SNOWMASS 2001

the future of particle physics

Beam-beam experiments with HERA's proton and electron beams

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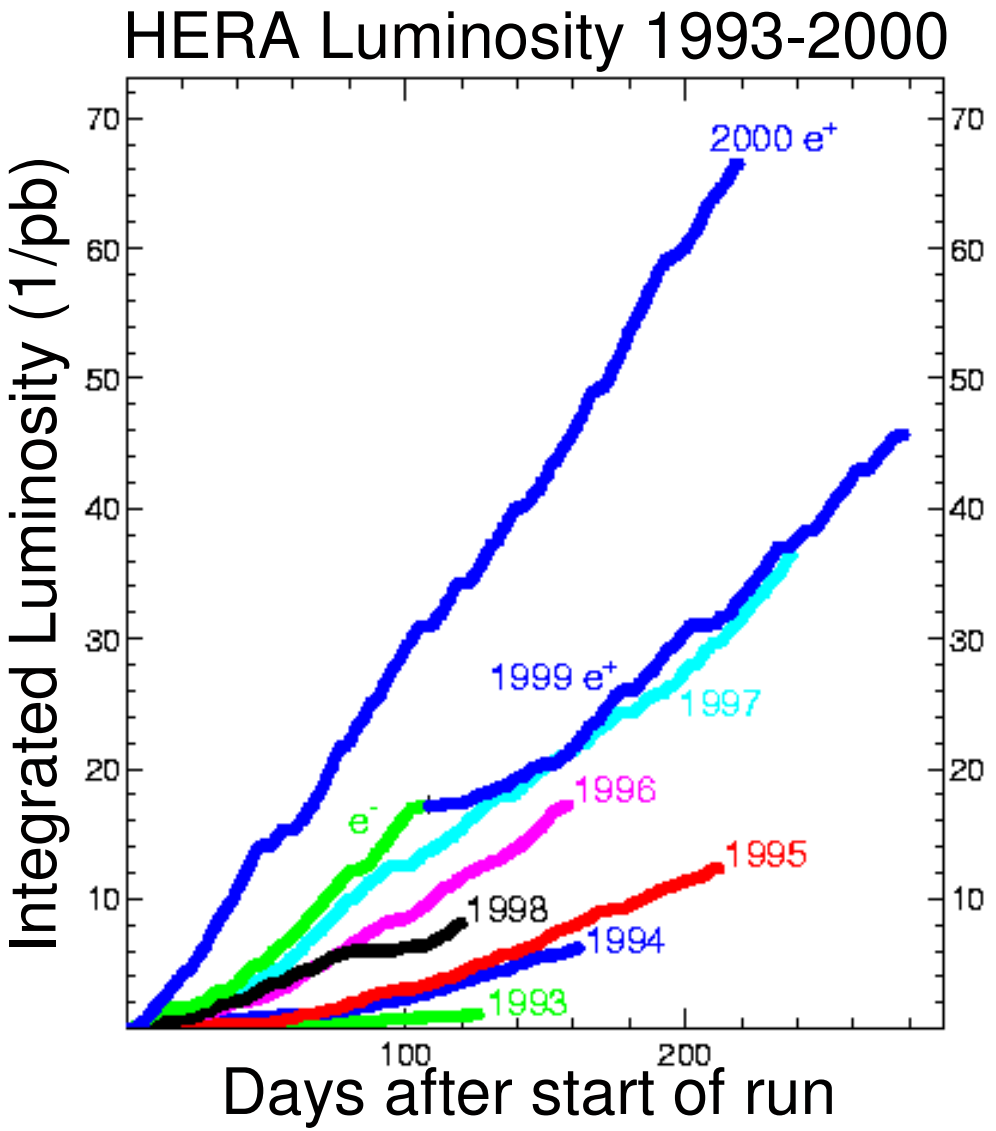
Development of the Luminosity

Linear increase of the integrated Luminosity

The time for a luminosity upgrade of HERA has come



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The HERA Lumi-Upgrade

$$\mathcal{L} = \frac{N^p_{ppb} \cdot I^e}{4\pi \cdot e \cdot \epsilon_p} \frac{1}{\sqrt{\beta_{px} \cdot \beta_{py}}} \qquad \begin{pmatrix} \sigma_e = \sigma_p \\ \epsilon_{px} = \epsilon_{py} \end{pmatrix}$$

In HERA the β_{px} and β_{py} will be decreased:

- reduced distance of proton IP quads (26m $\rightarrow$ 11m)
- needs most importantly early separation of e–p beams
- separation is simpler for reduced electron emittances (41$\rightarrow$20nm)

