# *Mosaic Copper Single Crystals for Laue Lenses*

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# Mosaic Copper Single Crystals for Laue Lenses
## A feasibility Study

- **Introduction**
  - The Monochromator Group - Our work
- **Mosaic Copper Single Crystals for Laue Lenses**
  - Recent Results and Progress
    - Growth of Cu single crystals
    - Preparation of thin copper pieces
    - Hard X-Rays Reflectivity measurements
- **Conclusion and Perspectives**

# Neutron Optics Laboratory *(K. Andersen)*

## Monochromator group *(P. Courtois)*

⇩

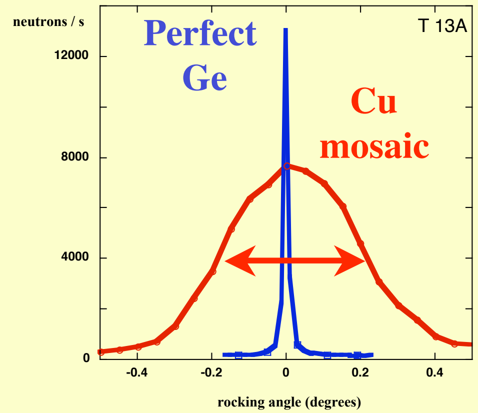
**Production of neutron monochromators based on Cu mosaic single crystals (also Ge, Si, Heusler alloy $Cu_2MnAl$….)**

## Mosaic Crystal

- **To match the neutron beam divergence** (typically 0.2 ° to 0.5 °)
- **To obtain adequate integrated reflectivity**
- **Anisotropic mosaic** ($fwhm_h$ / $fwhm_v$ > 1) **for focusing properties**

***mosaic = FWHM***

*Neutron rocking curve*



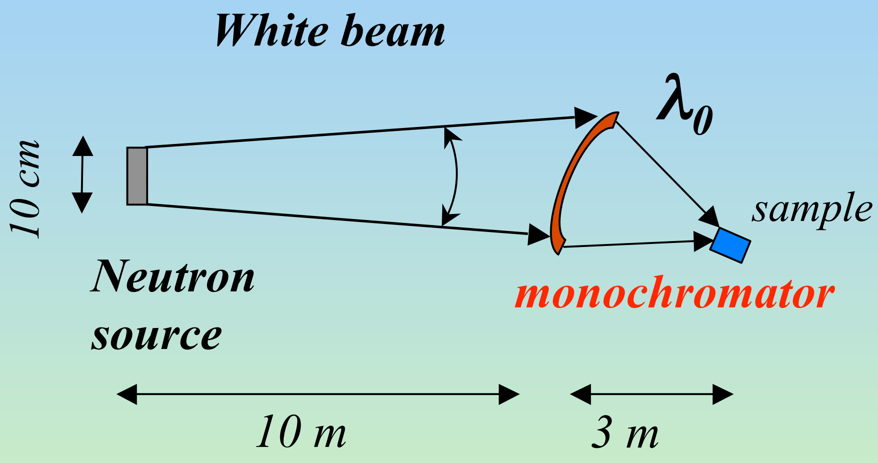
# Neutron monochromators

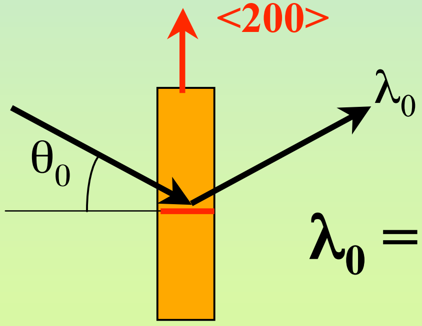
- ⇨ **1. Growth of high quality Cu mosaic single crystals** *(Bridgman technique)*
- ⇨ 2. Orientation
- ⇨ **3. Characterization of the quality of the as-grown crystal**
  - ⇨ Hard X-ray Laue Diffractometer (100 keV- 400 keV)
- ⇨ **4. Cutting**
  - ⇨ Spark-erosion machine
- ⇨ 5. Plastic deformation
  - ⇨ in order to increase the mosaic spread of the as-grown crystal up to the required value: fwhm ~ 0.3° - 0.5°
- ⇨ 6. Neutron Characterization and Crystal Mounting

# "A Neutron Laue Lens "

## Double-focusing Cu(200) monochromator (transmission geometry)


***fwhm = 0.4 º***
***optimized at λ = 1.3 Å (t=6.5mm)***
13 pieces 75 x 22 x 6.5mm$^3$




$$\lambda_0 = 2d_{200}\sin\theta_0$$

# Gamma Laue Lenses
# and the I.L.L.

- **What is required for Laue Lenses ?**
  - ⇨ **High quality Cu single crystals with a mosaic of 30'' of arc**
    - High Peak Reflectivity
    - High Integrated Reflectivity
    - ~ 8000 crystals of dimensions 15 x 15 x $\mathbf{e_{opt}}$ $mm^3$ ...

