LR Beam-Beam "Compensation", RHIC

N. Abreu, R. Calaga, W. Fischer, G. Robert-Demolaize

CM16, May 16-18, 2011 (Also presented at CERN-ATS Seminar, April 7)

- DC Wires in RHIC, Motivation
- Long-range experiments
- Single compensation attempt

Ack - CERN: U. Dorda, J.-P. Koutchouk, G. Sterbini, F. Zimmermann
USLARP: A. Kabel, H.J. Kim, J. Qiang, T. Sen
BNL Technical Staff

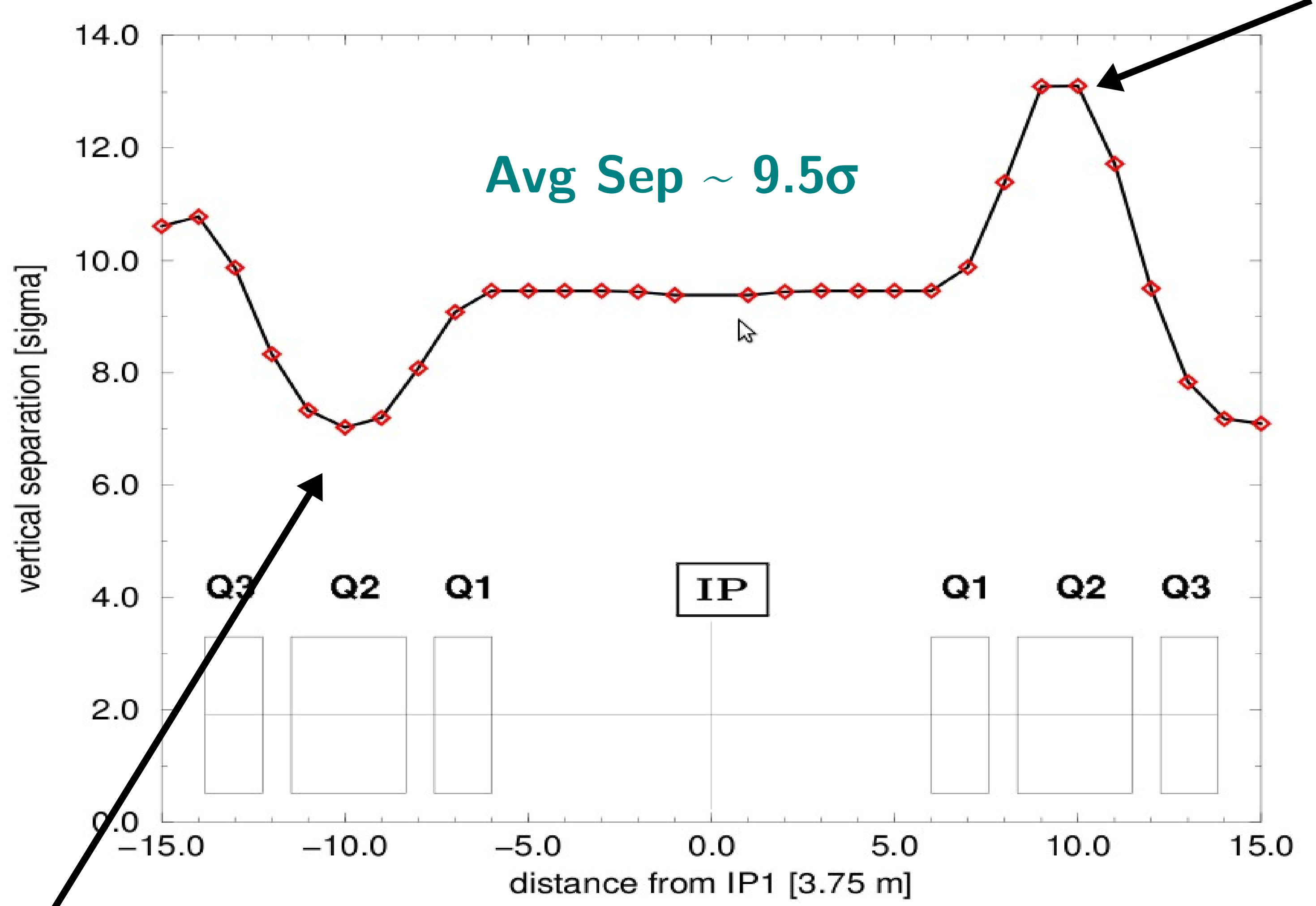
Some Numbers

	# of Bunches	HO (LR) Interactions	Normalized Separation	$\Delta\phi$ of LR [deg]	ξ_{HO}
weak-strong SP($\bar{p}$)S	3-6	2 (9)	6σ	Distributed	0.028
weak-strong Tevatron	36	2 (36)	6σ	Distributed	0.018
strong-strong RHIC	110	2 (4-40)	$>10\sigma$	6° (DX$\rightarrow$Wire)	0.016
strong-strong LHC	2808 (408)	4 (40-120)	$6\text{-}15\sigma$	$\sim 2^\circ$	0.03

- Many localized LR interactions in the LHC
- Crossing angle to avoid parasitic collisions

Transverse Separation, LHC

Max Sep ~ 13.5σ

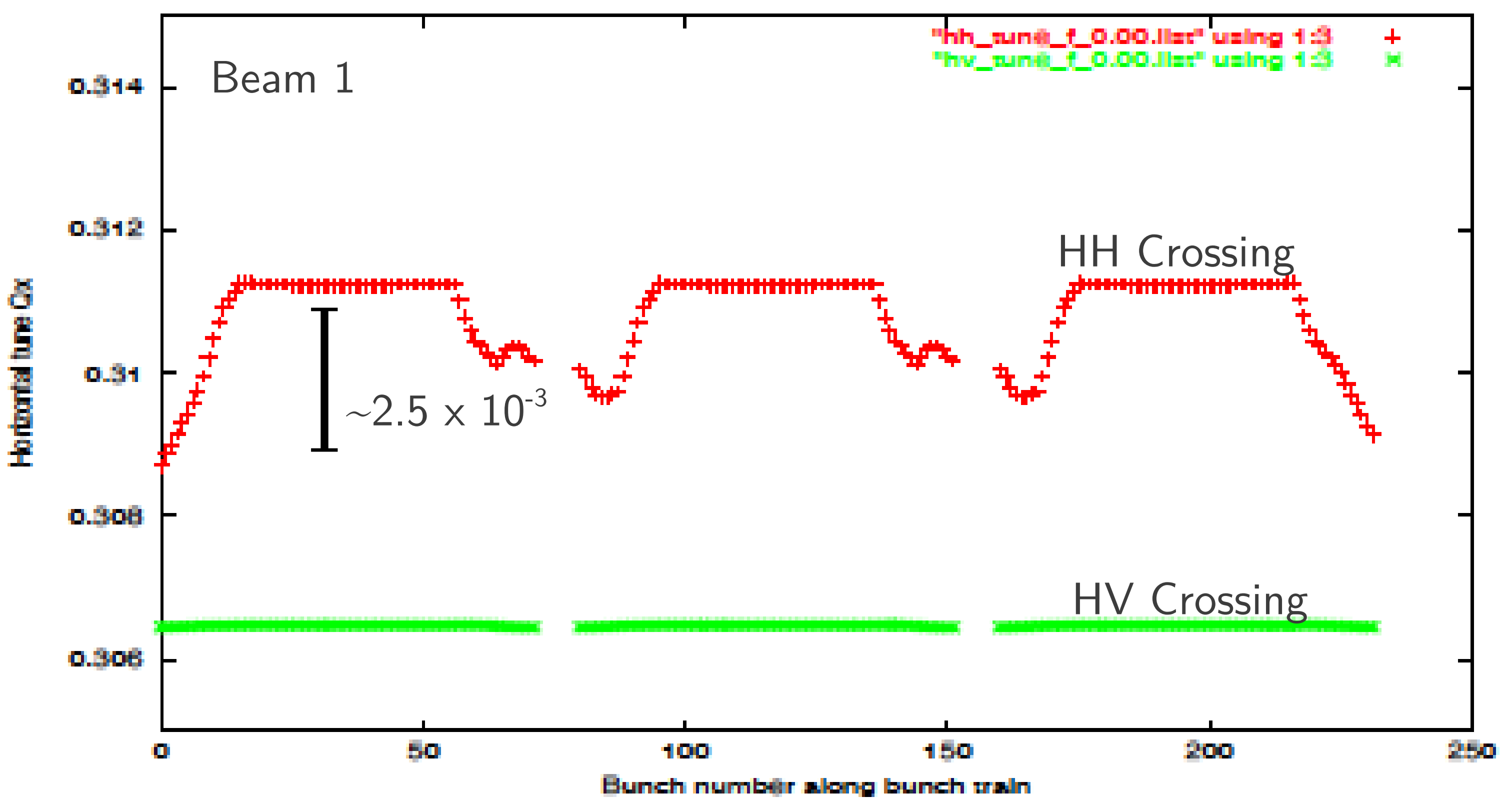


Min Sep ~ 6.5σ

Koutchouk, PAC01

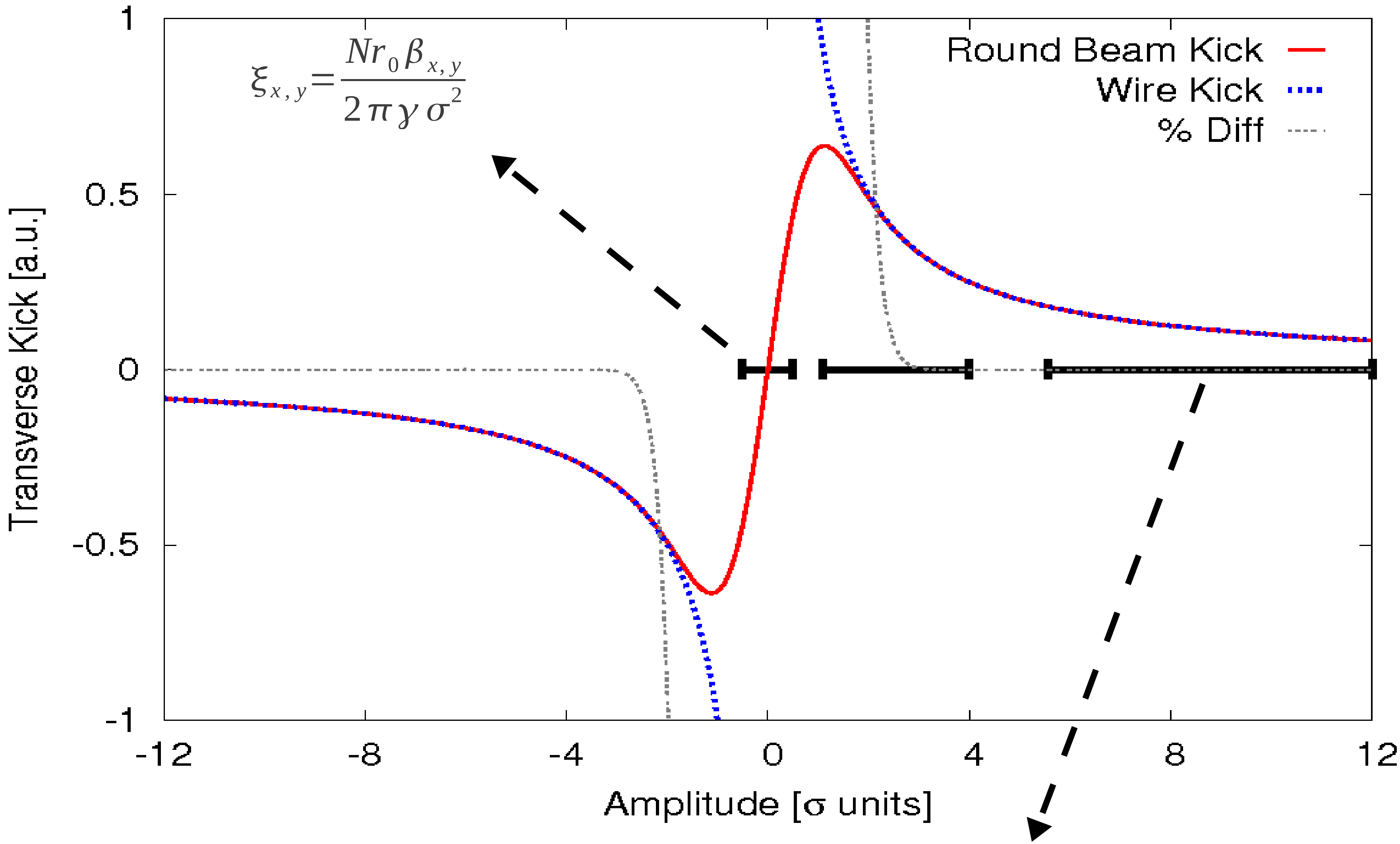
Long-Range Effects

- Additional tune spread and orbits effects (PACMAN)
  - Mitigated by HV-crossing scheme for passive compensation
- Reduced dynamic aperture, lifetime
  - Mitigated by increasing x-angle (but aperture, non-linearities, SB resonances)



W. Herr, LHC Proj Rep 39, 628

Long-Range & Wires



σ << d: $$\Delta x'(x,d)=-\frac{K}{d}.(1+\frac{x}{d}+\frac{x^2}{d^2}+...)$$

Koutchouk, PAC01, Herr, LHC Proj Rep 39

Remember: collimators sit at 6σ

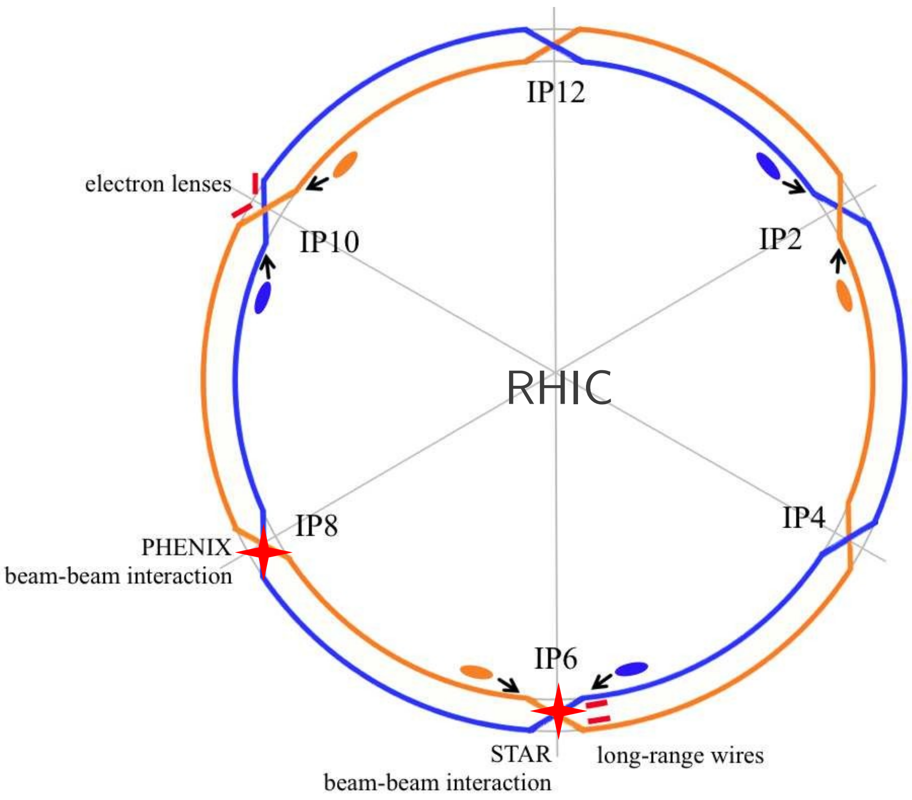
Why RHIC ?

