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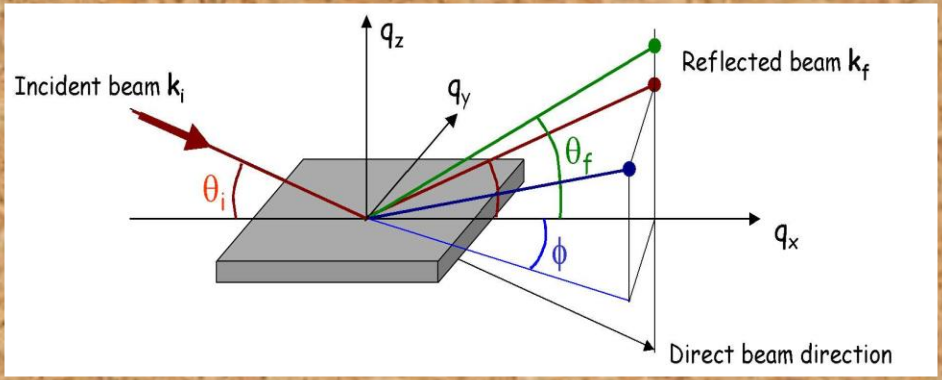
Project Title

Studying Nanostructure Magnetism with the use of Polarized Neutron Reflectometry

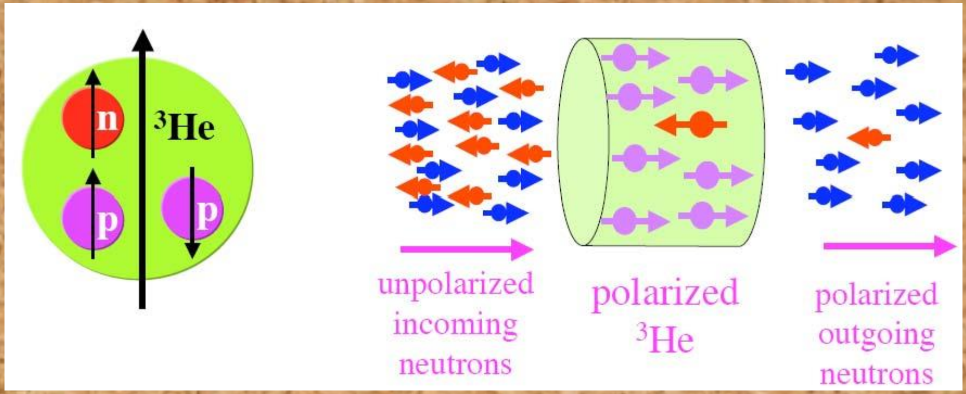
Polarized Neutron Reflectometry (PNR)



- A method used to determine the structure of materials by directing a beam of polarized neutrons onto an extremely flat surface.

- The intensity of the reflected neutrons is measured as a function of and neutron wavelength.

Polarized neutrons



- Polarized neutrons are a collection of neutrons whose spins have a preferential orientation with respect to a particular direction in space (usually the direction of a magnetic field), rather than being at random.

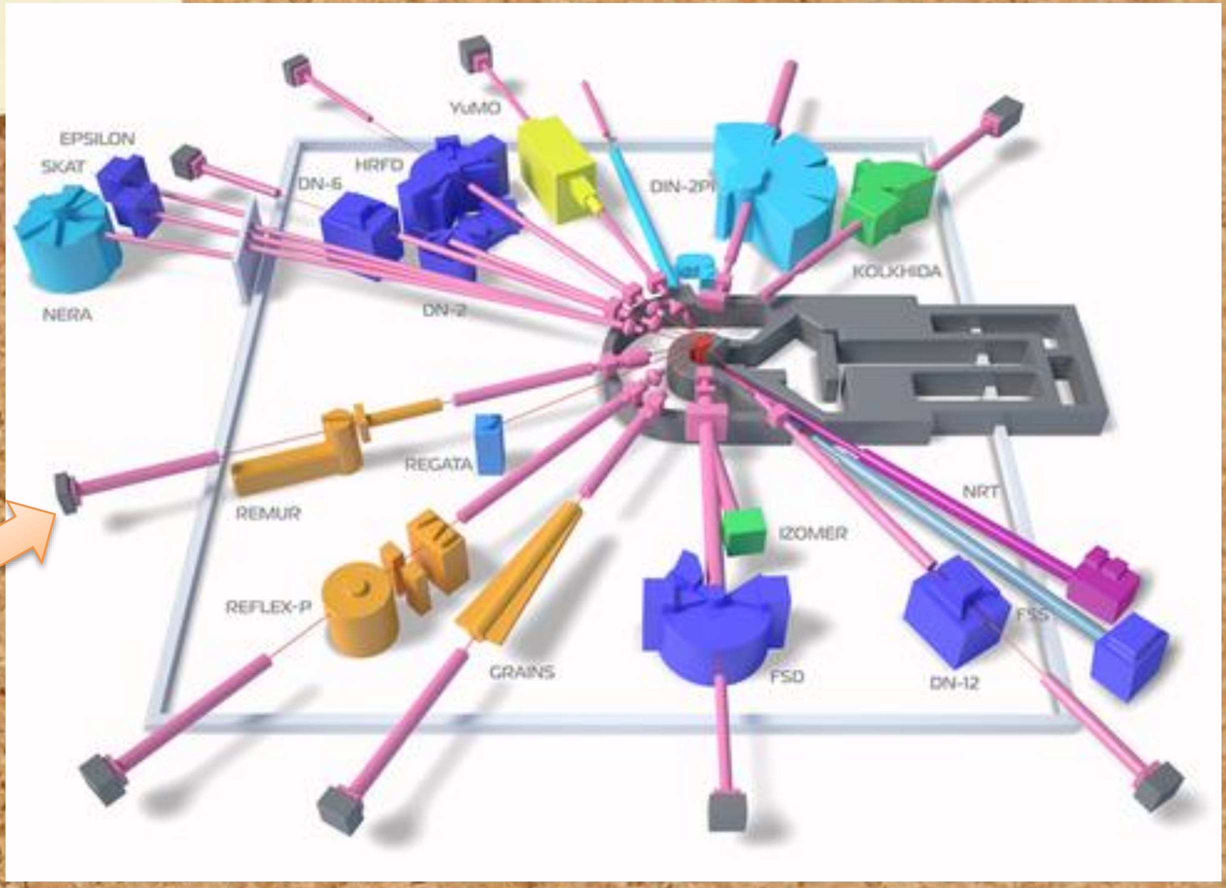
Using PNR for Research Purposes

- Separation of nuclear magnetic scattering.
- Determination of the magnitude and the orientation of the local magnetization of the sample.
- The measurement of the coupling between magnetic and nuclear structures.

