UVSORワークショップ
２００２年
３月５日

HiSORにおけるd,f電子系の高分解能低温光電子分光

広島大学放射光科学研究センター
島田賢也

内容

１．HiSORリニアアンジュレータービームライン BL-1

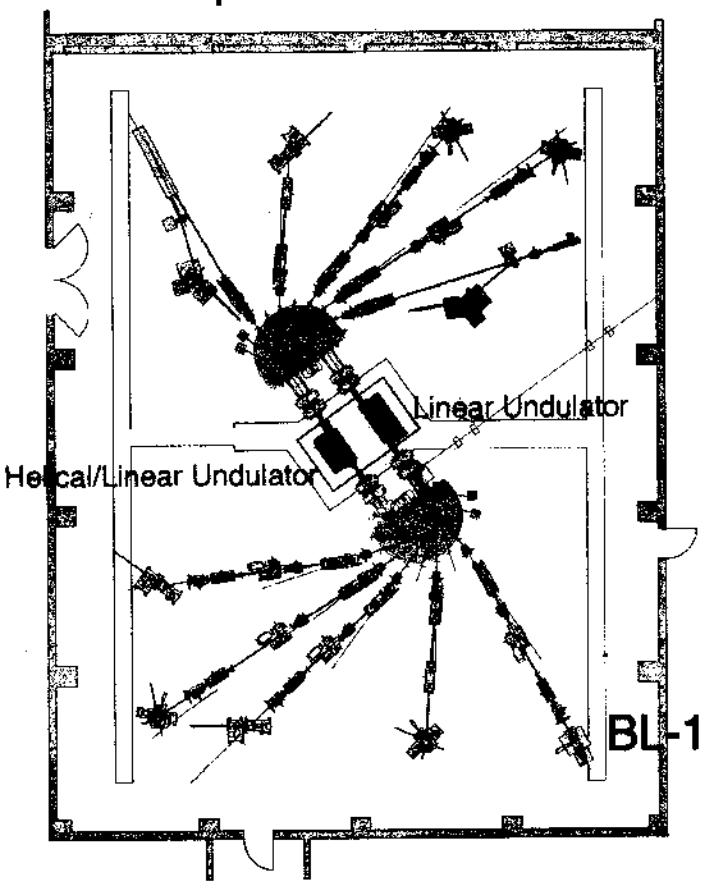
２、高分解能低温角度分解光電子分光装置の現状

３、HiSOR BL-1 共同利用研究（H13.11~H14.2）

４、今後の展望

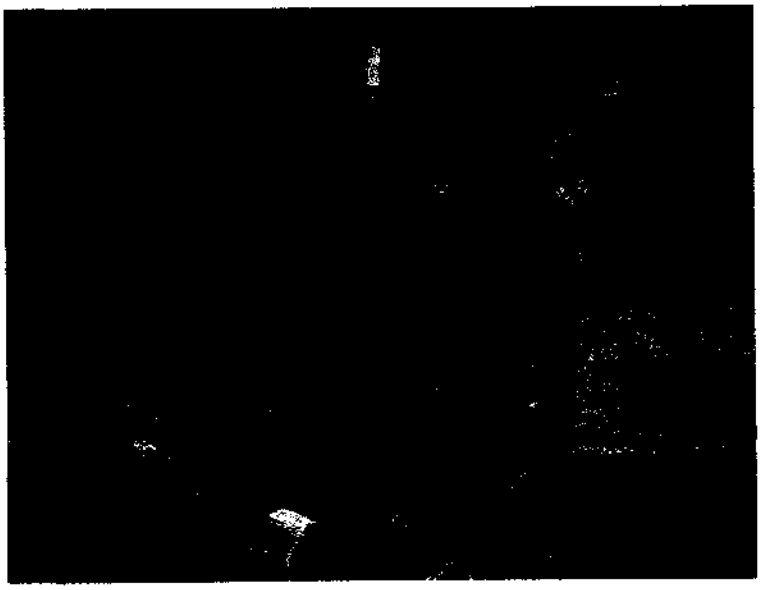
Hiroshima Synchrotron Radiation Center
Compact Eectron Storage Ring "HiSOR"
Electron beam energy: 700 MeV
Maximum beam current: 200 mA

Experimental Hall



30 eV ~ 300 eV

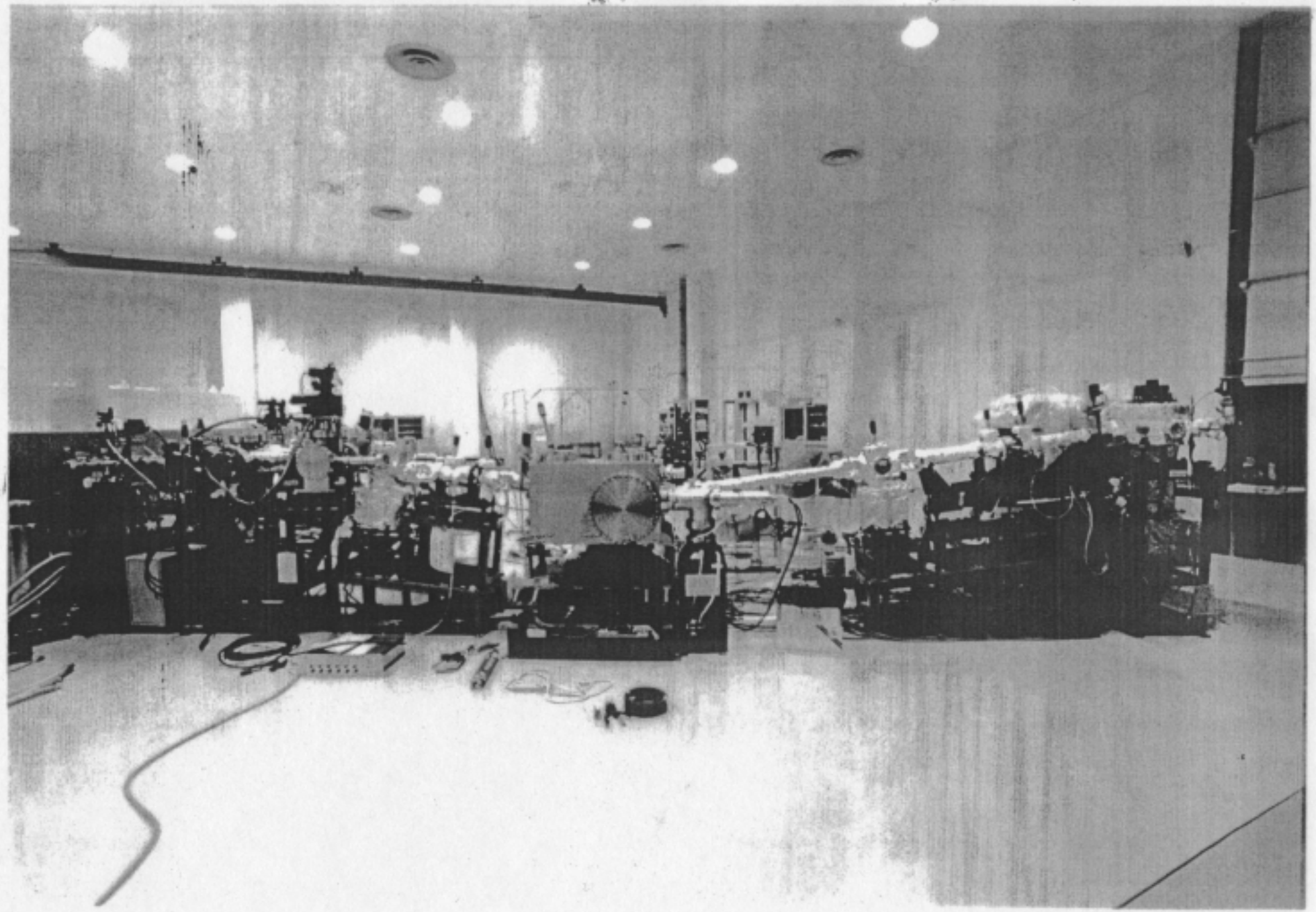
Linear Undulator



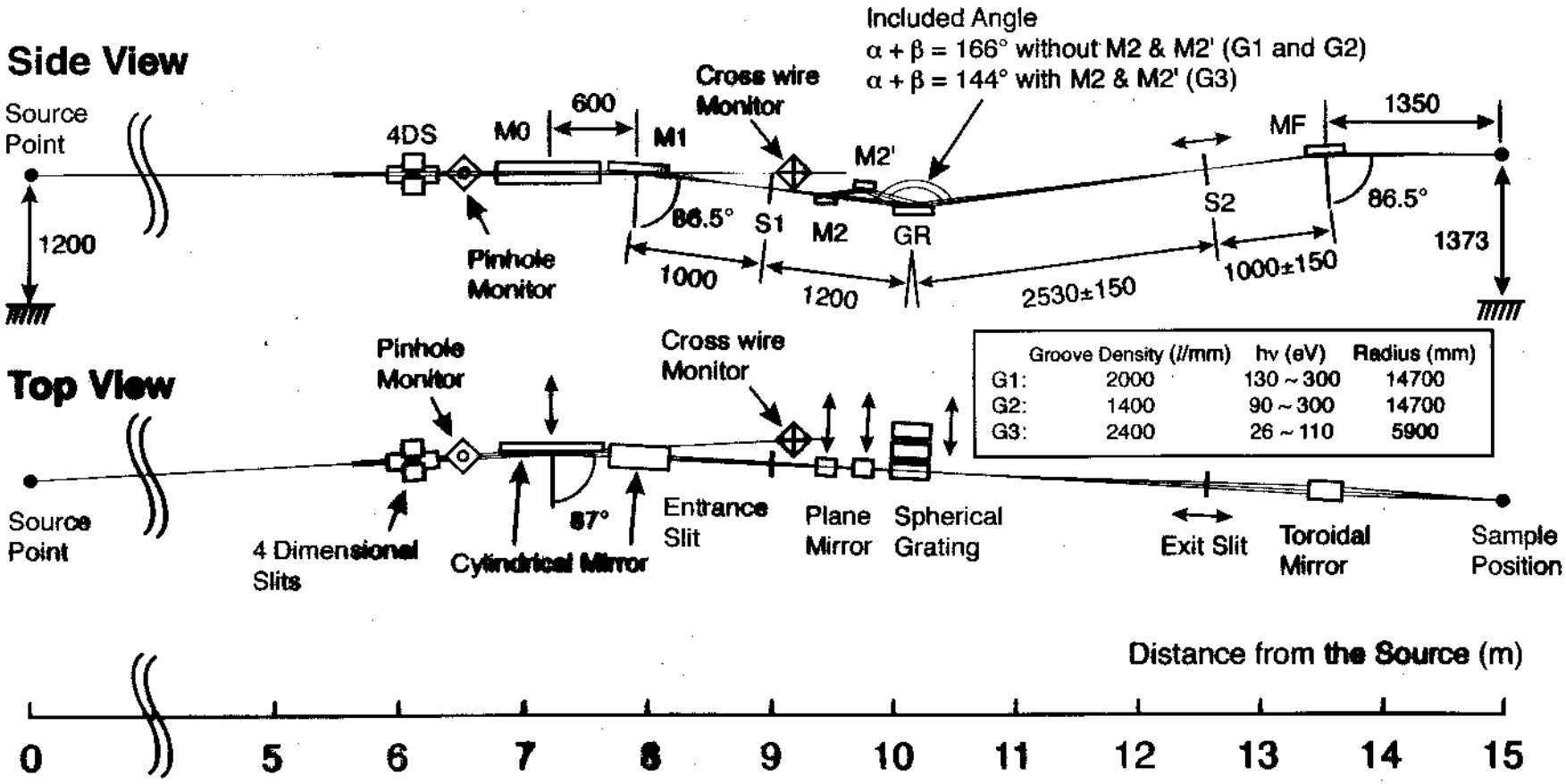
Parameters of the linear undulator at HiSOR

Period length (λ_u)	57 mm
Number of periods	41
Total length*	2354.2 mm
Gap distance	30 ~ 200 mm
MAX. magnetic field	0.41 T
Magnet material	Nd-Fe-B (NEOMAX-44H)

