Experience with ion and dust clearing in CERN AA and EPA

-CERN antiproton accumulator (AA) trapped ions (and dust) effects

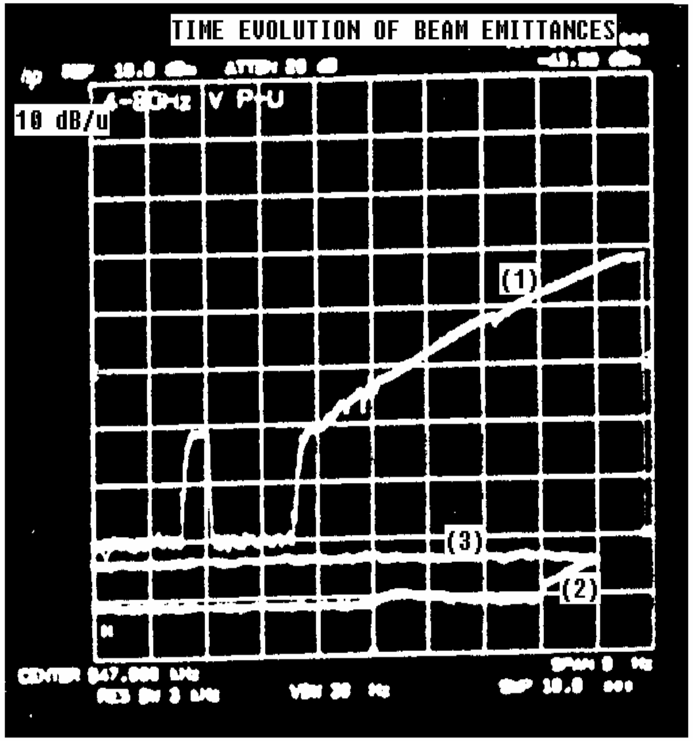
-CERN Electron and Positron Accumulator (EPA) trapped ion effects

- AA and EPA clearing systems :

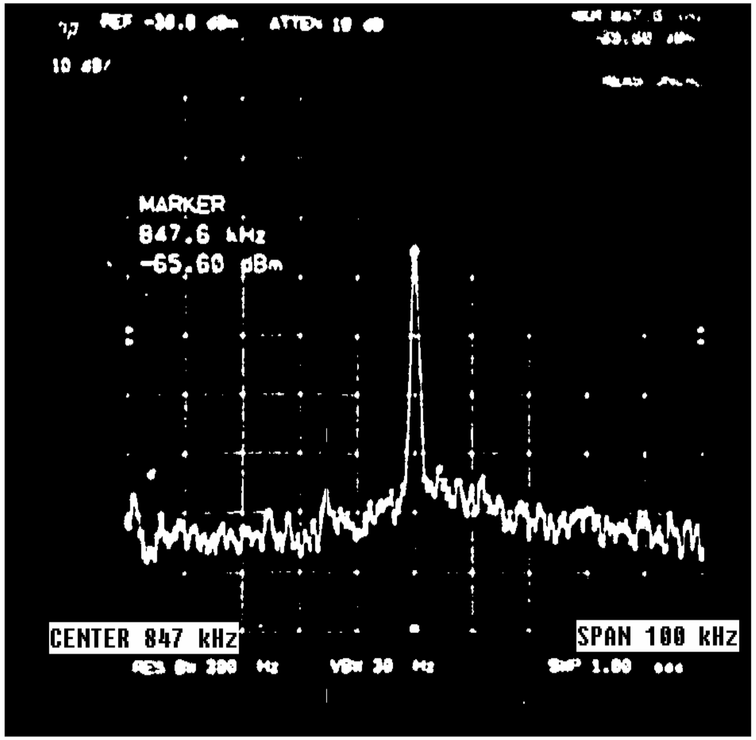
    # Clearing electrodes original design and evolutions
    # Beam shaking

- brief (!) summary of what we learned

Severe ion/pbar instability problems in AA
dipolar and quadrupolar
(coherent effect)



TRACE 1 : HORIZONTAL EMITTANCE (10 sec FULL SPAN)
TRACE 2 : " IDEM " (10 mn FULL SPAN)
TRACE 3 : VERTICAL EMITTANCE (10 mn FULL SPAN)



FREQUENCY SPECTRUM AROUND 847 kHz SHOWING THE COHERENT QUADRUPOLAR SIGNAL OF THE $(5-2Q_h)f_r$ MODE

AA neutralisation incoherent tune shift

Clearing ON:
Neutralisation <1%

Clearing OFF:
Neutralisation 60-70%

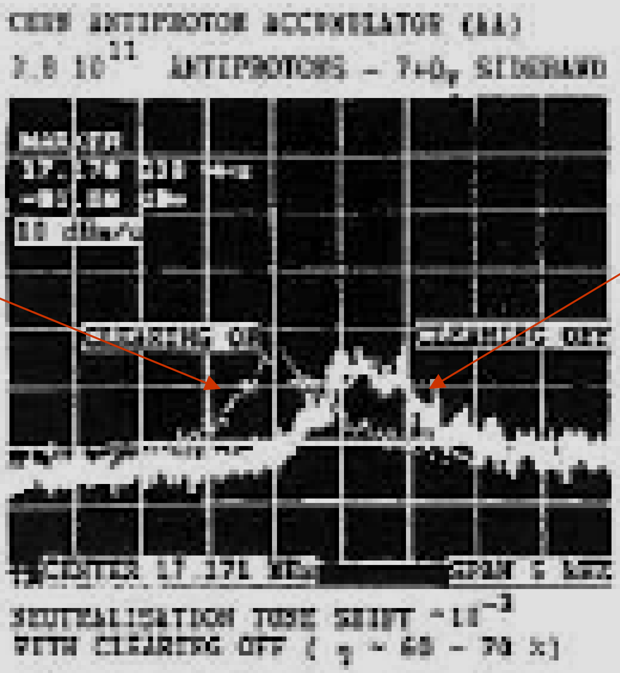
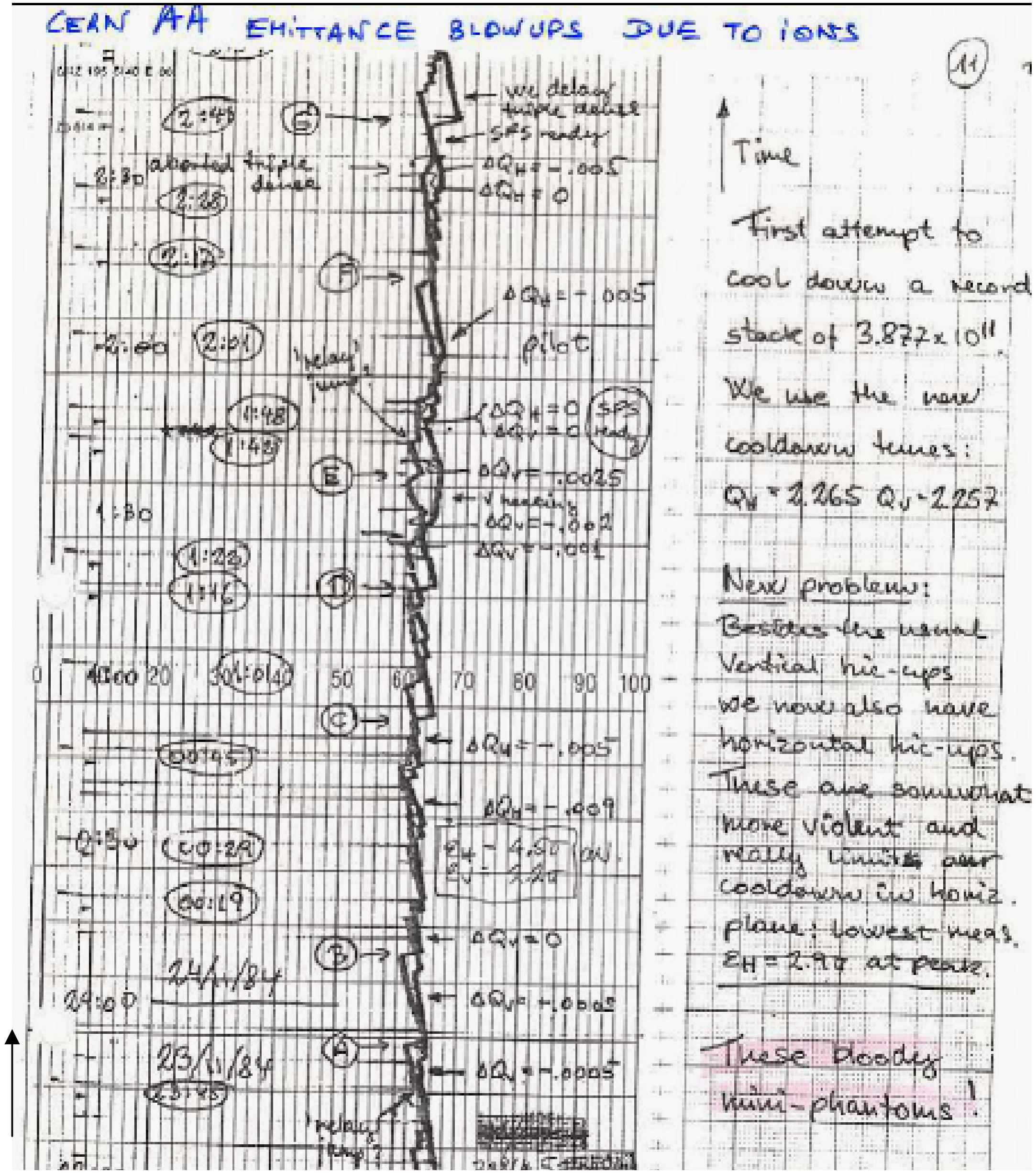


