A Modified Hall A line for 11 GeV Parity Experiments

Jay Benesch

Abstract

Difficulties in satisfying the constraints of HAPPEX-III suggest a re-organization of the Hall A line placing a quad doublet between the Compton and Moller systems and placing the raster after the last quad. This makes the raster size independent of the quad settings after the Compton so the quads may be set to provide a compromise between beam size at the target and phase advance between the last pair of BPMs. This altered beam line may be applicable to E-09-005 (MOLLER) and other parity experiments in hall A.

Initial conditions

To reduce cost the rework would begin at the exit of the differential pumping station which follows the Compton chicane with one exception. Girders are re-used wherever possible. A few BPMs and correctors are added to make it easier to steer through the raster and to the target. A few new stands may be needed. The raster is doubled in length.

The 11 GeV MOLLER experiment, tentatively approved by PAC 34, will place its target 5m upstream of the pivot. This design shows the diagnostic girder in its usual location but a 4.5m drift is placed immediately upstream to accommodate a move of most of the diagnostics. A tick mark is placed at the location of the 11 GeV Moller target so beam and raster sizes can be checked. See appendix one. Input Twiss parameters are those of the CD-3 baseline design. Particle tracking of the present 12 GeV accelerator design has not been completed.

Hall A baseline design

The baseline design in the author's repository is shown in the four figures which follow. The target is at 148.6m in these figures. Horizontal emittance is four times vertical emittance.

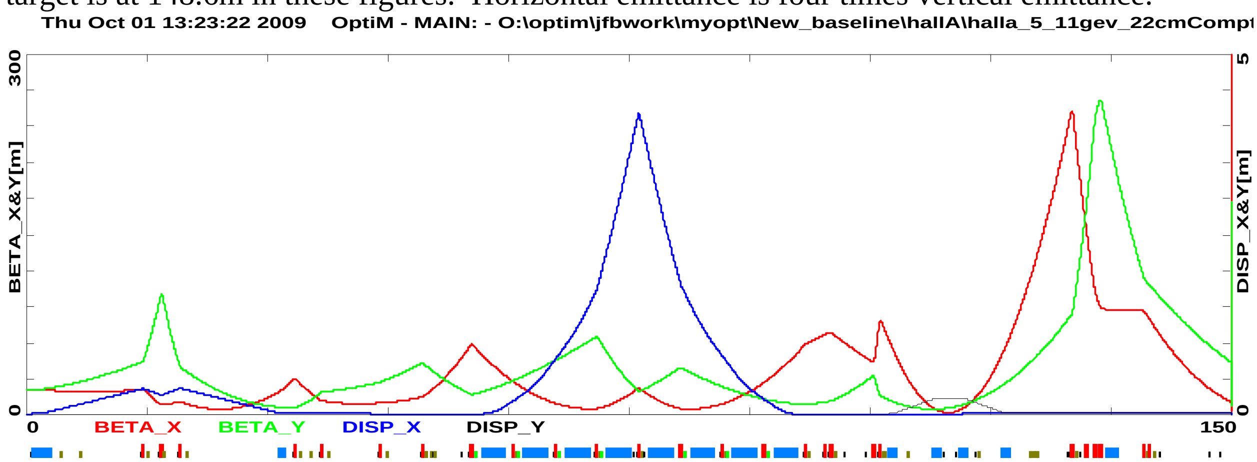


Figure 1. Betas and dispersion. Red horizontal beta, green vertical beta, blue horizontal dispersion, black vertical dispersion.

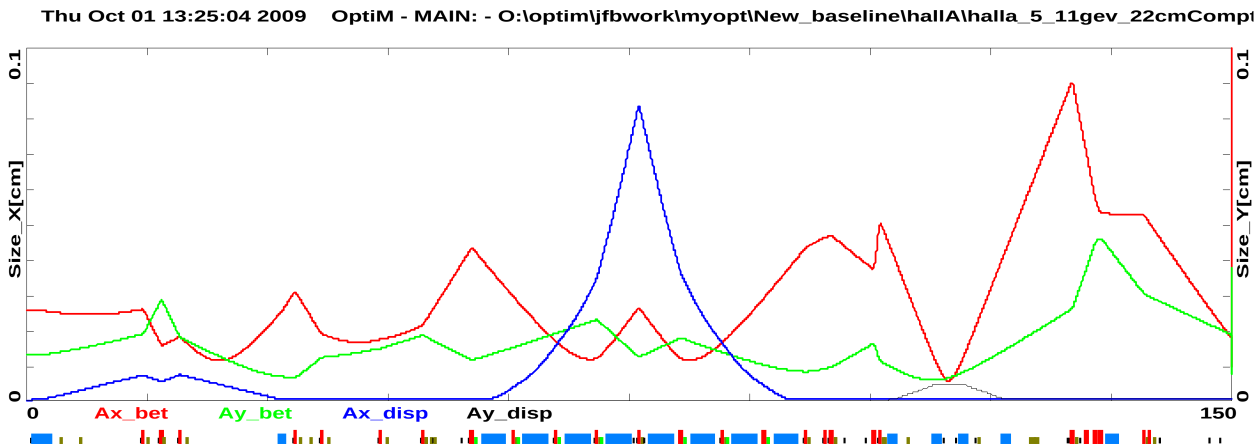


Figure 2. Beam envelopes. 1mm full vertical scale

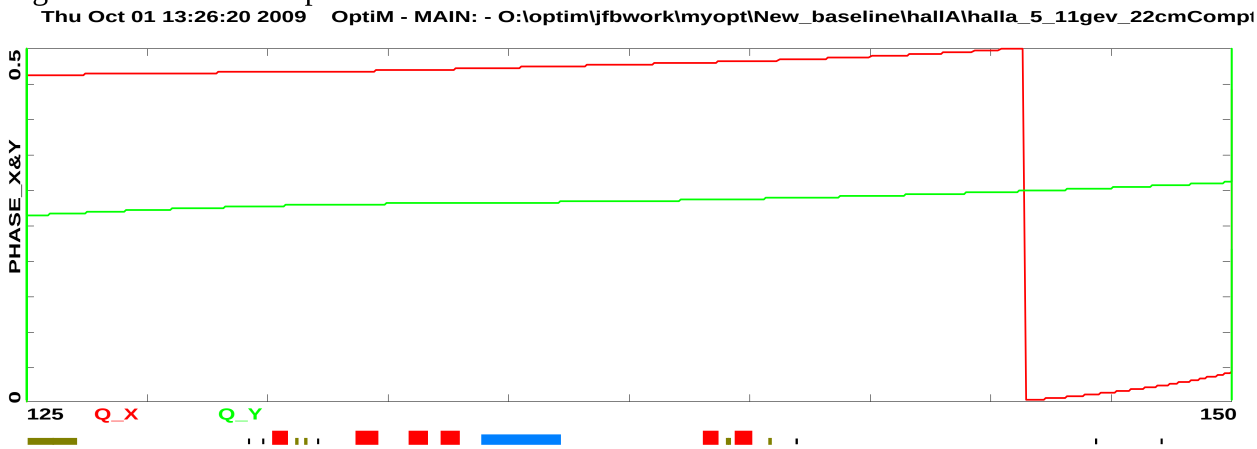


Figure 3. Phase advances starting at the fast raster. Very little vertical phase advance between the last two BPMs. Vertical scale is fraction of 2π

