CLS Diagnostic Beamlines

OSR – **O**ptical **S**ynchrotron **R**adiation

(λ = 500 nm)

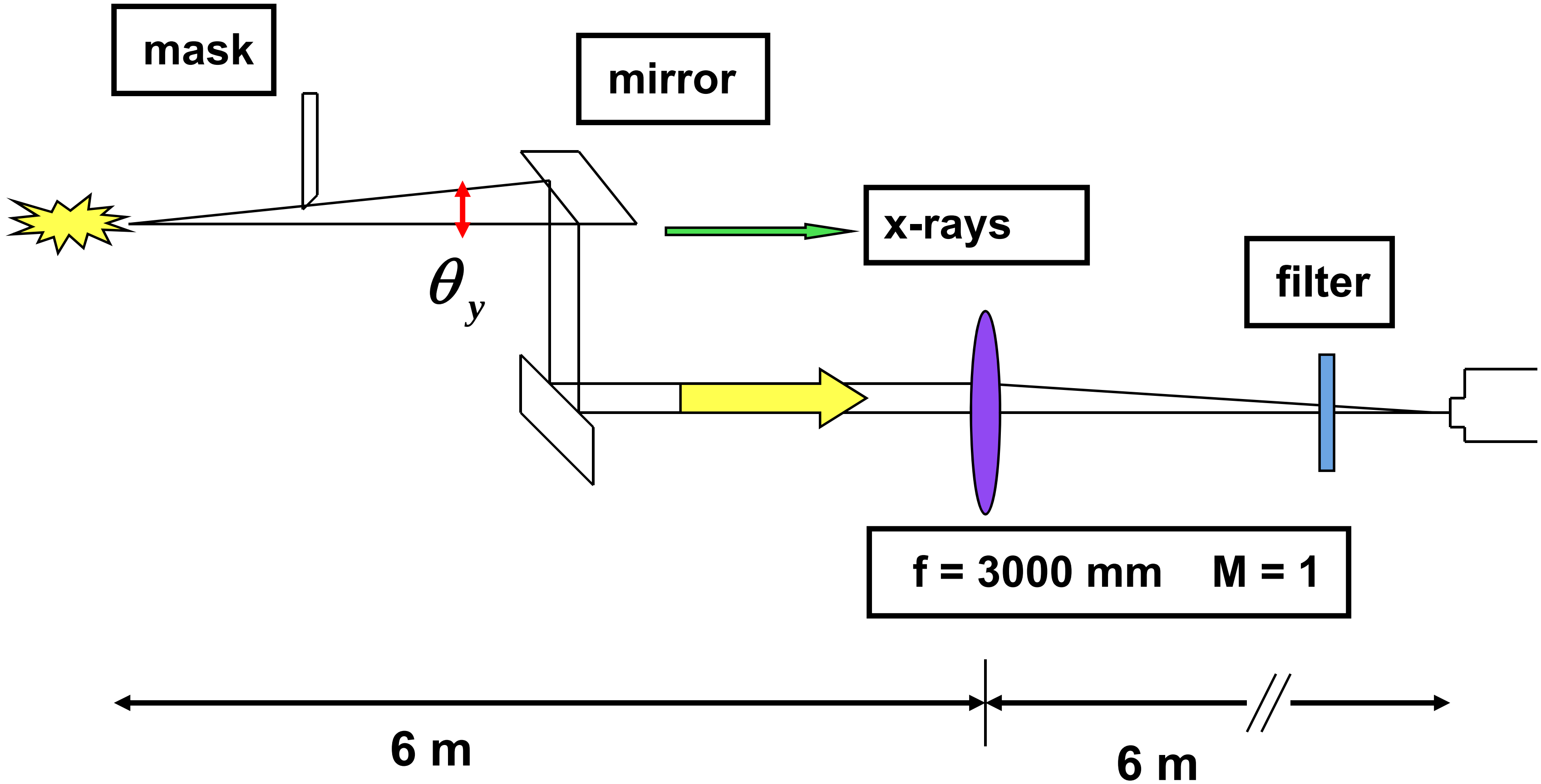
XSR – **X**-ray **S**ynchrotron **R**adiation

(λ ≤ 0.15 nm)

Goal:

