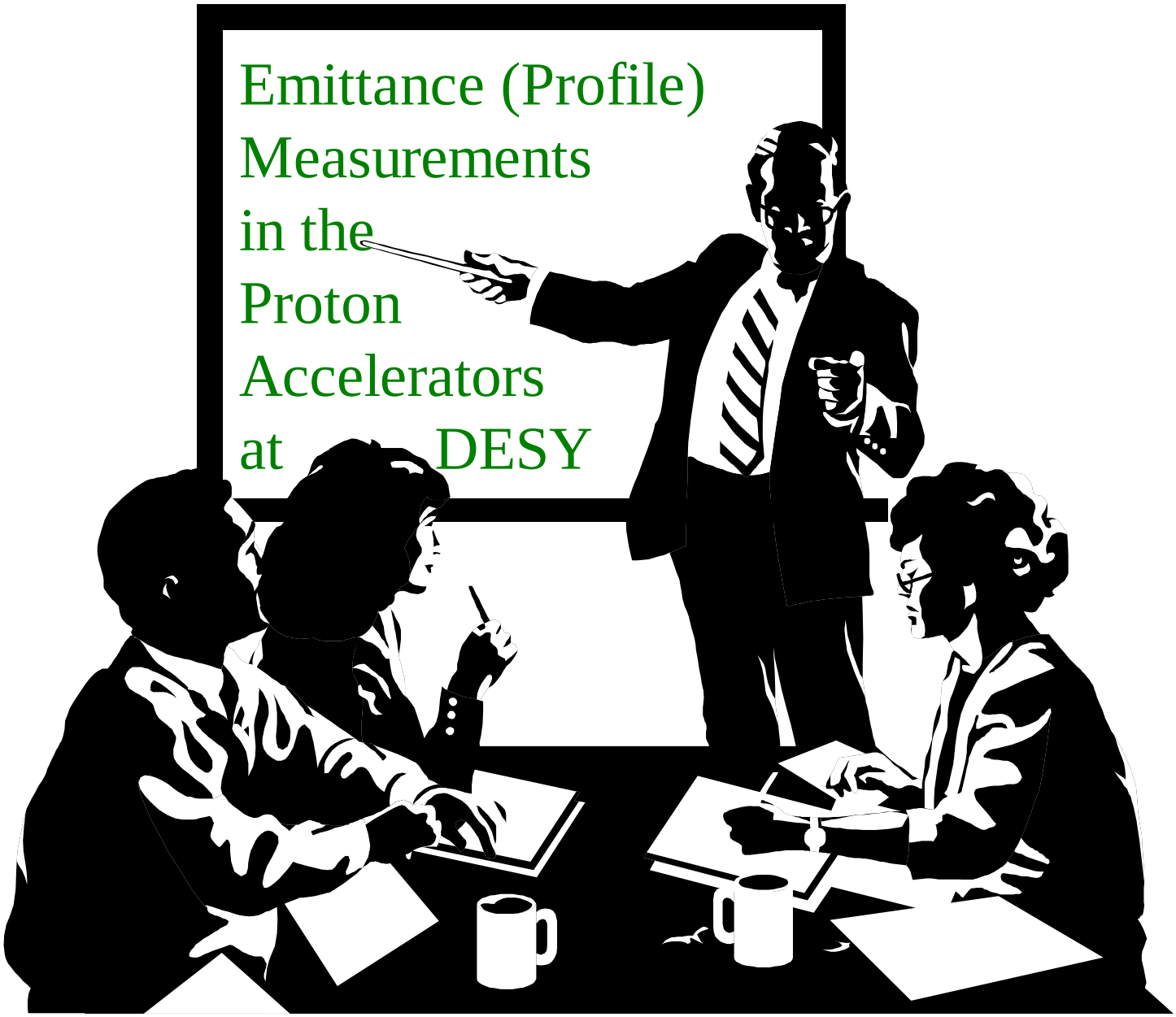
Emittance (Profile) Measurements in the Proton Accelerators at DESY



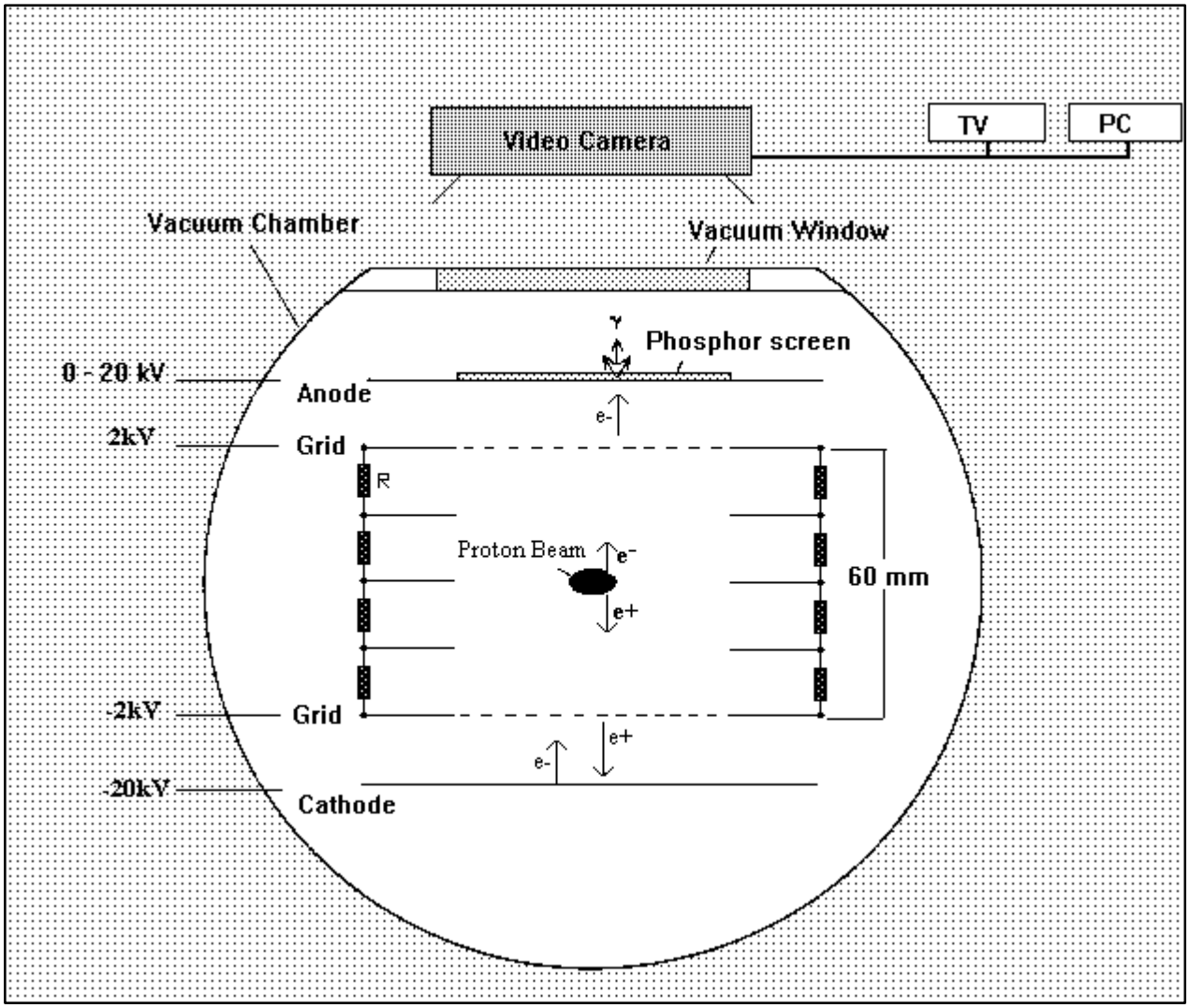
Kay Wittenburg, MDI

Deutsches Electronen Synchrotron
Hamburg, Germany

Profile Monitors in the Proton Accelerators

- DESY III:
  - » Wire Scanner, very old and new
  - » Residual Gas Ionization (Prototype)
- PETRA II:
  - » Residual Gas Ionization
  - » New Wire scanners (LEP type)
- HERAp:
  - » Residual Gas Ionization
  - » Wire Scanners, old and new
  - » (Synchrotron Radiation)

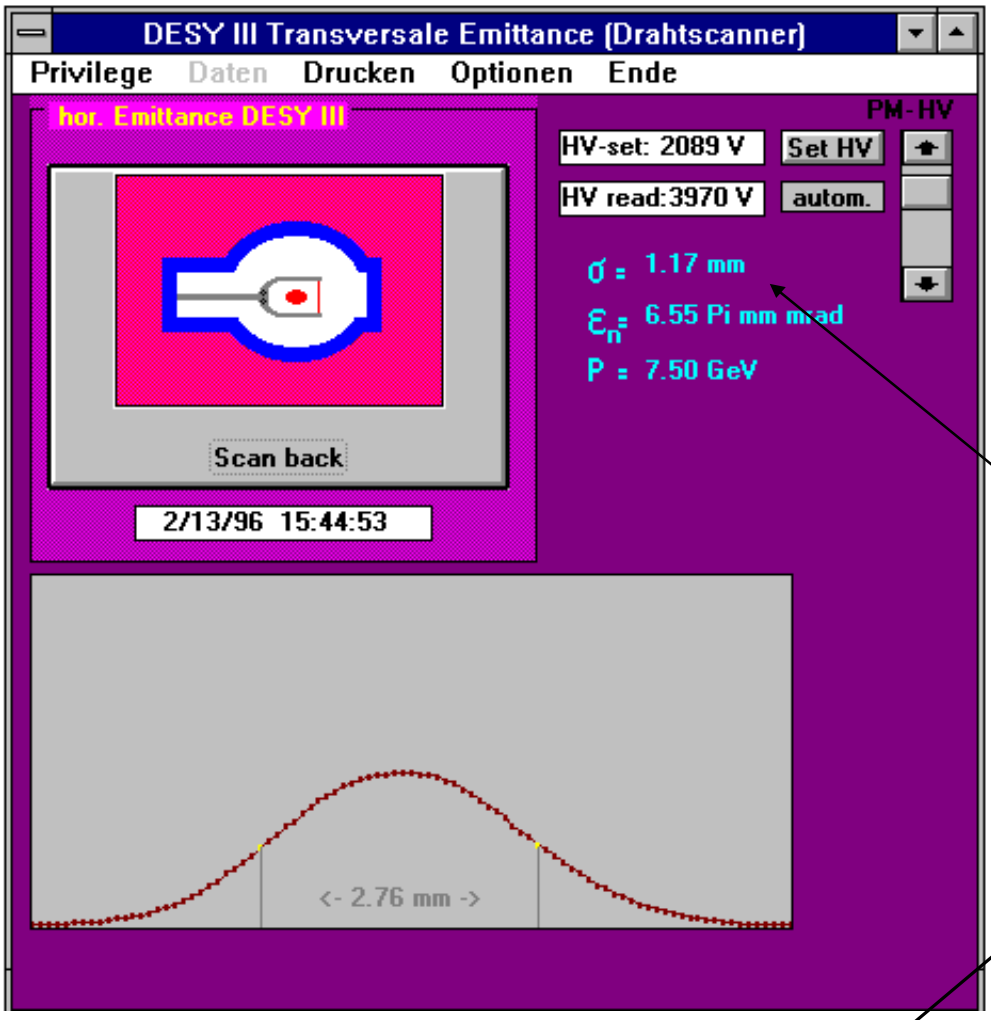
Residual Gas Ionization Profile Monitor in DESY III



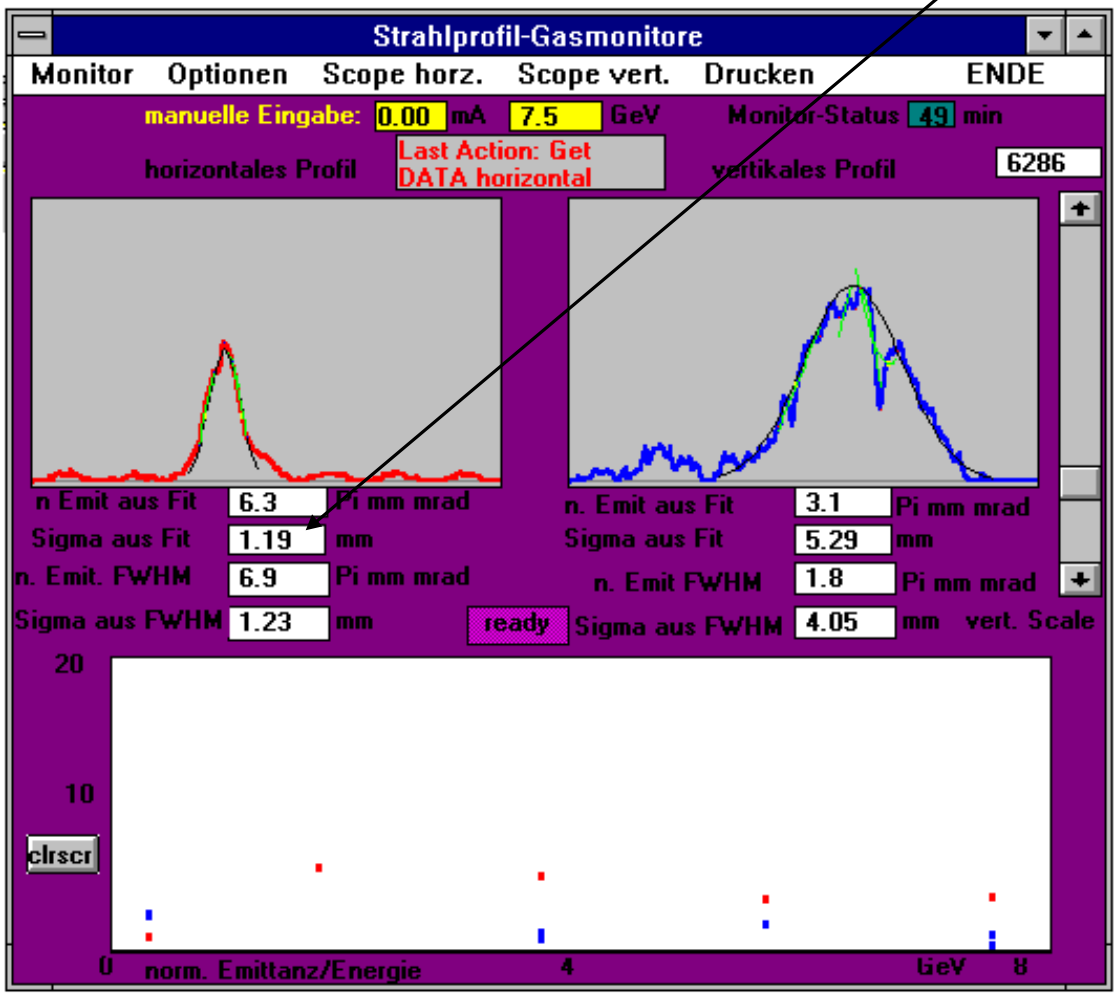
- Prototype with no MCP
- Amplification by SIT Camera

Residual Gas Ionization Profile Monitor in DESY III

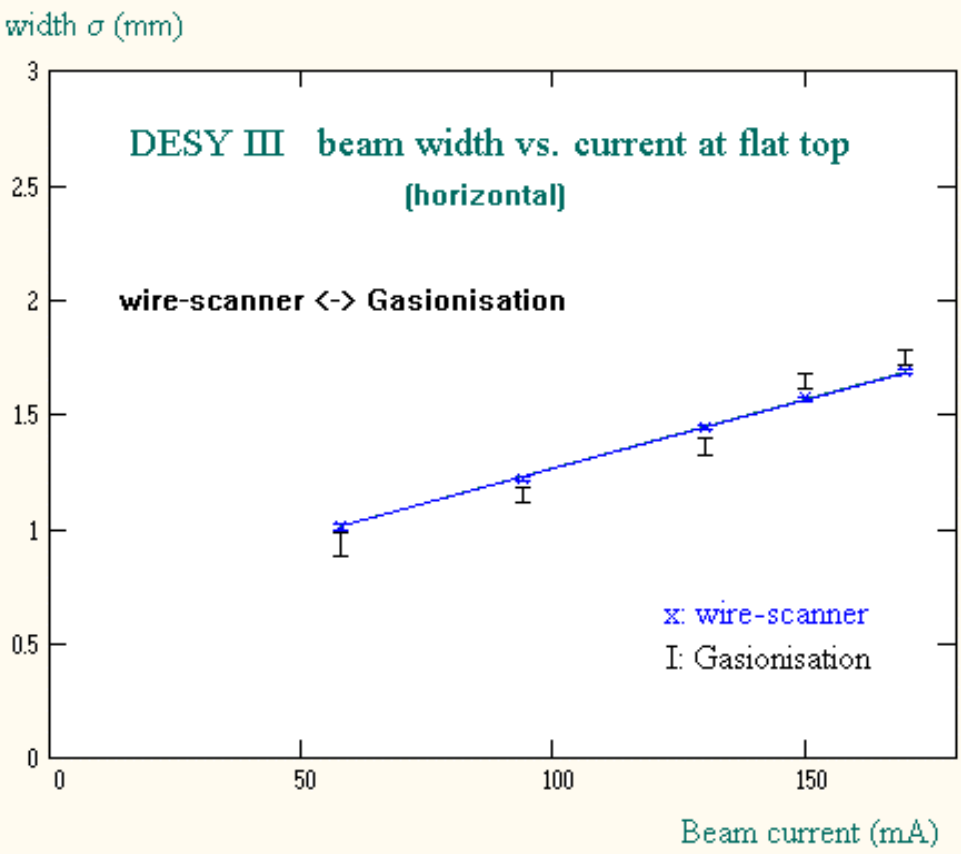
- Sensitivity at 10^{-8} mbar:
  - » reliable signals from 7-200 mA beam current using a sensitive SIT camera
- Resolution:
  - » Primary electrons
  - » Secondary electrons
  - » Ions
  - » Space charge
  - » Optic (electrons and light)
  - » Camera
  - » .....


