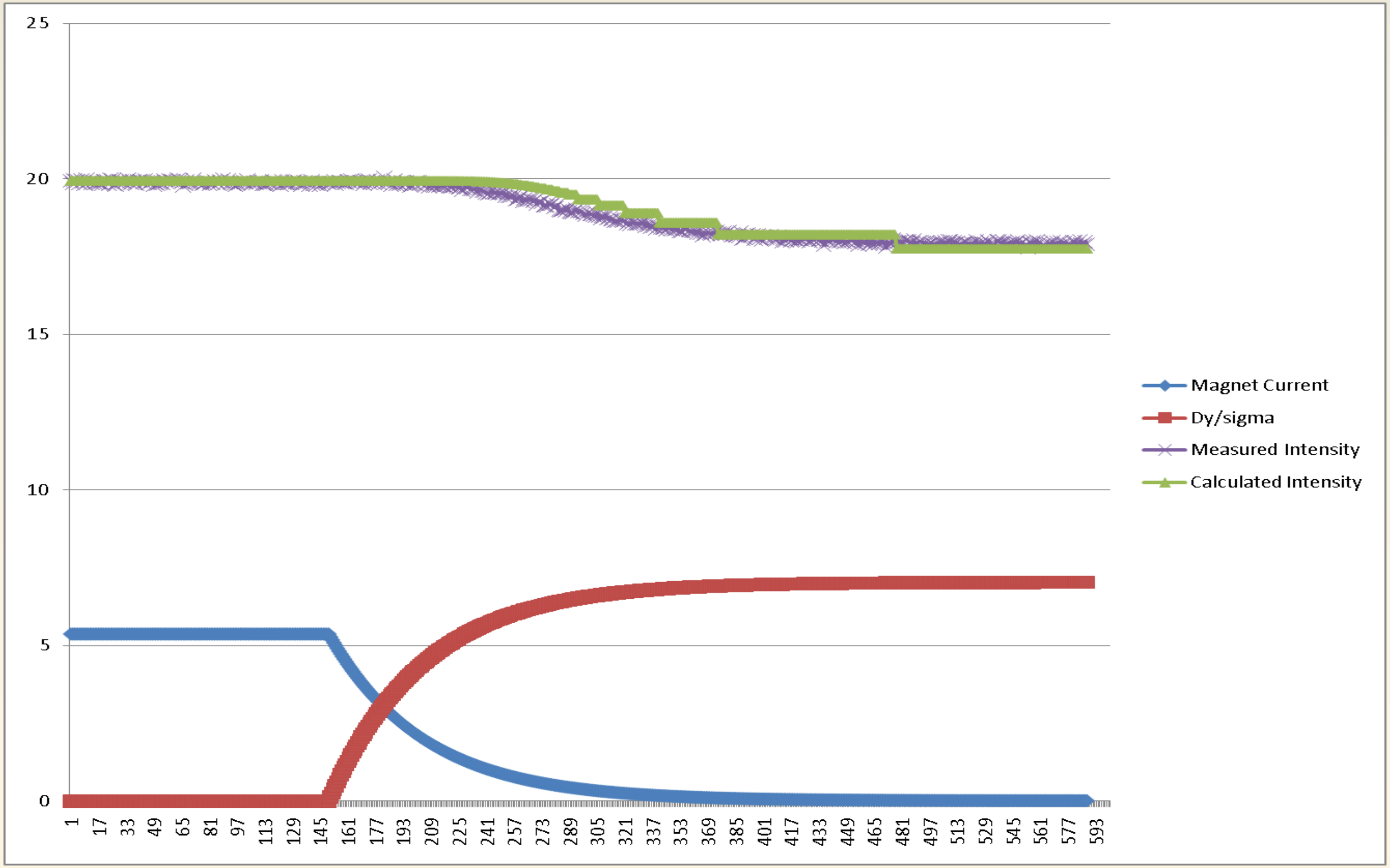


# *Progression with 20% increased emittance*

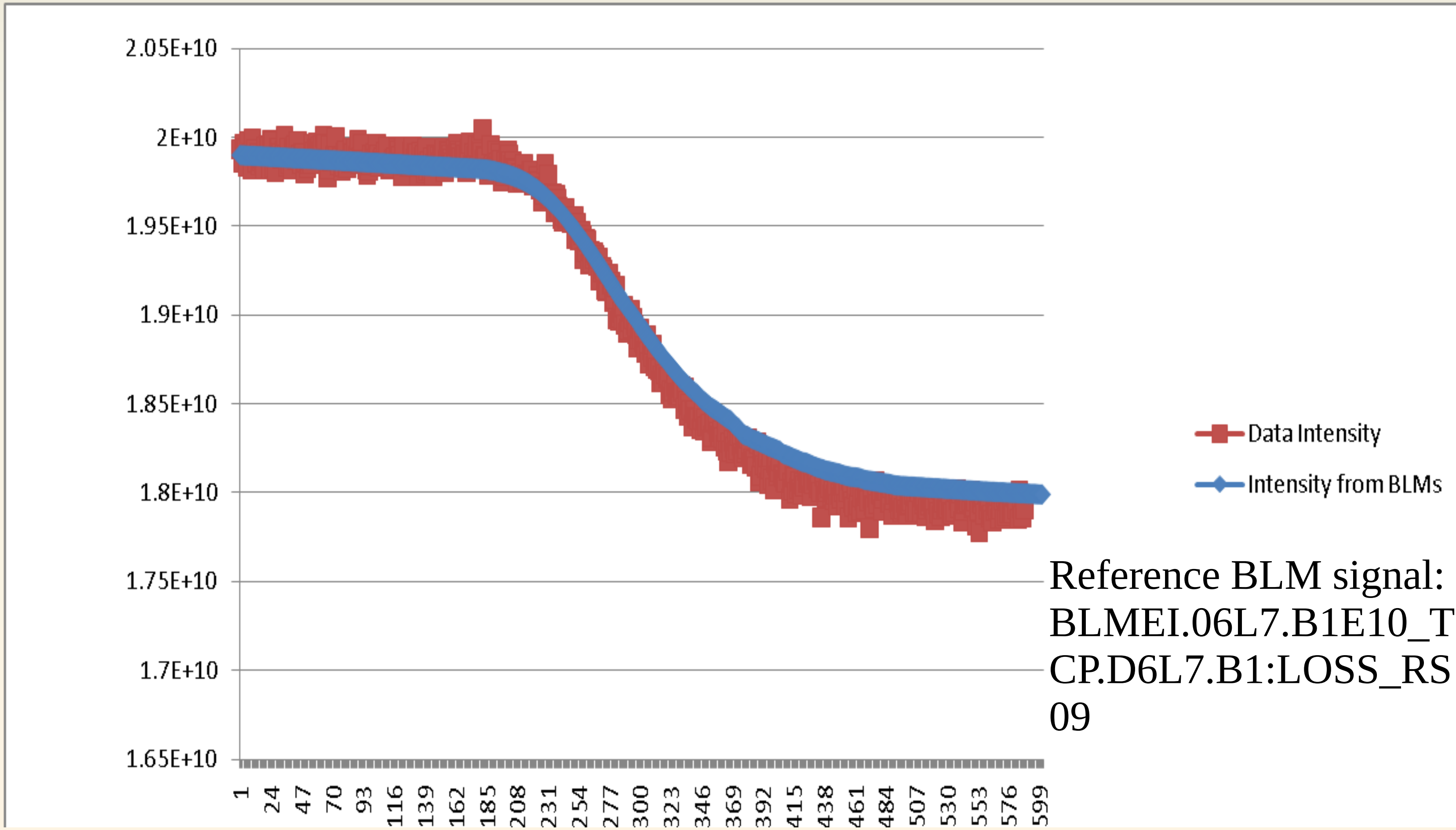




# *Progression with an σ/3 offset*



# *Logged intensity vs. calculated intensity from BLM losses*

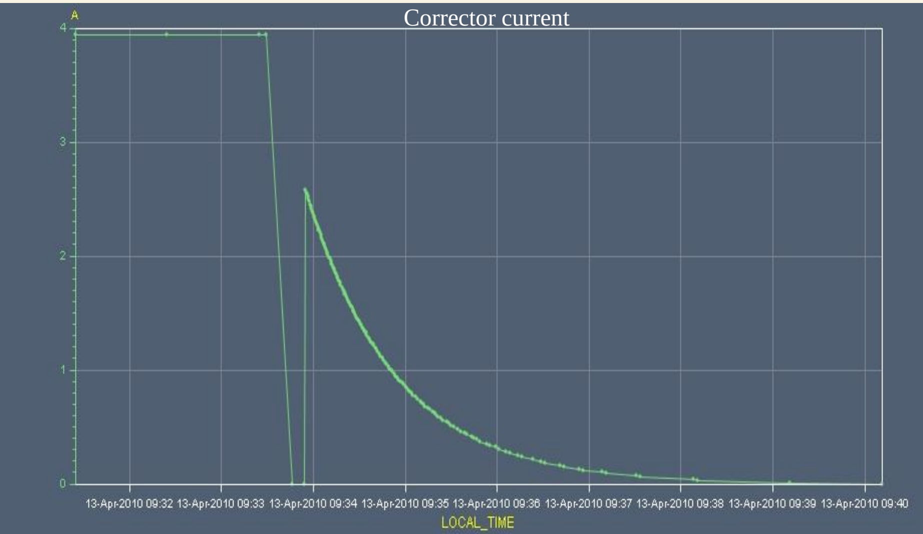



Reference BLM signal: BLMEI.06L7.B1E10_TCP.D6L7.B1:LOSS_RS09

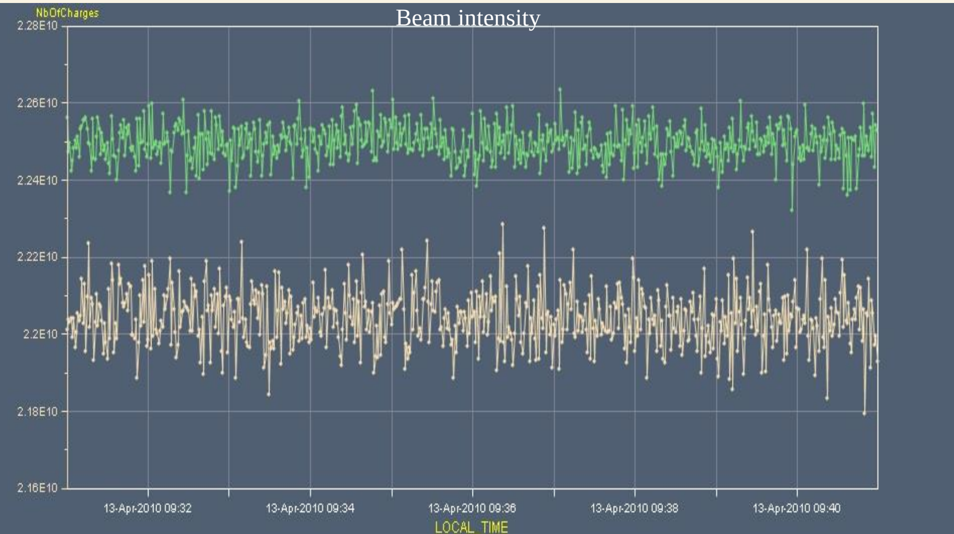
# *Corrector MCBV.17L1.B1*

- Time and date of event: 13/4 at 9:33
- Operating current : 3.94A
- Magnet kick: 12.2 μrad
- Intensity remains unchanged - no losses detected

Corrector current




Beam intensity



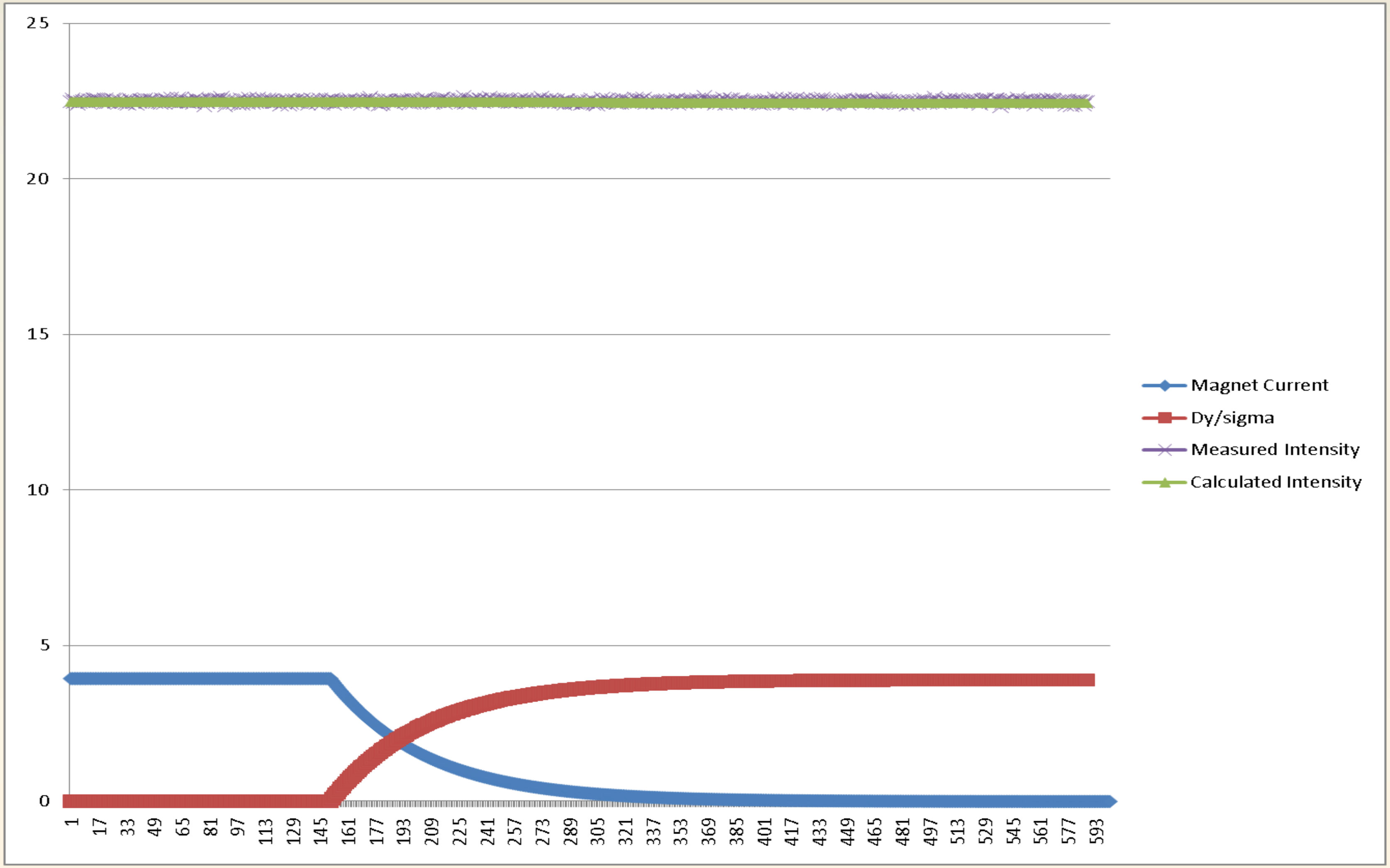
# *Beam at collimators*

- Calculated emittance from wire scanning: $\varepsilon = e^*/(\beta\gamma) = 5.3E\text{-}10m$ (2h before event)

