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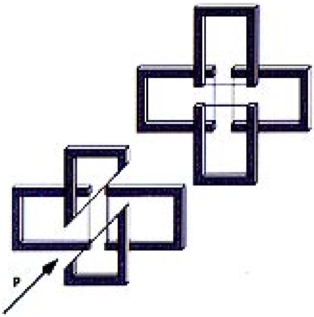
Uni–Dortmund
HERA–B Seminar Talk
3rd of March 1999

The HERA–B High Rate Target

– Overview & recent results –

- The target itself: Requests & technical realization
- The counting rate experiment: Target operation & control
- Target & HERA: Target behaviour & understanding

Requirements to the HERA–B Target



- Interactionrate & targetefficiency ϵ_T

  Interactionrate of 30–40 MHz needed, that means 4–5 IA/bx

  1 mA proton loss in 1 hour: 36 MHz
  → Beamscraping
  → Background (large angle scattering)

  Influence: Multiple scattering, aperture & collimators, Z of target material, beam optics, diffusion, ...

- Duration of measurement : $\geq 10^7$ sec/year
  → fast, secure and reliable target steering
  → simple handling/control
  → online monitoring
  → coordination with HERA/other exp.

- Reconstruction efficiency and limitation of detector performance
  → constant rate, no spikes
  → IA disributed equally on each wire
  → no or even small fluctuations
  → similar contribution of all bunches
  → no IA inside the bunch gaps
  (1 IA within 96 nsec, no satellites, etc.)

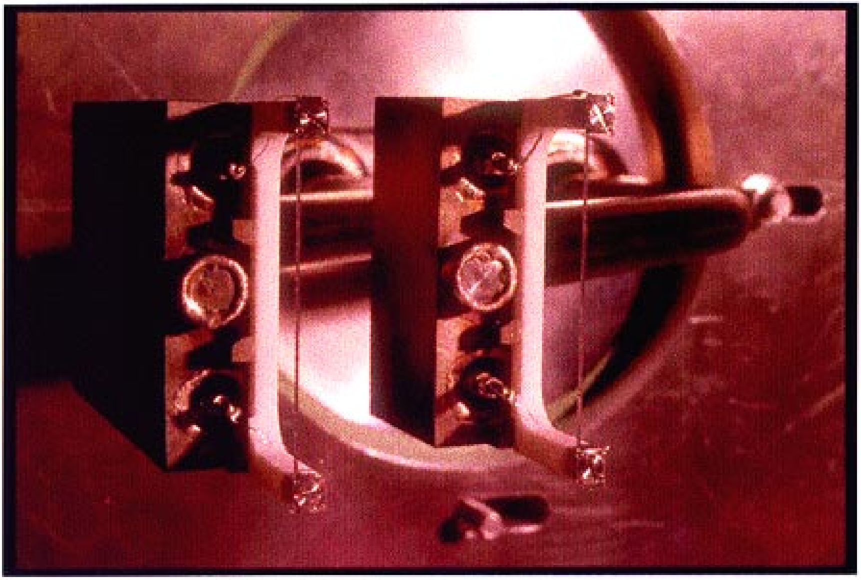
Target mechanics

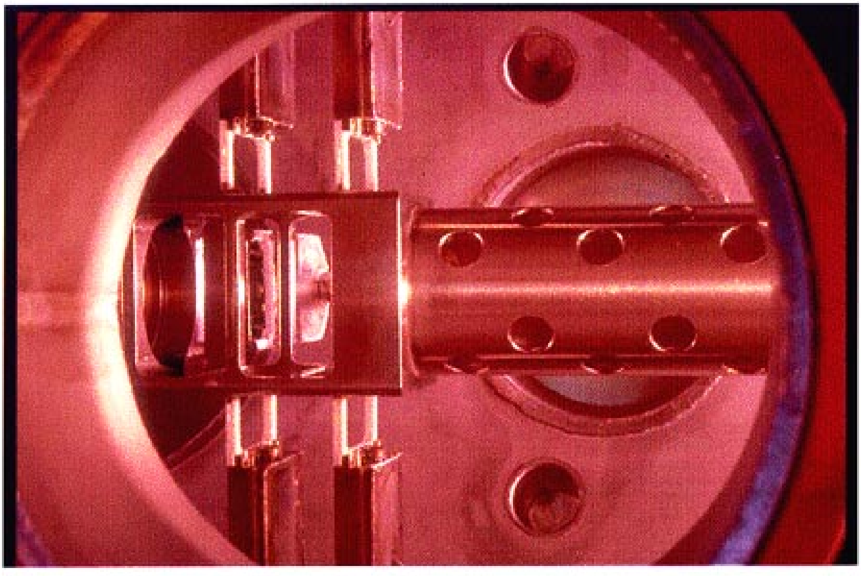
1998/1999: Eight individually movable wires ($500\mu m \times 50\mu m$) inside the vertex vessel.

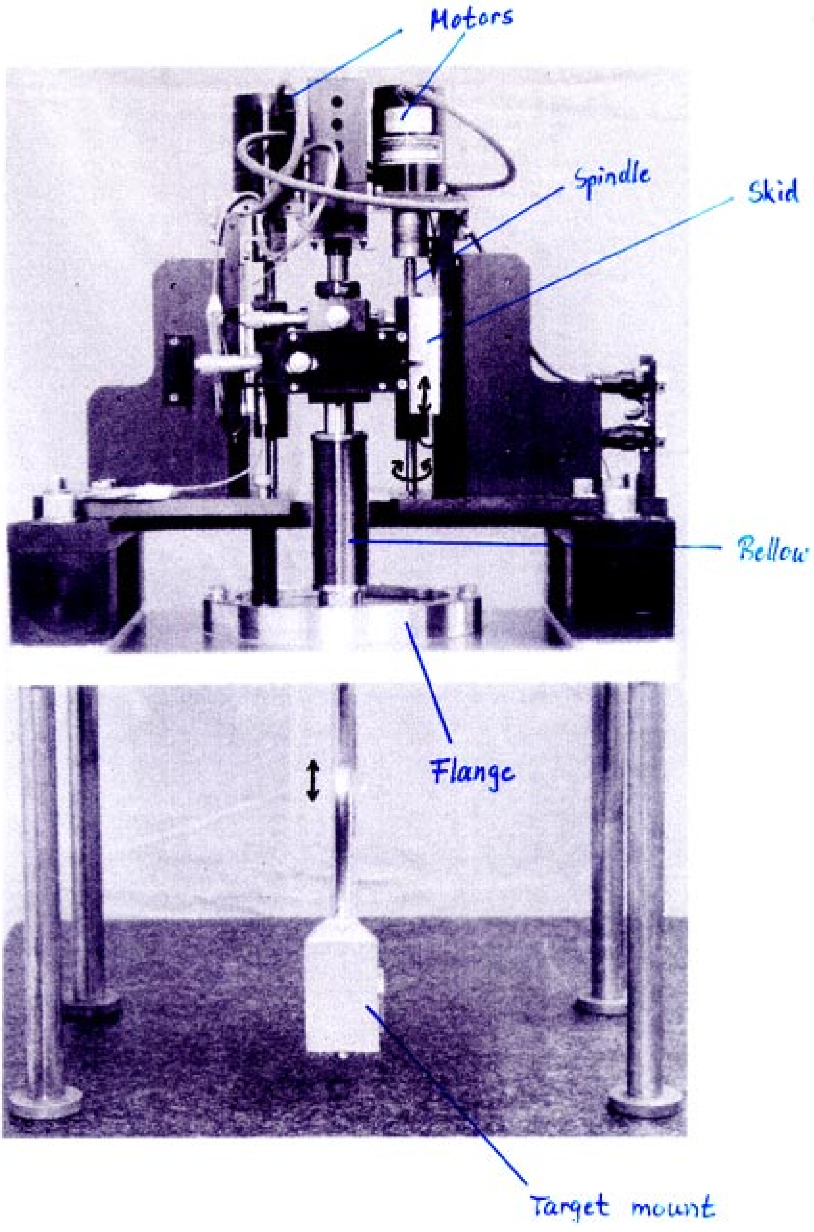
1. Station: INNER, OUTER, ABOVE $\hat{=}$ Al (90^o)
BELOW $\hat{=}$ Ti (90^o)
2. Station: INNER $\hat{=}$ carbon fibre bundle (90^o)
OUTER $\hat{=}$ Ti (90^o)
ABOVE $\hat{=}$ Fe (45^o)
BELOW $\hat{=}$ Ti (45^o)

- smallest stepsize of step motors: 50 nm (nominal), useful/necessary: $\mathcal{O}(\leq 1\mu m)$
- investigations of the movement properties & a survey of the target mechanics was done in detail in spring 1998 → accessibleness of required accuracy seems to be problematic:
    - ▷ fading and ageing
    - ▷ constructive weak points
- electrical connections for relative endswitches, charge integrators and target monitoring system

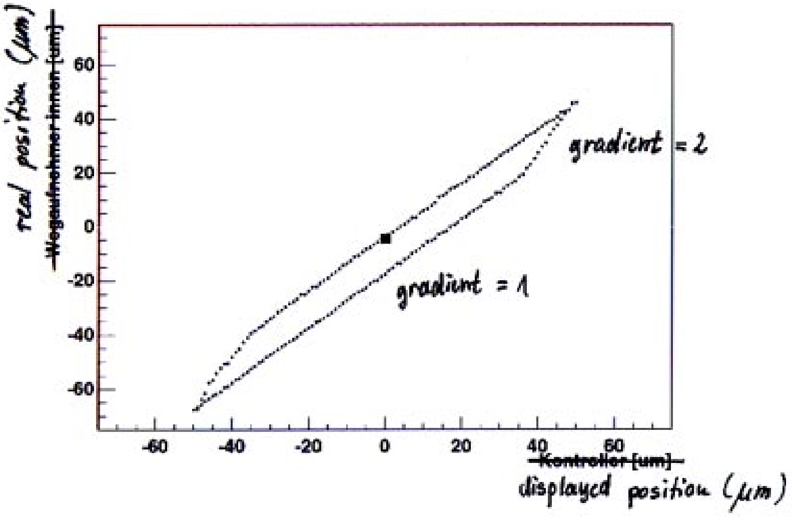
Target inside vertex vessel

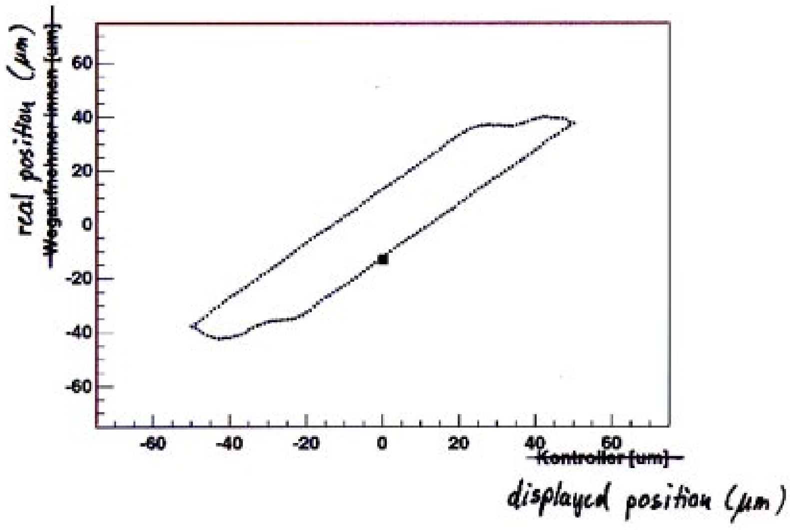





Motors
Spindle
Skid
Bellow
Flange
Target mount

Movement pattern of the target:
The hysteresis loop



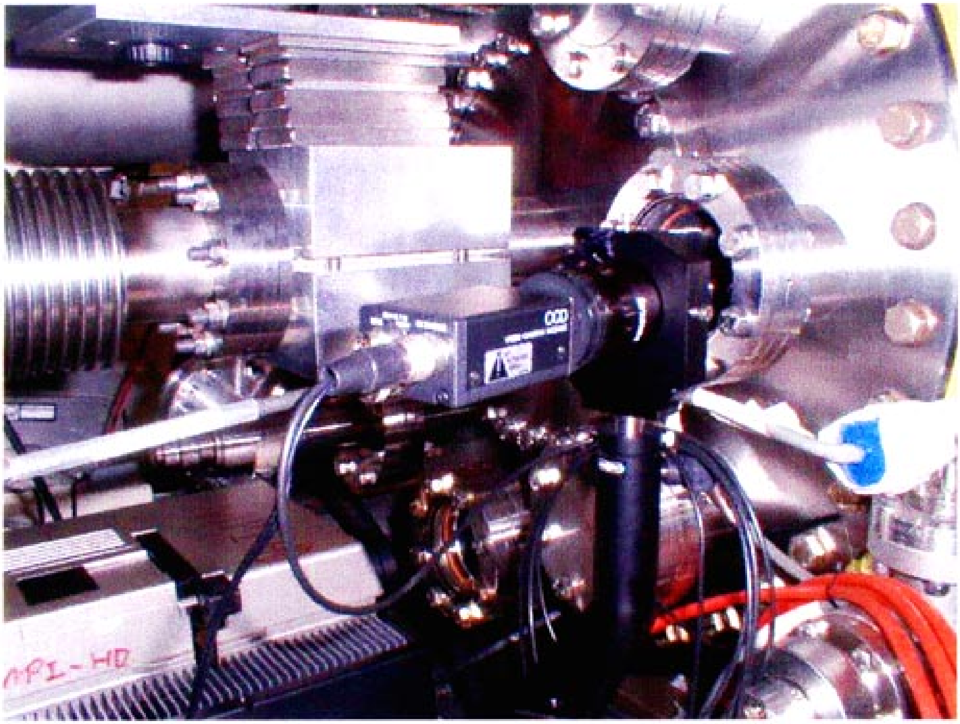


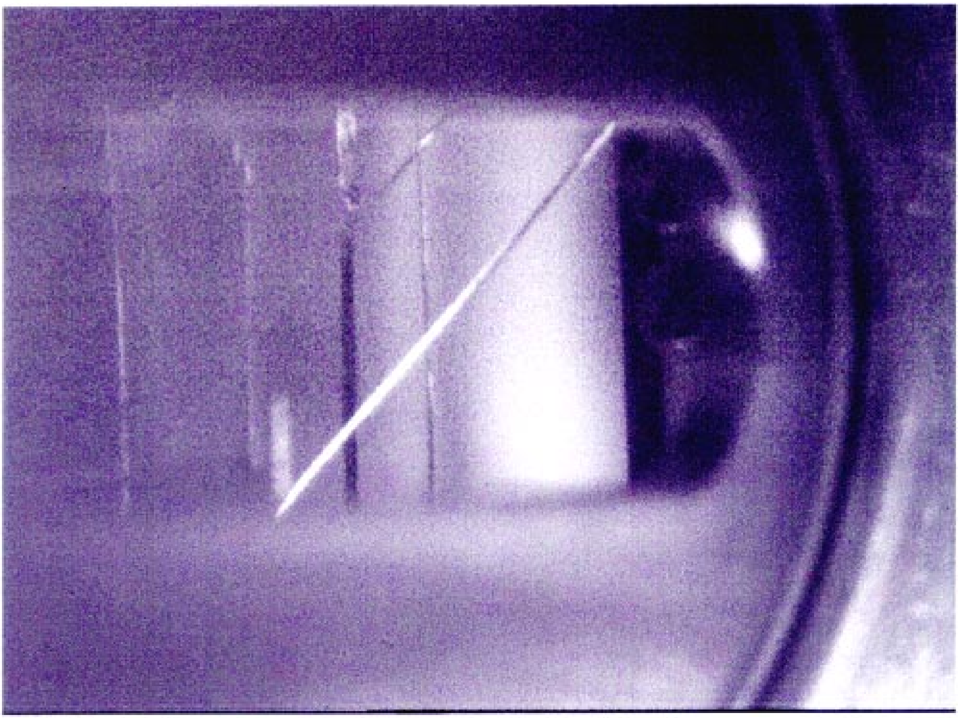
Target Viewing System TVS

CCD camera looks through flanges with windows onto the target wires.
Signals over 50 m to electronic hut – to a PC

