SPS RF

Thomas Bohl

AB/RF

Contents

Beams - Particles

Equipment

- PU
- TWC 200
- TWC 800

Proton fixed Target Beam

LHC Beam

Beams

Past:

e^+, e^-, p, $\bar{p}$, D, S, O,

In, Pb

2004:

p p^{FT}, CNGS, p LHC

Future

p : p^{FT}, CNGS, p LHC

Pb : ions LHC

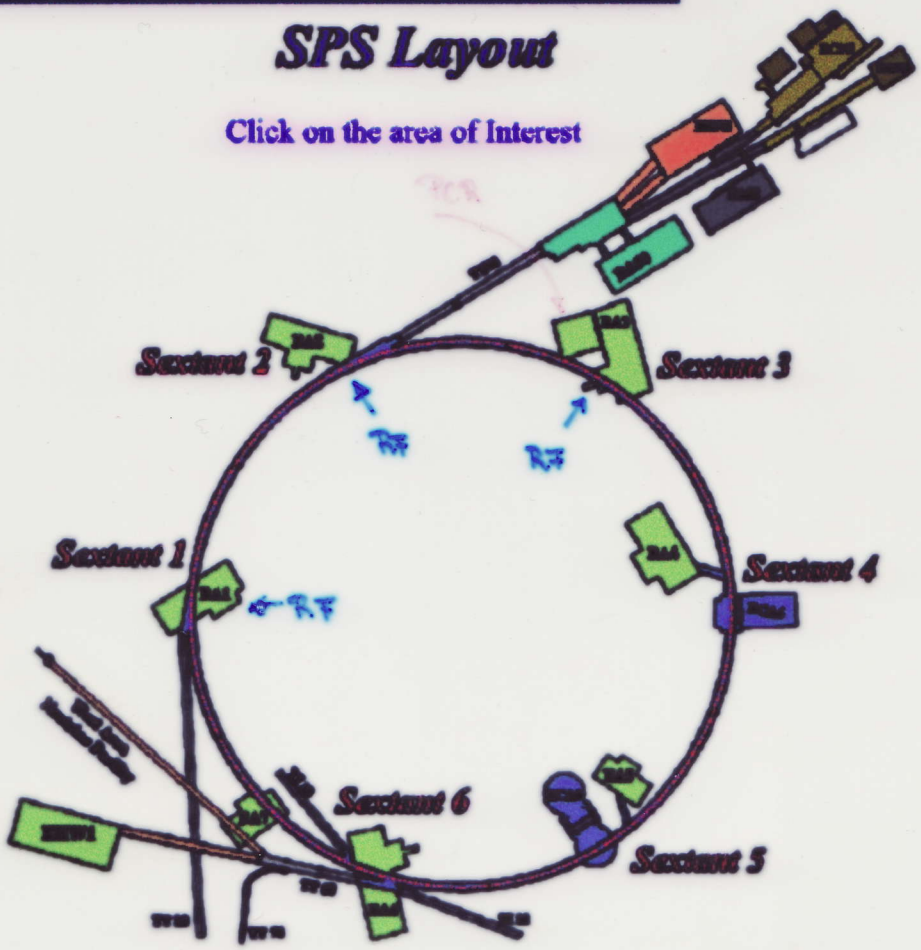
He, O, Ar, Kr, Sn : ions LHC

What kind of equipment do we have to do it?

CERN European Organization for Nuclear Research

SPS Layout

Click on the area of Interest



For comments and changes send e-mail to Paul.Collier@cern.ch

modified 07/04/99

Equipment

RF PUs : BA1, BA2, BA3

TWC 200 MHz : BA3

TWC 800 MHz : BA3

PU : 20

types : 8

BPSH

BPSV

AEW ✓

AESA ✓

AEG ✓

BPCR

AEP ✓

BPW ✓

AEW

RF pick-up electrode, wideband

- sampling scope (tunnel)
- beam current diagnostic (SA, wideband scope)
- peak detection
- beam current for feedforward
- long. damper
- pLHC synchro loop (ex)

- BW (~~-3dB~~): 4.4 MHz - 3.1 GHz (2 GHz)
  Z_T: 13 Ω

Dec 2002

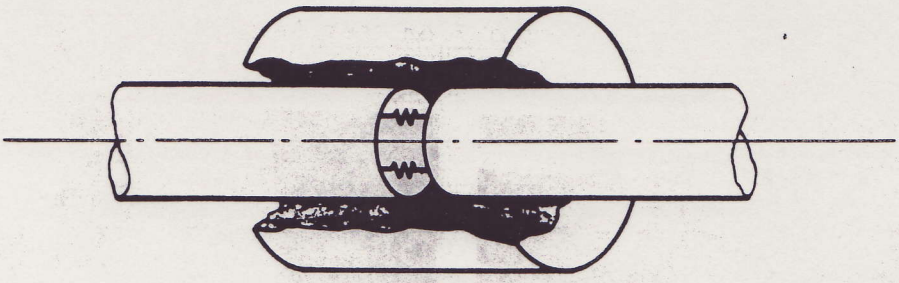


Fig. 9 - Sketch of wall current pick-up

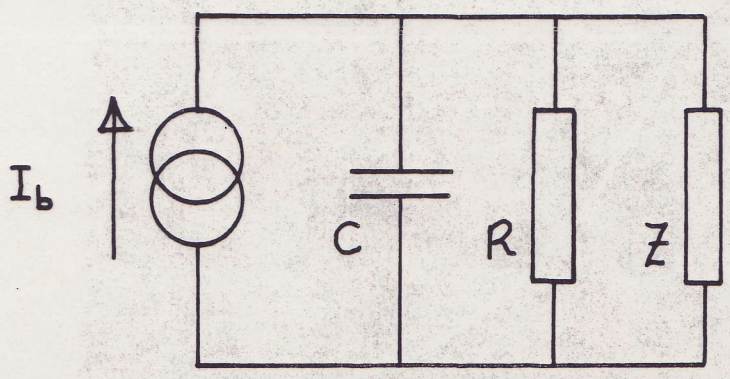
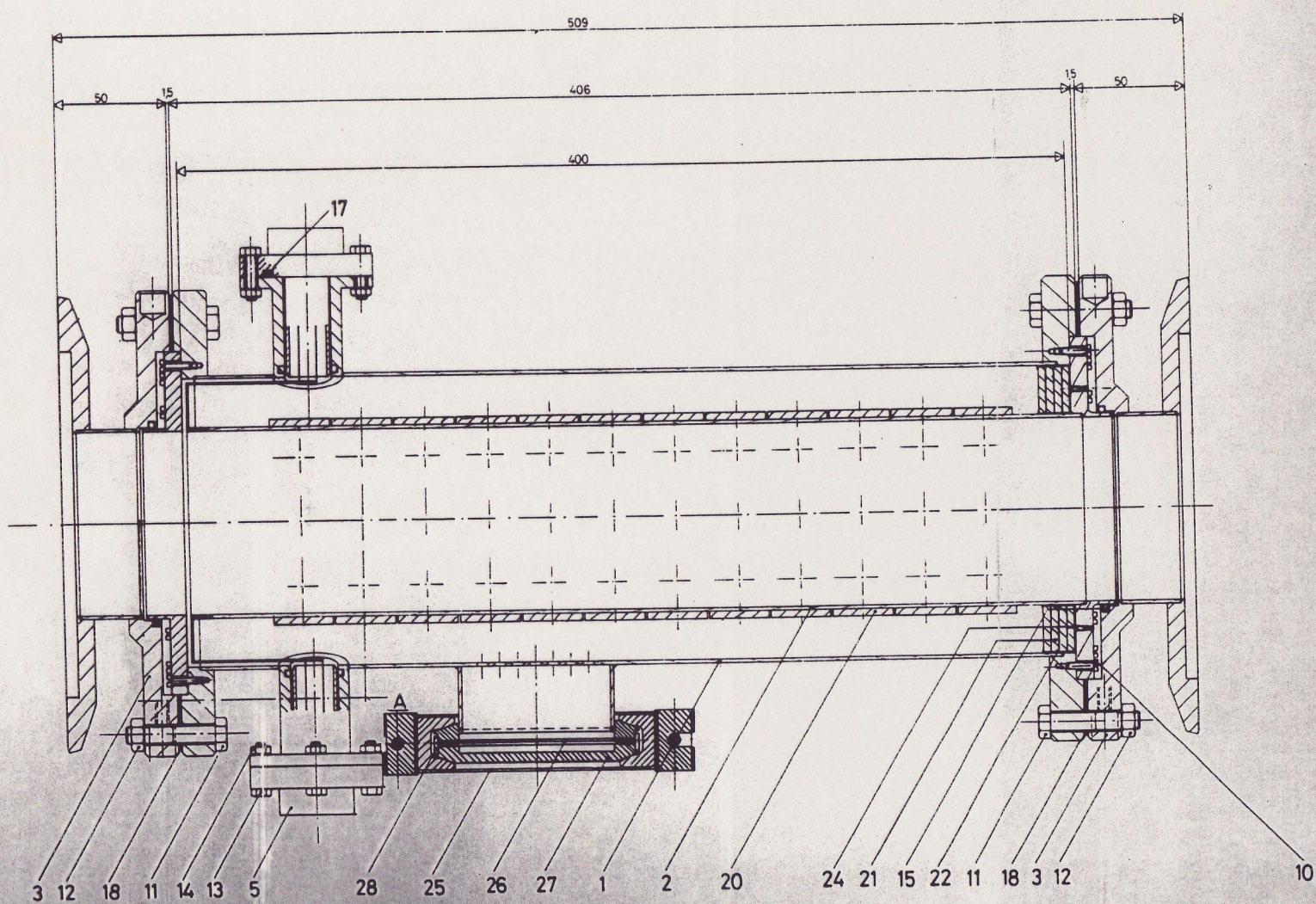


