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Absolute Bunch Length Measurements at Fermi@ELETTRA FEL

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Presentation Outline

- Theoretical Introduction
  - Overview on Coherent Radiation
- CBLM Design and Method Description
  - Working Principle of Absolute Measurement
- Method Validation
  - Comparison with Low Energy RF Deflector

Introduction

- Bunch Length Measurements are of crucial importance for accelerators.

- Relative Measurements based on Coherent Radiation
  - Can be used as feedback

- Absolute Measurements (Streak Camera, Transverse Radio Frequency Deflecting Cavity, Electro-Optic Sampling)
  - Involve destructive methodology, or require external device to be calibrated

- Novel experimental methodology to self-calibrate a device based on diffraction radiation from ceramic gap

Spectrum-angular distribution of the Energy Radiated

Form factor (F-Transform of longitudinal profile)

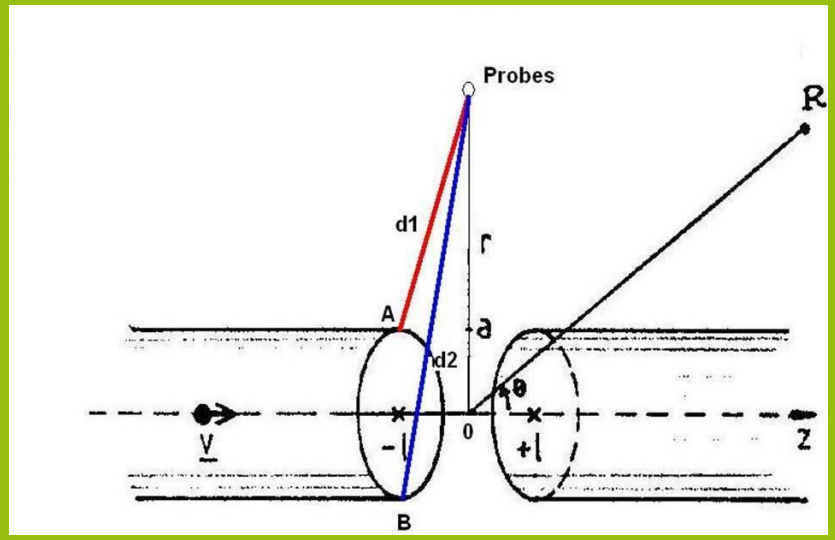
Single electron radiation

Incoherent radiation

$$\frac{d^2W}{d\omega d\Omega} = \frac{d^2W}{d\omega d\Omega}\bigg|_{1e^-} (N + N(N-1)|F(\omega)|^2)$$

Coherent radiation

Single Electron Gap Radiation



GAP → Faced coaxial waveguides
Charge passes through the gap →
currents induced on the pipe walls →
Source for electromagnetic field
Both from Step-out and Step-in

Step-out prevailing

Single Electron Gap Radiation Spectrum-angular Distribution

- The electromagnetic problem of the coherent radiation from a gap has been studied
- Formal solution exists (B. Bolotowskii, G. Voskresenskii)
- Based on Wiener-Hopf Factorization method
- In the case of high frequencies (ka>>1 with *k* the wave number and *a* the pipe radius) →
- Approximation of the formula

$$\left.\frac{d^2W(\theta)}{d\omega d\Omega}\right|_{1e^-} = \beta e^2 \frac{\sin^2\theta J_0^2(ka\sin\theta)}{4\pi^2 c(1-\beta\cos\theta)^2 I_0^2(\frac{ka}{\beta\gamma})} \cdot \left| \sqrt{\frac{1-\beta}{1-\cos\theta}} e^{jk\ell(1-\beta\cos\theta)/\beta} + \right.$$

$$\left. j\sqrt{\frac{1+\beta}{1+\cos\theta}} e^{-jk\ell(1-\beta\cos\theta)/\beta} \right|^2$$

Step-in

Step-out
(prevailing over step-in for ultrarelativistic velocities)

