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LHC-type beam in the PS Complex.
Production and Emittance measurements

Report from Machine Development sessions of
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Participants:

The following persons have either participated in beam measurements or in instrumentation devices setting-up and/or repair:
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Aim:

- Produce the highest beam brilliance possible with the present Linac preinjector, in view of the LHC.
- Measure the beam dimensions at 1 GeV with various instruments in the PSB, the PSB/CPS transfer line and in the CPS.

Machine conditions:

Linac:

The Linac output current was raised from the usual 145 mA to 165 mA (fig. 1) by

(i) increase of the source arc current;
(ii) opening the slit apertures in the LEBT (beam line between pre-accelerator and Linac);
(iii) increase of the RF power levels in the Linac tanks.

Note that the higher RF power reduces the useful beam pulse length from 100 to 20 µs. This is fine for the LHC beam but insufficient for high intensity users, thus these studies cannot be done in parallel with operation.

PS Booster:

The beam was injected at 50 MeV into ring 3 by 3-turn betatron stacking. The Q-tuning supplies were programmed to set a working point which varies during the acceleration cycle, starting at injection with (Q_x, Q_y) = (4.28, 5.45). Third order resonances were compensated, and the RF capture efficiency was improved by bunch-flattening with h=10 cavities. Five bunches were then accelerated to 1 GeV, yielding a momentum spread Dp/p of $\pm$ 0.13 % prior to ejection (fig. 2). About 1.8 10^{12} protons per pulse were available for the PS.

These five bunches were strictly stable in both transverse and longitudinal planes; apparently the corresponding feedback sytems, able to tackle almost 10^{13} protons per ring, had an easy job with this beam.

CPS:

The 5 bunches from the PSB were injected at 1 GeV into 5 consecutive, h=20 CPS buckets, filling one quarter on the PS circumference. One bunch was 53 ns long and contained 3.4 E10 particles. Having the same transverse emittance as one bunch of the beam for LHC, it suffered about the same space charge tune spread.

Beam was found particularly unstable in both transverse planes, with an instablity rise time of the order of 100 ms. These instabilities were cured by careful adjustment of the horizontal transverse feedback and introduction of a transverse coupling resulting in $(Q_x, Q_y) = (6.25, 6.25)$. (There is no vertical transverse feedback in the CPS).

Injection oscillation were minimized down to less than 1mm peak to peak.

The longitudinal bunch dimensions are presented in fig 3.

Comparison of MD beam with final LHC scheme:

	Final Scheme for LHC	Machine Study Sessions
Pre-Injector	RFQ 750 keV 200 mA	Cockcroft-Walton 750 keV 200 mA
Linac (50 MeV)	180 mA, $\varepsilon = 1.2\ \mu m$	165 mA, $\varepsilon = 1.5\ \mu m$
PS Booster	4 rings, h=1 bunch flattening by h=2 1.8 10^{12} p/ring 7.2 10^{12} p/pulse 1.4 GeV $\varepsilon = 2.5\ \mu m$ bunch length 190 ns	1 ring, h=5 bunch flattening by h=10 1.8 10^{12} p/ring 1 GeV $\varepsilon = 2.....3\ \mu m$ measured bunches length 5 x 53 ns
PS	flat-bottom 1.4 GeV (1) length 1.2 sec 2 PSB pulses @ 4 rings 1.44 10^{13} p/PS pulse acceleration on h=8 $\varepsilon = 3\ \mu m$	flat-bottom1 GeV (1) length 1.2 sec 1 PSB pulse @ 1 ring 1.8 10^{12} p/PS pulse 5 bunches on flat-bottom $\varepsilon = 2.....3\ \mu m$ measured

(1) Space-charge detuning ΔQ on flat-bottom about the same in both cases.

Measurements:

The bunched beam was kept at 1 GeV for more than one second and then dumped onto an internal target.

Four different measurement devices were used to measure the tranverse beam emittances in each plane:

1. Beamscope, in the PSB ring, triggered a few ms before transfer to the CPS,
2. Three SEM-Grids in the PSB measurement line,
3. Three SEM-Grids in the CPS ring, triggered at injection in the CPS,
4. A Wire scanner in the CPS ring, triggered at various instants along the 1 GeV flat-bottom in the CPS.

