Tevatron Helix Upgrade

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DOE Tevatron Operations Review

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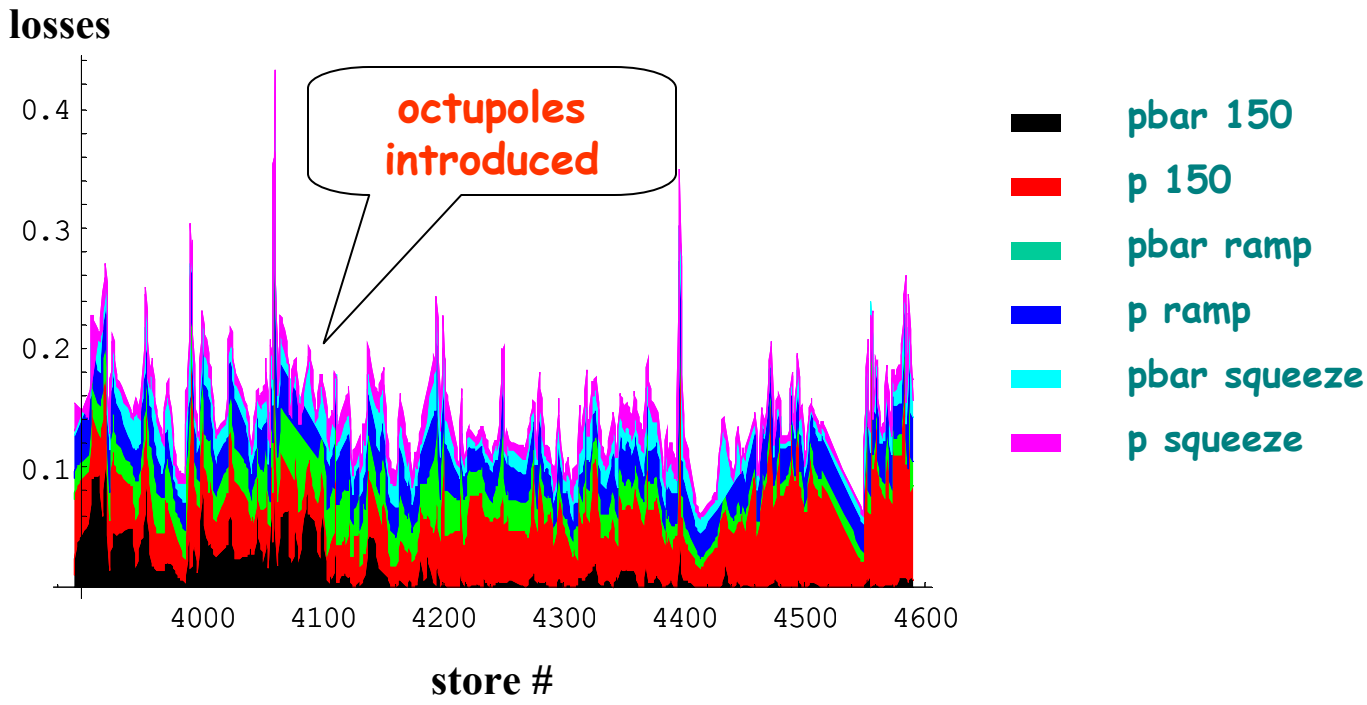
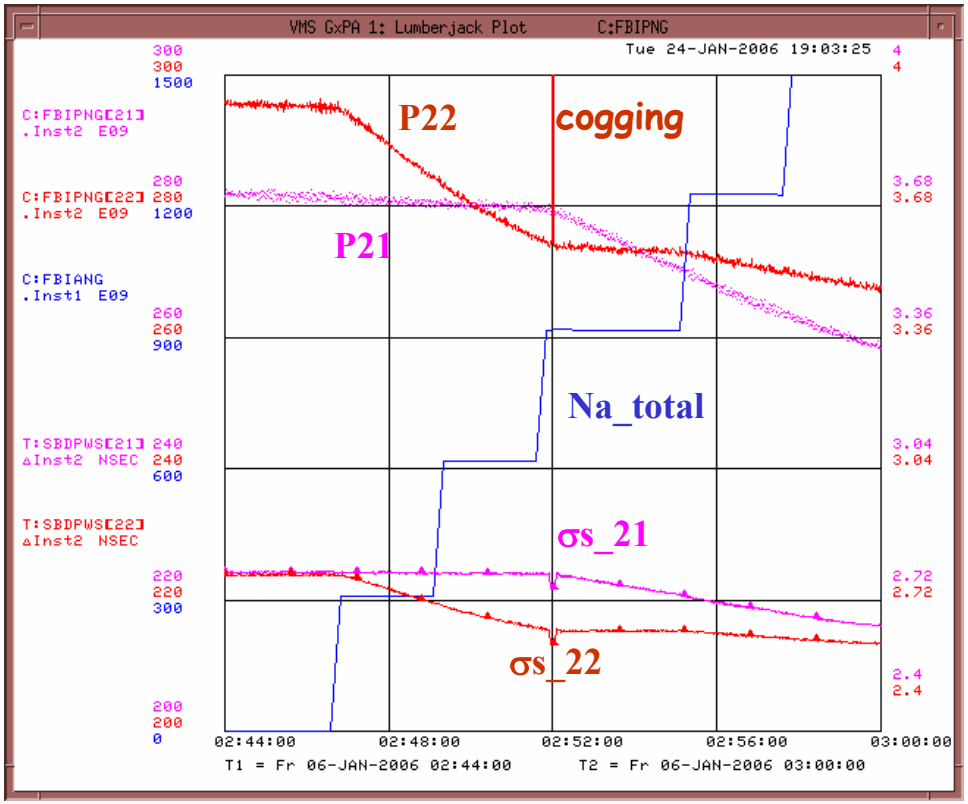
Tevatron Inefficiencies in 2005



