Phase-advance Interlocking
Experience from 2016 operation

PRELIMINARY

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Outline

- Introduction Phase Advance Interlocking
- Current Distribution in Stable Beams 2016
- Interlock Tolerances:
  - Settings 2016
  - Generation: 2016 vs. ATS optics
- Tolerances during current ramp

Motivation for Interlock on Phase

In case of an asynchronous beam dump, the dump kicker fires when beam passes.

Kicked beam could damage TCTs and triplets.

In order to protect the TCTs, it has to be ensured that phase advance between MKD (IR6) and TCTs in IP5/IP1 is

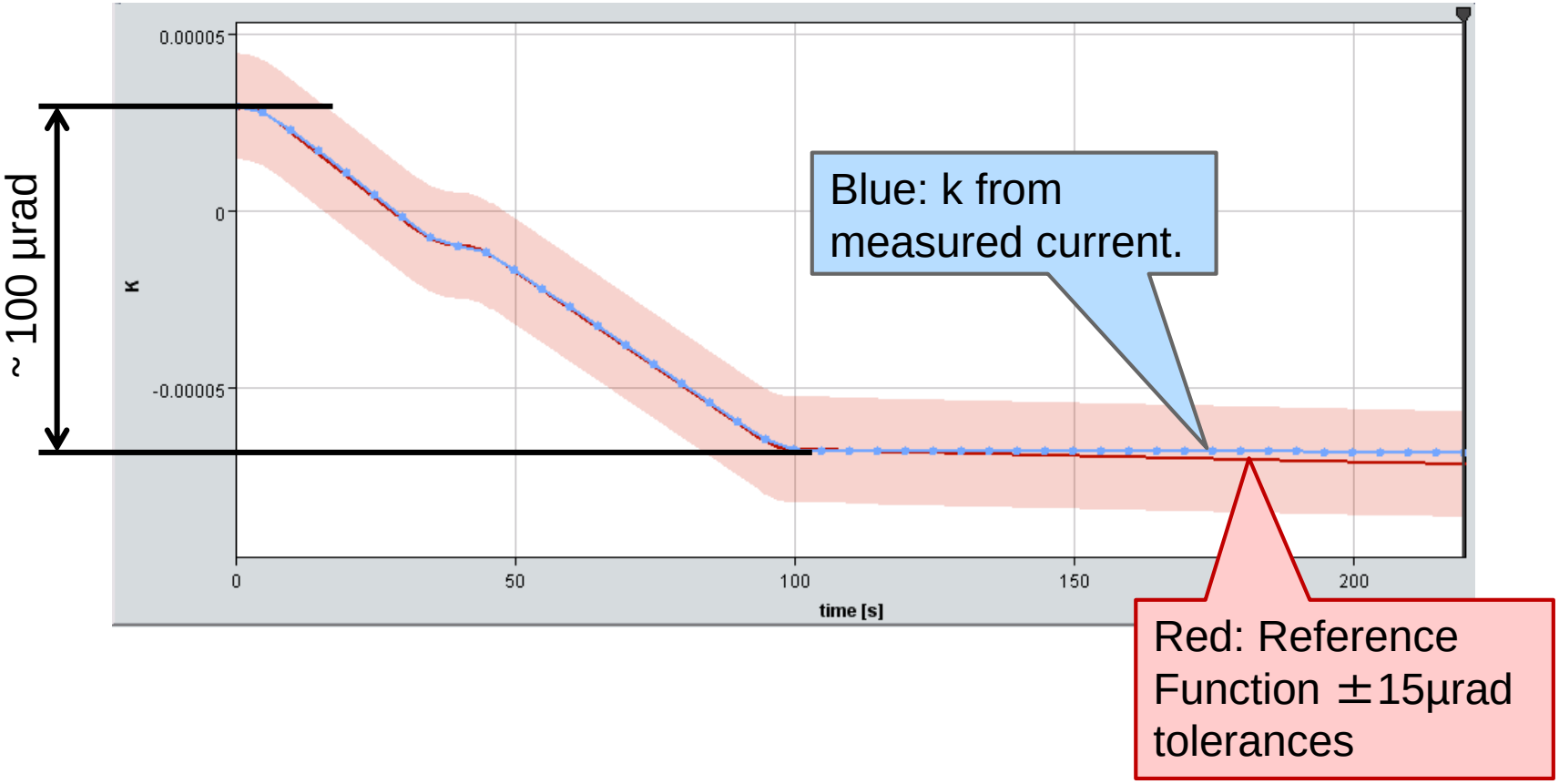
$\Delta\mu < 30^{\circ}$.

➔ Interlock on quadrupole currents with the aim to keep $\Delta\mu < 30^{\circ}$.

PC Interlock - Principle

Principle: Subscribes to Power Converters (PC) and compares current to reference ***functions*** ± tolerances (1 Hz).

Example: RCBYVS4.L8B2 **(Orbit corrector)** during COLLISIONS Beam Process:



Optics Interlocking

PC Interlock System was extended in 2016 to
Interlock all quadrupole PC individually

Quadrupole Families	Names	Number of Power Converters (PC)
Main Quadrupoles	RQD, RQF	each 1 PC/sector
Main Trim Quadrupoles	RQTD, RQTF	each 1 PC/sector
Triplets	RQX, RTQX1, RTQX2	6 PC/IP
Matching Quadrupoles	RQ4-RQ10, RQTL9-11, RQT12, RQT13	1 PC each (total count ~300)
Warm Quadrupoles	RQ4, RQ5, RQT4, RQT5	1 PC each

Settings in 2016

Total phase advance allowed between MKD and TCT: **30°**

Possible to match initial phase advance to 0°.

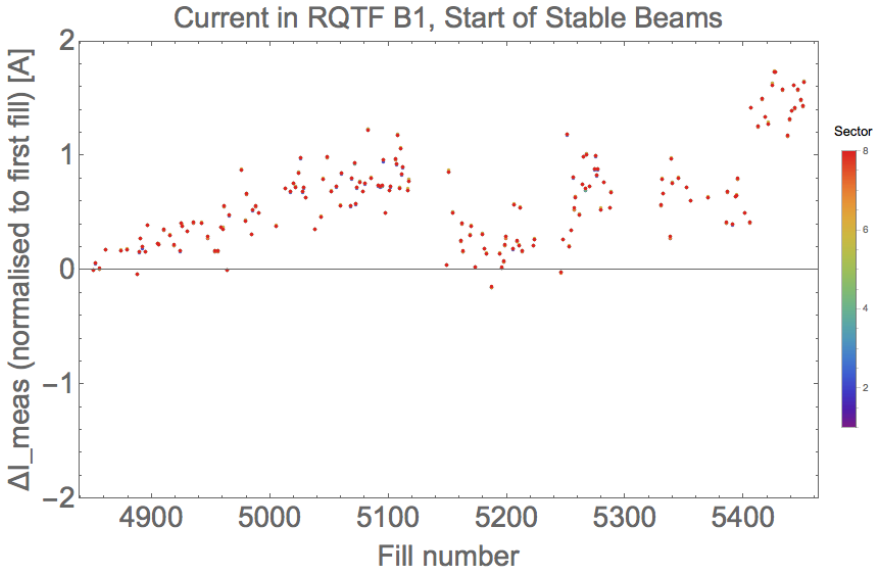
Distribution of total margin over all families for final optics point

