Spin-resolved Photoemission Studies of Gd(0001)

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now at ALS

Spin Resolved Photoemission on Gd

- ★ Surface Curie temperature (T_{surf} ~T_{bulk}+60K)
- ★ Canted magnetic moments
- ★ Stoner splitting vs. spin-mixing
- ★ Electron-magnon coupling NEW

Plan

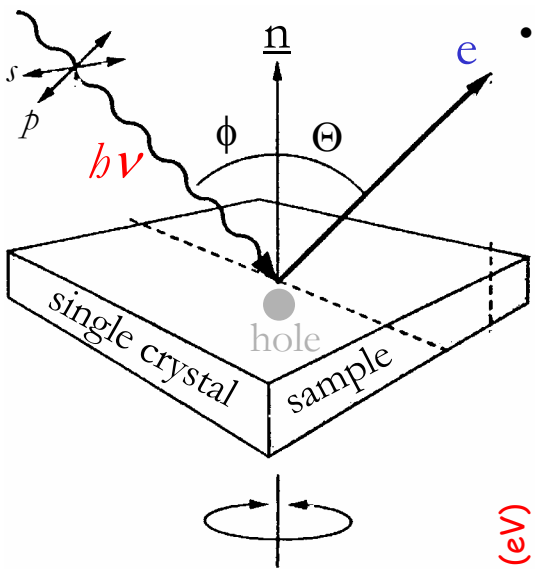
- ★ Photoemission, self energies, scattering rates,etc.
- ★ Micro-Mott spin polarimeter, achieving the high resolution
- ★ Scattering channels for the spin majority and minority photo-holes
- ★ Surface Curie temperature

Angle Resolved Photoemission
/band structure mapping/

Experiment

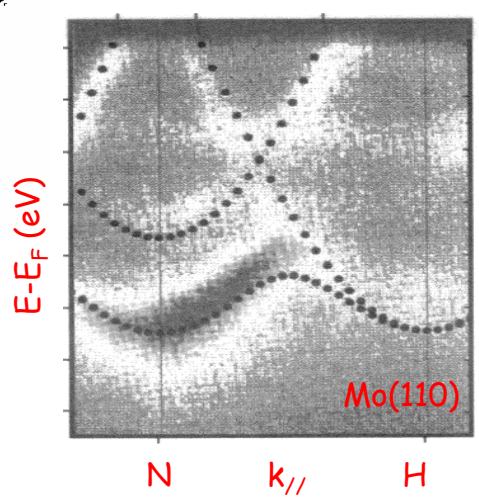
Excitation Radiation

- photon energy
- polarization
- angle of incidence



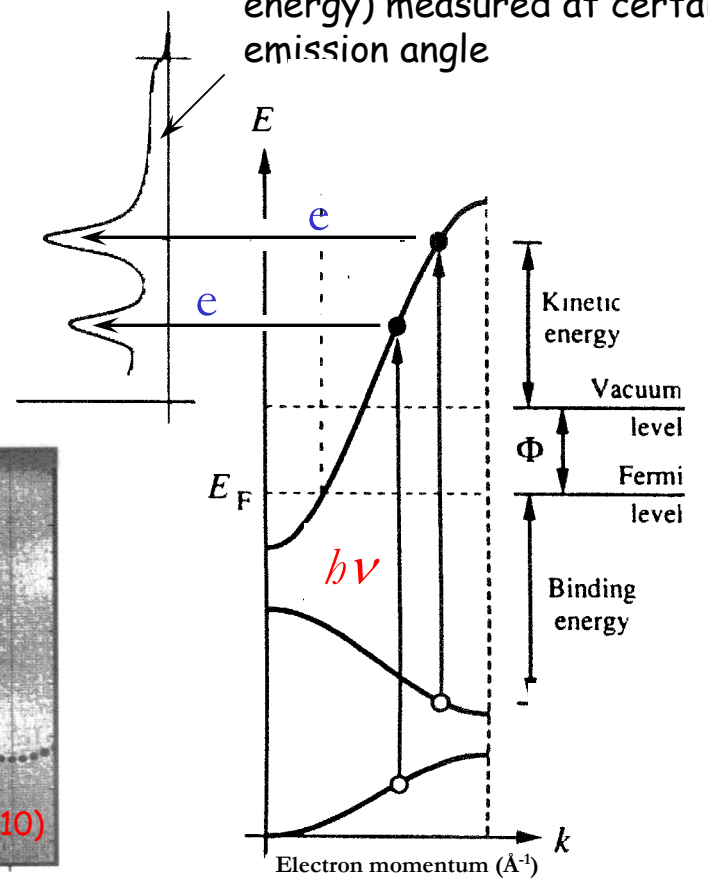
Photoelectrons

- kinetic energy
- emission angle
- **polarization**



Data

Energy Distribution Curves (photocurrent vs. kinetic energy) measured at certain emission angle

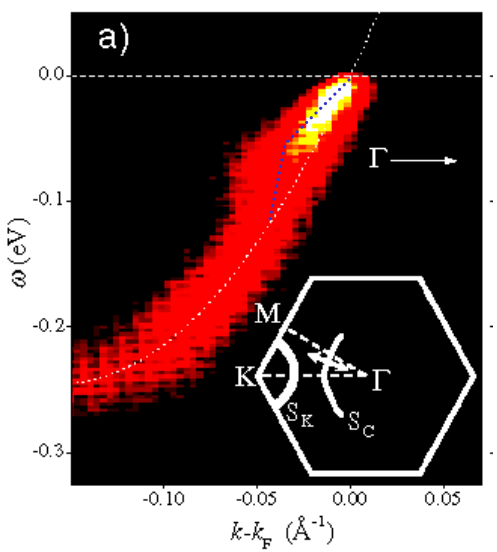


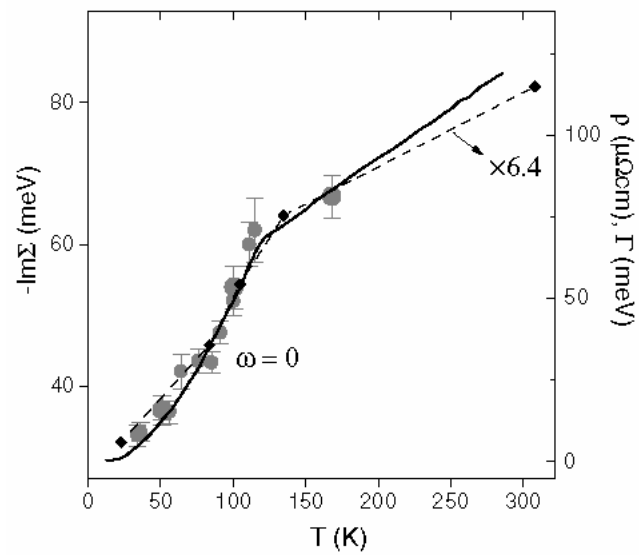
Angle Resolved Photoemission

/spectral function and self energy/

$$A(\kappa,\omega) = \frac{1}{\pi}\frac{\mathrm{Im}\Sigma(\kappa,\omega)}{\left[\omega-\varepsilon_\kappa-\mathrm{Re}(k,\omega)\right]^2+\left[\mathrm{Im}\Sigma(\kappa,\omega)\right]^2}$$

$\mathrm{Im}\Sigma(k,w) \sim 1/\tau$ and gives the scattering rate /e-ph, e-e, e-imp, e-magnon/



