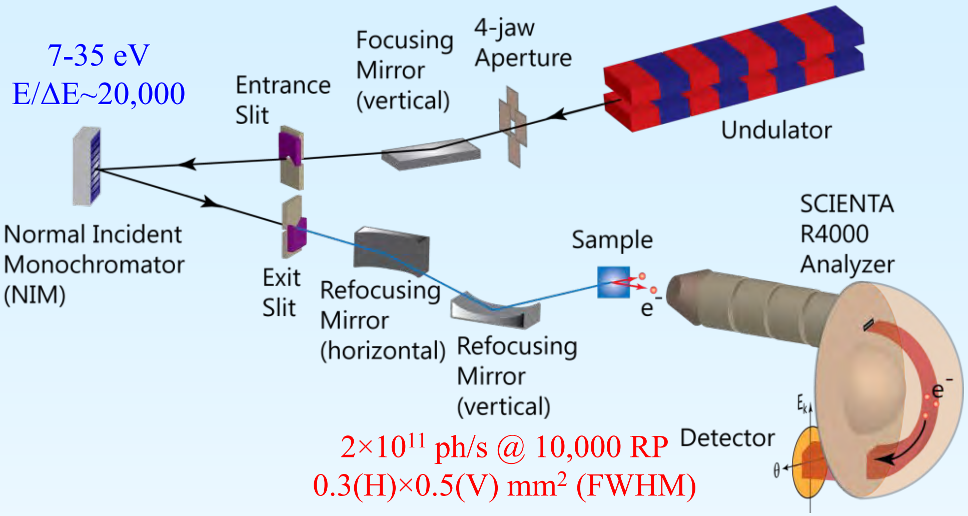
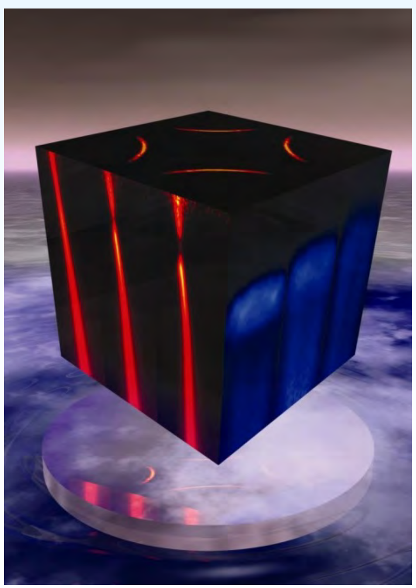
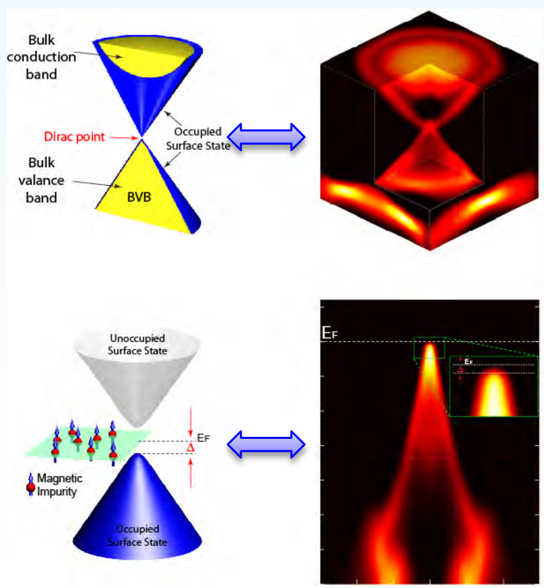
A New Photoemission Branch Line at SSRL Beam Line 5

Donghui Lu, Ruben Reininger, Tom Rabedeau

Present Status of ARPES System at SSRL







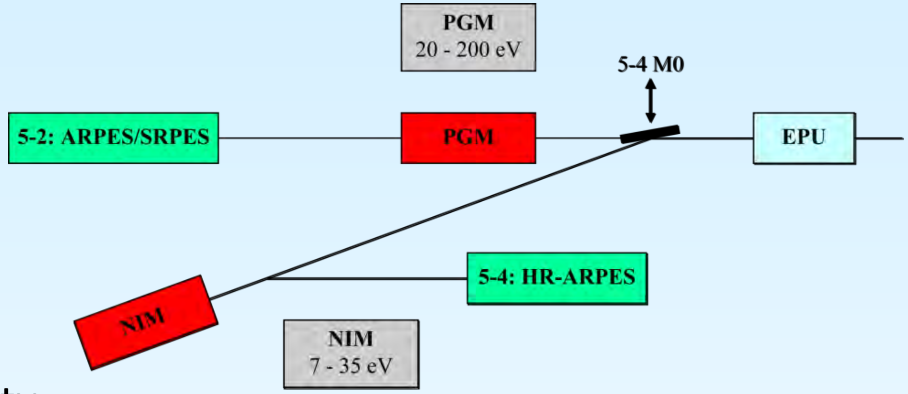
- **ARPES End Station on NIM Branchline**
  - ☺ Advantages:
    high resolution; low energy; high order suppression; good beam stability
  - ☹ Disadvantages:
    limited photon energy range; no polarization control; large beam size

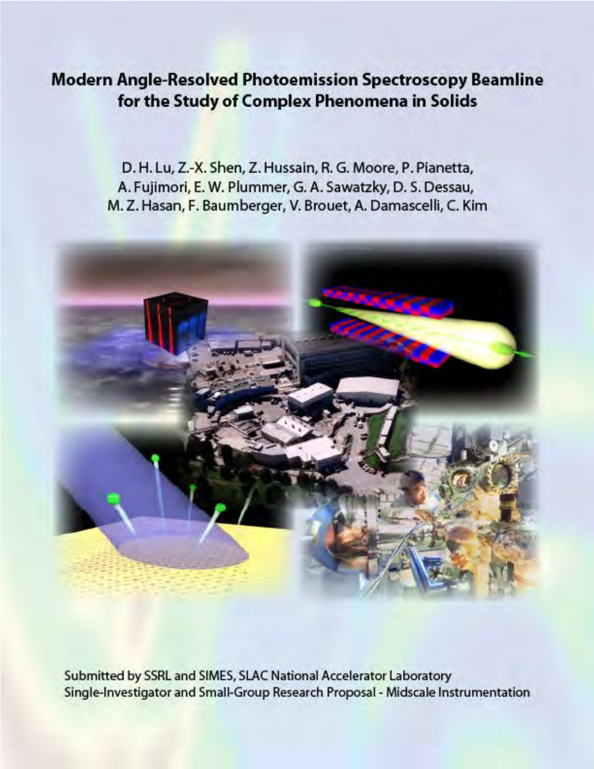
- **Dedicated for High Resolution ARPES**
  - o High temperature superconductors
  - o Complex oxides
  - o Novel low dimensional systems
  - o Materials in delicate balance
  - o Topological insulators
  - o ……

- **Planned Upgrade**
  - o New refocusing mirror
  - o New undulator PGM branchline

New Undulator Branchline

- **Significantly Improved Performance**
  - Wider photon energy
  - Variable polarizations
  - Smaller beam size
- **Complementary to NIM Branchline**
  - NIM – ultrahigh resolution in low energy
  - PGM – higher energy, higher flux, flexibility
    - spin-resolved ARPES
    - PLD-MBE thin film growth
- **Project Milestones**
  - First proposal submitted in Feb 2005
  - Resubmitted in 2006 & 2009
  - Funding received in Sept 2009
  - EPU procured in Sept 2010
  - CDR for optical design completed in Dec 2010
  - Monochromator and gratings procured in Sept 2011
  - Installation of new EPU during 2012 shutdown
  - Installation of PGM branchline after 2012 shutdown
  - Commission starts early 2013



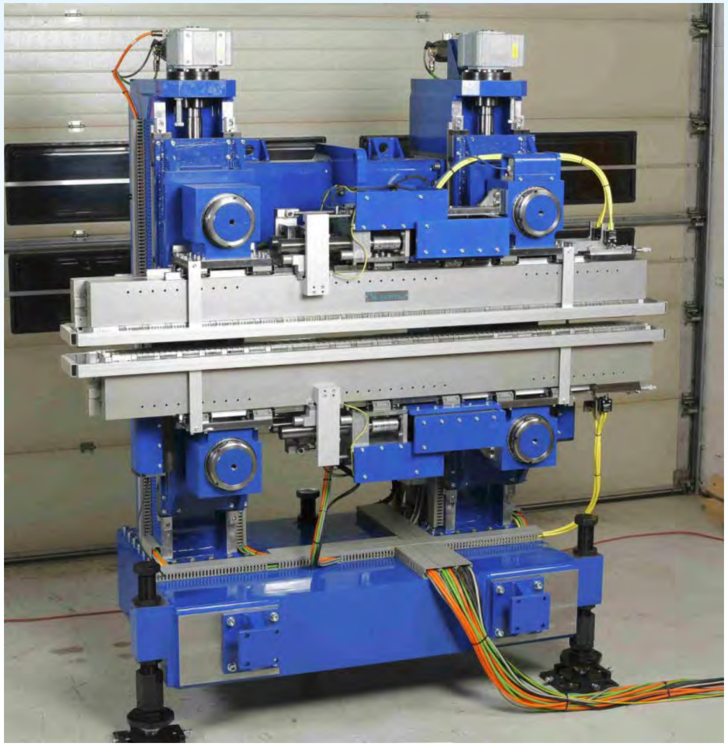


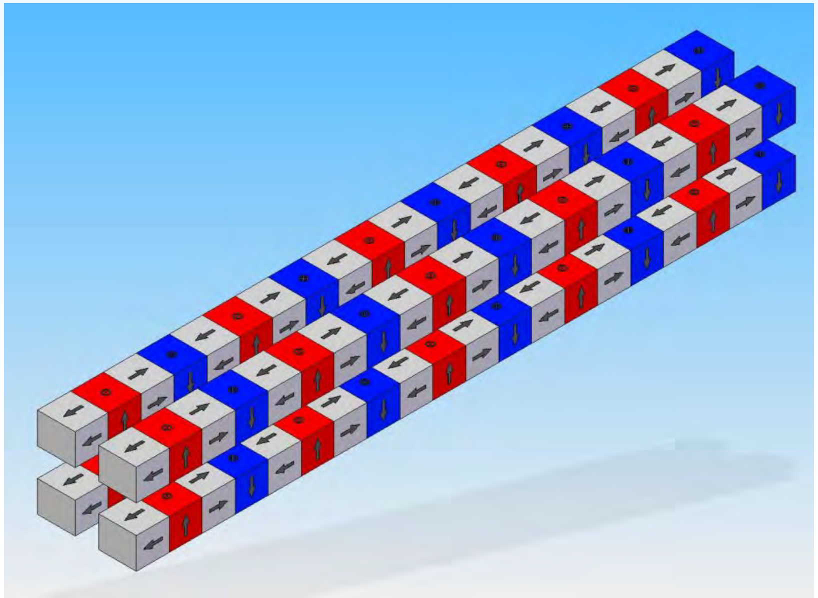
Design Goal

- Energy range between 20 and 200 eV
- RP> 25,000 in the high resolution mode
- RP> 10,000 in the high flux mode
- At RP 10,000 flux > 10^{12} photons/s
- Spot size < 100 × 50 μm^2 (hor. × ver.)
- Higher orders should be minimized
- Linear horizontal, vertical, and circular polarization
- Available space is 31 m from the ID center

Critical Decision I: Undulator

- **Existing Undulator**
  - Planar, 10-pd x 183mm, 18.5mm gap ⇒ 7 eV
- **Single *vs.* Twin Device**
- **New Undulator**
  - APPLE II, 15-pd x 140mm, 13mm gap ⇒ 7 eV
  - High K ⇒ strong high orders, high heat load





