Investigating Atomic Inner-shell Phenomena with High-energy X-rays

- Atomic Physics at the APS
- Double–K photoionization of heavy atoms
  $1\gamma \longrightarrow 2$ photoelectrons
  2 bound electrons $\longrightarrow 1\gamma$
- 2-photon decays in heavy atoms
  1 bound electron $\longrightarrow 2\gamma$
- Nuclear Excitation by Electronic Transition (NEET)
  time-reversed bound internal conversion
- Future needs

Atomic Physics Projects at the APS (1996-2004)

- Compton, Rayleigh, and Raman scattering in free atoms & molecules (12BM,12ID)
- Single/double ionization in He by photon impact (12ID)
- Nondipole photoionization of atoms & molecules (12ID)
- X-ray/Auger cascades in atoms & molecules (12BM,11ID)
- Double K-shell ionization of heavy atoms (12BM,11ID)
- Nuclear Excitation by Electronic Transition (11ID)
- 2γ Transitions (12BM,11ID)

Some Properties of K-shell Electrons

Property	Z Scaling	Z=92
Binding Energy	Z^2	116 keV
Orbital Radius	$1/Z$	0.006 Å
β	Z	0.7 ($\gamma = 1.4$)
Lamb Shift	Z^6	460 eV

Double–K Photoionization

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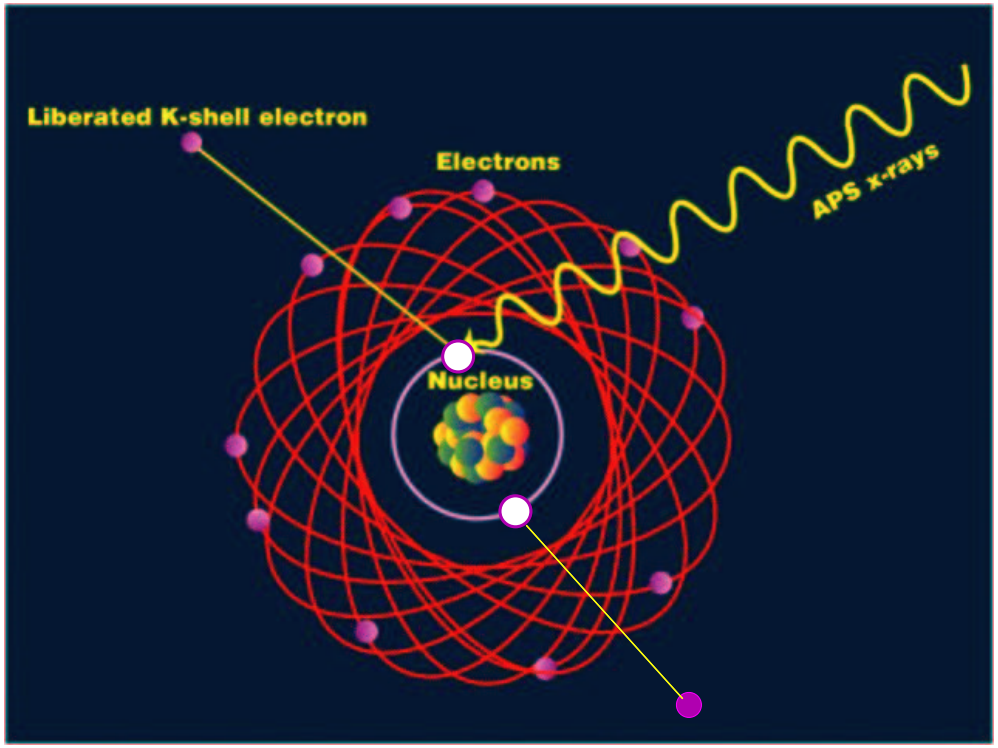
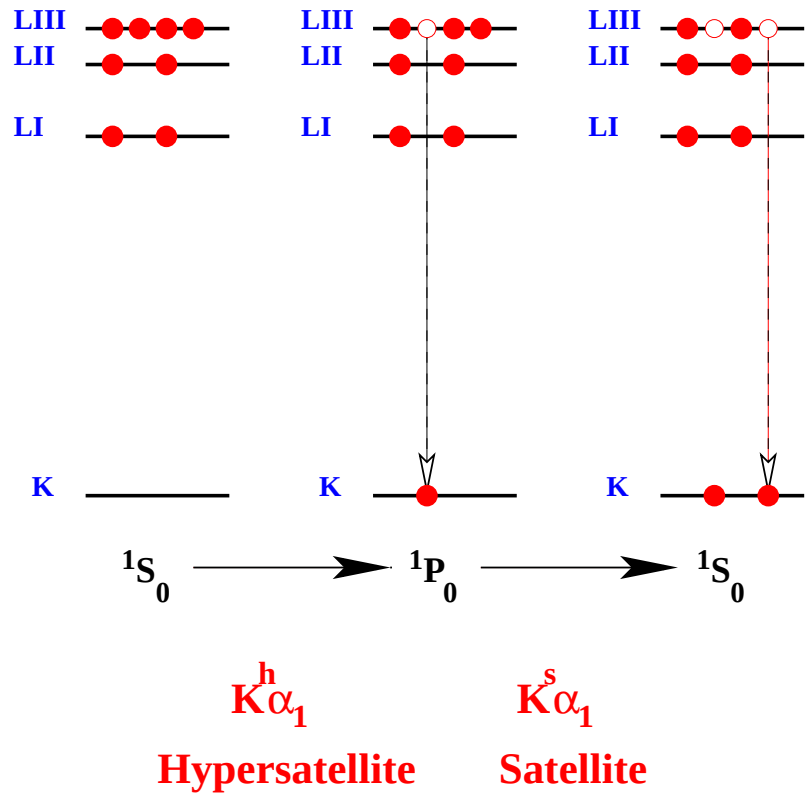
B. Krässig, S.H. Southworth, and L. Young



*Physics Division

How can we detect double-K photoionization?