Fig. 10 - Equivalent circuit

Dec 2002

output using coaxial lines



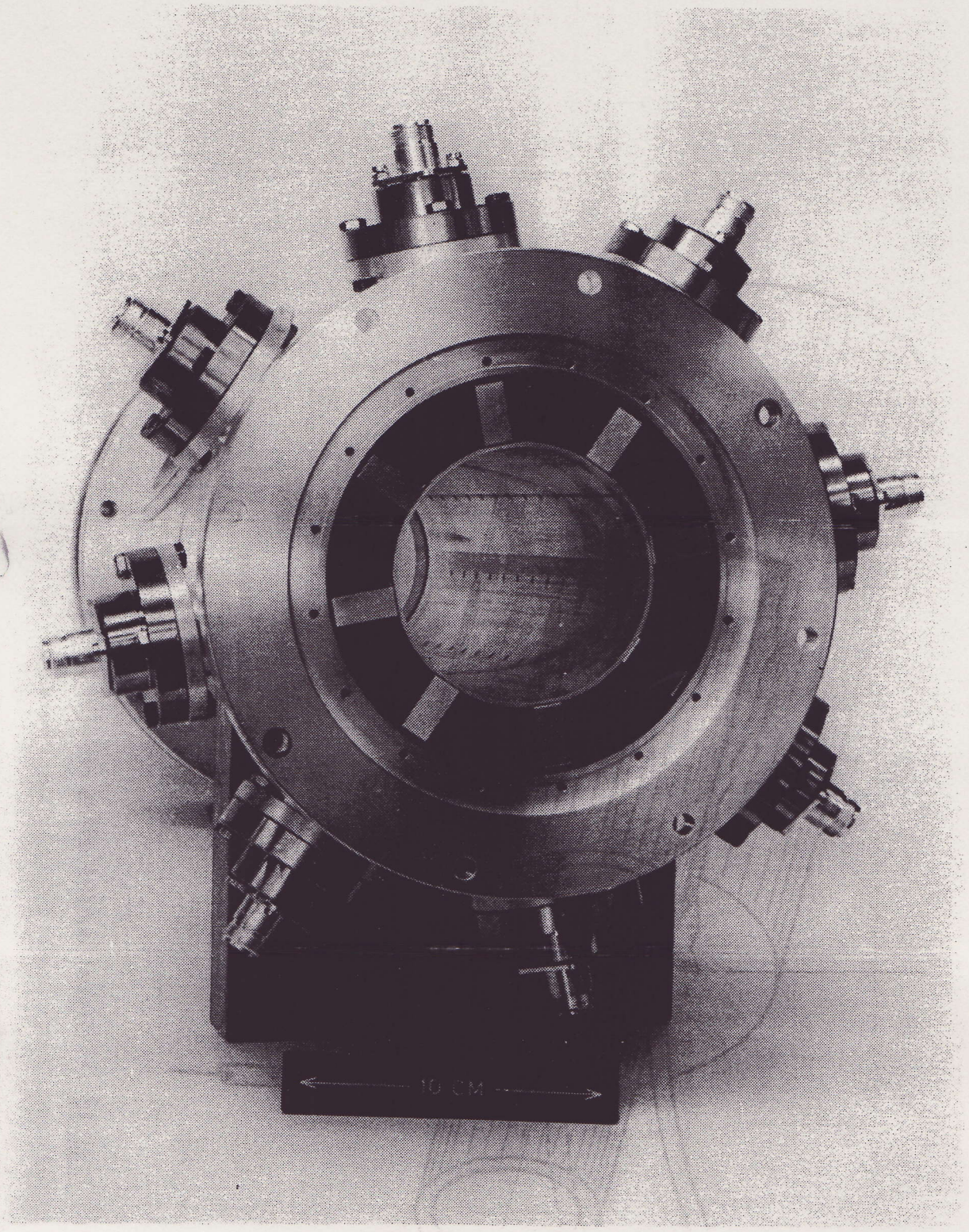


Fig. 12b - Wall current pick-up - end plate removed

B 7 W

pick up station, wideband

- directional coupler, exp.
- observation, transverse, instabilities
- BW (-3dB) : 140 MHz - 3.5 GHz

dec 2002

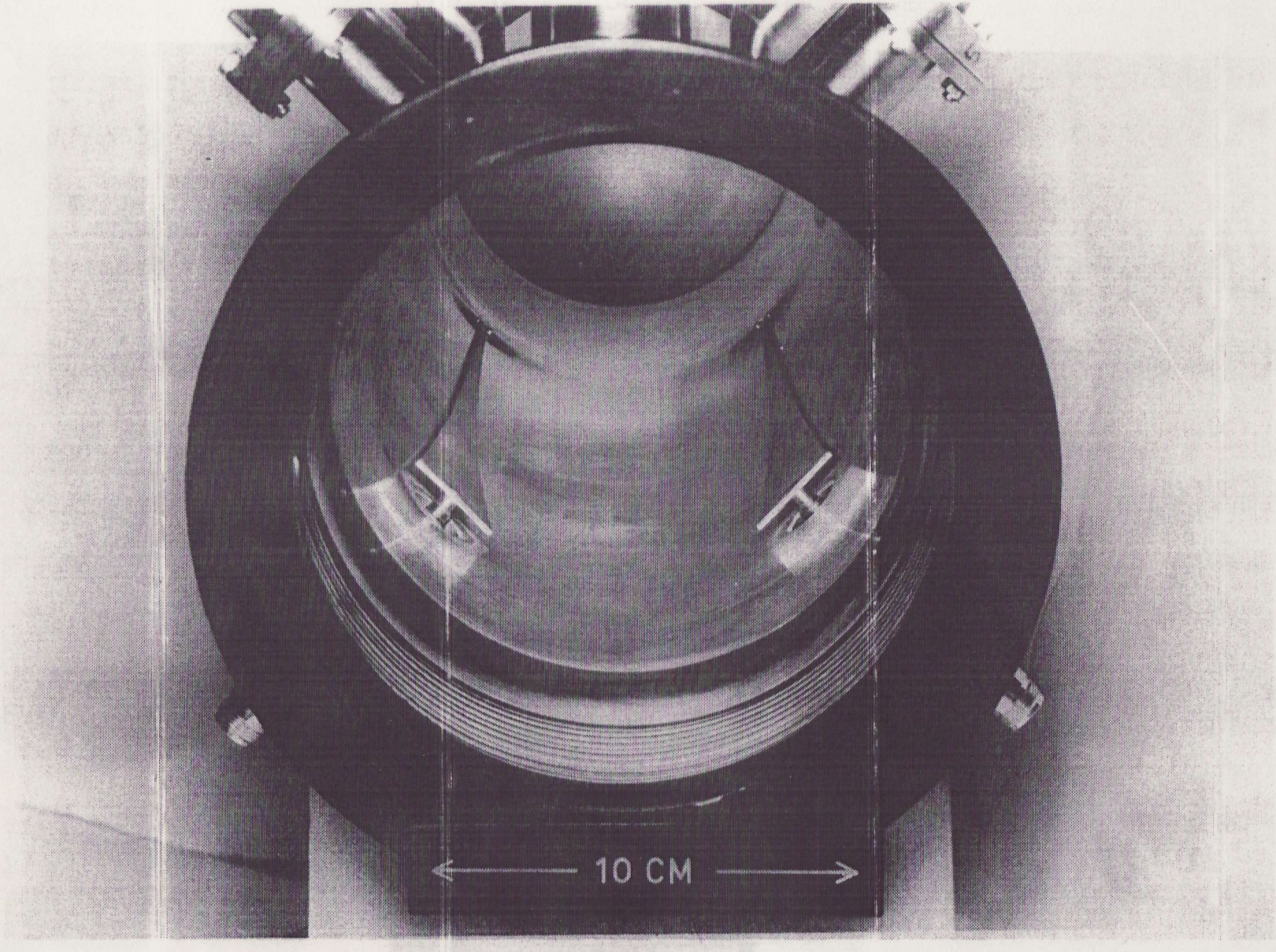
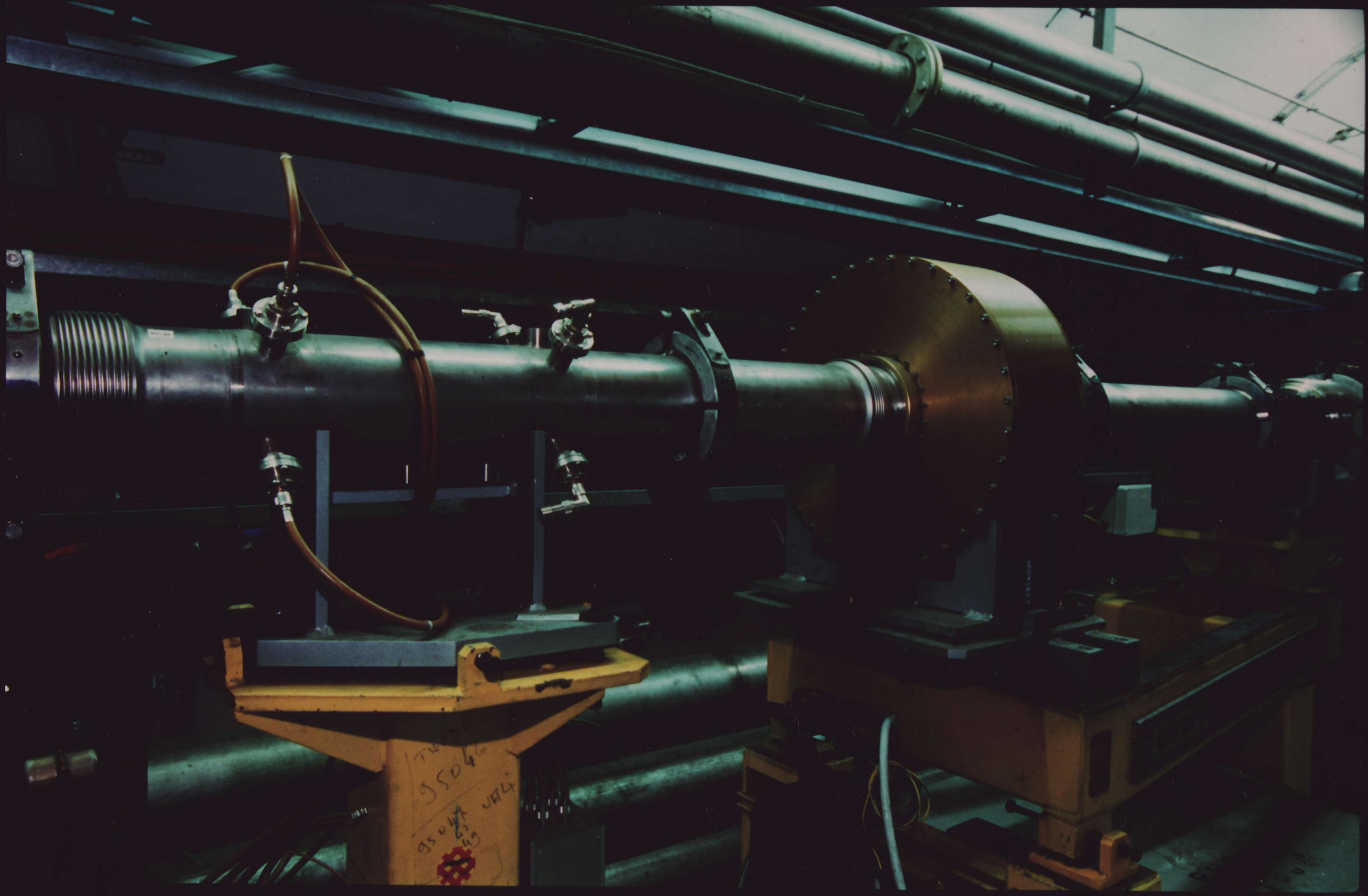


