SNOWMASS 2001

the future of particle physics

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

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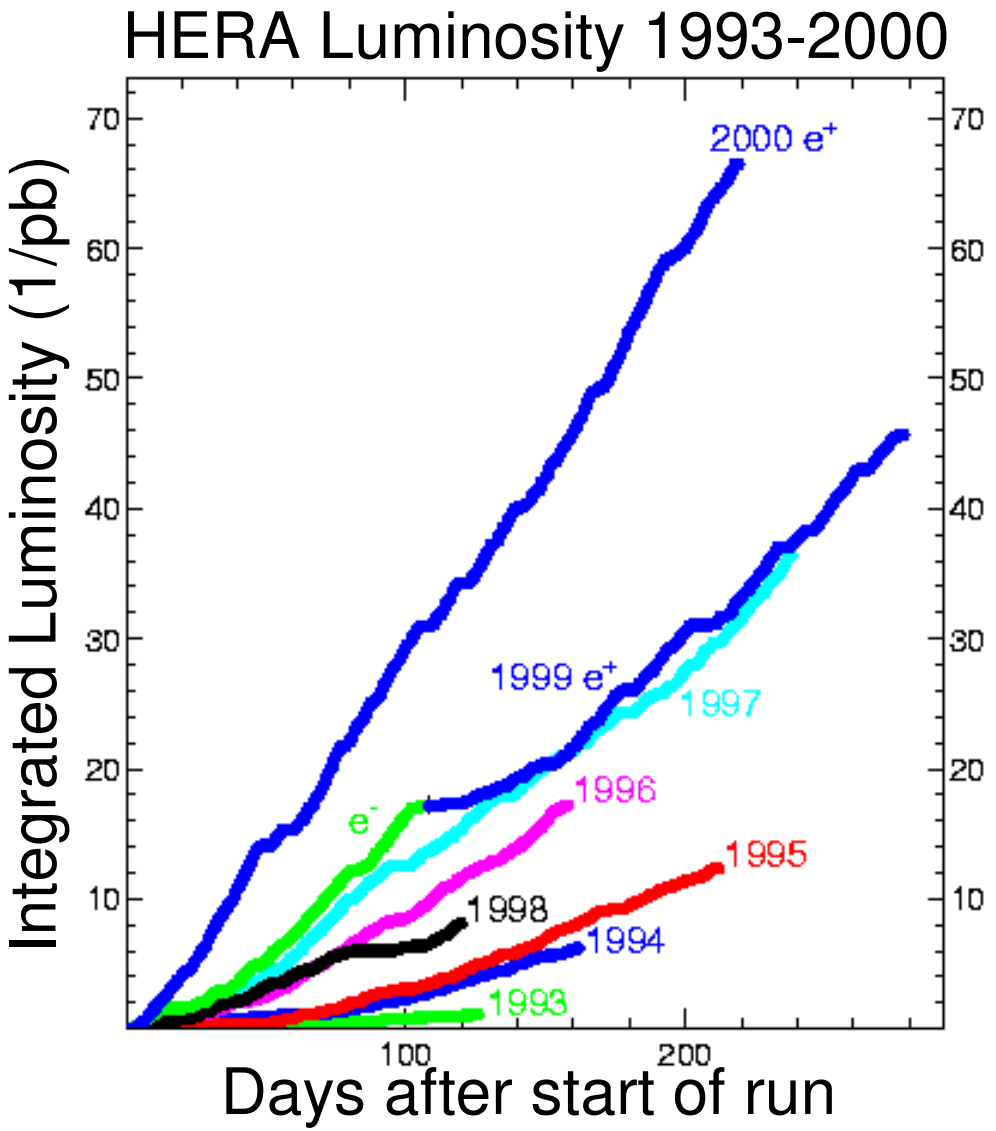
# Development of the Luminosity

