UCLA-ATF Chicane Compressor Experiment

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Outline

- ✓ Motivation for chicane studies
  - need for bunch compression
  - limitations of the simple model
- ✓ ATF compressor design and simulations
- ✓ Chicane Engineering
  - magnets and vacuum chamber
  - e-beam diagnostics
- ✓ Coherent Radiation Studies
  - bunch length measurements
  - CER (Coherent Edge Radiation)
- ✓ Experimental progress and future plans

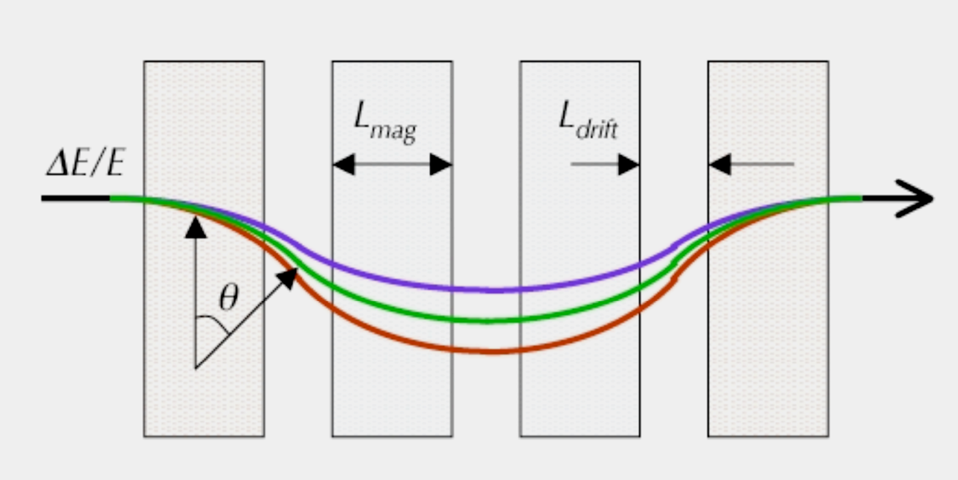
Magnetic Bunch Compression

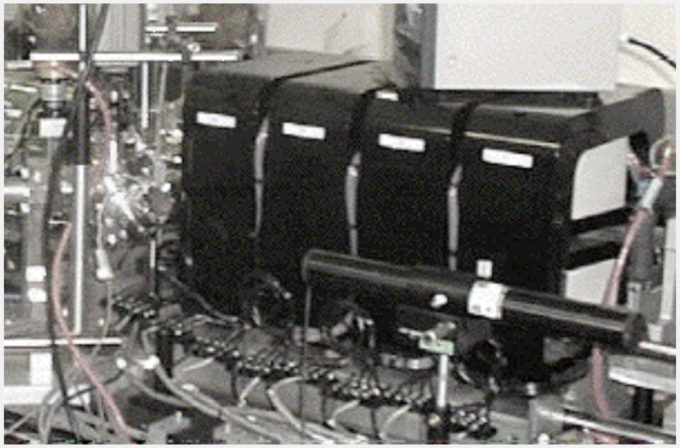
In the chicane larger energy particles move along the shorter trajectory. When the bunch is properly chirped in the linac before the chicane entrance (so that the more energetic particles are in the tail of the bunch) an overall bunch compression can be achieved.

$$\Delta L = R_{56}\frac{\Delta E}{E} + T_{566}\left(\frac{\Delta E}{E}\right)^2$$

The linear term is defined by the geometry of the magnets:

$$R_{56} = 2\theta^2(L_{dft} + \frac{2}{3}L_{mag})$$

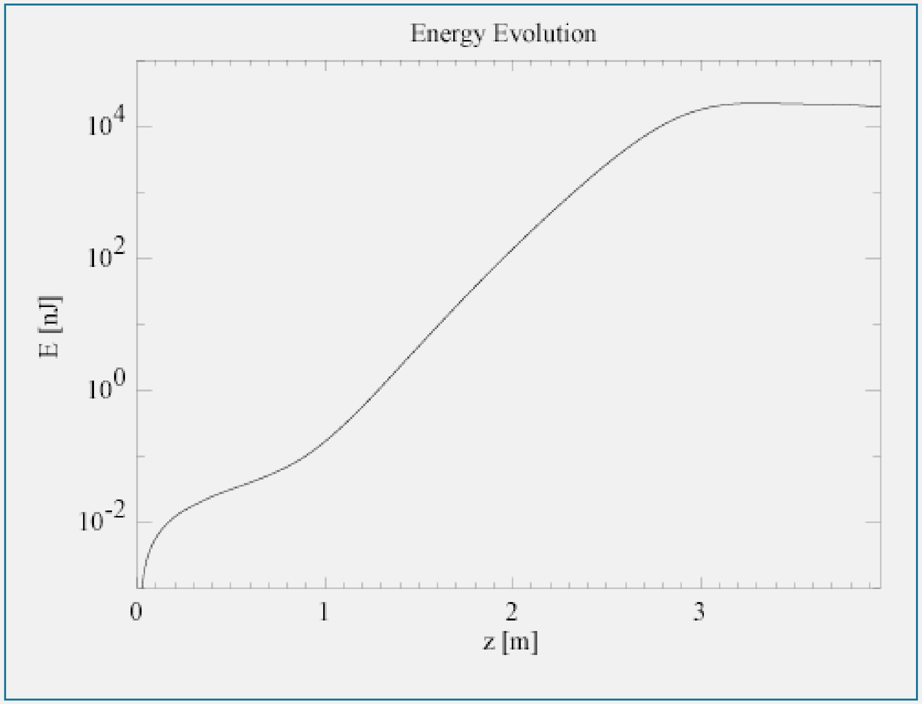




Motivation for Shorter Bunches

- ✓ Advanced Accelerator Schemes
  - Plasma-Beam Interactions
  - Laser-Beam Interactions
  - Wakefield Accelerators
- ✓ Light Sources
  - Free Electron Lasers
  - Inverse Compton Scattering

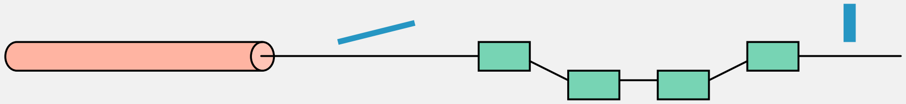
$I_P \sim 1.3$ A



VISA 2b example:
running chicane allows saturation
in less than 3 m.

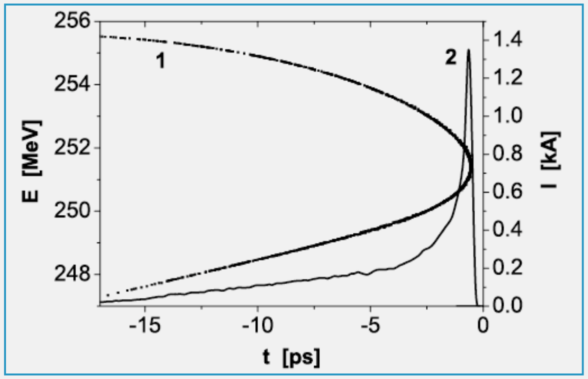
Limits of Magnetic Compression

In the ideal world, one can start with the linear chirp, and obtain a perfectly compressed beam, limited only by the uncorrelated energy spread :



Other limiting factors need to be considered:

- nonlinearities in the e-beam longitudinal phase space before after the linac
  - non-linear curvature
  - space charge induced energy modulation
  - non-flat current distribution
- imperfections in chicane construction
  - non-zero dispersion, due to asymmetry
- collective effects
  - CSR (Coherent Synchrotron Radiation)
  - velocity field effect
  - wakefields



Goals of UCLA/ATF Program

✓Enhance the ATF capabilities for the high peak current sensitive experiments.