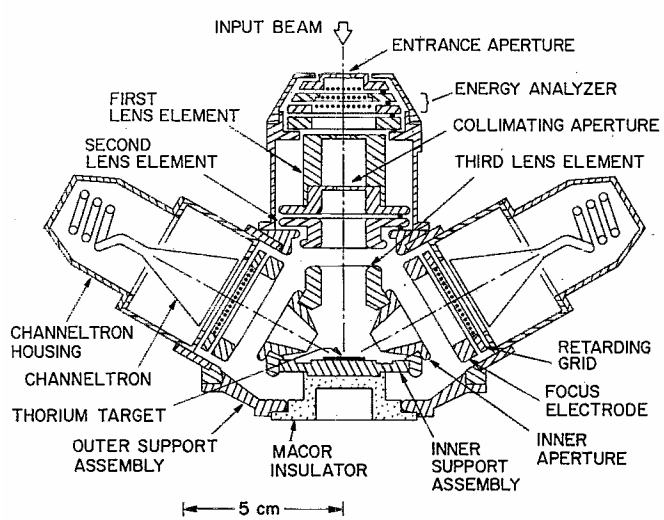


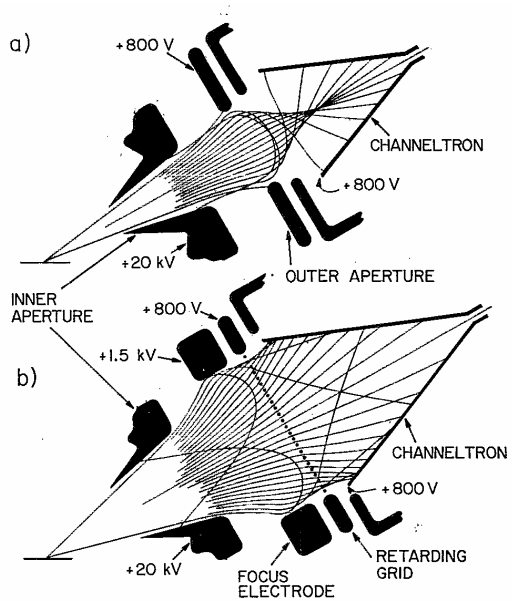
High-efficiency retarding-potential Mott polarization analyzer

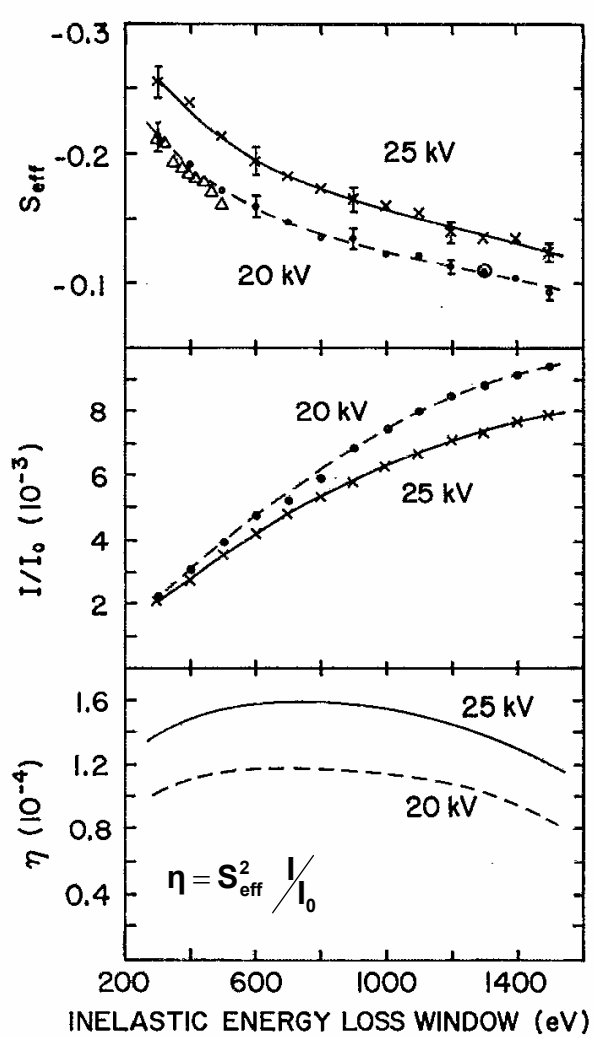
G. C. Burnett, T. J. Monroe, and F. B. Dunning
Department of Physics and the Rice Quantum Institute, Rice University, P.O. Box 1892, Houston, Texas 77251

(Received 17 January 1994; accepted for publication 14 March 1994)
/Rev. Sci. Instrum. **65**, 1893/

$$V_{so} = \frac{1}{2m^2c^2}\frac{1}{r}\frac{dV}{dr}\vec{s}\bullet\vec{l}$$







$$P = \frac{1}{S}\frac{\sqrt{I_L^+ I_R^-} - \sqrt{I_L^- I_R^+}}{\sqrt{I_L^+ I_R^-} + \sqrt{I_L^- I_R^+}}$$

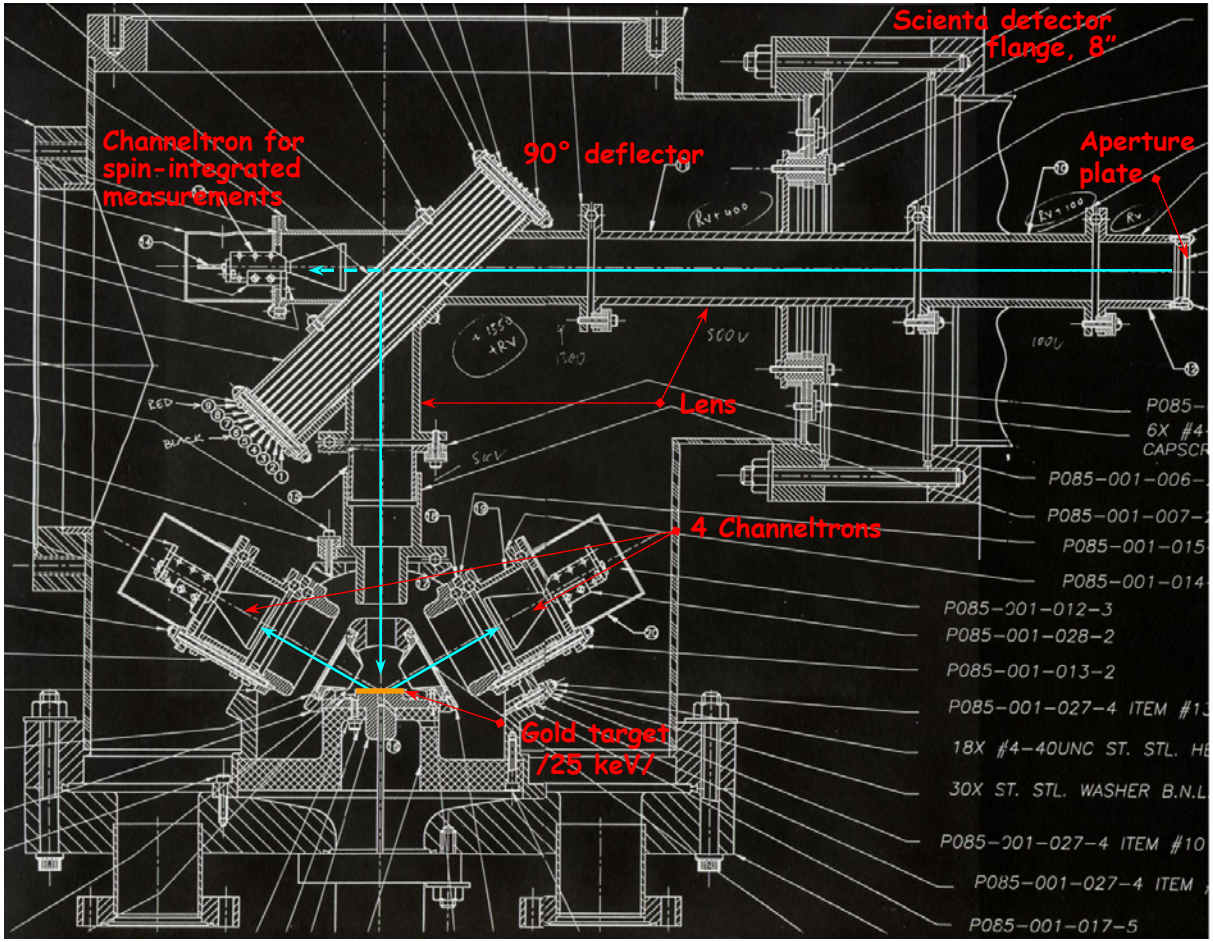
$$A = \frac{\sqrt{I_L^+ I_L^-}}{\sqrt{I_R^+ I_R^-}}$$ ← Instrumental asymmetry