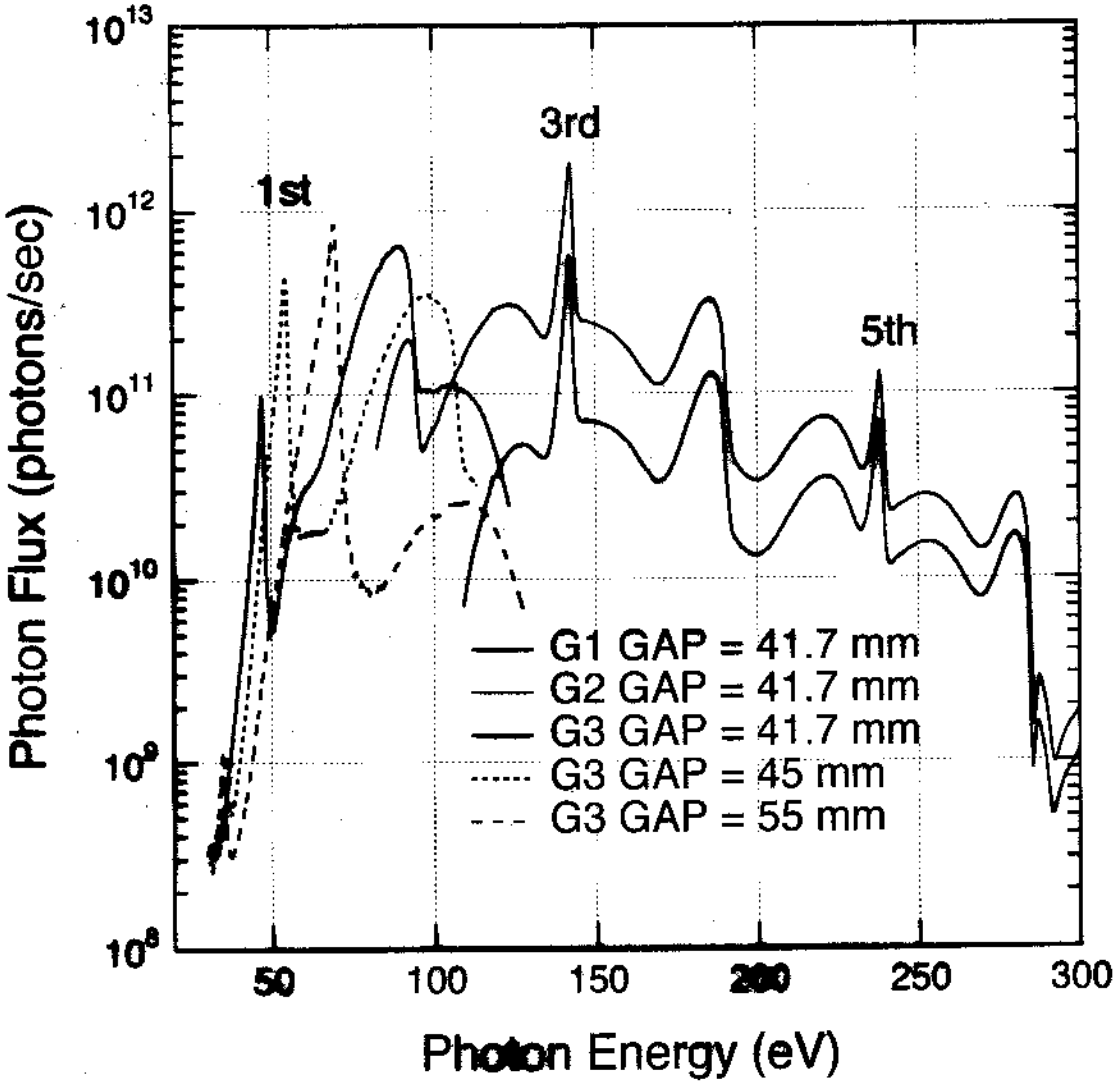
*including correction magnets



Schematic optical layout of the linear undulator beamline BL-1 at HiSOR

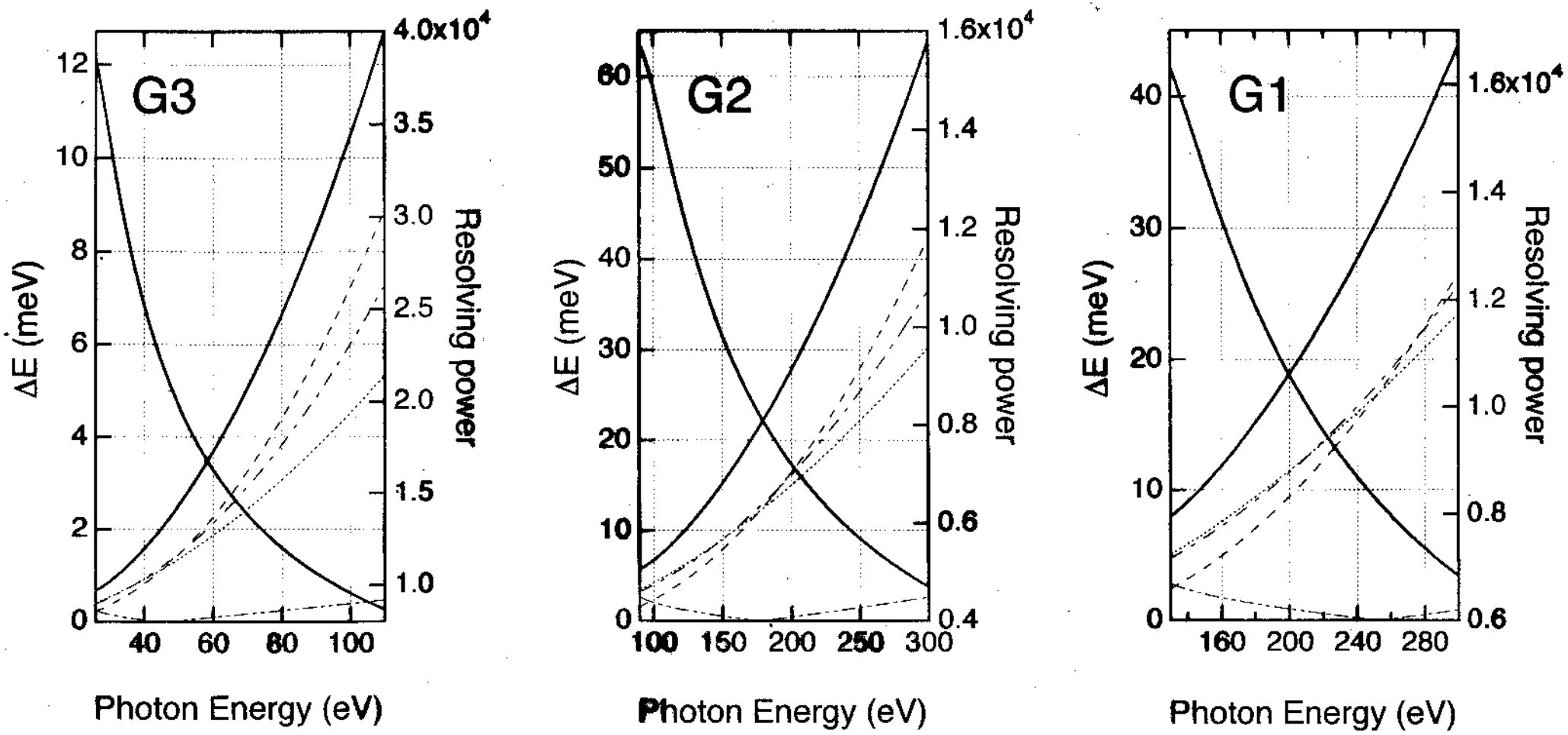


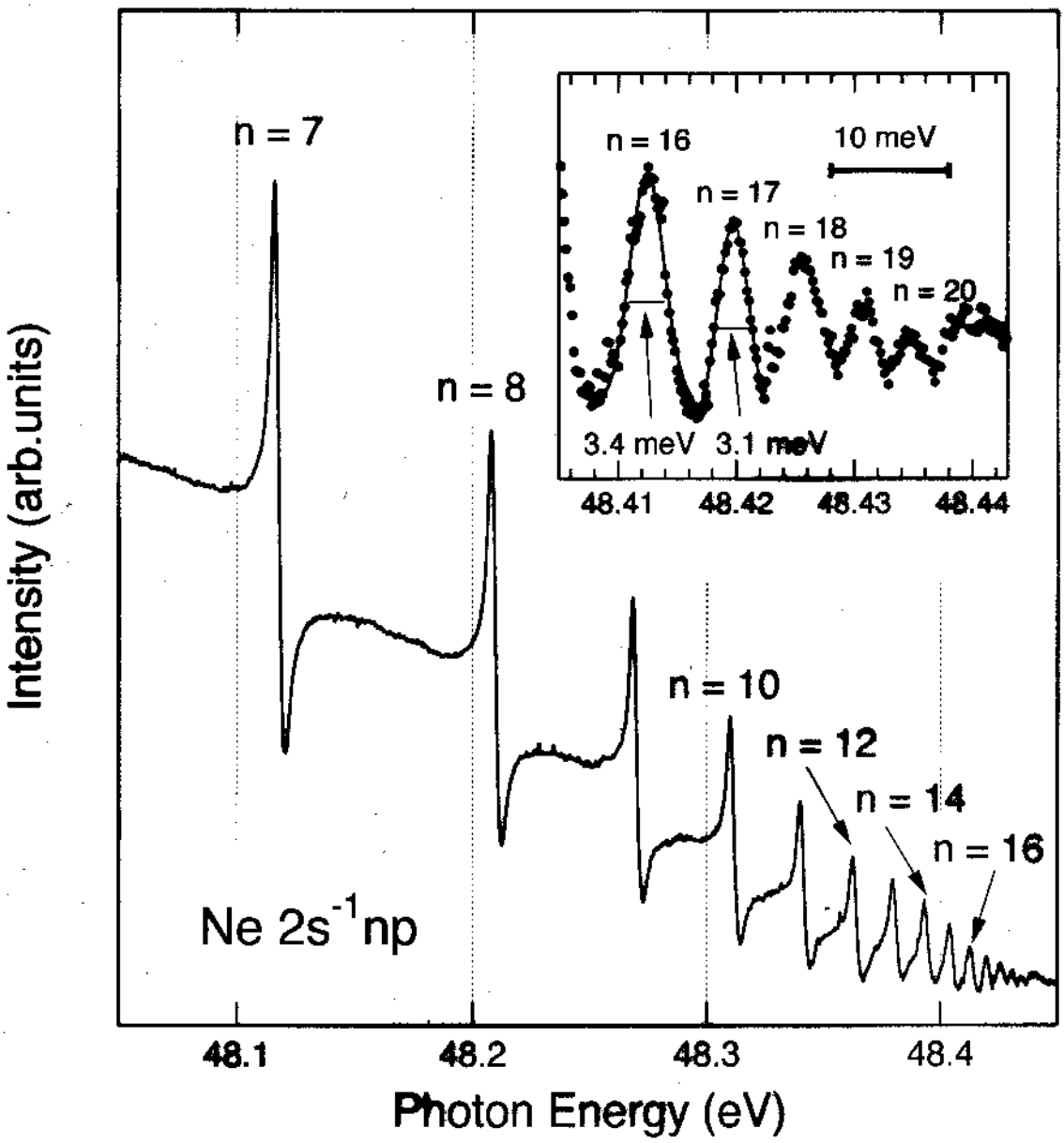
Measured photon flux at the sample position of BL-1, HiSOR

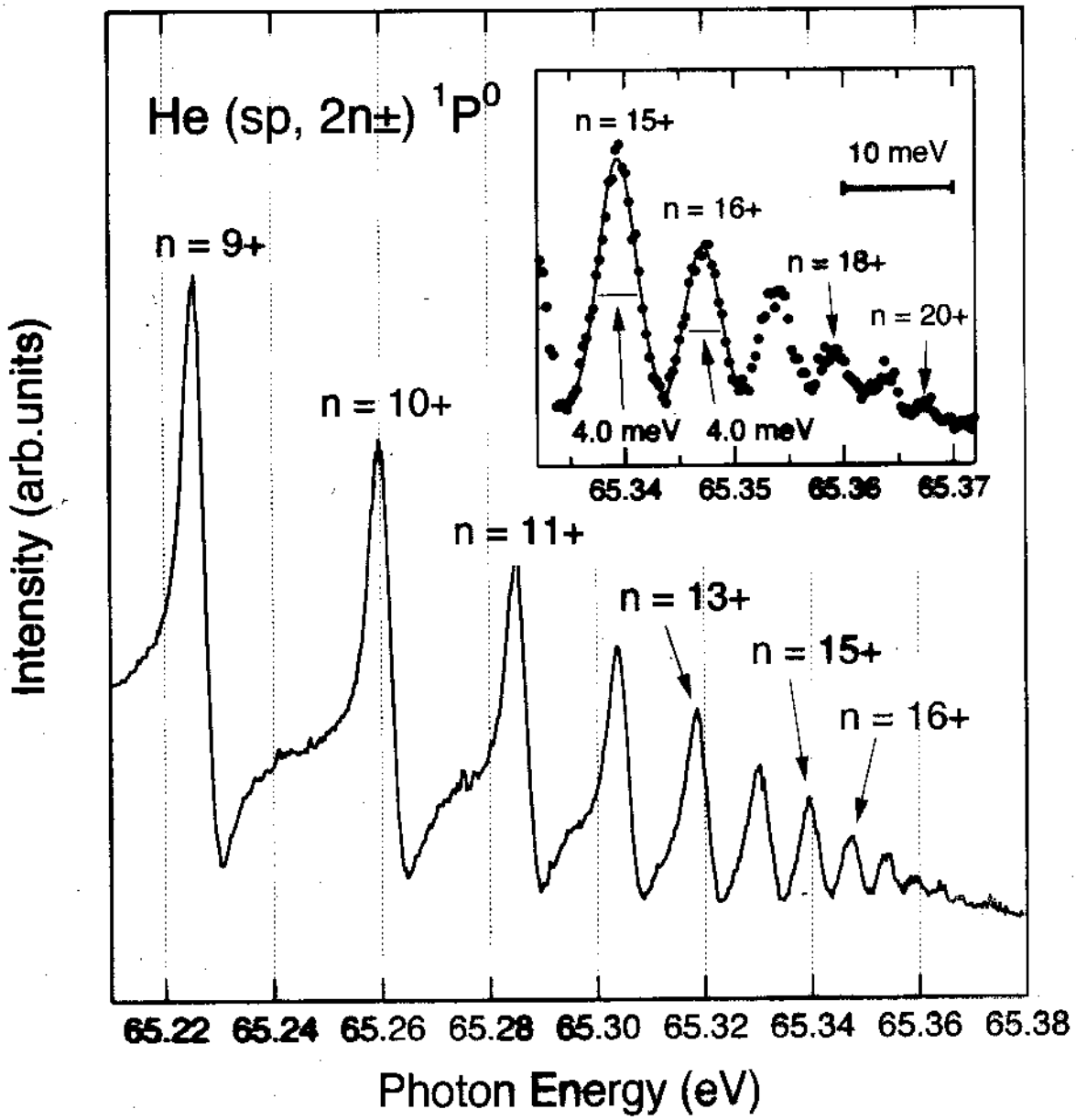


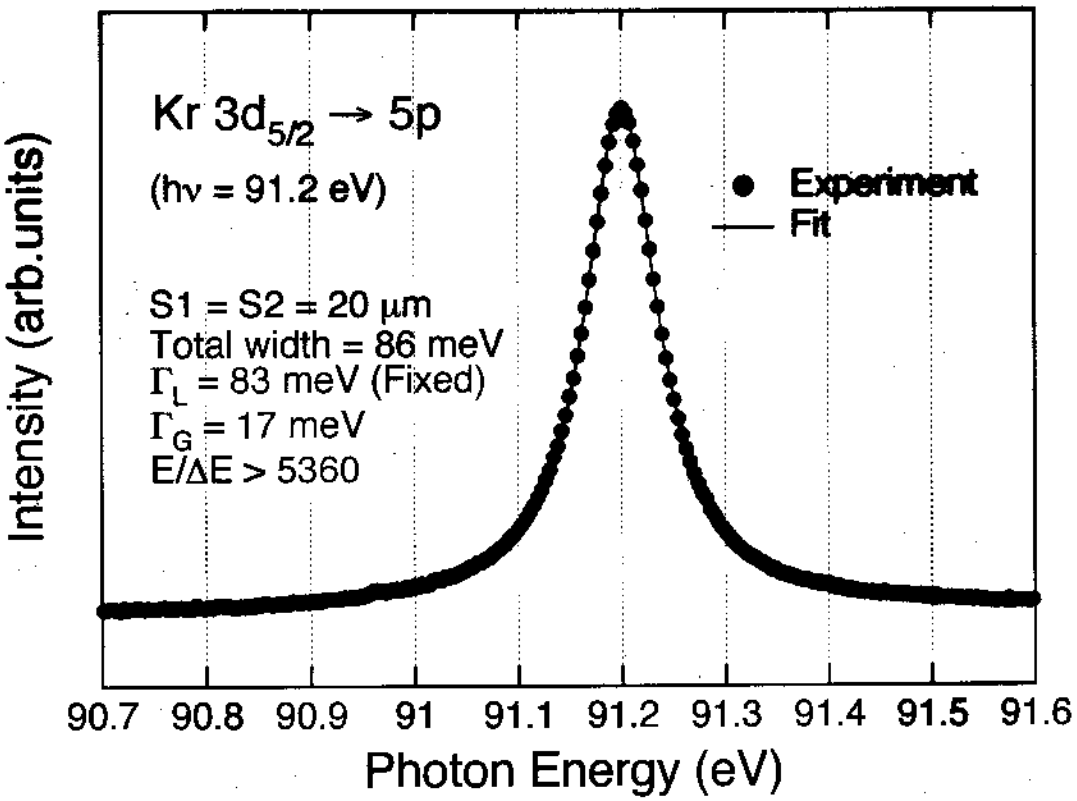
I_b = 200 mA
4 DS = 12 mm (H) × **2 mm** (V) = **1.9 mrad** (H) × 0.3 mrad (V)
S1 = S2 = 50 μm

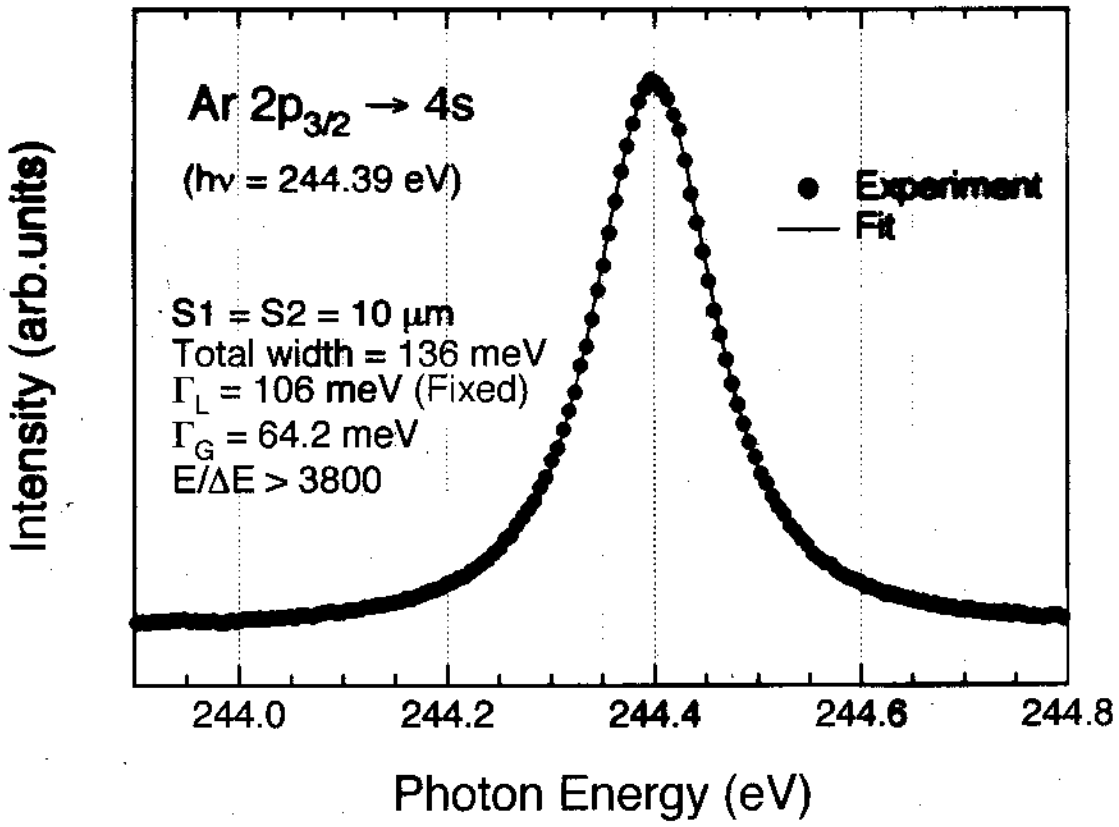
Calculated resolution limit of monochromator BL-1.