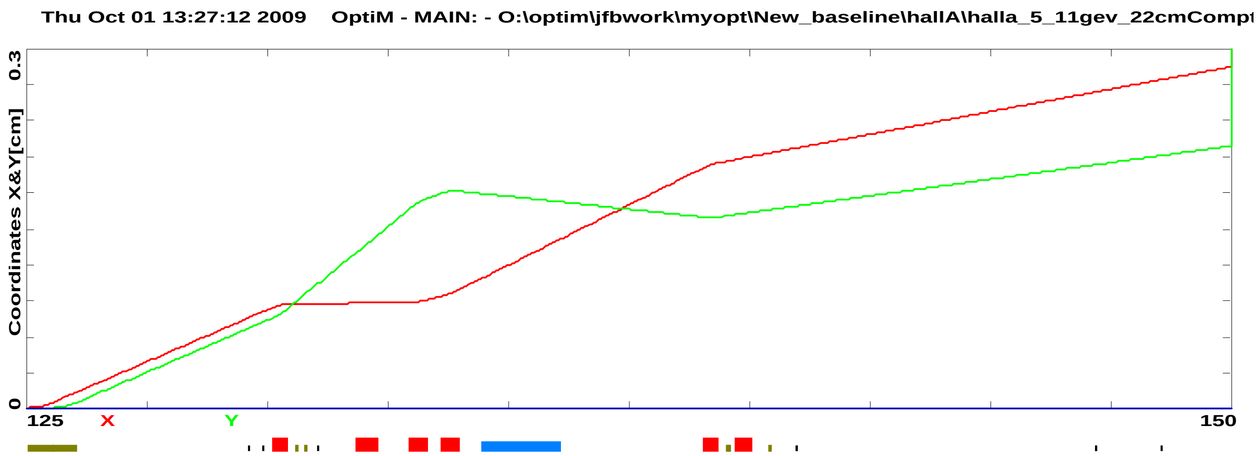


Figure 4. Fast raster excited at twice the 6 GeV maximum value. 3mm full scale. Pivot is 1.4m from the right vertical axis. No space is available to double the raster coil length due to eP.

Beam size at the pivot is 200 microns, round. Phase advance between the last pair of BPMs is minimal. Raster is 5.4 x 4.2 mm full extent at the pivot. There is one QA quad (red box) before the Moller system and a close pair of QAs after the Moller system. This pair is too close together to be an effective doublet above 1 GeV. The QA19-QA20 doublet which precedes the

Compton chicane, shown in figures 1 and 2, has unphysical values, even for a QR quad, because they are separated by only 50cm. There is not sufficient real estate available between the "French bench" used for arc energy measurement and the Compton chicane to separate these two quads. This is a problem which must be addressed for any energy over 7.2 GeV.

Proposed design

The 1C19-1C20 problem just described may be solved because A. Saha opened up a constraint at a meeting Nov. 13, 2009: a pair of quads with minimum separation may be hung between the two harps on the "French bench". I designate these MQA1C18A/MQA1C18B. This pair becomes the first element in the doublet which precedes the Compton chicane. A single QR would also suffice for this element with 50% headroom for tuning. The second element of the focusing doublet may be either MQA1C19 or MQA1C20; I chose the former. The quads between the harps must be turned off for arc energy measurements; MQA1C19 and MQA1C20 are both needed then. The dispersive optics is discussed later in this note.

A new quad doublet consisting of two QA girders follows the Compton. Since ~2m is needed between the quads so the girder with BCMs and the Unser was placed between them. This girder is between the Compton and raster now. Next is the existing Moller system with one change: the vacuum pipe after the Moller dipole is reduced from 4" diameter to 1" diameter 1m after exiting the dipole. Correctors must be added to the 4" pipe as the shielding for the primary beam in the Moller polarimeter dipole is beginning to saturate at 11 GeV. MIT has donated one set this size, compatible with CEBAF trim cards. A BPM, 2m of fast raster, another BPM and an H/V corrector pair replace the 2m of 4" pipe removed and the inverted quad girder. This is followed by 5m of drift and the existing hall A diagnostic girder. The ep system is eliminated but could be placed in the 4.5m drift if that space is not otherwise needed, e.g. because the MOLLER target is 5m in front of the pivot. Radiation from Moller may preclude this.

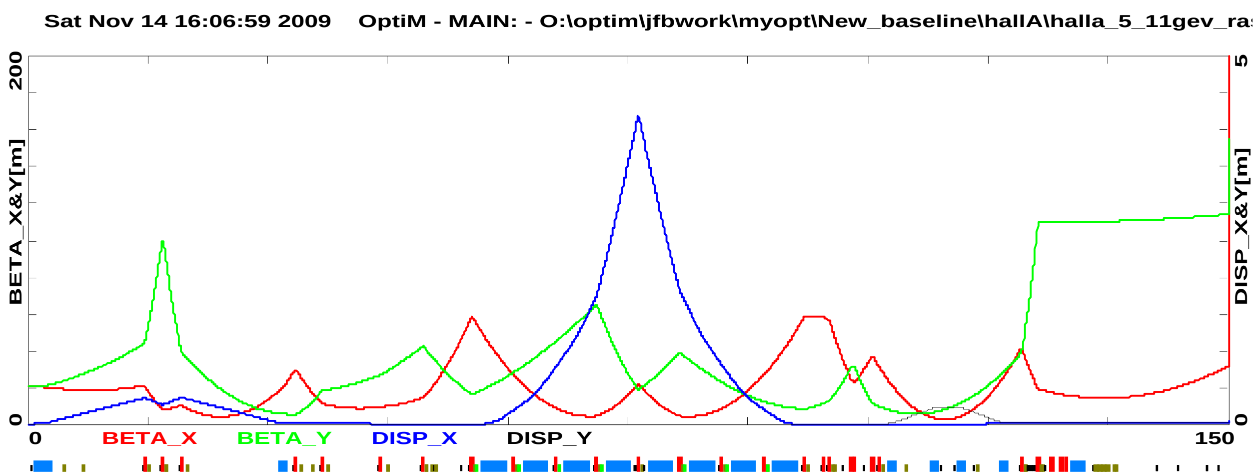


Figure 5. Betas and dispersion, new design. Only the quad doublet after the Compton is used in this plot. The Moller quads are turned off.

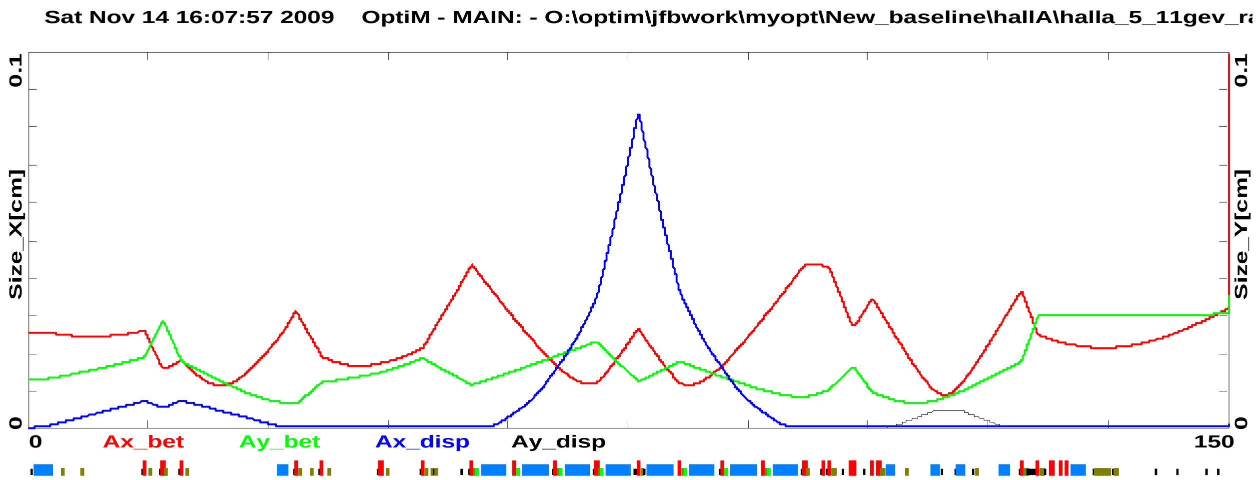


Figure 6. Beam envelopes, new design. If the Moller quads are turned on the beam size at the target will change and more phase advance may be obtained between the last pair of BPMs. Larger spot size is desirable per MOLLER collaborators.

