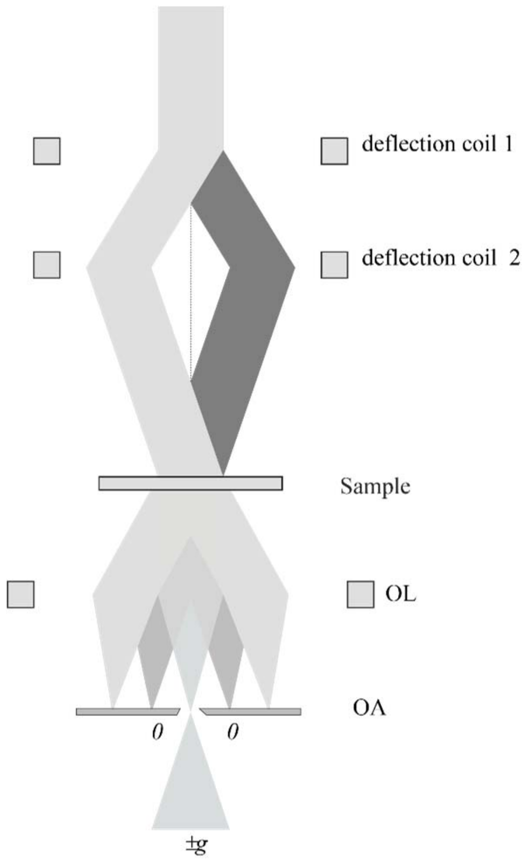
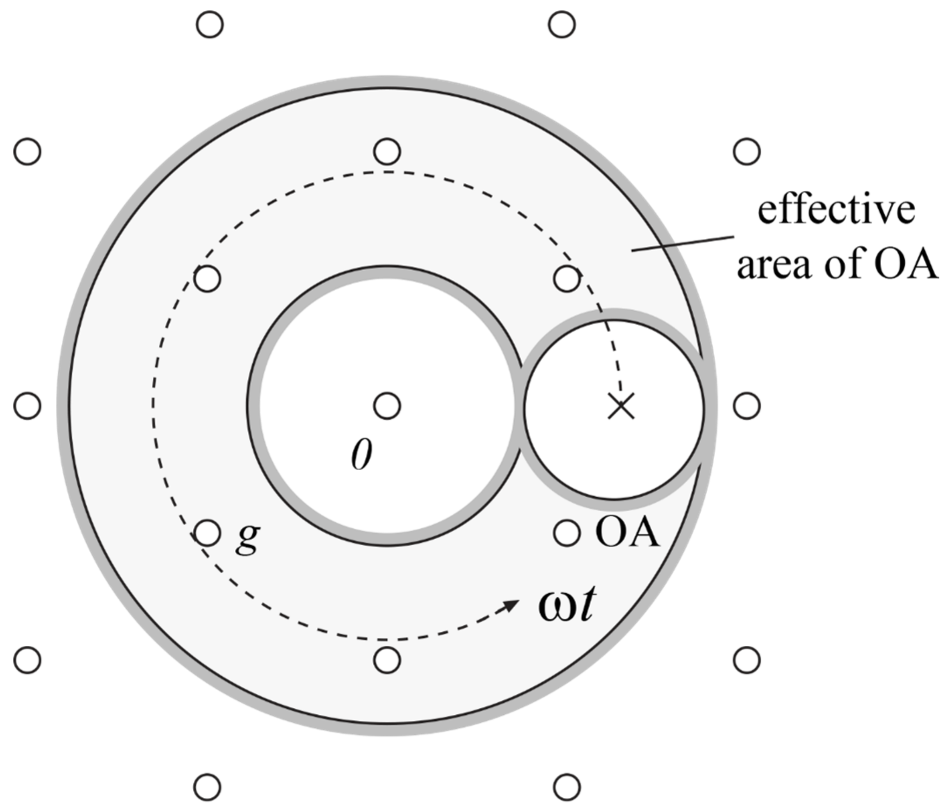
# Conical dark-field imaging