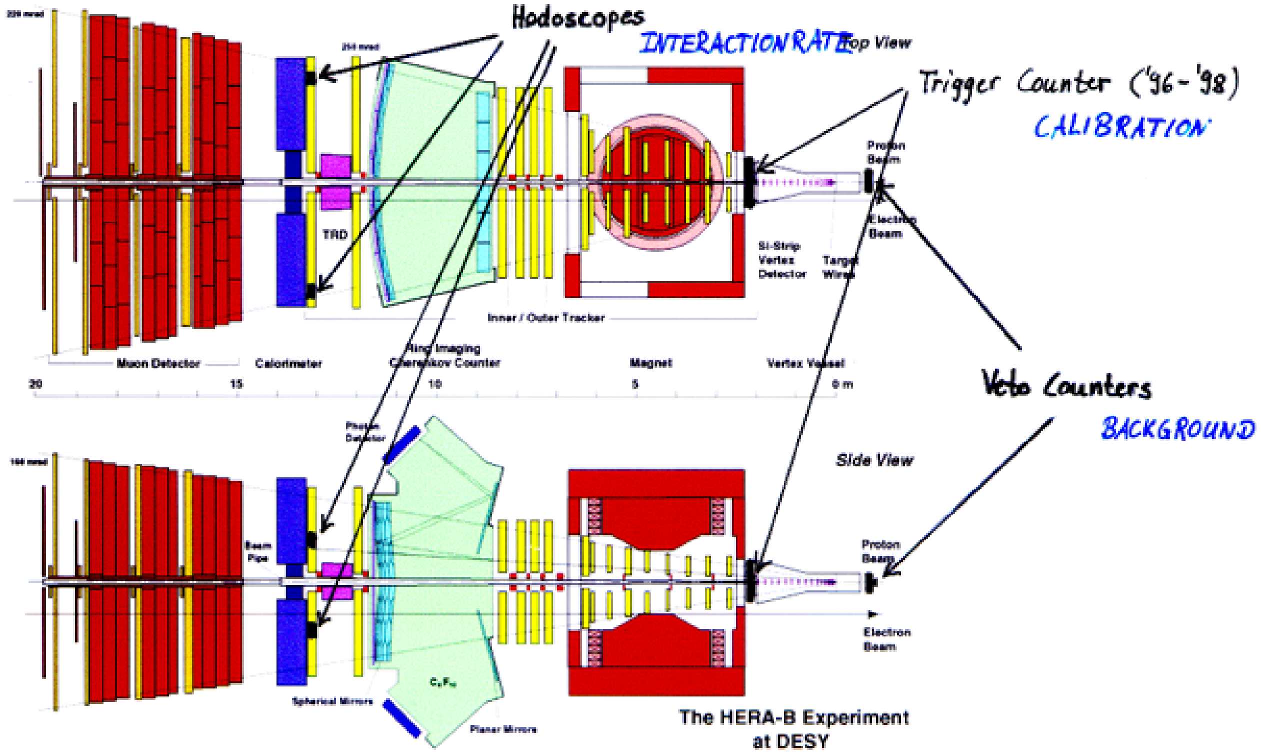
`http:\\hrbtvs`

- inspection of target mechanics
  → all wires ok ?
- control of target movements:
  - are the wires retracted ?
  - how close approaches opposite stations ?
- tool for survey of targets


CCD
API-HD



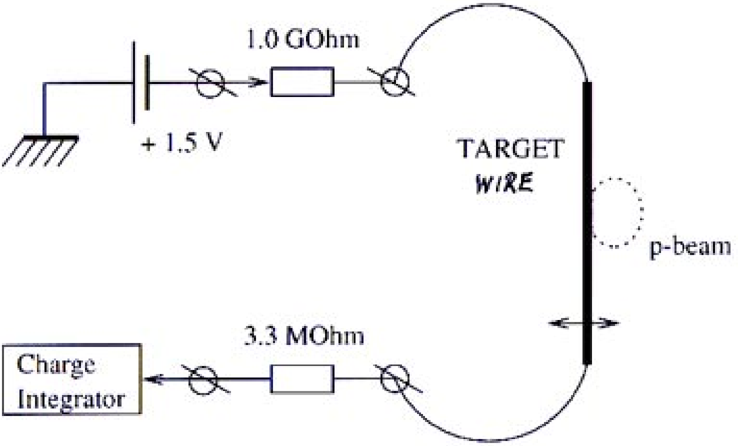
The counting rate experiment 1996–1999

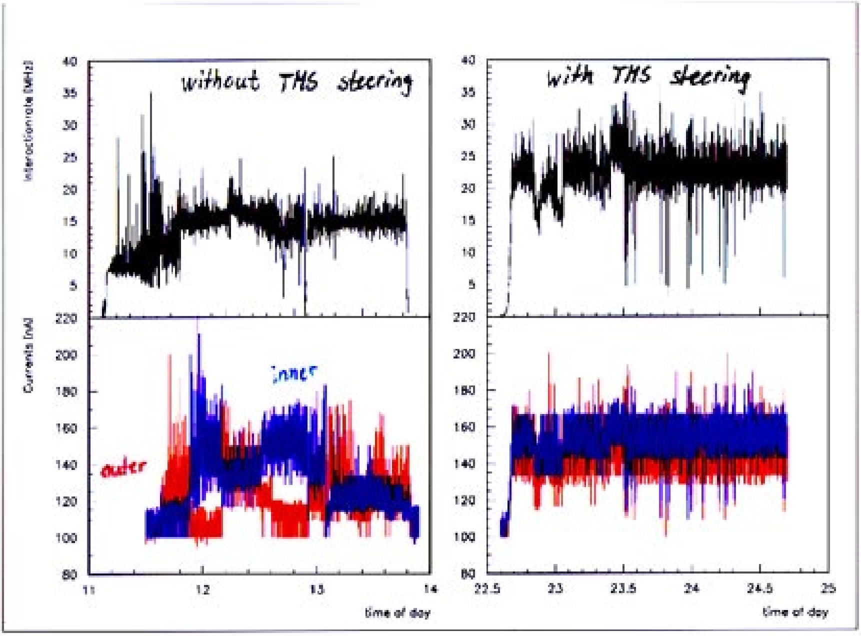


The HERA-B Experiment
at DESY

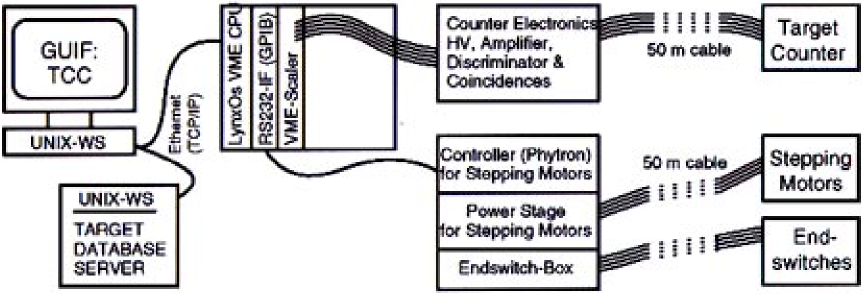
Target Monitoring System TMS

V. Pugatch
V. Aushev





TaCoS - Target Control System



Safety:

most important: avoid loss of protons, damage of detectors

Idea: very simple

- ▷ rate too high – move away from beam
- ▷ rate too low – move towards beam

Implementation: State machine

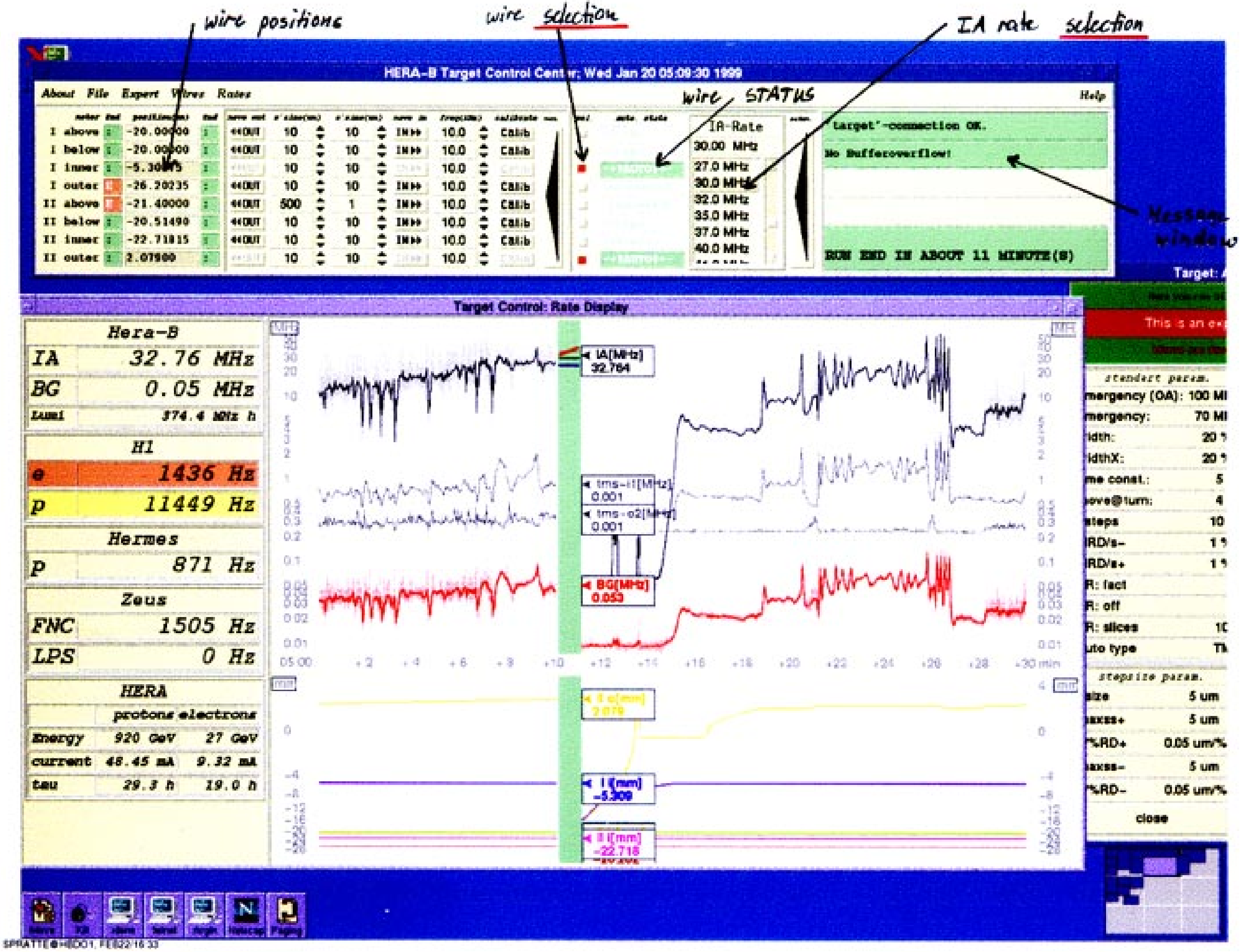
Features

- ▷ calculation of stepsize
- ▷ wire selection device (CI, SLT/TLT later on)
- ▷ beamfind automatic

Graphical user interface: TCC – simple, user friendly

- ▷ guarantee continuous operation

Data flow: preparation of target information inside DESY (WWW),
online information, data storage & archiving



HERA-B Target Control Center: Wed Jan 20 05:09:30 1999

I above	-20.00000	OUT	10	10	IN	10.0	Calib
I below	-20.00000	OUT	10	10	IN	10.0	Calib
I inner	-5.30875		10	10		10.0	
I outer	-26.20235	OUT	10	10	IN	10.0	Calib
II above	-21.40000	OUT	500	1	IN	10.0	Calib
II below	-20.51490	OUT	10	10	IN	10.0	Calib
II inner	-22.71815	OUT	10	10	IN	10.0	Calib
II outer	2.07900		10	10		10.0	

IA-Rate
30.00 MHz
27.0 MHz
30.0 MHz
32.0 MHz
35.0 MHz
37.0 MHz
40.0 MHz

'target'-connection OK.
No Bufferoverflow!
RUN END IN ABOUT 11 MINUTE(S)