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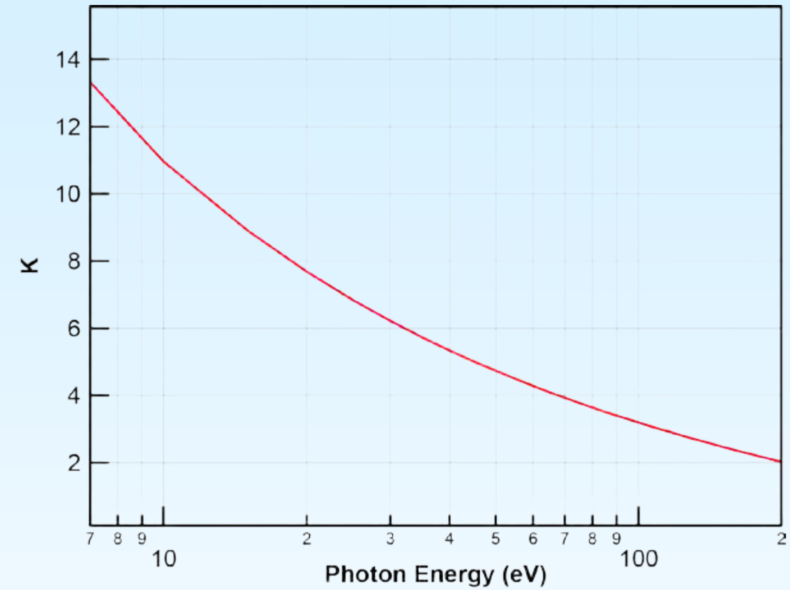
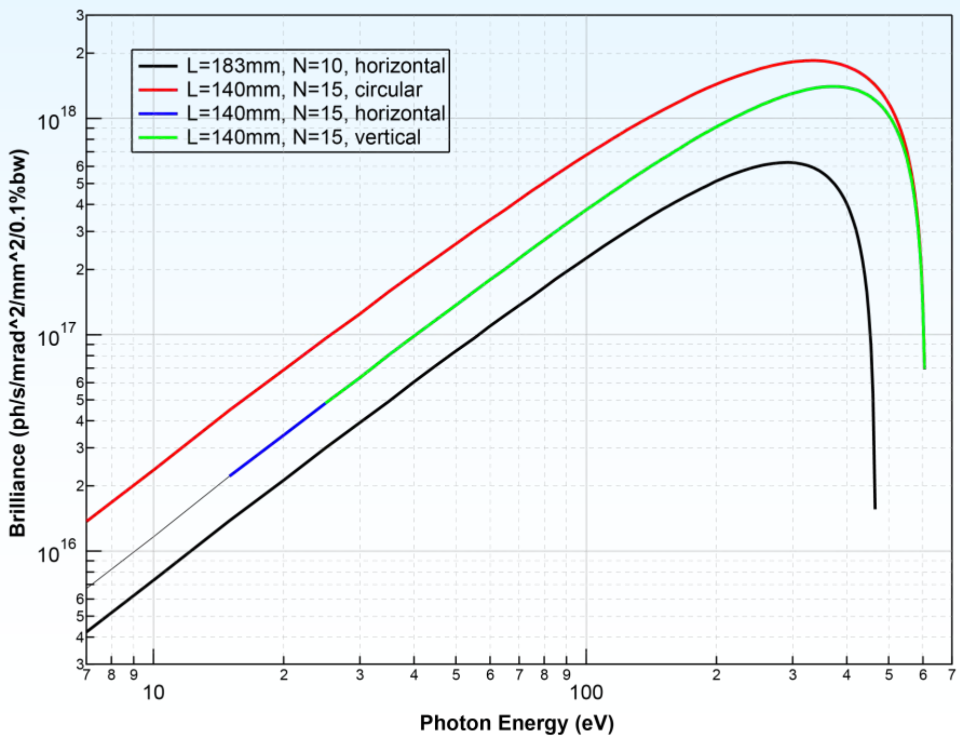
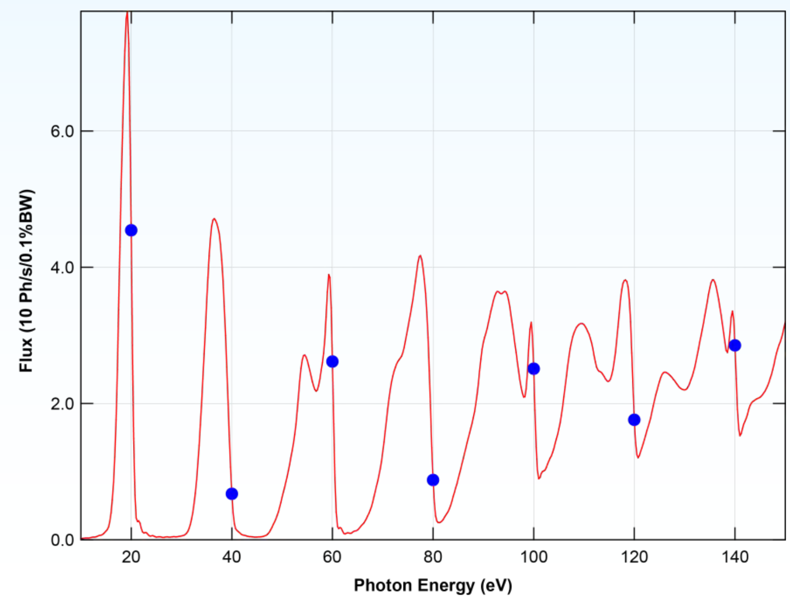
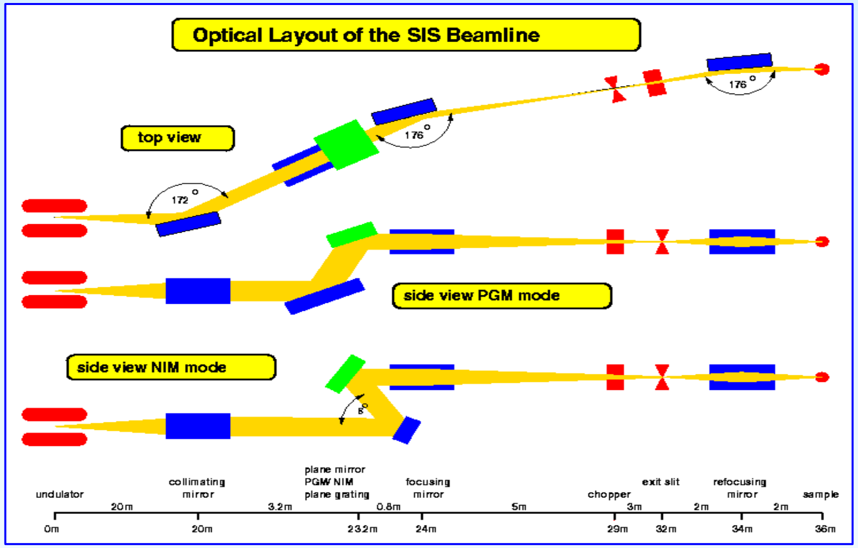




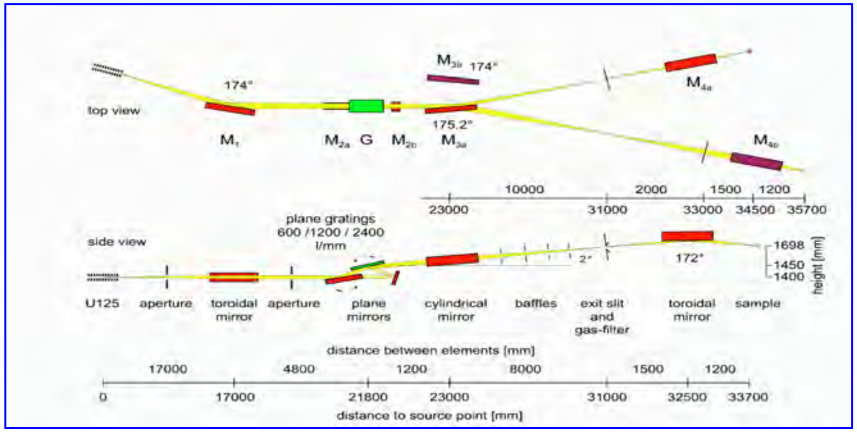


Critical Decision II: Monochromator

CPGM

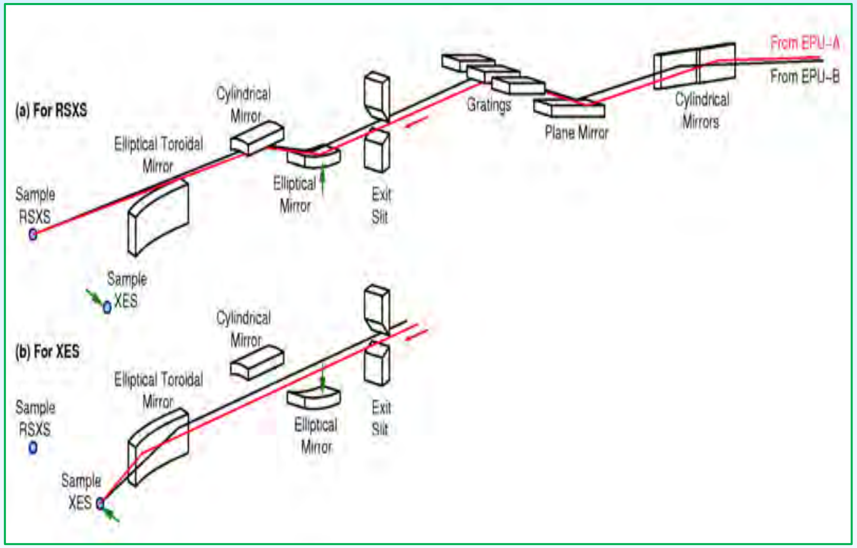


SLS - SIS

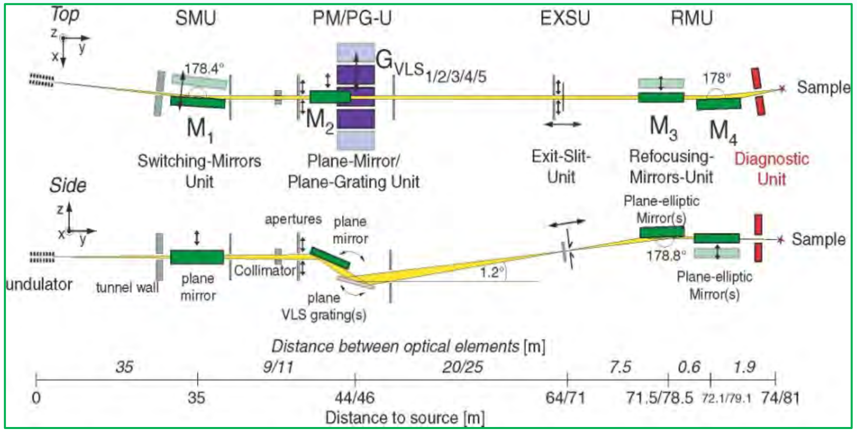


BESSY – UE112

FVLSPGM



CLS - REIXS



PETRA III – P04

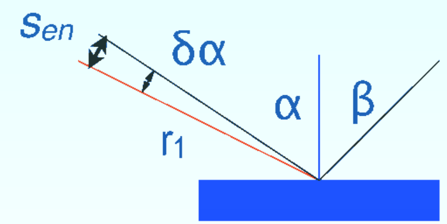
Resolution Terms

Grating Equation:

$$n\,k\,\lambda = \sin\alpha + \sin\beta$$

Resolution Entrance:

$$n\,k\,\delta\lambda_{en} = \cos\alpha\,\delta\alpha = \cos\alpha\,s_{en}/r_1$$



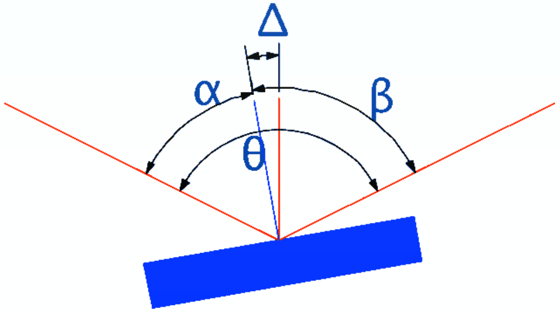
Resolution Exit:

$$n\,k\,\delta\lambda_{ex} = \cos\beta\,\delta\beta = \cos\beta\,s_{ex}/r_2$$

Slope error ϵ

$$\sin\alpha + \sin\beta = 2\ \cos\theta\sin\Delta$$

$$\theta = \frac{\alpha+\beta}{2};\ \ \Delta = \frac{\alpha-\beta}{2}$$

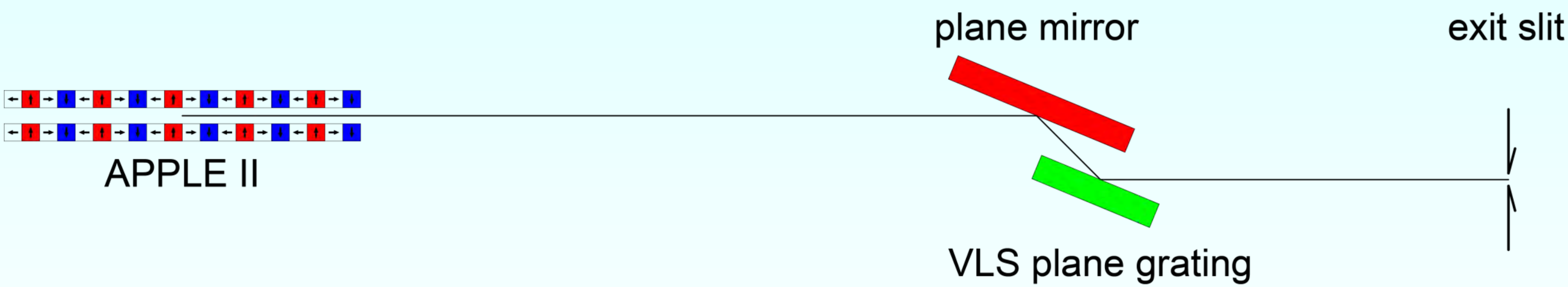


$$n\,k\,\delta\lambda_{err} = \delta(2\cos\theta\ \sin(\Delta+\epsilon)) \approx 2\epsilon\cos\theta\cos\Delta$$

$$n\,k\,\delta\lambda_{err} \approx \epsilon(\cos\alpha + \cos\beta)$$

Aberrations: Coma, spherical, astigmatic coma...

