Design Consideration of CTR/CDR Station at PITZ

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Outline

- Selection of screen stations to use as a CTR/CDR station
- Transition radiation calculations
- THz diagnostics
- What to prepare/buy?
- Summary
- Outlook

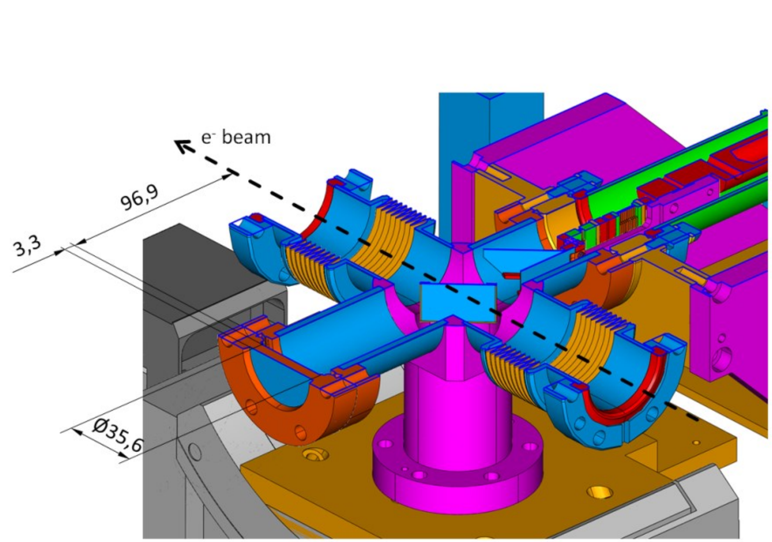
Selection of screen stations

- There are 4 types of screen stations downstream from the booster
  - EMSY screens: HIGH1.SCR1/3
  - Beamlet collector screens: HIGH4.SCR4/5
  - PST screens
  - HIGH1.SCR2
- Conditions for the selection are:
  - Viewport is available for a THz viewport
  - Largest acceptance angle

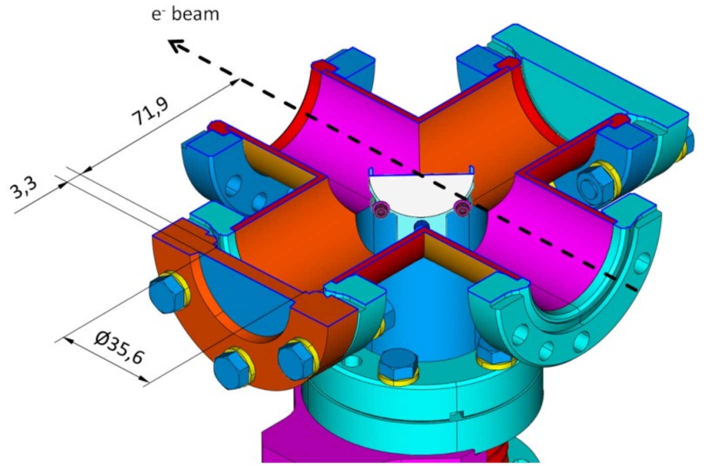
Selection of screen stations (2)

Courtesy: S.Philips

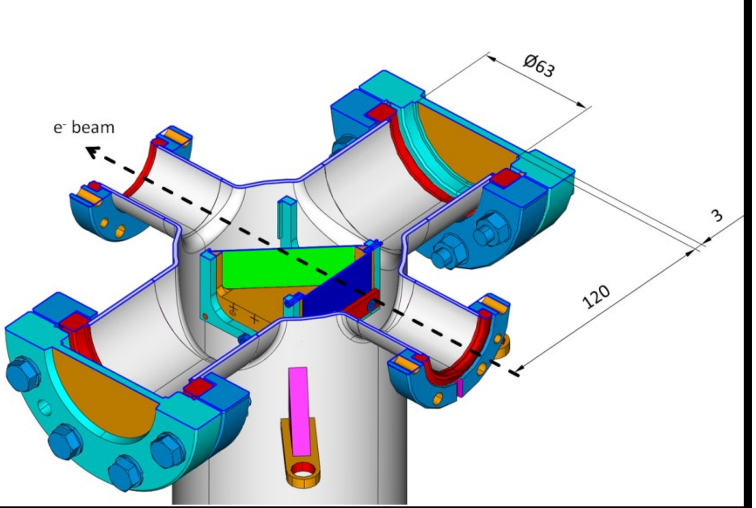
HIGH1.SCR1/3 (EMSY)