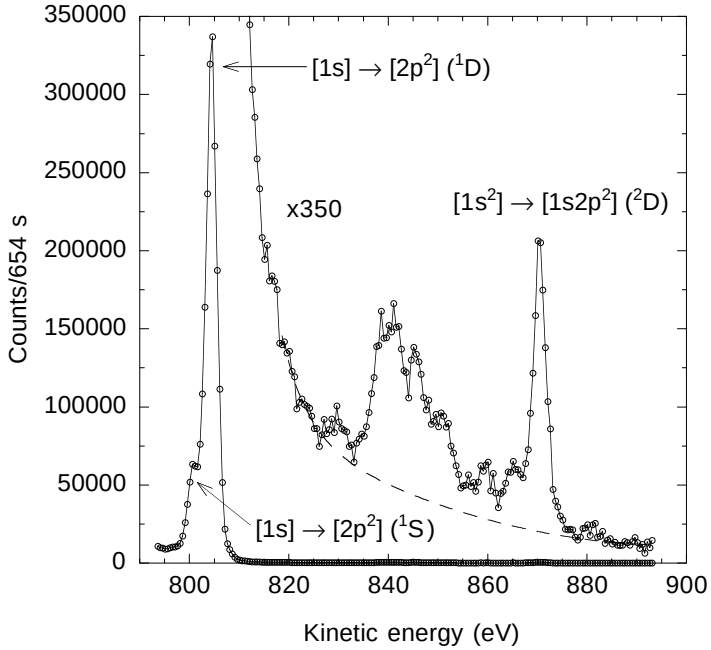
Low Z: High resolution Auger spectroscopy

