CTF3 Preliminary phase

Experiments done in LPI
and
planned in CTF3

L. Rinolfi

Motivations

The CLIC Test Facility (CTF3) has been proposed to demonstrate the technical feasibility of the key concepts of the CLIC RF power source:

1) generation of a high-current, high-frequency drive-beam by combination of electron bunch trains in an isochronous ring using transverse RF deflectors.
2) operation with a fully-loaded drive-beam accelerator.
3) CTF3 will also provide the 30 GHz RF power needed to test the CLIC accelerating structures and components at the nominal gradient and pulse length (150 MV/m for 130 ns).

These issues will be fully covered in the CTF3 Nominal phase (2004-2005)

- The Preliminary Phase of CTF3 (2001-2002) is a demonstration of the first point, but at low-charge and short pulse.
  - * Also acquire experience in combiner ring operation and develop tools for next phases.

This demonstration is possible using the existing hardware - However, it needs a large number of modifications of the former LPI (LEP Pre-Injector) complex.

CERN - European Laboratory for Particle Physics

CLIC Note 470

Beam dynamics for the CTF3 preliminary phase

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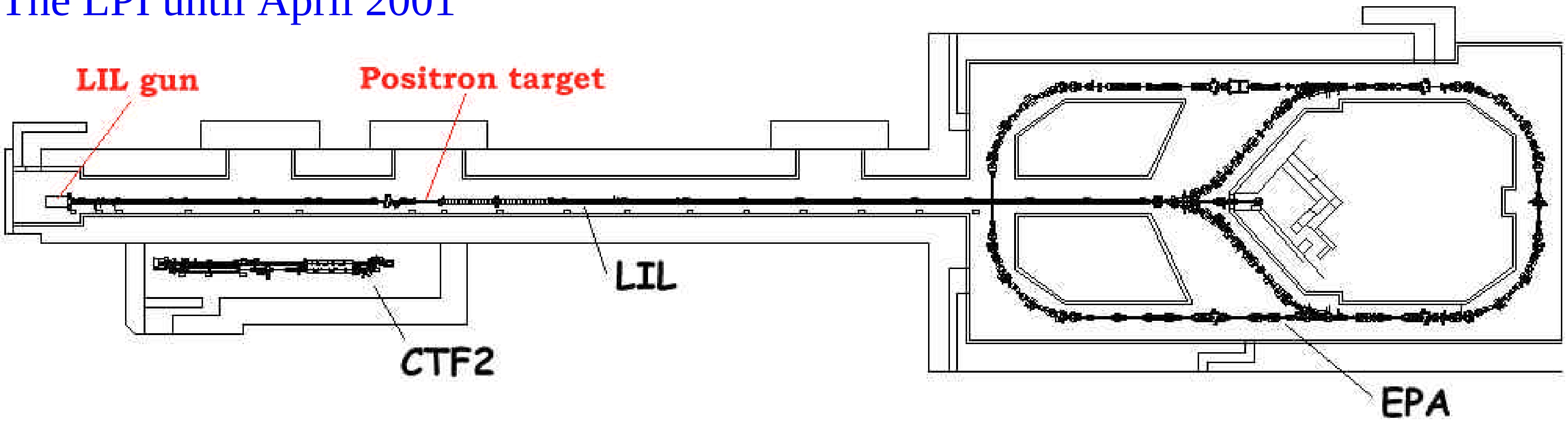
Abstract

In the framework of the CLIC RF power source studies, the new scheme of electron pulse compression and bunch frequency multiplication, using injection by RF deflectors into an isochronous ring, will be tested at CERN during the CTF3 preliminary phase. The present LPI complex will be modified in order to allow a test of this scheme at low charge. The design of the new front-end, of the modified linac, of the matched transfer line, and of the isochronous ring lattice is presented here. The results of the related beam dynamics studies are also discussed.

