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Collider Accelerator Department

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INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) is a versatile accelerator that supports operation with polarized protons of up to 250 GeV and ions with up to 100 GeV/nucleon [1]. During any running period, various operating scenarios with different particle species, beam energies or accelerator optics are commissioned. In this report we summarize the beam commissioning periods for establishing full energy beams ("ramp development periods") from the FY09 run and, for the purpose of motivating further developments, analyze the reasons for all failed ramps.

OVERVIEW

Figure 1 shows a summary of beam activities in FY09 [2]. Polarized proton operation commenced early in February at maximum beam energy of 250 GeV. Mid-April marked the start of the 100 GeV run. Beam setup time is shown in green, beam off time in blue, and the ramp development periods are indicated by red dots with the text referring to the name of the accelerator optic being commissioned.

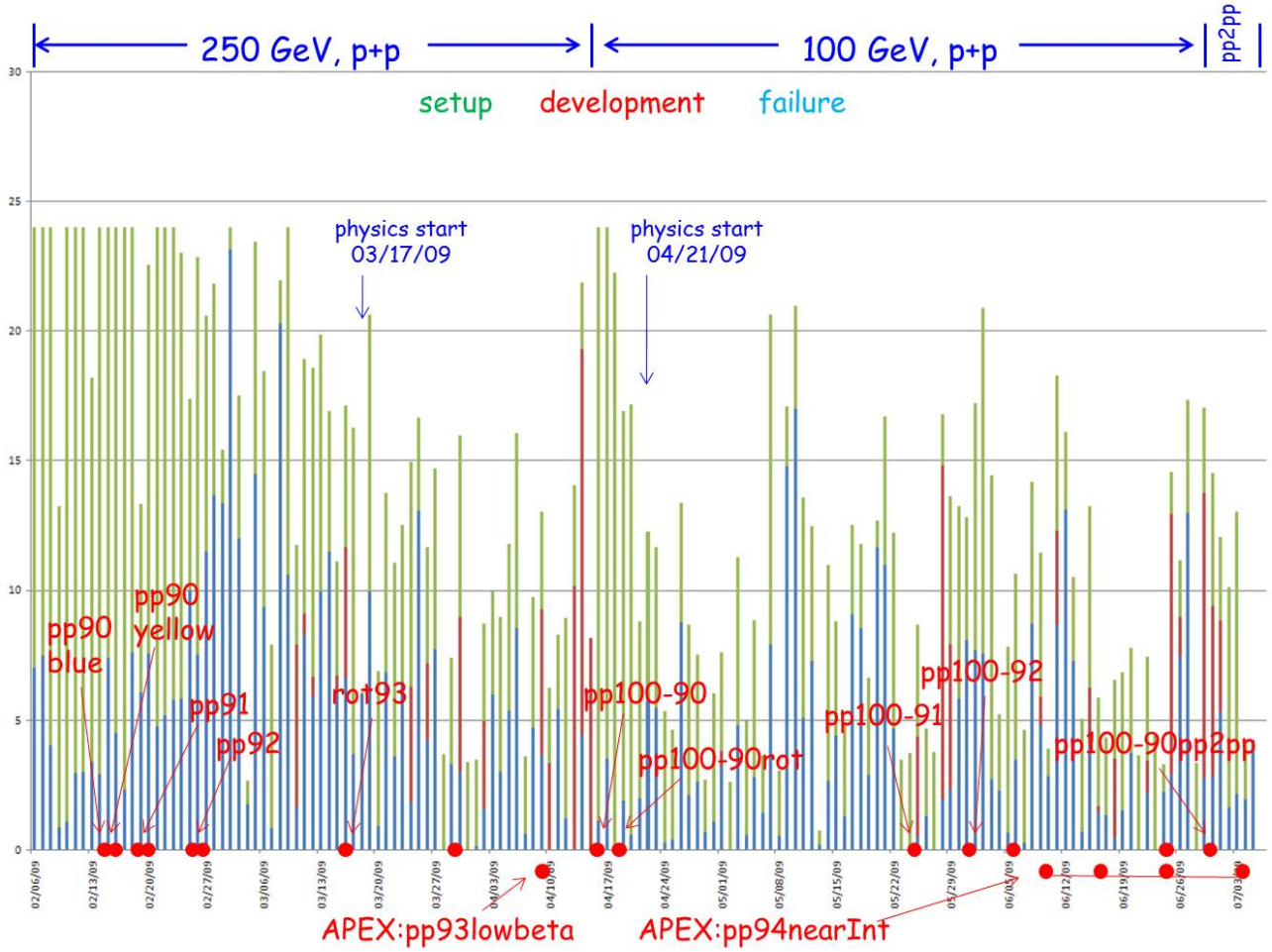

Figure 1: Overview of ramp development during the RHIC FY09 run.