Hera-B	
IA	32.76 MHz
BG	0.05 MHz
Lumi	374.4 MHz h

H1	
e	1436 Hz
p	11449 Hz

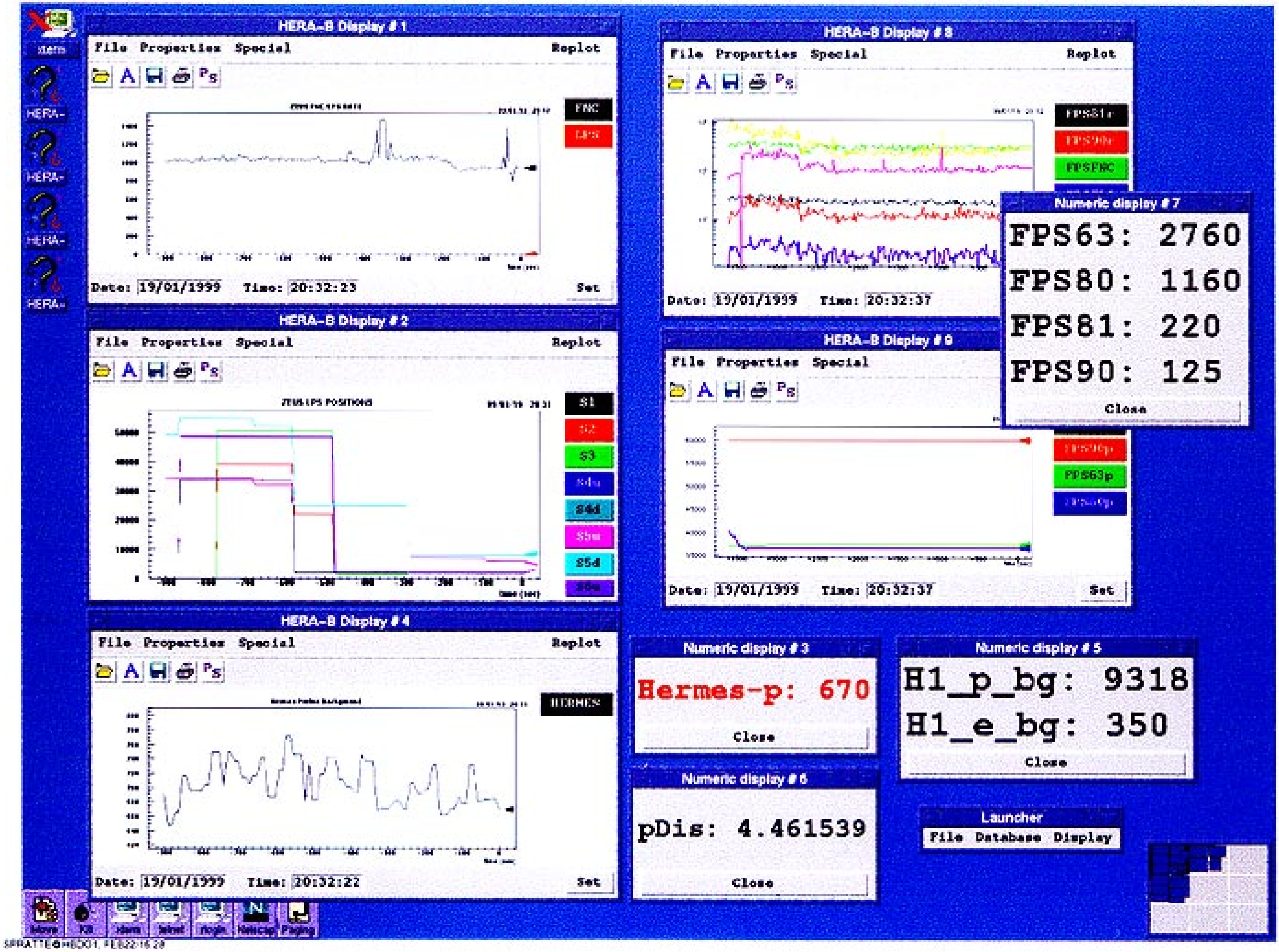
Hermes	
p	871 Hz

Zeus	
FNC	1505 Hz
LPS	0 Hz

HERA	protons	electrons
Energy	920 GeV	27 GeV
current	48.45 mA	9.32 mA
tau	29.3 h	19.0 h

standart param.
mergency (OA): 100 MI
mergency: 70 MI
idth: 20 %
idthX: 20 %
me const.: 5
ove@1um: 4
steps 10
RD/s- 1 %
RD/s+ 1 %
R: fact
R: off
R: slices 10
uto type Th

stepsize param.
size 5 um
axss+ 5 um
%RD+ 0.05 um/%
axss- 5 um
%RD- 0.05 um/%



Date: 19/01/1999 Time: 20:32:23

Date: 19/01/1999 Time: 20:32:22

Date: 19/01/1999 Time: 20:32:37

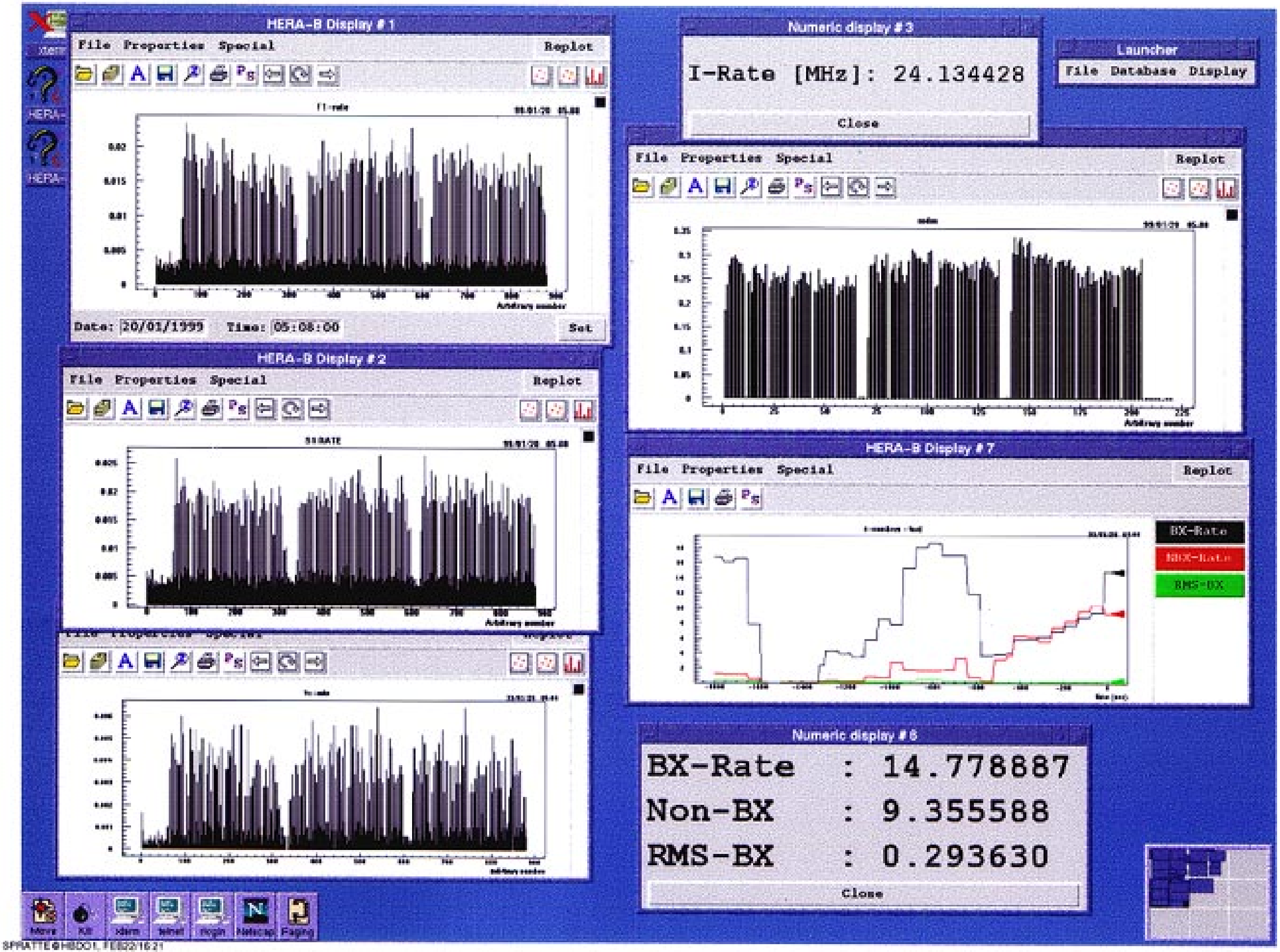
Date: 19/01/1999 Time: 20:32:37

FPS63: 2760
FPS80: 1160
FPS81: 220
FPS90: 125

Hermes-p: 670

H1_p_bg: 9318
H1_e_bg: 350

pDis: 4.461539

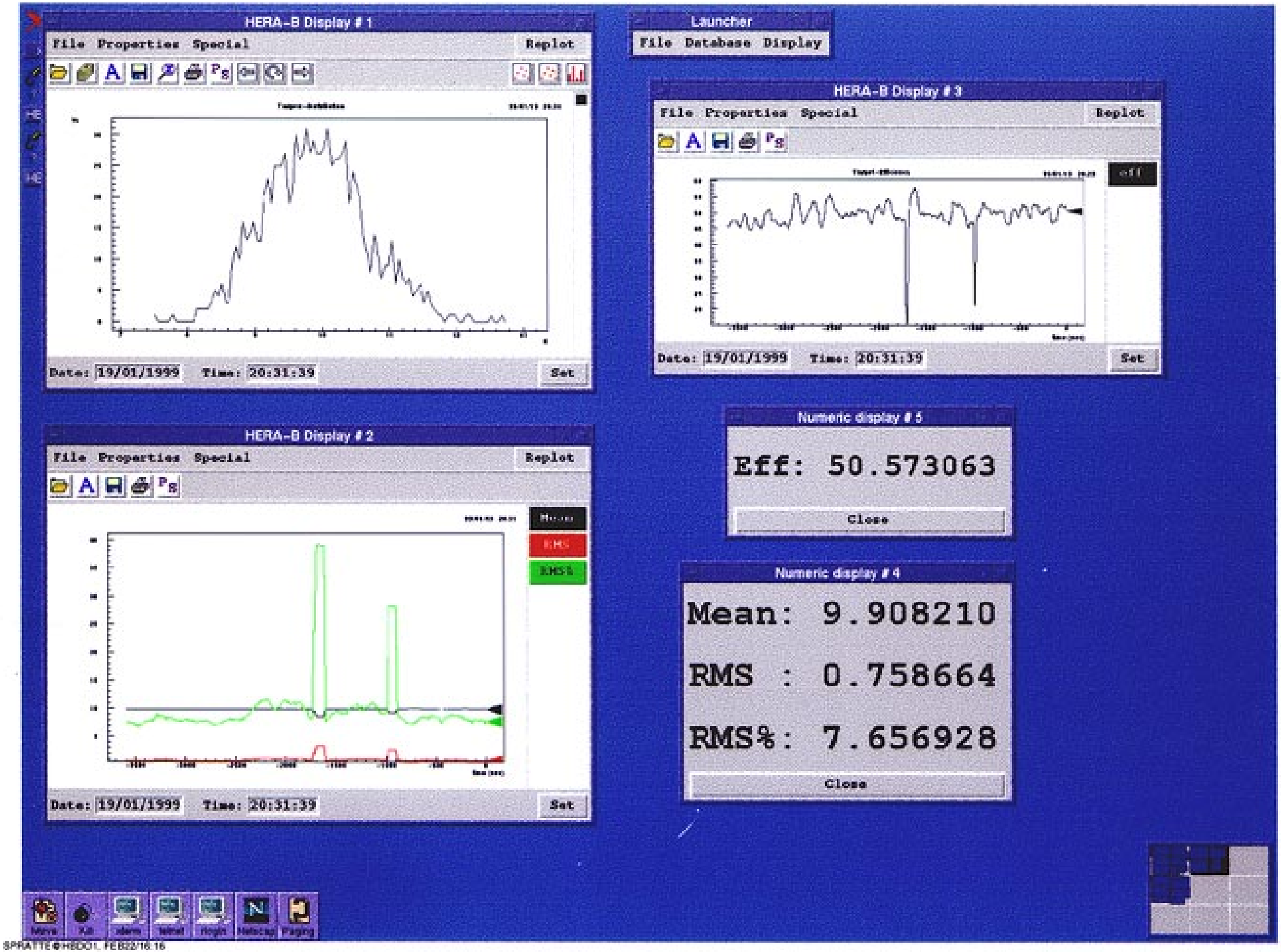


Date: 20/01/1999 Time: 05:08:00

I-Rate [MHz]: 24.134428

BX-Rate : 14.778887
Non-BX : 9.355588
RMS-BX : 0.293630

SPRATTE@HBDO1, FEB22/16:21



Date: 19/01/1999 Time: 20:31:39

Date: 19/01/1999 Time: 20:31:39

Date: 19/01/1999 Time: 20:31:39

Eff: 50.573063

Mean: 9.908210

RMS : 0.758664

RMS%: 7.656928

SPRATTE@HBDO1, FEB22/16:16

Acceptance Determination

– A small excursion –

Counters are not able to resolve multiple interactions

BUT

With basic approach of poisson statistics we're able to calculate the interactionrate R_{WW} from the measured rate R_x of individual counters with geometrical acceptance a_x:

$$\begin{aligned} R_x &= R_{bx}\left(1 - e^{-a_x\lambda}\right) \\ &= a_x\lambda R_{bx} = a_x R_{WW}\,, \quad \text{if } a_x\lambda \ll 1 \end{aligned}$$

That means:

Counters with small acceptance a_x (Experiment: Hodoscopes !) deliver the interactionrate

$\Longrightarrow$ Determination of a_x ?