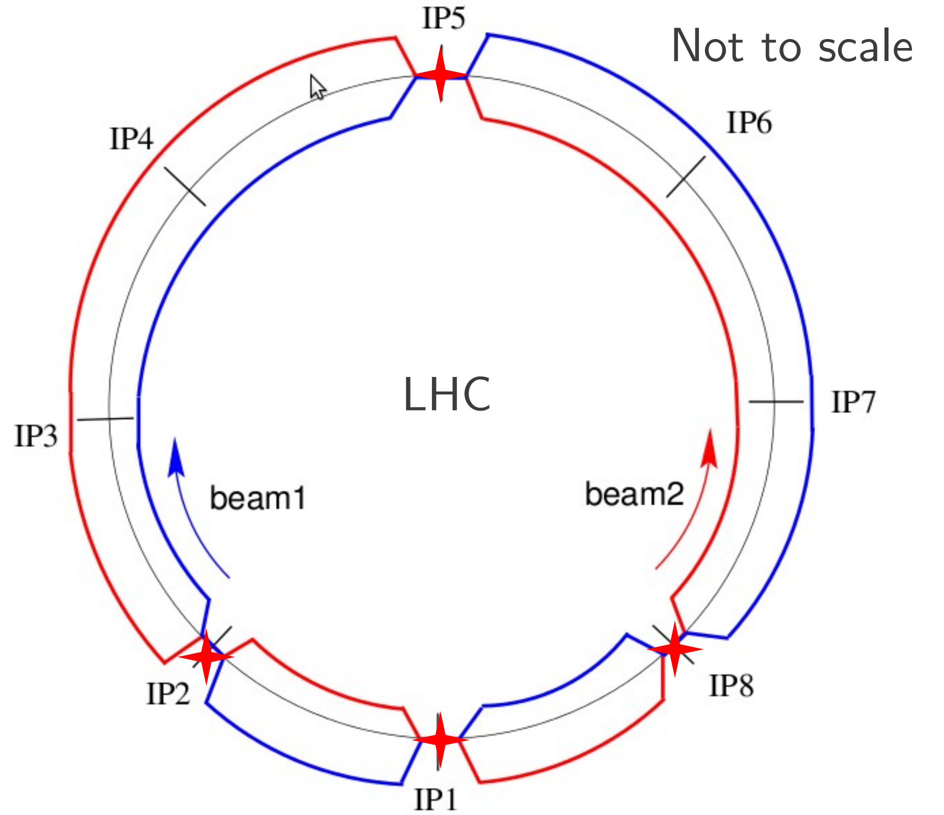
- RHIC beam lifetime typical to a hadron collider
- Test DC wires with head-on beam-beam
- Localized long-range interactions like the LHC
- Strong-strong beam-beam

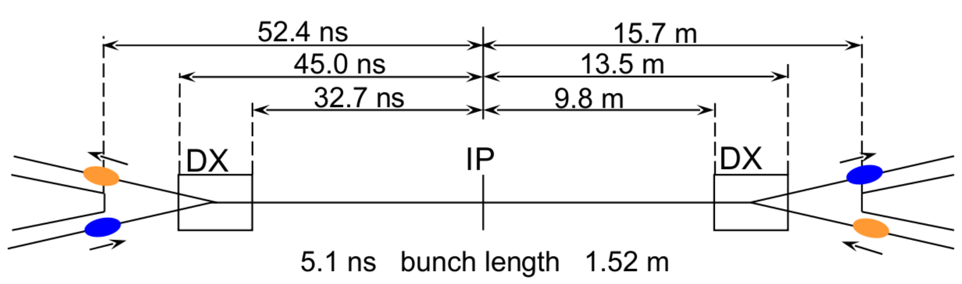
2 wires installed @IP6 in RHIC, 2006 shutdown

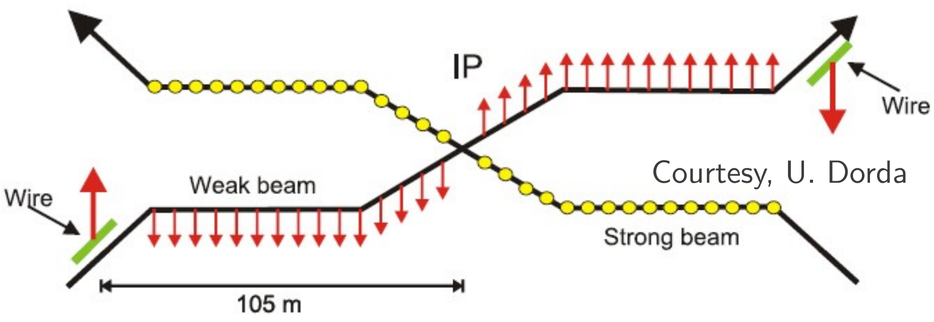
(supported by the US-LARP Program)

RHIC & LHC







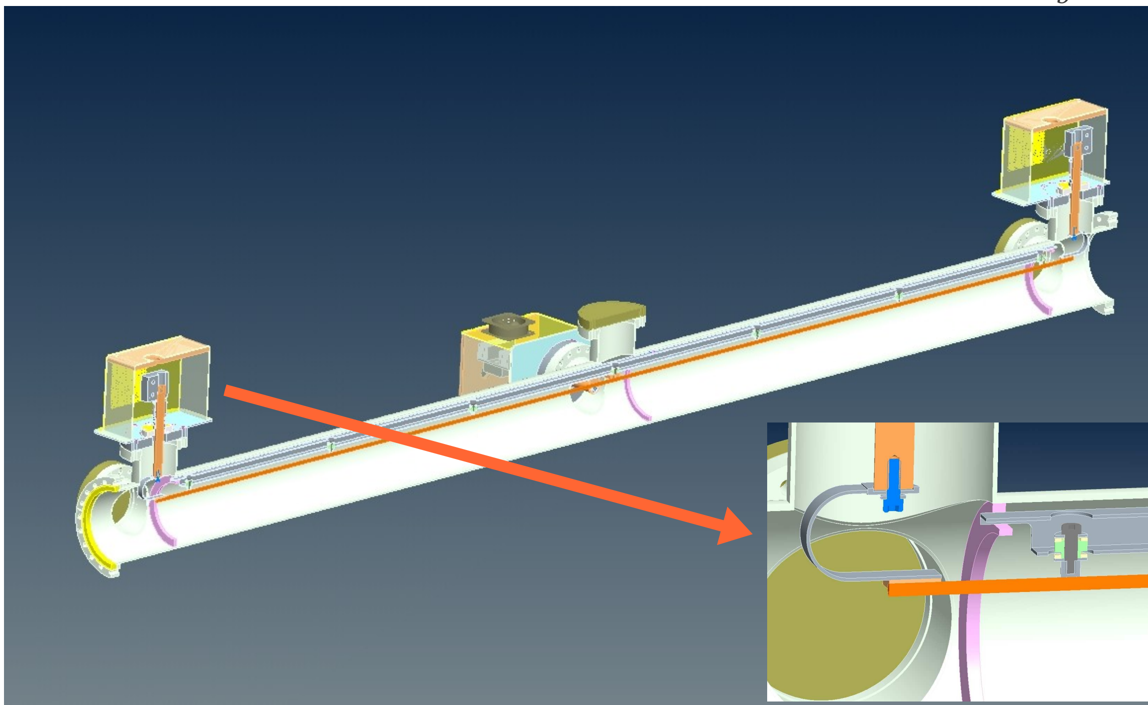


2 Head-on, (max 4) Long-Range

4 Head-on, 40-120 Long-Range

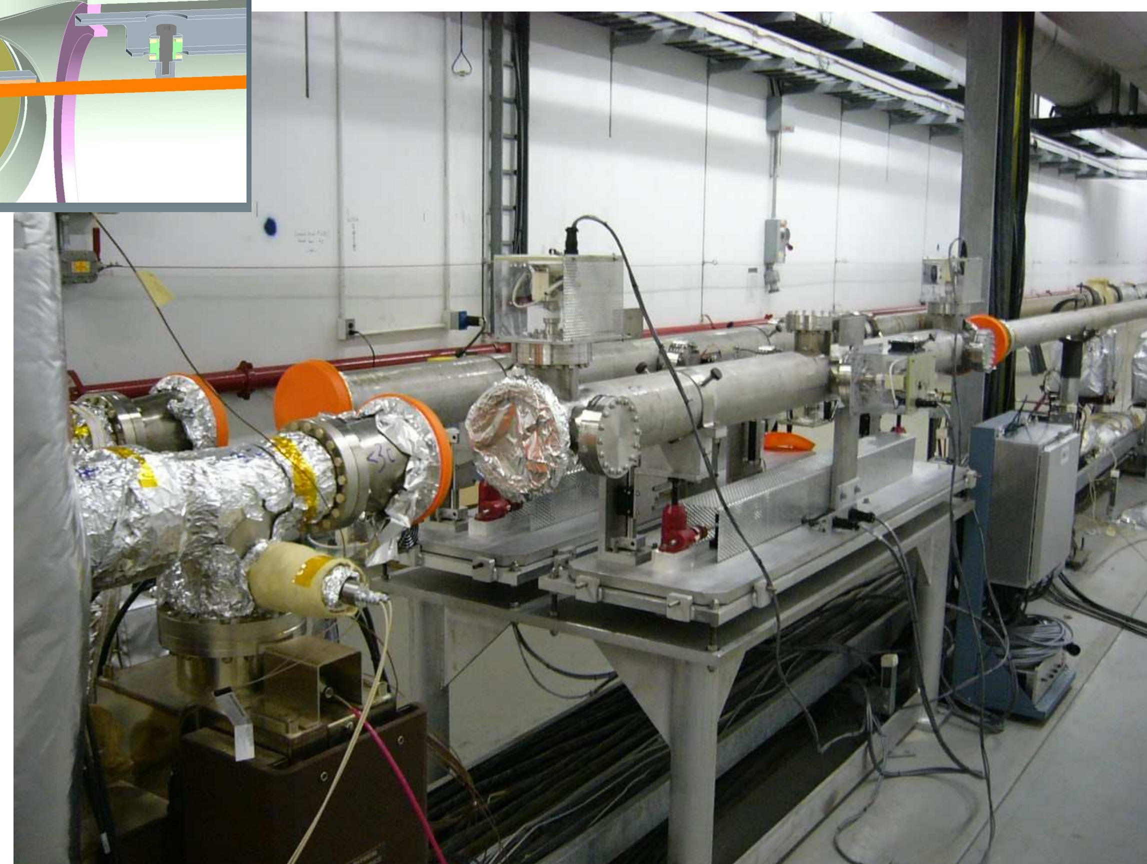
RHIC DC Wires

$$IL = N_b e c$$



- Based on experience from SPS
- Vertically movable wire in each ring
- Air cooled, $\Delta T_{max} = 15K$

quantity	unit	value
strength (IL), nominal	A m	9.6
max. strength $(IL)_{max}$	A m	125
length of wire L	m	2.5
radius of wire r	mm	3.5
number of heat sinks n	.	2
electrical resistivity ρ_e	Ω m	1.72×10^{-8}
heat conductivity λ	W m^{-1}K^{-1}	384
thermal expansion coeff.	K^{-1}	1.68×10^{-5}
radius of existing pipe r_p	mm	60
current I, nominal	A	3.8
max. current I_{max}	A	50
current ripple $\Delta I/I$ (at 50 A)	10^{-4}	< 1.7
electric resistance R	mΩ	1.12
max. voltage U_{max}	mV	55.9
max. power P_{max}	W	2.8
max. temp. change ΔT_{max}	K	15
max. length change ΔL_{max}	mm	0.4
vertical position range	mm/σ_y	65/10.6



Overview of Experiments

Approximately, 30 dedicated experiments performed over 5 years

{Proton, deuterons, Copper, Gold: 26, 100, 250 GeV}

- Effect of single LR interaction (protons)
- DC Wire on single beams (Gold & deuterons)
- DC wires with HO collisions & "compensation" of LR (protons)

