Feasibility of OSR Imaging at 40 MeV for NML: Part 1

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Low Gamma OSR Imaging Aspects

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- Electron beam transverse size can be assessed with optical synchrotron radiation (OSR) imaging techniques using focus-at-the-object optics in general.
- Low gamma beams do add the challenge of lower photon production in visible wavelengths per unit charge.
- Technique can be considered for high charge beams as a nonintercepting beam profile monitor.
- Proof-of-principle tests done at LANL in early 1990s at 38 MeV.
- Will use M.D. Wilke's paper on synchrotron radiation imaging at BIW94 as source material.

Analytical OSR Aspects

OPTICAL SYNCHROTRON RADIATION IMAGING

Analytical Optical Resolution Estimates

The following derivations of resolution use the definitions of Jackson for critical energy E_c

$$E_C = \frac{h\omega_C}{2\pi} = \frac{3h\gamma^3}{2\pi}\left(\frac{c}{\rho}\right) \qquad (1)$$

or, equivalently, the critical wavelength λ_c given by

$$\lambda_c = \frac{2\pi\rho}{3\gamma^3} \qquad (2)$$

where ω_c is the critical wavelength, $\gamma = 1/(1-(v/c)^2)^{1/2}$, ρ is the radius of the bend defined in Fig. 1, c is the speed of light, and h is Planck's constant(8). It should be noted that Jackson's value of E_C is two times the value used by many other authors.

$$\theta_c \cong \frac{1}{\gamma}\left(\frac{E_c}{E}\right)^{1/3} = \frac{1}{\gamma}\left(\frac{\lambda}{\lambda_c}\right)^{1/3} \qquad E_c \gg E, \qquad (3a)$$

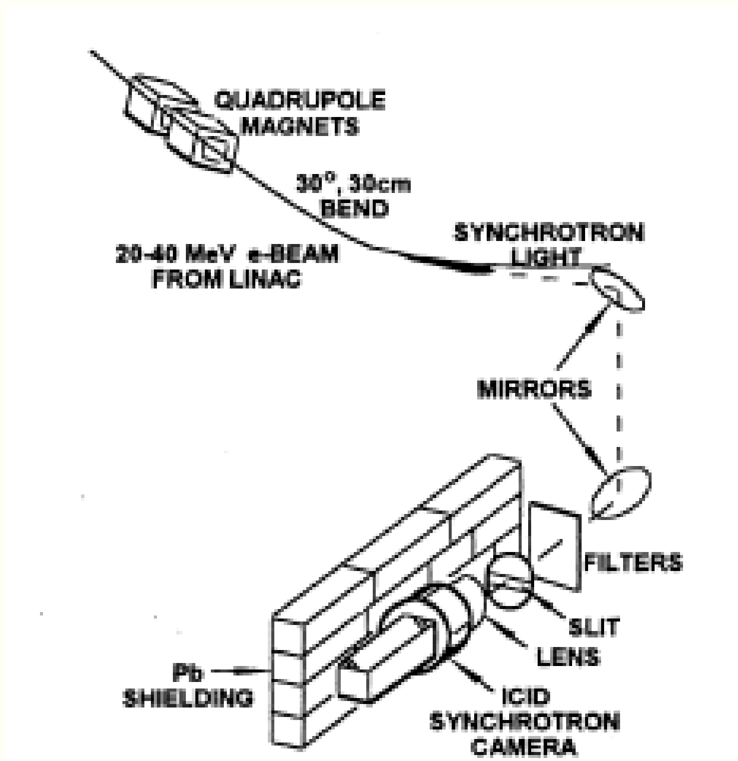
$$\theta_c \cong \frac{1}{\gamma} \qquad E_c \cong E, \qquad (3b)$$