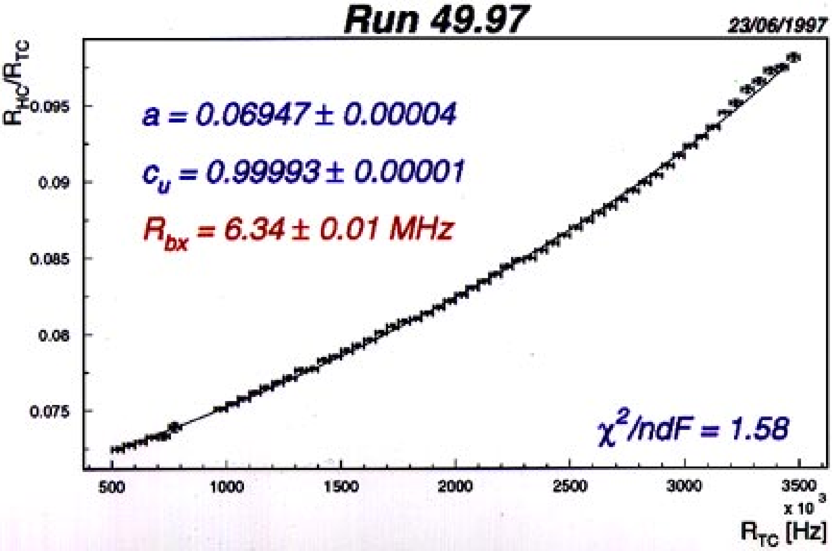
The Method

Use counters with large geometrical acceptance (Experiment: Triggercounters !), because acceptance can be calculated with small systematic error !

$$\frac{\overset{\text{measured}\searrow}{R_{HC}}}{\underset{\text{measured}\nearrow}{R_{TC}}} = \frac{a_{HC}}{\underset{\nwarrow\text{MC}}{a_{TC}}} \equiv a, \quad \text{if } \lambda \ll 1$$

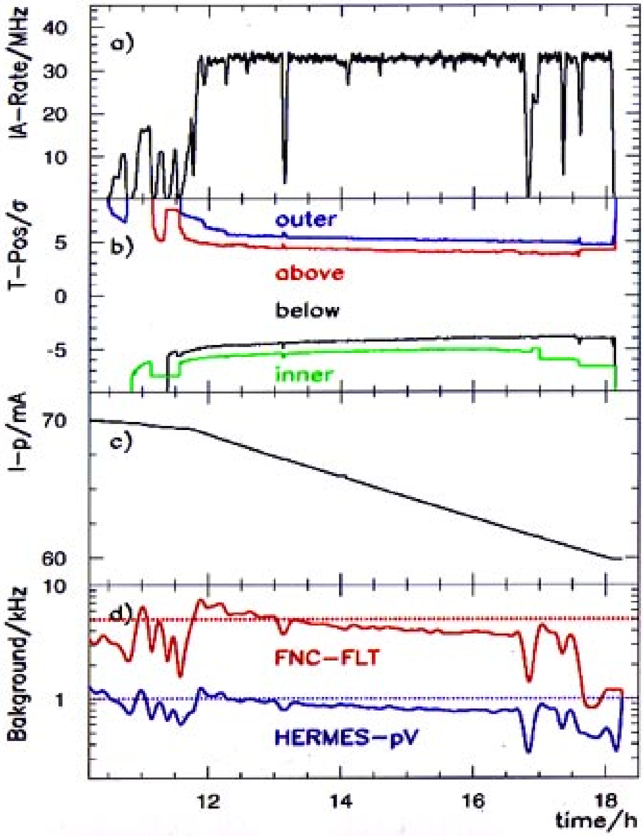
Reality: $\exists$ background, $\lambda \not\ll 1$

$$\Longrightarrow \quad \frac{R_{HC}}{R_{TC}} = f(R_{TC}) = \frac{R_{bx}}{R_{TC}}\left[1 - c_u\left(1 - \frac{R_{TC}}{R_{bx}}\right)^a\right]$$

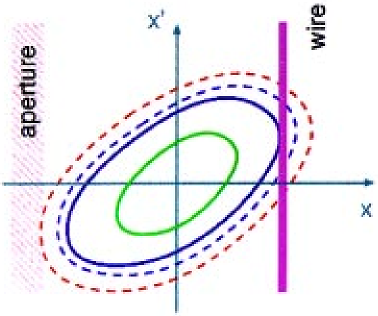


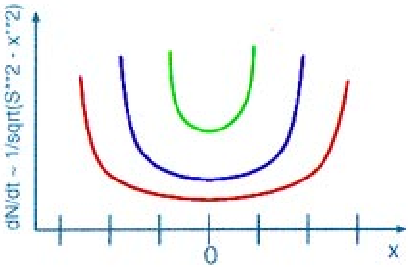
Target operation at high rates

- High rates (40 MHz) reachable, if $\epsilon_T \geq 50\%$
- Multiwire automatic working for 4 wires reliably
- no significant increase of background, if collimators are set properly



Functionality of the target





dN/dt (x=0) ~ 1/S

angular smearing due to mult. scatt.:

$$<\theta^2> = \left(\frac{14\,\mathrm{MeV}}{p}\right)^2 \frac{\lambda_I}{X_0}$$

$$\lambda_I = \begin{cases} 39{,}4\ \mathrm{cm - Al} \\ 15{,}1\ \mathrm{cm - Cu} \end{cases}$$

$$X_0 = \begin{cases} 8{,}89\ \mathrm{cm - Al} \\ 1{,}43\ \mathrm{cm - Cu} \end{cases}$$

$$<\theta^2> = \begin{cases} (35\ \mu\mathrm{rad})^2 - \mathrm{Al} \\ (55\ \mu\mathrm{rad})^2 - \mathrm{Cu} \end{cases}$$

natural beam divergence x':

$(\varepsilon/\beta) = (9{,}3\ \mu\mathrm{rad})^2$ for $\beta = 35$ m

The HERA–B Target is not a halo target:
HERA: $\tau_p \geq 1000$ h → drift velocity small
⇒ disturbancy of p-beam by scraping away protons
⇒ increase p–loss rate R_{loss}

The HERA–B Target is dominated by multiple scattering:
the protons are scattered outwards
→ smearing of betatron amplitude by 4...6 σ
→ hit probability drastically reduced
→ What about the target efficiency ϵ_T ?

The target efficiency ϵ_T

$$\epsilon_T = \frac{\textit{Interaction rate}}{\textit{Loss rate}}$$

Optics:

small β–functions decrease influence of multiple scattering

Aperture:

at least 4 σ free aperture relative to the wire for $\epsilon_T \geq 50\%$

Target dimensions:

- ▹ More material would help for a diffusion dominated halo target
- ▹ low Z materials decrease amount of multiple scattering
- ▹ more wires didn't increase ϵ_T, because protons are scattered independent wether it was the same wire or not

→ ϵ_T didn't add up, one gets the mean value

ϵ_T -Simulations

We have developed a simulation program with particle tracking and diffusion model.
Lot of parameters existing, not all well known:

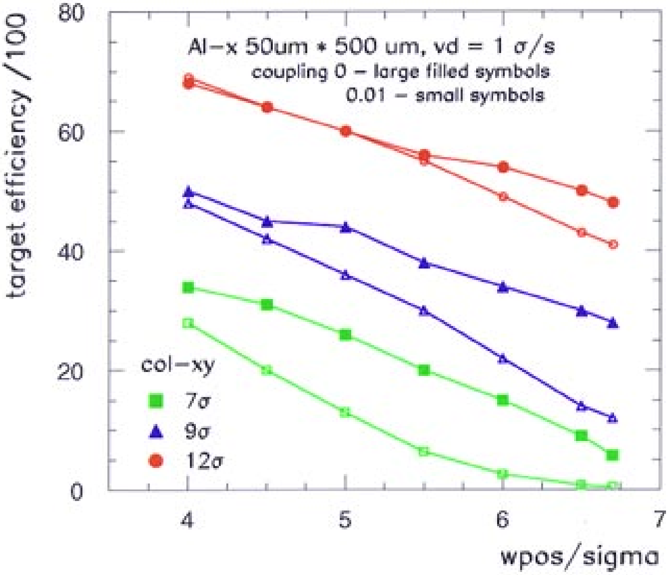
- aperture
- optics: β–function, coupling, dispersion
- diffusion, drift velocity (high $\tau_p \rightarrow v_d$ small)

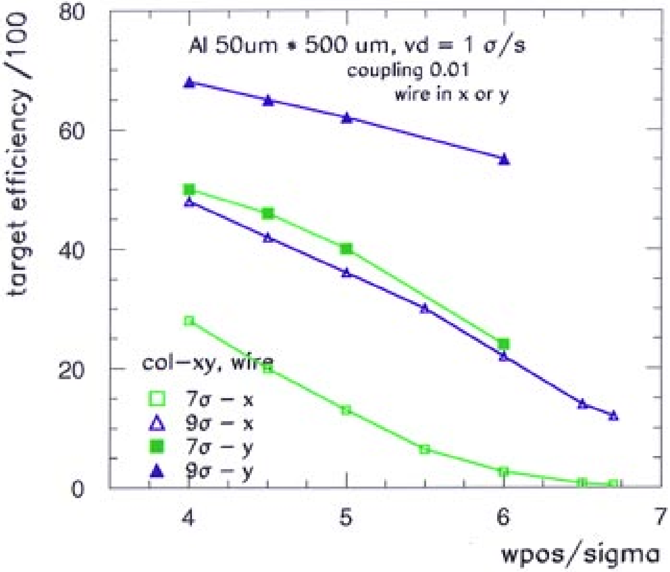
Is linear beam optics valid outside 4 σ ?
Or is this region dominated by nonlinear efects (high $\tau_p \rightarrow$ linear) ?
Impact of fluctuations, stability of machine ?

Some general results:

- free aperture, low Z material and low β helps
- more material is only for large v_d helpful
- qualitative good agreement to measurements, i.e. we understand the main impacts
- at our operation point ($4 - 5\ \sigma$) also the absolute values are in good agreement with measurements

MC–ϵ_T: Aperture





SPRATTE@HBOO1, MAR02/16:53

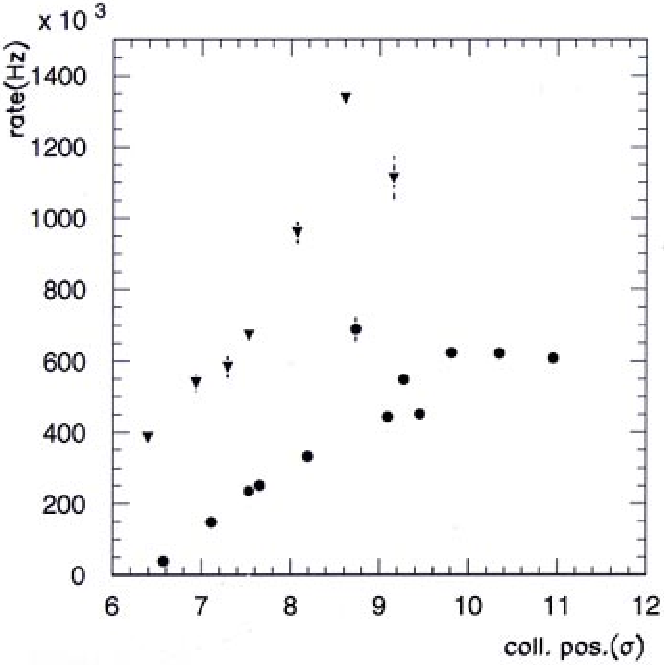
Dependence on Collimator Position

Wire position fixed:

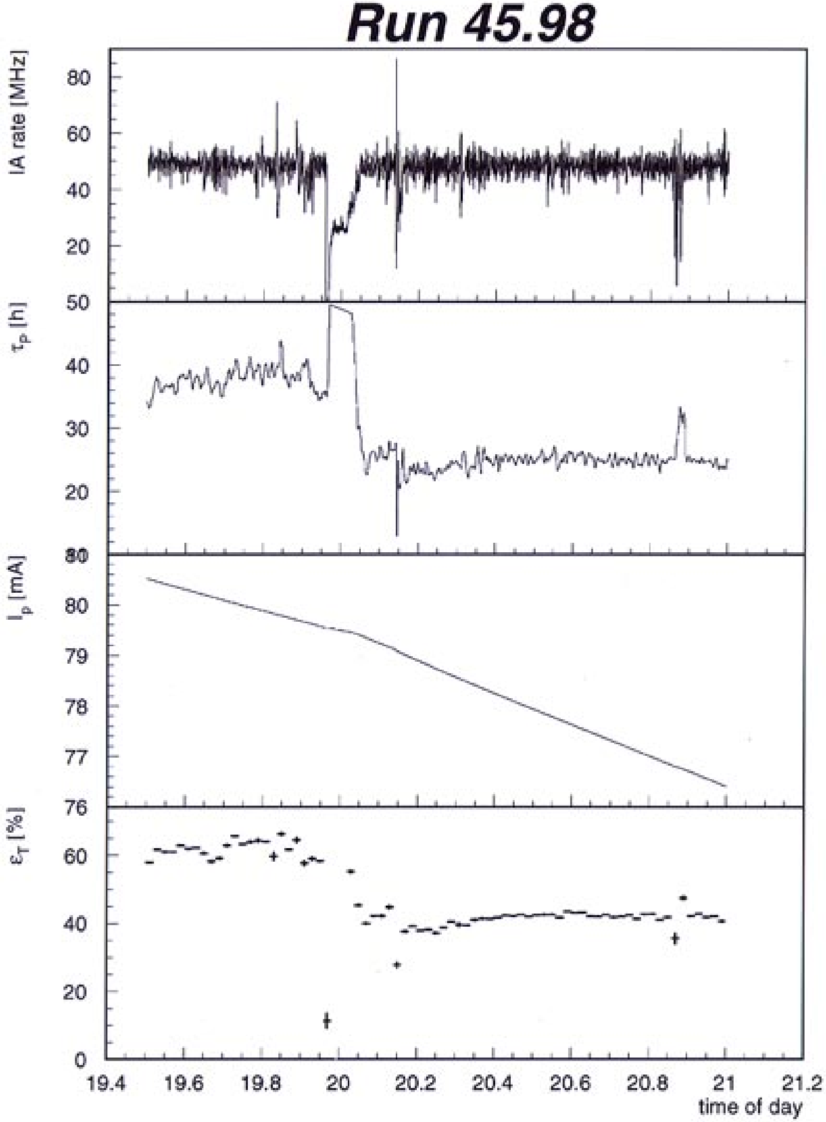
$-6.5\ \sigma$ (dots)

$-5\ \sigma$ (triangles)