- **What can I.L.L. do ?** **A feasibility Study**
  - ⇨ **Technical Aspects**
    - Is it possible to grow « almost perfect » Cu single crystals?
    - How to prepare small Cu pieces ?
  - ⇨ **X-ray Diffraction properties of Cu crystals produced at I.L.L.**
    - High Peak Reflectivity ?

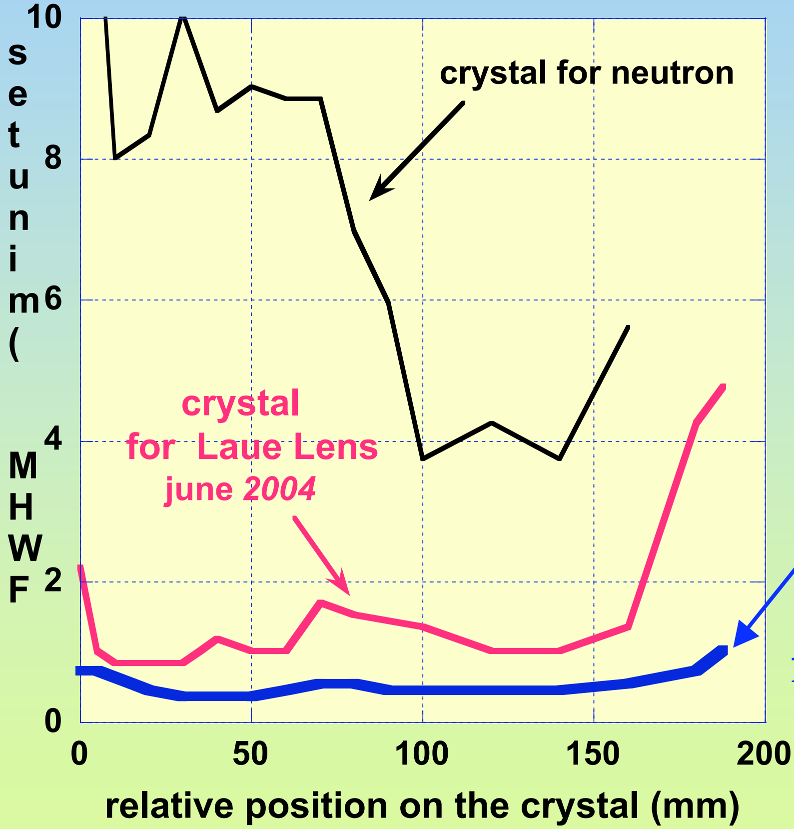
# The as-grown Cu single crystal ?

## *I.L.L. production*

## towards perfect Cu crystals

!!

