THE CERN PROTON DRIVER ACCUMULATOR & COMPRESSOR

R. CAPPI / CERN

- INTRODUCTION — where, what, why
- MAIN PARAMETERS — STILL CHANGING
- COLLECTIVE EFFECTS — A LIST OF
- E-CLOUD — A DANGEROUS EFFECT; RECENT MEASUREMENTS ON PS
- CONCLUSION

Contributors

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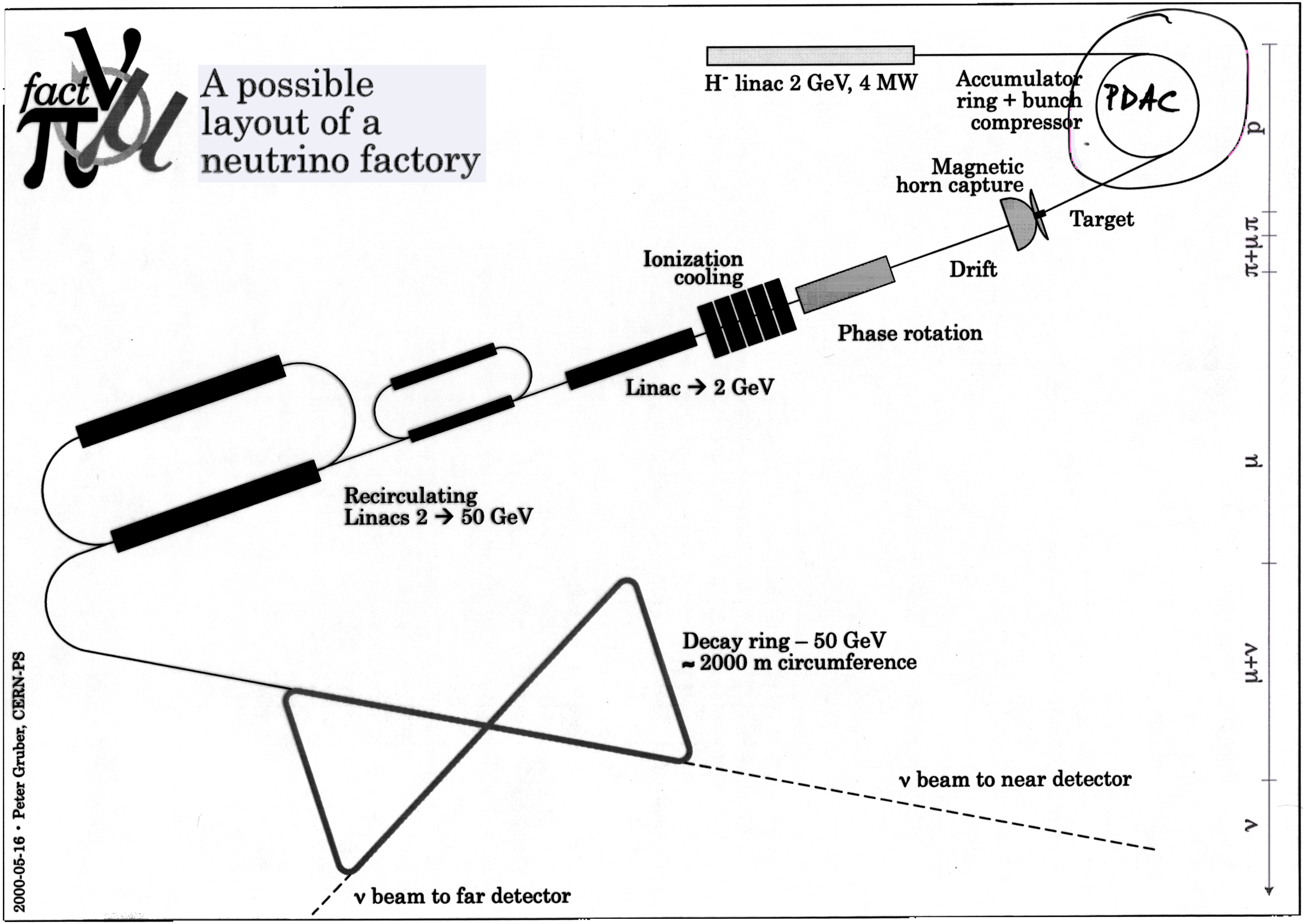
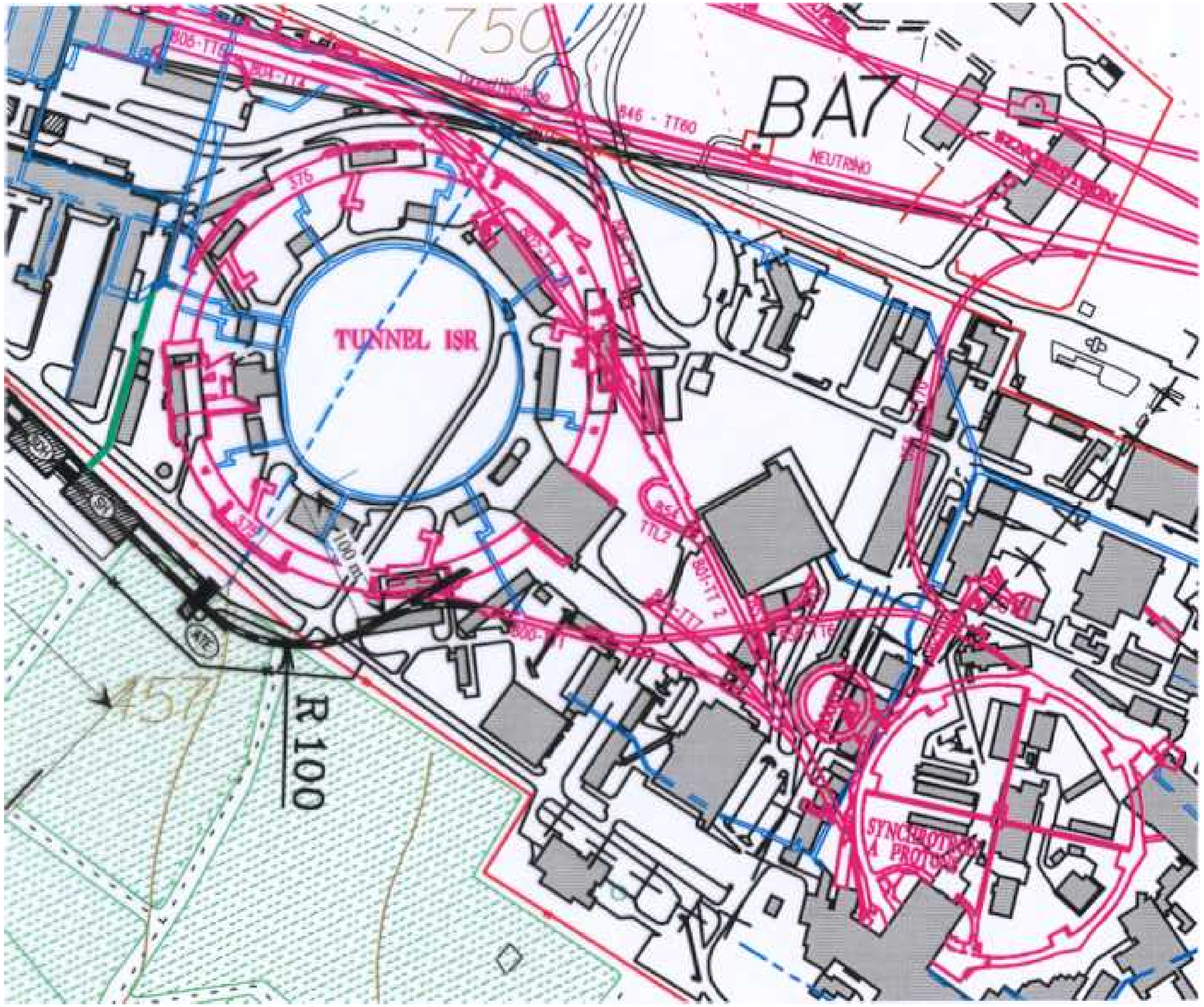
tks for pictures !


A possible layout of a neutrino factory
H⁻ linac 2 GeV, 4 MW
Accumulator ring + bunch compressor
PDAC
Magnetic horn capture
Target
Drift
Ionization cooling
Phase rotation
Linac → 2 GeV
Recirculating Linacs 2 → 50 GeV
Decay ring – 50 GeV
≈ 2000 m circumference
ν beam to near detector
ν beam to far detector
p
π+μ
μ
μ+ν
ν
2000-05-16 · Peter Gruber, CERN-PS

La... ı SPL



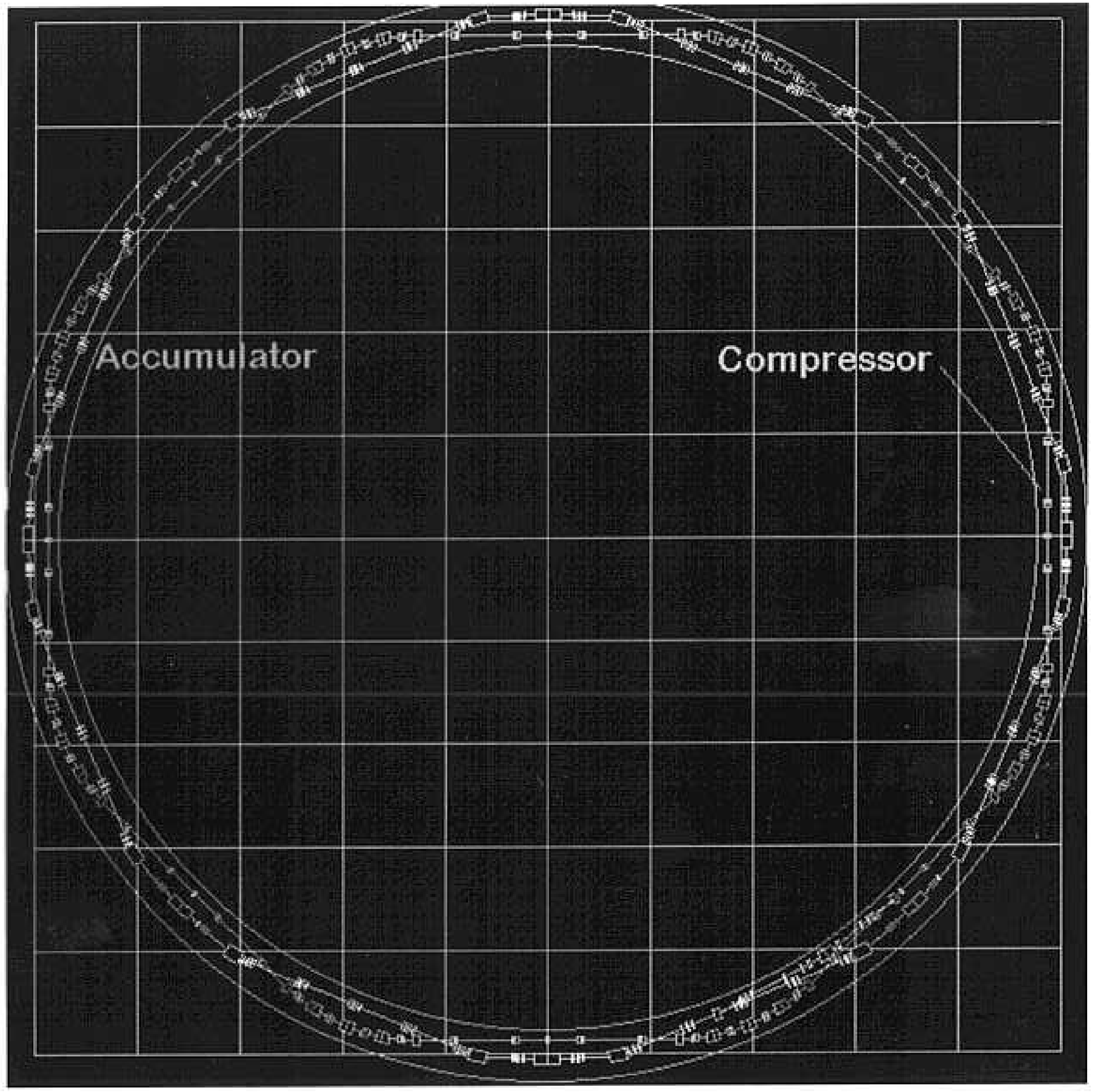
BA7
750
NEUTRINO
846 - TT60
TUNNEL ISR
100 m
R 100
457
SYNCHROTRON A PROTONS

