ATF2 Q BPM electronics

- Specification (Y. Honda, 02.2006)
- Design
- System
  - Hardware layout
  - Software
  - Calibration
- Testing
- Production schedule

ATF2 electronics group (SLAC), NanoBPM collaboration, and Y. Honda (KEK)

Specifications

2 Accuracy of BPM

In order to achieve the goal of tiny spot size at the IP, beam orbit has to be on the field center of all quadrupole magnets within a few μm. Otherwise beam suffers an undesired kick, which dilutes the spot size. To do the orbit tuning,

- BPMs which have better than a few μm accuracy are necessary. It means that the pulse-by-pulse outputs of the BPM system, after all online analysis process, should be reliable within a few μm error including all the random and systematic errors.
  - Beam intensity change should not affect the outputs of the beam position. Its effect must be removed by the online analysis over, say $0.2 \sim 1.2 \times 10^{10}$ e/bunch intensity range.
  - Gain (calibration factor) stability (or monitoring) is also important to realize the accuracy over the full range.
- The field center of the magnets should be known in better than the precision also (requirement on the accuracy of BBA). The accuracy of BBA requires to have a few μm resolution BPM.
  - Relative position between the field center of magnets and the electrical center of BPM has to have a good stability (a few μm) during beam operation. More specific, typical time scale considering here should be the interval of BBAs (a few days?).

Specifications

3 Resolution of BPM

In order to achieve the goal of beam position stability at the IP, beam orbit (or individual motion of magnets) must be stable within 100 nm (typically other than final magnets).

- To measure the beam jitter and find out its source, BPM should be able to measure pulse-by-pulse 100 nm orbit difference. It is not necessary to have a long term stability in this level.

  – It seems that a set of magnet and its BPM can be treated as a monolithic object (stable within 100 nm level) at least for the short time scale ($\sim$10 seconds) if they are attached rigidly. So the mechanical system should not be the problem for this aspect.

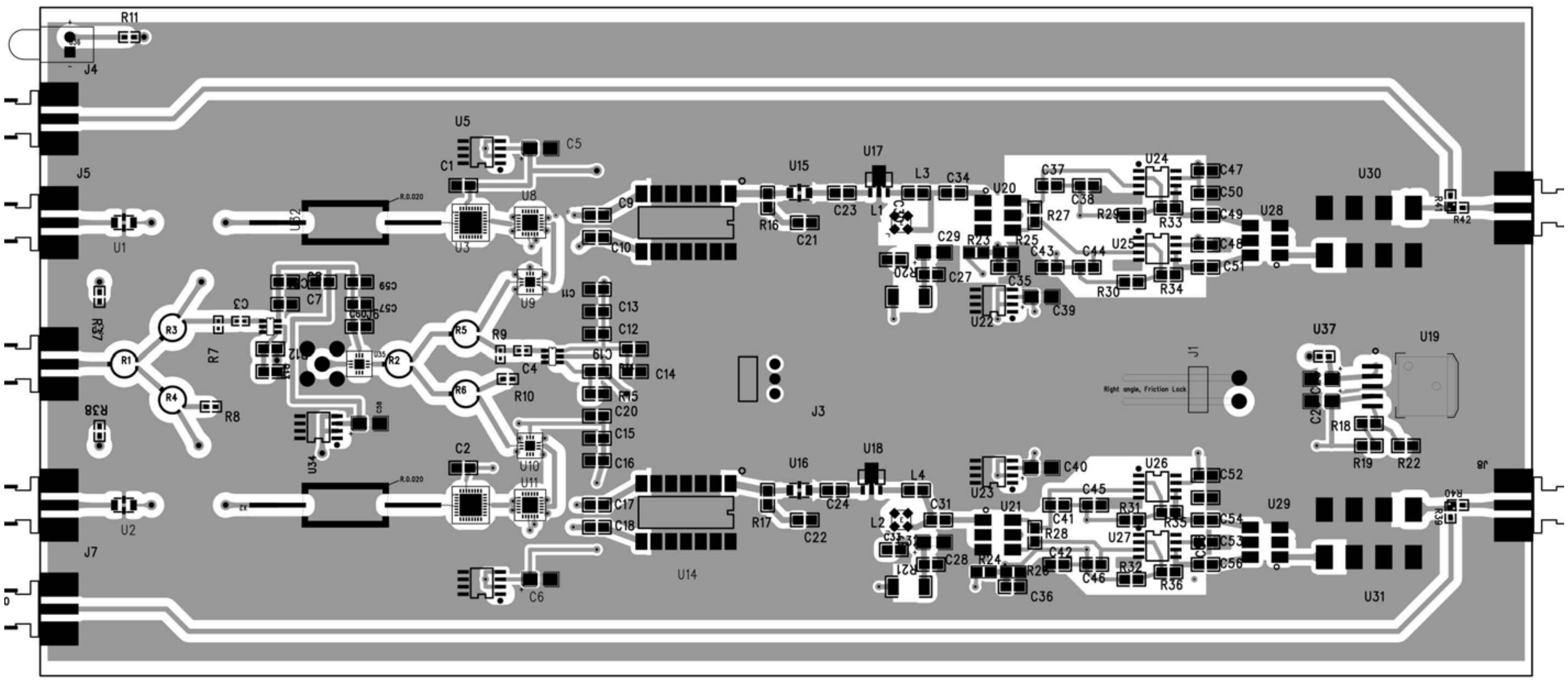
  – The amplifier noise limit of the electronics should be lower than 100 nm beam offset signal. This has been proved already.

  – The residual correlation to the beam intensity jitter should be smaller than 100 nm in a typical beam condition. Here we assume typical (a little worse than the best case) intensity jitter to be 20%. Even under the intensity jitter, BPM should be able to measure the real beam position jitter better than 100 nm resolution.

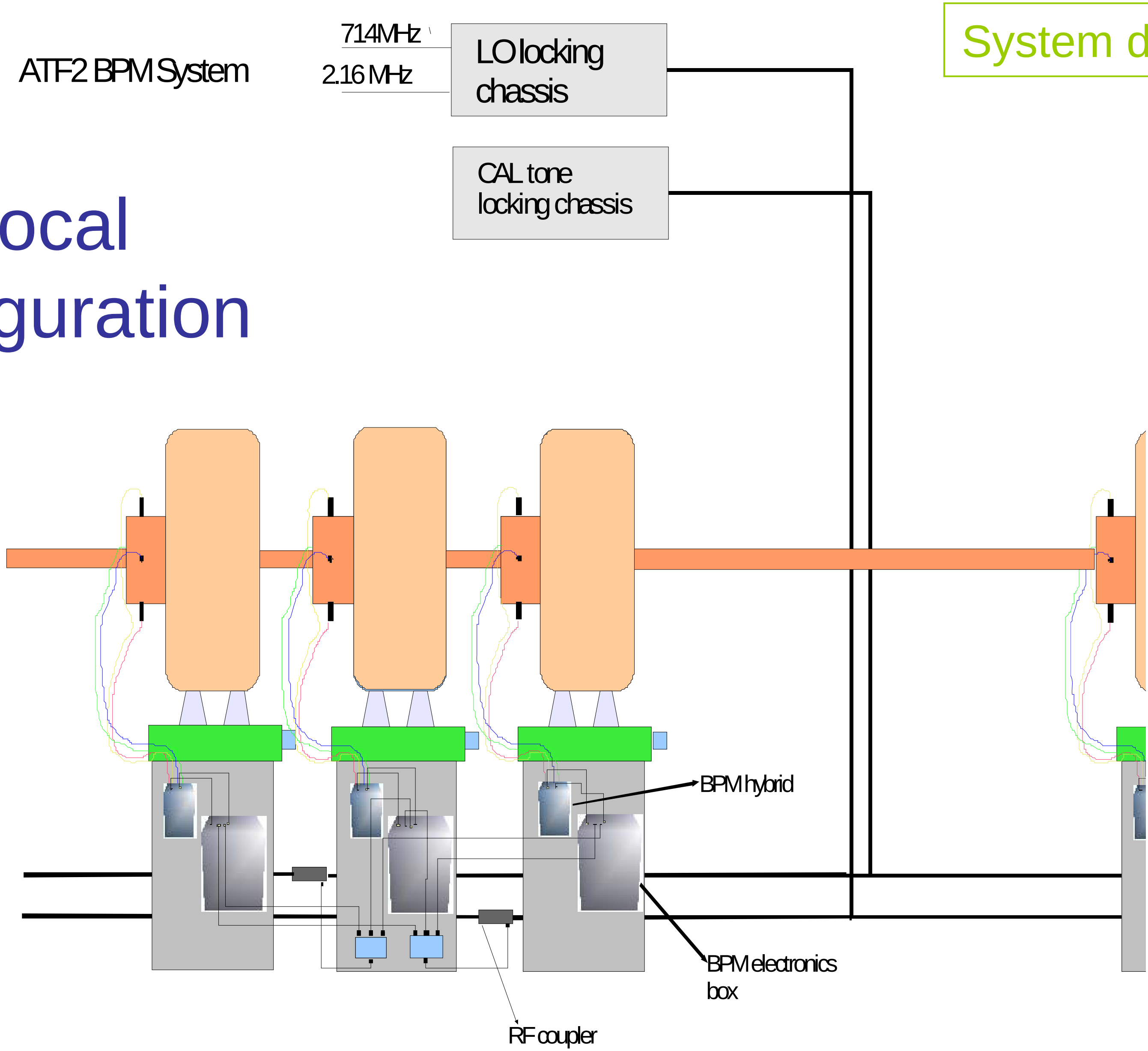
Design

New board layout

- Improved coupler and packaging
- More robust power and sensor connectors



Local configuration



Design

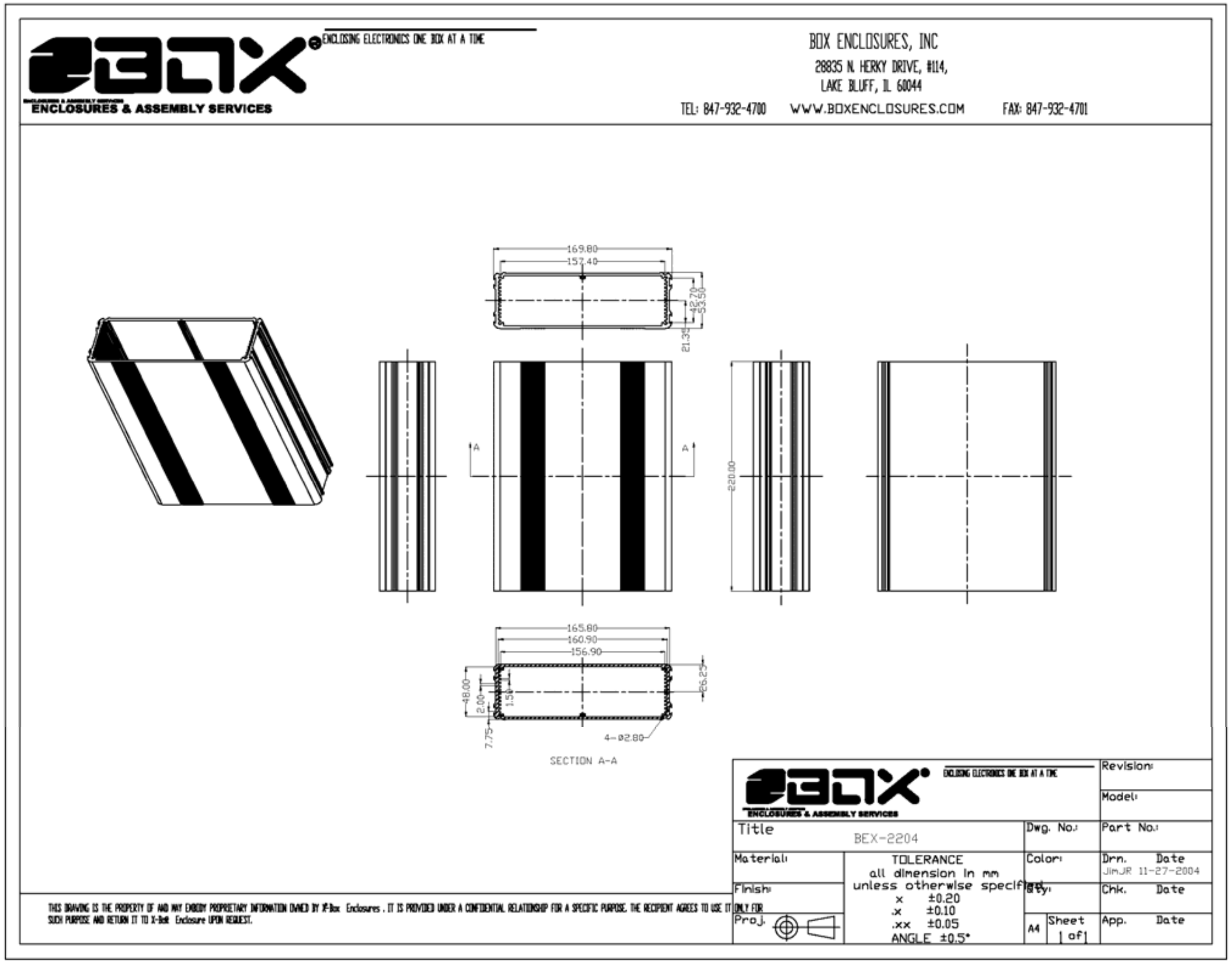
Electronics mounting

- The structure of the ATF2 magnet system will be a magnet, position adjustable support, mover and concrete base from top to bottom. You can mount the BPM electronics boxes on the side face of the concrete bases.
- But their height will be about 580 mm. So you had better place your boxes so that their dimension might be 300 mm vertically and 700 mm horizontally. I can install iron plates, which have several screw holes in order to mount your boxes, on the side face of the concrete bases.

Design

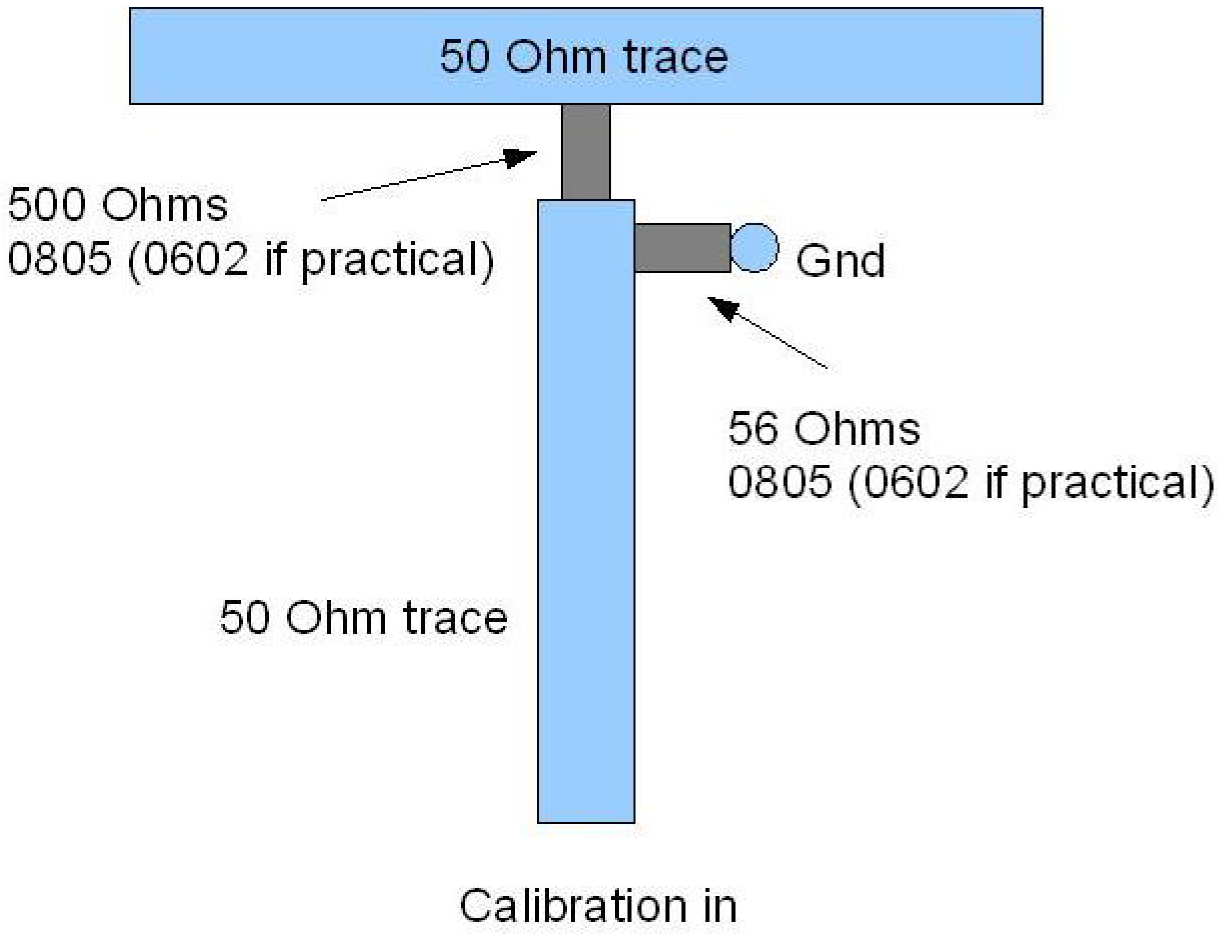
Electronics package

- Thermal tests done. Temperature rise of about 10 degrees in the closed box.



Calibration

- The purpose of this calibration system is to keep track of gain variations
- Typical variations are caused by temperature changes
- On-board calibration signal coupler (non-directional)
- On-board precision cal and LO power meter
- This type of calibration procedure has not been tested.



With a single tone calibration (away from the cavity resonance), the power meter will provide a few tenths of a percent calibration stability.

Calibration

The calculated gain stability vs. temperature of the ATF2 board is 0.02dB/C, or an amplitude change of 0.25% / C.

The temperature variation of the attenuation of the limiter is not known or specified. We could test this with a connnectorized limiter.

The cable variation is calculated at approximately 0.06%/C, if good cable is used.

The power meter chip has a variation of 0.16%/C, slightly better than the calculated stability of the board.

The power supplies are well regulated on the board, so input voltage variations are probably not important. However, if the input voltage varies, the power dissipated in the primary regulator will change, and the board temperature will change. It might be worth running a separate power cable to each board (in a multi-conductor bundle) so that changes in the number of operating boards doesn't change the board temperatures.

Since we believe (but need to measure) the board temperature variation is 0.25%/C, and the power meter variation is 0.16%/C (all numbers calculated - have not done measurements), it is not clear we can improve on the stability with calibration.

RECOMMENDATIONS

1: Use non-directional couplers. Include a temperature monitoring thermistor connected to the diagnostic cable. Include a pad for a thermistor in parallel with the gain resistor on the output amplifiers. Test board temperature stability.

1a. If the 2 channels match well, install a thermistor set to cancel the first order variation with temperature. Expect ~0.1%/C stability.

1b. If channels do not track, expect ~0.25%/C stability.

The default scheme would be to have a calibration synthesizer operate with a tone which we blank off for a few microseconds around beam time. The standard SIS data acquisition will then see some tone, and the cavity signal.

Operation

Two operation modes:

1: system calibration: This is used to find cavity frequencies, couplings to X,Y, etc. Optionally we could also do a tone sweep of the calibration synthesizer to map out the cavity resonance and possibly (if we are clever enough), the cable attenuation.

2: Operation mode: DDC is performed in the VME crate controller using the precalculated coefficients. The I and Q amplitudes are multiplied by previously calculated matricies to get X,Y. These X,Y are made available to the EPICs server.

The I and Q of the calibration tone is also made available for history buffering. We will need beam studies to determine if we want to adjust the calculated gain based on the measured calibration tone, or just use it as a check.

The crate controller should be fast enough to do DDC even for multi-bunch beams in real time.

Summary of ATF 2 electronics board test results.

Lab Tests

Boards tested: Boards #1-5, both channels were tested

Operating current: All boards were operated at 8.2V input.
Mean current: 592mA
Maximum current: 609mA
Minimum current: 583mA
Current calculated from circuit design 467mA. (quiescent only)

LO Power Meter readout at nominal LO power
Mean readout: 1.173 Volts
Minimum readout: 1.124 Volts
Maximum readout 1.259 Volts
Deviation: 3.9% (0.17dB)

Gain: measured at 6429 MHz RF, 20MHz IF
Mean gain: 33.66 dB
Minimum gain: 32.76 dB
Maximum gain: 34.69 dB
Standard deviation: 0.34dB
Calculated gain from circuit design (without limiters): 32.93 dB
Note, addition of limiters will reduce gain approximately 0.8dB

Noise Figure: 6429 MHz RF, 20MHz IF
Mean 6.11 dB
Min 5.50 dB
Max 6.74 dB
Calculated 5.29 dB

Linearity: With 2 tones, 1 MHz separation, each 6dB below full scale (combined peak power = full scale = 2V pk-pk), maximum spur line relative to full scale:
Mean 74.12 dB
Minimum 71.70 dB
Maximum 75.80 dB
Calculated 62.98 dB (calculation method assumes worst case addition of modes).

