Kossel X-ray standing-waves within a $Cr/B_4C/Sc$ multilayer excited by protons

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PHYSICS OF X-RAY AND
NEUTRON MULTILAYER
STRUCTURES WORKSHOP
2016

Outline

Introduction: a little of history

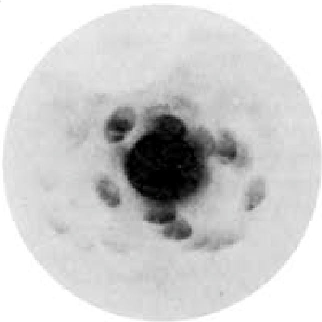
Sample: $Cr/B_4C/Sc$ multilayer

Methods:
- standing-wave technique *vs* Kossel diffraction
- proton-induced X-ray emission (PIXE)

Results and discussion

Conclusions and perspectives

A little of history



1912
M. von Laue, W. Friedrich, P. Knipping
First x-ray diffraction pattern on an hydrated copper sulfate ($P\bar{1}$ triclinic)

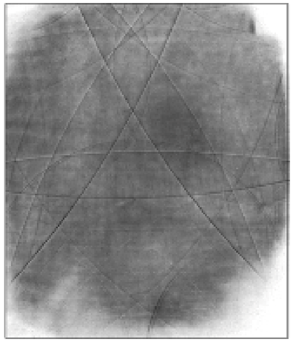
Max von Laue
(1879-1960)

1914
Nobel prize for physics for his discovery of the x-ray diffraction by crystals

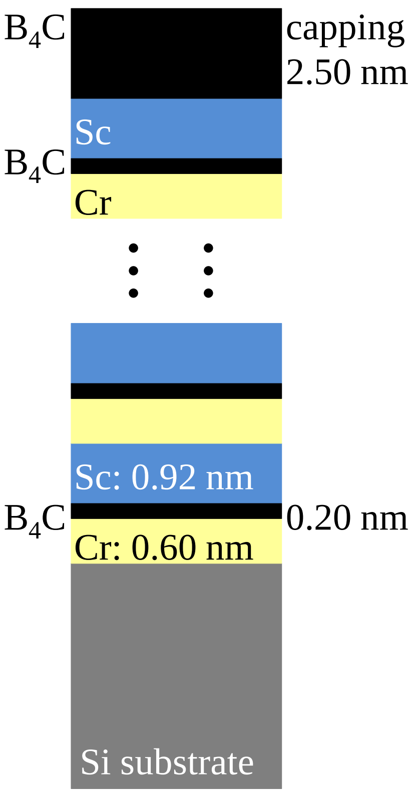
Walther Kossel
(1888-1956)