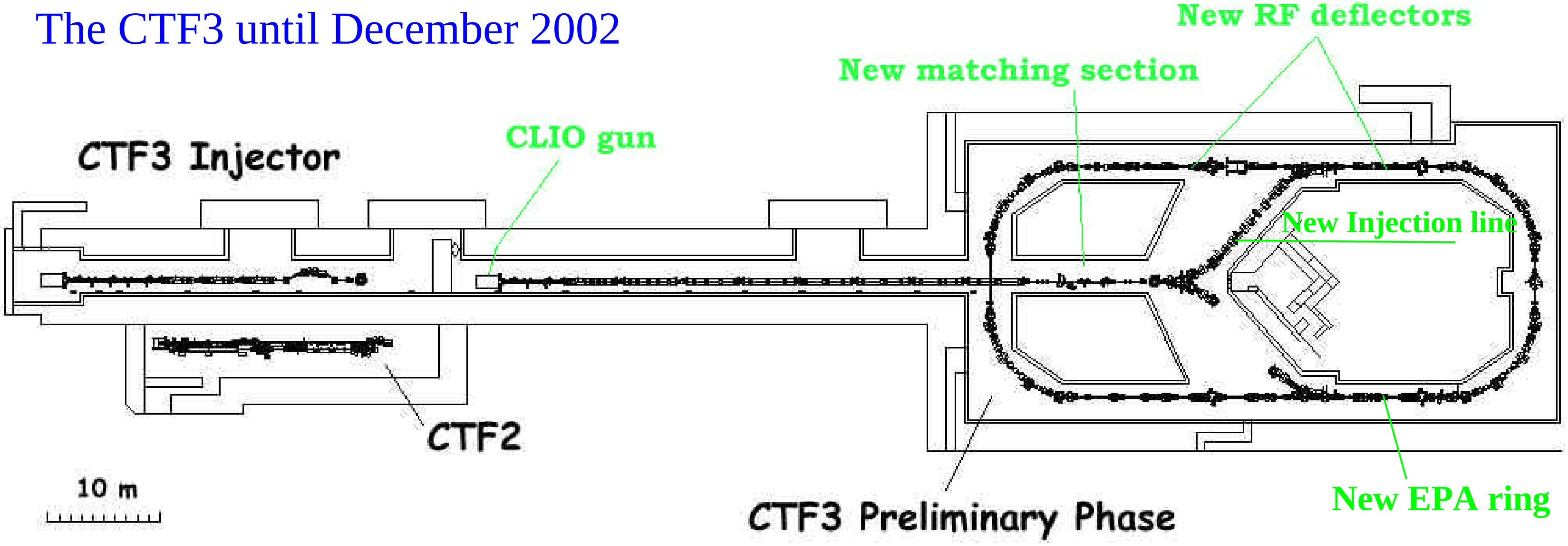
Geneva, Switzerland
January 30, 2001

Layout of CTF3 Preliminary phase

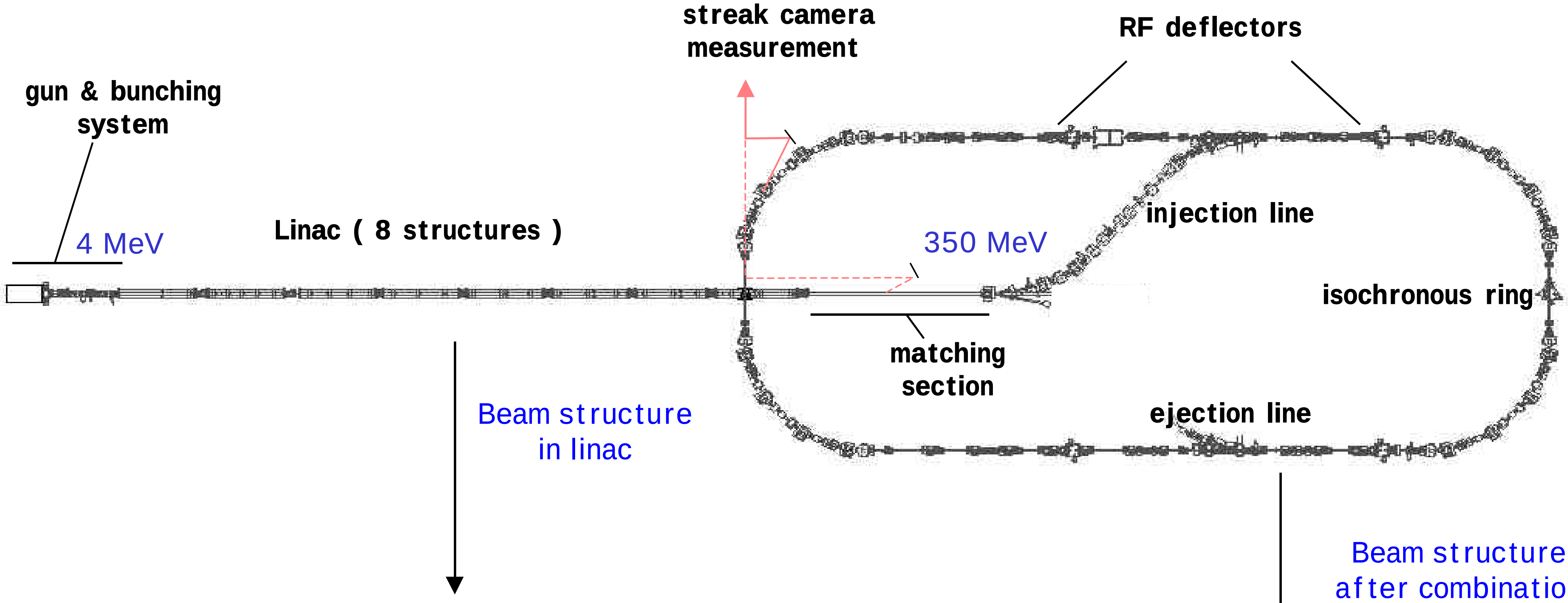
The LPI until April 2001



The CTF3 until December 2002



General description of CTF3 preliminary phase



streak camera
measurement

RF deflectors

gun & bunching
system

4 MeV

Linac (8 structures)

350 MeV

injection line

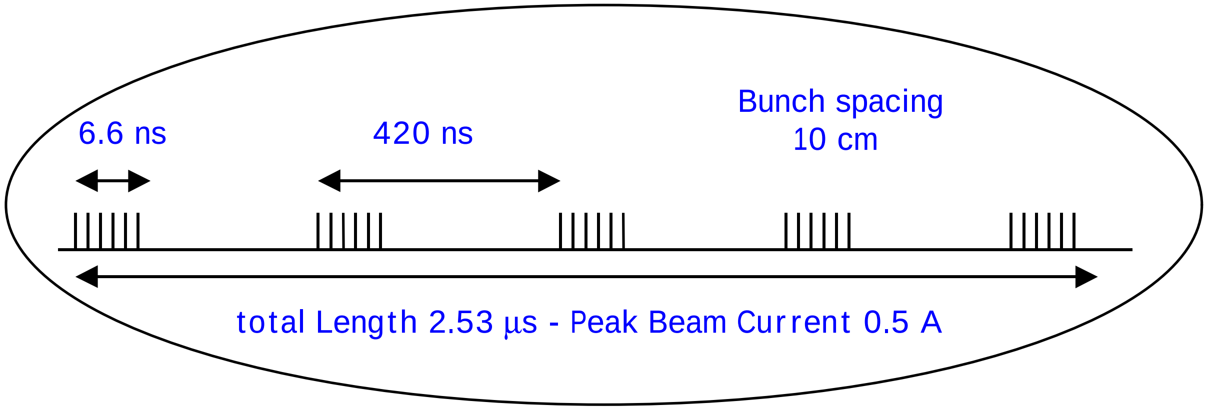
isochronous ring

matching
section

ejection line

Beam structure
in linac

Beam structure
after combination
(factor 5)