Quadrupole Families	Allocated phase margin [degree]	Resulting Current tolerances [A]
Main Quadrupoles	5	4.43
Main Trim Quadrupoles	5	22.2
Triplets	10	1.9/1.1
Matching Quadrupoles	5	0.8-5.1
Warm Quadrupoles	1	5.35/7.75
SUM	**26**	**-**

Current Stability during Physics

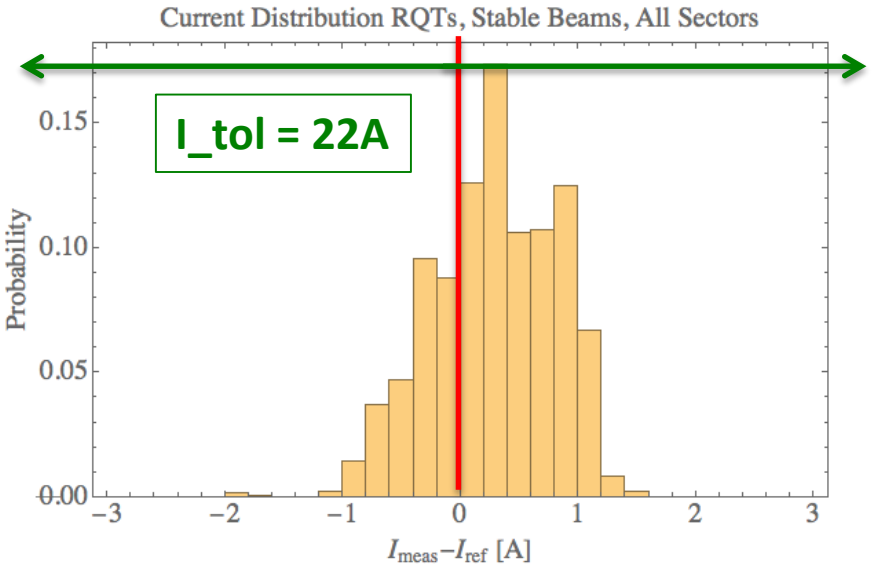
Main quadrupoles, Triplets, matching and warm quadrupoles have very stable currents from fill to fill and during collisions: **ΔI ≈ ±0.02A**

Only the **trim quadrupoles show large variations** …



Initial Current of RQTF-B1 start of Stable Beams

Drift through the year: ΔI = +2A



Distribution of all RQTs current values in Stable Beams, all fills, normalized to LSA reference.

Max. offset from Ref: ΔI = ±2-3A

Qualifying Current Tolerances

For the static optics point at 40cm the used tolerances seem very relaxed compared to the observed current fluctuations.

➔ **Margin to reduce tolerances for ATS.**

Quadrupole Families	Allocated phase margin [degree]	Resulting Current tolerances [A]	Current restriction form Measurement [A]
Main Quadrupoles	5	4.43	0.02
Main Trim Quadrupoles	5	22.2	3.0
Triplets	10	1.9/1.1	0.02
Matching Quadrupoles	5	0.8-5.1	0.02
Warm Quadrupoles	1	5.35/7.75	0.02

Tolerances with ATS Optics

Calculation of tolerances for ATS with same assumptions as for 2016
(current tolerance scales linearly with strength tolerance)

Quadrupole Families	Allocated phase margin [degree]	Ratio k_tol ATS/nominal	Resulting Current tolerances for ATS [A]
Main Quadrupoles	5	1.01	4.47
Main Trim Quadrupoles	5	0.98	21.7
Triplets	10	1.07	2.0/1.2
Matching Quadrupoles	5	1.22	1.0-6.2
Warm Quadrupoles	1	0.64	3.4/5.0
SUM	**26**		-

Tolerances with ATS Optics

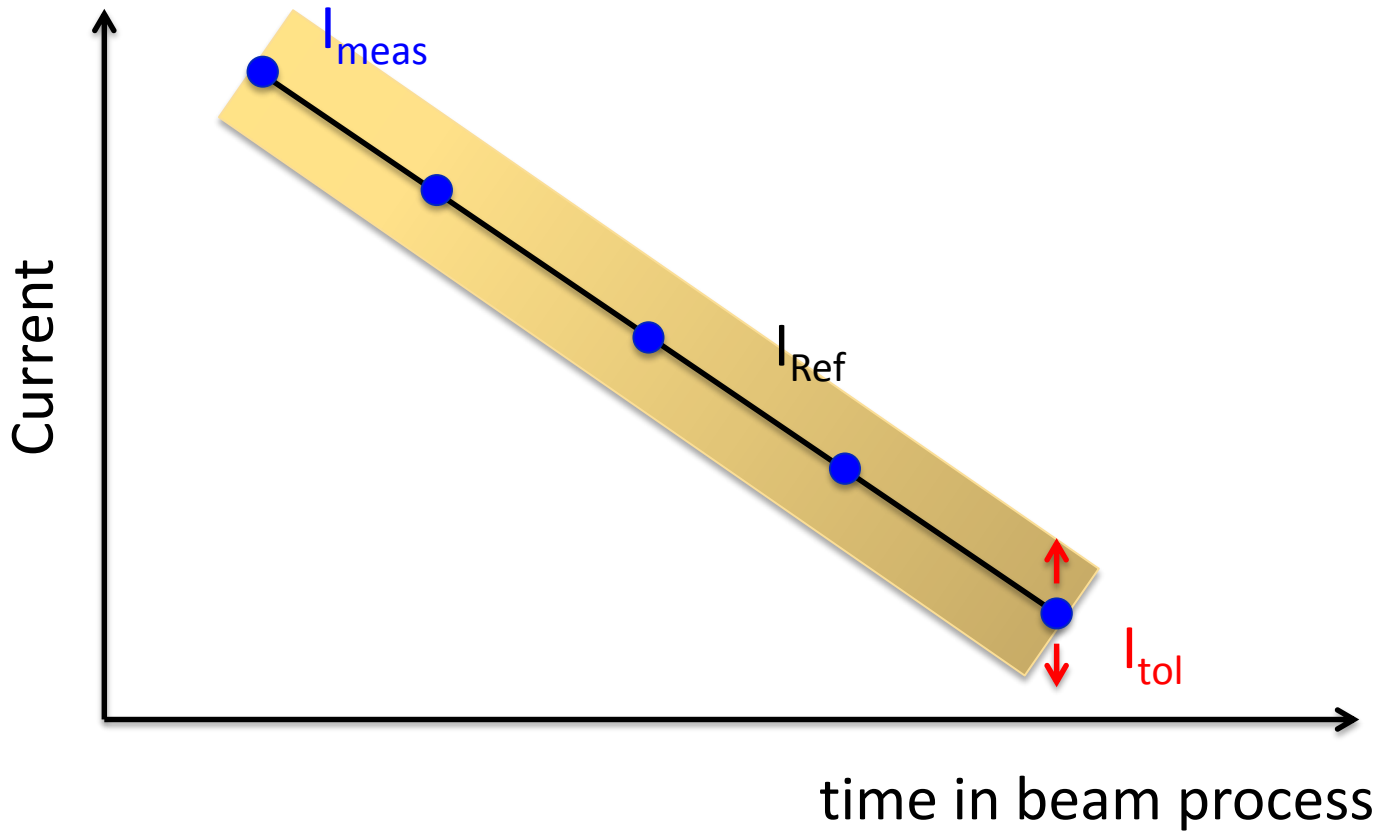
Initial phase advance between MKD and TCT is already 26°.