$$I^{\uparrow} = \langle I \rangle (1+P)$$

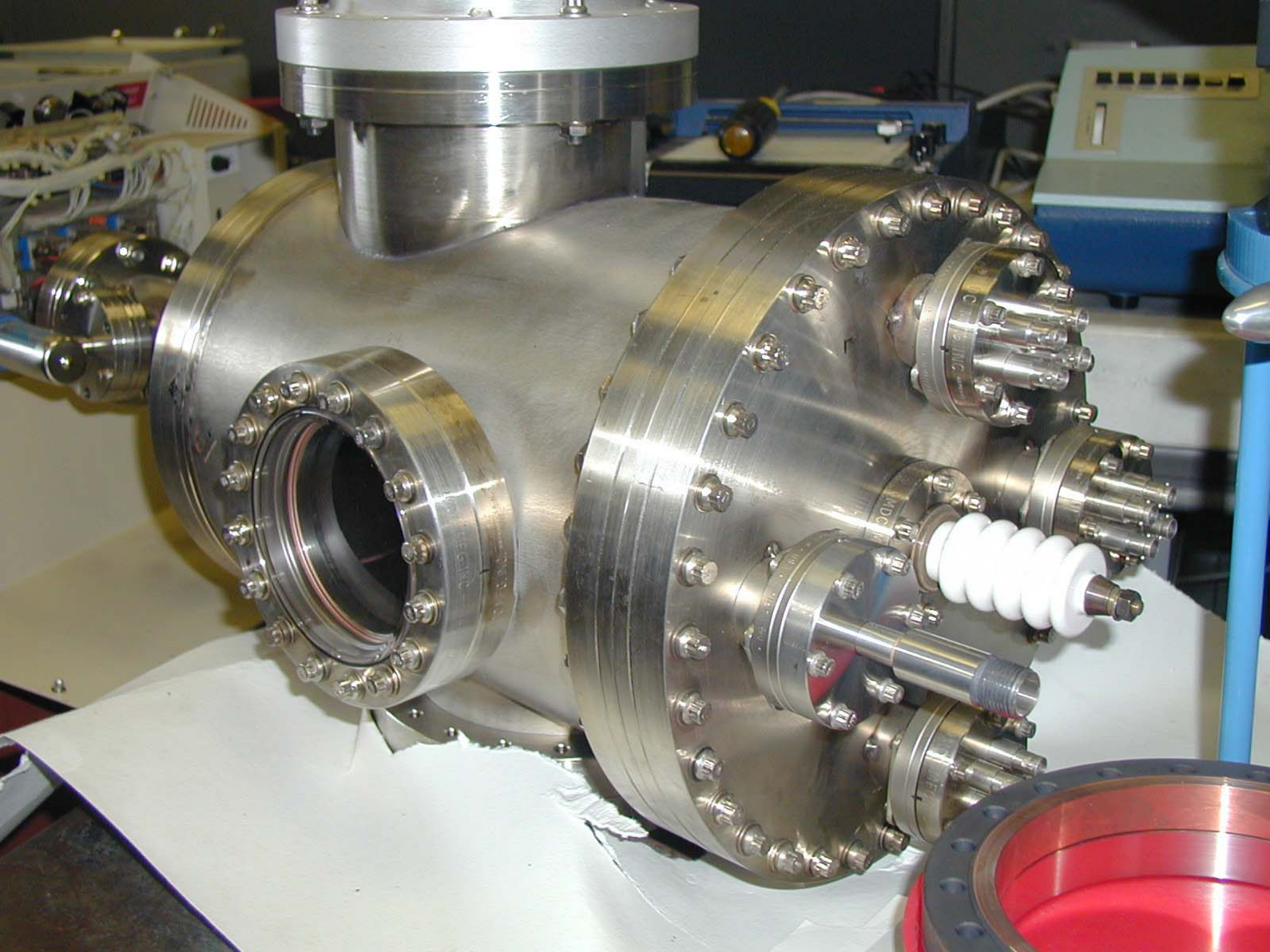
$$I^{\downarrow} = \langle I \rangle (1-P)$$

