

RHIC proton beam lifetime increase with 10- and 12-pole correctors

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Introduction

Proton beam lifetime dominated by

- **Nonlinear IR magnet errors**
- **Beam-beam interaction**
- **Parameter modulation**

Table 1: Parameters for RHIC polarized proton operation at 100 GeV in 2009.

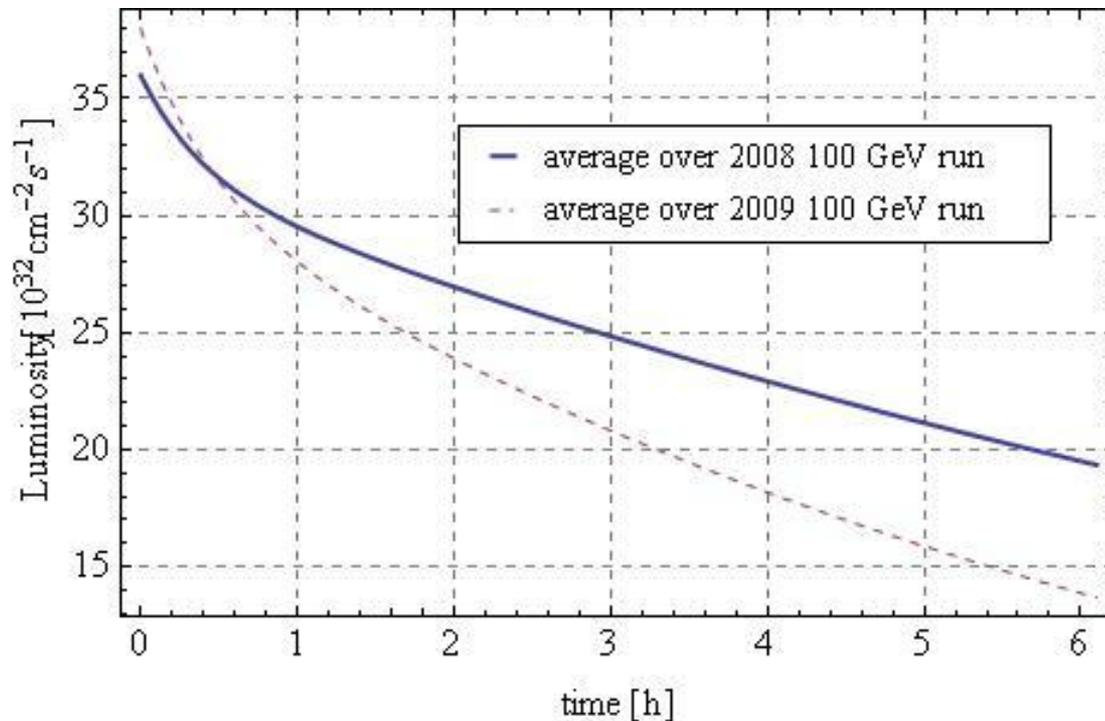
quantity	unit	value
total energy E_p	GeV	100
$\beta_{x,y}^*$ at IP6, IP8	m	0.7
lattice tunes (Q_x, Q_y)	...	(.695,.685)
no of bunches	...	109
bunch intensity N_p , initial	10^{11}	1.35
rms emittance ϵ_n , initial	mm mrad	2.5
rms bunch length σ_s , initial	m	0.85
rms momentum spread*, $\delta p/p$	10^{-3}	0.4
hourglass factor F , initial	...	0.70
beam-beam parameter ξ/IP	...	0.007
number of beam-beam IPs	...	2

Introduction

$$\mathcal{L}(t) = \mathcal{L}(0) \left[A e^{-t/\tau_1} + (1 - A) e^{-t/\tau_2} \right]$$

2008 ($\beta^* = 1.0$ m, $\varepsilon_n = 20$ mm mrad)
 $(A, \tau_1, \tau_2) = (12.1\%, 0.39$ h, 12.4 h)

2009 ($\beta^* = 0.7$ m, $\varepsilon_n = 18$ mm mrad):
 $(A, \tau_1, \tau_2) = (17.9\%, 0.46$ h, 7.4 h)



[Fits over first 3 h.]