➔ **Only 4° margin left** to total shift allowed.

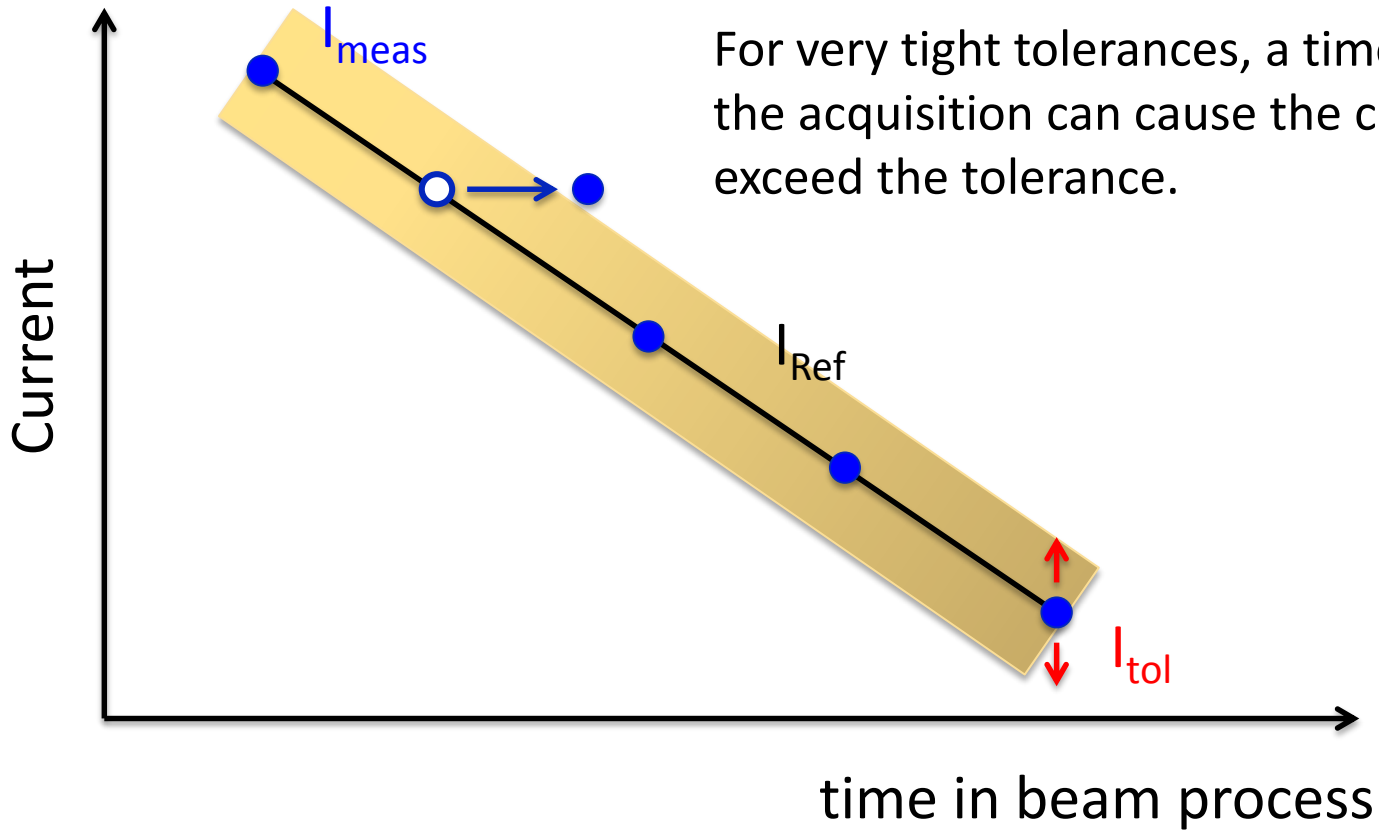
Calculation of tolerances with 4° total shift allowed (example)

Quadrupole Families	Allocated phase margin [degree]	Ratio k_tol ATS/nominal	Resulting Current tolerances [A]	Current restriction form Measurement [A]
Main Quadrupoles	0.2	0.04	0.18	0.02
Main Trim Quadrupoles	3.0	0.59	13.1	3.0 (6.0)
Triplets	0.4	0.04	0.08/0.04	0.02
Matching Quadrupoles	0.2	0.05	0.04-0.26	0.02
Warm Quadrupoles	0.2	0.13	0.7/1.0	0.02
SUM	**4**	-	-	-

Current Ramp during Squeeze



Current Ramp during Squeeze



For very tight tolerances, a time delay in the acquisition can cause the current to exceed the tolerance.

The ramp rate is limiting the min. tolerances during squeeze.

Current Ramp during Squeeze

- Naturally, the current in the **Matching Quads** and **Triplets** are changed during Squeeze.
- But for the 2016 optics also the **Trim** and **Main quads** move significantly.
- *The tolerances are linearly interpolated between initial and last point.*

Rough estimates of the max. ramp rate

Quadrupole Families	approx. Ramp Rate 2016 [A/s]	approx. Ramp Rate ATS [A/s]	min. tolerance limit ATS [A]
Main Quadrupoles	0.6	0	0
Main Trim Quadrupoles	0.16	0.01	0.02
Triplets	1.9	1	2
Matching Quadrupoles	12	17	32
Warm Quadrupoles	0	0	0

Assuming 2s timing delay seems to be realistic.

Conclusions

- PC interlock on quadrupole currents in place since ~May 2016.

