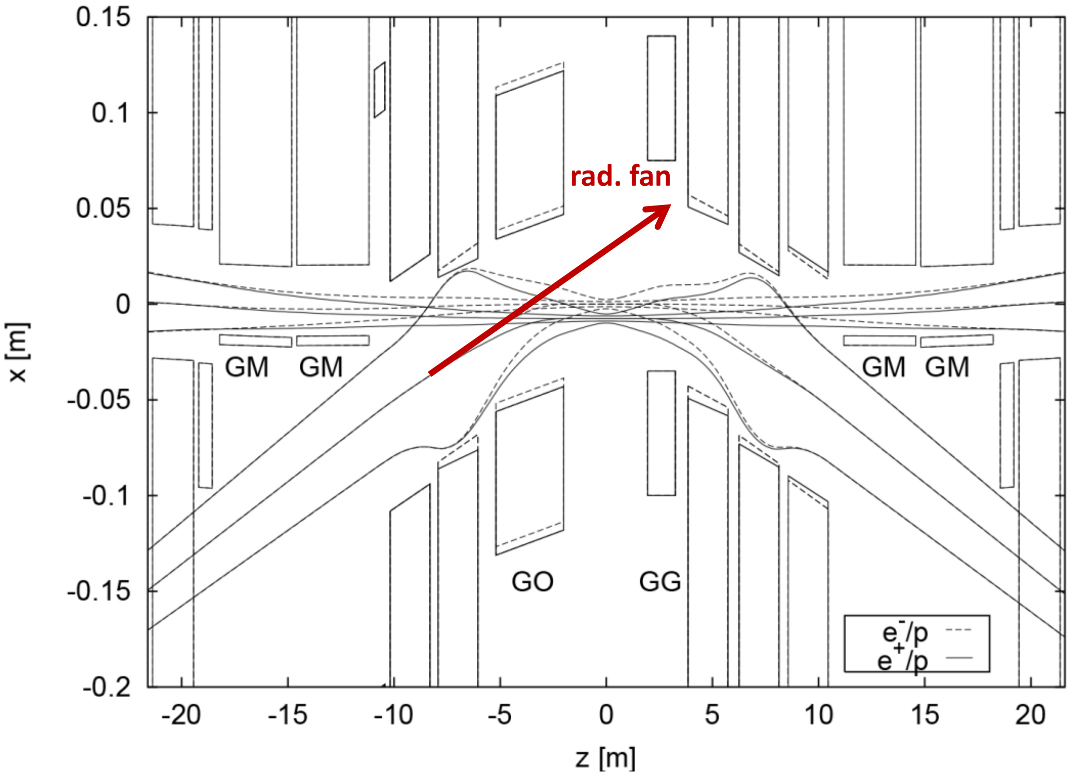
Operational experience from HERA

M.Seidel, PSI

- e^-/e^+ vs. p, (long.) polarized leptons
- 17.5 (inj. 14) GeV vs. 920 (inj. 40) GeV
- 6.3km circumference
- s.c. magnets, ~4.6T
- two stage collimation (12+4 jaws), inefficiency: few percent
- proton diffusion dominated by beam beam

colliding unequal beams

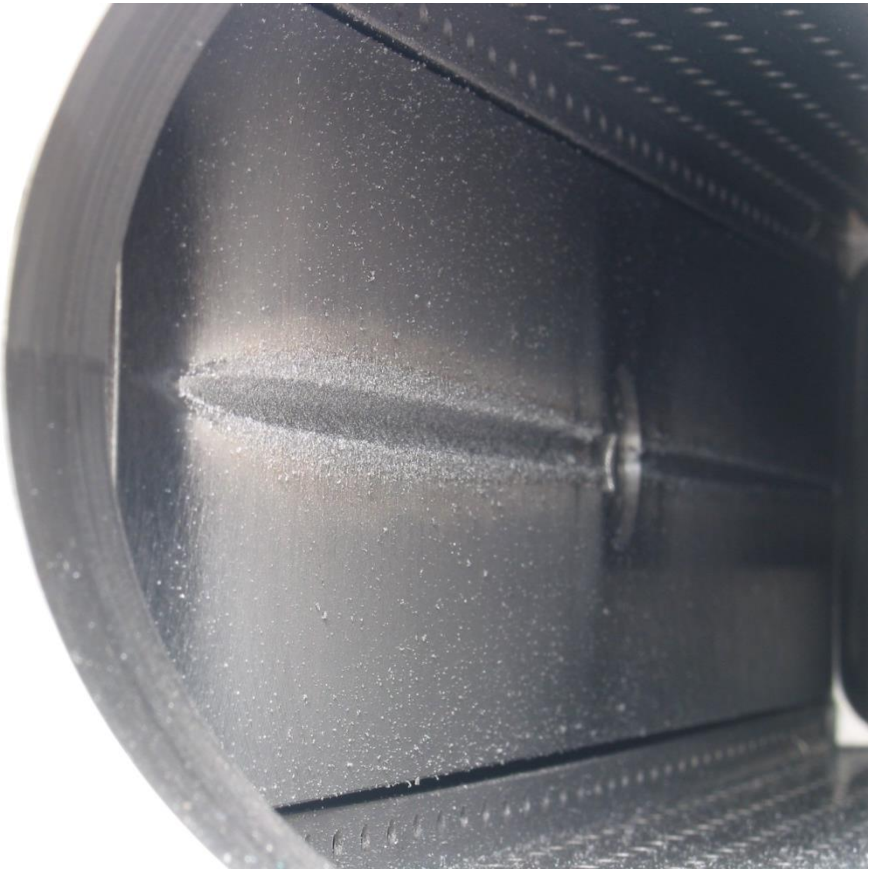
(impact on p diffusion)



