

Summary of experience with HERAp synchrotron light diagnostics

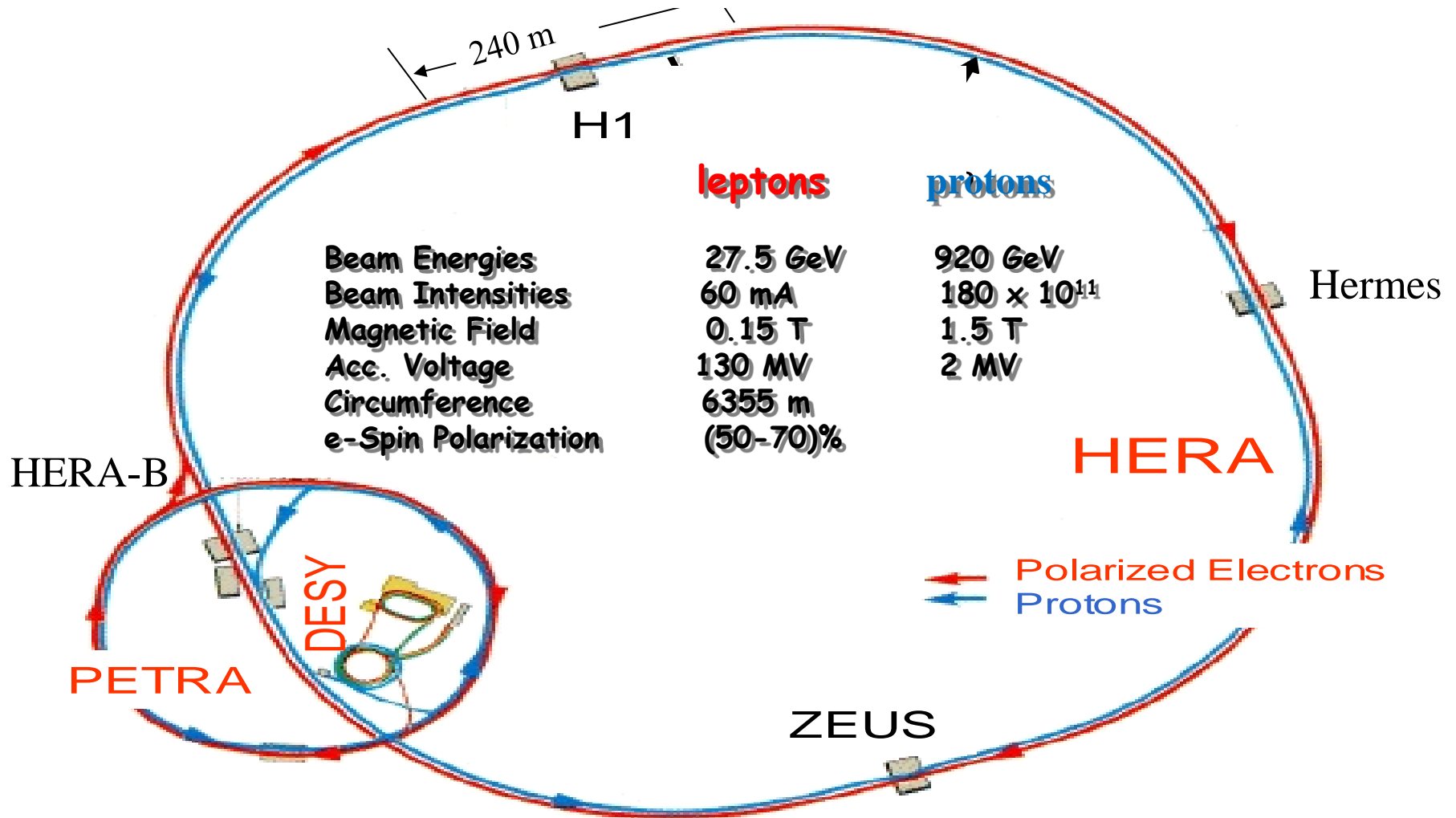
Kay Wittenburg @ Gero Kube
DESY / MDI

9th DITANET Topical Workshop on Non-Invasive Beam Size Measurement for High Brightness Proton and Heavy Ion Accelerators

15-18 April 2013, CERN

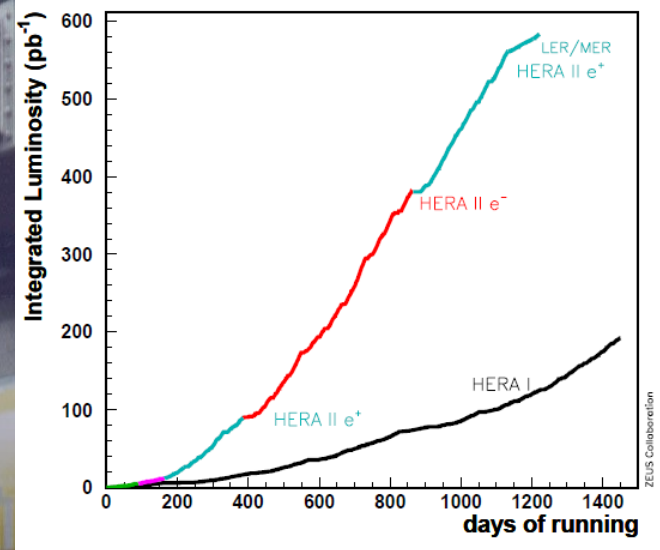
- History
- History
- More History
- Measurements

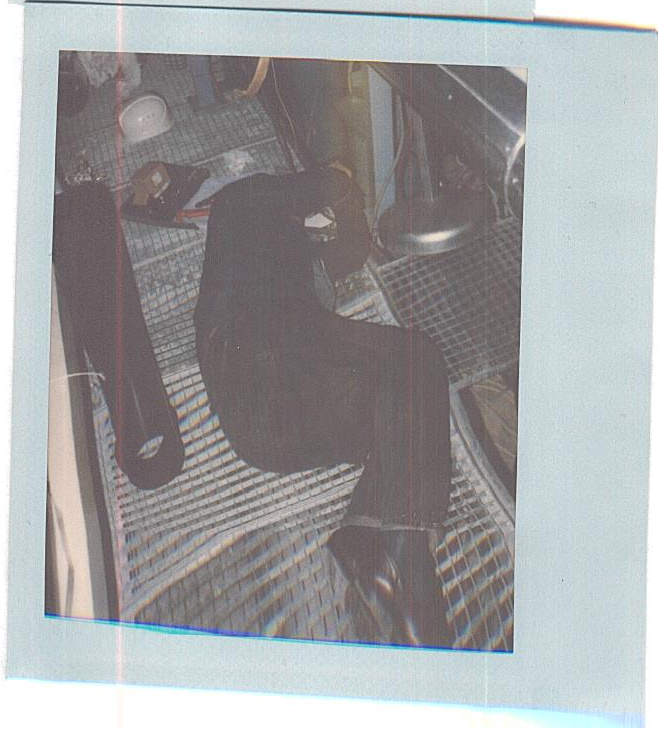
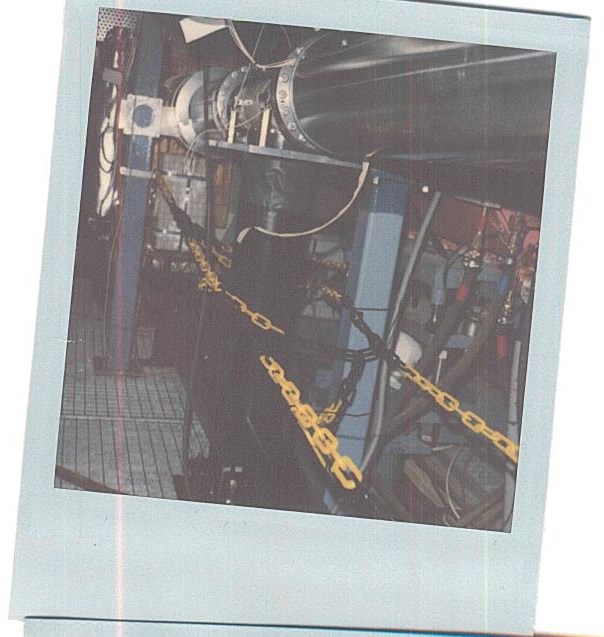
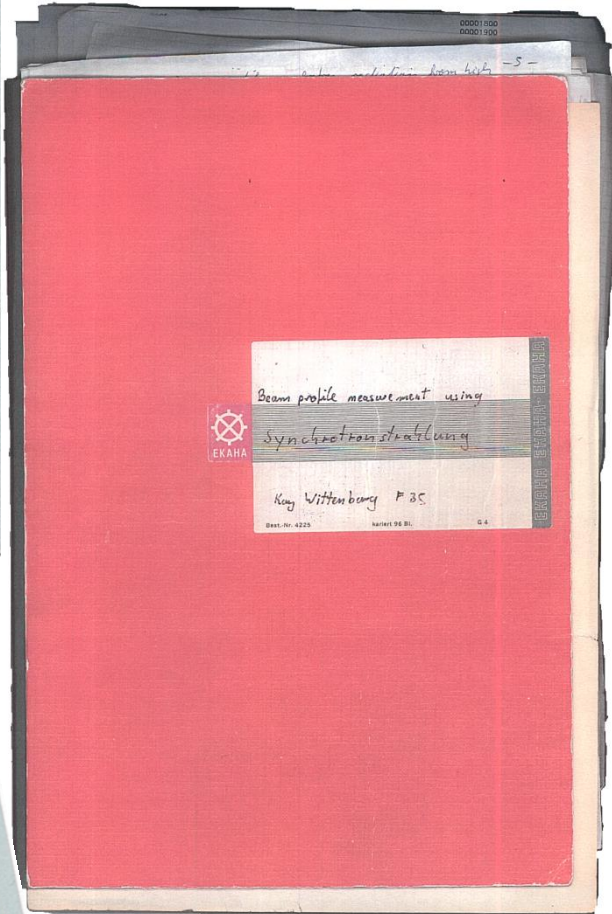
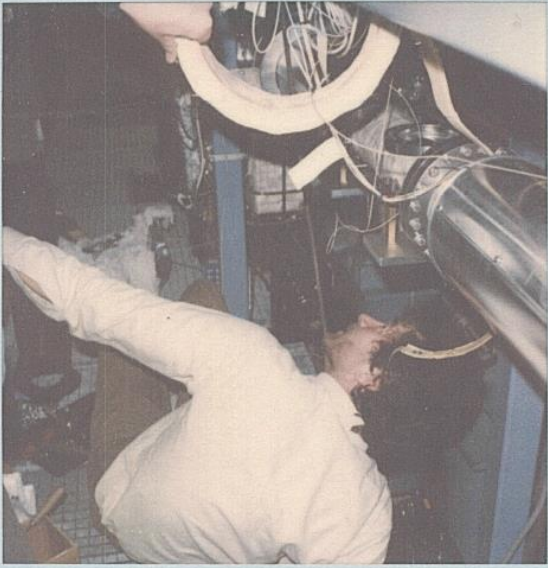
Overview of HERA



Milestones

- 1966 Star Trek and "Raumpatrouille Orion"
- 1981 Hera Proposal
- 1984 Start Building
- 1985 **Key for HERA**
- 1991 Commissioning, first Collisions
- 1992 Start Operations for H1 and ZEUS
- 1993 **First light from SR Monitor**
- 1994 Install 1. spin Rotators → longitudinal polarized leptons for HERMES
- 1996 Install 4th Interaction region for HERA-B
- 1998 Install NEG pumps against dust problem, Reliability Upgrade
- 1999 High Luminosity Run with electrons
- 2001 Install HERAII Luminosity Upgrade, Spin Rotators for H1 and ZEUS
- 2001/2 Recommissioning, severe background problems, HERA-B physics Run
- 2003 1st longitudinal polarization in high energy ep collisions, high Lumi Runs
- 2004 **SR Monitor delivered reliable profiles**
- 2007 Final shutdown of HERAII; after 16 years of running







DESY HERA 1986-06
Mai 1986

Strahlprofilmonitore für den HERA-Protonenring

Kay Wittenburg

Deutsches Elektronen-Synchrotron DESY, Hamburg.



STRAHLPROFILMONITORE FÜR DEN HERA - PROTONENRING

Kay Wittenburg
Deutsches Elektronen Synchrotron; DESY

In diesem Bericht werden verschiedene Monitore für die Protonenstrahl - Profilmessung vorgestellt. Da im HERA Speicherring die Protonen sehr häufig umlaufen, wurden ausschließlich Monitore untersucht, die möglichst wenig mit dem Protonenstrahl wechselwirken. Damit wird eine häufige, je nach Monitor sogar ständige Profilmessung möglich.

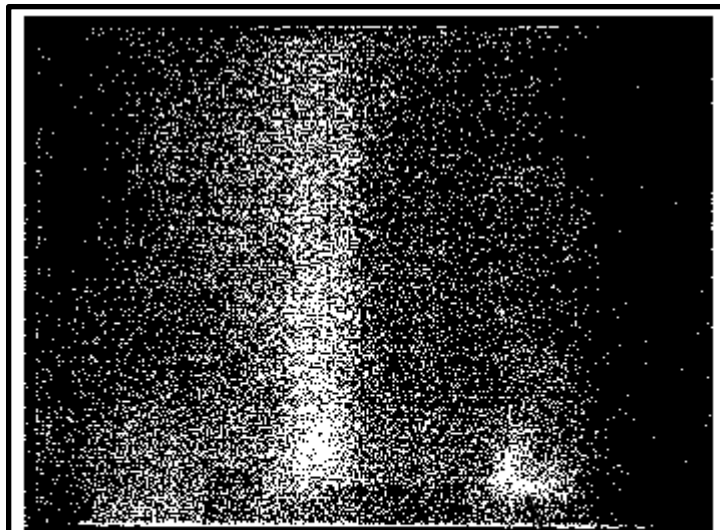
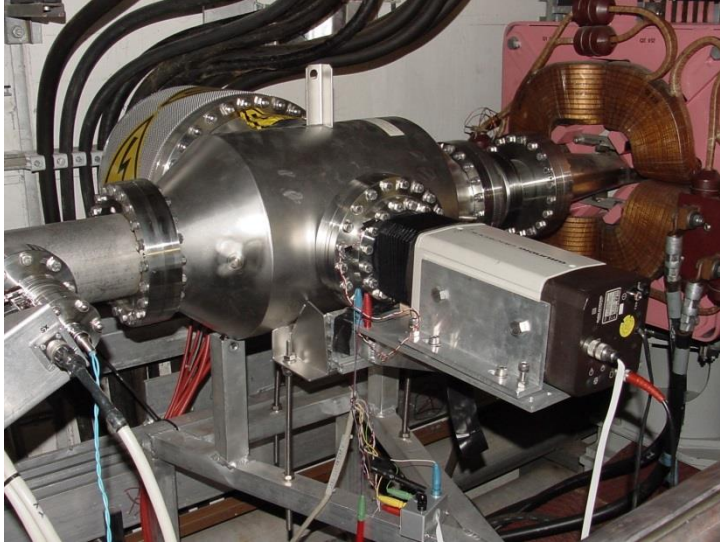
Da die Profilmontore sowohl im Beschleunigungs- als auch im Speicherbetrieb von HERA die Strahlparameter erfassen sollen, müssen sie über den gesamten Energiebereich von HERA (40 - 1000 GeV) Daten liefern können. Dies wird zum Teil nur durch eine Kombination von zwei verschiedenen Monitoren möglich sein. Die hier untersuchten Monitore wurden im HERA - Proposal (Ref. 48) schon kurz erwähnt:

Strahlprofilmessung durch:

1. Synchrotronstrahlung
 - a) Edge - Effekt
 - b) Undulator
2. Restgasionisation
3. Drahtscanner
4. Compton - Streuung von Laserphotonen