- The set tolerances **in Physics (const. current)** covered well the observed current variations.
  - Preliminary estimates show that it should be possible to reduce the tolerances during Physics.
  - The exact distribution of the available phase advance margin **needs to be studied more carefully.**

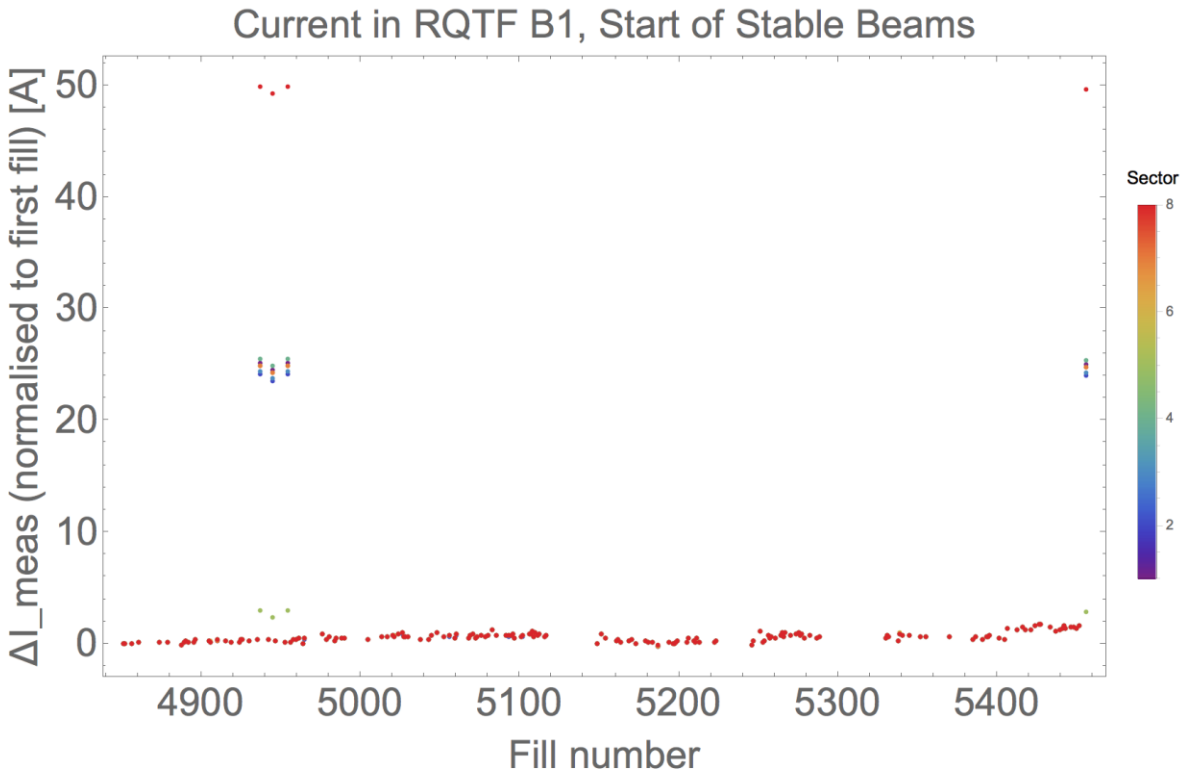
- Problematic are **current changes during the Squeeze**:
  - Timing issues can cause the current to exceed the tolerance.
  - **More studies needed.**

THANK YOU
FOR YOUR ATTENTION

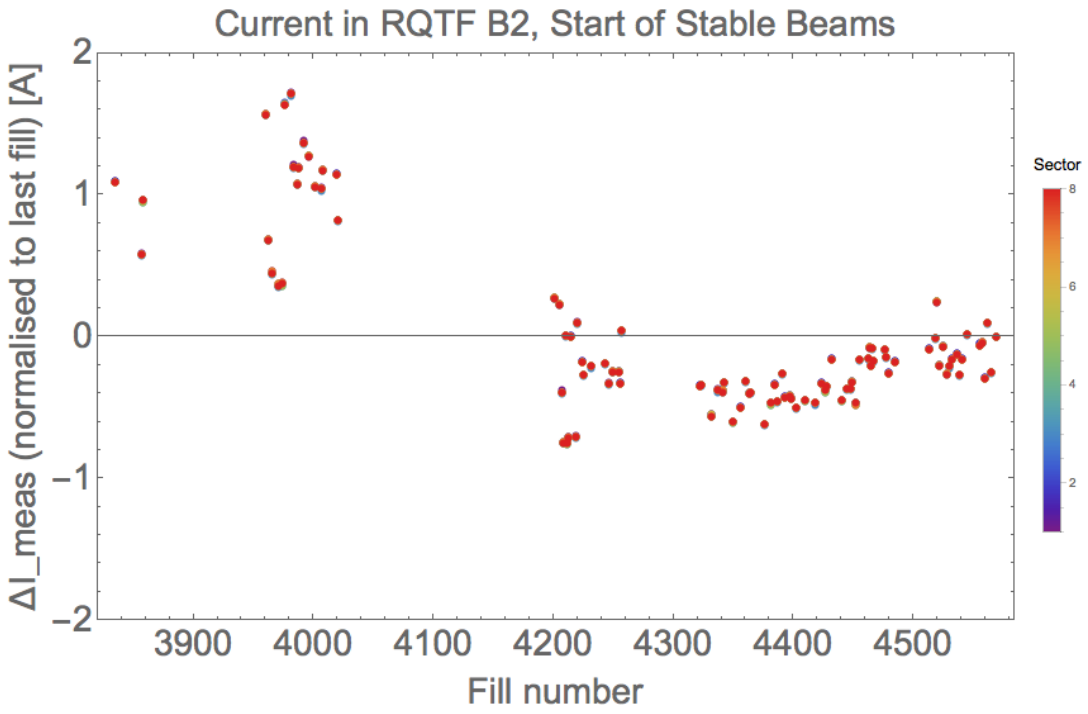
Backup

VdM Optics

In VdM Optics the RQT reference currents differ from the nominal optics.