Peak luminosity increase from 35 up to $50 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$
did not result in higher integrated luminosity.

Interaction region 10- and 12-pole errors

Table 2: Selected multipole errors in the RHIC IR magnets, quoted in units of 10^{-4} of the dipole field at the reference radius R and for 100 GeV proton energy [6]. Shown are 10- and 12-poles (b_5 and b_6) as well as the next significant errors.

magnet	multipole	mean	rms
DX ($R = 60$ mm) (6 magnets)	b_3	-1.12	1.89
	b_5	-3.06	0.46
	b_7	-1.84	0.10
	b_9	-1.09	0.07
	b_{11}	-1.13	0.02
D0 ($R = 31$ mm) (24 magnets)	b_3	0.15	1.38
	b_5	0.46	0.30
	b_7	0.22	0.07
Q1 ($R = 40$ mm) (26 magnets)	b_4	-0.01	0.74
	b_6	1.19	0.73
Q2 ($R = 40$ mm) (27 magnets)	b_4	-0.61	0.36
	b_6	-0.65	0.63
Q3 ($R = 40$ mm) (13 magnets)	b_4	-1.55	1.04
	b_6	0.08	0.29

10-poles:

2nd allowed harmonic
in dipoles (DX, D0)

12-poles:

1st allowed harmonic
in quadrupoles (Q1, Q2, Q3)

[IR magnets are shimmed,
for 250 GeV energy]

Interaction region 10- and 12-pole errors

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Table 3: 10^6 turn DA with beam-beam interaction for 100 GeV protons and 5 different angles A_y/A_x .

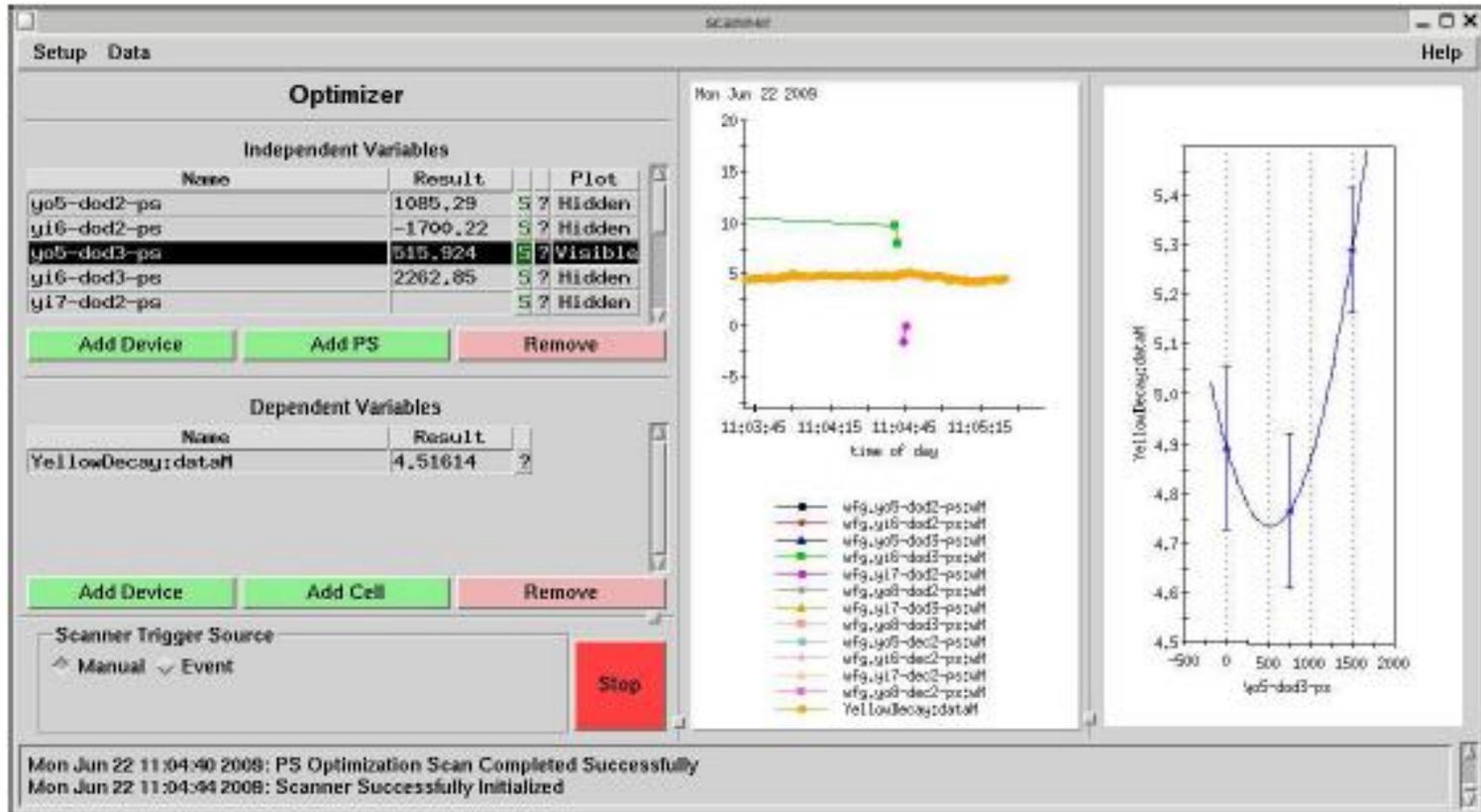
case	15°	30°	45°	60°	60°	Min
all errors	4.4	4.9	4.9	4.9	6.5	4.4
no b3	5.6	5.5	5.5	4.9	6.1	4.9
no b5	4.6	4.9	4.8	4.5	5.6	4.6
no b6	4.4	4.5	4.8	4.9	5.7	4.4