Derived parameters:
RMS output noise in counts: ~2.25 counts RMS.
RF input power for full scale out ~ -23.7dBm

Beam Tests of ATF2 electronics (Y. Honda)

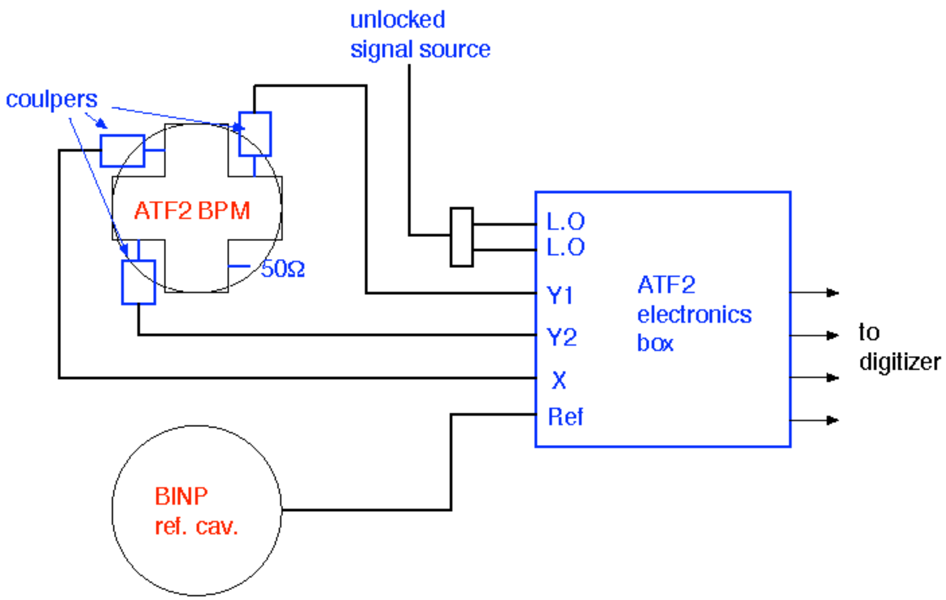
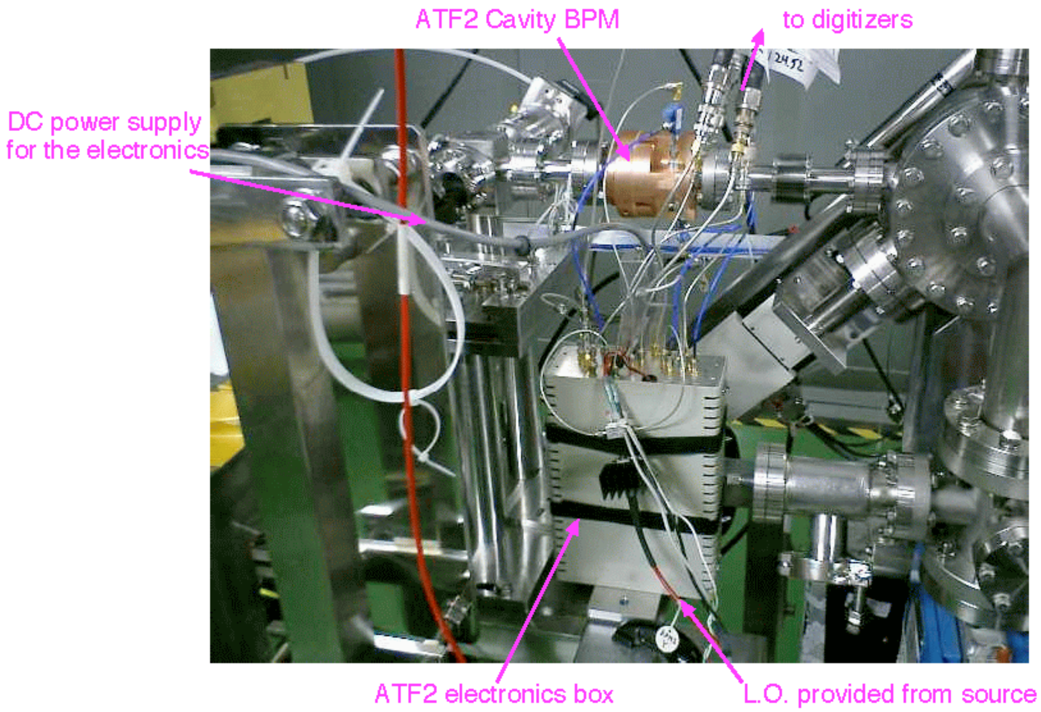
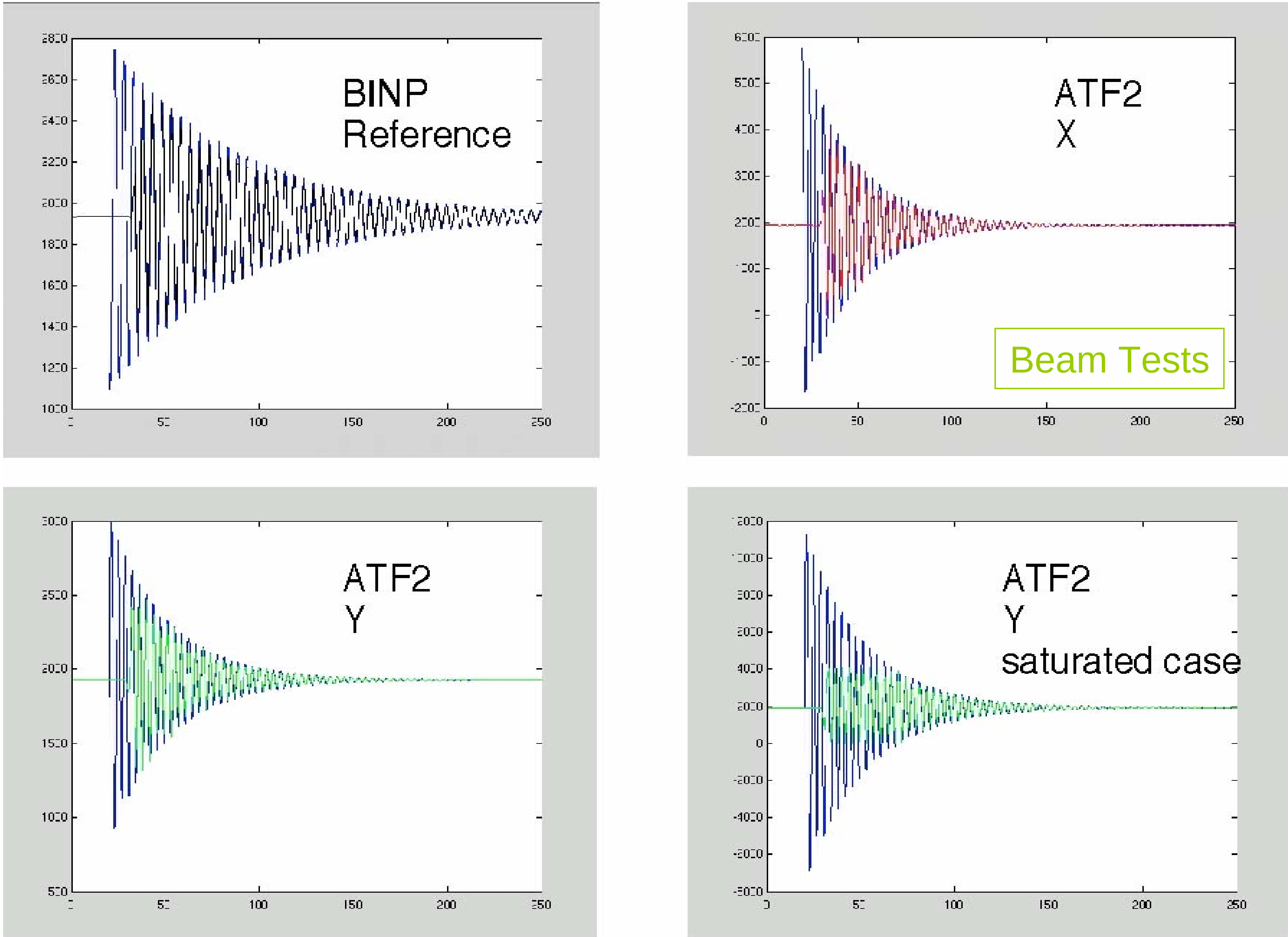
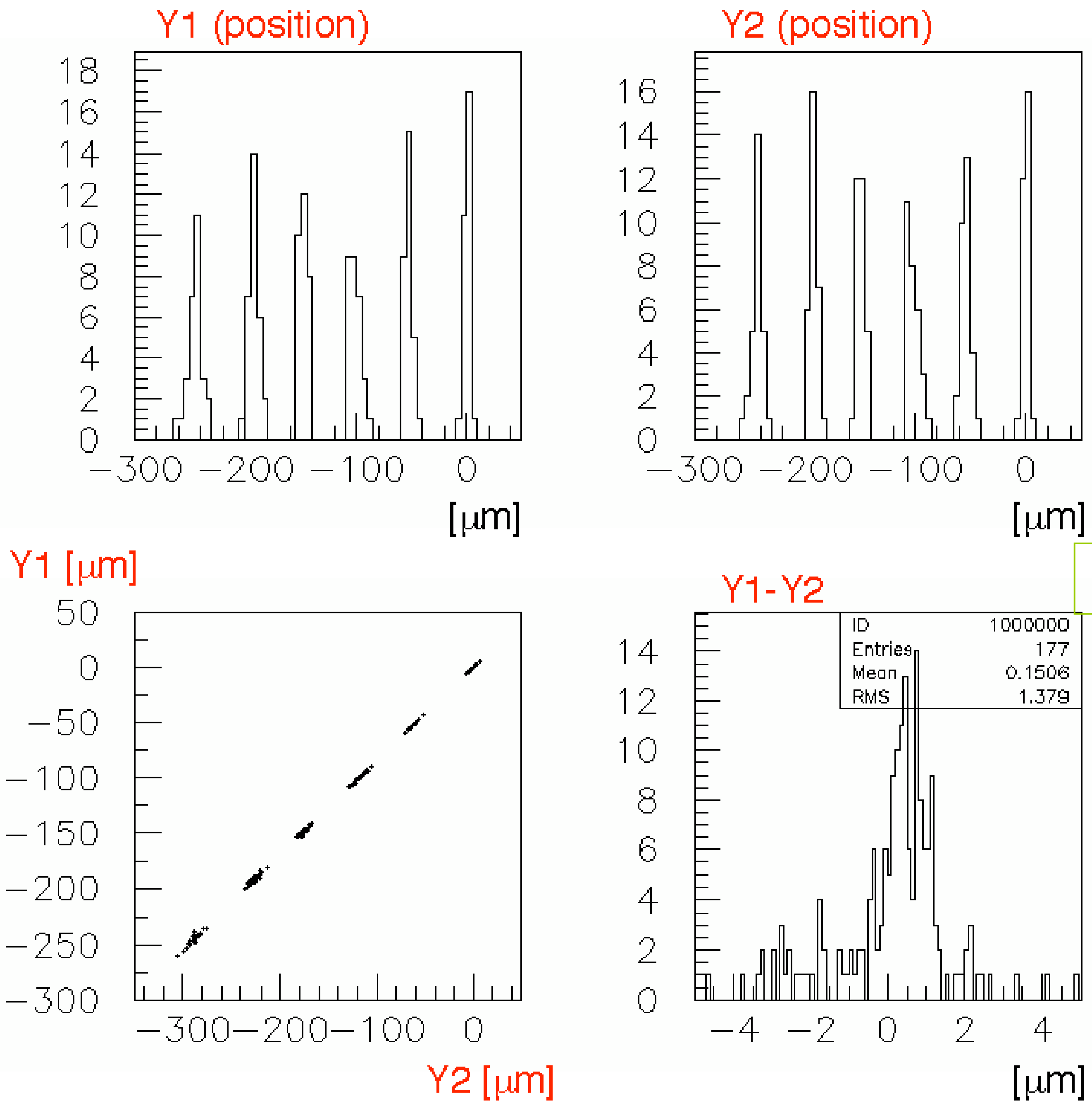