Used in HERAp

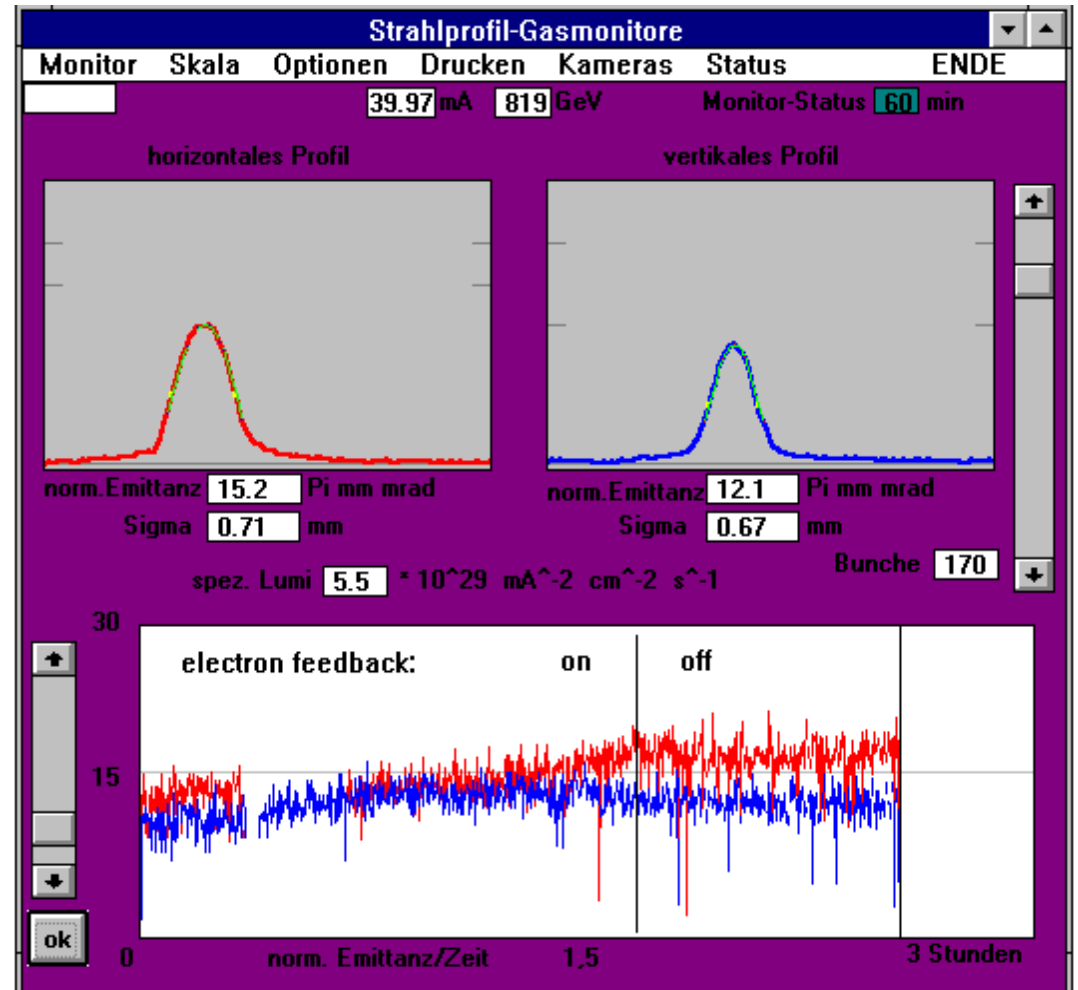
IPM in HERAp



- $I_p \leq 0.01 \mu\text{A}$ (!)
- $P_{\text{vac}} \approx 10^{-8} \text{ mbar}$
- $\text{FWHM} \approx 10 \text{ mm}$

MCP dark current

First circulating beam in HERAp (1991)



IPM: Suffers from space charge of small bunches at high charges (10^{11} protons, $\sigma < 1\text{mm}$, Ion collection, no magnetic field)

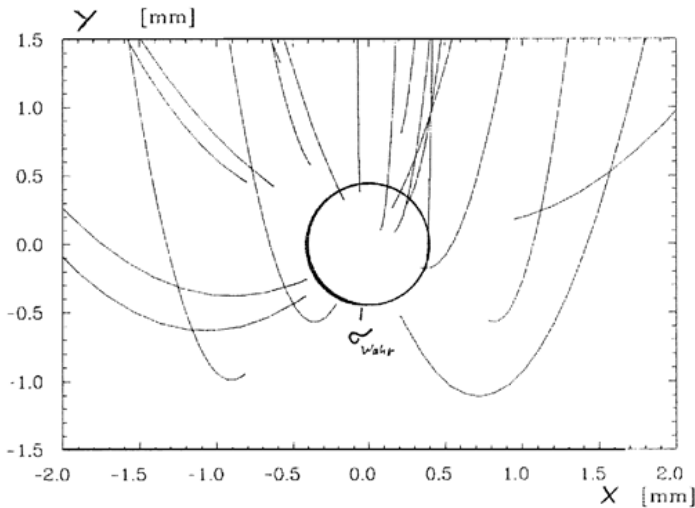


Abbildung 1: Beispiel von Ionenbahnen im Restgasionisations - Profilmonitor bei einem Bunchstrom von $I_B=700\ \mu\text{A}$ und $\sigma_{x,z}=0.5\ \text{mm}$.

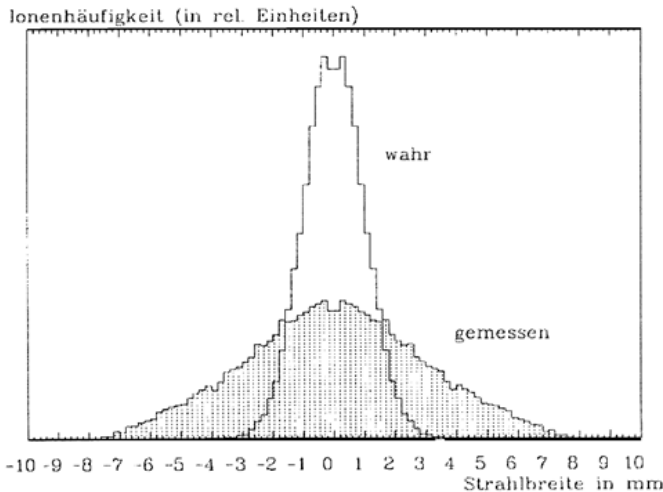


Abbildung 2: Häufigkeitsverteilung der Ionen am Strahl (wahre Breite $\sigma_{x,z}=1\ \text{mm}$) und an der Auslese des Monitors (messbare Breite FWHM = 4.5 mm), $I_B=600\ \mu\text{A}$

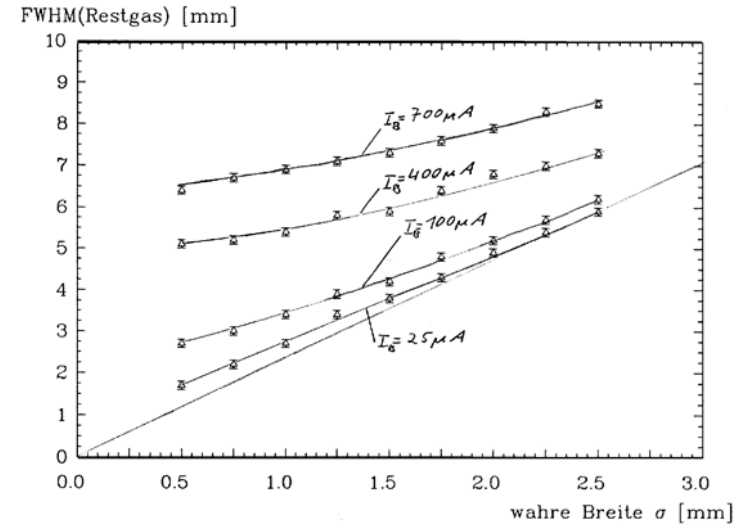


Abbildung 4: Beobachtbare Strahlbreite am Restgasmonitor für verschiedene Bunchströme I_B und wahre Strahlbreiten σ (Simulation.) Die durchgezogene Gerade ergibt sich ohne das Störfeld. Die Kurven nähern sich für steigende s asymptotisch der ungestörten Linie an.

In σ_{kor} gehen die oben genannten Abhängigkeiten ein. σ_{kor} läßt sich dann mit Näherungen auf weitere Naturkonstanten zurückzuführen:

$$\sigma_{\text{kor}}^2 = \left| \ln \frac{1}{2} \right| \cdot \frac{N \cdot e^2 \cdot d_g}{2 \cdot \pi \cdot \epsilon_0 \cdot c} \cdot \sqrt{\frac{1}{e \cdot m_p \cdot V_g}} \quad \text{Gl. 2}$$

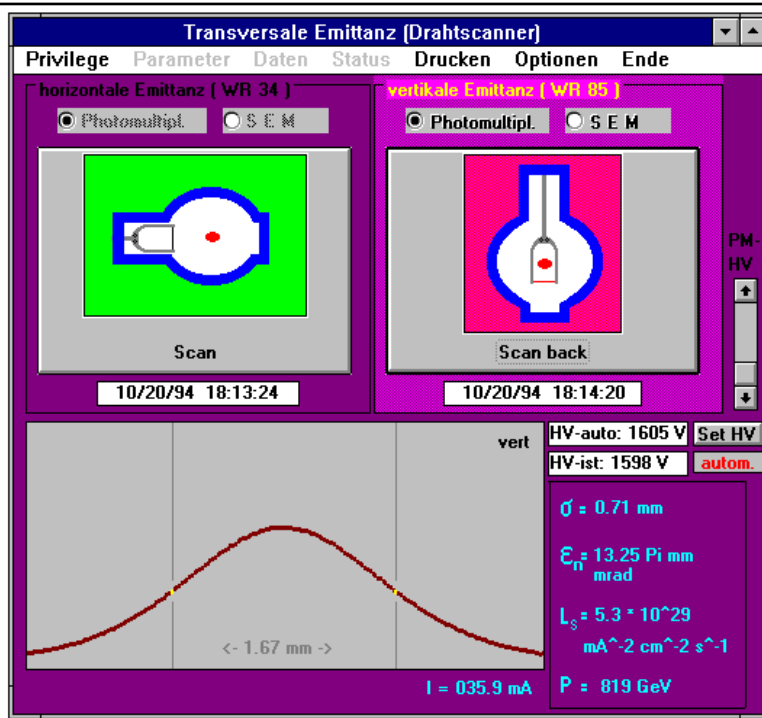
Hierbei ist (in metrischen Einheiten): e = Elementarladung, ϵ_0 = Dielektrizitätskonstante, m_p = Protonenmasse und c = Lichtgeschwindigkeit. Mit Gl.1 ergeben sich die in Abb. 5 gezeigten Kurven (für verschiedene N), die sehr gut die mit den Simulationsrechnungen errechneten Punkte beschreiben.
Die Korrektur

$$\sigma_{\text{wahr}} = \sqrt{\sigma_{\text{mess}}^2 - \sigma_{\text{kor}}^2} \quad \text{Gl. 3}$$



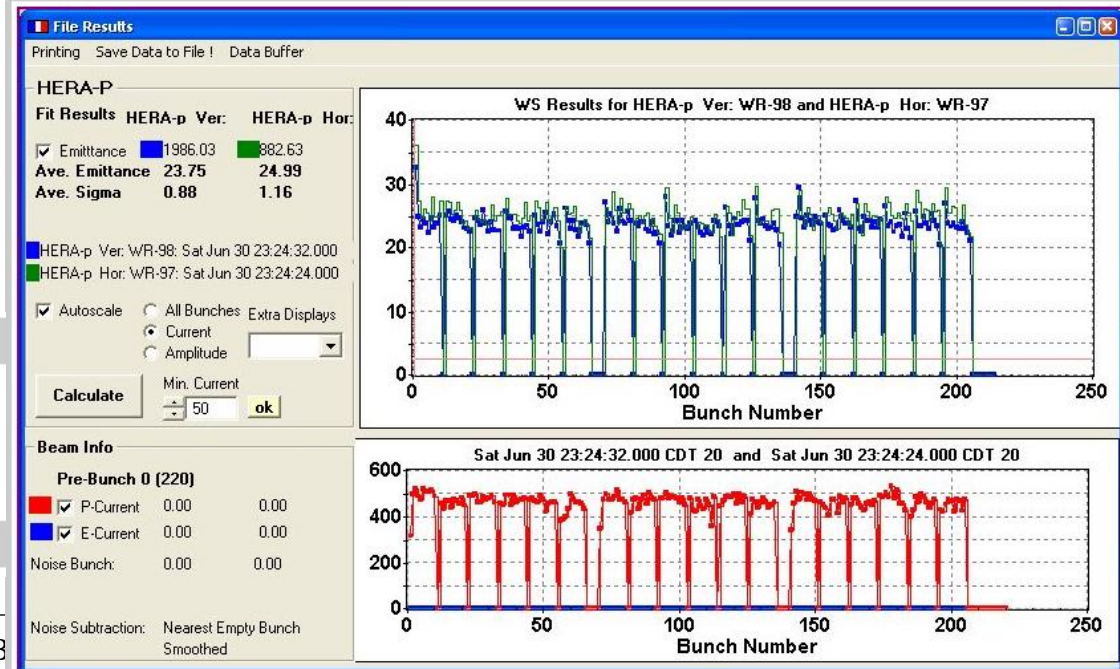
Wire Scanner at HERAp

Wire scanners were the working horse at HERAp



30.06.2007 23:24 M. Bieler Wirescan vor dem letzten p-Dump

Last HERA run



30.06.2007 23:38 R.Bacher Good Bye HERA

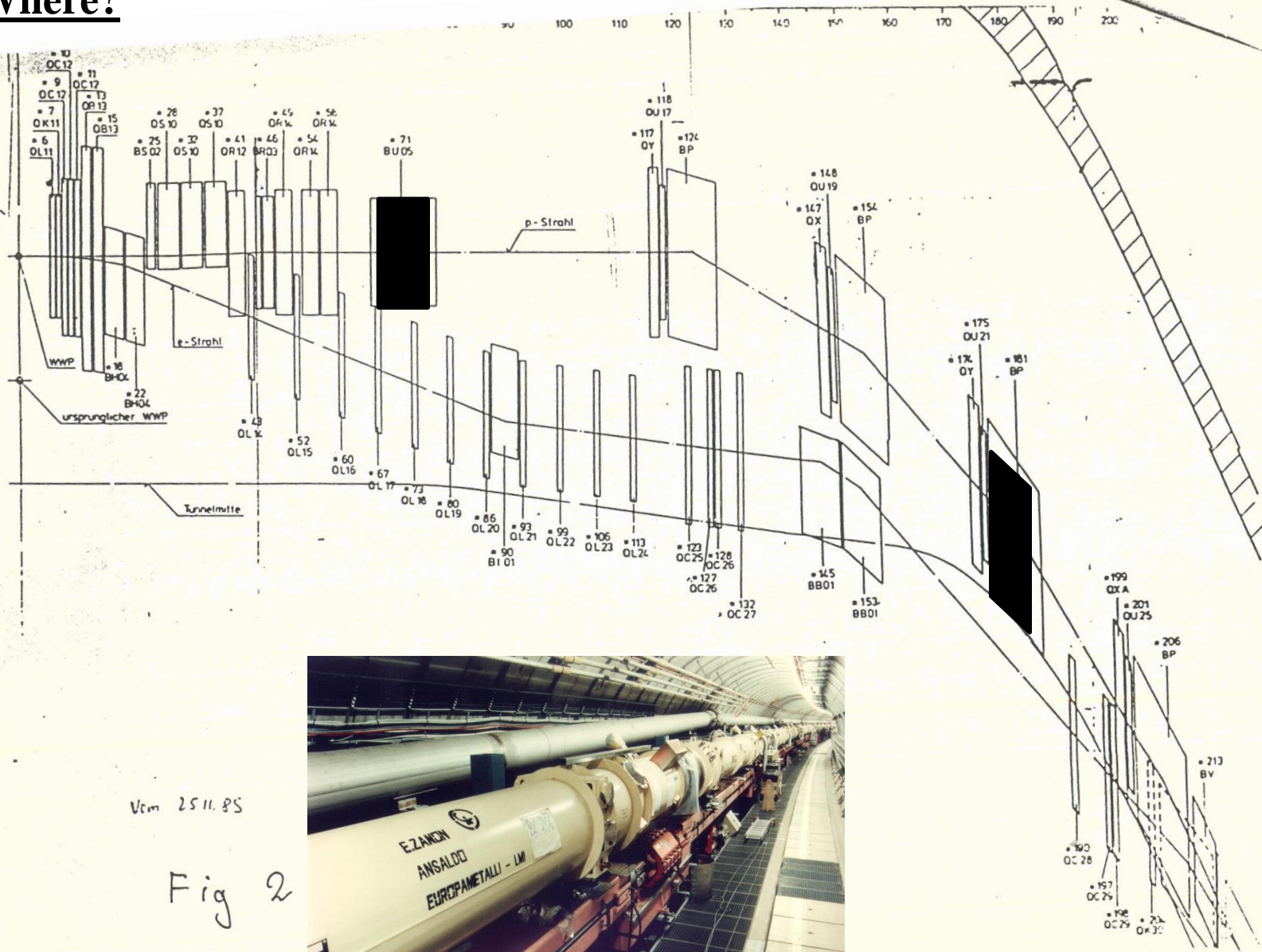
Good Bye HERA

Reinhard Bacher

30.06.2007 23:30 M. Bieler Der letzte Beamdump

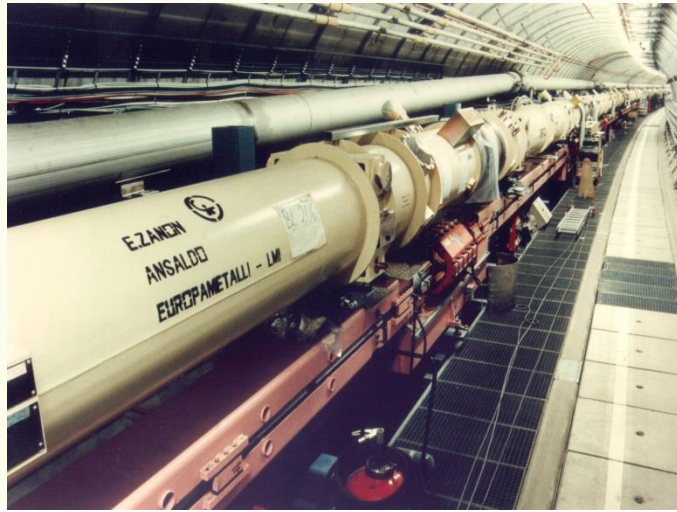
Synchrotron light monitor for Protons in HERA:

1: Where?