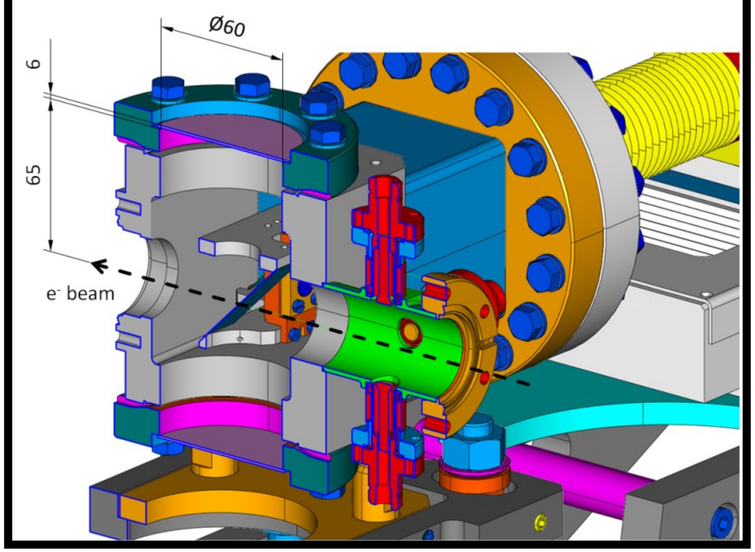
HIGH1.SCR2



HIGH1.SCR4/5



PST.SCR...



Selection of screen stations (3)

Courtesy: S.Philips

The best!

	EMSY	H1.S2	H1.S4/5	PST.SCR
Viewports Material Size	MDC 9722005-1 Fused silica CF 40	MDC 9722005-1 Fused silica CF 40	VAB SFK 63 Kodial CF 63 ✓	VAB SFK 63 Q Fused silica CF 63 ✓
Number available viewports	1	2 ✓	2 ✓	2 ✓
Drive system	Stepper motor ✓	Pneumatic	Pneumatic	Stepper motor ✓
Number of actuators needed for 3 screens*	1 ✓	2	2	1 ✓
Rotation possible	Yes ✓	no	no	no
Viewport diameter (mm)	35.6	35.6	63	60
Distance from centre of screen to viewport (mm)	96.9(+3.3)	71.9(+3.3)	120(+3)	65(+6)
Acceptance angle (rad) **	0.1758	0.2324	0.2507	0.3998 ✓

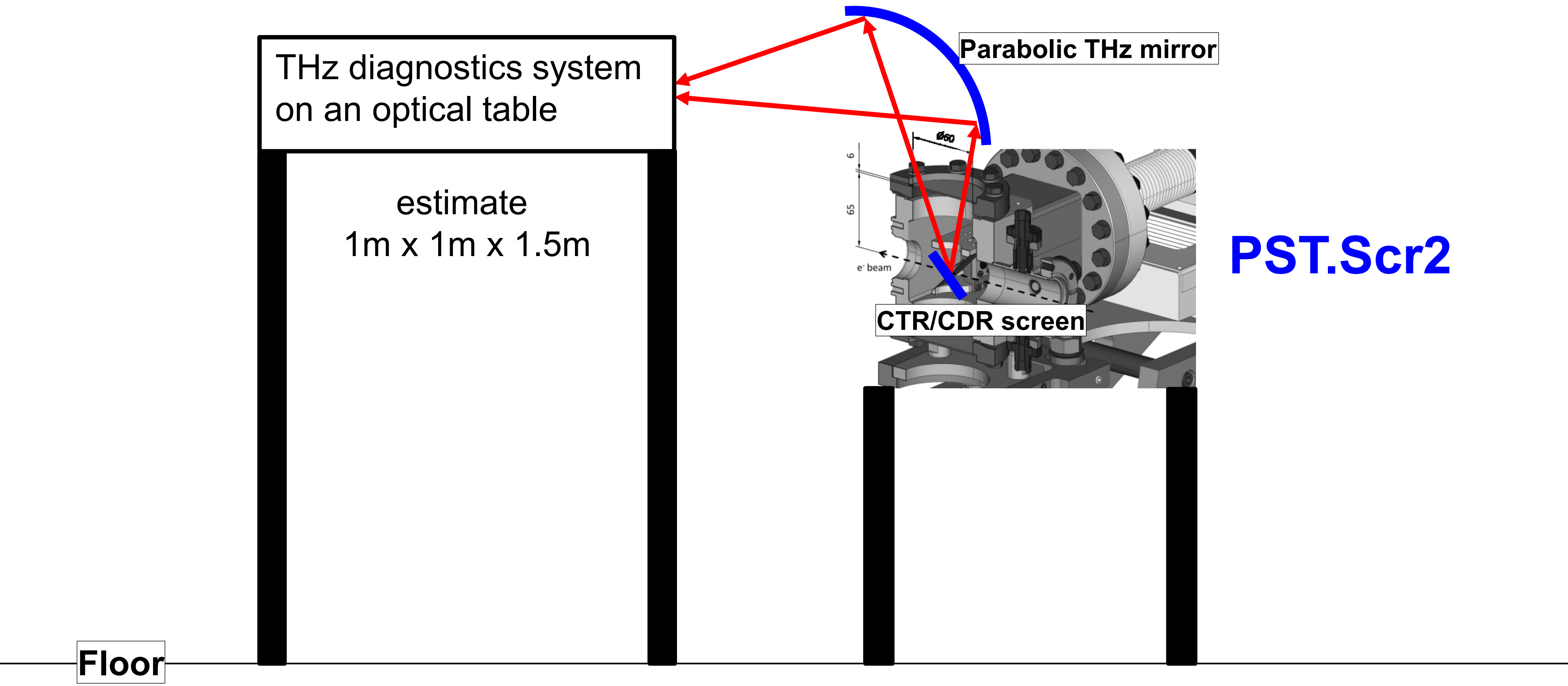
* 3 screens consist of YAG screen, CTR screen and CDR screen.

