Design issues for IP intra-train feedback

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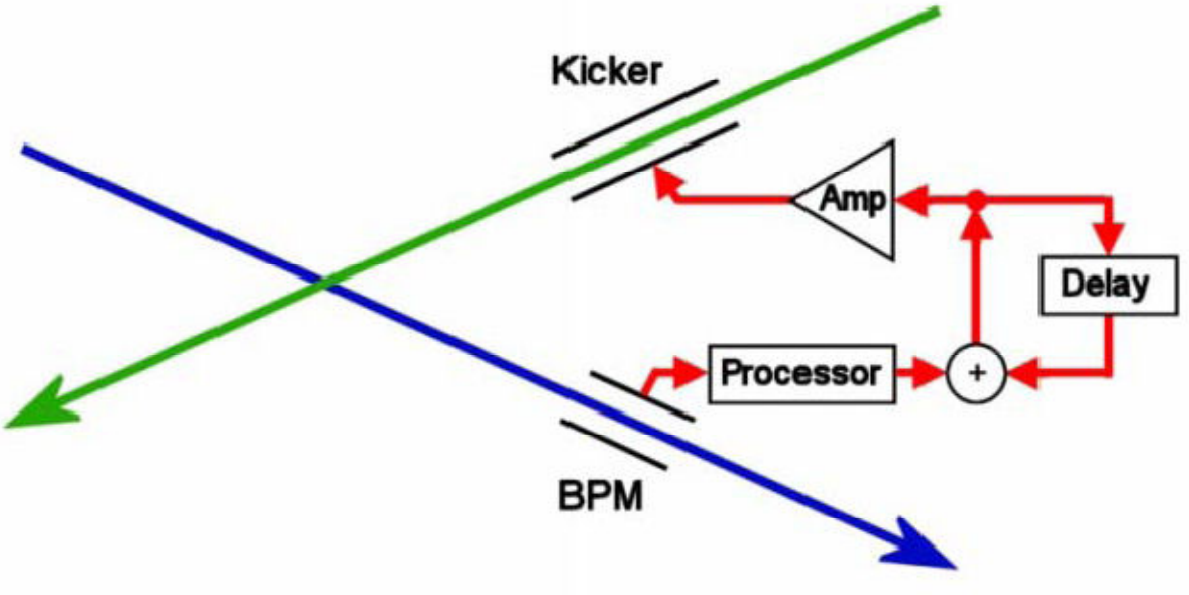
Outline

- General considerations for intra-train feedback system
- ILC RDR layout (comment on simulations)
- Engineering integration issues
- Prototype hardware (FONT systems)
- Summary

IP intra-train feedback system - concept

- Last line of defence against relative beam misalignment
- Measure vertical position of outgoing beam and hence beam-beam kick angle
- Use fast amplifier and kicker to correct vertical position of beam incoming to IR



FONT – Feedback On Nanosecond Timescales

(Oxford, Valencia, CERN, DESY, KEK, SLAC)

General considerations (1)

1. IP position feedback:

hardware located near IP

kicker at 90 degrees w.r.t. IP

2. IP angle feedback:

hardware ideally located near IP

kicker in phase w.r.t. IP

3. Additional possibilities:

(bunch-by-bunch) luminosity scan system (from BEAMCAL)

information from alignment systems (eg. QD0 etc.)

'feed-forward' information from upstream in machine (eg. DR)

…

General considerations (2)

Time structure of bunch train:

ILC (500 GeV): **c. 3000 bunches w. c. 300 ns separation**
CLIC (3 TeV): **c. 300 bunches w. c. 0.5 ns separation**

Feedback latency:

ILC: O(100ns) latency budget allows digital approach
CLIC: O(10ns) latency requires analogue approach

Recall speed of light: c = 30 cm / ns:

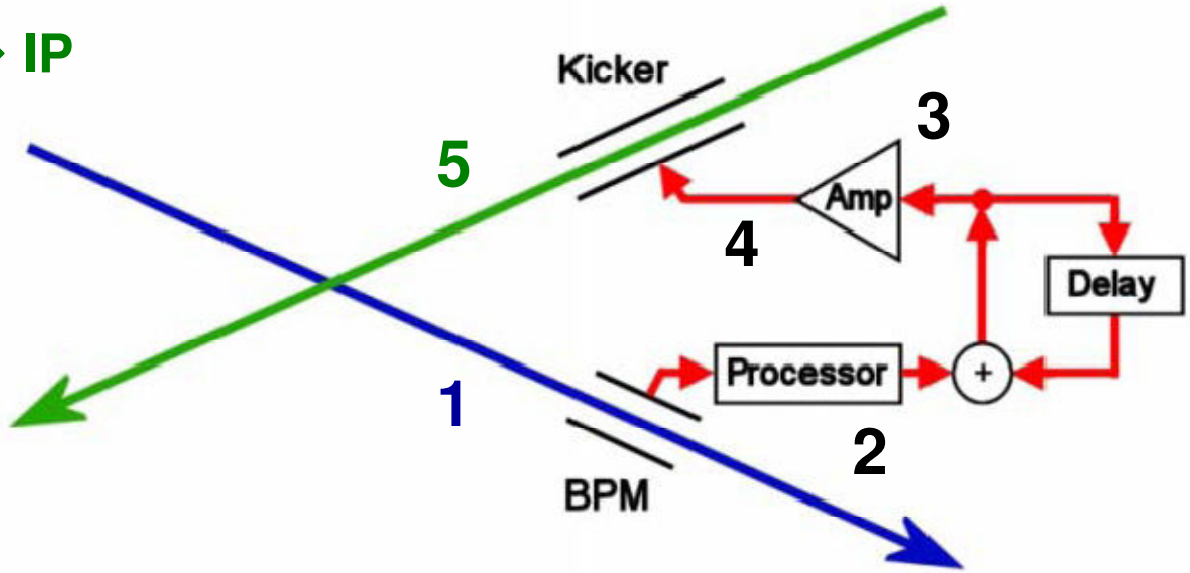
FB hardware should be close to IP (especially for CLIC!)

IP position feedback latency

Designed for (bunch-by-bunch) position correction of beams at IP

Latency:

1. **Beam flight time IP → BPM**
2. **Signal processing, FB calculation**
3. **Amplifier + kicker response time**
4. **Cable delays**
5. **Beam flight time kicker → IP**



Latency issues

- **BPM or kicker further from IP**
  - **→ longer beam flight distance**
  - **→ increase latency (3ns per metre)**
- **Electronics further from beamline**
  - **→ longer cable runs**
  - **→ increase latency (4-5ns per metre)**
- **FB system electronics latency**

ILC RDR Design (schematic)

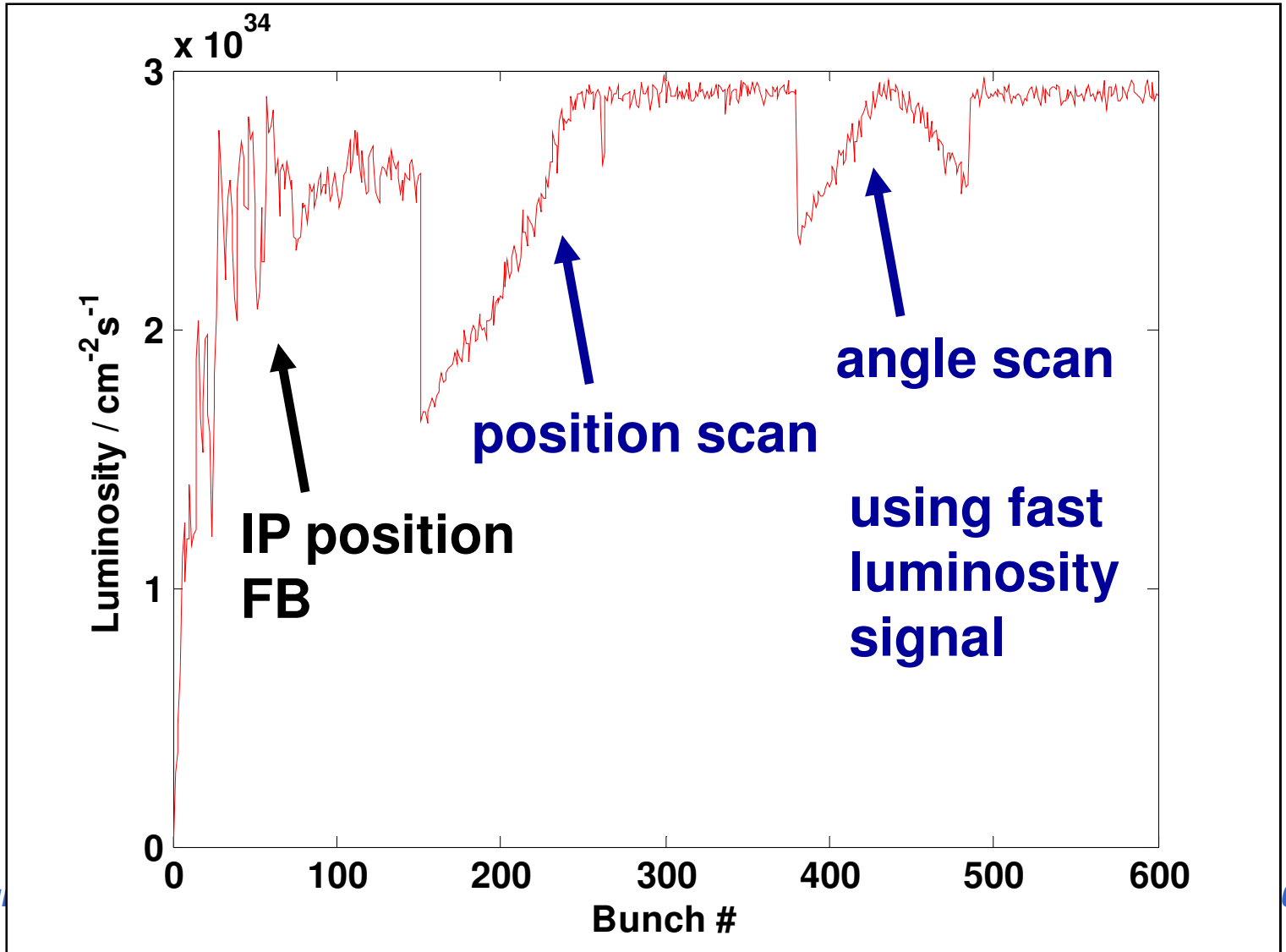
1. IP position feedback:
   provide IP beam position correction at +- 50 sigma_y level
   i.e. +- 300 nm of vertical beam motion at IP

2. IP angle feedback: hardware located few 100 metres upstream
   conceptually very similar to position FB, (arguably) less critical

3. Bunch-by-bunch luminosity signal (from BEAMCAL)

   'special' systems requiring dedicated hardware + data links

IP intra-train FB performance (White)



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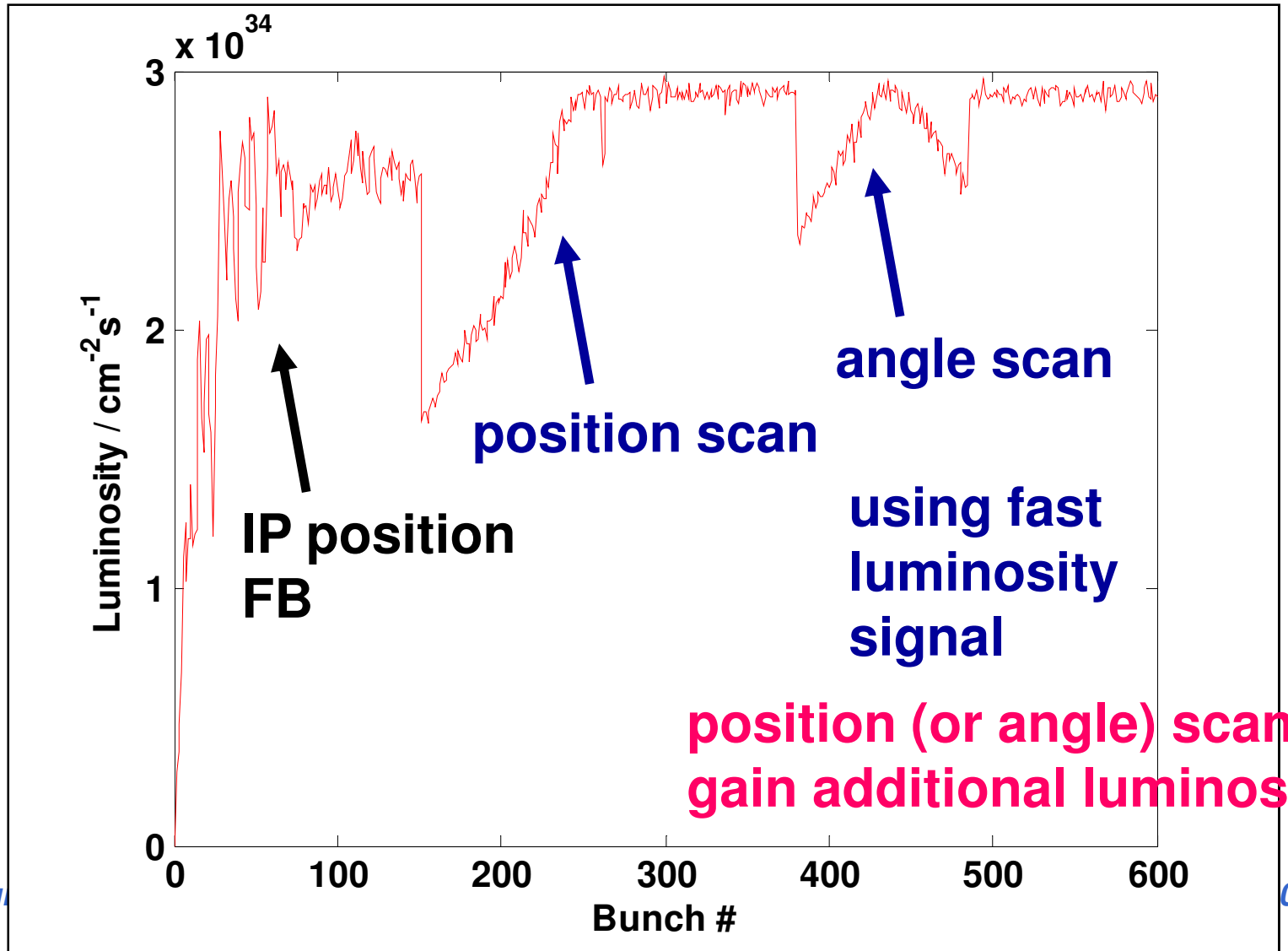
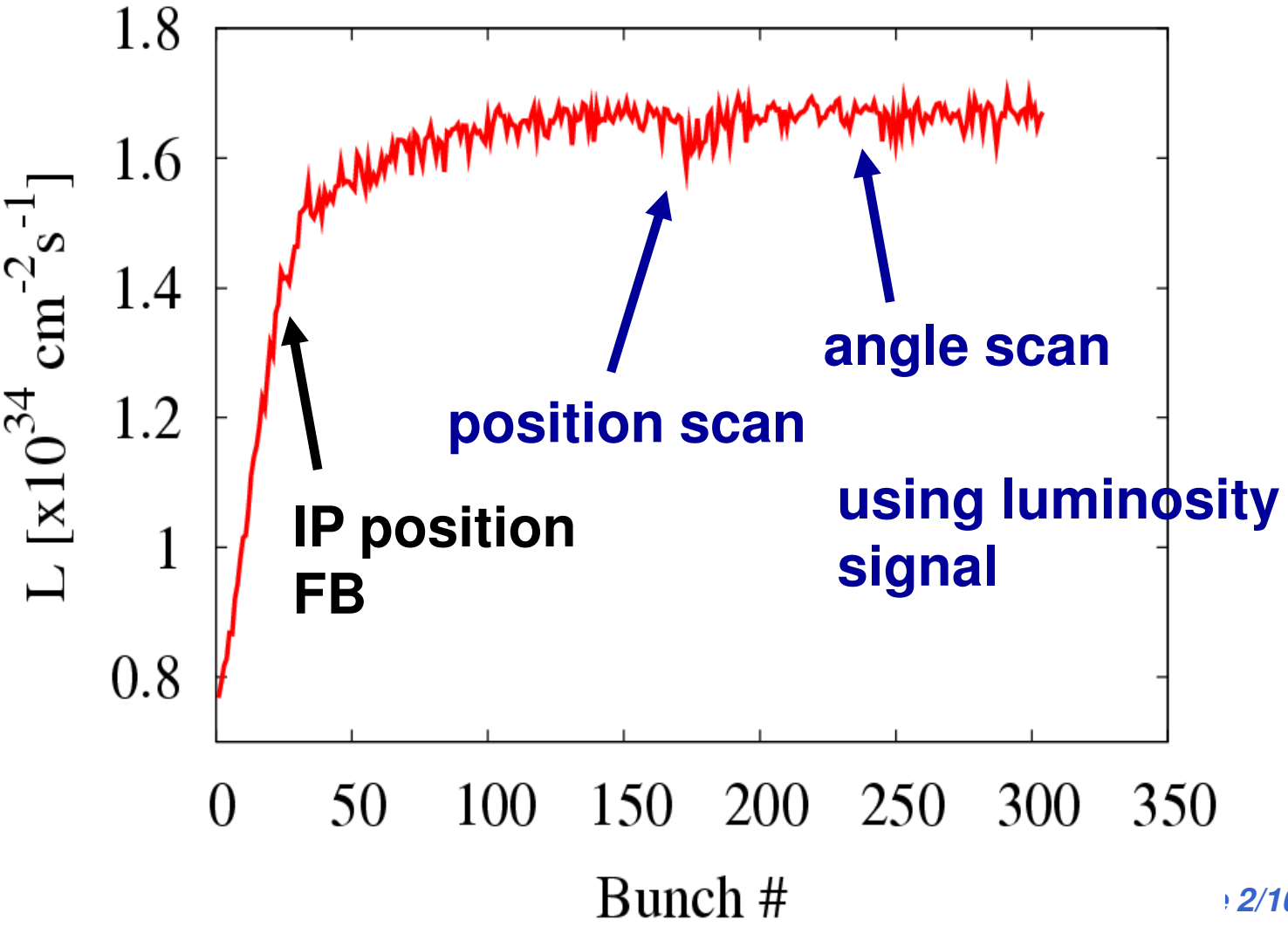
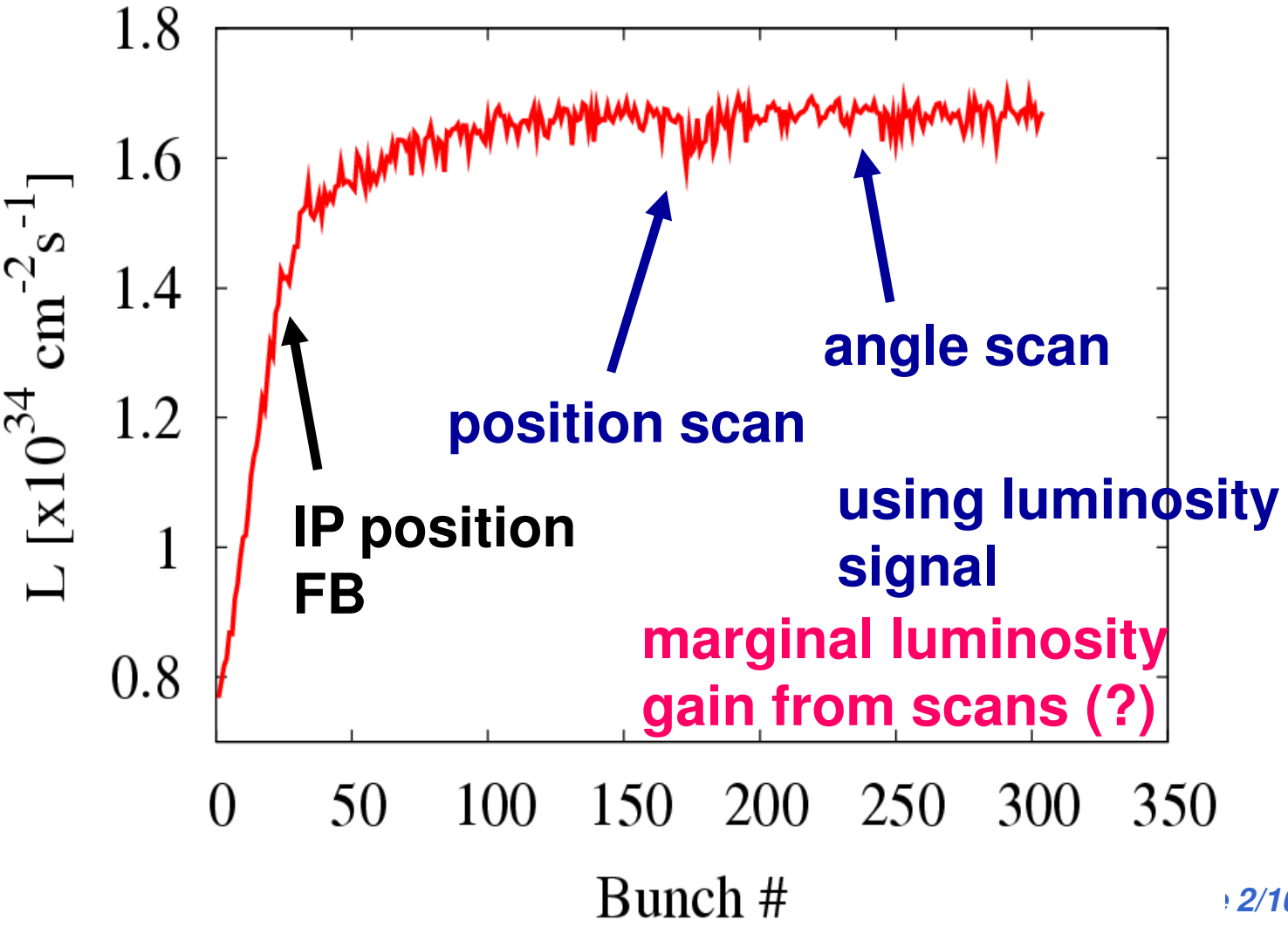