✓Comprehensive studies of the beam physics in the chicane:

- Beam compression efficiency studies;
- Transverse phase space tomography;

✓Collective effects

- CER spectrum characterization;

✓Development of numerical methods

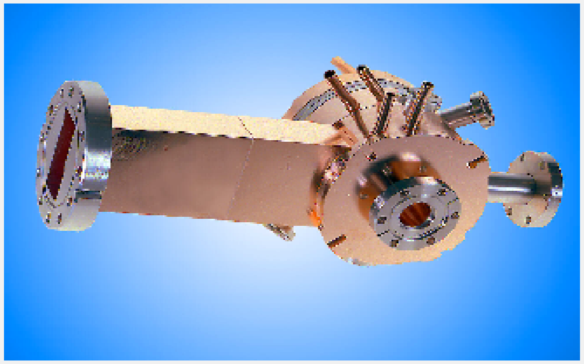
- Start-to-end simulations using PARMELA-ELEGANT;
- New code development to include collective effects;

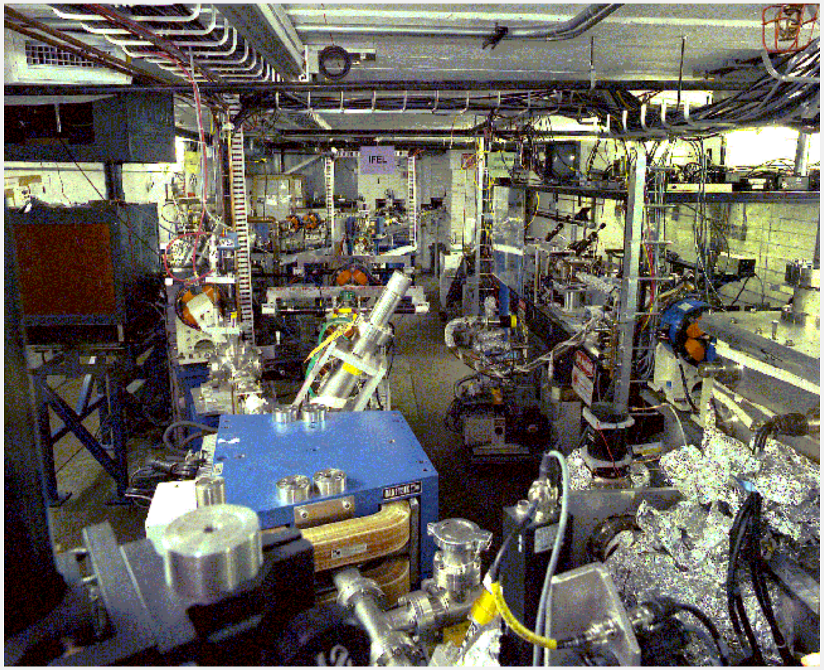
Collaborators:

- I. Ben-Zvi, M. Woodle, V. Yakimenko, **ATF-BNL**
- L. Palumbo, C. Vicario, A. Flacco, **INFN**
- R. Agustsson, G. Andonian, M. Fairchild, P. Frigola, S. Reiche, J. Rosenzweig, G. Travish, F. Zhou, **UCLA**
- U.Happek, **UG-Athens**

Accelerator Test Facility

- ✓ ATF-BNL is a state of the art photo-injector users facility.
- ✓ UCLA-SLAC-BNL RF gun
- ✓ 2 SLAC-type linacs capable to deliver up to 75 MeV beam
- ✓ 3 users beamlines



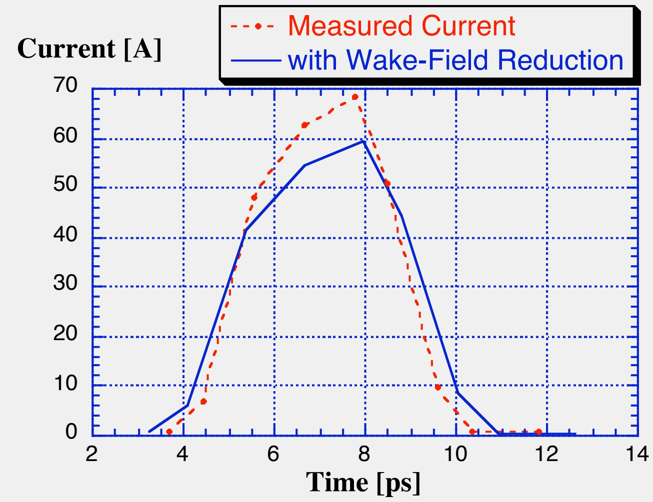


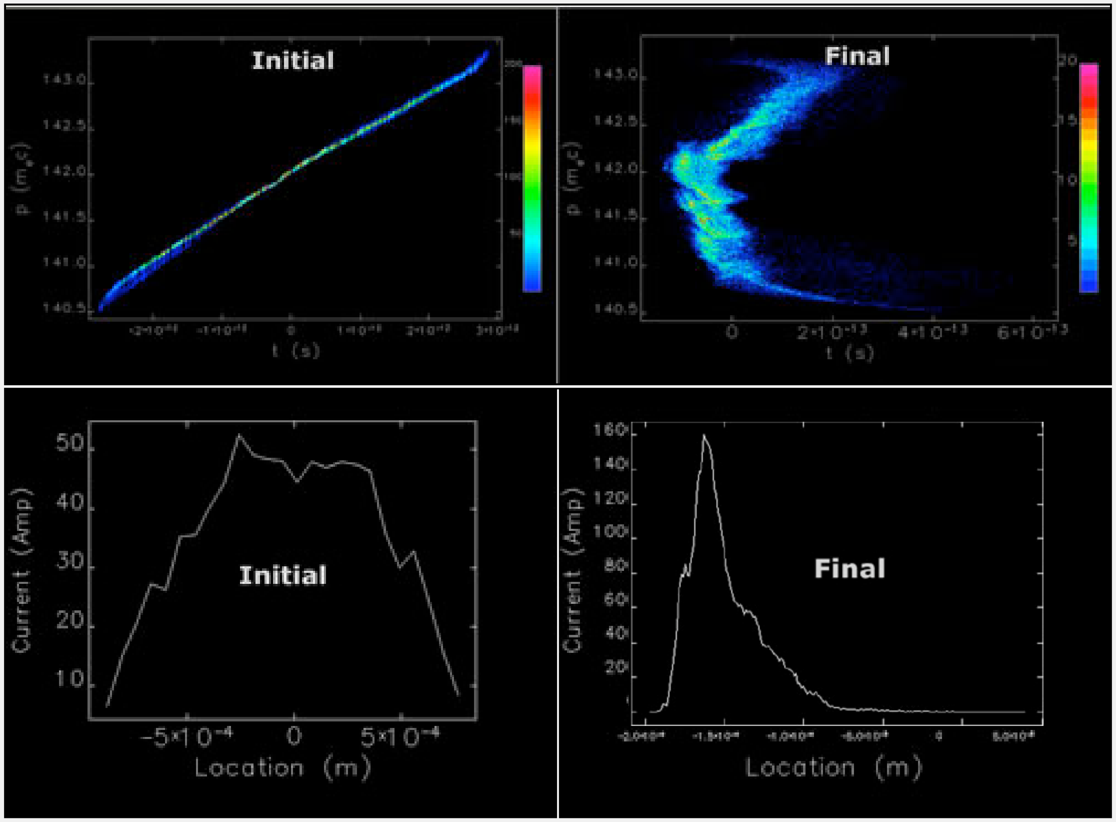
Design Parameters

✓ PARMELA - ELEGANT Simulations

Beam Parameters:

$\mathcal{E} \sim 72$ MeV **$Q \sim 200$ pC**
$\varepsilon_n \sim 1.5\ \mu$m **$I_p \sim 55$ A**