$$\langle I \rangle = \frac{I_L^+ + I_L^- + I_R^+ + I_R^-}{4}$$

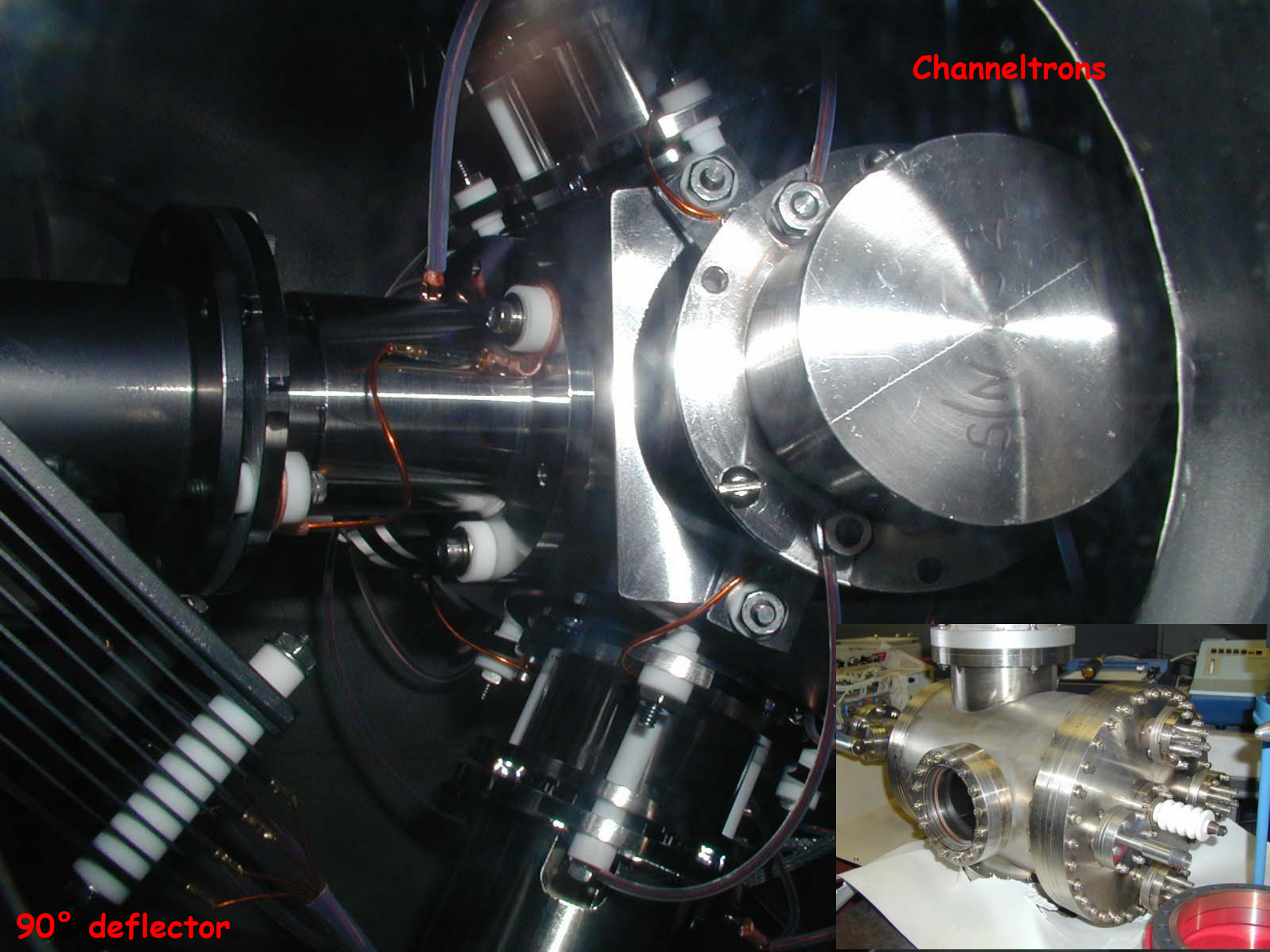
Spin polarimeter in BNL



Energy resolution: {Aperture/ØMCP}×{PE/10}

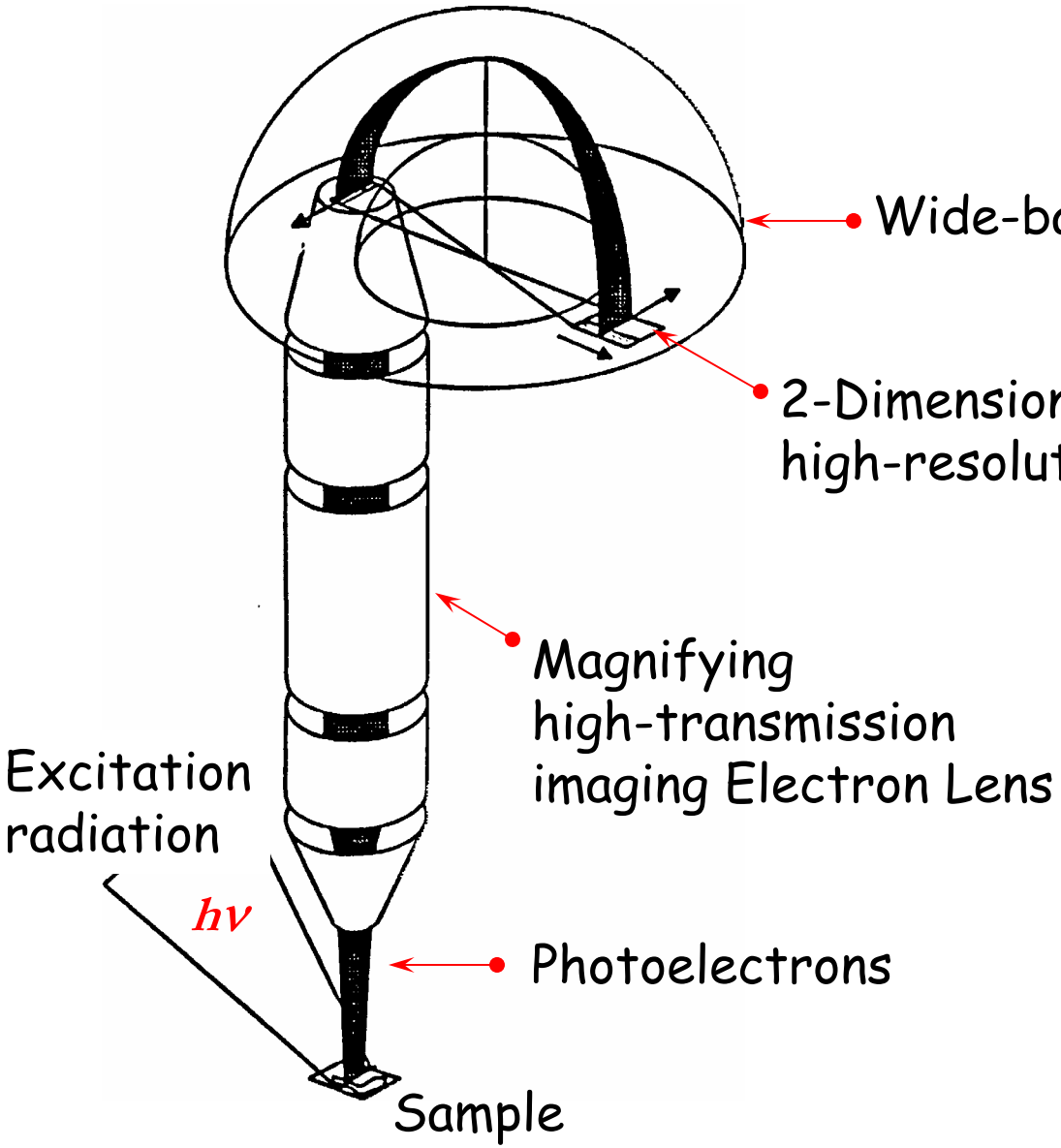


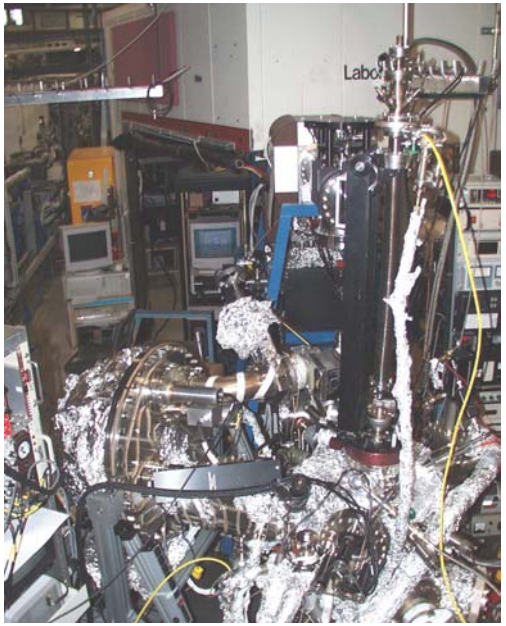
Aperture plate


Channeltrons
90° deflector

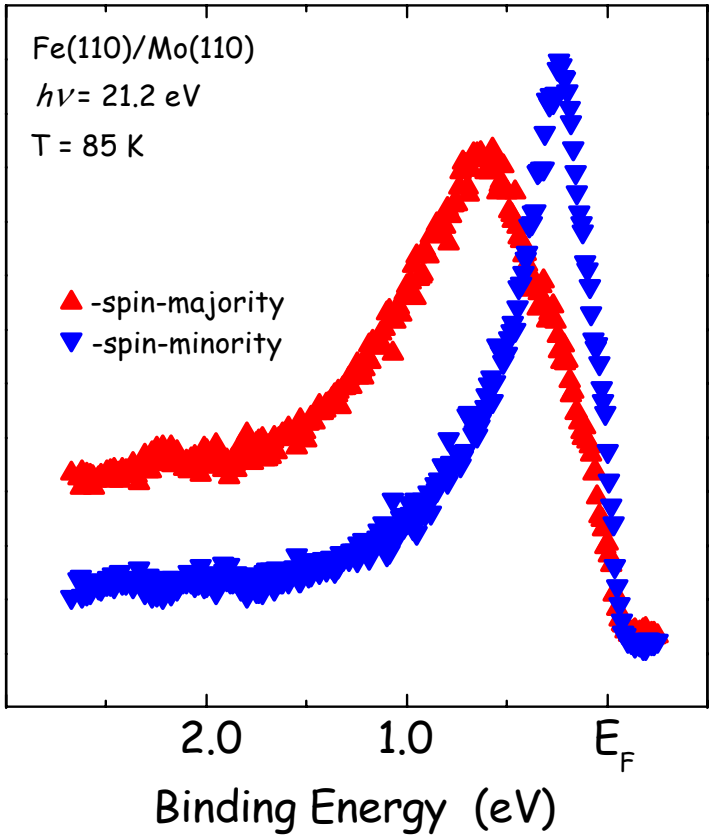
Photoelectron Spectrometer

/200-mm hemispherical analyzer from Scienta/



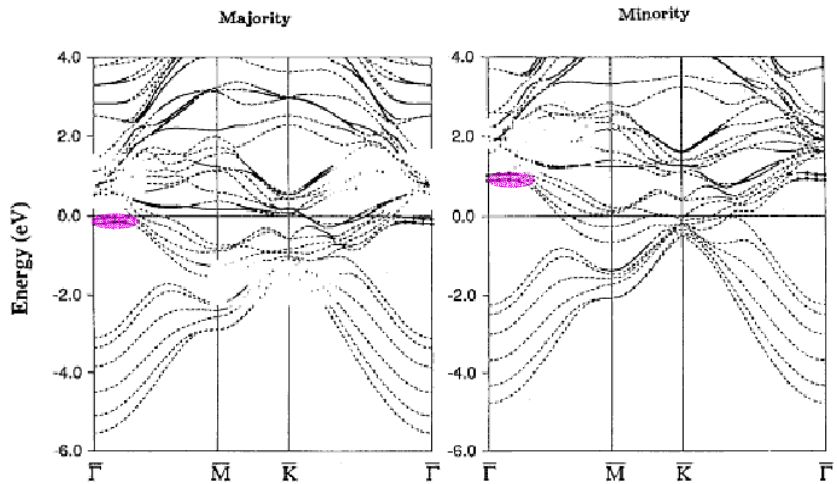


Test results: "in-plane" polarization in ferromagnetic iron films