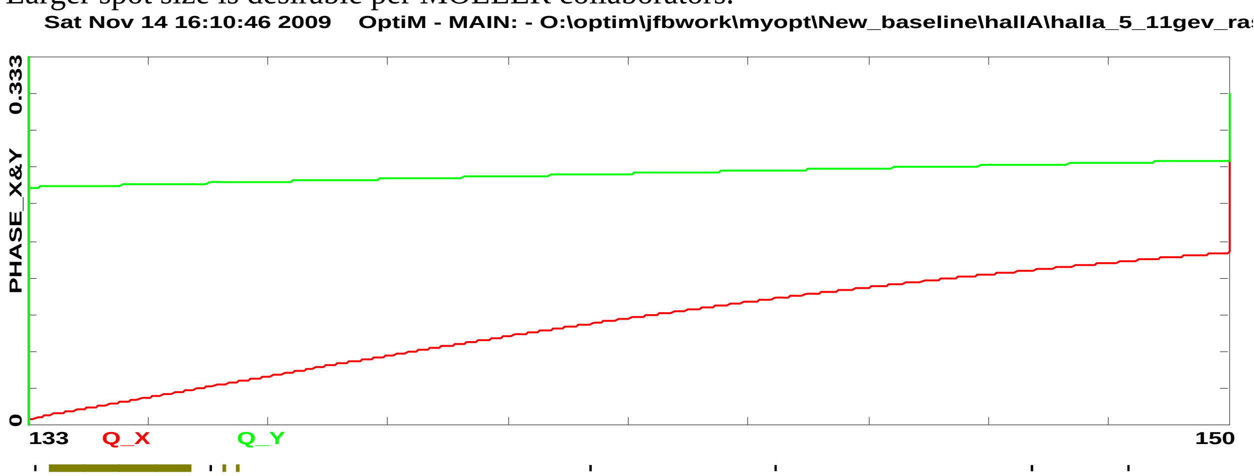


Figure 7. Phase advance from start of fast raster. Vertical axis 0 to $2\pi/3$. If more phase advance is desired, the Moller quads may be used. Compromise with beam size at target is necessary.

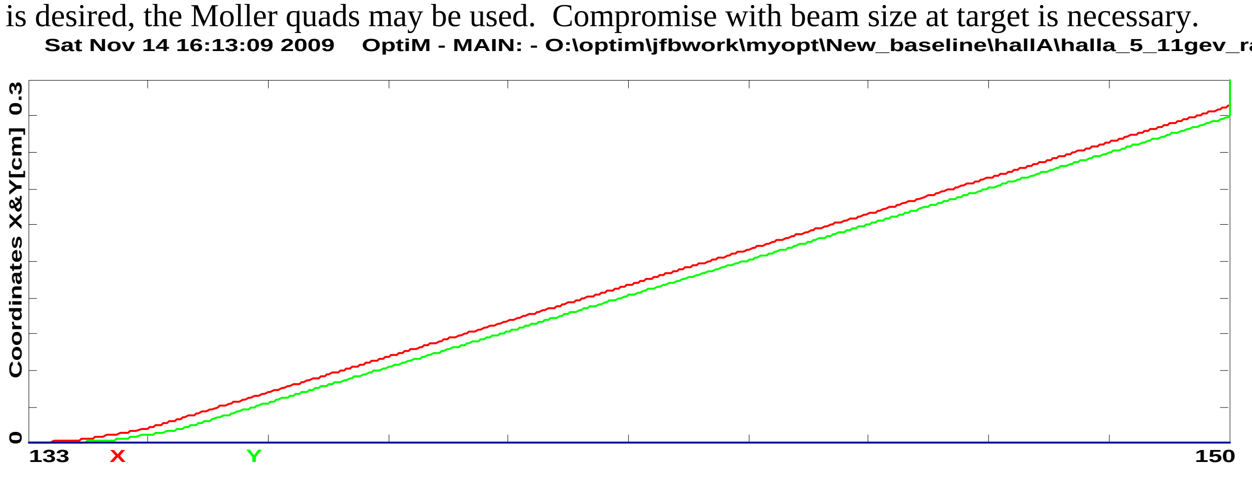


Figure 8. Fast raster excited at twice the 6 GeV maximum via twice the coil length. Coil length can't be doubled in the baseline design, so this design is easier to engineer than the baseline. 5mm square raster at the pivot. With the power supply implied in figure 4, the raster doubles that graphed.

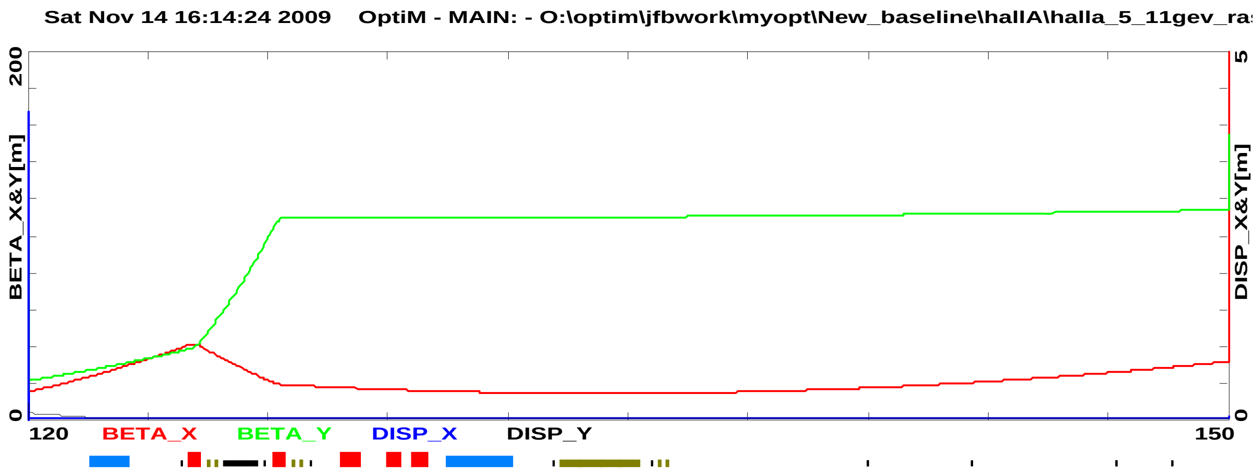


Figure 9. Beta functions starting near end of Compton chicane. One can more easily see here than in figure 5 that the Moller quads are turned off.

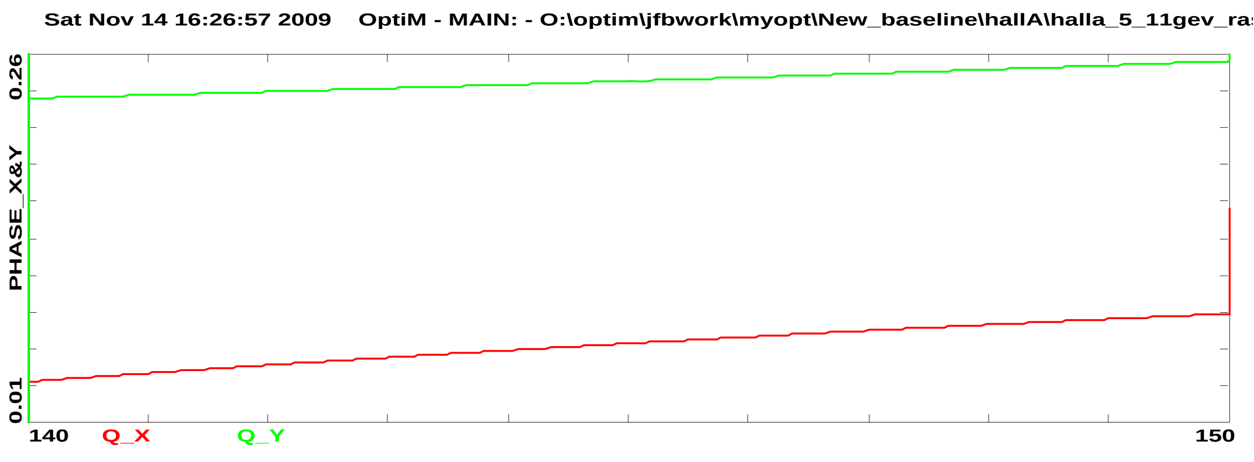


Figure 10. Phase advance between the last pair of BPMs. They are tick marks ~141m and ~147m. Note change of vertical axis vs figure 7. Vertical axis $\pi/2$ extent. Vertical phase advance about six degrees and horizontal about ten degrees.

