Introduction to Optical Transition Radiation

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Introduction to Optical Transition Radiation

- Basic
  - We study E-beams
  - cannot directly observe
  - need indirect means....radiation
- Transverse Diagnostic types and limits
  - scintillators
    - phosphor
    - YAG
  - SR ~270 μm (for similar beam parameters as LLNL)
  - wire scan
    - need low beam jitter
    - need very thin wires
  - TR
    - very good resolution (near point source diffraction limit)
    - relatively simple

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- **Why OTR?**
  - **TR is relatively flat to ~ω_p. of reflector**
  - **strongly attenuated above plasma freq.**
    - **may have coherence effects in IR range**
  - **most compelling...**
    - **optics and digital imaging devices invisible spectrum**
      - **readily available**
      - **cheaper**
      - **no shortage of photons within the typical spectral range of interest**

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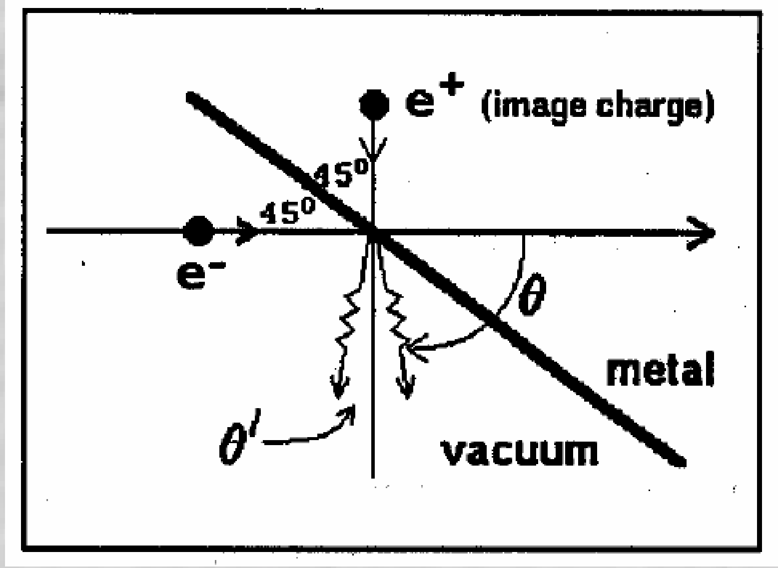
Theory

- **Transition Radiation**
  - **TR created when charged particle crosses boundary of different dielectric constants**
  - **fields must reorganize and some can be shaken off as TR**



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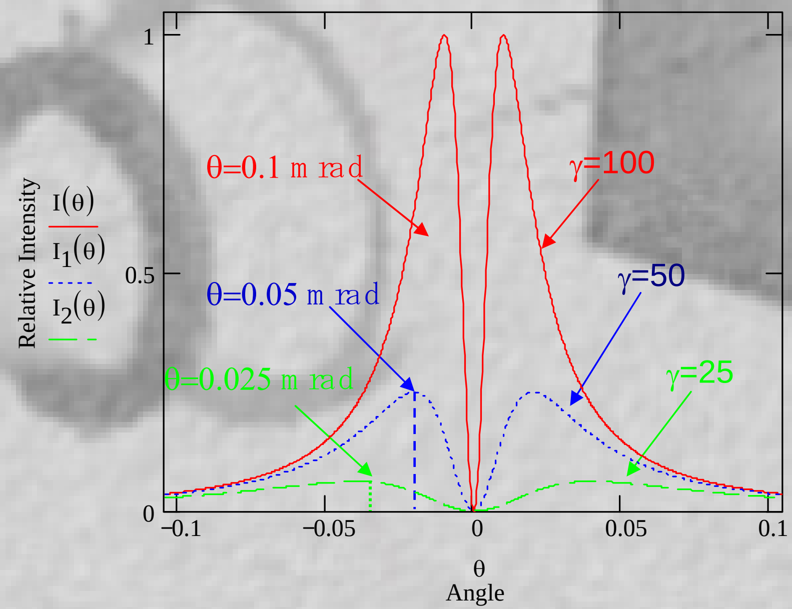
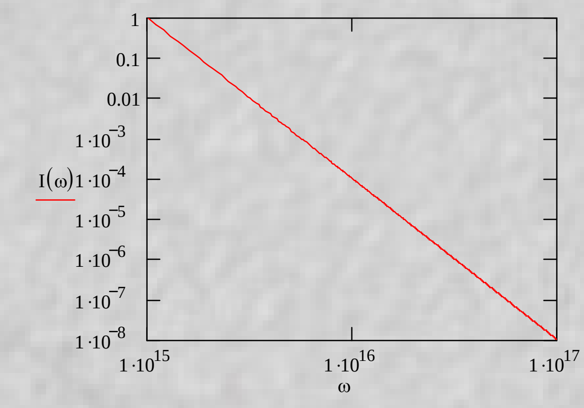
- **Transition Radiation**
  - **Characteristic angular dependence**
    - **energy dependence on shape**