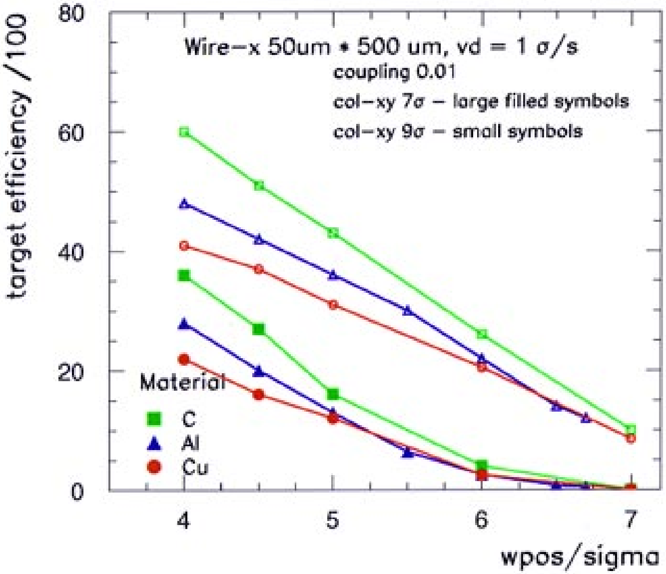
Collimator movements

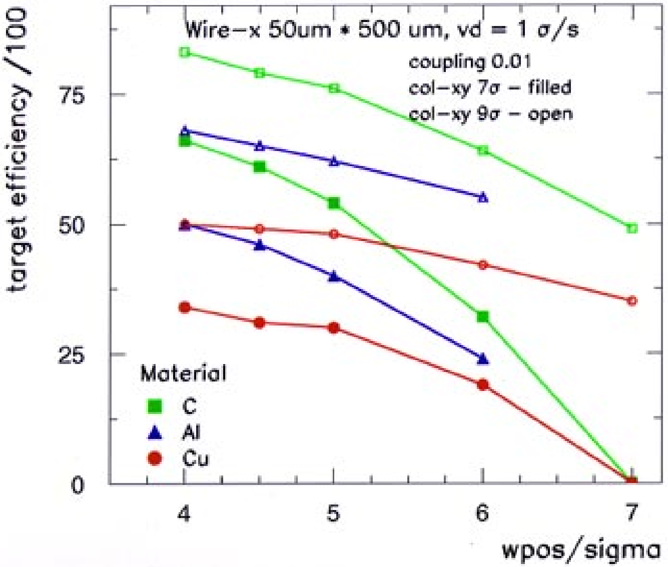


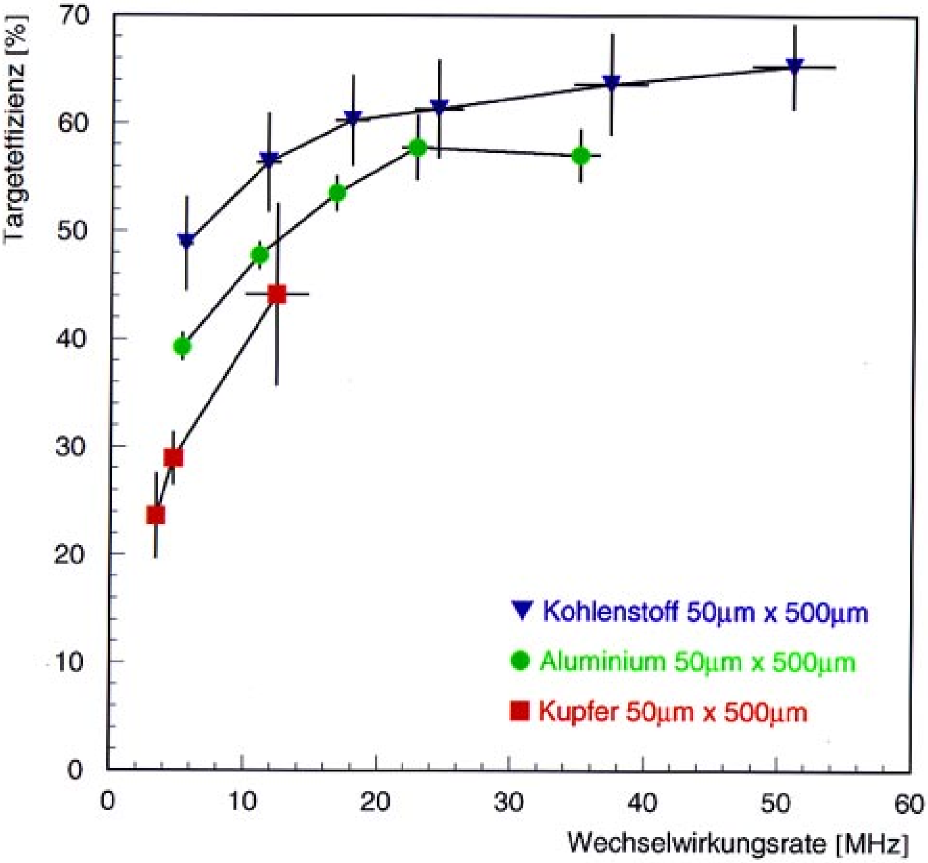
Collimators were moved at 8pm



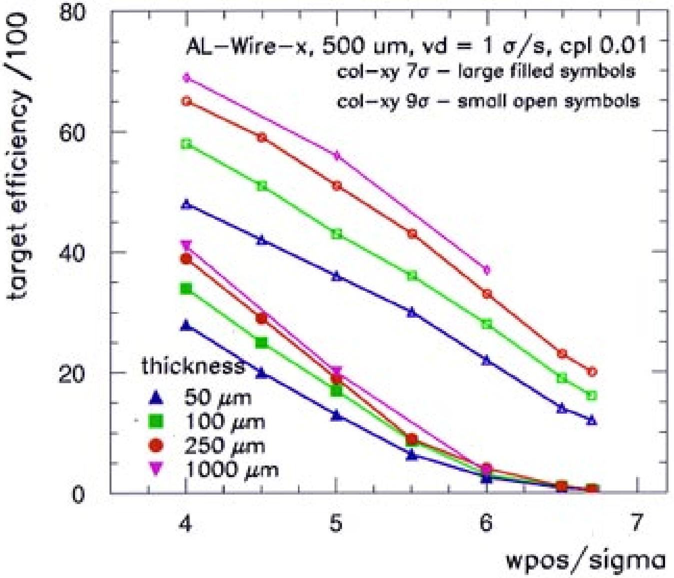
MC–ϵ_T: Z-Dependence

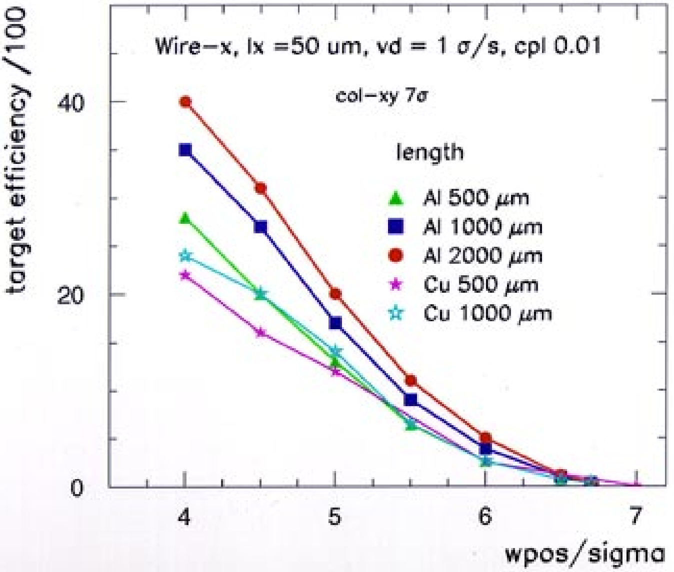





Targeteffizienz [%]
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
Wechselwirkungsrate [MHz]
▼ Kohlenstoff 50µm x 500µm
● Aluminium 50µm x 500µm
■ Kupfer 50µm x 500µm

MC-ϵ_T: Target geometry





SPRATTE@HSDO1, MAR0216:53

Target induced background – Run efficiency

Target induced background caused problems at ZEUS/HERMES/H1 in 1996/97

⇒ detailed studies

⇒ optimization of collimator settings

Reason: large angle scattered protons

Effect: these protons hit apperture limitations directly, especially the tight ones at the experiments interaction zones (ZEUS LPS, H1 FPS)

Remedy: optimized proton collimator system to shield the experiments. Important: beam position

Conflicts: Decrease of ϵ_T, optimization procedure time consuming and dangerous while luminosity

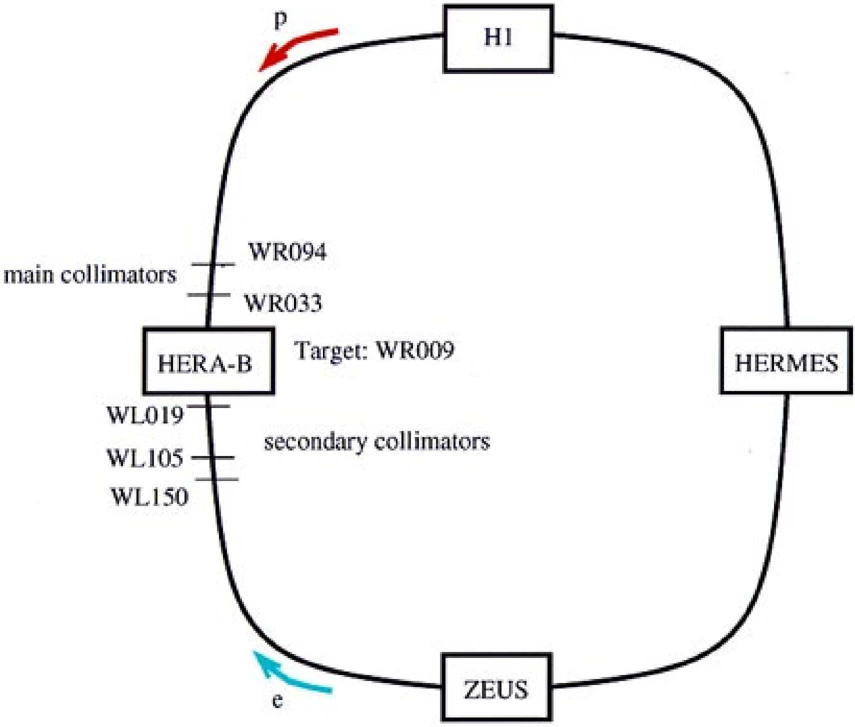
WIP procedure: successfully tested end of 1997. The target is inserted while lumi tuning. The collimators are set to the "cleaned" beam afterwards

⇒ optimized collimator positions

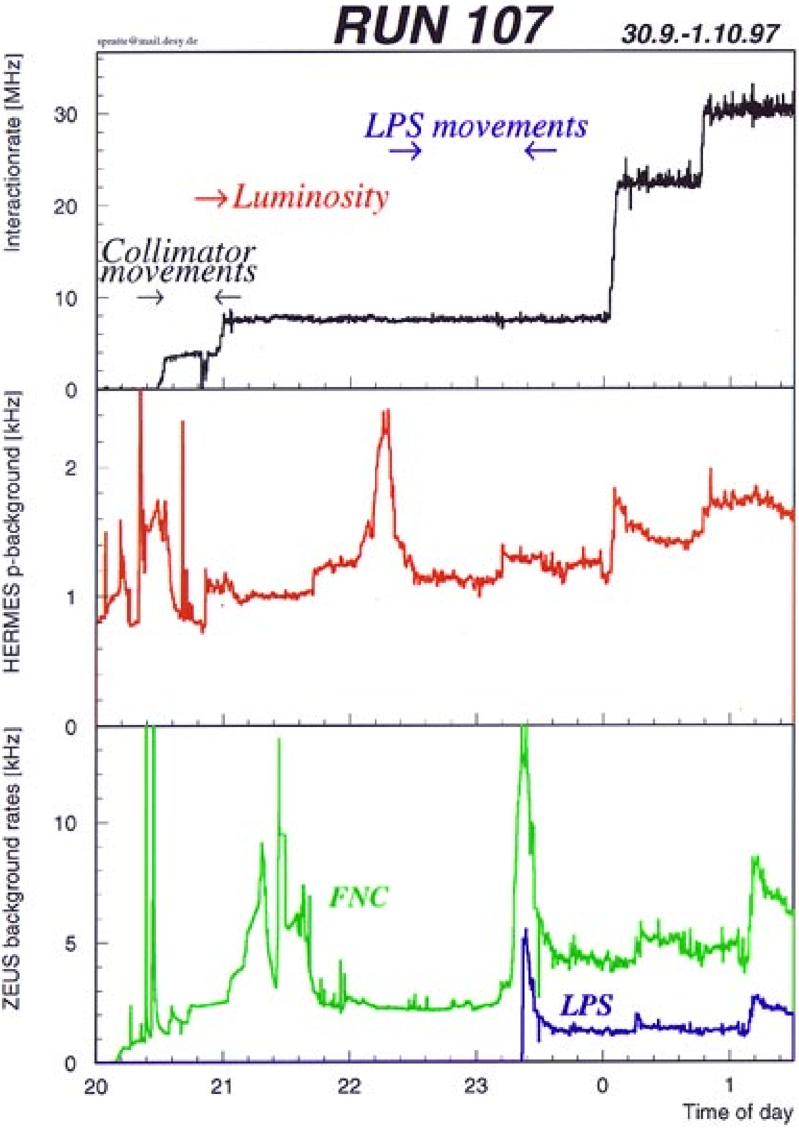
⇒ small background

⇒ high run efficiency (gain ≈ 30%)

The proton collimator system



The ~~new~~ old WIP



SPRATTE@HBD01, MAR02/16:53

Fluctuations & rate stability

Reason:

Beam scraping

→ steep edge of transversal beam density

→ very sensitive to interferences

$(\Delta\text{Rate}/\text{Rate})/\Delta w_{pos} \approx 2/10\ \mu\text{m}$

Effect:

Loss of efficiency (too much tracks), radiation damages – dangerous (high spikes)

Source of fluctuations:

Power supplies (50 – 600 Hz), vacuum pumps (48 Hz), tides (0.14 Hz), ...

