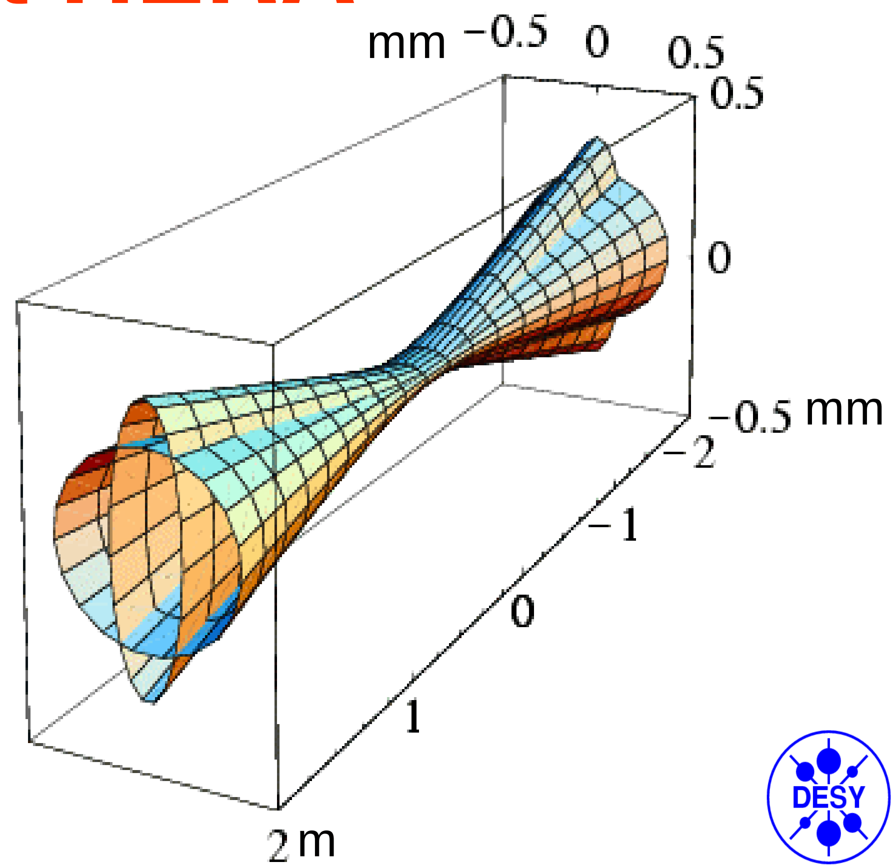
CASA Jefferson Lab's CENTER for ADVANCED STUDIES of ACCELERATORS

Seminar
03/21/03

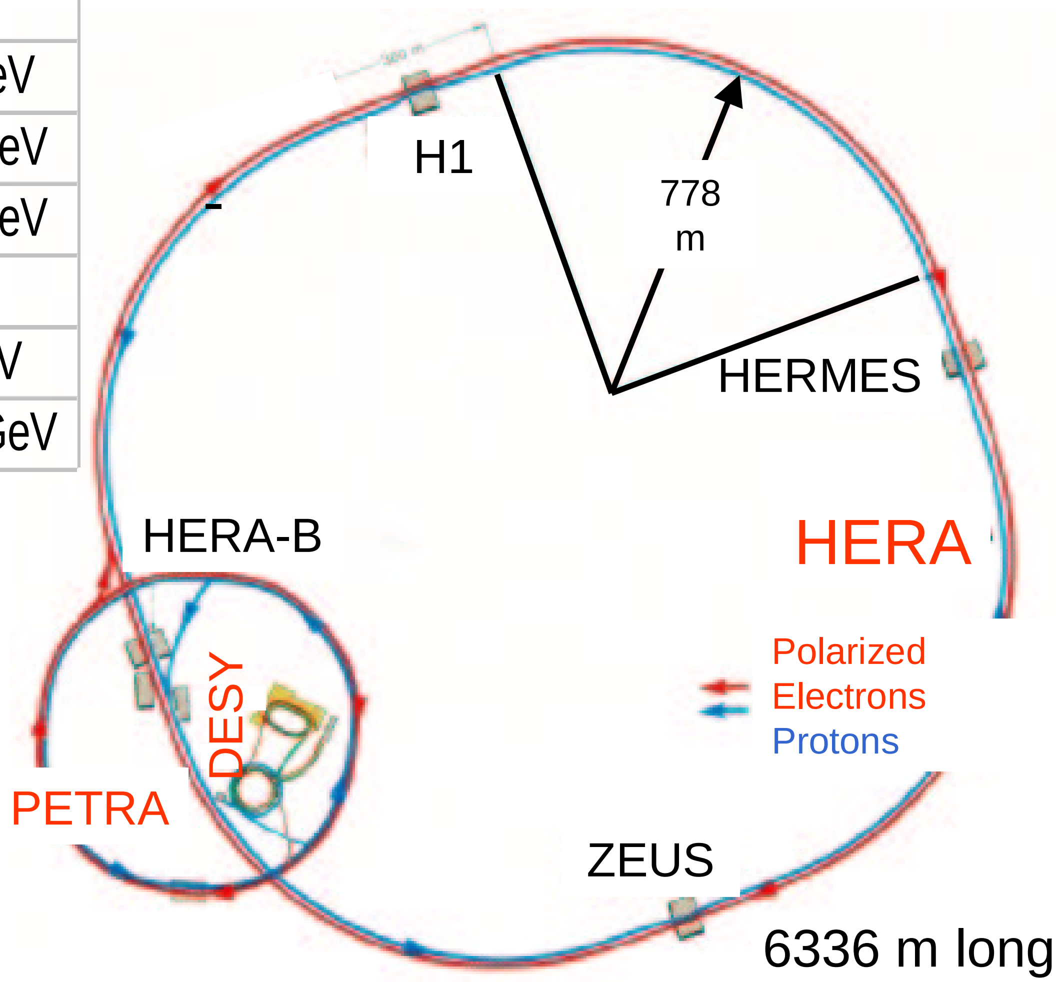
# Experiences with the beam-beam effect at HERA


Georg H.Hoffstaetter
Cornell University
(formerly DESY)

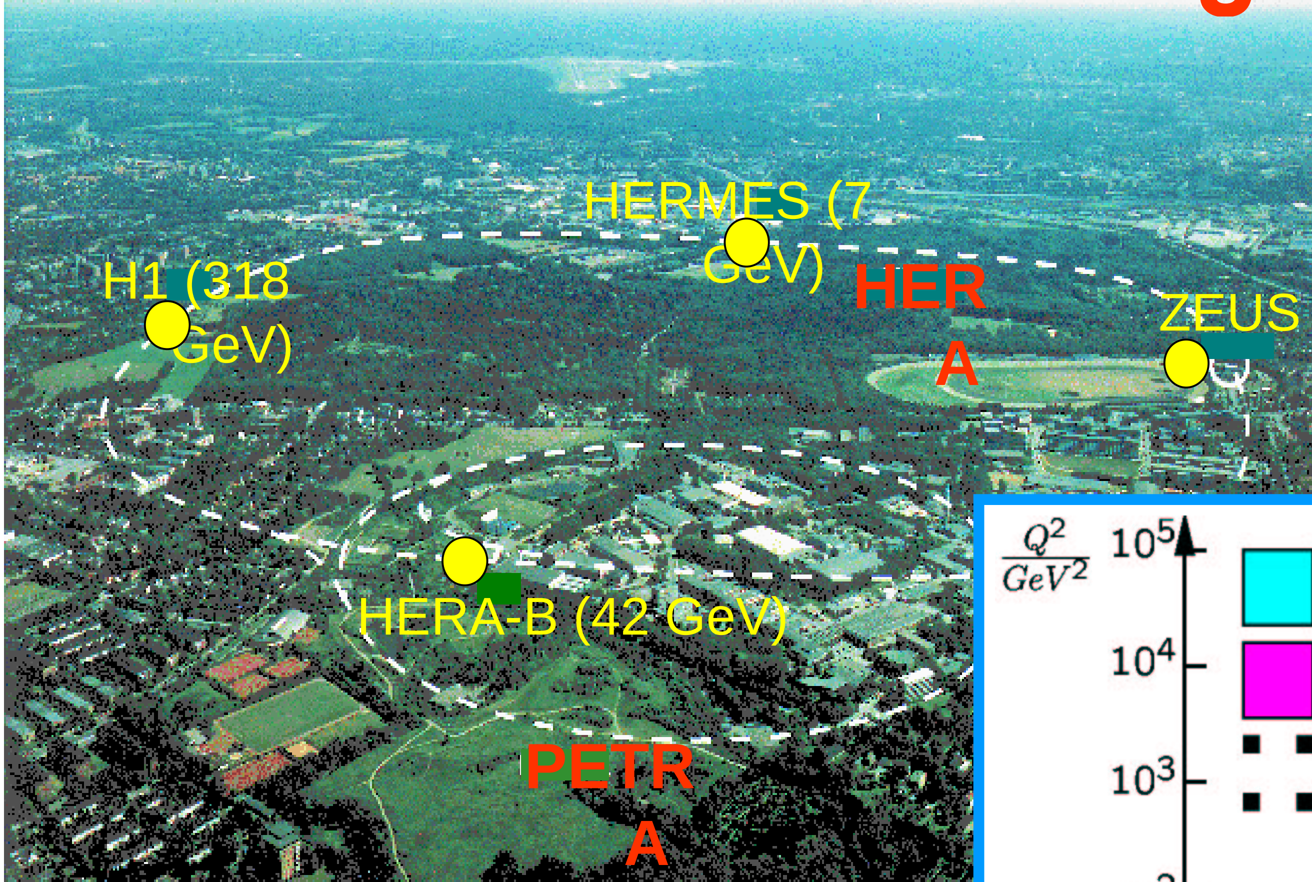



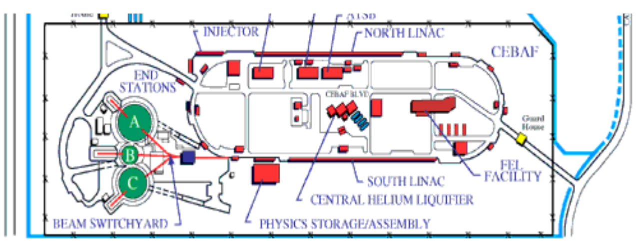
# HERA and its Pre-Accelerators

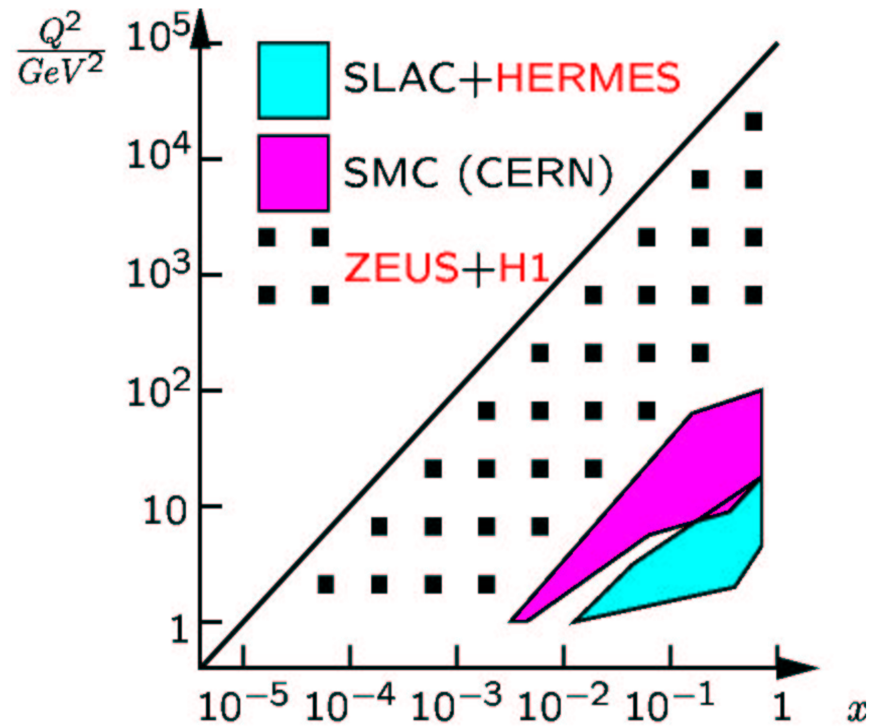
| | Protons | Electrons | |
|---|---|---|---|
| | | | |
| 20 keV | Source | Source | 150 keV |
| 750 keV | RFQ | Linac II | 450 MeV |
| 50 MeV | Linac III | Pia | 450 MeV |
| 8 GeV | DESY III | DESY II | 7 GeV |
| 40 GeV | PETRA | PETRA | 12 GeV |
| 920 GeV | HERA-p | HERA-e | 27.5 GeV |



