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Preliminary Computer Study of Charge Exchange (H^-) Injection into EHF Pre-Booster

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Injection into the EHF Prebooster was simulated with the Code ACCSIM developed at TRIUMF [1], which allows to take the effect of foil scattering into account as well as space-charge, chromaticity and linear coupling. The real beam is represented by an ensemble of 2000 superparticles.

The underlying Prebooster lattice corresponds to a version communicate end of September and differs from that published in the Proceedings of the XIV EHF Workshop in Eindhoven.

It basically features a 20 m long group of 3 straight dispersion-free straight sections, separated by quadrupole doublets whic produce low beta's at the centre.

Although these latters are favourable for keeping foil scattering effects low they render the injection geometry problematic, as the doublets force the separation of the H- beam into the central SS, being only 5.4 m long. It seems still be possible though using septum bumpers and rather strong (140 mrad) septa for incoming and unstripped H- beam, cf. Fig. 1.
The emerging Ho beam (ca. 2%) however would have to be dumped in the downstream, adjacent straight section which is possible at 211 MeV injection energy but may cause radiation problems for a future upgrading to 550 MeV, say.
Nevertheless this model was adopted to study the painting possibilities Both phase planes at the foil locations are represented in Figs. 2, 3 as well as the parameters of a matched linac beam. Dispersion matching to zero was assumed although it not clear whether this will be possible to achieve it in the injection line in view of the strong septum.

An alternative geometry using an asymmetric bump and normal bumper dipoles is shown in Figs. 5 and 6. It would also alloww to dump the Ho beam in the adjacent section or possibly even further downstream. On the other hand the problem of dumping the unstripped H- ions gains importance as there is no space for a septum to extract them properly.

Beam parameters :

For the circulating beam the normalized 2 sigma emittances are 25 pi mm mrad in both planes, or 35 pi in physical terms.
The same model distribution as in the old proposal gives a theoretical 100 % emittance of 44 pi, which we want to fill with a Linac physical emittance of 6.5 pi. The latter value corresponds to the old 1.5 pi (1 sigma) normalised emittance with a halo-factor of 3 .
In the longitudinal plane there is one linac bunch per bucket which will be injected with a fixed off-energy of 0.9 Mev and shall not have more than this half height, to comply with the bucket height of +- 2.4 MeV. The latter corresponds to a rather high value of 550 kV RF voltage, cf. a possible constant-voltage RF program (Fig. 14).

Painting Strategy :

The basic objective of a painting strategy is to produce evenly filled phase space distributions which are (ordered according to priority) supposedly stable, confined (in the sense of having no halo) and of low density peaks to reduce space-charge tune-shifts.
In order to evaluate the success of a particular painting scenario ACCSIM computes a few figure of merits which are also given in the figures showing the distributions. These f.o.m. are :

Eh,Ev the physical emittances containing 99 % of the superparticles We are aiming at values not too different form 44 pi in both planes.

Bf the Bunching Factor (average long. density/peak density), <1

G a transverse form factor (peak/average 2-dim. transverse density in physical space), i.g. >1. G = 1 for K-V distribution and can be <1 for hollow. distributions only.

dQh,dQv are the maximum transverse Laslett tune shifts for particles permanently in the beam centre. Meaningful only for G>=1.

% of superparticles exceeding a given acceptance - here taken to be 70 pi, i.e. half the machine acceptance and twice the nominal 2-sigma emittance of the circulating beam. To quantify the halo.

Number of superparticles lost : to quantify the loss to be expected for a machine acceptance of 140 pi. With the 2000 superparticles used here the statistics is necessarily not brilliant.

Average Number of Foil Traversals (per particle) : a measure for the effectiveness of the transverse painting to keep injected particles off the foil.

TF Turn factor : Total number of foil traversal / total number of particle turns

Longitudinal Painting :

We can rely on studies performed for the original EHF Booster, which apart from the injection enrgy, features comparable parameters. Their essential findingsapply equally to the present scenario : Ambitious painting schemes aiming at squae bunch shapes fail because of the strong space-charge forces originating from the steep slopes of the linac bunches. Best results are achieved with a "no-paint" scheme where the linac bunches are injected with an energy offset of about their half-height such that the lower edge of the microbunch paints the centre of the RF bucket. This imposes a limit to the energy width of the linac and may require debunchers in the injection line plus the necessary drift length. For the chosen RF voltage a full energy width of 1.9 MeV (in the model comprising 100 % of the linac beam) is required, possibly corrected to lower values to account for jitter of the mean energy. This simple strategy allows for bunching factors of 0.35 (0.38 were achieved with the former 2-out-of-8 linac scenario), which is adequate for the -0.2 tune-shift generally accepted.

Transverse Painting.

Amongst the various ways to paint the 2-dim. transverse plane, e.g. time-varying bumps in both planes, we chose a time-constant horizontal bump in conjunction with a moderate amount of linear coupling. to fill the other, vertical, plane. Note that fixed bumps, i.e. fixed offsets of the injected beam, paint annular domains in the respective phase spaces. These configurations, although a priori very effective in reducing space-charge tune shifts, are found to be unstable and to fill up the central regions fo phase (and real) space in an uncontrolled way, leading frequently to distributions less useful than those obtained with a controlled fill of the central regions.

Another promising development taken into consideration is the "post stamp foil" coming from PSR. Such a foil efficiently reduces the number of foil traversals and the ensuing blow-up. This partially compensates the absence of the usually employed technique of temporarily removing the circulating particles from the foil by profiting from longitudinal motion motion and dispersion, obviously not applicable here.

References:

[1] F.W. Jones, G. Mackenzie, H. Schönauer
1989 Tsukuba Int. Conf. Part. Acc.

INJECTION PROBLEM

LINAC → BOOSTER

microbunches
$\varepsilon_{\sigma} = 6.5\pi$ mm mrad
Transverse physical values

much larger bunches
$\varepsilon_{2\sigma} = 35\pi$ mm mrad

bunch → bucket scheme
uniform and controlled way of filling

Filling with the minimum charge density in the centre of the bunch

PAINTING (6 dim)