Fig. 2 AA transverse vertical Schottky scan showing the band $(7 + Q_v) f_{rev}$ with clearing electrodes turned OFF (full neutralisation) and ON (little neutralisation)

AA “bloody” phantoms !

Horizontal and Vertical emittances Versus time



CERN AA EMITTANCE BLOWUPS DUE TO IONS

⑪

Time

First attempt to cool down a record stack of 3.877x10¹¹

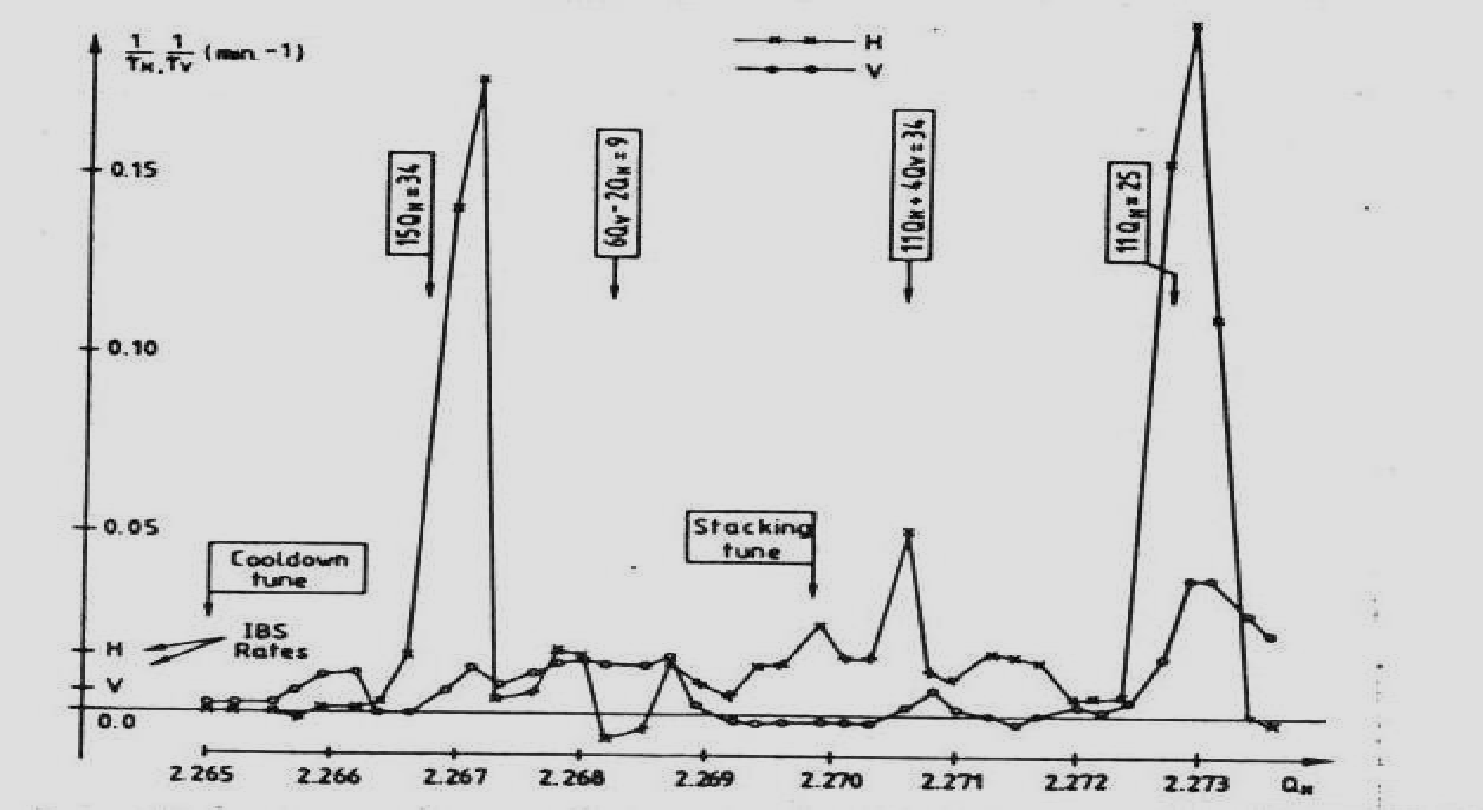
We use the new cooldown tunes: $Q_H = 2.265$ $Q_V = 2.257$

New problem: Besides the usual Vertical hic-ups we now also have horizontal hic-ups. These are somewhat more violent and really limits our cooldown in Horiz. plane: lowest meas. $\varepsilon_H = 2.9\pi$ at peak.

These bloody mini-phantoms !

time

Excitation of HIGH order resonances by ion pockets (AA) incoherent effect



CERN AA:effect of charged microparticles trapped into the beam

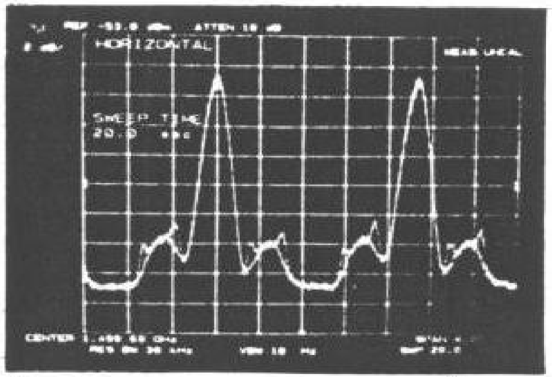


Fig 4. Schottky sidebands after 3min near $11Q_H = 25$.

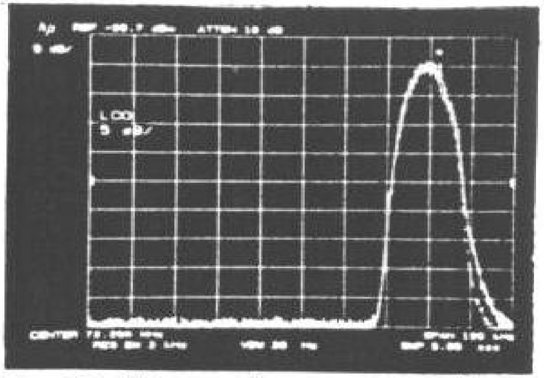


Fig. 5. Momentum distribution with low energy tail.

<u>Effects of Charged Microparticles Captured in the Beam</u>

The sudden onset of an intermittent and often violent emittance growth ($\tau \approx$ 1 min to 1 h), not accompanied by coherent signals is often observed. The abnormal growth sometimes disappears suddenly after a few minutes (Fig.6~~7a~~); sometimes it tapers off ~~(Fig. 7b)~~;

..and…
Beam loss !