** Acceptance angle = $\tan^{-1}$ [(viewport radius) / (distance from center of screen to viewport)]

Selection of screen stations (4)

- PST.Scr2 is the best option because:
  - Both available viewports of PST.Scr1 are already occupied.
  - PST.Scr1 is mainly used for another TDS measurement, not proper to use as THz radiation station.
  - PST.Scr2 is located downstream from the TDS so longitudinal beam profiles for THz generations can be measured beforehand.
  - Space around PST.Scr2 is available to install additional components.

Preliminary Layout of the CTR/CDR Station



Transition Radiation Calculation

PITZ Photo Injector Test Facility Zeuthen

Single electron, Backward radiation
45° incidence

Reference: C.Settakorn, SLAC-r-576

Radiation intensity for backward transition radiation contributed from the parallel and perpendicular polarization can be expressed as

$$\frac{dW}{d\Omega d\omega} = \frac{dW^{\parallel}}{d\Omega d\omega} + \frac{dW^{\perp}}{d\Omega d\omega}. \tag{1.5}$$

For a perfectly conducting medium ($\varepsilon \to \infty$), the two components are

$$\frac{dW^{\parallel}}{d\Omega d\omega} = \frac{e^2\beta^2\cos^2\psi}{\pi^2 c}\left[\frac{\sin\theta - \beta\cos\phi\sin\psi}{(1-\beta\sin\theta\cos\phi\sin\psi)^2 - \beta^2\cos^2\theta\cos^2\psi}\right]^2, \tag{1.6}$$

$$\frac{dW^{\perp}}{d\Omega d\omega} = \frac{e^2\beta^2\cos^2\psi}{\pi^2 c}\left[\frac{\beta\cos\theta\sin\phi\sin\psi}{(1-\beta\sin\theta\cos\phi\sin\psi)^2 - \beta^2\cos^2\theta\cos^2\psi}\right]^2. \tag{1.7}$$

For a case of 45° incidence ($\psi = 45°$), which is used extensively in our experimental setup, the two components reduce to

$$\frac{dW^{\parallel}}{d\Omega d\omega} = \frac{e^2\beta^2}{2\pi^2 c}\left[\frac{2\sin\theta - \sqrt{2}\beta\cos\phi}{(\sqrt{2}-\beta\sin\theta\cos\phi)^2 - \beta^2\cos^2\theta}\right]^2 \tag{1.8}$$

$$\frac{dW^{\perp}}{d\Omega d\omega} = \frac{e^2\beta^2}{2\pi^2 c}\left[\frac{\sqrt{2}\beta\cos\theta\sin\phi}{(\sqrt{2}-\beta\sin\theta\cos\phi)^2 - \beta^2\cos^2\theta}\right]^2. \tag{1.9}$$

In these formulas, θ represents the angle between the direction of emitted radiation $\mathbf{n}$ and the $-\mathbf{z}$ axis while ϕ is the azimuthal angle defined in the xy-plane with respect to the $-\mathbf{x}$ axis.