$$\frac{d^2 I}{d\omega d\Omega} = \frac{1}{4\pi^2 c}\left|\frac{-e\sin\theta}{1-\beta\cos\theta} + \frac{e\sin\theta'}{1-\beta\cos\theta'}\right|^2$$

- **Relative intensity vs ω (scaled to optical)**
  - **demonstrates strong attenuation above** $\omega_c = \gamma\ \omega_p$
  - **radiation at this frequency is absorbed by material**
    - **dielectric constant...not constant** → $\varepsilon(\omega)$

$$\frac{dI}{d\omega} = \frac{e^2}{6\pi c}\left(\frac{\omega_{cr}}{\omega}\right)^4 \quad for \quad \omega > \omega_{cr}$$





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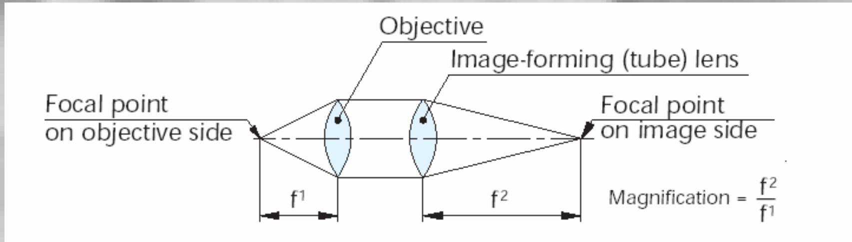
Optics

- **linear beam optics (very brief)**
  - **focal length**
  - **magnification**
    - **$M=f_2/f_1$**
- **definitions**
  - **numerical aperture (N.A.)**
    - **Sine of angle between optical axis and marginal ray**
  - **working distance (WD)**
    - **Distance within first lens must be placed**
  - **f/#**
    - **Focal ratio**
  - **depth of field (D_{field})**
    - **Range about which image is clear in object plane**
    - **Depends on N.A. of lens**
  - **depth of focus (D_{focus})**
    - **Range about which image is clear in image plane**



