

# High Spectral Resolution X-Ray Optics based on Pyrolytic Graphite

H. Legall, H. Stiel (MBI), V. Arkadiev (IAP e.V.)

A. Antonov, I. Grigorieva (Optigraph GmbH)

A. Bjeoumikhov (IfG GmbH), A. Erko (BESSY GmbH)

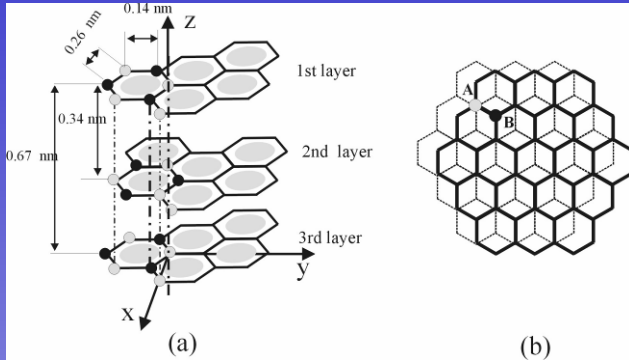
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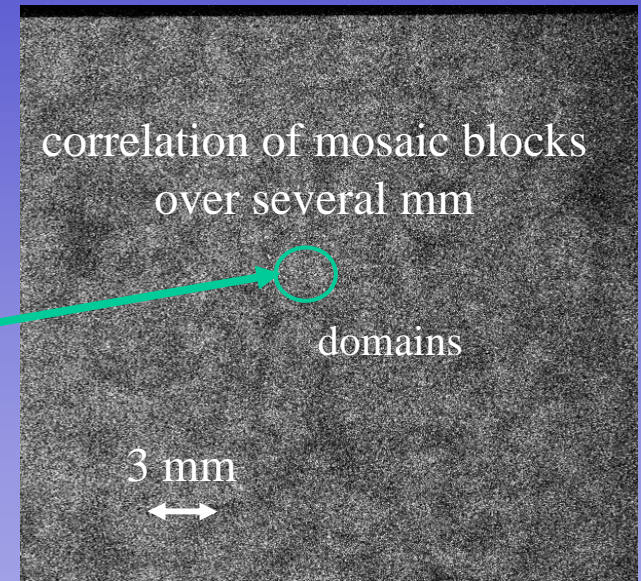
# Outlook

- **Introduction to Pyrolytic Graphite (PG)**
- **Diffraction Properties of PG crystals**
- **Experimental results**
- **Conclusions**

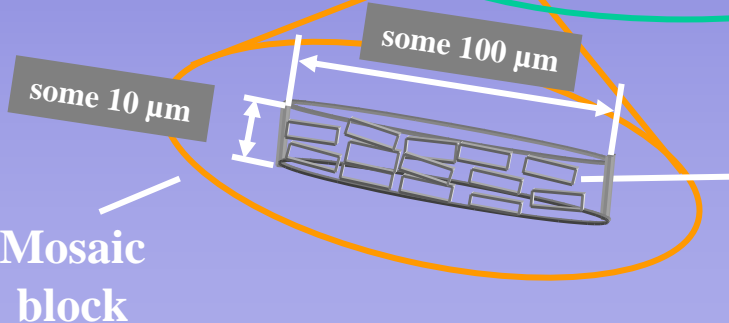
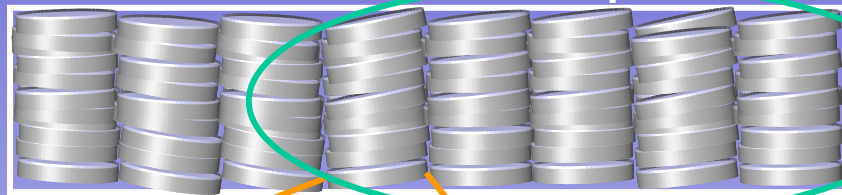
# Crystal structure Highly Oriented PG