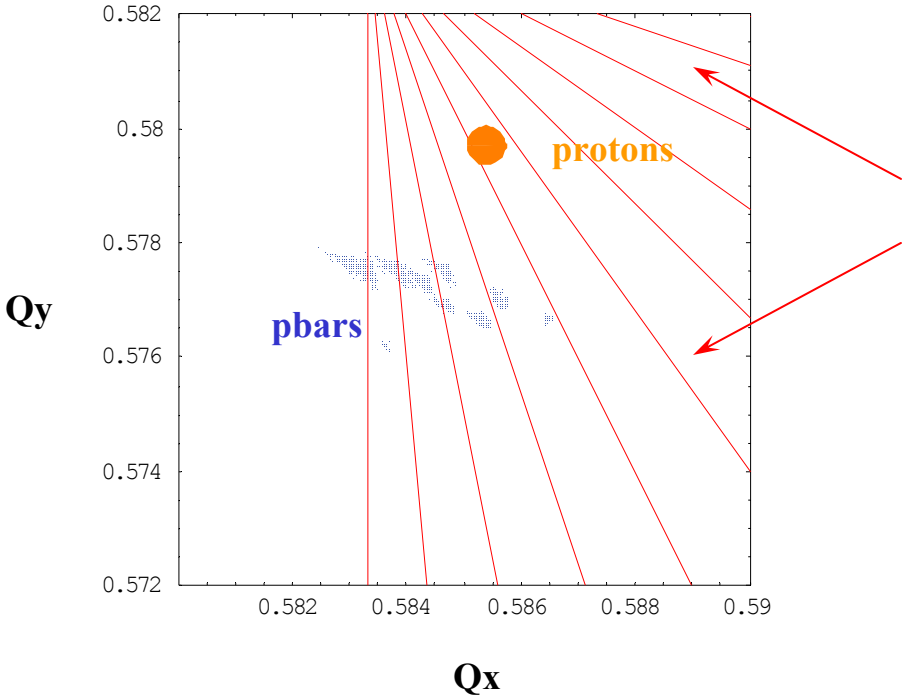
With increase in Na the proton losses during pbar injection became a major problem.

Proton losses at 150



- P22 suffers high losses after the first transfer while P21 starts loosing protons only after the cogging.
- It is protons with large synchrotron amplitudes that are being lost

Proton losses at 150



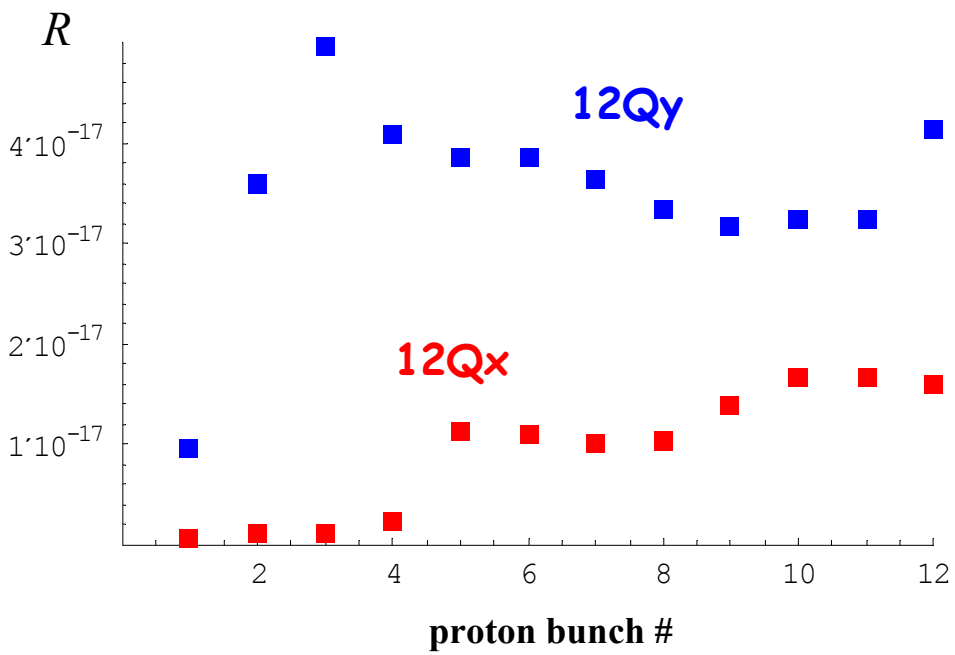
12^{th} order resonances:

mQx+nQy=integer

m+n=12

protons see 12^{th} order resonances with higher "n" – more vertical

Beam-beam resonances seen by protons



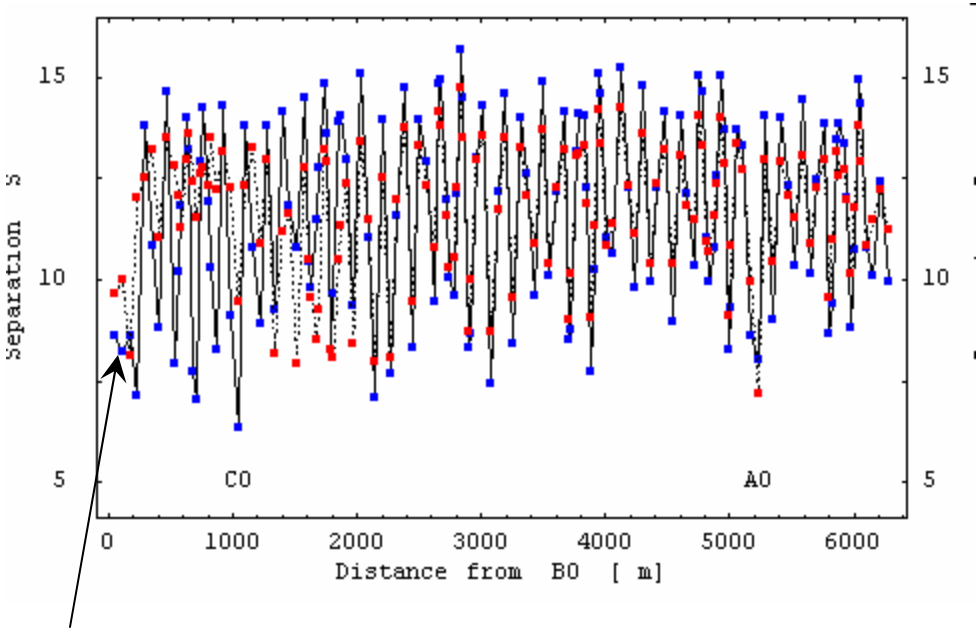
$$\frac{dI}{dn} = R,$$

$$\langle I \rangle = \varepsilon_{95\%} / 6\pi\gamma = 1.6 \cdot 10^{-8}$$

- Vertical resonance is much stronger than the horizontal – effect of a point with $\beta y >> \beta x$
- The first proton bunch in a train does not see that point

The resonance driving terms were calculated for the respective betatron amplitude = 3σ (reference emittance 15π), Na=50e9/bunch

Beam separation at injection



$$S = \sqrt{(\Delta x / \sigma_{x\beta})^2 + (\Delta y / \sigma_{y\beta})^2}$$

- "radial" separation (reference emittance 15π mm·mrad)

- present helix
- proposed "5-star" helix

IP #2:

Δx=5.3mm, βx=26.5m,
Δy=0.5mm, βy=111.6m

- at this point the first proton bunches (and the last pbar bunches) in the trains do not interact at all.
- after the first pbar transfer P22 interacts there with A1, while P21 does not interact

Proton losses at 150 - cures

Why pbars fare better than protons at injection:

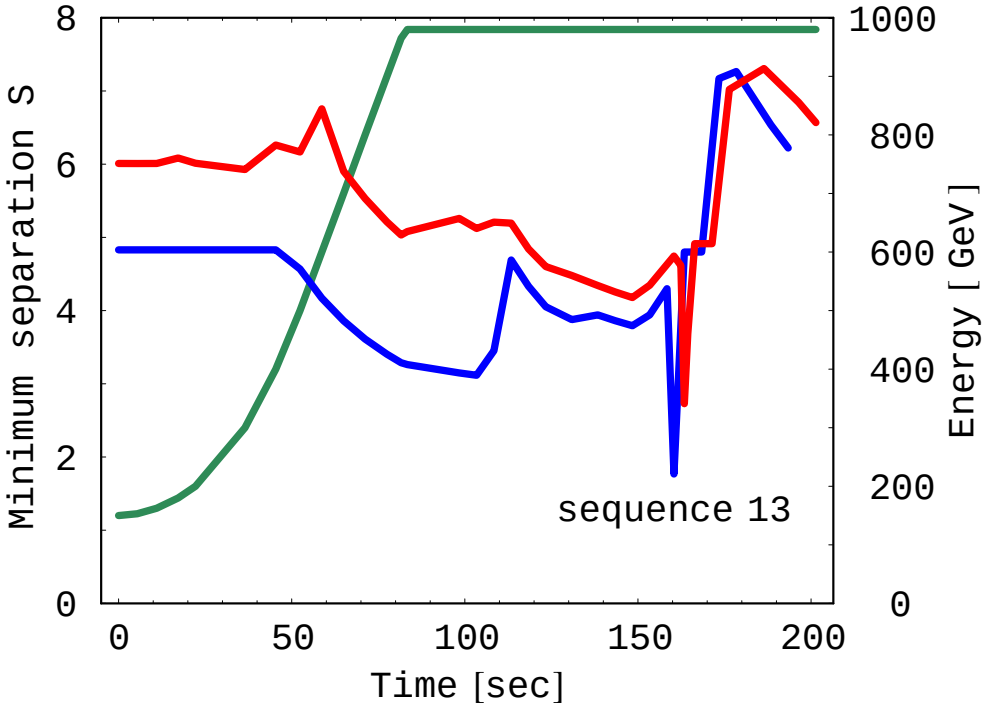
- tunes are farther from Qy=7/12
- chromaticity ~0 (thanks to the octupoles!)
- twice smaller emittance!

Cures:

- Move proton tunes above 7/12 (C49 file prepared but not tried in HEP)
- Change the working point
- Improve separation using additional separators (e.g. "5-star" helix):

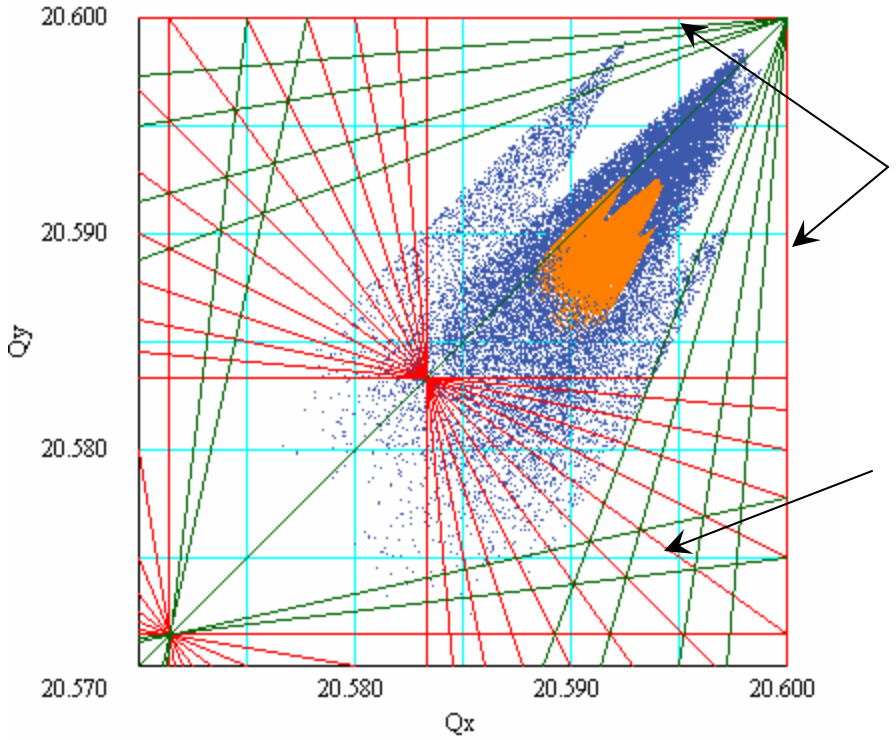
helix	separator voltage (kV)					S_{min}	tuneshifts		RDTs (m/turn)	
	B11H	B17H	B11V	C17V	C49V		$\lvert\Delta\nu_x\rvert$	$\lvert\Delta\nu_y\rvert$	$\lvert R_{50}\rvert\cdot 10^{11}$	$\lvert R_{07}\rvert\cdot 10^{13}$
Jan 2002	0	61.7	0	-61.7	0	4.83	.0045	.0020	1.95	7.06
May 2002	-37	64.3	-22.6	-58.8	0	6.01	.0028	.0019	0.92	1.77
"5 star"	-18.9	61.8	5.9	-68.4	21.8	7.34	.0020	.0009	0.80	0.55

