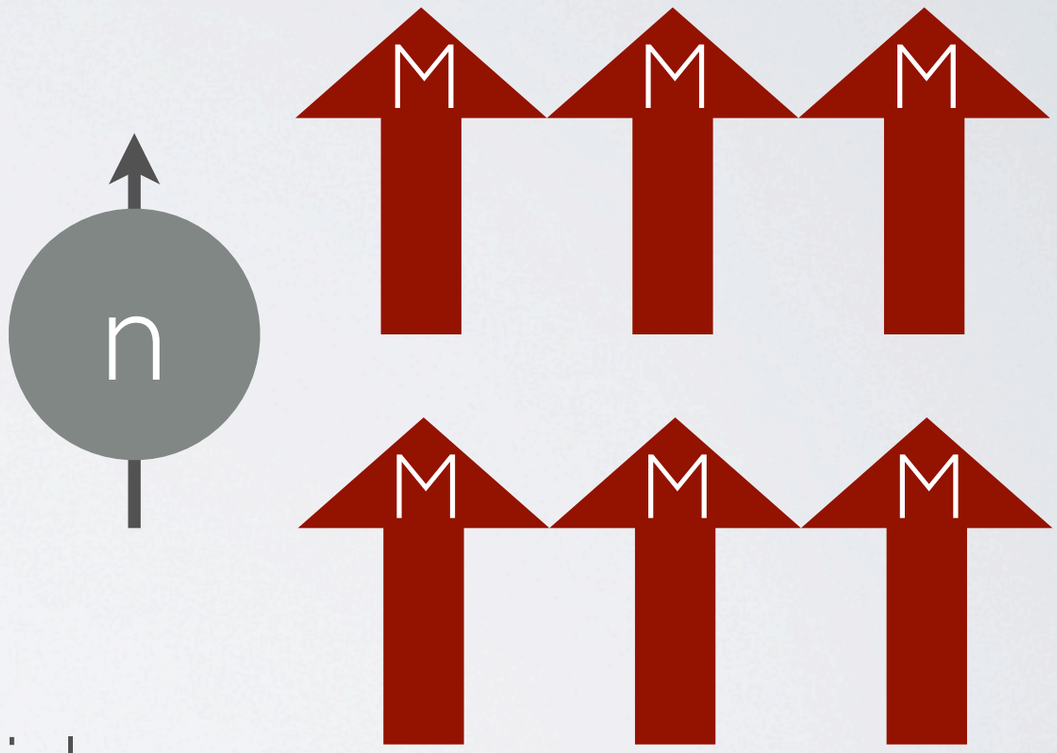
POLARIZED NEUTRON REFLECTOMETRY

2010 NIST Center for Neutron Research
Summer School on SANS & NR

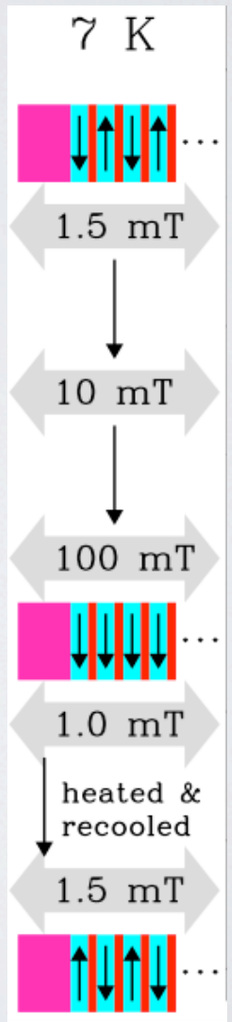
MAGNETIC SCATTERING

- nuclear scattering (nuclei)
- magnetic scattering (electrons)
- magnetization: density of "compass needles"
- neutron magnetic moment interacts with *magnetized* materials



MAGNETISM AND NR

- NR: depth profiling of thin films and multilayers
- determine individual layer *M* in magnetic nanostructures
- example: antiferromagnetic coupling



PRL **101,** 237202 (2008) PHYSICAL REVIEW LETTERS week ending 5 DECEMBER 2008

Carrier-Mediated Antiferromagnetic Interlayer Exchange Coupling in Diluted Magnetic Semiconductor Multilayers $Ga_{1-x}Mn_xAs/GaAs:Be$

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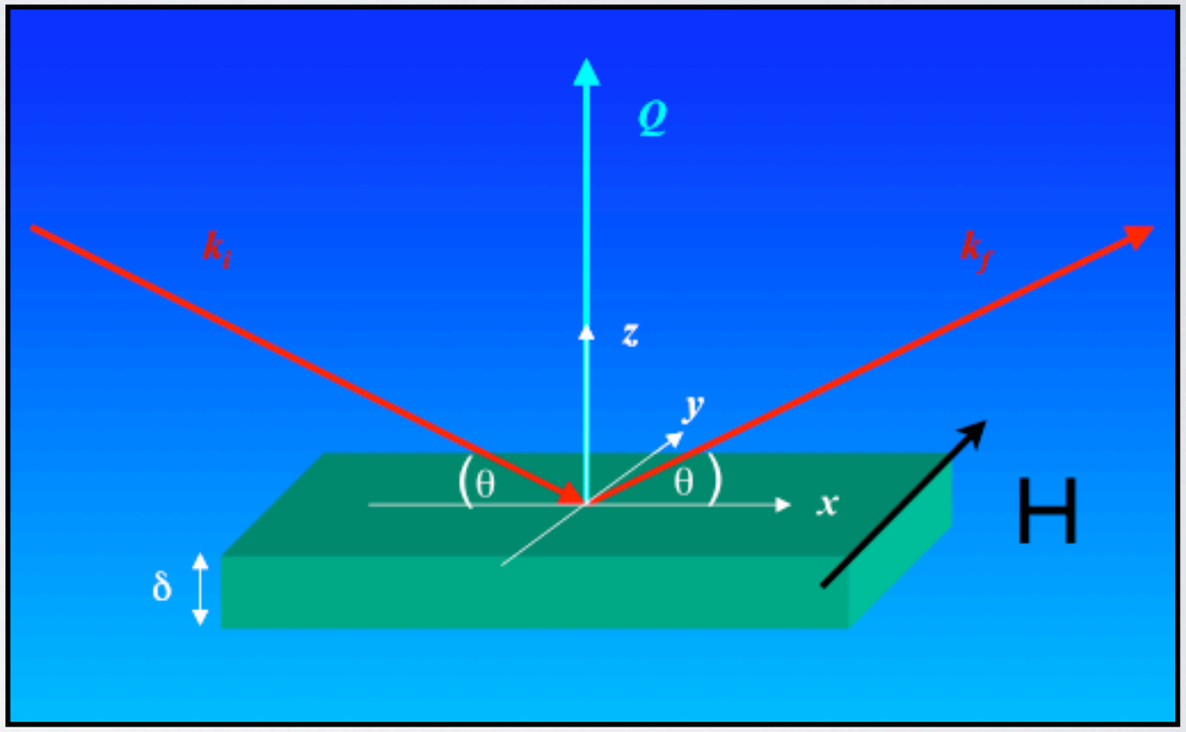
SPECULAR REFLECTOMETRY

- incident and scattered angles are the same
- *R*(*Q*z) function only of *n*(*z*)
- think of samples as stacks of slabs - a 1-D problem
- characterize buried layers and their interfaces