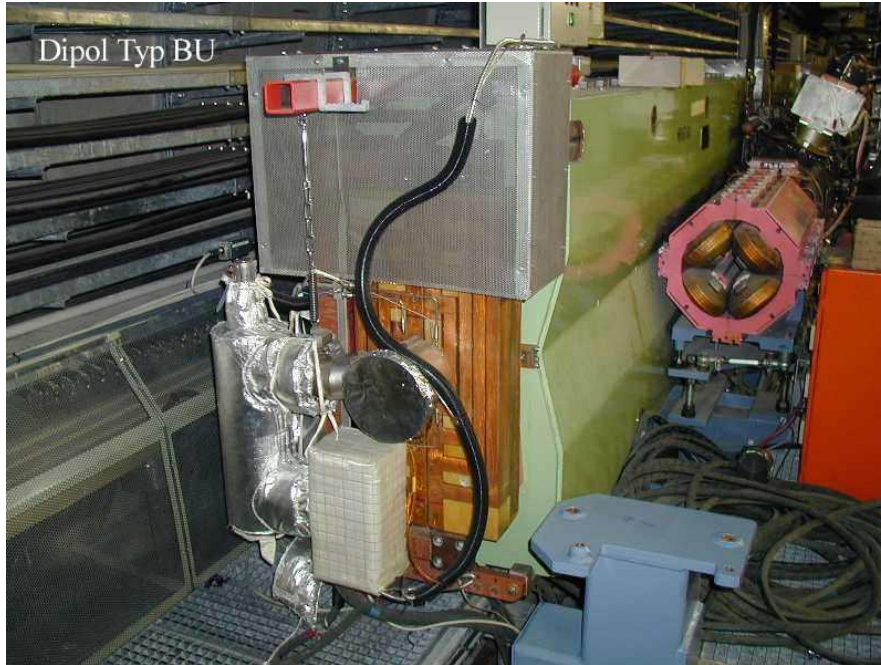
Vom 25.11.85

Fig 2



2: How much light?

Vertical bending magnet (warm)



Formula of R. Coisson was used:

Observing high energy proton beams by synchrotron radiation in non-uniform magnetic fields, Proc. Conf. Dubna 1980, p. 141-146

Comparison with CERN: should be okay for $E > 300$ GeV

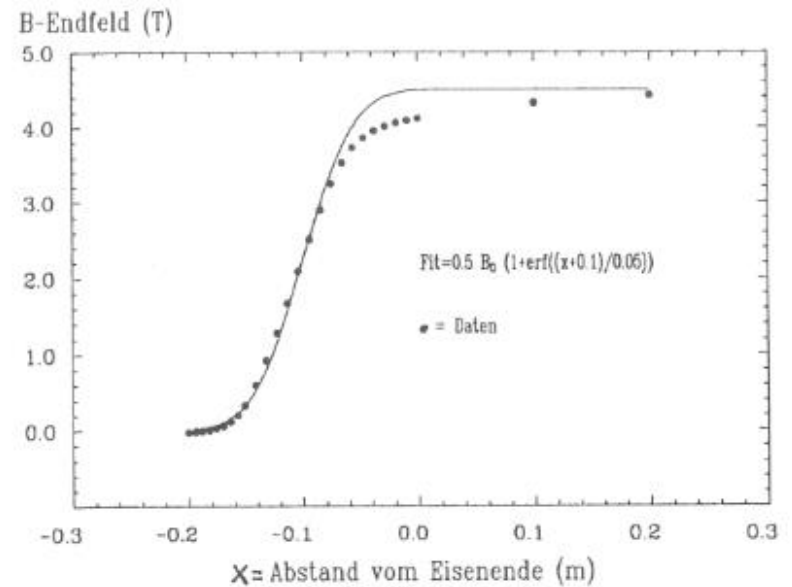


Abbildung 1. Magnet-Endfeld: Daten berechnet von Ref. 2

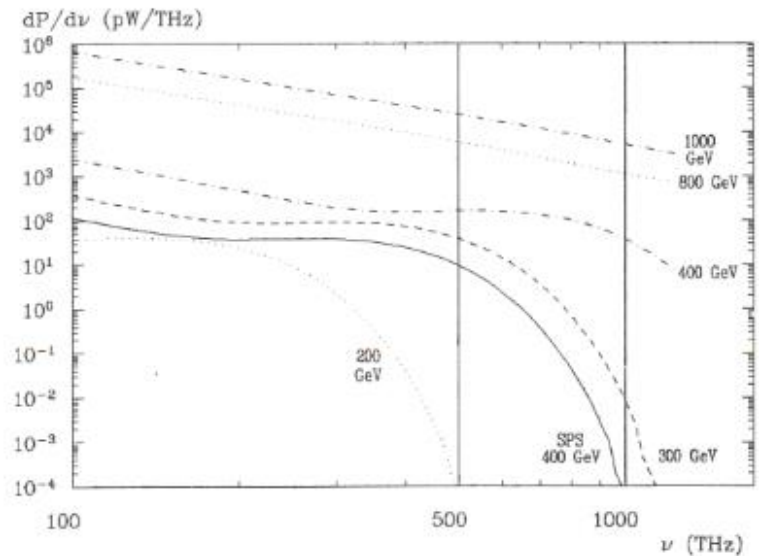
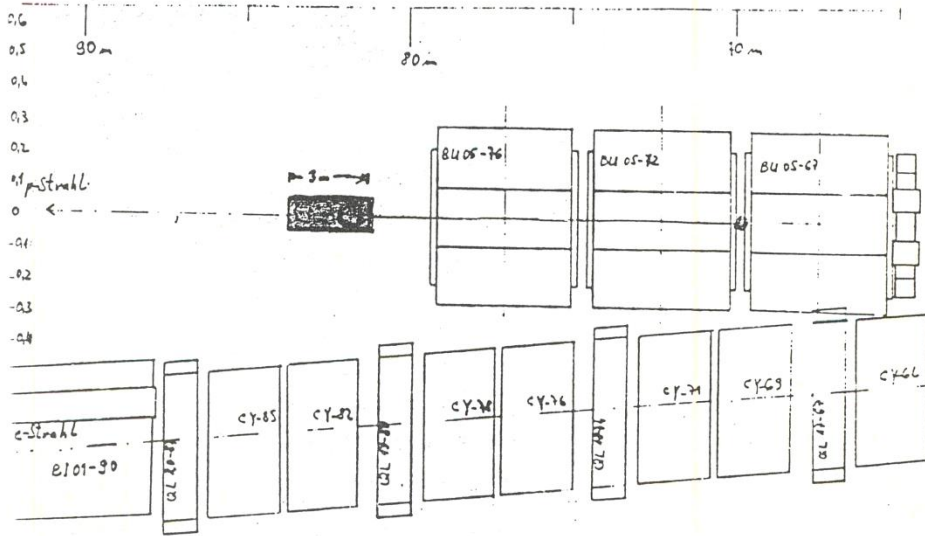


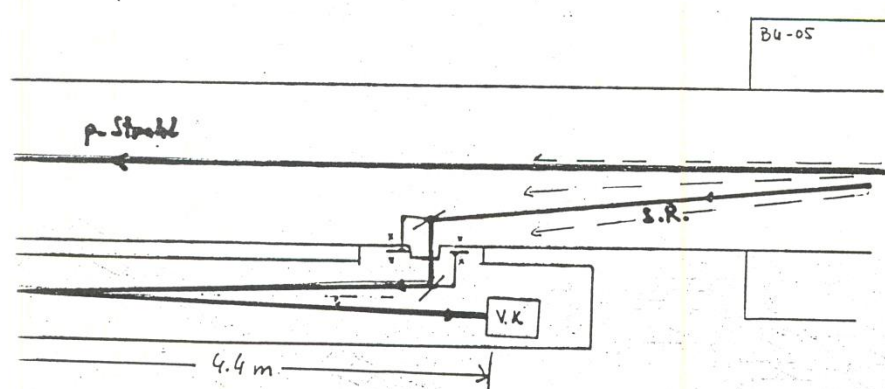
Abbildung 2. Spektralverteilung der SR durch den Edge-Effekt: Mit den senkrechten Strichen ist der Bereich der spektralen Empfindlichkeit einer Photokathode angedeutet.

3: How to get light out?



Skizze - Nord, Süd, Ost, West
Zentralstrahl

HERA OSJ Linac



Optik d. Monitors

$f = 3.2 \text{ m}$
 $g = 12 \text{ m}$
 $b = 4.4 \text{ m}$

476

(24)

BU-Positionen

BU OS	Anfang	Ende
BU OS(1)	65,33 m	69,5 m
BU OS(2)	70,12 m	74,29 m
BU OS(3)	74,91 m	79,08 m

Light

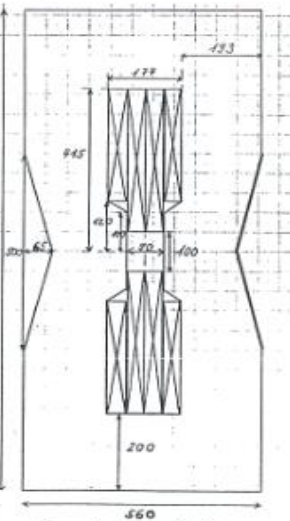
Spulenlänge (= Magnetlänge) = 4,17 m

Zwischenraum (ohne Spulenköpfe) = 0,62 m

3 Einheiten / Seite (N-O-S) $\alpha_{\text{total}} = 5,74 \text{ mrad}$

Dipol (vertikal)
BU-wicklung
(R. Heller)

$l_{\text{Fe}} \approx 4100 \text{ mm}$
 $9 \text{ Wdg/Spule (4+5)}$
 $40 \times 71 \text{ m}^2$
 $I_{\text{MAX}} = 6130 \text{ A}$
 $B_{\text{MAX}} = 1,54 \text{ T (1000 GeV)}$
 $R_{50} = 1,3 \text{ m}\Omega$
 $N = 50 \text{ KW}$
 $G = 20500 \text{ Kg}$



Spulen Köpfe!
(BBC, Tesla)