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 $\beta_{px}$ and $\beta_{py}$ 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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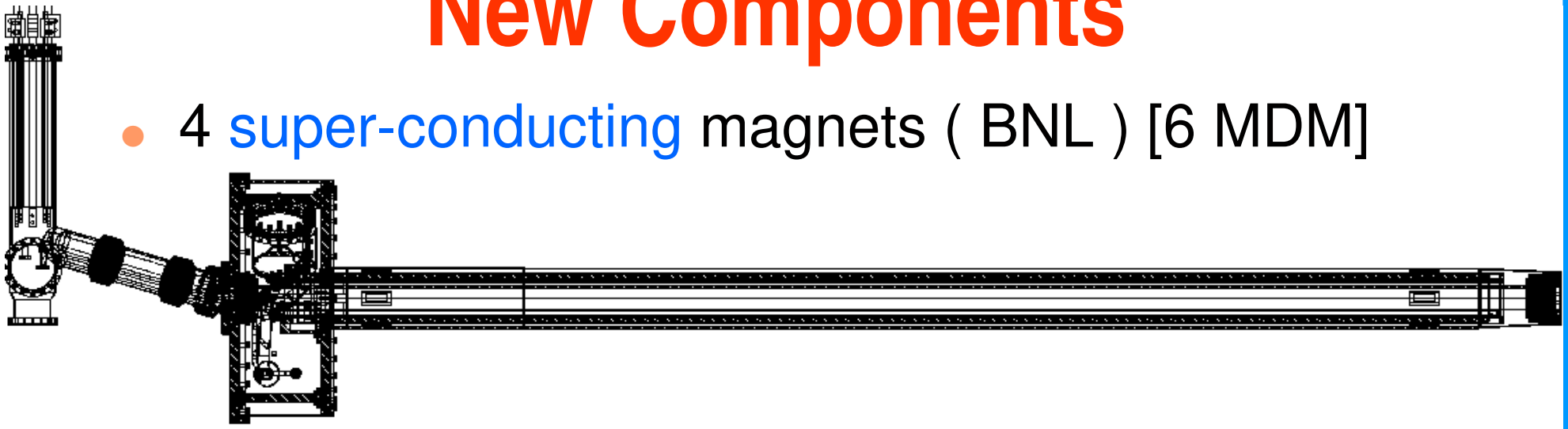
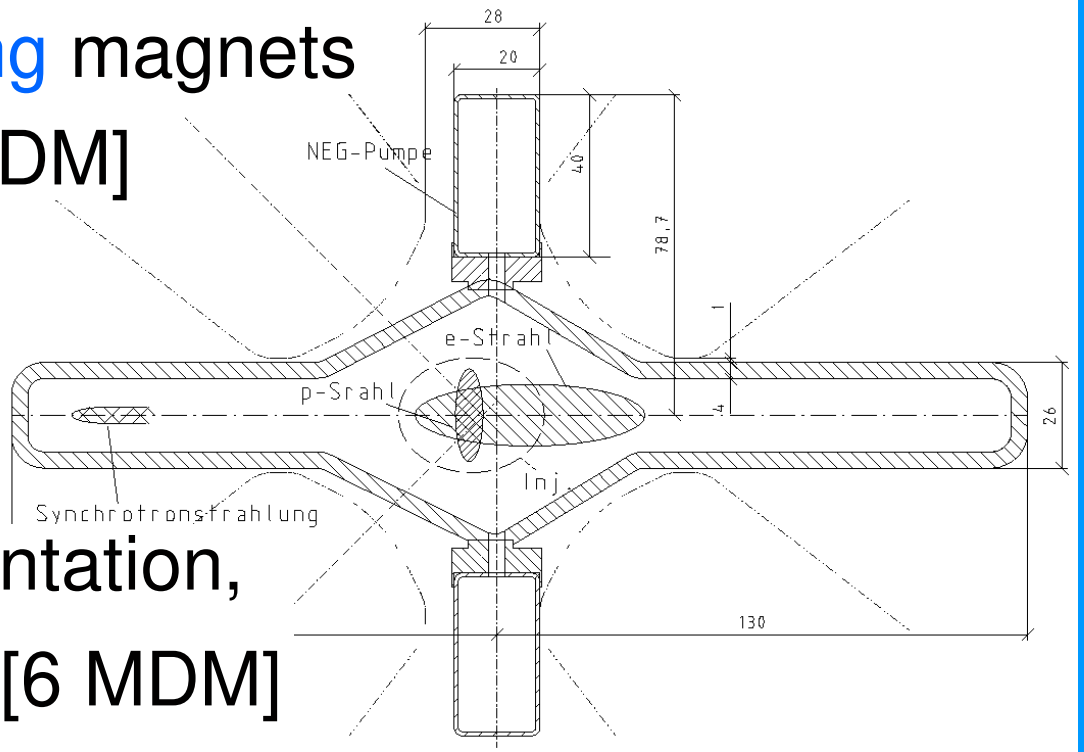
# New Components



- 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 |
| $\epsilon_x$(nm) | 41 | $\frac{5000}{\beta\gamma}$ | 20 | $\frac{5000}{\beta\gamma}$ |
| $\epsilon_y/\epsilon_x$ | 10% | 1 | 17% | 1 |
| $\sigma_x/\sigma_y(\mu$m) | 192/50 | 189/50 | 112/30 | 112/30 |
| $\sigma_z$(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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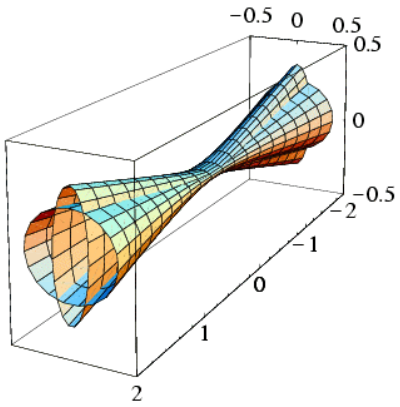
# Potential Problems