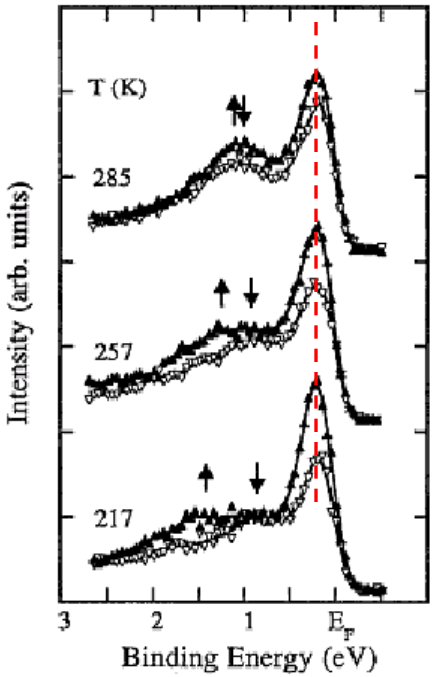
Resolution: 50 meV /PE=10eV/
Sherman function: 0.15

Surface state in Gd(0001)



R. Wu and A.J. Freeman, PRB **44**, 9400

D. Li et al., PRB **51**, 13895



ΔE~175 meV

Spin-resolved

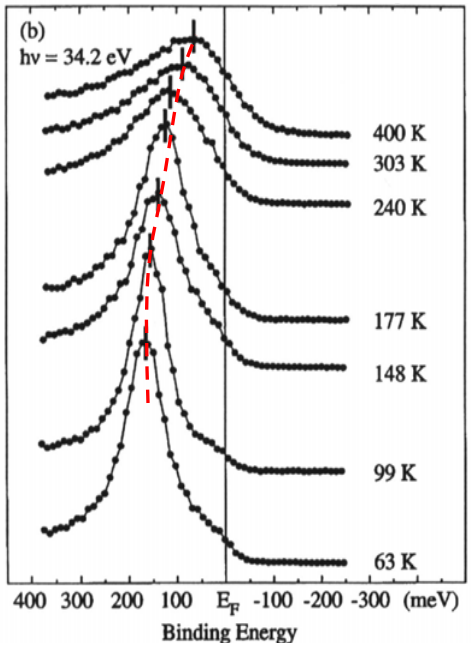
Spin-mixing

E. Weschke et al., PRL **77**, 3415

ΔE~ 60 meV

Spin-integrated

Stoner-like



Sample Preparation:

Epitaxial films of Gd on Mo(110)
Deposition at 200÷300 K
Annealing at ~800 K
Result: Gd(0001)

