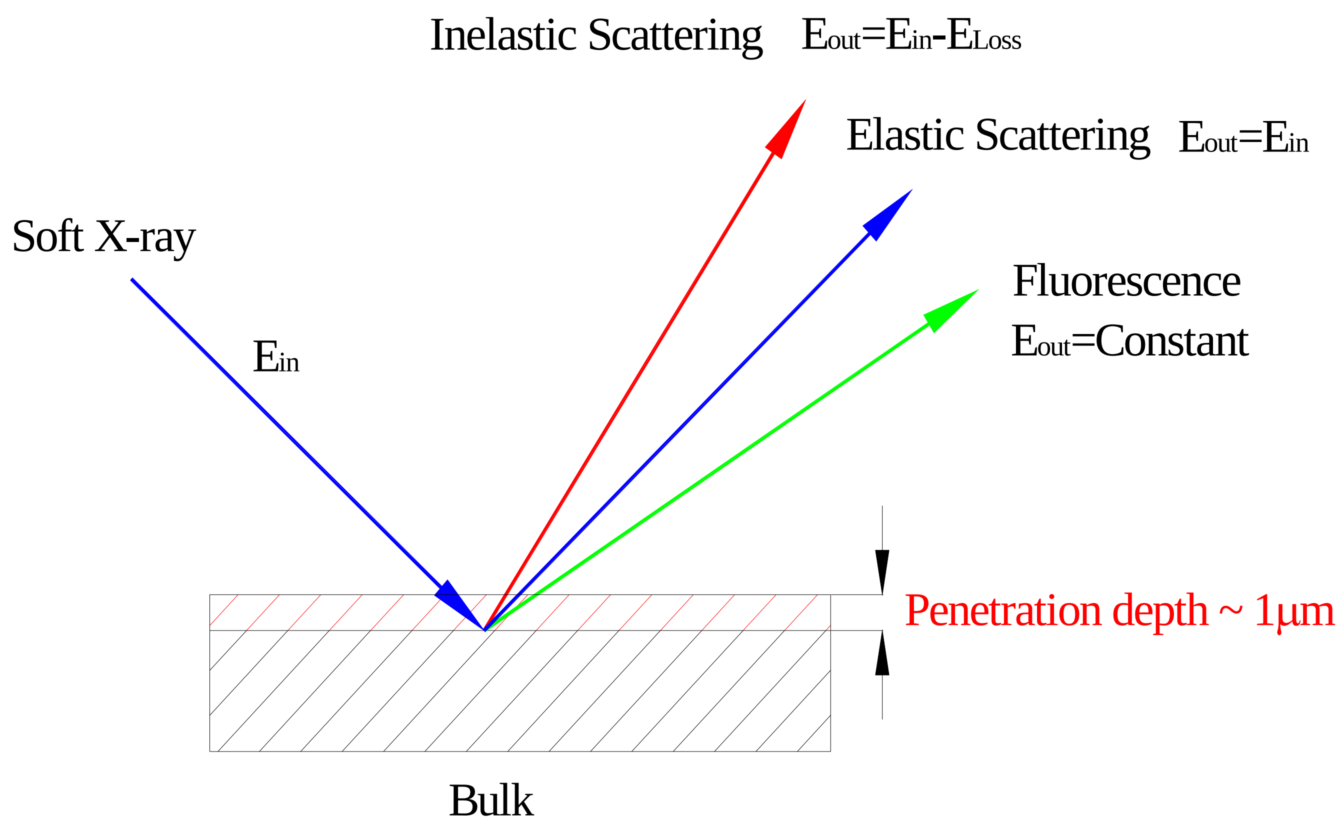
A Novel Active Grating Monochromator – Active Grating Spectrometer Beamline System for Inelastic X-ray Scattering Experiments

H. S. Fung*, C. T. Chen, L. J. Huang, C. H. Chang, S. C. Chung, D. J. Wang, T.C. Tseng and K. L. Tsang

- **Introduction**
- **From SGM to AGM**
- **AGM-AGS Beamline System:**
  Implementation of the energy compensation principle to enhance the IXS experiments
- **Performance Simulation:**
  CLS grating vs. VLS grating
- **Conclusion**
- **Acknowledgments**

The Concept of Inelastic X-ray Scattering (IXS)

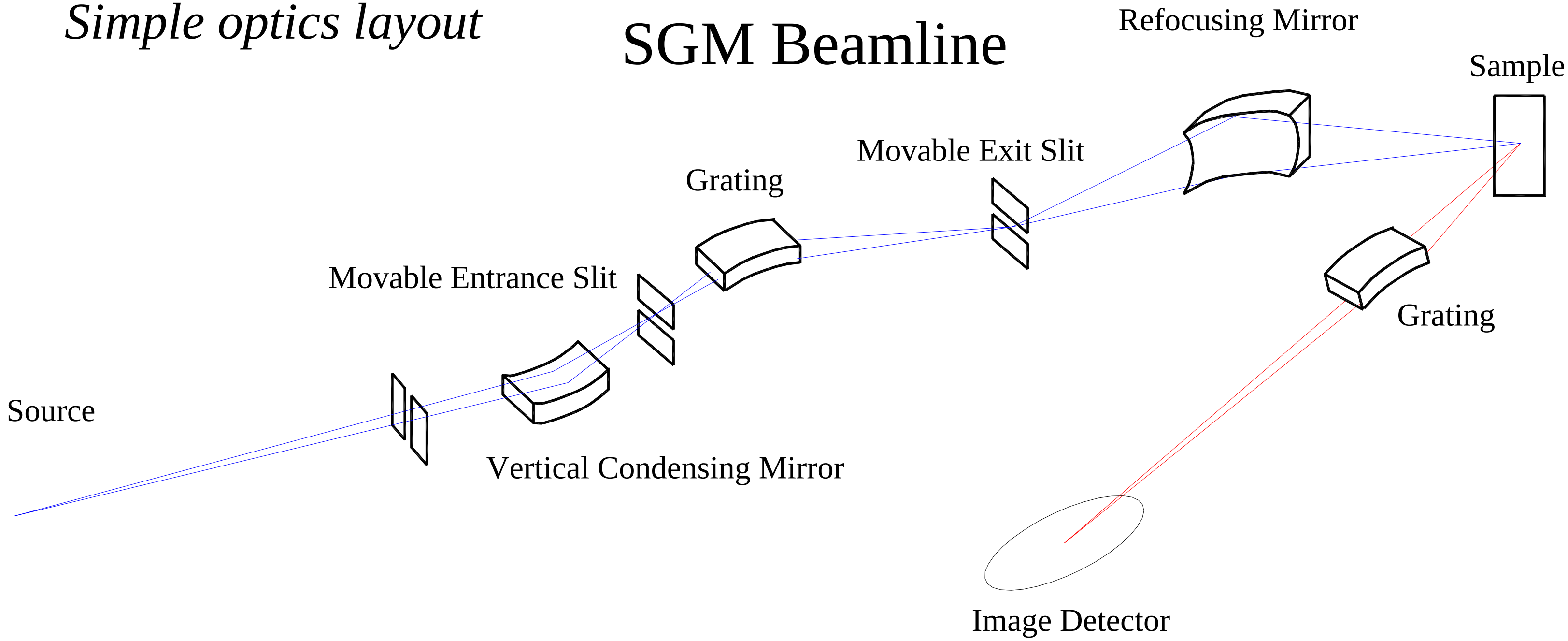
- Strong excitation photon flux: AGM
- High efficiency spectrometer: AGM-AGS



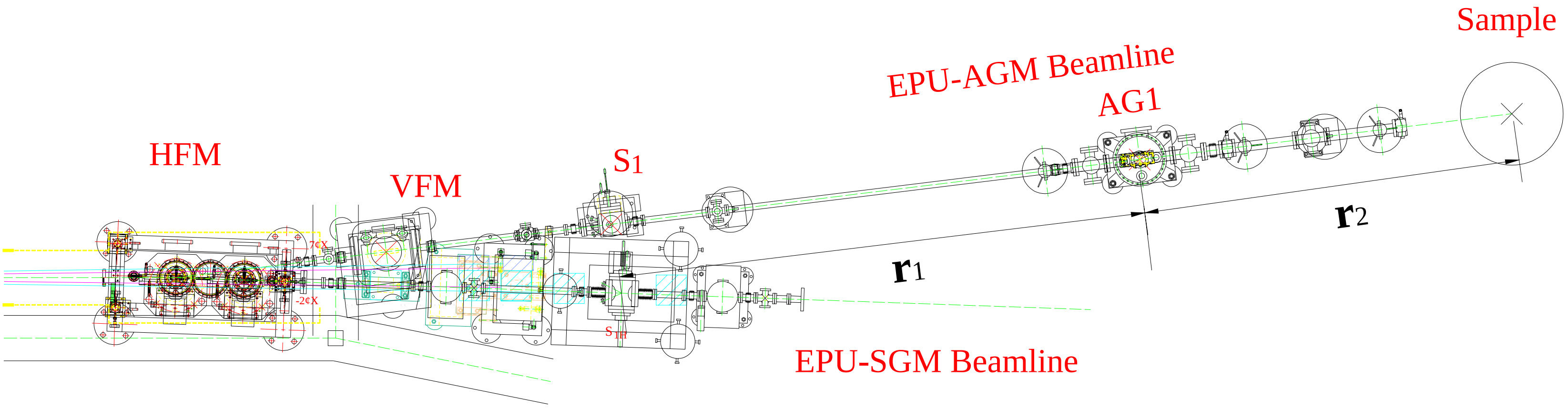
- **From SGM to AGM**

A Conventional SGM Beamline for IXS Measurements

Why SGM?
High performance
Simple optics layout



The Engineering Design of the AGM-AGS Beamline



Optical Path Difference (OPD)

$$OPD = APB - AOB + kN\lambda = 0$$

The grooves density : $N = n_0 w + n_1 w + \ldots$

The total number of grooves between O and P :