Konstruktion: P. Pietsch

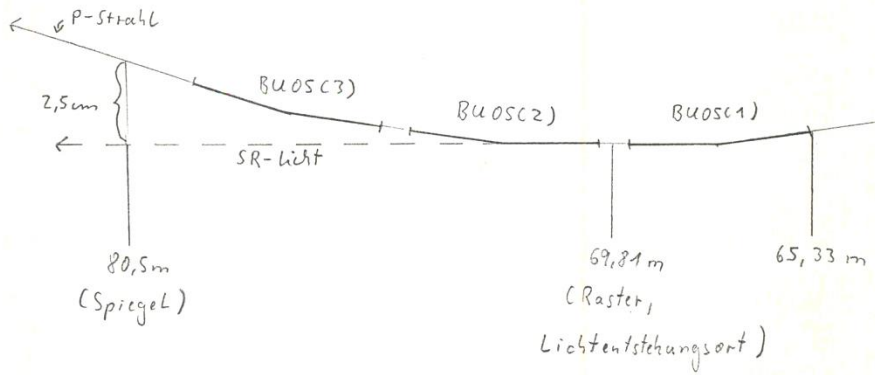


Abb. 1 Optik des p-Strahls und des SR-Lichtes

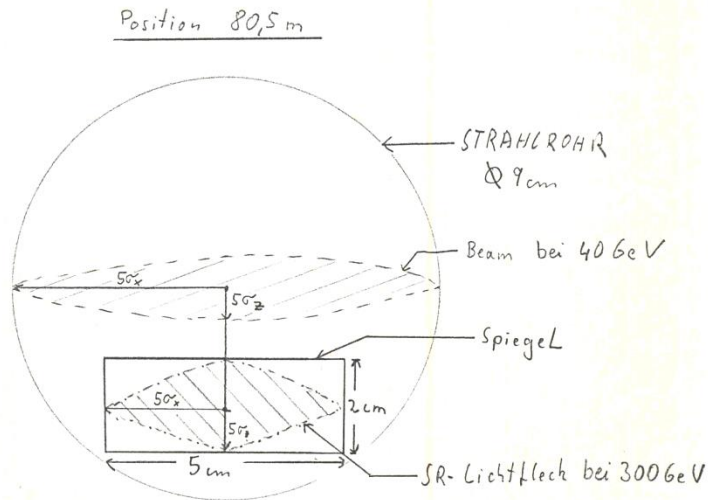
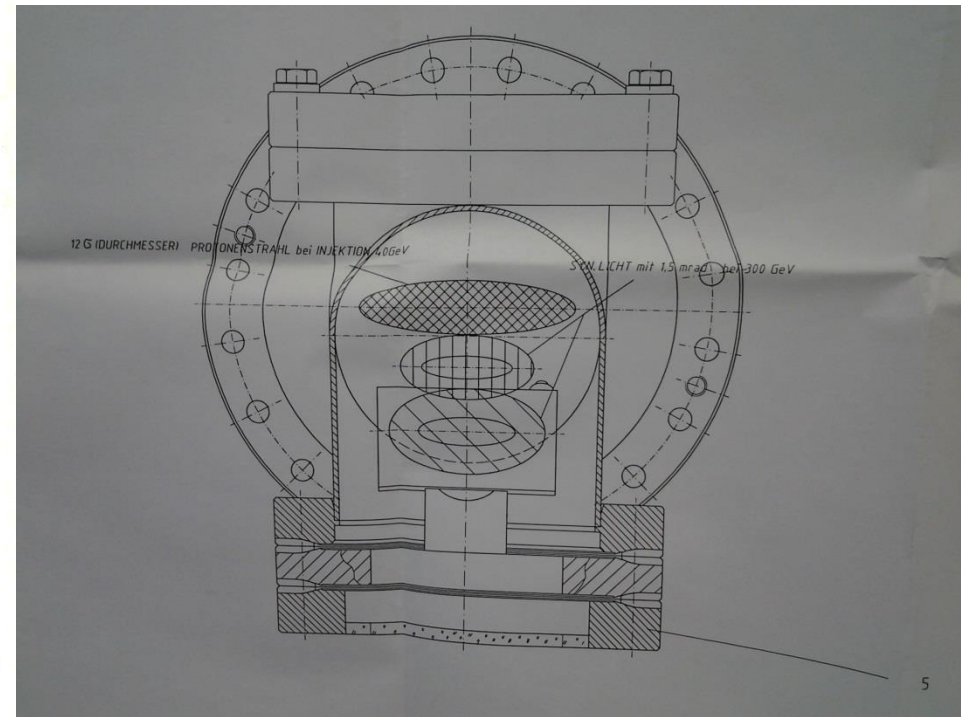
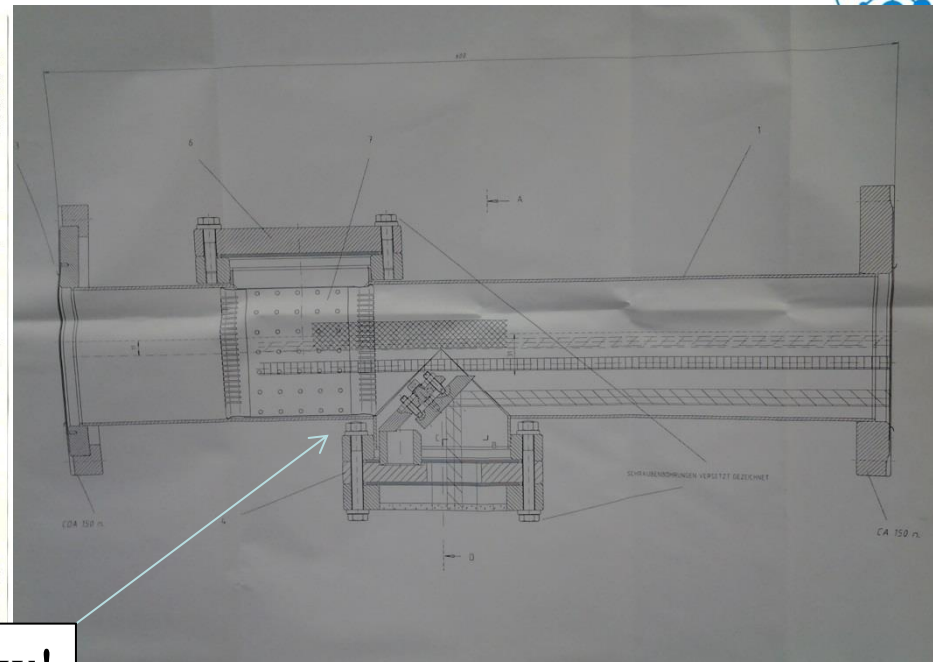
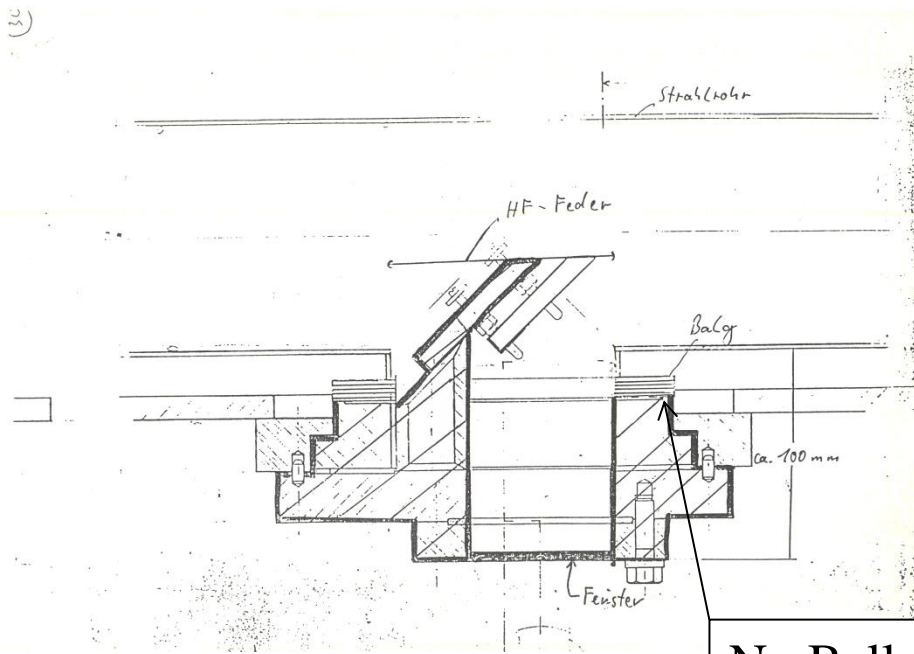


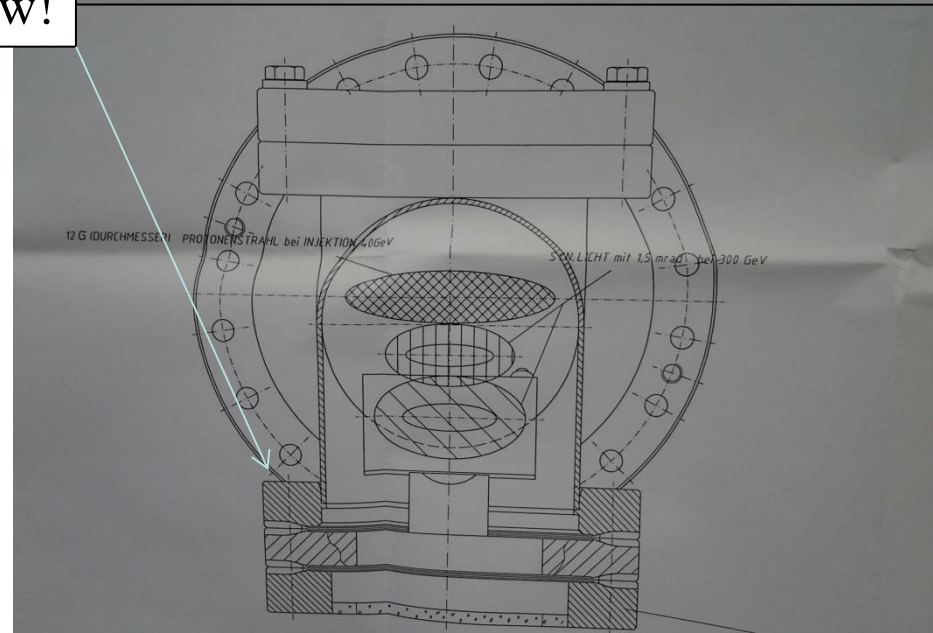
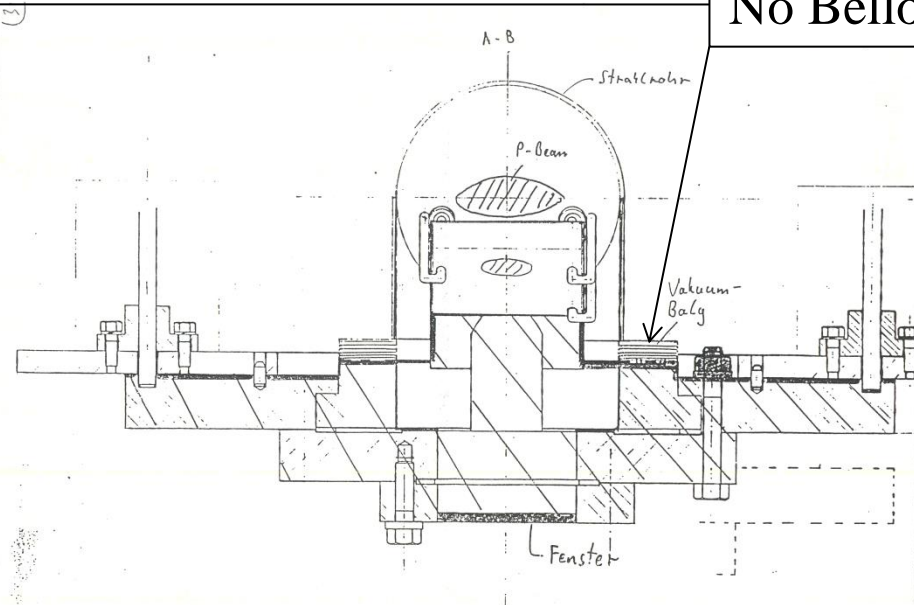
Abb. 2 Durchmesser des p-Strahles und des SR-Lichtes bei 80,5m



Find the differences



No Bellow!



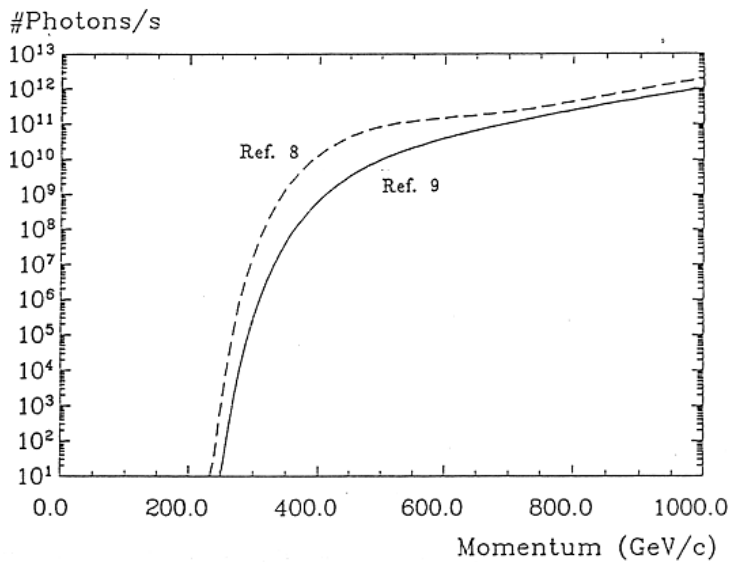


Figure 5: Intensity of the light from the 'Edge Effect'

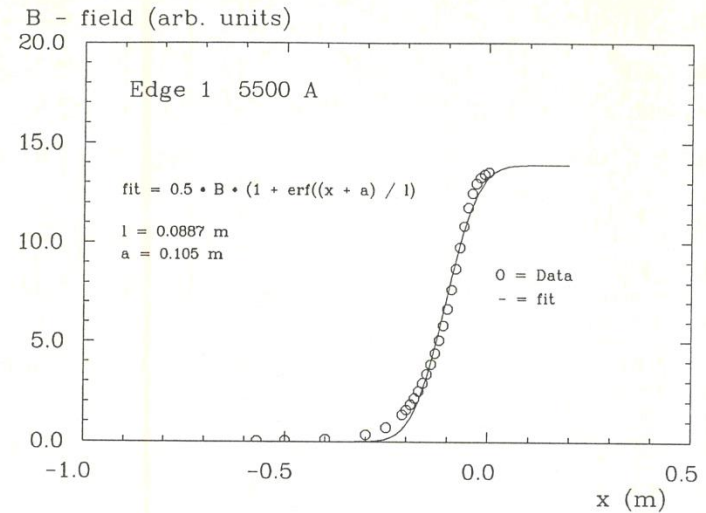


Abbildung 1: Edge 1 bei 5500 A mit Fit

Ref 8: R. Coisson; Angular-Spectral Distribution and Polarization of Synchrotron Radiation from a short Magnet

Physical Review A, Vol 20, Nr. 2, p. 524-528

Ref 9: W.Hain; Synchrotronstrahlung, 'Edge-Effekt'

Internal PKTR-Note No. 52, 1990

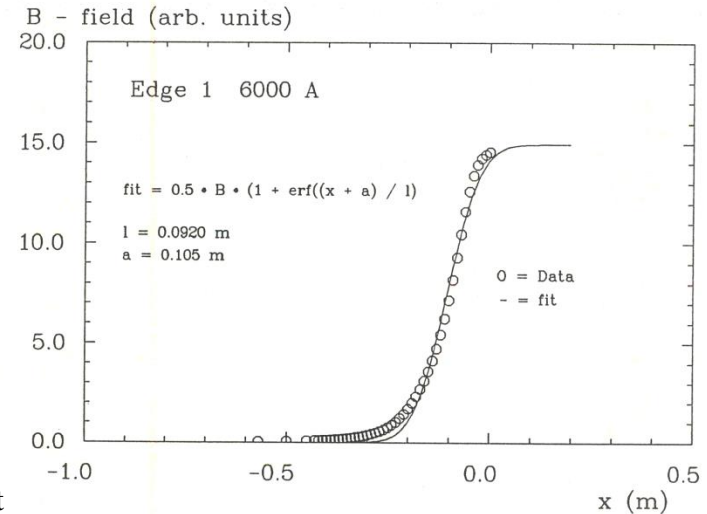
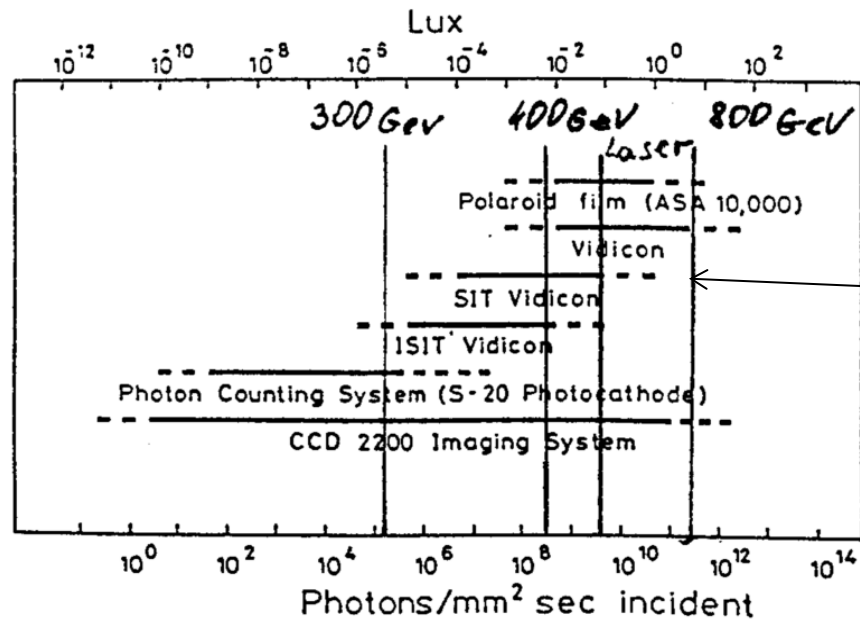


Abbildung 2: Edge 1 bei 6000 A mit Fit

“Intensity of the Synchrotron Light

An exact derivation of the theory of the edge effect gives a slightly different result than reported in Ref. 8. The expected detectable intensity is shown in Fig. 5. The minimum intensity which is needed to give an usual picture of the beam is about 10^7 photons/s. This will give a first light spot at about 300 GeV/c at a current of 160 mA. The intensity depends linear on the beam current.”



