Status of IP FB system design

Philip Burrows

Douglas Bett, Glenn Christian, Michael Davis, Alexander Gerbershagen, Colin Perry

John Adams Institute

Oxford University

Robert Apsimon, Ben Constance ***CERN***

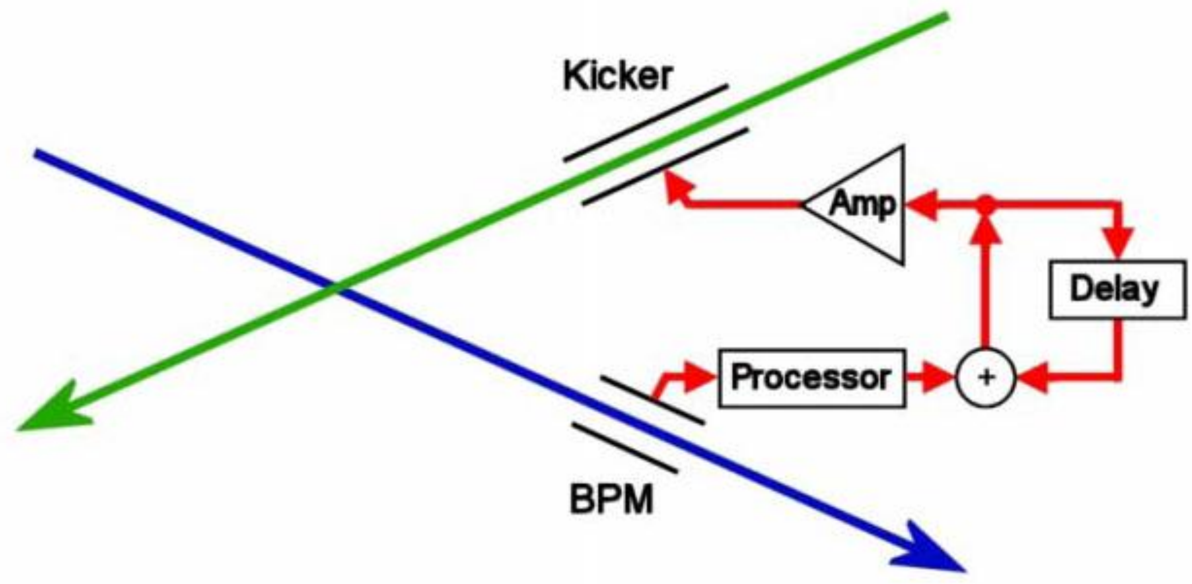
Javier Resta Lopez ***U. Valencia***

Outline

- System concept
- ILC design status
- CLIC design status
- FONT prototype systems performance
- Remaining technical issues
- Recent progress at ATF2

LC 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

IP FB Design Status: ILC

Conceptual design documented in ILC RDR (2007), fleshed out since:

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

More realistic engineering design now in progress for TDP document (2012)

ILC prototype: FONT4 at KEK/ATF

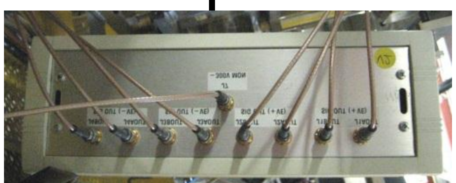
e-

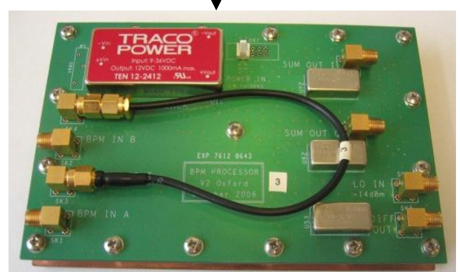
Kicker

BPM 1

BPM 2

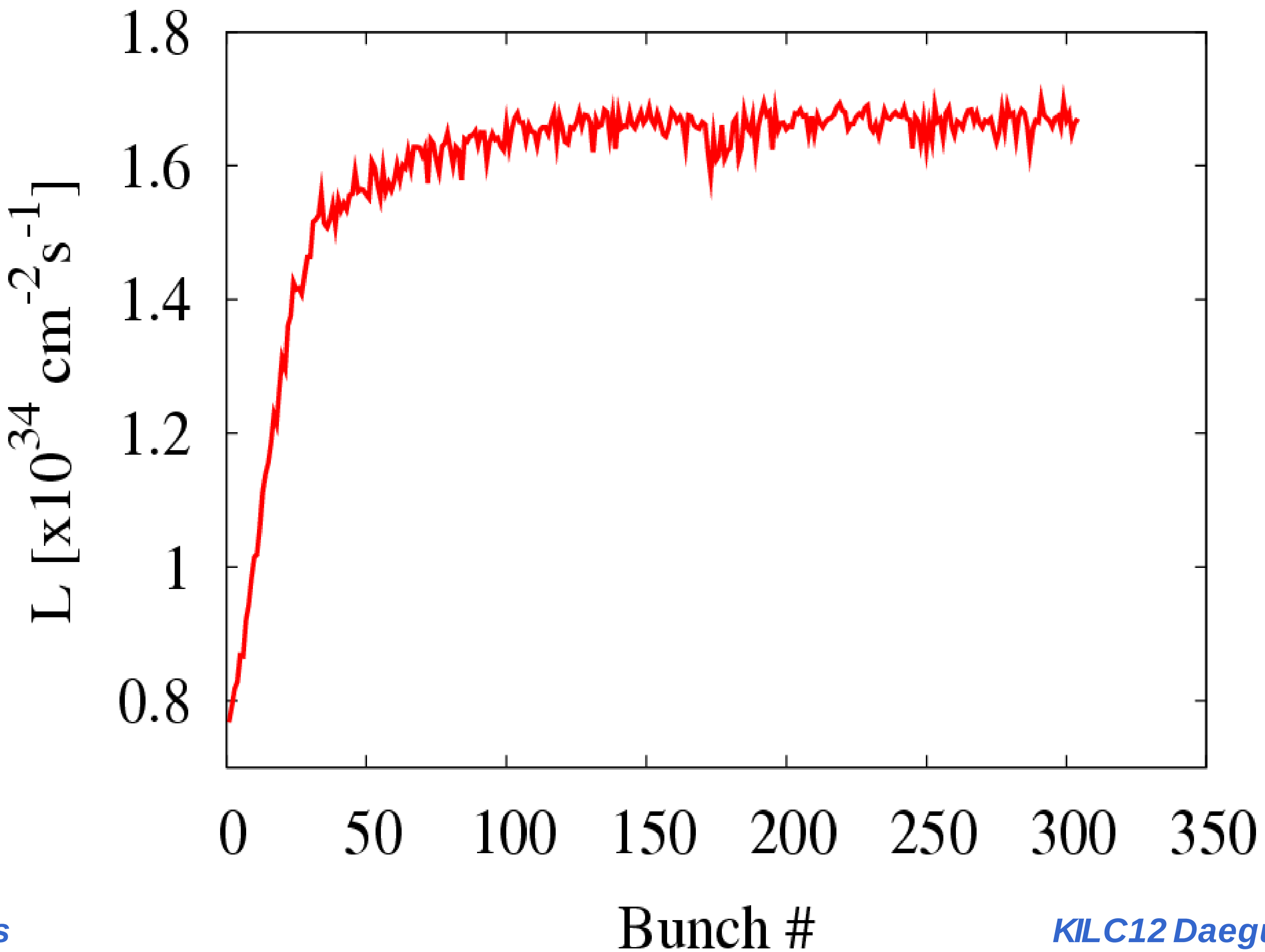
BPM 3





BPM resolution ~ 1um
Latency ~ 130ns
Drive power > +-300nm @ ILC

ILC IP intra-train FB performance



IP FB Design Status: CLIC

Conceptual design developed and documented in CLIC CDR (2011)

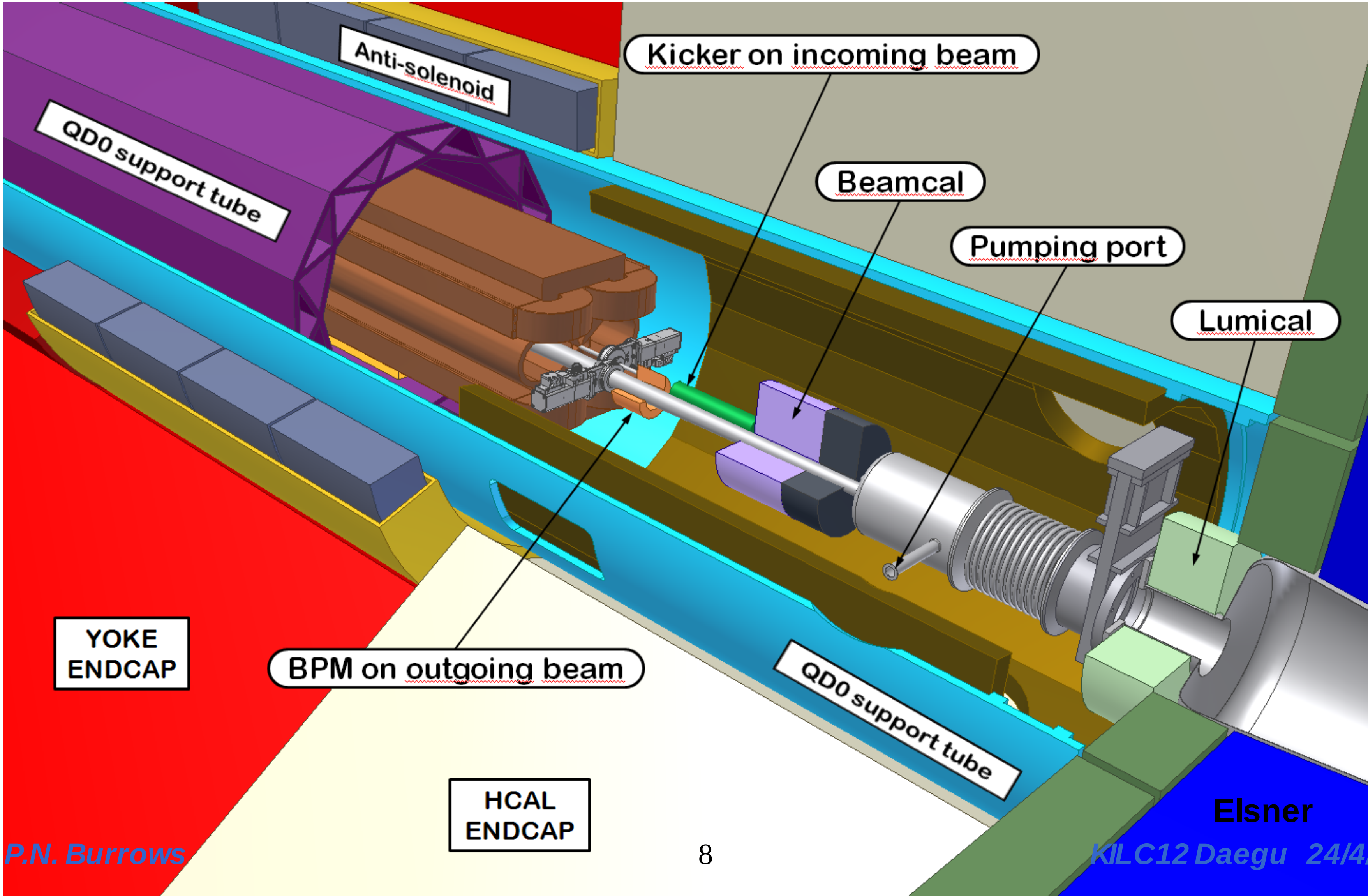
NB primary method for control of beam collision overlap is via vibration isolation of the FF magnets, and dynamic correction of residual component motions

IP position feedback:

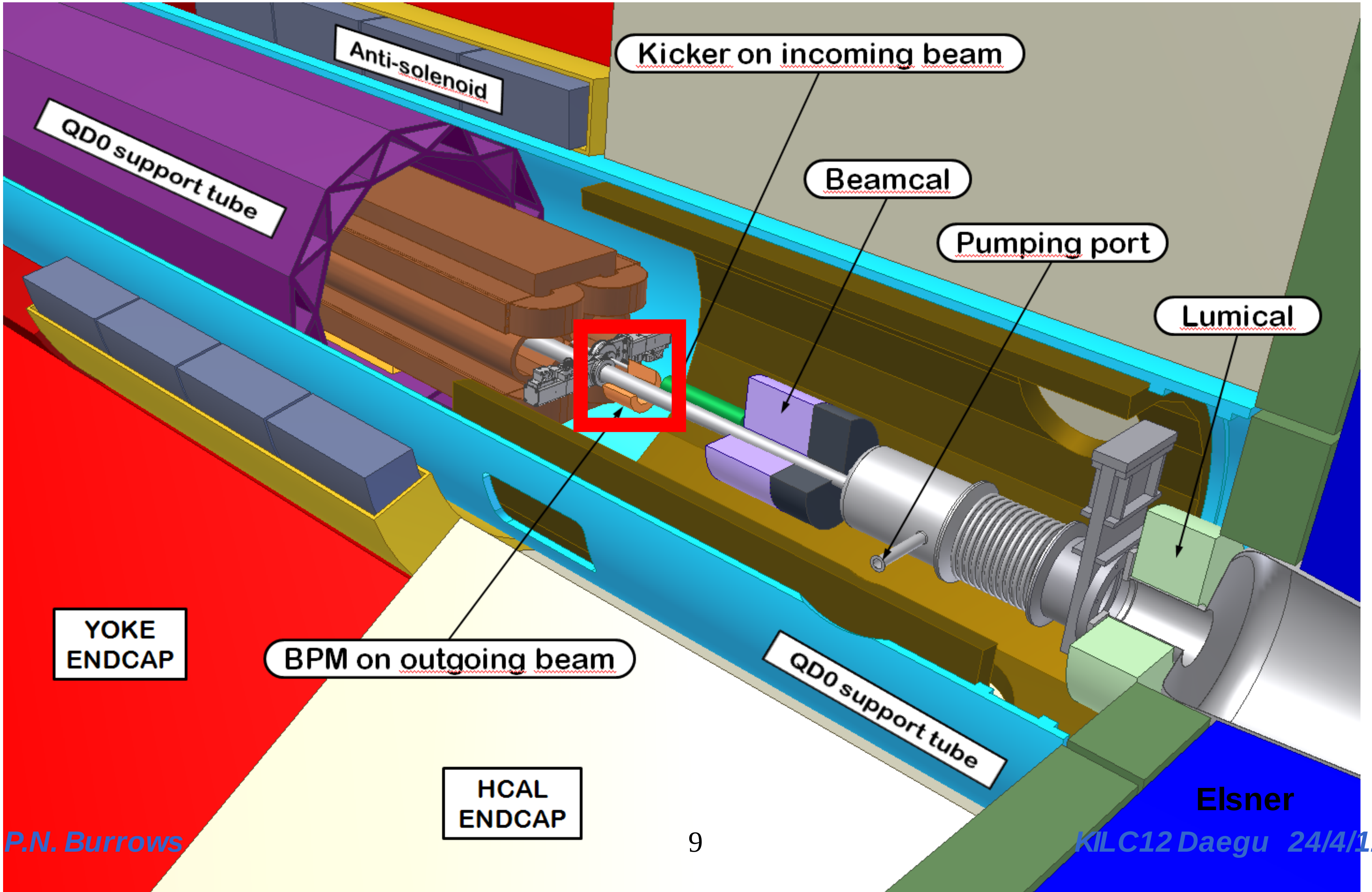
provide IP beam position correction of +- 50 nm of vertical beam motion