1935
Analysis of the fluorescence:

- produced within the crystal
- and diffracted by the crystal itself

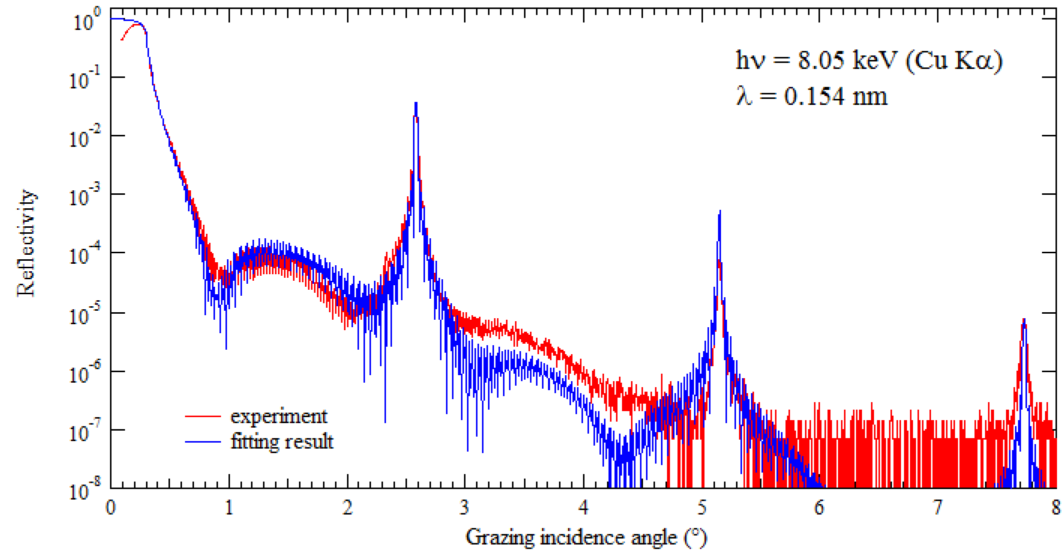


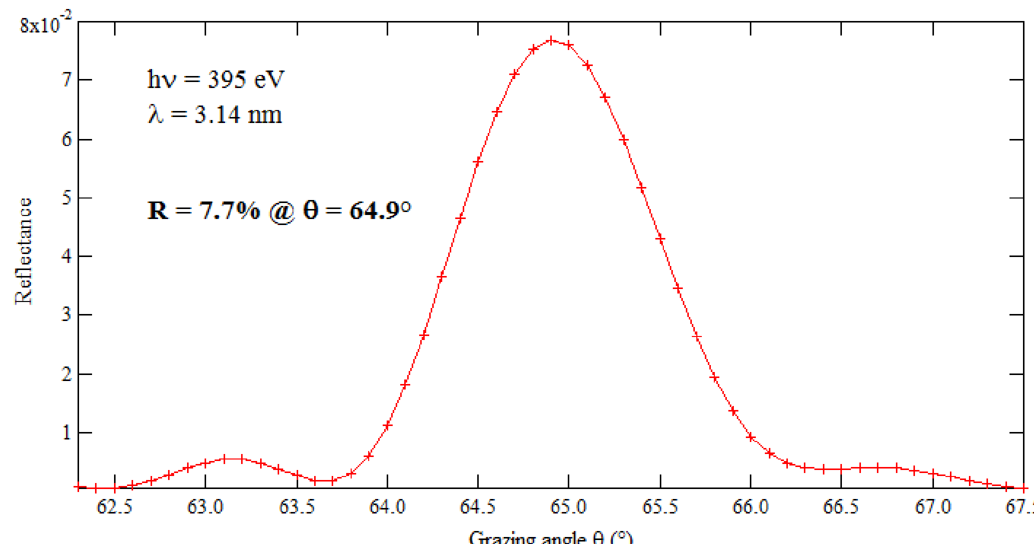
$Cr/B_4C/Sc$ multilayer



number of trilayers: 100
period d = 1.72 nm
applications: water window range
interdiffusion: Cr atoms present within B_4C layers
thin B_4C barriers

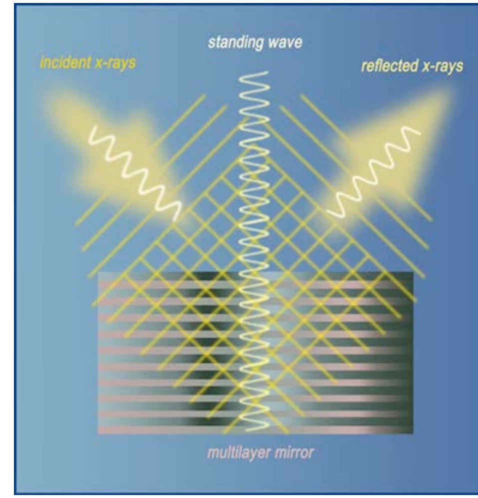
Reflectivity curves





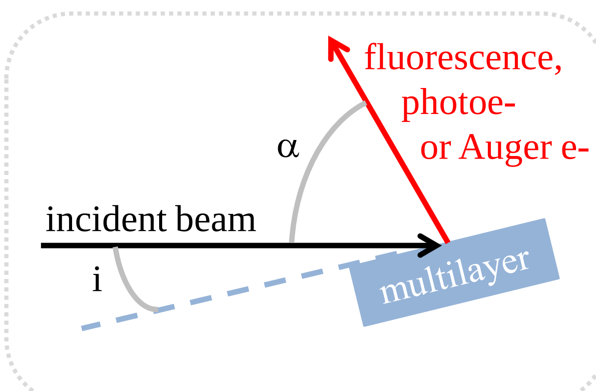
C. Burcklen *et al.*, J. Appl. Phys. 119 (2016) 125307 M. Prasciolu *et al.*, Appl. Opt. 53 (2014) 2126

