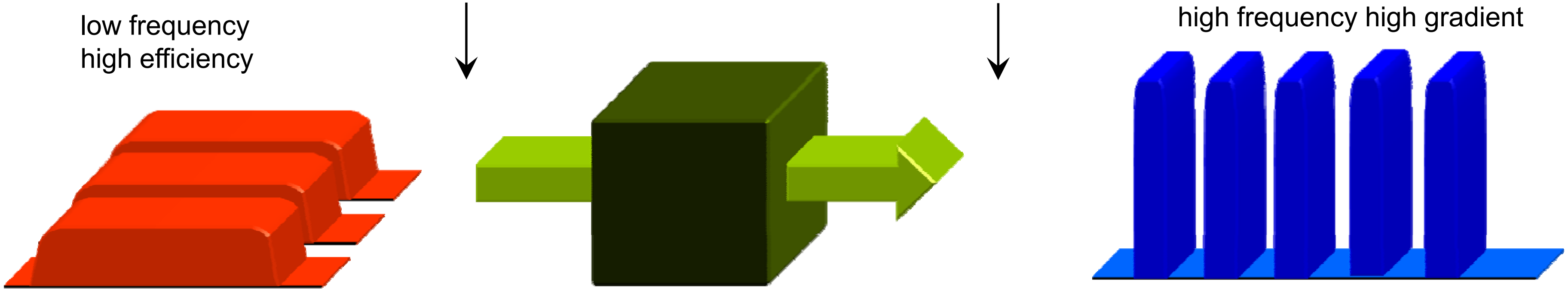
CTF3 versus CLIC

- CTF3 & CLIC Parameters
- Instrumentation already developed
- What will be done in the CLEX

What does the RF Power Source do ?

The CLIC RF power source can be described as a “black box”, combining *very long RF pulses*, and transforming them in *many short pulses*, with *higher power* and with *higher frequency*



800
Klystrons

low frequency
high efficiency

Power stored in
electron beam

Power extracted from beam
in resonant structures

144000
Accelerating Structures

high frequency high gradient

Long RF Pulses

P_0 , n_0 , τ_0

Electron beam
manipulation

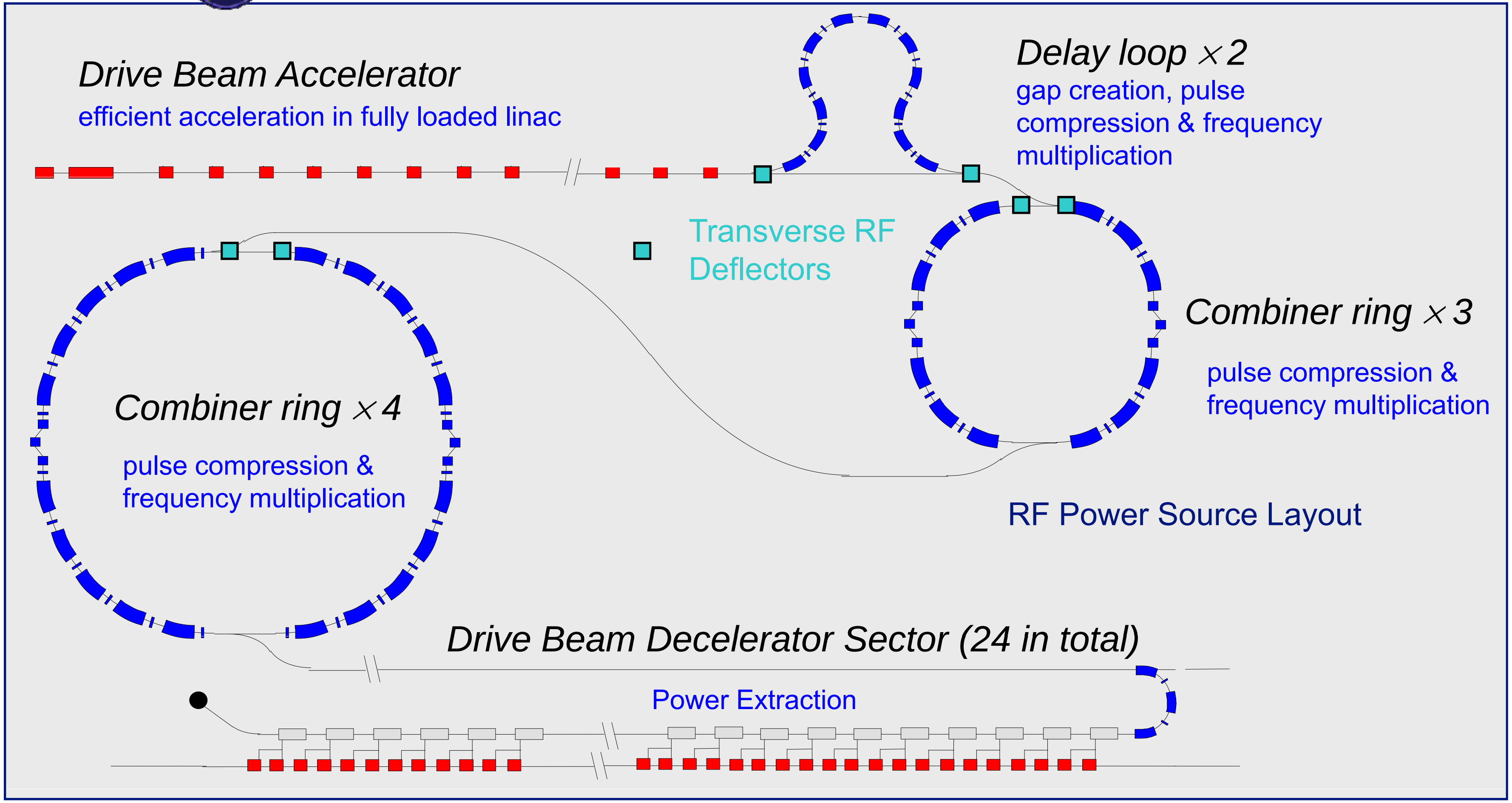
Short RF Pulses

$P_A = P_0 \times N_1$

$\tau_A = t_0 / N_2$

$\nu_A = \nu_0 \times N_3$

CLIC Drive Beam



Drive Beam Accelerator

efficient acceleration in fully loaded linac

Delay loop × 2

gap creation, pulse compression & frequency multiplication

Transverse RF Deflectors

Combiner ring × 3

pulse compression & frequency multiplication

Combiner ring × 4

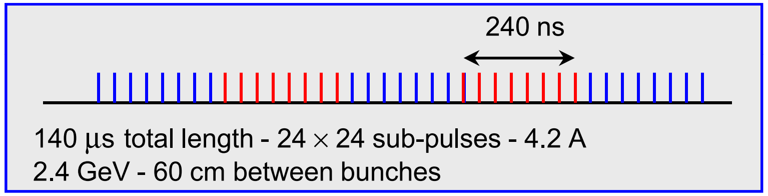
pulse compression & frequency multiplication

RF Power Source Layout

Drive Beam Decelerator Sector (24 in total)

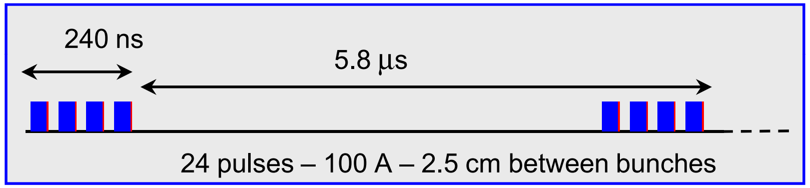
Power Extraction

Drive beam time structure - initial



140 µs total length - 24 × 24 sub-pulses - 4.2 A
2.4 GeV - 60 cm between bunches

Drive beam time structure - final



24 pulses – 100 A – 2.5 cm between bunches

Motivation

The *CLIC Technology-related* key issues as pointed out by ILC-TRC 2003

Covered by CTF3

R1: Feasibility

- R1.1: Test of damped accelerating structure at design gradient and pulse length
- R1.2: Validation of drive beam generation scheme with fully loaded linac operation
- R1.3: Design and test of damped ON/OFF power extraction structure

R2: Design finalization

- R2.1: Developments of structures with hard-breaking materials (W, Mo…)
- R2.2: Validation of stability and losses of DB decelerator; Design of machine protection system
- R2.3: Test of relevant linac sub-unit with beam
- R2.4: Validation of drive beam 40 MW, 937 MHz Multi-Beam Klystron with long RF pulse *
- R2.5: Effects of coherent synchrotron radiation in bunch compressors
- R2.6: Design of an extraction line for 3 TeV c.m.

Covered by EUROTeV

* *Feasibility study done – need development by industry.*
N.B.: Drive beam acc. structure parameters can be adapted to other klystron power levels

Motivation

Motivation and goals of CTF3 collaboration

Build a small-scale version of the CLIC RF power source, in order to demonstrate:

- ✓ **full beam-loading accelerator operation**
- ✓ **electron beam pulse compression and frequency multiplication using RF deflectors**

Provide the RF power to **test the CLIC accelerating structures and components**

CTF3 is being built at CERN by a collaboration modeled on the large physics experiments

23 institutes from 12 countries

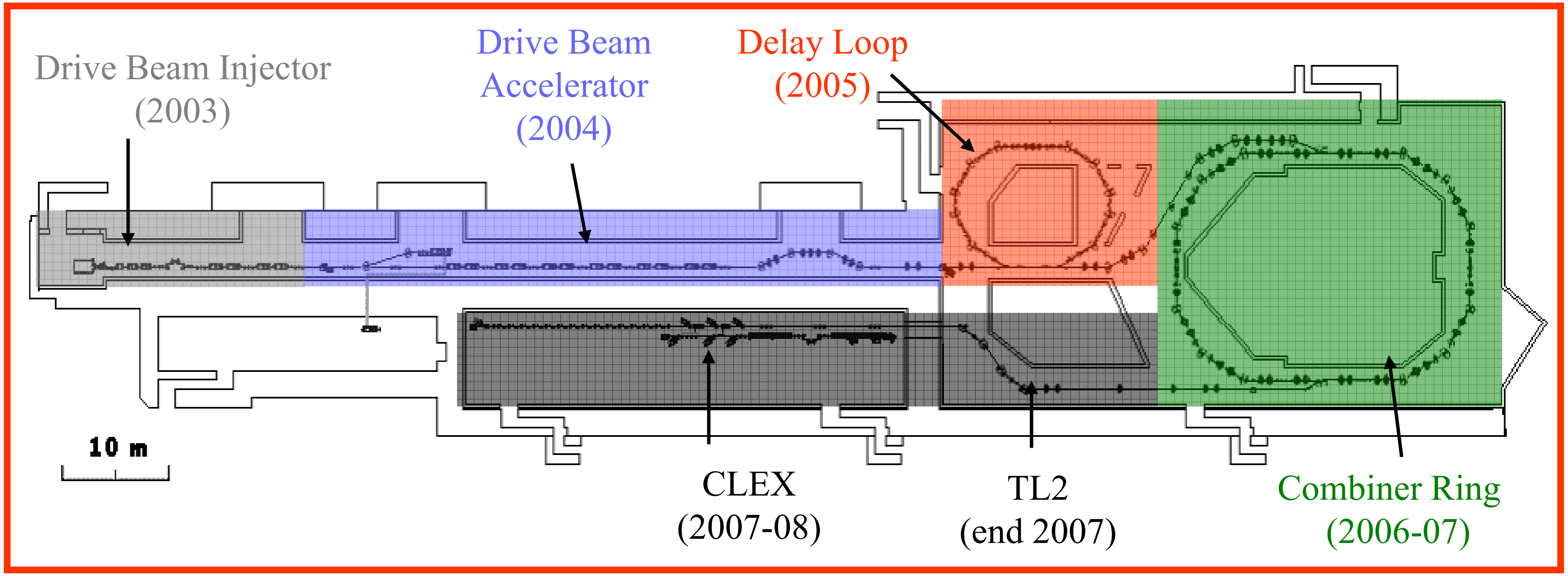
Chairman of collaboration Board: M. Calvetti (INFN-LNF)
Spokesperson: G. Geschonke (CERN)

➡ Will be largest LC test facility constructed

M. Huening, A. Mosnier, V. Shiltsev & T. Raubenheimer
CLIC Advisory Committee Report

CTF3 Complex

CLIC Test Facility 3 to show the feasibility of the CLIC RF Source & Two Beam Acceleration for a multi-TeV e^+-e^- collider



Drive Beam Injector (2003)

Drive Beam Accelerator (2004)

Delay Loop (2005)

CLEX (2007-08)

TL2 (end 2007)

Combiner Ring (2006-07)

16 Institutes

cea

ANKARA UNIVERSITY

HELSINKI INSTITUTE OF PHYSICS

LAL

Институт Прикладной Физики

esia

GAZİ UNIVERSITY

MINISTERIO DE EDUCACIÓN Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

INFN Istituto Nazionale di Fisica Nucleare

STANFORD LINEAR ACCELERATOR CENTER

Joint Institute for Nuclear Research

IN2P3 Institut National de Physique Nucléaire et de Physique des Particules

UPPSALA UNIVERSITET

Laboratori Nazionali di Frascati

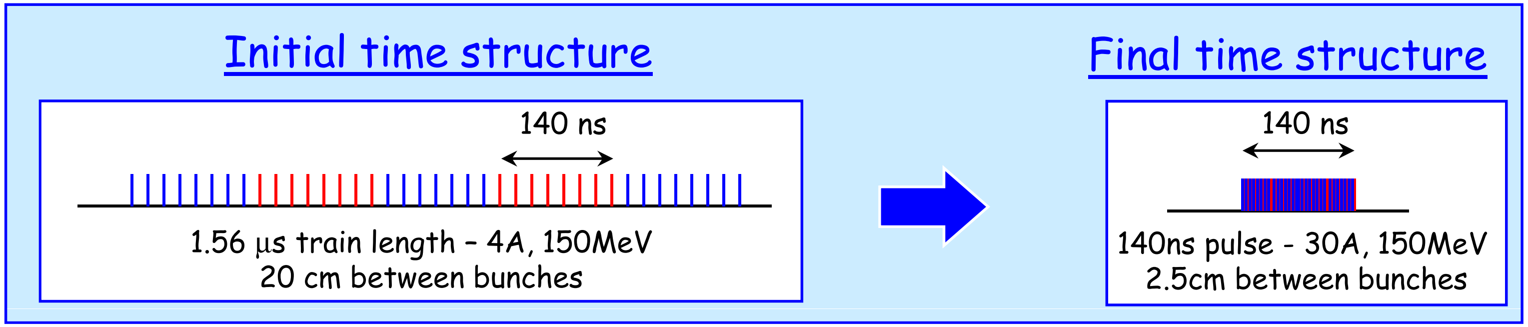
NORTHWESTERN UNIVERSITY

ANNECY lapp

CCLRC

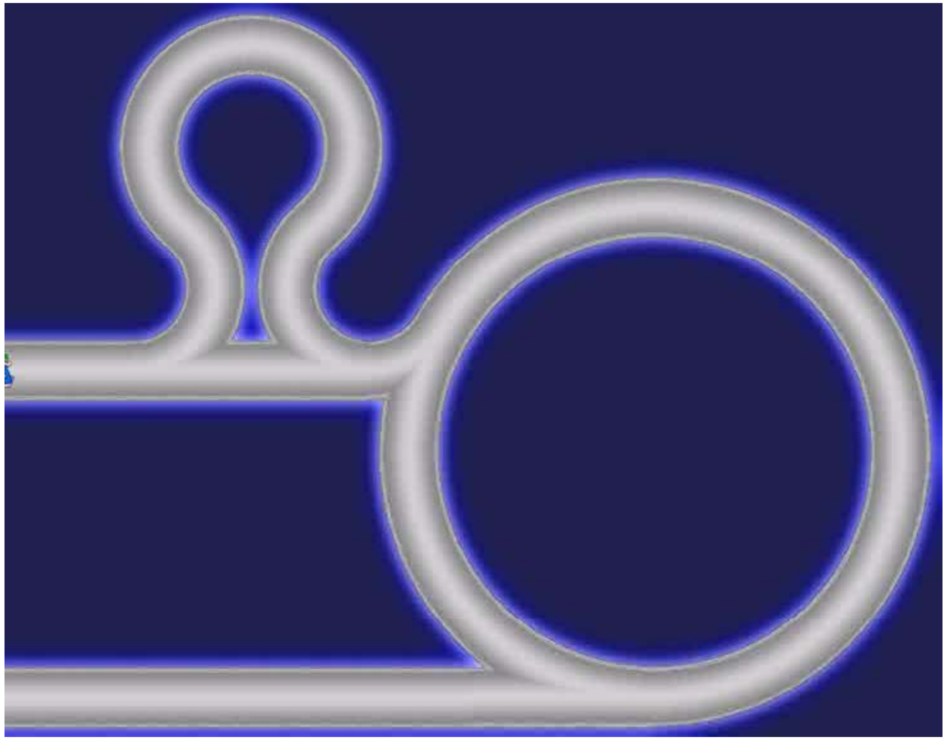
CTF3 Principle

Bunch frequency multiplication by a factor 8 : from 1.5 to 12GHz

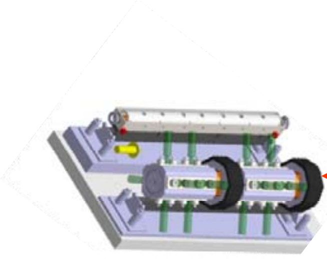


Linac
2-4ps bunch length

42m Delay loop x2 (8-10ps bunch length)



RF deflectors for injections in the rings



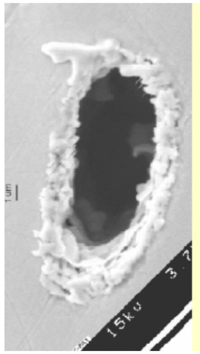
CLEX
(1ps bunch length)

84m
Combiner ring (x4)
(8-10ps bunch length)

CLIC Drive Beam / CTF3

Beam parameters	DB Generation Complex	DB Decelerator (24 units)	CTF3 Linac	CTF3 CLEX
Electrons energy	→ 2.38 GeV	2.38 → 0.238 GeV	→ 150MeV	150MeV
Beam current /charge	4.2A / 587µC	101A / 24.4µC	4A / 1.6µC	30A
Total Beam Energy	→ 1.397MJ	58→ 5.8kJ	→ 240J	240J
Bunch length	6-13ps	3.3ps	2-10ps	1ps
Minimum beam size	50µm	50µm	50µm	
Charge density	**3.7 10^9 nC/cm^2**	**1.5 10^8 nC/cm^2**	**1.1 10^7 nC/cm^2**	

The thermal limit for 'best' material (C, Be, SiC) is ~ 1 10^6 nC/cm^2



- Control of beam loss to prevent beam induced damage (10^{-4})
- Use of non-intercepting / non degradable beam diagnostic
- Strong scaling factor from CTF3 to CLIC