Mid Z: High resolution X-ray spectroscopy

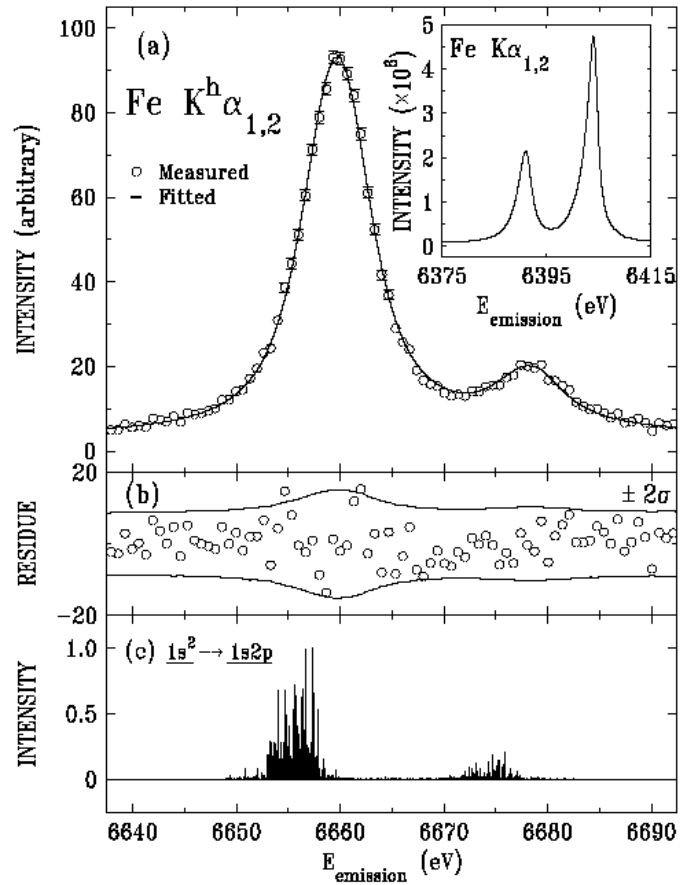
High Z: Coincidence X-ray spectrometry

High Resolution Spectroscopies

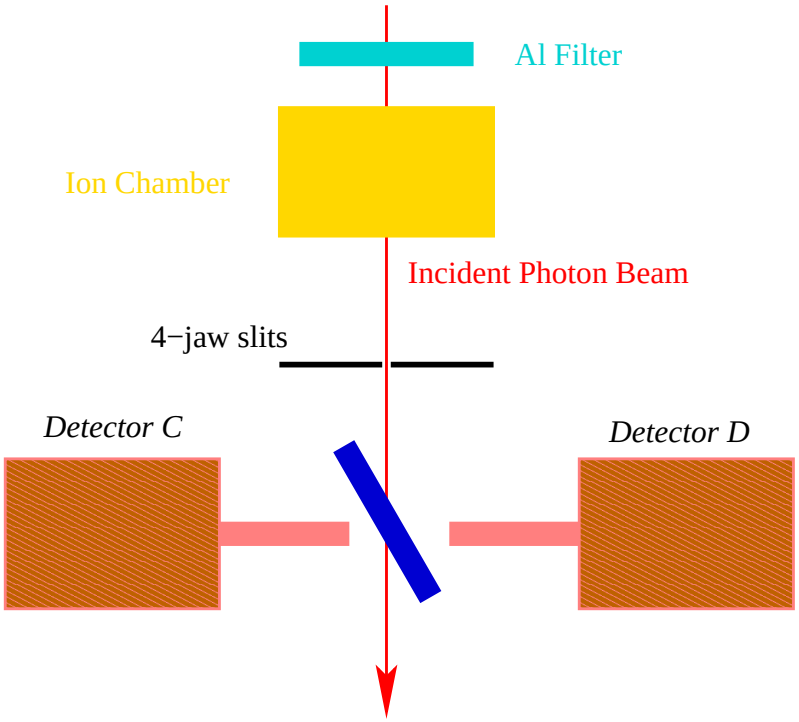
Ne Auger

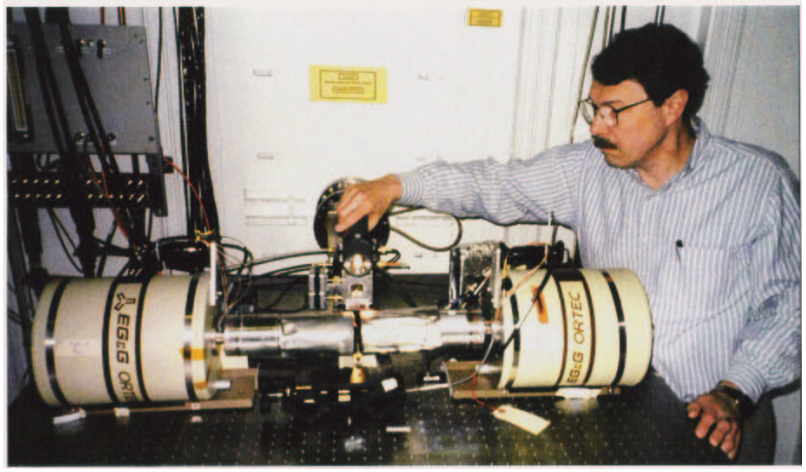


Fe X-ray

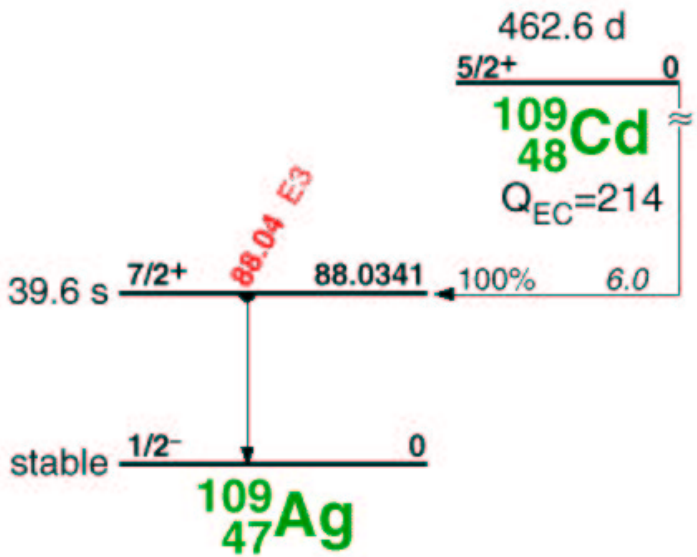


Experimental Apparatus in BESSRC 12BM-B





Phys. Rev. Lett. **83**, 508 (1999)

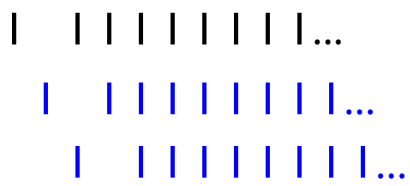


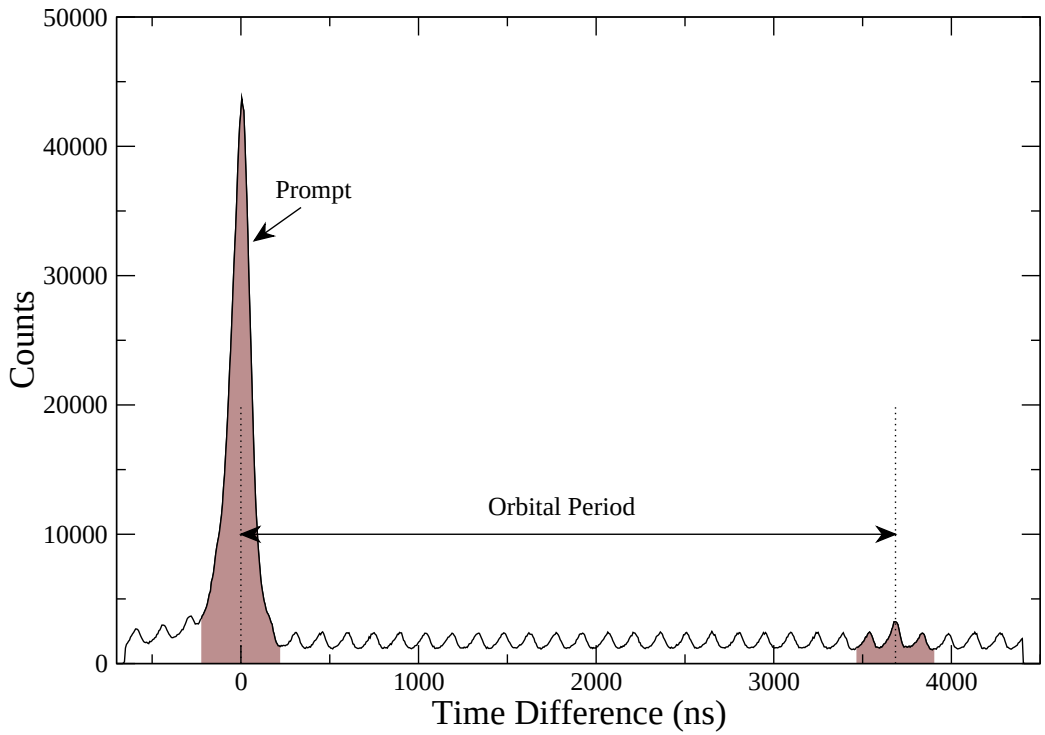
$$\begin{aligned} \mathrm{p} + \mathrm{e} &\longrightarrow \mathrm{n} + \nu \\ \mathrm{Cd}^0 &\rightarrow \left[\mathrm{Ag}^0(K^{-1})\right] \\ &\rightsquigarrow \mathrm{Ag}^{+1}(K^{-2}) + \mathrm{e} \end{aligned}$$