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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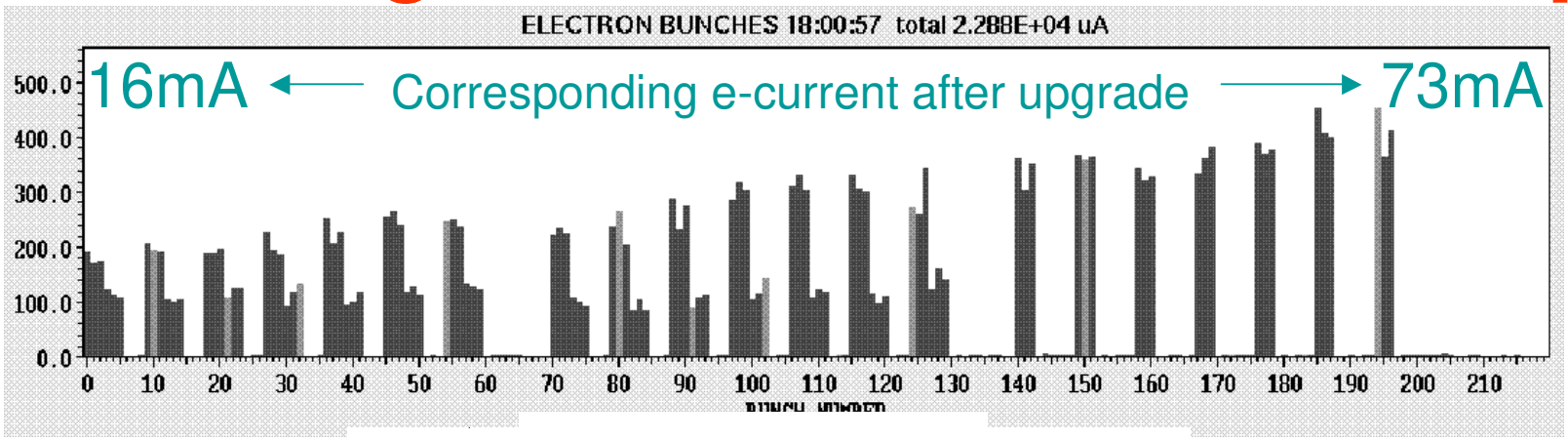
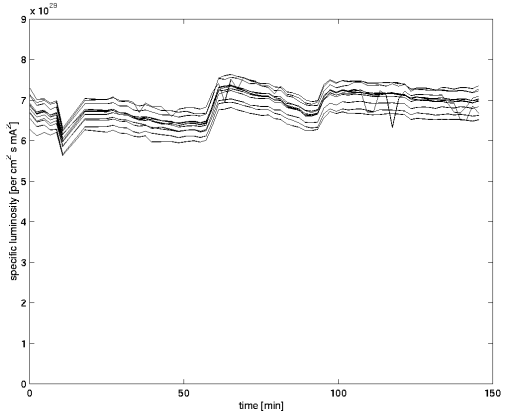
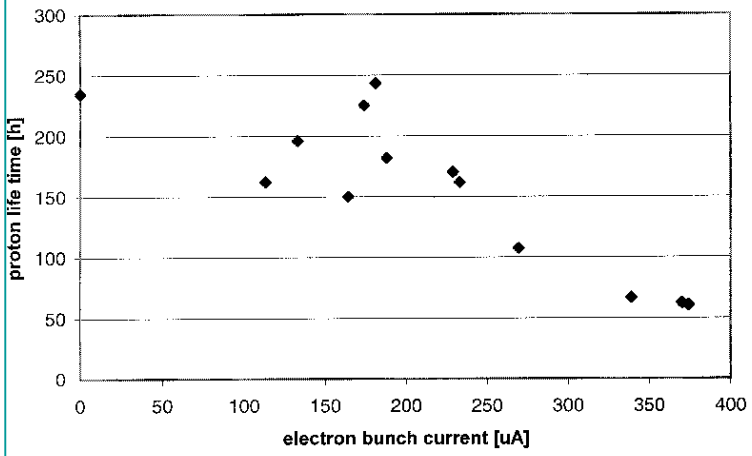
# Too Strong Beam-Beam Force on p?

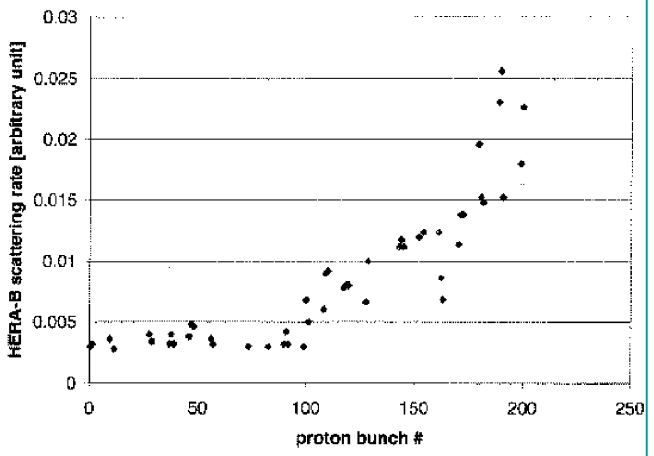



$\mathcal{L}_S$ is independent of e-current




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




Tails depend on e-current

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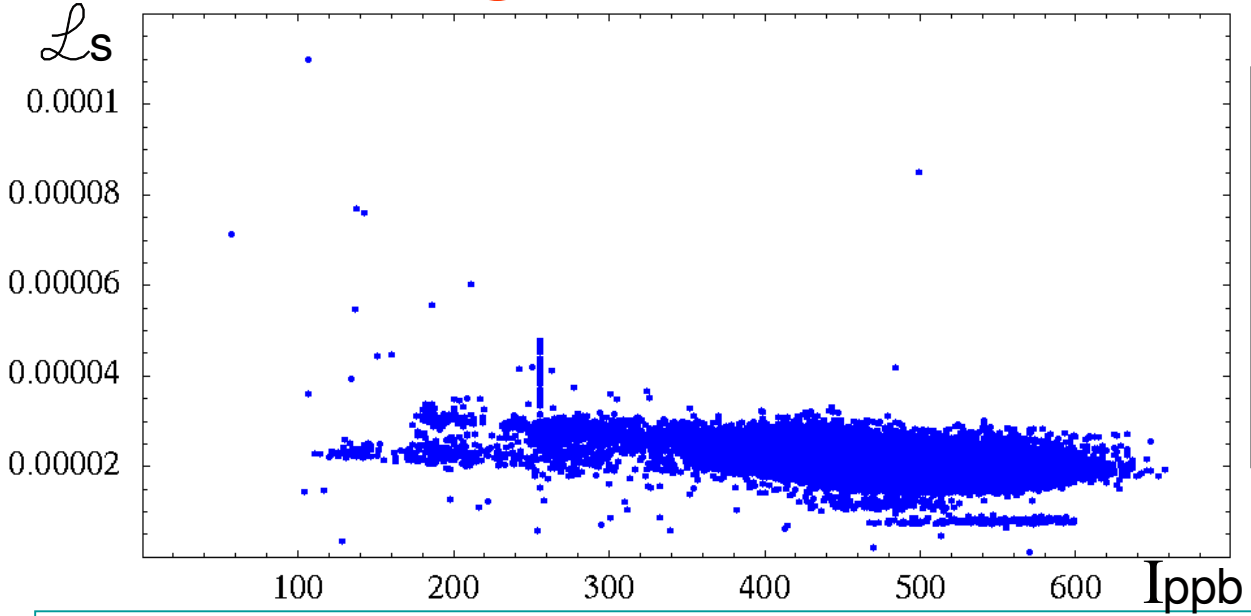
# Too Strong Beam-Beam Force on e?