DESY

Transition Radiation Calculation(2)

Single electron, Backward radiation
45° incidence

Reference: C.Settakorn, SLAC-r-576

Factor of 10 different between 5 MeV and 25 MeV cases

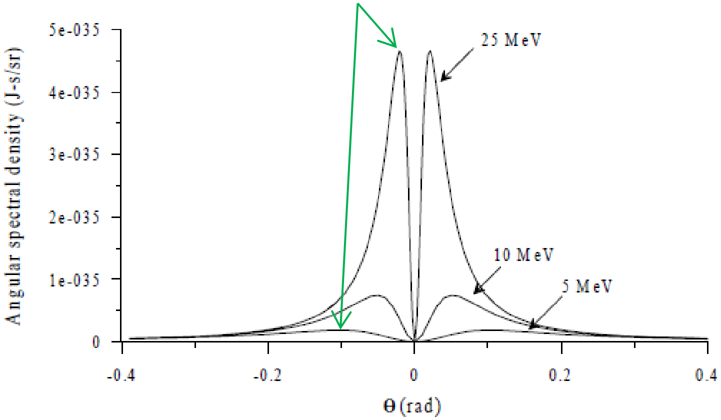
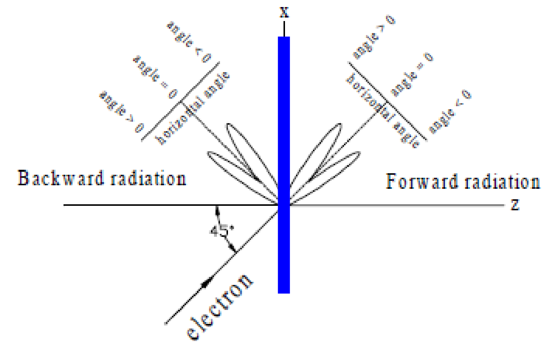
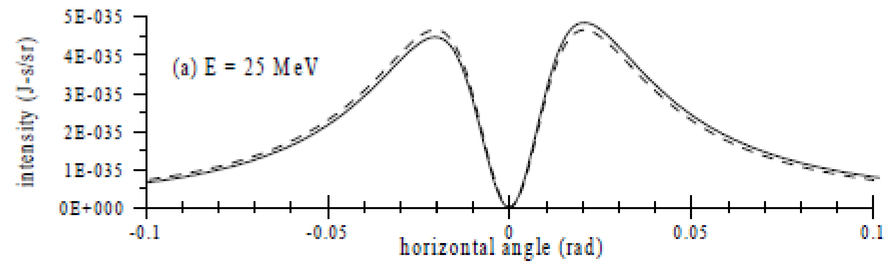


Figure 1.4: Angular distributions of normal incident transition radiation generated by 5 MeV, 10 MeV and 25 MeV electrons.

5 MeV ➔ $\gamma = 10.78$

$$0.4\,rad = \frac{0.4}{\left(\frac{1}{\gamma}\right)}\left(\frac{1}{\gamma}\right) = \frac{4.312}{\gamma}$$





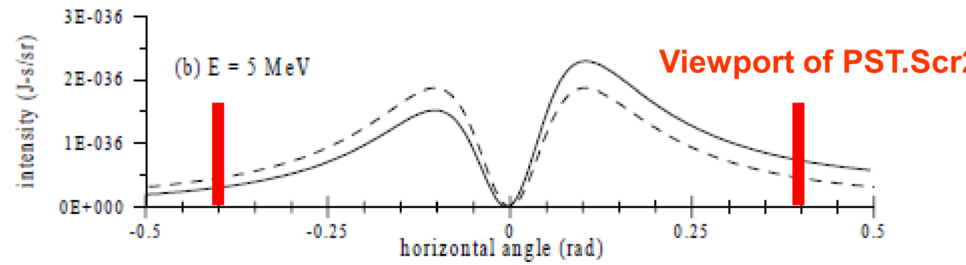


Figure 1.8: Angular distribution along the zero vertical angle of the radiation emitted from a 25 MeV (a) and a 5 MeV (b) electron for the case of normal incidence (dashed-line) and 45°-incidence (solid).

Transition Radiation Calculation(3)

PITZ Photo Injector Test Facility Zeuthen

Electron bunch, Backward radiation
Normal incidence

Reference: S.Casalbuoni et al.,TESLA 2005-15

- CTR calculations were performed by using **Ginzburg-Frank formula**
- Assumptions:
  - The radiation screen is a finite circular metallic screen with the radius $\boldsymbol{a}$.
  - Electron beam with transverse radius of $\boldsymbol{r_b}$ impinges normally to the screen.
- The spectral and spatial radiation energy in the far-field regime for backward CTR are given by

$$\frac{d^2U_{\text{bunch}}}{d\omega d\Omega} = \frac{e^2}{4\pi^3\varepsilon_0 c}\frac{\beta^2\sin^2\theta}{(1-\beta^2\cos^2\theta)^2}\cdot N^2\left|F_{long}(\omega)\right|^2\cdot\left[\frac{2c}{\omega r_b\sin\theta}J_0\left(\frac{\omega r_b\sin\theta}{c}\right)-\frac{2c\beta\gamma}{\omega r_b}I_0\left(\frac{\omega r_b}{c\beta\gamma}\right)T(\gamma,\omega a,\theta)\right]^2$$

