Physics Fest, University of Illinois at Chicago
April 10, 2015.

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Emission Properties of Elemental Metal Photocathodes

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DE-FG52-09NA29451

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DED P200A070409

Brightness: Transverse Emittance

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- Measure of transverse electron beam (or pulse) quality:

$$\varepsilon_T = \frac{1}{mc}\,\Delta x\,.\,\Delta p_T$$

… a conserved quantity in a 'perfect' system.

- Initial electron source parameters at photocathode:
  - Δx determined by laser spot size & limited by Child's Law
  - Δp_T is an ***intrinsic*** property of the photocathode material

- ***Standard*** theoretical expressions for transverse rms momentum:
  - Single-photon photoemission: $\Delta p_T = \sqrt{\frac{m(\hbar\omega - \varphi)}{3}}$

D.H. Dowell & J.F. Schmerge, *Phys. Rev. ST – Acc. & Beams* **12** (2009) 074201
K.L. Jensen et al., *J. Appl. Phys.* **107** (2010) 014903

Results: Metals

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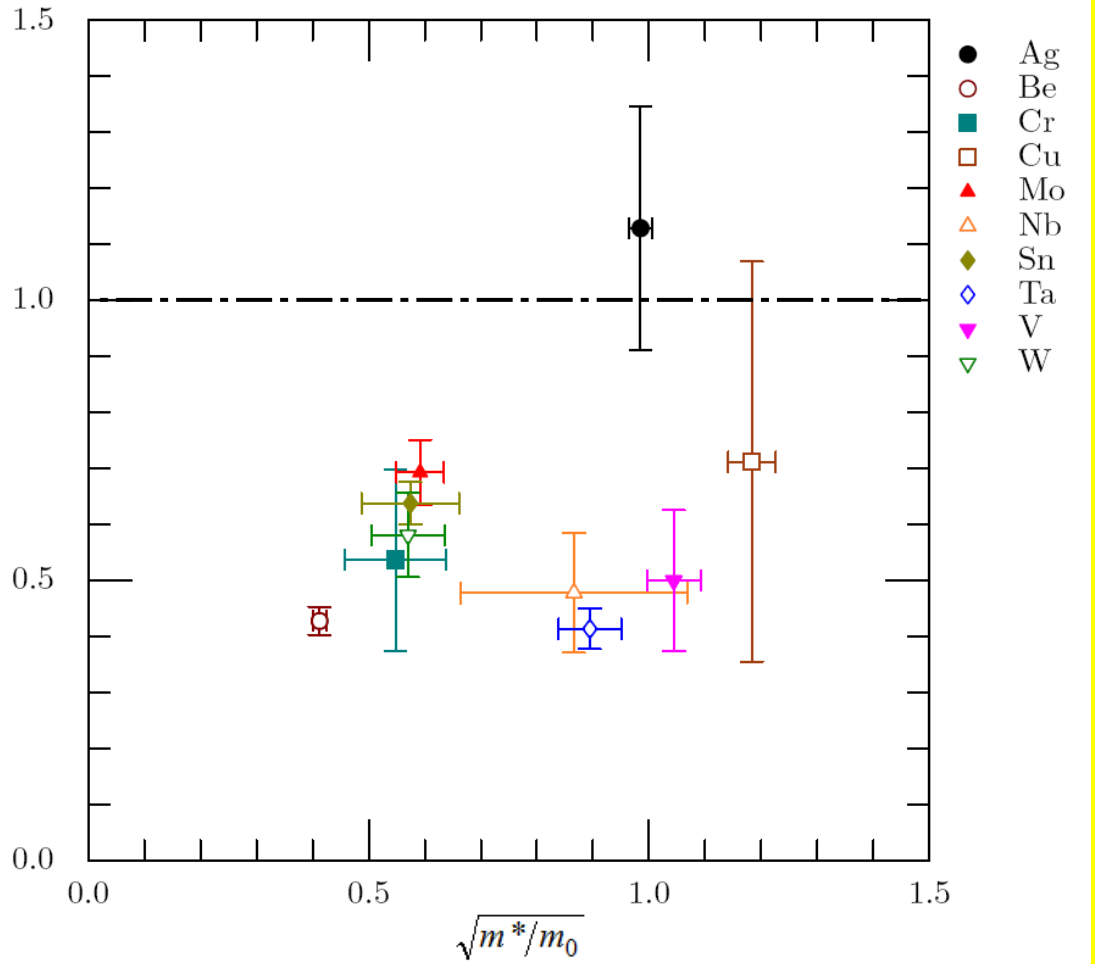
– Effective mass in metal photocathodes: dH-vA, CR …



Ten ***polycrystalline*** metal photocathodes

B.L. Rickman et al., *Phys. Rev. Lett.* **111** (2013) 23740

Fermi Surfaces

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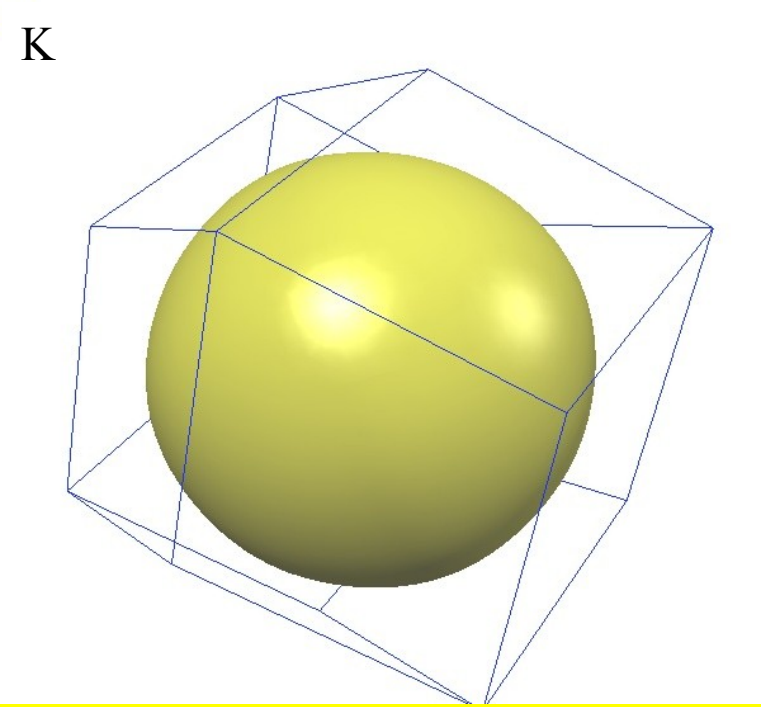