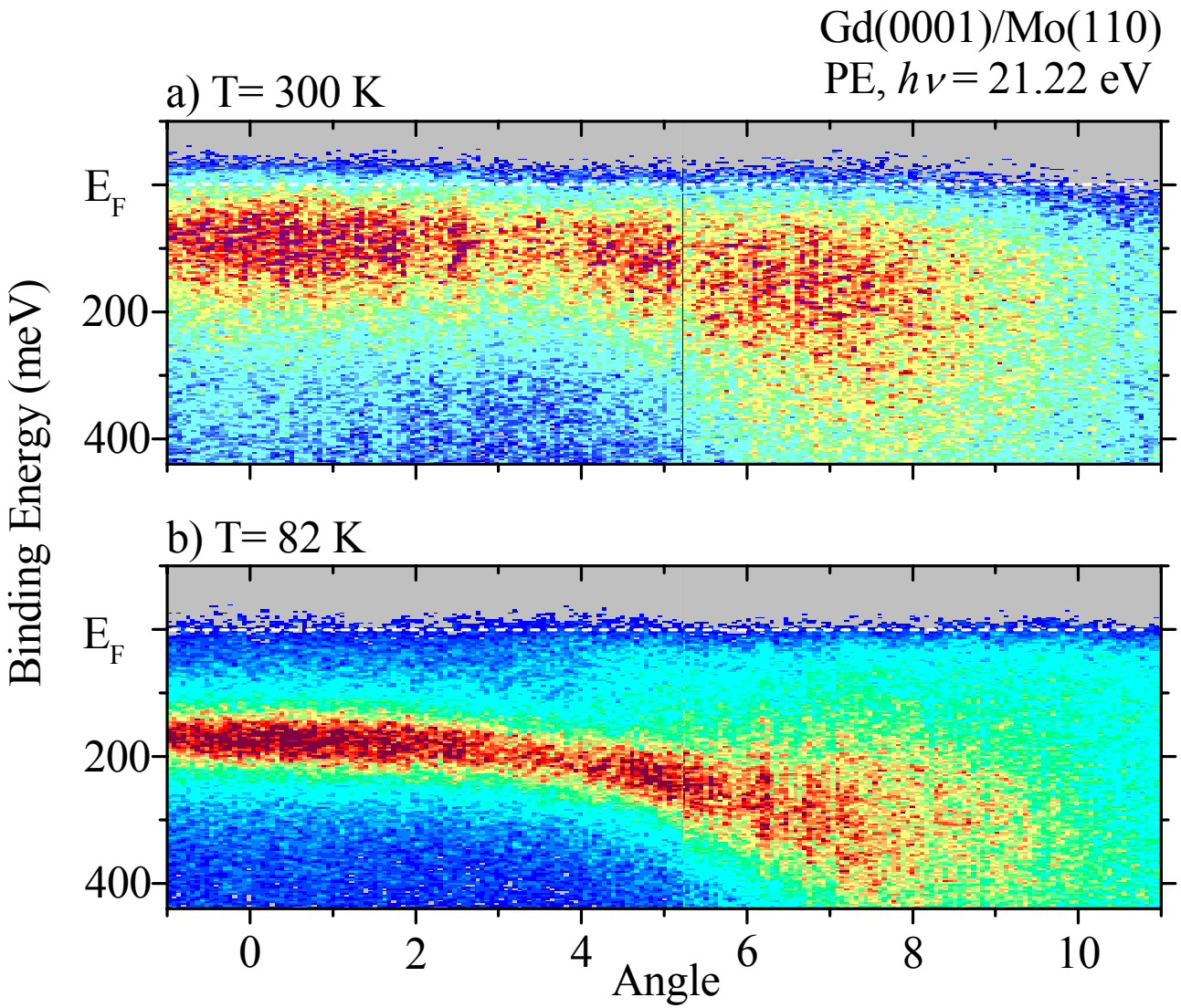
Sample lifetime ~ 48 Hours

Temperature range 20 K÷3000 K

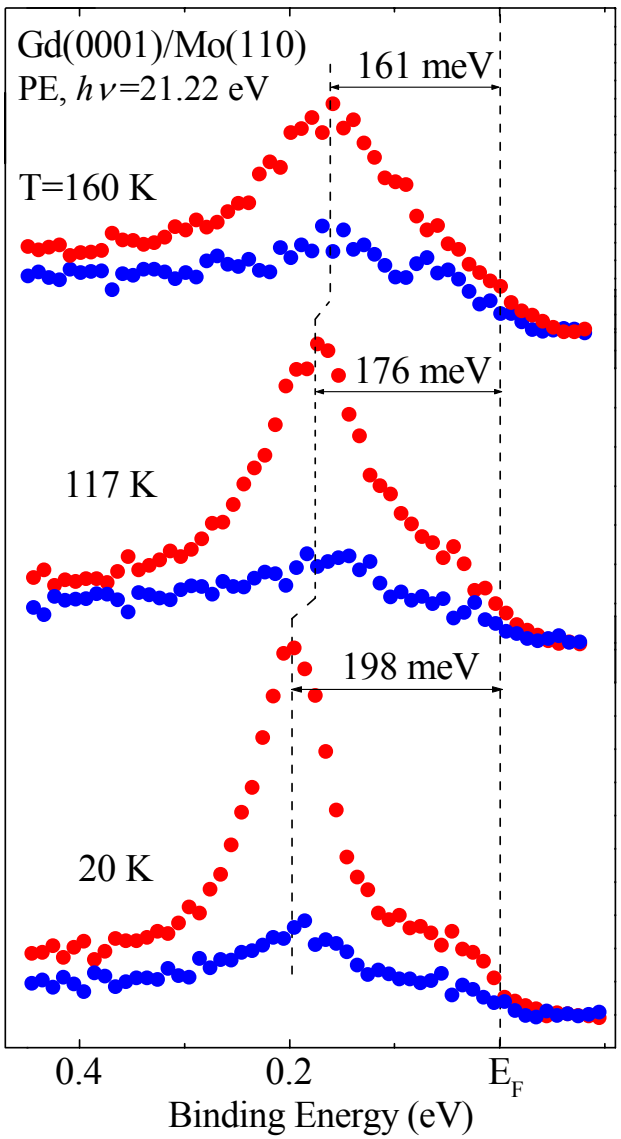
Base pressure 2×10^{-11} mbar

Angle-resolved spin-integrated data

/suggests Stoner-like behavior/



Spin-resolved data



Temperature-dependent shift of spin-majority peak agrees with Stoner behavior

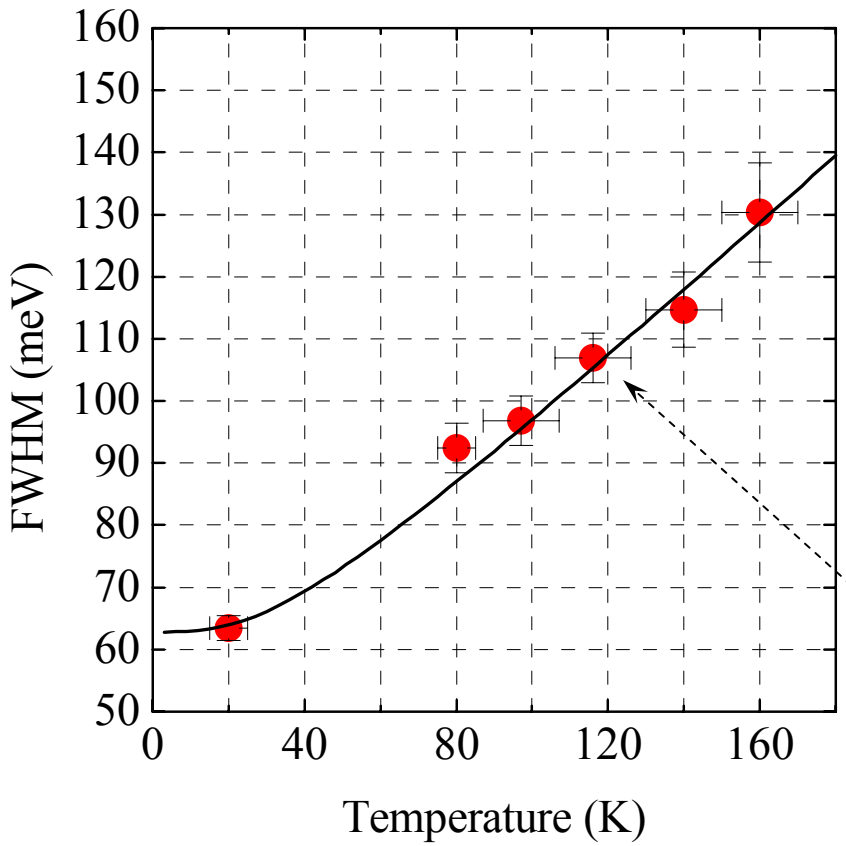
Spin-majority peak shows considerable broadening with temperature

Surface state is not 100% polarized even at 20K

Relative intensity of spin-minority component increases with temperature

Spectra were measured at six different temperatures: 20K, 80K, 98K, 117K, 140K, 160K

Width of spin-majority peak vs. temperature



Broadening of majority peak reflects mostly phonon contribution to the line-width

"Spin-resolved" electron-phonon coupling constants:
$\lambda\uparrow \sim 0.73$ $\lambda\downarrow \sim 0.31$ /P. Allen/

"Spin-averaged" constant: 0.4
/H.L. Skriver and I. Mertig, PRB **41**, 6553

Experiment: $\lambda \sim 0.9$

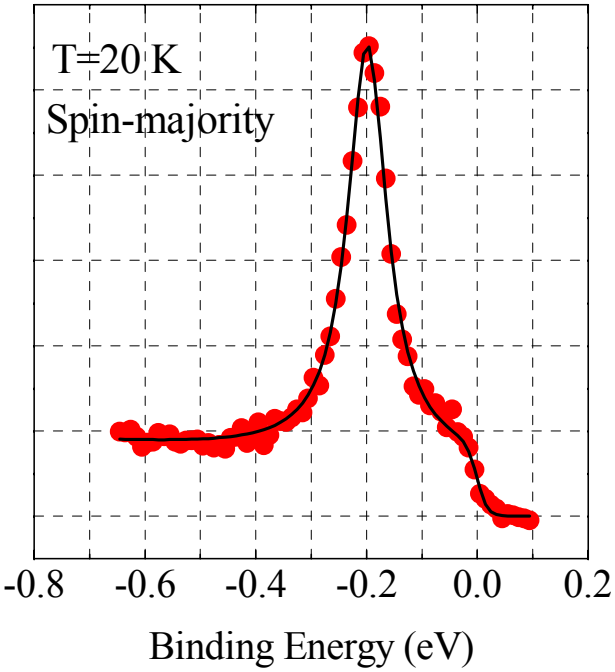
$$\mathrm{Im}\Sigma_{e-ph}(T,\omega) = \pi \int d\nu \alpha^2 F(\nu)\left[1 + 2n(\nu) + f(\nu+\omega) - f(\omega-\nu)\right]$$