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The beam development periods are summarized in Table 1. A "session" refers to a period of time dedicated to accelerating beams to full energies ("ramp development"). During the FY09 run, each and every ramp was performed using tune and coupling feedback [3,4]. Since this was the first time this important feedback-based control of beams was routinely used operationally, ramp development experience was carefully documented and analysed as described in the remainder of this report.

Table 1: Overview of ramp development periods during the RHIC FY09 run.

Species	Energy (GeV)	Date	Number Sessions	Comment
p+p	250	02/06/09 - 04/14/09	10	[5]
p+p	100	04/15/09 - 06/29/09	6	[6]
p+p	250	06/10/09, 06/16-17/09, 06/24/09, 07/04/09	4	near-integer tune
p+p	100	06/29/09 - 07/04/09	1	[6]

RAMP DEVELOPMENT SUMMARIES

The FY09 run comprised 4 different accelerator operating modes with 12 different accelerator optics. In the following tables are summarized the sessions and purpose for each operating mode. Detailed evaluations of each session are presented in the appendices. After each table are presented histograms showing (1) the total number of acceleration cycles ("ramps") and number of failed ramps per session and (2) the cause of failure using the data from the referenced appendices.

Table 2: Ramp development summary for 250 GeV polarized proton operation (02/06/09-04/14/09). The corresponding session-by-session breakdown for each ramp attempt is given in Appendix A.

Session	Date	Purpose
1	02/14/09 – 02/15/09	commission Blue Ring, optic = pp90
2	02/15/09 – 02/16/09	commission Yellow Ring, optic = pp90
3	02/17/09 – 02/18/09	commission new optic pp91 (remove exceeding trim current limit)
4	02/20/09	support new DSP code for rf systems
5	02/24/09	implement phase-out of drift compensation and phase-in of replay mode
6	02/24/09	polarization optimization (change in betatron tunes during acceleration)
7	02/26/09	commission new optic pp92 (addition of colliding beam stone)
8	03/16/09	commission additional optic rot93
9	03/30/09	polarization optimization (change in betatron tunes during acceleration)
10	04/08/09	commission new optic pp93lowbeta (dedicated accelerator studies, APEX)

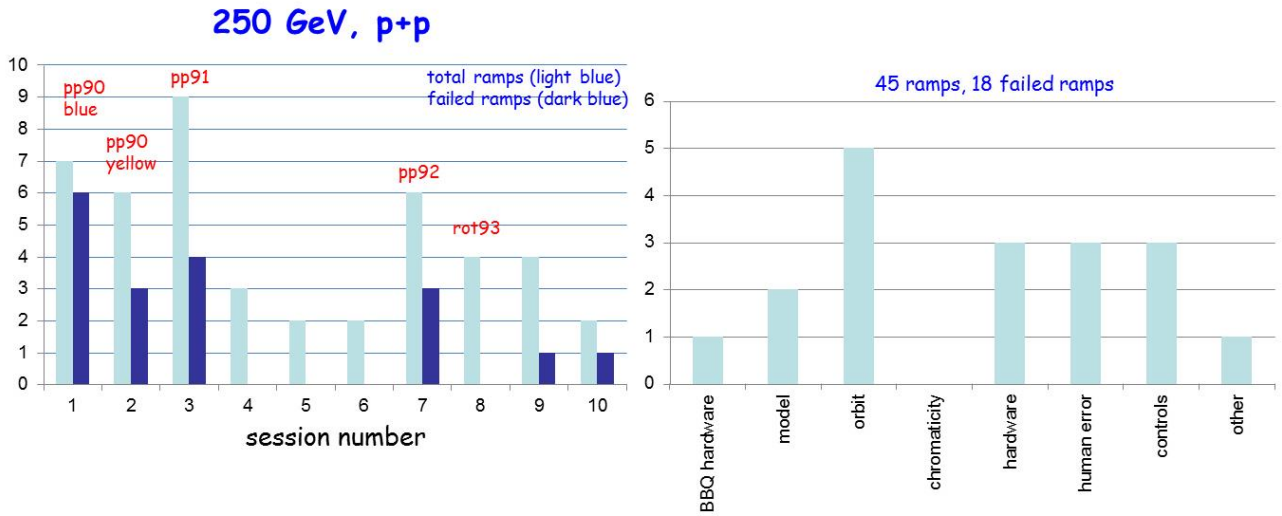

Figure 2: Ramp development statistics for the 250 GeV FY09 polarized proton run (left) and cause of ramp failure (right).

Table 3: Ramp development summary for 100 GeV polarized proton operation (04/15/09-06/29/09). The corresponding session-by-session breakdown for each ramp attempt is given in Appendix B.