Longitudinal Form factor of the e-beam

$$F_{long}(\omega) = \int_{-\infty}^{+\infty}\rho_{long}(t)e^{-i\omega t}dt$$

$$T(\gamma,\omega a,\theta) = \frac{\omega a}{c\beta\gamma}J_0\left(\frac{\omega a\sin\theta}{c}\right)K_1\left(\frac{\omega a}{c\beta\gamma}\right)+\frac{\omega a\sin\theta}{c\beta^2\gamma^2\sin\theta}J_1\left(\frac{\omega a\sin\theta}{c}\right)K_0\left(\frac{\omega a}{c\beta\gamma}\right)$$

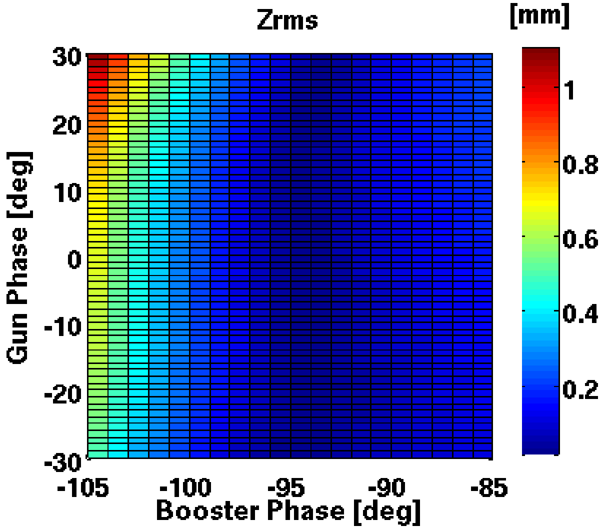
DESY

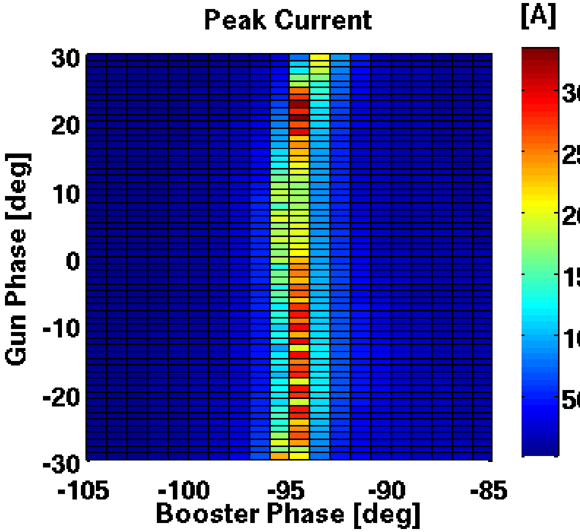
Transition Radiation Calculation(4)

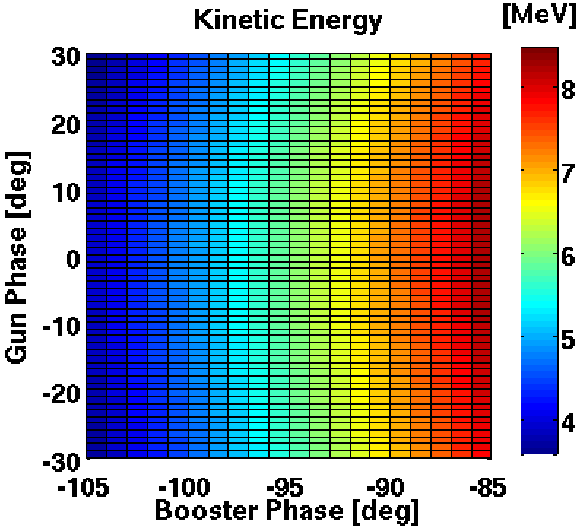
Electron bunch, Backward radiation
Normal incidence

Example PITZ Beam for the calculation
(Selected from the previous simulation work)

