Beam Monitoring Update

Mark Pitt, Virginia Tech January 23, 2015

- Beam Charge Monitor (BCM) Digital Receiver Bench Studies - Recent Progress
- Hall A MOLLER Beamline Instrumentation – needs for pre-R&D and full project

Random Beam Fluctuations and Beamline Instrumentation

Use Qweak experience (@ 1 kHz data rate) →

Assess MOLLER specifications (@ 2 kHz data rate) for beam fluctuations/monitoring

Random beam fluctuations ("jitter") @2 kHz:

Beam property	MOLLER spec.	Qweak observed
Intensity	< 1000 ppm	500 ppm
Energy	< 108 ppm	6.5 ppm
Position	< 47 μm	48 μm
Angle	< 4.7 μrad	1.4 μrad

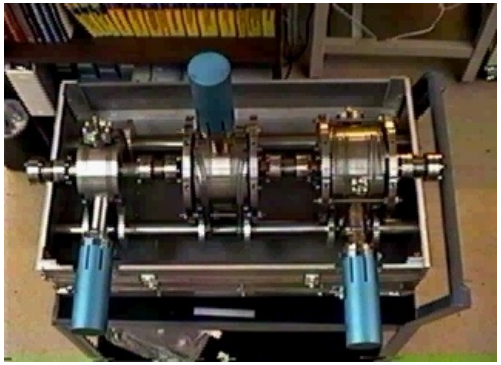
If 12 GeV machine is as "quiet" as 6 GeV machine, these will be easily satisfied!

Beamline monitor precision @2 kHz:

Monitor type	MOLLER spec.	Qweak observed
Beam charge	10 ppm	65 ppm
Beam position	3 μm	6 μm

- Position nearly satisfied
- Charge monitoring will require further developments

➔ Start with BCM digital receiver studies

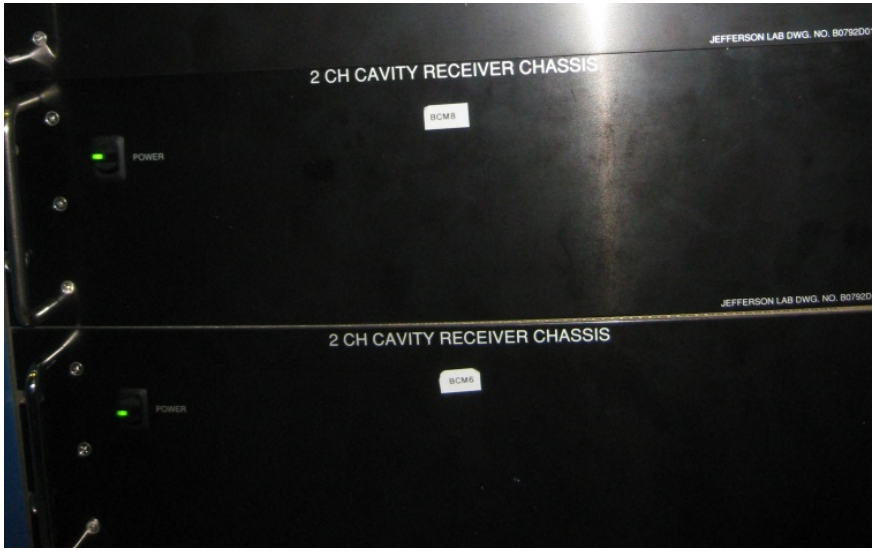


BCM Resolution with "Qweak" Digital Receivers

- MOLLER goal for charge monitor resolution is ~ 10 ppm for 1 kHz pairs
- Qweak best values ~ 46 ppm for effective 480 kHz pairs

Qweak got these results with:

- Standard BCM hardware (TM_{010} cavities)
- Most recent version of the "Musson/Allison" digital receiver chain



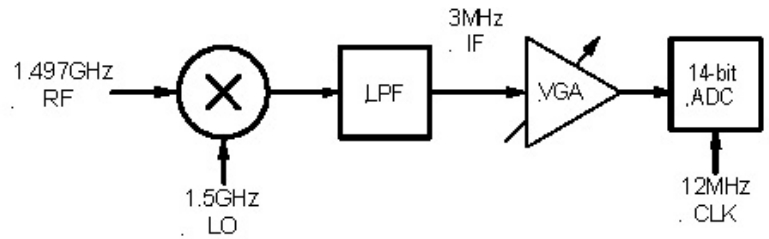


Figure 1: RF Front end downconverter.

