FAST INTERACTIONS WITH SURFACES

COHERENCE & DECOHERENCE

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OUTLINE

FAST ATOM DIFFRACTION

- General features
- Semi-quantum method

- Coherent lighting:
  van Cittert-Zernike theorem

- *Transversal* coherence effects:
  slit width, energy, and crystal spotting

- *Axial* coherence effects:
  normal momentum spread

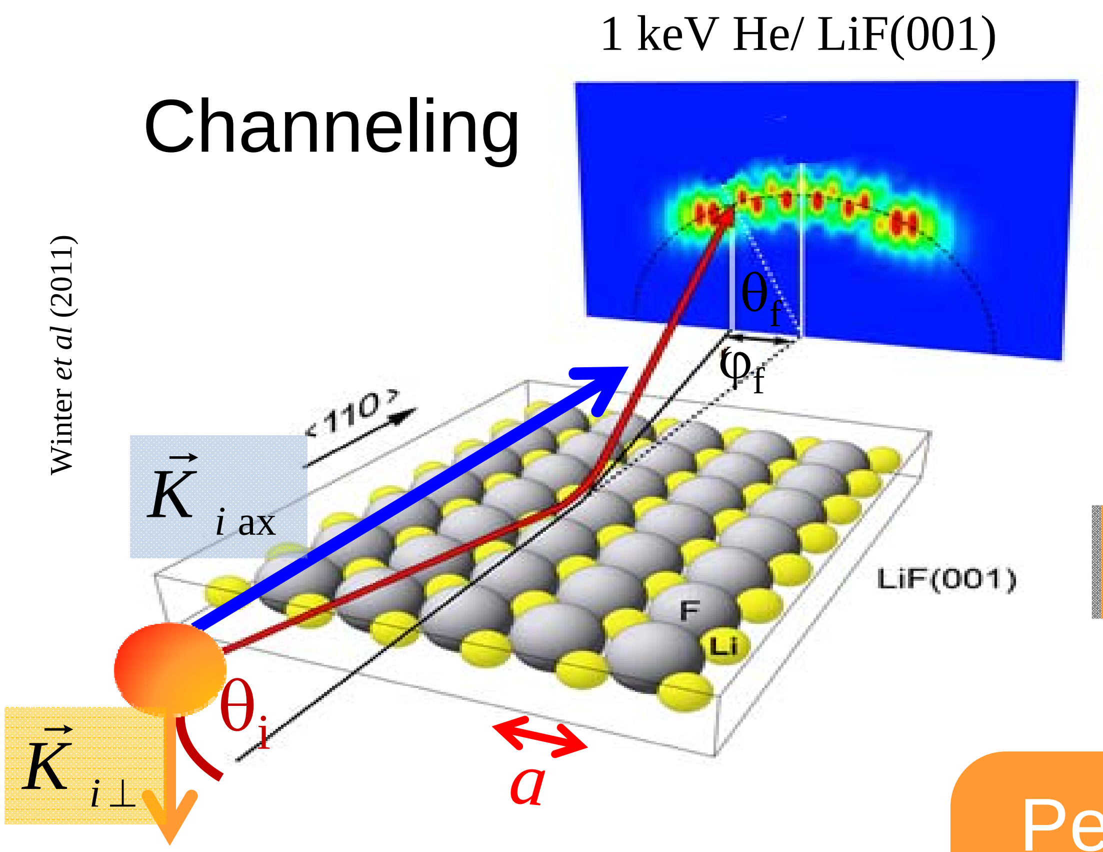
- Decoherent contributions:
  influence of the temperature

OUTLINE

- SURFACE ANALYSIS with:
  fast atoms and laser pulses

- **FINAL REMARKS**

FAST ATOM DIFRACTION



$$\lambda = \frac{2\pi}{K_i} \cong 0.008\ a.u. \ll a \cong 4.a.u.$$

DECOUPLING

Specular reflection

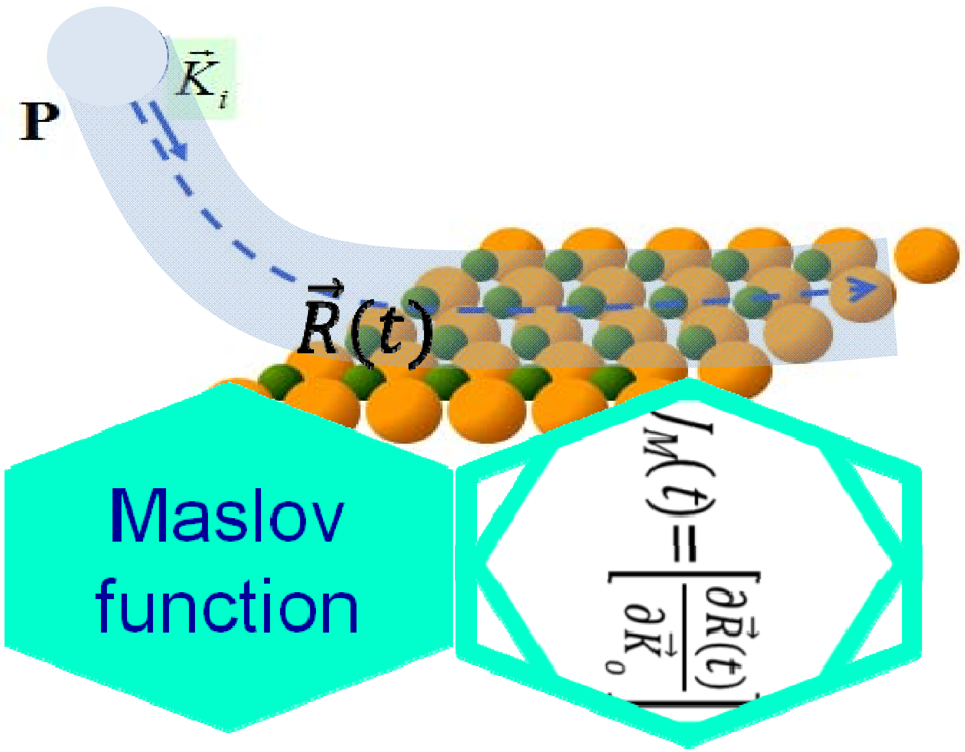
$$\theta_f \approx \theta_i$$

transverse | *axial*

Perpendicular motion

$$\lambda_\perp = \frac{2\pi}{K_{i\perp}} \cong 0.4\, a.u.$$

Surface Initial Value Representation (SIVR)



Based on the IVR method by Miller (1970)

Feynman path integral formulation

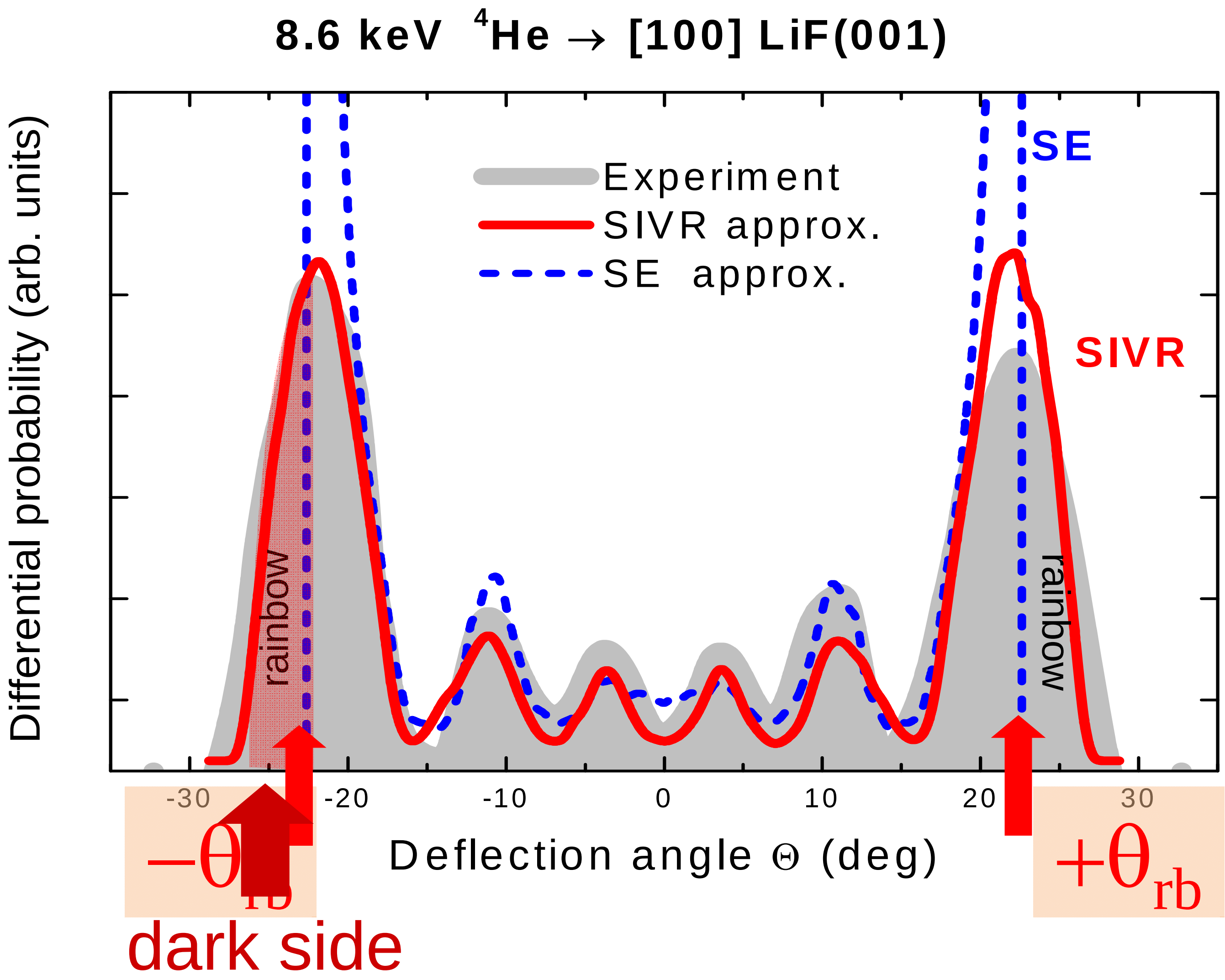
Semi-quantum method
without the stationary phase approx.

QUANTUM INTERFERENCE OF TRANSITION AMPLITUDES

Classically forbidden transitions

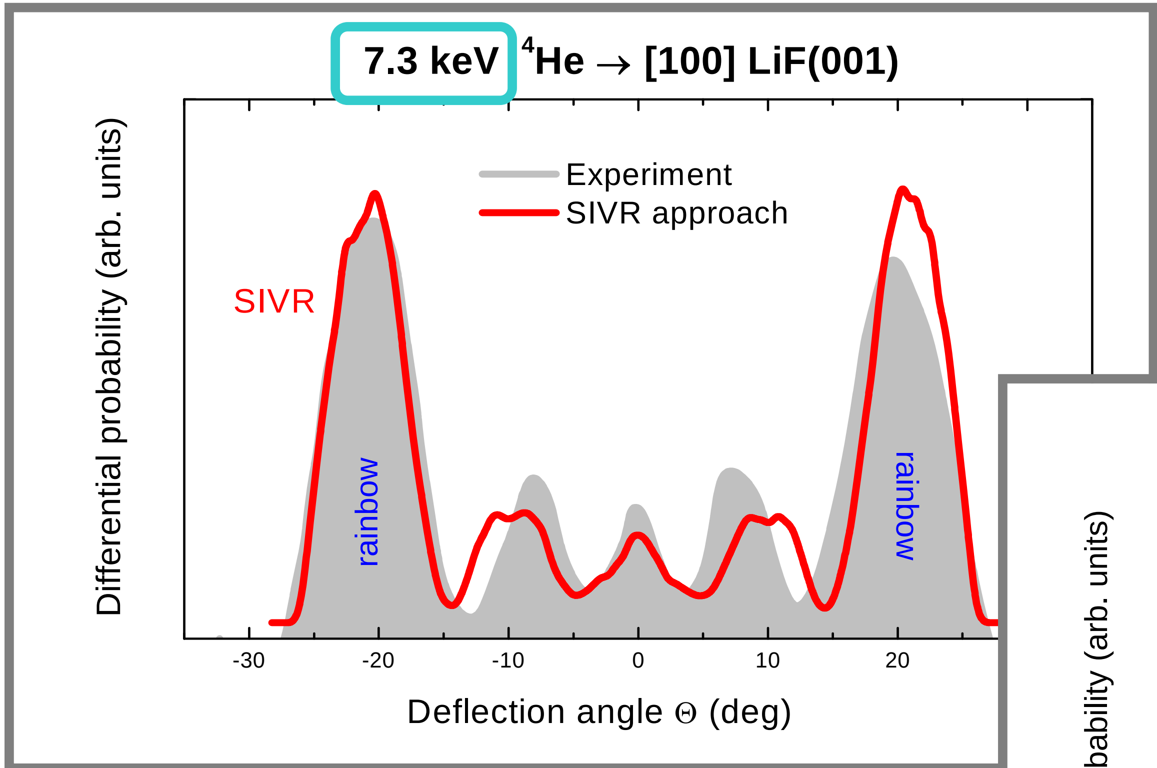
Gravielle *et al.*, Phys. Rev. A **90** (2014) 052718