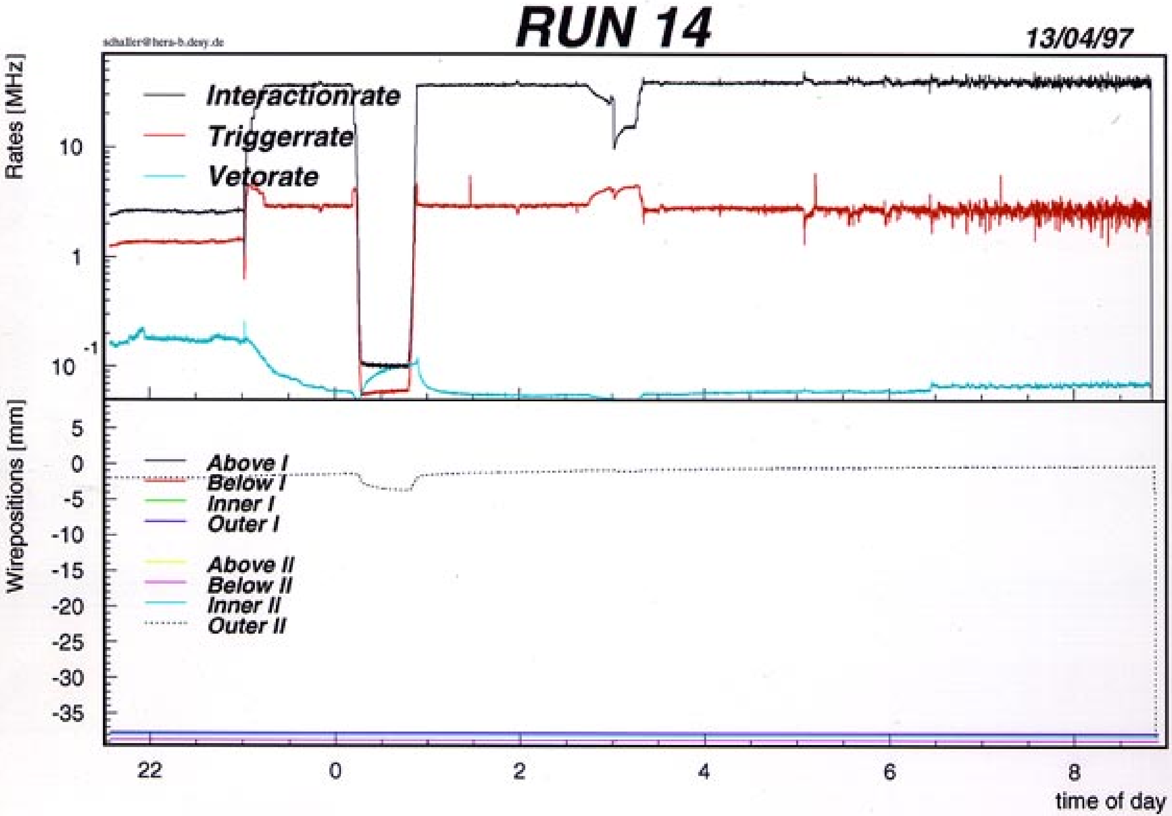
ground vibrations, S–Bahn, ...

coasting beam

Remedy (hopefully !):

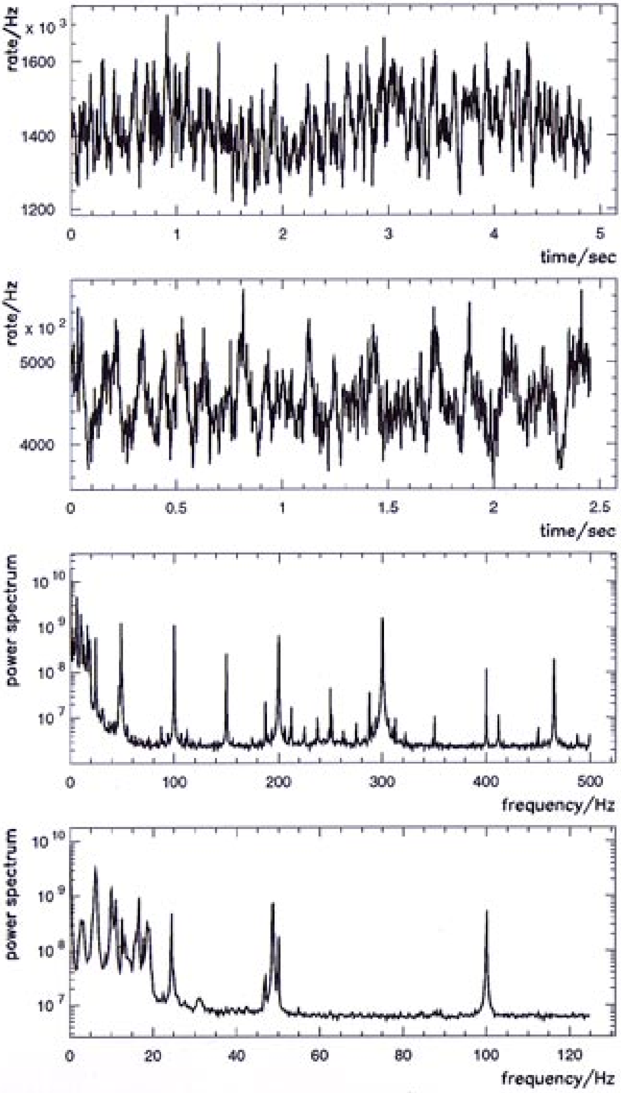
Beam excitation → more beam halo

→ smooth target operation, avoid spikes

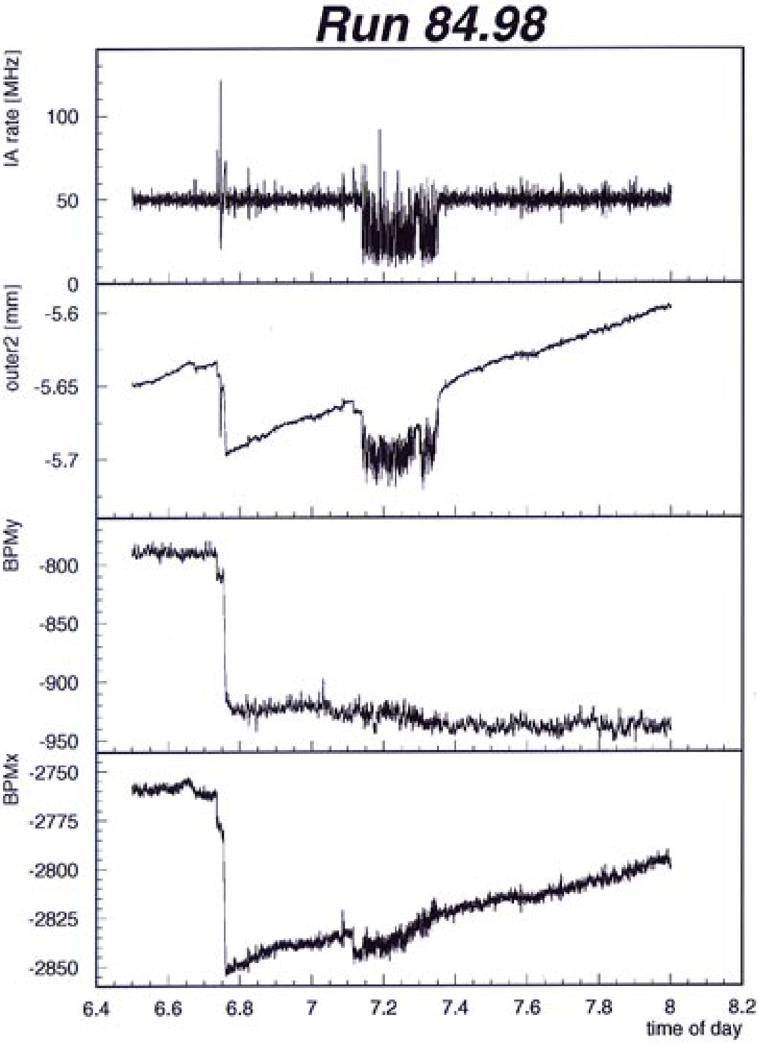


SPRATTE@HEDO1, MAR02/16:53

Frequency spectrum of IA rate



Ground vibrations - Oct. ‘98

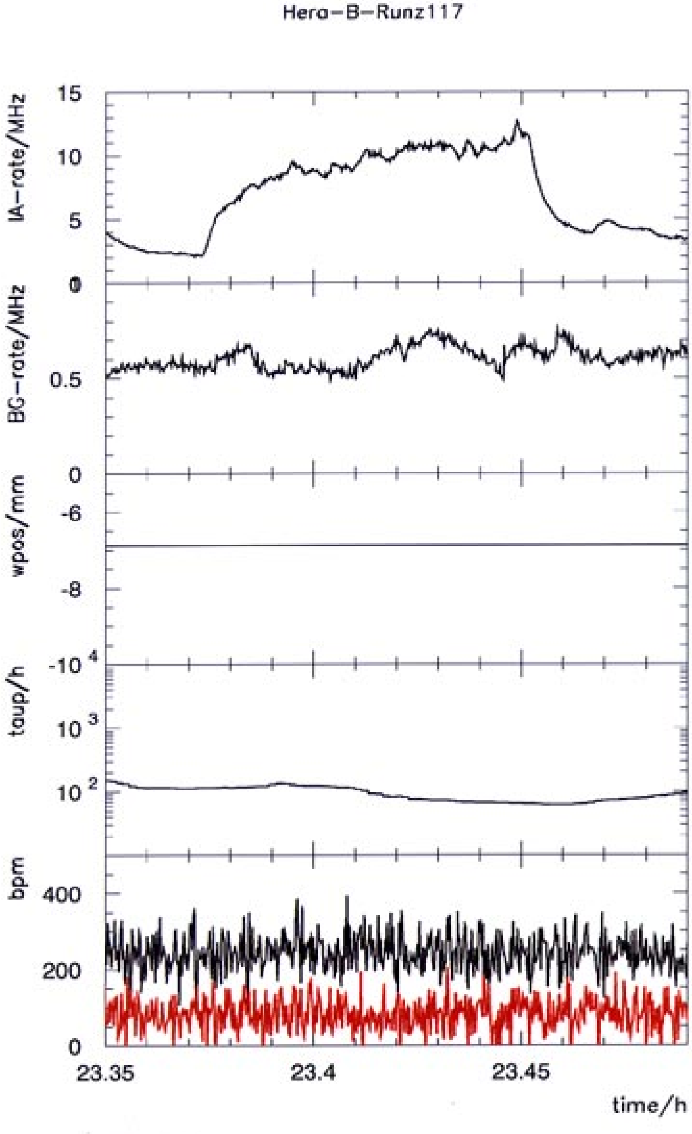


Run 84.98

SPRATTE@HEDO1, MAR02/16.53

Beam excitation - feedback kicker

$$f_{ex} = (41.410 \pm 0.005)\ \mathrm{kHz}$$



Individual bunch contribution

Bunch contributions are investigated since 1995.
Advanced setup since 1997.

Bunch to bunch fluctuations

Different contribution of individual bunches to the interaction rate: Timing problem at injection
→ slightly different emittances
→ target is not able to react

Nonbunch contribution

especially outer targets measure huge amount of contribution from “empty” bunches to the interaction rate (coasting beam)

Coasting beam observations

- tails of some beam σ at the outer side
- outer targets: up to 10 MHz
  above/below targets: 3–5 MHz
  inner targets: ≤ 1 MHz
  4 simultaneous wires: up to 5 MHz
- saturation of nonbunch contribution at high rates
- coasting beam population increases with increasing age of fill
- diffusion measurements show characteristic behaviour
- coasting beam strong correlated with spikes & background at other experiments

Consequence

Efficiency loss (track finding, gates, ...)
The HERA–B detector with trigger and DAQ needs exactly synchronized bunched interactions

Consequence

Efficiency loss (track finding, gates, ...)
The HERA–B detector with trigger and DAQ needs
exactly synchronized bunched interactions

Possible explanations

energy loss inside the target ?
∗ end of 1998: coasting beam at HERA even without target
∗ production mechanism not clear (RF, synchrotron
radiation, intra beam scattering, ...)
∗ energy loss inside target sufficient to produce
longitudinal instable protons → cross the seperatrix
dispersion at target positions leads to scattering of protons
to the ouside direction

HERA parameter

∗ natural beam divergence: $\Delta E/E \approx 6 \cdot 10^{-5}$
∗ seperatrix at $\Delta E/E \approx 2 \cdot 10^{-4}$
∗ impuls acceptance: $\Delta p/p \approx \cdot 10^{-3}$
∗ synchrotron frequency $f_s \approx 30/50\ Hz$
∗ HF–system: 52 MHz and 208 MHz (5 bzw. $20 \cdot f_{bx}$)
∗ $U_{RF} \approx 200/100\ and\ 320/920\ kV$
∗ Increase of longitudinal bunch length: 50%/10 h