- Switching off single multipole error has only small effect on DA
- DA must be used with caution in beam-beam problems:
evaluates particles at large amplitudes for which BB is small

[Note: 4D beam-beam model used in simulations, overestimates beam-beam effect.]

Correction method

Generic scanner (requested by M. Minty, implemented by S. Nemesure)



- scans magnet strength (for list of magnets)
- observes beam loss rate
- minimizes beam loss rate with strength

did almost all work with Yellow because Blue beam loss rate signal twice as noisy as Yellow

Correction result

Table 4: Summary of 10- and 12-pole corrector scans in the Yellow ring with 100 GeV proton beam in 2009.

date	06/20/09	06/21/09	06/21/09	06/22/09	06/22/09	06/23/09	06/25/09
fill no	10961	10963	10964	10968	10969	10972	10986
start	arbitrary	10961	10963	10964	10968	10969	10972
values		result	result	result	result	result	result
12-pole correctors (step size: 750 m ⁻⁵)							
corrector	[m ⁻⁵]	[m ⁻⁵]	[m ⁻⁵]	[m ⁻⁵]	[m ⁻⁵]	[m ⁻⁵]	[m ⁻⁵]
yo5-dod2	+1479	+678	+226	+985/+1932/+1085*	-214	-86/-523/-347*	+480
yi6-dod2	+3750	+183	-1251	-1700	-3012	-3750/-3750*	-3012
yo5-dod3	-117	+342	+894	+516	no further scan, used +584 →		
yi6-dod3	+1083	+1106	+1855	+2262	+2680	+2784	+2982
yi7-dod2	-513	-416	-545	-495	no further scan, used -485 →		
yo8-dod2	-769	+1564	+1231	+2176	+2545	+1351	+2502
yi7-dod3	-3750	-3336	-2393*	-2269	no further scan, used -2666 →		
yo8-dod3	-769	-659	-443	-424	no further scan, used -509 →		
10-pole correctors (step size: 5 m ⁻⁴)							
corrector	[m ⁻⁴]	[m ⁻⁴]	[m ⁻⁴]				
yo5-dec2	+3.4	+4.3	+5.5/+1.5* +6.1	no further scan, used +4.4 →			
yi6-dec2	+12.2	+16.4	+16.9/+15.2* +15.1	no further scan, used +15.9 →			
yi7-dec2	+25.0	+25.0	+25.0 +25.0	no further scan, used +32.2 [†] →			
yo8-dec2	+3.0	+0.2	+1.0 +0.8	no further scan, used +0.7 →			

