BCM bench studies, BPM plans in Hall A, Halo Monitoring Plans in Hall A

Mark Pitt, Virginia Tech March 26, 2015

- BCM, BPM resolution goals for MOLLER experiment
- BCM digital receiver bench tests
- Hall A beamline MOLLER R&D wish list and near term action plan
- Qweak halo monitor install in Hall A for Fall 2015 studies?

As I told Riad: Some of these plans are not concrete or approved by Hall A yet; they are just for discussion and feedback.

What is Beam Property Instrumentation and Control used for in Parity-Violation Experiments?

$$Y = \frac{S}{I}$$

S = integrated detector signal
I = integrated beam current

Normalized yield: Requires precise (relative) beam charge measurement

$$A_{meas} = \frac{Y_+ - Y_-}{Y_+ + Y_-} = A_{phys} + \sum_{i=1}^{N} \frac{1}{2Y}\left(\frac{\partial Y}{\partial P_i}\right)\Delta P_i$$

$\Delta P = P_+ - P_-$
P = beam parameter
→ energy, position, angle

Correction for helicity-correlated beam parameters: Requires

•Good polarized source setup (Pockels cell, etc.) for small value of ΔP
(Matt Poelker talk)

•Precise (relative) measurement of beam position (for energy, position, angle) for small error on measurement of ΔP

•Small beam noise or "jitter" (random fluctuations in ΔP) to keep systematic error on the correction small

•Ability to manipulate beam ("coil pulsing") to measure detector sensitivities $\frac{1}{2Y}\left(\frac{\partial Y}{\partial P_i}\right)$ precisely

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

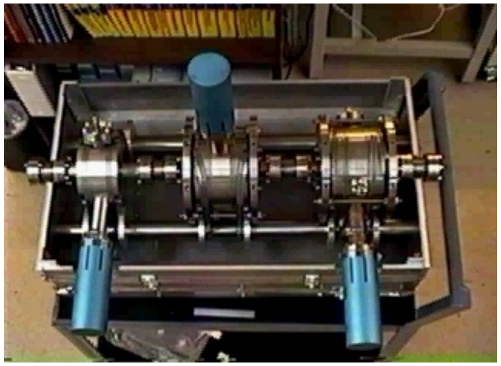
If 12 GeV machine is as "quiet" as 6 GeV machine, these will be easily satisfied!

Beamline monitor precision @2 kHz:

Monitor type	MOLLER spec.	Qweak observed
Beam charge	10 ppm	65 ppm
Beam position	3 μm	2 μm

- Position satisfied for striplines
- Charge monitoring will require further developments

➔ Start with BCM digital receiver studies



Setting Specification on BCM Resolution

BCM Monitor Resolution:

Yields are normalized to the charge monitors, but there will be remaining random fluctuations due to the finite precision of the charge monitors – this needs to be small enough so it does not significantly increase the counting statistics width:

$$\sigma_{random} = \sqrt{\sigma_{counting}^2 + \sigma_{BCM}^2}$$

Example of goal from MOLLER experiment: BCM resolution of 10 ppm (for 1 kHz pairs) limits contribution to counting statistics width of ~ 80 ppm to < 1%

Qweak: BCM Resolution and Intensity Jitter Results

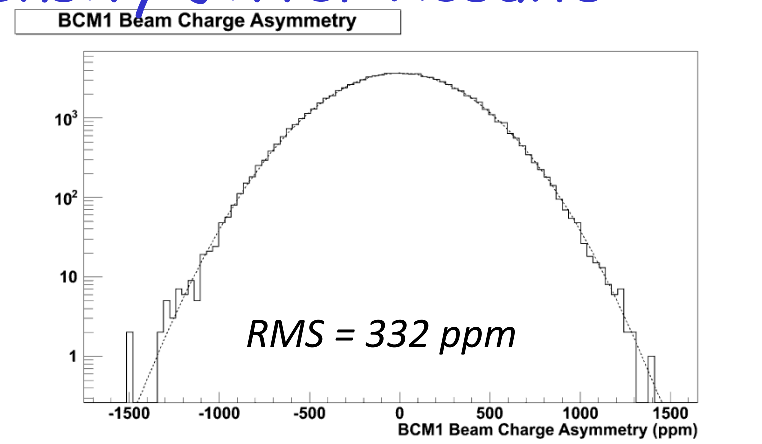
Beam "jitter" dominates the typical noise for a
charge asymmetry $A_Q = (Q_+ - Q_-)/(Q_+ + Q_-)$

Monitor resolution is determined by comparing the charge asymmetry from nearby monitors with a "double difference" ($A_{Q1} - A_{Q2}$) plot – gives the uncorrelated noise.

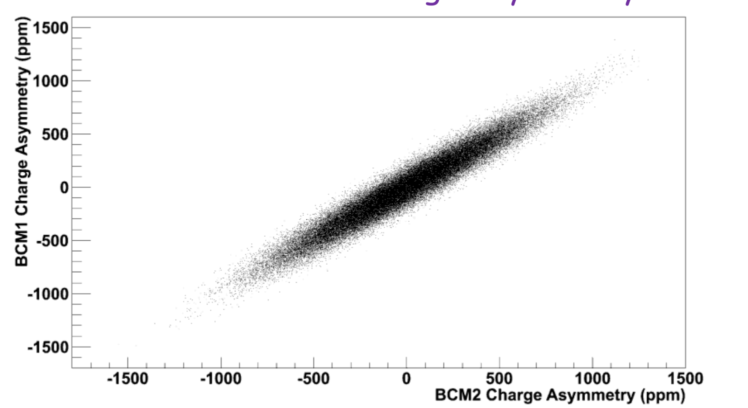
For a single BCM:
$\sigma(A_{Q1})$ *or* $\sigma(A_{Q2})$
$= \sigma(A_{Q1} - A_{Q2})/\sqrt{2}$ = 64 ppm

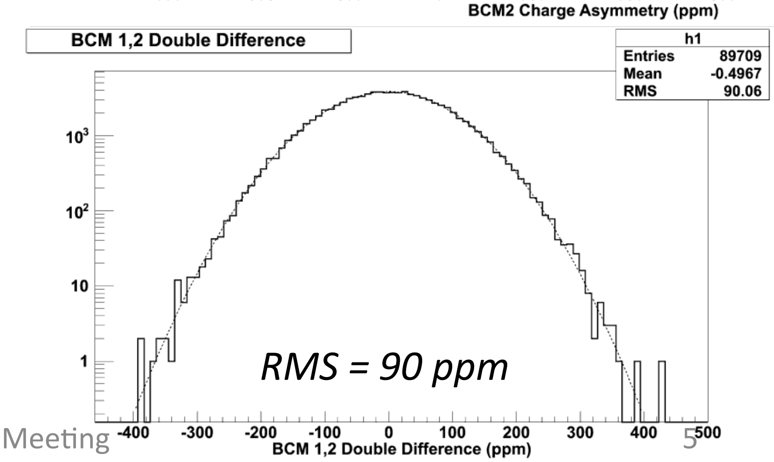
For the average of two BCMs:
$\sigma((A_{Q1} - A_{Q2})/2)$
$= \sigma(A_{Q1} - A_{Q2})/2$ = 45 ppm

so this additional random noise contribution increases Qweak statistical width by only ~ 2%
ie. $\sqrt{(240\text{ ppm})^2 + (45\text{ ppm})^2} = 244\text{ ppm}$