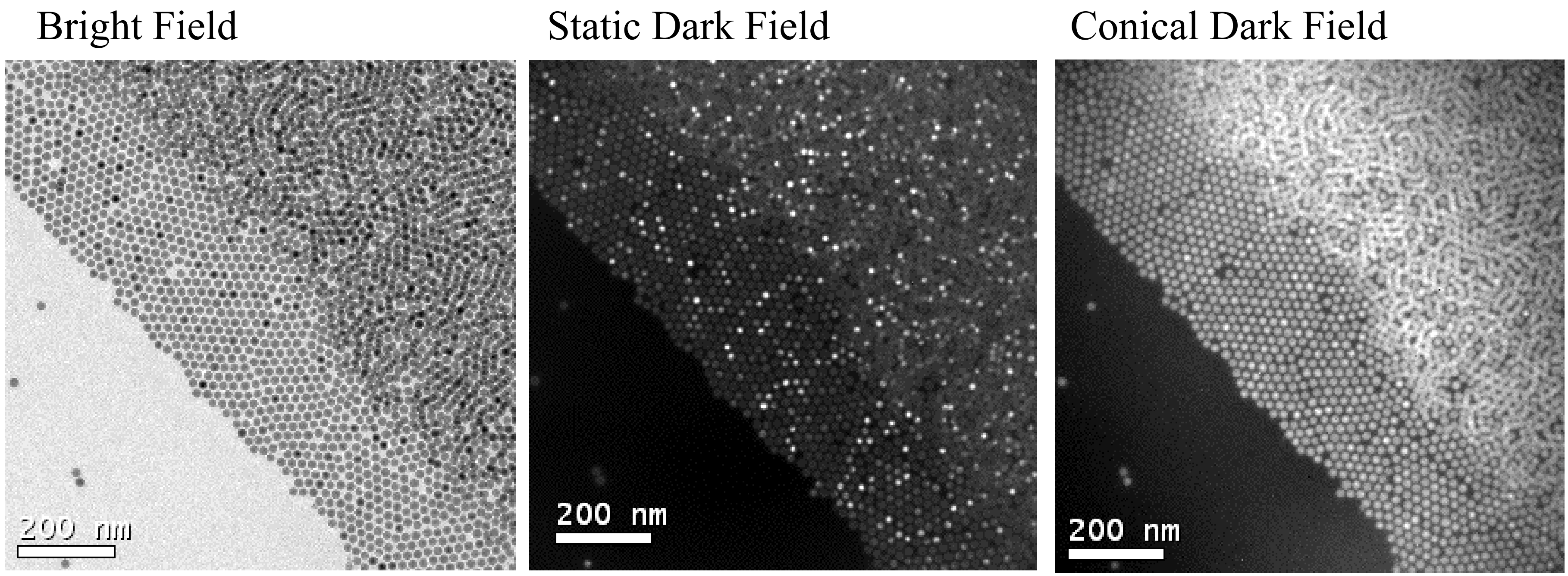
Direct beam is precessed around the optic axis
An entire diffraction ring can contribute
Centered dark-field conditions