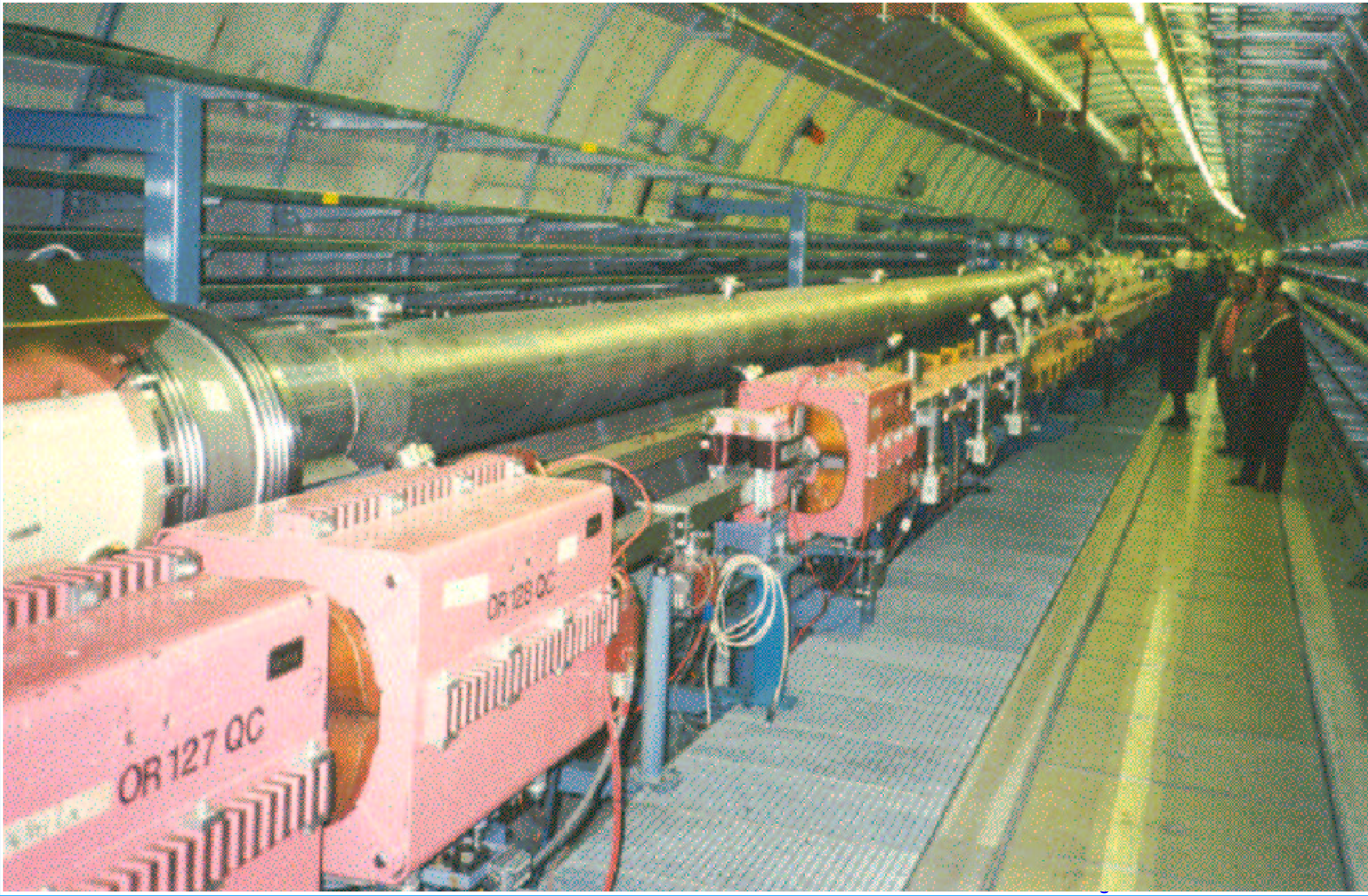
# HERA under Hamburg



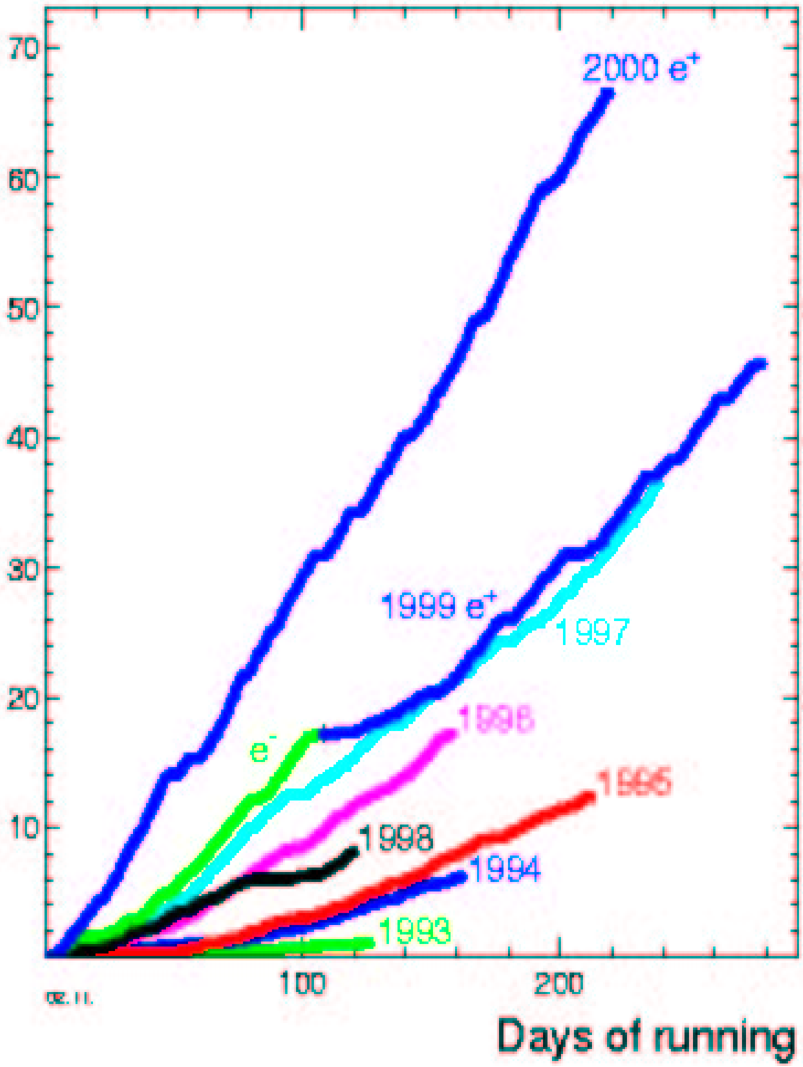



# Superconducting HERA-p + HERA-e

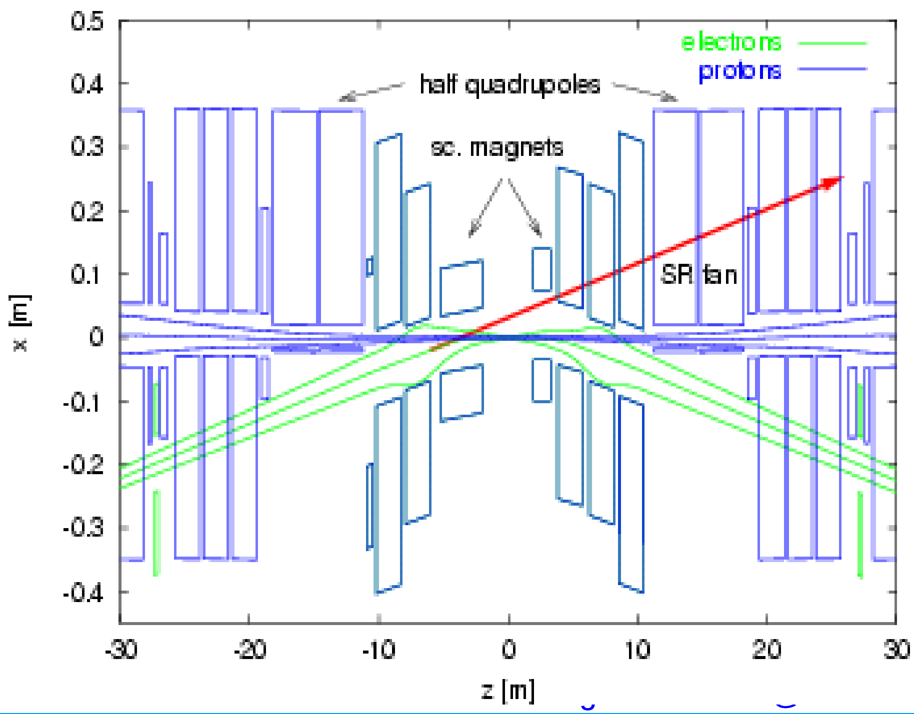


# Performance of HERA

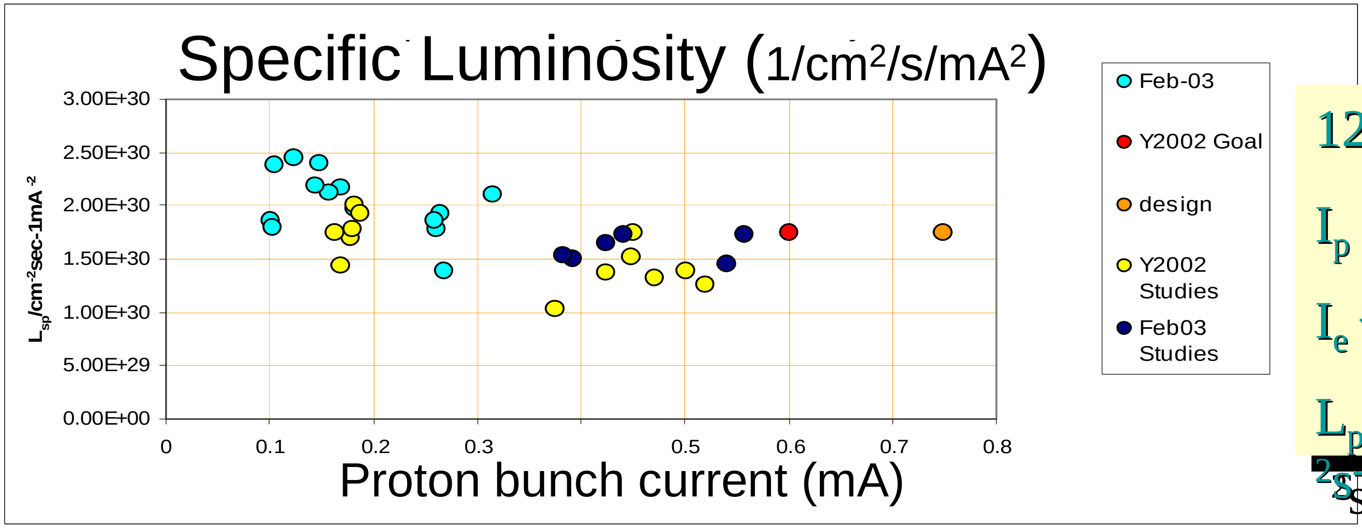
- Design luminosity had been surpassed
- Then an Upgrade was needed




- **Beam separation by super-conducting magnets in the detectors**
- **Focusing to ¼ of the old beam cross-section**



(Courtesy F. Willeke)

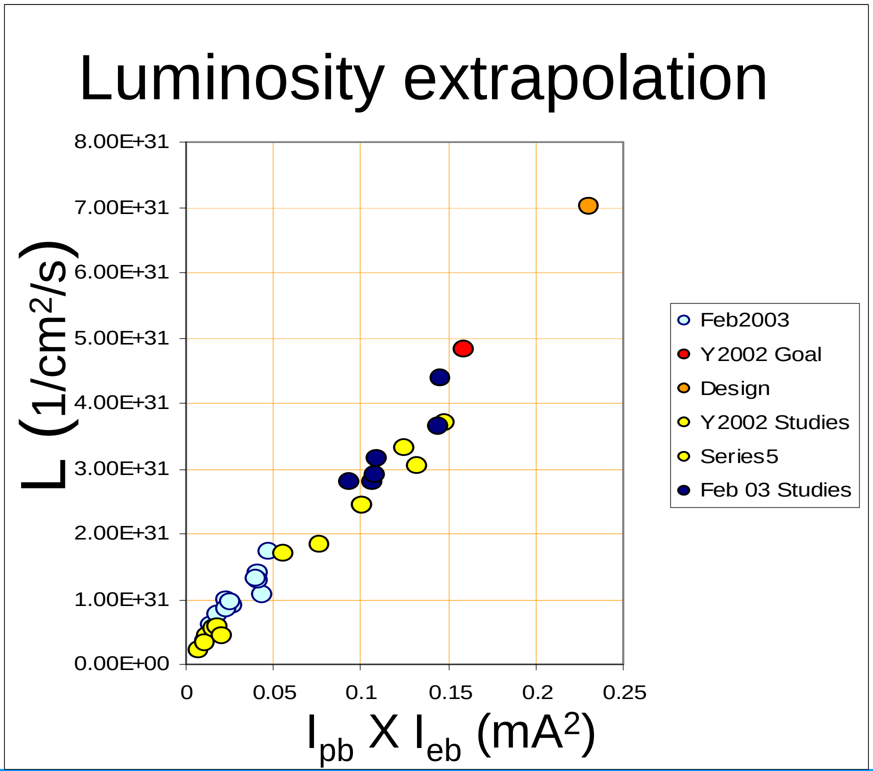


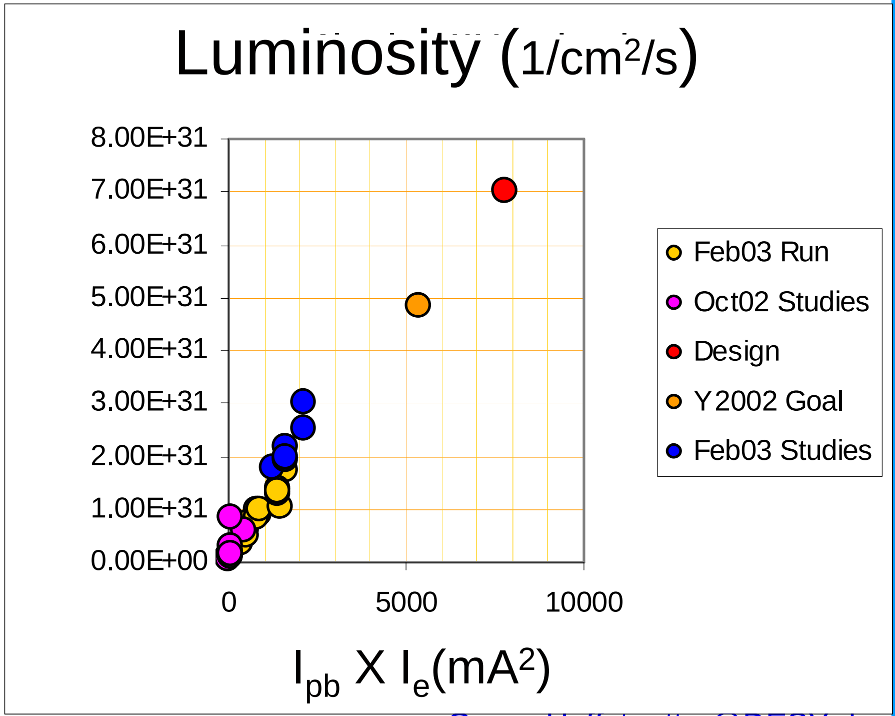

120 Bunches

$I_p < 70$ mA

$I_e < 35$ mA

$L_{peak} < 2.7 \times 10^{31}$ $cm^{-2}s^{-1}$

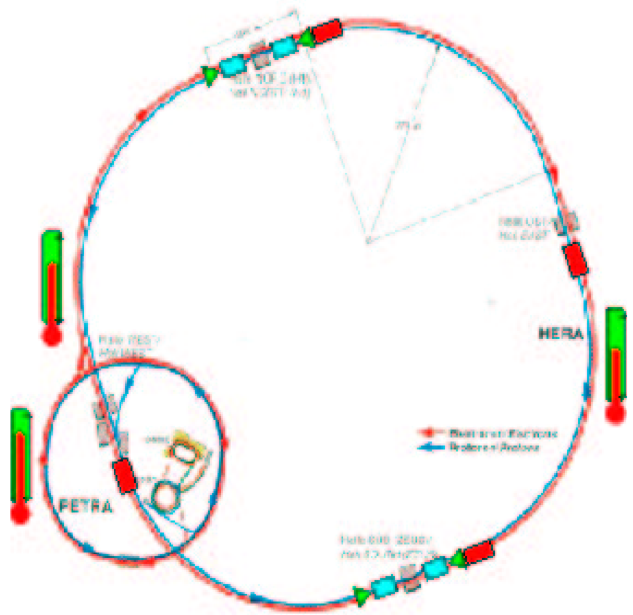



Georg.Hoffstaetter@DESY.de

# HERA III

## Polarized protons in HERA




- Polarimeters
- Flattening Snakes
- Spin rotators
- At least 4 Siberian Snakes

## e-A in HERA

- Deuteron acceleration: with same Linac
- Ion Acceleration requires:
  - a new Linac
  - high energy e-cooling
- Luminosity:

$$L_A = L_p \cdot \frac{1}{A} = 7 \cdot 10^{31} \cdot \frac{1}{A}$$

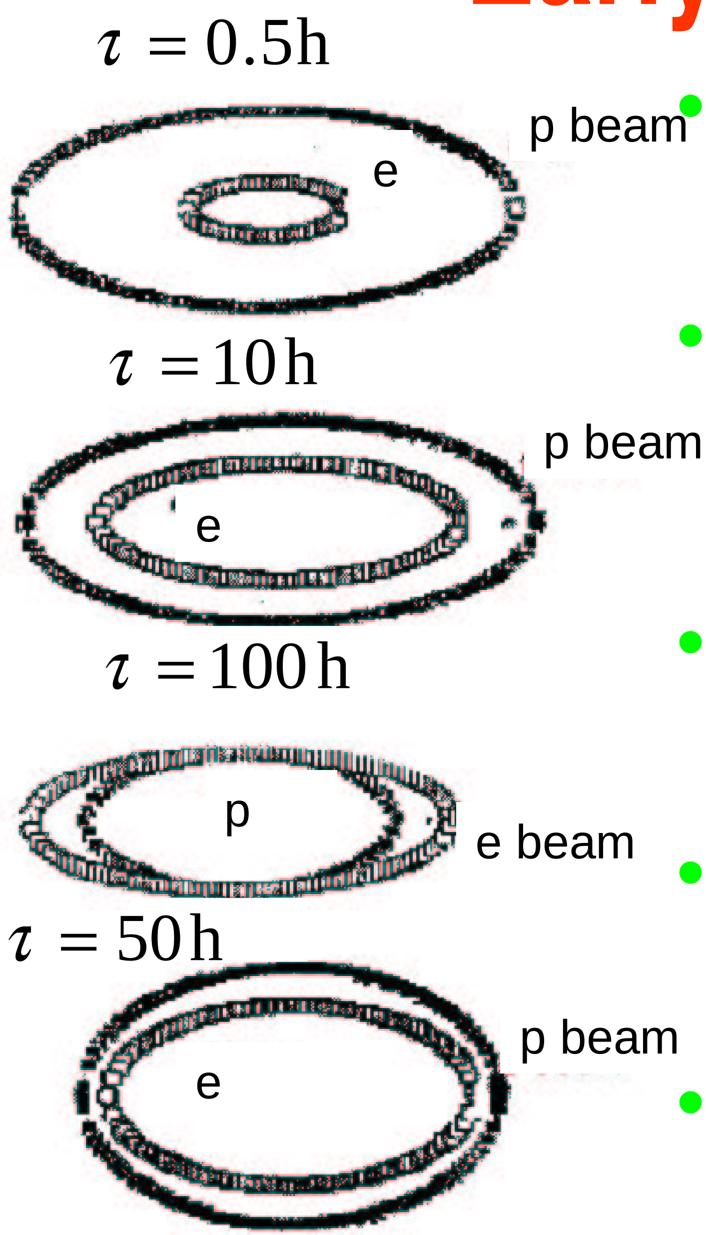
Georg.Hoffstaetter@DESY.de

# 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 |
| $\mathcal{L}(\text{cm}^{-2}\text{s}^{-1})$ | $16.9{\cdot}10^{30}$ | | $75.7{\cdot}10^{30}$ | |
| $\mathcal{L}_s(\text{cm}^{-2}\text{s}^{-1}\text{mA}^{-2})$ | $0.66{\cdot}10^{30}$ | | $1.82{\cdot}10^{30}$ | |

Georg.Hoffstaetter@DESY.de

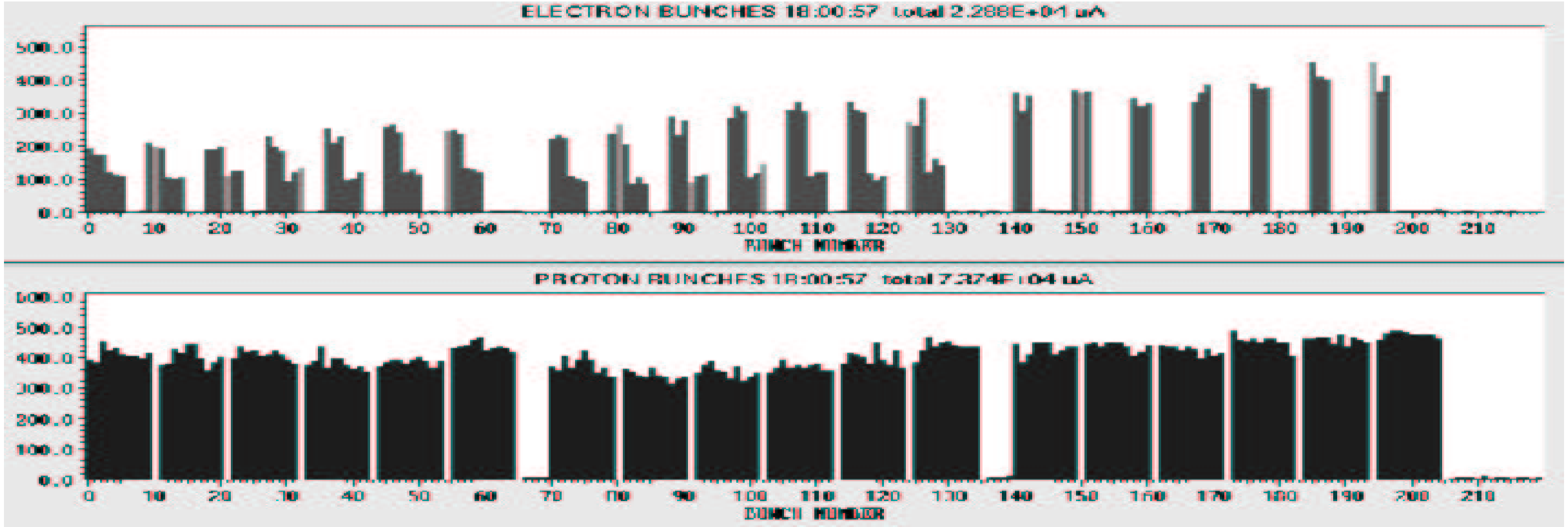
# Early experiences

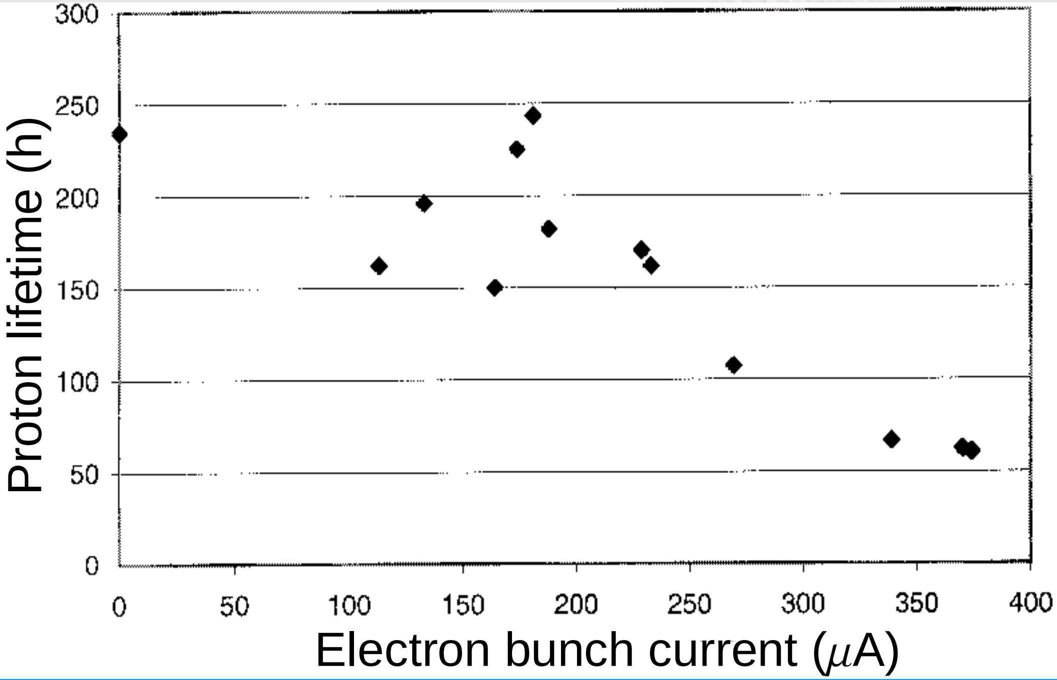



- Beam sizes have to be matched to let the proton lifetime be long.
- Beams have to meet head on to about 0.1 sigma to avoid bad electron lifetime.
- Proton and electron tunes have to be controlled to about 0.002.
- Tunes chosen to avoid resonances
  Qx=0.293 Qy=0.297
- Crossing angles were avoided.

Georg.Hoffstaetter@DESY.de

# p lifetime drops with e current

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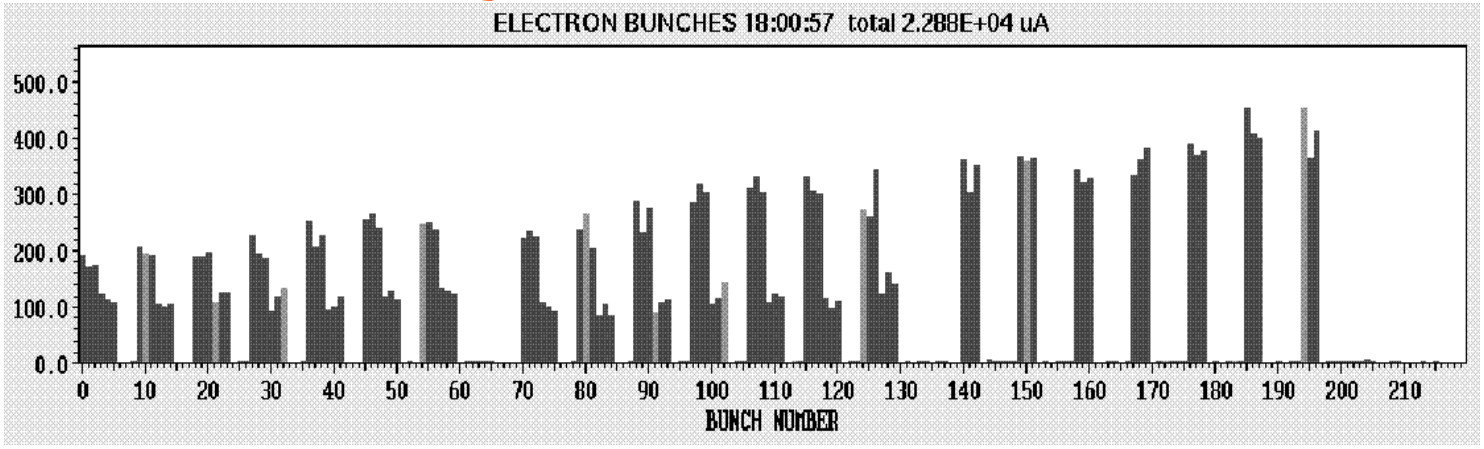
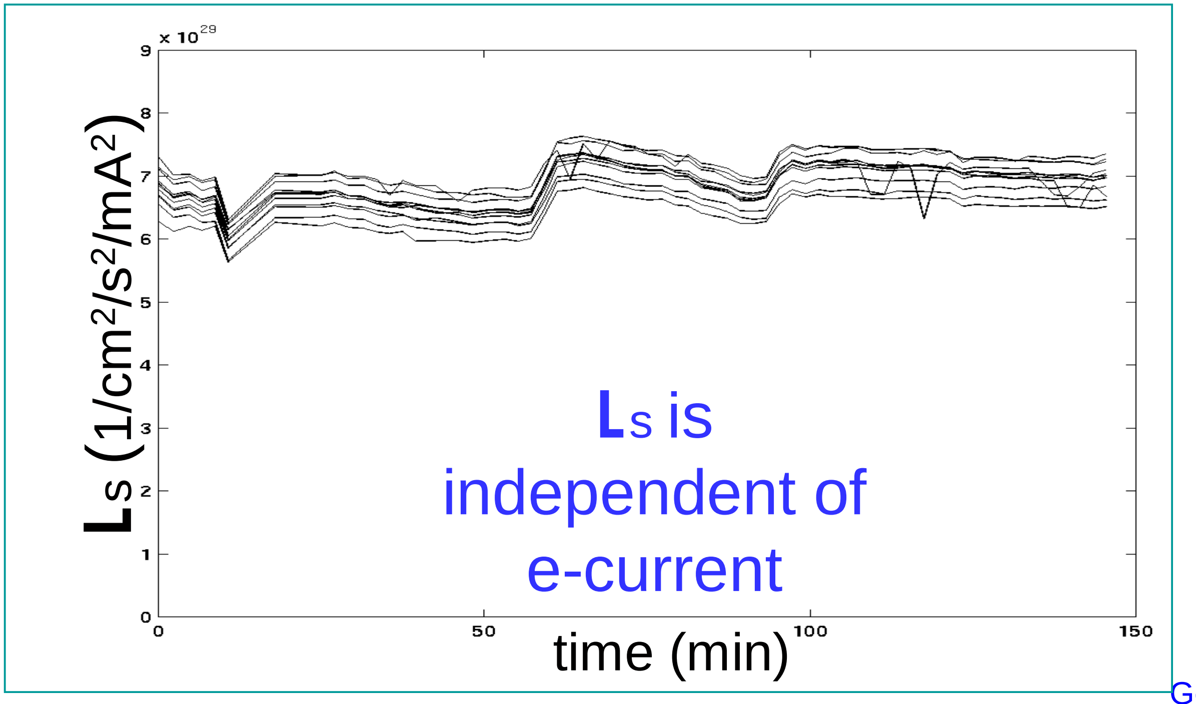
# Luminosity for different e currents