SCATTERING LENGTH DENSITY

- neutrons reflect at interfaces of differening *n*
- scattering length density:

$$\rho(z) = (1 - n^2)Q_z^2 / \pi$$

$$= \rho(z)_{nuclear} + \rho(z)_{magnetic}$$

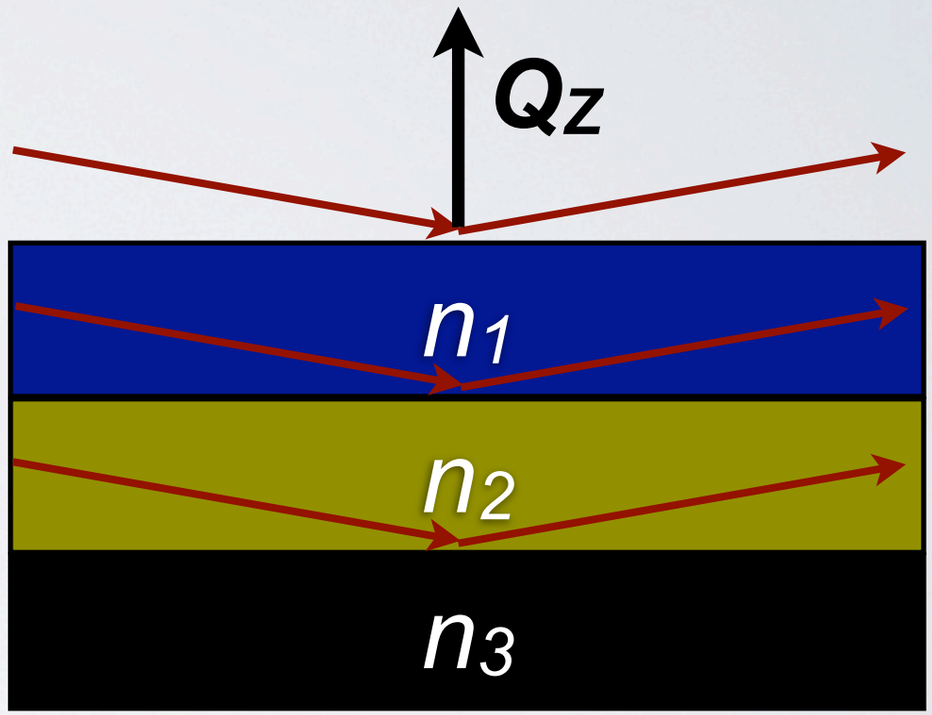
$$\rho_{nuclear} = \sum_i N_i b_i ,$$

N is the number density

b is the *scattering length*

$$\rho_{magnetic} = 2.853 \times 10^{-9} M \text{ (kA m}^{-1})$$

M is the magnetization



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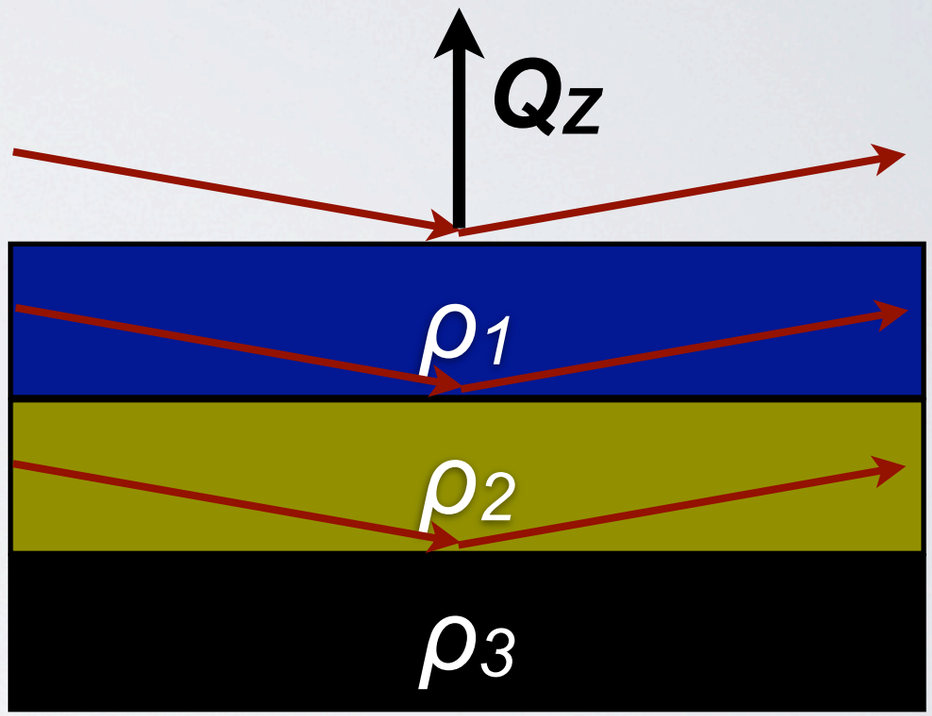
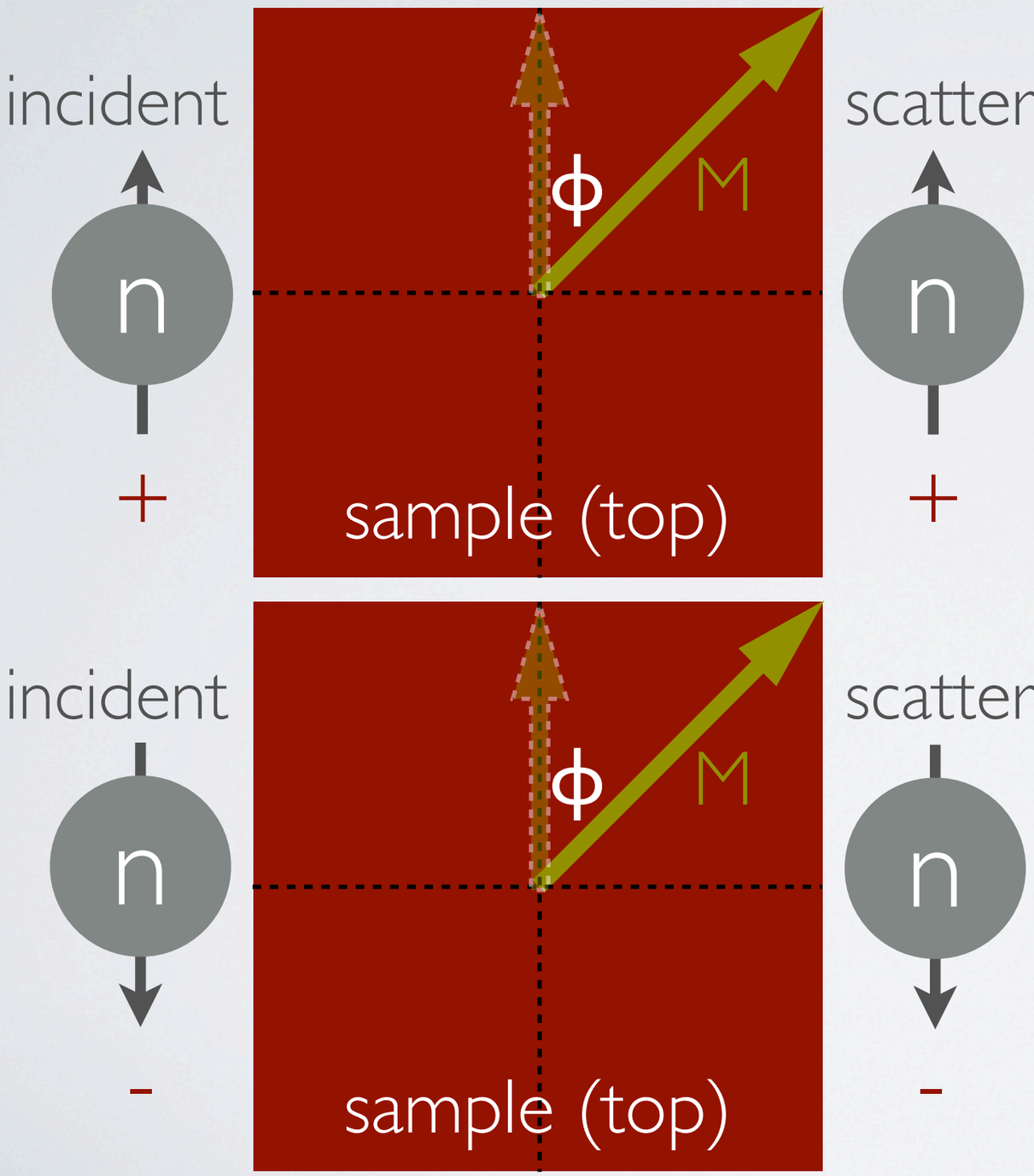