protons

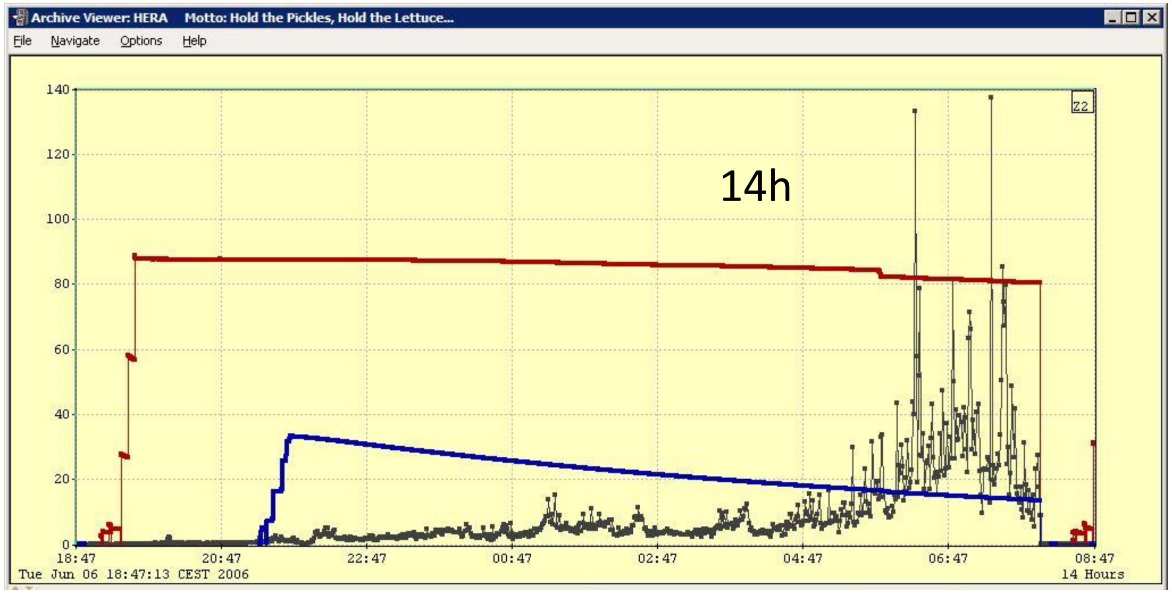
electrons,
positrons

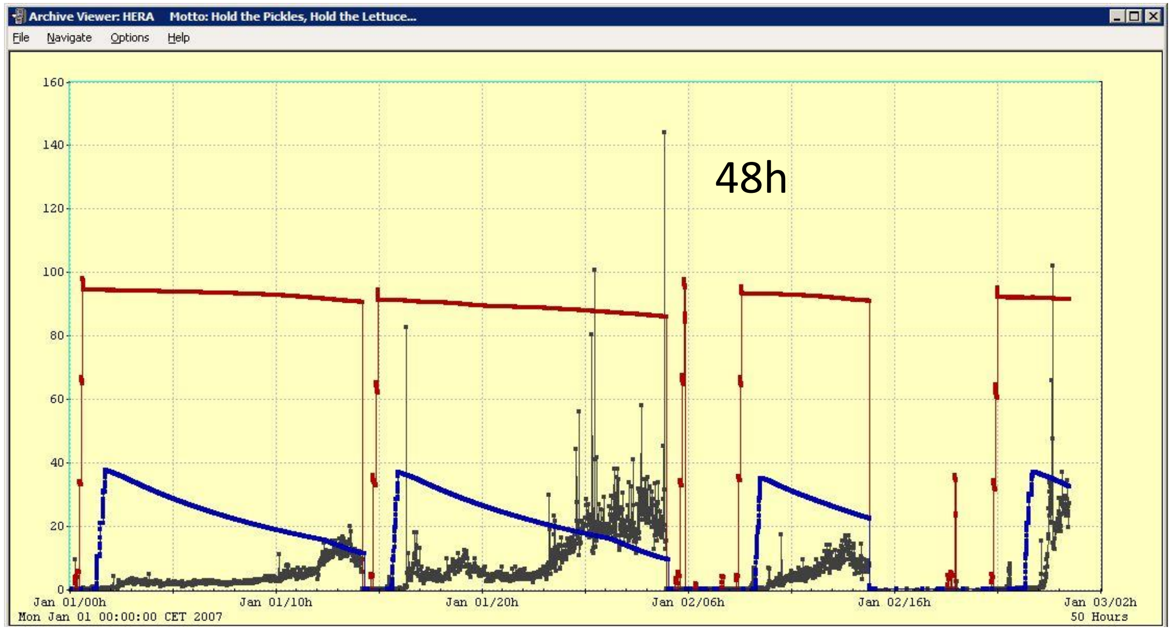
several primary p-collimators looked like this after few years of operation



- material Tungsten
- l = 400mm
- PIN diode based lossmonitor system with variable interlock threshold

spiked loss experience at HERA





data from 2006
[thanks to J.Keil]

- red: proton current
- blue: electron current
- black: loss rate at main collimator, max. value during time bin(!)

