CTF3 Instrumentation

T. Lefevre, CERN AB/BI

- The CLIC Test Facility 3
- Essential instruments
- CTF3 specific instrumentation
  - Time resolved spectrometry
  - Longitudinal beam diagnostics
- CLIC related development
  - Nanometer BPM
  - Beam Halo monitor
  - Beam Phase monitor

CLIC key issues

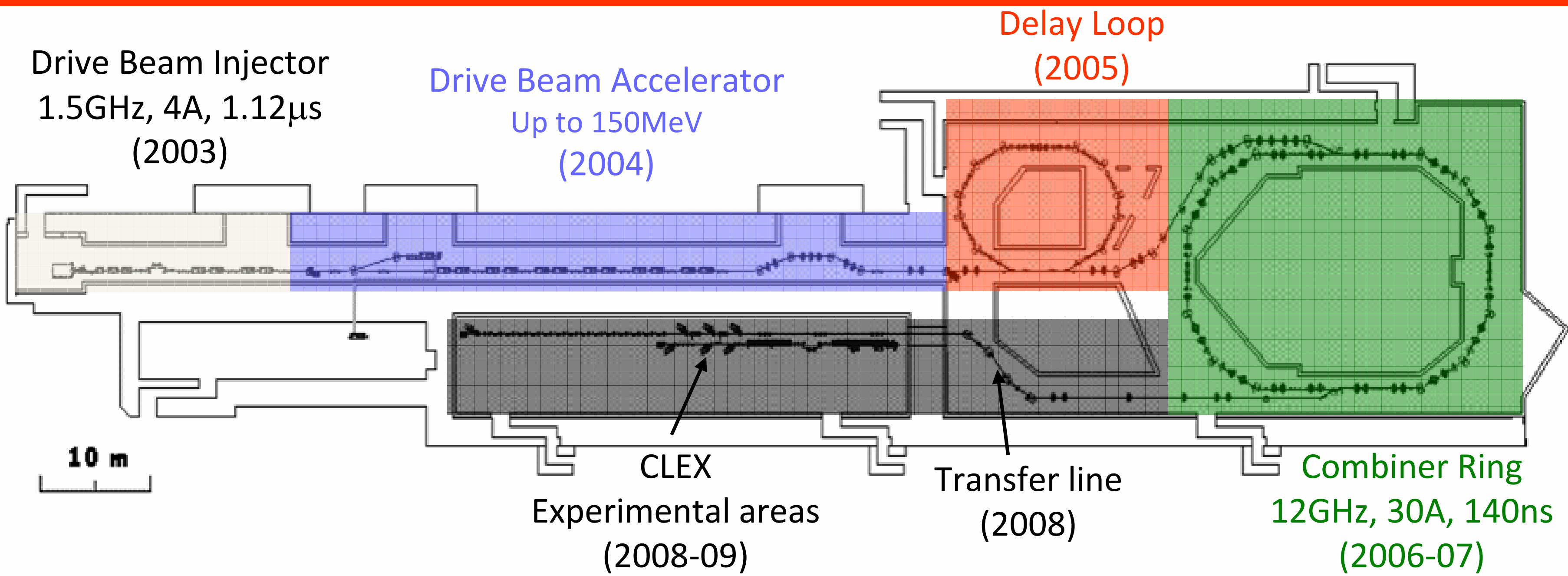
The *CLIC Technology-related* key issues as pointed out by ILC-TRC 2003

Covered by CTF3

Critical Key Issues

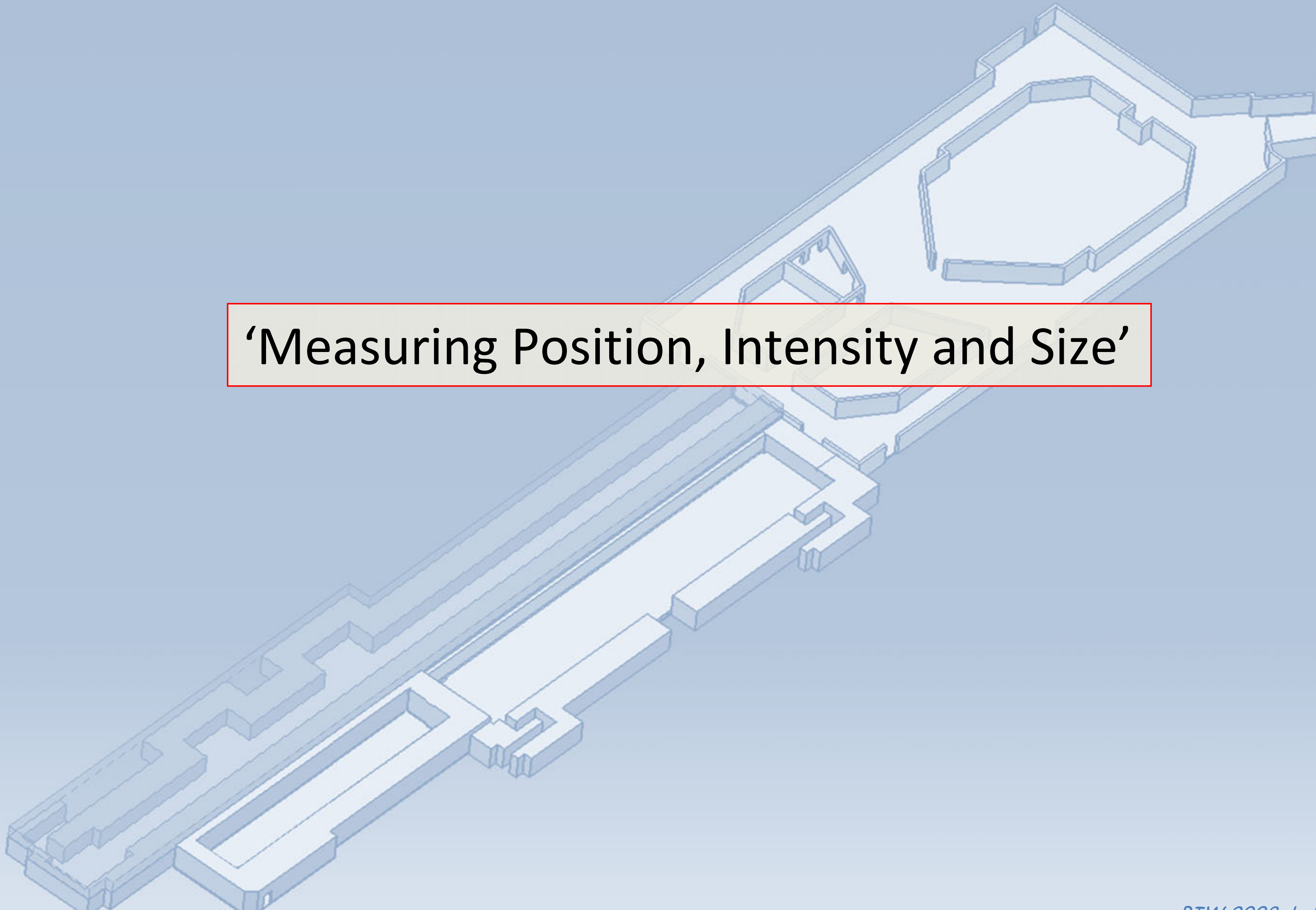
- Test of damped accelerating structure at design gradient (100MV/m) and pulse length (150ns)
- CLIC RF power source : based on the Two-beam acceleration scheme
  - Validation of Drive beam generation scheme (high frequency 12GHz, high current 100A) with fully loaded linac operation
  - Design and test of damped ON/OFF power extraction and transfer structure (PETS)
  - Validation of stability and losses of DB decelerator; Design of machine protection system
- Test of relevant linac sub-unit with beam : PETS/Drive Beam and Acc. Struct./Main Beam

CLIC Test Facility 3



23 institutes from 12 countries

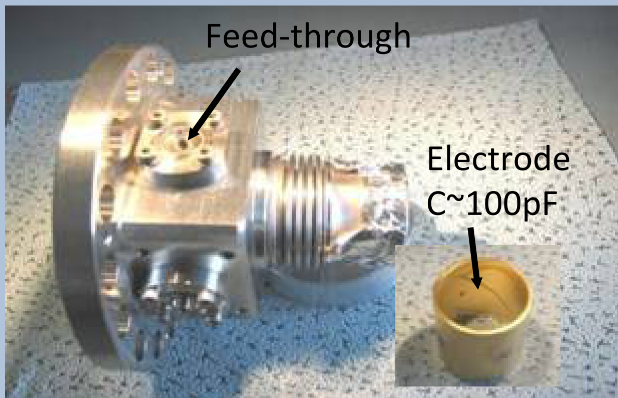
Essential Instruments



‘Measuring Position, Intensity and Size’

Position and Intensity monitors

Electrostatic Pick-up (BPE)

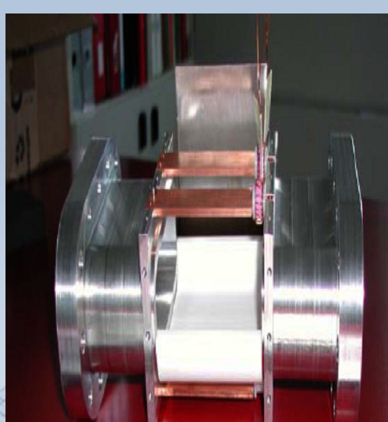


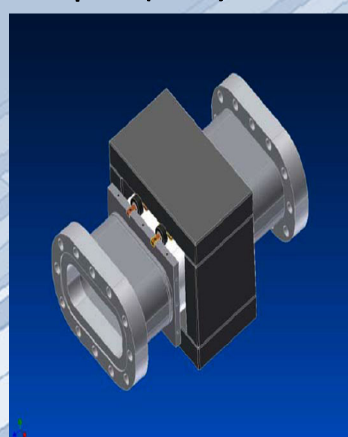
Developed by L. Søby, CERN

Inductive Pick-up's (BPM)

Developed by
M. Gasior, CERN

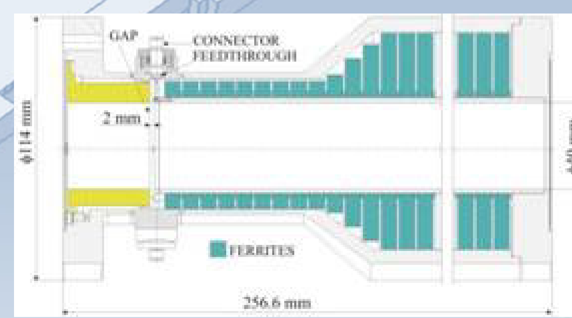
Inductive Pick-up's (BPI)

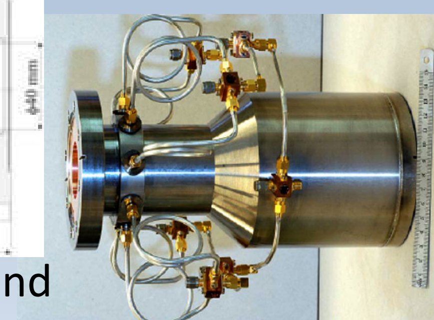




Developed by A. Stella, Frascati

Wall Current Monitor (WCM)





Developed by J. Durand and
P. Odier, CERN

Position and Intensity monitors

A total of 104 Monitors

	BPE	BPM	BPI
Transverse sensitivity, Δ= Σ [mm]	30	30	33 / 50
Resolution pos.	**0.1mm**	**0.1mm**	
Relative precision (3/4 half aperture)	0.2%	1%	1%
Longitudinal transfer impedance [Ω]	0.17 / 1.7	0.1 / 1	
Resolution current [mA]	12 / 1.2	10 / 3	
Low frequency cut off Δ / Σ [kHz]	**1 / 1**	**10 /0.15**	**~20 / 0.3**
High frequency cut off [MHz]	**200**	**200**	**200**
Calibration	Yes	Yes	Yes
ID / Length [mm]	46 / 130	40 / 168	90*39/240
Number of feed-throughs	4	0	0
Flange types	DN40CF	DN40CF	Racetrack
Max. bake-out temperature	130 °C	130 °C	130 °C

	WCM
Impedance	~5 ohms
Resolution	***
Absolute precision	**~ 1%**
Low freq. cut off	**10kHz**
High freq. cut off	**7GHz**
Calibration	No
Nb. of feed-throughs	8
Gap length	2mm
ID / Length	40 / 256.6mm
Flange types	DN63CF
Bake-out temp.	165 °C

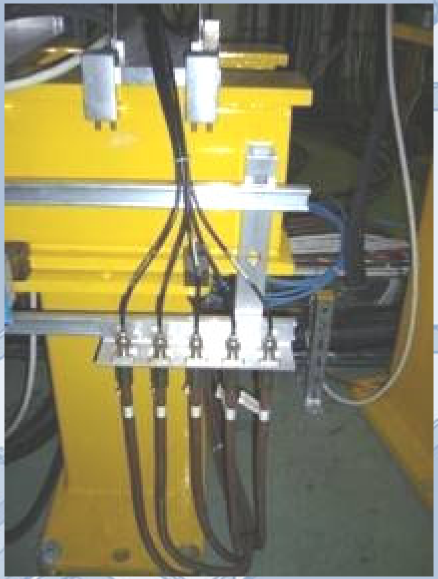
from march 2008
2 BPE's + 52 BPI's + 45 BPM's + 5 WCM's

Acquisition system

Linac and Combiner Ring

- Front-end electronics improve CMRR
- Δ and Σ connected to 100MS ADC's
- Calibration of position and intensity
- Distribution amplifier for the observation of analogue signals

Delay Loop

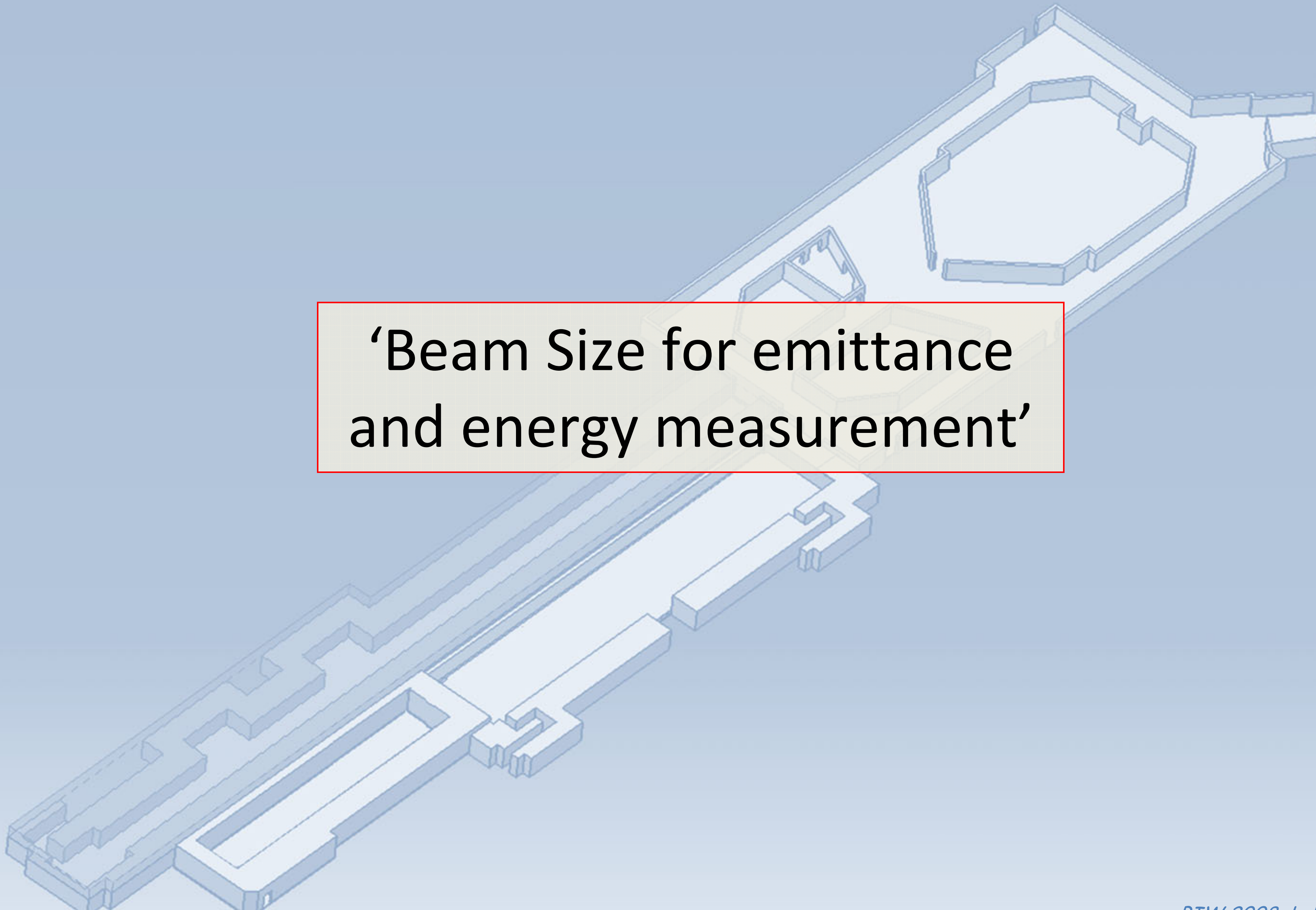


- No front-end electronics
- The four electrodes are via long cables directly connected to the 100MS ADC's
- Calibration of sum only.