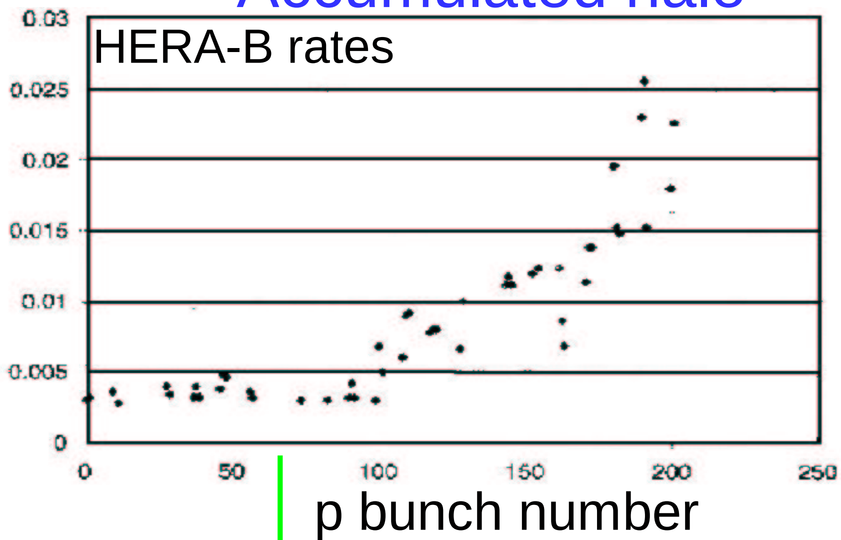


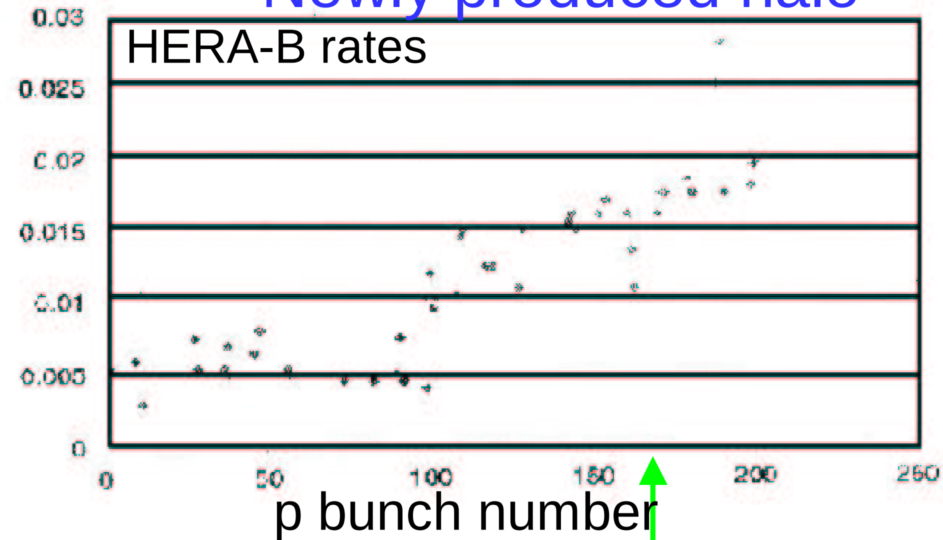

Georg.Hoffstaetter@DESY.de

# Higher p halo production for higher Ie

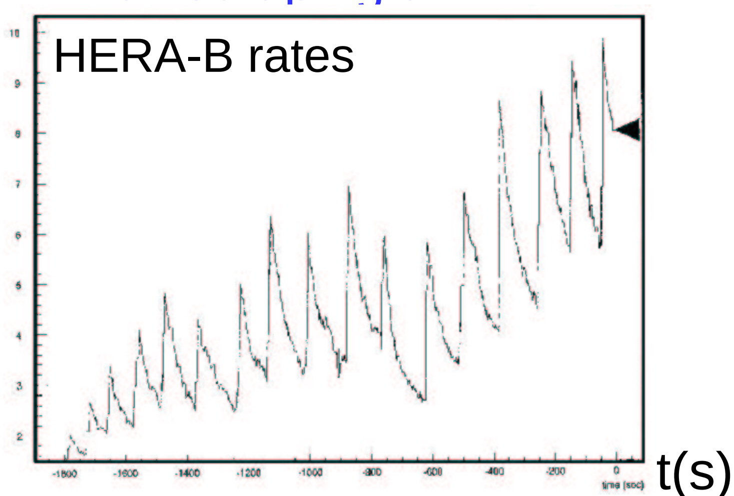
Accumulated halo




Newly produced halo

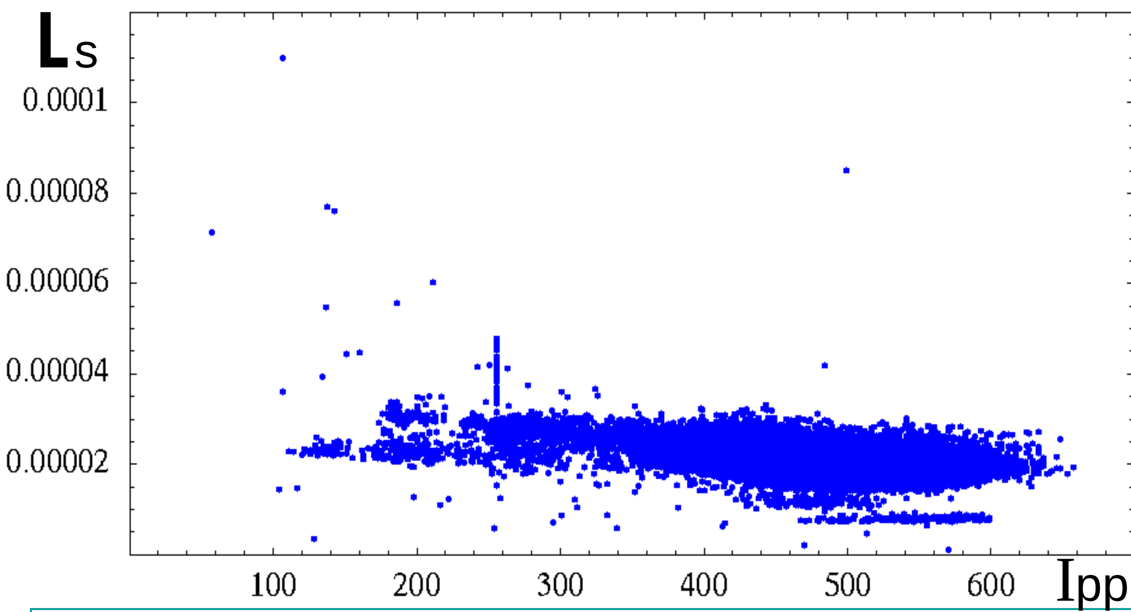



Tail scraping at HERA-B




Georg.Hoffstaetter@DESY.de

# Beam-Beam Force on e




So far no reduction of **L**s by the bunch current

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

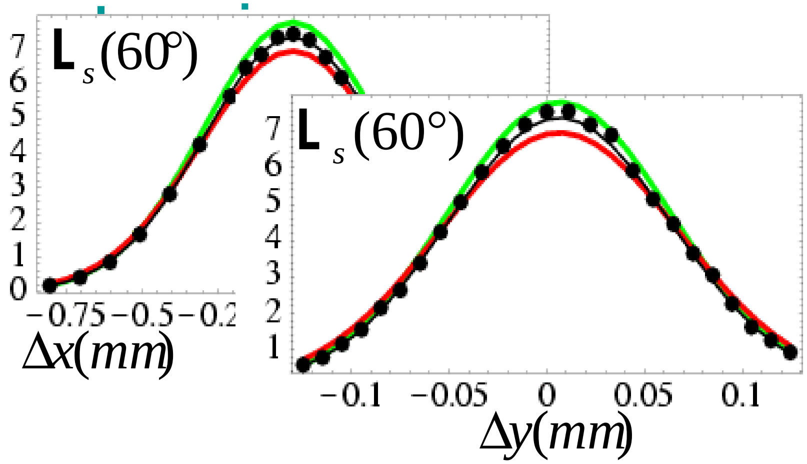
No reduction of **L**s by the second experiment

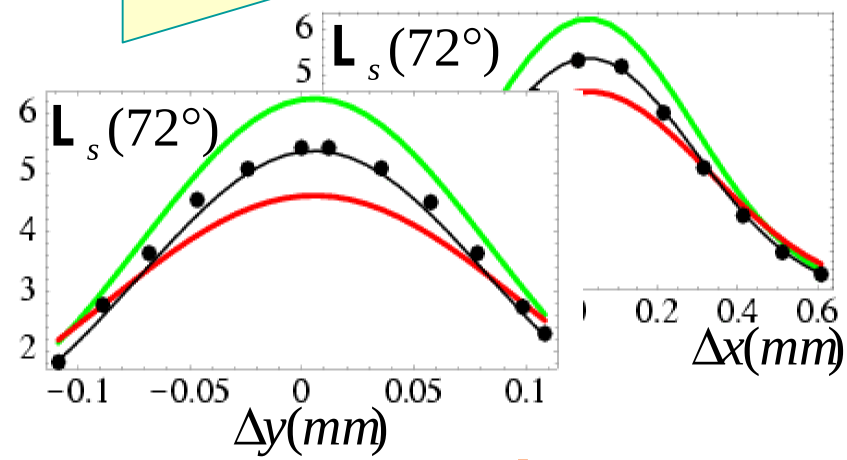
No reduction of **L**s by a larger $\beta$-funktionen

Georg.Hoffstaetter@DESY.de

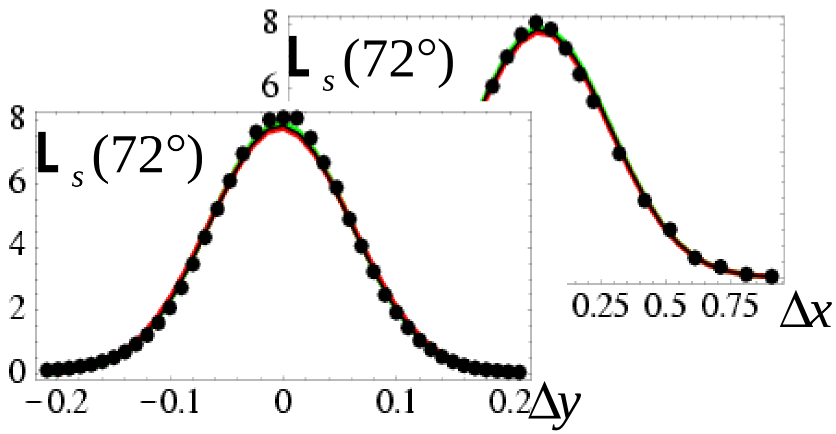
# The evaluation of lumi scans

- The Luminosity was initially too small:




Bunch has no product distribution: $\rho(x)\rho(y)$ b coupling

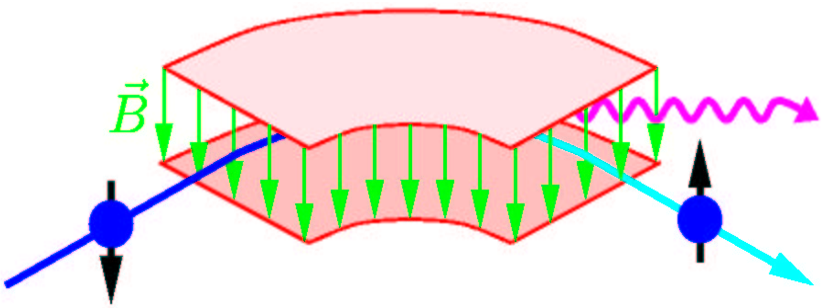



- A detailed analysis of lumi scans is only possible when the beam beam kick is taken into account.
- For strong beam beam forces also the changing $\beta$ during the ramp has to be considered.

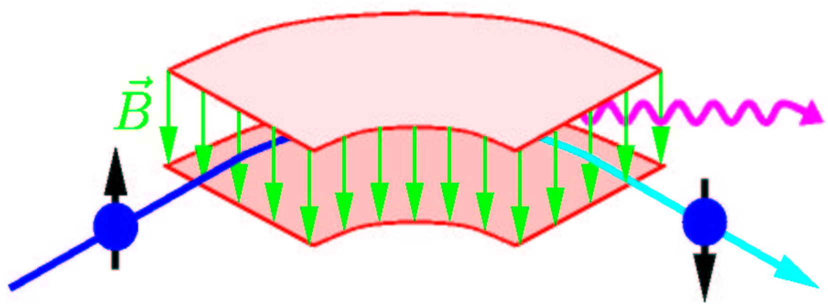
Georg.Hoffstaetter@DESY.de

# Self Polarization of the Electron Beam

Each $10^{10}$-th photon flips the spin of the electron




In HERA every 38.5 minutes




In HERA every 16.2 hours

| | |
|---|---|
| Ideal ring: | equilibrium polarization 92.38% |
| HERA: | routine operation with 60-65% polarization |