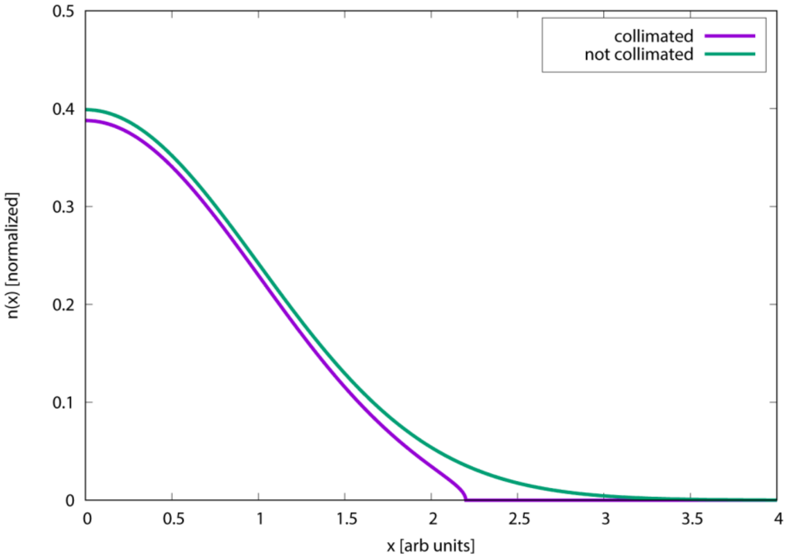
after some time in collisions losses become spiky

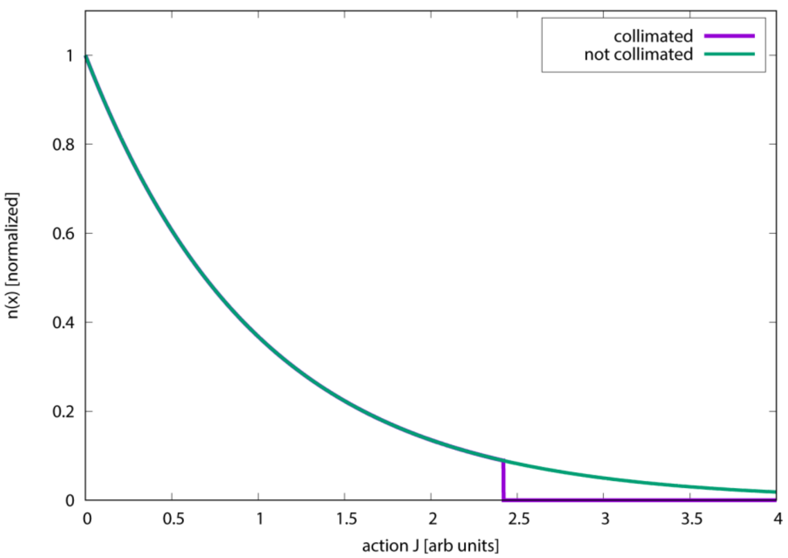
To consider collimation of a proton beam use the distribution in action J