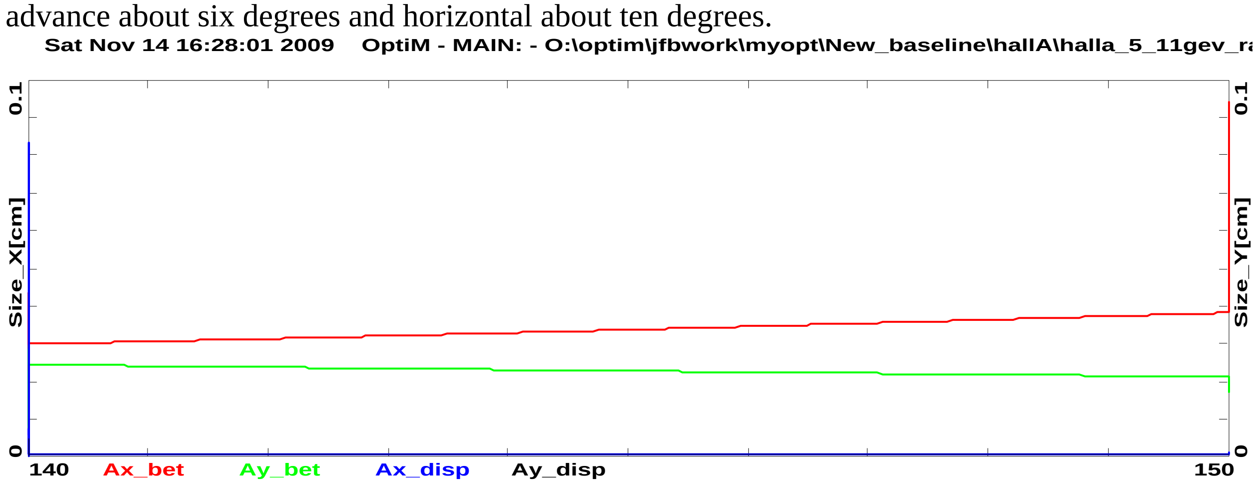


Figure 11. Beam envelope for region in figure 10 with those quad settings.

Dispersive mode - arc energy measurement

The insertion of a focusing element between the 18A and 18B harps used as part of the arc energy measurement requires a re-examination of the optics at the end of the line with all the quads from 1C08 through 1C18B turned off. It was found that adjustment of quads 1C07 and four at the end of the line kept the beam size under sufficient control for energy measurement.

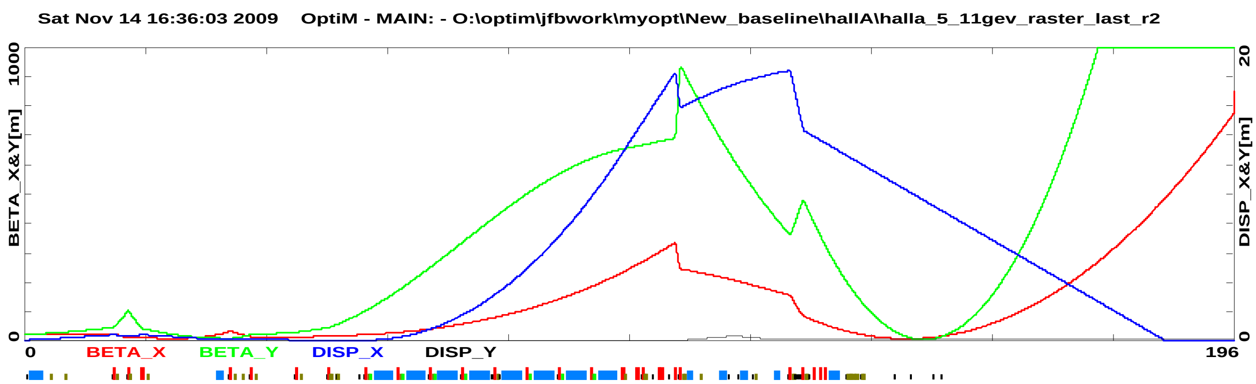


Figure 12. Beta functions and dispersion with arc quadrupoles turned off. Vertical axis for blue dispersion trace is 20m. Plot extends to beam dump.

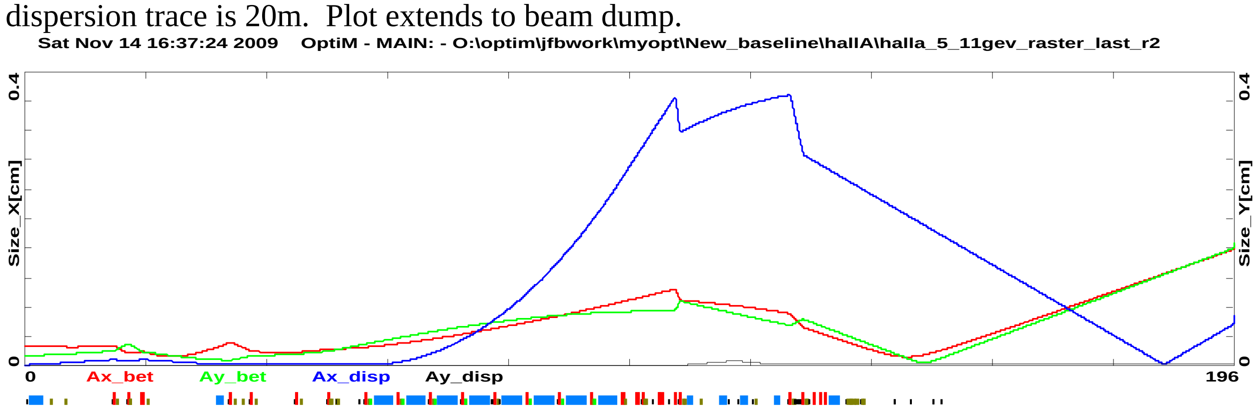


Figure 13. Beam envelopes corresponding to figure 12. Vertical axis 4mm. Dispersive term in blue again.

At peak dispersion the 22mm ID beam pipe is only five sigma in horizontal extent, so there will be beam loss. There's about seven sigma horizontally in new raster location.

Combined Optics

The Hall A collaboration is working on a Moller polarimeter target upgrade to allow high current polarimetry. This requires what has been termed "combined optics": the Moller polarimeter quads are set to focus the half-energy Moller electrons. The primary energy electrons are under-focused in one plane and over-focused in the other. O. Glamazdin provided Moller polarimeter quad values at 0.5 GeV intervals. Layouts with a quad doublet interleaved with the fast raster were evaluated. It was found that adjustmet of the doublet before the Moller polarimeter and just the first quad after the Moller polarimeter dipole were sufficient to adequately constrain the beam. Either phase advance between the last pair of BPMs or beam size at the pivot must be compromised with combined optics.

The following graphs show combined optics at 11 GeV with the single quad after the polarimeter dipole and before the fast raster. Phase advance between the last pair of BPMs is good in both planes. Beam envelope at the pivot is 200 μm H by 100 μm V. Phase advance and beam size may be traded off against each other.