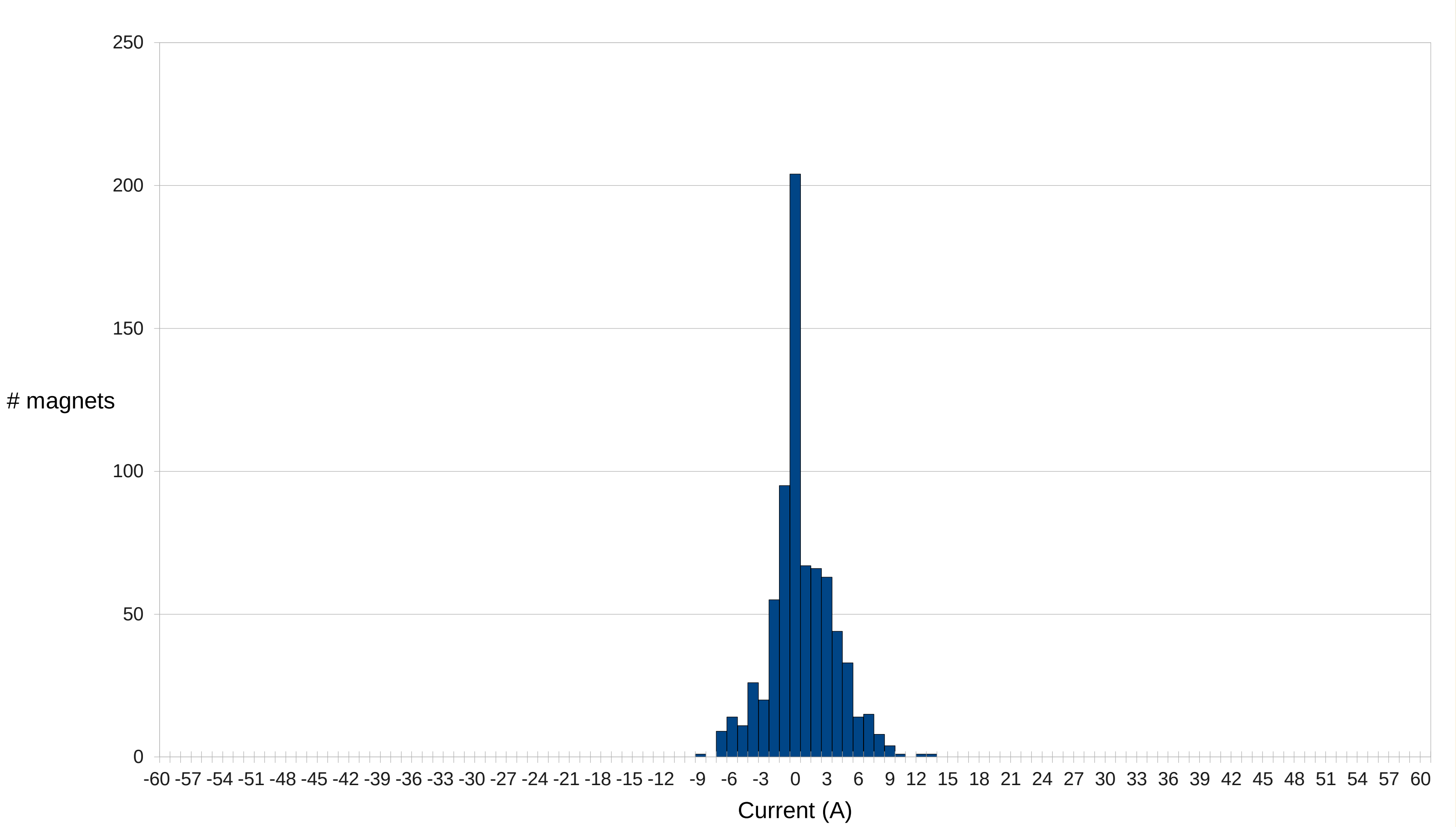
- Optics set to collision

| | TCP.D6L7.B1 | TCSG.D4L7.B1 |
|---|---|---|
| **cos() factor** | 0.9 | 0.9 |
| **Dy (mm)** | 0.8 | 0.7 |
| **Dy (sigma)** | 3.9 | 3.7 |
| **Collimator half gap (sigma)** | 7.6 | 11.5 |

# *Event progression*



# *Distribution of MCB operating current during fill*



# *Conclusions*

- Trips of MCB correctors, operated at expected currents, can potentially cause significant losses in the intensity.
- We have analyzed two cases and have found good agreement between what is observed and what we would expect from a simple calculation of losses.

# Orbit corrector analysis in the cycle

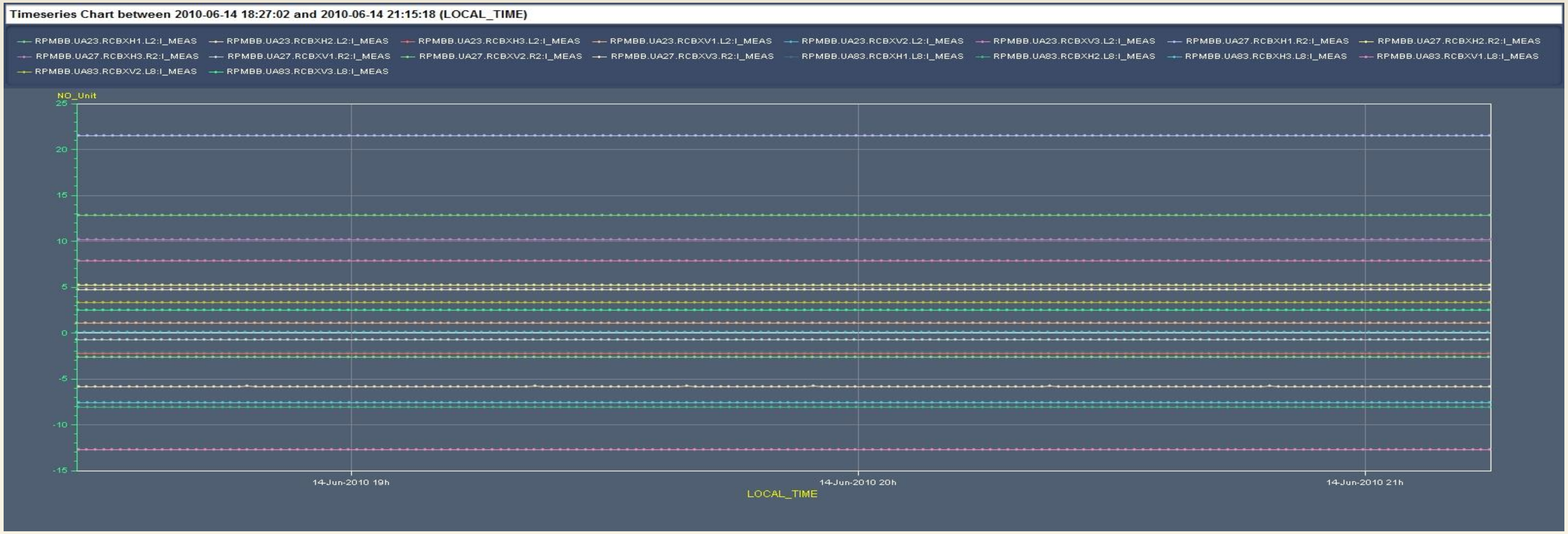
# Motivation

- An unnecessary (and undetected) closed bump in the machine is potentially dangerous.
- Understand how the CODs behave during the different phases of the cycle of the machine.
- How reproducible is the corrector currents from fill to fill?
- Is there a way to find abnormal COD values (for example, a forgotten closed bump/a misbehaving BPM) by comparing the COD currents between different fills?
- Ultimate goal: Can a (software) interlock be devised to guard against unwanted closed bumps?

# INJECTION ANALYSIS

(4 fills between 13/6 - 17/6)

# Injection features



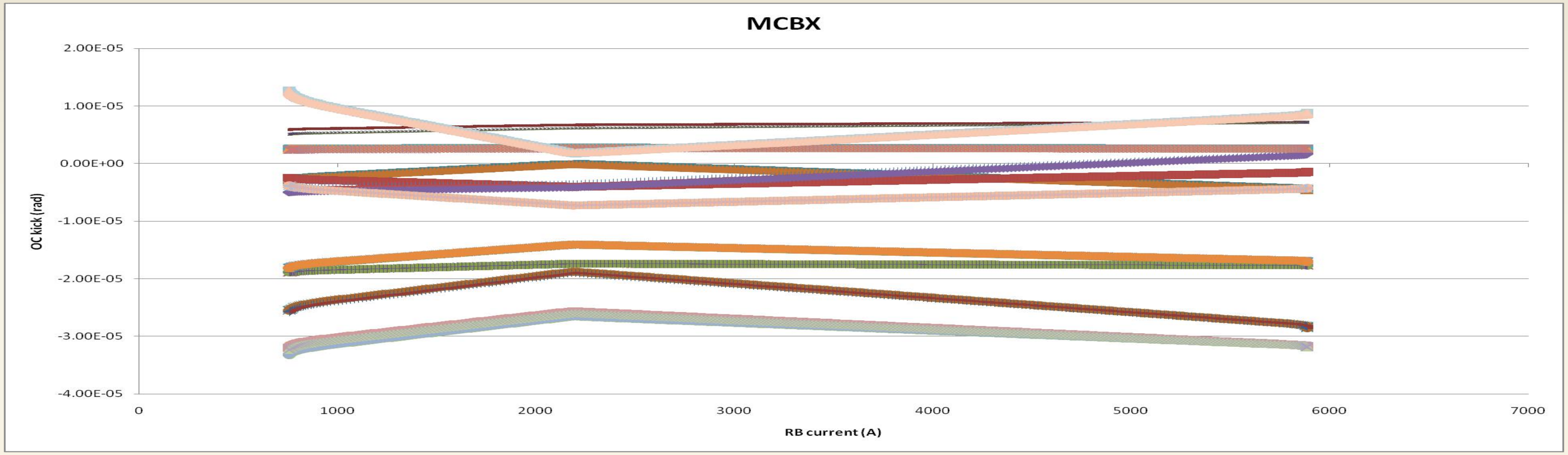

## Normally CODs remain constant during injection

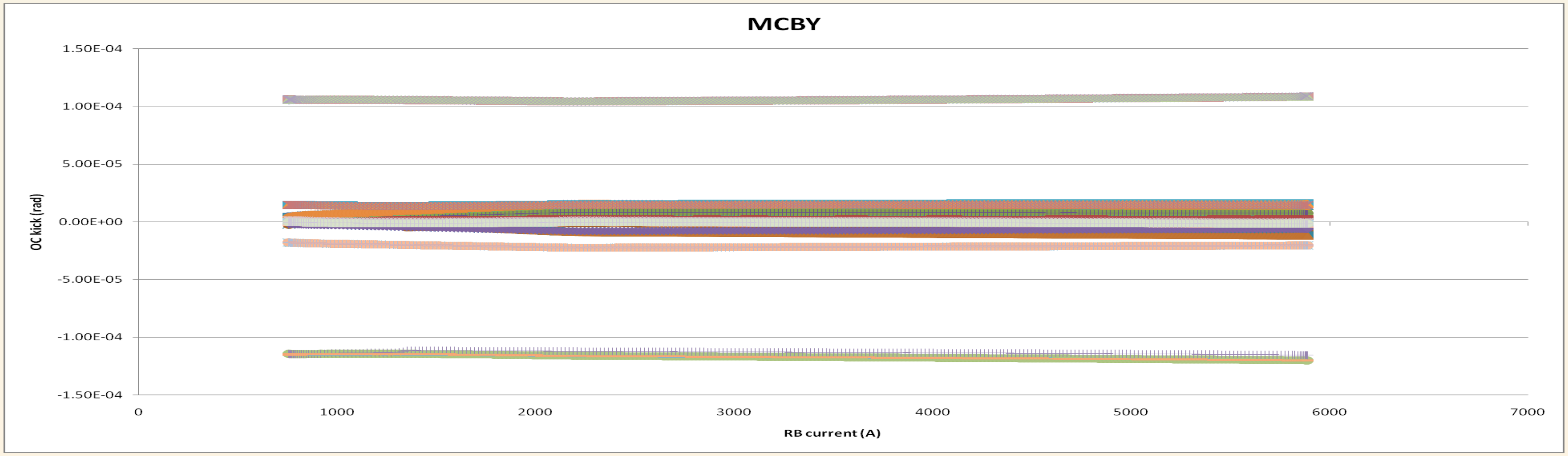
| | MAX | ST. DEV. |
|---|---|---|
| **MCBX** | 1.27E-05 | 5.30E-07 |
| **MCBY** | 1.06E-04 | 8.39E-07 |
| **MCBC** | 5.71E-05 | 1.26E-06 |

# ENERGY RAMP ANALYSIS

(4 fills between 13/6 - 17/6)