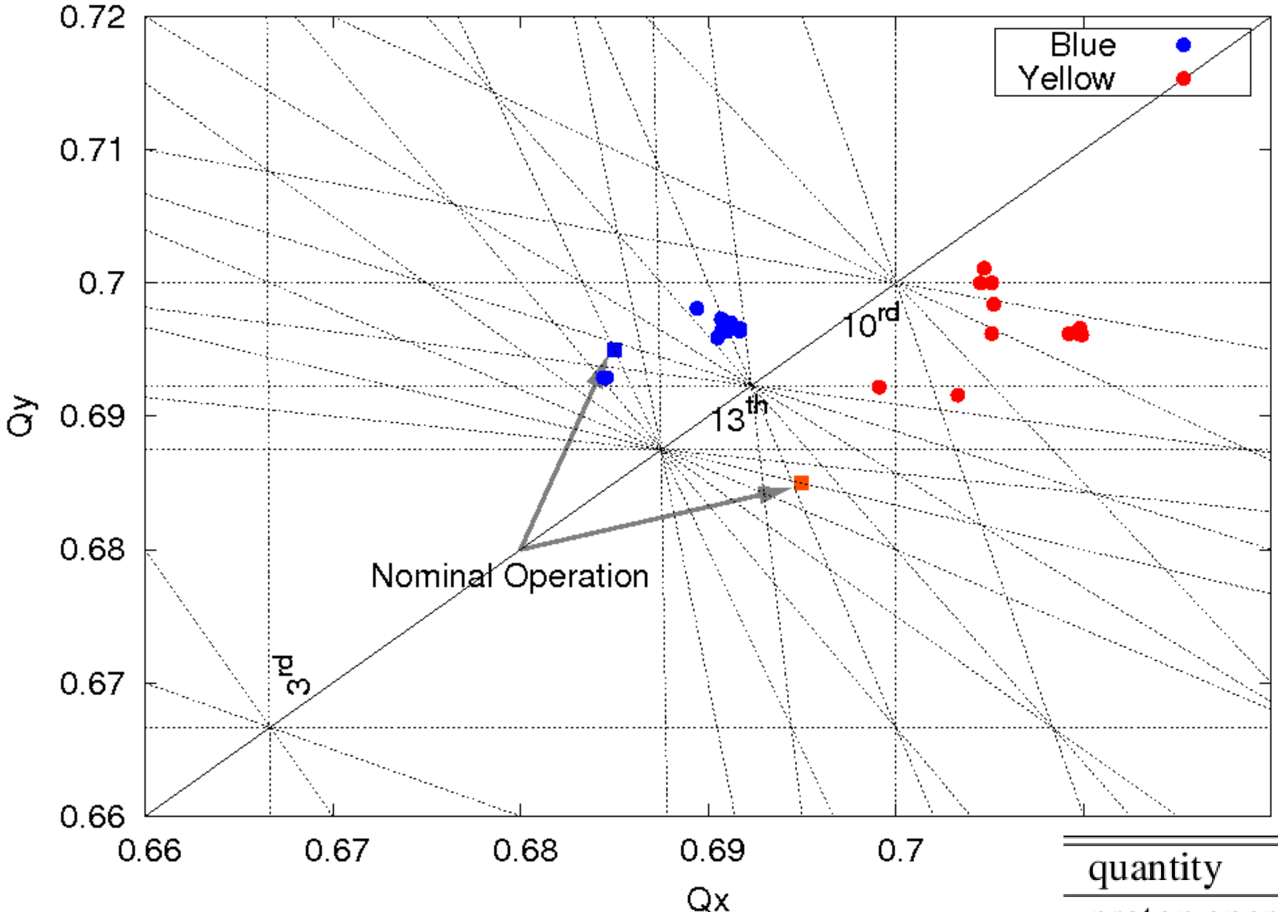
I 2005-06

II 2007-08

III 2009

fill no	ring	scan	species	rel. γ	bunches per ring	Q_x	Q_y	LR location	LR strength (IL)	LR separation d	fitted exponent p	d for $\tau < 20$ h	comment
...	...	...	...	...	...	...	...	...	A m	σ	...	σ	
2005													
6981	B	1	p	25.963	1	0.7331	0.7223	IP4	5.3	B moved			weak signal
6981	Y	1	p	25.963	1	0.7267	0.7234	IP4	5.3	B moved			weak signal
6981	B	2	p	25.963	1	0.7351	0.7223	IP4	5.8	B moved			weak signal
6981	Y	2	p	25.963	1	0.7282	0.7233	IP4	5.8	B moved			weak signal
6981	B	3	p	25.963	1	0.7383	0.7247	IR4 DX	8.6	Y moved			weak signal
6981	Y	3	p	25.963	1	0.7271	0.7218	IR4 DX	8.6	Y moved			weak signal
6981	B	4	p	25.963	1	0.7394	0.7271	IR4 DX	8.9	Y moved	4.9	6.5	
6981	Y	4	p	25.963	1	0.7264	0.7388	IR4 DX	8.9	Y moved	2.8		
2006													
7707	B	1	p	106.597	10			IR6 DX	6.7	B moved			weak signal
7707	Y	1	p	106.597	10			IR6 DX	6.7	B moved			weak signal
7707	B	2	p	106.597	10			IR6 DX	6.7	Y moved			weak signal
7707	Y	2	p	106.597	10			IR6 DX	6.7	Y moved			weak signal
7747	B	1	p	106.597	8			IR6 DX	7.9	B moved			weak signal
7747	Y	1	p	106.597	10			IR6 DX	7.9	B moved			weak signal
7747	B	2	p	106.597	8			IR6 DX	7.0	Y moved			weak signal
7747	Y	2	p	106.597	10			IR6 DX	7.0	Y moved			weak signal
7807	B	1	p	106.597	12	0.6912	0.6966	IR6 DX	8.2	Y moved	2.5	3.5	additional octupoles
7807	Y	1	p	106.597	12	0.7092	0.6966	IR6 DX	8.2	Y moved	1.5	3.5	additional octupoles
2007													
8231	B	1	Au	10.520	6	0.2327	0.2141	B-BBLR	12.5	B-BBLR moved	7.2	6.5	
8231	B	1	Au	10.520	6	0.2322	0.2140	B-BBLR	125	B-BBLR moved	7.8	9.0	
8405	B	1	Au	107.369	56	0.2260	0.2270	B-BBLR	125	B-BBLR moved	1.7	15.0	background test
8609	B	1	Au	107.369	23	0.2340	0.2260	B-BBLR	12.5	B-BBLR moved	7.4	6.0	
8609	B	2	Au	107.369	23	0.2340	0.2260	B-BBLR	125	B-BBLR moved	16.0	5.5	
8609	Y	1	Au	107.369	23	0.2280	0.2350	Y-BBLR	12.5	Y-BBLR moved	4.8	9.5	
8609	Y	2	Au	107.369	23	0.2280	0.2350	Y-BBLR	125	Y-BBLR moved	4.1	7.5	
8727	B	1	Au	107.369	23	0.2200	0.2320	B-BBLR	12.5	B-BBLR moved	5.2	9.5	
8727	B	2	Au	107.369	23	0.2200	0.2320	B-BBLR	125	B-BBLR moved	8.1	10.0	
8727	B	1	Au	107.369	23	0.2320	0.2280	Y-BBLR	12.5	Y-BBLR moved	6.3	4.5	
8727	B	2	Au	107.369	23	0.2320	0.2280	Y-BBLR	125	Y-BBLR moved	10.8	5.0	
8727	B	3	Au	107.369	23	0.2320	0.2280	Y-BBLR	125-0	-6.5			
8727	B	4	Au	107.369	23	0.2320	0.2280	Y-BBLR	125	-6.5			ver. chromaticity 2-8
8727	B	5	Au	107.369	23	0.2320	0.2280	Y-BBLR	125-0	-6.5			ver. chromaticity 8
2008													
9664	B	1	d	107.369	12	0.2288	0.2248	B-BBLR	125	B-BBLR moved	3.8	17.0	end of physics store
9664	B	2	d	107.369	12	0.2288	0.2248	B-BBLR	75-125	5.8			end of physics store
2009													
10793	B	-	p	106.597	36	0.691	0.688	B-BBLR	125	B-BBLR moved			with head-on collisions
10793	Y	-	p	106.597	36	0.695	0.692	Y-BBLR	125	Y-BBLR moved			with head-on collisions
10793	B	-	p	106.597	36	0.691	0.688	IR6 DX	12.5	B-BBLR moved			LR compensation
10793	Y	-	p	106.597	36	0.695	0.692	IR6 DX	12.5	Y-BBLR moved			LR compensation

I: Meta-Stable Working Point



Effect of 1 LR interaction, weak (nominal tunes)

Move tunes closer to 10^{th} order

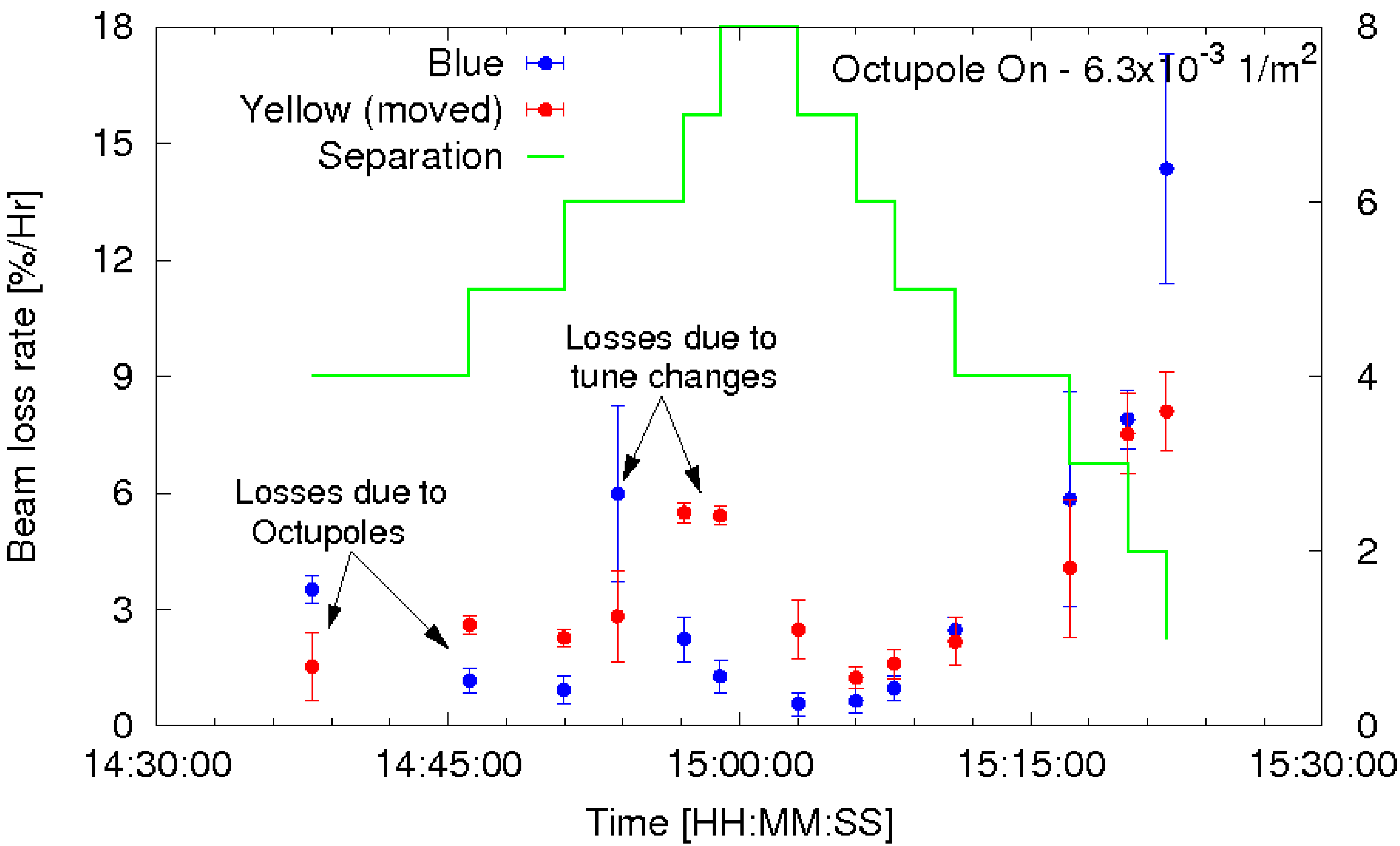
+ octupoles ($\Delta Q \sim 5 \times 10^{-4}$)

quantity	unit	value
proton energy	GeV	100.0
bunches per beam	...	12
bunch intensity	10^{11}	1.7
long-range location	m from IP	10.6
emittances $\epsilon_{x,y}$ (95%)	mm mrad	10-15
$\beta_{x,y}$, long-range location	m	105
tunes (Q_x, Q_y)	...	B(0.69,0.70)
		Y(0.71,0.69)
vertical separation	mm/σ	1–11/0.7–6.3