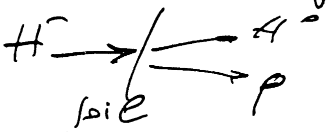
longitudinal

transverse

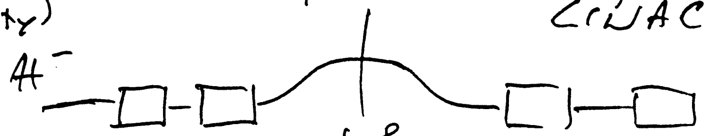
Space-charge detuning
$\Delta Q \propto \varrho$ density
(depends also on chromaticity)

multiturn injection

charge exchange injection



foil stripping
(quite lossless Technique to transfer the beam from the LINAC)



bump magnets foil bump magnets
powered only during injection

to increase efficiency of multiturn injection
add **skew quad**
excitation of linear coupling H → V during injection

reduction of foil hits
cheaper

to remove H oscillations energy to V plane

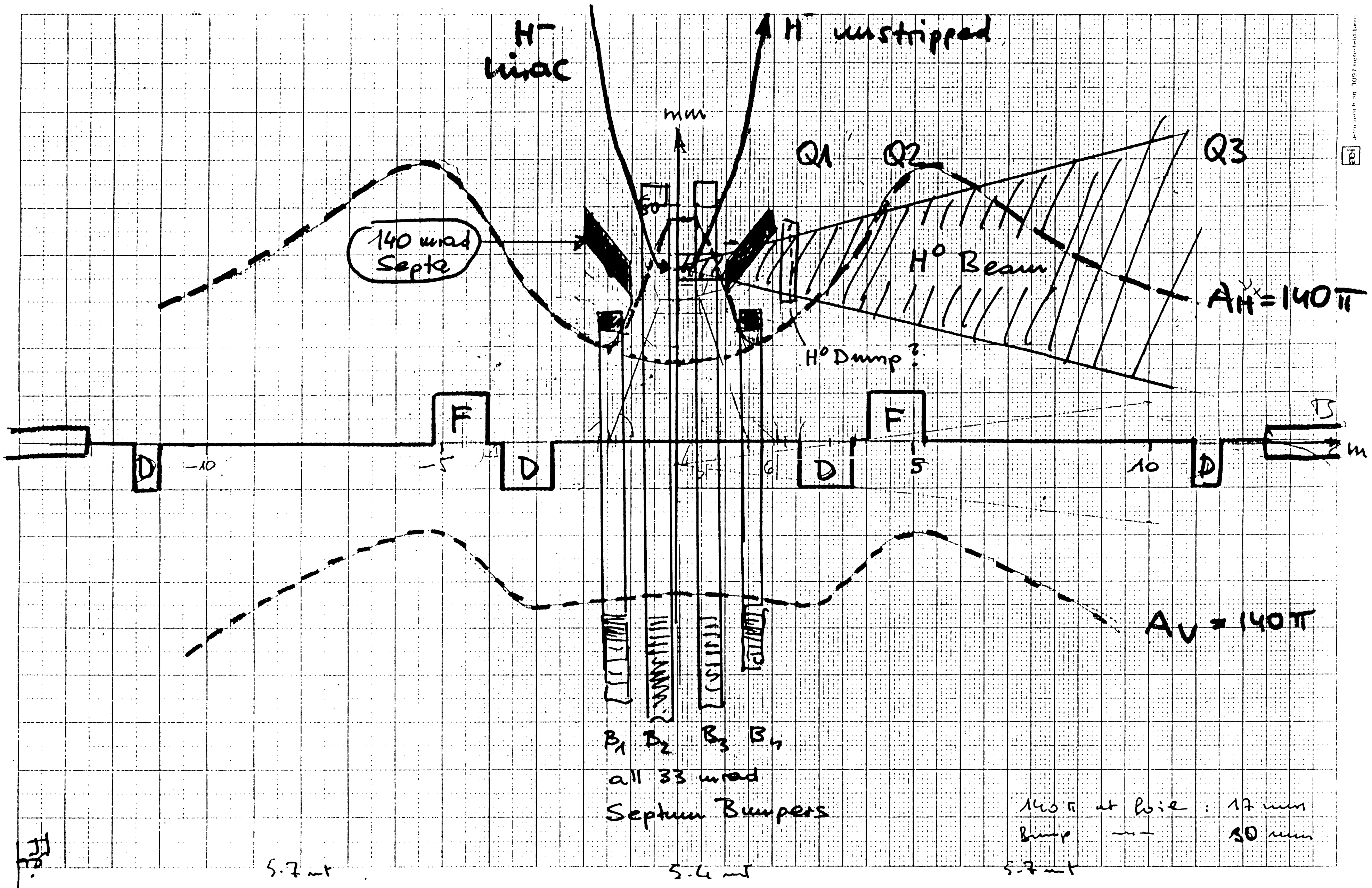


Fig. 1

Inj. Scenario #1

#1

HOR.