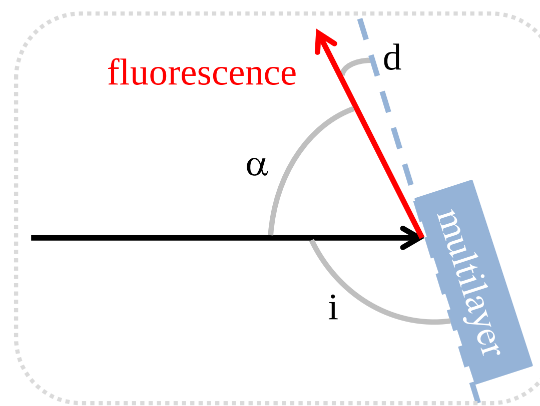
X-ray standing waves *vs* Kossel diffraction



In (or close to) **Bragg conditions,** a strong standing wave, having the period of the multilayer, develops inside and outside the multilayer.

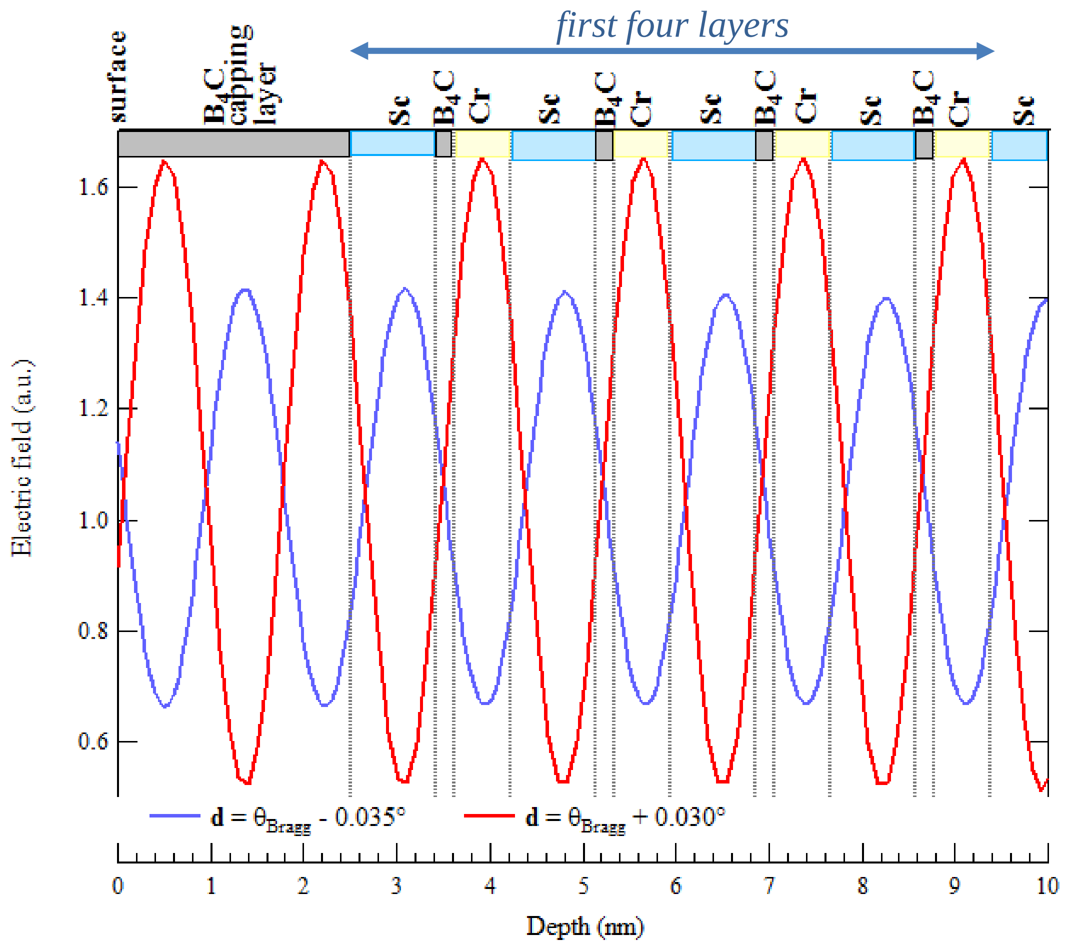
	XSW	KOSSEL
Excitation	x-ray **photon**	**proton** (2 MeV)
Sample	**crystal** or **multilayer** (bilayers)	**mutilayer** (trilayers)
Angular scan around θ_{Bragg}	glancing **angle** (i)	glancing **exit** (d)
To probe	• **thin layer** on **top** of the **multilayer** • **interfaces** within the multilayer	**interfaces** within the multilayer
Detection	fluorescence, photoe- or Auger e-	x-ray fluorescence