Bunch charge of 20 pC





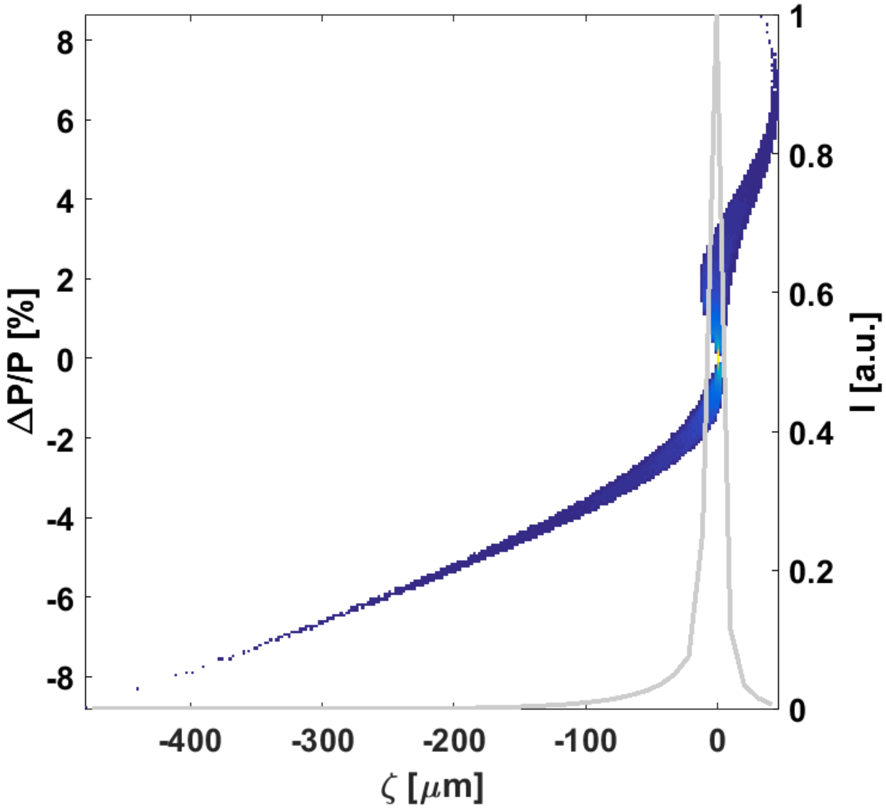


Beam from Φgun = 22° and Φbooster = -95° was selected.
(see profiles in the next slide.)