Musson: JLAB-TN-14-028

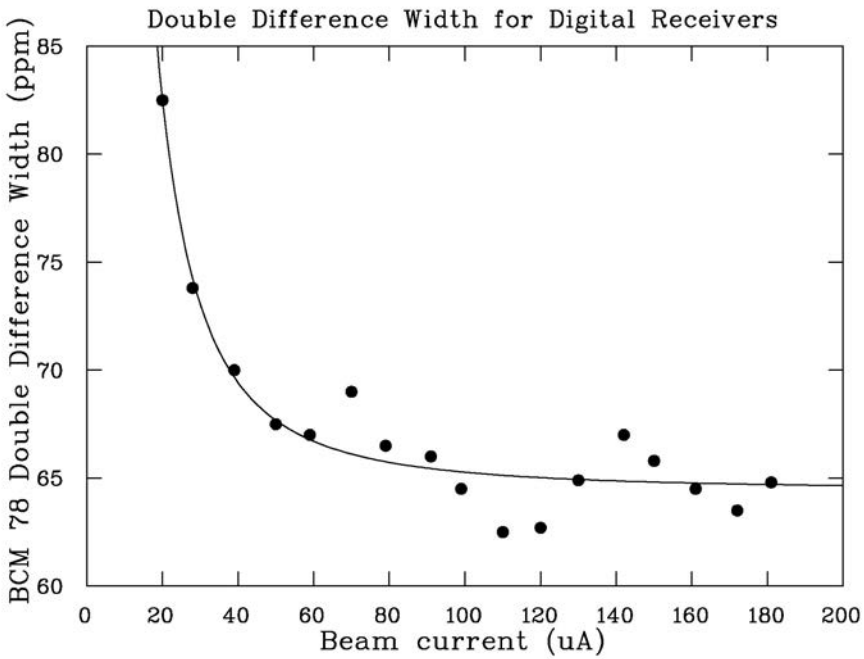
Each of the Qweak style digital receivers has two inputs going through separate chains sharing only the 1.5 GHz local oscilllator.

Best BCM Resolution with Digital Receivers

Qweak got these results with:

- Standard BCM hardware (TM_{010} cavities)
- Most recent version of the "Musson/Allison" digital receiver chain

Double difference
measures uncorrelated noise between two monitors



Fit by simple functional form:

$$\Gamma = \sqrt{\left(\frac{1032\,\text{ppm}\,\mu\text{A}}{I}\right)^2 + (64.5\,\text{ppm})^2}$$

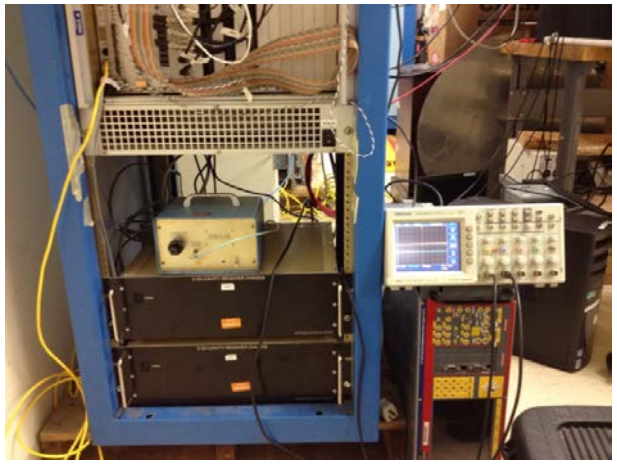
→ apparent noise floor at ~ 65 ppm

Near term question: can we understand (and improve upon) this noise floor with bench tests?