Session	Date	Purpose
1	04/16/09	commission optic pp100-90 (beta-star = 0.7 m)
2	04/19/09	commission optic pp100-90rot
3	05/29/09	commission optic pp100-91 (beta-star = 0.8 m)
4	06/01/09 - 06/02/09	commission optic pp100-92 (beta-star = 1.0 m)
5	06/05/09	machine development with pp100-90
6	06/24/09	machine development with pp100-90

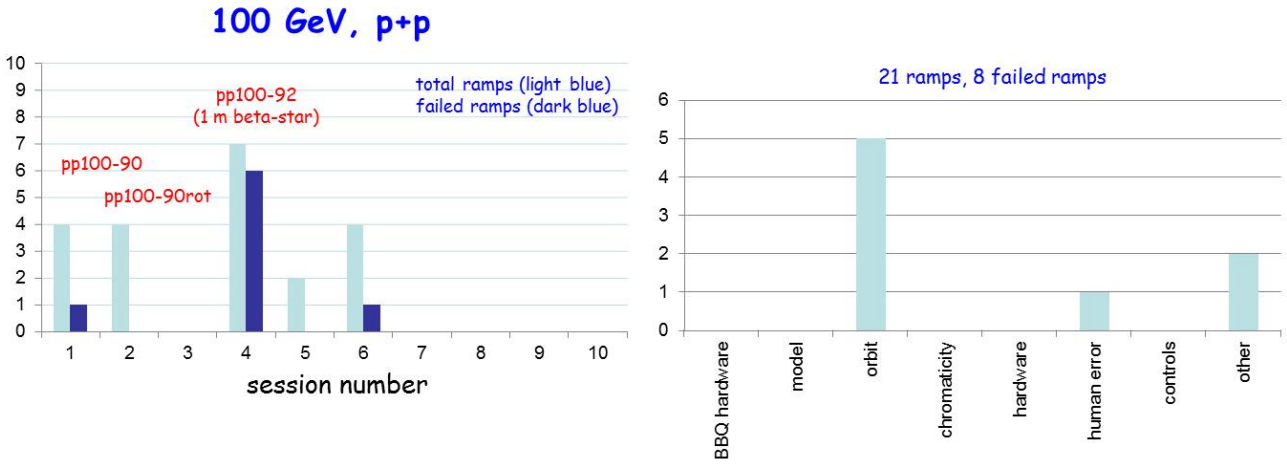

Figure 3: Ramp development statistics for the 100 GeV FY09 polarized proton run (left) and cause of ramp failure (right).

Table 4: Ramp development summary for 250 GeV polarized proton operation, near integer betatron tunesThe corresponding session-by-session breakdown for each ramp attempt is given in Appendix C.

Session	Date	Purpose
1	06/10/09	commission optic pp94nearInt
2	06/16/09 - 06/17/09	betatron tune optimizations for polarization, both Blue and Yellow Rings
3	06/24/09	polarization measurements during acceleration
4	07/04/09	betatron tune optimization for polarization, Blue Ring

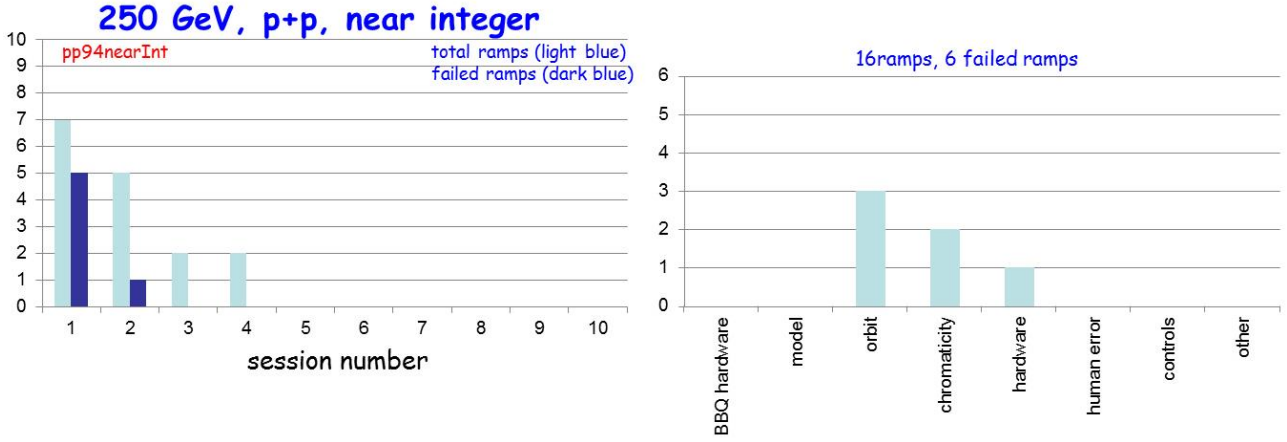

Figure 3: Ramp development statistics for the 250 GeV FY09 near-integer polarized proton optic development (left) and cause of ramp failure (right).