BCM1 vs. BCM2 Charge Asymmetry





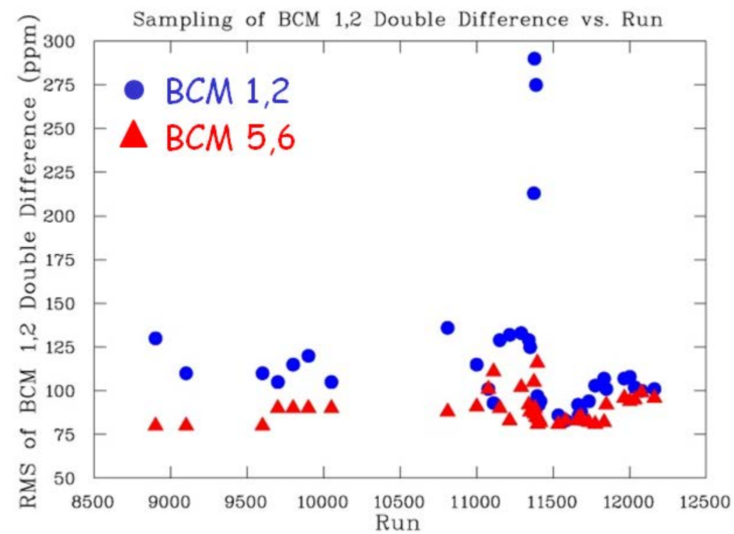
Some Qweak BCM Resolution Experience

BCM resolution has been adequate for Qweak's needs, but not adequate for MOLLER. The Qweak observations and experience can serve as initial R&D for MOLLER.

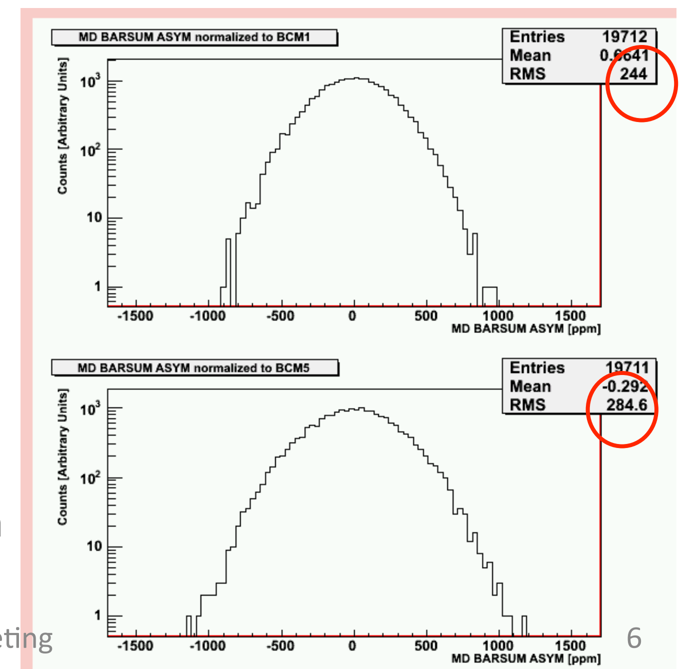
BCM1/2: "analog" electronics readout
BCM5/6: "digital" electronics readout

Double difference (uncorrelated noise) observations over ~ 4 months:

- Varied from ~ 90 ppm – 125 ppm for 150 – 180 μA
- BCM5/6 DD typically more stable and smaller
- "Bad period" when beam had high frequency ~ 20 – 30 kHz noise on it



Evidence for common mode noise in BCM5/6 chain – despite smaller DD, gives larger width than BCM1/2 when used as normalizer; should be improved for Run II



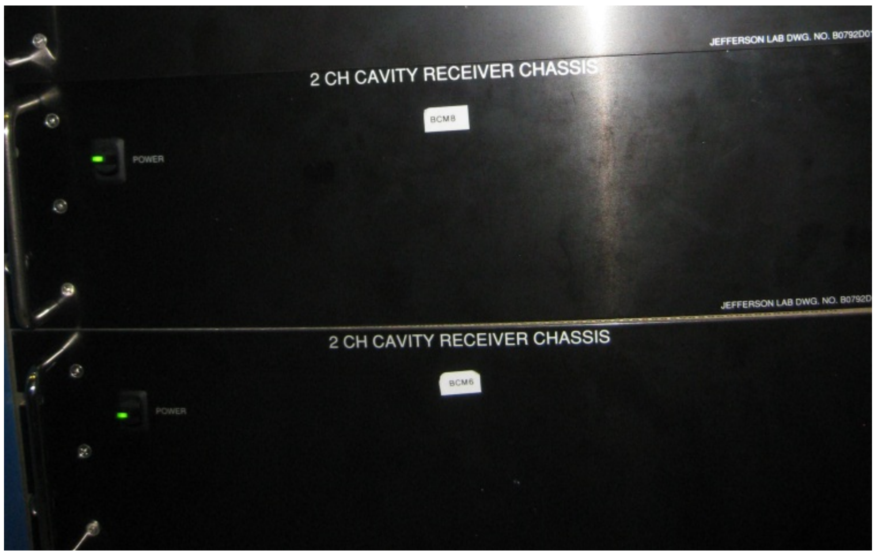
Note added: This cross-talk was eliminated in Run II with upgraded Musson/Allison digital receivers; ~ 65 ppm DD Consistently observed during "Run II".

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



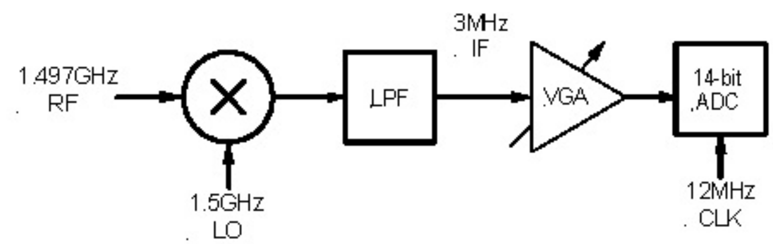


Figure 1: RF Front end downconverter.