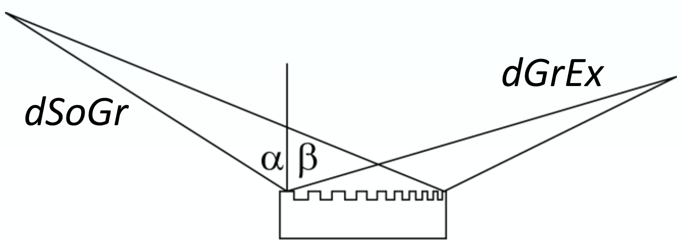
FVLSPGM



$$k(w) = k_0(1 + 2b_2\, w + 3b_3\, w^2 + ...)$$

$$f_{20} = \frac{\cos^2\alpha}{dSoGr} + \frac{\cos^2\beta}{dGrEx} - 2b_2\ n\ k_0\ \lambda$$

$$f_{30} = \sin\alpha \frac{\cos^2\alpha}{dSoGr^2} + \sin\beta \frac{\cos^2\beta}{dGrEx^2} - 2b_3\ n\ k_0\ \lambda,$$



$$\text{PM:} \quad \gamma = 0.5(\alpha - \beta)$$

$$n\,k\ \lambda = \sin\alpha + \sin\beta\ \&\ f_{20} = 0$$

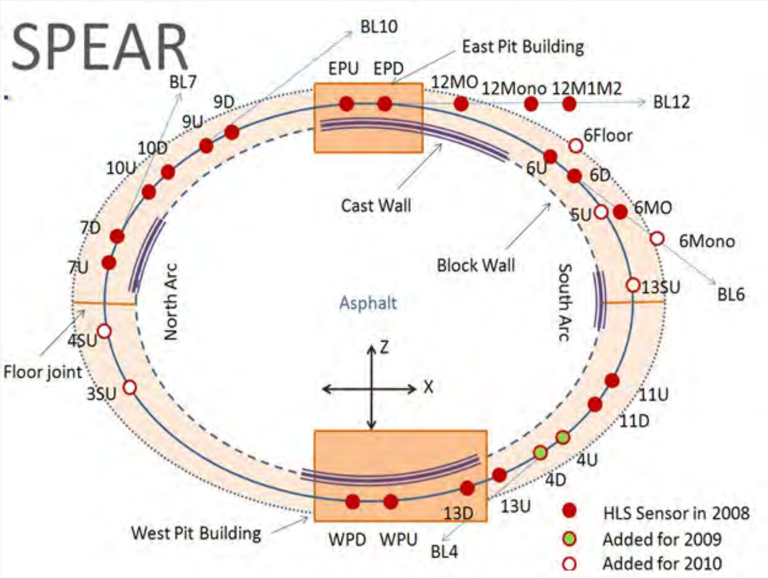
$$c = \cos\beta / \cos\alpha$$

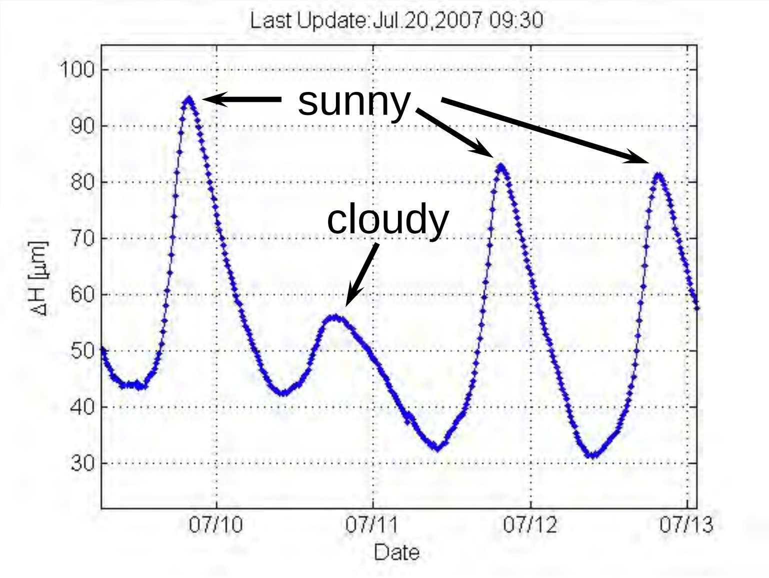
T. Harada, *et. al.*, Proc. SPIE, 503:114, (1984)
R. Reininger *et. al.*, Rev. Sci. Instrum., 79, 033108 (2008)

Critical Decision II: Monochromator

	FVLSPGM	CPGM
Mechanics	SX-700 type	SX-700 type
Fixed exit slit	Yes	Yes
c value	Fixed Some order suppression	Variable Slightly better order suppression Resolution vs Flux
Optical components	Can use only planes in between source and slit	+toroid and cylinder More reflections Cannot achieve 10^5 at 1 keV
Large horizontal Demagnification.	With single mirror	Two demagnifying mirrors.
Correct Heat Induced deformations M2	Yes, variable focal length.	No