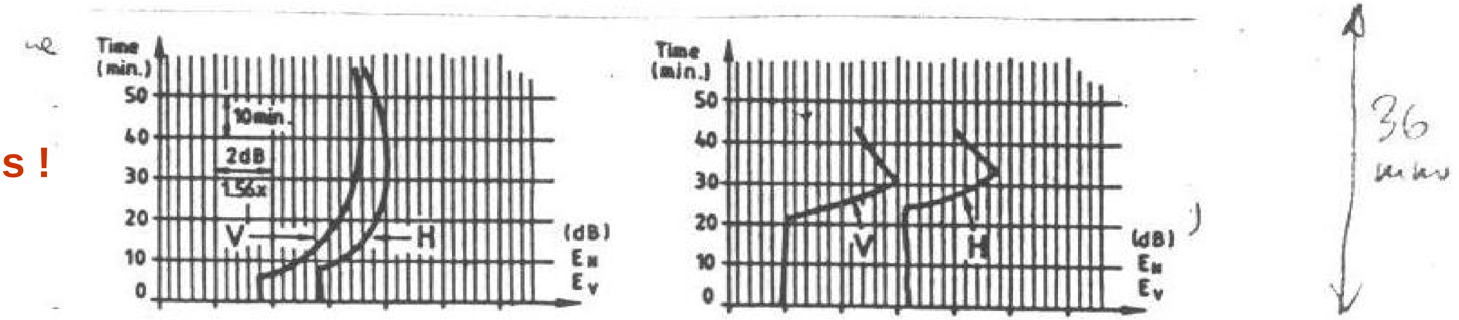


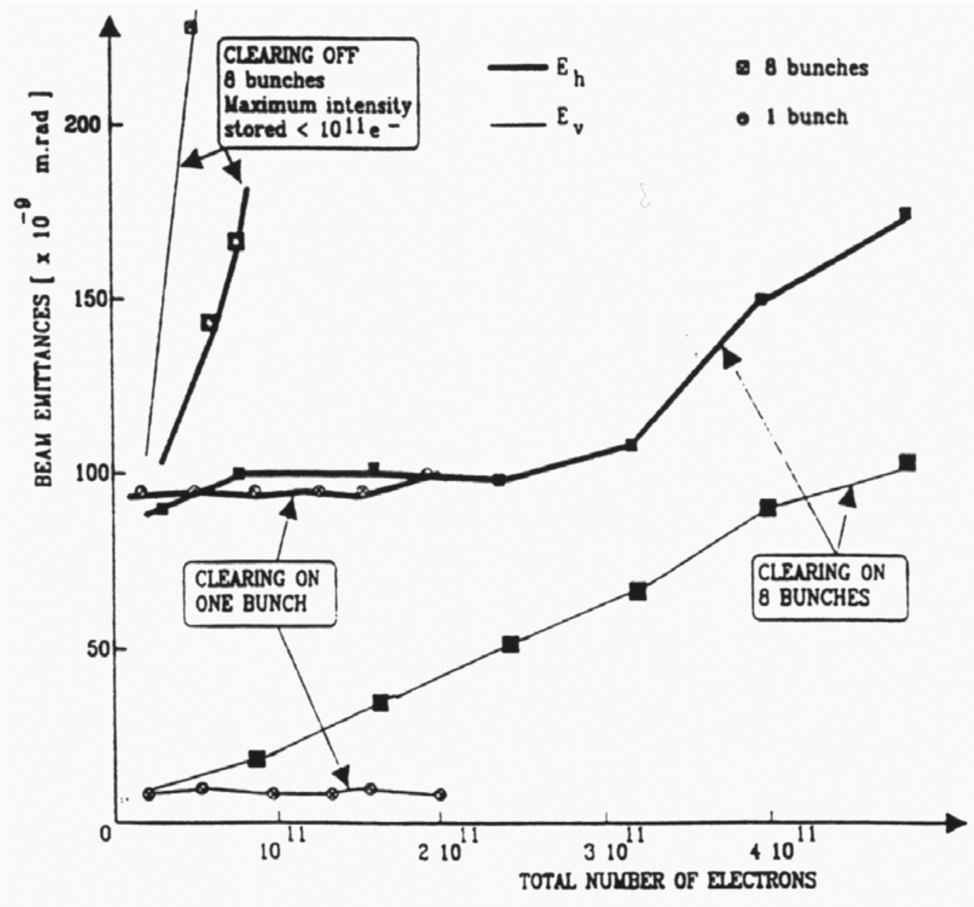
Fig.6~~7~~ - Sudden emittance growth from captured, charged microparticle.

Cern electron/position accumulator

(120 m, 600 MeV, 8 bunches)

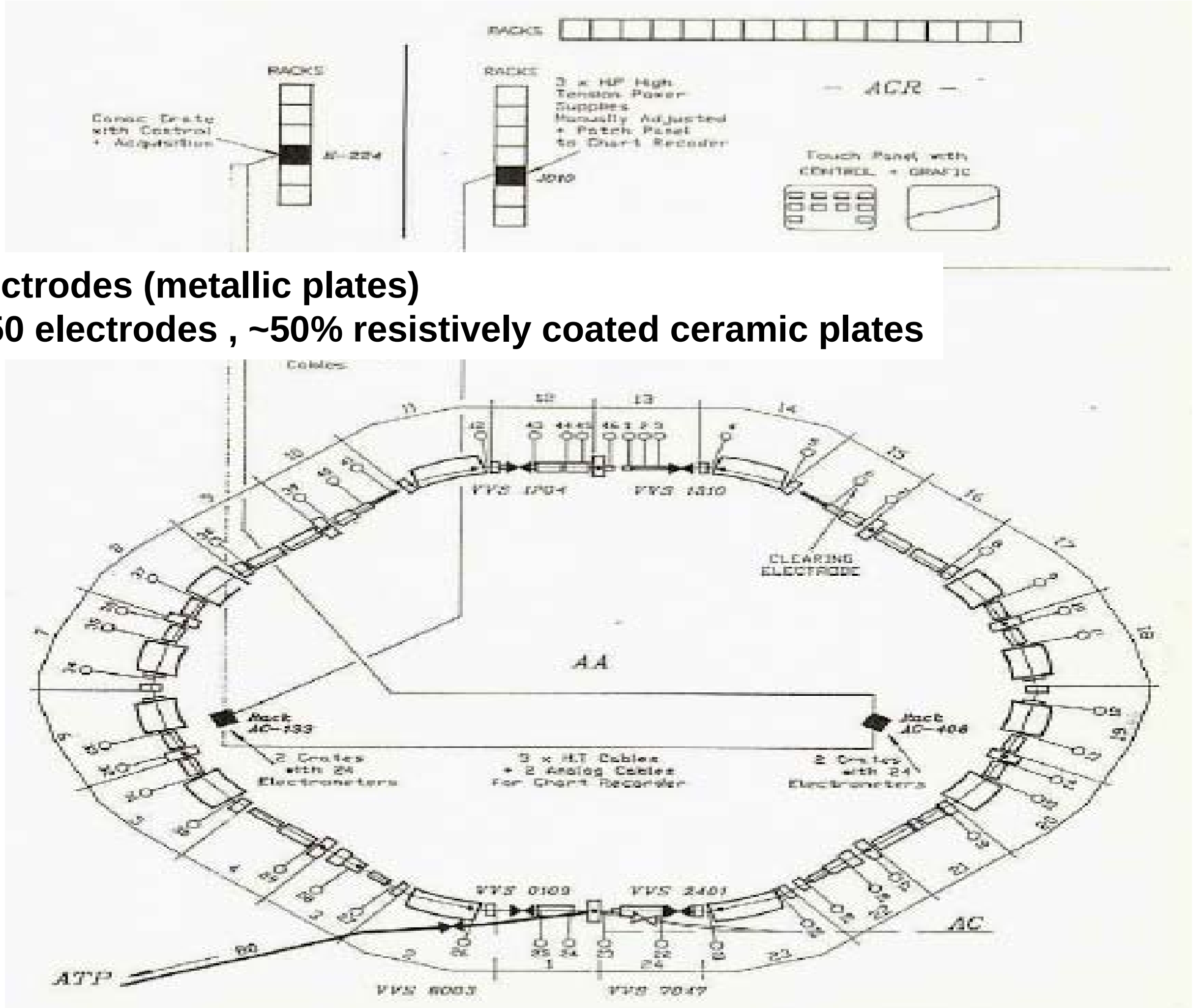
- Poor lifetime
& low beam current
with clearing
electrodes off.

