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Beauty 99
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Commissioning of the HERA-B Internal Target: Using the HERA Proton Ring as a B-Factory

- Motivation: HERA, HERA-B & CP violation
- Requirements
- Target: Basic Ideas, Setup & Impacts
- Measurements, Experience, Performance & Problems
  - Target Efficiency, Backgrounds
  - Rate Sensitivity & Fluctuations
  - Multi-wire Operation
  - Bunch Contributions & Coasting Beam
- Status & Conclusions

Additional Picture List

The DESY Rings

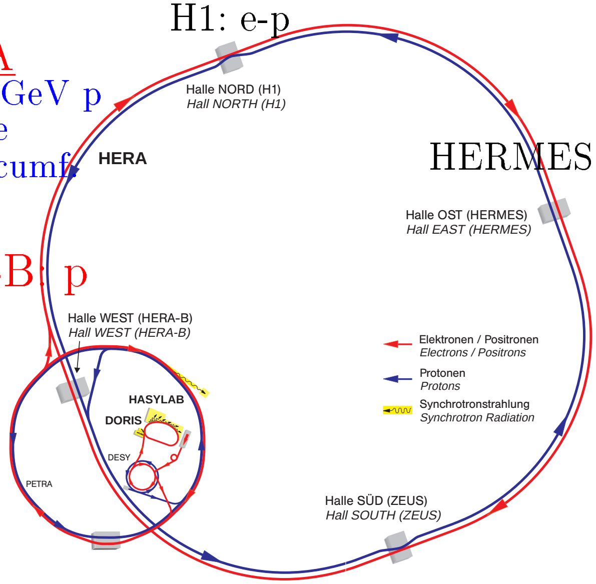
HERA
820/920 GeV p
30 GeV e
6 km circumf.

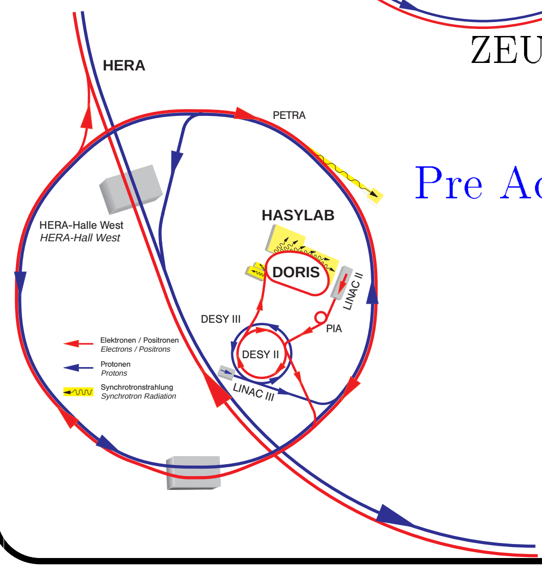
HERA-B: p

H1: e-p

HERMES: e

ZEUS: e-p





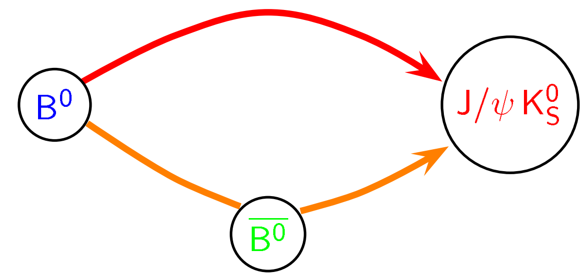
Pre Accelerators

Goal of HERA – B

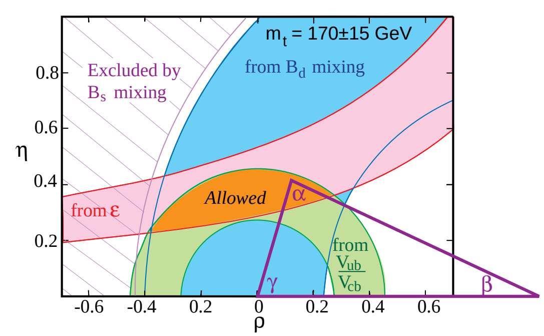
Detection of CP-violation in the B-System

$$A_f = \frac{\Gamma(B^0 \to J/\psi K^0_S) - \Gamma(\overline{B^0} \to J/\psi K^0_S)}{\Gamma(B^0 \to J/\psi K^0_S) + \Gamma(\overline{B^0} \to J/\psi K^0_S)} = \sin(2\beta) \cdot \sin(xt/\tau)$$

Difference in decay rates due to interference of two different decay amplitudes:



Well-defined test of Standard Model.