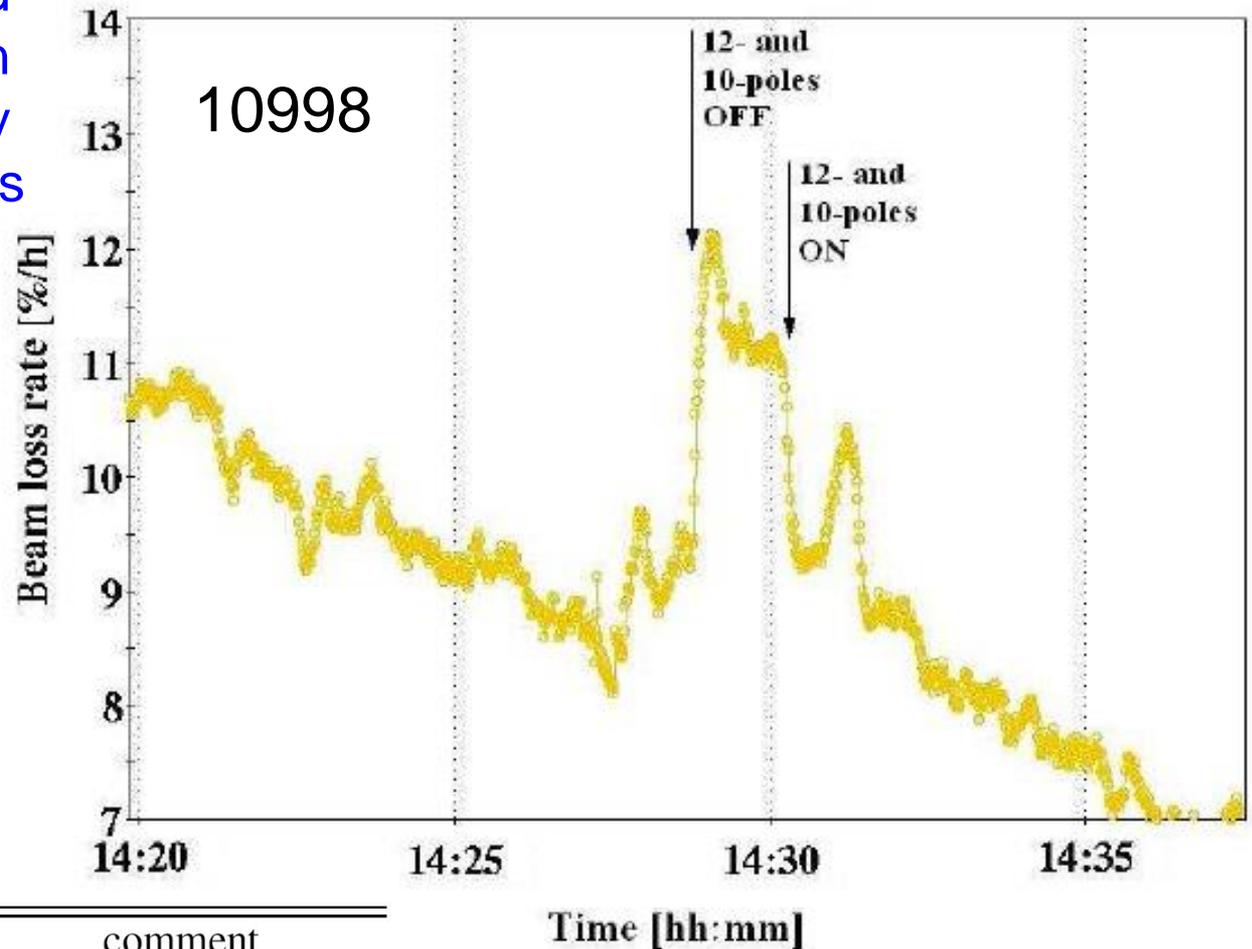
* The automatic scan was interrupted.

† At limit in previous scans. 32.3 m⁻⁴ is the result of 3 separate scans with increased limit in fill 10968.