Figure 1: Setup of the electronics



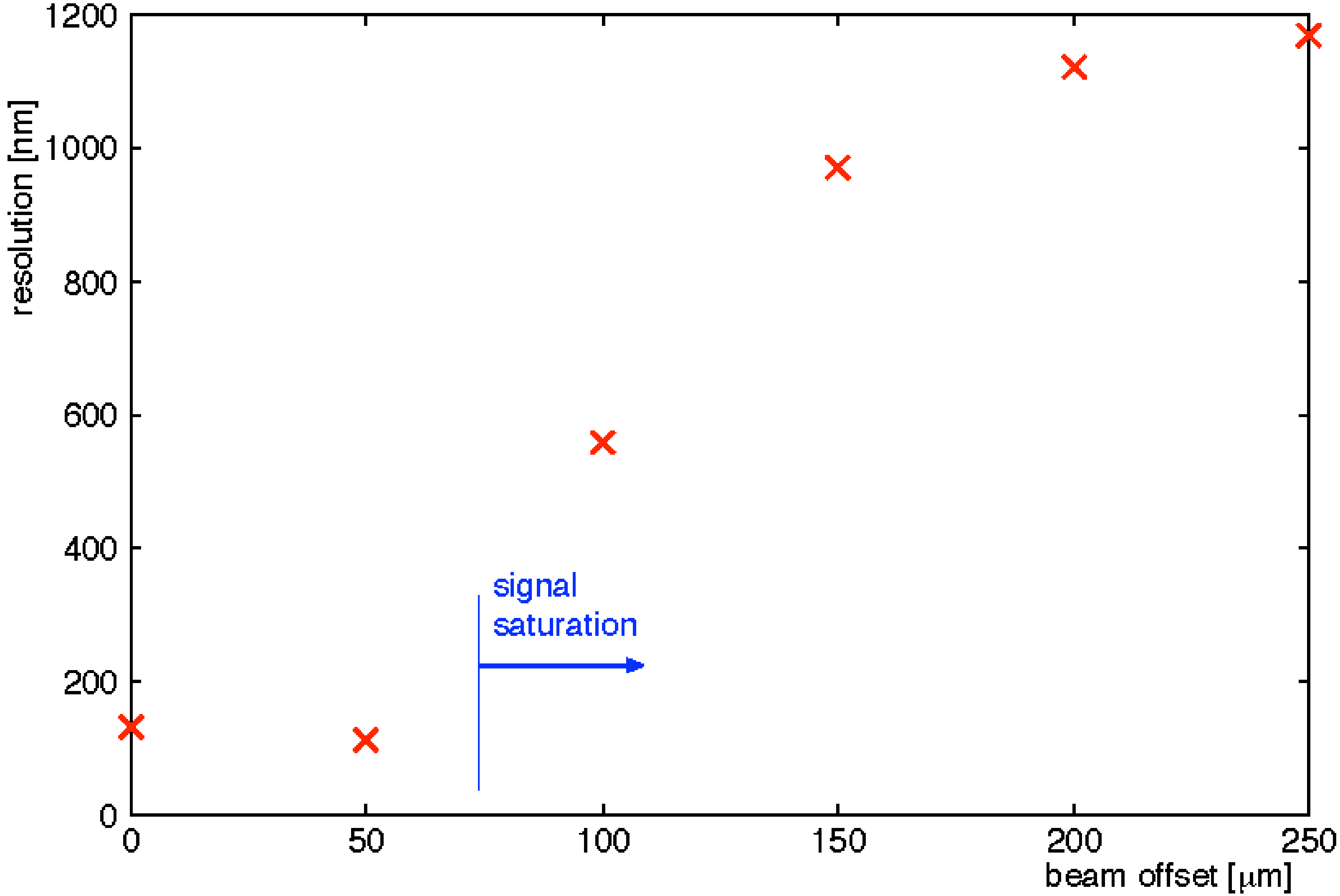

BINP
Reference
ATF2
X
Beam Tests
ATF2
Y
ATF2
Y
saturated case

Beam Tests



Y1 (position)
Y2 (position)
[μm]
[μm]
Y1 [μm]
Y2 [μm]
Y1-Y2
ID 1000000
Entries 177
Mean 0.1506
RMS 1.379
[μm]

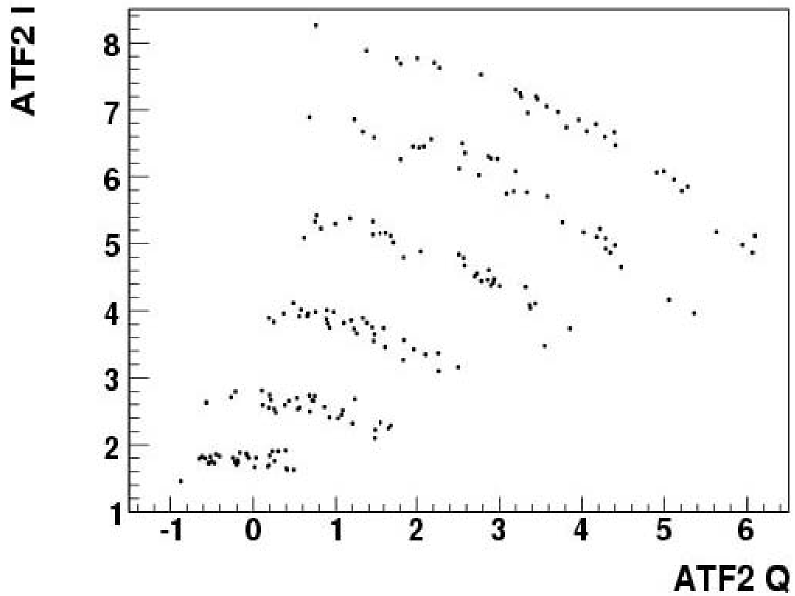
Beam Tests

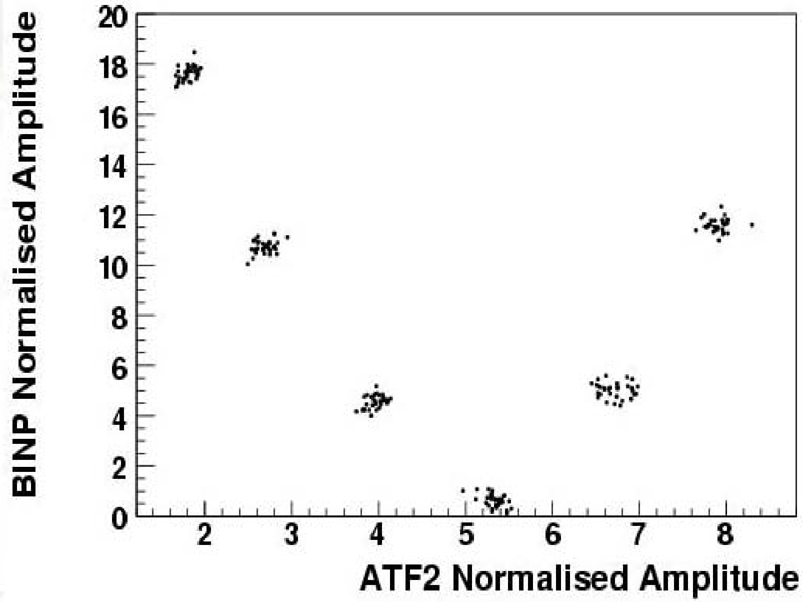


resolution [nm]
1200
1000
800
600
400
200
0
0
50
100
150
200
250
beam offset [μm]
signal
saturation

Sample results from April Run

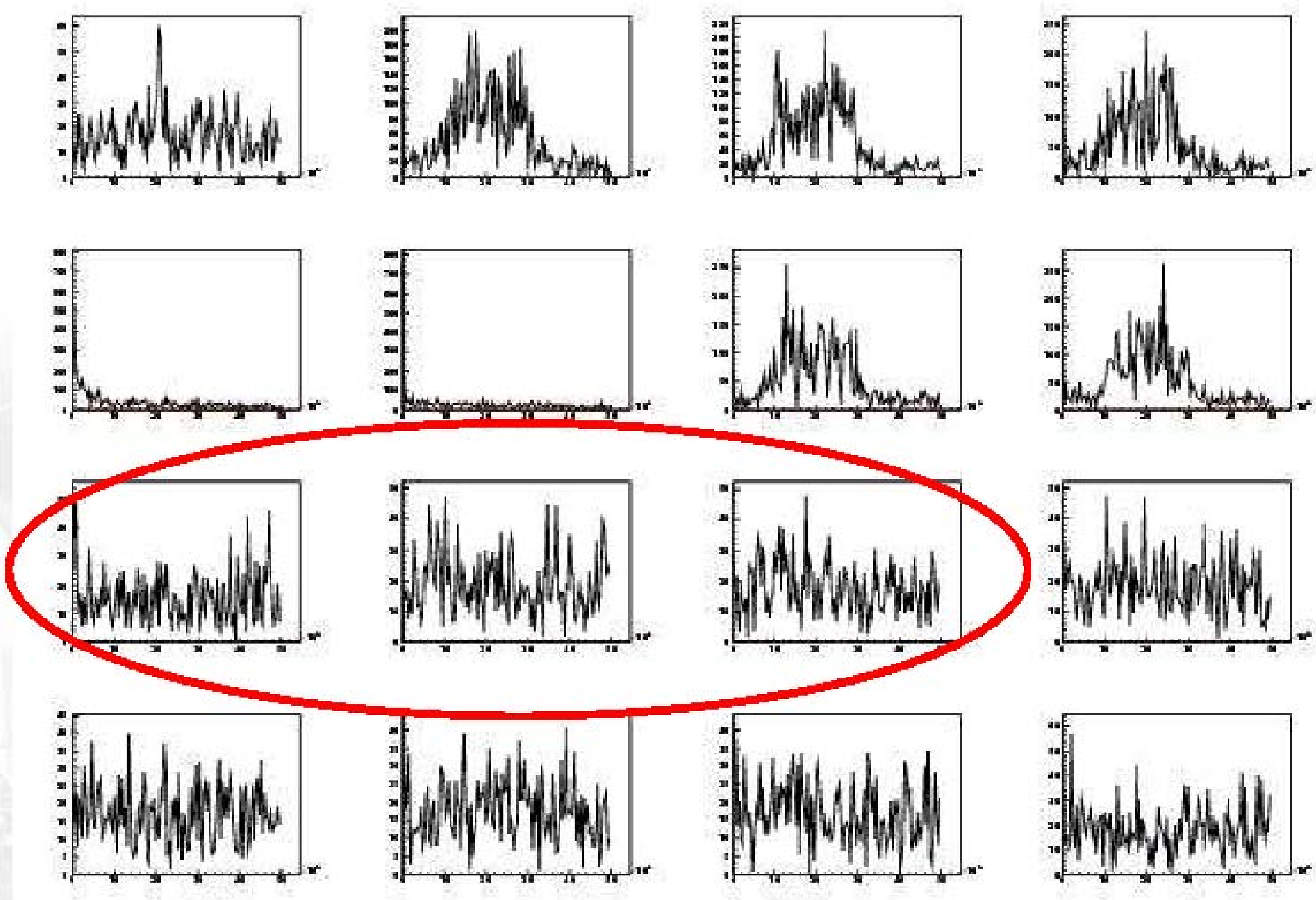
- Most of the data taken during the April run was with the ATF2 BPM set up in the 3rd SIS
- Examining the IQ plots from corrector scan data taken shows a problem with the phase determination
- However, the amplitude correlation through the corrector scan is good
- (data used was from 13th April Swing shift, 01_13->01_18)
- I think the phase problem could be due to either problems with the clocking for SIS3 or some analysis issue that manifests itself when going to 12-bit





Noise Results (1)

- On the last shift (21st April), the ATF2 electronics were attached to the central BINP BPM and transferred to the second SIS
- Using some 'no-beam' data, I have looked at the noise from the ATF2 electronics
- First, here are the FFTs of the waveforms:



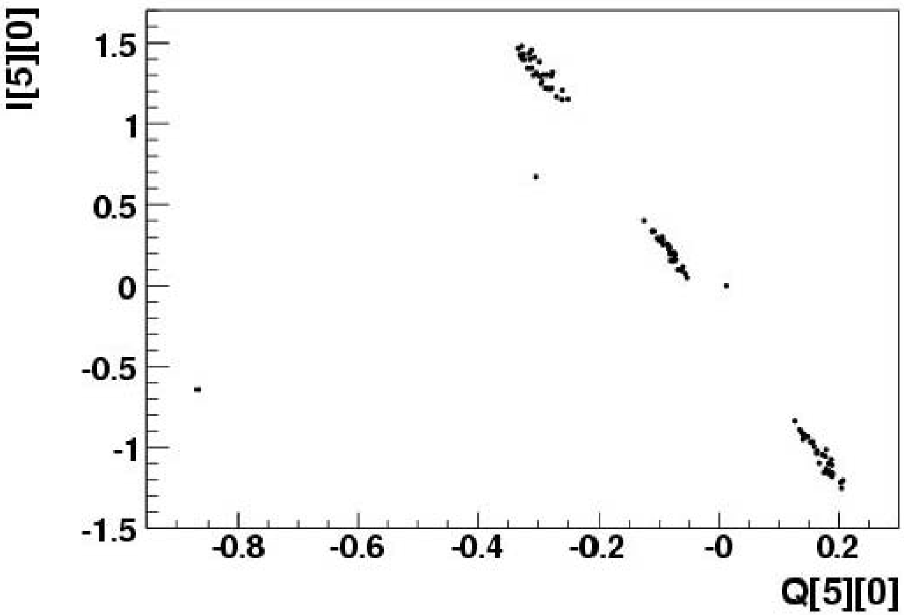
Noise Results (2)

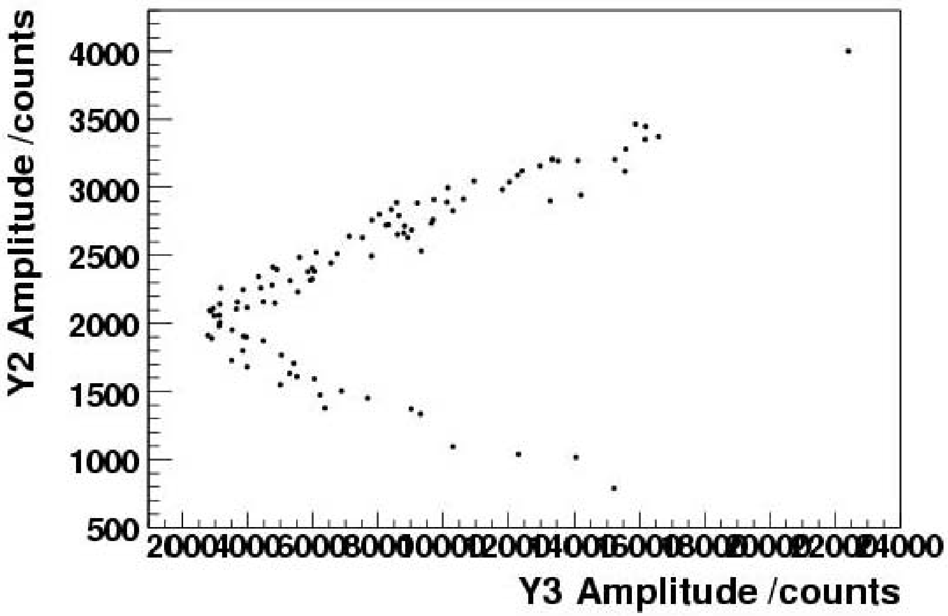
- To compare the level of noise coming from the two sets of electronics, I also calculated the RMS of the noise for both BINP and ATF2 systems
- This was complicated by the need to subtract the kicker signal from the original waveform
- See the shift entries for more details!