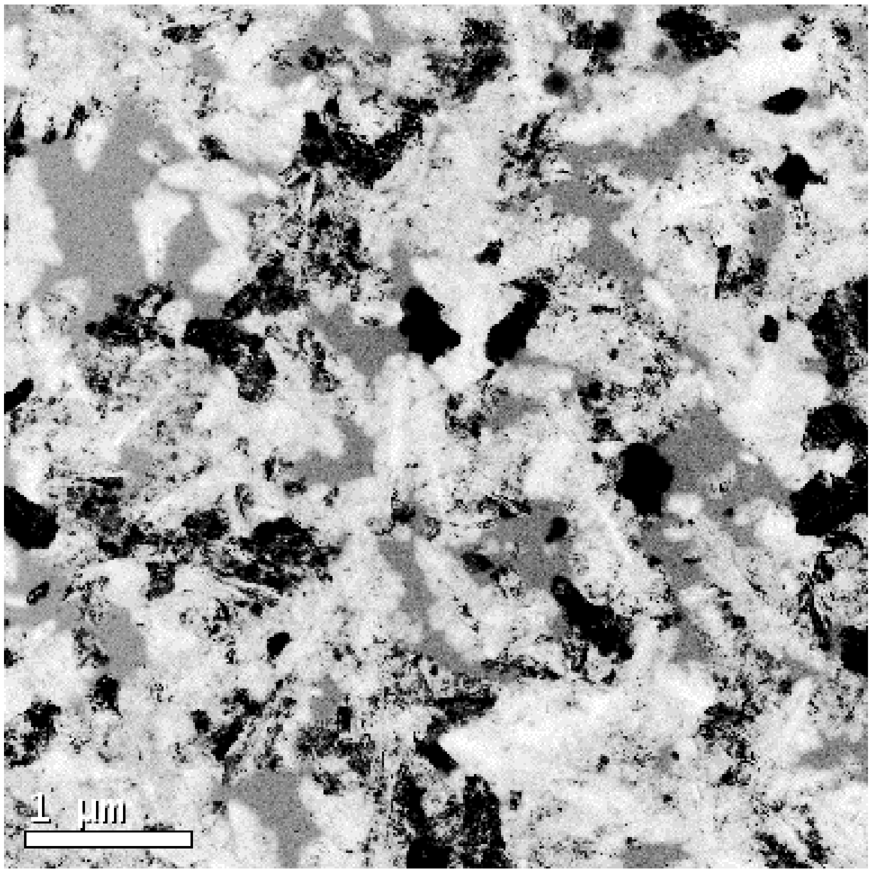

Useful for nanoparticles, and polycrystalline or amorphous materials

# Conical dark-field imaging of nanoparticles

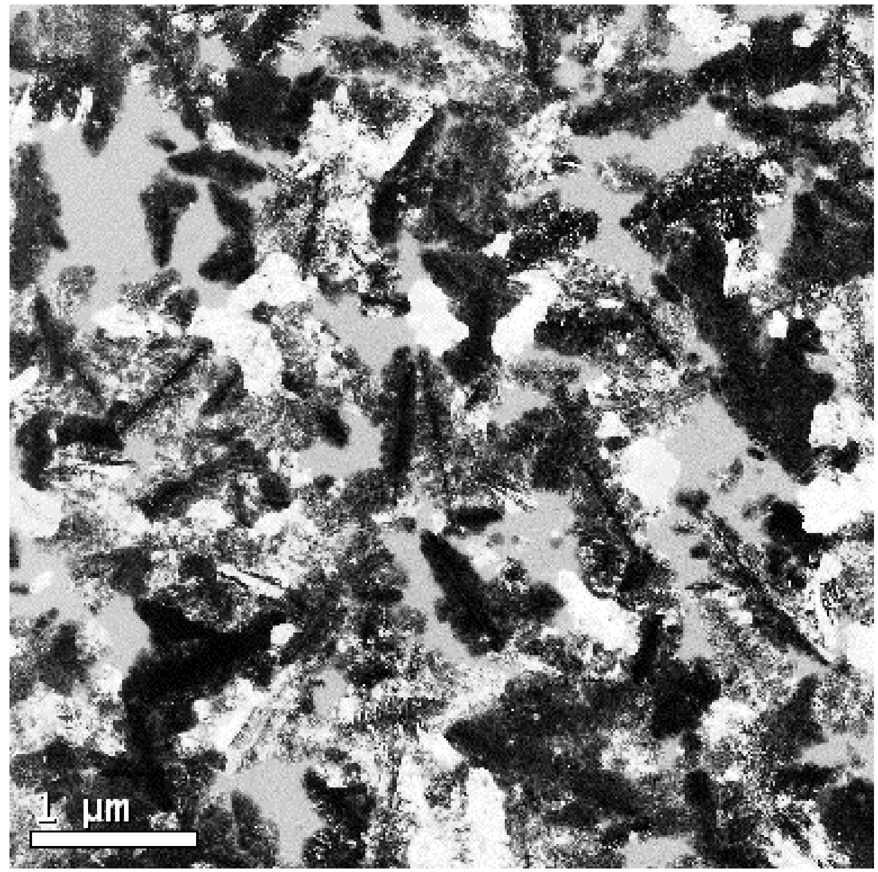


# Partially crystallized material

Bright Field




Conical Dark Field




a-Si:H

# Ewald sphere

Construction used to examine diffraction geometry