Fig. 31b - Interior of directional coupler pick-up



AEP

RF pick-up electrode for phase detection

- resonant PU
- phase PU : pPT, pLHC, ions
- f_0 : 200 MHz
- BW (-3dB) : 4 MHz

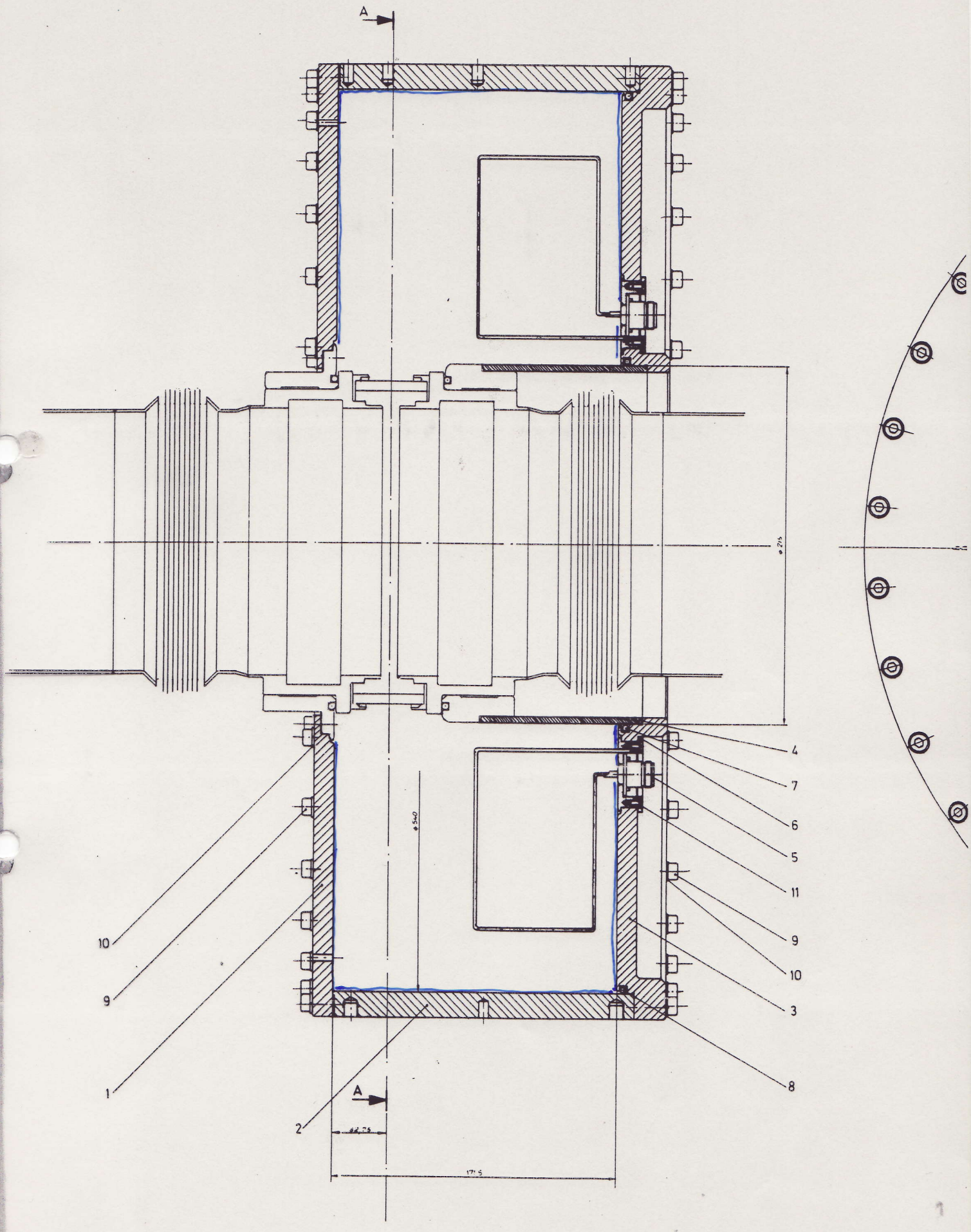


Fig. 51 - Phase pick-up

RADIAL PU

BPCR : directional coupler

200 MHz $\xrightarrow{\text{FC}}$ 10.7 MHz $\rightarrow \frac{\Delta}{\Sigma}$

AERB : - vertical beam position 98°

- 80 MHz AM $\rightarrow$ PM

- 200 MHz $\rightarrow$ 10.7 MHz (tunnel)
  $\xrightarrow{\text{FC}}$ Δ/Σ (ions)

- with resonators (ions)

Dec 2002

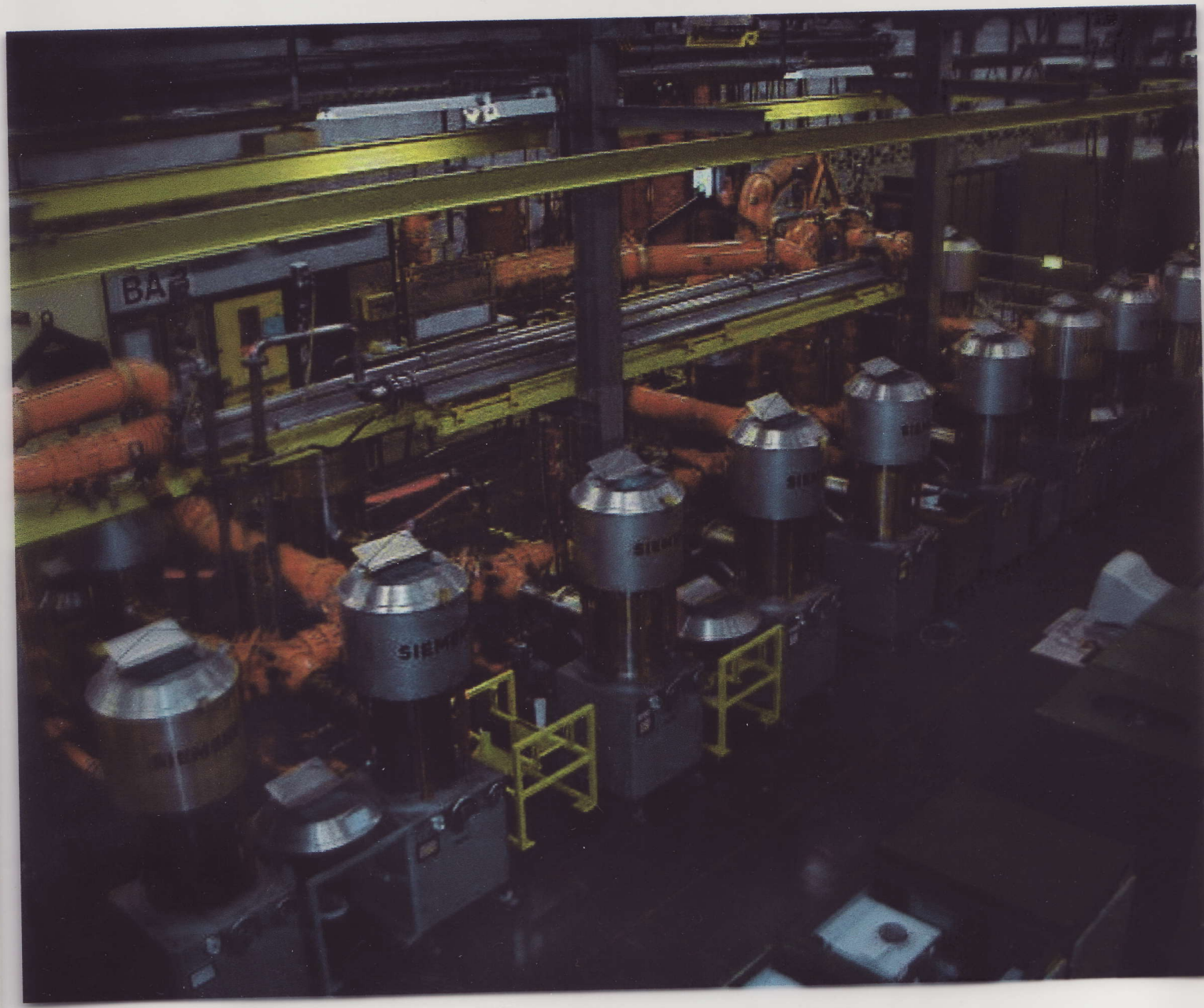
TWC 200 MHz

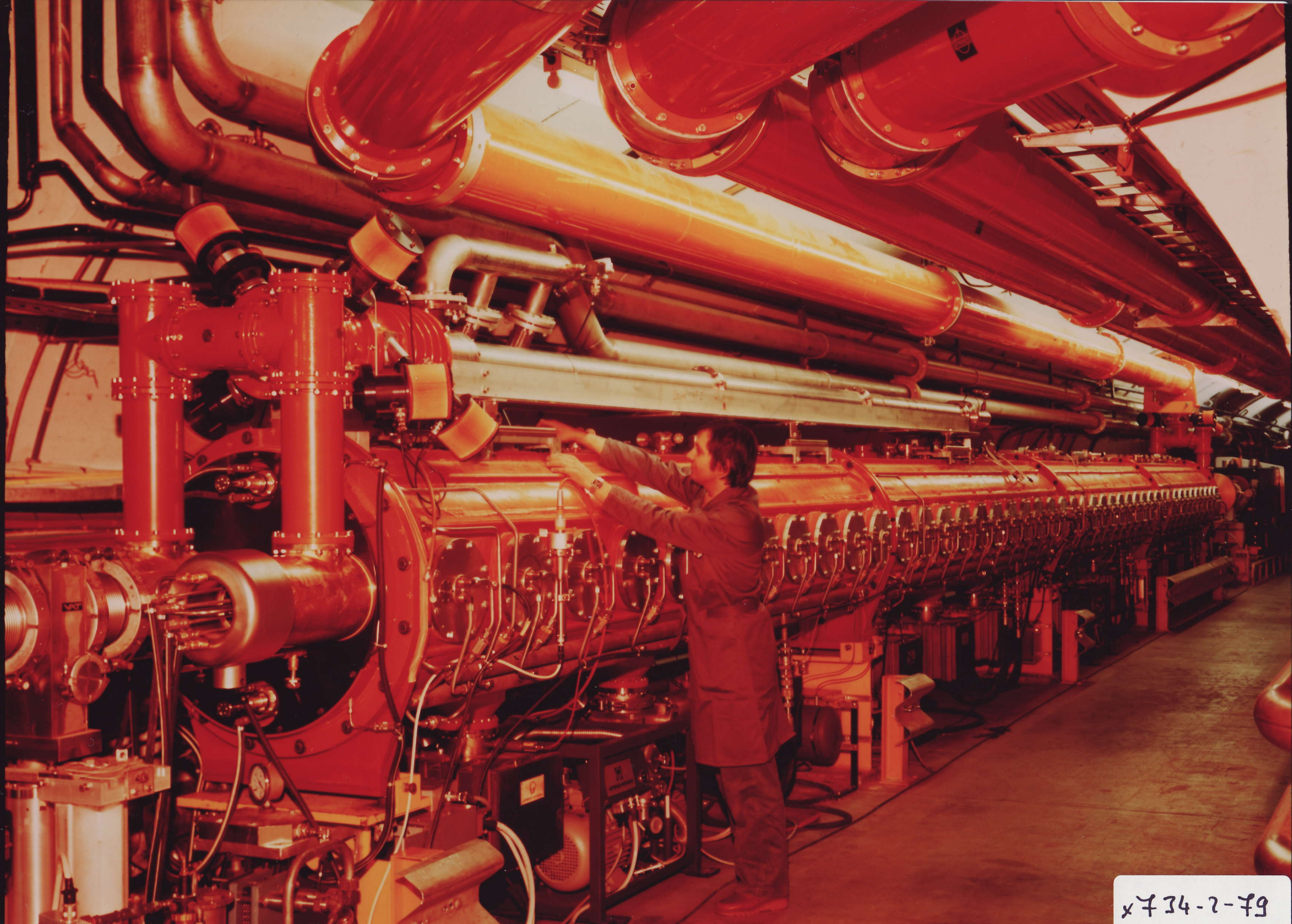
- main accelerating cavities for all beams

- 4 TWC (4 4 5 5), filling time ~ 600ns
- 8 amplifiers (tetrodes, 500 kW each)

  ⇒ 2.5 MV / cavity

- issues
  - impedance (Z_1, Z_2)
  - beam loading
  - no. of sections
  - multipacting ...
  - counterphasing





x734-2-79

x669-2-78

11182

TWC impedances

$$V = \underbrace{Z_1 i_g}_{V_{RF}} + \underbrace{Z_2 i_b}_{V_b}$$

$$Z_1 = \sqrt{\frac{R_2 l^2 Z_0}{2}} \cdot \frac{\sin \tau/2}{\tau/2}$$

$$Z_2 = -\frac{R_2 l^2}{8}\left[\left(\frac{\sin \tau/2}{\tau/2}\right)^2 - j 2 \frac{\tau - \sin \tau}{\tau^2}\right]$$

$$\tau = \frac{l}{v_g}(\omega - \omega_0)$$

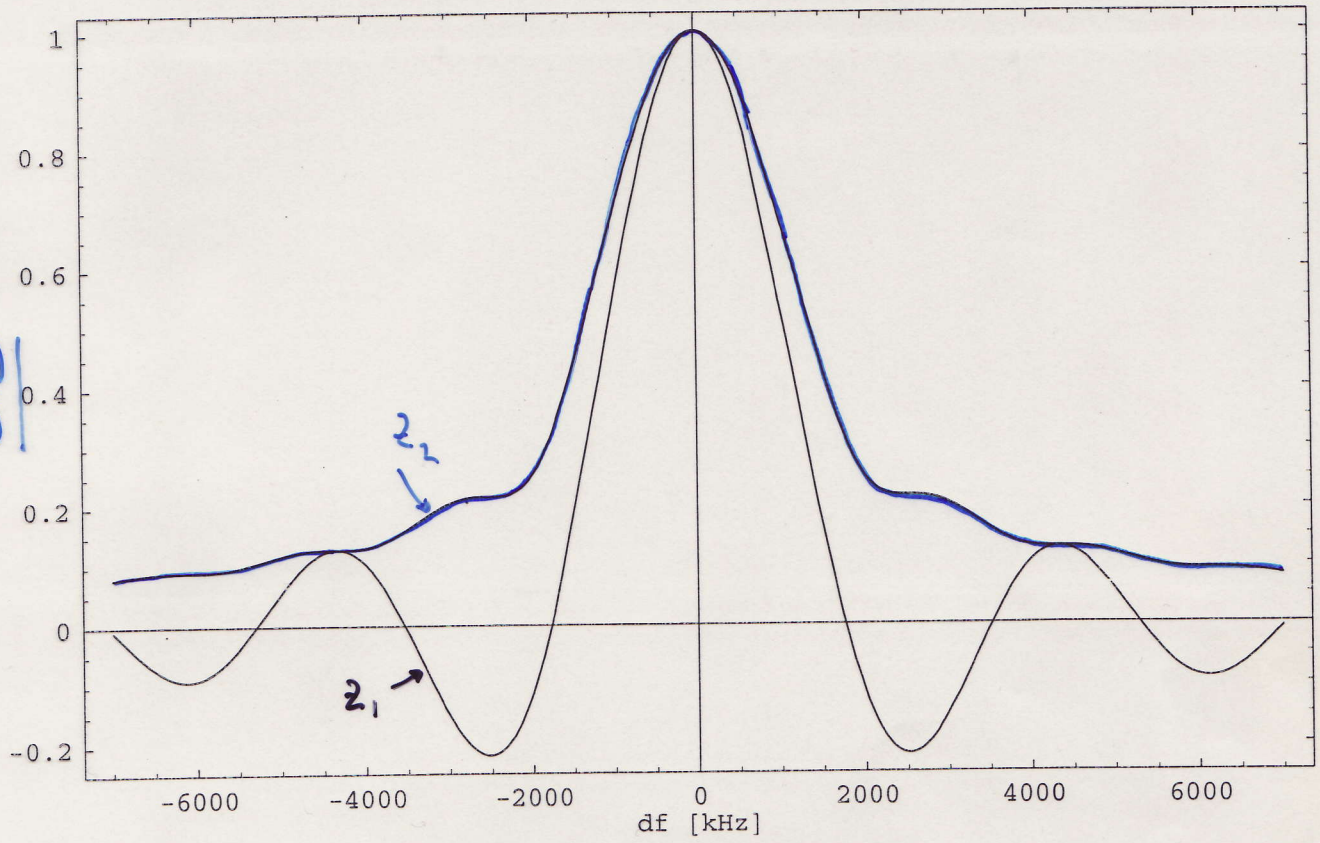
R_2 : TWC series impedance , 27.1 kΩ/m²

l : TWC interaction length

ω_0 : TWC centre frequency , $2\pi \cdot 200.222$ MHz

v_g : TWC group velocity , $v_g/c = 0.0946$

Z_0 : line impedance , 50 Ω (coax ampl. → TWC)



$\frac{z_1(df)}{z_1(0)}$

$\left|\frac{z_2(df)}{z_2(0)}\right|$

TWC 800 MHz

- higher harmonic
- bunch shortening (pLHC)
- noise excitation

- 2 TWC, filling time ~ 110 us
- 2 amplifiers of 225kW each
  (4 klystrons each)

=> 2 x 1.25 MV

- issues
  - power plant
  - low level upgrade (feedback?)