(high neutralisation)



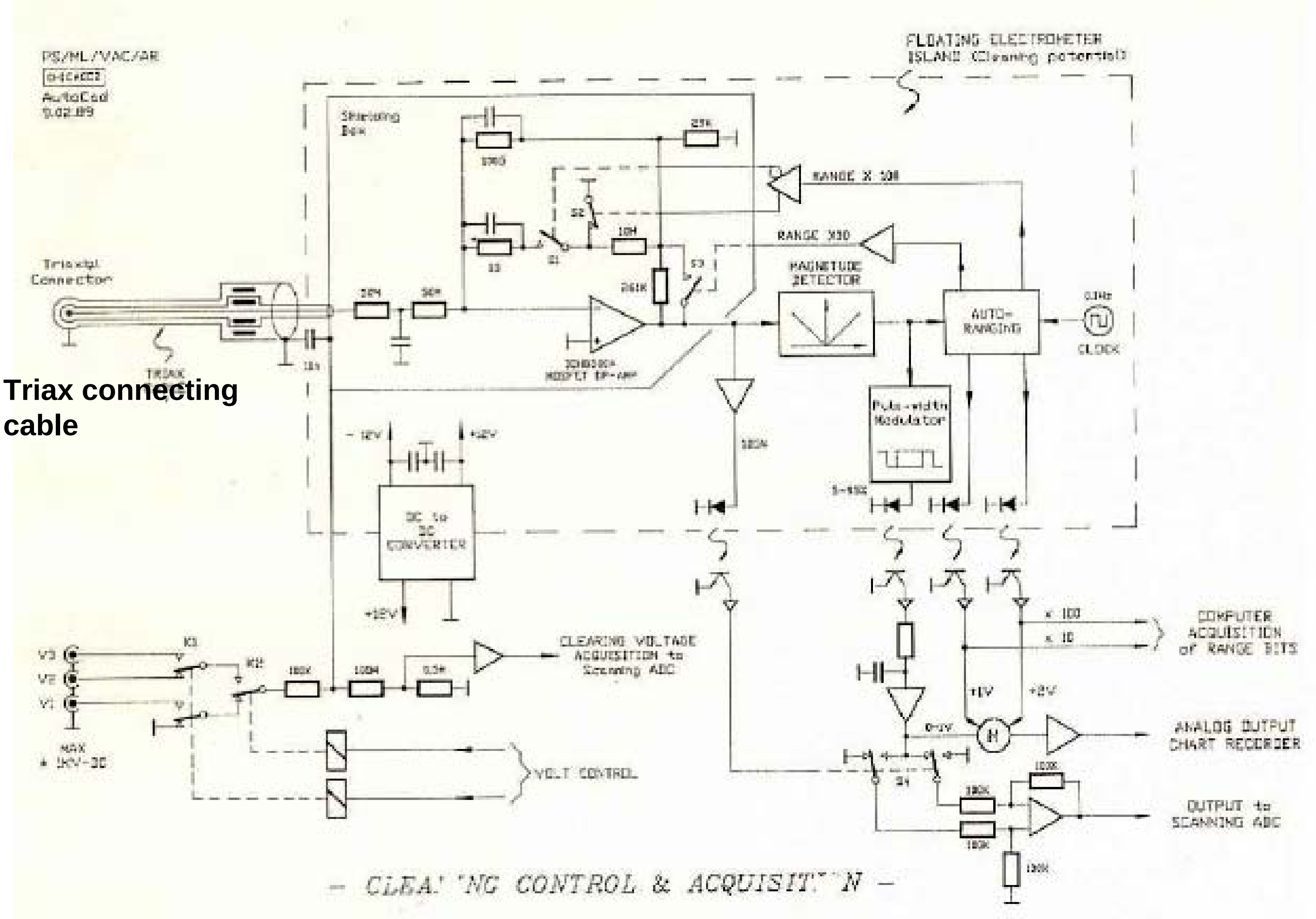
AA clearing system (after improvements)

Features:
- -“quick” change from positive to negative adjustable DC voltage
- -individual measurement of clearing current (in picoamps)
- -polarised BP PU’s in quads
- -continuous upgrade with resistively plated ceramics in LS and dipoles



Initially : 20 electrodes (metallic plates)
At the end : > 50 electrodes , ~50% resistively coated ceramic plates

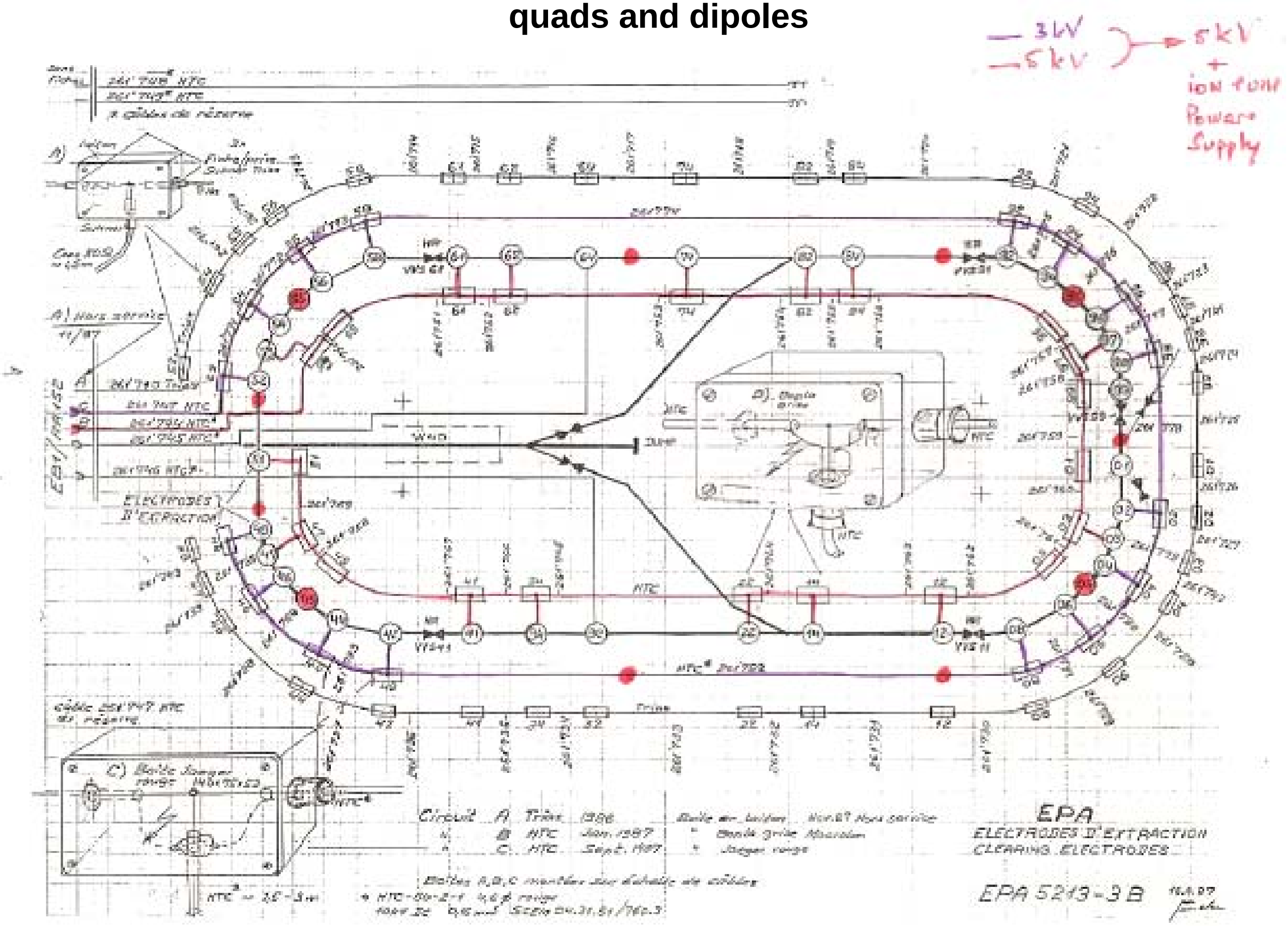
AA clearing electrode control and acquisition of the clearing current (F.Pedersen)