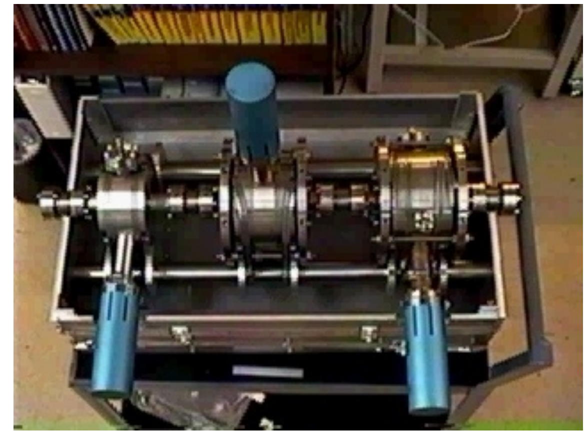
Musson: JLAB-TN-14-028

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

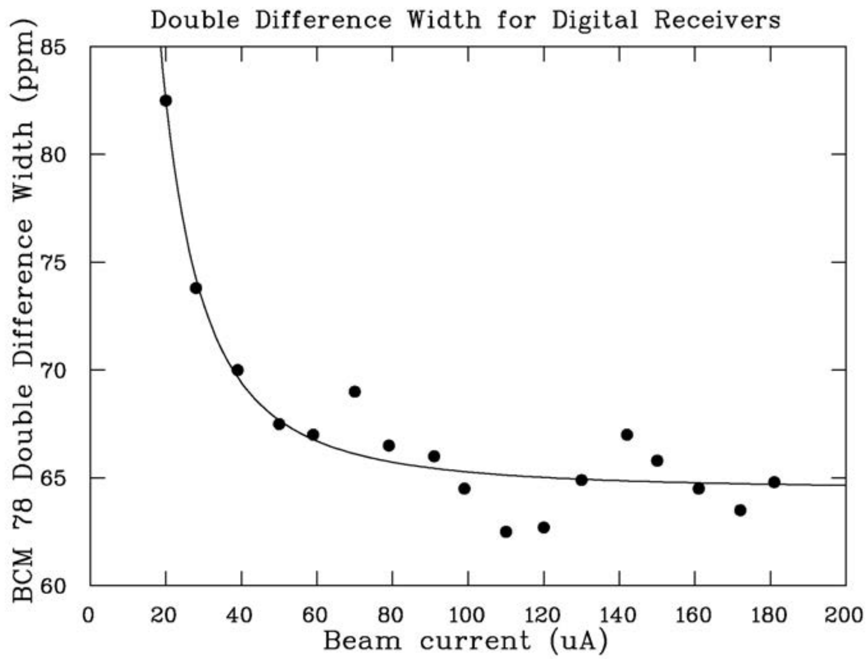
Best BCM Resolution with Digital Receivers

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;
data with electron beam during Qweak



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

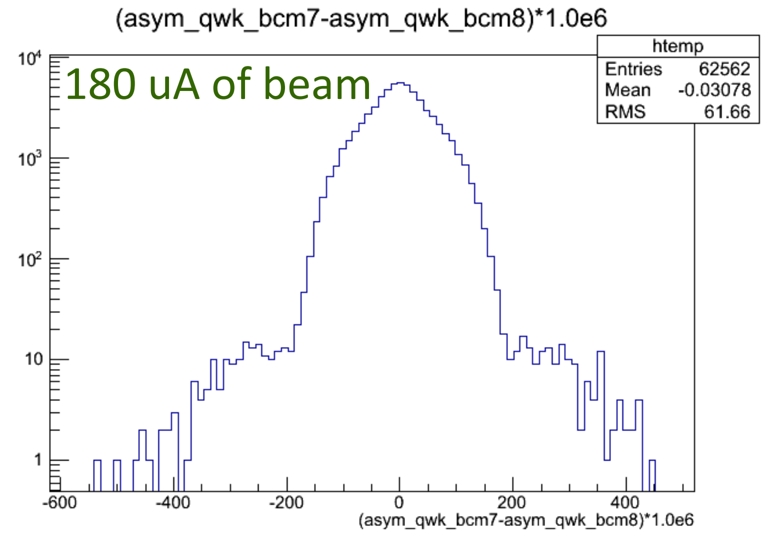
Visit to John Musson in December 2014

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

Walk out with this: fancy microwave function generator

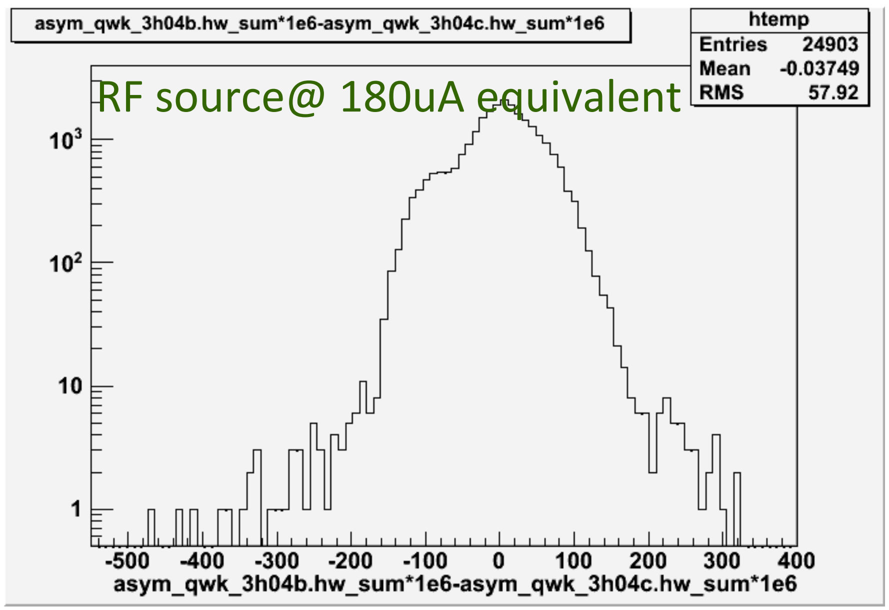
BCM Digital Receiver - RF Source vs. Real Beam

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



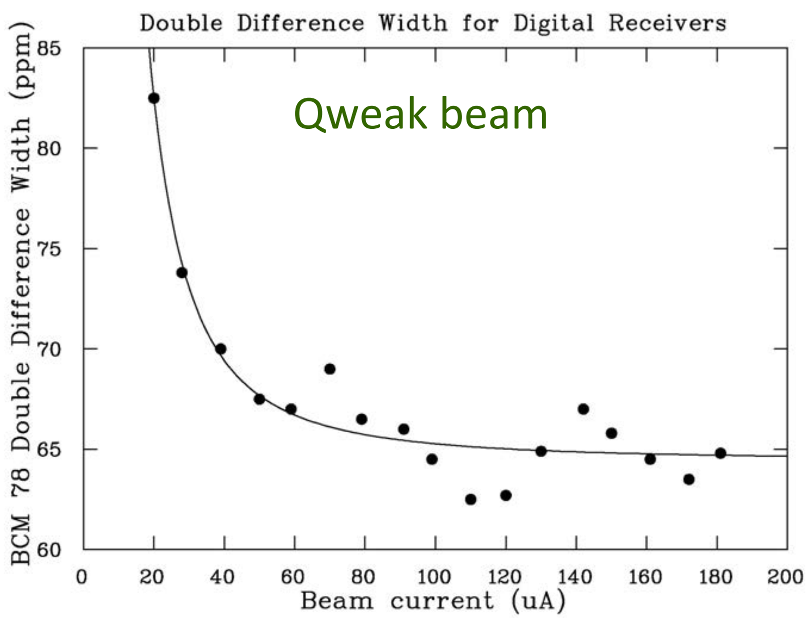
Both tests done with signals going into two separate digital receivers each with their own local oscillator