fr

PDAC

Layout n

SR Tunnel

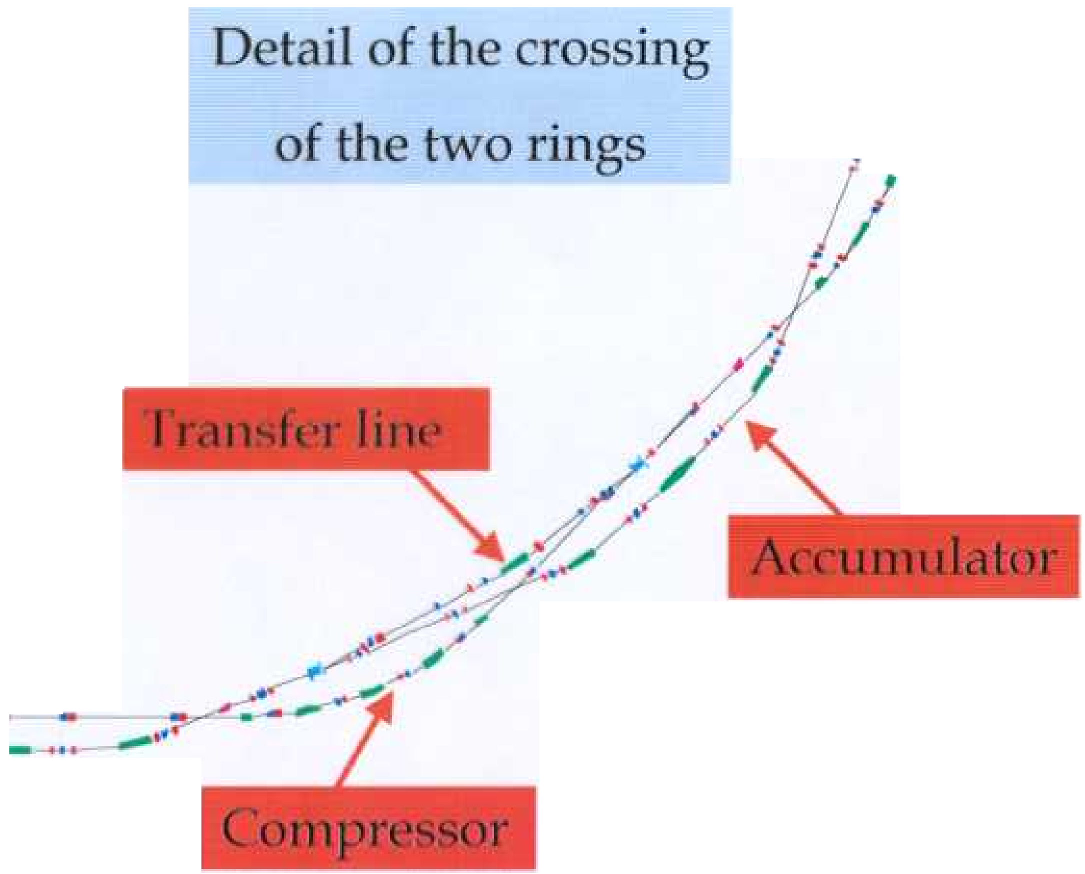


Muon Week 09/05/2001

Courtesy H. Schönauer

R 5

Accumulator-Compressor Layout

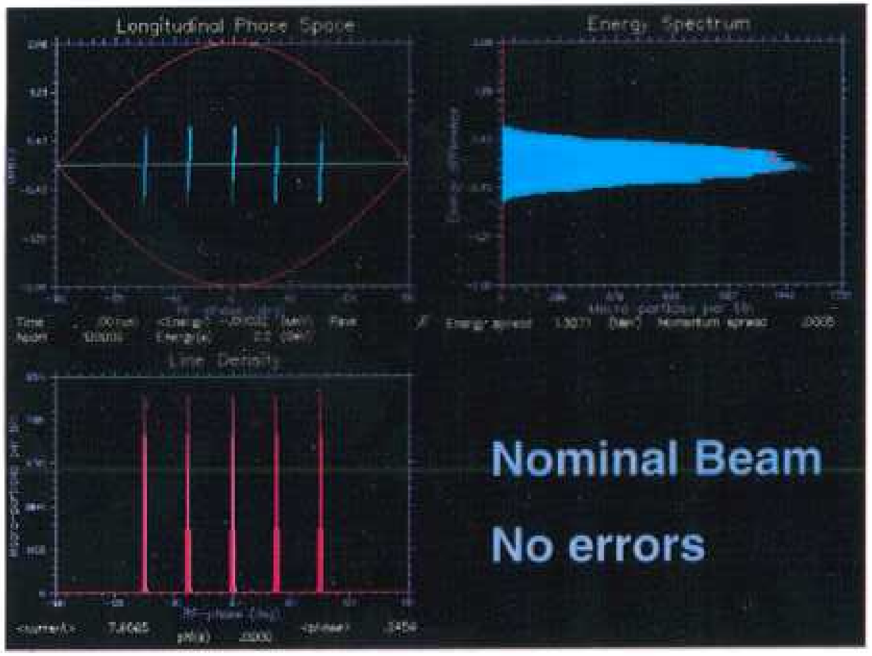


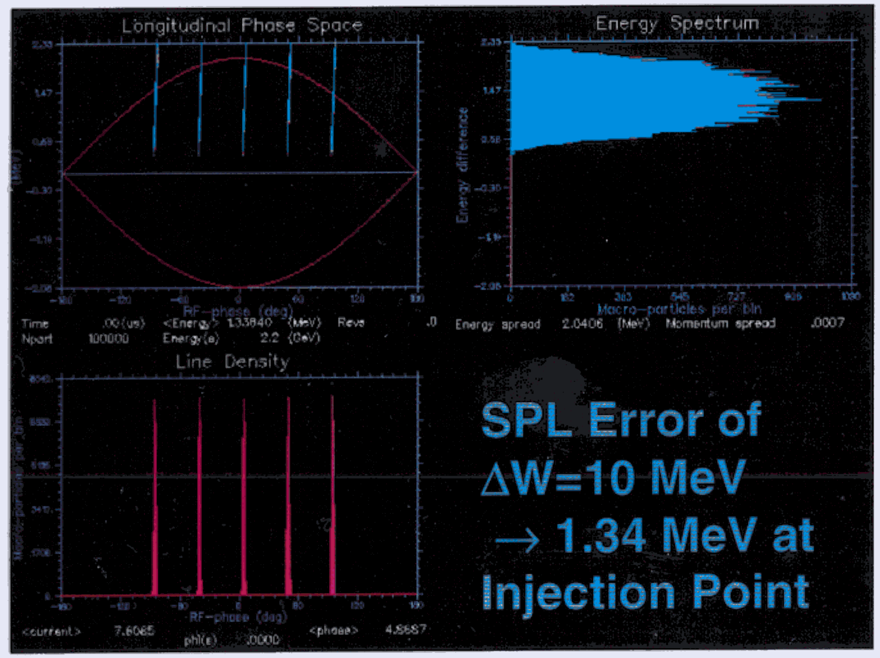
COURTESY M. MARTINI

5

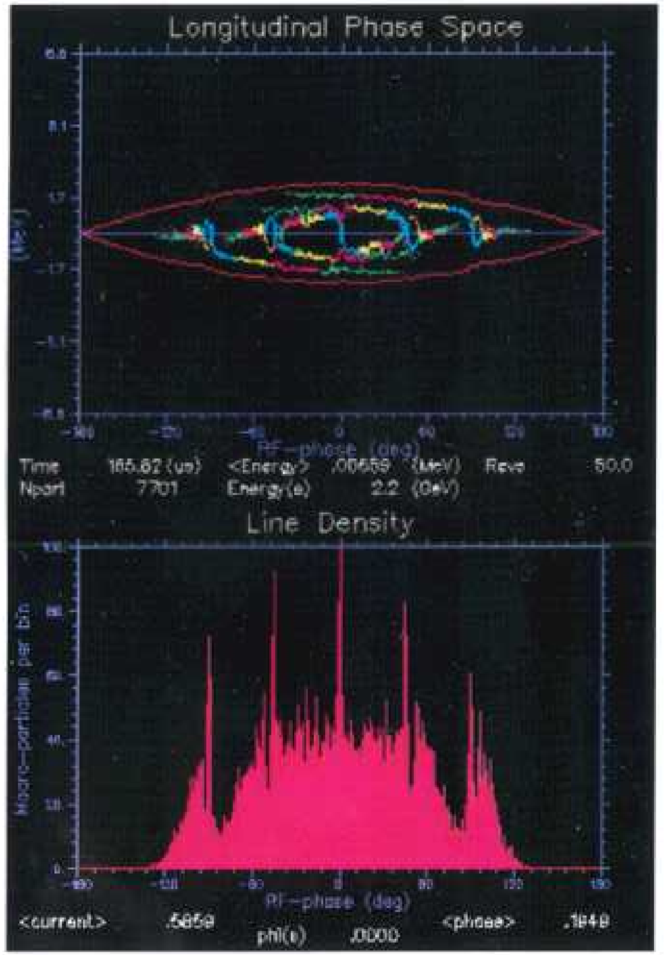
6

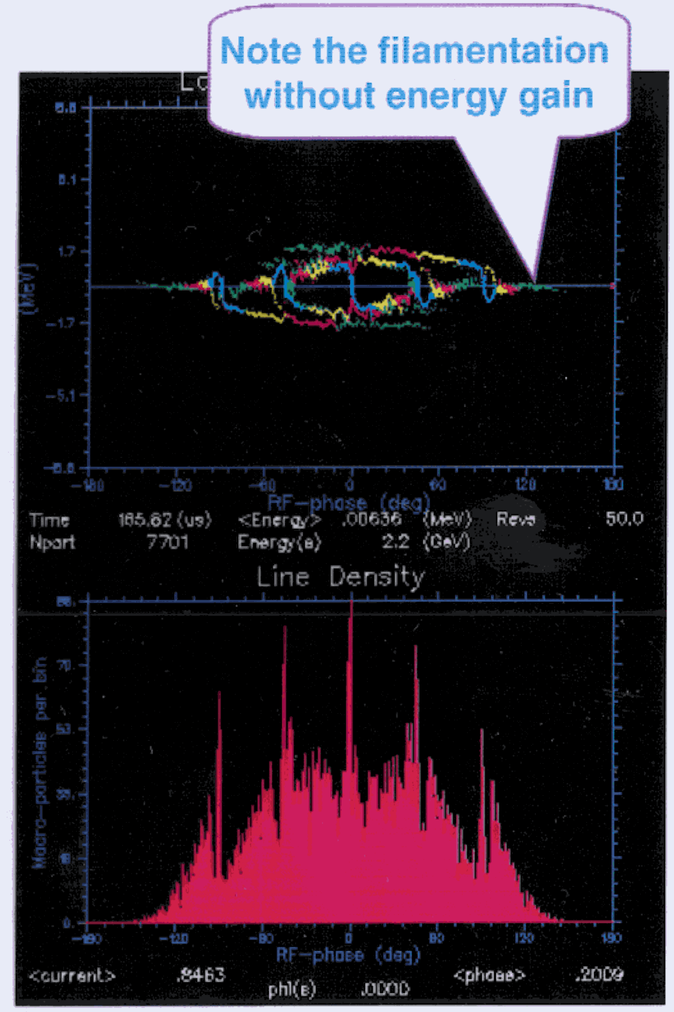
5 SPL Micro Bunches as njected n the Accumulator