EHFPB Foil at ¢ LS

$\beta_H = 2.02$ m

$\beta_V = 7.~~7~~8$

$\epsilon^*_H = 2\sqrt{\pi}$

$\gamma = 1.225$

$\beta = 0.577$

$\epsilon_{2\sigma} = 35\pi$

$[\epsilon_{100} = 44\pi]$

$A = 140\pi$

$B\rho = 2.21$ Tm

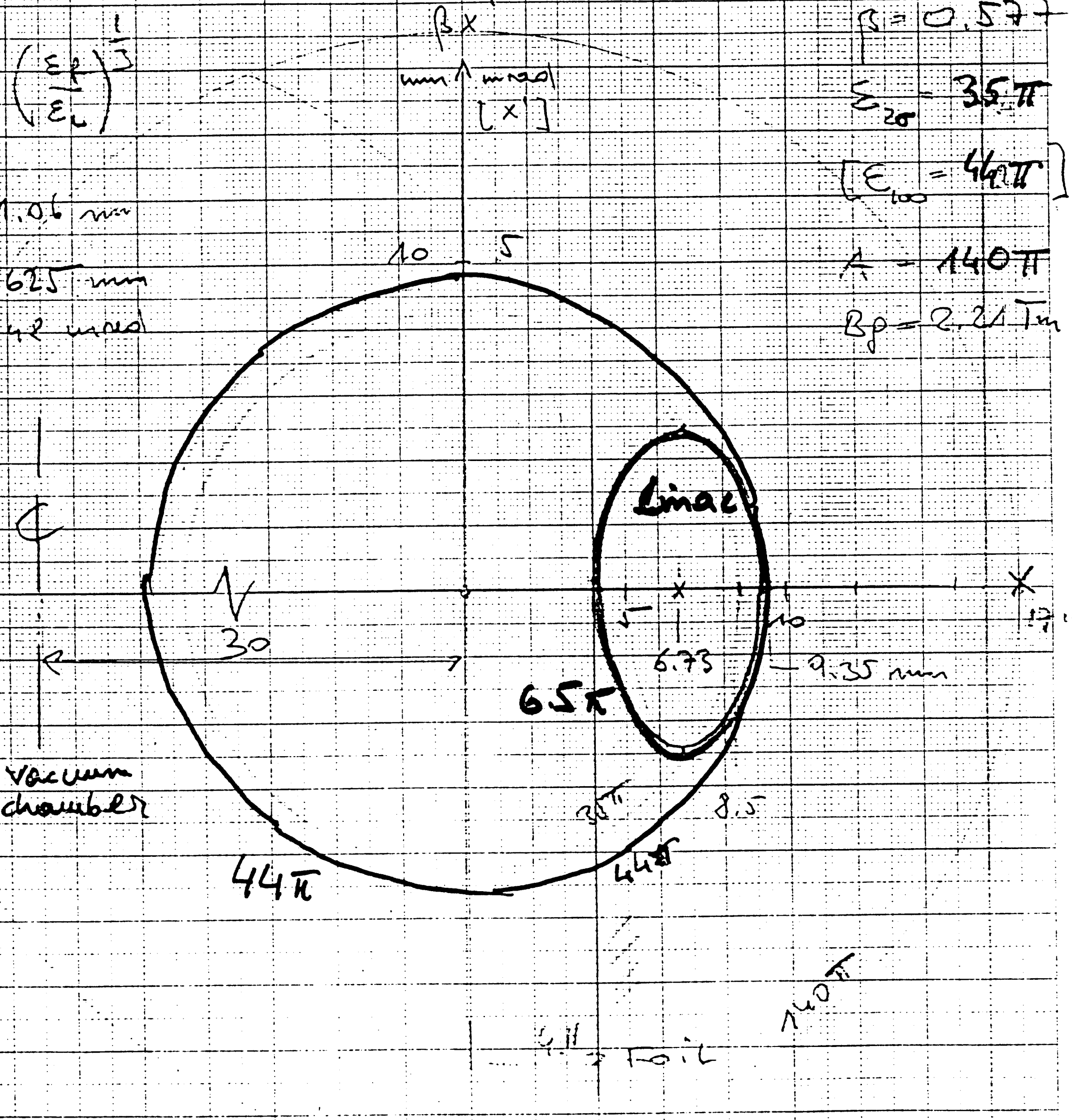
$\epsilon_L = 6.5$ mm mrad

$$\frac{\beta_f}{\beta_L} = \left(\frac{\epsilon_f}{\epsilon_L}\right)^{\frac{1}{3}}$$