L. Palumbo, CERN-LEP-TH/84-4 (1984)
B. Bolotowskii, G. Voskresenskii, SPTP 9, 546 (1946)

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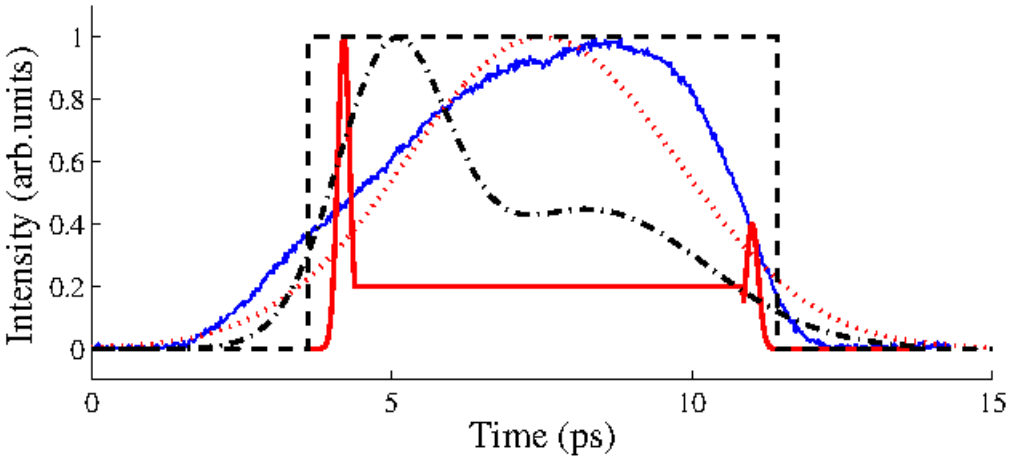
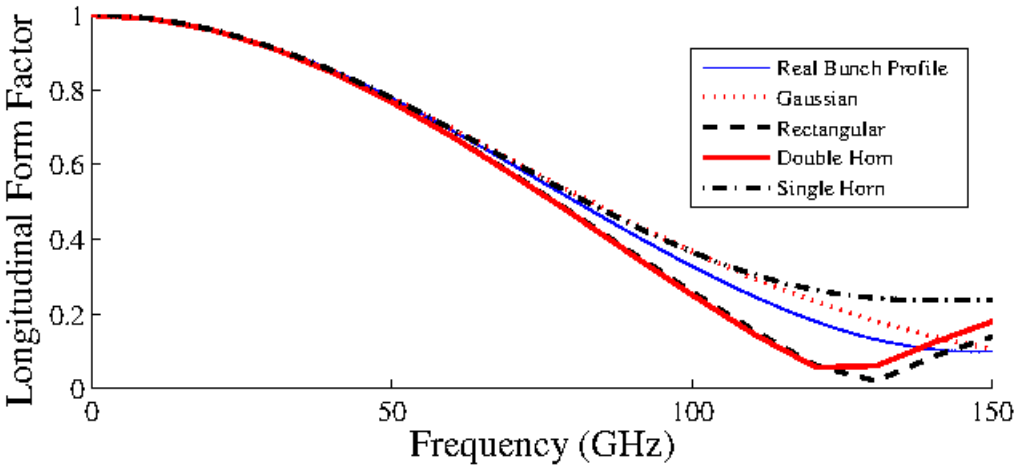
Coherent radiation

