真空紫外アンジュレータビームラインの高度化と物性科学, 2009年12月18日 於 東大物性研

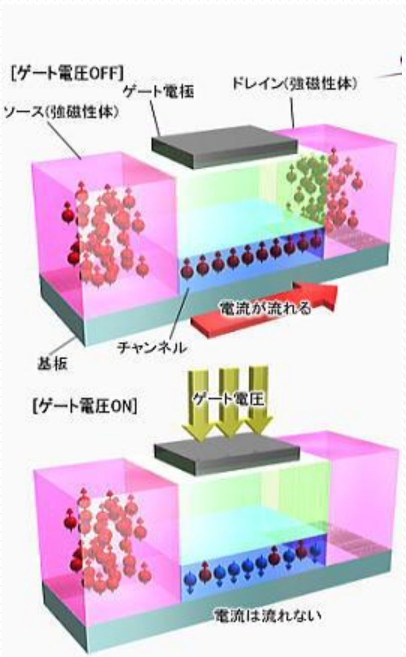
スピン分解光電子分光の新展開
COPHEEからESPRESSOへ

広島大学放射光科学研究センター

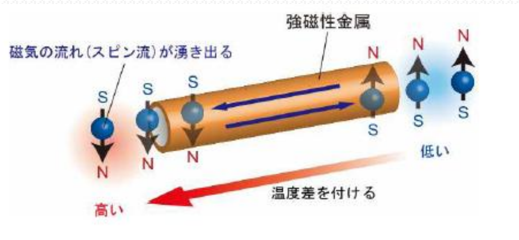
奥田太一

SPINTRONICS

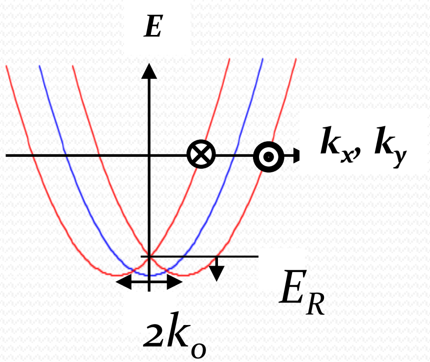
Spin transistor



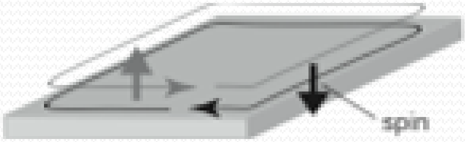
Spin Seebeck effect



<u>Rashba Spin splitting</u>

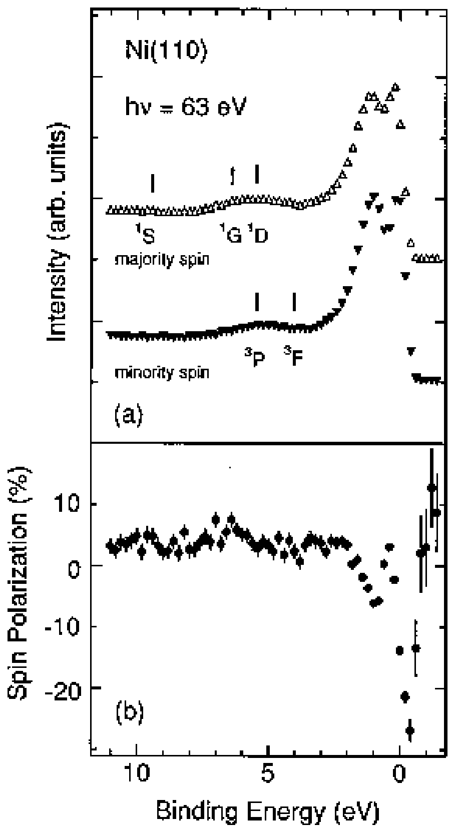


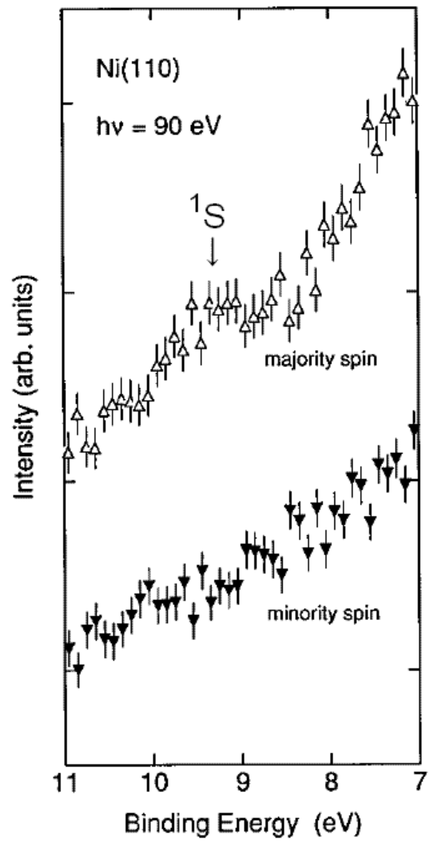
<u>Quantum Spin Hall effect</u>



<u>**Spin- and Angle-Resolved Photoemission Spectroscopy (Spin-ARPES) is powerful tool to investigate these phenomena**</u>

Spin resolved PES is time consuming experiment





Valence band satellites in Ni(110) (1997).

SHA50 + 25 keV Mott

ΔE ~ 400 meV

$\Delta\theta$ ～2 °

A. