Intra-train Beam Feedback Hardware Development

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International Fast FB Collaboration

- **FONT:**
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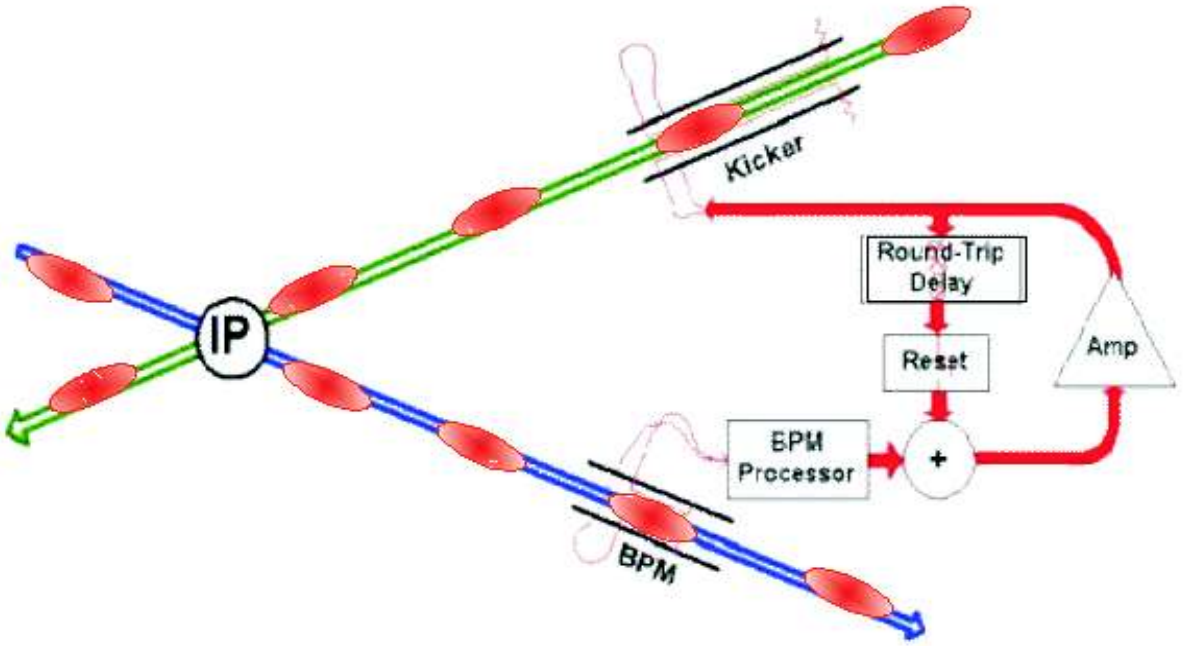
  - Daresbury Lab: Alexander Kalinin, Roy Barlow, Mike Dufau
  - Oxford: Colin Perry, Gerald Myatt
  - SLAC: Joe Frisch, Tom Markiewicz, Marc Ross, Chris Adolphsen, Keith Jobe, Doug McCormick, Janice Nelson, Tonee Smith, Steve Smith, Andrei Seryi, Mark Woodley, Linda Hendrickson.
- **FEATHER:**
  - KEK: Toshiaki Tauchi, Hitoshi Hayano
  - Tokyo Met. University: Takayuki Sumiyoshi, Hiroaki Fujimoto
- **Simulations:** Nick Walker (DESY), Daniel Schulte (CERN)

Intra-train Beam-based Feedback

Intra-train beam feedback is last line of defence against relative beam misalignment

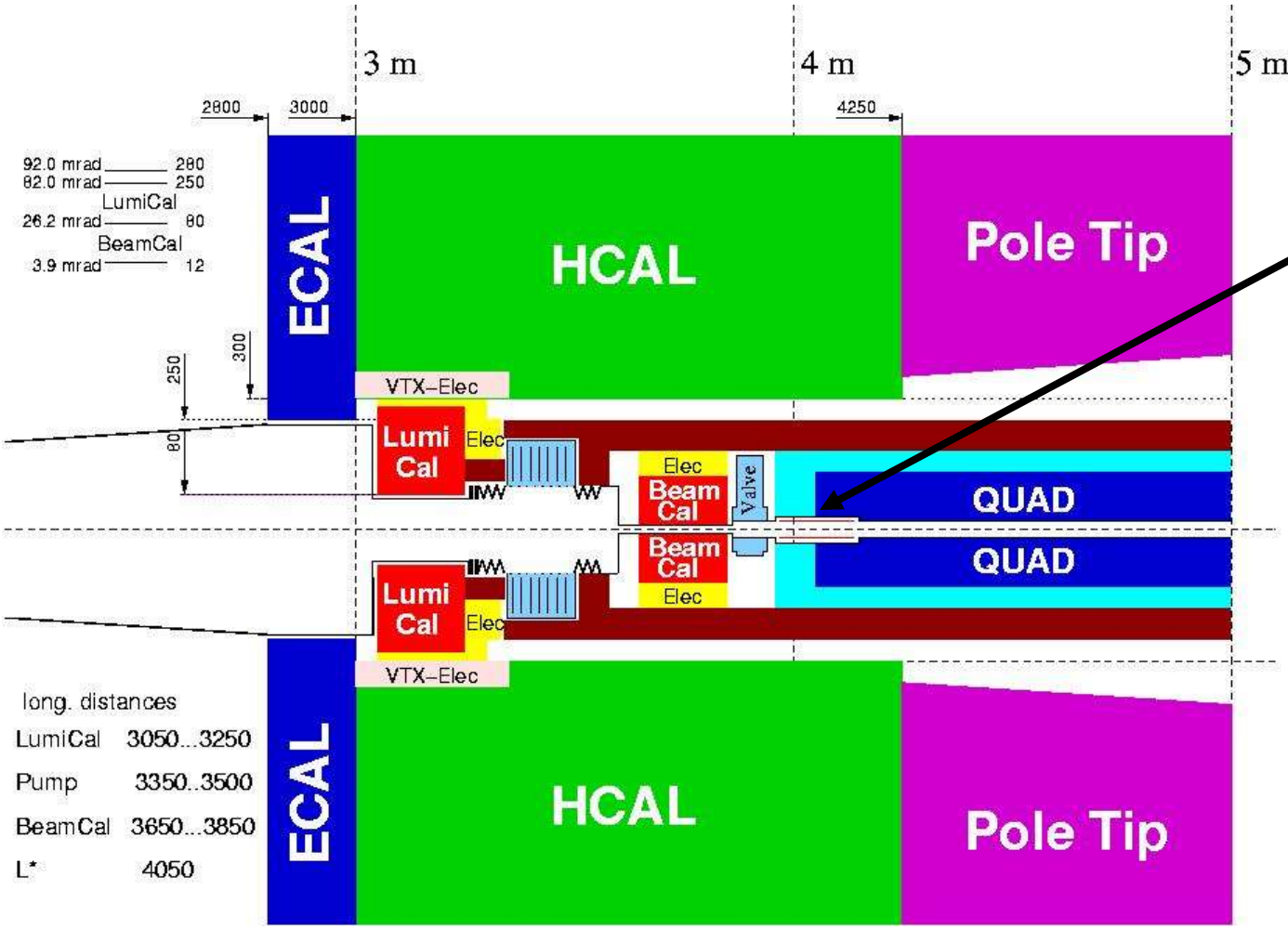


Key components:

- **Beam position monitor (BPM)**
- **Signal processor**
- **Fast driver amplifier**
- **E.M. kicker**
- **Fast FB circuit**

TESLA TDR: principal IR beam-misalignment correction

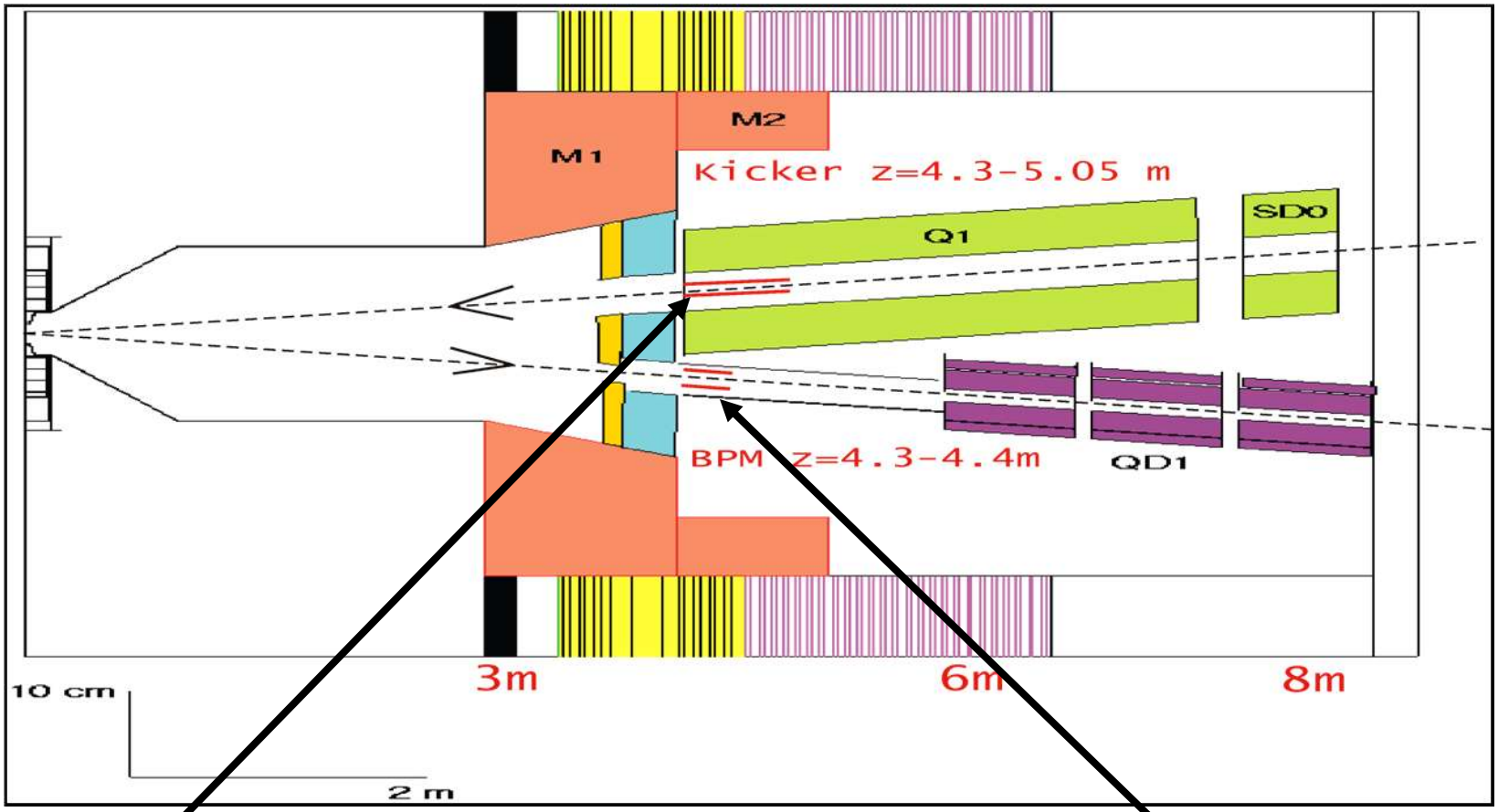
Zero-degree crossing angle (TESLA TDR)



FB BPM

Upstream kicker(s)

‘Large’ crossing angle (NLC)



Feedback Hardware Program Goals

Aim: prototype components required for ILC intra-train beam feedback system(s):

- **BPMs**
- **Signal processor**
- **Feedback circuit**
- **Amplifier**
- **Kicker**

and demonstrate system performance with real beam

FONT1 Prototype Feedback System

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

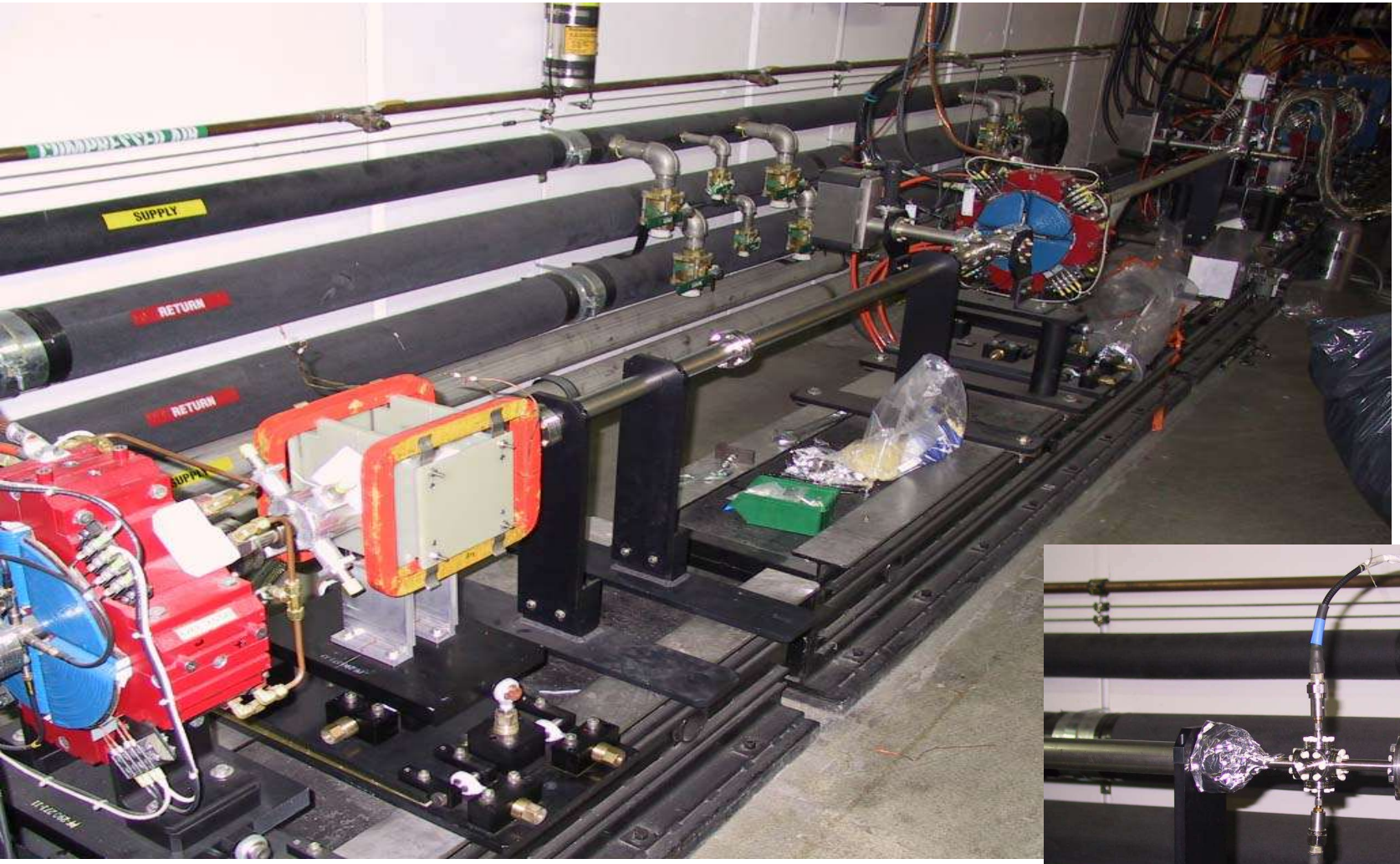
FONT1 (2001-2):

- **button BPM (X-band): difference/sum method**
- **charge normalisation: 1/sum using earlier pulse and AWG**
- **analogue signal processor**
- **high power 3-stage tube amplifier**
- **30cm stripline kicker**

First demonstration of closed-loop FB:

- **total latency 67ns (32ns TOF, 35ns electronics)**
- **beam moved by c. 1mm**

FONT1: beamline installation



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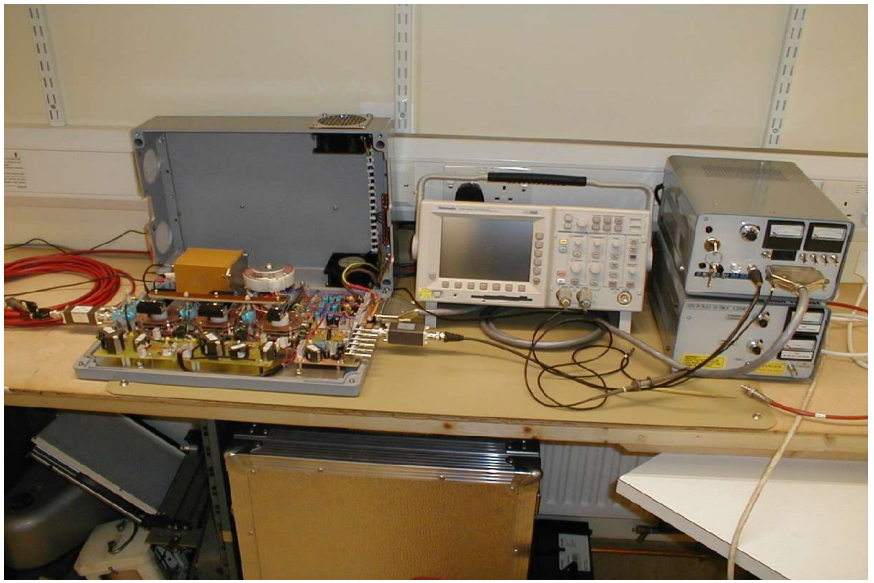
FONT1: kicker driver amplifier

3kW amplifier:

3 planar triode tubes;

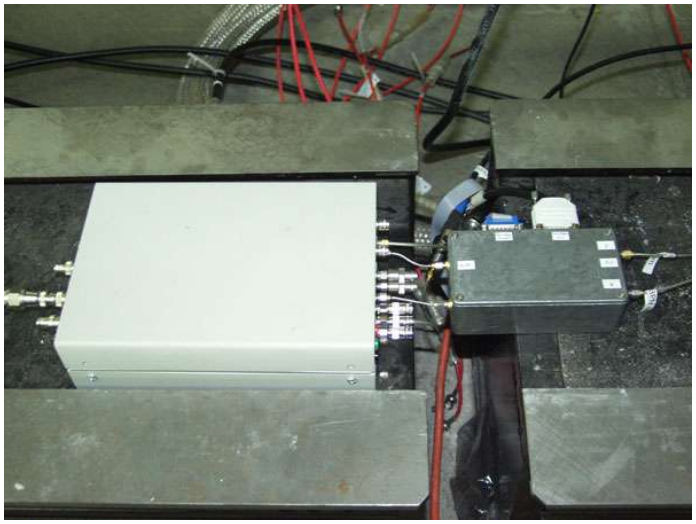
7.5 A, 350V o/p



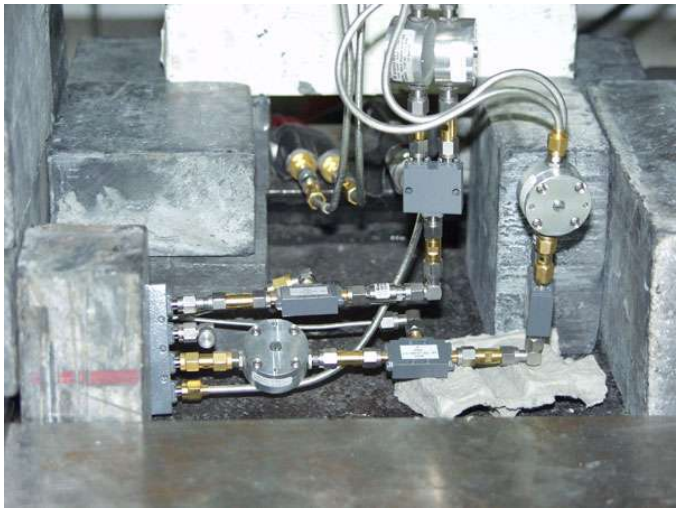
Allows us to move 65 MeV beam by +- 0.5 mm

FONT1: charge normalisation/feedback

2



1



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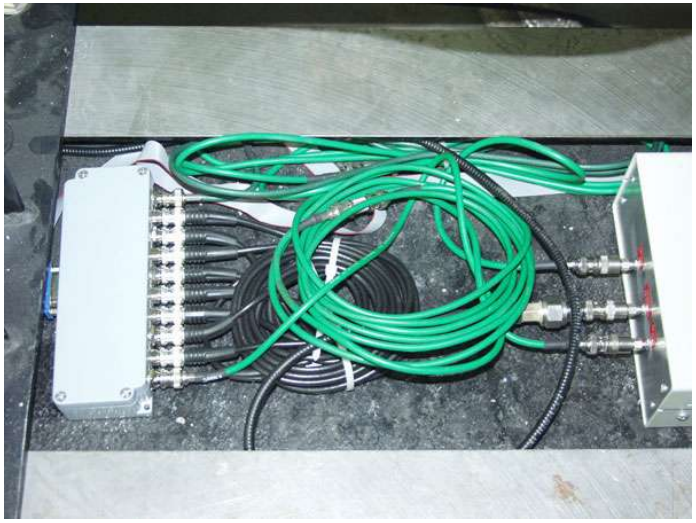

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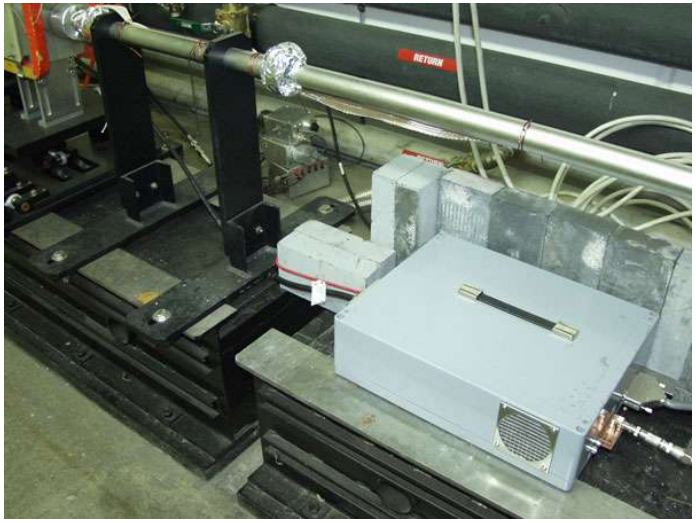
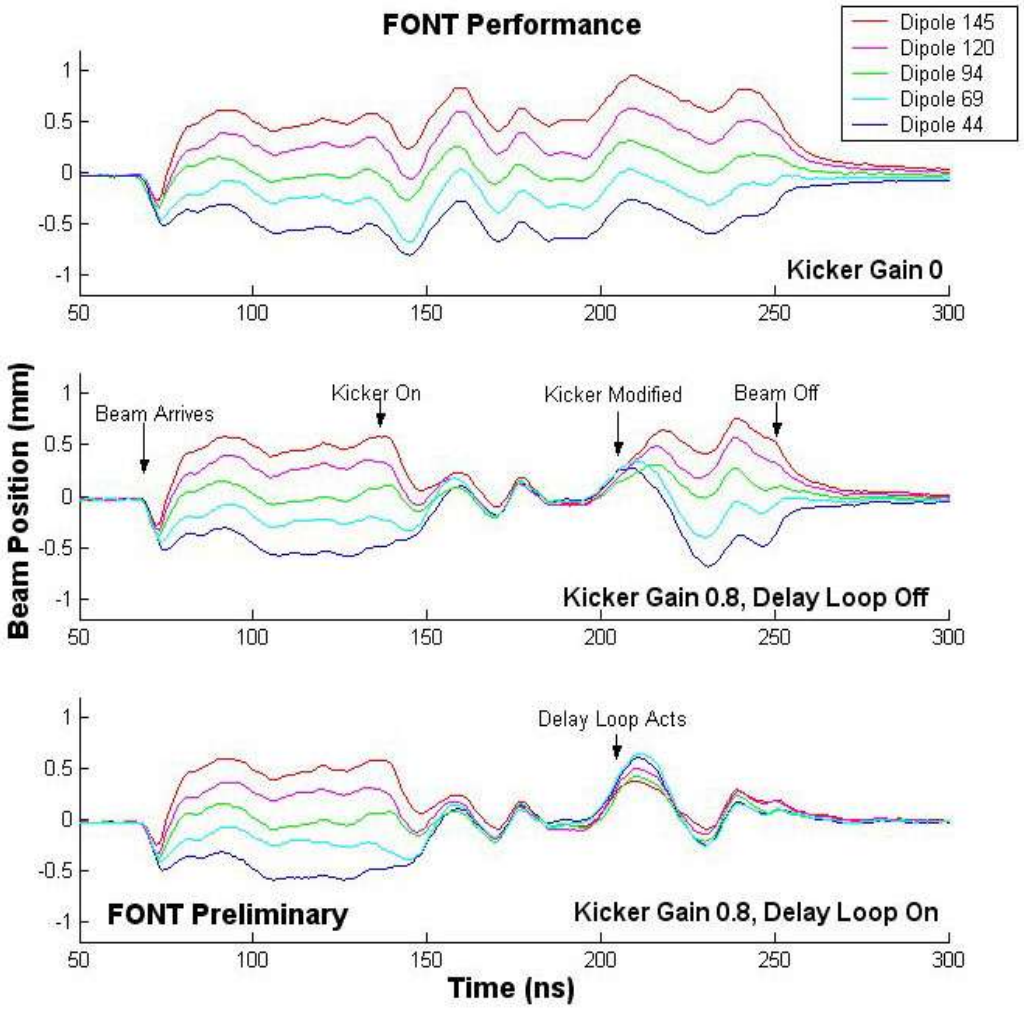


FONT1 results (Sept. 2002)



10/1 position correction of

65 MeV e- beam

achieved

latency of 67 ns

system tested in feedback and delay-loop modes

FONT2 Prototype Feedback System

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

FONT2 (2003-4):

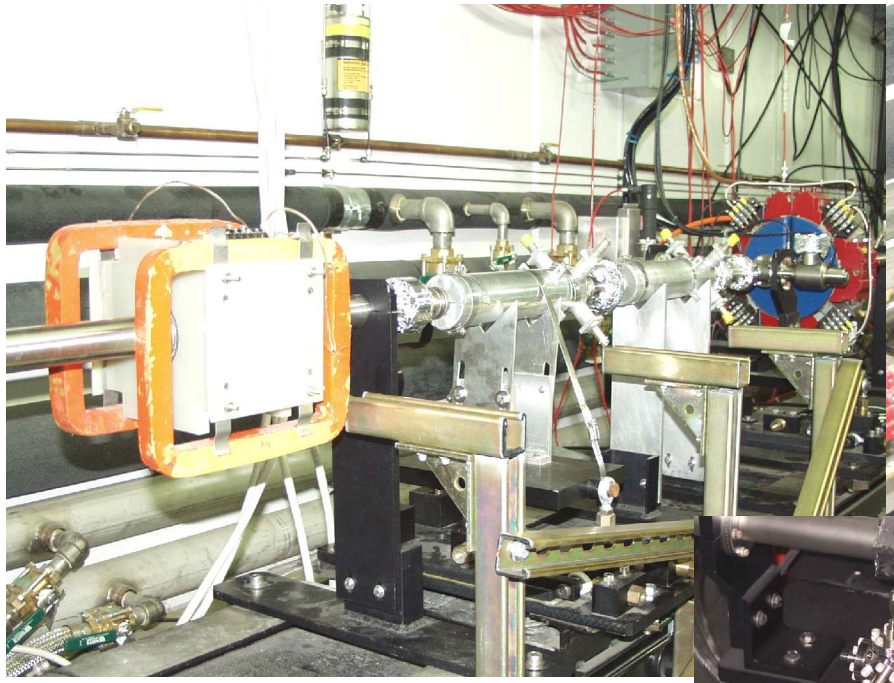
- **3 button BPMs (X-band): difference/sum method**
- **charge normalisation: real time with logarithmic amplifiers**
- **beam flattener to straighten train profile**
- **analogue signal processor**
- **high power solid-state amplifier**
- **½ lever-arm: two 30cm stripline kickers**

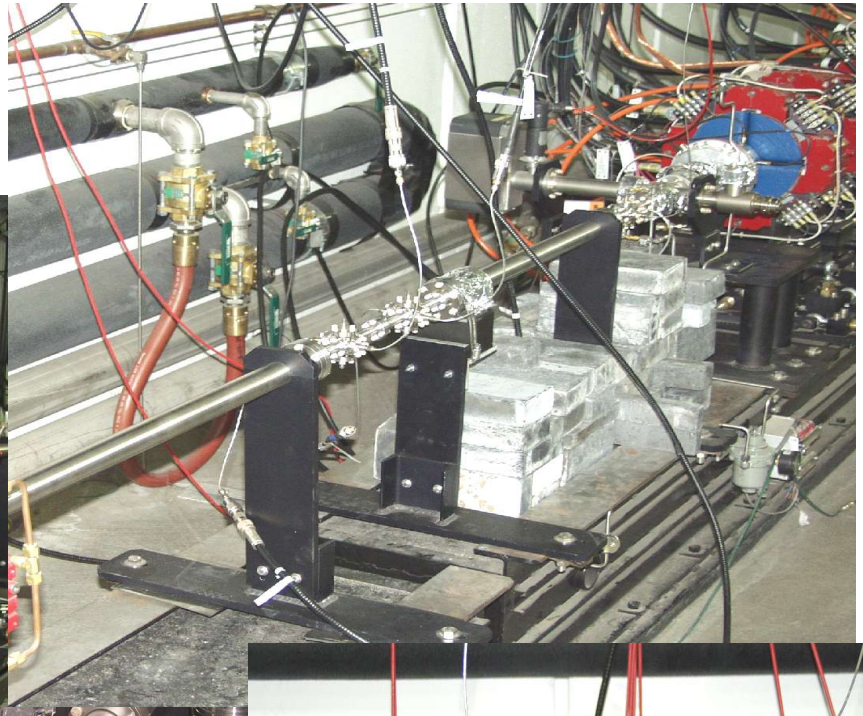
Improved demonstration of FB:

- **total latency 54ns (16ns TOF, 37ns electronics)**
- **beam moved by c. 1mm**

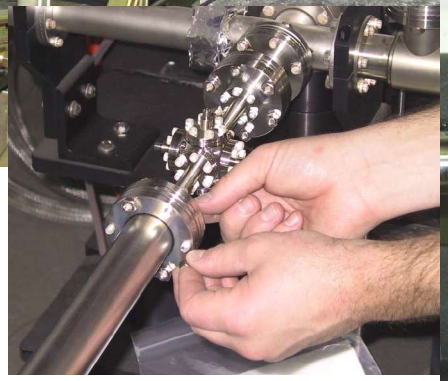
FONT2: beamline configuration

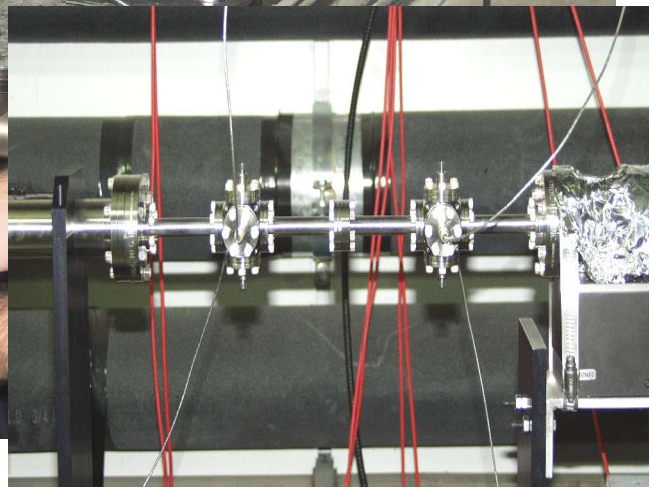
Dipole and kickers





BPMs





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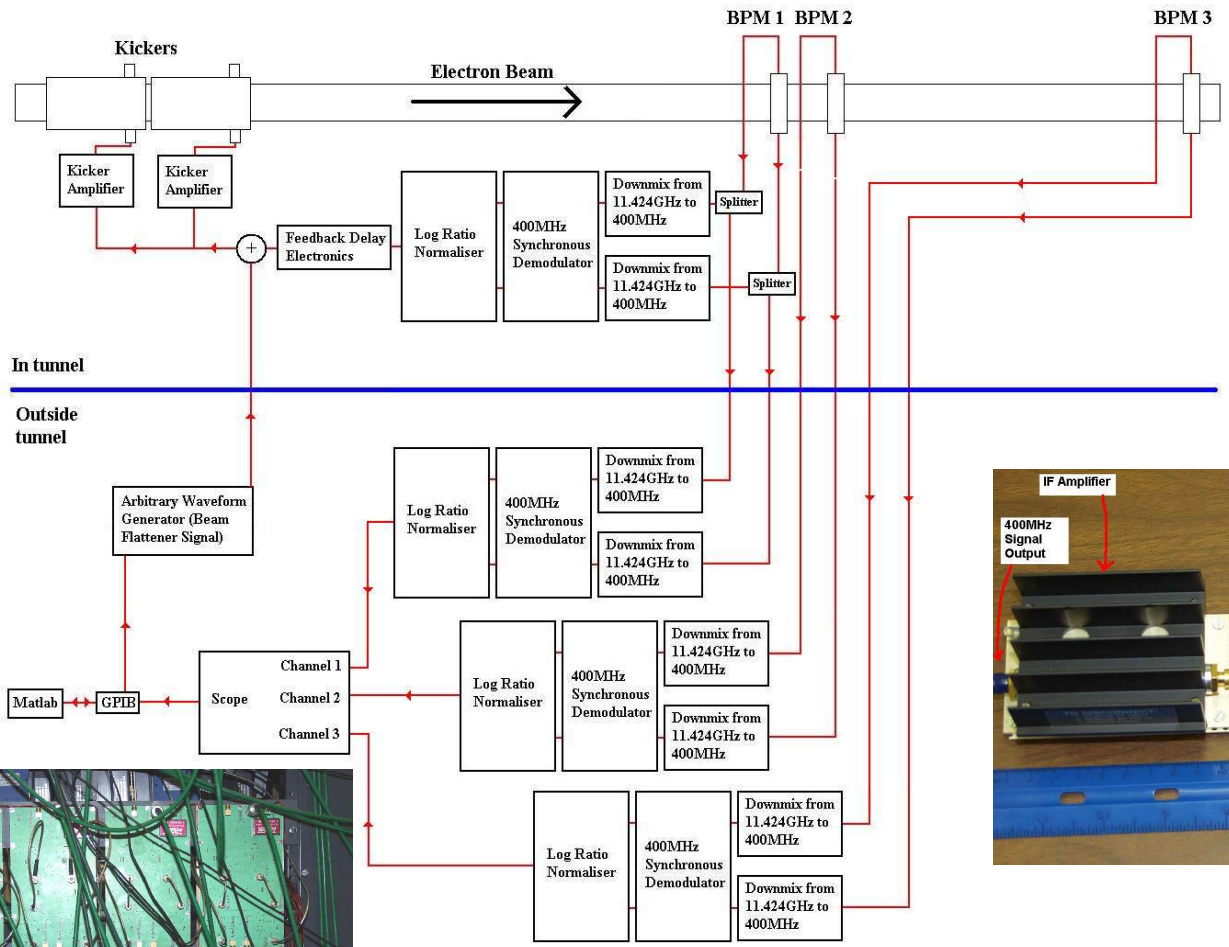
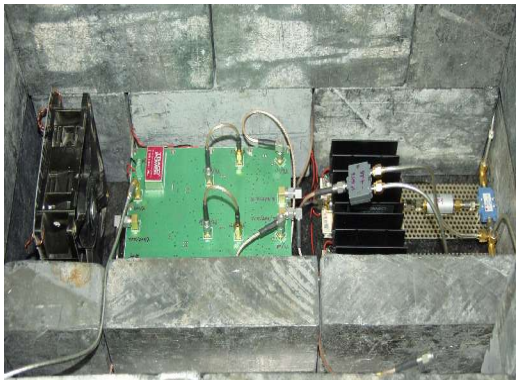
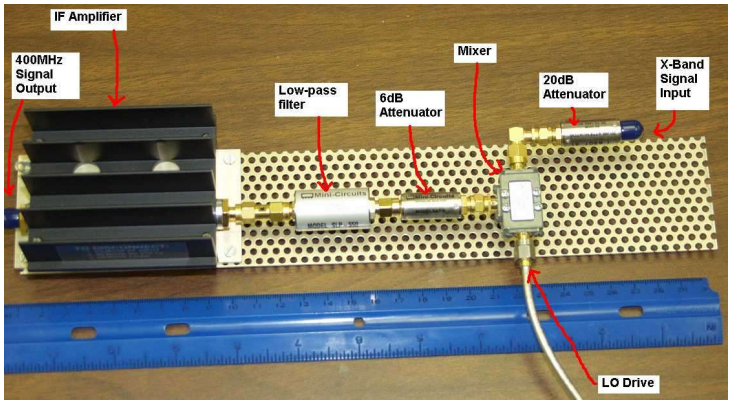
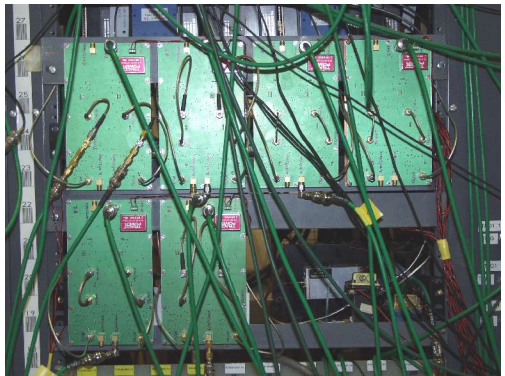
FONT2: BPM signal processing

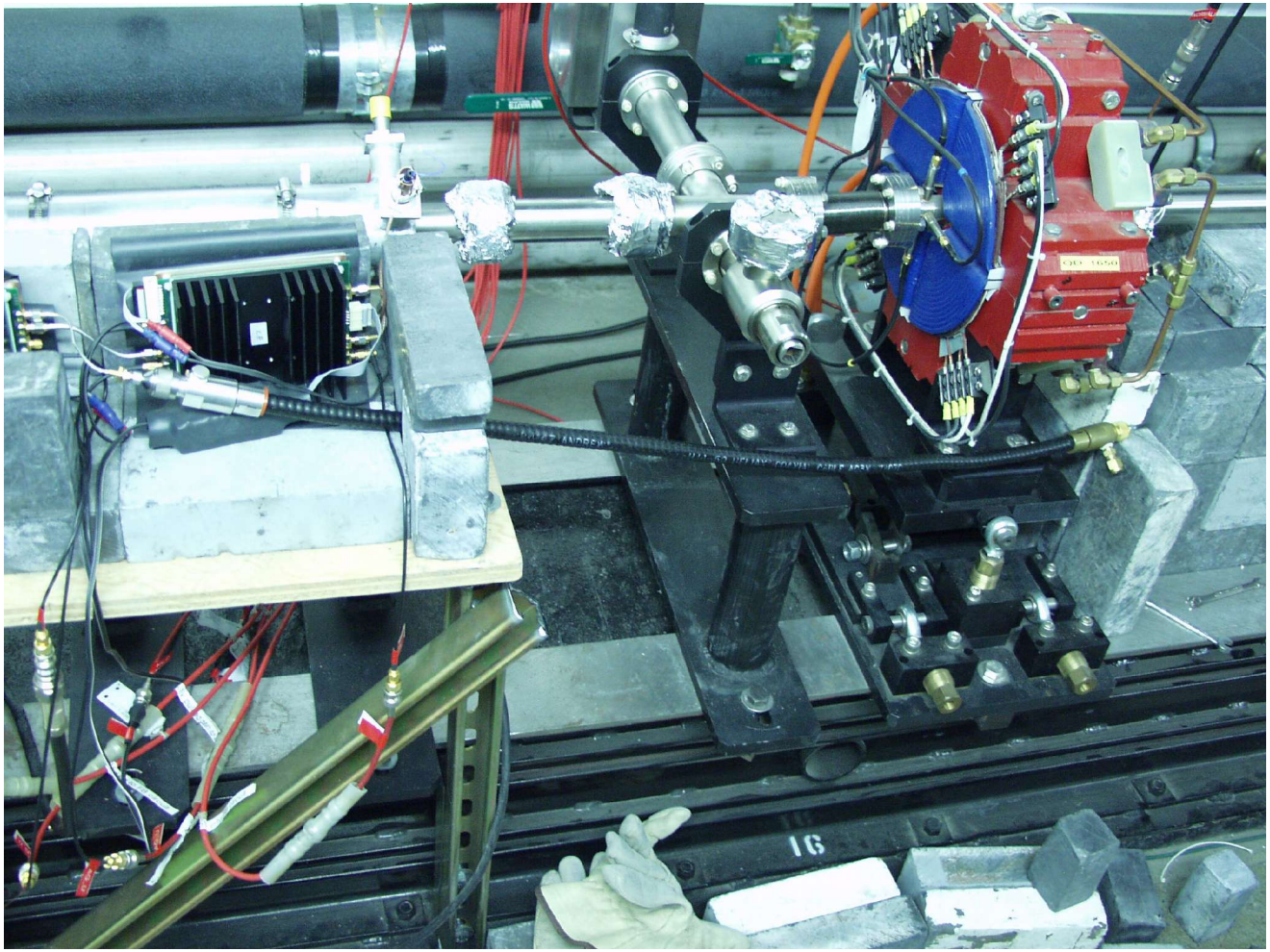






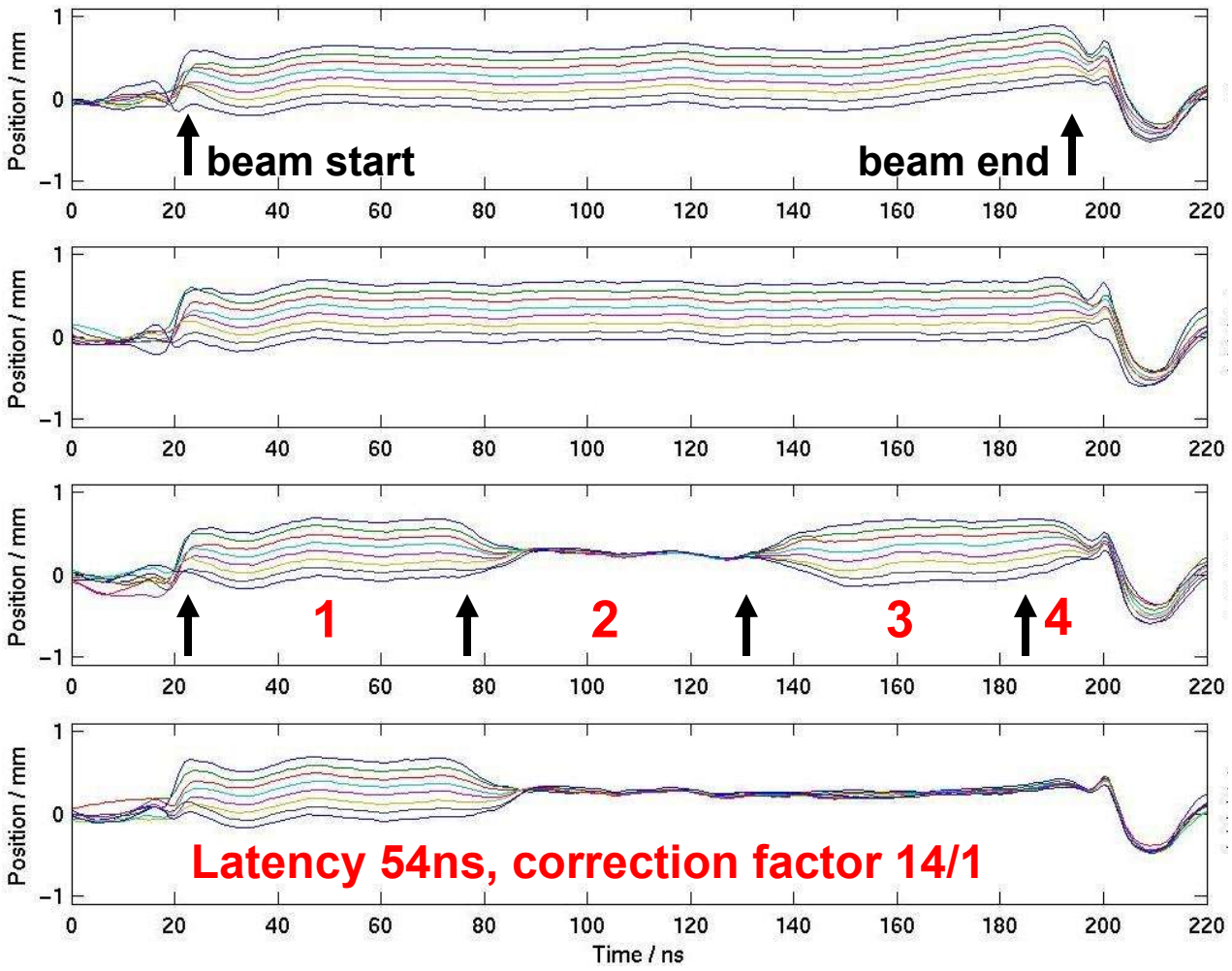


FONT2: amplifier



Bandwidthlimited (30 MHz)

FONT2 results: feedback BPM (Jan 2004)



Beam starting positions

Beam flattener on

Feedback on

Delay loop on

FONT3 Prototype Feedback System

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

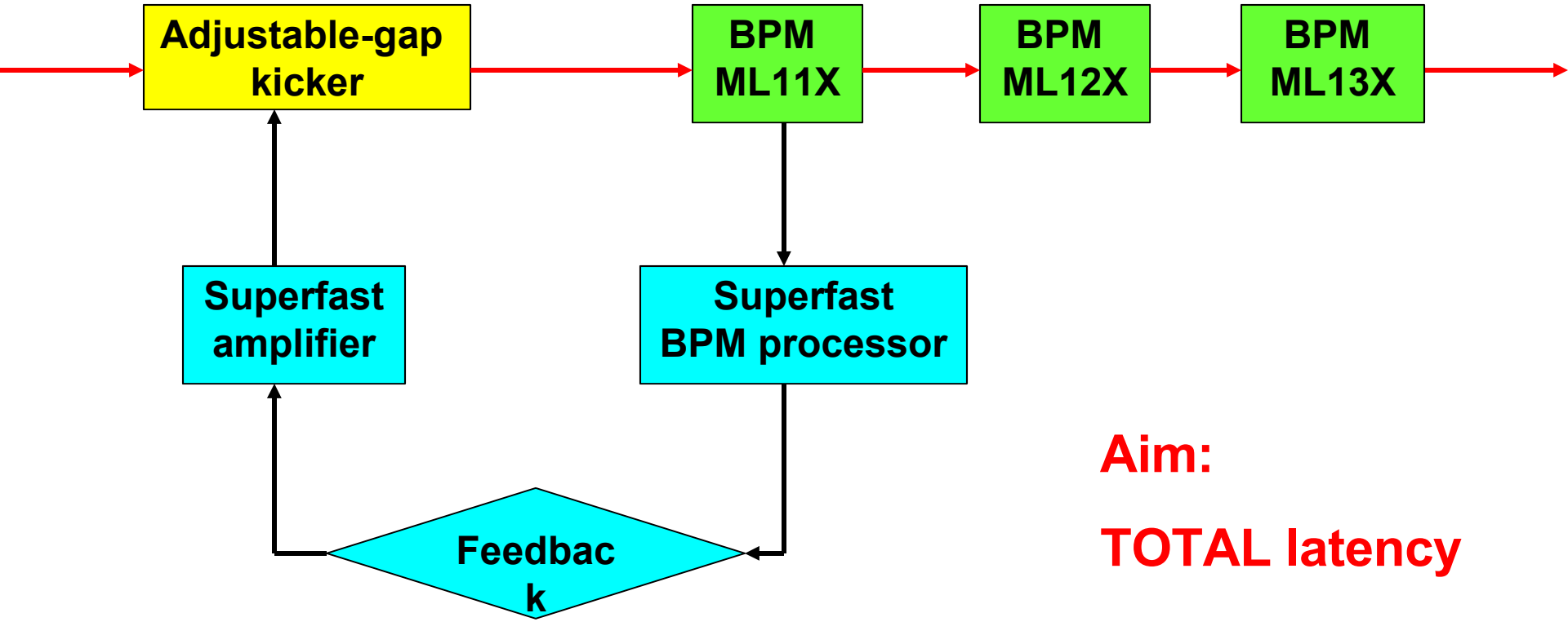
FONT3 (2004-5):