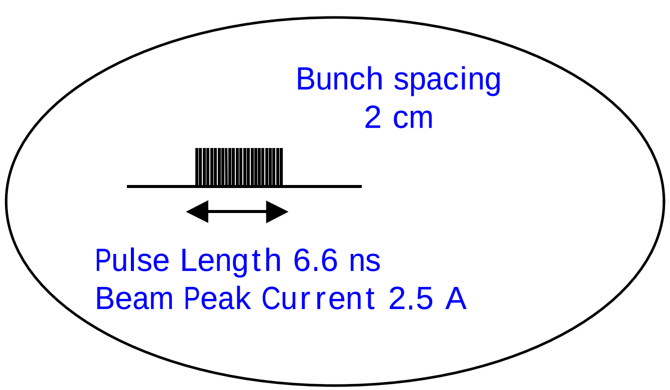


Bunch spacing
10 cm

6.6 ns

420 ns

total Length 2.53 µs - Peak Beam Current 0.5 A



Bunch spacing
2 cm

Pulse Length 6.6 ns
Beam Peak Current 2.5 A

Isochronous machine

$$\eta = \frac{1}{\gamma^2} - \alpha$$

where γ = Relativistic factor E/E_0 α = Momentum compaction

For leptons storage rings:

γ is very large, then $\eta \sim |\alpha|$

Momentum compaction

$$\alpha = \frac{1}{C}\int_0^C \frac{D(s)}{\rho} ds$$

Modification of dispersion using N quadrupoles [1]

$$C\,\Delta\alpha = -\sum_{i=1}^{N} \Delta K_i\, L_i\, D_i\, D_i^*$$

C = Ring circumference
ΔK = normalised gradient increment
L = quadrupole length
D = unperturbed dispersion at quadrupole
D* = modified dispersion at quadrupole

Small gradient change:

$$C\,\Delta\alpha \approx -\sum_{i=1}^{N} \Delta K_i\, L_i\, D_i^2$$

[1] T. Risselada, "Proceedings of the Fifth General Accelerator Physics Course", CERN 94-01, 1994.

