Excess Noise Tolerance
and
Charge Normalization Plans

D. Mack

b1/Azz Tensor Collaboration meeting

10/13/2025

Overview

The presentation I gave at Trento in 2023 was comprehensive and has aged well.

Tensor spin observables (10-July 14, 2023): A conceptual design to meet beam current monitoring requirements · ECT* Indico

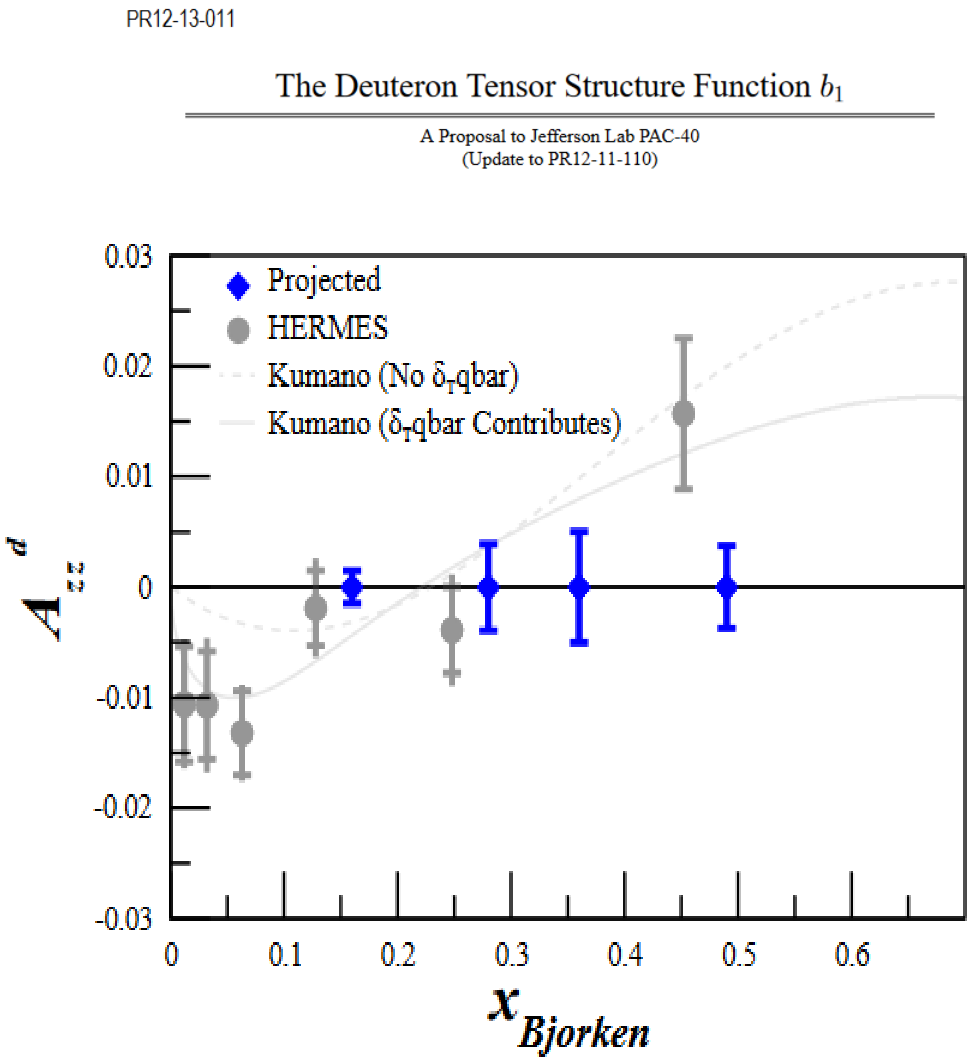
So what I'll do is:

- Start from there
- Update to reflect that plan that Polarized-Unpolarized "pairs" will only take hours not days
- Add didactic points that weren't appropriate for the Trento audience of experts/spokespersons/theorists
- Update to reflect other progress from the last 2 years

What is our error budget for
excess noise from all sources?