Debye model: $\alpha^2 F(w) = \lambda(\omega/\Omega_m)^2$ $\qquad 1/\tau \approx const + \pi\lambda k_B T$

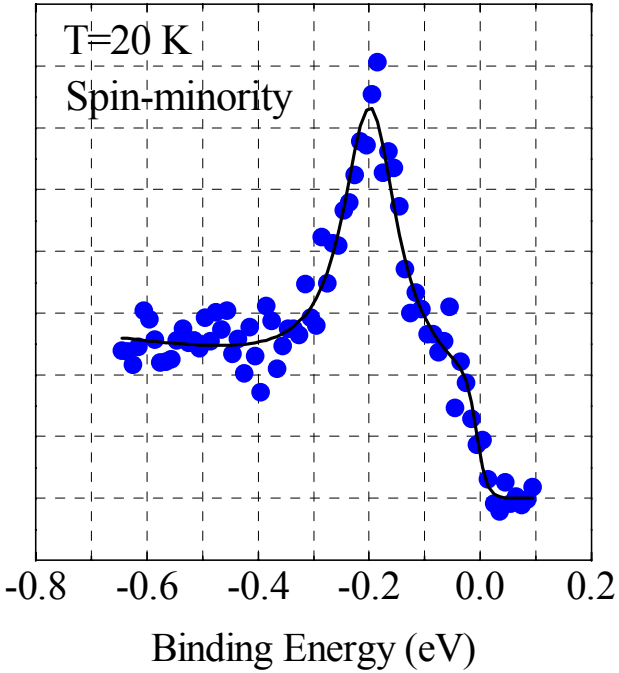
Extra broadening of spin-minority peak was detected at all temperatures

Least-square fits to Lorentzian + Fermi edge

86 meV

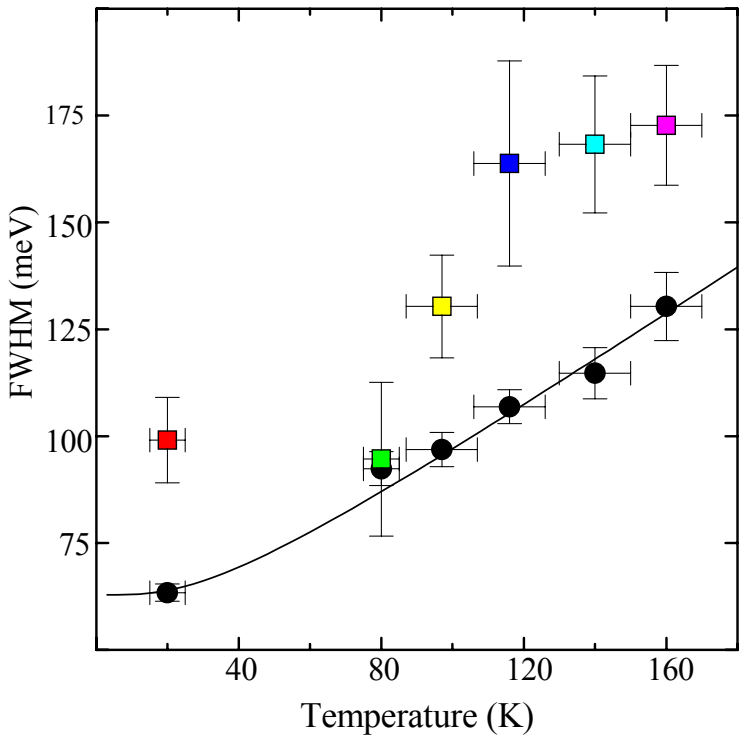


116 meV



Intrinsic width of the peak should not depend on the orientation of magnetic moment in domains

Broader minority spin channel indicates electron-magnon mechanism



P.B. Allen, PRB **63**, 214410 (2001)

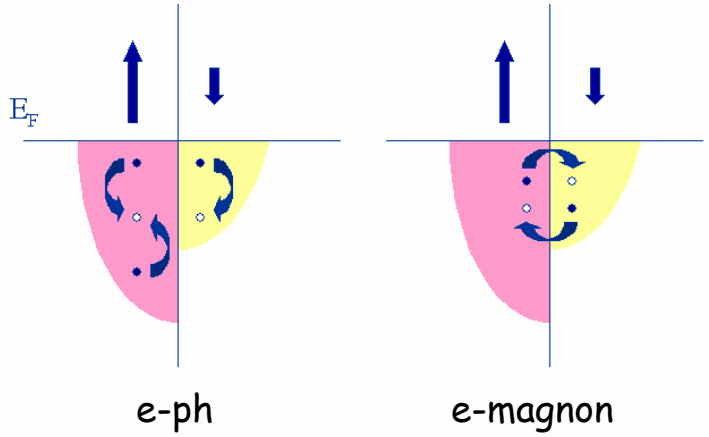
$$1/\tau^{\downarrow} \approx \frac{P(\uparrow)m^*}{S}\left(\frac{2JSa}{\eta}\right)^2$$

$$1/\tau^{\downarrow} \approx 0.095\text{eV}$$

$$1/\tau^{\uparrow} \approx 0.014\text{eV}$$

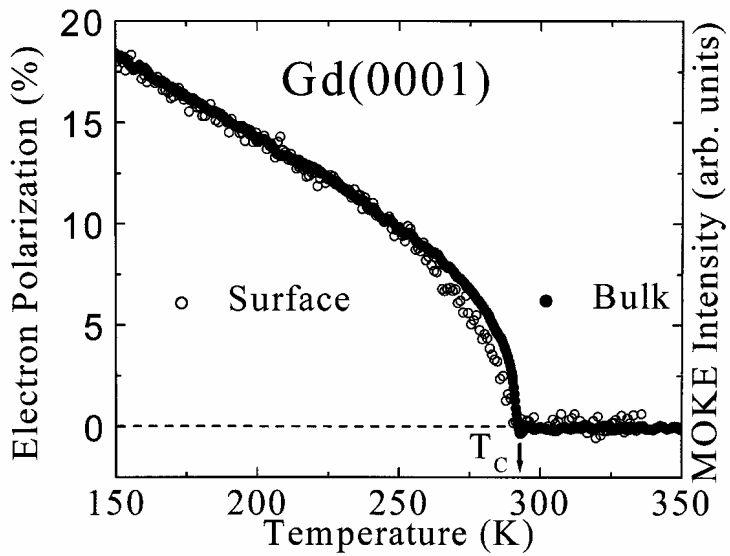
At low T majority spin hole decays primarily via lattice excitations, minority spin hole primarily via spin excitations

	Majority	Minority
Phonons	46 meV	10 meV
Magnons	14 meV	95 meV

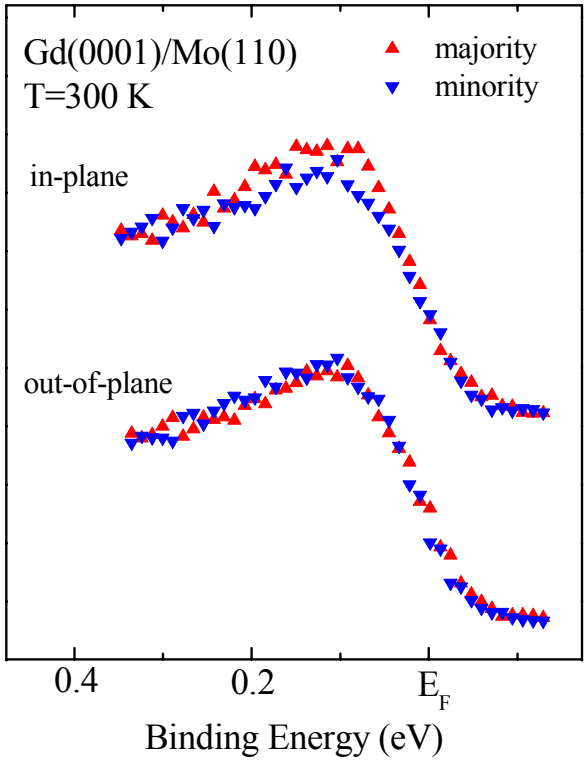


Surface transition temperature: enhanced or regular?