$$N = \int_0^w n(w')dw'$$

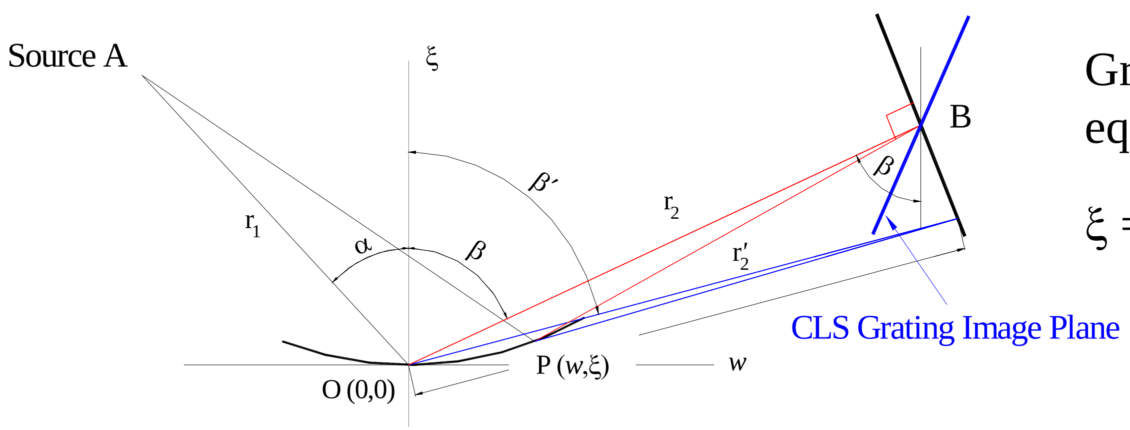
For Constant Line Space (CLS) case:

$$N = n_0 w$$

For Variable Line Space (VLS) case:

$$N = n_0 w + \frac{1}{2} n_1 w^2 + \ldots..$$

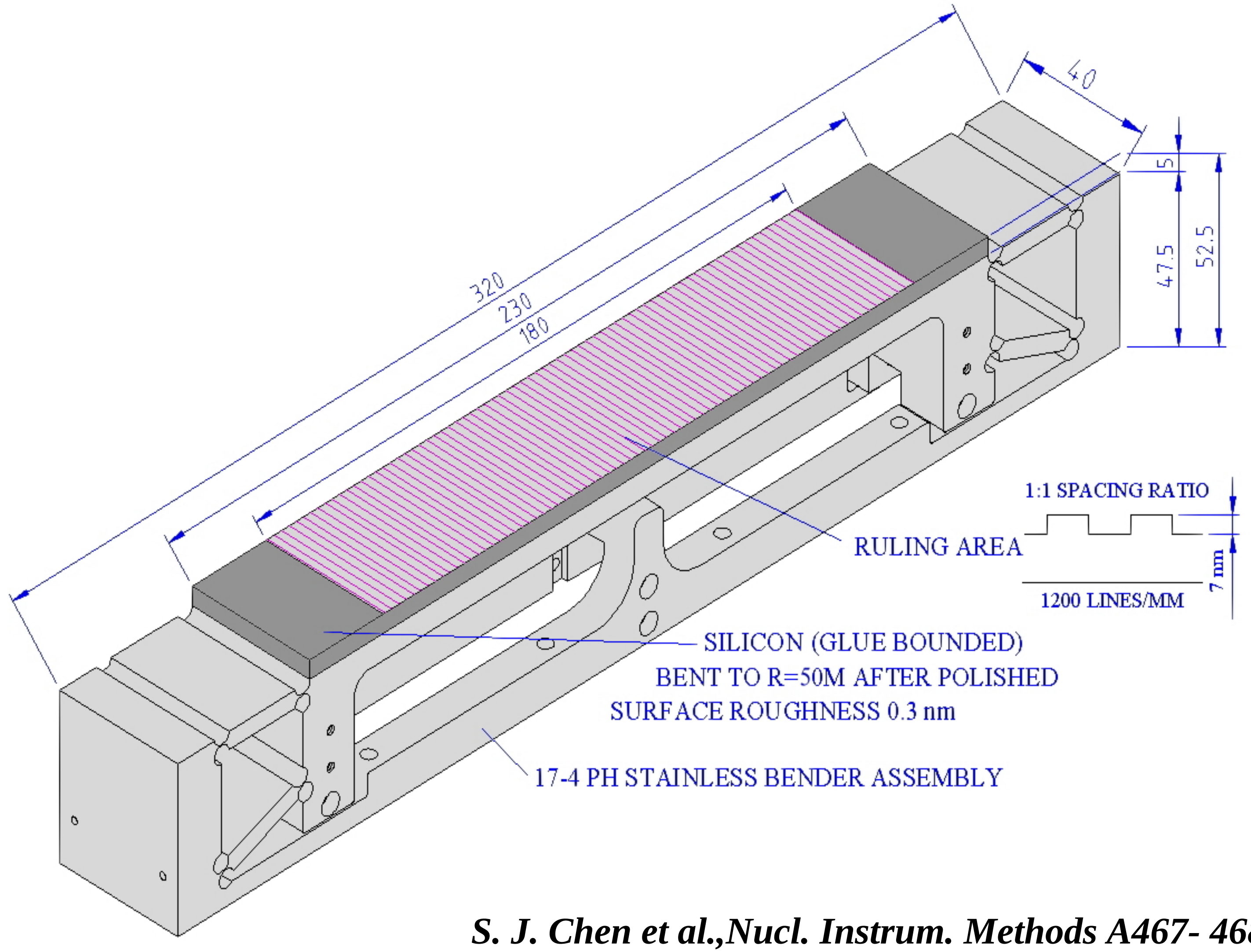
Sign convention: α and β are of opposite sign if they are on opposite sides of the normal. $\alpha - \beta =$ constant



Grating Surface equation

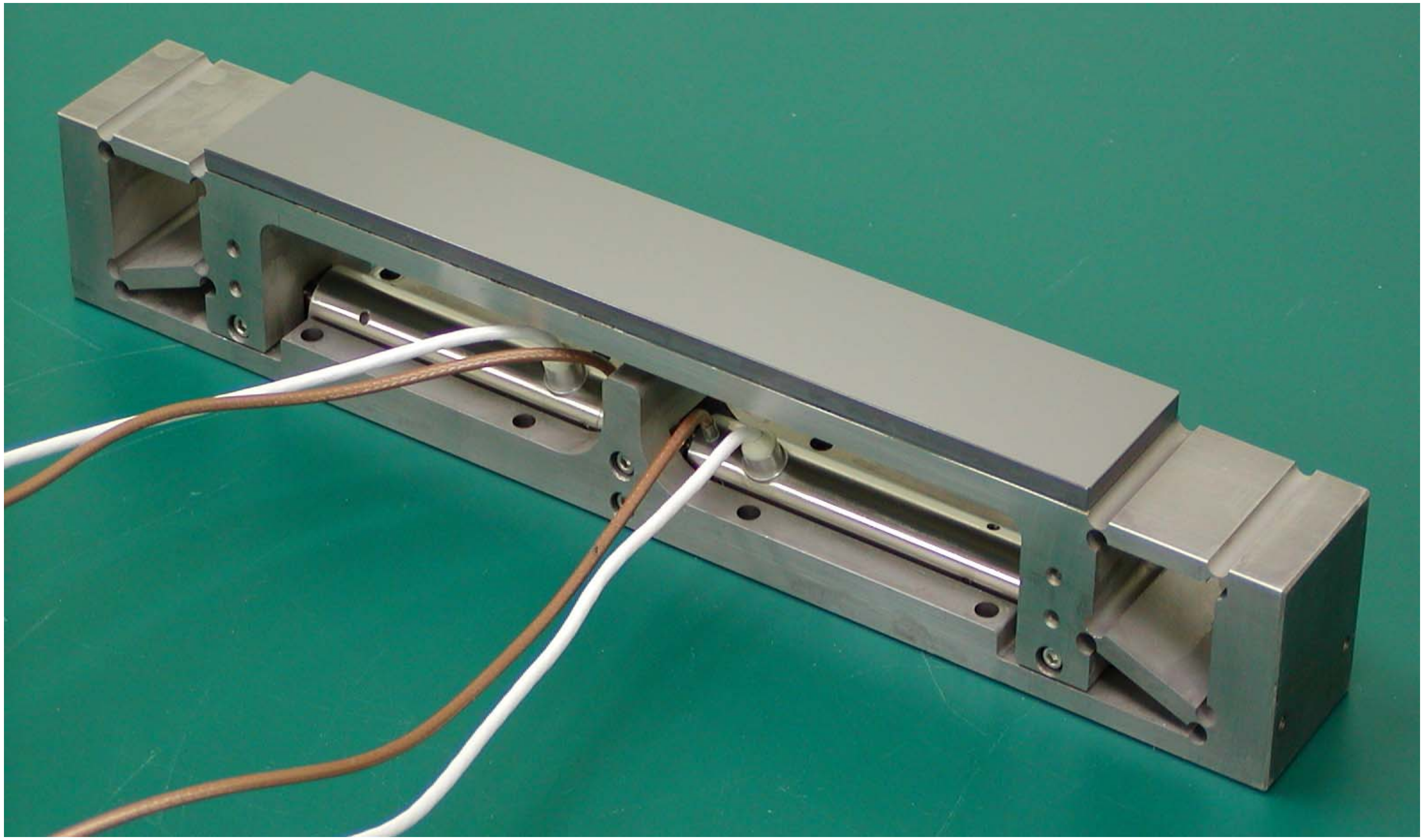
$$\xi = c_2 w^2 + c_3 w^3$$

Grating Bender Sketch

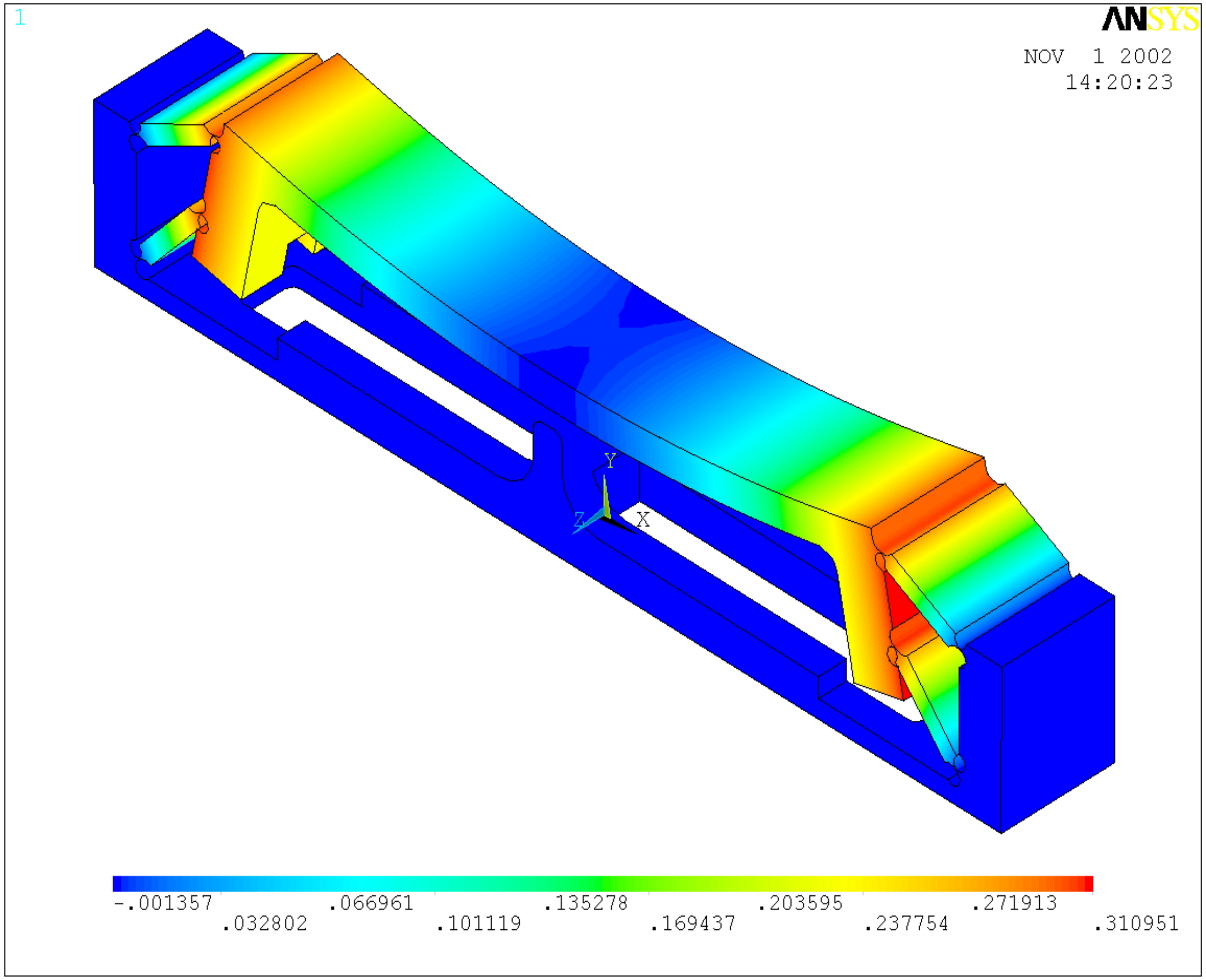


S. J. Chen et al.,Nucl. Instrum. Methods A467- 468, 445-448 (2001)

The Photograph of the Active Grating Bender



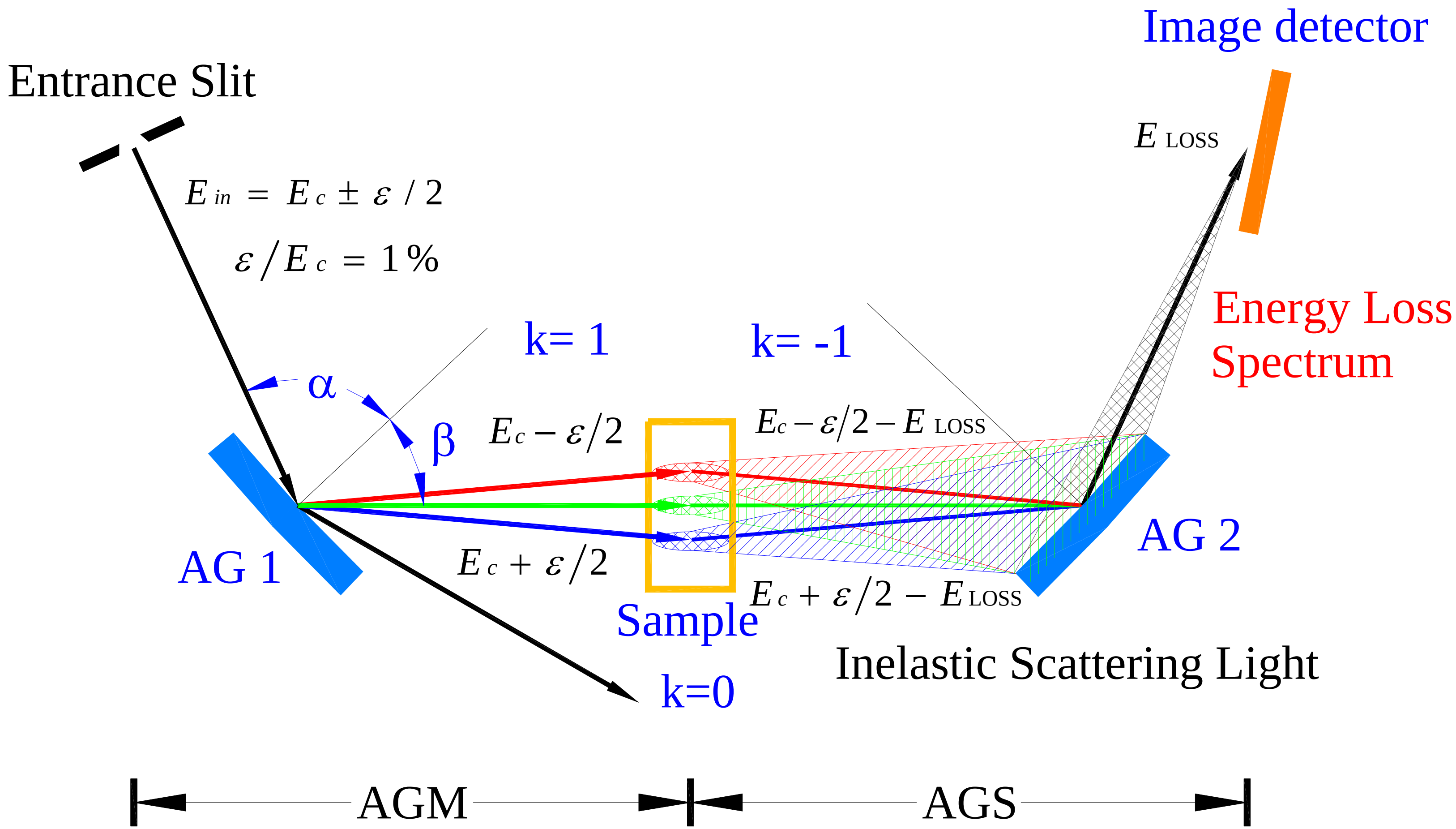
Finite Element Simulation of the Bender



- **AGM-AGS Beamline System**

How does the AGM/AGS work?

Energy Compensation

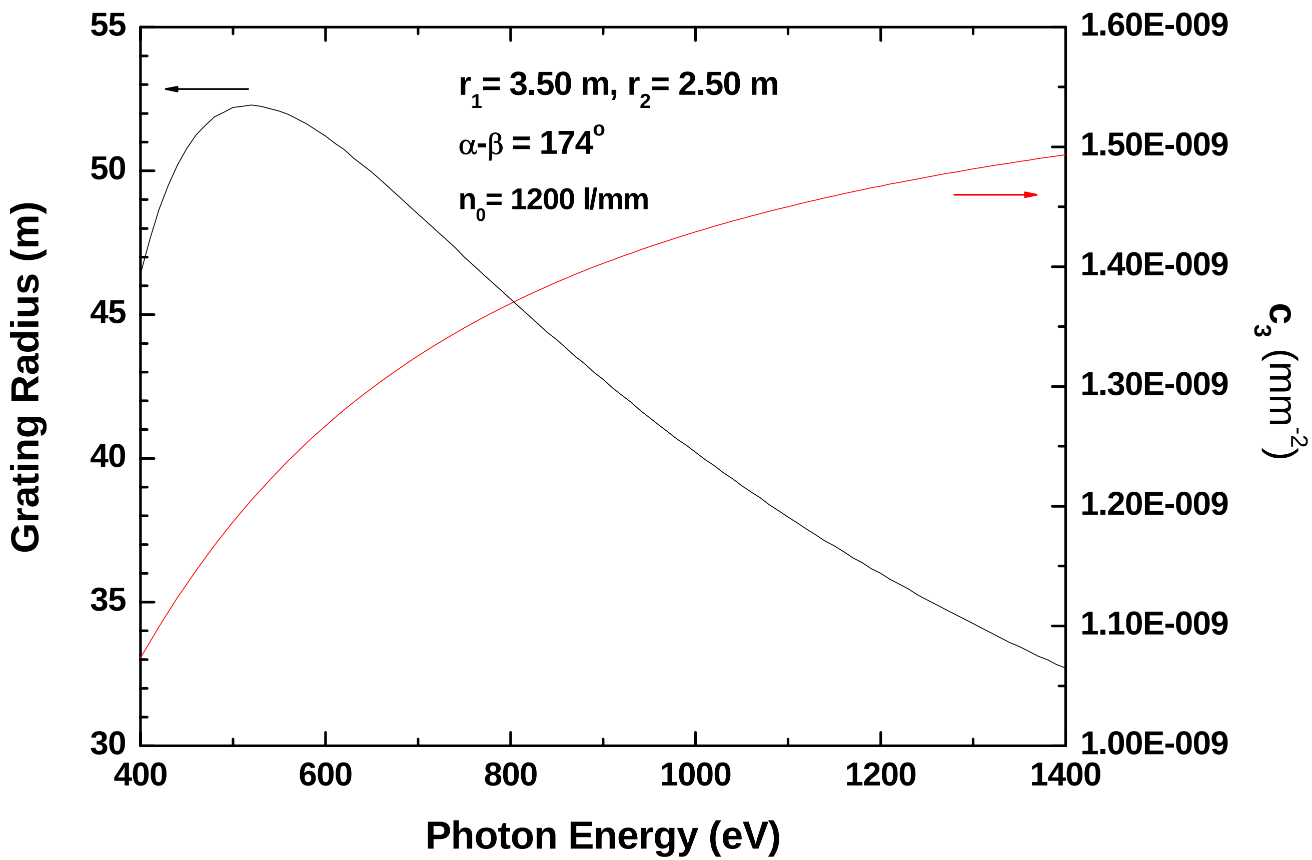


Constant Line Space Grating

$$c_2 = \frac{1}{2}\frac{r_2\cos^2\alpha + r_1\cos^2\beta}{r_1 r_2(\cos\alpha + \cos\beta)}; \quad R = \frac{1}{2c_2}$$

$$c_3 = \frac{\left(\begin{array}{l}\frac{1}{r_1}(\sin\alpha\cos\alpha)c_2 - \frac{1}{r_2}(\sin\beta\cos\beta)c_2 - \\ \frac{1}{2r_1^2}\sin\alpha + \frac{1}{2r_2^2}\sin\beta + \frac{1}{2r_1^2}\sin^3\alpha - \frac{1}{2r_2^2}\sin^3\beta\end{array}\right)}{\cos\alpha + \cos\beta}$$