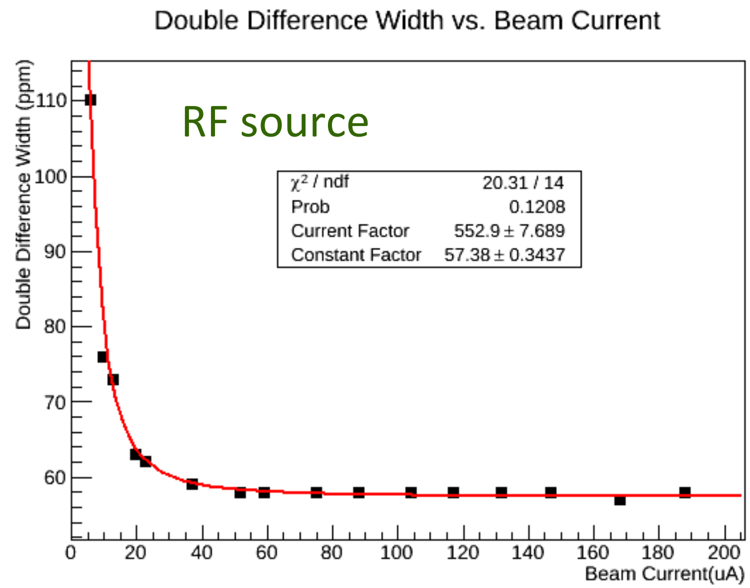
Double difference distributions show similar non-Gaussian structure and "wings"



BCM Digital Receiver Noise Floor – rf source vs. beam

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





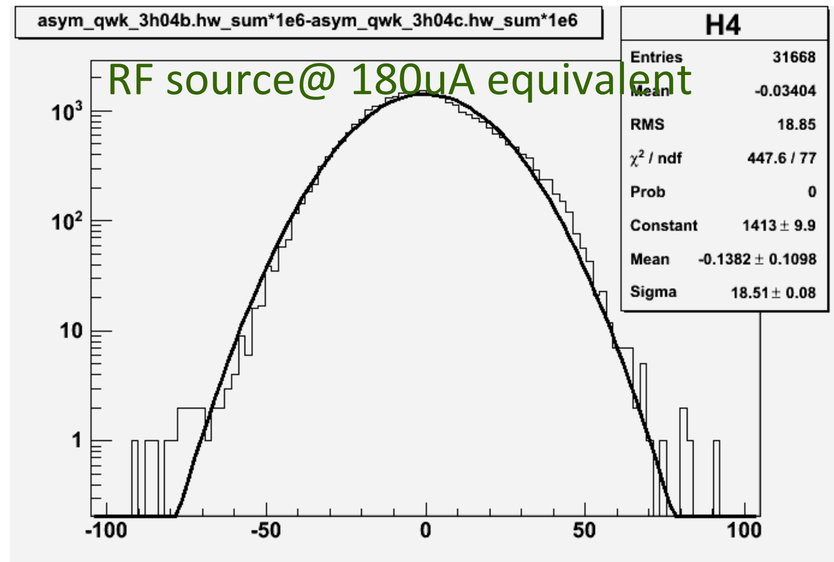
Fit by simple functional form:

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

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

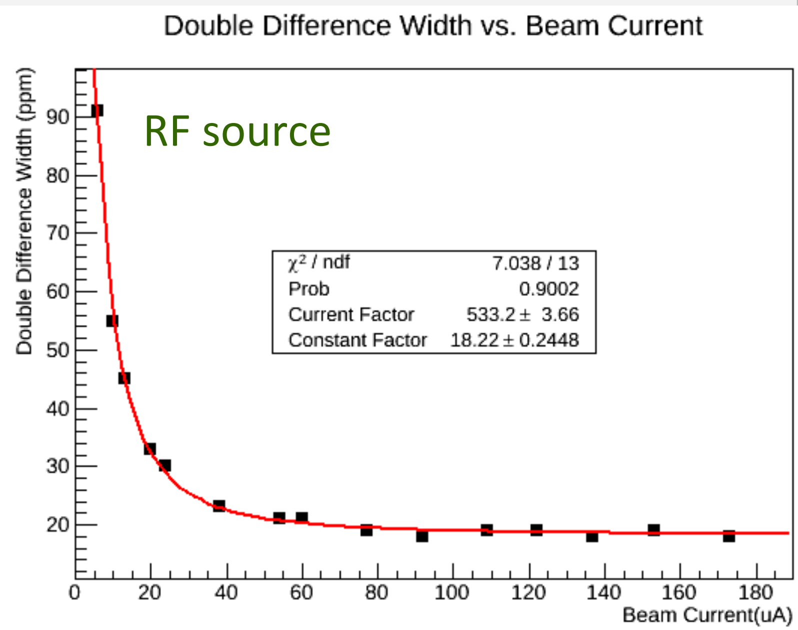
BCM Digital Receiver Noise Floor – Common Local Oscillator

- 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

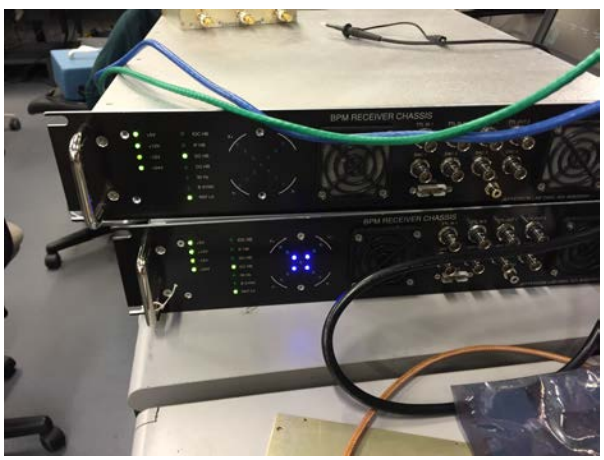
Future plans for BCM Digital Receiver Tests

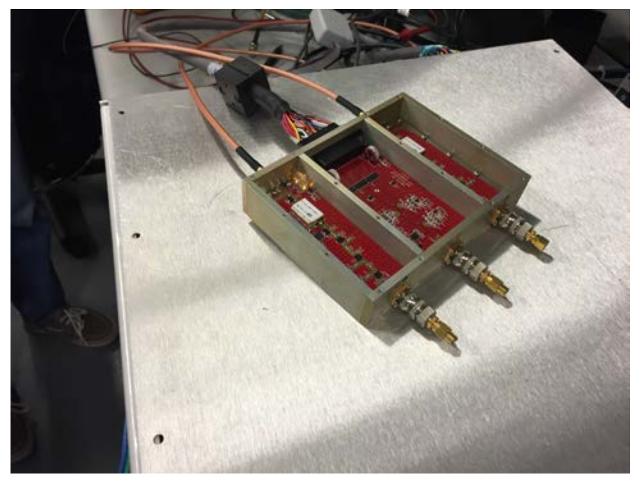
Over next couple months we will try to:

- 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/amplitude noise of local oscillator?)