white light continuum reflected  
by a 15  $\mu\text{m}$  thick PG film



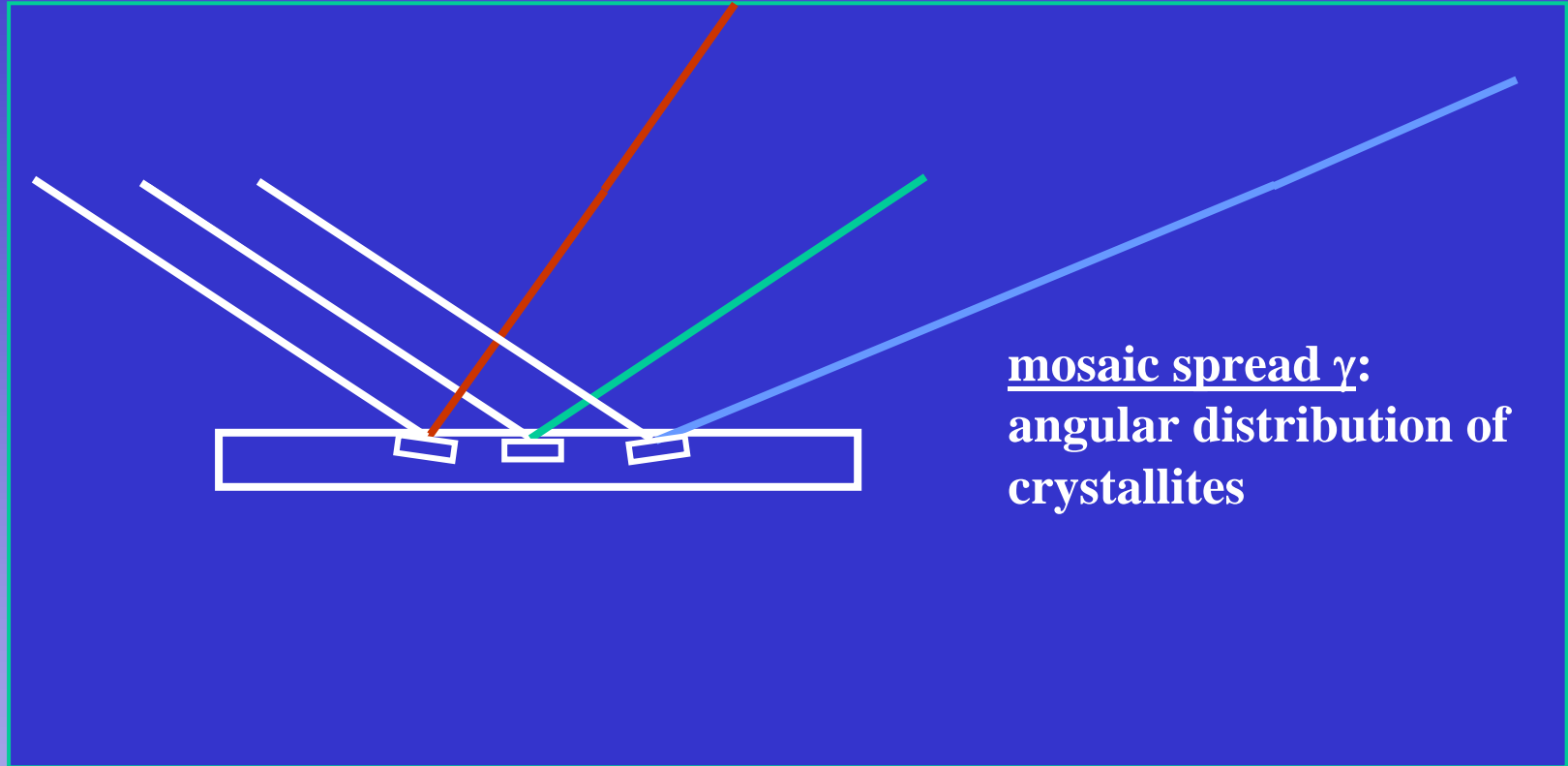
c - axis



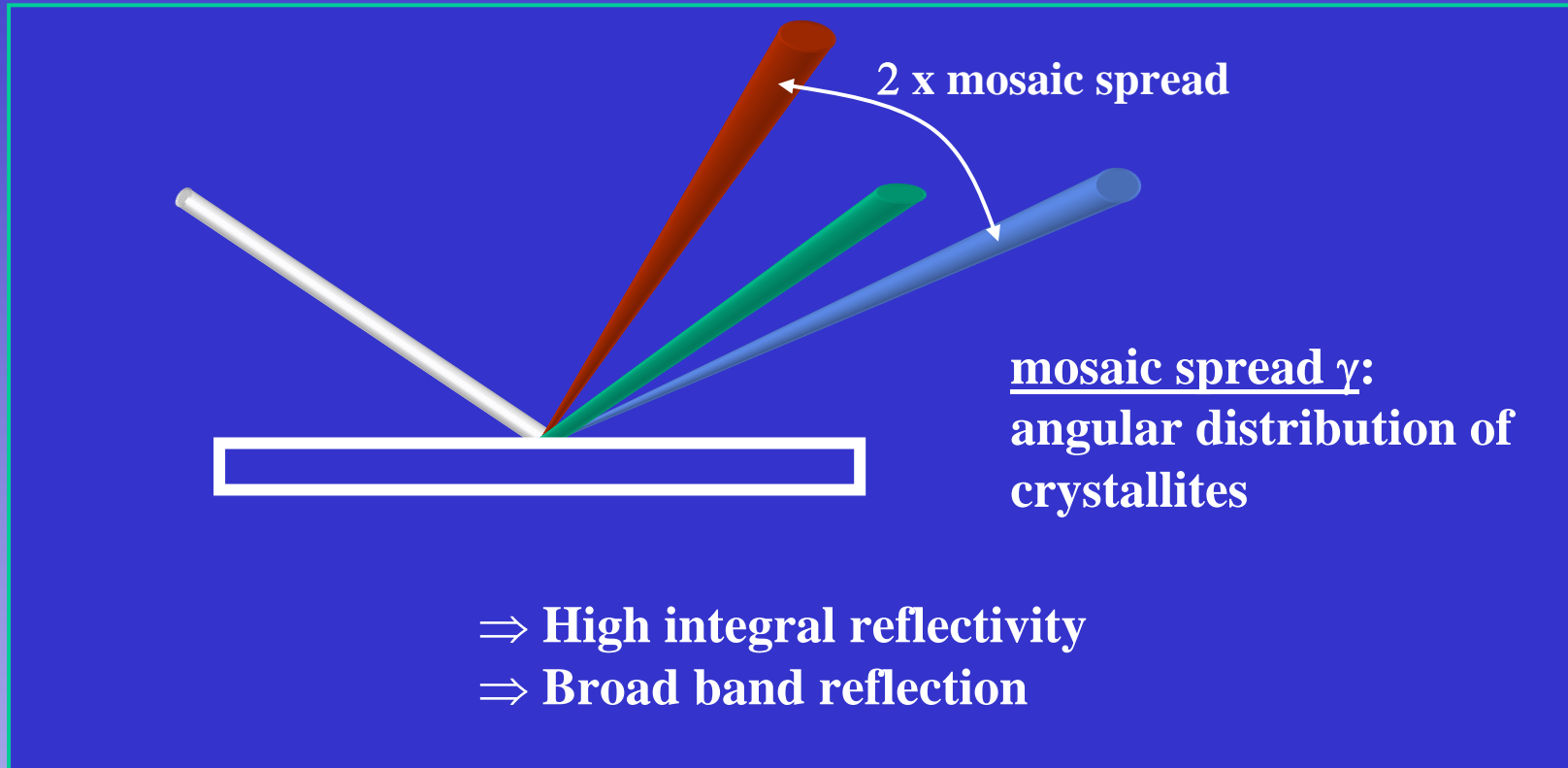
small Crystallite (some  $\mu\text{m}$  in size)

(data from Ohler et. al 1997)

# Parallel beam reflection



# Parallel beam reflection



**„Highly Oriented Pyrolytic Graphite (HOPG)“:**  
 **$0.1^\circ < \gamma < 3^\circ$ , high integral reflectivity (2 keV - several 10 keV)**

# Thermal properties of Pyrolytic Graphite crystals

	Graphite (HOPG)	Diamond	Silicon
thermal conductivity* [W/cmK]	17 (parallel (002))	21	1.25
	8 (perpendicular)	21	1.25
thermal expansion* [K <sup>-1</sup> x 10 <sup>-6</sup> ]	< 1 (parallel (002))	0.8	2.33
	20 (perpendicular)	0.8	2.33
Specific heat [J/g K ]	0.71	0.52	0.75
Density [g/cm <sup>3</sup> ]	2.25 (C)	3.5 (C)	2.3 (Si)
Absorption coeff. [cm <sup>-1</sup> ] (8keV)	10	16	148
Melting [°C]	3500	4300	1420

\*at room temperature

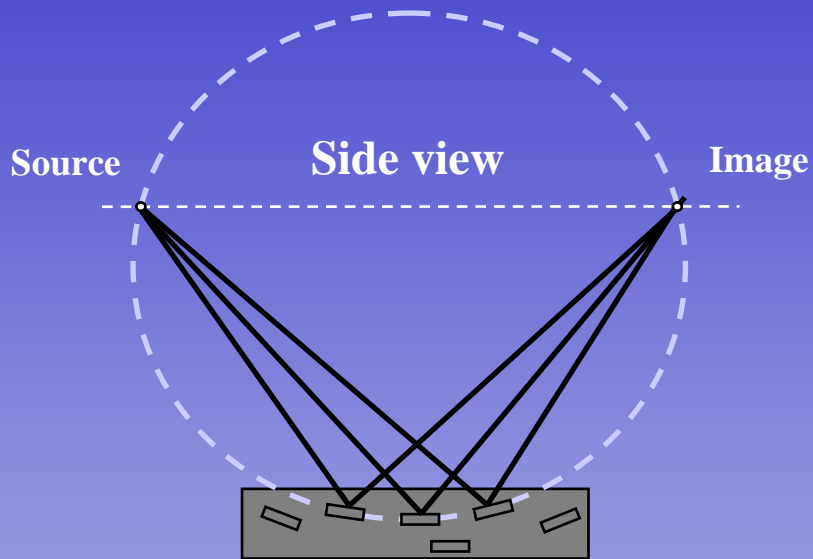
# Energy resolution

**What energy resolution can be obtained with  
Pyrolytic Graphite?**

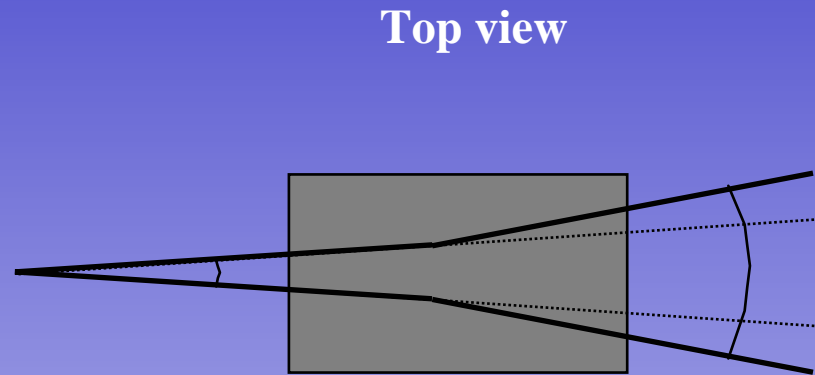
**Up to now it was commonly assumed, that the  
energy resolution of Pyrolytic Graphite is low**

**Reported values of  $E/\Delta E$  are well below 1000**

# Focusing properties of mosaic crystals



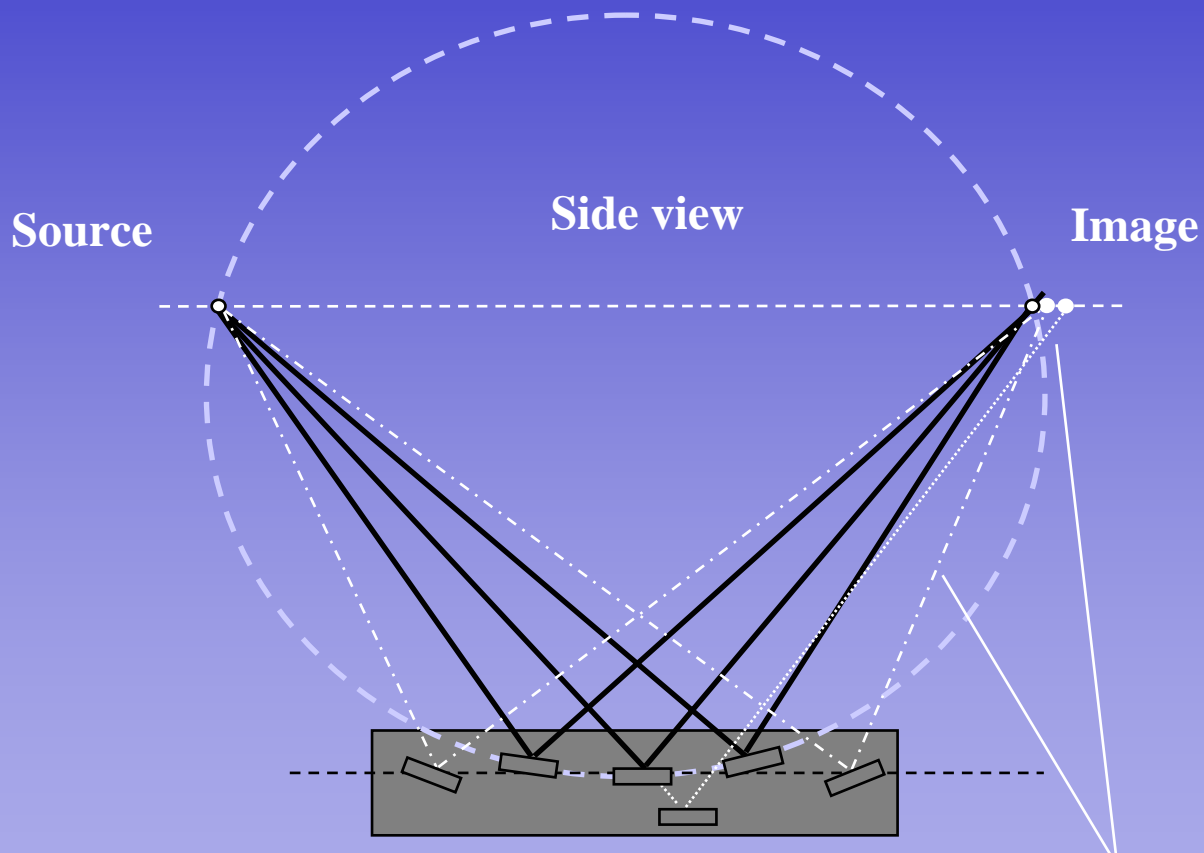
**Focusing in dispersion plane  
(„mosaic focusing“)**