The Grating Radius and c_3 Range with CLS Gratings



r_1 = 3.50 m

r_2 = 2.50 m

α-β = 174°

n_0 = 1200 l /mm

VLS Grating Case

$$\left(\cos\alpha + \cos\beta\right) c_2 = \frac{1}{2}\left(-kn_1\lambda + \frac{\cos^2\alpha}{r_1} + \frac{\cos^2\beta}{r_2}\right)$$

$$\left(\cos\alpha + \cos\beta'\right) c_2 = \frac{1}{2}\left(-kn_1\lambda' + \frac{\cos^2\alpha}{r_1} + \frac{\cos^2\beta'}{r'_2}\right)$$

$$c_2 = \frac{\left(\frac{\cos^2\alpha}{r_1}\right)(\lambda' - \lambda) + \left(\frac{\cos^2\beta}{r_2}\lambda' - \frac{\cos^2\beta'}{r'_2}\lambda\right)}{2\left[(\cos\alpha + \cos\beta)\lambda' - (\cos\alpha + \cos\beta')\lambda\right]}$$

$$c_3 = f(c_2, r_1, r_2, \lambda)$$

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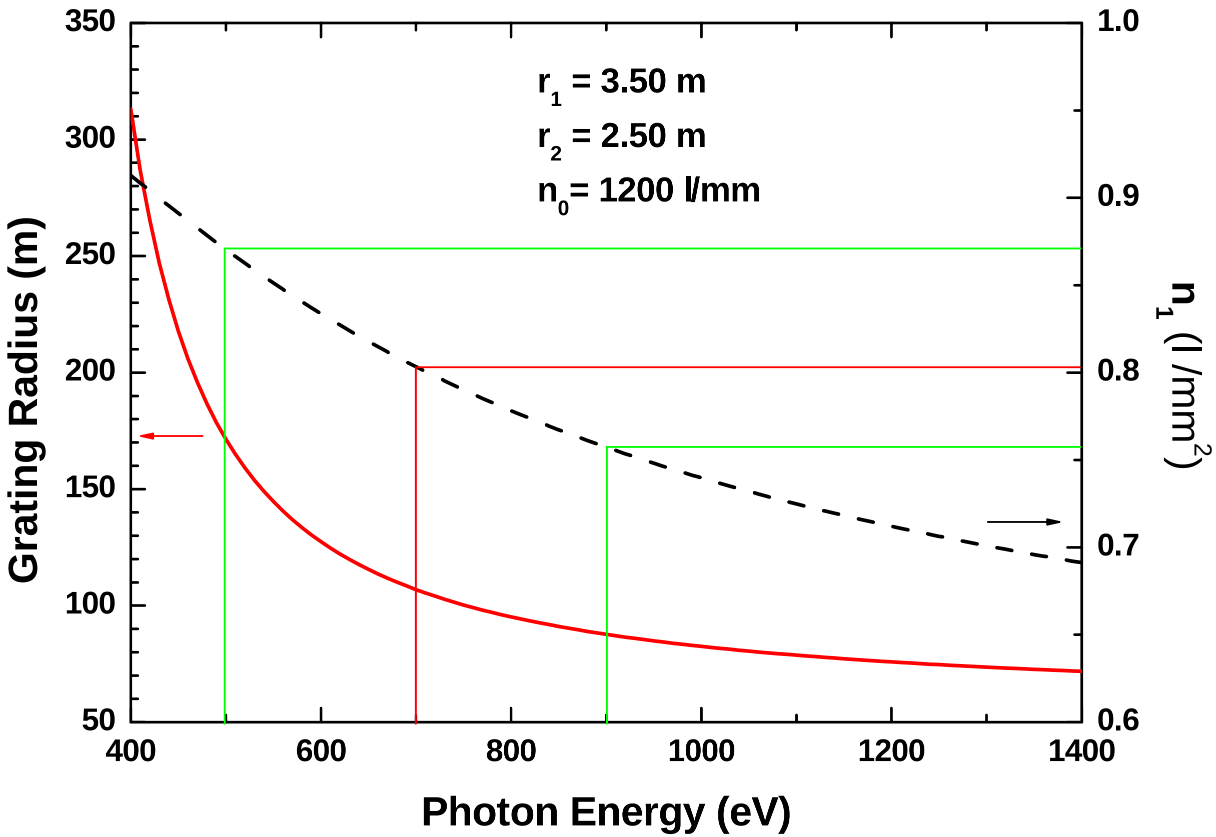
The Grating Radius (R) and n_1 Range with VLS Gratings



$r_1 = 3.50$ m

$r_2 = 2.50$ m

$\alpha\text{-}\beta = 174^\circ$

$n_0 = 1200$ l /mm

R and n_1, each as a function of the incident excitation photon energy, for making the image plane perpendicular to the grating's exit-arm

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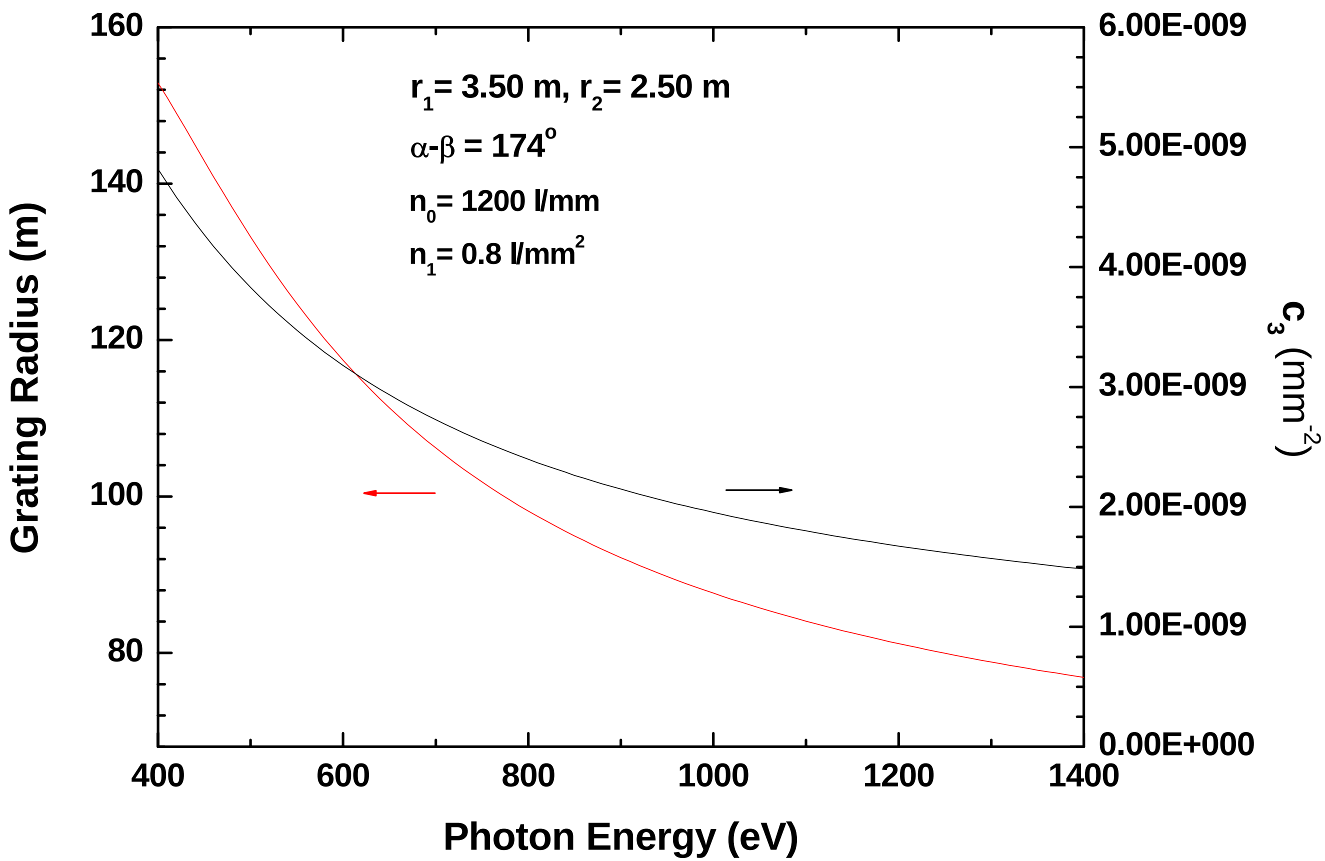
The Grating Radius and c_3 Range with VLS Gratings