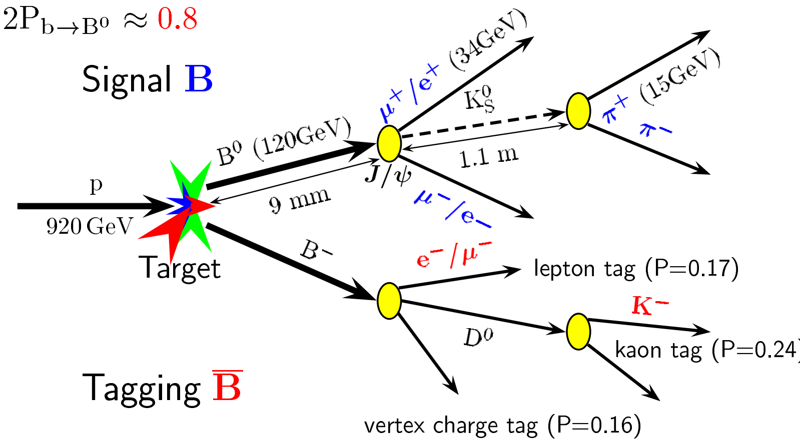
Golden Decay

production rate

$\sigma_{b\bar{b}}/\sigma_{inel} \approx 10^{-6}$

$2P_{b \to B^0} \approx 0.8$

$Br(B^0 \to J/\psi\, K^0_S) \approx 5 \cdot 10^{-4}$



$Br(J/\psi \to e^+e^-/\mu^+\mu^-) \approx 0.12$

$Br(K^0_S \to \pi^+\pi^-) \approx 0.69$

eff(trig, rec, vertex) ≈ 0.1

total Efficiency $\approx 3 \cdot 10^{-12}$

$\Delta \sin 2\beta = 0.13 \Longrightarrow 1000$ Events

Required interactions $\approx 4 \cdot 10^{14}$

$(\sigma^{tot}_{b\bar{b}} = 12\,nb, 1\,y\ @\ 40MHz)$

Target Requirements

physics goal: $\delta[\sin 2\beta] \approx 0.1...0.15$ (1 year)

Rates: ≈ 1000 events/year (10^7 sec)

$\Rightarrow 4 \cdot 10^{14}$ i.a./year = 40 MHz

bunch frequency: ≈ 8 MHz $\Rightarrow 5$ i.a./bx

Target Efficiency: $\epsilon_T = R_{ia}/R_{p-loss}$

1 mA p-loss in 1h $\to$ 36 MHz $\Rightarrow \epsilon_T > 50\%$

Impacts: multiple scattering ($\to$ backgrounds),

aperture & collimators, Z of material, optics...

Running Efficiency: $\geq 10^7$ sec/year .

$\to$ fast, secure & reliable steering, monitoring

$\to$ coordination with HERA and other experiment

Reconstruction Efficiency (limits of detector)

$\to$ constant rate without spikes

$\to$ equally distributed on all wires

$\to$ no or at least only small fluctuations

$\to$ equal contributions from all bunches

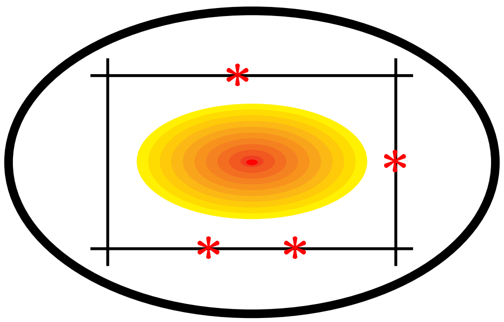
$\to$ i.a. only in proper p-bunch time window

(1 out of 96 nsec, no satellites etc.)

Use HERA-p as B-Factory

Introduce thin wires ($50\ \mu m * 500\ \mu m \approx \mathcal{O}(\sigma_{VX})$) into the beam (halo) - (stepsize $\leq 1\mu$m):

- absorb protons leaving beam core
- protons pass wire $\mathcal{O}(1000) \Rightarrow$ interaction ($\lambda_I = 39.4$ cm (Al) , 15.1 cm (Cu))



Advantages:

mechanical stable, easy to operate
well localized vertices distributed over wires

- 8 Targets: $500 \times 50\mu\text{m}^2$ (C, Al, Ti, Fe, Cu, W)
- p(920 GeV) + N(target) $\Rightarrow$ X + $b\,\overline{b}$

Target test operation since several years
since 1997: transition to continuous operation

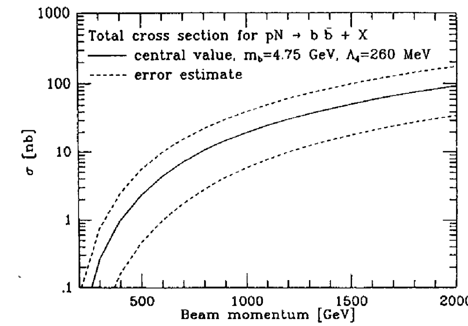
$b\overline{b}$ Cross Section

- QCD–Calculation to α_s^3

$\sigma^{tot}_{b\overline{b}} =$

12 nb @ 820 GeV

17 nb @ 920 GeV



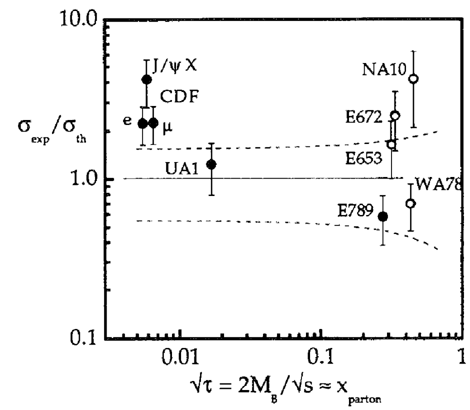
▷ depends on m_b (4.5–5 GeV)
▷ depends on scale for α_s calculation