(now that we know we’re reversing more like 1/hour rather than 1/day)

Expected Size of the Error on the Measured Asymmetry



I converted the projected statistical error on dAzz to dA_measured:

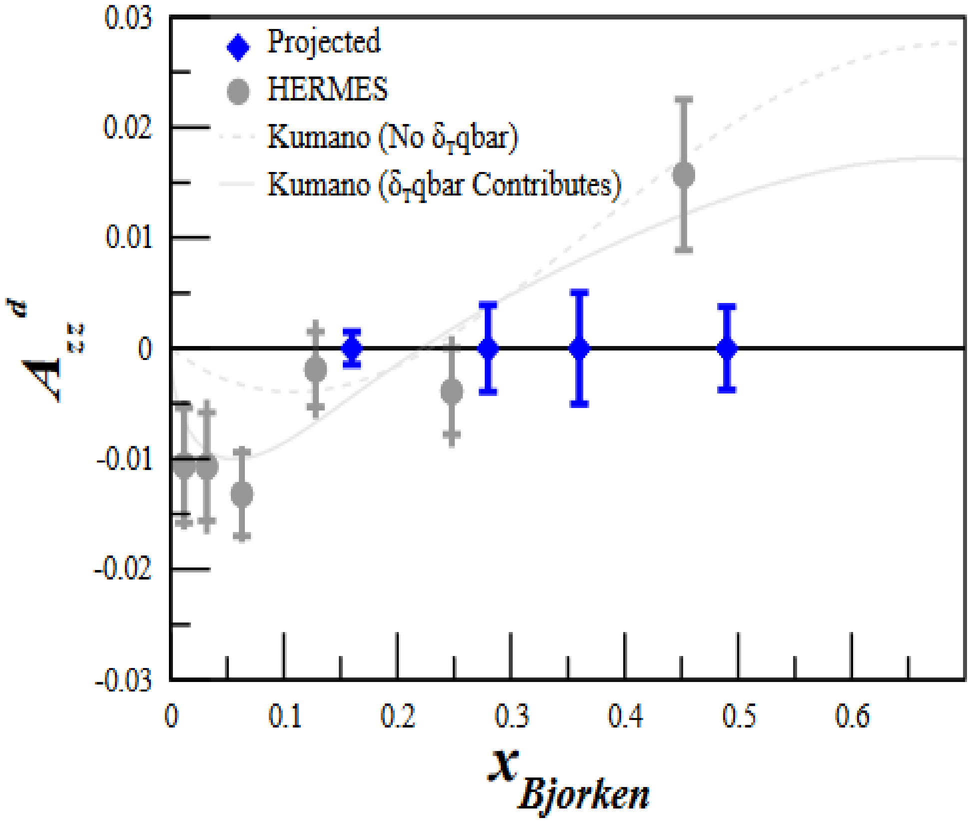
X_bj	Projected dAzz_stat (from Table 2 of the proposal)	dA_measured = f*Ptgt*dAzz_stat = 0.285*0.2*dAzz_stat
0.16	1.5e-3	8.6e-5
0.28	3.9e-3	2.2e-4
0.36	5e-3	2.9e-4
0.49	3.7e-3	2.1e-4

Expected Size of the Error on the Measured Asymmetry

PR12-13-011

The Deuteron Tensor Structure Function b_1

A Proposal to Jefferson Lab PAC-40
(Update to PR12-11-110)



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Takeaways:

- Due to dilution, etc, the required error bar on the measured asymmetry is of course much smaller than that of the physics asymmetry.
- The required statistical error on the measured asymmetry is O(1E-4) or 100ppm. (At this Q2, there may be 1-2σ pulls in the data from parity violation.)

Regarding the Challenging b1 Measurement

Double spin asymmetry (quickly averages to zero when P_B averages to zero)

PC Target single spin asymmetry (small and leads to b1)