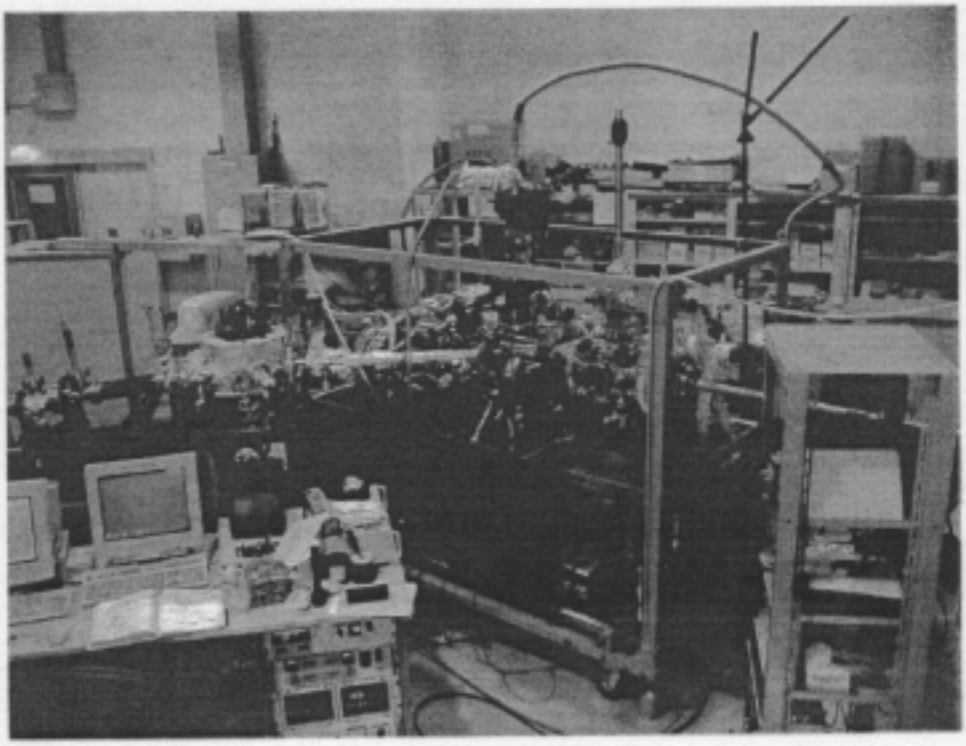

n = 7
n = 8
n = 10
n = 12
n = 14
n = 16
Ne 2s^{-1}np
Intensity (arb.units)
48.1
48.2
48.3
48.4
Photon Energy (eV)
n = 16
10 meV
n = 17
n = 18
n = 19
n = 20
3.4 meV
3.1 meV
48.41
48.42
48.43
48.44

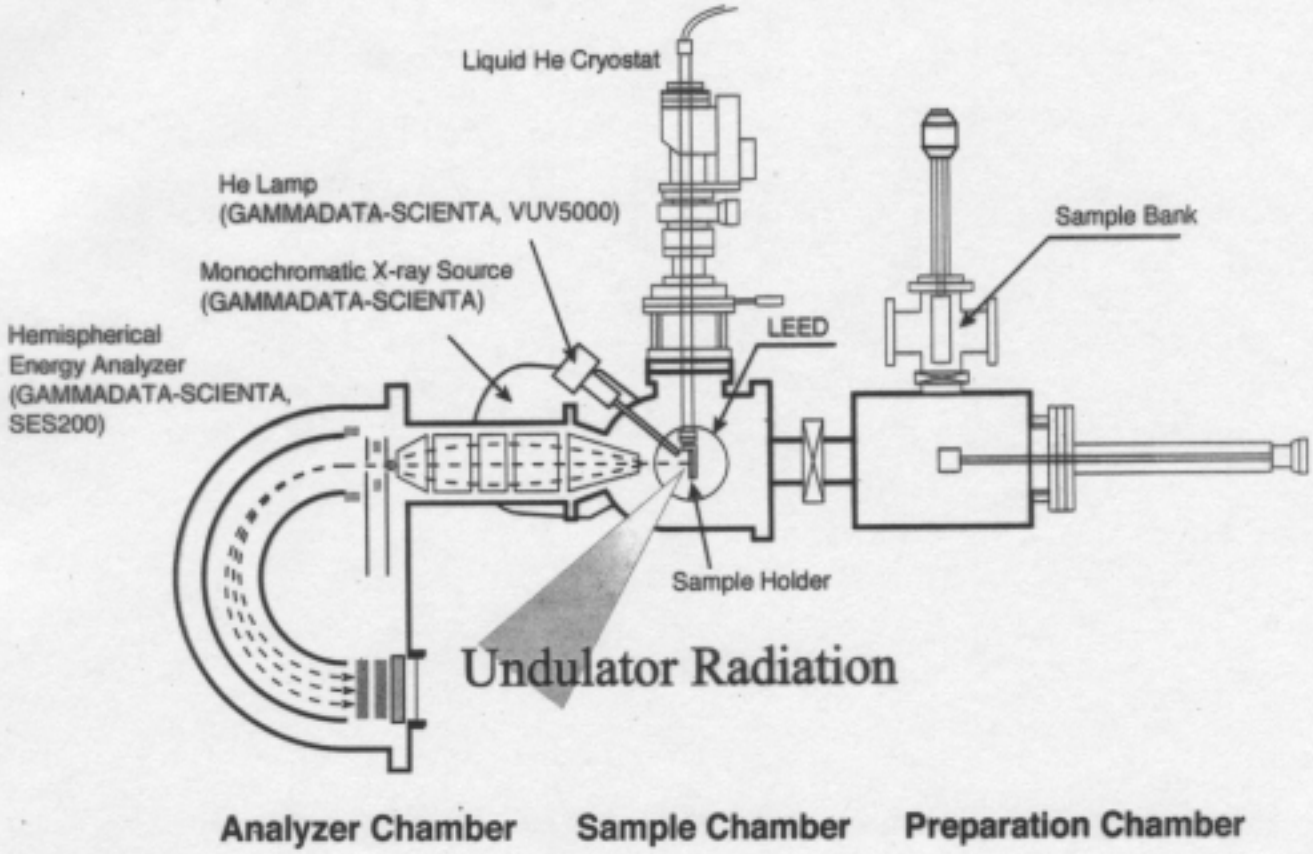

He (sp, 2n±) $^1P^0$
n = 9+
n = 10+
n = 11+
n = 13+
n = 15+
n = 16+
n = 15+
n = 16+
n = 18+
n = 20+
10 meV
4.0 meV
4.0 meV
65.34
65.35
65.36
65.37
Intensity (arb.units)
65.22
65.24
65.26
65.28
65.30
65.32
65.34
65.36
65.38
Photon Energy (eV)


Kr 3d5/2 → 5p
(hν = 91.2 eV)
S1 = S2 = 20 μm
Total width = 86 meV
ΓL = 83 meV (Fixed)
ΓG = 17 meV
E/ΔE > 5360
Experiment
Fit
Intensity (arb.units)
90.7 90.8 90.9 91 91.1 91.2 91.3 91.4 91.5 91.6
Photon Energy (eV)

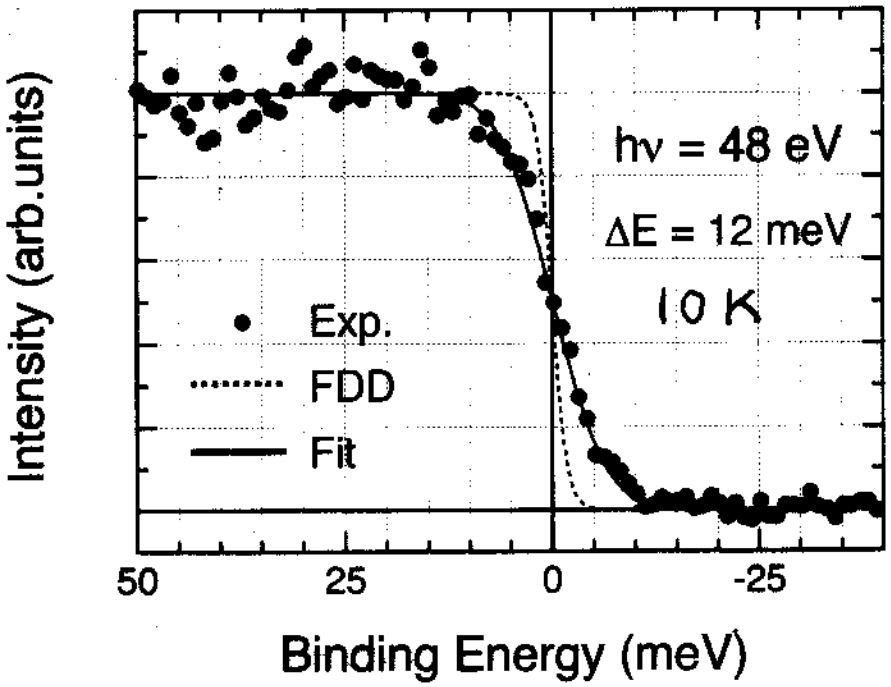

Ar 2p3/2 → 4s
(hν = 244.39 eV)
Experiment
Fit
S1 = S2 = 10 μm
Total width = 136 meV
ΓL = 106 meV (Fixed)
ΓG = 64.2 meV
E/ΔE > 3800
Intensity (arb.units)
244.0
244.2
244.4
244.6
244.8
Photon Energy (eV)

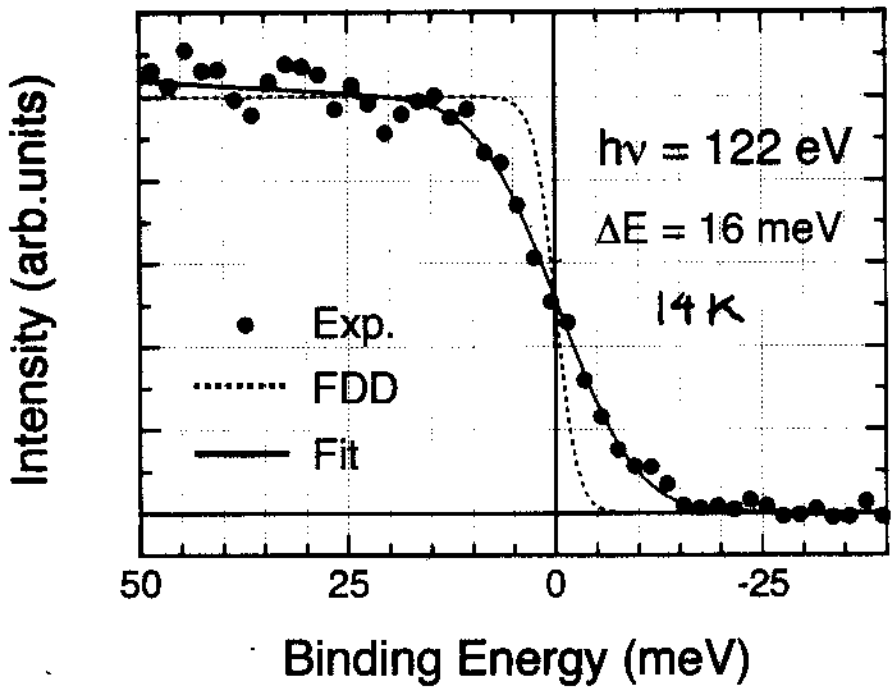
Low-temperature high-resolution photoemission spectroscopy measurement system (ESCA200) at HiSOR BL-1





Energy resolution





HiSOR BL-1共同利用研究

平成１３年１１月～平成１４年２月

１，近藤半導体CeRhAsおよびCeRhSb単結晶のCe4f電子状態の精密測定

島田賢也、小林賢一、成村孝正、生天目博文、谷口雅樹、末光敏明、笹川哲也、高畠敏郎

２，角度分解光電子分光によるT*相構造を持つ銅酸化物高温超伝導体の研究

井野明洋、成村孝正、小林賢一、島田賢也、生天目博文、谷口雅樹

３，高エネルギー分解能角度分解光電子分光法によるモリブデン酸化物のバンド分散及びフェルミ面の研究

櫻岸寛、櫻岸彩子、成村孝正、小林賢一、島田賢也、生天目博文、谷口雅樹

４，$CeMIn_5$(M=Rh, Ir)の高分解能低温共鳴角度分解光電子分光

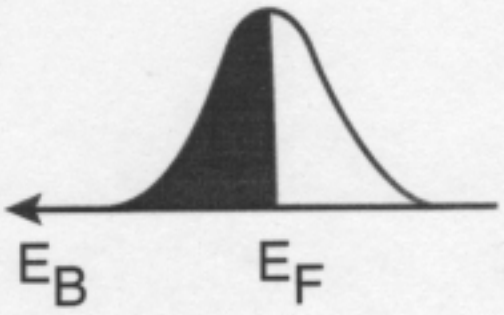
原研放射光：藤森伸一，岡本淳，間宮一敏，岡根哲夫
原研放射光・東大新領域：藤森淳
阪大産研：播磨尚朝
CEA：青木大
阪大理：池田修悟，宍戸寛明
原研先端研：芳賀芳範
阪大理・原研先端研：常盤欣文，大貫惇睦
広大院理：成村孝正、小林賢一
広大放射光セ：島田賢也、生天目博文、谷口雅樹

近藤半導体 CeRhAs

モデル

$T^* < T < T_K$

近藤効果
局所モーメント

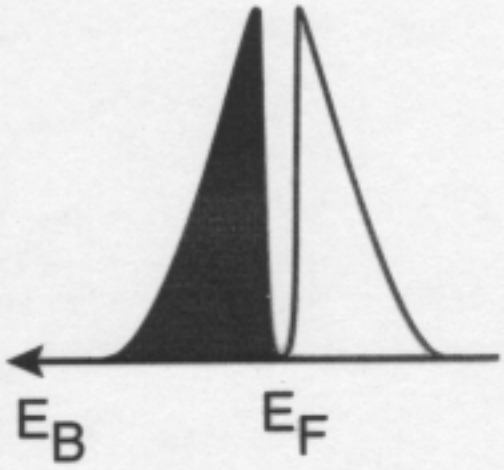


Crossover

T^*

$T < T^*$

常磁性基底状態
混成ギャップ
（多体効果）



研究の目的

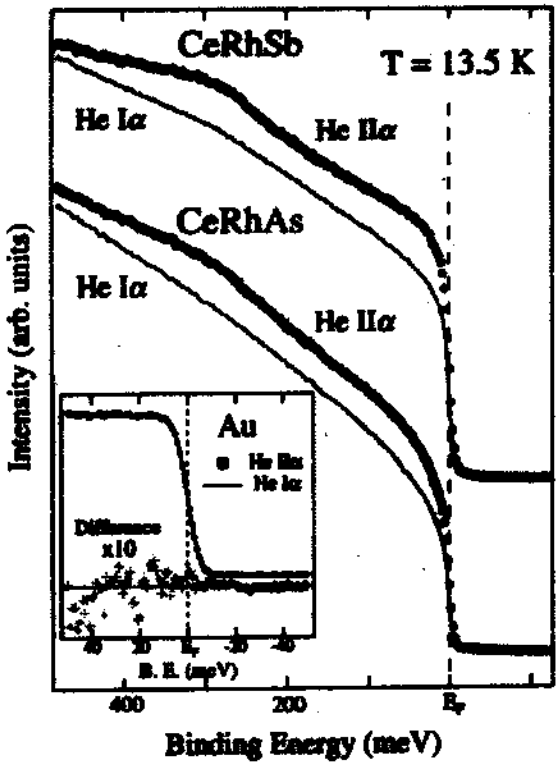
低温におけるフェルミ準位近傍のCe4f状態を直接観測し、近藤半導体の特異な基底状態を明らかにする。