BCM Digital Receiver Bench Test Progress

Work being done by VT graduate students Anna Lee and Wade Duvall with help from Mark Pitt and Paul King

- Re-established setup in EEL (one 8 channel VQWK ADC with usual parity triggering scheme @ 960 Hz and usual parity analyzer)
  - Replaced dead computer and established network communications with digital receivers (Summer 2014)



- Initial studies in August 2014 unreliable due to unreliable rf generator
- Visit John Musson! (December 2014)
- January 2015: good rf generator in use; reliably reproducing Qweak beam conditions with rf generator

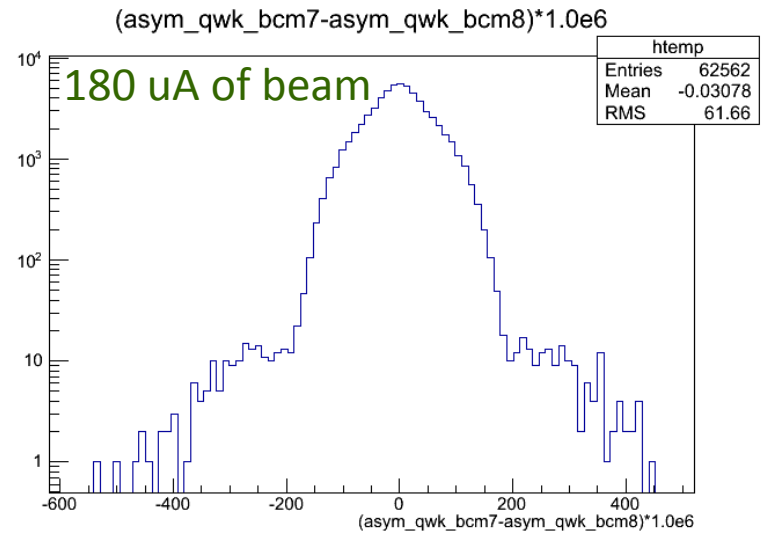
Visit to John Musson in December 2014

Walk in with this: John says: “Oh, one of our “go, no-go” boxes!”

Walk out with this: fancy microwave function generator

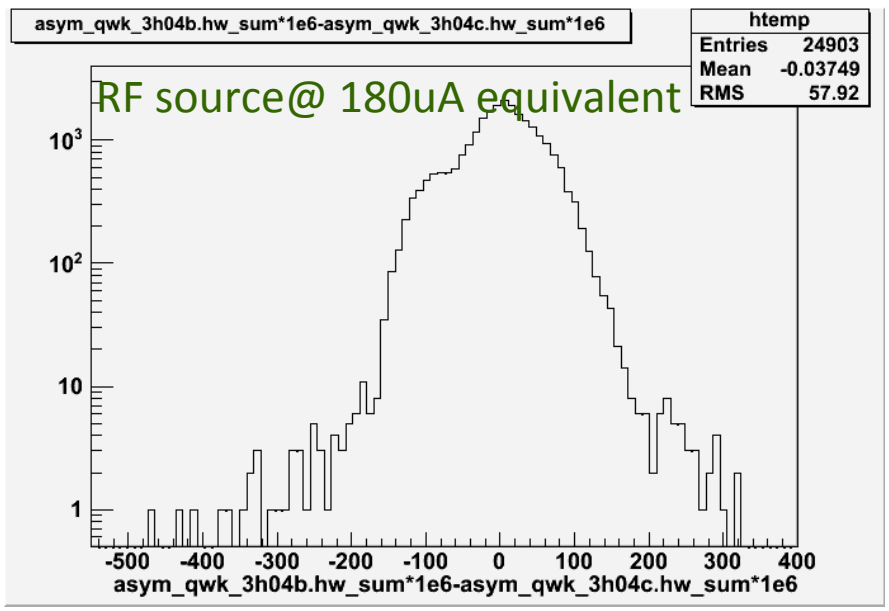
BCM Digital Receiver - RF Source vs. Real Beam