More realistic engineering design can be developed in next project phase

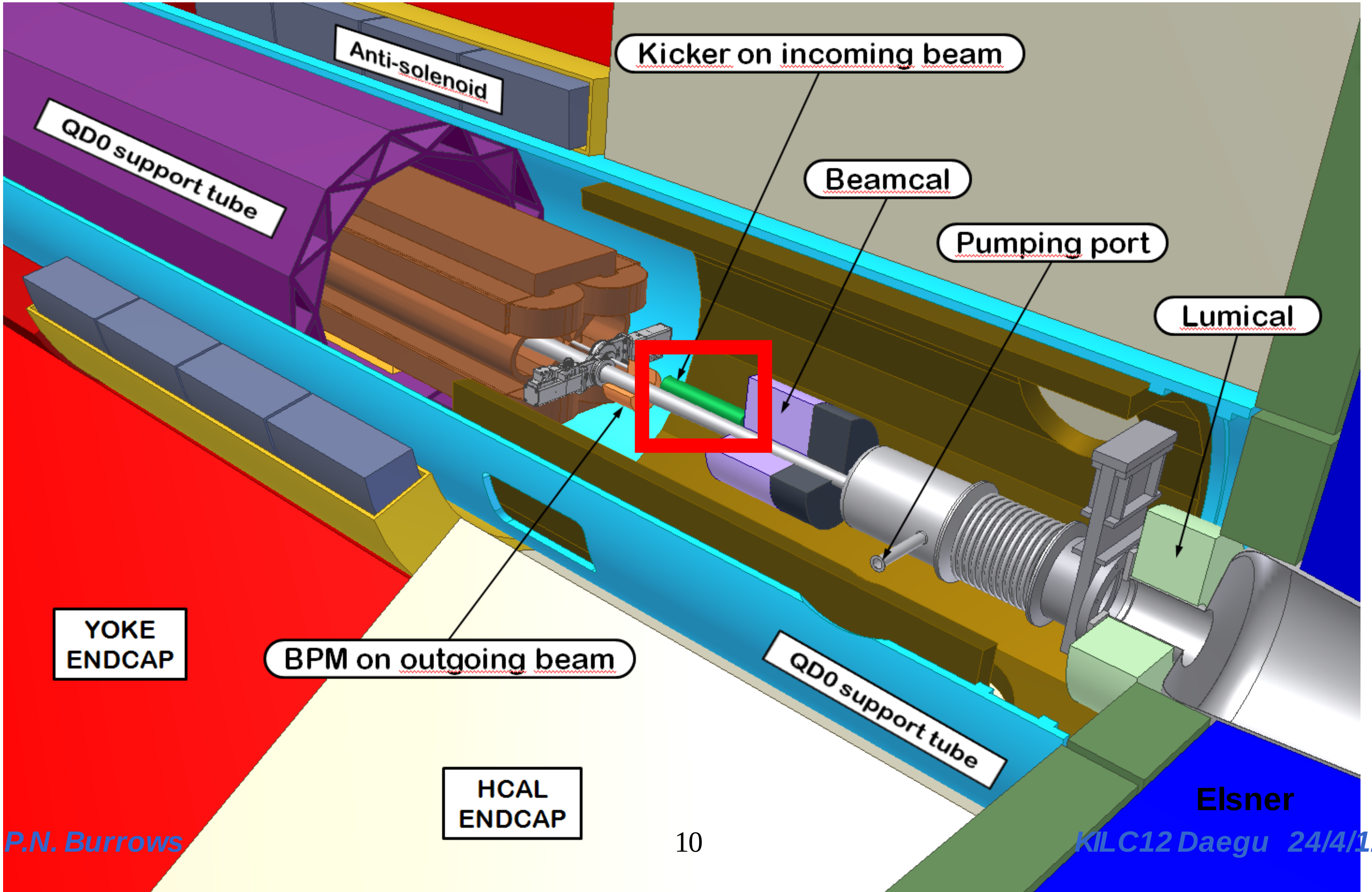
CLIC Final Doublet region



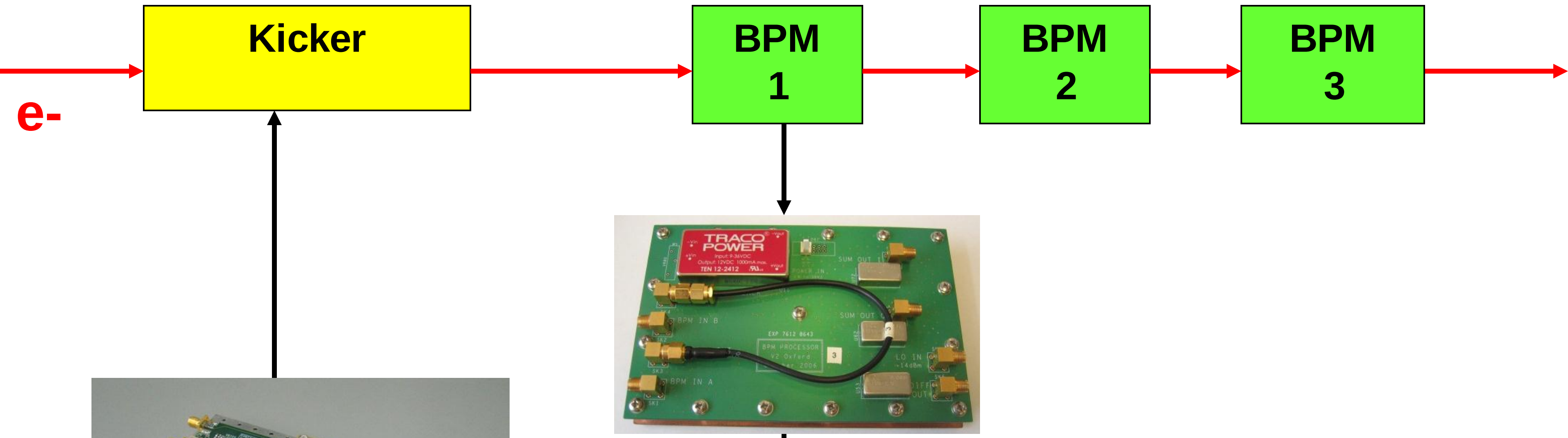
CLIC Final Doublet region

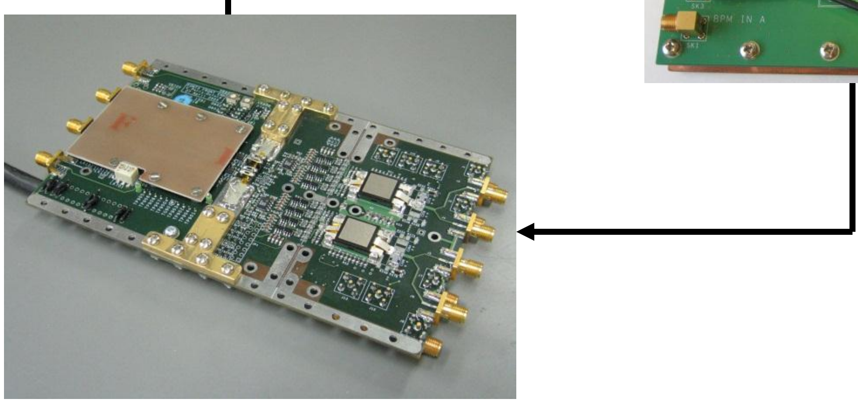


CLIC Final Doublet region



CLIC prototype: FONT3 at KEK/ATF



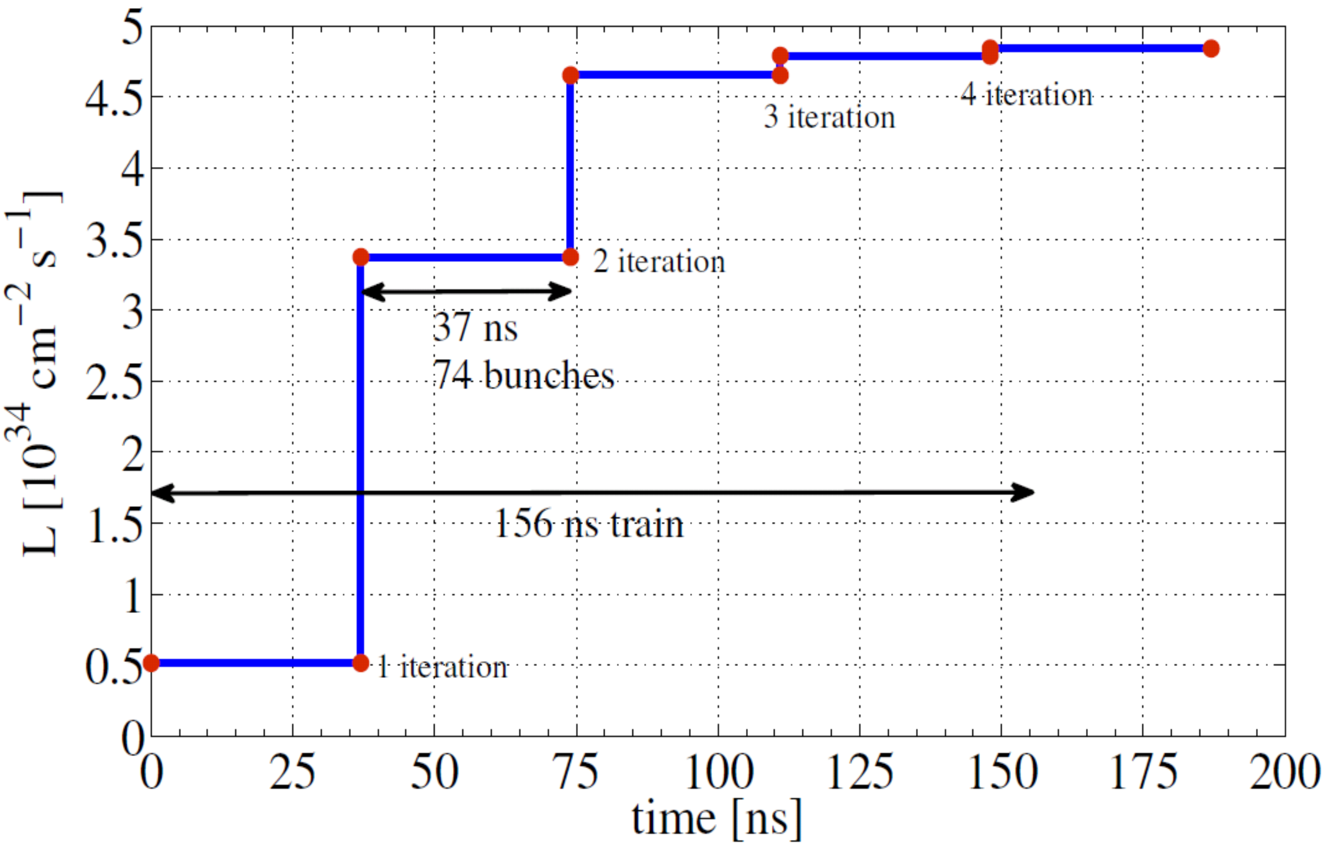


BPM resolution ~ 1um
Latency ~ 23ns
Drive power > +-50nm @ CLIC

Luminosity performance with IP FB

Resta Lopez

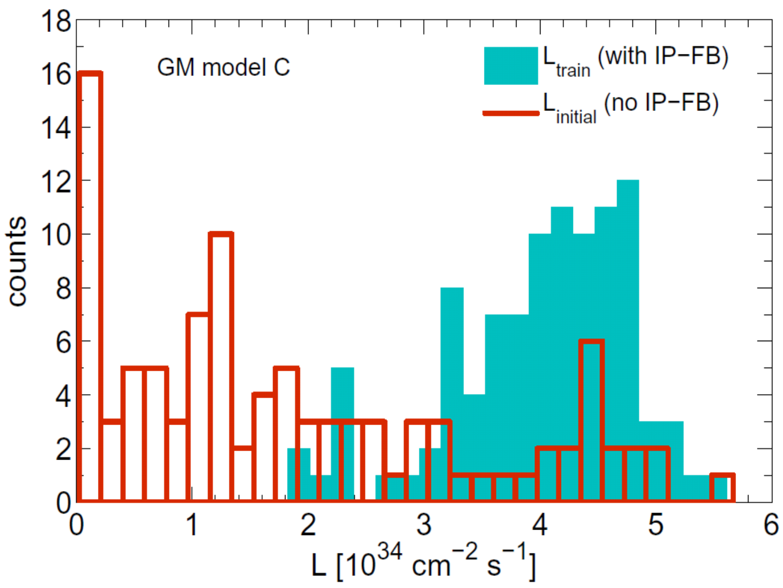
Simulation time structure:
Example applying a single random seed of GM C

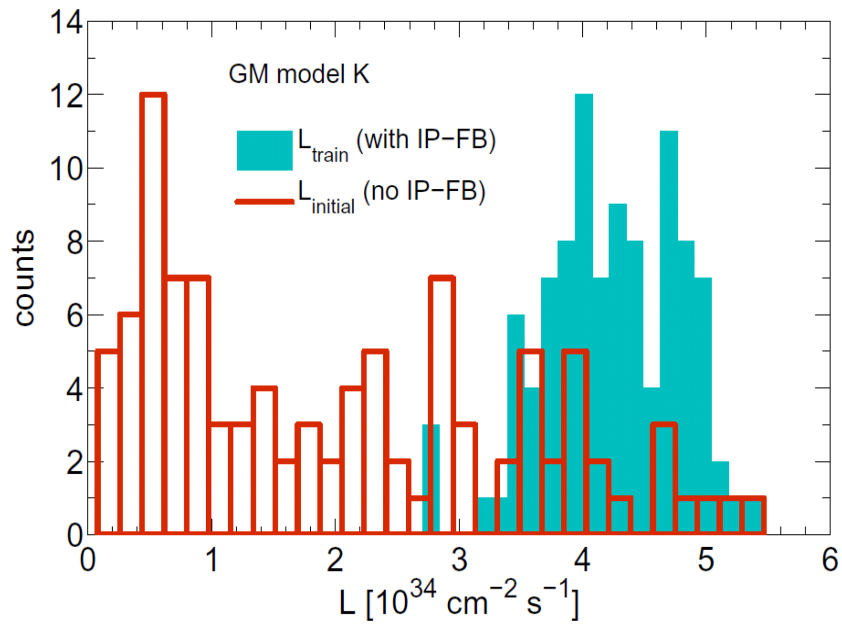


Luminosity performance with IP FB

Resta Lopez

For noisy sites:





Model C:

- Without any correction: mean $\square L/L_0 \square_{train}$=30.52%
  & High standard deviation!
- With IP-FB: mean $\square L/L_0 \square_{train}$=64.15%
  std reduced by a factor 2

Model K:

- Without any correction: mean $\square L/L_0 \square_{train}$=32.53%
  & High standard deviation!
- With IP-FB: mean $\square L/L_0 \square_{train}$=67.82%
  std reduced by a factor 3

Remaining technical issues

- **Engineering of real hardware optimised for tight spatial environment: BPM, kicker, cables …**
- **Large (and spatially-varying) B-field → operation of ferrite components in kicker amplifier?!**
- **Further studies of radiation environment for FB system:**

  was studied for ILC, so far preliminary for CLIC;

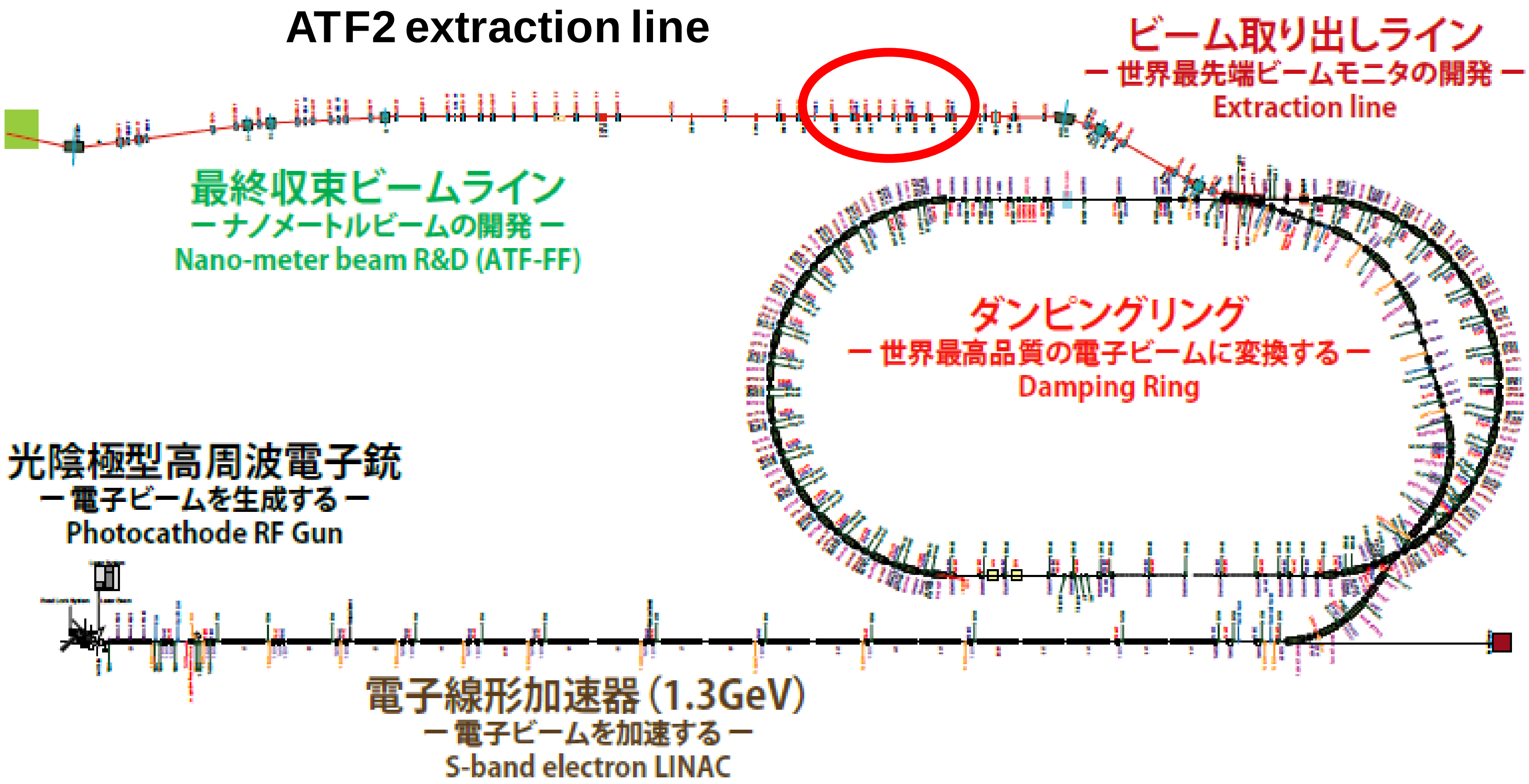
  where to put electronics?

  need to be rad hard? shielded?