www.phys.ufl.edu/fermisurface/

Fermi Surfaces

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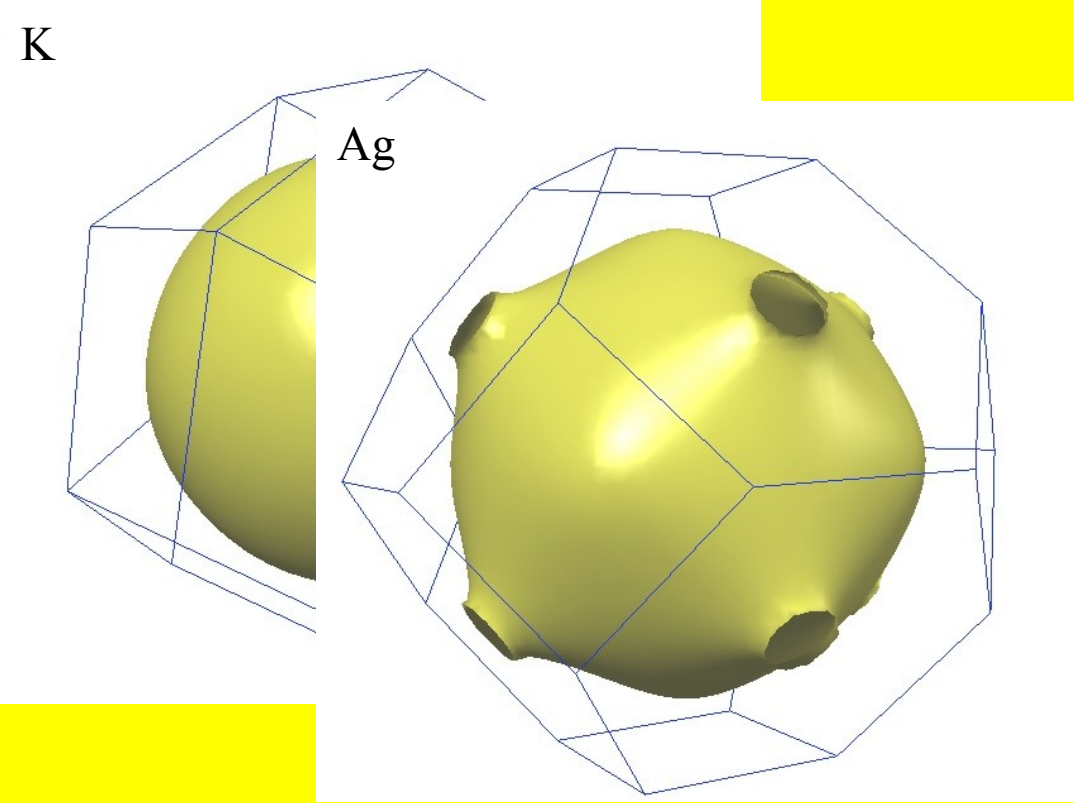

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Fermi Surfaces

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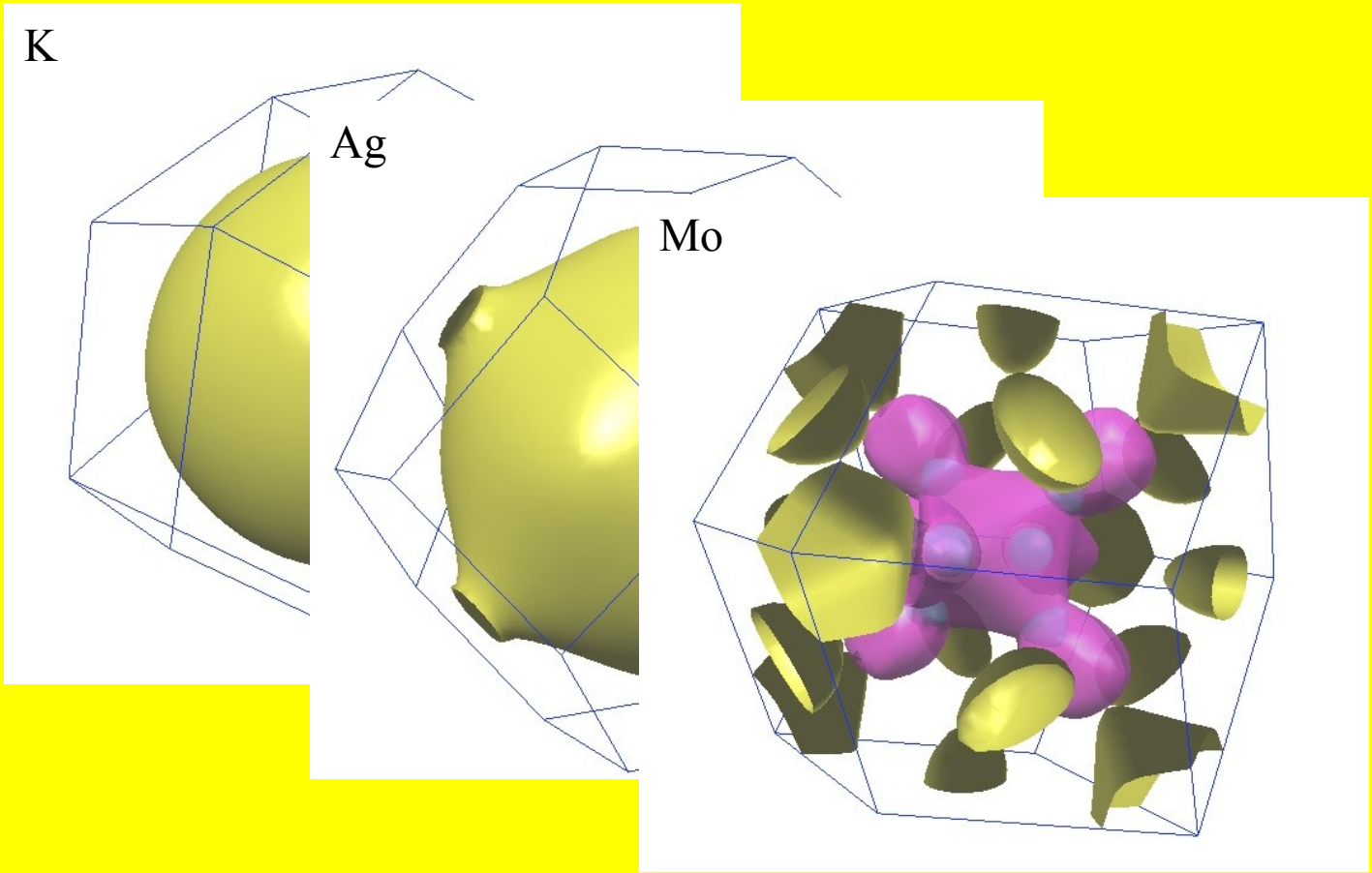

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Fermi Surfaces

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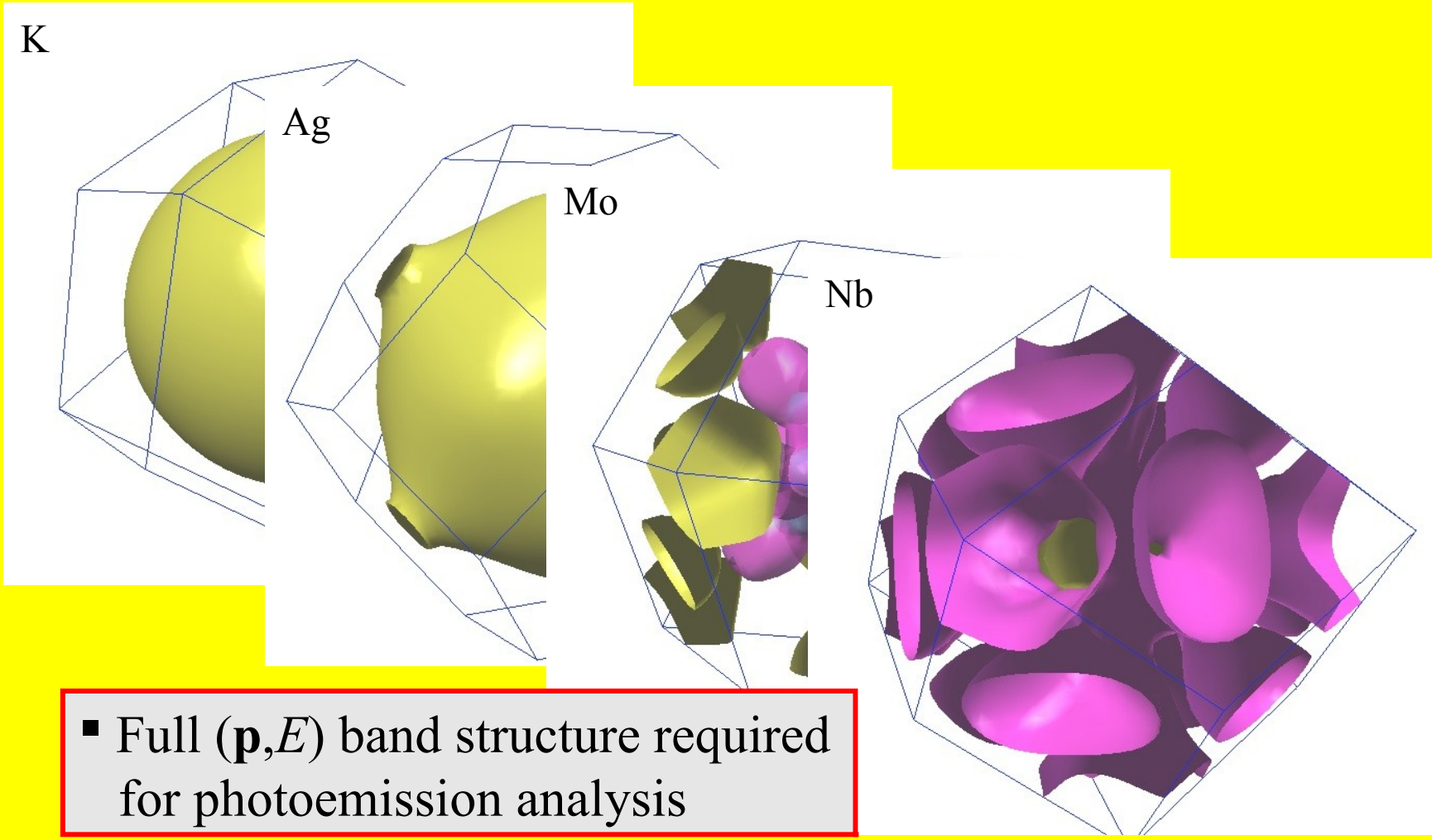