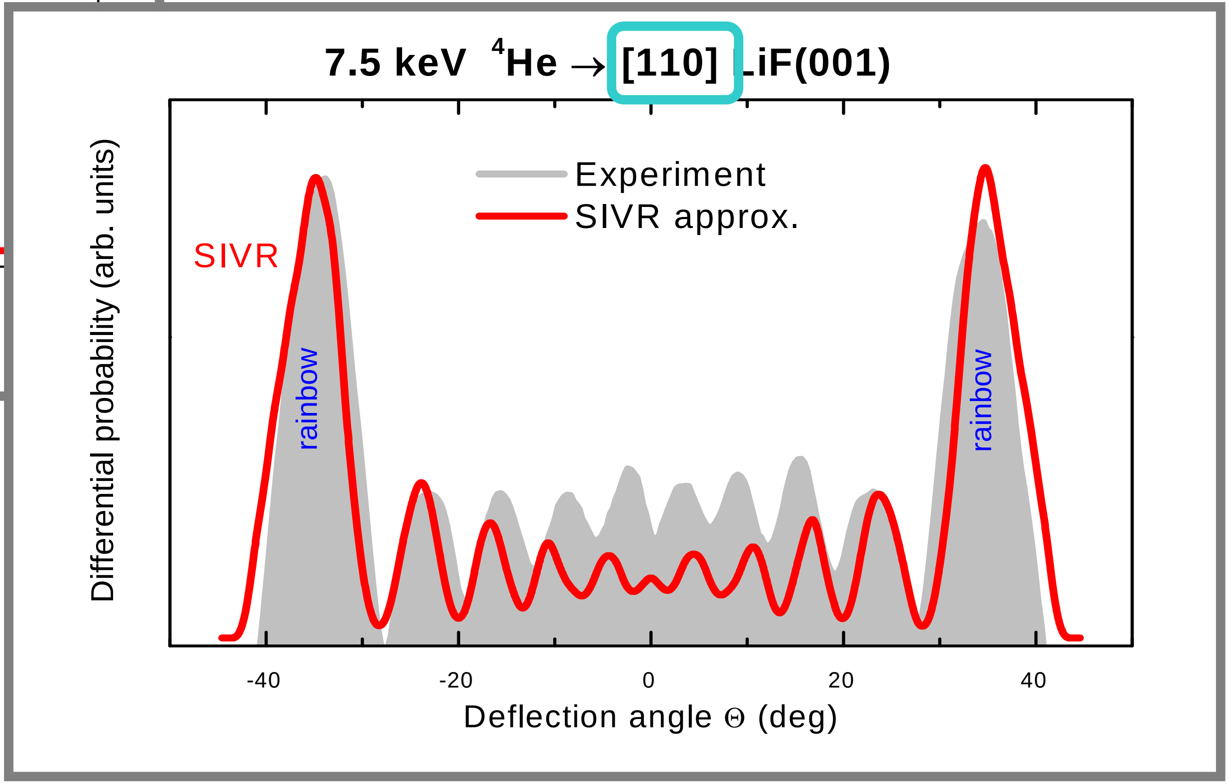
Surface Initial Value Representation (SIVR)



Gravielle *et al.*, Phys. Rev. A **90** (2014) 052718

Surface Initial Value Representation (SIVR)

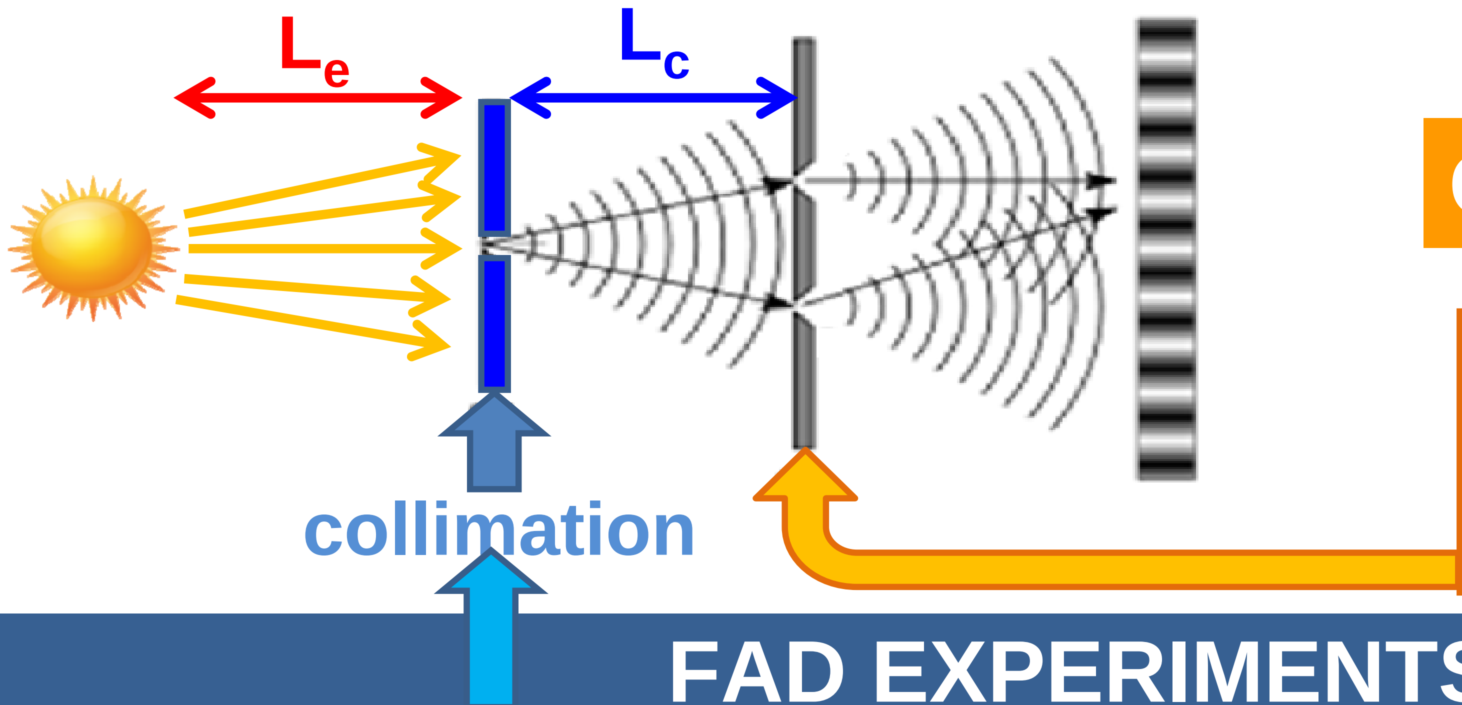




Gravielle *et al.*, Phys. Rev. A **90** (2014) 052718

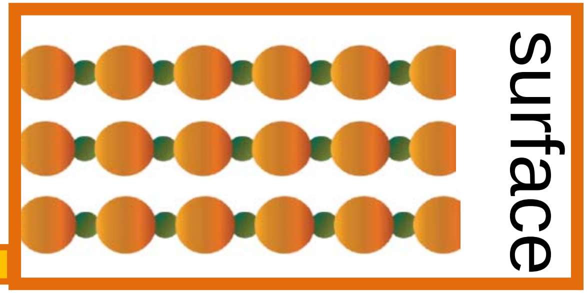
COHERENT LIGHTING

Atom interferometry



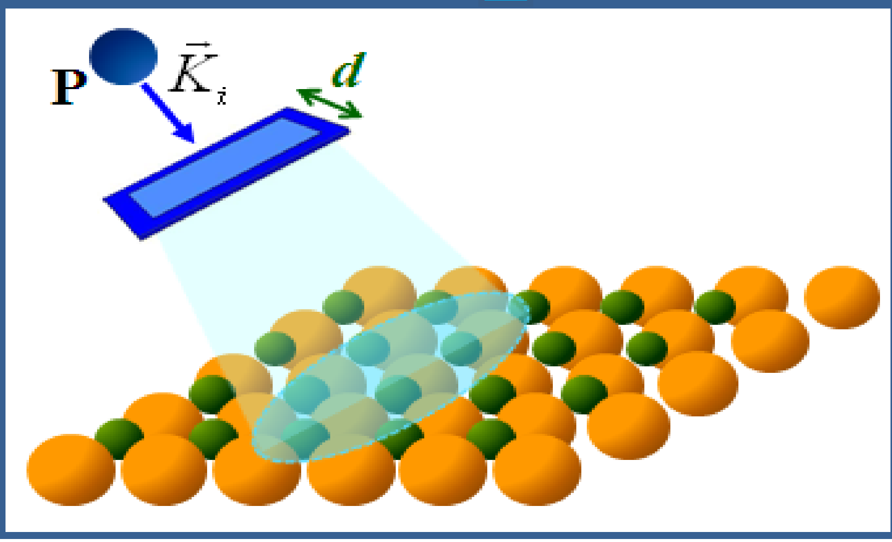
Needed:

COHERENCE



https://wikipedia.org

FAD EXPERIMENTS



1 keV He atoms: $\lambda \simeq 0.5$ pm

$L_e, L_c \leq \frac{d^2}{\lambda}$ → Near-field regime (Fresnel)

The van Cittert-Zernike theorem (1938)

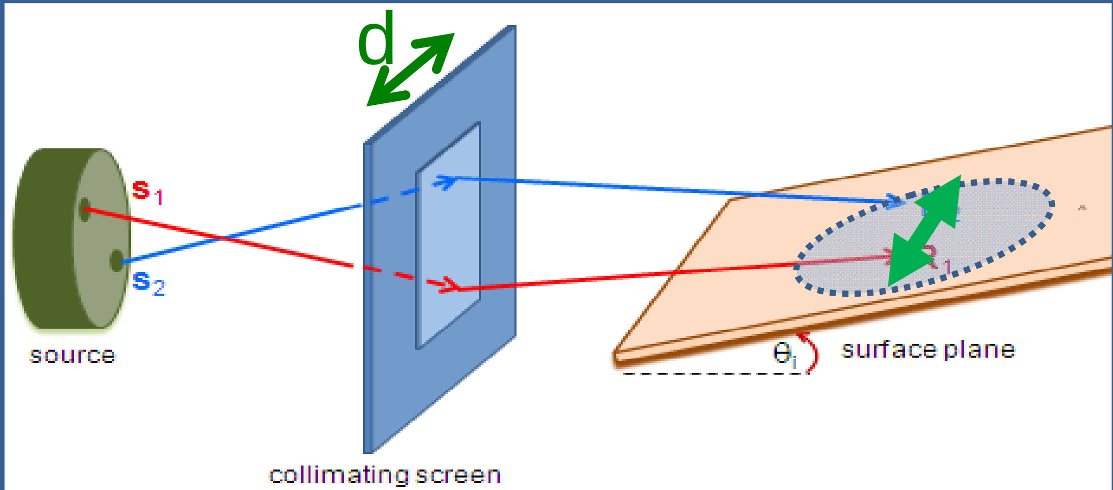
"The wavefront from an incoherent extended quasi-monochromatic source will appears mostly coherence at large distances"

Knox, Alonso and Wolf, Phys. Today **63**, 11 (2010)

coherent waves

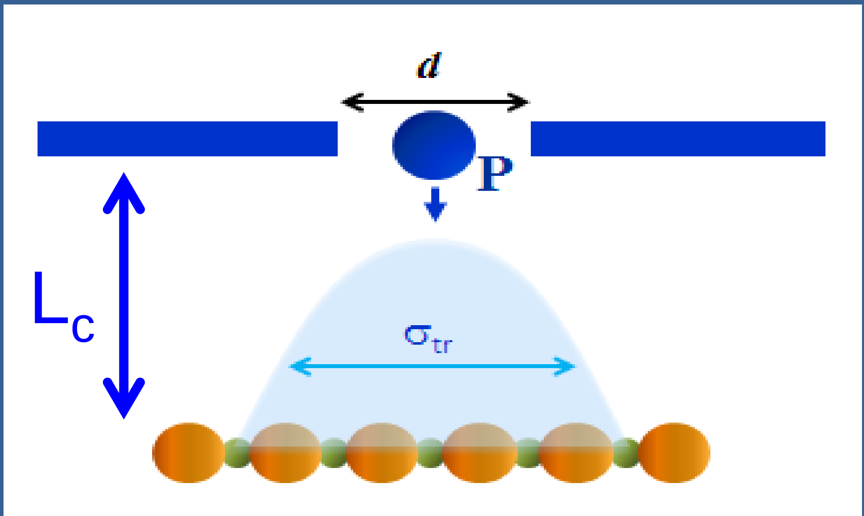
Degree of coherence: van Cittert-Zernike

Extended incoherent quasi-monochromatic source



Size of the wave packet:

Complex degree of coherence



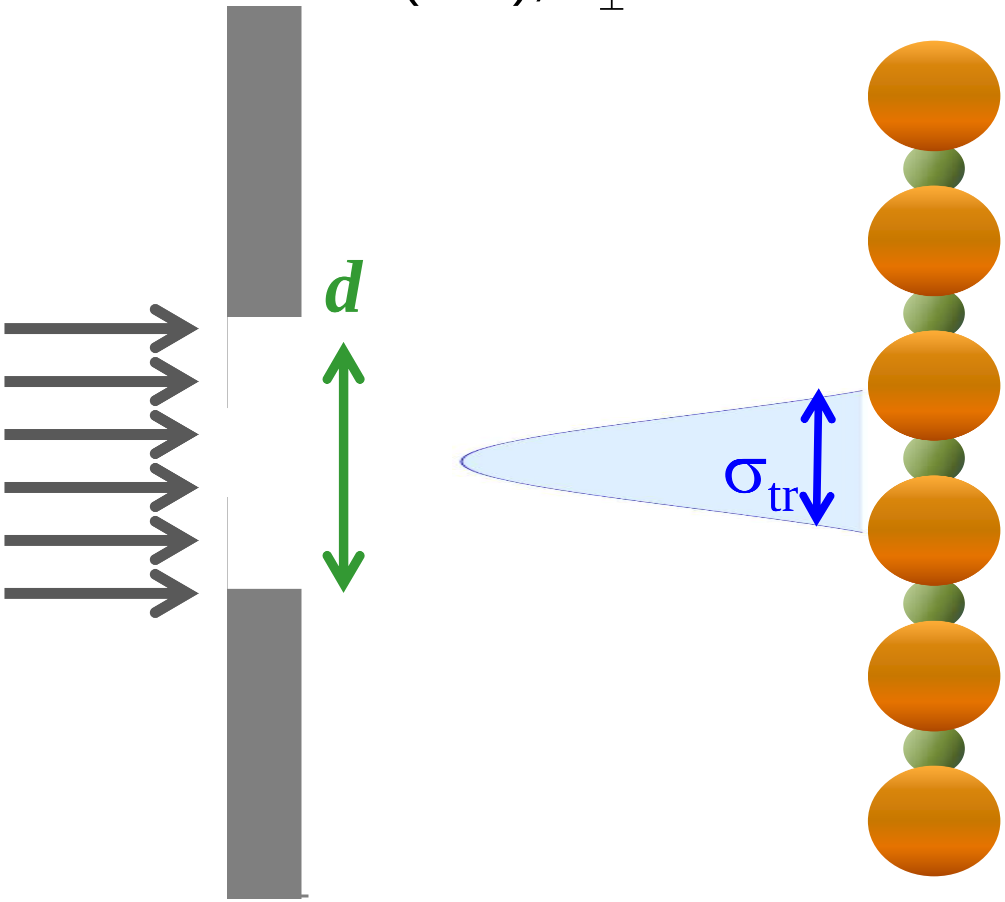
transversal coherence length

$$\sigma_{tr} = \frac{\lambda}{\sqrt{2}} \frac{L_c}{d}$$

Gravielle *et al.*, Phys. Rev. A **92** (2015) 062709

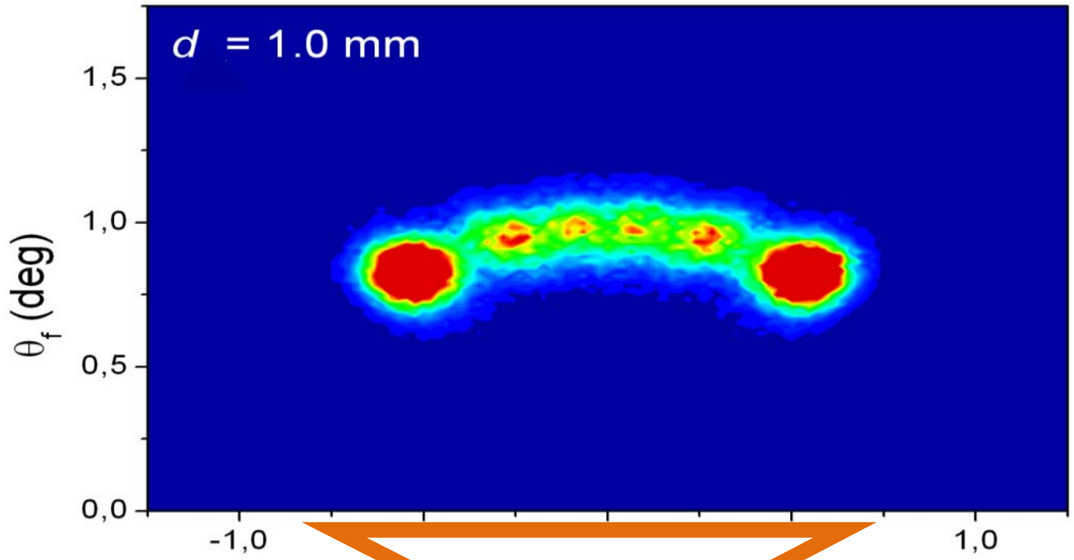
Transversal coherence: slit width

^{4}He →<110> LiF(001), $E_{\perp}$= 0.3 eV



surpernum. rainbows

unit-cell interference



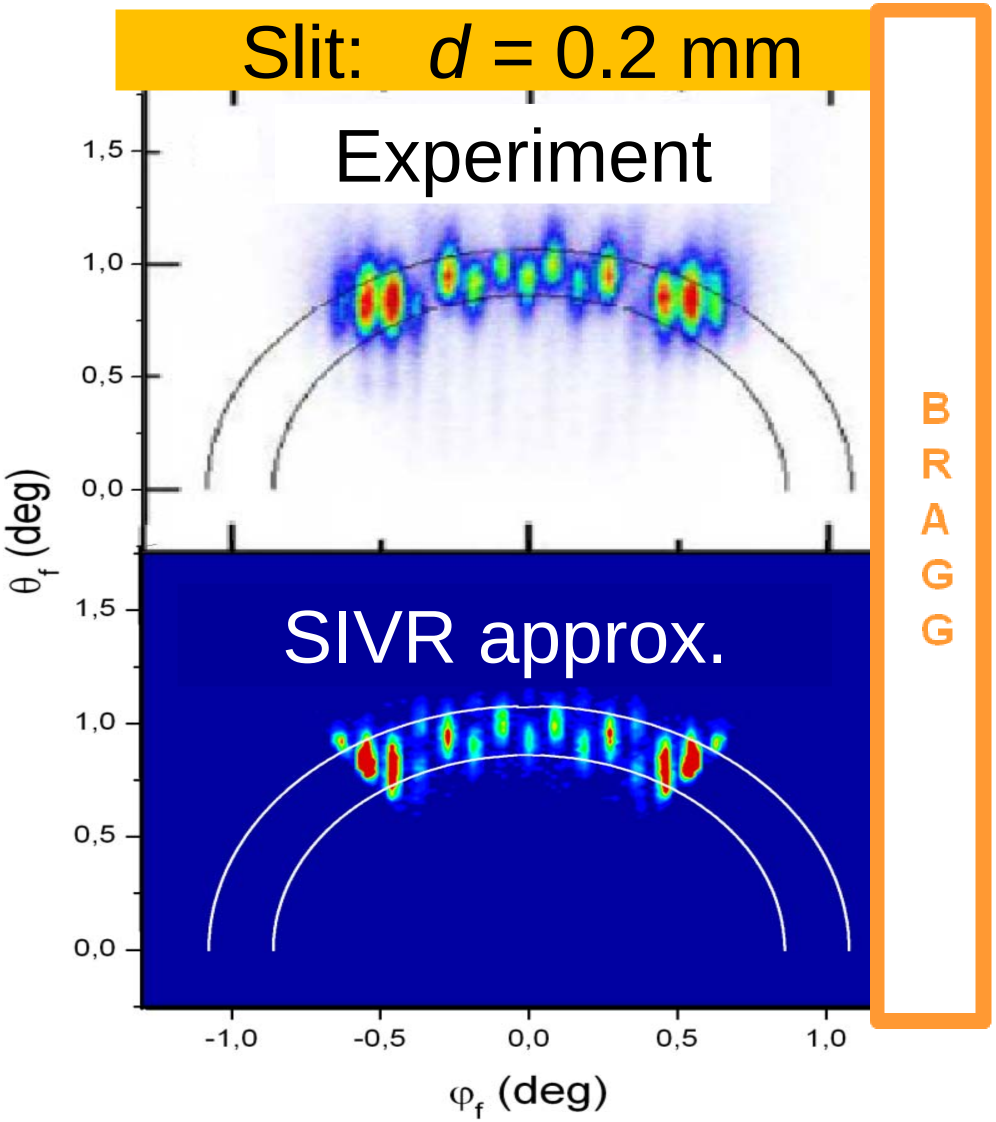
Corrugation of the potential

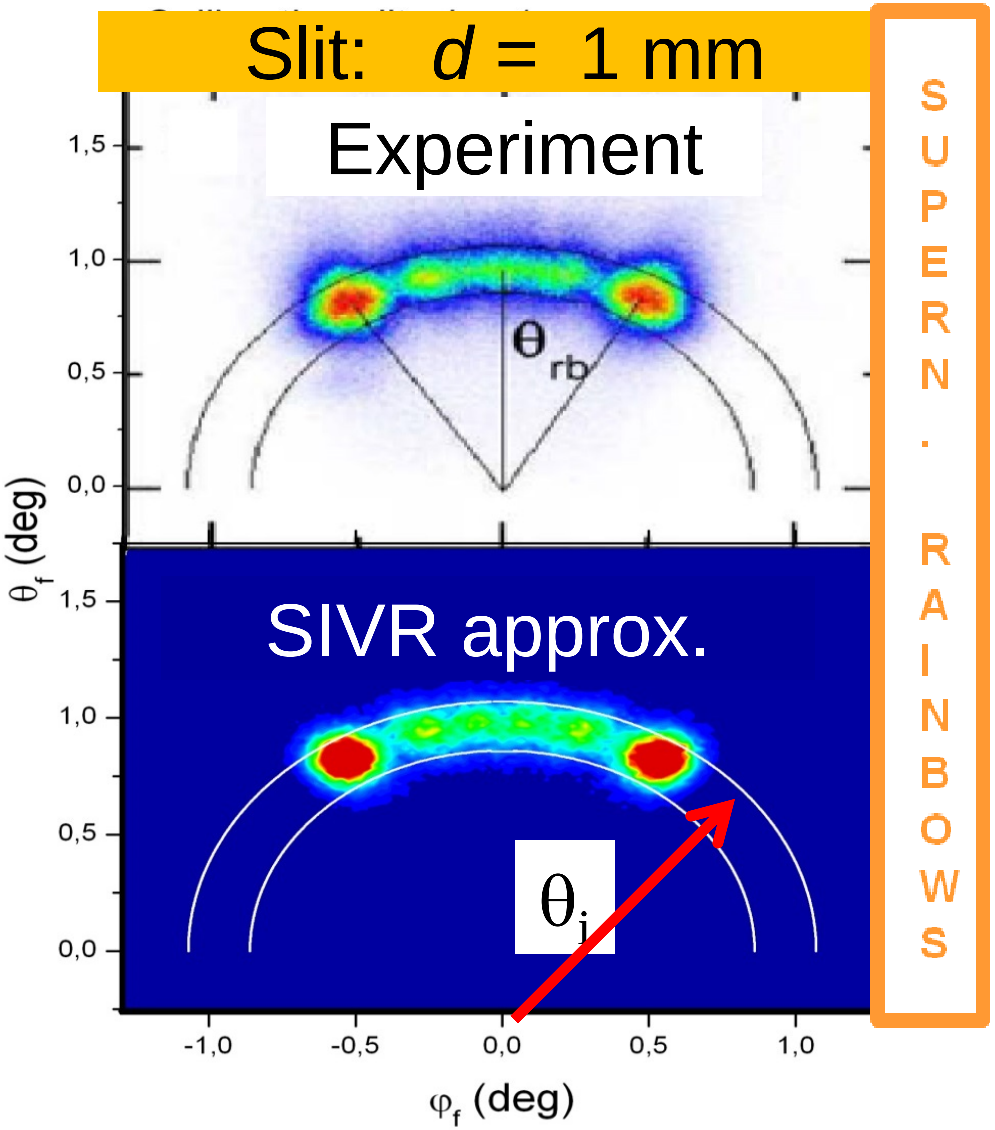
inter-cell interference

Gravielle *et al.*, Phys. Rev. A **92** (2015) 062709

