

## Final results of the drive beam feed-forward experiment

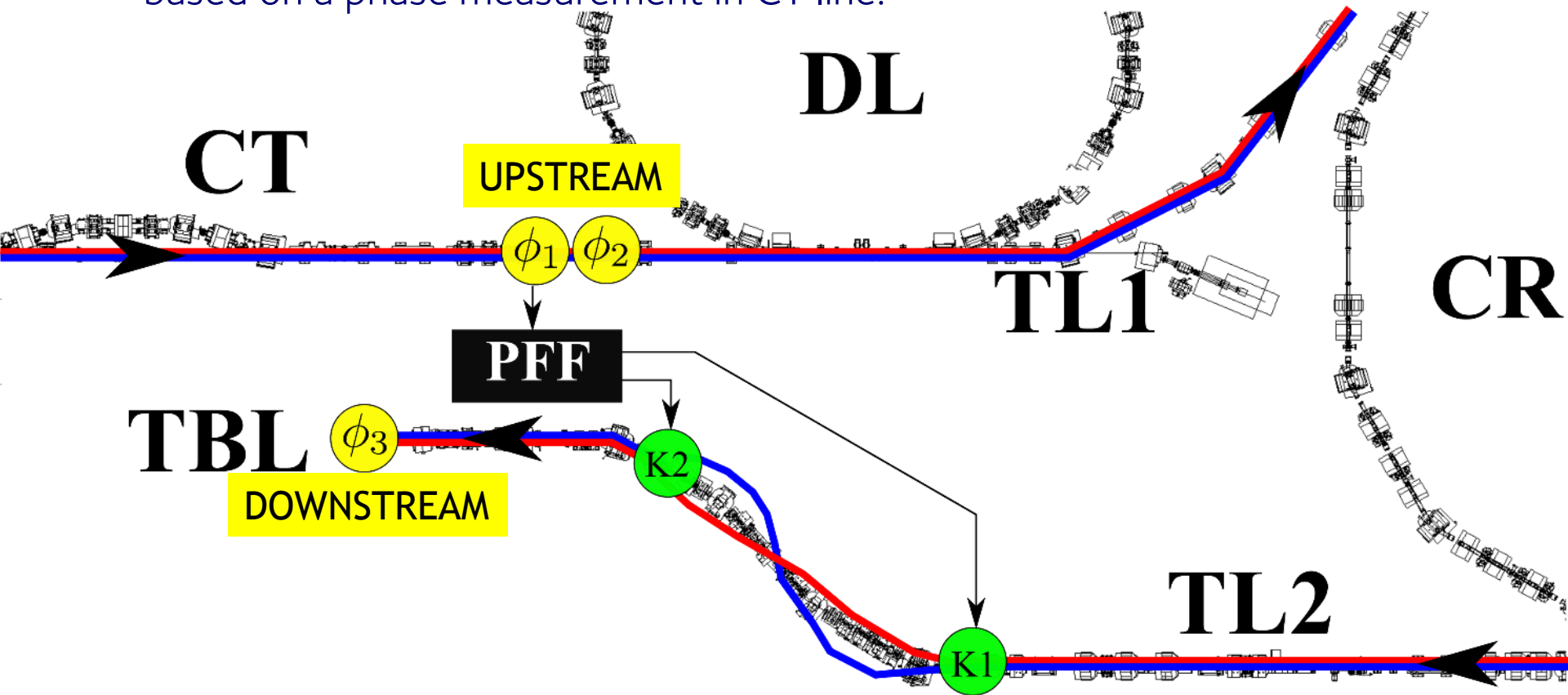
Jack Roberts



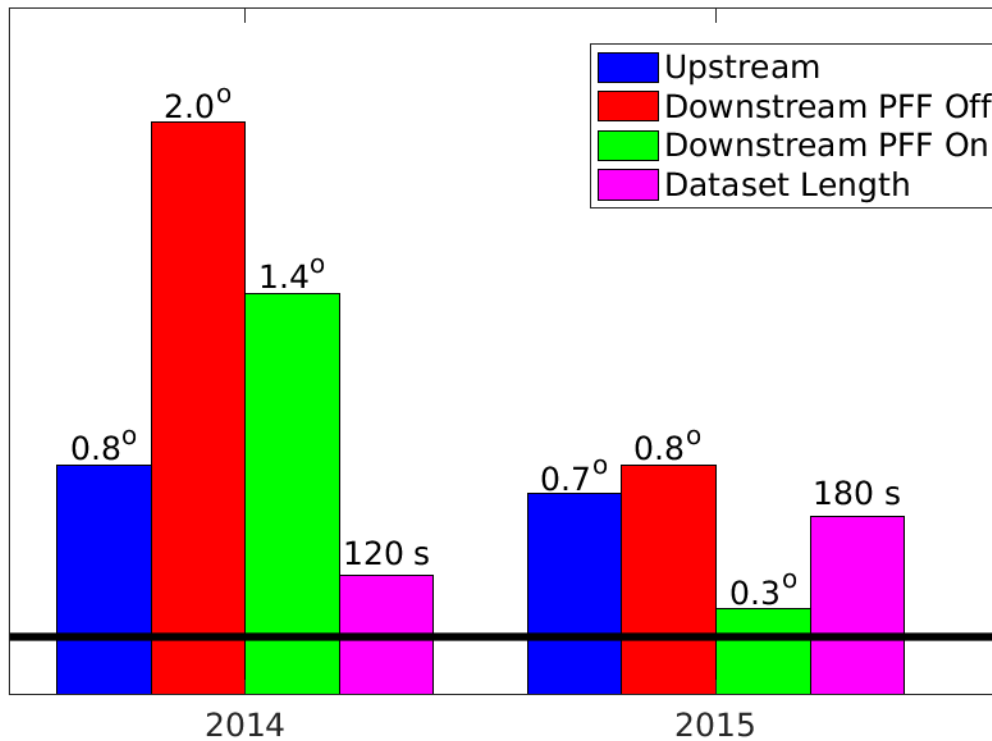
J. Roberts (Oxford, JAI and CERN)  
P.N. Burrows, G.B. Christian, C. Perry (Oxford, JAI)  
P.K. Skowronski, R. Corsini (CERN)  
A. Ghigo, F. Marcellini (INFN/LNF Frascati, Italy)

# Phase Feedforward (PFF) Prototype at CTF3

- Goal: Stabilise rms arrival time of drive beam to 50 fs, or 0.2 degrees at 12 GHz.
- Manipulate path length through TL2 chicane using electromagnetic kickers based on a phase measurement in CT line.



# Status CLIC Workshop 2016



# Progress in 2015

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- Identified energy dependent phase jitter as source of low upstream-downstream phase correlation.
- Corrected by manipulating R56 in TL1. Up to 93% correlation achieved.
- Changes to phase monitor electronics setup, achieving 0.14 degrees resolution.
- <0.3 degrees jitter achieved across a few minutes.

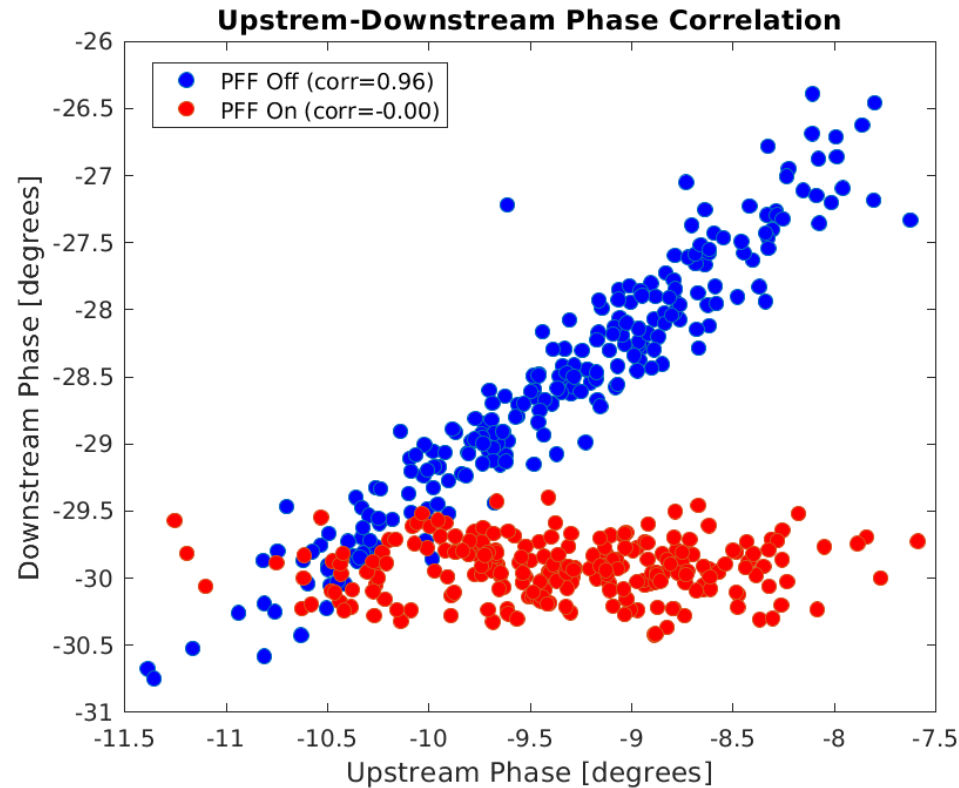
See CLIC workshop talks  
in previous years for details.