DESY III Transversale Emittance (Drahtscanner)
Privilege Daten Drucken Optionen Ende
hor. Emittance DESY III
PM-HV
HV-set: 2089 V
Set HV
HV read:3970 V
autom.
σ = 1.17 mm
εn= 6.55 Pi mm mrad
P = 7.50 GeV
Scan back
2/13/96 15:44:53
<- 2.76 mm ->

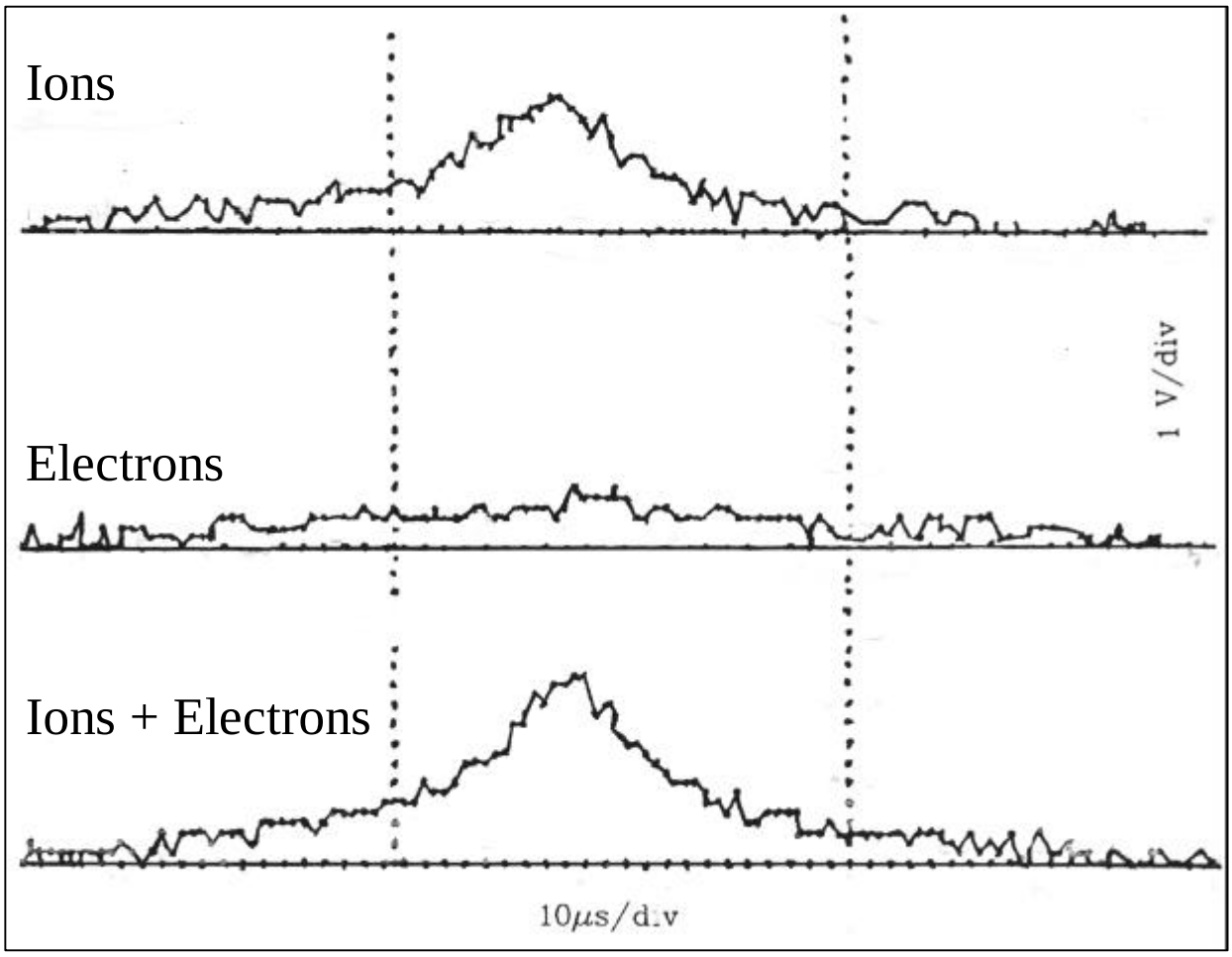
- 1.17mm
- 1.19 mm


Strahlprofil-Gasmonitore
Monitor Optionen Scope horz. Scope vert. Drucken ENDE
manuelle Eingabe: 0.00 mA 7.5 GeV
Monitor-Status 49 min
horizontales Profil
Last Action: Get DATA horizontal
vertikales Profil
6286
n Emit aus Fit 6.3 Pi mm mrad
Sigma aus Fit 1.19 mm
n. Emit. FWHM 6.9 Pi mm mrad
Sigma aus FWHM 1.23 mm
ready
n. Emit aus Fit 3.1 Pi mm mrad
Sigma aus Fit 5.29 mm
n. Emit FWHM 1.8 Pi mm mrad
Sigma aus FWHM 4.05 mm
vert. Scale
20
10
clrscr
0
norm. Emittanz/Energie
4
GeV
8

Residual Gas Ionization Profile Monitor in DESY III

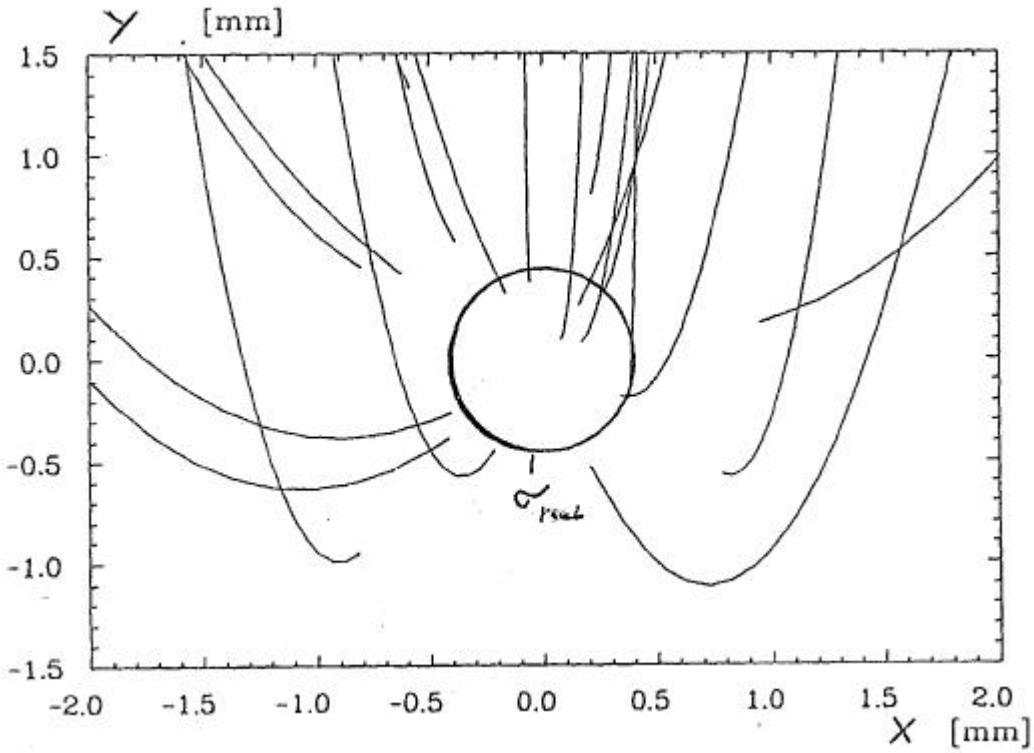


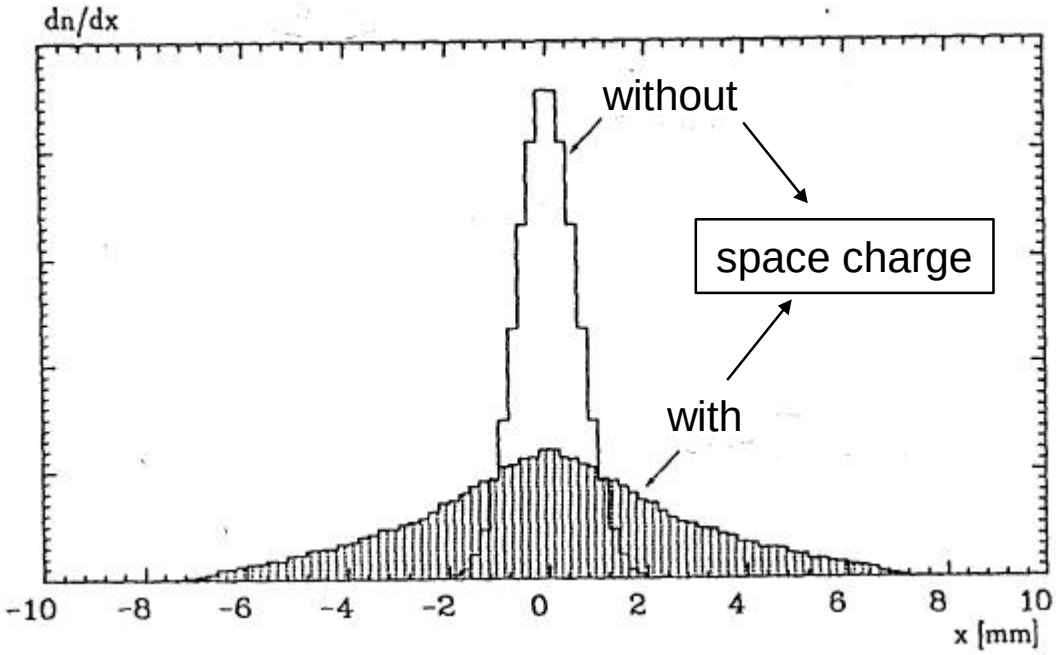
Residual Gas Ionization Profile Monitor



- **The "light" electrons are much more sensitive to the space charge of the beam than the "heavy" ions**