Compare RF source to Qweak beam at 960 Hz data-taking rate:



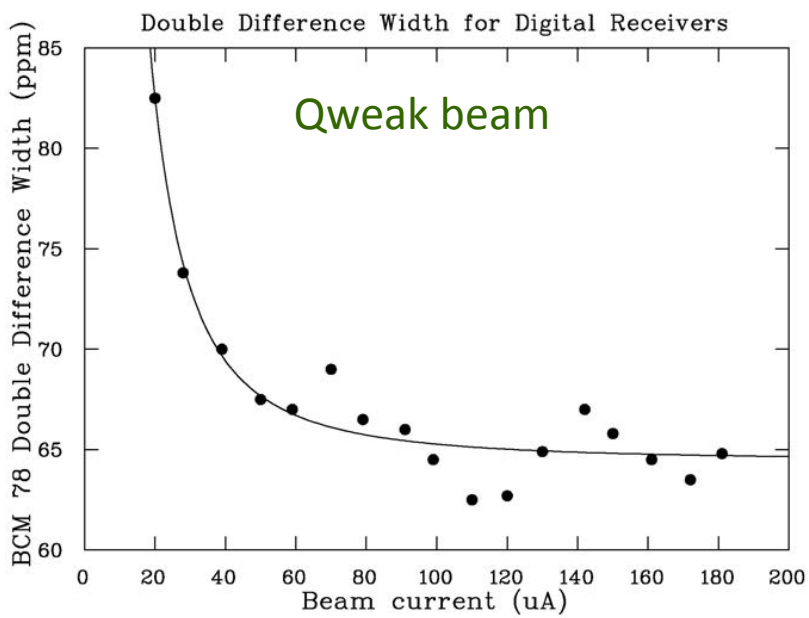
Both tests done with signals going into two separate digital receivers each with their own local oscillator

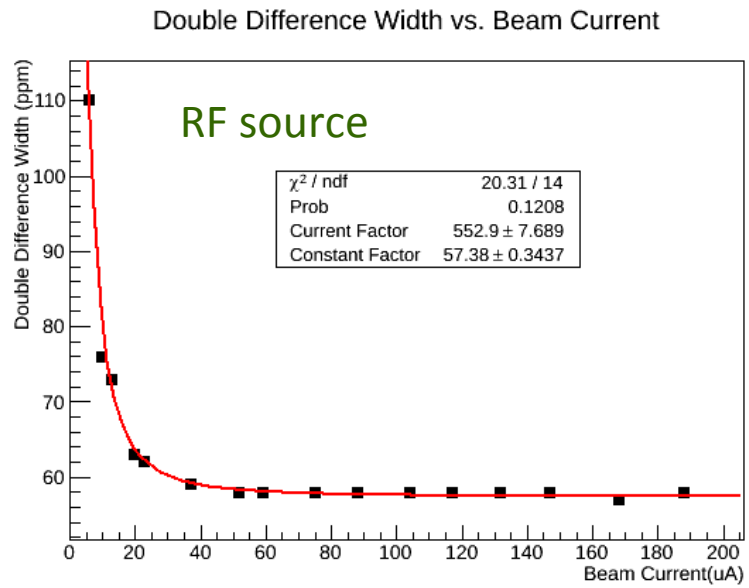
Double difference distributions show similar non-Gaussian structure and "wings"