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

| $\beta_x^e$ | $\beta_y^e$ | $\mathcal{L}_s^{ZEUS}$ (without H1) | $\mathcal{L}_s^{ZEUS}$ (with H1) | $\Delta\Phi \in [0, 2\pi]$ | $\Delta Q_x^e$ | $\Delta Q_y^e$ |
|---|---|---|---|---|---|---|
| 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 $\beta$-funktionen

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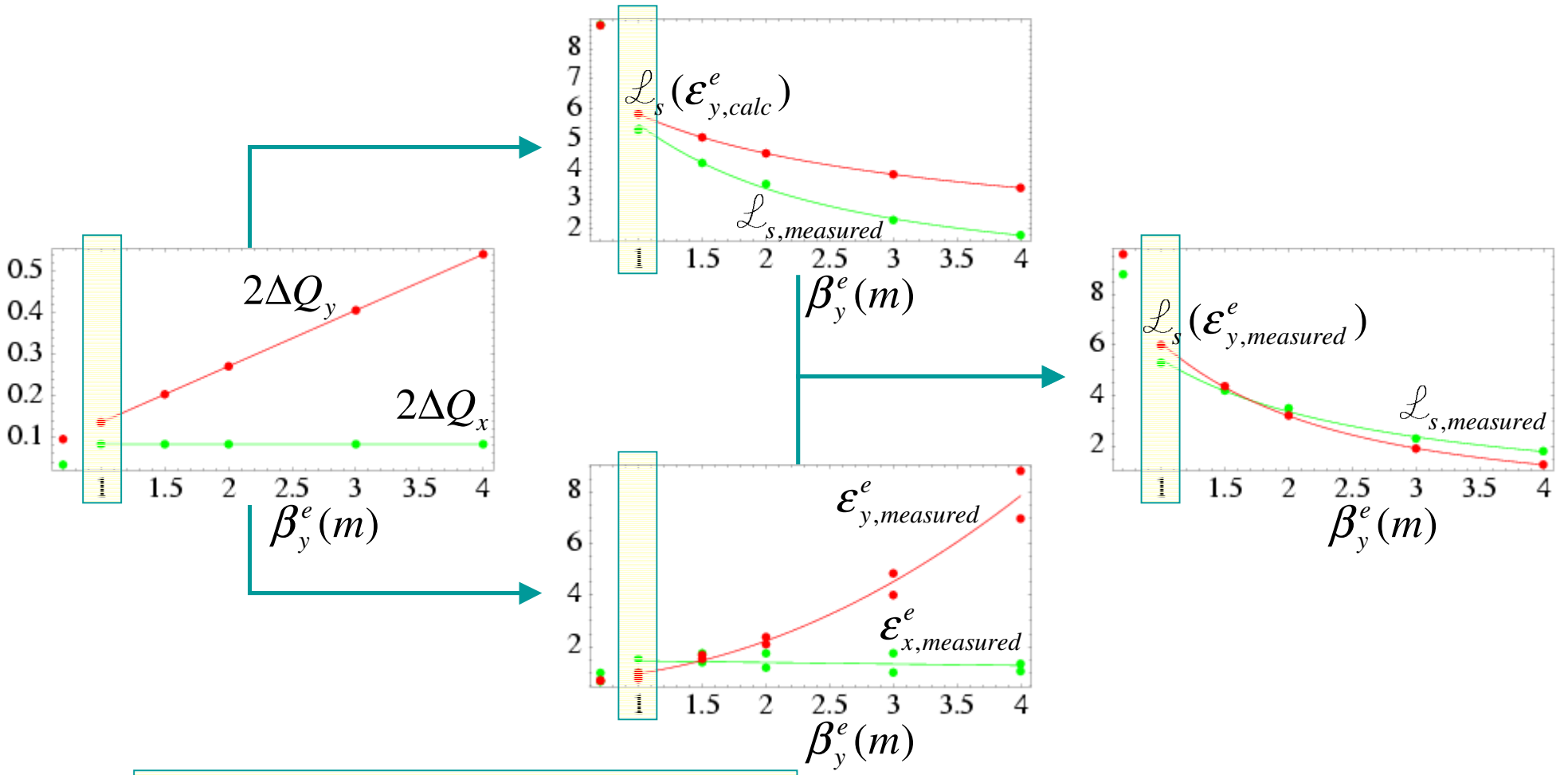
# Where are the Beam-Beam Limits?