# Goals for 2016

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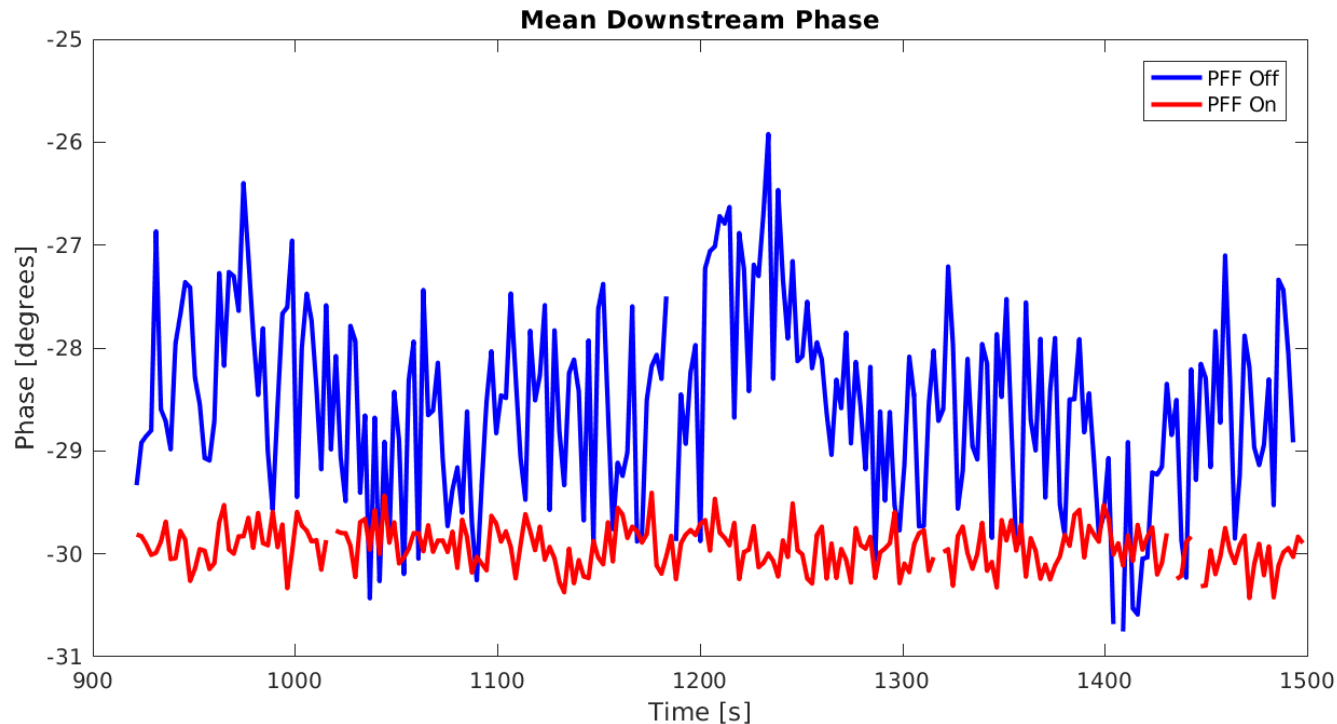
- CLIC-level phase stability (0.2 degrees downstream phase jitter).
- Achieve that stability in longer datasets.
- Demonstrate a larger factor reduction in downstream jitter (~factor 3 achieved 2015).
- Consolidate system setup (orbit closure, timing etc.)

# Best Achieved Stability: Mean Phase



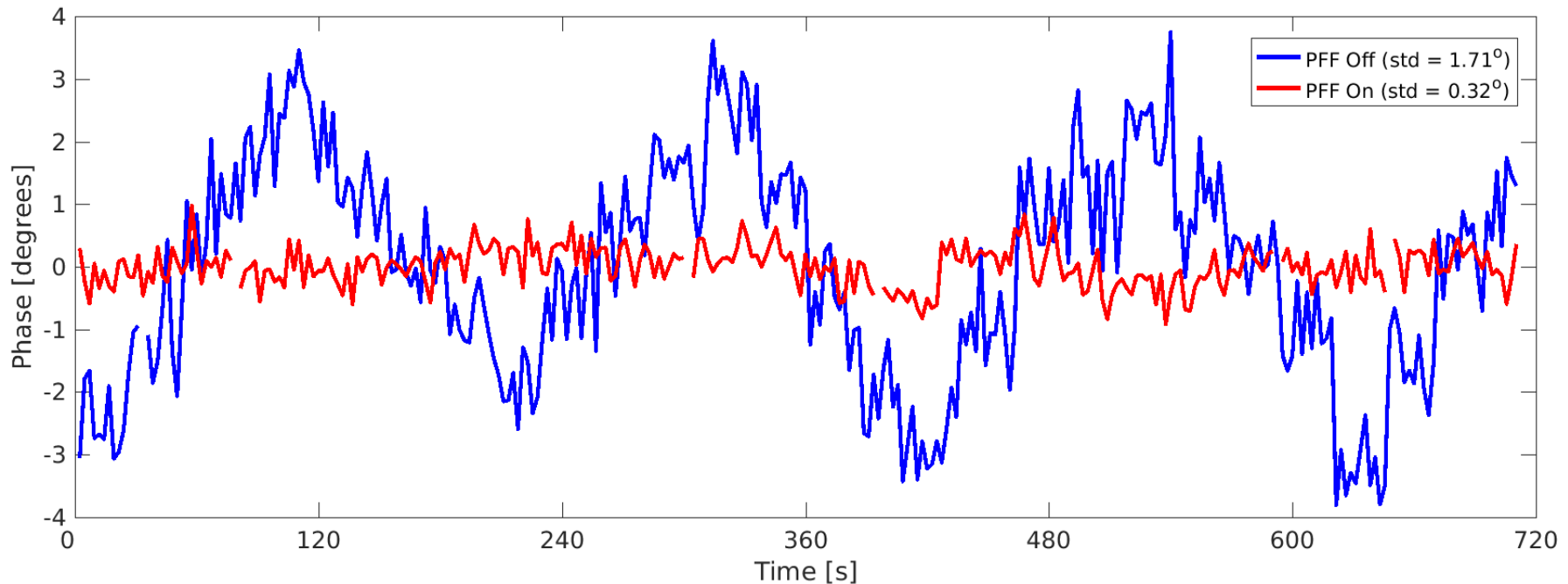
- Mean phase of each beam pulse (1 pulse every 1.2 s at CTF3).
- Interleaved data: Alternating pulses have correction on and off.
- All correlation removed by PFF system: from  $96 \pm 2\%$  to  $0 \pm 7\%$ .

# Best Achieved Stability: Mean Phase



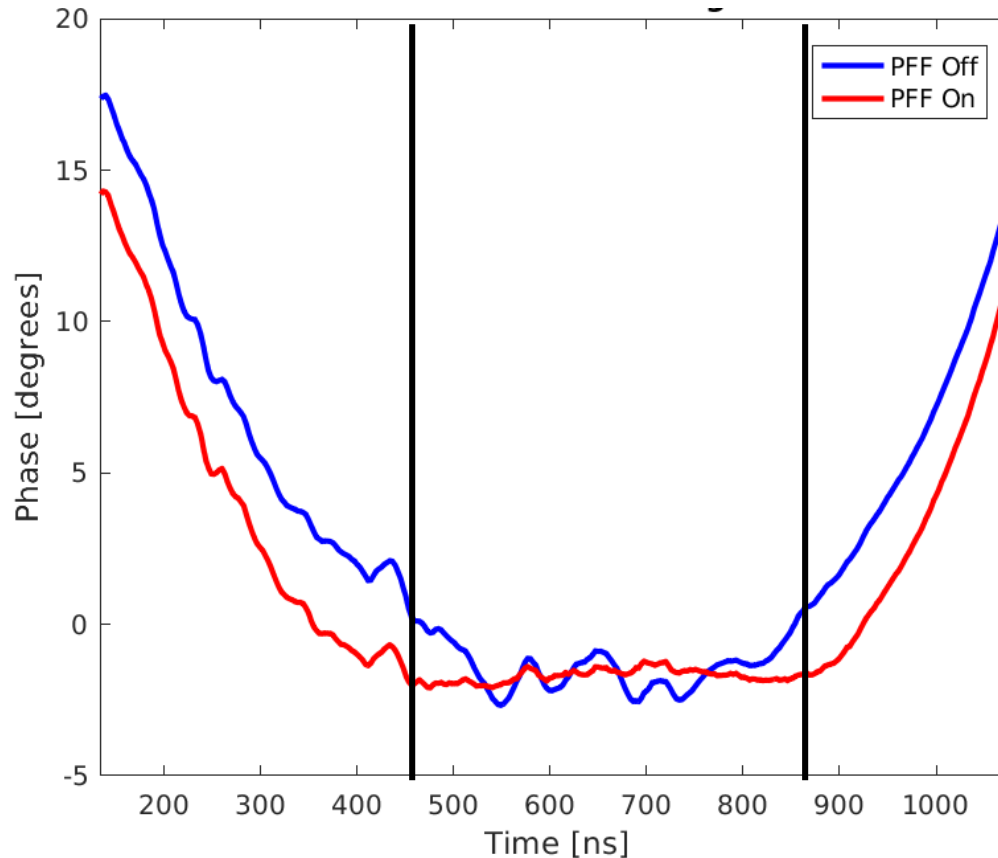
- Initial (PFF Off) downstream jitter:  $0.92 \pm 0.04$  degrees..
- Corrected downstream jitter:  $0.20 \pm 0.01$  degrees.
- 10 minutes.
- Predicted correction given beam conditions:  $0.26 \pm 0.06$  degrees.

# Correction with Additional Jitter Source



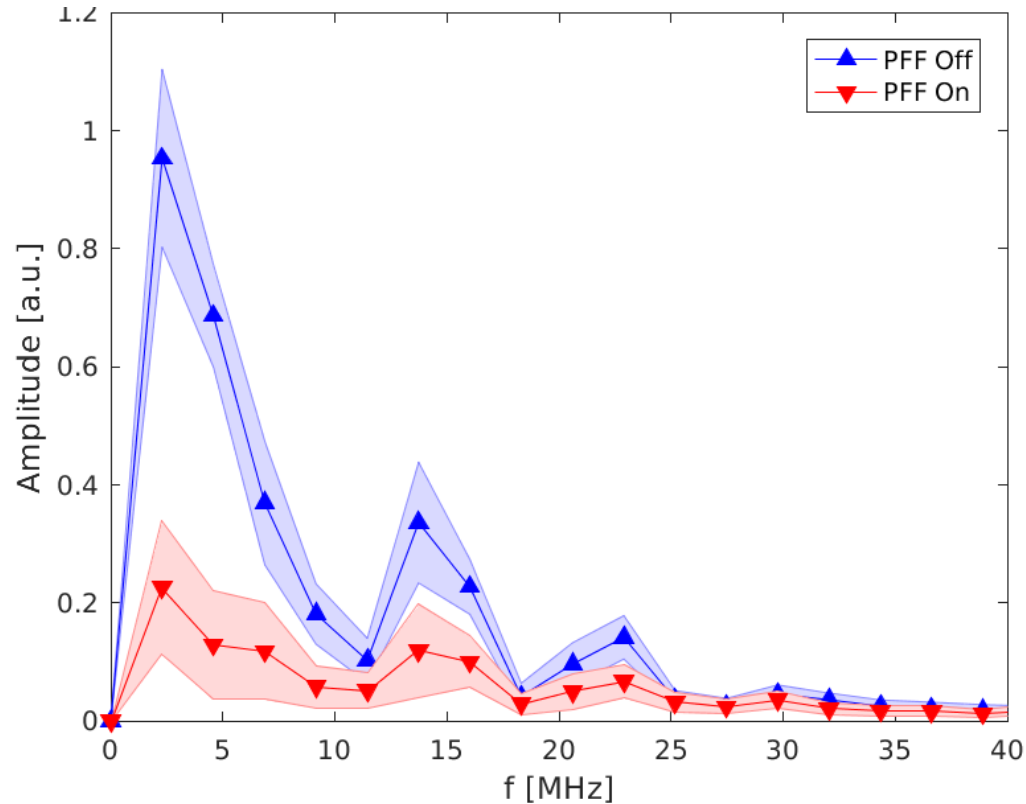
- Add slow, periodic drift to the incoming phase by manipulating klystron phases.
- Boosts correlation to >98%.
- Achieve more than a factor 5 reduction in downstream phase jitter:  $1.71 \pm 0.07$  degrees to  $0.32 \pm 0.01$  degrees.

# Intra-Pulse Phase Correction



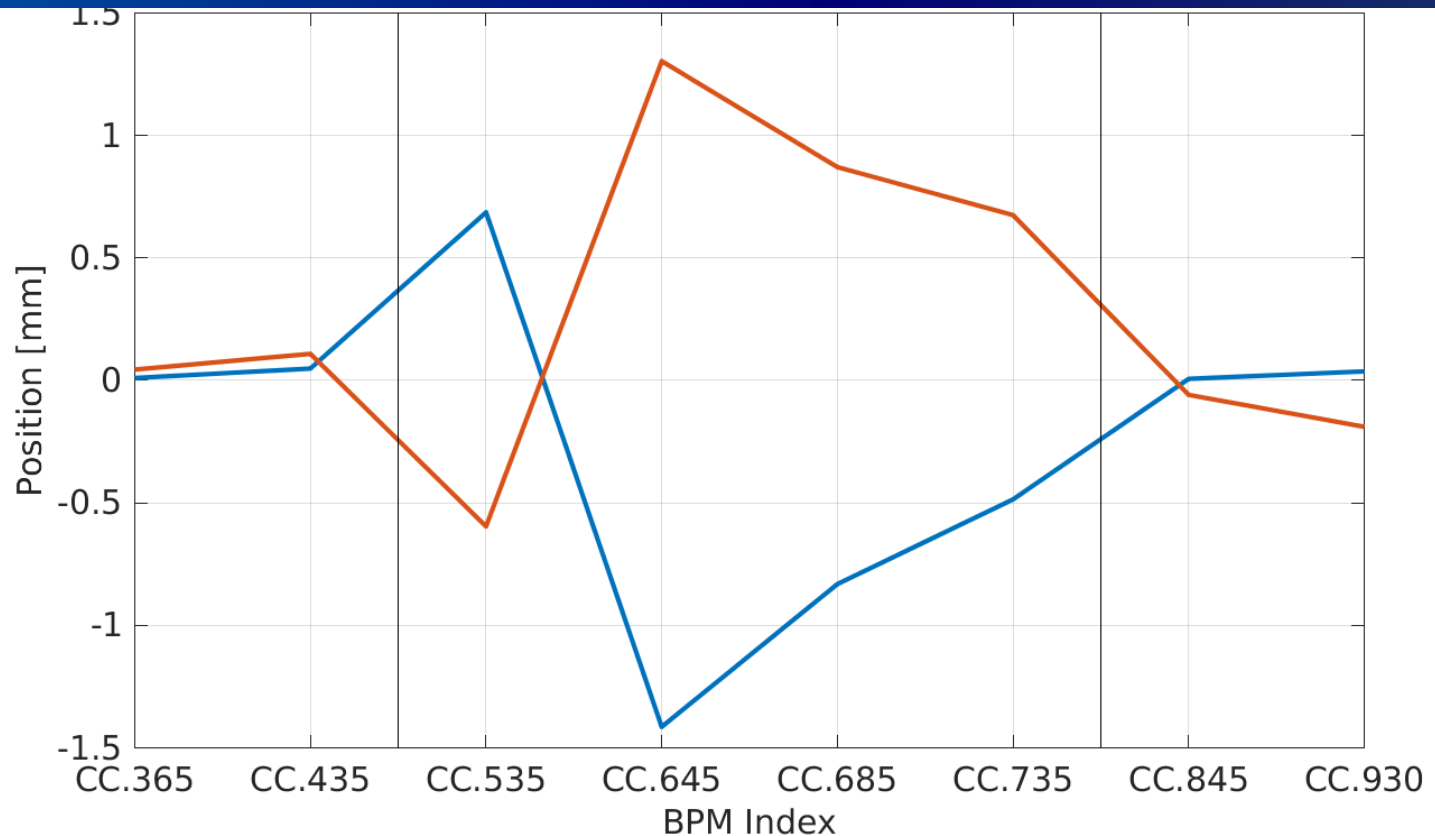
- High bandwidth correction – able to correct phase variations within the pulse.
- Correction range:  $\pm 6$  degrees, can correct  $\sim 400$ ns portion of  $1.2\mu\text{s}$  beam pulse.
- 0.96 degrees rms intra-pulse variation reduced to 0.28 degrees.

# Correction Bandwidth



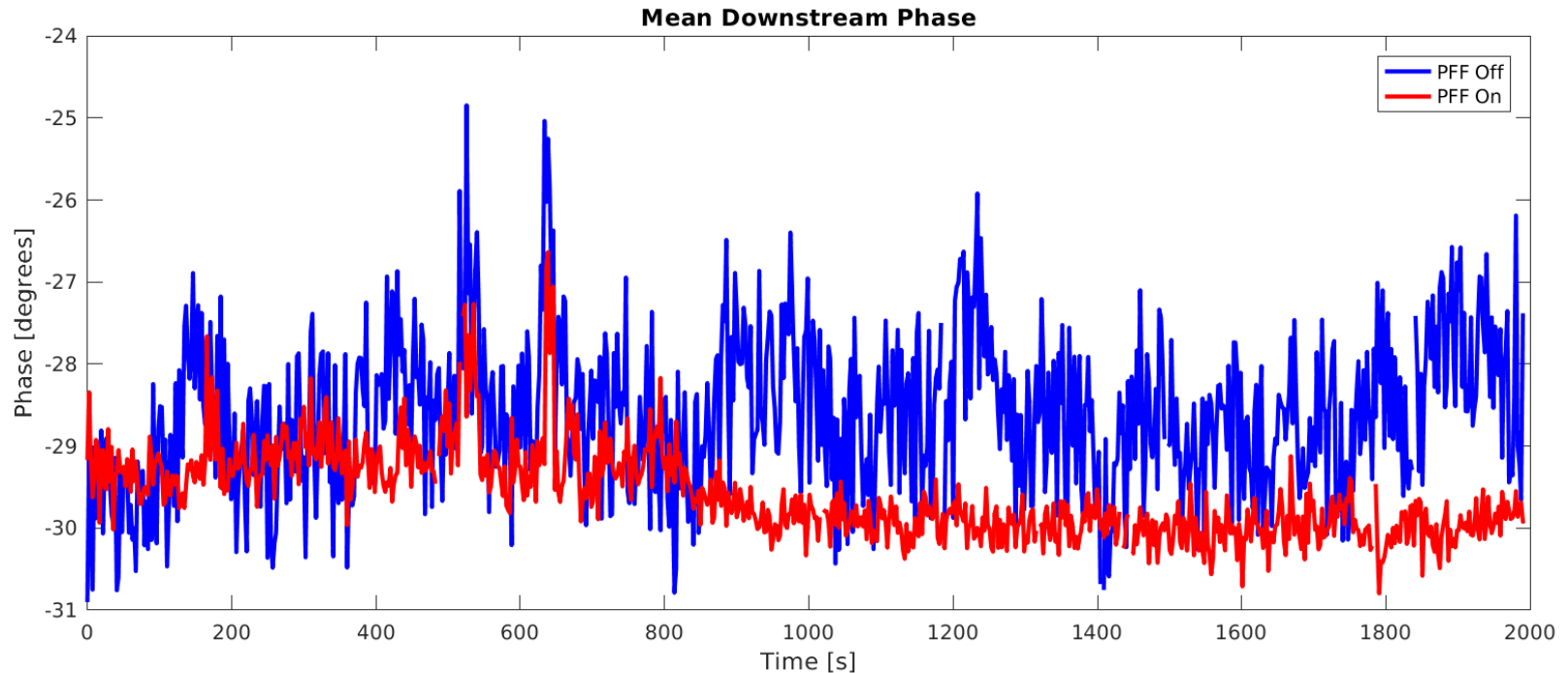
- System bandwidth (defined by phase monitor and kicker amplifiers) expected to be ~30MHz.
- Typically no phase errors above 25MHz at CTF3.
- PFF system verified to correct phase errors up to that frequency.

# Orbit Closure

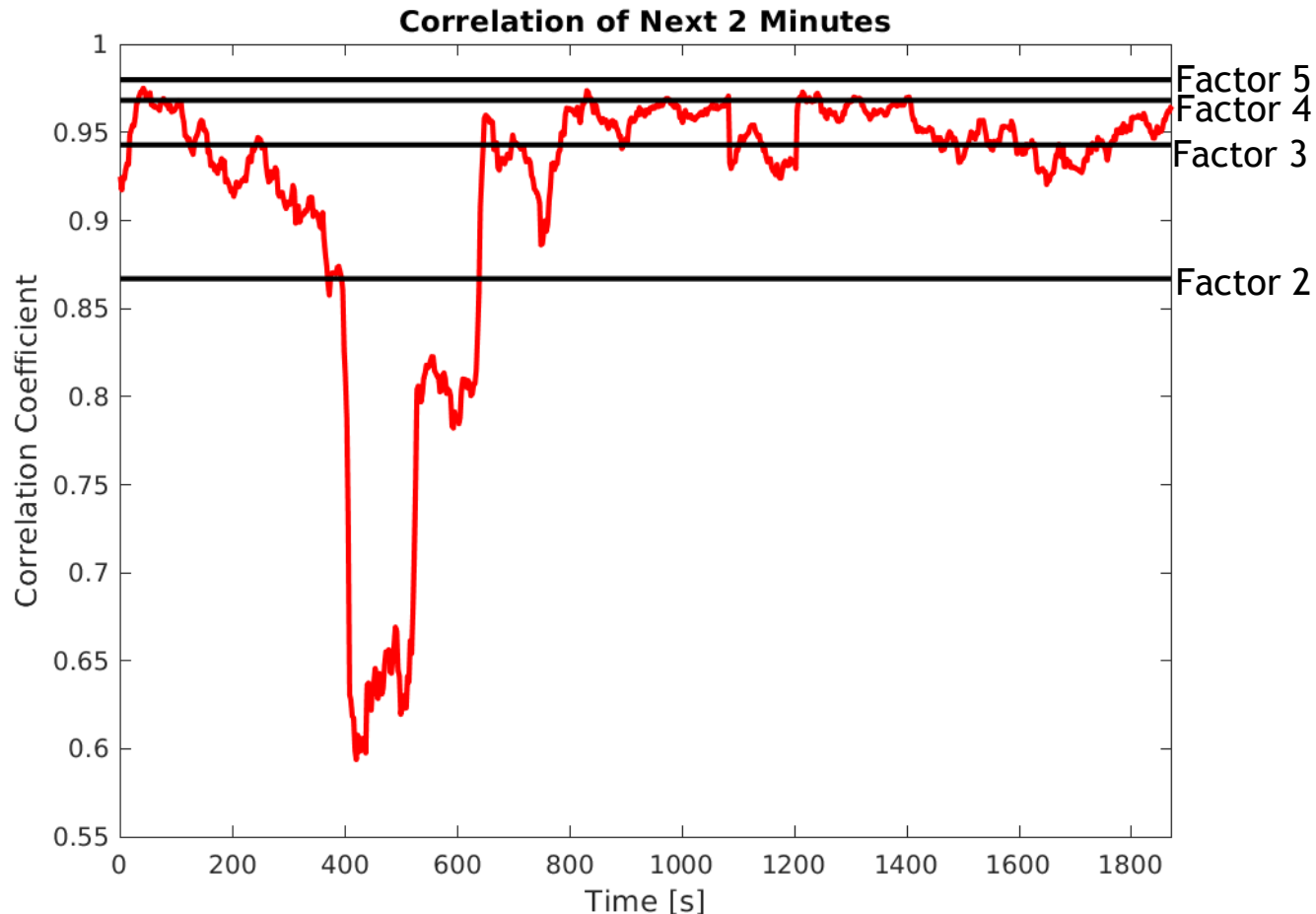


- PFF system must not degrade downstream beam orbit stability.
- 2015: 0.5mm offset in CC.930 at min/max kick.
- 2016: Better than 0.1 mm.

# Correction Across ~30 Minutes



# Phase Correlation



- <96% correlation: Beam limitations dominant.
- >96% correlation: phase monitor resolution starts to become relevant.

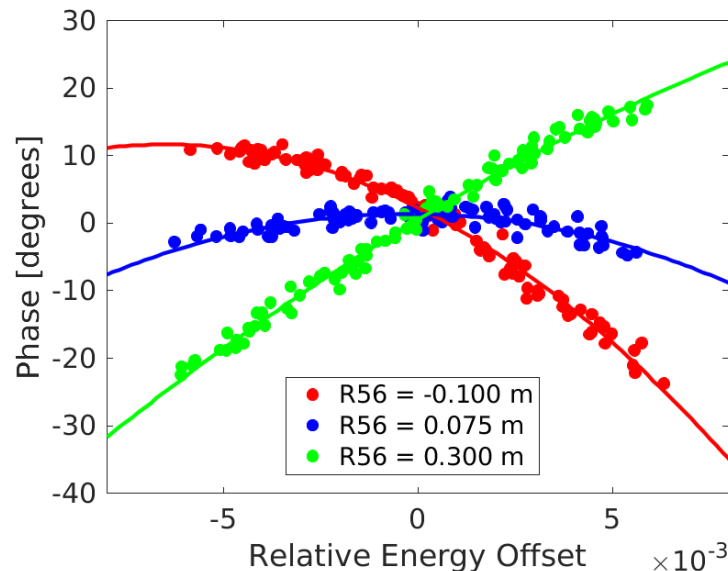
# System Limitations

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- Beam limitations (usually dominant)
  - Correlation between the upstream and downstream phase.
  - Phase drifts.
  - Energy drifts.
  - Other phase jitter sources.
  
- Hardware limitations
  - Phase monitor resolution.
  - Correction Range.

# Beam Limitations

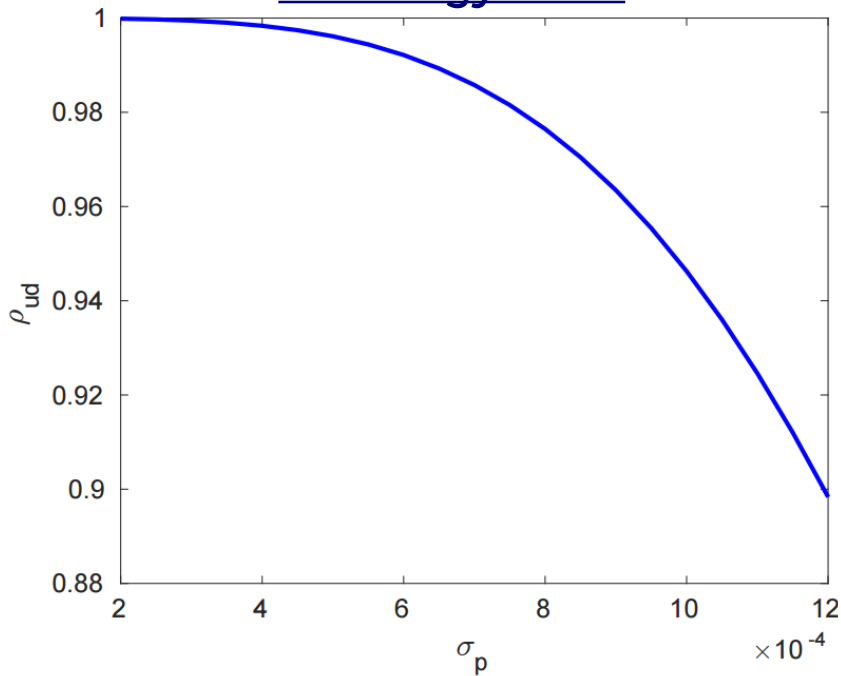
- Phase is very sensitive to energy changes
  - 1<sup>st</sup> order (R56) dependence corrected by optics changes.
  - 2<sup>nd</sup> order (T566) still present.
- Tool developed to measure R56 online (see Piotr Skowronski's talk).
- Benefitted from improved stability of CTF3 (see Lukas Malina's talk).
- Nevertheless, difficult to maintain correlation through klystron trips etc.
- Occasionally low correlation not dependent on energy seen.



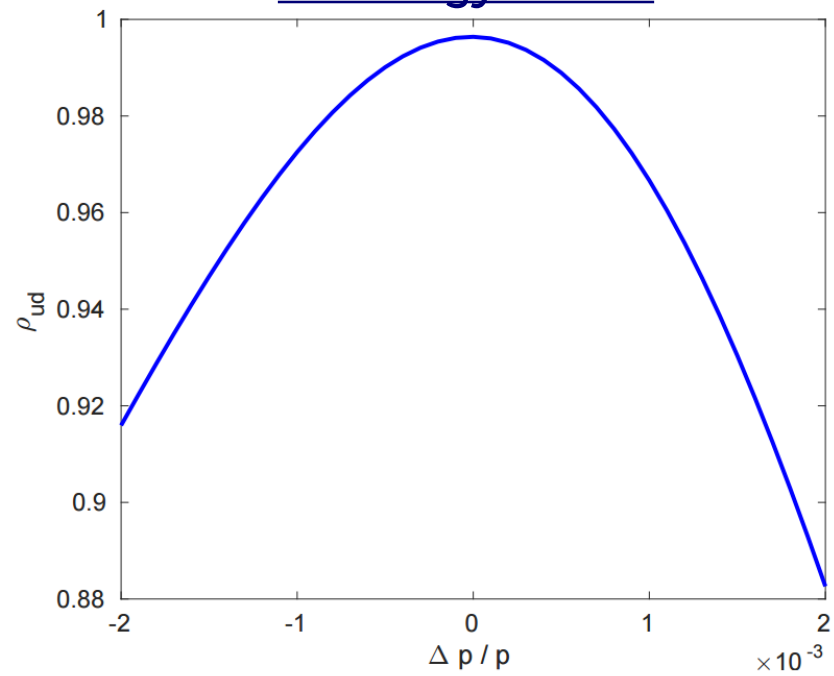
# Sensitivity to T566

- Simulations assuming 1<sup>st</sup> order phase-energy dependence (R56) is perfectly corrected.
- Require better than  $10^{-3}$  energy jitter and offset.