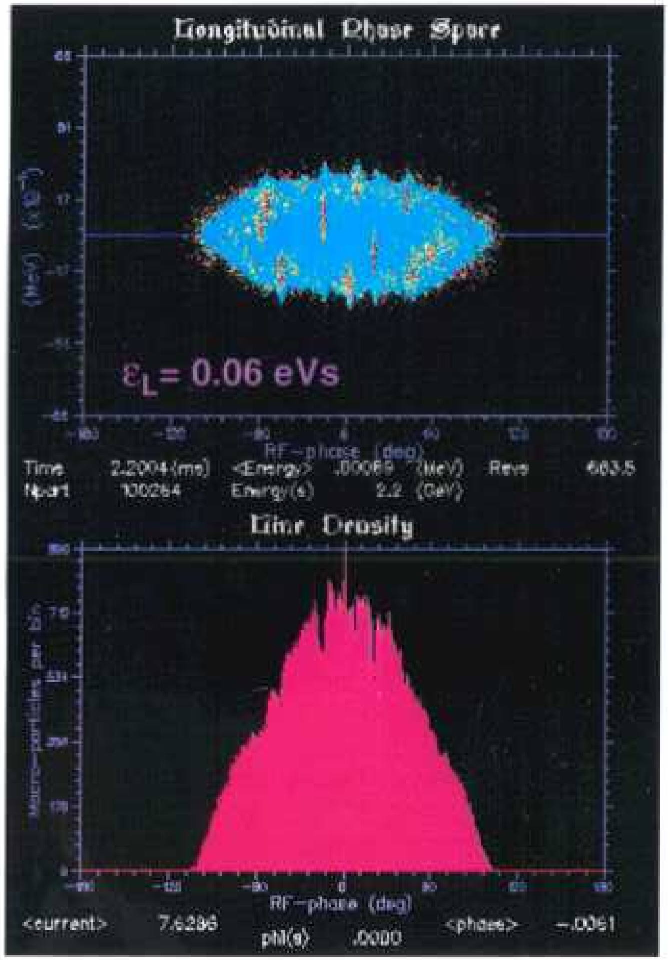
50 Hz Operation, I_{linac}= 27 mA: Microbunches after 50 Turns for 1.52 10^{14} p and 2.27 10^{14} p

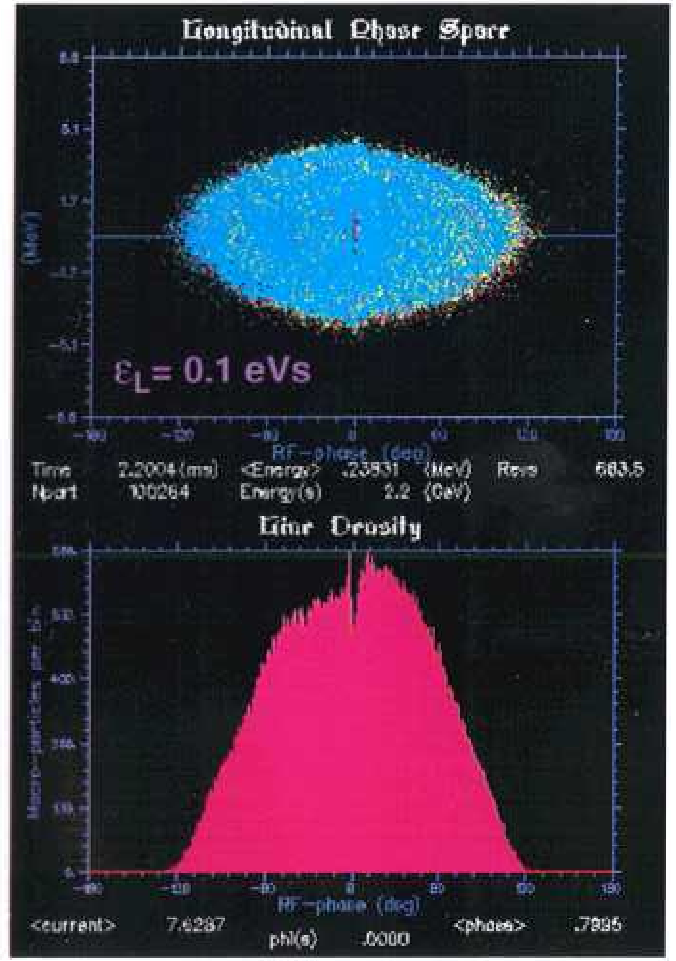




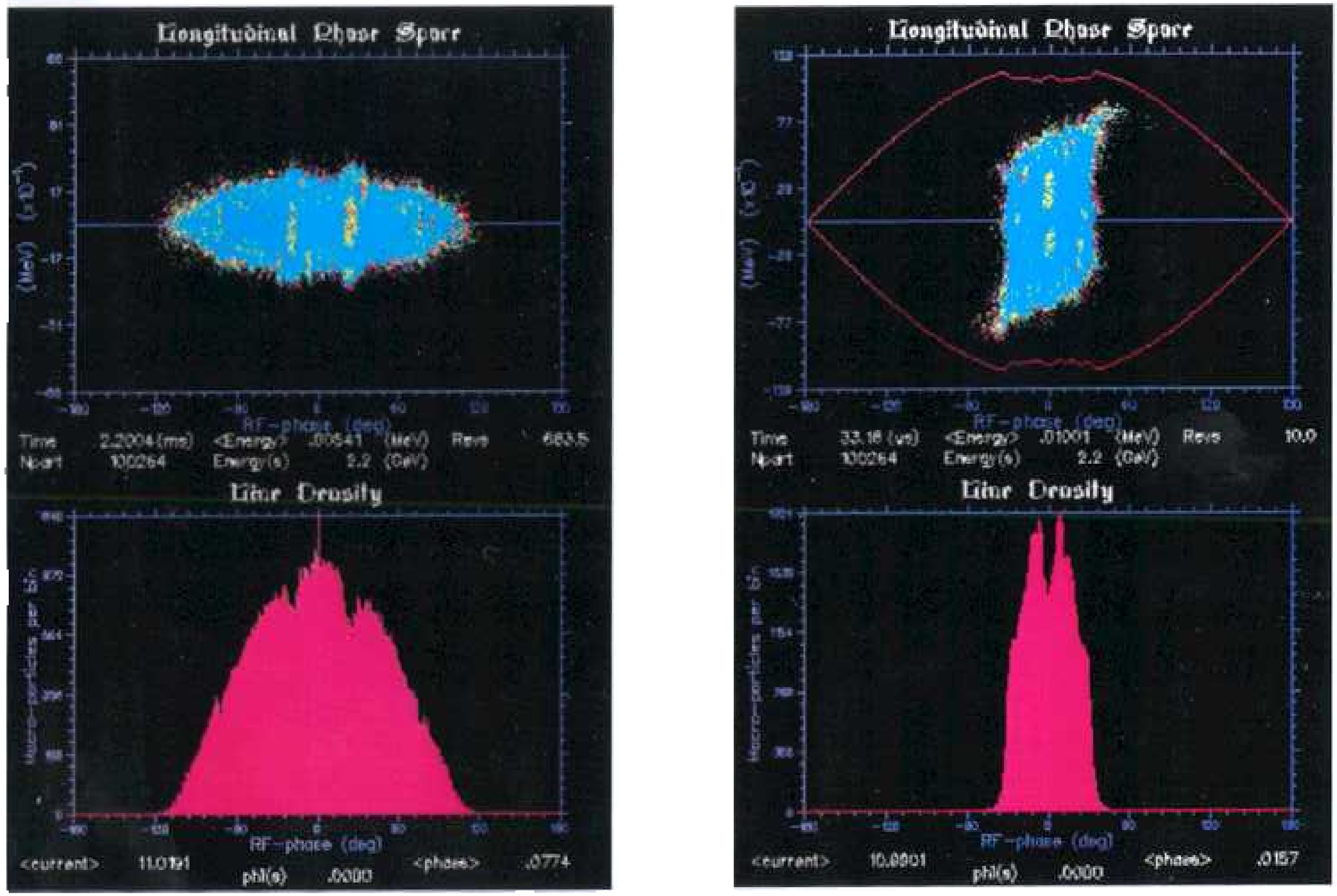
Bunches after 660 turns (End of nject on) n the Accumu ator

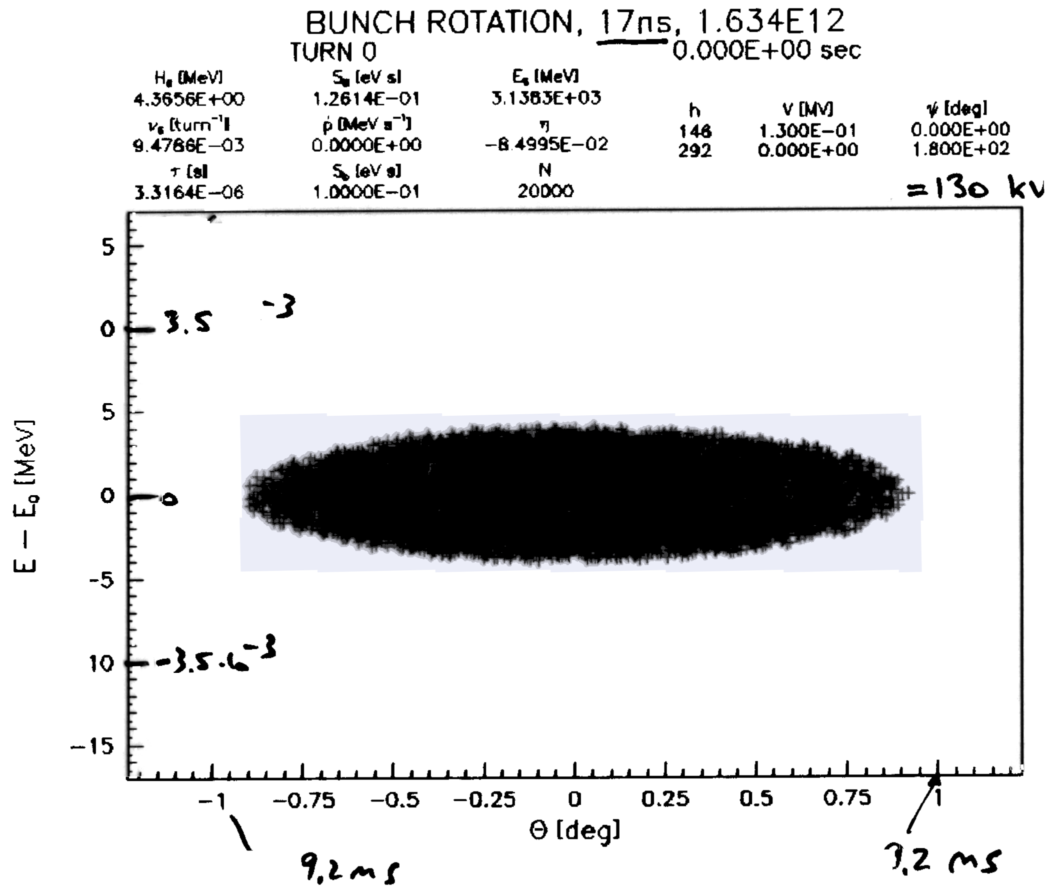
ΔW_{Linac}=10 MeV





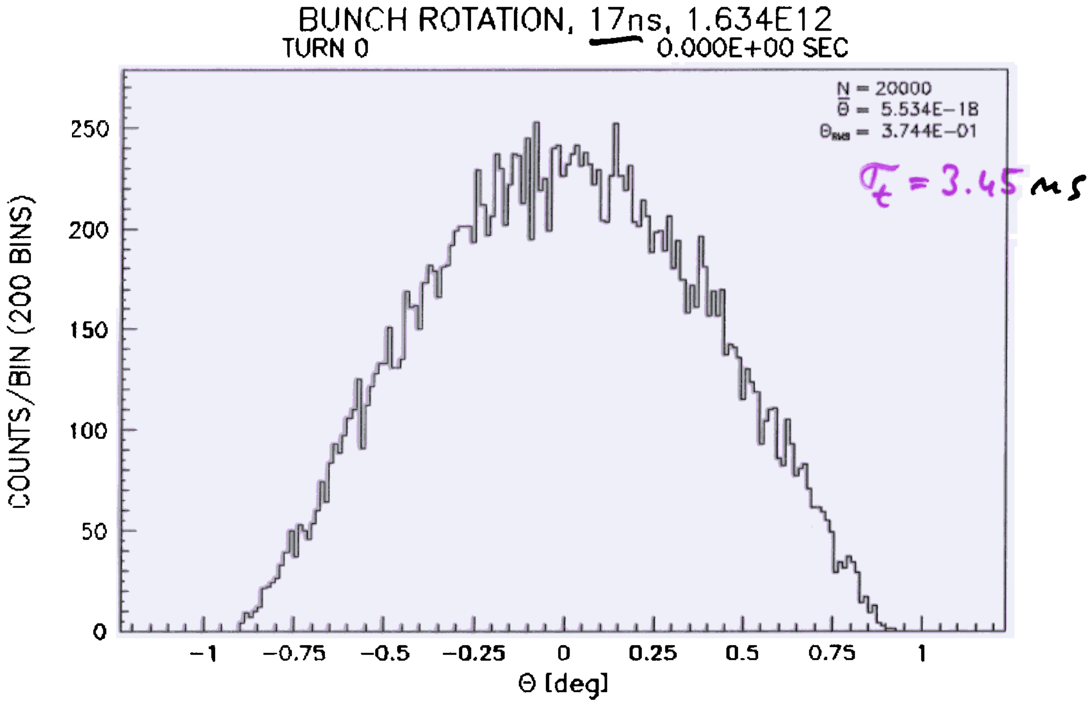
End of Accumulation and Compression with 2.27 10^{14} p : 50 Hz Operation, I_{linac}= 27 mA