- **3 stripline BPMs**
- **no charge normalisation**
- **analogue signal processor**
- **high power, very fast solid-state amplifier**
- **FEATHER adjustable-gap kicker**

Aiming for ultra-fast demonstration of FB:

- **total latency 20ns (10ns TOF, 10ns electronics)**
- **beam moved by c. 100 um**

FONT3 outline

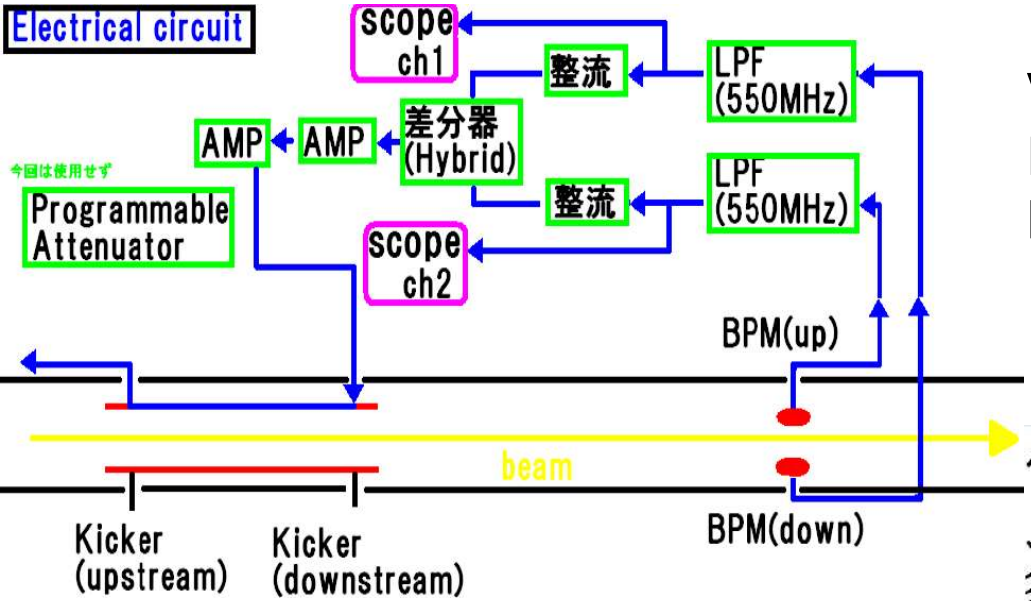


Aim:

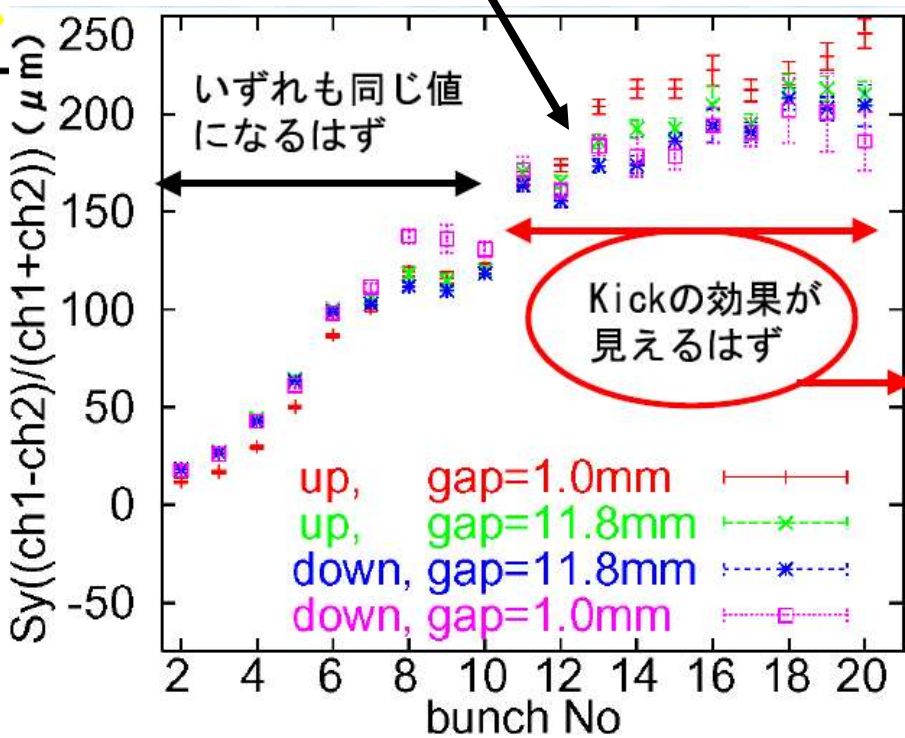
TOTAL latency

< 20 ns

FEATHER



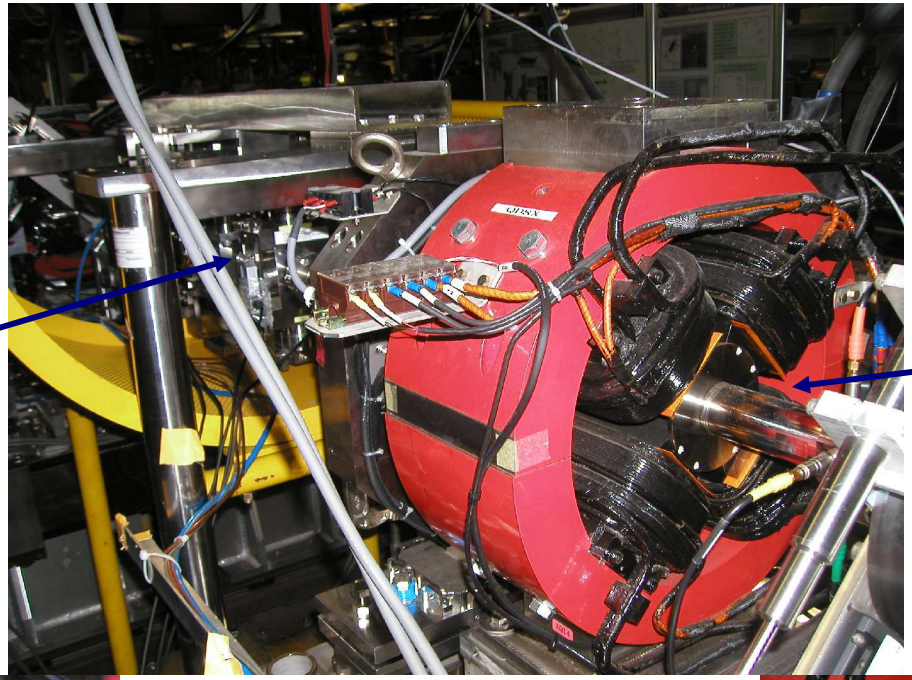
Varied gap between kicker strips: For 1mm gap observed kick after bunch 11 (latency c. 30 ns)



Conceptually similar BPM processor to FONT3

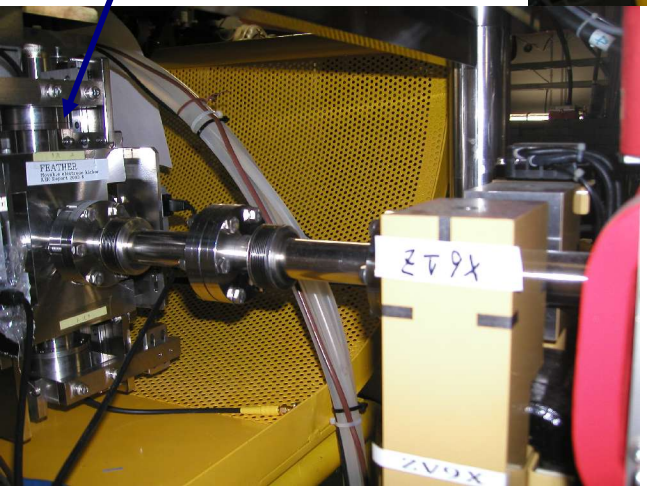
(Fujimoto 2005)

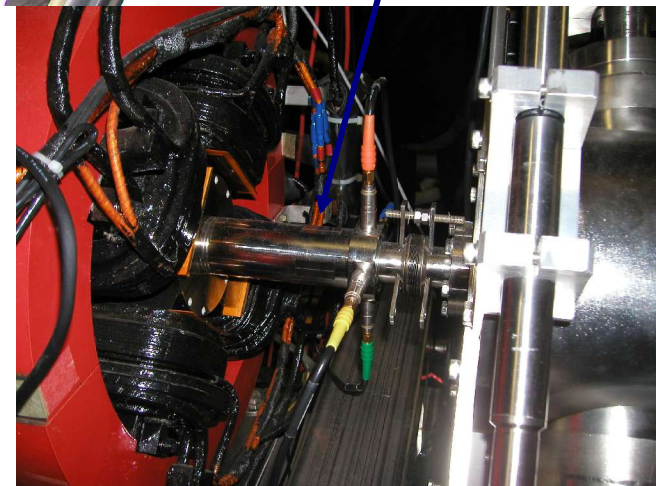
FONT3: beamline configuration



kicker

BPM
ML11X





FONT3: latency budget

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

  Irreducible latency: 10ns

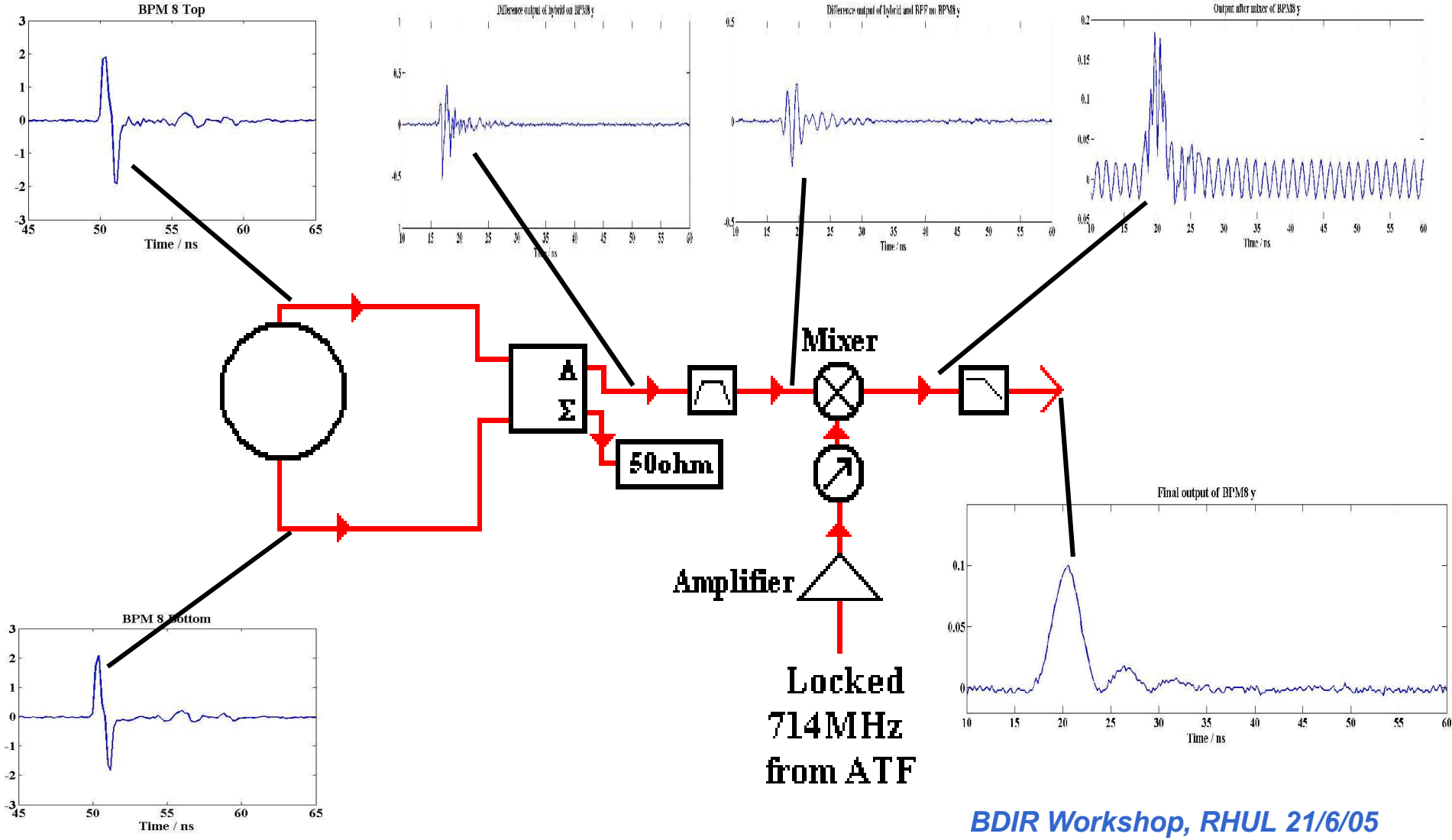
- BPM processor: 5ns
- Amplifier + FB: 5ns

  Electronics latency: 10ns

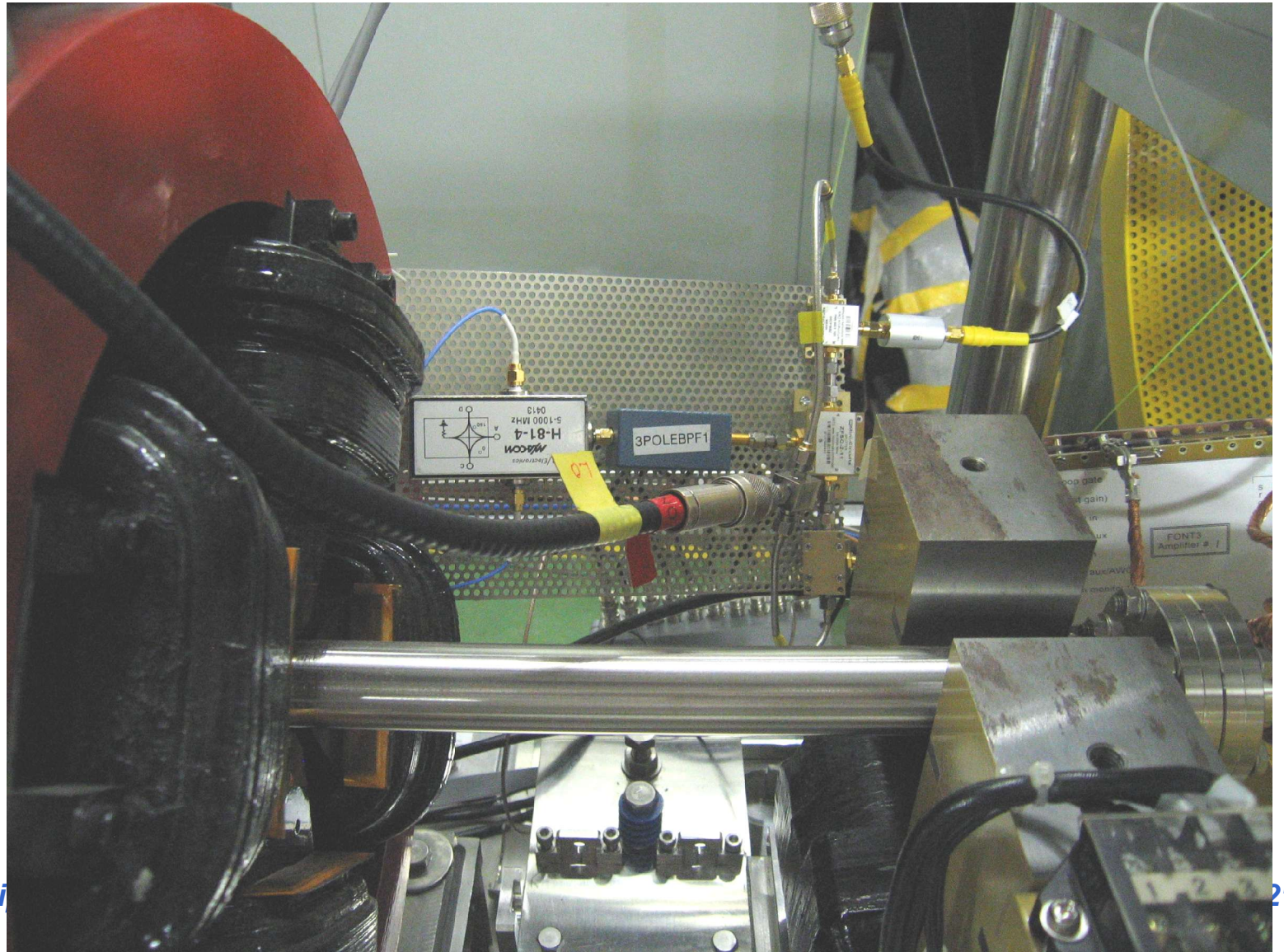
- Total latency budget: 20ns

Will allow 56/20 = 2.8 periods during bunchtrain

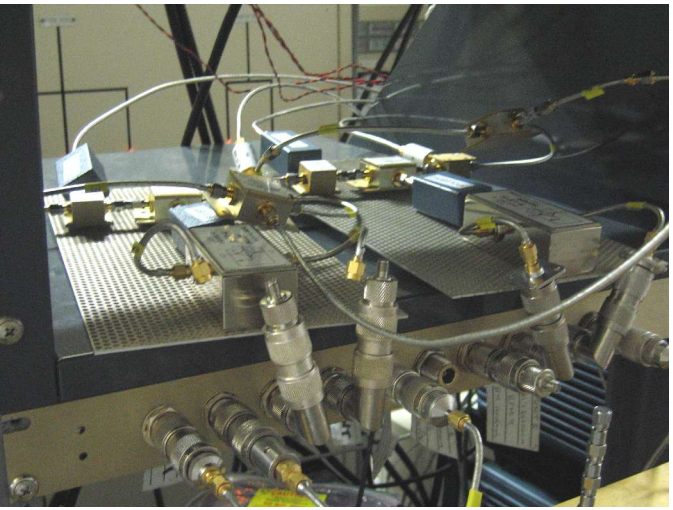
FONT3: BPM processor tests
(single-bunch, December 2004 beam tests)

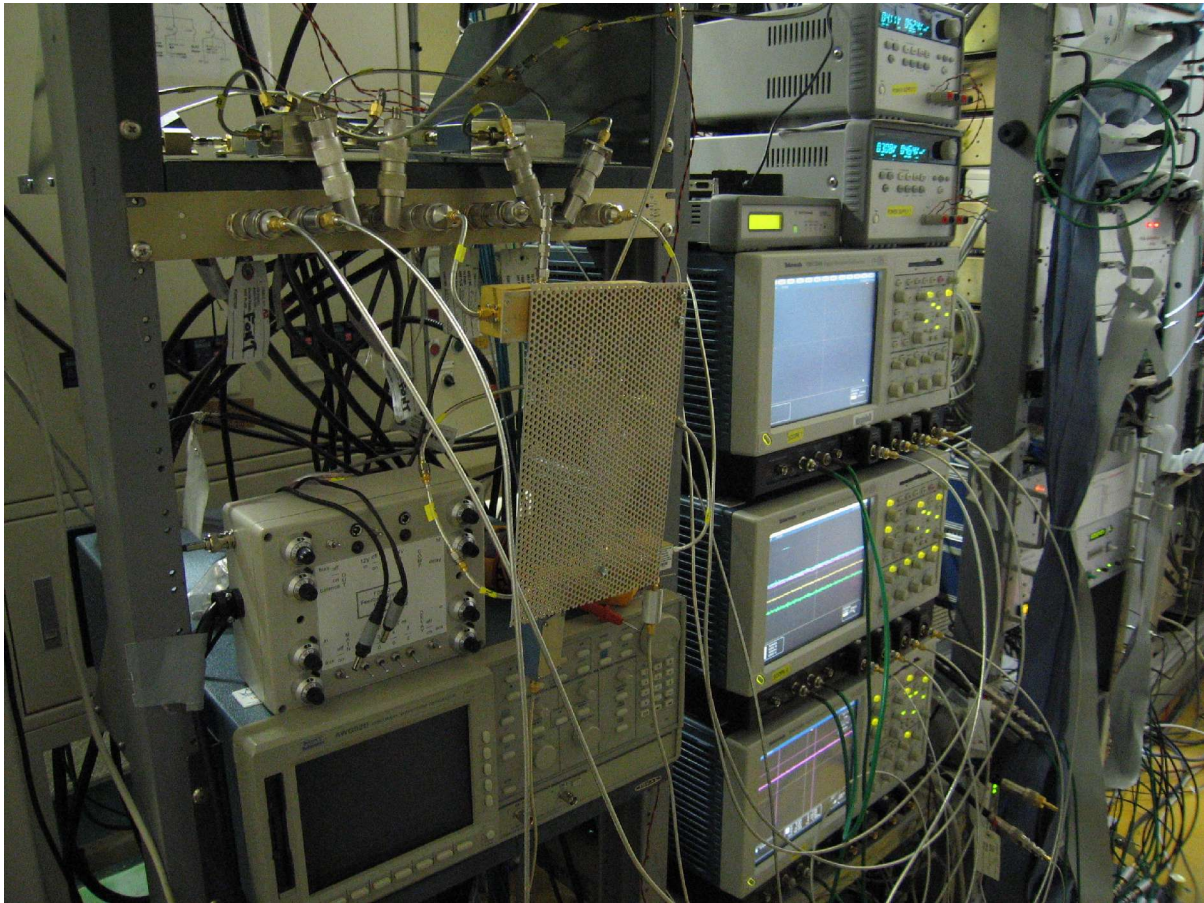


FONT3: BPM processor on beamline



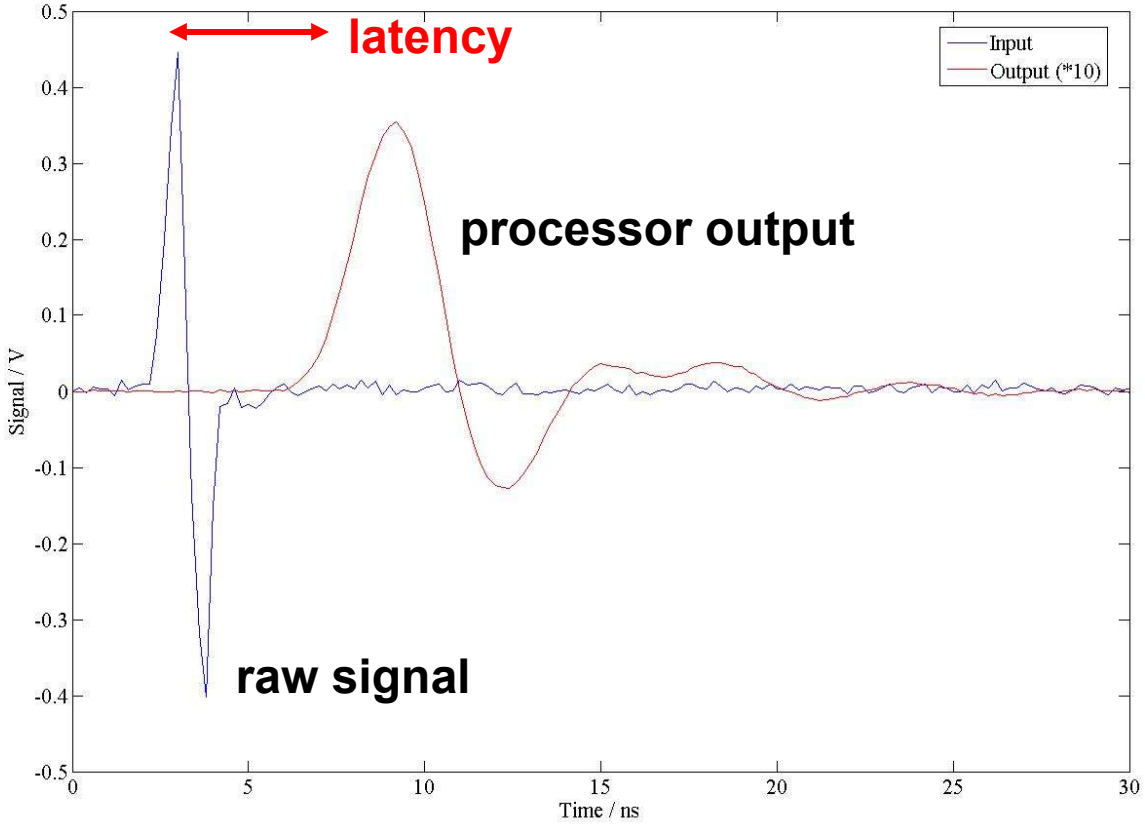
FONT3: external BPM processors



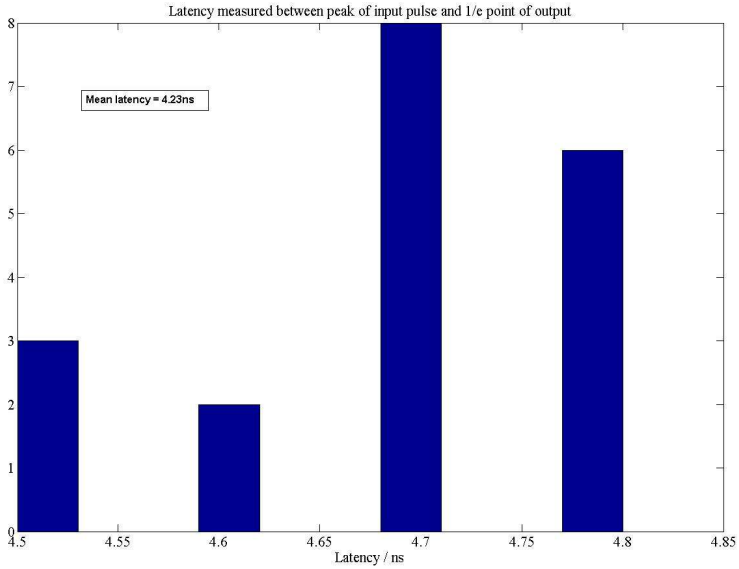


FONT3: BPM processor latency measurement

(single bunch, March 17 2005 beam tests)

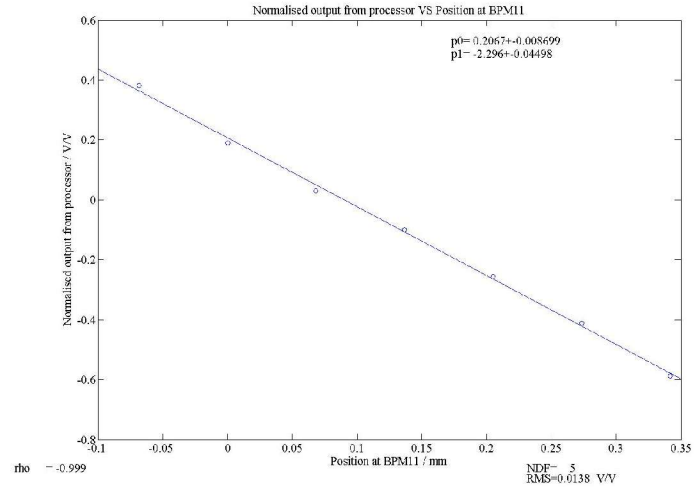


Distribution of latency:



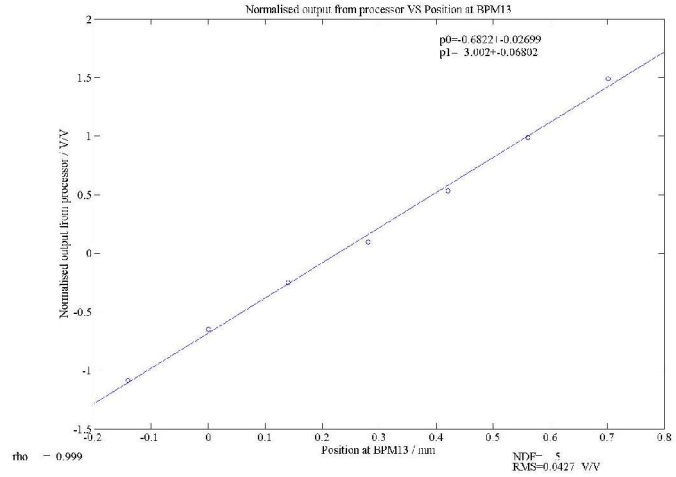
Latency 4.3 ns

FONT3: BPM scale calibration using correctors
(20-bunch data, March 17 2005 beam tests)

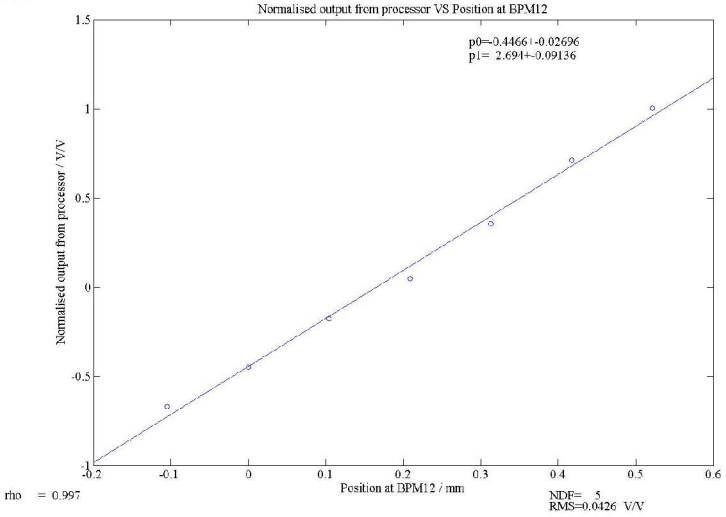


BPM11

BPM12



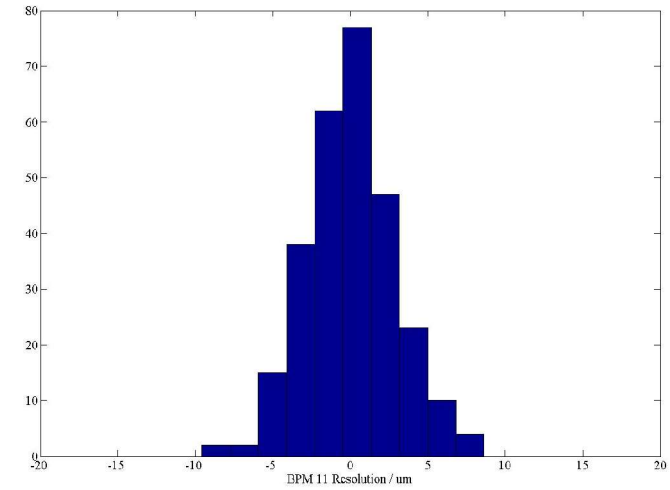
BPM13



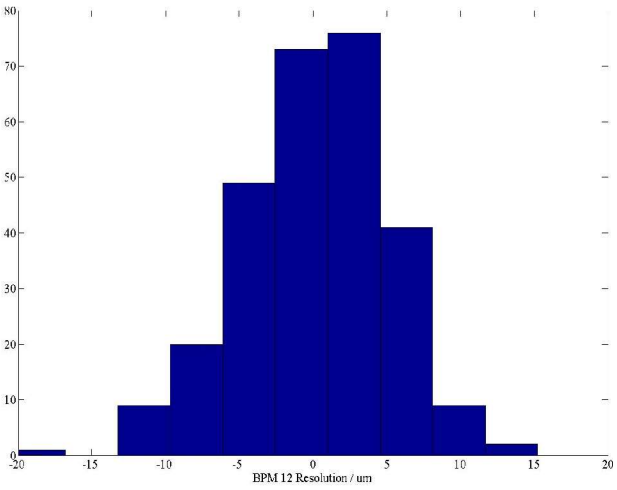
FONT3: BPM position resolution
(20-bunch data, March 17 2005 beam tests)