I: Beam Losses, Position Scan

Observe Blue lifetime from movement of Yellow beam

Separation 8 → 2 σ

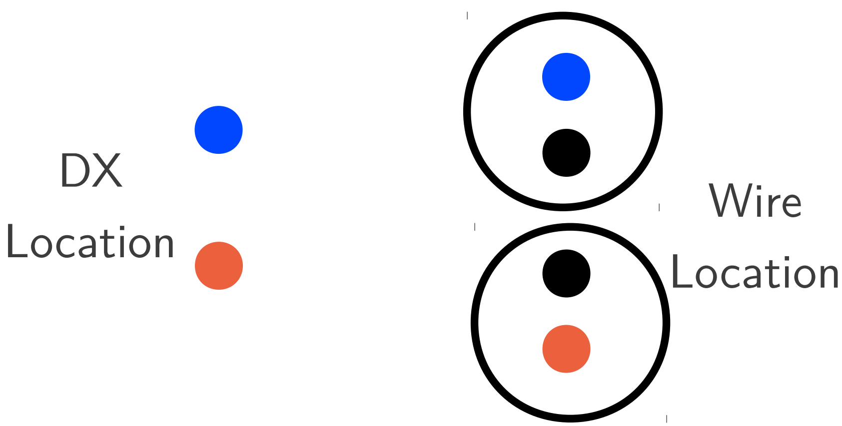


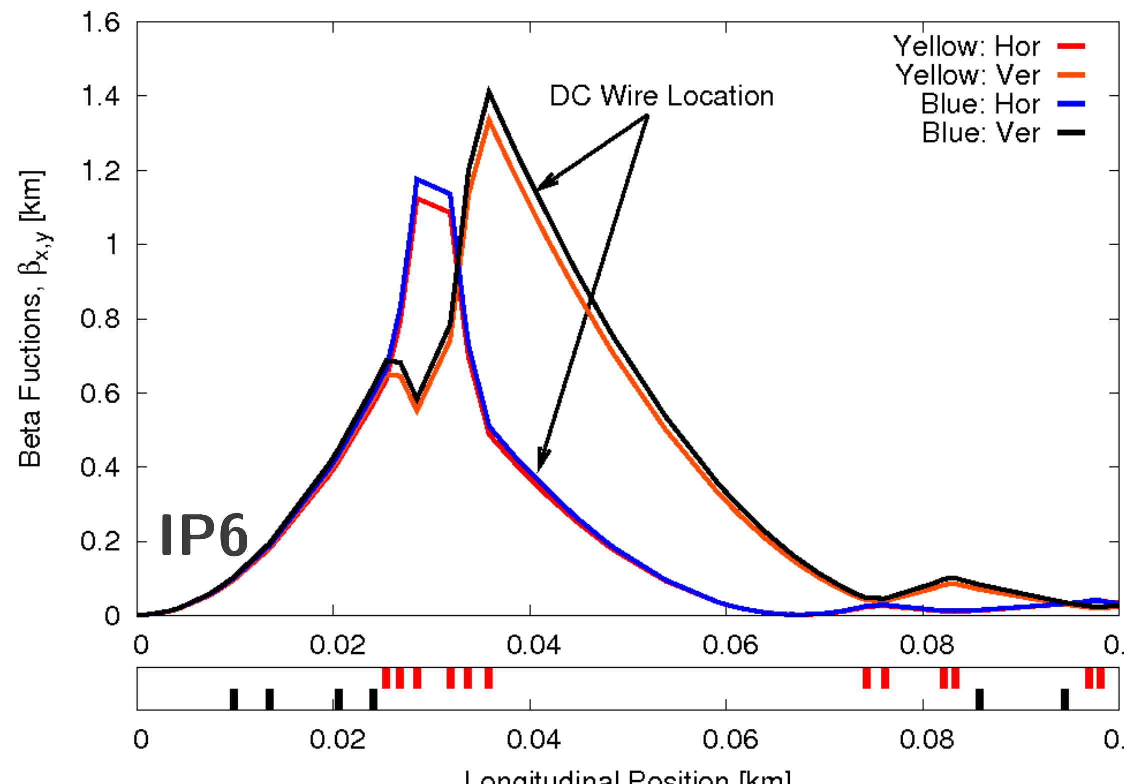
II: DC Wires in RHIC

quantity	unit	Blue	Yellow
beam energy E	GeV/nucleon	100	
rigidity $(B\rho)$	Tm	831.8	
number of bunches	...	6-56	
Norm. Emittance $\epsilon_{x,y}$	μrad	17	17
distance IP6 to wire center	m	40.92	
parameter K (at 50 A)	nm	-30.1	
hor. tune Q_x	...	28.234	28.228
hor. tune Q_y	...	28.226	29.235
β_x at wire location	m	1091	350
β_y at wire location	m	378	1067

Wires installed in both rings

2006 Shutdown

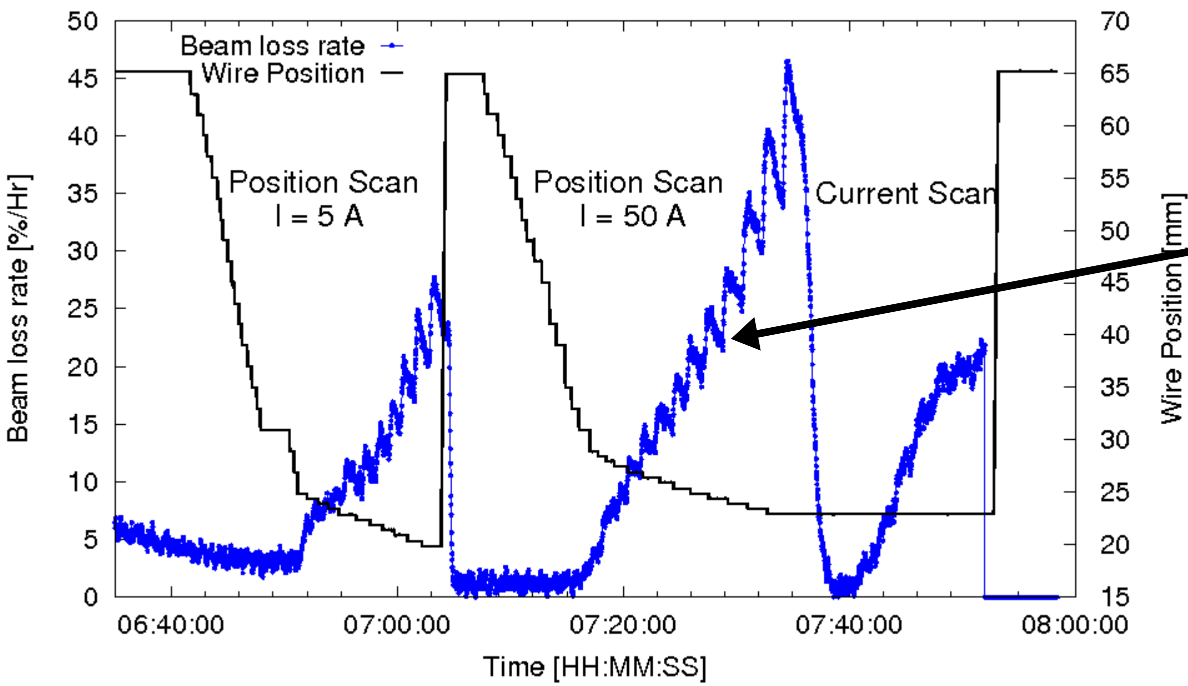




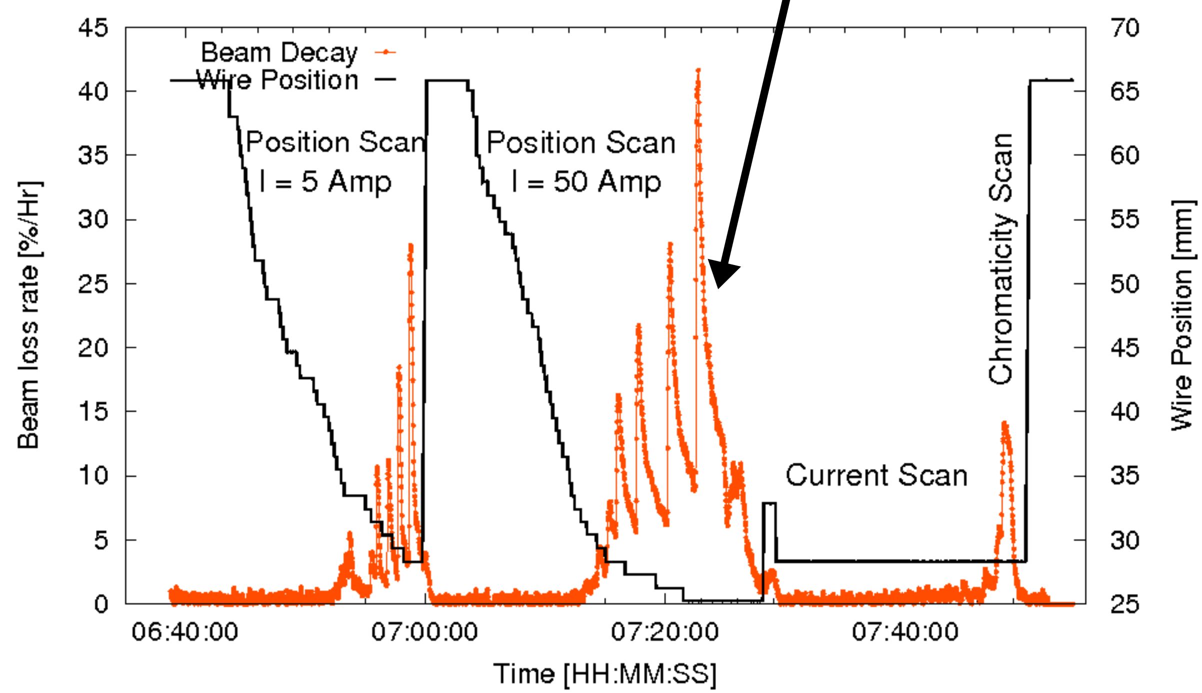
x3 difference in the vertical β-funtions