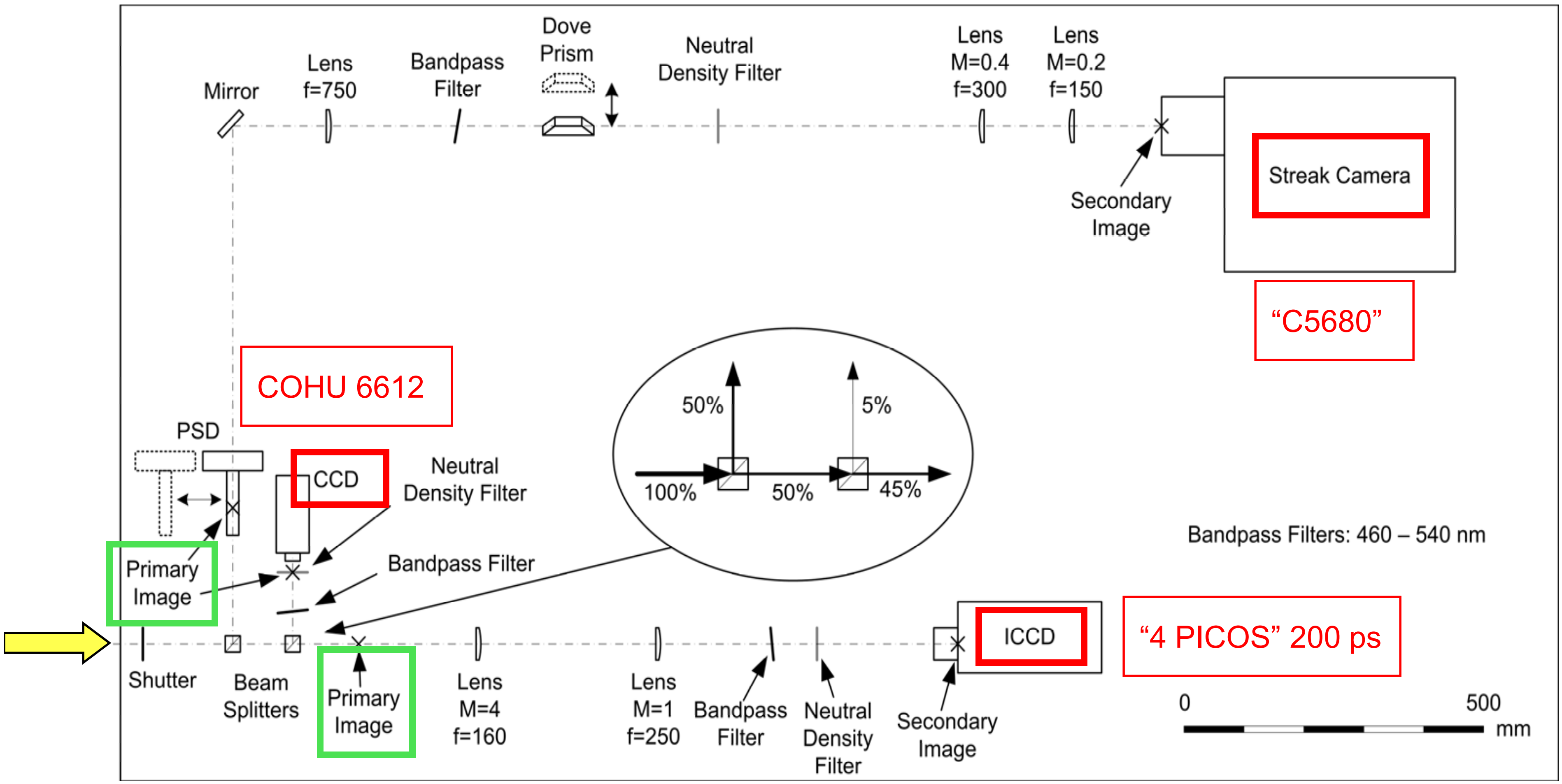
Mutually consistent results

OSR Diagnostic Beamline

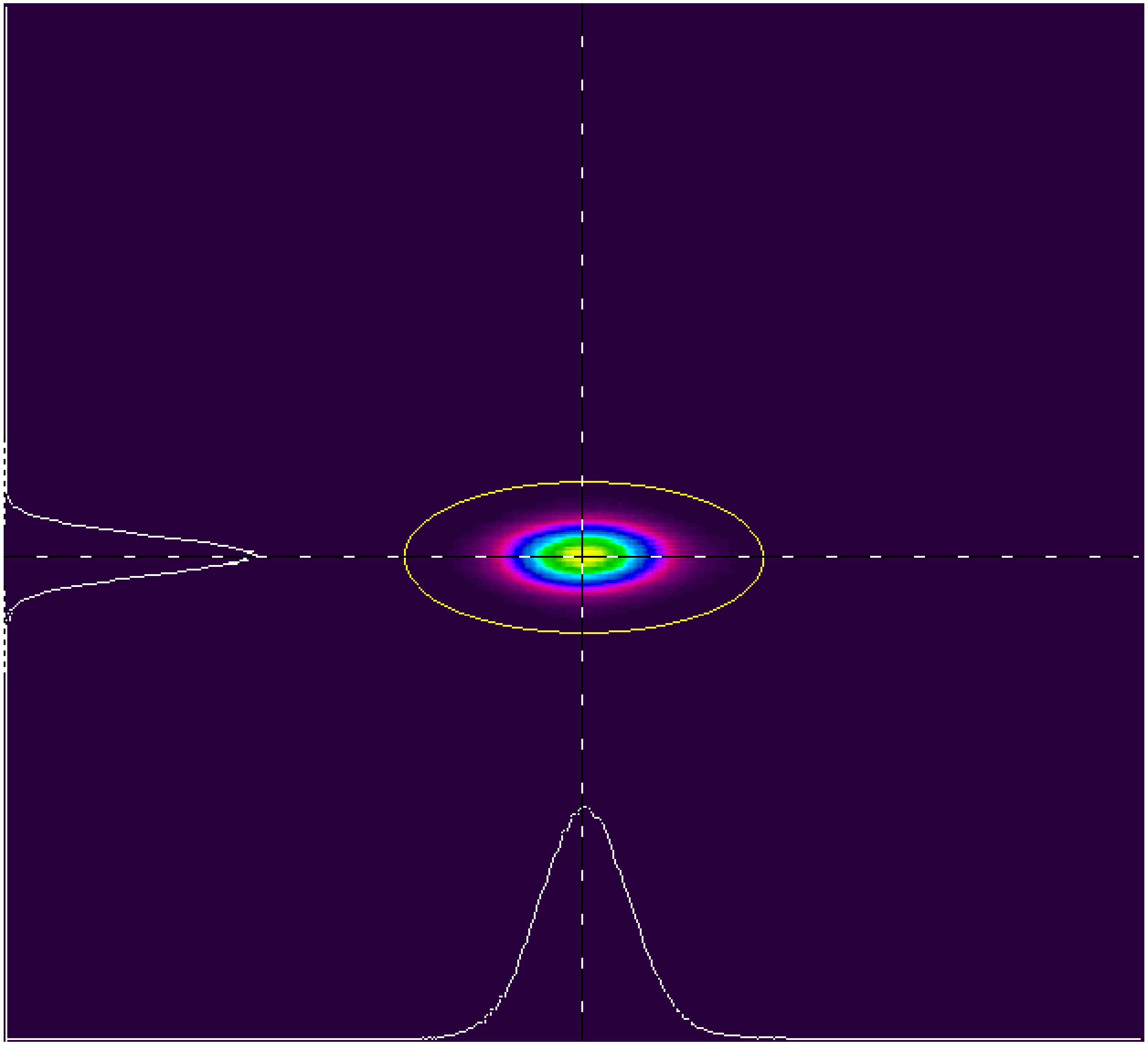