2nd Transfer Line and CLEX

- Front-end electronics maintained
- Signals digitized (Developed by LAPP) in tunnel $\rightarrow$ Big reduction in cable costs
- No analogue signal observation .

Essential Instruments



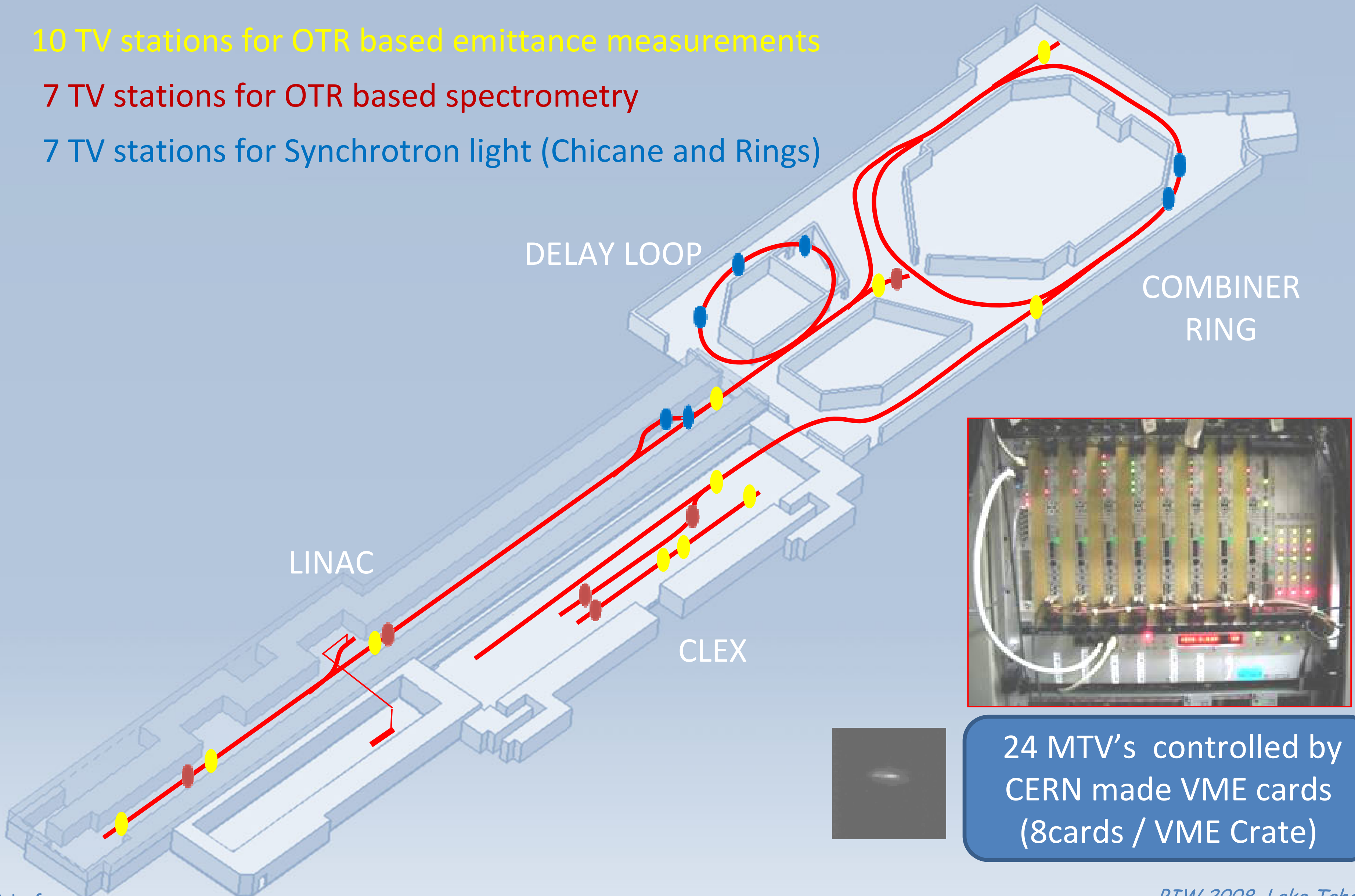
'Beam Size for emittance and energy measurement'

Profile monitors @ CTF3

10 TV stations for OTR based emittance measurements

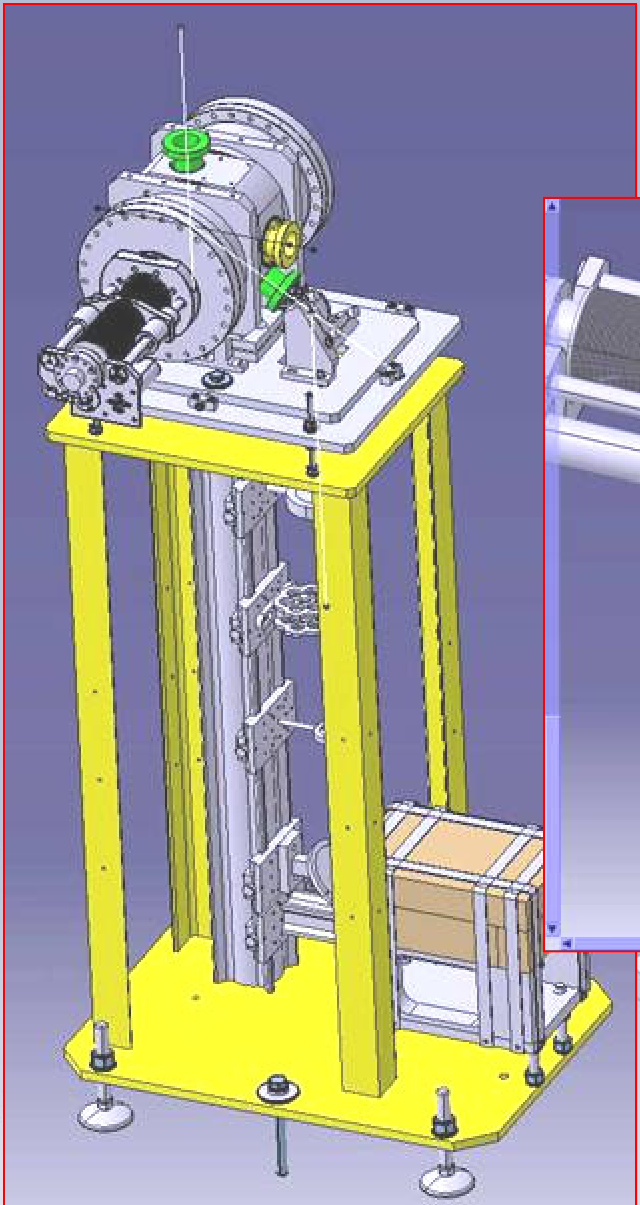
7 TV stations for OTR based spectrometry

7 TV stations for Synchrotron light (Chicane and Rings)

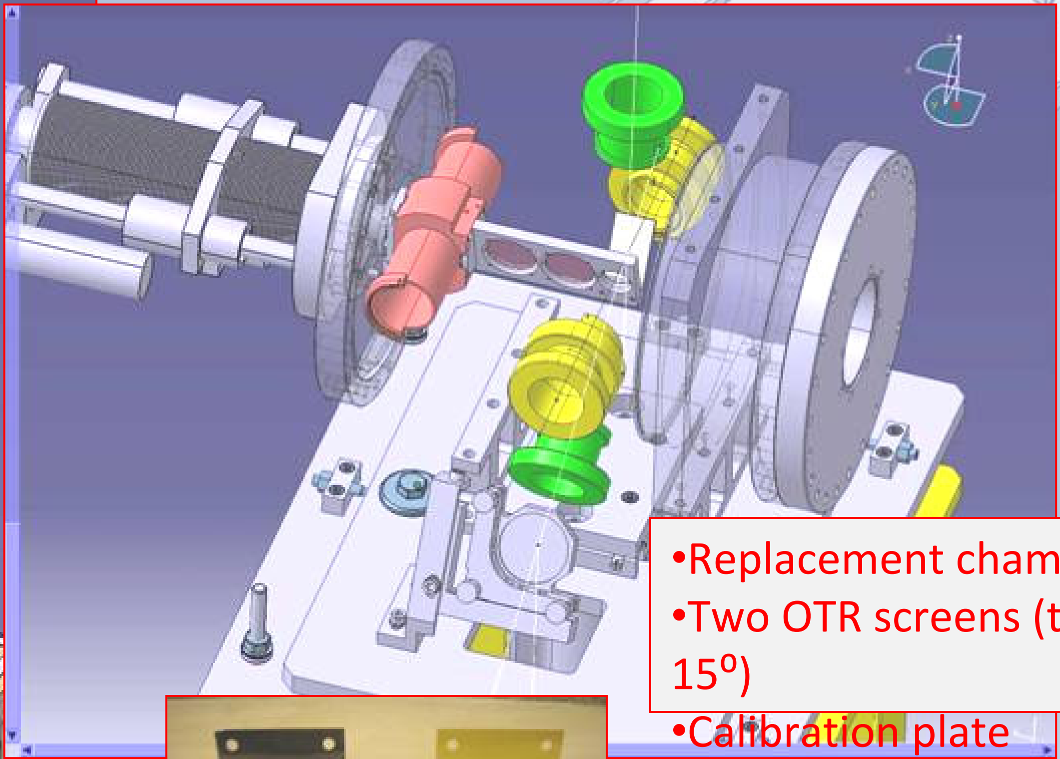


24 MTV's controlled by CERN made VME cards (8cards / VME Crate)

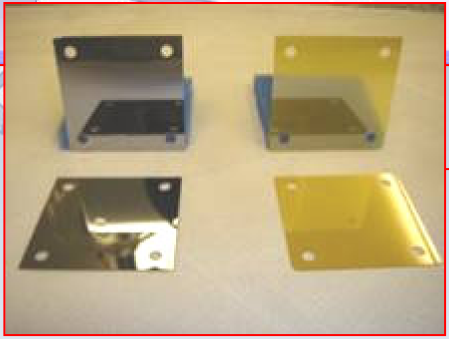
MTV for Emittance measurement



30mm diameter screen – 20-100μm spatial resolution

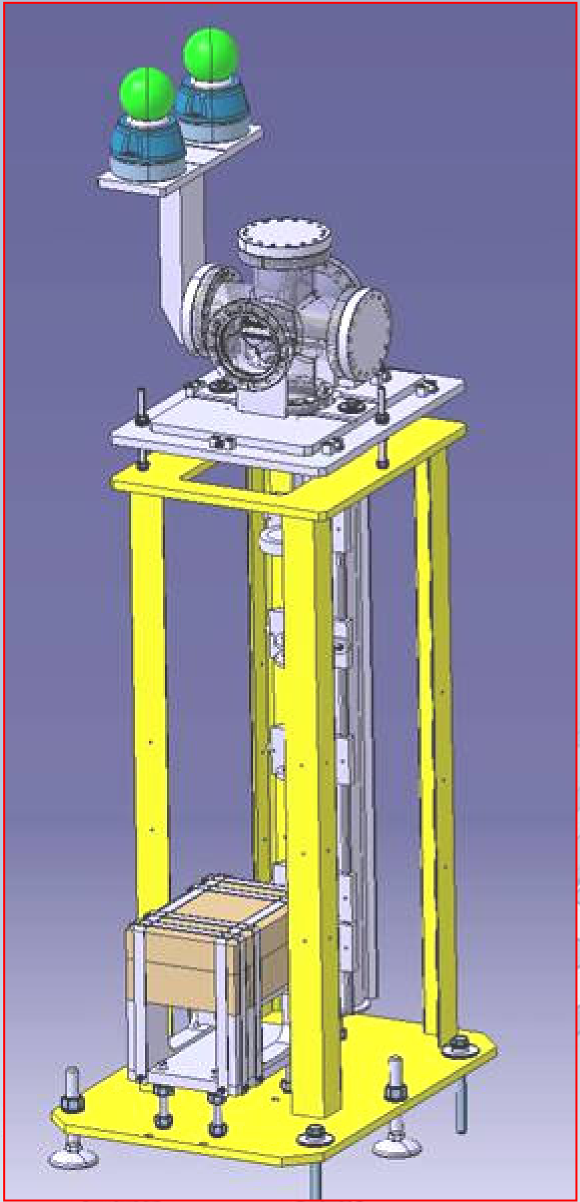


- Replacement chamber
- Two OTR screens (tilt angle 15^o)
- Calibration plate



200μm thick mirror polished Si and CVD SiC wafer

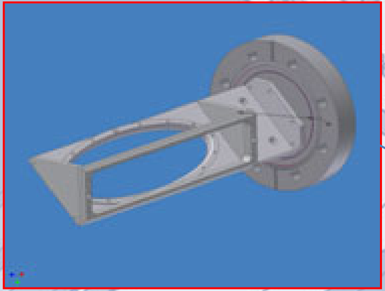
MTV for Spectrometry



Use a bending magnet to create energy dispersion and measure the beam position and size on a screen

120x50mm screen – 200µm spatial resolution

Fixed screen position with tilt angle of 45 ^{0}



Implement a carbon foil to suppress the SR light emitted in the bend

Parabolic OTR screen for better optical performances

CTF3 specific Instrumentation

High efficiency accelerator

'Fully loaded accelerating cavities requires time resolved spectrometry'

Full beam loading

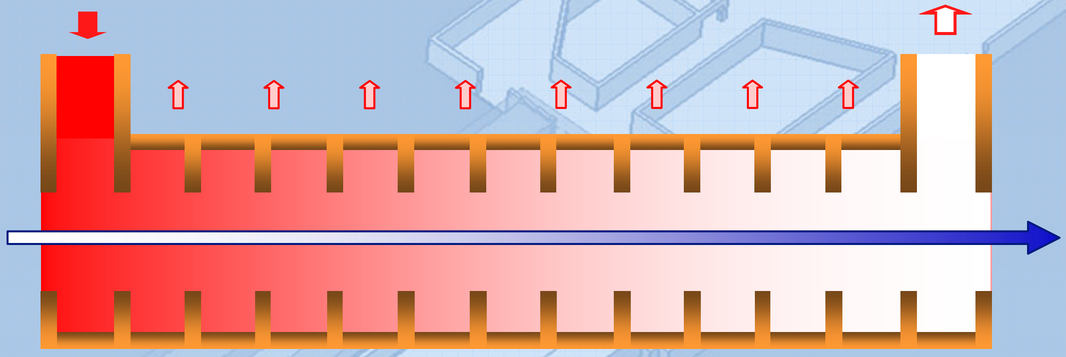
Full beam-loading acceleration in TW sections

RF in

No RF to load

No beam

High current beam

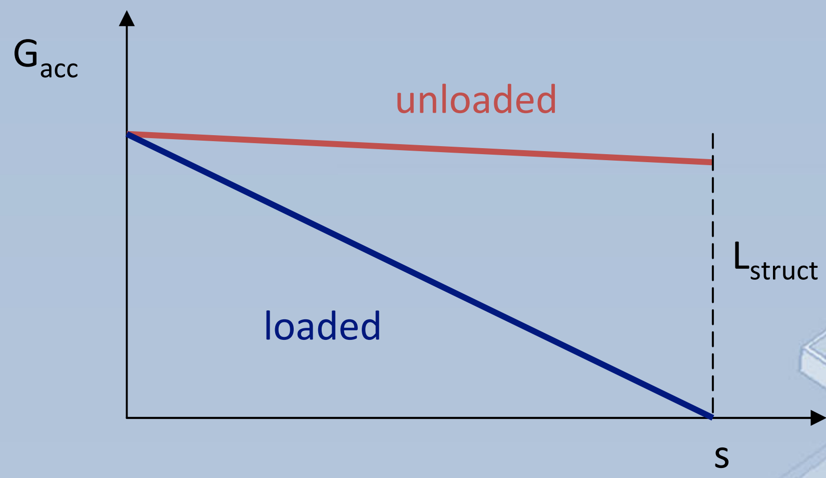


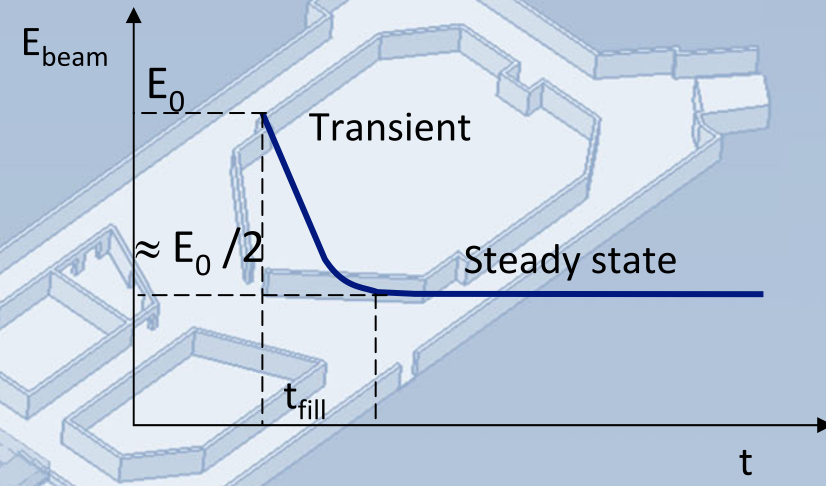
"short" structure - low Ohmic losses

most of RF power (≥ 95%) to the beam

Full beam loading

Full beam-loading acceleration in TW sections





Need to develop Time resolved spectrometry at the nanosecond level

Time Resolved Spectrometry

e-

Bending Magnet

Segmented Dump

OTR Screen & Segmented PMT

- 32 channels PMT (Hamamatsu)