高分解能低温共鳴光電子分光

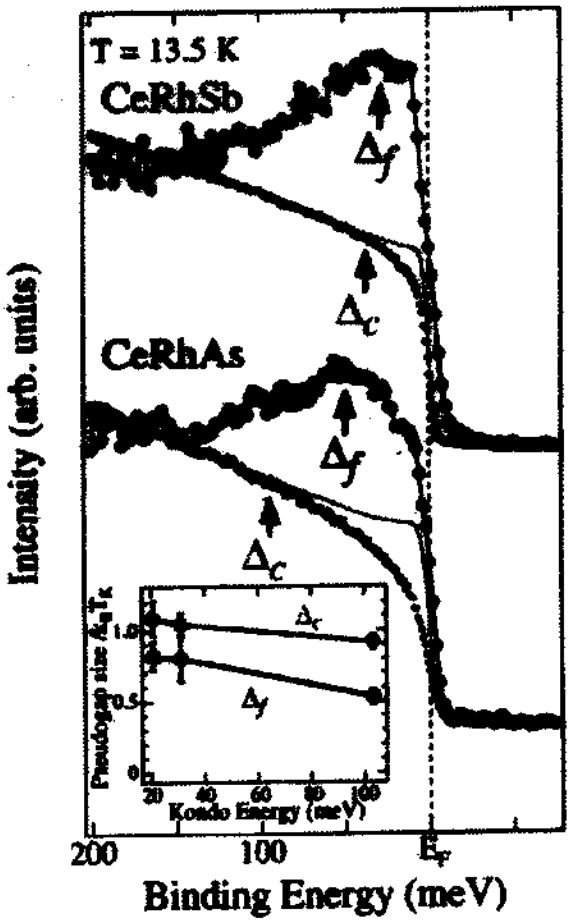
ΔE = 16–18 meV、10 K、$h\nu$ = 122–126 eV

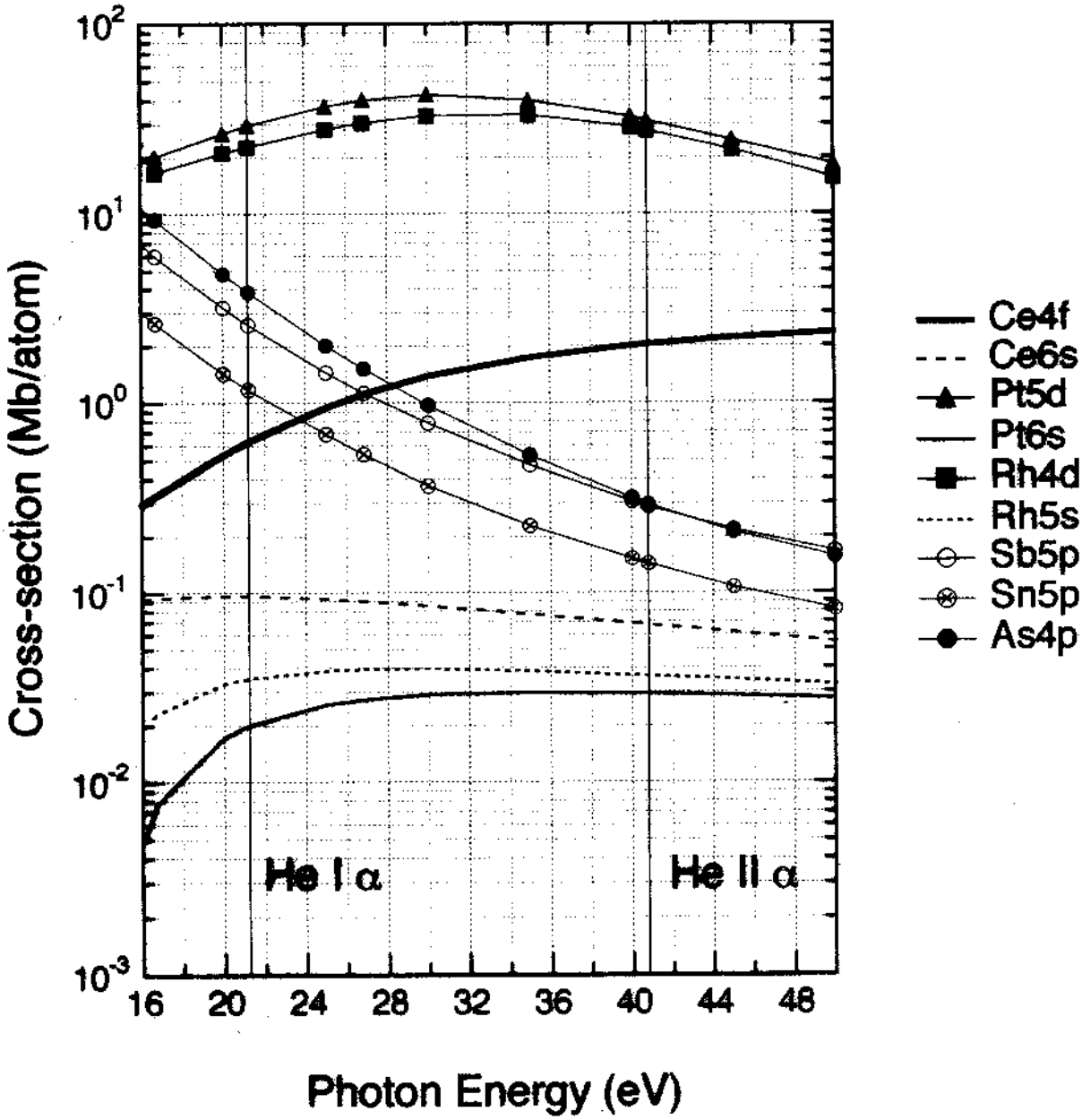
H. Kumigashira et al. Phys. Rev. Lett. 87 (2001) 067206-1

HeI&HeII, Polycrystal, Scraped Surface, ΔE = 8 meV, 13.5 K

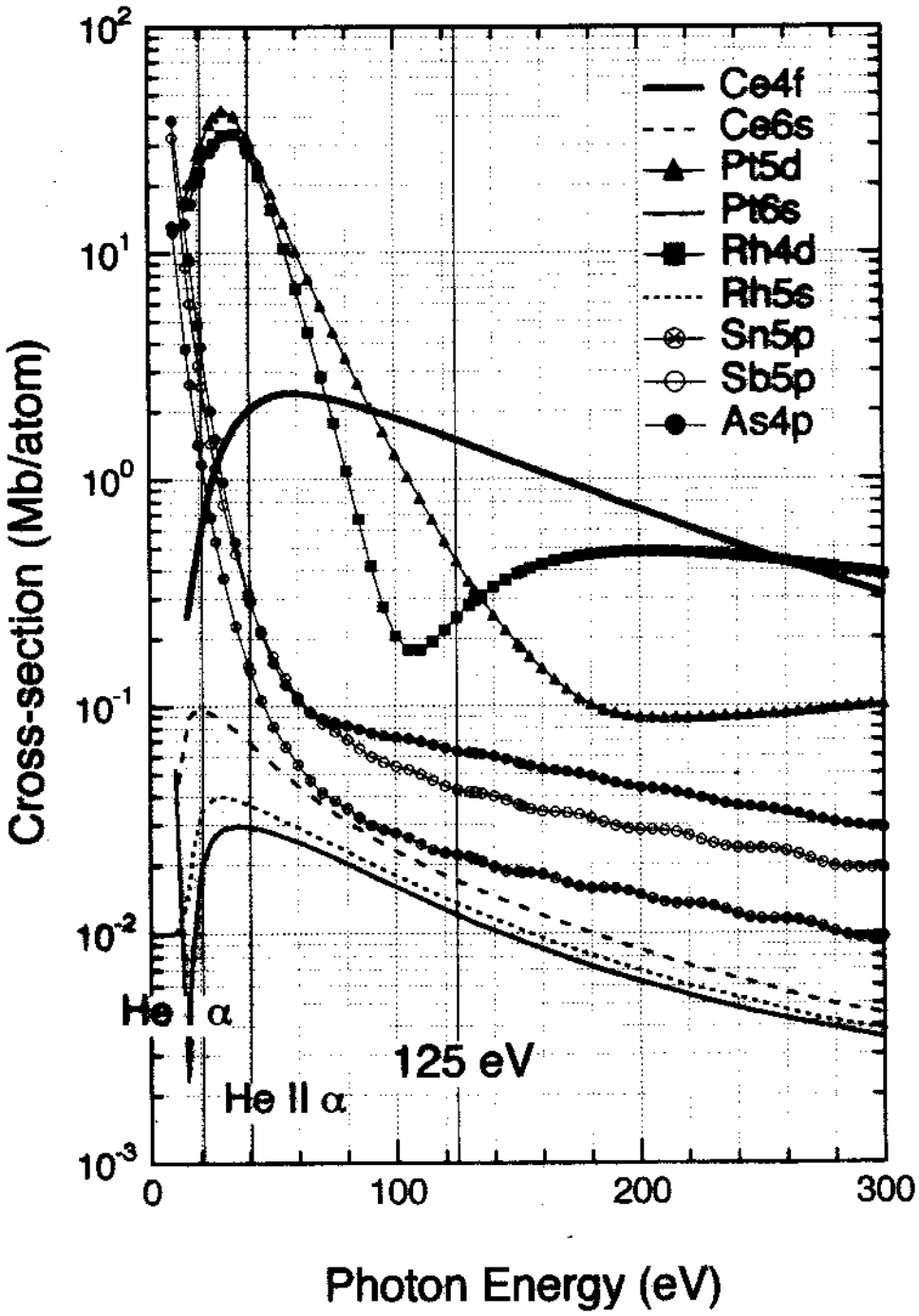


HeII - HeI Difference





J. -J. Yeh:
Atomic Calculation of Photoionization Cross-Sections and Asymmetry Parameters
(Gordon and Breach Science Publishers, 1993)



J. -J. Yeh:
Atomic Calculation of Photoionization Cross-Sections and Asymmetry Parameters
(Gordon and Breach Science Publishers, 1993)

Samples

[redacted]

CeRhAs 単結晶	近藤半導体	k_BT_K ~130 meV

Bridgman 法により作成。

電気伝導度、帯磁率

⇒ T. Sasakawa et al., (unpublished).

T_m ~ 510 K

CeRhSb 単結晶	近藤半金属	k_BT_K ~30 meV

Bridgman 法により作成。

電気伝導度、帯磁率、熱電能

⇒ T. Takabatake et al. Physica B **206&207** (1995) 804.

T_m ~ 120 K, 20 K (a-axis)

CePtSn 単結晶	近藤金属	$k_BT_K < 1$ meV

Czochralski 法により作成。

電気伝導度、帯磁率、比熱

⇒ T. Takabatake et al. Physica B **183** (1993)108.

T_N = 7.5 K

k_BT_K: Kondo temperature estimated from magnetic measurements

Experimental

Linear undulator beamline BL-1 at HiSOR

ESCA200 (GAMMADATA-SCIENA)

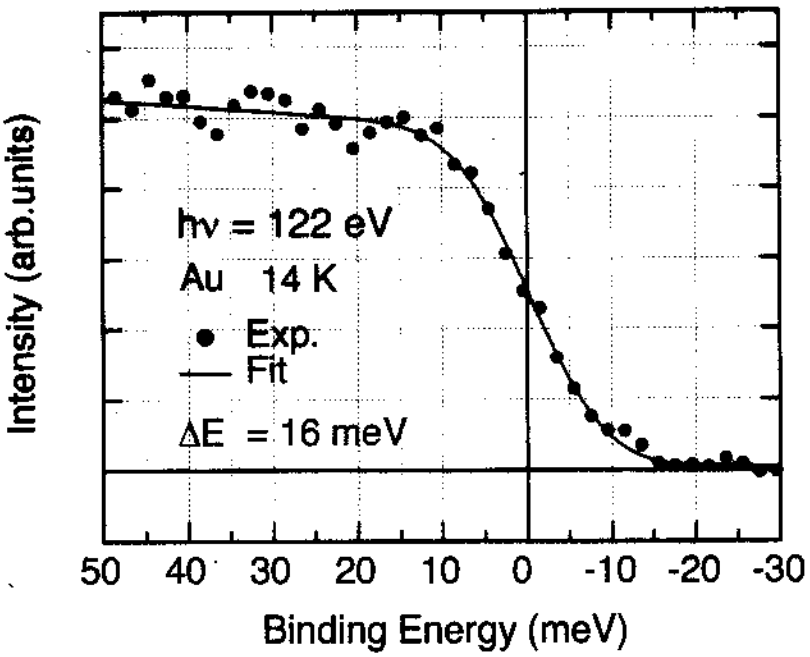
Total energy resolution:
ΔE = 16 - 18 meV at $h\nu$ = 122 eV
ΔE = 18 - 20 meV at $h\nu$ = 126 eV

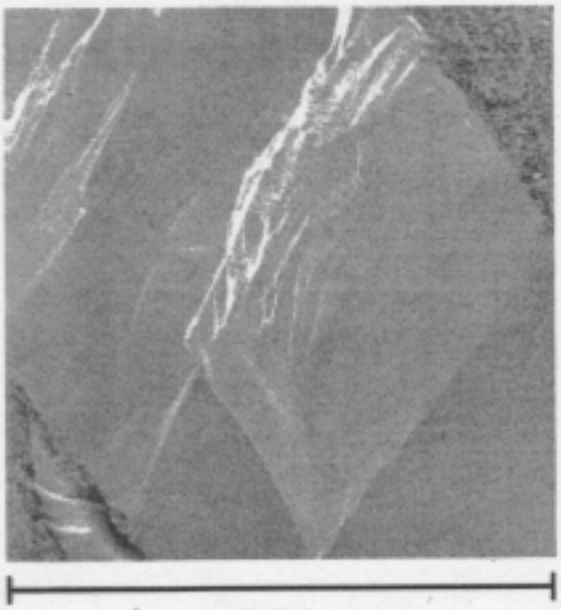
Temperature: 10 K - 12 K

Fractured surface

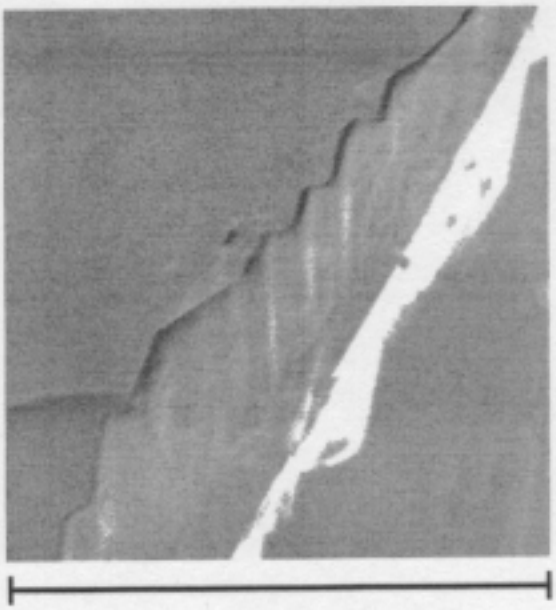
Pressure: 5×10^{-10} Torr

Energy calibration was done using the Fermi edge of Au.