$\sigma_t = 3.45$ ms

COURTESY E. METAL

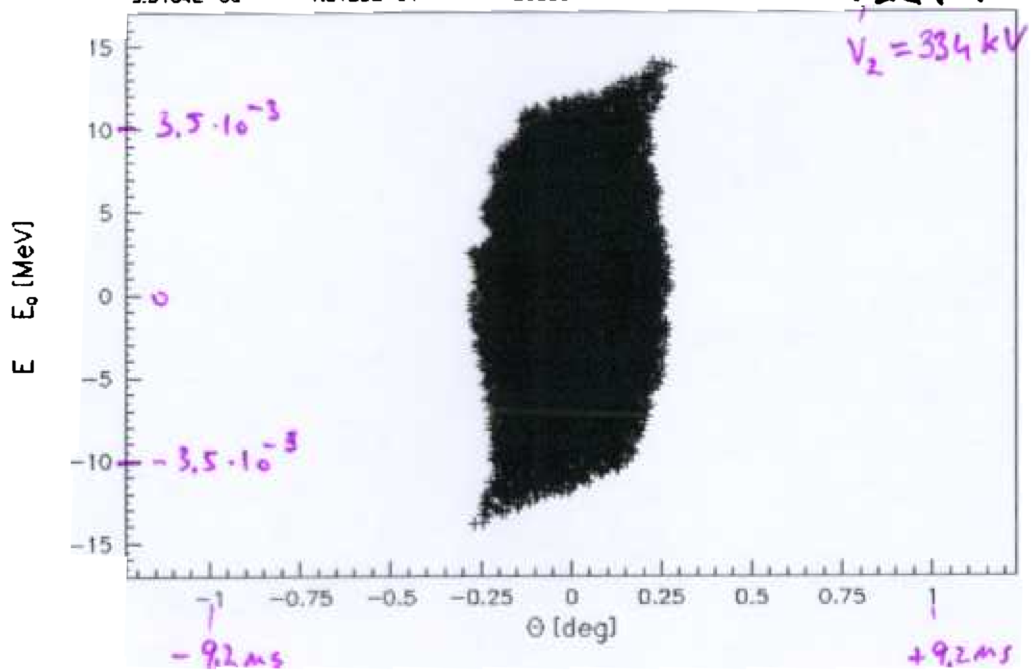

BUNCH ROTATION, 17ns, 1.634E12
TURN 0
0.000E+00 SEC
N = 20000
5.534E−18
3.744E−01
σt = 3.45 ns
COUNTS/BIN (200 BINS)
0
50
100
150
200
250
−1
−0.75
−0.5
−0.25
0
0.25
0.5
0.75
1
Θ [deg]

BUNCH ROTATION, 17ns, 1.634E12

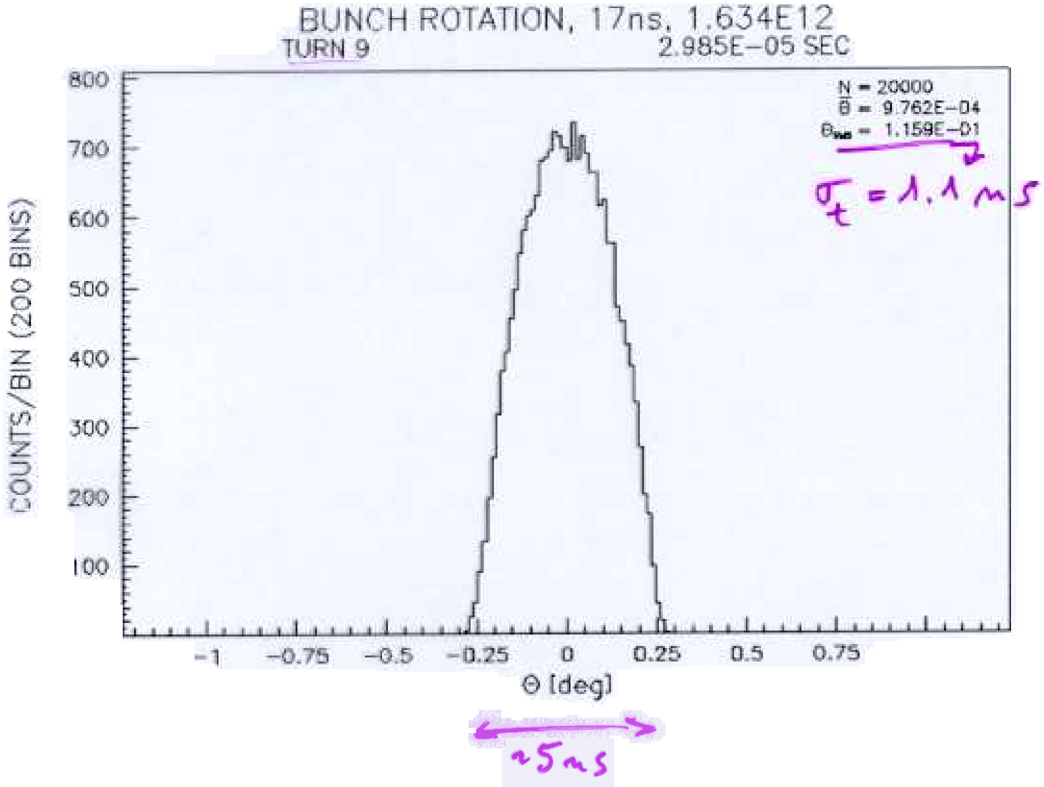
TURN 9 2.985E−05 sec

H_s [MeV]	S_e [eV s]	E_s [MeV]	h	V [MV]	ψ [deg]
1.7124E+01	4.9524E−01	3.1383E+03	146	2.000E+00	−1.759E−15
ν_s [turn^{-1}]	$\dot{p}$ [MeV s^{-1}]	η	292	3.340E−01	1.800E+02
3.7178E−02	−6.4818E−12	−8.4995E−02			
τ [s]	S_b [eV s]	N			
3.3164E−06	1.0183E−01	20000			

$V = 2\,MV$ h=148 292



$\sigma_t = 1.1\,ms$

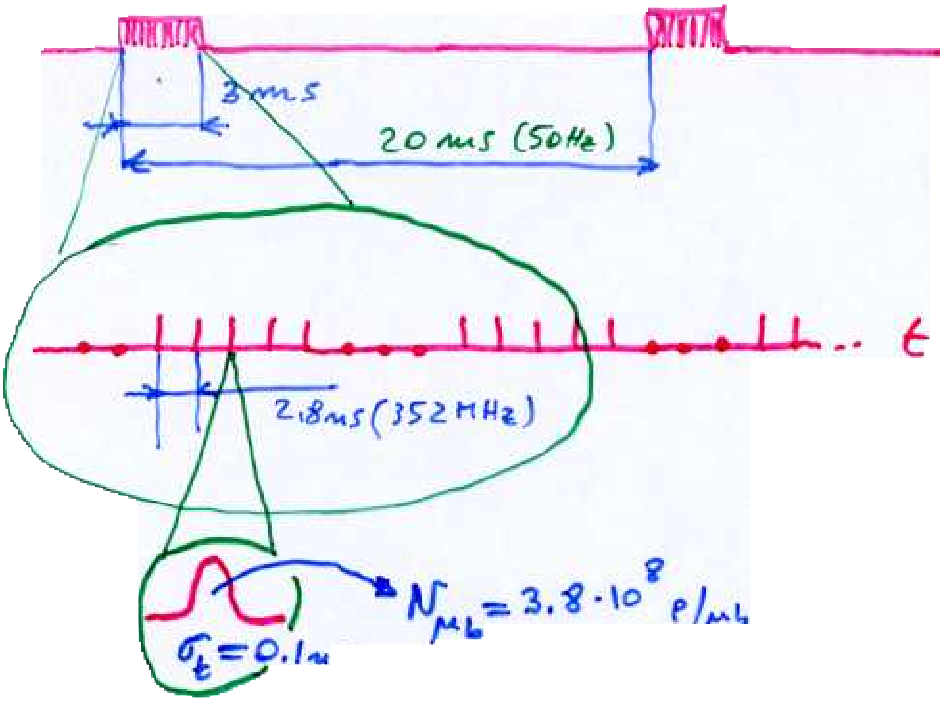

BUNCH ROTATION, 17ns, 1.634E12
TURN 9
2.985E−05 SEC
N = 20000
θ̄ = 9.762E−04
θrms = 1.159E−01
σt = 1.1 ns
COUNTS/BIN (200 BINS)
800
700
600
500
400
300
200
100
−1
−0.75
−0.5
−0.25
0
0.25
0.5
0.75
Θ [deg]
~5ns

WHY A PDAC

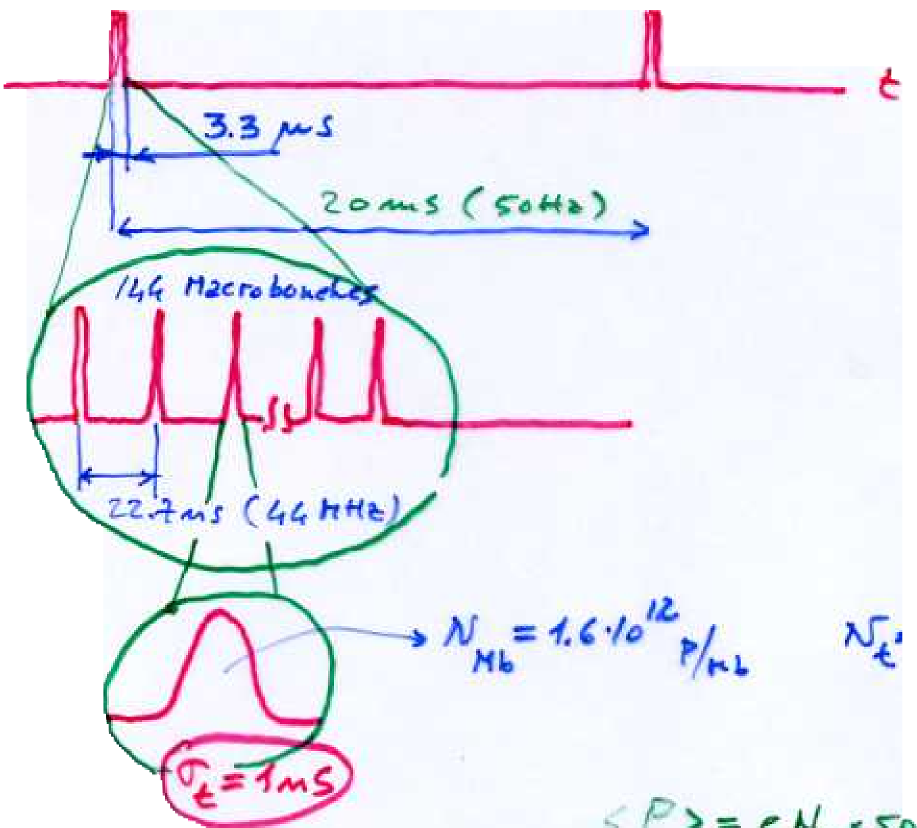
GOAL

4 MW
1 ms rms

SPL OUTPUT



PDAC OUTPUT



→ p0 Target

$N_t = N_{Mb} \times 144 \simeq 3 \cdot 10^{14}$ /pulse

$\langle P \rangle = e N_t \times 50\,\text{Hz} \times 2\,\text{GeV} = 4\,\text{MW}$

WHY TWO MACHINES ?