$\beta_L = 1.06$ m

$\Delta X_L = 2.625$ mm

$\Delta x'_L = 2.42$ mrad



Bump: 30 mm
Foil : 17 mm
X0 : 19.73

Fig 2.
21.9.80

#1

VERTICAL

BHFPB Foil at ⊕ L5

$\beta_L = 4.06$ m

$\epsilon_L = 6.5\pi$

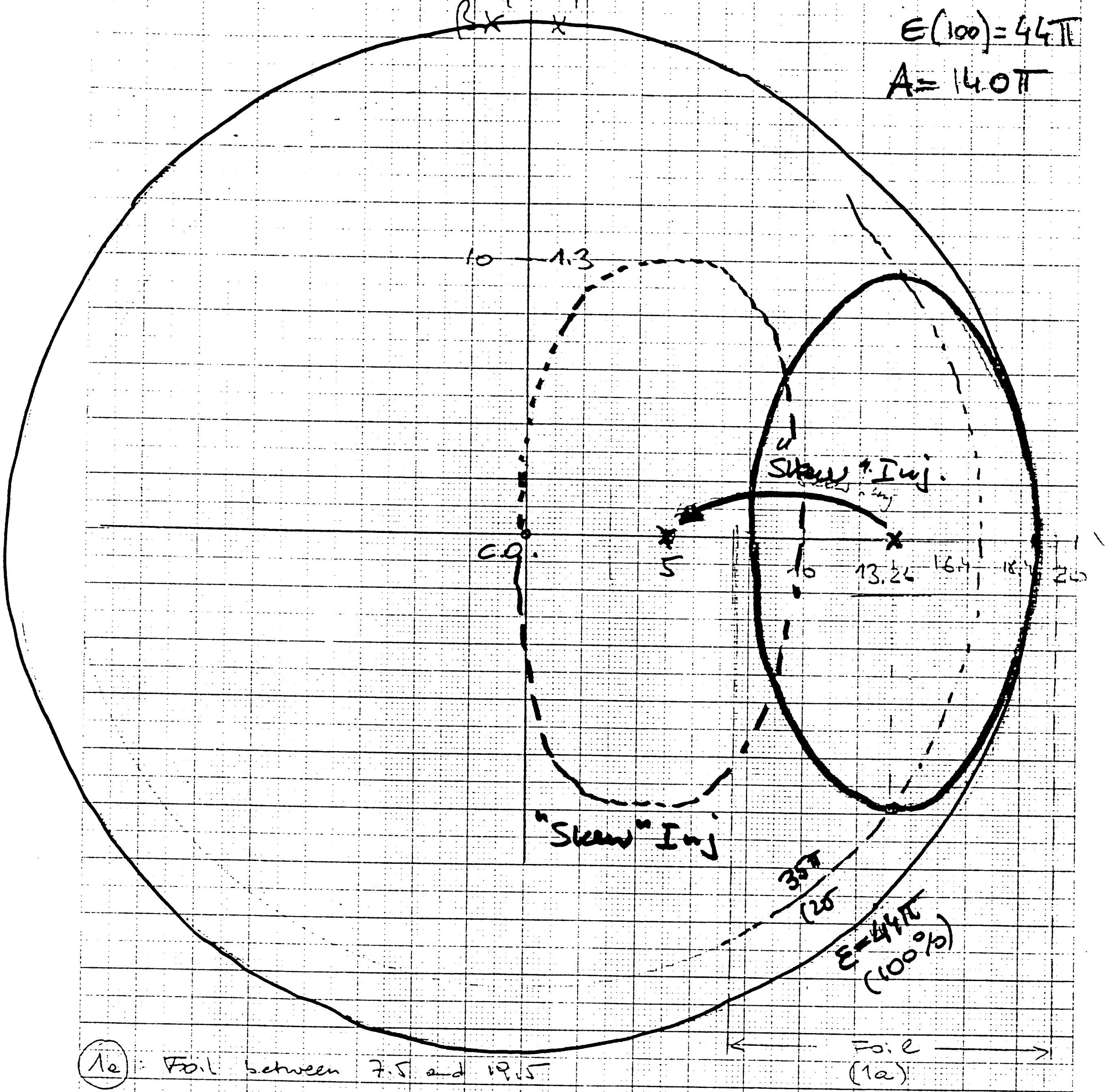
$\beta_V = 7.68$

$\epsilon_V^* = 25\pi$

$\epsilon(25) = 35\pi$

$\epsilon(100) = 44\pi$

$A = 14.0\pi$



①e : Foil between 7.5 and 19.5

$Y\Phi = 13.26$

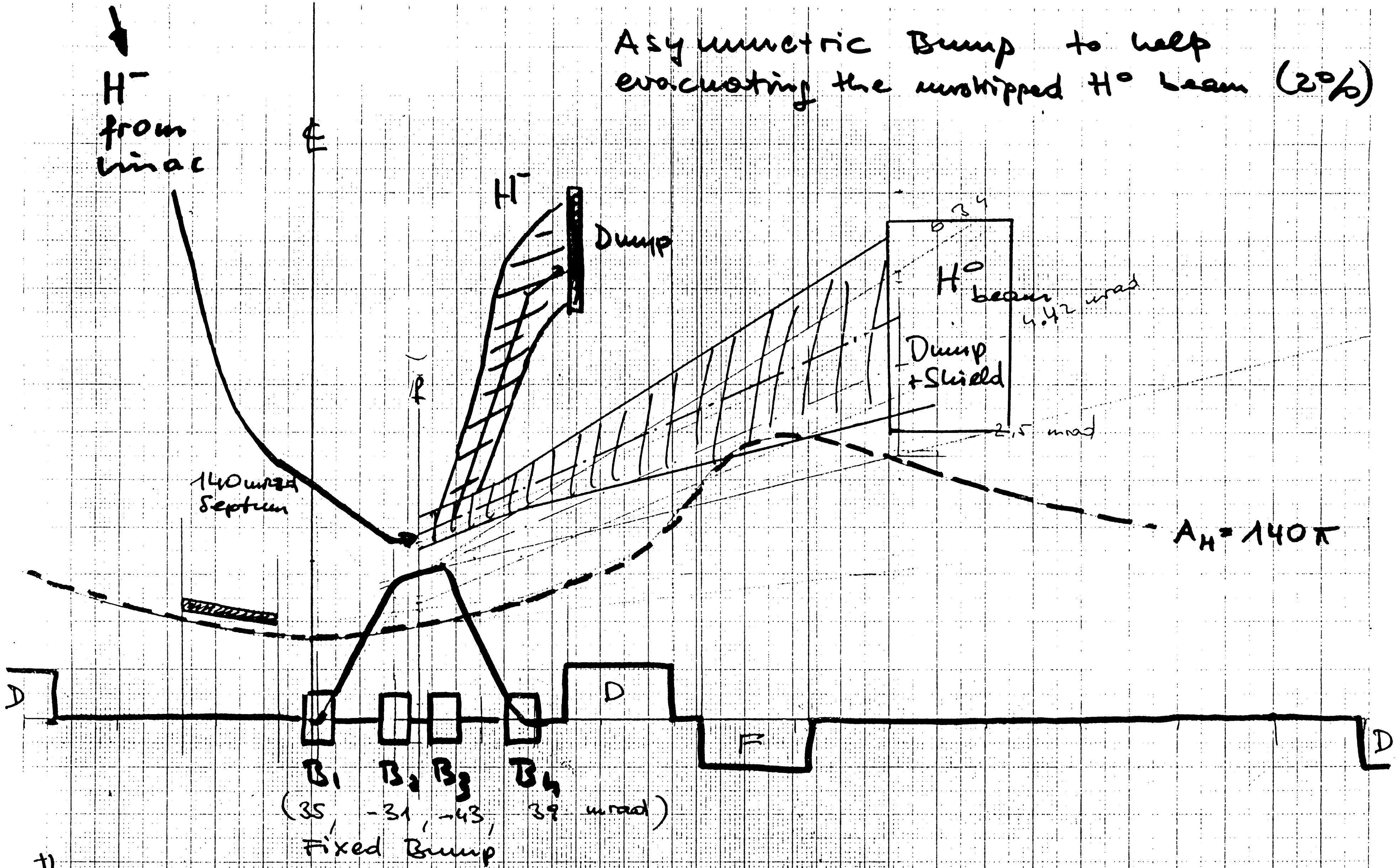
$\Delta y = 5.137$

$\Delta y' = 1.265$

Fig. 4

21.9.89

Asymmetric Bump to help evacuating the unstripped H° beam (2%)