channel	BINP: SIS1	BINP2: SIS2
0	1.27357 +/- 0.213076	1.27738 +/- 0.0834225
1	4.7852 +/- 0.301663	1.2332 +/- 0.0587844
2	4.2823 +/- 0.282773	1.2094 +/- 0.052829
3	4.41638 +/- 0.315655	1.21583 +/- 0.0528373
4	4.06145 +/- 0.829708	1.21557 +/- 0.0541741
5	2.11367 +/- 0.283968	1.23056 +/- 0.0546282
6	4.75563 +/- 0.306618	1.2247 +/- 0.0591261
7	4.5164 +/- 0.292181	1.22891 +/- 0.0518004

Resolution of ATF2 Electronics (1)

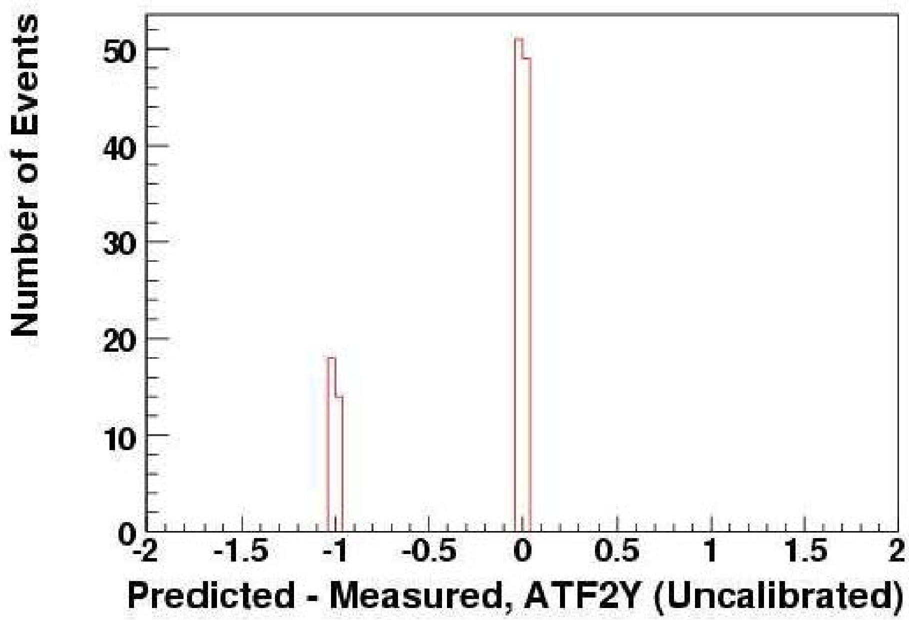
- Using the data taken on the 21st April, it was possible to estimate the resolution possible with the ATF2 electronics
- Unfortunately, due to poor beam stability and an error with the reference attenuation, there were very few complete calibration runs
- However, both the IQ plot and the correlations look a lot better

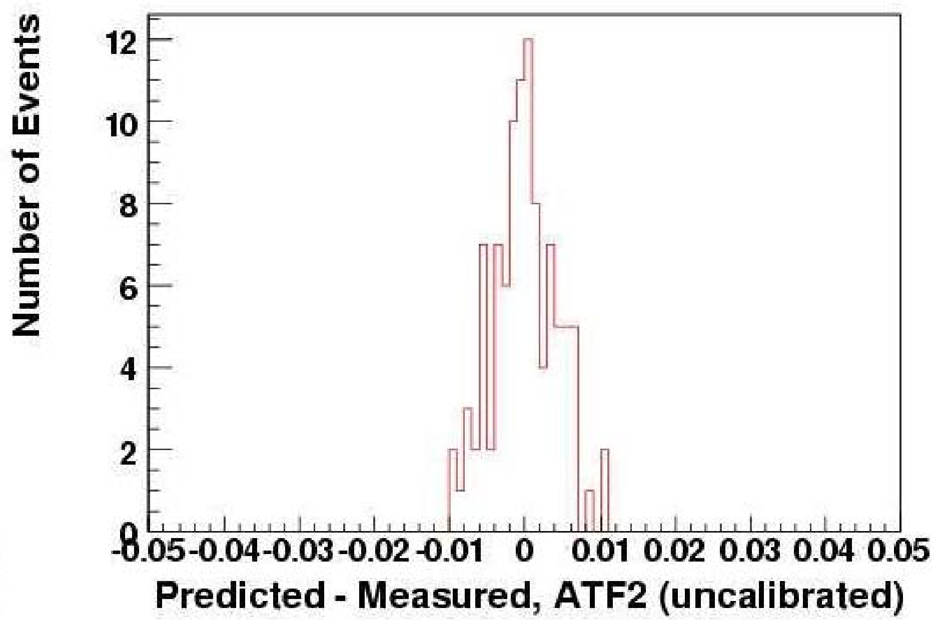




Resolution of ATF2 Electronics (2)

- I decided the easiest way to estimate the resolution was to use Honda-san/Sean's method
- This involves using the I's and Q's from the spectator BPMs to predict the I and Q in the central BPM and then using data with a known move to calibrate this distribution
- For the central BPM using the ATF2 electronics, a residual of 167nm was found
- This number includes:
  - The resolution of the spectator BPMs (15-50nm)
  - A factor ~4 smaller in gain (seen in the noise and relative scale measurements)





Basic Schedule Highlights

There are five targets in the Electronics Production track:

1. Coupler Design finished — done[1]
2. Board Design finished[2] — 6/7/06
    a. changes:
        i. power on/off LED,
        ii. coupler stub,
        iii. limiter pad with cutout, *done*
        iv. output IF trace routing options (front *vs* back), *done*
        v. fuse, *done*
        vi. thermistors (three total: one for readback, two in parallel with output IF OpAmp feedback reisitors)
3. Board Testing finished (prototype, burn-in, etc.) [3] — 6/30/06
    a. boards in to Sierra 6/7
    b. back 6/13, in to AmTech
    c. back from AmTech 6/16, burn-in test begins with limiter space jumpered
4. Board Production finished[4] — 7/21/06
5. Benchmark testing complete[5] — 8/18/06

There are two components in the Installation Production track, hard deadlines closer to actual completion of ATF2 beamline:

1. Enclosure Design and Fabrication
    a. enclosure
    b. connectors (bulkhead)
    c. internal cabling (if needed)
2. Installation design and preparation
    a. enclosure mounting
    b. signal cable plant
    c. 8Vdc power supply and distribution

Scheduled Reviews:
6/30/06 (review results of two-week powered test on five boards. Current plan includes 5 boards with DC power only, one board under power with RF and LO input.)

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[1] as in retired. We shall adopt Joe's non-directional coupler option.
[2] Includes review and final corrections/changes
[3] Includes time for production of final prototype board
[4] Assuming we didn't find anything fatal in the two-week burn-in, this is a full production run of the proven design, fully assembed except for the outstanding balance of the lmiter order (due 7/21).
[5] Gain, IP3, noise, thermal stability, pulsed response?

Remaining:

- Bench tests of coupling
- Bench tests of stability, lifetime and temperature response
- Beam test analysis
- Saturation tests and matching with digitizer
- Calibration tests
- System design