- Measurements of $\sigma_{b\overline{b}}$

E789:
$\sigma^{tot}_{b\overline{b}} \approx (7 \pm 2.5)$ nb

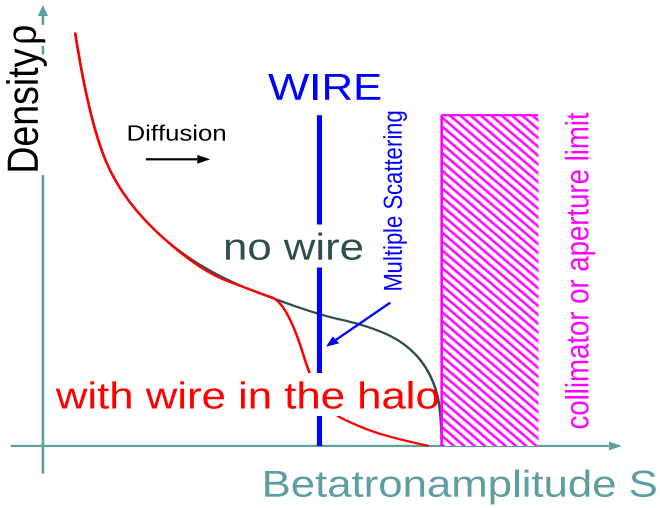
E771:
$\sigma^{tot}_{b\overline{b}} \approx (42 \pm 17)$ nb

new measurements favor larger $\sigma_{b\overline{b}}$



HERA-B estimates based on $\sigma^{tot}_{b\overline{b}} = 12$ nb

Principle of a Halo Wire Target



Efficient competition with collimators needed !

What is limiting the efficiency ?

Diffusion of Halo Protons

requires: small v_D and large Z (fast absorption)

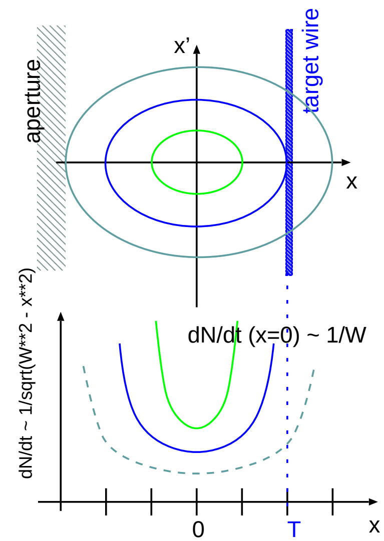
Multiple Scattering in Target

$\Delta\epsilon = \Theta^2\beta, \quad \Theta = 14\ \mathrm{MeV/p}\sqrt{X_{int}/X_{rad}}$

requires: small β-function, low Z

Multiple Scattering dominated Target

HERA-B target is dominated by multiple scattering
we disturb the p-beam, scrape away p's $\rightarrow$ reduce τ_p



angular smaering due to mult. scatt

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

e.g. Al $\lambda_I = 40$ cm, $X_0 = 9$ cm

$\rightarrow < \Theta^2 > = (35\mu\mathrm{rad})^2$

natural beam divergence x':

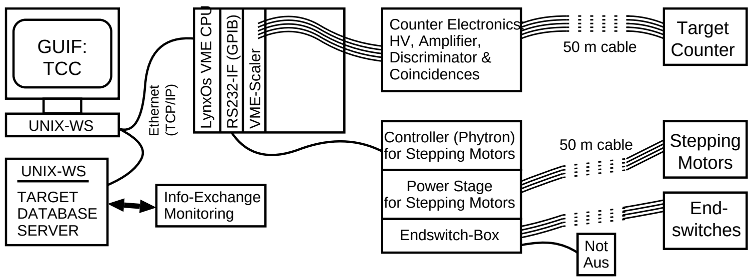
$\sigma^2_{x'} = \epsilon_x/\beta_x \approx (10\mu\mathrm{rad})^2$

with $\beta_{x,y} \approx 35$m

and $\epsilon_{x,y} \approx 4 \cdot 10^{-9}$radm

- smearing of betatron amplitude by 3...7σ
  $\rightarrow$ protons are scattered outward
  $\rightarrow$ hit probability on target reduced
- more wires didn't help to increase the efficiency
  $\rightarrow$ ϵ_t didn't add up, one gets the mean
- .low Z targets more efficient
- .small β functions required
- .enough free aperture (3 σ) necessary

TaCoS - Target Control System



Functionality: feedback from counters,
multiwire handling, beam finding,
easy and secure user interface,
data logging, monitoring & data exchange

