Outline

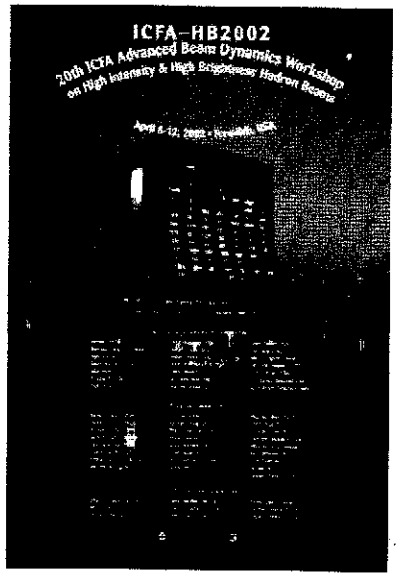
- Introduction
  - HERA at DESY
  - Parameters
- Sources of Emittance Dilution
  - Filamention of coherent oscilations
  - Scattering of particles
- Transverse Emittance at HERA-p
- Longitudinal Emittance at HERA-p
- Intra beam scattering
- Summary

Rainer.Wanzenberg@desy.de

Emittance dilution in HERA-p: lessons and overview

Rainer Wanzenberg
DESY, Hamburg, Germany

20th ICFA Advanced Beam Dynamics Workshop
High Intensity High Brightness Hadron Beams
Fermilab, April 8 - 12, 2002



Introduction

HERA at DESY:

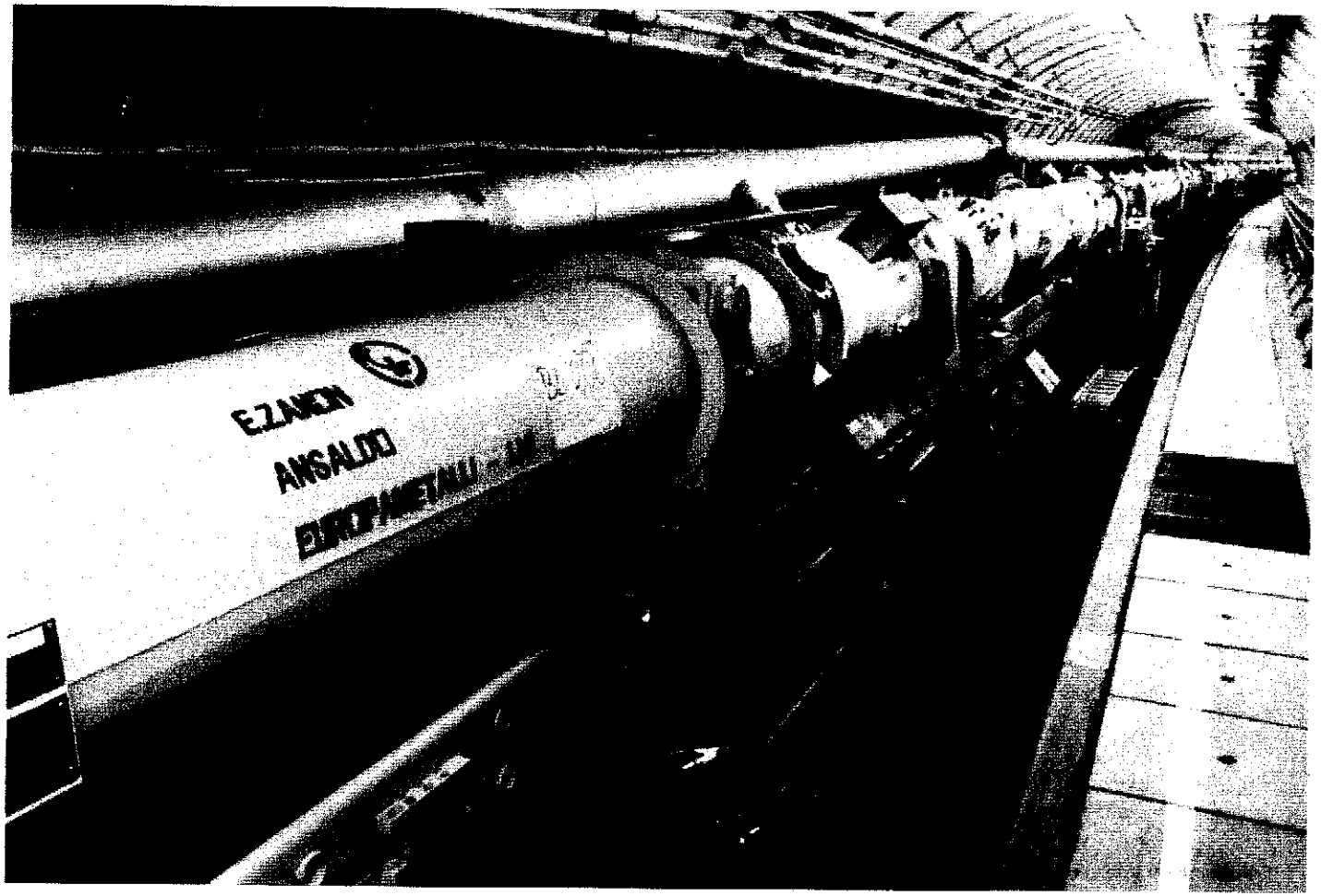
HERA:
p: 920 GeV
e: 27.5 GeV

circumference
6.3 km

Experiments:
H1
Zeus
Hermes
HERA-B

Rainer.Wanzenberg@desy.de

HERA tunnel:



p-ring
s.c.
magnets
920 GeV
protons

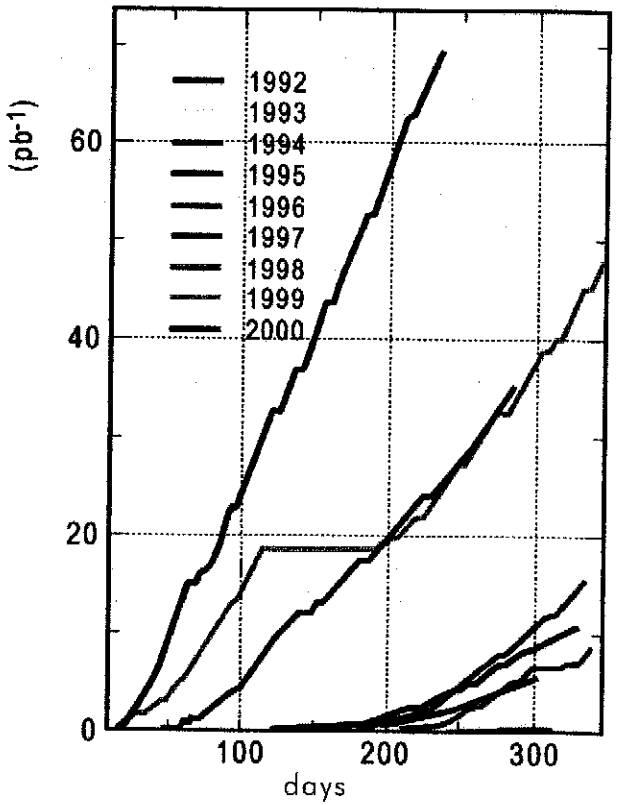
e-ring
n.c.
magnets
27.5 GeV
electrons

Rainer.Wanzenberg@desy.de

HERA Parameters

Parameter	HERA-p	HERA-e
E / GeV	920	27.5
I / mA	100	50
N / 10^{10}	7.3	3.5
# bunches	180	189
ε_x / nm	5.0	41
$\varepsilon_y / \varepsilon_x$	1	0.1
σ_z / cm	19	1.1
$4\beta\gamma\,\varepsilon_x$ / μm	20	8832
E_{inj} / GeV	40	12
$E_{transition}$ / GeV	26.2	0.02

HERA Luminosity 1992 - 2000



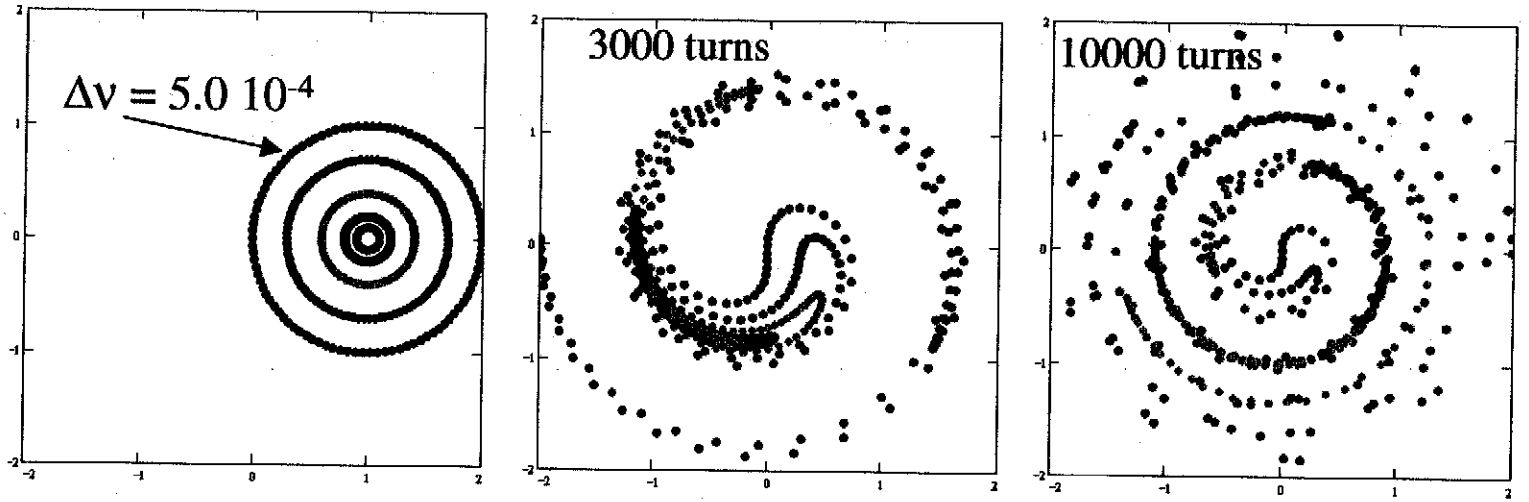
Interaction region	HERA-p	HERA-e	HERA-p	HERA-e
	until 2000		since 2001	
β_x / β_y / m	7.0 / 0.5	0.9 / 0.6	2.45 / 0.18	0.63 / 0.26
σ_x / σ_y / μm	189 / 50	192 / 50	112 / 30	112 / 30
				ε_x=20 nm, $\varepsilon_y / \varepsilon_x$=0.17
L_s / cm^{-2} s^{-1} mA^{-2}		$0.68\ 10^{30}$		$1.82\ 10^{30}$