2.1 Experimental Method

The measured DIS double differential cross section for a spin-1 target characterized by a vector polarization P_z and tensor polarization P_{zz} is expressed as,

$$\frac{d^2\sigma_p}{dx dQ^2} = \frac{d^2\sigma}{dx dQ^2}\left(1 - P_z P_B A_1 + \frac{1}{2} P_{zz} A_{zz}\right), \quad (16)$$

where, σ_p (σ) is the polarized (unpolarized) cross section, P_B is the incident electron beam polarization, and A_1 (A_{zz}) is the vector (tensor) asymmetry of the virtual-photon deuteron cross section. This allows us to write the positive polarized tensor, $0 < P_{zz} \leq 1$, asymmetry using unpolarized electron beam as,

$$A_{zz} = \frac{2}{P_{zz}}\left(\frac{\sigma_1}{\sigma} - 1\right) \quad (17)$$

where σ_1 is the polarized cross section for

$$P_{zz} = \frac{n_+ - 2n_0 + n_-}{n_+ + n_- + n_0}, \text{ for } n_+ + n_- > 2n_0. \quad (18)$$

Here n_m represents the portion of the ensemble in the m state.

Regarding the Challenging b1 Measurement

Double spin asymmetry (quickly averages to zero when P_B averages to zero)

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Not shown:
PV Target single spin asymmetry of possibly similar magnitude to Azz (averages to zero when the target vector polarization averages to zero)

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Statistical Error per Pair
(ie, for each Polarized – Unpolarized mini-measurement)

X_bj	Beam Days	Projected dA_measured (from previous slide)	Counts = (1/dA_measured)^2	Counts per Beam Second (Hz)	dA_measured Per 2 Beam hours	Upper Limit for Excess Noise for 10% increase in Total Random Error
0.16	6	8.6e-5	1.4E8	270	7.2E-4	3.3E-4
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Takeaways:

- Statistical errors are unavoidable. If the total random error is significantly larger than the statistical error, then we have too much “excess noise”.
- If we’re cycling the target once per beam hour, we’re usually OK if we keep sources of extra noise below the 1E-3 level.
- But the lowest X_bj point needs more care. An aspirational goal would be to try to limit any extra noise there below the 3E-4 level.

Potential Sources of Excess Noise

I worry much less about limiting excess noise to 1E-3 over 2 hours rather than 1E-4 over 2 days!
This list of excess noise sources from Trento remains the same, though one error now sounds systematic to me:

Target stuff:	Bead settling or slumping changing the fill factor
	Target field variations changing the acceptance
	Target temperature differences between polarized and unpolarized (This one sounds more like a potential systematic error.)
Detector stuff:	Errors in corrections for the deadtime
	Errors in corrections for the tracking efficiency
	Drifts in the Gas Cerenkov thresholds
	Drifts in the Pb Glass thresholds
Beam Parameter stuff:	Unmitigated drifts in beam energy
	Unmitigated drifts in beam position on target
Charge measurement stuff:	Charge normalization

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I'm confident the Target stuff will be thought about carefully.
Some of us will think about the Charge measurement stuff.
Other collaborators will need to think carefully about the Detector stuff and the Beam Parameter stuff.

Differential Nonlinearity

A charge measurement error I missed in that Trento list is differential nonlinearity.

We should (obviously?) keep the average beam current relatively fixed between polarization on/off measurements.
I'm not sure what is realistic, but a tolerance as large as +-5% might be acceptable.
This will also help noise from corrections for deadtime and tracking efficiency.

(The tolerance depends on how optimistic one is about the magnitude of the nonlinearity of the charge measurements, or how precisely it is known so it can be corrected. Precise measurements of nonlinearity are very difficult.)

Example:

Say the response of the current transducer has an integral nonlinearity which, between 0 to 100 nA, reaches 1%. Then