Data treatment and results:

The transverse rms. emittances are defined as

$$\varepsilon_{\beta_{x,y}} = \frac{\sigma^2_{\beta_{x,y}}}{\beta_{x,y}}$$

where $\sigma_{\beta_{x,y}}$ is the rms. betatron amplitude and $\beta_{x,y}$ is the Twiss amplitude parameter in the measurement plane. In the presence of momentum spread the horizontal beam size results from a convolution of the betatron distribution with the momentum distribution in the real space. Hence, assuming that the horizontal betatron beam size and the momentum deviation are uncorrelated random variables, the horizontal rms. beam size σ_x writes

$$\sigma_x = \sqrt{\sigma^2_{\beta_x} + D_x\sigma^2_\delta}$$

since the variance of the sum of two arbitrary uncorrelated random variables is equal to the sum of their variances. Here, σ_δ is the rms. momentum spread, and D_x is the dispersion function.

Samples of beam profiles and emittances measured by all 4 devices are presented in fig. 4 to 7. All emittance measurements are plotted in fig. 8 for comparison.

Conclusions:

1. Recent improvements on hardware and software, in particular on Beamscope and the SEM-Grids have been fruitful.
2. Improved consistency is found between measurements with the 4 different devices.
3. The apparent transverse blow-up between PSB and CPS could also be attributed to systematic divergence between the various devices.
4. No significant transverse blow-up is observed along the CPS flat-bottom at 1 GeV, once transverse instabilities are cured.

Next steps:

1. Further improvement of consistency between measurements.
2. Extend comparison to measurements with flip targets.
3. Investigate on instabilities.
4. Use of flat bunches in the PSB to reduce space charge effects.
5. Optimise dispersion matching between PSB and CPS.

Distribution:

PPC distribution list
G. Brianti

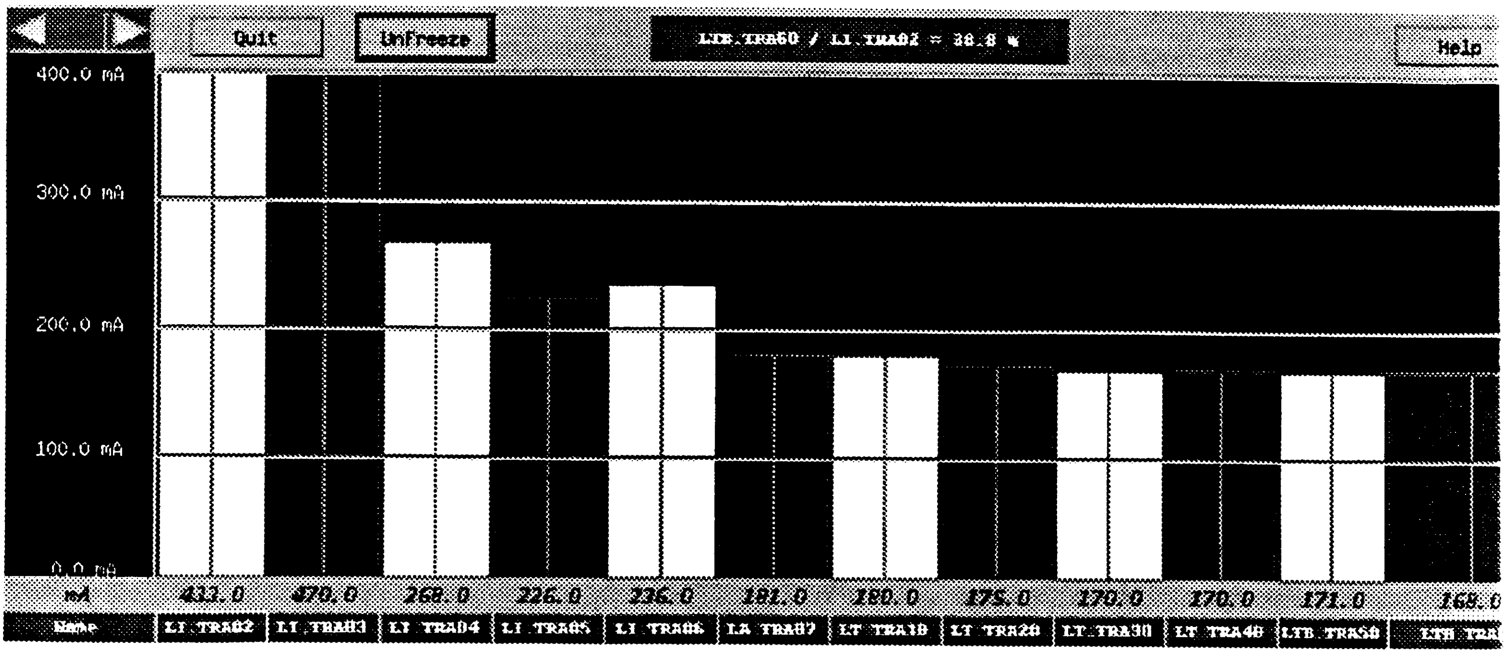


Fig. 1 Linac beam current

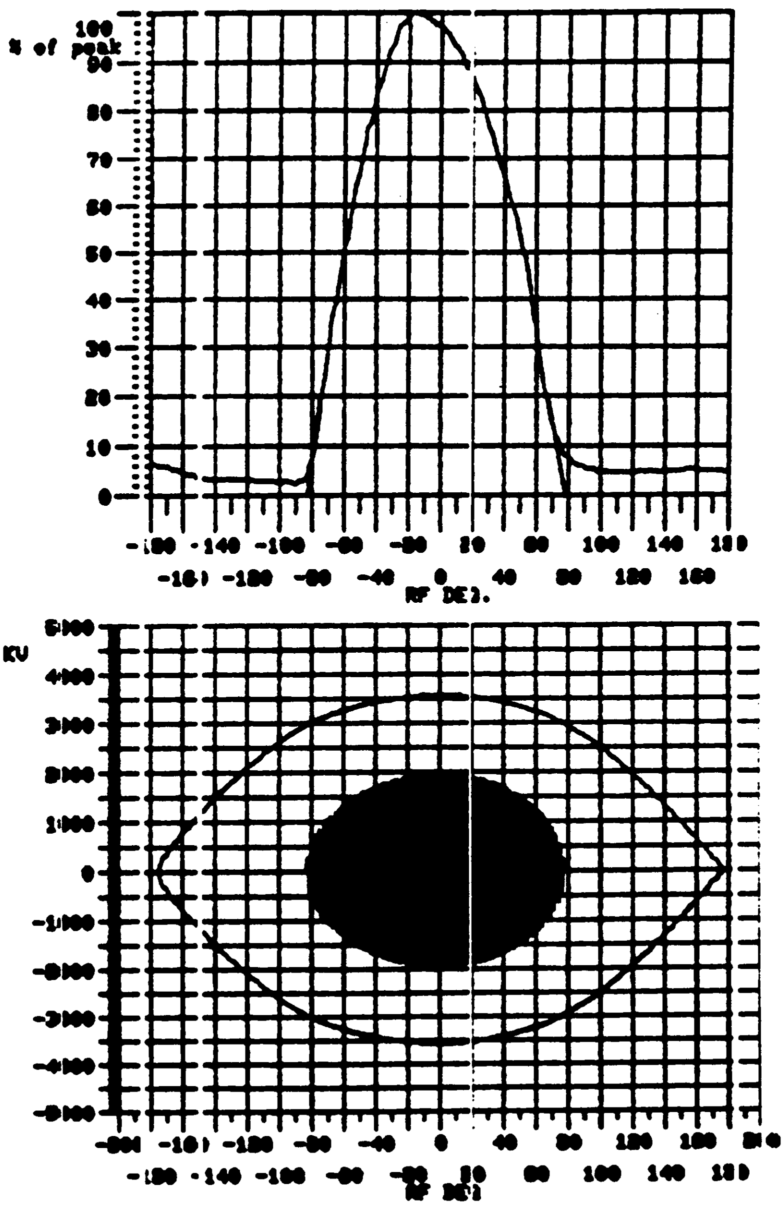


Fig. 2 Longitudinal bunch and bucket dimensions in the PSB