Bunch to bunch distance

Momentum compaction

$$\alpha = \frac{\frac{dC}{C}}{\frac{dp}{p}}$$

Time variation

$$dC = c\,dt = \alpha C\,\frac{dp}{p}$$

After N turns

$$N\,dt\ = \alpha\frac{C}{c}\frac{dp}{p}N$$

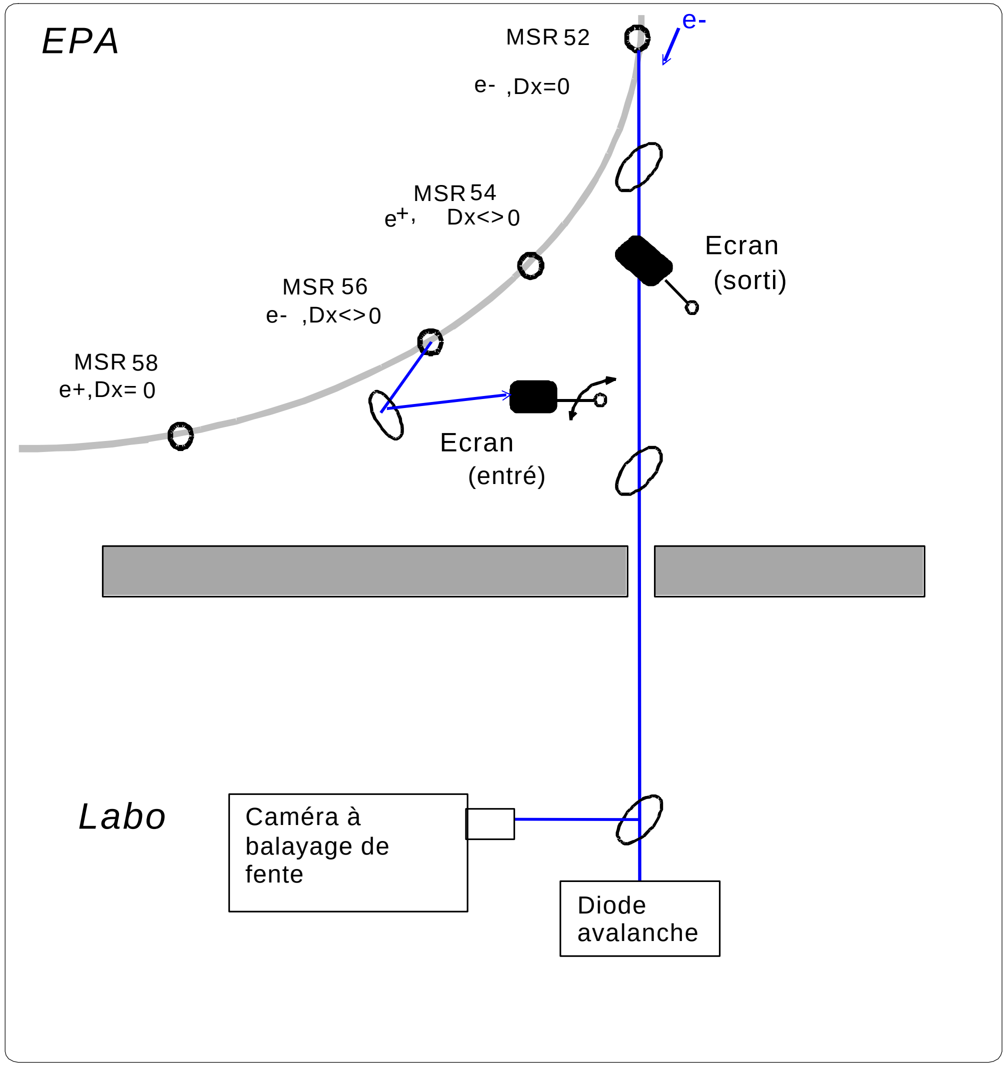
Bunch to bunch distance

$$\Delta t(N) = \Delta t(0) + N\,dt$$

Bunch to bunch distance versus α

$$\Delta t(N) = \Delta t(0) + \alpha\frac{C}{c}\frac{dp}{p}N$$

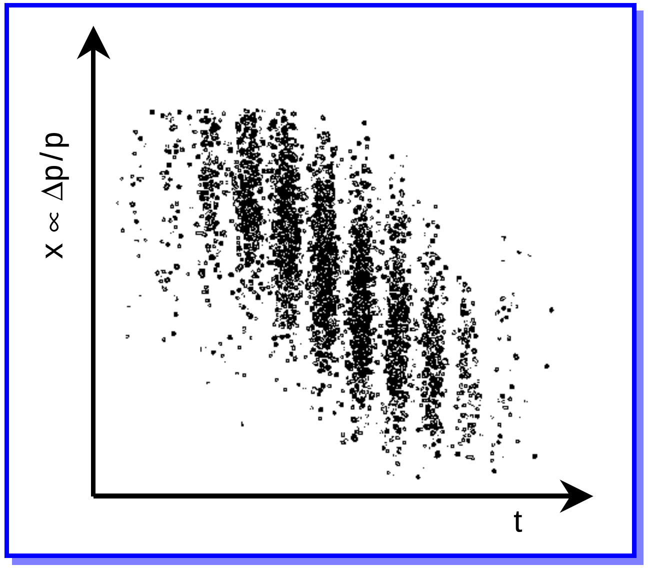
Streak Camera Layout



Layout for the micro-bunch measurements. A streak camera uses the synchrotron light coming from the EPA ring.

Two screens allow measurements in a dispersive region (MSR56) and in a non-dispersive region (MSR52).

Measurements with streak camera in EPA ring - 1

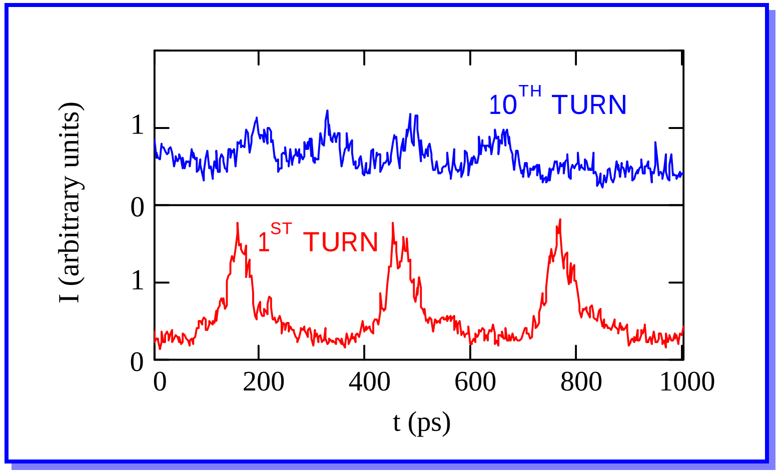


Streak camera image of the electron pulse
(April 1999)

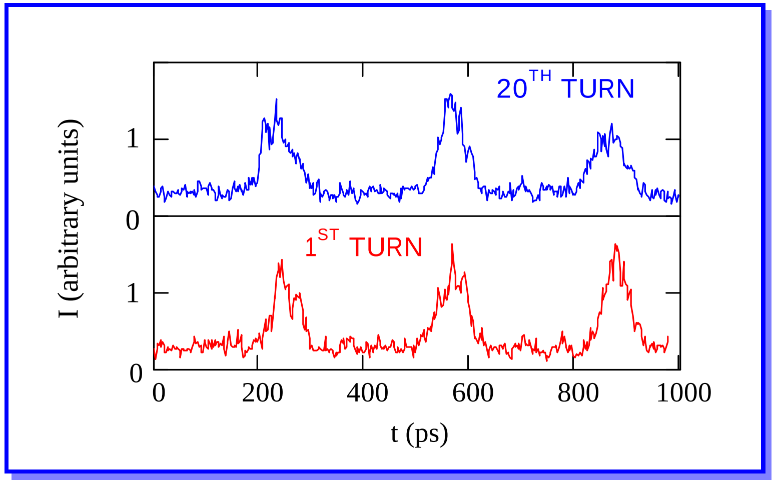
Streak camera image of the total
pulse and corresponding time profile