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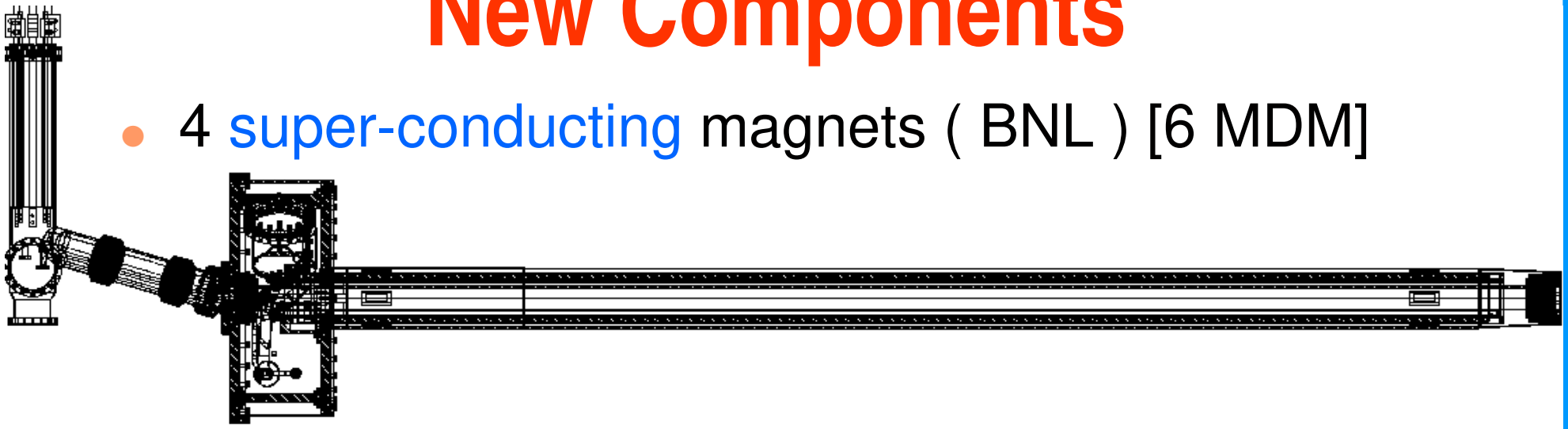
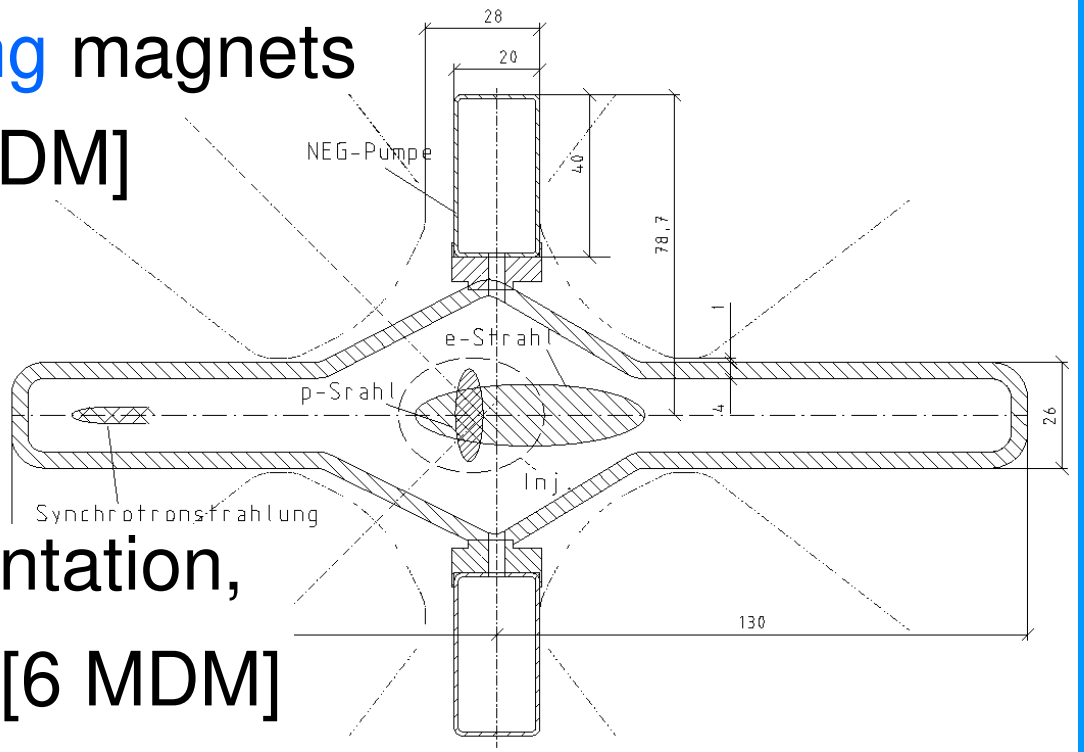
New Components



- 4 super-conducting magnets (BNL) [6 MDM]
- 56 normal-conducting magnets (Eframov Inst.) [6 MDM]
- 448 m UH Vacuum system [6 MDM]
- Absorbers, instrumentation, controls, stands, … [6 MDM]



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Parameters

Parameter	up to 2000		after the upgrade	
	HERA-e	HERA-p	HERA-e	HERA-p
E(GeV)	27.5	920	27.5	920
I(mA)	50	100	58	140
$N_{ppb}(10^{10})$	3.5	7.3	4.0	10.3
n_{tot}/n_{col}	189/174	180/174	189/174	180/174
$\beta_x^\star/\beta_y^\star$(m)	0.90/0.60	7.0/0.5	0.63/0.26	2.45/0.18
ϵ_x(nm)	41	$\frac{5000}{\beta\gamma}$	20	$\frac{5000}{\beta\gamma}$
ϵ_y/ϵ_x	10%	1	17%	1
$\sigma_x/\sigma_y(\mu$m)	192/50	189/50	112/30	112/30
σ_z(mm)	11.2	191	10.3	191
$2\Delta\nu_x$	0.024	0.0026	0.068	0.0031
$2\Delta\nu_y$	0.061	0.0007	0.103	0.0009
$\mathcal{L}(\mathrm{cm}^{-2}\mathrm{s}^{-1})$	$16.9{\cdot}10^{30}$		$75.7{\cdot}10^{30}$	
$\mathcal{L}_s(\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{mA}^{-2})$	$0.66{\cdot}10^{30}$		$1.82{\cdot}10^{30}$	

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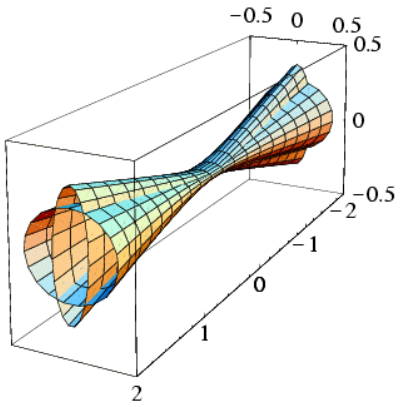
Potential Problems

Focusing:

- Dynamic Aperture OK?
- Polarization OK?, Luminosity OK?
- Can HERA be handled well?

f_{RF} increase:

- Polarization OK?, Luminosity OK?



- Too strong beam-beam force on p?
- Too strong beam-beam force on e?