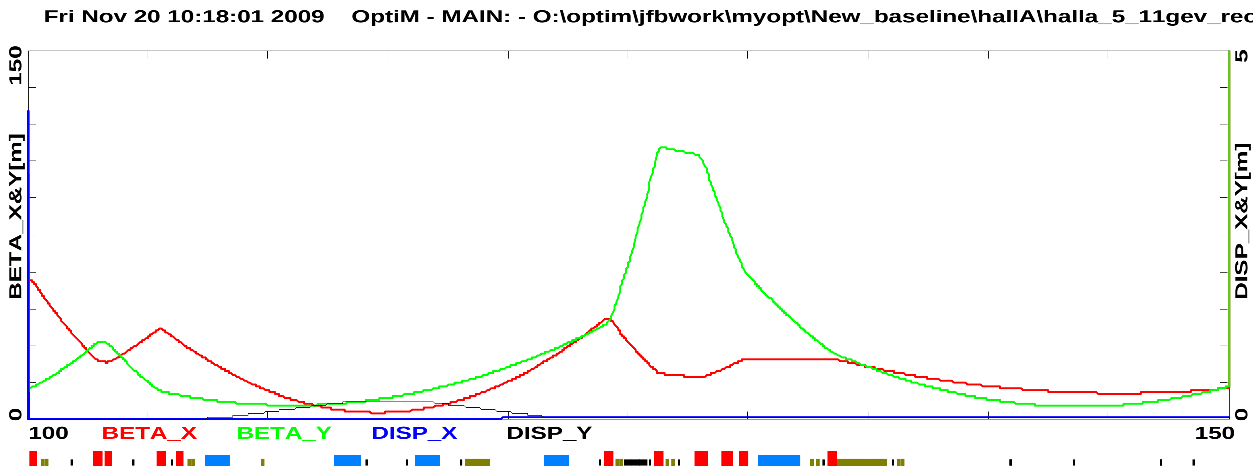


Figure 14. Combined optics at 11 GeV with new quad following Moller polarimeter dipole.

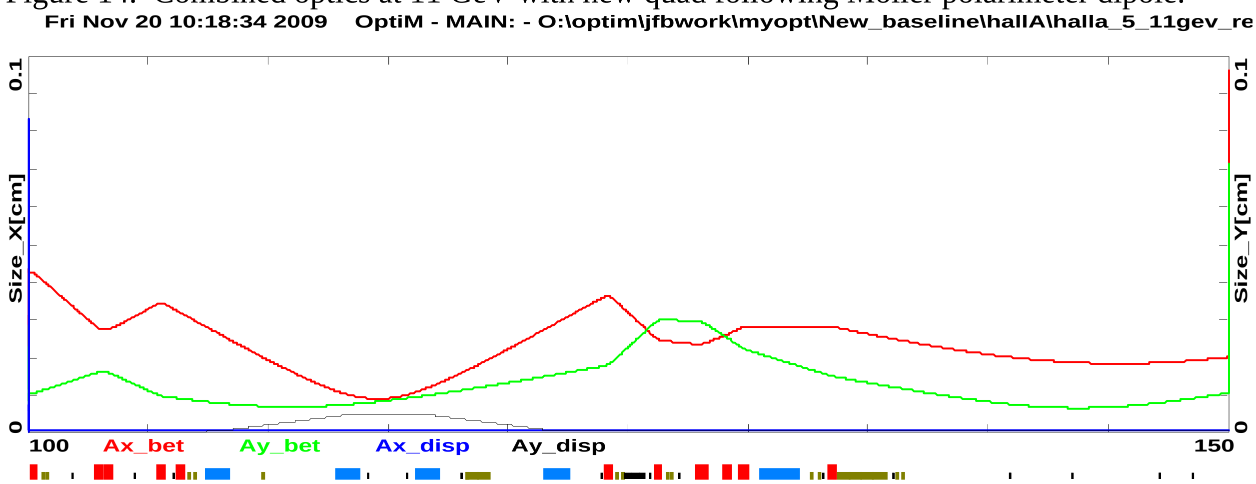


Figure 15. Beam envelope for region in Figure 14. 1mm vertical scale. Beam elliptical at pivot.

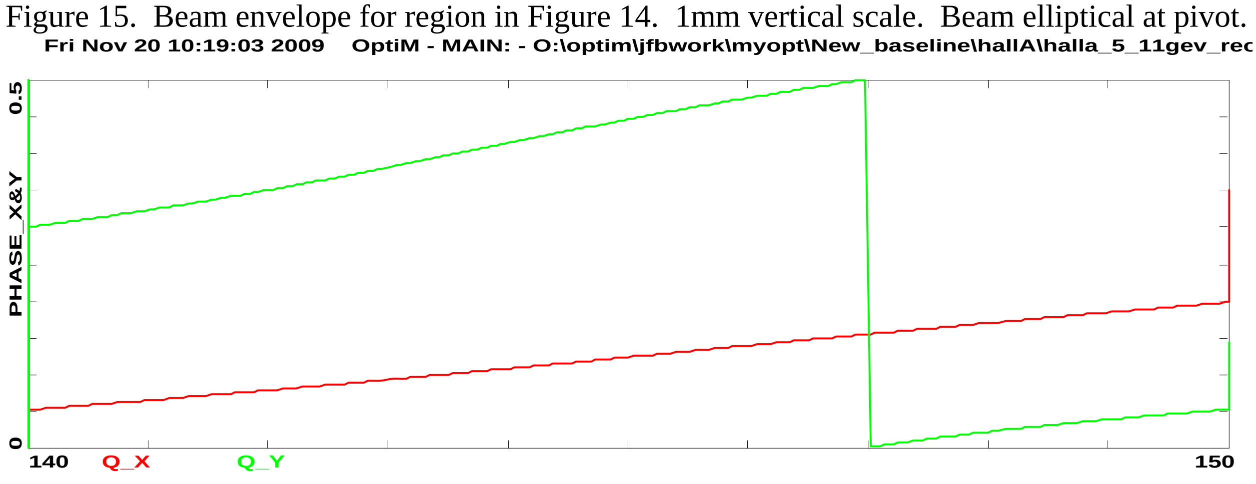


Figure 16. Phase advance, 180 degrees vertical scale. BPMs are at 140.7 and 147 m.

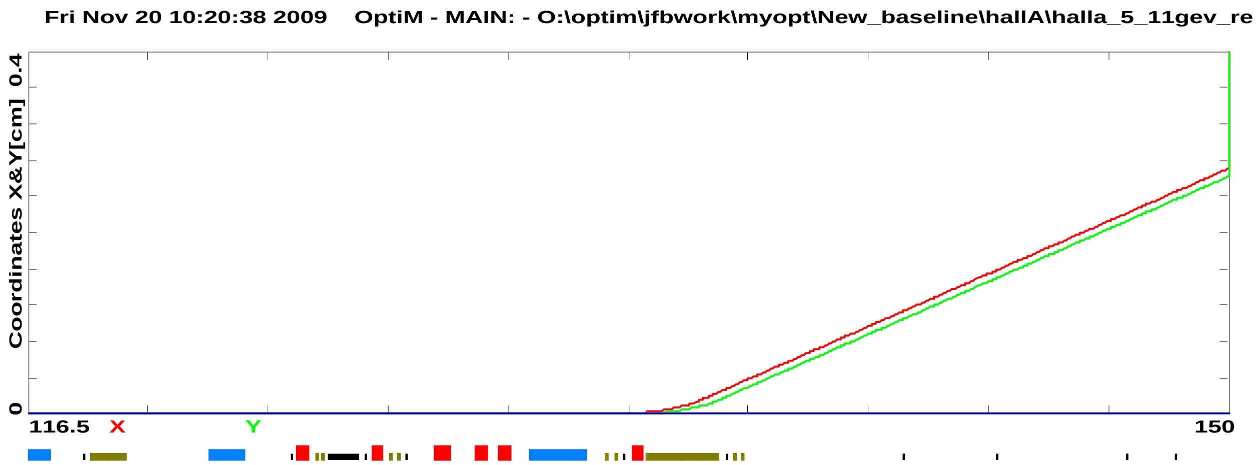


Figure 17. Fast raster response with reduced distance to the pivot vs Figure 8.