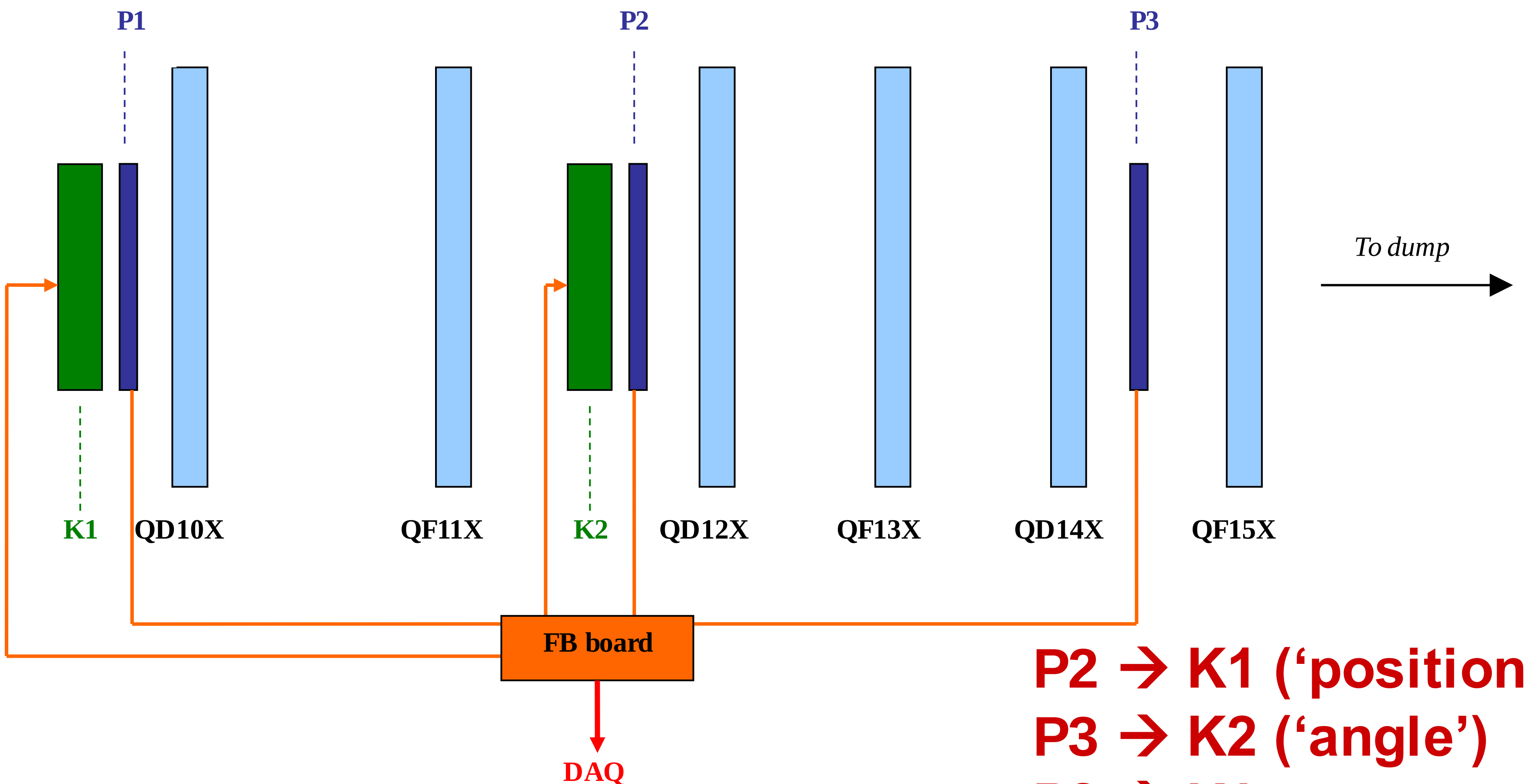
- **RF interference: beam ←→ FB electronics**

  kicker ←→ detector

FONT5 location

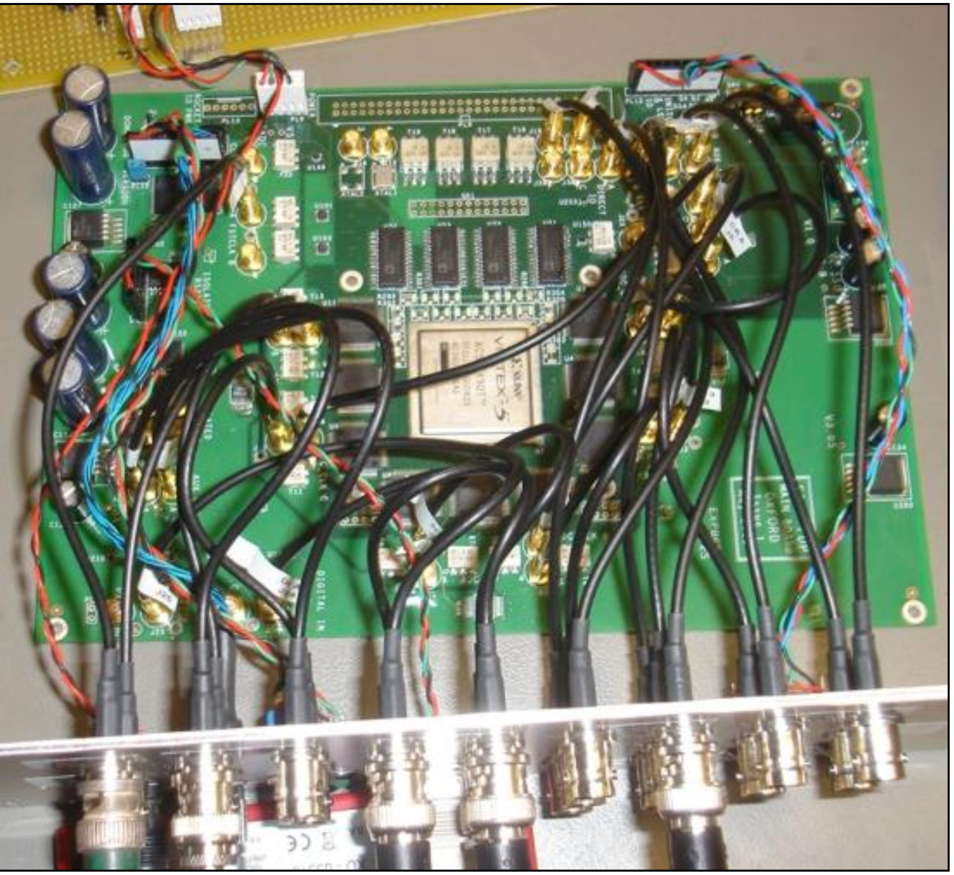


FONT5 setup



P2 → K1 (‘position’)
P3 → K2 (‘angle’)
P3 → K1
P2 → K2

FONT5 digital FB board



Xilinx Virtex5 FPGA

9 ADC input channels (TI ADS5474)

4 DAC output channels (AD9744)

Clocked at 357 MHz phase-locked to beam

4x faster than FONT4

Ongoing R&D

- **Improving BPM resolution:**

  Robert Apsimon PhD thesis

- **Understanding/improving FB performance:**

  further DR extraction kicker timing studies

  monitoring downstream BPMs + jitter tracking

  Douglas Bett PhD thesis

- **Design of an IP feedback system:**

  Michael Davis PhD thesis

Winter programme 2011-12

- Nov/Dec: 2 dedicated shifts in each of 3 weeks
- March/April: 2 shifts in each of 2 weeks

1) setup, commissioning, BPM resolution,

DR extraction kicker timing studies w. 2 bunches

2) re-establish FB, loop/gain studies

3) FB optimisation,

downstream stripline BPM + OTR monitoring,

simultaneous logging of cavity BPM data

BPM processor resolution tests

- **3 BPM processors (5,7,10) on BPM P2**

25/10/11 8-hour shift:

0.55 0.56 0.60 μm

0.56 0.54 0.51 μm

0.53 0.40 0.35 μm

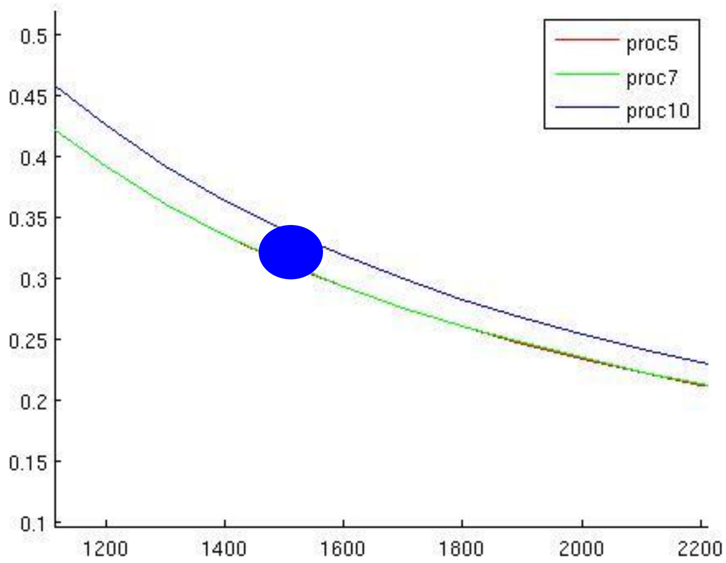
0.50 0.35 0.33 μm

0.45 0.44 0.35 μm

0.50 0.43 0.36 μm

Beam position jitter 3- 4 μm

expectation from ADC noise alone:



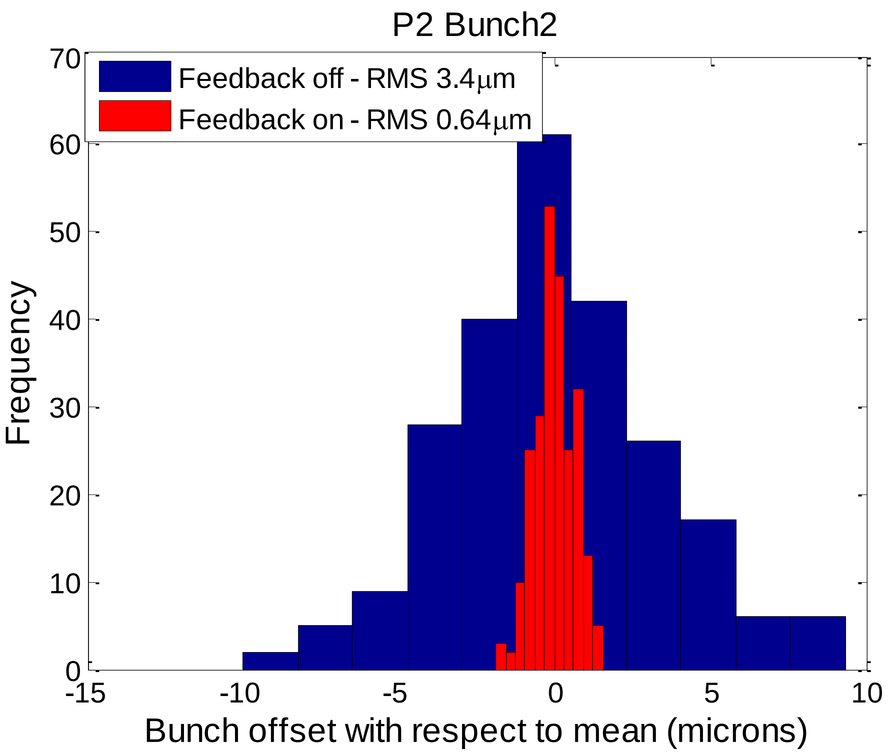
Feedback Performance

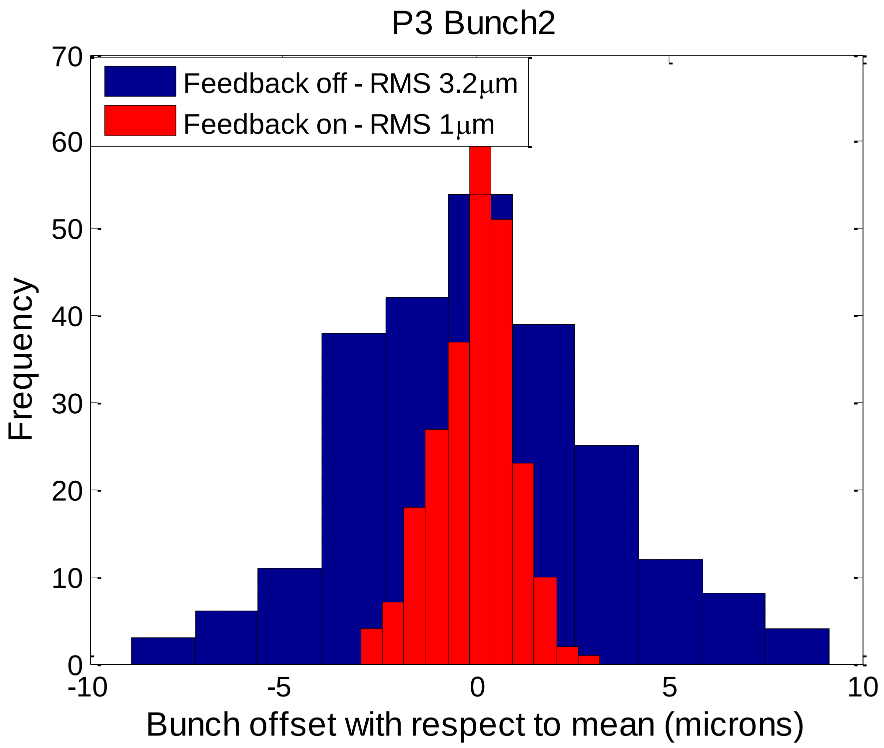
(example FB Run 6 13/12)

bunch	1	2
	FB off	FB off
Jitter P2	3.42	3.42
P3	3.24	3.21

Feedback Performance

(example FB Run 6 13/12)





Feedback Performance

(example FB Run 6 13/12)

bunch	1		2	
	FB off	on	FB off	on
Jitter P2	3.42	3.39	3.42	0.64
P3	3.24	3.16	3.21	1.04