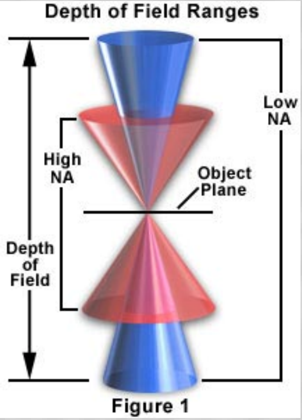
Infinity Correction System

$$N.A. = \frac{\phi}{2f}$$

$$f/\# = \frac{f}{\phi} \quad \phi \to clear\,aperature$$

$$D_{field} = \frac{\lambda}{2(N.A.)^2}$$

$$D_{focus} \cong M^2 D_{field}$$



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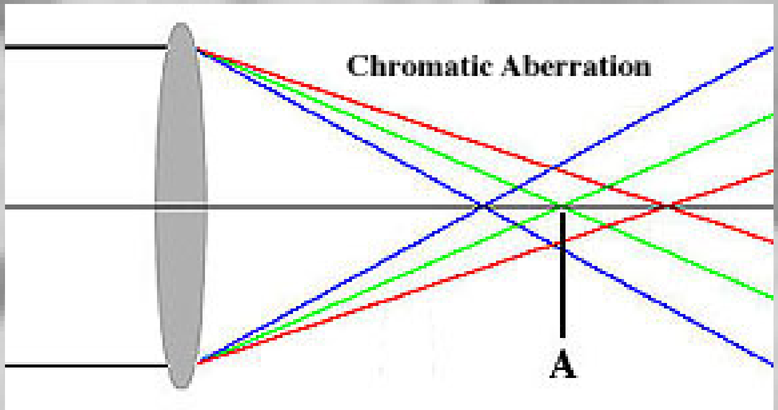
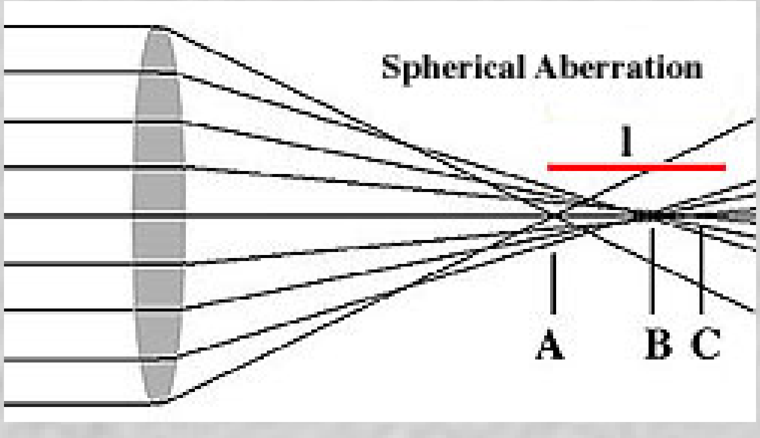
- Irregularities
  - chromatic aberrations
  - spherical aberrations
  - flatness
    - Given on orders of wavelength
  - scratch
    - Width of a reference scratch in ten-thousands of a mm
      - 80 scratch ~ 8μm (but not that precise)
  - Dig
    - Craters on the surface - defined as its diameter in hundredths of a mm
      - 50 dig = 0.5mm





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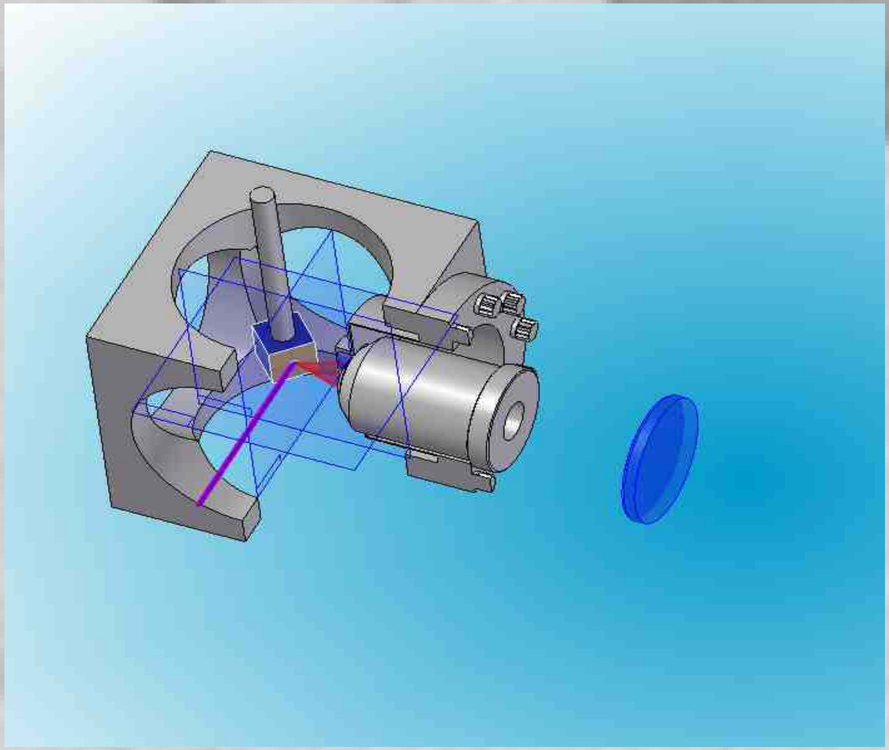
- LLNL Experiment
  - 50 MeV beam
  - Very small spot size
    ~20μm
  - large jitter
  - Will utilize existing infrastruce
    - 6"cube
    - Polished aluminum target, angled 45 deg.



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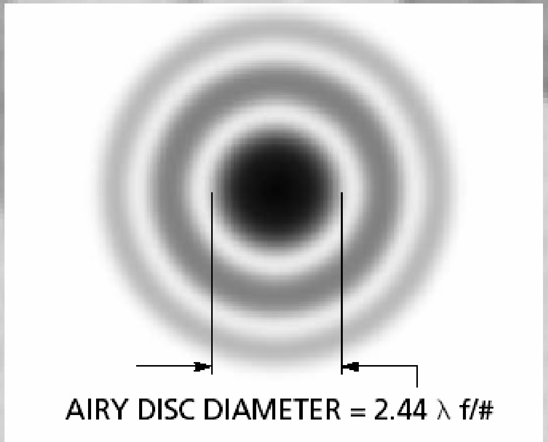
- **OTR experiment**
  - **motivated by a similar one at KEK**
  - **want diffraction limited optical system**
    - **Rayleigh criterion for point source (overlapping airy disks)**
      - **~1microns for 10x objective**
      - **~2 microns for 5x objective**