•Water-cooled Multislits collimator (400μm thick)

n plates (2mm

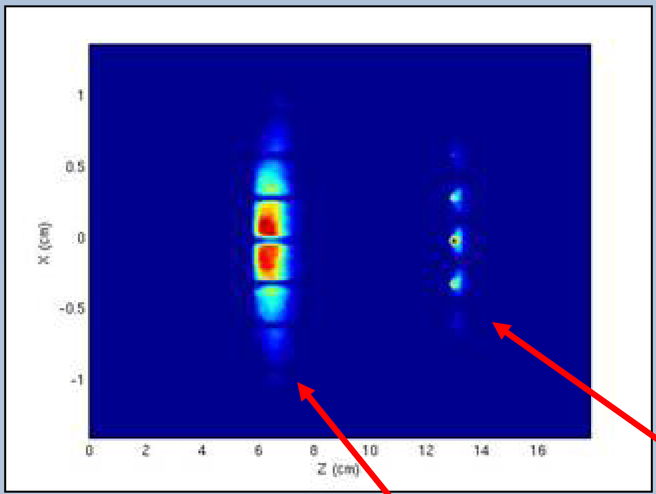
by ~ 1mm

to 50 Ω to the

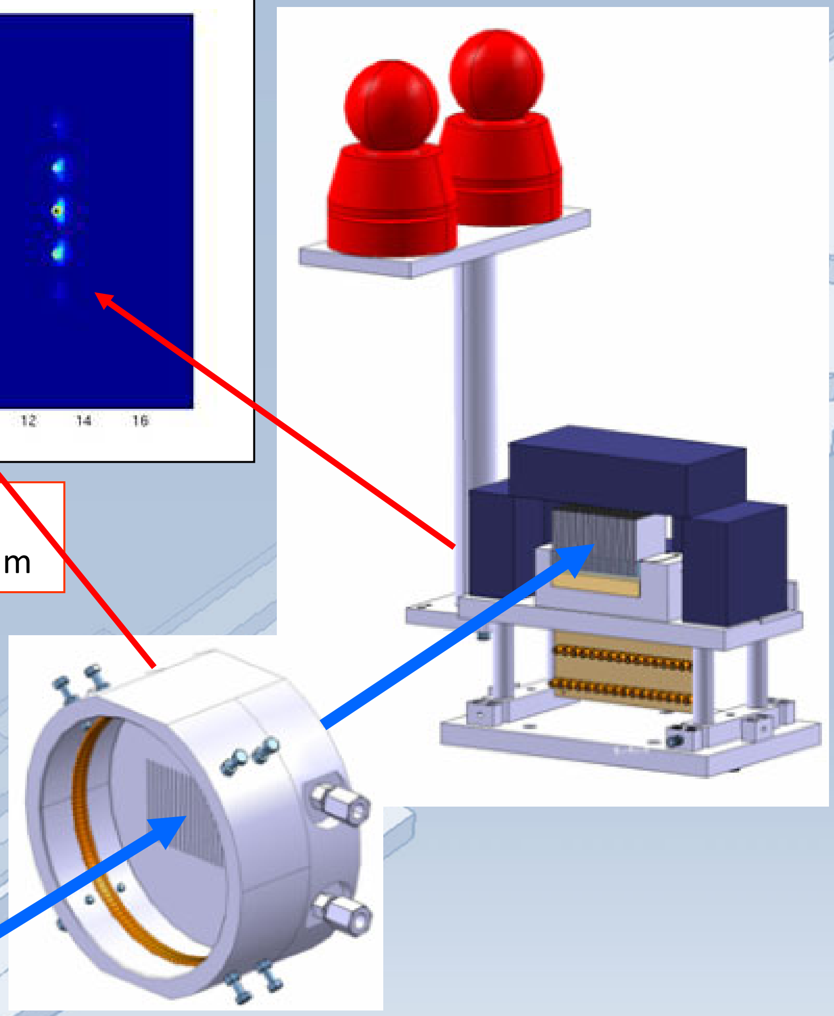
In 2008, one Multi-Anode Photomultiplier and Two Segmented Dumps

Segmented Dump

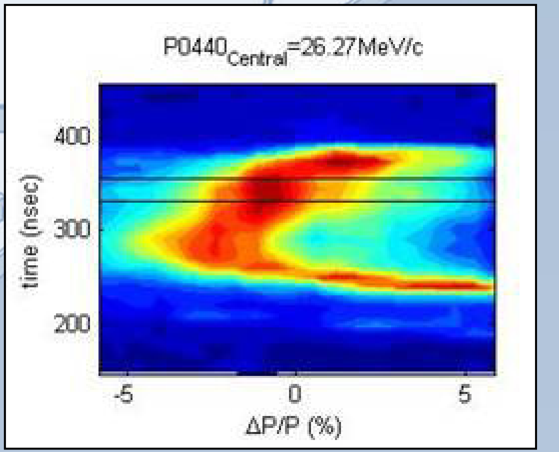
Fluka simulations
of energy deposition



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



Results



Time resolution of 10ns
limited by the sampling
rate of the ADC's

CTF3 specific Instrumentation

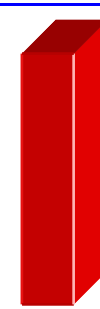
Longitudinal gymnastic

'How to transform a long low current low frequency beam in a short high current high frequency beam'

Initial time structure

1.12 μs train length – 4A, 150MeV
20 cm between bunches

Final time structure



140ns pulse - 30A, 150MeV
2.5cm between bunches

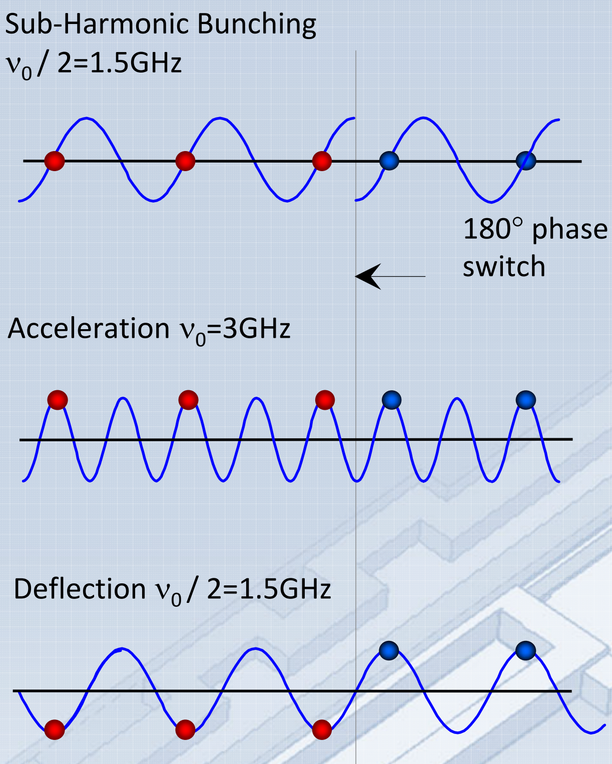
Delay Loop

Gap creation & first multiplication × 2

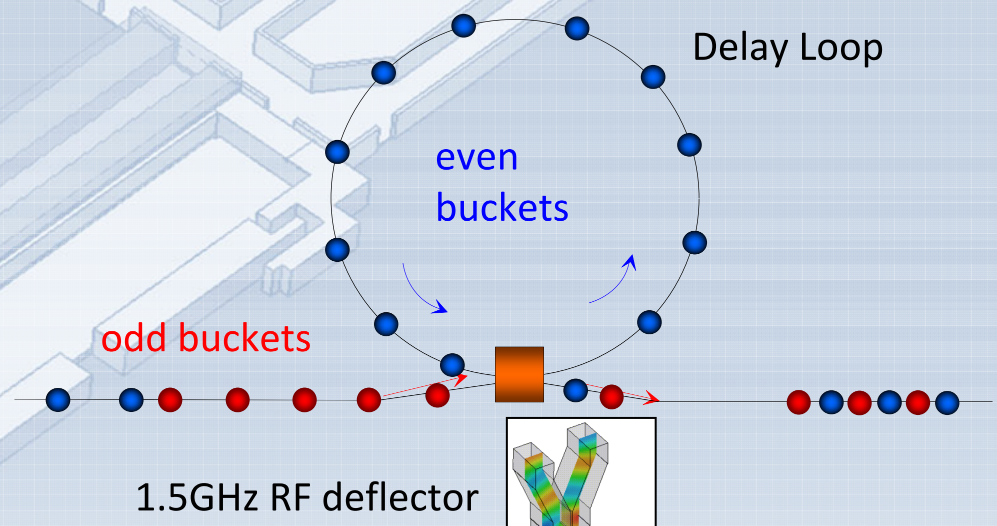
$$L_{delay} = n\,\lambda_0 = c\,T_{sub\text{-}pulse} = 42m$$

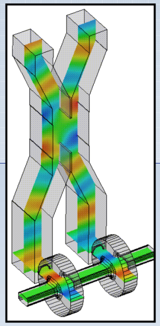
Phase coding

How to "code" the sub-pulses

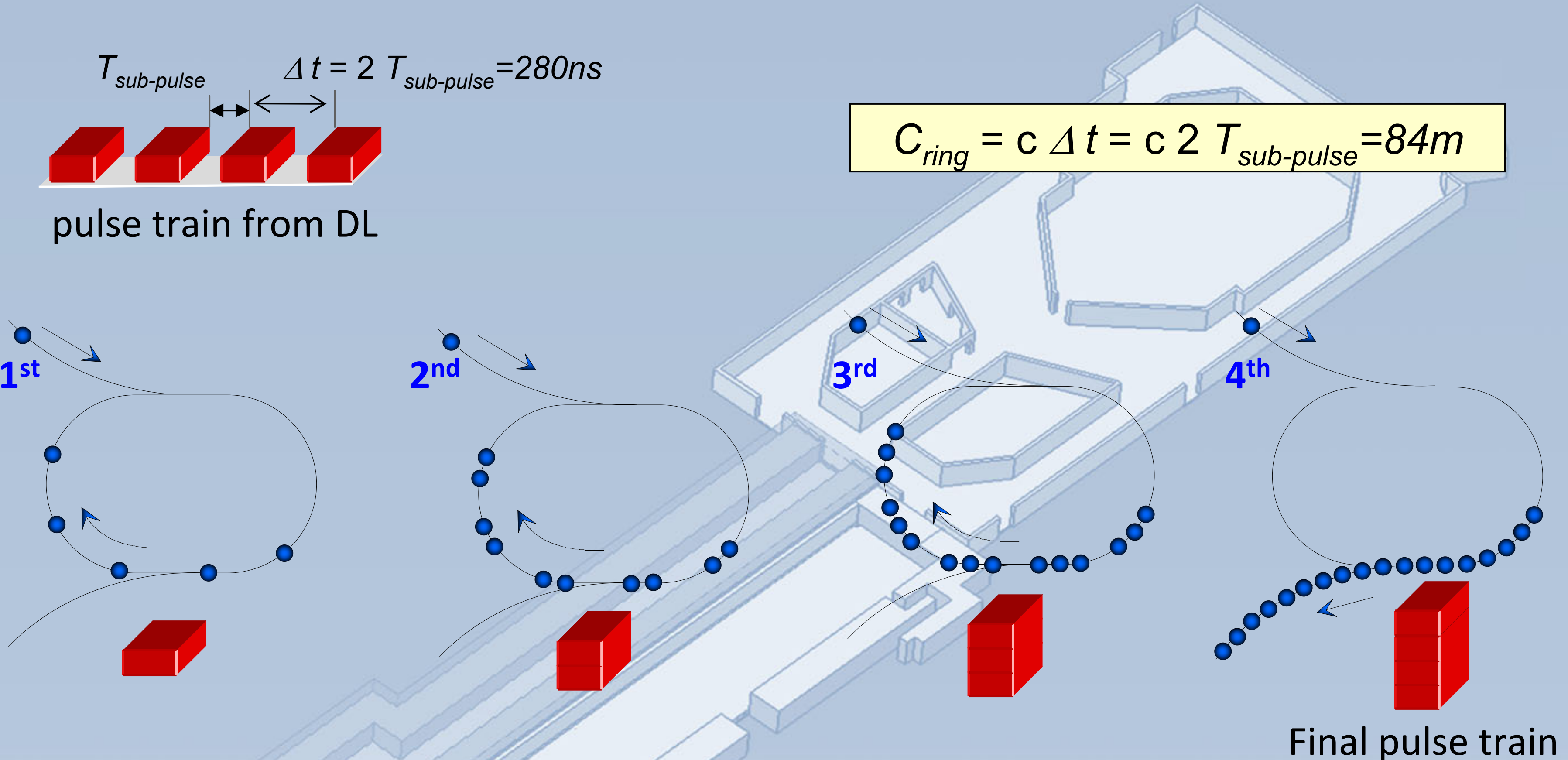


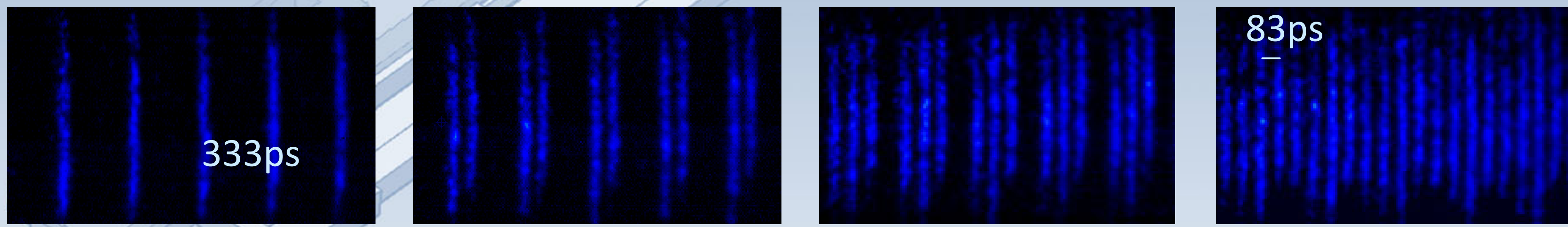
Combination scheme





Combiner Ring

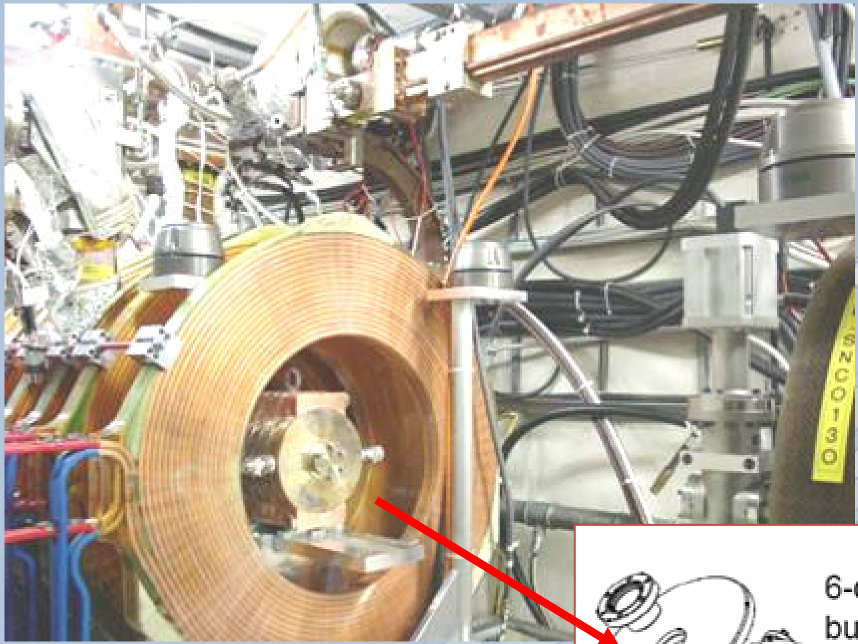


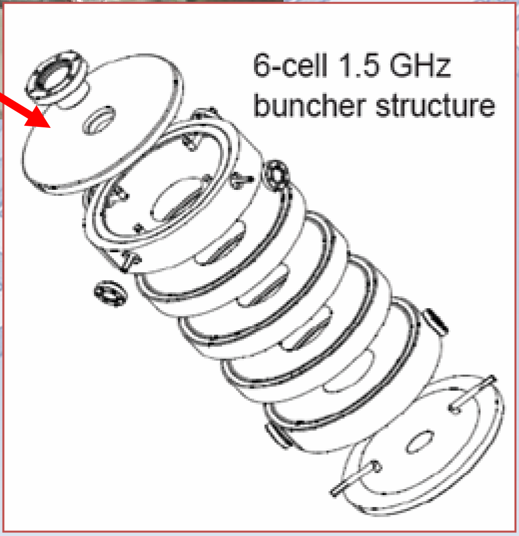


Bunch combination in 2003

Sub-Harmonic Bunching System

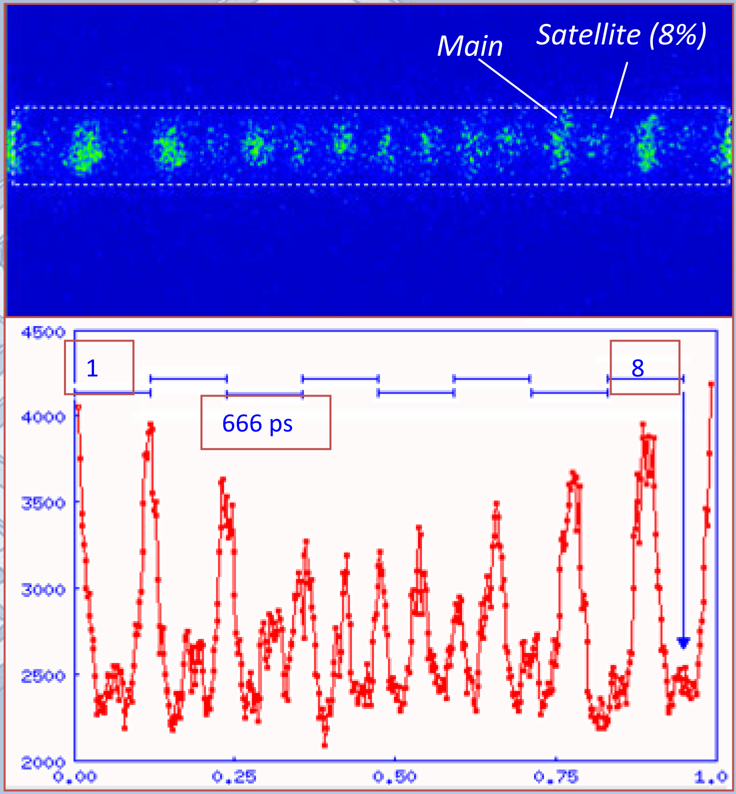
Fast phase switch from SHB system (CTF3)