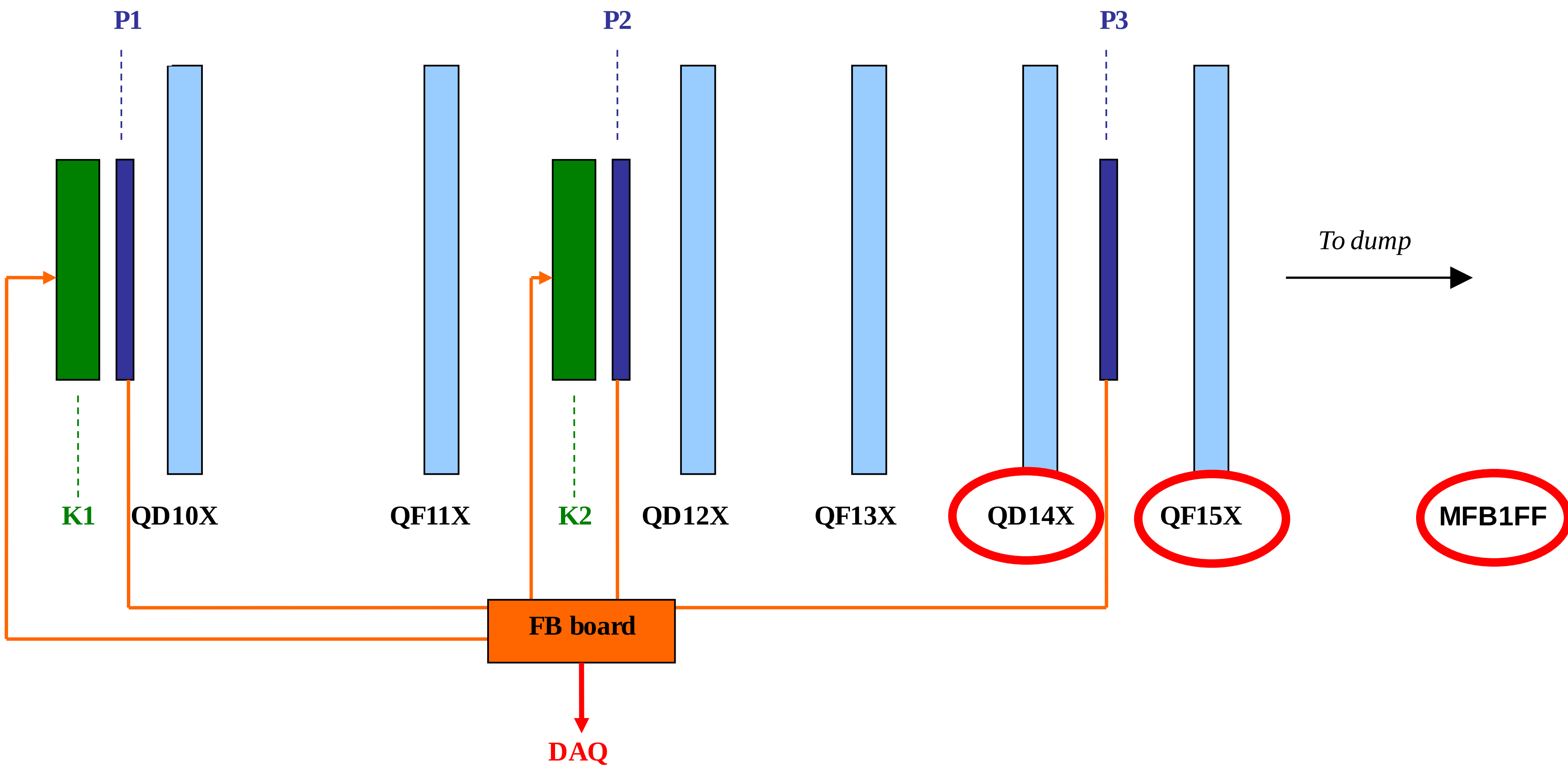
Feedback Performance

(example FB Run 6 13/12)

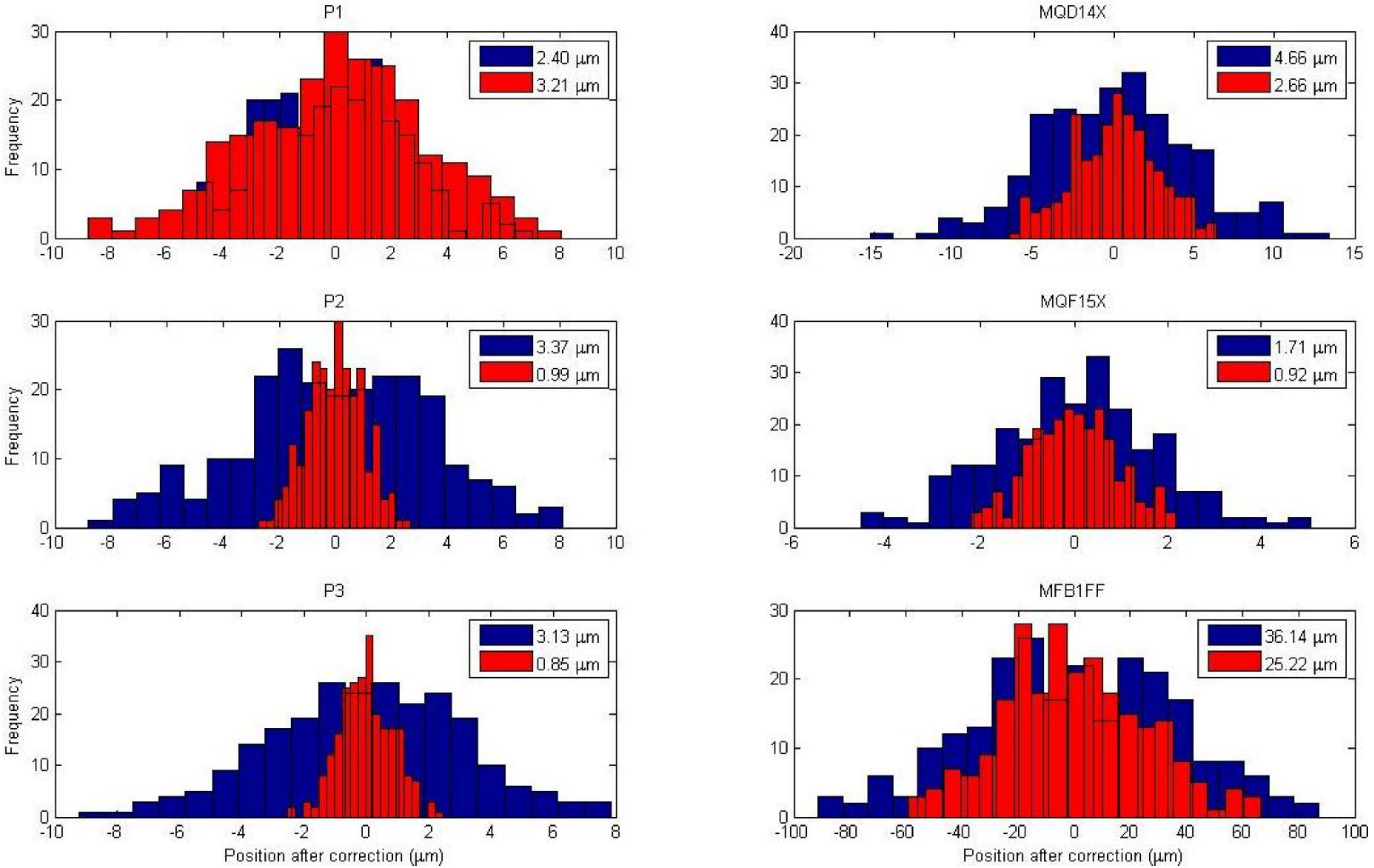
bunch	1		2		
	FB off	on	FB off	on	Pred.
Jitter P2	3.42	3.39	3.42	0.64	
1-2 correl 98%					0.67
P3	3.24	3.16	3.21	1.04	
1-2 correl 97%					0.83

$$\sigma_2'^2 = \sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\rho_{12} \geq 2\sigma_r^2$$

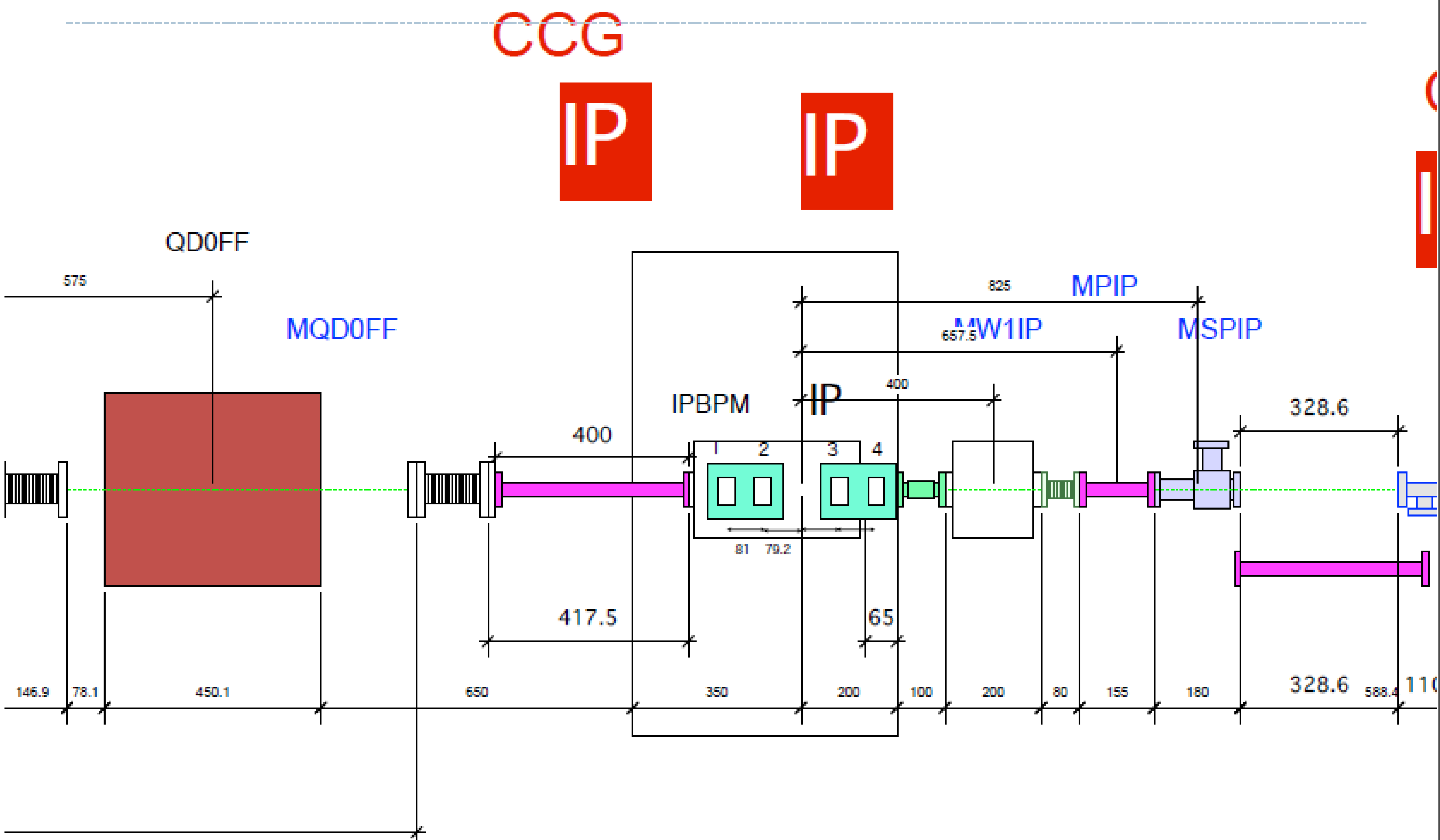
FONT5 setup Winter 2011-12



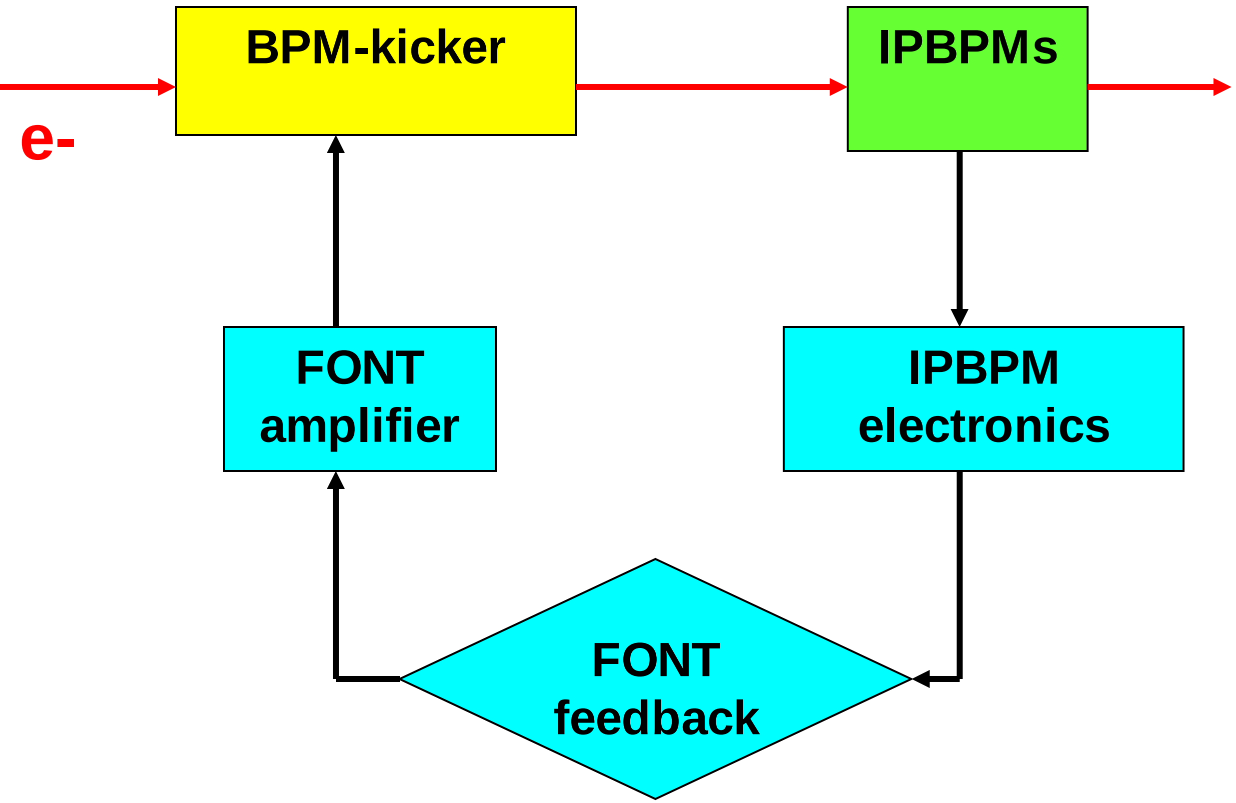
07/12 FB Run 23 (nom. optics)