- neutron polarization helps separate ρ_{nuc} & ρ_{mag}

POLARIZED BEAM: NON SPIN FLIP



Born approximation:

$$R^{++}(z)$$

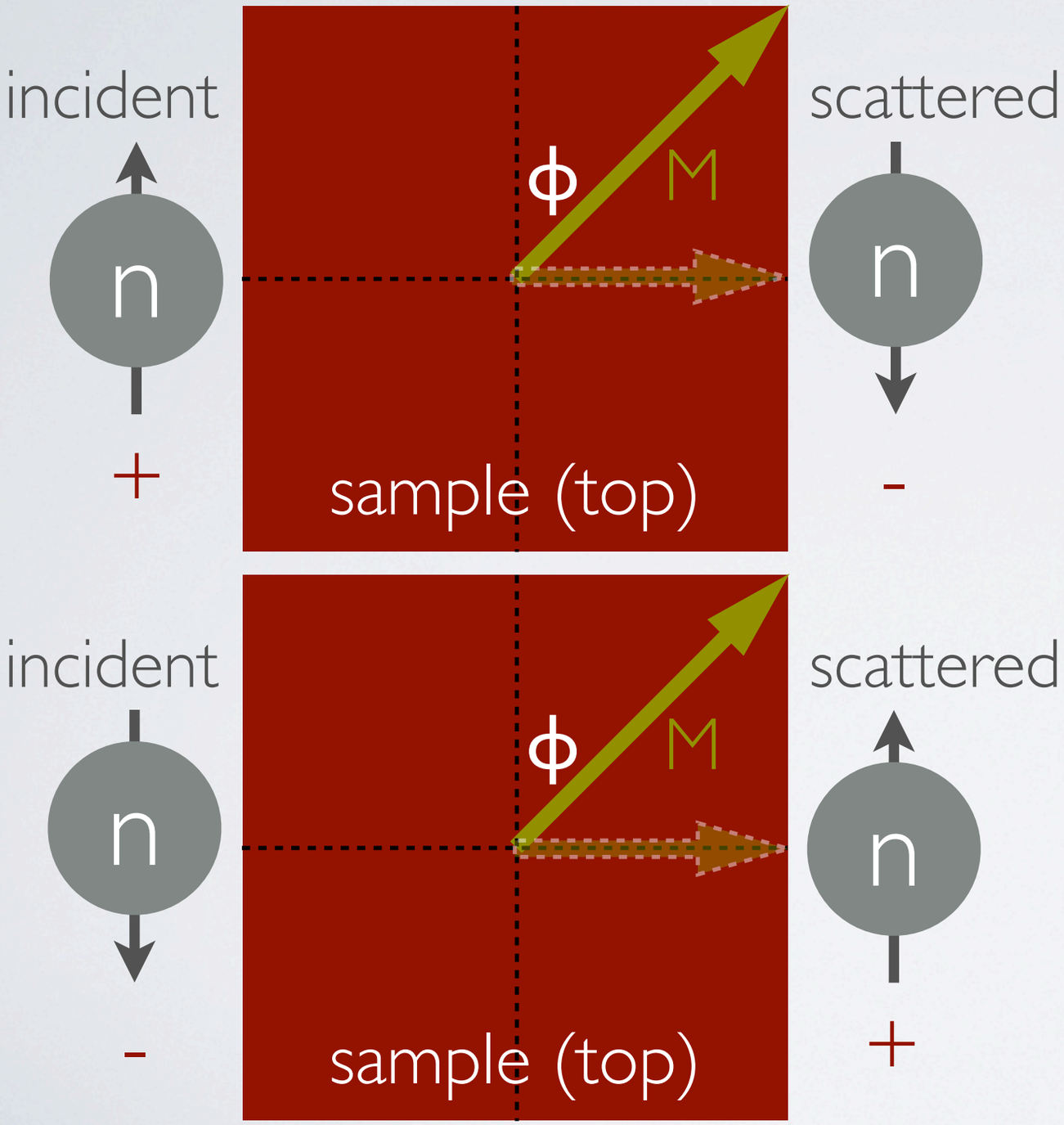
$$\alpha \int |\rho_{nuc} + \rho_{mag} \cos\phi| e^{iQ_{zz}} dz$$

$$R^{--}(z)$$

$$\alpha \int |\rho_{nuc} - \rho_{mag} \cos\phi| e^{iQ_{zz}} dz$$

nuclear & magnetic!

POLARIZED BEAM: SPIN FLIP



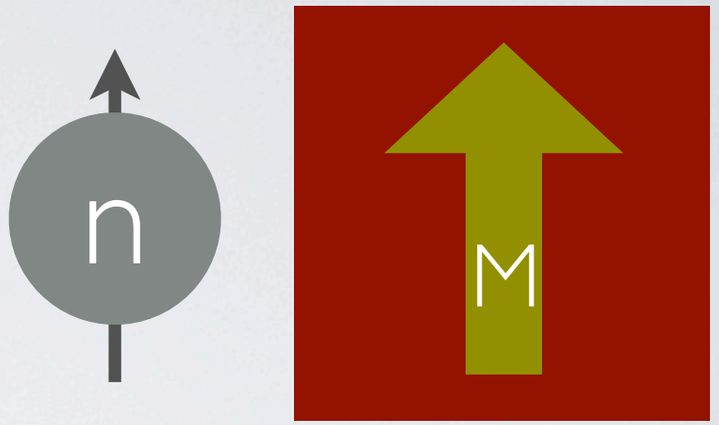
Born approximation:

$$R^{+-}(z) = R^{+-}(z)$$
$$\alpha \int |\rho_{mag} \sin\phi| e^{iQzz} dz$$

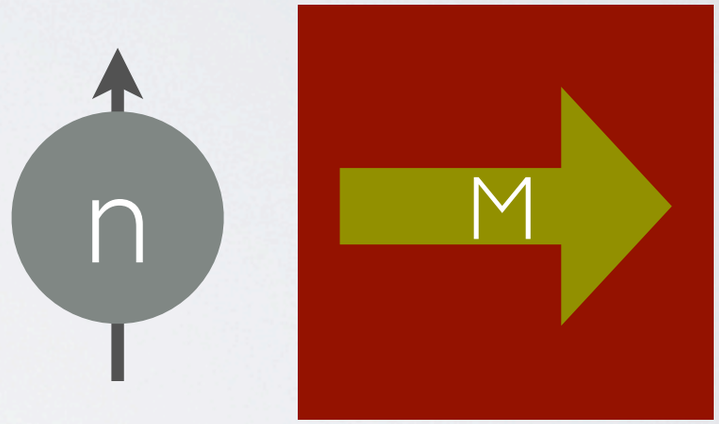
purely magnetic!

SELECTION RULES

1) projection of magnetization <u>parallel</u> to neutron spin causes non spin flip cross-sections (R^{++} & R^{--}) to be different

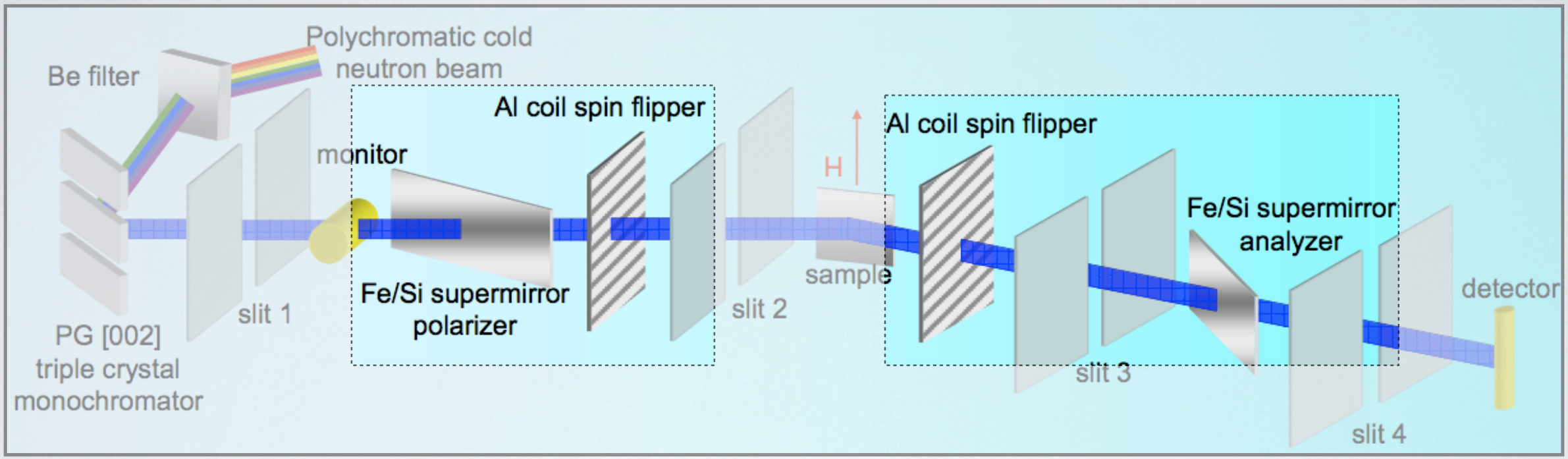


2) projection of magnetization vector perpendicular to neutron spin produces spin flip scattering (R^{++} & R^{--})