$$J = \frac{1}{2}\left(\gamma x^2 + 2\alpha x x' + \beta x'^2\right)$$

proj. distribution in x:
Gaussian

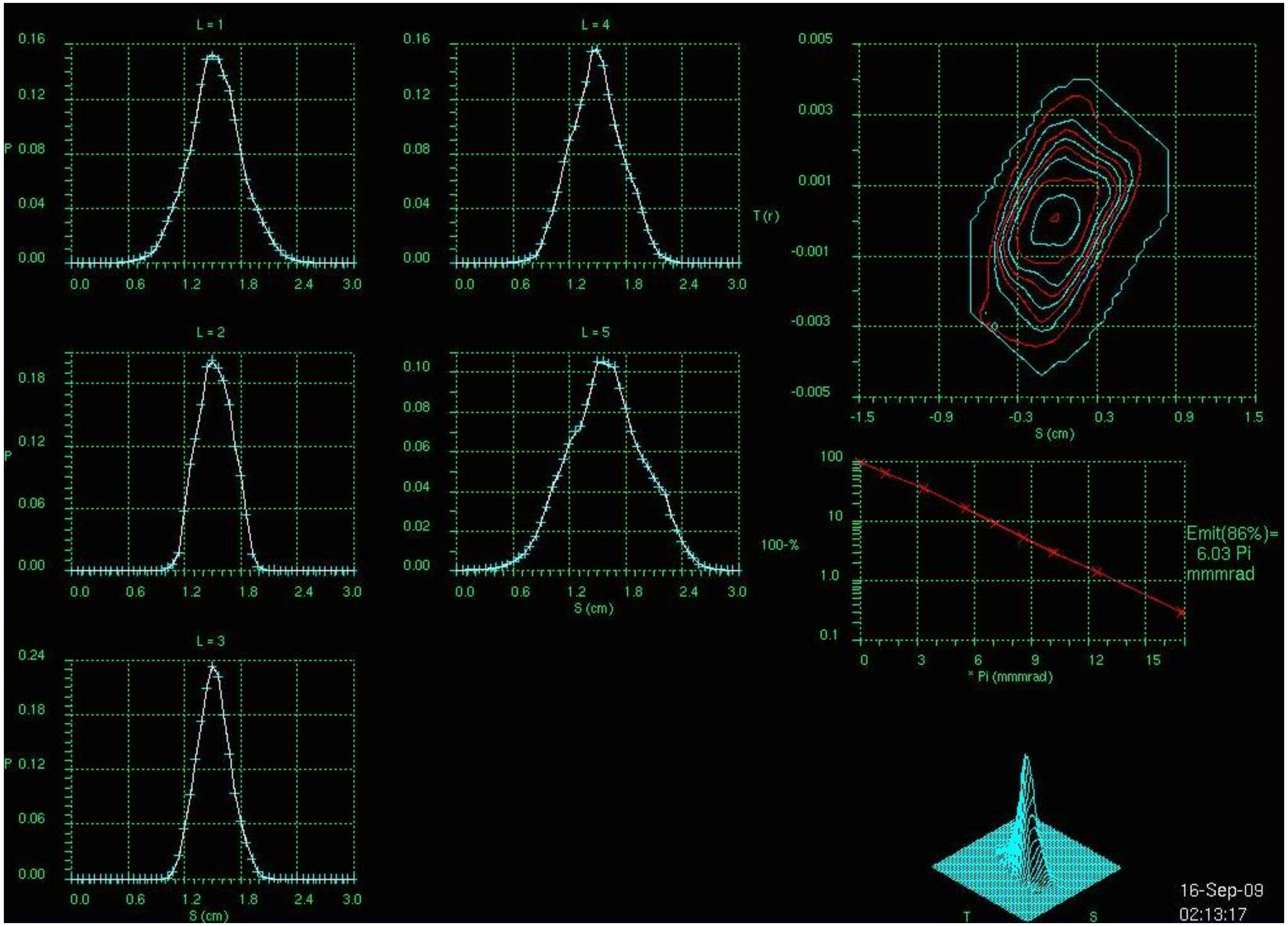
distribution in J:
Exponential





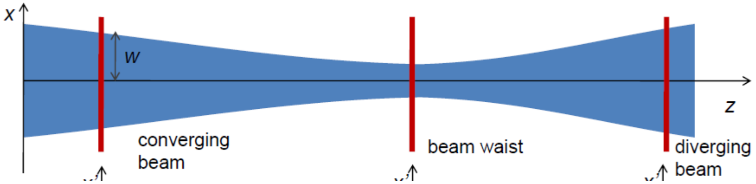
side note: tomographic phase space reconstruction using five wire scanners, PSI

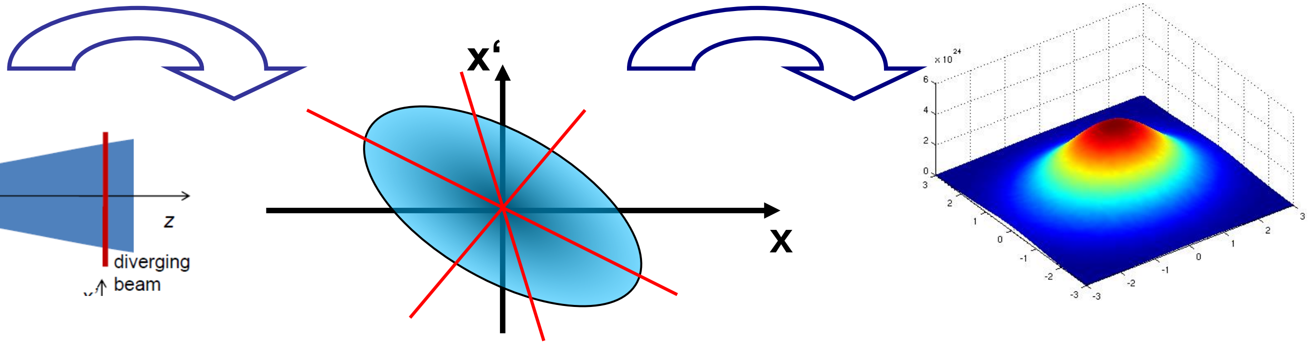
[D.Reggiani]