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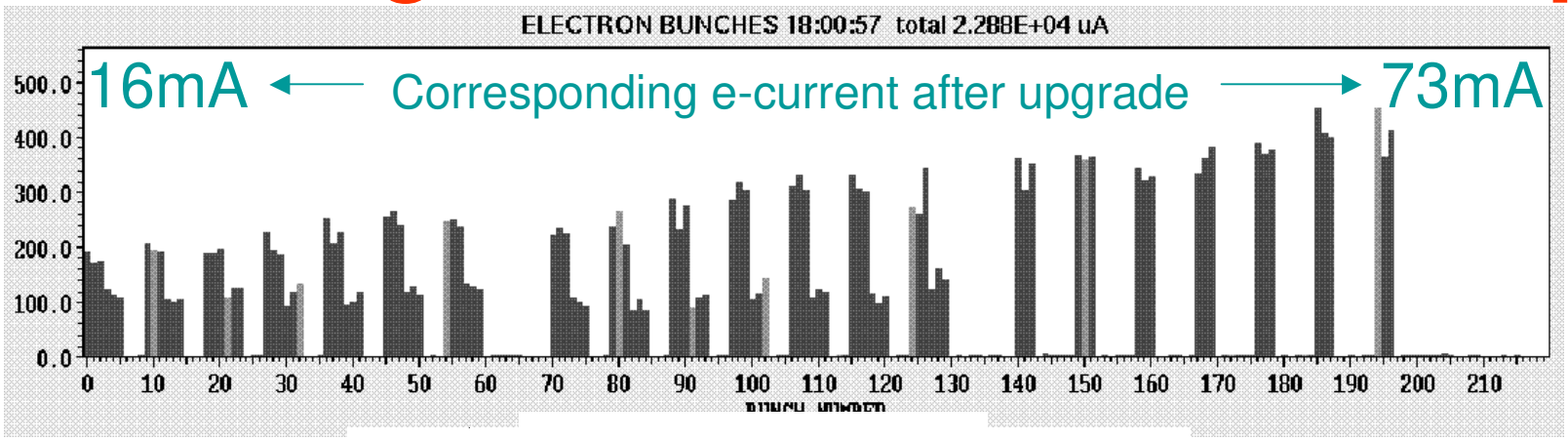
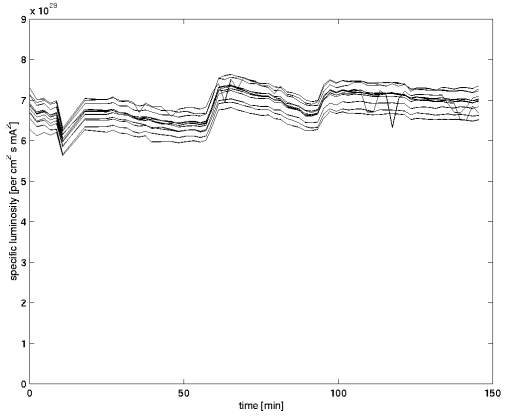
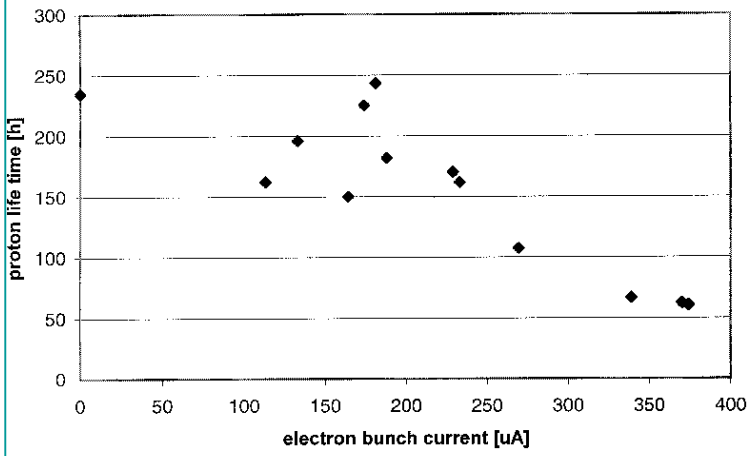
Too Strong Beam-Beam Force on p?

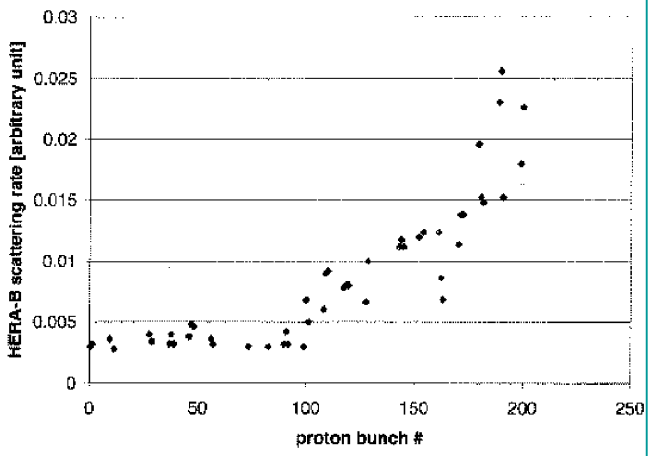




$\mathcal{L}_S$ is independent of e-current



$\mathcal{T}_p$ depends on e-current



Tails depend on e-current

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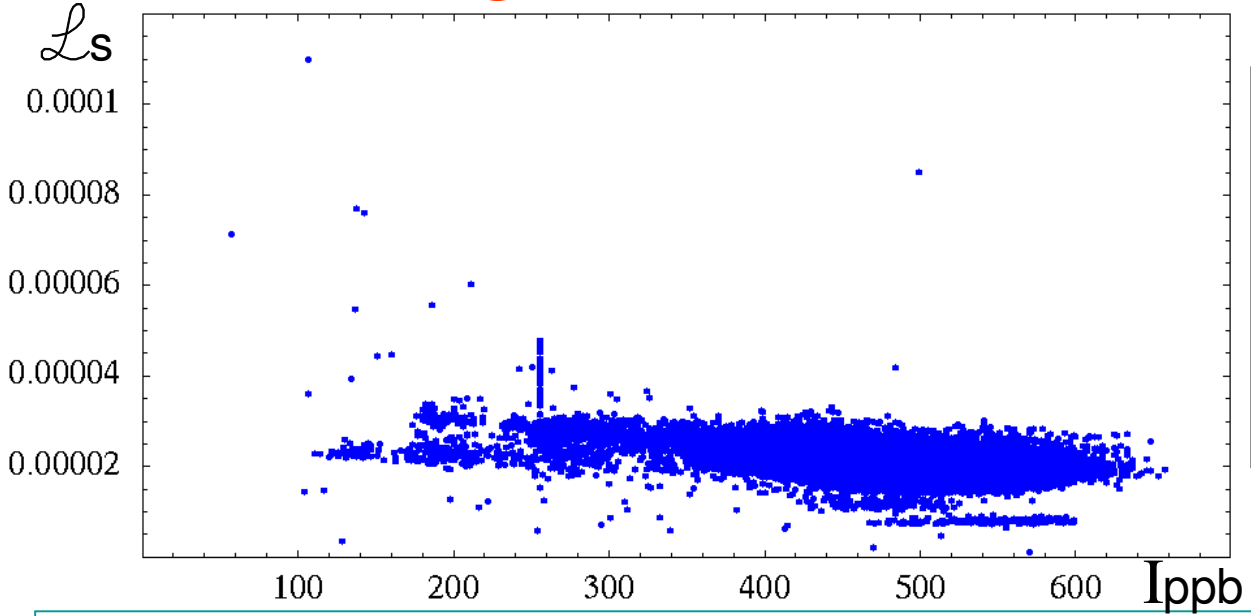
Too Strong Beam-Beam Force on e?