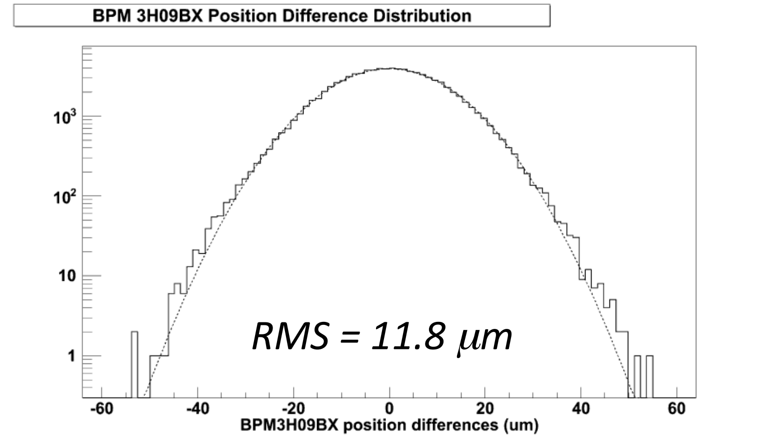




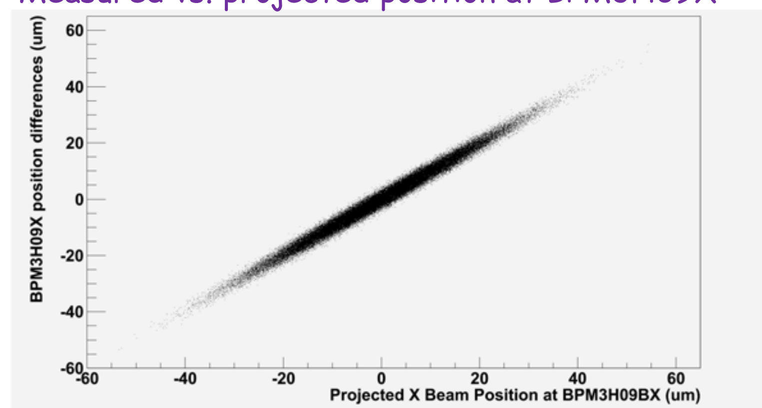
Qweak: BPM Resolution and Beam Jitter Results

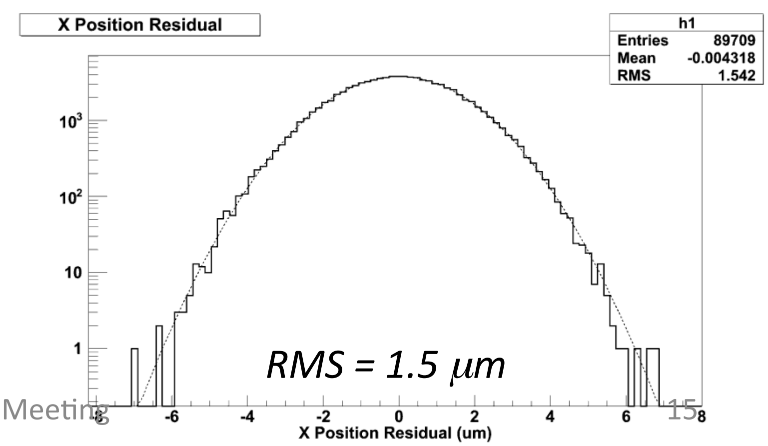
Beam "jitter" dominates the typical noise for a
"position difference distribution"; X+ - X-

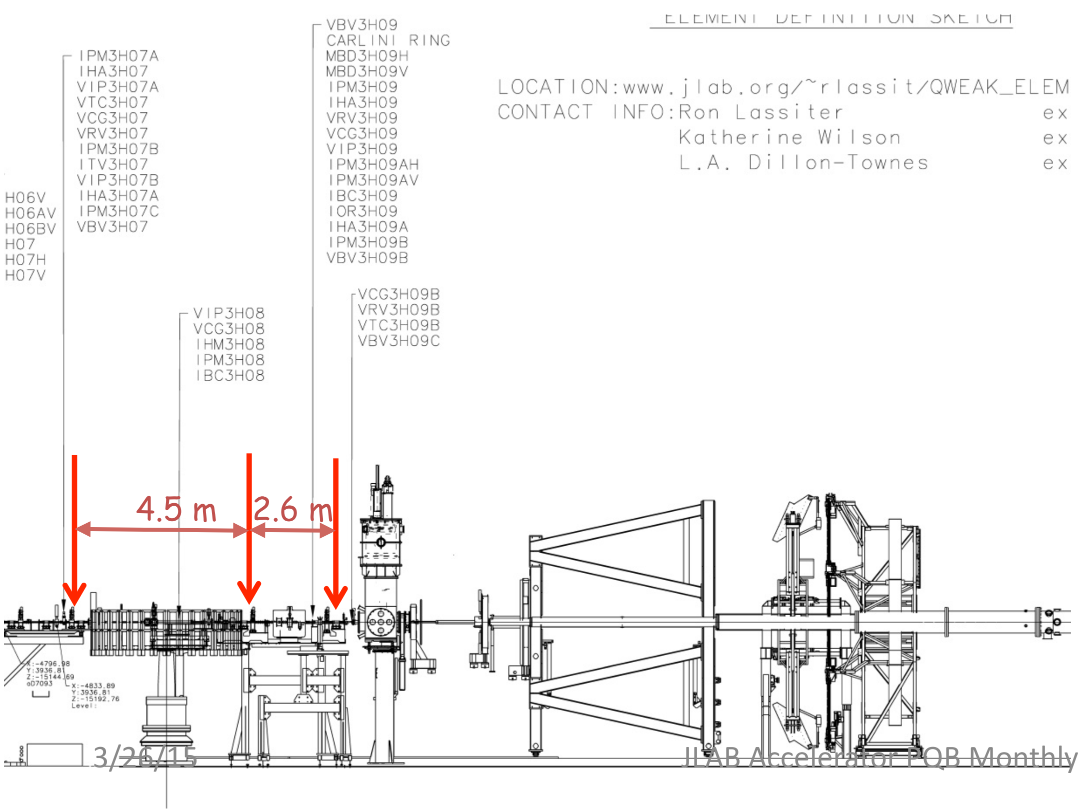
Intrinsic BPM resolution can be extracted by using two (or more) upstream monitors to project to a downstream monitor



Measured vs. projected position at BPM3H09X







"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)

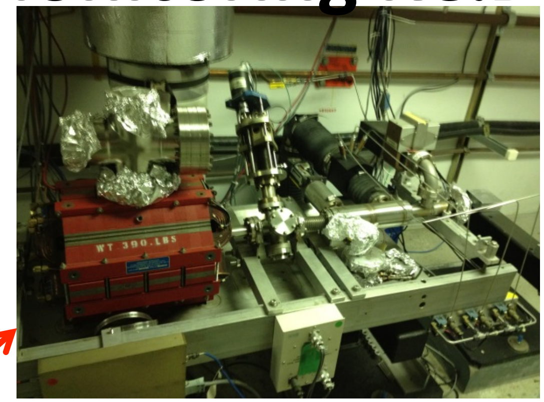
To achieve MOLLER's goals for beamline monitoring precision/redundancy, it would be very useful to have this hardware available for parasitic testing during early Hall A 12 GeV era running