BCM Digital Receiver Noise Floor – rf source vs. beam

- Signals going into separate digital receivers
- Data-taking done at 960 Hz





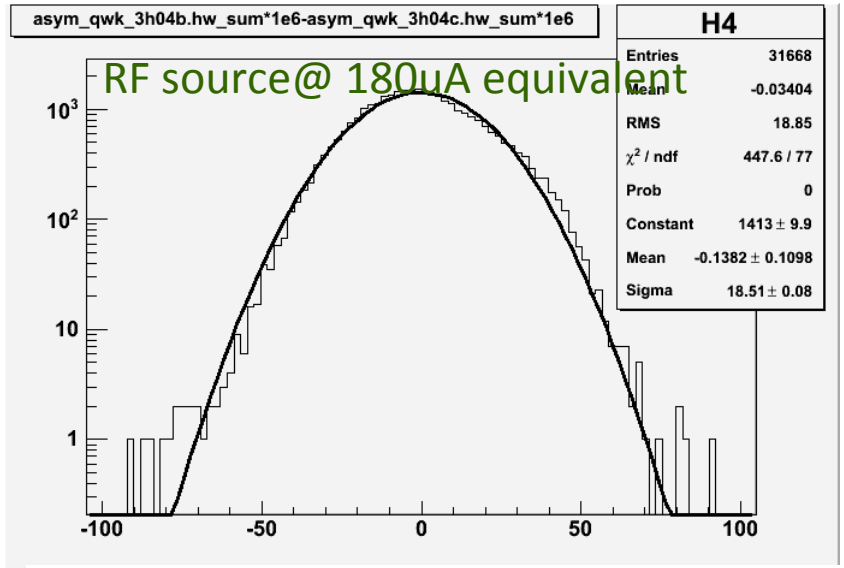
Fit by simple functional form:

$$\Gamma = \sqrt{\left(\frac{1032\,\text{ppm}\,\mu\text{A}}{\text{I}}\right)^2 + (64.5\,\text{ppm})^2} \qquad \Gamma = \sqrt{\left(\frac{553\,\text{ppm}\,\mu\text{A}}{\text{I}}\right)^2 + (57.4\,\text{ppm})^2}$$

→ Similar noise floor for both beam (65 ppm) and RF source (57 ppm)

BCM Digital Receiver Noise Floor – Common Local Oscillator

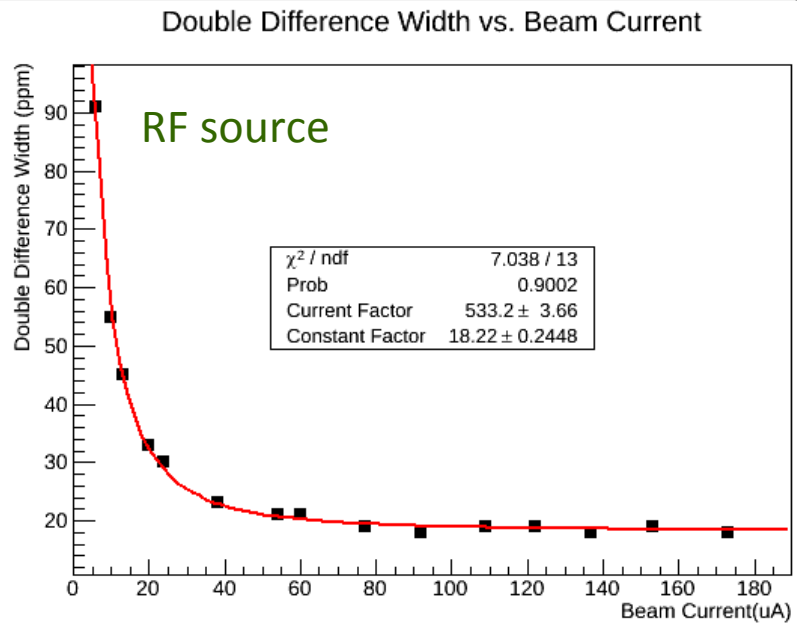
- Signals going into two channels (separate chains) of same receiver (shared local oscillator)
- Data-taking done at 960 Hz



$$\Gamma = \sqrt{\left(\frac{533\,\text{ppm}\,\mu\text{A}}{\text{I}}\right)^2 + (18\,\text{ppm})^2}$$