HR. 4.10.89

EHFPB : Foil 1.2 m downstream ℄ LS

HOR

Asymm. Bump

$\beta_H = 2.732$ $\alpha_H = -0.594$

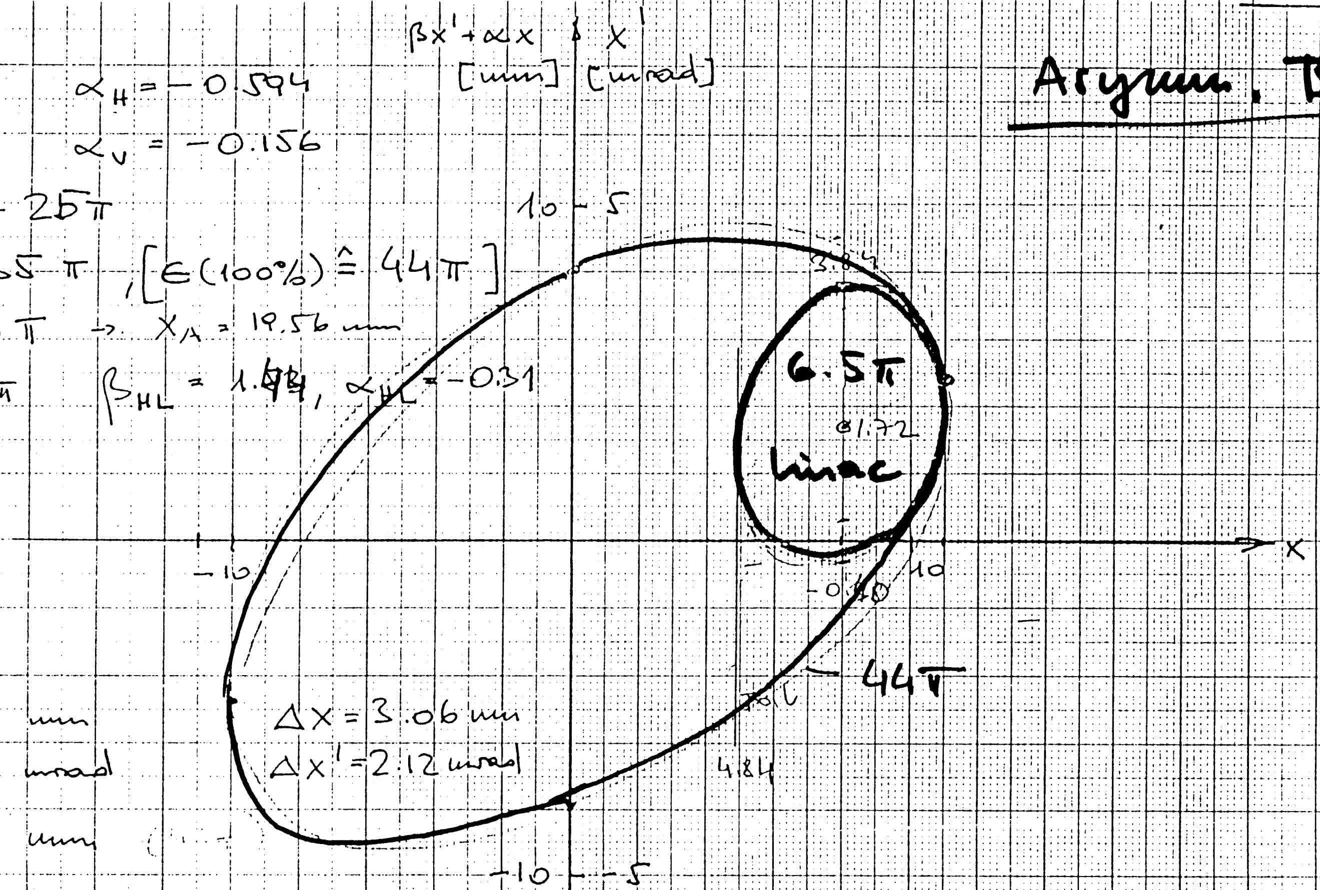
$\beta_V = 7.87$ $\alpha_V = -0.156$

$\epsilon_H^* = \epsilon_V^* = 25\pi$

$\epsilon(2\sigma) = 35\pi$, $[\epsilon(100\%) \hat{=} 44\pi]$

$A = 140\pi \rightarrow x_A = 19.56$ mm

$\epsilon_L = 6.5\pi$ $\beta_{HL} = 1.44$, $\alpha_{HL} = -0.31$



$\Delta x = 3.06$ mm

$\Delta x' = 2.12$ mrad

$\hat{x} = 10.96$ mm

$\hat{x}' = 2.38$ mrad

$x_0 = 7.90$ mm

$x_0' = 1.72$ mrad

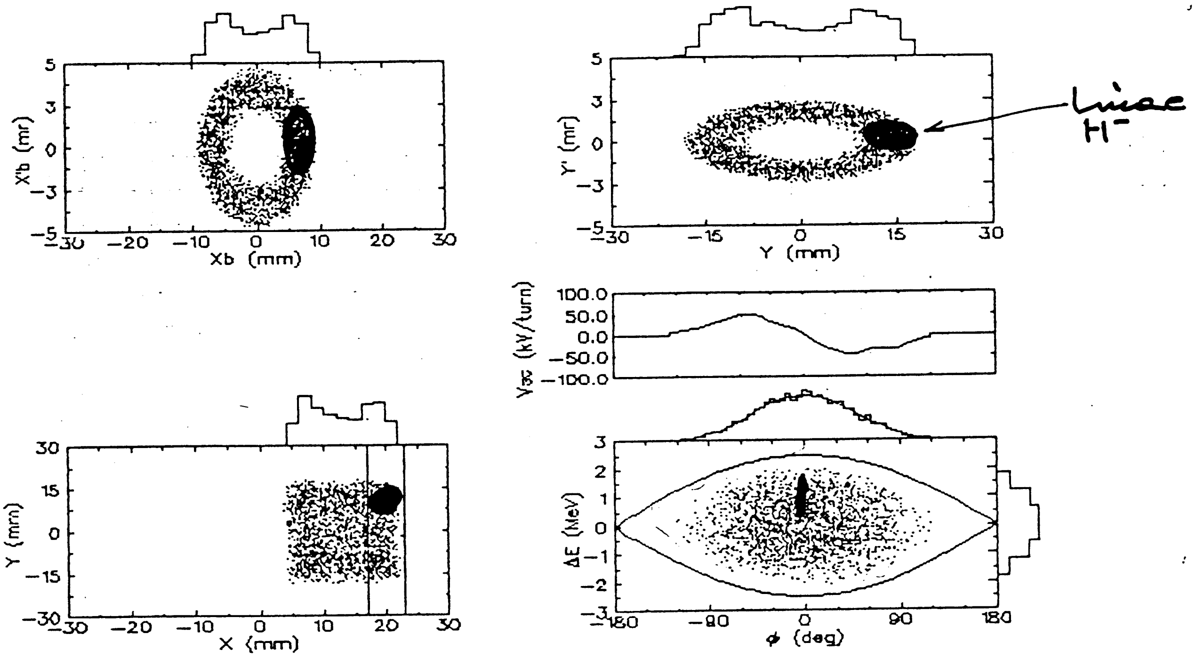
$x_{bump} \hat{=} x_A + \Delta x = 22.62$

AS 4.10.90

F. 6

EHF PREBOOSTER

"no FOIL" case



Beam hollow in both phase plane: would fill up in uncontrolled way due to instabilities:

$\varepsilon_{x,y}$ (99%) = 47, 44 π

G = 0.62

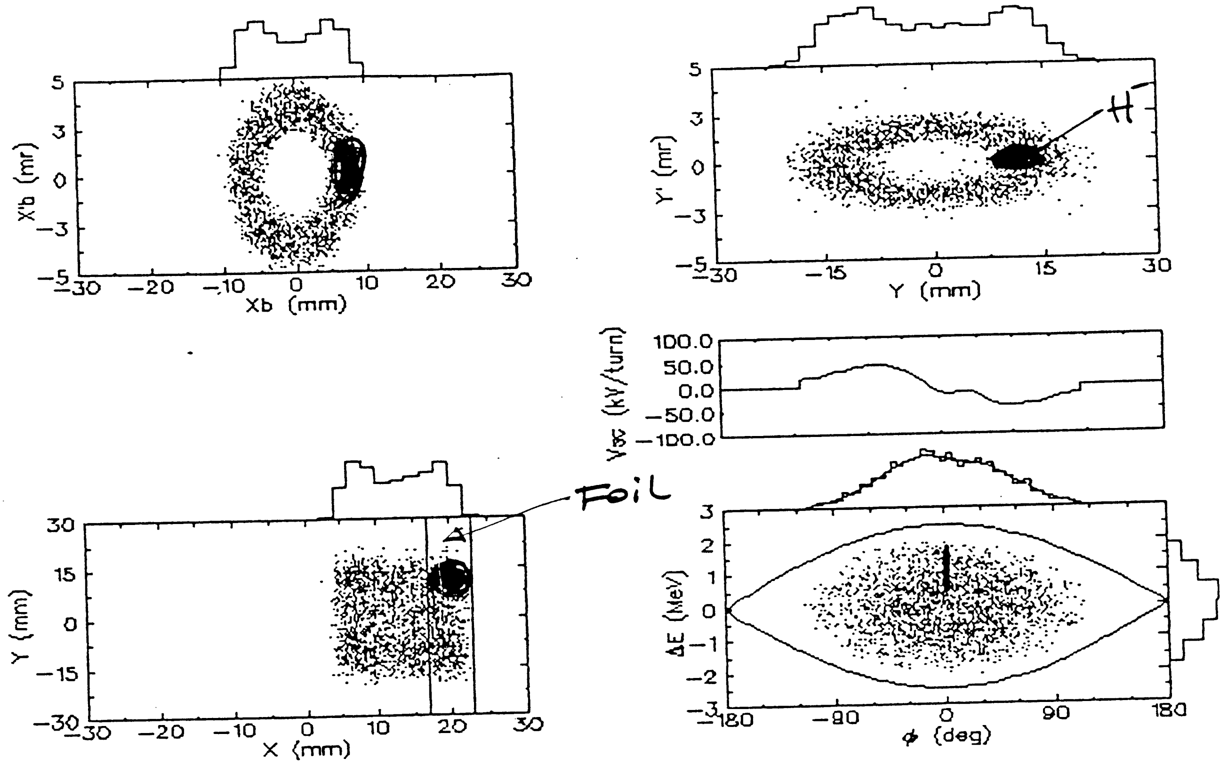
Av. # of Traversals : 35

Turnfactor : 0.3

ΔE_{off} = .9 MeV

Fig 7

EHF PB : 200 μg/cm² Strip Foil



$\varepsilon_{x,y}$ = 60, 112 π

G = 1.2

Av. # o.Tr. 35

T.F. 0.3

# of superparticles lost (of 2000) : 1 (>140π)

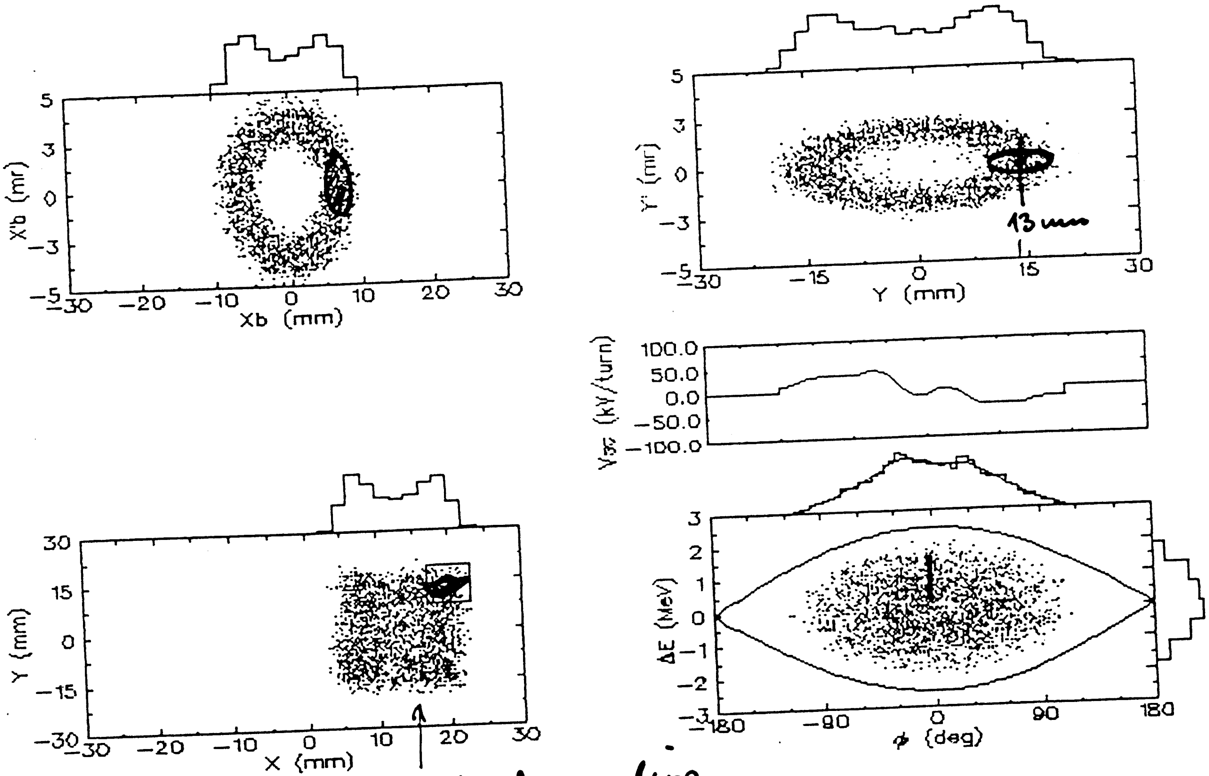
0.48 % > 70 π "Halo"

Fig. 8

EHF PB

200 $\mu g/cm^2$ Post Stamp Foil

very weak linear Coupling
(Skew Quadrupole) $k_1 L = 0.0026$



13 mm

effect of coupling

$\varepsilon_{x,y} = 47, 48\,\pi$

$G = 0.64$

Av # o. Tr. : 12.3

T.F. = 0.11

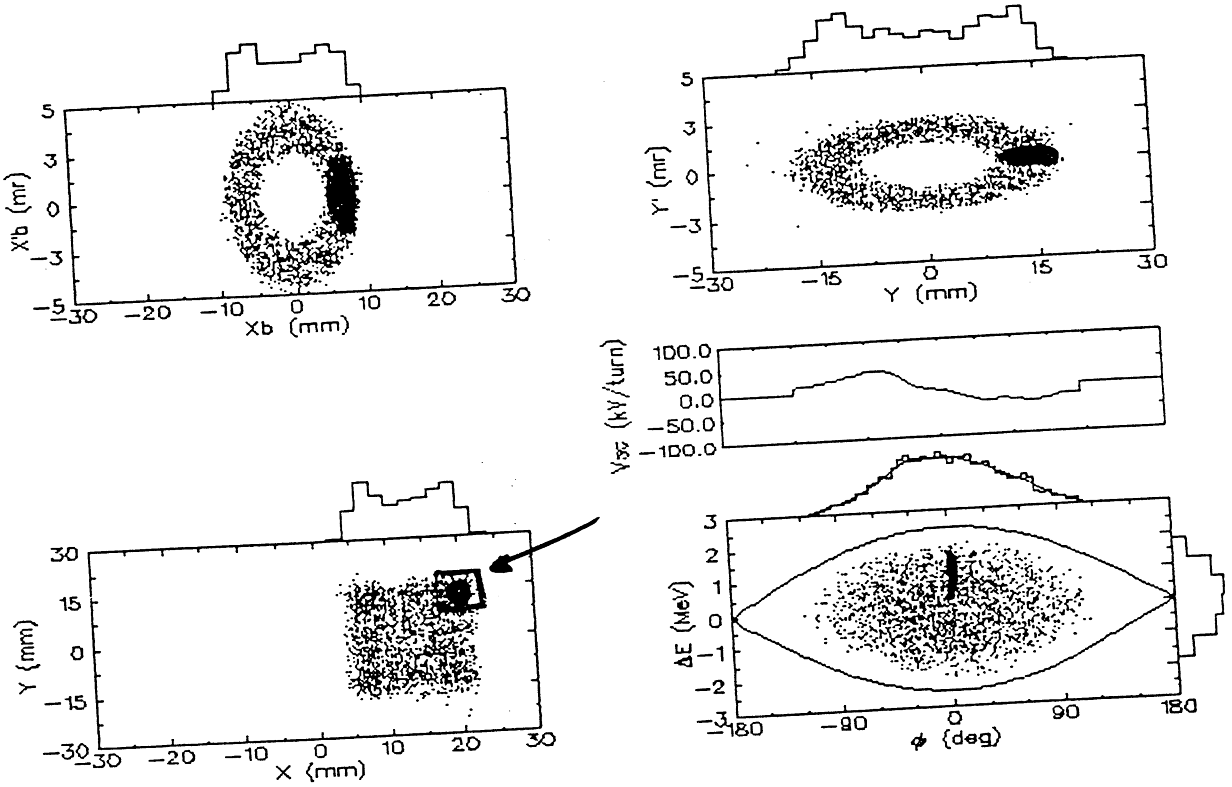
1 s.p. lost > 140π

0.09 % > 70π

Fig 9

EHF PB

200 μg/cm² Post Stamp Foil



$\varepsilon_{x,y}$ = 45, 47 π

G = 0.6 (hollow beam, unrealistic)