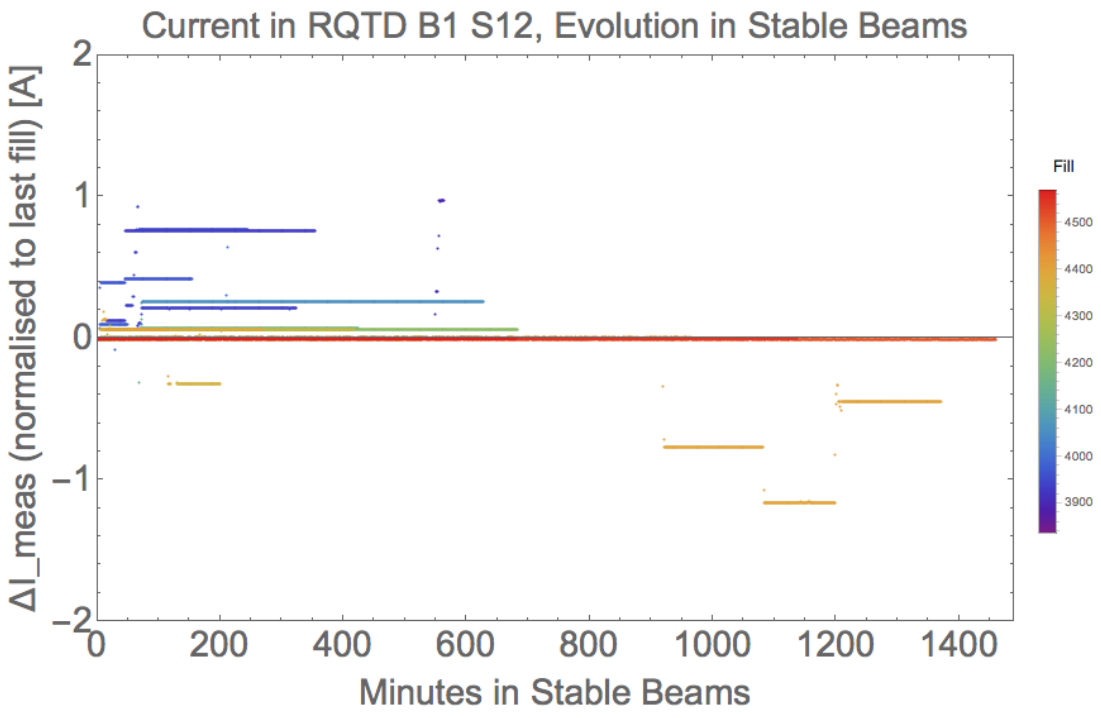
Current variations: RQTs (1) – 2015 Data



Current variation **from fill to fill**

- Example RQTF-B2 (family with the largest spread, see back up slides for the other families)
- All sectors are similar (color code)
- Data normalized to last fill (arbitrary)
- **|Max – Min| ≈ 3A**