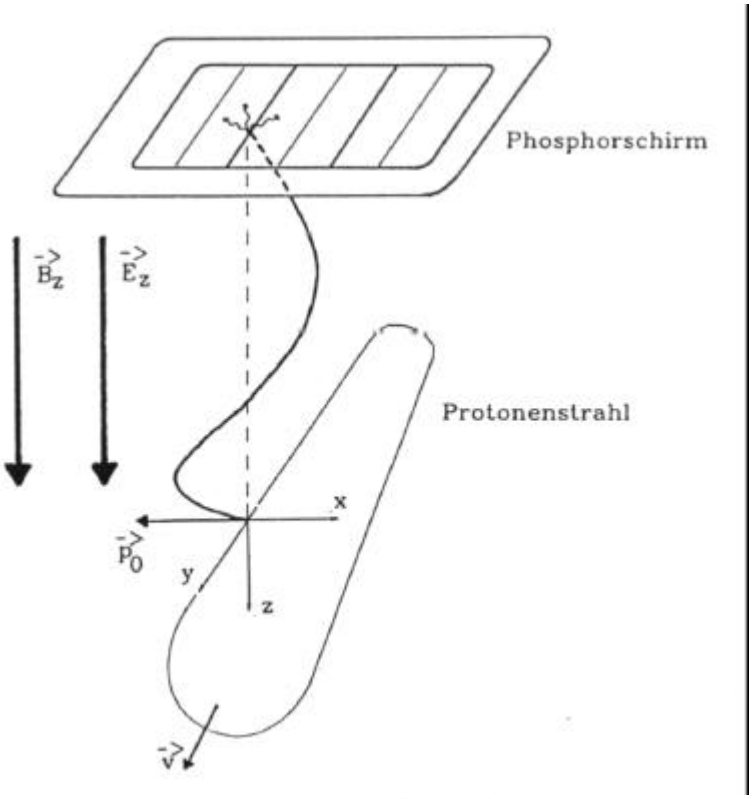
Simulation of space charge distortion

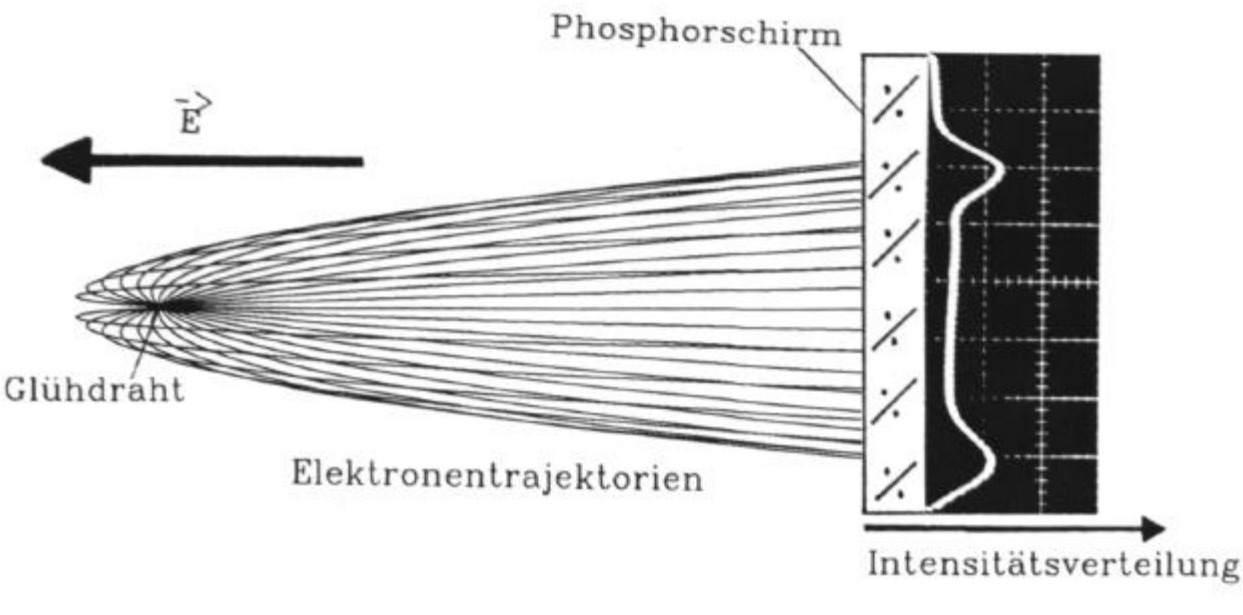




Helmholtzcoil

B_{focus}: Cyclotron frequency = time of flight

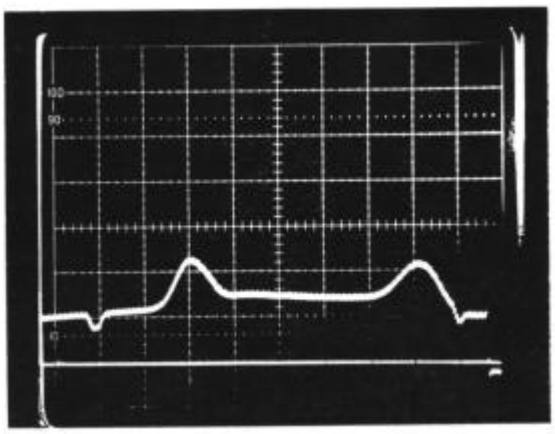




Wire Ø = 100 µm

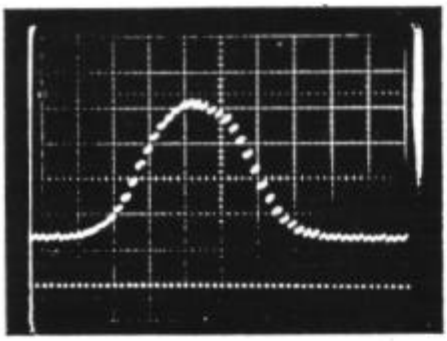
Helmholtzcoil

Test in Lab with a 100 mm wire



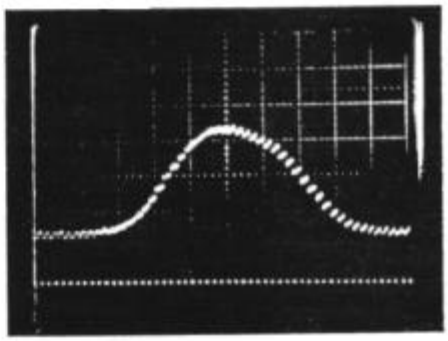
B = 0 Tesla

$B=9\cdot10^{-3}$ Tesla

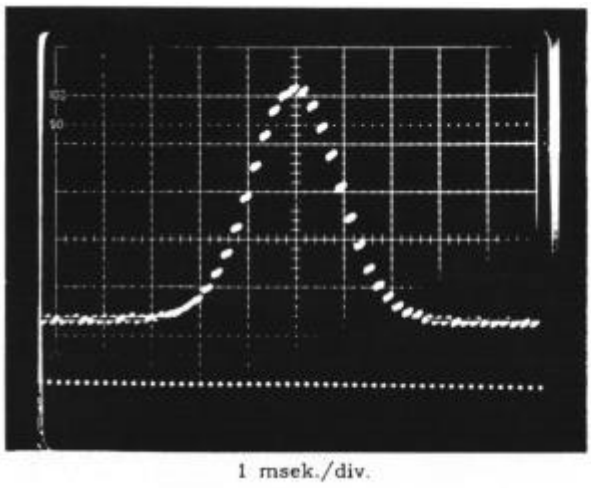


near resonance

$B= 1.1\cdot10^{-2}$ Tesla



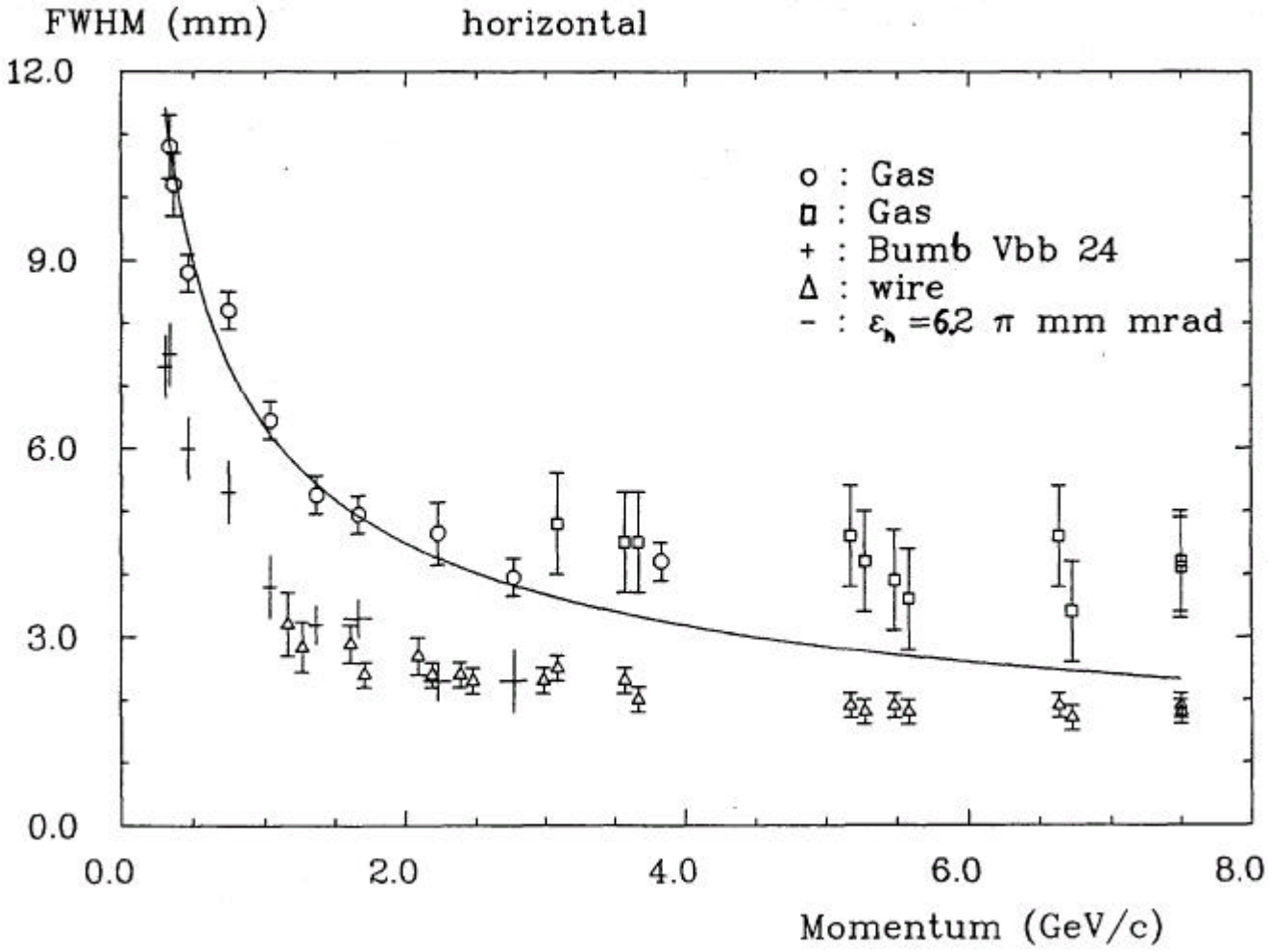
On resonance
$\sigma = 230\ \mu m$



B=0.01 Tesla

DESY III

Beam width versus momentum

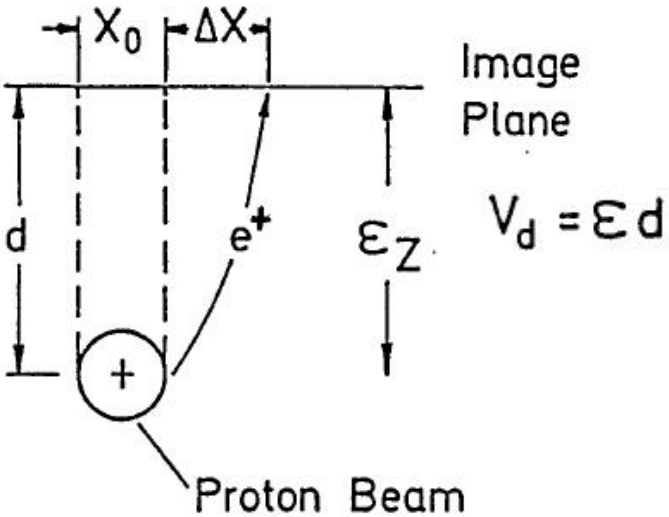


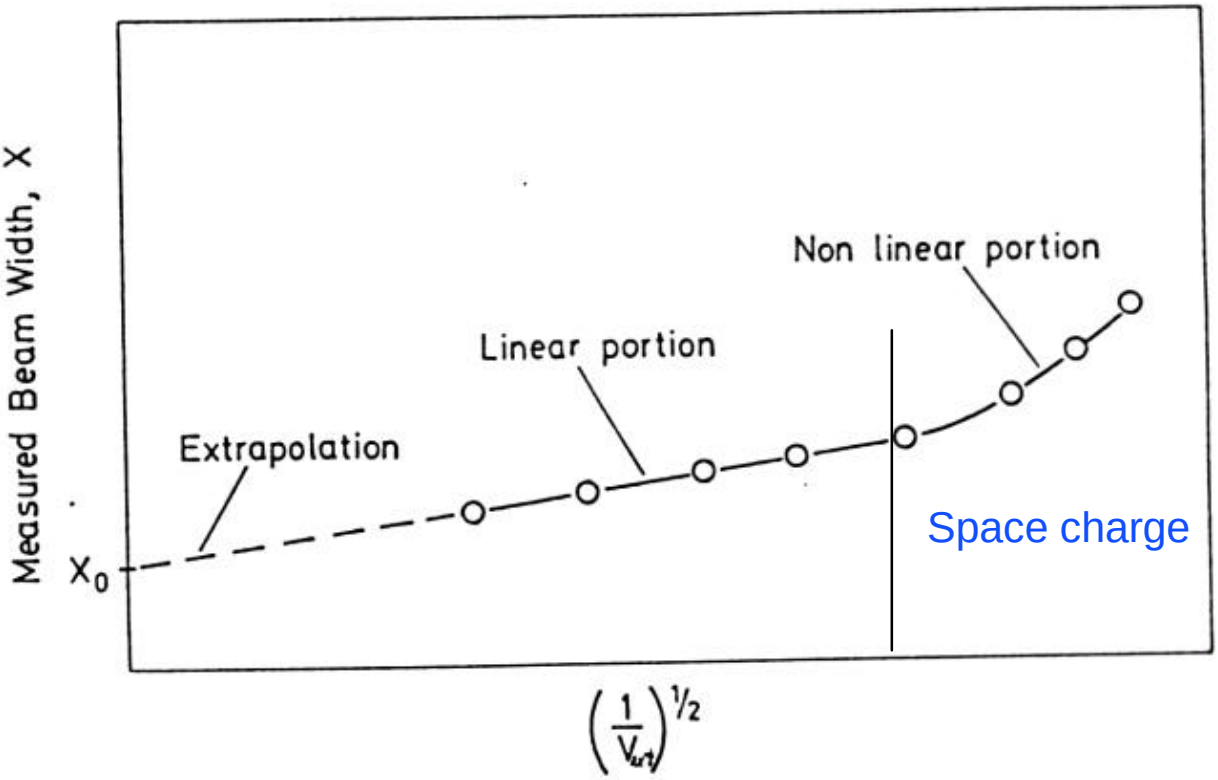
- 1.5 mm offset

Measurement of the transversal energies of the Electrons / Ions

$$FWHM = x_0 + 4 \cdot \sqrt{\frac{dE_x}{V_{ext}}}$$

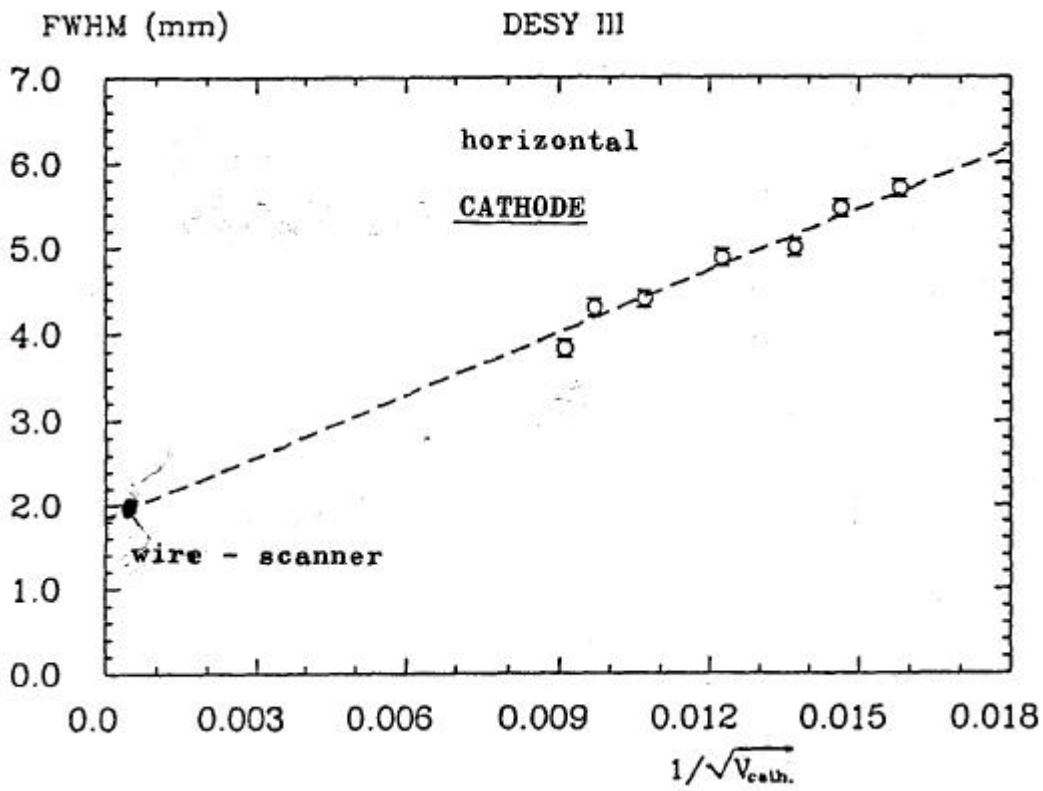
E_x = transv. Energy of particle

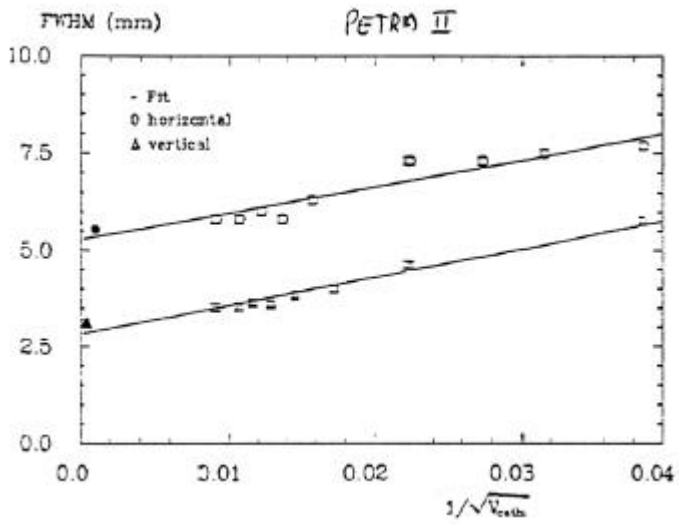


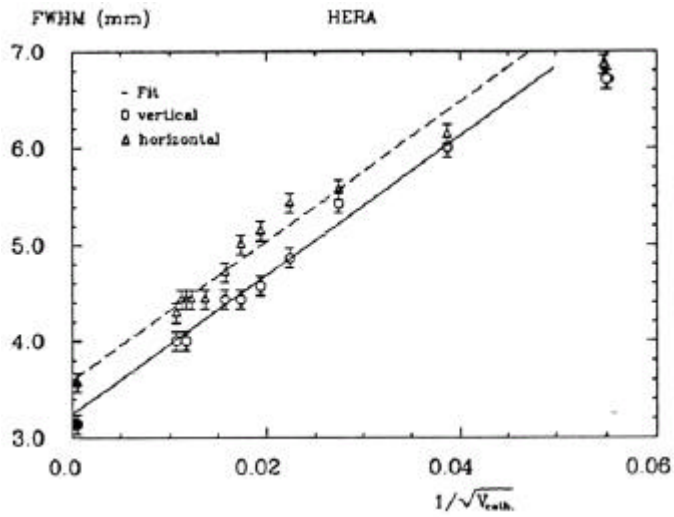


Distortion due to secondary emission from cathode

Changing the cathode voltage

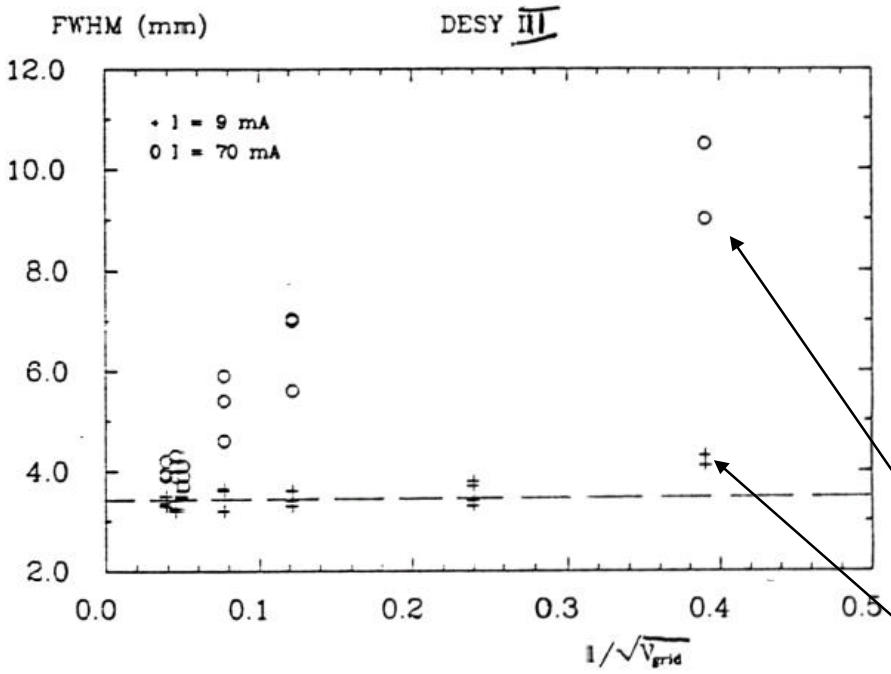


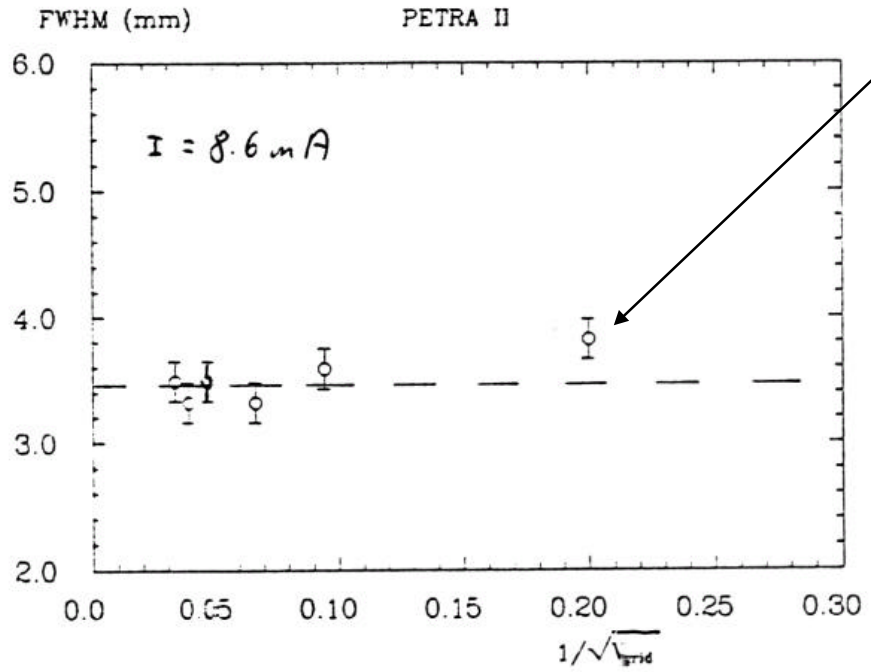




Distortion due to space charge of bunches

Changing the grid voltage





Space charge

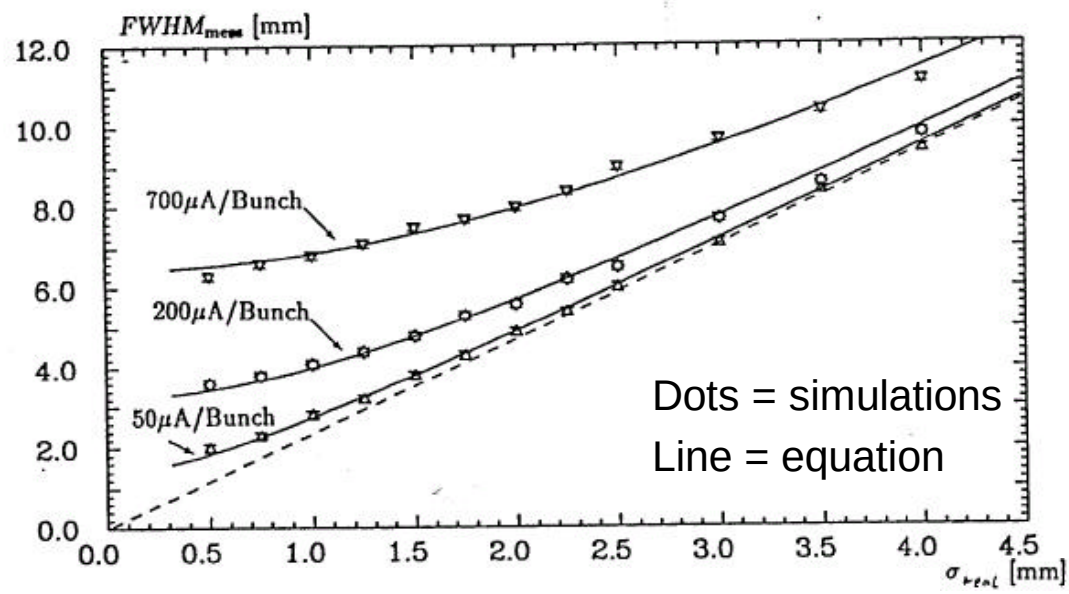
Space Charge Correction

by Th. Schotmann

$$FWHM_{meas} = \sqrt{2\ln 2}\sqrt{\sigma_{real}^2 + \alpha \cdot \frac{I \cdot U_a}{e \cdot N_b \cdot c} \cdot r_p \cdot d_g \cdot \sqrt{\frac{2m_p c^2}{e \cdot V_g}} \cdot \sqrt{\frac{\beta_x}{\beta_z}}}$$

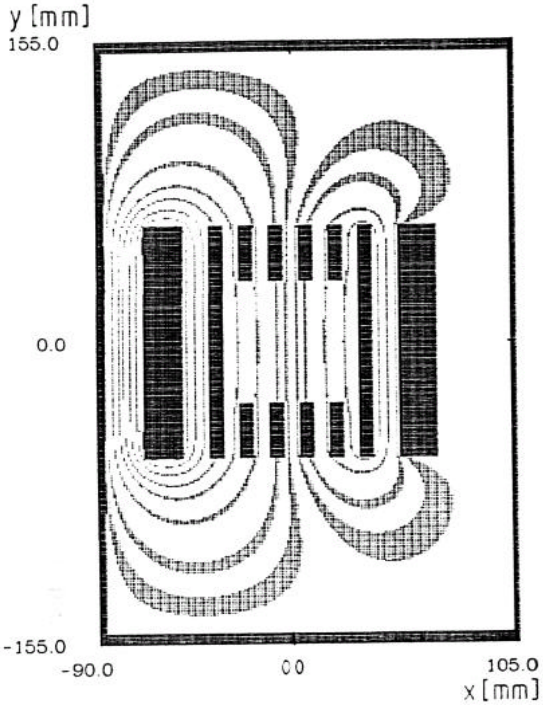
with:

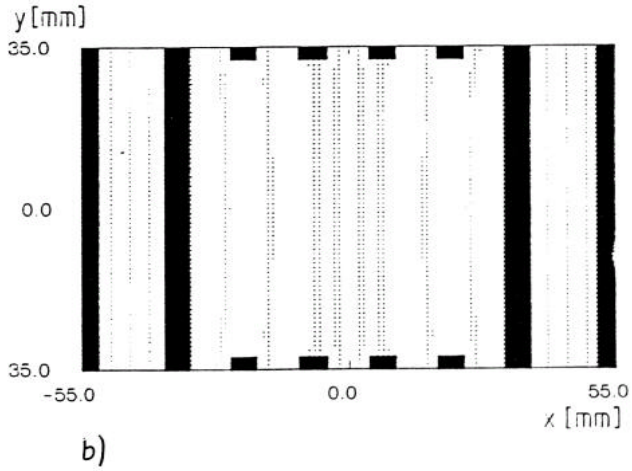
I = beam current
N_b = number of Bunches
U_a = circumference of the accelerator
r_p = classical proton radius
m_p = proton mass (if H_2 ions)
V_g = Potential between grids (Extraction field)
β_x = value of beta function at monitor (direction of measurement)
β_z = value of beta function at monitor (perp. to direc. of meas.)
α = fit parameter = 1.96



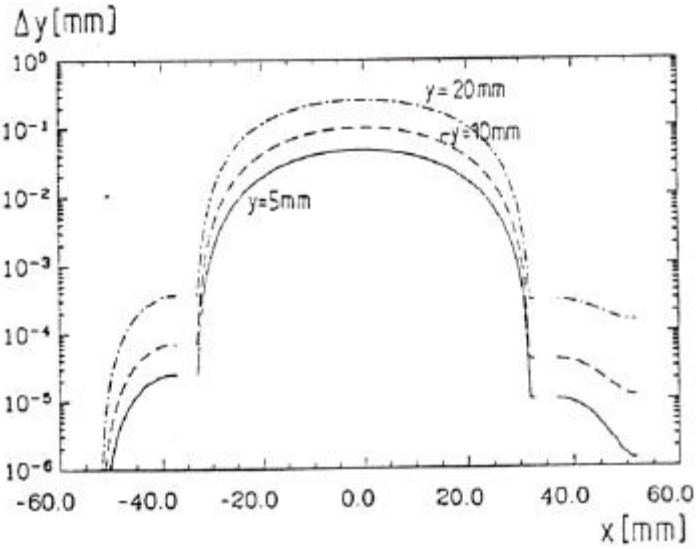
- 700 μA ≈ 10^{11} Protons/bunch in HERAp