So far no reduction of $\mathcal{L}_S$ by the bunch current

β_x^e	β_y^e	$\mathcal{L}_s^{ZEUS}$ (without H1)	$\mathcal{L}_s^{ZEUS}$ (with H1)	$\Delta\Phi \in [0, 2\pi]$	ΔQ_x^e	ΔQ_y^e
0.9m	0.6m	$7.1 \cdot 10^{29}$	$7.0 \cdot 10^{29}$	$[7.00, 7.20] \cdot 10^{29}$	0.0106	0.0311
1.0m	0.7m	$6.78 \cdot 10^{29}$	$7.0 \cdot 10^{29}$	$[6.67, 6.89] \cdot 10^{29}$	0.0118	0.0363
2.2m	0.9m	$5.18 \cdot 10^{29}$	$5.5 \cdot 10^{29}$	$[4.97, 5.42] \cdot 10^{29}$	0.0259	0.0467

No reduction of $\mathcal{L}_S$ by the second experiment

No reduction of $\mathcal{L}_S$ by a larger β-funktionen

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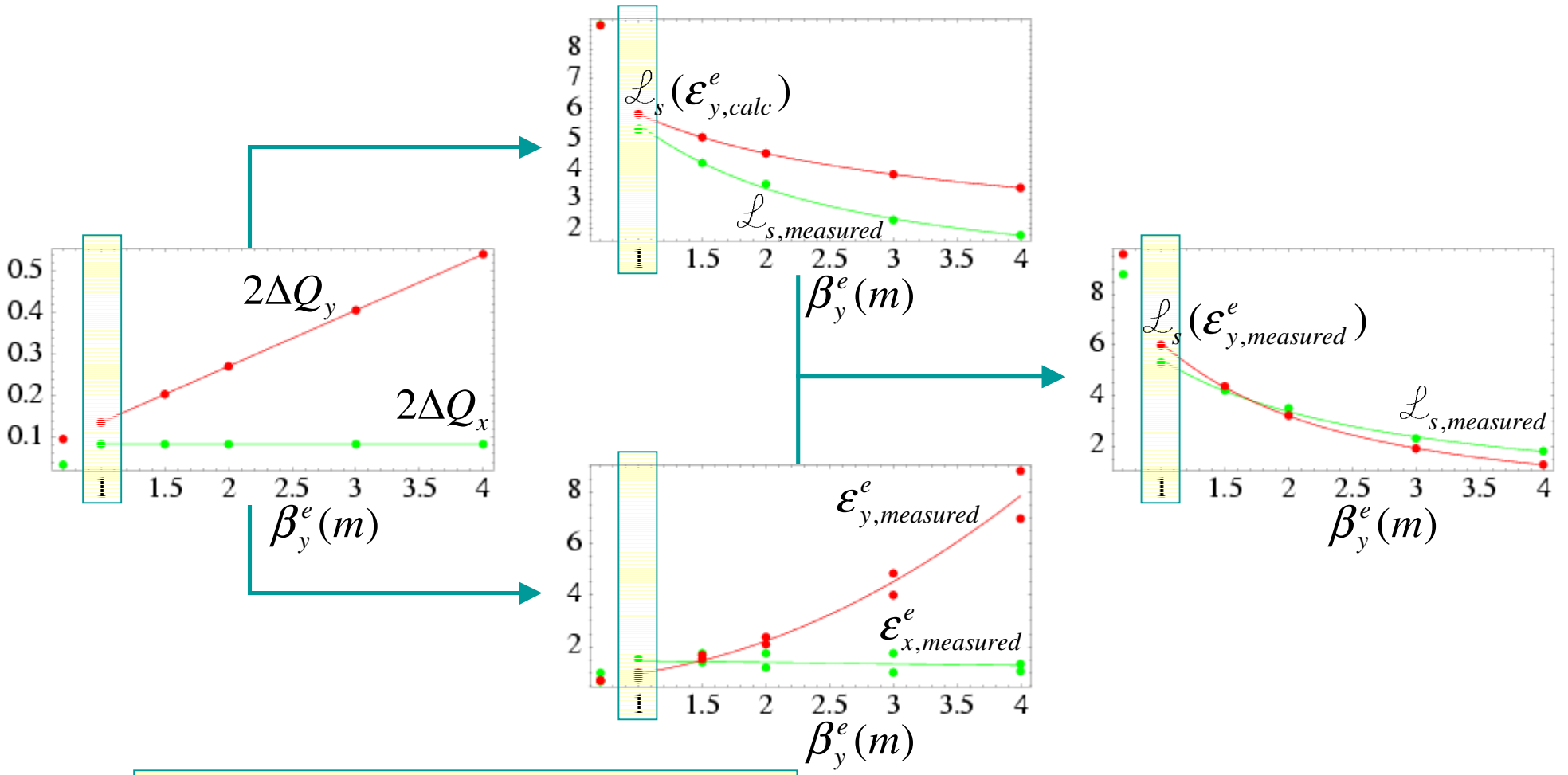
Where are the Beam-Beam Limits?