**Defocusing perpendicular to  
dispersion plane**



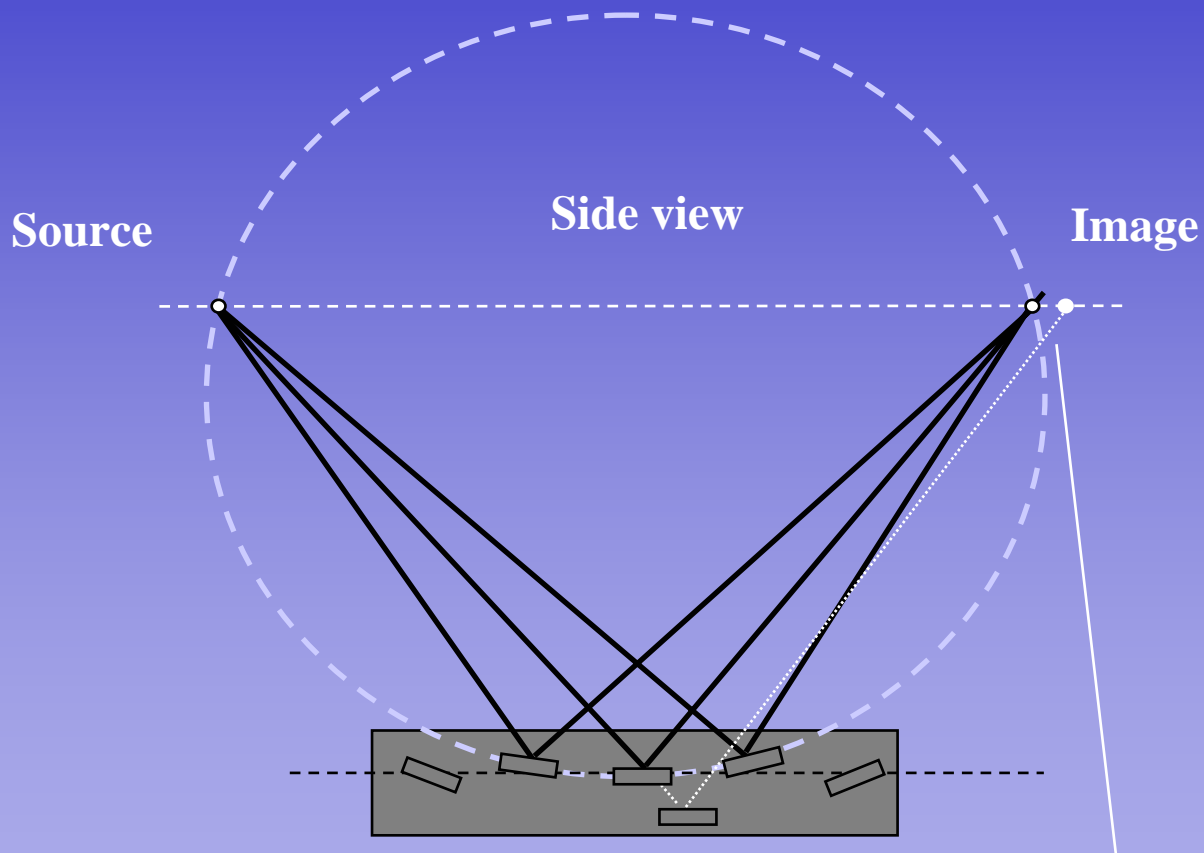
# Focusing properties of mosaic crystals



(cp. Ice & Sparks, J Nucl. Instr., 1990 )

**Focusing error**

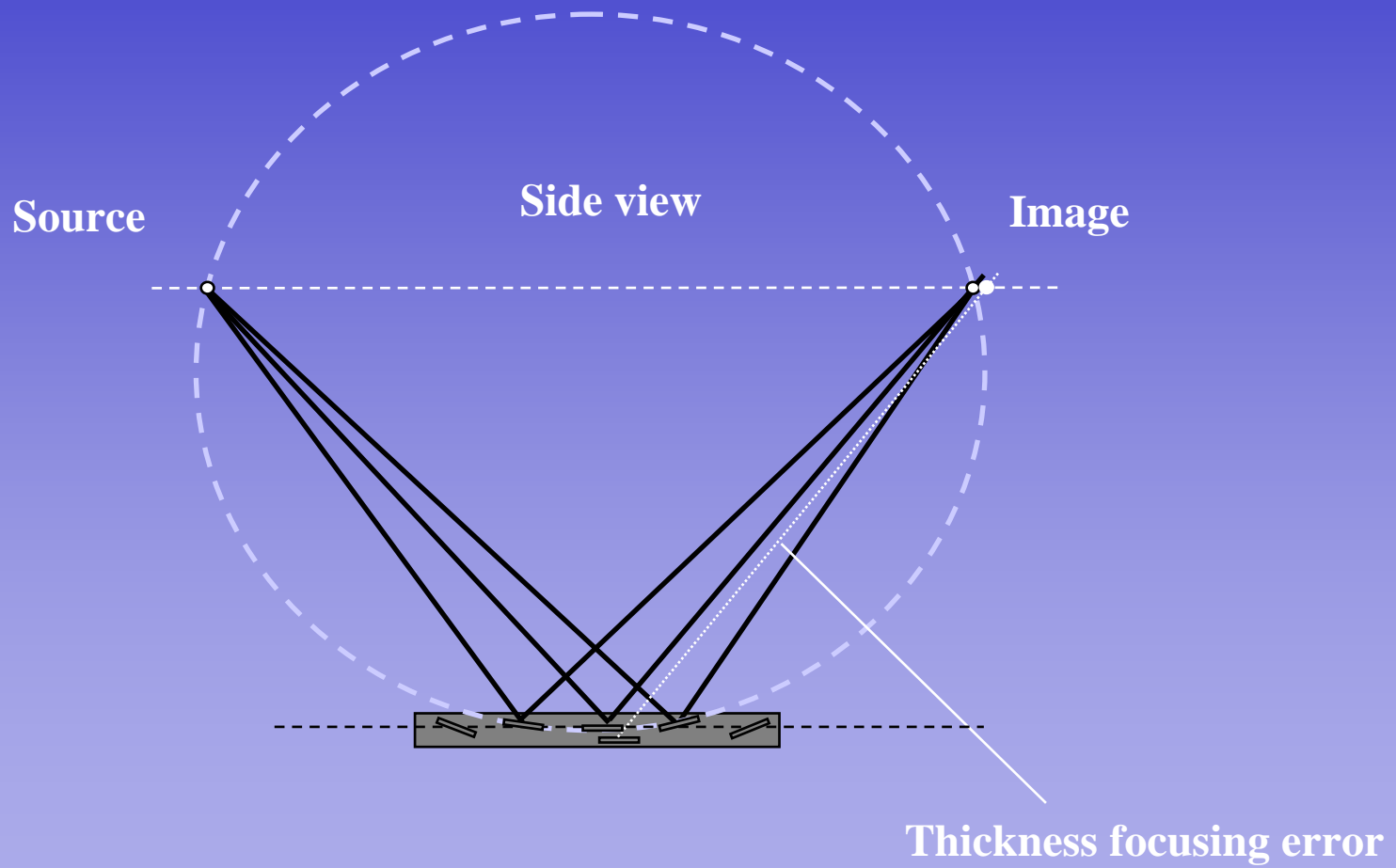
# Focusing properties of mosaic crystals