Distributions of residuals (240 beam pulses):

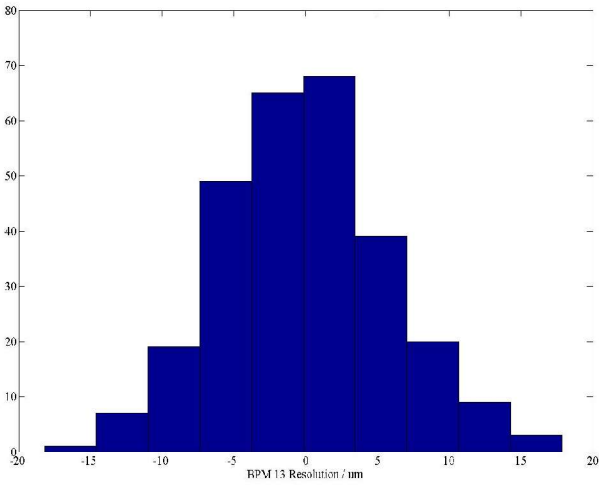
BPM11



BPM12

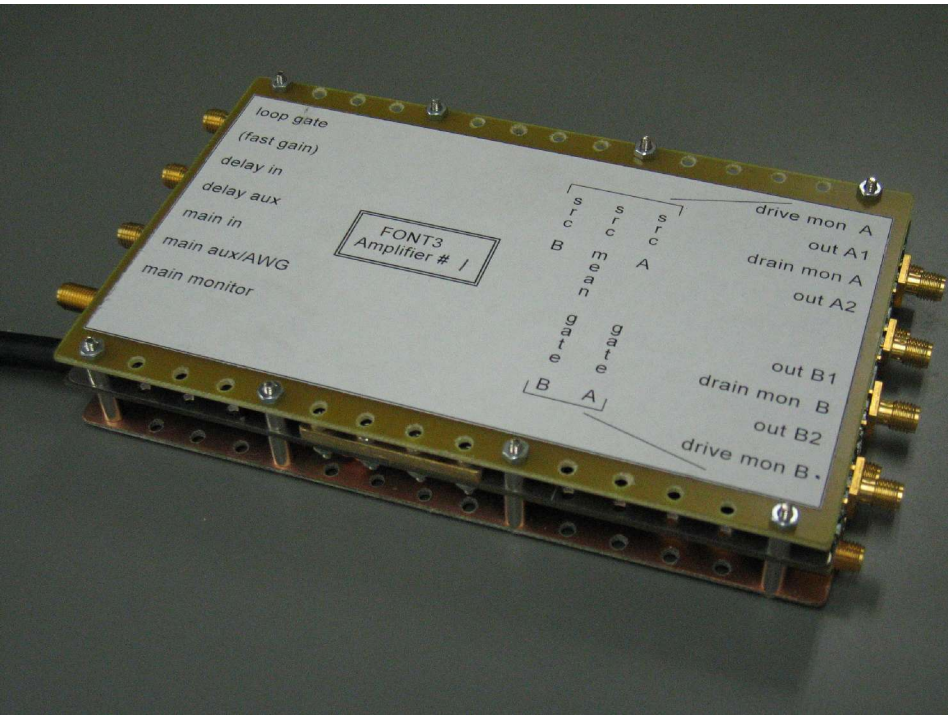


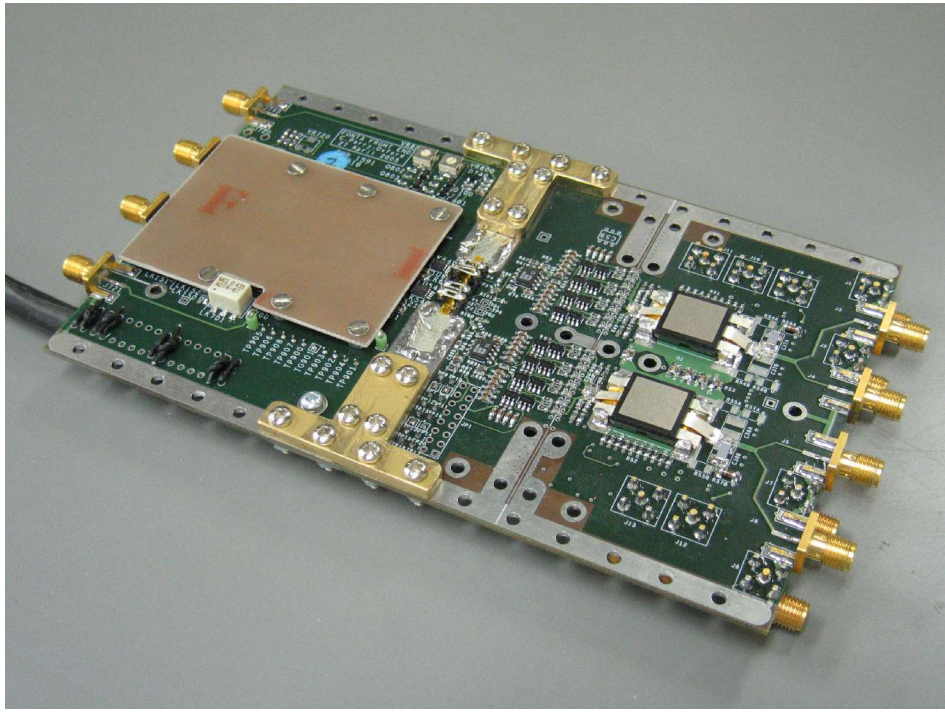
BPM13



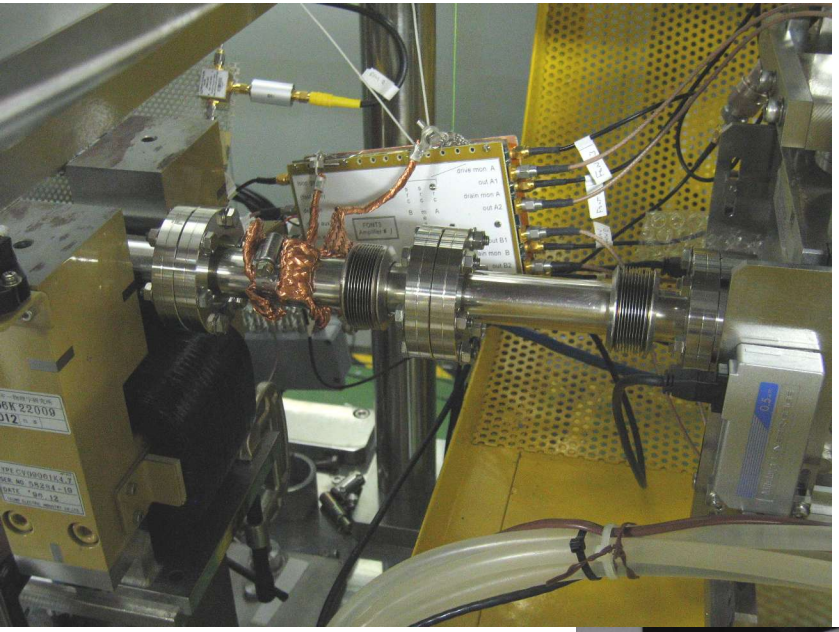
Resolution: 3 - 5 um

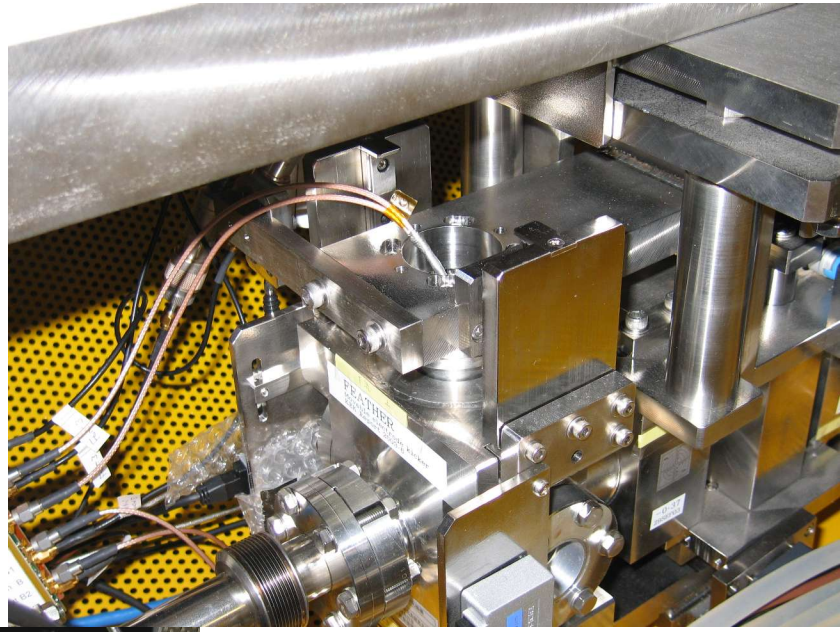
FONT3: Amplifier/Feedback Board

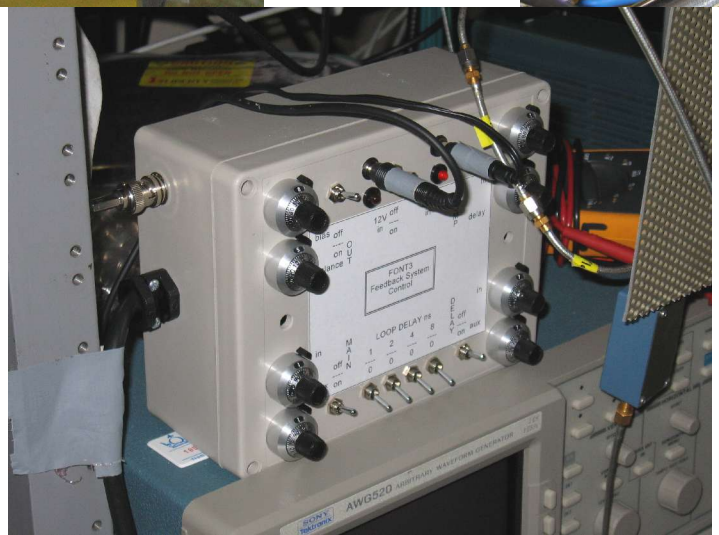




