Technical Homework Questions

Answers to Questions

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Jefferson Lab Moller Project
Director's Review

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Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Answer to Tuesday Jan. 14, HW Question 1, part 1

Present the list of recommendations from the recent MOLLER ***Cost Review*** and Design Review. Give the Project team's reaction to the recommendations. How much do they impact preparation for CD-1 review?

Cost Review Recommendations

1. Refine the cost estimate for the upstream beamline modifications prior to the December 2019 Design Review.

   First revision has added $1M to this cost. This is included in the cost estimate shown today (1/14/20). Engineering Division has since taken a more careful look at this and has reduced the estimate by $0.5M.

2. Review estimates to ensure that shipping costs, duties, fees and any taxes are taken into account in the project plan.

   Project activities have been scrubbed with this in mind and resulting changes have been implemented. Allowances for QA/QC inspections were also revised.

3. Develop means for tracking risk mitigation measures as identified in the risk registry.

   Tracking forms and procedure already in place (inherited from 12GeV Project).

4. Develop a plan such that in the case risk opportunities are realized, the project updates the baseline, tracks progress and provides oversight for those activities.

   Such a plan is described in the pPEP.

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2. Review estimates to ensure that shipping costs, duties, fees and any taxes are taken into account in the project plan.

   Project activities have been scrubbed with this in mind and resulting changes have been implemented. Allowances for QA/QC inspections were also revised and are shown explicitly. Total costs, shipping FOB JLab, duties, etc. are to be included in quotations.

3. Develop means for tracking risk mitigation measures as identified in the risk registry.

   Tracking forms and procedure already in place (inherited from 12GeV Project). Jessie showed a sample tracking form. They are also in prebrief.

4. Develop a plan such that in the case risk opportunities are realized, the project updates the baseline, tracks progress and provides oversight for those activities.

   Such a plan is described in the pPEP. "…in the event that non-DOE funding for project scope is obtained, or that project scope contribution opportunities are realized, the project will update the baseline accordingly, continue to track the scope's progress, and provide oversight for those activities."

TIME IS NEEDED TO INCORPORATE 1 AND 2 IN RLS. OTHERWISE NO IMPACT ON CD-1 REVIEW.

Cost Review follow-up…

Cost Review Recommendation 1—
Refined cost estimate for upstream beamline:
(noted in Butler's Risk Management Talk)

Note: Estimated cost of Beamline reconfiguration was reduced $500k after database was frozen for this review.

(WBS 1.06.04 $1.5M→$1.0M)

This correction has NOT been applied to any slides.

Cost Review Recommendation 2—
Scrubbed activity list for needed QA/QC tests, inspections

Activity ID	MOI BOE	Activity Name	Start	Finish	Planned Duration	Planned Labor Units	Planned Labor Cost	Planned NL Units	Planned NL Cost	Mat
10302130	EJ	JLab receipt acceptance test for coils-Labor	16-Aug-22	29-Aug-22	10	78	$10,866	0	$0	
10302135	EJ	JLab receipt acceptance test for coils-M&S	16-Aug-22	29-Aug-22	10	0	$0	5000	$5,900	
		Write Specification for the Air Light Guides	01-Jul-21	08-Jul-21	5	80	$7,043	0	$0	
		Prepare Shower Max Detector Air Light Guides Procurement Package	12-Jul-21	16-Jul-21	5	8	$782	0	$0	
		Vendor effort Shower Max Detector Air Light Guides	20-Jul-21	14-Sep-21	40	0	$0	0	$0	
		ACCEPT: Shower Max Detector Air Light Guides	15-Sep-21	15-Sep-21	1	0	$0	0	$0	
		Assemble and Inspect Air Light Guides	16-Sep-21	08-Oct-21	17	95	$8,061	0	$0	
		Write Specification for Tungsten Sheets	01-Jul-21	08-Jul-21	5	60	$5,444	0	$0	
		Prepare Shower Max Detector Tungsten Sheets Procurement Packa	12-Jul-21	16-Jul-21	5	8	$782	0	$0	
		Vendor effort Shower Max Detector Tungsten Sheets	20-Jul-21	12-Oct-21	60	0	$0	0	$0	
		ACCEPT: Shower Max Detector Tungsten Sheets	13-Oct-21	13-Oct-21	1	0	$0	0	$0	
		Inspect Tungsten Sheets	14-Oct-21	27-Oct-21	10	30	$2,805	0	$0	
		Write Specification for Shower Max Detector Phototubes	09-Jul-21	15-Jul-21	5	40	$5,109	0	$0	
		Prepare Shower Max Detector Phototubes Procurement Package	19-Jul-21	23-Jul-21	5	8	$782	0	$0	
		Vendor effort Shower Max Detector Phototubes	27-Jul-21	24-Jan-22	120	0	$0	0	$0	
		ACCEPT: Shower Max Detector Phototubes	25-Jan-22	25-Jan-22	1	0	$0	0	$0	
		Inspect Phototubes	26-Jan-22	15-Feb-22	15	90	$7,273	0	$0	
		Write Specification for Phototube Bases	16-Jul-21	22-Jul-21	5	40	$5,109	0	$0	
		Prepare Shower Max Detector Phototube Bases Procurement Packa	26-Jul-21	30-Jul-21	5	8	$782	0	$0	
		Vendor effort Shower Max Detector Phototube Bases	03-Aug-21	02-Nov-21	65	0	$0	0	$0	
		ACCEPT: Shower Max Detector Phototube Bases	03-Nov-21	03-Nov-21	1	0	$0	0	$0	
		Inspect Phototube Bases	04-Nov-21	30-Nov-21	17	60	$5,039	0	$0	

Answer to Tuesday Jan. 14, HW Question 1, part 2

Present the list of recommendations from the recent MOLLER Cost Review and ***Design*** Review. Give the Project team's reaction to the recommendations. How much do they impact preparation for CD-1 review?