Upgrade and Ip=140mA: emittance starts to grow

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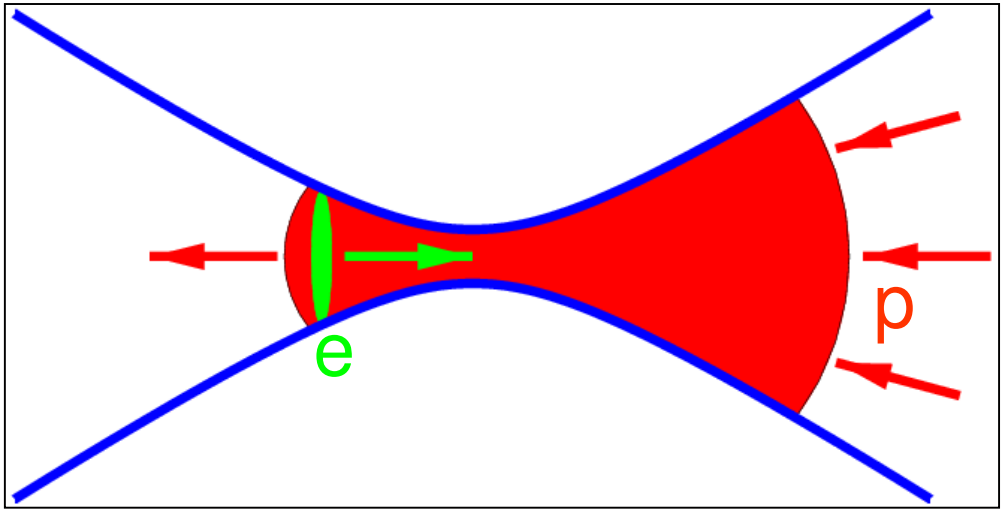
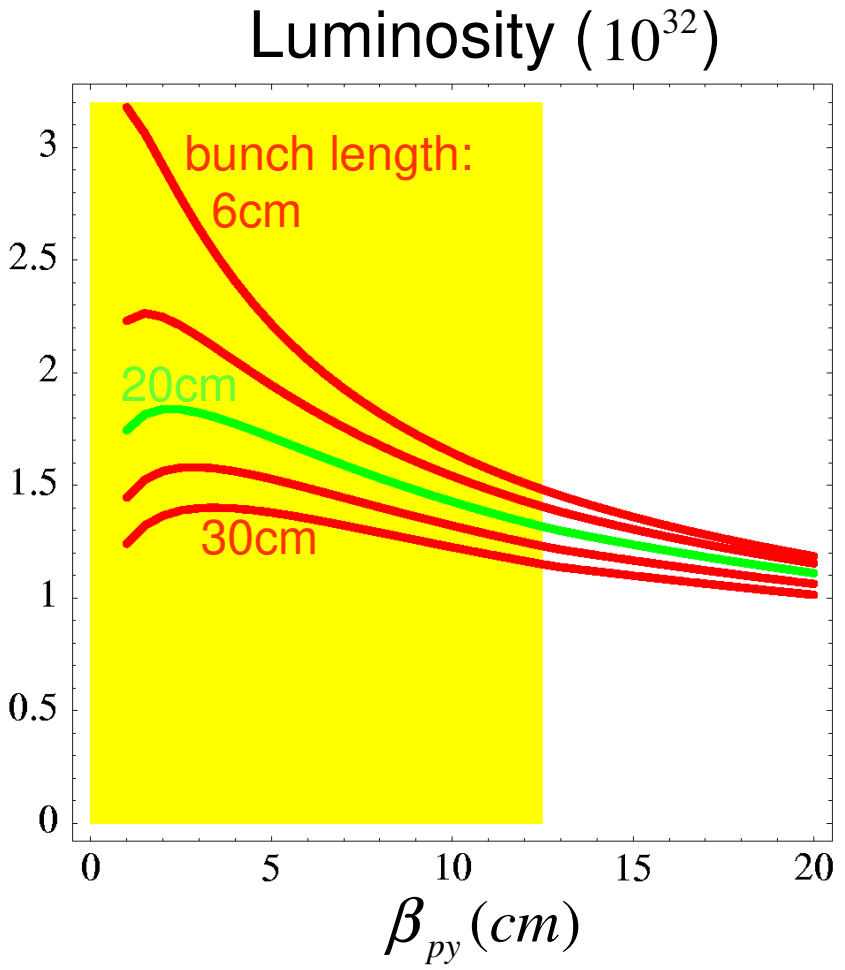
Lumi Reduction by Hourglass Effect



Length 19cm: $\frac{\mathcal{L}(\beta_{py} = 12.5cm)}{\mathcal{L}_0} = 1.75$

12cm: $\frac{\mathcal{L}(\beta_{py} = 12.5cm)}{\mathcal{L}_0} = 1.9$



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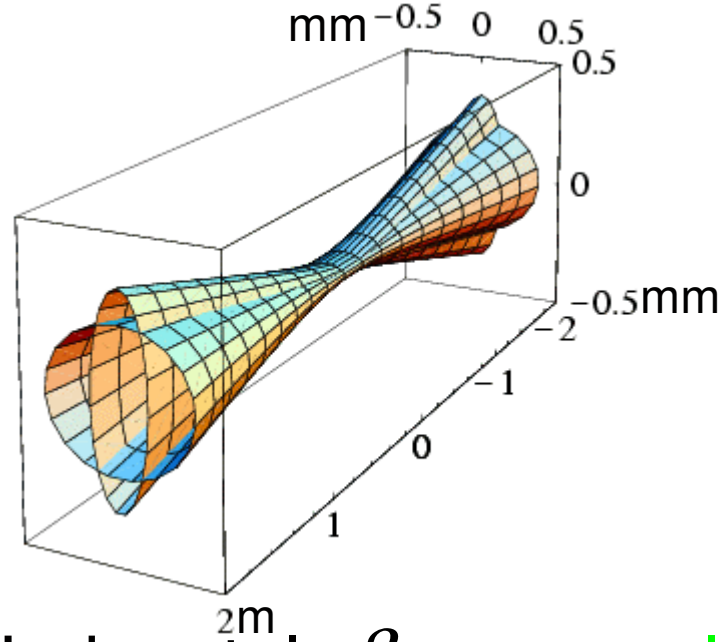
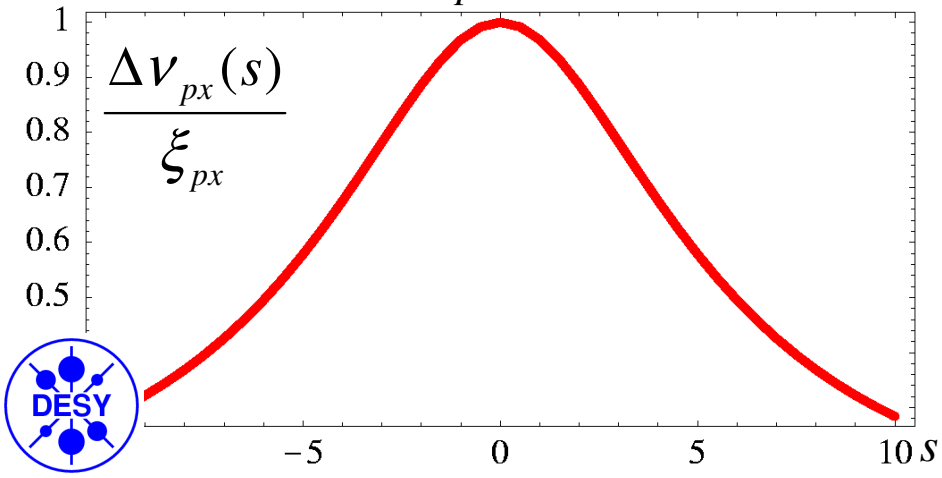
Tuneshift Change by Hourglass Effect