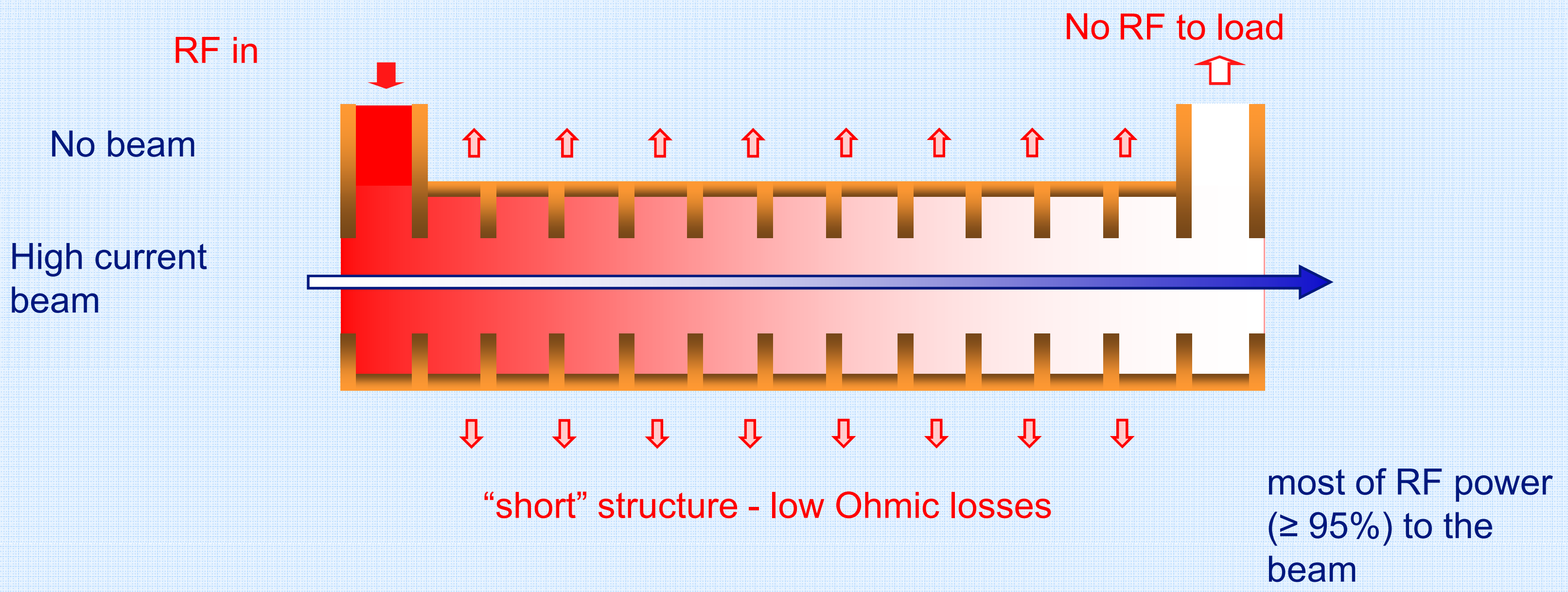
Measurement @ CTF3

Beam Parameters	CTF3 detector Type	CTF3 detector Performances
Intensity Σ	Wall Current Monitor	Dedicated talk
Position x,y	Inductive Pick-up	Dedicated talk
Energy spread $\Delta E/E$	🟥	🟥
Bunch length σ_z	RF pick-up, RF deflector, Streak camera	Talk on RF pick-up
Beam size & emittance σ	🟥	🟥
Beam loss	Ionization chamber, ACEM, Cherenkov monitor	Dedicated talk
Bunch frequency multiplication	RF techniques	Dedicated talk
Phase stability	RF techniques	Dedicated talk

What is presented in this talk

High efficiency acceleration scheme

Full beam-loading acceleration in TW sections



RF in

No beam

High current beam

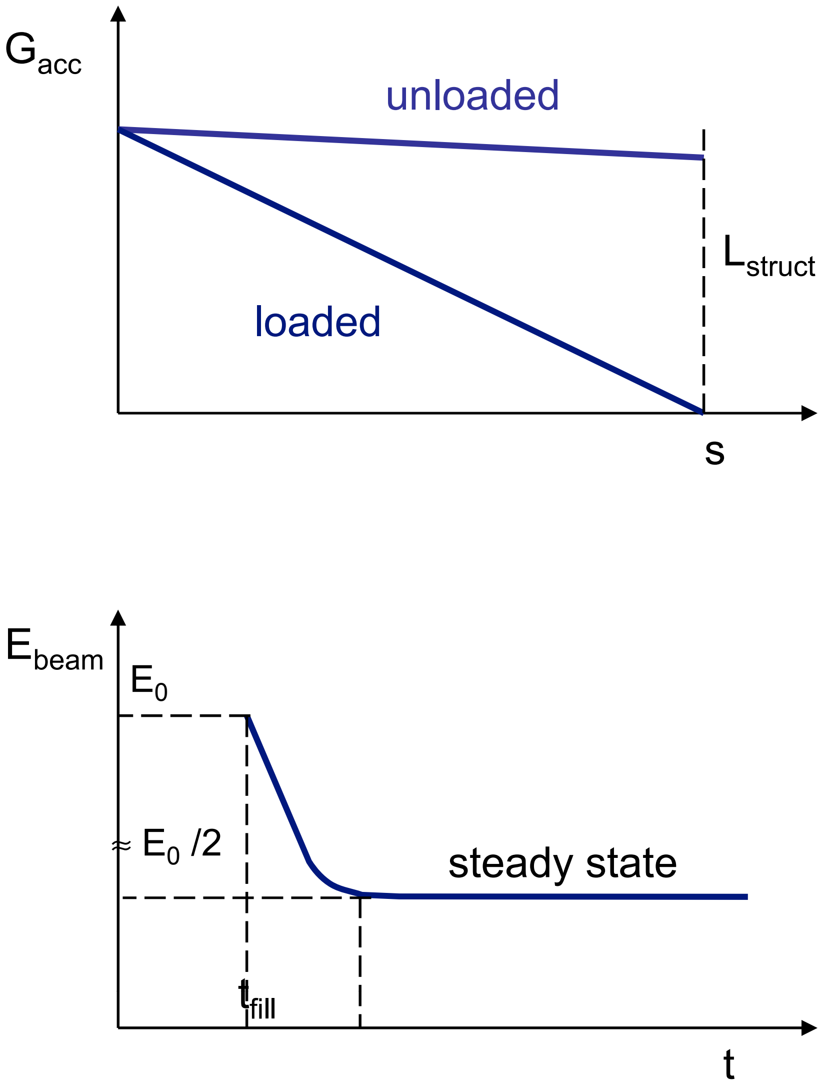
No RF to load

"short" structure - low Ohmic losses

most of RF power (≥ 95%) to the beam

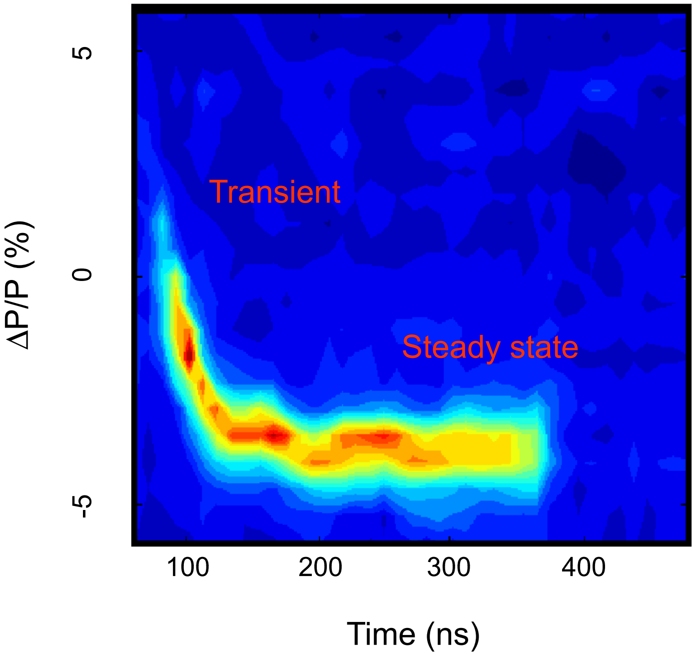
Time resolved spectrometry @ CTF3

RF Power Source “building blocks”

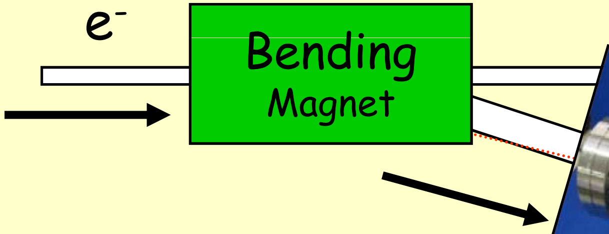


Full beam-loading acceleration in TW sections

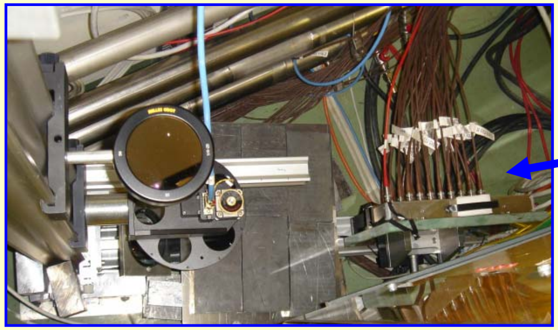
Time resolved beam energy spectrum measurement in CTF3



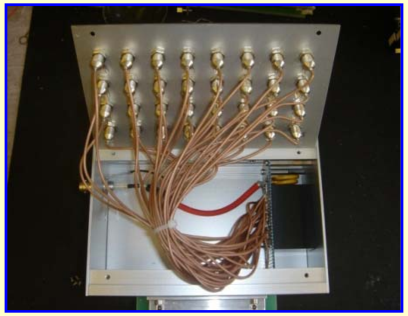
Time resolved spectrometry @ CTF3



Segmented Dump
Or Slit Dump



OTR Screen
&
Segmented PMT



- 32 channels PMT (Hamamatsu)
- 2mm spatial resolution
- 36dB, 100MHz amplifier in the klystron gallery

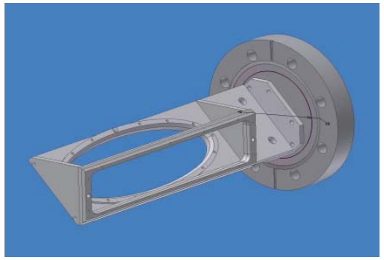
- 24 Tungsten plates (2mm thick) spaced by ~ 1mm
- Connected to 50 Ω to the ground

- Slit dump (2mm slit and a dump in steel)

OTR & Segmented Photomultiplier

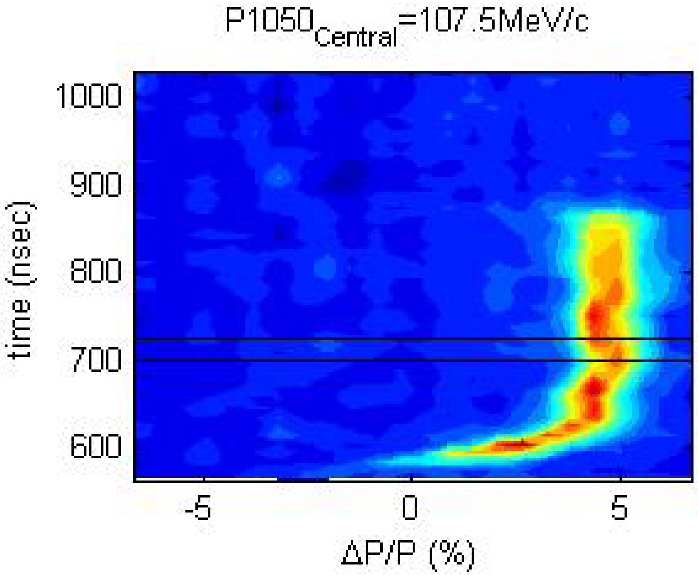
- Problem with synchrotron light in the bending magnet

@ 100MeV: ph/e-: $4{\cdot}10^{-3}$(SR) versus $9{\cdot}10^{-3}$ (OTR)



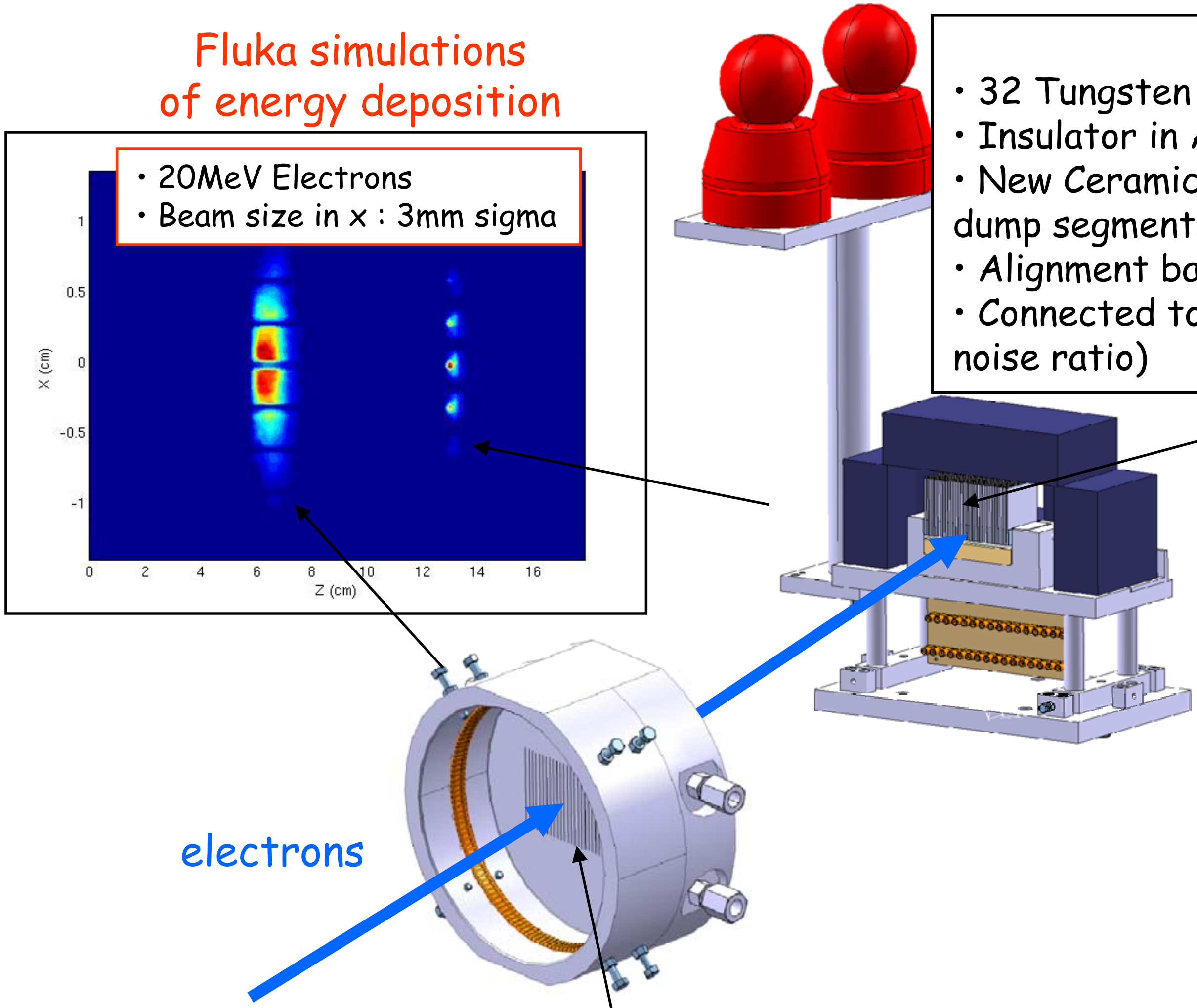
Implement a carbon foil as SR light shielding

- Parabolic OTR screen in order to optimize the collection of the light



Segmented Dump

Fluka simulations
of energy deposition



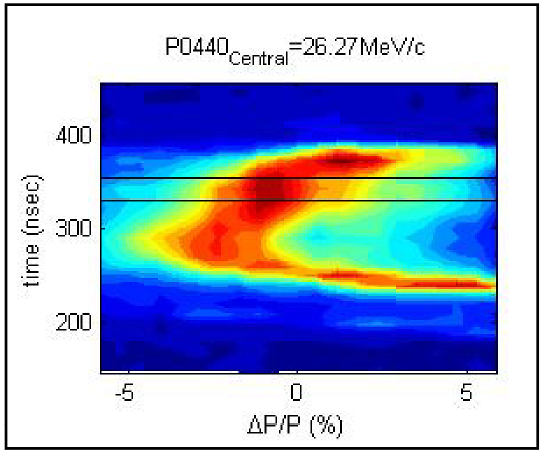
- 20MeV Electrons
- Beam size in x : 3mm sigma

<u>Segmented DUMP</u>

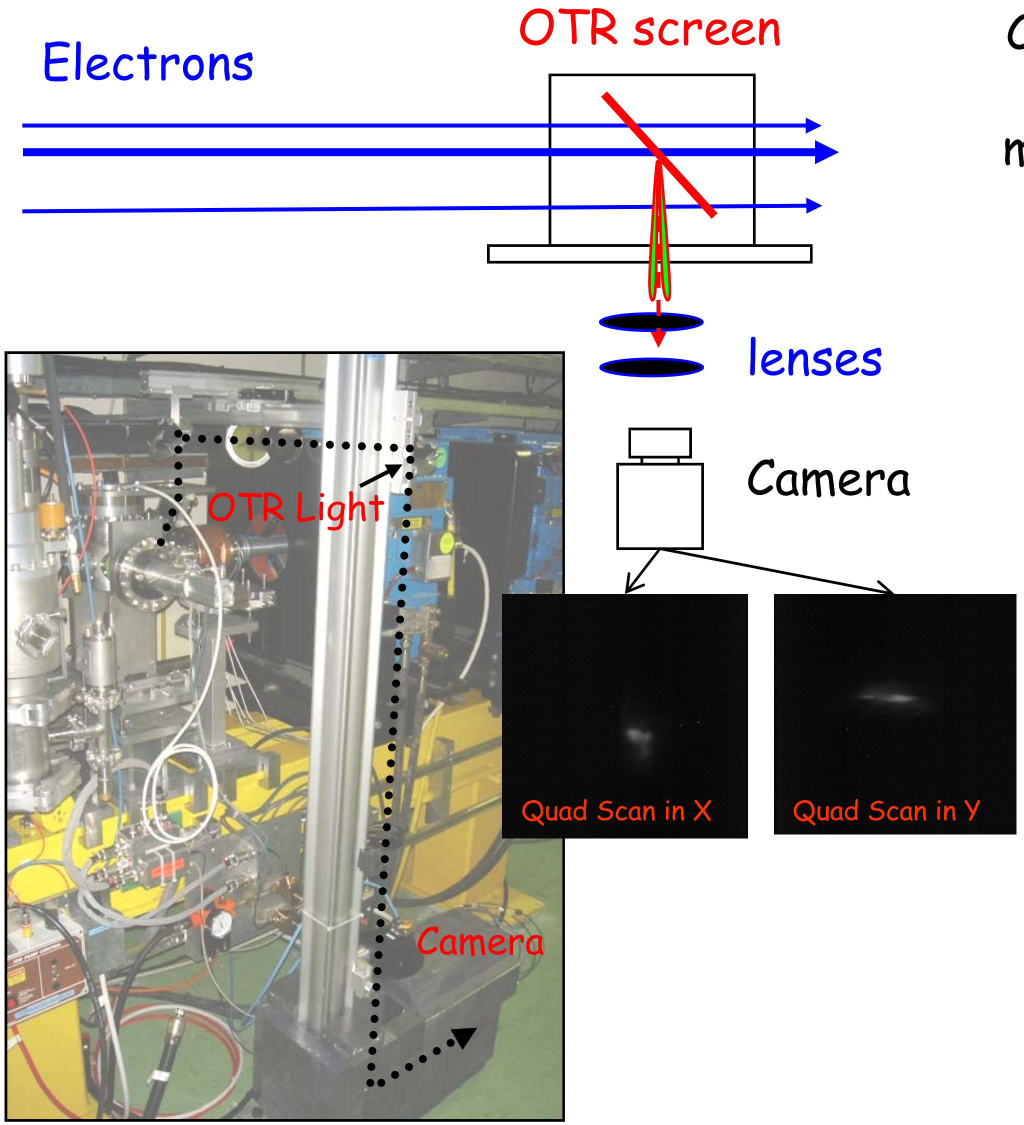
- 32 Tungsten plates (2mm thick) spaced by ~ 1mm
- Insulator in Alumina (rad-hard)
- New Ceramic electronic card connected to the dump segments
- Alignment balls has been added
- Connected to 50Ω to ground (increasing signal to noise ratio)