IP intra-train FB performance (Lopez)



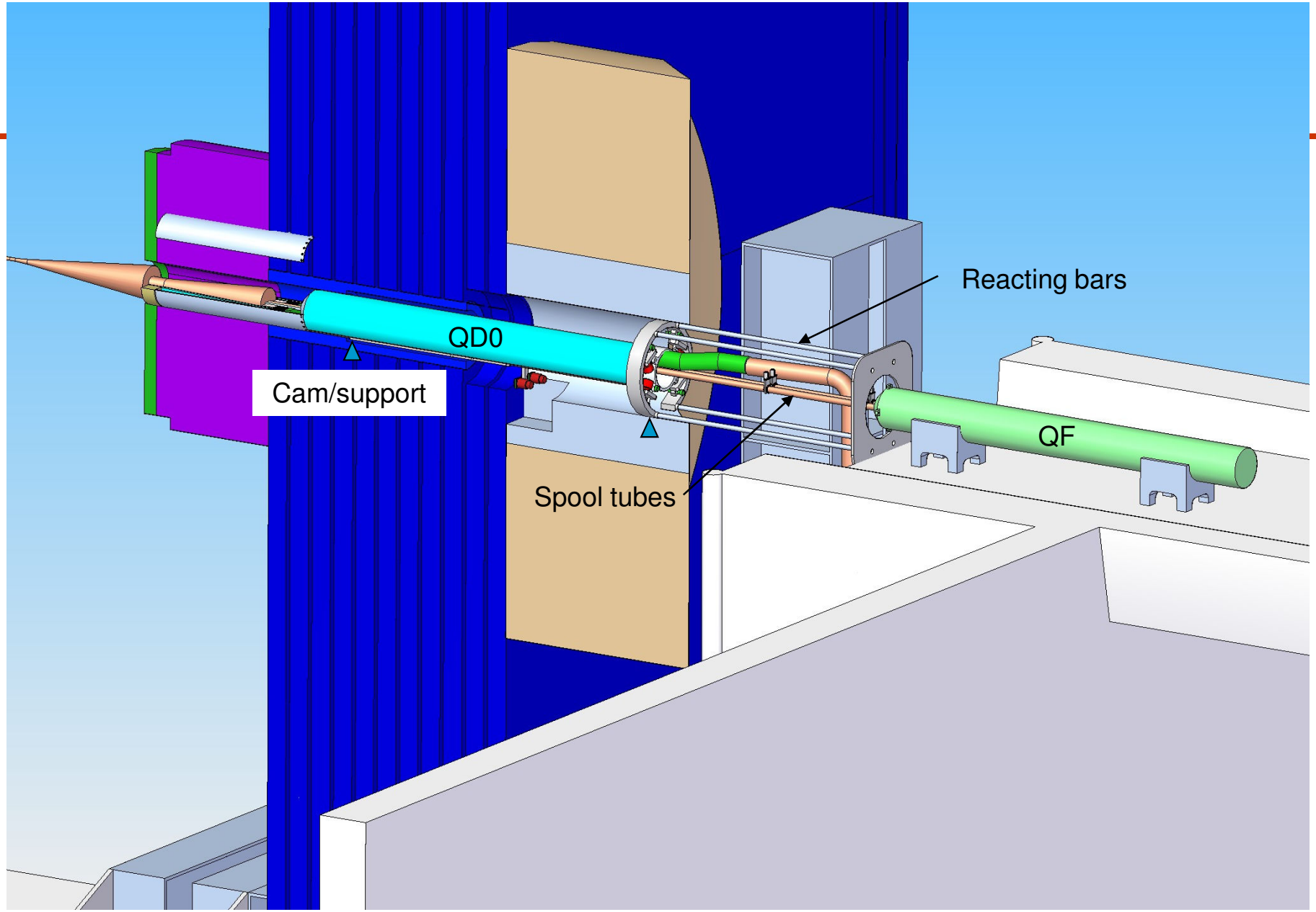
IP intra-train FB performance (Lopez)



IP feedback engineering considerations

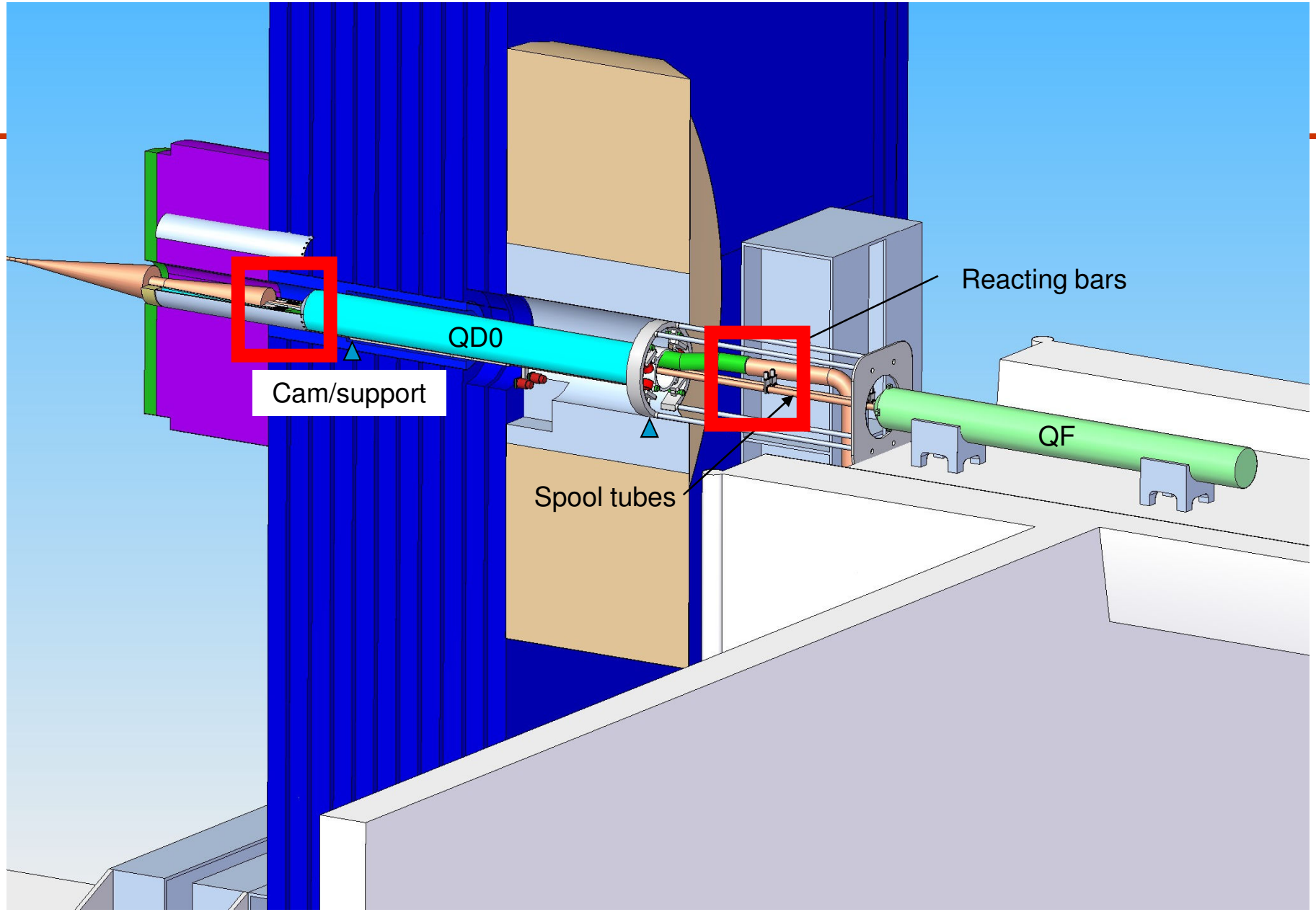
System component locations + specs listed in ILC RDR

Final Doublet Region (SiD for illustration) - Oriunno



Opening 2 m on the beam

Final Doublet Region (SiD for illustration) - Oriunno



Opening 2 m on the beam

IP feedback engineering considerations

System component locations + specs listed in ILC RDR

No detailed engineering work done in terms of:

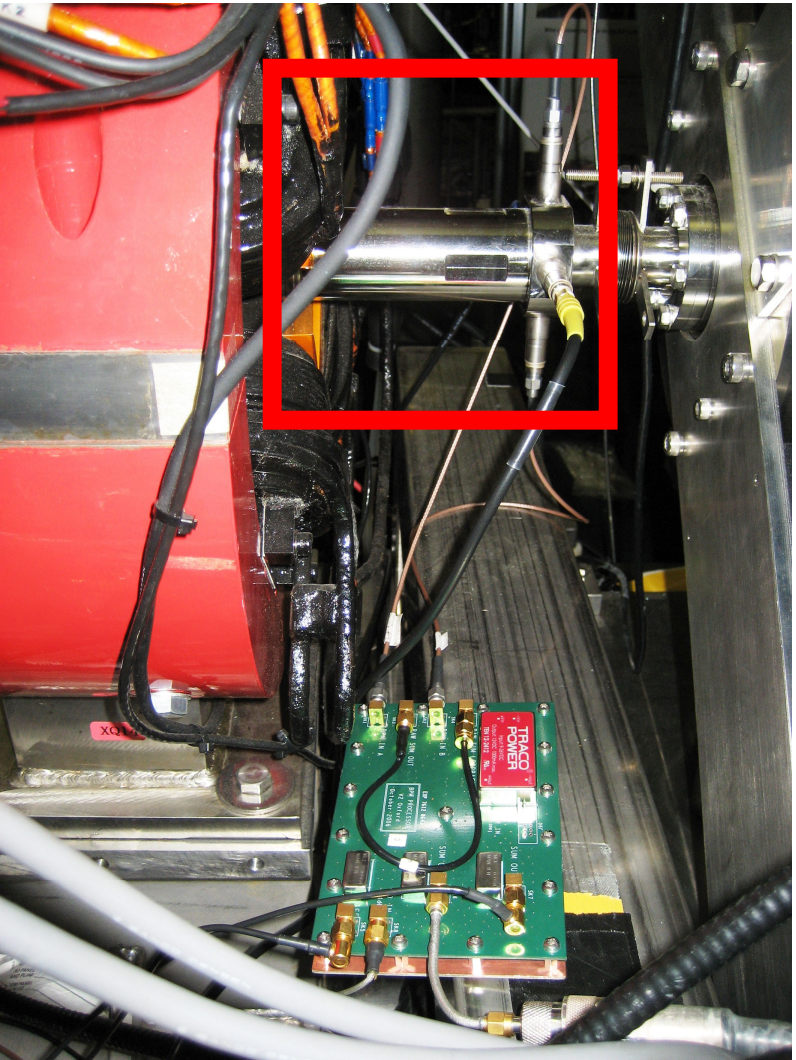
- **actual designs of BPM and kicker**
- **integration into beamline design**

However, components are envisaged to be 'standard':

- **Stripline BPM c. 10-20cm long (ATF: 12.5cm)**
- **Stripline kicker c. 30-60cm long (ATF ~ 30cm)**
- **Stripline radius c. 1-2cm (ATF ~ 1cm)**

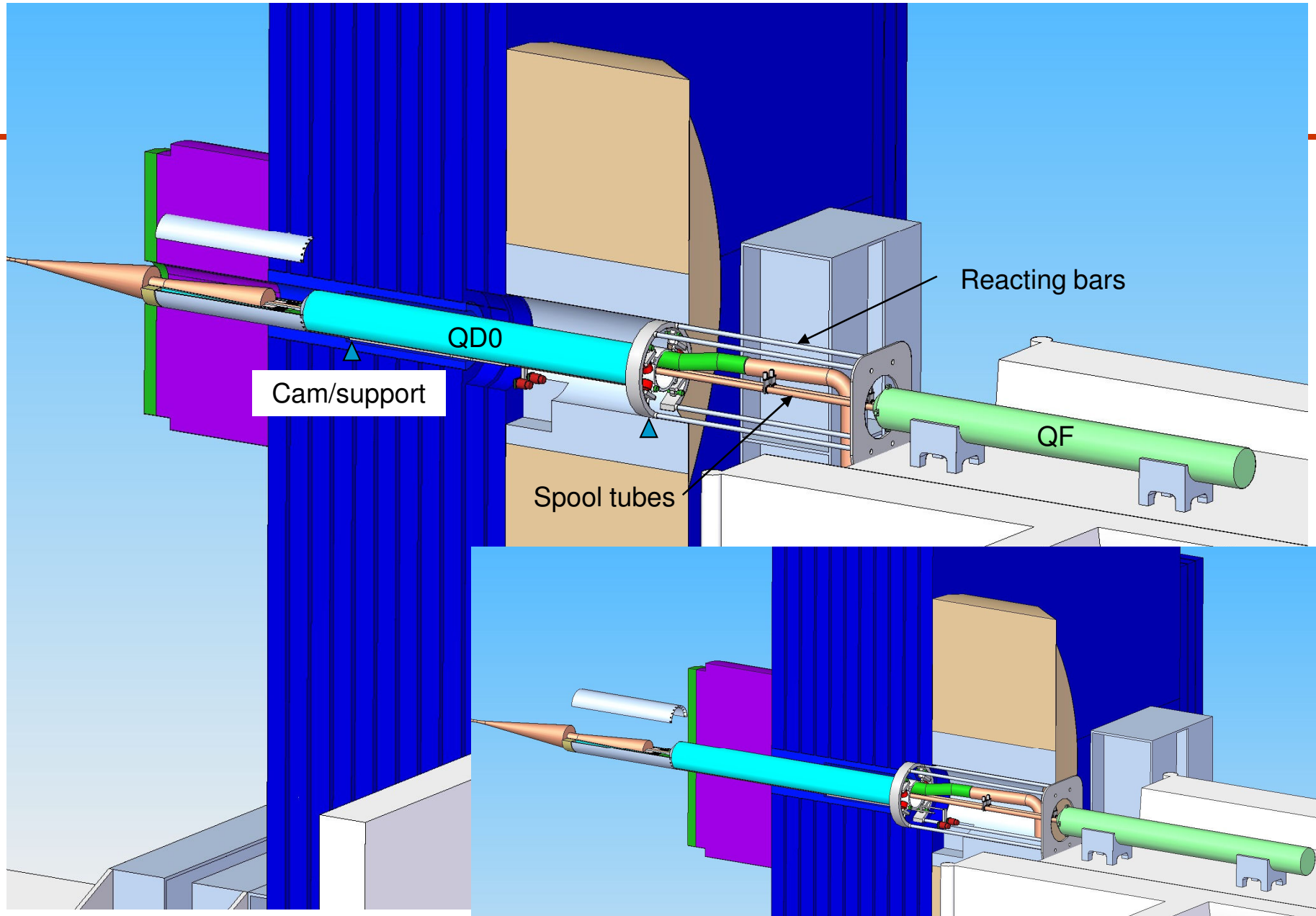
Probably want to customise designs to fit into tight beamline environment