Vertical Chicane : 500 mm vertical offset

OSR Optical Table Layout

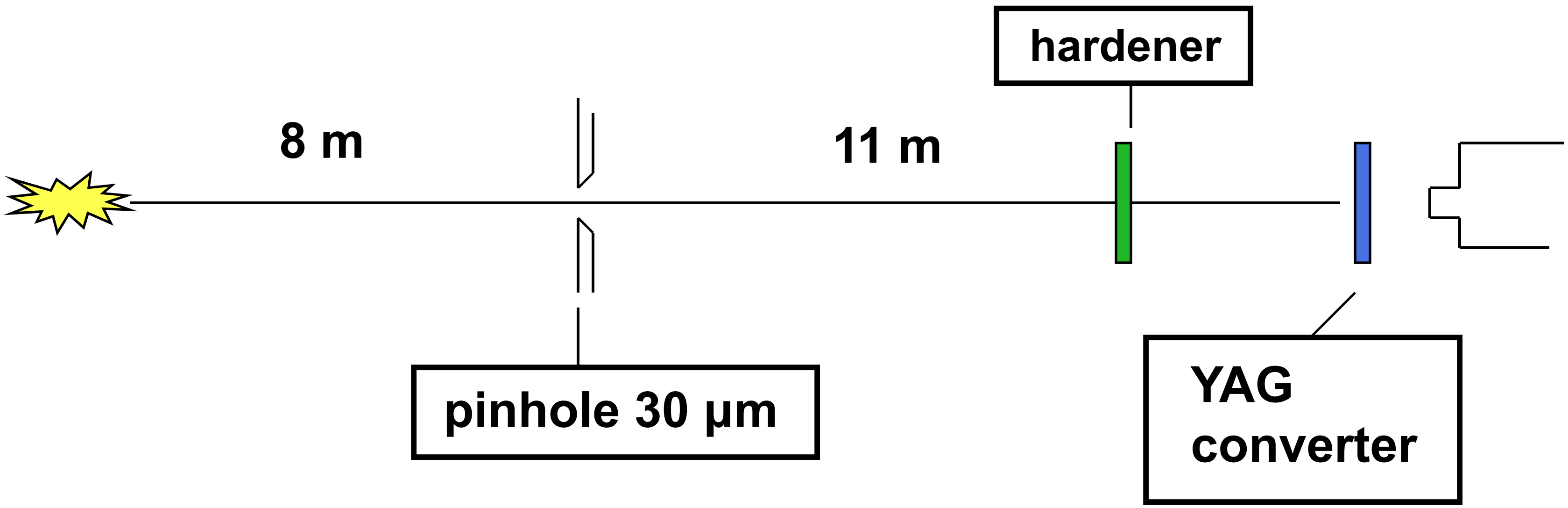


OSR Beam Image [Spiricon Processing]