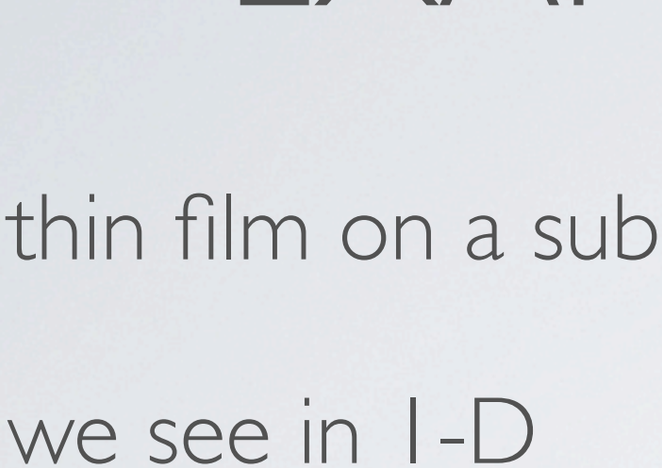
3) projection of magnetization parallel to *Q* <u>does not</u> scatter neutrons

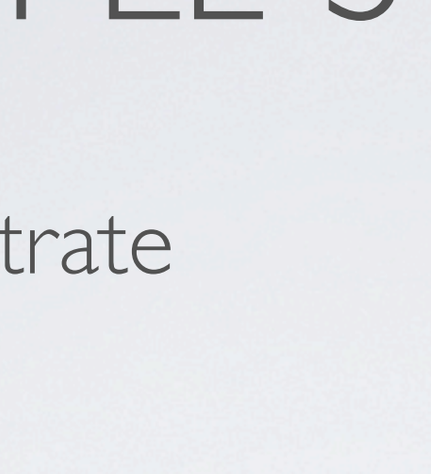
POLARIZATION ELEMENTS



EXAMPLE STRUCTURE

- thin film on a substrate
- we see in 1-D
- magnetic scattering comparable to nuclear





$\hat{z}$

500 Å Fe

$\rho_{nuc} = 8.00 \times 10^{-6}$ Å^{-2}

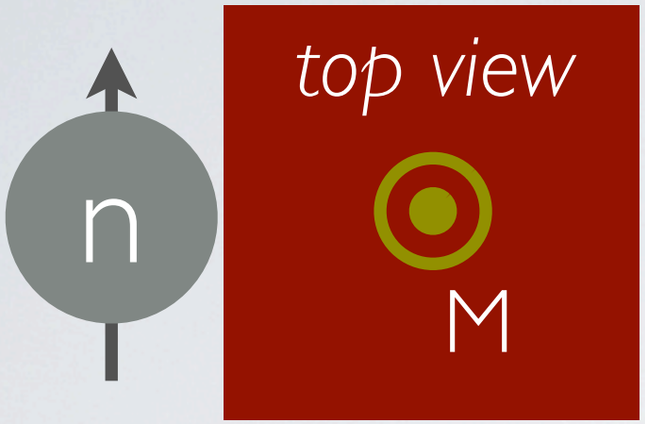
$\rho_{mag} = 4.97 \times 10^{-6}$ Å^{-2}

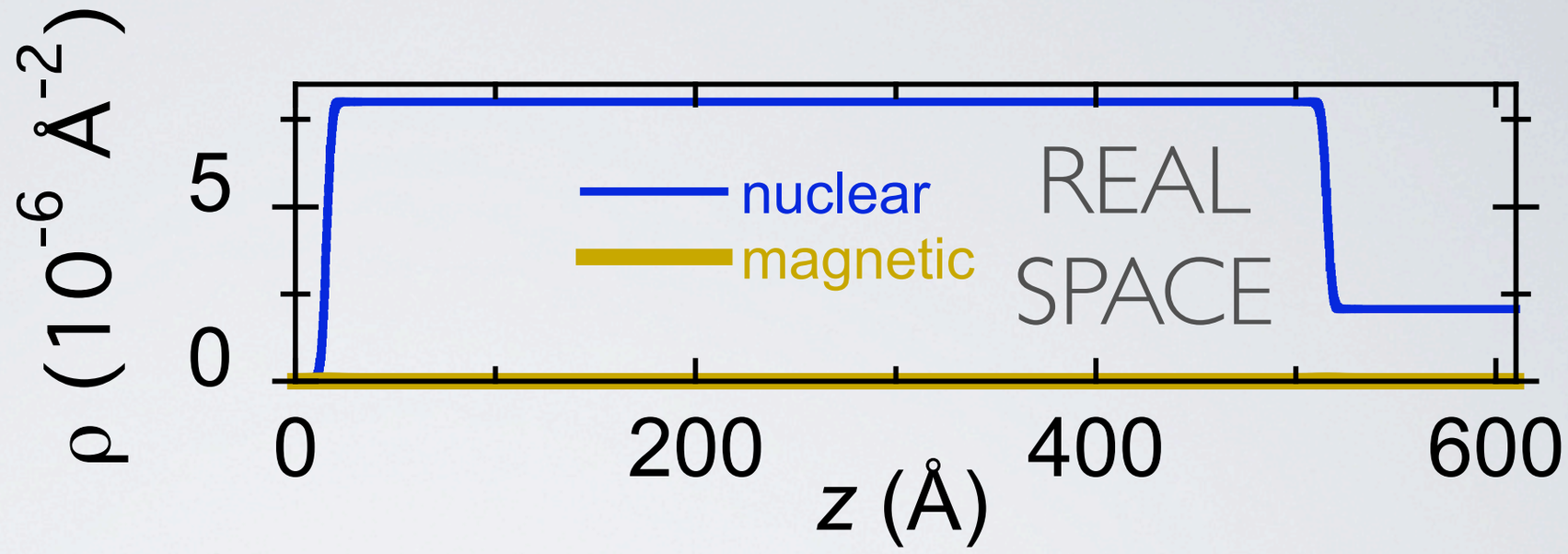
Si substrate (infinite)