- scanned correctors always in same order (shown above)
- scan of all 12- and 10-poles takes about 1 h
- removed correctors from scan when stable
- one octupole scan (10986) did not show any improvements

Correction result

Tested effect of 10- and 12-pole correctors on beam loss rate by switching off all correctors

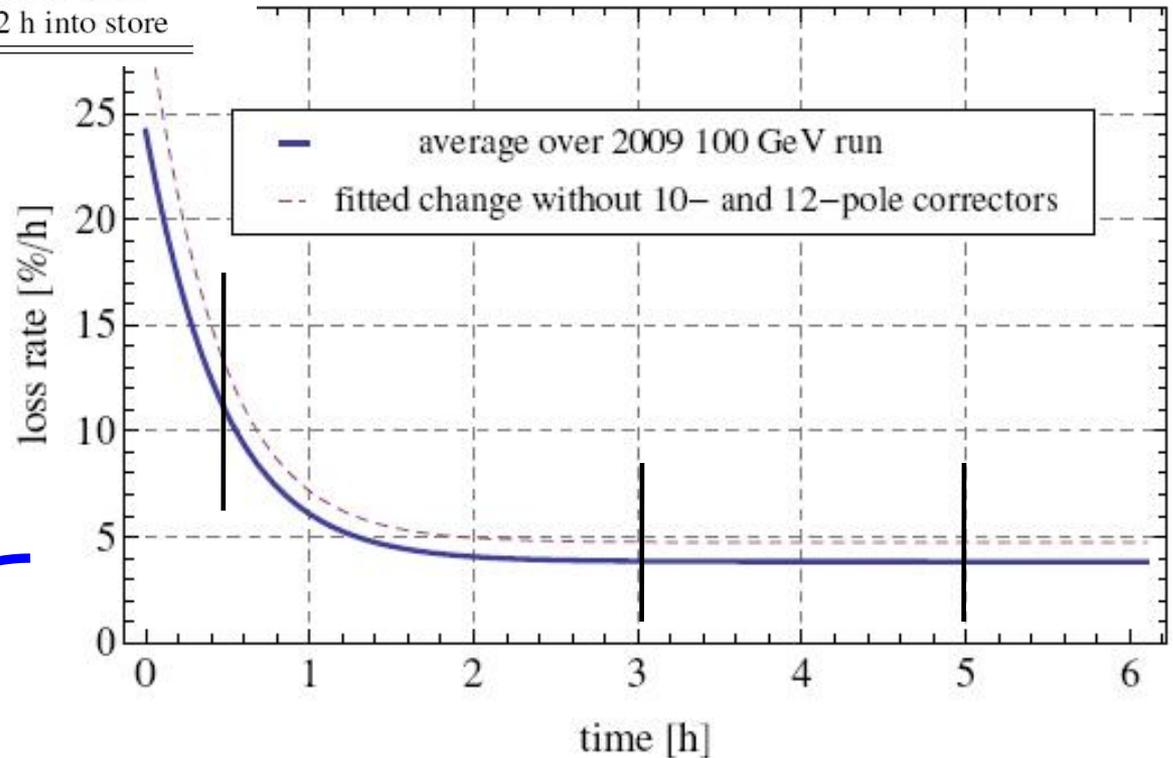


date	fill no	rate change	comment
06/22/09	10968	4 → 5%/h	3 h into store
06/26/09	10995	2.7 → 3.5%/h	5 h into store
06/26/09	10998	9 → 11%/h	1/2 h into store

Estimate of luminosity gain

Table 5: Increase in the Yellow beam loss rate due to turning off of the 10- and 12-pole correctors.

date	fill no	rate change	comment
06/22/09	10968	4 → 5%/h	3 h into store
06/26/09	10995	2.7 → 3.5%/h	5 h into store
06/26/09	10998	9 → 11%/h	1/2 h into store



$$\frac{\Delta L}{L} = \frac{\int_0^{T_{store}} [N_Y(t) - N_{Y\Delta}(t)] dt}{\int_0^{T_{store}} N_{Y\Delta}(t) dt} \approx \underline{4.3\%}$$

Summary

- During Run-9 100 GeV p-p operation, used 10- and 12-pole correctors for the first time operationally
- Correctors were set with automatic scanning procedure parasitic to physics stores; procedure converged after a few scans (7 scans with fewer and fewer correctors)
- Integrated luminosity gain per store with correction in one beam estimated to be about 4%
- No lifetime improvement seen with octupole scan (one attempt)