Upgrade and Ip=140mA: emittance starts to grow

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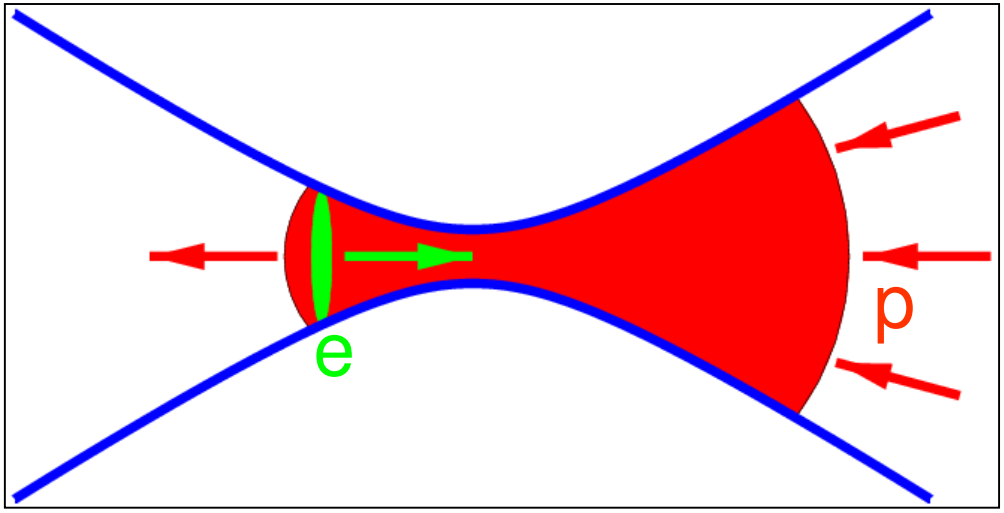
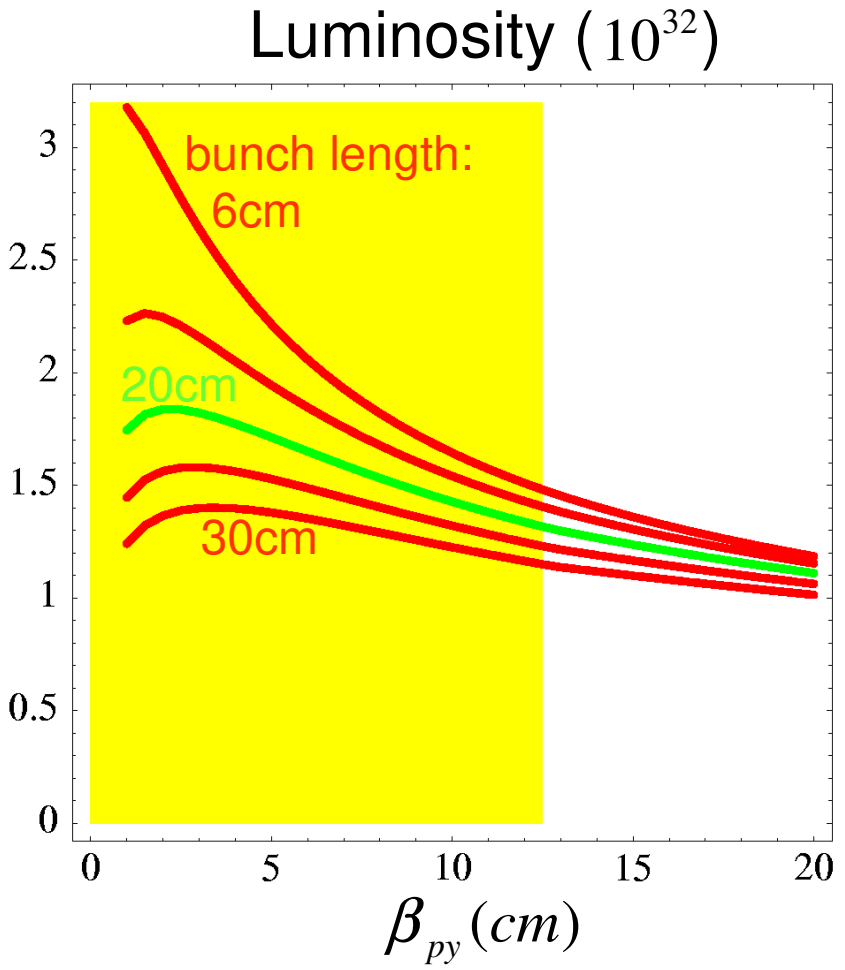
# Lumi Reduction by Hourglass Effect