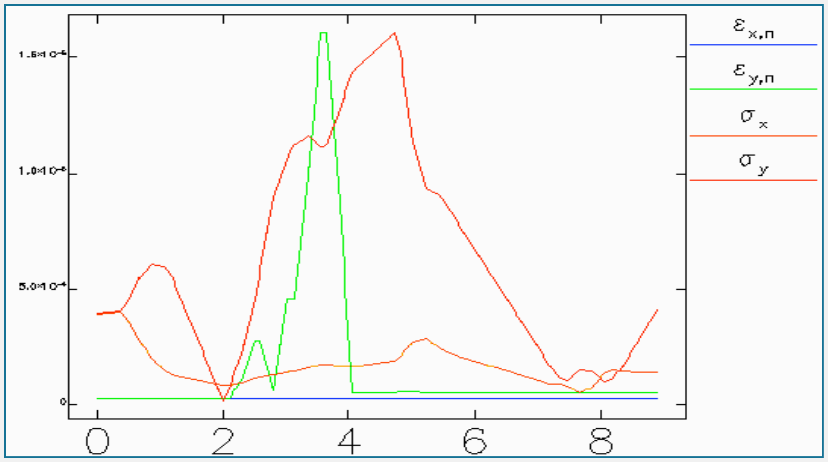


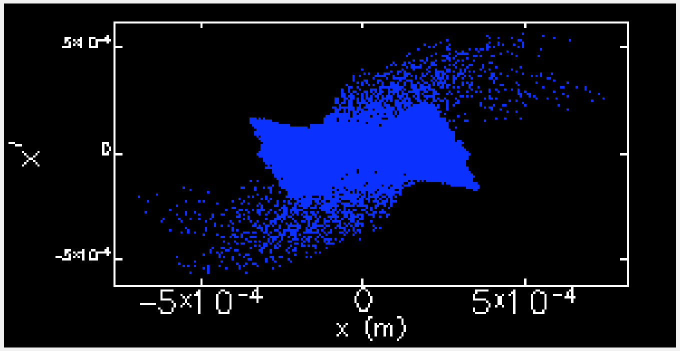


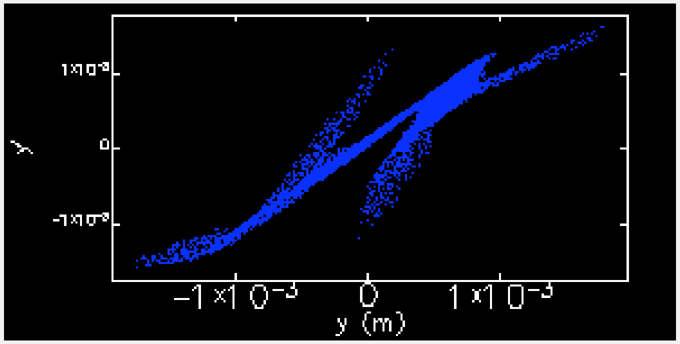
Emittance Growth

Two mechanisms of $\epsilon_{y,n}$ growth:

- 2nd order effects due to large beam size
- CSR and velocity field effects







Initial beam:
$\epsilon_{n,x}$= $\epsilon_{n,x}$ ~1.5 μm

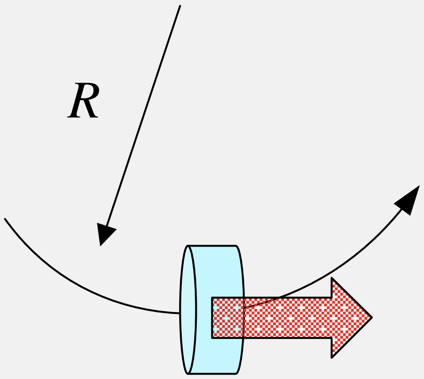
Final beam:
$\epsilon_{n,x}$ ~1.5 μm (no change)
$\epsilon_{y,x}$ ~3.1 μm (without CSR) and 5.8 μm w/CSR

Model Limitations

ELEGANT CSR model limitations:

- No velocity field is included;
- No boundaries are included;
- CSR model is based on a “thin beam” limit:

$$\sqrt{\frac{\sigma y}{R}} << \frac{\sigma z}{\sigma y}$$



With the design parameters the Derbenev criterium is not satisfied:

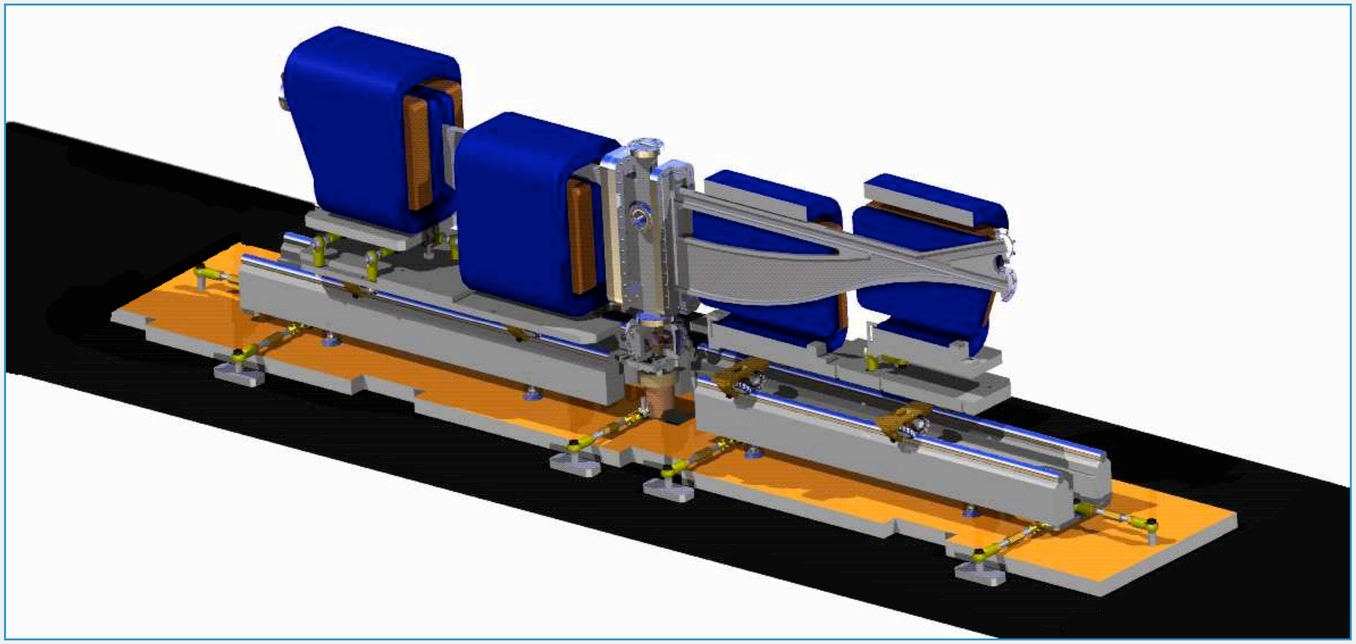
σ_y~1 mm

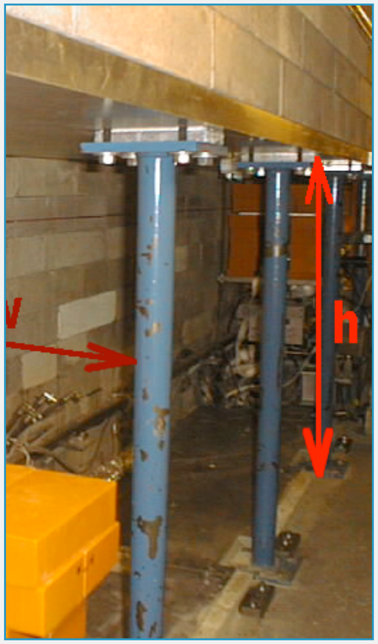
σ_z~20 μm

R=1.2 m

UCLA develops a new code, to directly calculate LW potentials.

Engineering Design

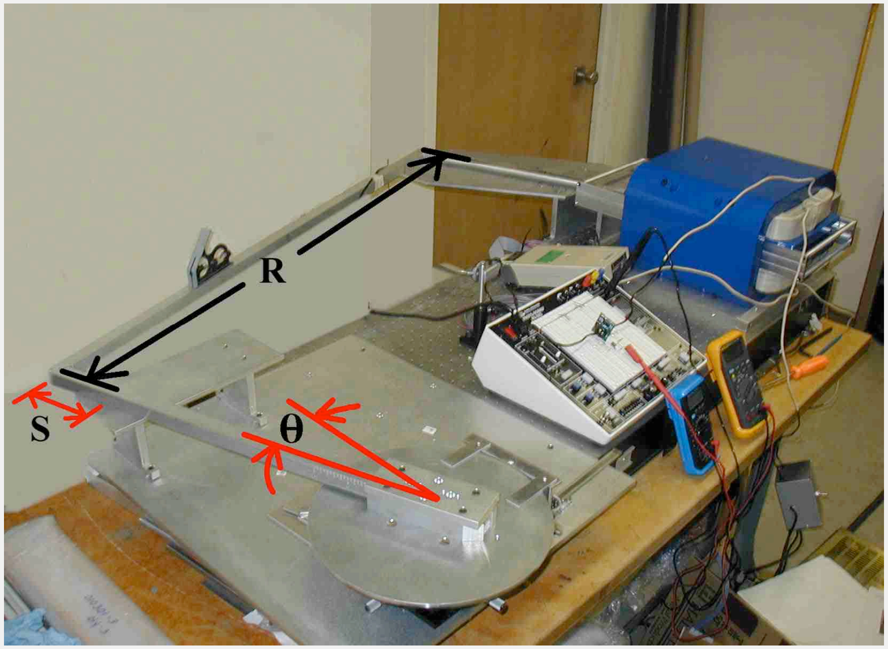


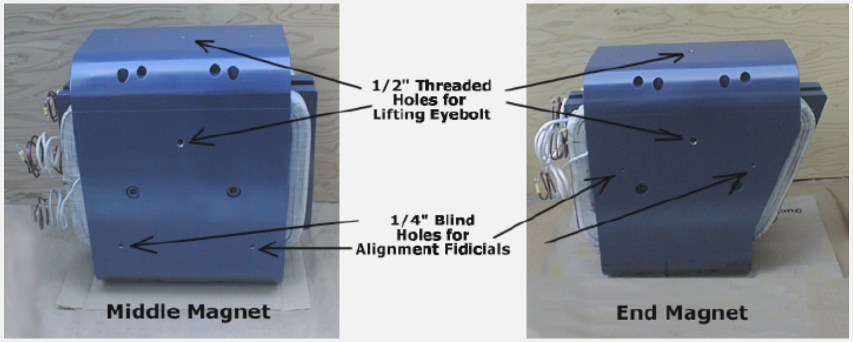


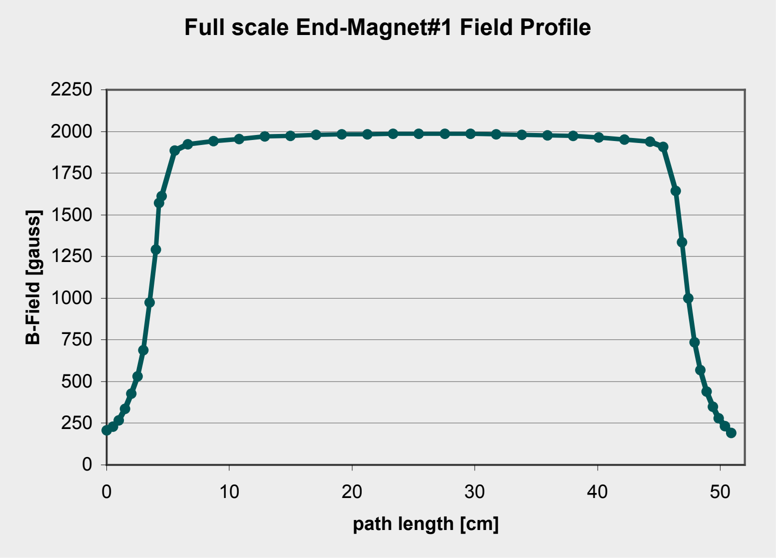
- ✓ System components: magnets, vacuum chamber, stand and rail system, centerpiece e-beam diagnostics, radiation port.

Magnets

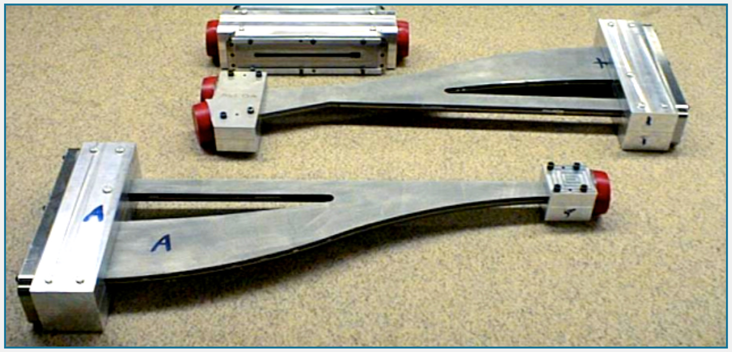
Magnet's edges provide for vertical focusing, while fringe fields provide for horizontal.