Design Review Recommendations

1. We recommend that MOLLER specify in one location the physics acceptance and collimation for the experiment.

Before CD-1: aim for Feb 15

2. We recommend that MOLLER formulate a plan to search for the possible sources of the inconsistency of the beam current monitors and continue to improve the noise performance of the beam current monitors.

Before CD-2: aim for July 1

3. We recommend that MOLLER simulate the single-sector and whole detector sensitivities for the existing design with the tolerances specified in the CDR.

After CD-1: aim for early summer

4. We recommend that Jlab with input from MOLLER organize a preliminary liquid hydrogen target and associated shielding structure safety review for design input.

Definitely after CD-1; under discussion about relationship to CD-2

5. We recommend that MOLLER study in simulation the robustness of the background extraction procedure and MOLLER asymmetry with respect to hotspots, soft backgrounds, etc.

Aim for early Fall, after 6) and then 3) are completed

6. We recommend that MOLLER recheck and record their estimates of the sensitivity of the response of the different components of the detector signals to the raster motion.

Before CD-1: aim for Feb 15

Commentary on Action Plan

- Recommendation **2**: aim for July 1.
  - Revisit the Qweak experience and quantitatively assess the possible problem and also study possible time dependence of a possible BCM discrepancy (first attempt in backup slide)
  - Evaluate the performance of Hall A BCMs during PREX-II and CREX (though sensitivities are not quite the same)
  - Document the proposed plan for improvements including bench tests to be carried out (short summary in backup slides)
    - ***10 ppm resolution: Run Phase I (3 to 4 months) ~ 0.5 ppb sensitivity***
  - Formulate a plan for parasitic tests during SBS running
- Recommendation **3**: aim for early summer
  - Once recommendation 6 is documented, a series of test cases by varying collimation around the specified tolerances can be simulated
- Recommendation **5**: aim for early Fall
  - Once recommendation 3 is completed and we are done optimizing the quartz tile segmentation for optimal background subtraction, run a series of simulations with asymmetric soft backgrounds to evaluate impact on extraction of signal and background from global fit

Answer to Tuesday Jan. 14, HW Question 5

Question: Present projected physics measurement and the impact if one only uses the currently achieved beam related systematic uncertainties from the 6-GeV and 12-GeV PV measurements at JLab.

HCBA	HAPPEX-II	Qweak	PREX-2	MOLLER (required)
Intensity	400 ppb	30 ppb	25 ppb	10 ppb
Energy	0.2 ppb	0.8 ppb	2 ± 1.2 ppb	<0.7 ppb
Position Differences	1.7 nm	5 nm	<4 ± 4 nm	0.6 nm
Angle Differences	0.2 nrad	0.2 nrad	<0.4 ± 0.8 nrad	0.12 nrad
Size Asymmetry	-	$< 10^{-4}$	$< 10^{-5}$	$<10^{-5}$

Error Source	Fractional Error (%)
Statistical	**2.1**
Absolute Norm. of the Kinematic Factor	0.5
Beam (second order)	0.4
Beam polarization	0.4
$e + p(+\gamma) \rightarrow e + X(+\gamma)$	0.4
Beam (position, angle, energy)	0.4
Beam (intensity)	0.3
$e + p(+\gamma) \rightarrow e + p(+\gamma)$	0.3
$\gamma^{(*)} + p \rightarrow (\pi, \mu, K) + X$	0.3
Transverse polarization	0.2
Neutral background (soft photons, neutrons)	0.1
Linearity	0.1
Total systematic	**1.1**
Total uncertainty	**2.4**

MOLLER projected uncertainties

Error Source	Fractional Error (%)
Statistical	**2.1**
Absolute Norm. of the Kinematic Factor	0.5
Beam (second order)	0.4
Beam polarization	0.4
$e + p(+\gamma) \rightarrow e + X(+\gamma)$	0.4
Beam (position, angle, energy)	0.7
Beam (intensity)	0.8
$e + p(+\gamma) \rightarrow e + p(+\gamma)$	0.3
$\gamma^{(*)} + p \rightarrow (\pi, \mu, K) + X$	0.3
Transverse polarization	0.2
Neutral background (soft photons, neutrons)	0.1
Linearity	0.1
Total systematic	**1.5**
Total uncertainty	**2.6**

MOLLER projected uncertainties using best observed values from 6 and 12 GeV eras

Physics impact: MOLLER result would be 4.6 times (rather than 5) better than E158; model independent mass reach would be 7.2 TeV (rather than 7.5 TeV).

Homework question 2

Present all the project reviews that appear in the MOLLER RLS including Conceptual, Preliminary, Final Design Reviews, Safety Reviews, Procurement Readiness Review and Annual Reviews. Summarize the time and resources dedicated to the reviews in the RLS.