Examples of PNR experiments

- **Specular Reflection:**
  - ✓ A polarized incident beam with no analysis.
  - ✓ A polarized incident beam with analysis.
- **Off Specular Reflection:**
  - ✓ A polarized incident beam with no analysis.
  - ✓ A polarized incident beam with analysis.

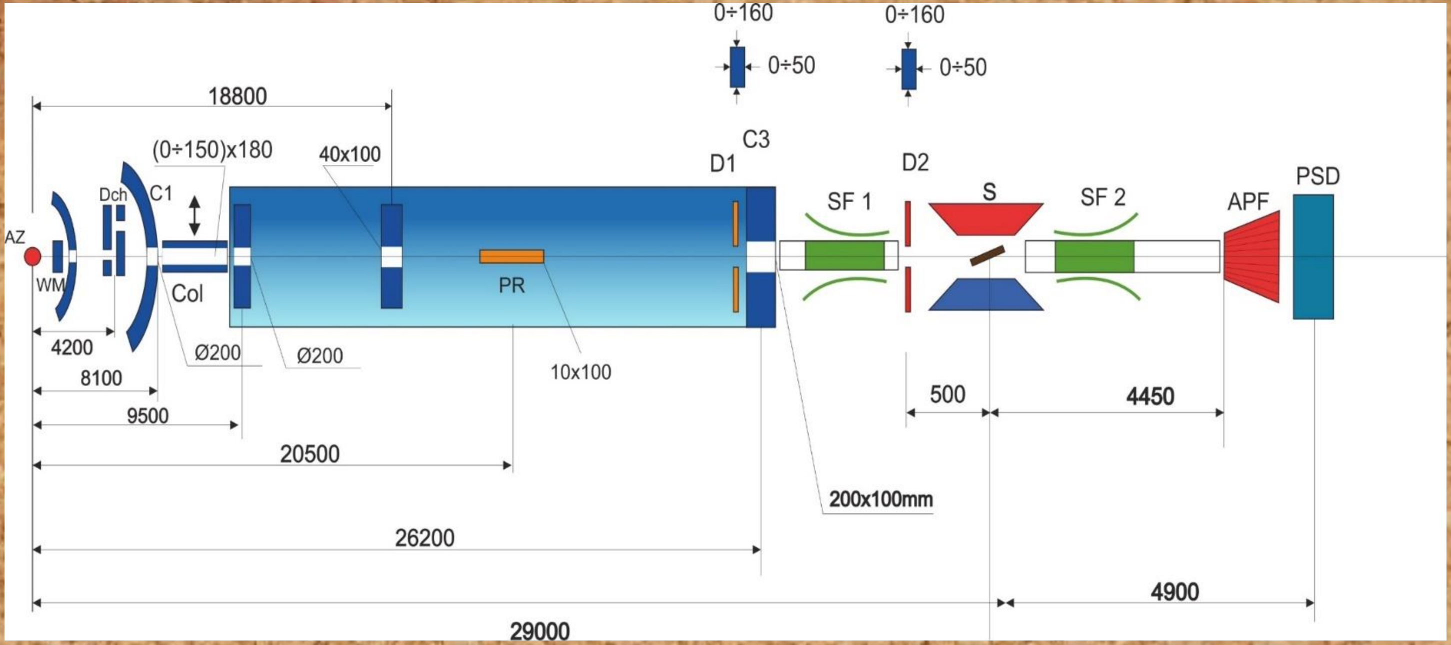
REMUR at FLNP



REMUR channel on the IBR-2 reactor

Schematic of REMUR

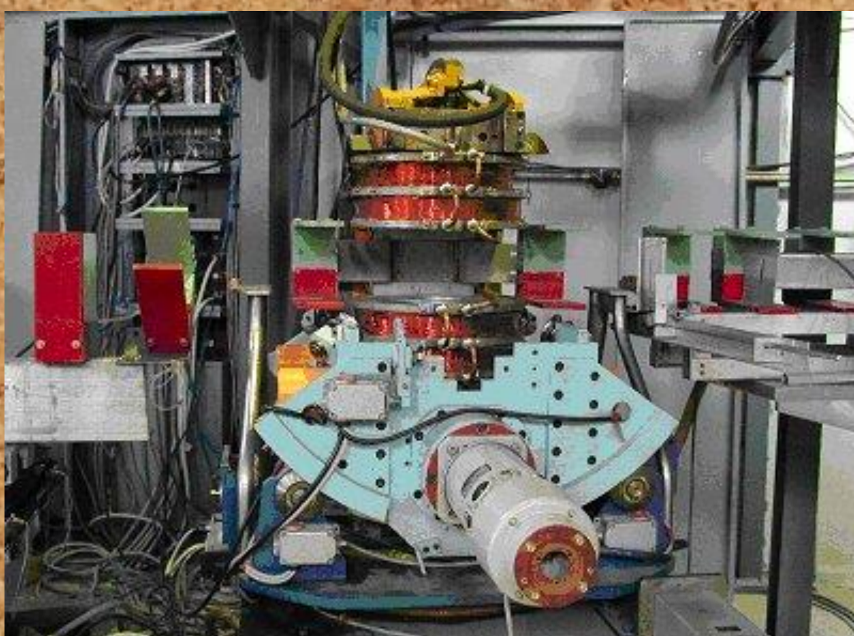
AZ – active zone, **WM** – water moderator, **Dch** – chopper, **Col, C1(2,3)** – collimators, **D1(2)** – diaphragms, **PR** – polarizer, **SF1(2)** – spin-flippers, **S** – sample position, **APF** – polarization analyzer, **PSD** – position secretive detector.



REMUR spectrometer

Parameters of the REMUR:

- Sample plane: vertical
- Scattering plane: horizontal
- Neutron wavelength: 0.9 – 10 Å
- Wavelength resolution: $\delta\lambda$ = 0.011 Å
- Scattering angle range: 1 – 100 mrad
- Sample – detector distance: 4.9 m
- Detector's spatial resolution: 1.5 mm
- Neutron flux in two polarization modes:
  - two polarizers (PR1+PR2): 10^4 neutron/(sec•cm^2)
  - the second polarizer (PR2): 3•10^4 neutron/(sec•cm^2)