*Length 250 mm*
*Diameter 80 mm*




**Last result**
**july2005**

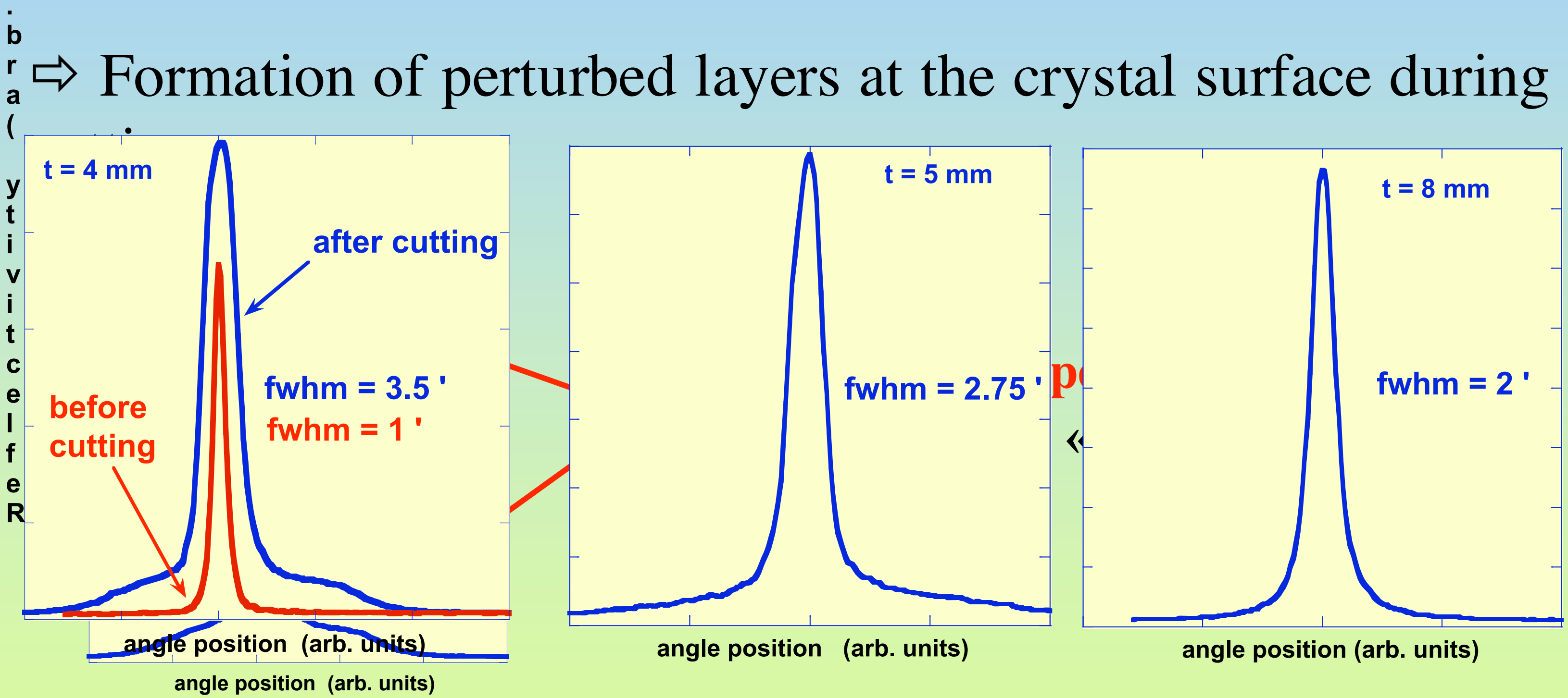
**fwhm = 30'' !!**

# BUT…

## After cutting the as-grown crystal

⇨ **Mosaic of the as-grown crystal affected by the cutting process (spark-erosion)**

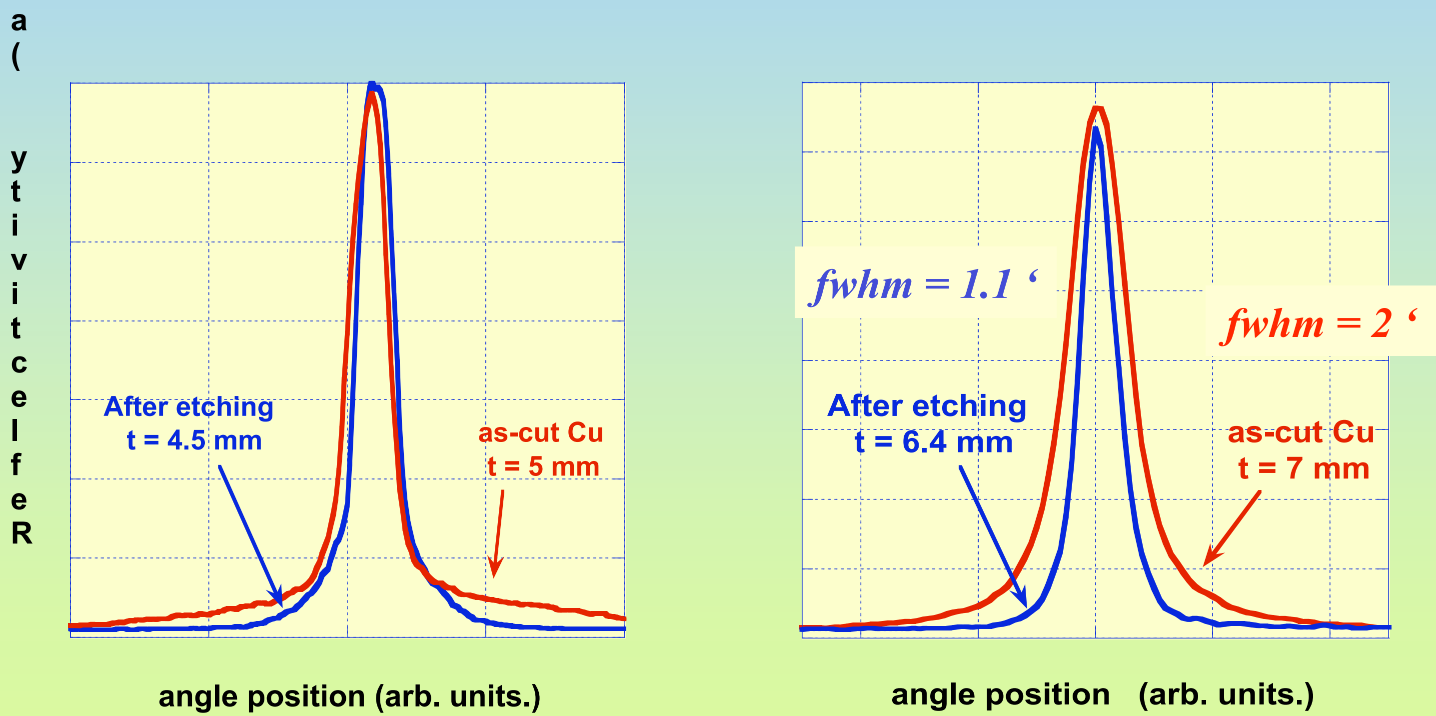
⇨ Formation of perturbed layers at the crystal surface during the