Activity ID	Activity Name	Date
1-2	SVT - From 2-01005M (CD-2/3A Review)	1-Oct-20
1-4	SVT - From 2-01010M (CD-3 Review)	3-Jan-22
2-01000M	CD-1 Review	21-Feb-20*
2-01005M	CD-2/3A Review	21-Aug-20*
2-01010M	CD-3 Review	30-Nov-21*
2-01015	SVT - From 2-01010M (CD-3 Review)	30-Sep-22
2-01015M	FY22 Review	30-Sep-22
2-01020	SVT - From 2-01015M (FY22 Review)	29-Sep-23
2-01020M	FY23 Review	29-Sep-23
2-01025	SVT - From 2-01020M (FY23 Review)	30-Sep-24
2-01025M	FY24 Review	30-Sep-24
2-04010	SVT - From 3-05035M (Target Hydrogen Service Code & Documentation Review)	22-Apr-22
2-04010M	Target Hydrogen Safety System Design Review	22-Apr-22
2-06000M	MOLLER Detectors Preliminary Design Review	1-Oct-20
2-06020	SVT - From 3-06090M (GEM Final Design Review)	25-Aug-23
2-06020M	GEM Final Design Review	25-Aug-23
3-03065M	Spectrometer Design Reviews Complete	19-Jun-23
3-05015M	Target Controls Review	21-Dec-21
3-05020M	Target Prelim Design Review	16-Aug-19
3-05035M	Target Hydrogen Safety System Design Review	29-Mar-22
3-06000M	MOLLER Detectors Preliminary Design Review	1-Oct-20
3-06090M	GEM Final Design Review	1-May-23
3-07000M	DAQ & Trigger Preliminary Design Review	30-Jun-20
3-07005M	DAQ & Trigger Design Review	1-Apr-21
10101030	MOLLER Reviews M&S (FY20)	30-Sep-20
10101035	MOLLER Reviews M&S (FY21)	30-Sep-21
10101040	MOLLER Reviews M&S (FY22)	30-Sep-22
10101045	MOLLER Reviews M&S (FY23)	29-Sep-23
10101050	MOLLER Reviews M&S (FY24)	30-Sep-24
10202005	Vacuum System Design Review	31-Mar-21

Homework question 2 -- p2

Activity ID	Activity Name	Date
10203080	Hydrogen System Safety Systems Design Review	29-Mar-22
10204040	Helium Service Design Review	29-Mar-22
10205145	Target Loop Design Review	17-Mar-23
1030202135	Toroid Enclosure - Preliminary Design Review	11-Jan-23
1030202145	Toroid Enclosure - Final Design Review	27-Mar-23
10302050	Coils Preliminary Design Review	12-Jan-21
10302070	COILS + STRONGBACKS + FRAME - Final Design Review	13-Jul-21
1030302130	Toroid Enclosure - Preliminary Design Review	12-Dec-22
1030302140	Toroid Enclosure - Final Design Review	30-Jan-23
10303095	Coils Preliminary Design Review	7-Apr-22
10303115	COILS + STRONGBACKS + FRAME - Final Design Review	10-Aug-22
10305035	Conduct Preliminary Design Review for Collimator #1	28-May-21
10305075	Conduct Final Design Review for Collimator #1	2-Sep-21
10305085	Conduct Preliminary Design Review for Collimator #2	22-Sep-22
10305100	Conduct Final Design Review for Collimator #2	6-Jan-23
10305110	Conduct Preliminary Design Review for Collimator #4	28-May-21
10305150	Conduct Final Design Review for Collimator #4	12-Aug-21
10305160	Conduct Preliminary Design Review for Collimator #5	14-Sep-21
10305175	Conduct Final Design Review for Collimator #5	29-Nov-21
10305185	Conduct Collimator/Blocker #6 - Preliminary Design Review	6-Jan-22
10305225	Conduct Collimator/Blocker #6 - Final Design Review	22-Mar-22
10305235	Conduct Collimator/Blocker #7 - Preliminary Design Review	21-Apr-22
10305250	Conduct Collimator/Blocker #7 - Final Design Review	6-Jul-22
10306020	Conduct Preliminary Design Review for Water Chiller	5-Apr-23
10306030	Conduct Final Design Review for Water Chiller	5-Jun-23
10307070	Conduct Preliminary Design Review for Beam Pipes	17-May-23
10307080	Conduct Final Design Review for Beam Pipes	19-Jun-23
10311010	Conduct Experimental Readiness Review	24-Sep-24
10501038	Vendor effort Complete Design and Hold Final Design Review	1-May-23

Homework question 2 – p3

Summarize the time and resources dedicated to the reviews in the RLS.

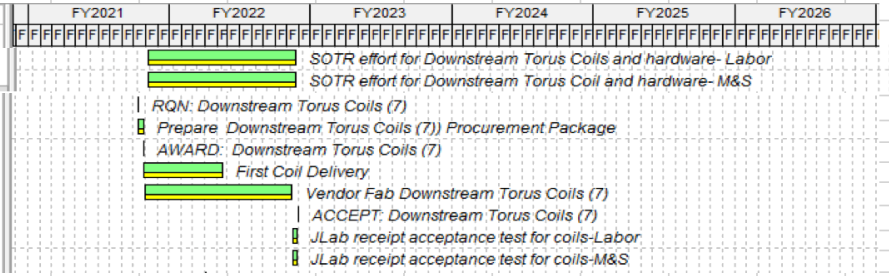
There are 45 reviews in the RLS.

- The CAMs and Project Leadership time is Level-of-Effort. This effort includes preparing for and participating in reviews. In addition, the RLS carries the following on-project loads that explicitly support reviews:
  - Labor Hours – 1,199
  - Labor Cost - $178,364
  - Non Labor Cost - $107,400

Homework Question 3

3) Describe how the time and resources for significant procurements are planned in the MOLLER RLS.

	Activity ID	Activity Name	Planned Labor Units	Planned Nonlabor	Planned Material Cost
7	10302005	SOTR effort for Downstream Torus Coils and hardware- Labor	383.00	0.00	0.00
7	10302010	SOTR effort for Downstream Torus Coil and hardware- M&S	0.00	36000.00	0.00
1	10302100	RQN: Downstream Torus Coils (7)	0.00	0.00	845,118.00
2	10302105	Prepare Downstream Torus Coils (7)) Procurement Package	23.00	0.00	0.00
3	10302110	AWARD: Downstream Torus Coils (7)	0.00	0.00	845,118.00
	10302115	First Coil Delivery	0.00	0.00	0.00
4	10302120	Vendor Fab Downstream Torus Coils (7)	0.00	0.00	0.00
5	10302125	ACCEPT: Downstream Torus Coils (7)	0.00	0.00	845,118.00
6	10302130	JLab receipt acceptance test for coils-Labor	78.00	0.00	0.00
6	10302135	JLab receipt acceptance test for coils-M&S	0.00	5000.00	0.00



Procurements follow a Template, they each have the following activities:

1	A Requisition - Lets the CAM Know when the PR needs to be submitted to Jlab procurement office. **Jlab uses these activities when developing a Funding profile.
2	The preparation of the procurement package - Any Project Labor associated with Technical Evaluations or Negotiations. Note the Procurement Staff only charges to the project for Travel associated with a procurement.
3	The Award activity - Shows when the money has been obligated to the Vendor.
4	A Vendor Effort activity - Depicts the duration the vendor need to produce the hardware or service.
5	An Accept activity - This is when the payment will be made to Vendor. ** Jlab uses this when developing the Cost profile.
6	An Inspection activity- Not always needed as some procurements come with documentation. Sometimes requires travel to the Vendor for the inspection.
7	SOTR(Sub Contracting Officer Technical Representative) Effort - This is the Jlab Technical effort to manage the vendor, sometimes will have a travel budget. These are not always needed based on the size or complexity of the procurem

Note: This template is used for most procurements. Small procurements may not have the SOTR effort. All procurements will have the Requisition, Award and Accept.

Homework question 3 (enlarged)

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	10302115	First Coil Delivery	0.00	0.00	0.00
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Note: This template is used for most procurements. Small procurements may not have the SOTR effort. All procurements

Homework question 4

Is there a distinction between the lab and EC member in the L3 box in terms of their roles and responsibilities? Who is in charge of making decisions?

- "Lab" refers to a JLab staff SME who was identified as a technical resource who could help the CAMs develop and refine their cost/schedule. This SME is usually not otherwise working on MOLLER, and is not paid by the project.
- "EC" (Experiment Contact) is a MOLLER collaborator having in-depth knowledge of the particular L2 subsystem. This person provides the primary technical guidance for the CAM.
- Making Decisions: It is the CAM's responsibility to deliver the scope as defined by the approved CD-2 scope baseline. **The CAM makes the decisions** based on *input* from the collaboration and any external experts or reviews that he/she (or the PM or other JLab leadership) chooses to consult.

Homework question 6

If there were to be a CD-3A what would be included in the request, how much would it cost and when would the orders need to be placed?

- At present, these items in the RLS are logical successors of CD-3A:
  - Downstream and Upstream Toroid Coils ($1M)
  - PMTs for Main Quartz, ShowerMax, and Scanner detectors ($400K)
  - GEM Modules ($800K)

- None of these M&S PROCUREMENTS are actually required to start as early as the scheduled CD-3A (10/1/20).
  - Coil procurement starts in July, 2021
  - PMT procurement starts in May, 2021

- GEM Design/Prototype/Production is planned as a procurement from UVa. This entire chain of activities concludes with installation in Hall-A in Nov., 2024. It is close to (not ON) the Critical Path. We need to identify a way for this to begin as early as October 2020. First activity is “Prototype & Design …($17K)”, so perhaps OK prior to CD-3A? (GEM Procurement start is 10/1/21).

Homework question 7

Can you summarize the actuals and commit to date for the project?

- Actuals (through December, 2019) : $368,881
- Commit: $0

Thank You

Appendix

Appendix slides go here.

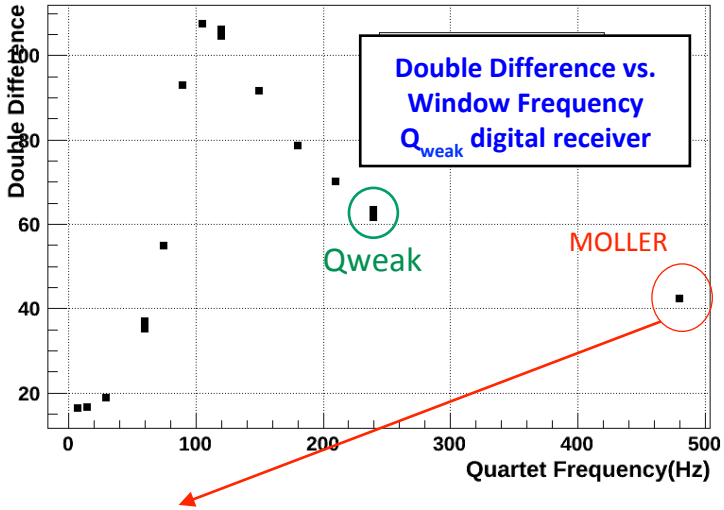
BCM resolution

(Critical Design Question #4)