Eventual IP configuration



IP FB loop


BPM-kicker
IPBPMs
e-
FONT amplifier
IPBPM electronics
FONT feedback

New kicker

- Don’t (in principle) need much drive for nm-level correction at IP
- Short kicker OK – necessitated by space available
- Simple proposal:

  modify stripline BPM design

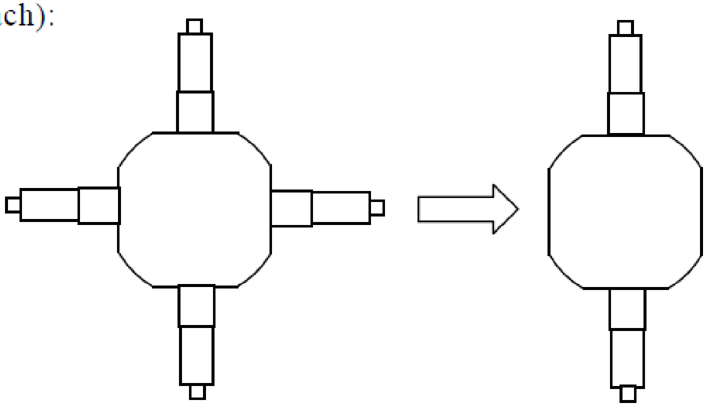
  for driving as a kicker

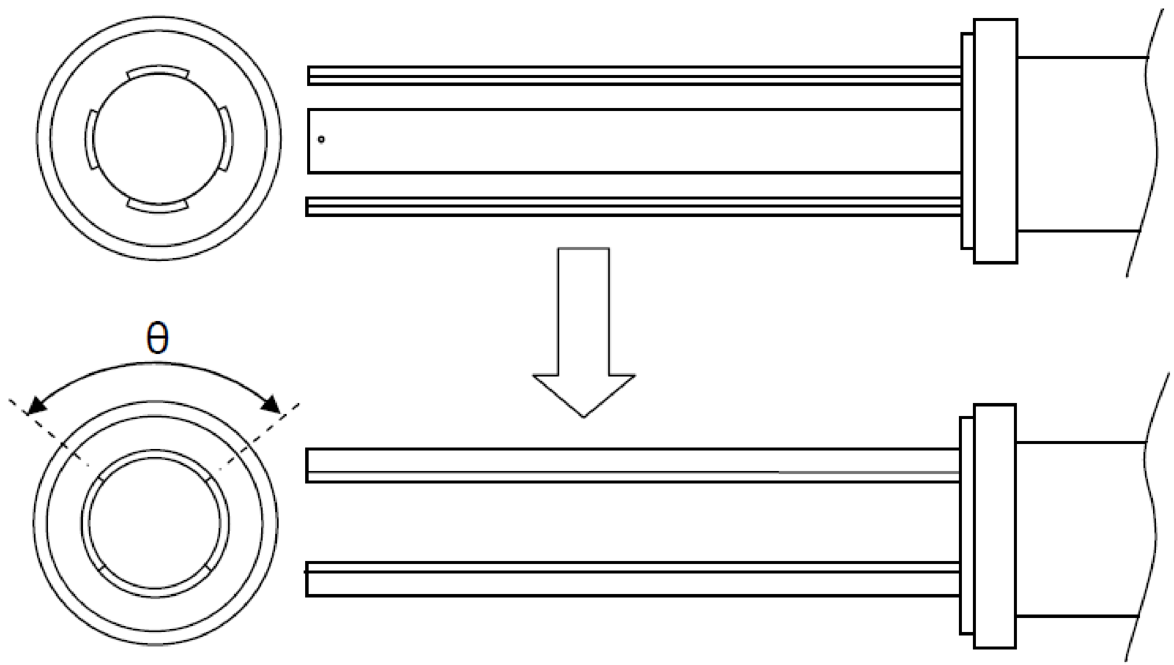
  use FONT amplifier

  (plenty of drive)

BPM modified as kicker

ach):





New kicker

Working assumptions (1)

- **Kicker centre ~ 0.5m upstream of IPBPM**
- **Stripline aperture ~ 24 mm**
- **Stripline length ~ 12 cm**

Working assumptions (2)

Dynamic correction range:

- **Beam y jitter ~ beam size (?)**
- **3 sigma correction range:**

  37nm beam → 100nm range → 200nrad kick

  100nm → 300nm → 600nrad kick

- **FONT amplifier/kicker provides +- 50 μrad**
- **Amplifier not matched to new BPM-kicker, but will be more than adequate!**

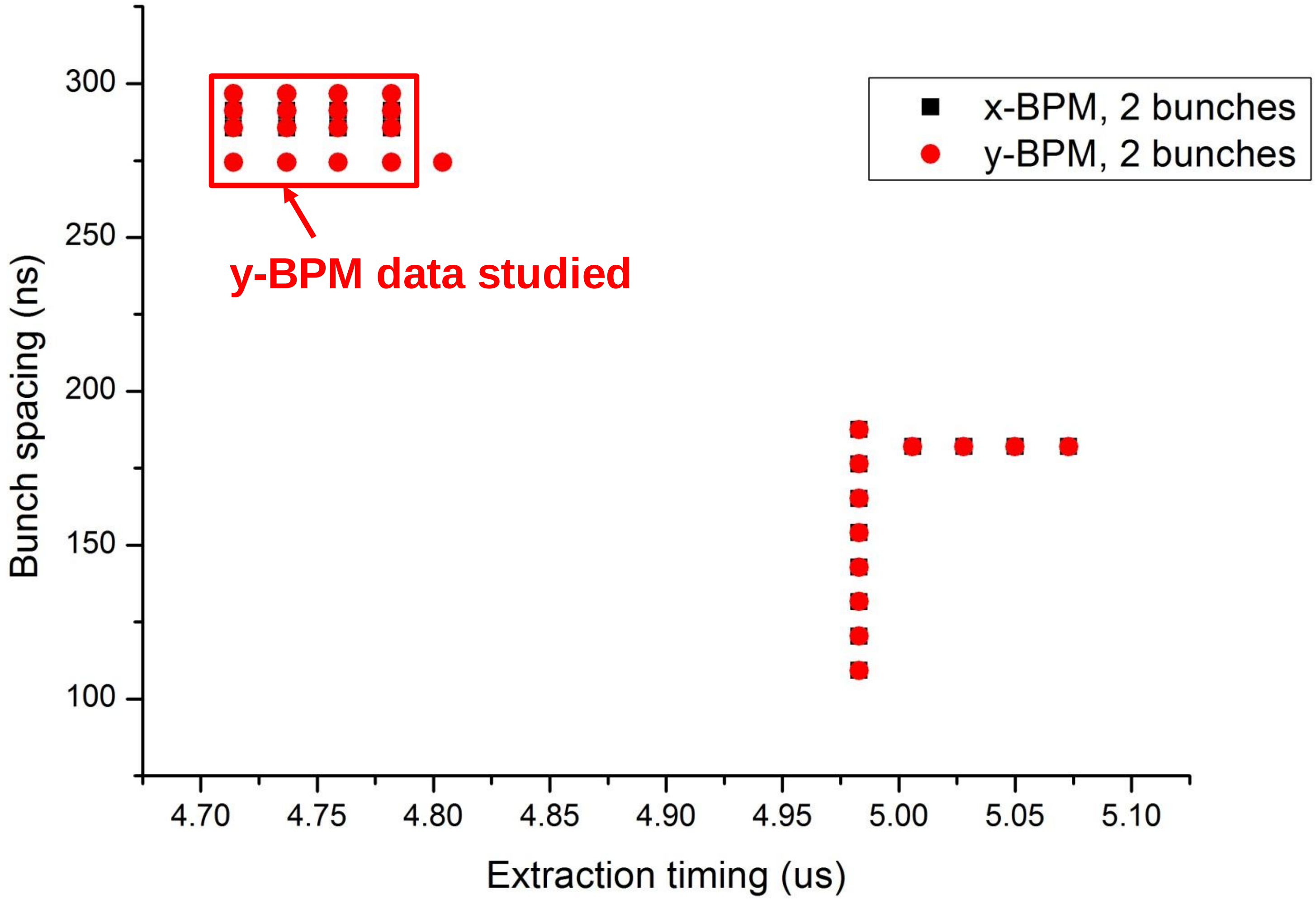
Latency estimate

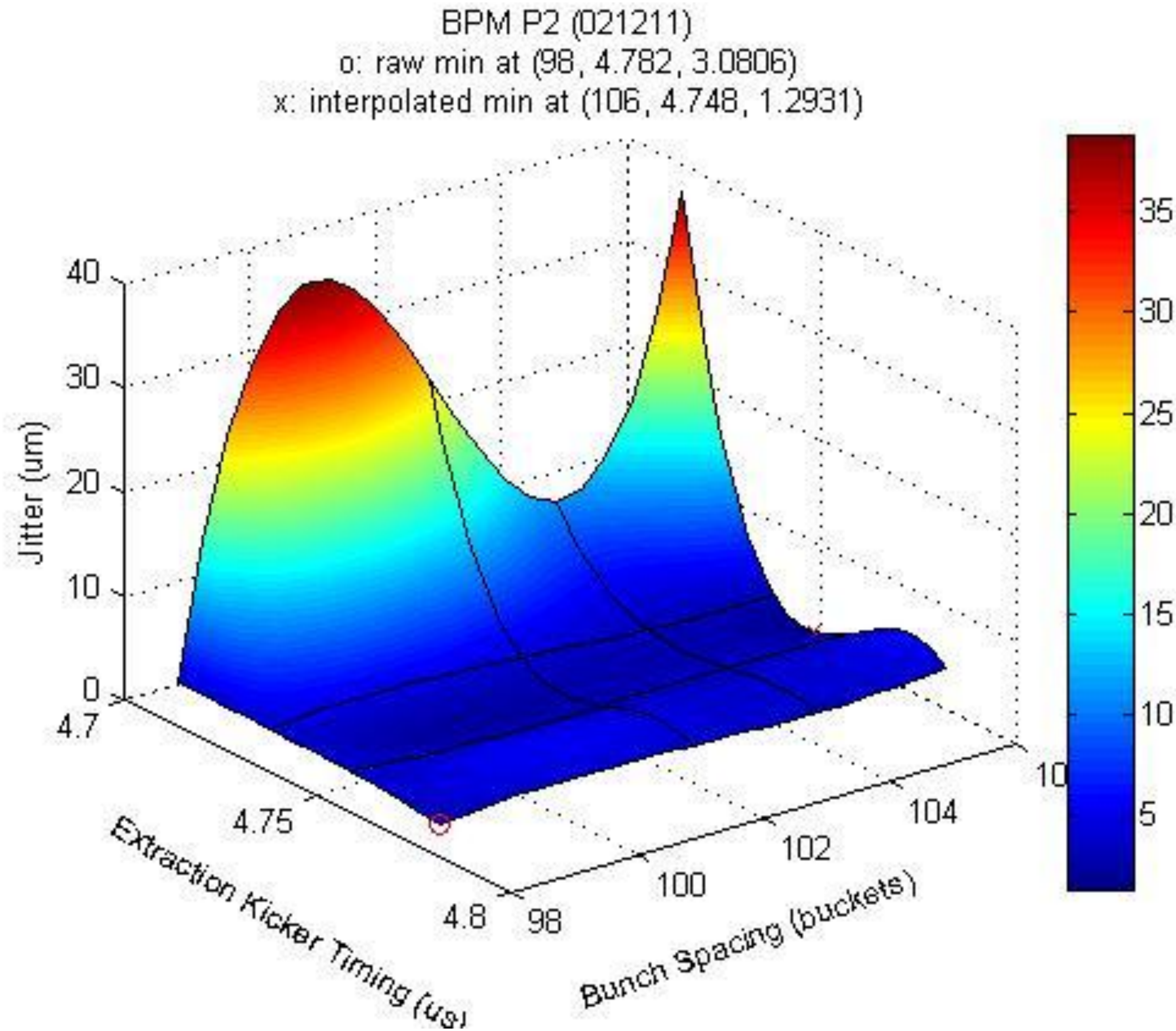
• Amplifier	35ns
• Kicker fill (12cm)	0.5ns
• Beam flight time amplifier → IPBPM	2ns
• Cables (3 x 1.5m?)	23ns
• IPBPM electronics	X
• Digital FB processing	60ns
Total	**120 + X ns**
Bunch spacing < 300ns →	**X < 180ns**

2-bunch train

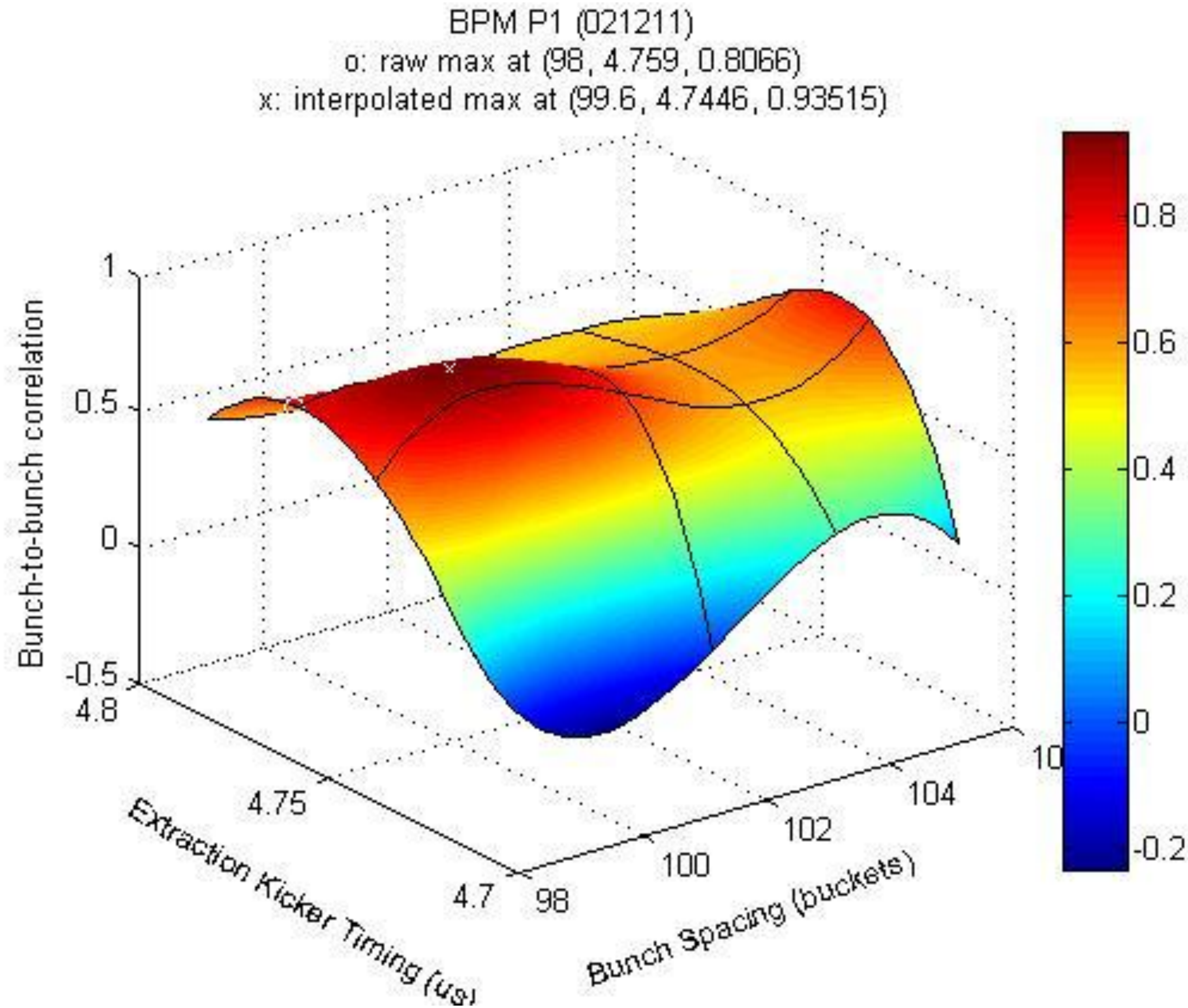
- **Intra-train beam feedback requires extremely high degree of spatial correlation between the bunches**
- **Better off extracting just 2 bunches**
- **Removes requirement for multibunch cavity BPM signal processing for input to FB**
- **Increases latency budget available for FB loop**
- **December FONT running investigated optimal extraction kicker parameters**

Setting map: bunch spacing vs. extraction timing (021211)





BPM P2 (021211)
o: raw min at (98, 4.782, 3.0806)
x: interpolated min at (106, 4.748, 1.2931)
Jitter (um)
40
30
20
10
0
4.7
4.75
4.8
Extraction Kicker Timing (us)
98
100
102
104
10
Bunch Spacing (buckets)
35
30
25
20
15
10
5


BPM P1 (021211)
o: raw max at (98, 4.759, 0.8066)
x: interpolated max at (99.6, 4.7446, 0.93515)
Bunch-to-bunch correlation
1
0.5
0
-0.5
4.8
4.75
4.7
Extraction Kicker Timing (us)
98
100
102
104
10
Bunch Spacing (buckets)
0.8
0.6
0.4
0.2
0
-0.2