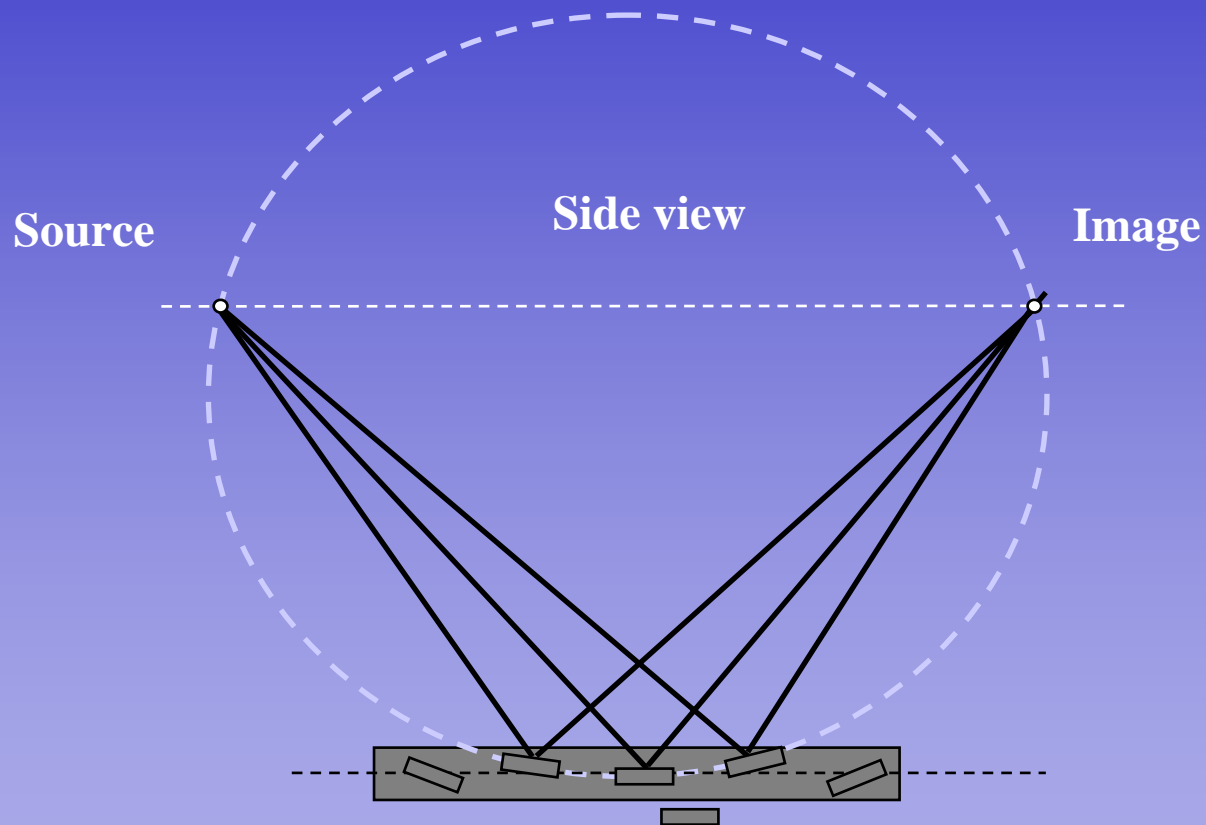
(cp. Ice & Sparks, J Nucl. Instr., 1990 )

**Thickness focusing error**

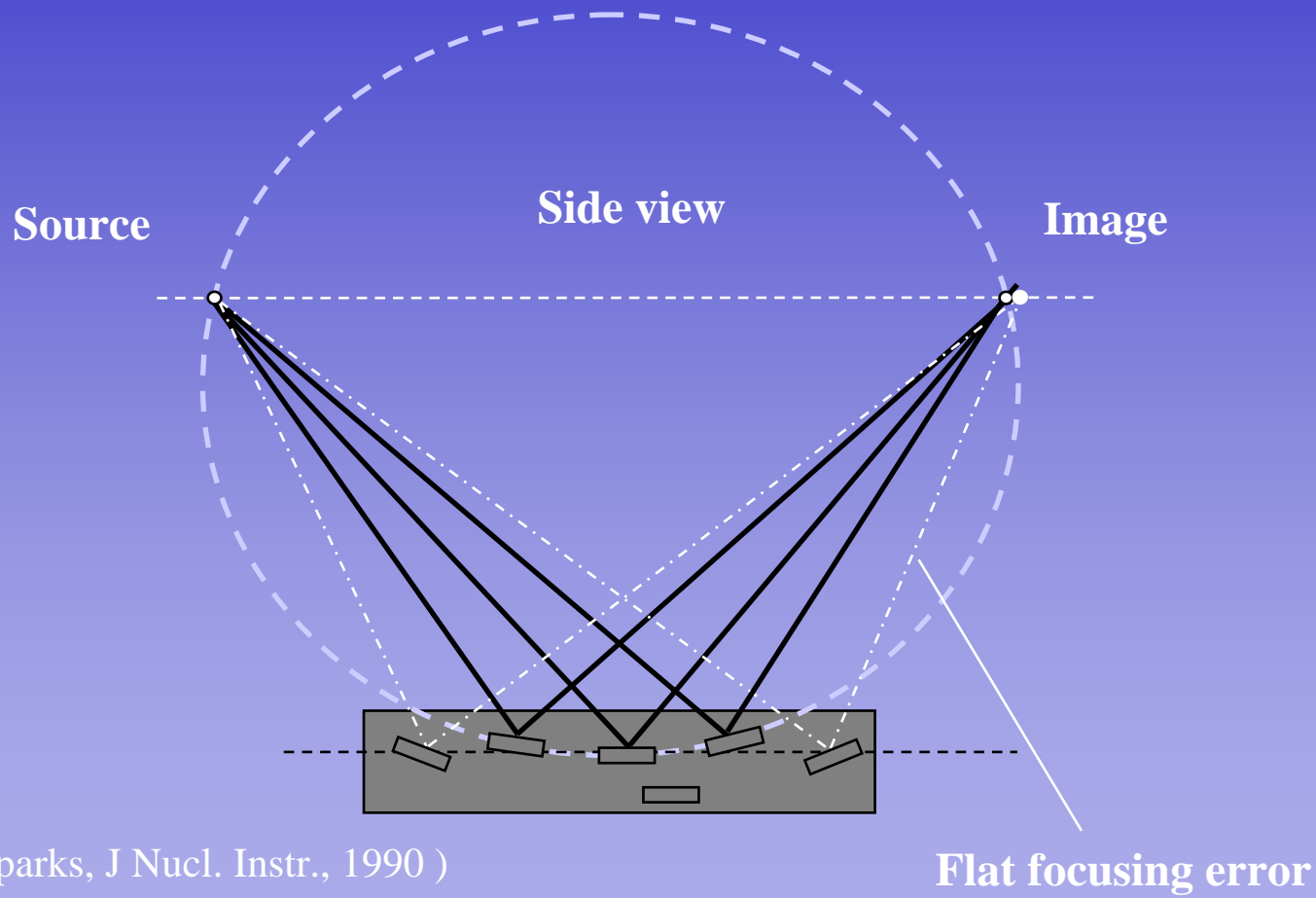
# Focusing properties of mosaic crystals