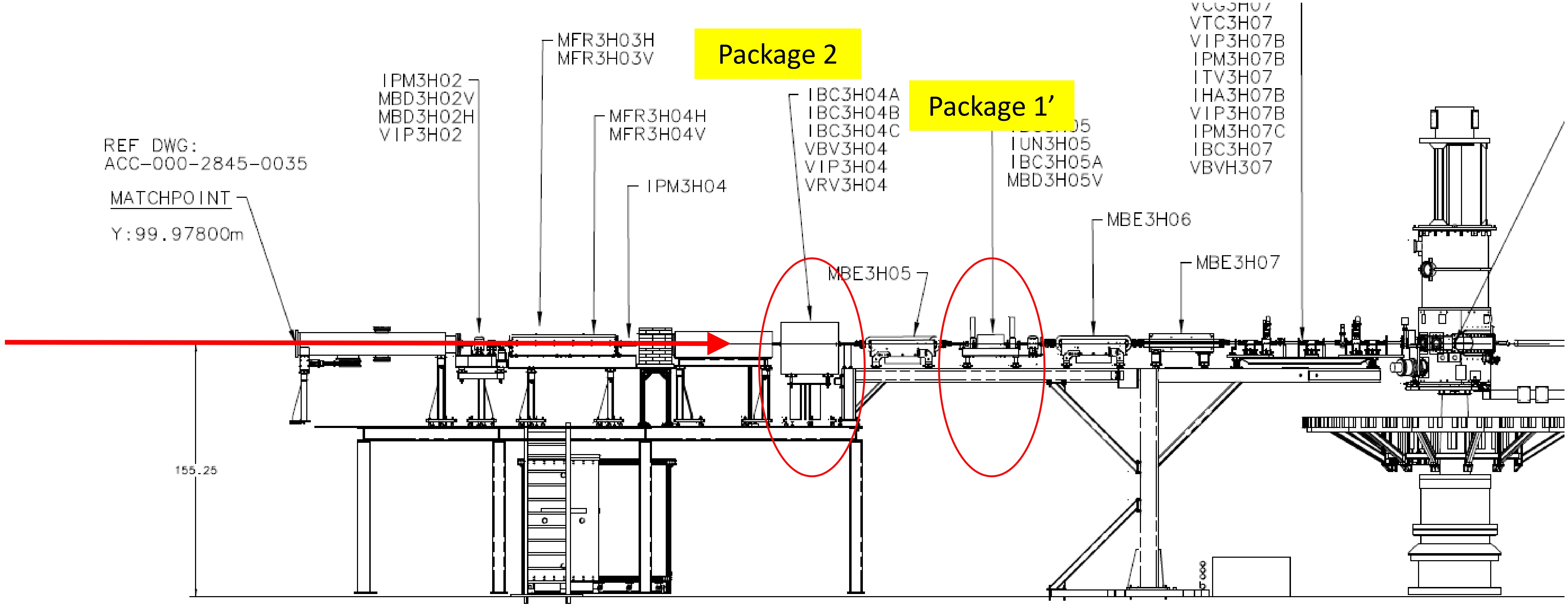
$$V = I + \varepsilon I^2 = I(1 + \varepsilon I)$$

where the nonlinearity parameter ε would be 1E-4 per nA.

If we measure with the target polarized at 100 nA, then unpolarized at 110 nA, the relative error on the normalization would be 1E-4/nA*10nA = 1E-3.

That's too big of an error, because (if uncorrected) it would saturate our entire budget for excess noise.
I can possibly get the integral nonlinearity down to the 0.3% level, but it's better to conservatively assume 1%.

What's the BCM Situation for Polarized Target Running?



There are presently 2 BCM thermal enclosures. But for polarized target running:

- Package 2 will be removed and replaced by the Slow Raster
- Package 1 will be upgraded using the thermal enclosure from Hall A.