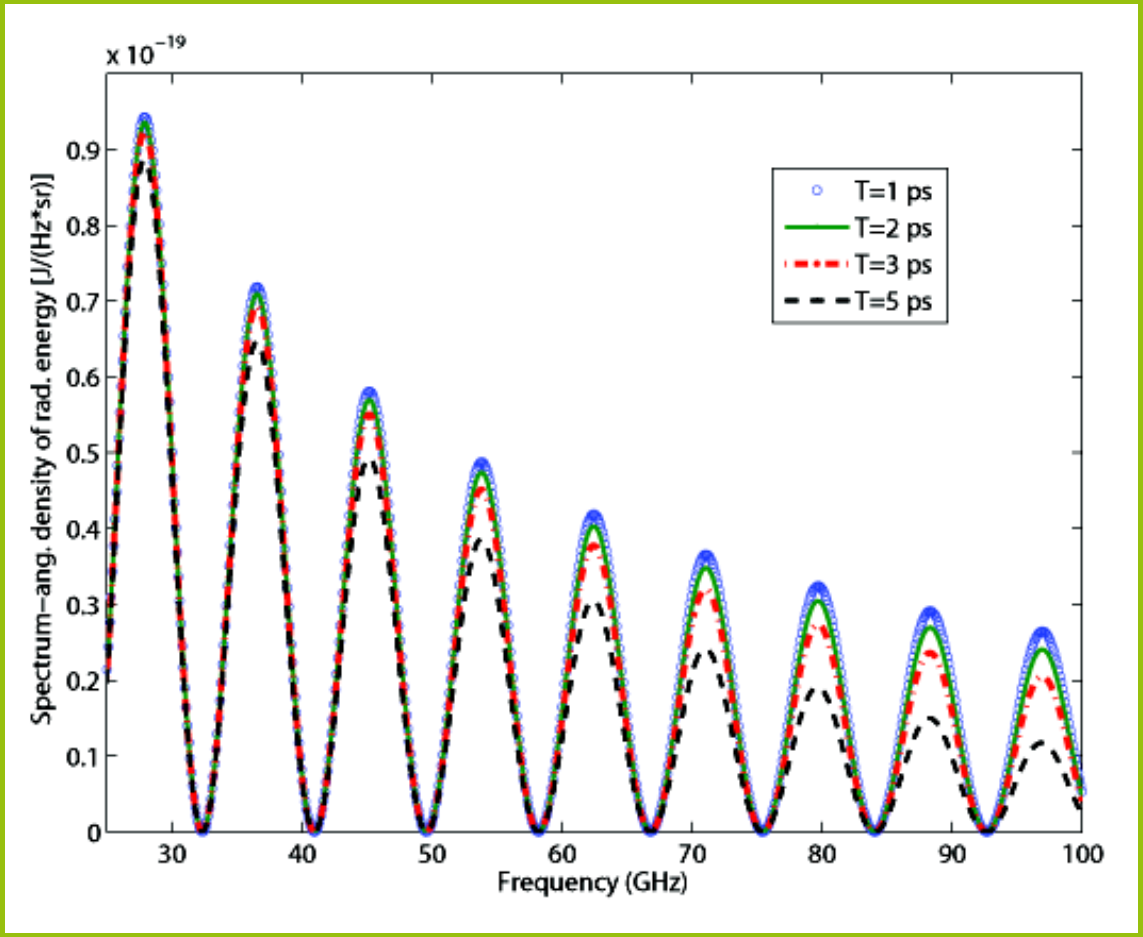
Single Electron Gap Radiation





- Profiles and Form Factor of 2.3 ps rms length
- At 30 GHz, Form Factor not sensitive to the details of the Profile
- Allows to use rectangular bunch for calculations
- 30 GHz diode ok for ~ 2.3 ps long bunches
- Shorter bunches require higher frequency detectors