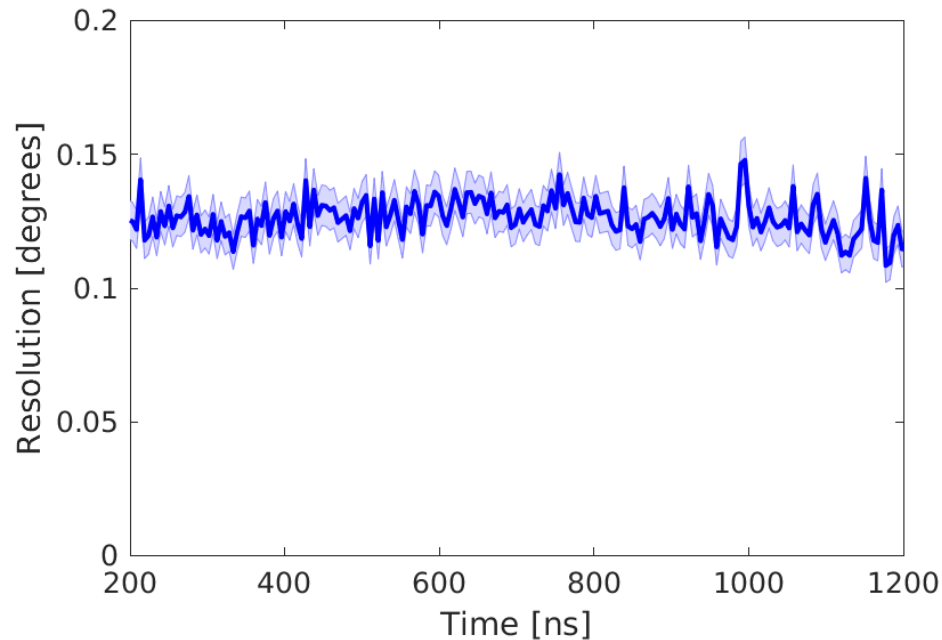
Correlation Dependence  
on Energy Jitter

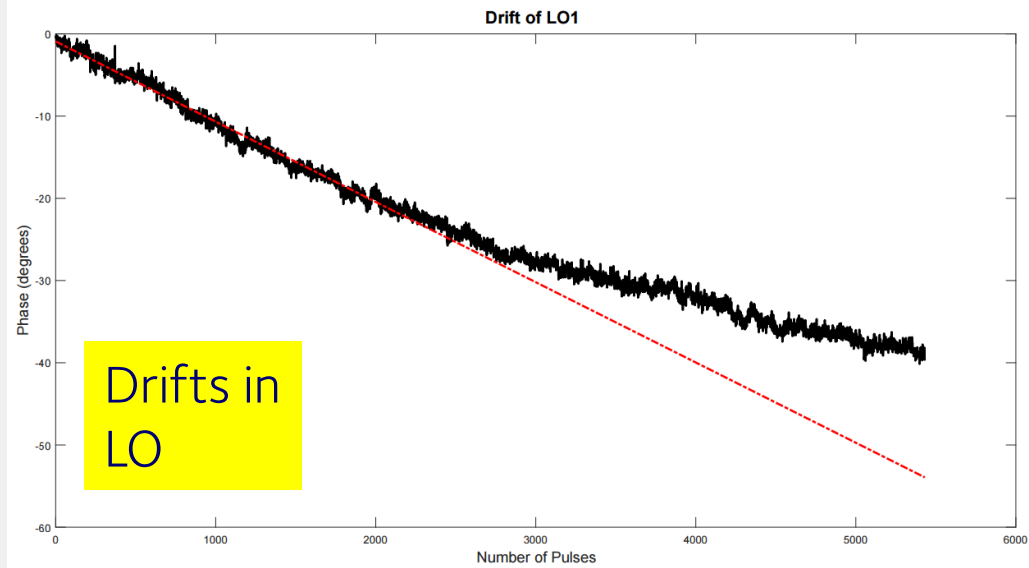
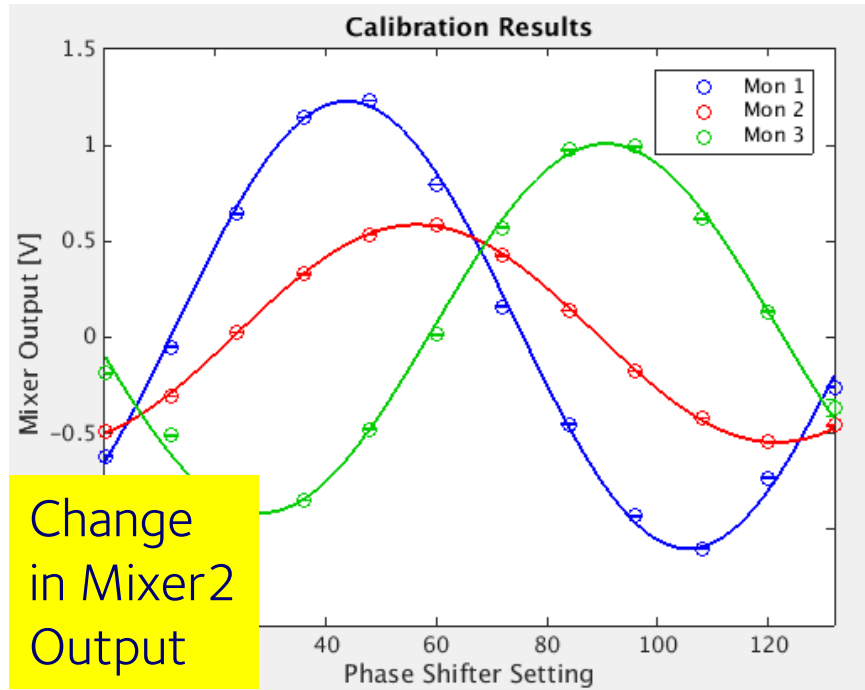
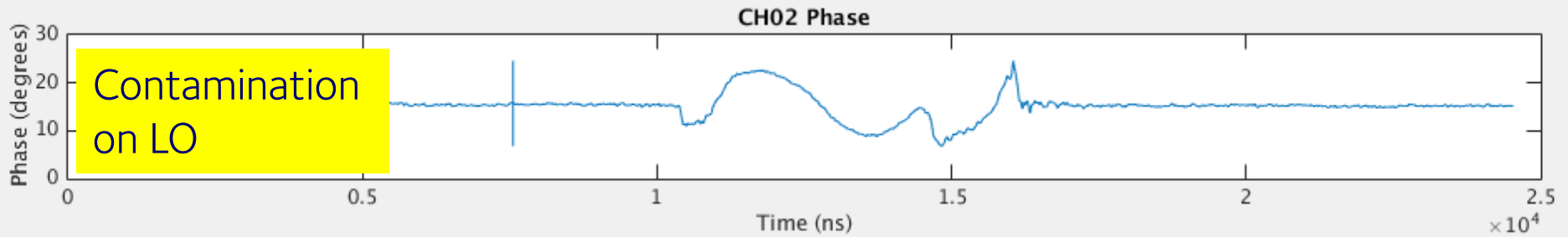