Safety: main design issue - avoid p-loss and damages

Basic steering: very simple

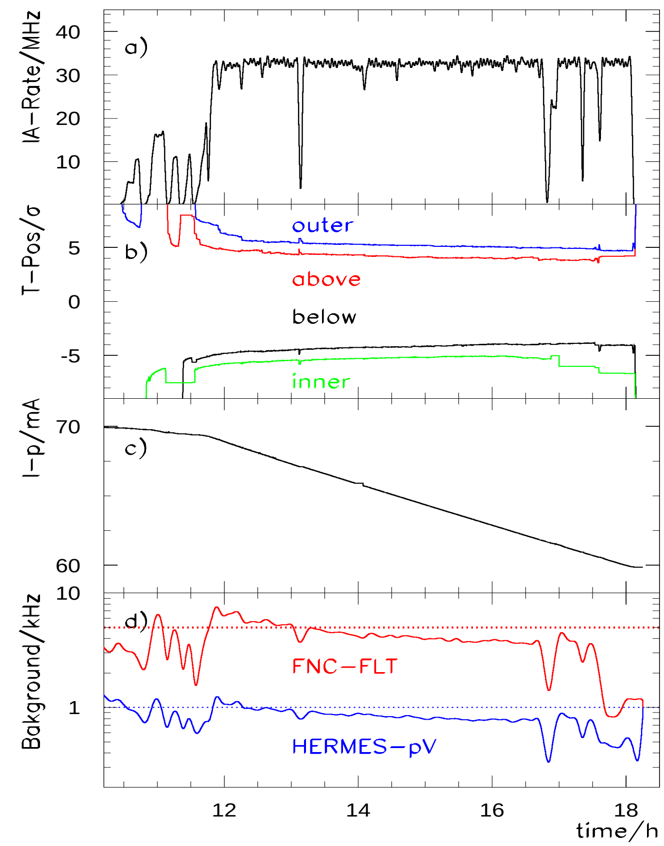
- rate too high: retract wires
- rate too small: move wires closer to the beam
- wire selection: e.g. feedback from charge integrators

Implementation & Features: - statemachine

- nominell stepsize: 50 nm (necessary $\approx 1\mu$m)
- calculation of stepsize
- GUIF: TargetControlCenter (TCC)
- and many more (monitoring, safety, ...)

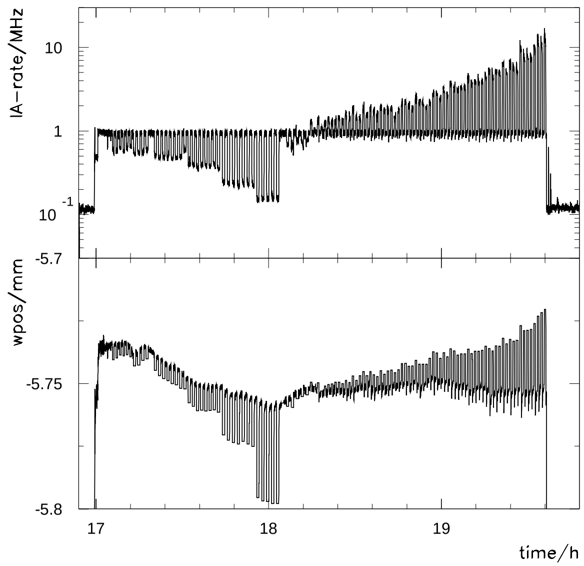
Target Operation

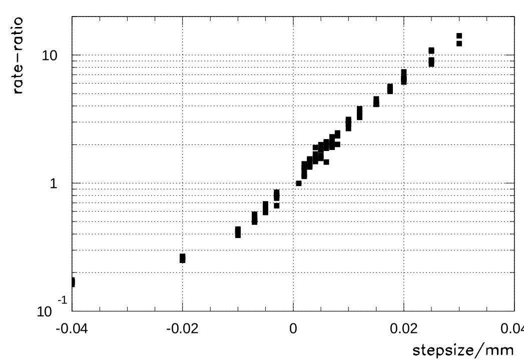
- high rates (40 MHz) achieved, $\epsilon_T \geq 60\%$
- reliable, secure multiwire automatic
- small background at other experiments



Rate Sensitivity

step function measurements





Fluctuations & Rate Stability

- rate drops at fixed target position
- high intrinsic p-lifetime

target has to disturb the p-beam to keep rate constant ($\mathcal{O}(100\mu m/h)$)

→ beam scraping (multiple scattering)

→ steep edges of beam

→ very sensitive to disturbances

(rate change)/$\Delta w_{pos} \approx 2/10\ \mu m$

→ observations:

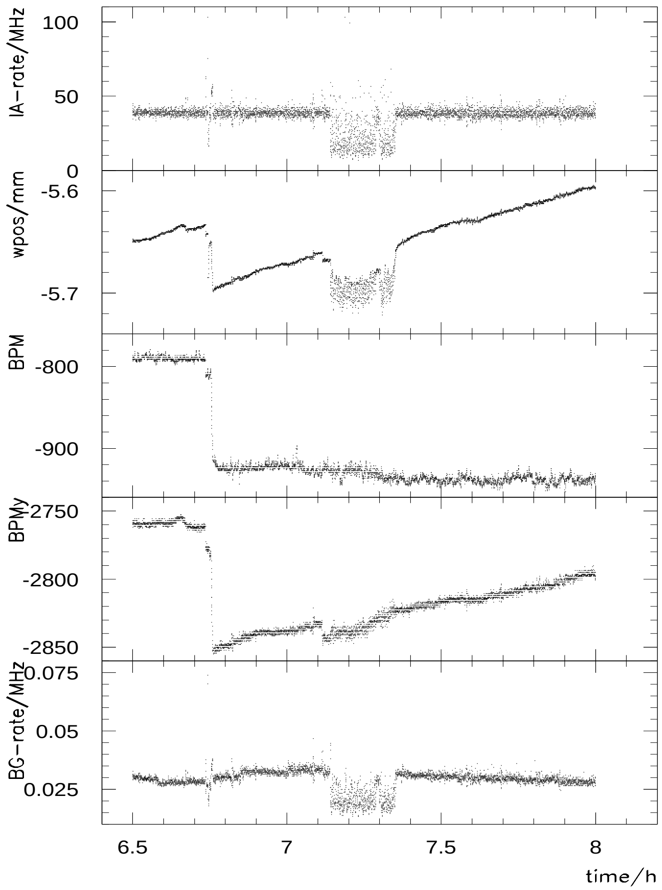
- power supplies (50 Hz - 600 Hz)
- vacuum-pumps (48 Hz)
- ground-vibration (Hz)
- steering oscillations (long reaction of rate on target movements)
- S-Bahn (5 min), ...

- problem: loss in efficiency - $\mathcal{O}$ (10%)
  and huge spikes (radiation damage - dangerous)
- hope: beam excitation - more halo

⇒ smooth target operation, avoid spikes

Ground-vibration

caused by heavy work in the Volkspark Stadion
$\tau \approx 1.6$ sec - ground motion measurement
no problem for e-p Lumi experiments
regular observed and correlated



Beam Excitation

HERA-B has rather a beam than a halo target
- reduction of p-lifetime (10...100)
Together with HERA we developed proposals how to produce more halo protons without disturbing the beam core (beam tail shaping)

RF-Noise: amplitude noise at 2∗ or 4∗
synchrotron-frequency (30/50 Hz)
synchro-betatron coupling (due to dispersion)
spectral width: 10 Hz, amplitude $10^{-5}...10^{-4} U_{RF}$

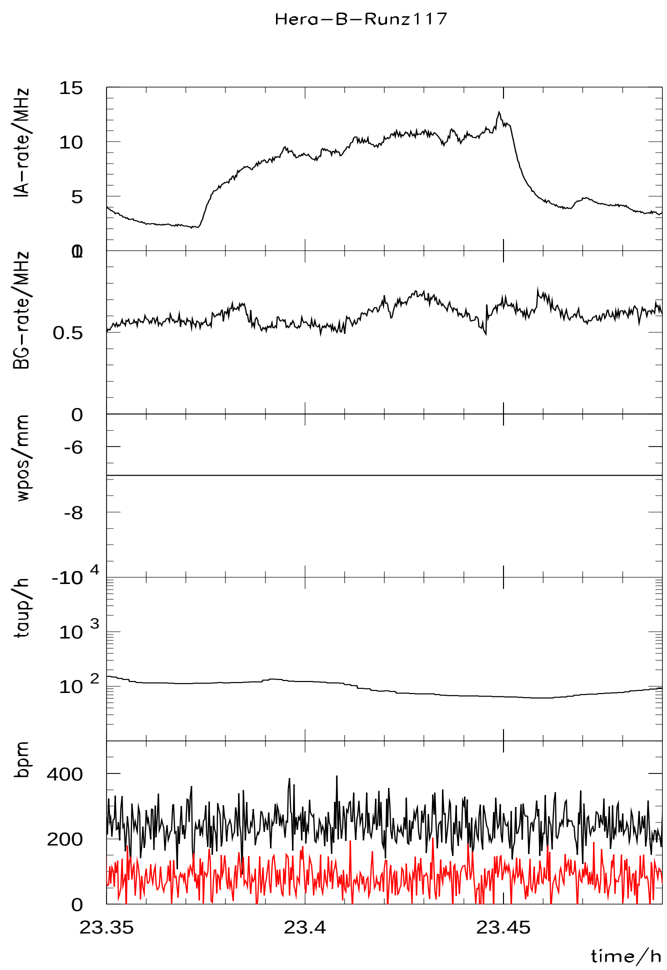
Tune-Modulation: excite quadrupol magnet with some frequencies (50 Hz...1.5 kHz). This gives sidebands & add. resonances (tune depends on S).
→ beam excitation $m \cdot Q_{x,y} + n \cdot \frac{f_{mod}}{f_{rev}} = k$

Dipole Kicks: with feedback kicker on 3. resonance of betatron-frequency (maybe noise)

→ increase halo population
without blowing up beam core
→ first tests in 1998
→ now with noise from CD

Tail Shaping - Feedback kicker

$f_{ex} = 41.410 \pm 0.005 kHz$



Multi-wire Operation

feedback : using charge integrators connected to wires for wire selection

performance : looks very promising

- technical parts of steering code fine
  i.e.: able to handle different situations
  emergencies are working
- performance: reasonable good with respect to what one expects