Table 4: Ramp development summary for 100 GeV polarized proton operation for pp2pp experiment (06/29/09-07/04/09). The corresponding session-by-session breakdown for each ramp attempt is given in Appendix D.

Session	Date	Purpose
1	06/29/09	commission optic pp100-90pp2pp

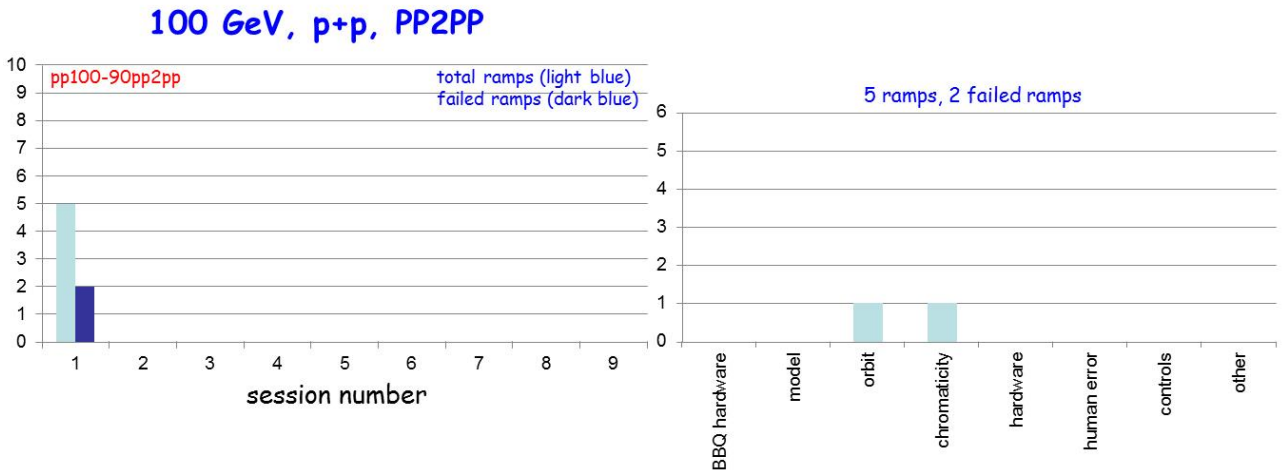

Figure 4: Ramp development statistics for the100 GeV FY09 polarized proton run for the pp2pp experiment (left) and cause of ramp failure (right).

SUMMARY

The overall summary of failed ramps from the FY09 RHIC Run is shown in the histogram in Fig. 5. A total of 87 ramps were executed, all supported by tune and coupling feedback, of which 34 ramps failed. Noteworthy are the following: (1) the sources of failure were identified in all but one case, (2) the leading cause for failed ramps was loss of control of the beam orbits, and (3), contrary to experiences from previous runs where ramps failed due for numerous reasons including imprecise or incorrect measurement of the betatron tunes [7], the tune/coupling feedback systems did not cause any failed ramps. During the shutdown following the FY09 run, an intensive effort was launched to realize both global orbit feedback [8] and a dedicated feedback for compensation of orbit variations at ~ 10 Hz frequencies [9].