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

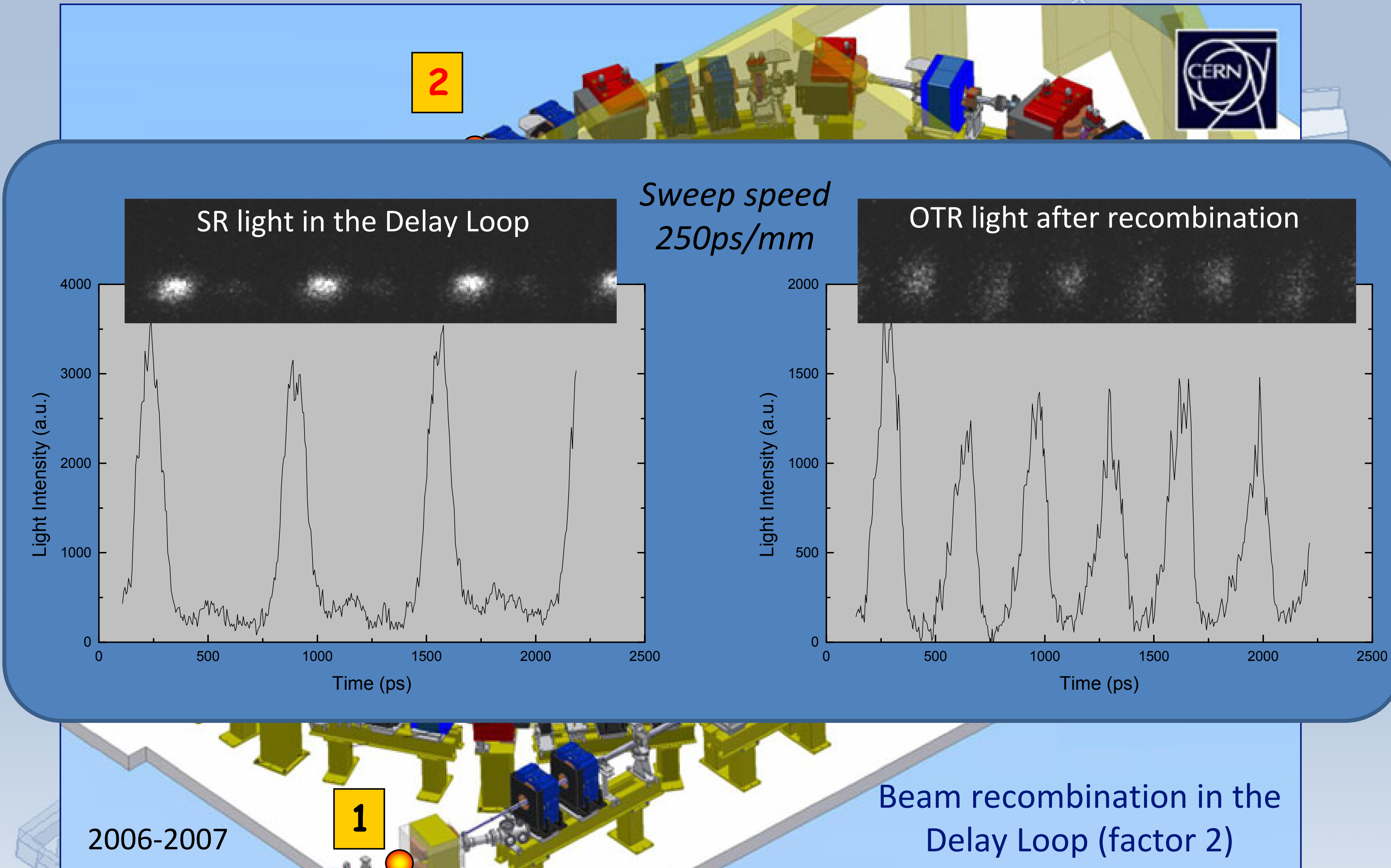
Streak camera – 500 ps/mm



Switch time

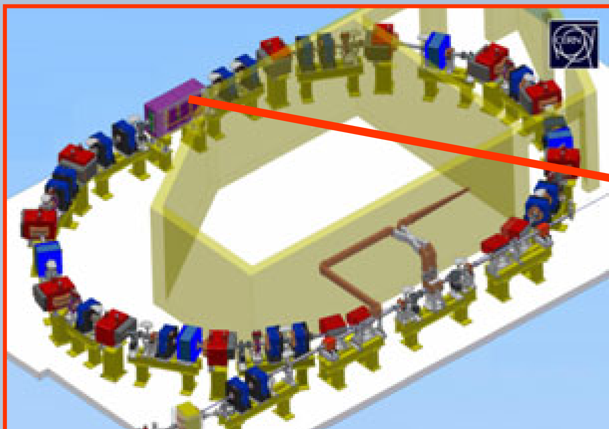
$8.5 \cdot 666\ \text{ps} = 5.7\ \text{ns}$

Delay Loop


2
Sweep speed 250ps/mm
SR light in the Delay Loop
Light Intensity (a.u.)
Time (ps)
4000
3000
2000
1000
0
0
500
1000
1500
2000
2500
OTR light after recombination
Light Intensity (a.u.)
Time (ps)
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
1
2006-2007
Beam recombination in the Delay Loop (factor 2)

Phase Monitor

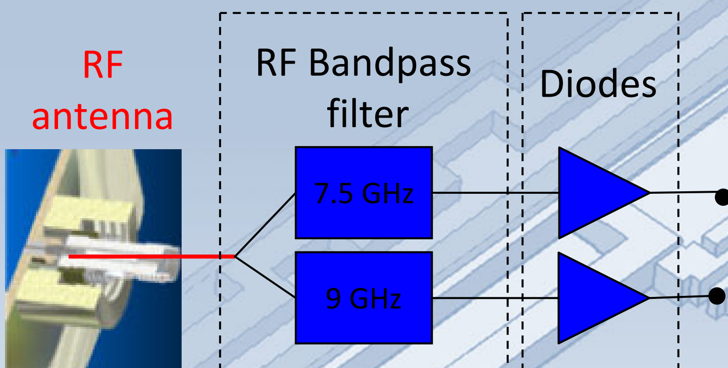
‘ The optimization of the combination is done by adjusting the delay loop length with a magnetic wiggler’



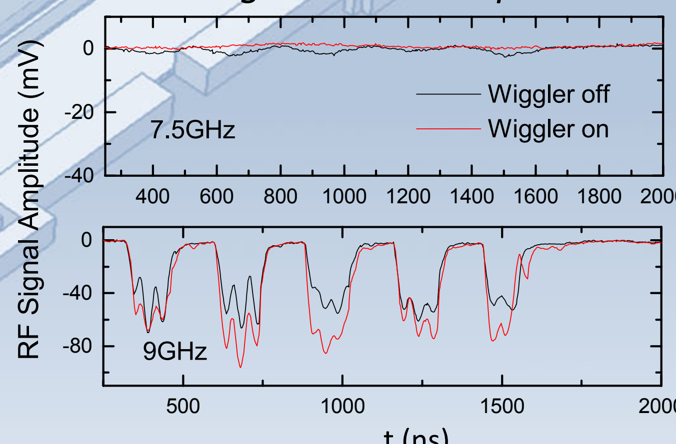
Measure phase errors in the bunch combination

- *Streak camera*
- *Non-intercepting device*

➡ *Measure the beam power for frequencies harmonic of 1.5 and 3GHz*



Digital Oscilloscope



Better RF combination

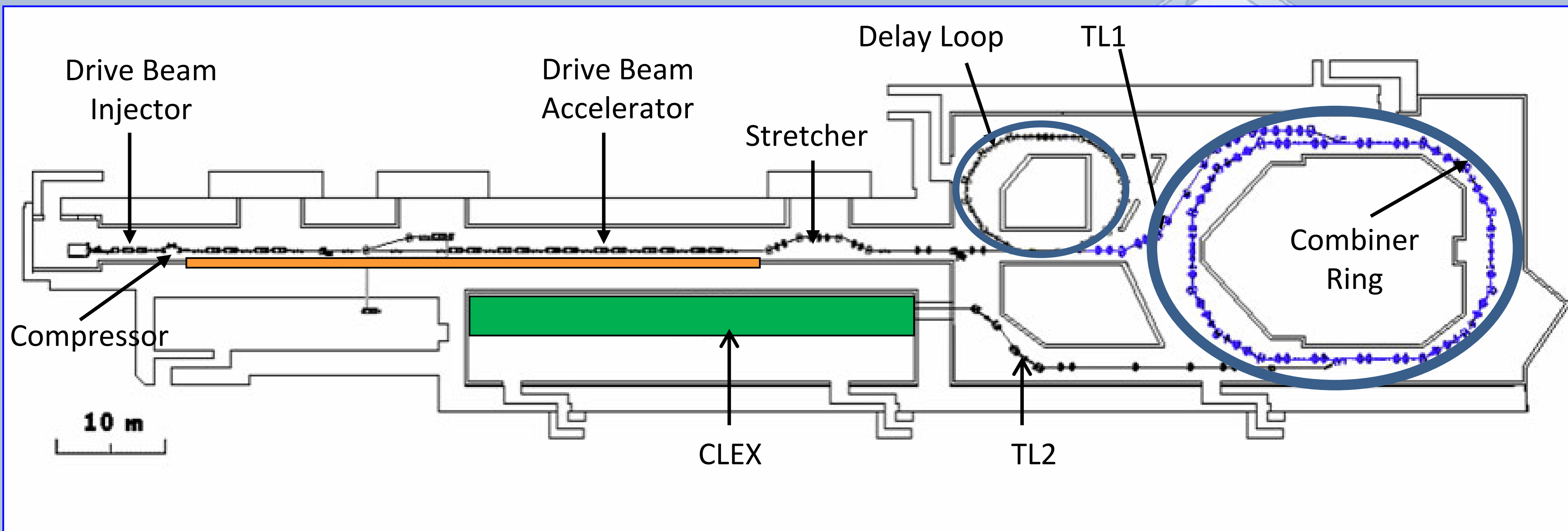
- 7.5GHz ↘
- 9GHz ↗

CTF3 specific Instrumentation

Longitudinal gymnastic

‘Optimizing the bunch length to the different parts of the machine’

Bunch length @ CTF3



LINAC ≈ 1- 6 ps

Delay Loop and Combiner Ring > 8 ps

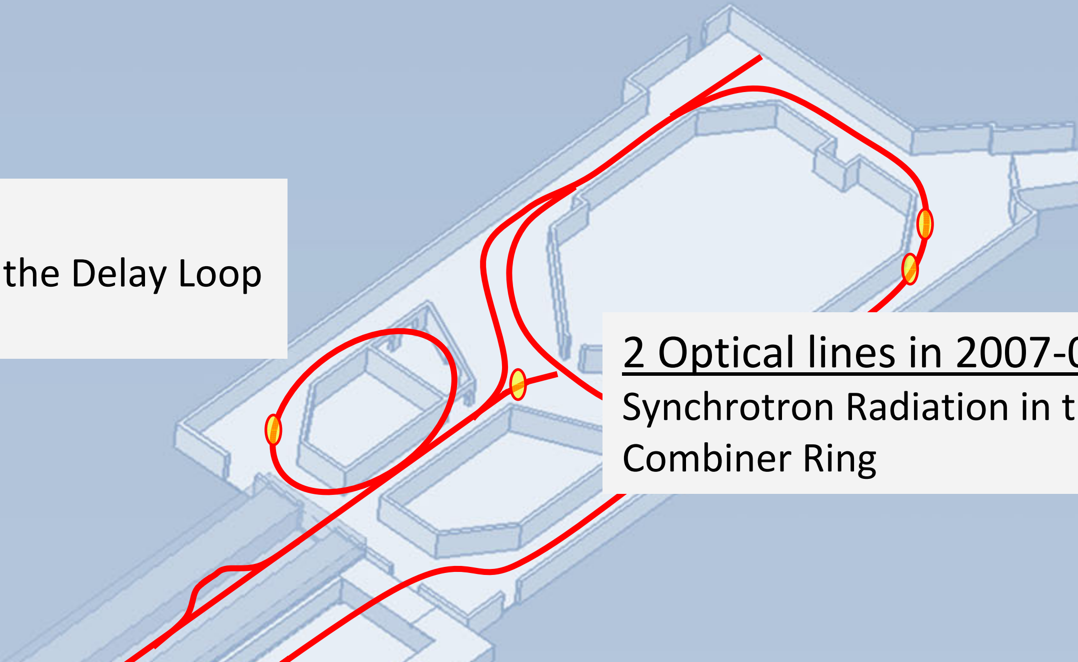
CLEX ≈ 1- 2 ps

Probe beam (Califes) < 1 ps

Streak Camera

<u>2 Optical lines in 2006</u>

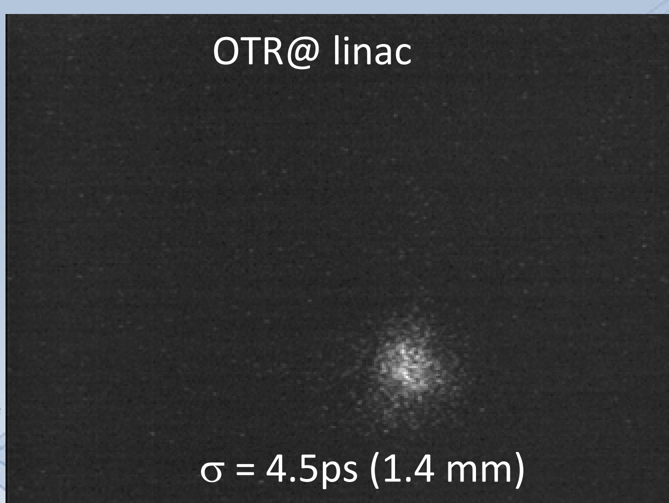
- Synchrotron Radiation in the Delay Loop
- OTR in the linac in TL1



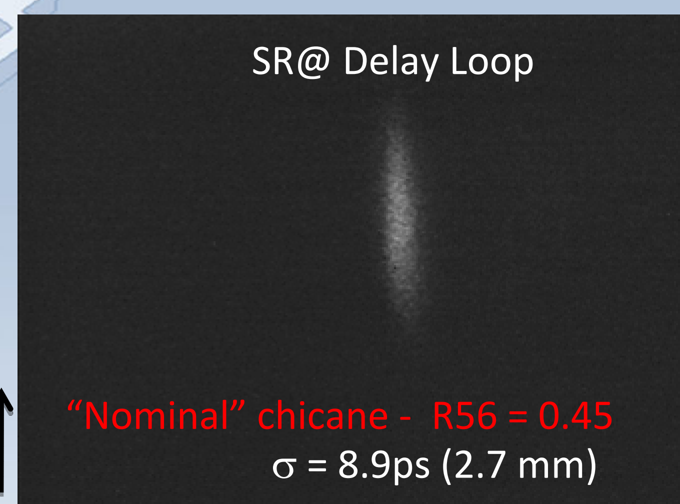
<u>2 Optical lines in 2007-08</u>

Synchrotron Radiation in the Combiner Ring

Sweep speed of 10ps/mm

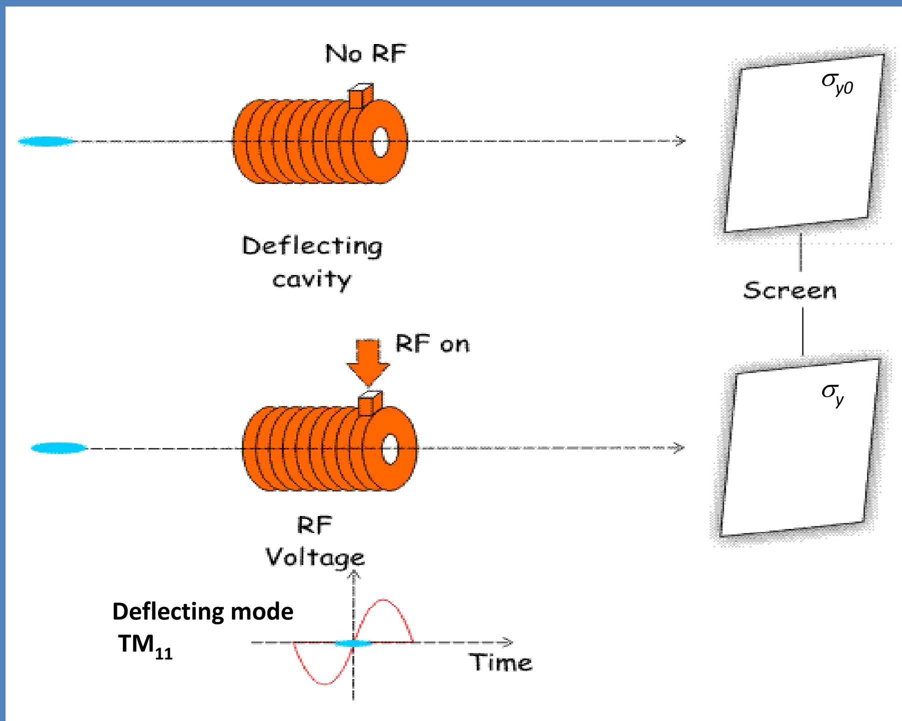


time



time

RF Deflector



- Present at CTF3 for bunch train combination
- Easily provide a sub-ps resolution
- Calibration done using a beam position monitor and doing a phase scan

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

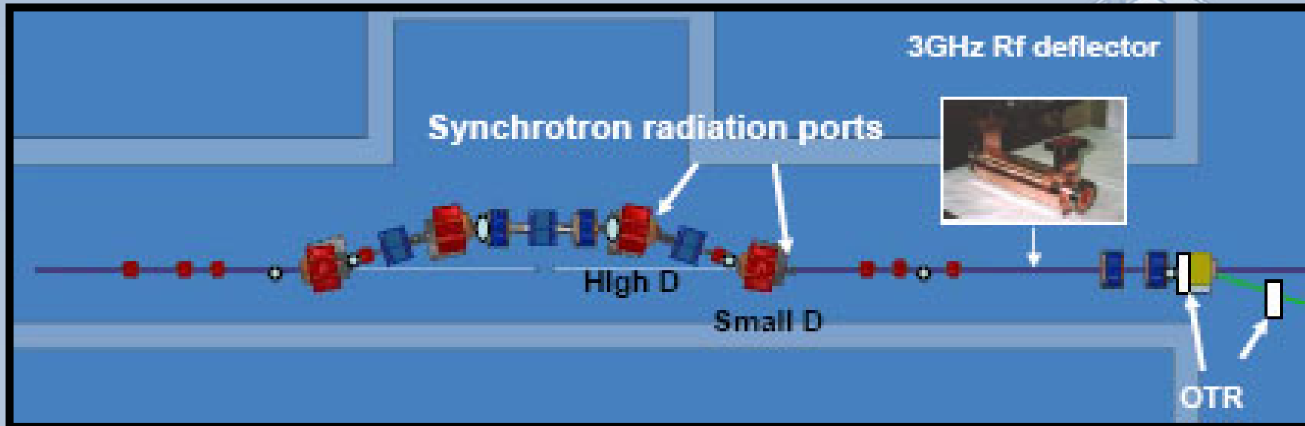
Beta function at cavity and profile monitor

RF deflector wavelength

Beam energy

Betatron phase advance (cavity-profile monitor)

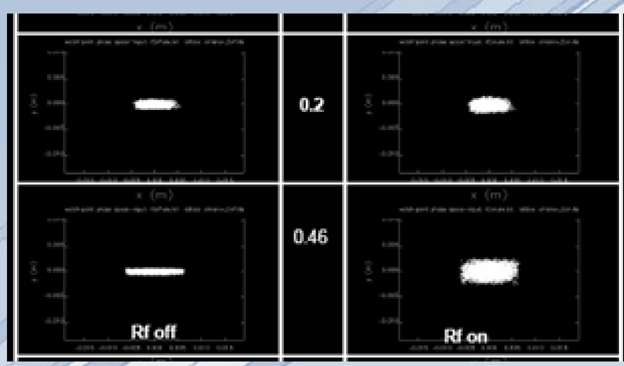
RF Deflector



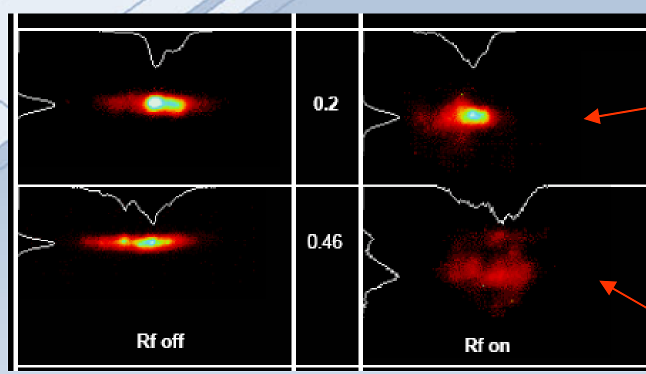
30^{o} off-crest on the last klystron in the linac

Done in 2004

Simulations



Measurements

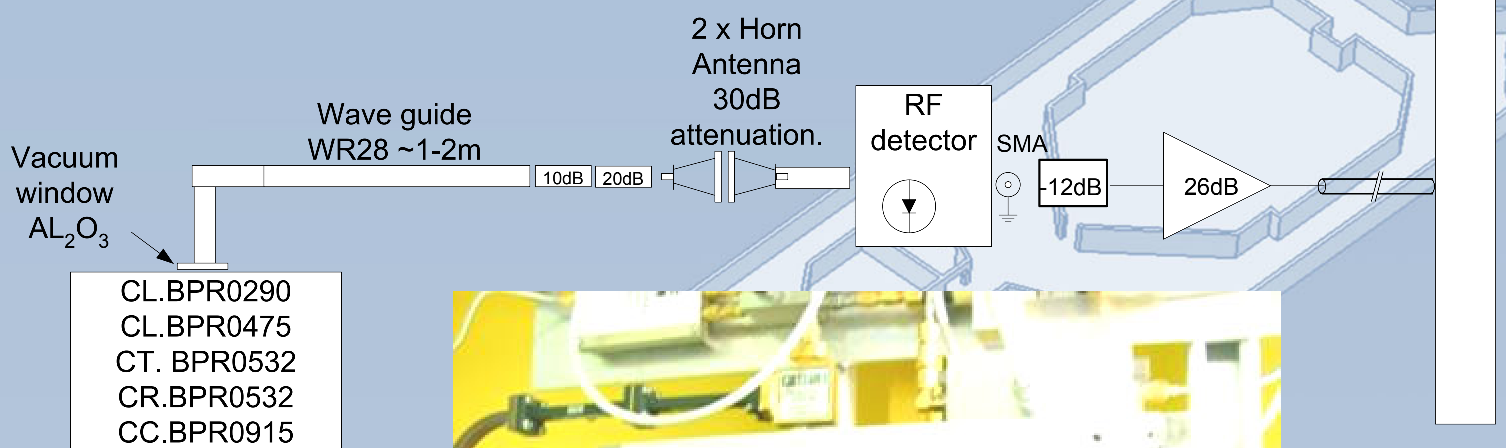


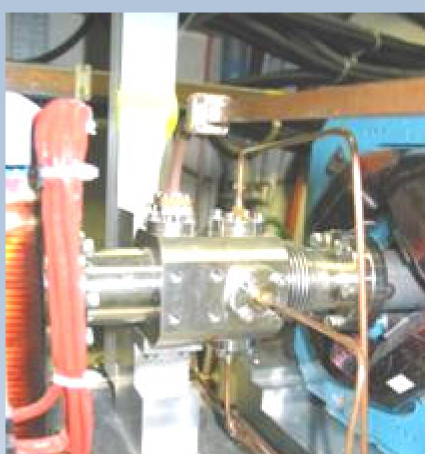
Bunch length 0.5mm (1.2ps)

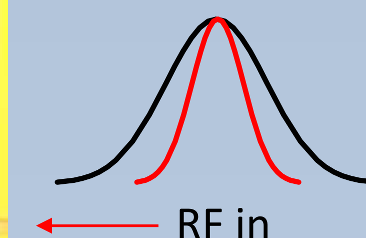
Bunch length 2.5mm (6ps)

Waveguide Pick-up's (BPR)

Motivation to develop non intercepting bunch length monitor





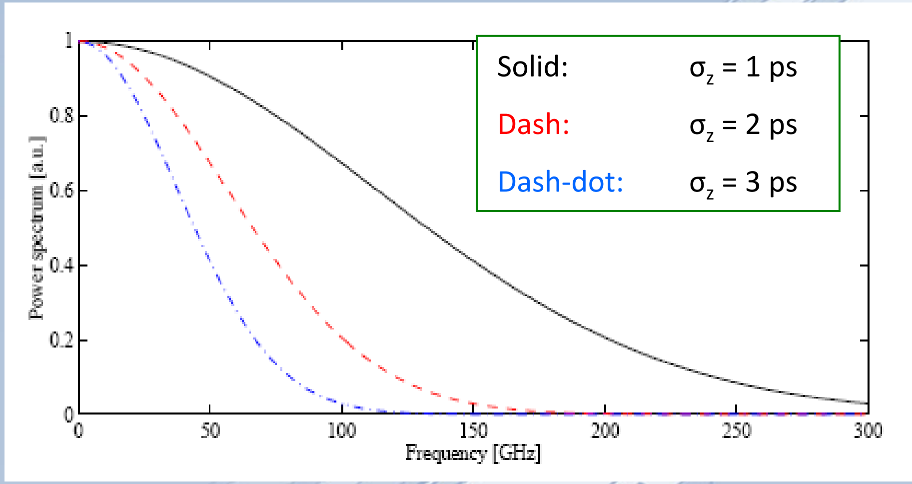


Shorter bunches means more power

Developed by L. Soby, CERN

RF-Pickup

In order to measure the bunch length more accurately
Measure the **power spectrum** of the beam at **(30 – 39) ; (45-69) ; (78-90) & (157-171) GHz**



Setup @ CTF3 was installed & first data taking in Nov 2006

➔ Non-intercepting device, easy to implement in machine, sub-ps resolution, **self calibrating** if bunch length scan is performed

➔ RF deflector and/or a streak camera @CTF3 provide an excellent cross calibration of device

PAC07 proceedings: http://doc.cern.ch/archive/electronic/cern/preprints/ab/ab-2007-070.pdf

RF-Pickup

Filters, Horns and mixers

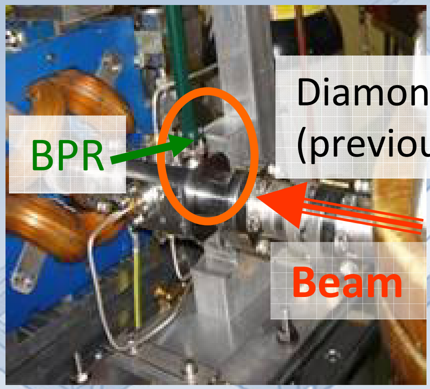
- Reflecting High pass filter- **4** frequency-band detection stages
- Parabolic filter @ 143 GHz (measure beam frequencies (157 ± 14) GHz) & re-focus better reflecting signal
- Series of 2 down mixing stages at each detection station.

Acquiris DC282 Compact PCI Digitizer

4 channels, 2 GHz bandwidth, 2-8 GS/s sampling rate

Data acquisition controlled by a Labview program, with built in Matlab FFT analysis routine

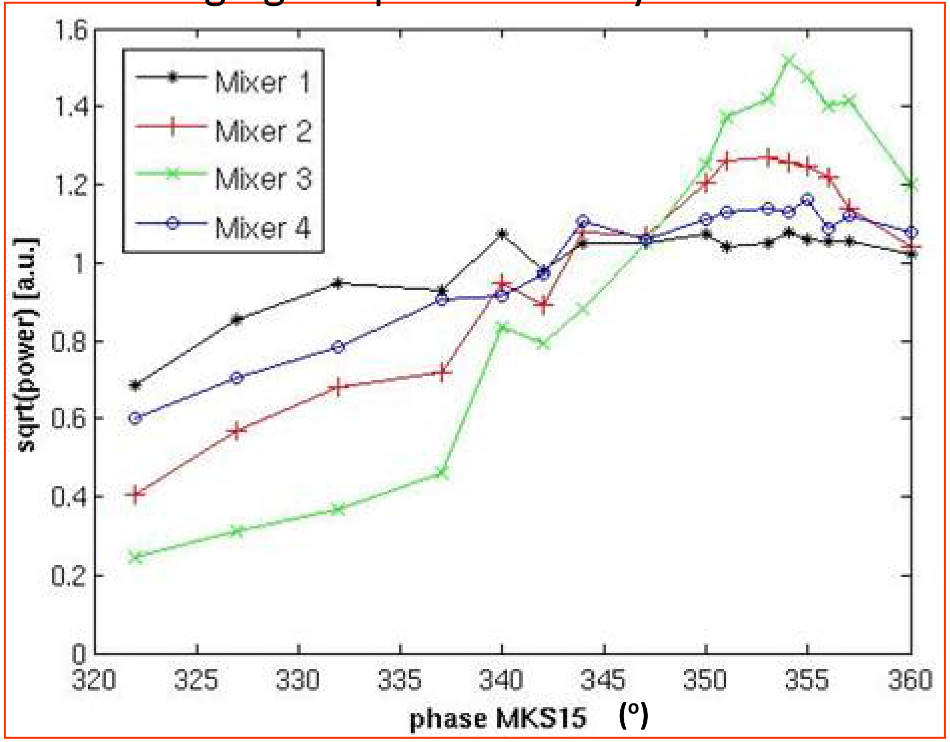
WR-28 Waveguide ~20m

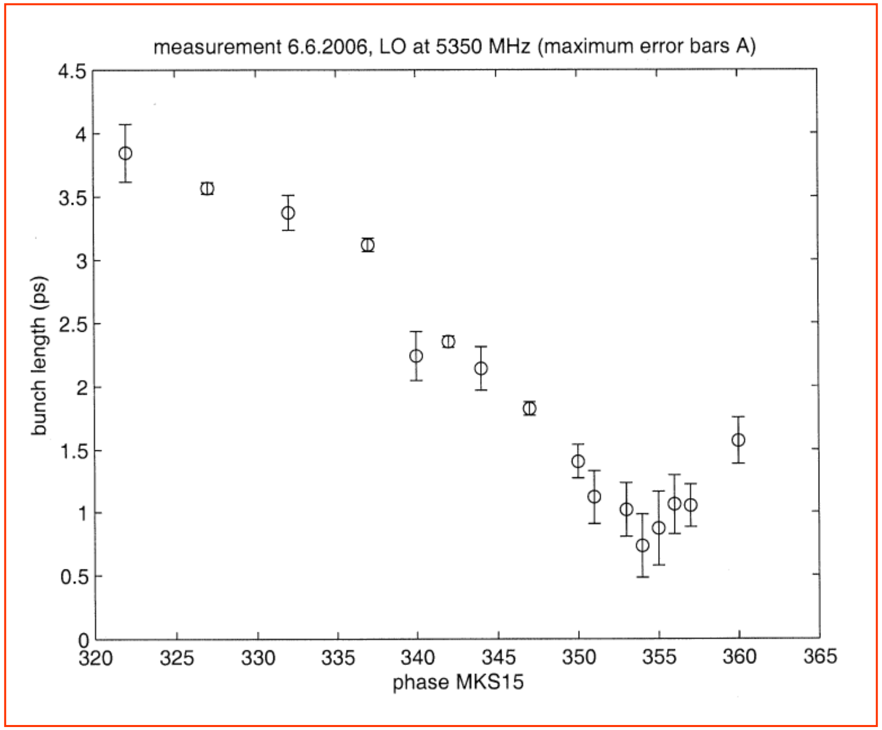


Diamond window (0.5mm thick) (previously ~ 3mm thick Al_2O_3)

RF-Pickup

‘ Changing the phase of a klystron ’