Beams

pFT (FT, CNGS)

pLHC (LHC)

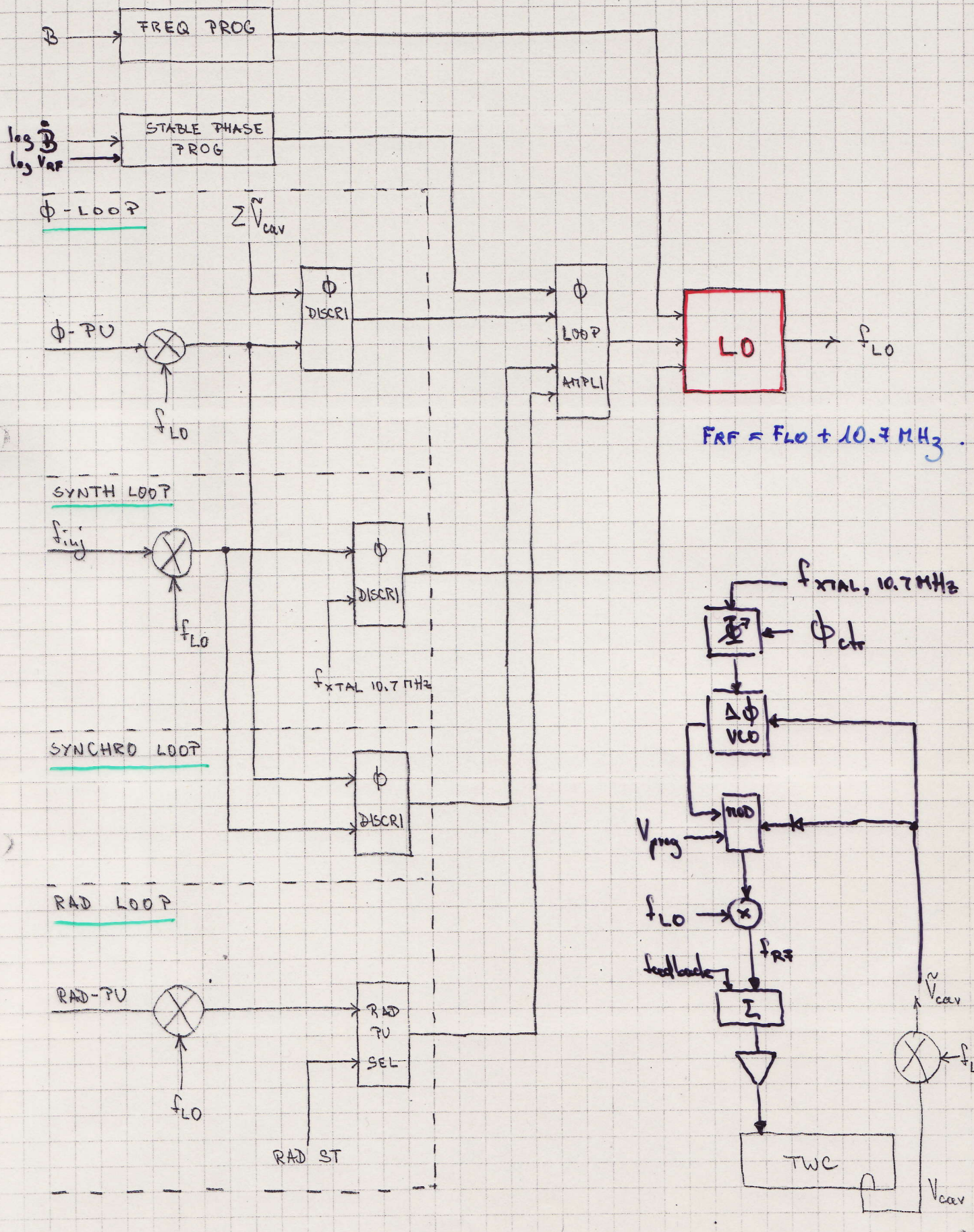
~~ions~~

Proton

Fixed Target

Beam

SIMPLIFIED RF BEAM CONTROL FOR HI f_{LO} GENERATION

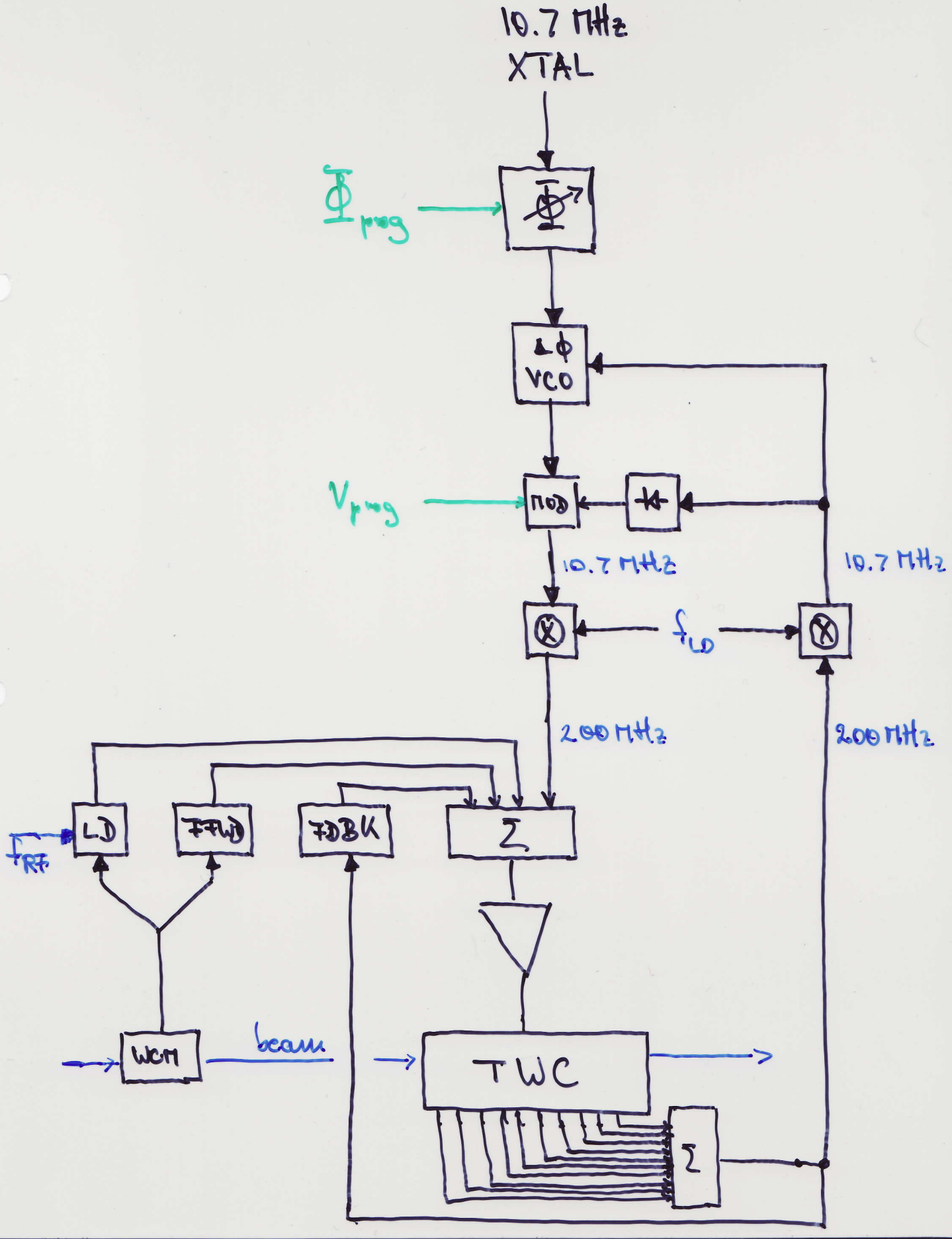


$F_{RF} = F_{LO} + 10.7\ MHz$.

$f_{IF} = 10.7\ MHz$

1994

Cavity Loops



1 batch

5 turn CT

2100 bunches

$N_p \approx 10^{10}$ protons / bunch

N_{tot} (2 batches, 450 GeV/c)

$4.8 \cdot 10^{13}$

$h = 4620$

$T_{rev} \approx 23\,\mu s$

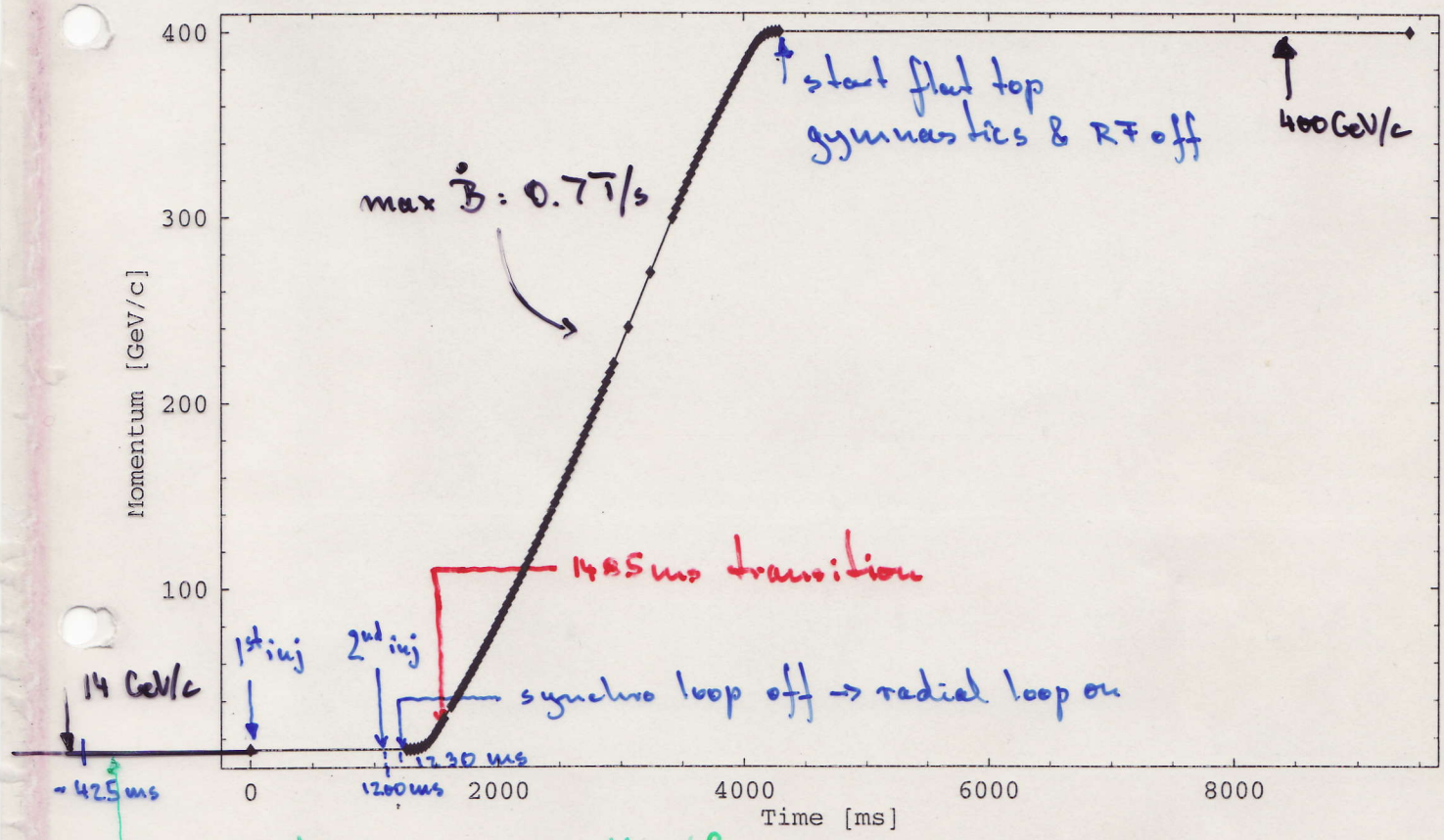
$199.5\ MHz \leq f_{RF} \leq 200.4\ MHz$