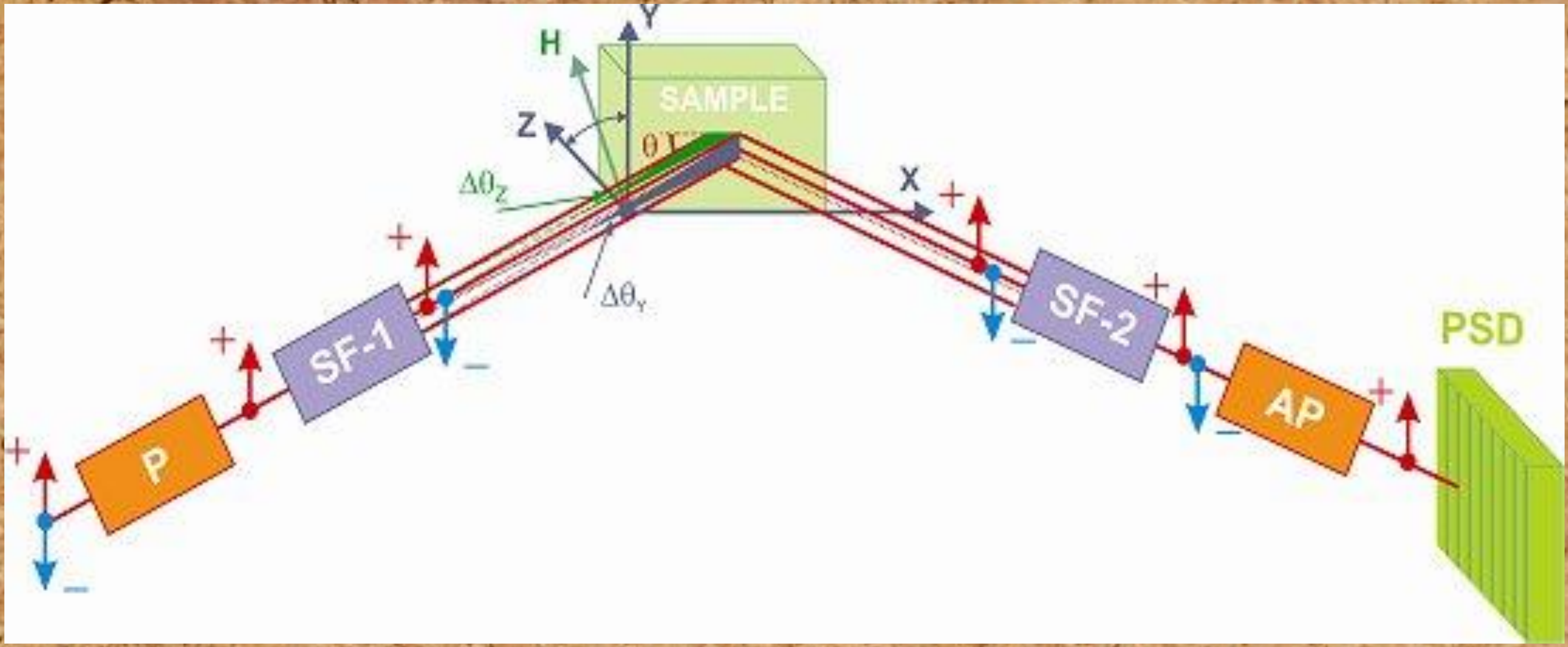


Cyrostat

Goniometer

Layout of PNR

- P : Polarizer
- SF-1 : Spin flipper
- SF-2: Spin flipper
- AP : Analyzer of polarization
- PSD : Photo-sensitive Detector



Materials under study

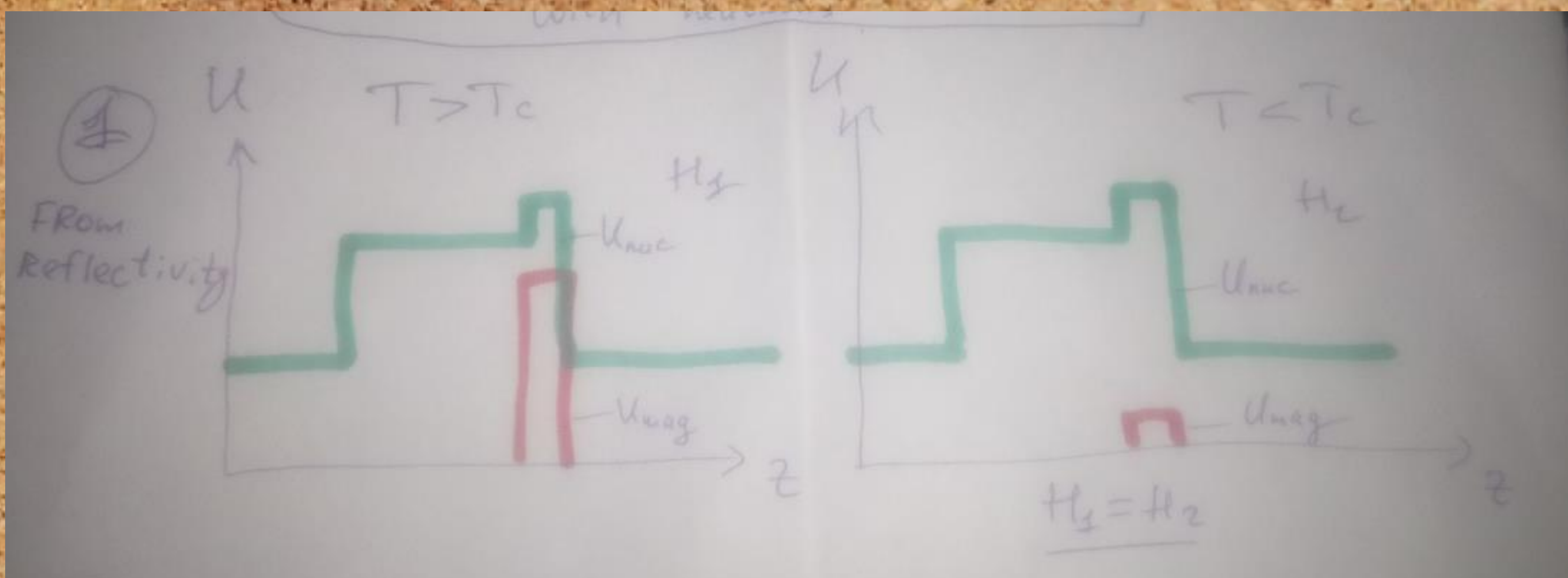
- **Ferromagnetic and superconducting layered nanostructures for example:**
  - ✓ **Fe/Cr and Fe/V nanoystems**
  - ✓ **Ta/V/$Fe_{0.7}V_{0.3}$/V/$Fe_{0.7}V_{0.3}$/Nb/Si**
- **Material of interest:**
  - ✓ **Si/Nb/$Ni_{0.7}Cu_{0.3}$/Si**

Crypto-ferromagnetism

- Crypto-ferromagnetic state is observed in non-homogeneous magnetic heterostructures that consists of a bulk superconductor and ferromagnetic thin layer that can be due to the influence of the superconductor.

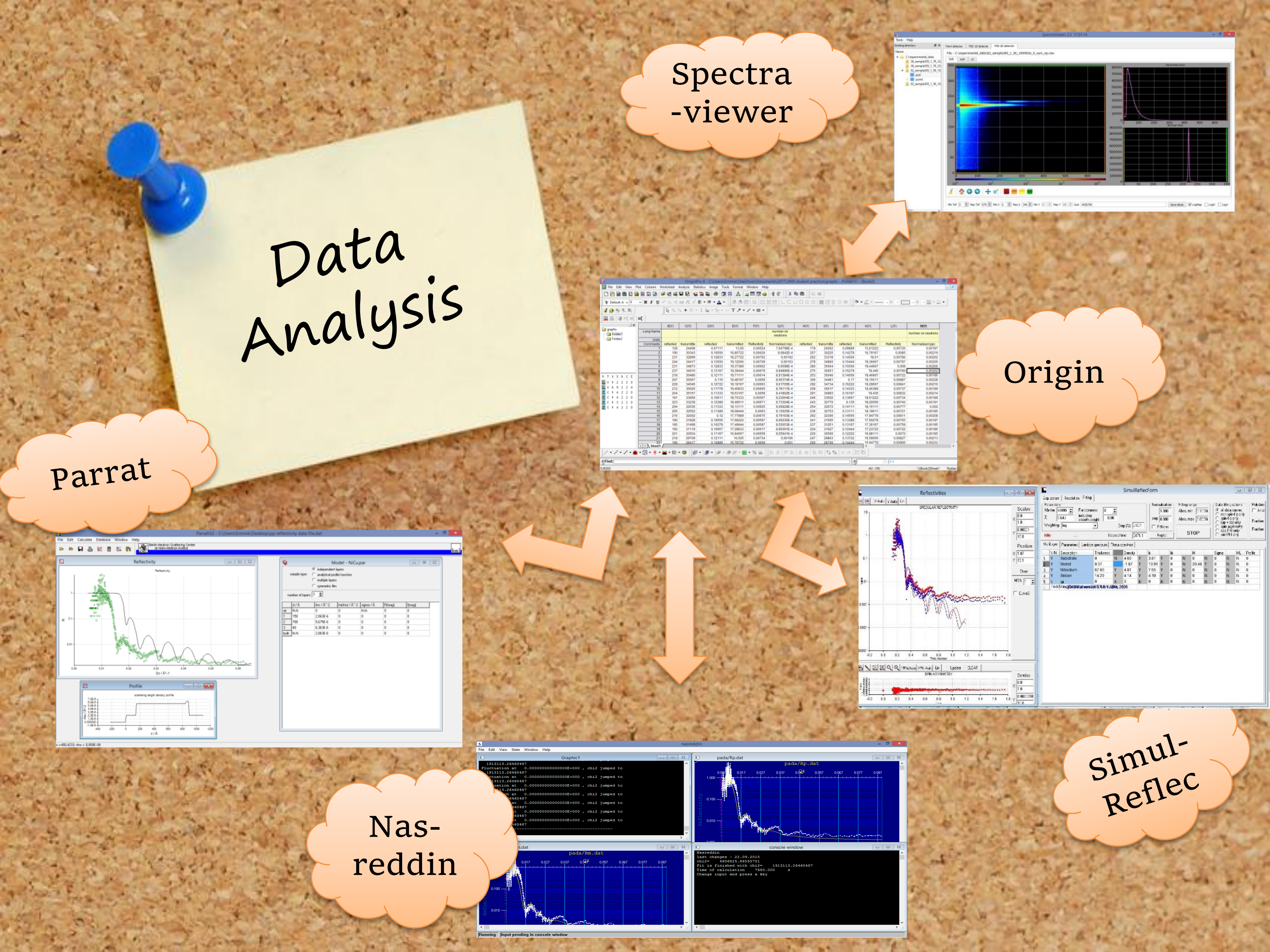
How cryptoferro-magnetism is observed

From Scattering measurements we can determine the size of the material.



AIM

- To study crypto-ferromagnetism using polarized neutron reflectometry (PNR) of ferromagnetic and superconducting layered nanostructures