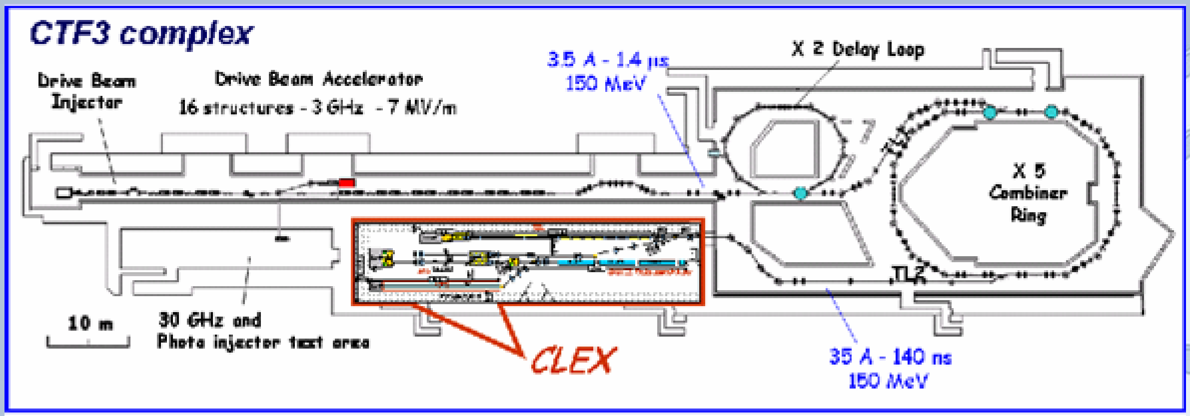


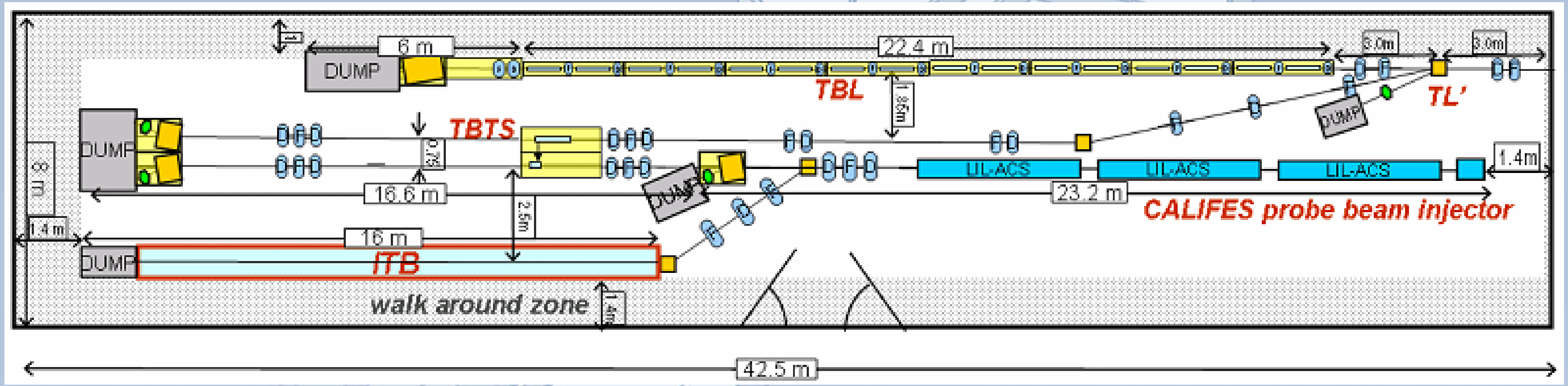


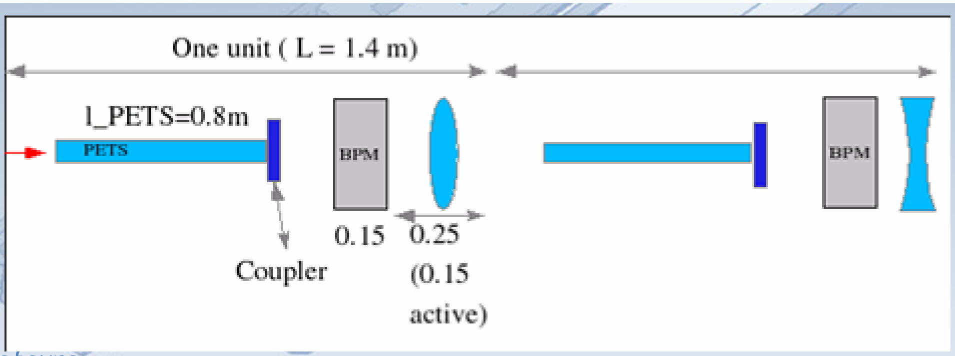
- 16 measurements (corresponding to 16 different phase settings of MKS15)
- Self calibration procedure → Chi square minimization.
- 20 free parameters fit → Response amplitudes @ each frequency bands and 16 bunch lengths

$$\chi^2 = \sum_{j}^{16} \sum_{i}^{3} \left(A_i e^{(-(2\pi f_i)^2 (\sigma_j)^2} - y_{ij} \right)^2$$

What comes next on CTF3



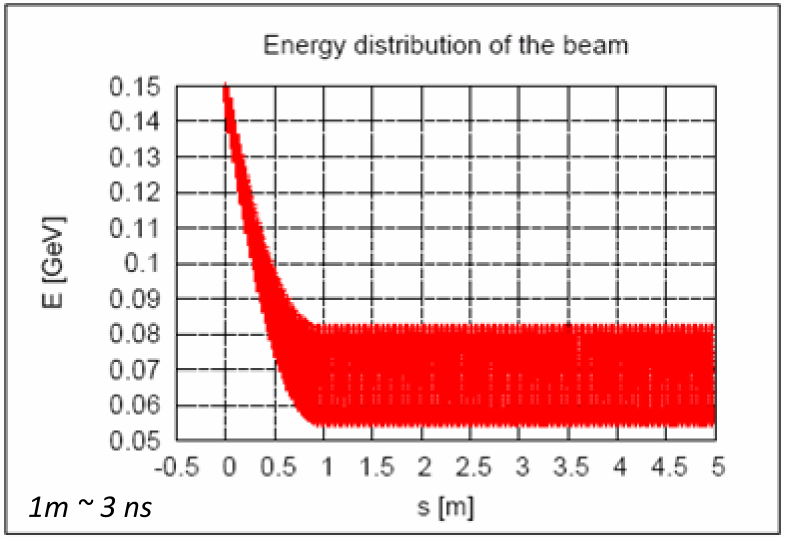




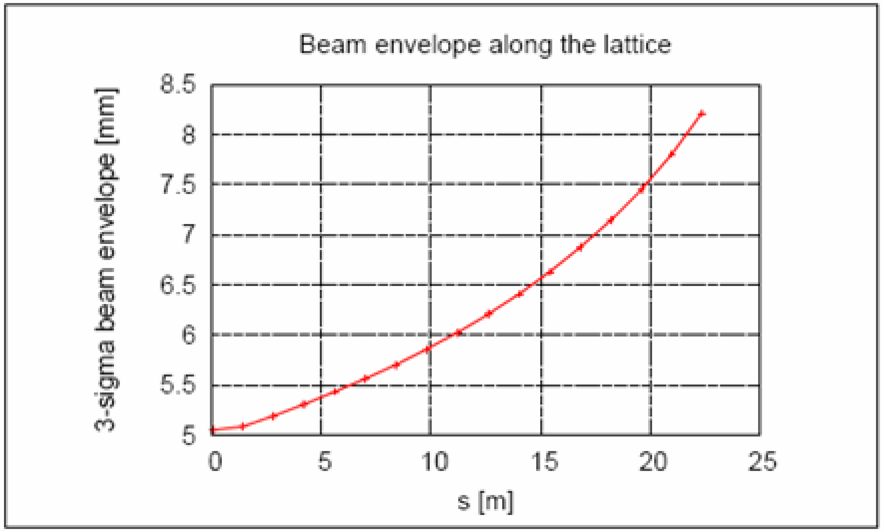
TBL Lattice: 16 units of one of each:

- PETS + coupler
- Quad
- BPM

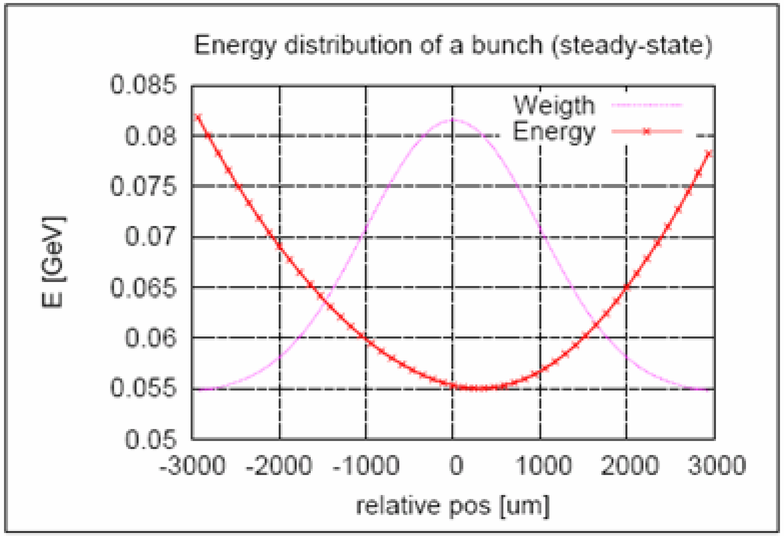
Decelerator Beam Properties



Beam energy after lattice



3-σ beam envelope along lattice (adiabatic effects alone)



Steady state bunch energy profile

<u>Different parameters:</u>

* E0 ~ 150 MeV, I ~ 30 A, t ~ 140 ns

However, the TBL will show the same beam dynamics effects as the CLIC decelerator:

* envelope growth

* decelerated energy profile with 60% energy spread

Decelerator instrumentation

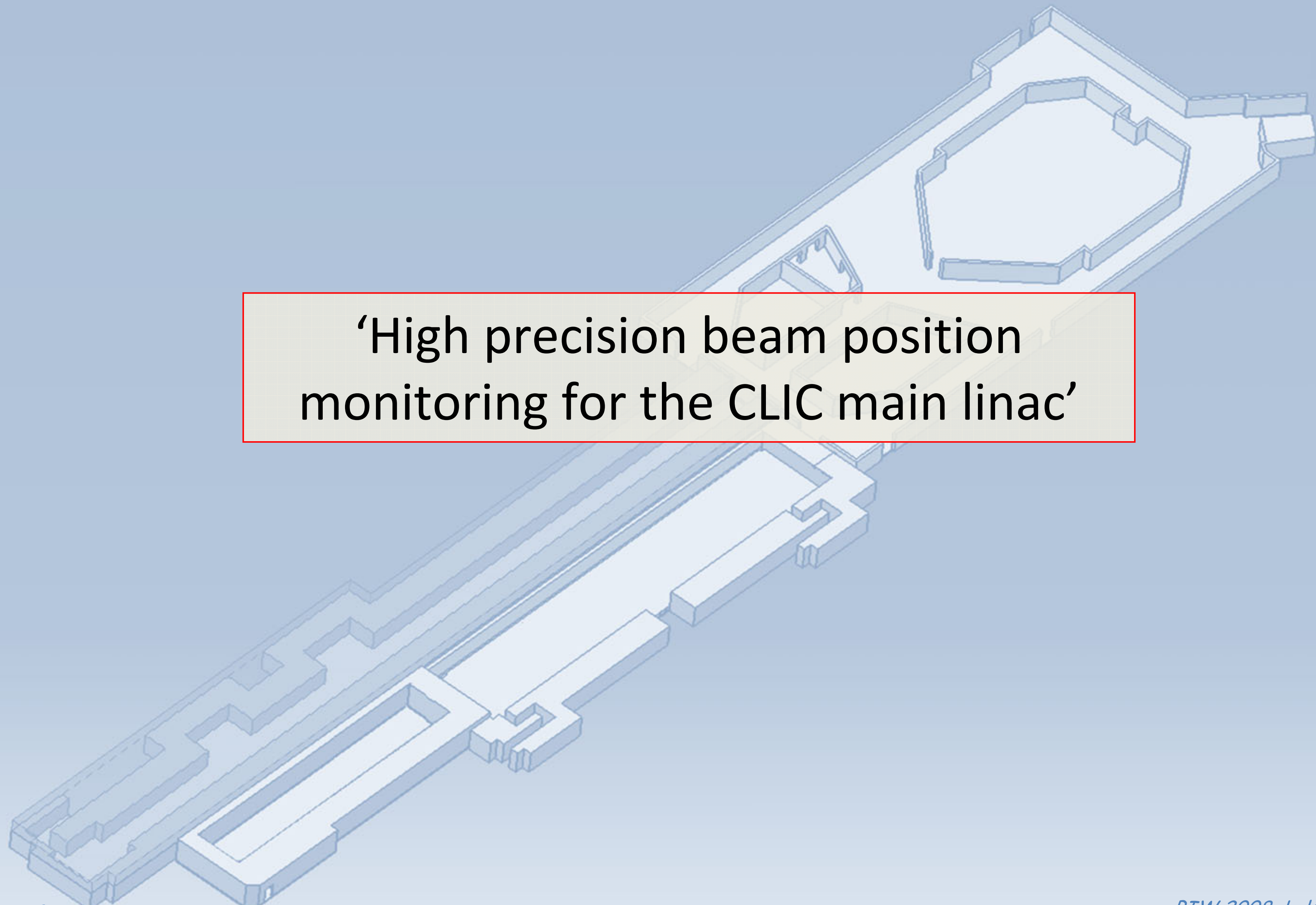
Requirements

- Spectrometer with a very fast time response
    - Intrabunch resolution (ps or less : RF deflector)

- Profile / Emittance measurement on a high energy spread beam
    - Classical method like 'Quadrupoles scans' does not work
    - Beam loss / Beam Halo monitor

Study has just started. Suggestions welcome ?

CLIC related developments



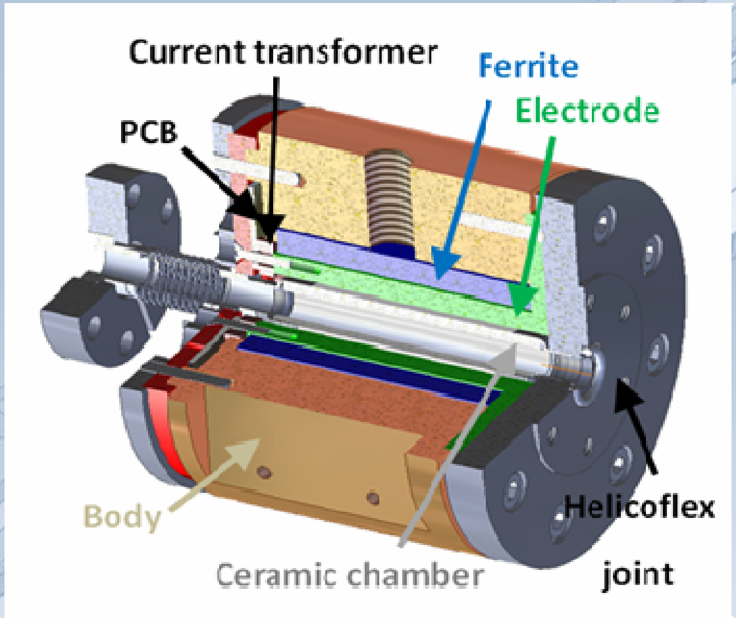
‘High precision beam position monitoring for the CLIC main linac’

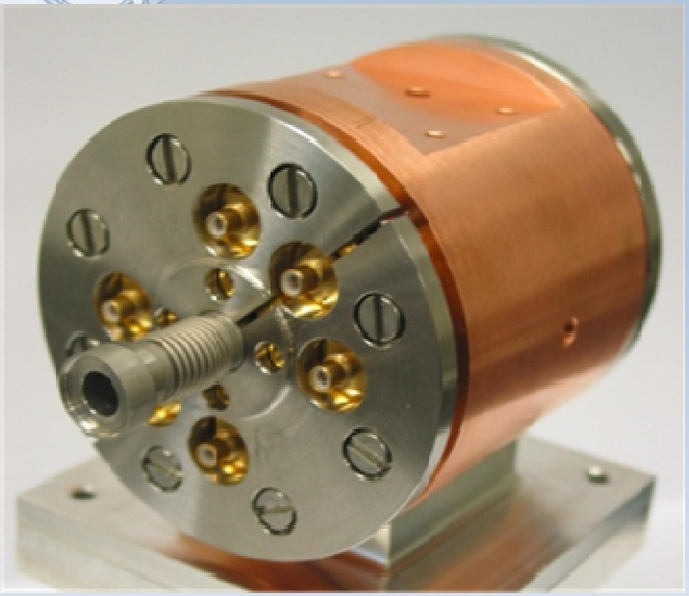
High precision BPM

Goal *L Soby – I. Podadera*

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:

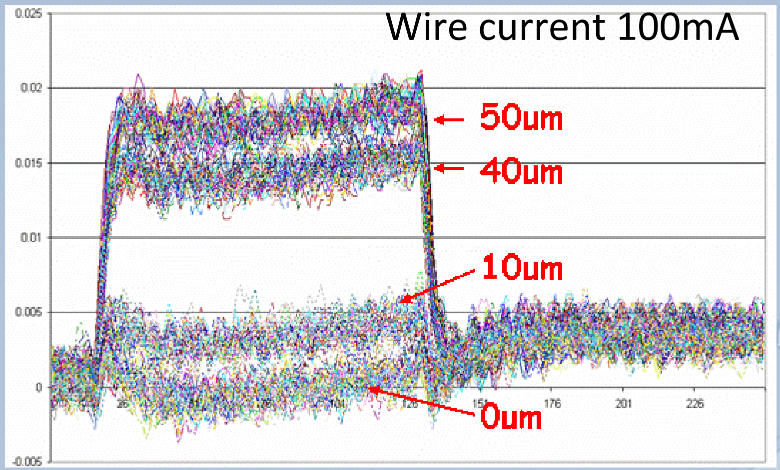
- Resolution: 100 nm.
- Aperture: 4-6 mm.
- Absolute precision: 10 μm.
- Rise time: 15 ns.