Distortion due to electron optic





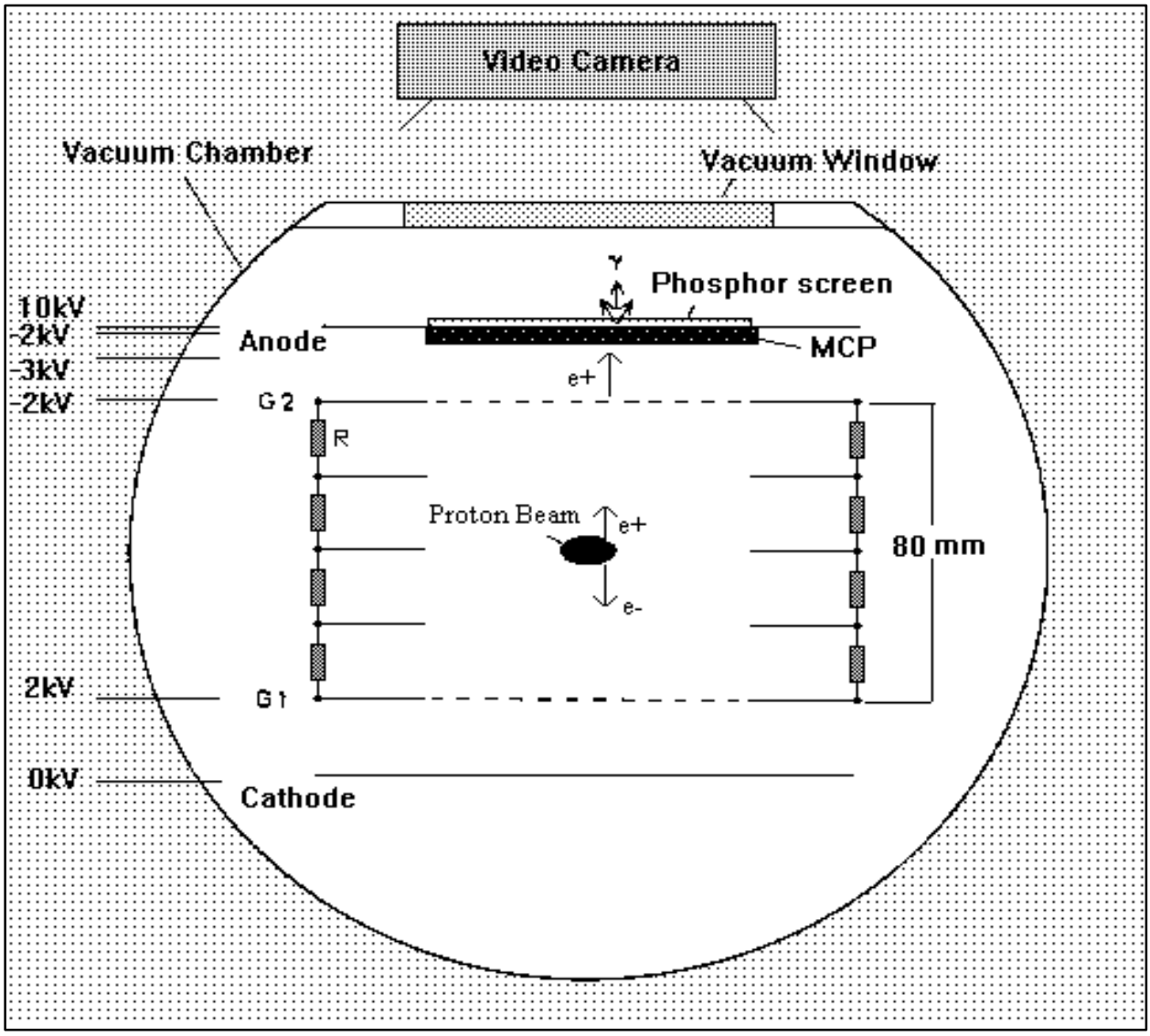
Potential lines in the IPM



y=beam radius

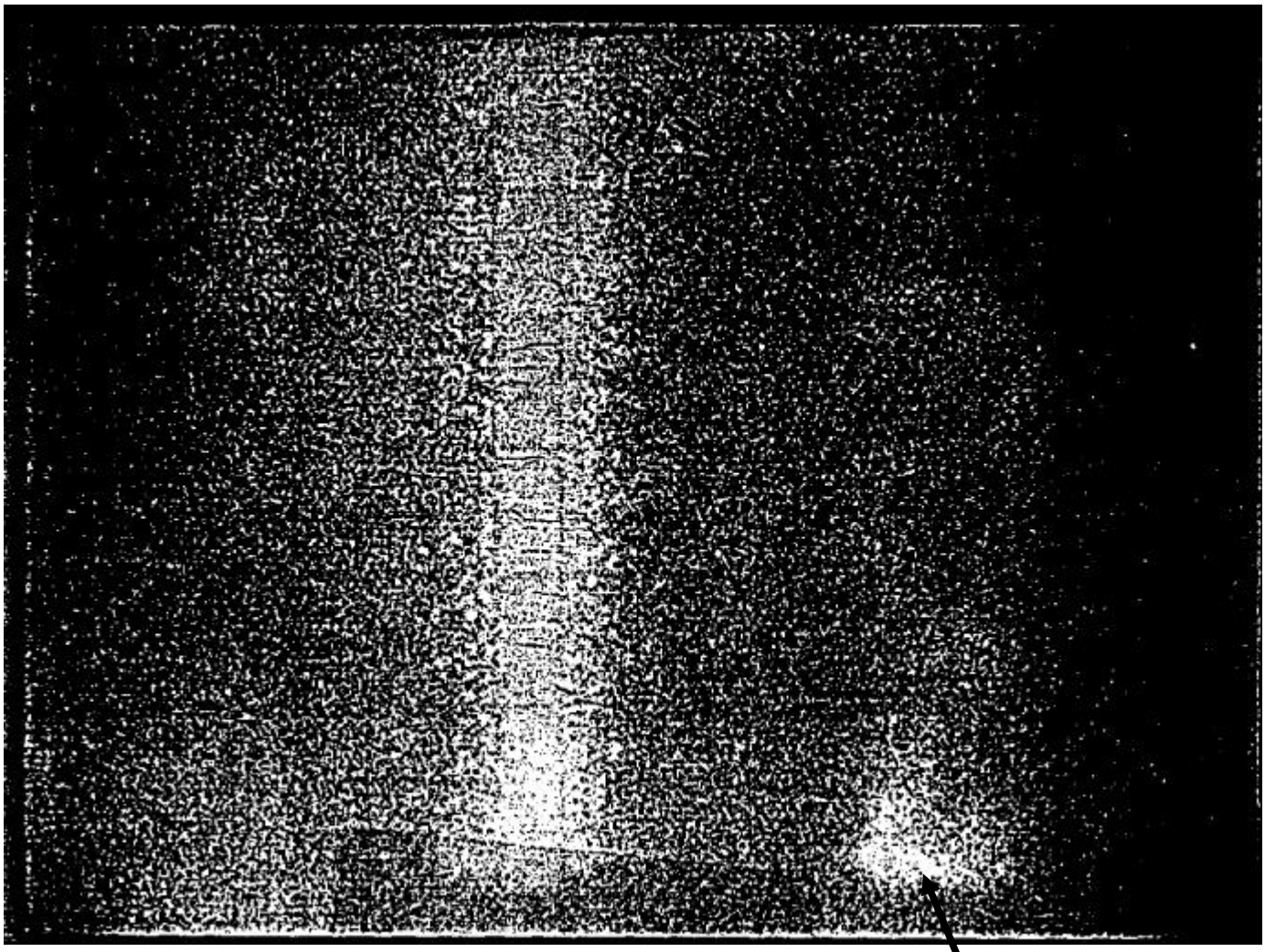
Profile distortion: focussing effect < 50 μm

Residual Gas Ionisation Profile Monitor in PETRA II and HERAp



- Vacuum 10^{-9} mbar
- 1 - 60 - 210 Bunches => << 0.1 - 160 mA
- 7.5 - 40 - 820 GeV/c
- beam width << 1 mm, length 30 - 3 cm

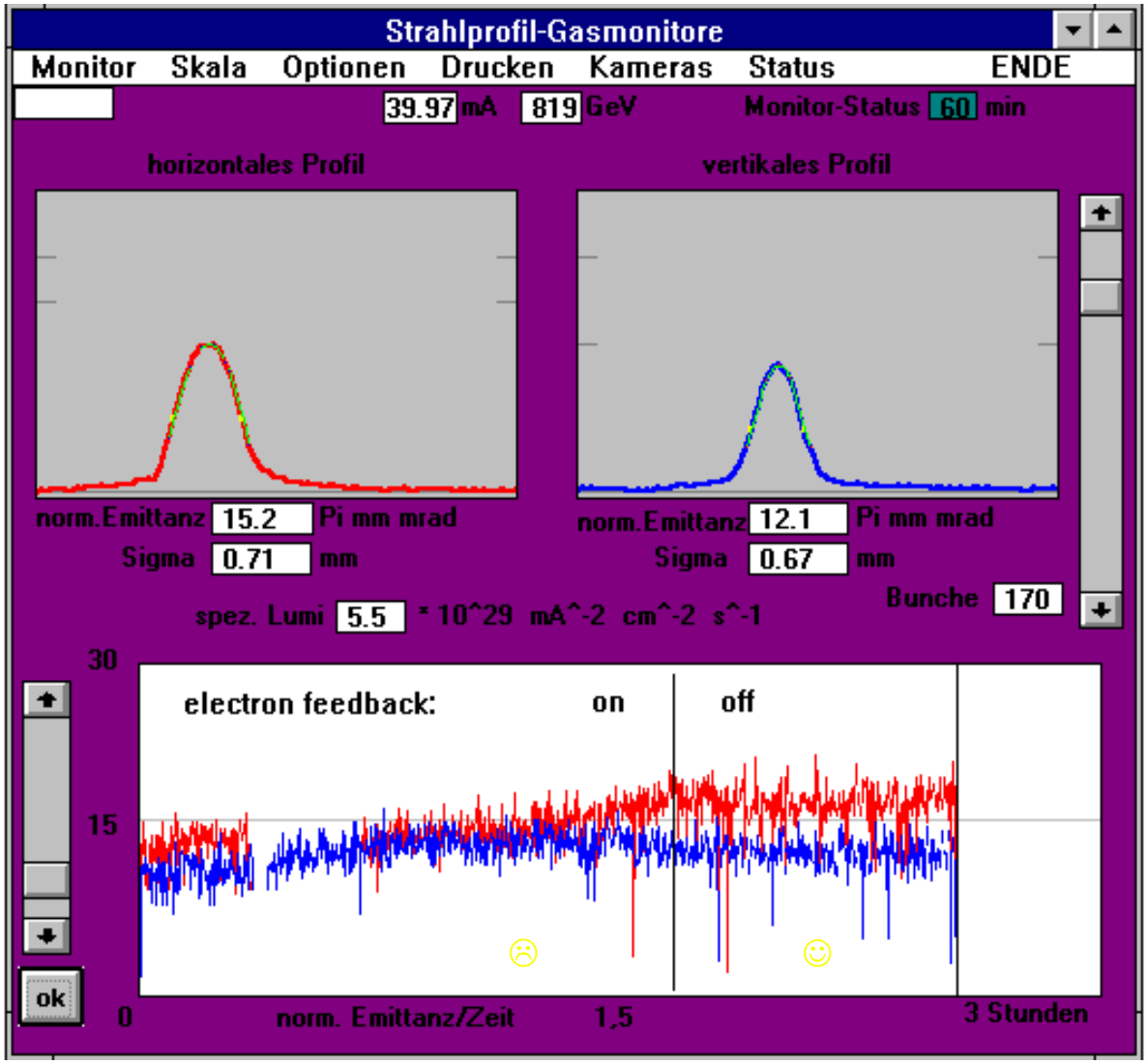
First circulating beam in HERAp (1991)



MCP dark current

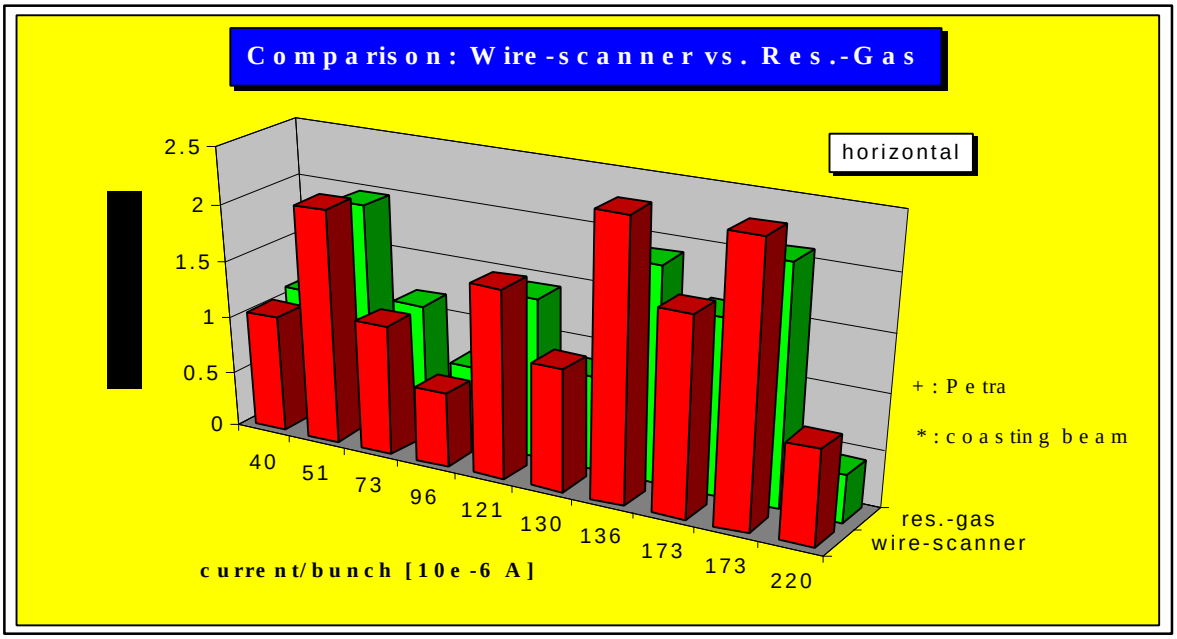
- I_p £ 0.01 µA (!)
- P_{vac} » 10^{-8} mbar
- FWHM » 10 mm

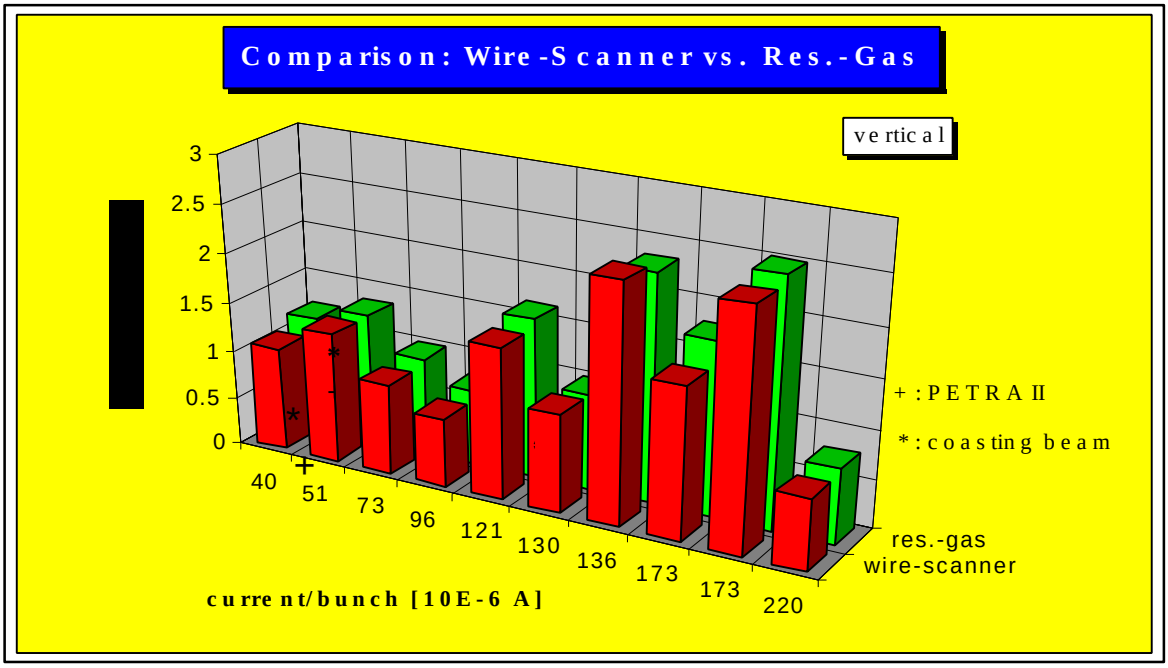
Residual Gas Ionisation Profile Monitor in HERAp



- Continuous observation
- no absolute width measurement
- observation of changes at injection and ejection (PETRA)

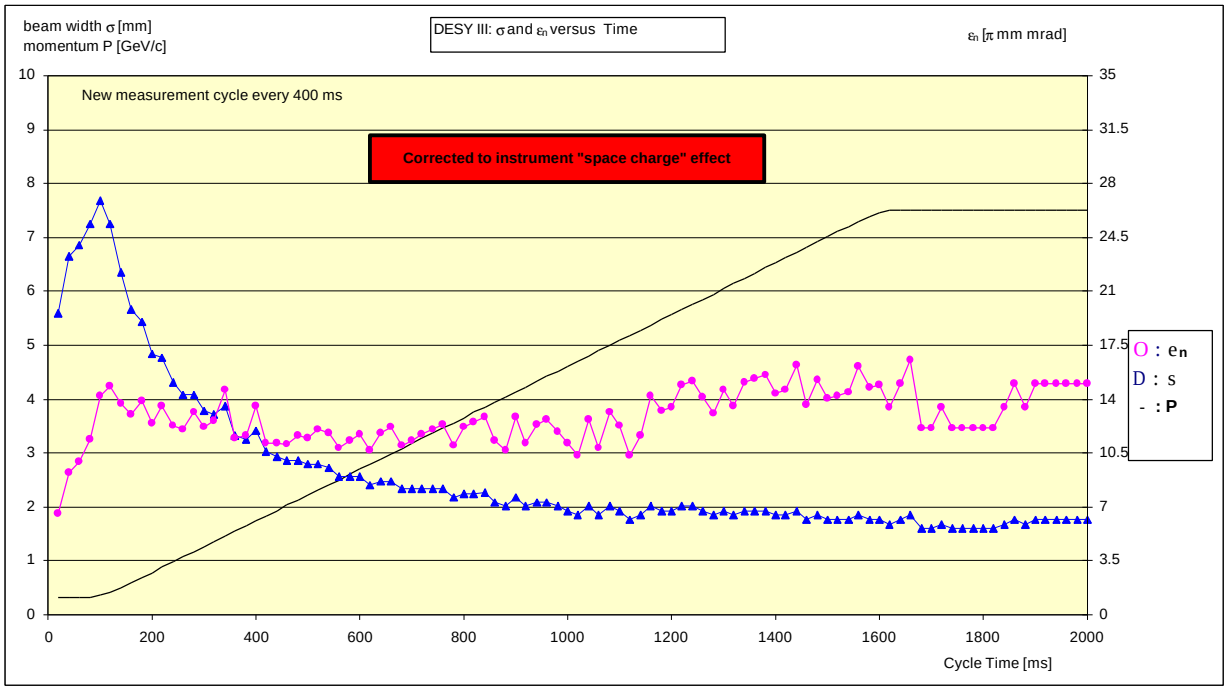
Residual Gas Ionisation Profile Monitors at Petra II and HERAp