Data Analysis
Spectra
-viewer
Origin
Parrat
Simul-
Reflec
Nas-
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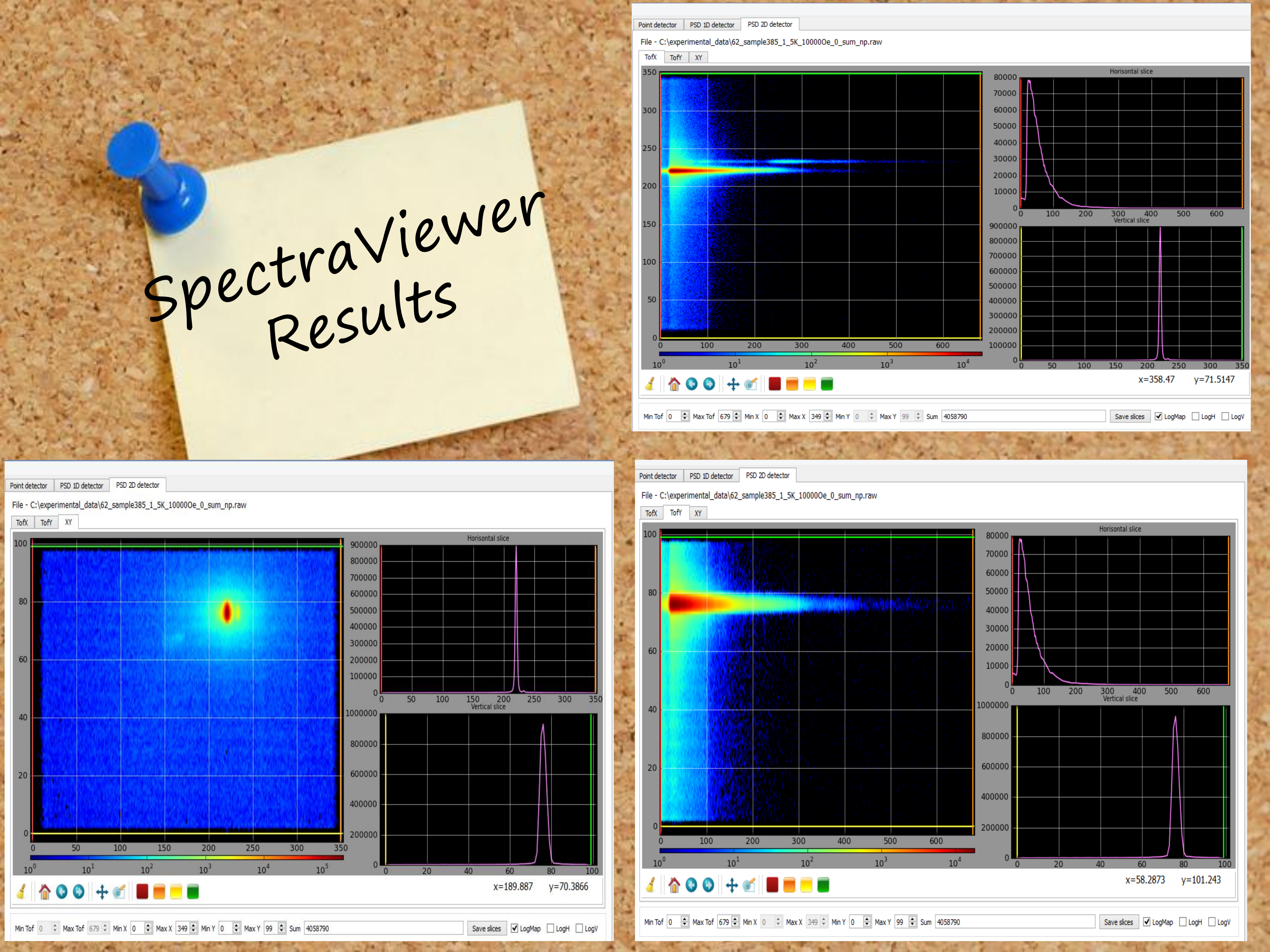
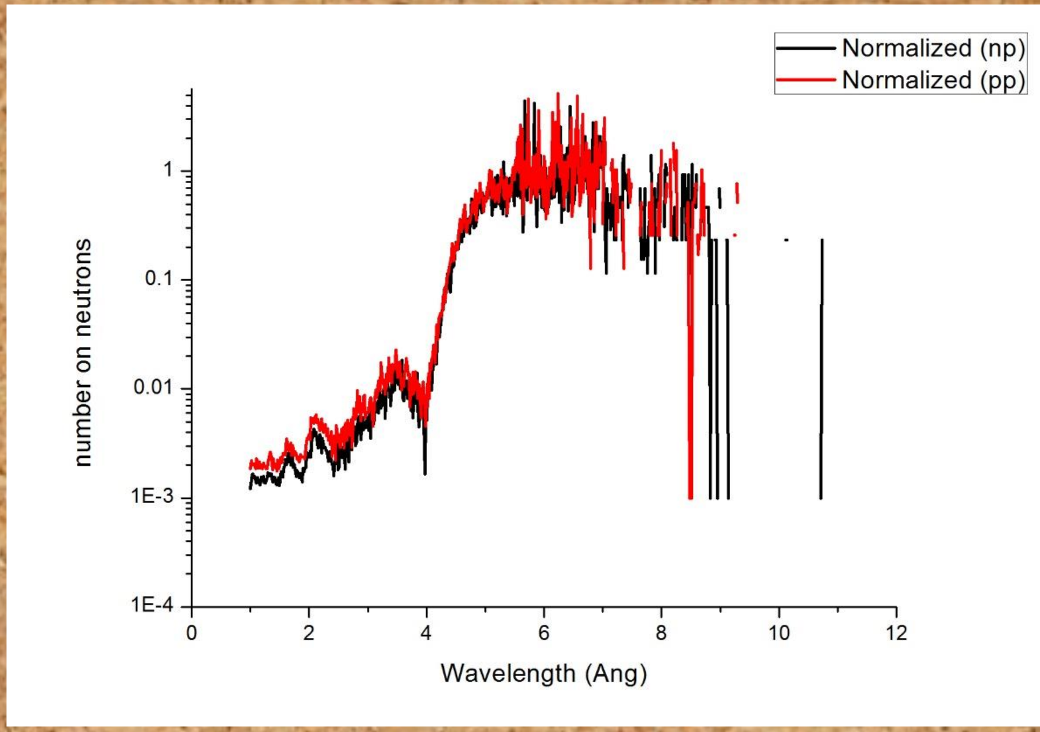
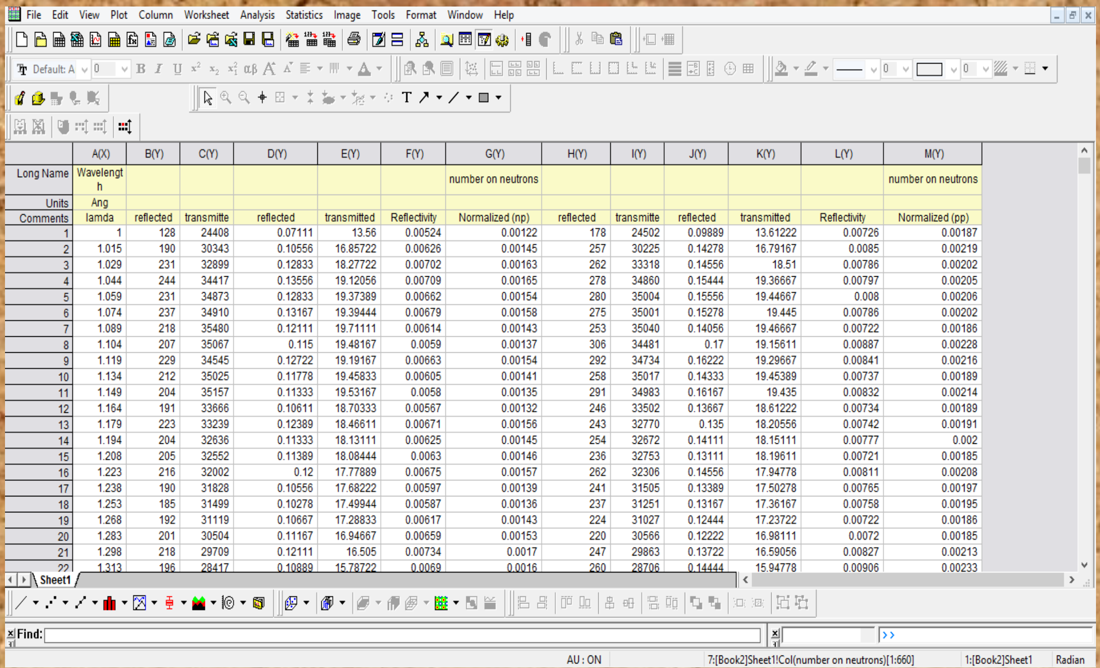

SpectraViewer
Results
Point detector
PSD 1D detector
PSD 2D detector
File - C:\experimental_data\62_sample385_1_5K_10000Oe_0_sum_np.raw
TofX
TofY
XY
Horisontal slice
Vertical slice
x=358.47
y=71.5147
x=189.887
y=70.3866
x=58.2873
y=101.243
Min Tof
Max Tof
Min X
Max X
Min Y
Max Y
Sum
4058790
Save slices
LogMap
LogH
LogV