$r_1 = 3.50$ m

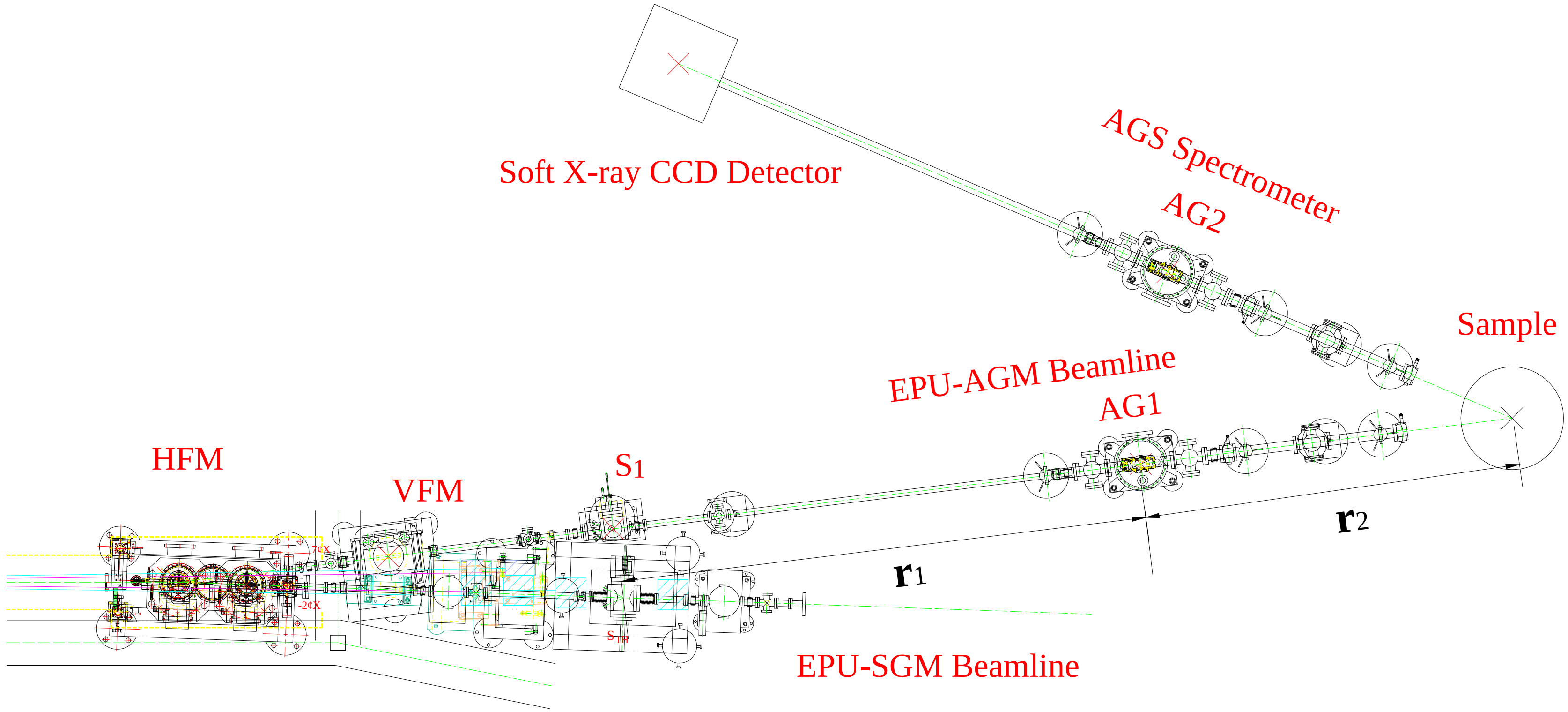
$r_2 = 2.50$ m

$\alpha\text{-}\beta = 174^\circ$

$n_0 = 1200$ l /mm

$n_1 = 0.8$ l /mm^2

The Engineering Design of the AGM-AGS Beamline



- **Performance Simulation:**

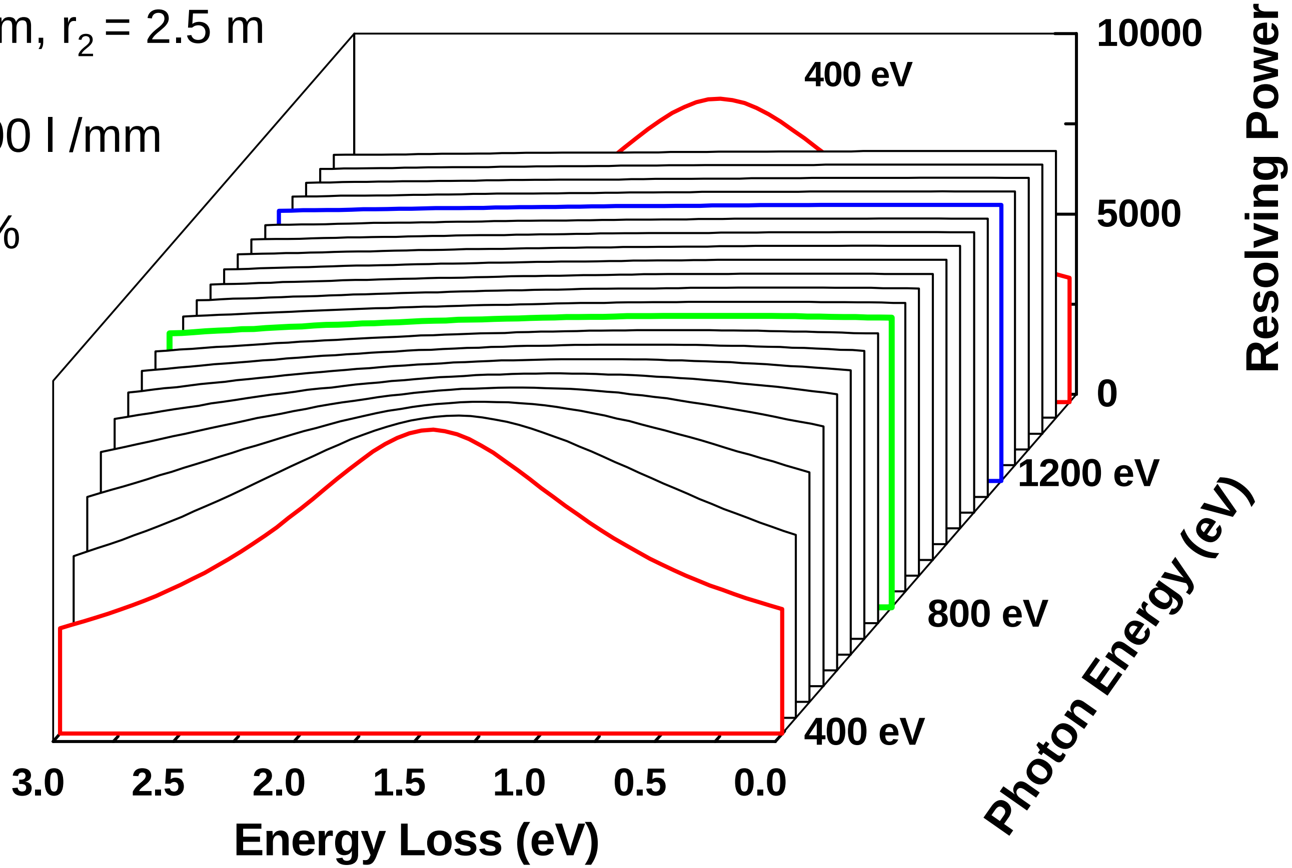
CLS grating vs. VLS grating

Energy Loss Spectrum Resolving with CLS Gratings

$r_1 = 3.5$ m, $r_2 = 2.5$ m

$n_0 = 1200$ l /mm

$\varepsilon/E = 1\%$



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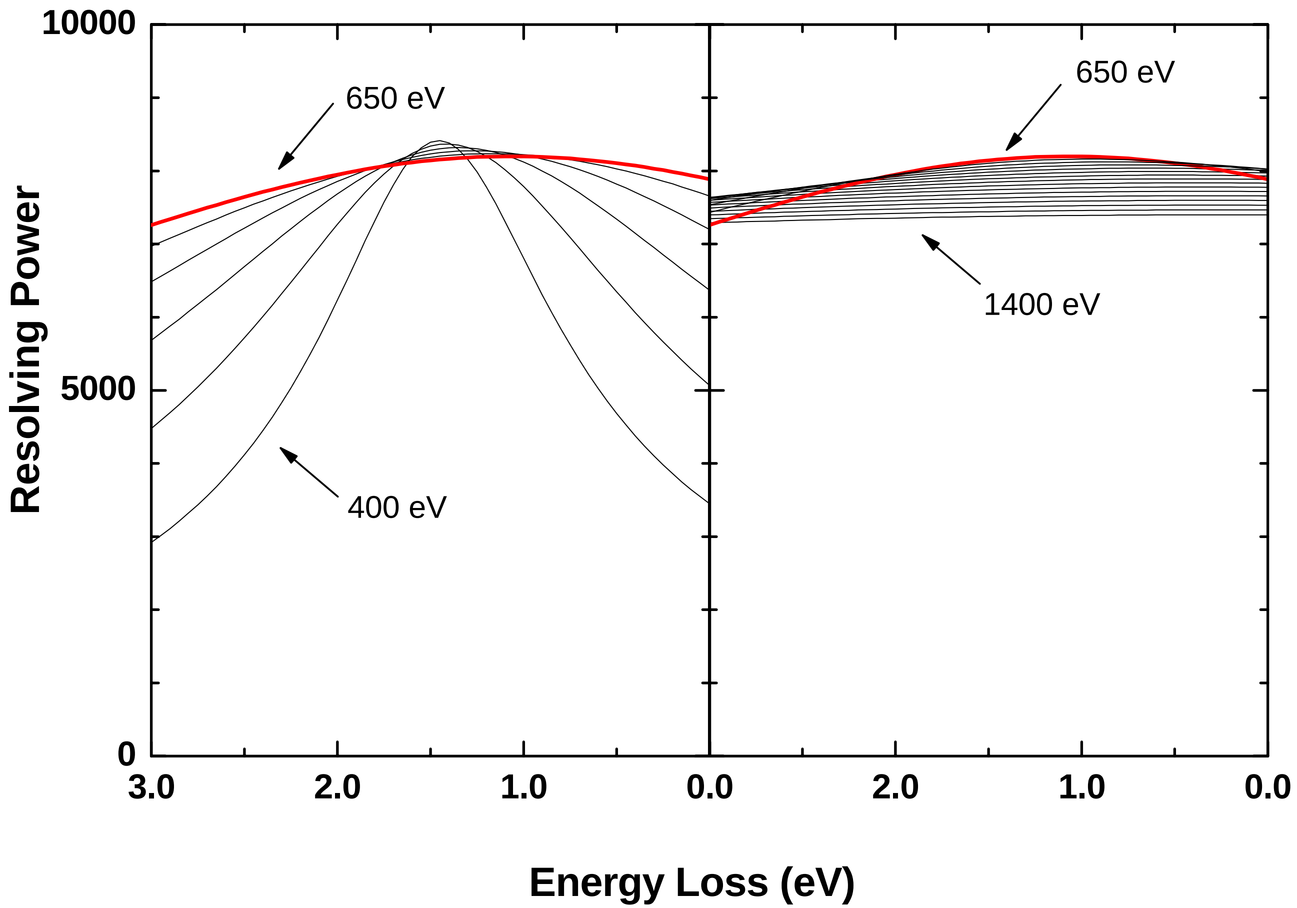
The Resolving Power with CLS Gratings



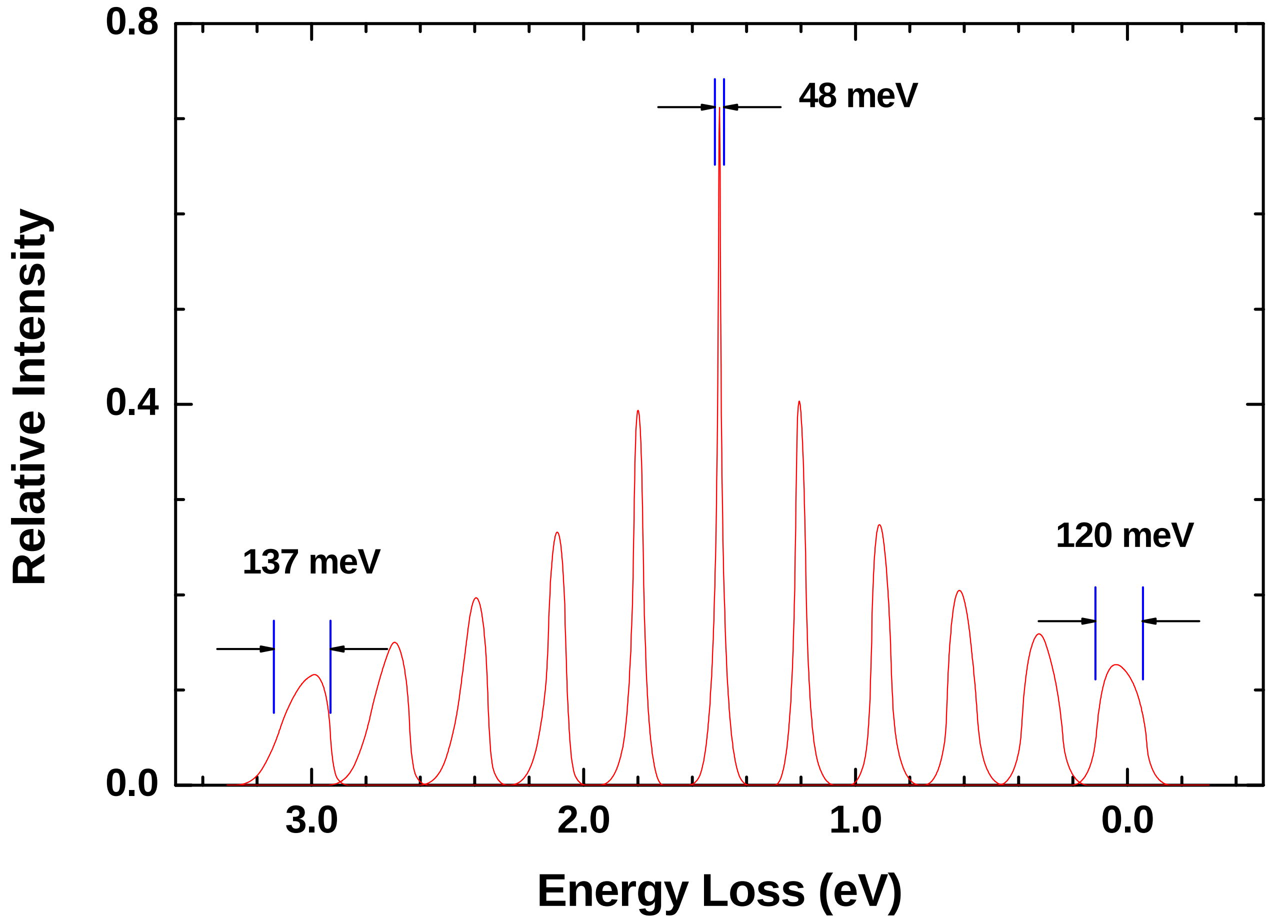
$r_1 = 3.5$ m

$r_2 = 2.5$ m

$n_0 = 1200$ l /mm

$\varepsilon/E = 1\%$

Simulated Energy Loss Spectrum with CLS Gratings



$r_1 = 3.5$ m

$r_2 = 2.5$ m

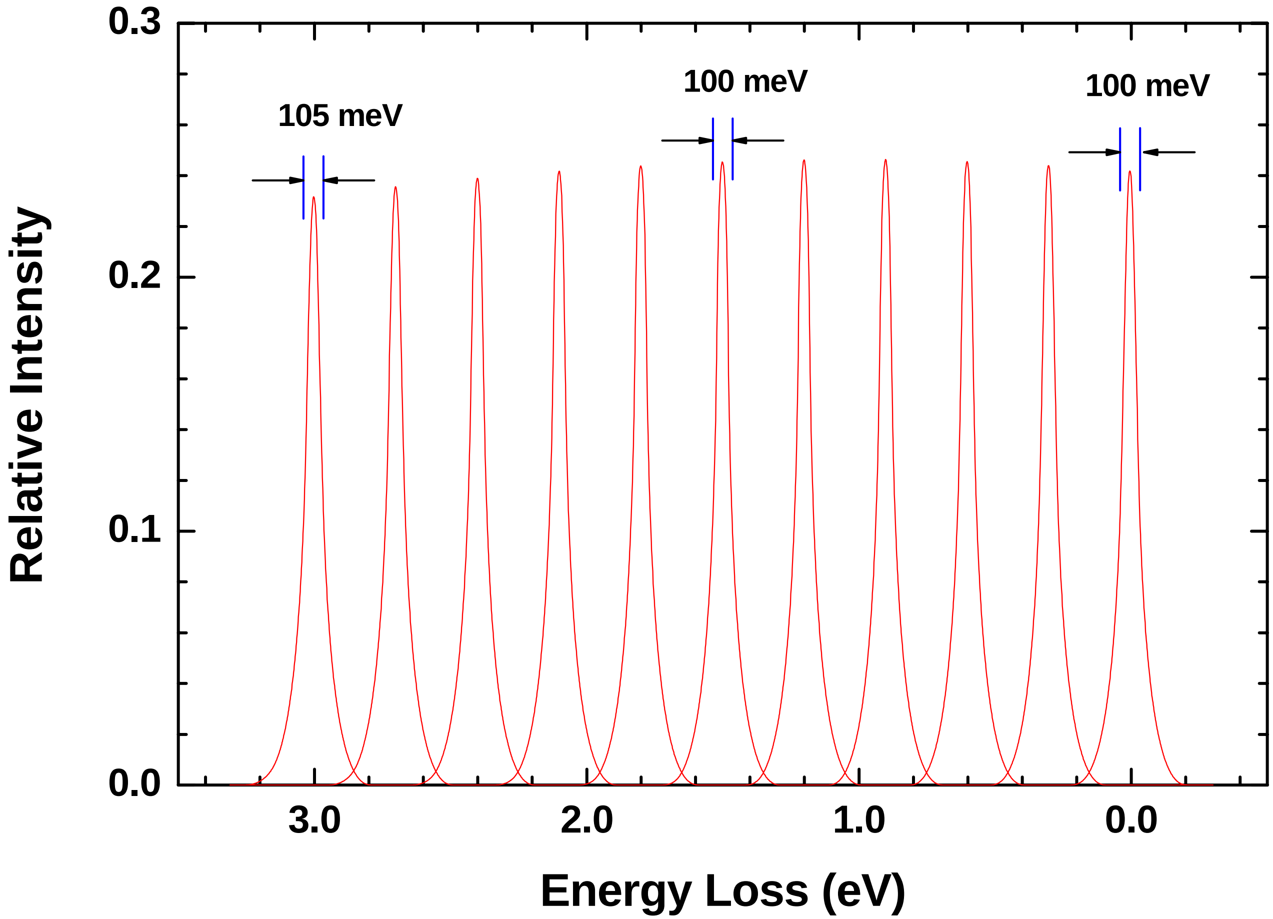
$n_0 = 1200$ l /mm

$E_{in} = 400$ eV

$\varepsilon = 4$ eV

The AGS grating is optimized for 1.5 eV energy loss.

Simulated Energy Loss Spectrum with CLS Gratings



r_1 = 3.5 m

r_2 = 2.5 m

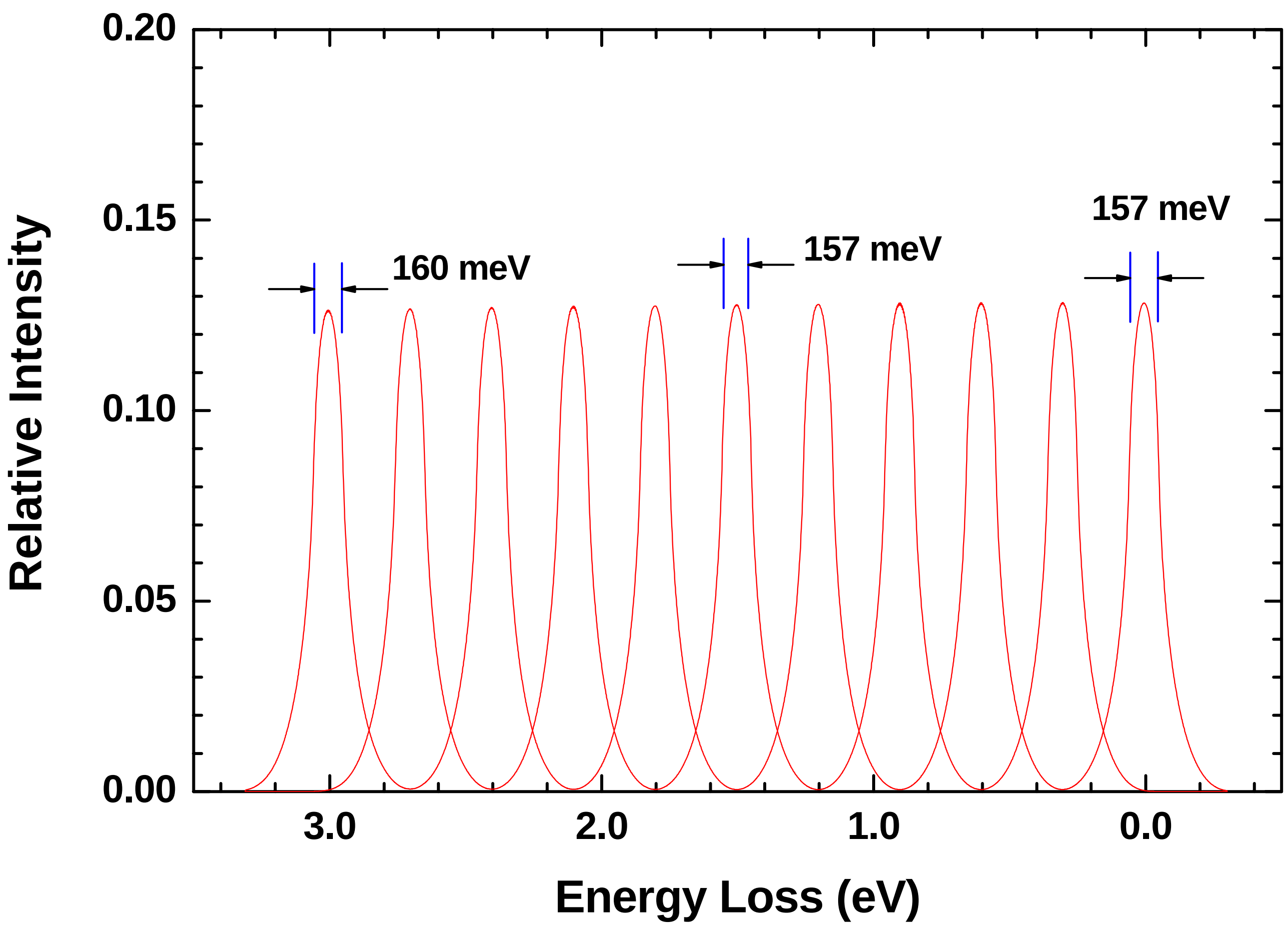
n_0 = 1200 l /mm

E_{in} = 800 eV

ε = 8 eV

The AGS grating is optimized for 1.5 eV energy loss.