Beam Separation during ramp & squeeze



- total losses during acceleration and squeeze amount to less than 5%
- however, a sharp peak at lbseq=13 (now 17) creates problems with CDF
- temporary voltage hike reduced losses but not eliminated completely

Beam-Beam Effects at Collisions

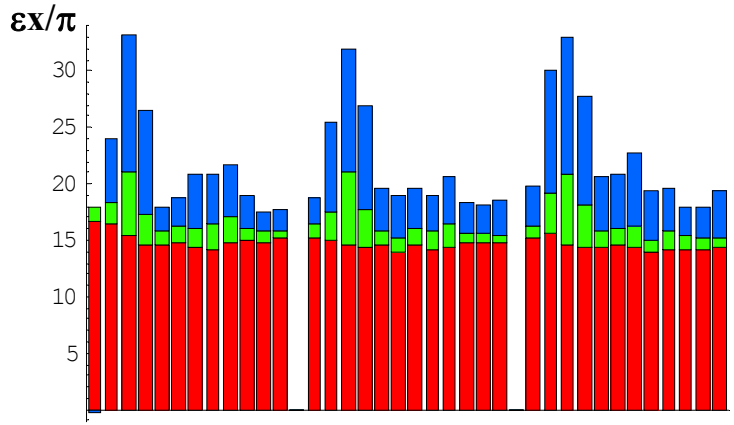


5th order resonances ⇒ emittance blow-up

12th order resonances ⇒ losses/lifetime

Calculated tune distribution of protons (orange) and pbars (blue) in collision (coupling ignored)

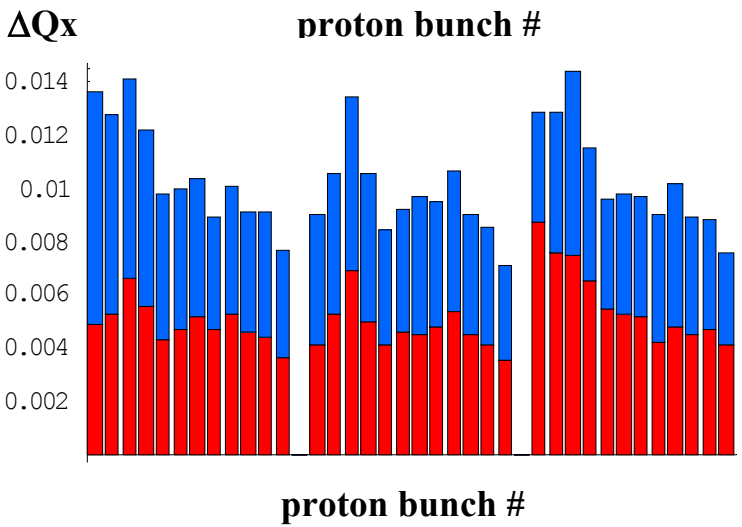
Proton emittance blowup (store #4581)



start of HEP

initiate collisions

end of squeeze

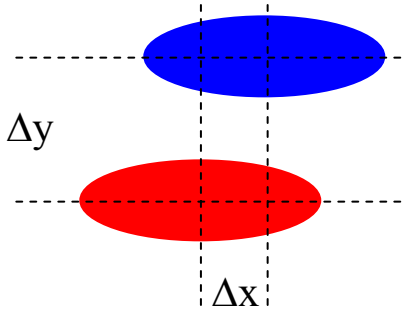


- proton bunches with higher tuneshifts suffer more ⇒ Qx=3/5 is to blame;
- the first p-bunches do not suffer ⇒ the upstream parasitic IPs (where $\beta x \gg \beta y$) produce all the effect