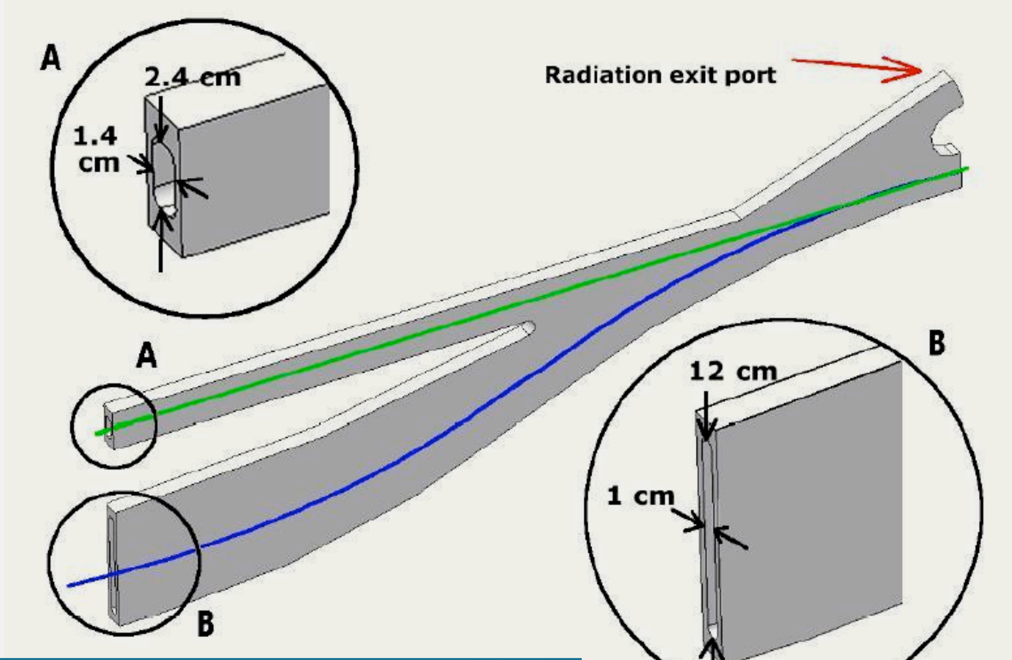




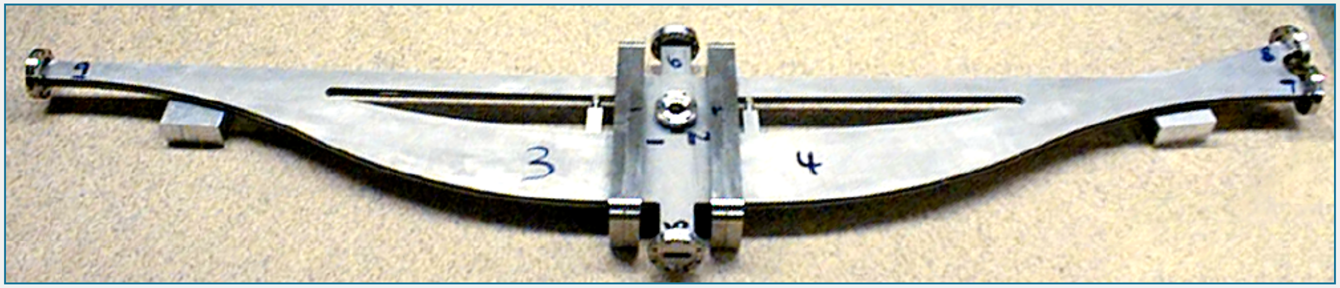


Vacuum Chamber



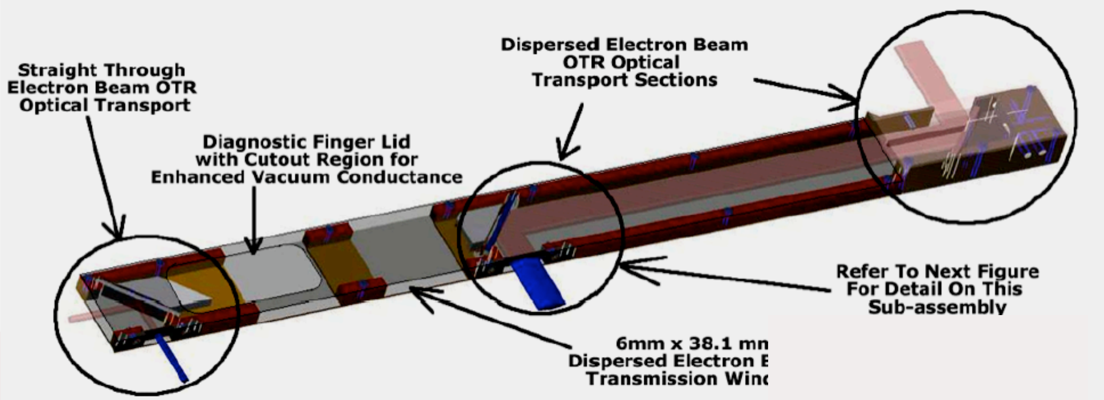


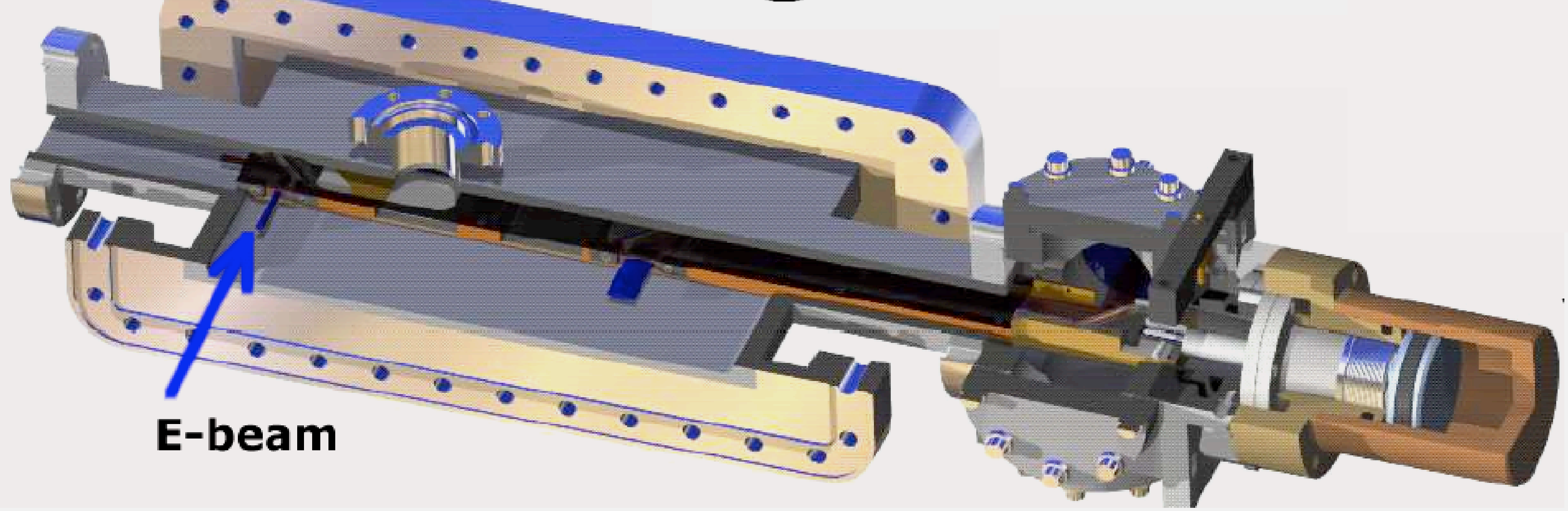
Dual aperture chamber:
A-magnets off, B-magnets on.



Diagnostic Section

Beam profile can be measured in 2 positions: on a straight pass or with the magnets turned on.

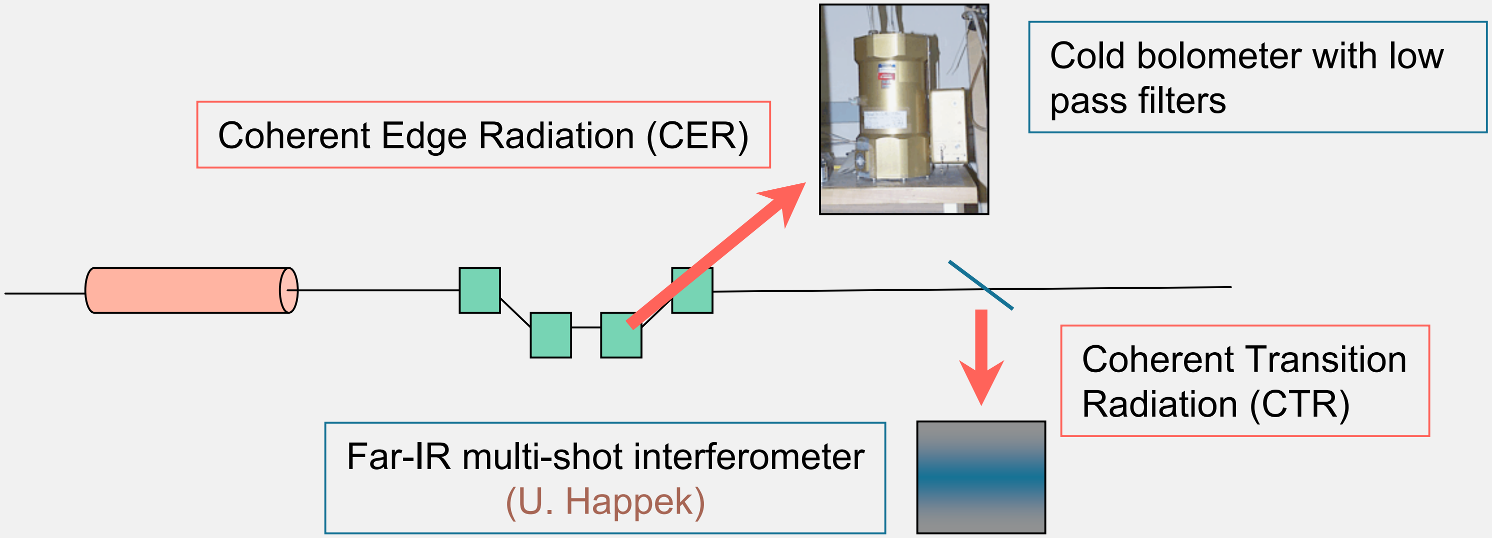




Coherent Radiation Measurements

For an electron beam, the radiated spectral intensity depends on the longitudinal profile of the electron beam:

$$\mathcal{E}(\omega) \propto \mathcal{E}_0(\omega) N_e^2 \left| \frac{1}{Q} \int I(t) e^{i\omega t} dt \right|^2 \sim \mathcal{E}_0(\omega) \left| \tilde{I}(\omega) \right|^2$$