1 turn delay feedback

DFT

File: cy946.pmom.dat
SPS Supercycle 946 ; Proton 1 Fixed Target: Momentum ; 2001-07-17 ;
Index Segment Time (ms) ;

pmom-analysis.nb v00.03; 6.12.2002 18:5:57



synth. loop on : synth. / f_{LO}

RF on

phase loop on, synth. loop off (V_{cav} / f_{RF})

1st inj :

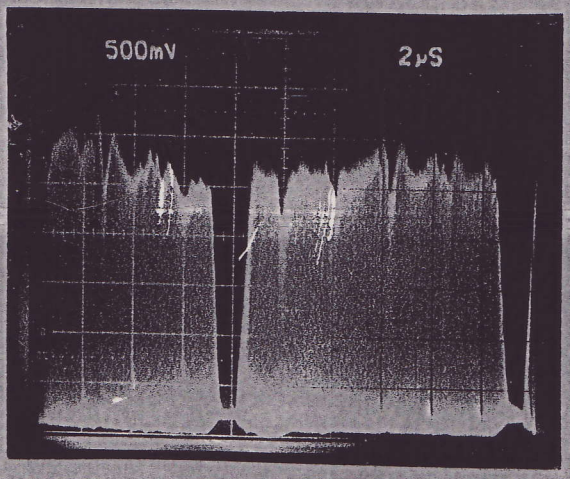
phase loop : V_{cav} / Φ_{beam}

synchro loop : f_{inj} / f_{RF}

capture of 200 MHz modulated beam (no bunch to bucket)

▷ 1 TRF Feedback ON.

Batch Structure



: = $3.3 \cdot 10^{13}$ p

1 batch

5 turn CT

2100 bunches

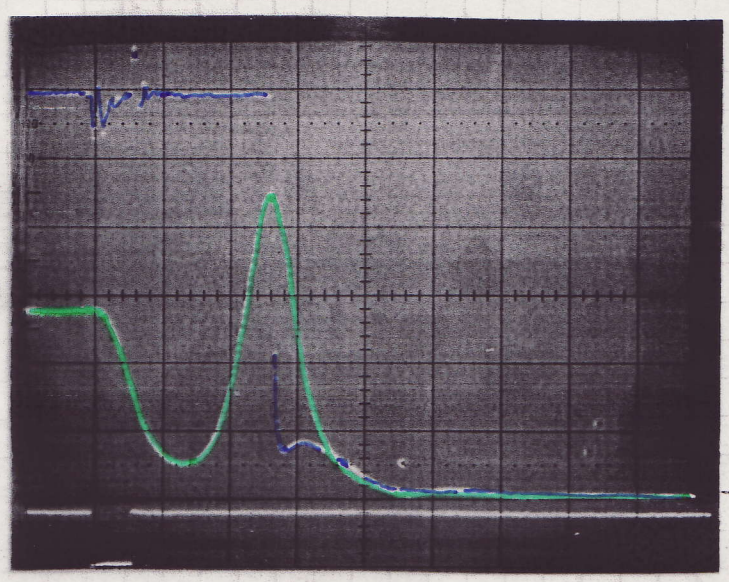
$N_p \approx 10^{10}$ protons / bunch

N_{tot} (2 batches, 450 GeV/c)

$4.8 \cdot 10^{13}$

14- APR- 1997

RF Gymnastics



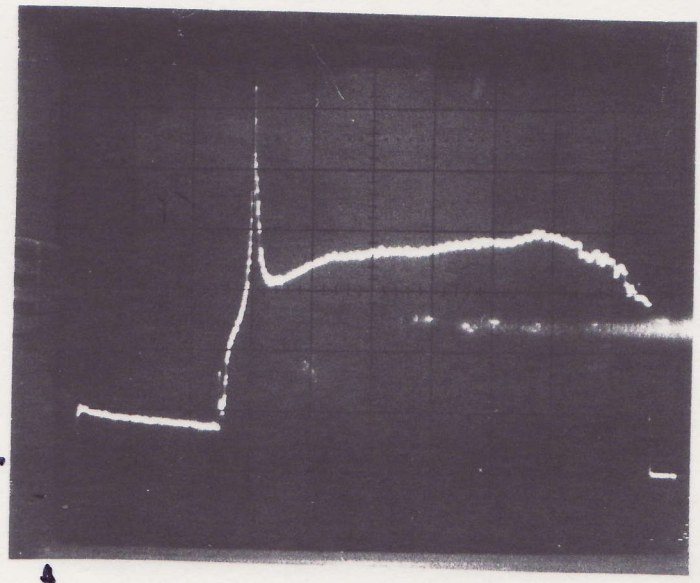
RF voltage

AEW_{pk}

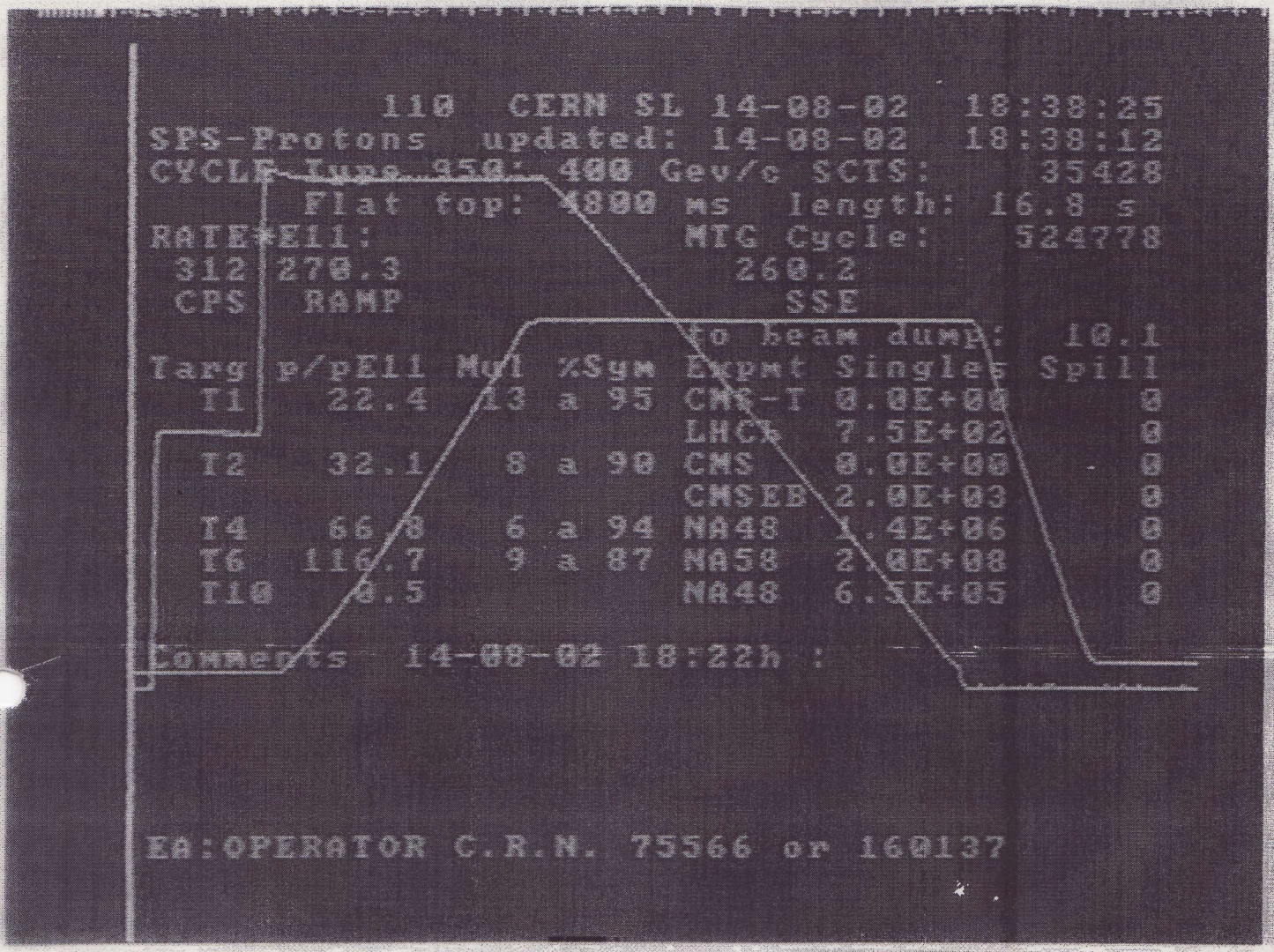
t_0 = 4739 ms , 1 ms / div

h : parameter to be optimized

Bunch Length



i = 3.3·10¹³ p



113 CERN SL 14-08-02 18:37:25
SPS-Protons update: 14-08-02 18:37:39

PS	TT 10		LOSS	INJC	LOSS
1518	1362	1372	10.3	1353	0.7
1586	1417	1435	10.7	1417	0.0

	I/E10	LOSS	TRNS	TIME
INJECT	2770	0.3	99.7	
END FB	2743	1.0	98.7	1260
20 GeV	2719	0.9	97.8	1470
27 GeV	2703	0.6	97.3	1530
50 GeV	2695	0.3	97.0	1740
400 GeV	2695	0.0	97.0	4320