Rectangular Gap Radiation

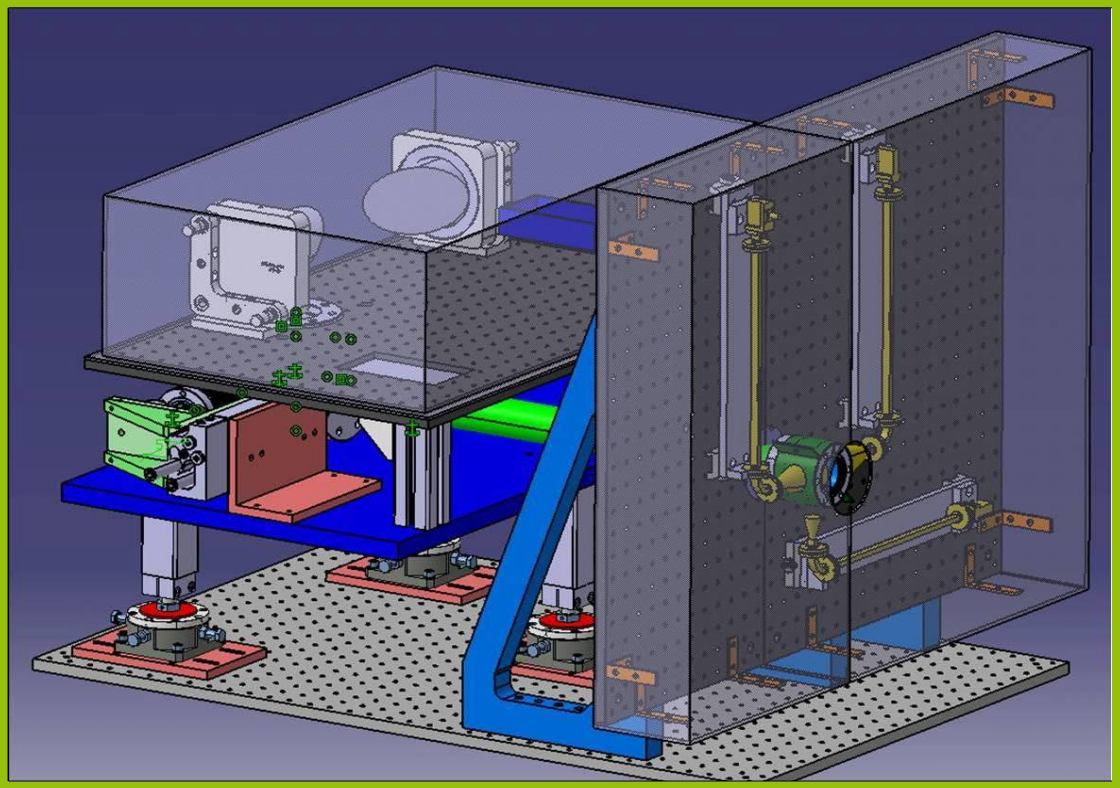


- Intensity drops as frequency increases
- Relative variation of intensity is larger for larger bunches
- Eventually, for shorter and shorter bunches variation becomes negligible →