Rainer.Wanzenberg@desy.de

DESY

Sources of Emittance Dilution

Phase space filamentation after a coherent oscillation

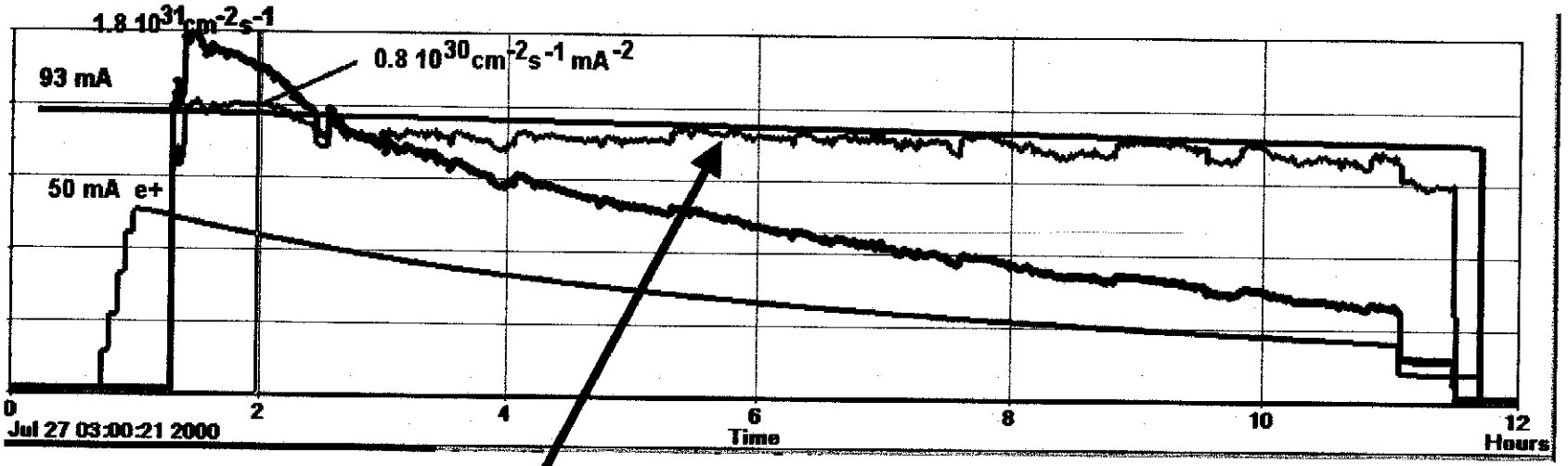


- Injection oscillation
- Mismatch of the linear beam optics
  - Beta-function
  - Dispersion
- Nonlinear fields
- Instabilities

Rainer.Wanzenberg@desy.de

Scattering of particles
- residual gas scattering
- intra beam scattering

IBS: multiple Coulomb scattering of charged particles in a bunch
rise times in all 3 dimensions => decay of luminosity



specific Luminosity

$$\frac{1}{\tau_{L_{spec}}} \approx 80 \text{ h}$$

$$L_{spec} = \frac{1}{\omega_0 e^2 \sqrt{\sigma_{x,e}^{\ 2} + \sigma_{x,p}^{\ 2}} \sqrt{\sigma_{y,e}^{\ 2} + \sigma_{y,p}^{\ 2}}}$$

Rainer.Wanzenberg@desy.de

Transverse Emittance Dilution in HERA-p

Emittance at injection: $\varepsilon = 0.12\,\mu\text{m}$

Injection errors:

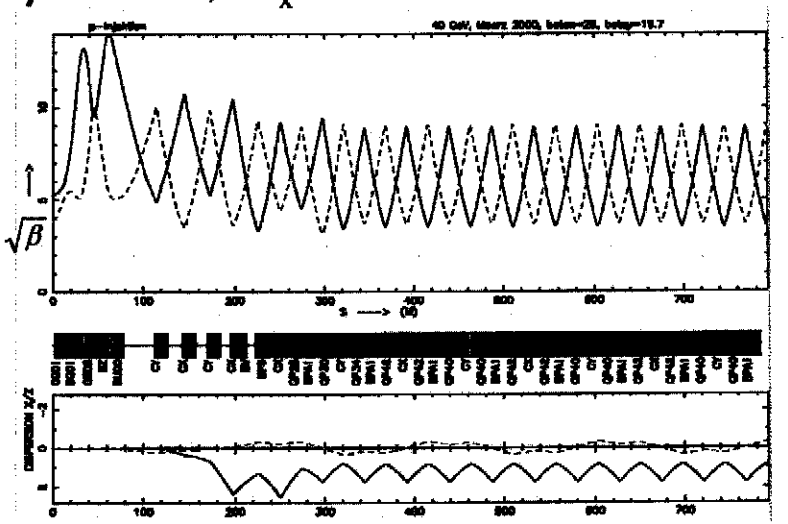
- reproducibility of the injection trajectory
- BPM precision 0.5 mm (resolution 0.1 mm)
- kicker riple 1 %

total injection error ~ 1 mm

Emittance dilution $\dfrac{\Delta\varepsilon}{\varepsilon} \approx 8\ \%$

Injection optics, arcs:

$\beta \approx 90\,\text{m},\ D_x \approx 2\,\text{m}$



The trajectory of the injected beam is carefully adjusted on the closed orbit (pilot injection with a few bunches).