# How to Remove the perturbed layers ?

⇨ Polishing and mechanical machining ? NO : **Cu is too soft**

⇨ **Chemical Etching** allows to remove defects induced by spark-erosion without affecting the structure of the crystal



# Xrays Diffraction Properties

## Real crystal = ideal mosaic crystal ?

- **Experimental reflectivity** *(Hard Xrays Diffractometer)*
  - **White Beam** with a divergence $\alpha \sim 1'$ of arc
  - Energy between 100 and 400 keV
  - Cooled Ge detector
  - **Samples**
    - Cu(200) pieces cut from a crystal of 1' of mosaicity (FWHM)
    - Crystals with different thickness (etching)

      t = 2.5mm, 4 mm, 4.6mm, 5.65mm, 7.45mm, 12.6 mm …
- **Theoretical reflectivity** calculated from the model of ideal imperfect mosaic crystal (P. Bastie)

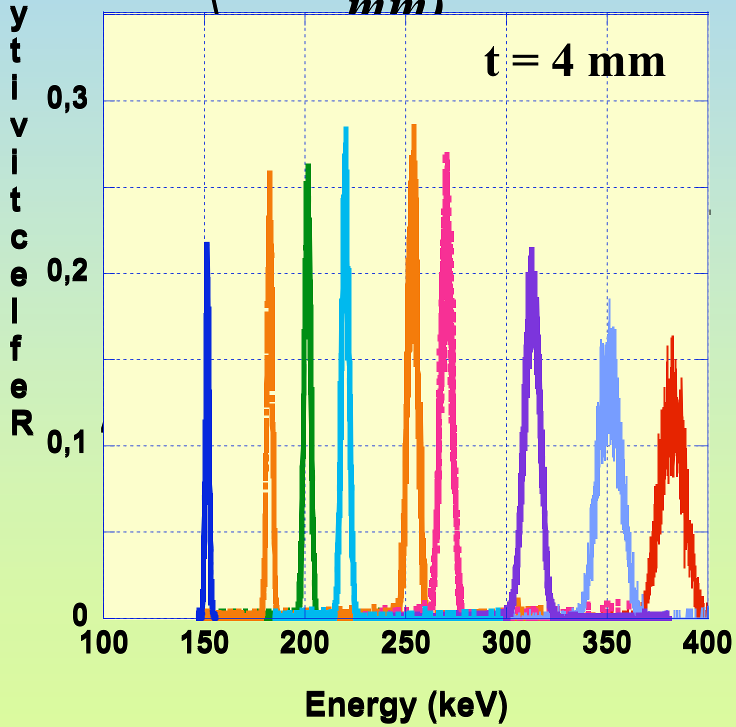
# Experimental Reflectivity - Principal Results