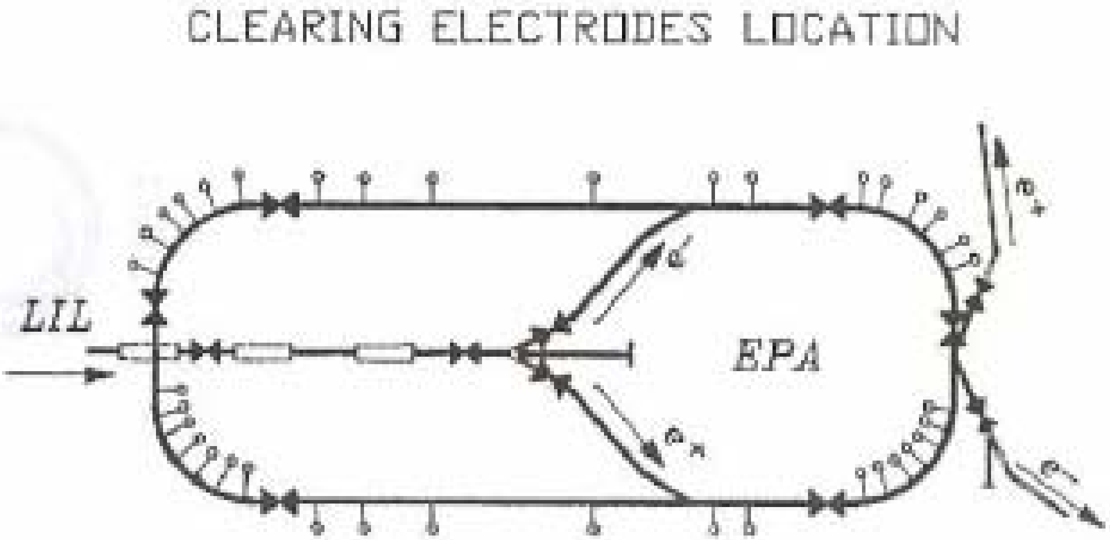
Triax connecting cable

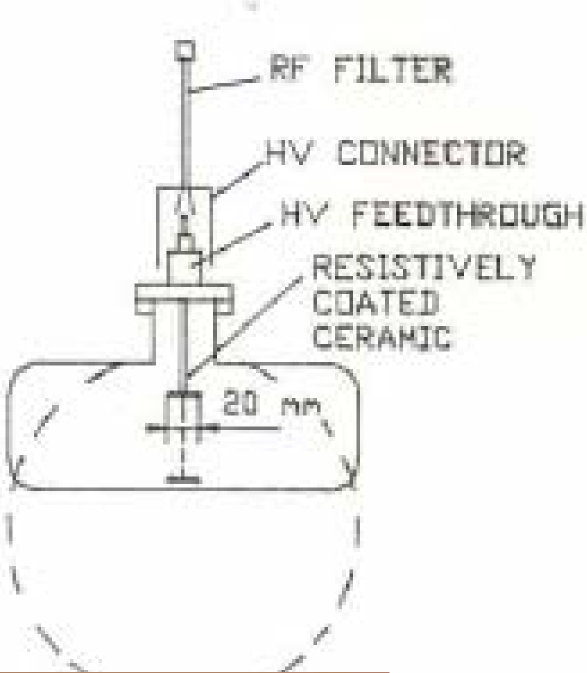
EPA clearing system after improvements

Features:
- -3 series circuits (triax 1986, HV jan 1987, HV sept 1987)
- -global measurement of clearing current (in nanoamps) (triax circuit)
- -polarised BP PU's in quads
- -continuous upgrade with resistively plated ceramic buttons in LS , quads and dipoles

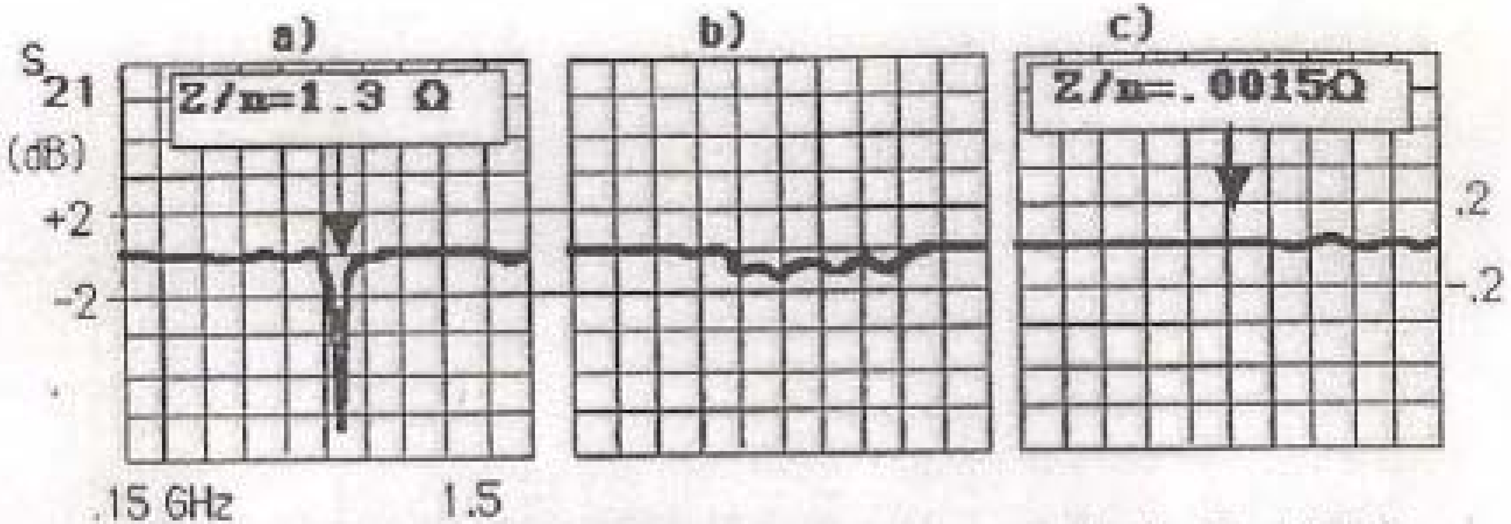


“Button” EPA clearing electrodes





Possible electrode drawback : coupling with the beam (from F.Caspers):