- <u>Collimator in Steel</u>
  - Mounted on the beam tube
  - 32 vertical slits 400microns thick
  - Water cooled

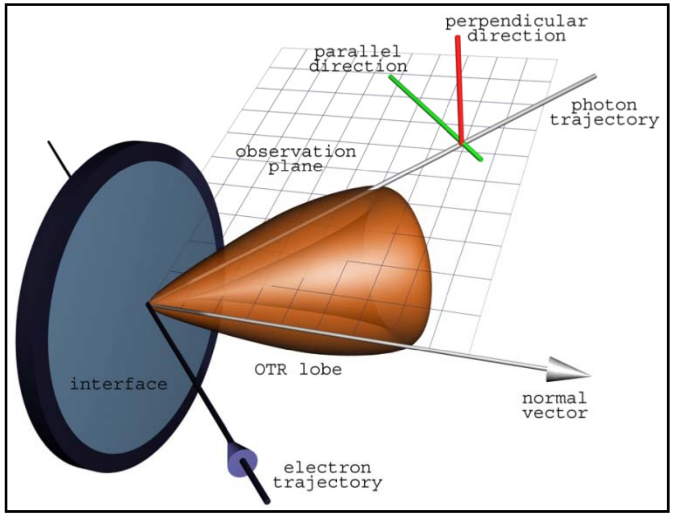
Results



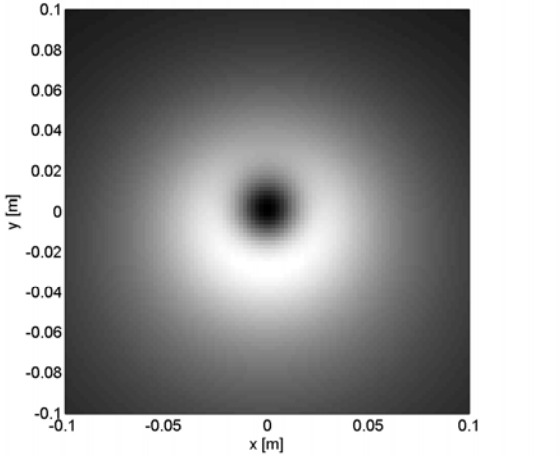
OTR Screens



Created when charged particles pass through the interface between two materials with different permittivity



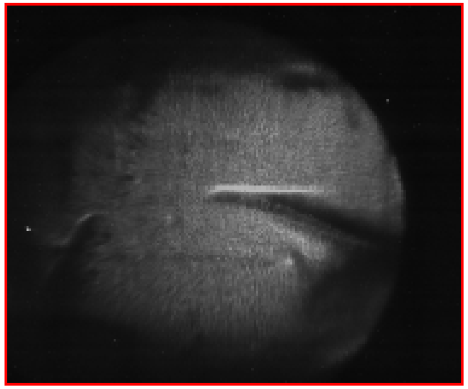
Angular distribution of OTR



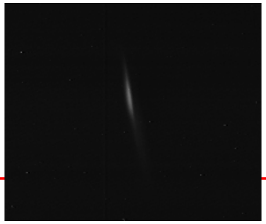
OTR Screens limitations

High reflectivity screens for low charge beam

- Thin Al foil is fragile

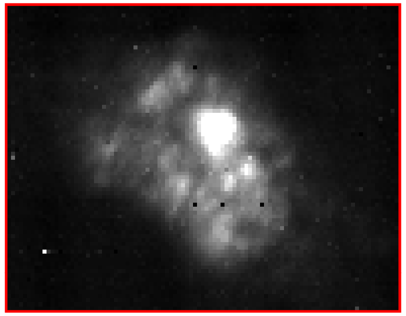


- Using 200µm Si wafer with a very good surface quality
- Adding an Aluminum coating to provide an excellent reflectivity coefficient (90%)



Thermal resistant material for high charge beam

•Non homogeneous surface of C



- 200µm thick Polished CVD SiC

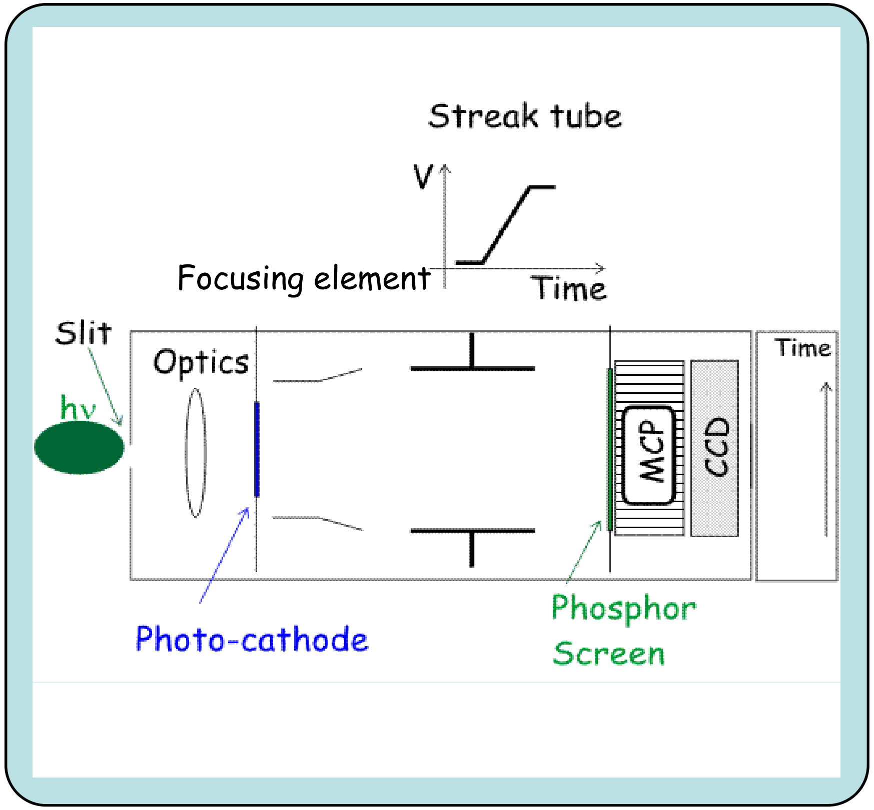
30% Reflectivity coefficient

Bunch length monitoring

- Streak Camera -

Use Synchrotron light produced in the rings or OTR/Cherenkov screens in a linac

‘Streak cameras uses a time dependent deflecting electric field to convert time information in spatial information on an intensified CCD’



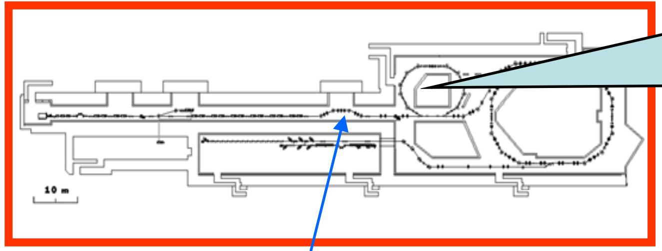
- 200fs time resolution at best using state of the art Cameras : FESCA 200
- Limitations :

  (i) Initial velocity distribution of photoelectrons : *narrow bandwidth optical filter*
  (ii) Spatial spread due to the size of the slit
  (iii) Dispersion in the optics

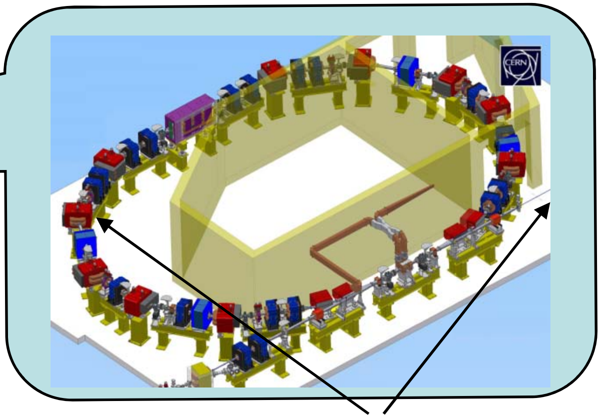
TUPB29, TUPC11, WEPB05, WEPB12, WEPB20

Bunch length monitoring

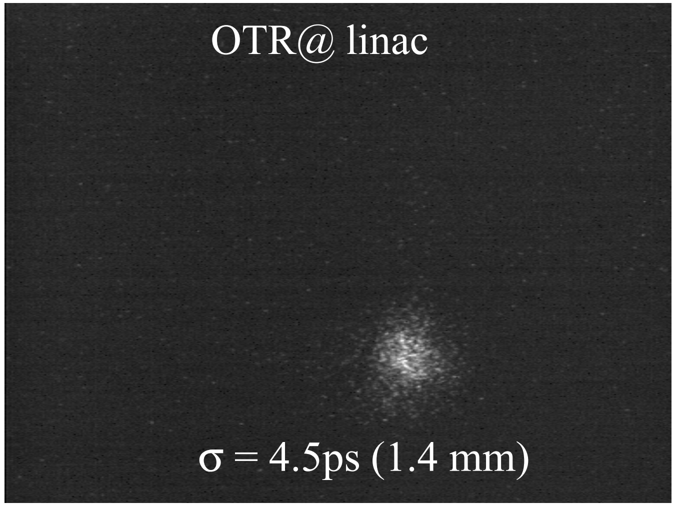
‘ CTF3 Complex’



Bunch length can be manipulated at the end of the linac using a magnetic chicane



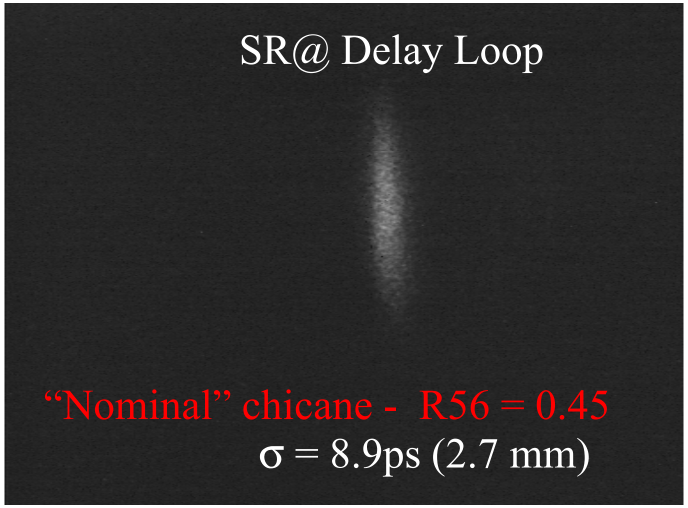
2 Optical lines to the streak camera
- Synchrotron Radiation in the Delay Loop
- OTR in the linac at the exit of the Delay Loop



OTR@ linac

σ = 4.5ps (1.4 mm)

Sweep speed of 10ps/mm



SR@ Delay Loop

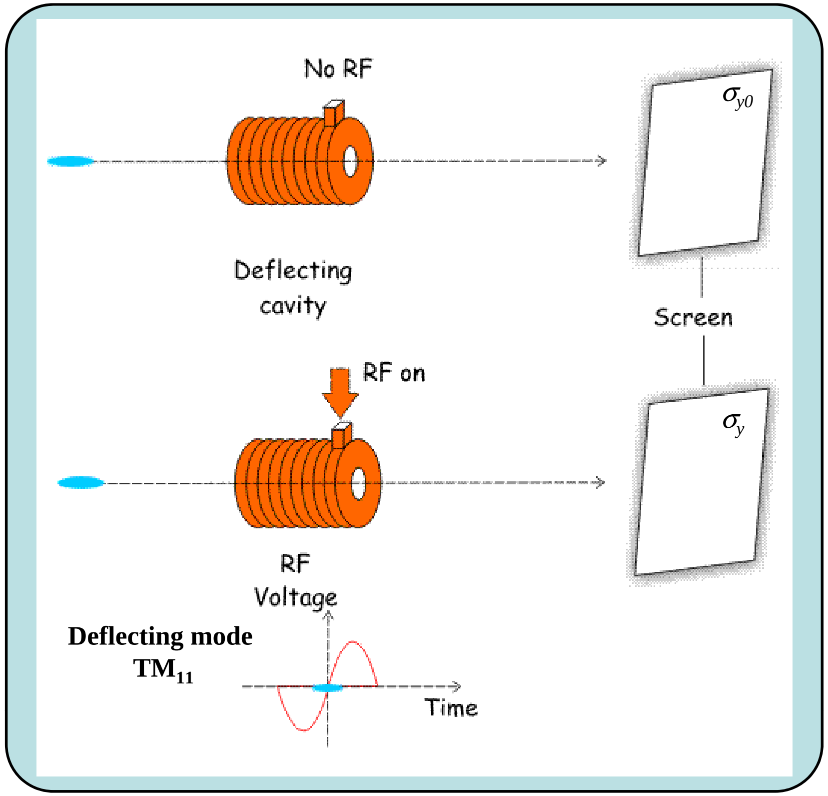
“Nominal” chicane - R56 = 0.45

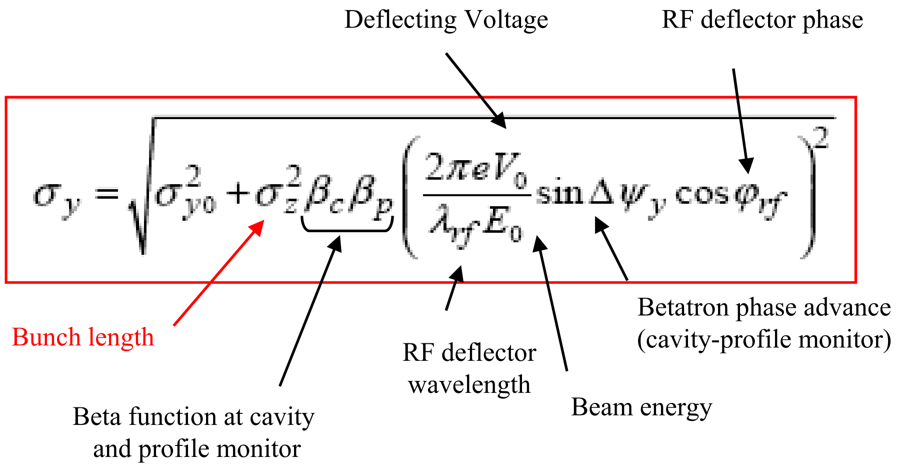
σ = 8.9ps (2.7 mm)

Bunch length monitoring

Old (1960-70's) idea to use RF deflector as a bunch length monitor

- *The RF Deflector can be seen as a relativistic streak tube.*
- *The time varying deflecting field of the cavity transforms the time information into a spatial information*
- *The bunch length is then deduced measuring the beam size at a downstream position using a screen (or Laser Wire Sanner)*





Deflecting Voltage

RF deflector phase

$$\sigma_y = \sqrt{\sigma_{y0}^2 + \sigma_z^2 \underbrace{\beta_c \beta_p}\left(\frac{2\pi e V_0}{\lambda_{rf} E_0} \sin \Delta\psi_y \cos\varphi_{rf}\right)^2}$$

Bunch length

Beta function at cavity and profile monitor

RF deflector wavelength

Beam energy

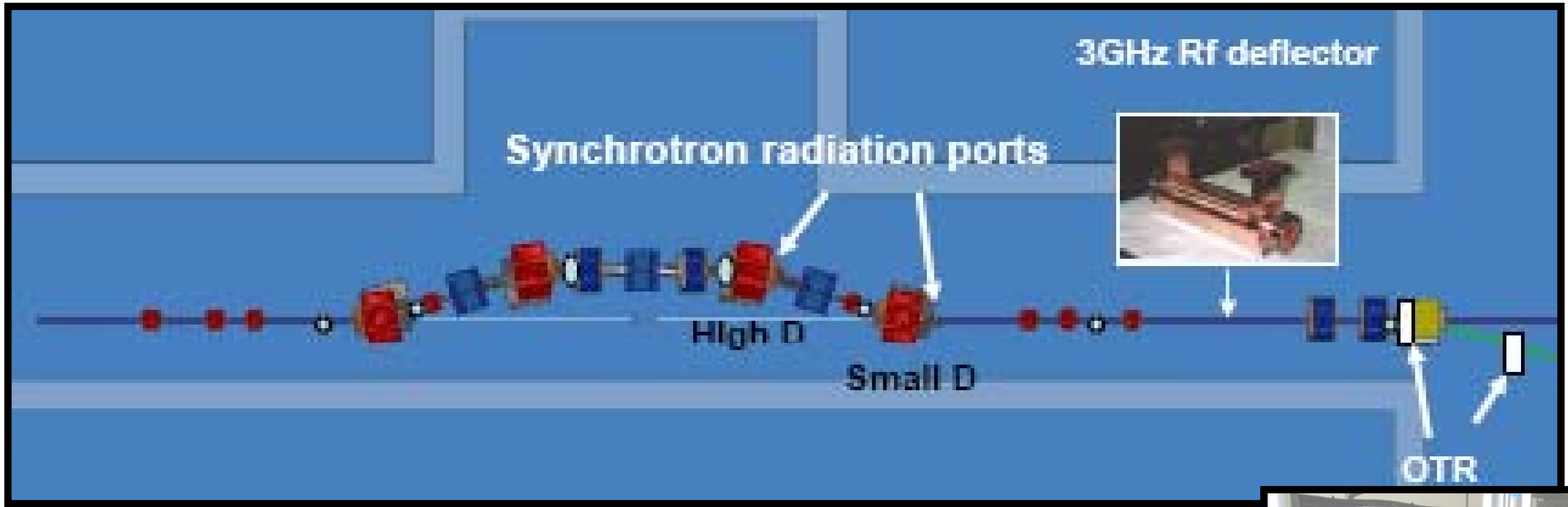
Betatron phase advance (cavity-profile monitor)