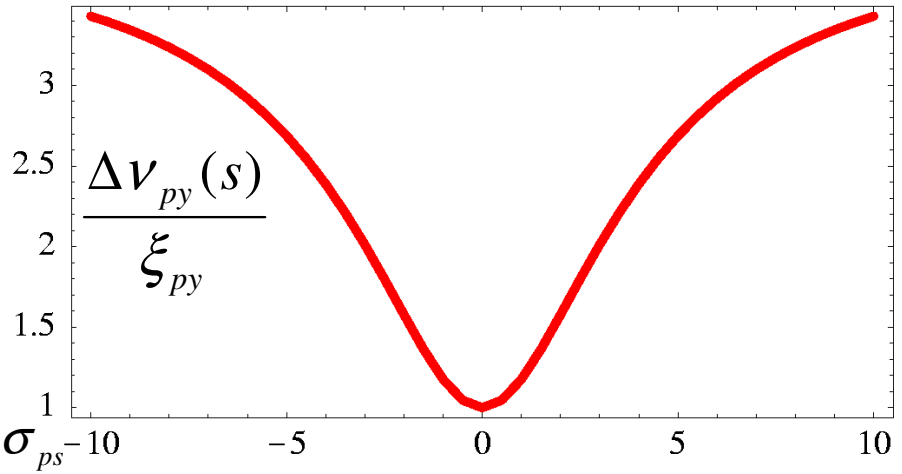


Protons	Electrons
$\beta_{px} = 2.45m$	$\beta_{ex} = 0.63m$
$\beta_{py} = 0.18m$	$\beta_{ey} = 0.26m$

Horizontal: β_{px} grows slower



Vertical: β_{py} grows faster



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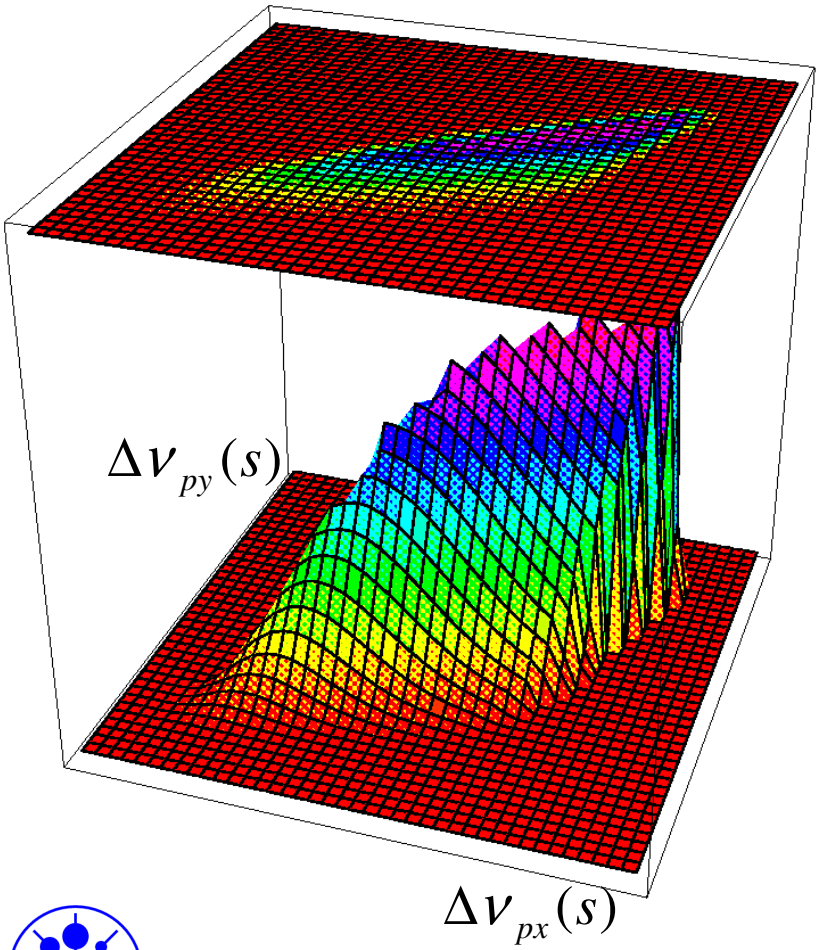
Tune Shift with Bunch Length Effect



How will the tune shift parameters change and have these been analyzed by accelerator experiments ?