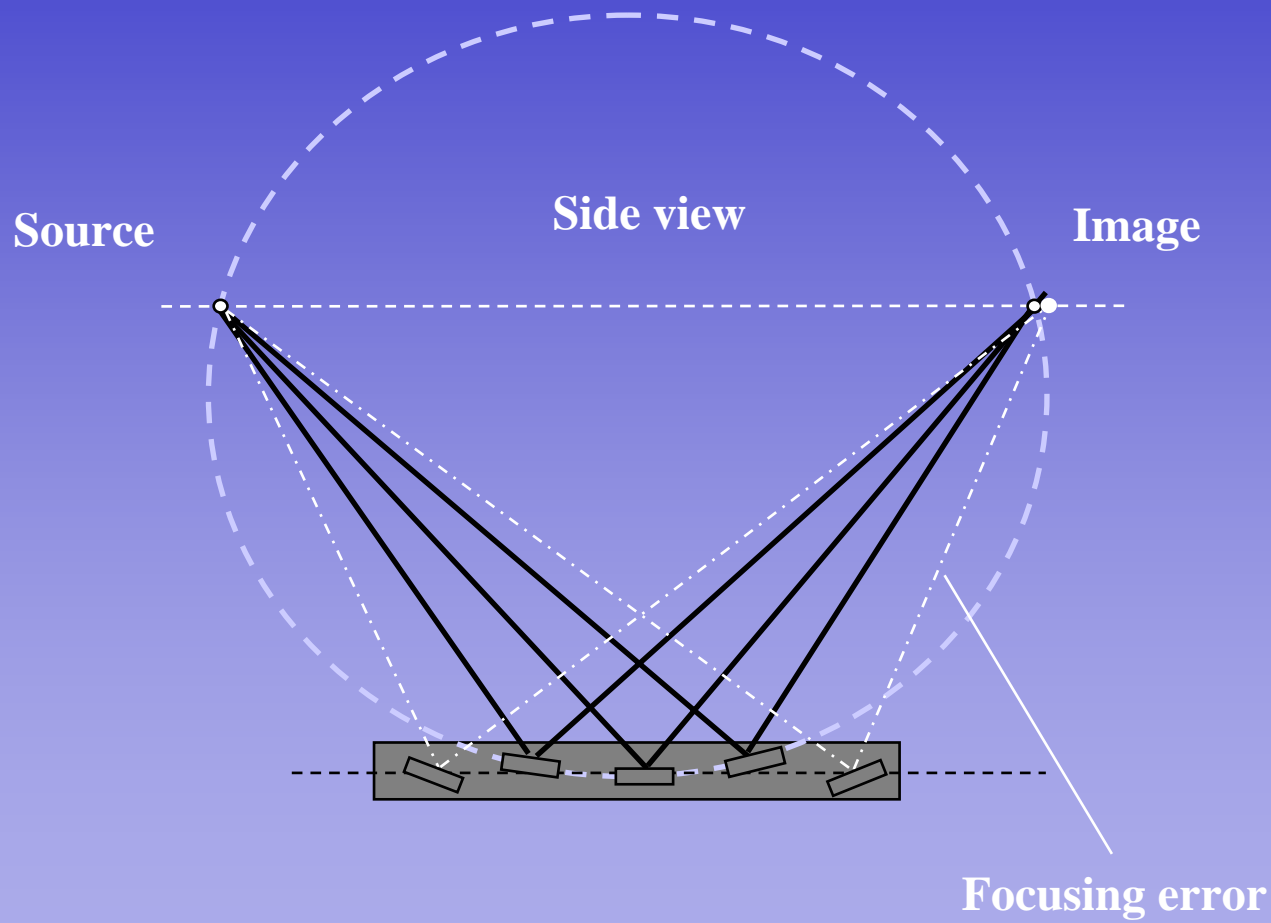
# Focusing properties of mosaic crystals



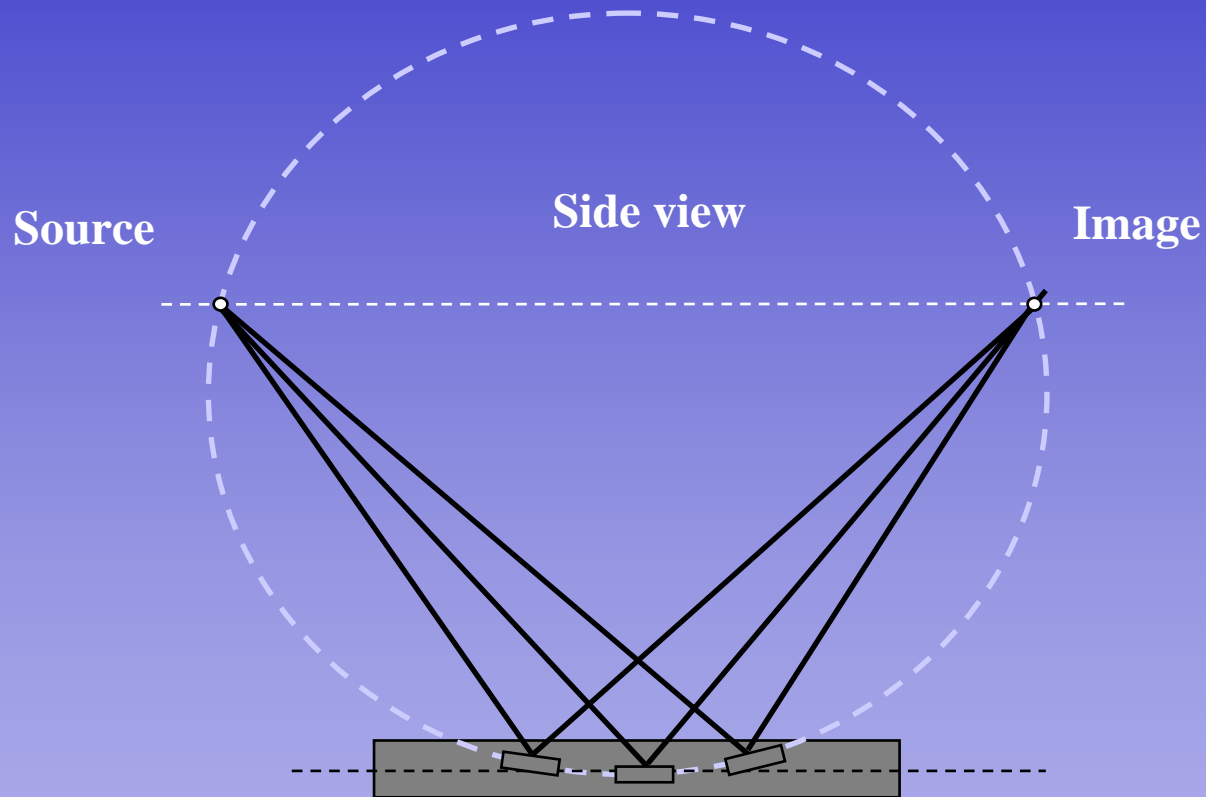
# Focusing properties of mosaic crystals



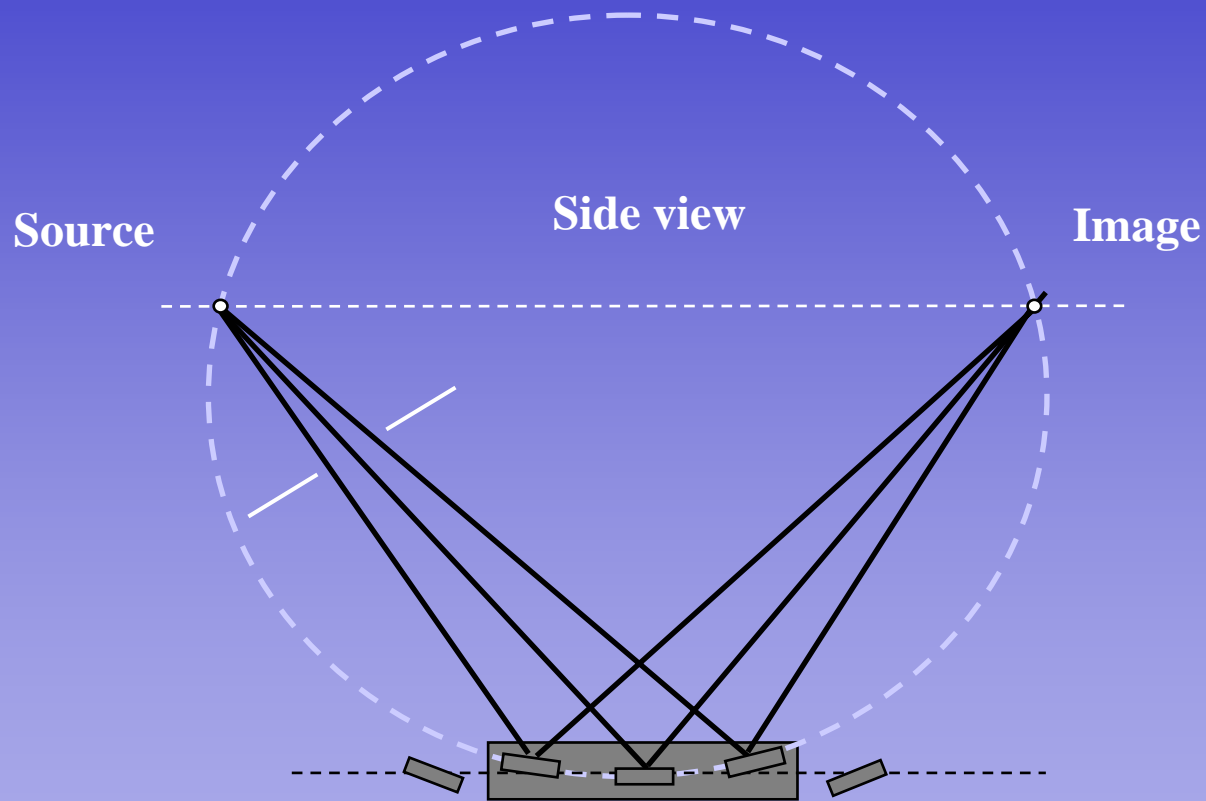
# Focusing properties of mosaic crystals