Pulse profiles in time

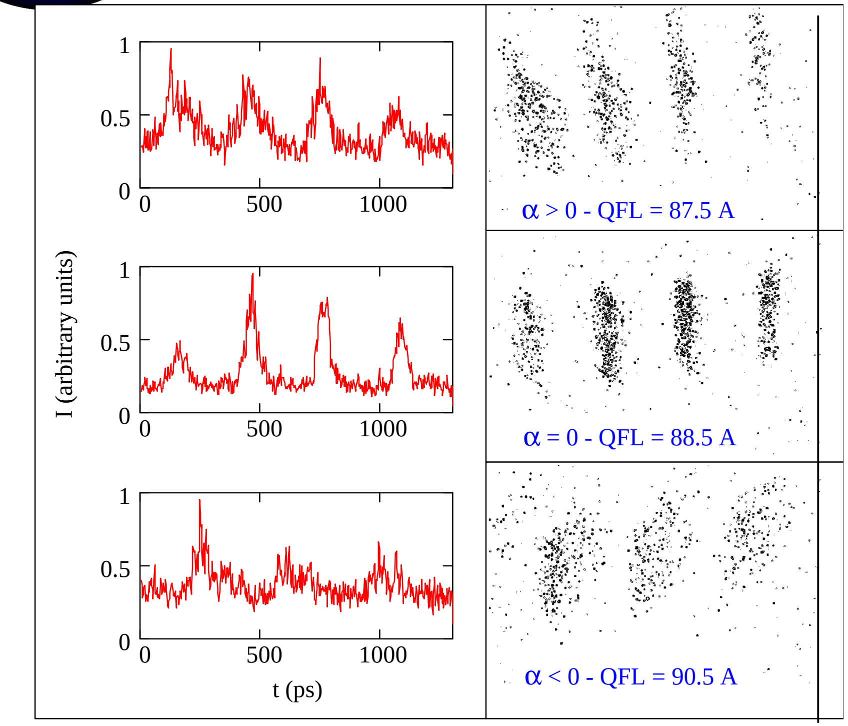
Nominal EPA optics



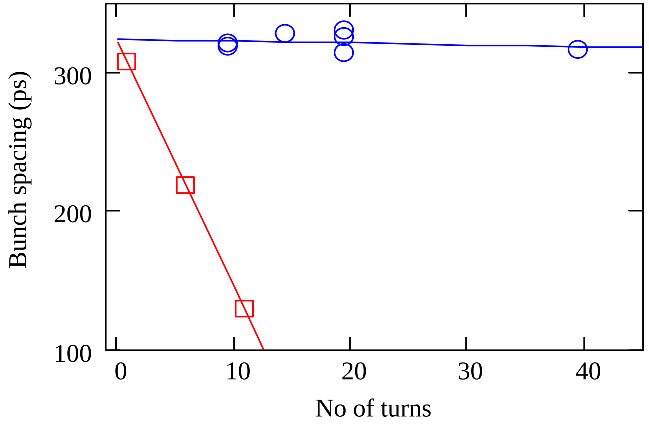
Isochronous EPA optics



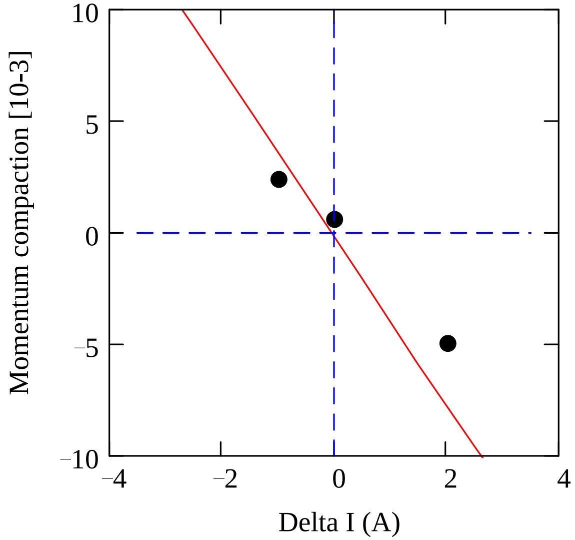
Measurements with streak camera in EPA ring - 2



Streak camera images and time profiles for different settings of the QFL quadrupole family, around *a* = 0 (20 turns)



Bunch-to-bunch spacing as a function of the number of turns for the normal (squares) and the isochronous optics (circles).

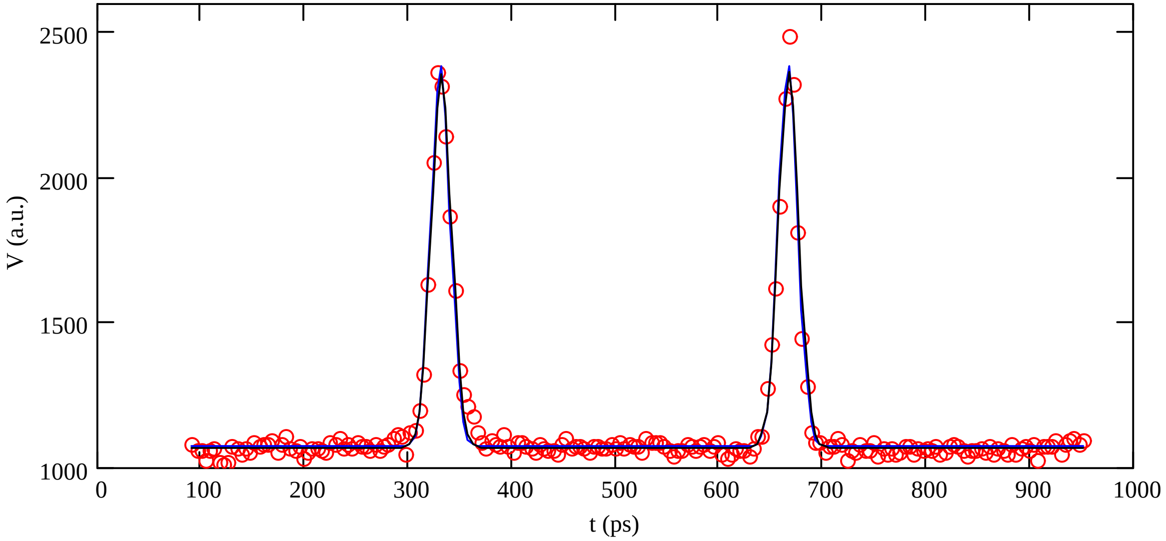


Comparison between the momentum compaction evaluated with MAD (solid line) and the estimation based on the measured bunch distance (circles) as a function of QFL current variation

nominal optics (**a** = 3.4 x 10^{-2})
isochronous optics (**a** = 2.3 x 10^{-4})