S.K. Ko *et al.* Nucl. Phys. A **641**, 49 (1998)

$$\begin{aligned} \mathrm{P_{KK}} = \quad & (4.2 \pm 0.5) \times 10^{-5} \quad \mathrm{EC} \\ & (4.3 \pm 0.5) \times 10^{-5} \quad \mathrm{IT} \end{aligned}$$

Timing Issues

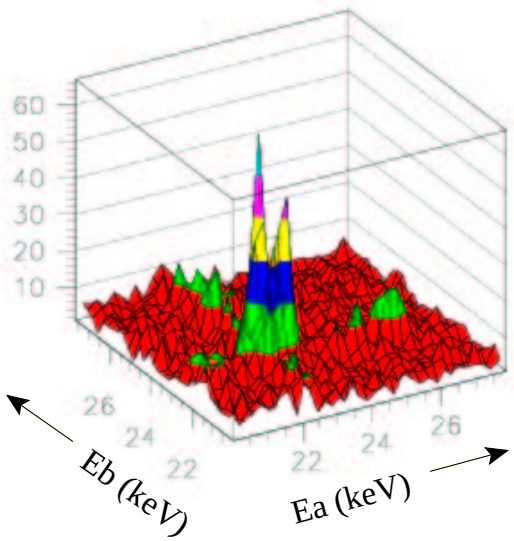




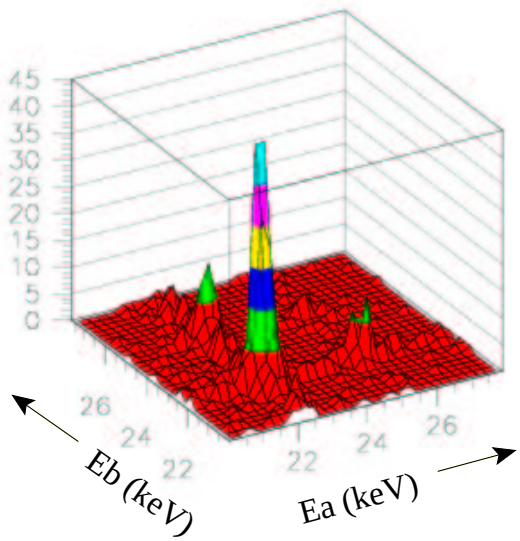
K–K X-ray Coincidences