$$d_{\min} = \frac{.61\lambda}{N.A.}$$

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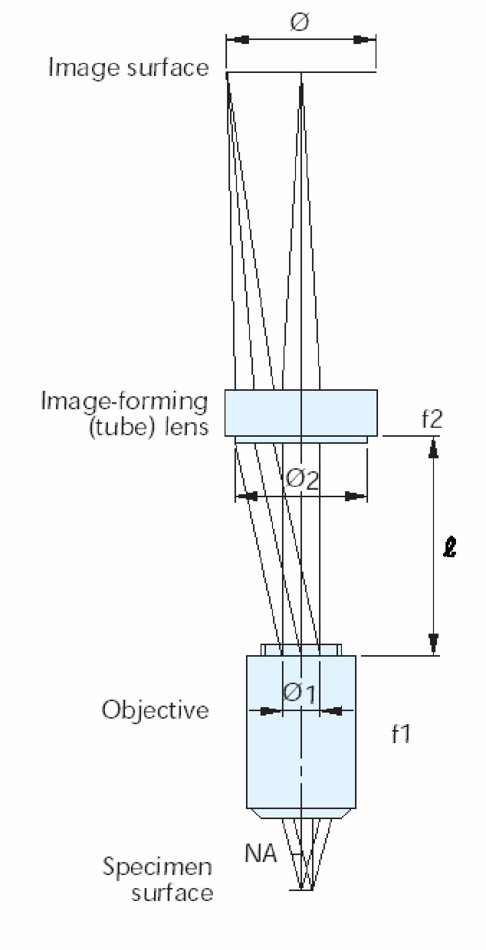
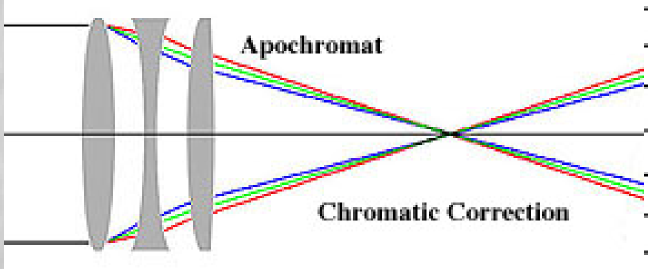
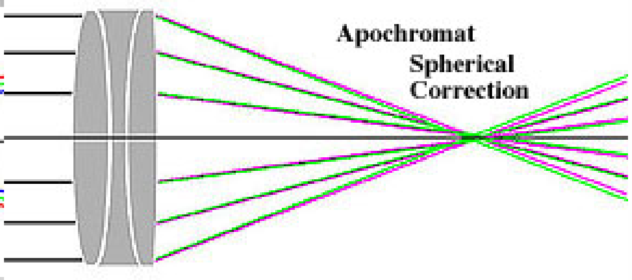
- **Plan Apochromat Objective**
  - **"10x" (with 200mm tube lens)**
    - **focal length 20mm**
    - **W.D of 33.5 mm**
    - **NA of .28**
  - **"5x" (with 200mm tube lens)**
    - **focal length 40mm**
    - **W.D of 34 mm**
    - **NA of .14**







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- Need to place objective very close to target
  - re-entrant design
  - thin window
  - differential pumping w/mylar?
- Recall magnification is f_2/f_1 so need 'long' focal length "tube lens" and 'long' tube
- Depth of field is only 3.5 microns for "10x" and 14 microns for "5x"
  - need to tilt the CCD to compensate for this
  - but depth of focus ~7.5mm and ~30mm respectively
- Will be difficult to do the initial focusing
  - maybe move target and rotatable mount for ccd
- Finally need to consider effects of spherical aberrations
  - window
  - tube lens
  - optics simulations needed
- Rough calculations with ½"CCD, 50x magnification & 100μm FOV
  - get ~0.2μm/pixel, defined by "circle of confusion" for this system
  - Beyond the diffraction limit, so its over designed (by linear theory)
  - Need to relax some parameters.

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Conclusions

•May be able to create a 'diffraction limited' optical system for OTR imaging

•Several parameters need to be defined by LLNL and PBPL prior to LVO

•Mechanical design issues need to be kept under consideration when defining parameters

•More work needs to be done to fully understand the optical system (simulations)