- Full (**p**,*E*) band structure required for photoemission analysis

Work Function Anisotropy

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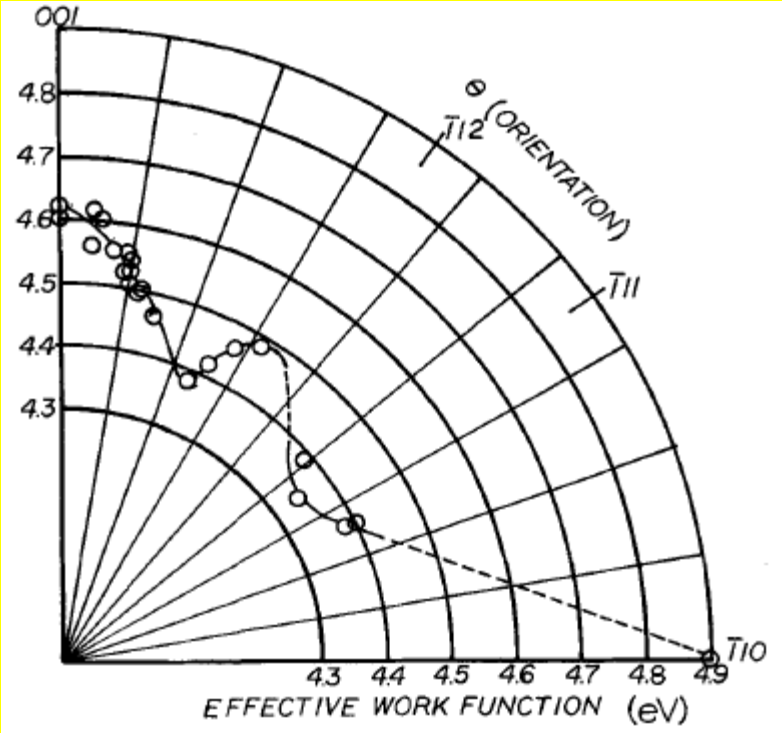
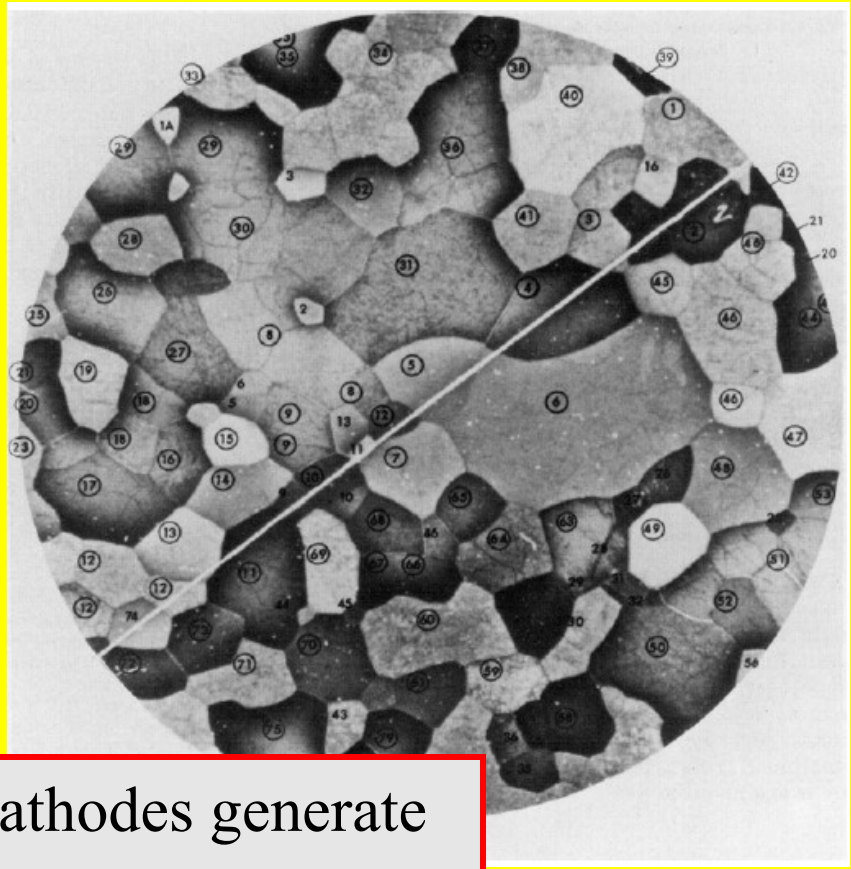
– Example: $\phi_{(ijk)}$ for Mo by electron emission microscopy





- Polycrystalline metal photocathodes generate *inhomogeneous* electron beams
- Any photoemission analysis ***must*** include $\phi_{(ijk)}$

D. Jacobson & A. Campbell, *Metall. Trans.* **2**, 3063-3066 (1971)

Photoemission Simulation: Ag

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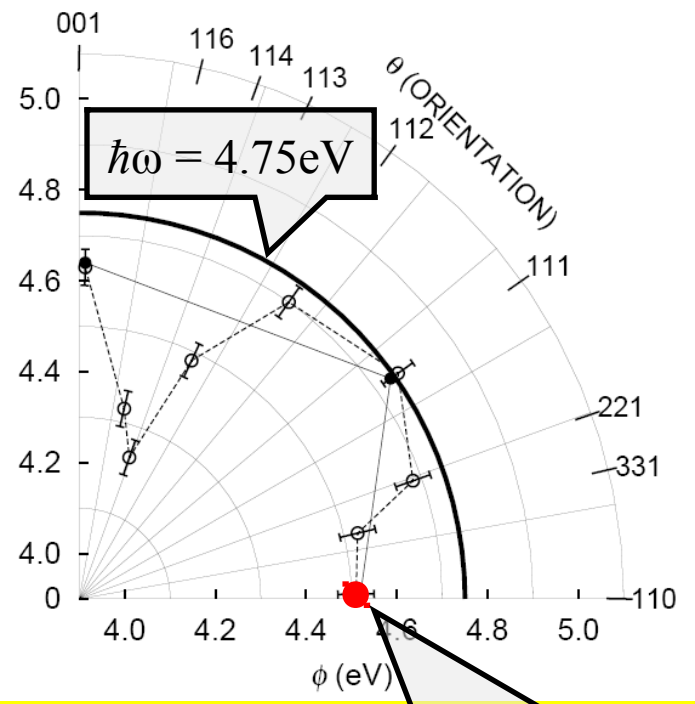
– fcc crystal lattice