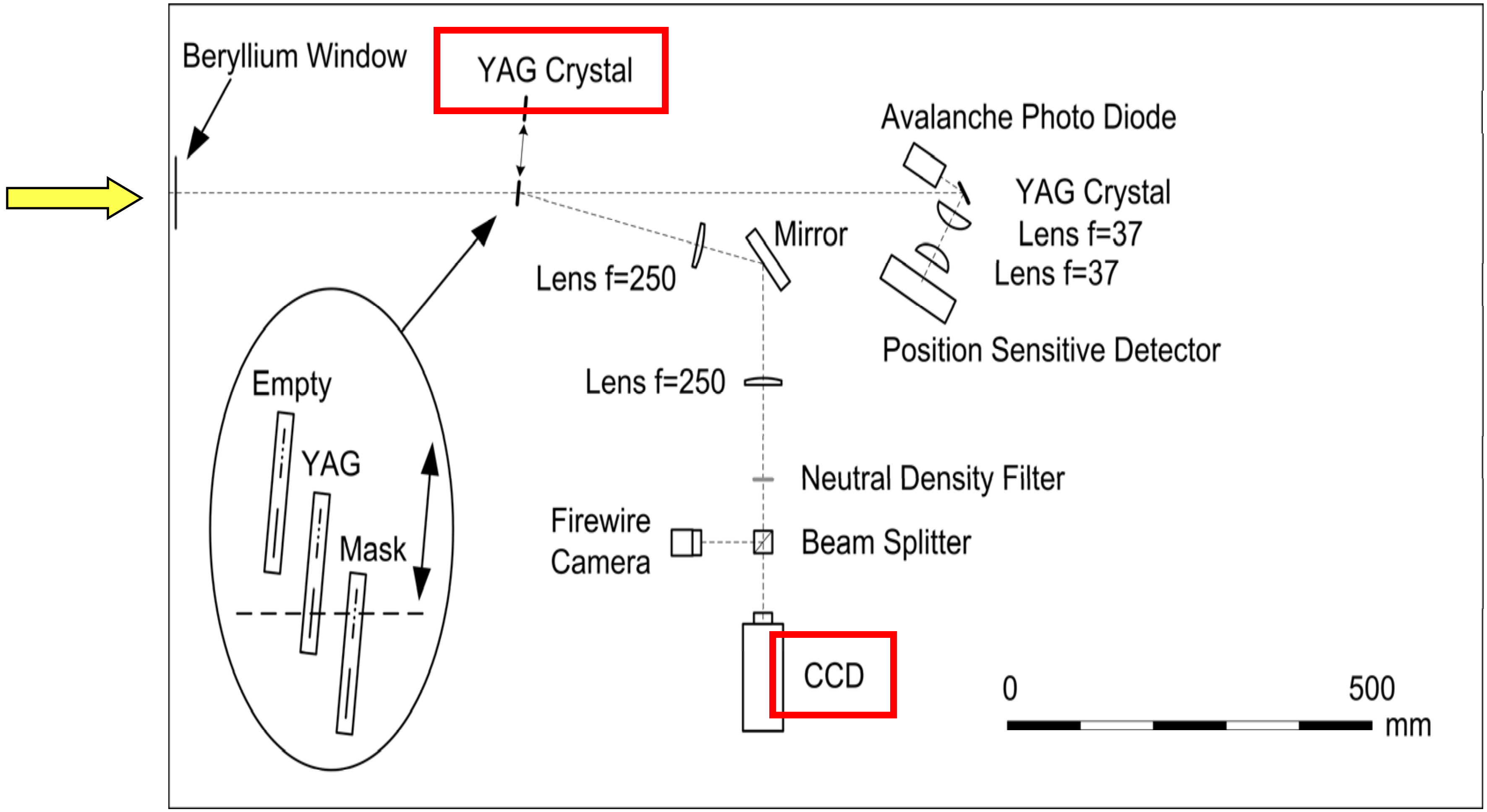


XSR Diagnostic Beamline

(Pinhole Camera)

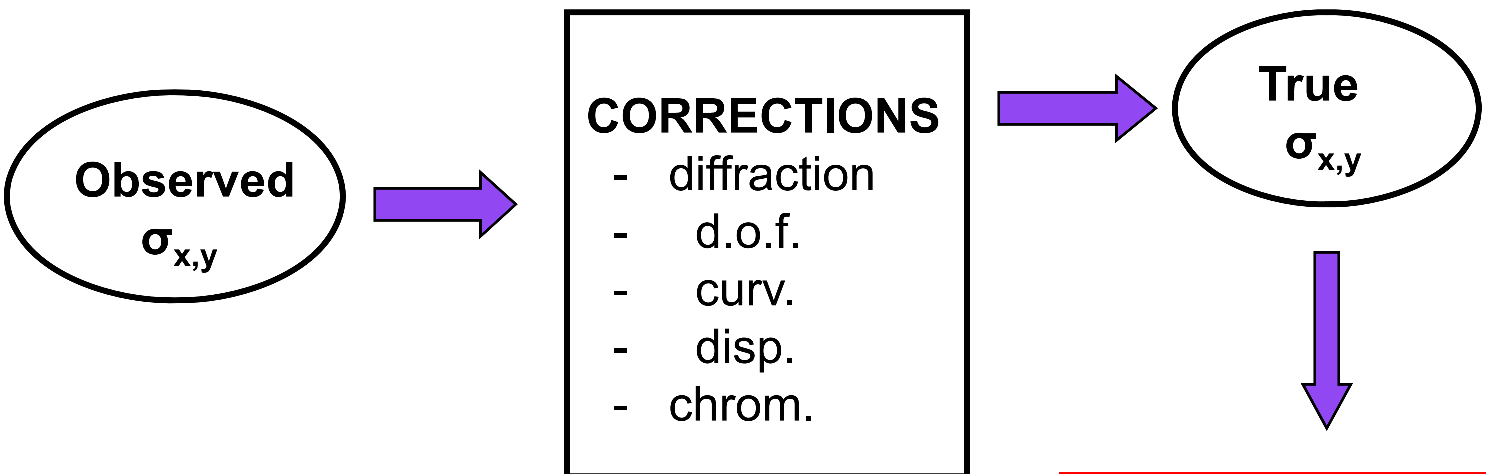


XSR Optical Table Layout



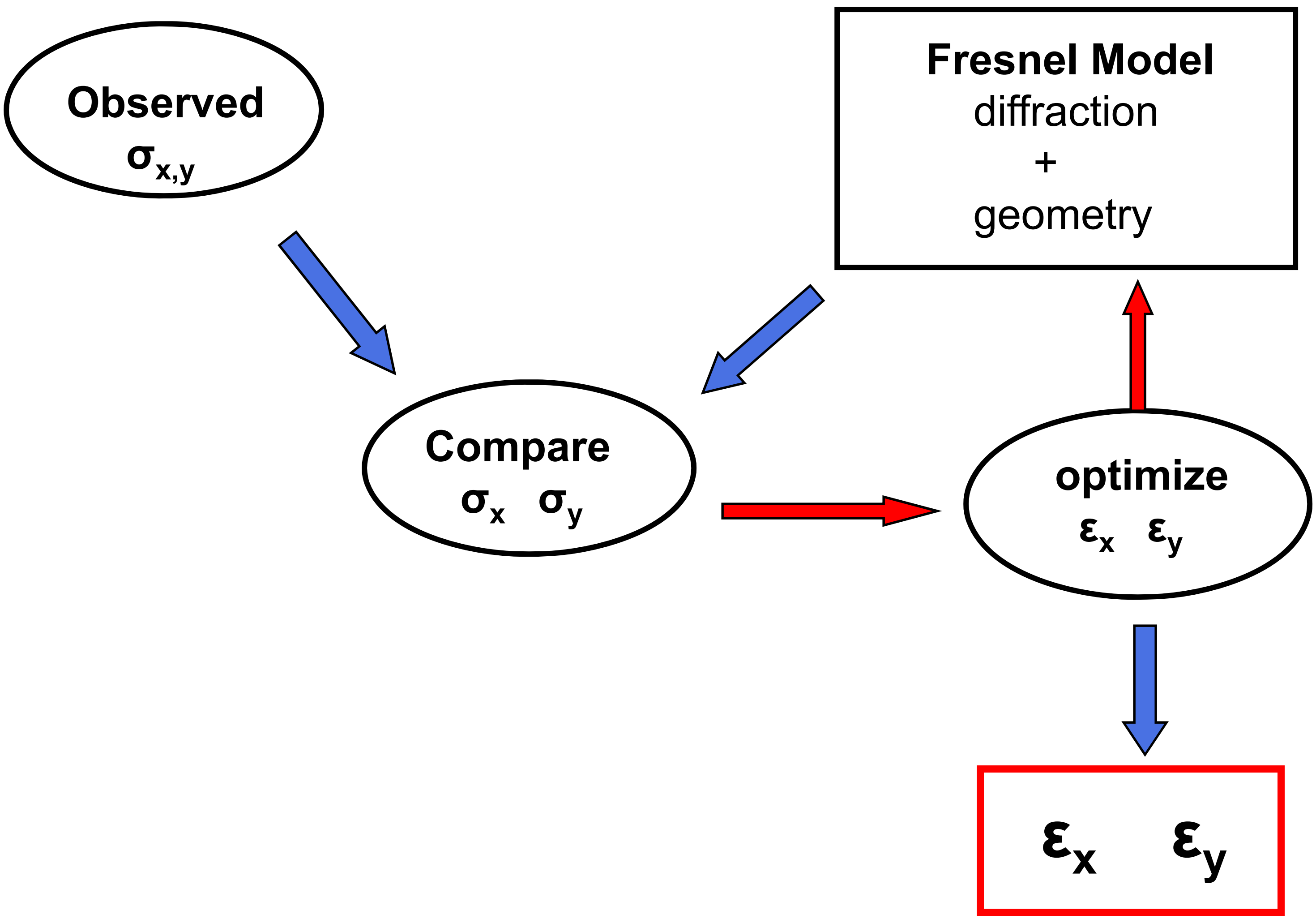
OSR & XSR – Very different analysis procedures