# CODs during ramp

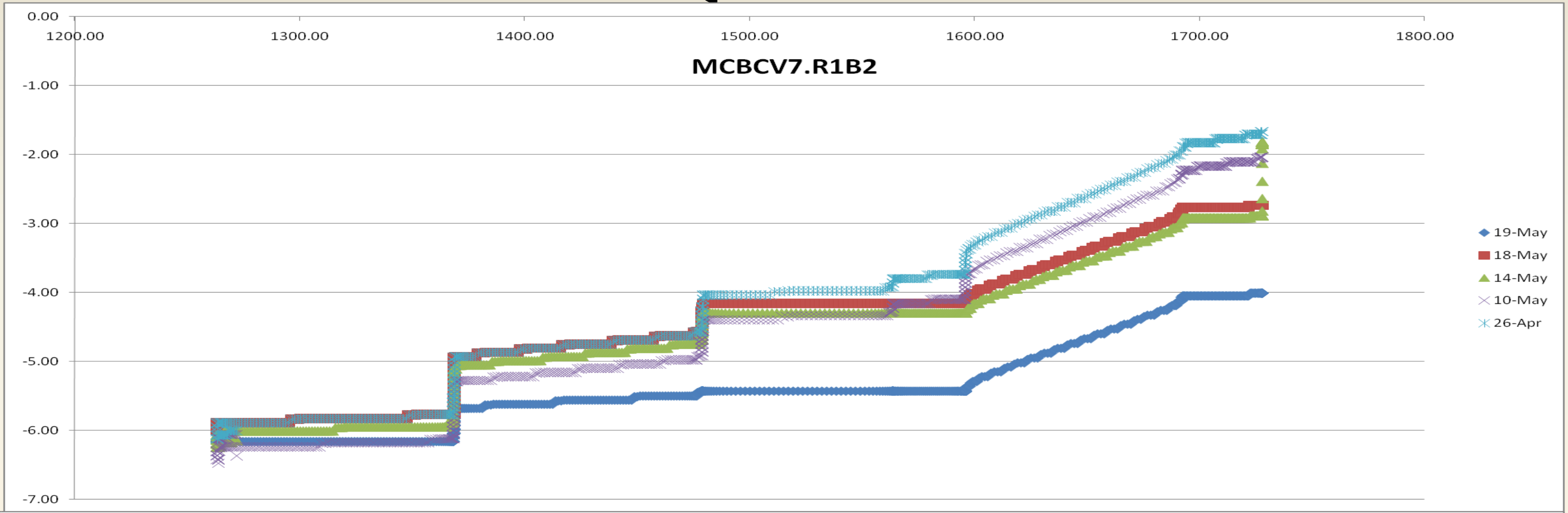


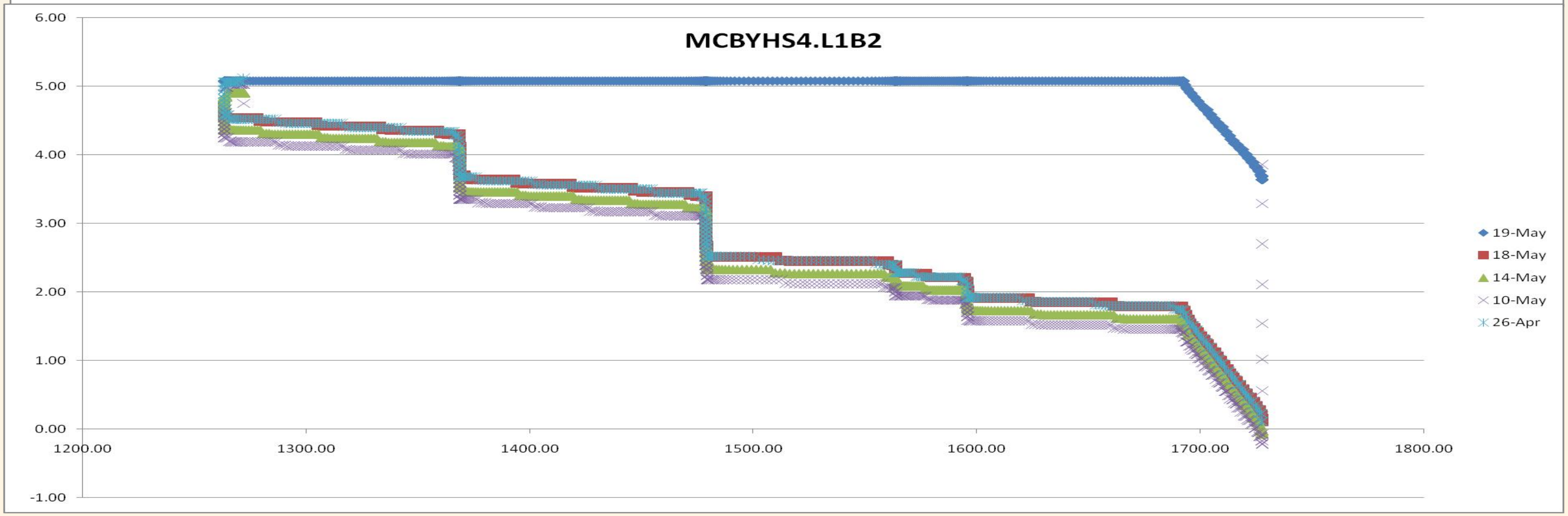



# SQUEEZE ANALYSIS

(5 fills between 26/4 - 19/5)

# COD current vs. Quad current for 5 fills



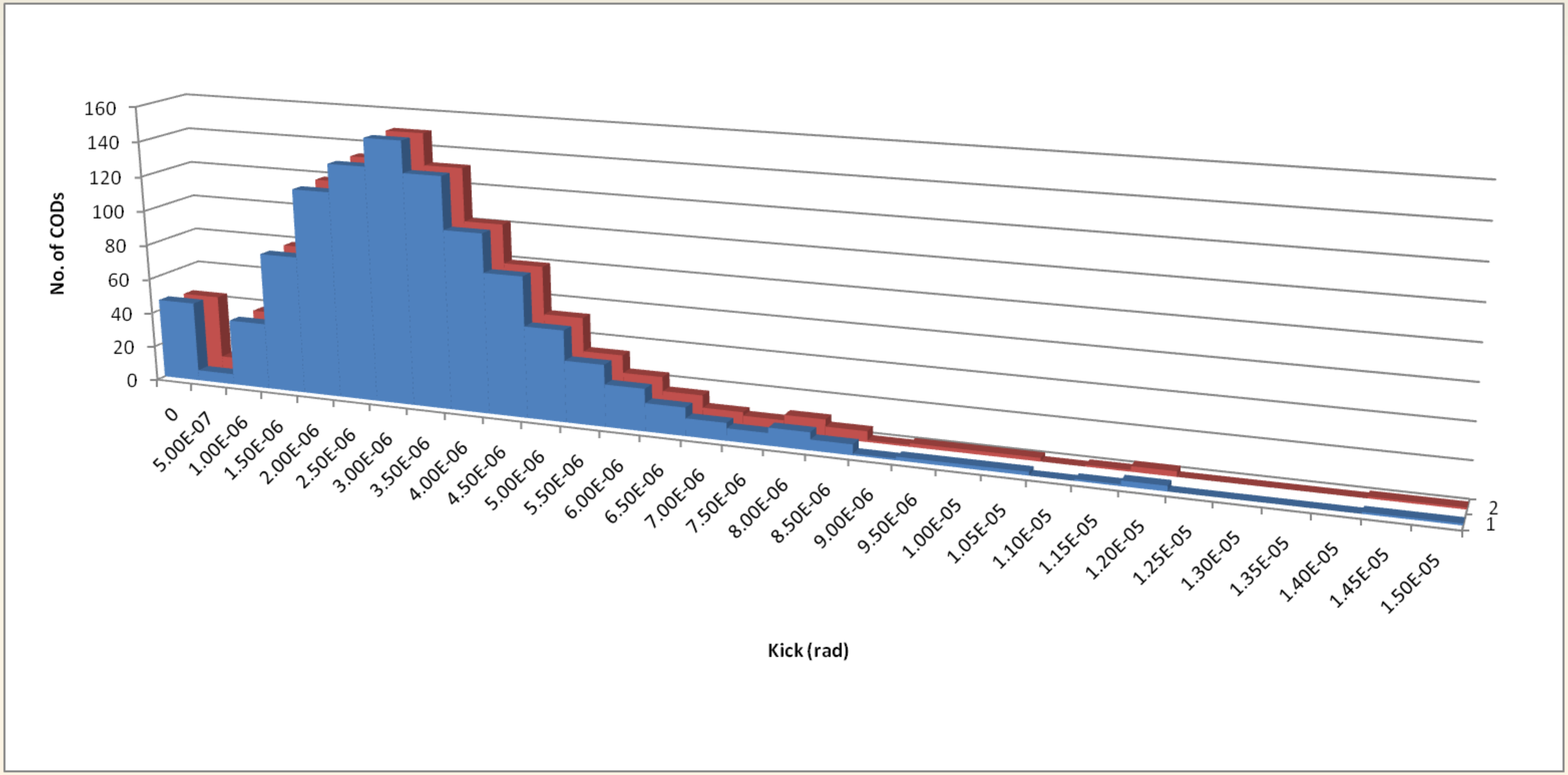
# STABLE BEAMS ANALYSIS

(11 fills between 24/6 – 5/7)

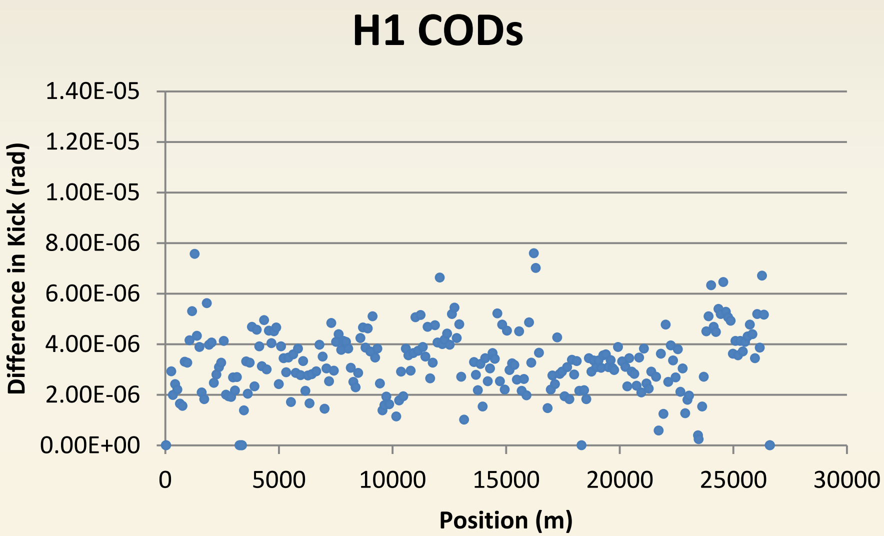
# Analysis

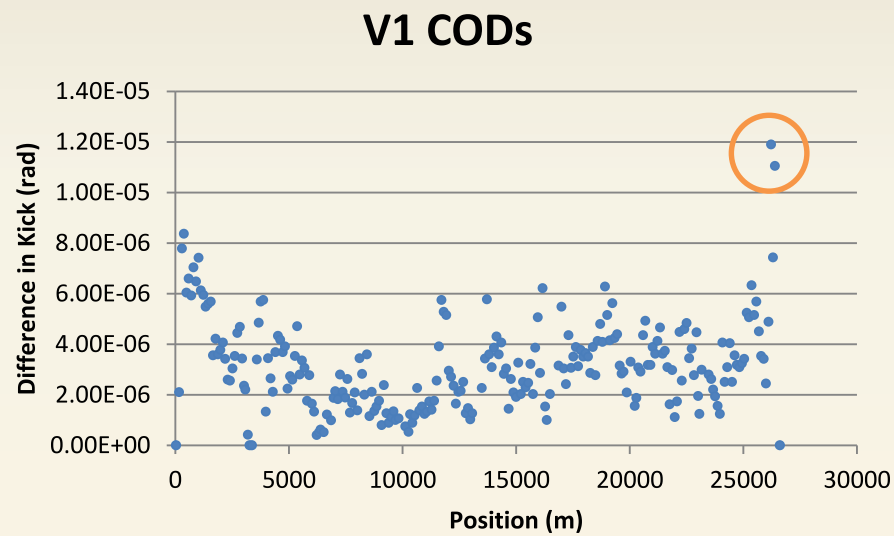
- We look at data from all CODs (1061) during stable beams mode
- During a fill there is normally no significant change. We have looked at different times during a fill, especially after an intensity drop.
- We then calculate the kick variation during different fills.
- 11 recent fills have been analyzed (fills 1179 – 1199)

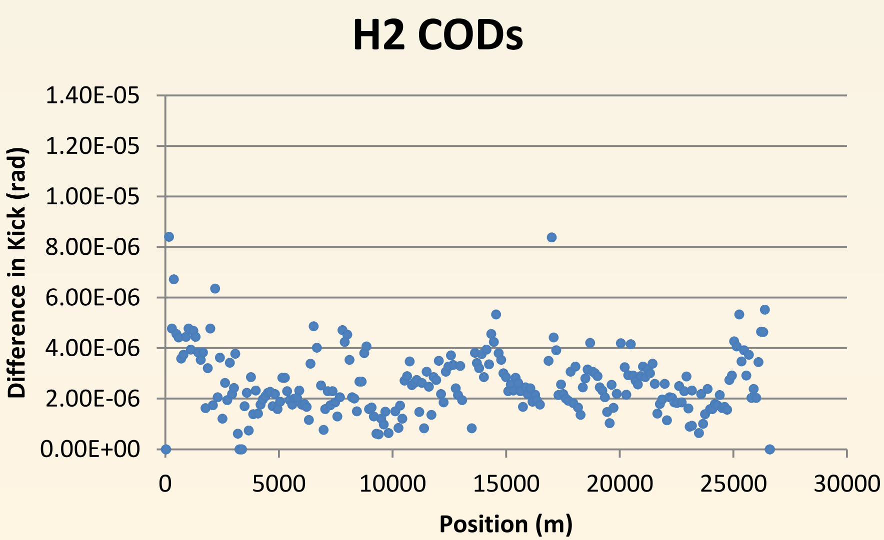
# Largest – smallest kick (11 fills) of all CODs during stable beams