Correlation Dependence  
on Energy Offset

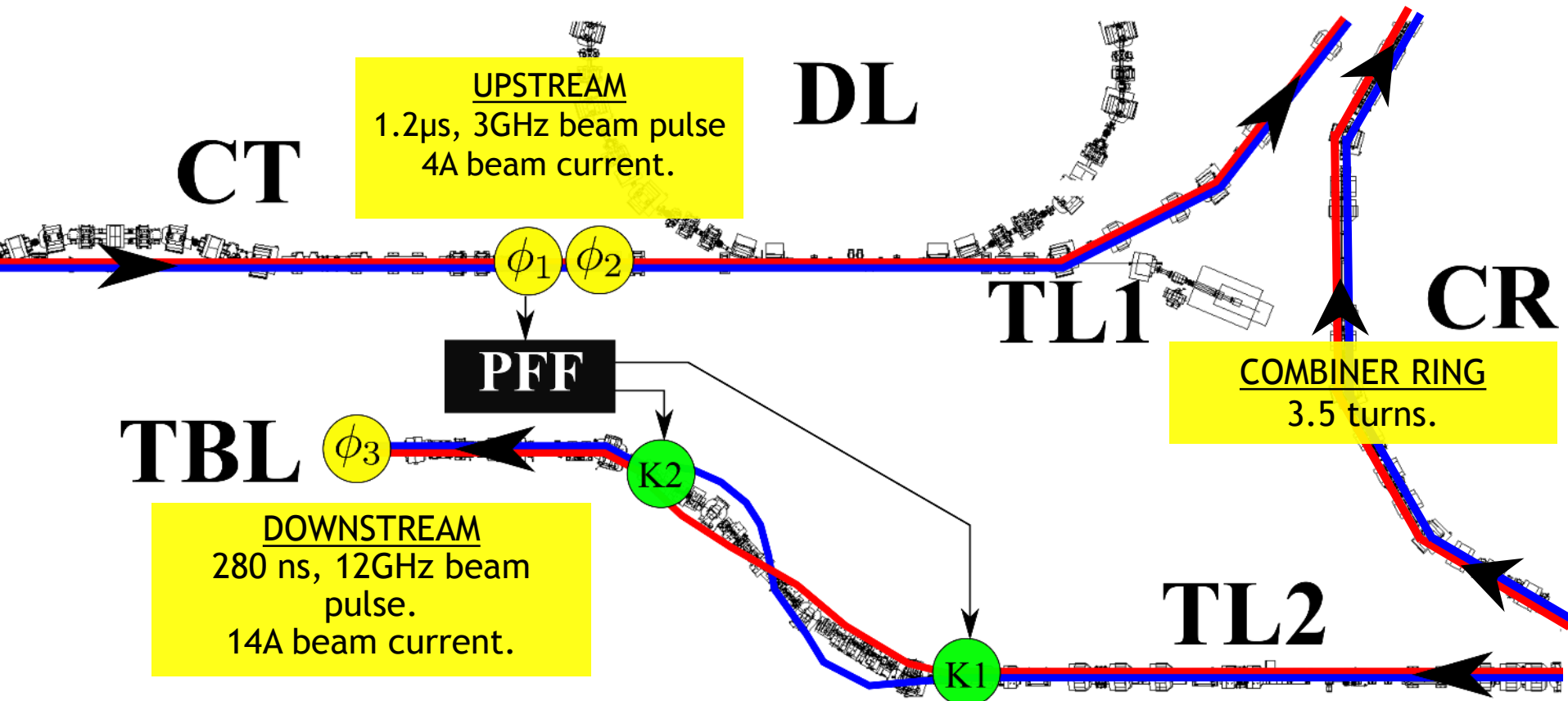


- Achieved 0.12 degrees point-by-point resolution.
- Best PFF results getting close to resolution limit.
- 0.20 degrees measured jitter  $\sim$ 0.17 degrees actual beam jitter if resolution subtracted.
- Nevertheless, still had several issues with the electronics...



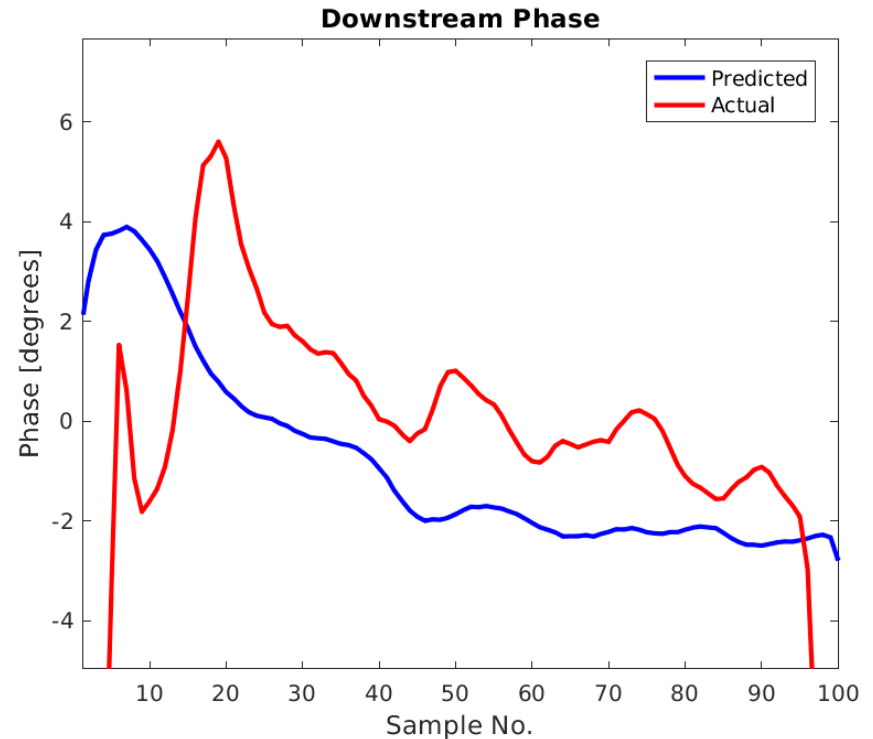
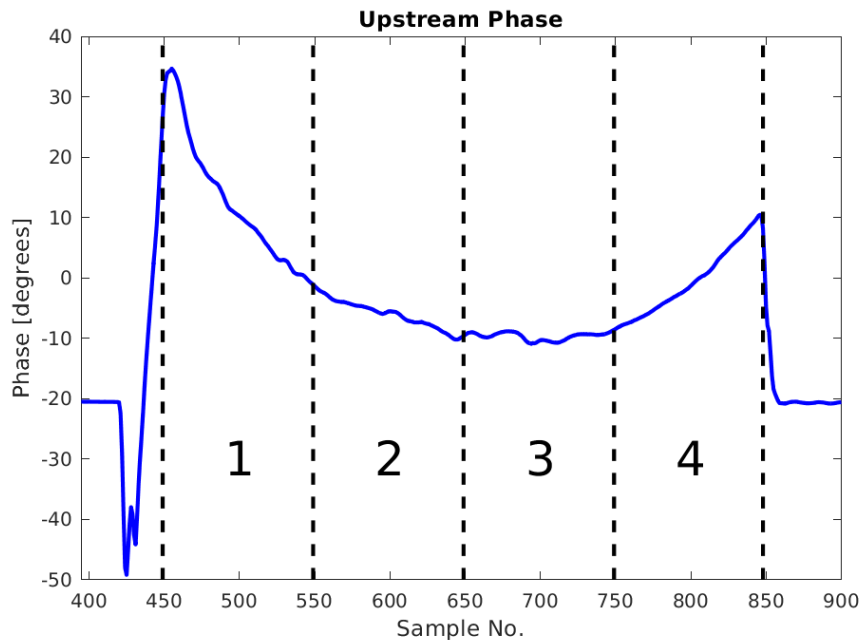


# Correction of Combined Beam



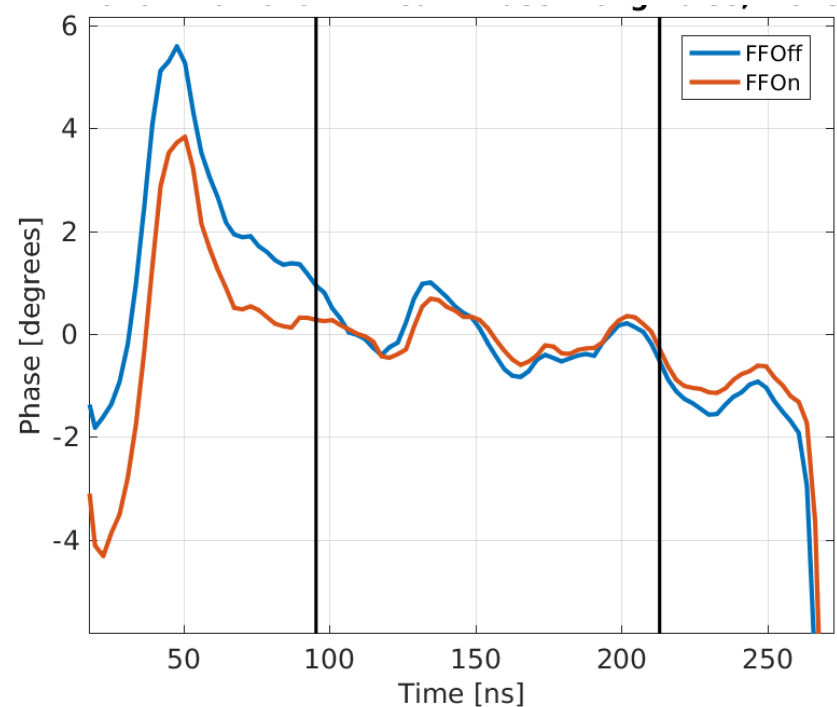
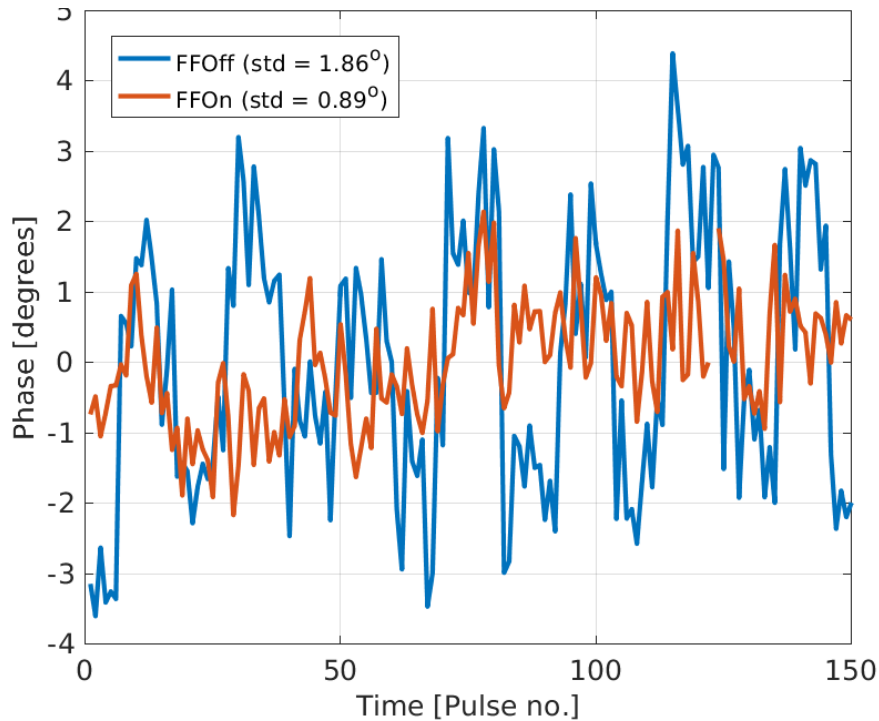
# Correction of Combined Beam