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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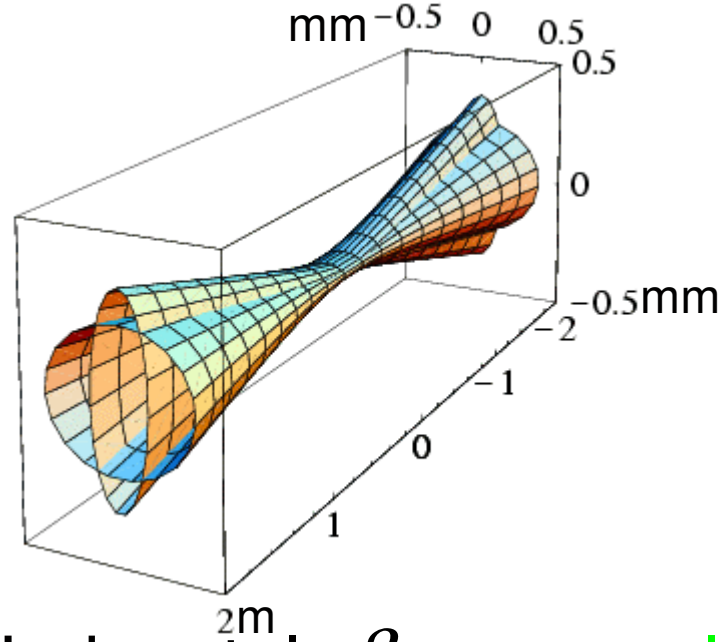
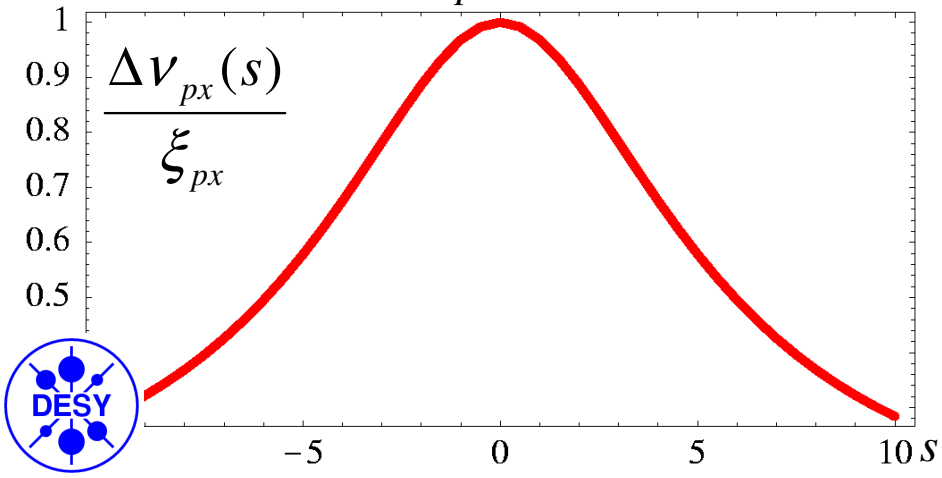
# Tuneshift Change by Hourglass Effect

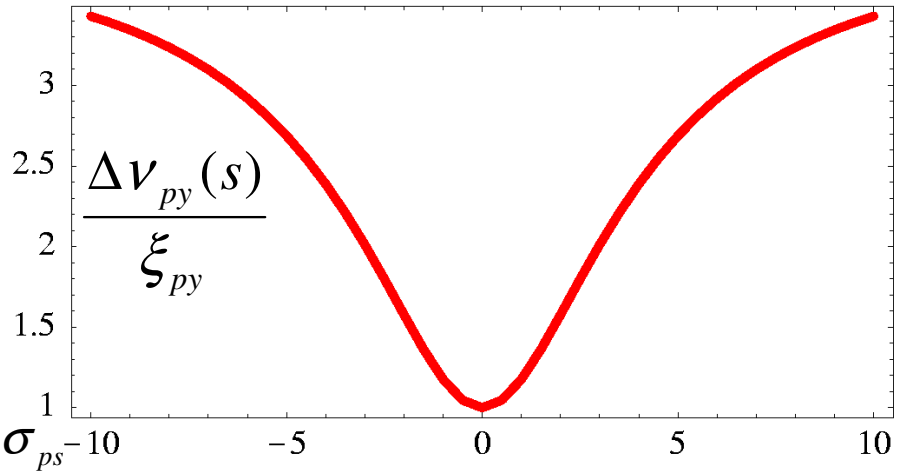



| Protons | Electrons |
|---|---|
| $\beta_{px} = 2.45m$ | $\beta_{ex} = 0.63m$ |
| $\beta_{py} = 0.18m$ | $\beta_{ey} = 0.26m$ |

Horizontal: $\beta_{px}$ grows slower




Vertical: $\beta_{py}$ grows faster

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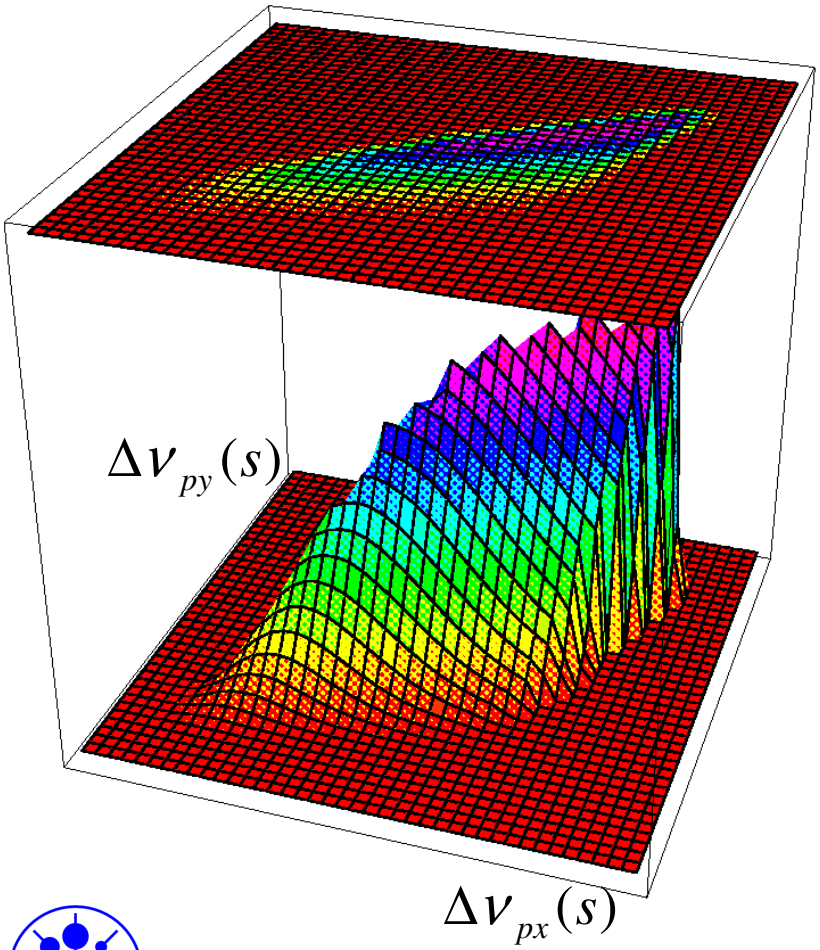
# Tune Shift with Bunch Length Effect