	$\Delta\nu_{x0}$	$\Delta\nu_x(5)$	$\Delta\nu_{y0}$	$\Delta\nu_y(5)$
initial p	0.0016	0.00081	0.00044	0.00011
ultimate p	0.0022	0.00060	0.00059	0.00147
studies p	0.0022	0.0017	0.00061	0.00080
initial e	0.024	0.024	0.045	0.044
ultimate e	0.034	0.036	0.069	0.070
studies e	0.041	0.041	0.085	0.083

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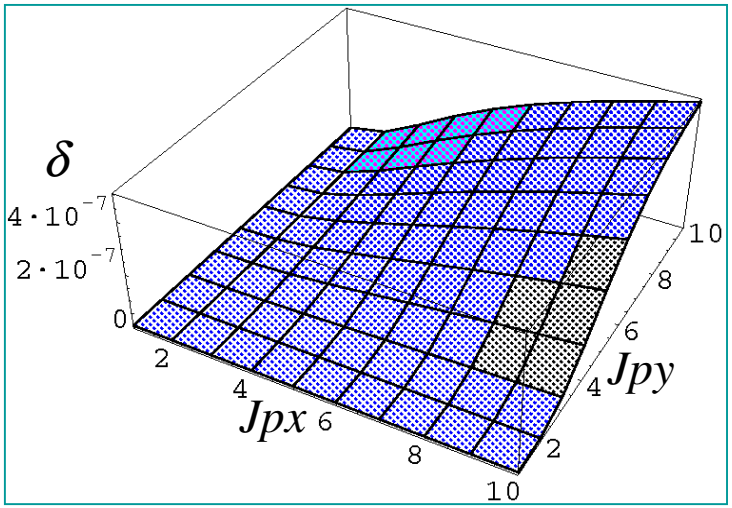
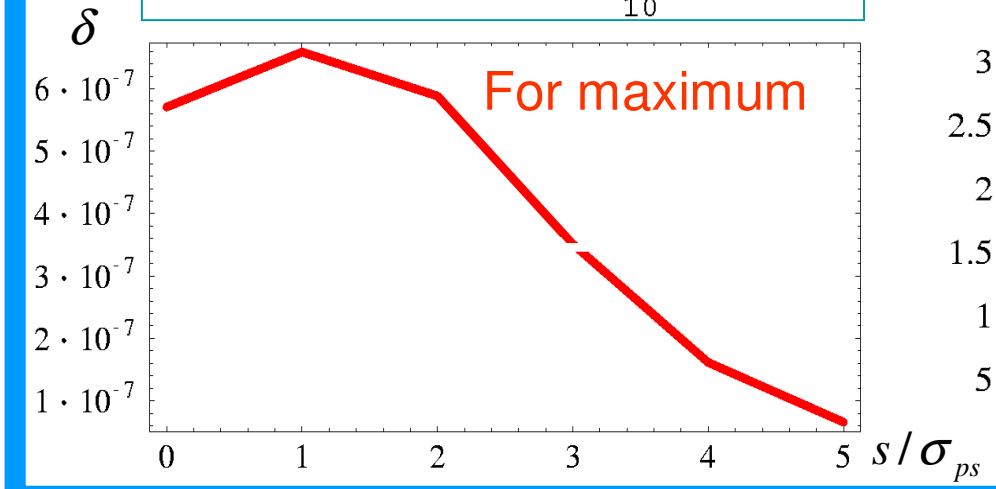
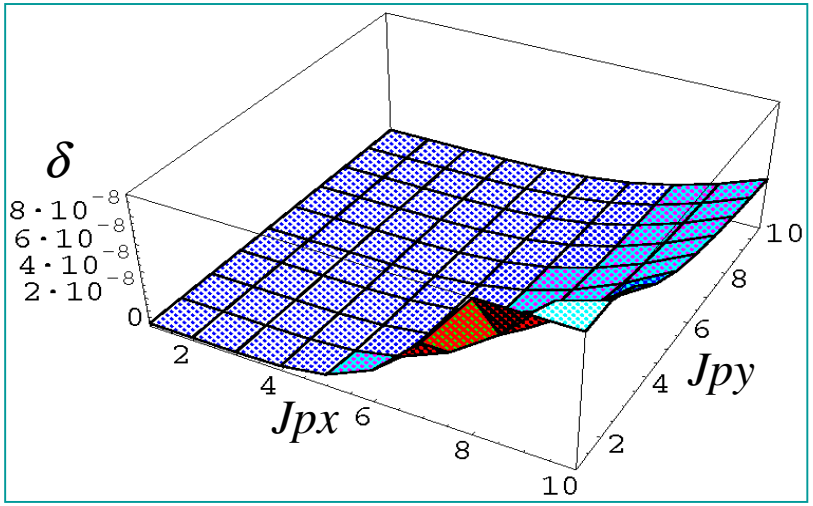
Bunch Length Dependent Resonances

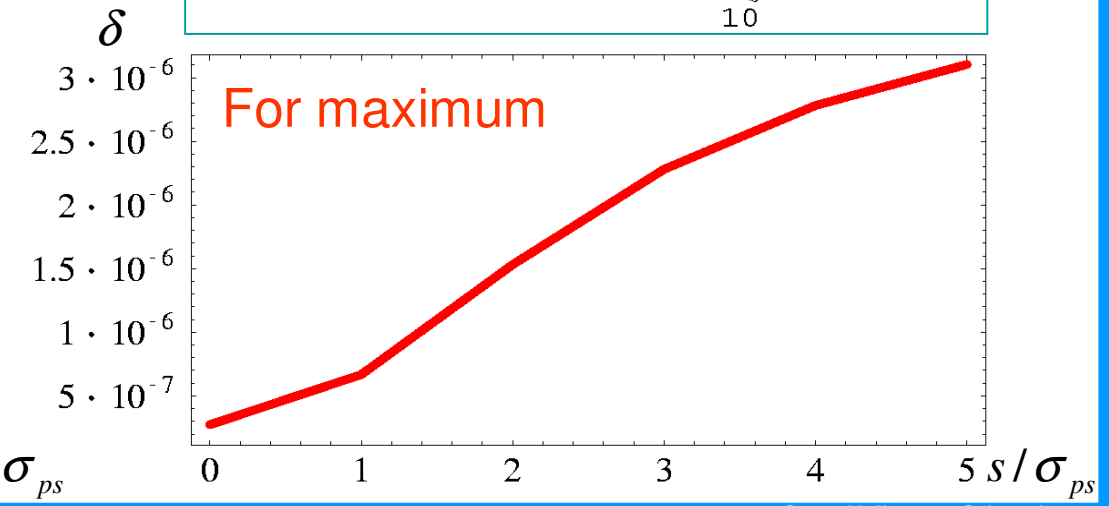
6Qx+4Qy Resonance





10Qy Resonance





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Resonances with Bunch Length Effect

	initial	ultimate	studies
$\delta(4Q_{ex}+2Q_{ey})$	0.00020	0.00031	0.00045
$\delta(2Q_{ex}+8Q_{ey})$	0.000012	0.000018	0.000036