LONGITUDINAL IMPEDANCE: $Z = 2 Z_0 (10^{(S_{21}/20)} - 1)$; $Z_0 = 125\ \Omega$

S_{21} : TRANSMISSION COEFFICIENT

a) metallic electrode

b) Metallic electrode with RF filter

c) Ceramic electrode with resistive coating and RF filter

Required clearing field to fully remove ions

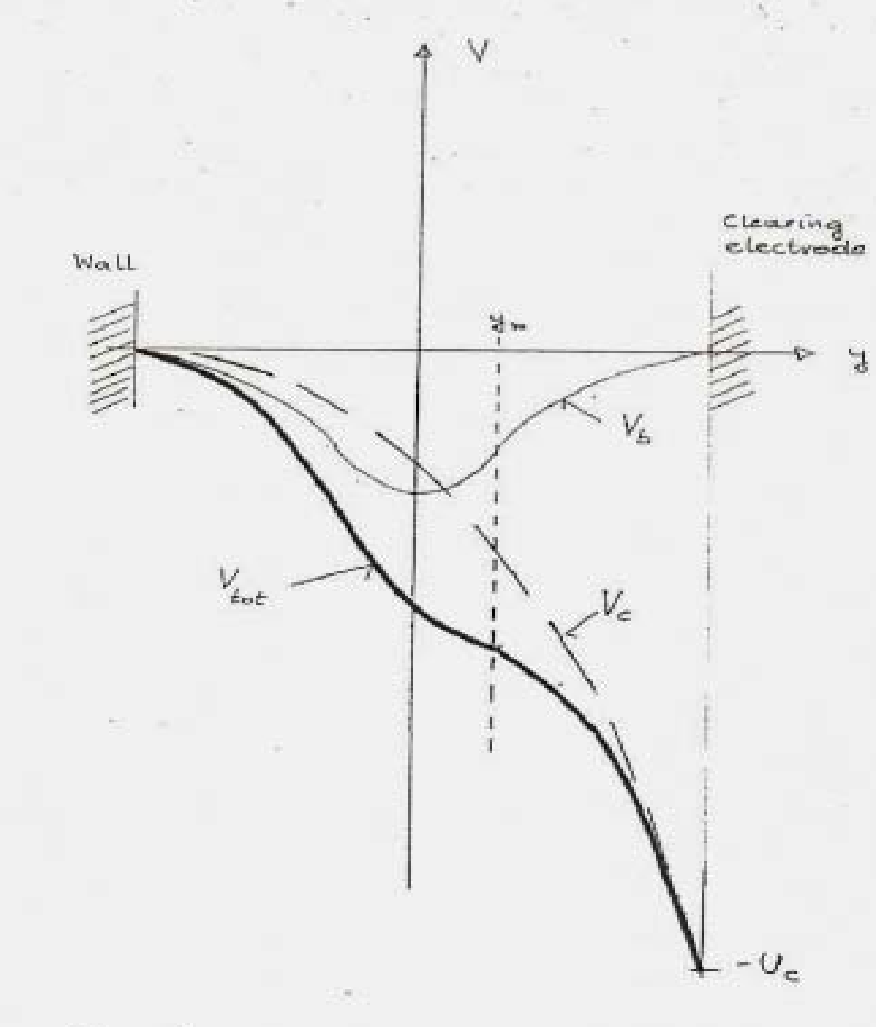
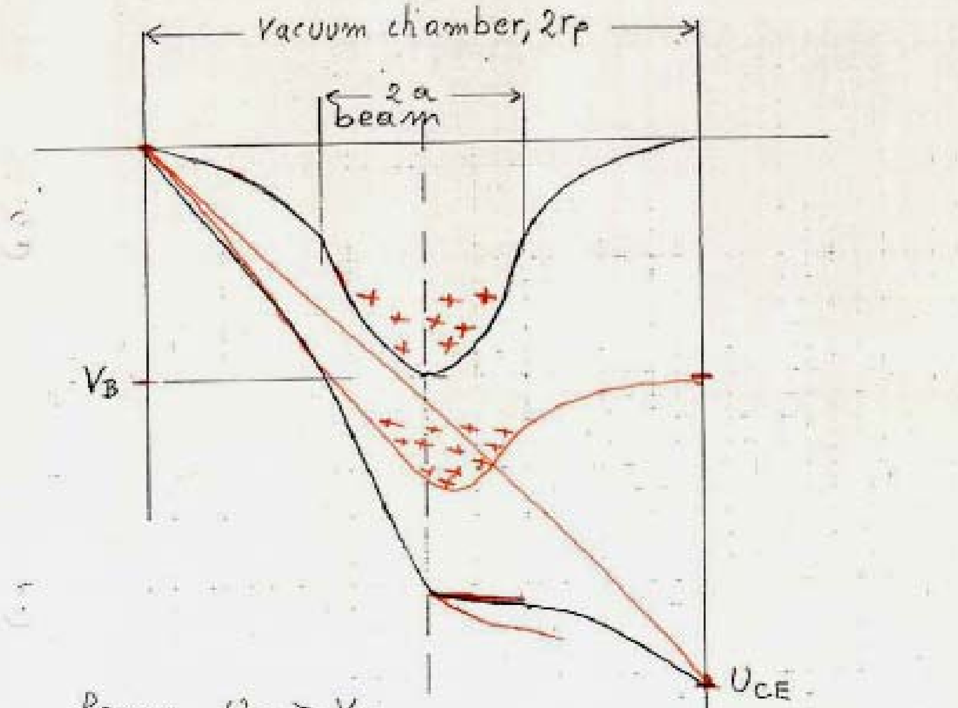


Fig. 1 Beam potential V_b, clearing potential V_c and total potential V as a function of y at electrode (x=0).

Clearing electrodes

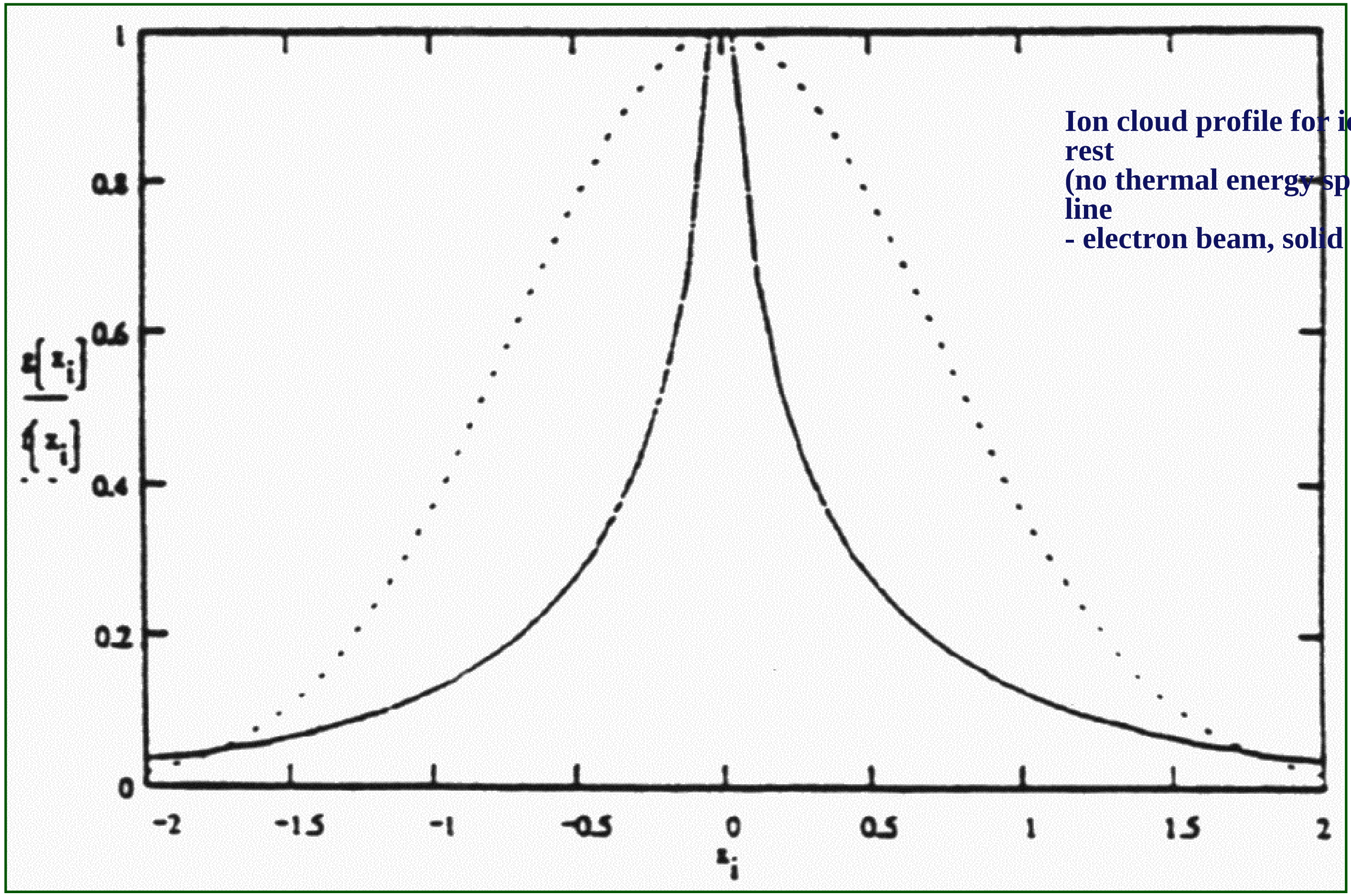
must create locally an external electric field > field of the beam



Hence $U_{CE} > V_B$
Clearing field provides also longitudinal gradient.