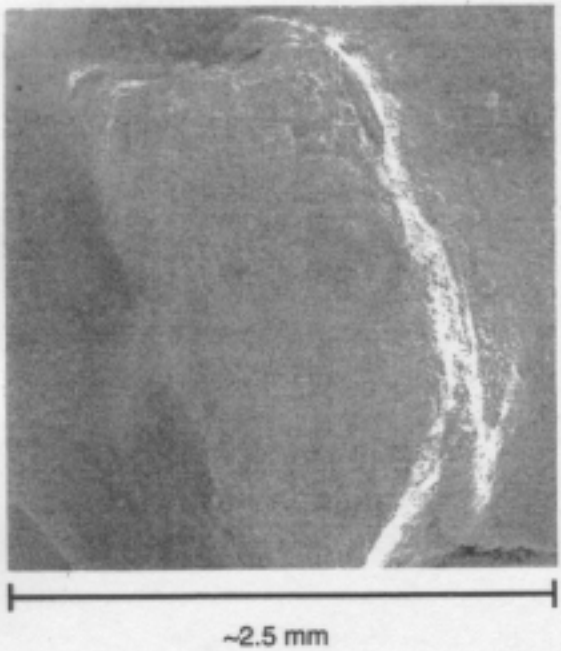




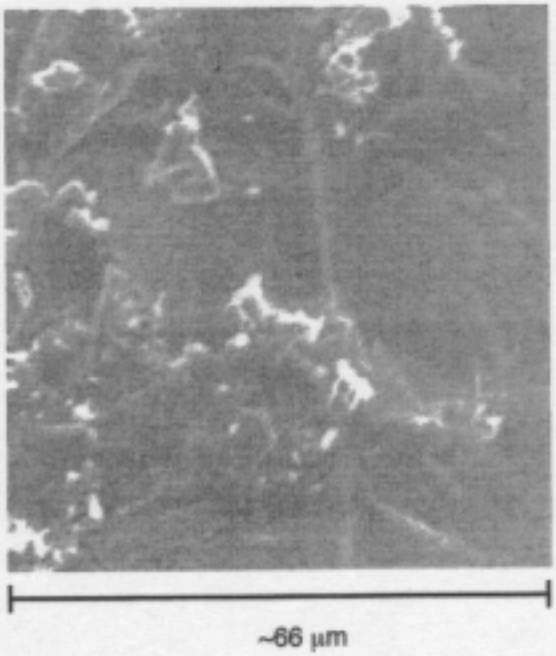
CeRhSb single crystal
fractured surface
×125



CeRhSb single crystal
fractured surface
×1500



CeRhSb single crystal
scraped surface
×40



CeRhSb single crystal
scraped surface
×1500

SEM011119

HiSORにおける
高分解能光電子分光実験

測定試料

物性のよく評価された単結晶試料

清浄試料表面

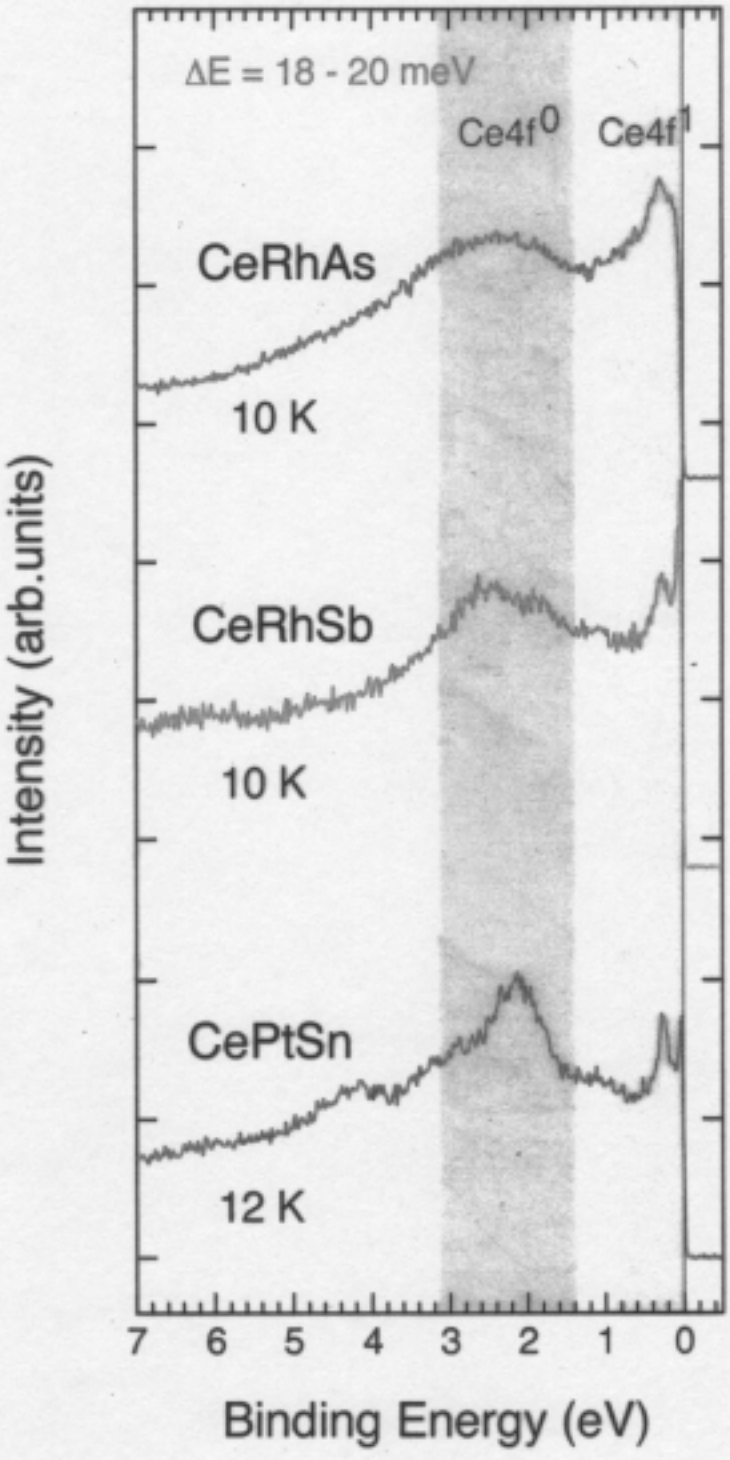
劈開もしくは破断

近い将来には、

イオンエッチング＆アニール、
分子線エピタキシー、レーザーアブレーション
によるin situ試料作成

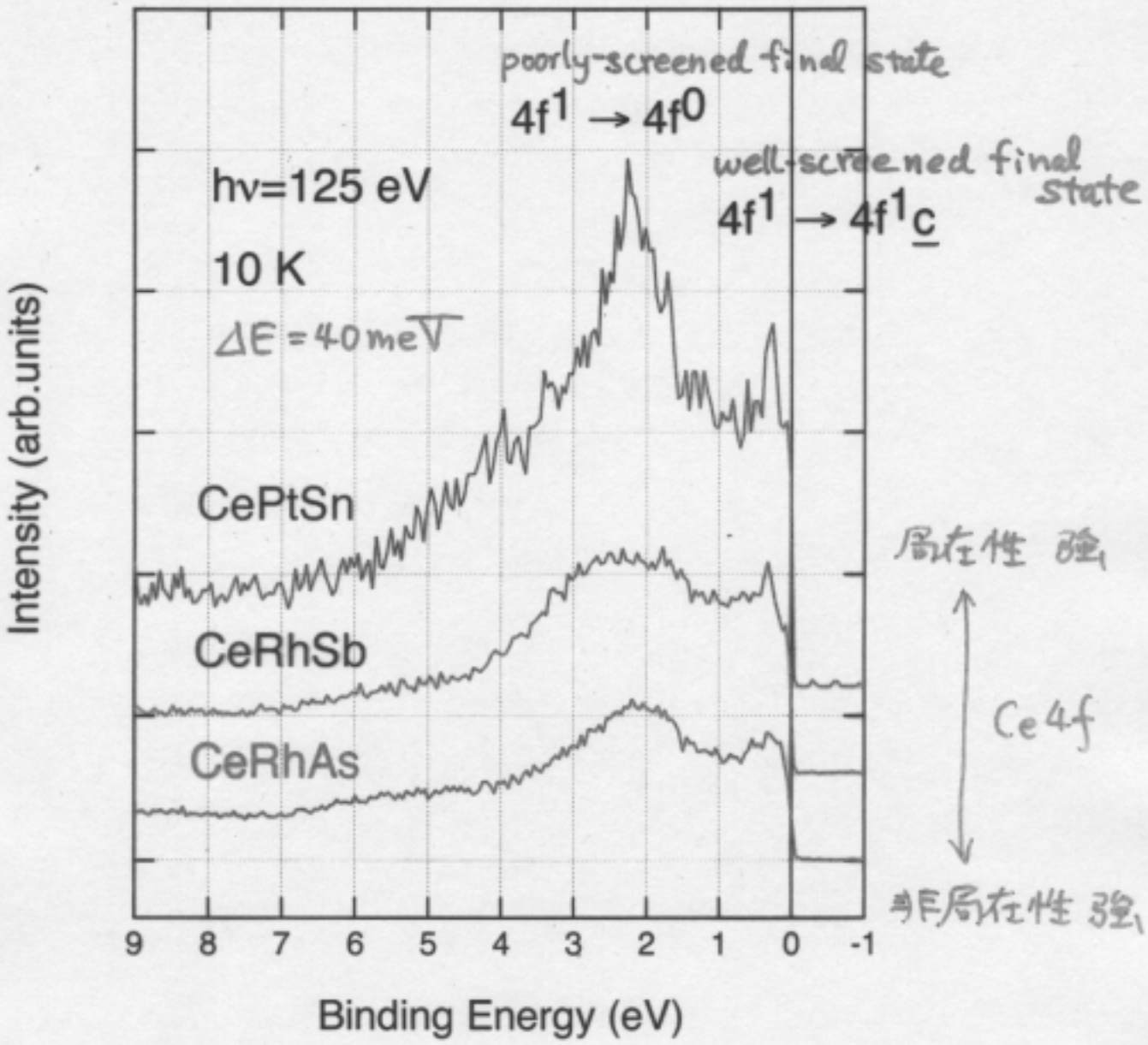
CeMX valence band spectra at hν = 126 eV