ToDo : detailed analysis and understanding of rate distribution (width)

- investigation of sensitivity to wire displacement

Running Conditions : Pretty Fine

- stable rates

→ multi-wire shows less fluctuations -

backgrounds at other experiments stable (CB)

- but: CB contributions of several MHz

Further Plans : Use Vertex Info - SLT/TLT

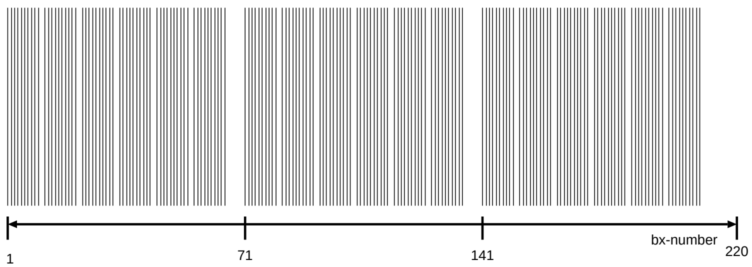
→ final system

Measuring Bunch Contributions

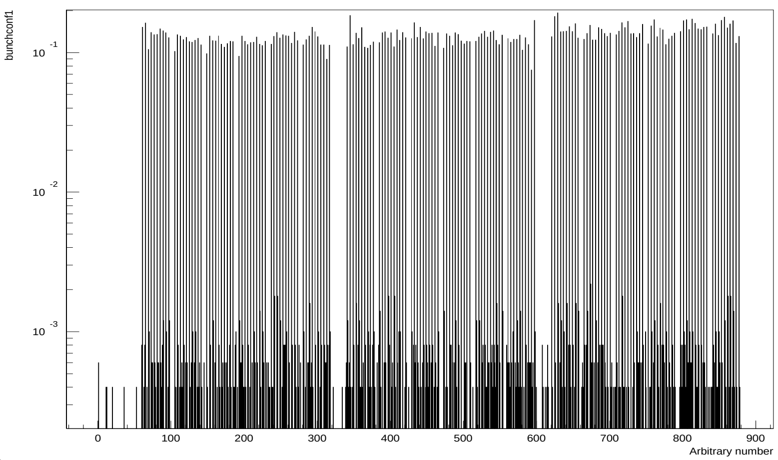
HERA p-bunch filling scheme:

bunch distance: 96 nsec, bunch length: 0.5 nsec

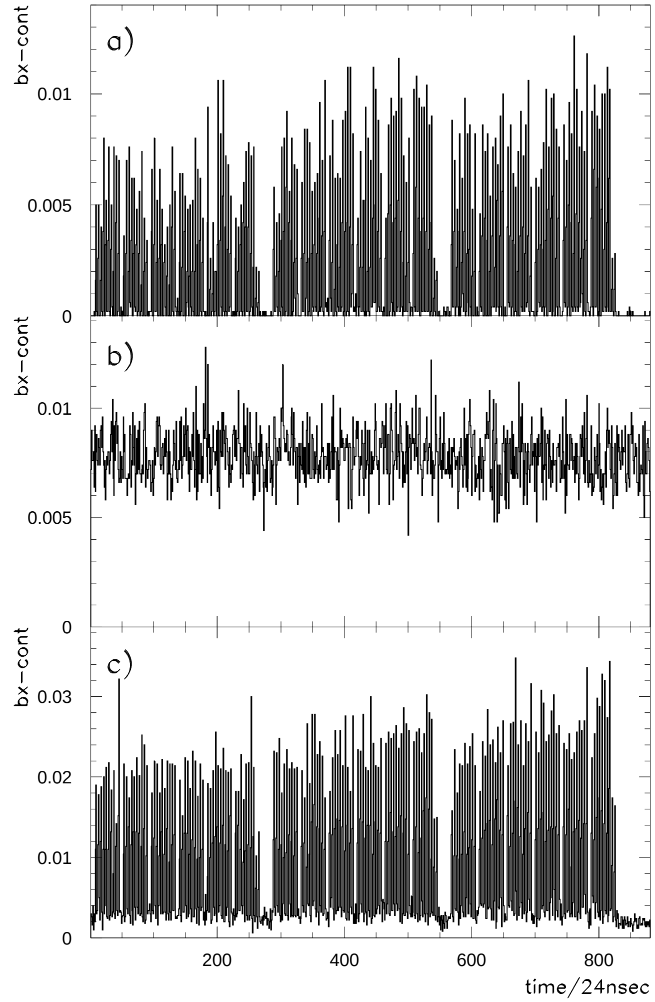
HERA Bunch Filling Scheme:
3 * (6 trains plus 4 free RF-buckets)
each train with 10 filled and one free bucket