<u>Resolution will depend on :</u> *(sub-100fs)*

- Screen spatial resolution
- *Deflecting power*
- *Beam optic between the deflector and screen*

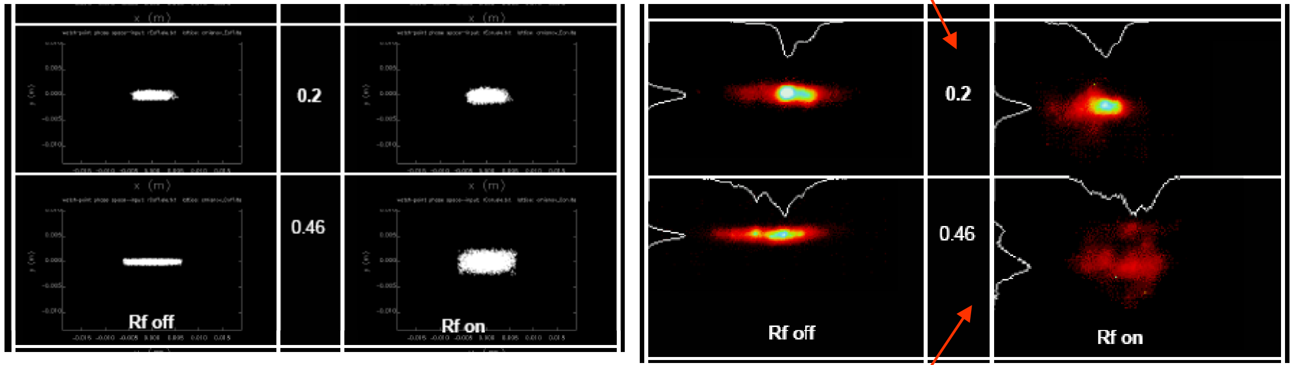
MOO2A02, TUPB13, TUPB3 & WEO2A03 by A. Cianchi,

Bunch length monitoring

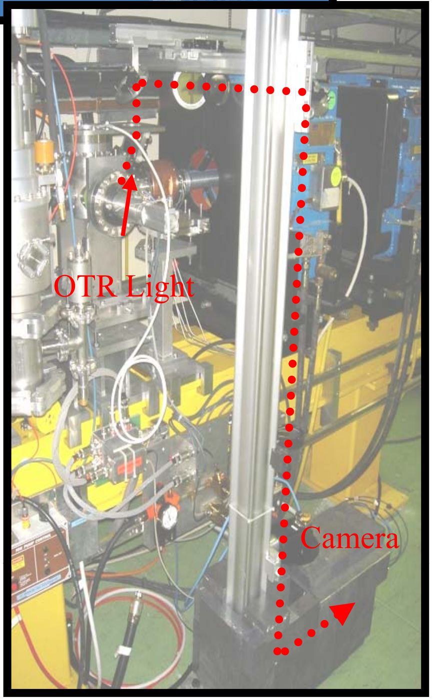


30º offcrest on last klystron

Bunch length 0.5 mm (1.2ps)



Bunch length 2.5 mm (6ps)

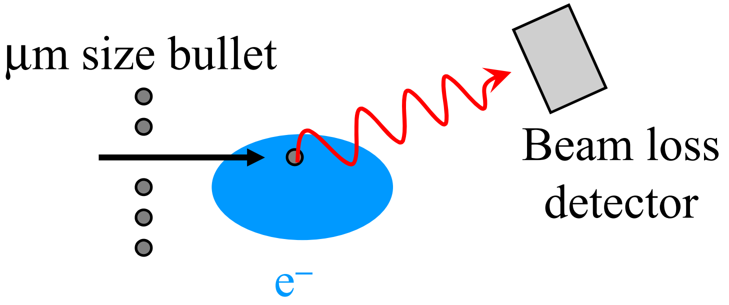


No conclusion

How can we make profile monitor for the Drive Beam Linac

- No non-intercepting transverse profile monitor available for low energy electron beams in a linac

- Degradable profile monitor
  - 'Kalachnikov' : bullet scanner



- Neutral beam scanner : Gas jet

C. Dimopoulou, PS/BD note 99-12

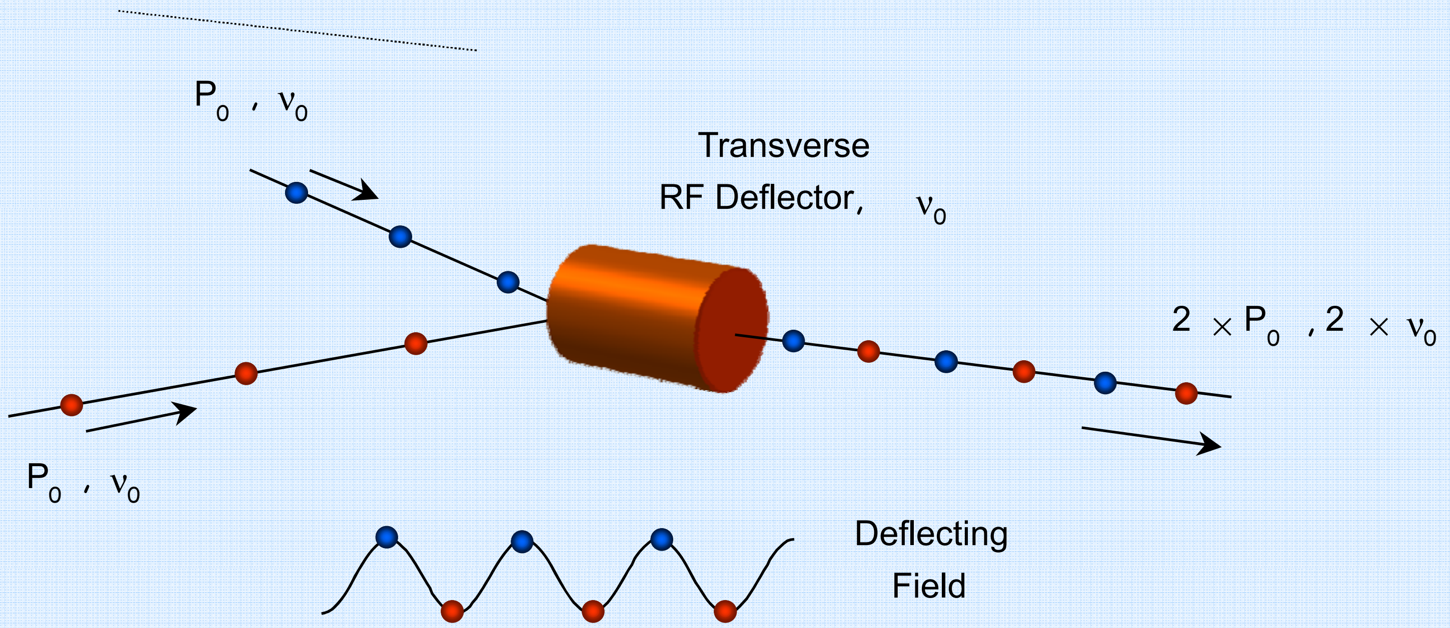
- Any new idea highly welcome…

Back-up Slides

RF Deflector

RF Power Source “building blocks”

Beam combination/separation
by transverse RF deflectors



P_0 , ν_0

Transverse
RF Deflector, ν_0

$2 \times P_0$, $2 \times \nu_0$

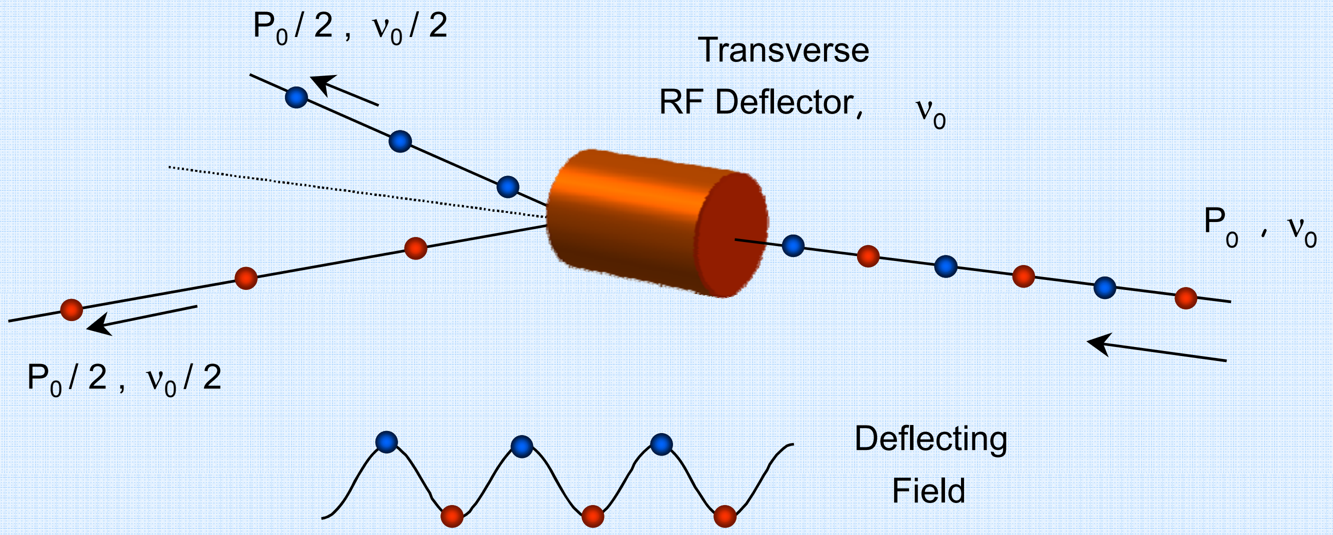
P_0 , ν_0

Deflecting
Field

CLIC Drive Beam

RF Power Source “building blocks”

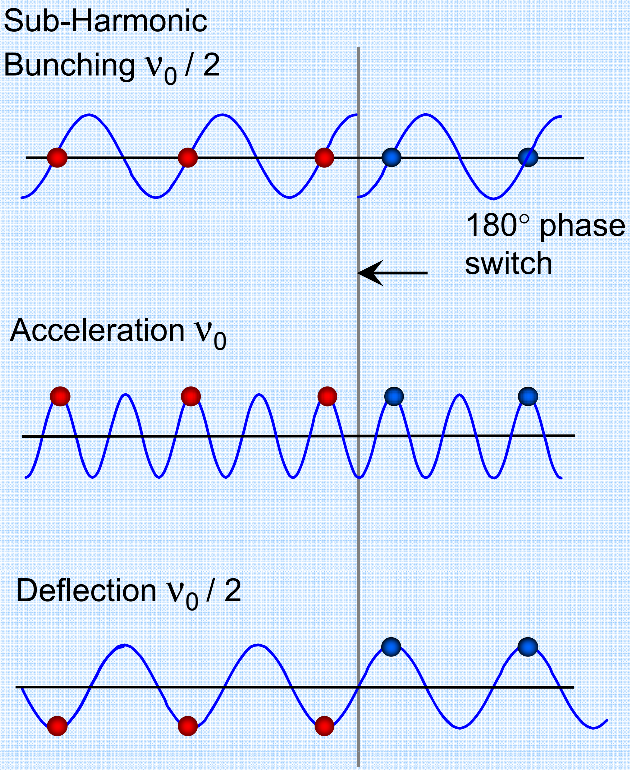
Beam combination/separation
by transverse RF deflectors



Delay Loop

Phase coding

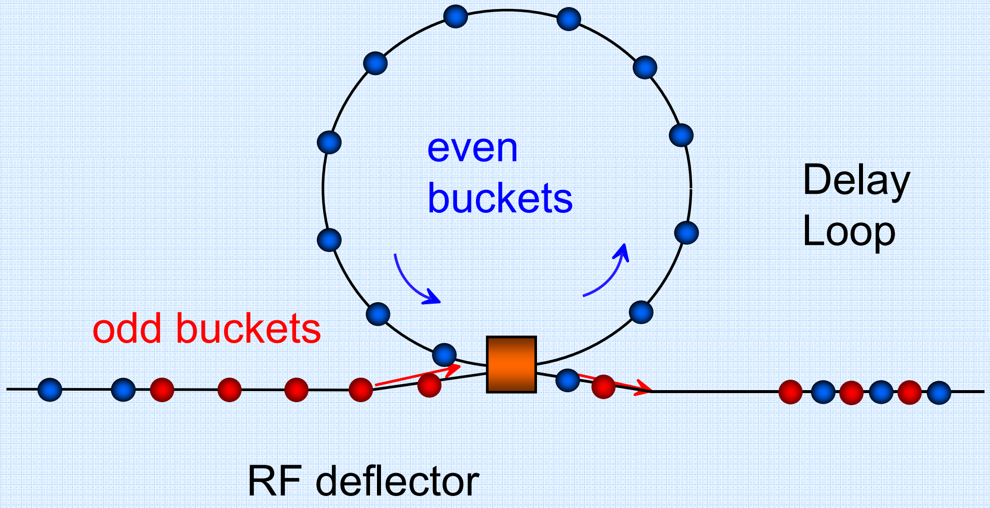
How to "code" the sub-pulses



Gap creation & first multiplication × 2

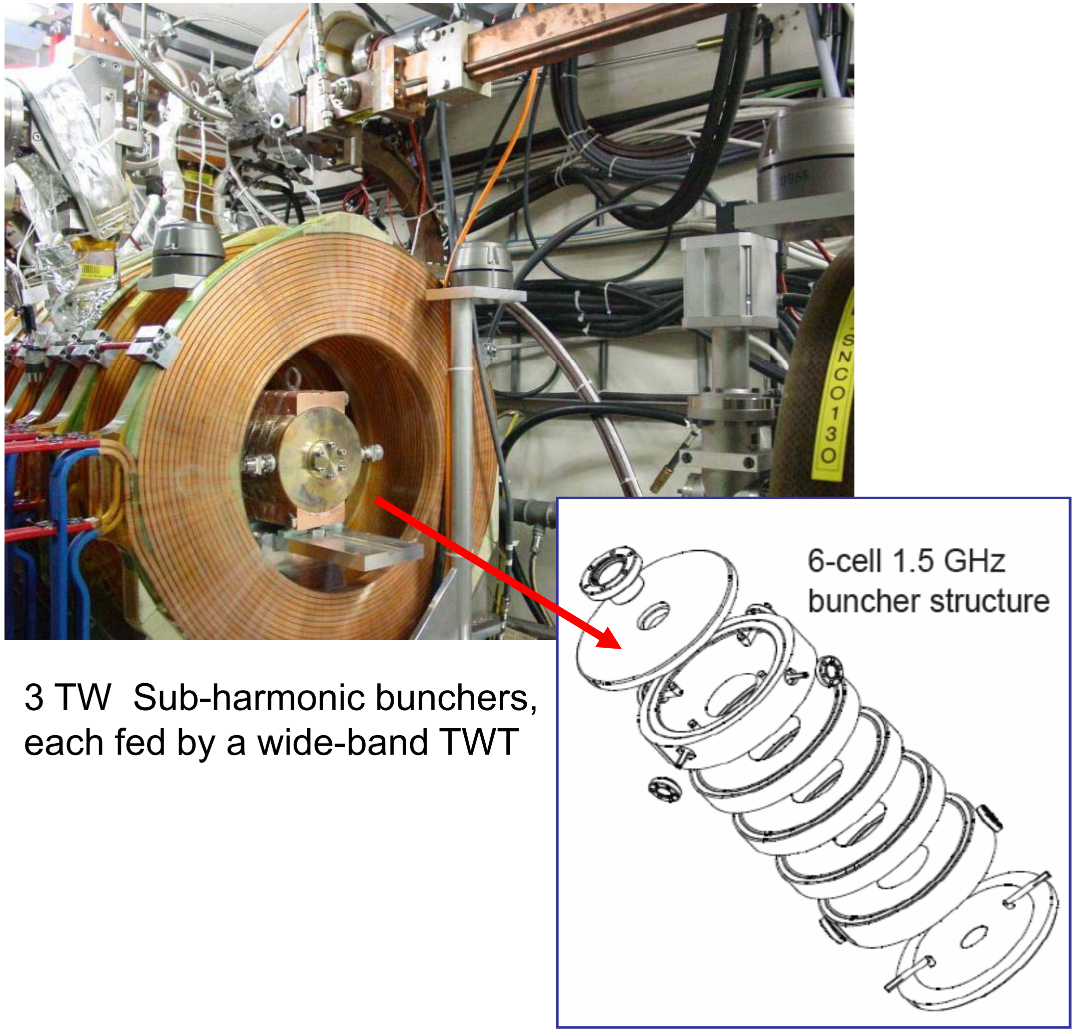
$$L_{delay} = n\ \lambda_0 = c\ T_{sub\text{-}pulse}$$

Combination scheme



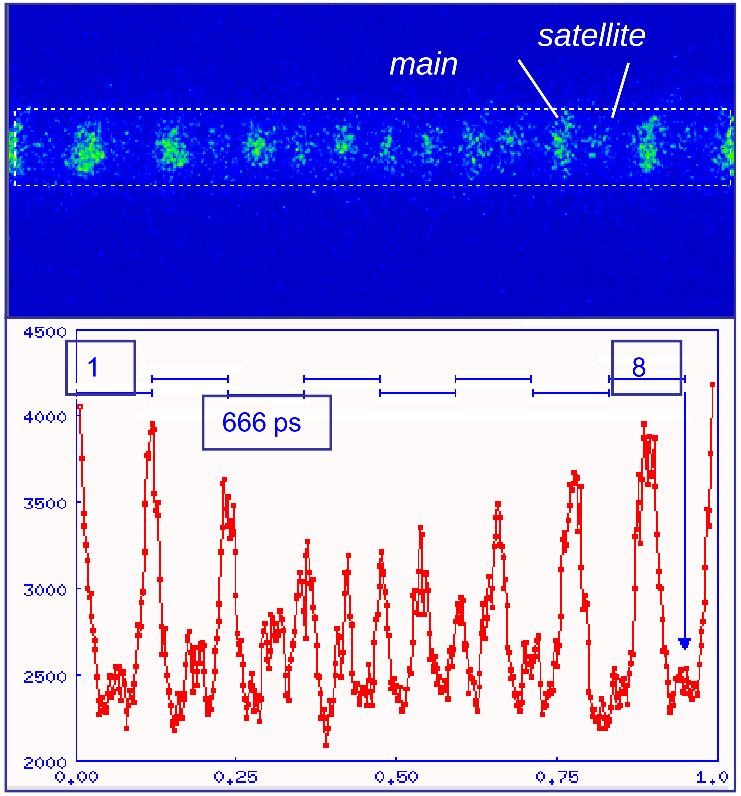
Sub-harmonic bunching system

Fast phase switch from SHB system (CTF3)