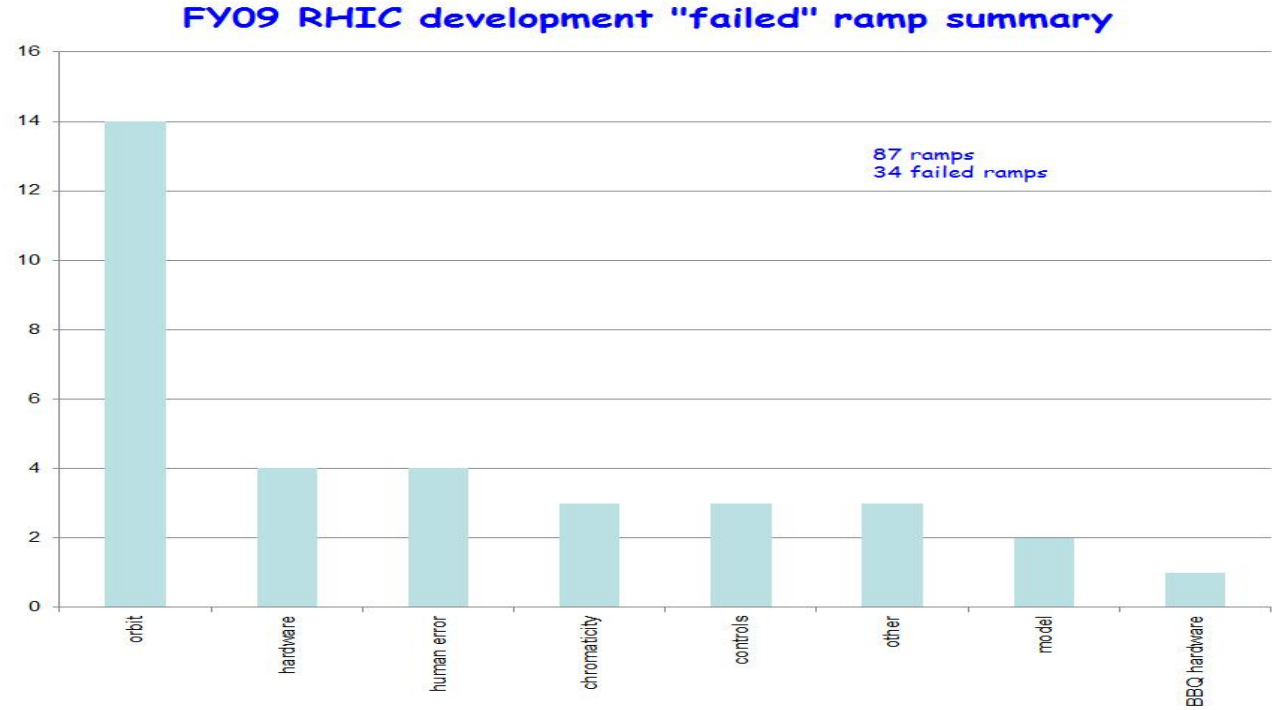

Figure 5: Summary of the causes of unsuccessful ramps during the FY09 RHIC run.

ACKNOWLEDGEMENTS

Ramp development at RHIC in FY09 involved many colleagues (see authorship in Refs. [5] and [6]). For the tune and coupling feedback operated routinely during all development runs for the first time in FY09, recognition is due to the developers of this (see Ref. [3]) and for this run to L. Hoff, A. Curcio, C. Dawson, K. Mernick, A. Marusic, P. Oddo, T. Russo, and M. Wilinski all of whom contributed to its robust performance. A special thank you to the FY09 RHIC run coordinators M. Bai and C. Montag and to management, T. Roser and W. Fischer, for their confidences and encouragement.

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APPENDIX A: 250 GEV POLARIZED PROTONS (02/06/09 – 04/14/09)

Ramp development details for the 10 ramp development periods are given below.

1) Tune/Coupling Feedback ramp history to 250 GeV, RUN09 in Blue Ring 02/14/09-02/15/09, optic: PP90

FB Ramp	Fill	Date	Time	Energy Attained (GeV)		Cause for Beam Loss
1	10050	02/14/09	23:13	24		gamma T event
2	10051	02/15/09	00:24	< 154		orbit
3	10052	02/15/09	01:45	< 174		model
4	10053	02/15/09	04:02	< 195		orbit
5	10054	02/15/09	04:40	< 195		orbit
	10055	02/15/09	05:02			(no acceleration)
6	10056	02/15/09	05:38	< 241		model
7	10057	02/15/09	06:16	250	BLUE	(success)
1	10057	02/15/09	06:16	< 37	YELLOW	orbit (start in Yellow Ring)

2) Tune/Coupling Feedback ramp history to 250 GeV, RUN09 in Yellow Ring 02/15/09-02/16/09 optic: PP90

FB Ramp	Fill	Date Time	Energy Attained (GeV)	Mode	Cause for Beam Loss / Efficiency
1	10057	02/15/09 06:16	250 BLUE	tune	(success)
			< 37 YELLOW	tune	orbit
2	10058	02/15/09 06:56	171 BLUE	tune	QLI, instrumental
			171 YELLOW	tune	QLI, instrumental
3	10081	02/16/09 01:13	247 BLUE	tune	orbit (blue)
			247 YELLOW	tune	
4	10082	02/16/09 01:51	250 BLUE	tune	72.6%
			250 YELLOW	tune	81.8%
5	10083	02/16/09 02:57	250 BLUE	tune	99.6%
			250 YELLOW	tune	97.9%
6	10084	02/16/09 04:04	250 BLUE	tune	99.9%
			250 YELLOW	tune	94.7%
7	10085	02/16/09 06:12	250 BLUE	replay	69.0%
			250 YELLOW	replay	97.1%

3) Tune/Coupling Feedback ramp history, continued (250 GeV, RUN09): 02/17-18/09; purpose: new ramp, optic: PP91 (remove Q89 trim current overflow)