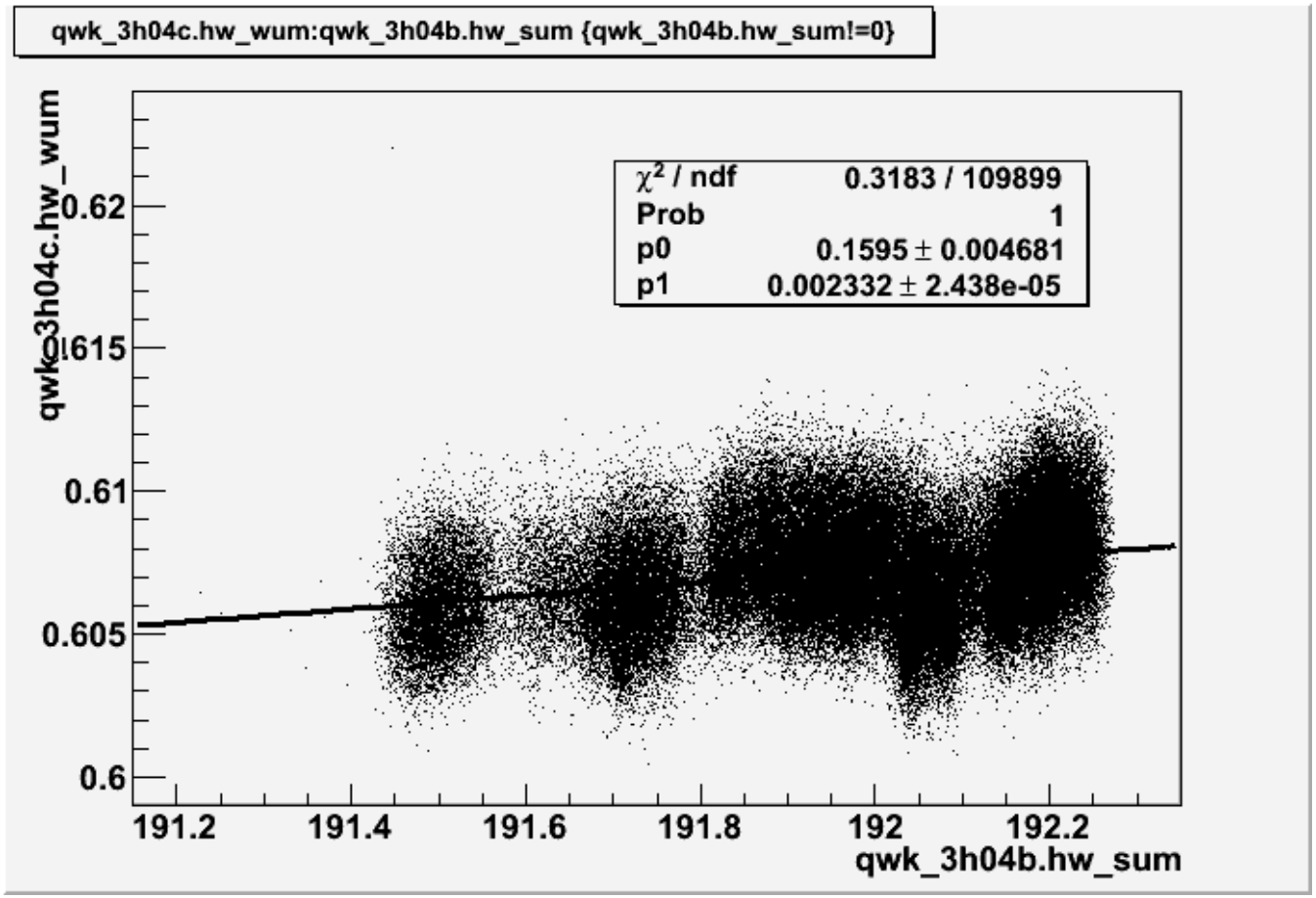
→ apparent noise floor at ~ 18 ppm

Consistent with (but not proof for) the local oscillator (phase and amplitude) noise being responsible for the 65 ppm noise floor