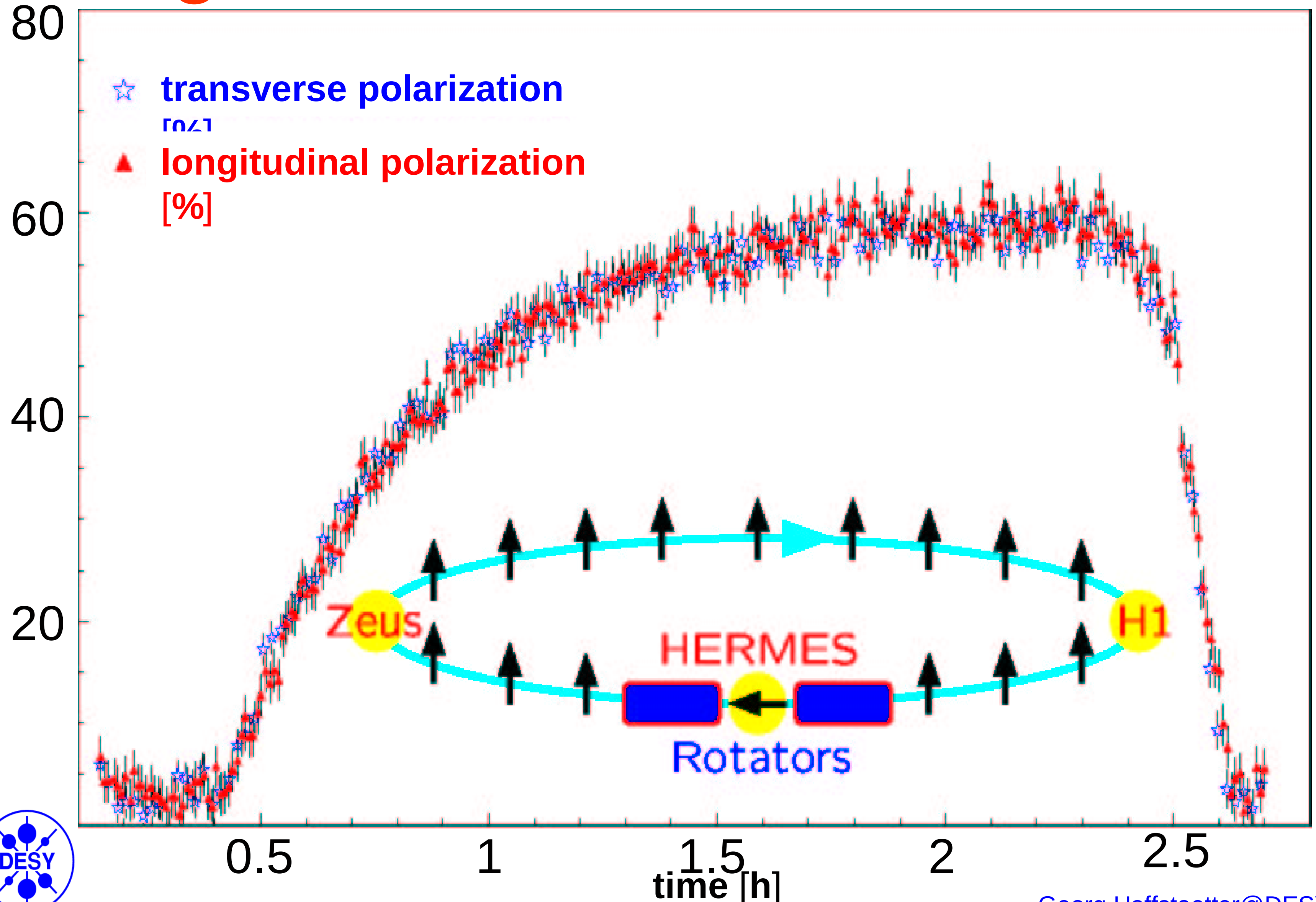
Georg.Hoffstaetter@DESY.de

# First longitudinal lepton polarization

| | | | |
|---|---|---|---|
| VEPP | 1970 | 80% | 0.65 GeV |
| ACO | 1070 | 90% | 0.53 GeV |
| VEPP-2M | 1974 | 90% | 0.65 GeV |
| VEPP-3 | 1976 | 80% | 2.0 GeV |
| SPEAR | 1975 | 90% | 3.7 GeV |
| VEPP-4 | 1982 | 60% | 5.0 GeV |
| CESR | 1883 | 30% | 5.0 GeV |
| DORIS | 1983 | 80% | 5.0 GeV |
| PETRA | 1982 | 70% | 16.5 GeV |
| LEP | 1993 | 57% | 47 GeV |
| HERA | 1994 | 70% | 27.5 GeV **(longitudinal)** |

Georg.Hoffstaetter@DESY.de

# Longitudinal Electron Polarization

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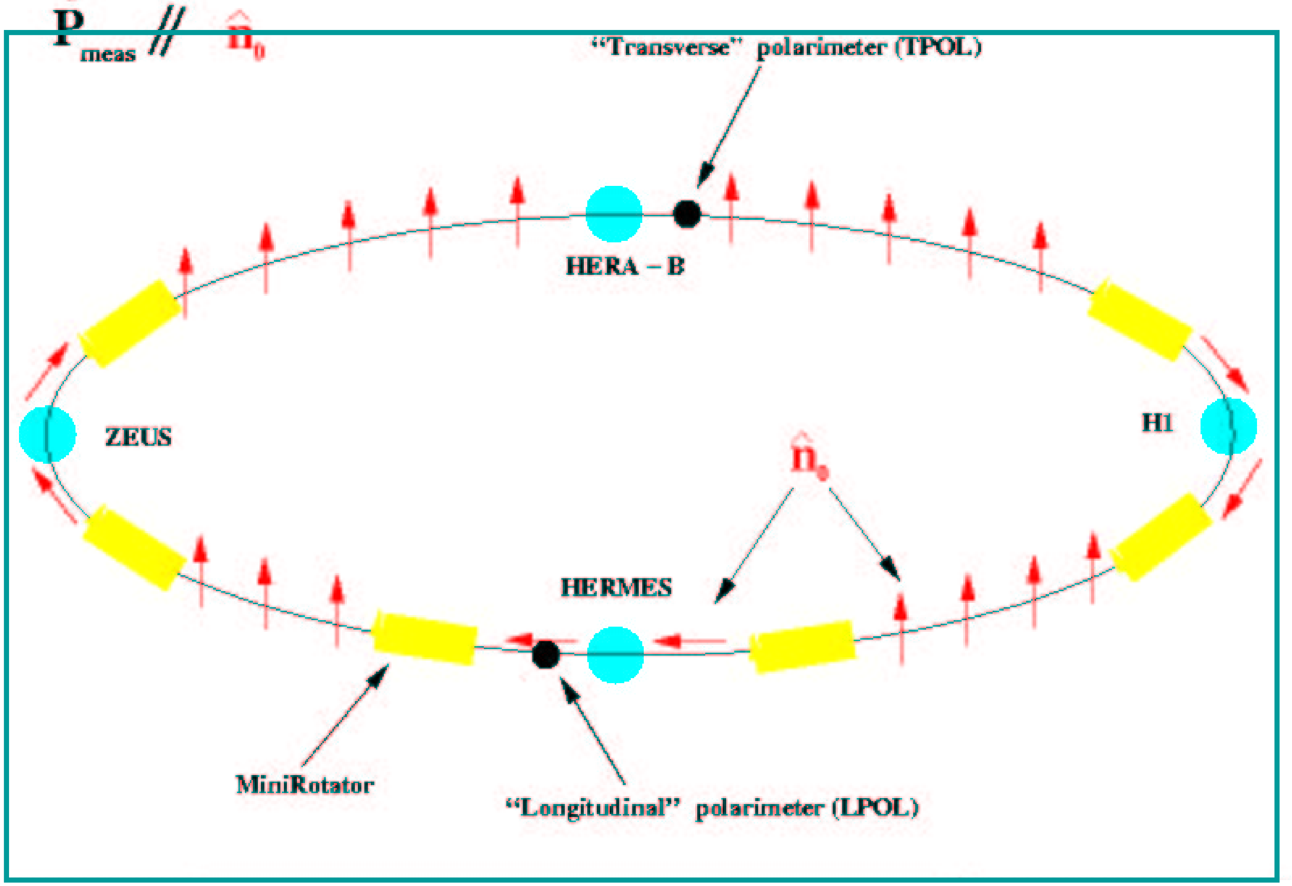
# Longitudinal polarization at 3 IRs




(courtesy M. Minty)

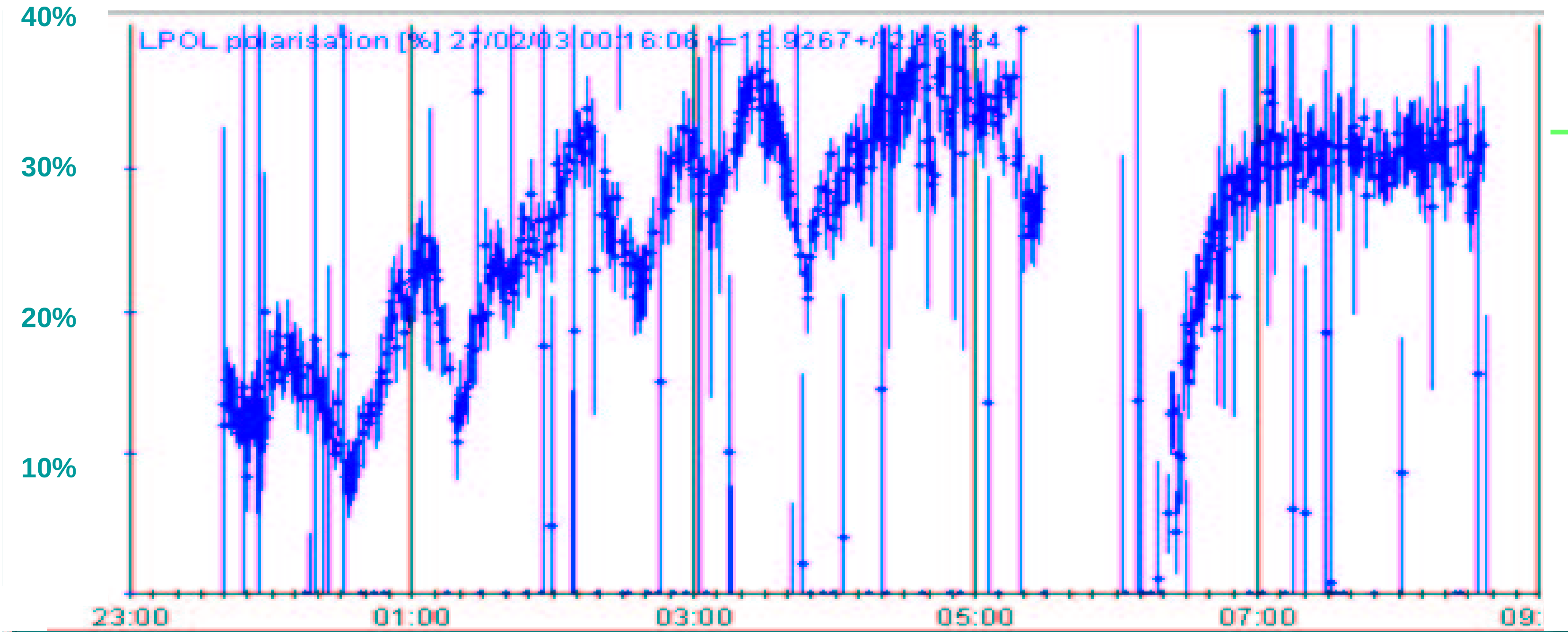
Goal: longitudinal polarization at ZEUS (new), H1 (new), and HERMES using the new spin rotators

Challenges: The experimental solenoid requires longitudinal polarization at ZEUS & H1, otherwise there is no significant buildup.

# First polarization at H1 and Zeus

3 Rotator Polarization Studies with Harmonic Bumps 26.-27. February 2003

51%

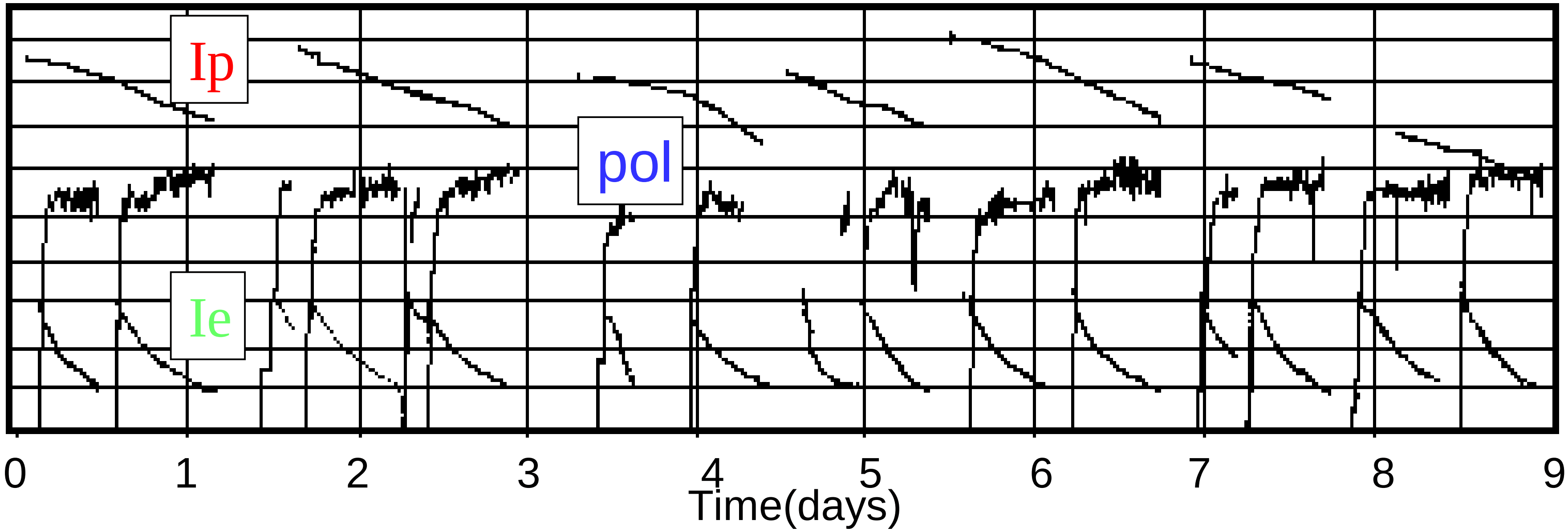



51% polarization with e/p collisions was possible with Specific luminosities close to the design:

Luminosity at H1, Lsp = 1.7 (su)    Luminosity at ZEUS, Lsp = 1.4 (su)

Georg.Hoffstaetter@DESY.de

# Second e-fills have more polarization




**Explanation:** The first fill and the refilling procedure have increased the proton emittances and decreased the beam beam force that acts on spins.