OSR Procedure: Image ***Reduction***



$$\varepsilon_x = \frac{\sigma_x^2}{\beta_x} \qquad \varepsilon_y = \frac{\sigma_y^2}{\beta_y}$$

XSR Procedure: Image ***Synthesis***



OSR Analysis

- **Fraunhofer Diffraction** [N.I.M. A562 (2006) 495]

  Vertical Plane:

  - Intensity varies with θ_y
  - Aperture limits on θ_y

    $\theta_y(\min) \longrightarrow$ *Mirror bottom*

    $\theta_y(\max) \longrightarrow$ *Photon mask*

- $I(y) = |E(y)|^2$

$$\boldsymbol{E(y)} = \int_{\theta(\min)}^{\theta(\max)} [\boldsymbol{E}_\sigma(\boldsymbol{\theta}_y),\ \ \boldsymbol{iE}_\pi(\boldsymbol{\theta}_y)] \cdot \boldsymbol{e}^{-iky\theta_y} \boldsymbol{d\theta}_y$$

Horizontal Plane:

- Uniform illumination
- Textbook rect. aperture formula

Typical diffraction corrections

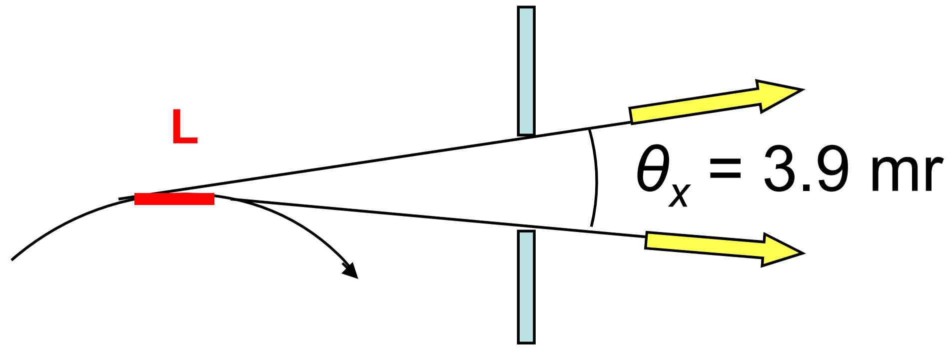
$\sigma_{diff\text{-}x}$= 48 μm $\sigma_{diff\text{-}y}$ = 57 μm

- **Dispersion**

  - $\sigma_{disp\text{-}x} = \eta_x(\Delta p/p)_{rms}$

Typical dispersion correction $\sigma_{disp\text{-}x}$ = 68 μm

- **Depth-of-Field**



$$L = \rho(\theta_x + 2\theta_{\gamma-rms})$$

$$\sigma_{dof-x} = \tfrac{1}{12} ML\theta_x \qquad (M = 1)$$

$$\sigma_{dof-y} = \frac{1}{\sqrt{12}} ML\theta_{\gamma-rms} \qquad (\theta_{\gamma-rms} < \theta_y)$$

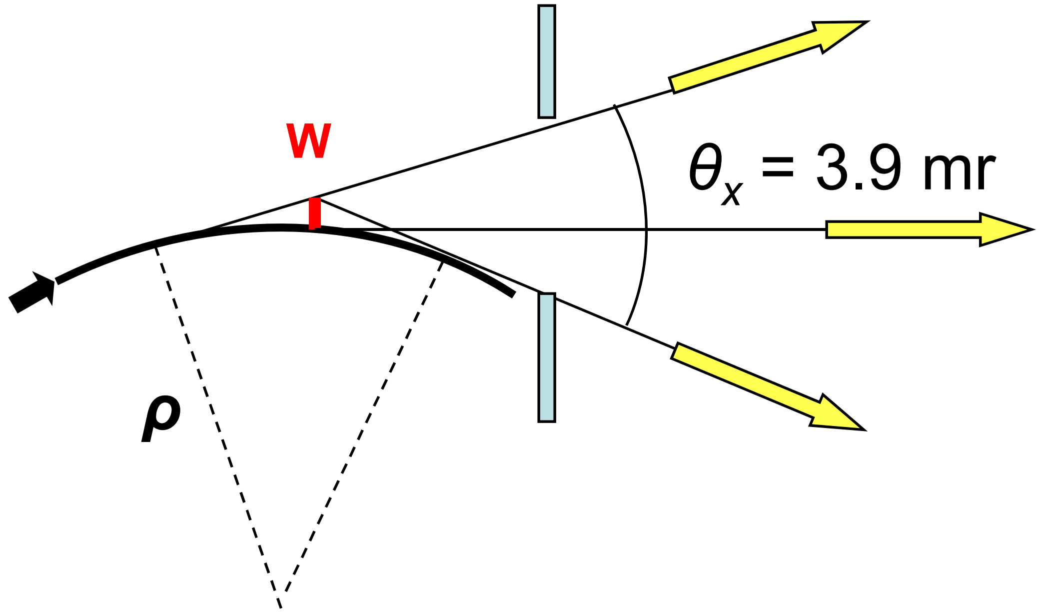
Typical DOF corrections: $\sigma_{dof\text{-}x}$ = 18 µm $\sigma_{dof\text{-}y}$ = 30 µm