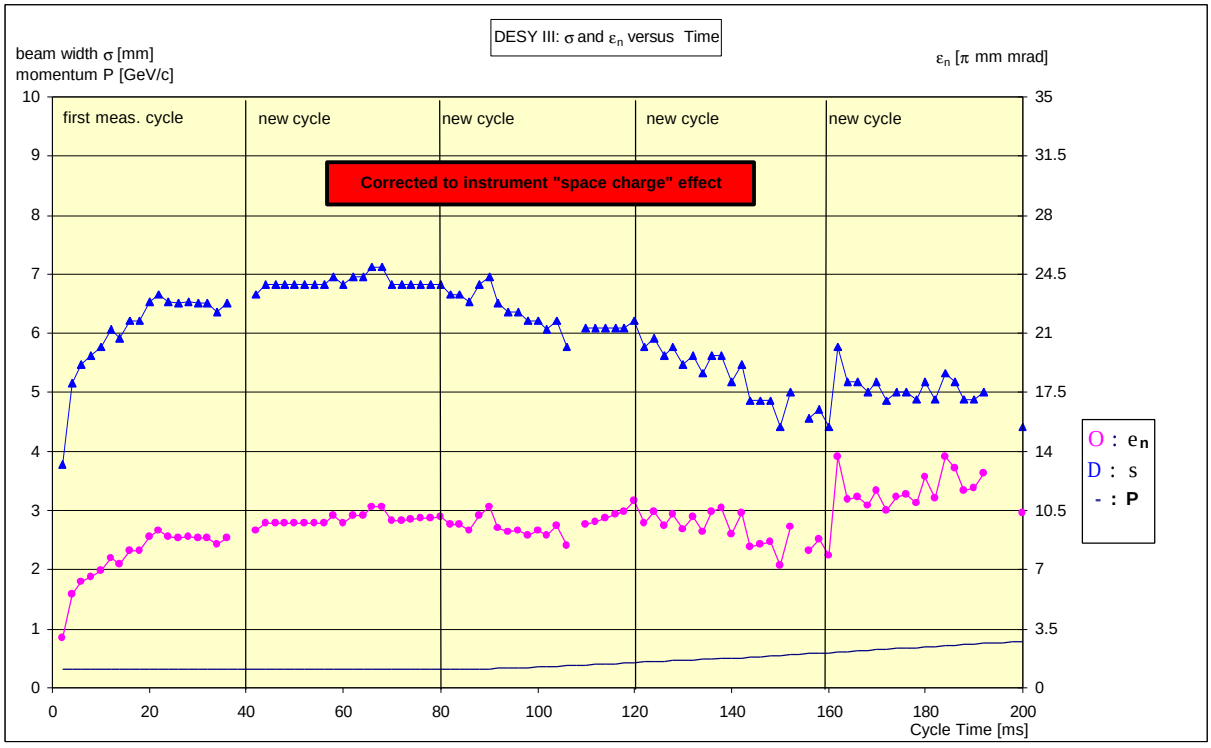




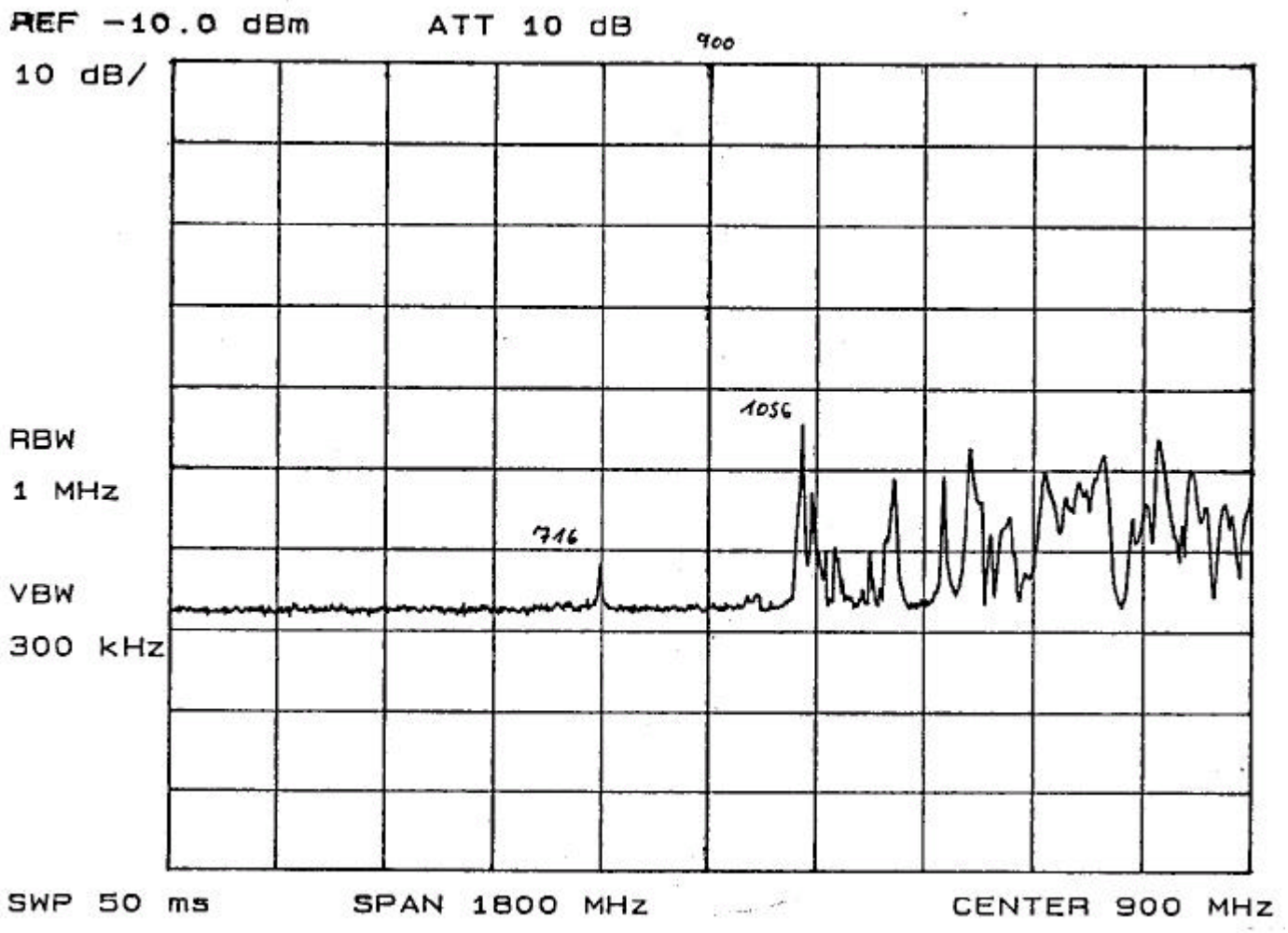
- Ok. up to 220 μA/bunch (=ca. $3 \cdot 10^9$ Protons/bunch) incl. space charge correction

Fast Evolution of the normalized emittance and the beam width in DESY III measured with a linear sensor and a local gas bump.



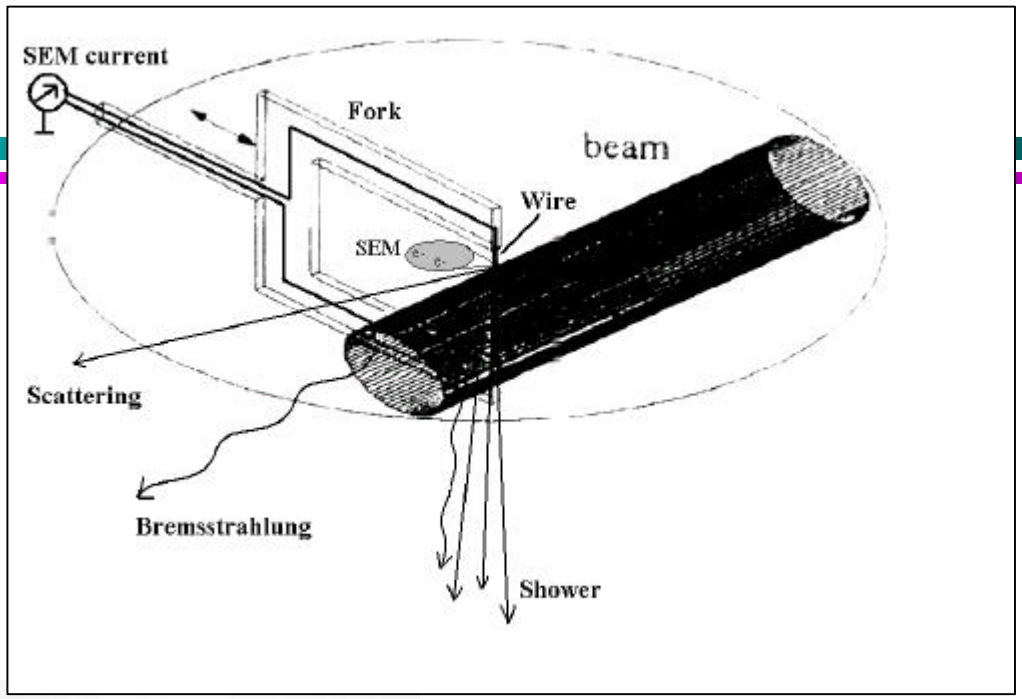


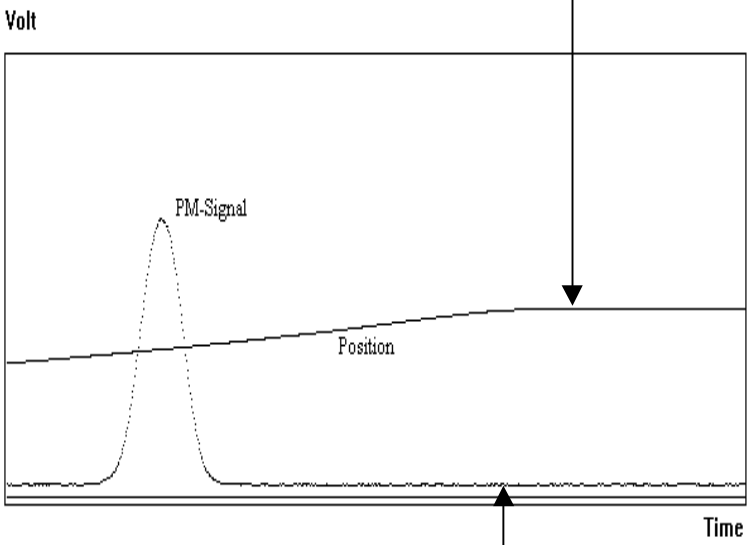
Higher order mode losses in the IPM

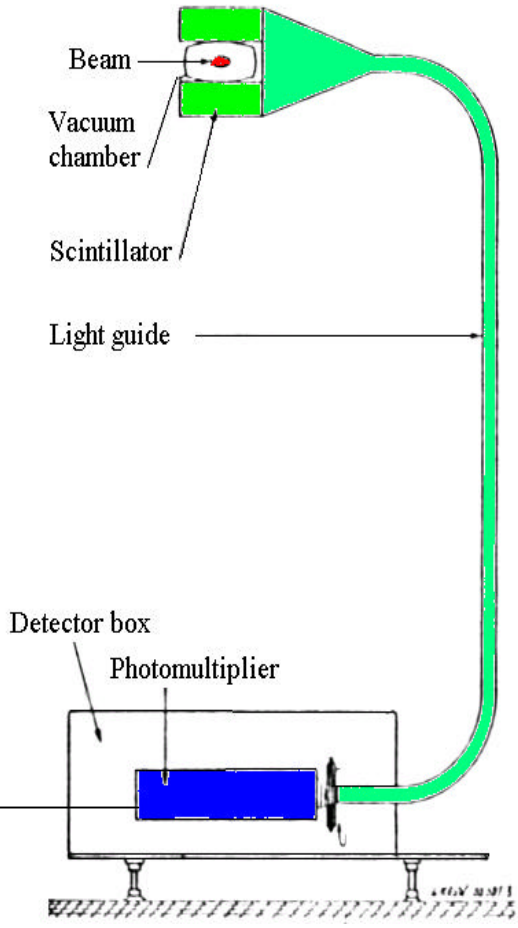


- For the long proton bunches no problem

Wire Scanners at DESY

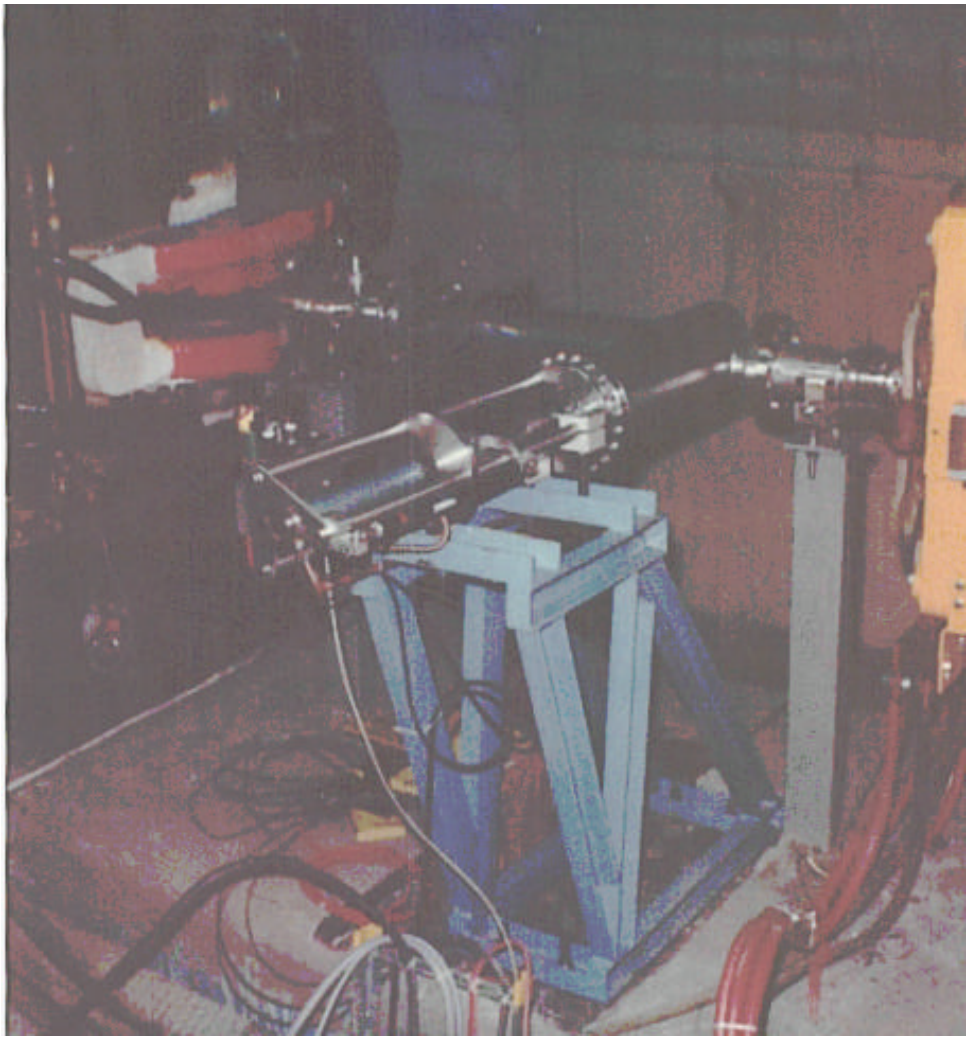




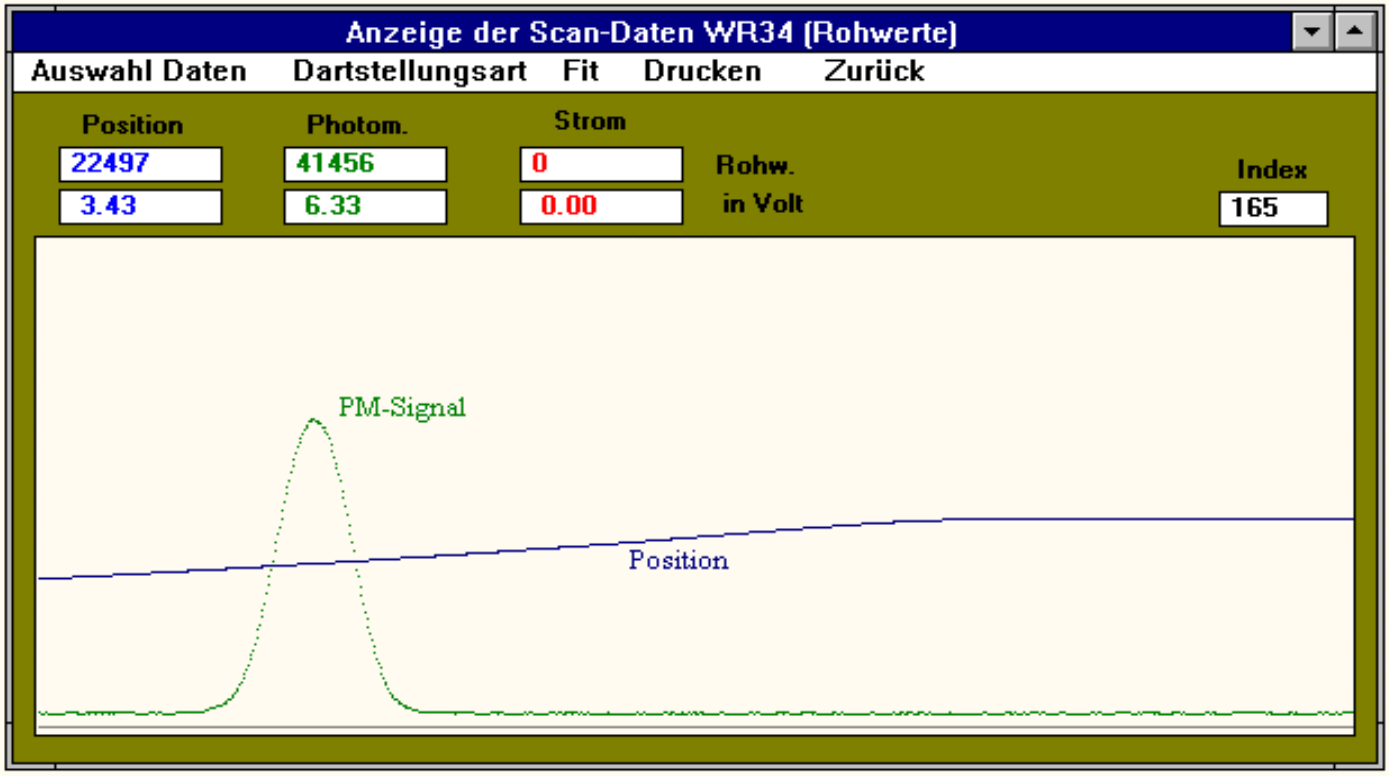


Wire Scanner in DESY III

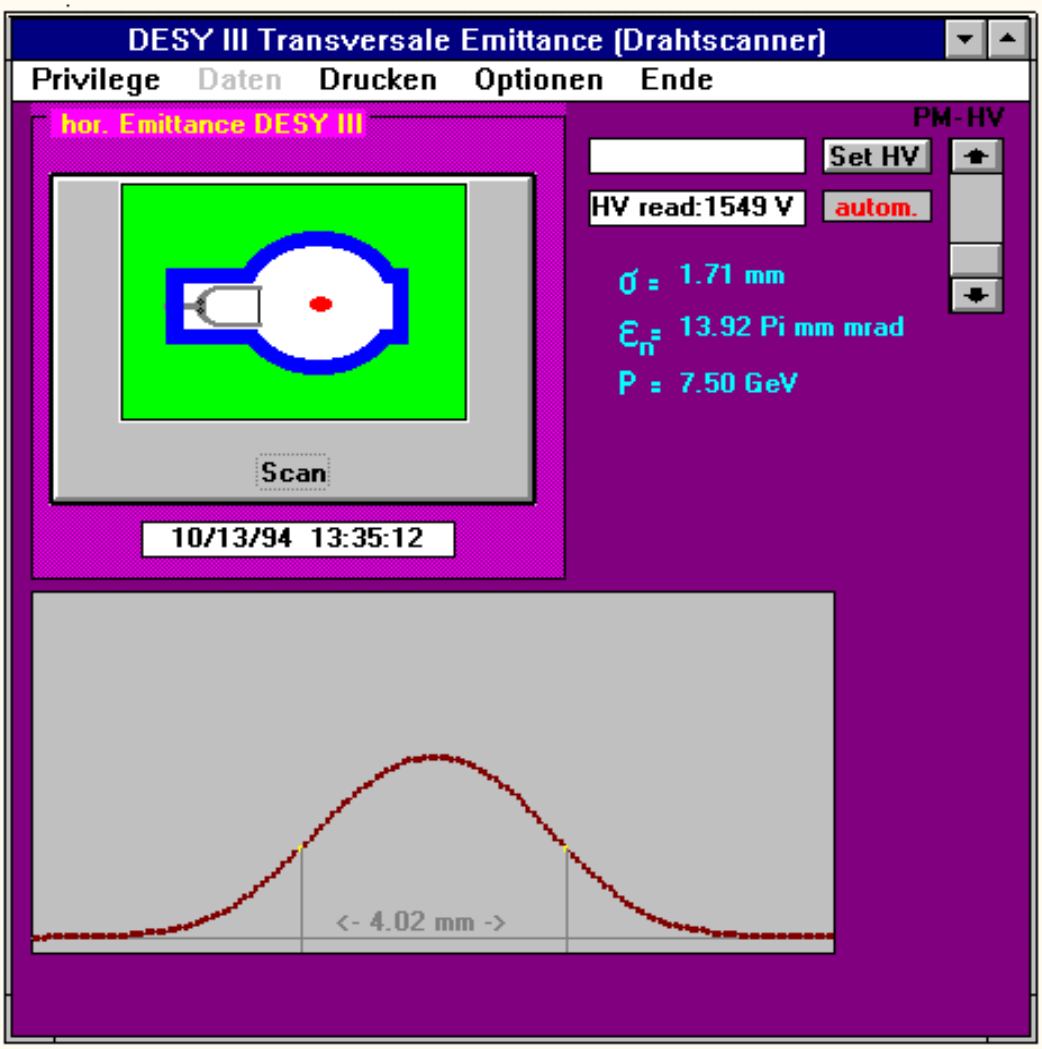
- linear, pressed air
- v = 1m/s
- Carbon wire
- Ø = 7 µm
- Szintillator + Photomult. readout