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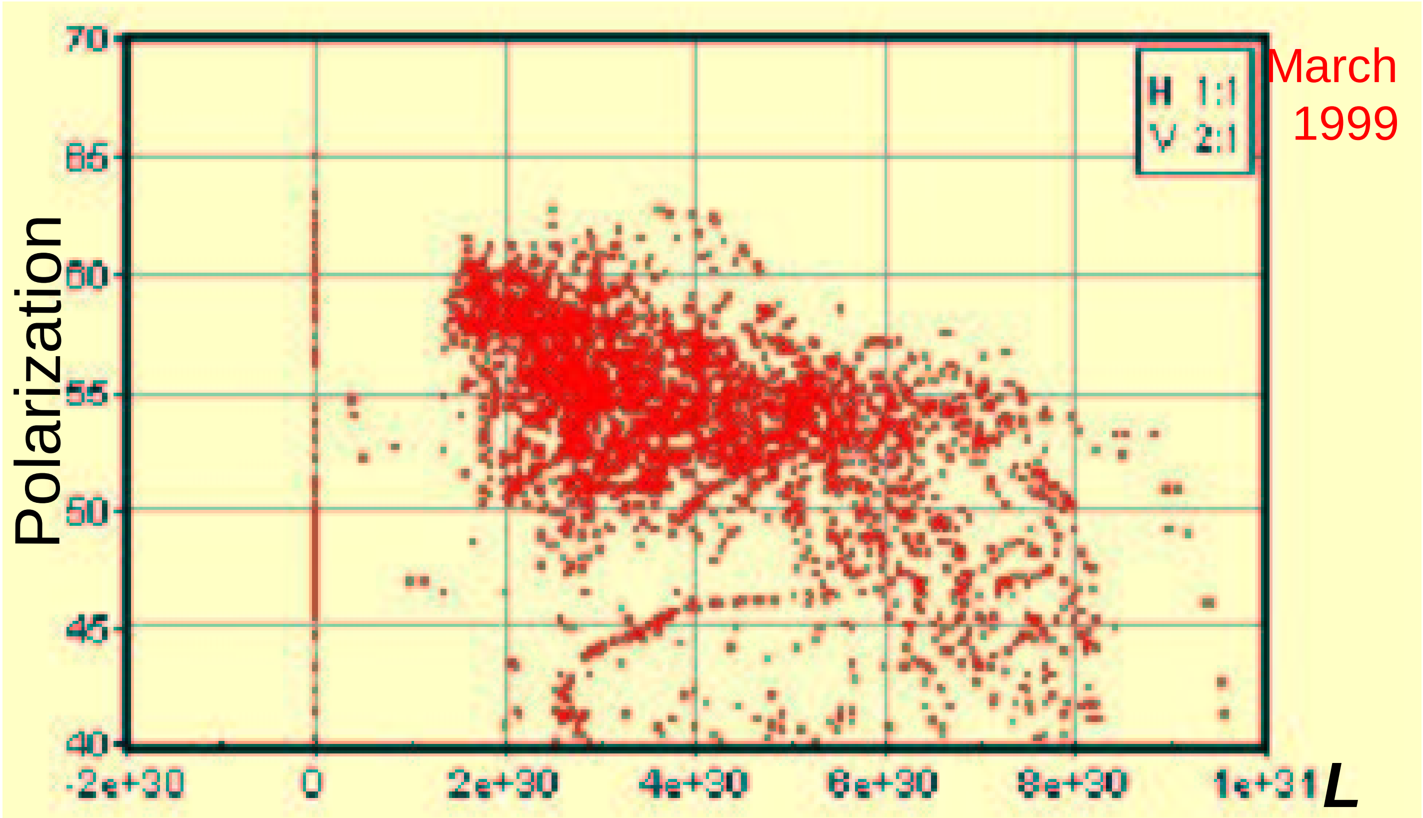
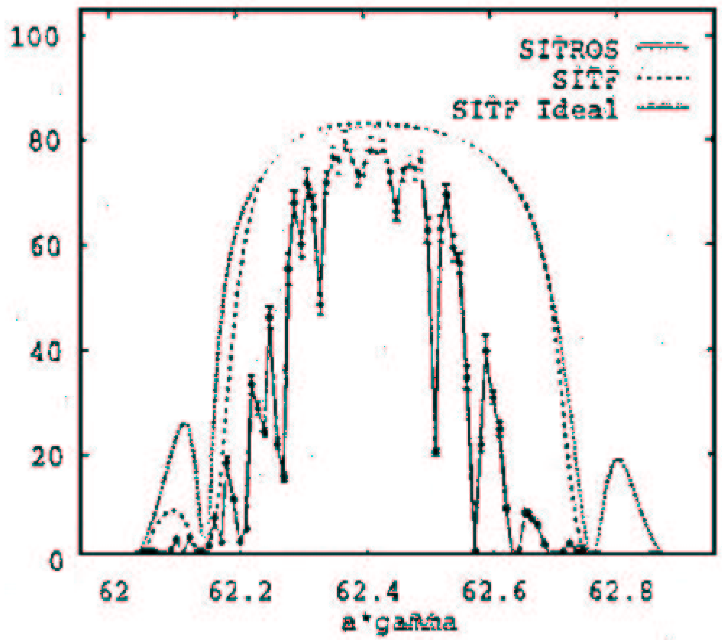
# Runs with more lumi have less pol.



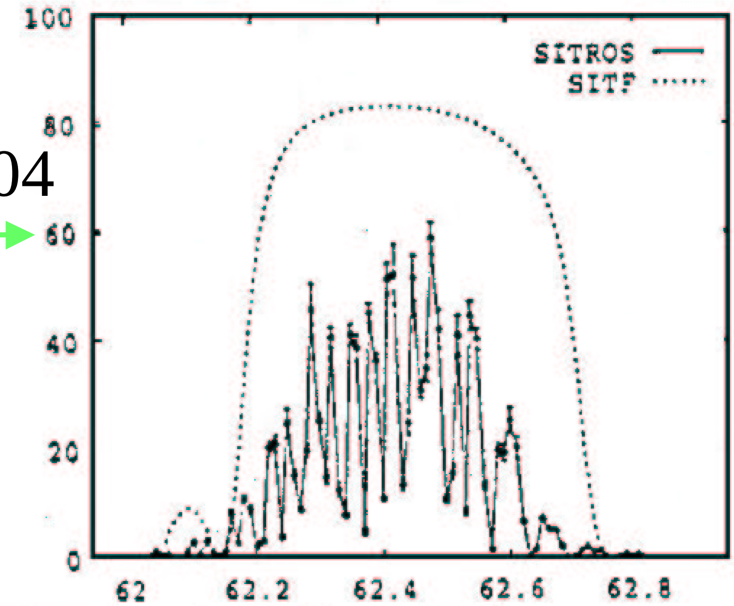

**Explanation:** Runs with more initiall lumi (that is at the time of maximum lumi in this run) have a higher beam beam force than runs with lower initial lumi, given that the initial electron current is about the same from run to run.

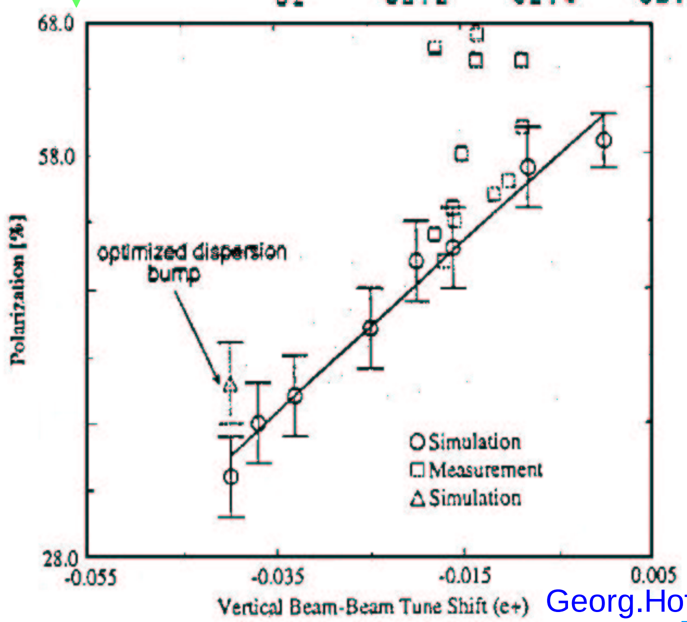
Georg.Hoffstaetter@DESY.de

# Simulation by spin/radiation tracking




$$\xi_{ey} = 0.04$$

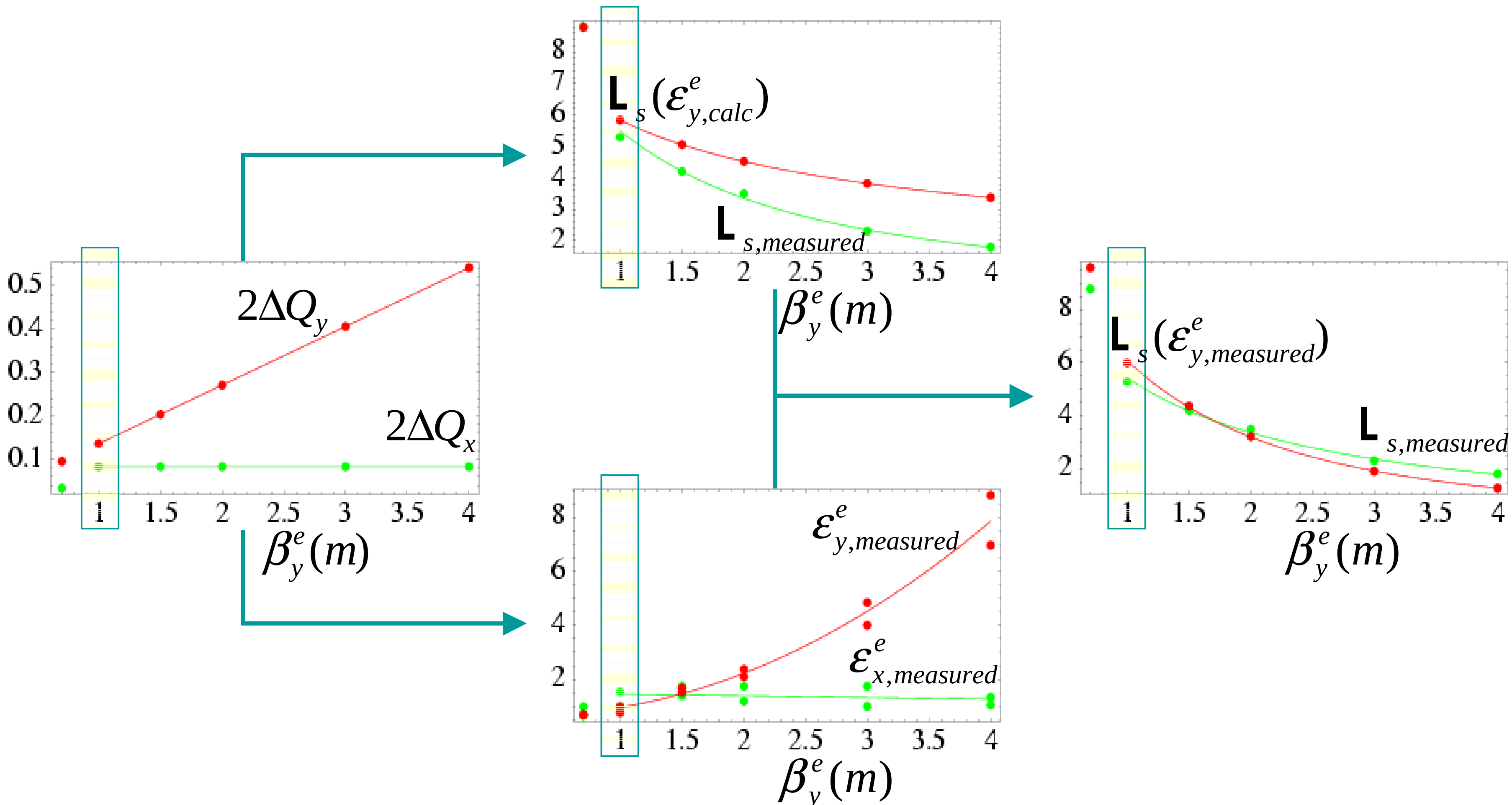



**Explanation:** The achievable polarization is the maximum of a dens resonance structure. This makes quantitative predictions hard, but a dependence on the beam beam tune shift is clearly visible.

Georg.Hoffstaetter@DESY.de

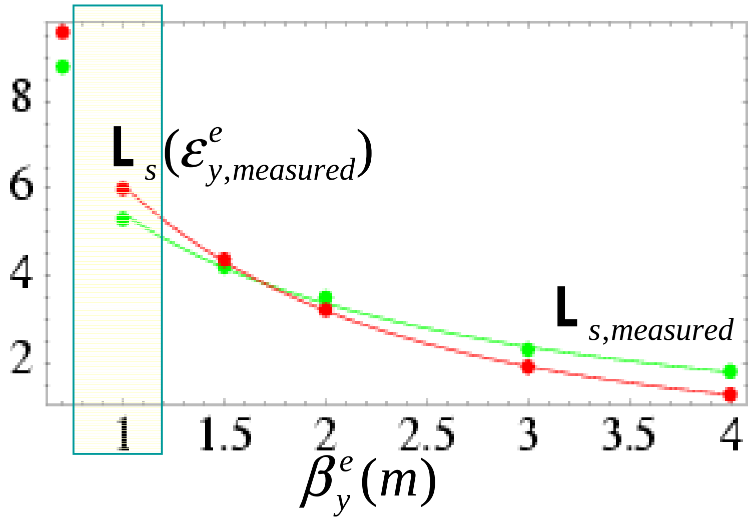
# Where are the Beam-Beam Limits?