Experimental confirmation

^{4}He →<110> LiF(001), $E_\perp$= 0.3 eV

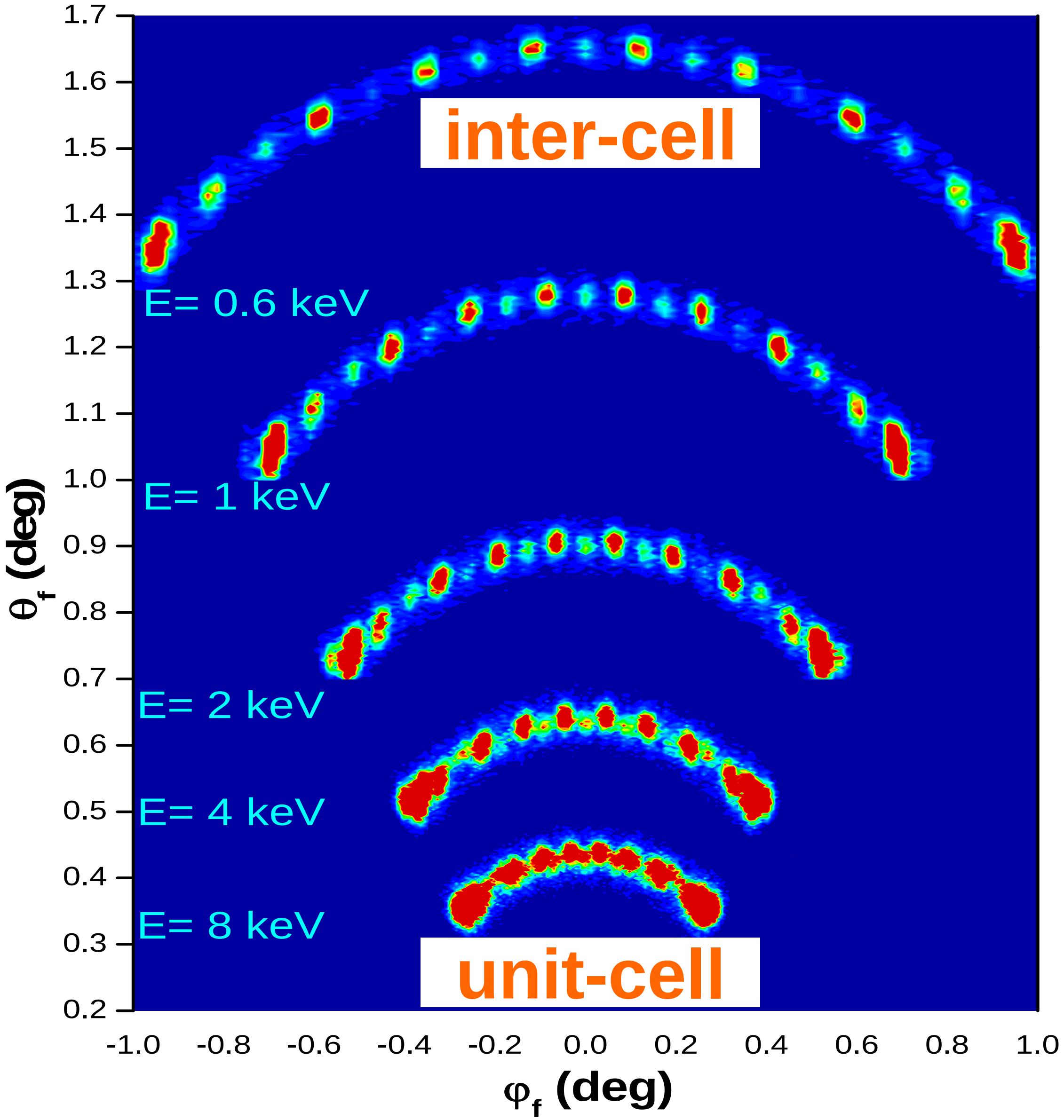




Expt. : Seifert *et al.* , Nucl. Instr. Meth. B **350** (2015) 99

SIVR:: Gravielle *et al.*, Phys. Rev. A **92** (2015) 062709

Transversal coherence: impact energy



$^4He \rightarrow$ <110> LiF(001) $E_\perp$= 0.5 eV

Fixed collimation: *d*= 0.2 mm

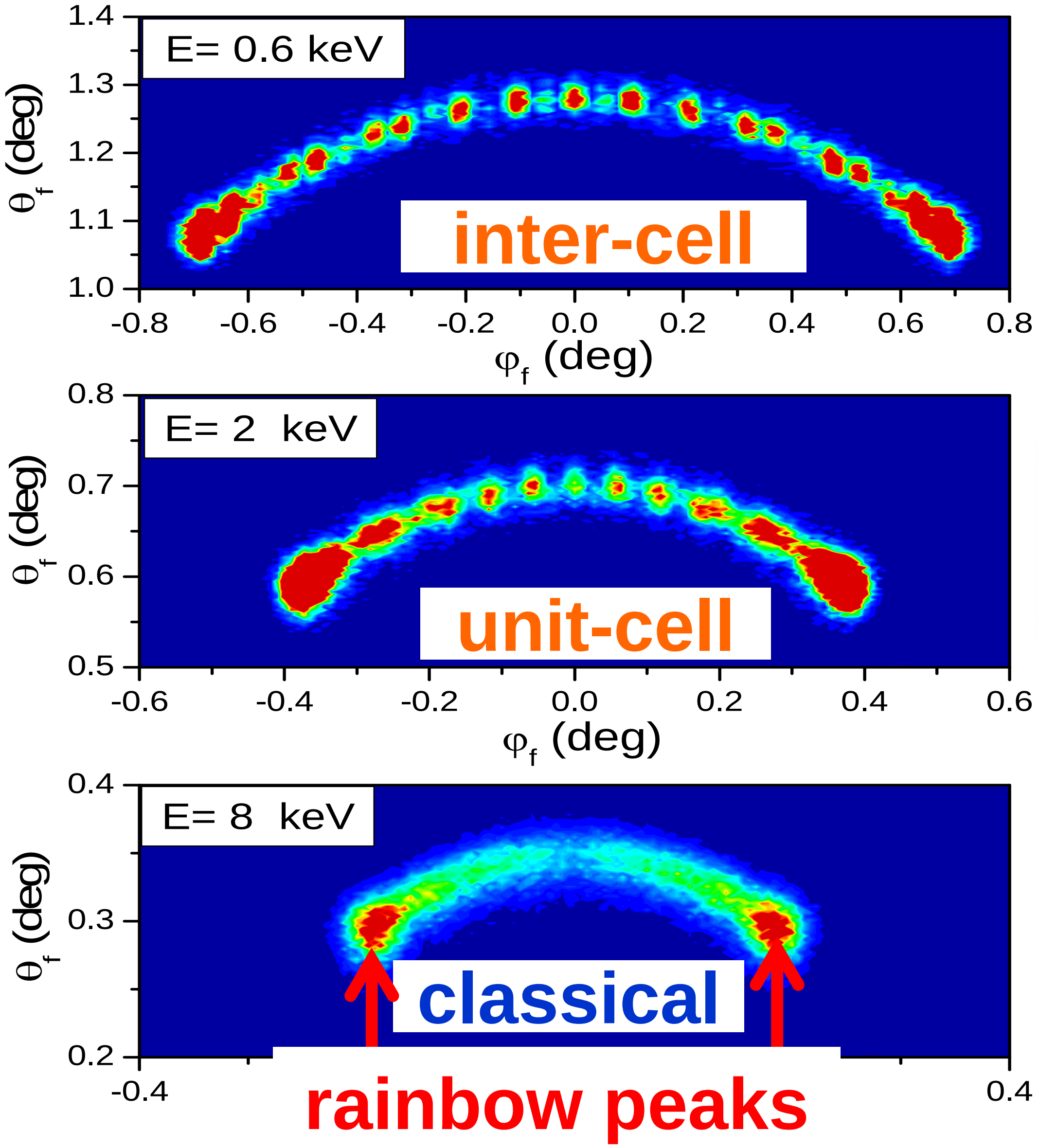
transversal coherence length

$$\sigma_{tr} = \frac{\lambda}{\sqrt{2}} \frac{L_c}{d} \propto \frac{1}{\sqrt{E}}$$

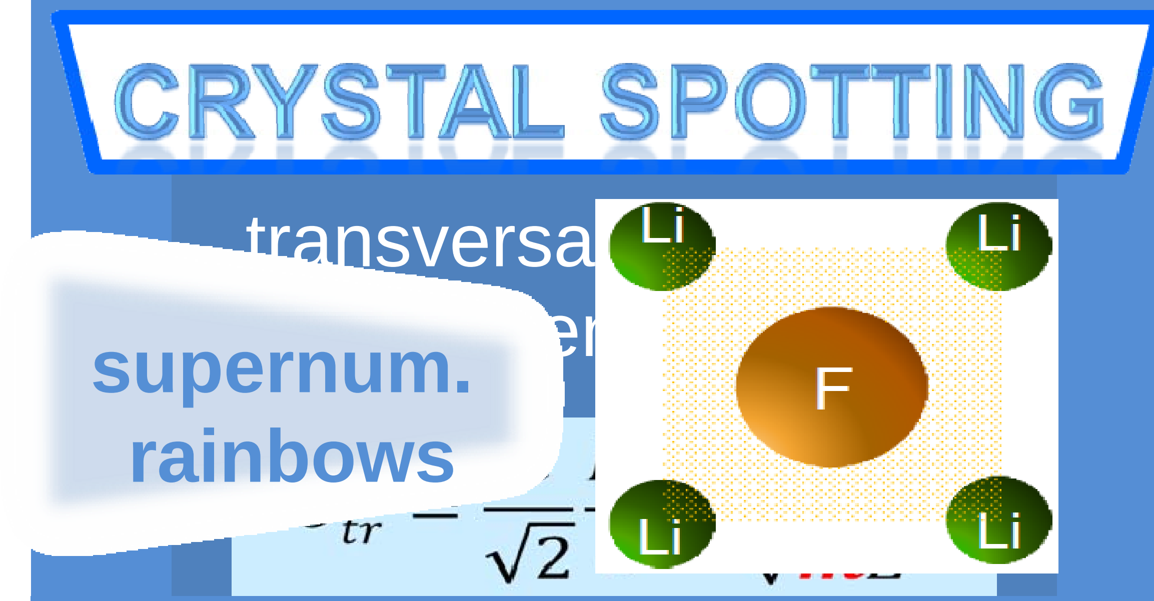
Independent of:

- inelastic contributions
- detector resolution

Transversal coherence: atomic mass

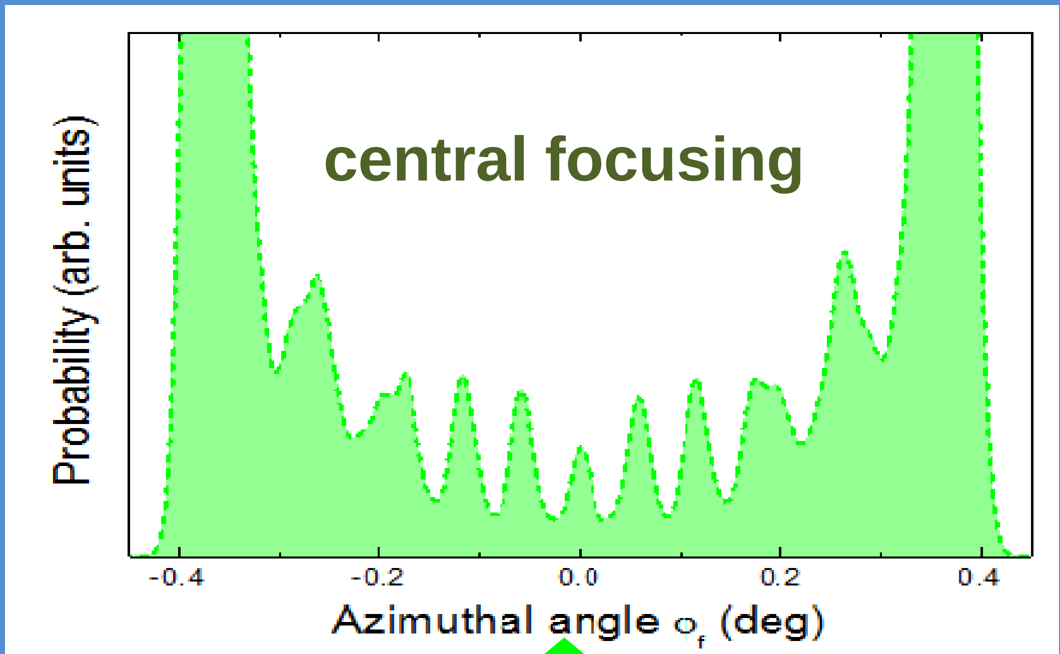


$^{20}Ne \rightarrow$ <110> LiF(001), $E_{\perp}$ = 0.3 eV



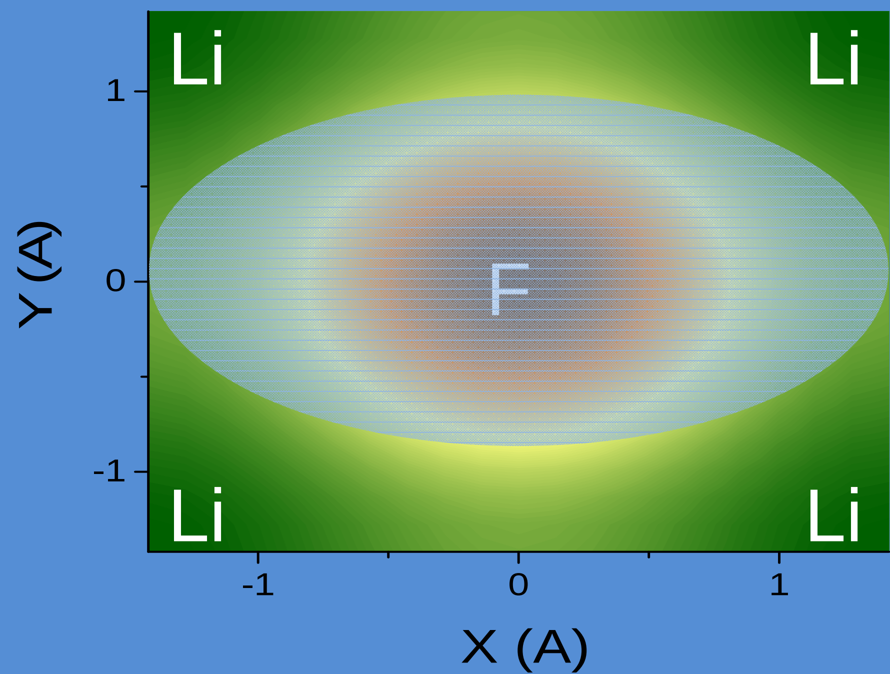
Crystal spotting

2 keV Ne → <110> LiF(001), $E_{\perp}$= 0.3 eV



incidence direction

surface potential



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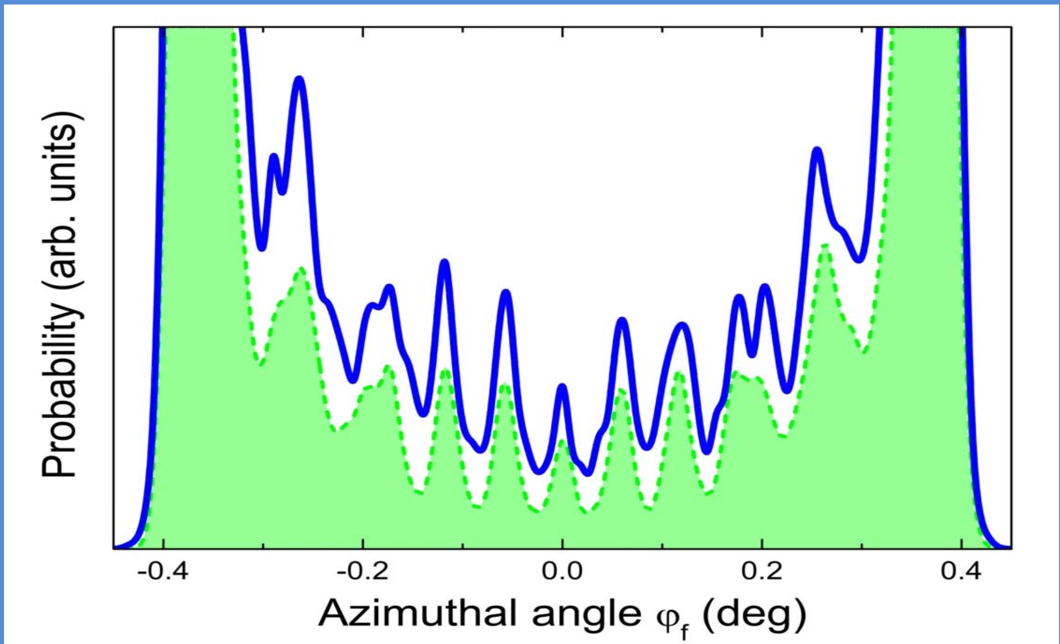
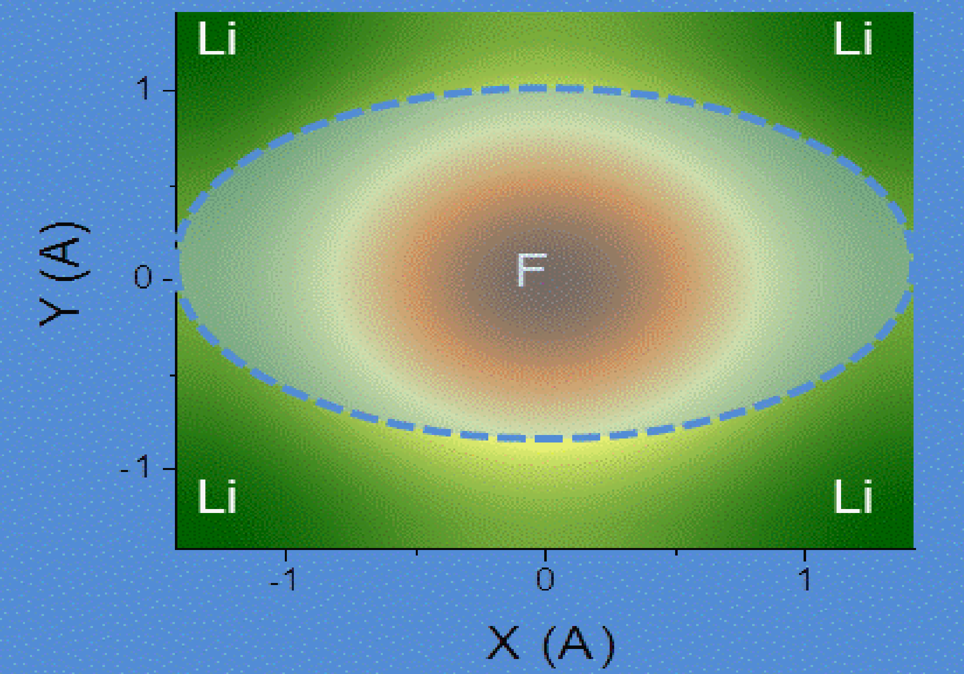
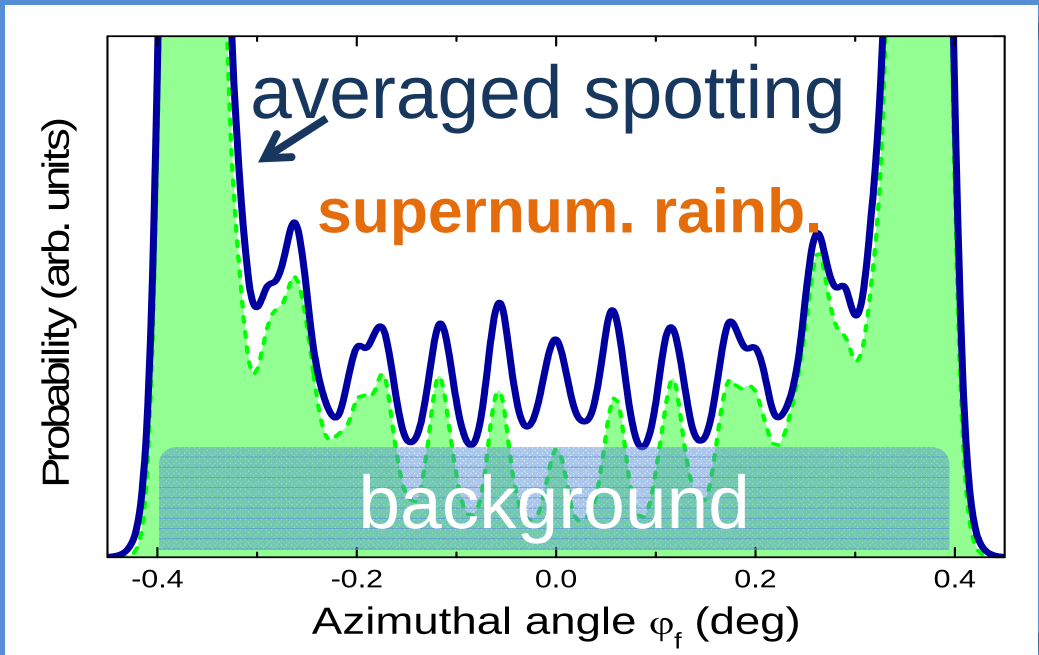


surface potential



Crystal spotting

2 keV Ne → <110> LiF(001), $E_\perp = 0.3$ eV

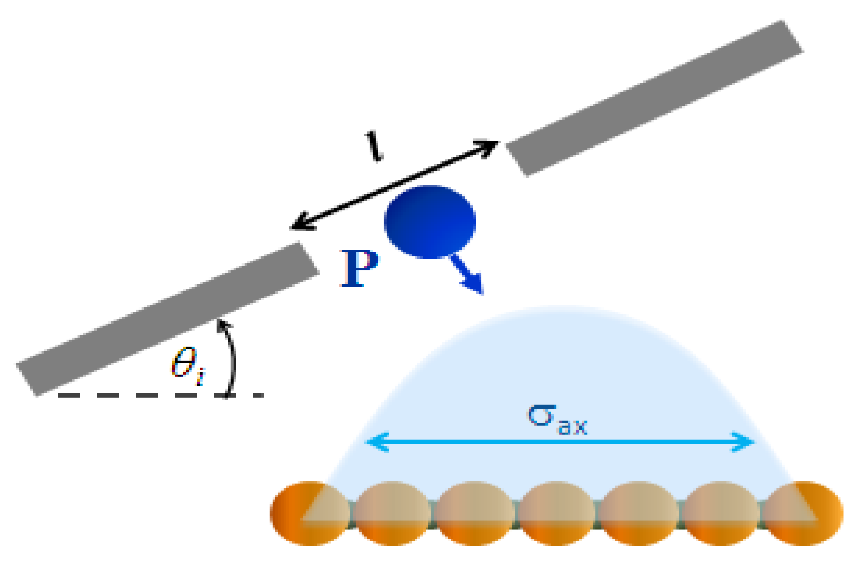


- keeps peak positions
- decoherent background
- quasi-unit-cell interference

Several coherently lighted cells: negligible

Axial coherence: slit length

Initial wave-packet:
axial width

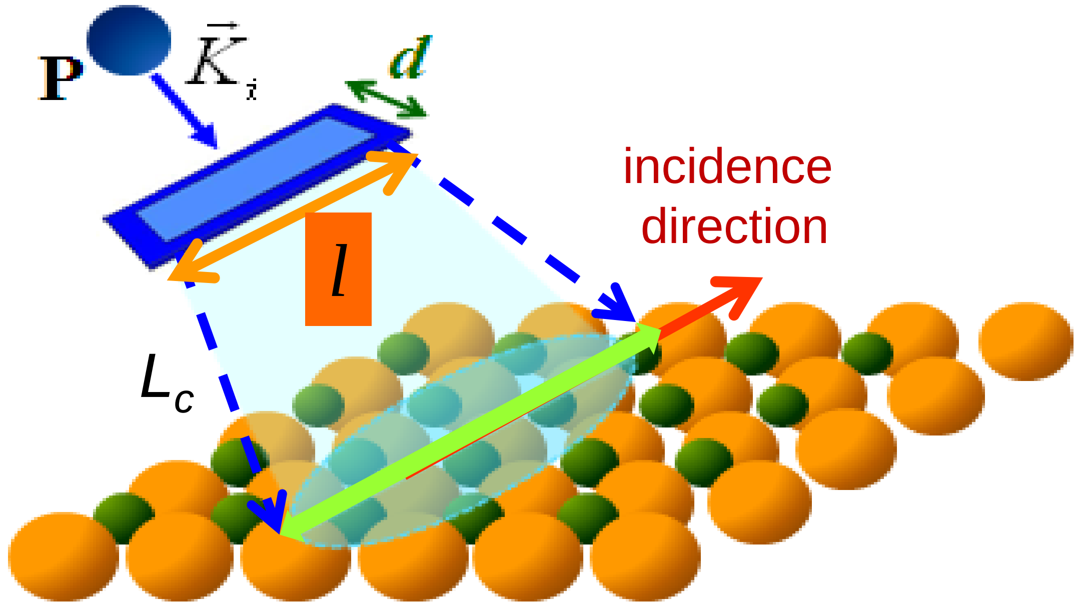


Uncertainty principle

$$\Delta X_o \Delta K_{ox} \approx 1$$

polar angle spread

$\Delta\theta_o$



$$\sigma_{ax} = \frac{\lambda_\perp}{\sqrt{2}} \frac{L_c}{l}$$

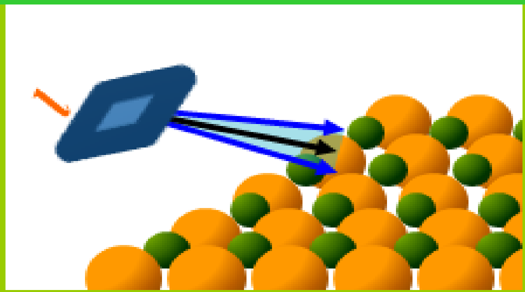
axial coherence length

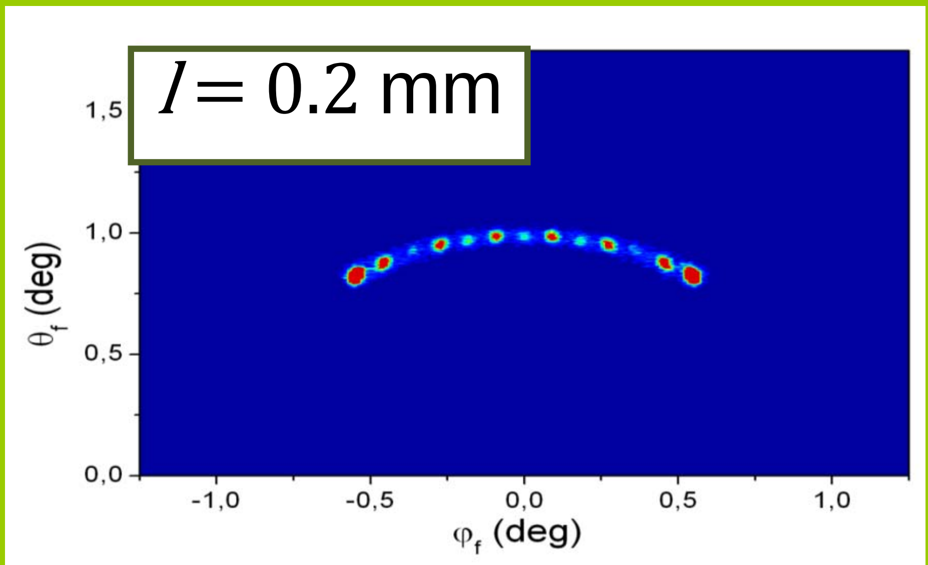
$$\lambda_\perp = 2\pi/(K_i \sin\theta_i)$$