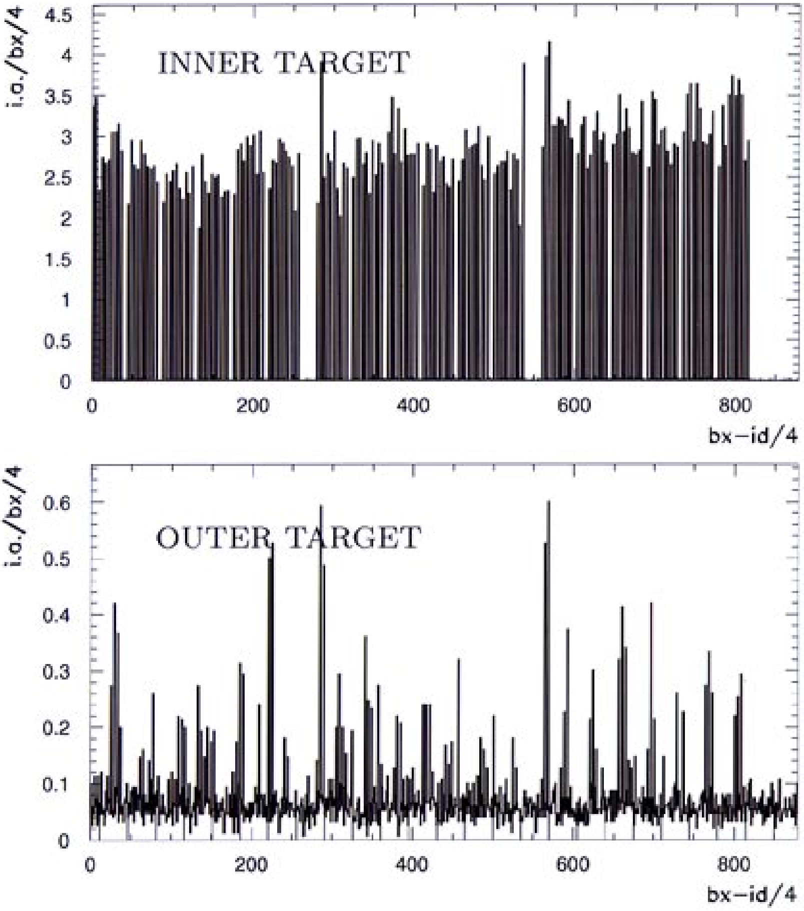
MC calculations

properties of the longitudinal phase space

Coasting beam studies

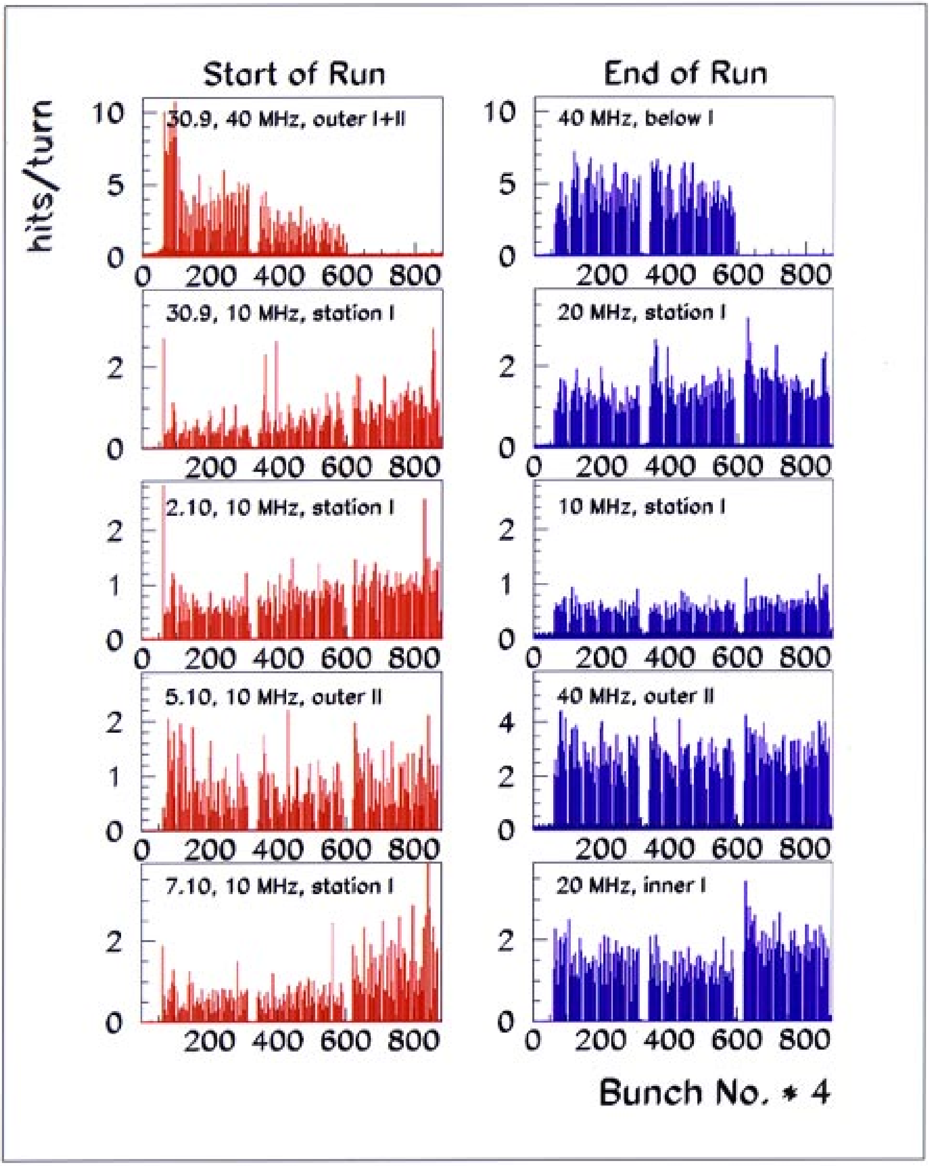
realisation together with HERA

Bunch to bunch variations



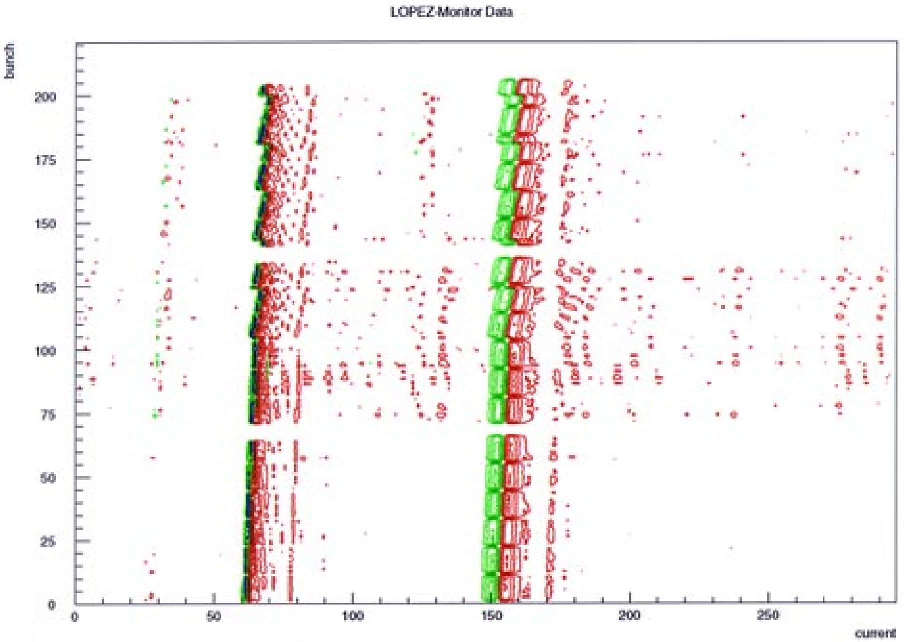
(Big) Difference between contribution of individual bunches

Some HERA-Fills in Sept/Oct

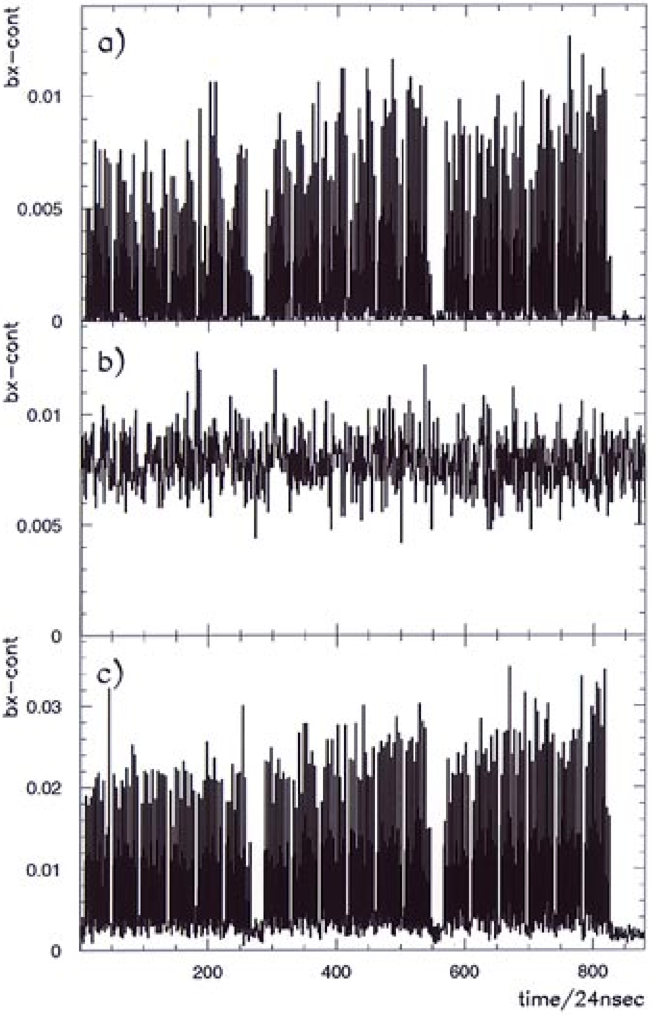


Bunchcurrents from the LOPEZ-Monitor

- The first bank are positrons, the second bank are the protons.
- The small islands between are also positrons.
- The time in ns is spread on the x-axis, the bunchnumber is on the y-axis.
- Mark the shift in time for the bunches (especially for the last 80).