Parameter	Noise (65 μA)
Statistical Width (1016 μs)	**~82 ppm**
Target Density Fluctuation	30 ppm
Beam Intensity Resolution	10 ppm
Beam Position Noise	7 ppm
Detector Resolution (25%)	21 ppm (3.1%)
Electronics Noise	10 ppm
Measured Width	**91 ppm**

with existing receivers and 7 monitors:
~ 16 ppm resolution
~ 1% excess width
(91 ⟶ 92 ppm)

BCM Digital Receiver Bench Test



- Double difference = 42 ppm for 480 Hz quartets; ⟶ 60 ppm for 960 Hz pairs (white noise)
- Implies resolution of 60 ppm / sqrt(2) = 42 ppm
- With seven of these monitors (planned for MOLLER), average to get 42 ppm / sqrt(7) ~ 16 ppm

Two strategies for improvement

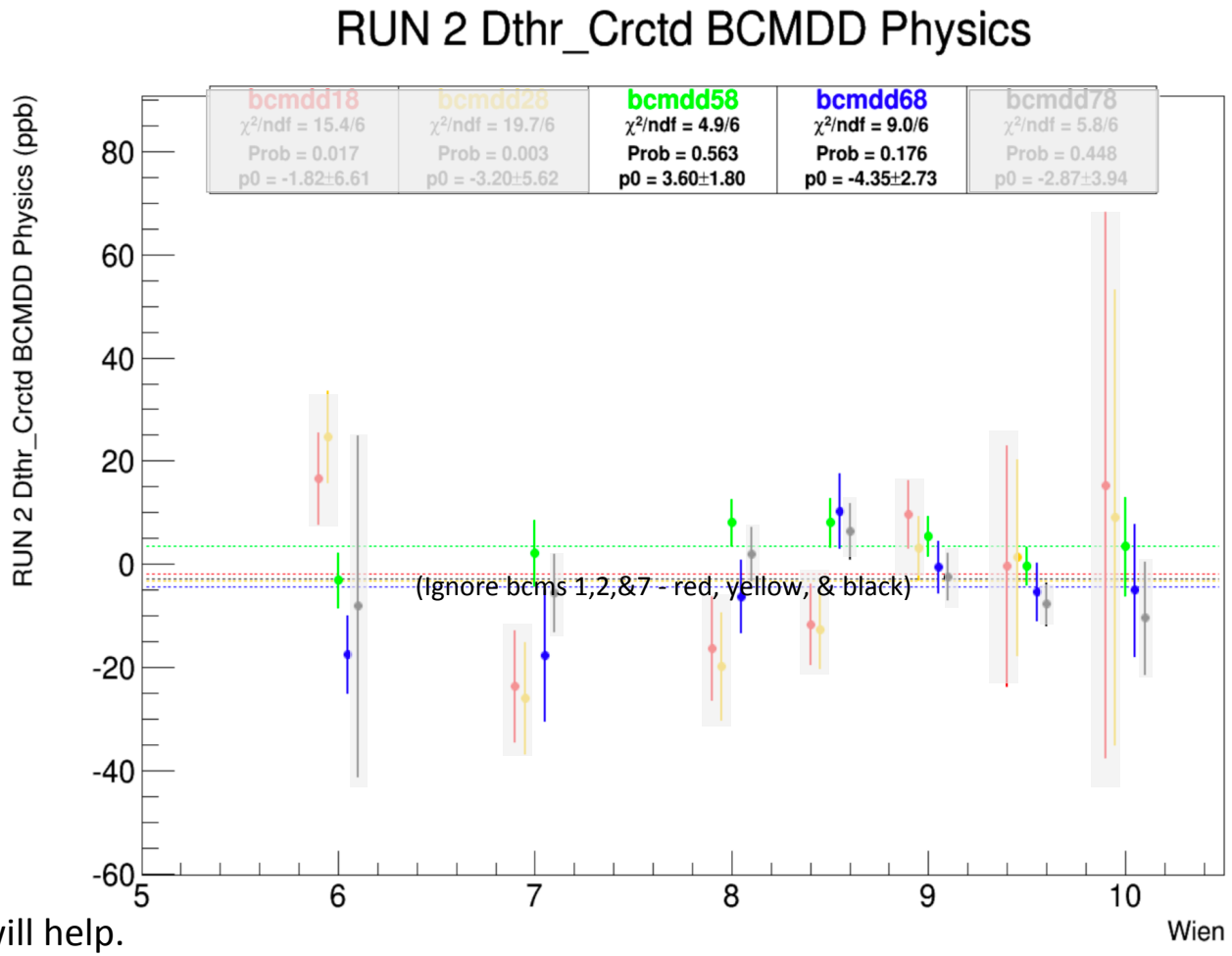
- New version of Musson electronics has been fielded; bench tests showed factor-of-two improved resolution (for Qweak conditions). So ~22 ppm resolution for single monitor would be possible. Further improvements could be possible by improving local oscillator (bench tests).
- LBNL (Kolomensky and group): All-digital processor prototype developed; eliminates need for local oscillator. Uses high sampling rate (> ~3 Gsps) and high dynamic range (>10 bits) ADC's that are capable of direct RF sampling. Initial bench studies give ~ 10 ppm resolution for 960 Hz window pairs.