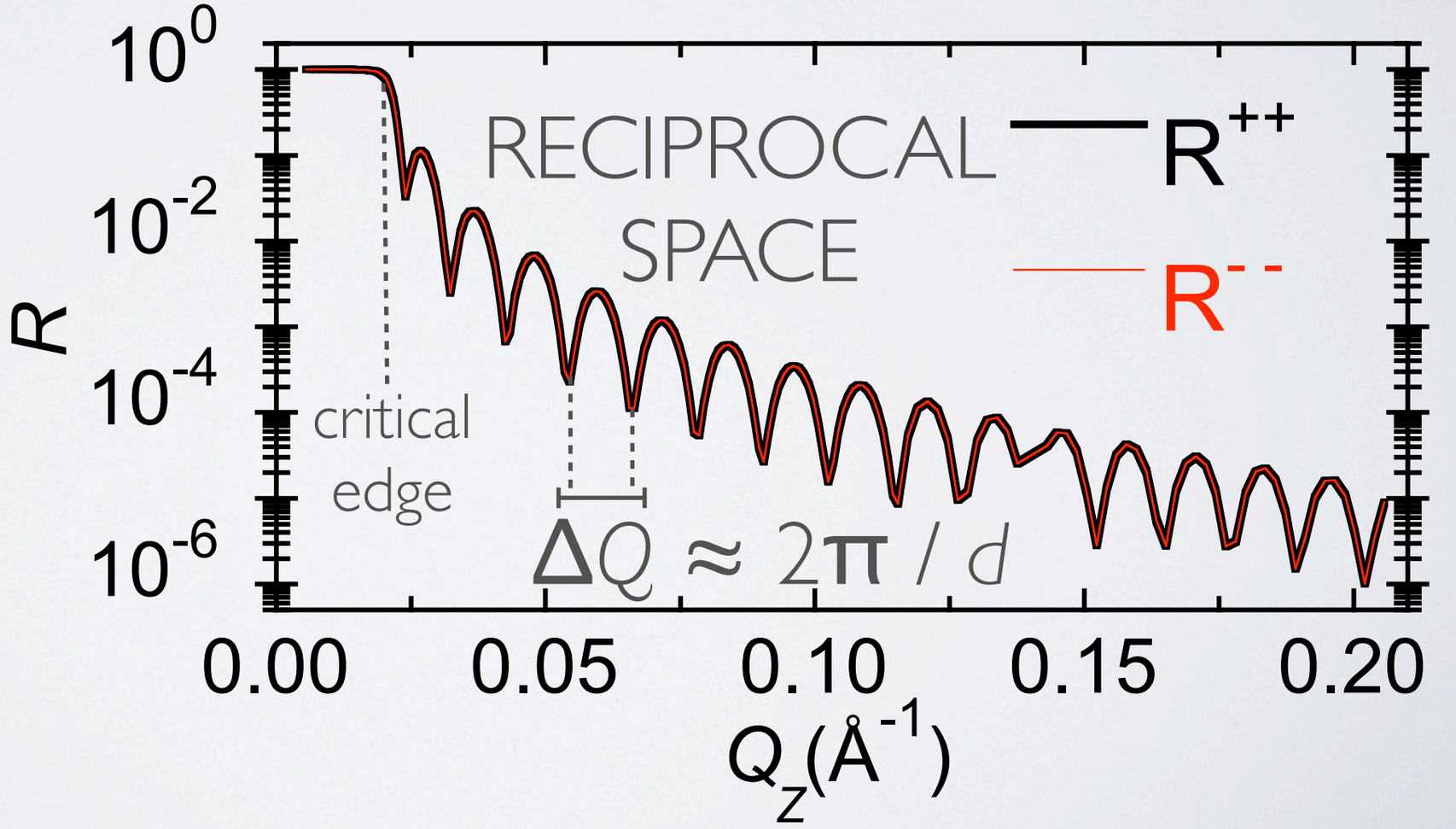
$\rho_{nuc} = 2.07 \times 10^{-6}$ Å^{-2}