BPM engineering issues

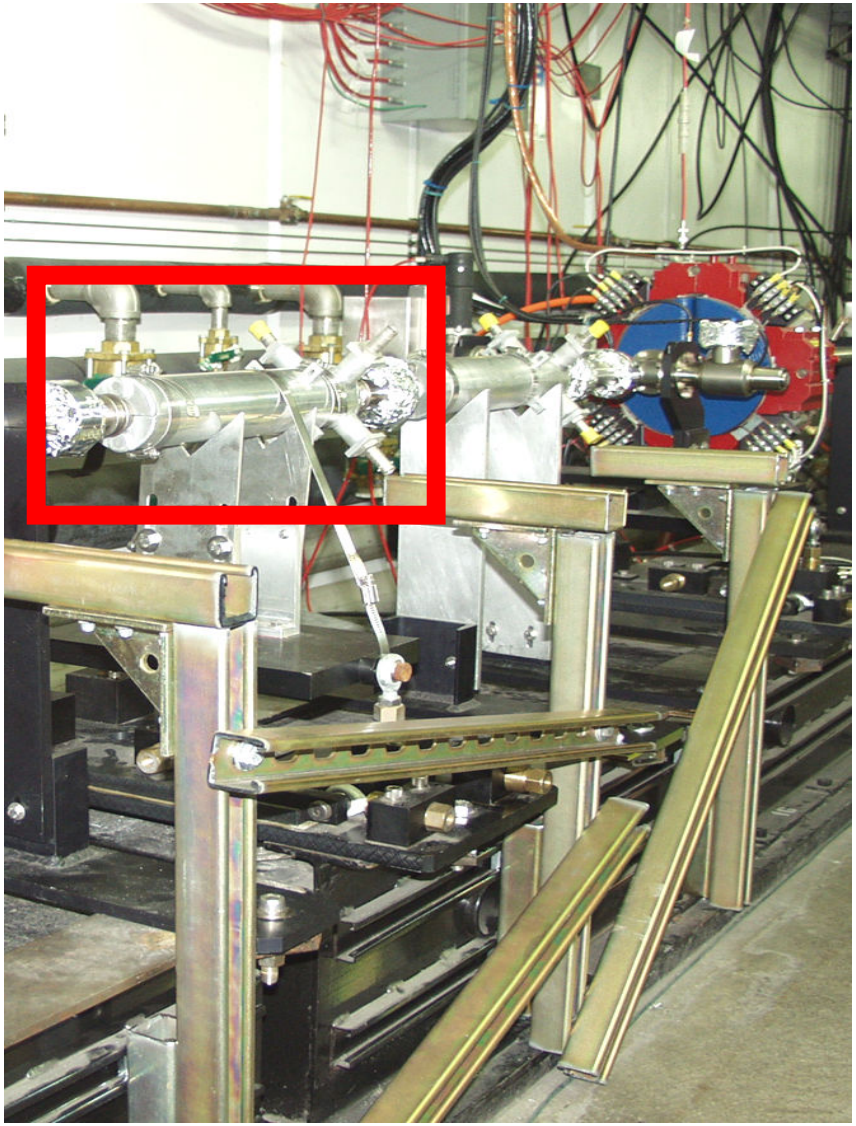


- Connections to BEAMCAL, QD0 cryostat?
- Bellows, at both ends?
- Shorten pickoffs?
- Electronics off to side and shielded?
- Define cable runs: door opening, push-pull?

Final Doublet Region (SiD for illustration) - Oriunno



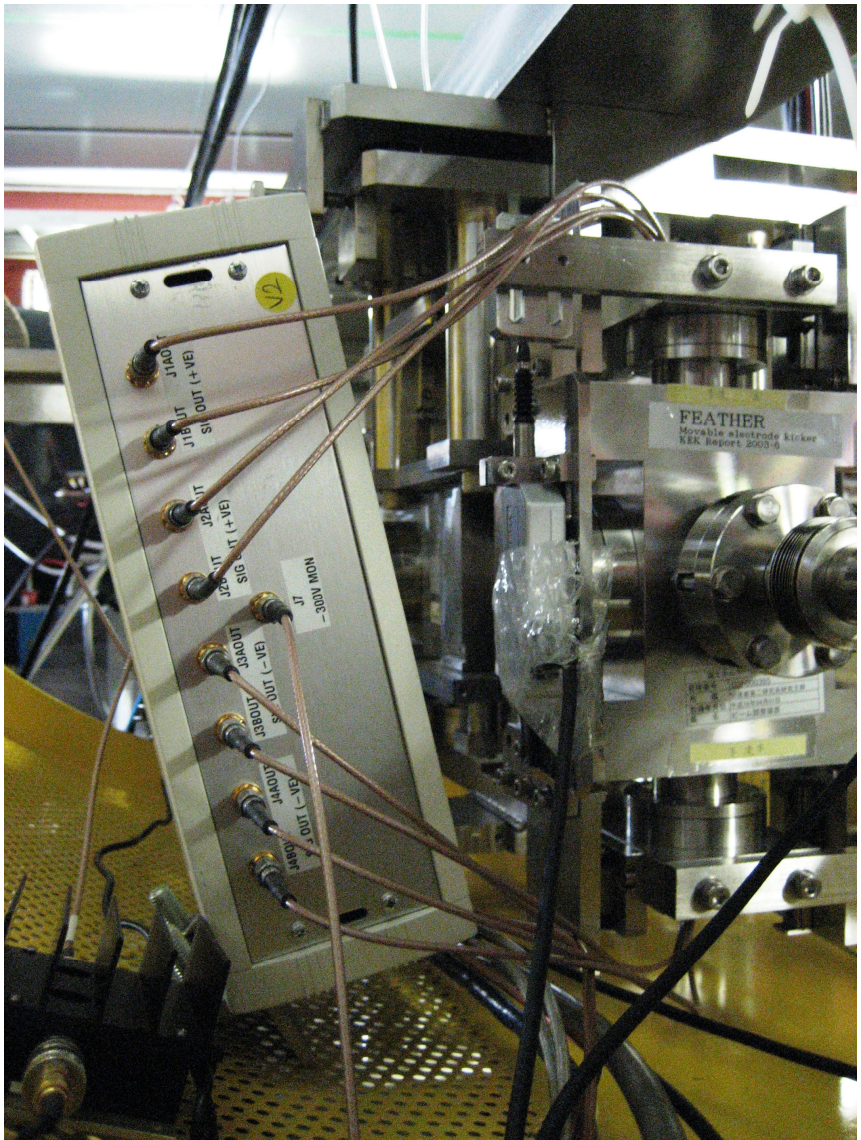
Kicker engineering issues



Real-estate more generous

- **Does warm section move with detector in push-pull?**
- **Amplifier detector-side or machine-side of break?**
- **Flanges, bellows, at both ends?**
- **Shorten pickoffs?**

Amplifier engineering issues



FONT4 amplifier performance:

Kicker 30cm long, 2cm aperture, 1kW drive

100 nrad deflection (250 GeV beam)

lever arm 4m

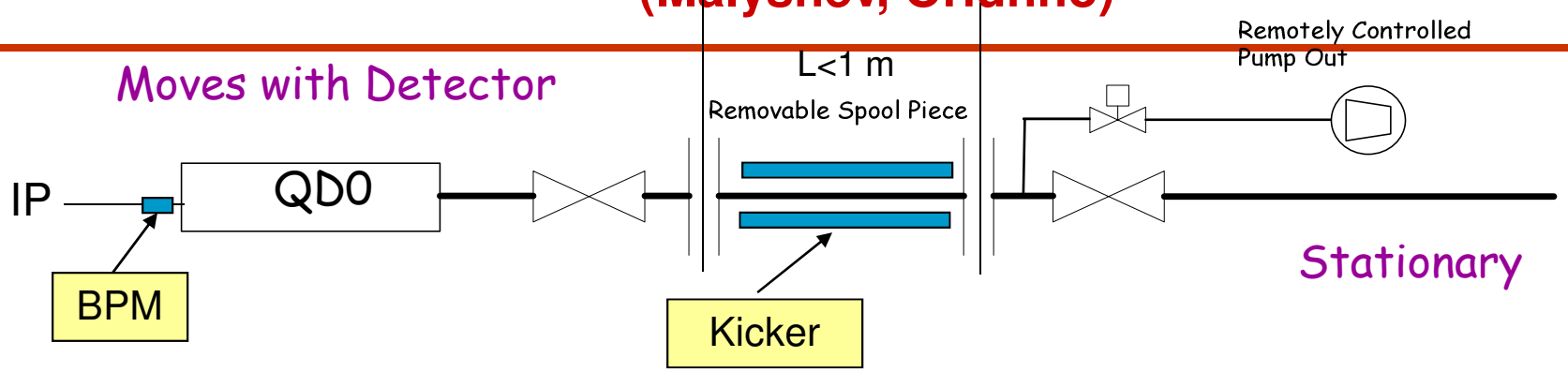
+- 400 nm at IP

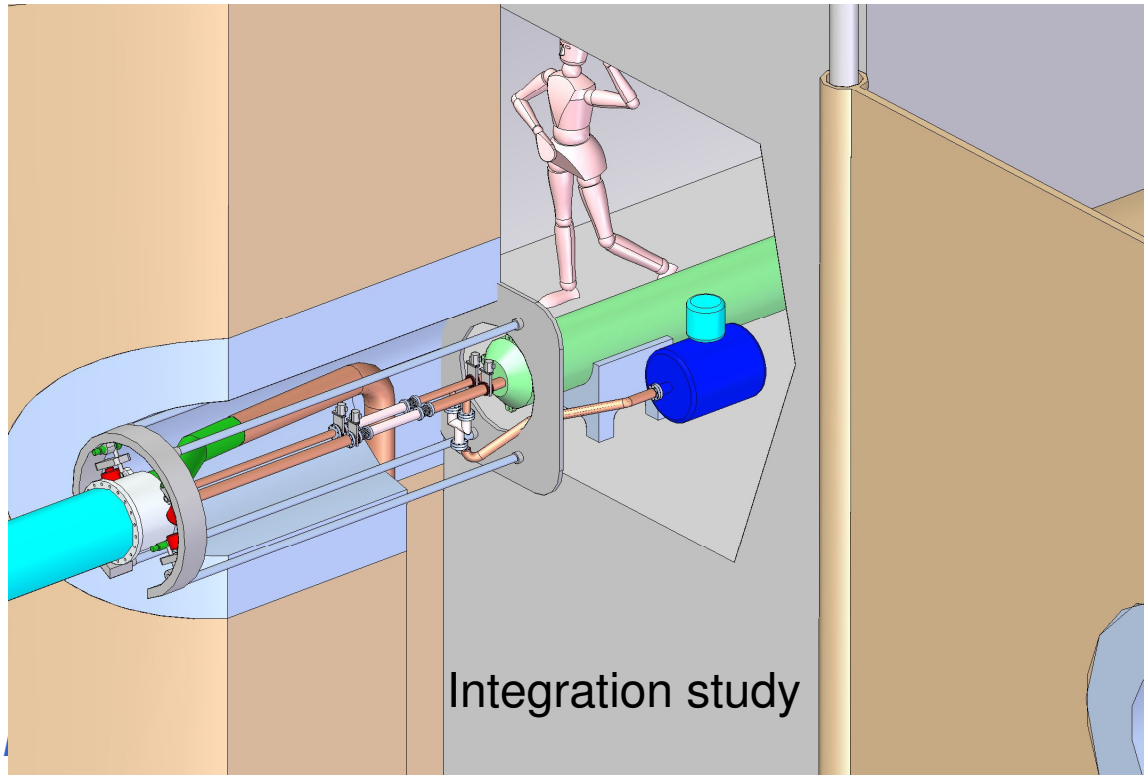
(> 50 sigma_y)

Kick ~ I, 1/r, sqrt(P), 1/p …

Feedback Instrumentation & Vacuum Design

(Malyshev, Oriunno)





Present vacuum requirements :

P < 1nT in the BDS

P < 100nT in the experimental region

•We may rely on the cryopumping from QD0

•We do not need extra pumps

•We do not need periodic bake out *in situ.*

Open point :

•The beam instrumentation required

•Shut-off valves

Summary of engineering issues

Several prototype intra-train feedbacks developed by FONT – see next

Detailed mechanical/integration engineering needs to be done for ILC and more work on conceptual design for CLIC

Radiation environment for BPM electronics, feedback electronics, kicker amplifier:

radiation tolerance, locations, shielding …

EM interference:

Pickup on BPM or kicker

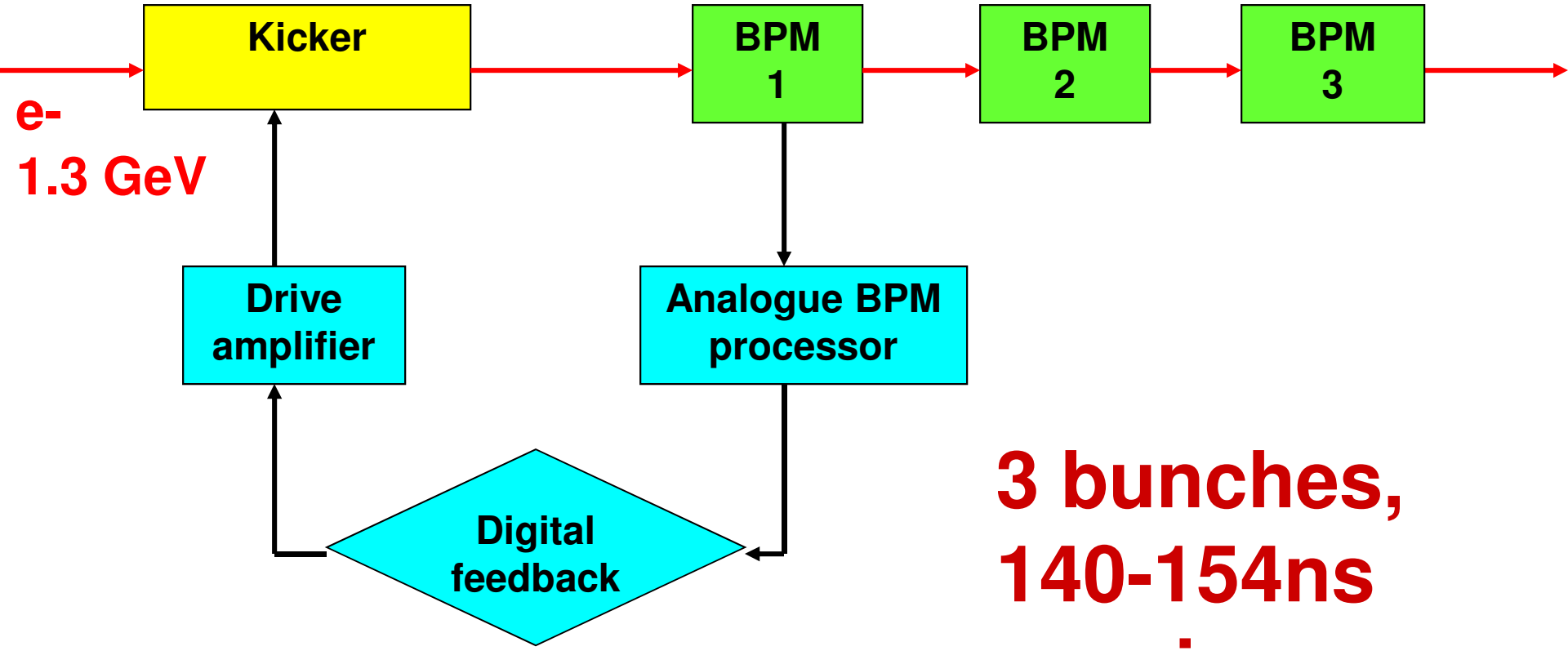
Broadcast RF (eg. to detector!)

Ground loops

Interface to BEAMCAL for luminosity scan system

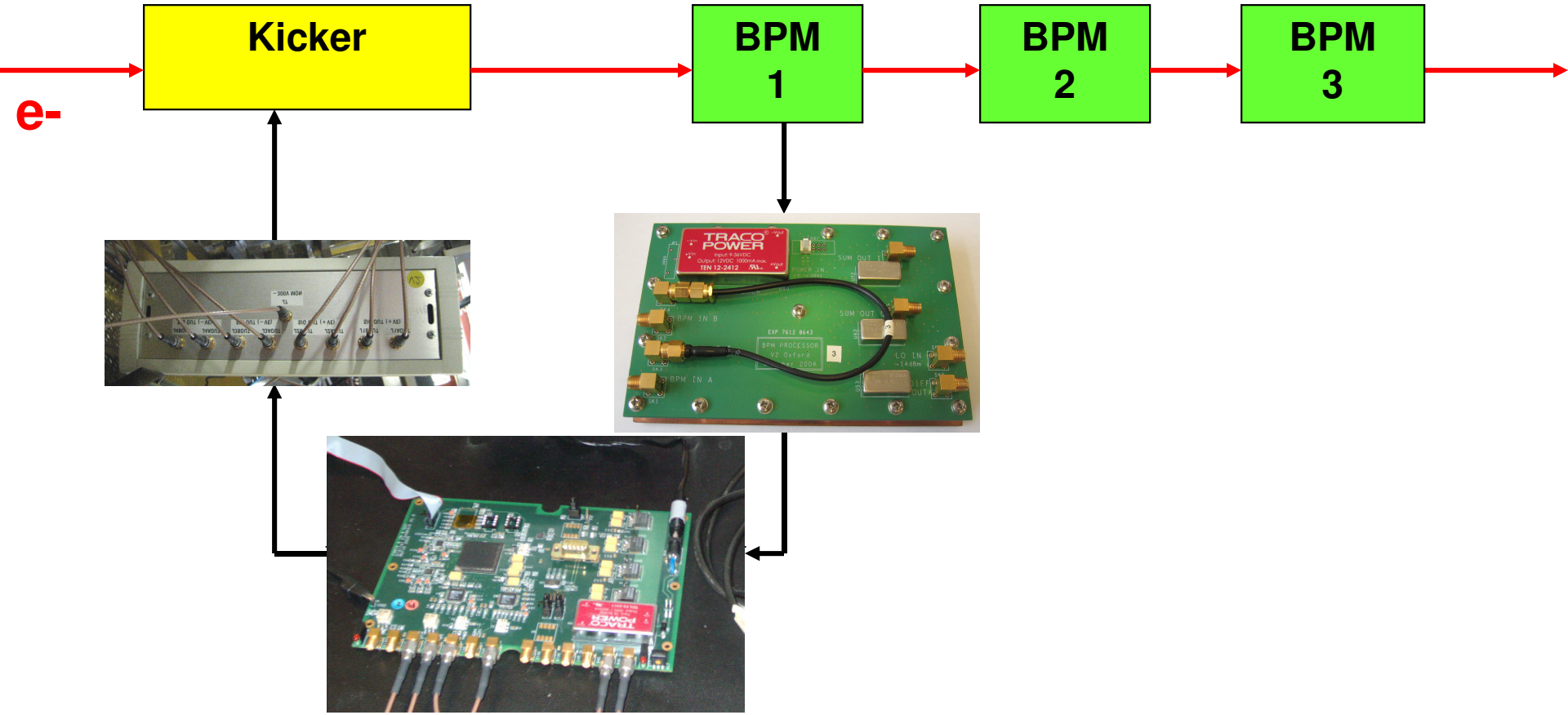
ILC feedback prototype status

FONT4 ILC prototype at KEK/ATF



3 bunches, 140-154ns spacing

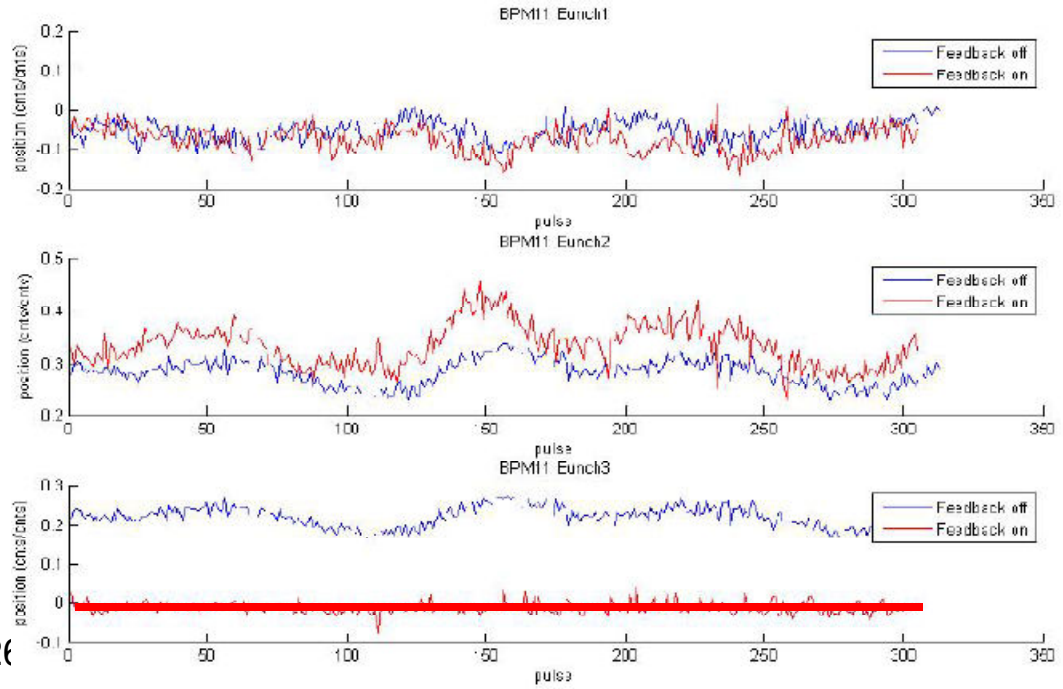
FONT4 ILC prototype at KEK/ATF



FONT status

- **FONT4 basic operation demonstrated in 2008 running:**

  beam feedback along single axis (y) with few micron resolution

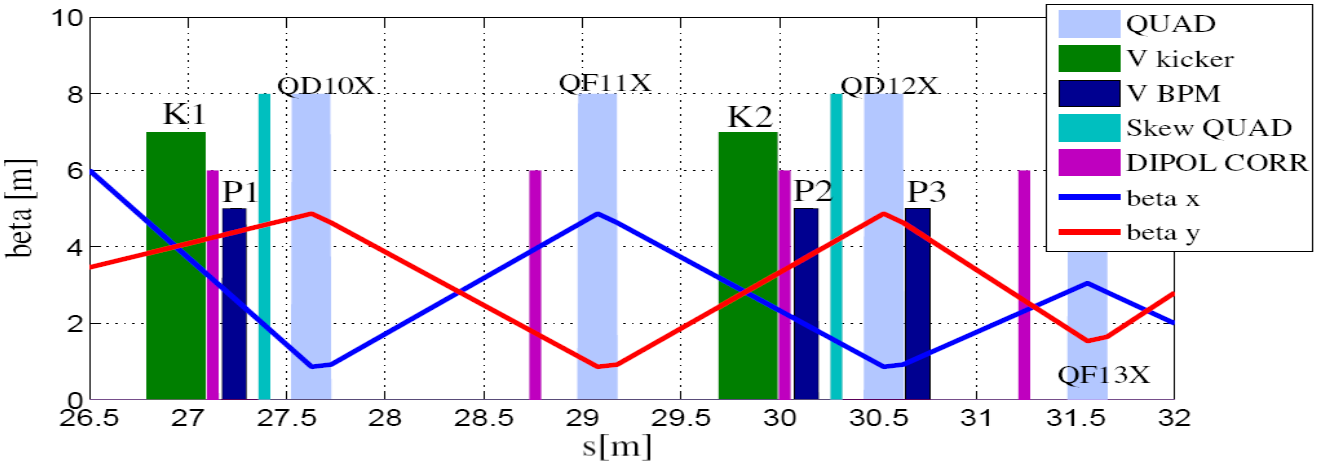


FONT operations in 2009

- **FONT4 installation was dismantled when ATF extraction line was reconfigured late 2008**

ATF2 FB system

Dedicated system:



- **2 stripline kickers + fast drive amplifiers**
- **3 stripline BPMs + fast analogue front-end electronics**
- **9-channel digital FB processor**

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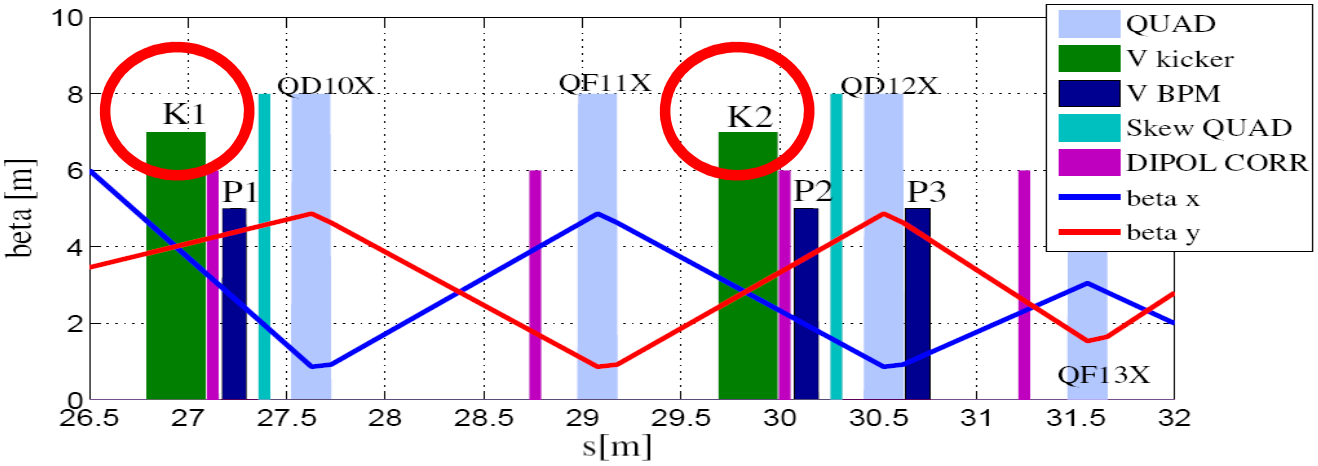

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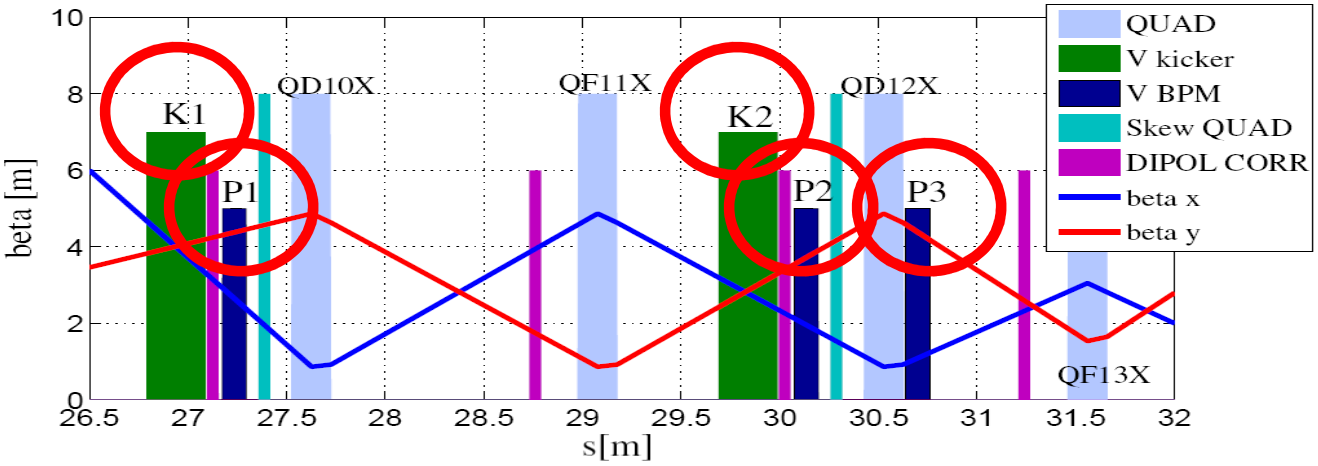

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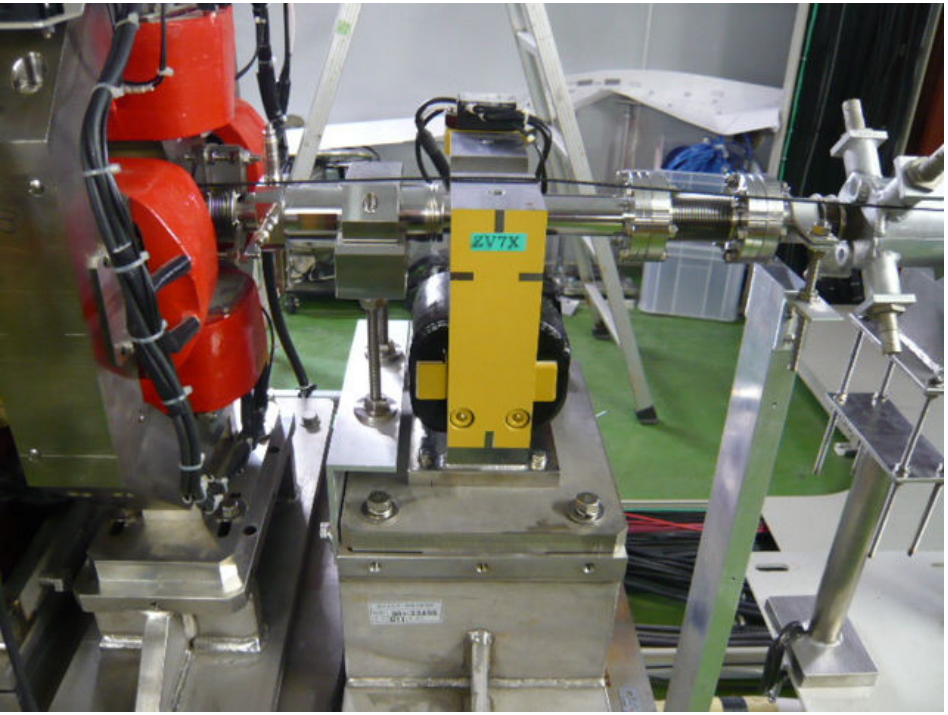
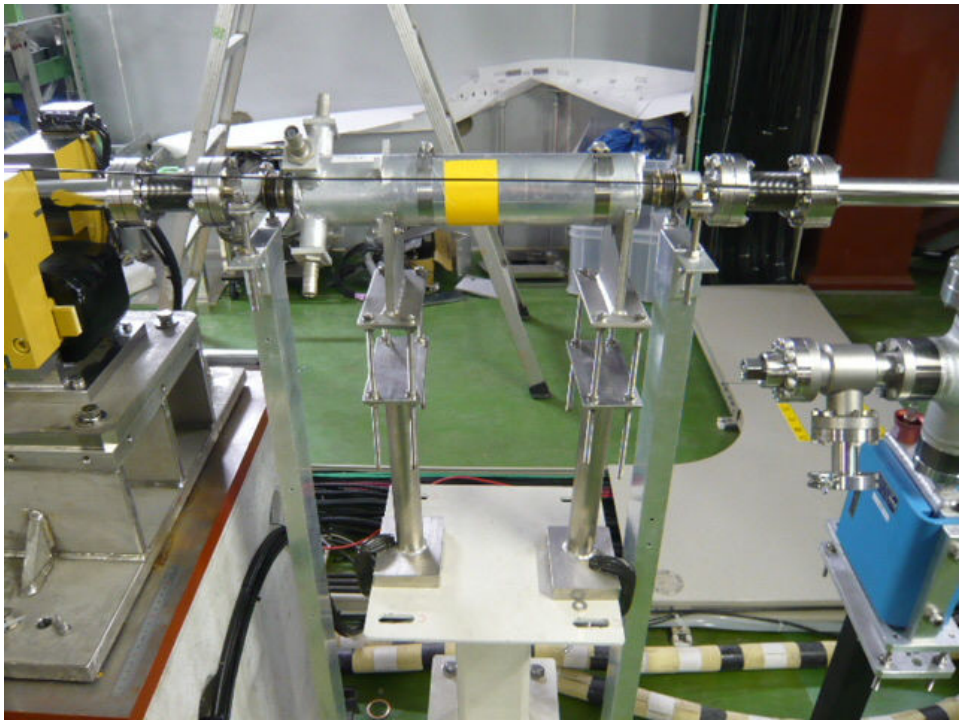
FONT operations in 2009

- **FONT4 installation was dismantled when ATF extraction line was reconfigured late 2008**
- **3 new BPMs and 2 new kickers installed in new ATF2 extraction line week of February 9**

New FONT ATF2 hardware

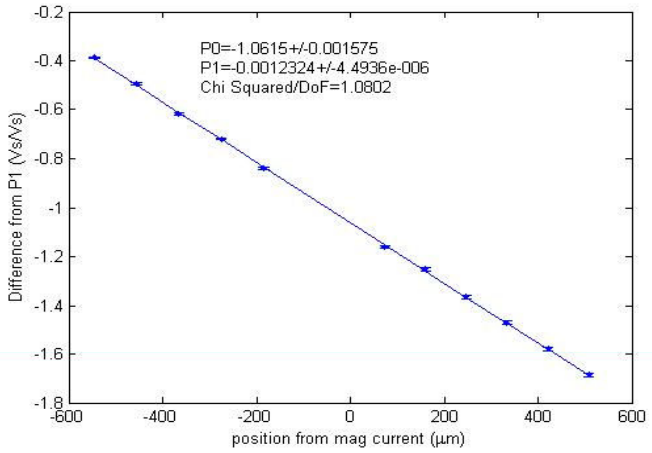


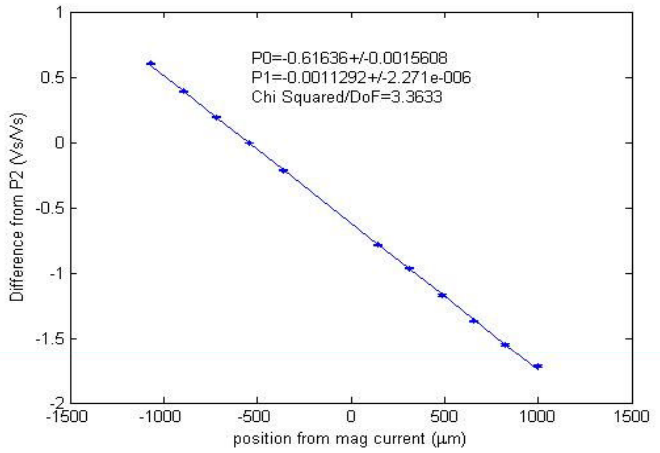


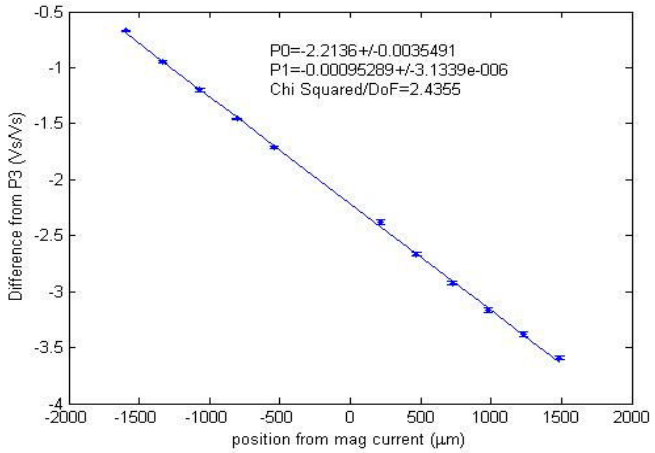
FONT operations in 2009

- FONT4 installation was dismantled when ATF extraction line was reconfigured late 2008
- 3 new BPMs and 2 new kickers installed in new ATF2 extraction line week of February 9
- Main aims:
  1) commission new BPMs and kickers (digital DAQ)
  2) work on improved resolution → 1 um level
  3) understand beam dynamics in FONT region
- Much commissioning work done parasitically - now have FONT 'standalone' hardware
- We typically requested 1 shift per week March - May, and took a total of 5 or 6 shifts

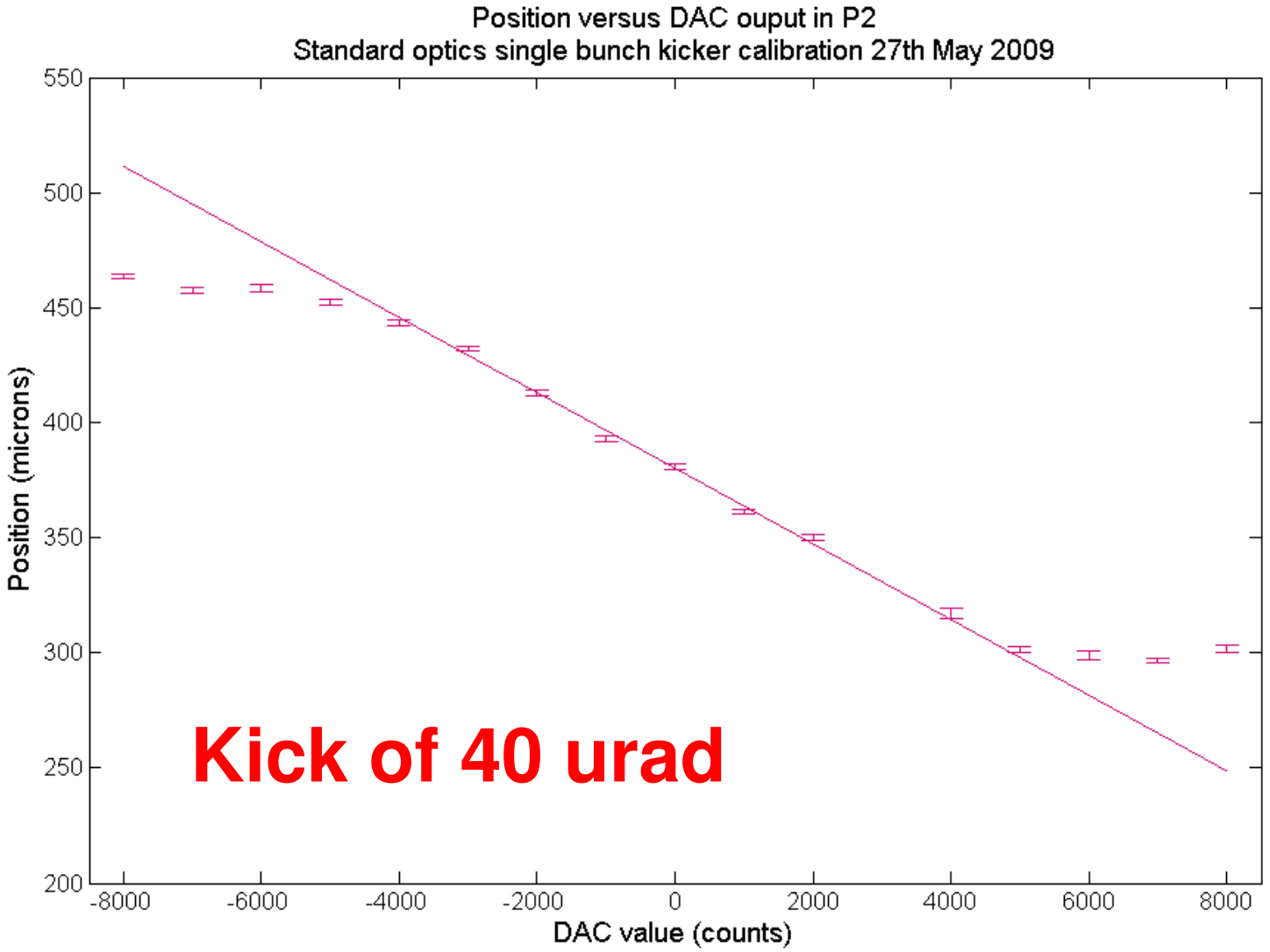
Example: BPM calibrations



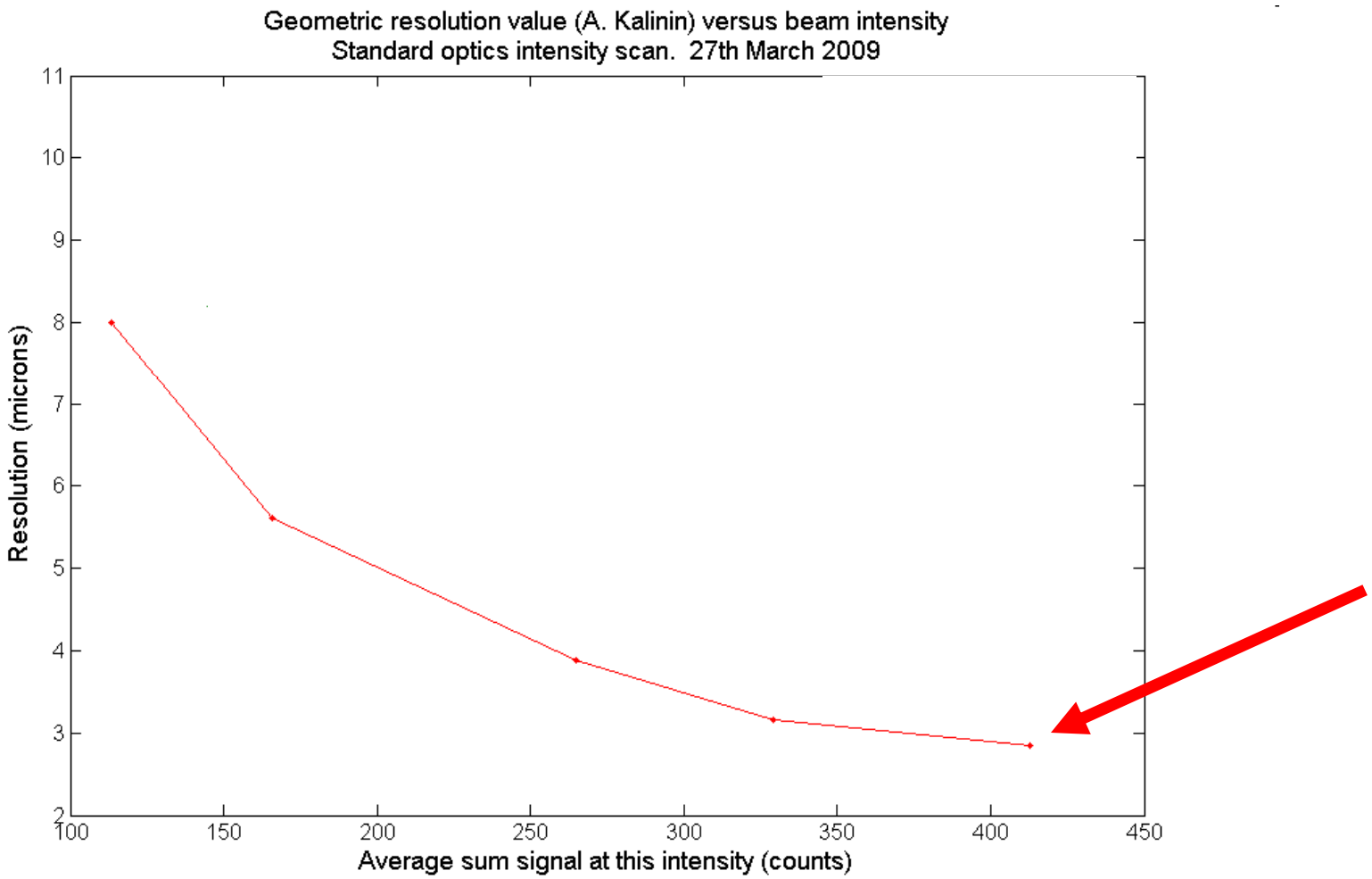




Example: kicker calibration



Example: resolution vs. bunch Q



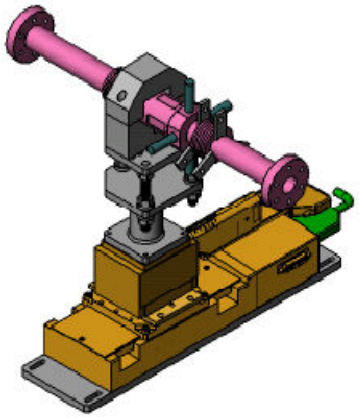
FONT plans for rest of 2009

- **New FONT5 9-channel FB/FF board (y, y') has been assembled: bench tests in Oxford now**

  ready for beam tests November

- **New FONT BPM movers built by Valencia: 1st ready for installation (early October) – can be commissioned without beam**

Valencia Mover



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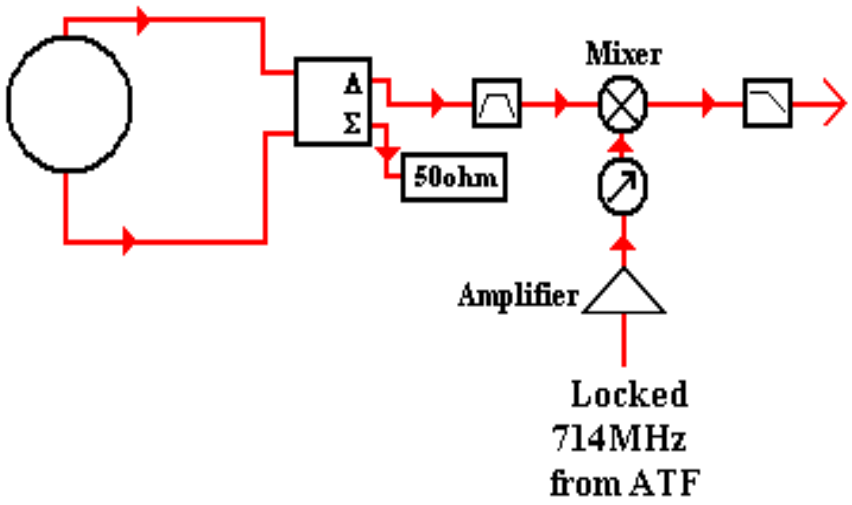
- New FONT5 9-channel FB/FF board (y, y') has been assembled: bench tests in Oxford now

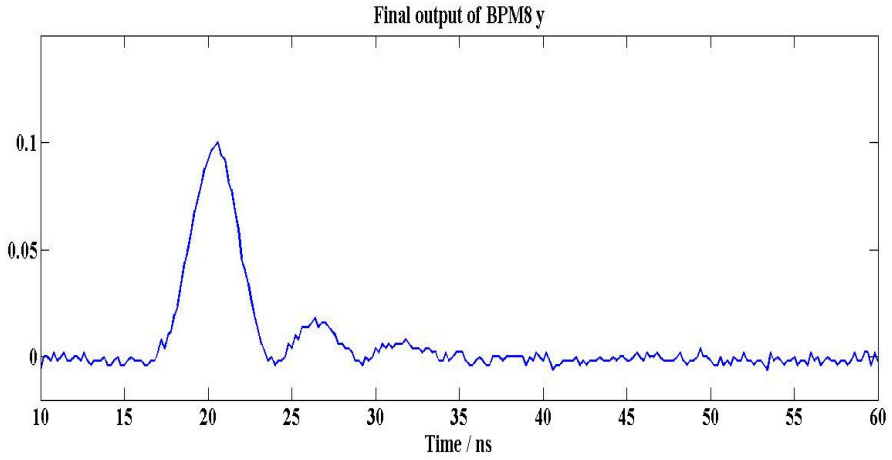
  ready for beam tests November
- New FONT BPM movers built by Valencia: 1st ready for installation (early October) – can be commissioned without beam
- Replace the LO-based BPM processor

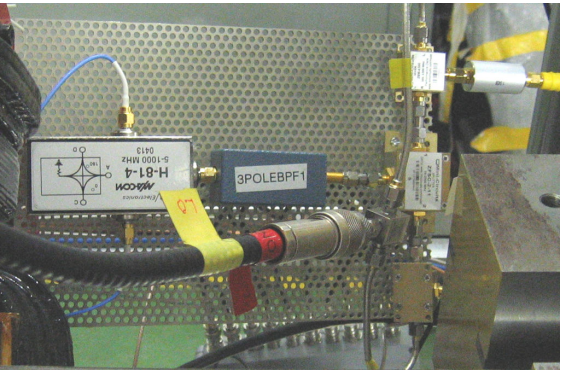
  with a 'baseband' scheme: preliminary design; first tests late 2009 / early 2010
- Commission 3-bunch train mode

Extra material

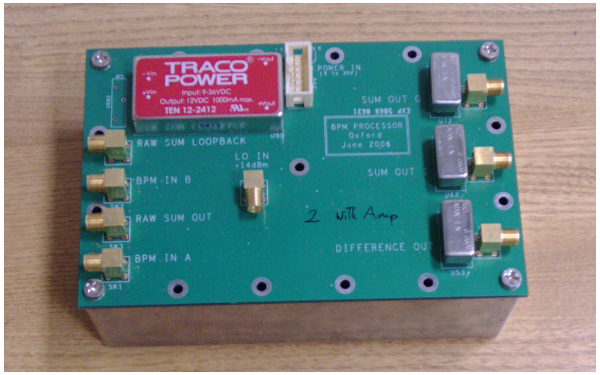
BPM processor



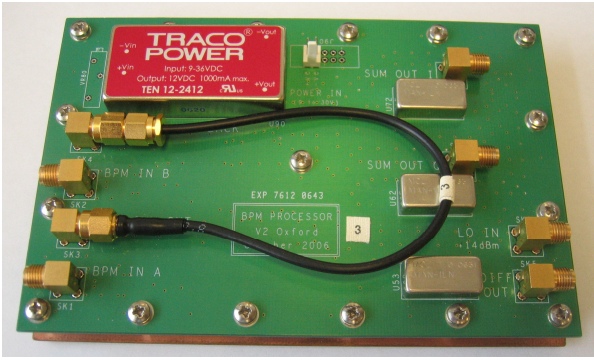




2005

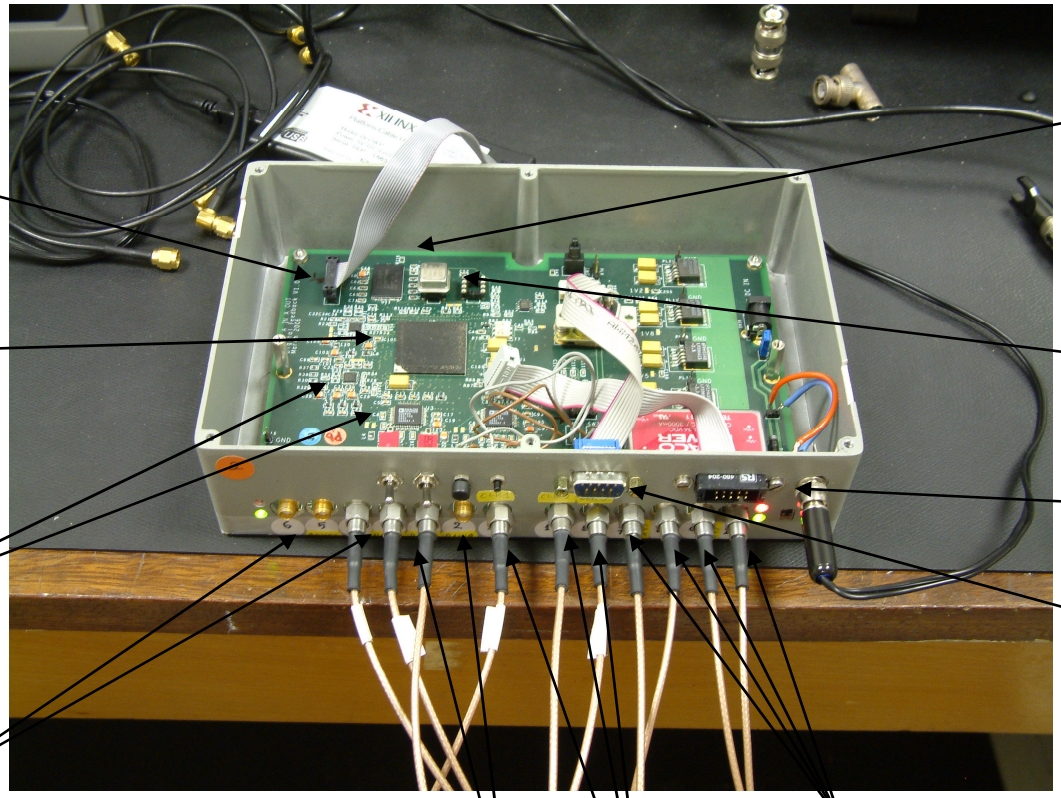


2006



2007

Digital Feedback Board



Kicker driver amplifier

Specifications:

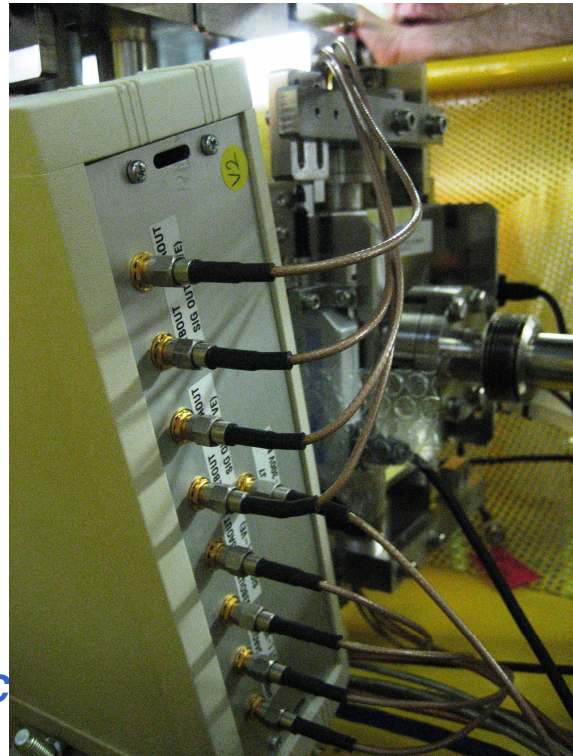
- **+- 15A (kicker terminated with 50 Ohm)**
- **+- 30A (kicker shorted at far end)**
- **35ns risetime (to 90%)**
- **pulse length 10 us (specified for 20-60 bunches)**
- **repetition rate 10 Hz**

Outline design done in Oxford

Order placed with TMD Technologies Sept 06

Two prototype units delivered Dec 06

Tested numerous times with beam in 2007 and 2008



Latency estimate

- Time of flight kicker – BPM: 4ns
- Signal return time BPM – kicker: 10ns

  Irreducible latency: 14ns

- BPM processor: 10ns
- ADC/DAC (3.5 89 MHz cycles) 40ns
- Signal processing (9 357 MHz cycles) 28ns
- FPGA i/o 3ns
- Amplifier 35ns
- Kicker fill time 3ns