Needs filters

TYC 9 A (1)

SIT-Restlichtkamera

0511/8606357
457

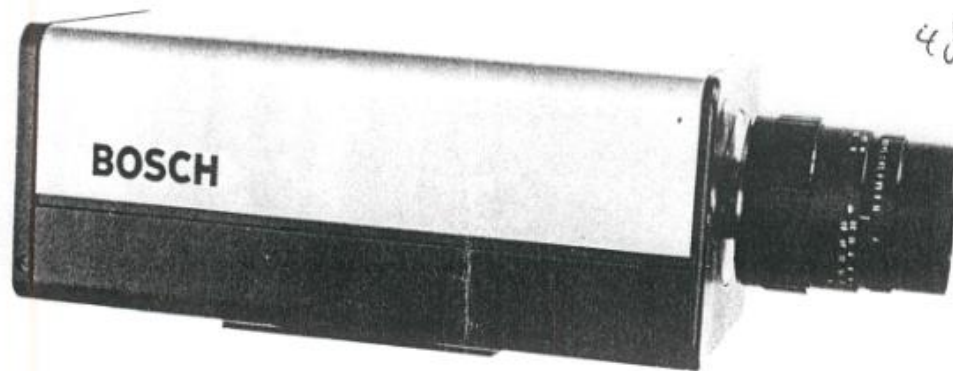
~~Gesichte~~
Augen Unger

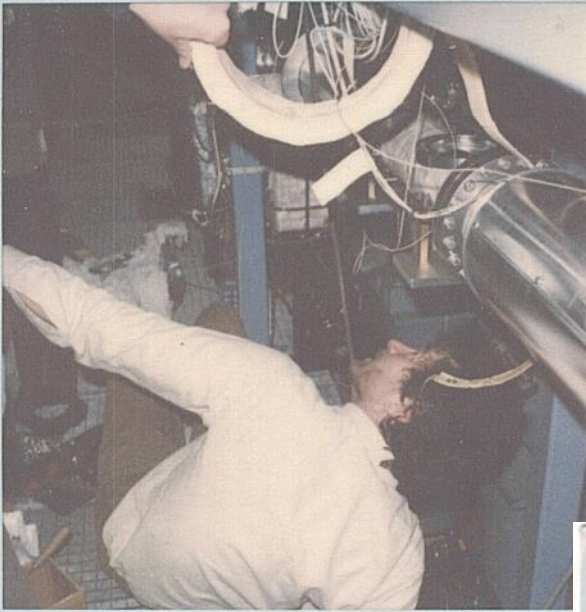
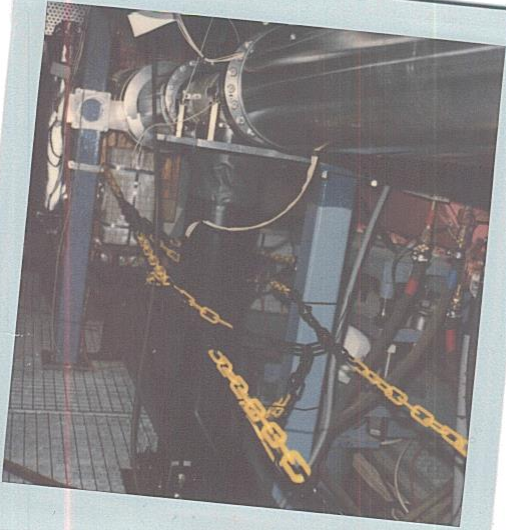
Kamera für Rohre

5200 DM + 350 DM Netzteile

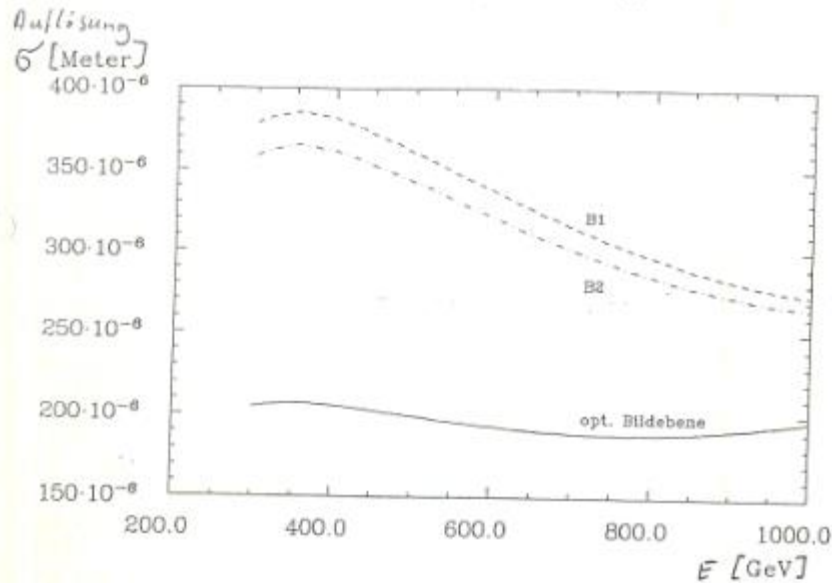
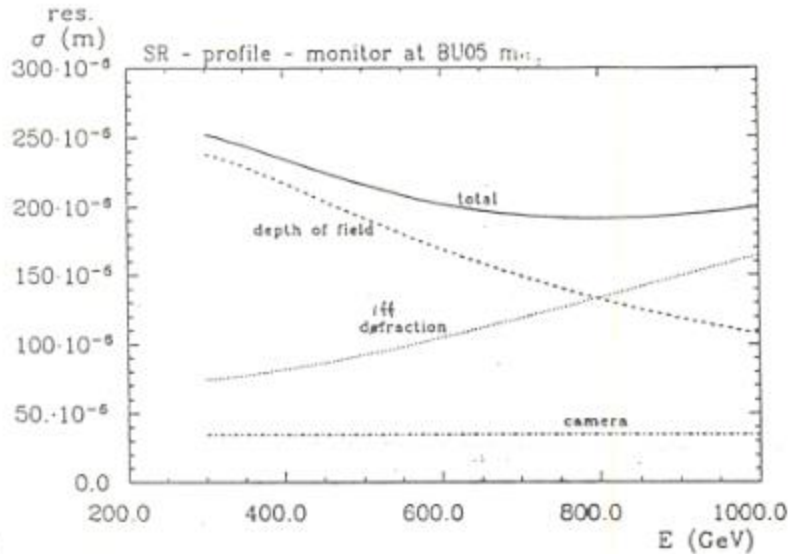
4804 (1) · 1 = 9770

λQ 1337 = 7.800





4: Expected resolution



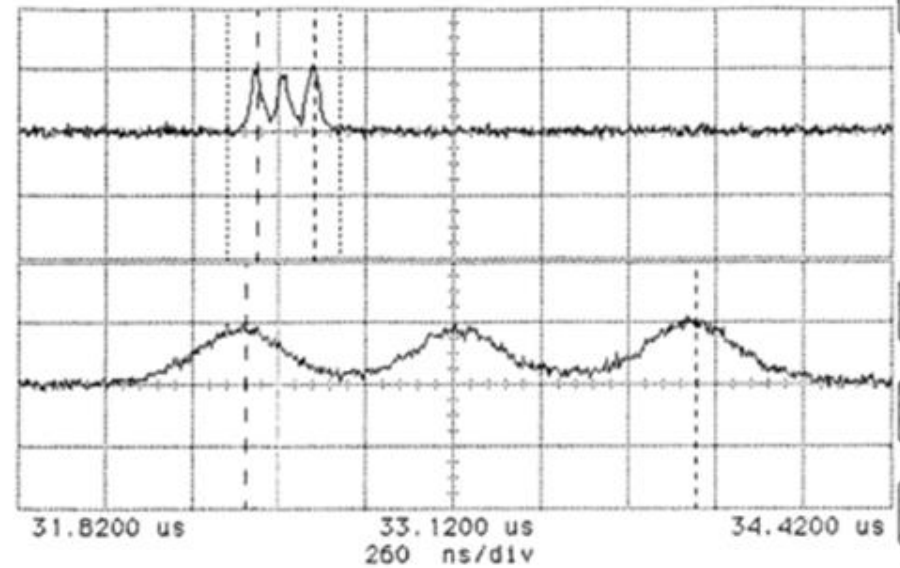
4.3: Auflösung bei verschiedenen Bildebenen (edge - effect am BU05)

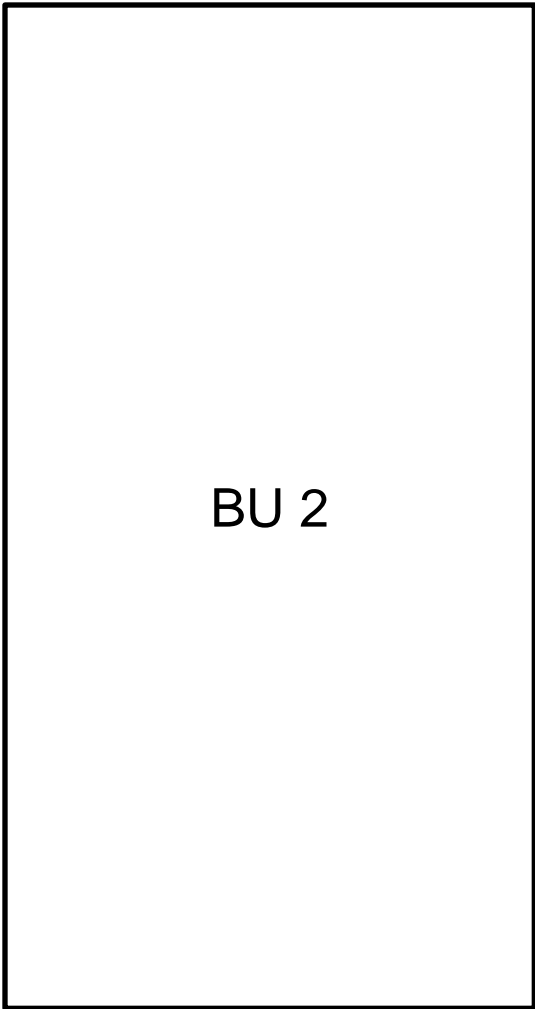
Focus = 3 m ; Gegenstandsweite = Entfernung Cere 2 - Linse = 10 m

Test of the optics:

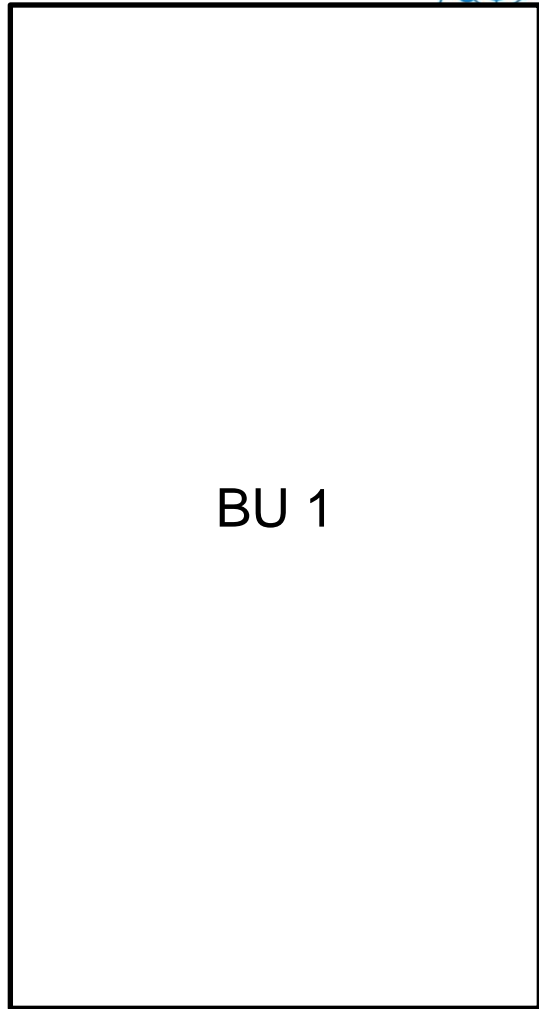
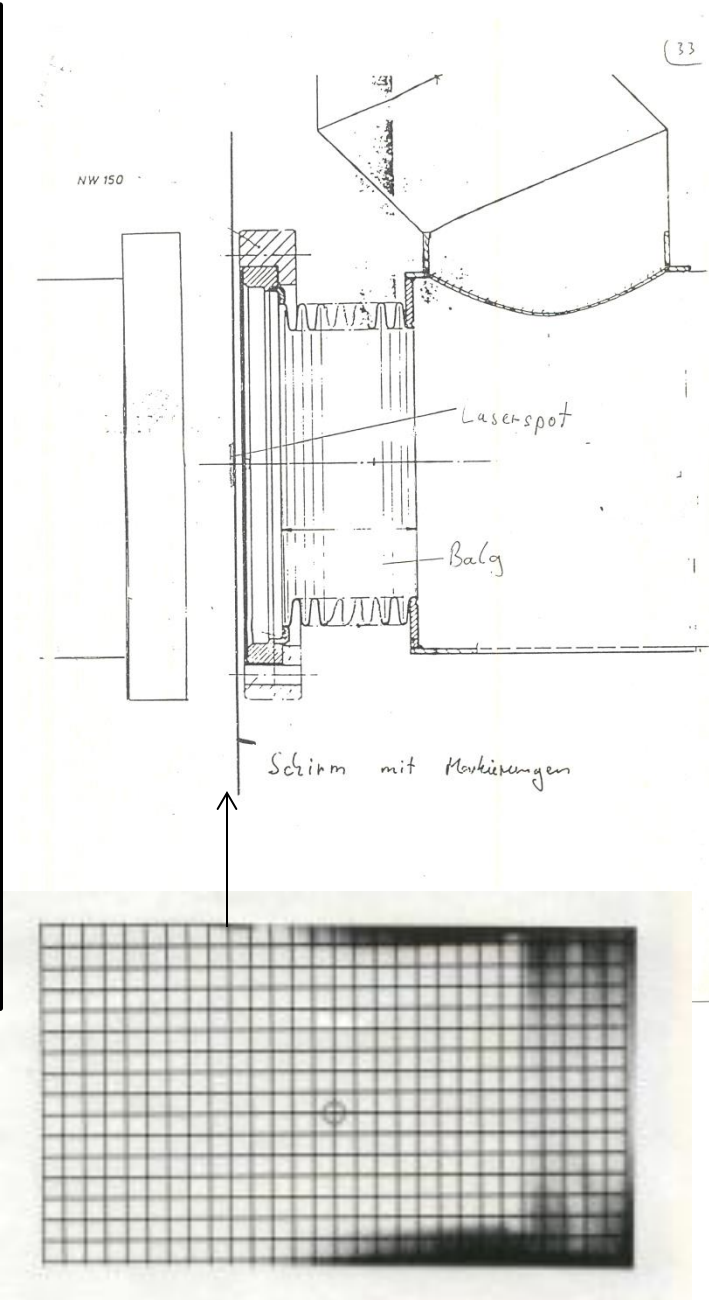
Using a 1.7 mrad laser the optics and cameras can resolve three 250 μm slits of 500 μm distance

hp running





BU 2



BU 1

5: First measurements with beam



okay

Das Füllen von 90 Bunchen bereitet große Schwierigkeiten. Wie anschließen uns die Intensität in DESY zu reduzieren. Man speizt 3x3mA. Das geht so stark. Man erspart sich den Strahl. Am Morgen sind wir etwa 300 GeV aufgetreten. Werden jedesmal erfolgreich mit positiven horizontalen Septupolströmen bekämpft.

5.00 7.4 mit Betriebsmodus Elektroneninjektion vorbereitet. Juni 1993

PR-Weg heruntergefahren.

EL-Weg massiert

Keine Elektronen von PETRA

Senderstromversorgung muß repariert werden

Horizontale Emittanz mit WIRE-SCANNER

$E_{xN} = 13.1 \mu\text{m mrad}$

Vertikale

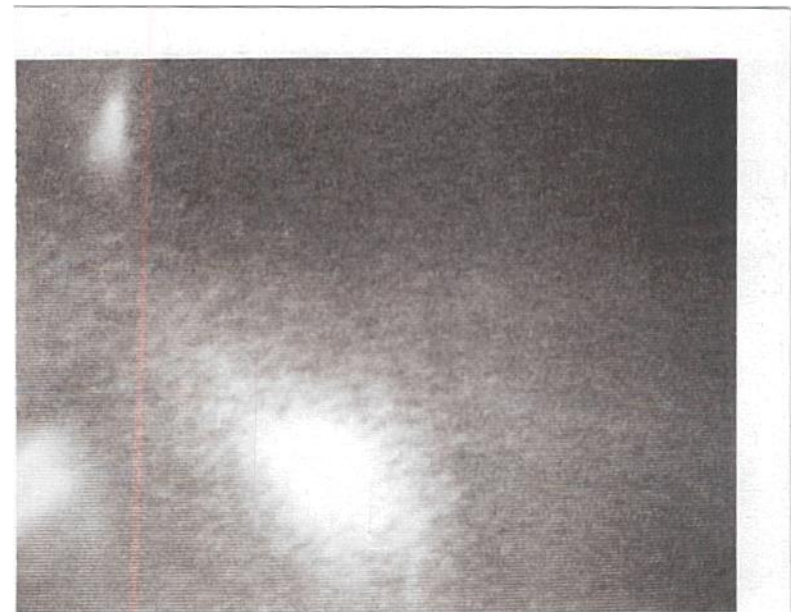
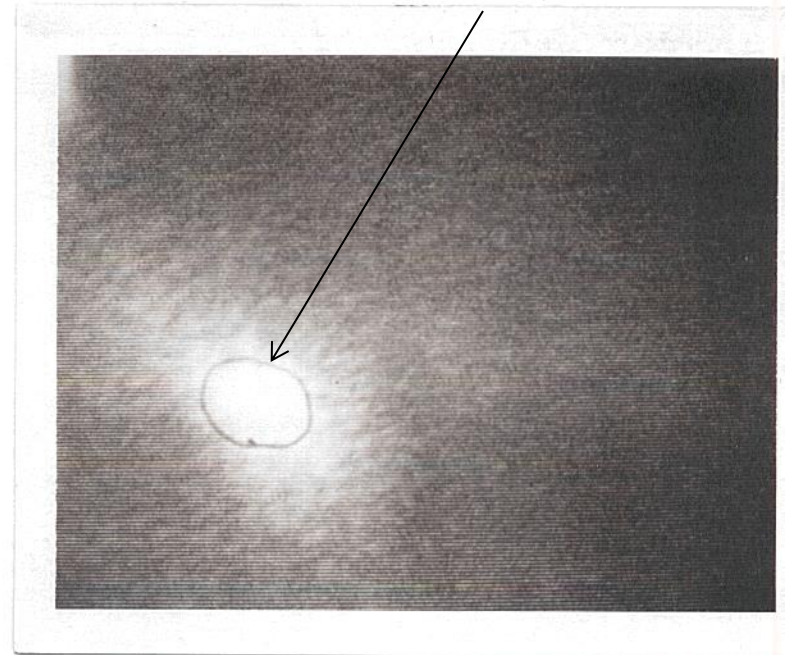
$E_{zN} = 9.1 \mu\text{m mrad}$



Ist das Synchrotronlicht von den Protonen?

ja, es ist!