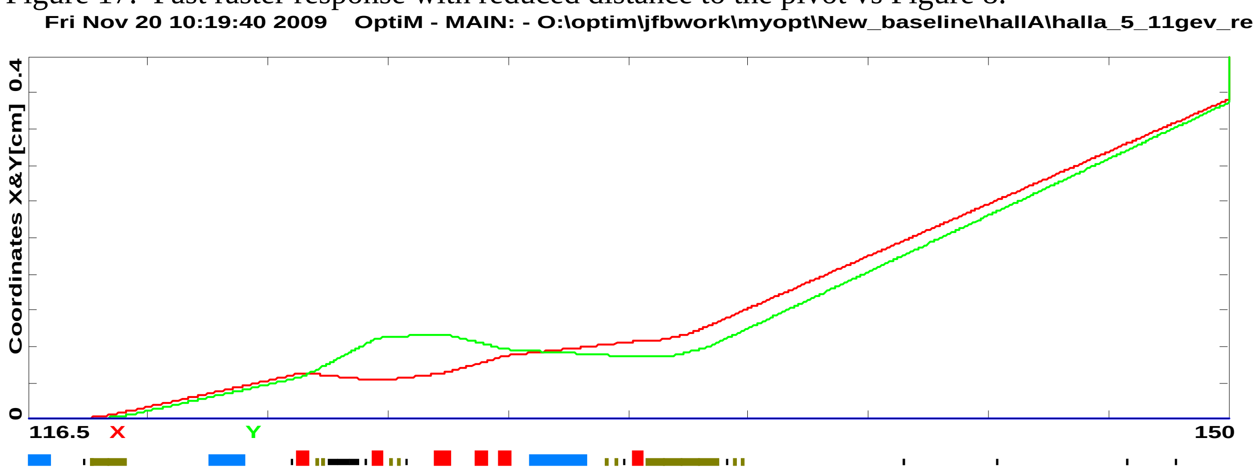


Figure 18. Existing fast raster moved to final leg of Compton chicane to provide raster for high current Moller target. Target raster also on at same field. These show DC kicks - raster phasing is important

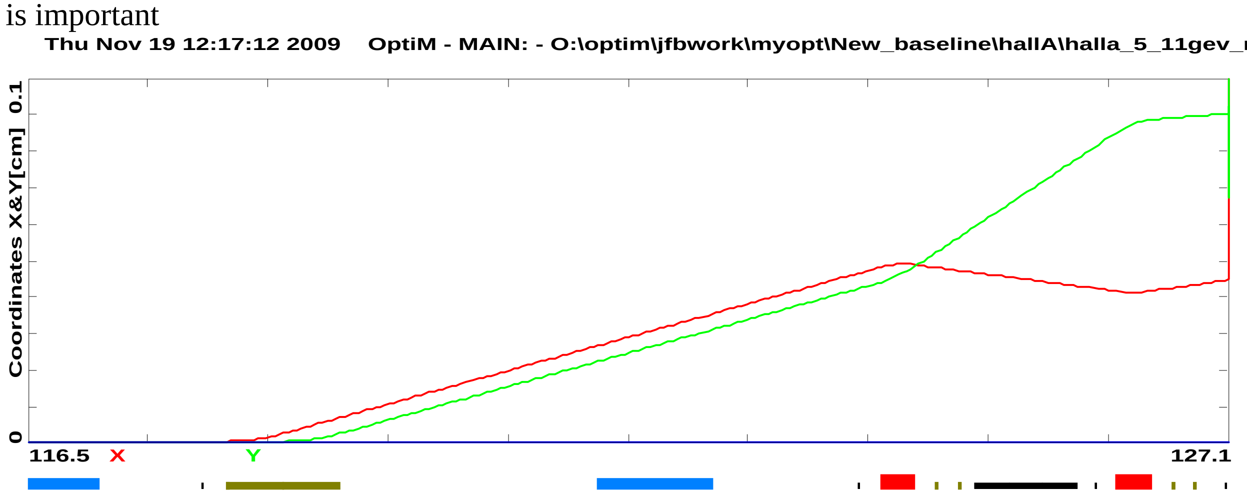


Figure 19. Enlargement of figure 18. Moller polarimeter target is at right end of plot. Vertical axis 1mm. Double these values for full raster pattern. Spot ~300 microns round at Moller polarimeter target - see figure 15.

Smaller target spot

K. Kumar requested an evaluation of smaller spots at the target. As shown below, it is possible to achieve ~100 µm round at the expense of deeper minima at the pivot. The minimum can be moved up to the MOLLER target. Will the steeper paraboli mean more sensitivity to spot size via mA changes in quad values?

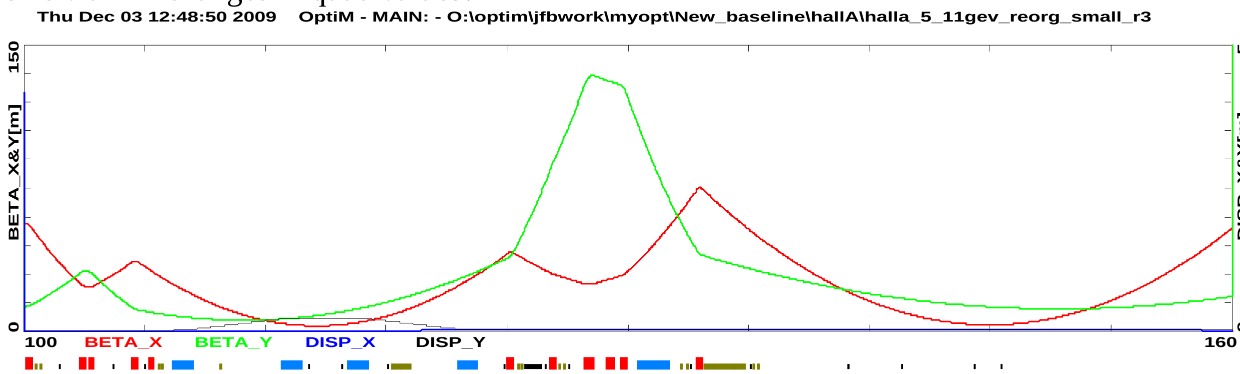


Figure 20. Betas for smaller spot at pivot. I show 10m more than in most of the figures so one can see how moving the minima via mismatch will change beam size. Pivot is ~149m, just before the minimum in the horizontal (red) curve.

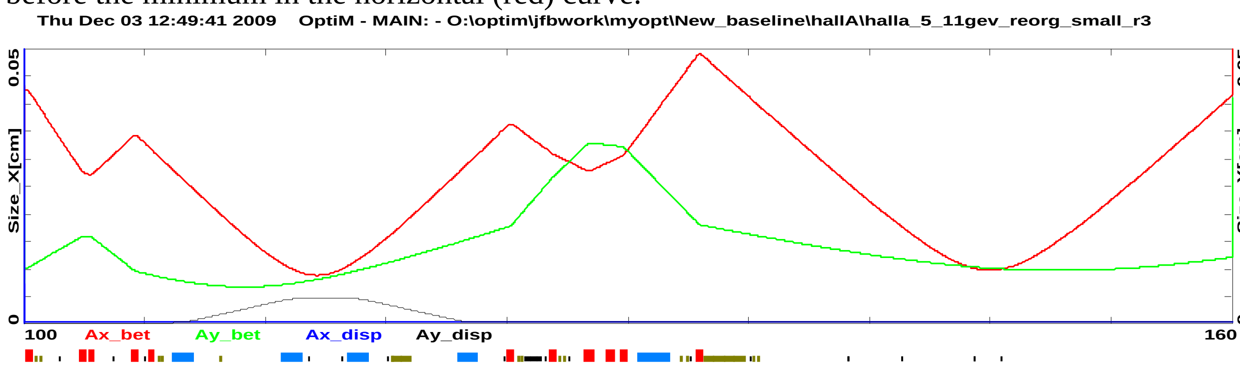


Figure 21. Beam envelope for optics above. Note that horizontal σ is 0.5mm at the fast raster and 0.1 mm at the pivot. If the match can be accomplished +- 20 σ to tube wall in the raster is acceptable.