Lowest index face
with lowest $\phi_{(ijk)}$

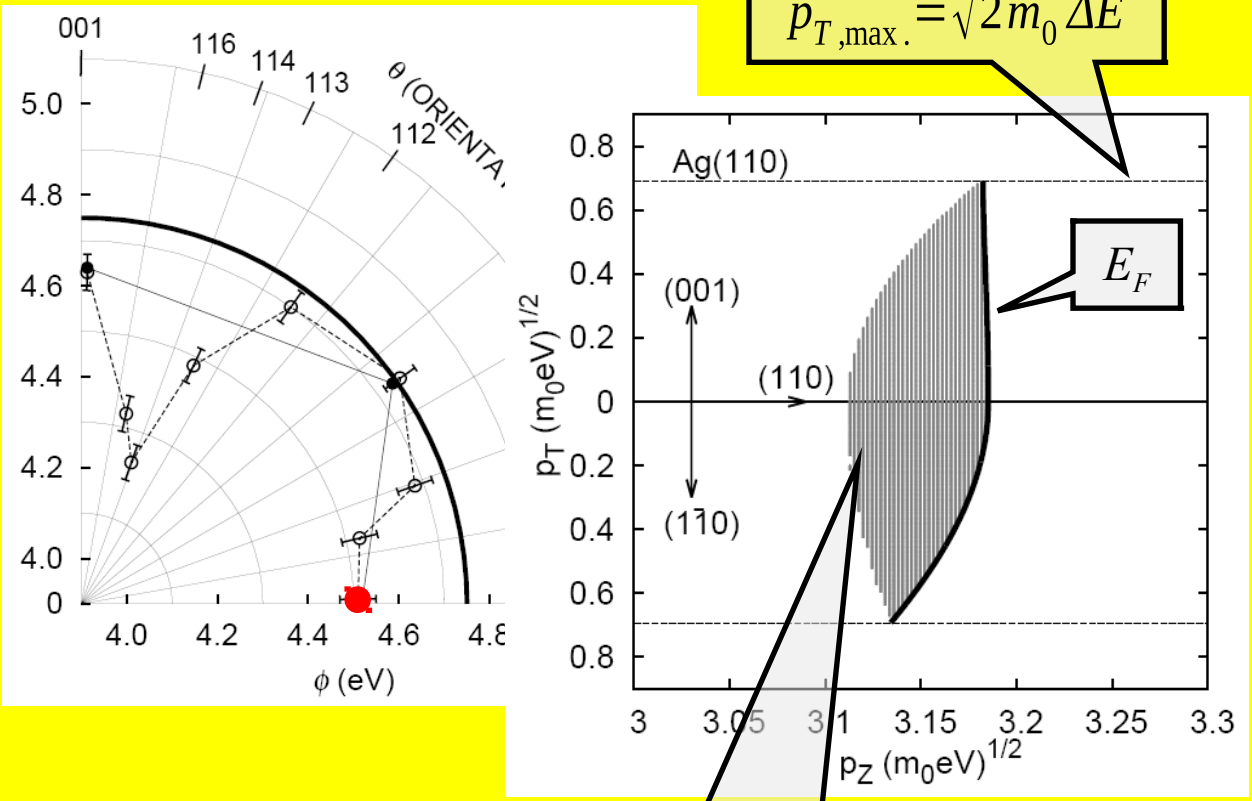
$\Delta E = \hbar\omega - \phi_{(110)} = 0.23\text{eV}$

… ±50meV error in $\phi_{(ijk)}$

Photoemission Simulation: Ag

UIC

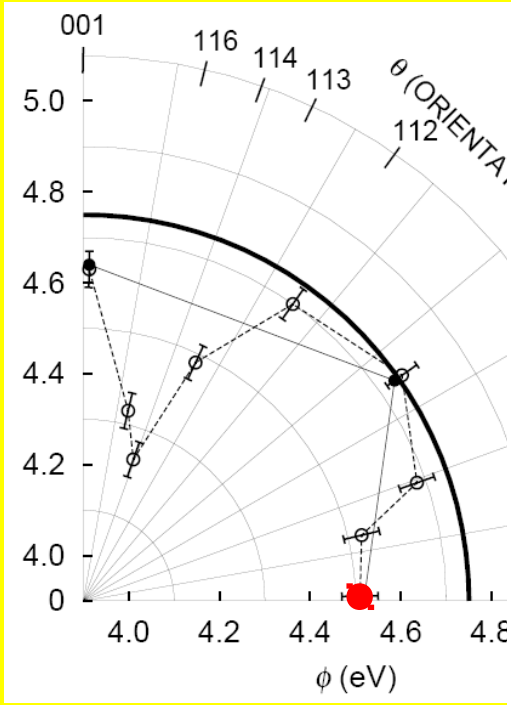
– fcc crystal lattice

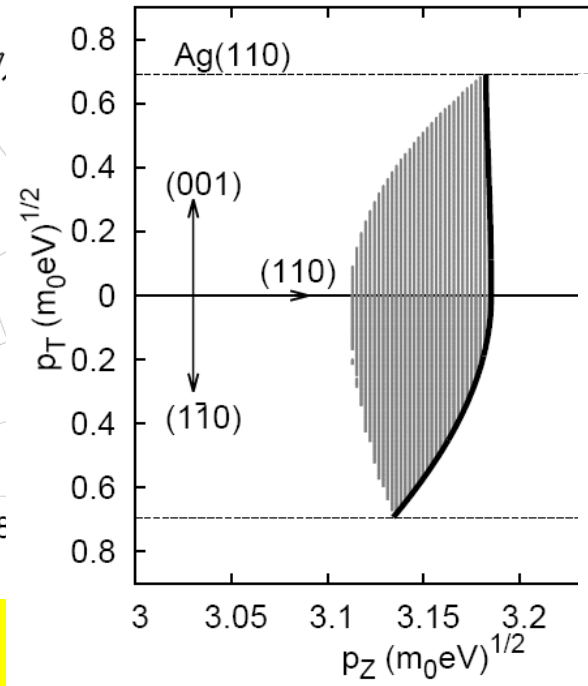


Photoemission Simulation: Ag

UIC

– fcc crystal lattice

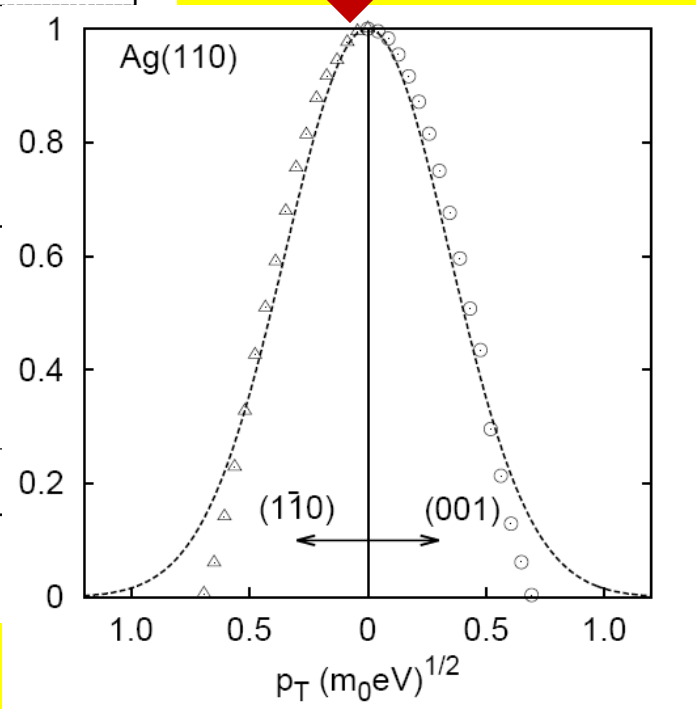




E, $\mathbf{p}_T$ conservation

PLUS

Barrier transmission, $T(p_z,p_{z0})$



Spatially-averaged

$\Delta p_T = 0.267$ (m_0.eV)$^{1/2}$

Photoemission Simulation: Mo

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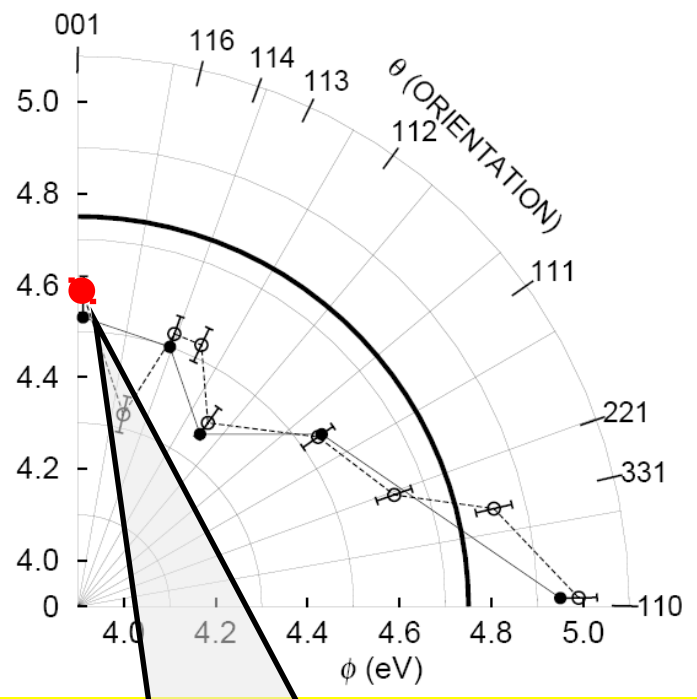
– bcc crystal lattice



Lowest index face
with lowest $\phi_{(ijk)}$

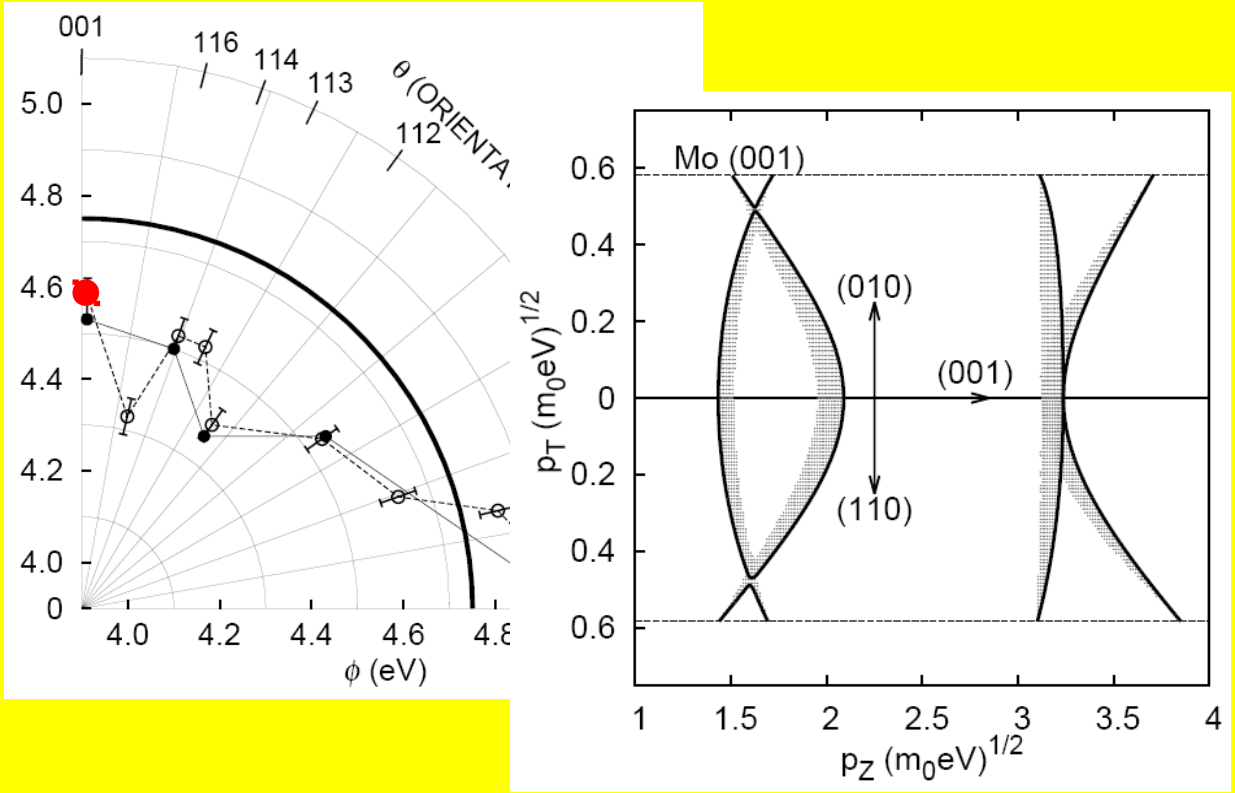
$\Delta E = \hbar\omega - \phi_{(001)} = 0.22\text{eV}$

… ±50meV error in $\phi_{(ijk)}$

Photoemission Simulation: Mo

UIC

– bcc crystal lattice

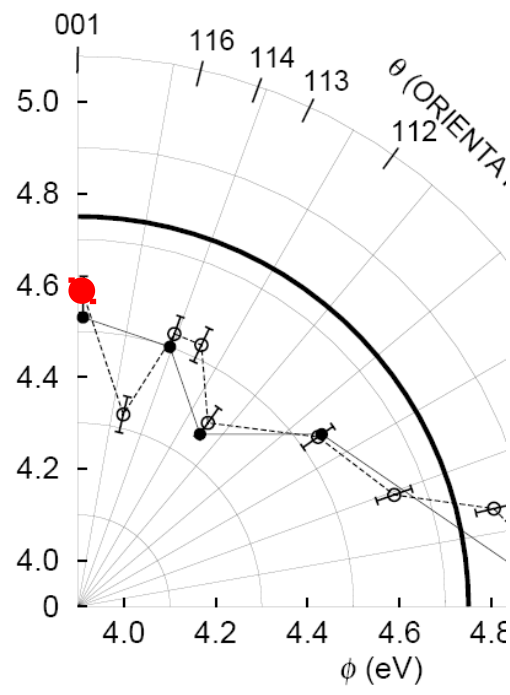


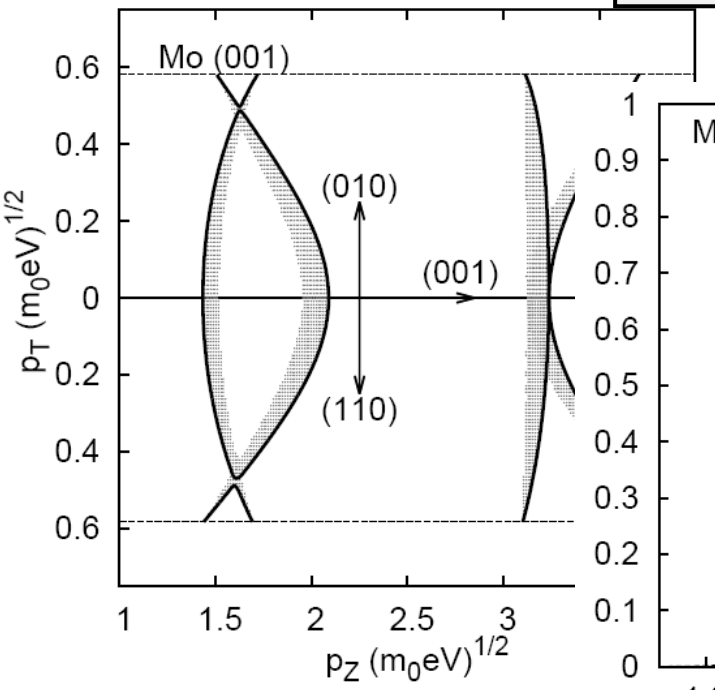
Both electron- and hole-like states contribute to photoemission