Rainer.Wanzenberg@desy.de

DESY

Transverse Emittance Dilution in HERA-p (cont.)

Mismatch of the linear beam optics

- Betafunction $\frac{\Delta\beta}{\beta} \approx 10\ \%$

$$\frac{\Delta\varepsilon}{\varepsilon} \approx 3\ \%$$

- Dispersion $\frac{\Delta D}{D} \approx 10\ \%$

Coupling in the transfer line

Nonlinear fields in the transfer line

$$\frac{\Delta\varepsilon}{\varepsilon} \leq 1\ \%$$

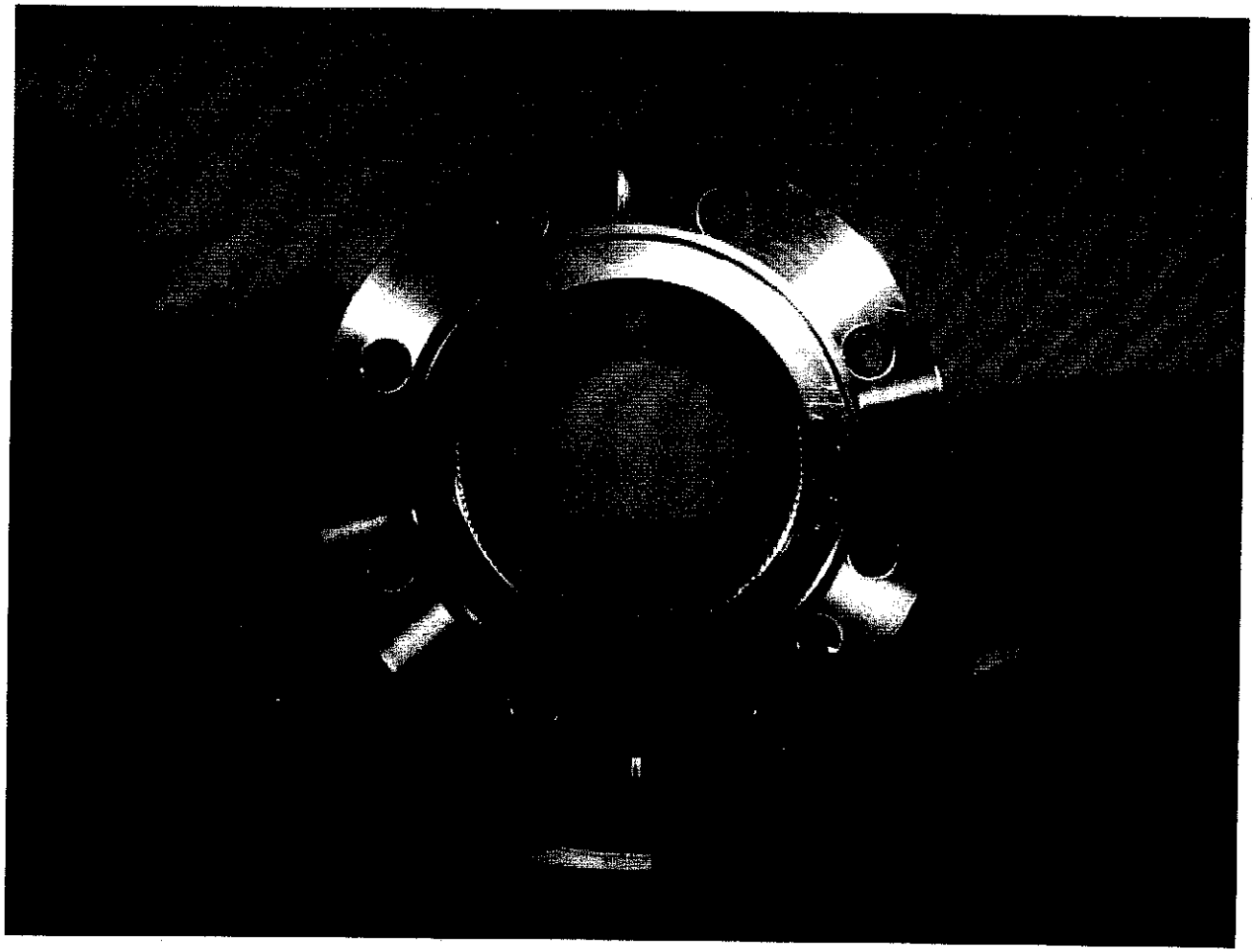
Total dilution during injection:

$$\frac{\Delta\varepsilon}{\varepsilon} \approx 12\ \%$$

Rainer.Wanzenberg@desy.de

Transverse Emittance Dilution in HERA-p (cont.)