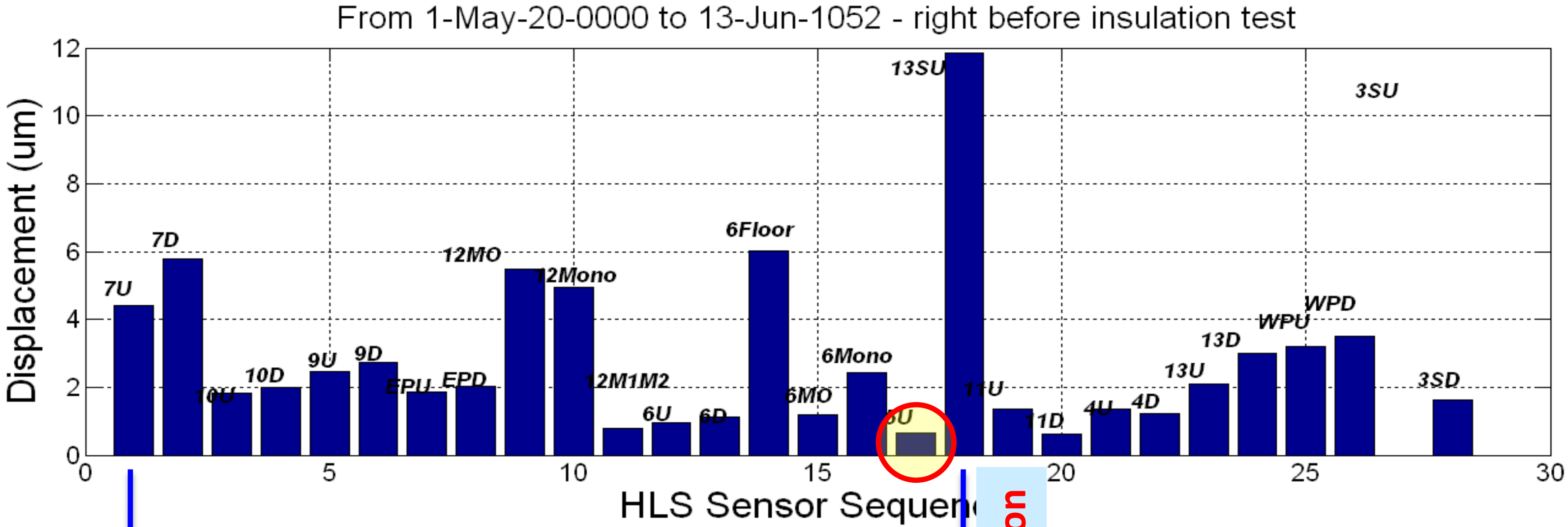
Critical Decision III: Entrance Slit



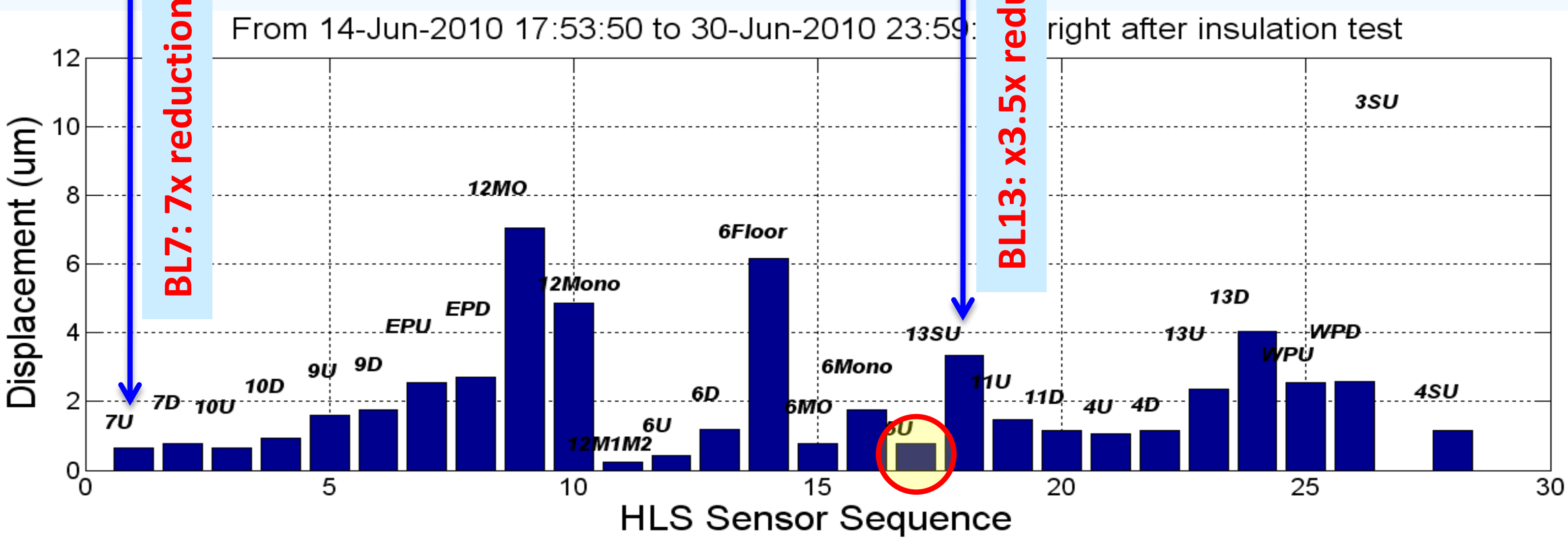


Critical Decision III: Entrance Slit

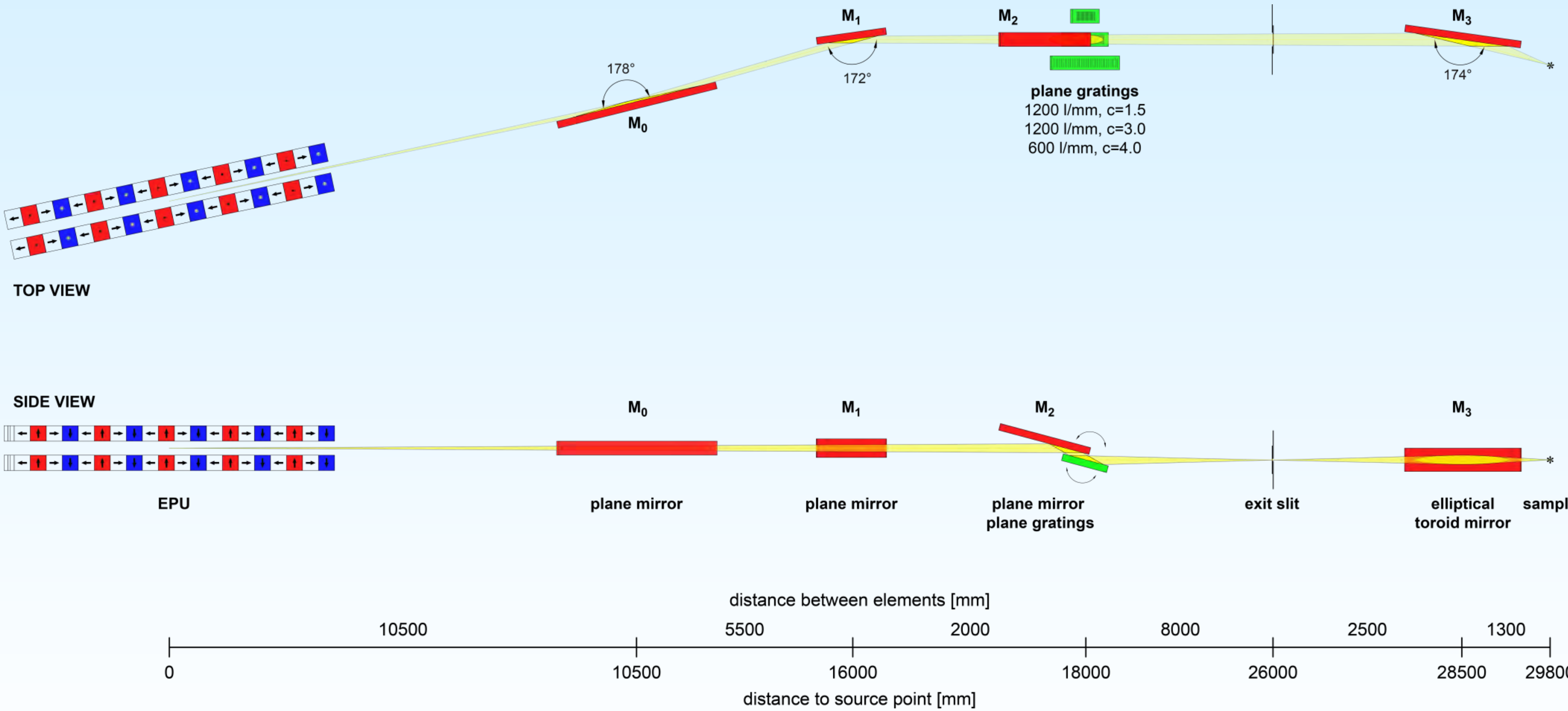
Before Insulation



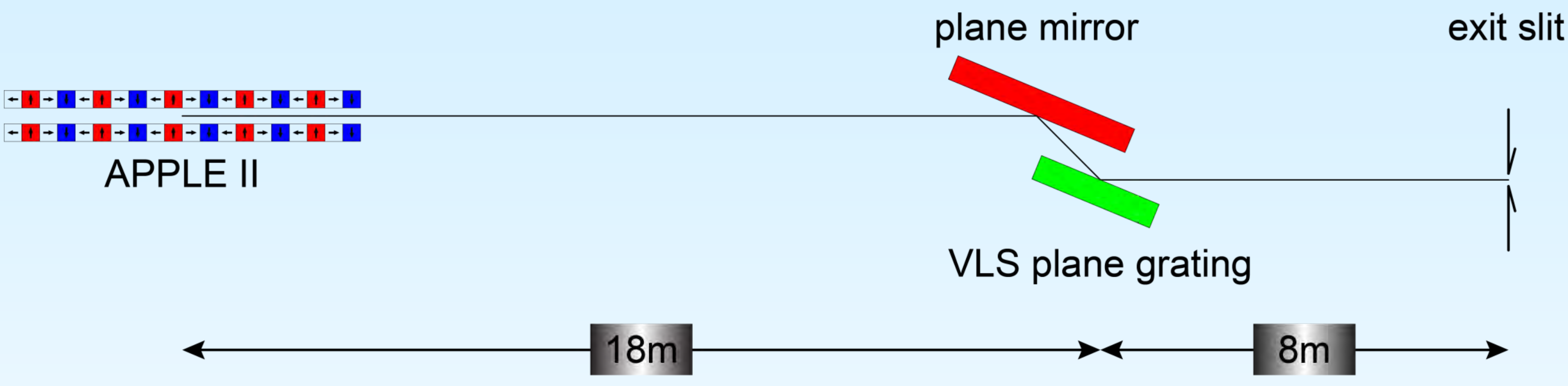
After Insulation

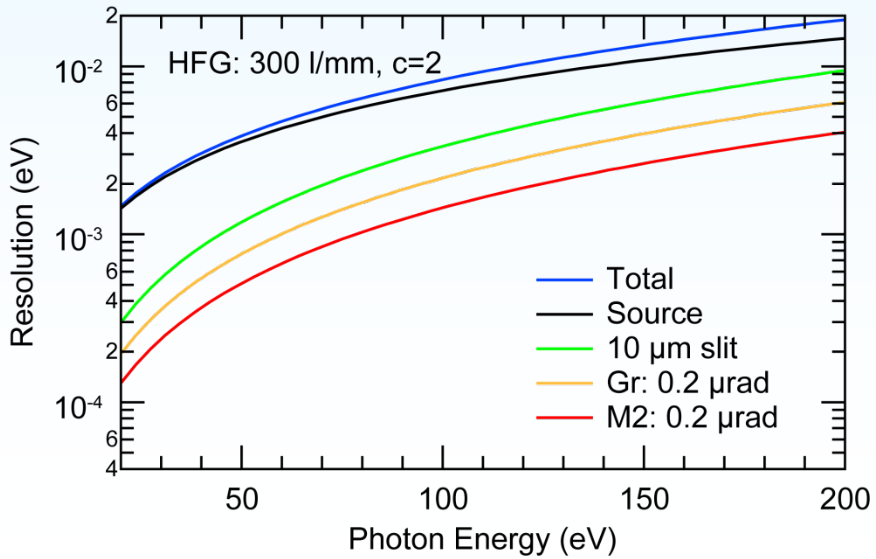


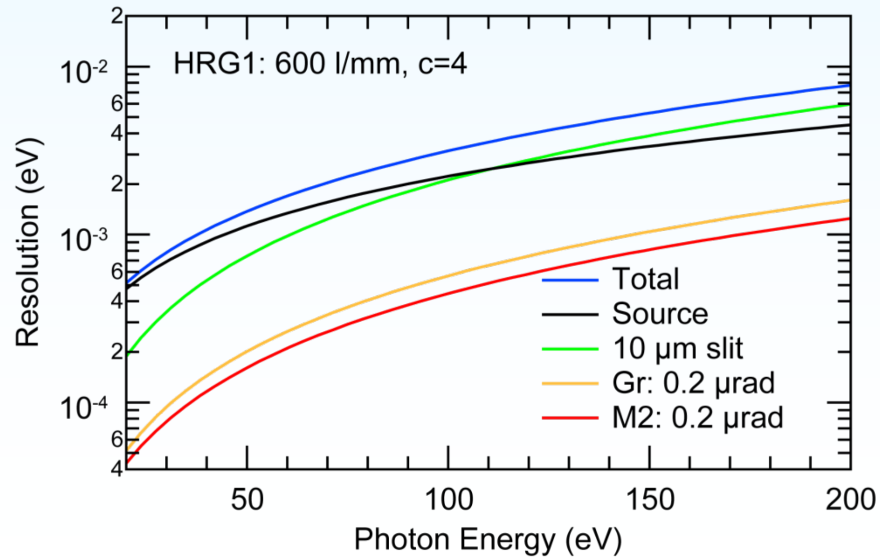
Optical Layout



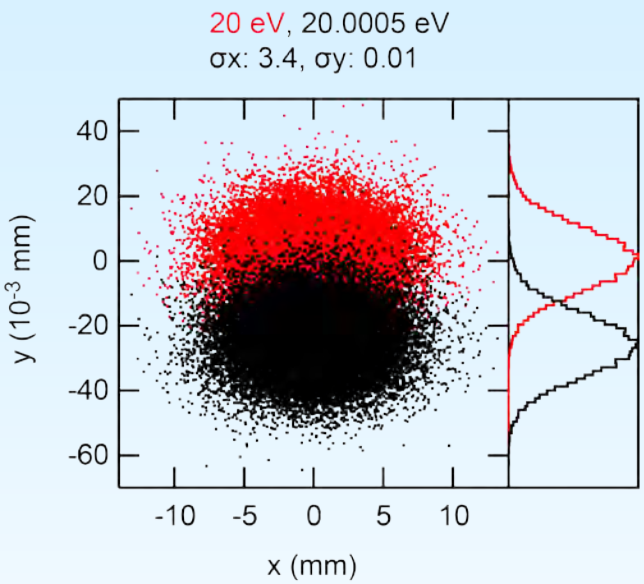
Resolution

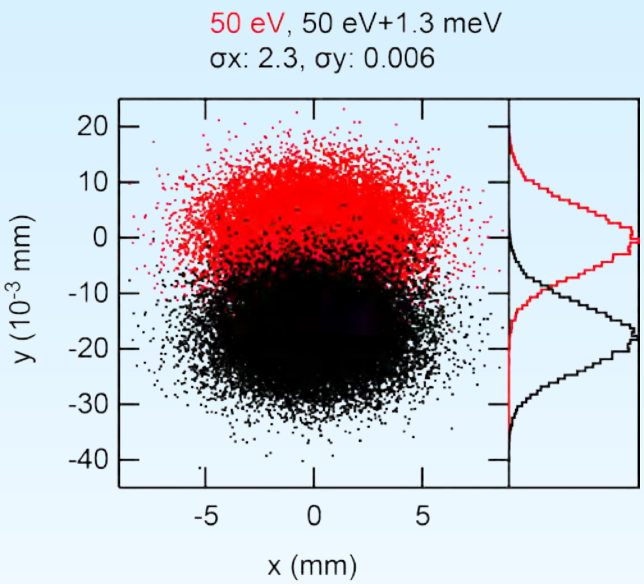

plane mirror
exit slit
APPLE II
VLS plane grating
18m
8m

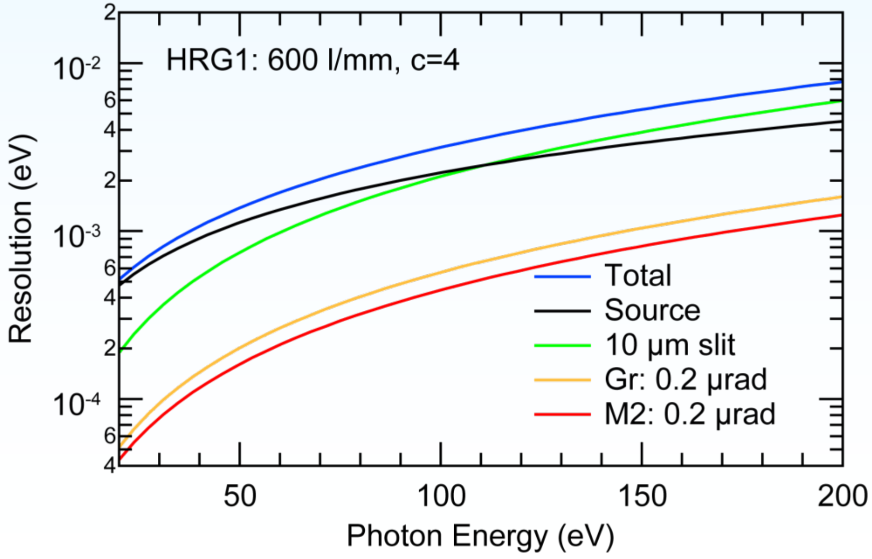

HFG: 300 l/mm, c=2
Resolution (eV)
Photon Energy (eV)
Total
Source
10 μm slit
Gr: 0.2 μrad
M2: 0.2 μrad


HRG1: 600 l/mm, c=4
Resolution (eV)
Photon Energy (eV)
Total
Source
10 μm slit
Gr: 0.2 μrad
M2: 0.2 μrad

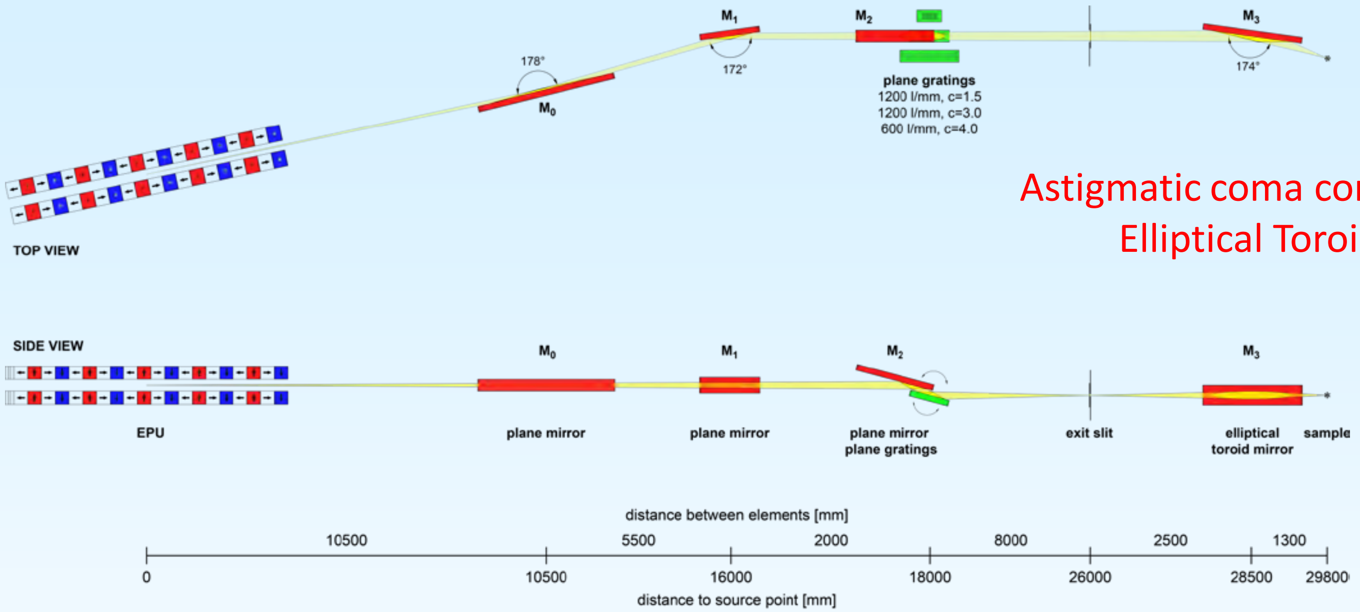
Ray Tracing: HRG1





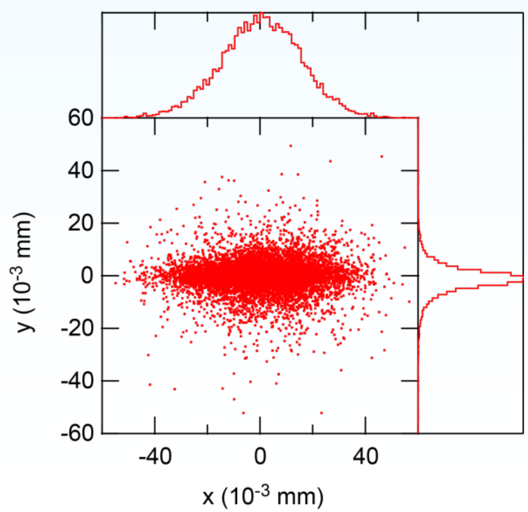


Ray Tracing: Refocusing

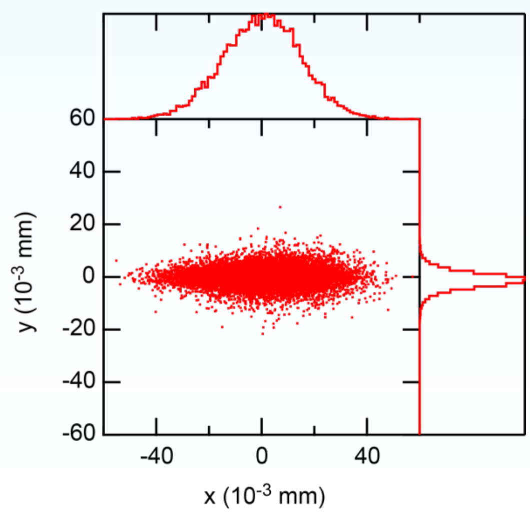


Astigmatic coma corrected
Elliptical Toroid

Sample, 20 eV HFG, 10 μm slit
σx: 0.015, σy: 0.006



Sample, 50 eV HRG1, 10 μm slit
σx: 0.015, σy: 0.0033

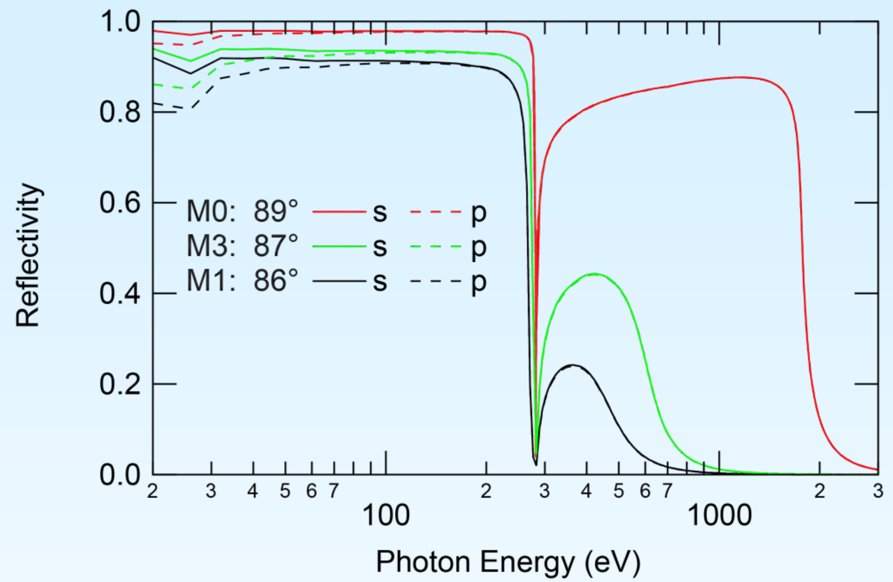


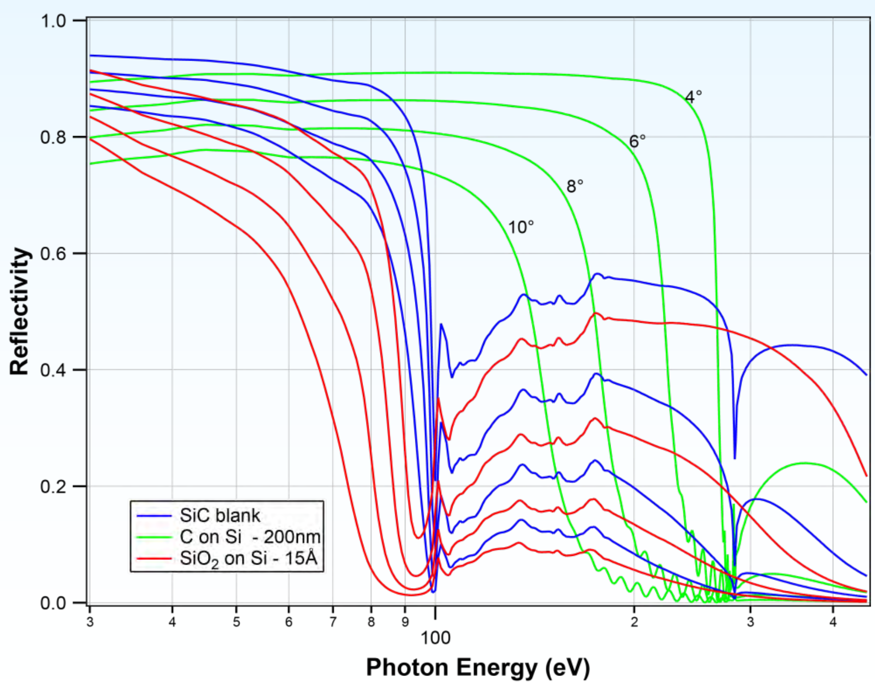
$$rm_2 = rs_2 = \frac{rm_1 \times rs_1}{2rm_1 - rs_1}$$