Radius = 1/λ

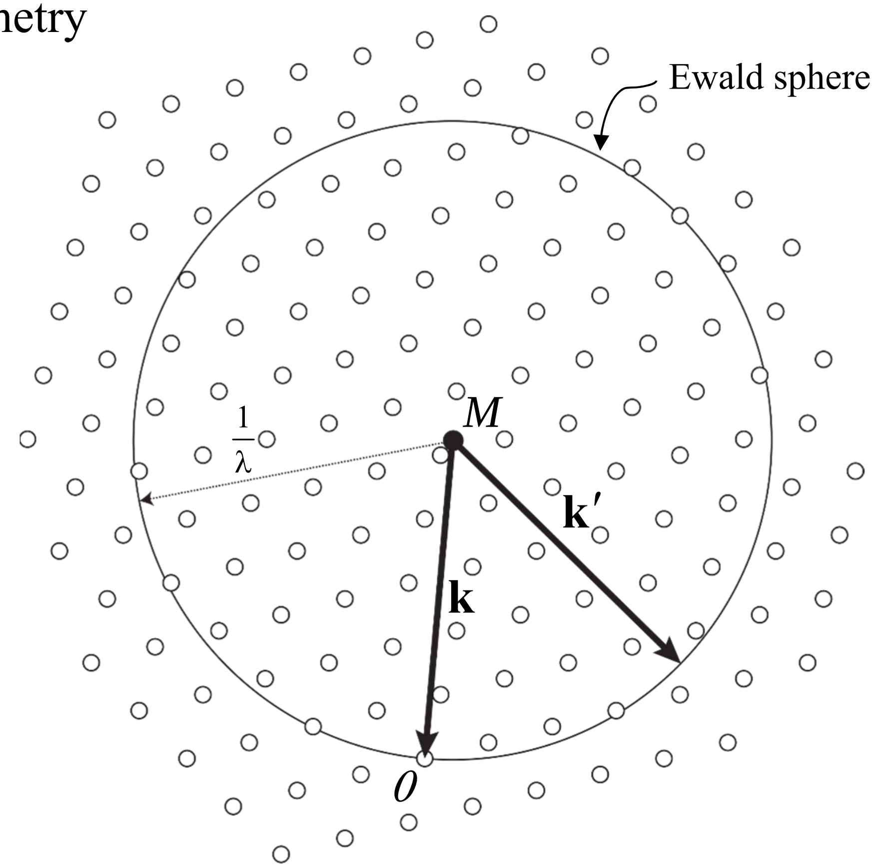
"Excitation Point" at the center

Reciprocal-space origin *0* always
on the sphere surface

Incident wave vector points from *M* to *0*.

Diffracted wave vectors terminate on surface

Proximity of reciprocal-lattice point to sphere indicates deviation from Bragg condition