Enhanced Ce 4f derived states



Normalized at $Ce4f^0$ peak

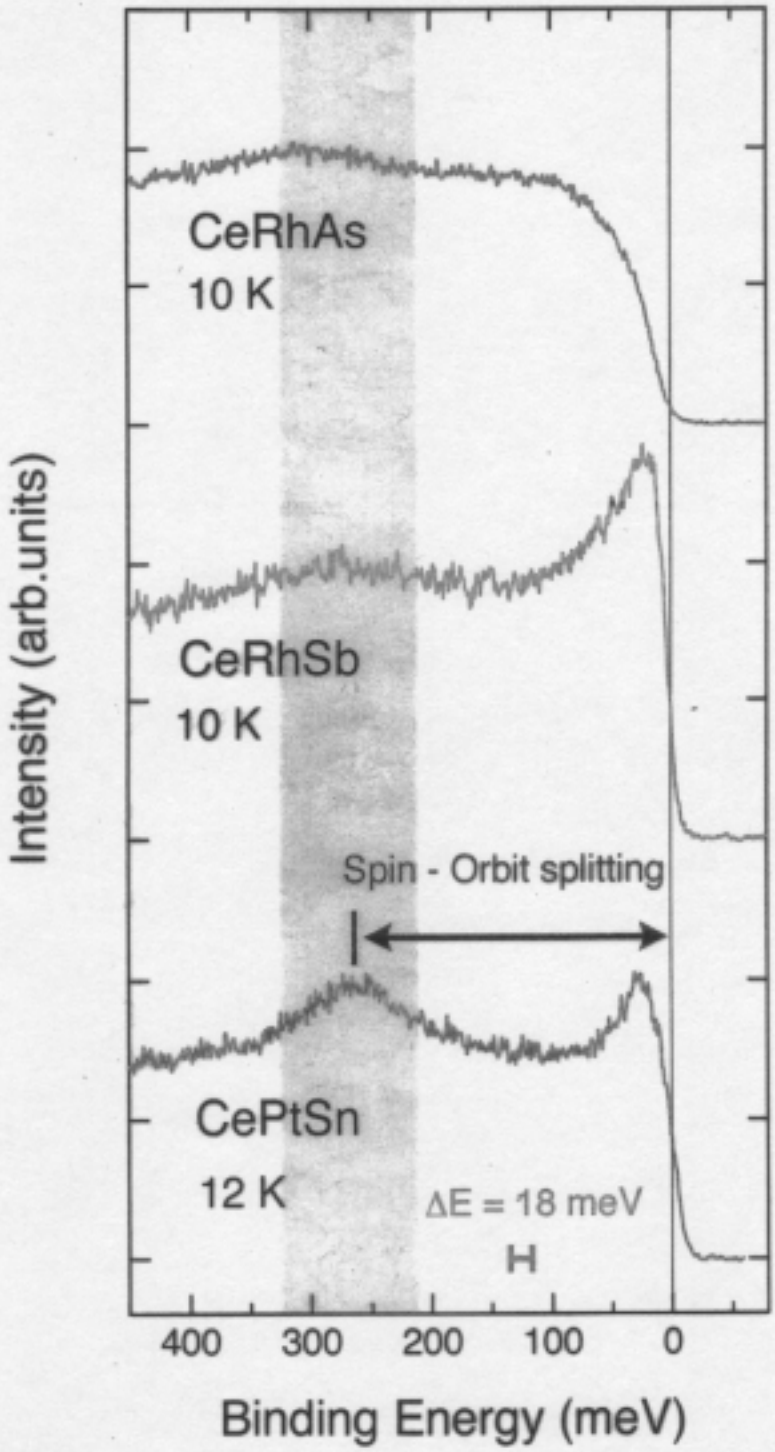
CeMX spectra



$\underline{c}$: Hole in the conduction band

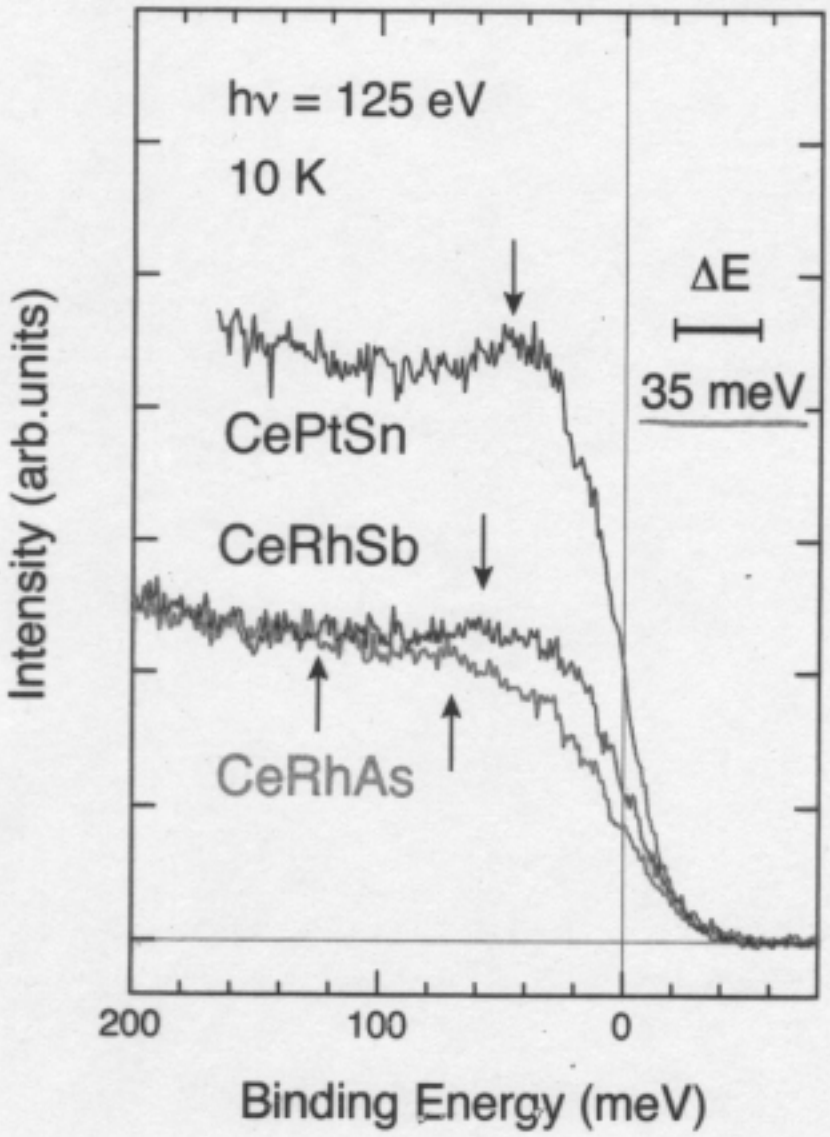
やすりがけ表面

CeMX Ce $4f^1$ spectra at hν = 126 eV



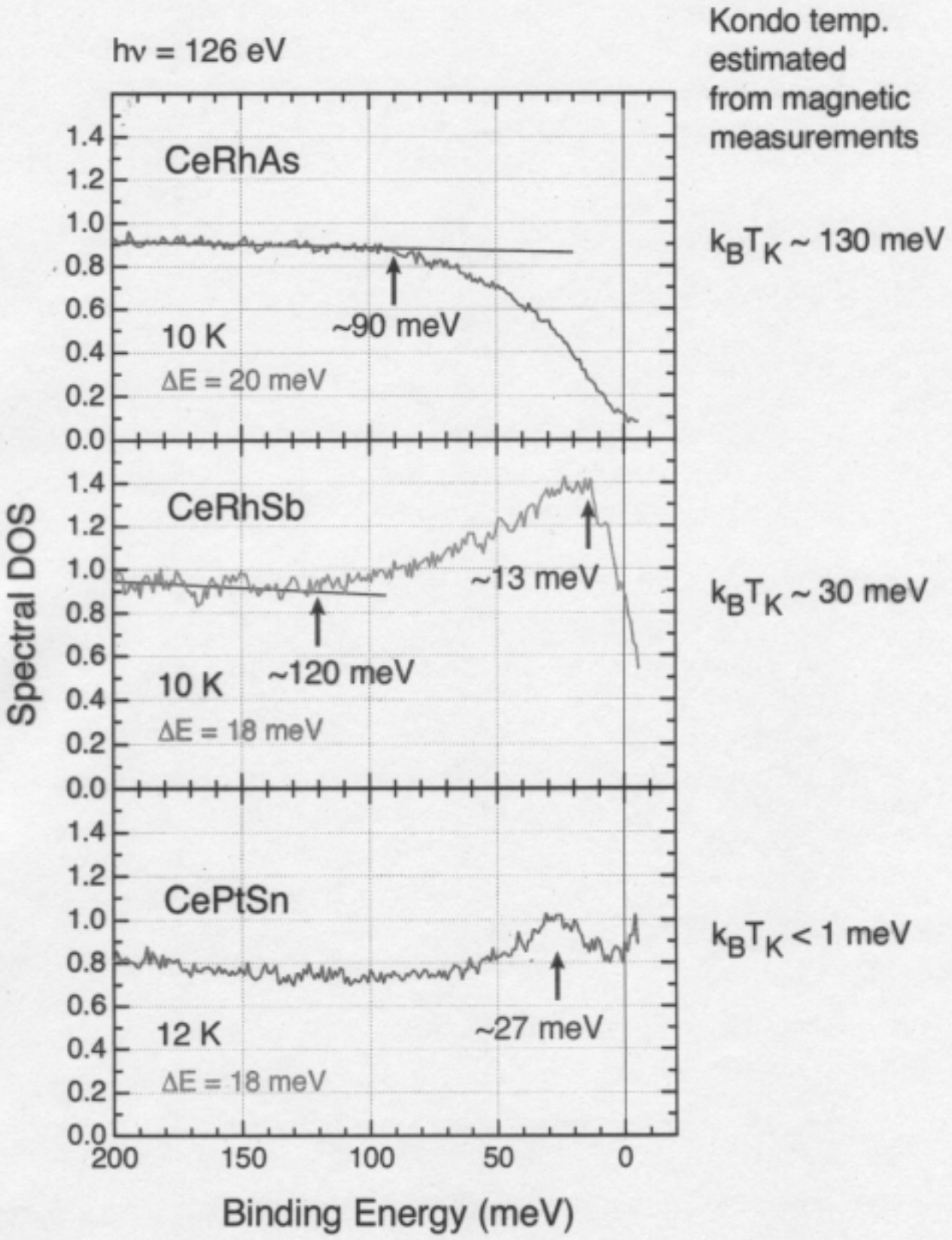
Normalized at $Ce4f^1_{7/2}$ peak

Ce $4f^1_{5/2}$ spectra

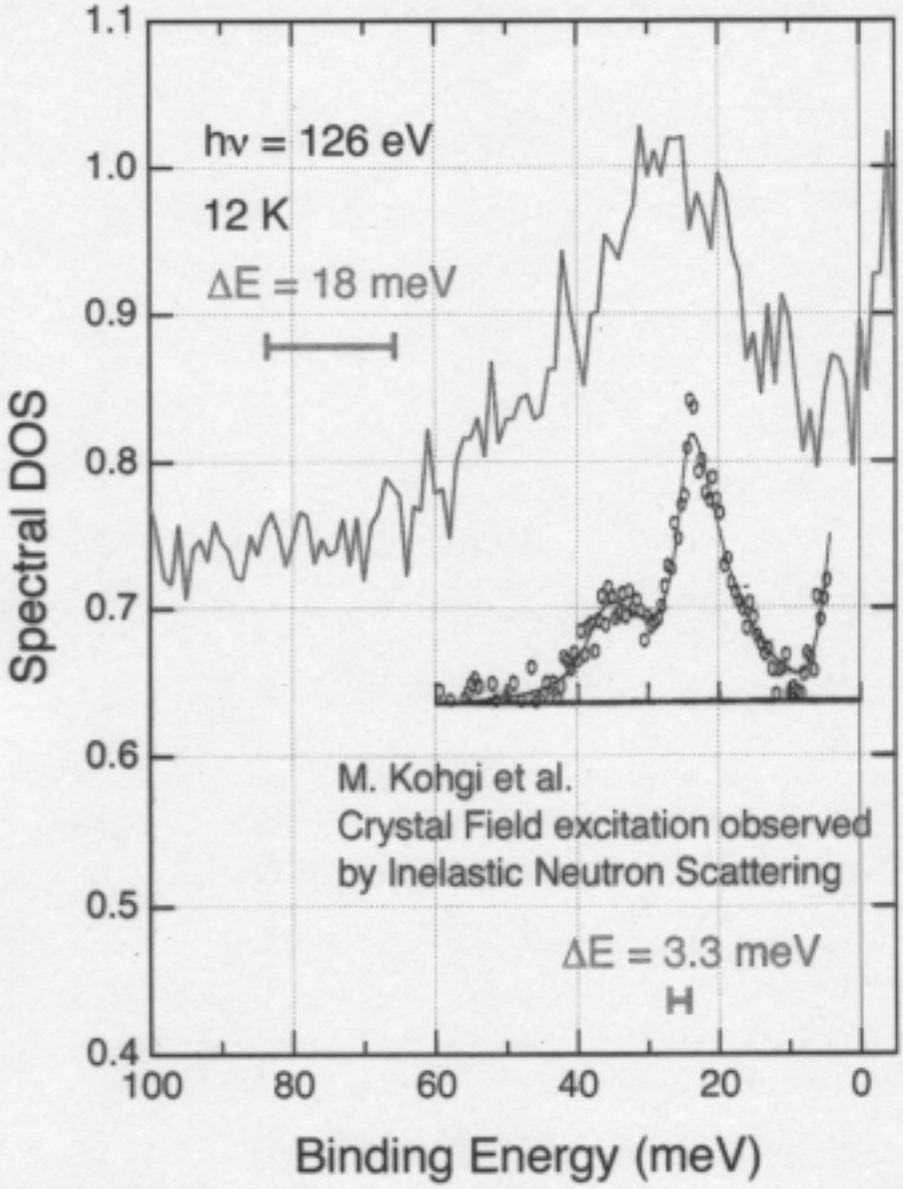


やすりがけ表面

CeMX Ce $4f^1$ spectral DOS at E_F

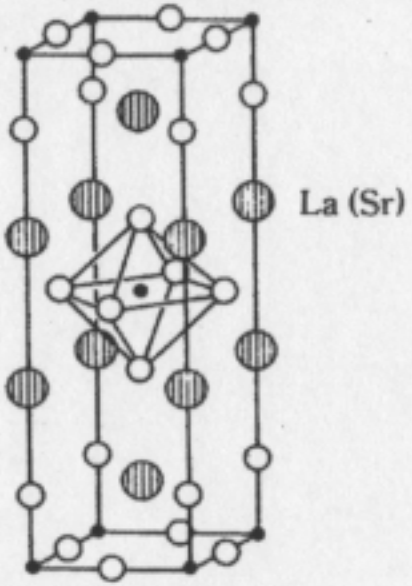


Crystal Field splitting in CePtSn



Crystal structures of single-plane high-Tc cuprates

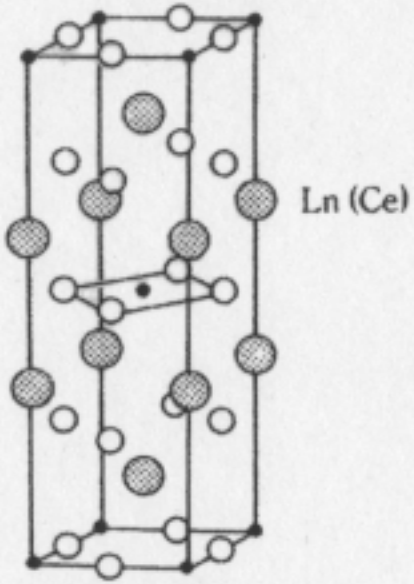
T-phase



(a) T 相

$La_{2-x}Sr_xCuO_4$ など

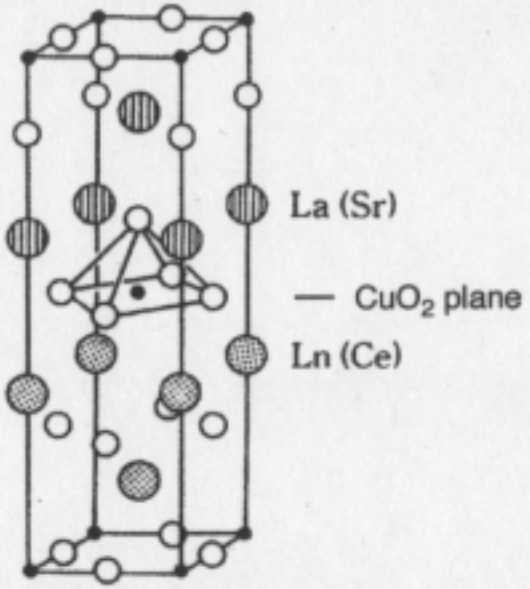
T'-phase



(b) T' 相

$Ne_{2-x}Ce_xCuO_4$ など

T*-phase

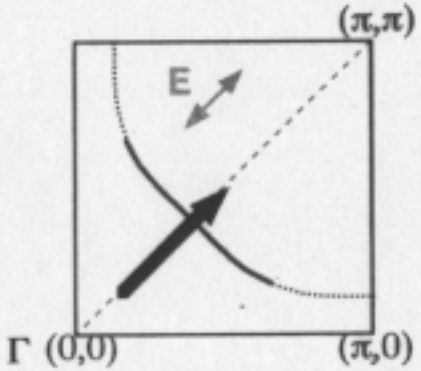


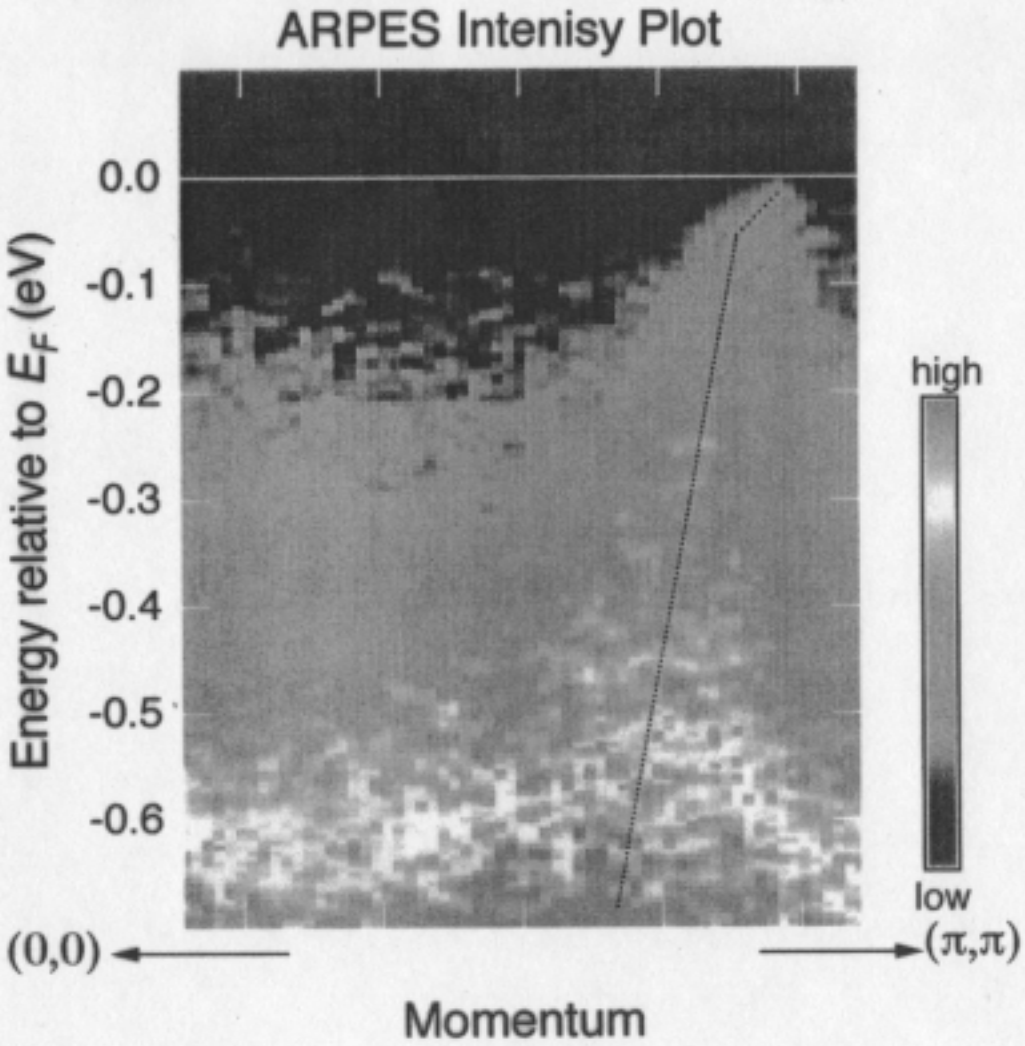
(c) T* 相

$SmLa_{1-x}Sr_xCuO_4$ など

Fermi Surface Crossing of $SmLa_{0.8}Sr_{0.2}CuO_4$ (T*-cuprate)

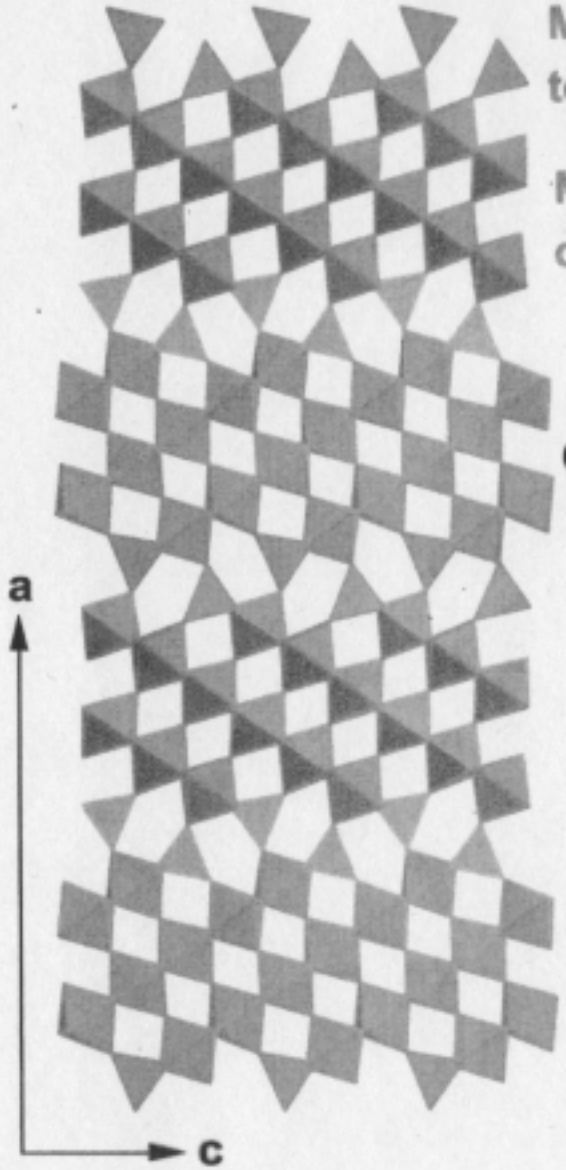
HiSOR BL1
$h\nu$ = 55.5 eV





Crystal structure of γ -Mo_4O_{11}

H.-K. Fun et al. Powder Diffr. 14, (1999) 284.