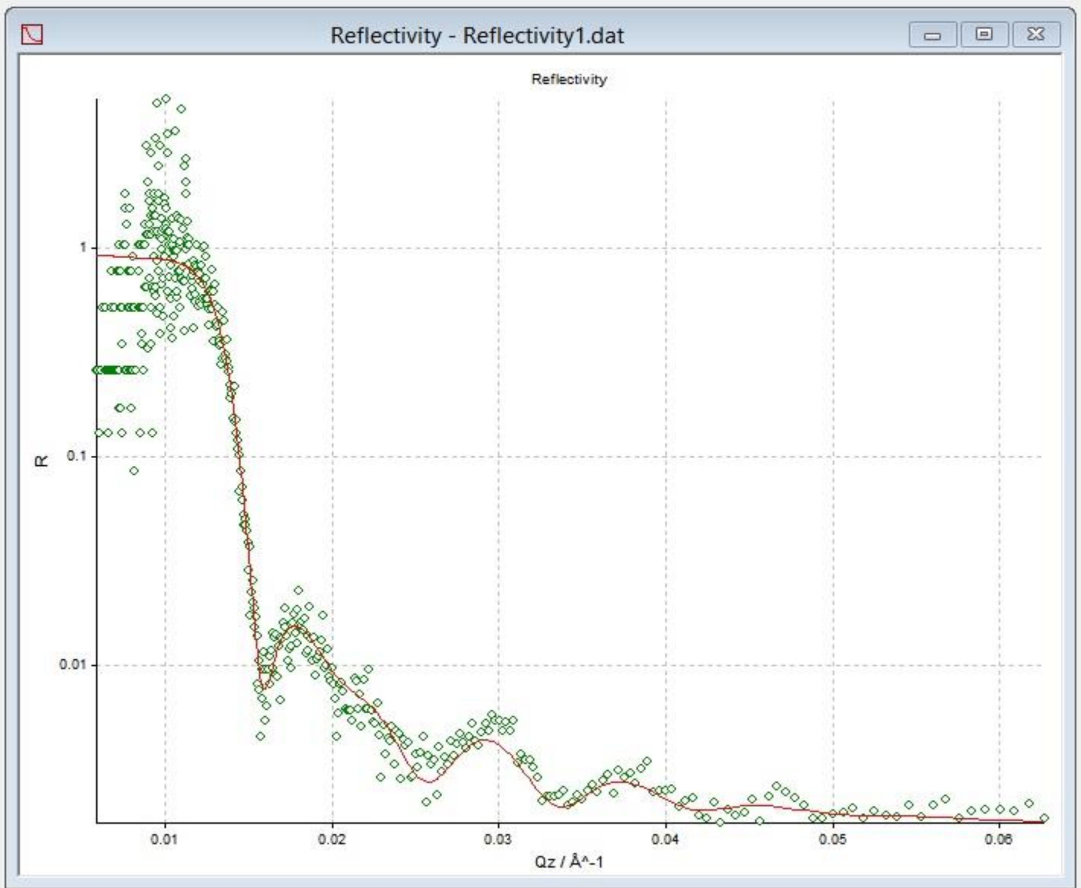
	A(X)	B(Y)	C(Y)	D(Y)	E(Y)	F(Y)	G(Y)	H(Y)	I(Y)	J(Y)	K(Y)	L(Y)	M(Y)
Long Name	Wavelength						number on neutrons						number on neutrons
Units	Ang												
Comments	lamda	reflected	transmitte	reflected	transmitted	Reflectivity	Normalized (np)	reflected	transmitte	reflected	transmitted	Reflectivity	Normalized (pp)
1	1	128	24408	0.07111	13.56	0.00524	0.00122	178	24502	0.09889	13.61222	0.00726	0.00187
2	1.015	190	30343	0.10556	16.85722	0.00626	0.00145	257	30225	0.14278	16.79167	0.0085	0.00219
3	1.029	231	32899	0.12833	18.27722	0.00702	0.00163	262	33318	0.14556	18.51	0.00786	0.00202
4	1.044	244	34417	0.13556	19.12056	0.00709	0.00165	278	34860	0.15444	19.36667	0.00797	0.00205
5	1.059	231	34873	0.12833	19.37389	0.00662	0.00154	280	35004	0.15556	19.44667	0.008	0.00206
6	1.074	237	34910	0.13167	19.39444	0.00679	0.00158	275	35001	0.15278	19.445	0.00786	0.00202
7	1.089	218	35480	0.12111	19.71111	0.00614	0.00143	253	35040	0.14056	19.46667	0.00722	0.00186
8	1.104	207	35067	0.115	19.48167	0.0059	0.00137	306	34481	0.17	19.15611	0.00887	0.00228
9	1.119	229	34545	0.12722	19.19167	0.00663	0.00154	292	34734	0.16222	19.29667	0.00841	0.00216
10	1.134	212	35025	0.11778	19.45833	0.00605	0.00141	258	35017	0.14333	19.45389	0.00737	0.00189
11	1.149	204	35157	0.11333	19.53167	0.0058	0.00135	291	34983	0.16167	19.435	0.00832	0.00214
12	1.164	191	33666	0.10611	18.70333	0.00567	0.00132	246	33502	0.13667	18.61222	0.00734	0.00189
13	1.179	223	33239	0.12389	18.46611	0.00671	0.00156	243	32770	0.135	18.20556	0.00742	0.00191
14	1.194	204	32636	0.11333	18.13111	0.00625	0.00145	254	32672	0.14111	18.15111	0.00777	0.002
15	1.208	205	32552	0.11389	18.08444	0.0063	0.00146	236	32753	0.13111	18.19611	0.00721	0.00185
16	1.223	216	32002	0.12	17.77889	0.00675	0.00157	262	32306	0.14556	17.94778	0.00811	0.00208
17	1.238	190	31828	0.10556	17.68222	0.00597	0.00139	241	31505	0.13389	17.50278	0.00765	0.00197
18	1.253	185	31499	0.10278	17.49944	0.00587	0.00136	237	31251	0.13167	17.36167	0.00758	0.00195
19	1.268	192	31119	0.10667	17.28833	0.00617	0.00143	224	31027	0.12444	17.23722	0.00722	0.00186
20	1.283	201	30504	0.11167	16.94667	0.00659	0.00153	220	30566	0.12222	16.98111	0.0072	0.00185
21	1.298	218	29709	0.12111	16.505	0.00734	0.0017	247	29863	0.13722	16.59056	0.00827	0.00213
22	1.313	196	28417	0.10889	15.78722	0.0069	0.0016	260	28706	0.14444	15.94778	0.00906	0.00233

Normalize data and plot the reflectivity.