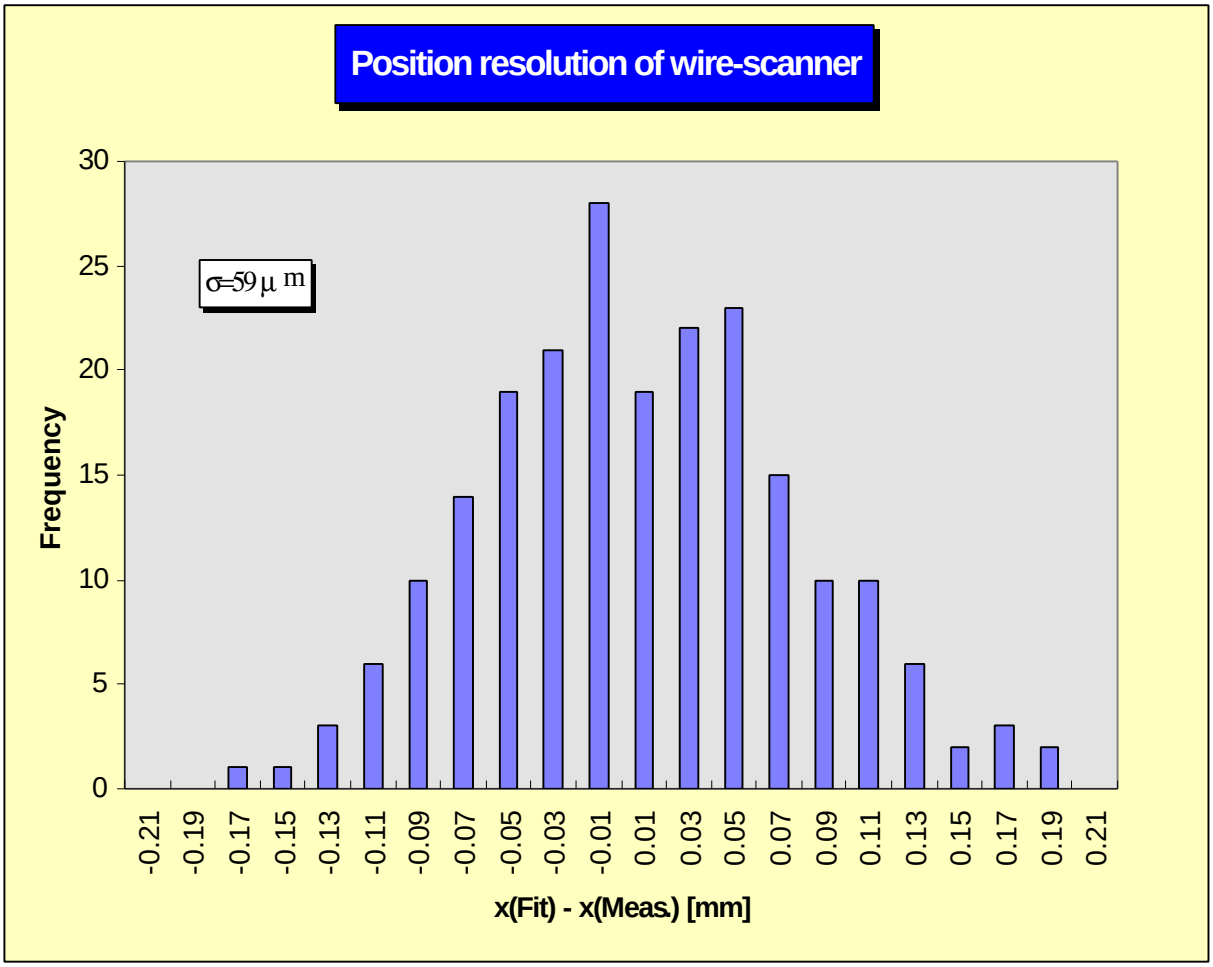
Wire Scanner
in DESY III



Wire Scanner in DESY III



Wire scanner in DESY III



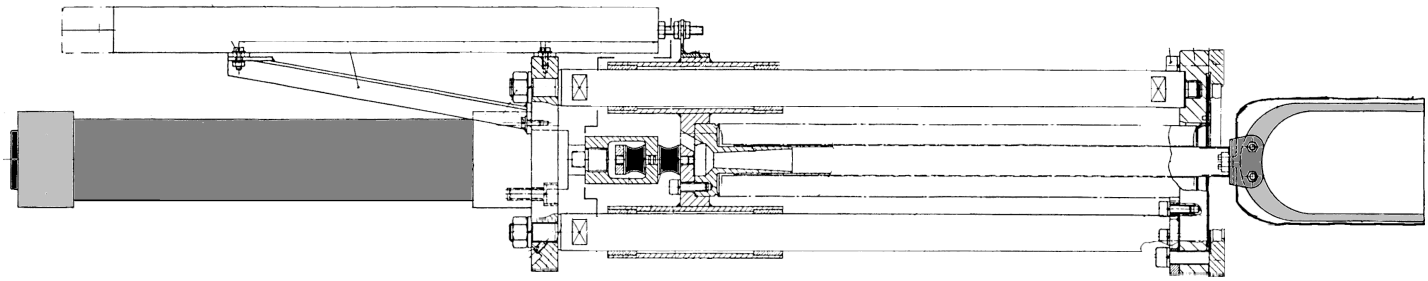
- measured position vs. linear fit

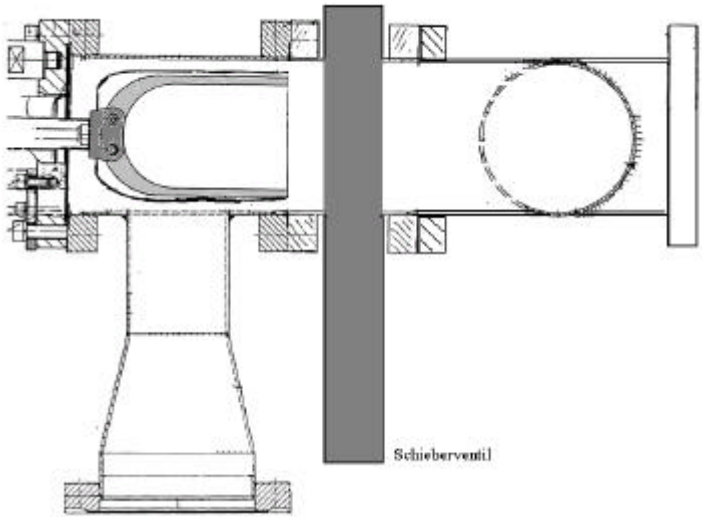
Wire Scanner in DESY III

- Wire - Temperature:
  - » Calc. Tmax = 3400 ^{0}C at I=160 mA
- Emittance blow up:
  - » 10%/scan at 310 MeV to 0.01%/scan at 7.5GeV/c
- Beam losses:
  - » <0.1 %/scan

No broken or burned wire,no detectable beam loss or emittance blow-up! ☺☺☺

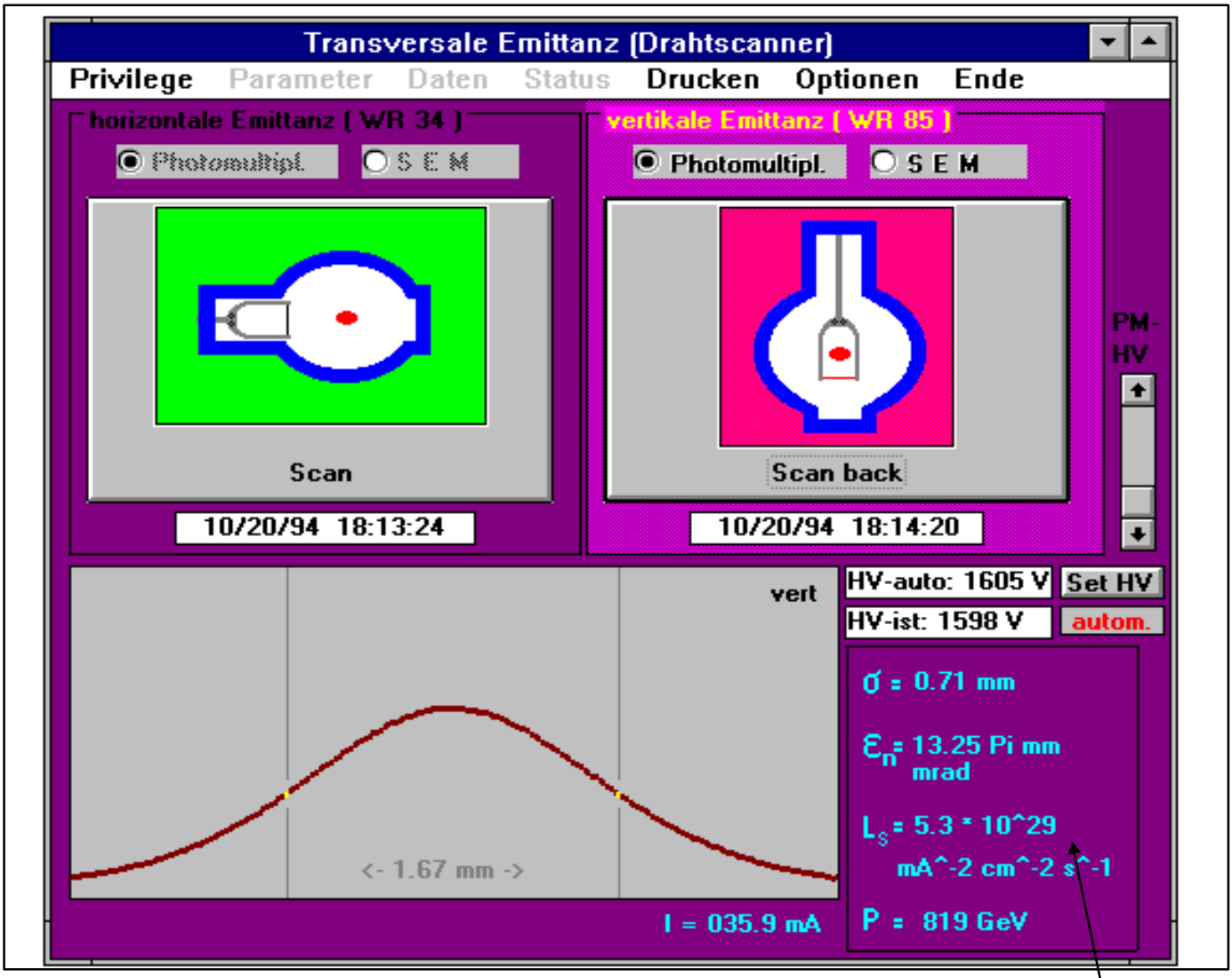
Wire Scanner in HERAp





- Movement by pressed air
- Wire speed: 1 m/s
- Wire material : Carbon
- Wire diameter: 7 µm
- Signal: Scintillator + SEM

Wire scanners at HERAp

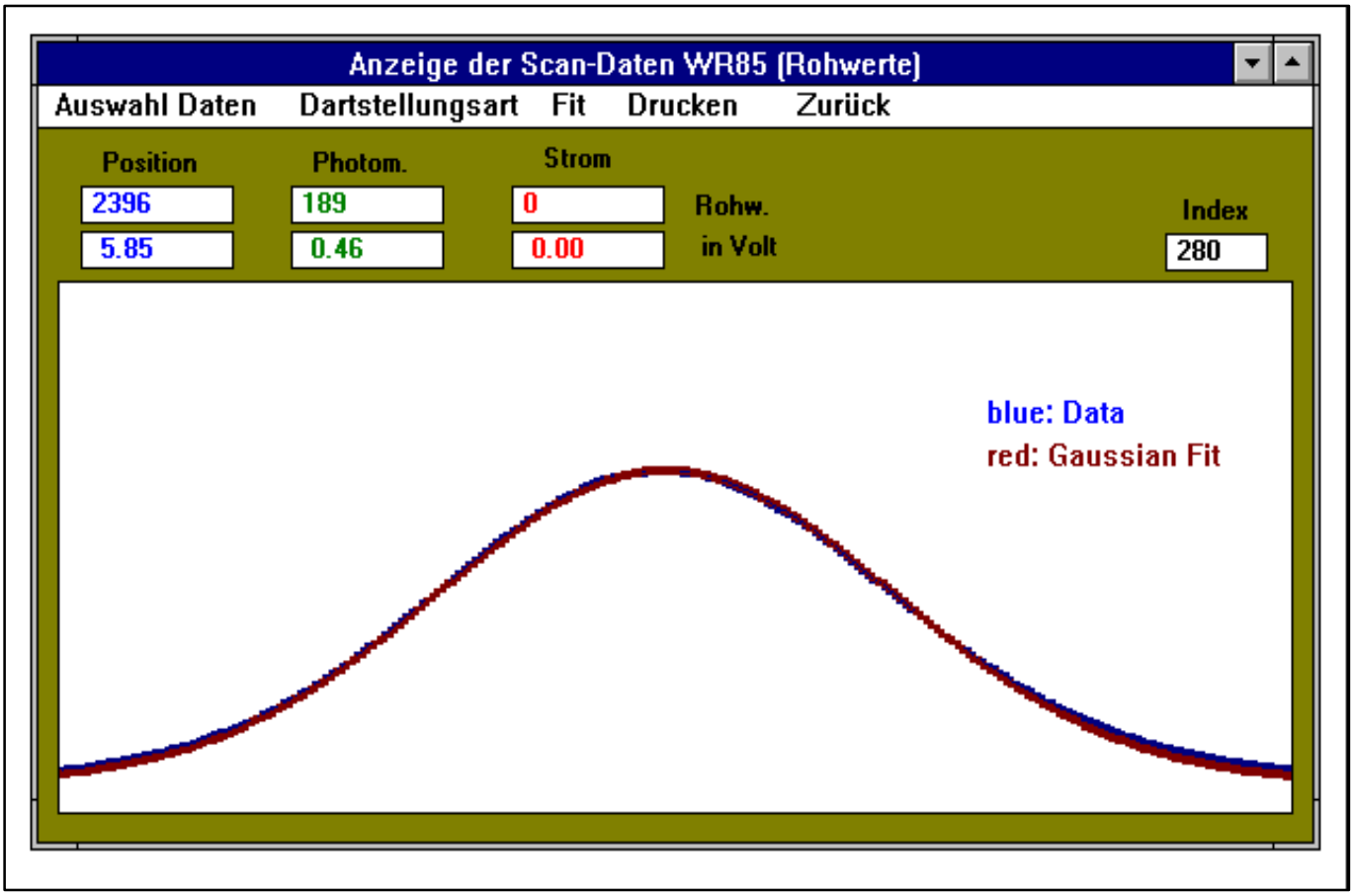


☺ Since start of HERA (1990) 3 broken or burned wire, no detectable beam loss or emittance blow up due to wire-scans!

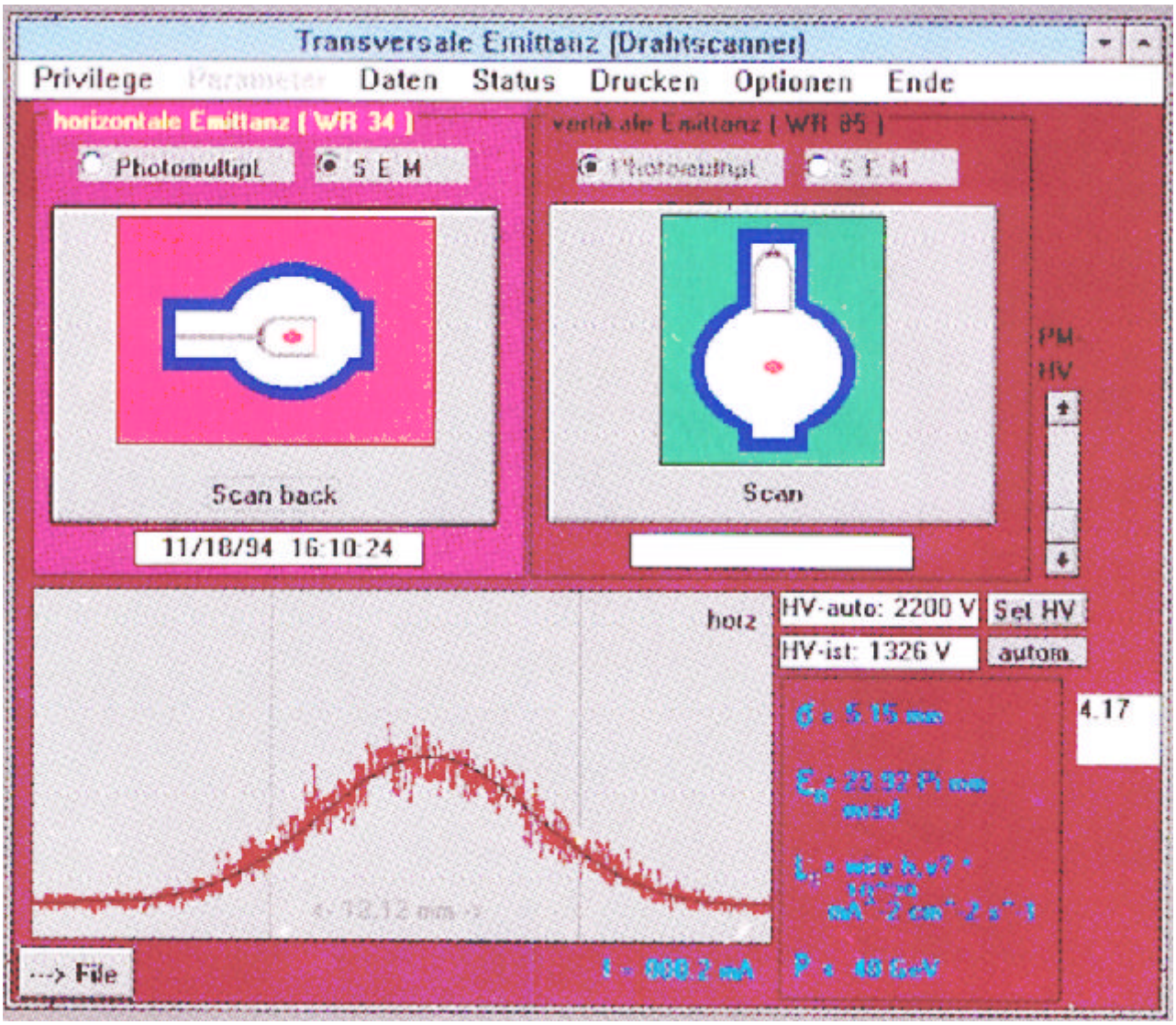
☹ Increased background measured by the experiments.

☹ Specific Lumi agrees within 0-20% with experiments

Wire Scanners
in HERAp - Fits

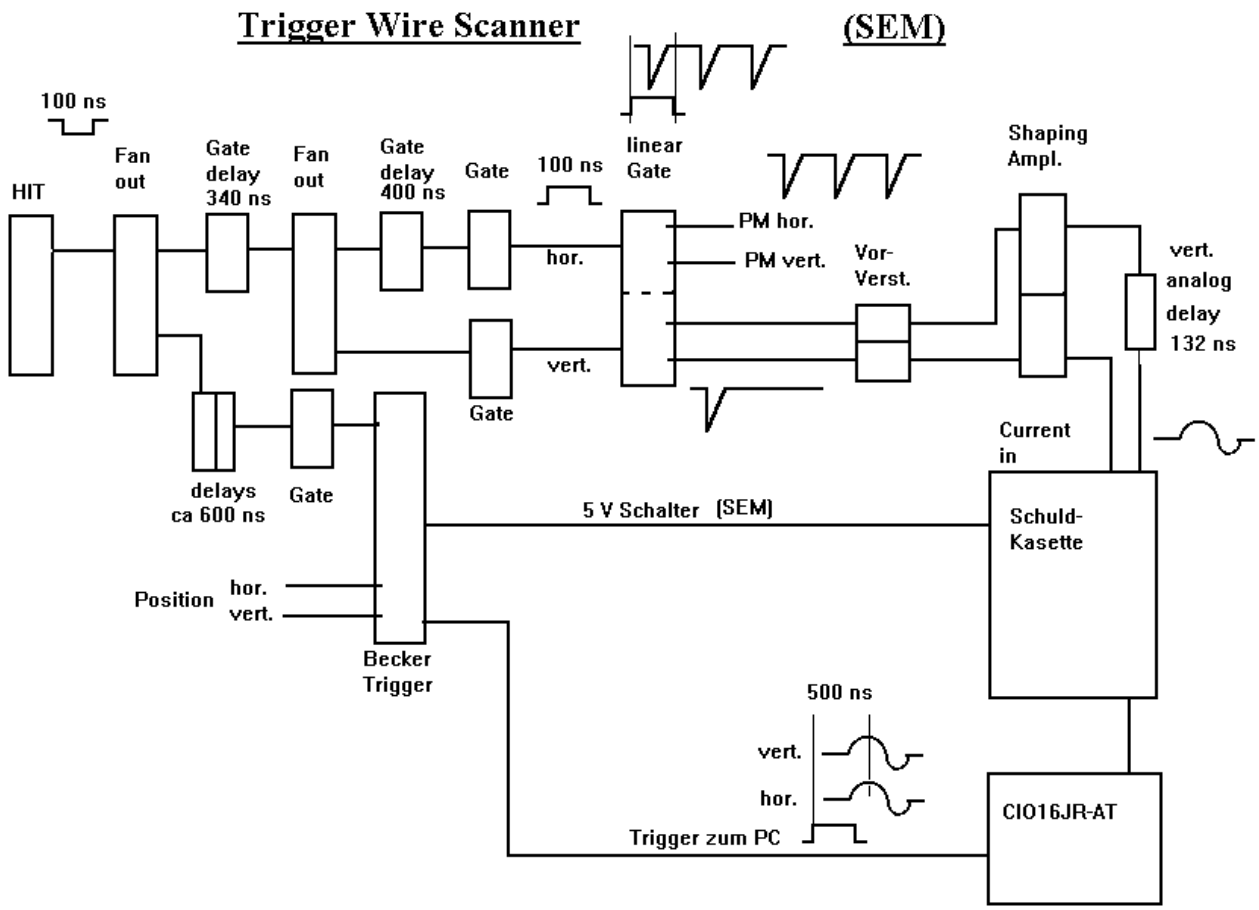


Single bunch emittance measurement with the HERAp wire scanner



- σ = 5.15 mm
- ε_n - 23.92 π mm mrad
- p= 40 GeV

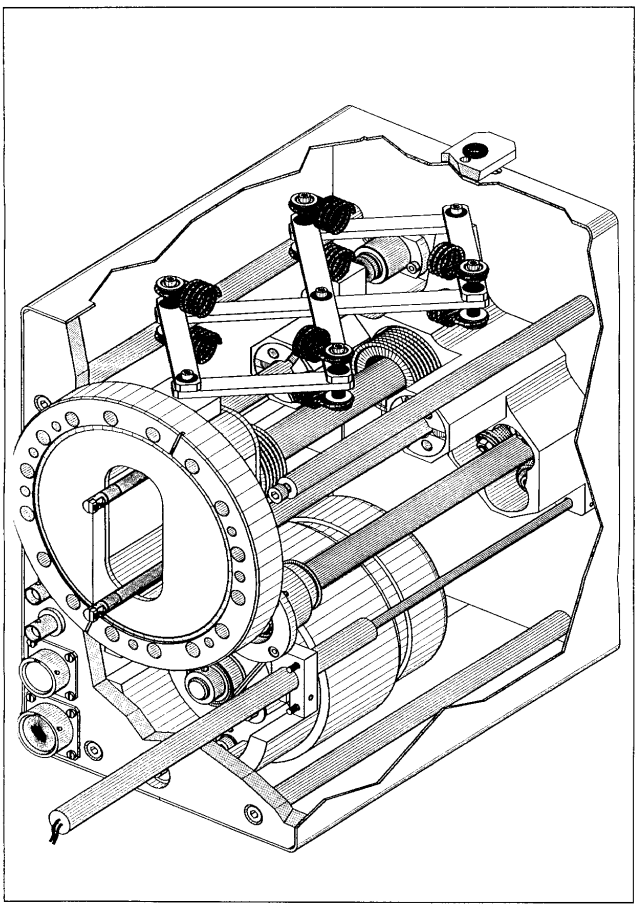
Trigger logic for the single bunch emittance measurement