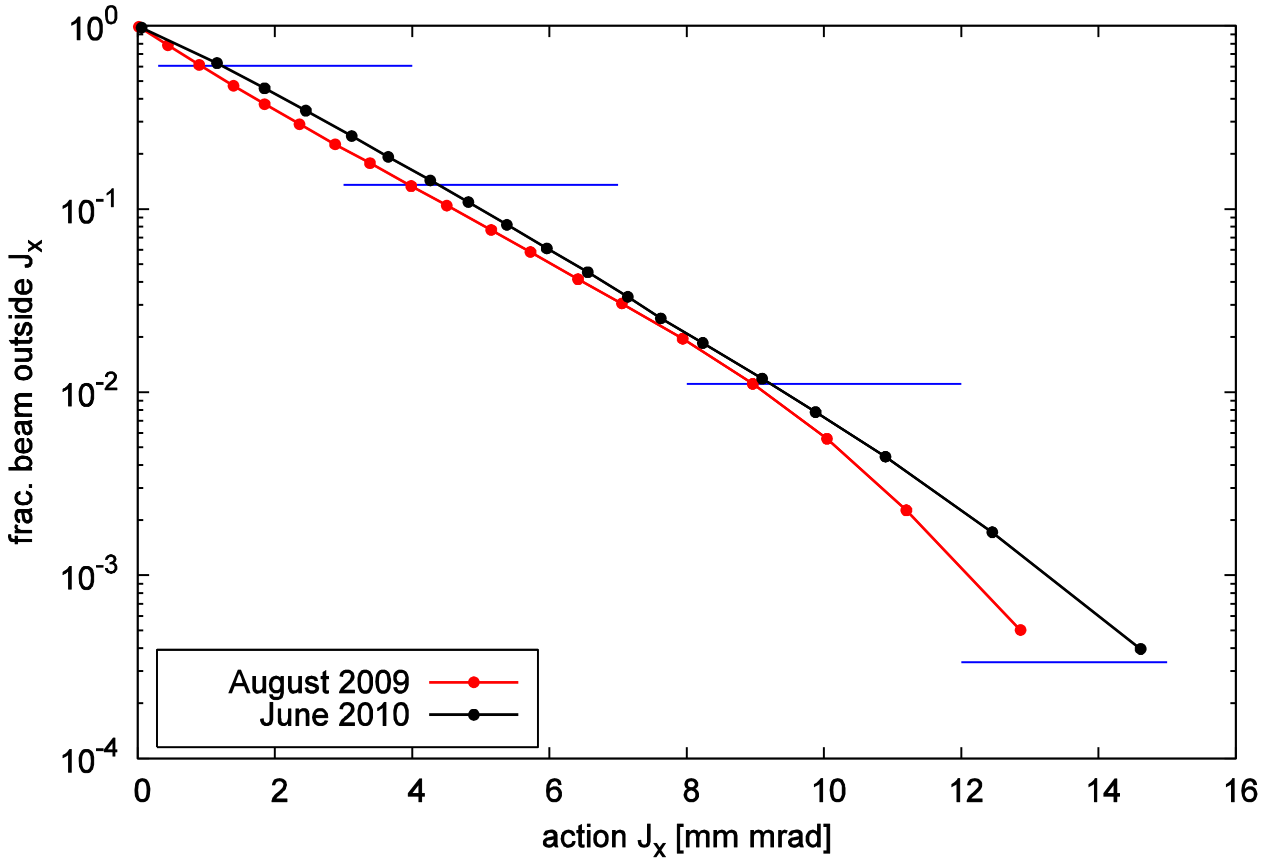
72 MeV:
ε_x (2σ) = 6 mm mrad

method:
maximum entropy





side note: particle action distribution, measured at HIPA



fractions corresponding to n=1,2,3,4 indicated

Measurement:
D.Reggiani

Diffusion Equation

$$j(J) = -D\frac{\partial n(J,t)}{\partial J} \quad + \quad \frac{\partial n(J,t)}{\partial t} + \frac{\partial j(J,t)}{\partial J} = 0$$

flow is proportional to
slope of distribution and
to diffusion coefficient

continuity equation

$$\frac{\partial n(J,t)}{\partial t} = \frac{\partial}{\partial J} D \frac{\partial n(J,t)}{\partial J}$$

note: $\Delta J \propto \sqrt{\Delta t}$ i.e. sharp features washed out quickly, then slower ...

observed rate evolution after collimator movement

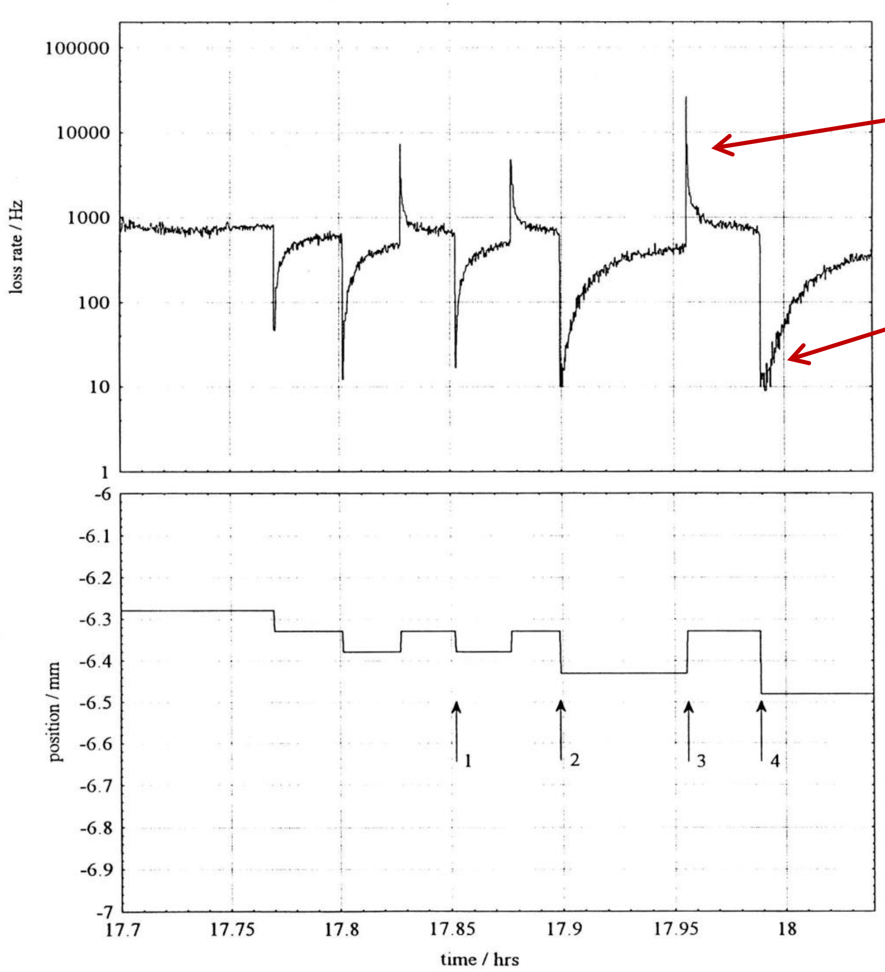
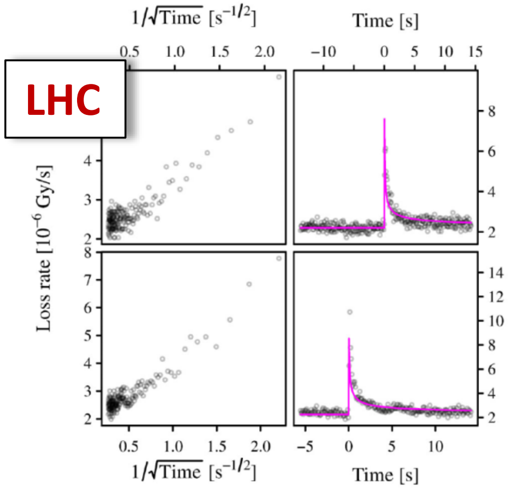


Fig. 5.5: Observed shower rates during collimator movements (upper plot). The jaw position is given on the lower plot. The time marks correspond to the following collimator movements:
1.) Δx = - 50 µm; **2.)** Δx = - 100 µm; **3.)** Δx = +100 µm; **4.)** Δx = -150 µm

$$\dot{n} \propto \frac{\Delta J}{\sqrt{Dt}}$$

$$\dot{n} \propto \left(1 - \mathrm{erf}\left(\frac{\Delta J}{\sqrt{4Dt}}\right)\right)$$

NIM A 351, 279 (1994)



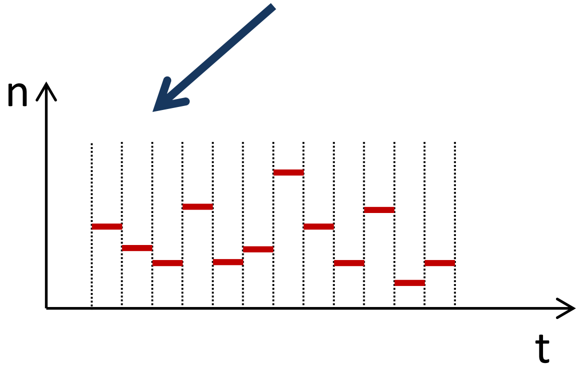
(a)Inward collimator jaw movement

Valentino et al

frequency spectrum of losses (HERA-p)

a purely digital measurement:
- **electronics counts loss events in bins**
- **perform an FFT**
- **average many FFT‘s**

→ no analog noise, e.g. 50Hz!