# Focusing properties of mosaic crystals

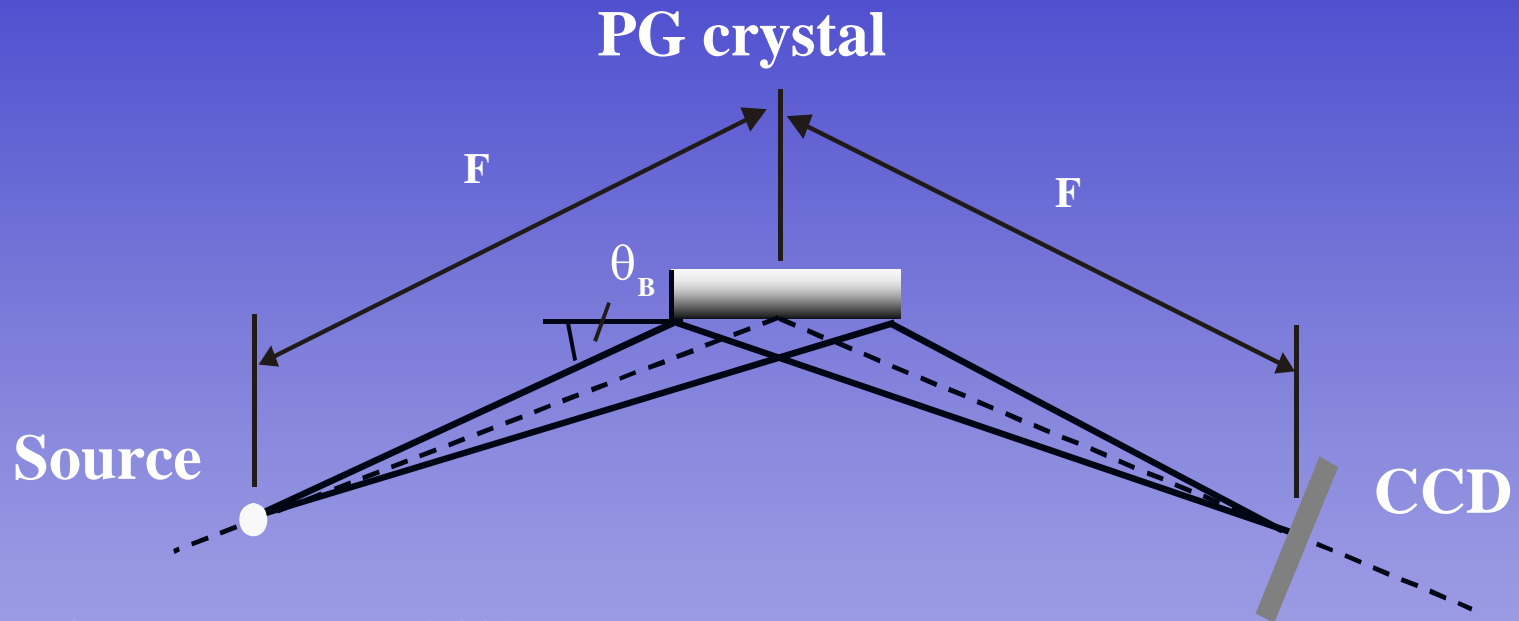


# Focusing properties of mosaic crystals





# Experimental setup for testing PG



Micro focus X-ray tube (IfG)

Anode : Cu

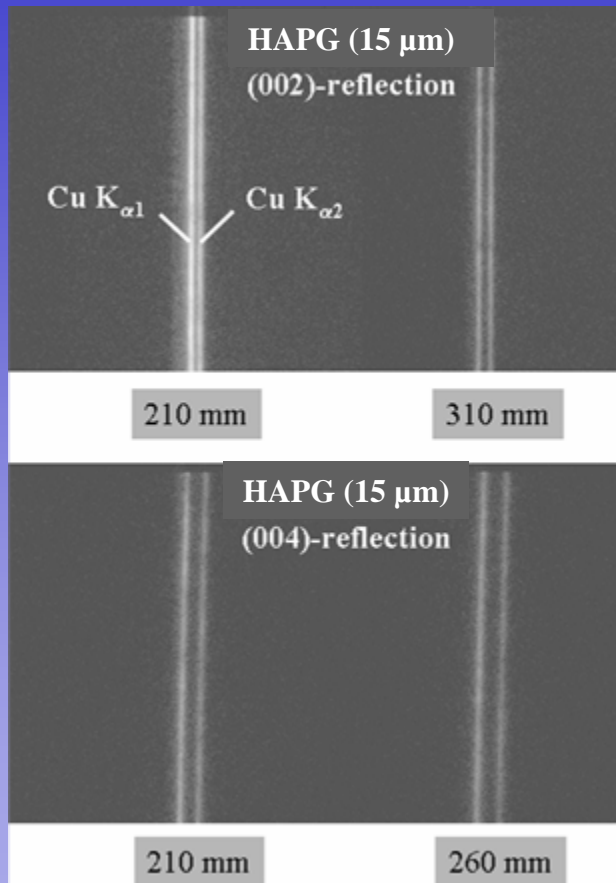
Source size: 50  $\mu\text{m}$

cooled 16-bit

deep depletion CCD

(Roper Scientific)

# Specific features of Pyrolytic Graphite crystals



Opt. Express, H. Legall et. al (2006)

energy resolution of a 15  $\mu\text{m}$  flat PG  
crystals at 8 keV ( $F = 260$  mm):

**2900 in (004)-reflection (with integral  
reflectivity comparable to Ge(111))**



modified fabrication process

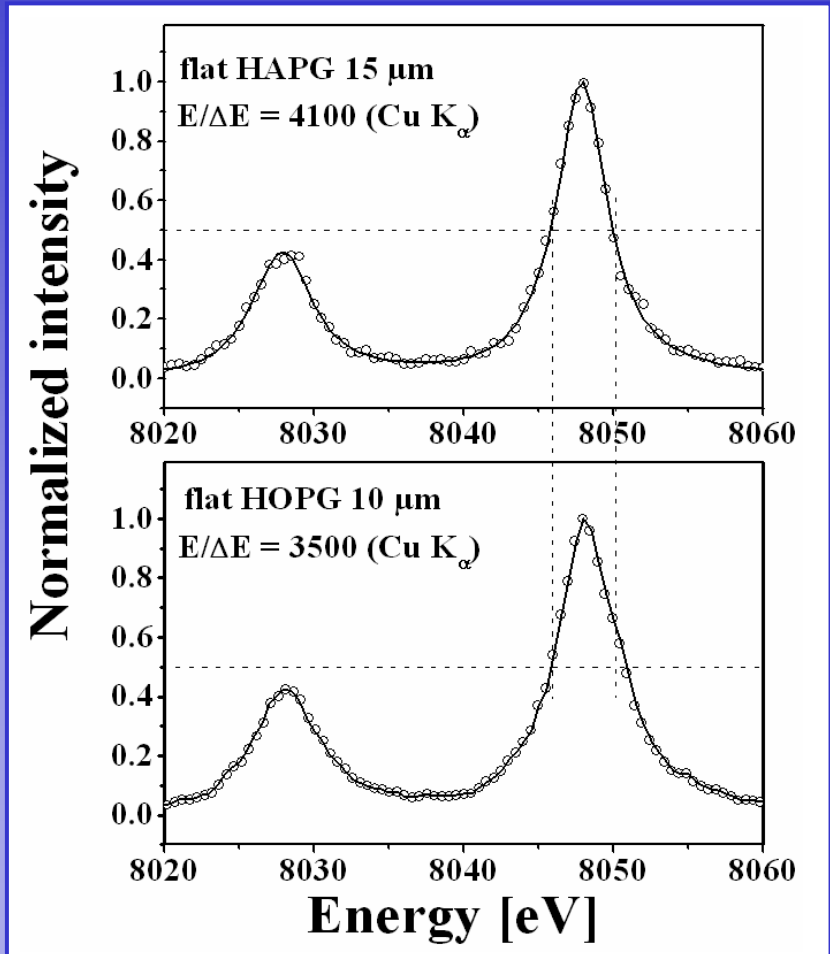
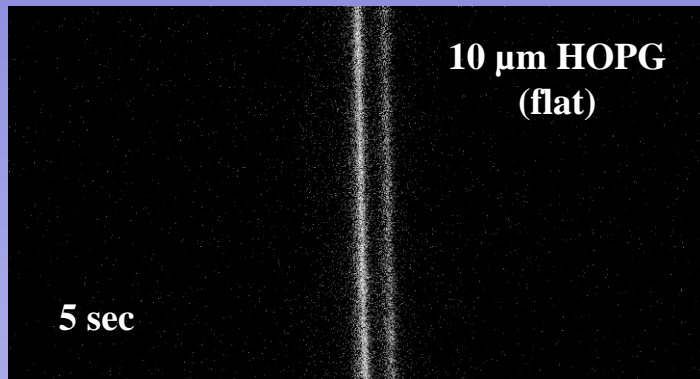
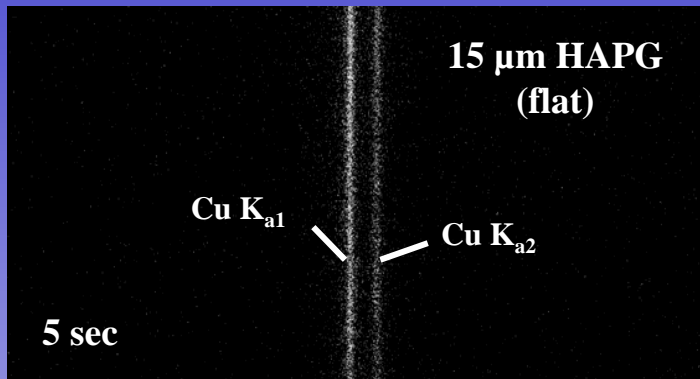