Photoemission Simulation: Mo

UIC

– bcc crystal lattice

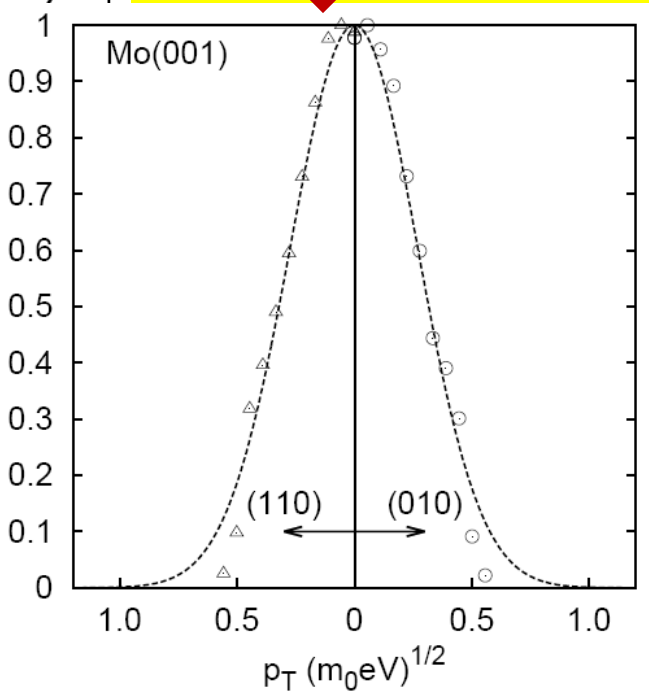




E, $\mathbf{p}_T$ conservation

PLUS

Barrier transmission, $T(p_z,p_{z0})$



Spatially-averaged

$\Delta p_T = 0.219\ (m_0.eV)^{1/2}$

Photoemission Simulation: Nb

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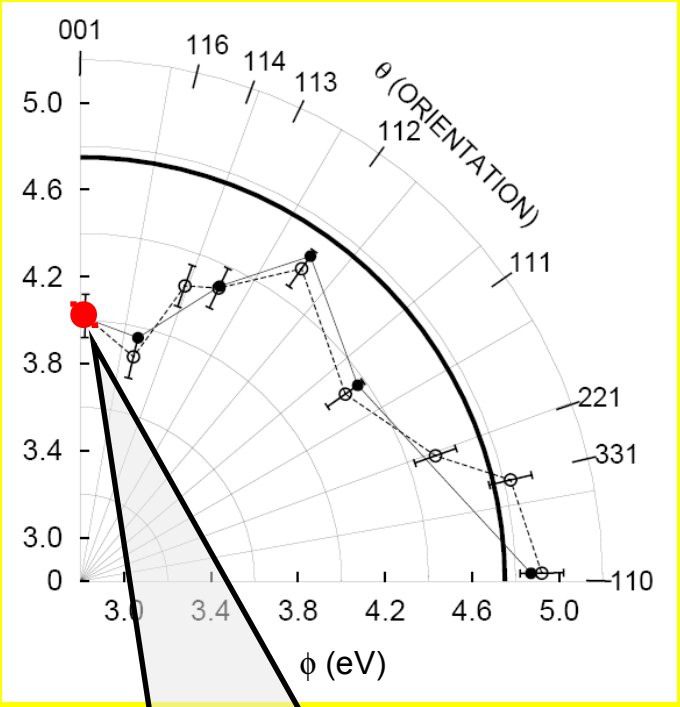
– bcc crystal lattice



Lowest index face
with lowest $\phi_{(ijk)}$

$\Delta E = \hbar\omega - \phi_{(001)} = 0.73\text{eV}$

… ±50meV error in $\phi_{(ijk)}$

Photoemission Simulation: Nb

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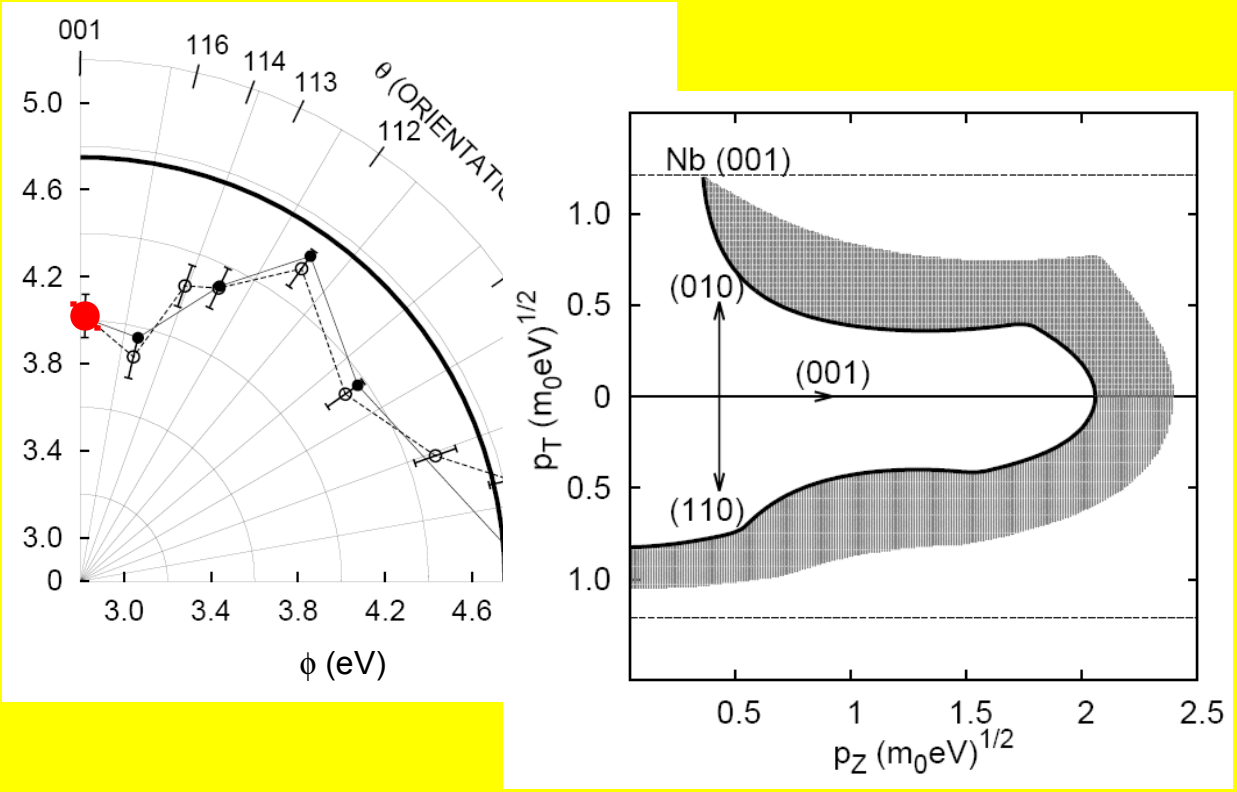
– bcc crystal lattice