Ramp	Fill	Date	Time (GeV)	Energy	Mode	Ramp Eff.	
1	10116	02/17/09	18:31	250	tune	99.9% / 99.4%	
2	10117	02/17/09	20:46	250	tune	62.8% / 70.9% loss at 52 s	(dipole)
3	10118	02/17/09	21:47	250	tune	78.5% / 88.8% loss at 52 s then revert to 10116	(dipole)
4	10119	02/17/09	23:49	250	tune	90.2% / 99.4%	
5	10120	02/18/09	00:53	249	tune	0% / 0%, double-feedforward	
6	10121	02/18/09	01:49	249	tune	0% / 0%, incorrect backout	
7	10122	02/18/09	03:16	23	tune	0% / 0%, broken BBQ connector	
8	10123	02/18/09	06:08	212	replay	0% /0% (fill 10119) , slow losses due to ARTUS bunch	
	10124	02/18/09	07:45	NA	NA	(hysteresis ramp)	
9	10125	02/18/09	08:40	250	replay	93.9% / 98.1%	
10	10126	02/18/09	09:17	250	replay	94.2% / 99.0%	

4) Purpose: retune after new rf DSP code release (with correction term for path length)

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.
1	10163	02/20/09	17:57	250	tune	64.8% / 84.9%
2	10164	02/20/09	19:07	250	tune	52.7% / 96.2%
3	10165	02/20/09	20:10	250	replay	78.9% / 94.2%

5) Purpose: retune with modifications for handshake between drift compensation phase out and replay phase in

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.
1	10218	02/24/09	08:35	250	tune	96.2% / 99.8%
2	10219	02/24/09	11:50	250	replay	98.9% / 99.5%
	10220	02/24/09	15:58	250	replay	95.8% / 93.2%

6) Purpose: polarization optimization with change in tunes

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	
1	10221	02/24/09	17:48	250	tune	98.3% / 98.1%, QLI upon dumping	
	10222	02/24/09	18:24	NA	NA	QLI without beam	
	10223	02/24/09	19:45	NA	NA	hysteresis ramp	
2	10224	02/24/09	20:38	250	replay	98.5% / 98.0%	

7) Purpose: new ramp, optic: pp92 (colliding beam stone added)

Ramp	Fill	Date	Time (GeV)	Energy	Mode	Ramp Eff.	
1	10241	02/26/09	13:56	250	tune	0% / 0%	PLI – BLM aborts: "new option…to compare wfgs and currents with requirements from RampManager" added
2	10242	02/26/09	15:15	250	tune	0% / 0%	
	10243	02/26/09	15:28	NA	NA	no ramp	
	10244	02/26/09	16:28	NA	NA	hysteresis	
3	10245	02/26/09	17:23	242	tune	0% / 0%	yellow abort kicker prefire
	10246	02/26/09	17:37	NA	NA	no ramp	
	10247	02/26/09	18:35	NA	NA	hysteresis	
4	10248	02/26/09	19:14	250	tune	99.5% / 97.8%	
5	10249	02/26/09	19:59	250	tune	99.2% / 95.7%	
6	10250	02/26/09	20:46	250	replay	76.1% / 88.9%	

8) Tune/Coupling Feedback ramp history, continued (250 GeV, RUN09):
03/16/09, purpose: rotator ramp development: rot93

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.
1	10376	03/16/09	14:19	250	tune	97.8% / 96.1%
2	10377	03/16/09	16:58	250	tune	97.6% / 92.3%
	10378	03/16/09	19:59	NA	NA	hysteresis ramp
3	10379	03/16/09	20:38	250	tune	99.4% / 97.0%
4	10380	03/16/09	23:59	250	replay	99.6% / 96.8%

9) Tune/Coupling Feedback ramp history, continued (250 GeV, RUN09): 03/30/09, purpose: polarization optimization optic: pp93

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	
1	10458	03/30/09	13:59	250	tune	96.9% / 92.2%	optimizing desired tunes for optimum polarization
2	10459	03/30/09	15:05	250	tune	96.8% / 92.1%	
3	10460	03/30/09	16:19	250	replay	0% / 0%	loss due to handshake error between energy and rotator ramps (270 vs 275 seconds)
4	10461	03/30/09	17:05	250	replay	97.1% / 95.3%	

10) Purpose: new ramp, optic: pp93lowbeta (APEX)

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	
1	10511	04/08/09	14:35	250	tune	88.1% / 96.6%	
	10512	04/08/09	15:29	NA	NA	hysteresis	
2	10513	04/08/09	16:49	194	tune	0% / 0%	quad PS transition

Table A.1: Summary of failed ramps for 250 GeV polarized proton operation.

session #	purpose	total ramps	failed ramps	tune and coupling fb	model	orbit	chrom-aticity	hardware	human error	controls	other	comment
1	pp90, blue	7	6		2	3			1			gamma-t event
2	pp90, yellow	6	3			2		1				instrumental QLI
3	pp91	9	4	1					2		1	connector
												double-feedforward
												ARTUS-induced beam loss
4	rf DSP code	3	0									
5	drift comp phase out	2	0									
6	polarization optimizatior	2	0									
7	pp92	6	3					1		2		yellow abort kicker prefire
												PS not tracking command
8	rot93	4	0									
9	polarization optimizatin	4	1							1		handshake between energy
												and rotator ramp
10	pp93lowbeta	2	1					1				main magnet PS transition
	totals	45	18	1	2	5	0	3	3	3	1	

APPENDIX B: 100 GEV POLARIZED PROTONS (04/15/09 – 06/29/09)

Ramp development details for the 6 ramp development periods are given below.