BCM systematics

(Critical Design Question #3)

Qweak Experience:
Reasonable agreement between BCMs for short time intervals (runs, slugs), but margir discrepancies emerge with “wien level” comparisons, suggesting systematic bias between monitors or else very unfortunate statistical variation

The precision of the BCMs was marginal for testing this before the end of the run.



MOLLER:
Greater number of functional monitors (7) will help.

Better resolution (either in digital-to-analog or the new all-digital LBNL system) would be a big help, providing a way to consistency during the run.

Unfortunately, PREX did not have a consistent set of more than two monitors continuously over the run. We are still developing the kind of cross-comparison shown above for periods of the run for specific redundant BCMs. To the extent that we have made comparisons so far, we see consistency, with precision about ~10 ppb.

BCM Reproducibility issue from Qweak

In the high-statistics Run 2 of Qweak, the beam current was measured by three independent BCM (beam current monitors): BCM 5,6 and 8.

With three independent monitors, one can determine the individual monitor uncertainty* from the combinations of the widths of the "double difference" distributions, eg. from $DD\downarrow 56 = \sigma(A\downarrow BCM5 - A\downarrow BCM6)$.

* = $\sigma/\sqrt{\#quartets}$ over all of the Run

The three extracted BCM resolution contributions were:

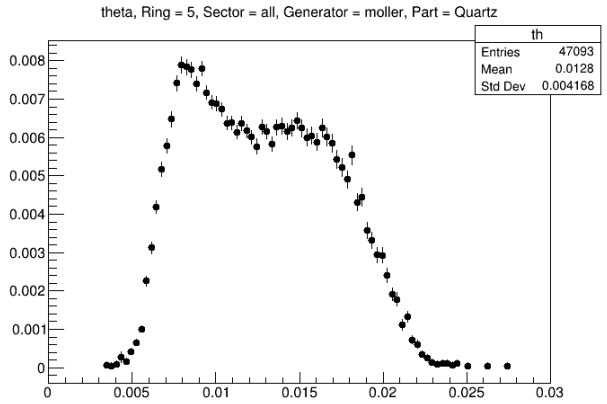
BCM5 = 1.36 ppb BCM6 = 2.46 ppb BCM8 = 1.18 ppb

The consistency between the charge measurements from the 3 monitors can be extracted by normalizing the detector asymmetry by each individual BCM in sequence:

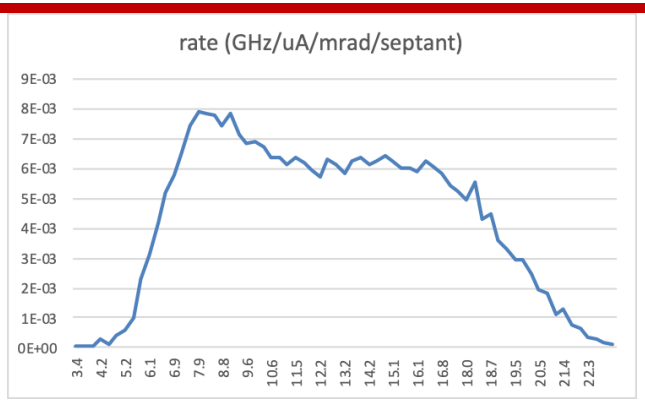
$$A\downarrow 5 = -167.86 \pm 1.36 \text{ ppb}$$
$$A\downarrow 6 = -159.91 \pm 2.46 \text{ ppb}$$
$$A\downarrow 8 = -164.26 \pm 1.18 \text{ ppb}$$

If the BCMs were reproducible, these three numbers should agree within statistical errors. The *p*-value based on $\chi\uparrow 2/dof$ = 4.54 for these three numbers to be consistent is 10.3%, *i.e.* no statistically significant evidence for non-reproducibility of the BCMs.

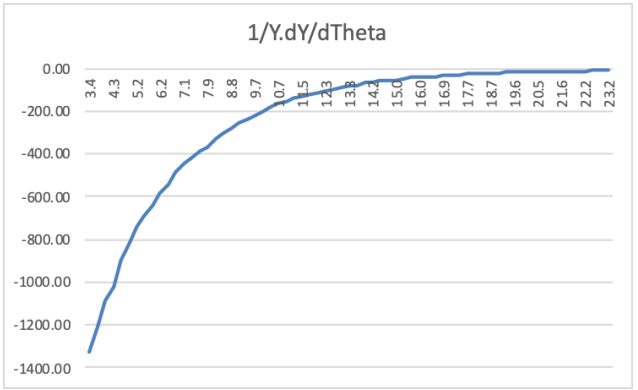
Homework Question 2 Answer, part 1



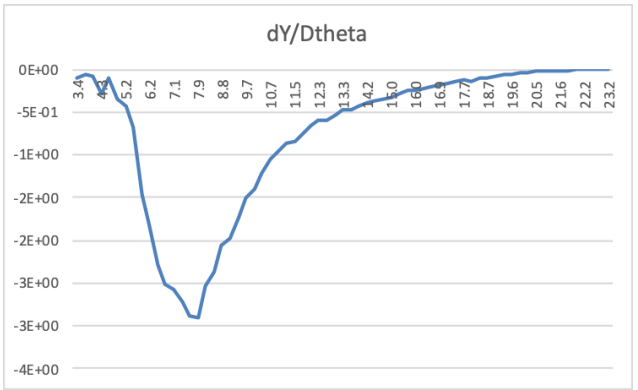
Rate $Y = \Sigma_i Y_i$



Sensitivity as a function of angle $\frac{1}{Y_i}\frac{dY_i}{d\theta_i}$



Total change in rate $\frac{dY}{d\theta} = \Sigma_i Y_i \left(\frac{1}{Y_i}\frac{dY_i}{d\theta_i}\right)$