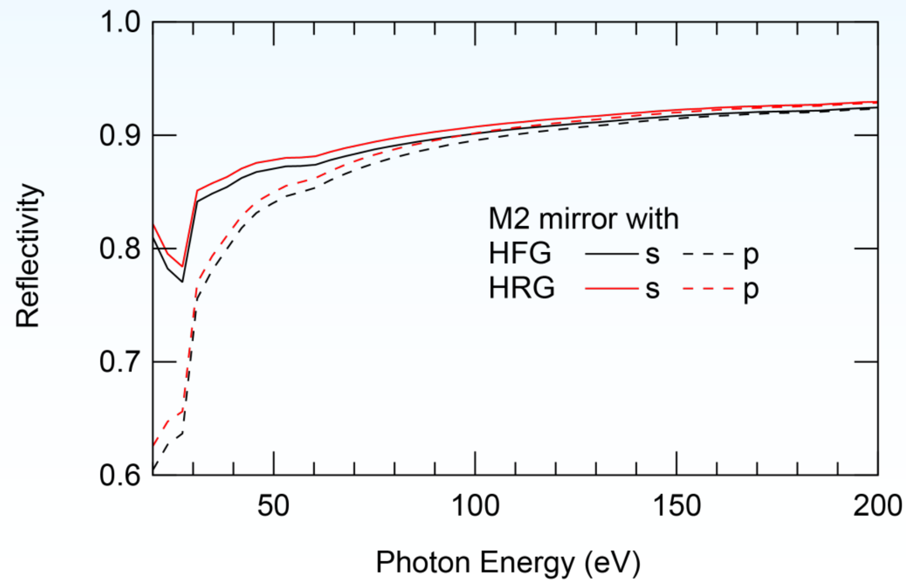
28.5:1.3 meridional horizontal
2.5:1.3 sagittal vertical

Mirror Coating and Reflectivity

- Best choice: C coated Si
  - High reflectivity
  - Suppress higher orders
- Other options: SiC or Si
- Use APPLE II to correct phase and s/p ratio

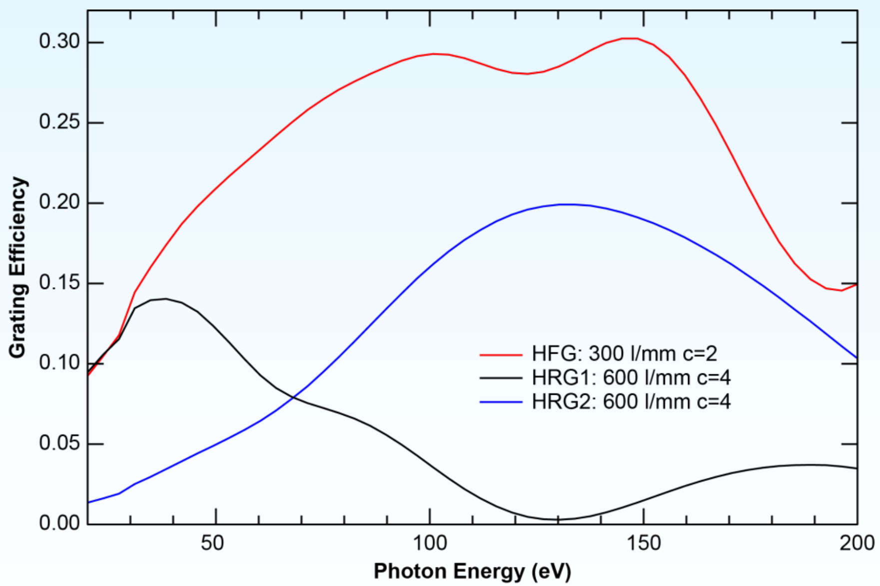


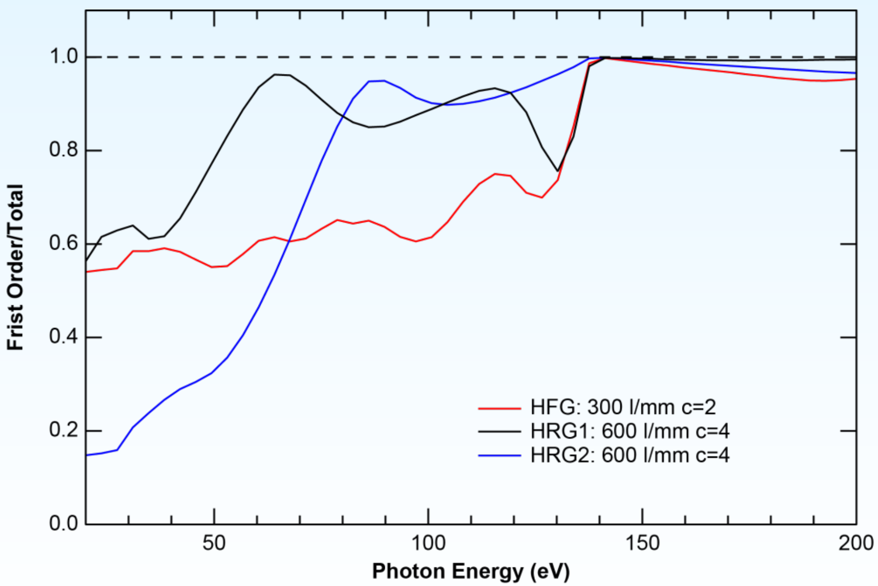




Grating Efficiency and Order Suppression

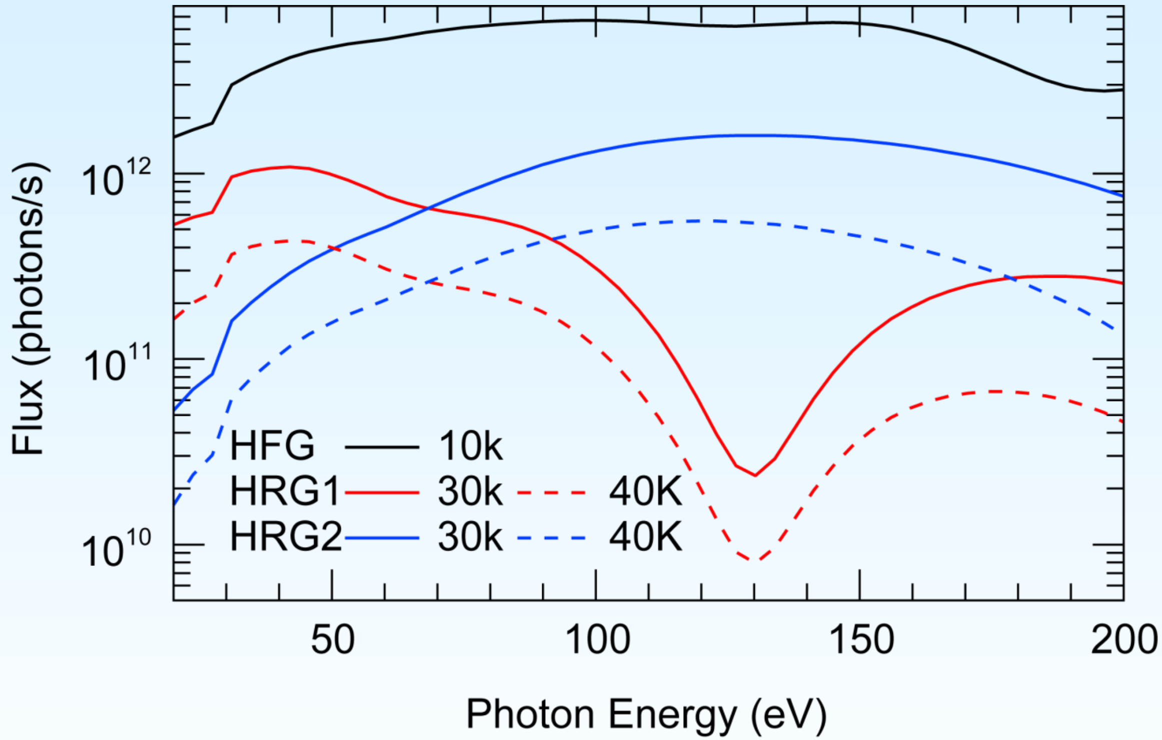
Grating	c	Line Density k_0	Trapezoidal angle	Groove Depth	Groove Width
HFG	2.0	300 l/mm	28°	40 nm	2.4 μm
HRG1	4.0	600 l/mm	28°	75 nm	1.5 μm
HRG2	4.0	600 l/mm	28°	30 nm	1.5 μm





$$\frac{E1 \times R1}{E1 \times R1 + E2 \times R2 + E3 \times R3 + E4 \times R4}$$

Flux at Sample



ID

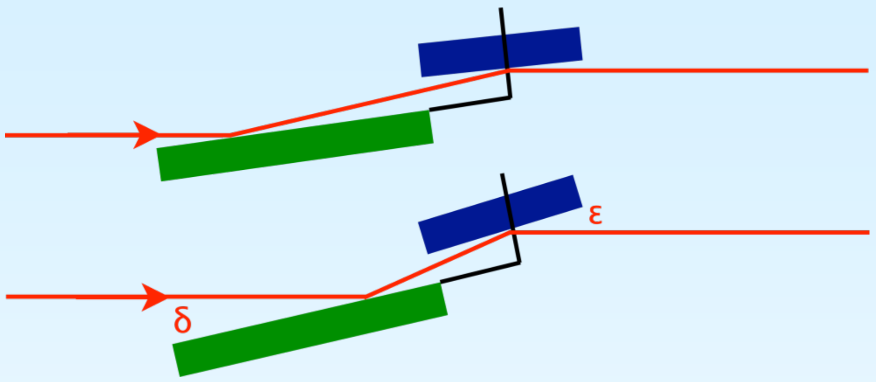
Band pass correction

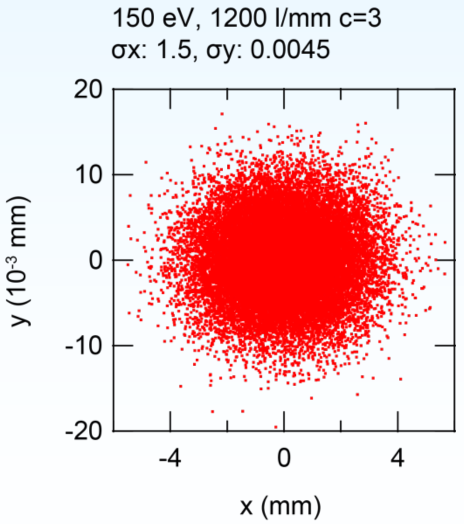
Grating efficiencies

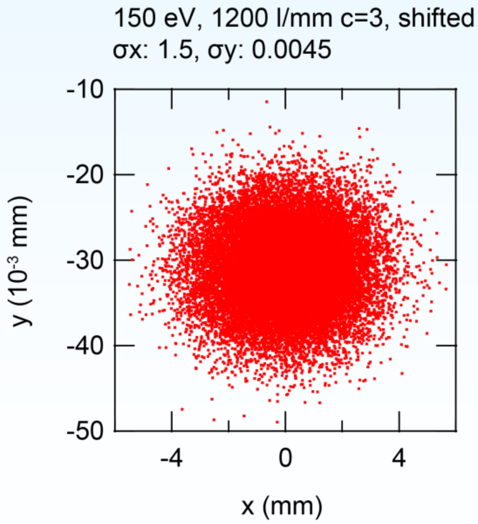
Reflectivity M0, M1, M2, M3

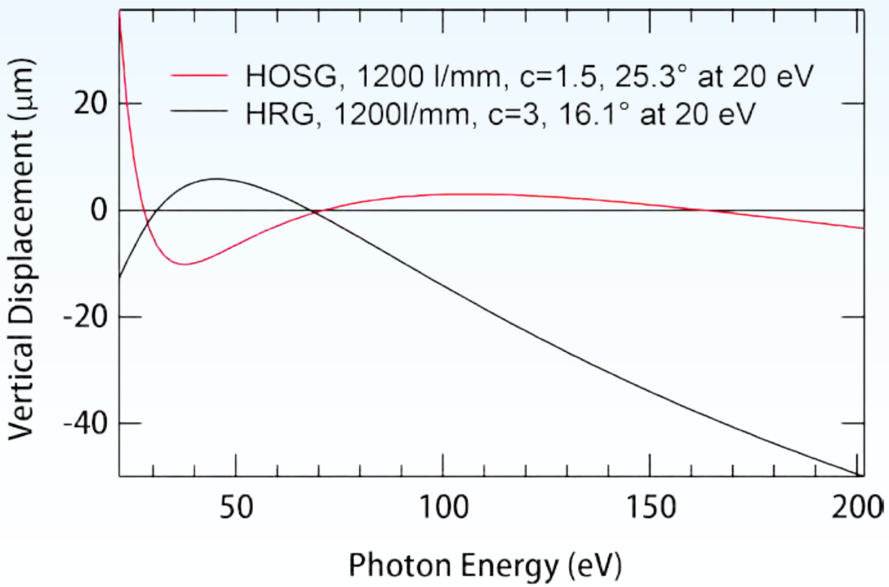
Large Angle Mono

- δ<12°, ε<17°
- δ<27°, ε<33.5°
- can use higher line density, small *c*
- higher order suppression
- beam walking behavior