Electron bunch, Backward radiation

Normal incidence

Longitudinal profiles of the example beam



Pmean = 5.78 MeV/c

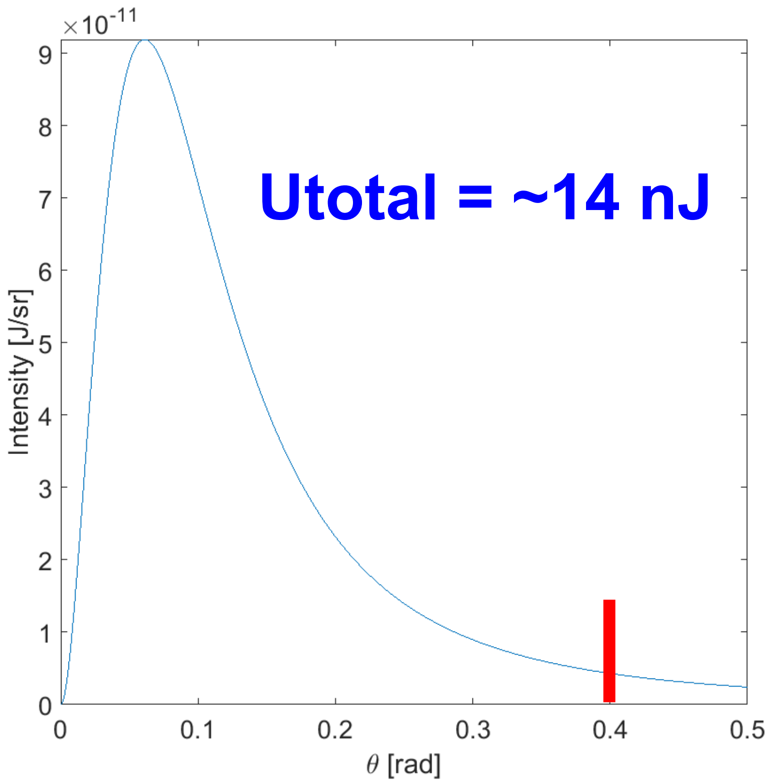
Zrms = 29 μm = 97 fs

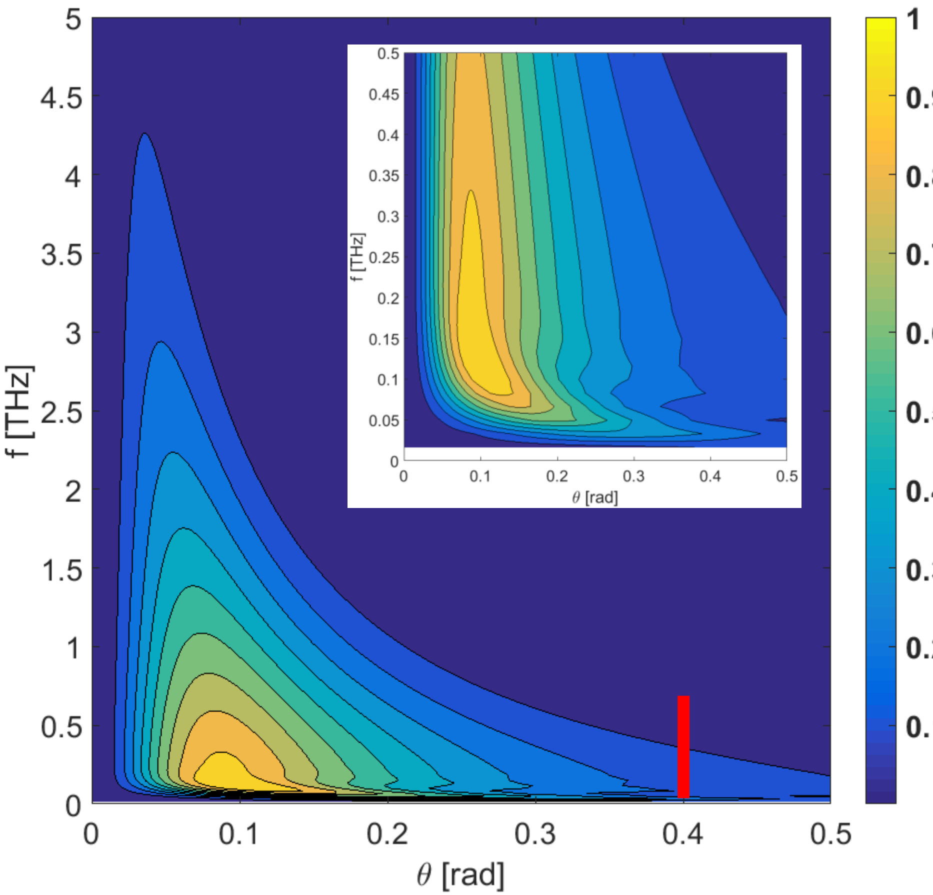
Zrms*2.4 = 70 μm = 233 fs

Ipeak = 20pC/233fs = 85.8 A

Electron bunch, Backward radiation
Normal incidence

Calculated CTR energy from the example beam





THz Diagnostics

- THz energy/power measurement
  - Detector choices: Golay, **Pyroelectric**, Bolometer, EOS
- Frequency Measurement
  - **Michelson Interferometer**, Martin-Puplett interferometer
  - Applications: bunch length measurement, bunch profile reconstruction
- Spatial distribution measurement
- Polarization measurement
- Electric fields profile measurement **?**
- THz diagnostics planned to have 2 setups:
  - 1. For Michelson Interferometer (MIF)
  - 2. For Spatial distribution measurement (SD) **?**

What to prepare/buy ?

- THz detector: Pyroelectric detector
- Signal amplifier ?
- CTR screen(s) and CDR screen(s)
- THz viewport
- Parabolic mirror (first mirror after the viewport) and its holder
- Optical table (estimate 1m x 1m x 1.5m)
- Components of Michaelson interferometer
  - 2 THz mirrors, beam splitter, moving stage actuator …
- Moving stage actuator (for the spatial distribution measurement)
- THz polarizer
- Frequency filter ?
- Controller!

What to prepare/buy ?(2)

- Companies to look for…

THORLABS

radiabeam TECHNOLOGIES

DEL MAR PHOTONICS

soliton

BRUKER

COHERENT

TOPTICA PHOTONICS

TYDEX®

BR BORROW& DONATE©

…etc.,…

Summary

- PST.Scr2 is ideal station to modify to be CTR/CDR station
  - Largest acceptance angle, 5 MeV beam is possible to use.
  - Downstream from TDS, beforehand/crosscheck bunch length measurement can be done.
- Design consideration of CTR/CDR station at PITZ has been started.
- Challenges (difficulties)
  - Experience with THz CTR/CDR generation experiments
  - Low electron beam energy, 5 MeV
  - Water absorption of THz radiation ➔ Dry gas/In-vacuum diagnostics
  - Timeline
  - Go towards publication(s)

Outlook

- Finalize the design
  - Calculation of radiation transport (Zemax)
  - List components with company's product names
  - Discuss with engineers and THz experimental experts
  - Finalize the design
- Order the components
- Install the components
- Beam dynamics simulations ➔ radiation calculations
- Detailed experimental plan
- THz generation (CTR/CDR) experiments

Appendix

Homemade Michelson Interferometer

Reference: C.Settakorn, SLAC-r-576

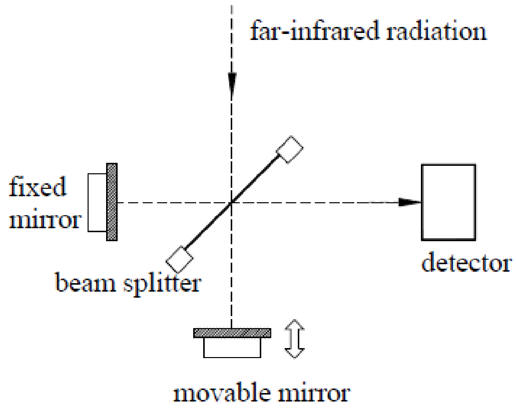


Figure 3.8: A schematic diagram of a Michelson interferometer.