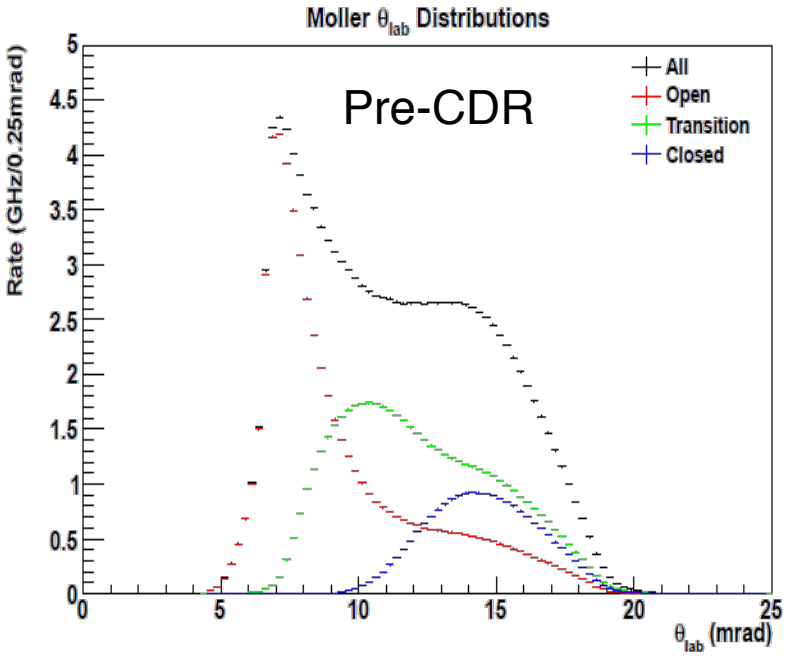


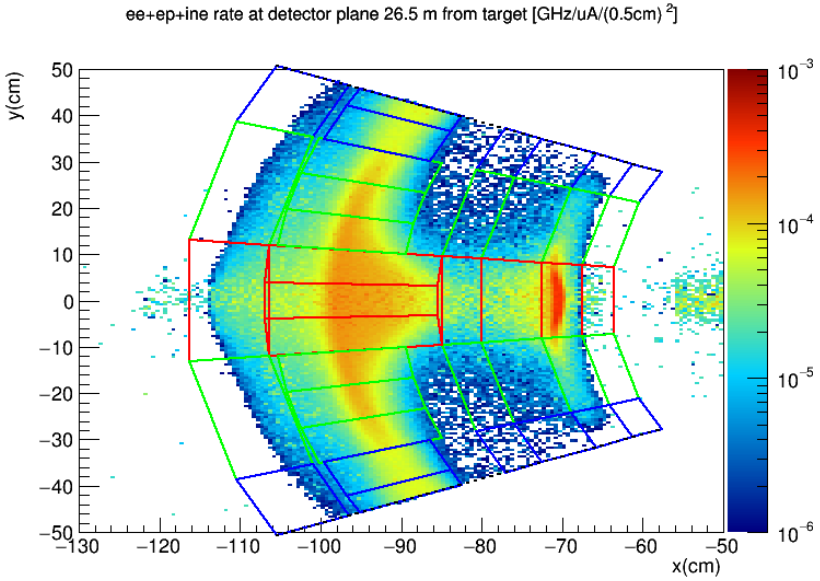
Sensitivity $\frac{1}{Y}\frac{dY}{d\theta}$ = -165 ppm/μrad

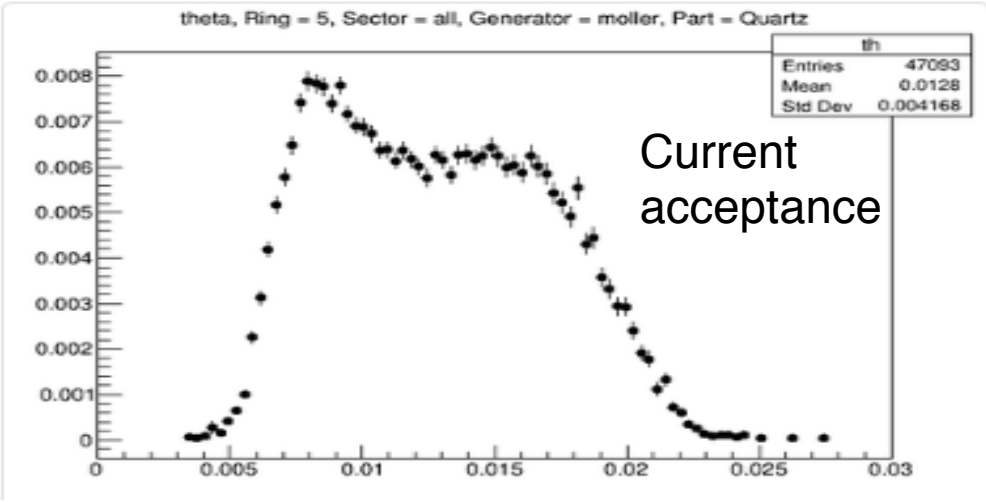
±150 μrad * 165 ppm/μrad = ±25000 ppm = 2.5%