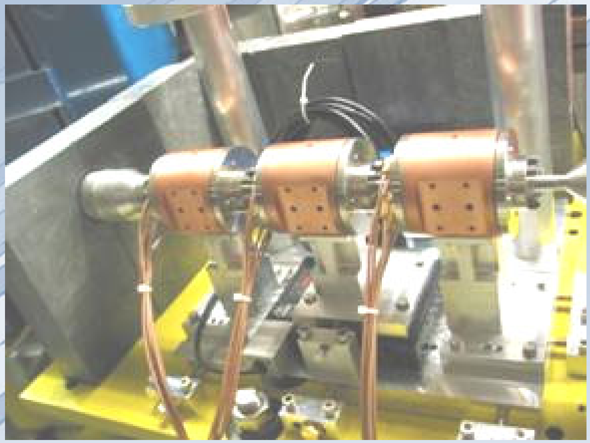


High precision BPM

Calibrated in the lab



Sensitivity Δ=Σ	12mm
Linearity error [±500µm]	**1%**
Electrical offset	**50µm**
Meas. Resol. (100mA, 3kHz BW)	σ_H=40nm σ_V=40nm
Resolution CLIC	$\boldsymbol{\sigma_H}$**=260nm** $\boldsymbol{\sigma_V}$**=260nm**
Resolution ILC	σ_H =4µm σ_V=4µm
24H stability/ 5 deg. C	2µm
Bandwidth	Δ = 300kHz-80MHz Σ = 5kHz-80MHz

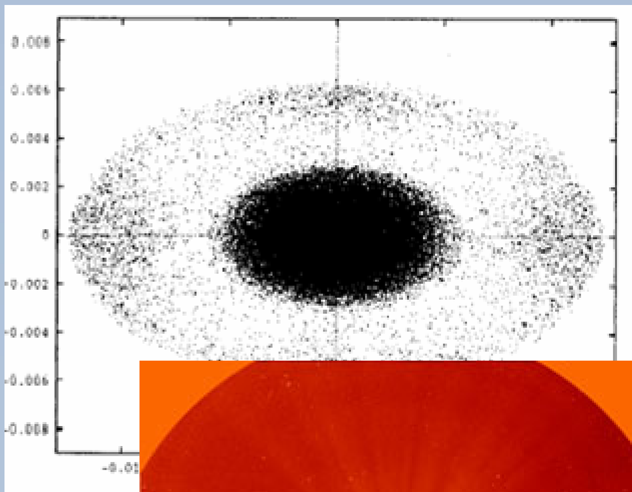


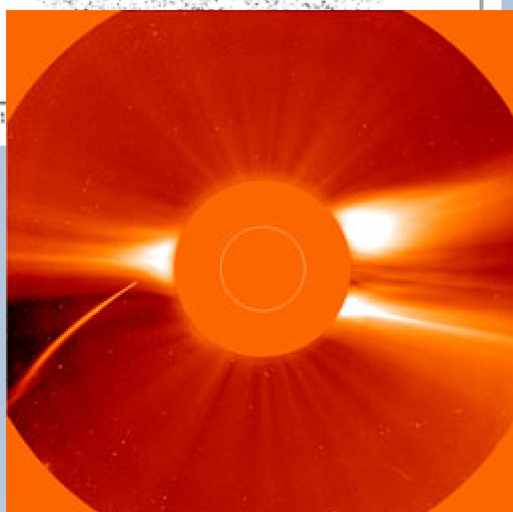
To be tested in CTF3 this year

CLIC related developments

‘Beam Halo investigation’

Beam Halo Studies





- 2004: Test of high dynamic range beam imaging system using a core masking technic with a fixed mask. (achieved 10^4 DR)

  EPAC 2004 ; CERN-AB-2004-091

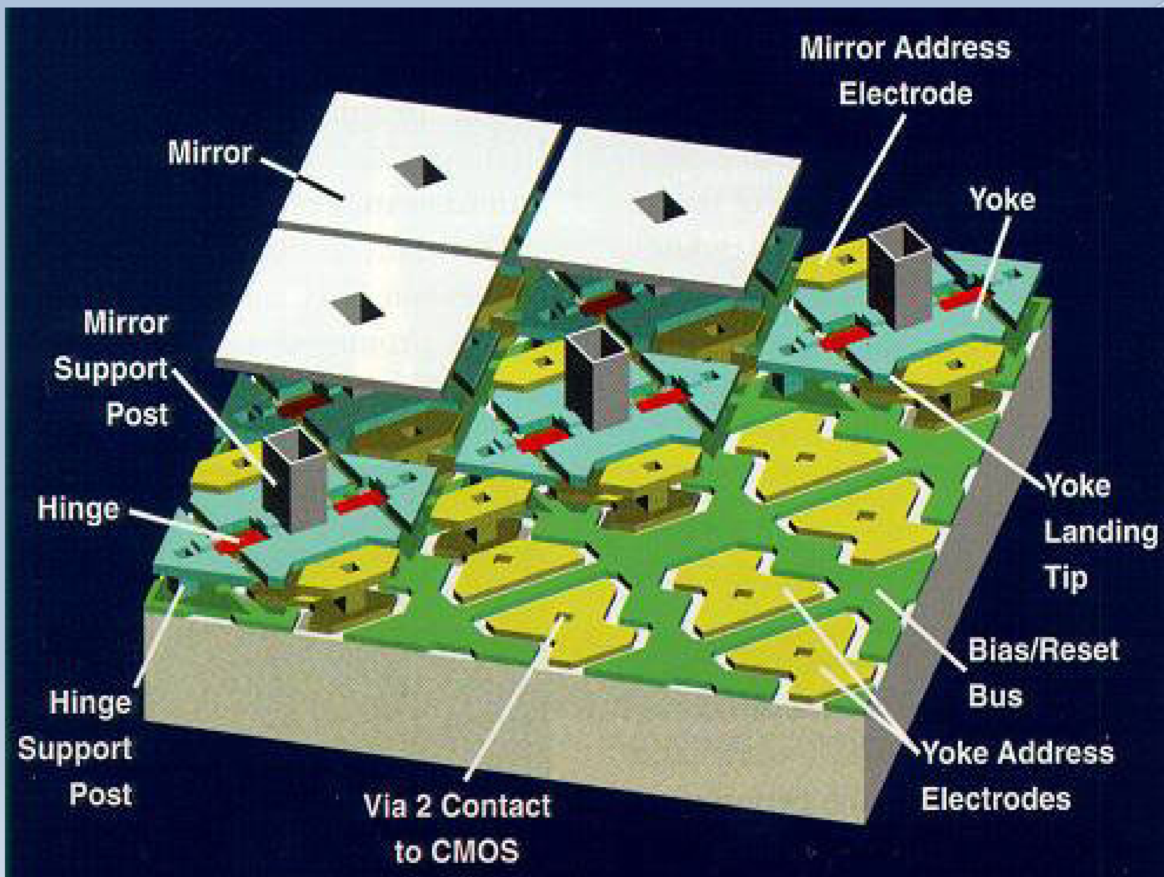
- 2005-06 Test of several high dynamic range systems like SpectraCAM CID camera

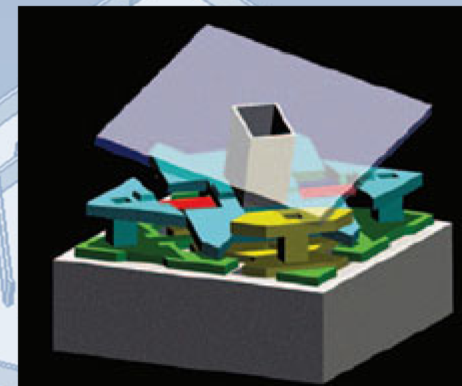
  Meas. Sci. Technol. **17** (2006) 2035–2040

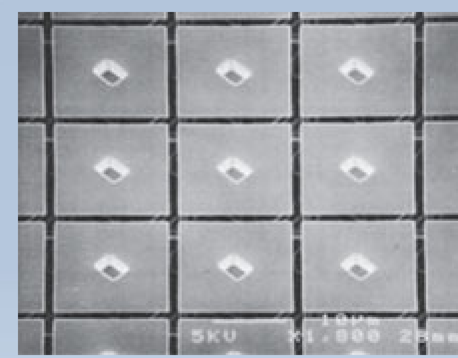
- 2007 – Back to a core suppression technique using adaptive optics – DLP technology

  Laser conference 2007

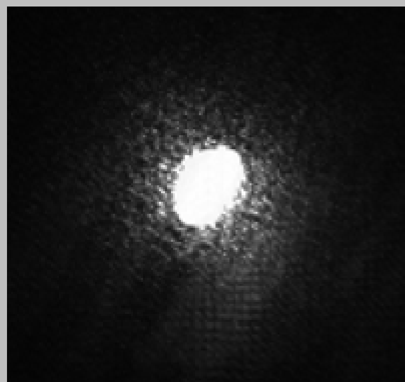
Micro Mirror Array



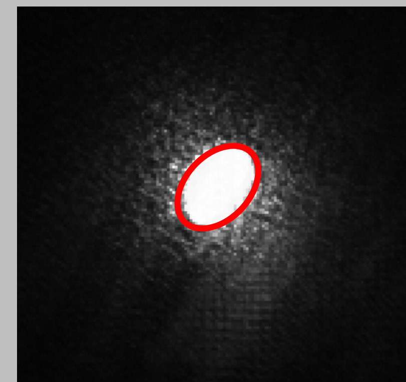




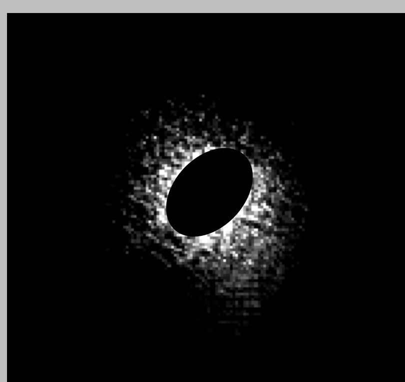
Beam Halo Studies



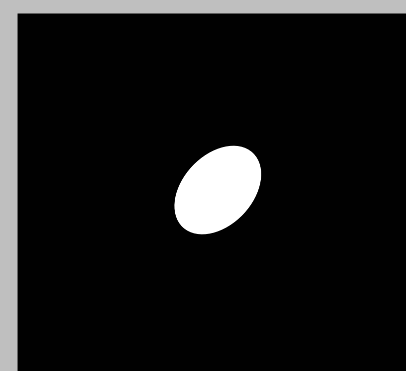
(1) Acquire profile



(2) Define core

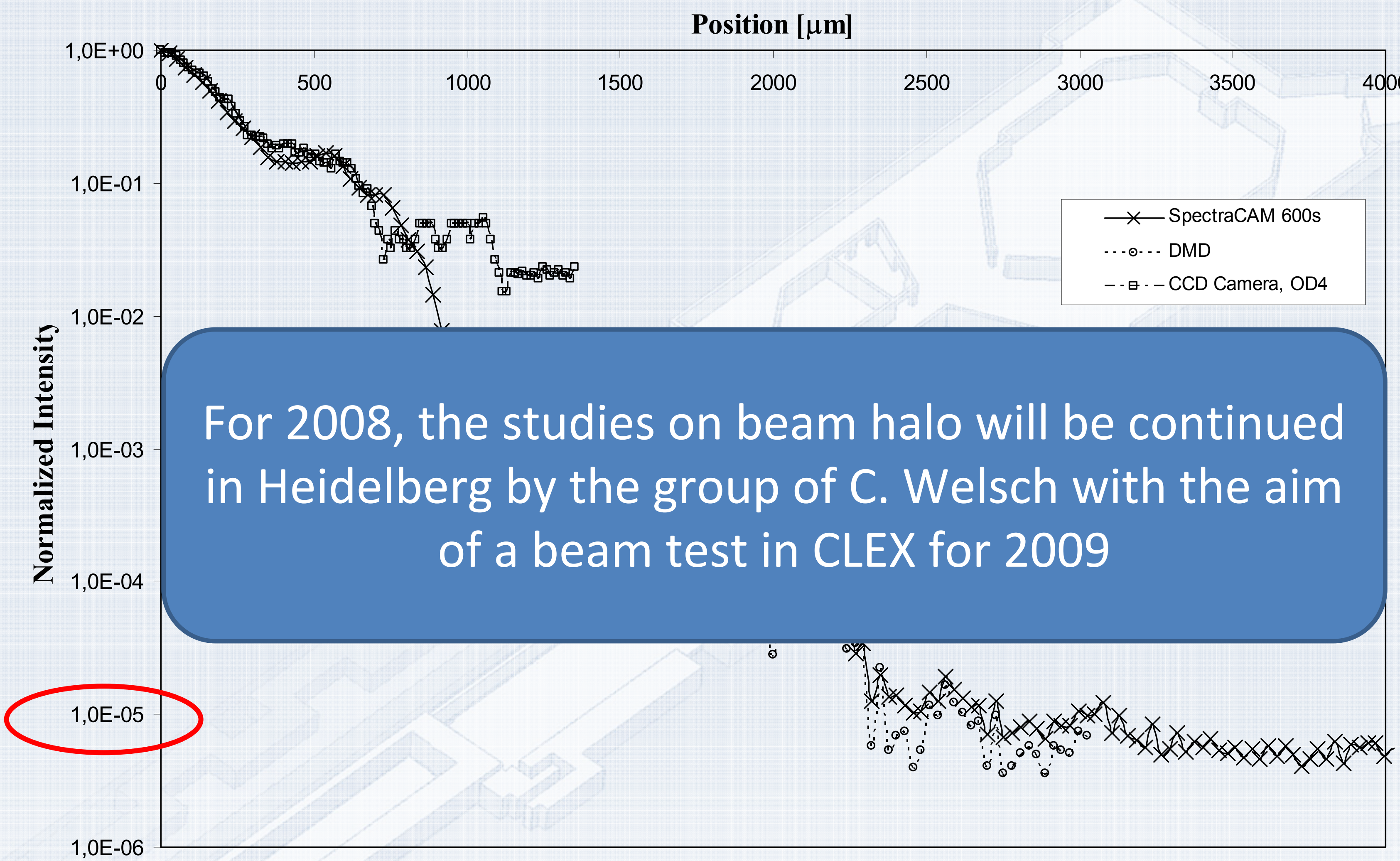


(4) Re-Measure



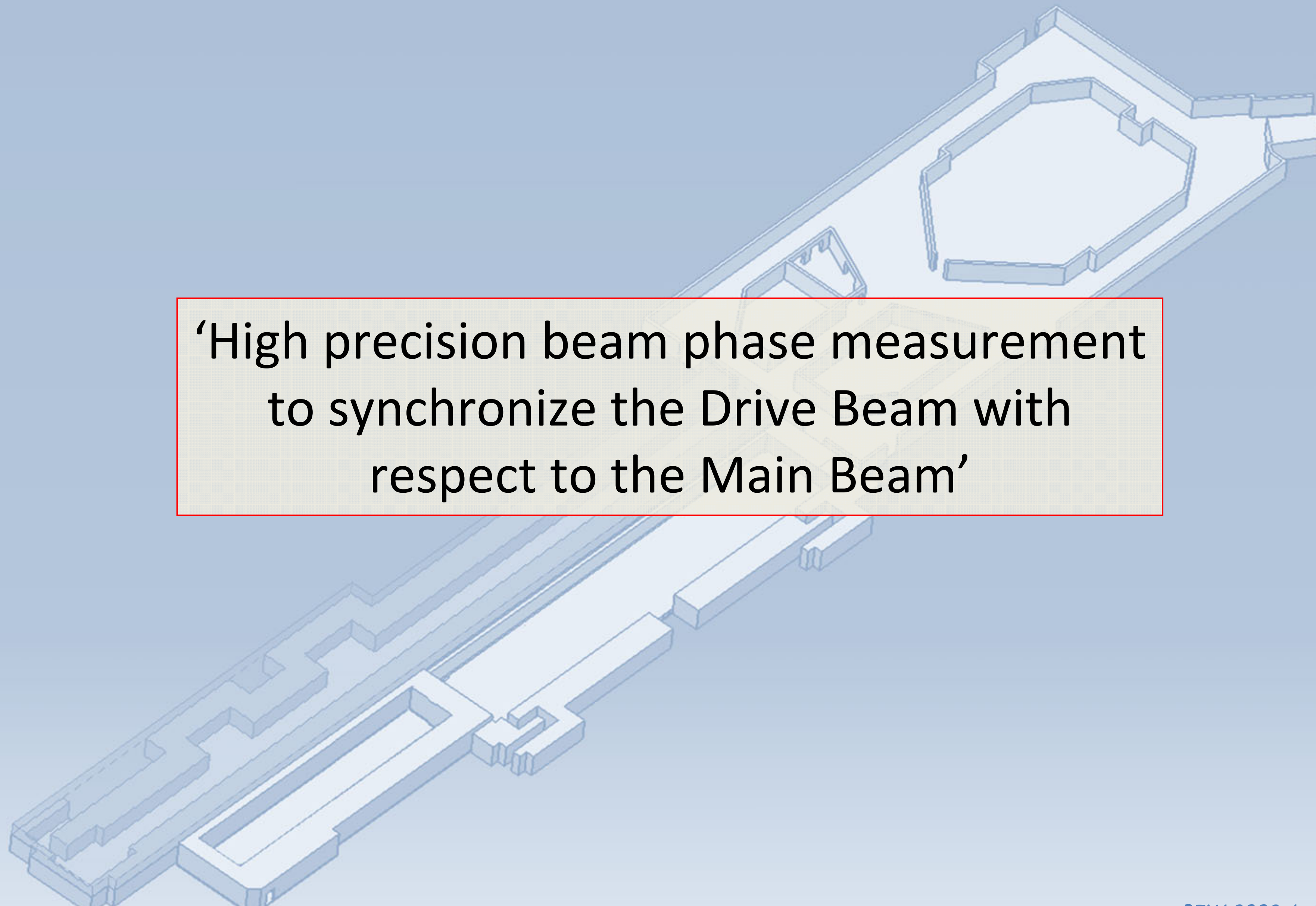
(3) Generate mask

Beam Halo Studies



For 2008, the studies on beam halo will be continued in Heidelberg by the group of C. Welsch with the aim of a beam test in CLEX for 2009