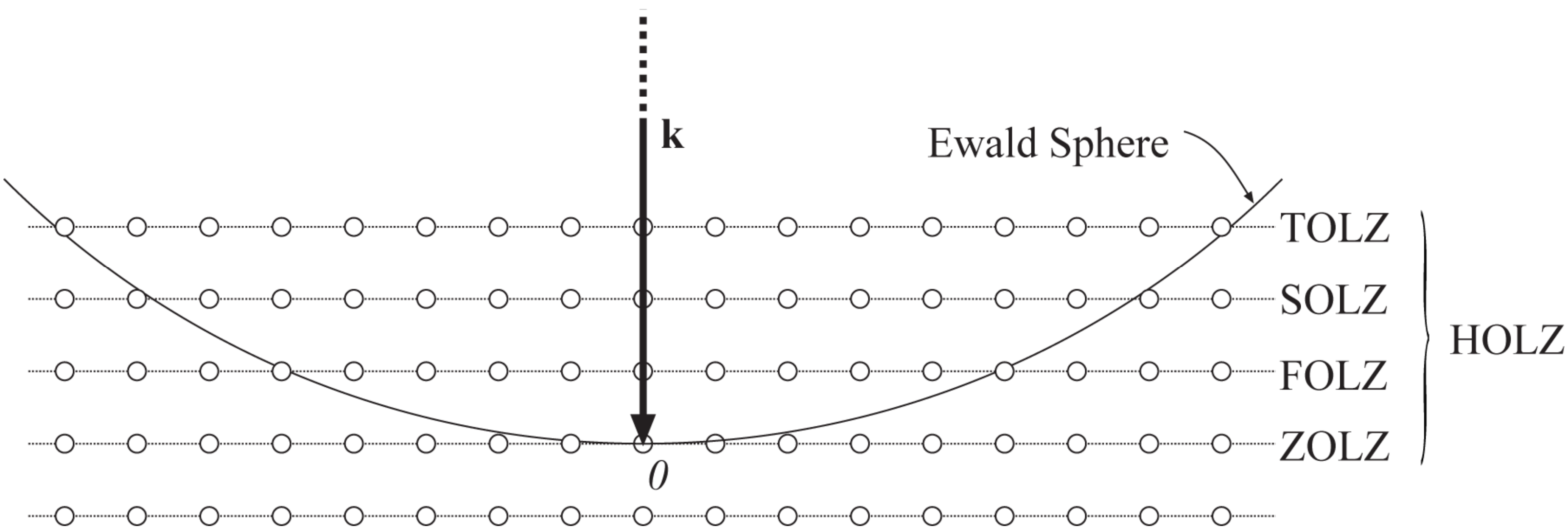


# Higher-order Laue zones

Intercepted by Ewald sphere at high angle