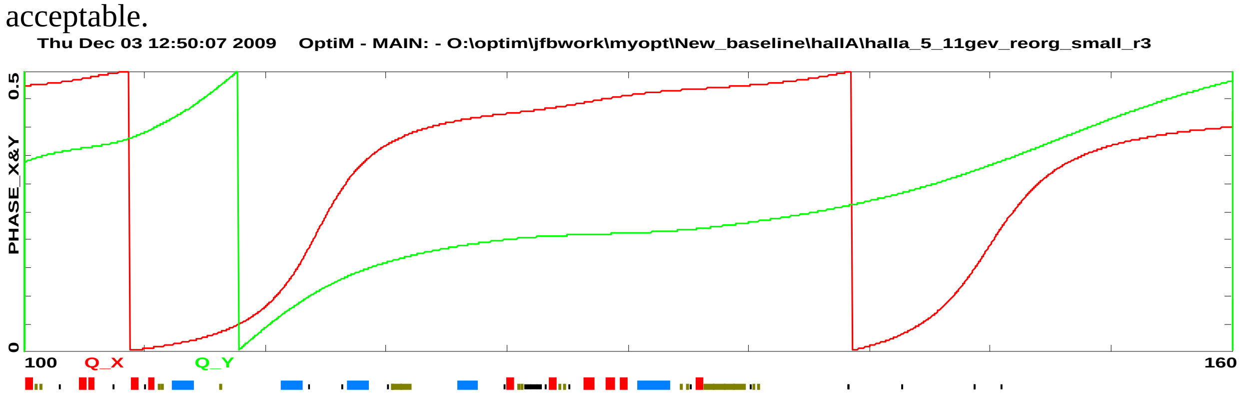


Figure 22. Phase advance for same region. Lots of phase advance for the BPMs at the end of the line.

Further work needed

Most important, a decision must be made about Moller polarimetry at high current. This requires an additional quad after the Moller dipole and makes the fast raster 5% more difficult to upgrade than discussed below.

A layout must be developed with the mechanical engineering group. The "French bench" at 1C18 must be checked for interference with the proposed inverted quads between the harps and modifications designed.

The MOLLER proposal has the target 5m in front of the pivot. It assumes a 5mm x 5 mm raster. This cannot be achieved by simply doubling the existing raster. The present raster has 30 cm coils on 50cm long assemblies with central ~40cm ceramic and ends stainless steel. There is one of these for each plane. If an assembly 100 cm long with 90 cm ceramic or glass tube were purchased, the raster coils could be increased to ~42 cm each, a 40% increase in length. Power supply would have to deal with the increased inductance and another 15% in current to reach 60% increase in raster per segment, achieving 5 mm x 5 mm with two such 100cm assemblies. Larson Electronic Glass can supply such custom glass assemblies. Slit a G-10 tube of appropriate size longitudinally and RTV it to the glass to improve shatter resistance. Or simply wrap it with Kapton tape. It would be good to design the power supply and raster coil combination to double the present BdL per raster, via 40% increase in length and 40% increase in current. This would provide headroom to move the rasters closer to the pivot.

The second most important open question the author is aware of is S/N in the Moller polarimeter detectors. The 2.95m by 4" tube which now exits the polarimeter dipole MMA1H01 must be reduced to 1" after 1m to allow insertion of fast rasters between the arms of the Y. This will increase background in the detectors. Modeling is required.

During Moller polarimetry measurements the unscattered beam goes through a magnetically shielded region of the Moller polarimeter dipole. The unscattered beam is slightly deflected and proceeds to the normal beam dump. The effectiveness of this shielding at 11 GeV must be evaluated, as must the resulting orbit through the rasters. Necessary vertical corrector strength must be calculated.

Conclusions

A rework of the Hall A line is proposed which eliminates one constraint, raster pattern, in setting the quadrupoles downstream of the Compton chicane. Four quadrupoles are available to set beam size at the target and phase advance in the last eight meters before the target with less difficulty than in the 6 GeV machine, albeit with coupling between these constraints. Ion chamber trips will be much reduced. BPMs and correctors are added to reduce scraping at apertures. Provision is made to quadrupole raster strength, a factor of 2.8 via coil length and a factor of 1.4 via power supply improvements.

Appendix two gives nominal quad values and notes six changes required for 11 GeV operation, four of them in the unchanged portion of the line.

Appendix One - changed portion of lattice

N	Name	S[cm]	L[cm]	B[kG]	G[kG/cm]
180	oD4013	10178.9	100		
181	iIHA1C18A	10178.9	0	0	0
182	oD4033a	10280	101.1		
183	qMQA1C18A *new quad*	10310	30	0	-1.99114
184	oD4033b	10322	12		
185	qMQA1C18B *new quad*	10352	30	0	-1.99114
186	oD4033c	10440	88		
187	iIHA1C18B	10440	0	0	0
188	oD4013	10540	100		
189	qMQA1C19	10570	30	0	2.5254
190	oD4027	10600	30		
191	iIPM1C20	10600	0	0	0
192	oD4019	10620	20		
193	qMQA1C20	10650	30	0	0
194	oD4031	10669.3	19.3		
195	kMBC1C20H	10669.3	1e-06	0	0
196	oD4032	10688.9	19.6		
197	kMBC1C20V	10688.9	1e-06	0	0
198	oD4034	10742.6	53.74		
199	gMMC1P01	10742.6	0		
200	bMMC1P01	10842.6	100.007	14.9605	0
201	gMMC1P01	10842.6	0		
202	oD4035	10972.5	129.875		
203	kMBT1P01H	10972.5	1e-06	0	0
204	oD4036	11283.4	310.901		
205	gMMC1P02	11283.4	0		
206	bMMC1P02	11383.4	100.007	-14.9605	0
207	gMMC1P02	11383.4	0		
208	oD4037	11412	28.6		
209	iIPM1P02A	11412	0	0	0
210	oD4038a	11494	82		
211	oD4038b	11575.7	81.7		
212	iIPM1P02B	11575.7	0	0	0
213	oD4039	11613.4	37.7		
214	gMMC1P03	11613.4	0		
215	bMMC1P03	11713.4	100.007	-14.9605	0
216	gMMC1P03	11713.4	0		
217	oD4040	11804	90.6033		
218	iIPM1P03A	11804	0	0	0
219	oD4041	11826.1	22.0365		
220	kMBT1P04H	11826.1	1e-06	0	0
221	kmxRast *moller raster*	11876.1	50	0	0