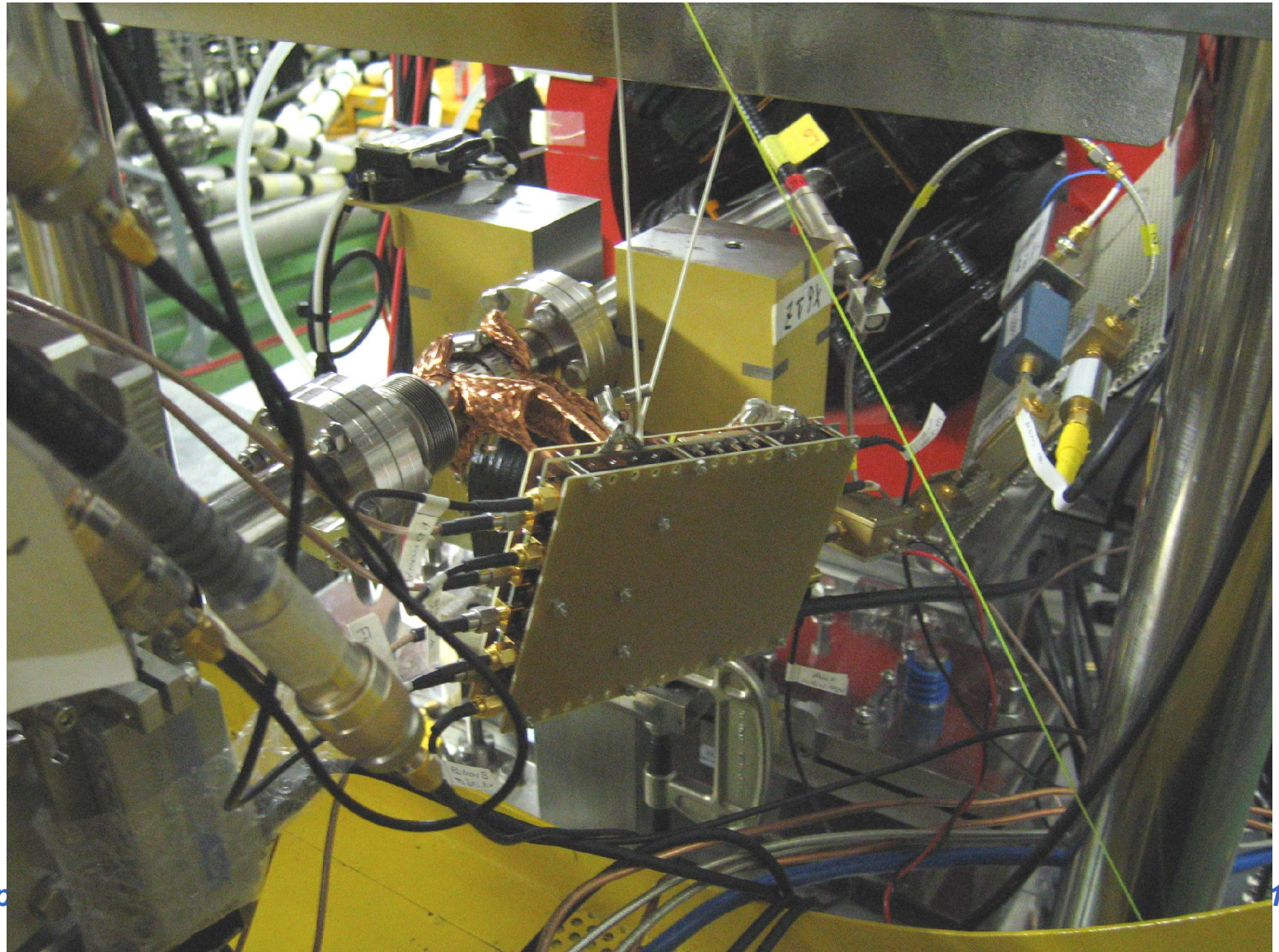
FONT3: Amplifier/Feedback Installation





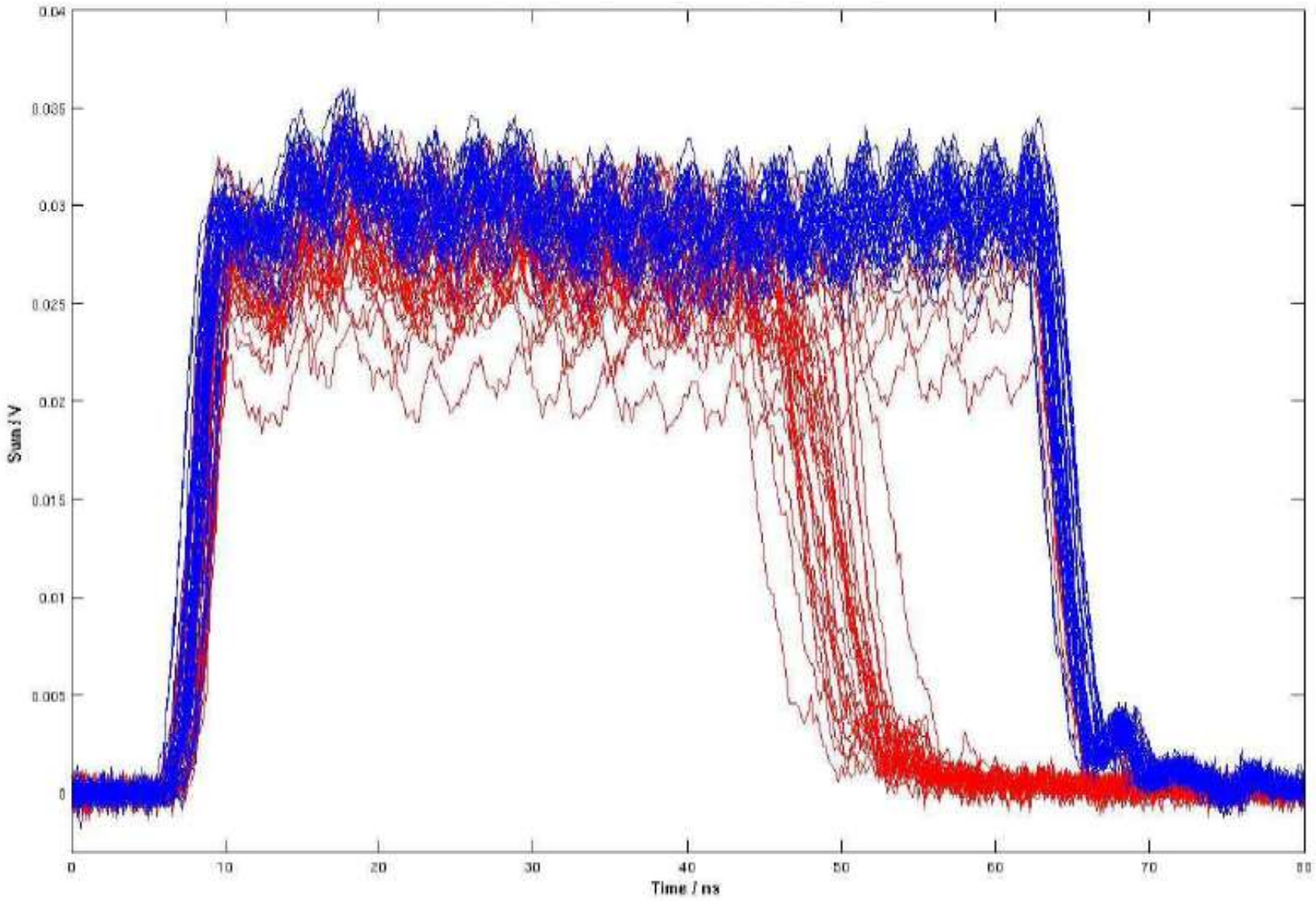


FONT3: Beamline Installation



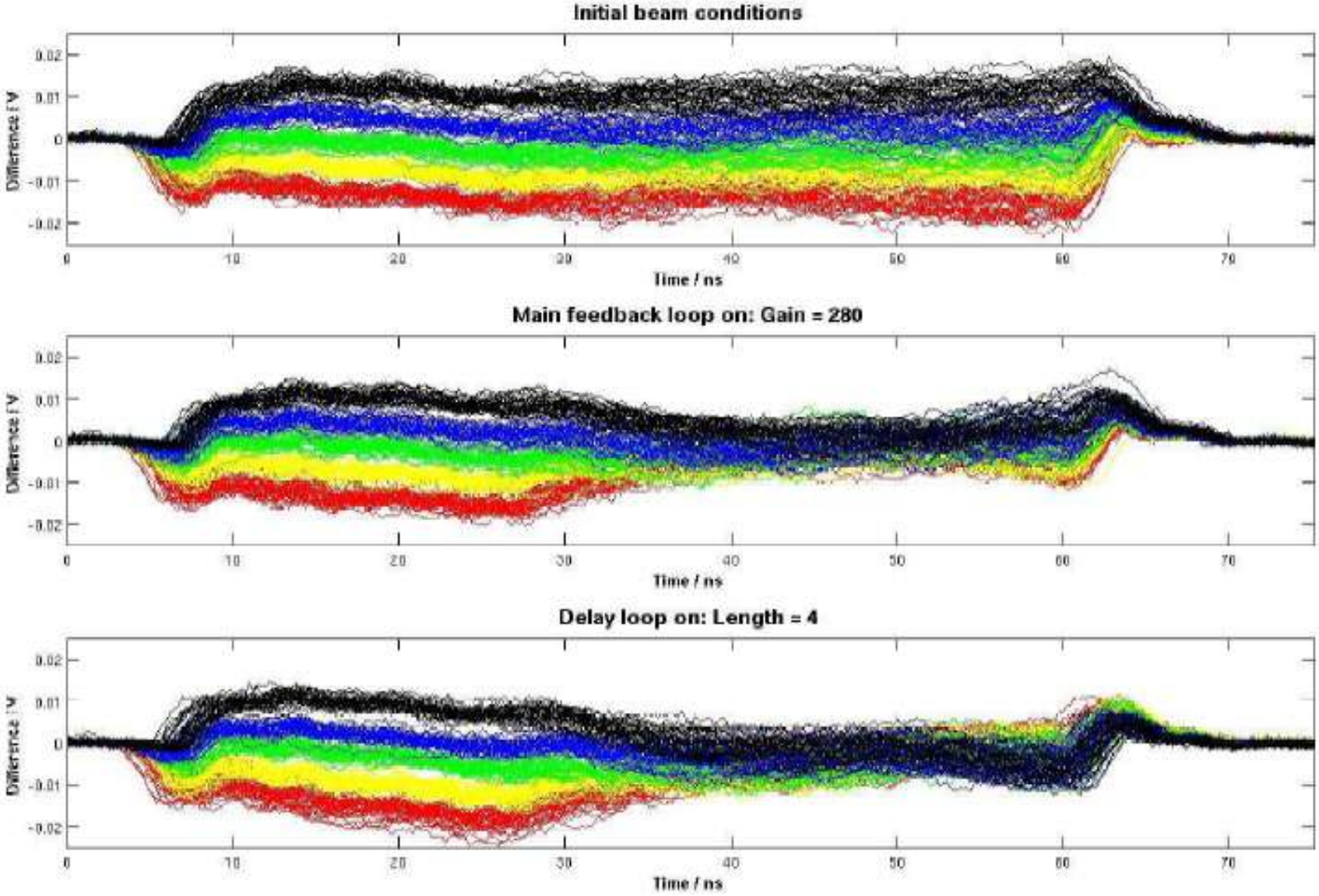
FONT3: Results (June 3 2005)

BPM13 sum signal showing ‘flyers’

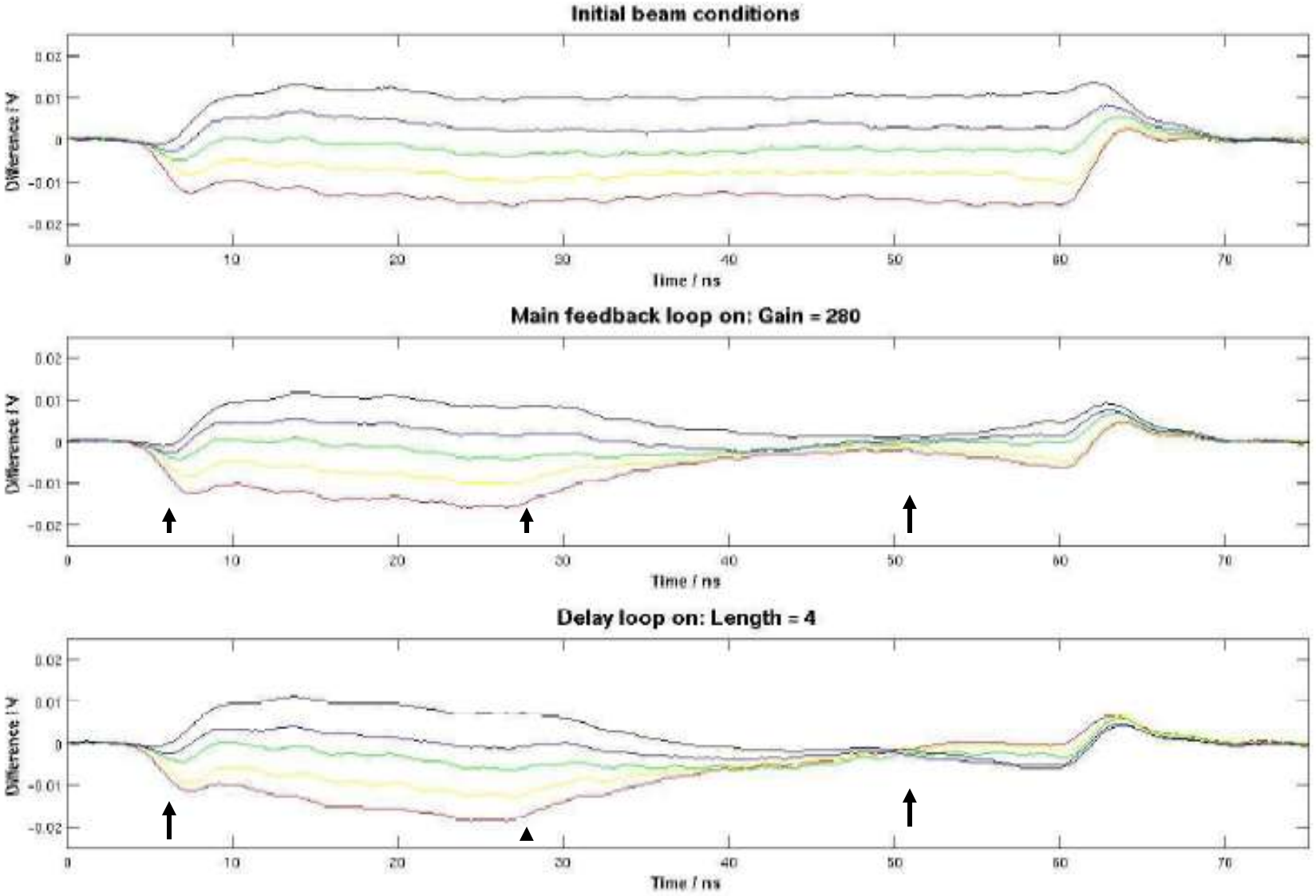


FONT3: Results (June 3 2005)