Wires placed below Blue, above Yellow

II: Wire Experiments, Single Beam



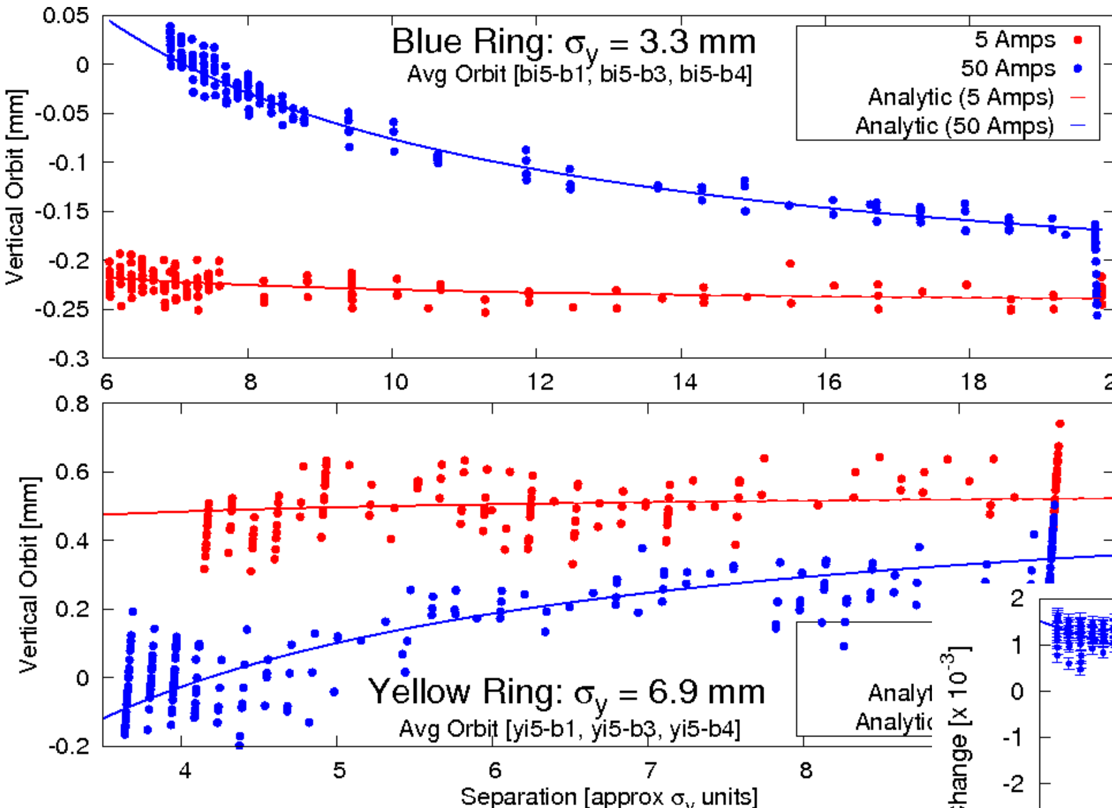
Different beam loss rates



Yellow generally more sensitive

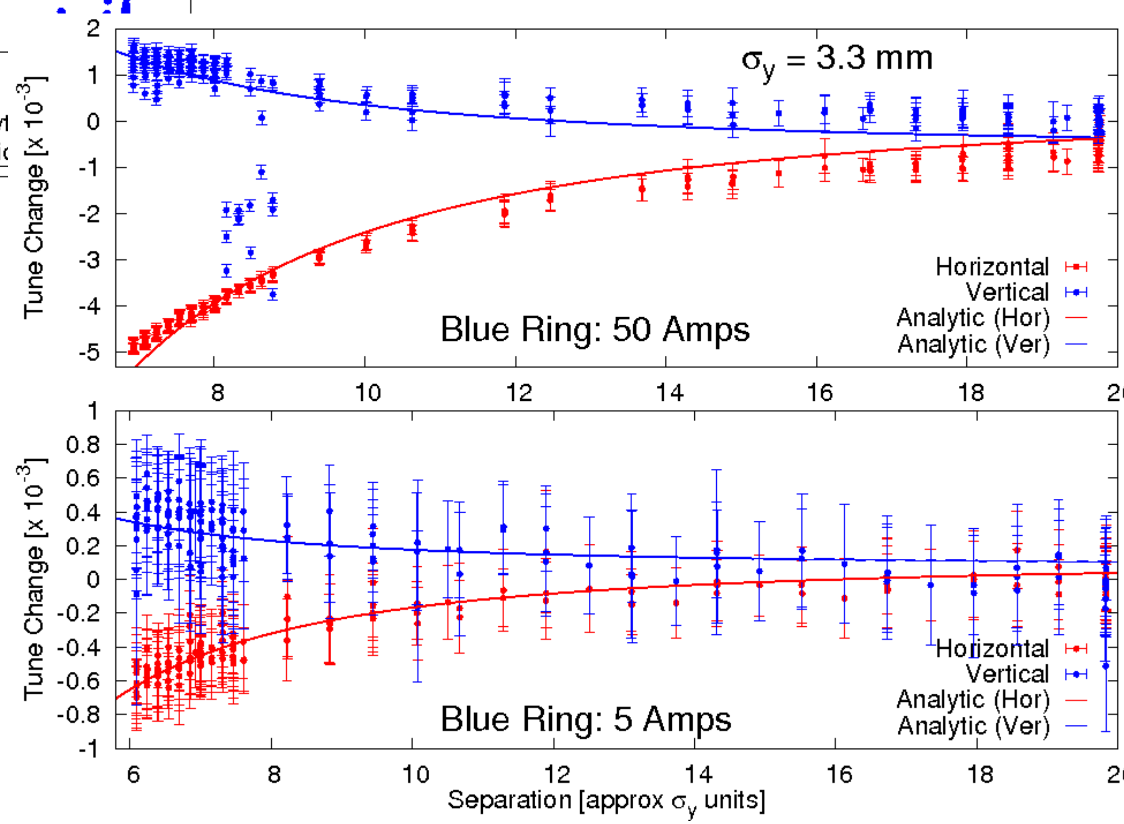
Yellow β-funtion larger

II: Orbits and Tunes



Measurements agree well with Analytical formulae for wire kicks

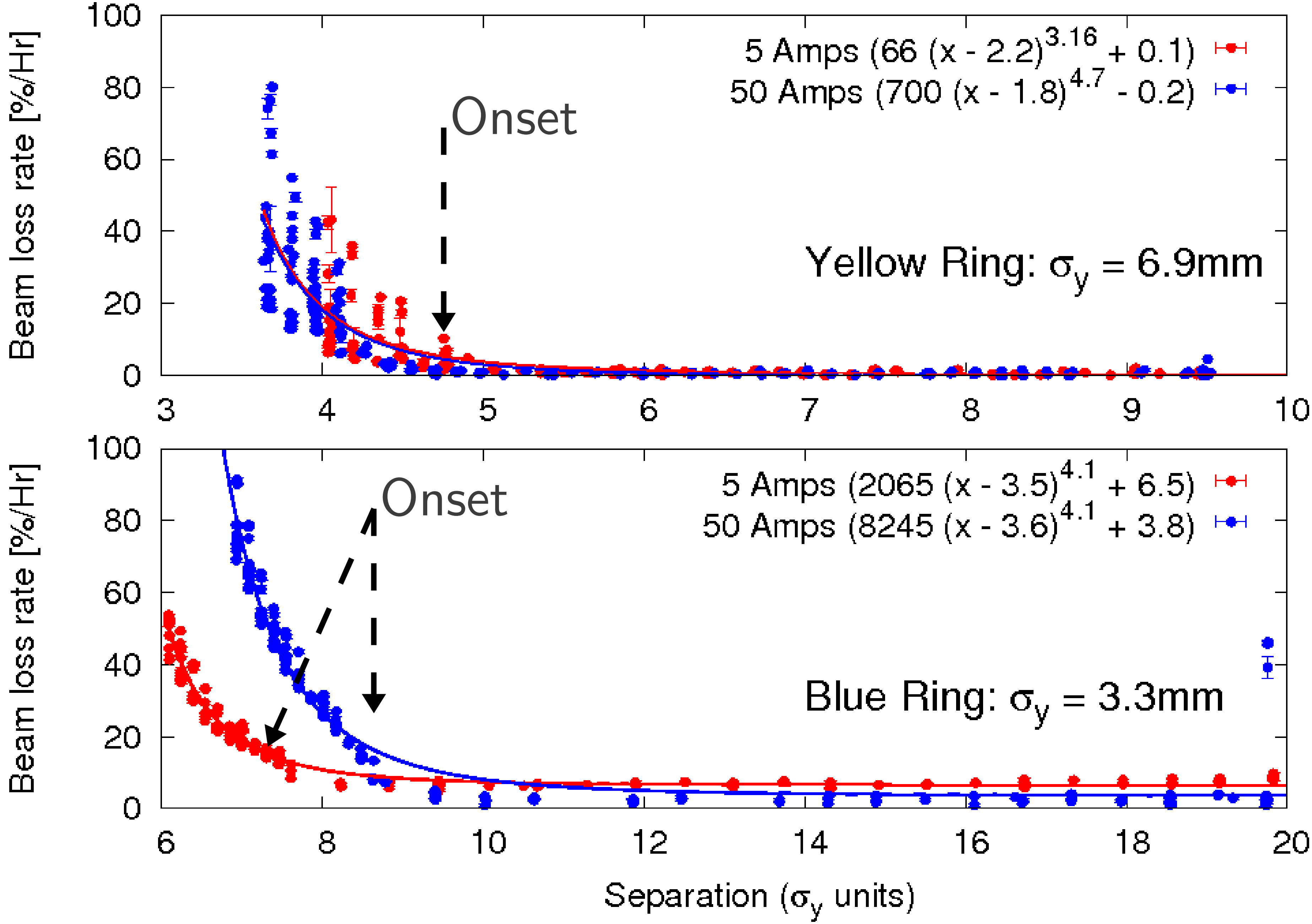
$$\Delta\, y \propto \frac{1}{d_{sep}}$$



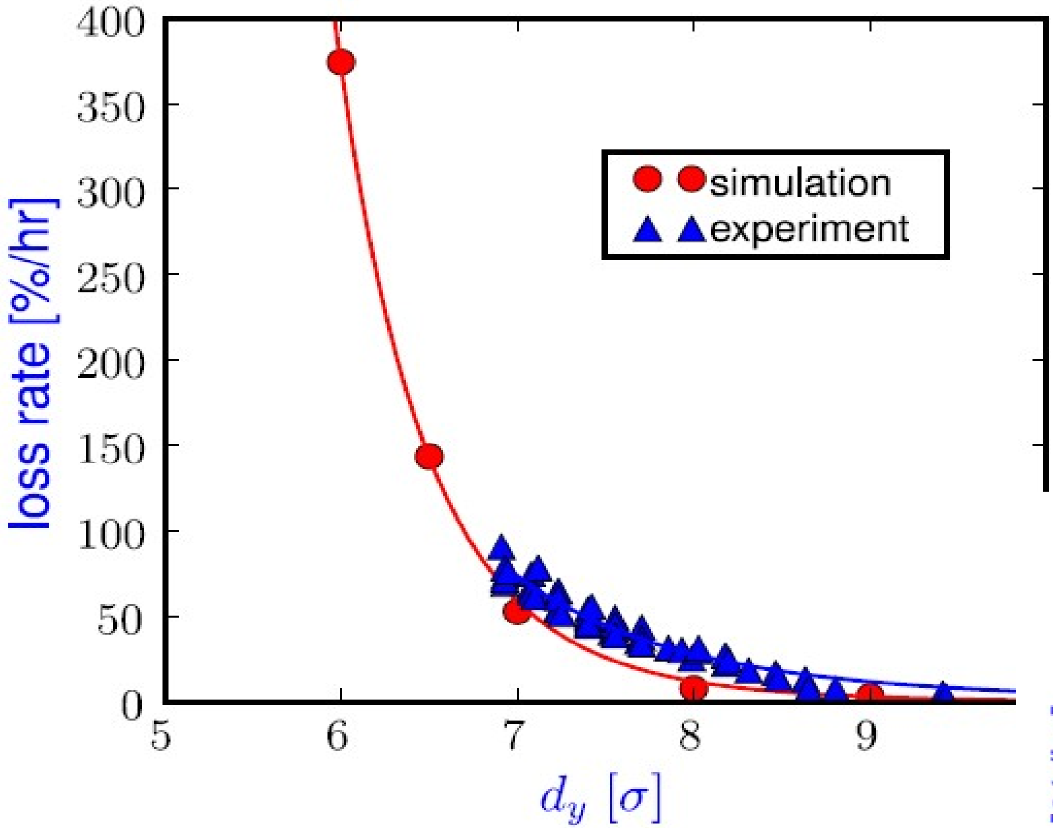
$$\Delta\, Q_{x\,,\,y} \propto \frac{1}{d_{sep}^2}$$

II: Onset of Beam Losses

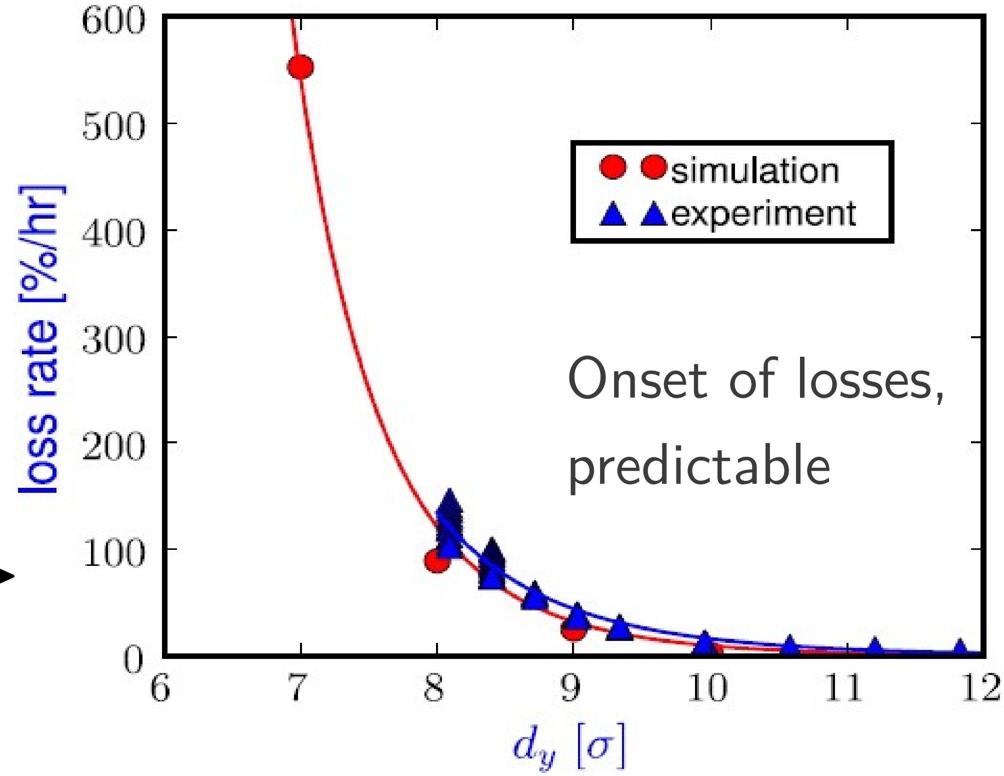
Power law fits



II: Loss Rates & Simulations



Au @100 GeV
Wire Current, 50 A



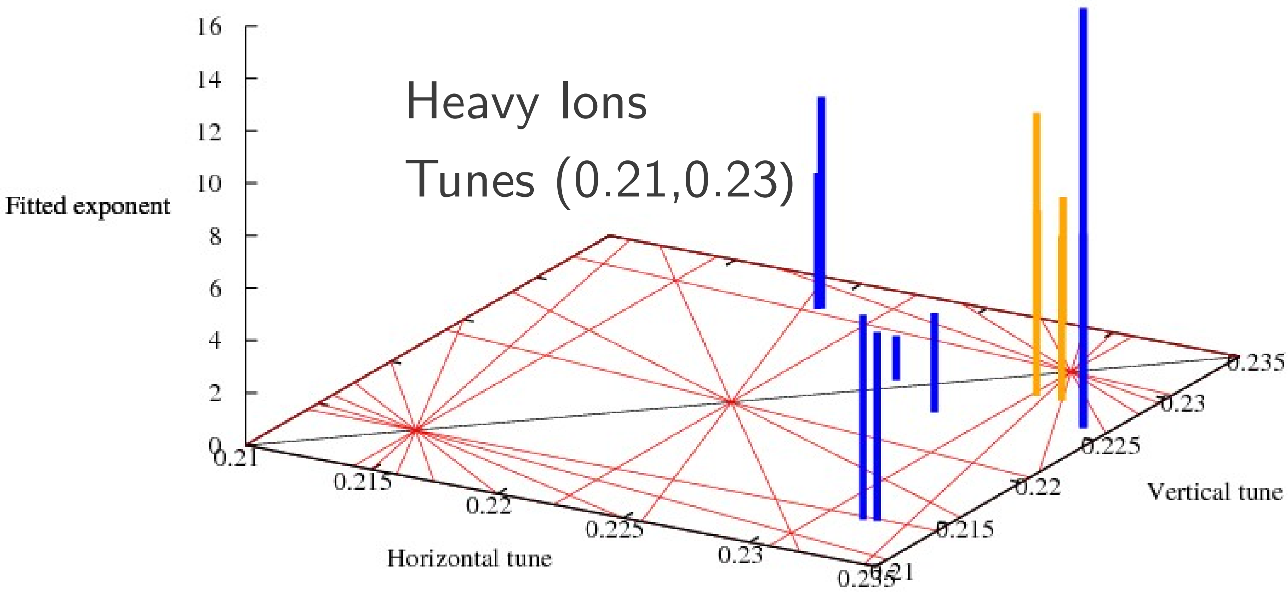
Onset of losses, predictable

Deuterons @100 GeV
Wire Current, 50 A

BBSIMC Code, T. Sen, H.-J. Kim

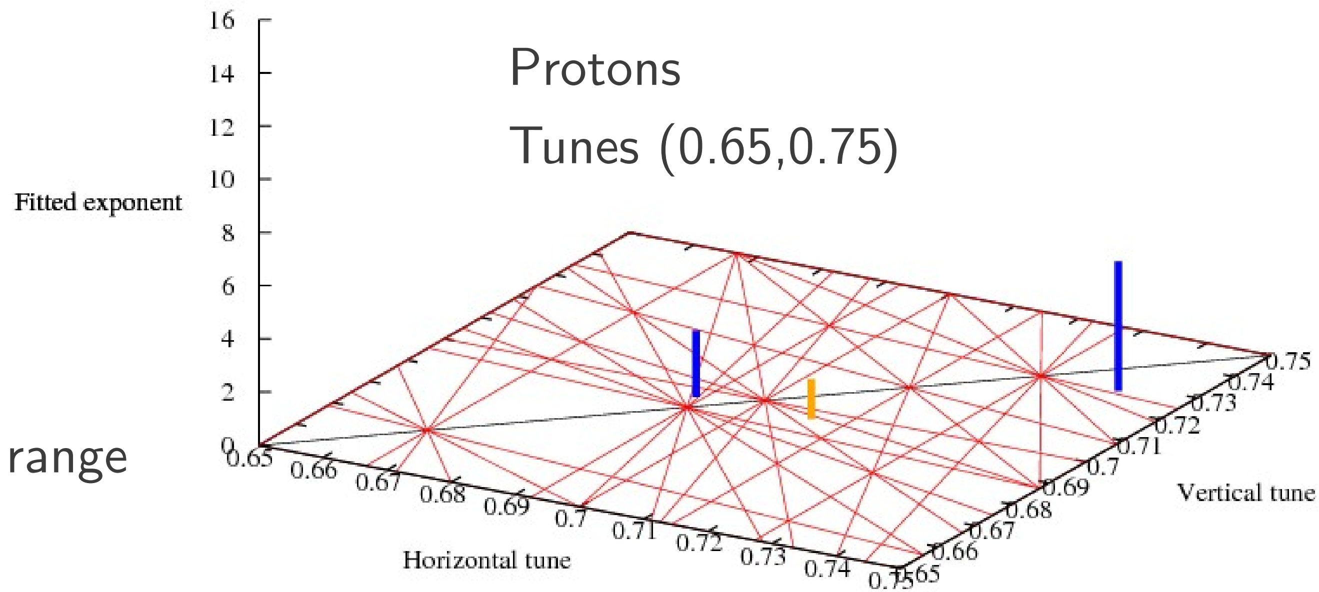
H.-J. Kim et al., PRST-AB 12, 031001 (2009)