BCM Digital Receiver – Crosstalk Check

How coupled are the two chains in a given receiver?
Quick cross-talk test: put signal into one chain; look for any coupling in the output of the channel with no signal



Cross talk at the level of ~ 0.2%

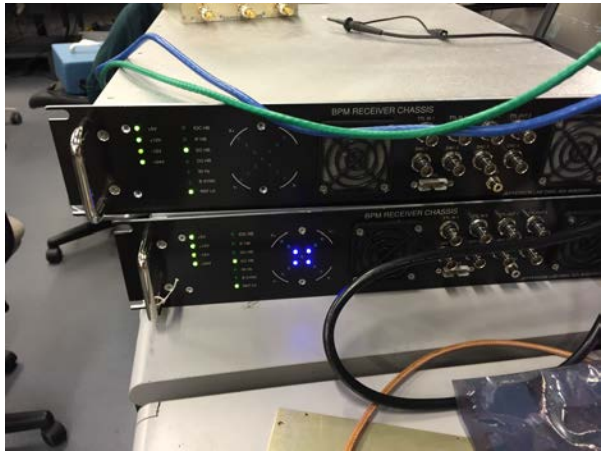
Future plans for BCM Digital Receiver Tests

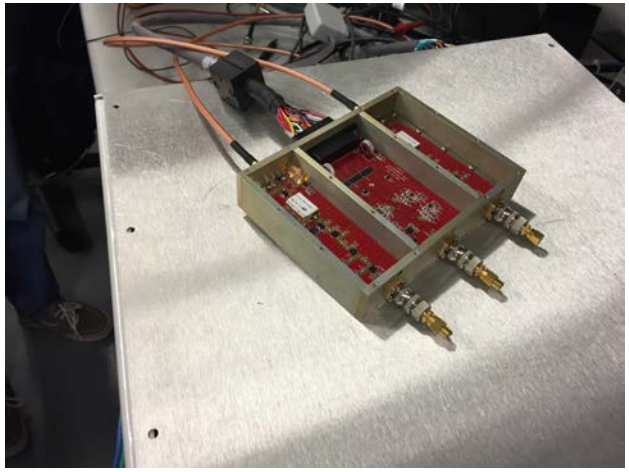
Over next couple months we will try to:

- Finish data-taking with "Qweak-style" digital receivers
  - Look at double-differences as function of data-taking rate (up to 2 kHz)
  - Look at double-differences right at MOLLER operating point (80 uA @ 2 kHz)

- Redo all of the above with the "next-generation" digital receivers

- Evaluate where we are at
  - Are we there with the new receiver?
  - Do we need further work? (ie. improved phase/amplitued noise of local oscillator?)





"Wish List" for MOLLER Beamline Monitoring R&D

In January 2013, memo outlining "Near-term Hall A Beamline Instrumentation for MOLLER Development" was prepared at Thia's request
(authors: Krishna Kumar, Bob Michaels, Kent Paschke, Mark Pitt, Paul Souder)
(see MOLLER docdb: https://hallaweb.jlab.org/doc-private/ShowDocument?docid=77)

To achieve MOLLER's goals for beamline monitoring precision/redundancy, it would be very useful to have this hardware available for parasitic testing during early Hall A 12 GeV era running

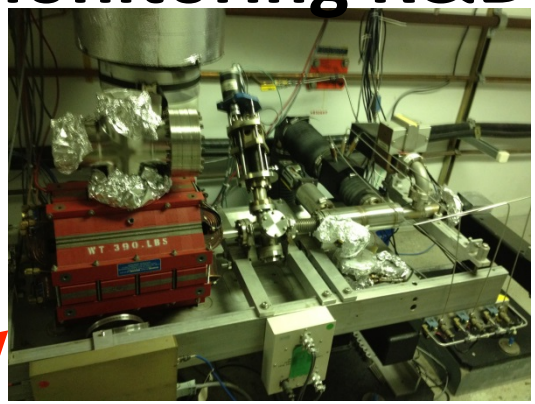
1. Three XYQ cavity monitor assemblies in non-dispersive region ➔ in progress
    - All exist in the Hall (2 near target, 1 – from G0/Qweak girder – ready to be installed)
    - Motivation: Allow definitive measurement of beam position resolution of the cavity monitor hardware/receivers (recall: MOLLER goal is 3 μm position resolution for 1 kHz "window pairs")