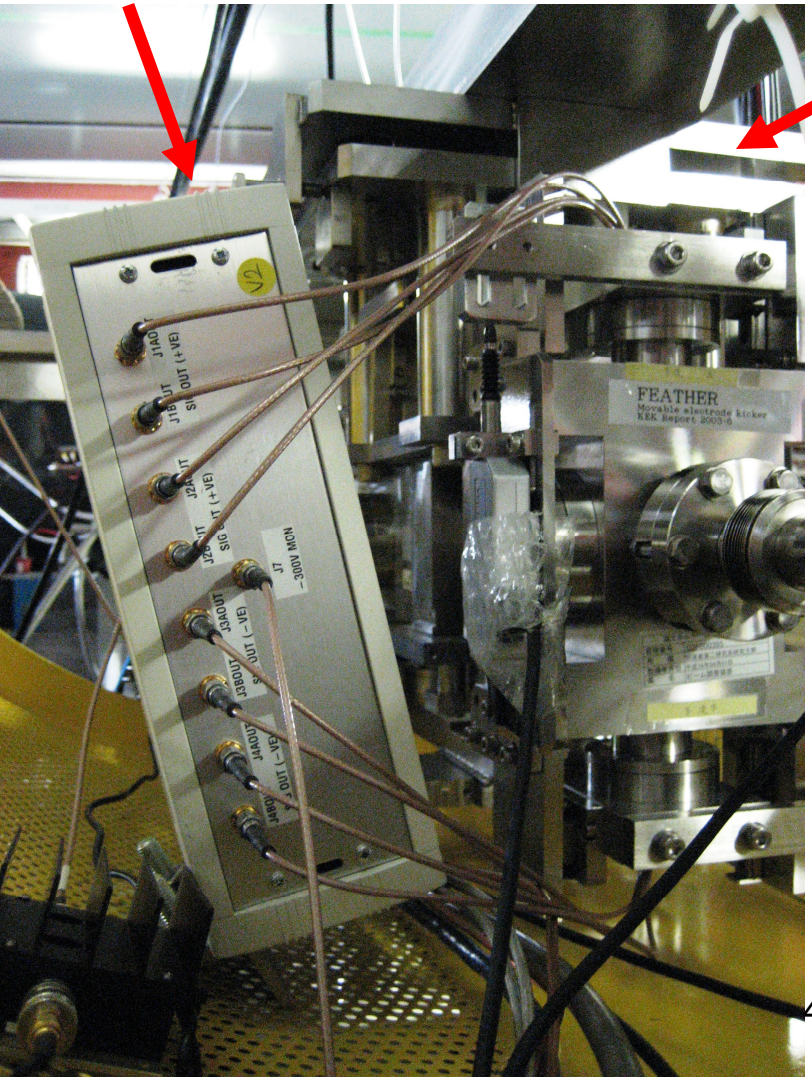
  Electronics latency: 119ns

- Total latency budget: 133ns

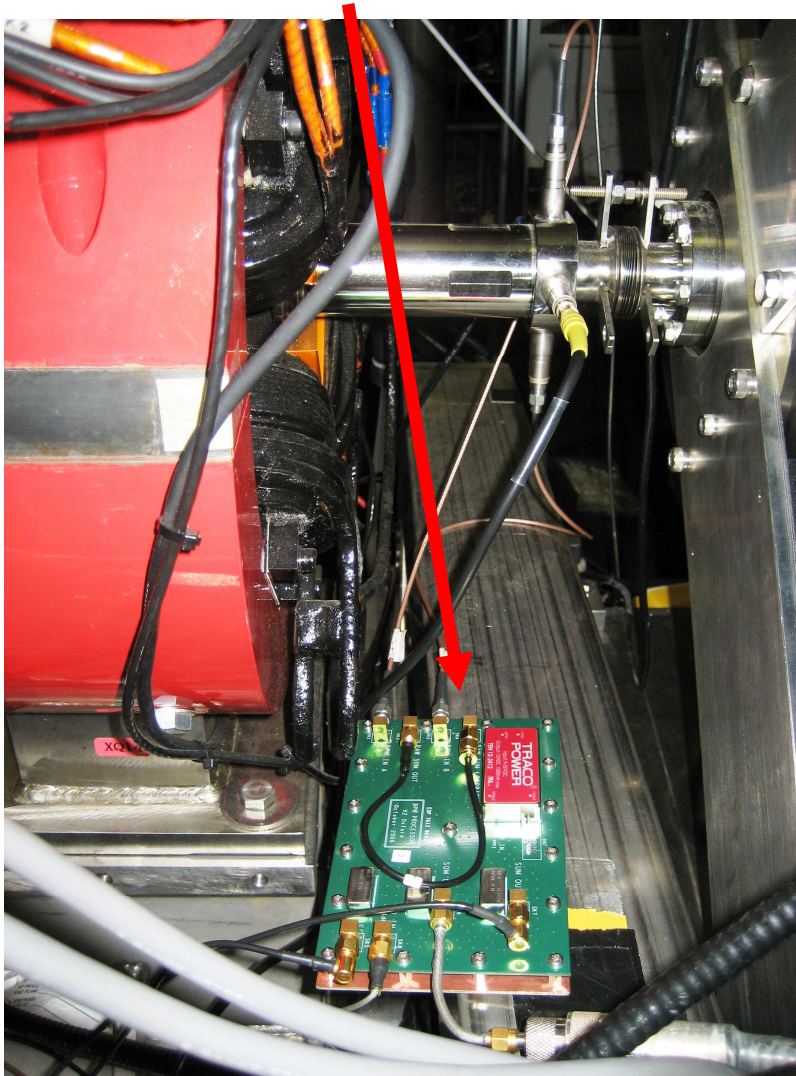
FONT4 beamline section

Amplifier

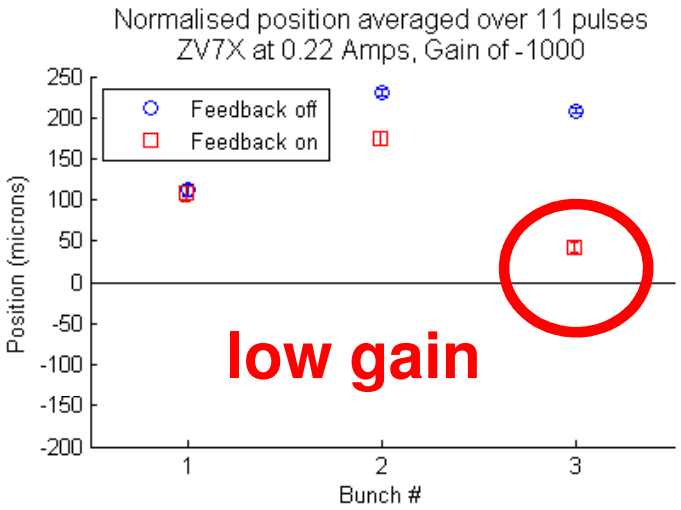
FEATHER
Kicker

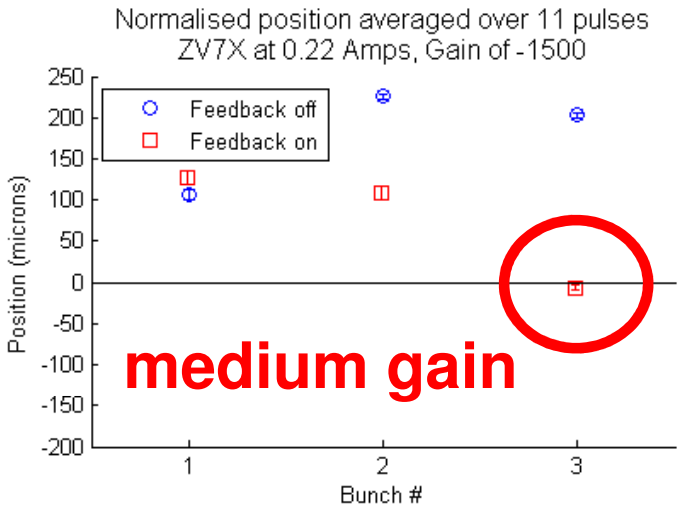


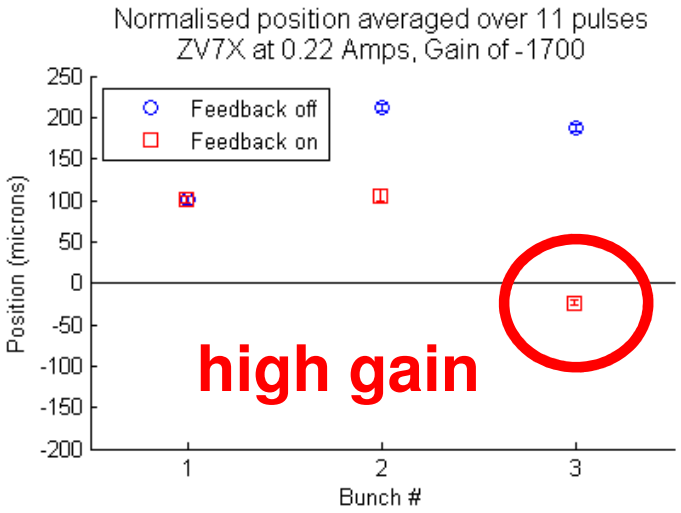
BPM processor board



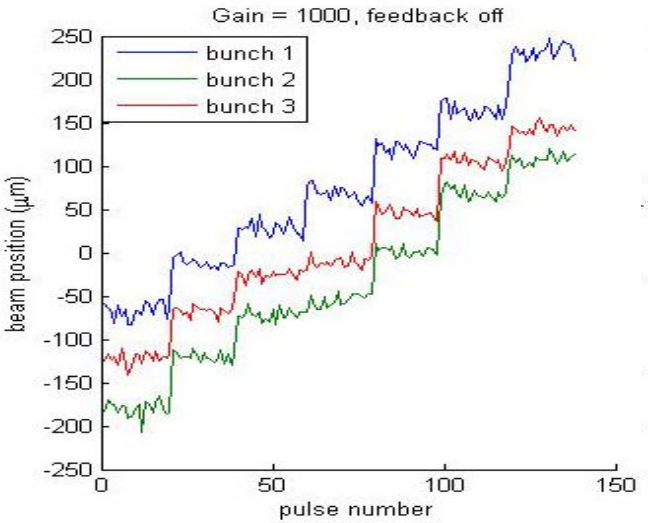
Example (1) of Results

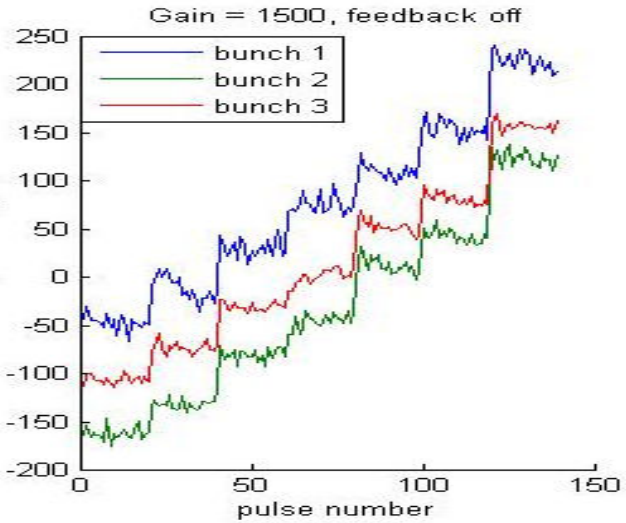


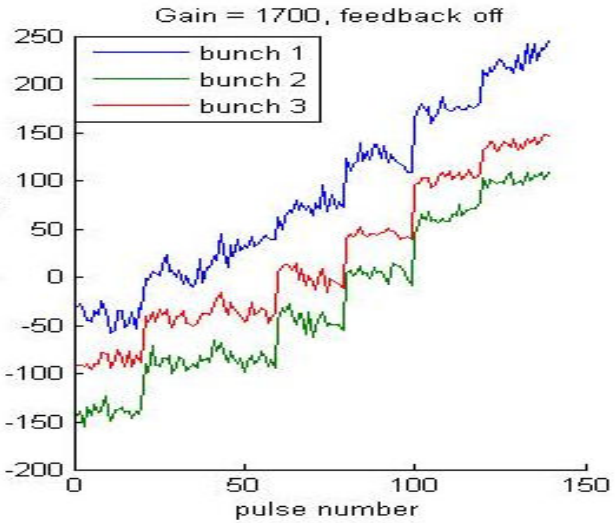


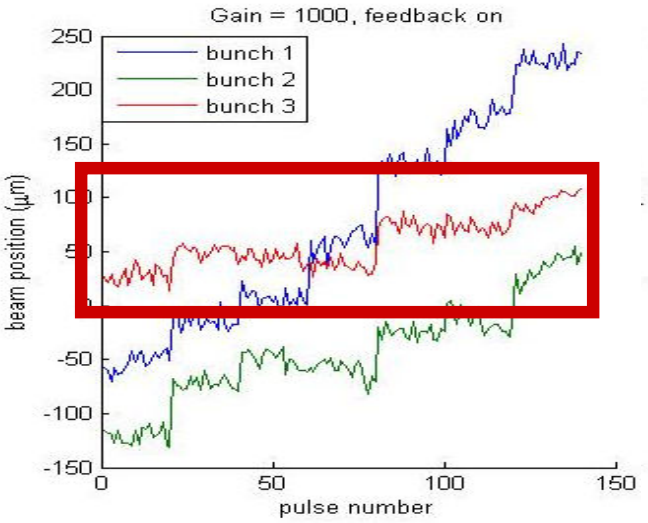


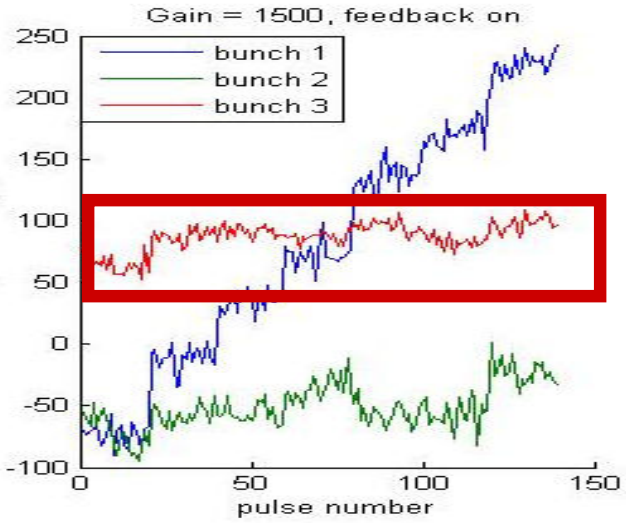
Example (2) of Results

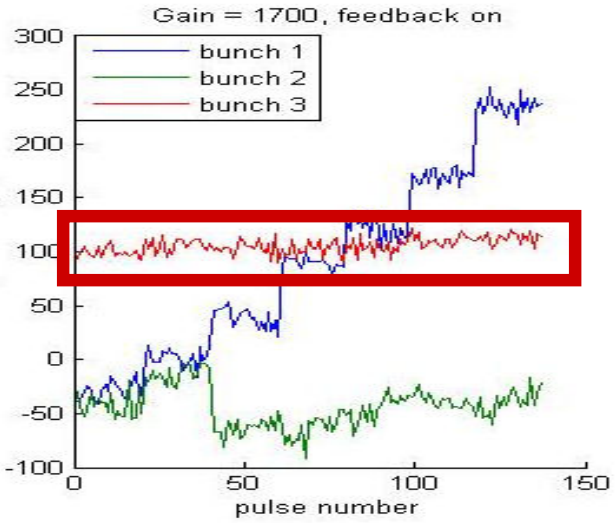




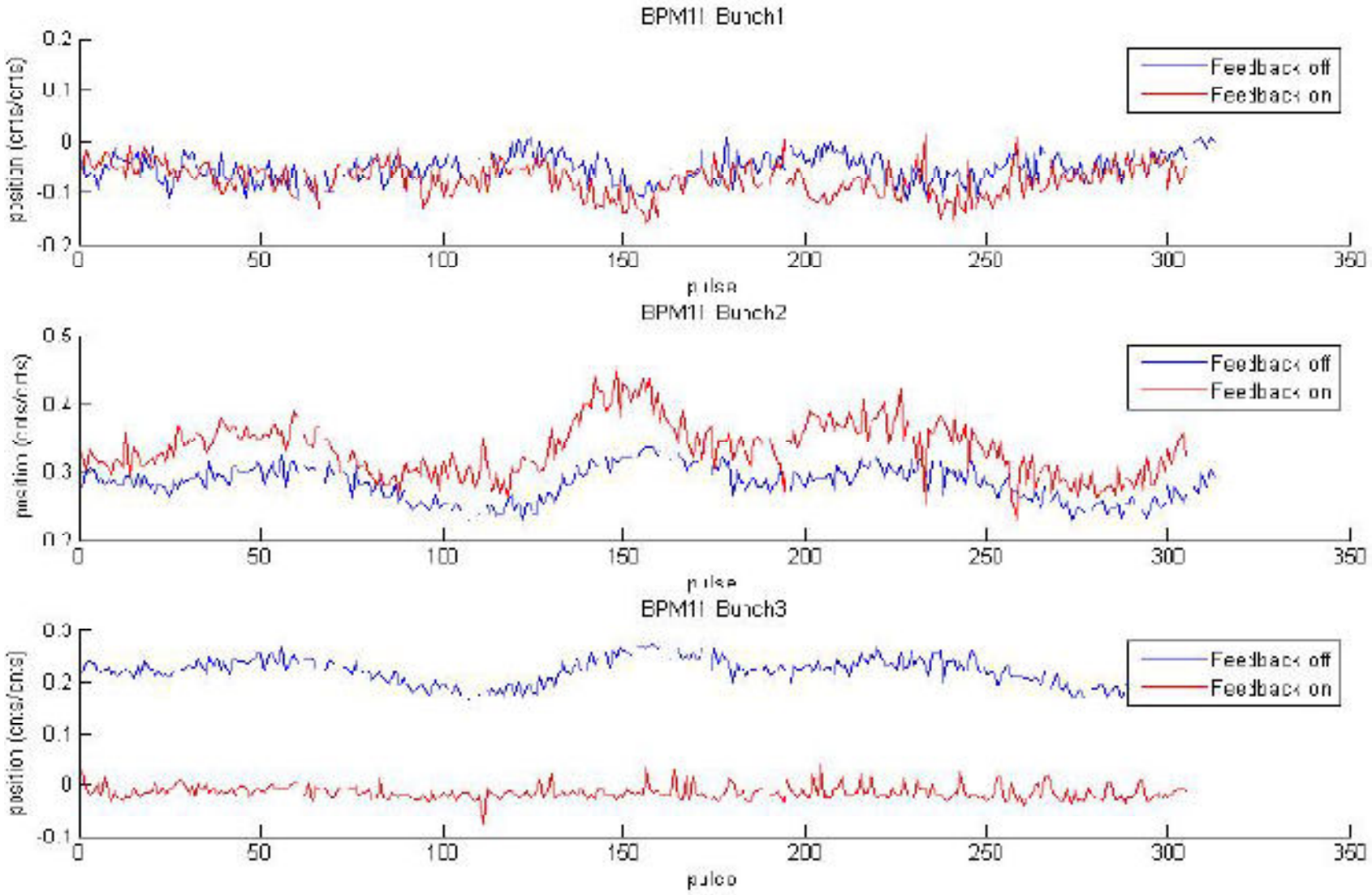




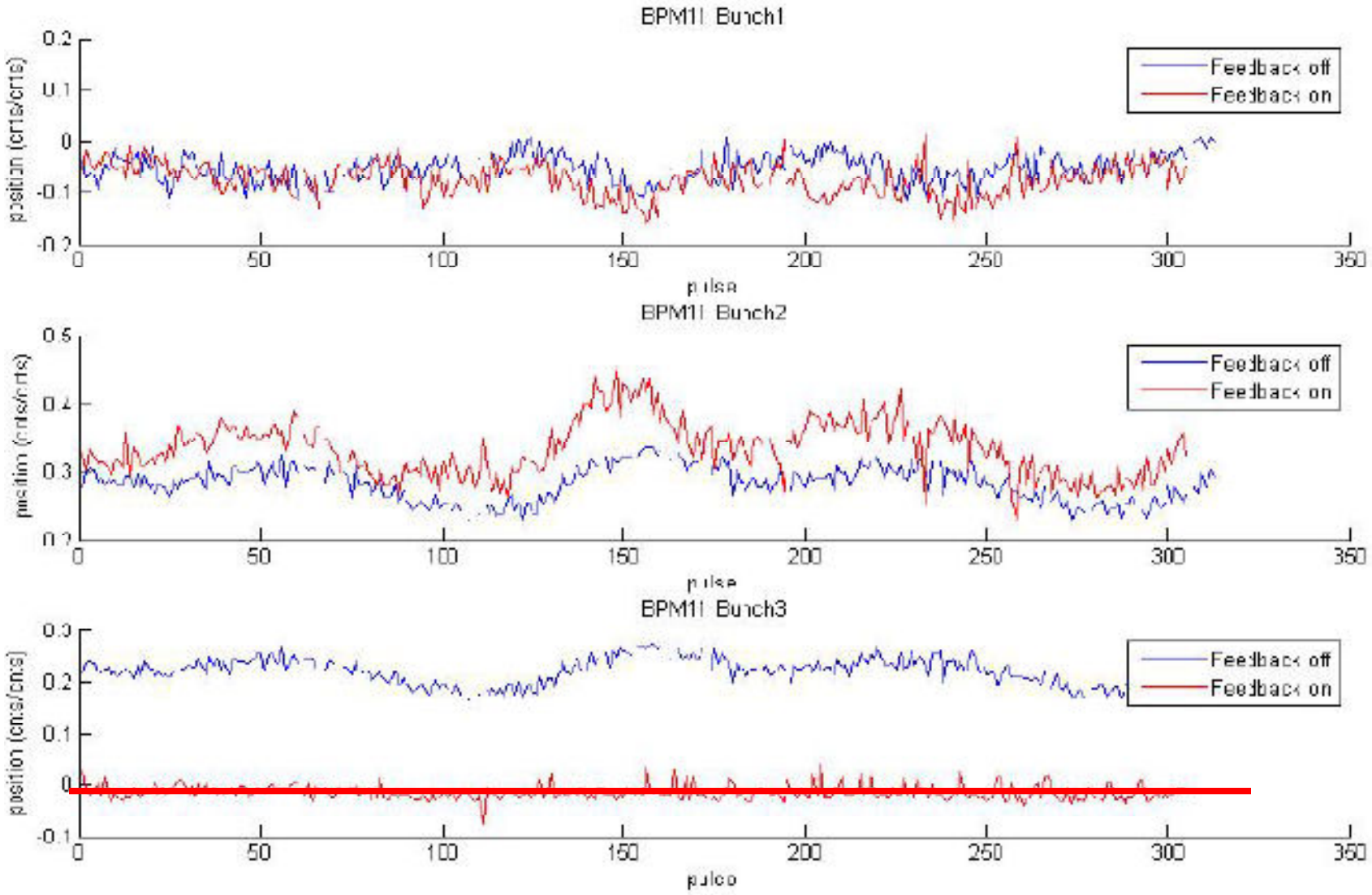




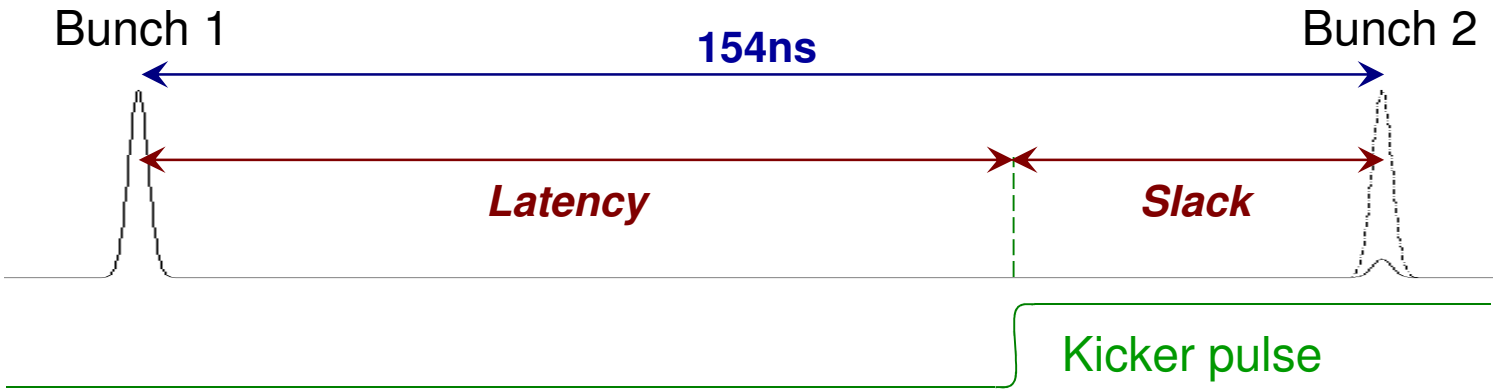
Example (3) of Results

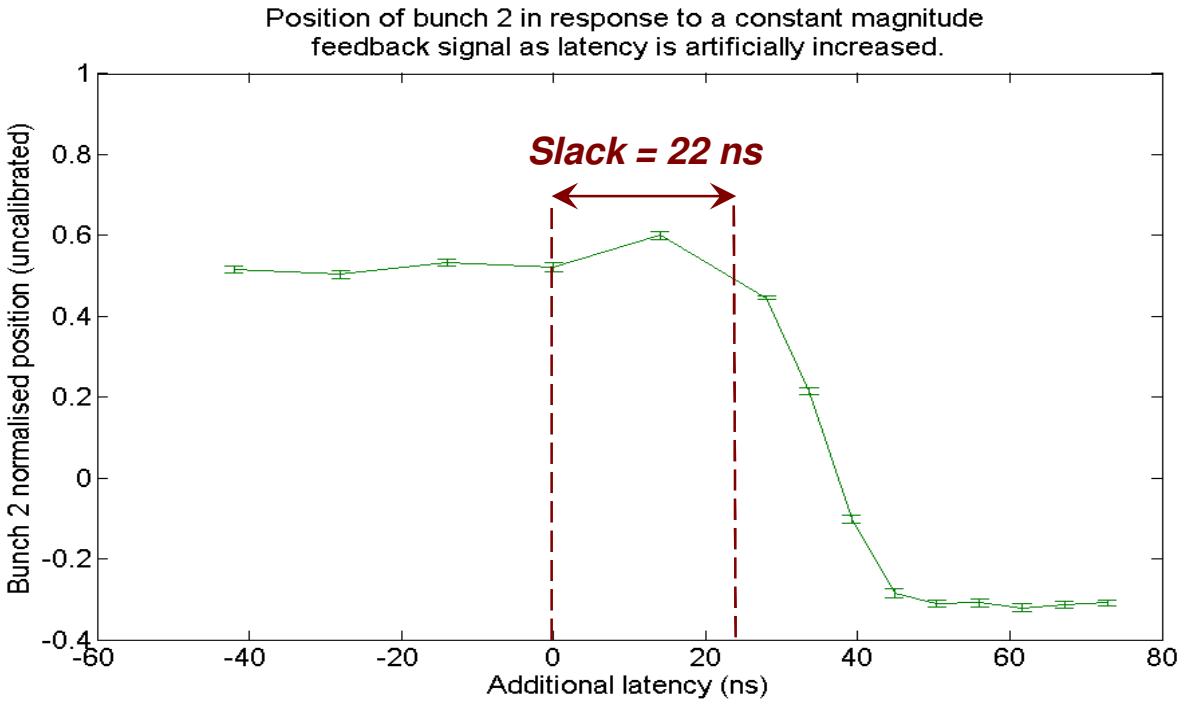


Example (3) of Results