II: Beam Lifetime, Fitted Exponents



$$\tau = A\,d^{p}$$

p: 1.7 - 16



SPS, p ~ 5

Tevatron, p ~ 3

Exponents were within limited range

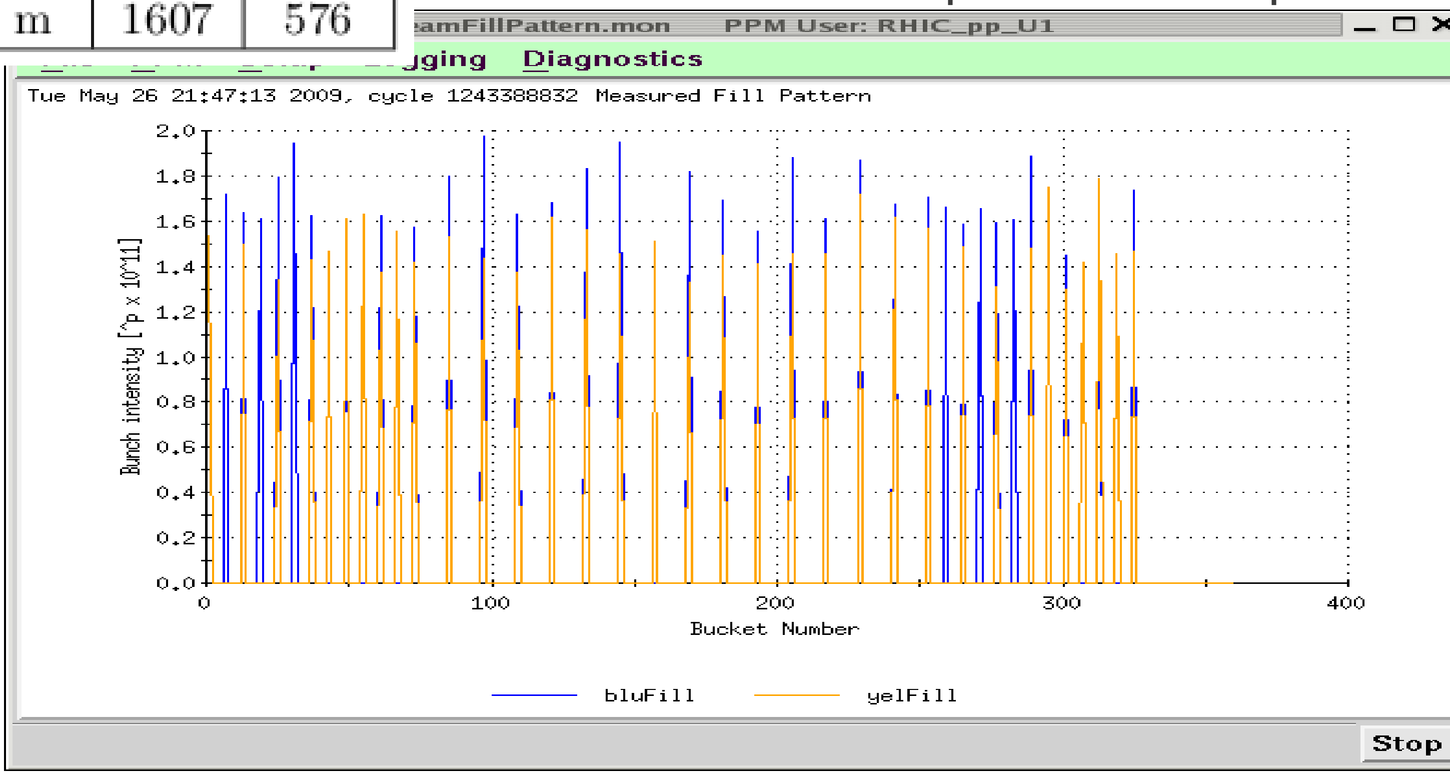
III: LR Experiments, with Head-On

quantity	unit	Blue	Yellow
beam energy E	GeV	100	
rigidity $(B\rho)$	Tm	333.5	
number of bunches	-	36	
# of colliding bunches	-	30	
bunch intensity	10^{11}	1.7	1.7
norm. Emittance $\epsilon_{x,y}$	μrad	25,24	49,19
horizontal tune Q_x	...	28.691	28.232
vertical tune Q_y	...	29.688	29.692
chromaticities (ξ_x, ξ_y)	...	(+2, +2)	
β_x at wire location	m	556	1566
β_y at wire location	m	1607	576

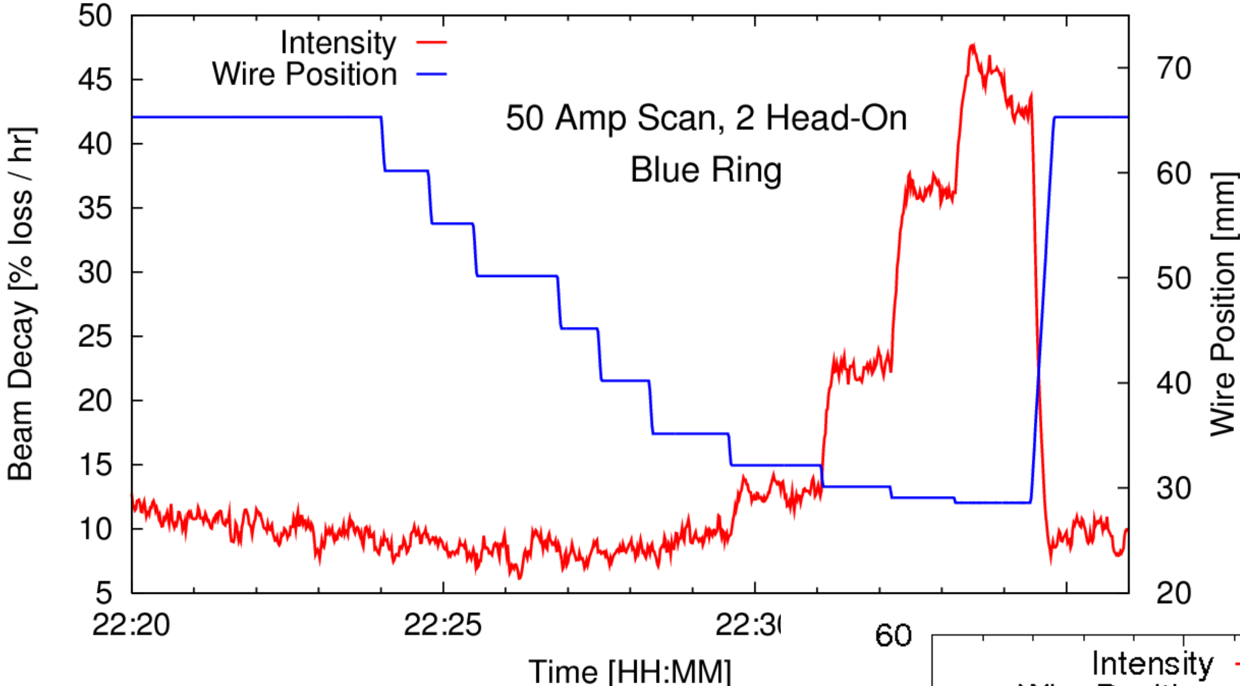
Yellow Hor emittance big
(large error bar)