Kossel diffraction

Depth distribution of the electric field corresponding to the Sc Kα radiation generated within the multilayer (θ_{Bragg} = 5.086°)



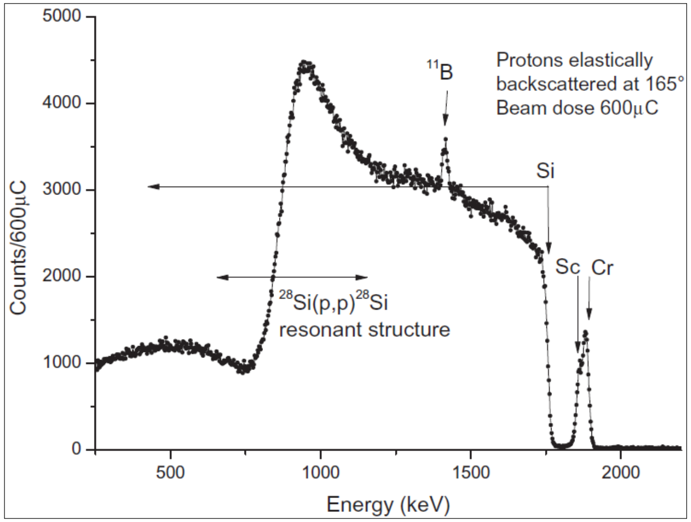
Varying the value of the detection d angle around that of θ_{Bragg} allows probing different emitting depths of the multilayer.

Proton-induced X-ray emission (PIXE)

Experimental platform SAFIR (Système d'Analyse par Faisceaux d'Ions Rapides)
Institut des NanoSciences de Paris, UPMC

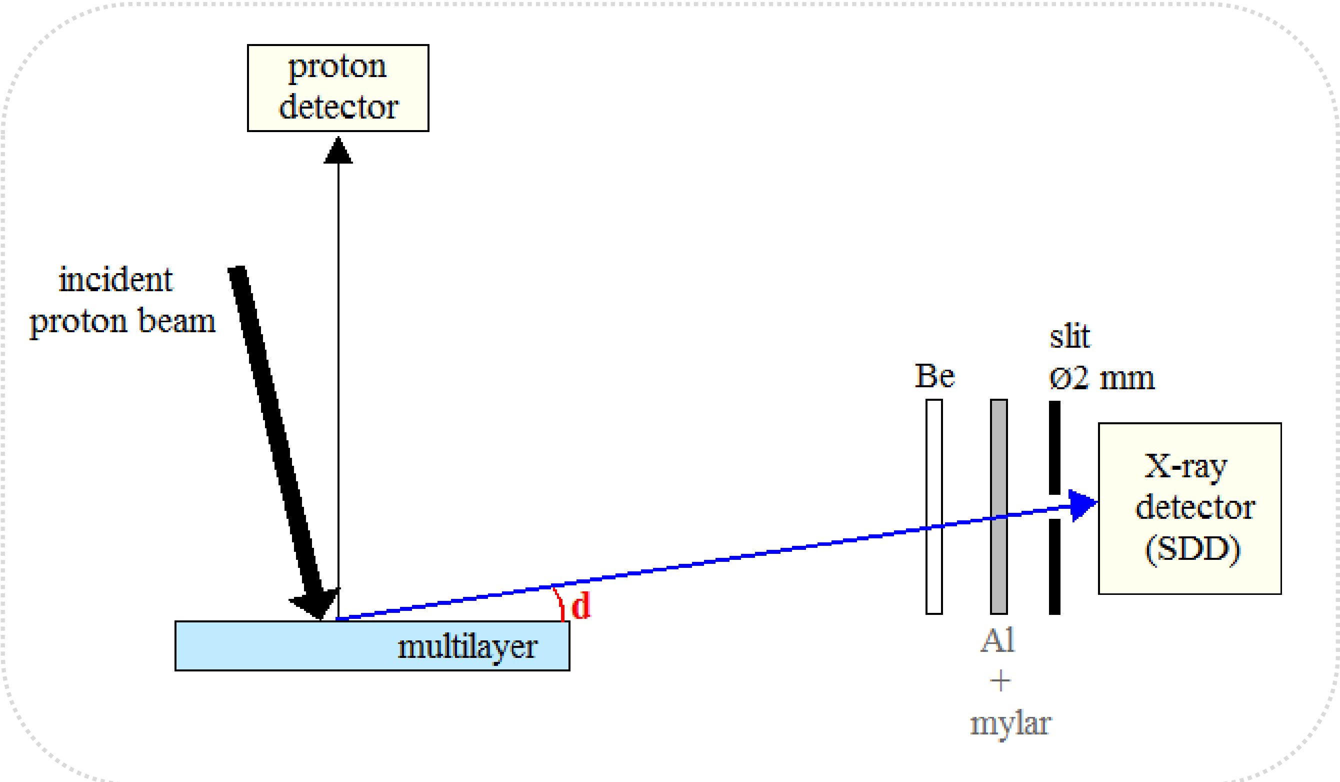
Van de Graaf accelerator
Beam current = 100 and 150 nA
Size of the beam on the sample: ~ 2mm