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

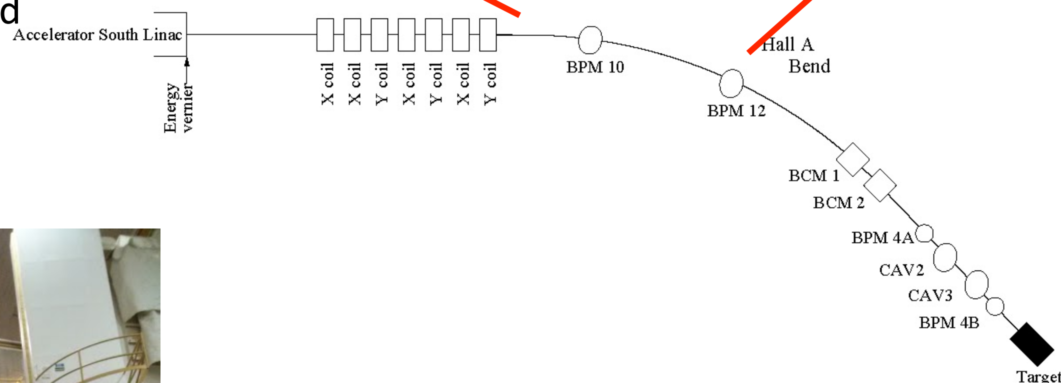
3. An XYQ cavity monitor assembly in the dispersive region
    - Possible candidate is the unconnected XYQ cavity assembly that is further upstream in the arc
    - Motivation: to have redundant measurement of helicity-correlated beam energy fluctuations (in addition to the usual "stripline" BPM12)

“Wish List” for MOLLER Beamline Monitoring R&D



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

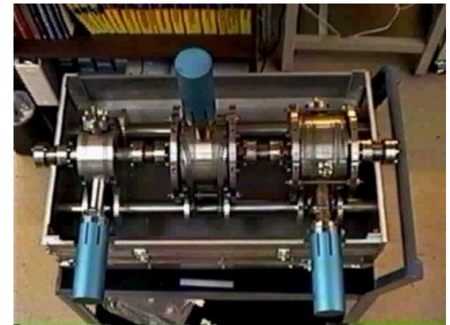
BCM cavity triplet could go here?



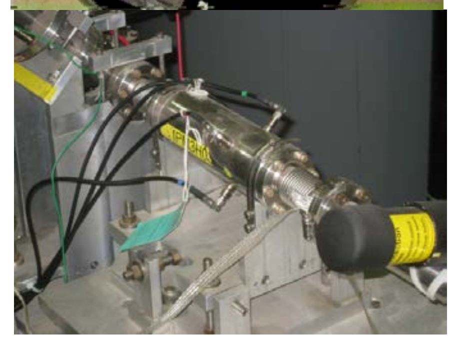
XYQ from old G0/Qweak girder, on floor in Hall A, can go in here – room exists according to Ed Folts

Thoughts for Discussion

1. Implementing third XYQ cavity monitor assembly in Hall A beamline likely will proceed, allowing a reliable measurement of the position resolution of that system



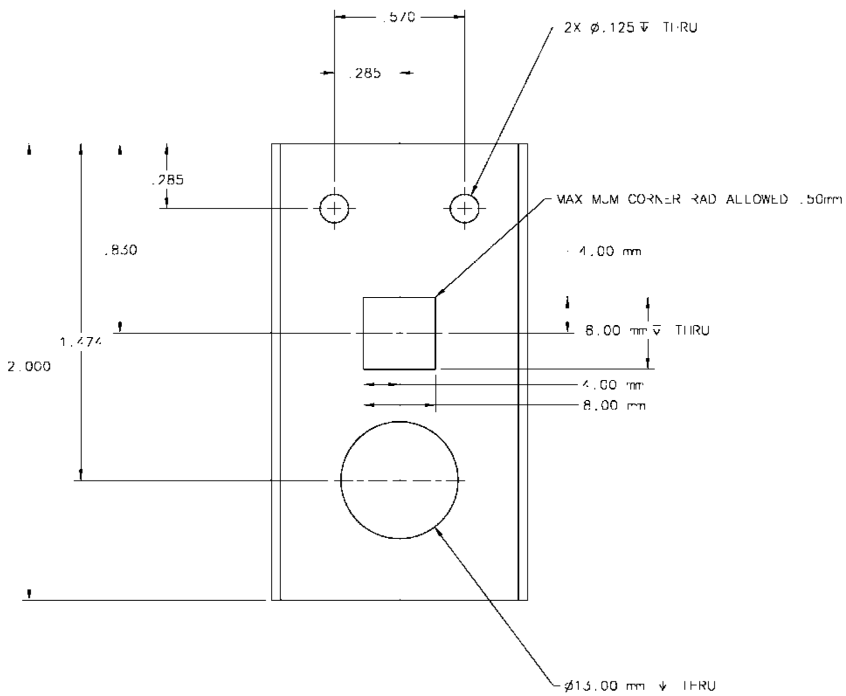
2. New “true” stripline monitors (official name for these?)

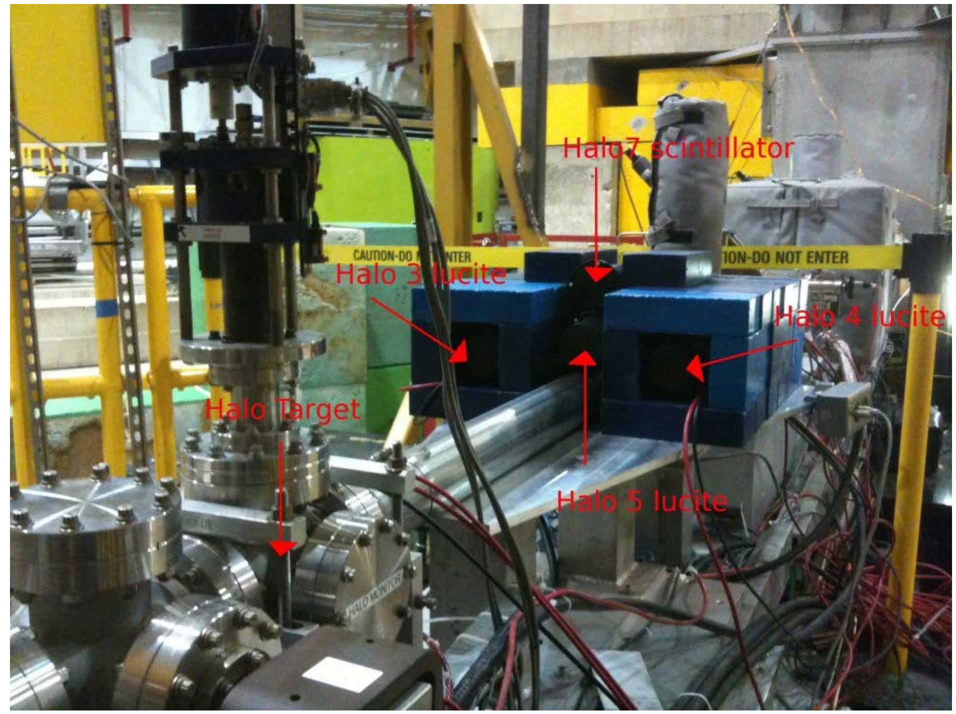


   - Casual conversation with Jay Benesch and John Musson indicates these should have good (~ 1 um) resolution
   - Question: do the new Musson digital receivers still do the SEE (switched electrode electronics) style readout?
   - One concern raised from parity experimenters in the past (in advocating for cavity style monitors) is the SEE nature of the readout
   - Bottom line: it would be nice to install at least one of these in Hall A beamline for Fall 2015 to test its performance for the parameters (resolution) that we care about for parity work

3. There has been a long-standing issue about the active aperture of the cavity monitors; Musson “G-line” measurements indicate it is much smaller (~ 1 mm) than MAFIA simulations suggest; this could probably be checked with the cavity XYQ triplets in Hall A in Fall 2015 if still an issue.