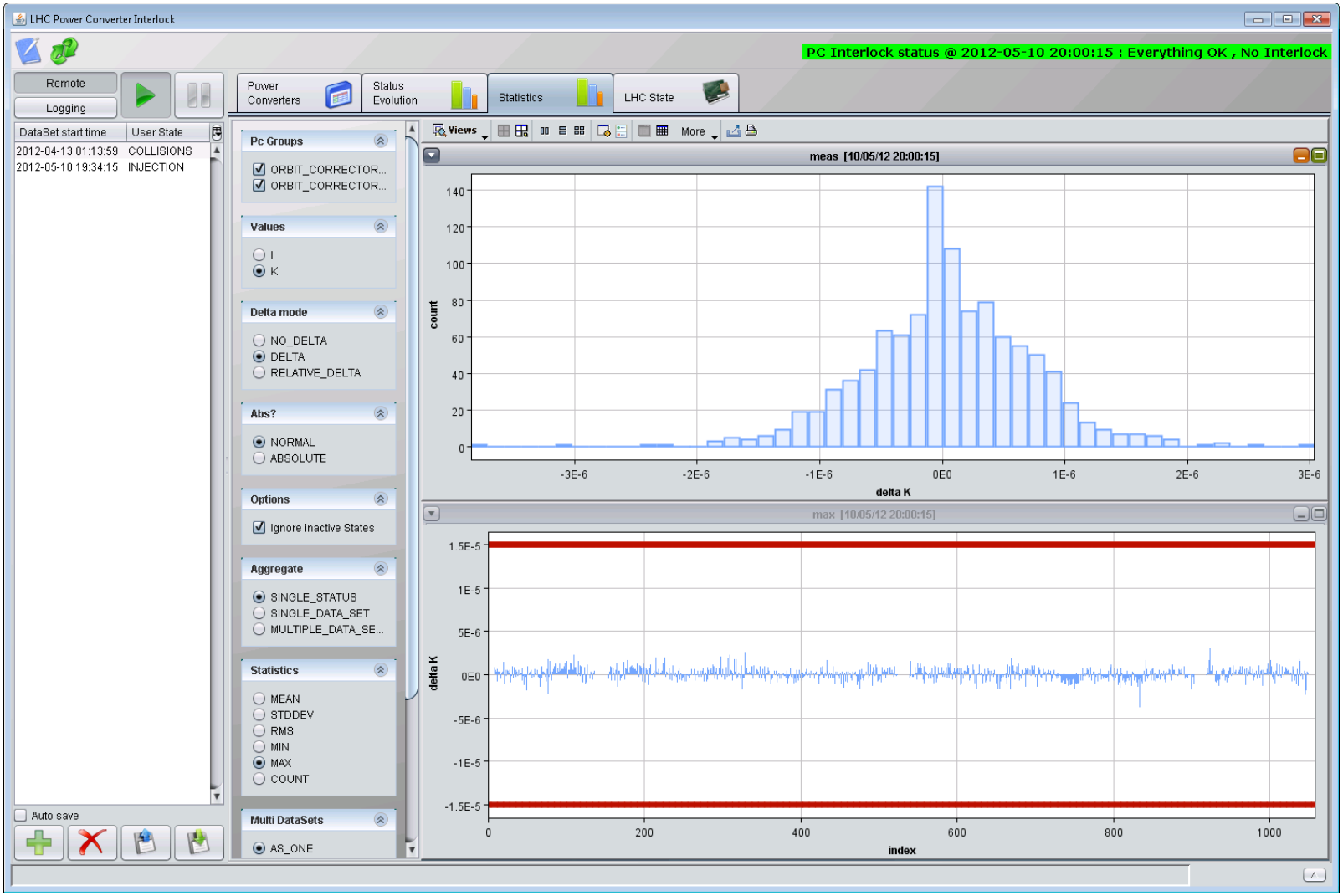
Current variations: RQTs (2) -2015 Data



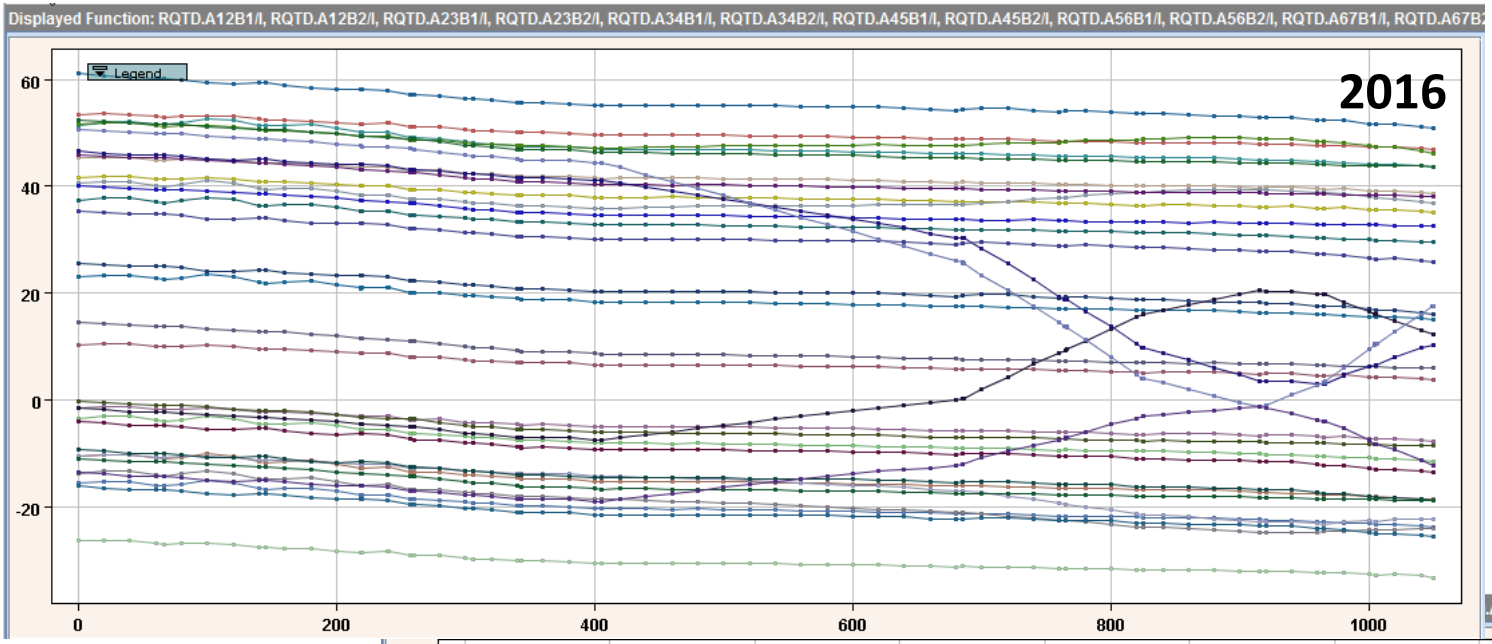
Current variation **during Collisions**

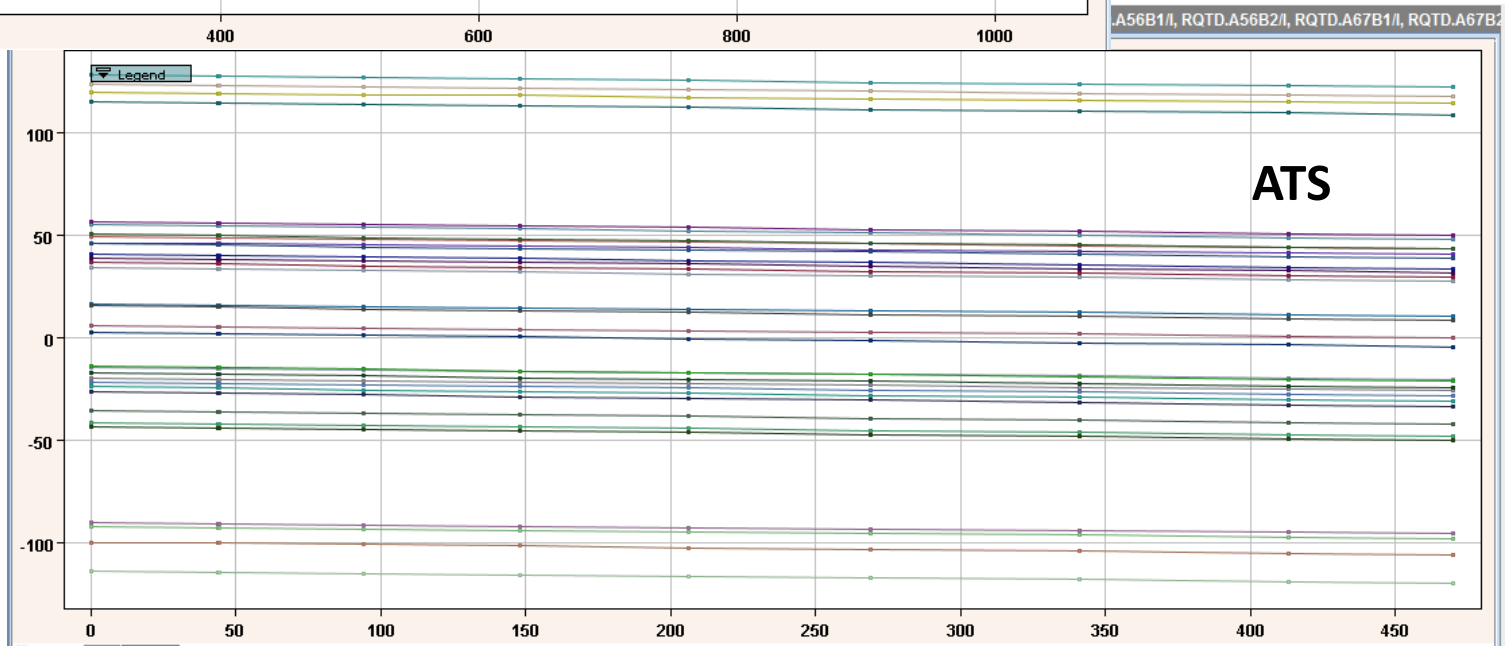
- Example RQTD-B1 (family with the largest spread, see back up slides for the other families)
- All sectors are similar (color code)
- Data normalized to initial value of each fill
- **ΔI ≈ ±1.5A**