ASYMPTOTIC BEHAVIOUR EXPLOITED TO PERFORM ABSOLUTE BUNCH LEGTH MEASUREMENT

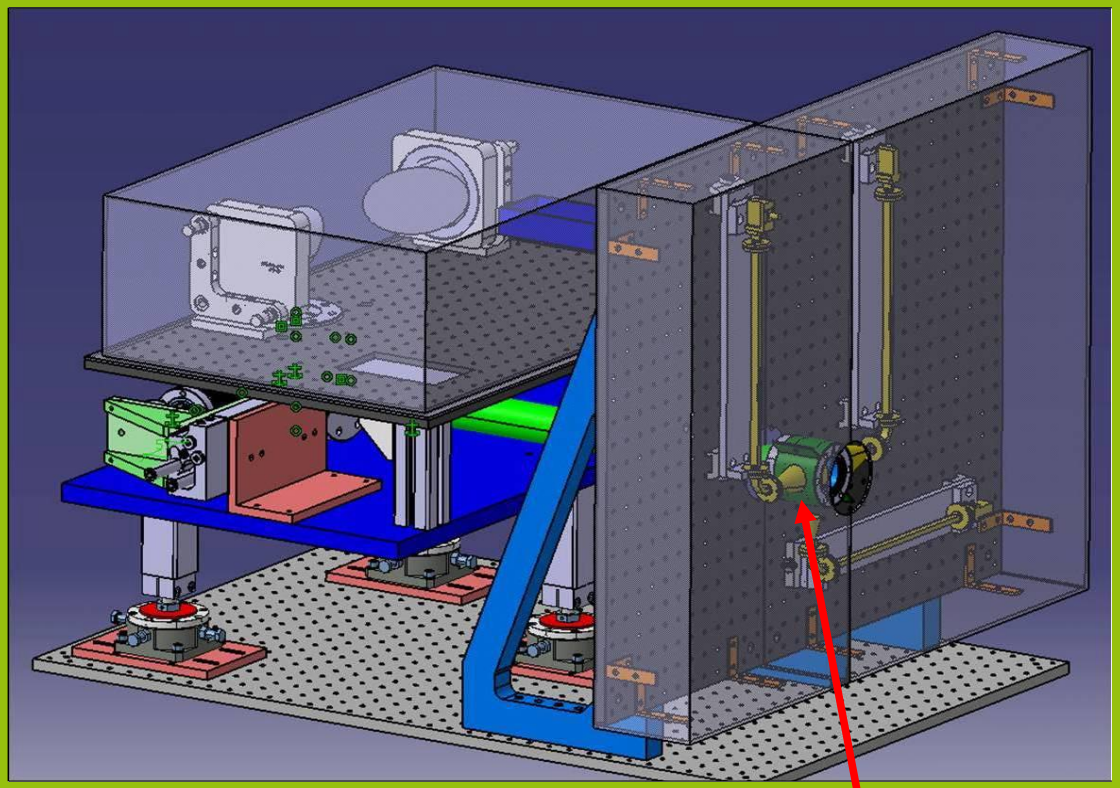
Coherent Bunch Length Monitor Layout

Coherent Bunch Length Monitor Layout

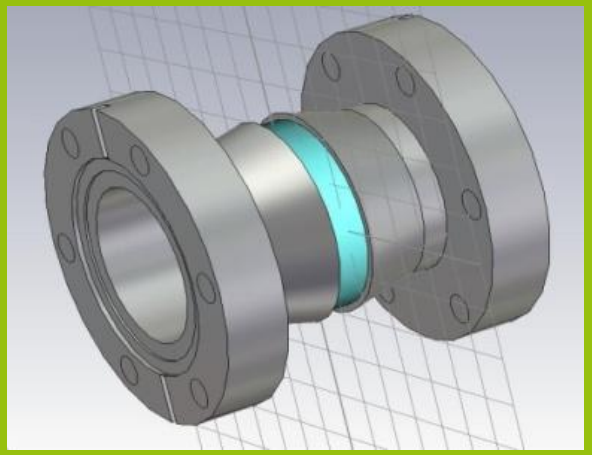


Courtesy M.Tudor