(10^{-8})	δ_0^i	δ_{max}^i	δ_{max}^u	δ_{max}^s
$\delta(10Q_{px})$	175	175	230	220
$\delta(8Q_{px}+2Q_{py})$	73	73	97	99
$\delta(6Q_{px}+4Q_{py})$	43	55	65	60
$\delta(4Q_{px}+6Q_{py})$	24	55	60	44
$\delta(2Q_{px}+8Q_{py})$	14	65	68	32
$\delta(10Q_{py})$	22	251	300	68
$\delta(14Q_{px})$	3.1	3.1	4.1	4.1
$\delta(12Q_{px}+2Q_{py})$	2.9	2.9	3.8	3.7
$\delta(10Q_{px}+4Q_{py})$	4.4	4.4	5.8	5.8
$\delta(8Q_{px}+6Q_{py})$	5.9	5.5	5.8	5.3
$\delta(6Q_{px}+8Q_{py})$	2.6	7.0	6.0	4.3
$\delta(4Q_{px}+10Q_{py})$	1.2	8.8	8.0	3.2
$\delta(2Q_{px}+12Q_{py})$	0.37	8.5	6.6	1.4
$\delta(Q_{py})$	0.33	22	22	1.7

How will the resonance strength change and have these been analyzed by accelerator experiments ?

All large resonance strength are due to the proton bunch length

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Nominal and Ultimate Parameters

	p	e	p	e
Energy–p/e	920 GeV	27.5 GeV		
Emit. hor/vert	$5/5\pi$ mm mrad	20/3.4 nm	$3.5/3.5\pi$ mm mrad	20/2.7 nm
β^* at IP hor/vert	2.45/0.18 m	0.63/0.26 m	1.7/0.125 m	0.42/0.17 m
Aperture hor/vert	$12/12\,\sigma$	$20/20\,\sigma$	$10/10\,\sigma$	$12/12\,\sigma$
p per bunch and e-cur.	$1.03{\cdot}10^{11}$	58 mA		
Tune shift hor/vert	0.0016/0.0004	0.034/0.051	0.0017/0.0005	0.047/0.069
Bunch Length	191 mm	10.3 mm		
Luminosity	$0.74 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$		$1.3 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	

- The performance goal of HERA is not unrealistic and should not be too hard to achieve.
- A shortfall of beam intensity in the short term can be compensated.

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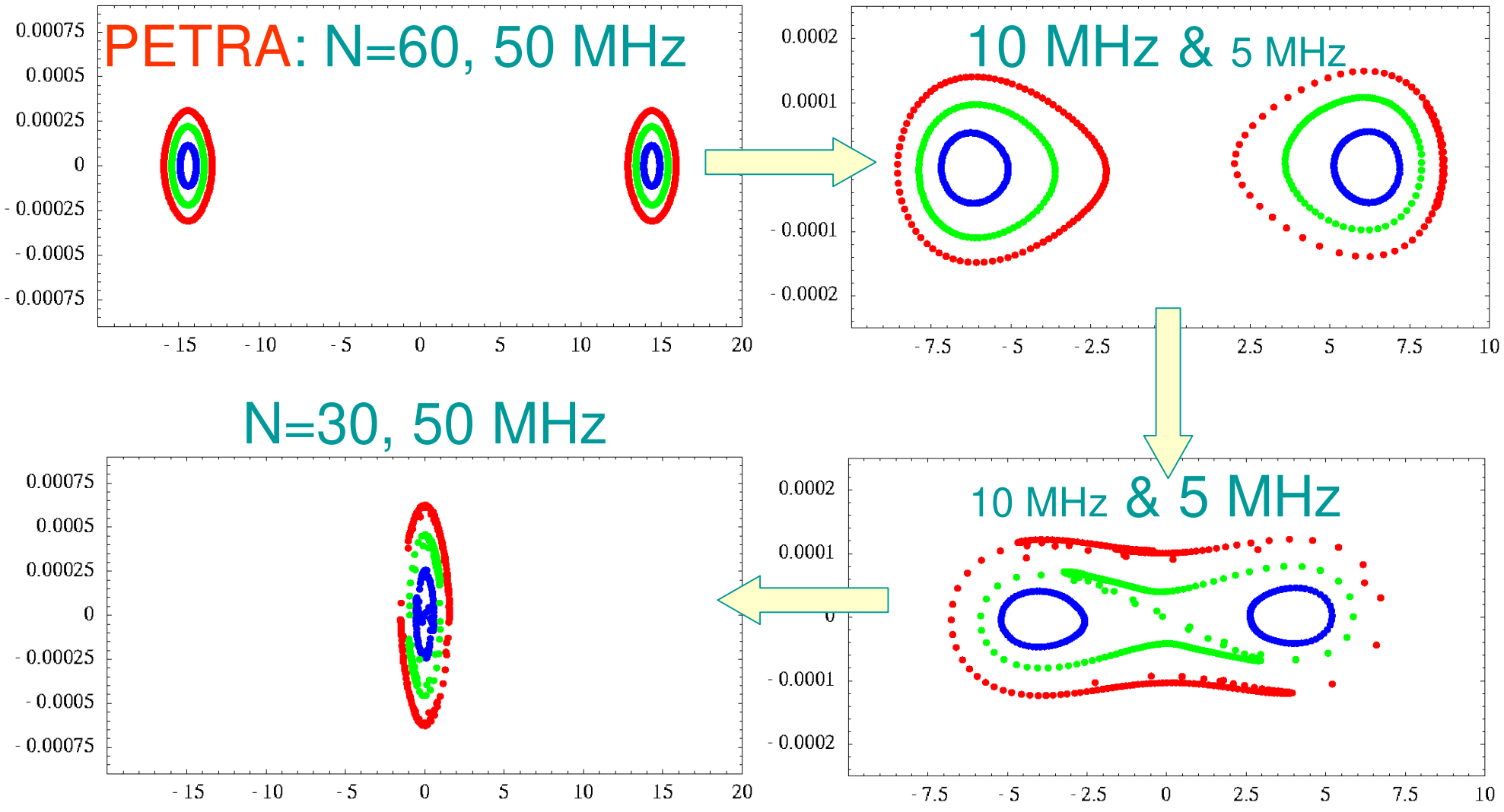
Increasing the Proton Current



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