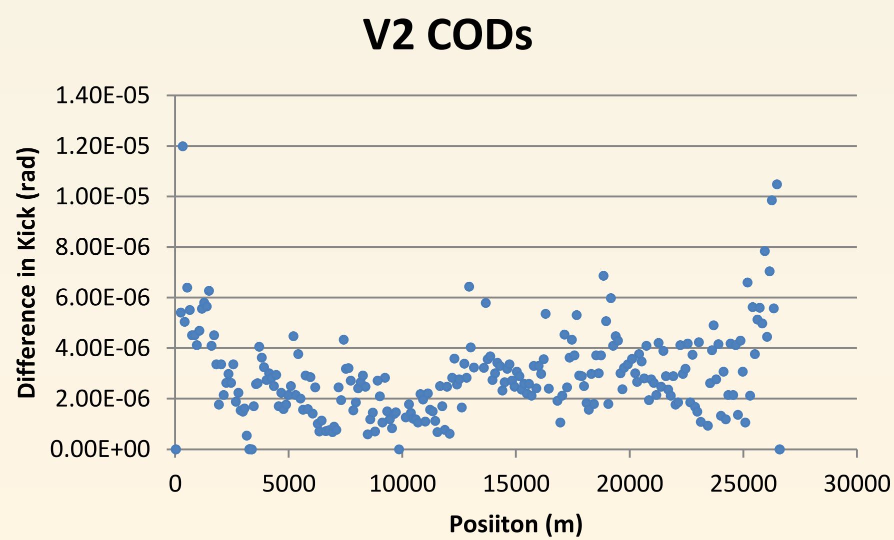


# Kick difference in respect to position - grouped by plane/beam

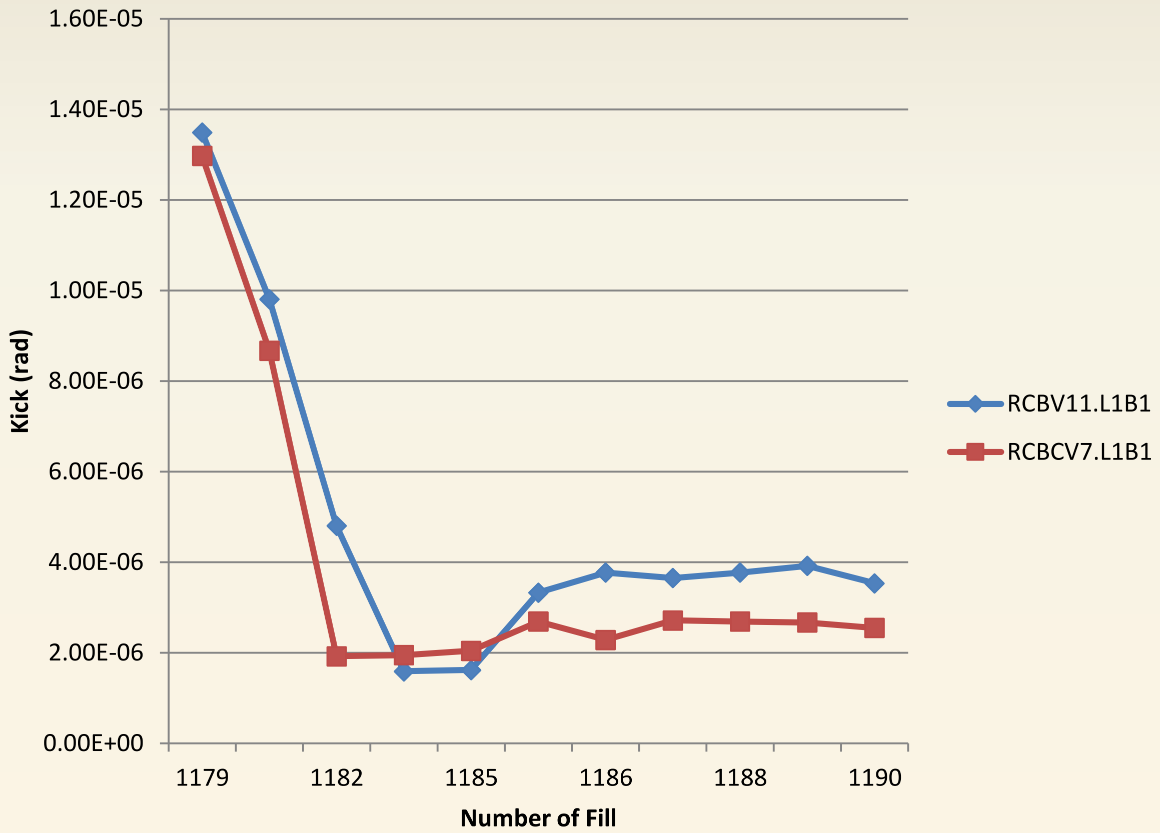


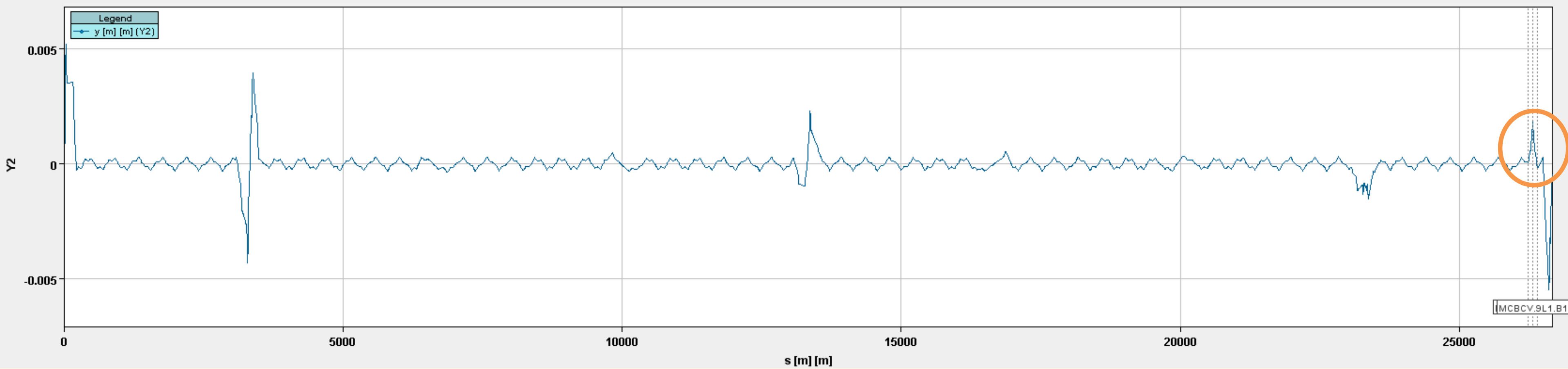
# Progression




Seems to be a bump that has been taken out

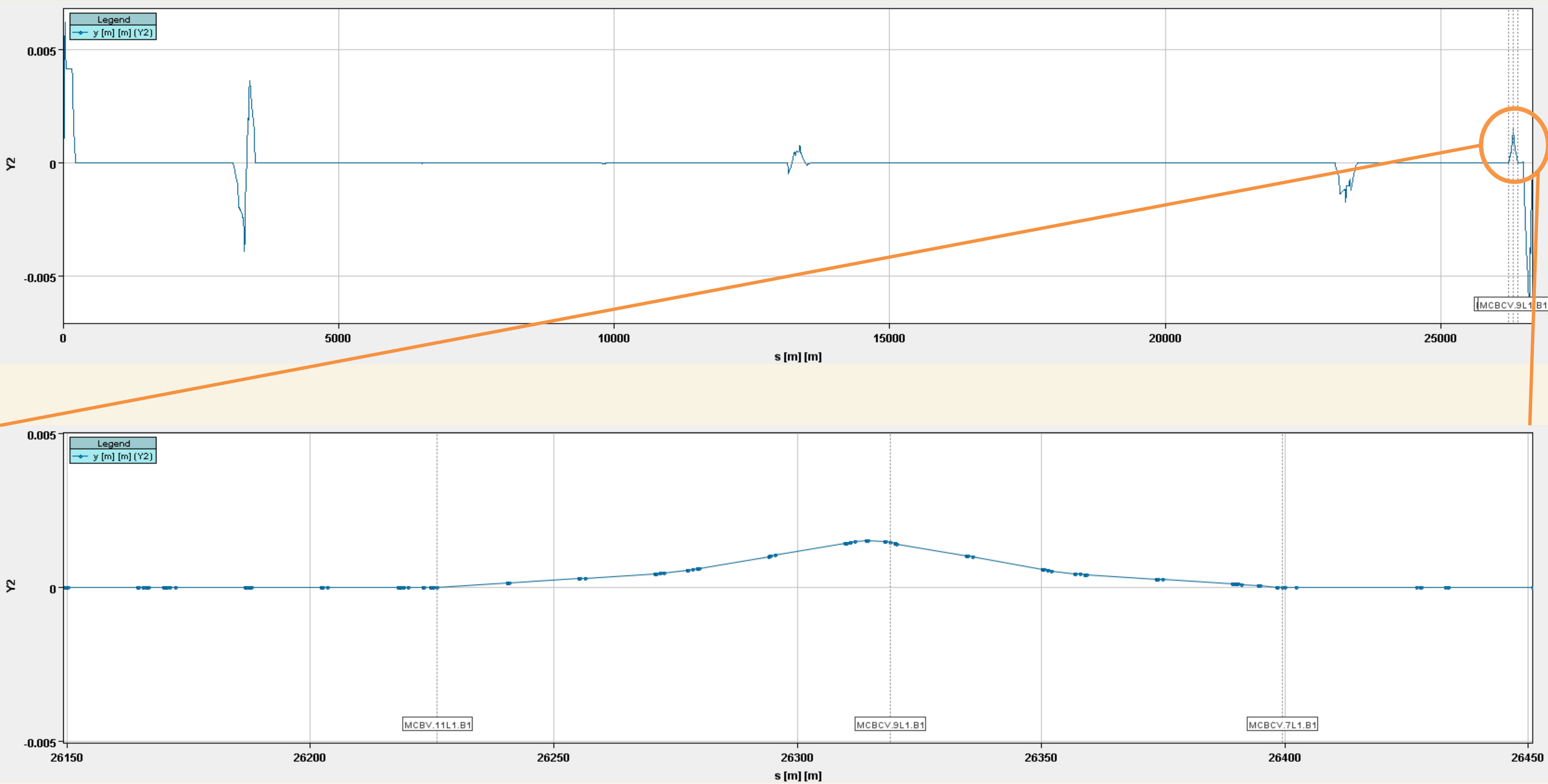
# Case study for Closed Bump

## Orbit simulation of the case

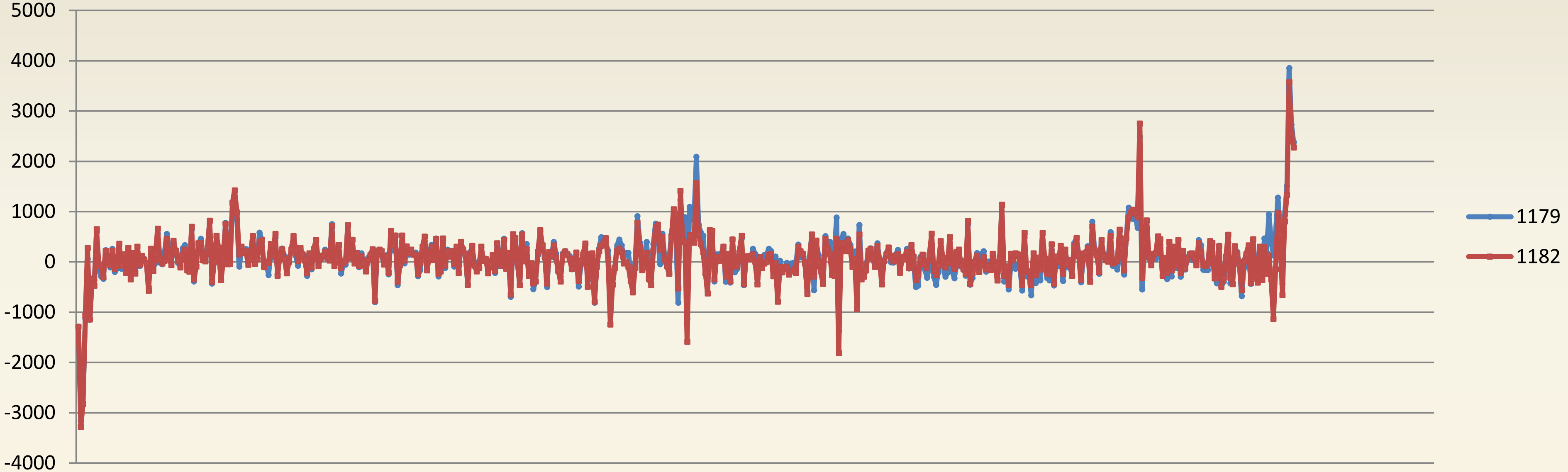


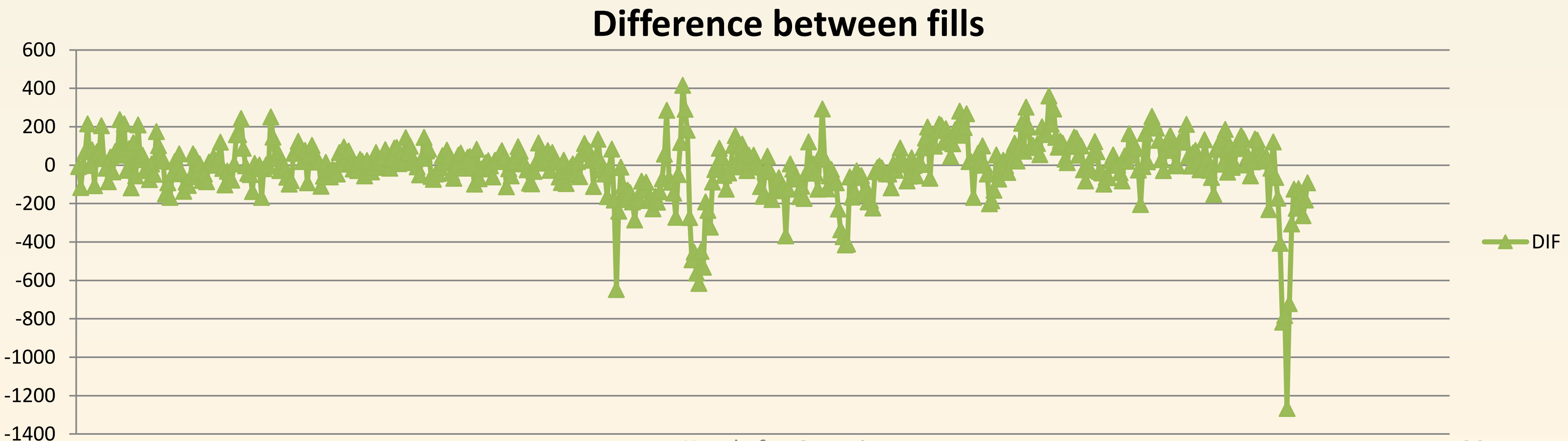

| | MCBV.11L1.B1 | MCBCV.9L1.B2 | MCBCV.7L1.B3 |
|---|---|---|---|
| β | 175.655 | 187.046 | 120.746 |
| ϕ | 58.103 | 58.25 | 58.618 |
| k (from data) | 1.35E-05 | 7.42E-06 | 1.30E-05 |
| k (plot) | 1.35E-05 | 0 | 1.30E-05 |
| k (closed bump next slide) | 9.96E-06 | 1.23E-06 | 1.30E-05 |

# Simulation of the closed bump using intermediate magnet



# Orbit logged from BPMs



# Conclusions

- We have noted typical COD behavior during the different phases of the cycle.
- A close observation and analysis of the CODs can reveal abnormal behavior and maybe detect potentially unsafe operation.
- Possible development: a tool that indicates and warns on potential problems.