PC Interlock - GUI

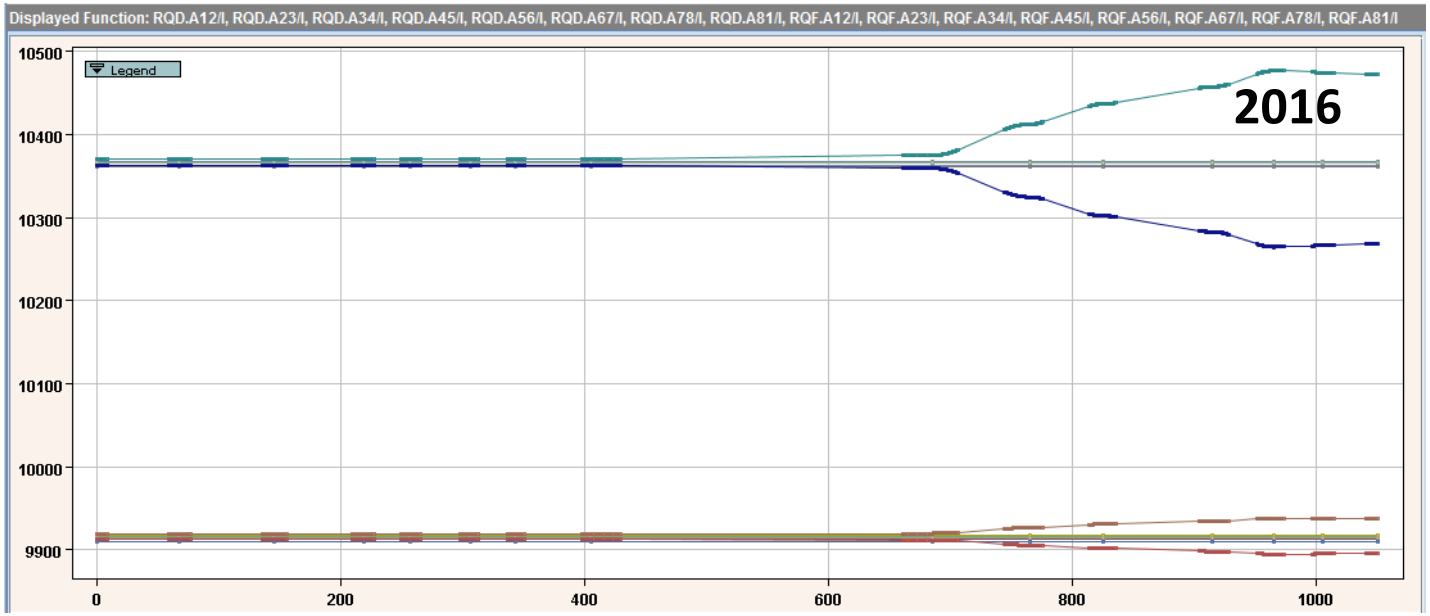


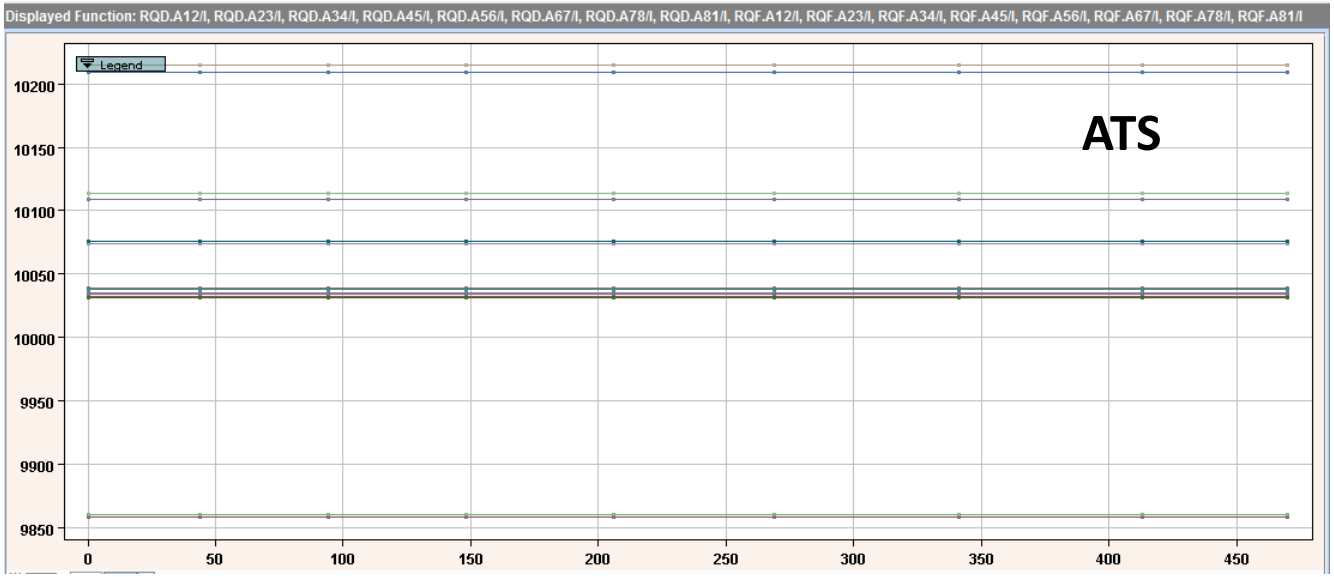
Squeeze – Trim Quads



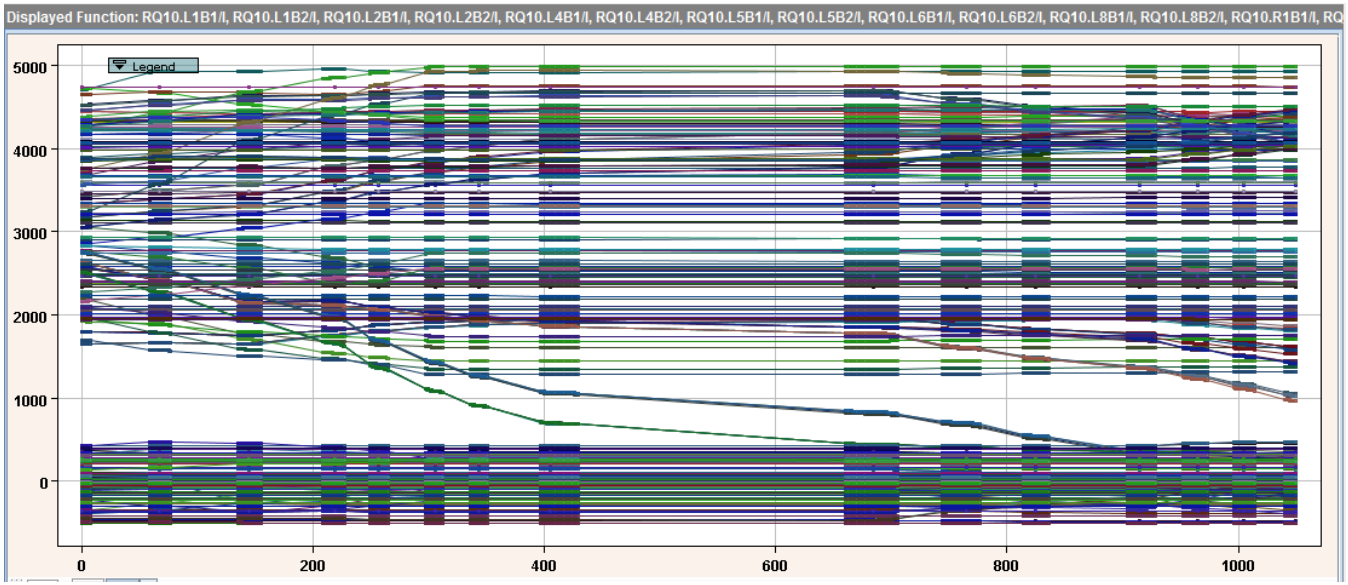


Squeeze – Main Quads