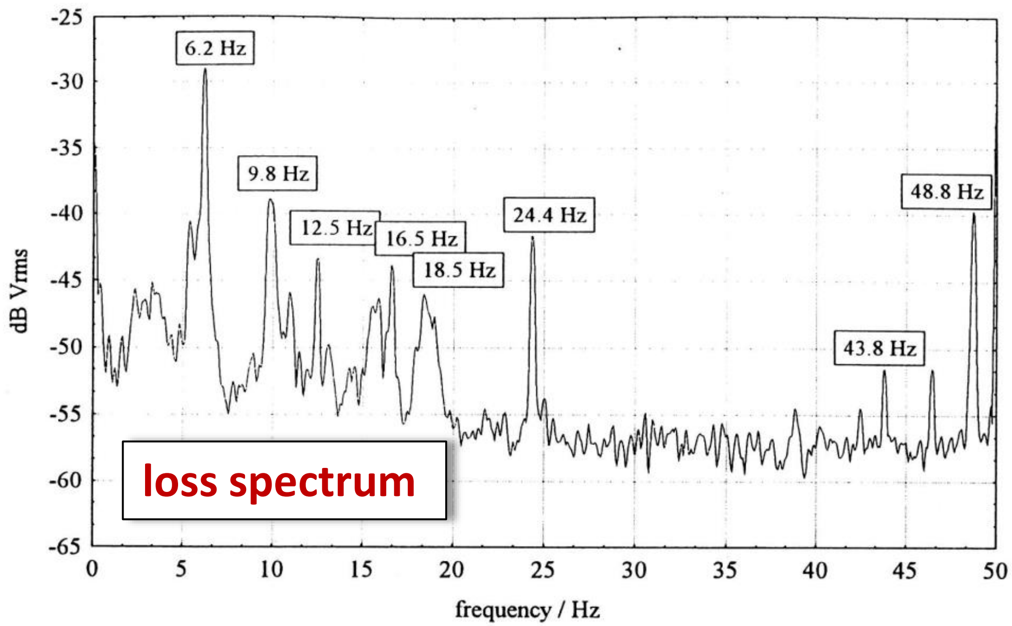


Fig. 5.11: Frequency spectrum of shower rates in the range up to 50 Hz, measured downstream of the collimator.