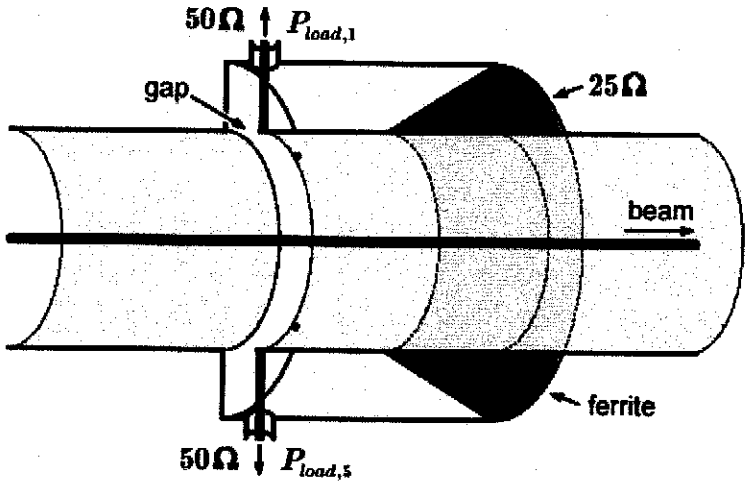
HERA stripline BPM:



(M. Wendt)

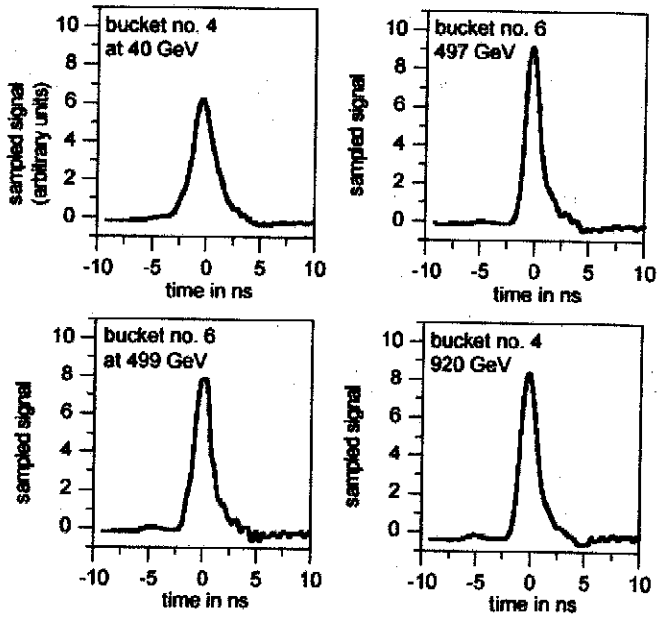
Rainer.Wanzenberg@desy.de

Longitudinal Emittance in HERA-p



Resistive gap monitor
Tektronix SCD5000 oscilloscope
(analog bandwidth 4.5 GHz)

Longitudinal Bunch
Shape measurements



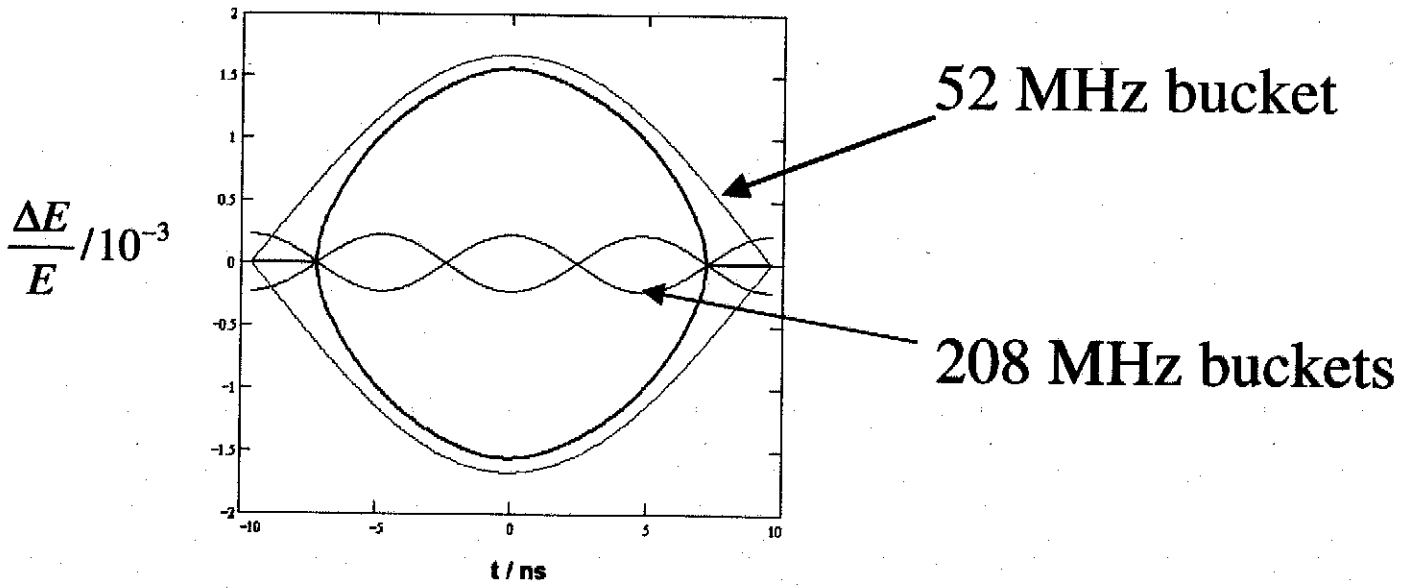
- Bunch signals from different turns are use to match the HERA energy to the injected beam

Rainer.Wanzenberg@desy.de

Longitudinal Emittance in HERA-p (cont.)

RF-Systems: 52 MHz and 208 MHz
at 40 GeV 140 kV ~ 10 kV

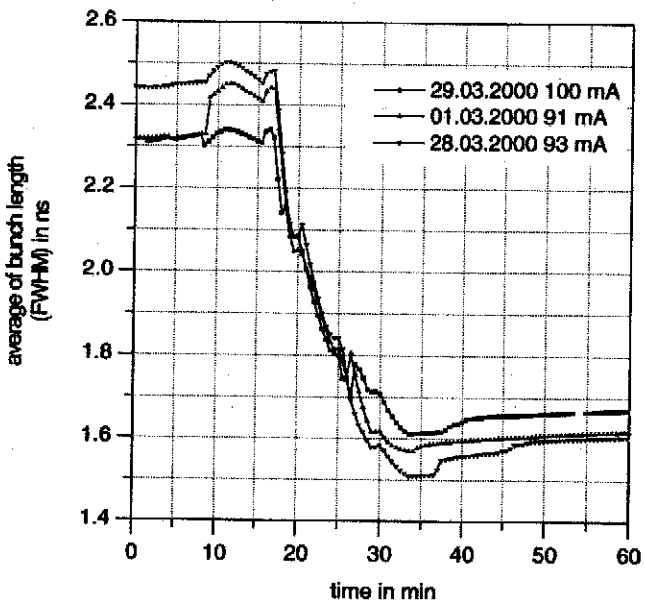
Nonlinear rf-potential at
injection energy: increased Landau Damping

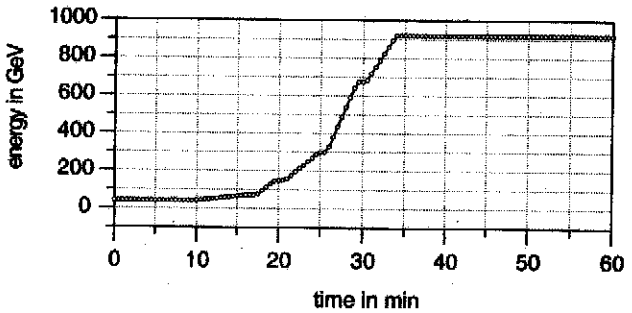


Rainer.Wanzenberg@desy.de

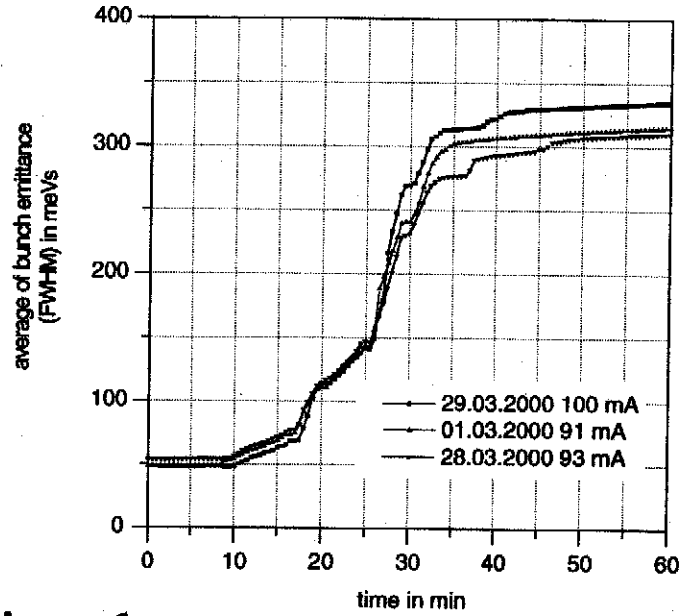
Longitudinal Emittance in HERA-p (cont.)

bunch length during ramp
(FWHM in ns)





Longitudinal emittance
(FWHM in meVs)



During the ramp:
longitudinal emittance growth
50 meVs → 300 meVs
due to a coupled bunch instability