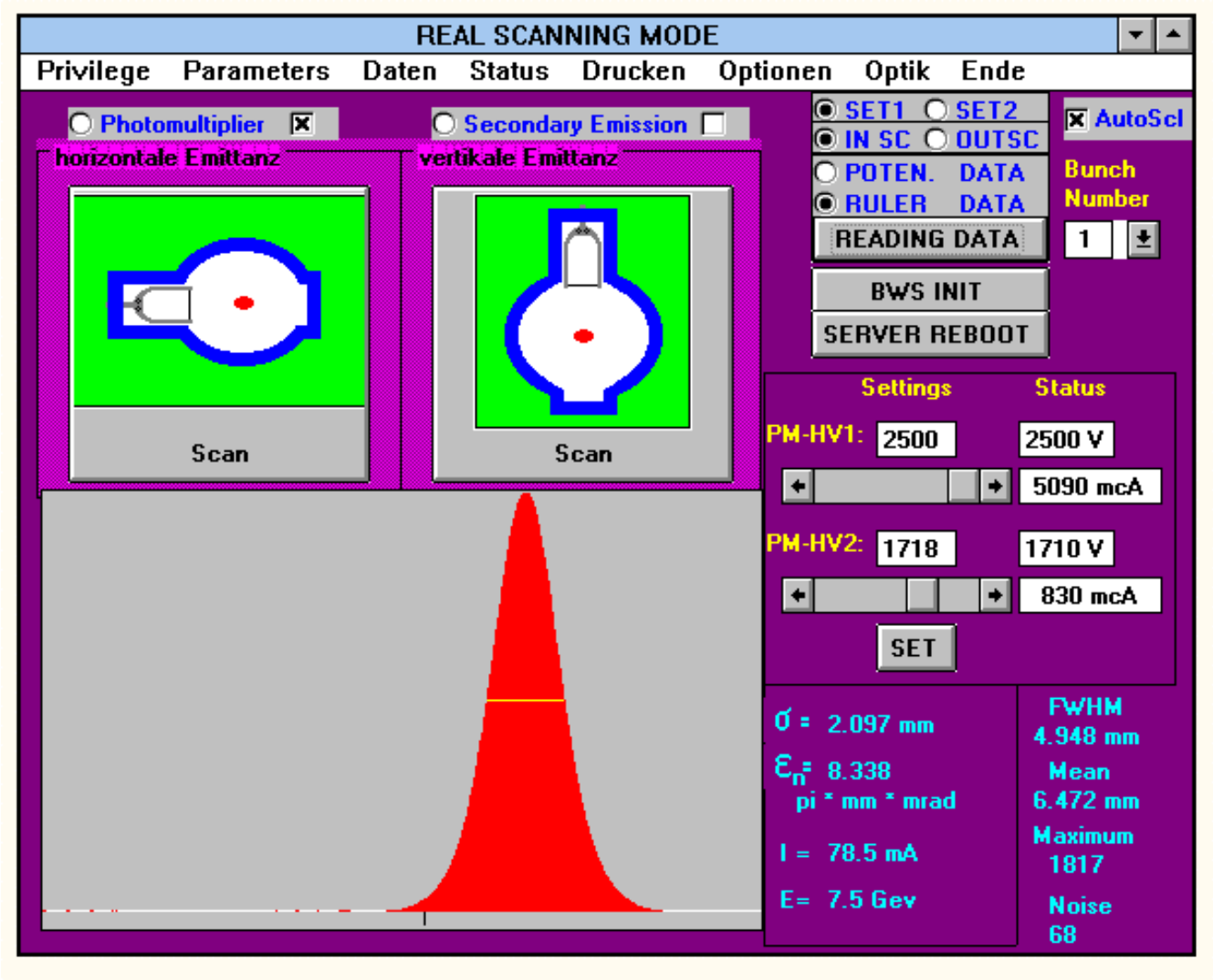
The LEP Wire Scanner in all circular accel. and in TTF

Advantages:

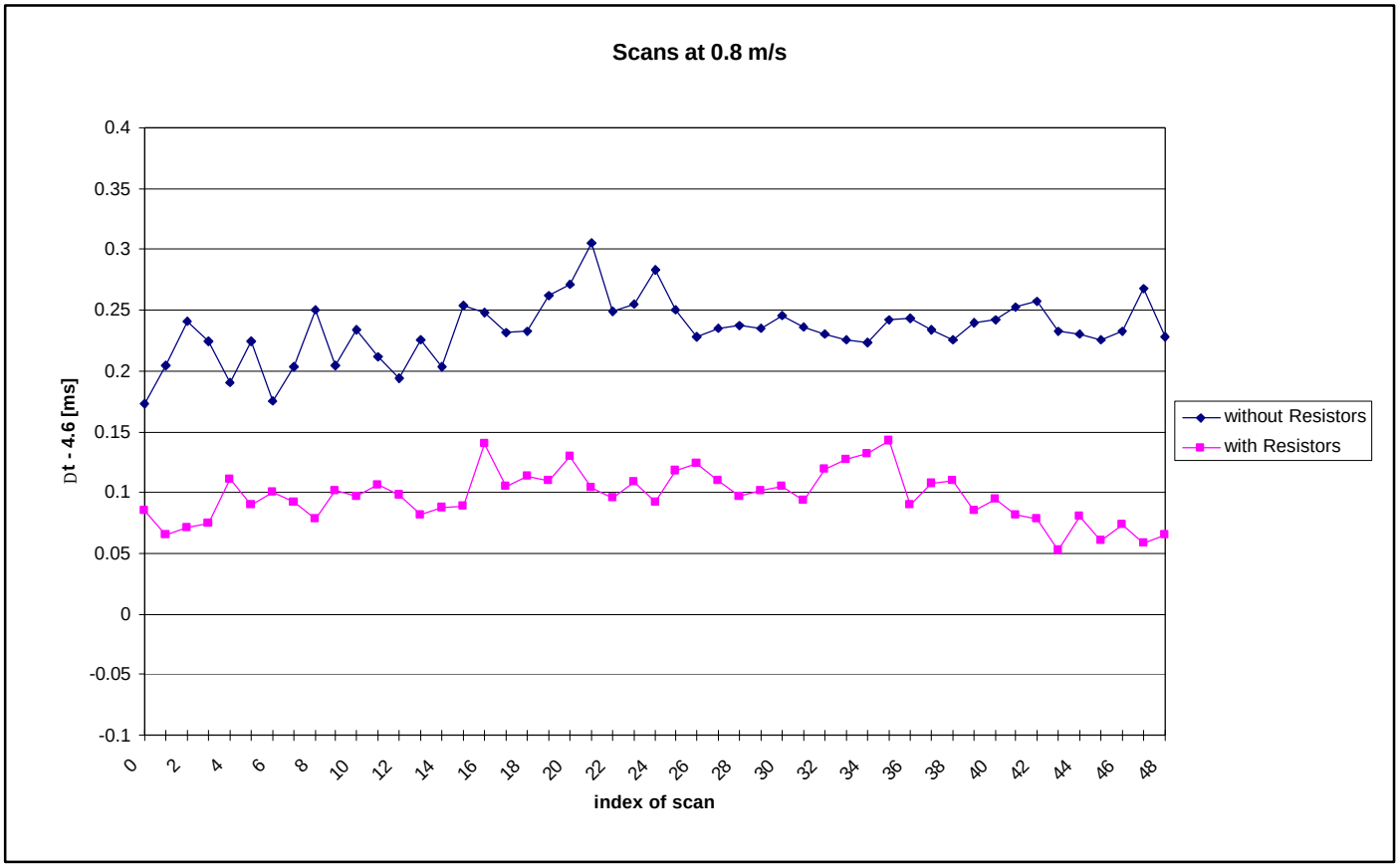
- Variable speed -> Tail measurements
- Small synchronization jitter
- Small size
- Very precise (<2 microns)
- Suitable for all accelerators in DESY



The LEP Wire Scanner in PETRAp



Triggered scan for TTF and DESY III



- **Synchronization jitter < ±200 ms**

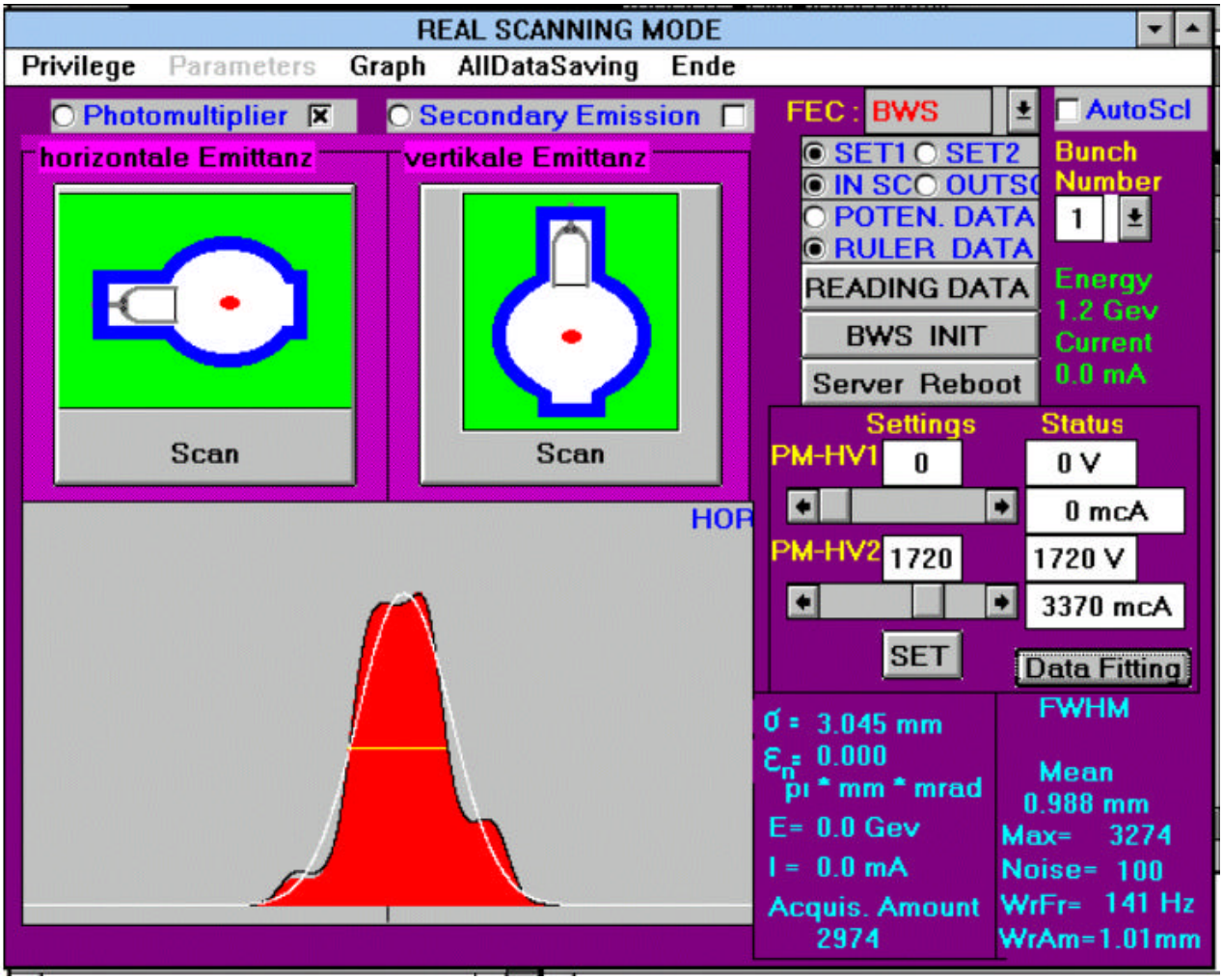
Temperature of the wire (v=1m/s)

	Num. of part.	Typ. Beam diam.	Temp. after scan [C]	Eqi. - Temp [Celsius]
HERAp	1 *10^13	0.7 mm	4000	4600
HERAe	6.5 * 10^12	0.2 mm	6500	4500
PETRAp	4.8*10^12	2 mm	1300	3000
PETRAe	1.5*10^12	0.1 mm	6300	5700
DESYIII	1.2*10^12	1 mm	3400	5300
TTF fast	2.8*10^13	0.05 mm	4000	7400
TTF slow	2.8*10^13	0.05 mm	230 000	2000

Melting temperature = 3500 ºC for Carbon
= 1700 ºC for Quartz

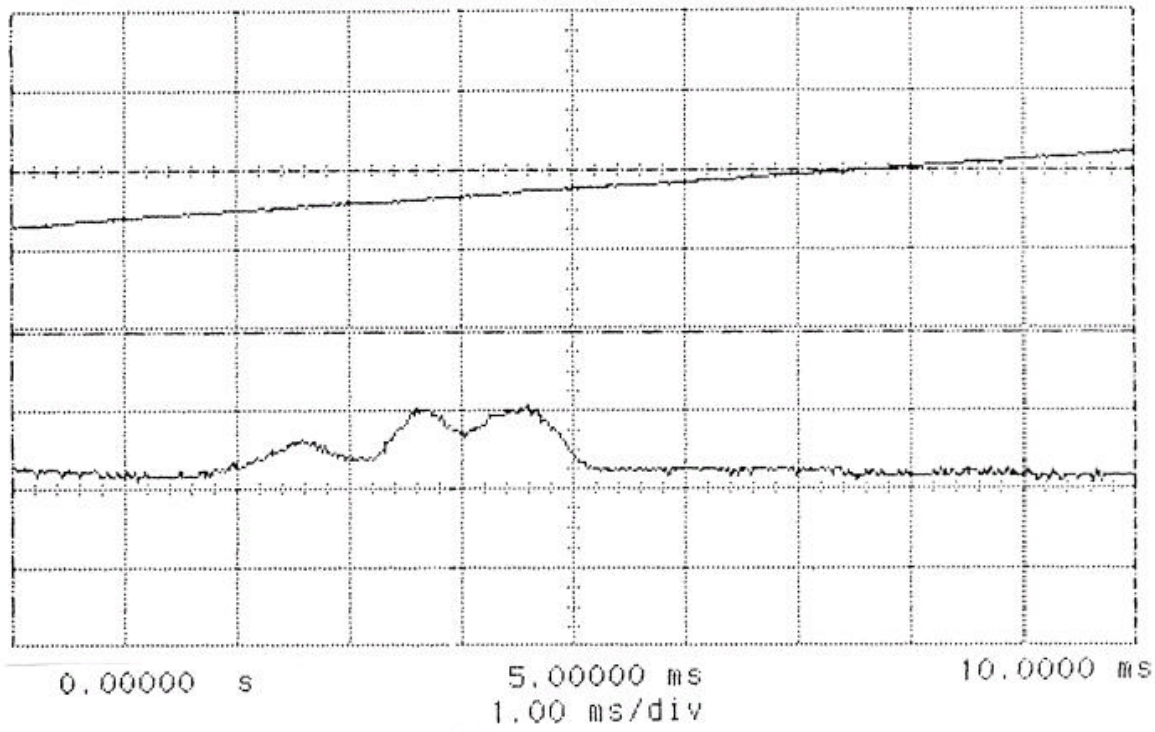
The wire in DESY III still exists with 200 mA = $1.25 \cdot 10^{12}$ p
In HERA 3 burned wires in the last two years

Wire Vibrations

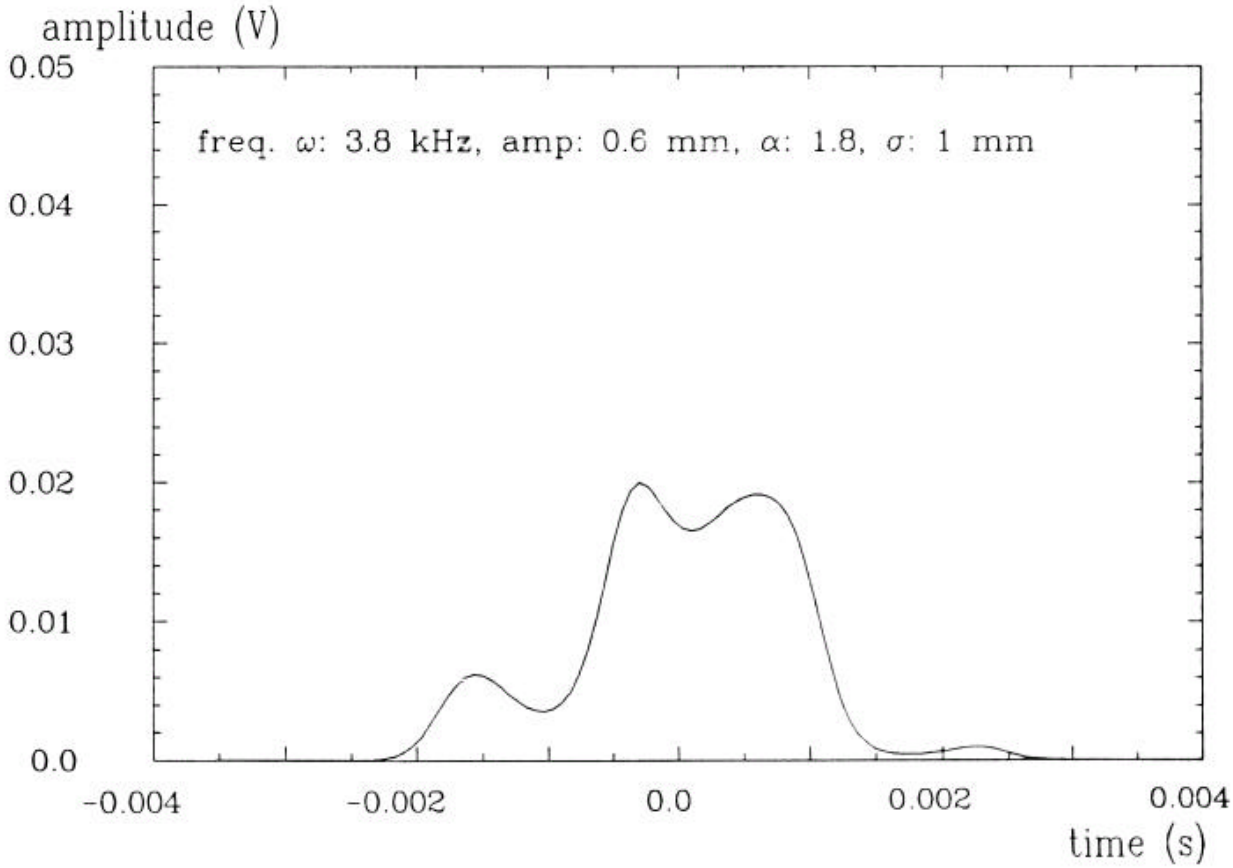


- Wire mounting not fixed
- Black line = Fit of Gauss + Sinus
- White line = fit of real beam