Summary: LC FB design

- **Well developed IP FB system concept for both ILC and CLIC**
- **Simulations demonstrate luminosity recovery capability**
- **Demonstrated prototypes with required performance parameters**
- **Progress on designing customised beamline components for ILC case**

Summary: ATF2 IPFB

- Conceptual IPFB design established
- New kicker has been fabricated
- Use FONT amplifier to drive kicker
- Use FONT5 FB board for digitisation + signal processing
- Measurements indicate good beam quality for 2-bunch mode with up to 300ns bunch spacing

Extra material

General considerations (1)

Collision optimisation – based on beam-beam deflection:

1. Interaction point position feedback:

hardware located near IP

kicker at 90 degrees w.r.t. IP

2. Interaction point angle feedback:

hardware ideally located near IP

kicker in phase w.r.t. IP

3. Additional (feed-forward) inputs:

information from alignment systems (eg. QD0 etc.)

information about beam from upstream in machine (eg. DR)

Luminosity optimisation – based on measured luminosity:

fast luminosity signal (from BEAMCAL)

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:

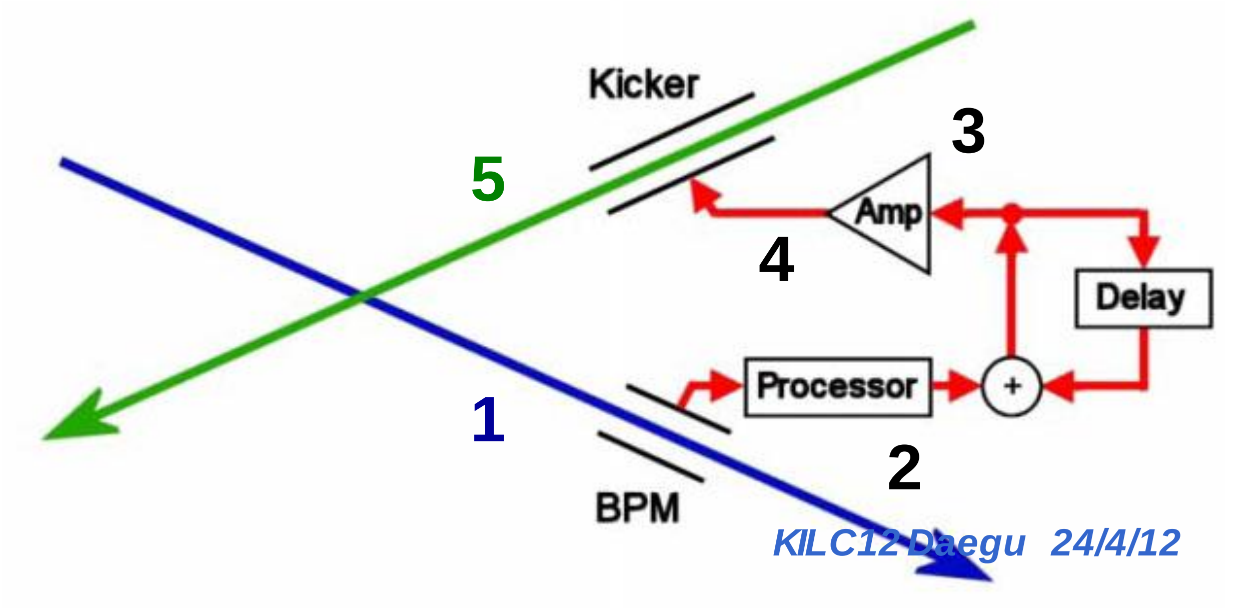
FB hardware should be close to IP (especially for CLIC!)

Two systems, one on each side of IP, allow for redundancy

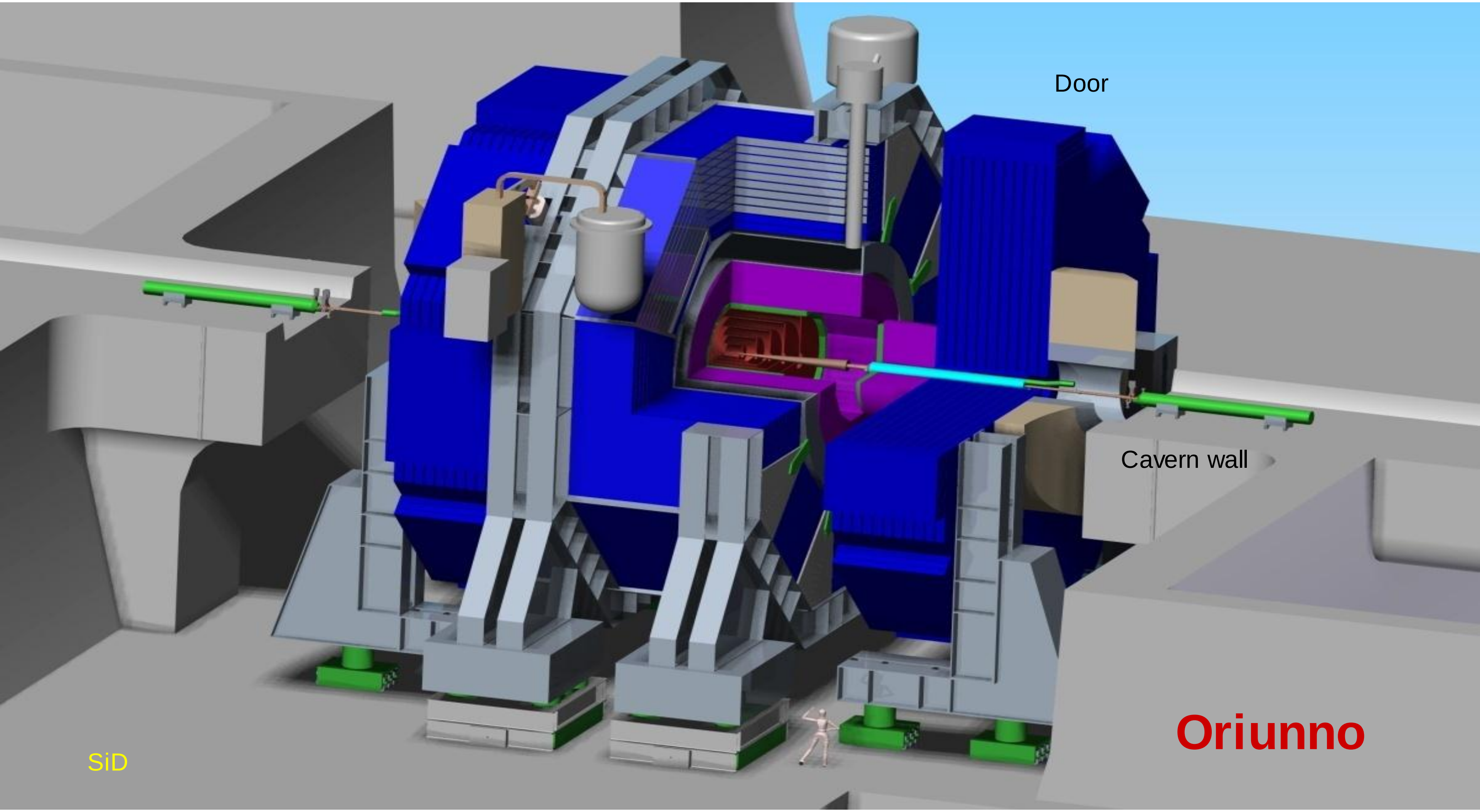
Interaction point FB latency

Latency:

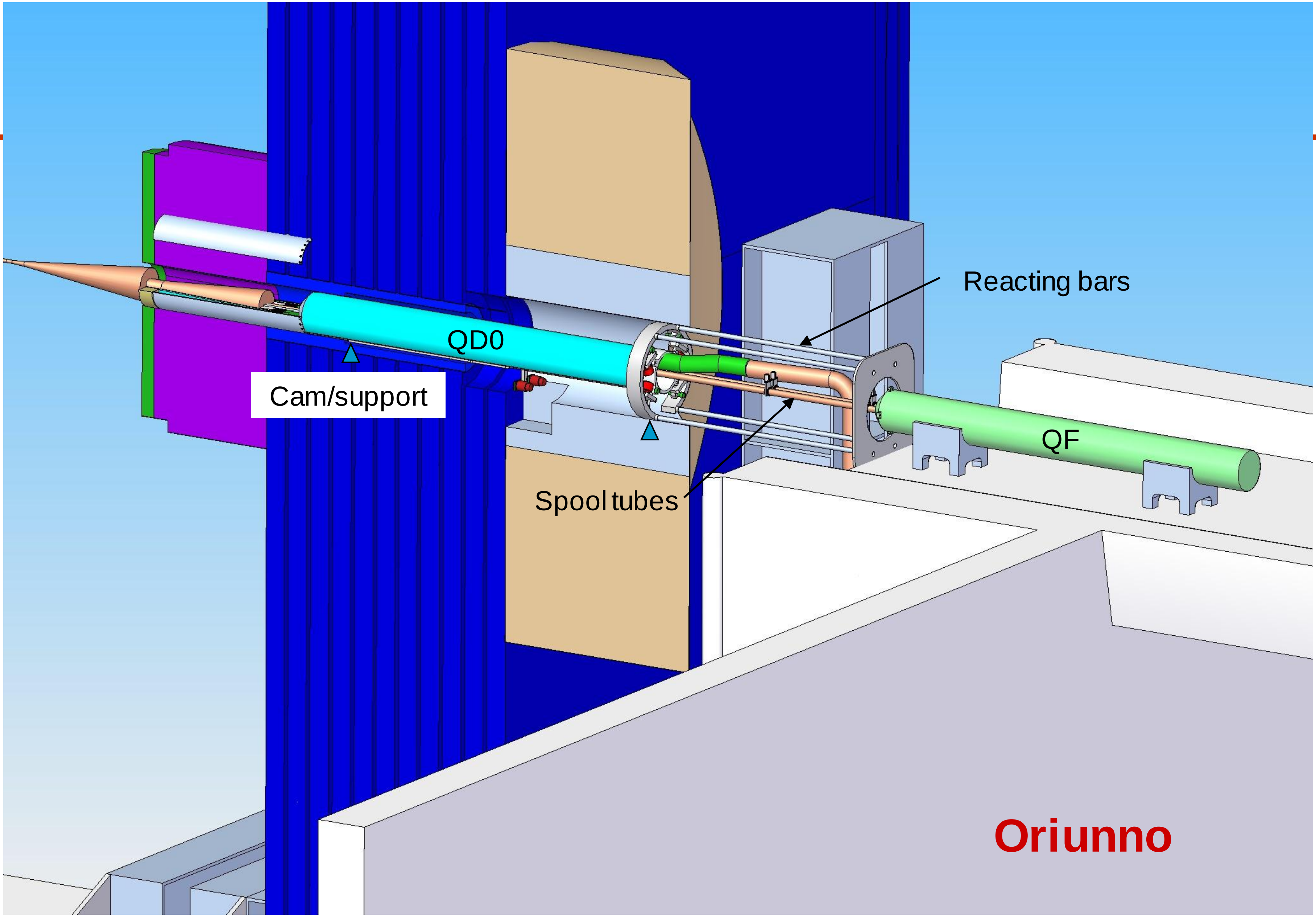
1. **Beam flight time IP → BPM**
2. **Signal processing, FB calculation**
3. **Amplifier + kicker response time**
4. **Cable delays**
5. **Beam flight time kicker → IP**