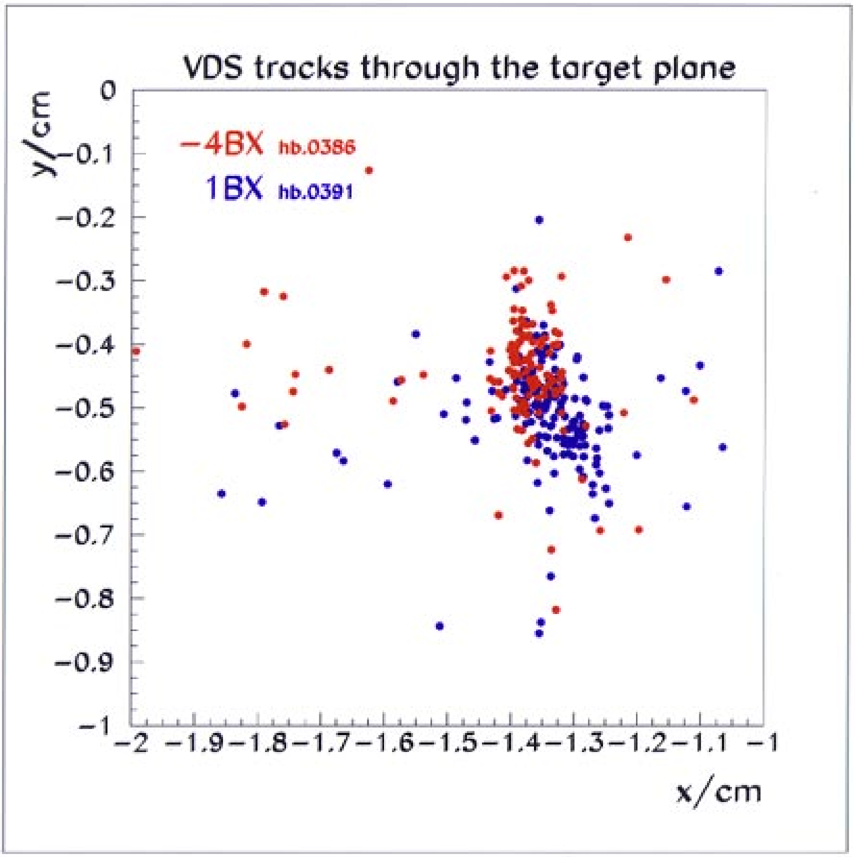


Bunch structure – 3 states

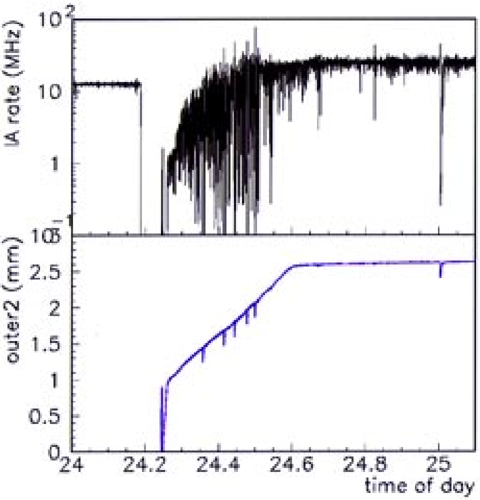


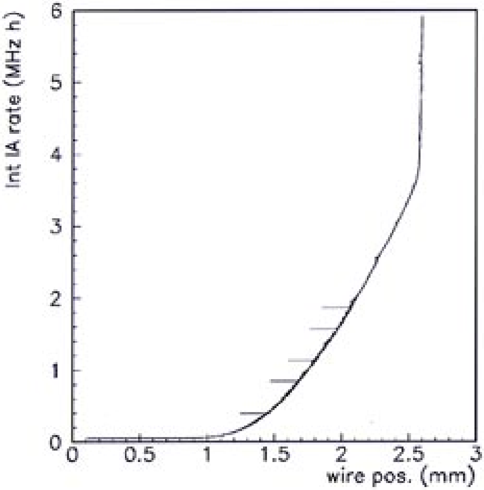
BX–contribution: VDS

- same signature from events in kicker gap

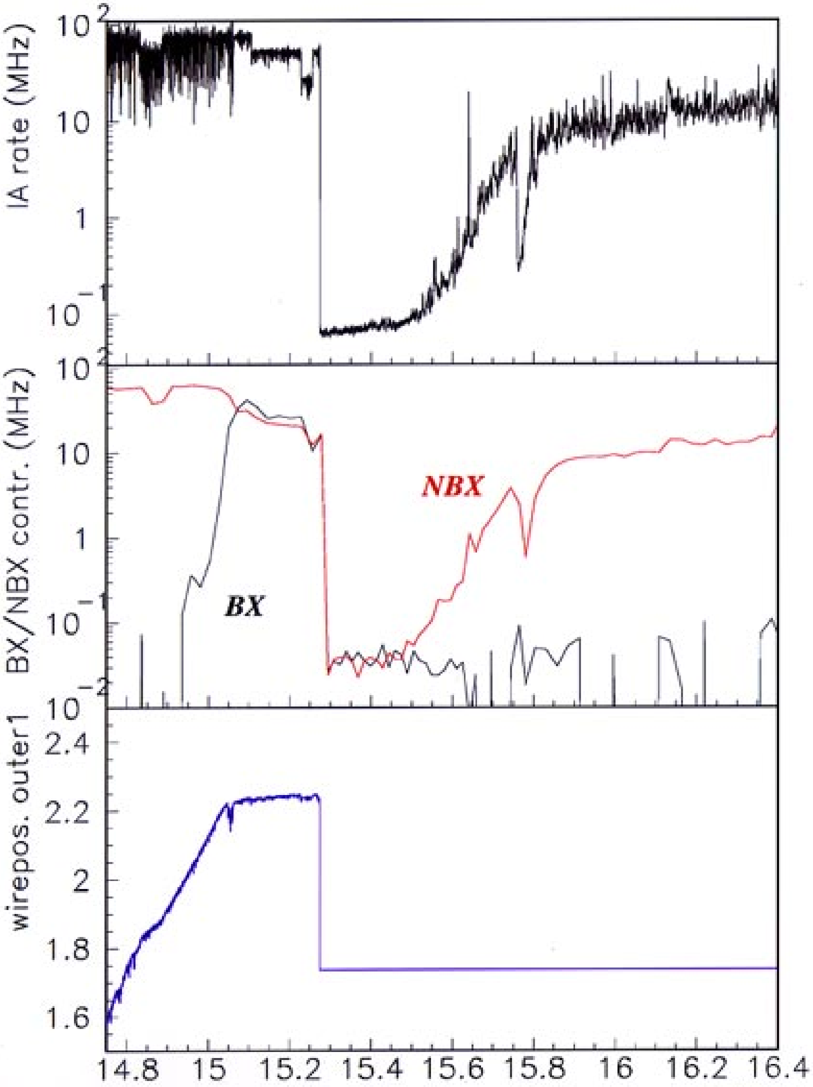


Coasting beam scraping

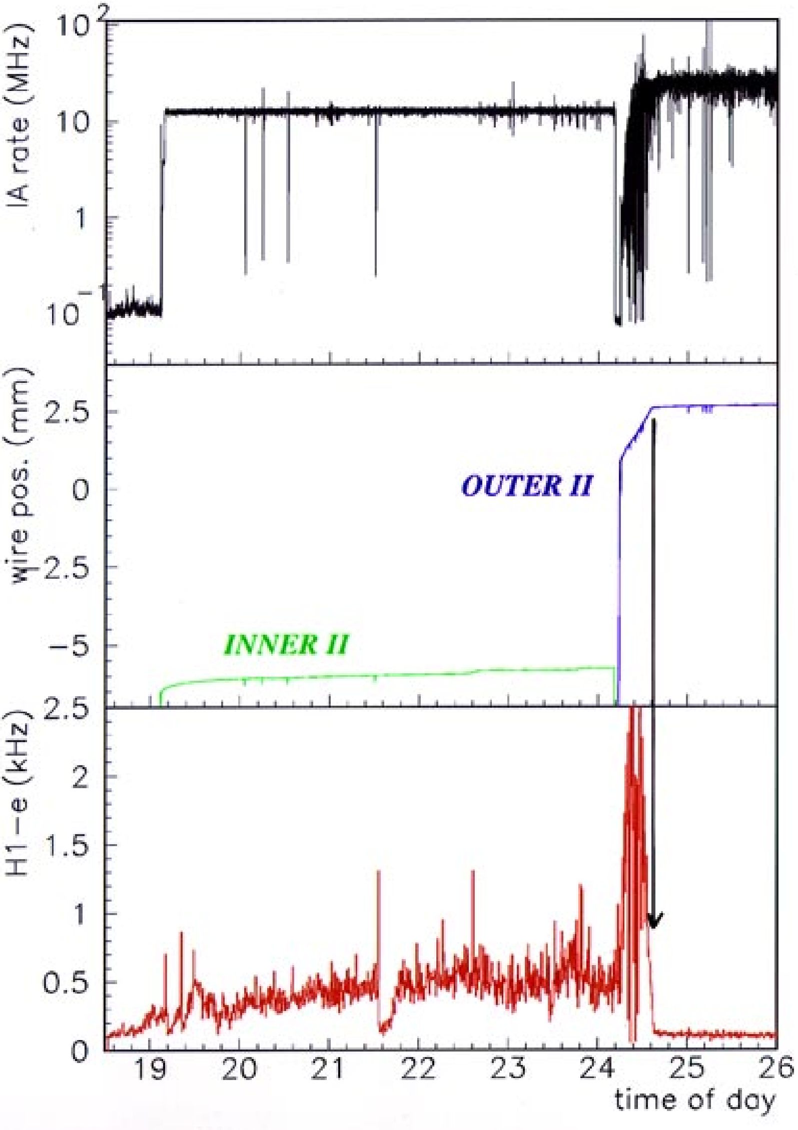




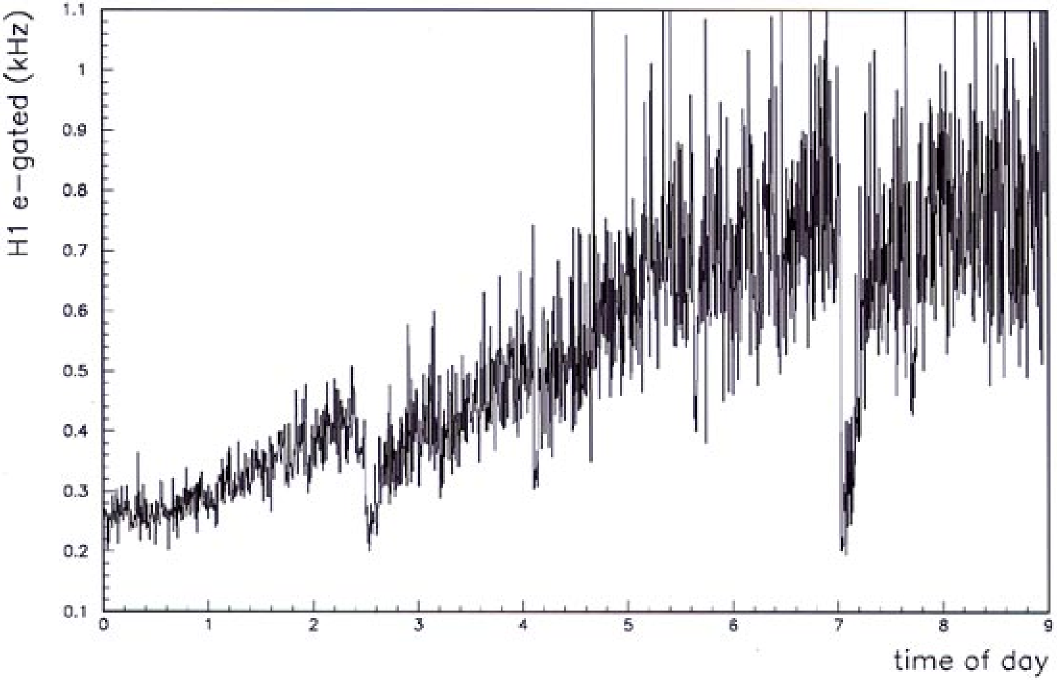
Diffusion measurement



H1 e–gated, CB–scraping

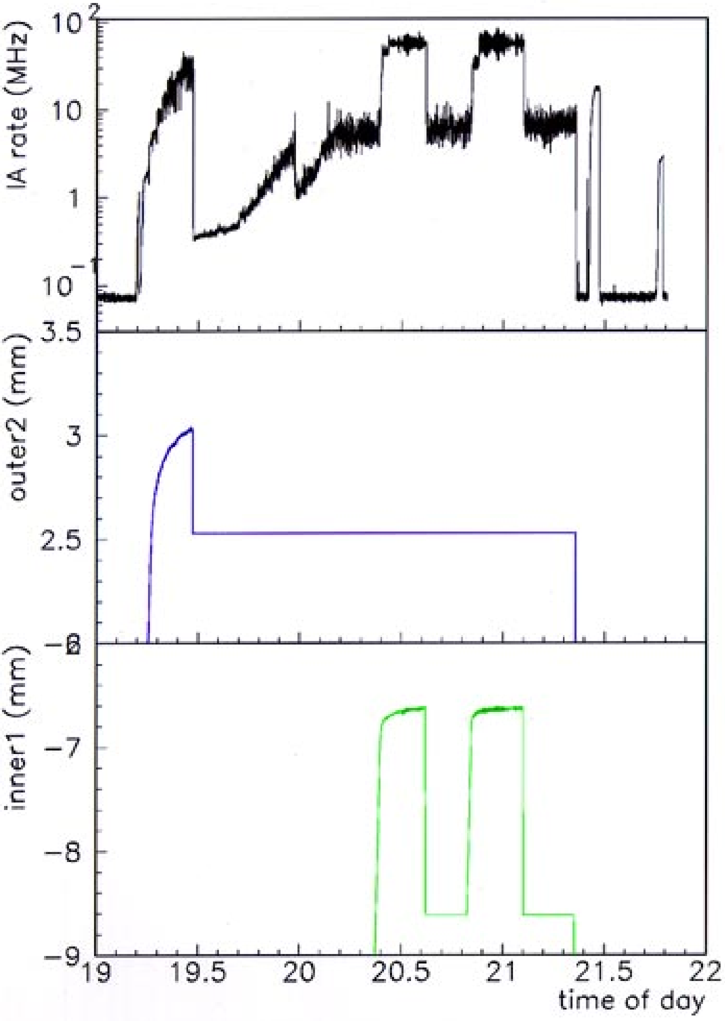


H1 e–gated without target

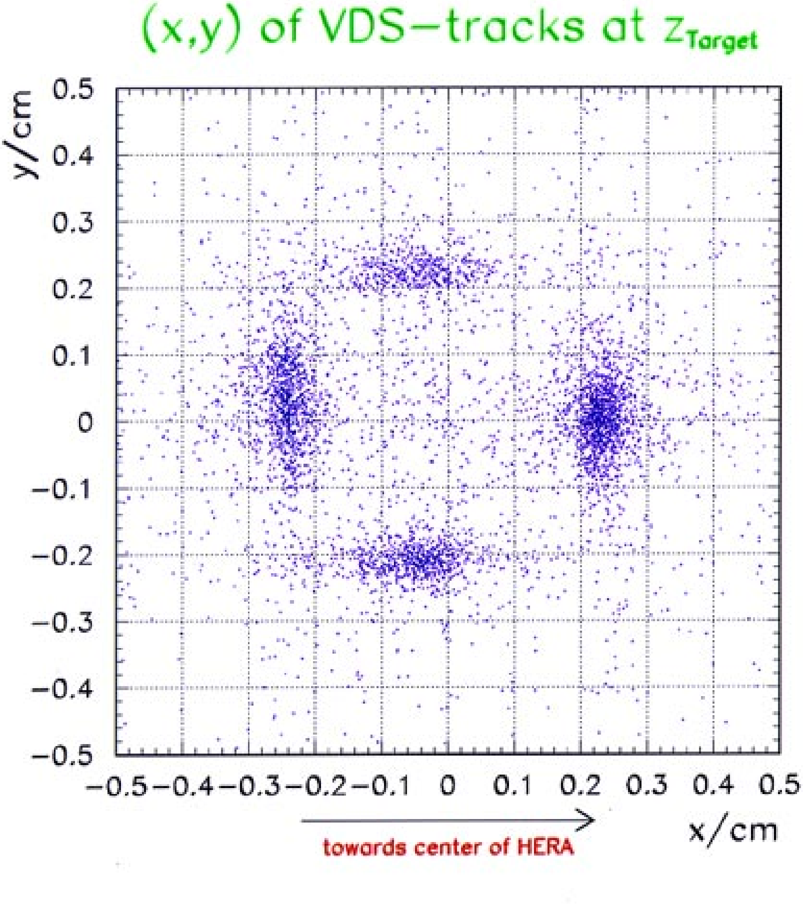


SPRATTE@HSDO1, MAR02/16:53

CB production with target



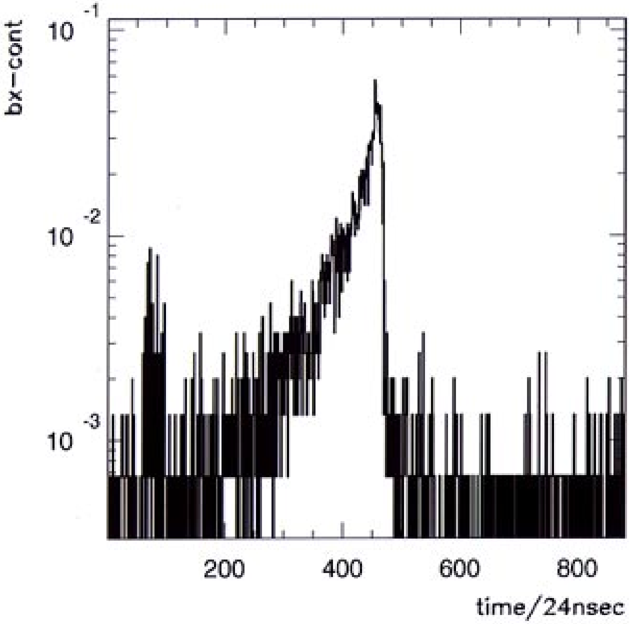
SPRATTE@HEDO1, MAR03/13.44



SPRATTE@HEDO1, MAR02/16.53

Coasting beam studies

Excitation of non–filled bunch



- momentum comp. factor $\alpha \approx 1.3 \cdot 10^{-3}$
- $T_{CB} \approx 80 sec$
- lifetime of p in vicinity of target: $\approx sec$

Coasting beam – HERA shifts

Together with a group of HERA people we discuss/investigate the problems and prepare for special Target–HERA machine shifts to study the problem and find a measure against nonbunch related (target) interactions.

Impact of collimators: Off–energy protons on different orbit due to dispersion
$\rightarrow$ scrape them away

Increase RF amplitude U_{RF}: Energy acceptance (seperatrix) increases with $U_{RF}^{1/2}$
energy spread of the beam $\sim U_{RF}^{1/4}$
$\rightarrow$ protons should stay longer in RF buckets

Kick of coasting protons inside dump gap: (15 empty buckets) with feedback kickers
$dL/L = \alpha \cdot dp/p, \ \alpha \approx 1.3 \cdot 10^{-3}$
(mom. comp. factor)
Max. time for a proton close to the seperatrix $(2 \cdot 10^{-4})$ to travel once around the beam is ≈ 80 sec.
this is large compared to the typical lifetime of a proton in the vicinity of the target – $\mathcal{O}(1$ sec$)$

Modifications of optics: β–function, dispersion, ...

Conclusion

- Target tests & counting rate experiments since 1992

- Basic requirements fulfilled:
  - ▹ Target operation & control system established
  - ▹ Operation at design rate of 30–40 MHz routinously ($\epsilon_T \geq 50\%$)
  - ▹ Multiwire operation (≤ 4 wires) working, optimization on the way
  - ▹ Background situation improved/optimized

- Priorities on
  - ▹ Understanding and minimization of fluctuations/spikes (beam excitation)
  - ▹ Interaction rate measurements & determination (new set of counters mid of 1999/ECAL Energy Inhibit Card)
  - ▹ Coasting beam studies & understanding