perpendicular de Broglie wavelength

Slit length: normal momentum spread

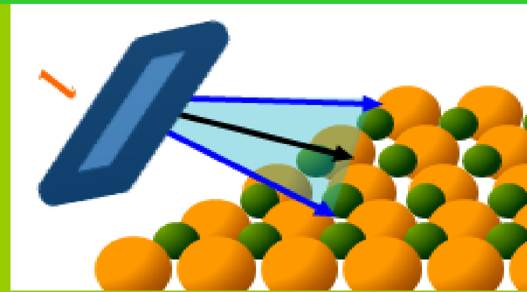
small square slit

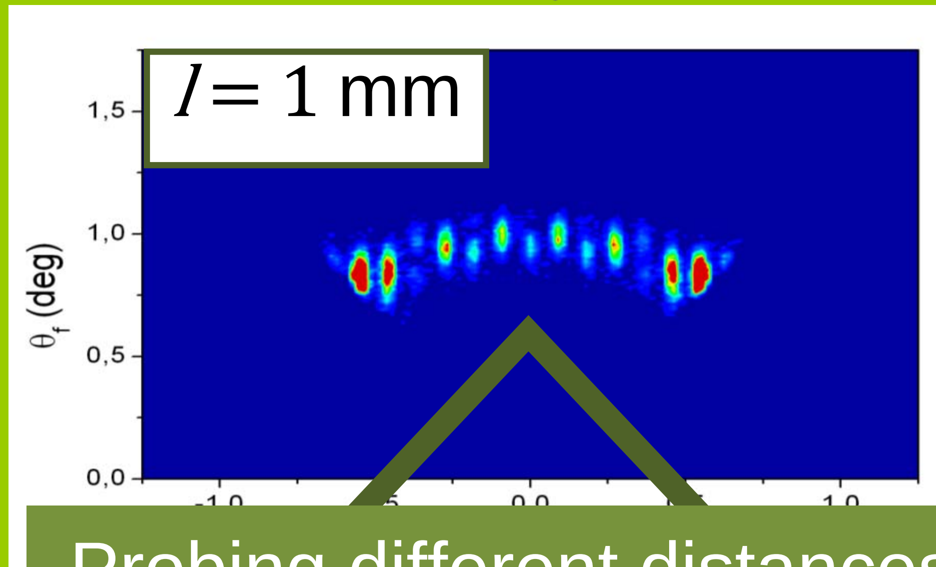




$^4He \rightarrow$ <110> LiF(001), $E_\perp = 0.3$ eV

long rectangular slit

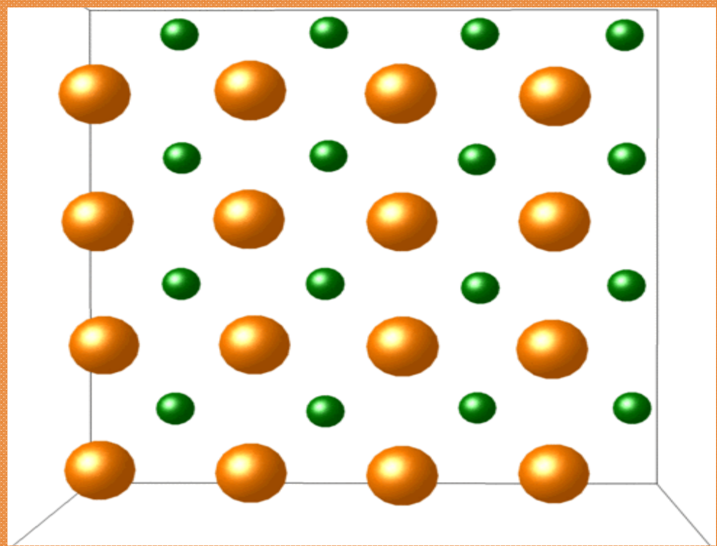




Probing different distances

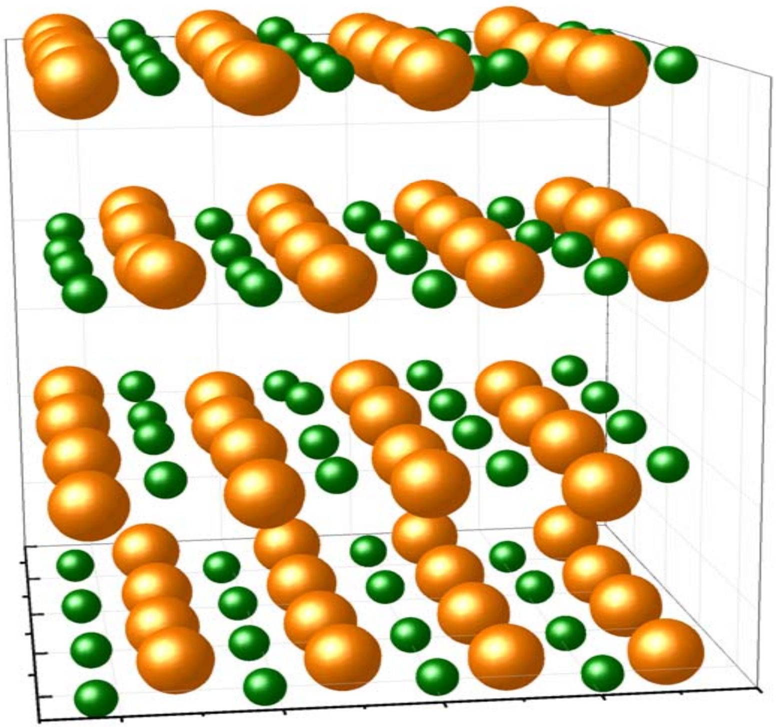
Gravielle *et al.* , Nucl. Instr. Meth. B **382** (2016) 42

DECOHERENT HEATING



Influence of the temperature

T= 300 K



LiF(001)

$^{20}Ne \rightarrow$ <110> LiF(001), $E_{\perp}$= 0.3 eV

Influence of the temperature

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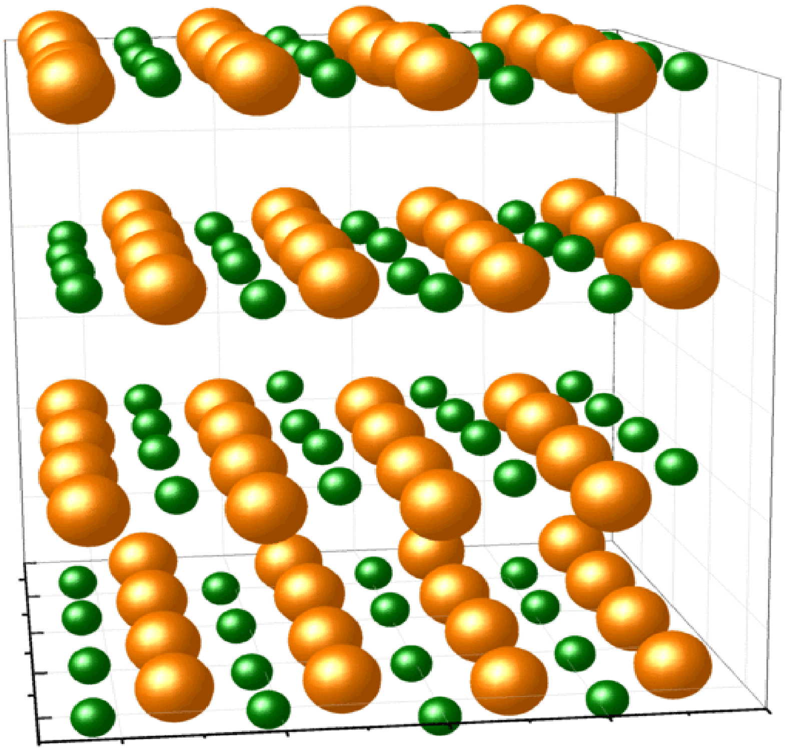

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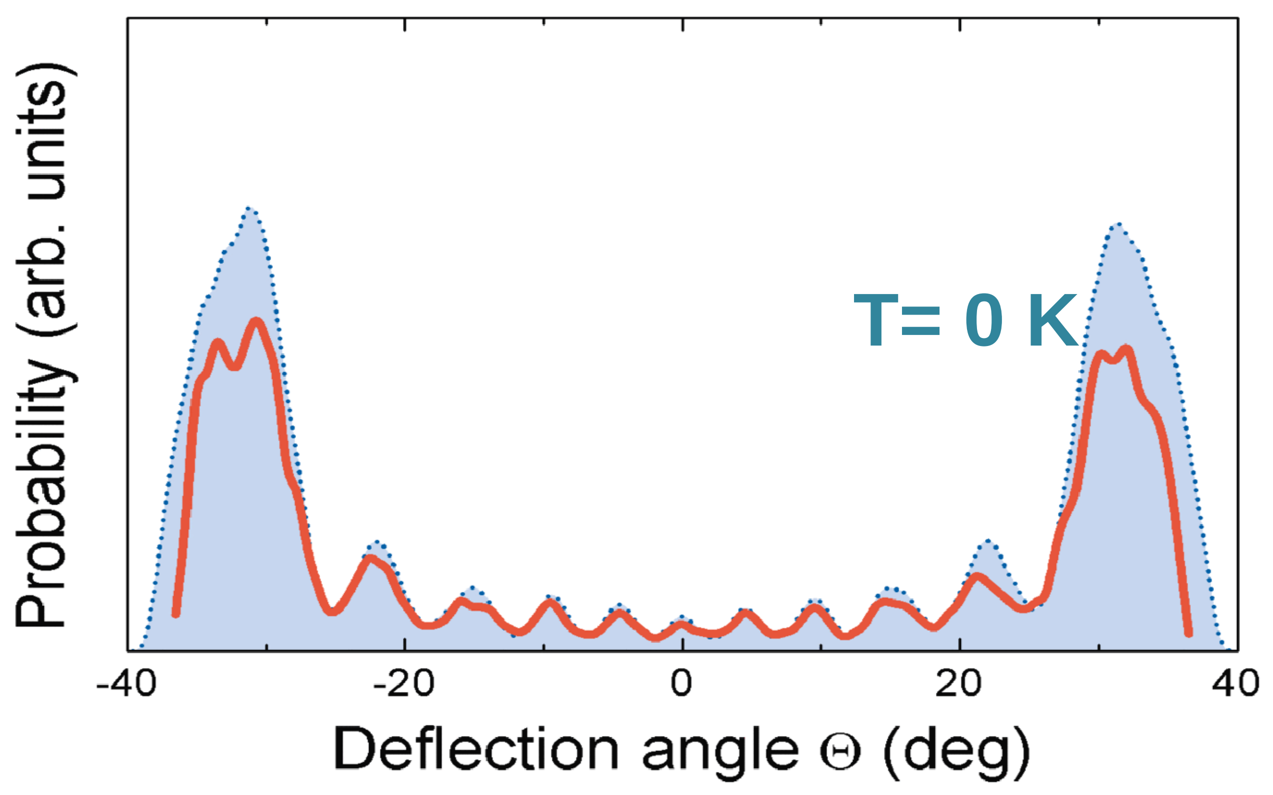

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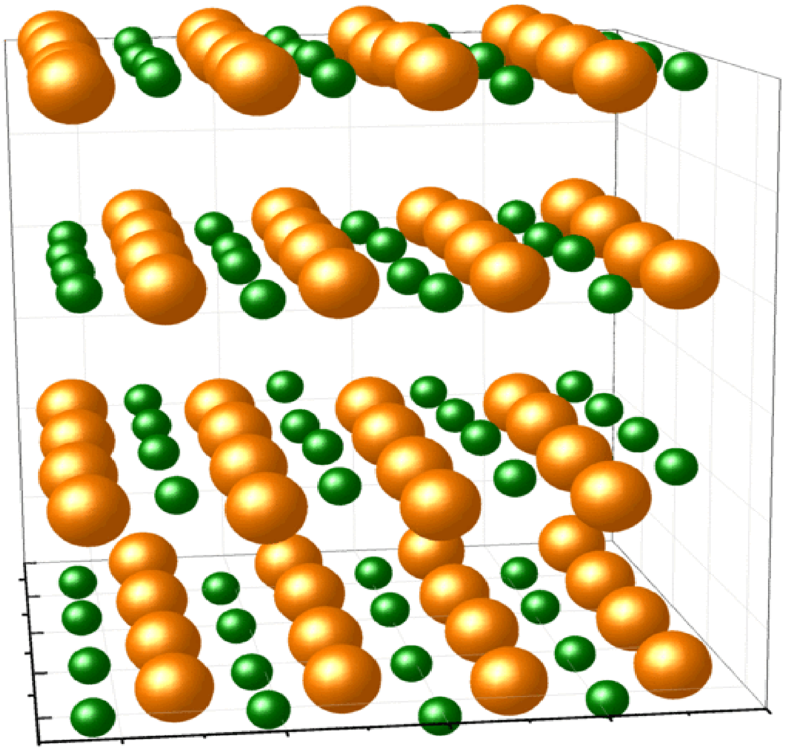

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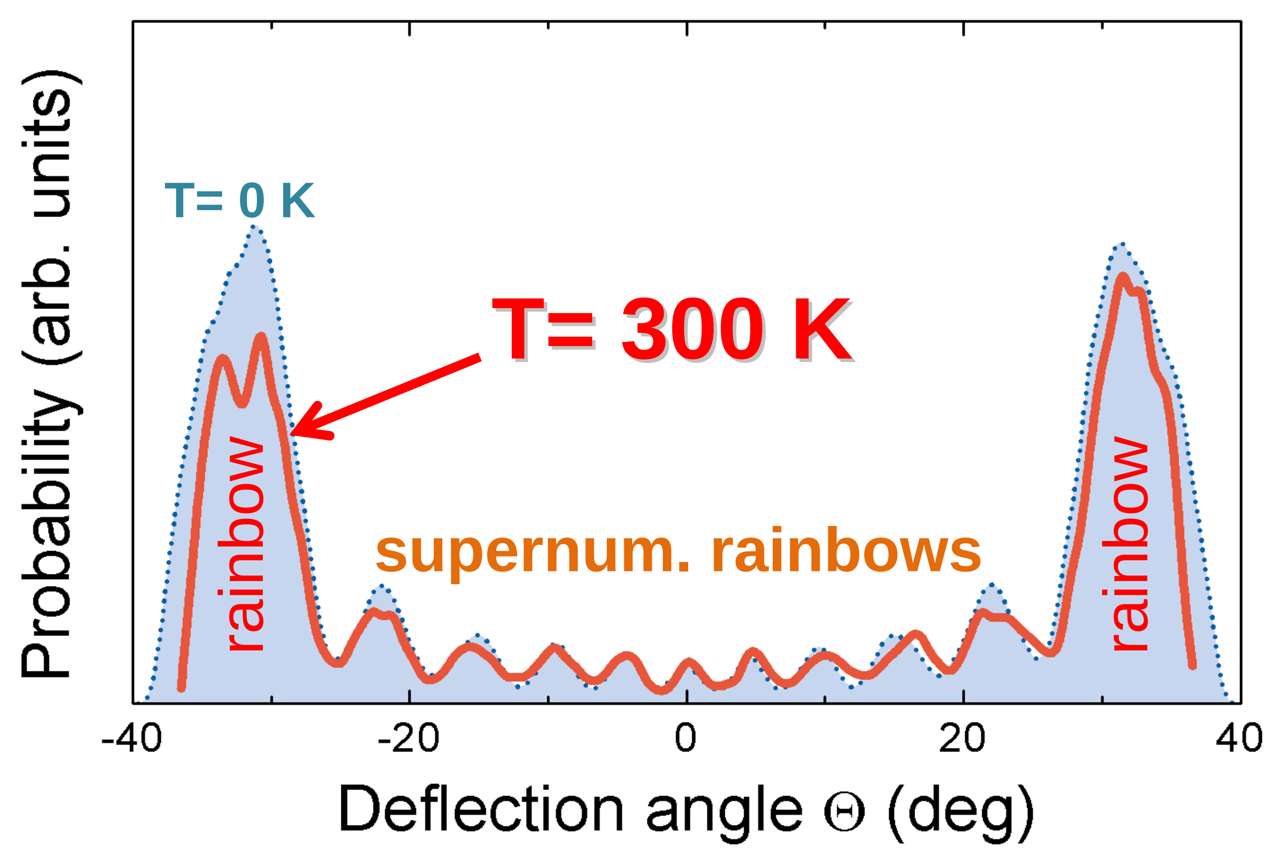
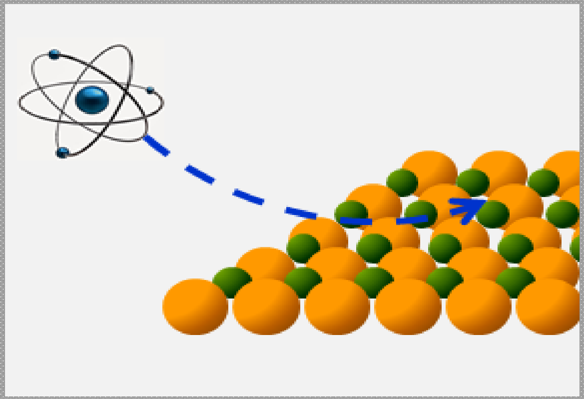
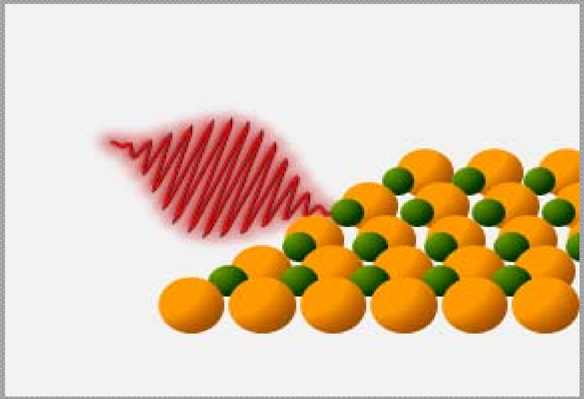