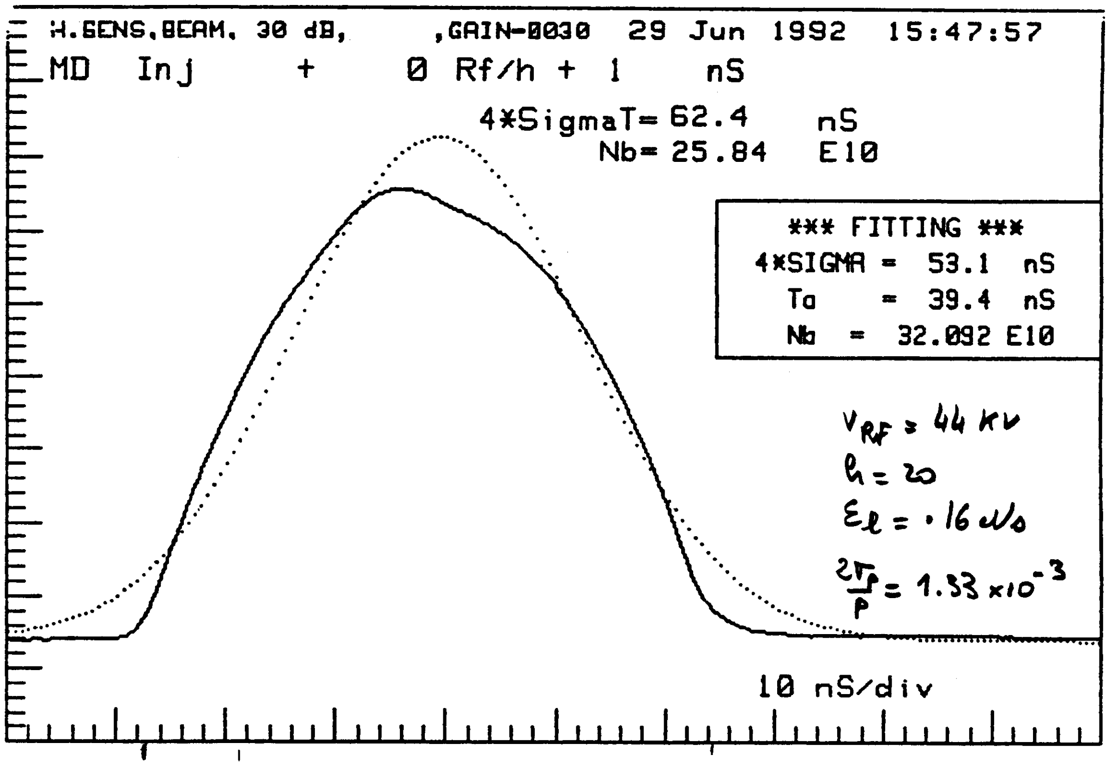


Fig. 3 Longitudinal bunch shape in the CPS

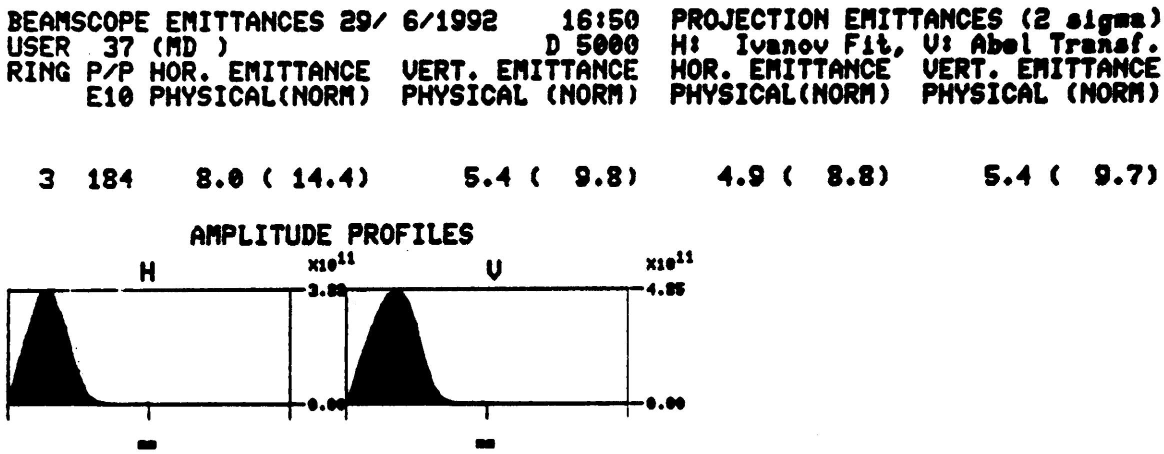
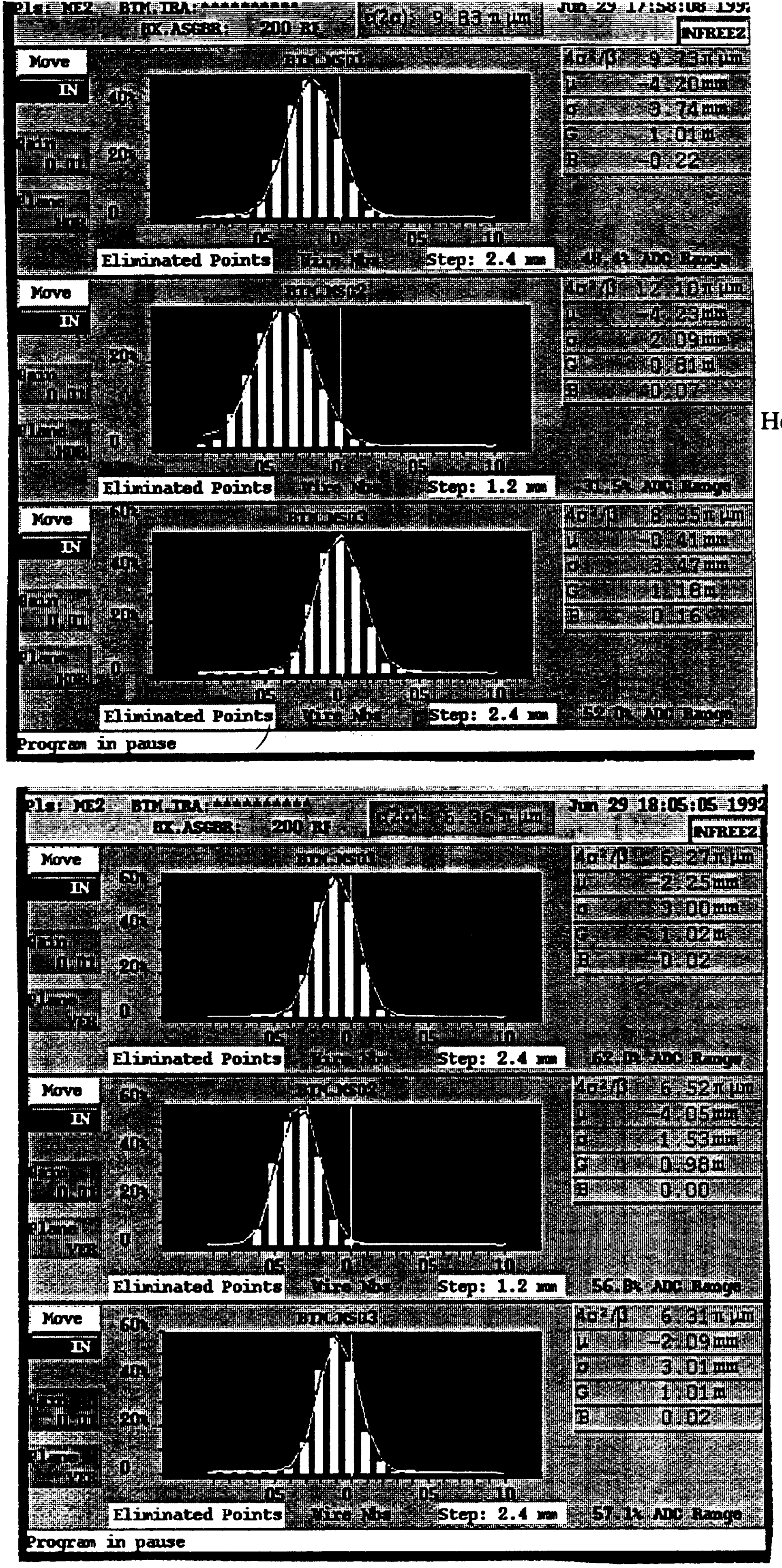


Fig. 4 Amplitude profiles of the beam in the PSB
measured by Beamscope



Horizontal

Vertical

Fig. 5 Transverse beam profile measured on the SEM-Grids of the PSB/CPS transfer line