Latency measurement





Latency

= 154 - slack

= 132 ns

+ 8ns (1/Q)

CLIC feedback prototype status

FONT Prototype Analogue Feedback Systems

- **NLCTA: 65 MeV beam, 170ns train, 87ps bunch spacing**

FONT1 (2001-2):

First demonstration of closed-loop FB: latency 67ns

10/1 beam position correction

FONT2 (2003-4):

Improved demonstration of FB: latency 54ns

real time charge normalisation with logarithmic amplifiers
beam flattener to straighten train profile
solid-state amplifier

- **ATF: 1.3 GeV beam, 56ns train, 2.8ns bunch spacing**

FONT3 (2004-5):

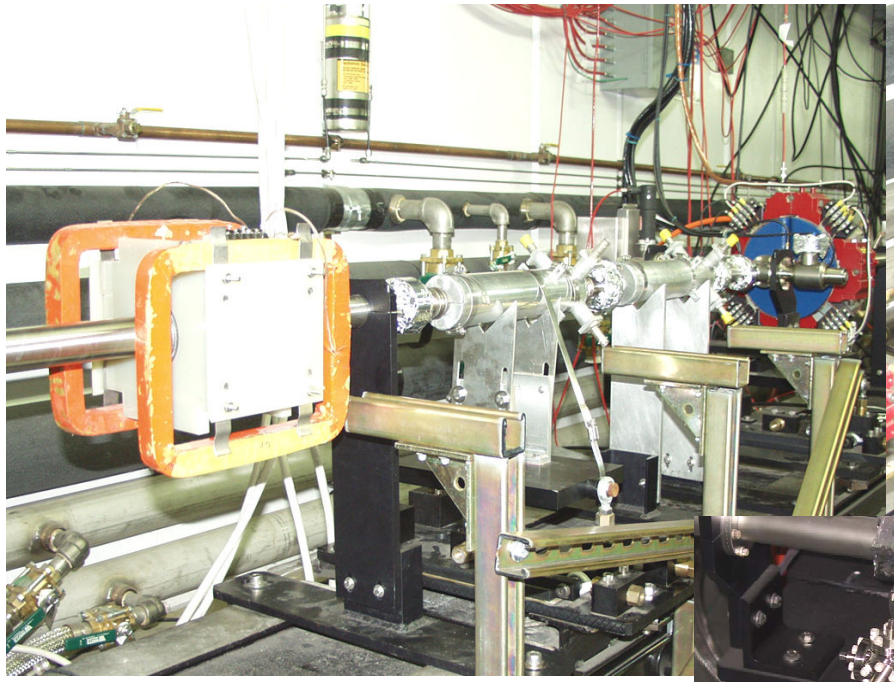
Ultra-fast demonstration of FB: latency 23 ns

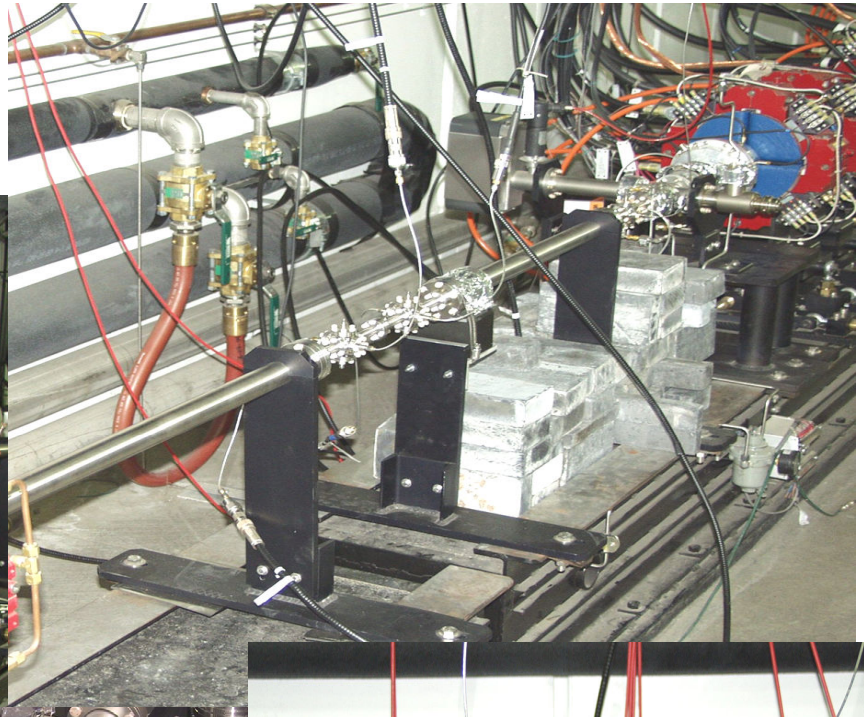
3 stripline BPMs
high-power solid-state amplifier

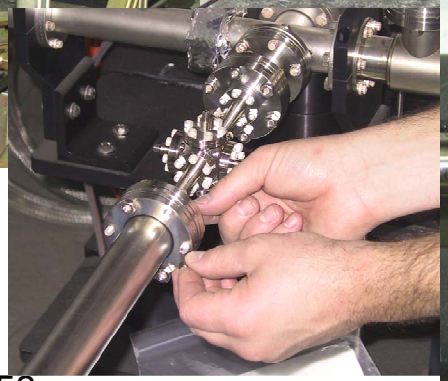
FONT2 beamline installation at SLAC NLCTA

(65 MeV 170ns-long train @ 87ns spacing)