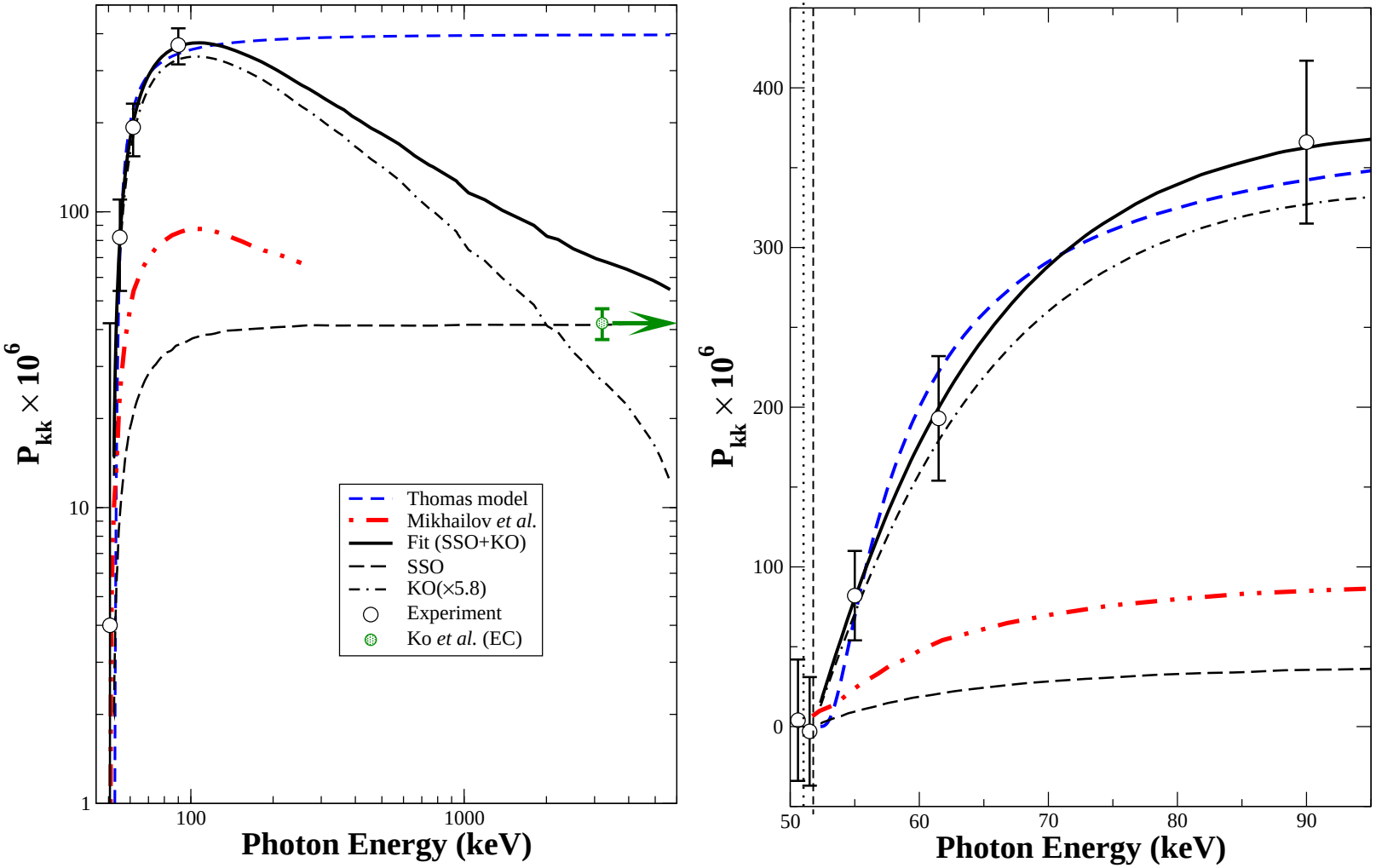
90 keV γ → Ag

Coincidences

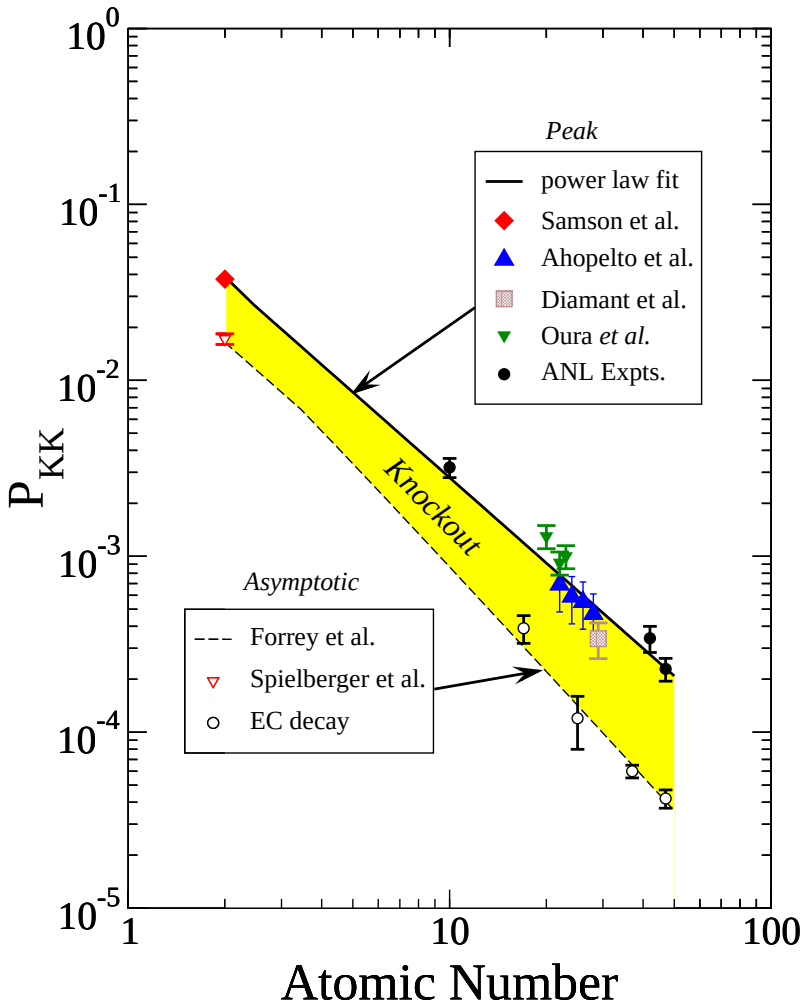


Randoms





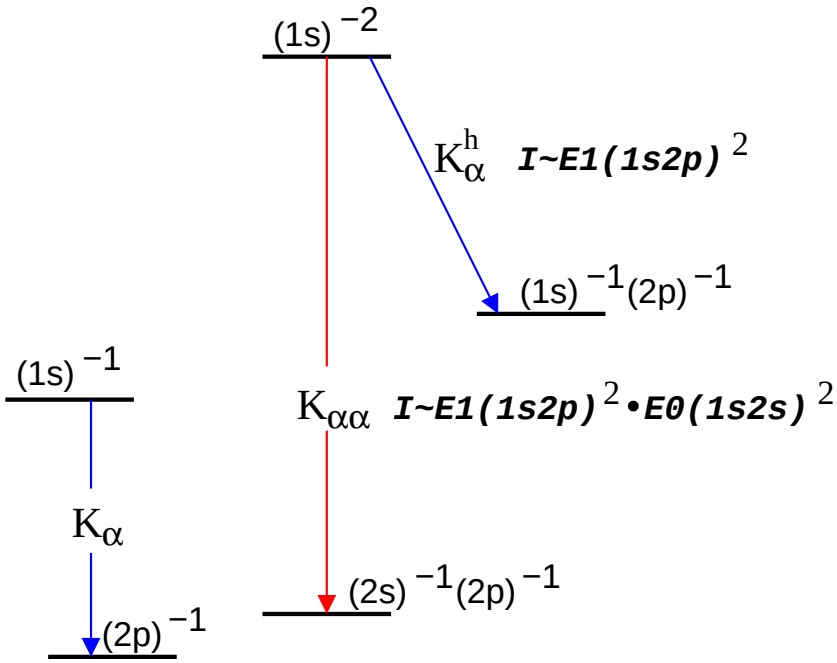
Energy-Dependence of Ag Double–K Ionization



Z-dependence of P_{KK}

- Asymptotic limit falls as $\sim 1/Z^2$
- Peak value falls slower ($\sim 1/Z^{1.6}$)
- KO *grows* with Z