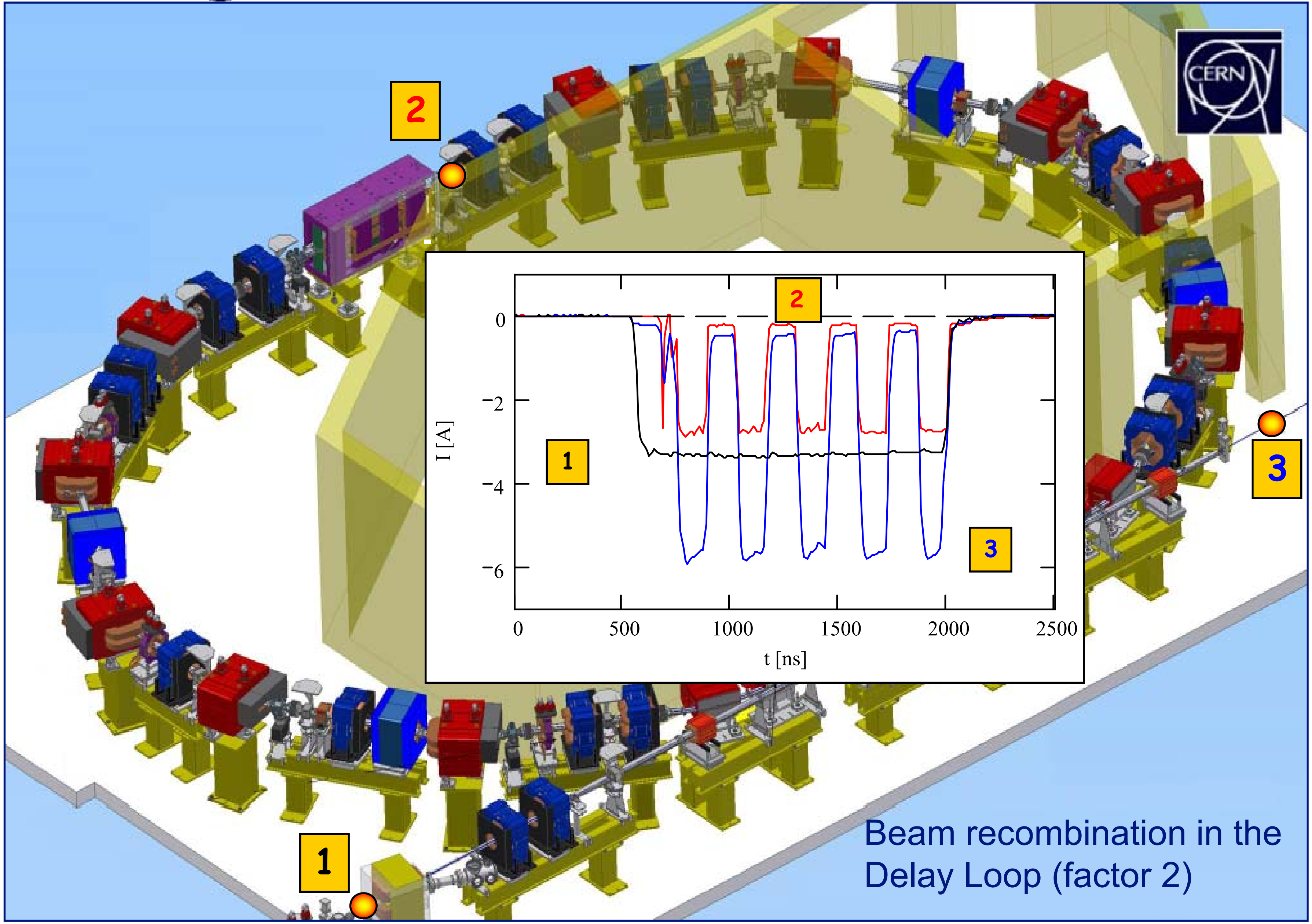
3 TW Sub-harmonic bunchers, each fed by a wide-band TWT

Streak camera – 500 ps/mm



8.5 · 666 ps = 5.7 ns

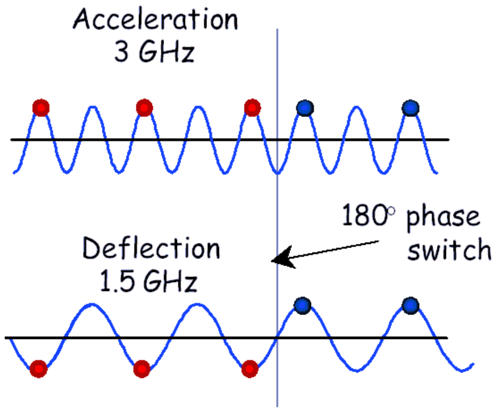
Delay Loop @ CTF3



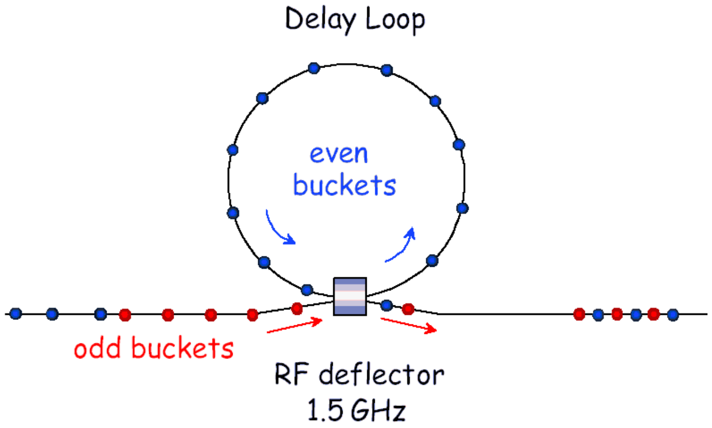
Beam recombination in the Delay Loop (factor 2)

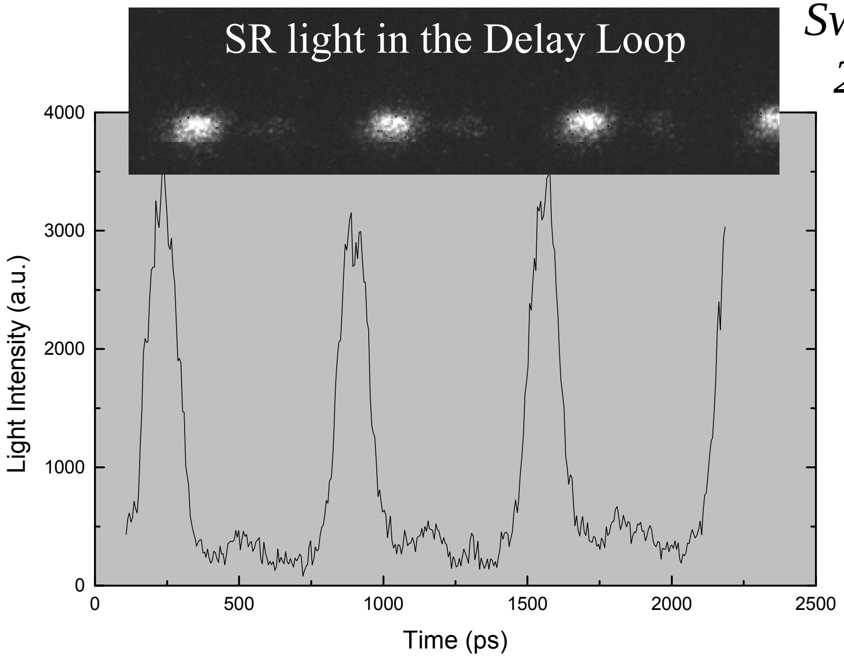
CTF3 bunch train combination

Phase coding in the sub-harmonic bunching system

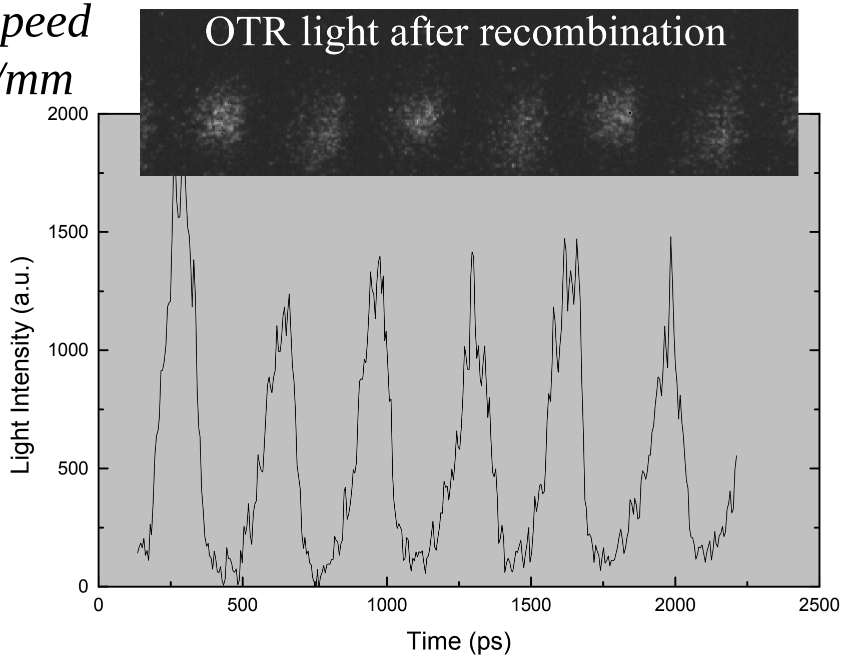


Bunch frequency multiplication in delay loop





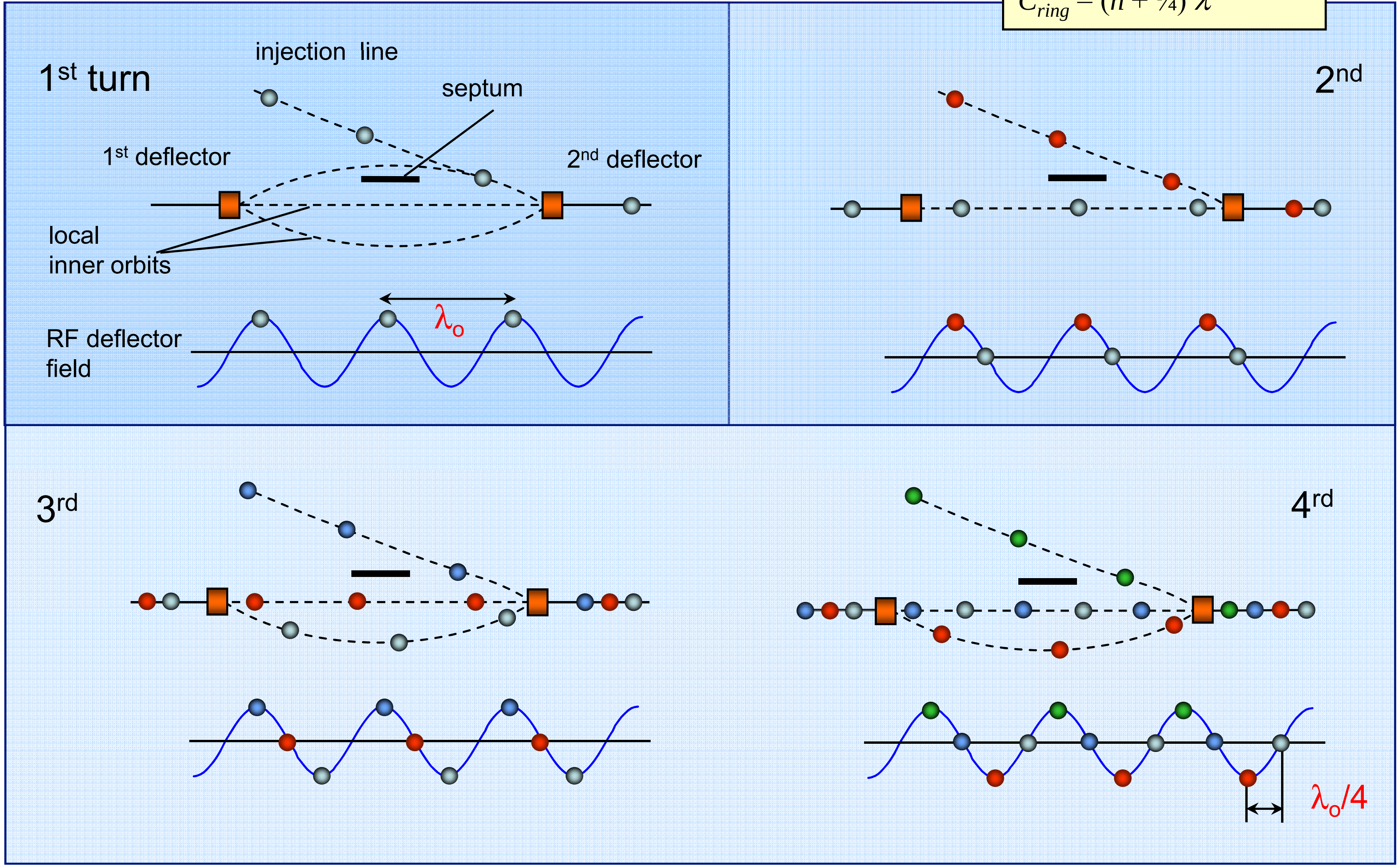
Sweep speed
250ps/mm



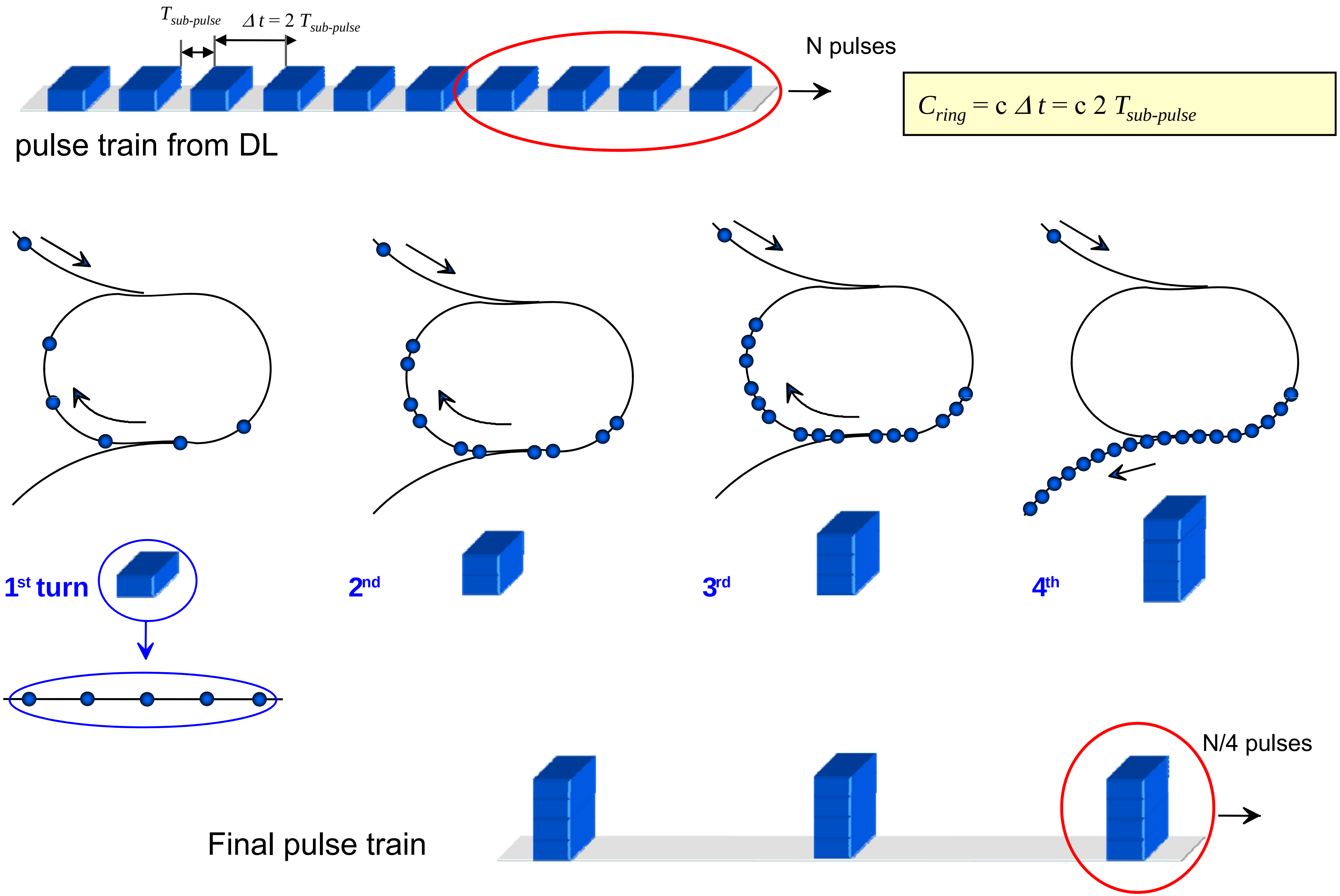
Frequency multiplication - Combiner Ring