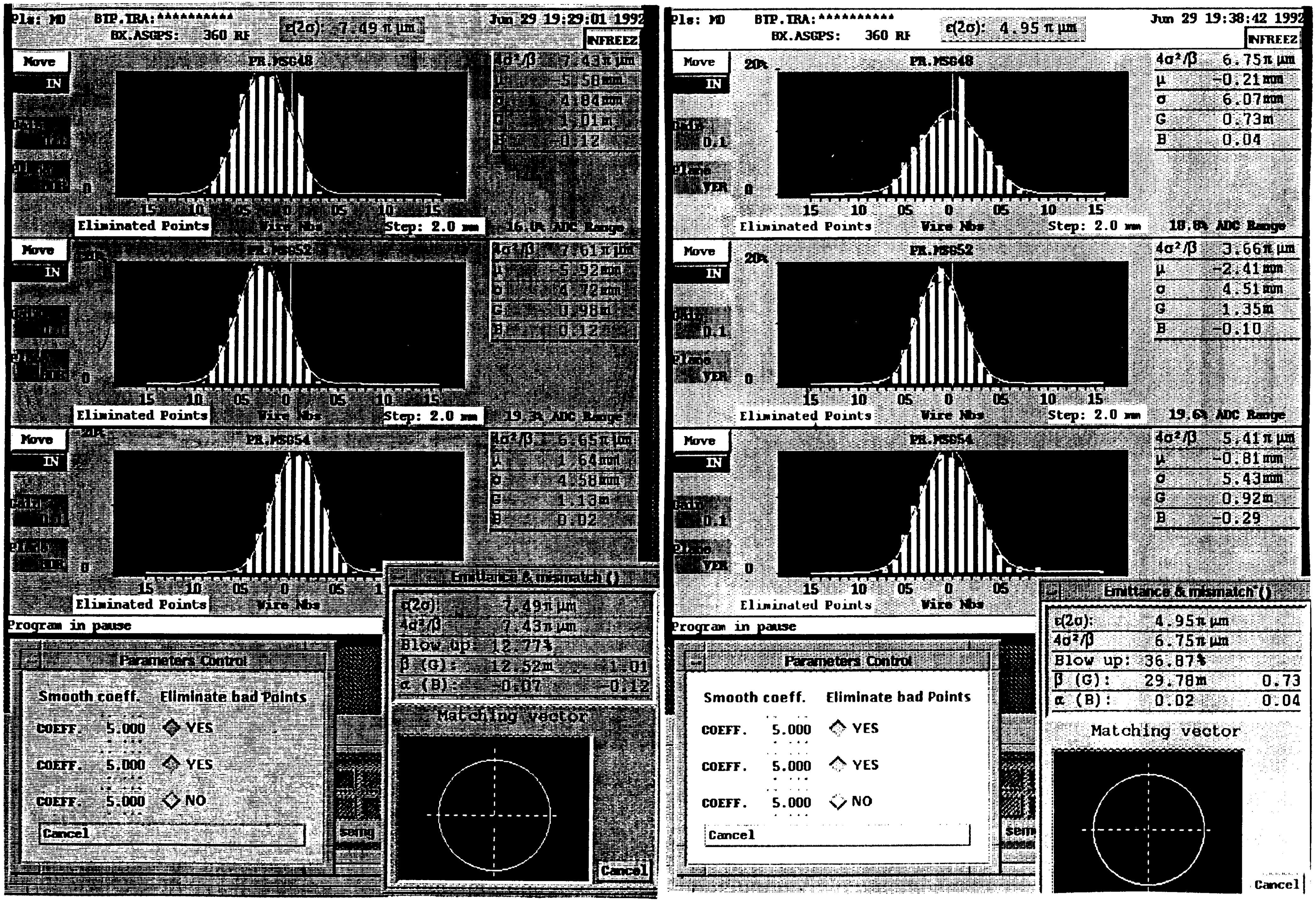
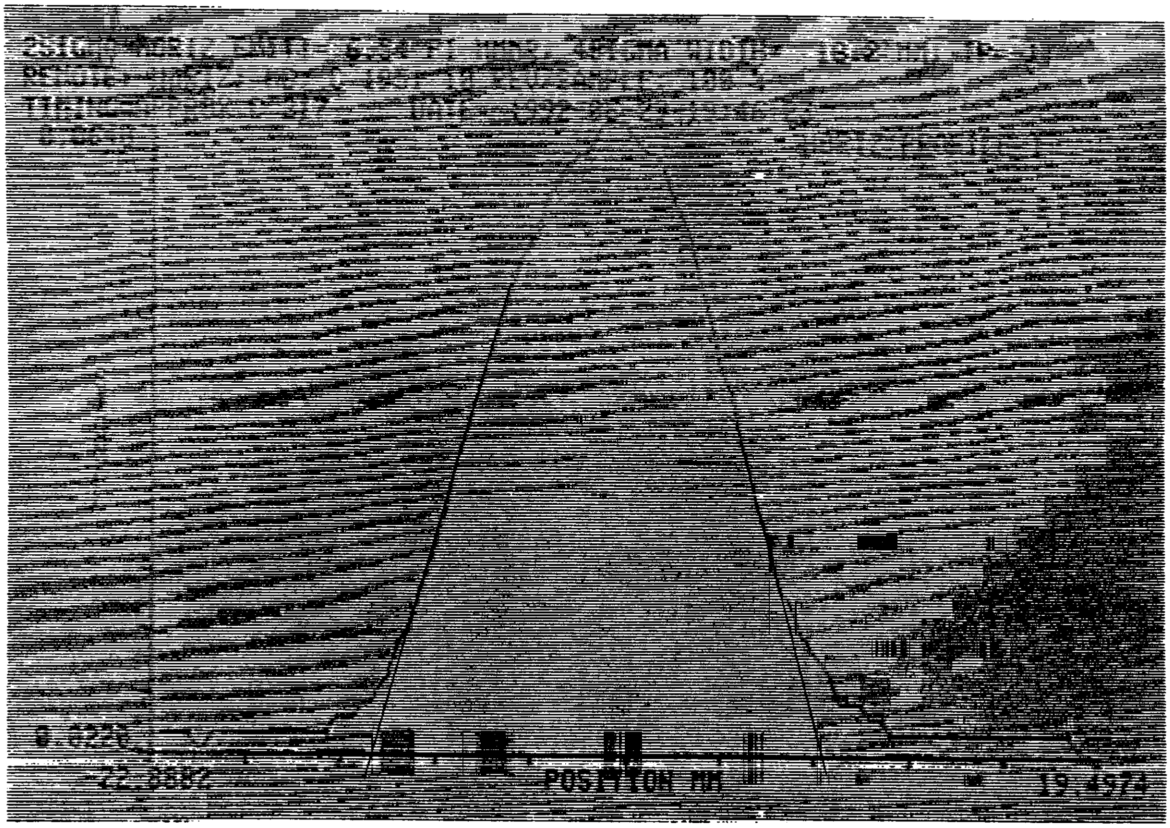