2009, Protons

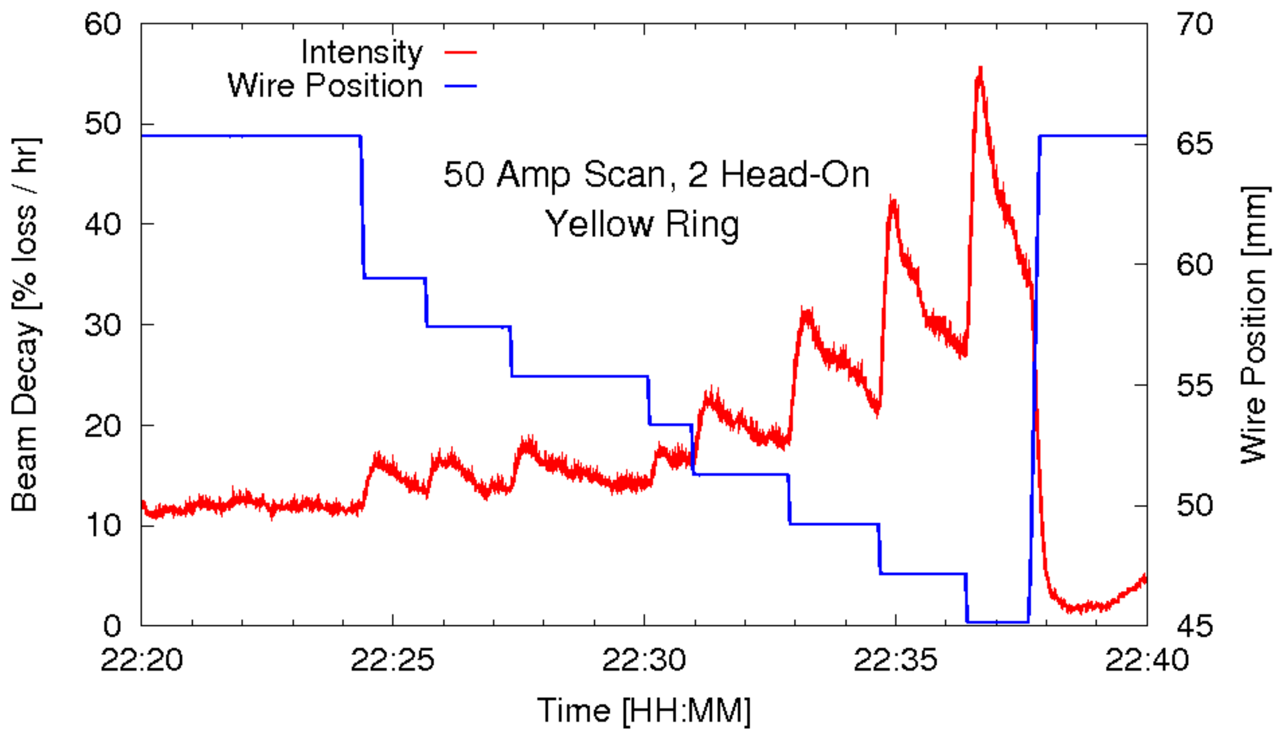
Special 36x36 pattern



III: 50 Amp Wire Scans, 2 HO



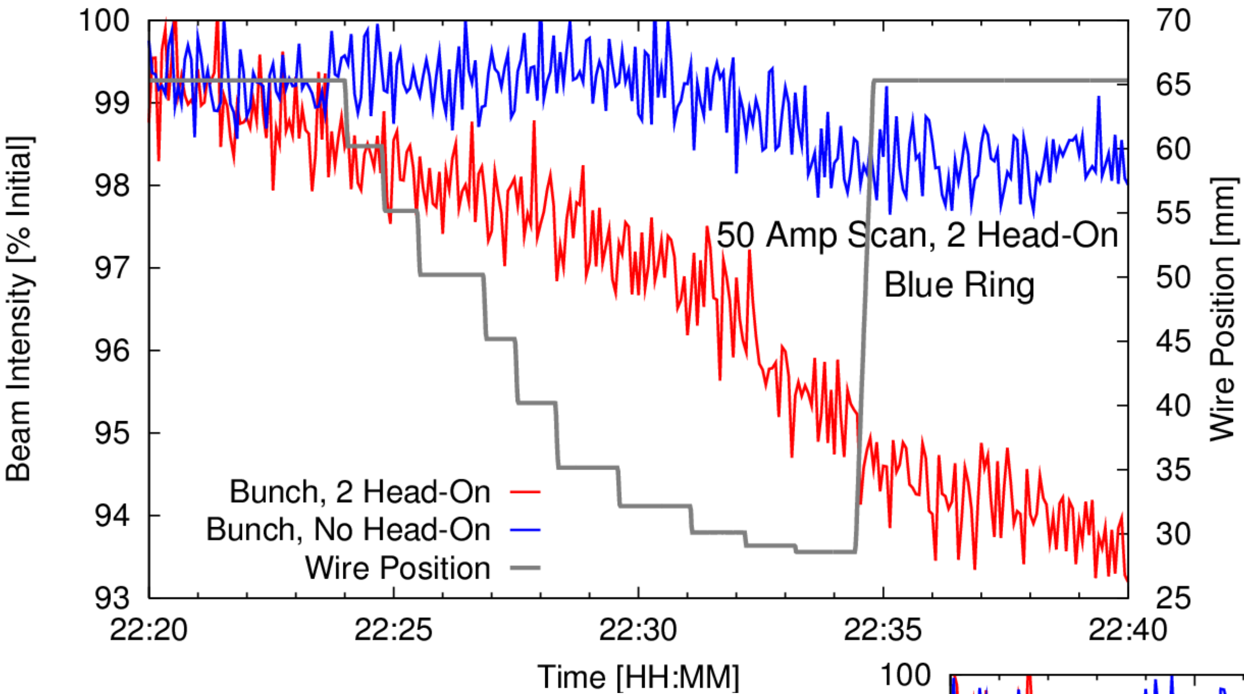
Blue Ring



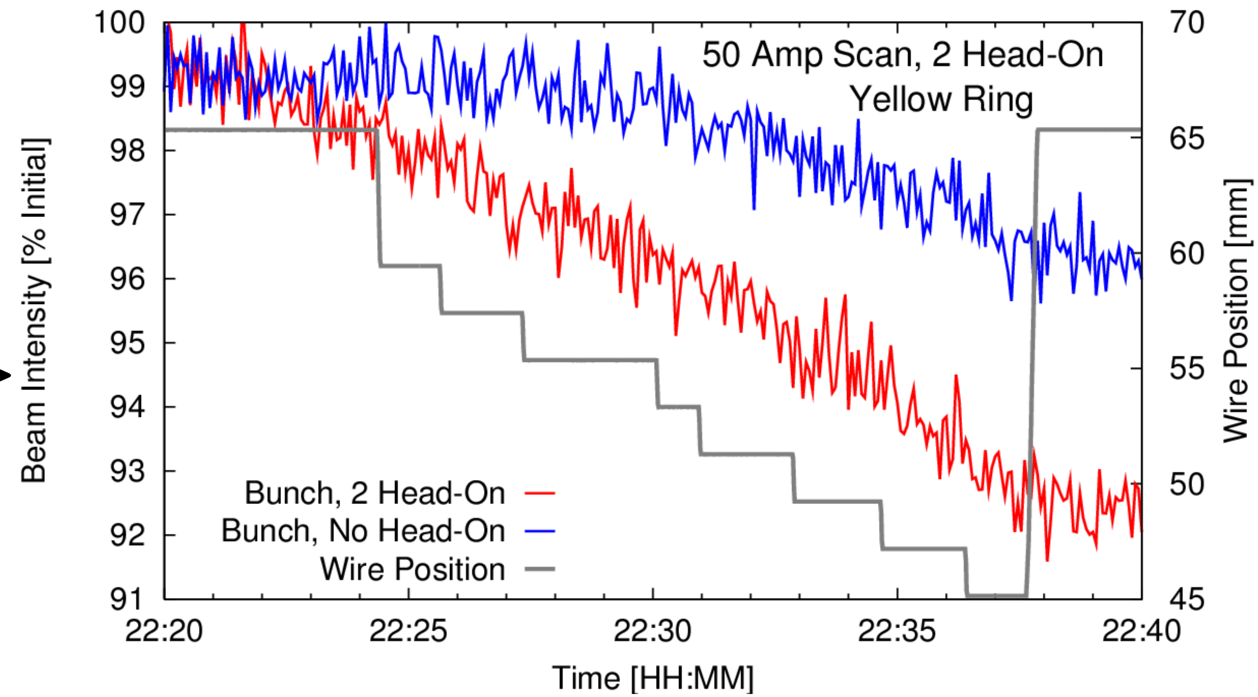
Yellow Ring

Yellow sensitive even in par
position with 50 A

III: HO Vs. No HO, 50 A

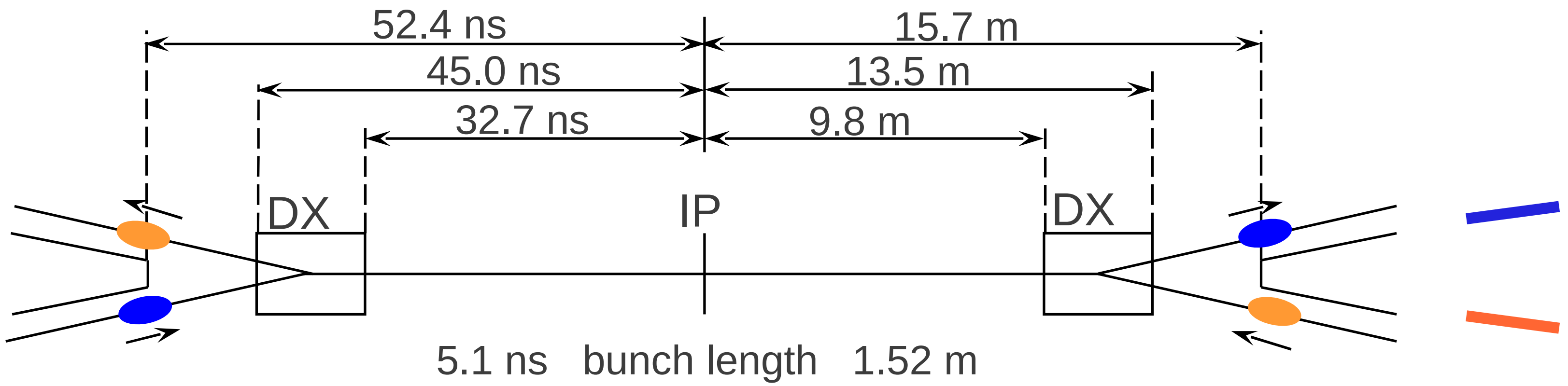


Blue Ring



Yellow Ring

III: LR "Compensation" Exp, 5A



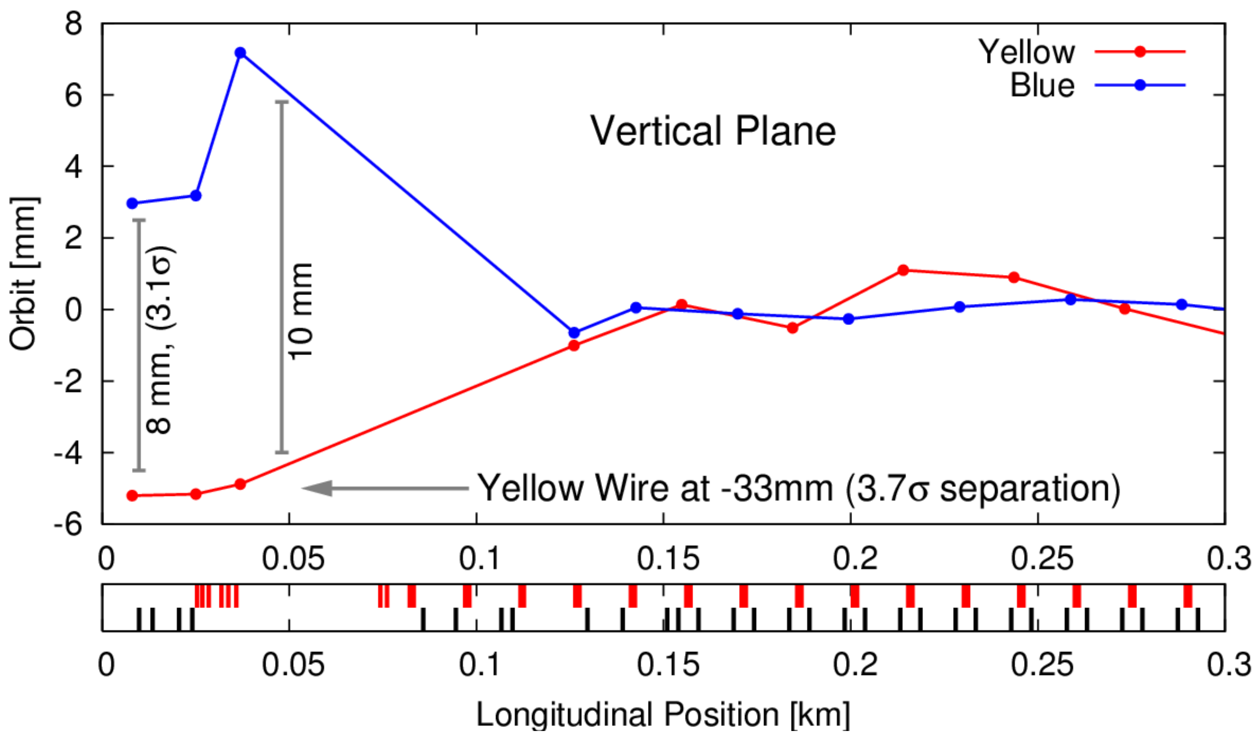
$\beta_y \sim 1.45$ km (wire position)

$\beta_y \sim 170$ m (LR position)