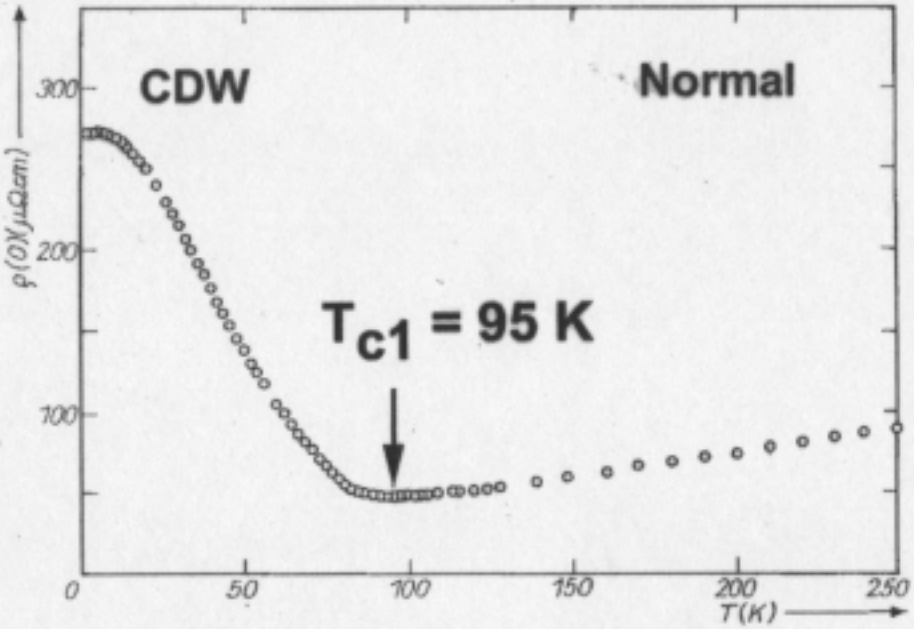
MoO_4 tetrahedron

MoO_6 octahedron

Orthorhombic
$Pna2_1$
a = 24.4756 Å
b = 5.4572 Å
c = 6.7516 Å

Charge density wave

M. Inoue et al. Phys. Status Solidi (b) 148, (1988) 659.



$$\sigma = \sigma_0 + A \exp [-\Delta_R (T) / k_B T]$$

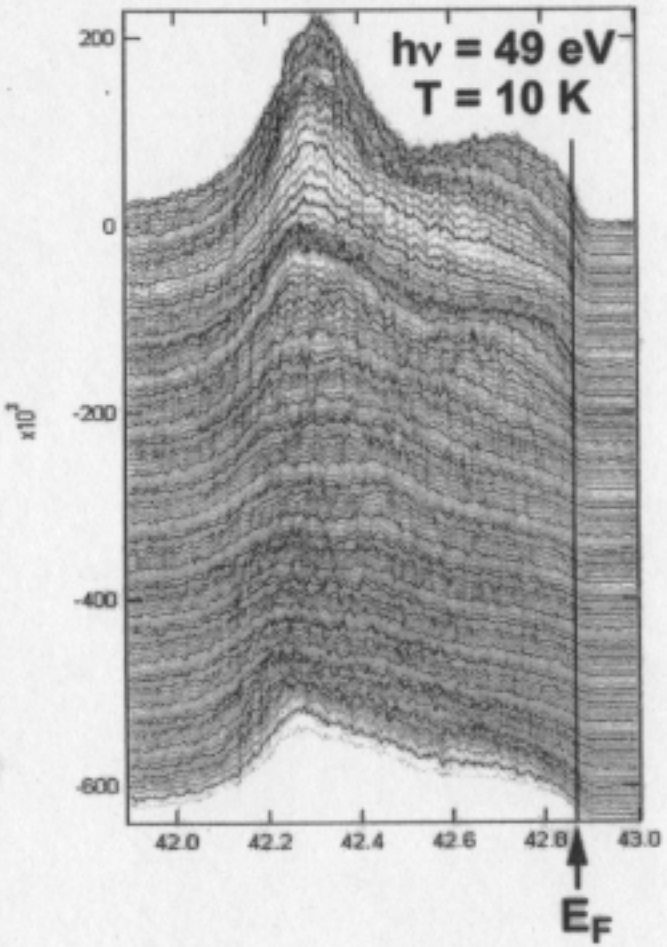
$$\Delta_R (T) = \Delta_R (0) [(1- (T/T_{c1})^2]$$

$$\rightarrow \Delta_R (0) = 9.5 \text{ meV}$$

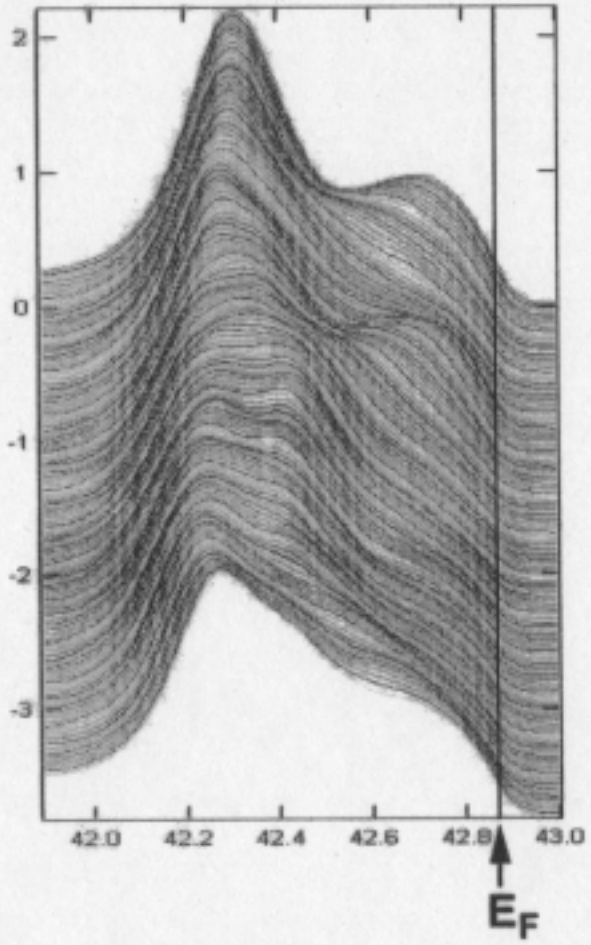
Nesting vector: $q_1 = (0, 0.23b^*, 0)$

ARPES of γ -Mo_4O_{11}

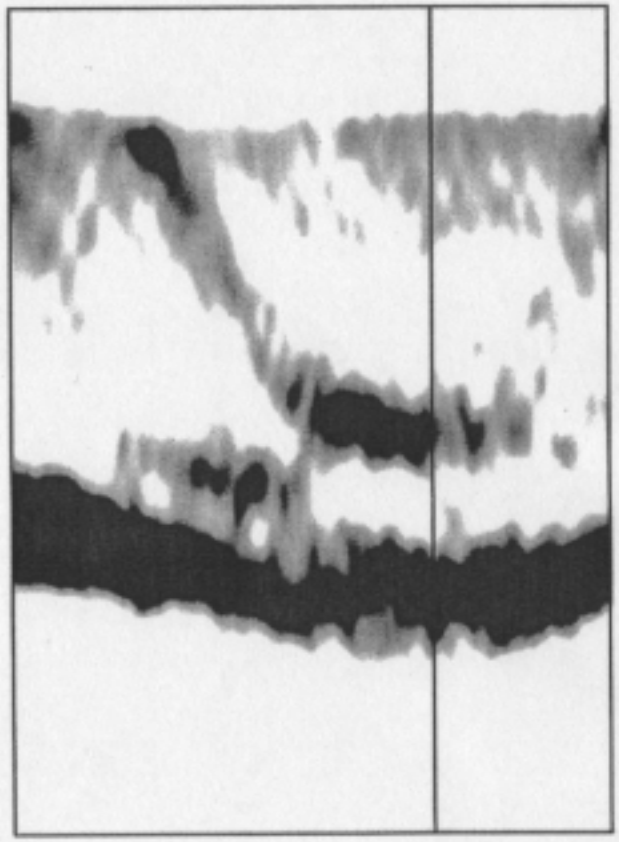
raw spectra
along Γ–Z (c*)



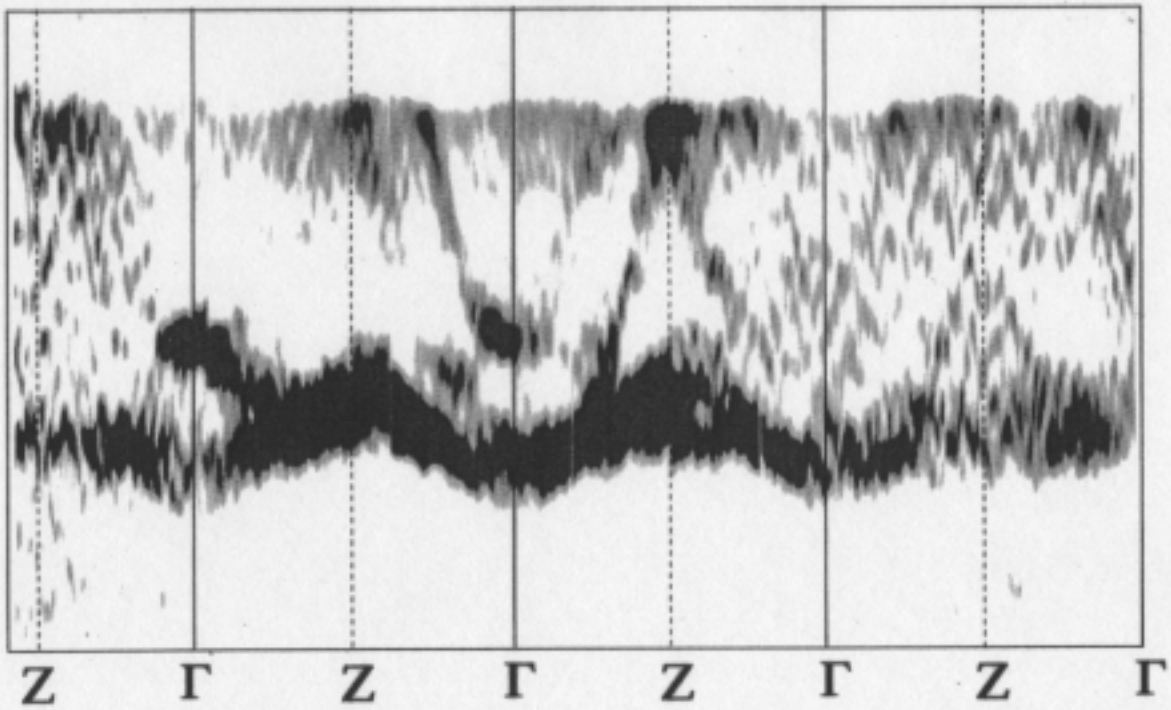
smoosed spectra
normalized by area



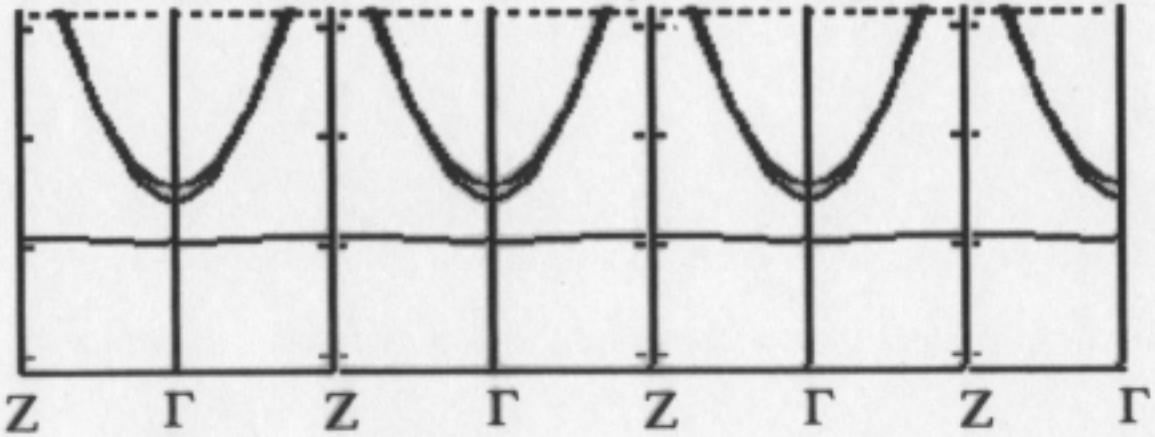
10.88 degree



Dispersion curve of γ-Mo_4O_{11} along c*-axis



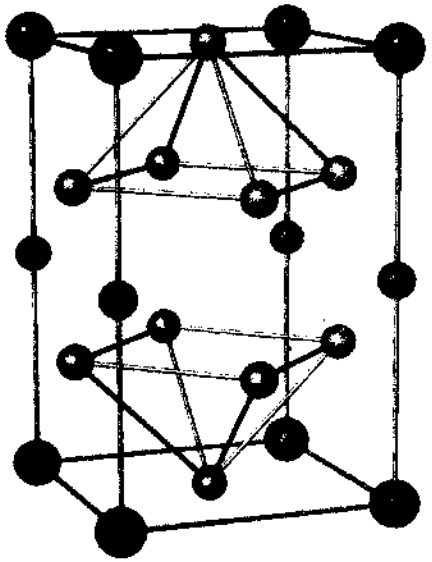
Calculated curves by Whangbo group



$CeTIn_5$: quasi-2D Ce compounds

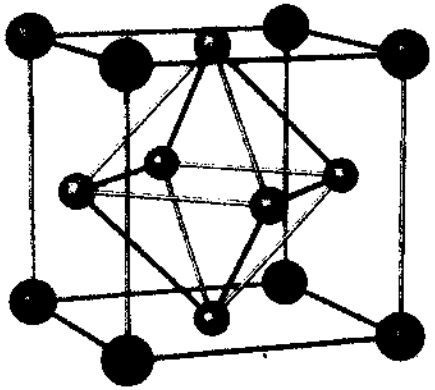
crystal structure

$CeRhIn_5$, $CeIrIn_5$



$HoCoGa_5$-type structure

$CeIn_3$



$AuCu_3$ structure

- Ce
- Rh or Ir
- In

lattice constants

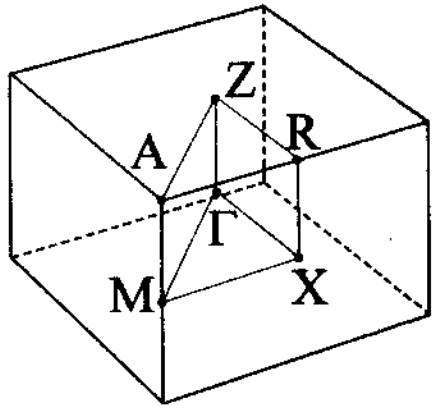
$CeIn_3$	a=4.689Å
$CeRhIn_5$	a=4.652Å, c=7.542Å
$CeIrIn_5$	a=4.666Å, c=7.517Å