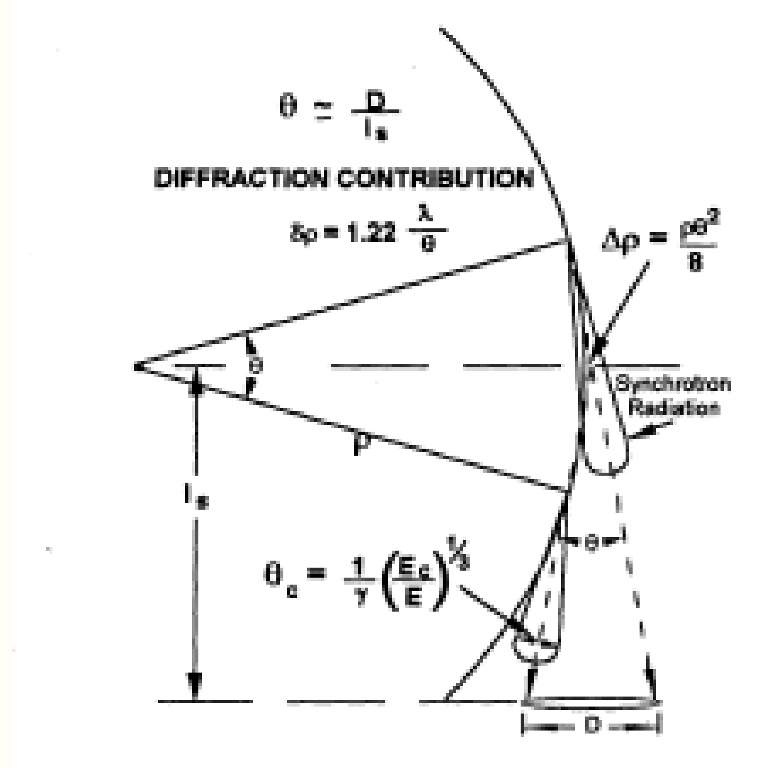
$$\theta_c \cong \frac{1}{\gamma}\left(\frac{E_c}{3E}\right)^{1/2} = \frac{1}{\gamma}\left(\frac{\lambda}{3\lambda_c}\right)^{1/2} \qquad E_c < E. \qquad (3c)$$

M. Wilke, BIW94

LANL OSR Setup

- As shown in the figure, one must balance the beam size blur in the arc and the diffraction effects.





Analytical OSR Aspects

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D is small and the wavelength of observation λ is long, diffraction becomes important and the particle appears to have an effective width $\delta\rho = 1.22\lambda/\theta$. The resolution of the imaging system resulting from the combined effects of the particle motion and diffraction is then given approximately by

$$R = \sqrt{(\Delta\rho)^2 + (\delta\rho)^2} = \sqrt{\left(\frac{\rho\theta^2}{8}\right)^2 + \left(1.22\frac{\lambda}{\theta}\right)^2}. \quad (4)$$

The optimum value of θ defined as θ_o, and therefore the optimum value of D given by $D_o = l_s\theta_o$, is found by minimizing R with respect to θ, and is given by

$$\theta_o = 1.9\left(\frac{\lambda}{\rho}\right)^{1/3}. \quad (5)$$

Therefore, the optimized resolution, R_o, is given by

$$R_o = 0.78\left(\rho\lambda^2\right)^{1/3} = 0.78\,\rho^{1/3}\left(\frac{hc}{E}\right)^{2/3}. \quad (6)$$

In order to compare θ_o with θ_c, we can note that the optics system will image at wavelengths in the visible so that $\lambda \gg \lambda_c$ ($E \ll E_c$). Substituting Eq. 2 for λ_c in Eq. 3a gives

$$\theta_c = \left(\frac{3}{2\pi}\frac{\lambda}{\rho}\right)^{1/3} = 0.78\left(\frac{\lambda}{\rho}\right)^{1/3}, \quad (7)$$

which by Eq. 4 gives the resolution R_c of an optical system when the aperture is $D = l_s\theta_c$

$$R_c = 1.56\left(\rho\lambda^2\right)^{1/3} = 1.56\,\rho^{1/3}\left(\frac{hc}{E}\right)^{2/3}. \quad (8)$$

The resolution therefore appears to be worse than R_o by a factor of two. The instantaneous cone implies a resolution given by Eq. 8. However, analogous to the enhancement of resolution in synthetic aperture radar, the horizontal resolution of an image produced by the synchrotron radiation beam scanning the whole aperture is given by Eq. 6 and not Eq. 8. The approximate vertical resolution is given by Eq. 8.

Above E_c, the emitted synchrotron power per unit frequency falls rapidly. We may define an approximate limit to the achievable resolution of an optics system, which is determined by the usable signal level. When $E \cong E_c$, so that from Eq. 3b $\theta \sim 1/\gamma$, the major contribution to R is from the diffraction term $\delta\rho$. If one substitutes $\Delta\rho$ and $\delta\rho$ in terms of θ into Eq. 4 and sets $\theta = 1/\gamma$ and $\lambda = \lambda_c$ as given by Eq. 2, then the defined limiting resolution R_l of an optics system that images a synchrotron beam at the critical energy is given by

$$R_l = 2.6\frac{\rho}{\gamma^2}. \quad (9)$$

There is also a technological limit to the achievable resolution, because as λ becomes shorter, it becomes more difficult to produce diffraction-limited optics.