Data from DESY III



Simulation

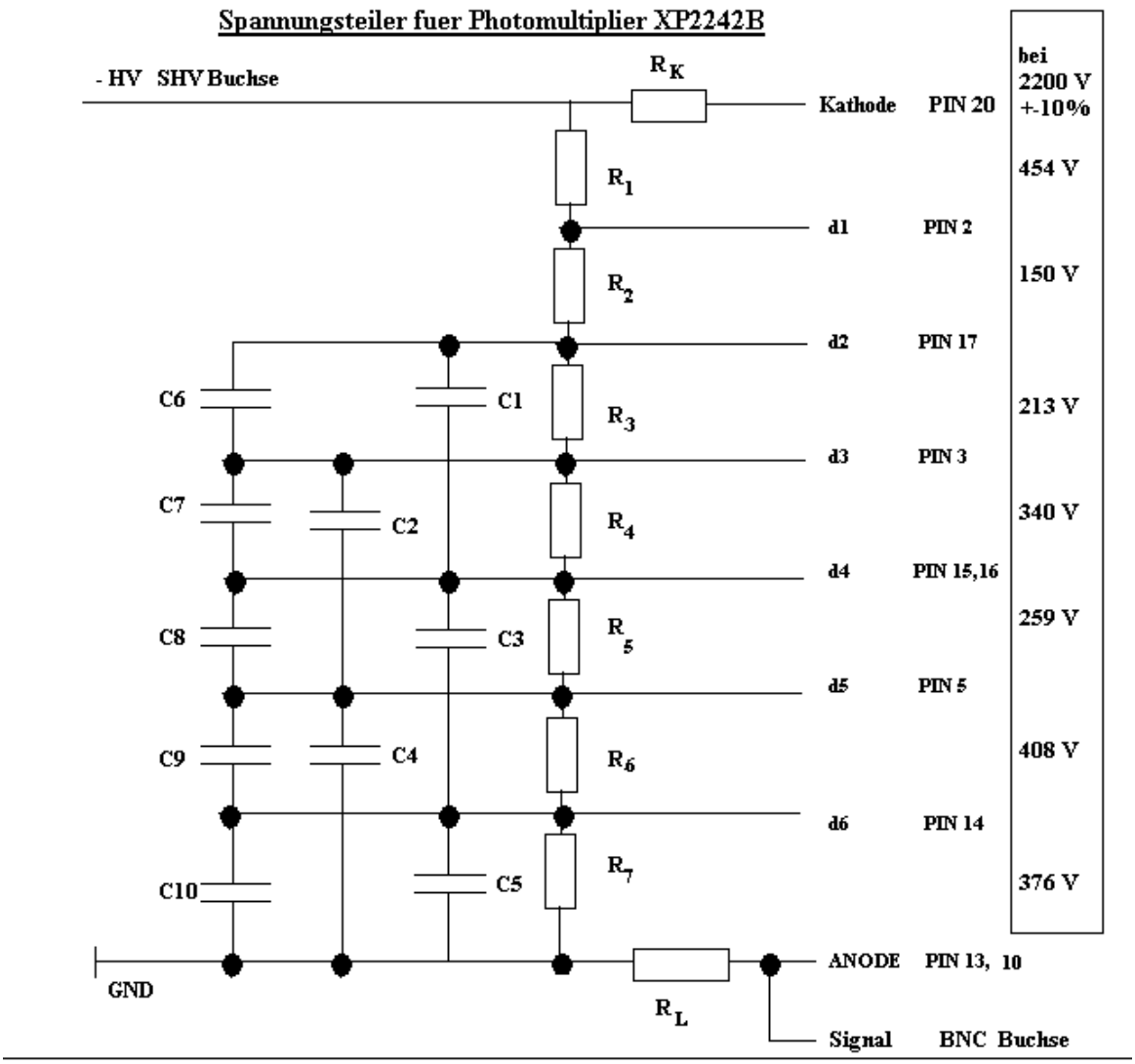


Photomultipliers for wire scanners

type	sensitivity [microA/lm]	ampl.	Photom.	Stages	max lin. [mA]	Diam. [mm]	volt [kV]	continuous curr. [mA]	rise time [ns]	used at
R2238	60	5*10^5	Bi	12		76	1.5	0.1	5.5	CERN PS
XP 2243/B	160	2*10^5	tri	6	200	44	2.5	0.2	1.6	CERN SPS/DESY
XP 2203 B	165	4*10^6	tri	10	200	44	1.2	0.2	3.5	Tevatron
XP2020	70	2*10^8	Bi	12	280	44	3	0.2	1.5	SLAC
			tri = trialkali Photokathode with lower resistance than bialkali							

- Good linearity at high peak output

High peak current voltage divider



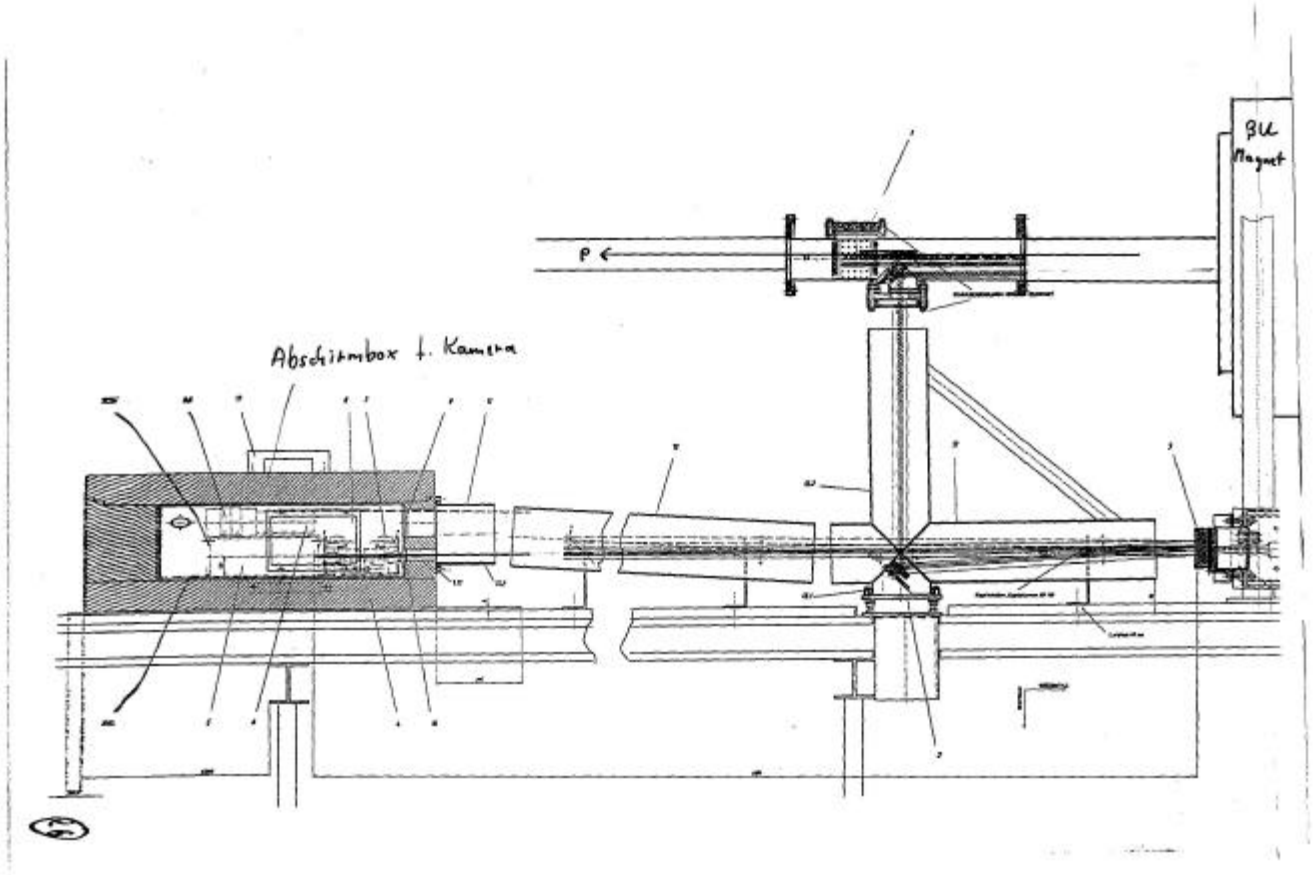
	Widerstaende: Ohm +- 10%	Watt minimum
RK = 1MOhm	R1 = 100 k,	2 W
RL = 1 kOhm	R2 = 33 k,	0.7 W
	R3 = 47 k,	1 W
	R4 = 75 k,	1.5 W
	R5 = 57 k	1.2 W
	R6 = 90 k,	1.9 W
	R7 = 83 k,	1.7 W

Summe = 485 k, 4.5 mA bei 2.2 kV

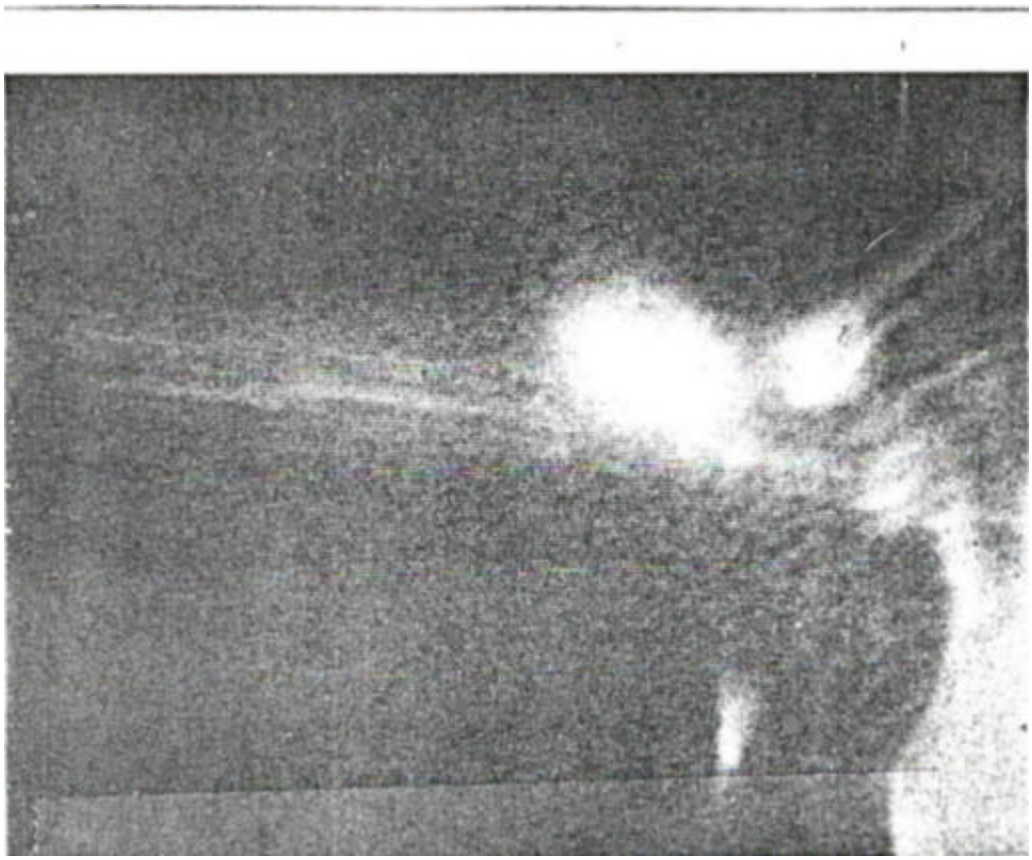
Kapazitaeten:

	Farad +-10%
C1	= 1 n
C2	= 1 n
C3	= 3.3 n
C4	= 4.7 n
C5	= 4.7 n
C6	= 4700 n
C7	= 4700 n
C8	= 10000 n
C9	= 15000 n
C10	= 47000 n

Synchrotron Radiation (edge effect) in HERAp



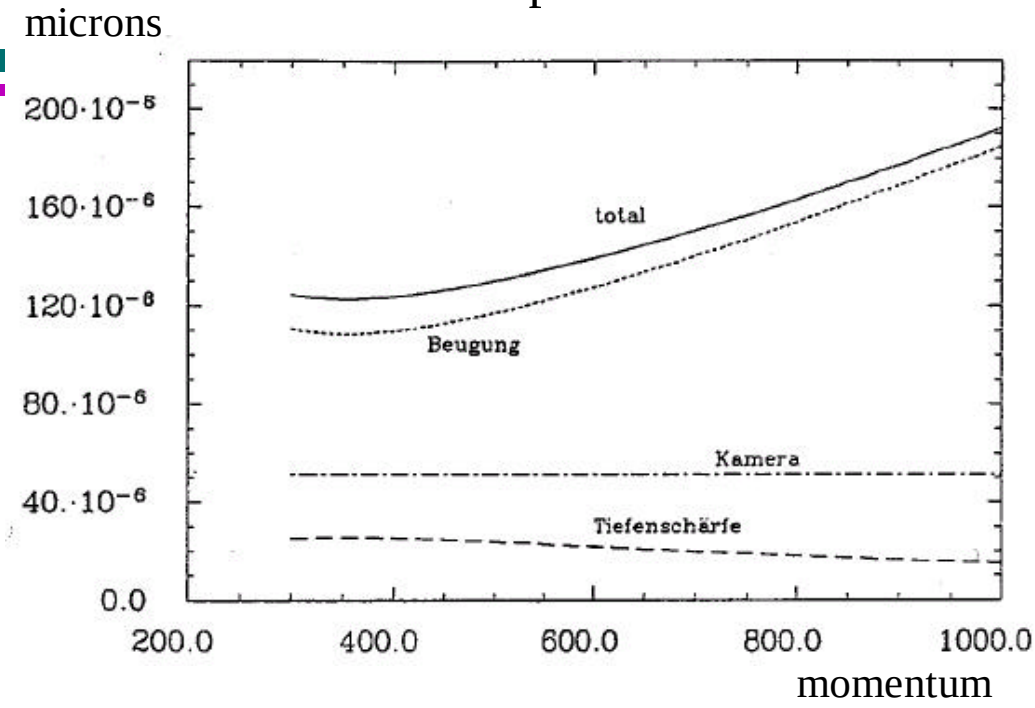
Synchrotron Radiation (edge effect) in HERAp



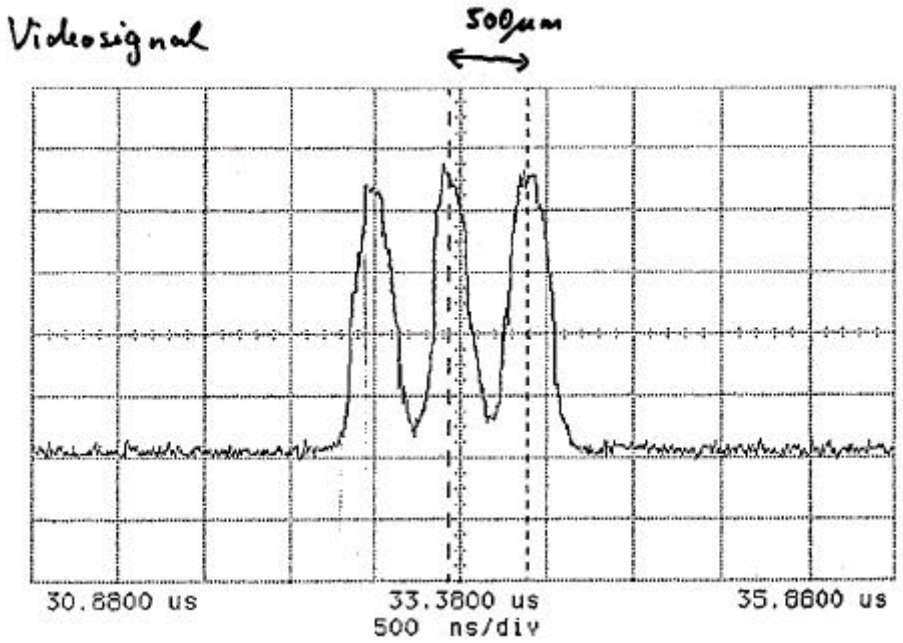
- The first spot of SR-light

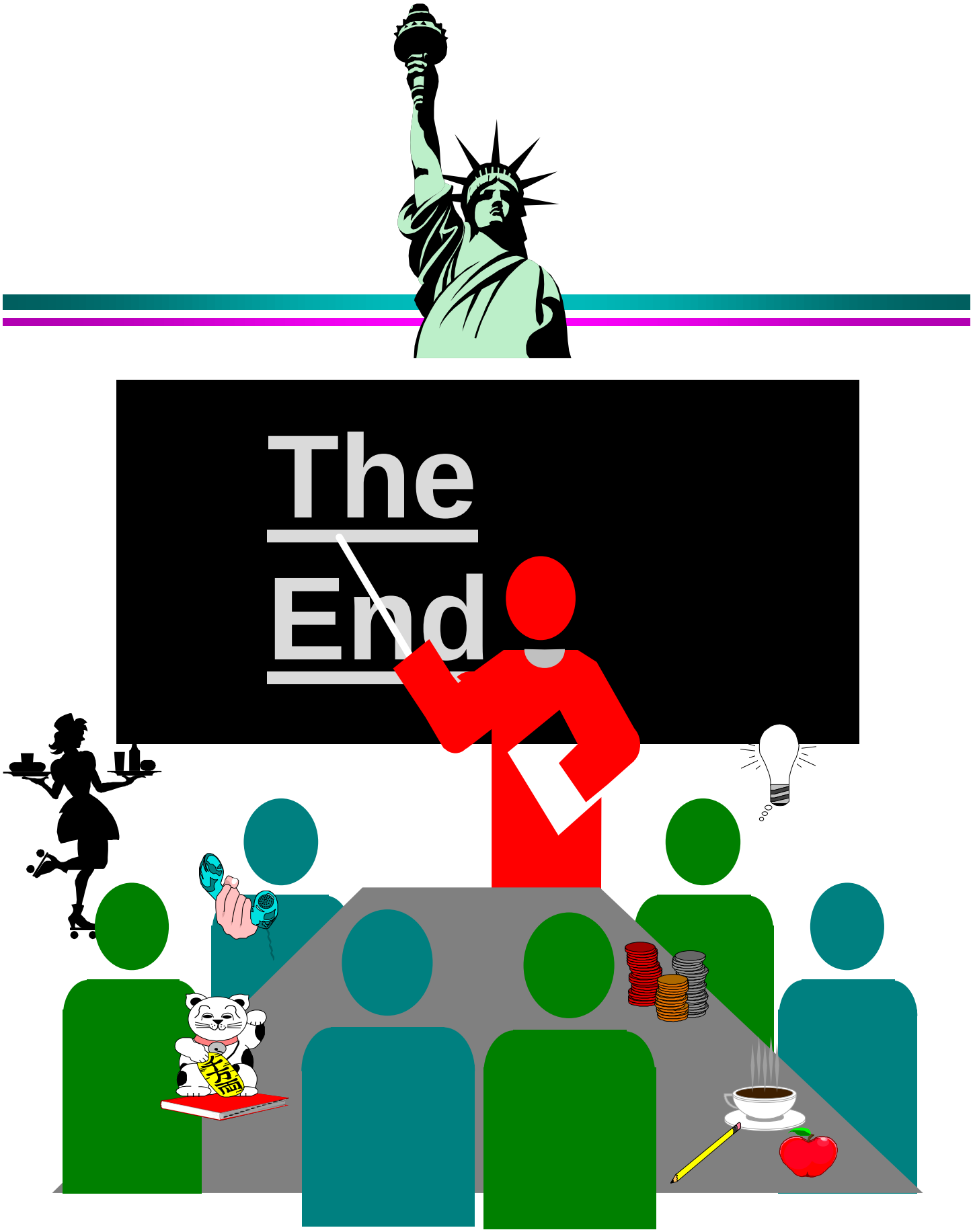
Spatial Resolution

Theoretical Spatial Resolution



Measurement with Laser and 3 slits (500 μm)




The
End