Simulated Energy Loss Spectrum with CLS Gratings



$r_1 = 3.5$ m

$r_2 = 2.5$ m

$n_0 = 1200$ l /mm

$E_{in} = 1200$ eV

$\varepsilon = 12$ eV

The AGS grating is optimized for 1.5 eV energy loss.

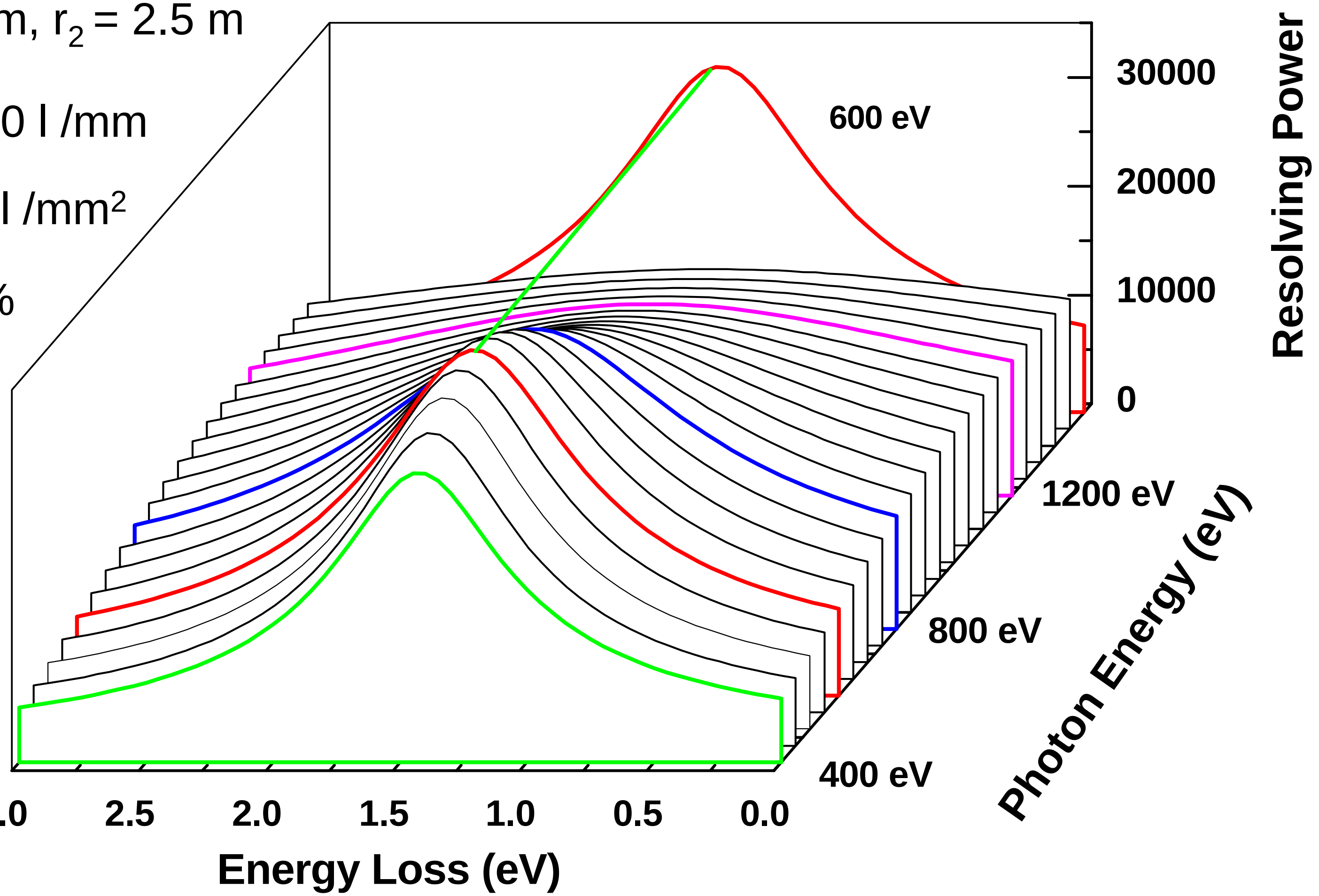
Energy Loss Spectrum Resolving with VLS Gratings