Manson *et al*., Phys. Rev. B **78** (2008)
Aigner *et al*, J. Phys. Conf. Ser..**133** (2008)

SURFACE ANALYSIS



Atoms

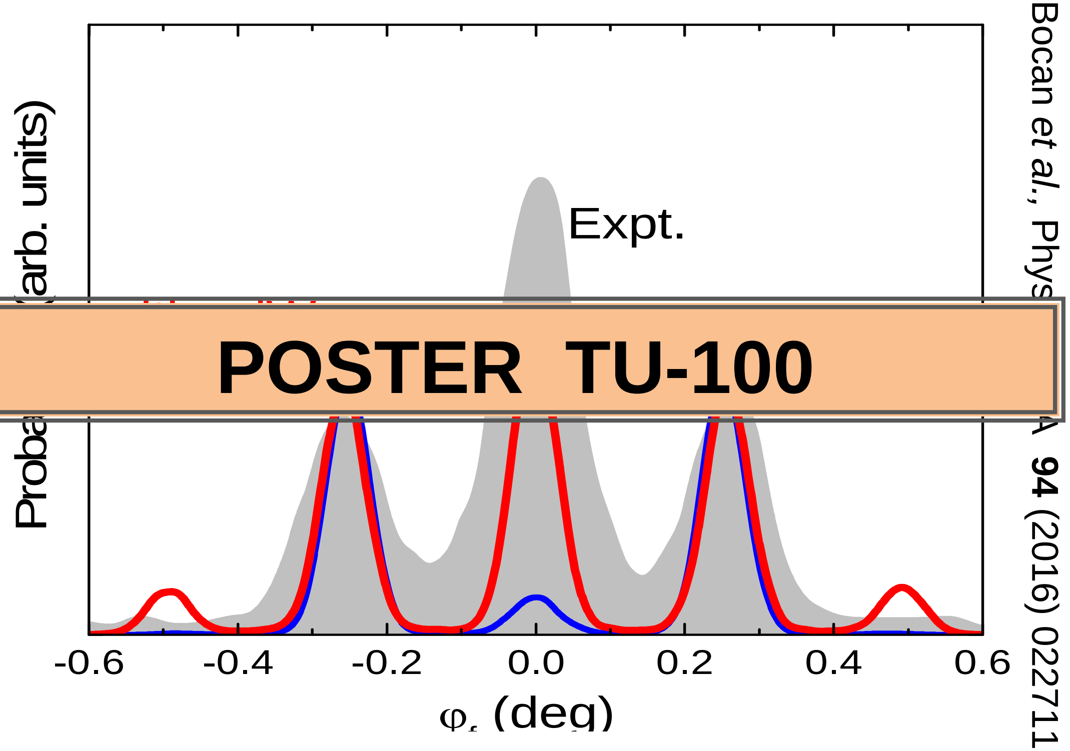


Laser pulses

SURFACE ANALYSIS

ATOMS

van der Waals effects

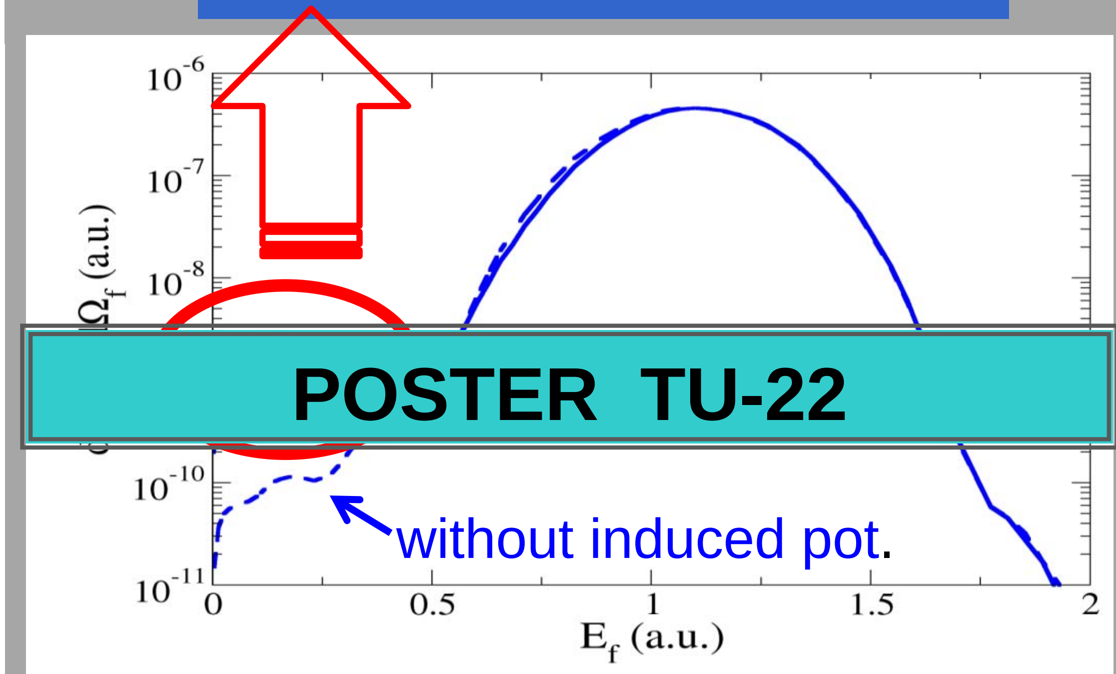


POSTER TU-100

H → <100> LiF(001), $E_\perp = 0.3$ eV

LASER PULSES

surface electronic states



POSTER TU-22

XUV pulse → Al(001), **ω=1.5 a.u.**

Ríos Rubiano *et al.*, Phys. Rev. A **94** (2016) 022711

FINAL REMARKS

SIVR approach

Semi-quantu …
•very good … s
•intuitive …

coherent lighting

• gove … tterns
• de … nditions

collimating slit

• wid … lassic
• lengt …

decoherent heating

• broadens …

COHERENCE for DIFFERENT TARGETS:

clusters

molecules

atoms

COLLABORATORS

ATOMS:

- J. Miraglia
- G. Bocan
- J. Fuhr

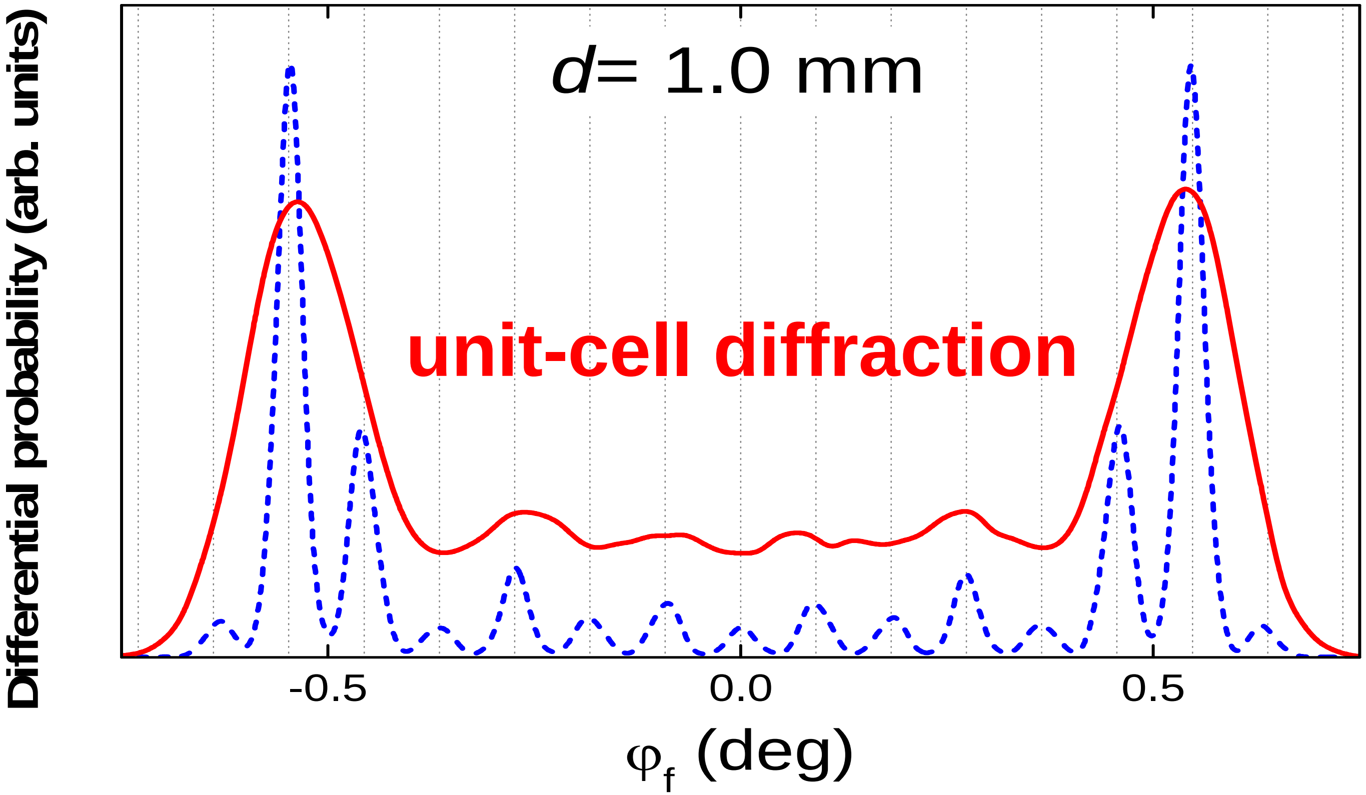
LASER PULSES:

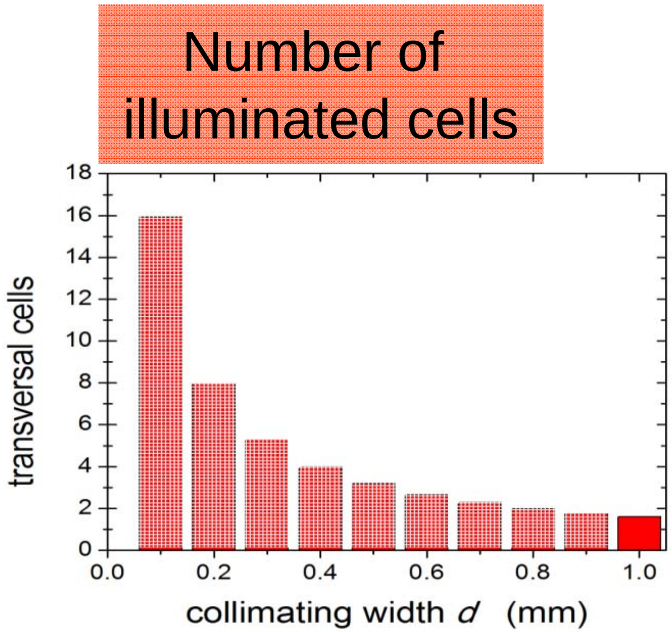
- C. Ríos Rubiano
- R. Della Picca
- D. Mitnik
- V. Silkin (Spain)

THANKS FOR THE ATTENTION

FAD spectra vs. slit width

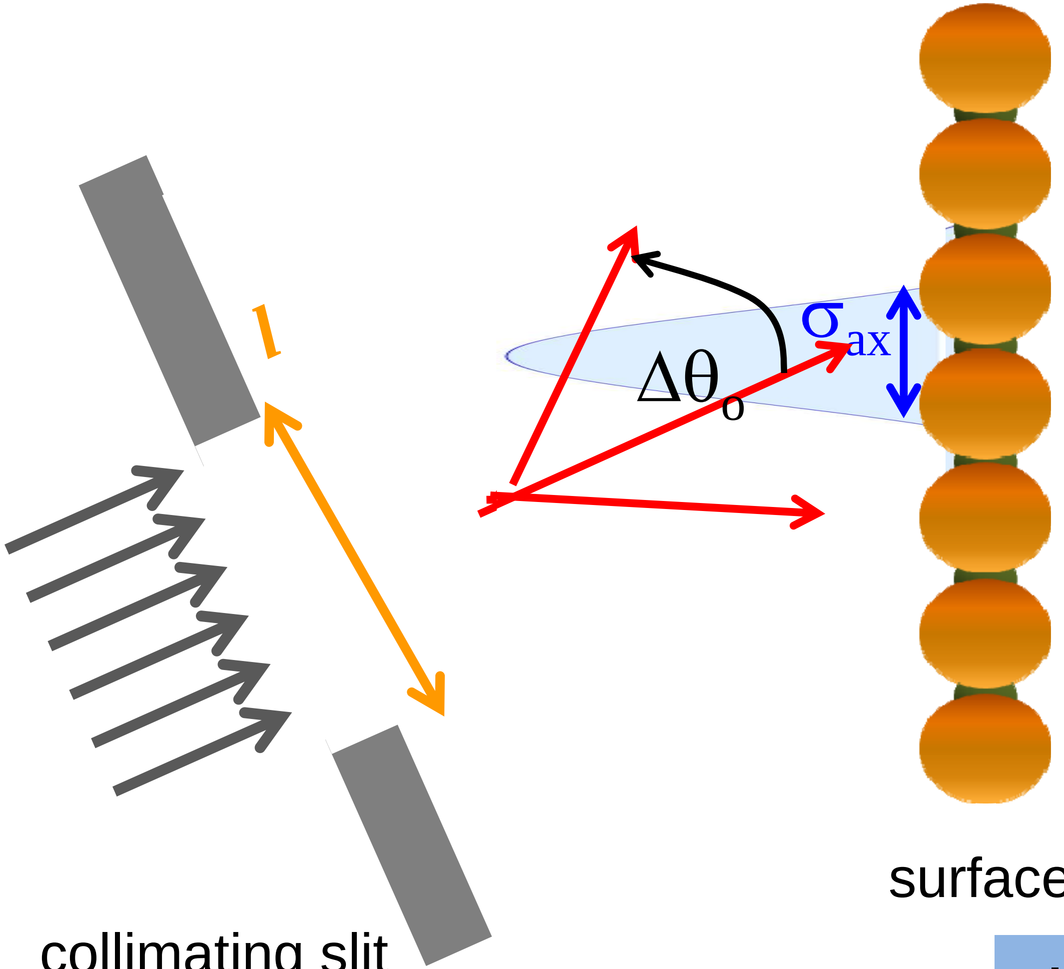
^{4}He → <110> LiF(001), E= 1 keV, θ_i= 0.99 deg