Av. # o. Trav.: 11.4

T.F: 0.1

no loss

0.17% > 70 π

Fig 10

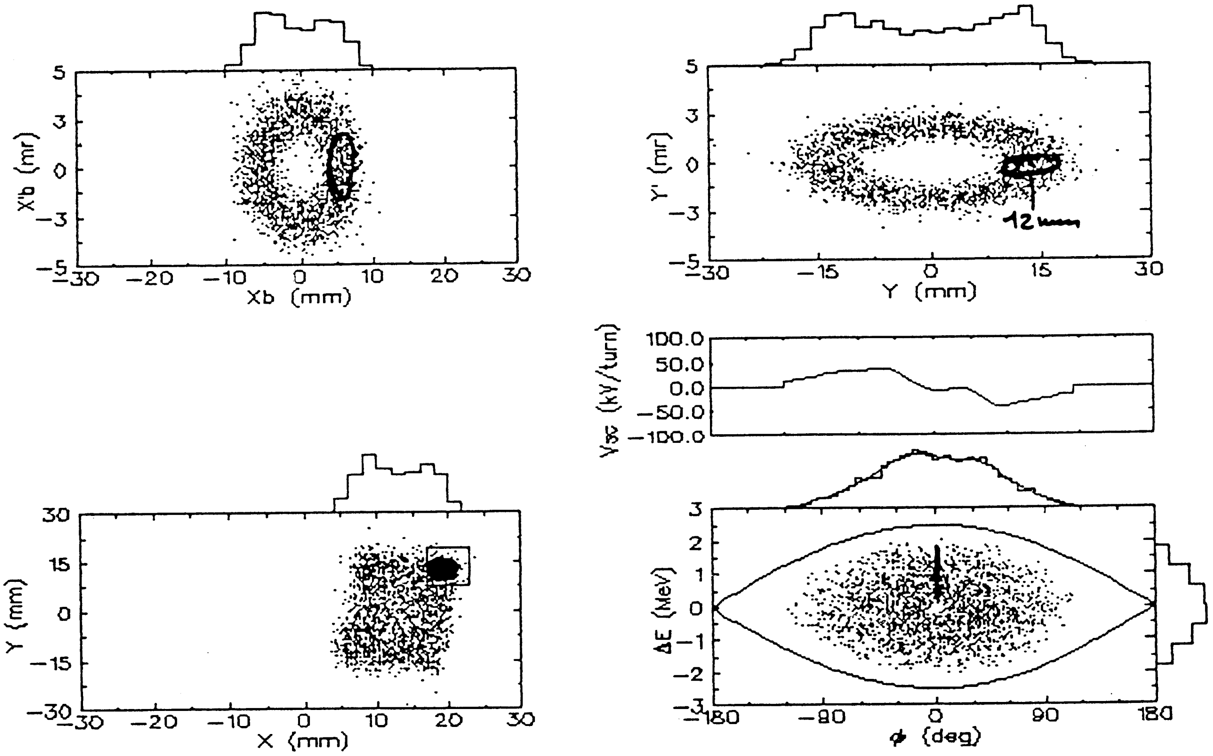
([illegible])

EHF PB

200 μg/cm² Post Stamp Foil

Linear Coupling (1 Skew Quad $k_s L = 0.026$)

Vert offset Y_0 = 12 mm



$\varepsilon_{x,y}$ = 45, 58 π

G = 0.83

Av # o.Tm : 11.5

T.F. : 0.1

1 S.P. lost

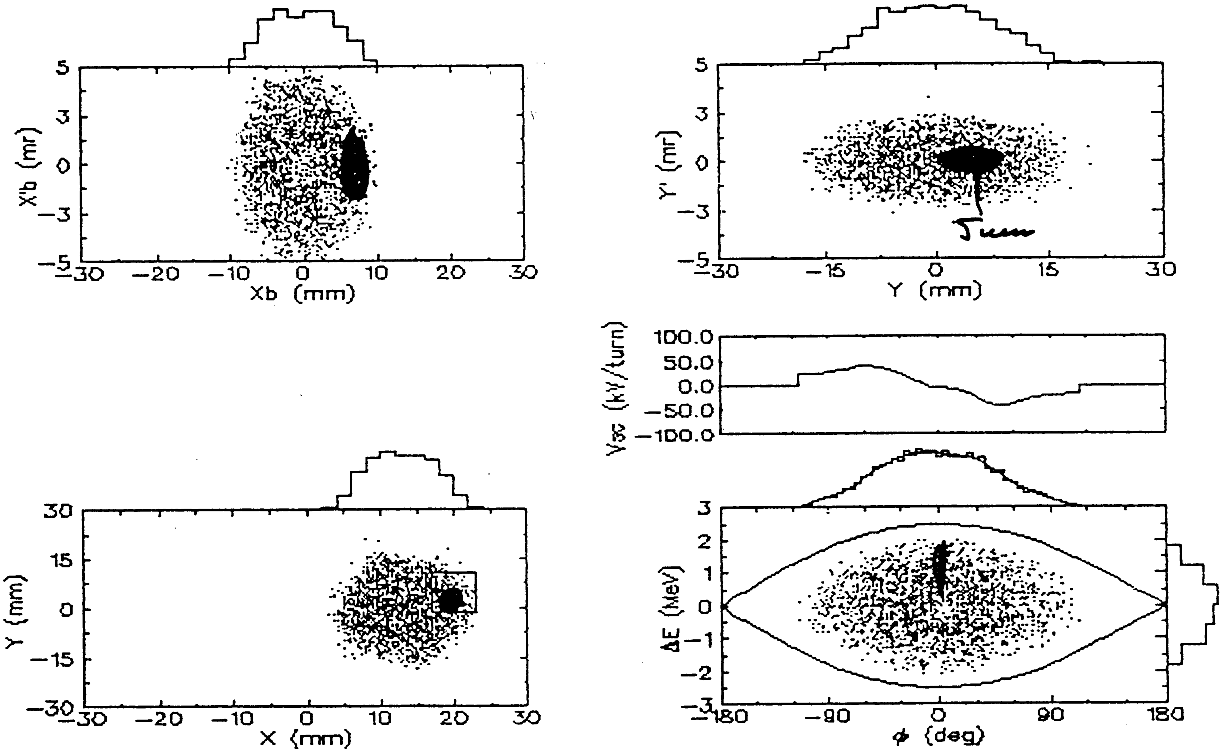
1.6 % > 70 π

EHF PB

200 $\mu g/cm^2$ Post Stamp Foil

Lin. Coupling (SQ $K_s L = 0.026$)

VERT. OFFSET $Y_0 = 5$ mm



$\varepsilon_x, \varepsilon_y$ = 49, 42

G = 1.56 less good, but realistic (stable) distribution

Av. N.o.Tr: 16 —"—

T.F 0.14 —"—

No Loss

0.2% > 70π good, little halo!