OSR at 40 MeV

- **One can obtain an improvement in the horizontal resolution by using $D \sim l_s \theta_0$, but the vertical resolution will be diffraction limited by θ_c to R_c = 133 μm.**

Table 1. Calculated parameters of a system imaging an electron beam at λ=500 nm.

γ	λ_c (nm)	E_c (eV)	θ_o (rad)	θ_c (rad)	t_D (ps)	R_o (μm)	R_c (μm)	$R_l \approx 2.6\rho/\gamma^2$ (μm)
LANL E_b =40 MeV ρ = 30 cm								
79	1261	0.984	0.023	0 .005	23	30	133	95
NML: E_b =40 MeV ρ= 80cm								
79	3354	0.370	0.017	0.0036	61	41	184	253

LANL 30 Deg Bend Area

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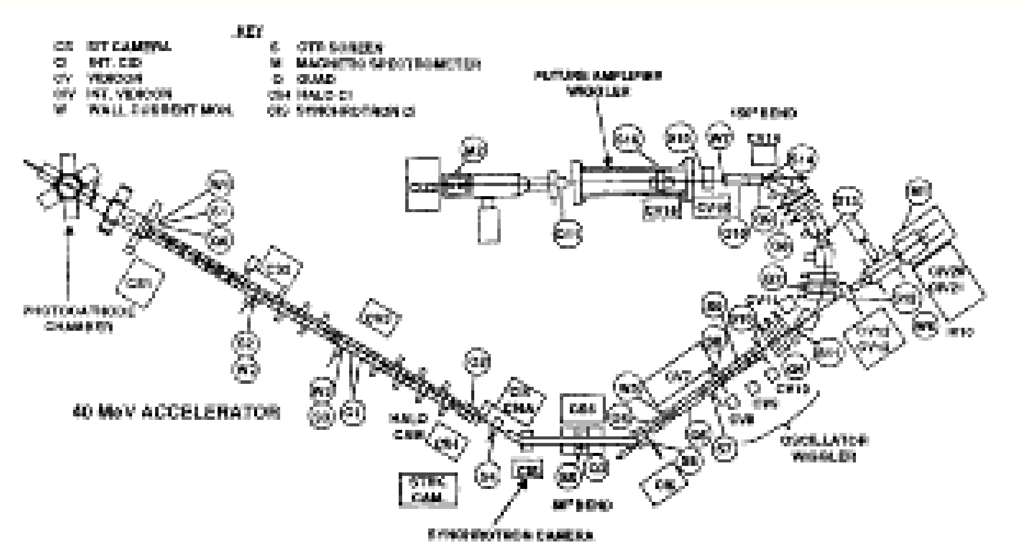
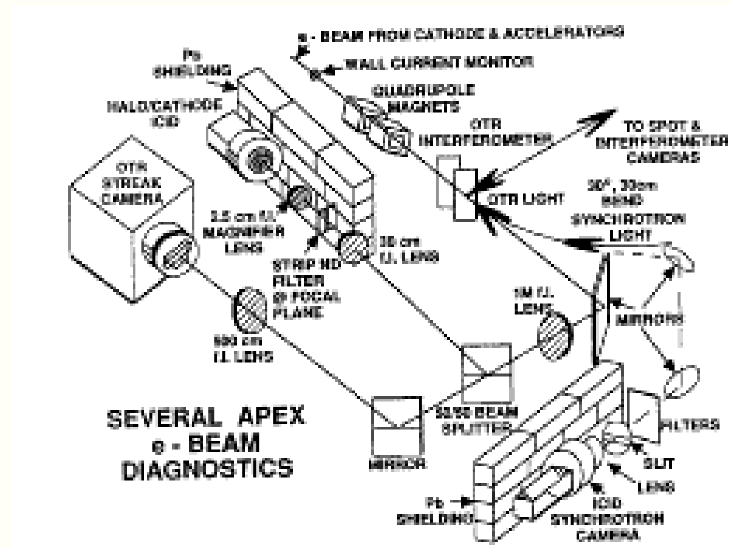
- **Extensive diagnostics options provided before and after the FEL wiggler.**





LANL OSR Images at 38 MeV

- **Images with a) beam focused in both directions and b) with an optimal horizontal focus.**

$\delta_{x,y}$ = 765 µm (FWHM)