ACCUMULATOR

• SLOW ~3 ms ⇒ INSTABILITIES CAN DEVELOP ⇒ $\frac{Z}{n} \ll$

• LOW VOLTAGE (300 kV) ⇒ FEW (3) CAVITIES ⇒ LOW Q ⇒ low $\frac{Z}{n}$
STRONG BEAM LOADING

ON COMPRESSION

• FAST (~20 μs) ⇒ INSTABILITIES CANNOT DEVELOP ⇒ $\frac{Z}{n} \gg$

• VERY HIGH VOLTAGE (2 MV) ⇒ MANY (10) CAVITIES BUT HIGH Q DUE TO LOW BEAM LOADING (modest RF power !) $\frac{Z}{n}$ high

Conclusion ⇒ contradictions ⇒ "2 machines" is better

WHY 4 MW ? required # of ν / year

WHY 1 ns$_{rms}$? After muon bunch rotation: $\Delta t \to \Delta p$
small small

WHY 50 Hz ? many systems are pulsed, e.g.: target, horn
RF's,

WHY 44 MHz ? to match the 44 MHz RF OF THE COOLING channel

PDAC2.2 50Hz

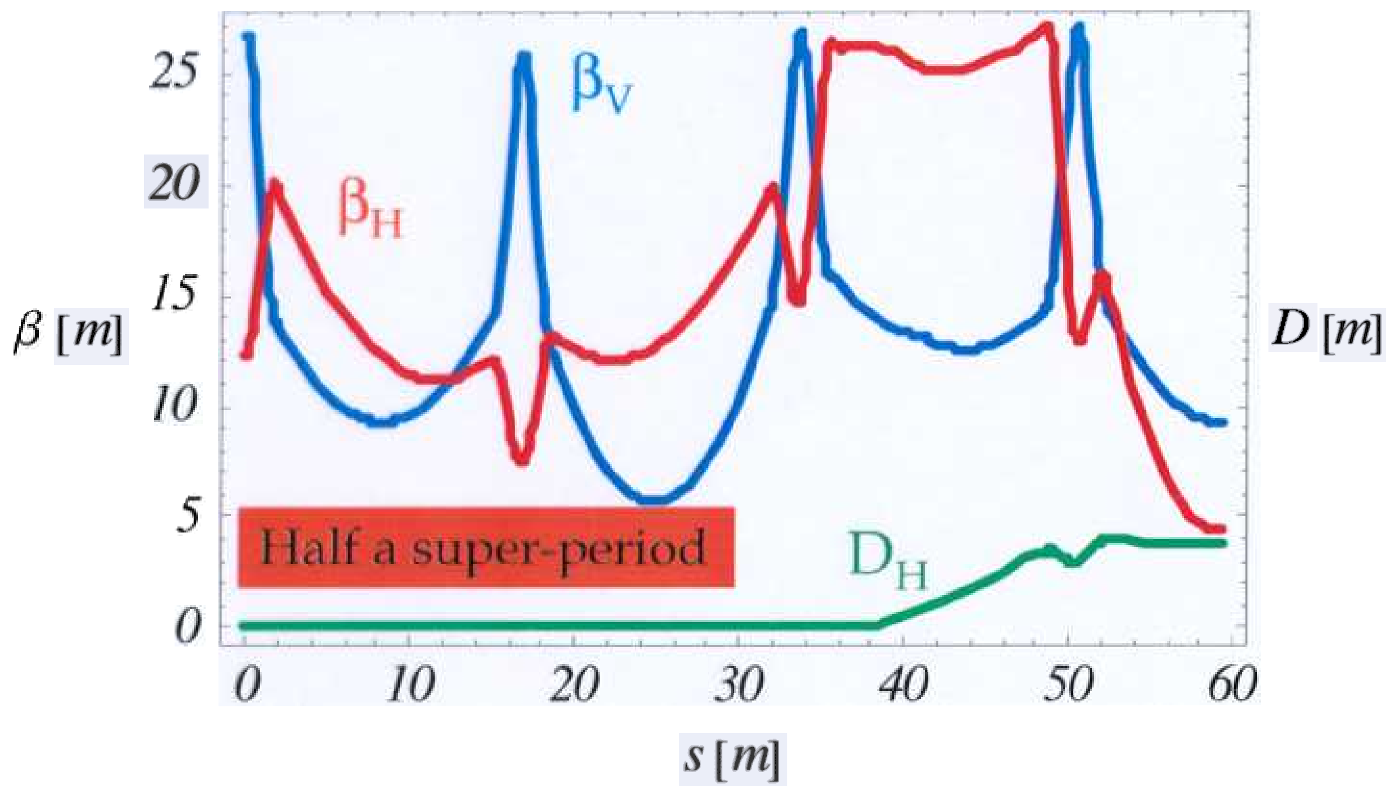
ACCUMULATOR output beam characteristics (approx.)

Parameter	Unit	Value
Beam		
kinetic energy, T	GeV	2.2
γ		3.34
β		0.954
$\beta\gamma$		3.19
pulse frequency	Hz	50
pulse duration	µs	3.3
# of bunches		144
pulse intensity	p/pulse	2.3 E14
bunch spacing	ns	22.7
bunch intensity	p/bunch	1.6 E12
bunch length (4σ)	ns	15
rel. momentum spread (2σ)		1.4E-3
long. emittance (2σ)	eVs	0.1
norm. hor. emittance (1σ)	µm	55
norm. vert. emittance (1σ)	µm	55
max. hor. beam size, $4\sigma_x$	m	0.086
max. vert. beam size, $4\sigma_y$	m	0.082
# of injected turns		830
Machine		
radius, R	m	151
main dipole magn. field, B	Tesla	0.7
η		-0.085
γ-transition		14.69
β_x max.(= β_y)	m	27
D_x min., max.	m	0, 4
Q_x, Q_y		11.22, 13.32
vac. ch. h. width x h. height	m	0.1 x 0.07
RF		
RF voltage, V_{RF}	MV	0.03-0.3
harm. number, h		146
synchrotron frequency, f_s	kHz	1.5-4
RF frequency, f_{RF}	MHz	44.02

COMPRESSOR output beam characteristics (approx.)

Parameter	Unit	Value
Beam		
kinetic energy, T	GeV	2.2
γ		3.34
β		0.954
$\beta\gamma$		3.19
pulse frequency	Hz	50
pulse duration	µs	3.3
# of bunches		144
pulse intensity	p/pulse	2.3 E14
bunch spacing	ns	22.7
bunch intensity	p/bunch	1.6 E12
bunch length (4σ)	ns	5
rel. momentum spread (2σ)		4 E-3
norm. hor. emittance (1σ)	µm	55
norm. vert. emittance (1σ)	µm	55
max. hor. beam size, $4\sigma_x$	m	0.086
max. vert. beam size, $4\sigma_y$	m	0.082
Machine		
radius, R	m	151
main dipole magn. field, B	Tesla	0.5
η		-0.084
γ-transition		14.03
β_x max.($= \beta_y$)	m	25
D_x min., max.	m	0, 2
Q_x, Q_y		16.28, 16.32
vac. ch. h. width x h. height	m	0.1 x 0.07
RF		
RF voltage, V_{RF}	MV	2 ← + 300 kV at 88 MHz ?
harm. number, h		146
synchrotron frequency, f_s	kHz	~8
RF frequency, f_{RF}	MHz	44.02

2.2 GeV Accumulator Lattice



Triplet lattice

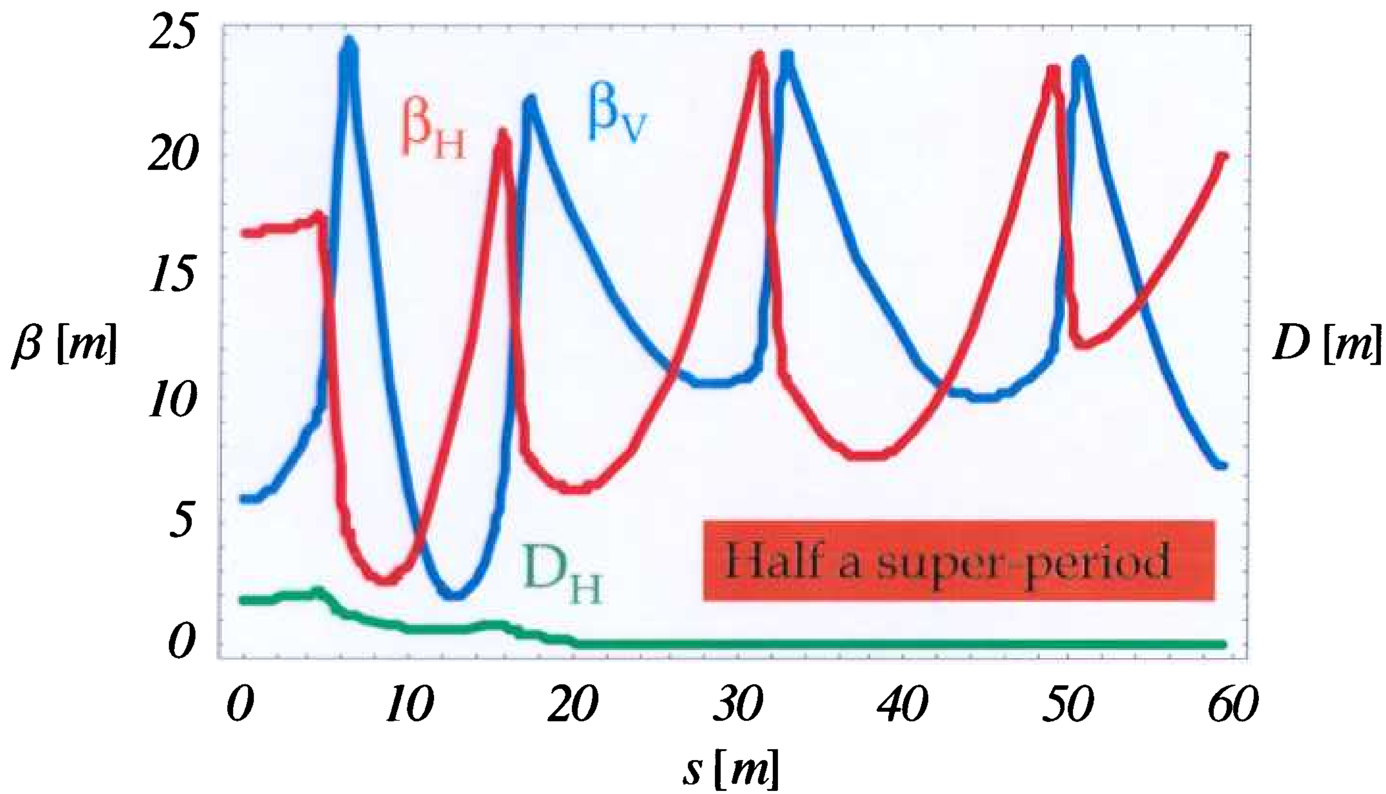
- η=-0.085 γ_t=14.69
  $Q_{H/V}$= .22/13.32