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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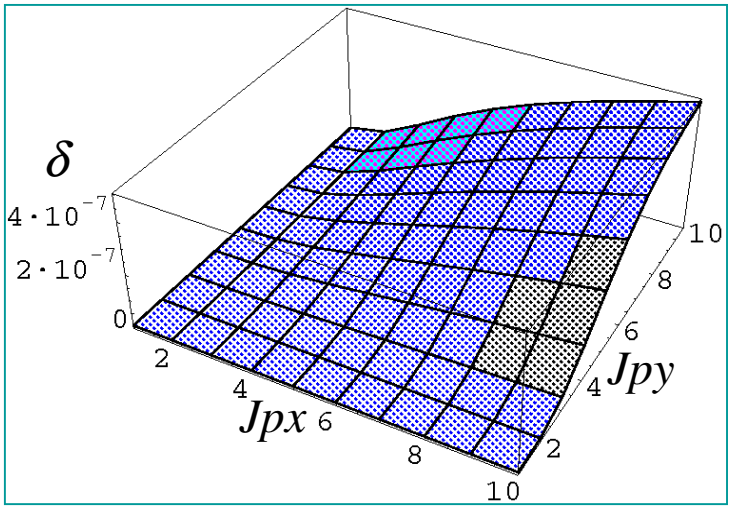
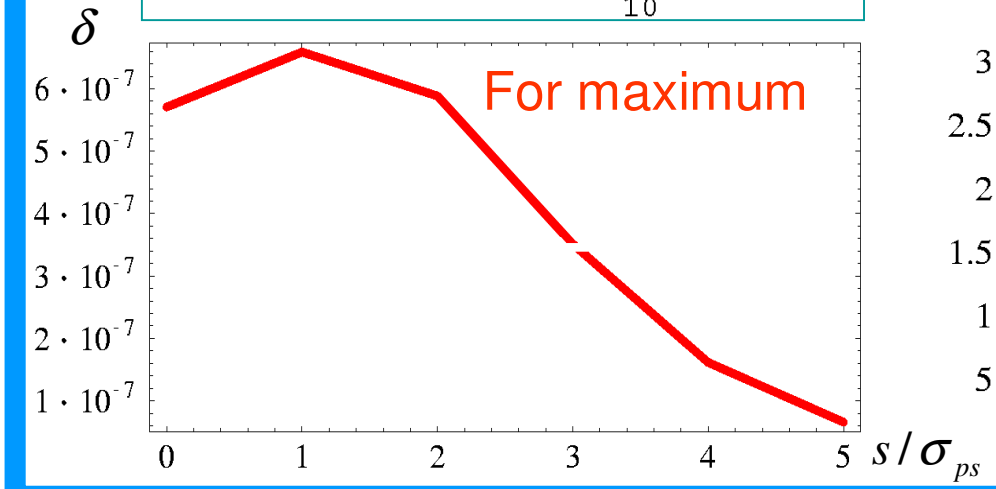
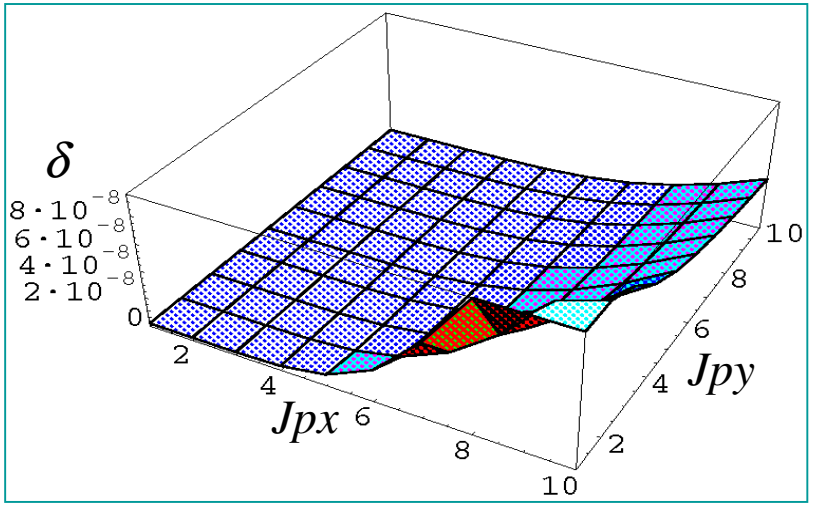
# Bunch Length Dependent Resonances