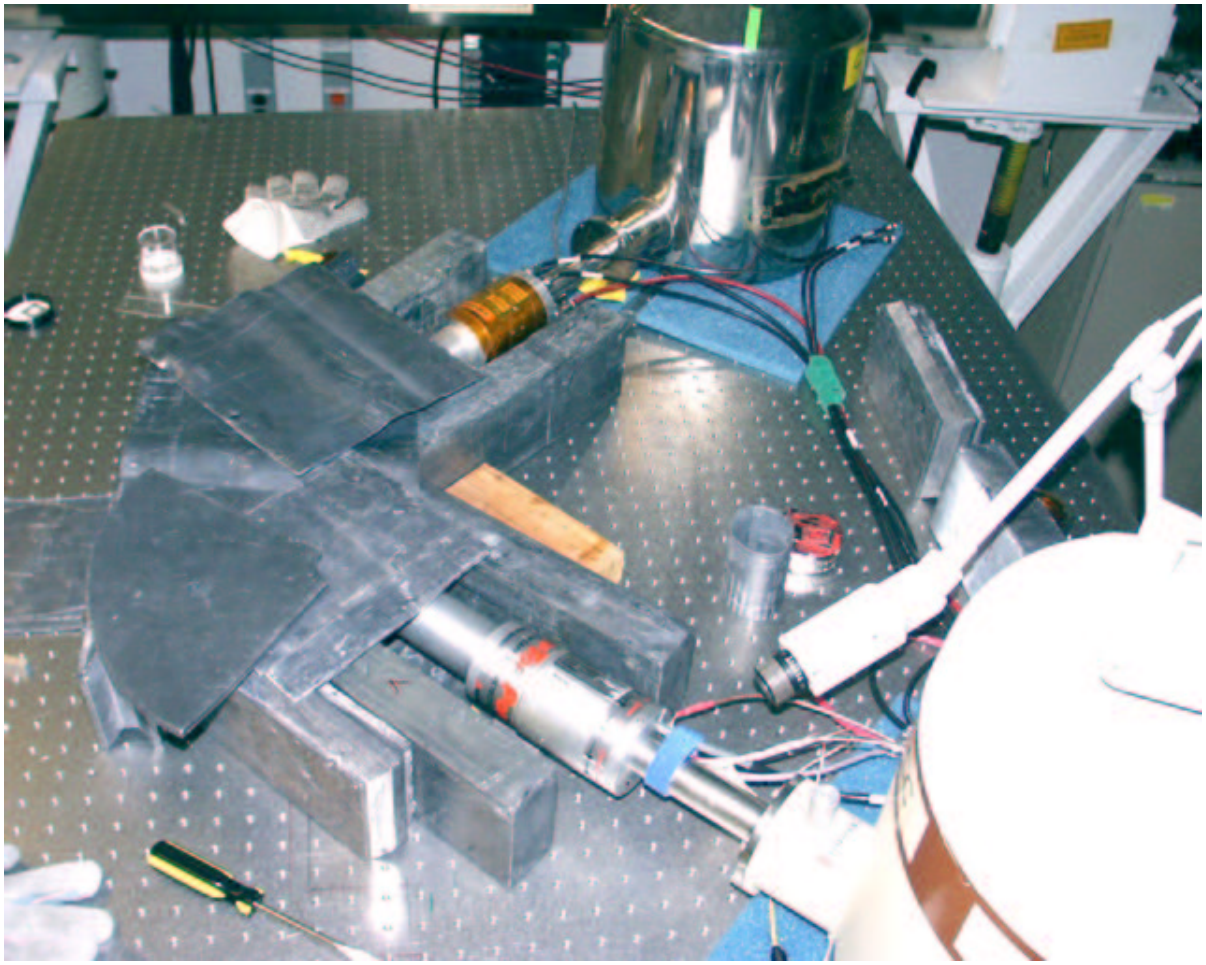
Two−electron, One−photon Transitions



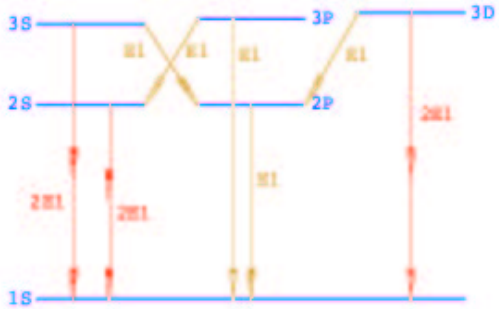
$$\frac{K_{\alpha\alpha}}{K_\alpha^h} \sim E0(1s2s)^2$$