# The end

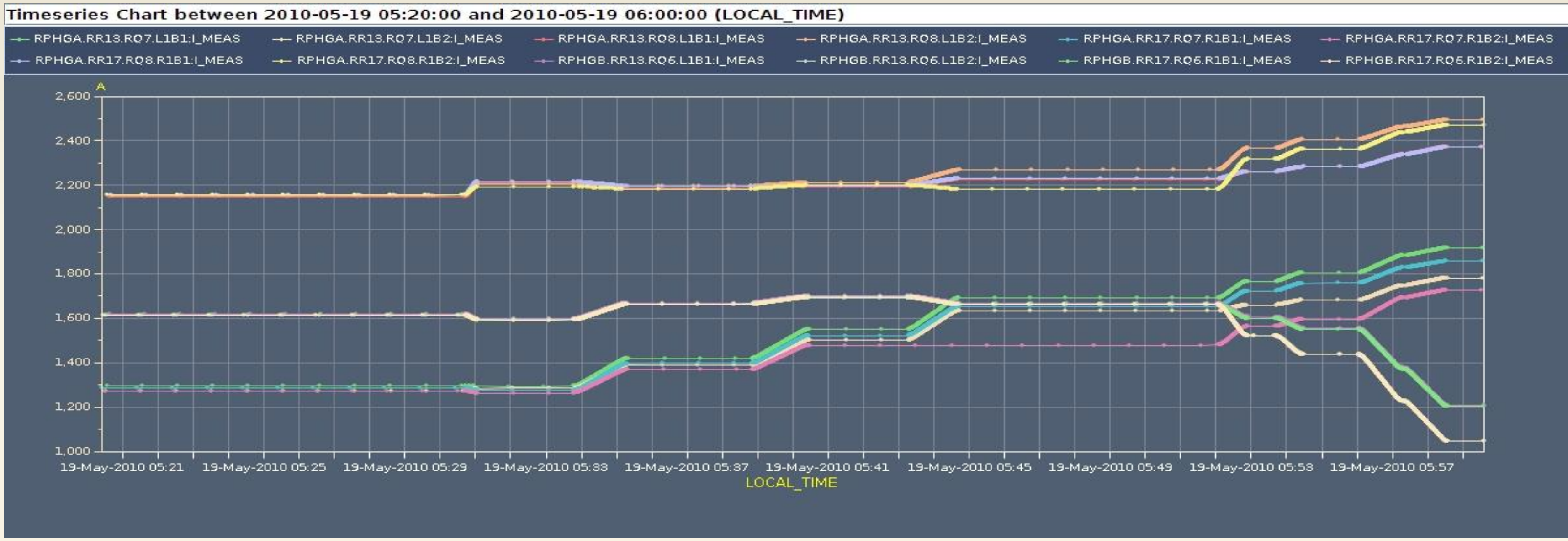
Thanks for you attention

# EXTRA SLIDES

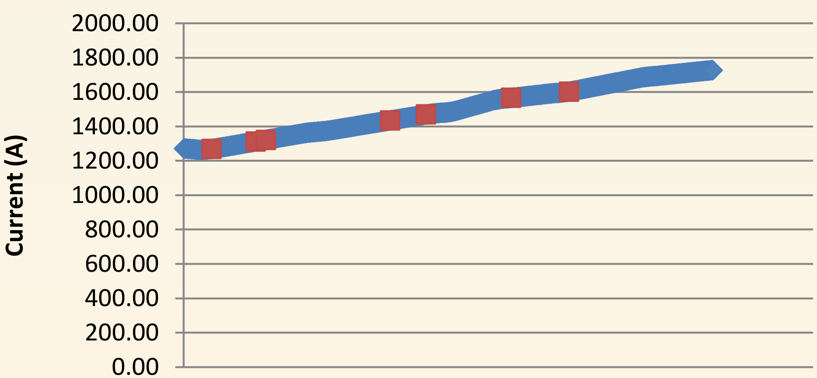
# SQUEEZE ANALYSIS

(5 fills between 26/4 - 19/5)

# Quad current during squeeze



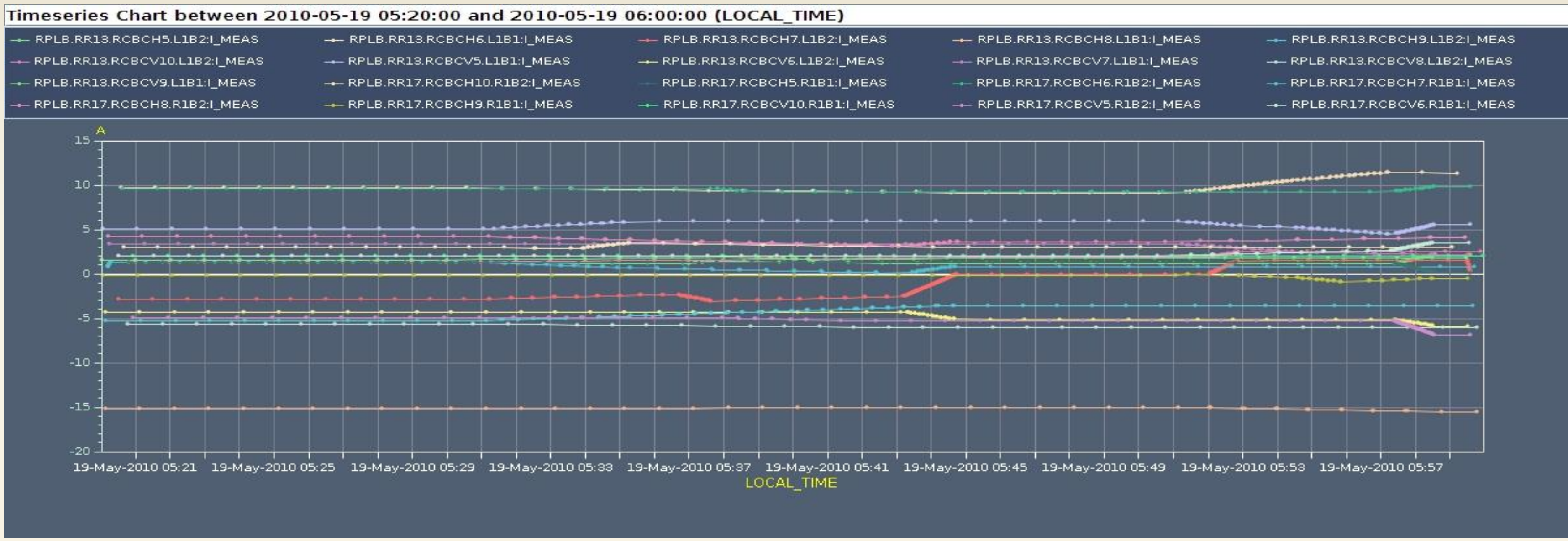

**RQ7.R1B2** → Reference quad (monotonic)




Quad current same in every fill (RQ4-RQ8)

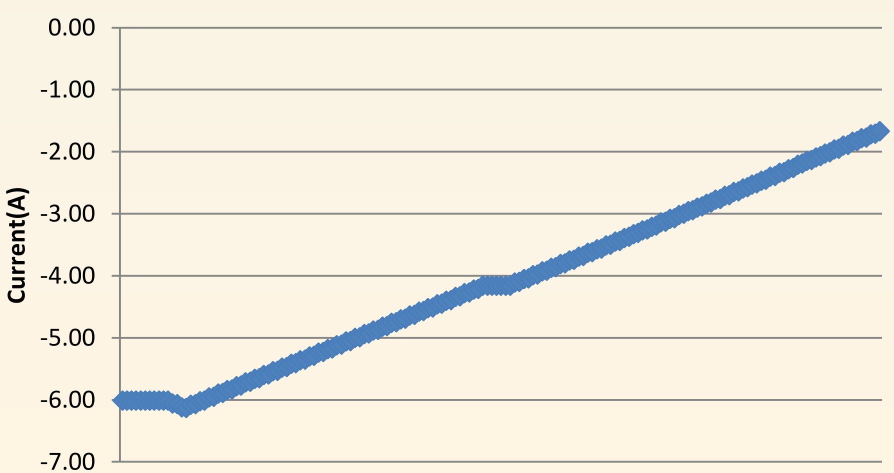
Squeezing steps (β* in m): 11->9->7->5->3.5->2.5->2