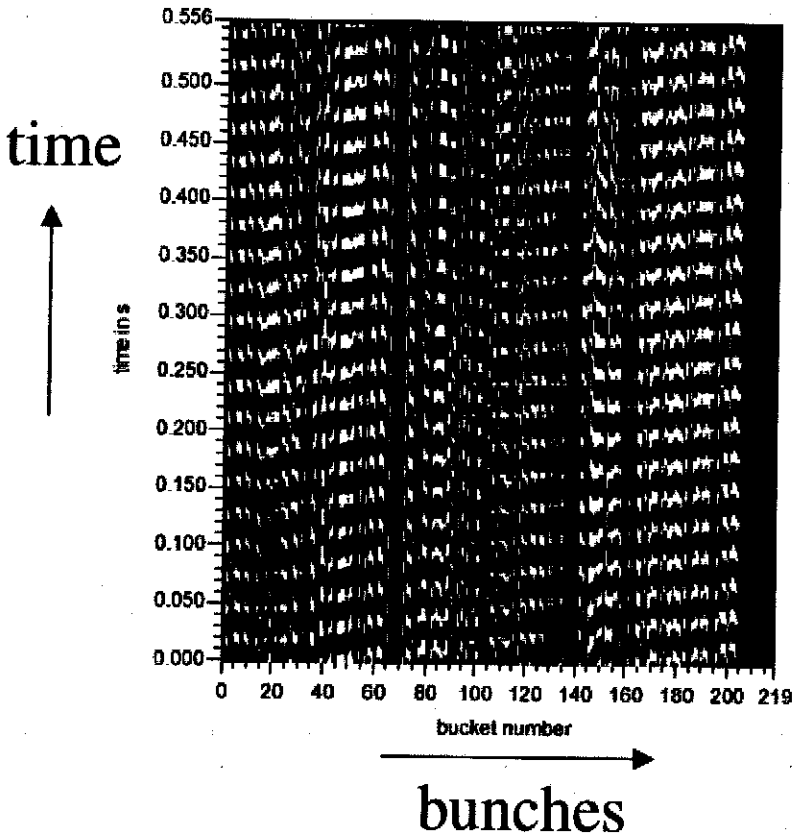
(Data from E. Vogel, Thesis, Univ. Hamburg, 2002)

Rainer.Wanzenberg@desy.de

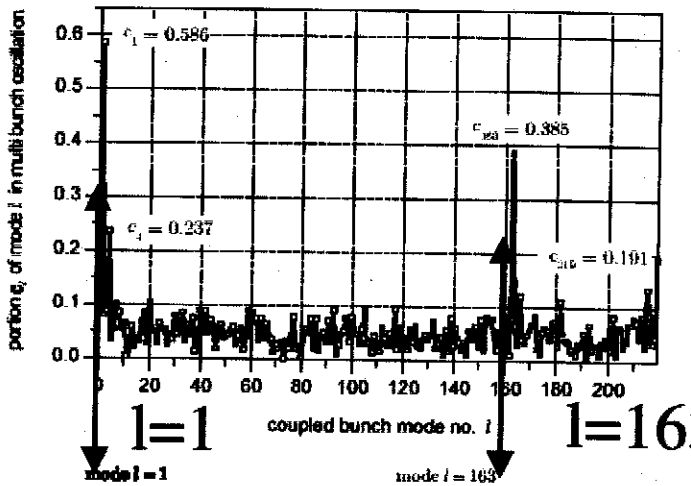
DESY

Longitudinal Emittance in HERA-p (cont.)

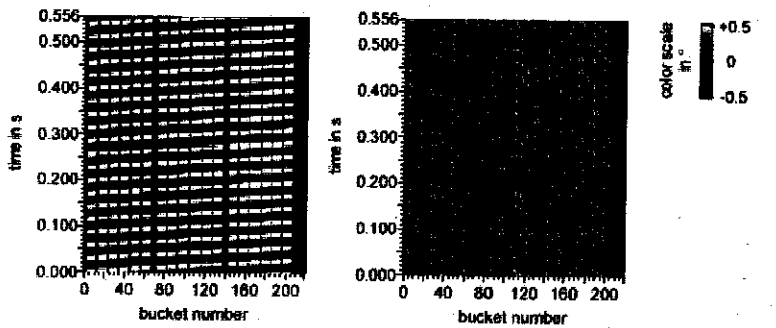
Multibunch phase oscillation during the ramp (at 830 GeV)



Modal spectrum:



Mode l=1 l=163

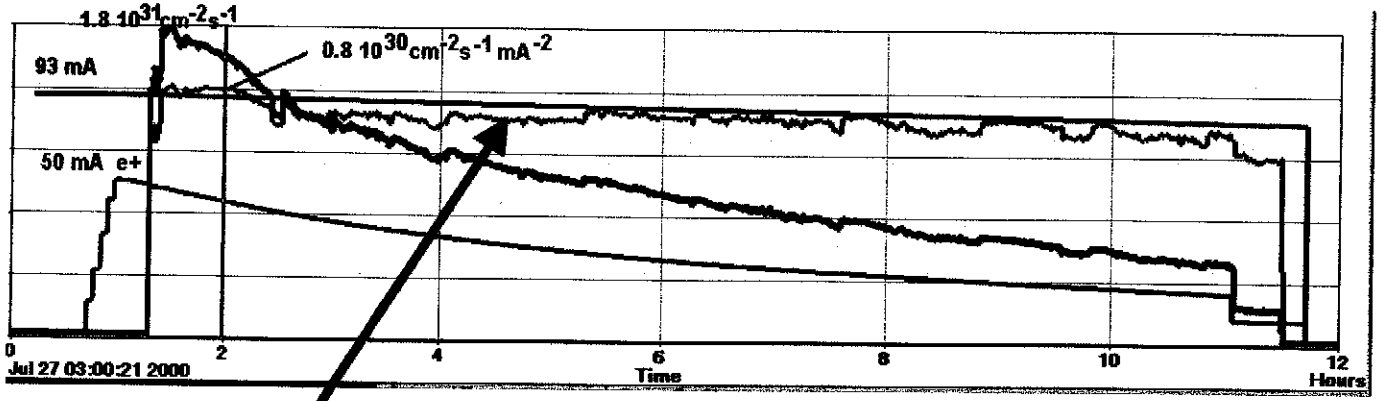


(Data from E. Vogel, Thesis, Univ. Hamburg, 2002)