Coherent Edge Radiation (CER)

Cold bolometer with low pass filters

Coherent Transition Radiation (CTR)

Far-IR multi-shot interferometer
(U. Happek)

45° - Transition Radiation

For long wavelengths ($\lambda >> \sigma_p$), spectral intensity of the coherent diffraction radiation from a single electron is flat

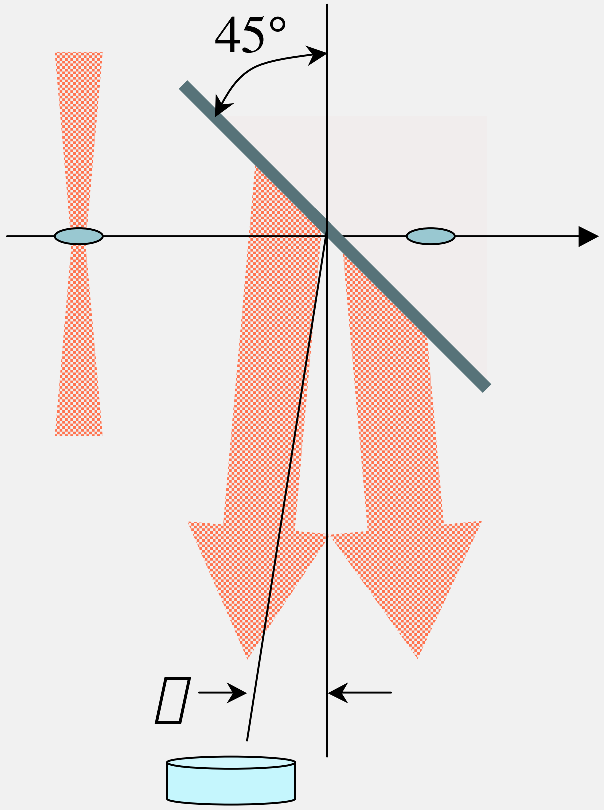
$$\frac{d^2\mathcal{E}_0}{d\omega d\Omega} \approx \frac{e^2\gamma^4}{4\pi^3\varepsilon_0 c}\left[\frac{\theta}{1+\gamma^2\theta^2}\right]^2$$

(peaked at $\gamma\theta \sim 1$)

$$\mathcal{E}_0(\omega) \approx \frac{e^2}{2\pi^2\varepsilon_0 c}\, ln(\gamma)$$

CTR

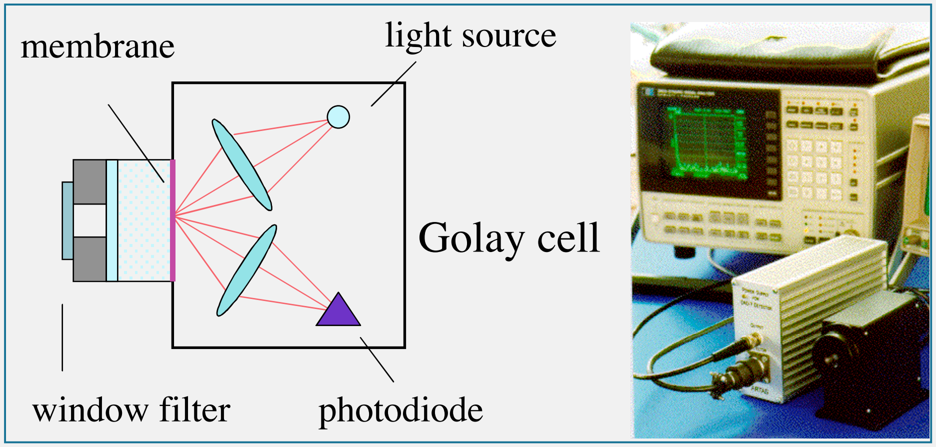
$$\boxed{\mathcal{E}(\omega) \sim \left|\tilde{I}(\omega)\right|^2}$$

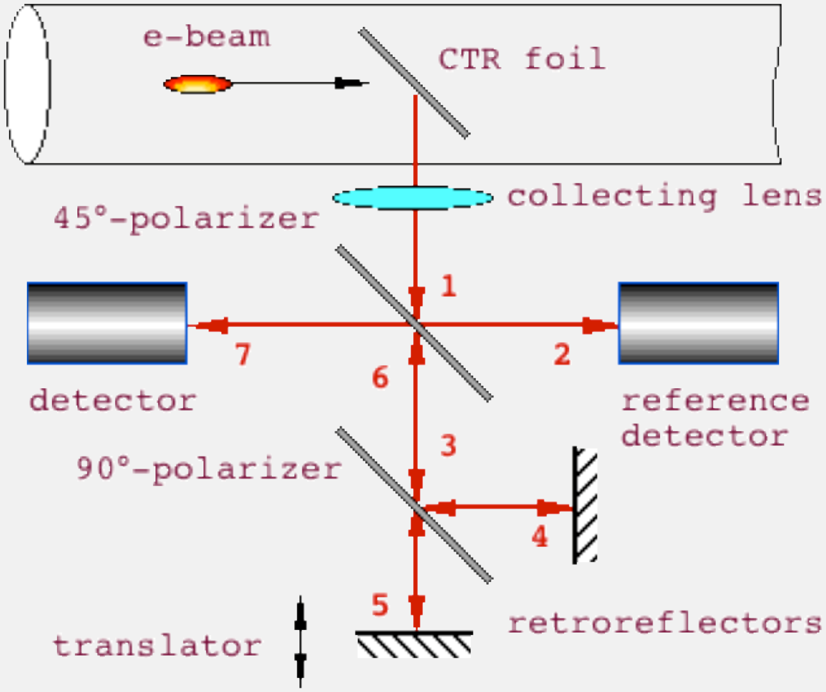


CTR Interferometer

- ✓ Changing one arm of the interferometer allows to measure the autocorrelation of the CTR signal:

$$S(\tau) \sim \int I(t)I(t+\tau)\,dt$$





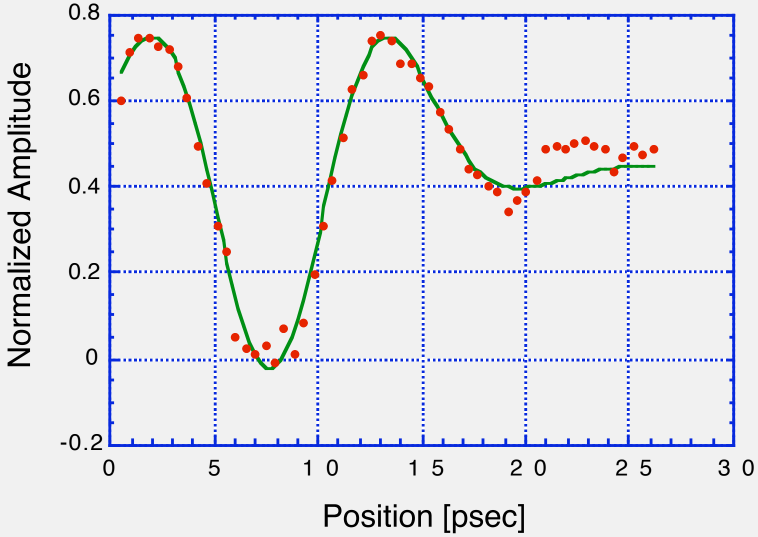
(Golay cell window has a low-pass cut-off ~15-20 μm)

Data Analysis

Fourier transform measured autocorrelation function:

$$\tilde{S}(\square) \sim \left|\tilde{I}(\square)\right|^2 k_{LOSSES}(\square)$$

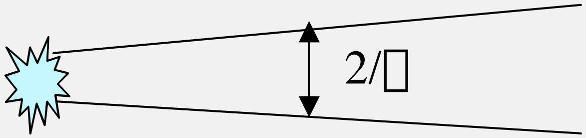
$$k_{LOSSES}(\square) = e^{\square\square^2\square^2}$$