2. A "triplet" of cavity charge monitors (BCMs) wherever convenient
    - Motivation 1: would provide large redundancy in the critical charge measurement (recall: MOLLER goal is 10 ppm charge resolution for 1 kHz "window pairs")
    - Motivation 2: would provide self-contained set of nearby BCMs to study the position dependence of the charge measurement

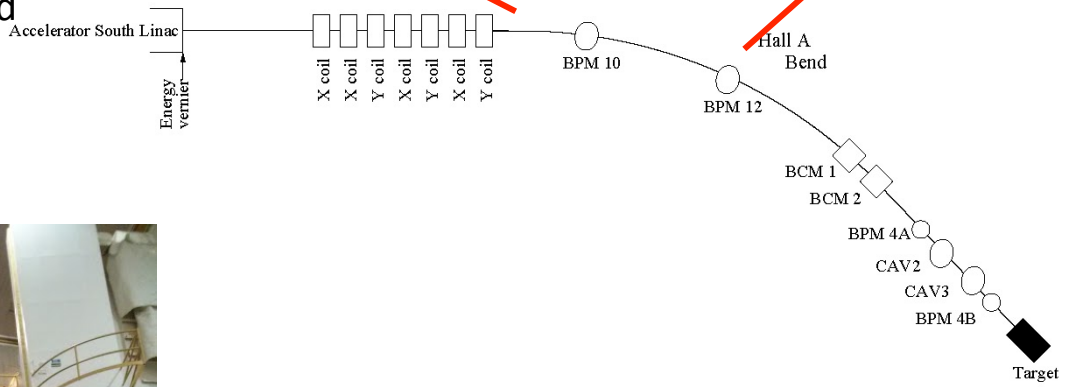
3. An XYQ cavity monitor assembly in the dispersive region
    - Possible candidate is the unconnected XYQ cavity assembly that is further upstream in the arc
    - Motivation: to have redundant measurement of helicity-correlated beam energy fluctuations (in addition to the usual "stripline" BPM12)

“Wish List” for MOLLER Beamline Monitoring R&D

“12” girder; XYQ monitor (from upstream in arc) could go here? – energy measurement



BCM cavity triplet could go here?



XYQ from old G0/Qweak girder, on floor in Hall A, can go in here – room exists according to Ed Folts

"Wish List" MOLLER Beamline Monitoring – Cost Estimate

1. Three XYQ cavity monitor assemblies in non-dispersive region
   - Microwave cavity assembly exists (came from G0 girder); sitting in hall
   - Cost for outfitting rest – per John Musson
     - Blanket $2.5 k
     - SSR + Temp Control $1.0 k
     - 3/8" Heliax free!
     - Digital receiver $6.0 k

     Total ~ $10k -→ request this in "pre R&D" request

2. A "triplet" of cavity charge monitors (BCMs) wherever convenient
   - Microwave cavity assembly does not exist (unless Hall C would "give" us the one that Qweak used) → cost for complete new assembly ~ $100k
     include as part of Project budget

3. An XYQ cavity monitor assembly in the dispersive region
   - Microwave cavity assembly exists (in Hall A arc)
   - Rest of outfitting ~ $10k
   - need to estimate engineering cost of getting it in the C12 location where the dispersive point is
   - also include as part of Project budget (or maybe Prex wants it to happen too?)

Summary

- BCM Digital Receiver Bench Studies
  - Plan to have tested both “Qweak” and “latest” style digital receivers over the next two months; then evaluate next steps

- Hall A MOLLER Specific Beamline Instrumentation
  - Will cost out the additions we have proposed (to go into “pre-R&D” request or the Project budget)