Coherent Bunch Length Monitor Layout

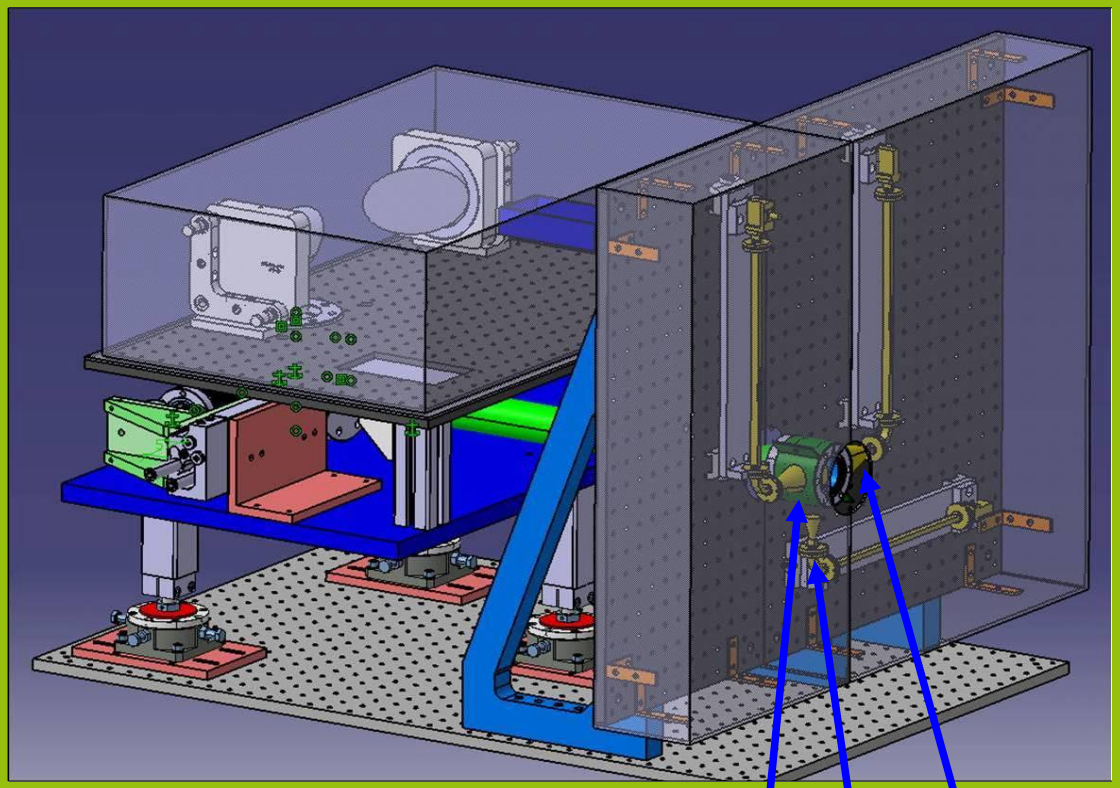


Courtesy M.Tudor



Ceramic gap

Coherent Bunch Length Monitor Layout



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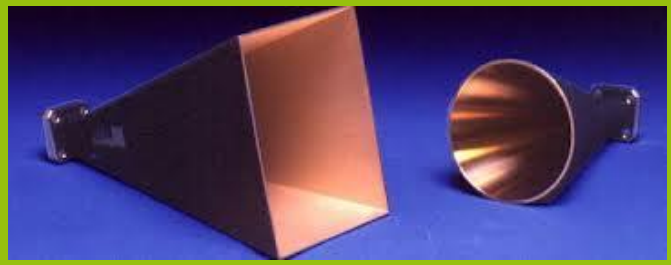
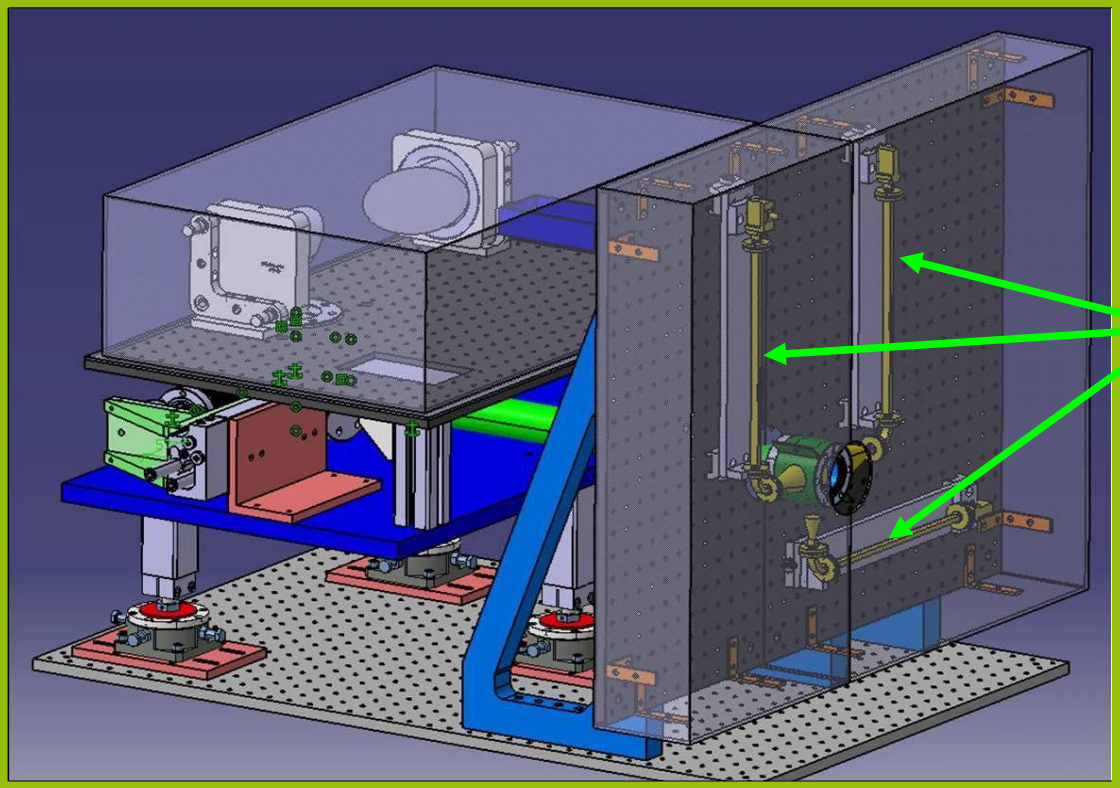