3

COURTESY M MARTIN

18

2.2 GeV Compressor Lattice



- Quadruplet lattice
- η=-0.084 γ_t=14.03
- $Q_{H/V}$=16.28/16.32

PDAC @ 50Hz COLLECTIVE EFFECT REVIEW

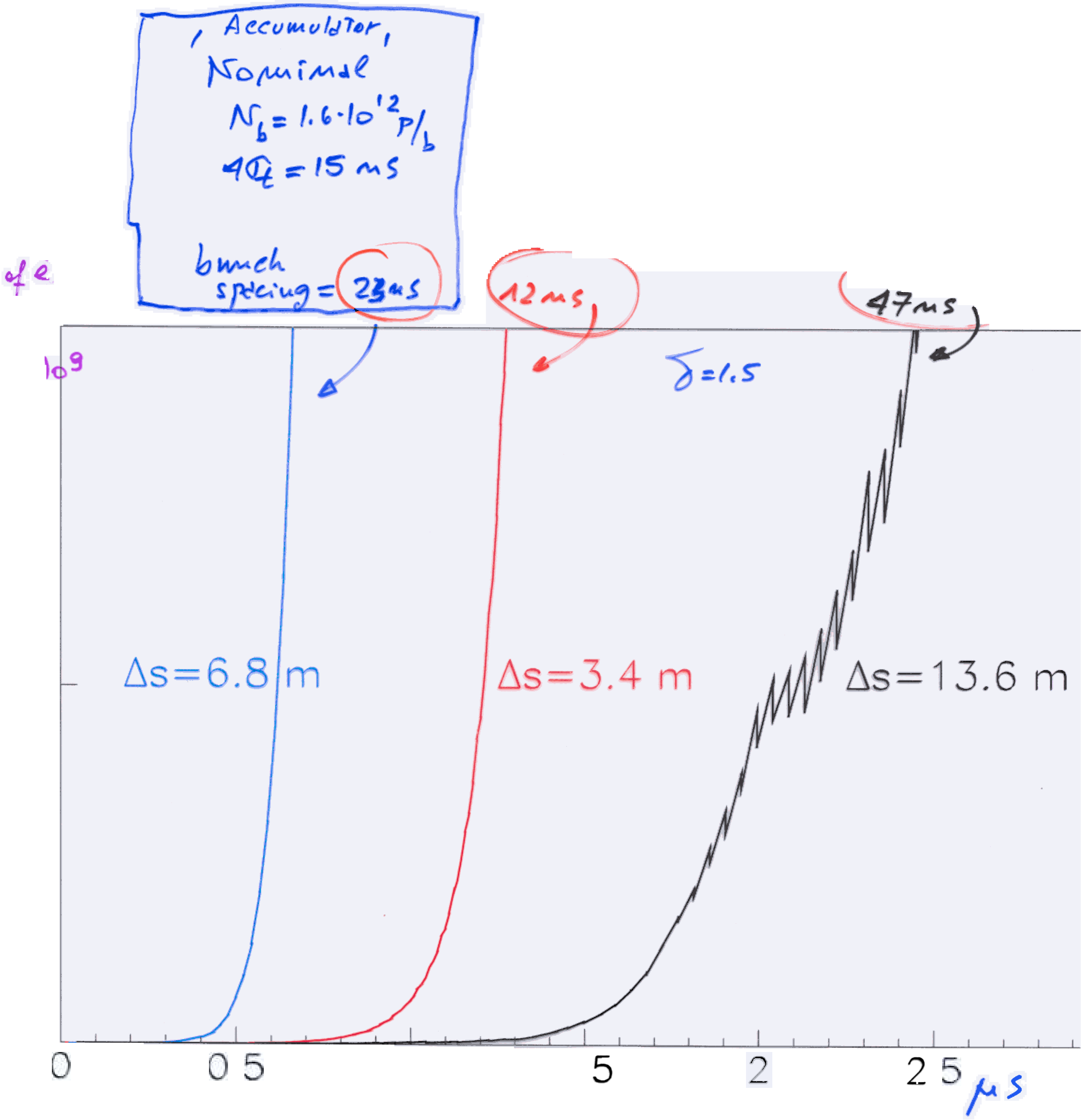
Instability type	Beam type	Impedance type	Comments	Limits	
Tr. Space Charge	μbunch	-	$\Delta Q_{ix,y}$ -0.1		☺
	Mbunch (accum.)	-	-0.1		☺
	Mbunch (compress.)	-	-0.3		☺
Long. Space Charge	μbunch	-	-j178 Ω 50 kV		😐
	Mbunch (accum.)	-	-j88 Ω 160 kV		😐
Tr. h-t single bunch	Mbunch	RW	m=2, $\rho = 10^{-6}\ \Omega$m	rise time ~ 100 ms	☺
Tr. coupled bunch	Mbunch	RW	n = 134, m = 1	~ 7 ms	☺
TMC	μbunch	BB	m = -1, m = 0 stable	$N_b < 2\ 10^{12}$	☺
	Mbunch (accum.)	BB	m = -1, m = 0 stable	$N_b < 5\ 10^{13}$	☺
BBU single bunch	μbunch	BB	stable	$Z_l/n < 400\ \Omega$	☺
	Mbunch (accum.)	BB	stable	$Z_l/n < 10\ \Omega$	☺
BBU multi bunch	μbunch	BB	stable	$Z_l/n < 2\ \text{k}\Omega$	☺
Long. coupl. bunch	Mbunch (accum.)	HOM's	68, 13, 6 ms stable		☺
Long. μwave	Mbunch (accum.)	BB + Sp. Ch.	rise time ~ 0.5 ms	$Z_l/n < 1\Omega$	☹

RW = Resistive Wall
BB = Broad Band resonator, f_c = 0.7 GHz, Q = 1

e-CLOUD

ORECAST FOR PDAC

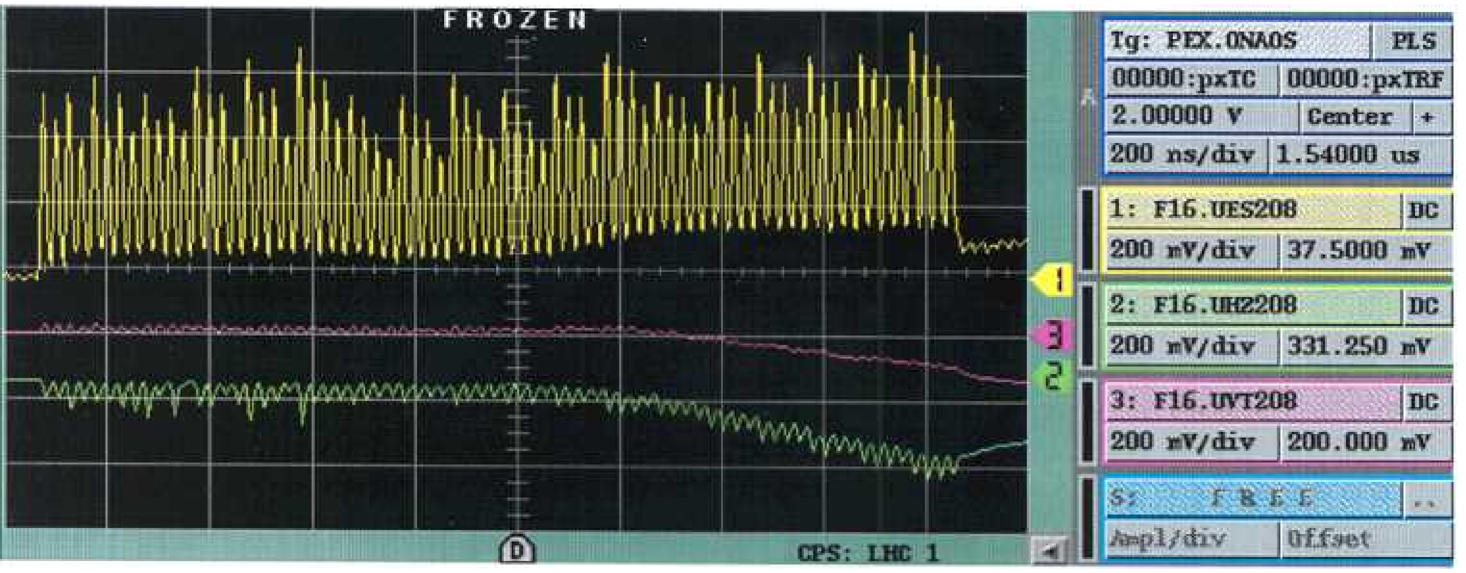
by F. Zimmermann



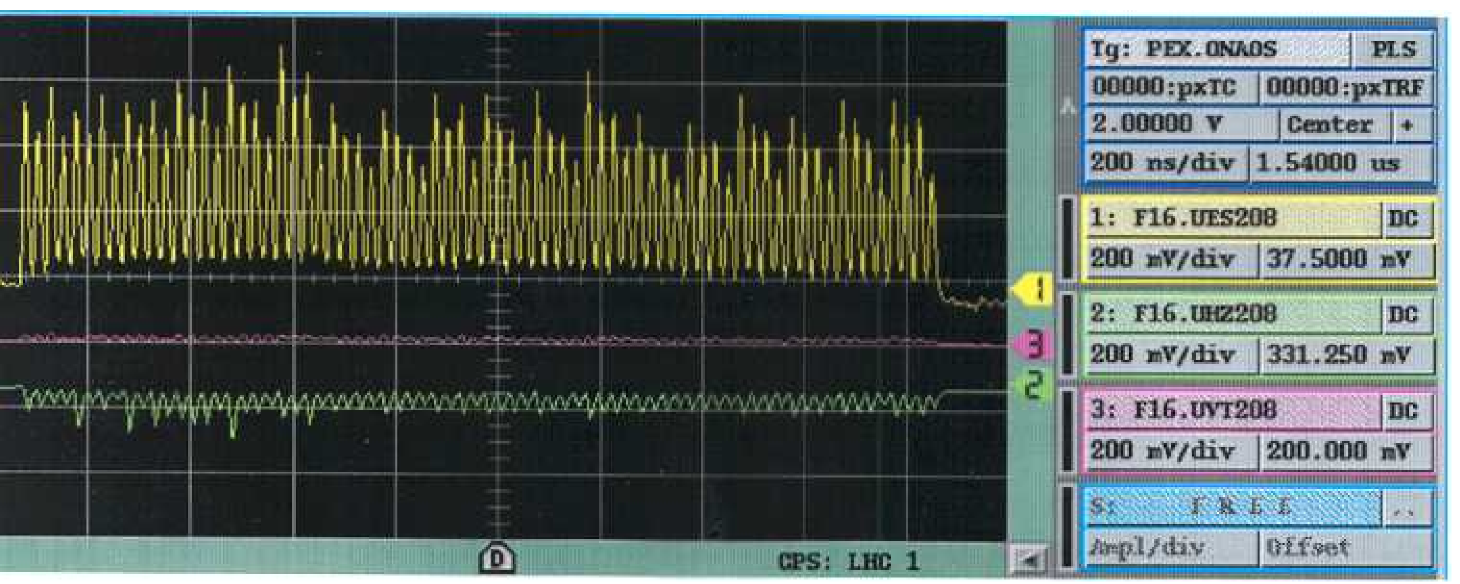
PS FOR LHC beam extracted from The PS AT 26 GeV/c.

$k_b = 72$, $N_b = 10^{11}$ p/b , b. spacing = 25 ns , $\varepsilon^*_{x,y} \leq 3 \mu m$

e-CLOUD EFFECT SINGLE PASS



SOLENOID OFF



SOLENOID ON

e-cloud hor instability
in the PS.

AMPLITUDE OF (1-9)