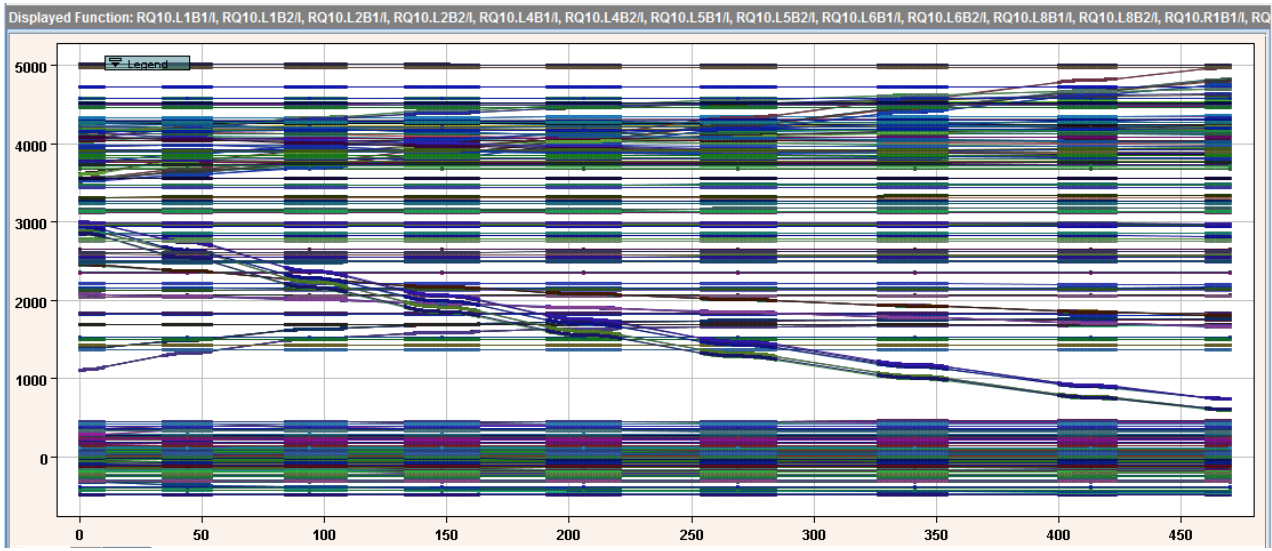


Squeeze – Matching Quads

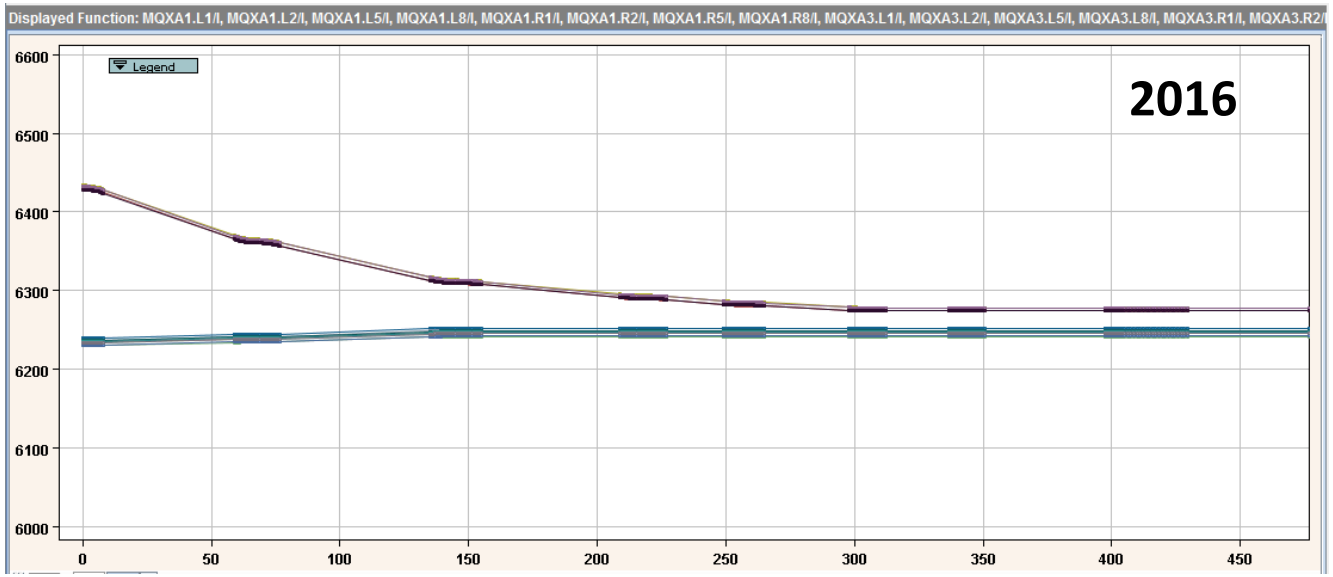


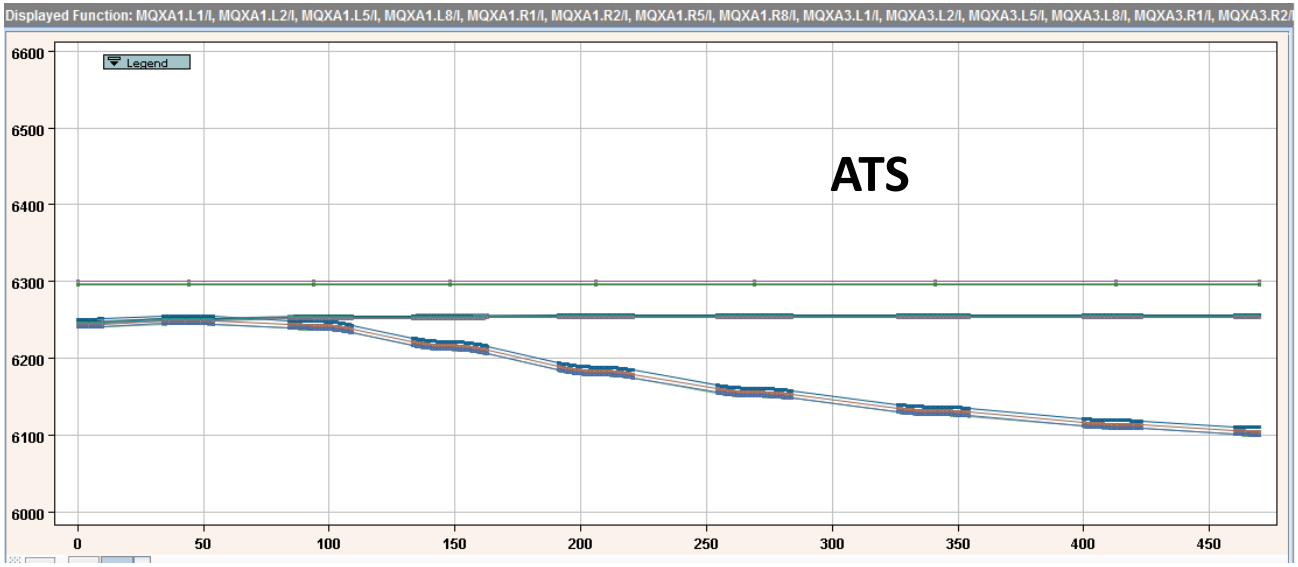
2016

ATS



Squeeze - Triplets





Squeeze – Warm Quads