2 MeV protons
Ionization of the K shell of Sc and Cr atoms uniformly over the full multilayer thickness
Nominal energy for stability of the proton beam
Optimized Sc K and Cr K ionization cross section



Possible damaging of the sample?
Limited charge dose on the multilayer
Monitoring of the backscattered proton spectrum

Scheme of the experimental setup



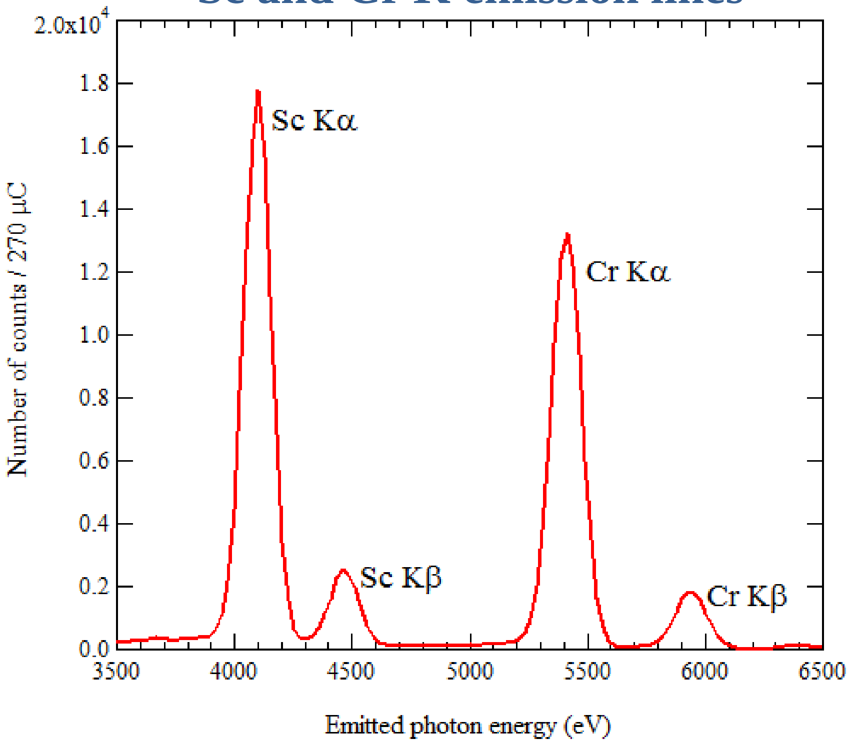
Scan of the d angle around the θ_{Bragg} value for the Sc (~5.1°) and Cr (~3.8°) Kα emission.

Strong requirement for angular resolution.