CLIC related developments



‘High precision beam phase measurement to synchronize the Drive Beam with respect to the Main Beam’

Beam Phase monitor

CLIC synchronization between the Main beam and the Accelerating RF power

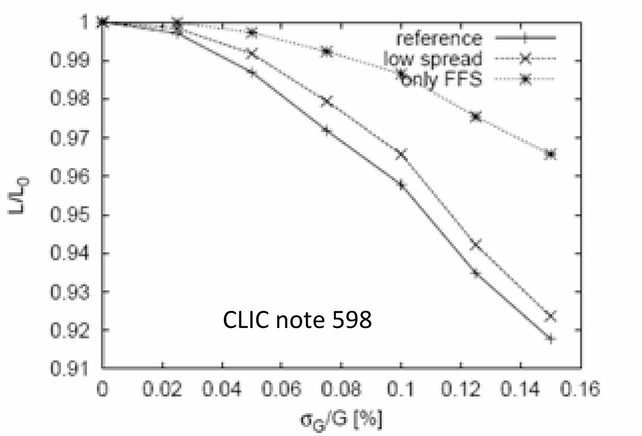
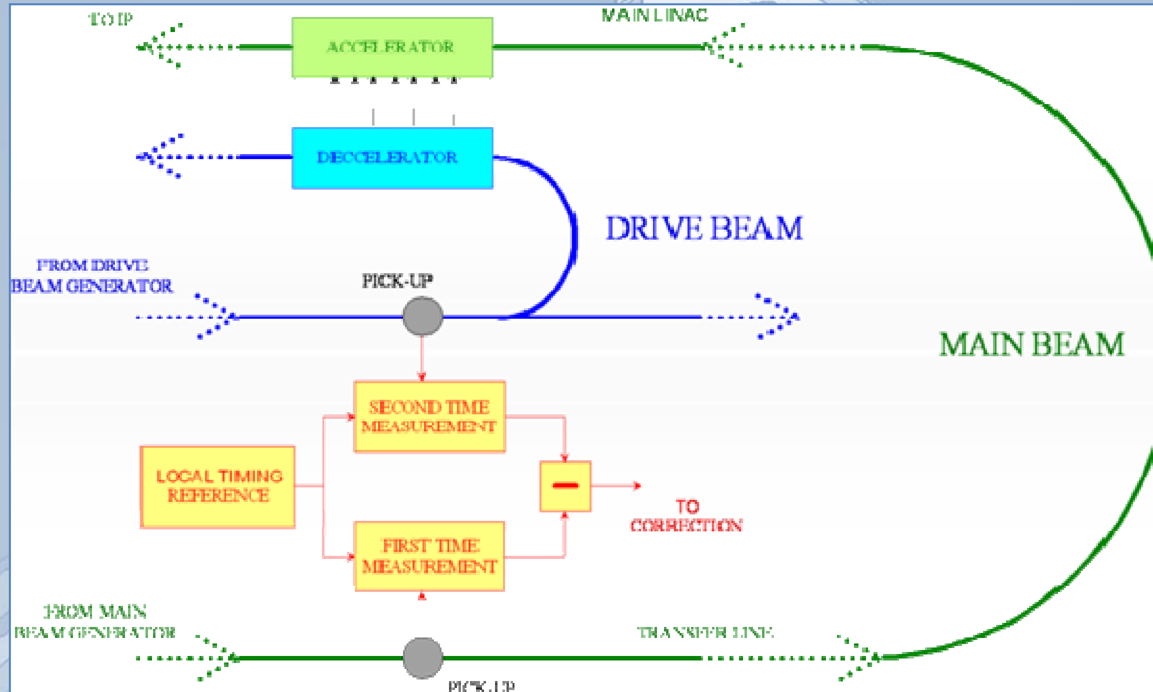


Figure 1: The relative luminosity as a function of a coherent gradient error in the main linac.



4% luminosity reduction

For σ_f = 0.225°; Δ_z = 6 µm

Developed by J. Sladen and A. Andersson, CERN

A large quantity of phase jitter sources in the power production chain ensures that phase error correction is required

Requirements for the phase monitor:

Single-shot

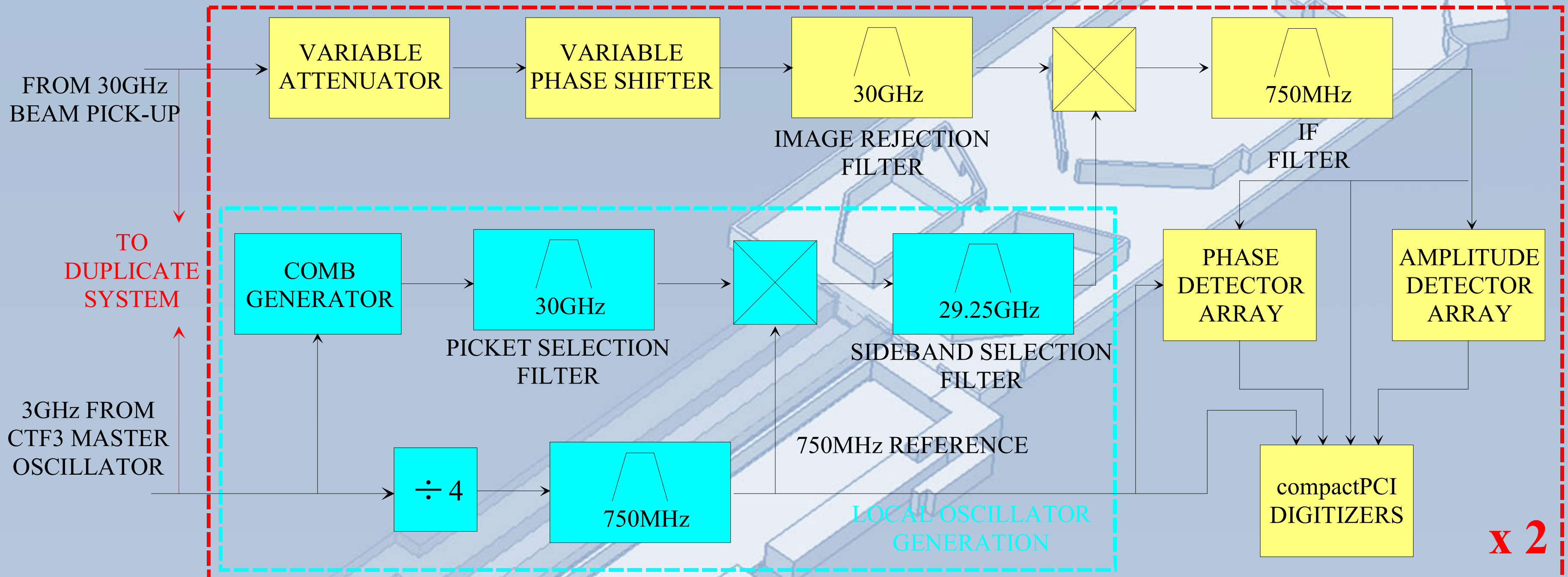
± 50-100MHz bandwidth

0.1 degree resolution

Limited linear range OK

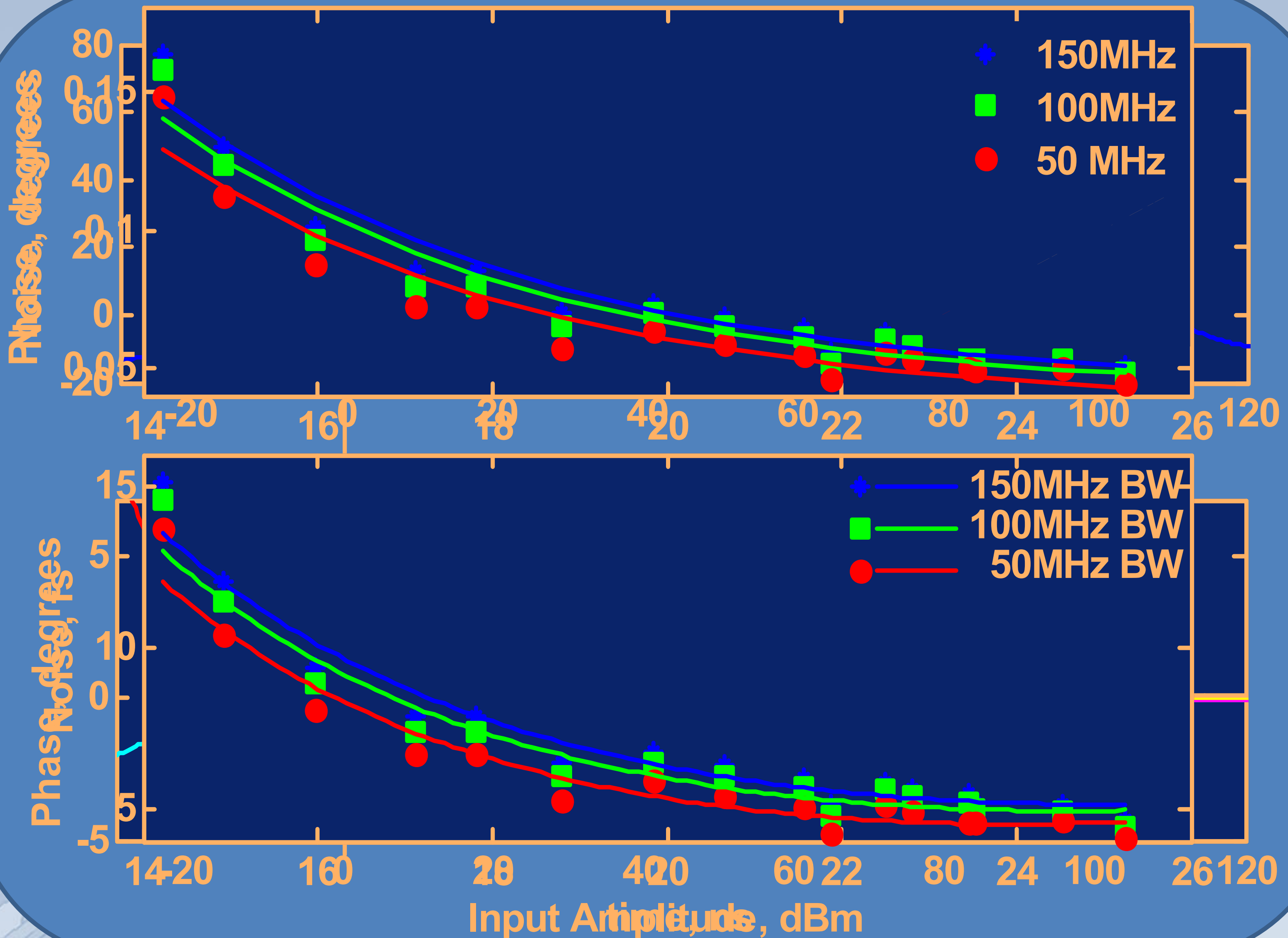
Amplitude range 6dB?

CTF test setup



- Generate a Local oscillator @ 29.25GHz from the 3GHz CTF3 master oscillator
- Mix it down with a 30GHz signal from the beam
- Measure the phase and the amplitude of the 750MHz : to reduce the noise, by summing arrays of analog multipliers and logarithmic amplitude detectors

Beam Phase monitor



Perspectives

For 2010, preparation of CLIC conceptual design report with a cost estimate

Review of beam instrumentation has been initiated for each CLIC sub-systems

- CTF3 beam diagnostic – directly portable to CLIC ?

- CLIC instrumentation already under development at CTF3

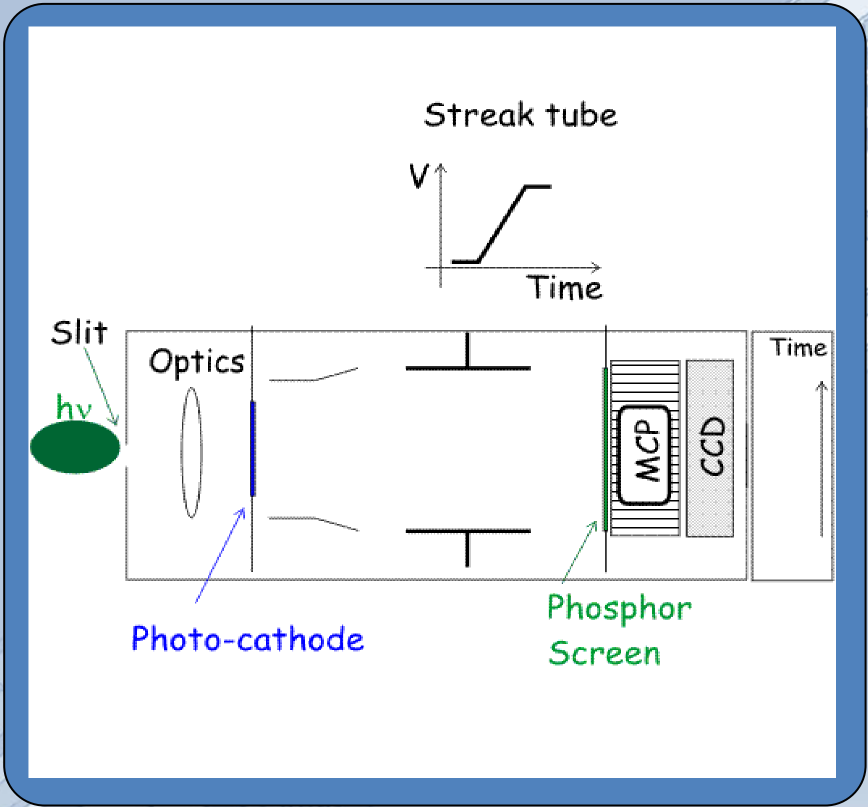
- Just started CLIC instrumentation
    - Machine protection system : Beam loss monitor
    - Luminosity monitors
    -……

- Common interest Instrumentation with ILC and light sources (SR light or FEL's project)
    - Measuring small beam size
    - Polarization monitor
    - Energy measurements
    - Damping ring instrumentation
    -……..

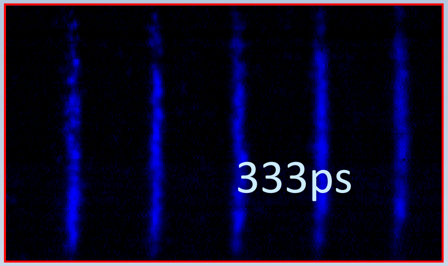
Thanks all the CLIC/CTF3 collaborators who contribute to these developments

Streak Camera

Synchrotron or OTR light from the beam



- 2 Optical lines installed in **2006** in and after Delay Loop
- 2 Optical lines installed in **2007** in Combiner Ring
- **2009 → Optical lines foreseen for CLEX**



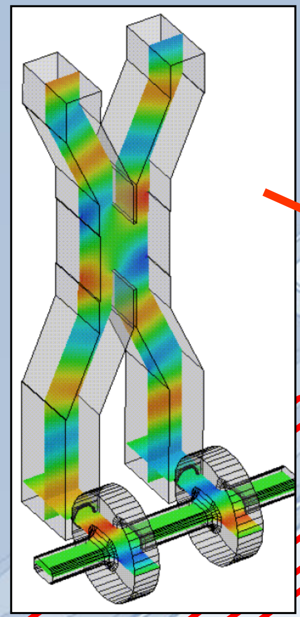
Max sweep 10ps/mm

RF Deflector

2006-2007

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

- Maximum power of 20MW
- 5degrees @1.5GHz = 9.25ps



OTR screen

σ_{noRF} = 0.35mm
σ_{0Xing} = 2.9mm (6.7ps)