M. Helt



Juni 1993 (Hera Logbook)

6: Improvements

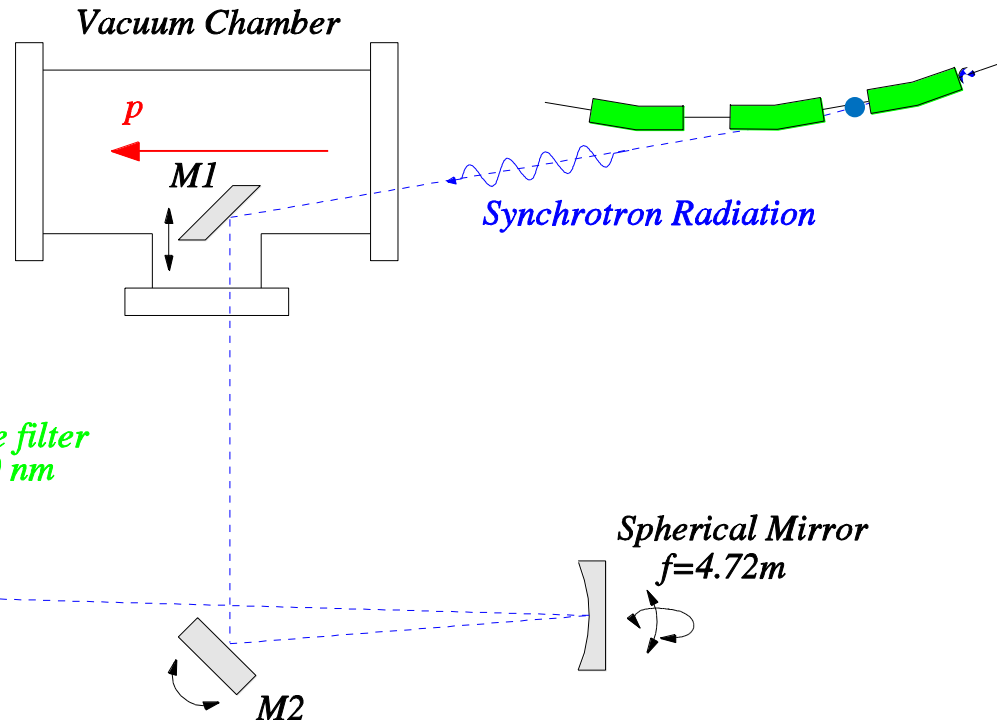
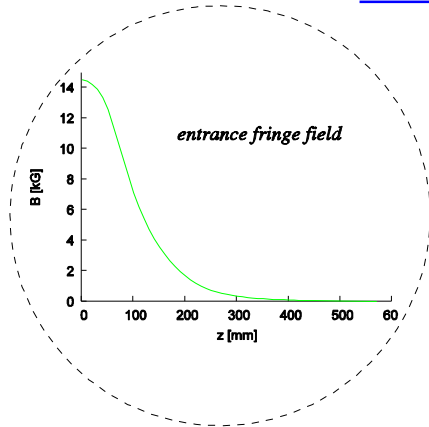
Setup changes in 2003+05 (G. Kube, Ch. Wiebers):

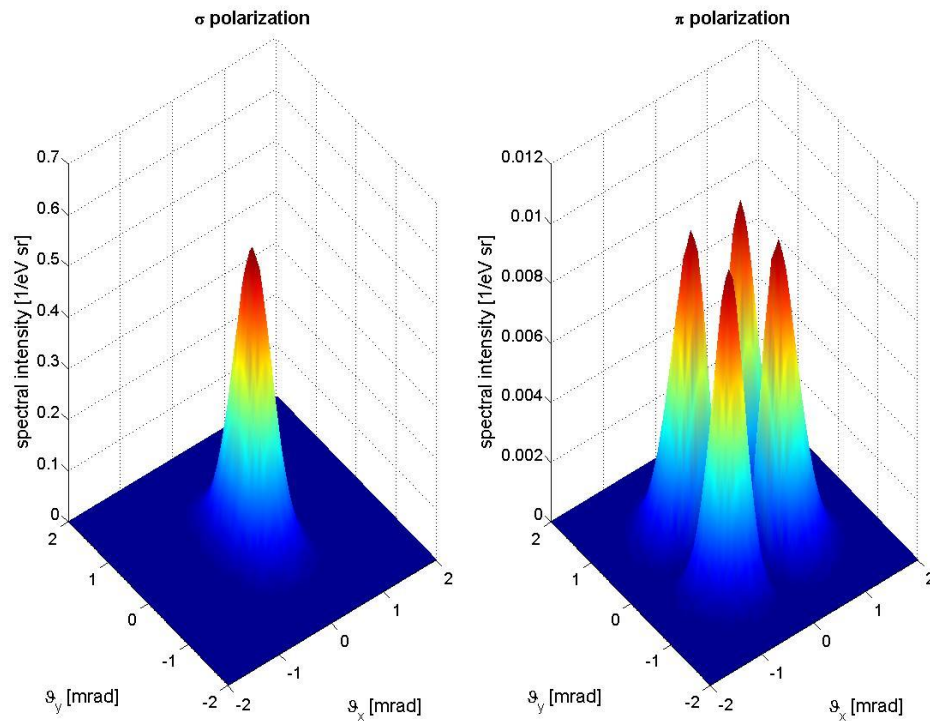
Improving optic (avoids reflections)

Moveable mirrors (bellow!) and camera (2006)

Filters

CCD Camera (JAI CV-M300E) + PMT





Compared to the intensity of the σ polarization component the π component is less by more than one order of magnitude. Nevertheless for purposes of beam diagnostics the contribution of the latter polarization component should be avoided because the broader angular distribution leads to an increase of diffraction broadening, thus spoiling the spatial resolution of a beam profile monitor... The resolution broadening contributions determined are

$$\Delta\sigma_x \approx 84 \mu m, \quad \Delta\sigma_y \approx 144 \mu m.$$

6: Improvements

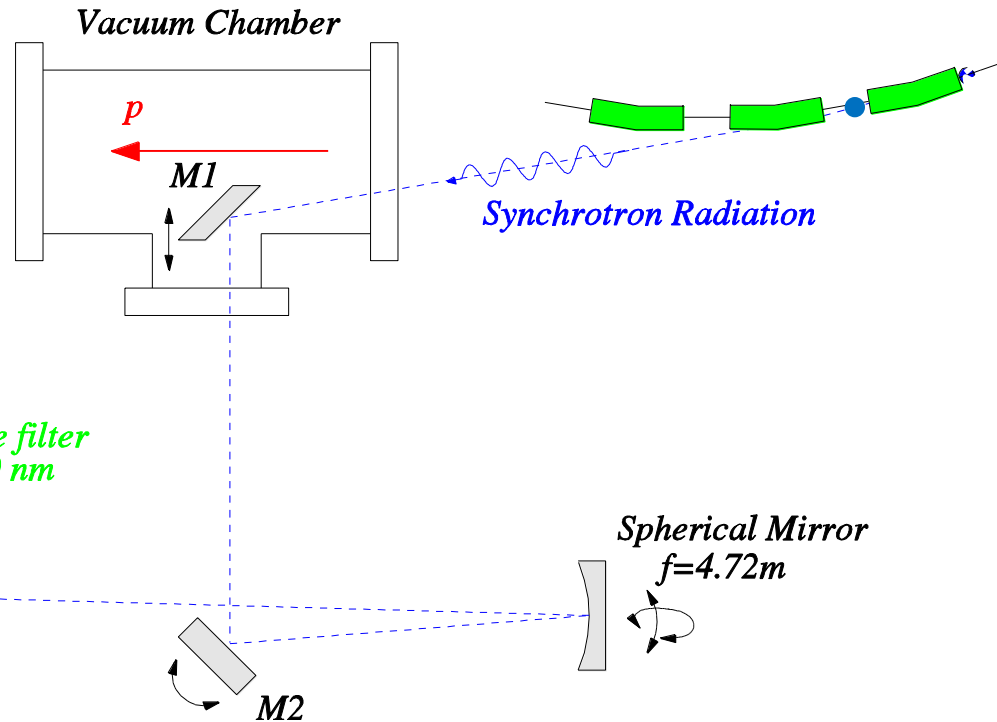
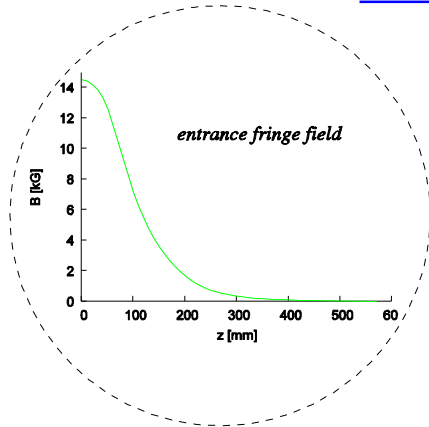
Setup changes in 2003+05 (G. Kube, Ch. Wiebers):

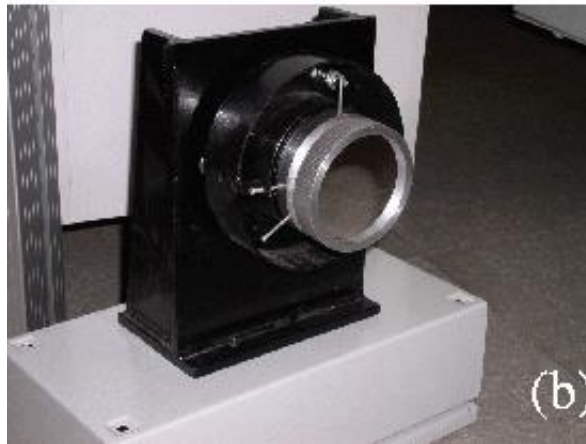
Improving optic (avoids reflections)

Moveable mirrors (bellow!) and camera (2006)