Only hole-like states contribute to photoemission

Photoemission Simulation: Nb

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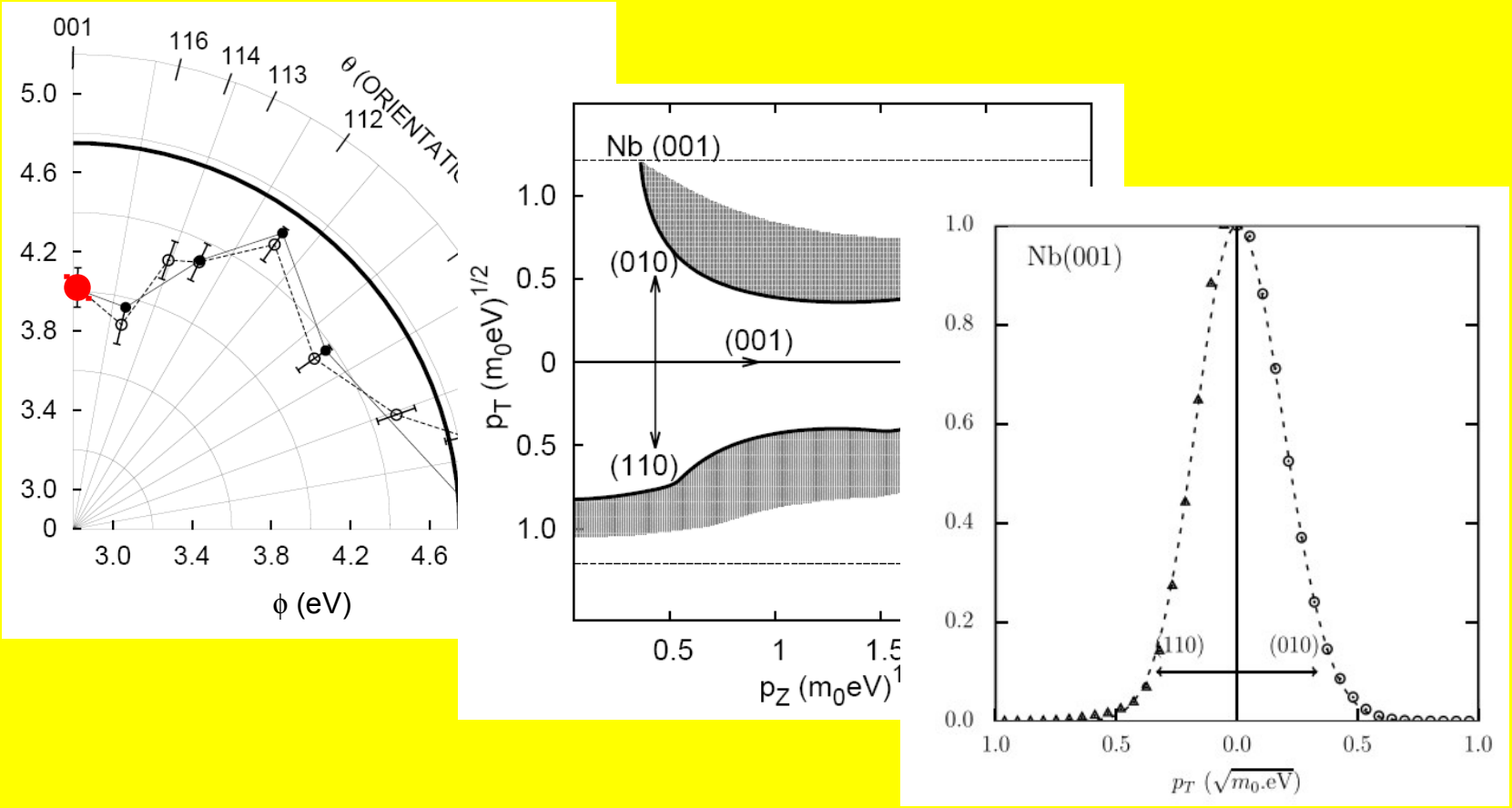
– bcc crystal lattice



Experiment vs. Theory

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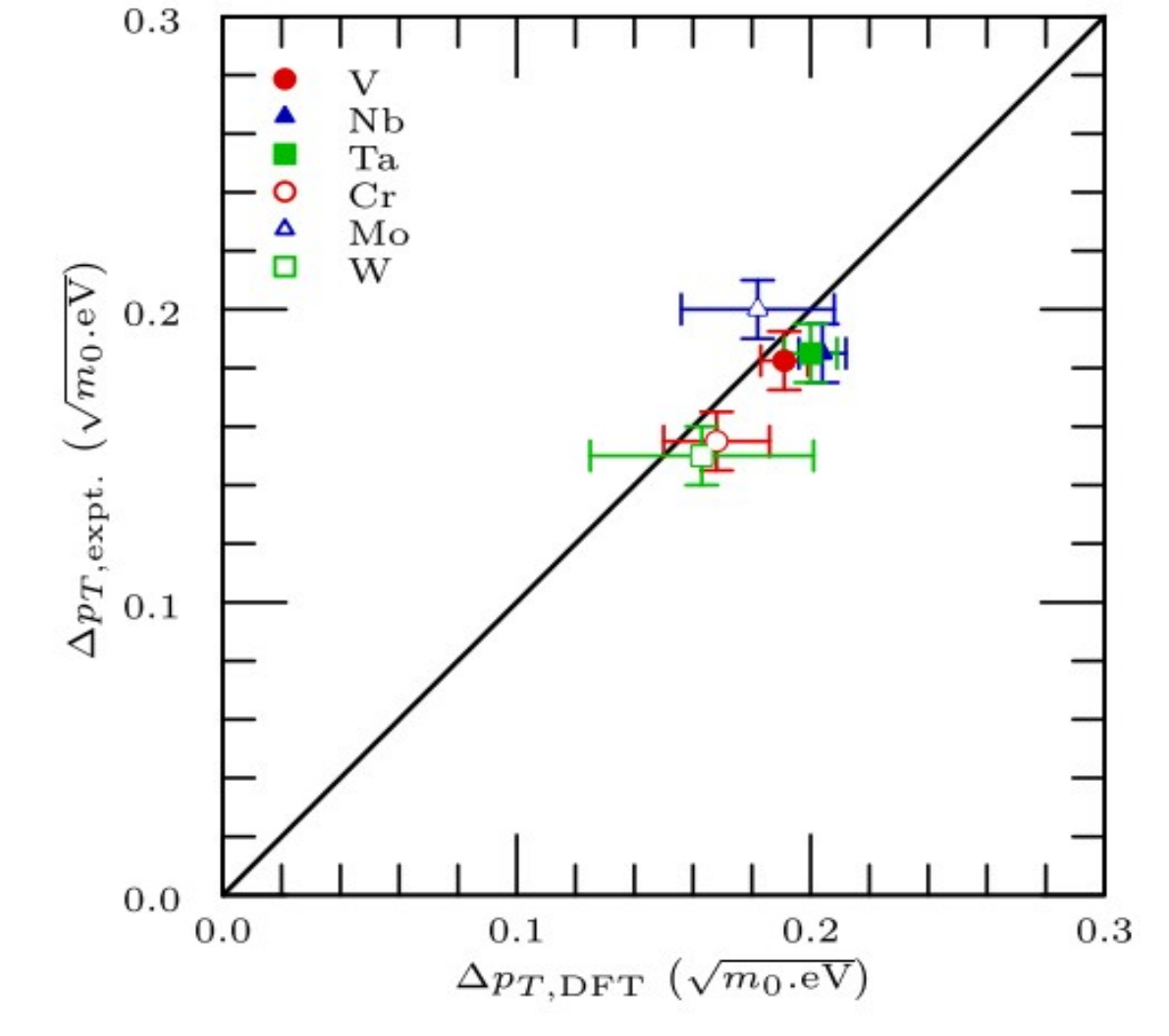

Li, Tuo and Rickman, B.L. and Schroeder, W. A, Journal of Applied Physics, 117, 134901