# COD current during squeeze

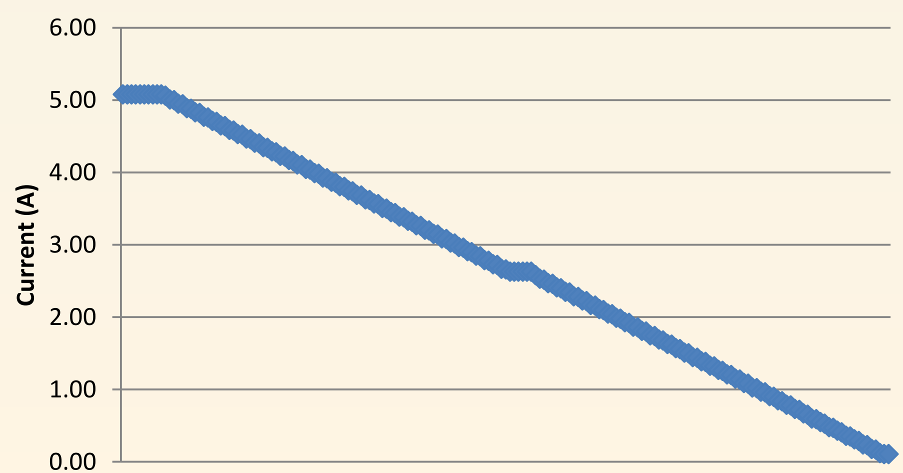



## Reference COD's

**MCBCV7.R1B2**



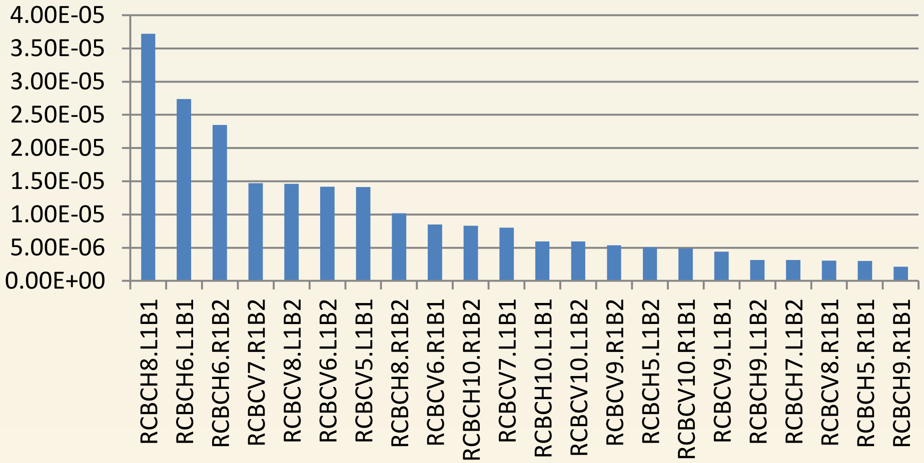

**MCBYHS4.L1B2**



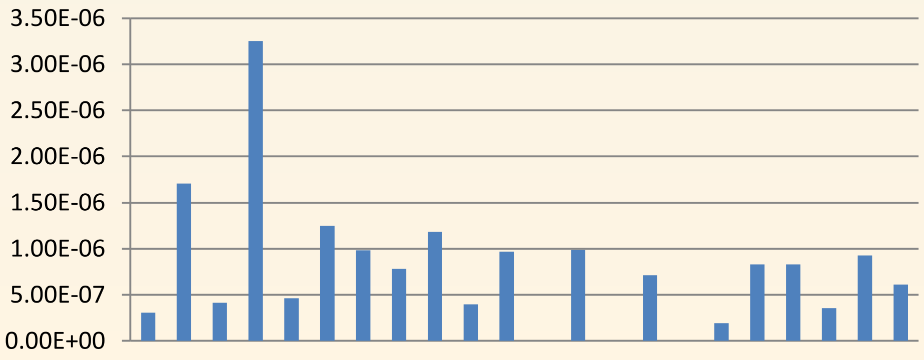
# COD statistics during squeeze

## MCBC Kick

### MAX

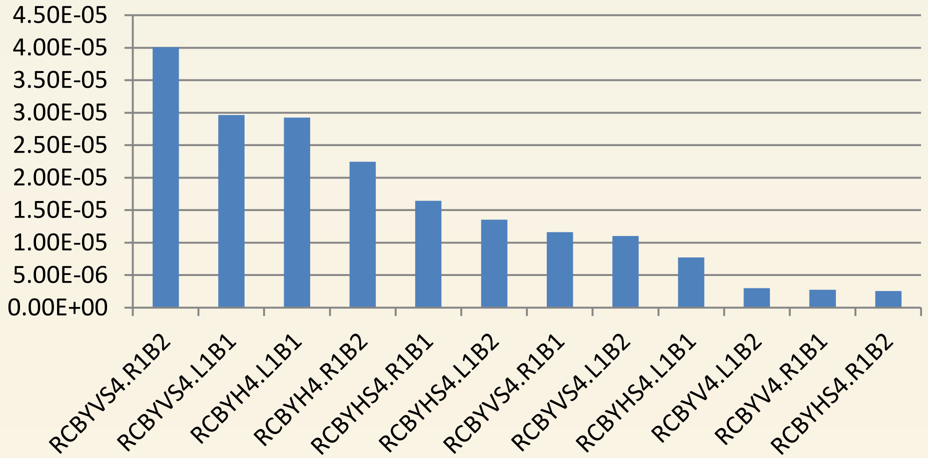



### ST DEV

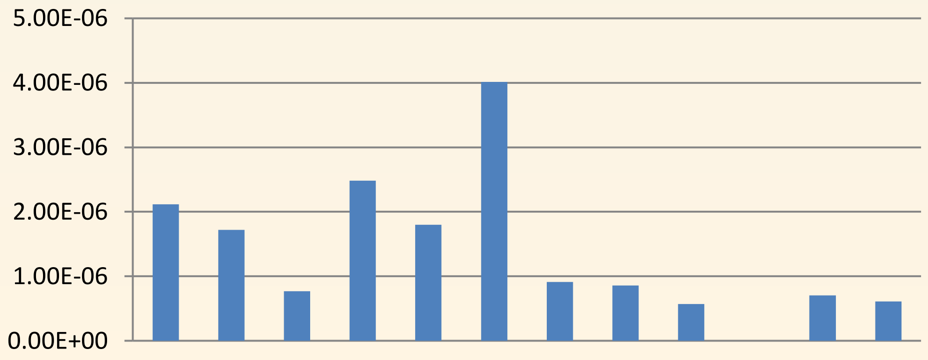



## MCBY Kick

### MAX

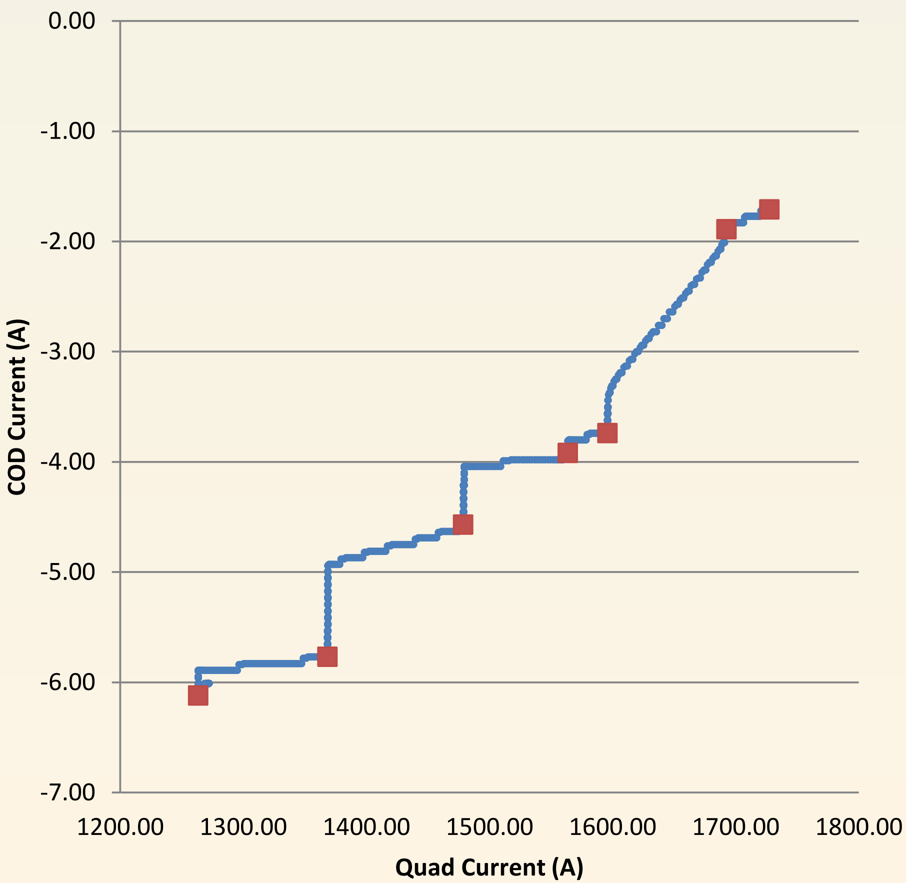



### ST DEV

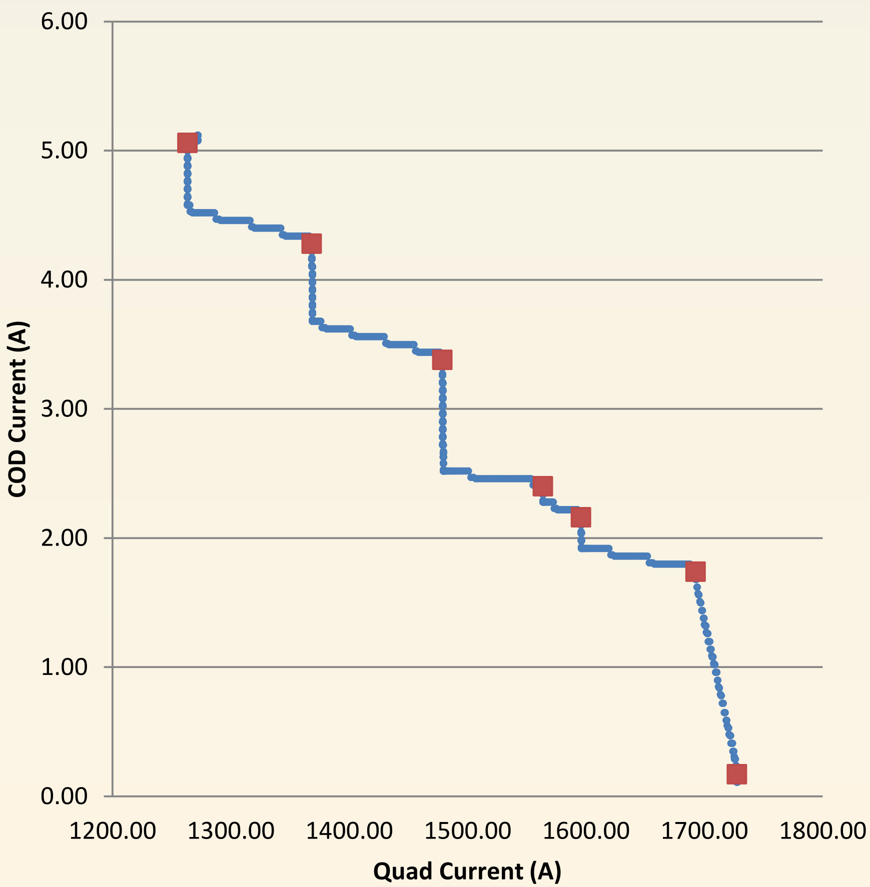


# COD current vs. Quad current

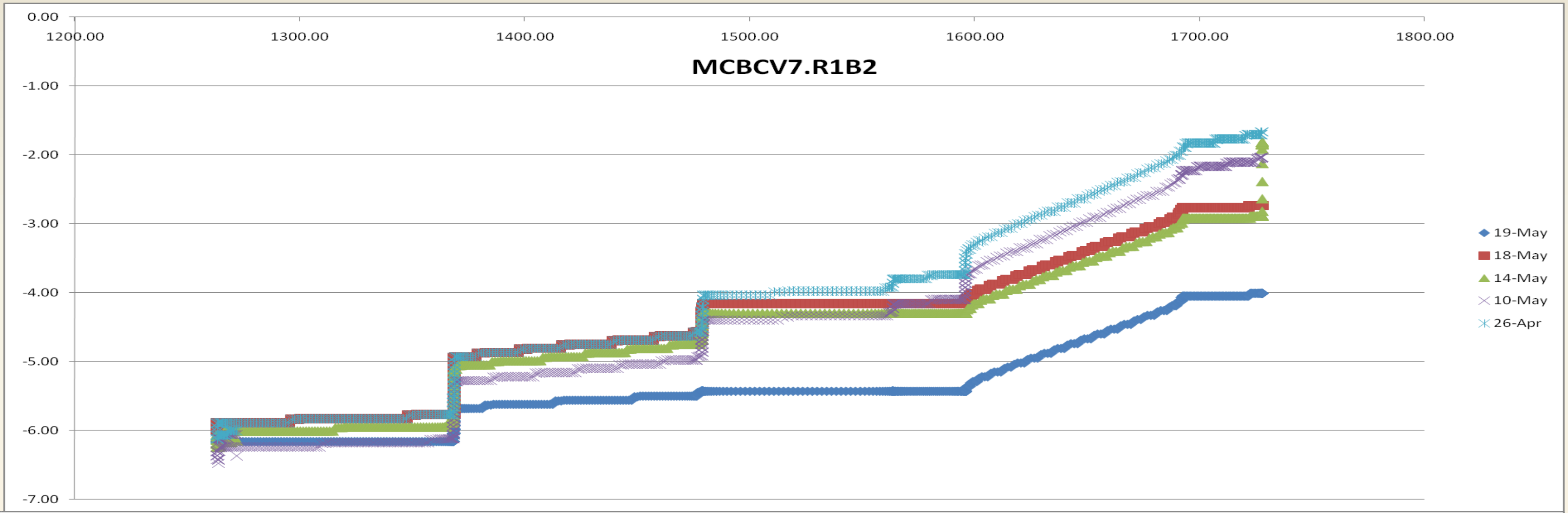
## MCBCV7.R1B2

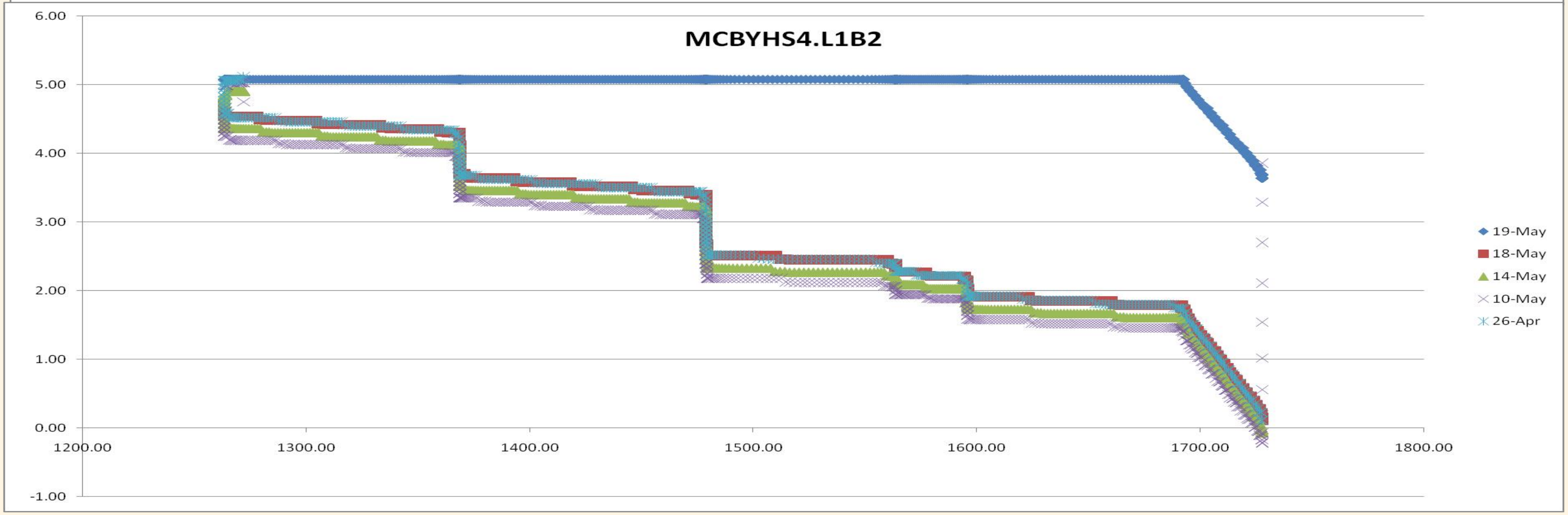



## MCBYHS4.L1B2



# For 5 different fills

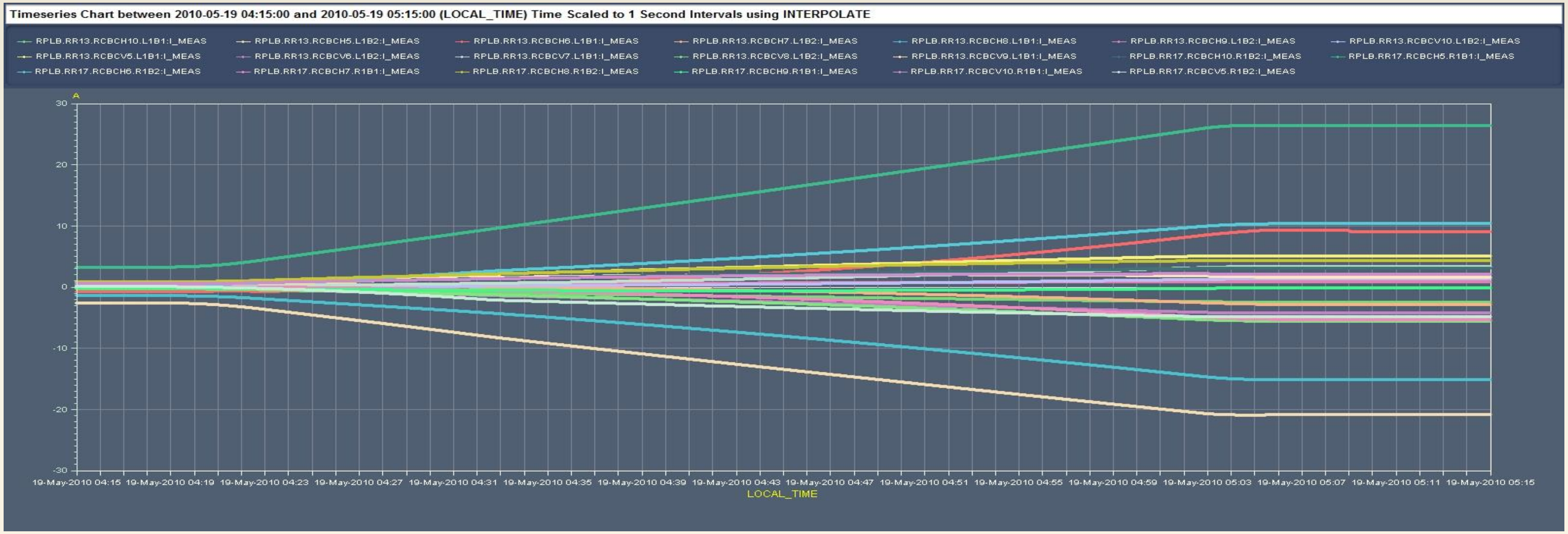


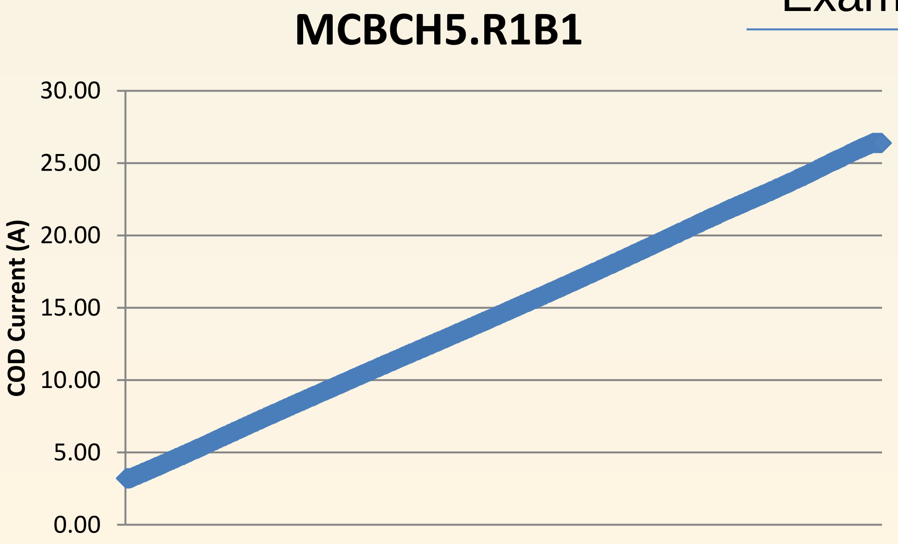
# ENERGY RAMP ANALYSIS

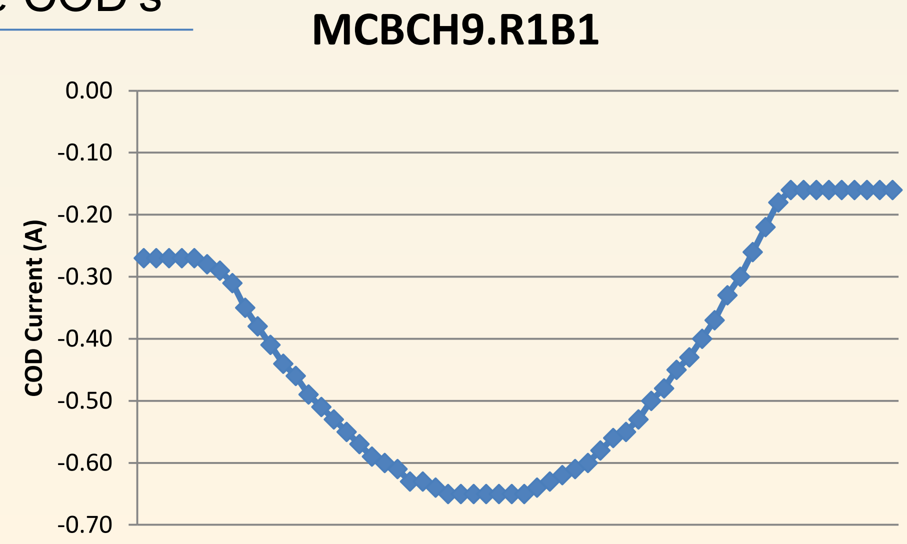
(4 fills between 13/6 - 17/6)