CTF3 & CLIC requirement **|a|** ≤ ± 1 x 10^{-4}

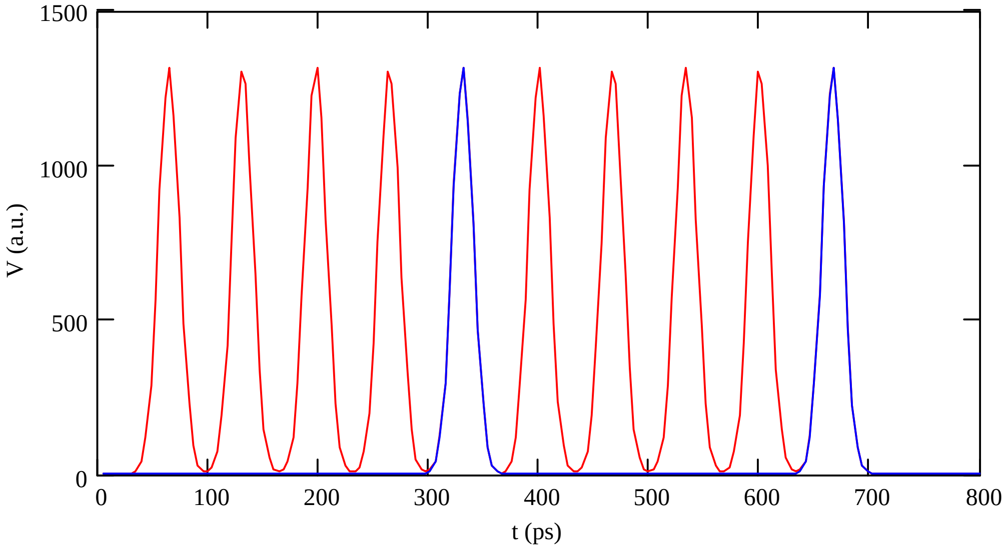
Measurements with streak camera in EPA ring - 3



Bunch length measurements
(December 2000)

The Gaussian fit gives a bunch length of about 20 ps FWHM

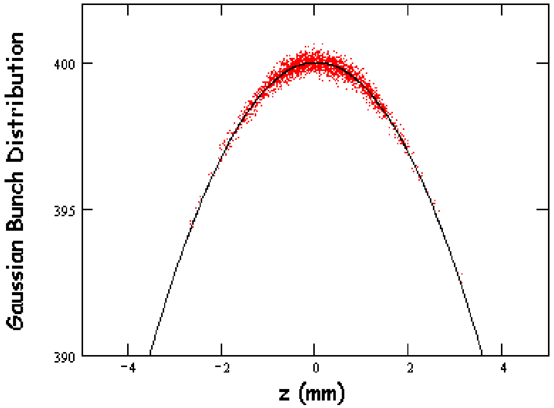
Simulations of bunch combination by a factor 5 assuming 20 ps FWHM bunches



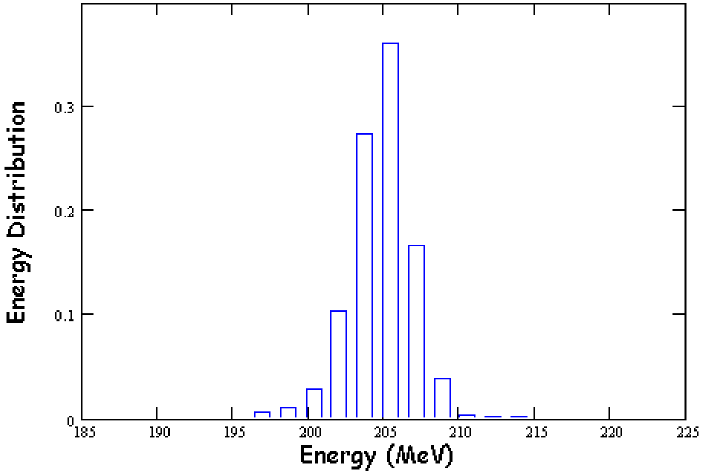
Bunch Length Measurements - 1

For a given bunch length, the energy spread depends on the phase of the bunch with respect to the rf wave in the linac.

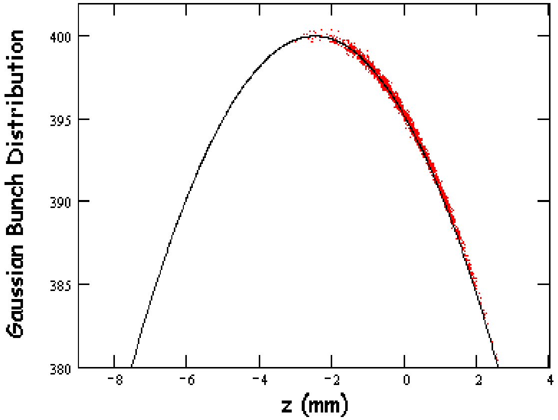
The contribution of beamloading to the energy spread is made negligible by reducing the pulse charge.