**Highly Annealed Pyrolytic Graphite (HAPG)**



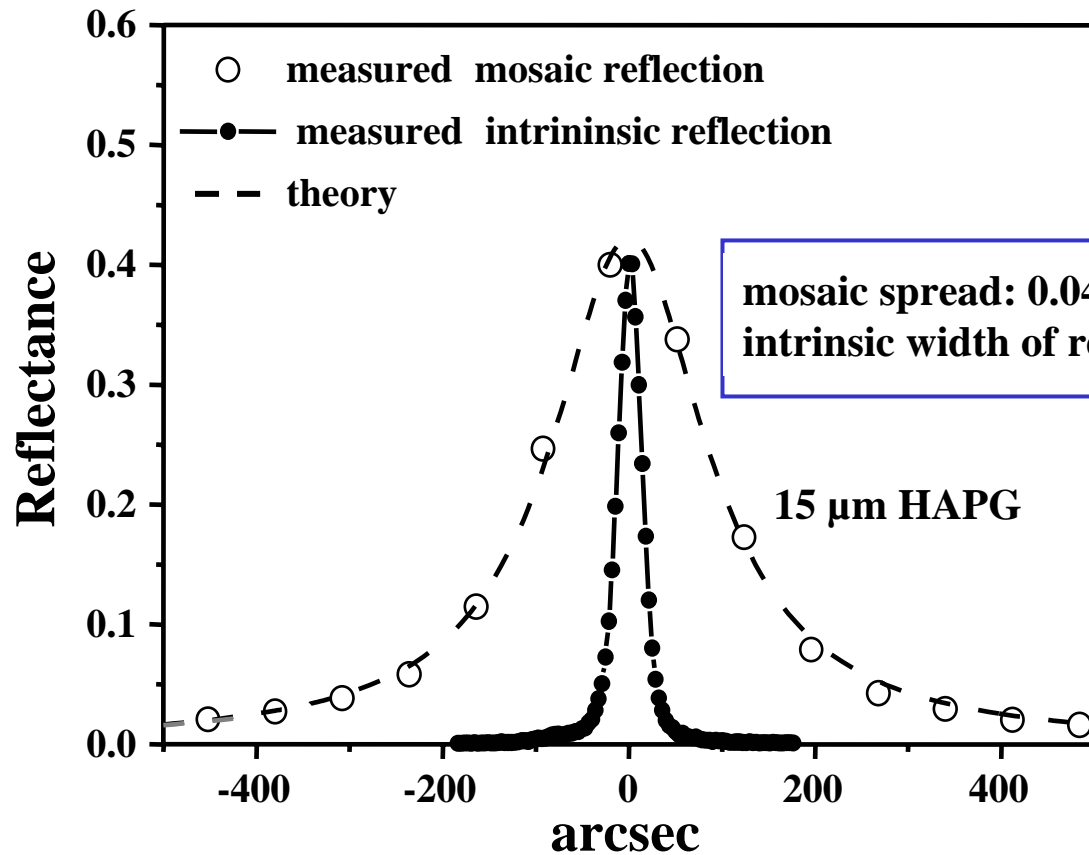
# Comparison of HOPG and HAPG

(004)-reflection in distance  $F = 400$  mm



# Rocking curve measurements

## Rocking curve measurement in (002)-reflection



# Bending PG crystals

- thin foils, which can be bent easily => **arbitrary geometry**



Cylindrical PG

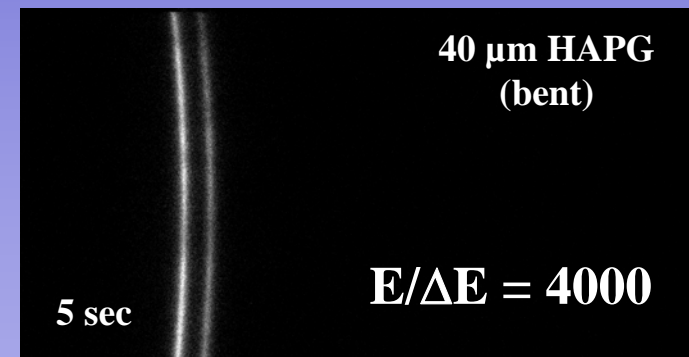
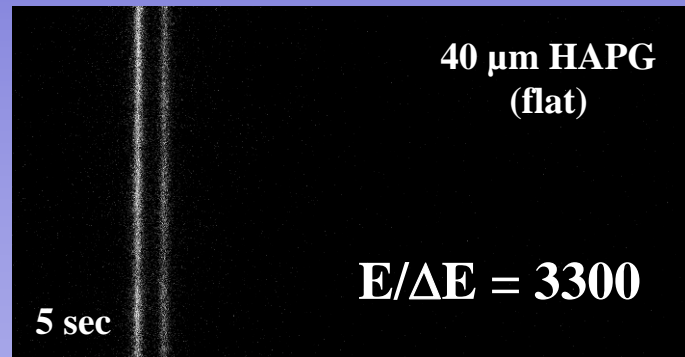
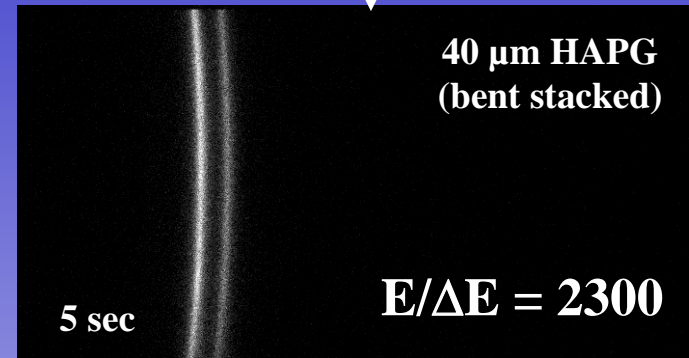
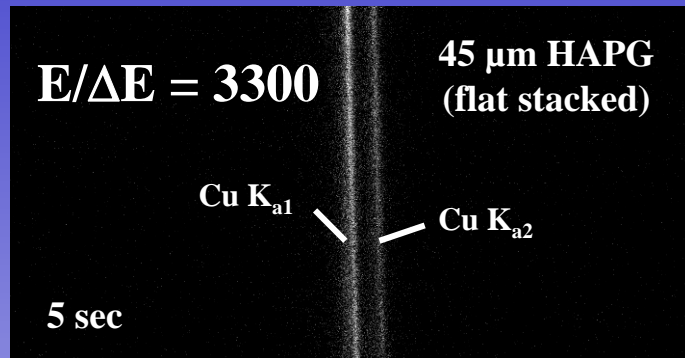


ellipsoidal PG

? Which spectral resolution can be obtained with bent PG's?