- New PFF algorithm shapes correction output based on average of upstream sub-pulses.

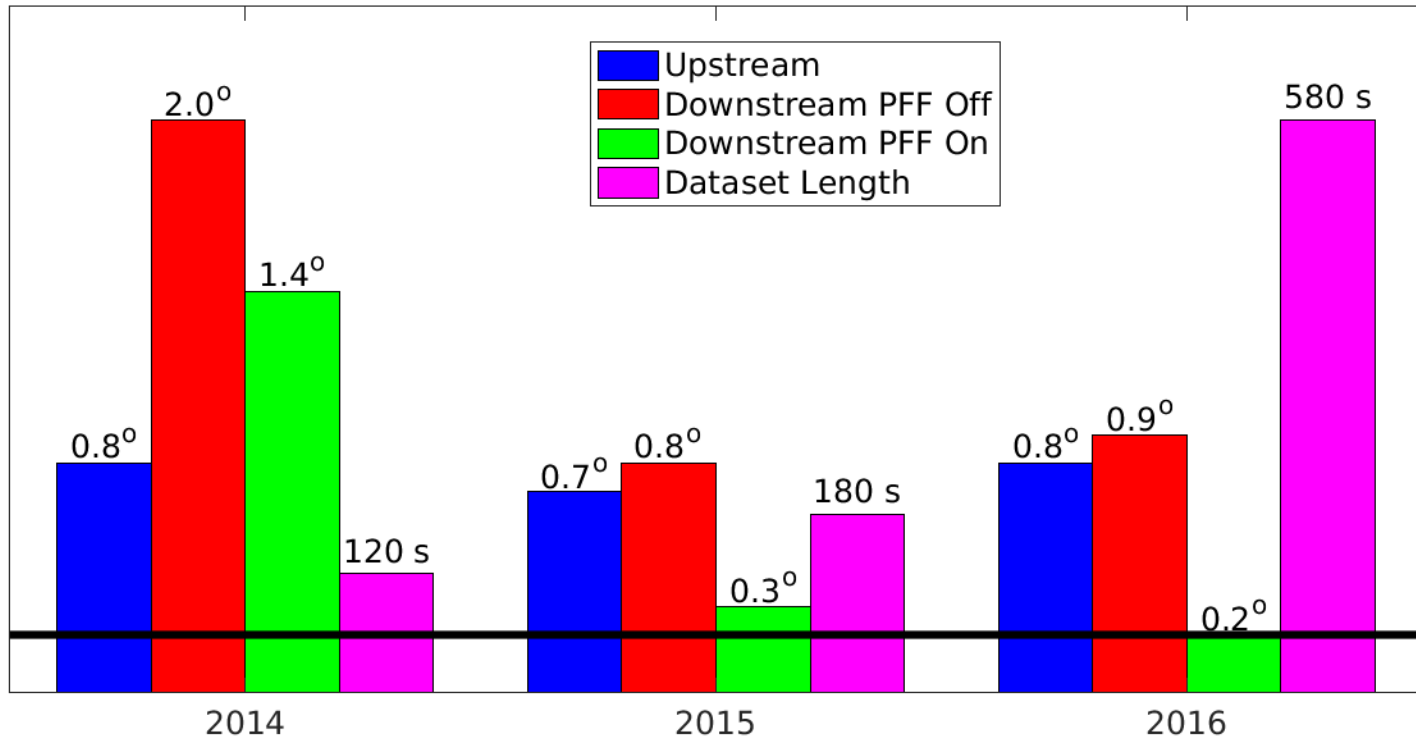


# Correction of Combined Beam

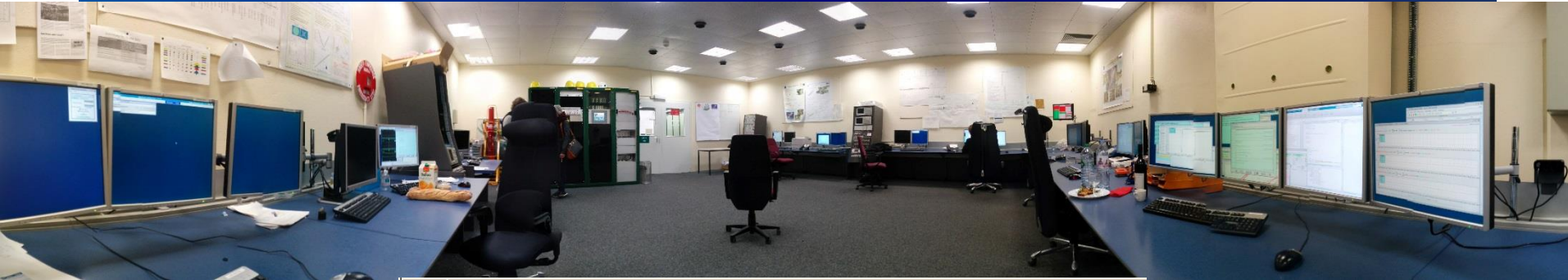
- Up to ~70% correlation between upstream and combined downstream pulse. Can be boosted further by wiggling klystrons.
- Clear correction of mean phase, modest improvement to pulse shape.

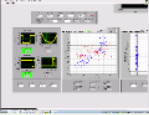
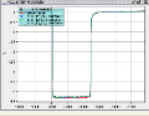
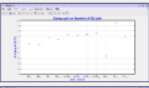




# Summary - Final Status



# Thanks CTF3!



|       |   |
|-------|---|
| 16:53 | Last ever PFF (and CTF?!) dataset! (JR GC RC)<br><br>name: 20161216165303.png<br>desc:   |
| 16:55 | END of CTF3 Operation.<br>Last beam pulse.  |
| 16:59 | <br>name: 20161216170056.png<br>desc:  |
| 17:04 | Data processing of last turns in DL and CR<br><br>name: 20161216170509.png<br>desc:<br><br>name: 20161216170637.png<br>desc: |
| 17:05 | > CTF > CALIFES<br>CALIFES stopping for the last time this year.<br>It will relive as CLEAR next year   |
| 17:10 | > CTF > CALIFES<br>CALIFES STOPPED FOR THE LAST TIME<br>HOPE FOR A CLEAR FUIURE<br>(...)  |
| 17:17 | Klystrons, power supplies off. :-(<br><br>name: 20161216171813.png<br>desc:  |
| 17:22 | I asked the CCC to trip the safety chain a final time before the end of their shift tonight.<br>So long and thanks for all the fish!<br>(FI)  |