Parrat

- **Fitting the experimental data to a theoretical model.**
- **Experimental data is represented by the green dots and theoretical fit is the red line.**

BUT ….we could not measure the magnetization

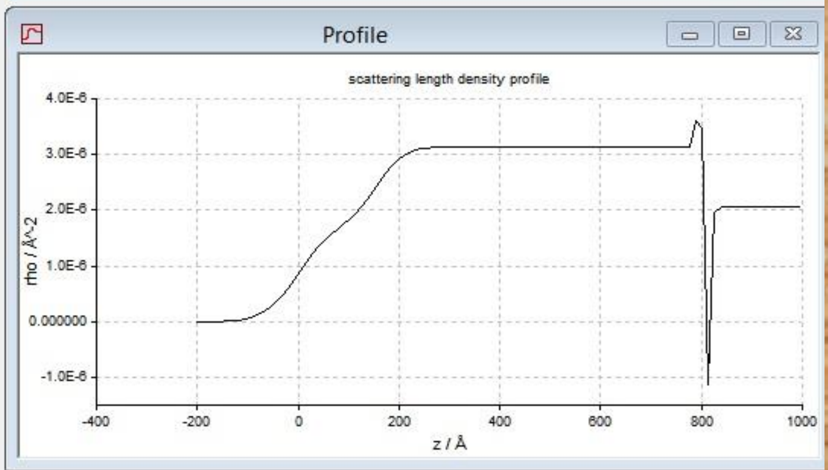


Model - Model filet.par

sample type: (•) independent layers ( ) analytical profile function ( ) multiple layers ( ) symmetric film

number of layers: 3

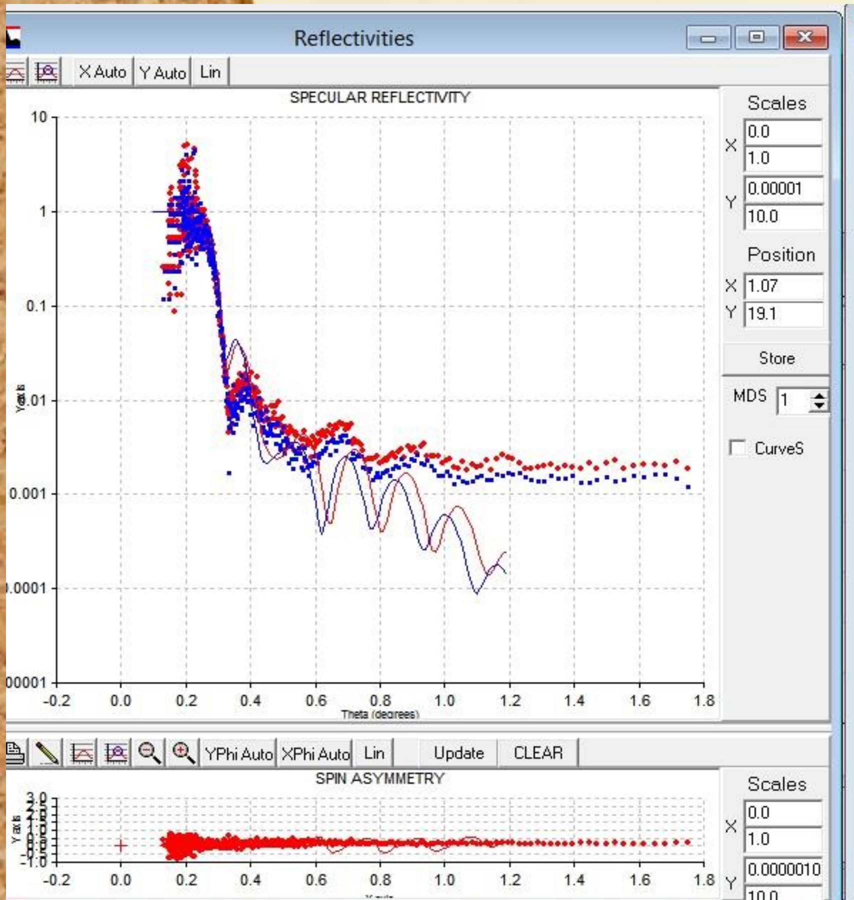
	d / Å	rho / Å^-2	Im(rho) / Å^-2	sigma / Å	R(mag)	I(mag)
air	N/A	0E+0	0E+00	N/A	0	0
1	155,25	1,736E-6	1,769E-07	53,309	0	0
2	647,57	3,132E-6	-9,166E-08	43,307	0	0
3	3,46	-1,816E-5	-9,108E-07	0,891	0	0
bulk	N/A	2,07E-6	5,445E-08	8,089	0	0

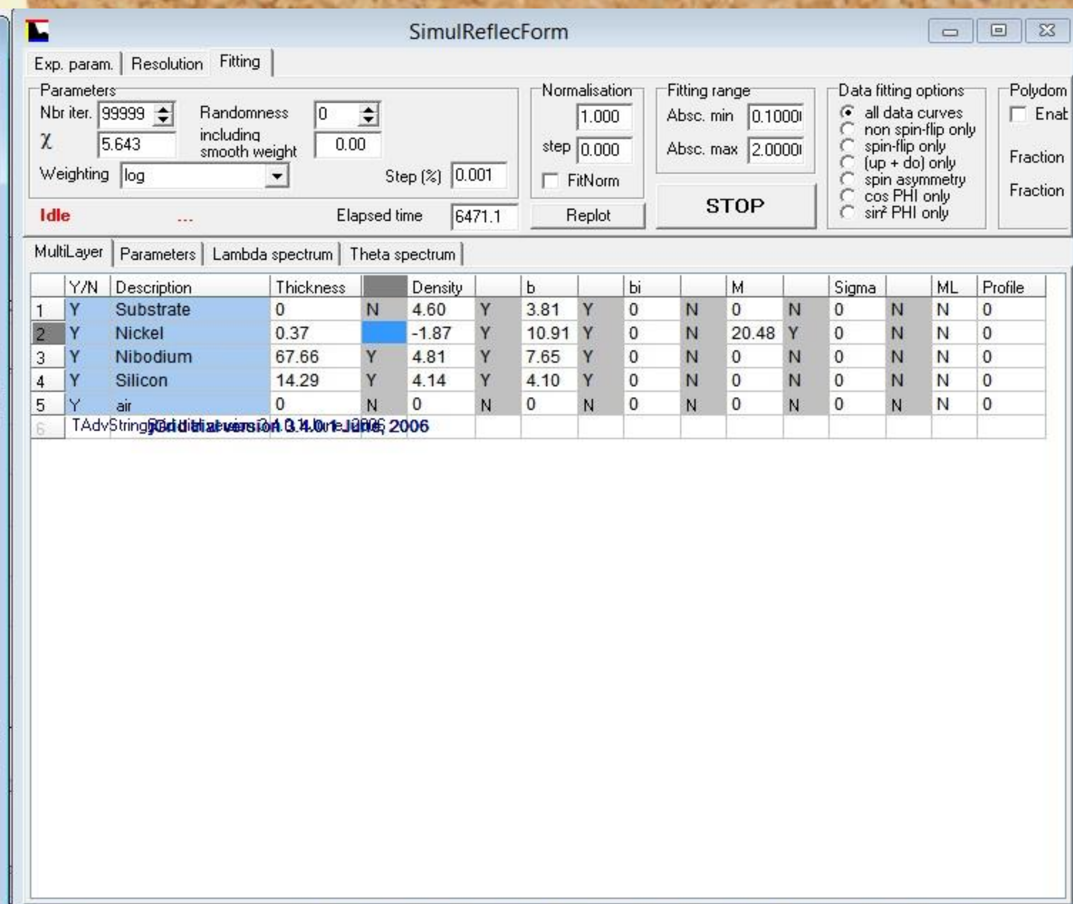


SimulReflec

- **Fitting the experimental data to a theoretical model.**
- **Experimental data is represented by the green dots and theoretical fit is the red line.**