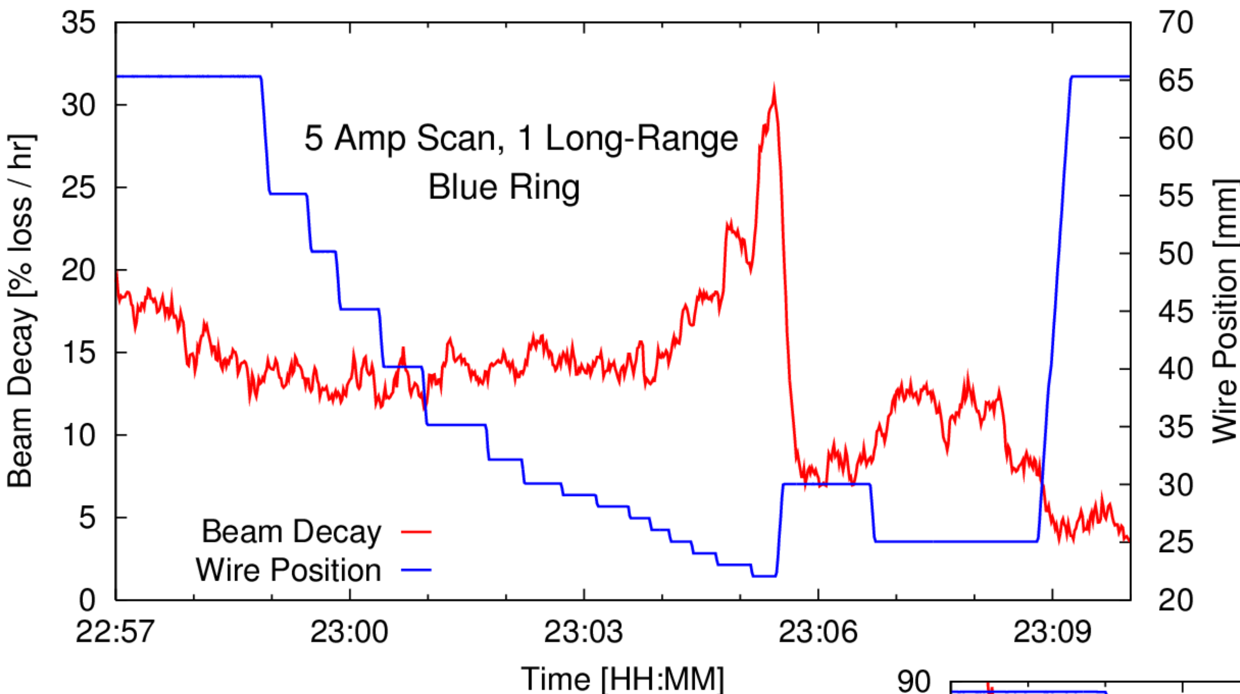
$\varepsilon_y \sim 4.2$ µm

LR separation ~ 3.1 σ

Beam ↔ wire separation ~ 3.7 σ

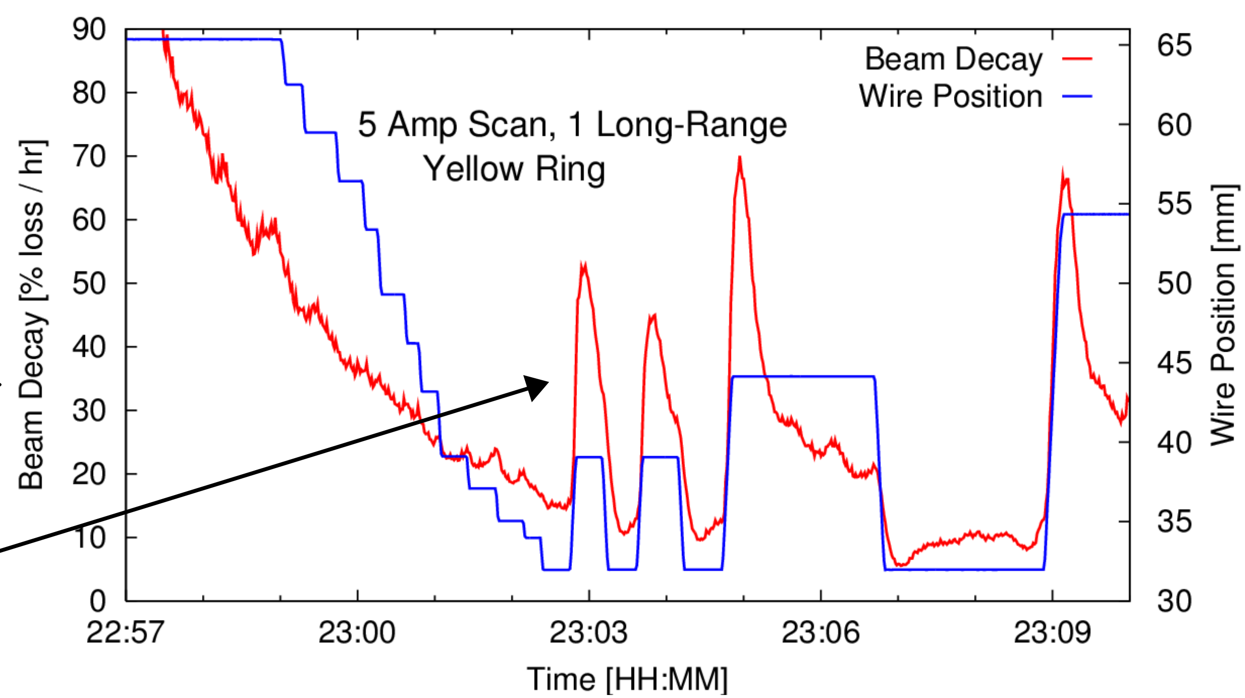


III: LR "Compensation" Exp, 5A



Blue Ring

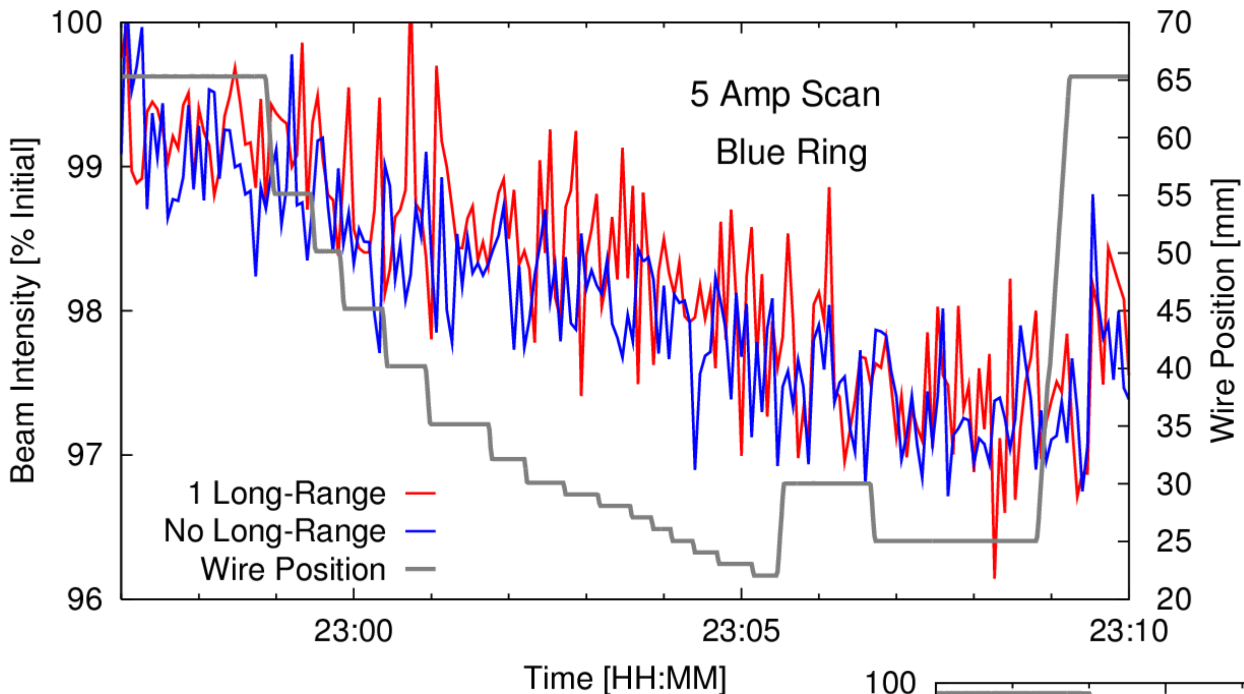
No visible effect



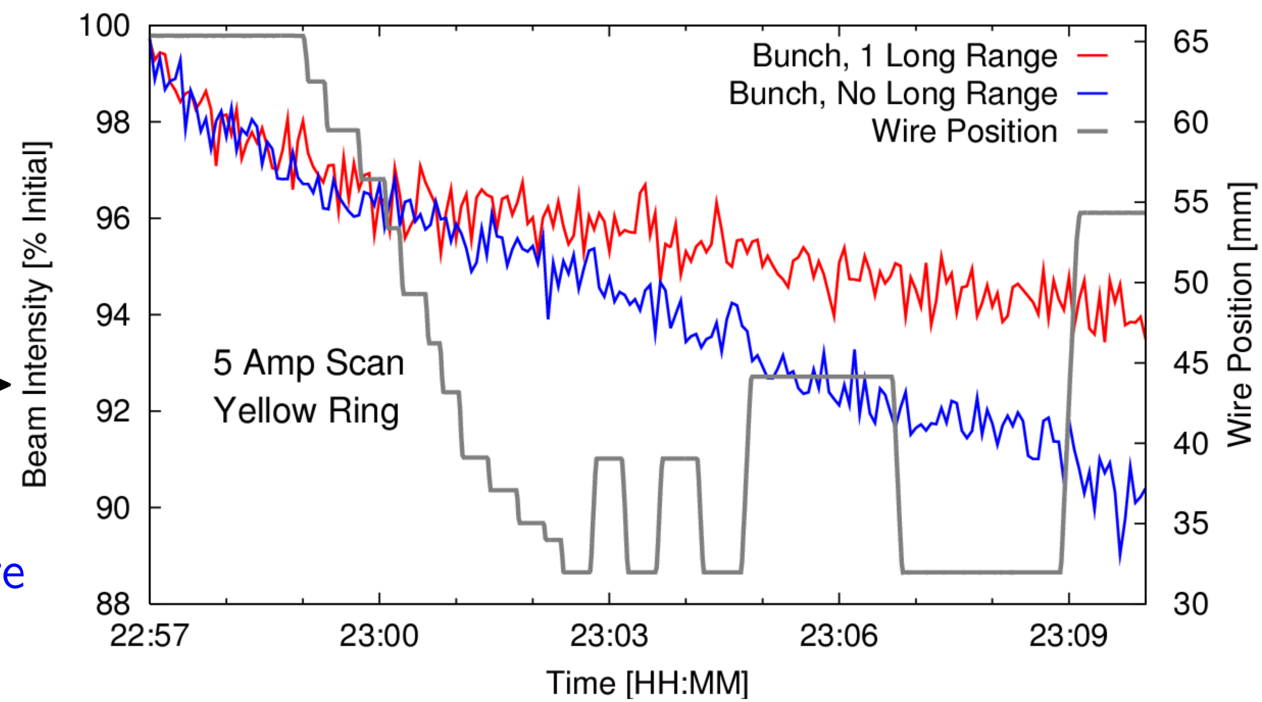
Yellow Ring

Losses increase when compensation is removed !!!

Bunches With/Without Long Range



Blue Ring



Yellow Ring

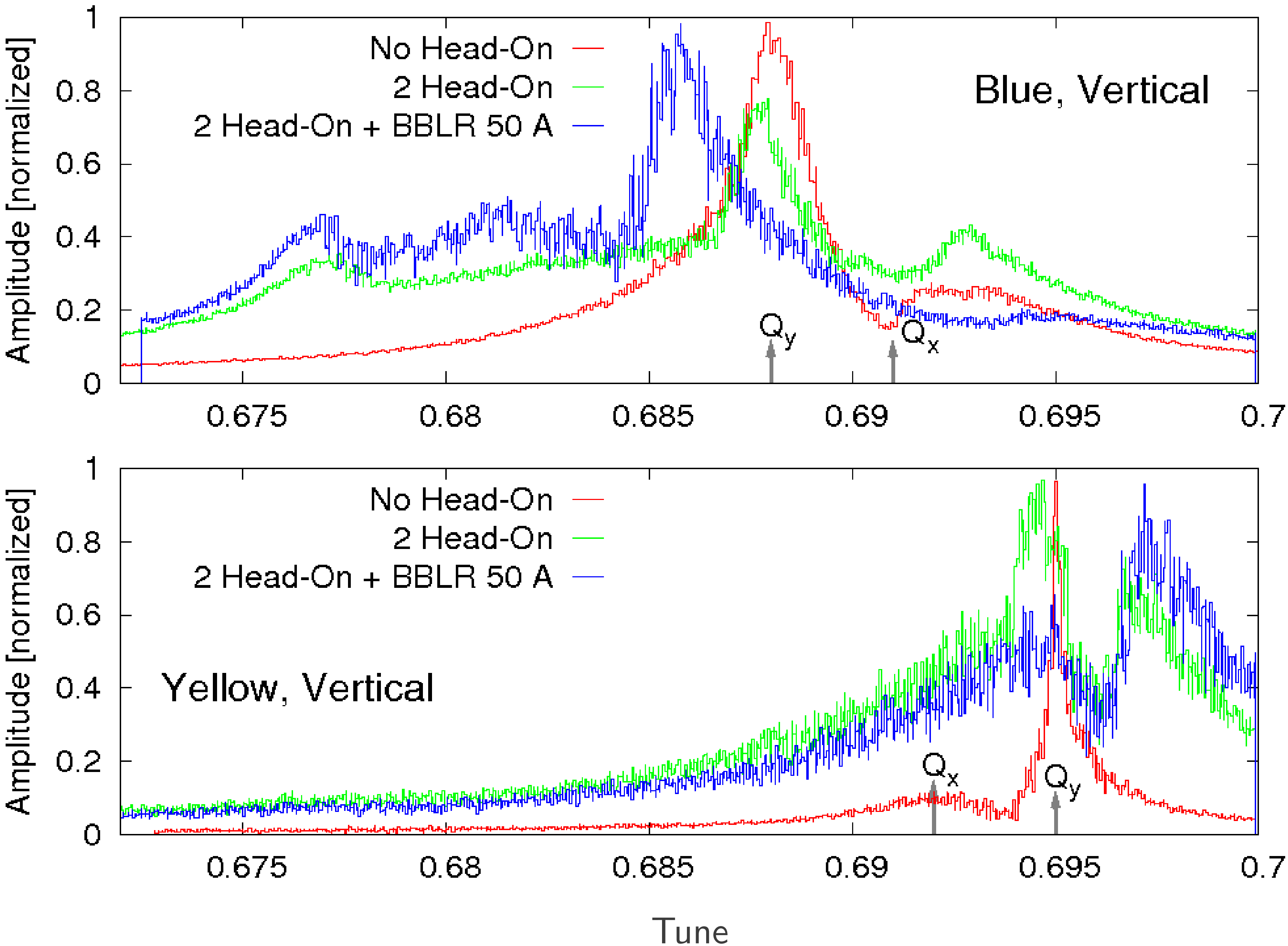
Bunches without LR suffer more losses due to the wire !!!

Conclusions

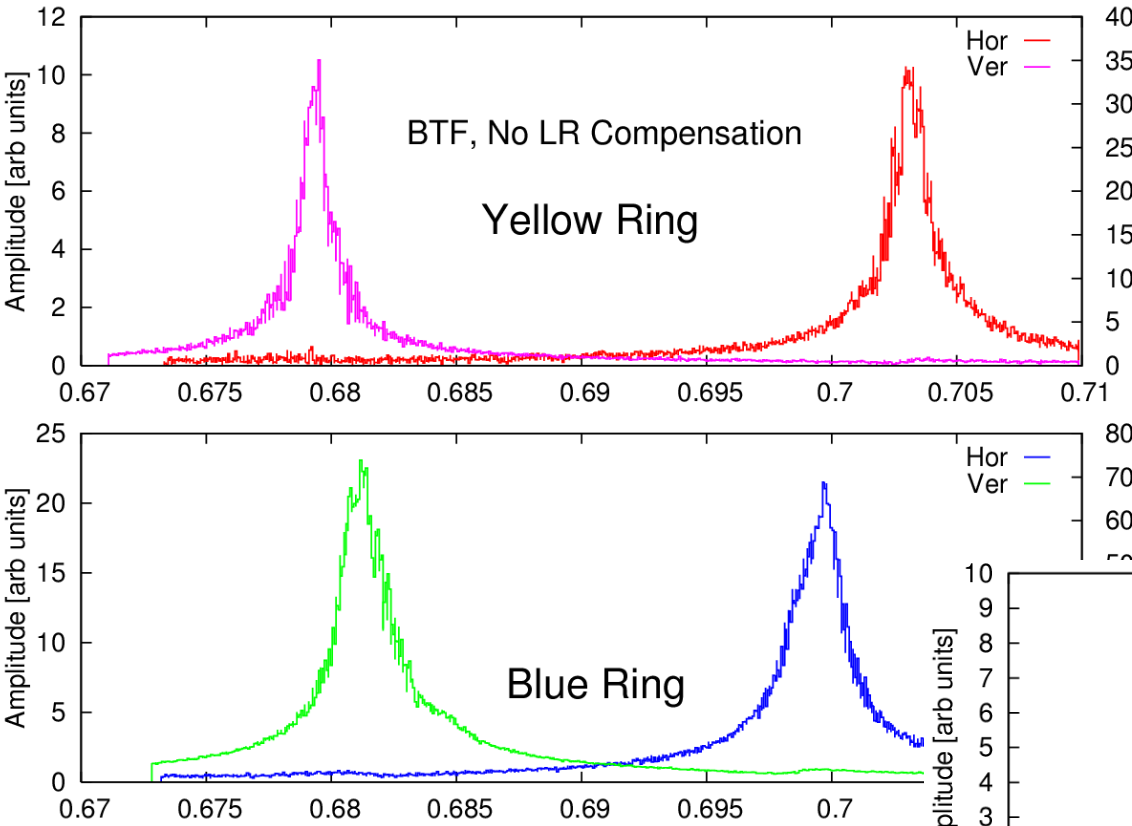
- Single long-range experiments reveal “weak” LR effects
  - Beam in a meta-stable state to observe losses
- DC wire experiments were carried out at RHIC
  - Onset of losses clearly visible, simulations show agreement within 1σ
  - Differences visible between the 2 beams
- LR effects are enhanced with head-on
- Single LR “compensation” attempt was performed
  - Improvement in Yellow lifetime was seen, but not reproduced in Blue beam

Exciting LHC long-range experiments are ahead of us!

A1: Tunes, With/Without Head-On

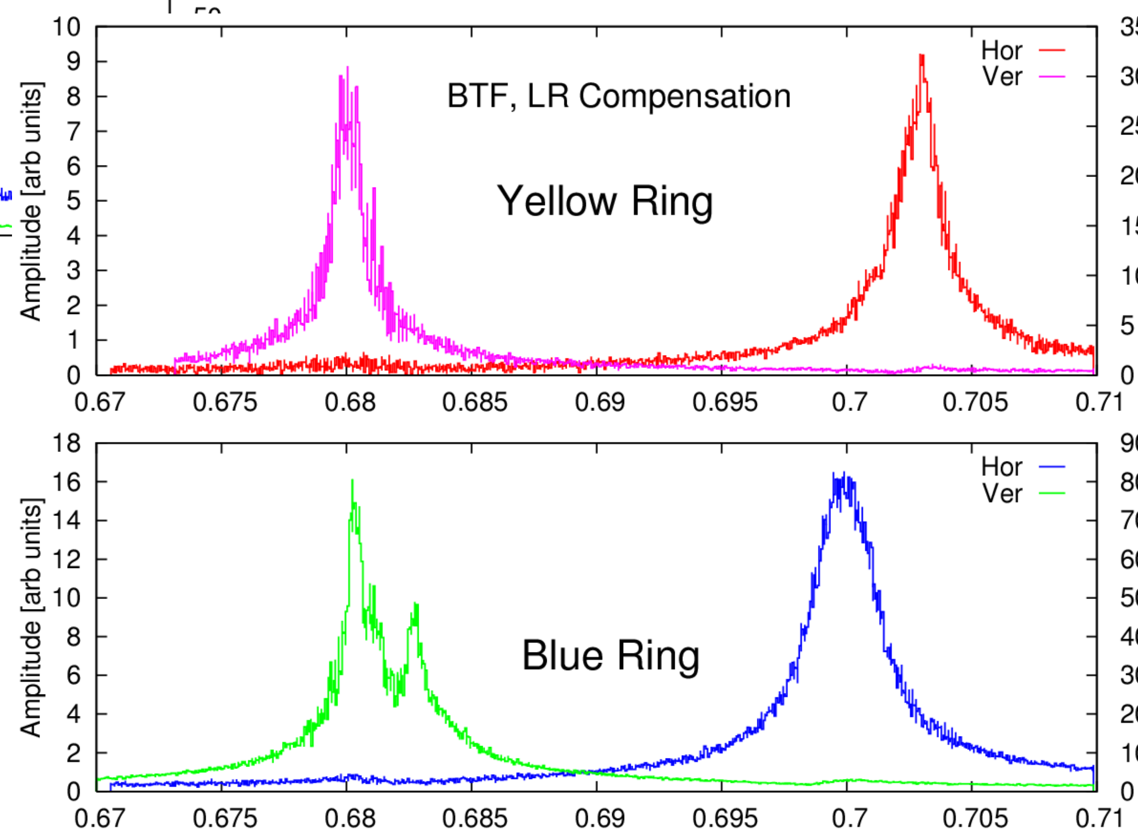


A2: Tunes, with & w/o Compensation



No Compensation

Wire Compensation



No observable tune changes in Yellow Ring.