1) Tune/Coupling Feedback ramp history to 100 GeV, RUN09 04/16/09, pp100-90

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	
1	10566	04/16/09	04:48	~24	tune	0% / 0% (hysteresis)	
2	10567	04/16/09	05:42	100	tune	23.3% / 36.2	
3	10568	04/16/09	06:54	100	tune	23.6% / 19.6%	
4	10569	04/16/09	07:47	100	replay	86.3% / 2.9%	
5	10573	04/16/09	12:57	100	tune	85.7% /12.3%	(by operations)
6	10574	04/16/09	13:54	100	tune	87.7% / 12.0%	
7	10575	04/16/09	15:04	100	tune	89.5% / 76.3%	
8	10576	04/16/09	16:15	100	tune	89.1% / 75.6%	
9	10577	04/16/09	16:59	100	replay	89.4% / 81.7%	

2) Tune/Coupling Feedback ramp history to 100 GeV, RUN09 04/19/09, rotator ramp development, pp100-90rot (70 cm beta-star)

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.
1	10617	04/19/09	10:32	100	tune	94.2% / 74.5%
2	10618	04/19/09	12:16	100	tune	87.9% / 78.9%
3	10619	04/19/09	14:38	100	tune	84.5% / 74.3%
4	10620	04/19/09	16:01	100	replay	87.5% / 80.4%

3) Tune/Coupling Feedback ramp history to 100 GeV, RUN09 05/25/09, rotator ramp development, pp100-91rot (80 cm beta-star)

(tune/coupling feedback not used)

4) Tune/Coupling Feedback ramp history to 100 GeV, RUN09
06/01/09, rotator ramp development, pp100-92 (100 cm beta-star)

Ramp	Fill	Date	Time	E (GeV)	Mode	Ramp Eff.	Cause for loss
1	10832	06/01/09	20:50	26	tune	0% / 0%	unknown
	10833	06/01/09	21:36	NA	NA	hysteresis	
	10834	06/01/09	21:59	NA	NA	hysteresis	
2	10835	06/01/09	22:45	100	replay	0% / 0%	orbit
3	10836	06/01/09	23:41	26	tune	0% / 0%	orbit
4	10837	06/02/09	00:21	26	tune	0% / 0%	orbit, chrom
5	10838	06/02/09	01:01	100	replay	0% / 0%	orbit, chrom
6	10839	06/02/09	01:52	100	replay	0% / 0%	orbit, chrom
7	10840	06/02/09	02:22	100	replay	94.3% / 95.1%	
8	10841	06/02/09	02:57	100	replay	94.0% / 91.9%	
9	10842	06/02/09	03:39	100	tune	99.3% / 88.3%	
10	10843	06/02/09	04:16	100	replay (BR)	0%	orbit, chrom
					tune (YR)	0%	
11	10844	06/02/09	07:05	100	replay	99.8% / 98.3%	
12	10845	06/02/09	07:45	100	replay	99.2% / 97.8%	

5) Tune/Coupling Feedback ramp history to 100 GeV, RUN09
06/05/09, refresher ramp, pp100-90rot (70 cm beta-star)

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.
1	10868	06/05/09	18:36	100	tune	94.6% / 87.2%
2	10869	06/05/09	19:36	100	replay	95.8% / 89.2%

6) Tune/Coupling Feedback ramp history to 100 GeV, RUN09
06/24/09, refresher ramp, pp100-90rot (70 cm beta-star)

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	
1	10982	06/24/09	18:06	100	tune	94.5% / 92.9%	
2	10983	06/24/09	18:52	28	tune	0% / 0%	wiggles ramp (APEX fallout)
3	10984	06/24/09	19:42	100	tune	90.4% / 91.7%	
4	10985	06/24/09	21:39	100	replay	95.2% / 80.8%	(wiggles ramp)
5	10986	06/24/09	22:38	100	replay	96.3% / 88.7%	

Table B.1: Summary of failed ramps for 100 GeV polarized proton operation.

session #	purpose	total ramps	failed ramps	tune and coupling fb	model	orbit	chrom-aticity	hardware	human error	controls	other	comment
1	pp100-90	4	1								1	hysteresis
2	pp100-90rot	4	0									
3	pp100-91rot	0	0									
4	pp100-92	7	6			5					1	unknown
5	MD w/ pp100-90	2	0									
6	MD w/ pp100-90	4	1						1			post APEX chromaticity controls
	totals	21	8	0	0	5	0	0	1	0	2	

APPENDIX C: 250 GEV POLARIZED PROTONS WITH NEAR INTEGER BETATRON TUNES

Ramp development details for the 4 ramp developments periods are given below.