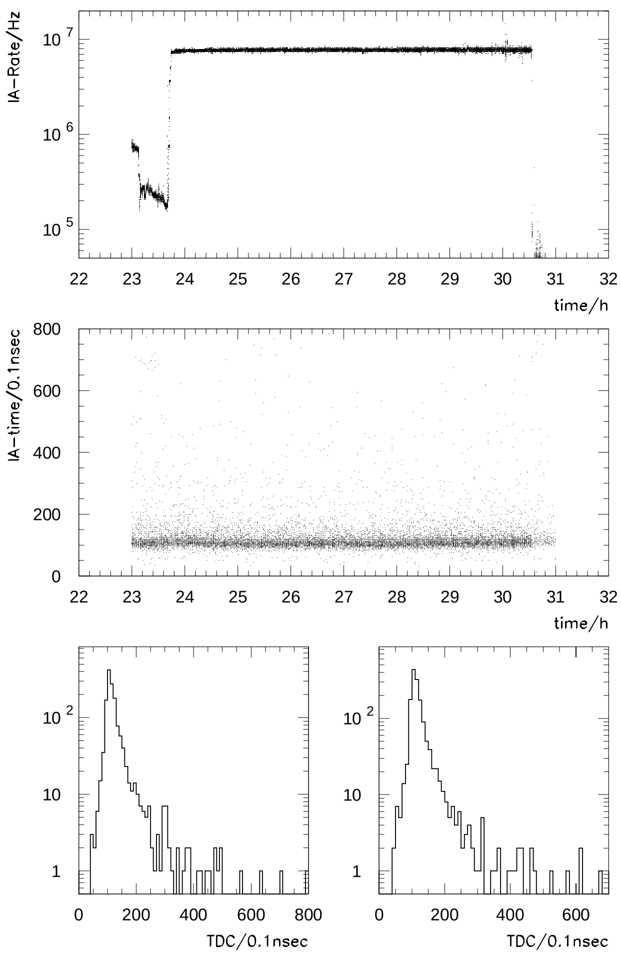
How it should be: I inner 30 MHz



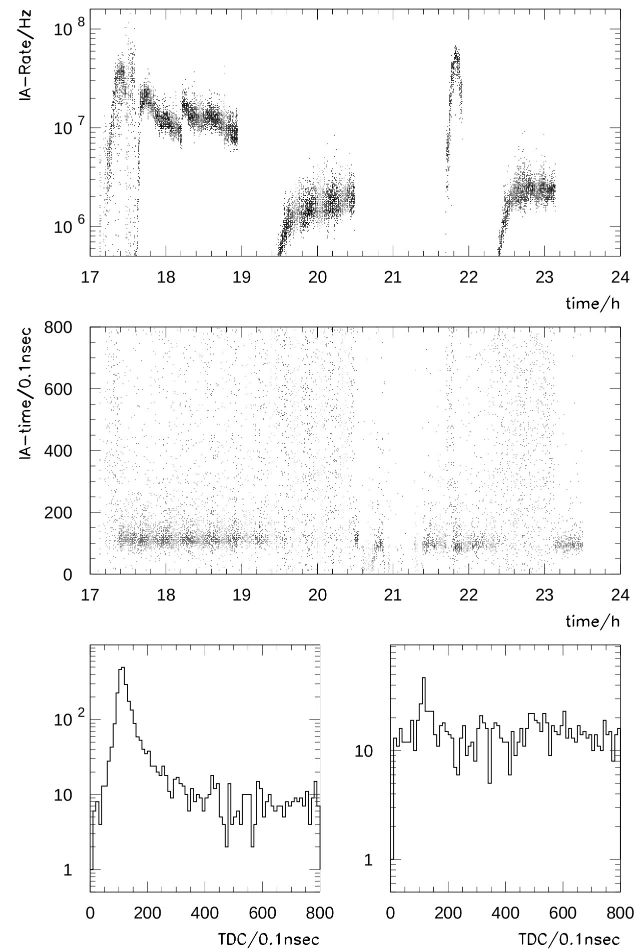
Bunch Structure - 3 States



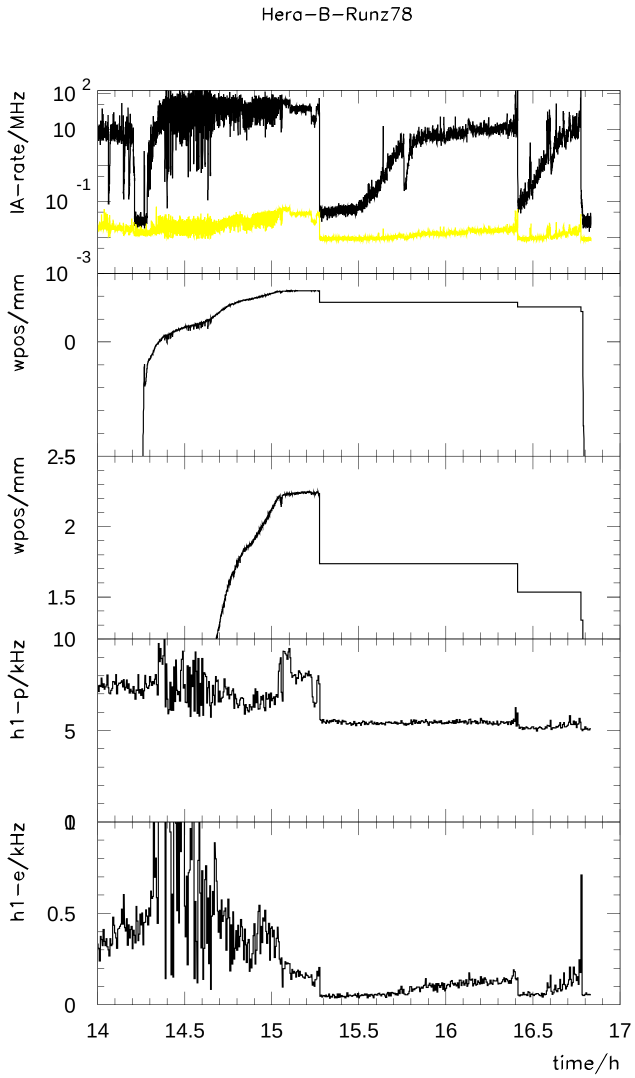
TDC Measurements - Clean Spectra



TDC Measurements - Coasting Beam

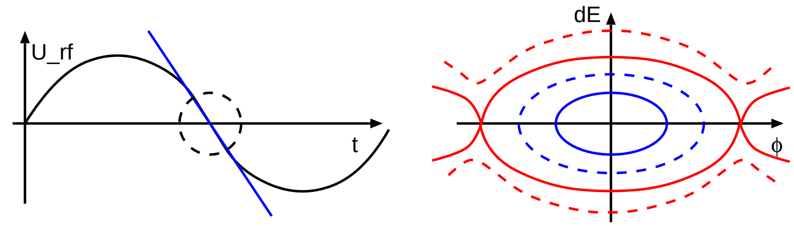


old p-fill



What is Coasting Beam ?

longitudinal beam dynamics
synchrotron oscillations and the seperatrix
(just like a pendelum)



HERA parameters :

* natural beamwidth $\Delta E/E \approx 6 \cdot 10^{-5}$
* seperatrix at $\Delta E/E \approx 2 \cdot 10^{-4}$
* momentum acceptance at $\Delta p/p \approx \cdot 10^{-3}$
* synchrotronfrequency $f_s \approx 30/50\ Hz$
* RF-system: 52 MHz and 208 MHz
* growth of longitudinal bunchlength: 50%/10 h
* dispersion at target ($D_x = -\ 0.47$ m):
  $\Delta x = D_x \cdot \Delta E/E$

Target Measurements: non BX related i.a.

* large on outer side, small on inner side
* several σ broad transversal tails
* population increases with age of fill
* strong correlations with backgrounds/spikes

Coasting Beam - Impacts & Cures

E-loss in Target: $\approx 200\ \mathrm{MeV}/\lambda_{int}$

sufficient to make some p unstable

$\rightarrow$ not the main contribution

Production in HERA: observed end 1998

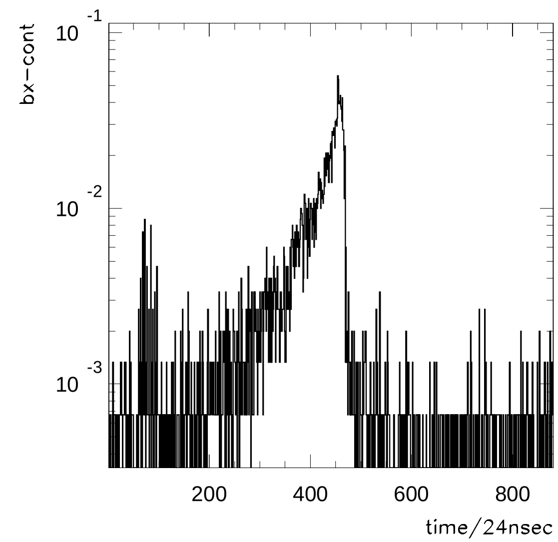