Qweak Beam Halo Measurement System





Halo target: thin aluminum with two holes, mounted near usual Hall C pivot on superharp linear drive mechanism

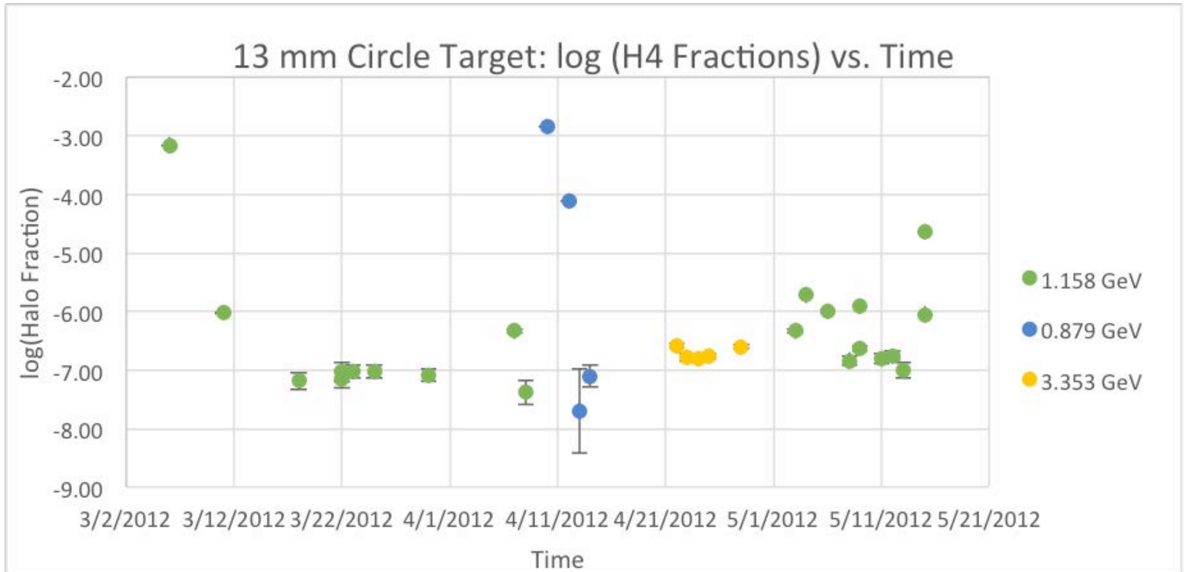
- 8 x 8 mm square hole (for invasive check on beam halo "specs")
- 13 mm diameter hole; to put in place during routine production running

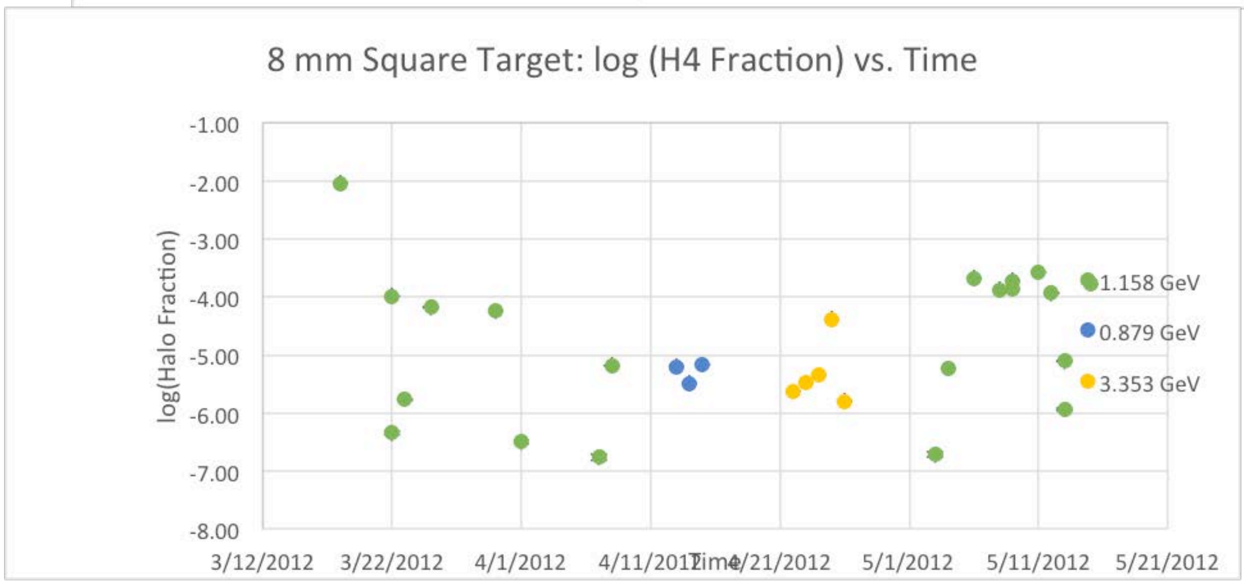
→ size of the smallest aperture in the experiment – tungsten beam collimator

Monitored with lead shielded lucite+ 2 inch PMT "halo monitors"

Calibrated by putting 1 nA of beam directly into halo target frame

Typical Qweak Halo Characterization Results





13 mm Halo “Circle” Target: Typical: 10^{-7} – 10^{-6} but as large as 10^{-3} observed

8 mm “Square” Target: Typical: 10^{-7} – 10^{-4} but as large as 10^{-2} observed