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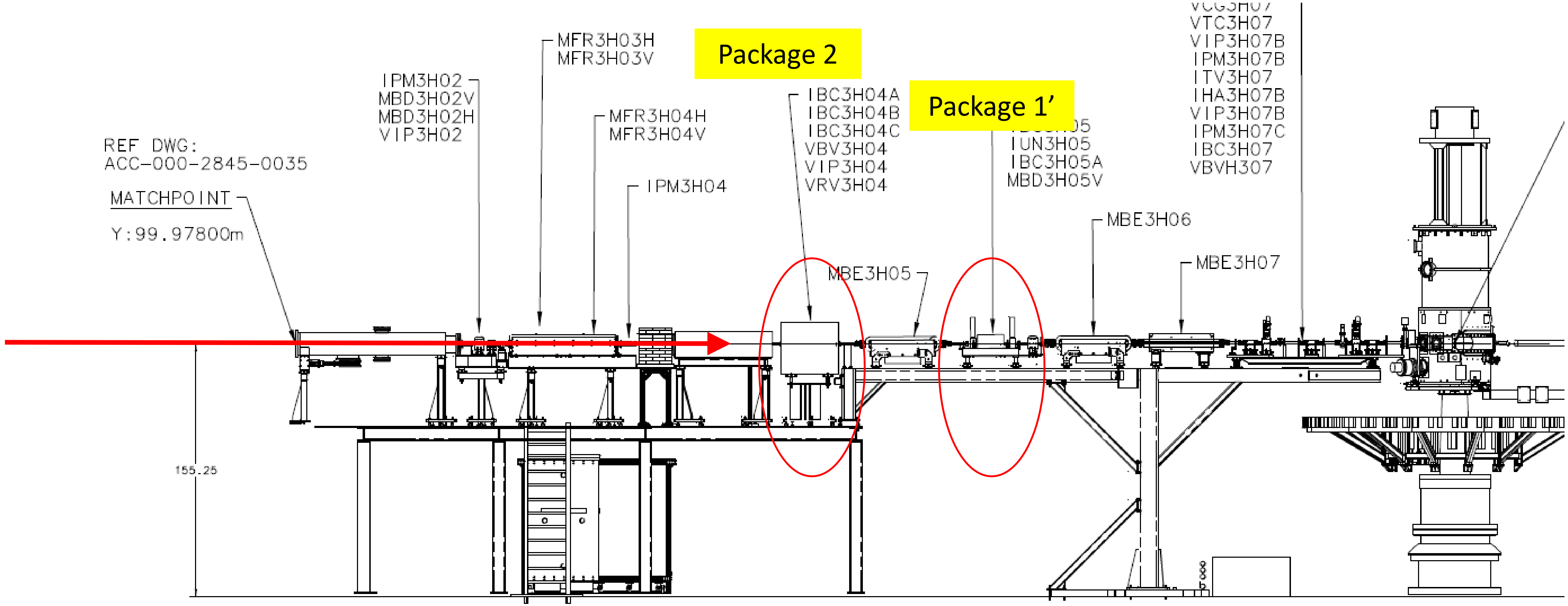

There are presently 2 BCM thermal enclosures. But for polarized target running:

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- Package 1 will be upgraded using the thermal enclosure from Hall A.

If runs are a minimum of an hour long, we should have no problem getting the BCM thermal cycling noise down to the required 1E-3 level.

BCMs: Recent Experience Running LAD at 300nA

Good news:

With an RF signal generator, it was relatively straightforward to set up the BCM electronics for low current running, as well as to measure/bound their linearity.

We found we could get the beam cleanly enough thru the accelerator to Hall C. (At least on that particular day.) With the other halls turned off, this allowed us to use the injector FC for an absolute calibration with probably better than 5% uncertainty.

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Other news:

At such low signal magnitudes though, the digital receivers (DR's) tended to lock on the leaking signals from the local oscillators in the old analog receivers (AR's) in the adjacent rack. The DR's are generally more linear than the AR's, but the DR's also sometimes jump gain after a few months. It was a Sophie's choice moment:

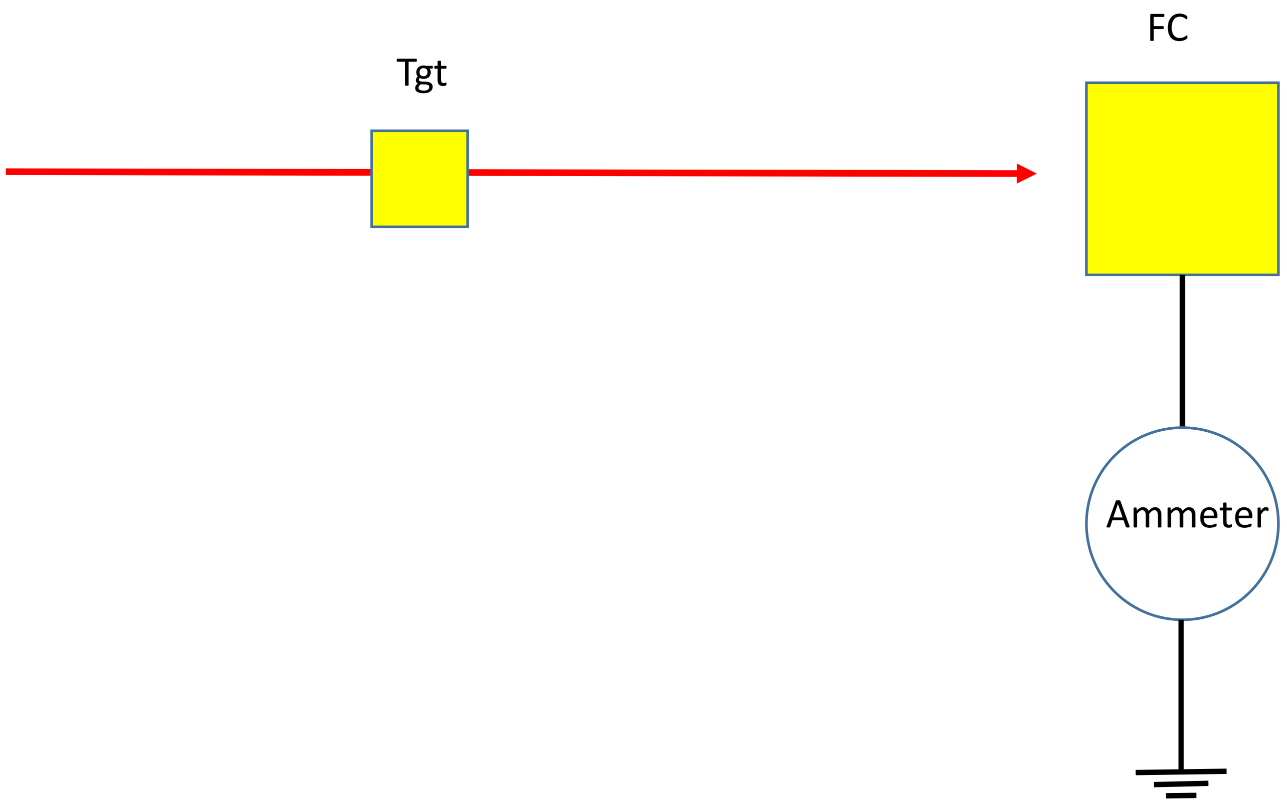
I turned off the old AR's. We might run only with DR's for tensor polarized target running.

What's the FC Situation for Polarized Target Running?

Potentially accurate at the 1E-4 over hours, or 1E-3 over months.

(The latter would be essential for 2 photon exchange measurements in the positron era. This will be good experience.)

Hector will show some GEANT4 simulations in his talk. On the next slide, I'll try to motivate those simulations.



FC Issue: beam spot growth

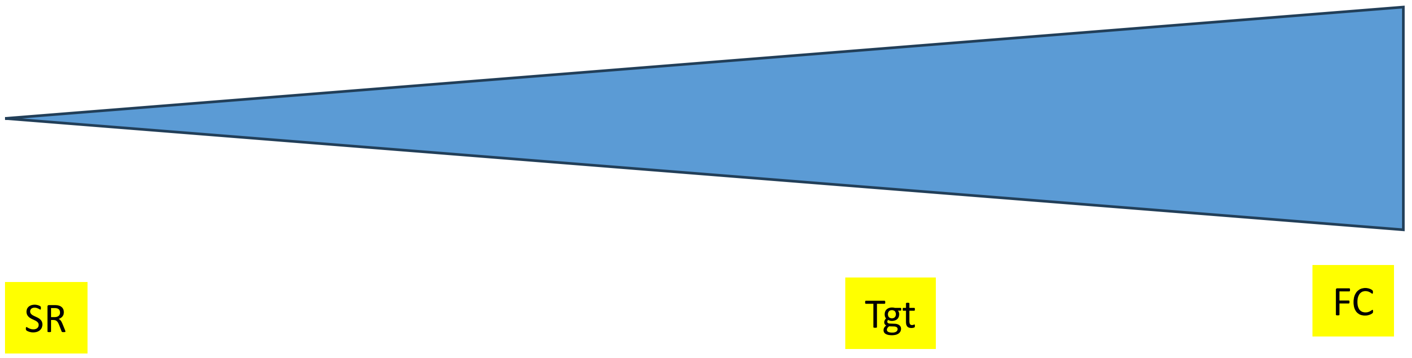
The slow raster is conical.