APEX 1: Tune/Coupling Feedback ramp history to 250 GeV, near integer tune, 06/10/09, optic: pp94nearInt, ramp development

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	Cause for Beam Loss
1	10892	06/10/09	17:48	25	tune	0% / 0%	orbit
2	10893	06/10/09	18:51	27	tune	0% / 0%	orbit
3	10894	06/10/09	19:41	250	tune	67.4% / 19.4%	(with 8mm orbits)
4	10895	06/10/09	21:08	249	tune	0% / 0%	chromaticity
5	10896	06/10/09	22:25	250	tune	0% / 0%	ps (bi8-bv2)
6	10897	06/10/09	23:14	250	tune	88.5% / 54.0%	chromaticity
7	10898	06/10/09	23:48	223	tune	0% / 0%	chromaticity

APEX 2: Tune/Coupling Feedback ramp history to 250 GeV, near integer tune, 06/16/09-06/17/09, optic: pp94nearInt

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	Cause for Beam Loss
1	10940	06/16/09	23:57	250	tune	87.2% / 34.5%	
2	10941	06/17/09	01:00	250	tune	94.7% / 75.7%	
3	10942	06/17/09	02:12	26	tune/replay	0% / 0%	orbit at snapback
4	10943	06/17/09	03:13	250	tune/replay	92.7% / 78.6%	
5	10944	06/17/09	04:19	250	replay	95.6% / 88.5%	
	10945	06/17/09	05:17	250	replay	96.2% / 86.5%	
	10946	06/17/09	06:34	250	replay	96.8% / 86.8%	
	10947	06/17/09	07:09	250	replay	95.1% / NA	

APEX 3: Tune/Coupling Feedback ramp history to 250 GeV, near integer tune 06/24/09, optic: pp94nearInt

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	Cause for Beam Loss
	10975	06/24/09	10:21	250	replay	71.4% / 0%	
	10976	06/24/09	11:20	250	replay	80.9% / 84.3%	
	10977	06/24/09	12:14	250	replay	95.4% / 0.0%	(wiggles ramp)
Blue ring only:							
1	10978	06/24/09	12:59	250	replay	98.4%	(wiggles again)
2	10979	06/24/09	13:57	250	replay	99.3%	
3	10980	06/24/09	15:31	250	tune	65.1%	
4	10981	06/24/09	16:09	250	replay	98.2%	

APEX 4: Tune/Coupling Feedback ramp history to 250 GeV, near integer tune 07/04/09, optic: pp94nearInt

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.
1	11035	07/04/09	15:36	250	tune	93.0%
2	11036	07/04/09	17:46	250	replay	98.5%

Table C.1: Summary of failed ramps for 250 GeV polarized proton operation.

session #	purpose	total ramps	failed ramps	tune and coupling fb	model	orbit	chrom-aticity	hardware	human error	controls	other	comment
1	pp94nearInt	7	5			2	2	1				power supply
2	pp94nearInt	5	1			1						
3	pp94nearInt	2	0									
4	pp94nearInt	2	0									
	totals	16	6	0	0	3	2	1	0	0	0	

APPENDIX D: 100 GEV POLARIZED PROTONS (06/29/09 – 07/04/09)

Ramp development details for the single ramp development period are given below.

Tune/Coupling Feedback ramp history 100 GeV, 20m beta* for PP2PP
06/29/09, optic: pp100-90pp2pp

Ramp	Fill	Date	Time	Energy (GeV)	Mode	Ramp Eff.	Cause for Beam Loss
1	11008	06/29/09	12:20	100	tune	0% / 0%	orbit
2	11009	06/29/09	13:05	100	tune	98.6% / 0%	chromaticity
3	11010	06/29/09	13:54	100	tune	99.9% / 91.8%	
4	11011	06/29/09	15:02	100	tune	99.5% / 97.0%	
5	11012	06/29/09	16:13	100	replay	99.9% / 98.8%	(wiggles ramp)
6	11013	06/29/09	18:23	100	replay	99.9% / 98.7%	

Table D.1: Summary of failed ramps for 250 GeV polarized proton operation.

session #	purpose	total ramps	failed ramps	tune and coupling fb	model	orbit	chrom-aticity	hardware	human error	controls	other	comment
1	pp100-90pp2pp	5	2			1	1					
	totals	5	2	0	0	1	1	0	0	0	0	