← head-on collisions at D0

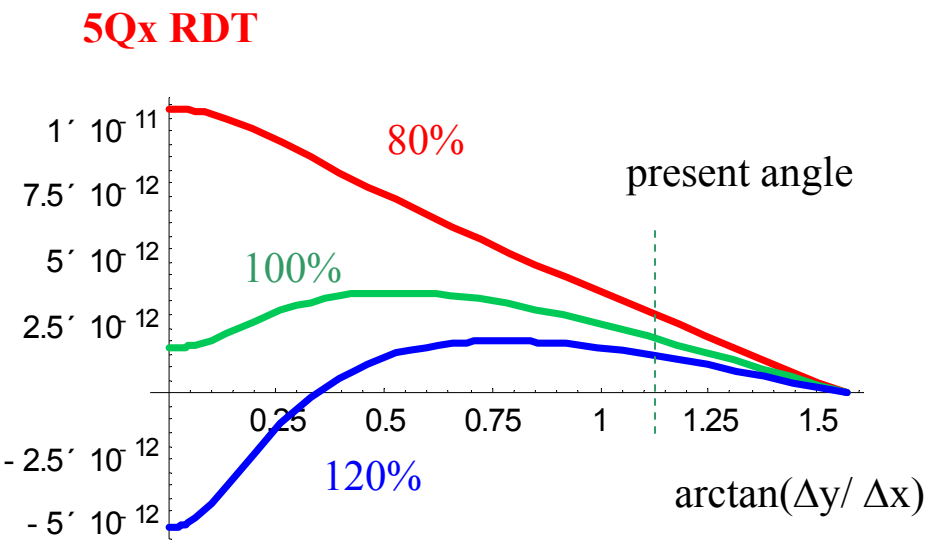
← head-on collisions at CDF

5th-order Beam-Beam Resonance



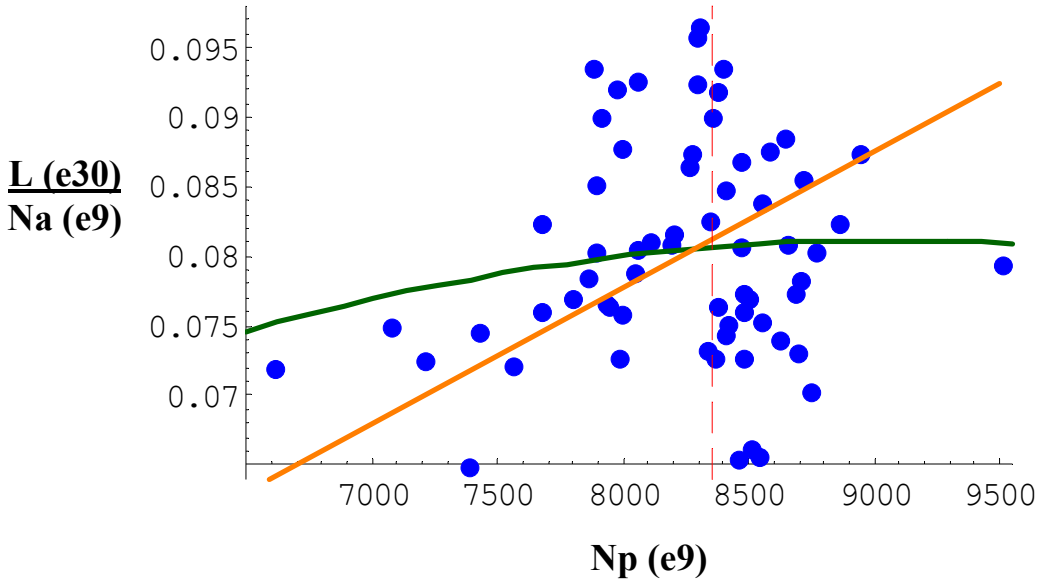
At upstream parasitic IPs the separation is mainly vertical (~2σx), at the downstream - horizontal

To minimize excitation of 5th order resonances separation should be increased vertically at the upstream IPs and horizontally at the downstream IPs



Driving term of 5Qx resonance from upstream IP at 3σ amplitude as function of the separation angle

How much Luminosity we lose to "scallops"?



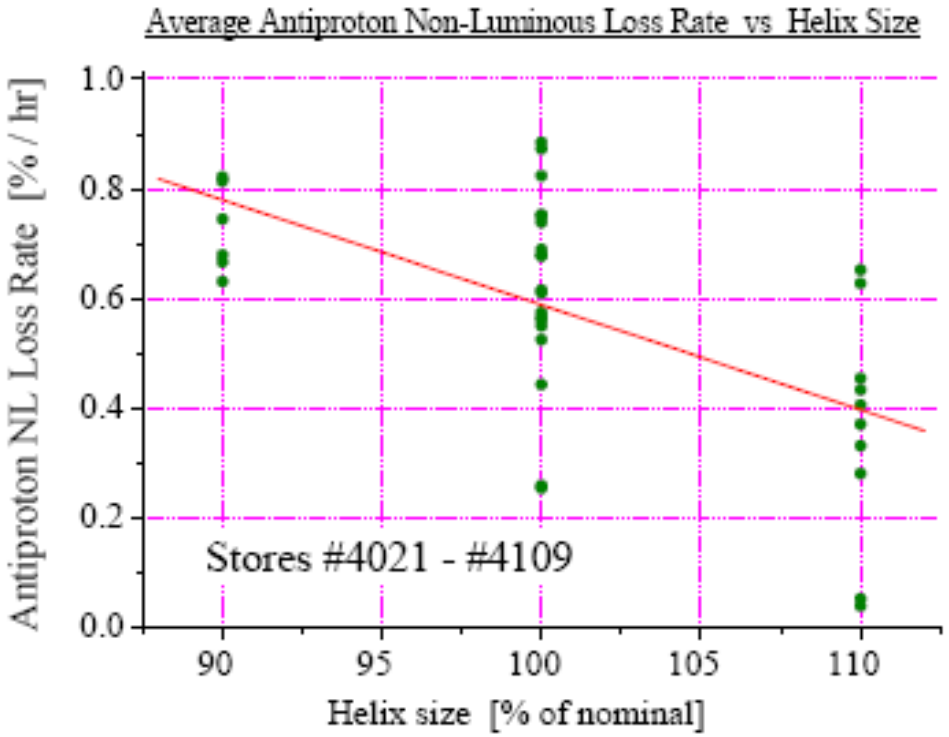
linear fit:
$L/Na=9.7*10^{-6}Np$

quadratic fit:
$L/Na=1.8*10^{-5}Np \times(1-5.5*10^{-5}Np)$

Specific Luminosity in Stores with β^*=28cm (4395-4590)