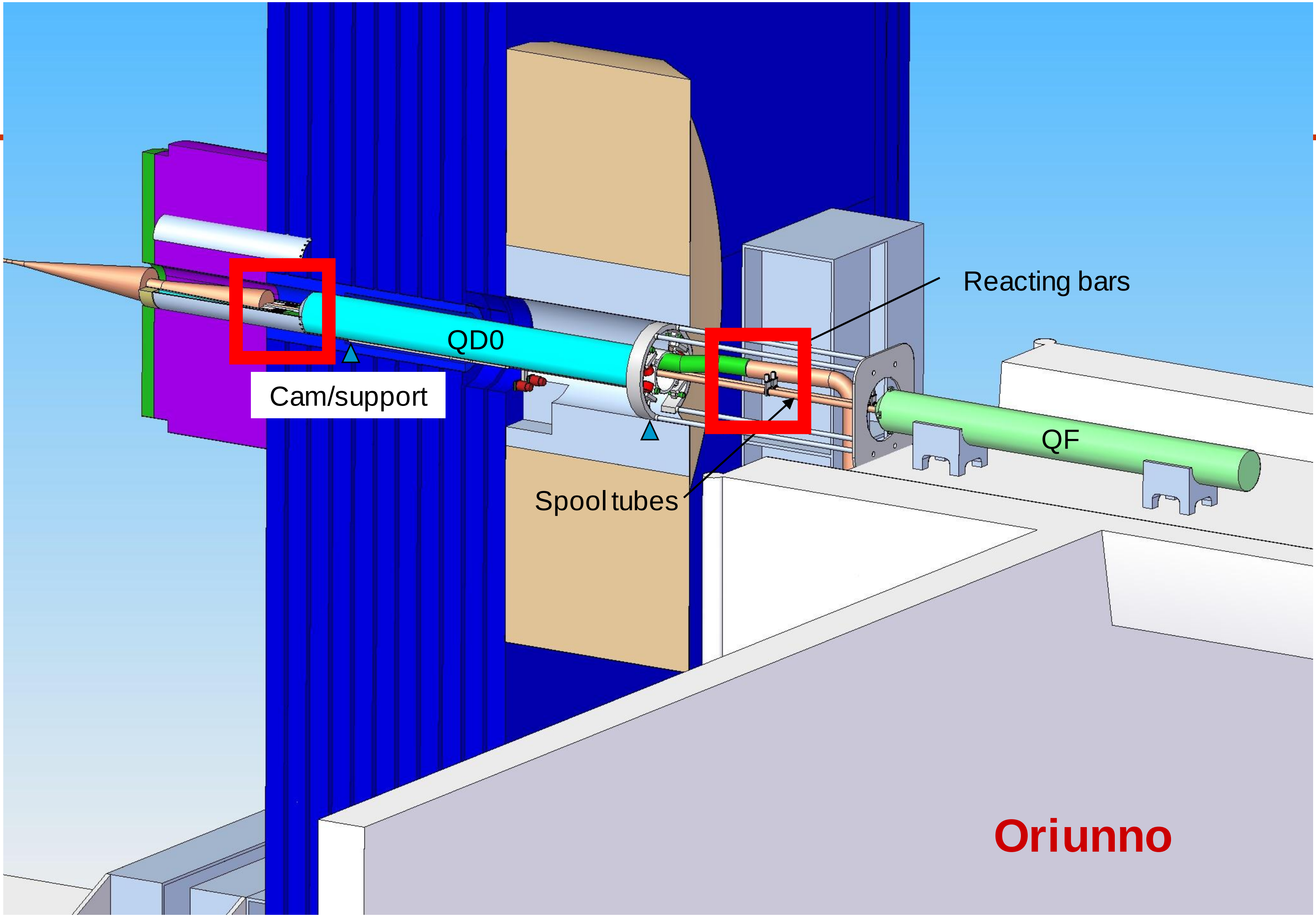
ILC IR: SiD for illustration



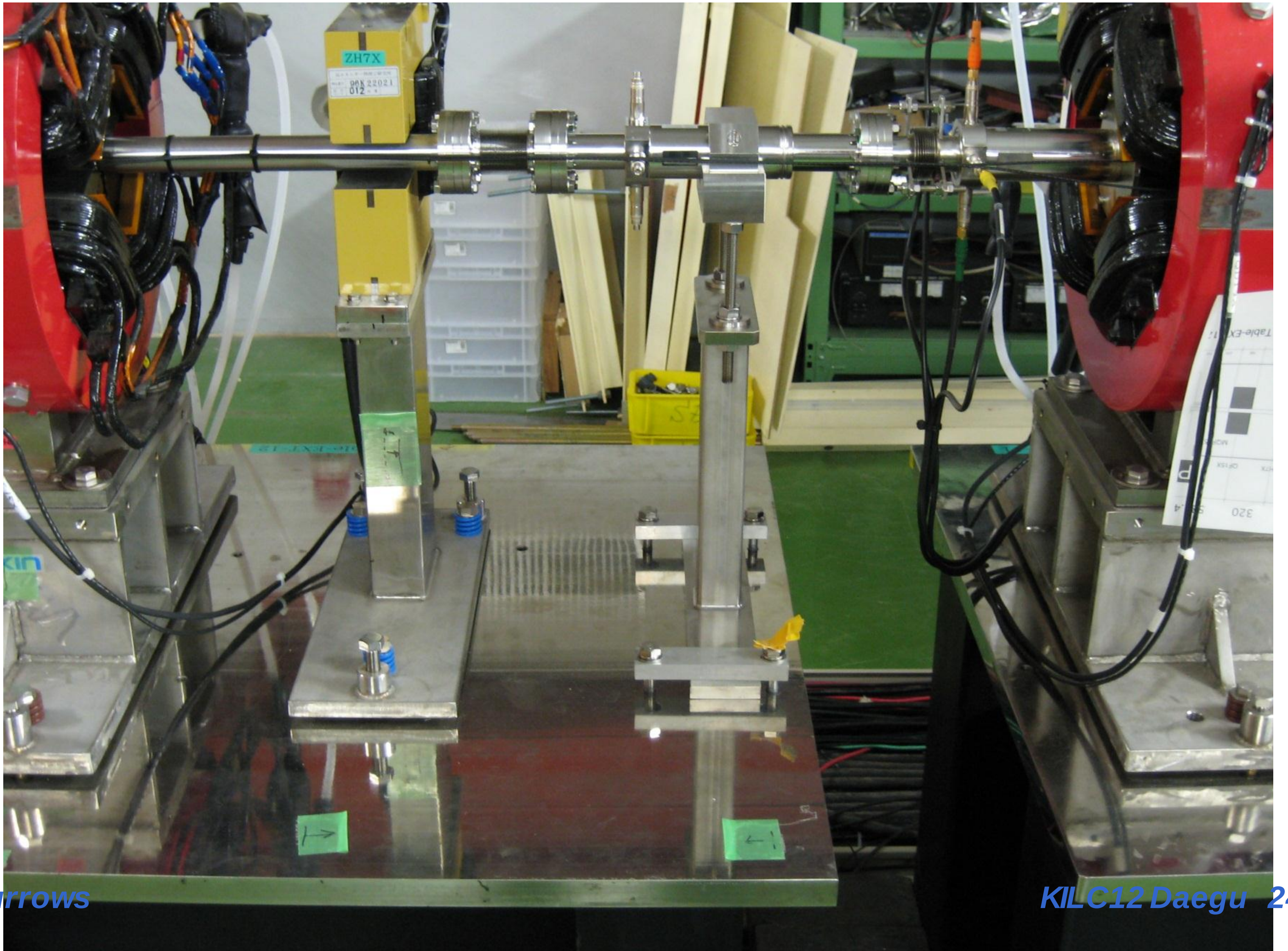
Final Doublet Region (SiD for illustration)



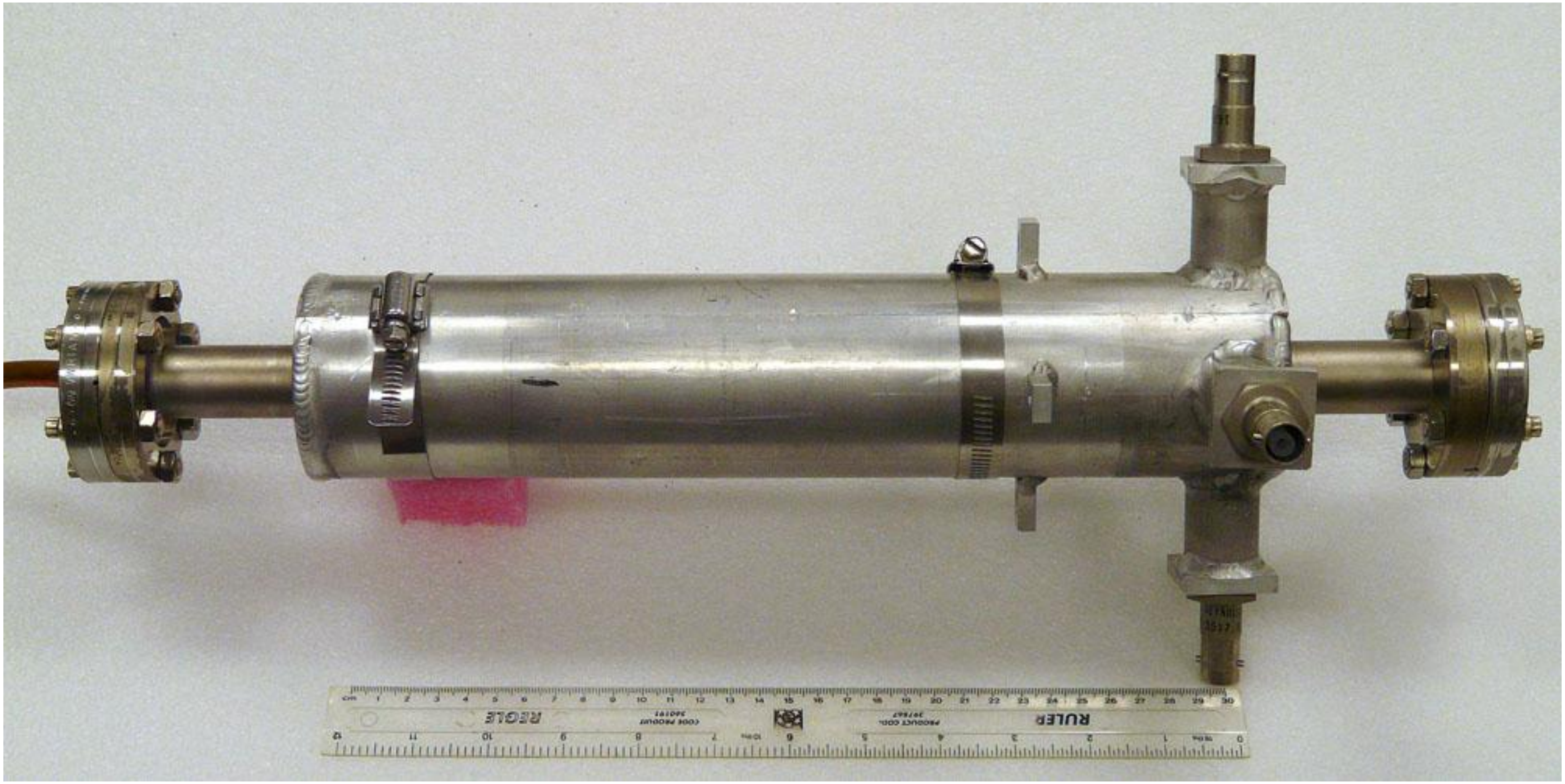
Final Doublet Region (SiD for illustration)