## Comparison between experimental and calculated datas

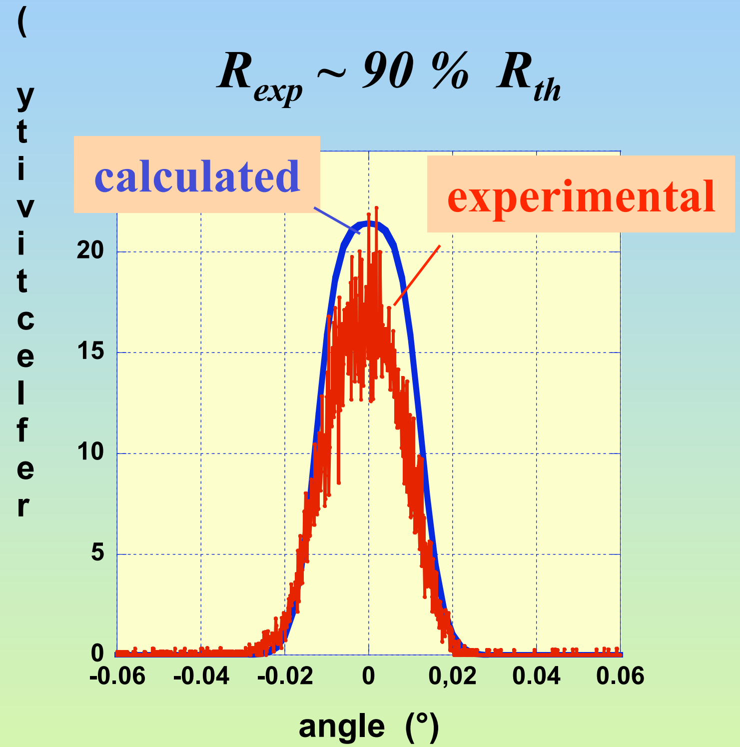
### Cu(200) Laue geometry

$$R_{experimental} = I_{diffracted} / I_{direct}$$

$$R_{theoretical} = R(\eta = 30'', t = 4 \text{ mm})$$




$R_{exp} \sim 90\ \%\ R_{th}$



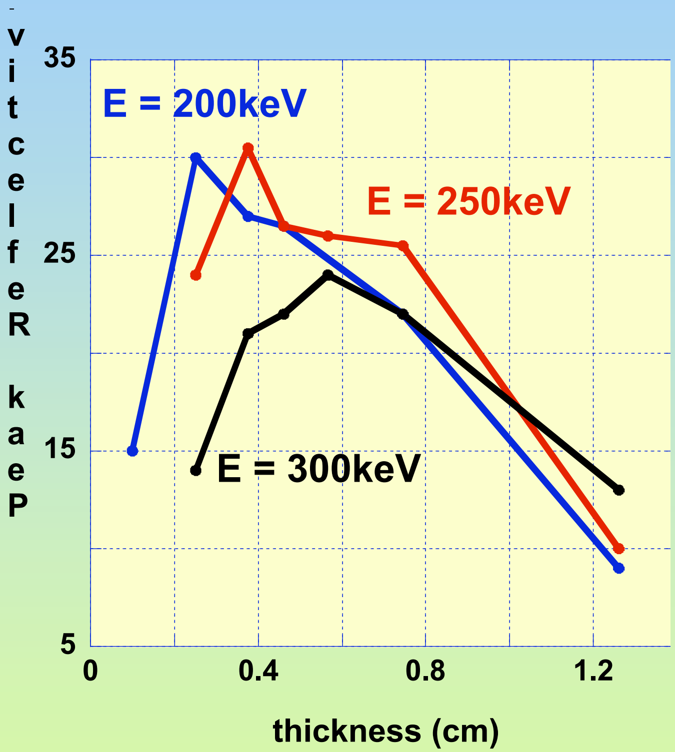

**E = 300 keV**

**t = 7.5 mm**

# Experimental Reflectivity - Principal Results

## Optimum Thickness $t_{opt} = f(E)$ ?

### Cu(200) Laue geometry




Optimum thickness (cm)

| E(keV) | Measured | Calculated |
|---|---|---|
| 200 | ~ 0.25 | 0.22 |
| 250 | ~ 0.35 | 0.30 |
| 300 | ~ 0.55 | 0.39 |

⇨ $t_{opt}$ experimental > $t_{opt}$ theoretical…..

# Conclusion

**Mosaic Copper single crystals of 30 seconds of arc are now available at I.L.L.**

**Cu Crystals of high quality adapted for a gamma Laue lens**

- Homogeneous structure
- High peak Reflectivity $R_{exp} \sim 80\text{-}90\ \%\ R_{th}$
- Difficulties involved in the preparation of thin Cu crystals overcome using chemical etching

# In the Future

- **Study of diffraction properties of Cu** single crystals using a parallel monochromatic beam at ESRF (E = 100-800 keV )

- **Bent copper crystals** for the lens ?
  ⇨Minimize the number of crystals (in a ring)
  ⇨Optimize focusing properties


5 flat crystals 15 x 15 $mm^2$ ⟺ 1 bent crystal 75 x 15 $mm^2$