# COD current during ramp

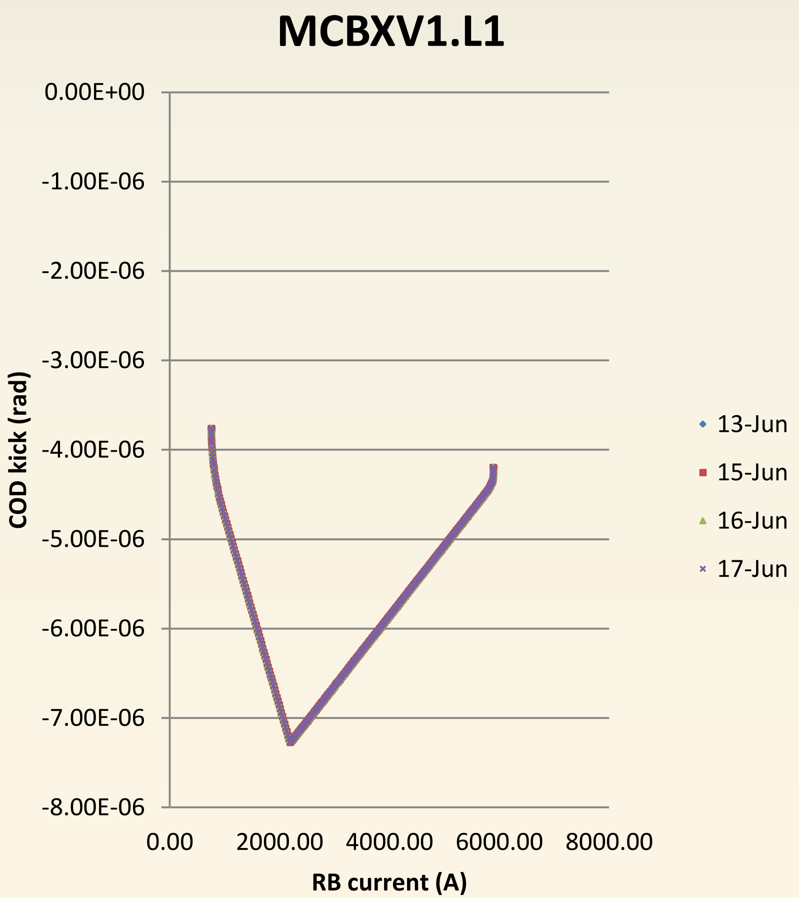


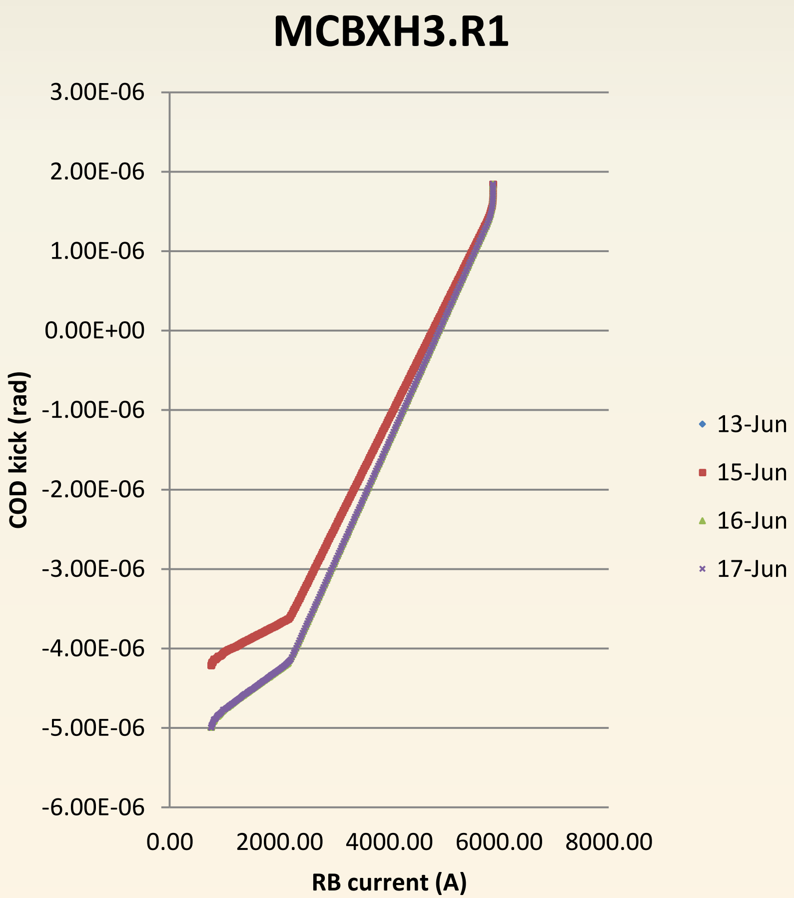

Example COD's



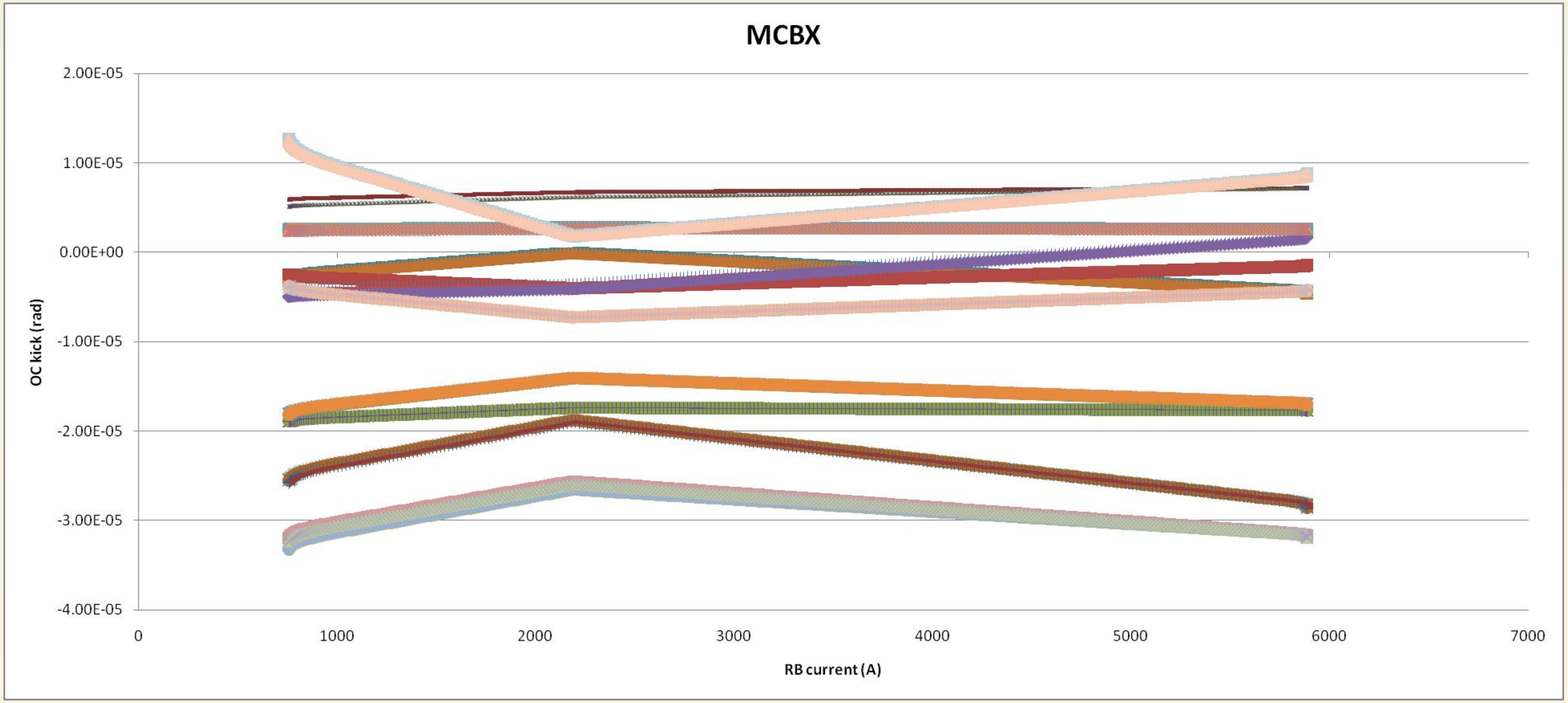



# MCBX magnets

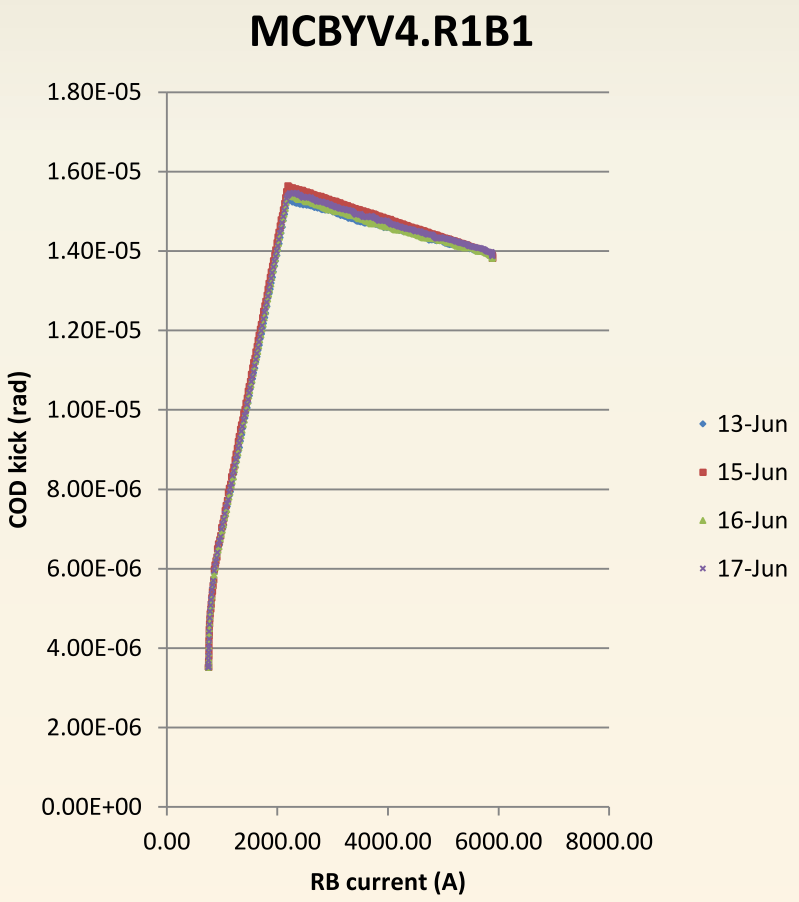


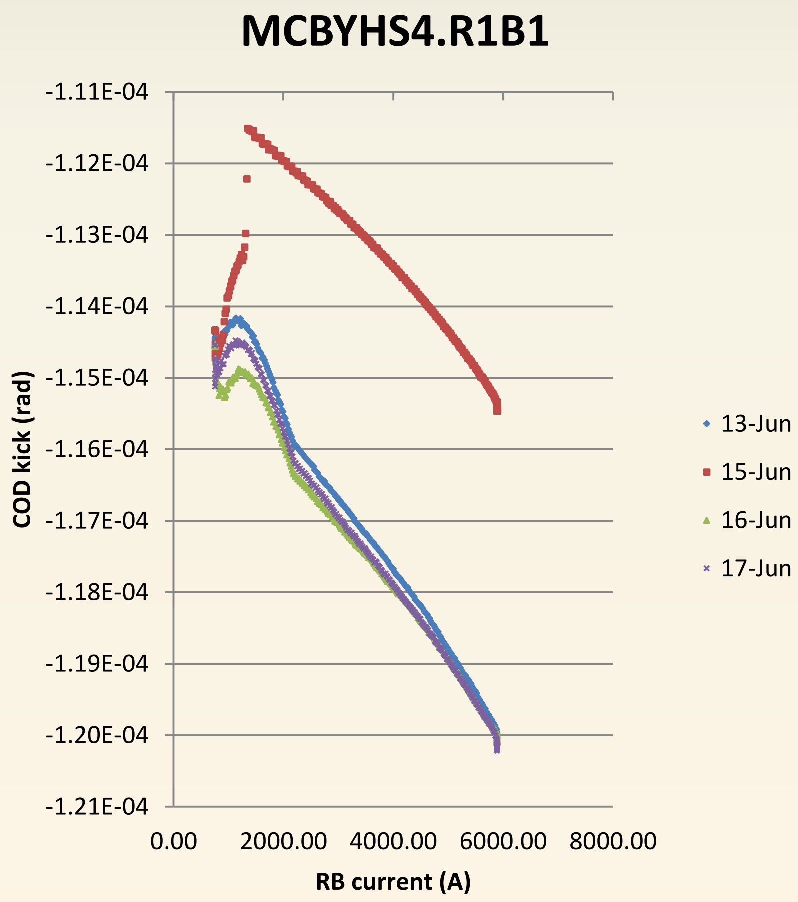



# Kick of MCBX magnets during ramp as a function of dipole current

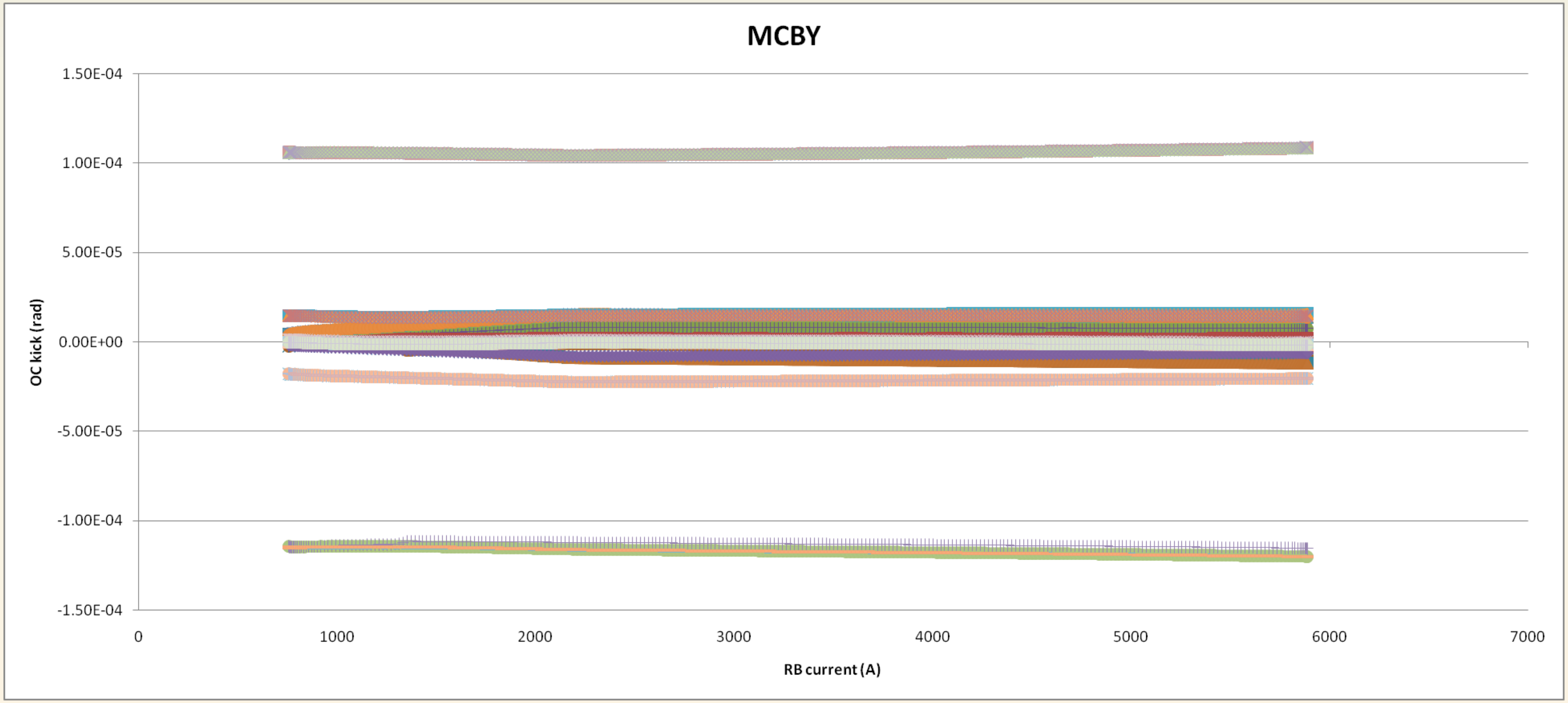


# MCBY magnets

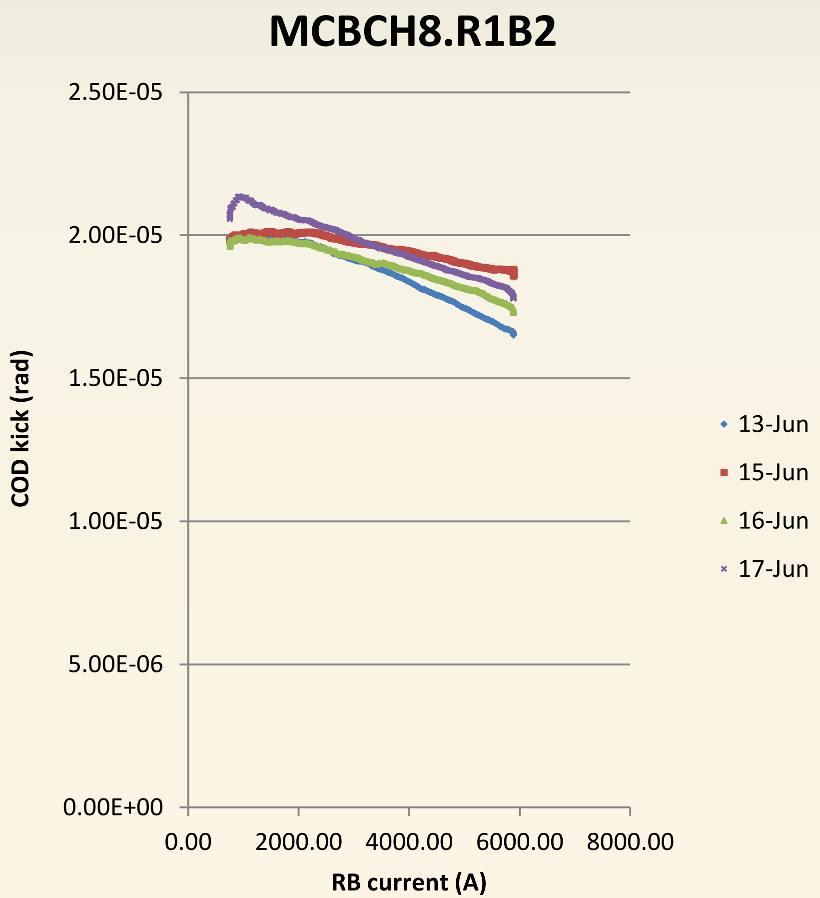


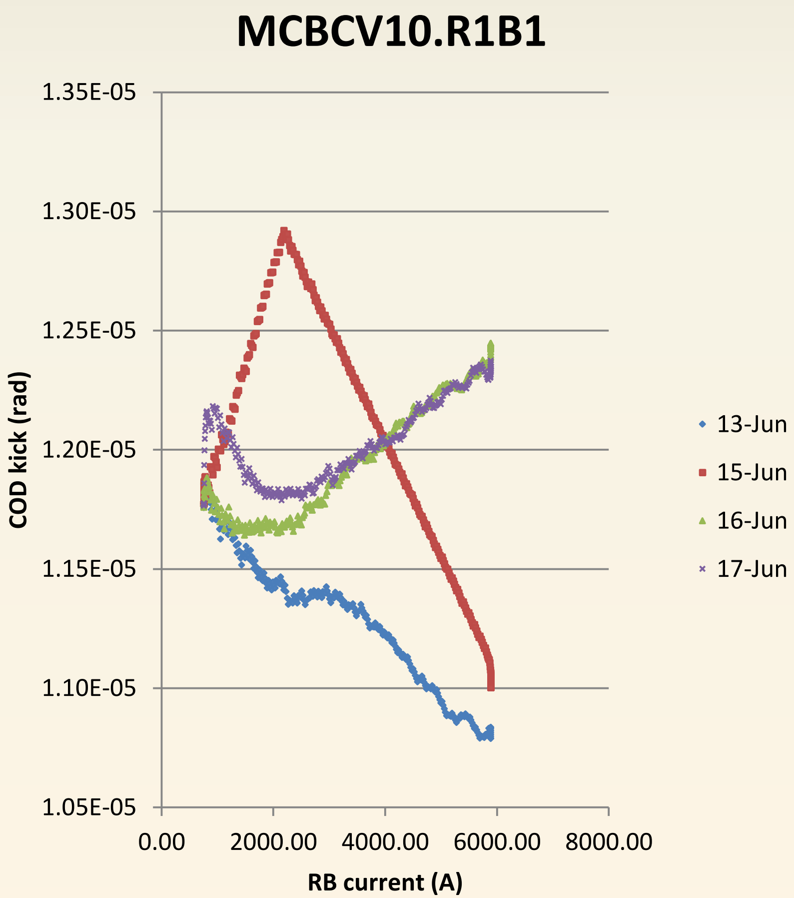



# Kick of MCBY magnets during ramp as a function of dipole current

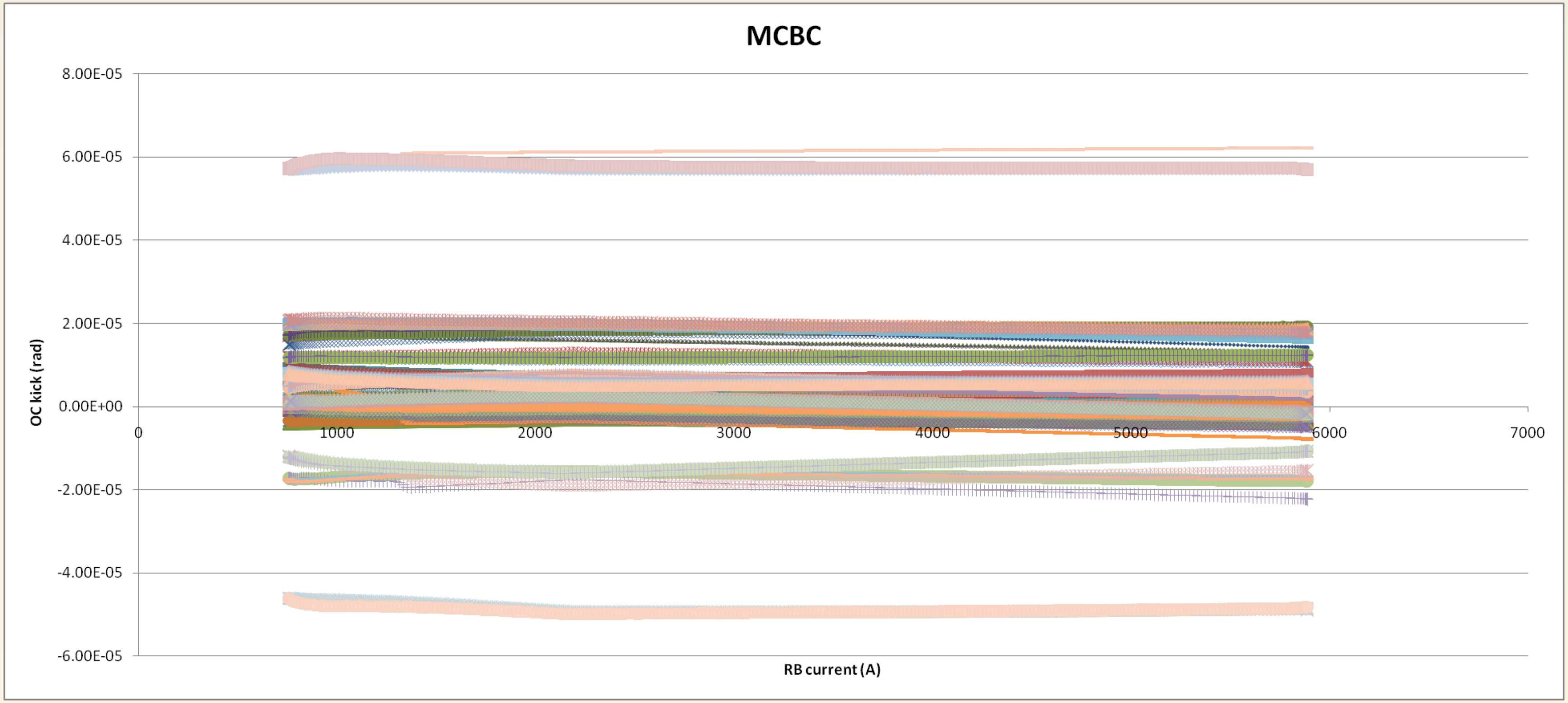


# MCBC magnets



# Kick of MCBC magnets during ramp as a function of dipole current



# Formula of the kick of an orbit corrector

$$\theta = 2 \cdot \sin^{-1}\left(\frac{L}{2\rho}\right)$$

where :

$$\rho = \frac{p}{B \cdot e} = \frac{E \cdot \beta}{c \cdot B \cdot e} : \text{bending radius}$$

E : current energy

B : magnetic field (propotional to magnet current)

L : magnet length

# Calculated displacement for worst case scenario (b=200, cos=1)

**MCBCV7.R1B2**

- 0.98 mm
- 3.26 sigma

**MCBYHS4.L1B2**

- 2.12 mm
- 7.68 sigma

[Difference due to large beta in this magnets (3 times higher)]