$r_1 = 3.5$ m, $r_2 = 2.5$ m

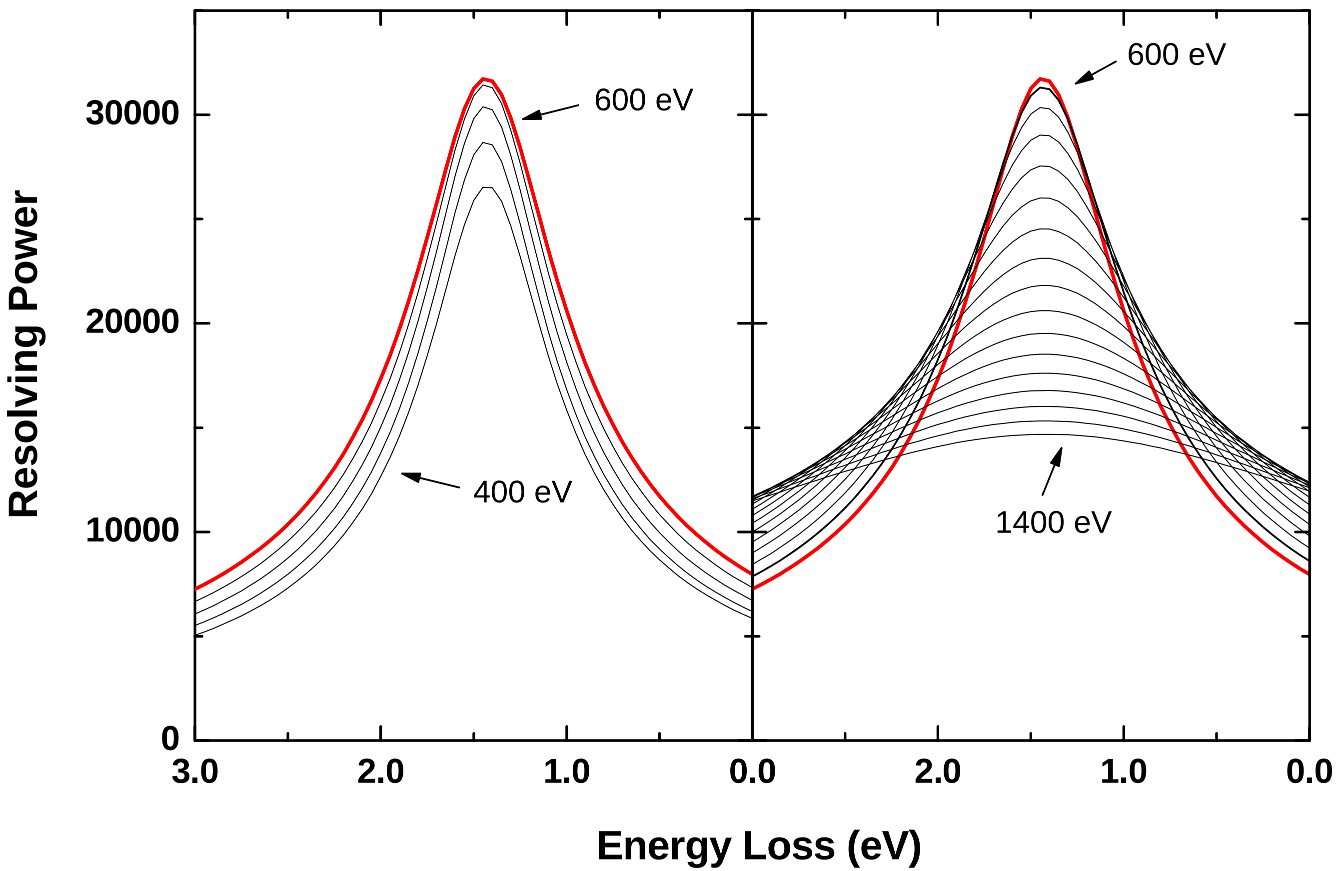
$n_0 = 1200$ l /mm

$n_1 = 0.8$ l /mm^2

$\varepsilon/E = 1\%$



Energy Loss Spectrum Resolving with VLS Gratings



$r_1 = 3.5$ m

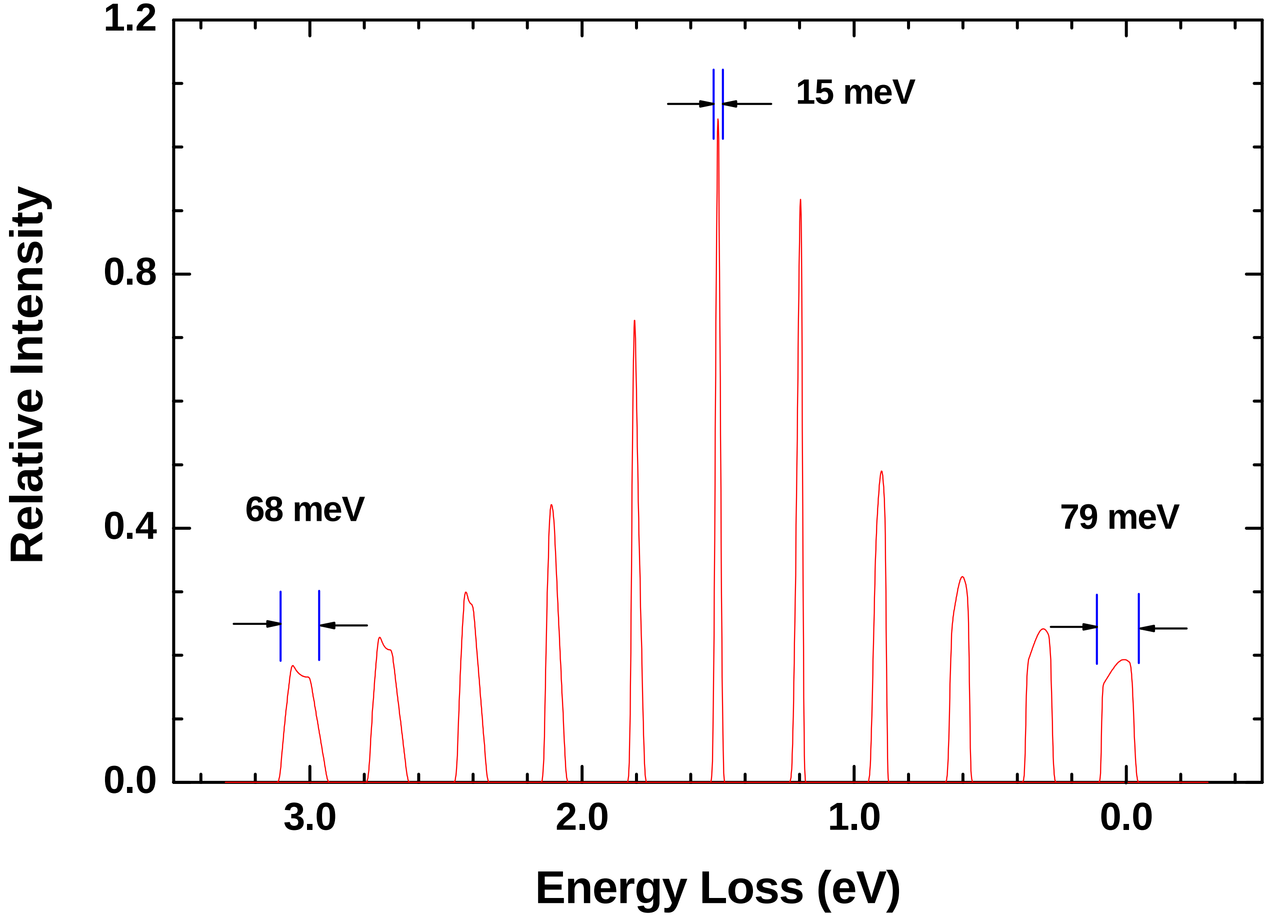
$r_2 = 2.5$ m

$n_0 = 1200$ l /mm

$n_1 = 0.8$ l /mm^2

$\varepsilon/E = 1\%$

Simulated Energy Loss Spectrum with VLS Gratings



$r_1 = 3.5$ m

$r_2 = 2.5$ m

$n_0 = 1200$ l /mm

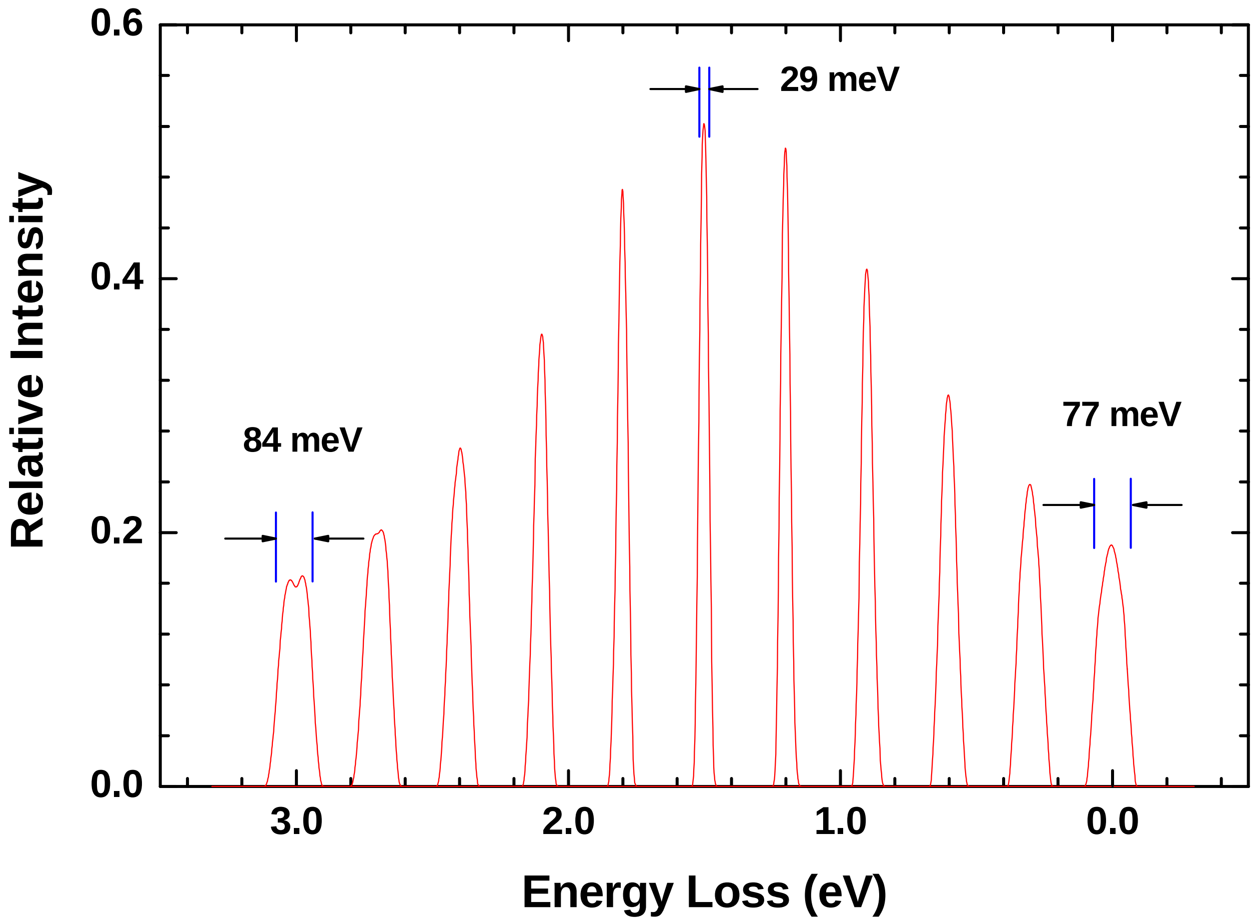
$n_1 = 0.8$ l /mm^2

$E_{in} = 400$ eV

$\varepsilon = 4$ eV

The AGS grating is optimized for 1.5 eV energy loss.

Simulated Energy Loss Spectrum with VLS Gratings



$r_1 = 3.5$ m

$r_2 = 2.5$ m

$n_0 = 1200$ l /mm

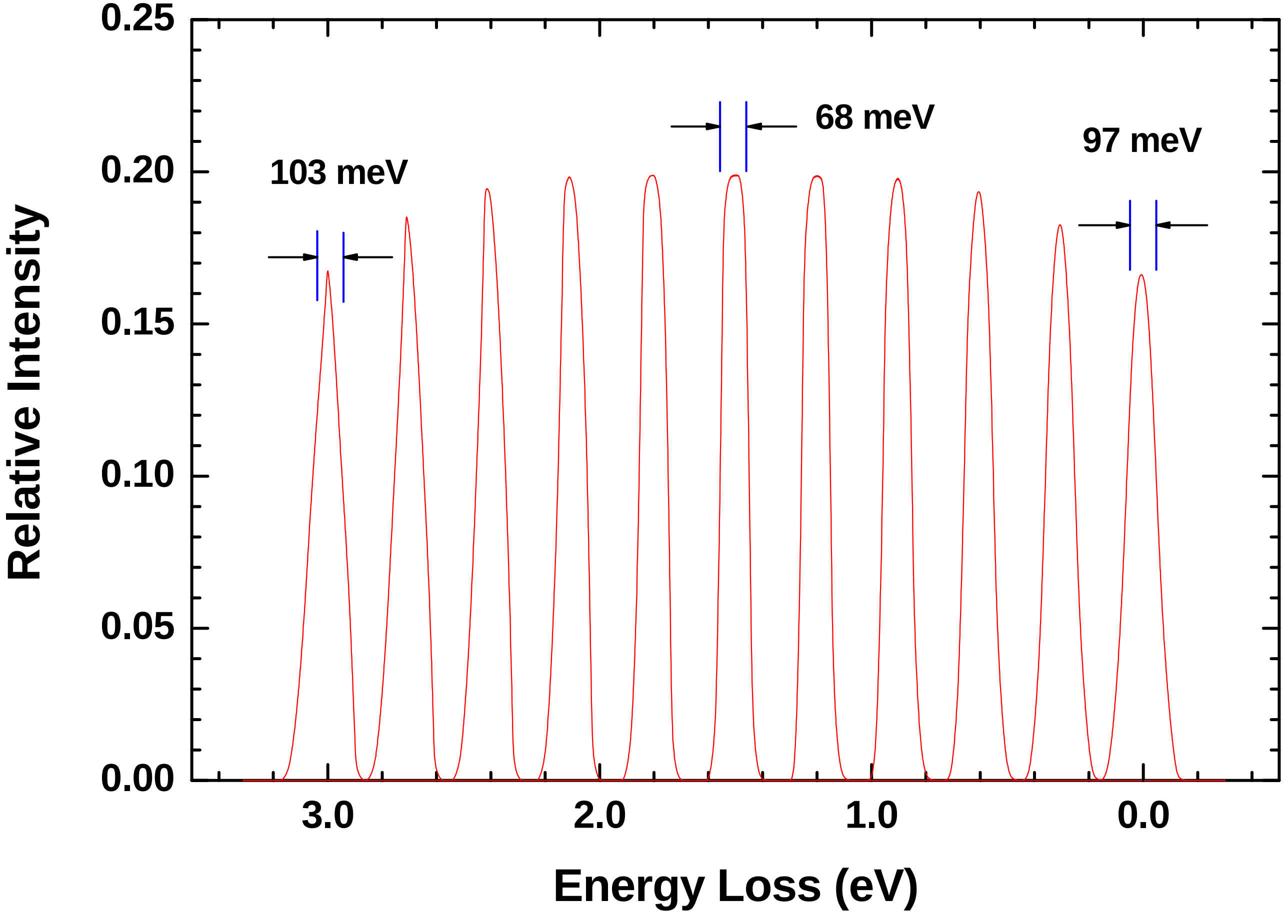
$n_1 = 0.8$ l /mm^2

$E_{in} = 800$ eV

$\varepsilon = 8$ eV

The AGS grating is optimized for 1.5 eV energy loss.

Simulated Energy Loss Spectrum with VLS Gratings



$r_1 = 3.5$ m

$r_2 = 2.5$ m

$n_0 = 1200$ l /mm

$n_1 = 0.8$ l /mm^2

$E_{in} = 1200$ eV

$\varepsilon = 12$ eV

The AGS grating is optimized for 1.5 eV energy loss.

Conclusion

- **Superior Resolution**
  The AGM/AGS system applying energy compensation principle, with a VLS grating, can enhance the IXS resolving power to an unprecedented 30,000.

- **High Efficiency**
  While under such a high resolution, the signals can be two orders of magnitude higher than those of the conventional setup.

- **Benefits of the Active Bendable Grating**
  Fixed exit slit position
  Eliminate Coma term

- **Advantages of the VLS Grating**
  Higher resolving power (30,000) than that of the CLS grating (8,000)
  Larger radius amenable to bending directly from the plane grating

Acknowledgements

We would like to thank the staff of NSRRC who participate in this work, especially those in the Instrumentation Development and Beamline Group.