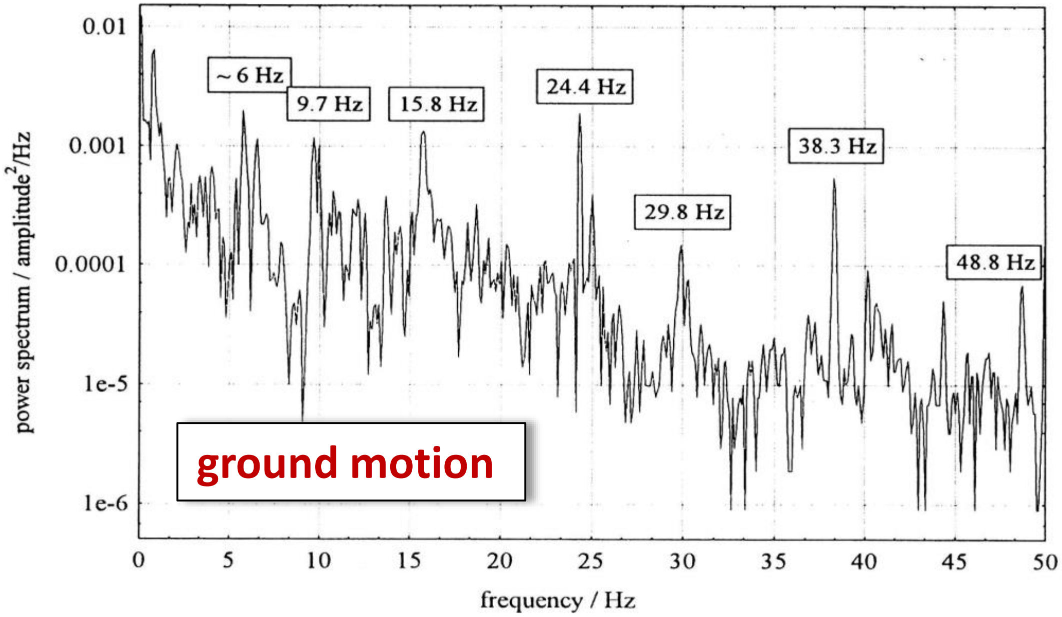
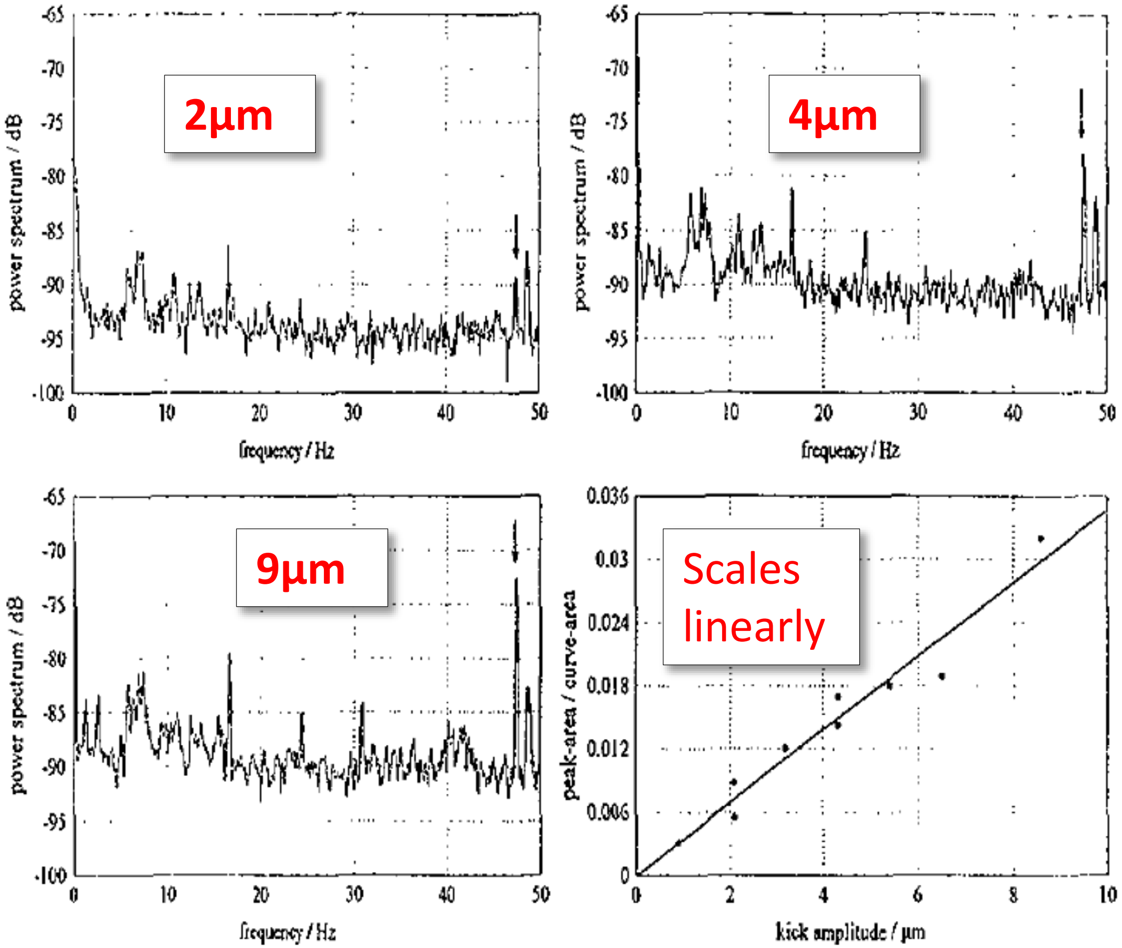


Fig. 5.12: Frequency spectrum of ground motion, measured in one of the superconducting quadrupoles.

known beam excitation for comparison



2µm

4µm

9µm

Scales linearly

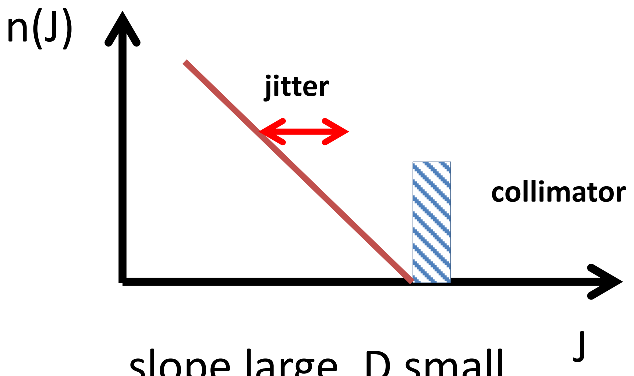
Fig. 5.15: Response of artificially induced orbit oscillations in the beam loss spectrum. The excitation amplitudes are : upper left picture: 2.1 µm, upper right picture: 4.3 µm, lower left picture: 8.6 µm. In the lower right picture the dependence of the peak area, normalised on the area of the whole spectrum, is shown as a function of the excitation amplitude. The response is in good approximation linear.