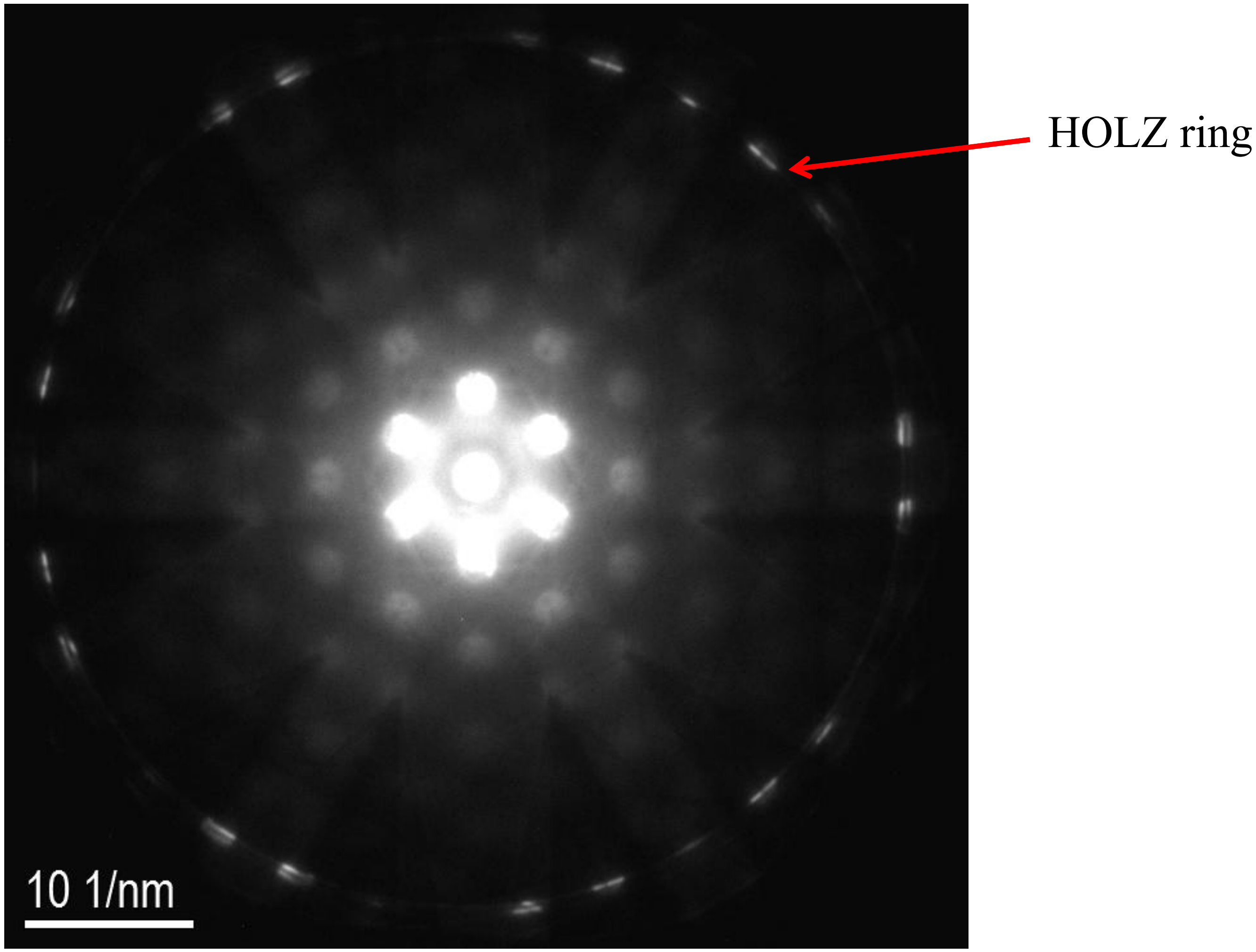
More pronounced at lower energy (greater curvature)