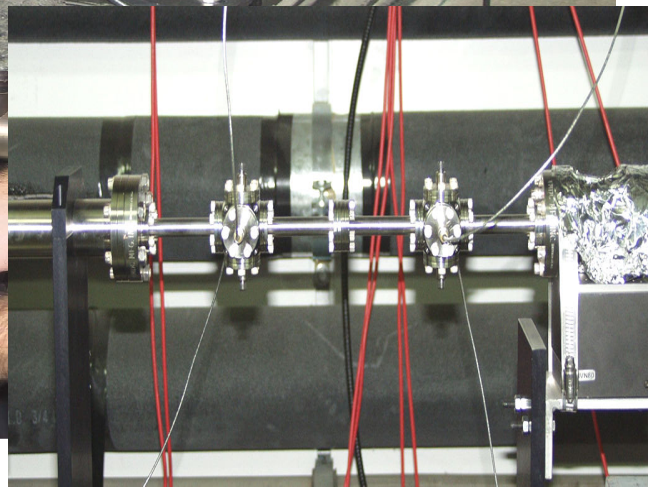
Dipole and kickers



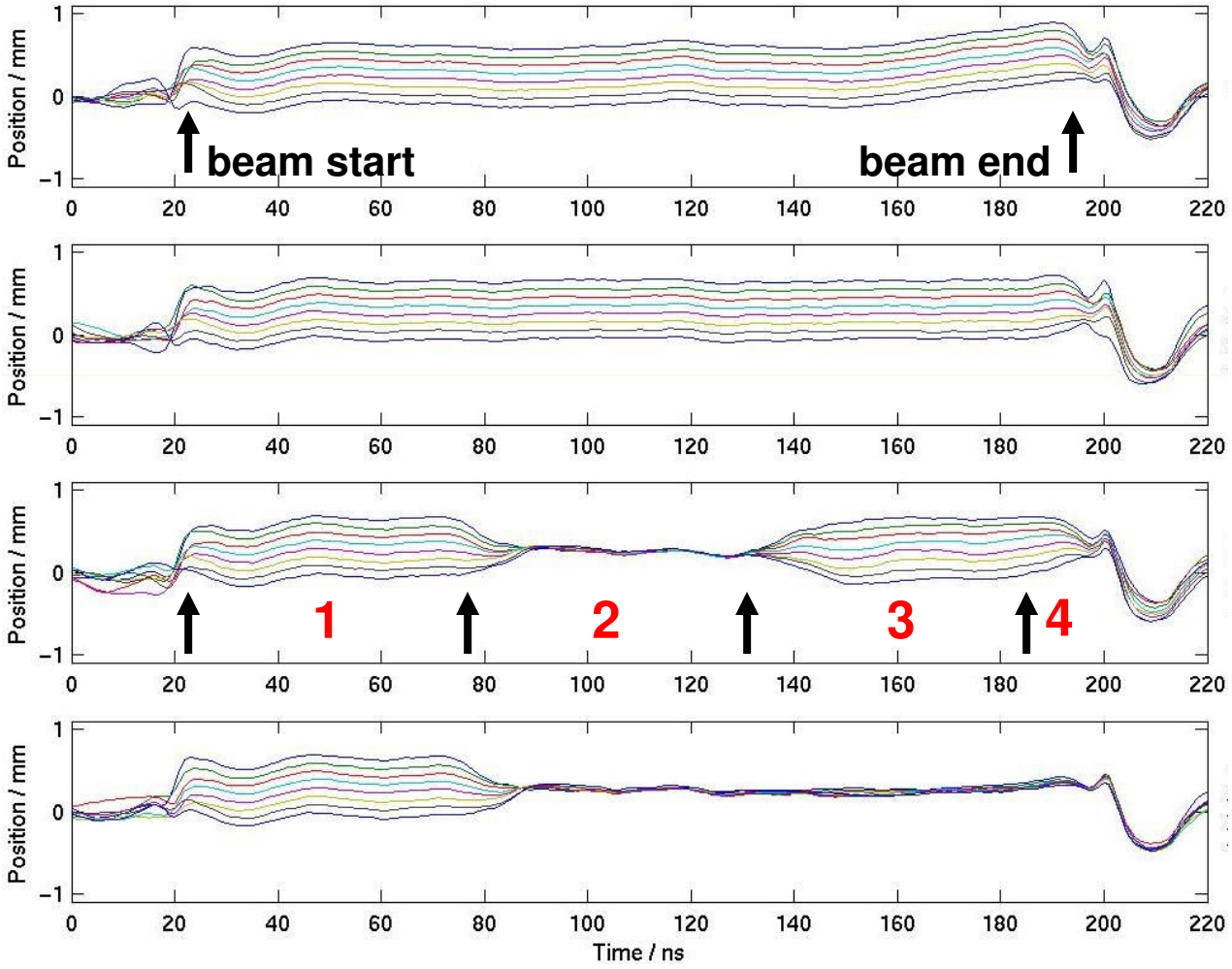




New BPMs



FONT2 results: feedback BPM



Beam starting positions

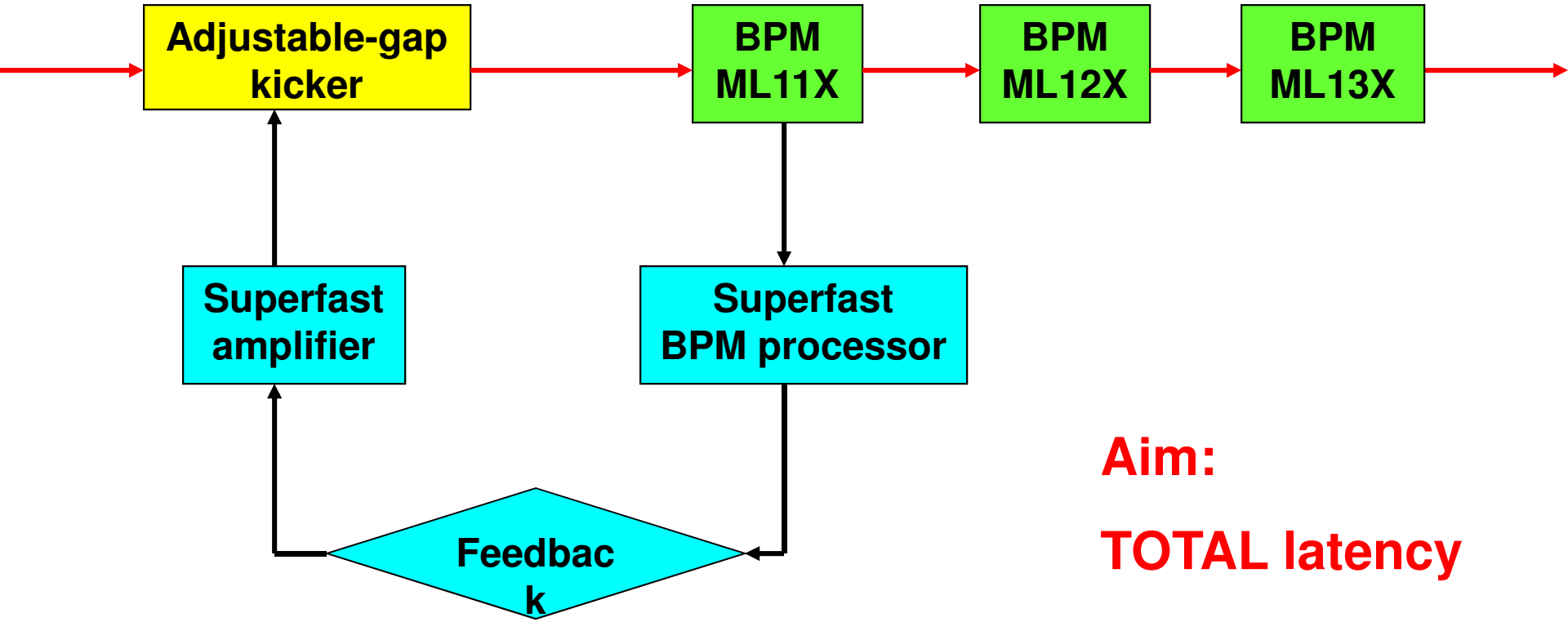
Beam flattener on

Feedback on

Delay loop on

FONT3

ATF: 1.3 GeV beam, 56ns-long train @ 2.8ns spacing



Aim:

TOTAL latency

< 20 ns

FONT3: latency budget

- Time of flight kicker – BPM: 4ns
- Signal return time BPM – kicker: 6ns

  Irreducible latency: 10ns

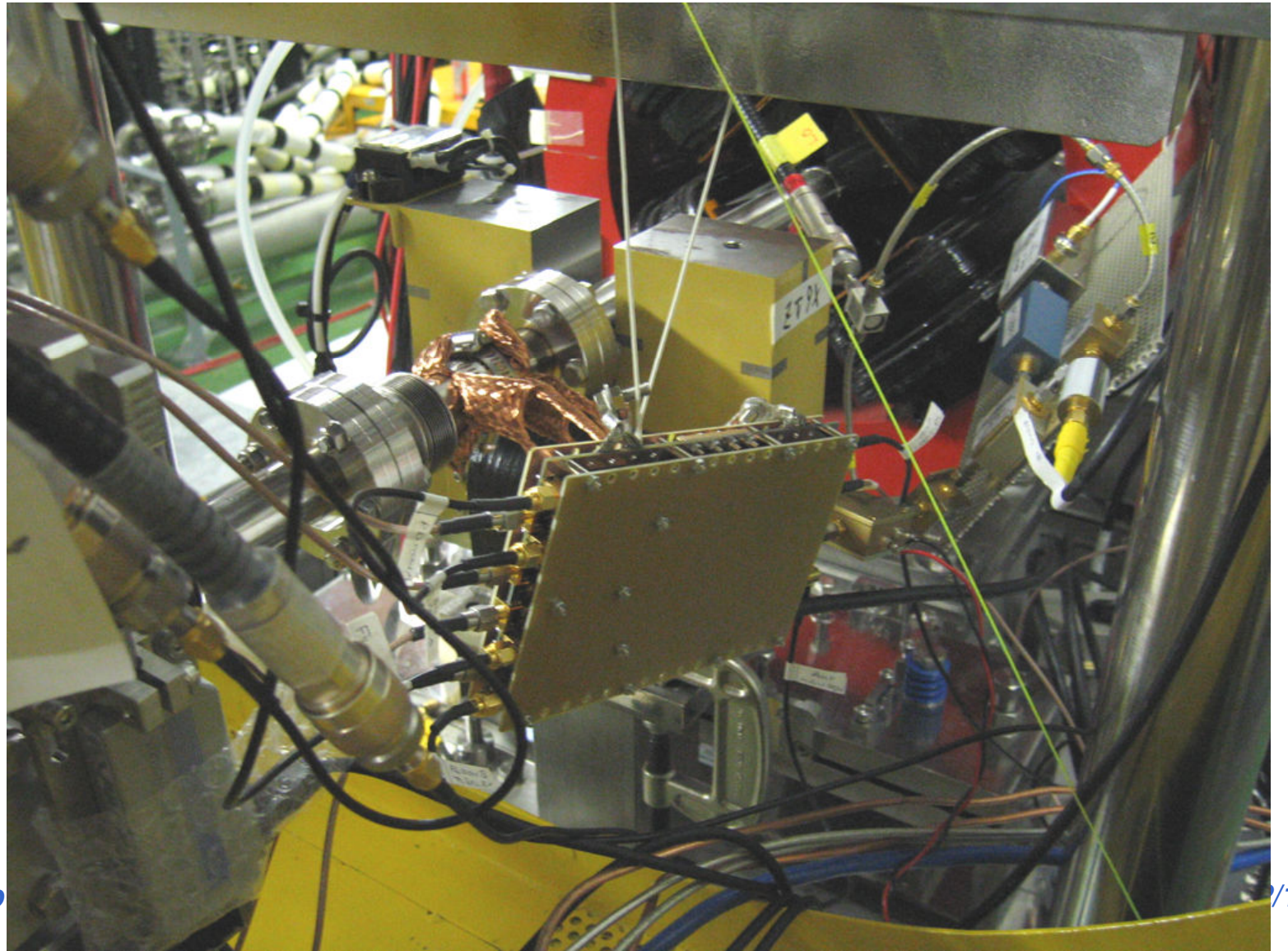
- BPM processor: 5ns
- Amplifier + FB: 5ns

  Electronics latency: 10ns

- Total latency budget: 20ns

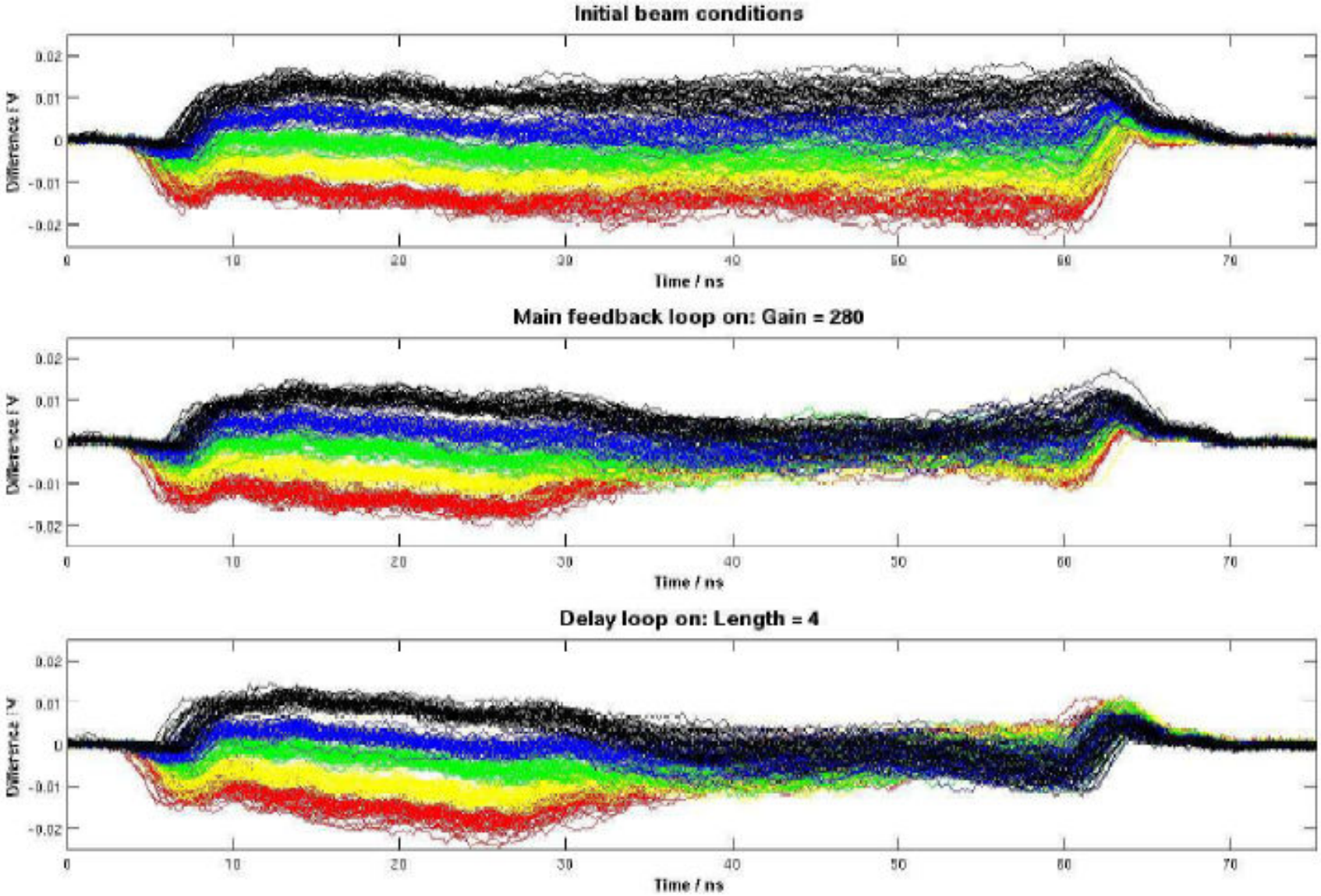
Allows 56/20 = 2.8 periods during bunchtrain

FONT3: Beamline Installation

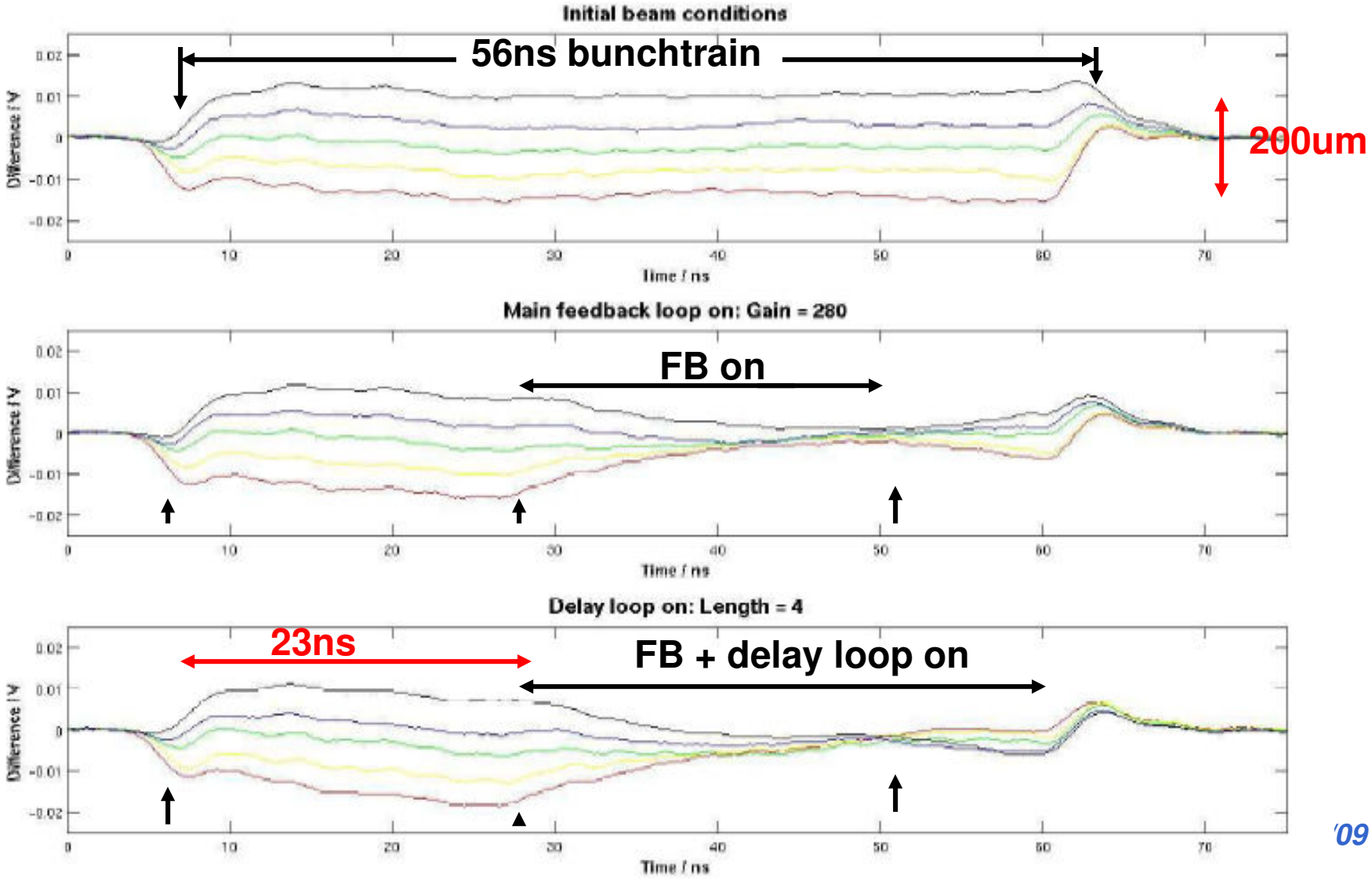


FONT3: Results (June 3 2005)

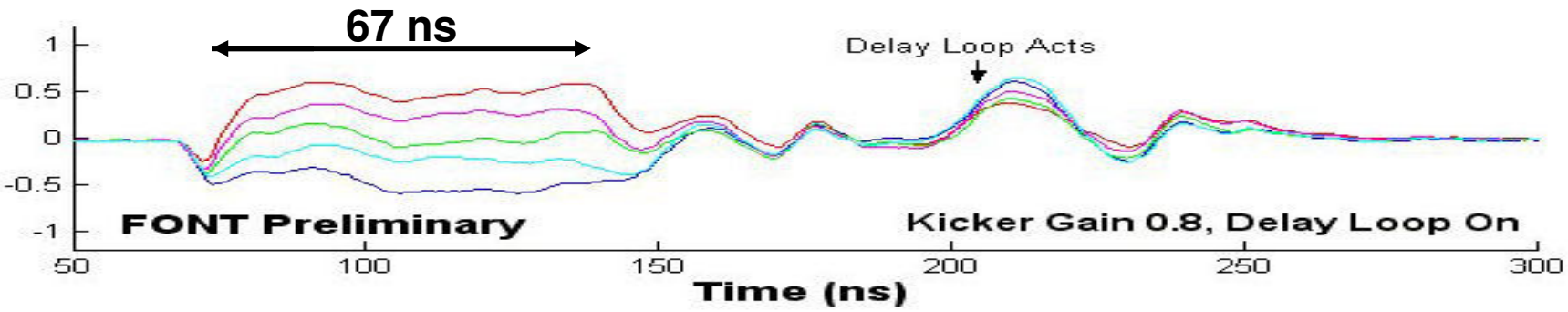
40 pulses per position setting

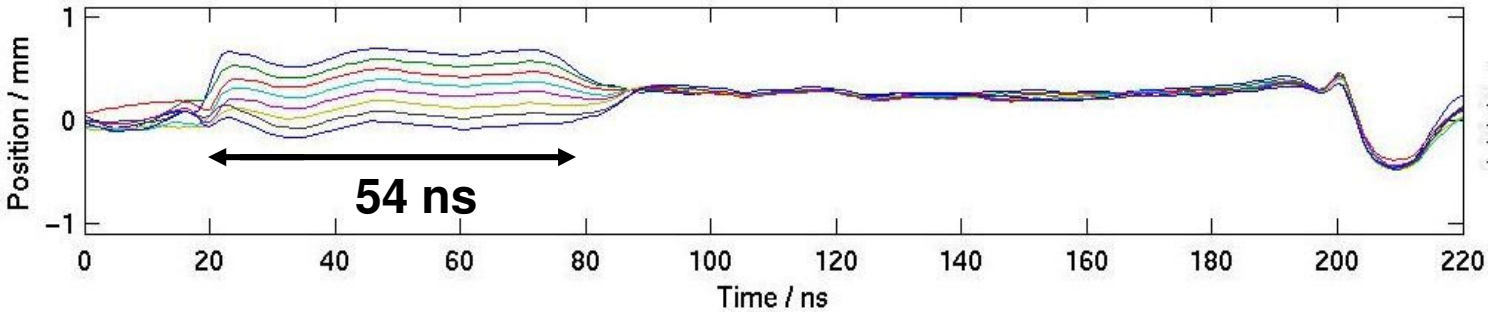


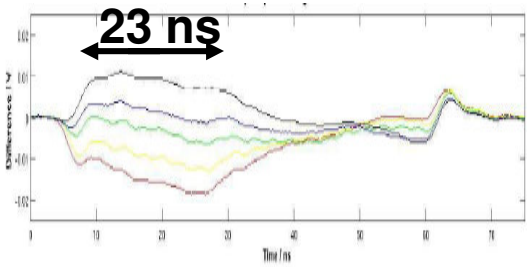
FONT3: Results (June 3 2005):
Delay-loop feedback w. latency 23 ns



FONT1,2,3: Summary







Fast enough for CLIC intra-train FB!