RF injection in combiner ring (factor 4 for simplicity)

$$C_{ring} = (n + \tfrac{1}{4})\,\lambda$$

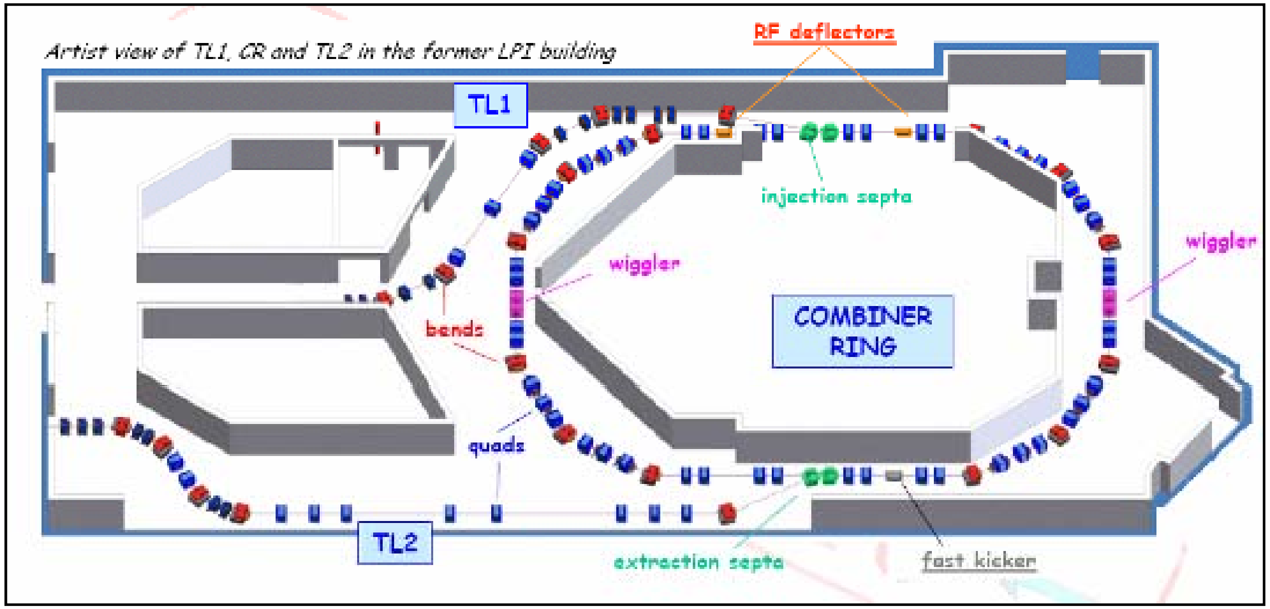


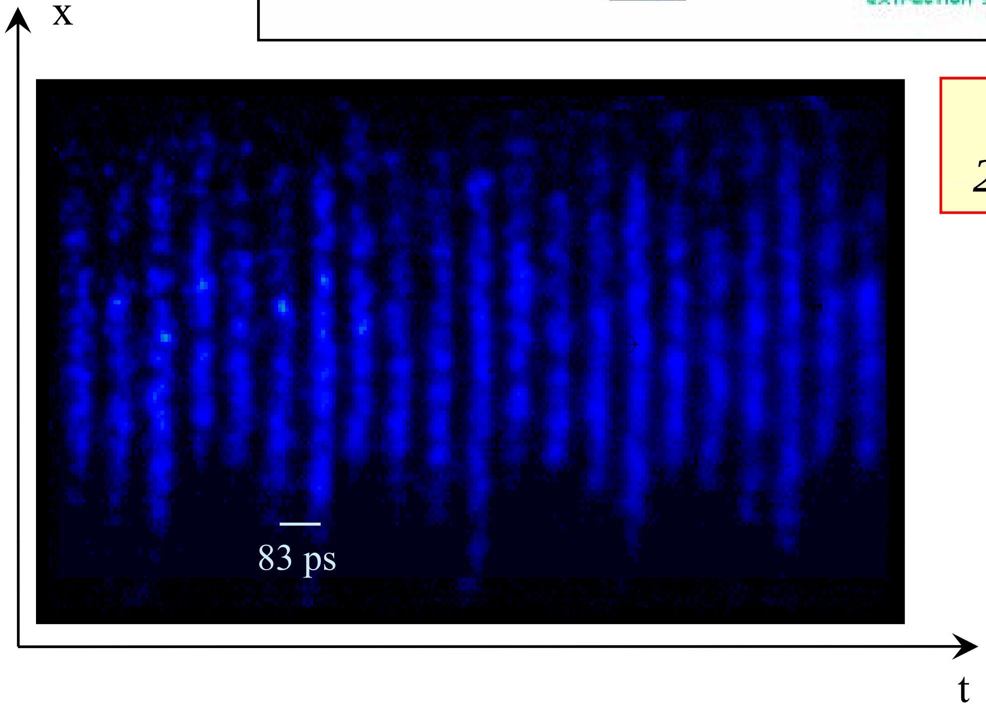
Frequency multiplication - Combiner Ring



$$C_{ring} = c\ \Delta t = c\ 2\ T_{sub\text{-}pulse}$$

Combiner ring bunch manipulation



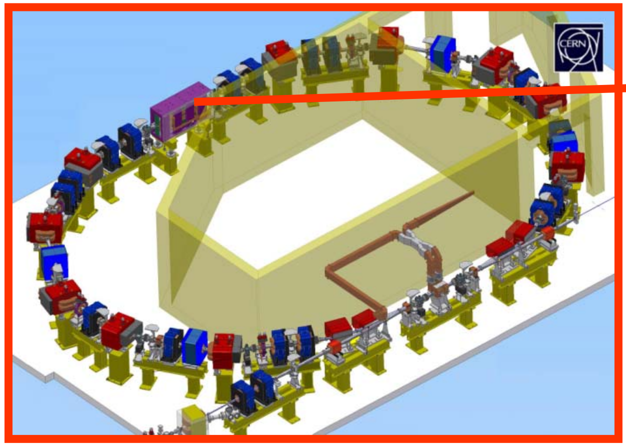


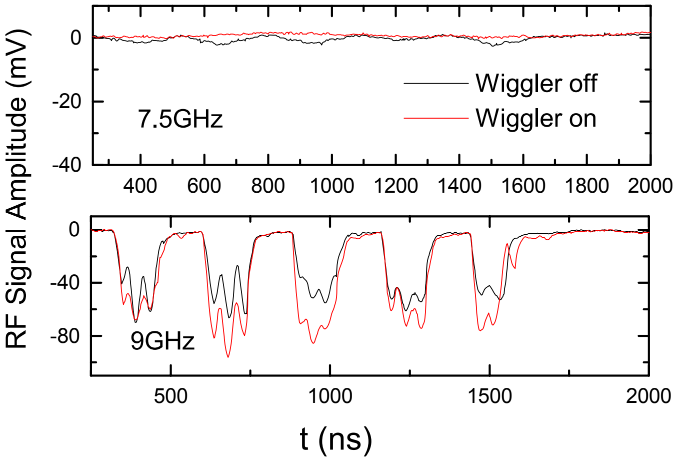
Bunch combination (factor 4)
2003 CTF3 Preliminary Phase results

Bunch train combination

T. Lefevre

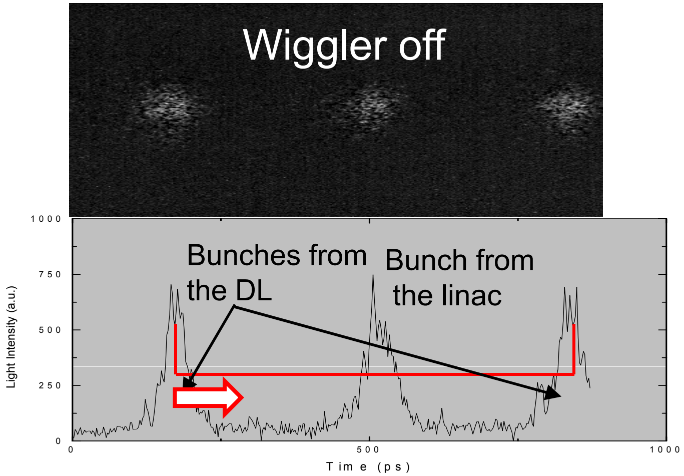
‘ Adjust the delay loop length with a magnetic wiggler’



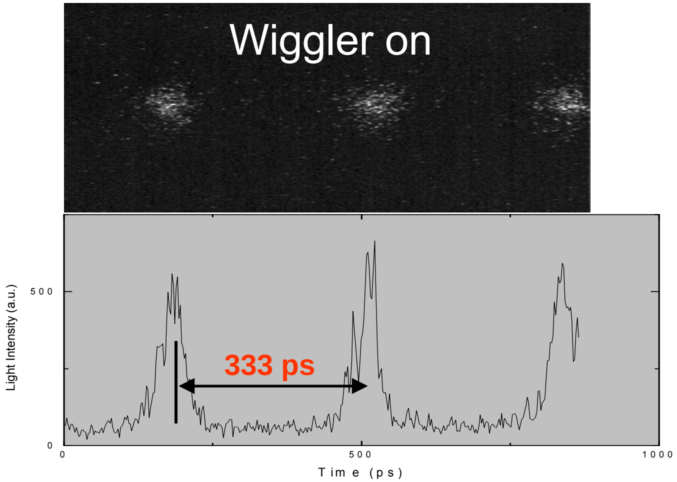


Better RF combination
- 7.5GHz ↘
- 9GHz ↗

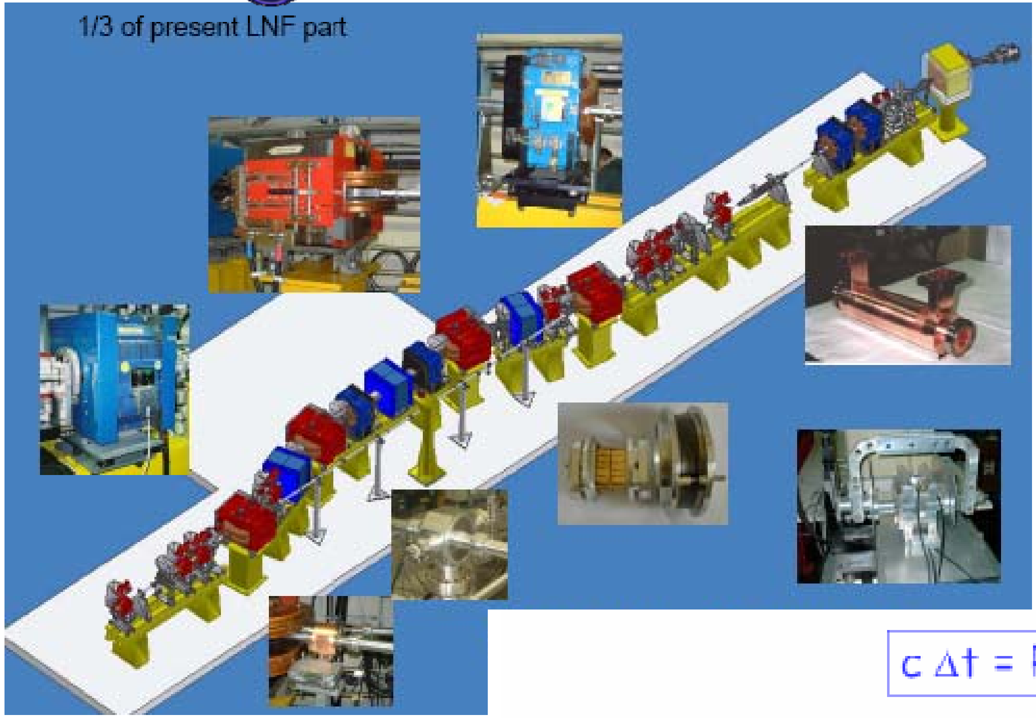
OTR light and sweep speed 100ps/mm



Bunches from the DL later by 12ps (3.6mm)



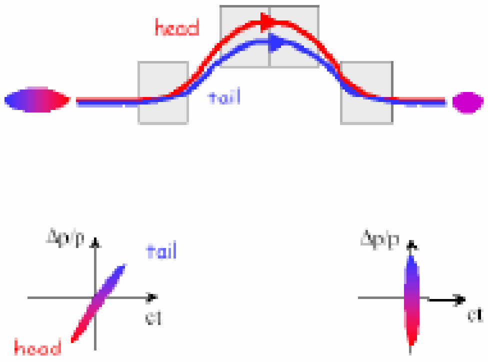
Stretching in the Frascati Chicane



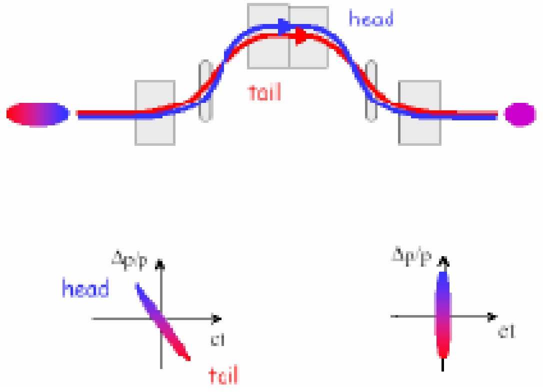
$$c\,\Delta t = R_{56}\,\Delta p/p$$

$$R_{56} = \int \frac{D}{\rho}\, ds$$

$R_{56} > 0$

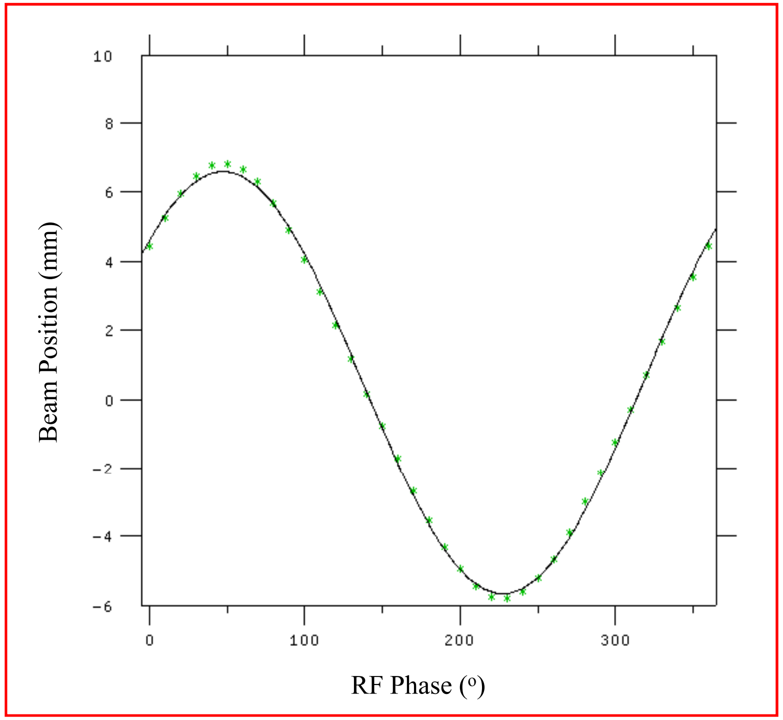


$R_{56} < 0$



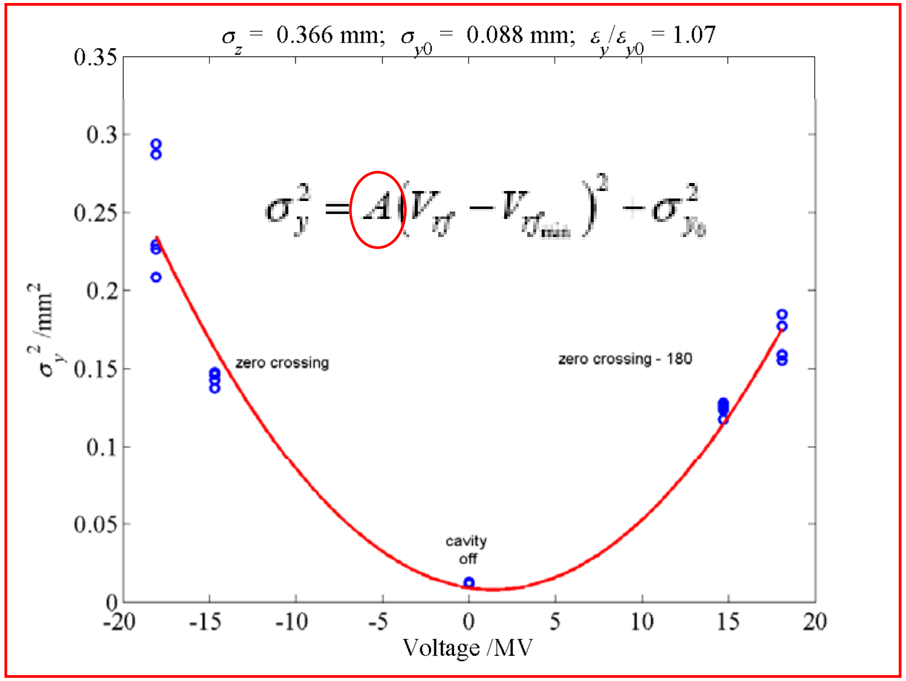
Bunch length monitoring

- Calibration of RF Deflector -



Use a Beam Position Monitor close to the Profile monitor to calibrate the deflection angle

R34 = transfer Matrix element from cavity to the BPM

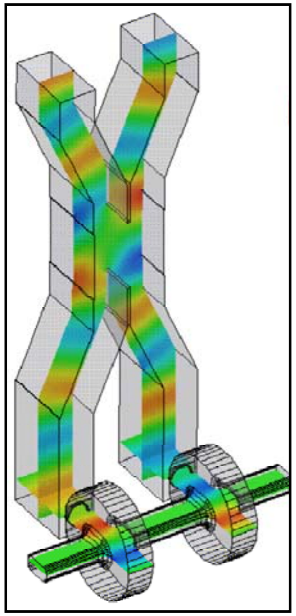


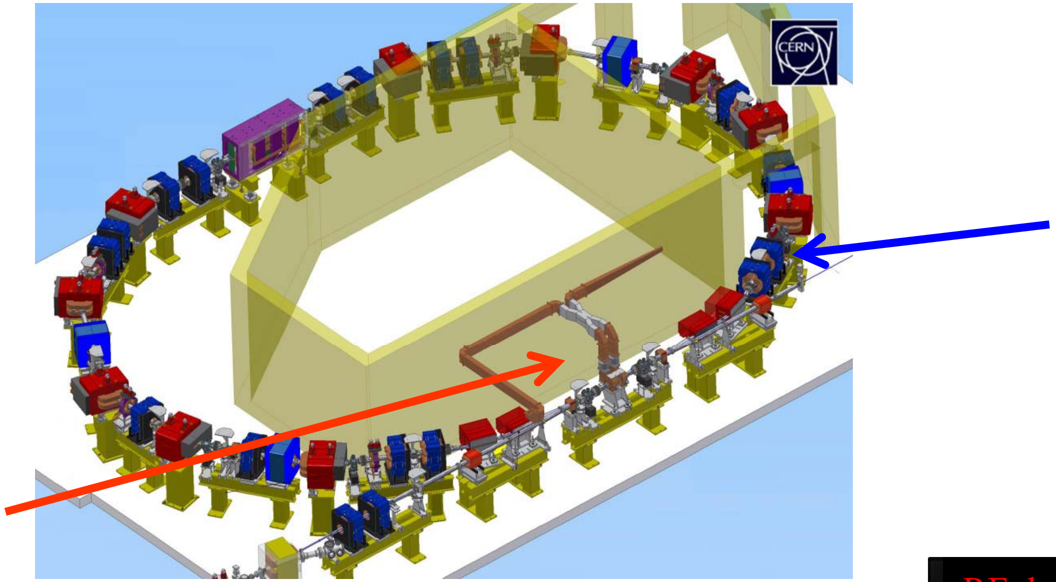
Make a power scan at zero crossing and (zero crossing – 180°) to check if there is no perturbation from linac wakefields

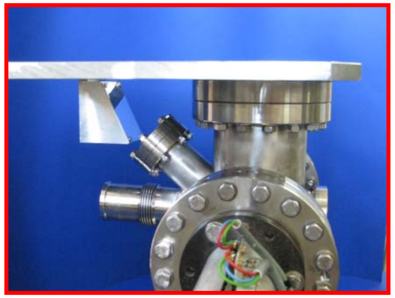
$$\boxed{\sigma_z = A^{1/2} \frac{E_0 \lambda_{rf}}{R_{34} 2\pi}}$$