BETATR NE TIME

VERT log scale

HO 20 ms/d

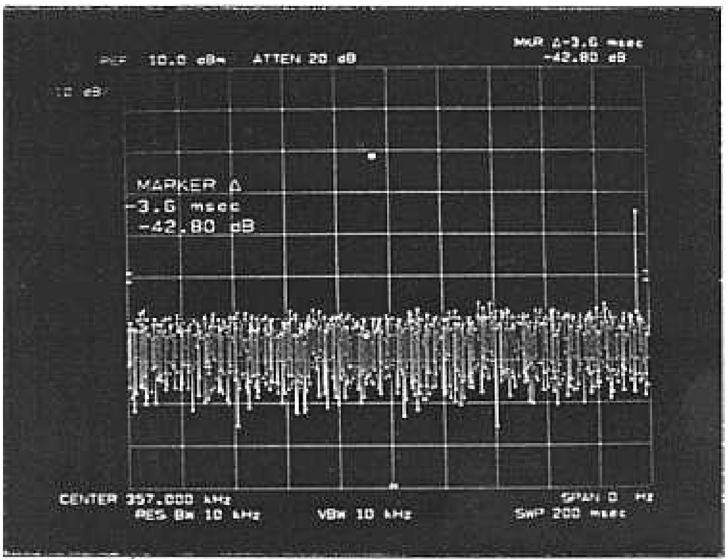
'N_t = P

$N_\perp$ ↑

le e = 8

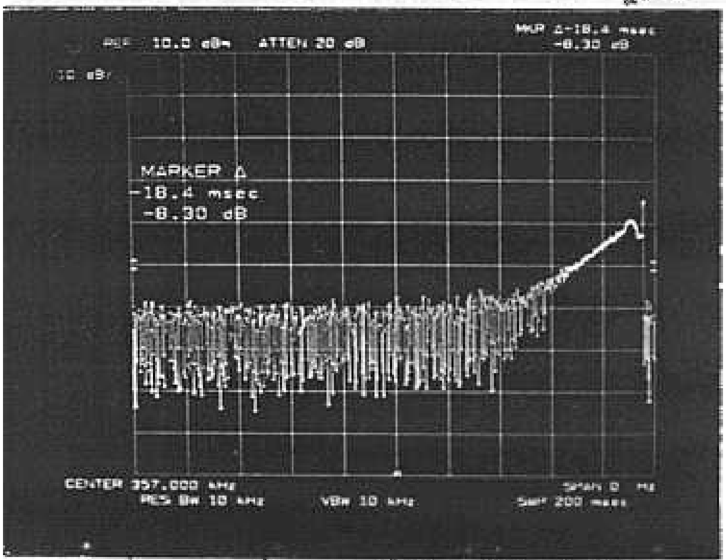
4

#



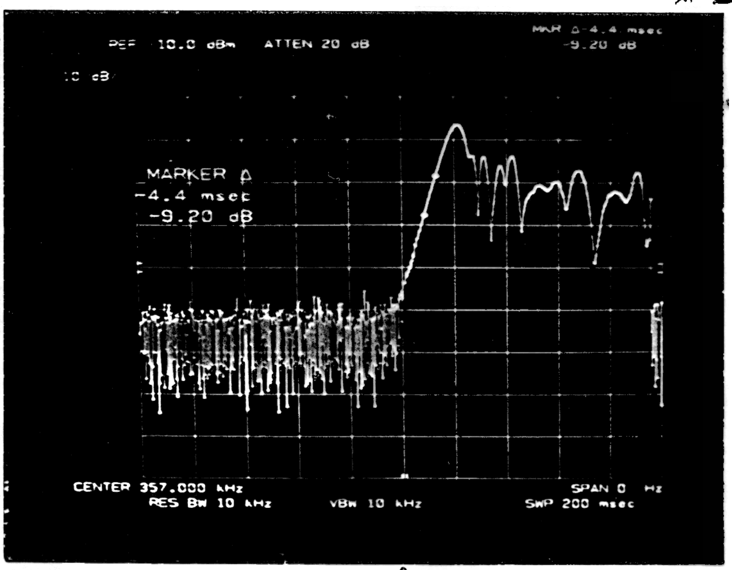
↑C 2200 $N_t = 300 \cdot 10^{10}$

2



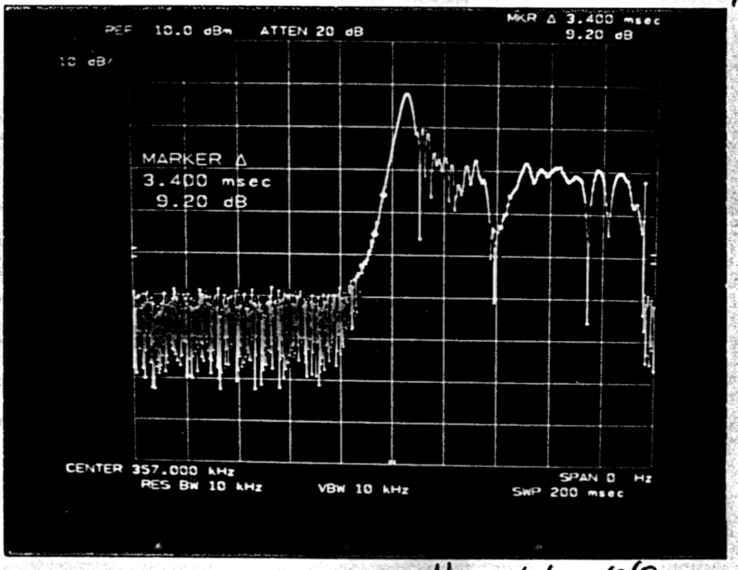
C 2200 2300↑ $N_t = 330 \cdot 10^{10}$

3



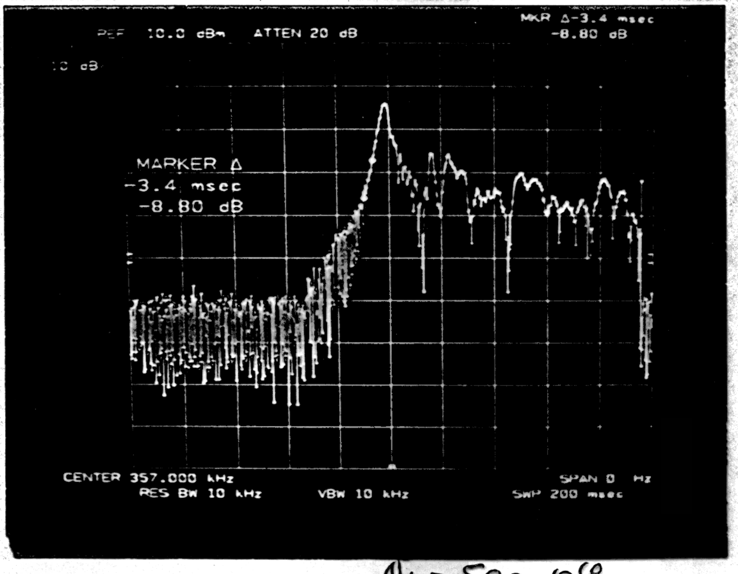
$N_\perp = 400 \cdot 10^{10}$

* 4



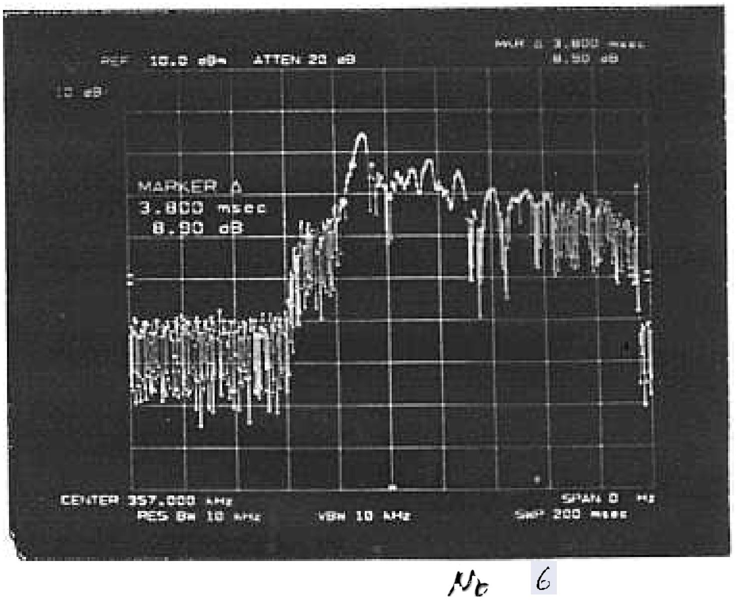
$N_t = 460 \cdot 10^{10}$

* 5



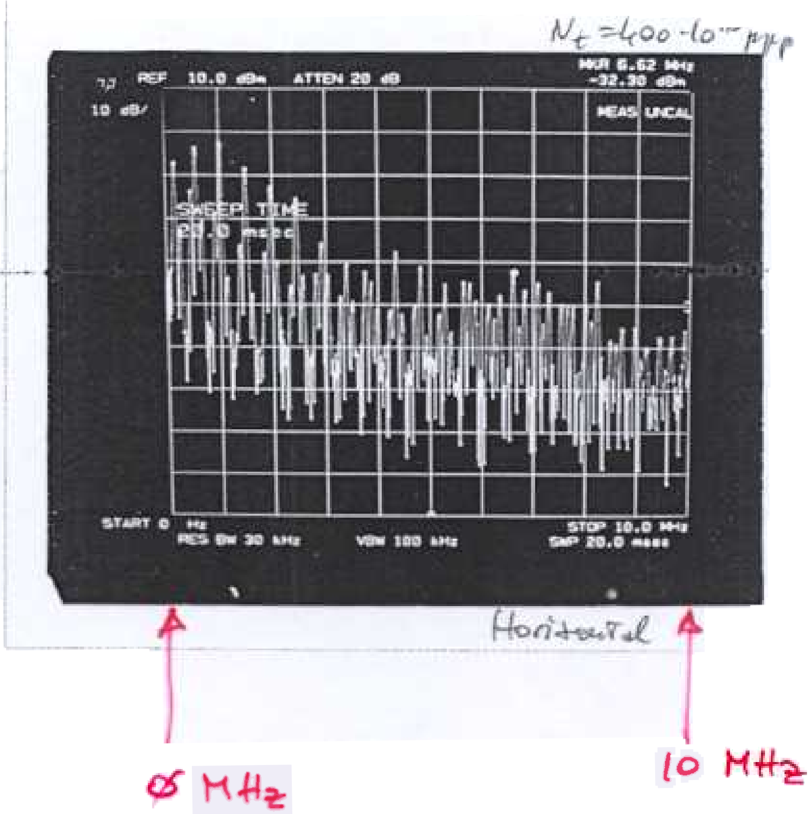
$N_t = 500 \cdot 10^{10}$ ppl

* 6

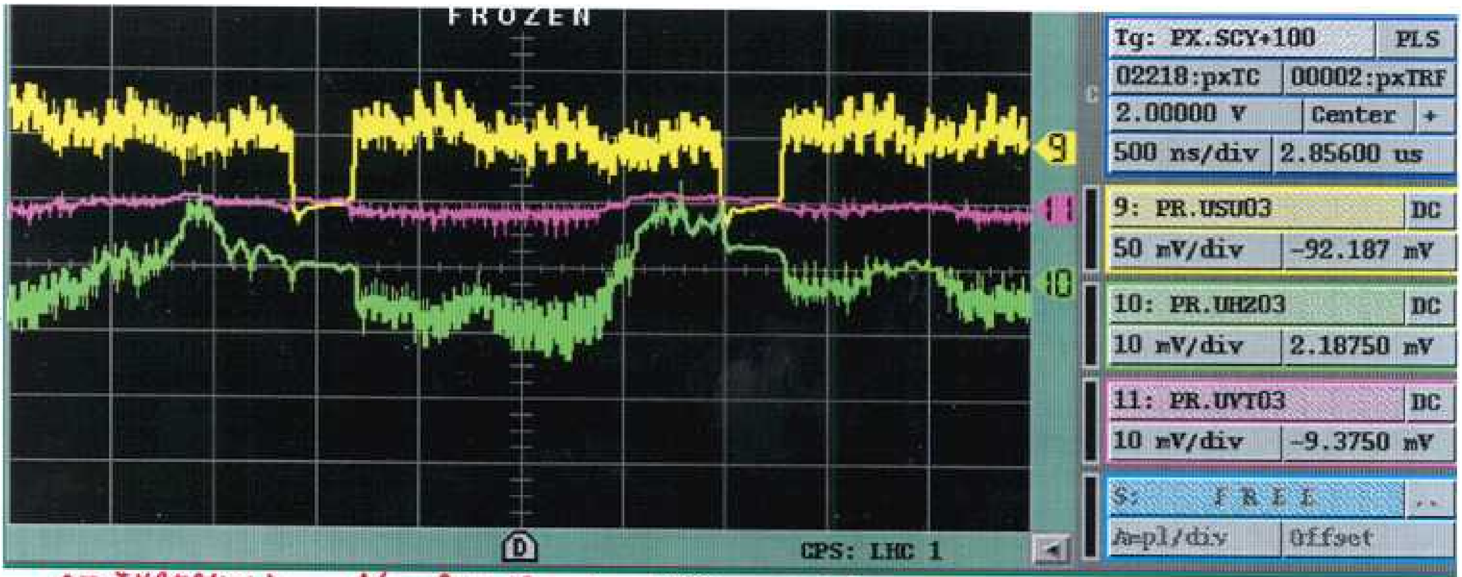


N_t 6

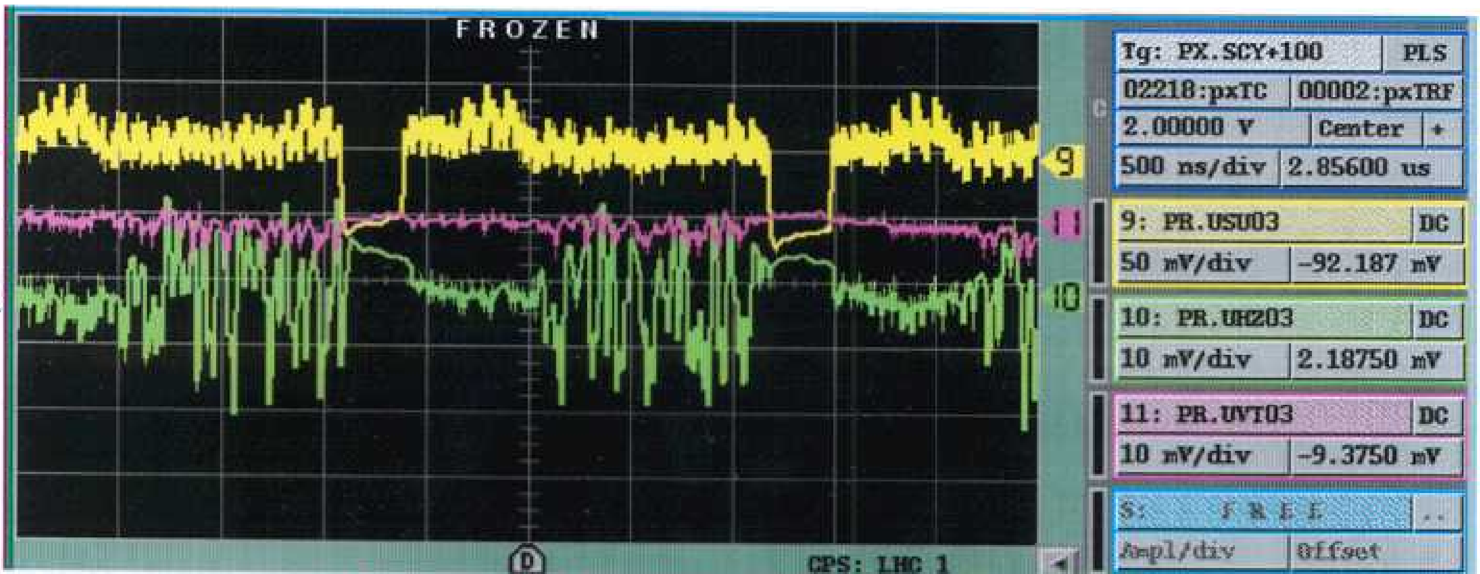
N FREQUENCY DOMAIN



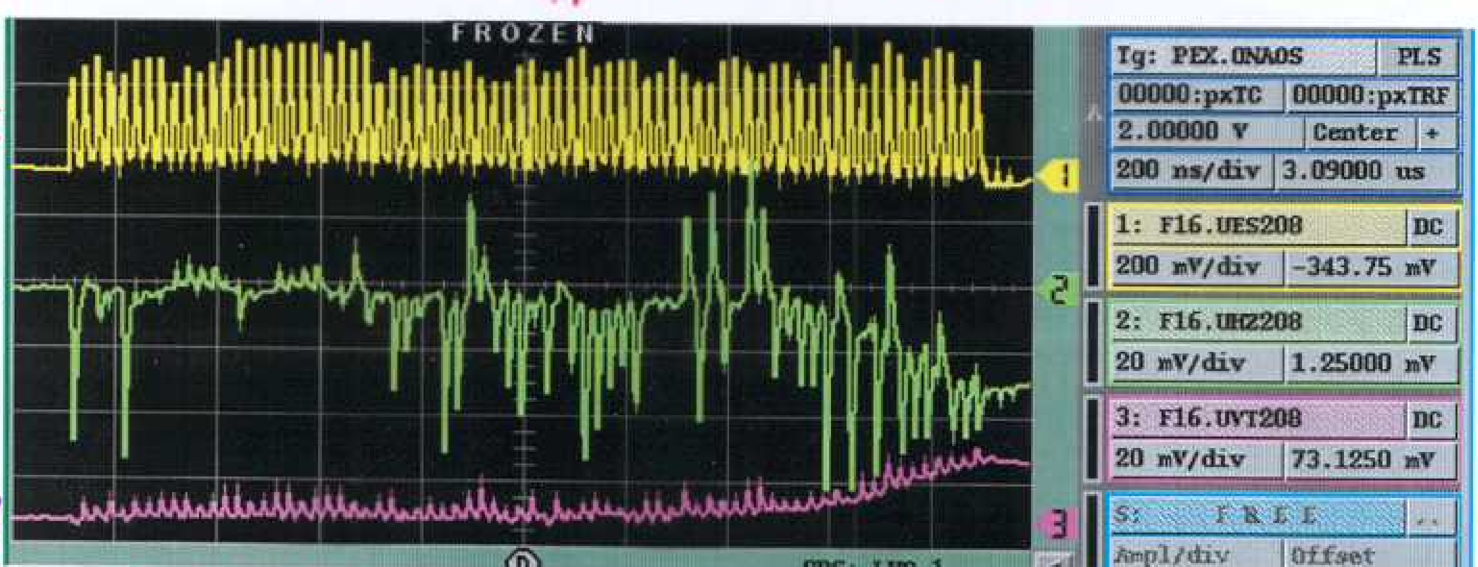
BPM SIGNALS DURING e-cloud instability



AT THRESHOLD $N_t = 3 \cdot 10^{12}$ p/p BPM IN THE RING 500 ns/d

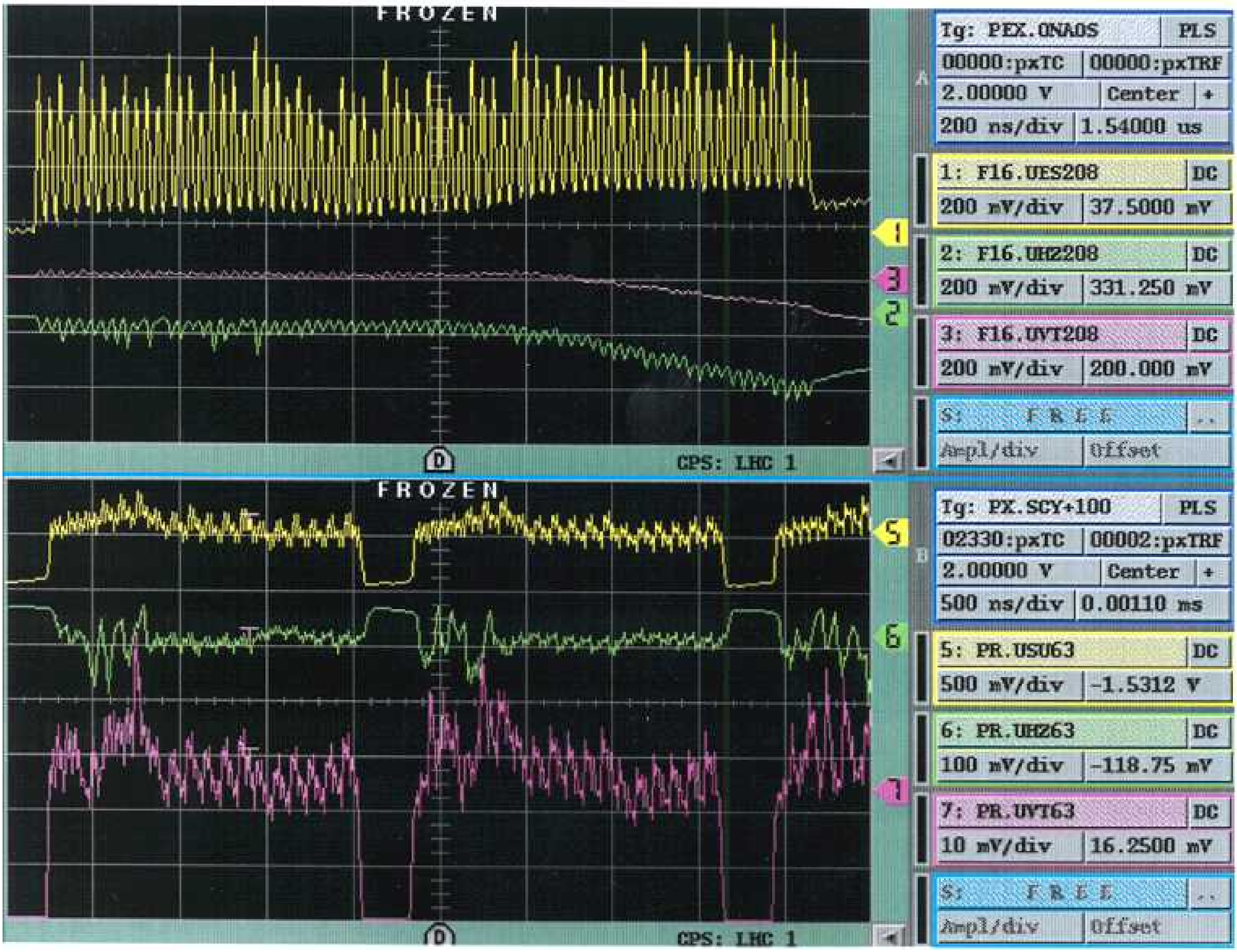


$N_t = 4 \cdot 10^{12}$ p/p BPM IN THE RING 500 ns/d



$N_t = 6 \cdot 10^{12}$ p/p , in Extraction line 200 ns/d
BPM IN THE EXTR. LINE

27a



FROZEN
Tg: PEX.ONAOS
PLS
00000:pxTC
00000:pxTRF
2.00000 V
Center
200 ns/div
1.54000 us
1: F16.UES208
DC
200 mV/div
37.5000 mV
2: F16.UH2208
DC
200 mV/div
331.250 mV
3: F16.UVT208
DC
200 mV/div
200.000 mV
S: FREE
Ampl/div
Offset
CPS: LHC 1
FROZEN
Tg: PX.SCY+100
PLS
02330:pxTC
00002:pxTRF
2.00000 V
Center
500 ns/div
0.00110 ms
5: PR.USU63
DC
500 mV/div
-1.5312 V
6: PR.UH263
DC