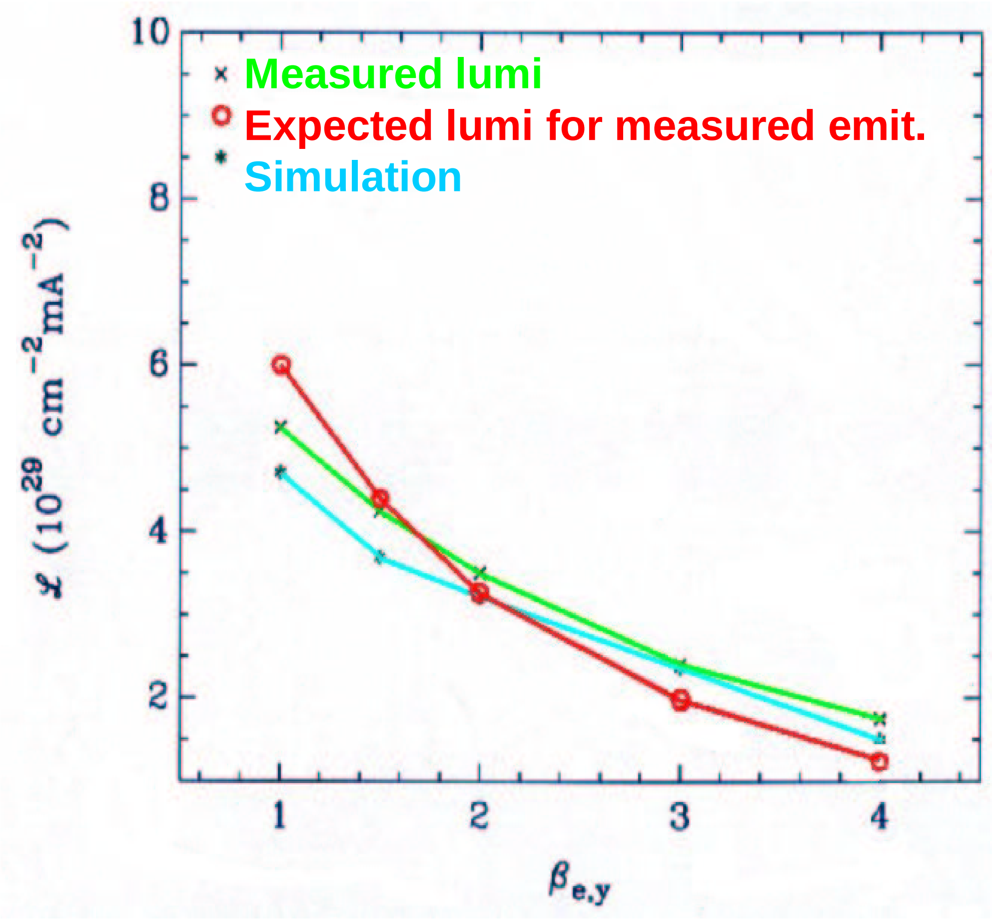



Upgrade and Ip=140mA: emittance starts to grow

Georg.Hoffstaetter@DESY.de

# Simulation of large beam beam forces




Georg.Hoffstaetter@DESY.de

# Dipole modes of Gaussian bunches

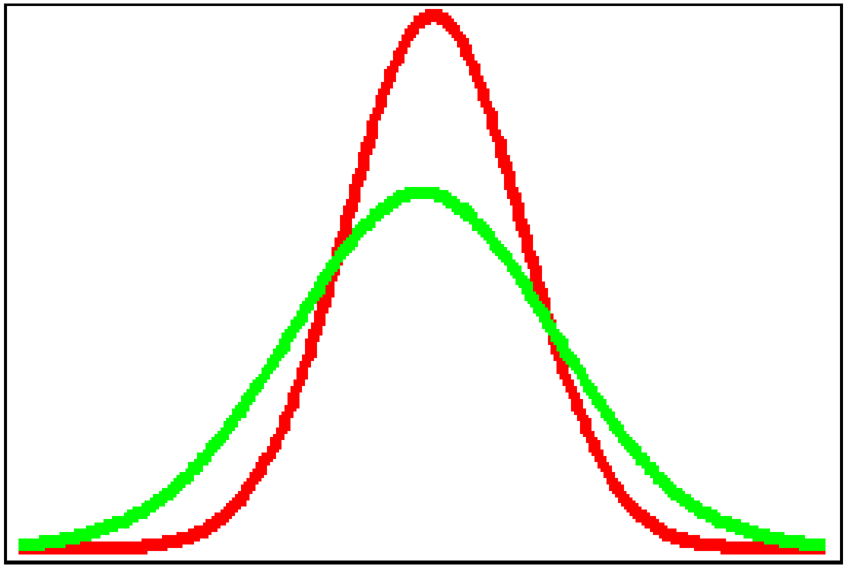
- Beam beam tune shift for one particle in the beam beam field of a Gaussian bunch:

$$\xi_{ex} = \beta_{ex} \frac{r_e}{2\pi\gamma_e} \frac{N_{ppb}}{\sigma_{px}(\sigma_{px}+\sigma_{py})}$$

- Shift in the dipole modes oscillation Frequency of a Gaussian bunch:

$$\Delta Q_{ex} = \xi_{ex} \frac{\sigma_{px}(\sigma_{px}+\sigma_{py})}{\Sigma_{px}(\Sigma_{px}+\Sigma_{py})}$$

Assumption: the bunches remain Gaussian



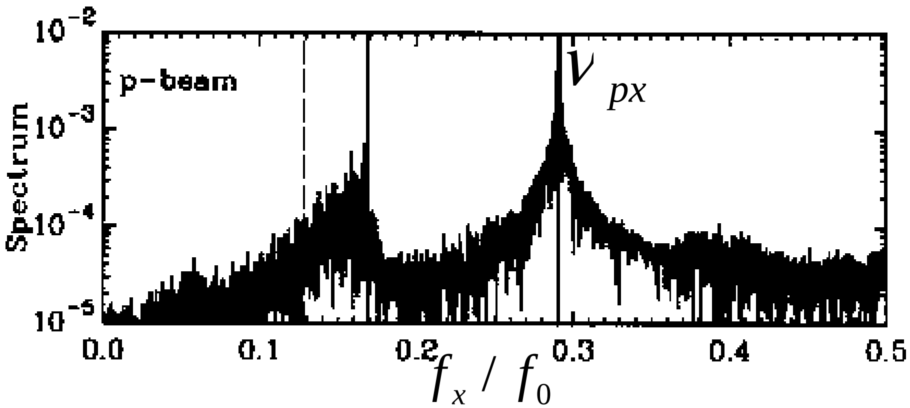
This approximation is justified for a stiff beam hitting a much less stiff beam when the first beam creates a small beam beam kick.

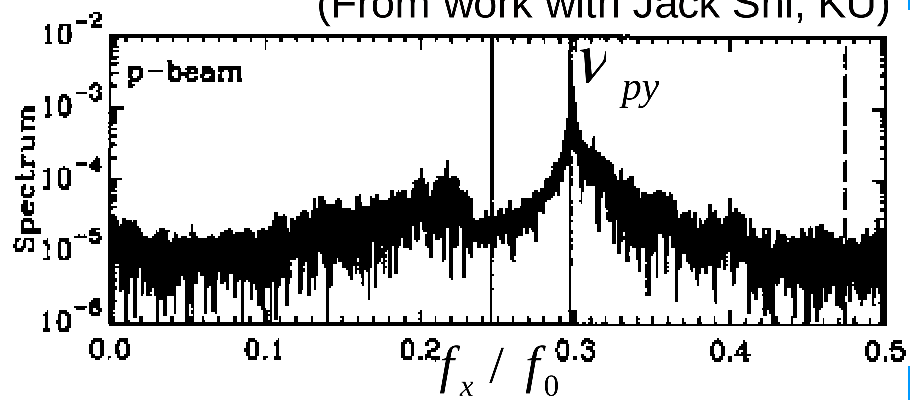
Georg.Hoffstaetter@DESY.de

# Simulated coherent modes

$\beta^*_{ey} = 4.0\text{m}$ + $\xi_{ex} = 0.041$, $\xi_{ey} = 0.272$ → $dQ_{ex} = 0.027$, $dQ_{ey} = 0.082$ Why? how ? → $\Delta\nu^m_{ex} = 0.009$, $\Delta\nu^m_{ey} = 0.013$

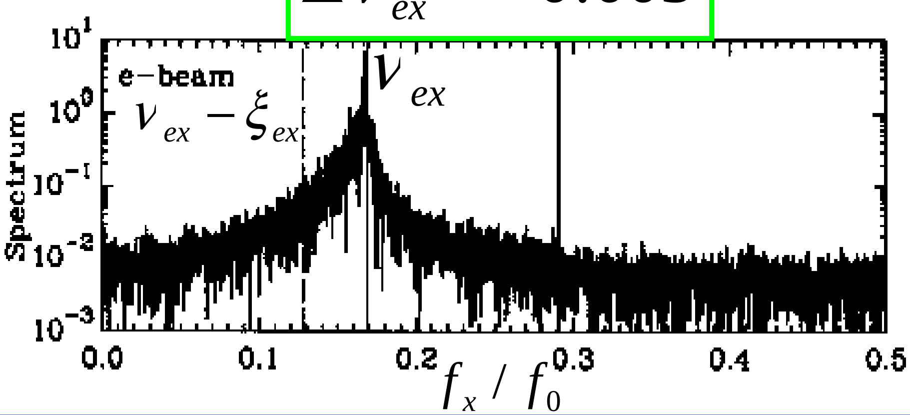
(From work with Jack Shi, KU)

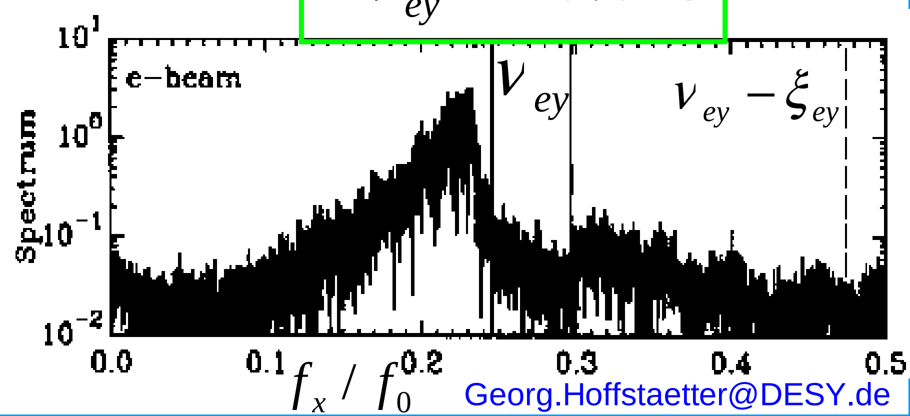



$\Delta\nu^{sim}_{ex} = 0.003$

$\Delta\nu^{sim}_{ey} = 0.013$

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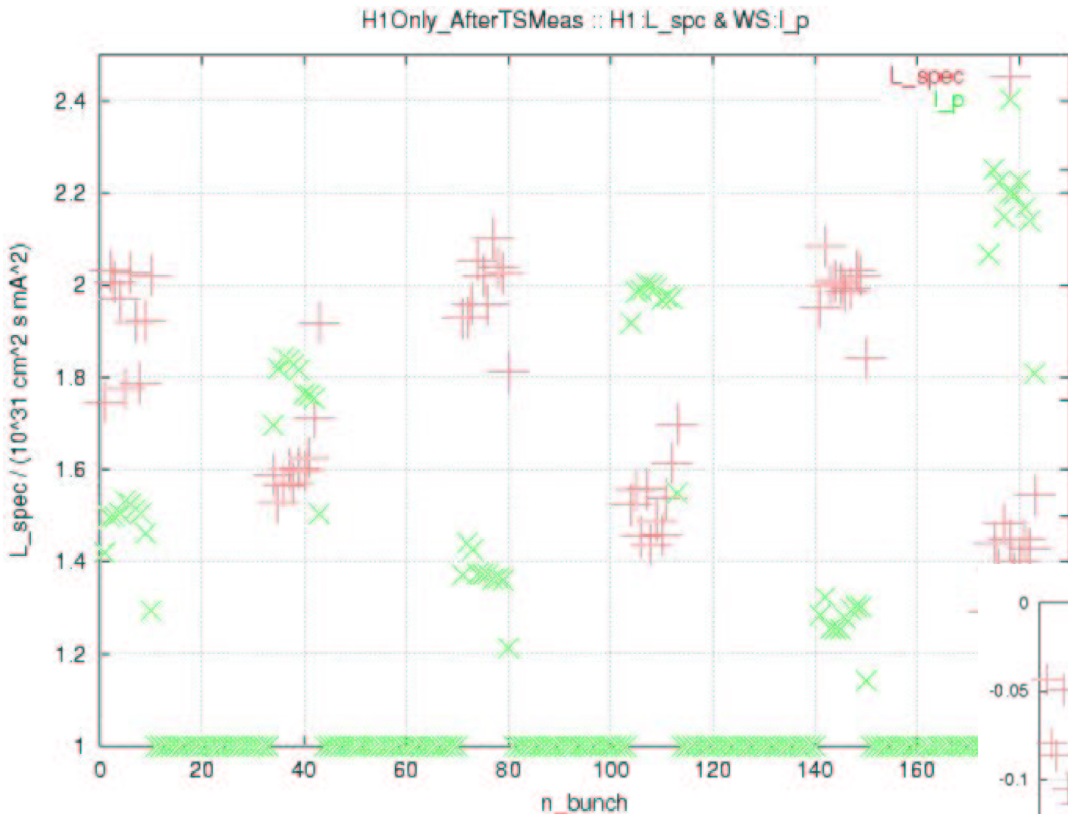
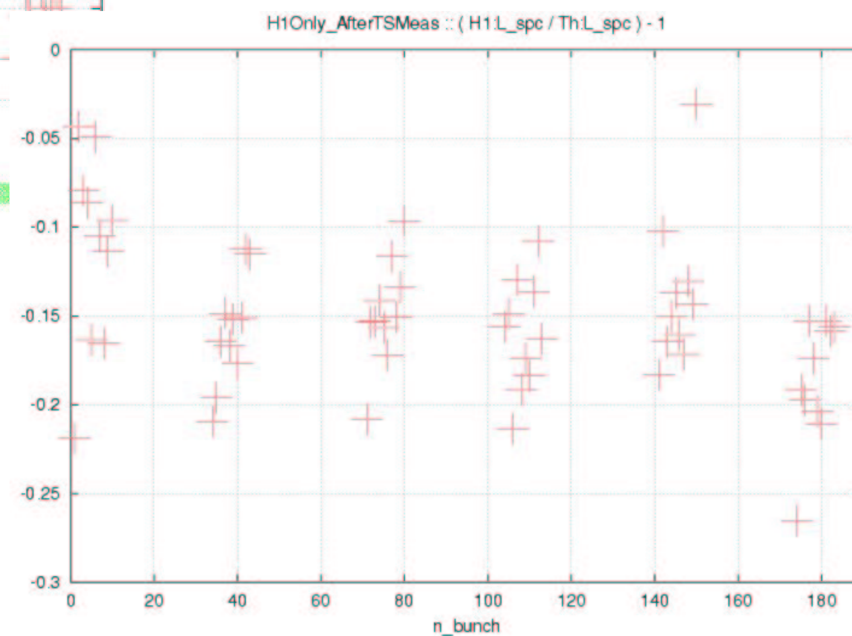
# Beam Beam experiments of Feb. 2003




Unexplained lumi change over each bunch train:



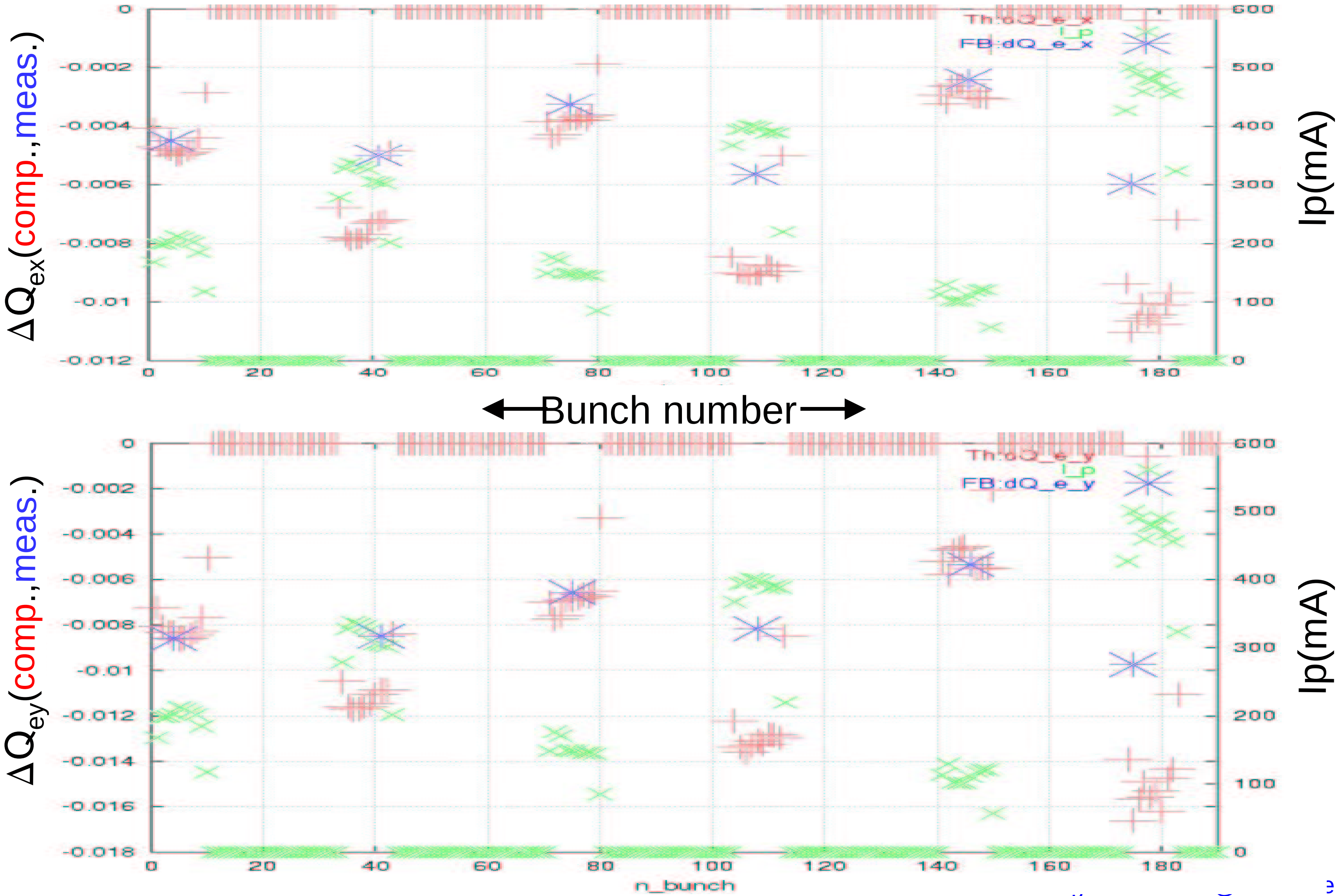

Higher p current

↓

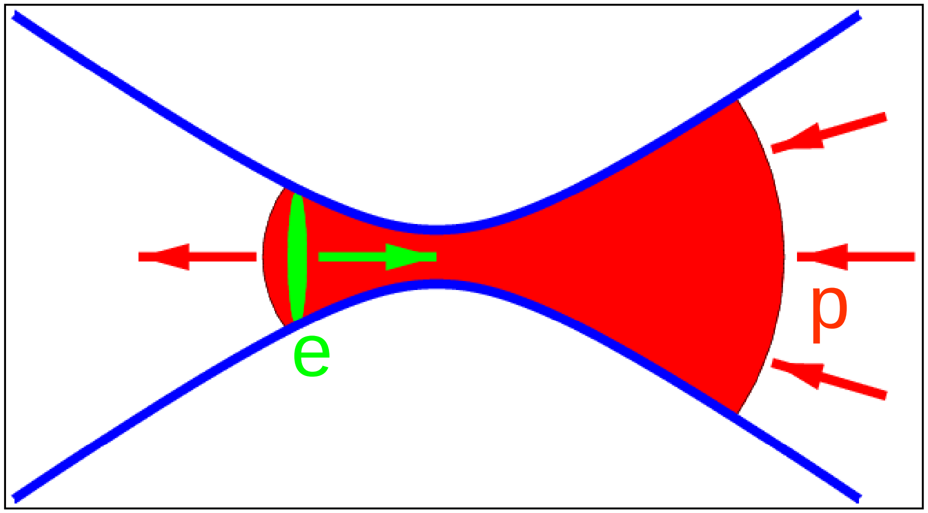
Lower specific luminosity

Georg.Hoffstaetter@DESY.de

# Beam Beam Tune shifts



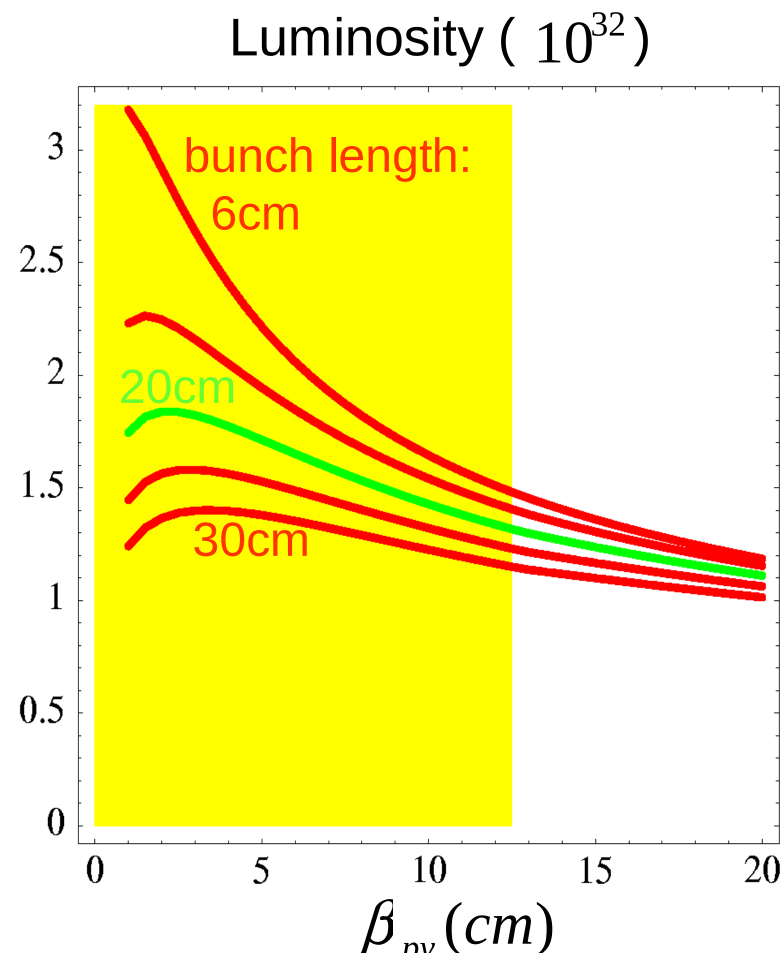
# Lumi Reduction by Hourglass Effect




Length

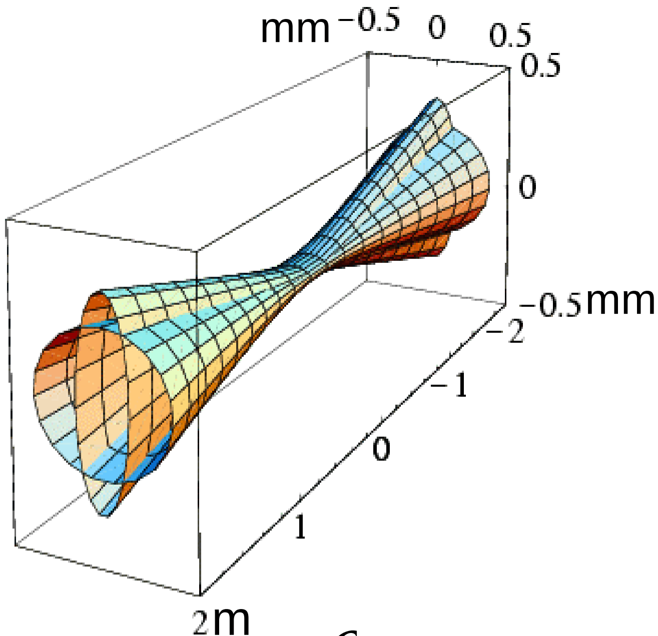
19cm: $\frac{L(\beta_{py}=12.5cm)}{L_0}=1.75$

12cm: $\frac{L(\beta_{py}=12.5cm)}{L_0}=1.9$




Georg.Hoffstaetter@DESY.de

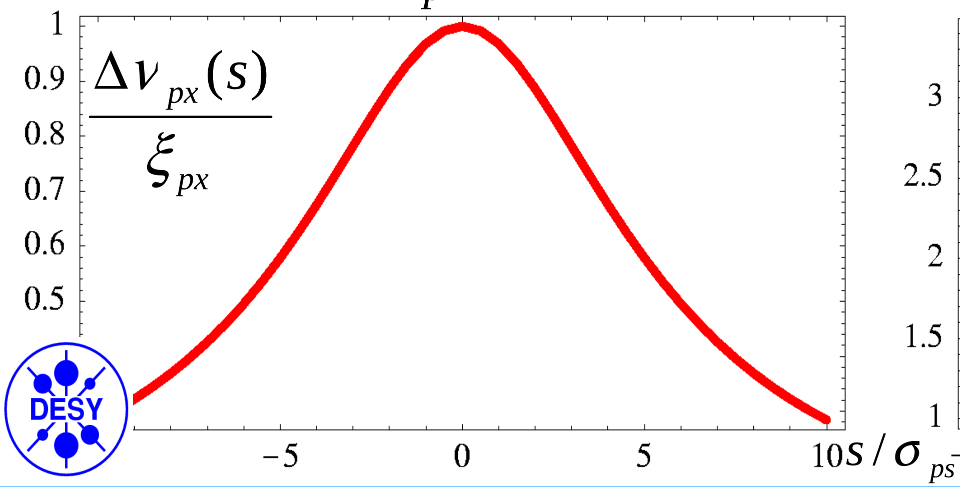
# Tuneshift Change by Hourglass Effect

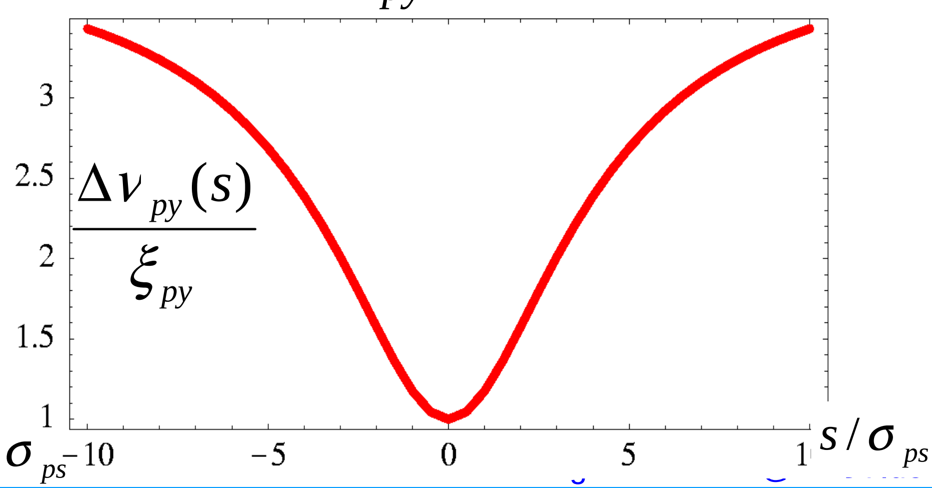



| Protons | Electrons |
|---|---|
| $\beta_{px} = 2.45m$ | $\beta_{ex} = 0.63m$ |
| $\beta_{py} = 0.18m$ | $\beta_{ey} = 0.26m$ |

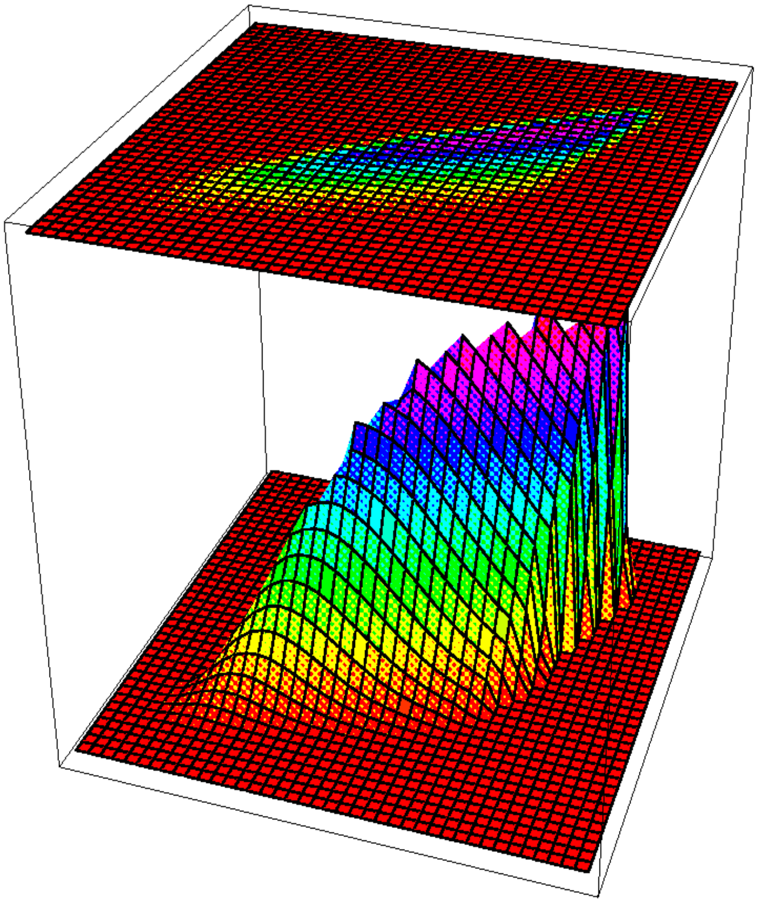
Horizontal: $\beta_{px}$ grows slower

Vertical: $\beta_{py}$ grows faster



# 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 |

Georg.Hoffstaetter@DESY.de

# 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

Georg.Hoffstaetter@DESY.de