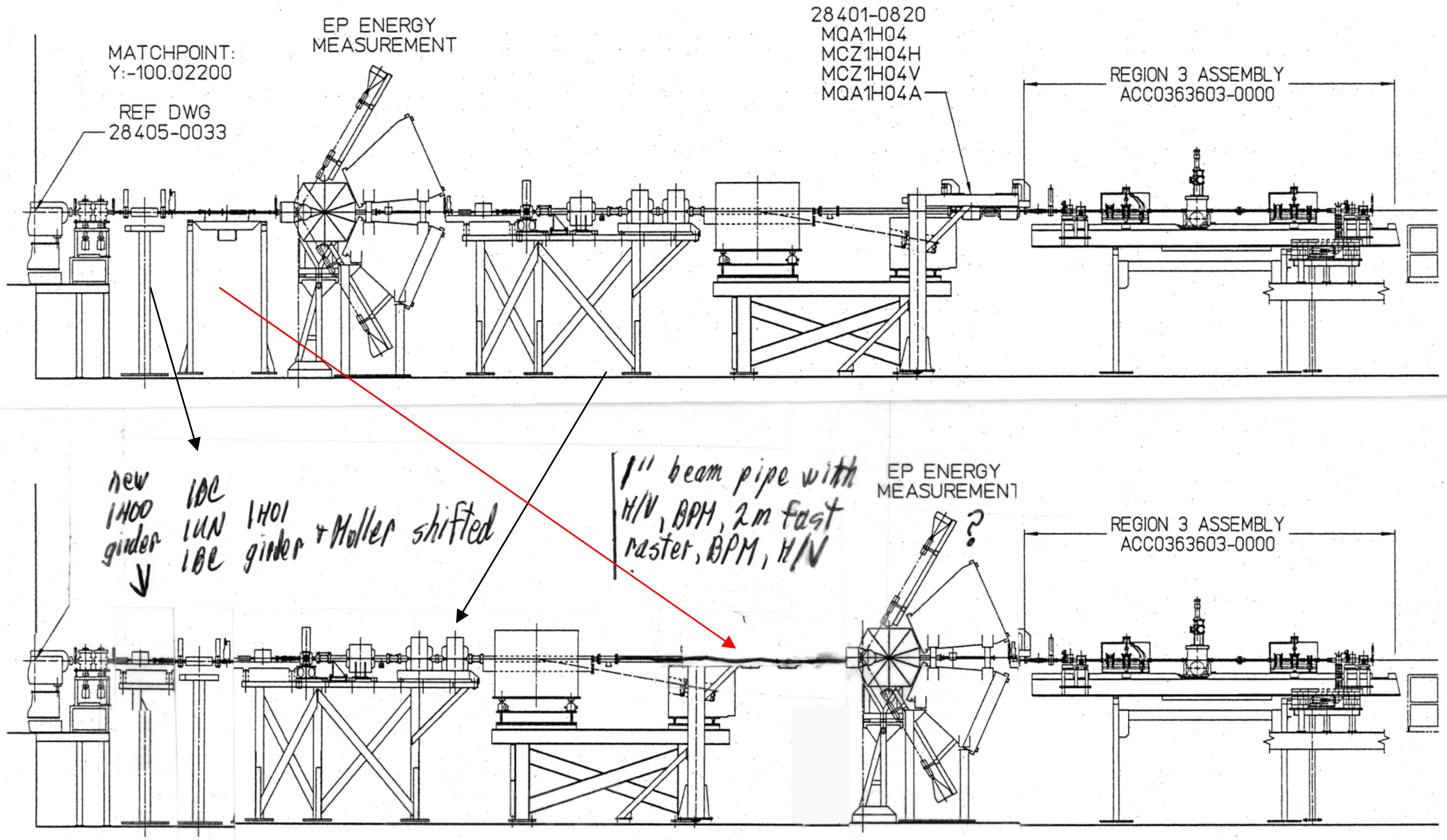
222	kmyRast *moller raster*	11926.1	50	0	0
223	oD4042	12154.2	228.136		
224	gMMC1P04	12154.2	0		
225	bMMC1P04	12254.2	100.007	14.9605	0
226	gMMC1P04	12254.2	0		
227	oD41dp	12354.2	100		
228	oD4045	12383	28.8		
229	iIPM1H00	12383	0	0	0
230	oD4019	12403	20		
231	qMQA1H00 *new*	12433	30	0	3.205
232	oD4031 *new*	12452.3	19.3		
233	kMBD1H00H *new*	12452.3	1e-06	0	0
234	oD4032 *new*	12471.9	19.6		
235	kMBD1H00V *new*	12471.9	1e-06	0	0
236	oD4106	12486.9	14.95		
237	iIBC1H00	12516.9	30	0	0
238	iIUN1H00	12546.9	30	0	0
239	iIBC1H00A *iIHA1H00 follows if space*	12576.9	30	0	0
240	oD4106	12591.8	14.95		
241	iIPM1H01	12591.8	0	0	0
242	oD4019	12611.8	20		
243	qMQA1H01	12641.8	30	0	-2.54
244	oD4031	12661.1	19.3		
245	kMAT1H01H *MBC?*	12661.1	1e-06	0	0
246	oD4032	12680.7	19.6		
247	kMAT1H01V *MBC?*	12680.7	1e-06	0	0
248	oD4046	12706.8	26.1		
249	iMoelTarg	12706.8	0	0	0
250	oD4047	12784.3	77.475		
251	qMQM1H02	12829.3	45.05	0	-1.06931
252	oD4048	12897.2	67.865		
253	qMQO1H03	12933.4	36.22	0	-0.15003
254	oD4049	12962.9	29.48		
255	qMQO1H03A	12999.1	36.22	0	1.11803
256	oD4050	13048.7	49.59		
257	bMMA1H01	13210.5	161.8	0	0
258	oD4102a	13260.5	50		
259	kMCB1H03H *4"corrector*	13260.5	1e-06	0	0
260	oD4102b	13290.5	30		
261	kMCB1H03V *4"corrector*	13290.5	1e-06	0	0
262	oD4102c	13310.5	20		
263	iIPM1H03 *3”? new*	13310.5	0	0	0
264	oD4103	13330.5	20		
265	oD4107	13340.5	10		

266	qMQA1H04 *new*	13370.5	30	0	0.65
267	oD4107	13380.5	10		
268	kaxRast *42cm coi*l	13430.5	50	0.064	0
269	kayRast *42cm coi*	13480.5	50	0.064	0
270	kaxRast *42cm coi*	13530.5	50	0.064	0
271	kayRast *42cm coi*	13580.5	50	0.064	0
272	oD4104	13607	26.5		
273	iIPM1H03B *new*	13607	0	0	0
274	oD4031	13626.3	19.3		
275	kMBD1H04H *new*	13626.3	1e-06	0	0
276	oD4032	13645.9	19.6		
277	kMBD1H04V *new*	13645.9	1e-06	0	0
278	oD4105 *H/V corr. and BPM or MOLLER target space*	14095.9	450		
279	iIPM1H04A	14095.9	0	0	0
280	iIHA1H04A	14095.9	0	0	0
281	oD4055a	14356.6	260.7		
282	iMoelTarg *MOLLER target*	14356.6	0	0	0
283	oD4055b	14719.6	363		
284	iIPM1H04B	14719.6	0	0	0
285	iIHA1H04B	14719.6	0	0	0
286	oD4056	14856.6	137		
287	iTARGET	14856.6	0	0	0
288	oD4057	19856.6	5000		

Appendix 2 - quad values combined optics at 11 GeV

MQA1C01.BDL	72647.550	
MQA1C02.BDL	-118404.060	*replace with QR for headroom*
MQA1C03.BDL	74278.020	
MQA1C04.BDL	88899.990	
MQA1C05.BDL	-50219.550	
MQA1C06.BDL	6022.581	
MQA1C07.BDL	-39770.220	
MQA1C08.BDL	55394.790	
MQA1C09.BDL	0.000	
MQA1C10.BDL	0.000	
MQA1C11.BDL	-44964.270	
MQA1C12.BDL	90180.180	*20A power supply*
MQA1C13.BDL	-39324.720	
MQA1C14.BDL	0.000	
MQA1C15.BDL	0.000	
MQA1C16.BDL	25196.826	
MQA1C17.BDL	7503.828	
MQA1C18.BDL	40284.390	
MQA1C18A.BDL	-59734.320	*18A/B pair may be one QR*
MQA1C18B.BDL	-59734.320	
MQA1C19.BDL	75761.850	*20A power supply*
MQA1C20.BDL	0.000	
MQA1H00.BDL	96150.000	*QR required for 50% tuning headroom*
MQA1H01.BDL	-76200.000	*20A power supply for tuning headroom*
MQM1H02.BDL	-48172.415	
MQO1H03.BDL	-5434.087	
MQO1H03A.BDL	40495.047	
MQA1H04.BDL	19500.000	

1C02 and 1C12 provide horizontal dispersion correction
1C18A/B pair and 1C19 provide tuning for Compton match
1H00 and 1H01 provide tuning for target match, 1H04 is a final trim for combined optics



Old and new beamlines from end of Compton to pivot. Only 4.5m is available where the ep system is shown in the new beamline.