but not yet understood (RF-noise, synchrotronradiation, intra beam scattering ...)

measures against CB: .

- increase RF amplitude U_{RF}
- kick coasting p's in dump gap
- modifications of optics: β
  and dispersion and scrape with collimators
- accellerate and deaccelerate p beam

Beamstudies Coasting Beam

Excite non filled bunches with feedback kicker



- momentum comp. factor $\alpha \approx 1.3 \cdot 10^{-3}$
- $dL/L = \alpha * dp/p$

$\rightarrow T_{CB} \approx 80$ sec to travel once around beam

- lifetime of p in vicinity of target: $\approx sec$

Status & Conclusions

- HERA-B target is in continuous operation
- most essential problems (steering, ϵ_T, backgrounds ...) are solved
- rate stability is still a problem (efficiency loss): scraping at the beam causes large sensitivity
  $\rightarrow$ beam tail shaping
- variation of individual bunch contributions:
  $\rightarrow$ improved injection timing (HERA)
  $\rightarrow$ beam tail shaping
- target discovered coasting beam at HERA
  serious problem with still many open questions
  nonlinear beam dynamics & chaos
- target very sensitive device for beam diagnostic to study beam dynamics (together with HERA-B detector):
  halo population, diffusion, instabilities, ...
- Target is ready to produce Beauty