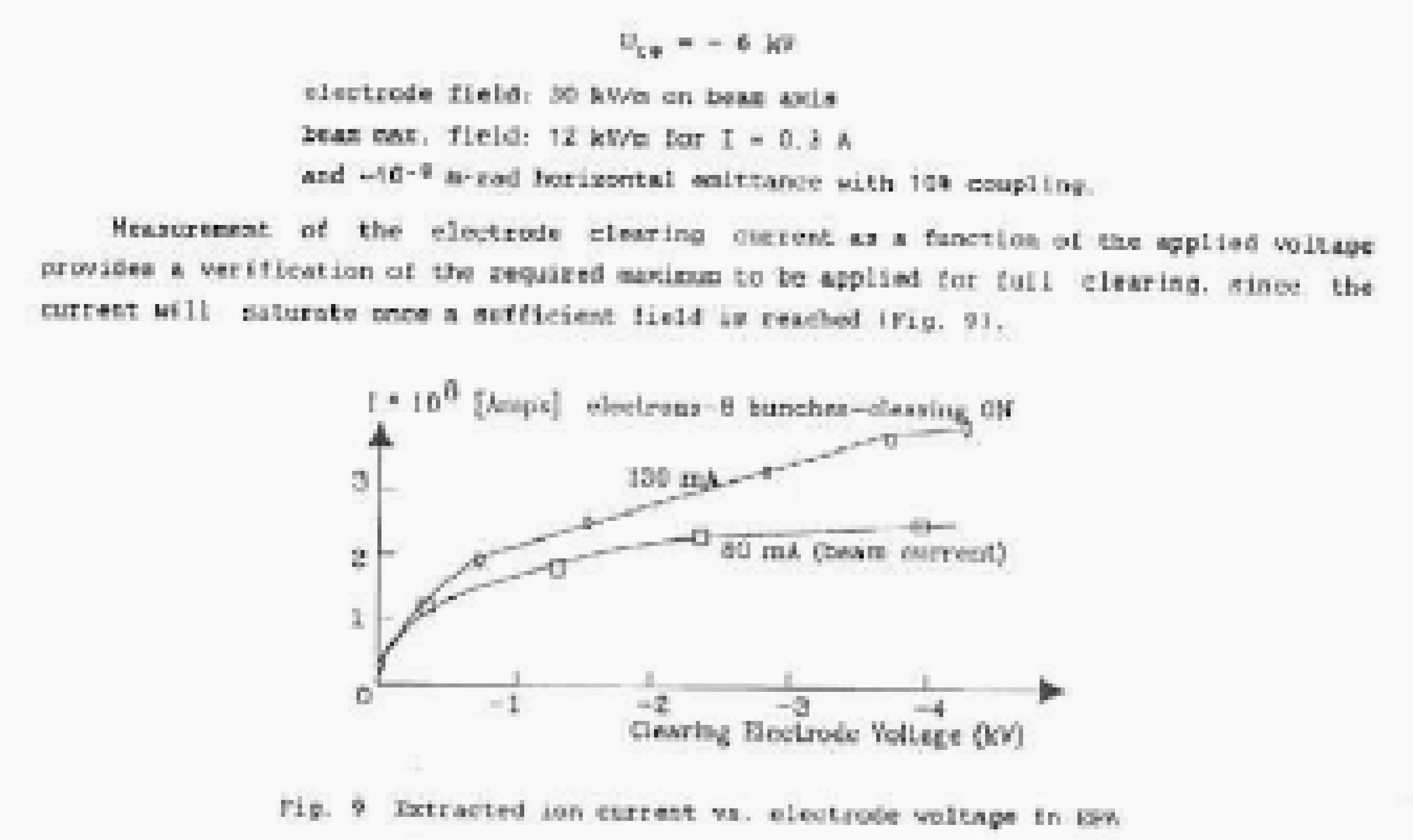
$$E(a) = \frac{I}{2\pi\beta c\varepsilon_0 a} < \frac{U_{CE}}{2r_p}$$

Required clearing field to fully remove ions…caveat : transverse ion distribution is not (necessarily) a replica of the beam ! (P.Tavares) (one must also take into account longitudinal drift velocities)



Ion cloud profile for ions created at rest (no thermal energy spread) Dashed line - electron beam, solid line - ion cloud.

EPA clearing current as function of clearing voltage



$U_{cw} = - 6$ kV

electrode field: 30 kV/m on beam axis

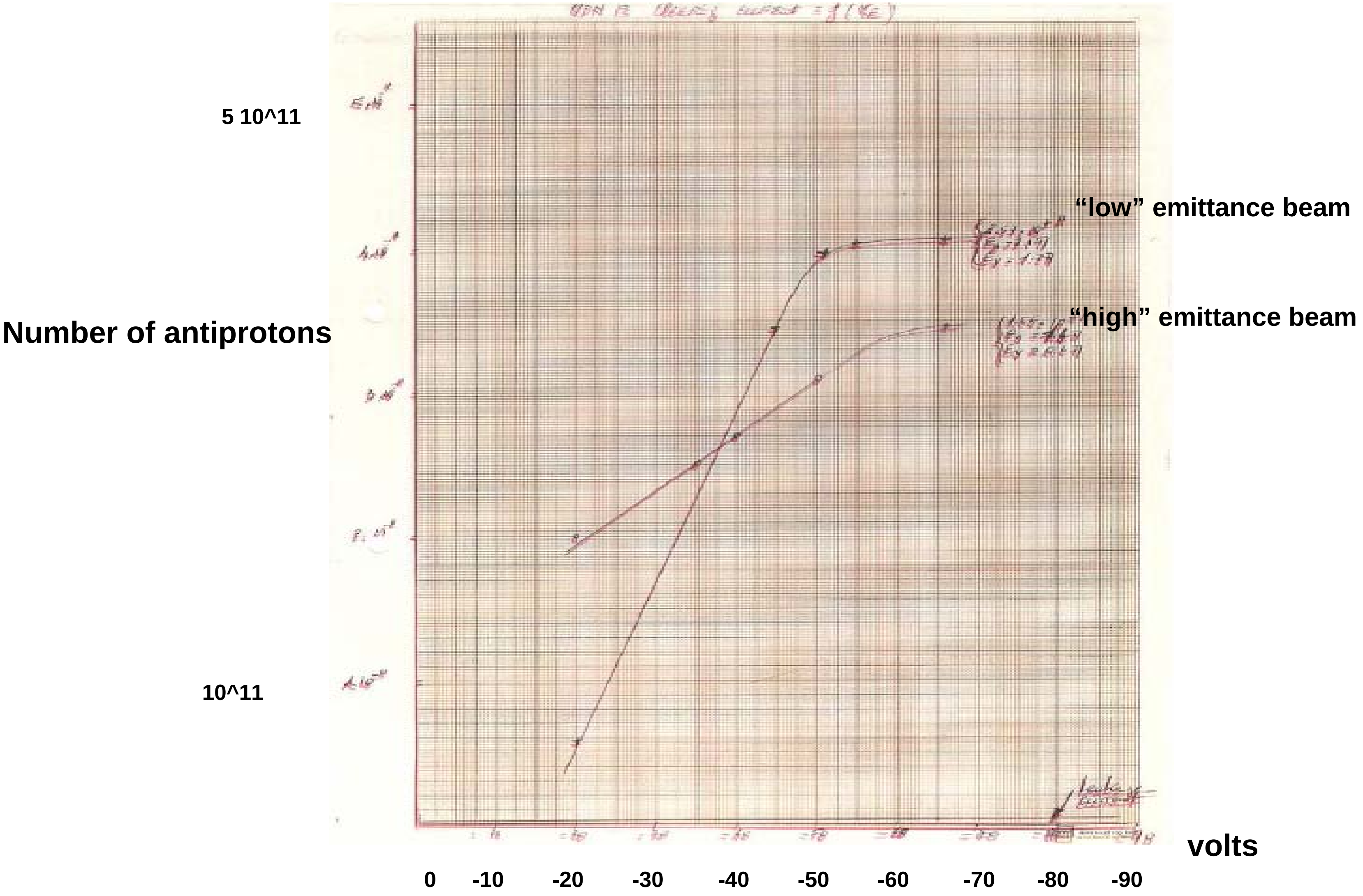
beam max. field: 12 kV/m for I = 0.3 A

and ~10^{-8} m·rad horizontal emittance with 10% coupling.