LOSS 1-2INJ 1.2% LOSS T.L. 8.5%

Issues

- batch structure (staircase)
- transmission
- reliability

LHC

Essentials

Loops

- synchro loop f_{prog} / f_{RF}

  ↑ freq. progr. (DDS)

- phase loop (beam / cavity)

(- rephasing loop)

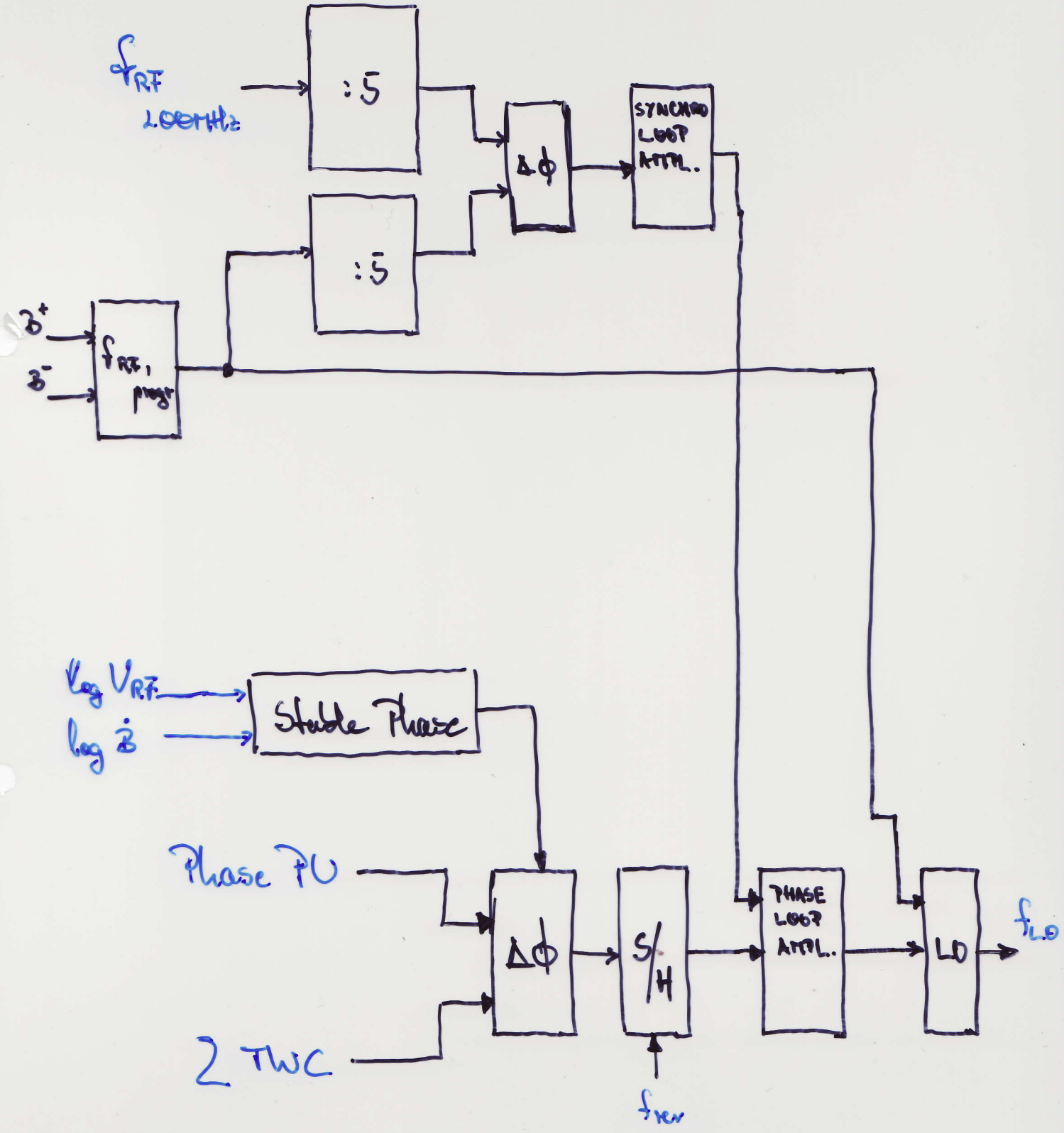
TWC 200

- feedforward
- 1 turn delay feedback
- long. damper (sub woofer)

TWC 800

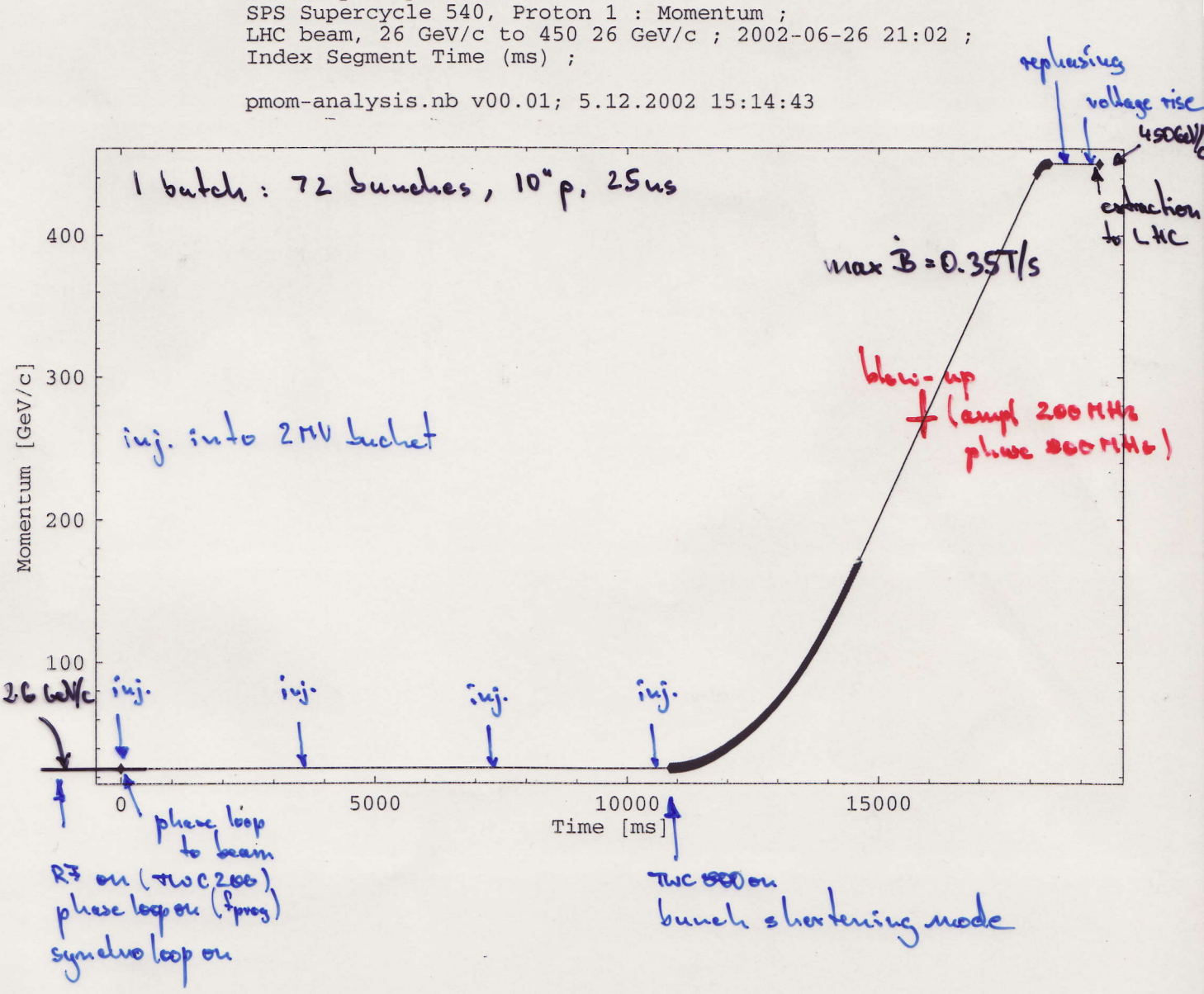
- BS

pLHC Beam Control, simplified



1 turn delay feedback : impedance reduction (beam loading & coupled bunch inst.)

long. damper : coupled bunch inst. (low order modes) & inj. damping for 2nd, 3rd, 4th inj. (dipole)