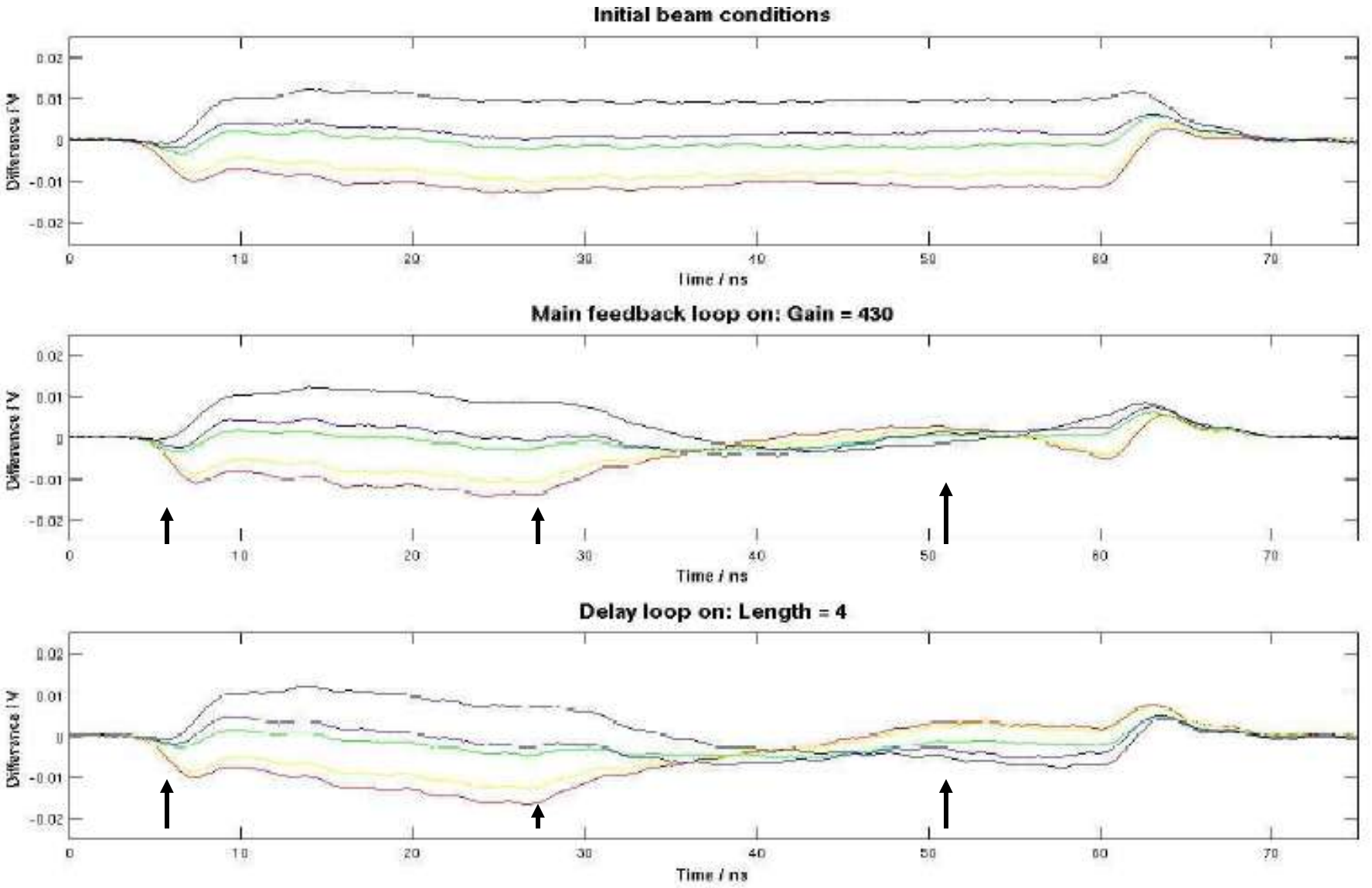
40 pulses per position setting



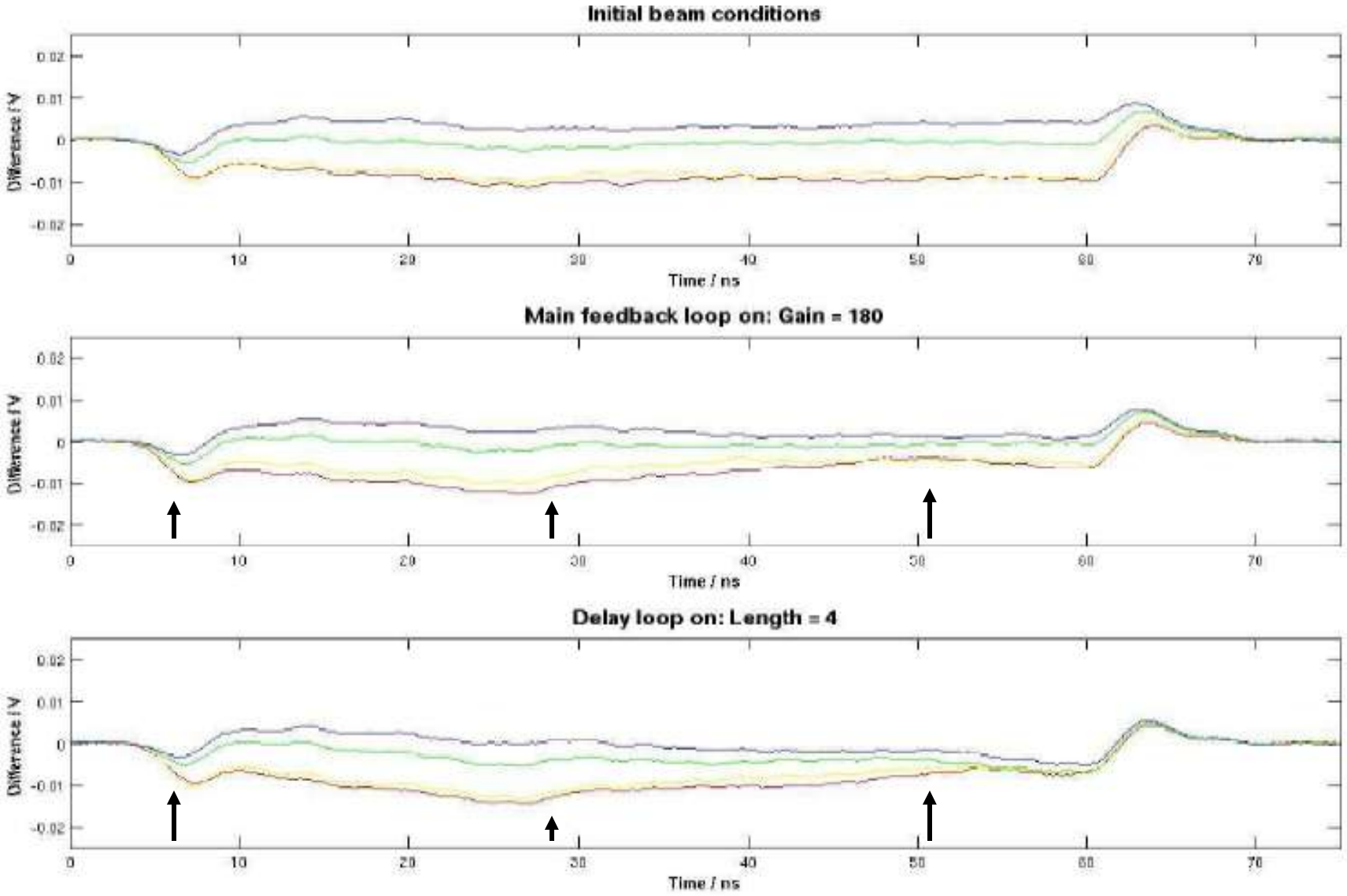
FONT3: Averaged results (flyers rejected)
(nominal gain + delay settings)



FONT3: Averaged results
(HIGH gain, nominal delay settings)

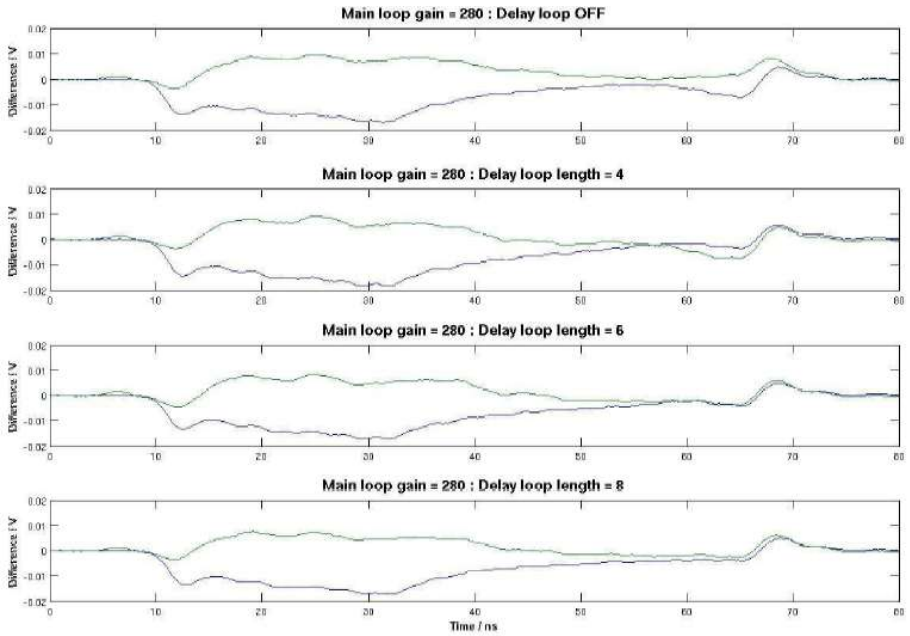


FONT3: Averaged results
(LOW gain, nominal delay settings)

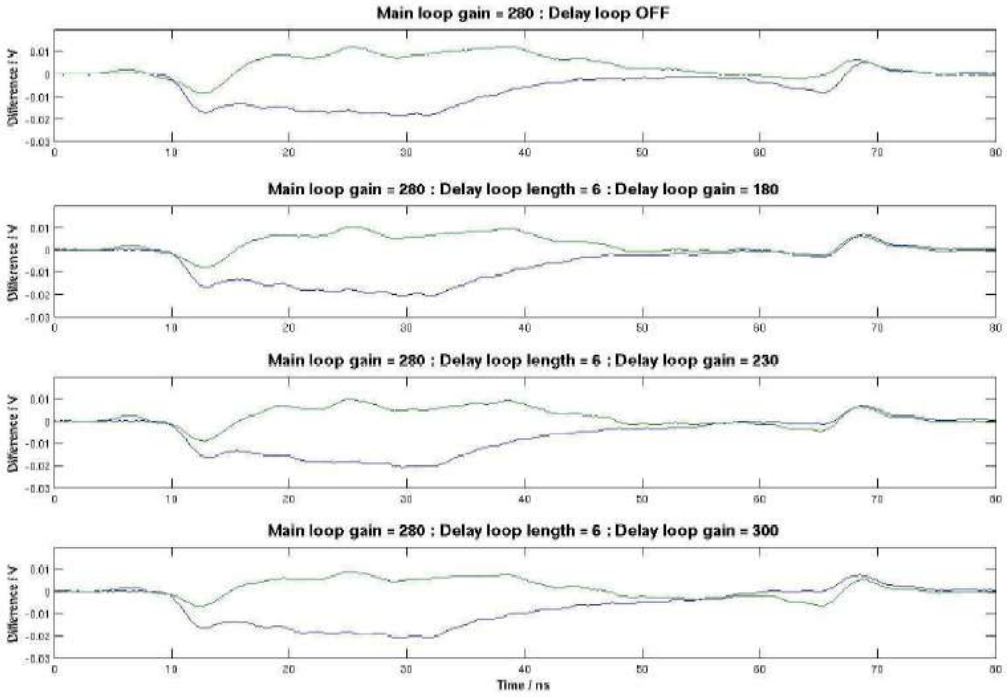


FONT3: Average results
(variation of delay-loop settings)

Delay loop length



Delay loop gain



Philip Burrows

FONT3: Summary

Demonstrated feedback with delay loop

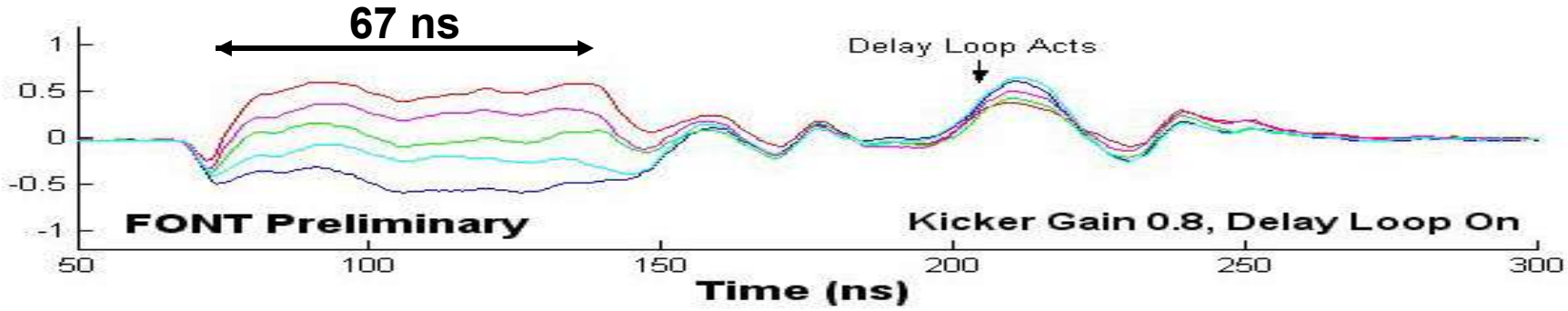
Ultra-fast system: total latency 23 ns

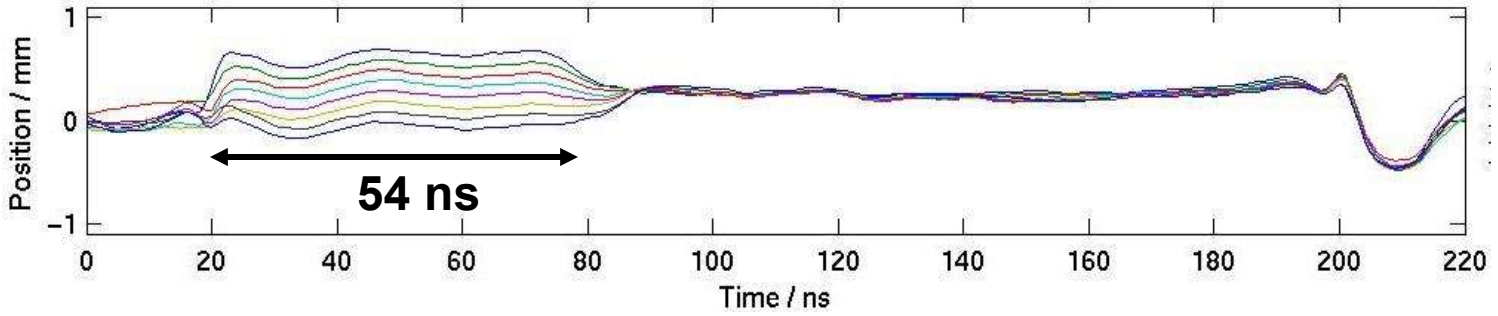
Varied main gain, delay loop length, delay loop gain

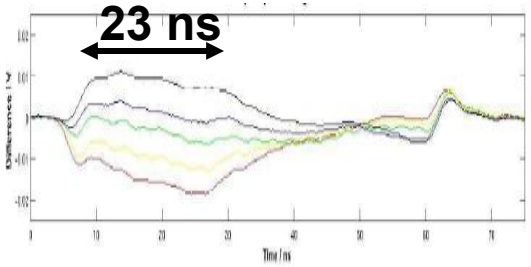
- **system behaves as expected**

Beam quality + limited time (6 shifts) did not allow detailed optimisation of system parameters

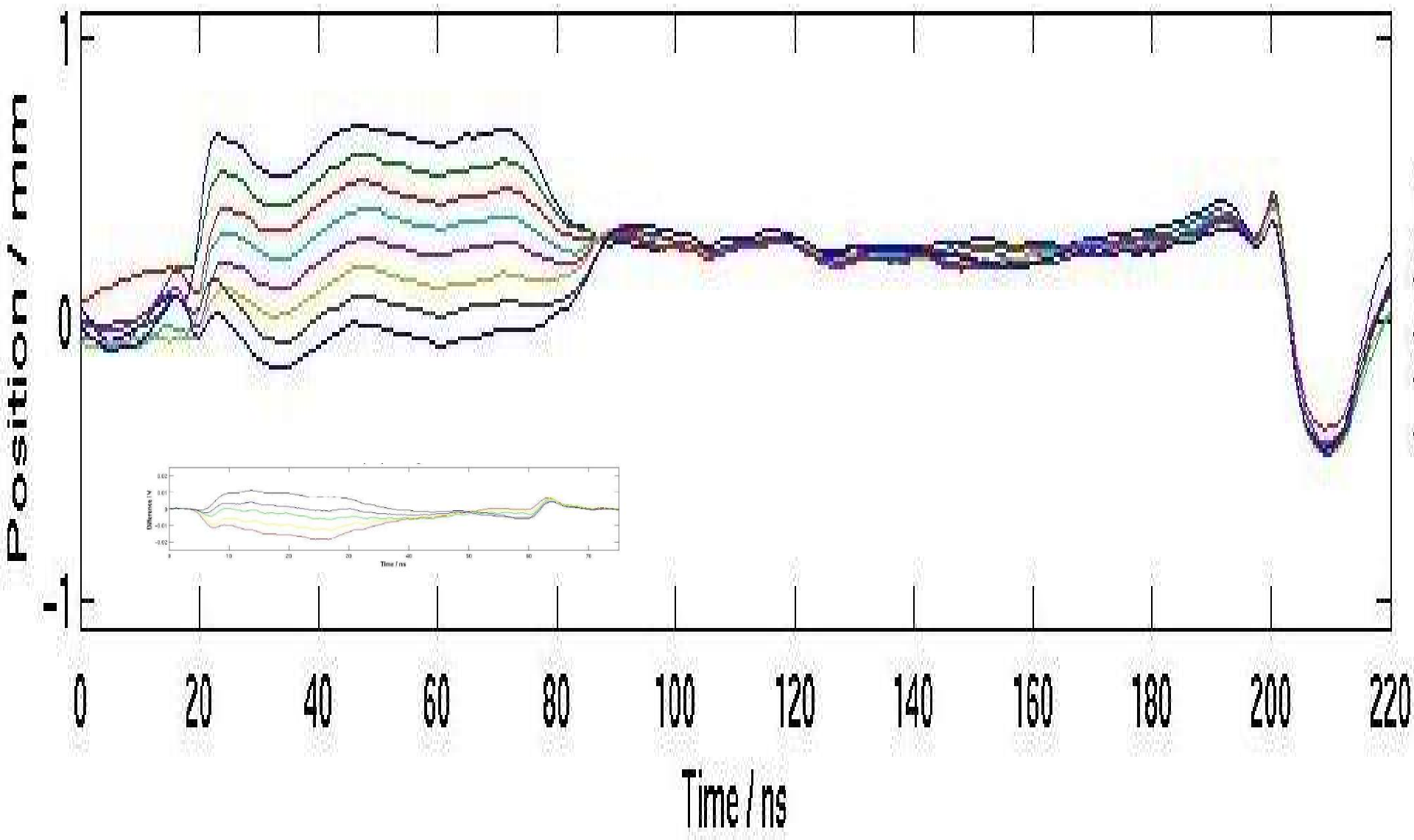
FONT1,2,3: Summary







FONT2,3: Comparison on same scales



FONT4: Prototype Digital Feedback System

ATF: 1.3 GeV beam, 3 bunches with spacing c. 150ns

FONT4 (2005-6):

- modified FONT3 BPM front-end signal processor
- digital FB system
- modified FONT2 solid-state amplifier: 300ns long o/p pulse
- FEATHER adjustable-gap kicker

Aiming for first demonstration of FB w. ILC-like bunches:

- latency 100ns (electronics)
- stabilisation of 3rd bunch at um level

Possible first component tests at ATF December 2005/March 2006

FONT5 Multibunch Feedback System?

ATF: 1.3 GeV beam, 20? bunches with spacing c. 300ns
- depends on success of fast ring extraction program

FONT5 (2007?):

FONT4 with improved digital FB system:

FB algorithm development

adaptive gain

inclusion of feed-forward information

…

Vital component of ATF2 beam stabilisation systems

FONT@ESA

ESA: 30 GeV beam, single bunch

BPM survivability tests (2006-7):

- **produce 'spray beam' to model ILC primary e+e- flux**
- **mechanical mockup of forward material in ILC IR**
- **showering -> secondary e+e- and gammas**
- **irradiate BPM in realistic environment, study:**
  - **noise on direct beam signals**
  - **long-term BPM stability and performance**