- quasi-two-dimensional electronic structure
- $CeRhIn_5$ experiences a chemical pressure of ~14kbar relative to $CeIn_3$
- $CeIrIn_5$ corresponds to the pressure-induced $CeRhIn_5$

Experimental

- Samples
  single crystals (dimensions of ~2mm x 2mm x 2mm)
  grown by self-flux method
  cleaved *in situ*

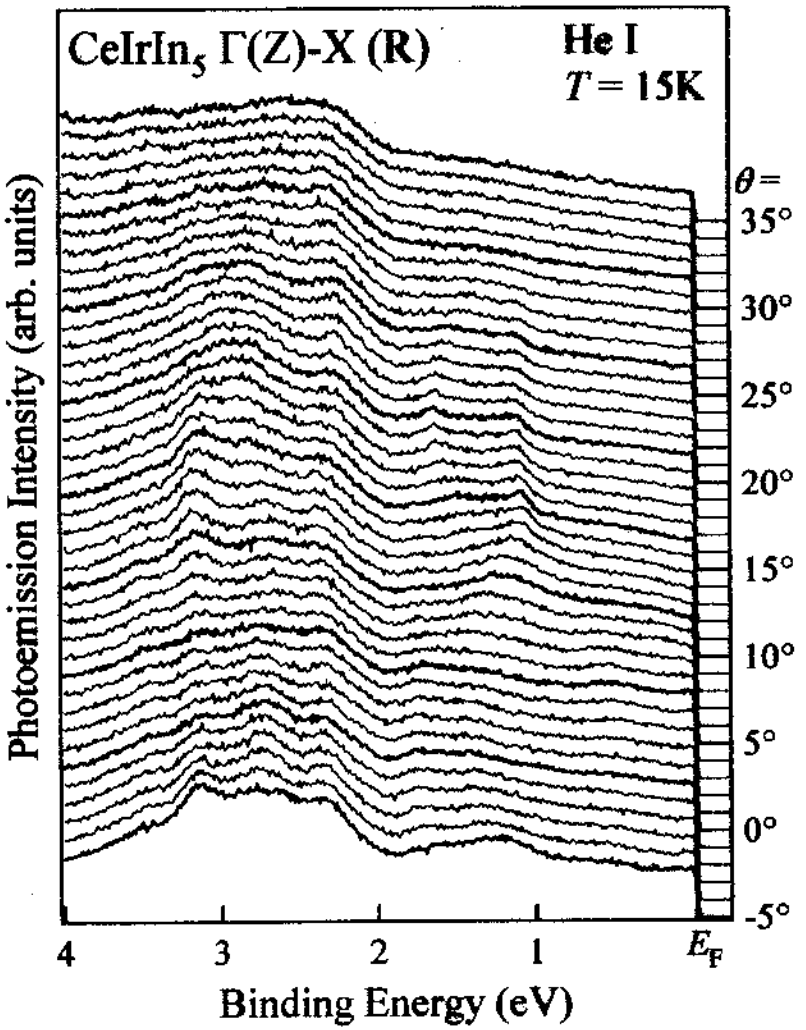
Brillouin zone



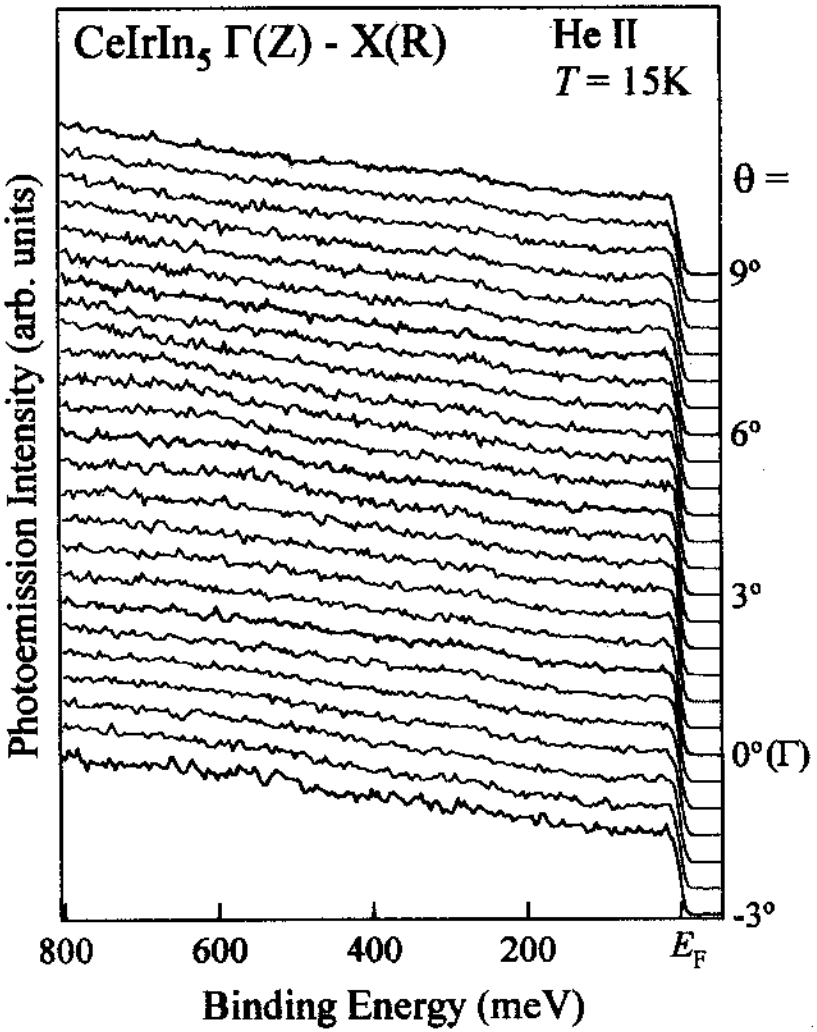
- Photoemission experiments
  1. angle-resolved photoemission experiments
     BL-23SU PES station @Spring-8
     He I ($h\nu$ = 21.2 eV), HeII ($h\nu$ = 40.8 eV)
     energy resolution : 15 meV
     sample temperature : ~15 K
  2. angle-resolved resonant photoemission experiments
     HiSOR BL-1
     $h\nu$ = 122 eV (on-resonance), $h\nu$ = 115 eV (off-resonance)
     energy resolution : 30 meV($h\nu$ = 122 eV),
     50 meV ($h\nu$ =115 eV)
     sample temperature : 10 K

$CeIrIn_5$: ARPES (He lamp)

He I

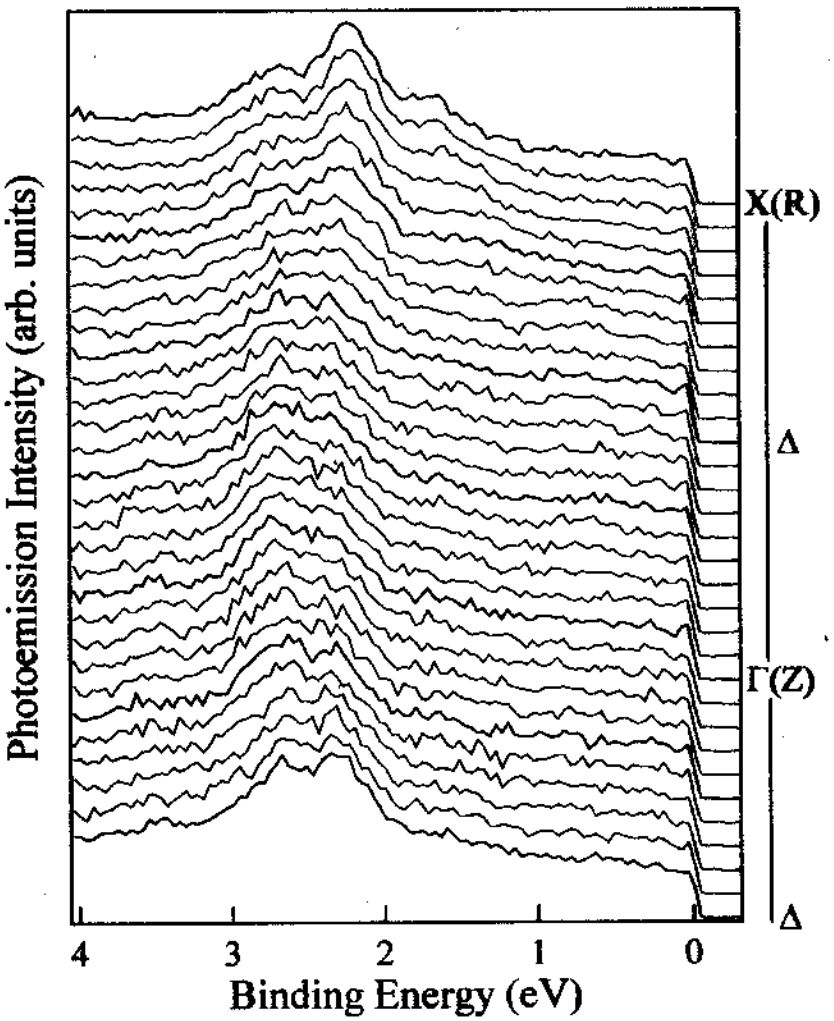


He II

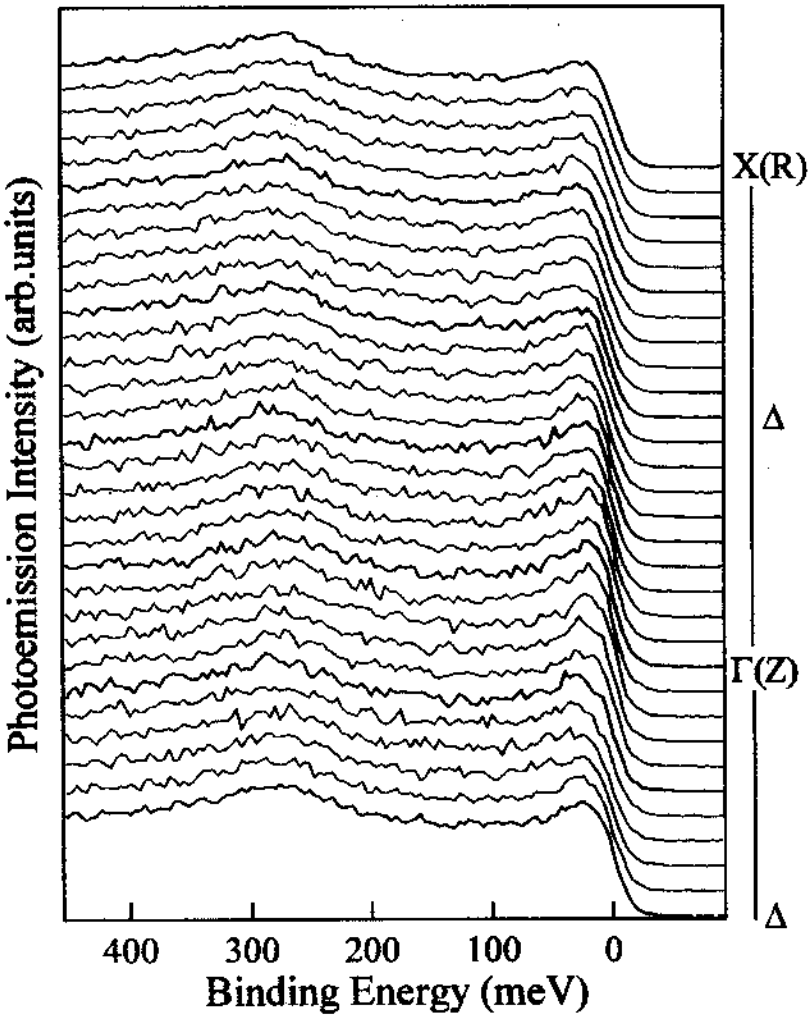


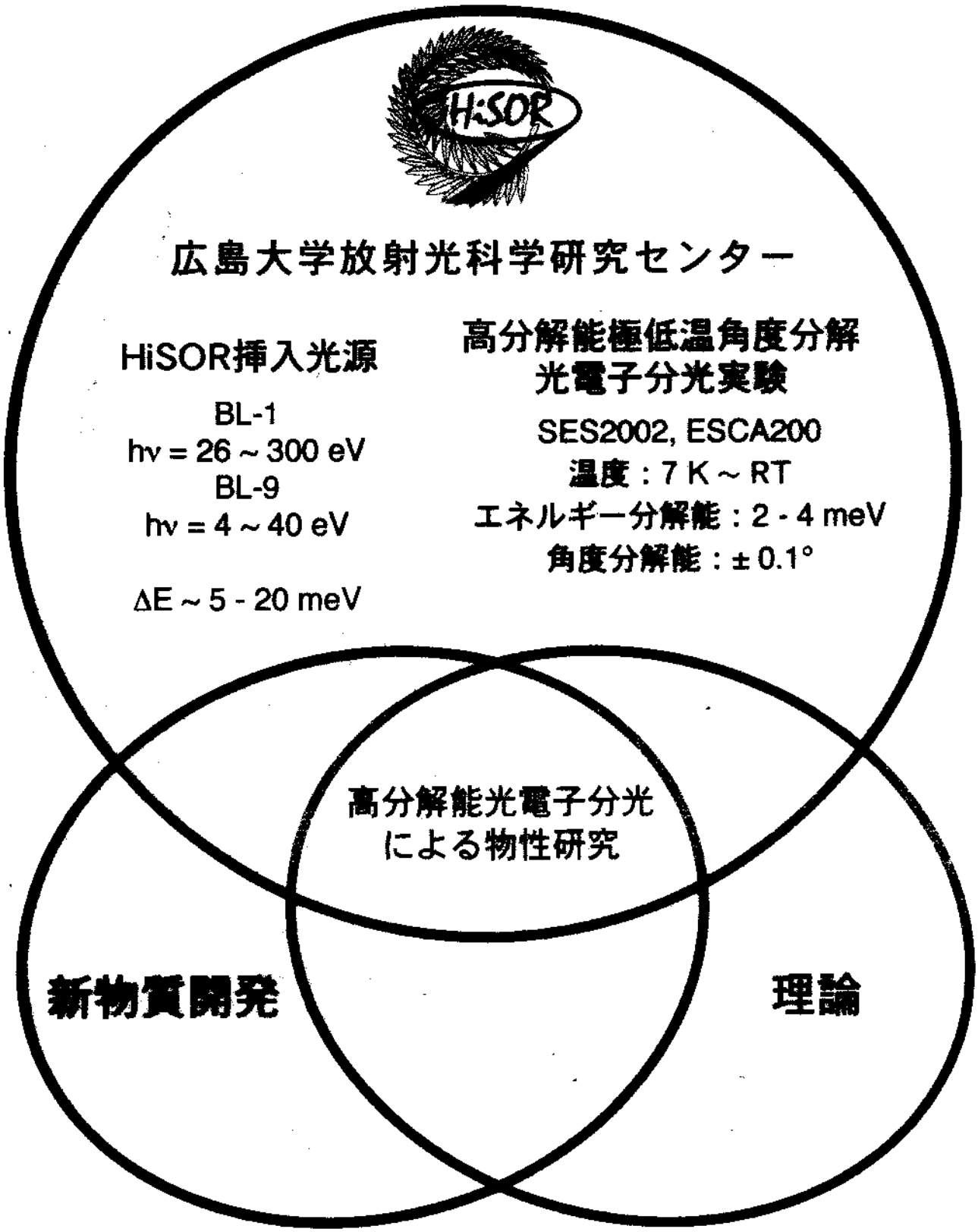
$CeIrIn_5$: 4*d*-4*f* resonant ARPES (HiSOR BL1)

off-resonance



on-resonance (near E_F)




広島大学放射光科学研究センター
HiSOR挿入光源
BL-1
hν = 26 ~ 300 eV
BL-9
hν = 4 ~ 40 eV
ΔE ~ 5 - 20 meV
高分解能極低温角度分解
光電子分光実験
SES2002, ESCA200
温度：7 K ~ RT
エネルギー分解能：2 - 4 meV
角度分解能：± 0.1°
高分解能光電子分光
による物性研究
新物質開発
理論