Horn antennas

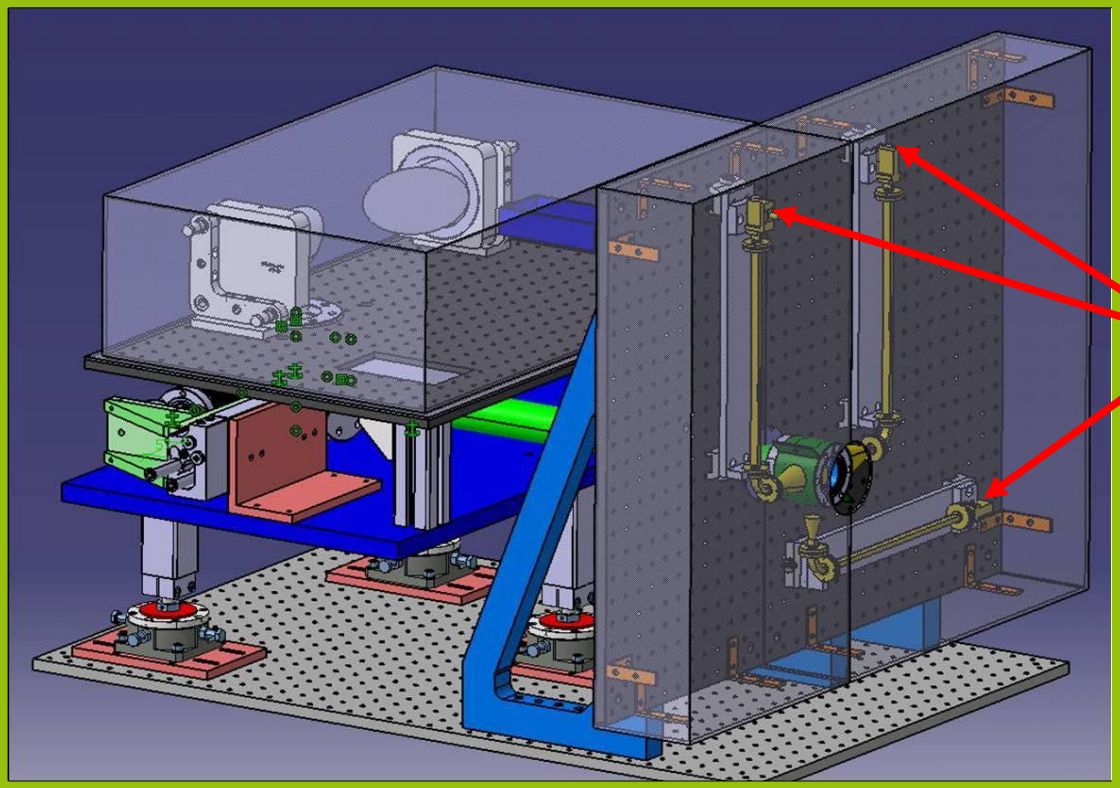
Coherent Bunch Length Monitor Layout



Waveguides

Courtesy M.Tudor

Coherent Bunch Length Monitor Layout



Schottky Diodes

Working in the 'Square root of power' region

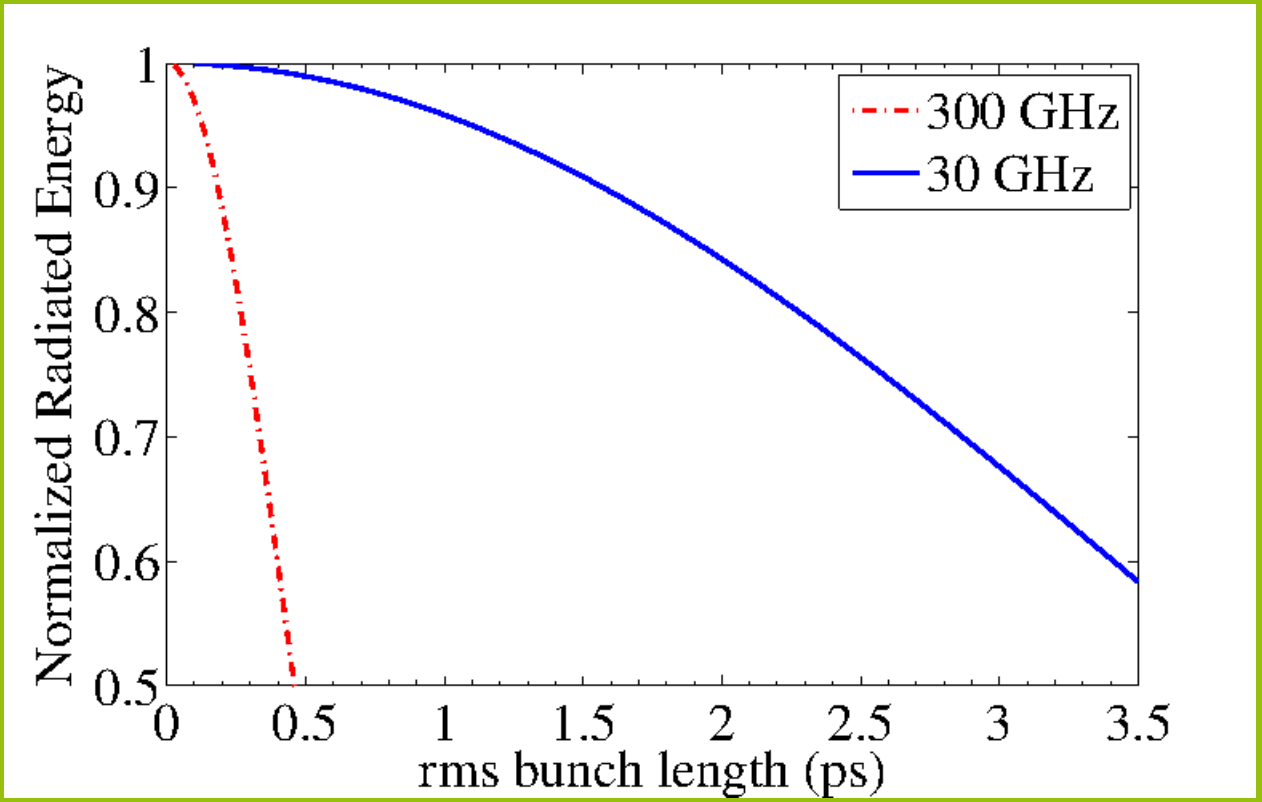
$$\text{Diode signal} \propto N$$

Courtesy M.Tudor

Method Highlights

Method Highlights

- Increasing compression factor → bunch length decreases
- Energy radiated increases, up to an asymptotic value
- Register this value as reference
- Diode output signal normalized → Theoretical fitting curve, obtained for rectangular bunches, is used to convert from Energy to bunch length

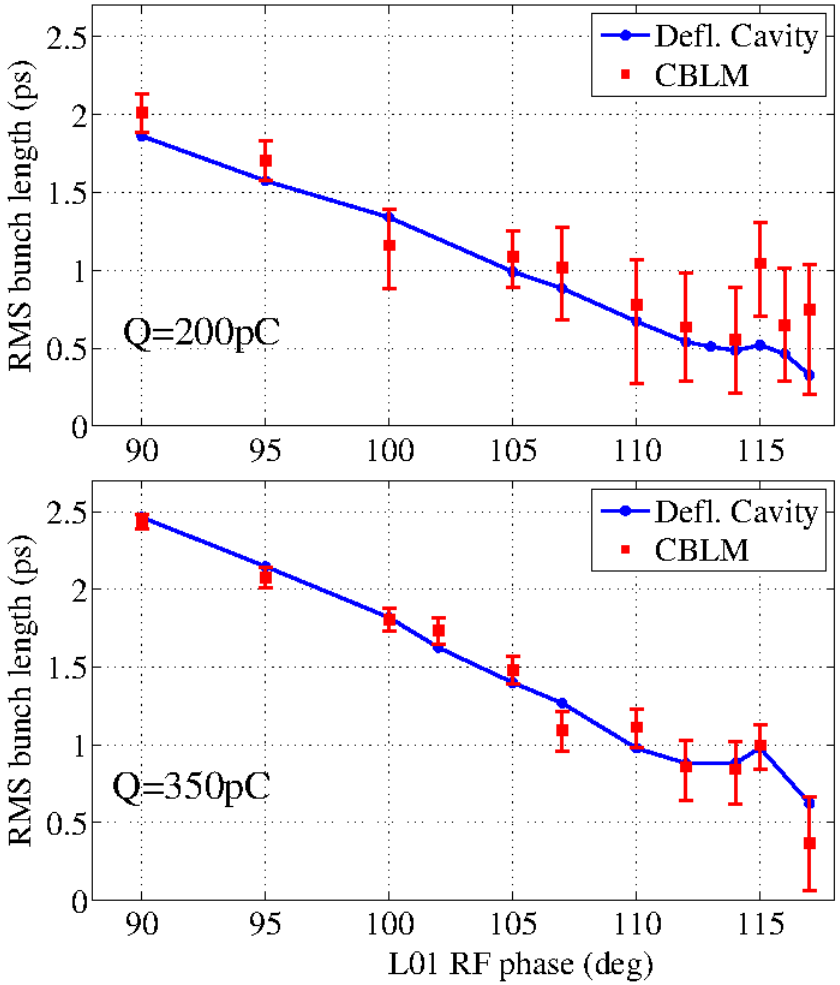


- Energy radiated by a rectangular electron bunch at 30 and 300 GHz

- Curves obtained integrating the Spectrum-angular density over the antennas acceptance angle and the diode bandwidth

Method Validation

CBLM vs Low Energy RF Deflector



- Bunch Length vs Compression Factor
- Comparison between length measured with CBLM and rf deflecting cavity
- Values averaged over 50 consecutive bunches
- Saturation for 0.5 ps
- Good agreement

Conclusions

- Presented a self-calibration method for Bunch Length Monitor at Fermi@ELETTRA
- Provides absolute length measurements without the need of an external calibration device
- Validation by means of the comparison with Low Energy RF Deflector measurements
- Good agreement and validity of the method shown

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