Missing long frequencies due to:

- Golay Cell window acceptance
- Beamsplitter Efficiency Losses
- Radiator size

$2\square\square_{eff}\ \square\ \square\square/2$

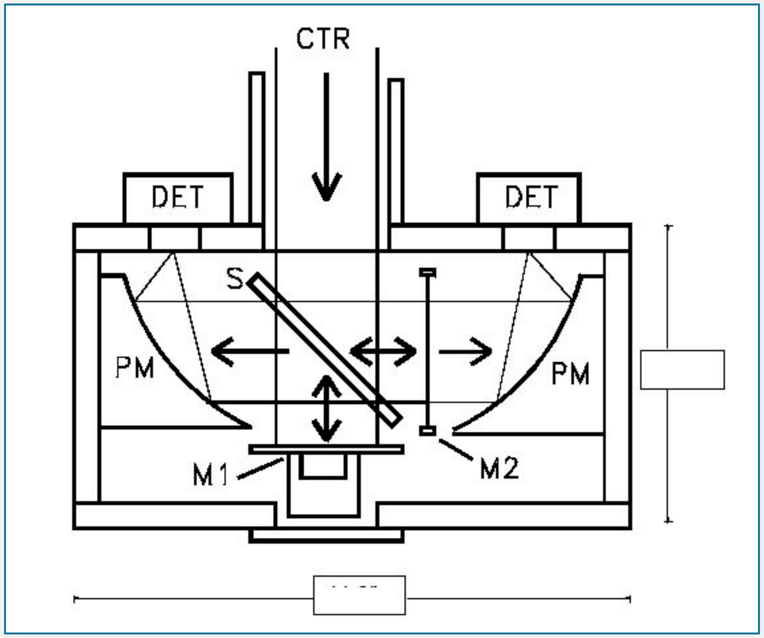


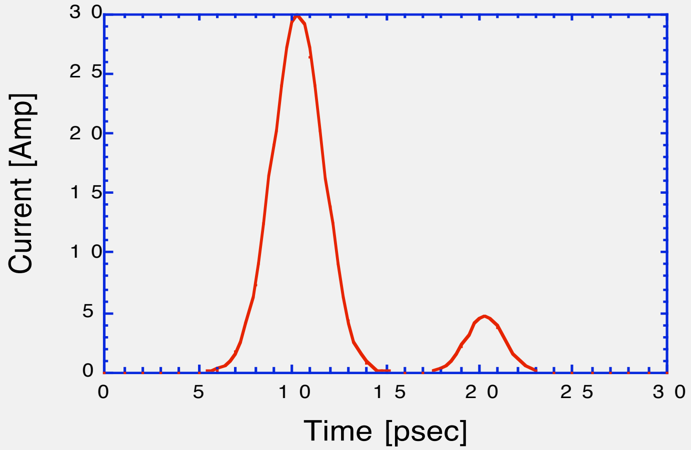
For the ATF beam the problems appear at □ ~ 300 μm
(□~140 => $2\square\square_{eff} \sim 2.1$ cm)

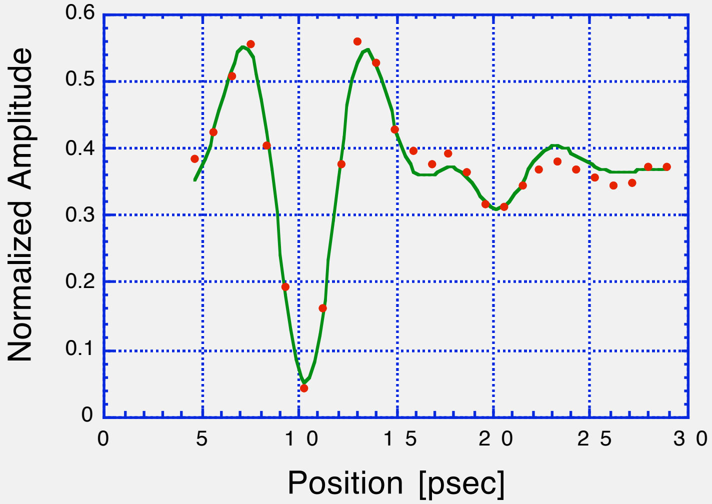
$$S(\square) \sim \begin{bmatrix} e^{\square\frac{\square^2}{4\square_t^{\,2}}} \square \frac{2\square_t}{\sqrt{\square_t^{\,2} + \square^2}} e^{\square\frac{\square^2}{4(\square_t^{\,2}+\square^2)}} + \frac{2\square_t}{\sqrt{\square_t^{\,2} + 2\square^2}} e^{\square\frac{\square^2}{4(\square_t^{\,2}+2\square^2)}} \end{bmatrix}$$

New Model of Interferometer

New model of interferometer was developed at UG. More sophisticated fitting algorithms can be applied, given the increased resolution of the system.

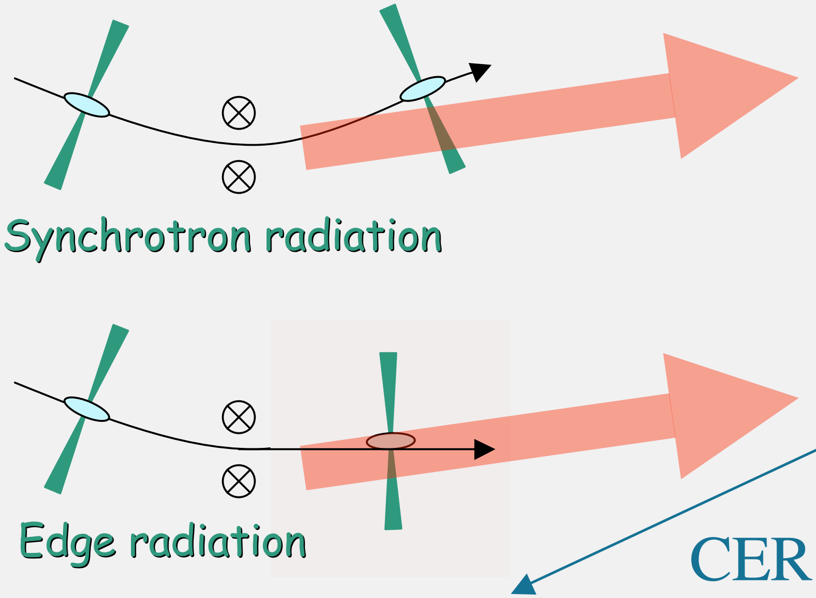






Edge Radiation Spectrum

Edge radiation is a form of the synchrotron radiation while the beam crosses the boundary of a magnet.

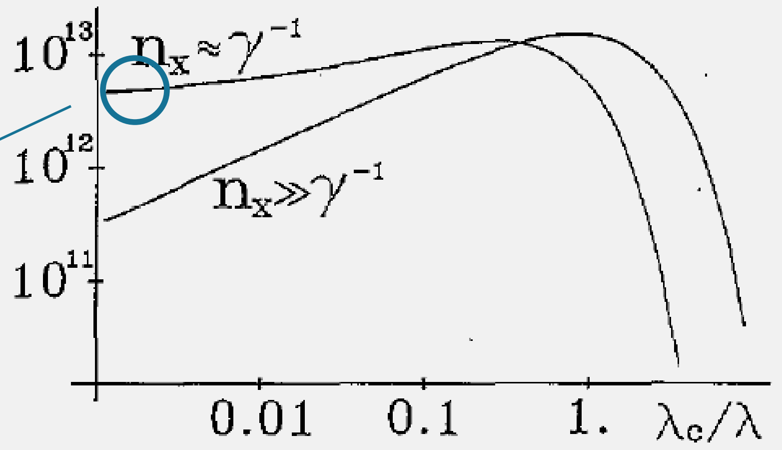


$\mathcal{E}_0(\square) \sim \square^{2/3}$

$\left[\frac{\square c}{\square R} << \square << \square_c\right]$

(peaked at $\square\square \sim 1$)