Homework Question 2 Answer, part 2

Acceptance Function







Appendix: Run Periods, Experiment Optimization for Approaching 2% Precision

65 μA, 90% polarization

Run Period	1 kHz Width	PAC Days (prod)	Stat Error (ppb)	Stat Error (%)	Eff %	Notional Calendar Weeks Production	Notional Commissioning Weeks	Notional Total Weeks
I	101	14	2.96	11.4	40	5	6	11
II	96	95	1.08	4.2	50	27	3	30
III	91	235	0.65	2.5	60	56	4	60
Total		**344**	**0.55**	**2.1**			**13**	**101**

Multiple run periods allow for both statistical width and systematic errors to evolve to ultimate precision.

Run Period 1

- Spectrometer optics, acceptance, alignment
- First look at backgrounds
- Test sufficiency of beam correction tools and analysis
- Beam quality (asymmetry and halo)
- Tests of polarimetry precision

Result: near precision of SLAC-E158

Run Period 3

- Ultimate precision, ultimate systematic uncertainty

Result: $\delta(\sin^2\vartheta_W)$=0.00024 (stat), 0.00028 (stat+syst)

Run Period 2

- Statistical behavior of beam asymmetries, measured asymmetry
- Quality of "slow" reversals (Wien, g-2)
- Precision on background, normalization, beam corrections, polarization

Result: 2.5x beyond SLAC-E158

$\delta(\sin^2\vartheta_W)$=0.00044 (stat), 0.00047 (stat+syst)

~ 3 – 5 month break needed between Run Period 1 and Run Period 2

Appendix – Evolution of Statistical Width Budget

Ultimate random noise uncertainty budget

Parameter	Random Noise (65 μA)
Statistical width (0.5 ms)	$\sim$ **82 ppm**
Target Density Fluctuation	30 ppm
Beam Intensity Resolution	10 ppm
Beam Position Noise	7 ppm
Detector Resolution (25%)	21 ppm (3.1%)
Electronics noise	10 ppm
Measured Width (σ_{pair})	**91 ppm**

Possible evolution of statistical width

Run Period	I	II	Ultimate
Measured Width Goal	**101 ppm**	**96 ppm**	**91 ppm**
Excess noise over statistics	59 ppm	50 ppm	40 ppm
Margin for unknown noise sources	43 ppm	30 ppm	—

Appendix – Evolution of Systematic Uncertainty Budget

Ultimate systematic uncertainty is not achieved on day 1.
As more data is taken and techniques are refined, the systematic uncertainty will improve.

Uncertainty Source	I	II	Ultimate
Statistical	**11.4**	**3.9**	**2.1**
Kinematic normalization	3	0.7	0.5
Beam (second moment)	2	0.4	0.4
Beam Polarization	1	0.4	0.4
$e+p\ (+\gamma) \rightarrow e+X\ (+\gamma)$	1	0.4	0.4
Beam (position/angle/energy)	2	0.4	0.4
Beam (intensity)	1	0.3	0.3
$e+p\ (+\gamma) \rightarrow e+p\ (+\gamma)$	2	0.4	0.3
$\gamma^{(*)} + p \rightarrow (\pi,\mu,K) + X$	1	0.4	0.3
Transverse beam polarization	2	0.2	0.2
$e+Al\ (+\gamma) \rightarrow e+Al\ (+\gamma)$	0.5	0.15	0.15
Neutral backgrounds	0.5	0.1	0.1
Linearity	0.1	0.1	0.1
Total systematic	**5.4**	**1.3**	**1.1**

Path to achieving MOLLER goals

	Source	Adiabatic Damping	Slow Reversals	Feedback
Intensity	**<10 ppm (injector)**	-	**~10x**	**100x**
Position/ angle	**~20 nm (injector)**	**~100x (150x max)**	**~10x (IHWP, g-2, ISM)**	**~10x, control jitter**
	(Past: 50-200 nm)	Past: 10-30x (95x max)	Past: ~10x IHWP, ISM	Past: ~10x, not often used
Spot Size	**(source) $\Delta\sigma/\sigma$ $<10^{-5}$**	~10x synch light	**~10x (IHWP, g-2, ISM)**	—
	Past: $\Delta\sigma/\sigma$ $<10^{-4}$			

Intensity: run averaged goal <10 ppb

- ~1% correction accuracy (0.1 ppb systematic)

Position/ angle: run averaged goal < 1.2nm / 0.12 nrad

- Factors here combine to ~ 0.002 nm, 500x better than specification!

Spot size asymmetry: $<10^{-5}$

- Cannot be directly measured on e-beam. Measurements on source laser will provide suitable limit.
- Slow Reversals provide safety margin
- emittance growth due to synchrotron emission - increases the spot size, dilutes the helicity-correlated asymmetry from the source. Additional suppression of ~10x.

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Jefferson Lab