using a correction coil to excite the beam at 47.5Hz

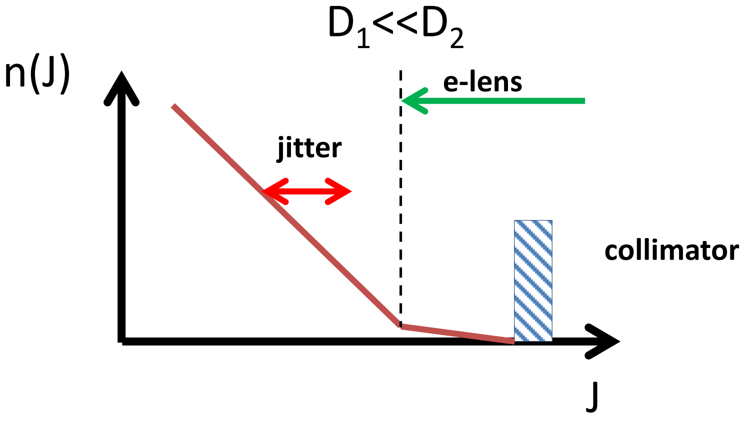
Effect of hollow electron lens

$$j(J) = -D\frac{\partial n(J,t)}{\partial J}$$

flow equal in both situations



slope large, D small



D large → slope small → loss rate less sensitive to jitter

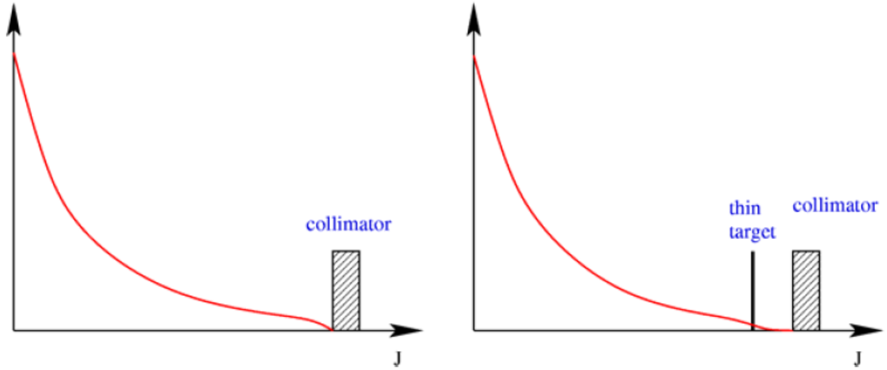


Fig.: Qualitative particle density distribution with and without thin target.

LHC Collimation review report, 2004, proposal of thin target for diffusion enhancement
http://lhc-collimation-project.web.cern.ch/lhc-collimation-project/review-report04/report-complete.pdf

Tune Modulation @ HERA

- Tune modulation was tested to compensate power supply ripples on quads
- It could also be used to introduce a **controlled diffusion rate which is amplitude dependent**; however, this was not used in practice

[work of O.Brüning, HERA 94-01]

artificial tune modulation in loss spectrum

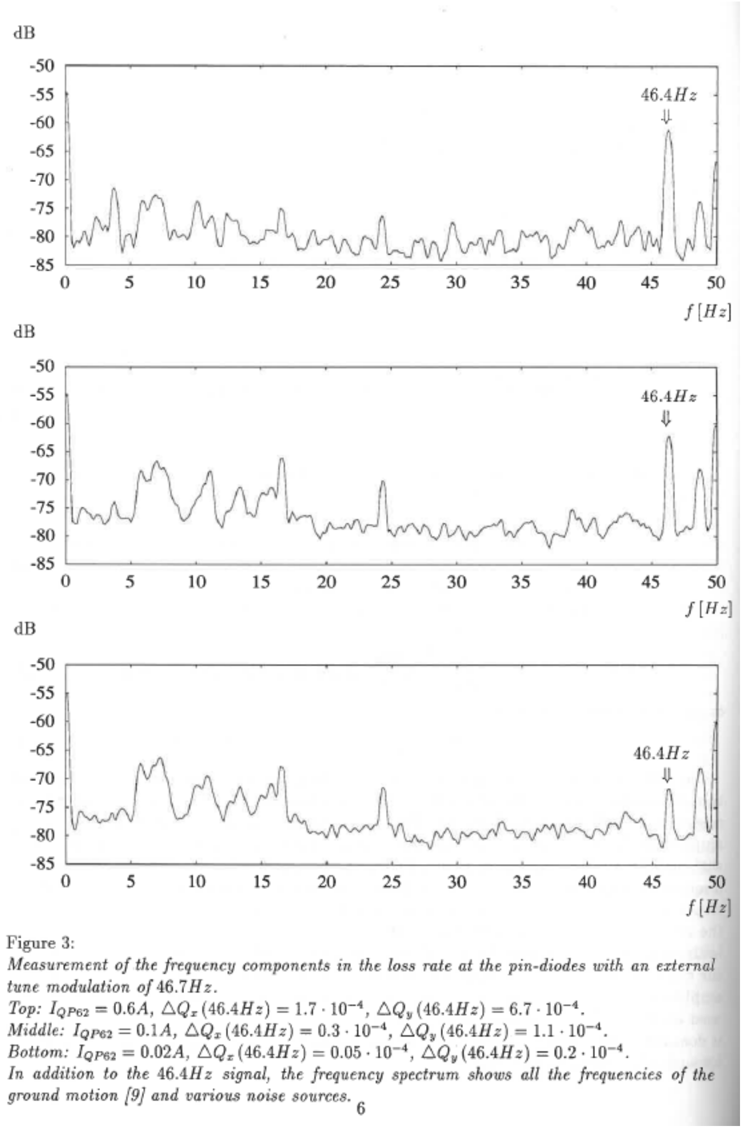


Figure 3:

Measurement of the frequency components in the loss rate at the pin-diodes with an external tune modulation of $46.7Hz$.

Top: $I_{QP62} = 0.6A$, $\Delta Q_x(46.4Hz) = 1.7 \cdot 10^{-4}$, $\Delta Q_y(46.4Hz) = 6.7 \cdot 10^{-4}$.

Middle: $I_{QP62} = 0.1A$, $\Delta Q_x(46.4Hz) = 0.3 \cdot 10^{-4}$, $\Delta Q_y(46.4Hz) = 1.1 \cdot 10^{-4}$.

Bottom: $I_{QP62} = 0.02A$, $\Delta Q_x(46.4Hz) = 0.05 \cdot 10^{-4}$, $\Delta Q_y(46.4Hz) = 0.2 \cdot 10^{-4}$.

In addition to the $46.4Hz$ *signal, the frequency spectrum shows all the frequencies of the ground motion [9] and various noise sources.*

conclusion

- at HERA spiked losses had a bad impact; physics detectors tripped frequently; will LHC suffer from spiked losses?
- Tune modulation was discussed as mitigation measure, but never really implemented; experiments adapted to the situation, more operational experience helped to reduce spikes
- hollow electron beam
  - can disperse spiked losses; would have helped for HERA problem
  - but long (seconds) periods of high losses will still lead to high losses at primaries
  - cannot be destroyed by loss spikes; improves impact parameter on primary → collimation efficiency
- but: hollow electron beam eats up some aperture margin