# Bent versus flat HAPG

(004) - reflection in distance  $F = 400$  mm,  $r = 150$  mm



# Properties of Pyrolytic Graphite

- **Thermal properties are promising !**
- **High integral reflectivity (between 2 keV up several 10 keV)**
- **Broad band reflection**
- **High energy resolution can be obtained for thin PG films**
- **No decrease in energy resolution for bent single sheets of HAPG was found**

# Conclusion

**„High energy resolution“ and high integral reflectivity with  
Highly Annealed Pyrolytic Graphite (HAPG) crystals  
even in bent geometry**

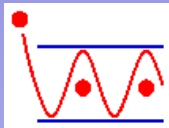
## Applications

**„High energy resolution“  
single shot spectroscopy**



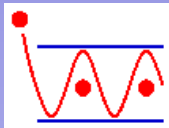


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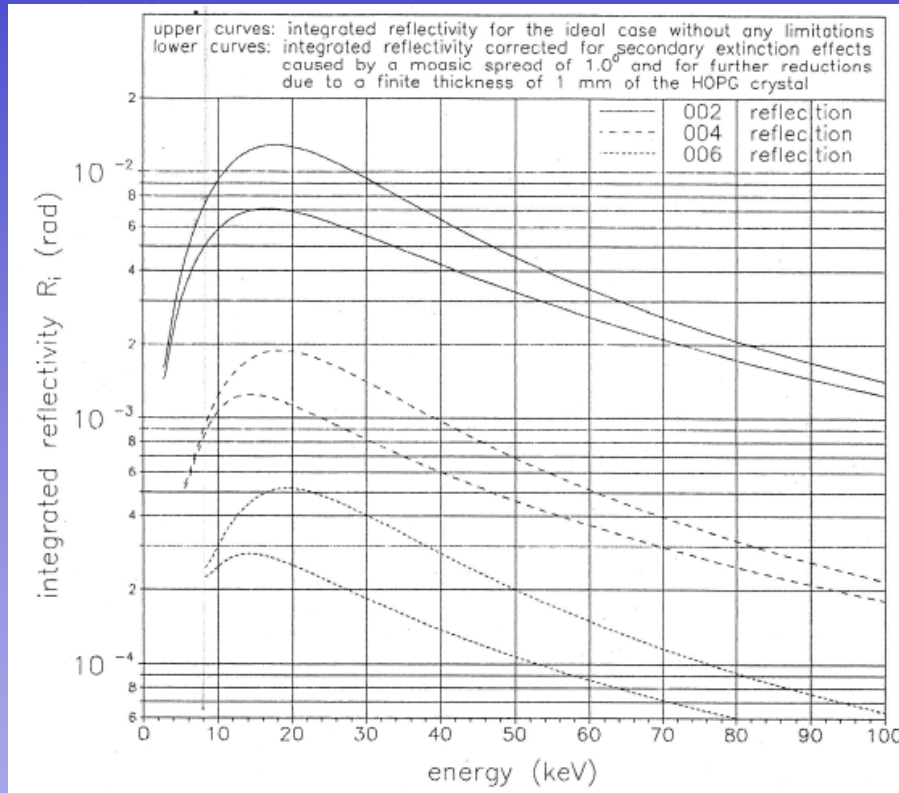




Thank You



# Integral reflectivity



(B. Beckhoff et al, SPIE 1996)

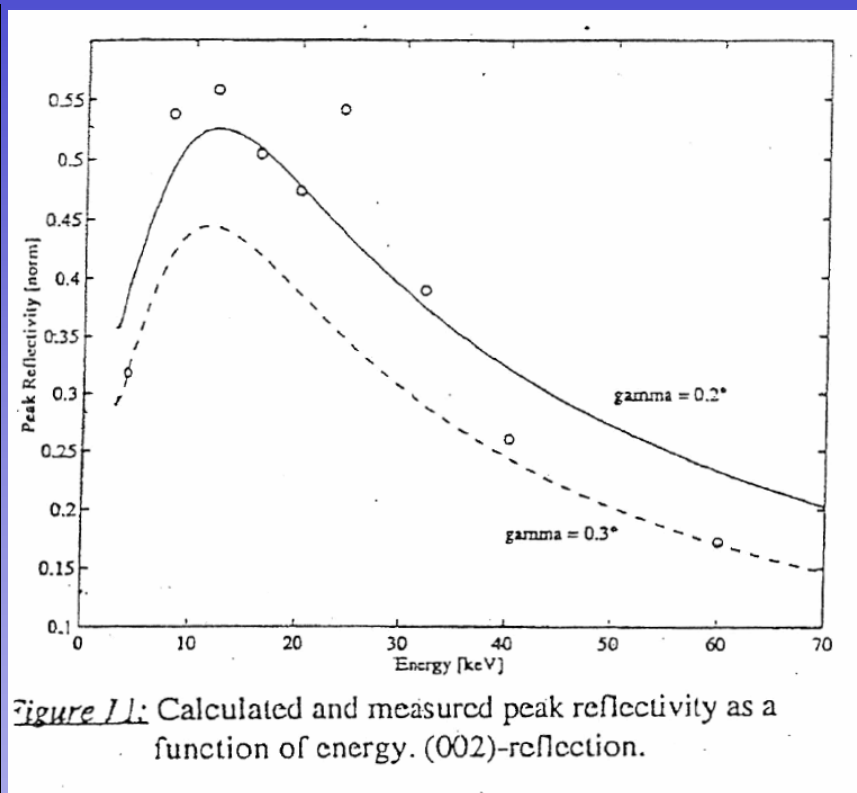
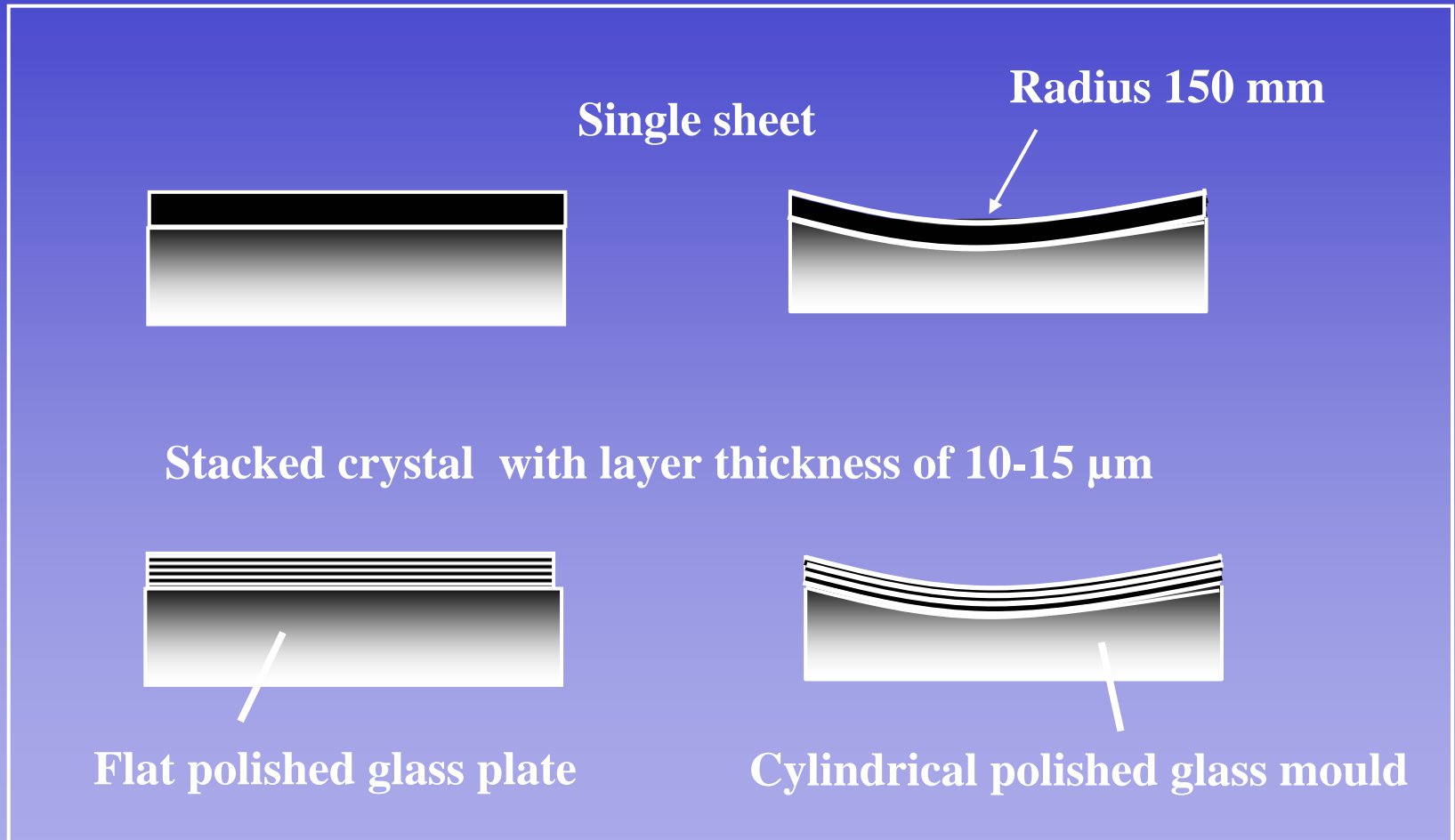


Figure 11: Calculated and measured peak reflectivity as a function of energy. (002)-reflection.

(A. Freund et al, SPIE 1996)

# Sample preparation



# Energy resolution of thicker bent HAPG

distance  $F = 400$  mm in (004)-reflection