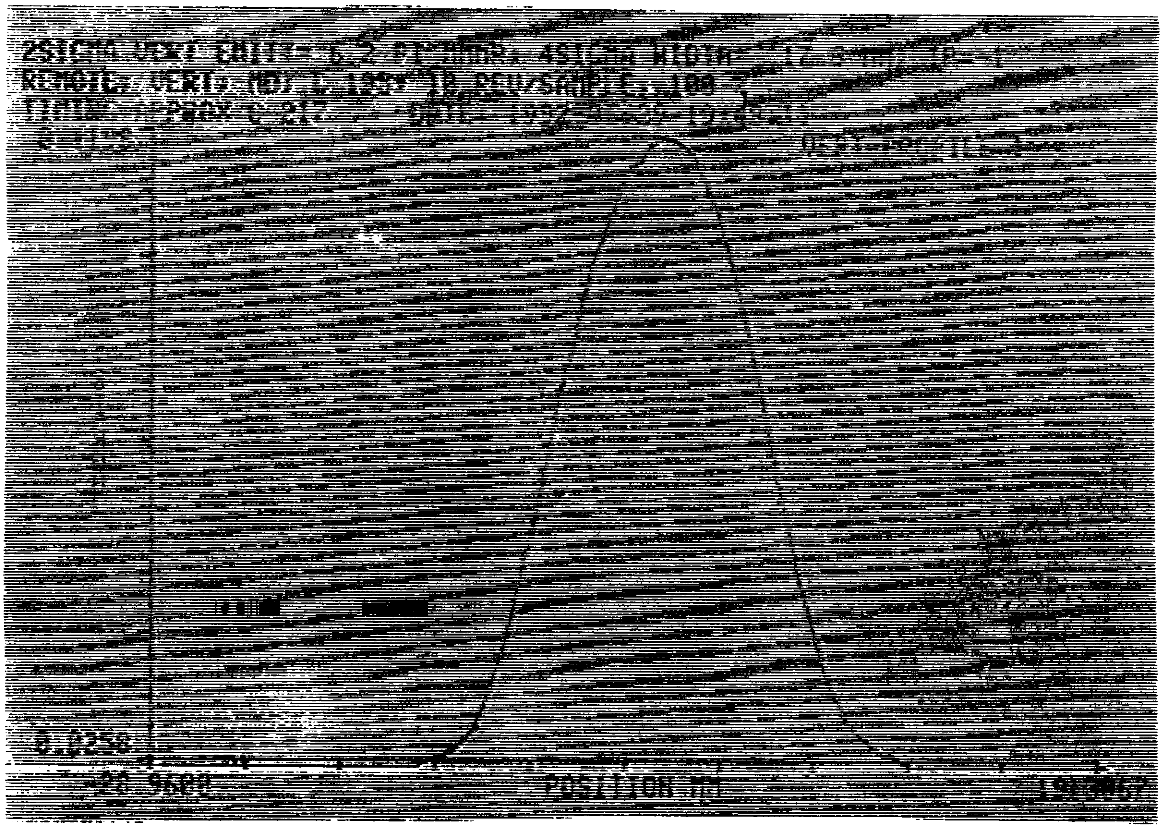