$\Delta p_T(T_e)$ for V(001) emission

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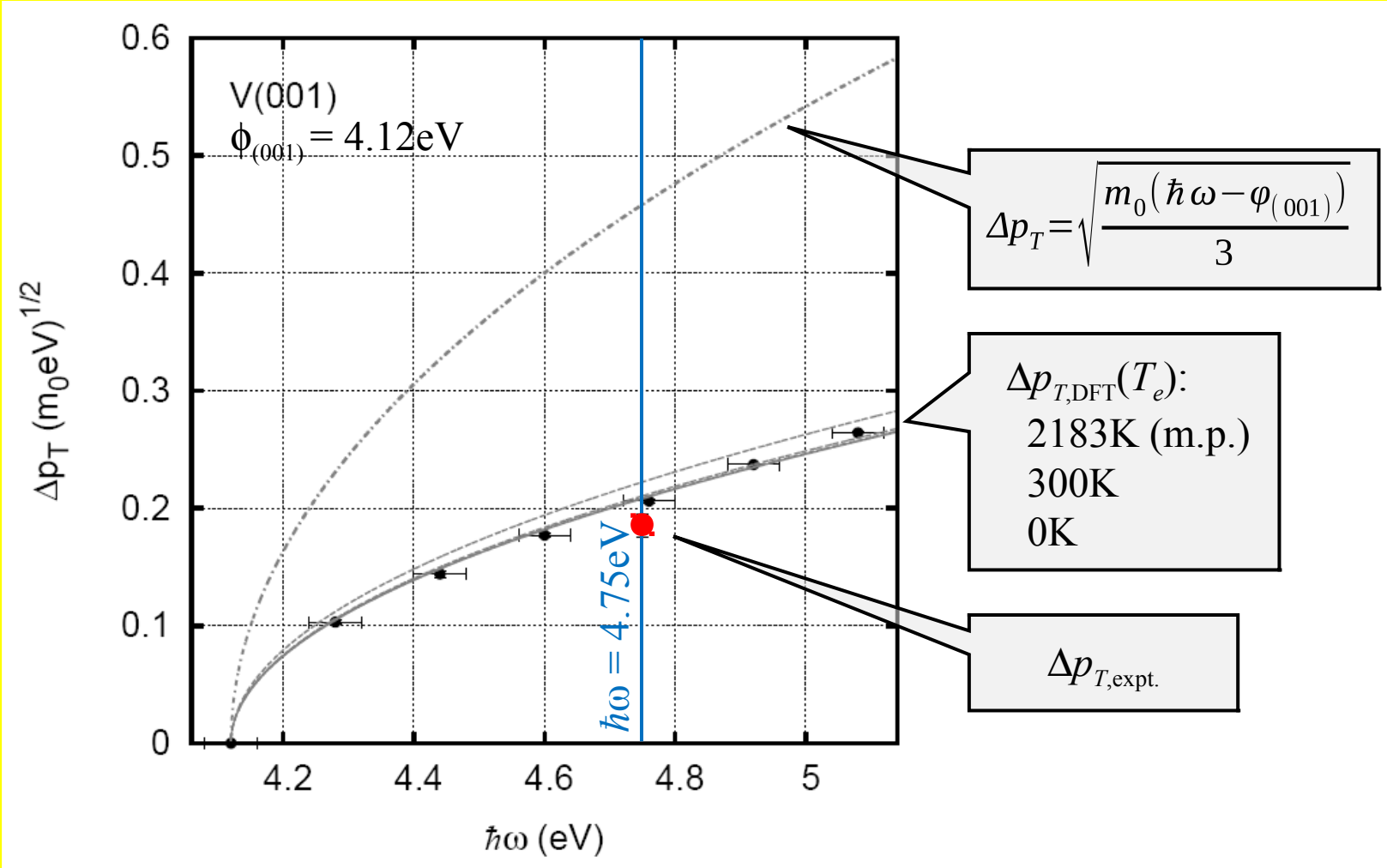
– DFT band structure with Fermi-Dirac distribution for electrons



Summary

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- Work function anisotropy $\phi_{(ijk)}$

  $\Rightarrow$ Intrinsically inhomogeneous electron beam from polycrystalline photocathodes

- Band structure complexity (non-spherical Fermi surface)

  $\Rightarrow$ DFT-based photoemission analysis for evaluation of Δp_T (knowledge of electronic state ($\mathbf{p}$,E)-distribution is fundamental)

Hexagonal Close-Packed Metals

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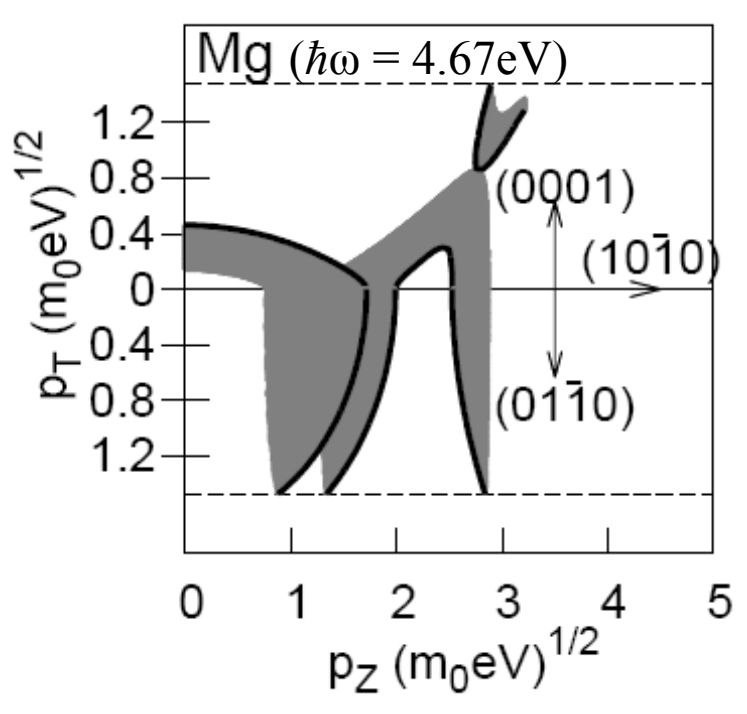
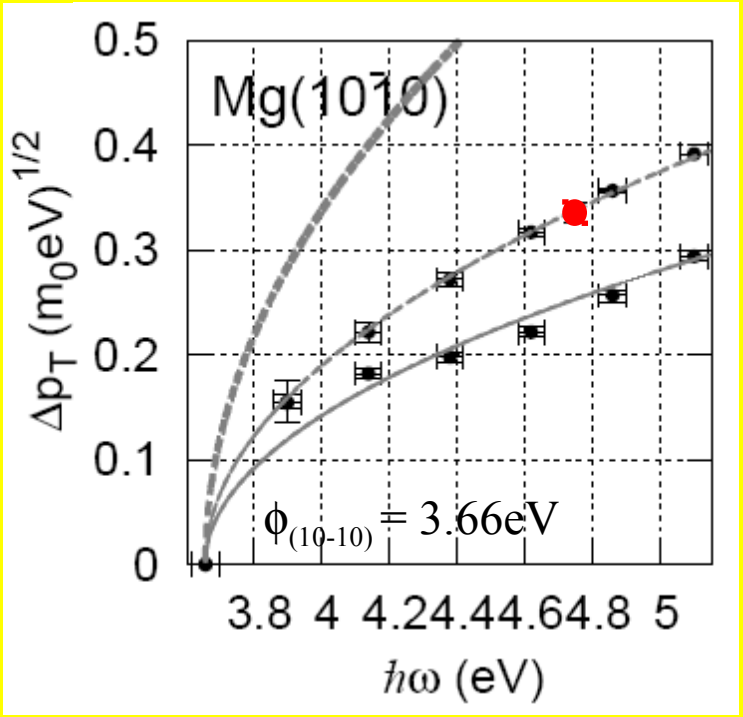
Δp_T(ijk) for ***all*** elemental metals

http://people.uic.edu/~tli27/Database.html





Tuo Li, B.L.Rickman, W.A.Schroeder, Physical Review ST Accelerators and Beams (Submitted).

Thank you!

The authors are indebted to Juan Carlos Campuzano, Serdar Ogut, Christopher Grein, Randall Meyer for their valuable discussions.