$\rho_{mag} = 0$

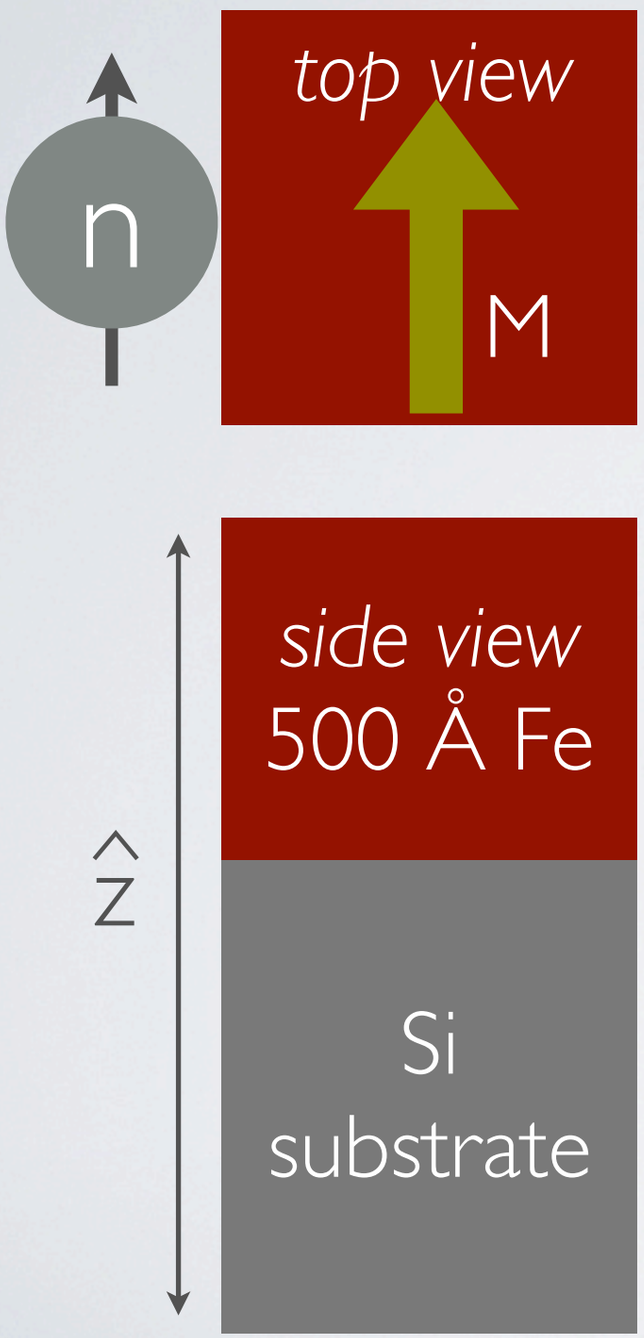
M PARALLEL TO Q

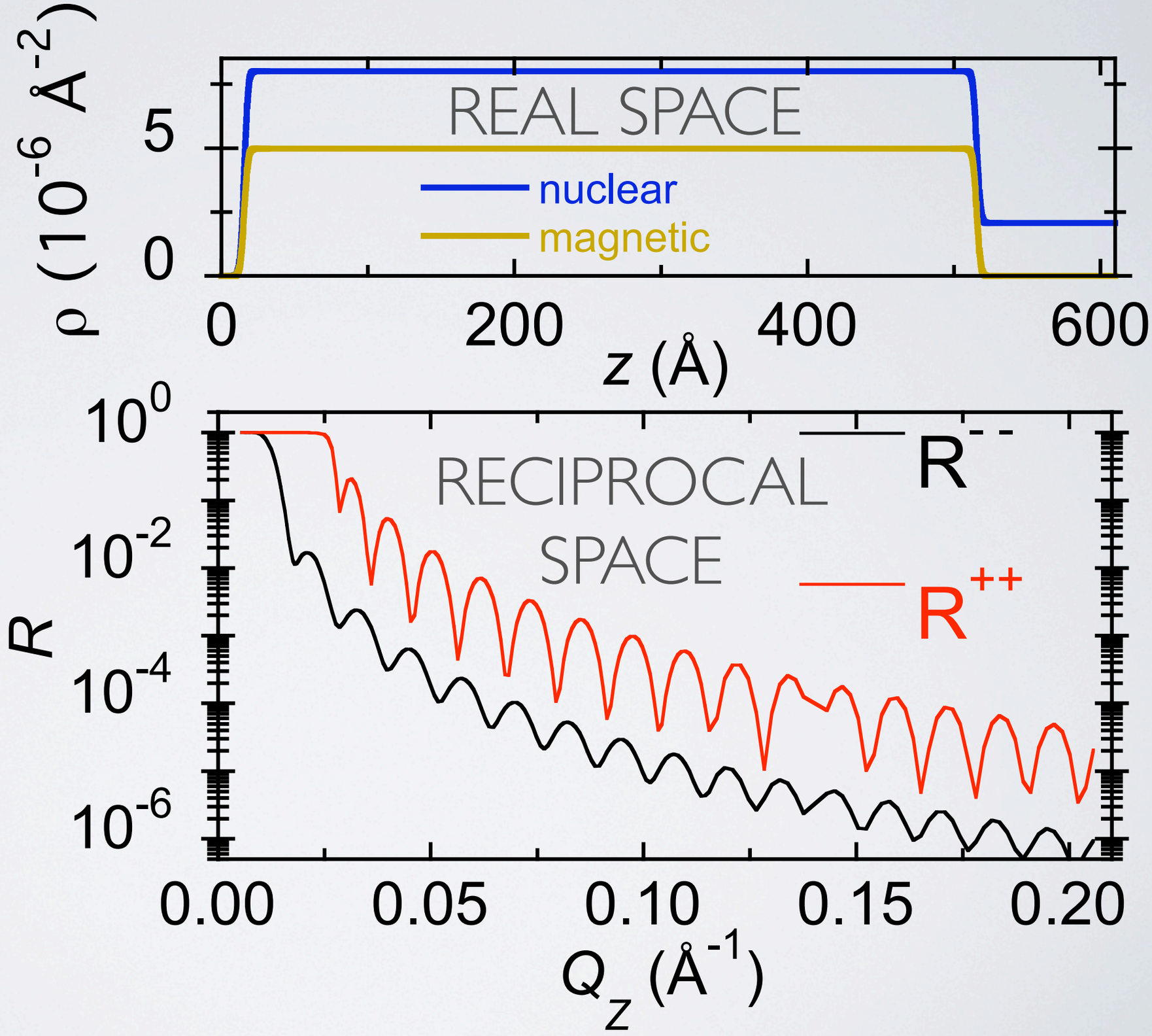






M PARALLEL TO N-SPIN





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