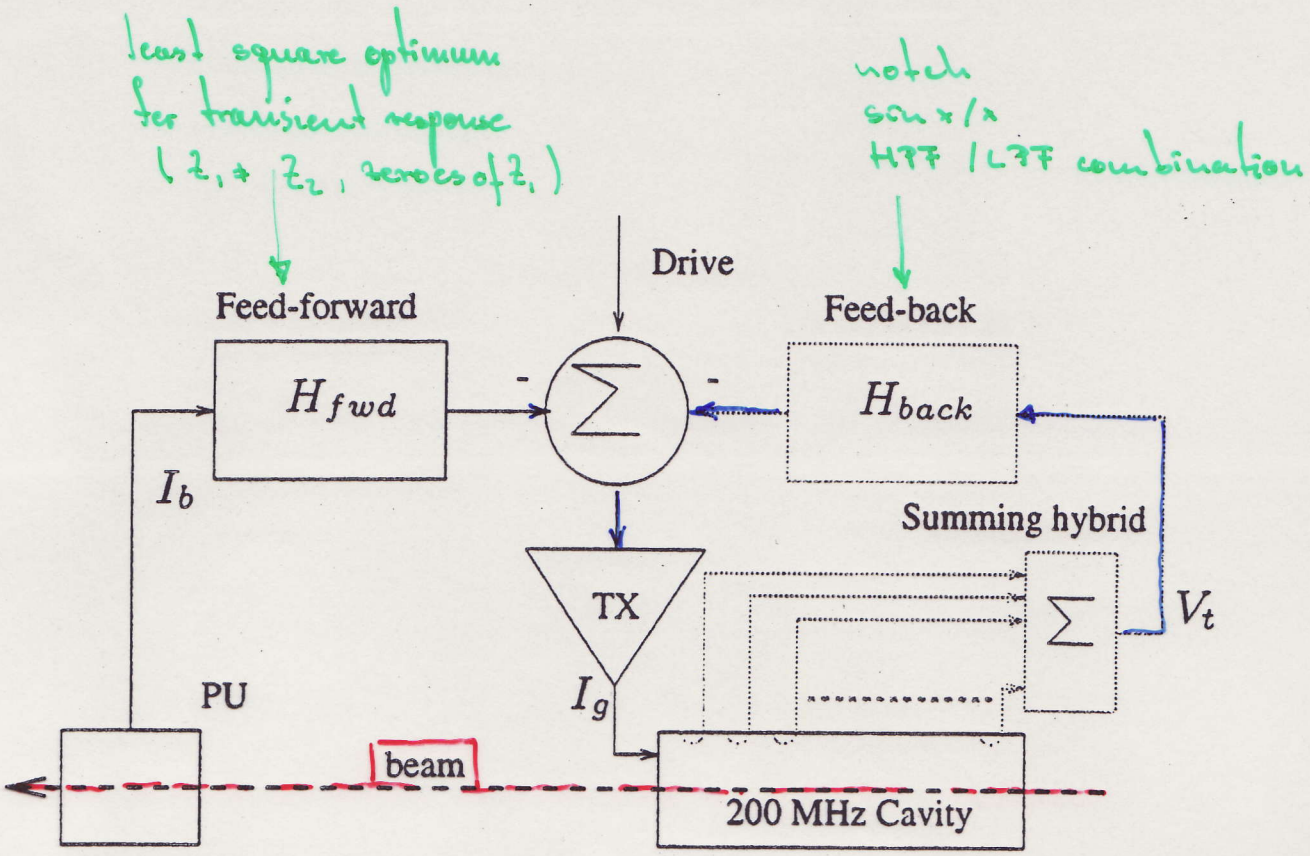
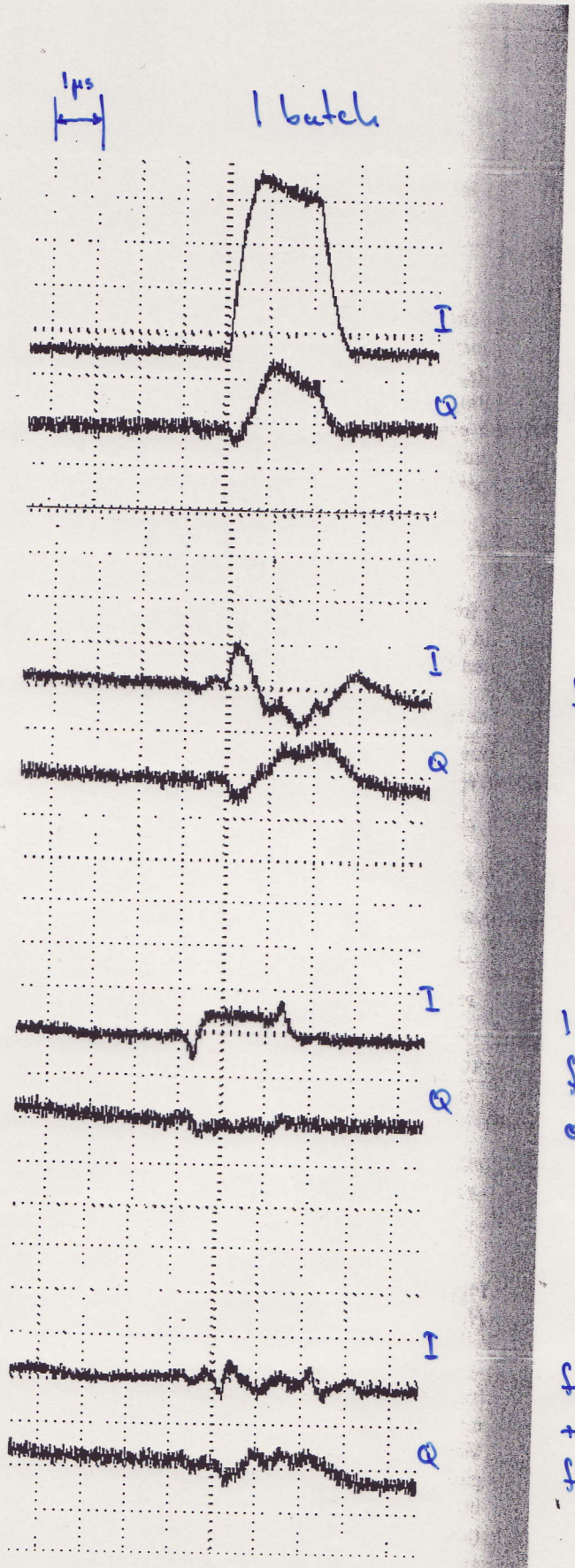


Figure 11: Beam loading correction by a feed-forward and feed-back pair.



no compensation

feedforward only

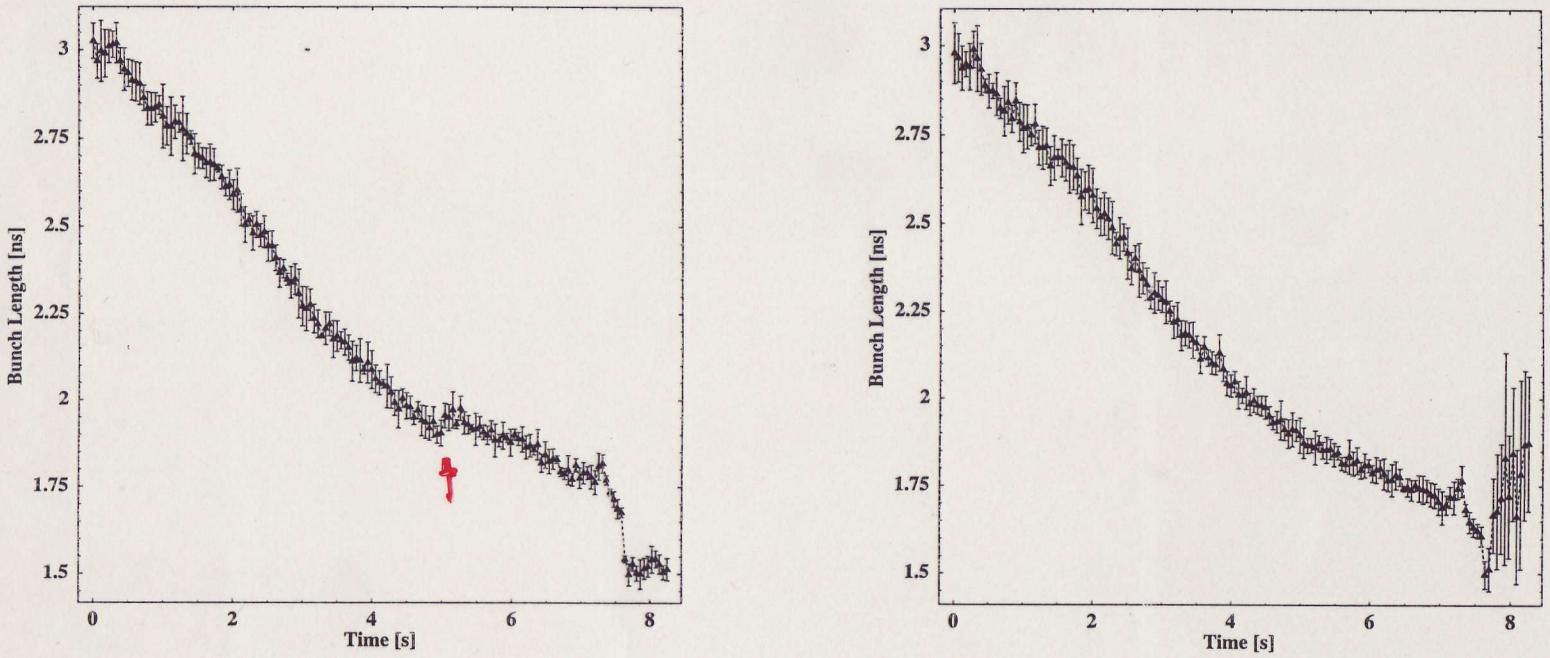
1 turn delay feedback only

feedforward + feedback

Figure 18: Beam loading compensation with the LHC batch of $2\mu s$ ($1\mu s$ per division). I and Q components of the beam loading. From top to bottom: no compensation, feed-forward only, feed-back only, feed-forward and feed-back pair. (5 sections cavity, feed-back with low-pass branch H_{lp} only).

P. Baudrenghien, Reducing the impedance ..., Chamonix 2000

Bunch length during the cycle. MD on 26.09



Average (for 5 bunches) bunch length during the cycle with bunch excitation at 16.0 s and without.

Issues

- long. emittance, ε
- bunch length, z_b
- bunch phase error

} for LHC

- differences between batches (ε, z_b)
- identification of coupled bunch modes (with TWC 800 off)
- controlled long. blow-up
- mismatch at injection
- TWC 800 low level upgrade (feedback?)