- quadratic fit over-dramatize the beam-beam effect on luminosity
- according to the linear fit L=240e30 at Na=2500e9 and Np=10000e9
- however, there is an obvious reduction in L/Na at Np>8500e9, to achieve such luminosity "scallops" must be eliminated

Effect of Helix Size on Losses

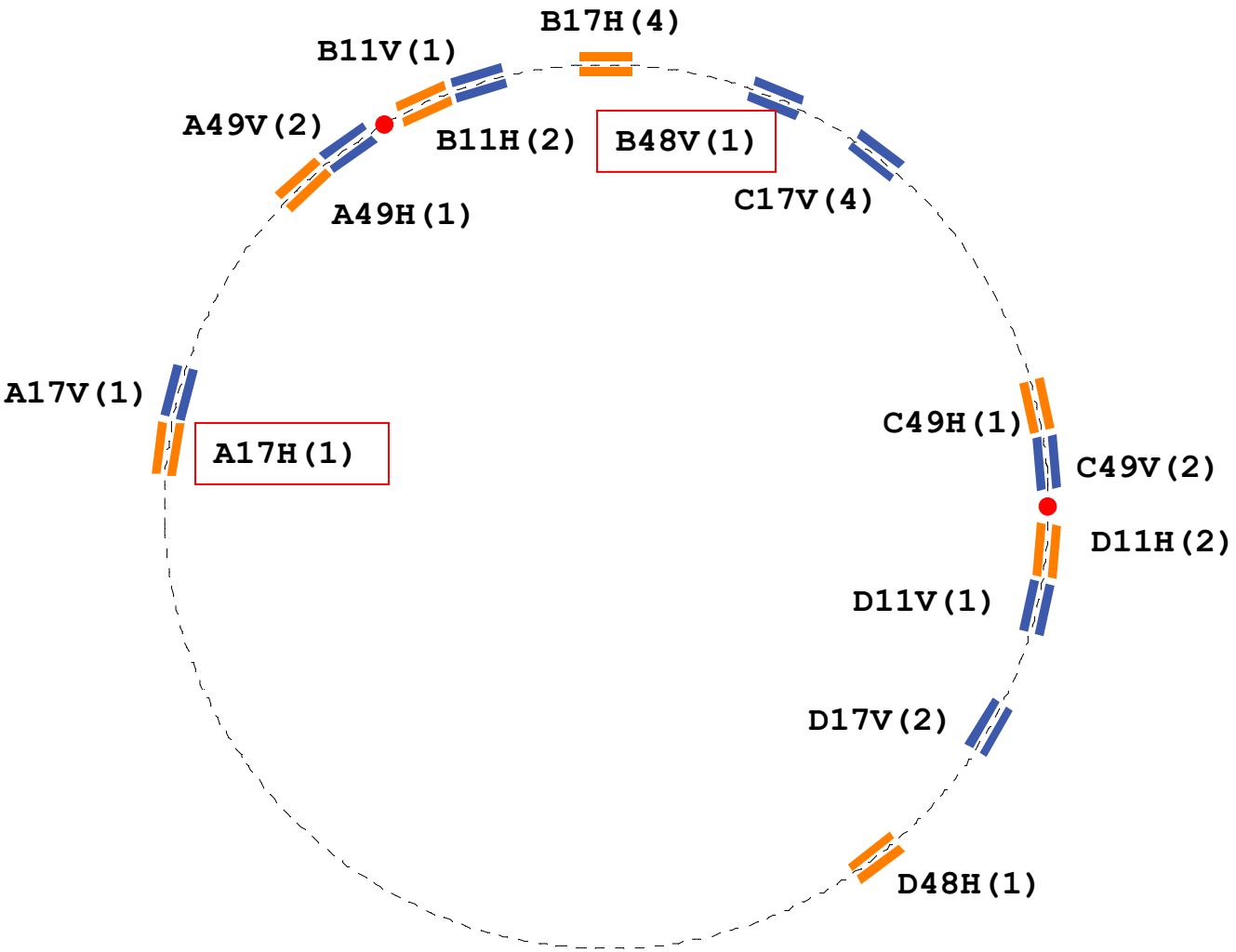


Increase in separation noticeably reduce pbar losses (courtesy of R.Moore)