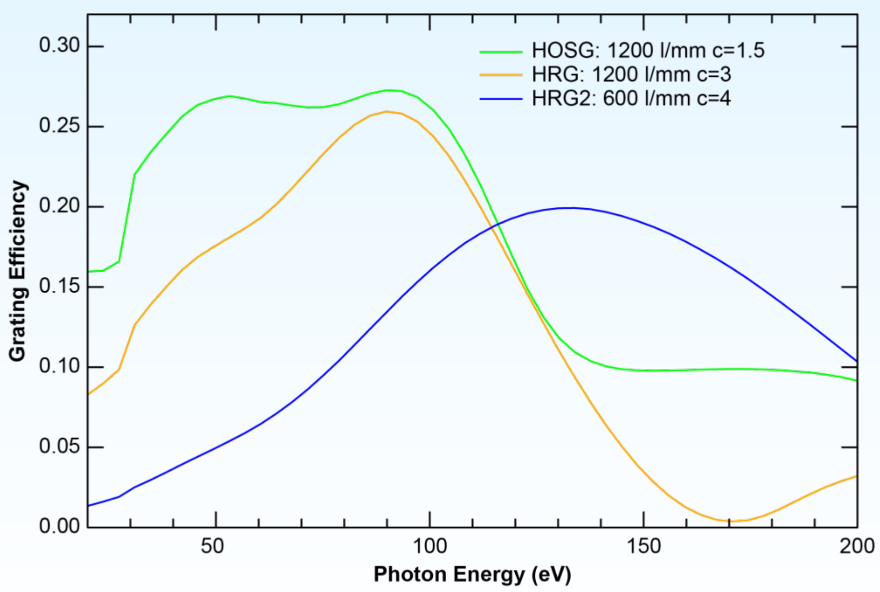


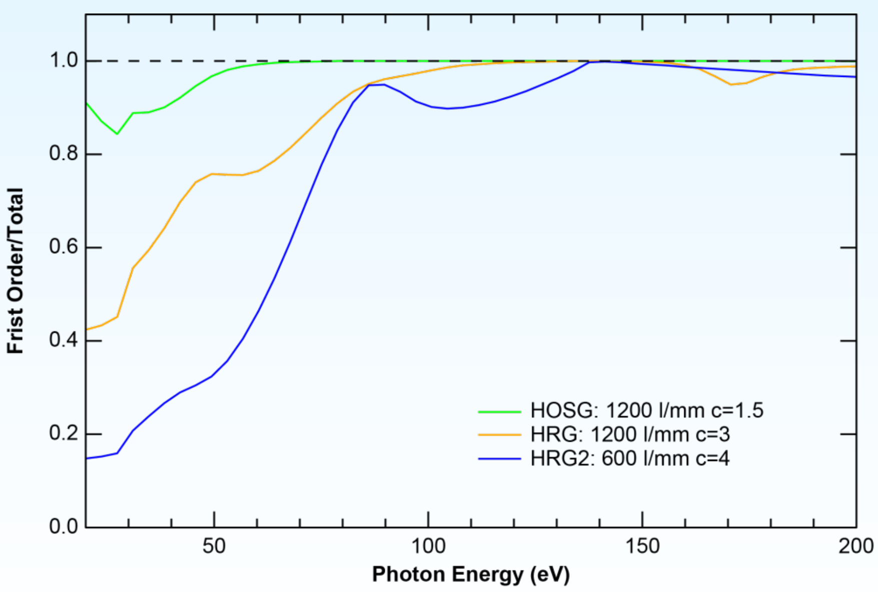




Large Angle Mono - Grating Efficiency

Grating	c	Line Density k_0	Trapezoidal angle	Groove Depth	Groove Width
HOSG	1.5	1200 l/mm	28°	23 nm	0.45 µm
HRG	3.0	1200 l/mm	28°	30 nm	0.65 µm
HRG2	4.0	600 l/mm	28°	30 nm	1.5 µm

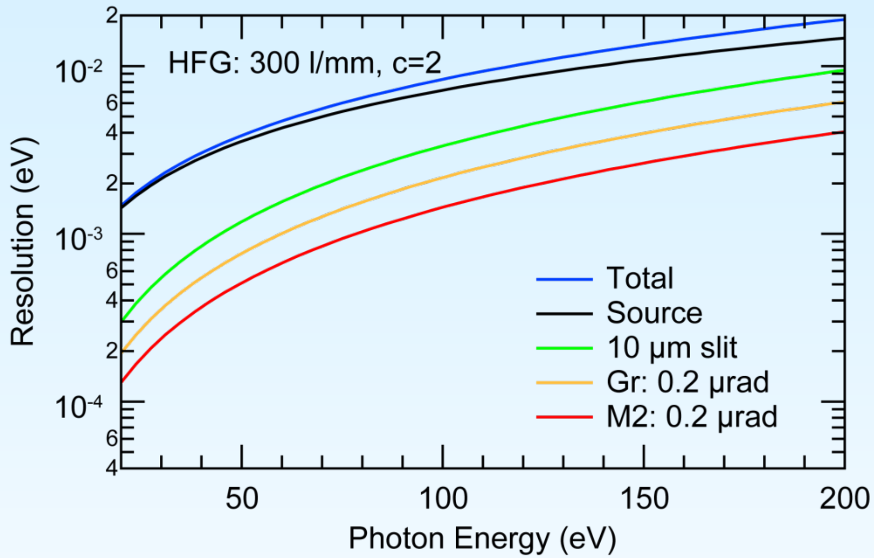


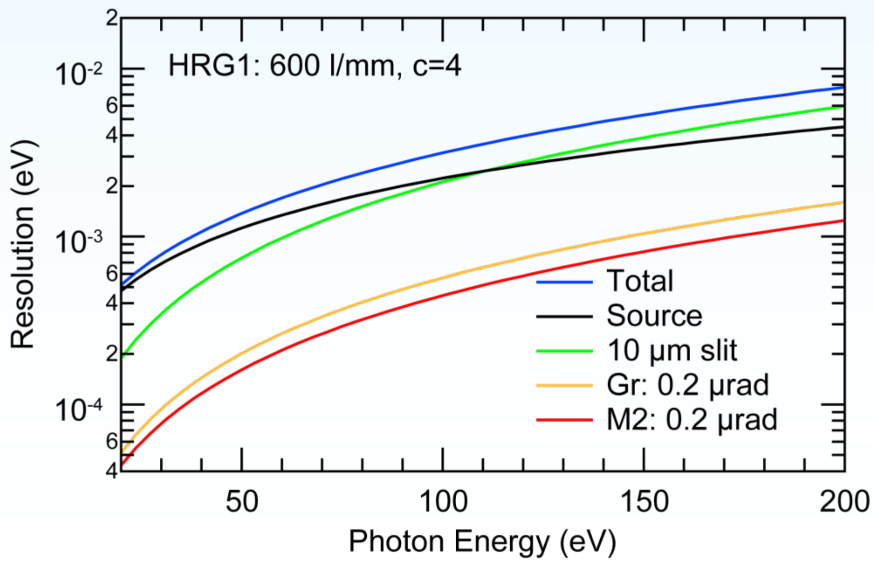


$$\frac{E1 \times R1}{E1 \times R1 + E2 \times R2 + E3 \times R3 + E4 \times R4}$$