Rainer.Wanzenberg@desy.de

DESY

Intra beam scattering

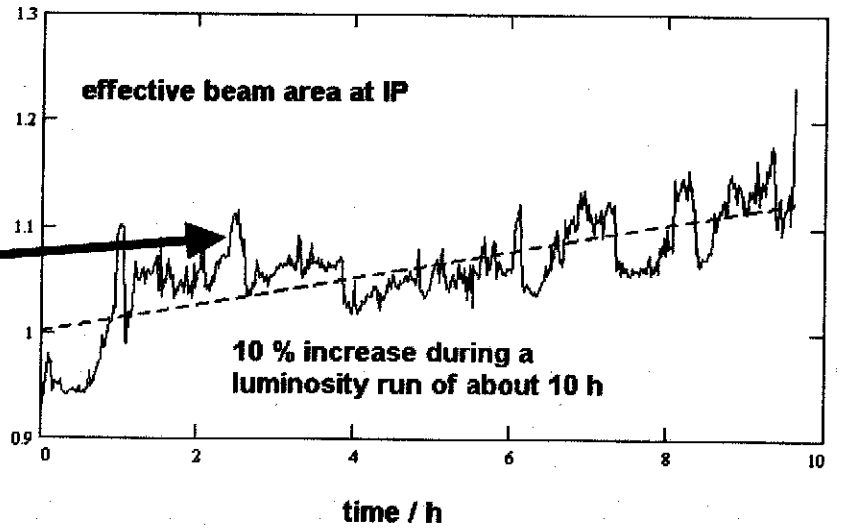


specific Luminosity

$$L_{spec} = \frac{1}{\omega_0 e^2 \sqrt{\sigma_{x,e}^{\ 2} + \sigma_{x,p}^{\ 2}} \sqrt{\sigma_{y,e}^{\ 2} + \sigma_{y,p}^{\ 2}}}$$

effective beam area at IP

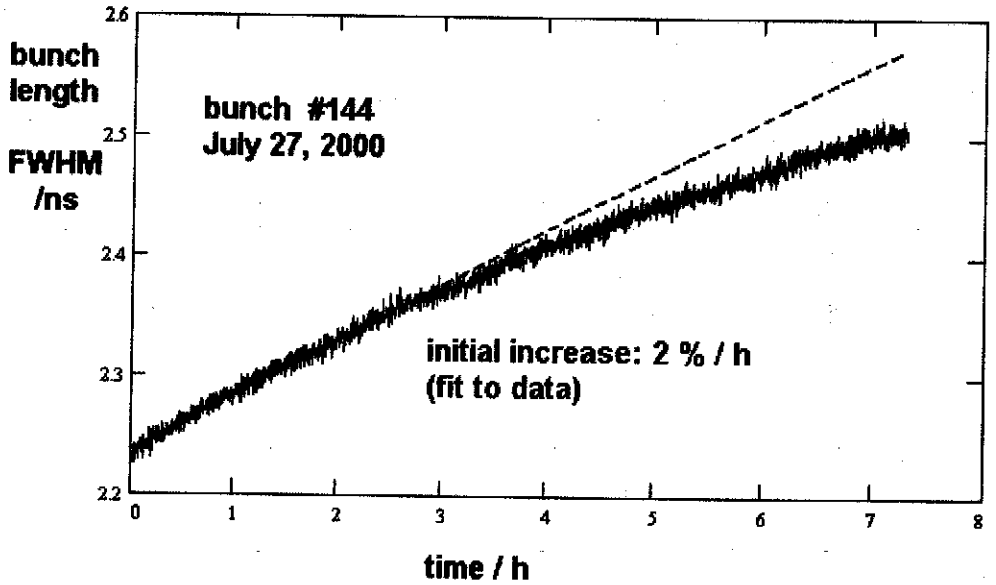
$$\sigma_{x,eff} \cdot \sigma_{y,eff} = \frac{1}{\omega_0 \ e^2 \ L_{spec}}$$



Rainer.Wanzenberg@desy.de

Intra beam scattering (cont.), longitudinal

Measurement



measured
initial increase
2 % / h

Theory (A. Piwinski, 1974, see CERN school 1991, CERN 92-01)

$$\frac{1}{\tau_s} = \left\langle A \frac{\sigma_h}{\sigma_p} f(a,b,q) \right\rangle, \quad a = \frac{\sigma_h \beta_x}{\gamma \sigma_{x\beta}}, \quad b = \frac{\sigma_h \beta_y}{\gamma \sigma_{y\beta}}, \quad q = \sigma_h \sqrt{\frac{2d}{r_p}}$$

predicted
initial increase
1.8 % / h

Rainer.Wanzenberg@desy.de

Summary

Transverse Emittance Dilution

dominant effect: injection errors

cure: pilot injections to adjust the trajectory

Longitudinal Emittance Dilution

Nonlinear rf-potential for Landau damping at 40 GeV

instability during the ramp

Intra Beam Scattering

increase of bunch length and

decay of specific luminosity are

dominated by intra beam scattering

Rainer.Wanzenberg@desy.de