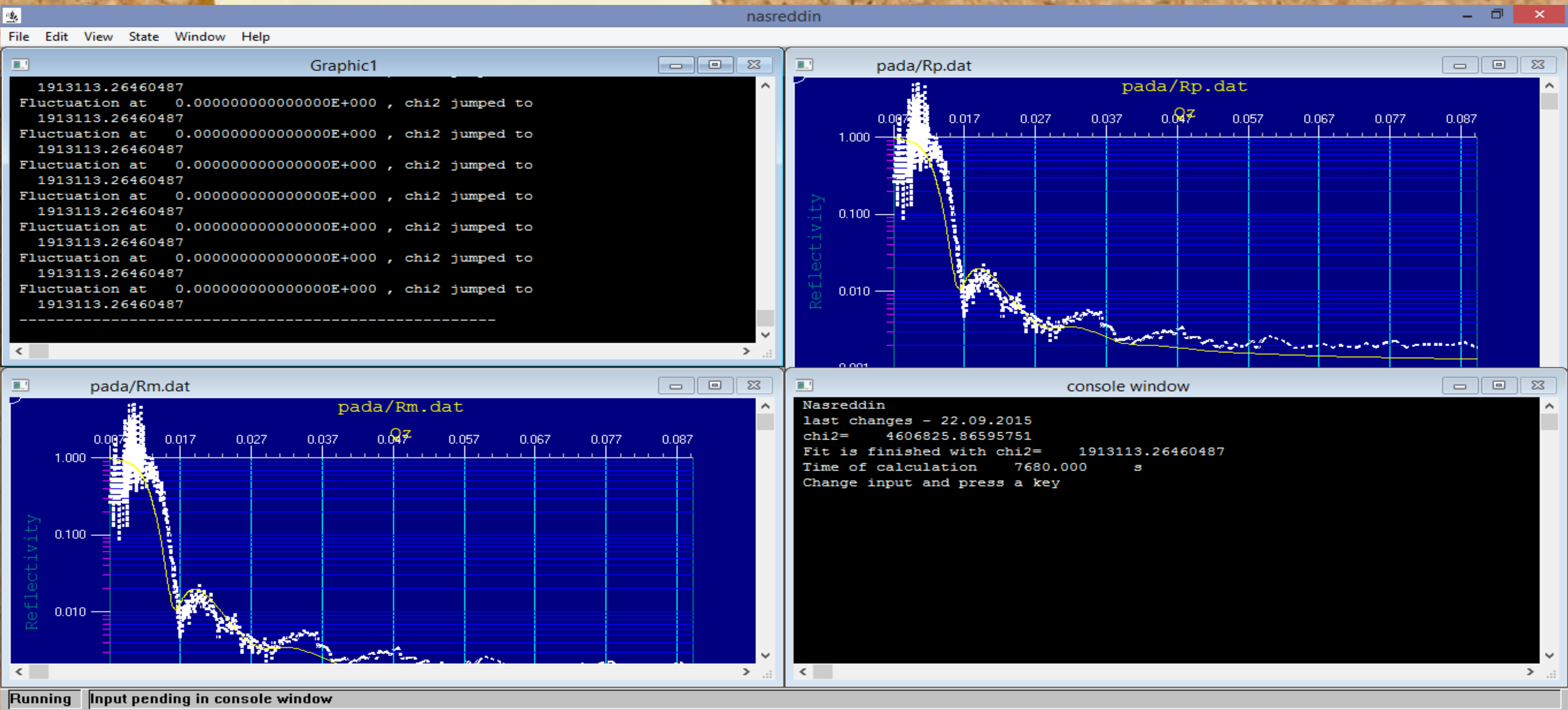
BUT… we could not subtract the background from the theoretical model





- Fitting the experimental data to a theoretical model.
- Experimental data is represented by the green dots and theoretical fit is the red line.

Finally…we could both subtract the background and measure magnetization from the theoretical fit.



Closing Remarks

- The experimental data yielded a perfect fit using the Parrat program but unfortunately we could not measure the magnetization of the sample.
- SimulReflec could not give a perfect fit as a result of not being able to subtract the background on the theoretical fit.
- I learnt how to fit data using various software and gained a lot of knowledge about PNR.

Acknowledge-ments

Project supervisors

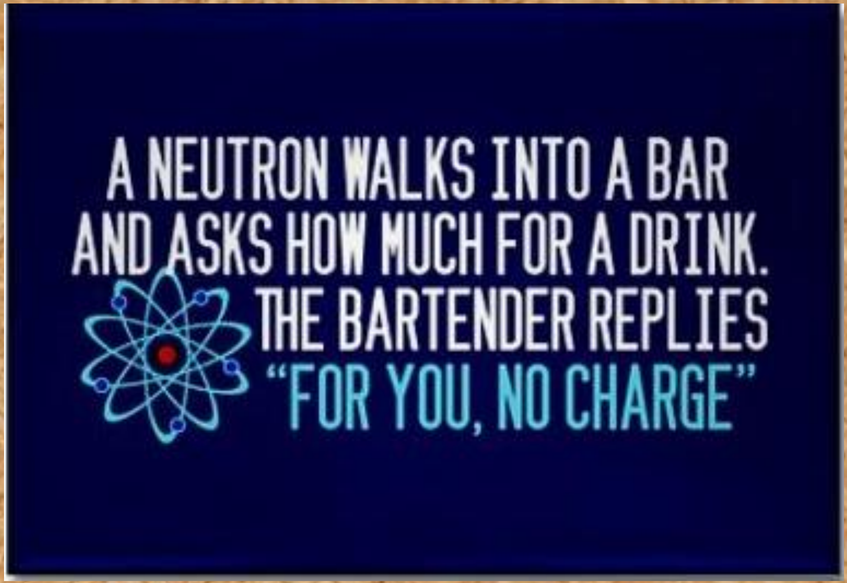
iThemba LABS

NRF

JINR

Julia Rybachuk and Lisa Budennaya

Questions ???



Thank you for your time ☺