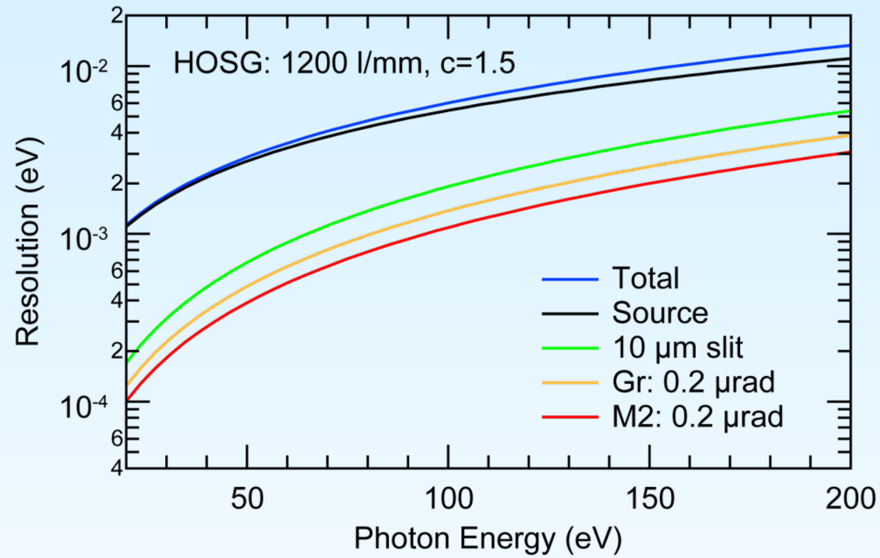
Large Angle Mono – Resolution

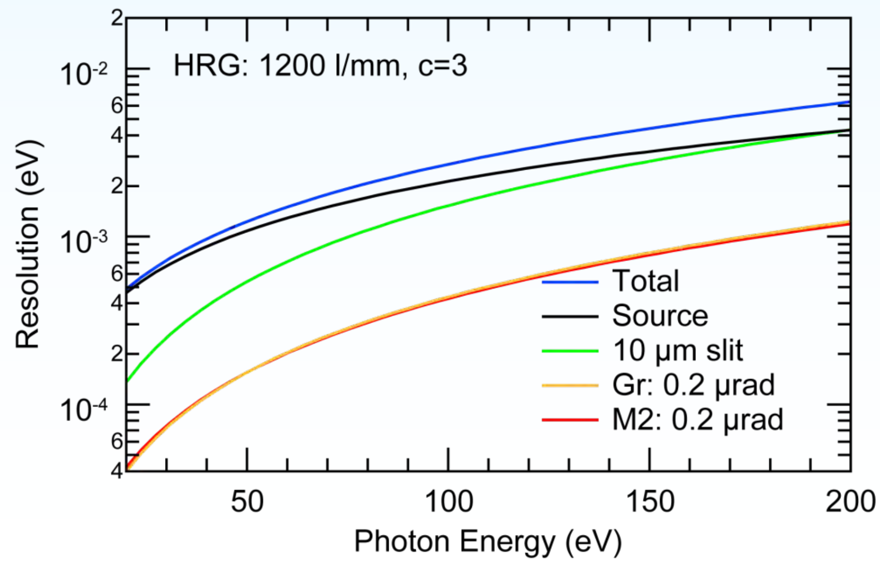
δ<12°, ε<17°





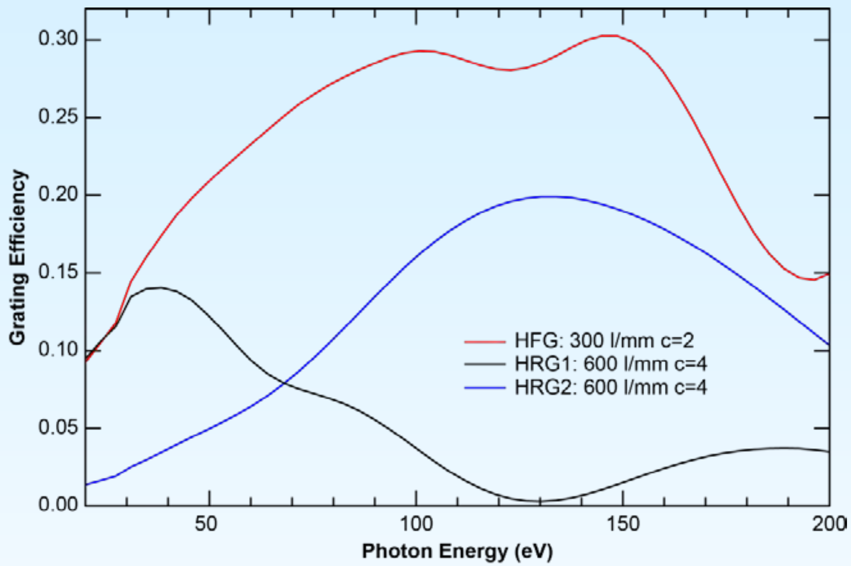
δ<27°, ε<33.5°

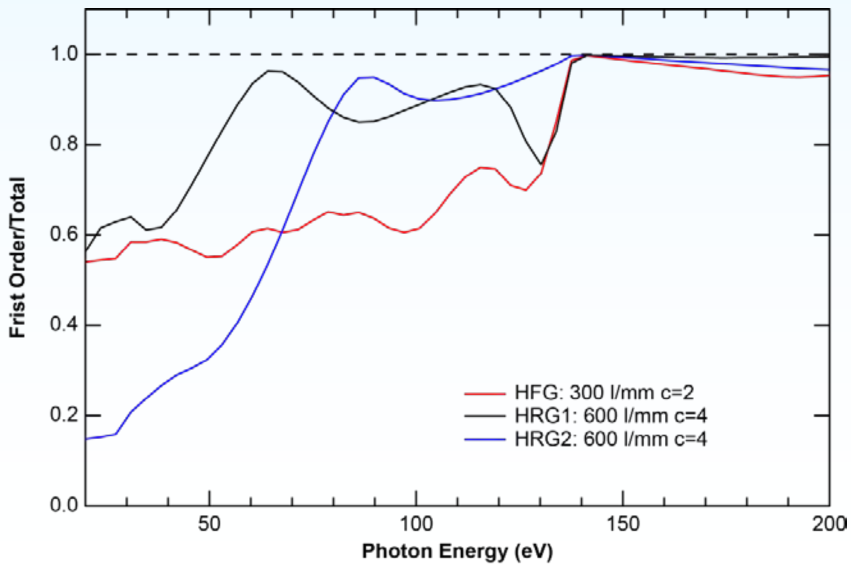




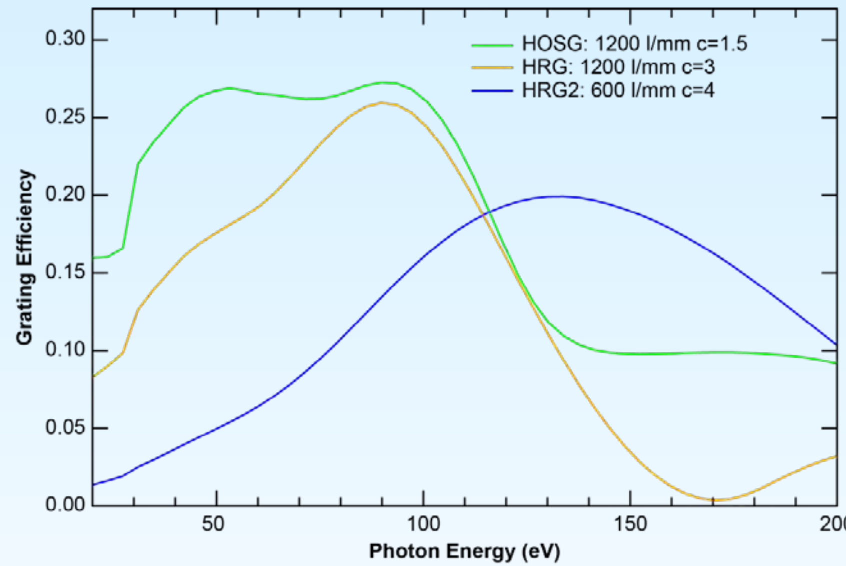
Large Angle Mono – Grating Efficiency

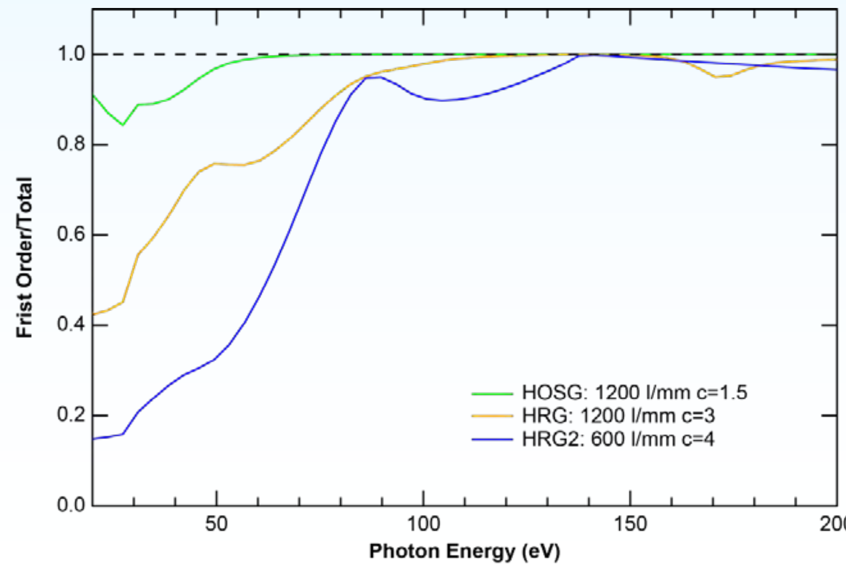
$\delta < 12°$, $\varepsilon < 17°$



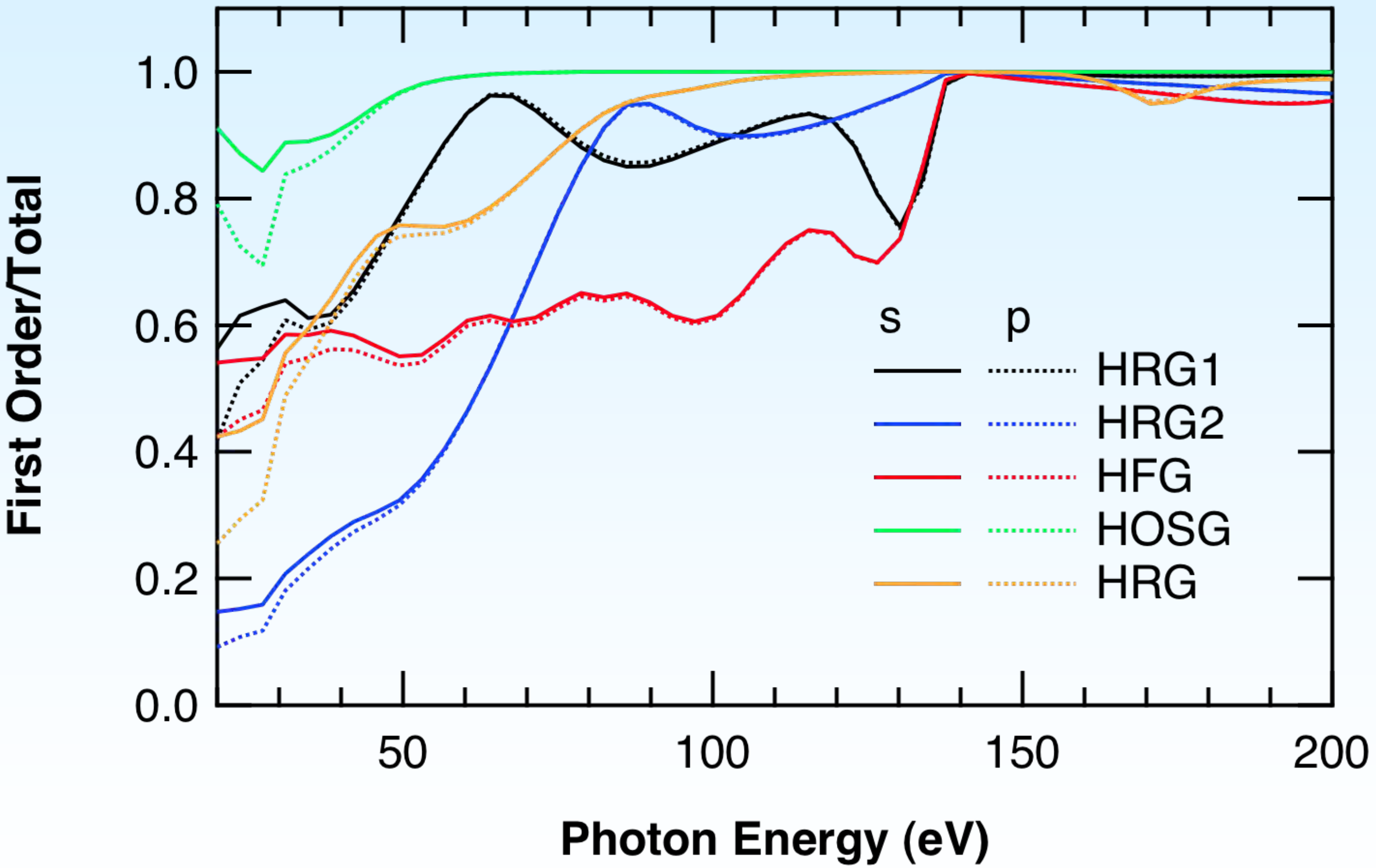


$\delta < 27°$, $\varepsilon < 33.5°$

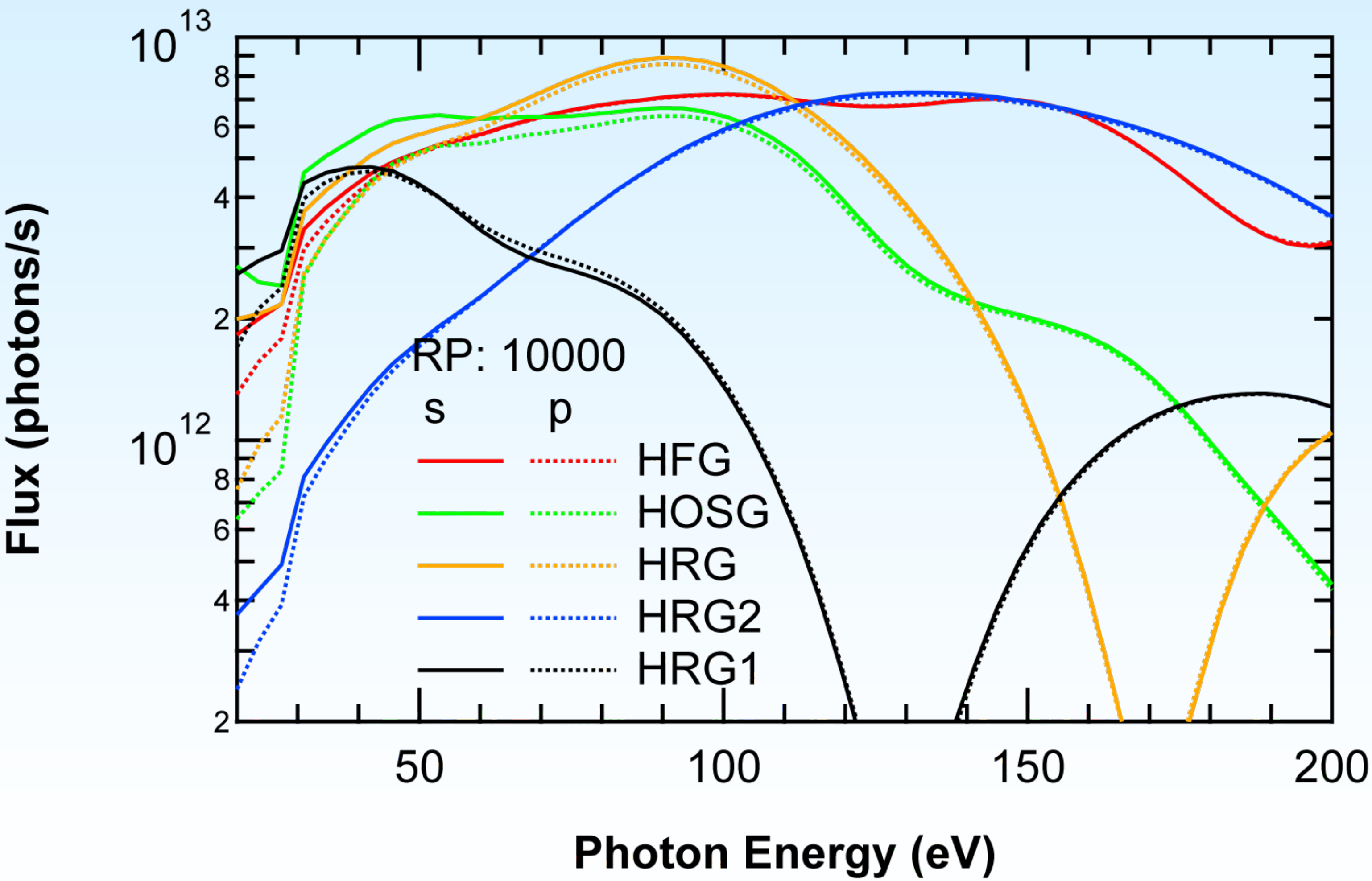




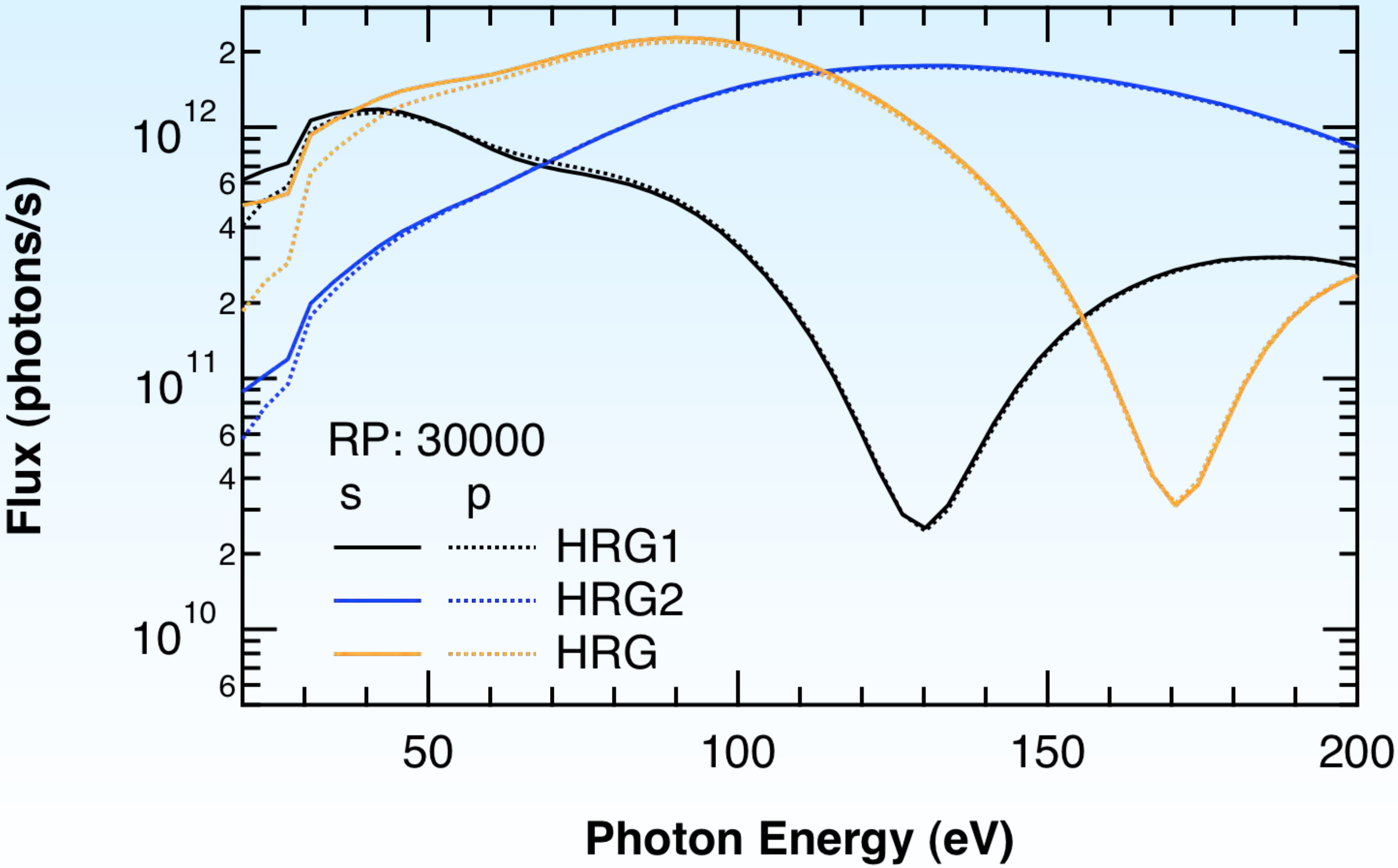
High Order Suppression



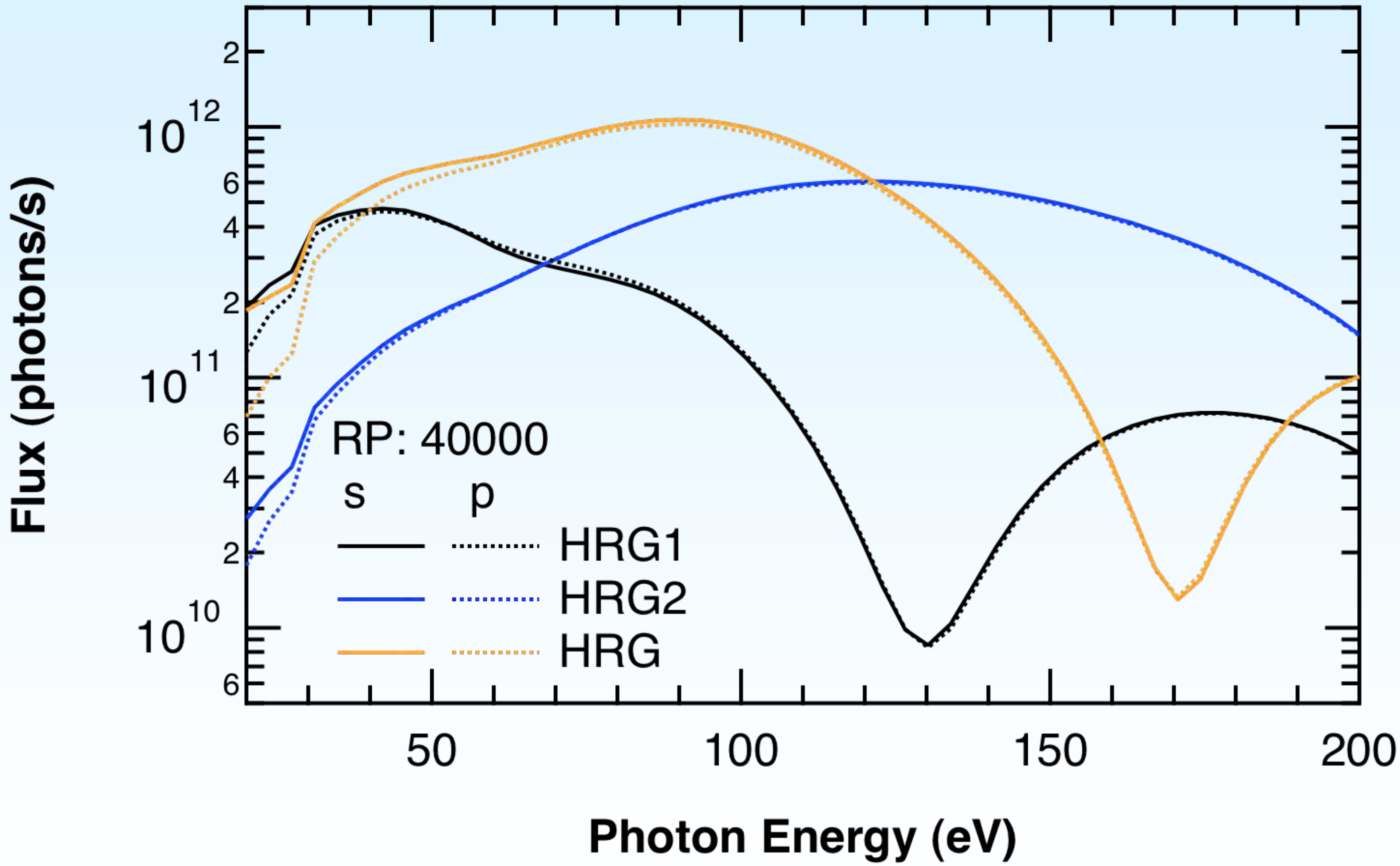
Flux Comparison



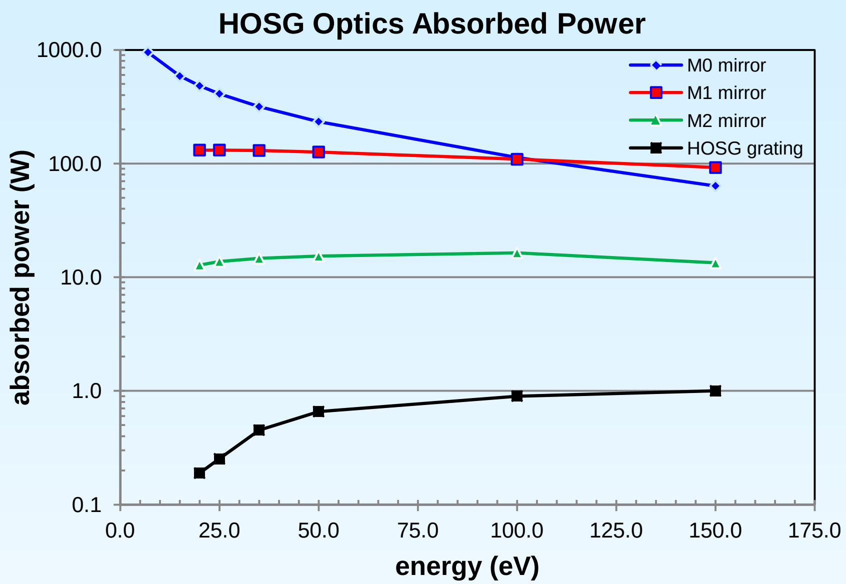
Flux Comparison

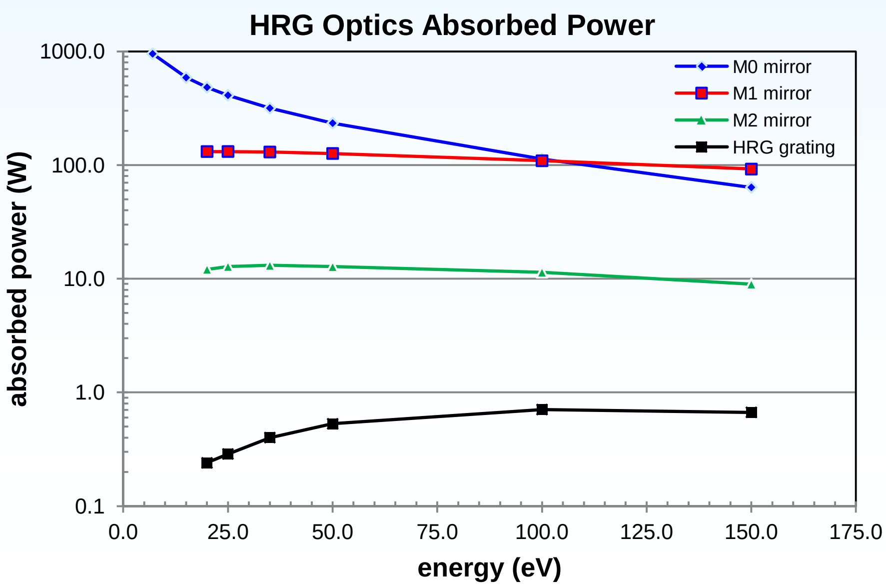