Fig. 6 Transverse beam profiles measured on the CPS SEM-Grids.



Horizontal



Vertical

Fig. 7 Transverse beam profiles measured with the CPS wire-scanner

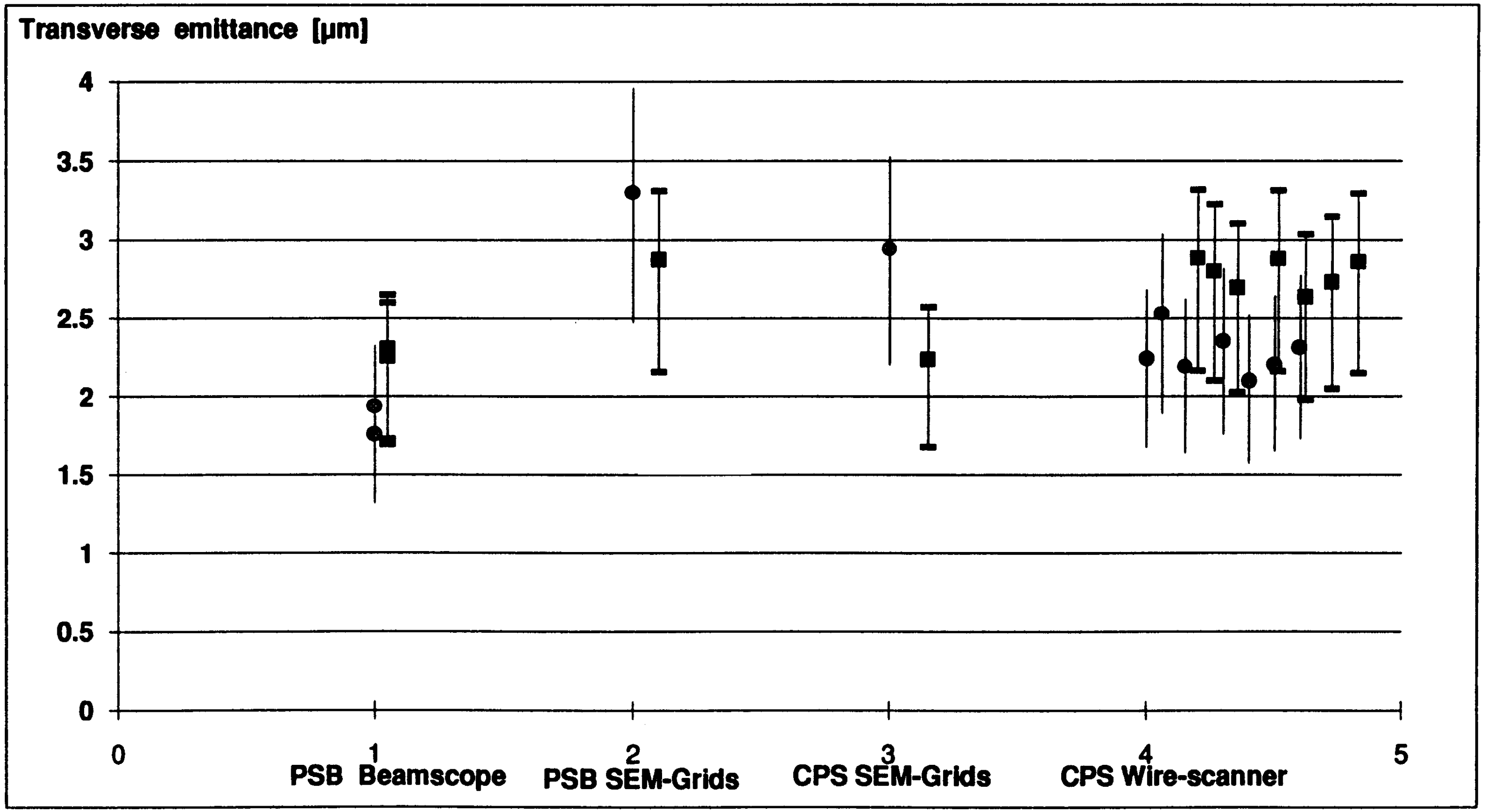


Fig. 8 Transverse emittances measured with various devices in the PSB and CPS.

(horizontal, vertical)