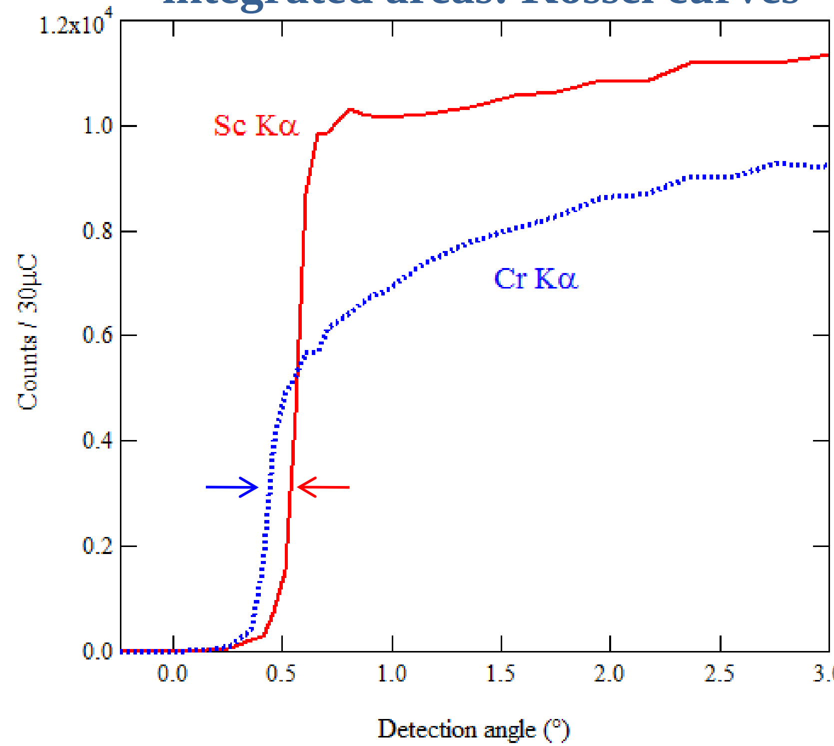
The (Al + 60 mm Mylar film) filters are inserted to block the scattered protons.

X-ray emission spectrum of the Cr/B_4C/Sc multilayer

Sc and Cr K emission lines



integrated areas: Kossel curves



Low proton-induced Bremsstrahlung:

- no fitting nor background substraction
- quantitative analysis: areas under peaks

Goniometer uncertainty: $\Delta d = \pm 0.05°$

Total reflection of the radiation emitted within the sample: angular calibration $\pm 0.01°$

Shift of 0.15°: different mean optical indices

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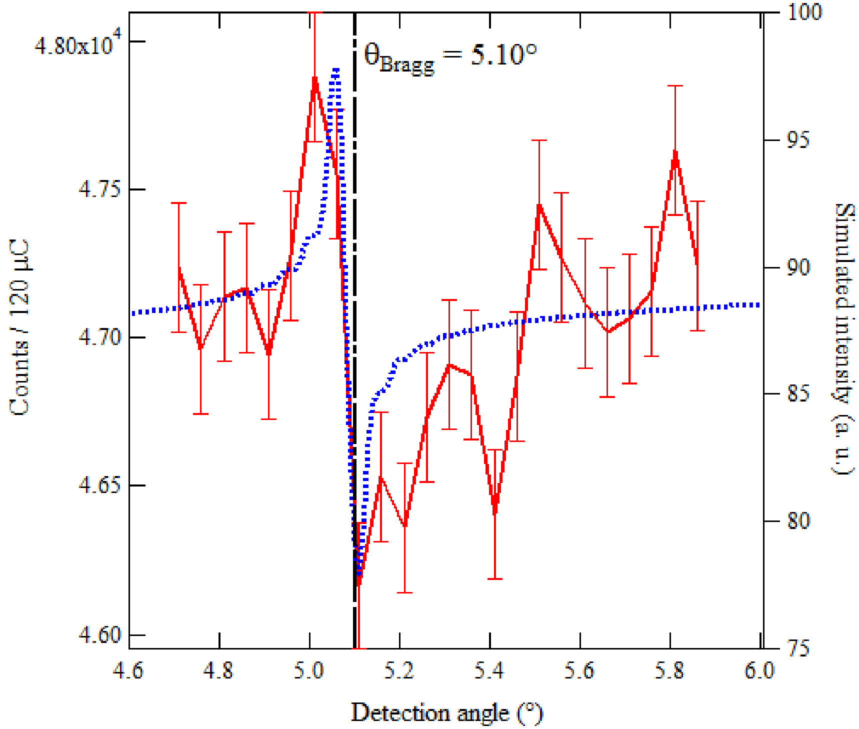
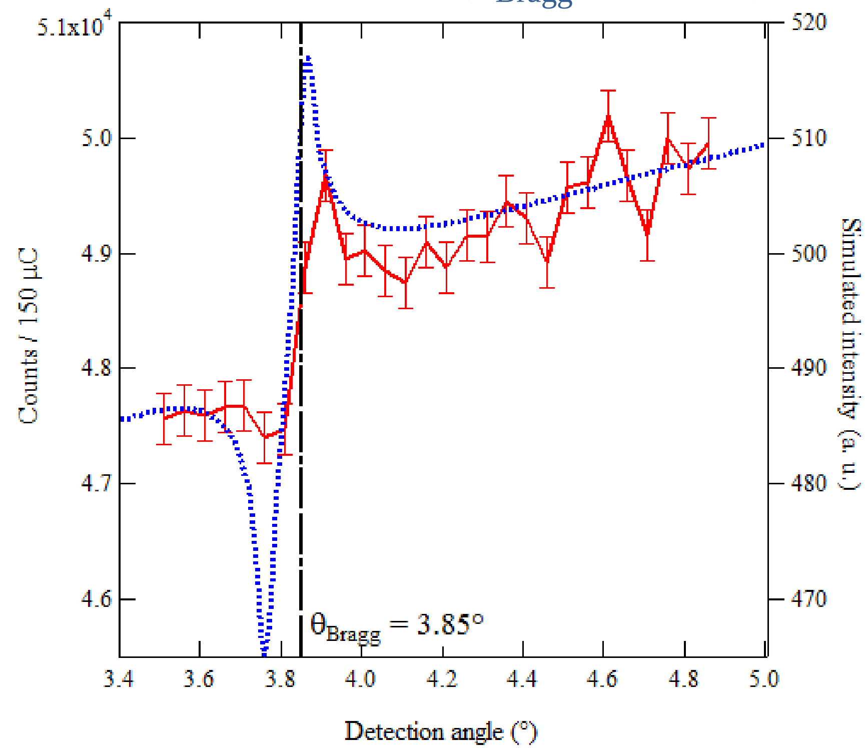
Kossel curves around the first Bragg peak