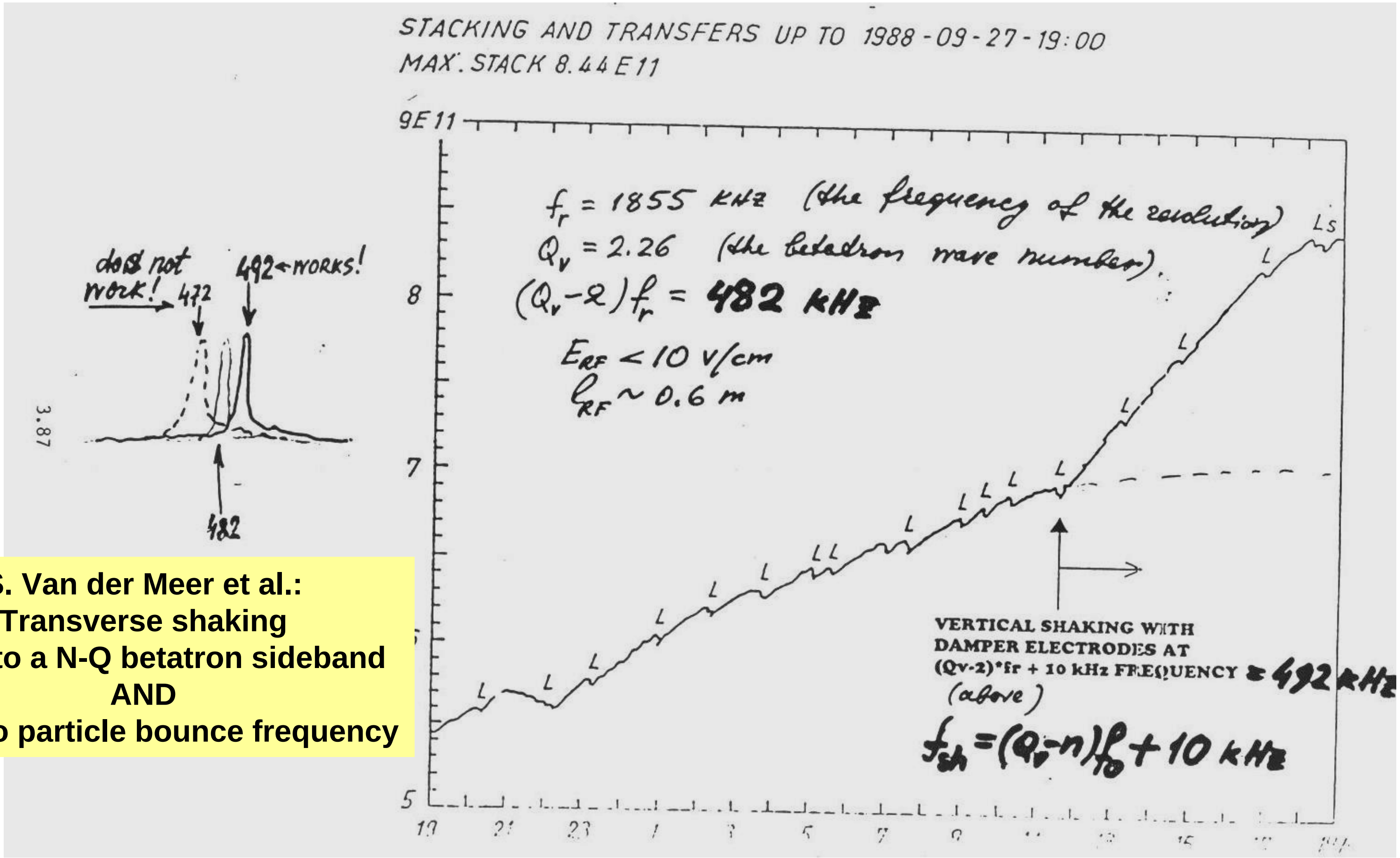
Measurement of the electrode clearing current as a function of the applied voltage provides a verification of the required maximum to be applied for full clearing, since the current will saturate once a sufficient field is reached (Fig. 9).

Fig. 9 Extracted ion current vs. electrode voltage in EPA

AA clearing currents as a function of DC clearing voltage

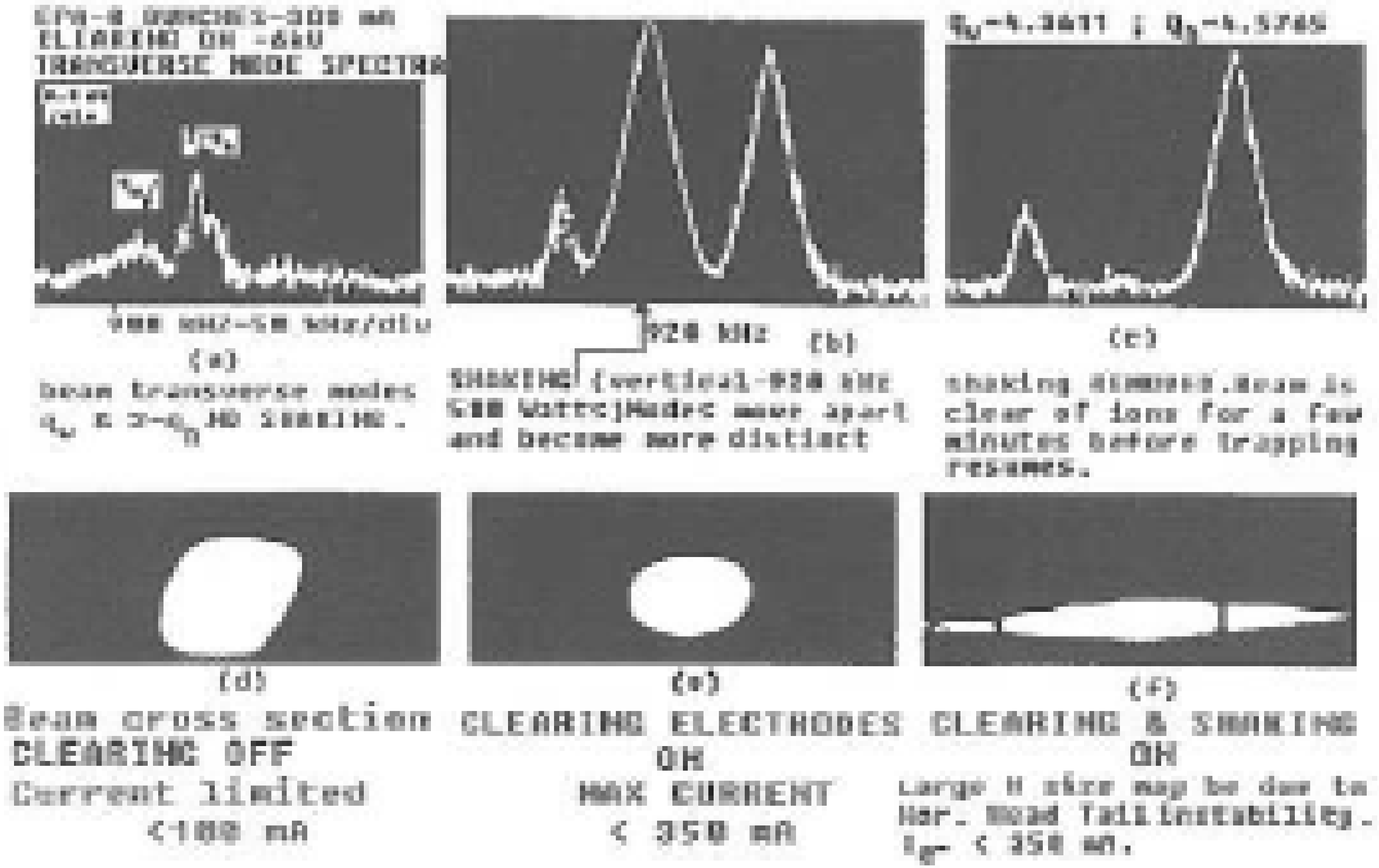


Fermilab AA : effect on accumulation rate of shaking the beam (works only with clearing on)



S. Van der Meer et al.:
Transverse shaking
Close to a N-Q betatron sideband
AND
Close to particle bounce frequency

CERN EPA : effect of shaking the beam (works only with clearing ON)



(a) beam transverse modes q_v ≈ 3-q_h NO SHAKING.

(b) SHAKING (vertical-920 kHz 500 Watts)Modes move apart and become more distinct

(c) shaking STOPPED. Beam is clear of ions for a few minutes before trapping resumes.

(d) Beam cross section CLEARING OFF Current limited <100 mA

(e) CLEARING ELECTRODES ON MAX CURRENT < 350 mA

(f) CLEARING & SHAKING ON Large H size may be due to Hor. Head Tail instability. I_B < 350 mA.

Fig. 15 Transverse Schottky scans and beam cross-sections in EPA showing the effect of shaking the beam (920 kHz vertically)

What we – AA “ghost busters” - learned…: (for machines like AA and EPA prone to trapping of course !)

- Clearing electrodes are essential (but not enough ?!)
- “low impedance” design works
- Sufficiently high extraction DC voltage is required (!)
- Shaking the beam near an N-Q sideband close to trapped particle bounce frequency is very efficient to further reduce neutralisation effects
- Shaking in AA’s and EPA worked…if one had clearing electrodes turned ON !
- Avoid ion “pockets” ! (e.g. continuous beam pipe profile)
- However…very difficult to go below 0.1% neutralisation (pockets)

And

- Continuous DC electrodes in magnetic fields might be necessary (some evidence for this in AA and EPA)
- Provide the best possible VACUUM !