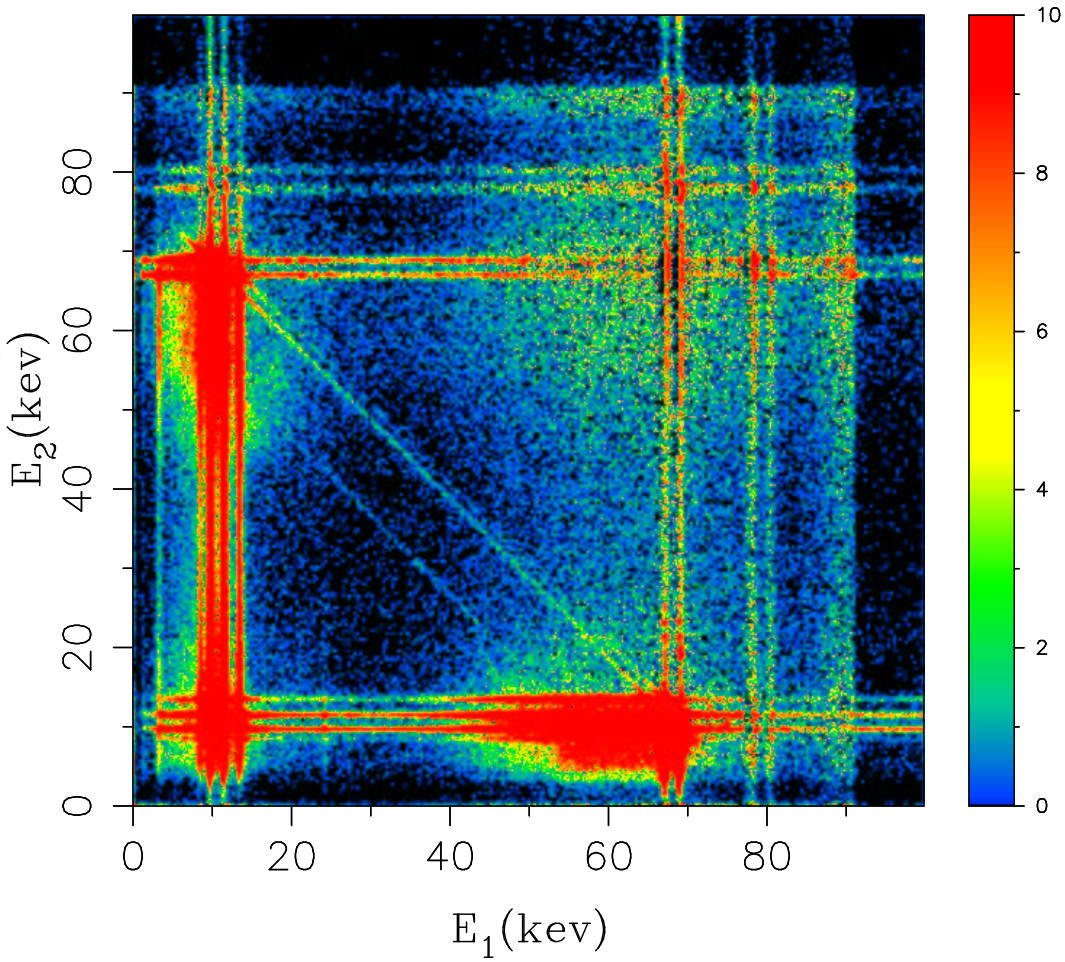
2γ Decay Experiment at 11-ID

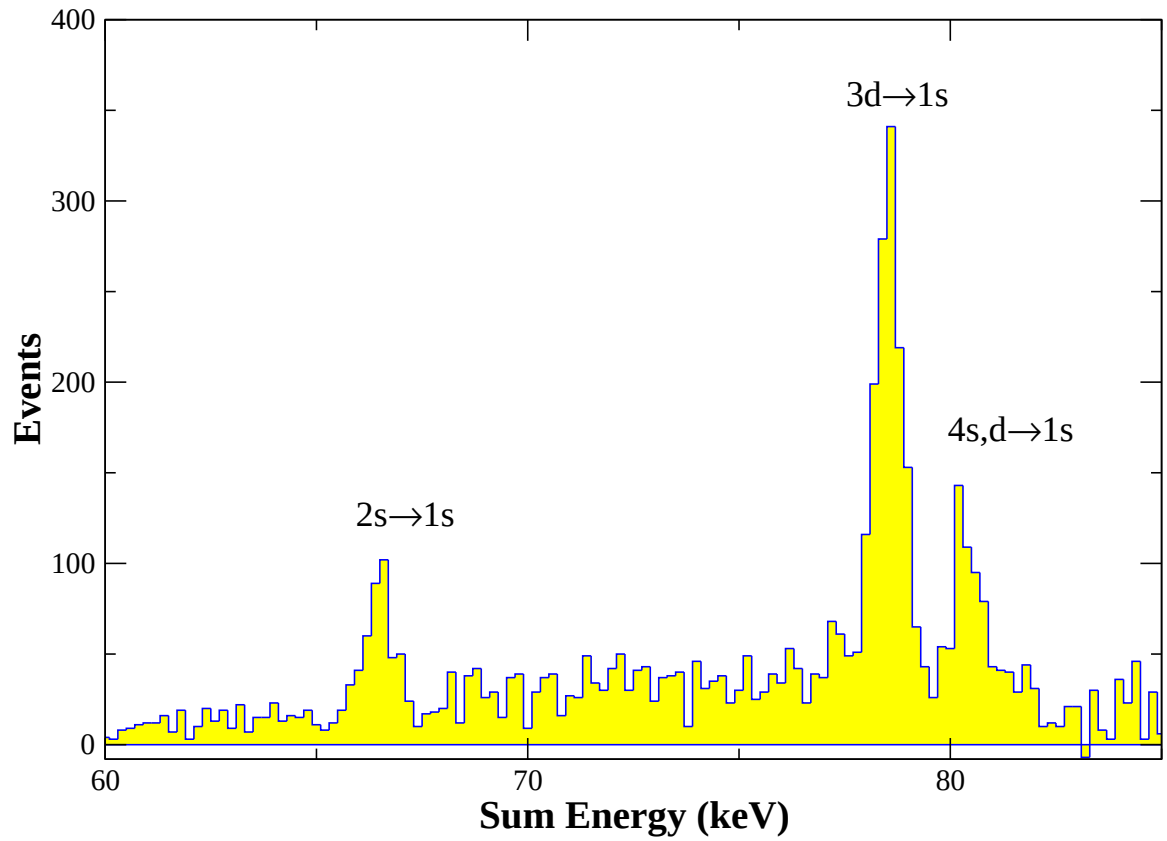
But need lots of Pb!!!