Reveal lattice constant parallel to beam

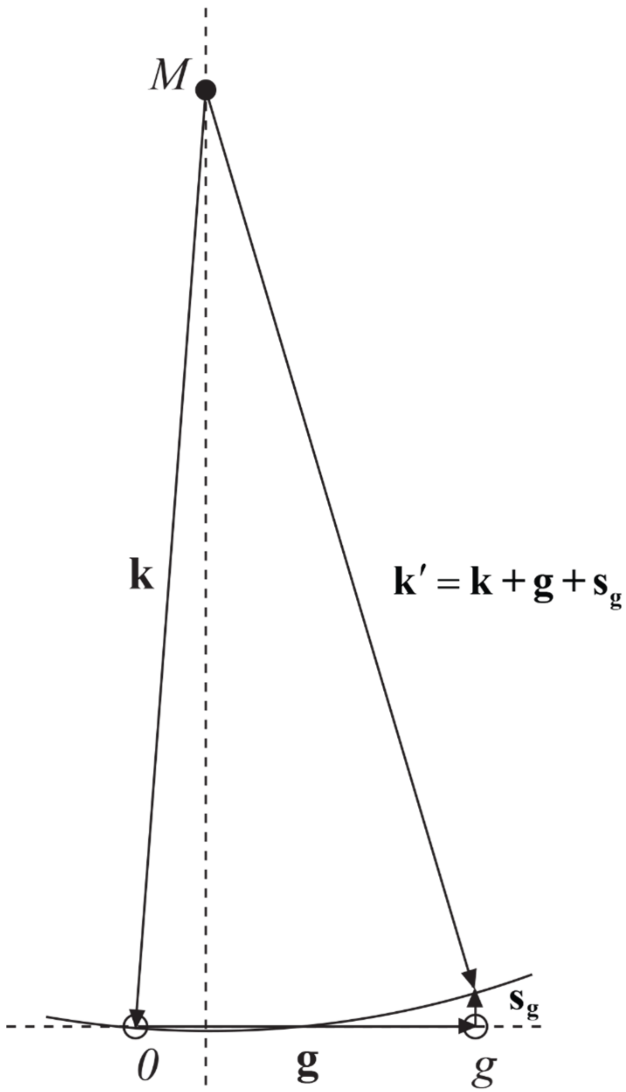



Tilting the beam excites a circular section of the ZOLZ

# Si <111>



# Excitation error (deviation parameter)




Vector pointing from $g$ to Ewald sphere

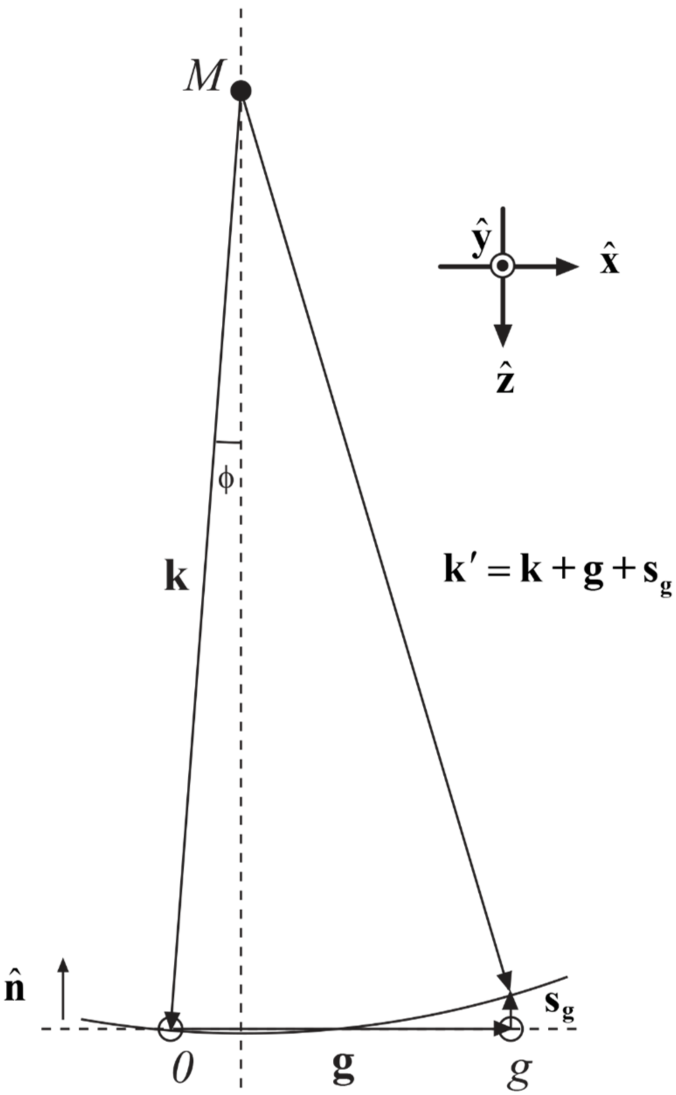
Direction not uniquely defined, *e.g.*:
1) perpendicular to **g**
2) parallel to **k**
3) normal to foil surface
4) shortest distance to sphere

Bragg Condition: $|\mathbf{s}_g|=0$

Unchanged if sample (or beam) rotated about **g**

$$k = |\mathbf{k}| = |\mathbf{k} + \mathbf{g} + \mathbf{s}_g|$$

# Evaluating excitation error




Tilted beam w.r.t. foil normal

$$\mathbf{k} = k \cdot \left(-\sin\phi\,\hat{\mathbf{x}} + \cos\phi\,\hat{\mathbf{z}}\right)$$

Let's say: $\mathbf{g} = g\hat{\mathbf{x}}$ $\qquad$ $\mathbf{s_g} = s_\mathbf{g}\hat{\mathbf{z}}$

By convention, $s_\mathbf{g}<0$ if $g$ is outside the sphere.

$$k = \left|\mathbf{k_g}\right| = \left|\mathbf{k} + \mathbf{g} + \mathbf{s_g}\right|$$

$$\cancel{k^2} = \cancel{k^2} + 2\mathbf{k}\cdot\left(\mathbf{g} + \mathbf{s_g}\right) + \left(\mathbf{g} + \mathbf{s_g}\right)^2$$

$$s_g = -k\cdot\cos\phi\left[1 \pm \sqrt{1 + 2\left(\frac{g}{k}\right)\frac{\tan\phi}{\cos\phi} - \left(\frac{g}{k\cos\phi}\right)^2}\,\right]$$