Bunch length monitoring

- Bunch Length Measurement with the 1.5GHz RF Deflector of the Delay Loop -

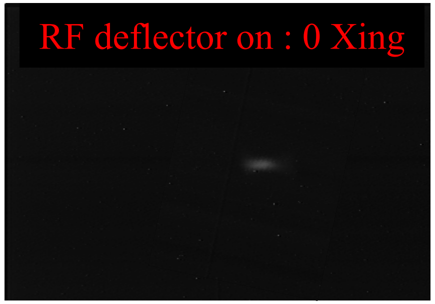






OTR screen

- Maximum power of 20MW
- 5degrees @1.5GHz = 9.25ps (4mm)



With this setting, the resolution is better than 1ps
More tests must be done to check where the limits are

$\sigma_{noRF} = 0.35mm$
$\sigma_{0Xing} = 2.9mm\ (6.7ps)$

Beam Position monitor

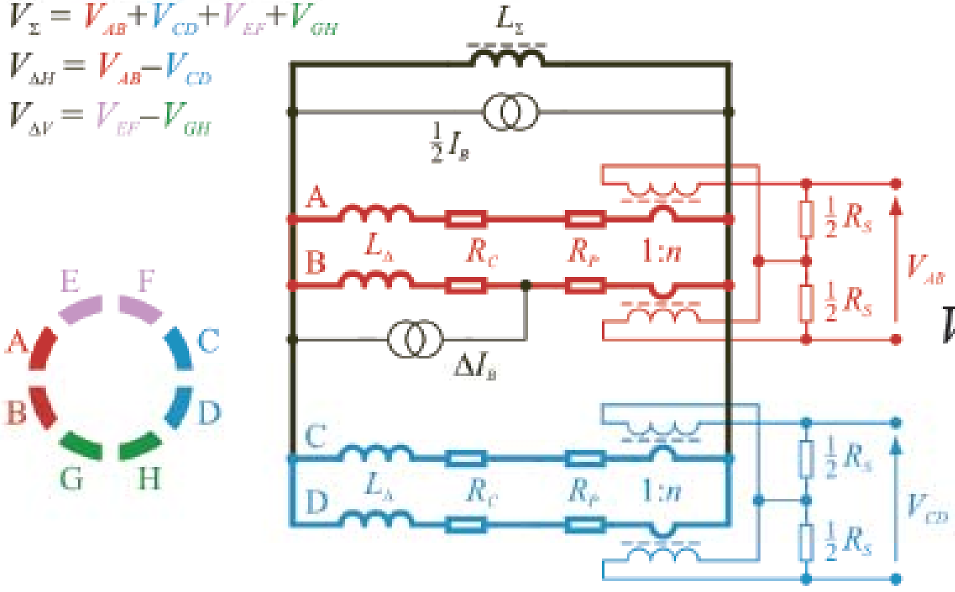
T. Lefevre

Inductive Pick-up @ CTF3

$V_\Sigma = V_{AB} + V_{CD} + V_{EF} + V_{GH}$

$V_{\Delta H} = V_{AB} - V_{CD}$

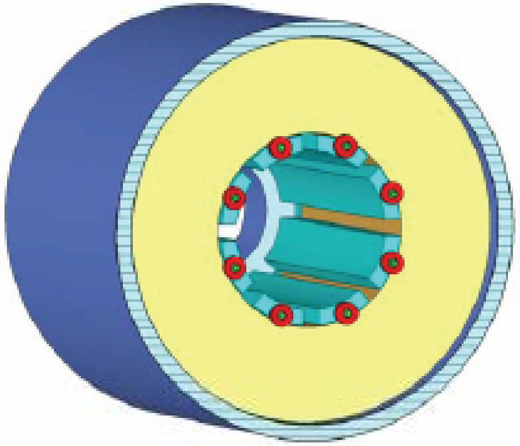
$V_{\Delta V} = V_{EF} - V_{GH}$



$$R_P = \frac{R_S}{2n^2}$$

$$V_{Out} = \frac{I_{Beam} * R_{Load}}{n}$$

Inductive Pick-up @ CTF3



Dipole mode:

$$f_{Low-Delta} = \frac{R_s}{n^2 \cdot 2 \cdot \pi \cdot L_{Electrodes}}$$

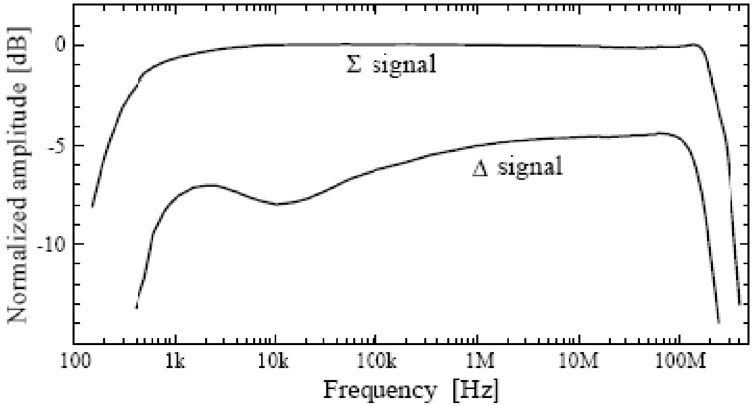
- Measure the beam image current on the beam pipe using 8 electrodes
- Electrodes are combined in pairs so that each transformer sees half of the load
- Frequency low cut-offs are limited by connection parasitic resistances and primary electrode inductance

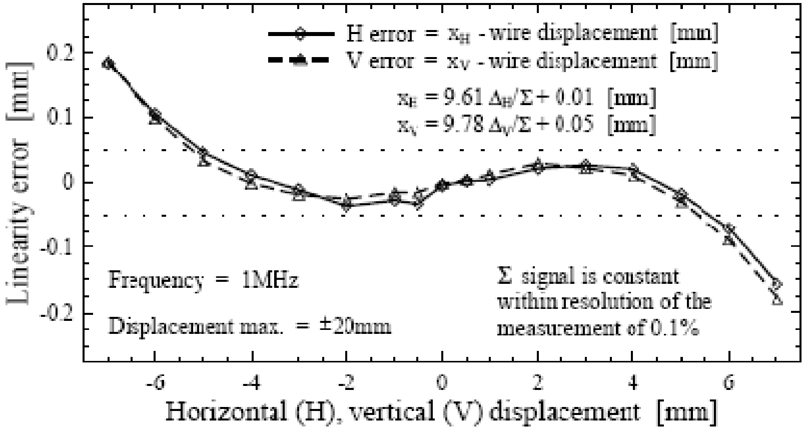
Design by Marek Gasior : CERN-AB-2003-063

Beam Position monitor

Inductive Pick-up @ CTF3

Transverse sensitivity	Δ=Σ @ ~10mm
Resolution	10um / 50um
Relative precision (±5mm)	1%
Longitudinal coupling impedance	0.1 / 1 ohm
Resolution	6mA / 3mA
Absolute precision [I]	~ 1%
Low frequency cut off	1kHz
High frequency cut off	200MHz
Calibration	Yes
ID / Length	40mm / 168mm
Number of feedthroughs	0
Flange types	DN40CF
Max. bake-out temperature	130 °C

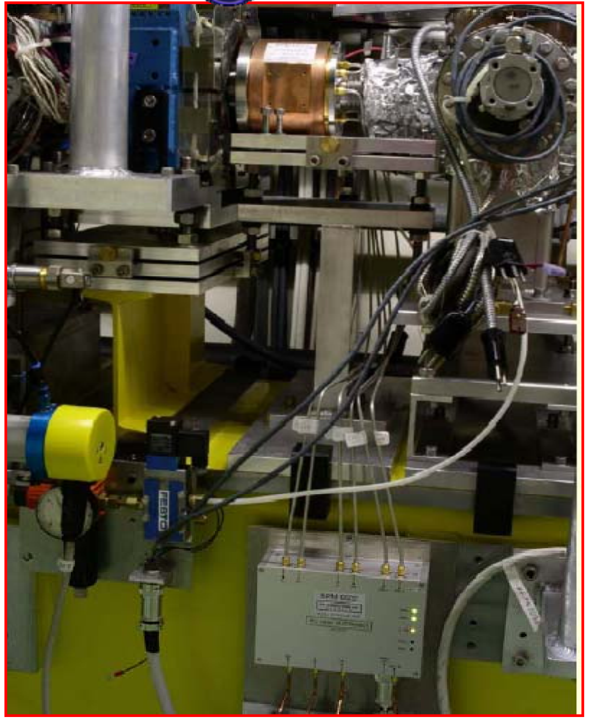




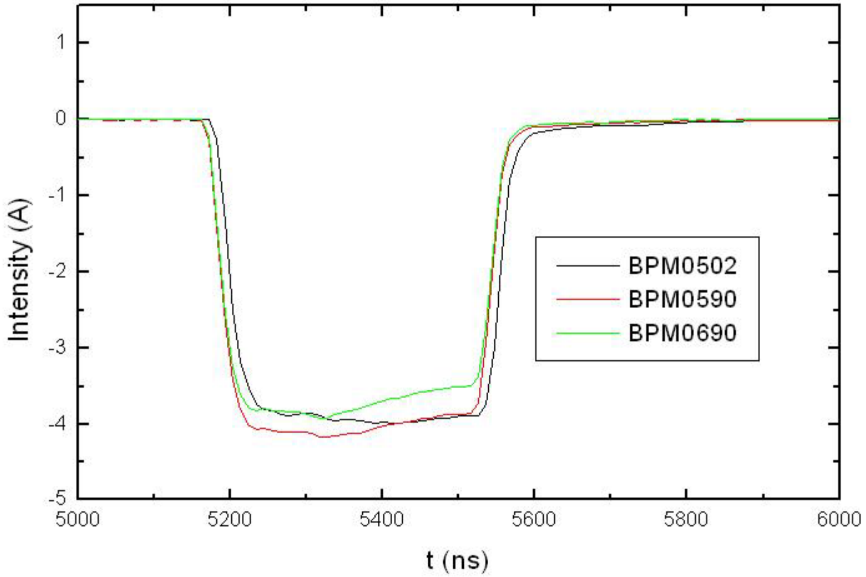
- Resolution already $\Delta I/I = 10^{-3}$

- For CLIC Drive Beam (100µs pulse duration) need to lower the low frequency cut off

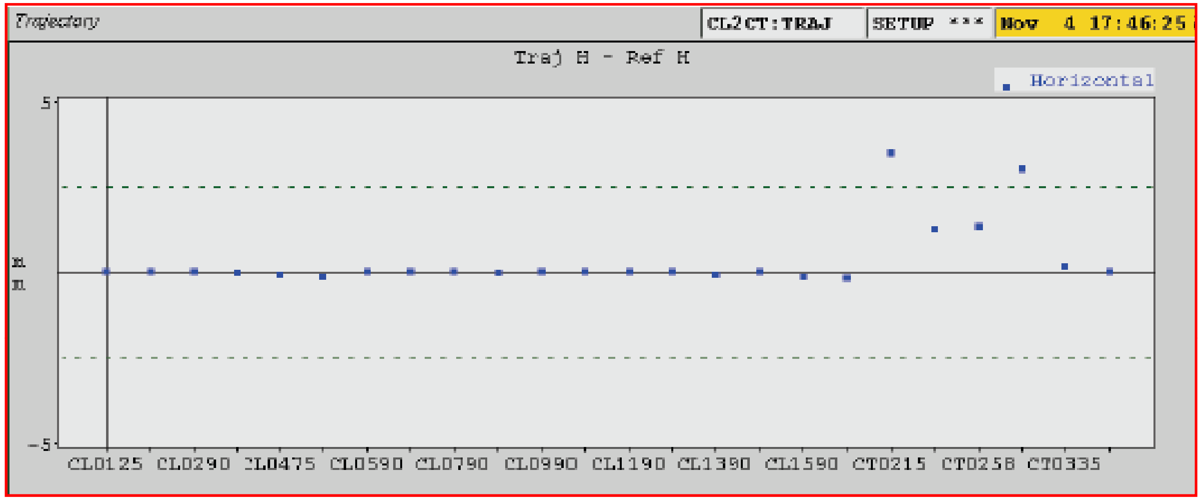
Beam Position monitor



Inductive Pick-up @ CTF3



>15 BPMs already installed in CTF3



High precision position measurement

Goal

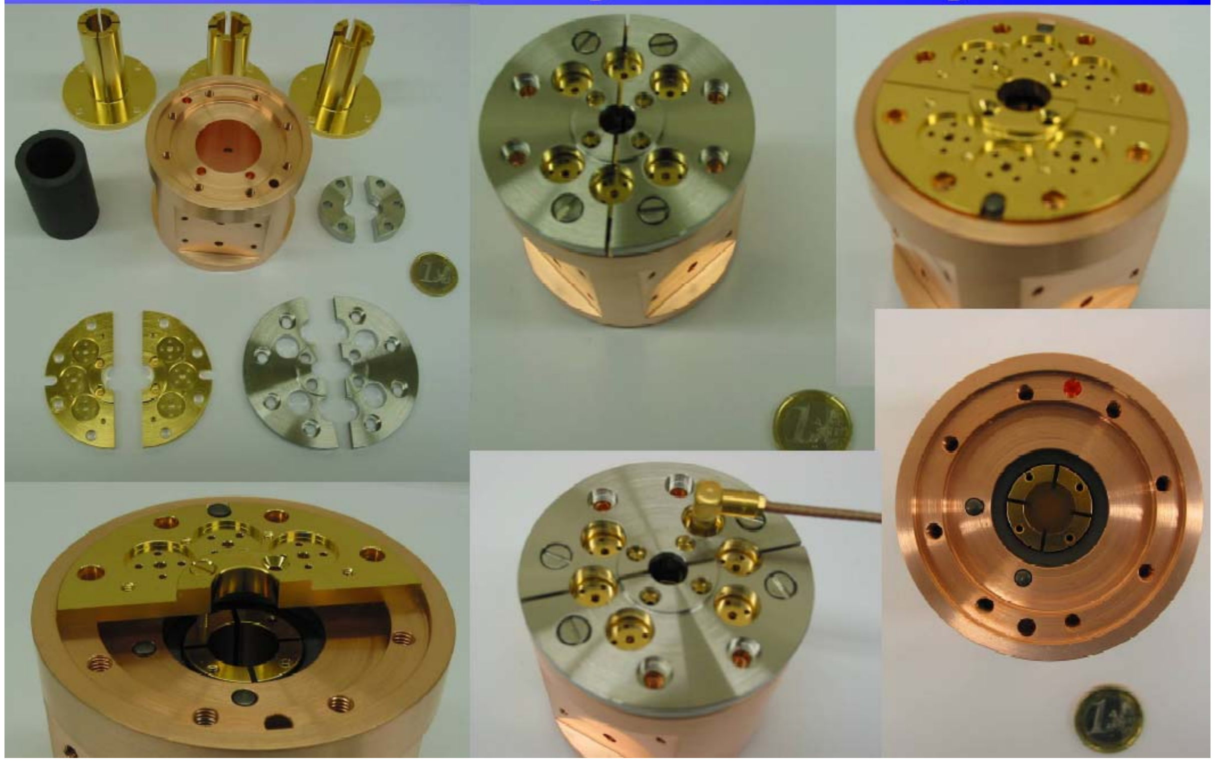
L Soby – I. Podadera

Diagnostics
Beam position

Measurement of the beam position and current in the main linac (attached to the quadrupoles) of the next generation colliders (ILC and CLIC) with the specifications:

- Resolution:100 nm.
- Aperture: 4-6 mm.
- Absolute precision: 10 μm.
- Rise time: 15 ns.

Preliminary assembly



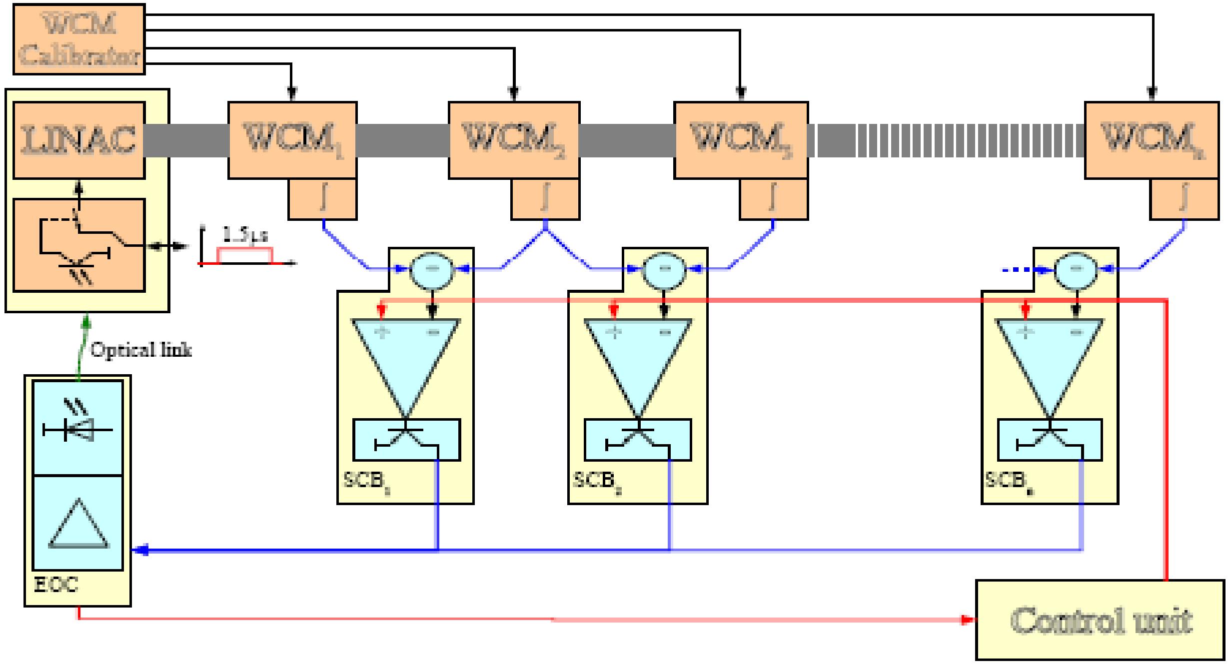
Test in CTF3 late this year

Manipulating high beam charge

Machine protection system @ CTF3

- Compare signals from consecutive Wall Current Monitors
- If losses is detected, the electron gun is switched off
- Time response dominated by cable length (>311ns)