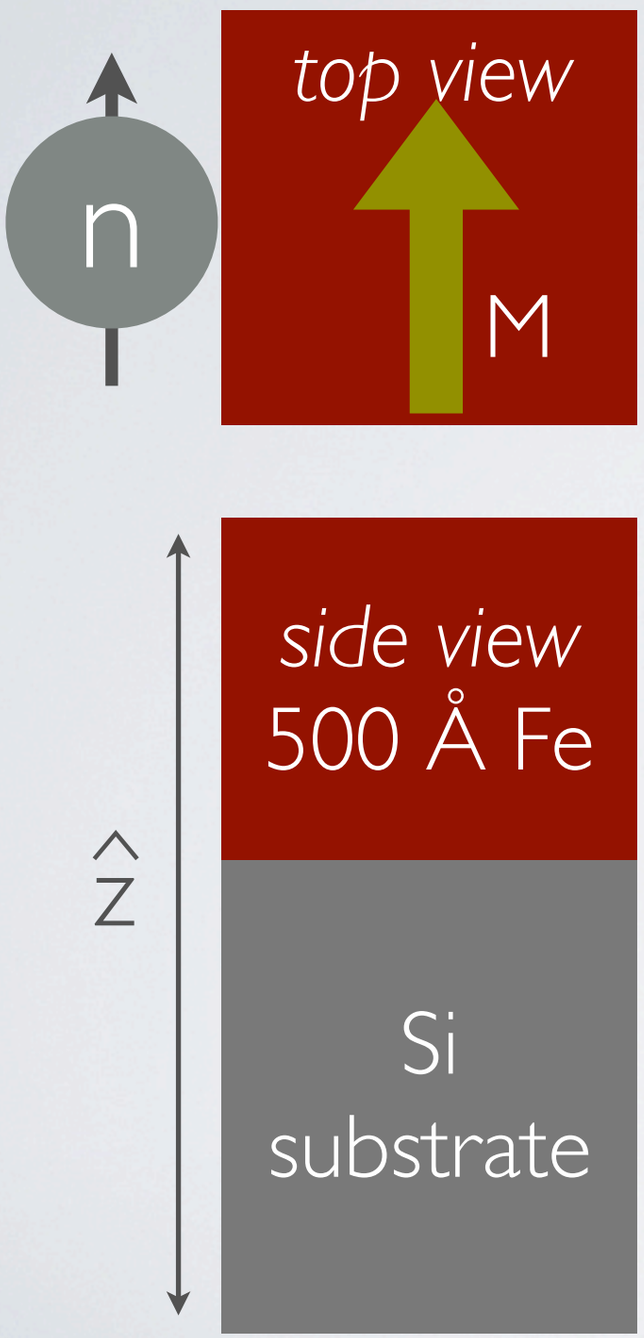
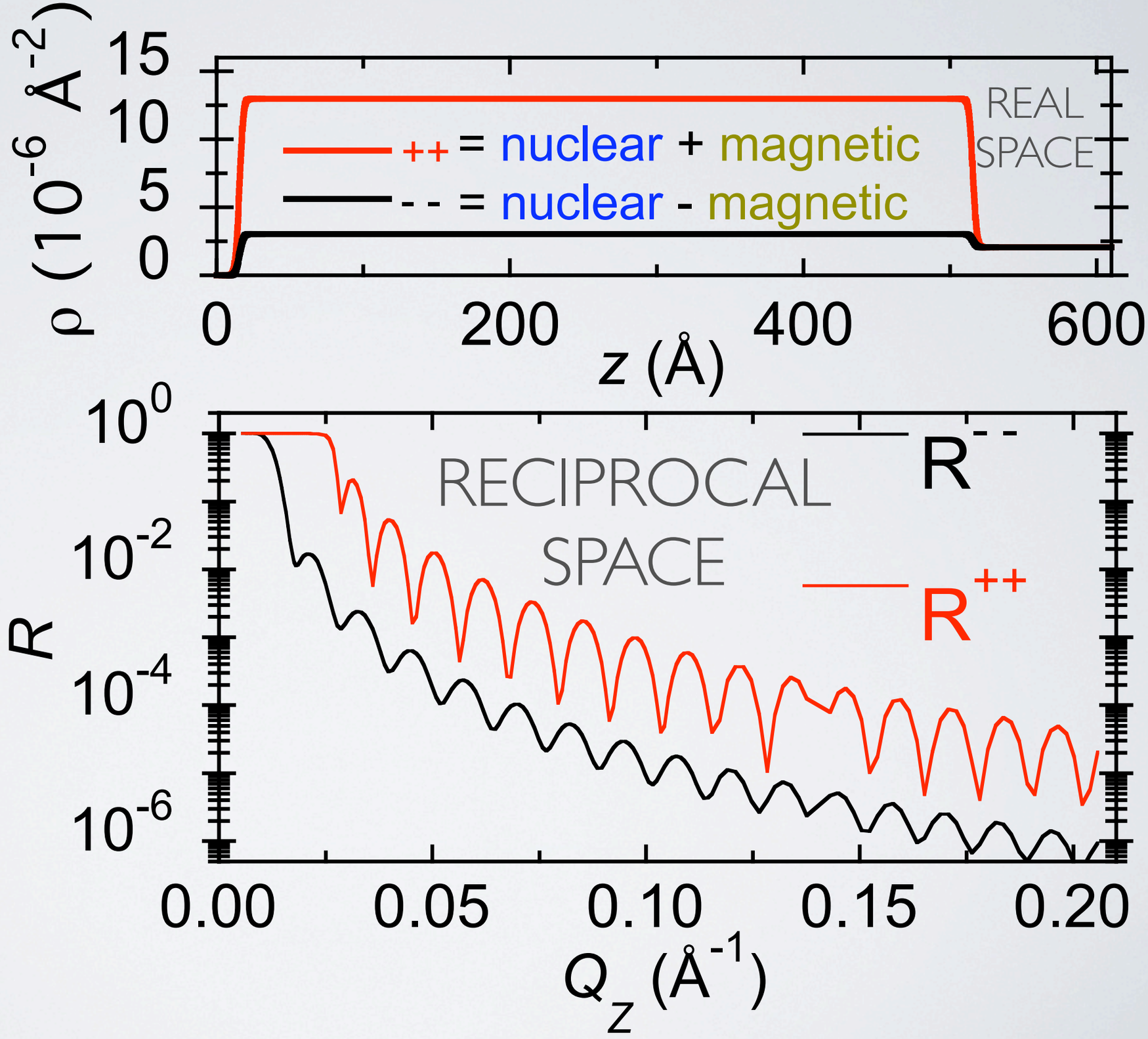
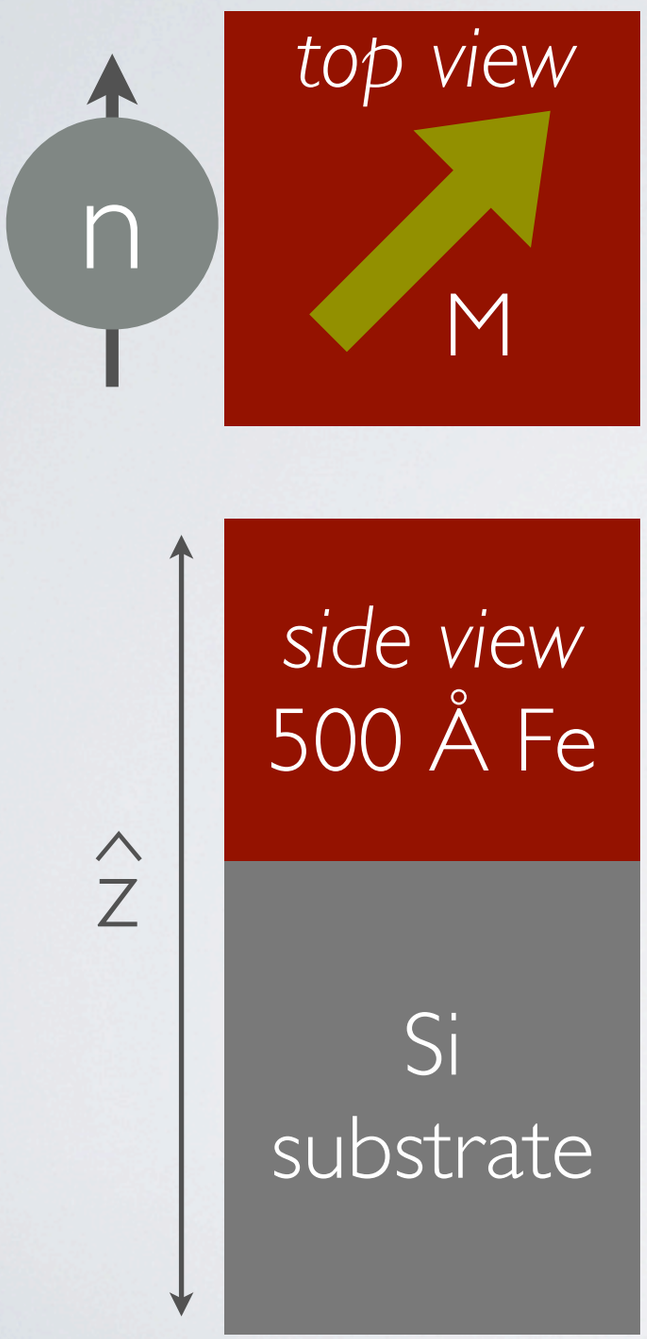
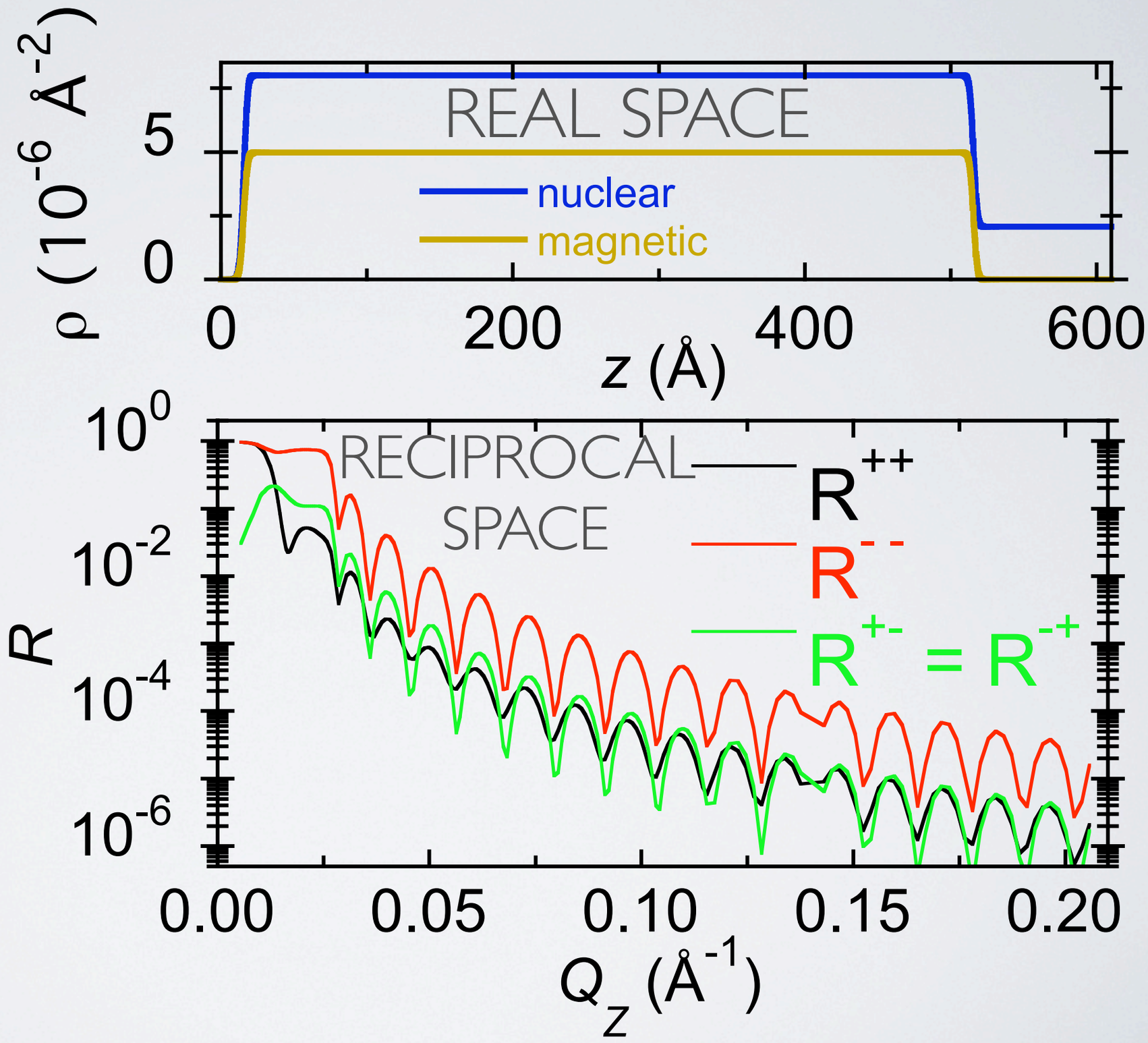