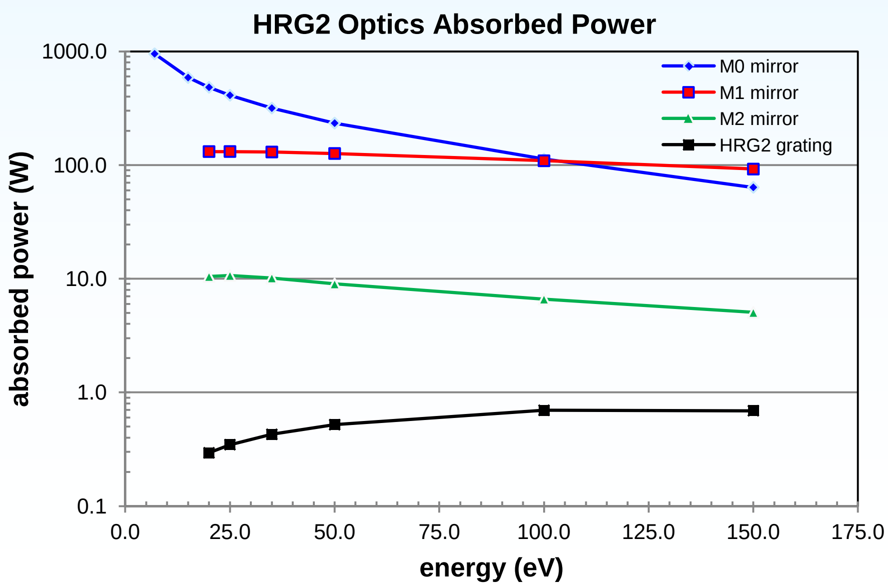
Flux Comparison



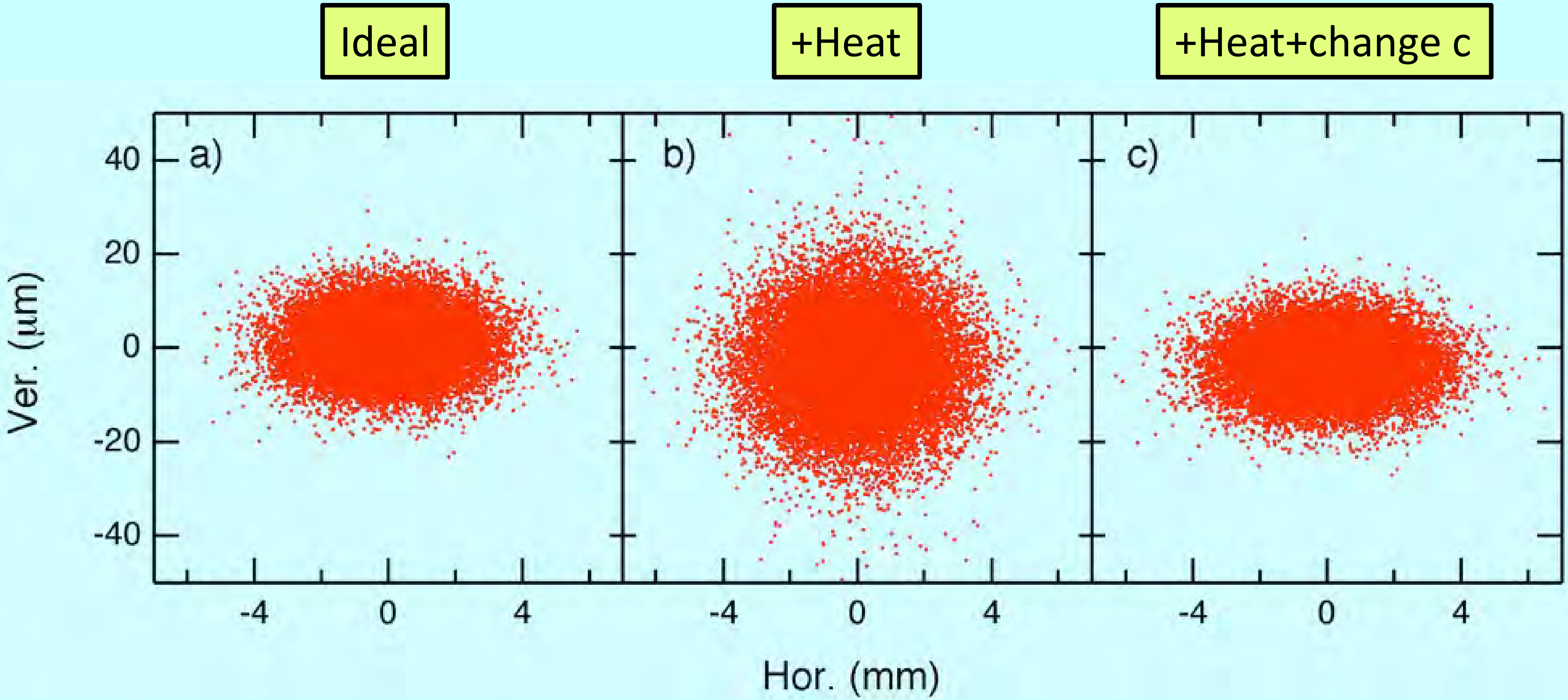
Heat Load


HOSG Optics Absorbed Power
absorbed power (W)
energy (eV)
1000.0
100.0
10.0
1.0
0.1
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
M0 mirror
M1 mirror
M2 mirror
HOSG grating


HRG Optics Absorbed Power
absorbed power (W)
energy (eV)
1000.0
100.0
10.0
1.0
0.1
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
M0 mirror
M1 mirror
M2 mirror
HRG grating


HRG2 Optics Absorbed Power
absorbed power (W)
energy (eV)
1000.0
100.0
10.0
1.0
0.1
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
M0 mirror
M1 mirror
M2 mirror
HRG2 grating

Heat Load Compensation



c value
2.183 to 2.201
93% beam