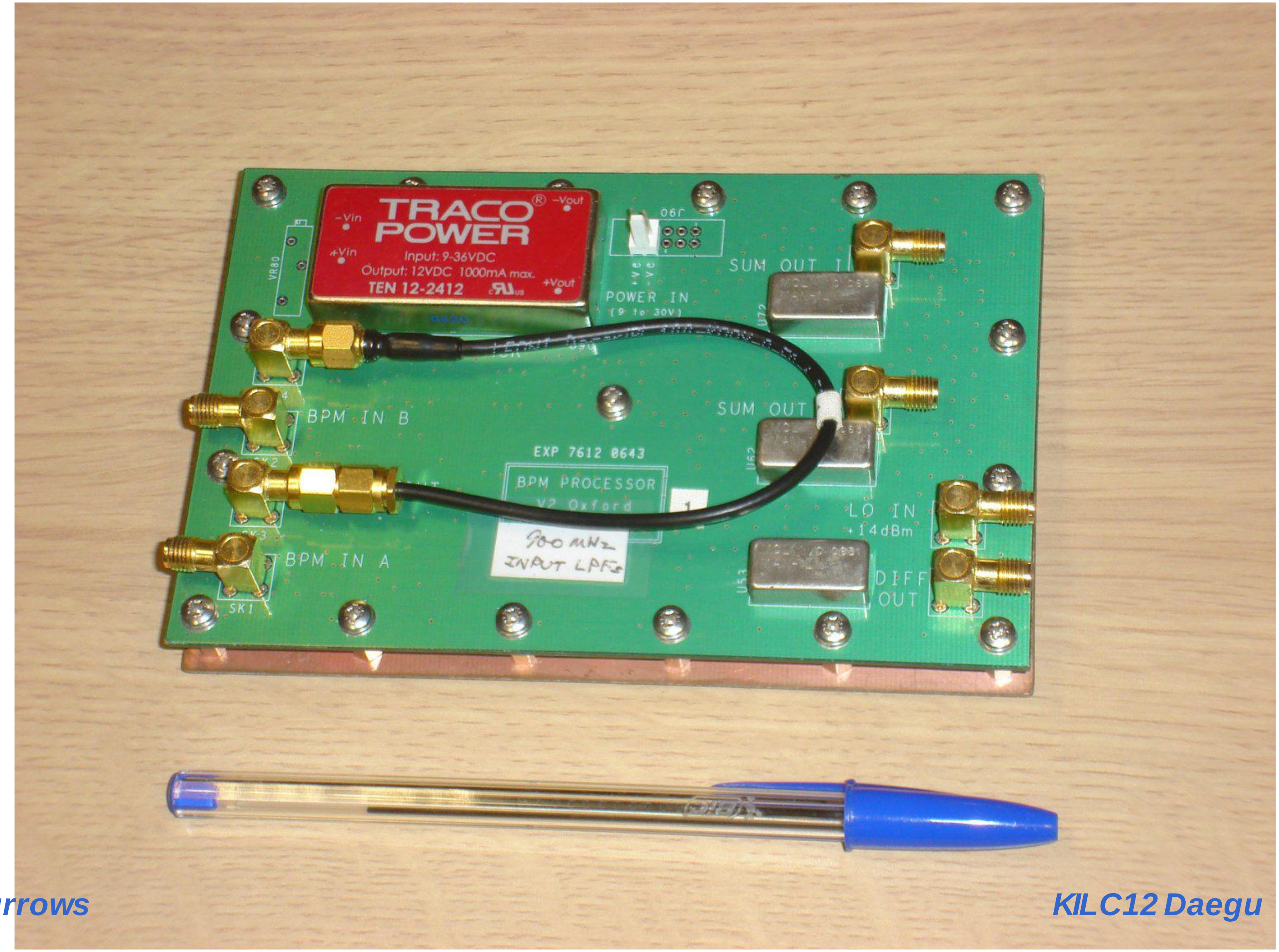
Off-shelf BPM



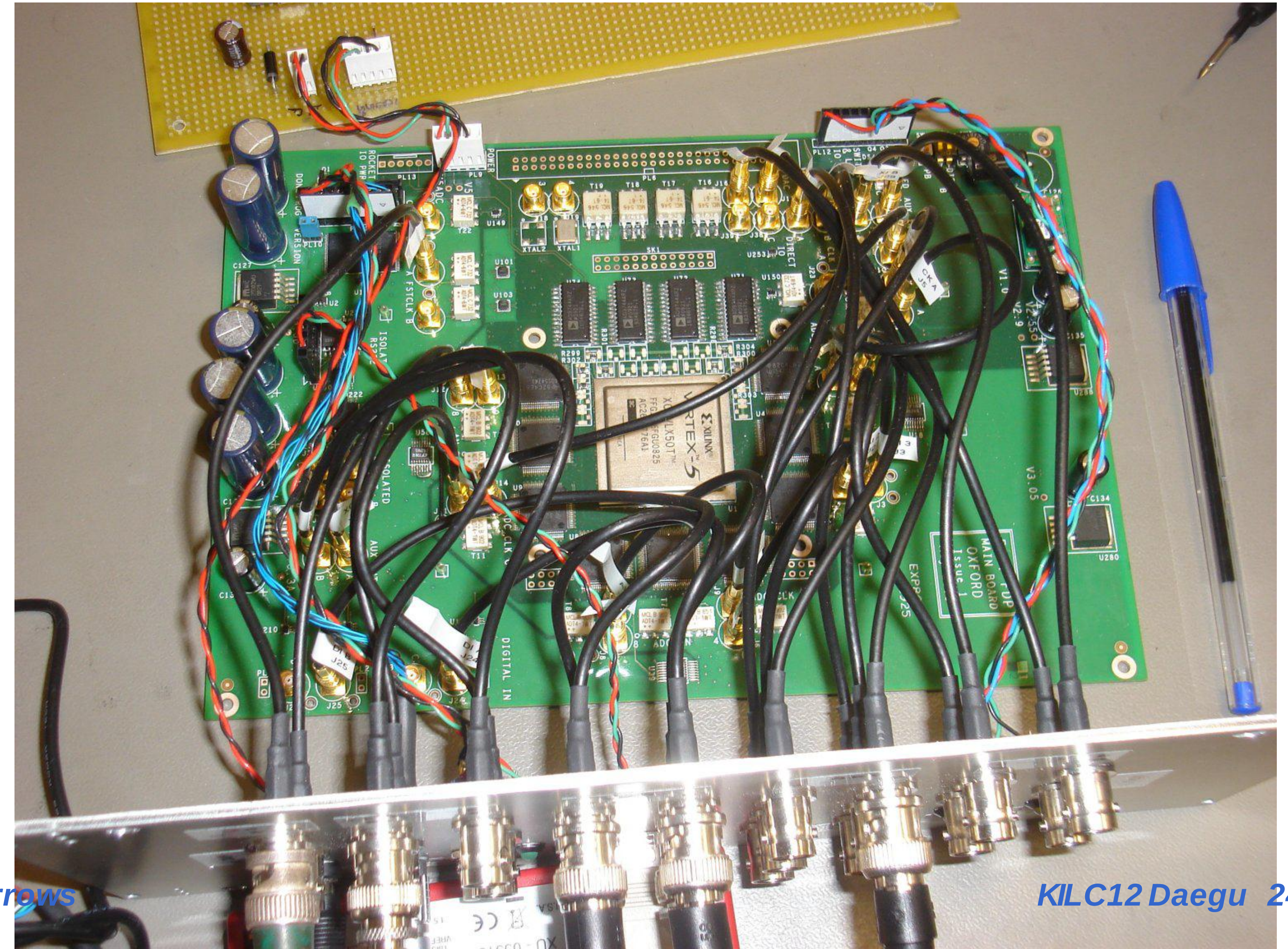
Off-shelf kicker



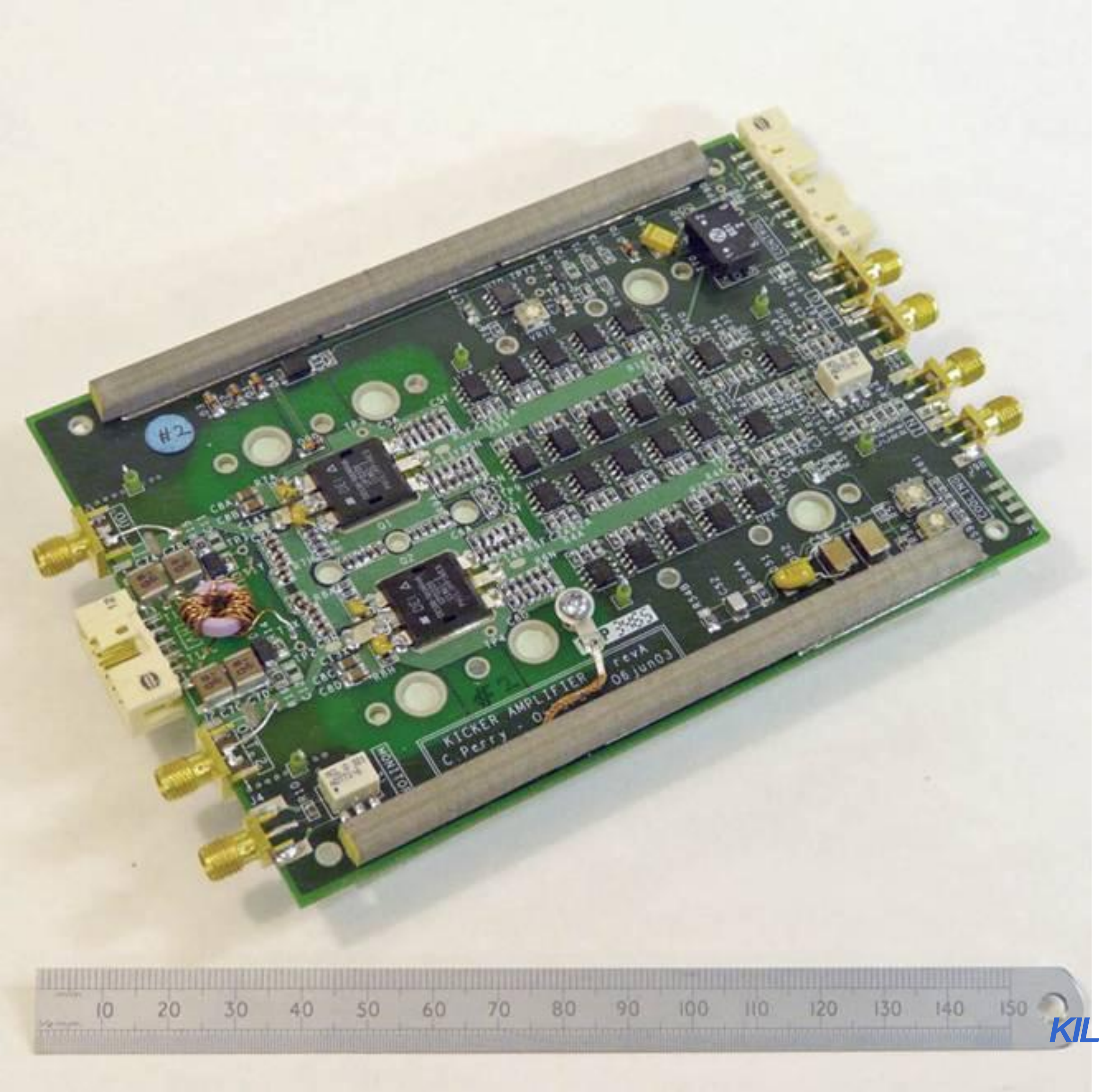
BPM processor



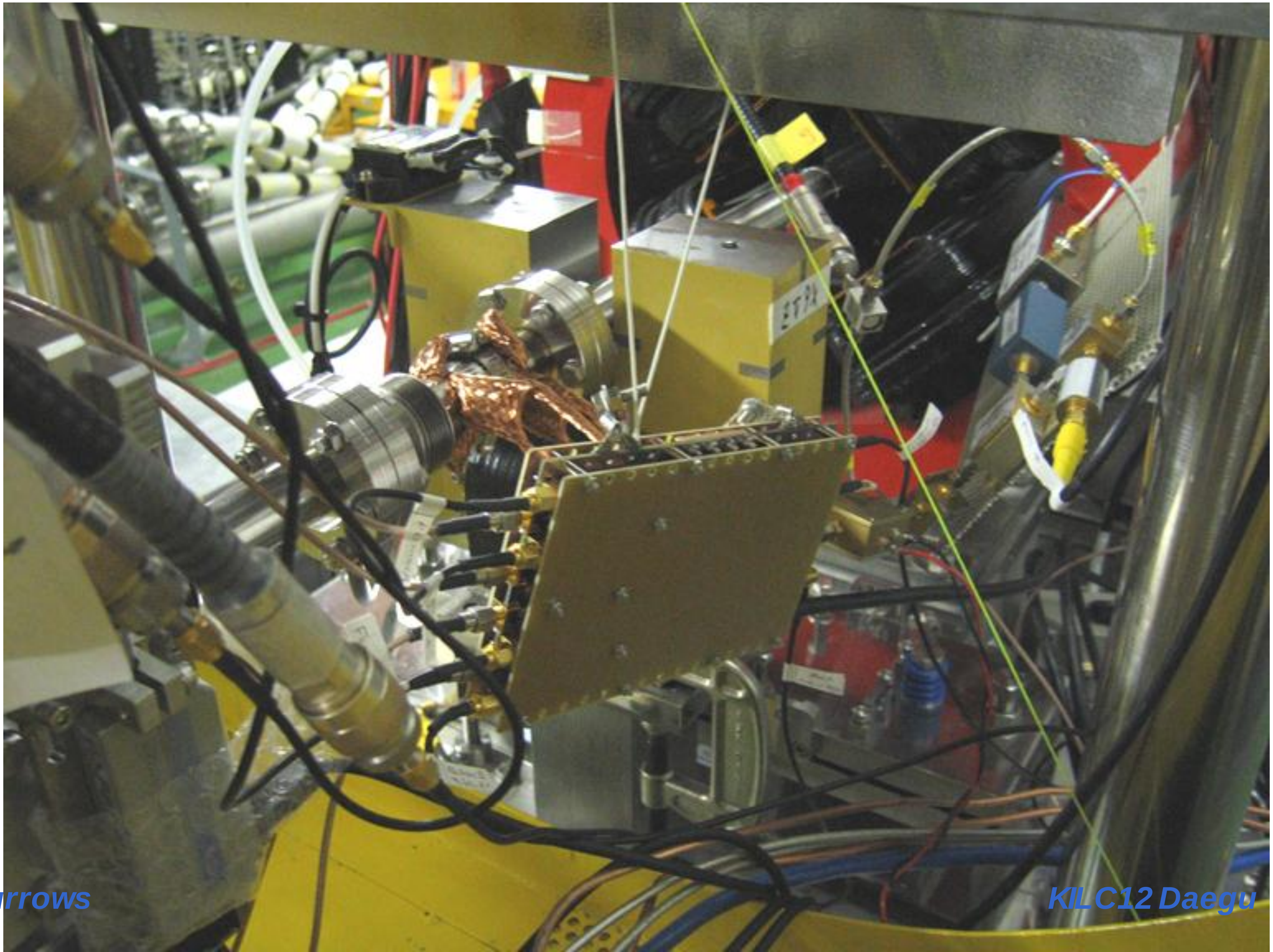
FB board



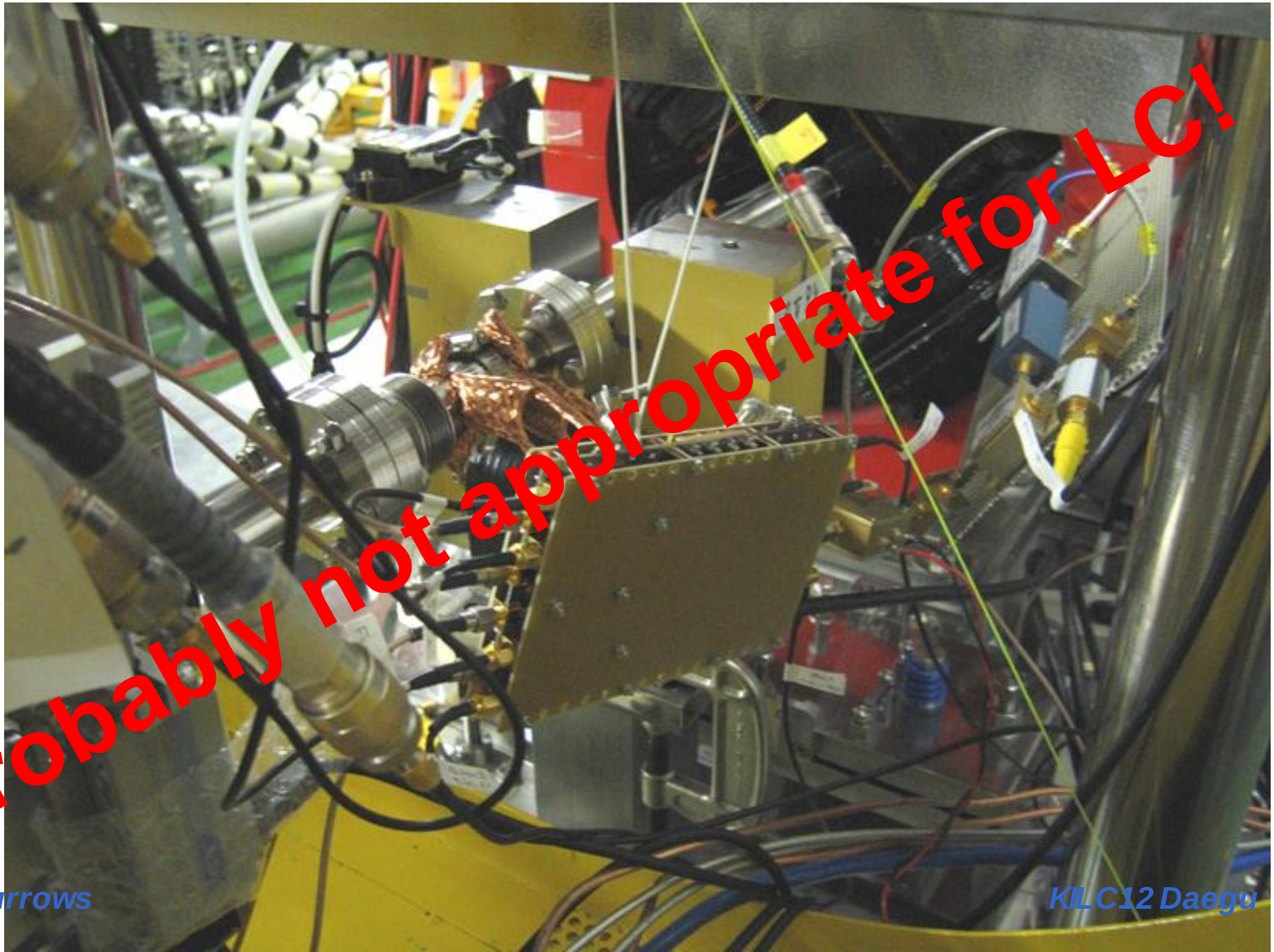
Drive amplifier



A pragmatic approach!



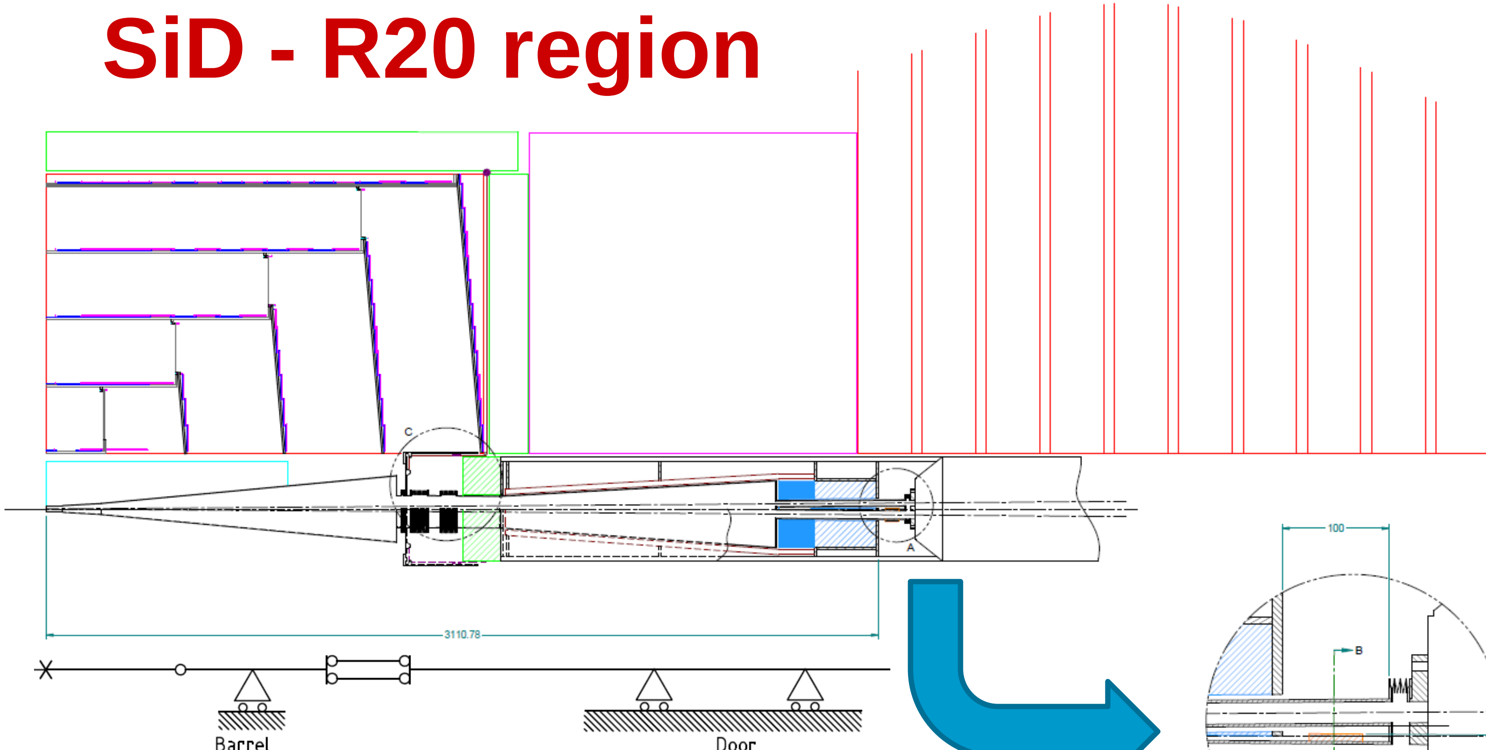
A pragmatic approach!



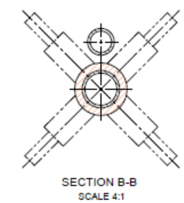
Probably not appropriate for LC!

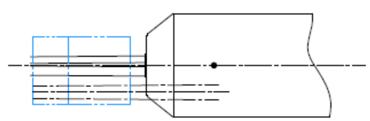
SiD - R20 region

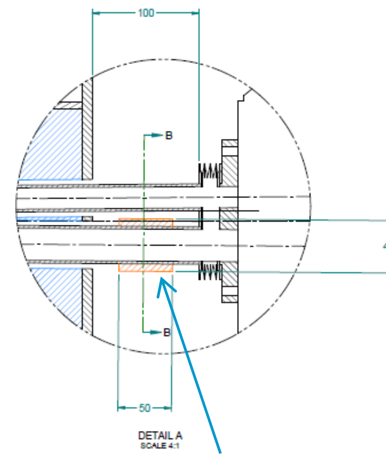
Marco Oriunno



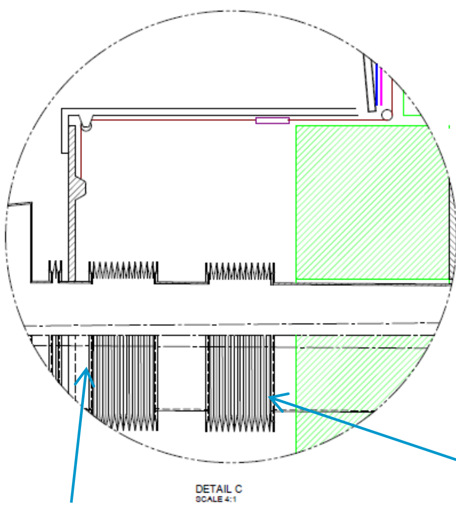
BPM arrangement, under study







Gap Lumical vs. QD0
BPM for IP Lum. Fedback



Multi convolution bellows
Stress Relief QD0 vs. VTX

Single convolution bellow
Kinematic Mount. VTX

Custom BPM design

	Table 1). Beam Position Monitor Transducer Parameters.		
Parameter	Symbol	Value	Comments
Distance to IP	Z_{bpm}	3.2 m	approximate
Duct radius	R	15 mm	
Stripline length	L_{strip}	100 mm	
Stripline roundtrip time	dt	0.67 ns	
Stripline Impedance	Z_{bpm}	50 Ohms	
Stripline Width		4.4 mm	

Steve Smith

Custom kicker design

Table 3. Kicker Parameters.		
Parameter	Value	Comments
Distance to IP	8 m	
Duct diameter	2 cm	
Stripline length	1 m	
Stripline roundtrip time	6.7 ns	
Stripline radius	10 mm	
Stripline Impedance	50 Ohms	
Stripline azimuthal coverage	120 degrees	
Chamber inner diameter	34 mm	
Drive voltage needed	140 mV / nm or 28 V max	Per stripline
Drive power	0.4 mW / nm^2 or 16 W max	Each amplifier
Maximum IP correction	200 nm	

Steve Smith