Filters

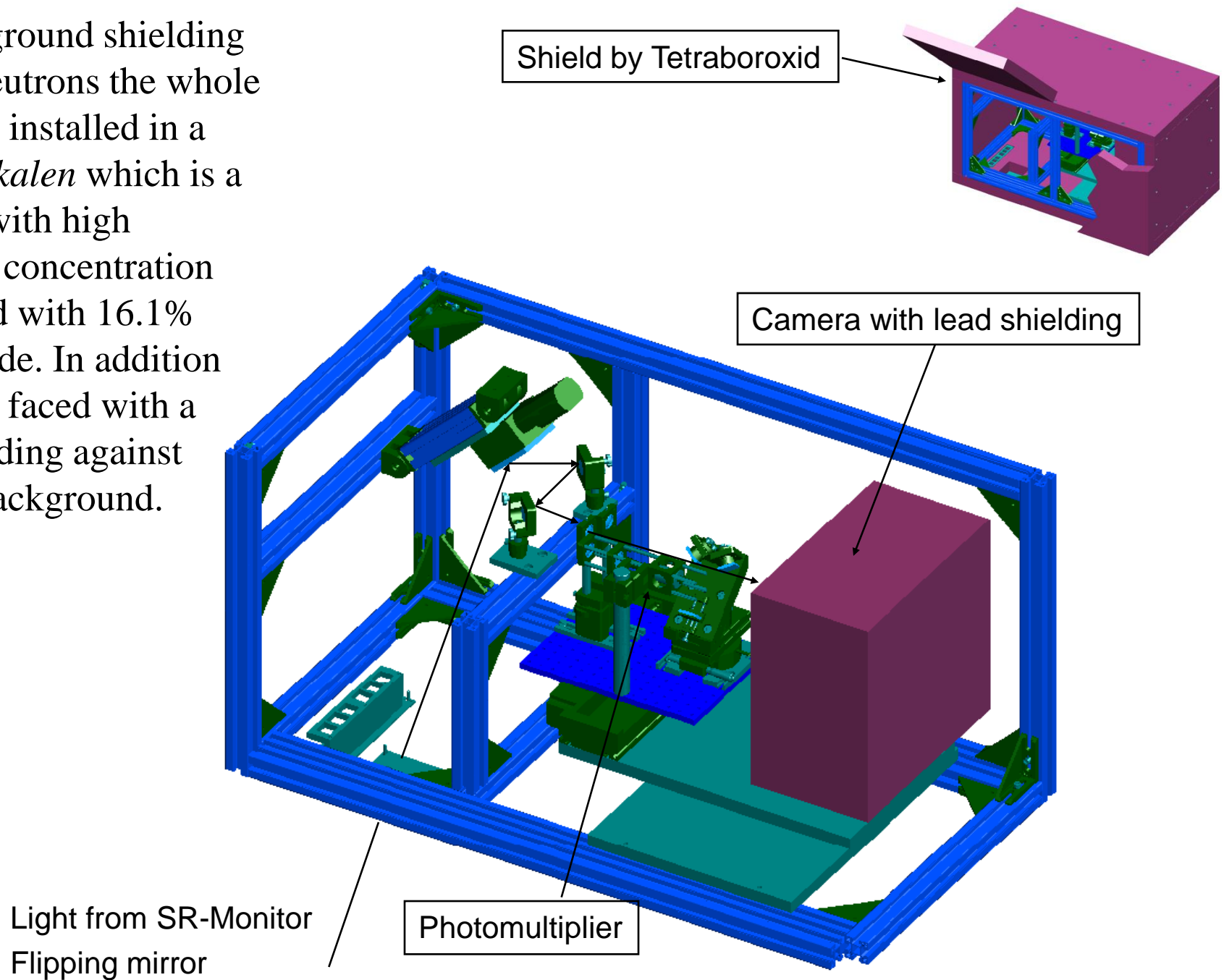
CCD Camera (JAI CV-M300E) + PMT



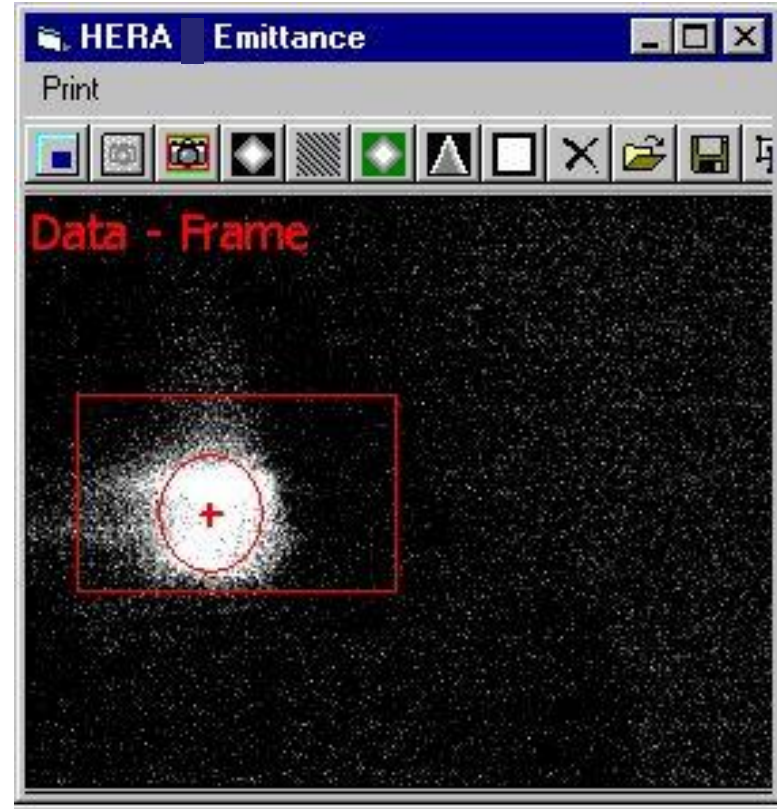
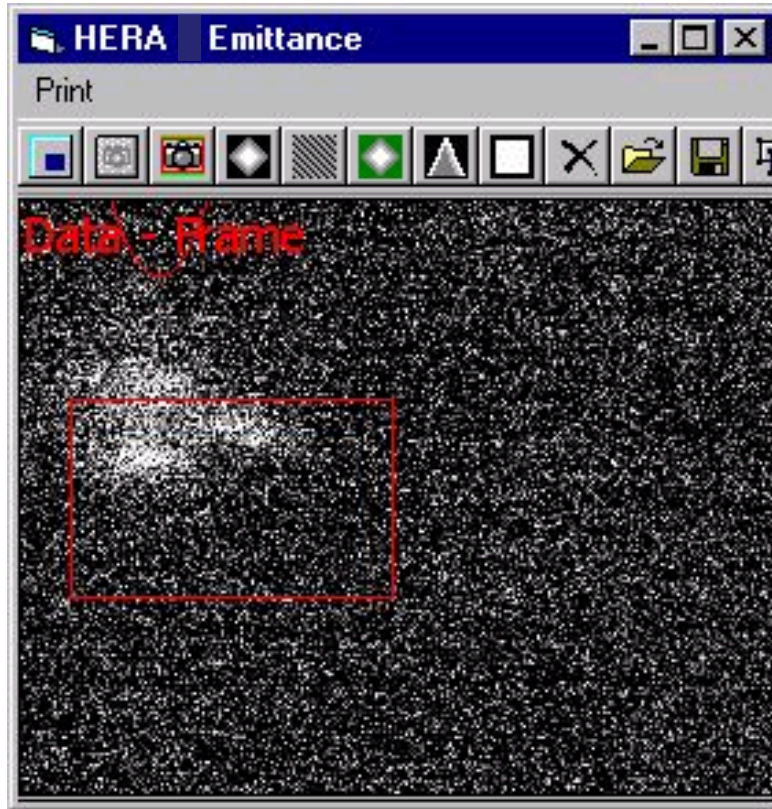


Photos of the monitor setup. (a) View in the beam tube on the extraction mirror. (b) Setup of the spherical mirror. (c) The new detector setup. The camera together with a photomultiplier are mounted on an alignment system which consists of three stepper motors used to adjust the detectors in three translational degrees of freedom. Two filter wheels in front of the detectors allow to attenuate the intensity and to select the polarization direction.

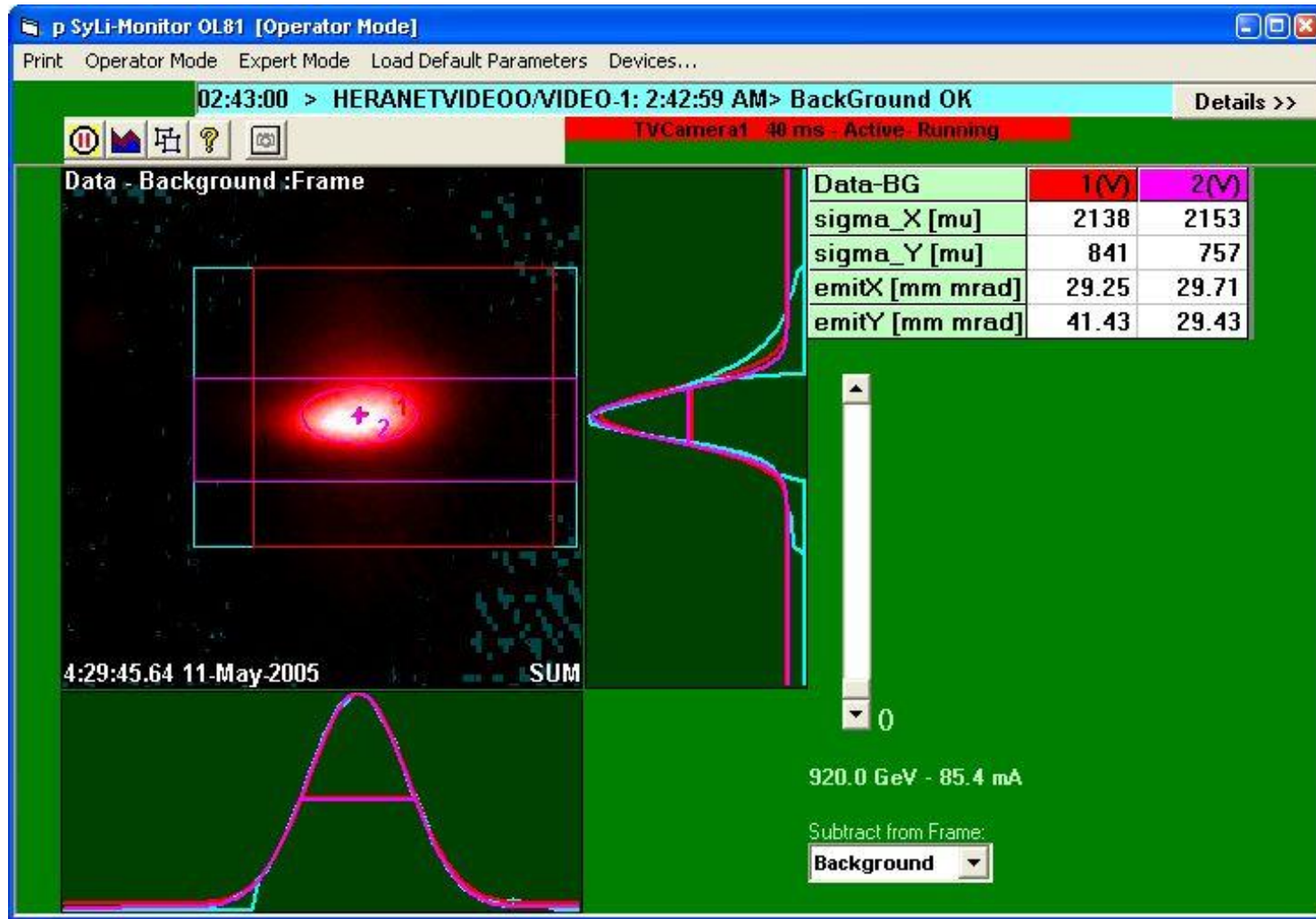
For background shielding against neutrons the whole setup was installed in a box of *Tekalen* which is a material with high hydrogen concentration and doped with 16.1% boron oxide. In addition the box is faced with a lead shielding against gamma background.

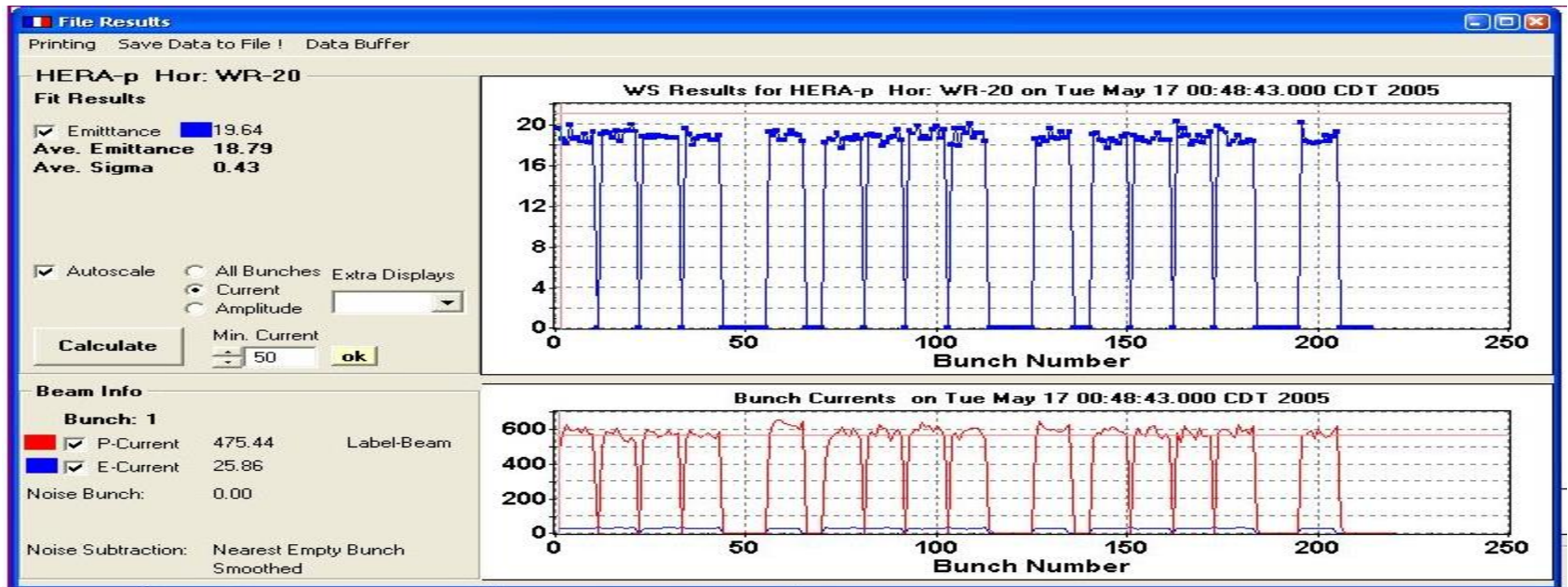
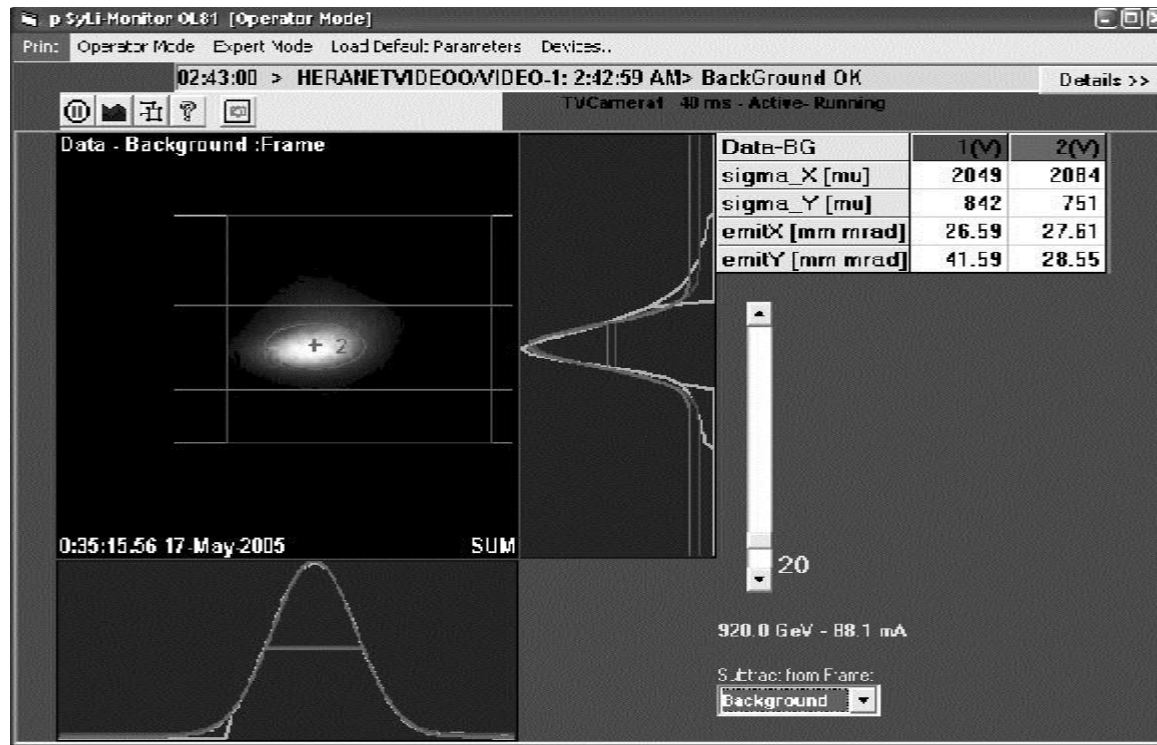


7: First measurements with new setup



8: After some optimisation (moveable!): A real beam profile!!!






p SyLi-Monitor OL81 [Operator Mode]

Print Operator Mode Expert Mode Load Default Parameters Devices...

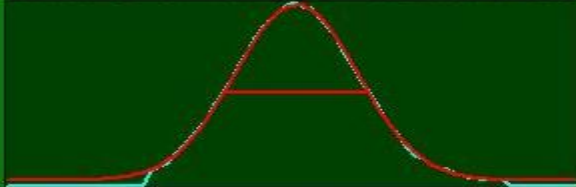
No messages Details >>

TVCamera1 40 ms - Active - Running

Data - Background :Frame



7:05:20.04 4-Jun-2005



Data-BG	1(M)
sigma_X [mu]	2447
sigma_Y [mu]	882
emitX [mm mrad]	39.35
emitY [mm mrad]	47.76

920.0 GeV - 45.8 mA

Subtract from Frame:
Background



File R

Printing Save Data to File ! Data Buffer

HERA-p Hor: WR-20

Fit Results

Emittance ■ 33.73
 Ave. Emittance **35.42**
 Ave. Sigma **0.59**

Autoscale
 All Bunches Extra Displays
 Current
 Amplitude

 Min. Current:

Beam Info

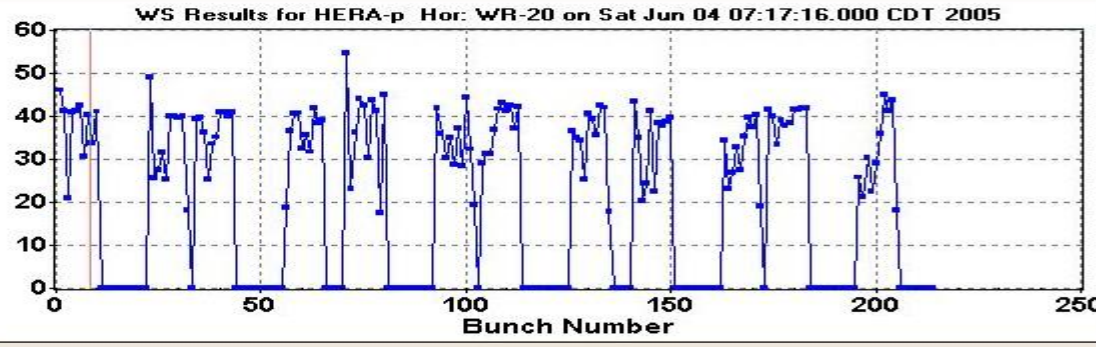
Bunch: 9

P-Current 376.66 0.00
 E-Current 32.38

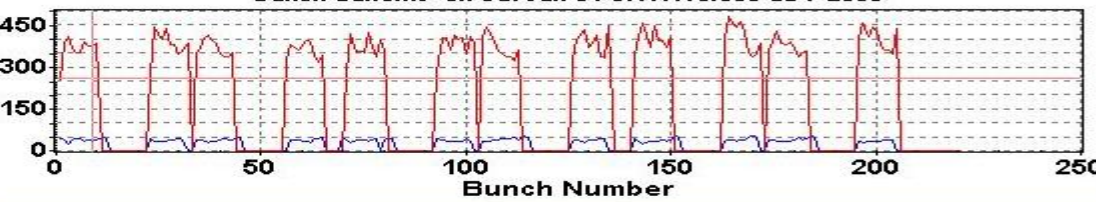
Noise Bunch: 13.00

Noise Subtraction: Nearest Empty Bunch Smoothed

WS Results for HERA-p Hor: WR-20 on Sat Jun 04 07:17:16.000 CDT 2005



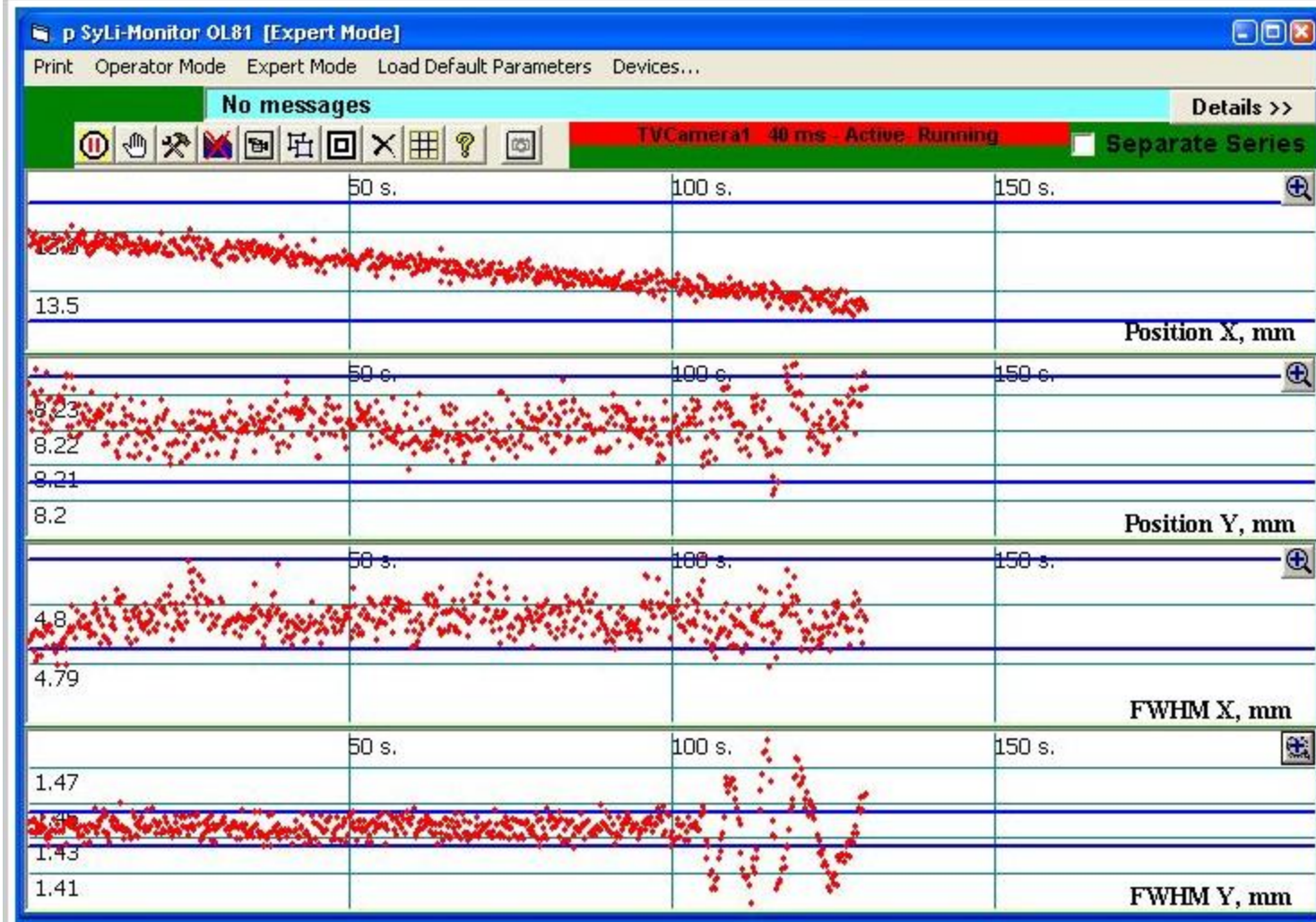
Bunch Currents on Sat Jun 04 07:17:16.000 CDT 2005



22.08.2005 04:46

Kube p SyLi-Monitor: Protonen fangen an zu schwingen ?

Collimators were moved to the beam

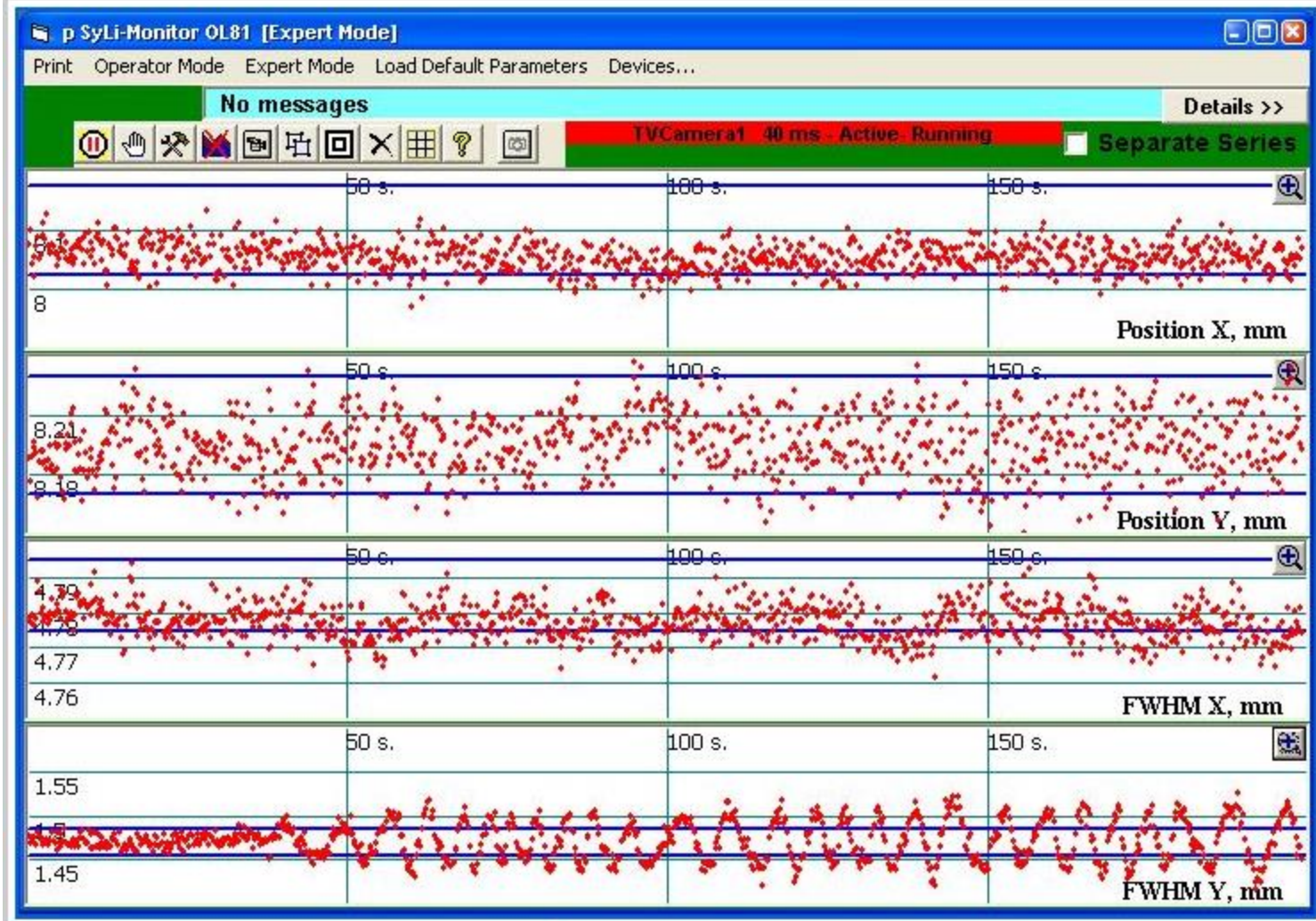


22.08.2005 08:22

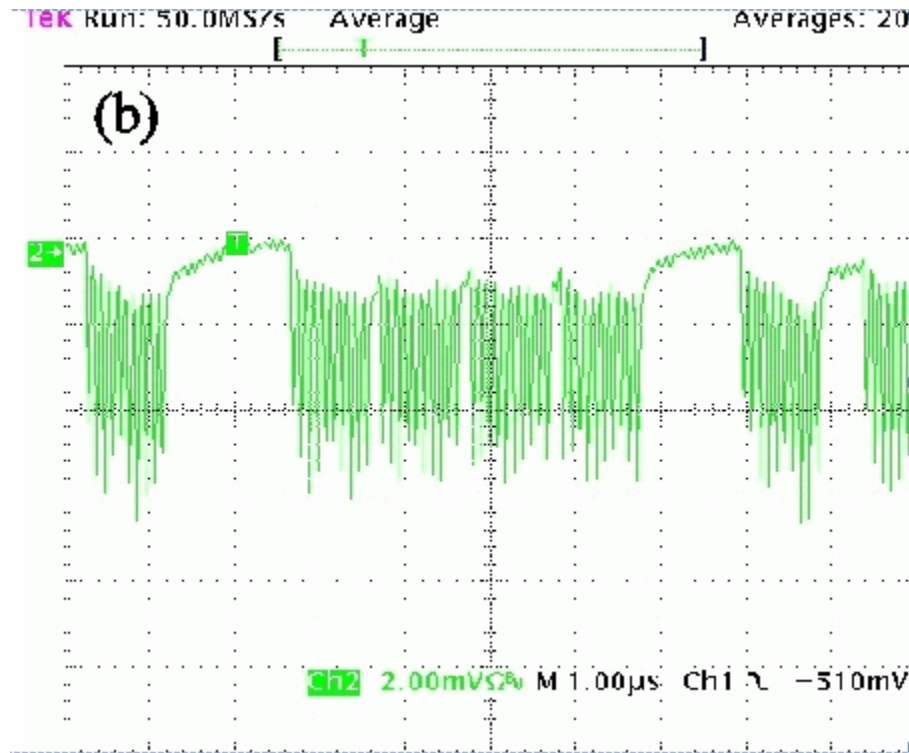
E. Kot

p-SyLi nach der Verschiebung des vertikalen Tunes.

Tau_p steigt aber auf 100h.



The bunch pattern (with PMT)



2006:

“After the improvements and the start up of HERA (with electrons) ... proton SR is already detected by the photomultiplier. The multiplier signals observed with an oscilloscope reproduce nicely the fill pattern of the HERA proton ring. However, the alignment procedure of the imaged beam spot onto the chip of the CCD camera through the optical telescope is still in process ...”

9 ... and here the story finds its final end.

Quite abrupt

07.03.2006 17:50 Kube Protonen SyLi-Monitor

Erster zarter Lichtschein auf Kamera gefaedelt.

Ist bislang zwar noch eine Reflektion, aber immerhin ein Signal, auf das man optimieren kann...

p SyLi-Monitor OL81 [Expert Mode]

Print Operator Mode Expert Mode Load Default Parameters Devices...

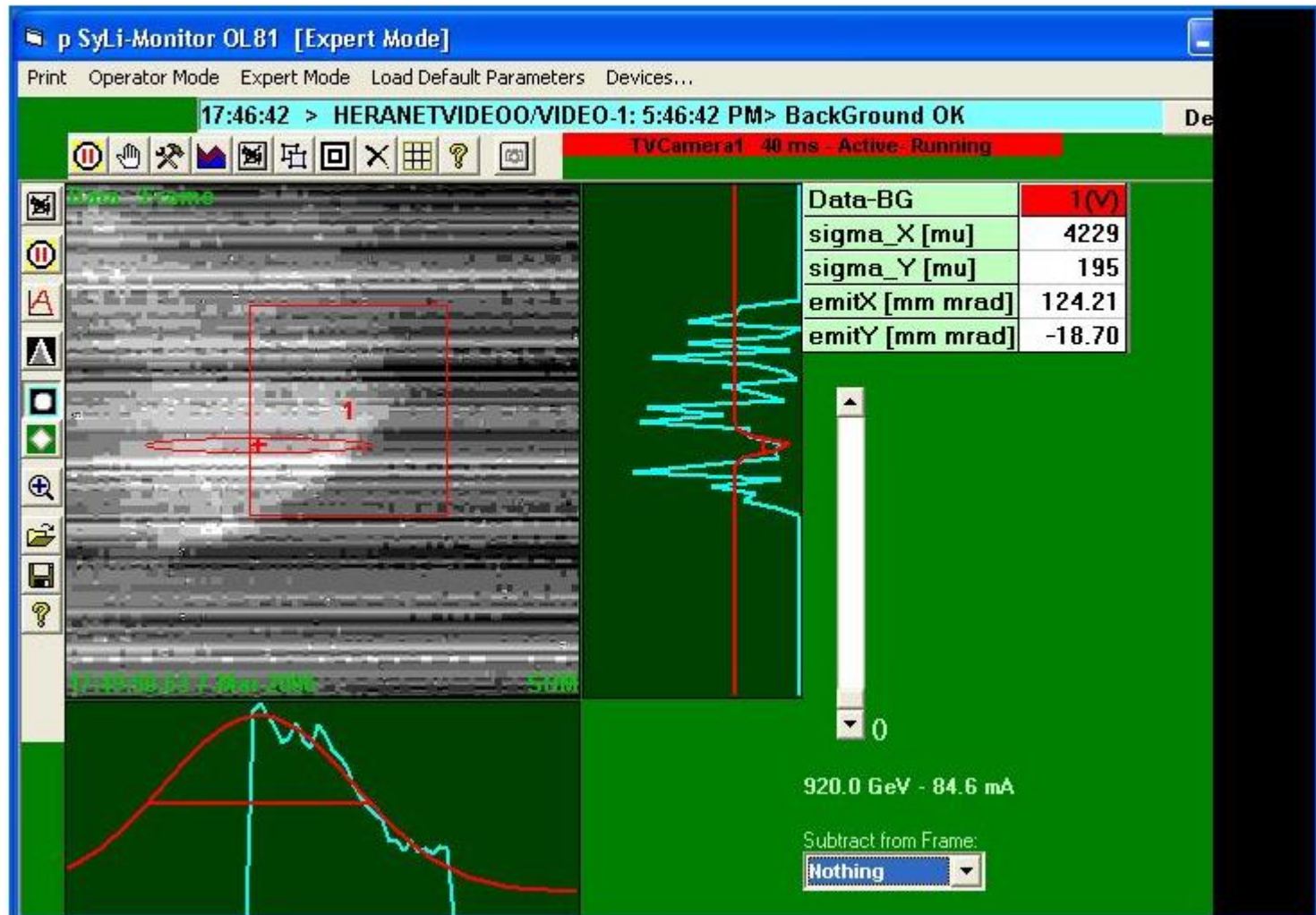
17:46:42 > HERANETVIDEO0/VIDEO-1: 5:46:42 PM> BackGround OK

TVCamera1 40 ms - Active - Running

Data-BG	1 (M)
sigma_X [mu]	4229
sigma_Y [mu]	195
emitX [mm mrad]	124.21
emitY [mm mrad]	-18.70

920.0 GeV - 84.6 mA

Subtract from Frame:
Nothing



The screenshot displays the 'p SyLi-Monitor OL81 [Expert Mode]' interface. It features a central video frame showing a noisy image with a red rectangular box and a red ellipse overlaid. To the right of the video frame is a histogram with a red vertical line. Below the video frame is a plot showing a red curve and a cyan line. The interface includes a menu bar with options like 'Print', 'Operator Mode', and 'Expert Mode'. A status bar at the top shows the time '17:46:42' and the camera status 'TVCamera1 40 ms - Active - Running'. A data table on the right lists parameters such as 'sigma_X [mu]', 'sigma_Y [mu]', 'emitX [mm mrad]', and 'emitY [mm mrad]'. At the bottom, it shows the beam energy '920.0 GeV - 84.6 mA' and a 'Subtract from Frame' dropdown menu set to 'Nothing'.

The End

Thanks to G. Kube for many information