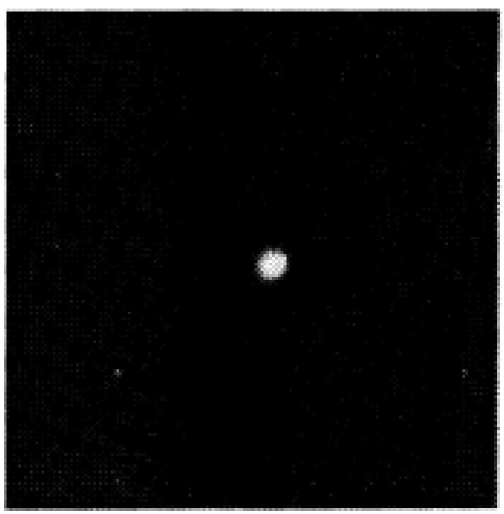


Figure 3a

δ_{x} = 382 µm (FWHM)

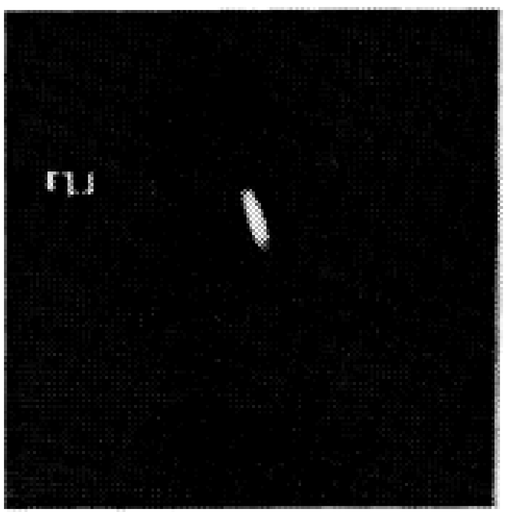


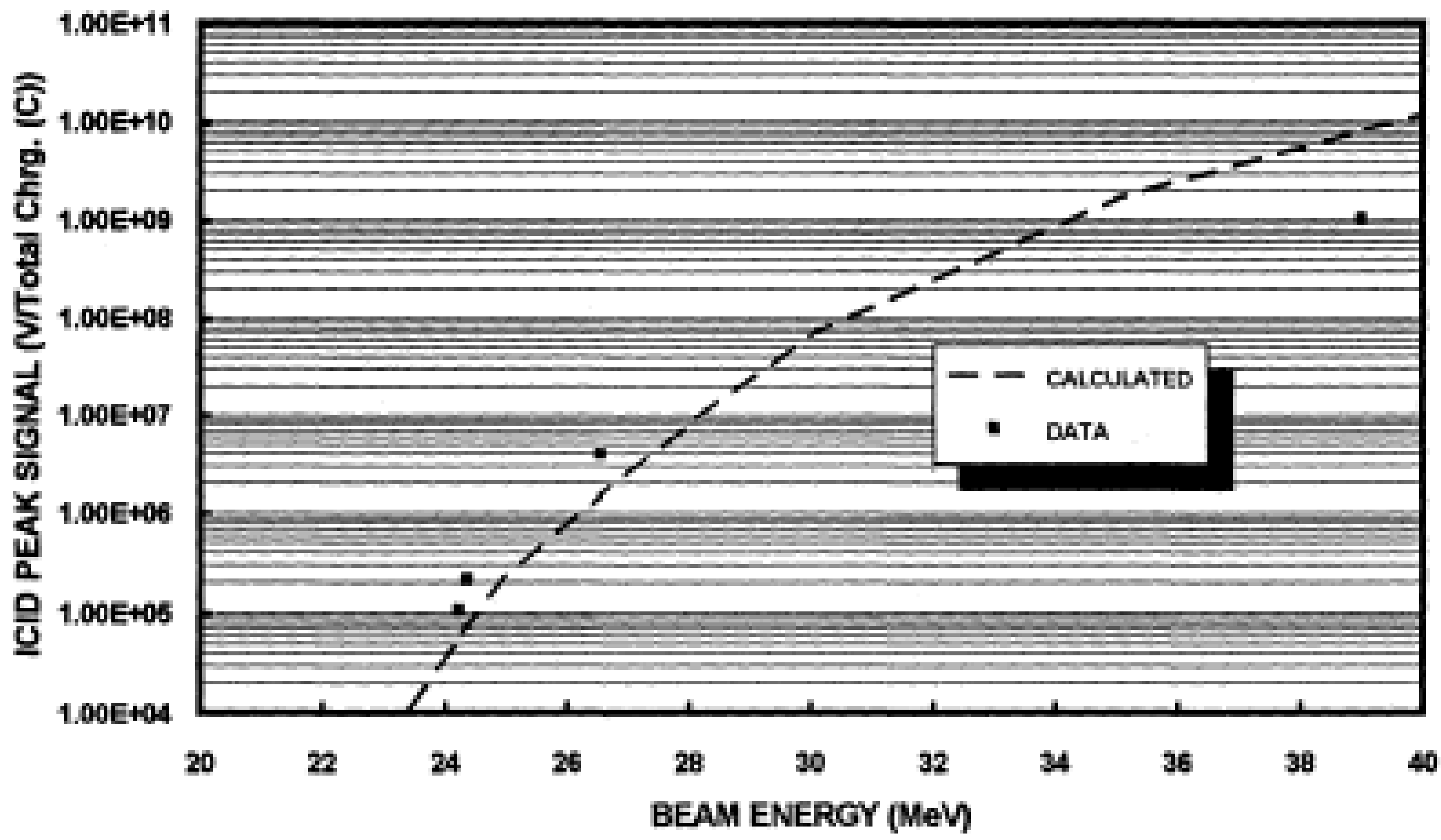
Figure 3b

SCALE

~10 mm

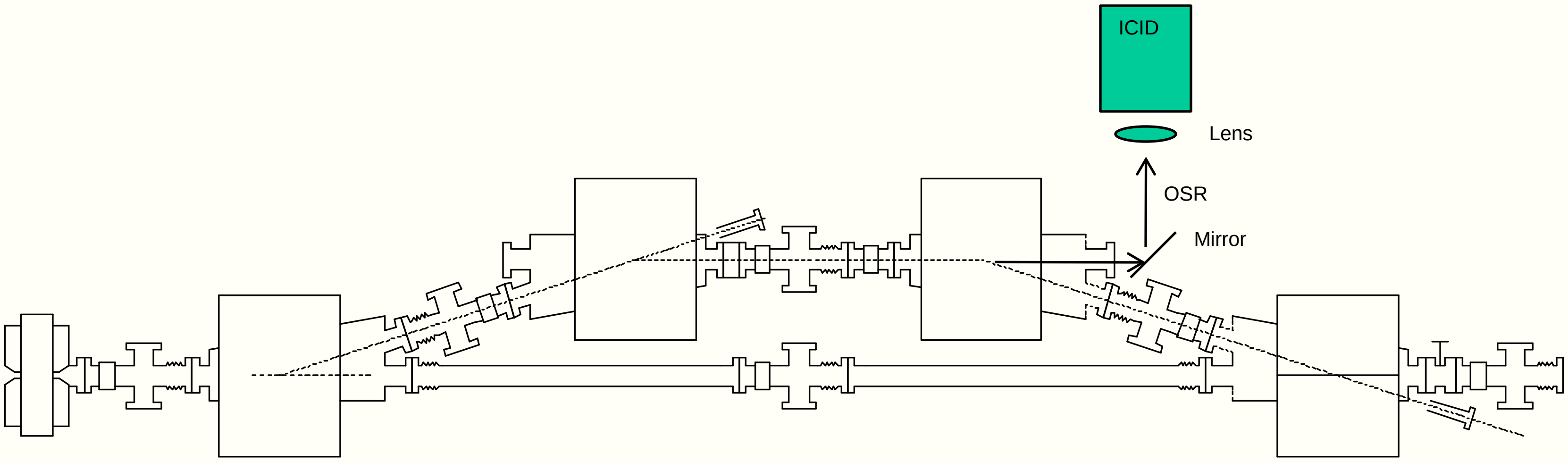
OSR vs. Beam Energy

- Charge –normalized OSR image signal for 30 cm bend and ICID. The noise floor is 4×10^3 V/C.



NML Chicane Case

E= 40 MeV
ρ = 80 cm



Wakefields from ports issue TBA

Chicane from M. Church

SUMMARY

- **A description of the electron beam transverse measurement procedures with OSR have been provided at ~40 MeV beam energy.**
- **Beam size (200 μm) and profile would be feasible with visible light OSR.**
- **An ICID or ICCD camera is needed with beam charges on the order of 1000 nC integrated into the image.**
- **Randy is working on OSR and edge radiation (ER) modeling to look at this NML case in more detail.**