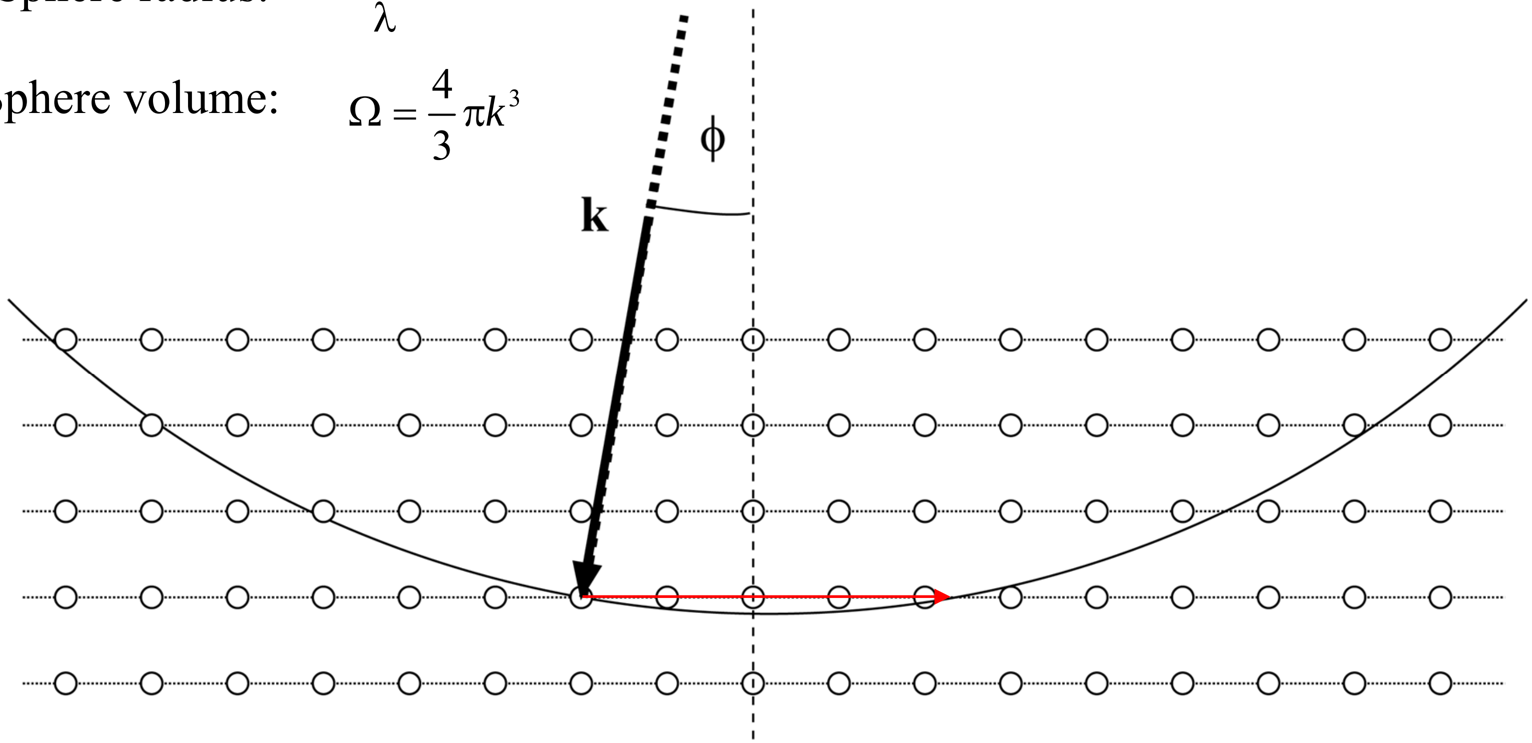
pick (-)

$$g \ll k \quad \Rightarrow \quad s_g \approx g\cdot\tan\phi - \frac{g^2}{2k\cos\phi}$$

# Sphere volume and ZOLZ intersection

Sphere radius: $k = \dfrac{1}{\lambda}$

Sphere volume: $\Omega = \dfrac{4}{3}\pi k^3$




Intersection of sphere with ZOLZ:

$$s_g = 0 \Rightarrow 0 = g \cdot \tan\phi - \frac{g^2}{2k\cos\phi}$$

$$g = 2k \cdot \sin\phi$$

Diameter of intersection:

$$g \approx 2k\phi = \frac{2\phi}{\lambda}$$