The spot size has to be very large at the polarized target, then it keeps on growing further downstream.

The present beam entrance hole is too small. We'll need to drill a larger hole.

We think we know the FC's position along the beamline, so it was just trig to estimate the beam size.

Now we're trying to include multiple scattering (actually, multiple + single scattering) to make sure we capture enough of the exhaust beam.



FC misc

- The beam spot will be nearly as large as the old entrance pipe on the scattering chamber.

We'll have to switch to one of the large ports on the bottom of the scattering chamber.

- Although the FC will be nearly hermetic, RadCon will want to estimate the site boundary dose, etc.

Summary

Measuring the small, target single spin asymmetry b1 is not business as usual.

Hour-scale polarization on/off cycles will help keep excess noise from dominating the random error. Most of the X_bj settings will “only” need to limit excess hour-to-hour errors at the 0.1% level.

Keeping the average beam current constant using feedback will help control errors. A tolerance of +-5% seems conservative.

We haven’t run at 100nA in years. Experience setting up the BCMs for LAD near 300 nA was very encouraging.

We should have the Target and Charge measurement stuff covered. But we’ll probably need other experts to think about Detector stuff and Beam parameter stuff.

Two technologies for charge monitoring:

BCM outlook – improved thermal enclosure from Hall A, 2 cavities only, digital receivers only, setup with RF signal generator

FC outlook – we have a location in mind, need to accommodate the large beam spot size, work with RadCon

extras

Tungsten-Copper Calorimter

Left-over from an
old Hall A project.

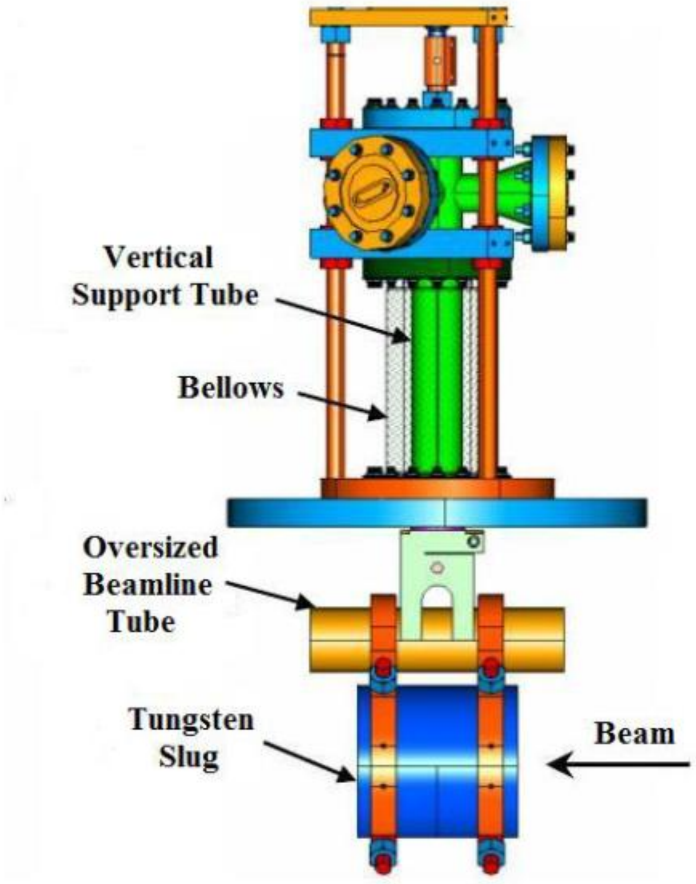


Figure 2: Slug with vertical tube.

95% W, 5% Cu

16cm long (45.7 X_0)
8cm radius (22.9 X_0)

Very thin wrt SLAC FC.
But given the large proposed relative error on A_zz, charge losses of 1% would be no problem as long as any drifts are small during a target cycle.

Hole is the wrong size (0.5cm radius, and 2.5cm deep).
Since it is mildly activated, drilling to the right size and aspect ratio could be a pain.

M.M. Ali et al, "Precision Absolute Current Measurement of Low Power Electron Beam", Proceedings of BIW2012, Newport News, VA, USA.