Sc Kα emission (θ_{Bragg} = 5.086°)



Cr Kα emission (θ_{Bragg} = 3.840°)



Experimental *vs* simulations

Intensity modulation over a narrow angular range (< 0.5°)

Acquisition time: ~ 1 day

Low intensity: poor contrast

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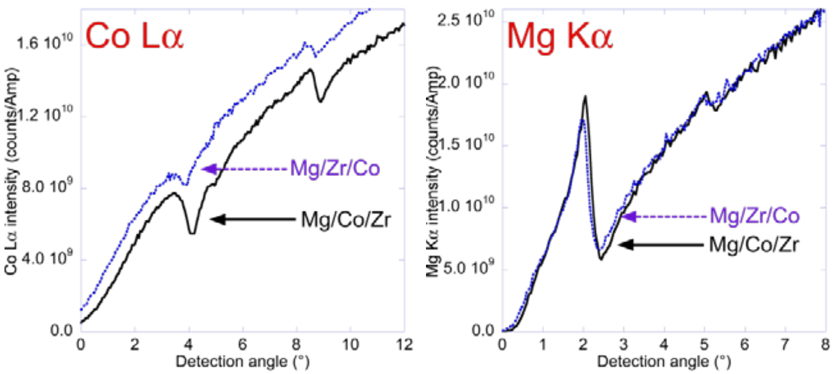
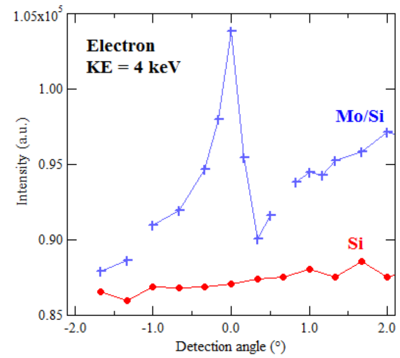
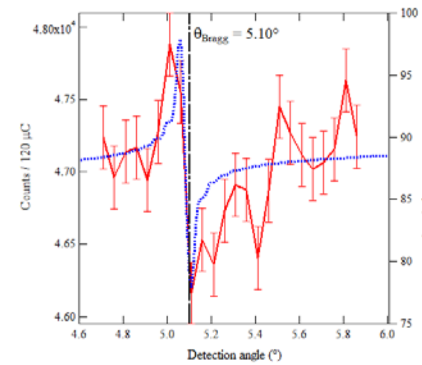
Summary and perspectives

In our team, combination of Kossel detection mode and standing wave with excitation by:

photon	electron	proton
		
Mg/Co, Mg/Zr/Co and Mg/Co/Zr	Mo/Si	Cr/B_4C/Sc

Proof of principle experiment
To our knowledge, it is the first measurement of Kossel curves originating from a multilayer excited using protons.

Low contrast in the Kossel curves
- low intensity
- no available information on interfaces

Future: improvement of the detection
« color camera »: no more angular scan