Beam-Beam Effects at Collisions - Cures

- Compress pbar tune footprint with TELs (S.Kamerdzhiev)
- Achieve intrinsic cancellation of 12^{th} order resonances by redistribution of phase advances between IPs
- Move tunes to a new working point (A.Valishev)
- Increase beam separation with additional separators

Schematic of Separator Arrangement



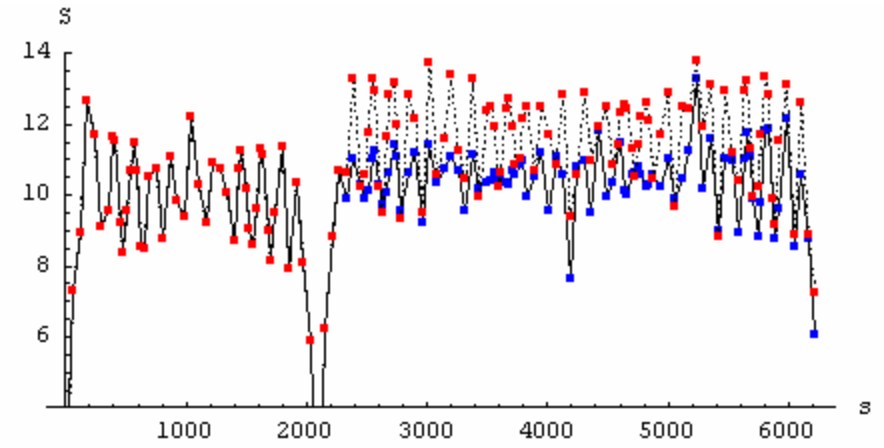
Collision Helix Status

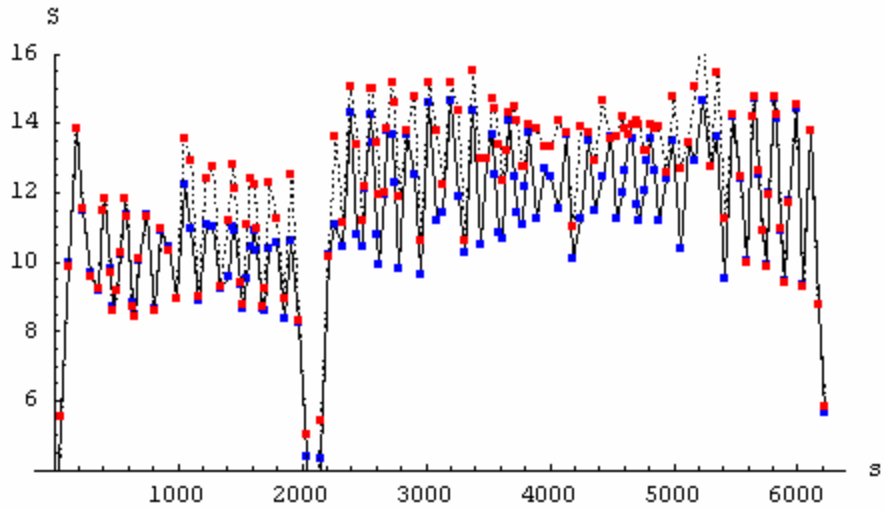
date	B11H	B17H	C49H	D11H	D48H	A49H
05/13/04	105	45.72	104	96	61.96	104
01/07/05	99.43	43.33	100	96.15	64.75	100
01/06/06	100	58.99	83.24	88.70	29.07	100

date	B11V	C17V	C49V	D11V	D17V	A17V	A49V
05/13/04	110	56.1	102.6	115	-	20.44	86.86
01/07/05	100	54.37	94.8	100	92.7	40	100
01/06/06	98.19	47.76	87.23	97.62	98.38	13.61	101.2

Elimination of beta-beating with introduction of β^*=28cm optics had an unwanted effect on the helix closure reducing separation at parasitic IPs around D0

Collision Helix Upgrade





β*=35cm optics (design):

- 12 separators
- 13 separators (D17V+)

β*=28cm optics (fit):

- 13 separators
- 15 separators (A17H & B48V +)

- more than 10% increase in separation at the nearest parasitics

Prospects

- Proton losses at 150 can be reduced by
  - shifting proton tunes above 7/12
  - commissioning "5-star" helix
- Losses during squeeze can be reduced by
  - changing collision helix polarity (possible after CDF roman pots removal)
  - employing new separators
- Emittance blowup and nonluminous losses can be reduced by
  - increasing separation at nearest parasitics with new separators
  - intrinsic cancellation of 12^{th}-order resonances
  - moving to a new working point (both 1/2 and 2/3 options look promising)

Luminosity over 240e30 is quite feasible with the achieved number of pbars!