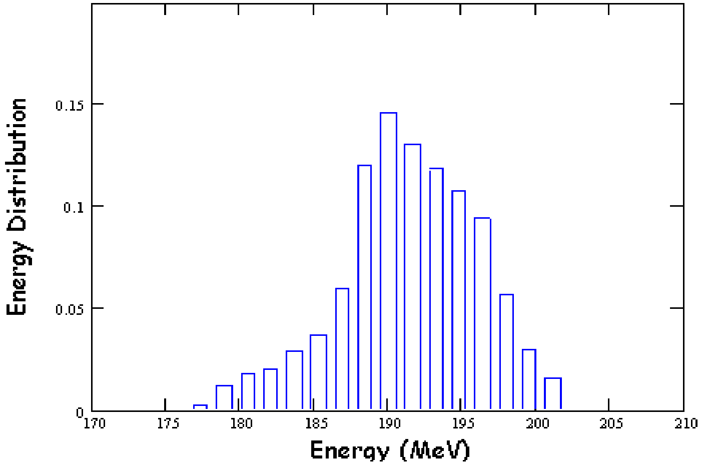
$f = 0$



SEM-Grid



$f \neq 0$



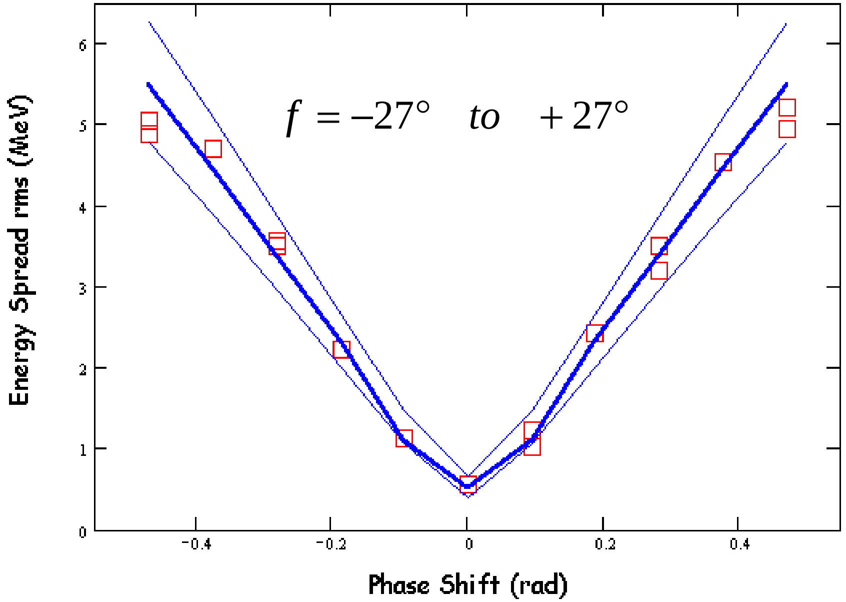
Bunch Length Measurements - 2

The phase between the bunch and the rf wave is changed and the energy spread is recorded using a SEM-grid at 2 different energies in the linac (LIL).

From the energy spread, the bunch length is deduced in the linac.