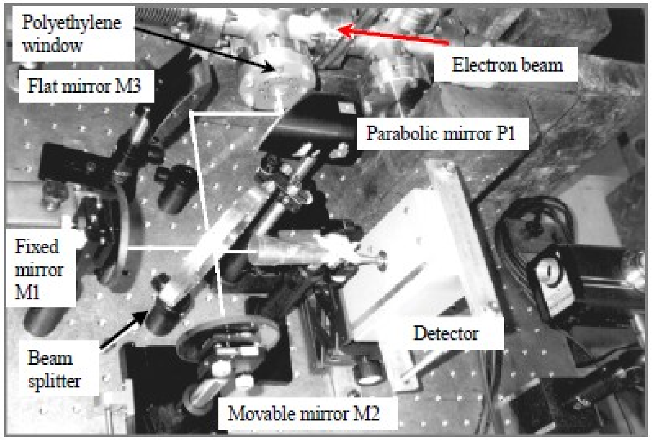


Figure 3.12: The Michelson interferometer setup with the white trace representing the radiation path.

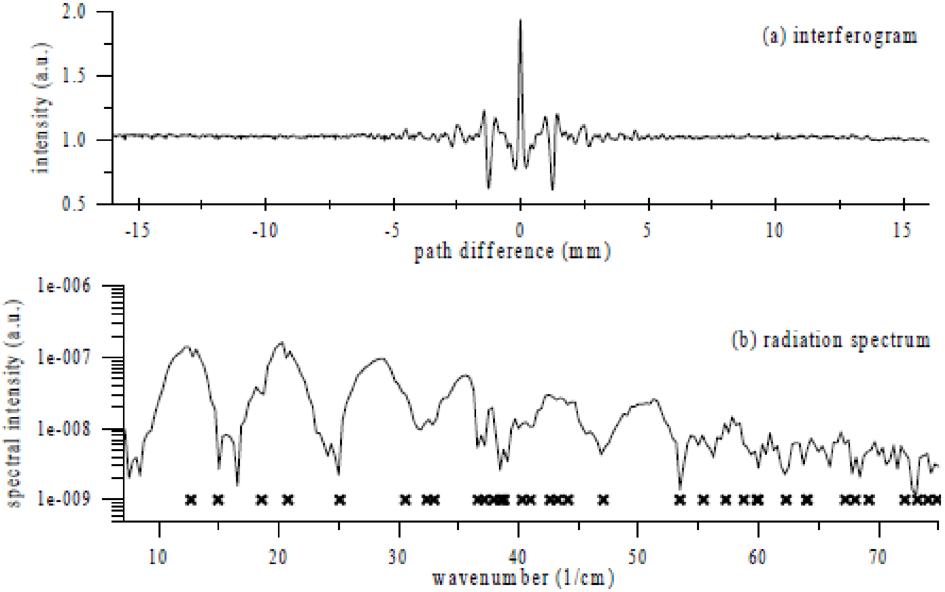


Figure 3.13: (a) interferogram and (b) radiation spectrum obtained from the Michelson interferometer set up in ambient air.

Spatial Distribution(+polarization) Measurement Setup

Reference: C.Settakorn, SLAC-r-576

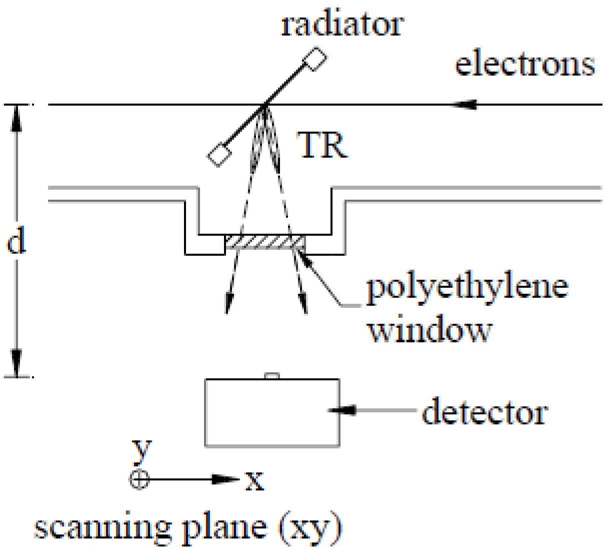


Figure 4.7: Experimental setup diagram for the total energy meaurement and for the radiation distribution measurement.