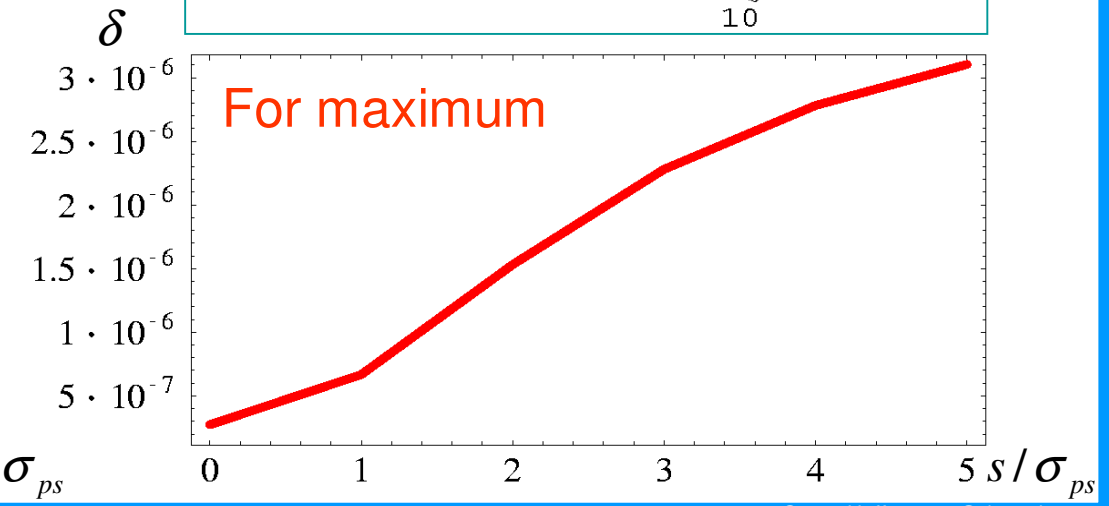
## 6Qx+4Qy Resonance




## 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 |

| $(10^{-8})$ | $\delta_0^i$ | $\delta_{max}^i$ | $\delta_{max}^u$ | $\delta_{max}^s$ |
|---|---|---|---|---|
| $\delta(10Q_{px})$ | 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 |
| $\beta^*$ 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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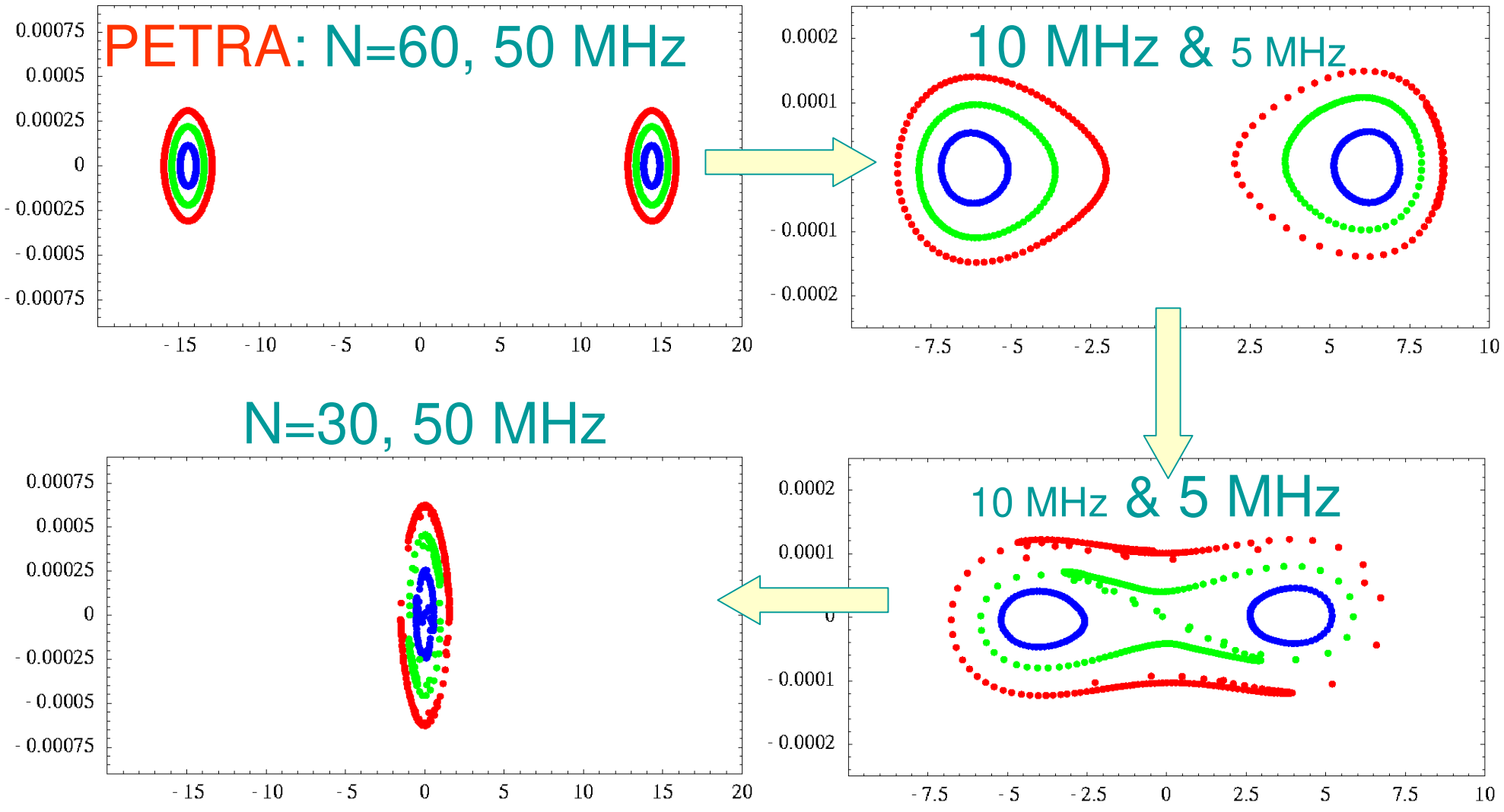
# Increasing the Proton Current

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