C.S. Arnold and D.P. Pappas,
PRL 85, 5202 (2000):
Common Curie temperature
for surface and bulk

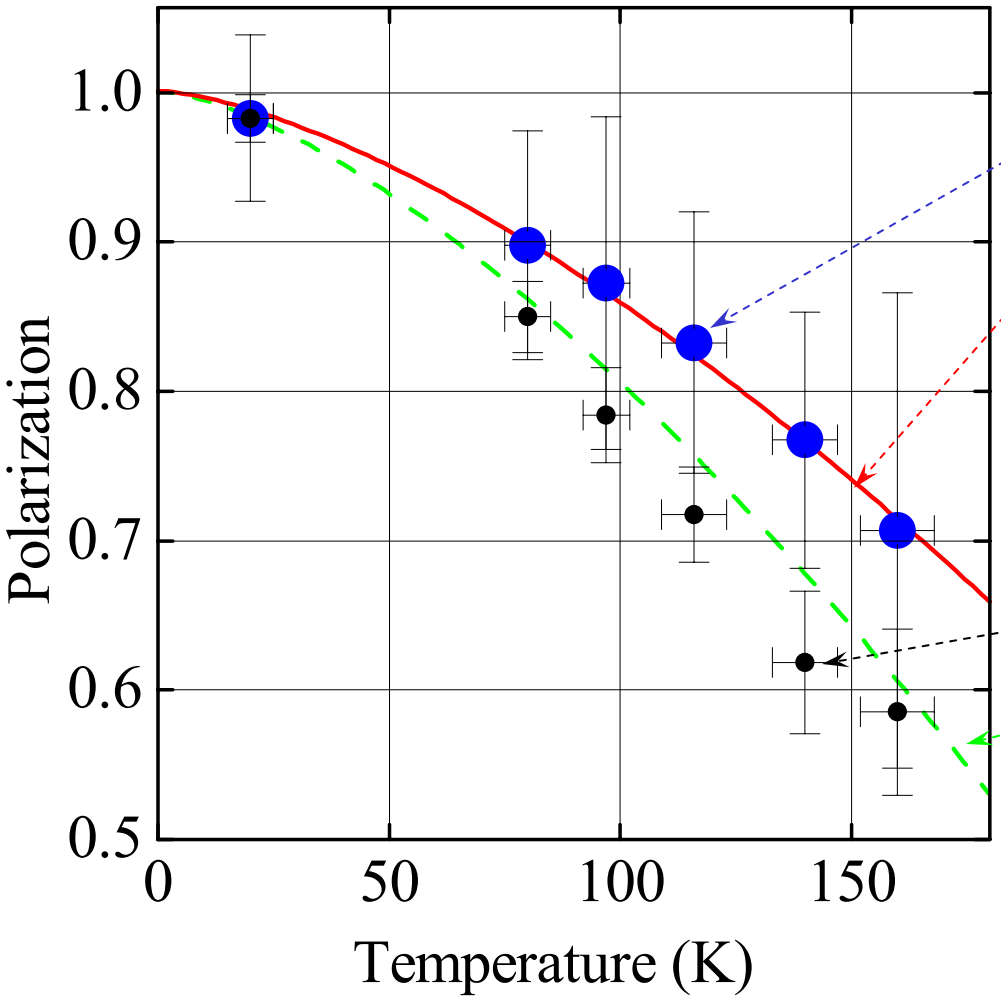


Present work at ~300 K:
Hint for the enhanced T_C



Polarization of the surface state vs. temperature

Polarization = {n↑-n↓}/{n↑+n↓}



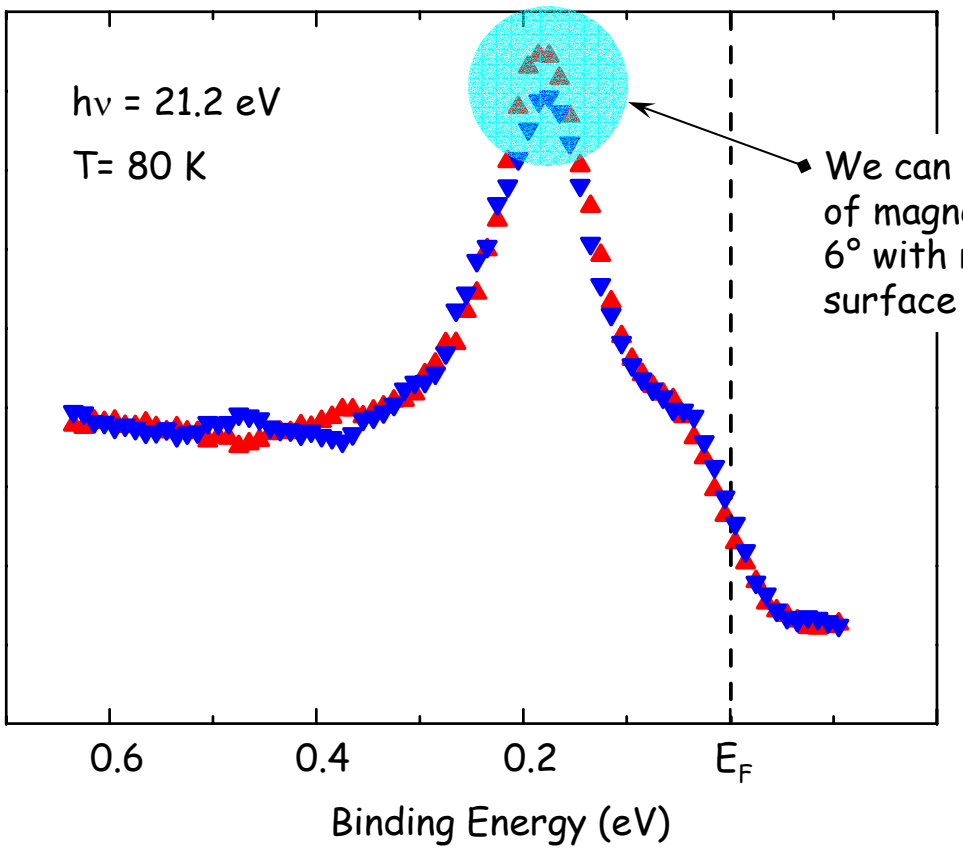
Polarization of the surface state

Fit with "$T^{3/2}$" law found in bulk Gd:
$P(T)=P_0\times(1-T/T_C)^{3/2}$)
⇓
T_C= 362 K /in agreement with reports on enhanced surface Curie temperature/

Polarization of background

Simulation for T_C= 293 K /bulk/

Measuring "out-of-plane" component in Gd



We can estimate the canting of magnetic moment: 6° with respect to the surface plane