100 mV/div
-118.75 mV
7: PR.UVT63
DC
10 mV/div
16.2500 mV
S: FREE
Ampl/div
Offset
CPS: LHC 1

COMMENTS ON e-CLOUD EFFECTS

WITH INCREASING INTENSITY e-CLOUD EFFECTS SHOW-UP IN TWO STAGES:

① A "LOW FREQUENCY NOISE" → ~DC OFFSET ON BPM SIGNALS WHICH DOES NOT HURT BEAM QUALITY. SEEN ON A SINGLE PASS → DEVELOPS QUICKLY

② ABOVE A GIVEN THRESHOLD A TRANSV. (HOR.) INSTABILITY STARTS WITH A RISETIME ~ 2-5 ms

($N_t \gtrsim 3 \cdot 10^{12}$ p/p. $\tau_b = 10$ ns, b. spacing = 25 ns $N_b \gtrsim 4 \cdot 10^{10}$ p/b)

→ SINGLE BUNCH INSTABILITY

→ THE INST. 'SATURATES' AT $\Delta R \simeq 0.5$ cm ⇒ NO BEAM LOSS

→ $\varepsilon_{x,(y)}$ BLOW-UP (~ × 10)

→ SMALL SENSITIVITY TO GAPS, OCTUPOLES

→ HIGH SENSITIVITY TO BUNCH LENGTH AND SPACING : e.g. WITH BUNCH SPACING = 50 ns

⇒ NO INSTABILITY

→ HIGH SENSITIVITY TO 'GHOST' BUNCHES (i.e. it is better)

AND VARIATIONS IN BUNCH POPULATION

i.e. no instability for ~50% modulation

CONCLUSION

WE ARE AWAITING FOR HARP RESULT

⇒ PRESENT ACTIVITY IS 'LOW'

SIMULATIONS OF ACCUMULATION / FOIL HEATING / BEAM DISTRIBUTIONS etc ARE BEING PERFORMED USING VARIOUS CODES

- INJECTION LINE (AND EXTRACTION LINE) ARE ALSO UNDER STUDY
- WE SHOULD START 'HALO' STUDIES
- WHAT TO DO FOR e-CLOUD ?
  - NEW BUNCH SPACING ? → NEW RF ? 80 MHz ?
  - VAC. CHAMBER COATING ?
  - SOLENOIDS ?
  - FEEDBACK ?
  - OTHER CURES ? ... WE NEED TO UNDERSTAND BETTER THE PHYSICS