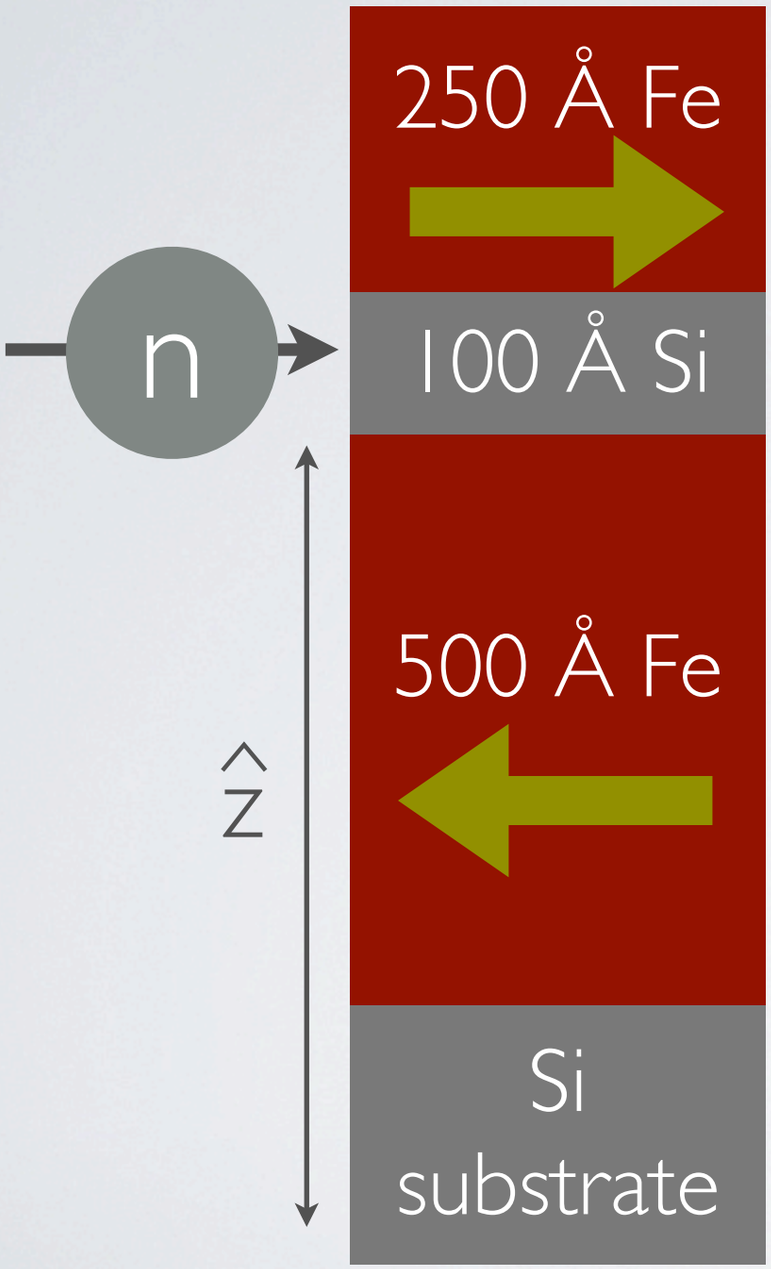


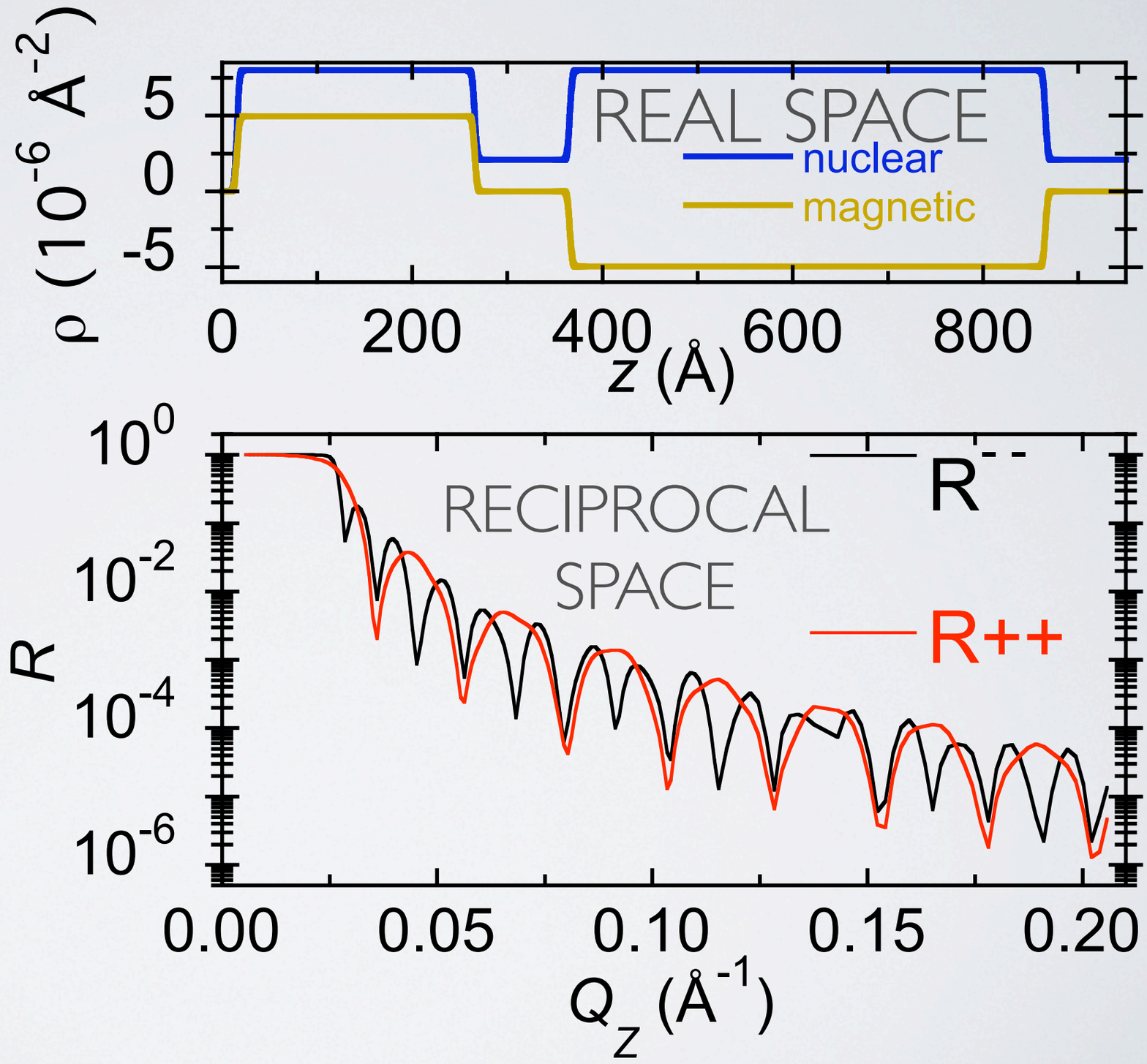
PARALLEL & PERPENDICULAR





MAGNETIC MULTILAYER





POLARIZED BEAM SUMMARY

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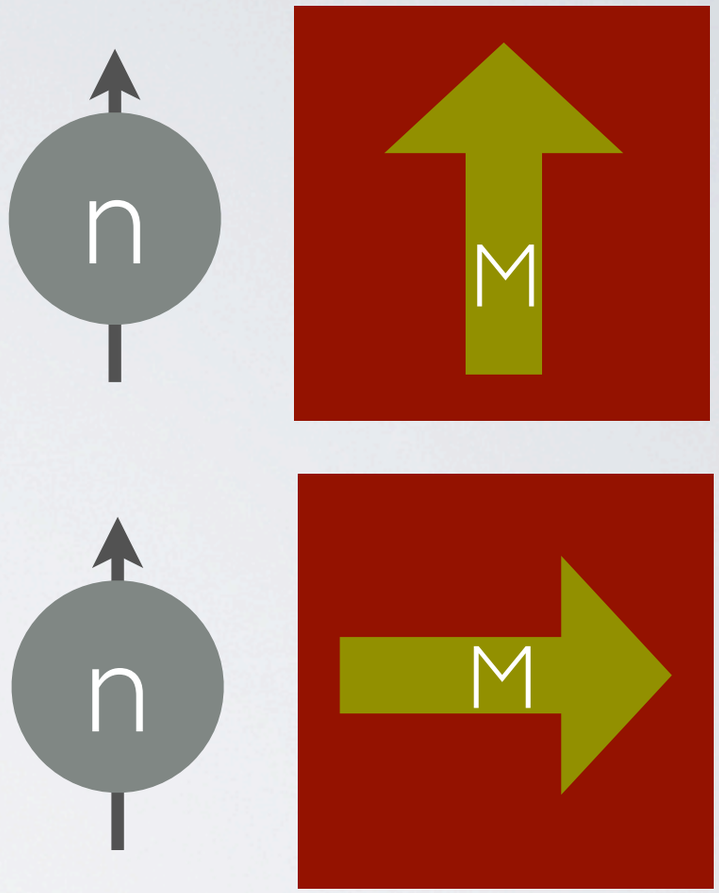

2) projection of magnetization vector perpendicular to neutron spin produces spin flip scattering (R^{++} & R^{--})

3) projection of magnetization parallel to *Q* <u>does not</u> scatter neutrons