- **Chromatic (DOF): Δλ = 80 nm**

  - ZEMAX study

σ_{chrom} = 14 µm

- **Curvature**



$$\sigma_{curv-x} = \frac{1}{16}\rho M\left[\frac{1}{5}\theta_x^4 + 8\theta_x^2\theta_{\gamma-rms}^2 + 16N\theta_{\gamma-rms}^4\right]^{1/2}$$

(N ≈ 3)

Typical curvature correction: $\sigma_{curv\text{-}x}$ = 15 μm
$\sigma_{curv\text{-}y}$ = 0

Total OSR Corrections (typ): $\sigma_x \approx 88$ μm
$\sigma_y \approx 66$ μm

- **where to look:**

Total OSR Corrections (typ): **$\sigma_x \approx 88\ \mu m$**   **$\sigma_y \approx 66\ \mu m$**

To measure small vertical emittances:

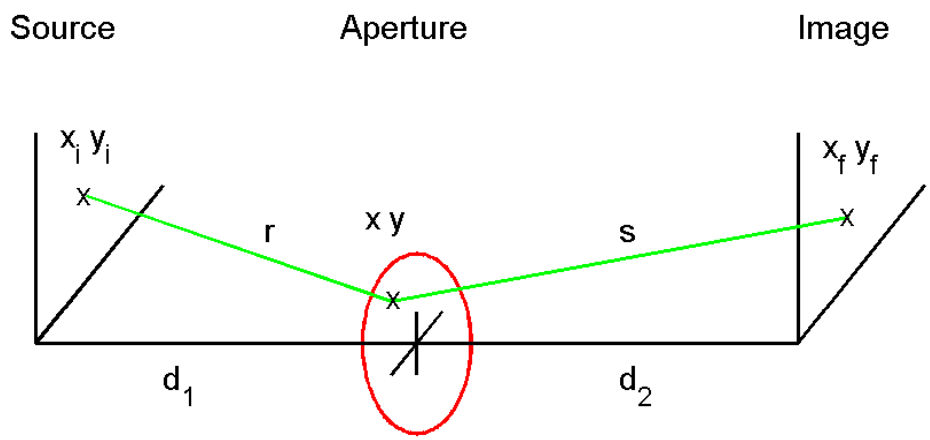
observe beam at large β_y

OSR: $\beta_y = 25$ m
$\sigma_y = 21\ \mu m$

ID: $\beta_y = 2.5$ m
$\sigma_y = 7\ \mu m$

XSR Analysis

- Fresnel Diffraction



- Point source at x_i y_i
- Diffracted-wave amplitude at x_f y_f

$$U(x_f y_f) = \frac{B}{\lambda} \cdot \iint_{aperture} e^{ik(r+s)} dA$$

- Expand ***r*** & ***s*** through 2nd order.
- Rectangular Aperture ⟹ Intensity *factors* into x & y:

$$I\left\{[x_i, x_f],[y_i, y_f]\right\} \equiv \left|U(x_f y_f)\right|^2$$

$$= I(x_i x_f) * I(y_i y_f)$$

- Point source ⟹ Distributed **photons** *ρ(x_i)* *ρ(y_i)*

⟹ $$I(y_f) = \int_{-\infty}^{+\infty} \rho(y_i) \cdot I(y_i y_f) \cdot dy_i$$

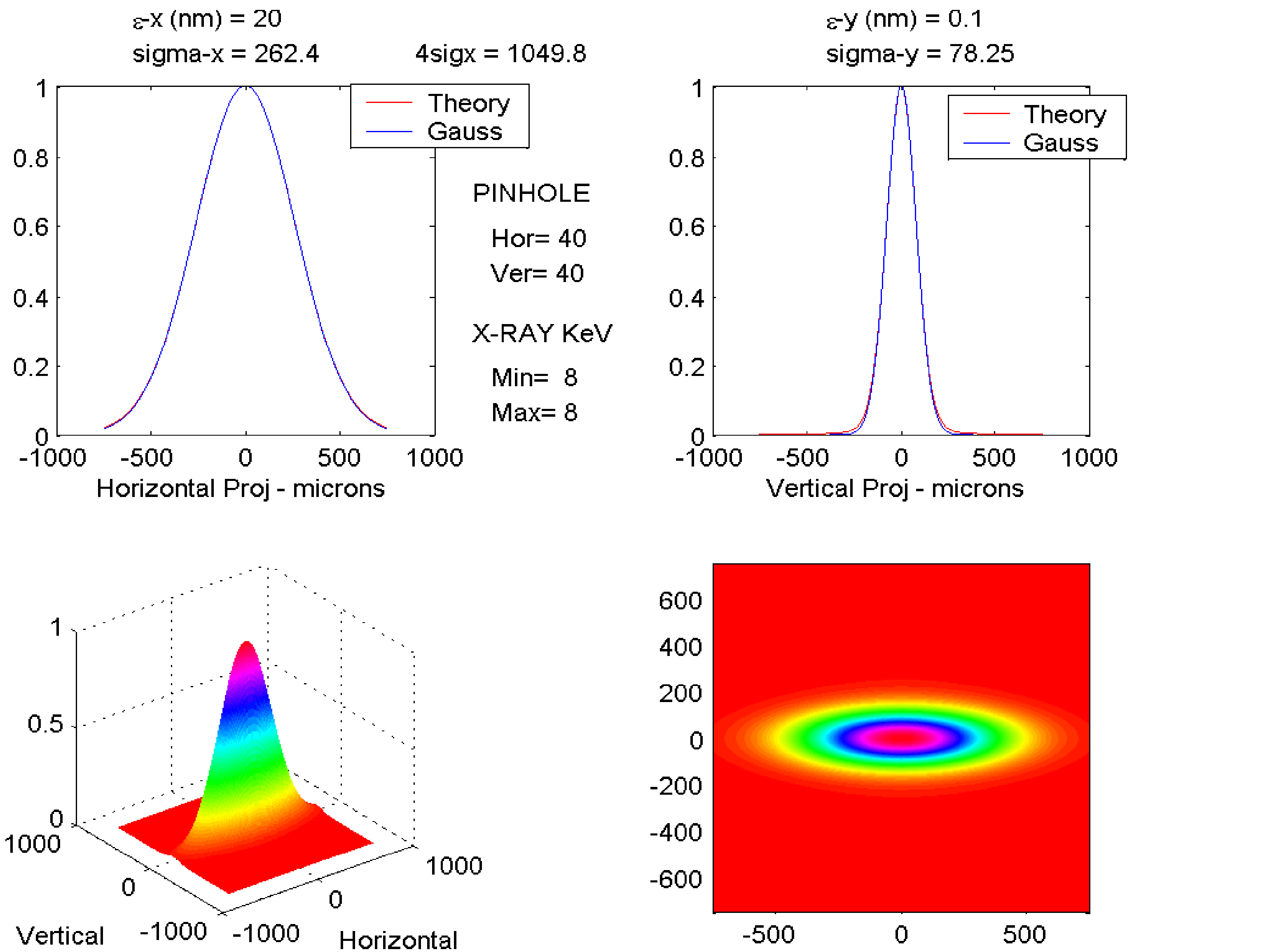
- Photon density: $\rho(y,\varphi) = \frac{1}{2\pi\varepsilon_y} \cdot e^{-(\gamma y^2 + 2\alpha y\varphi + \beta\varphi^2)/2\varepsilon_y}$ etc.

- And Some Clever Manipulations ....

$$I(y_f) = \int_0^1 \frac{e^{-Az^2}}{z} \cdot \sin Bz(1-z) \cdot \cos Cy_f z \cdot dz$$

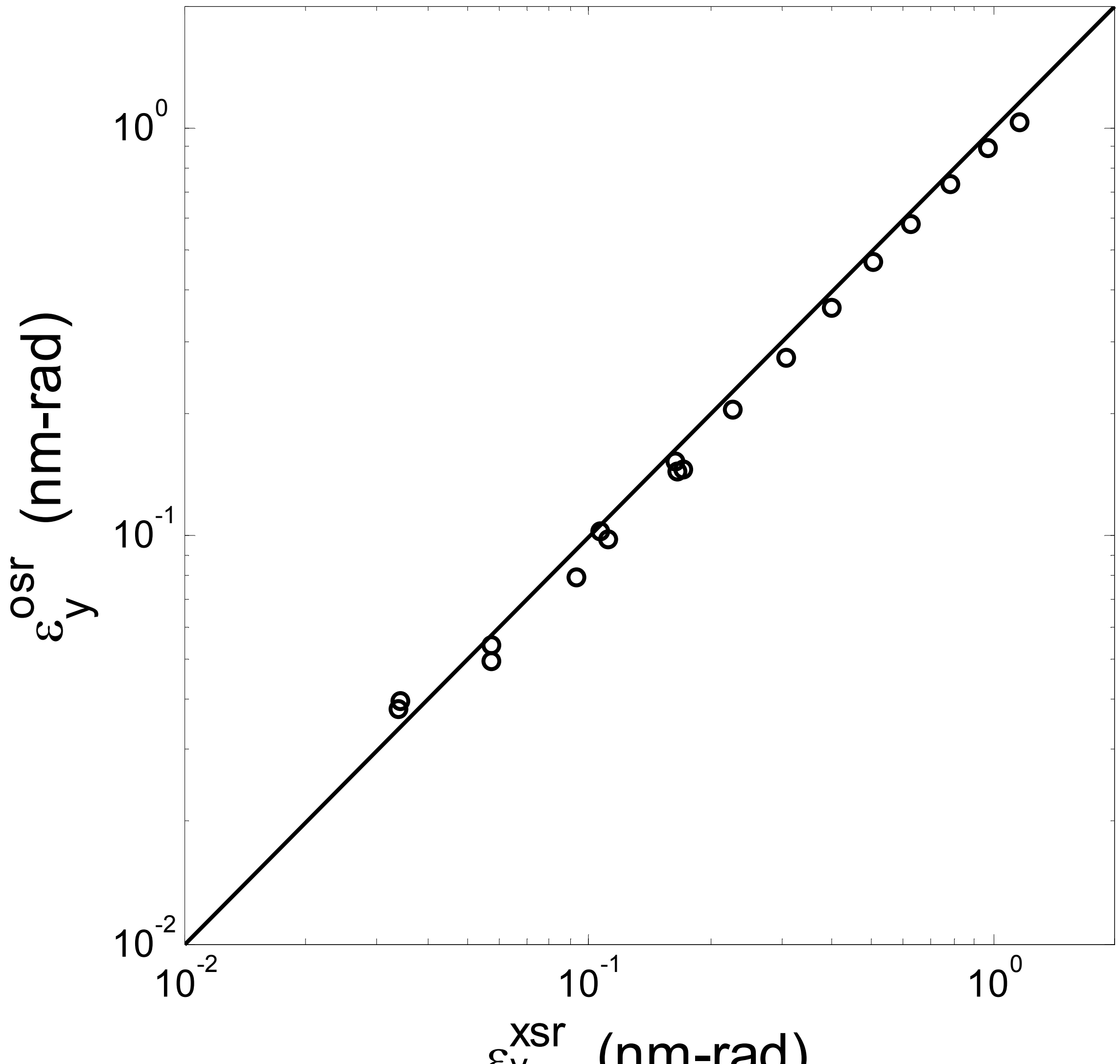
- *A* – Depends on ε_y
- *B,C* – Depend on Slit Width
- *cos* term – Entire y_f dependence.
- *I*(y_f) – Encompasses both Geometric and Diffraction aspects.
- *I*(y_f) – Fold with X-Ray Spectrum.