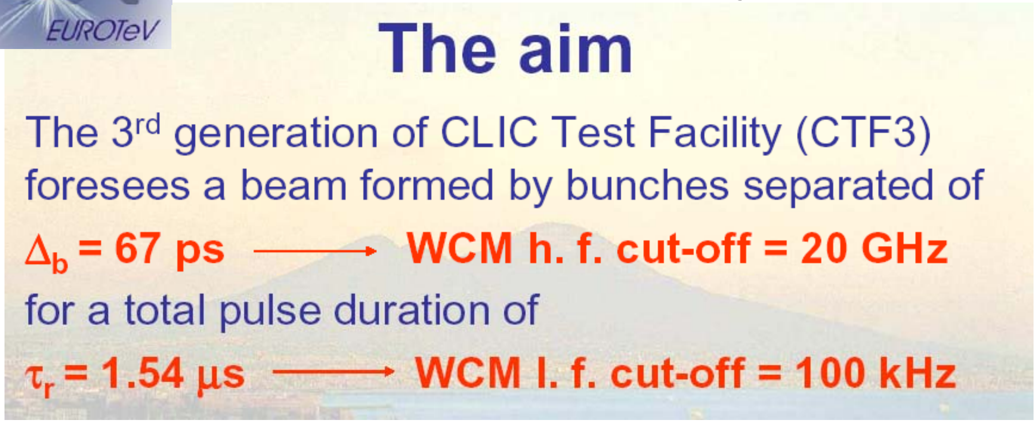
D. Belohrad, Dipac Conference,
Lyon, p.255, (2005)
P. Odier, CERN-AB-2003-069



For CLIC DB the system will have to rely on
Beam Loss Monitors

High Bandwidth Wall Current Monitor

L Soby – A. D'Elia



The aim

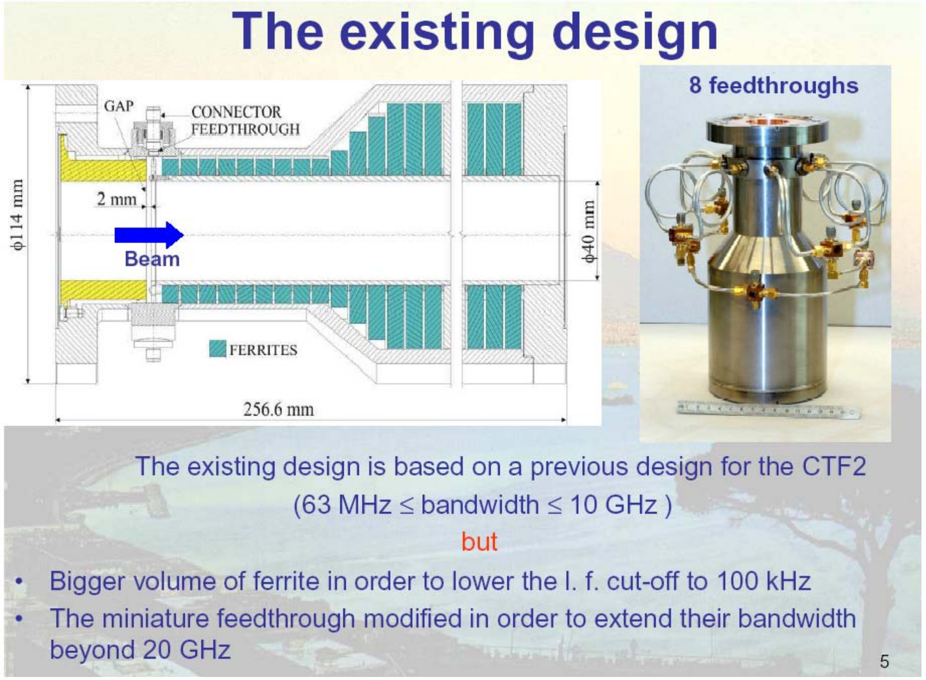
The 3rd generation of CLIC Test Facility (CTF3) foresees a beam formed by bunches separated of

Δ_b = 67 ps ⟶ WCM h. f. cut-off = 20 GHz

for a total pulse duration of

τ_r = 1.54 μs ⟶ WCM l. f. cut-off = 100 kHz

Diagnostics
Wall Current Monitor



The existing design

The existing design is based on a previous design for the CTF2 (63 MHz ≤ bandwidth ≤ 10 GHz)

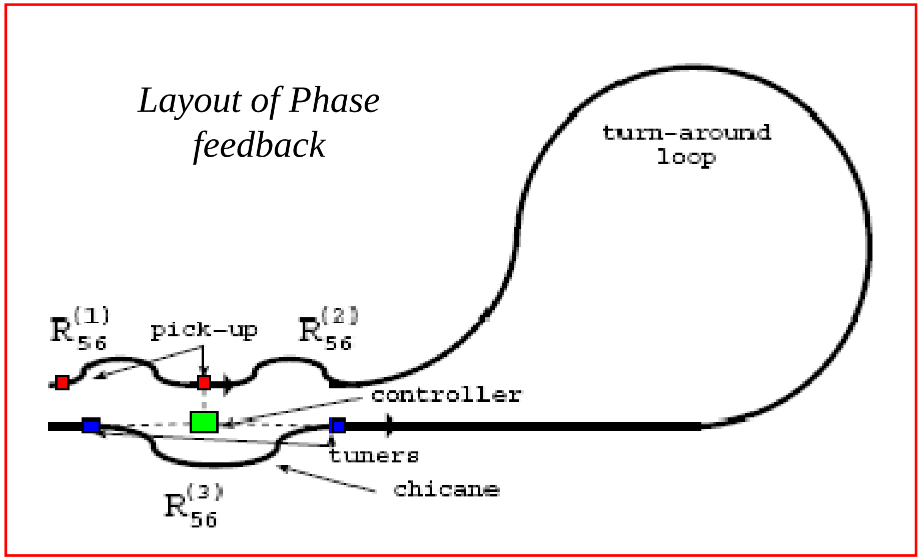
but

- Bigger volume of ferrite in order to lower the l. f. cut-off to 100 kHz
- The miniature feedthrough modified in order to extend their bandwidth beyond 20 GHz

Beam Phase monitor

Drive Beam Longitudinal stability

- Use RF pick-up (30GHz) to measure the Drive Beam phase at 2 locations (≠ longitudinal dispersion)
- Use tuners to correct the phase error


Layout of Phase feedback

Possible candidates for Tuners
- RF deflectors in a dispersive and anisochronous area
- Accelerating structures and chicane

Controller

- Single shot device
- +/- 50MHz bandwidth (react fast)
- 10fs resolution for phase measurement (0.1° @ 30GHz)
- +/- 5degrees range
- 6dB amplitude range

Beam Phase monitor

Main/Drive Beam Phase stability

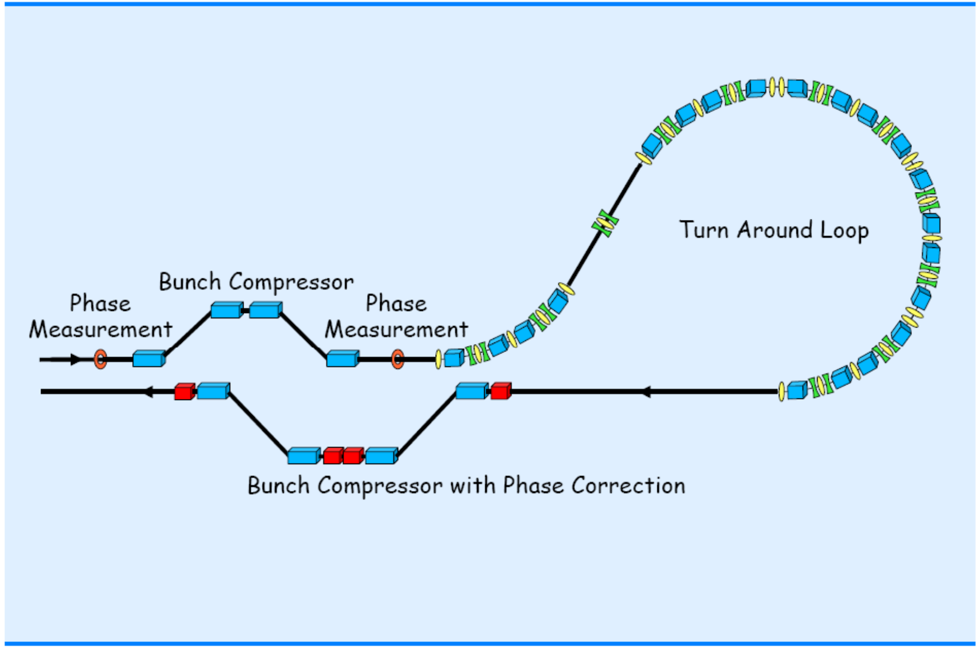
The Impact of Longitudinal Drive Beam Jitter on the CLIC Luminosity

CLIC Note 598

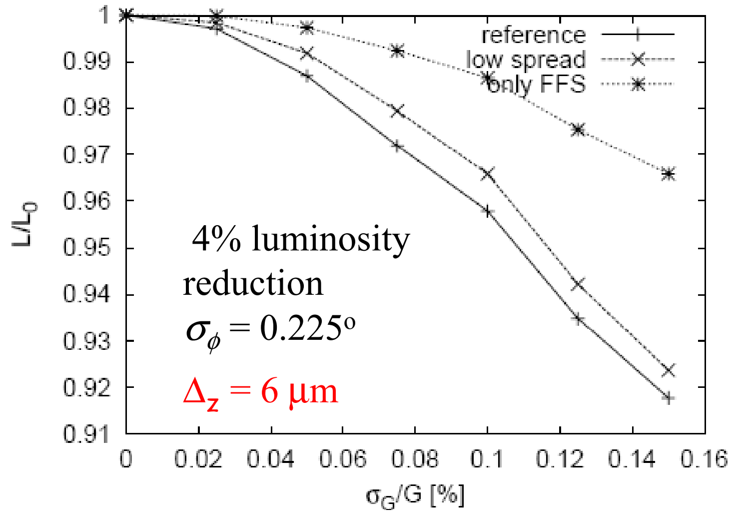
D. Schulte, E. J. N. Wilson, F. Zimmermann

F. Stulle -PSI

Beam Line Overview



Frank Stulle, CLIC Seminar, 06.10.2006

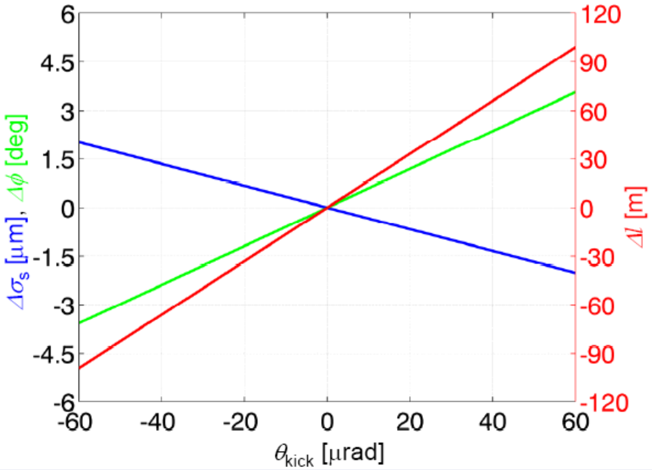


4% luminosity reduction

$\sigma_\phi = 0.225^o$

$\Delta_z = 6\ \mu m$

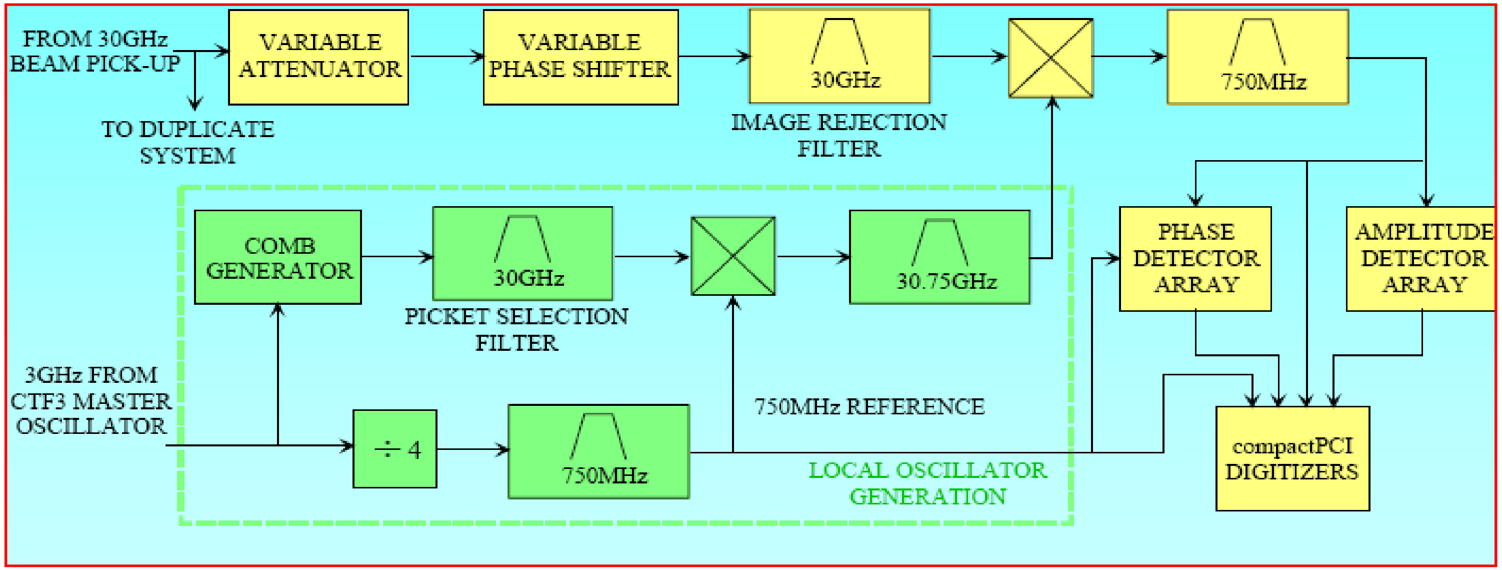
Figure 1: The relative luminosity as a function of a coherent gradient error in the main linac.



Beam Phase monitor

Femtosecond Phase detection

- Mixing the 30GHz signal from the beam down to 750MHz
- Measure the 750MHz signal Phase and Amplitude



FROM 30GHz BEAM PICK-UP

VARIABLE ATTENUATOR

VARIABLE PHASE SHIFTER

30GHz

IMAGE REJECTION FILTER

750MHz

TO DUPLICATE SYSTEM

COMB GENERATOR

30GHz

PICKET SELECTION FILTER

30.75GHz

PHASE DETECTOR ARRAY

AMPLITUDE DETECTOR ARRAY

3GHz FROM CTF3 MASTER OSCILLATOR

÷ 4

750MHz

750MHz REFERENCE

LOCAL OSCILLATOR GENERATION

compactPCI DIGITIZERS

- Goal to find a phase detector@750MHz with noise below 0.03°
- Phase detector can be multipliers or mixers

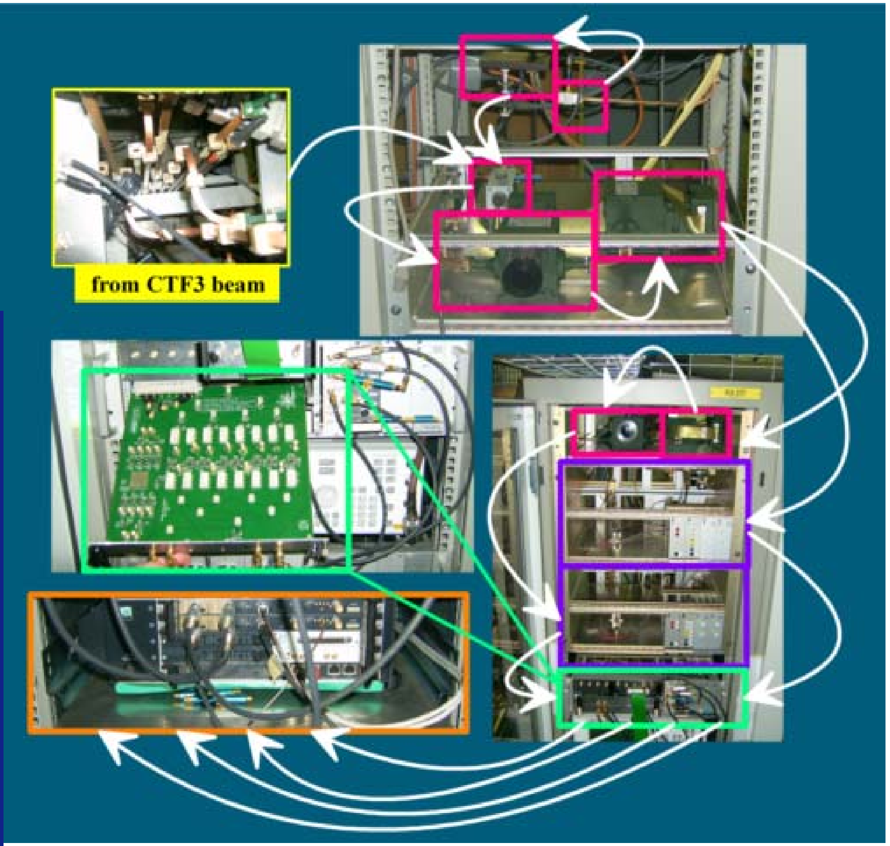
By J. Sladen and A. Andersson

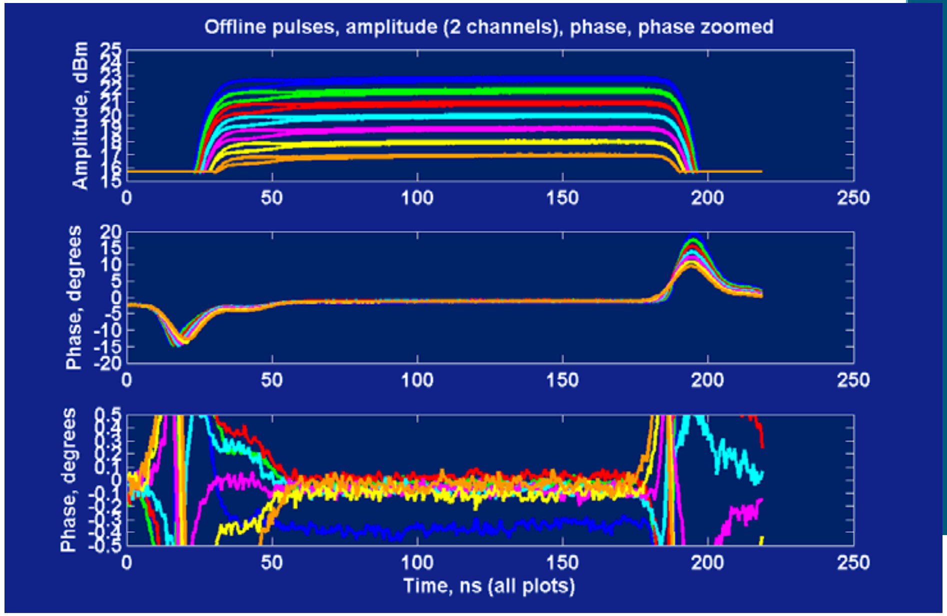
Beam Phase monitor

J. Sladen, A. Andersson

Diagnostics
Phase measurement

- Phase accuracy: 0.1°
- Amplitude range: ~6dB
- Bandwidth: 50MHz, system investigated up to 250MHz





CLic Experimental Areas (CLEX)