B.F. = 0.35, $\Delta Q_x = -.167$

$\Delta Q_y = -.208$

Fig. 12

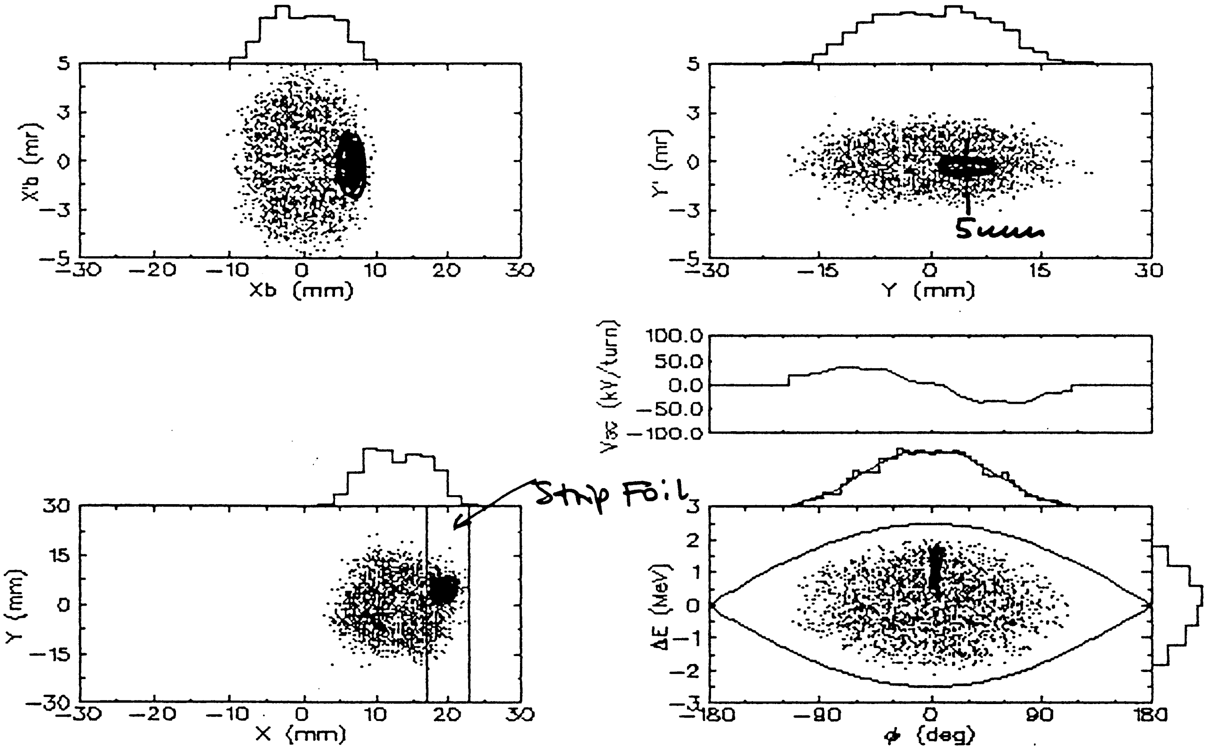
EHF PB

200 μg/cm² STRIP FOIL

otherwise as # 10, Fig. 12

SQ $k_n L = 0.026$

$Y_0 = 5$ mm



$\varepsilon_{x,y} = 49, 44\,\pi$

$G = 1.51$

Av. # of Tr. : 25

T.F. 0.22

1 S.P. lost

0.26% > 70

B.F. = 0.35, $\Delta Q_x = -.157$
$\Delta Q_y = -.187$

} Although less good than with Post Stamp Foil, other Fig's of merit about the same!

Fig. 13

(11)

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EHF Prebooster      Protons

               Values  20-S

Radius (m)             42.4410
Bend Radius (m)        20.0000
Gamma trans.            3.9500
Harmonic No.           50.0000
Qx                      4.8000
Qz                      4.8000
Chamber W./2 (m)        0.0650
Chamber H./2 (m)        0.0400
Wall Z/n (Ohm)         10.0000
Frep (Hz)              50.0000
Vrf (kV)              550.0000
RMS Disp. (m)           0.7000
Rise Fraction           0.7500
Trans.Distr. G          1.2500
Tinj (GeV)              0.2110

Final T (GeV)                                              1.2000



GLOBAL PARAMETERS

Particle current (uA)    38.00
SEXN (pi mm-mr)          25.00
SEZN (   "     )         25.00
EL  (eV-s)                0.055000

OValues  20-S Frep= 50.Hz, rise=.75, R= 42.4m, h= 50., Gt=  4.0, indZ/n= 10.0ohm, Np=0.474E+13, Qx=  4.80, Qz=  4.80, HHt=.040m
                                                                                  e1z,e2z,x1x,x1z= .13 .42 .14 .58
   T     B    Frf    Vrf  Phis Phib Iac  Pow  Phi1  Phi2   Bf    Pf  dp/p    Qs   srkt  srkc  srkb jZ/n  -dQx -dQz  -dQx -dQz -dQx  -dQz
 (GeV) (T)  (MHz)  (kV) (deg)(deg)(Amp)(MW) (deg) (deg)                (%)                         (ohm)  inc  inc   imag imag  coh   coh
  0.21 0.11 32.46  550.  0.0  0.0 0.6 0.00-121.1 121.1 .409 .866 .468 .0809 0.976 .810 0.706 668. 0.150 .172 -.009 .009-.0024 .0390
  0.23 0.12 33.44  550.  3.8  5.7 0.7 0.02-110.6 128.8 .404 .903 .453 .0765 0.975 .813 0.704 637. 0.143 .163 -.009 .009-.0024 .0357
  0.28 0.13 36.04  550.  7.2 10.5 0.7 0.04 -98.9 131.1 .389 .918 .417 .0656 0.974 .823 0.709 558. 0.126 .143 -.007 .007-.0024 .0283
  0.38 0.15 39.42  550.  9.9 13.9 0.9 0.06 -87.5 127.0 .367 .906 .377 .0529 0.972 .841 0.731 461. 0.106 .119 -.006 .006-.0022 .0207
  0.51 0.18 42.74  550. 11.7 15.5 1.0 0.07 -77.4 118.2 .339 .869 .344 .0416 0.970 .862 0.767 369. 0.088 .099 -.005 .005-.0021 .0149
  0.66 0.22 45.49  550. 12.3 15.6 1.1 0.08 -69.1 107.5 .311 .810 .321 .0328 0.967 .885 0.804 294. 0.074 .083 -.004 .004-.0019 .0111
  0.82 0.25 47.54  550. 11.7 14.2 1.2 0.08 -63.3  96.7 .285 .740 .306 .0265 0.965 .904 0.835 239. 0.064 .071 -.003 .003-.0018 .0086
  0.97 0.28 48.95  550.  9.9 11.7 1.3 0.07 -60.1  86.7 .263 .670 .296 .0221 0.962 .920 0.857 201. 0.057 .063 -.003 .003-.0016 .0071
  1.09 0.30 49.85  550.  7.2  8.3 1.3 0.05 -59.4  77.9 .247 .606 .291 .0193 0.960 .930 0.871 177. 0.052 .058 -.002 .002-.0015 .0062
  1.17 0.32 50.35  550.  3.8  4.3 1.3 0.03 -61.0  70.5 .238 .556 .289 .0178 0.959 .936 0.879 163. 0.050 .055 -.002 .002-.0015 .0057
  1.20 0.32 50.51  550.  0.0  0.0 1.4 0.00 -64.8  64.8 .235 .520 .289 .0173 0.958 .939 0.882 159. 0.049 .055 -.002 .002-.0015 .0055
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Fig. 14