Gravielle *et al.*, Phys. Rev. A **92** (2015) 062709

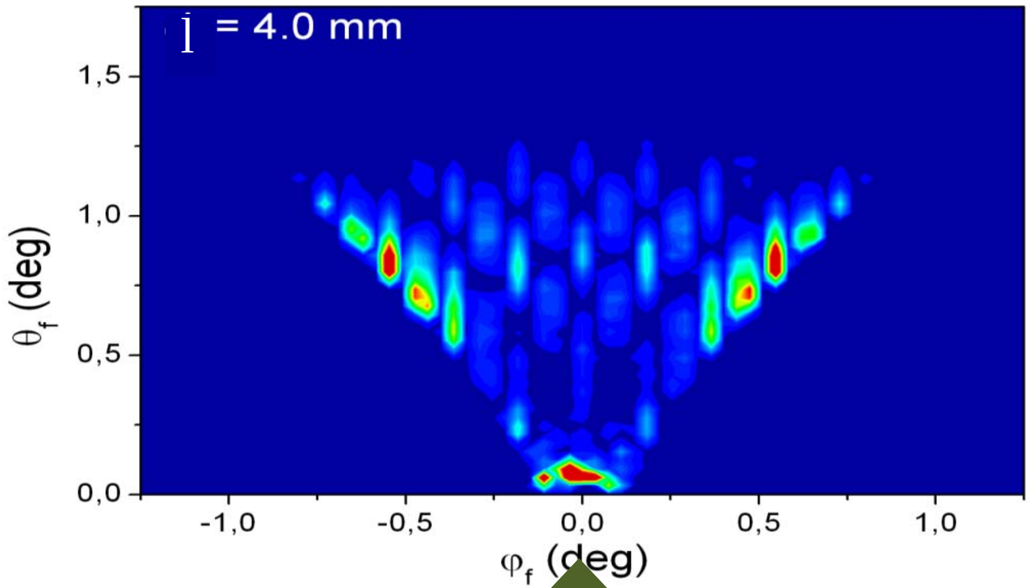
Slit length: normal momentum spread



surface

collimating slit

^{4}He → <110> LiF(001), $E_\perp$= 0.3 eV



To probe different distances

Incid

Gravielle *et al.* , Nucl. Instr. Meth. B **382** (2016) 42

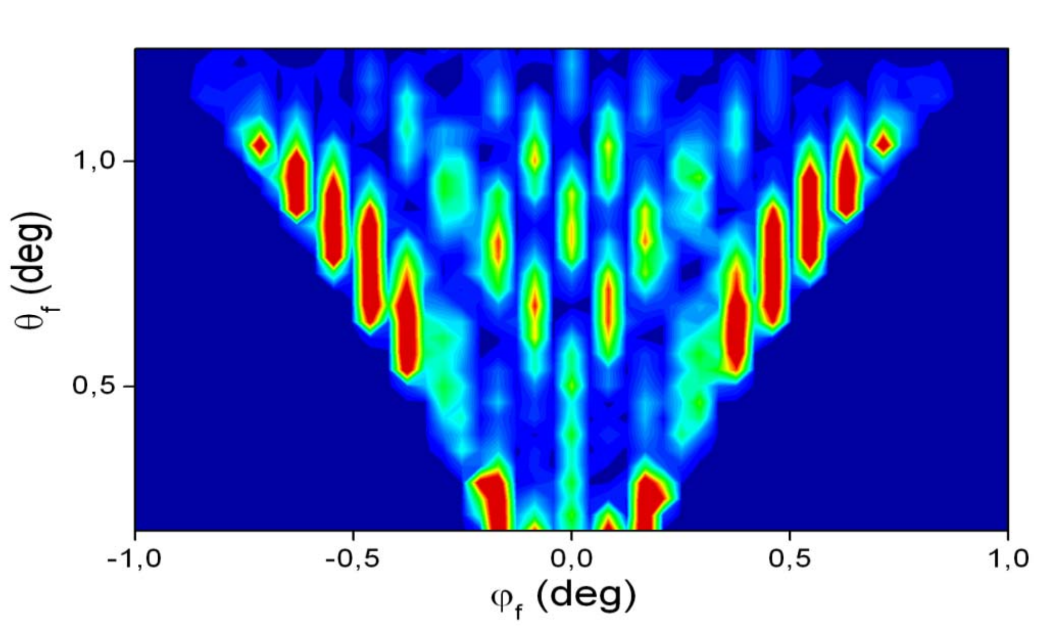
Long slit collimation vs. diffraction chart

Angular spectrum

Long slit : ***l* = 5 mm**

Useful for probing potentials

Fixed θ_i

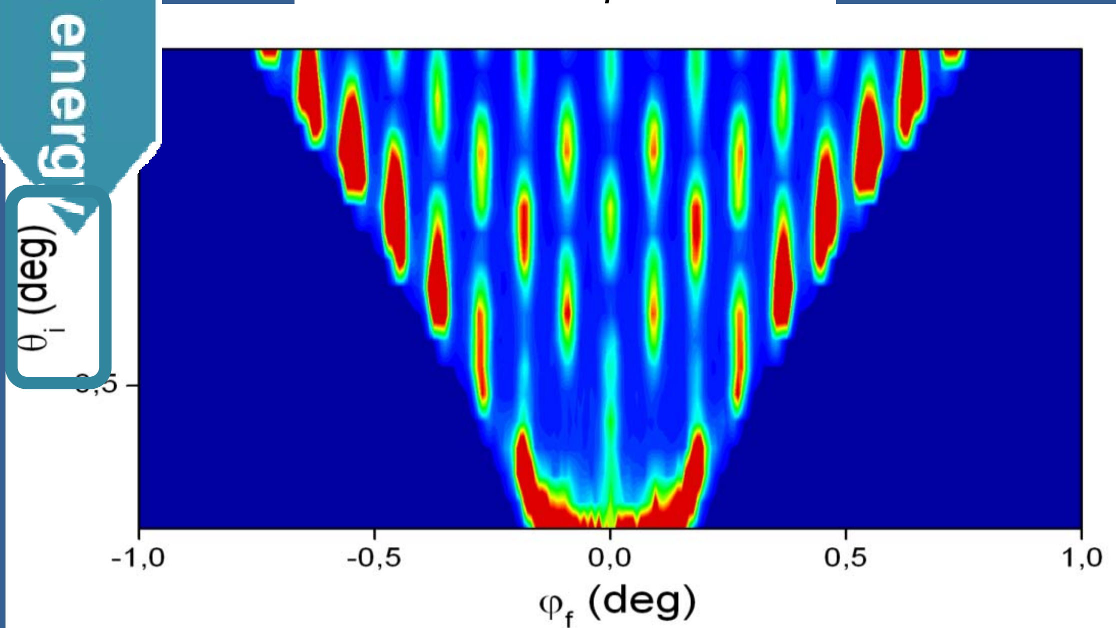


Diffraction chart

Short slit : ***l* = 0.2 mm**

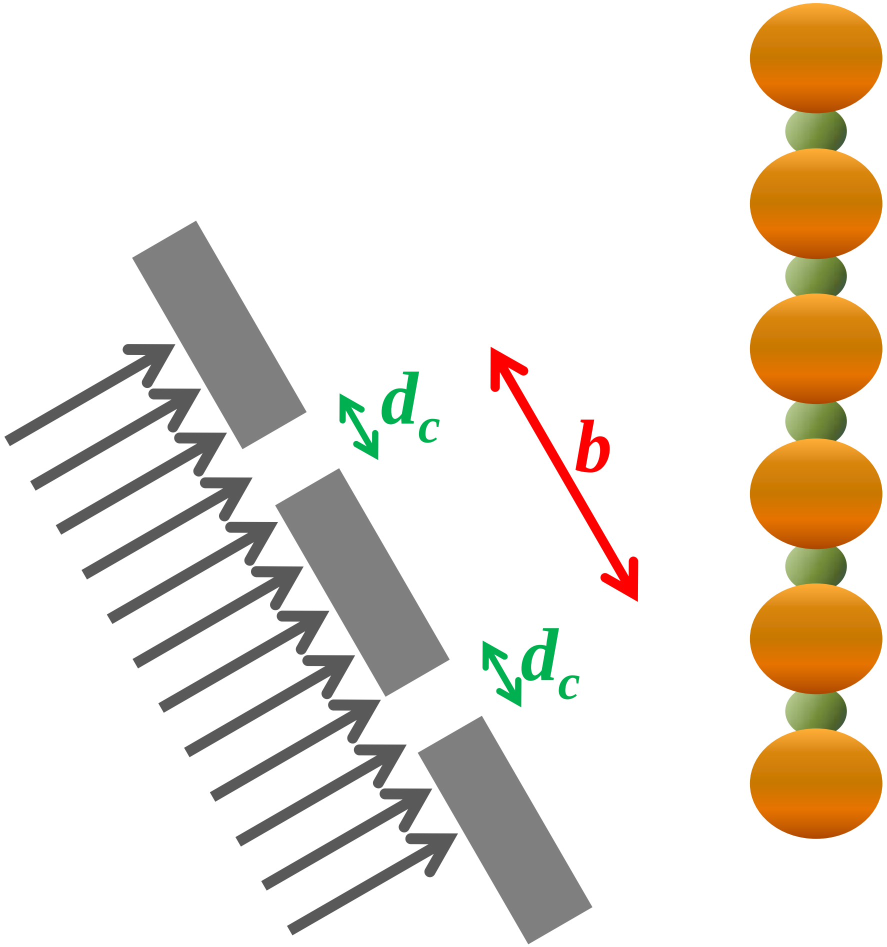
Normal energy

Different θ_i values

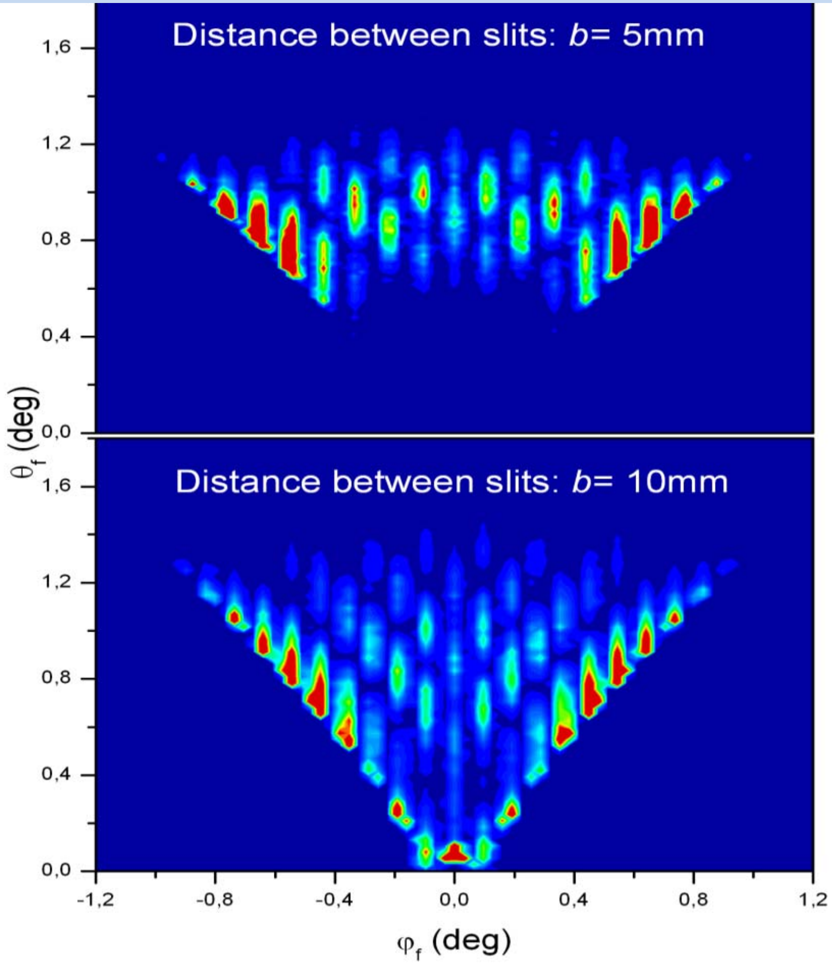


1 keV ^{4}He → <110> LiF(001) Gravielle *et al.* , Nucl. Instr. Meth. B **382** (2016)

DOUBLE SLIT COLLIMATION



Double slit: *d*= *0.2* mm, *l*= *0.2* mm



^{4}He → <110> LiF(001), *E*= 1 keV, θ_i= 0.99 deg

Gravielle *et al.* , Nucl. Instr. Meth. B **382** (2016)