Two Photon Decay in Au





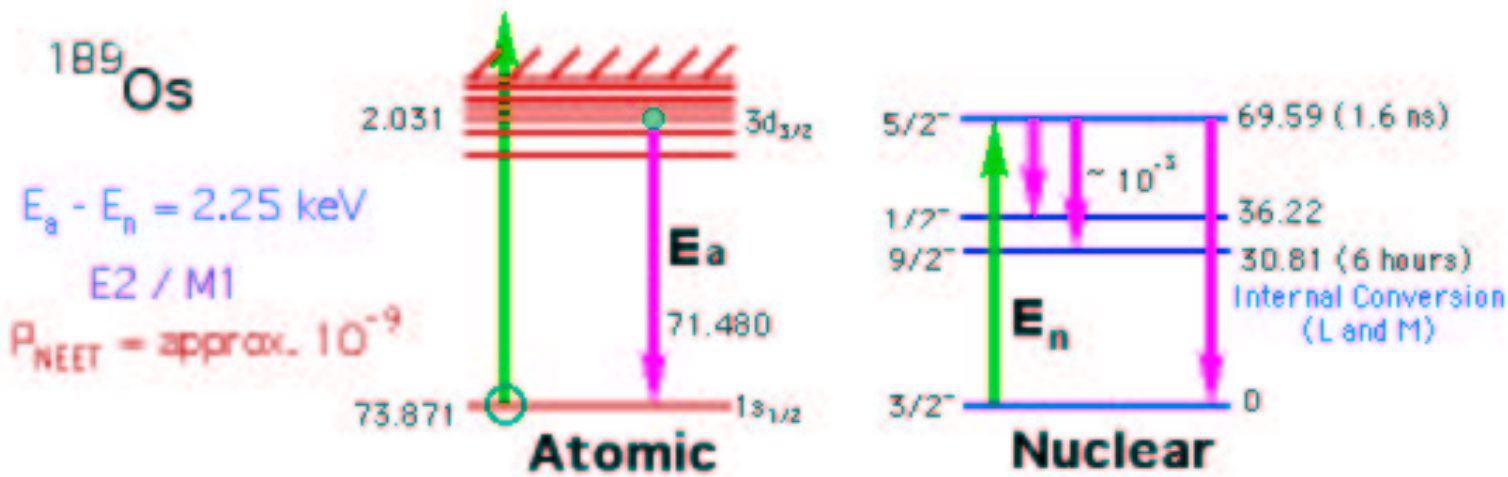


$$100\ \mathrm{keV}\ \gamma + \mathrm{Au} \rightarrow 2\gamma$$

Phys. Rev. A **67**, 054501 (2003)

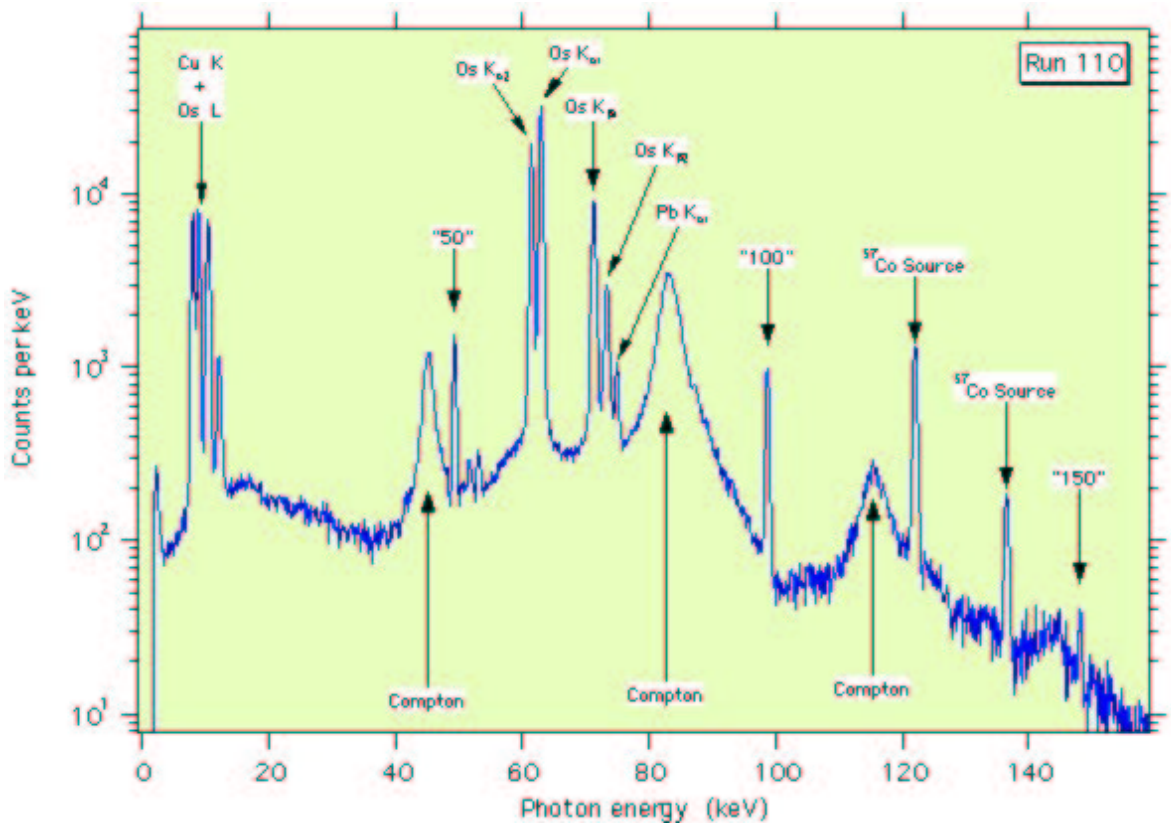
NEET

Nuclear Excitation by Electronic Transition



Phys. Rev. C **61**, 051304 (2000)

Scattered Photon Spectrum
($E_\gamma = 98.74$ **keV**)



Some Future Problems

- Extend Ag coincidences to 500 keV
- Search for 2e-transition (K$\alpha_{1,2}\alpha_3$)
- Investigate very high Z (Au, Pb, U)

Future Needs

- Monochromatic beams ($E_\gamma > 100$ keV)
- Suppression of higher harmonics
- Modest flux requirements (10^7/sec often sufficient)
- Uniformity/Constancy of fill pattern for coincidence
- Long measuring times (3 days/point for double-K)