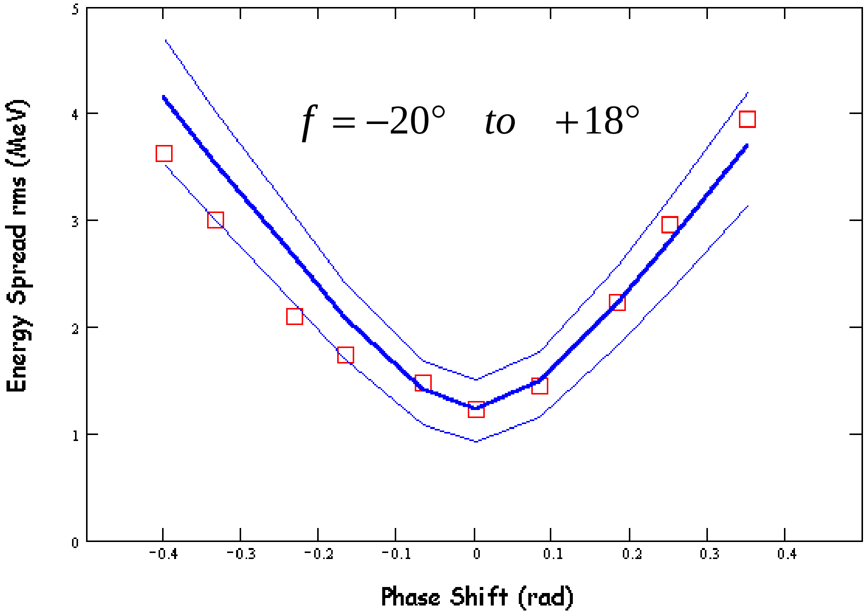
At 200 MeV

$s_L = 7 \pm 1$ ps FWHM



At 500 MeV

$s_L = 7.5 \pm 1$ ps FWHM



RF Frequency variation - measurements

$$C = n \lambda_o \pm \lambda_o / N$$

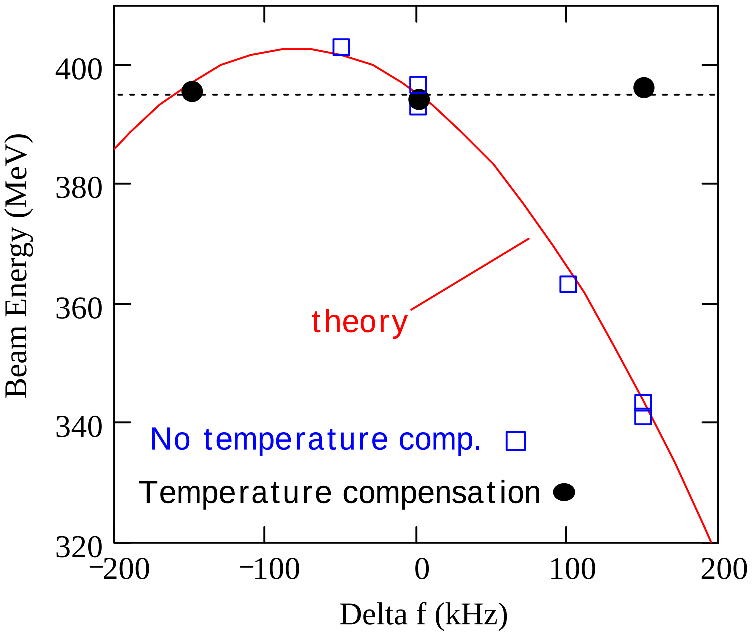
ring circumference

Combination factor

RF wave length

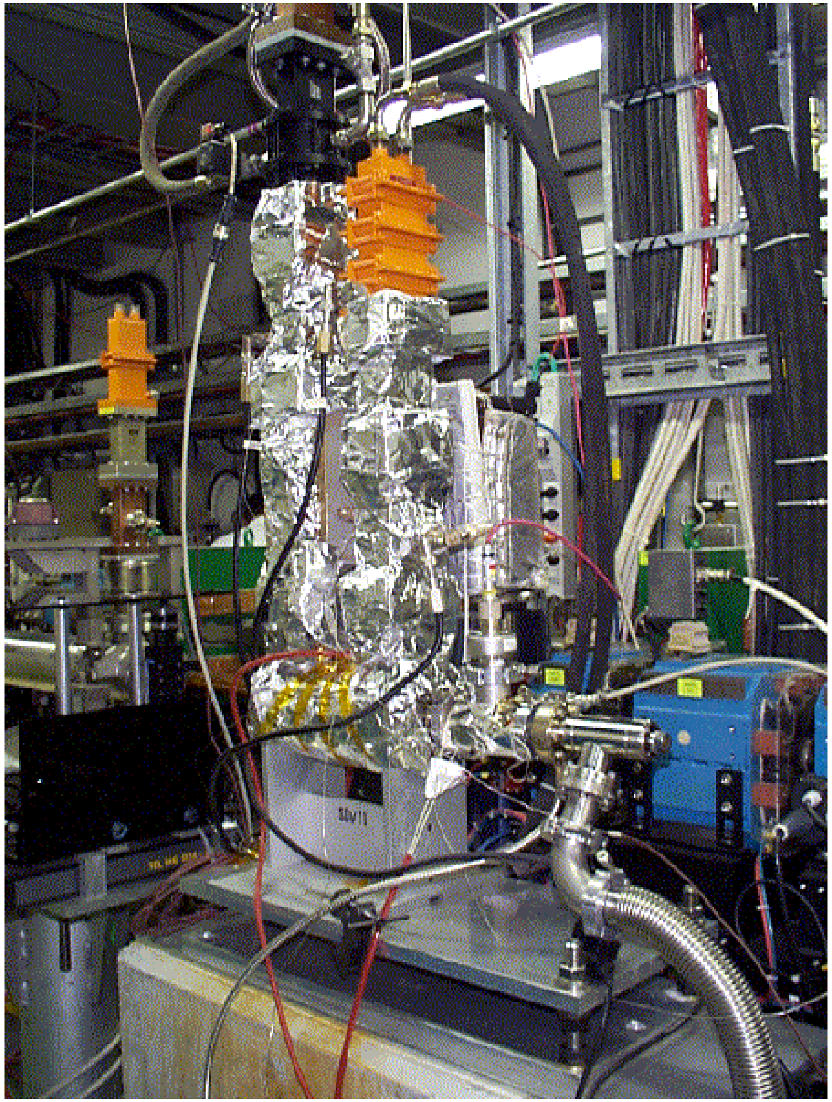
- In order to cover combination factors from 3 to 5, a frequency variation of ± 150 kHz is needed
- The frequency change must be followed by a corresponding change of ± 3º C in the operating temperature of the bunching system, the accelerating structures and the RF deflectors
- The behavior of the bunching system and of the accelerating structures has been tested experimentally in December 2000

- No temperature compensation
  - The bunching system OK for a frequency range of -50 / +100 kHz
  - The accelerating gradient is reduced, as expected
- Temperature compensation
  - No measurable effect on beam performance (bunch length, beam energy and momentum spread) over the full frequency range



Beam energy at the end of the Linac versus RF frequency change

Power Tests of the RF deflectors



MW

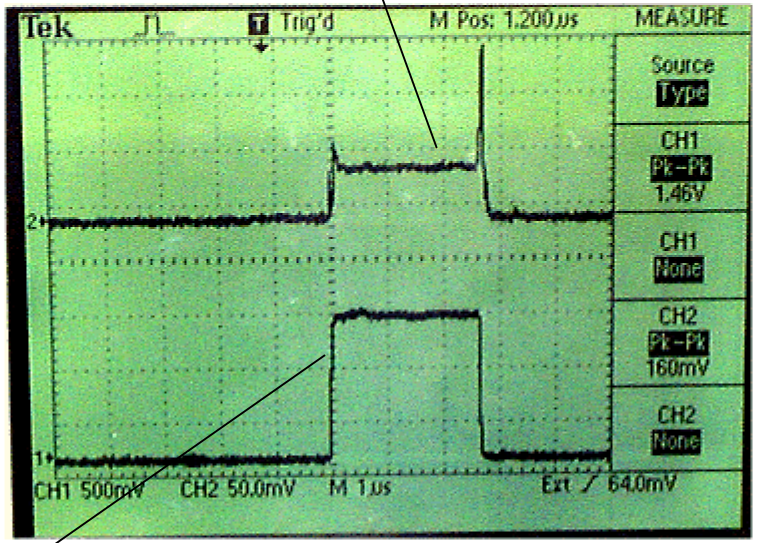
mrad

$$f \approx 585\frac{\sqrt{P}}{E}$$

MeV

Nominal deflection angle f = 4.5 mrad
Nominal beam energy E = 350 MeV
Nominal input power P = 7 MW

Both RF deflectors conditioned up to 13 MW



Reflected power signal

Forward power signal (2.5 ms, 7 MW, 3 GHz)

Other Beam Studies done and planned

The linac: Twiss parameters and emittances, Energy gains in the RF structures, Trajectory measurements, ….

The ring: Circumference measurements, Synchrotron frequency, ...

Experimental program for 2001 and 2002

Tests of injection with RF deflectors in the isochronous ring (single pulse)

Demonstration of bunch train combination for combination factors 3, 4, 5

Possible further tests:

- Bunch length and phase HF monitor (Uppsala University)
- Test of new deflector prototypes (INFN-Frascati)
- RF deflector stability studies
- Coherent Synchrotron Radiations studies,
- …….

First beam in CTF3 (3 pulses)

Friday 21st September 2001

1.00 GSa/s Peak Detect

1 On ☑ 1.00 V/div

2 On ☑ 200 mV/div

3 On ☑ 1.00 V/div

4 On ☑ 50 mV/div

H 500 ns/div

90.000 ns

T 1.129 V

Buncher loop

Wall current monitor
after the bunching system

Capacitive electrode before
bunching system (exit of gun)

R. Corsini, B. Dupuy, L. Rinolfi, P. Royer, F. Tecker

Contributions to the CTF3 Preliminary phase

- Collaboration with other Institutes
  - LAL (CLIO gun)
  - Frascati (RF deflectors)
  - Uppsala University (Optics design)
  - IPN Orsay (RF wave guides installation)

- Technical Installation Committee (TIC)
  - All groups of the PS Division
  - EST, LHC, ST, TIS Divisions

- People participating in the 2001 commissioning with beam
  - CERN: 5 accelerator physicists
  - Uppsala University: 1 accelerator physicist (part-time)
  - Frascati: 3 accelerator physicists per week with beam (part-time)
  - Possible other contributions from CERN and external Institutes (under discussions)