Thoughts for Discussion

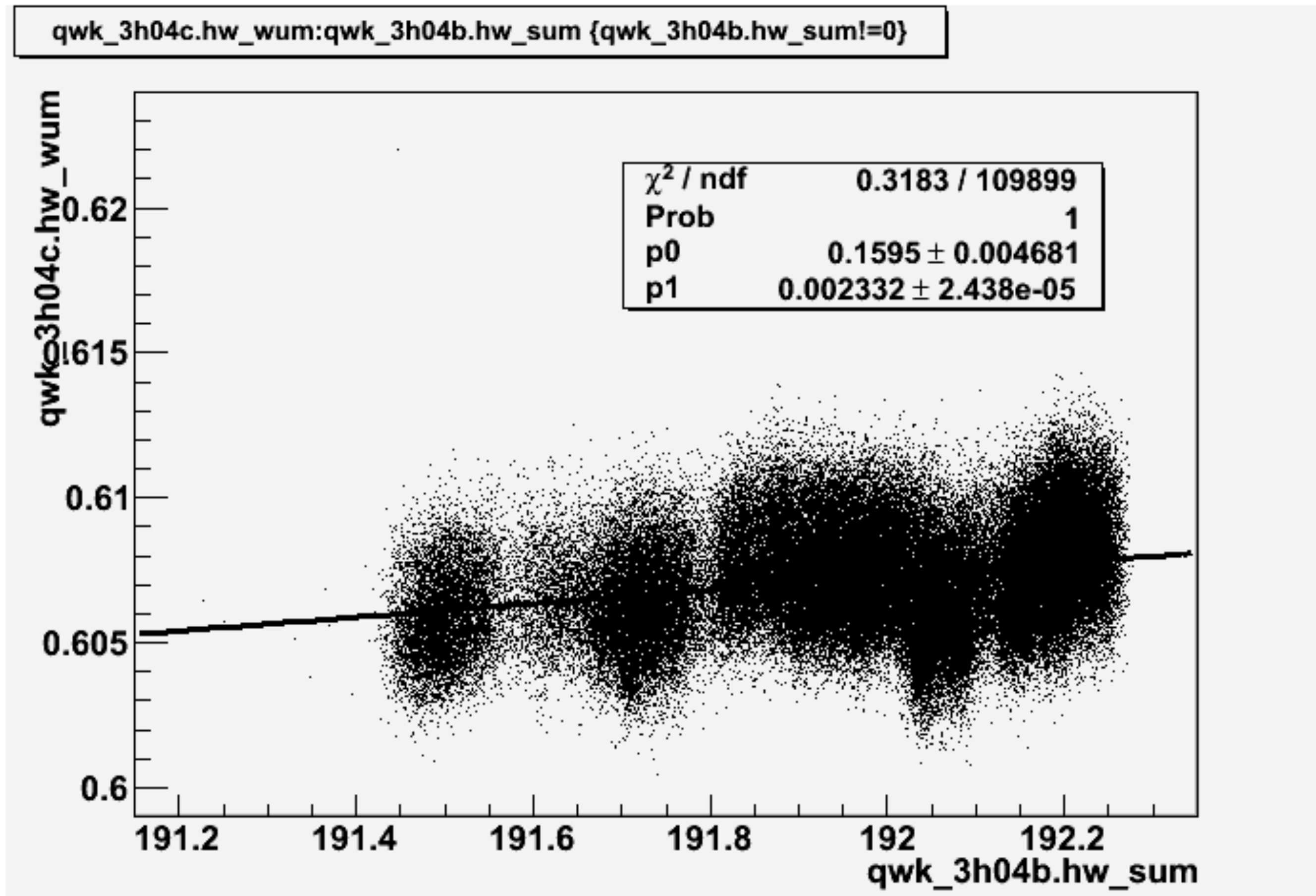
1. Qweak halo monitor could go in "as-is" to Hall A beamline for Fall 2015 initial tests as desired:
   - due to only one axis (vertical) of motion this could require a two step process (as it did for Qweak)
   - Determine nominal beam centerline (in horizontal) and then have new hole target made with the horizontal offset to nominal incorporated

2. If this device turns out to be useful we should probably implement some upgrades for long term operation:
   - 2 axis motion capability
   - Optimized, symmetric array of particle detectors downstream of halo target (lucite/scintillator?, pre-radiator or not?; or implement array with all these possibilities)

Backups

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

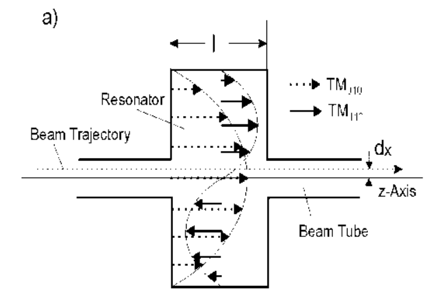


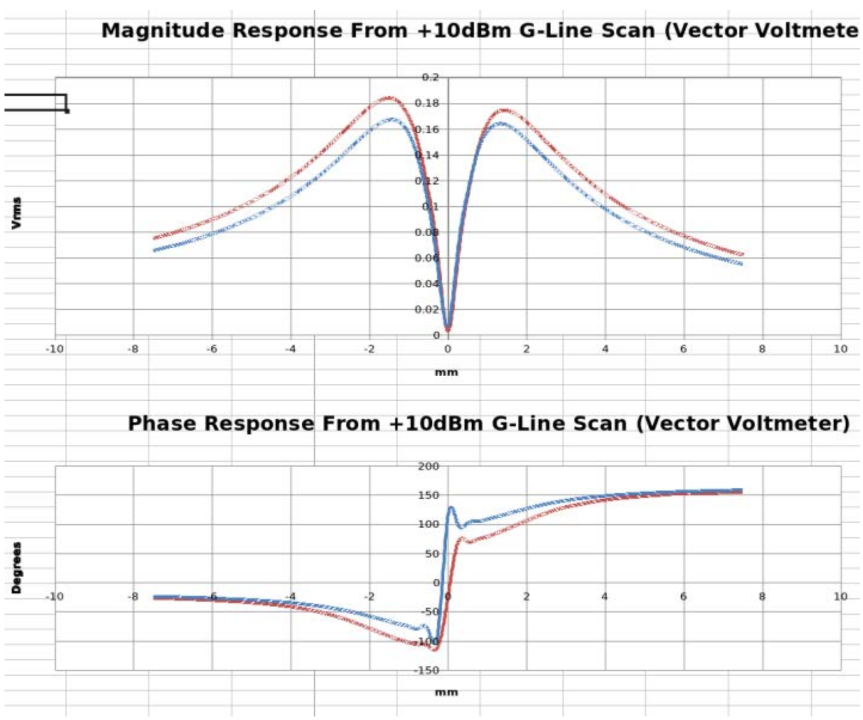
Cross talk at the level of ~ 0.2%

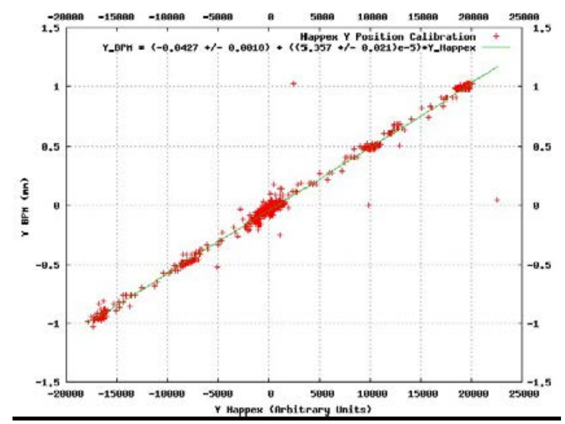
What is real cavity BPM/BCM aperture?

John Musson "G-line" tests indicate only +/- 1 mm active aperture instead of the designed +/- 1 cm aperture indicated by MAFIA simulations

➔ This issue is best resolved directly with a beam test.







Best existing data (Dong et al. PAC2005) only looked at range ±1 mm

Direct beam test with unrastered beam and comparison to nearby stripline would be best

According to Doug H. a +/- 2 mm aperture looks to be achievable (based on previous bullseye scans)