Example: ε_x = 20 nm ε_y = 0.10 nm



Comparison between OSR & XSR:

Vertical Emittance – x-y Coupling 0.16 – 5.0 %



- 8 % diff.
- No η_y correction

Lifetime Measurements

- $1/\square = 1/\square_T + 1/\square_V$ Touschek and Vacuum
- $1/\square_T = 1/(\varepsilon_y^{1/2}\square_{T*})$ $\square_V$ = constant

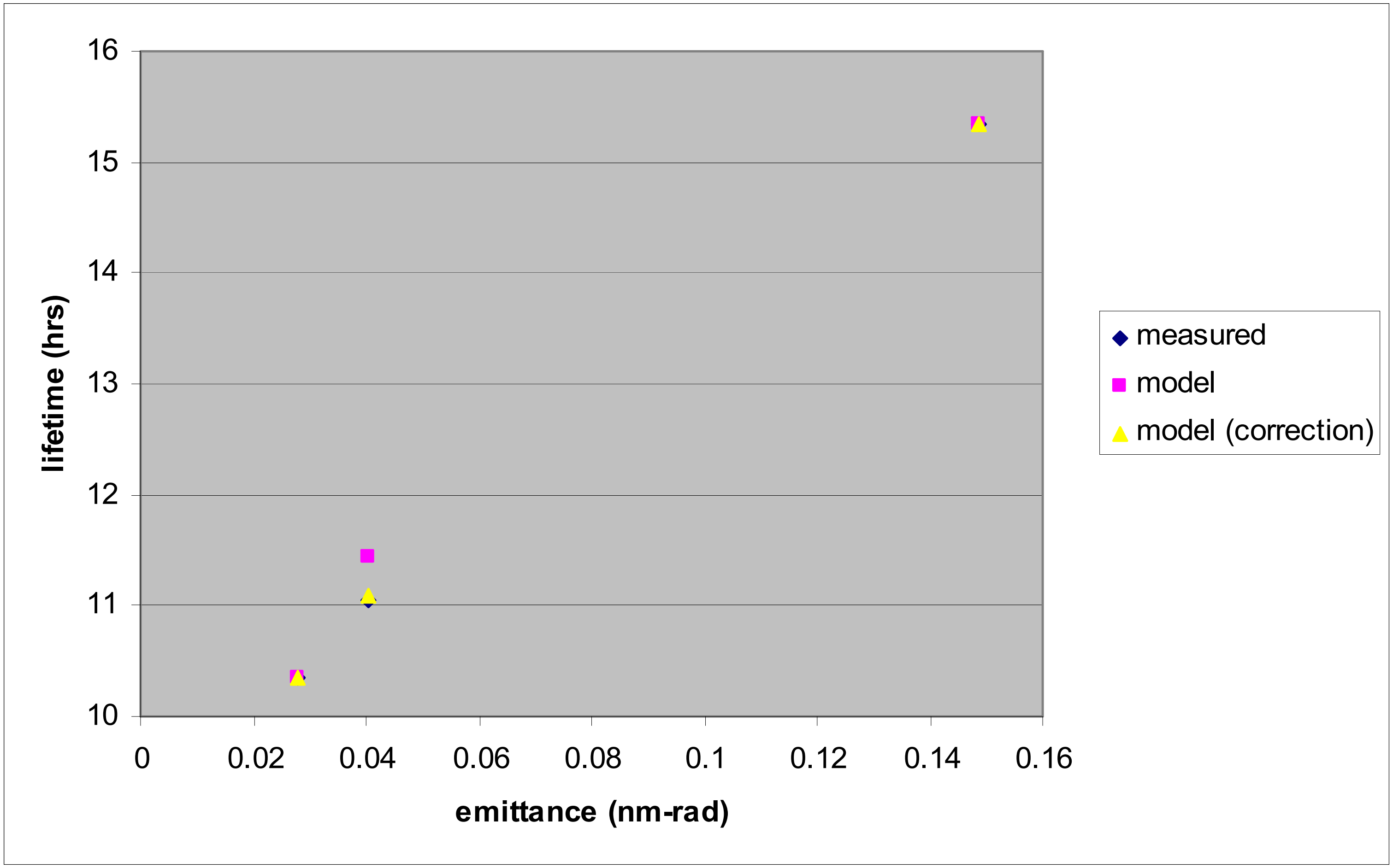
ε_y	0.0279	0.0403	0.1486
□	10.34	11.05	15.35

measured from XSR

ε_y	0.0300 +7%	0.0375 -7%	0.1382 -7%
□	10.34	11.05	15.35

model
$\square_V$ = 26.5 hr
$\square_{T*}$ = 98.1 hr

Lifetime Measurements



Conclusions

- Consistency (< 8 %) between OSR & XSR over the range $\varepsilon_y \approx 0.04 - 1.00$ nm-rad.

- Therefore, confidence in the analysis procedures.

- Now use XSR to study "small" x-y couplings: Q ≤ 0.3 % [$\varepsilon_y \leq 0.05$ nm-rad].