$\square_c \sim 50$ nm

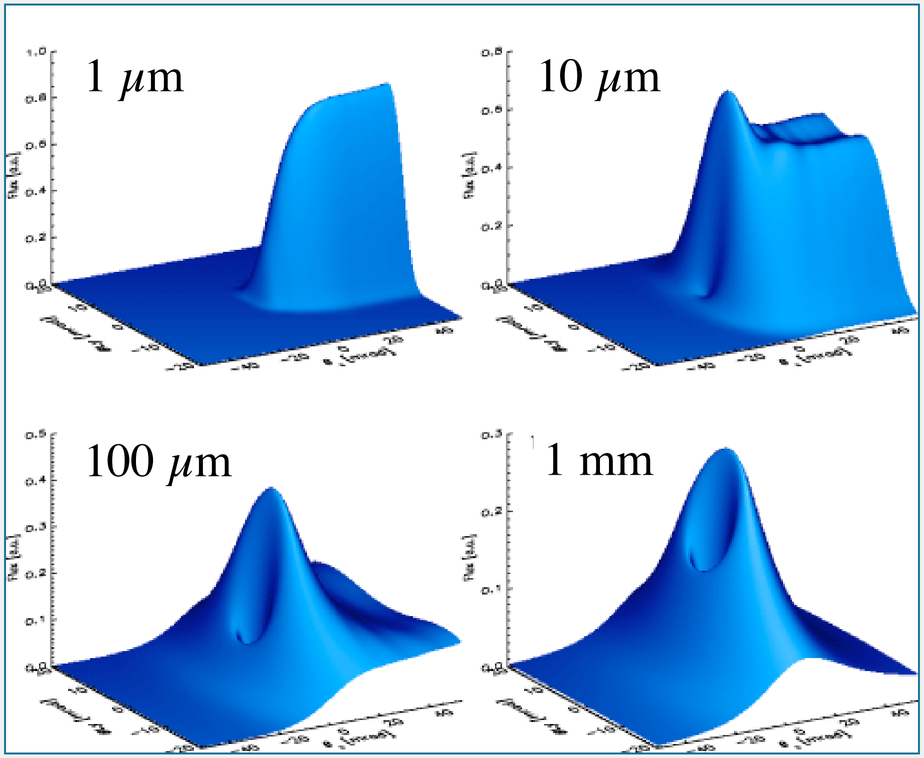


O.V. Chubar, N.V. Smolyakov, J.Optics, **24**(3), 117 (1993)

$$\boxed{\mathcal{E}(\square) \sim \left|\tilde{I}(\square)\right|^2}$$

CER Angular Spectrum

□□1/□

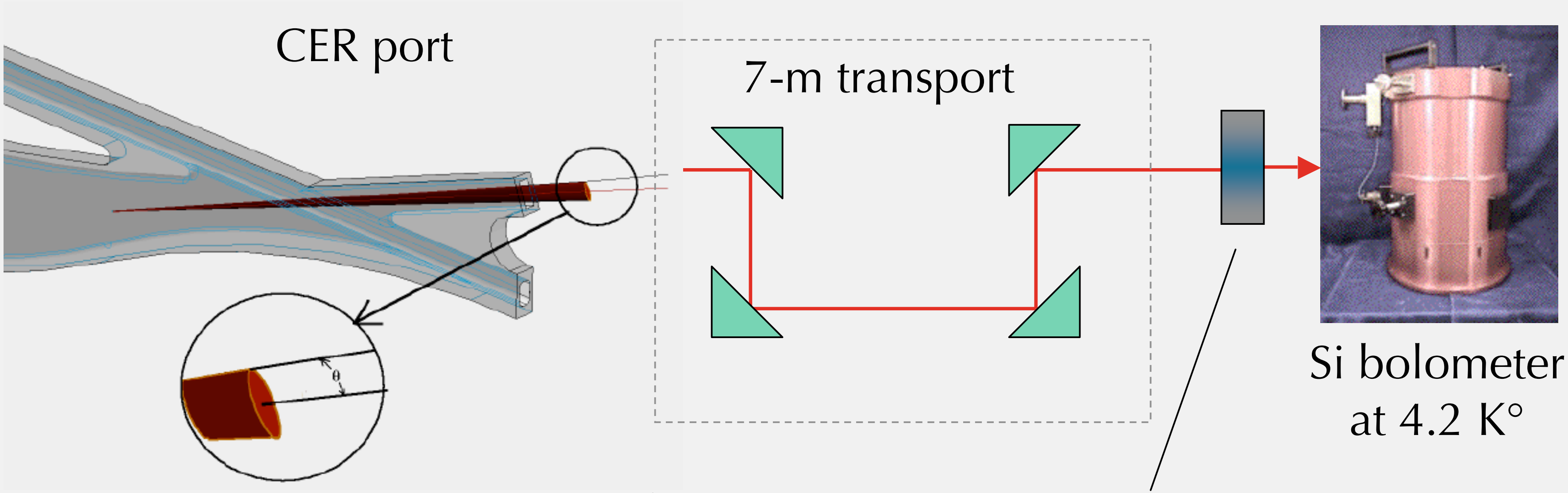


Limitations of the model:

- presence of the vacuum chamber walls
- beam aspect ratio

CER Measurements System

- ✓ Radiation port in the vacuum vessel allows extracting CER generated between 3-rd and 4-th dipoles.
- ✓ Bolometer was purchased from IR labs, to measure CER spectrum.



CER port

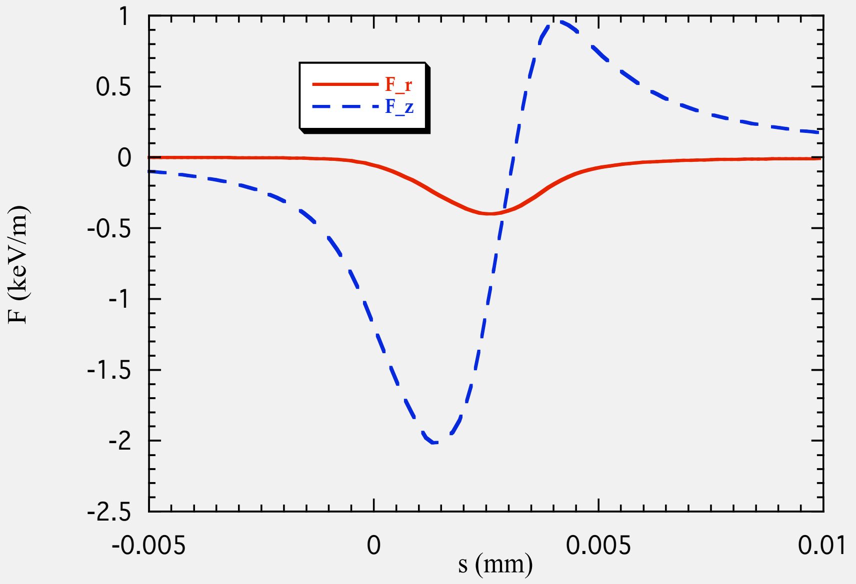
7-m transport

Si bolometer
at 4.2 K°

Cold filter wheel (low pass):
(13, 27, 45, 103, 285 μm)

Experimental Goals

- ✓ Measure CER spectrum;
- ✓ Complement interferometric measurements with CER, to obtain data on the bunch length evolution for different chicane settings;
- ✓ Look for the signs of microbunching instability:



Sample CSR “wake” calculation using TREDI

Progress and Plans

- ✓ Vacuum vessel and magnets are installed and tested;
- ✓ Beam was propagated through the chicane (small dispersion);
- ✓ Interferometer is being purchased by INFN collaborators
- ✓ Bolometer was purchased;
- ✓ CER transport is under construction;
- ✓ New numerical code is being developed;
- ✓ VISA -2b simulations show possibility of deep saturation FEL operation;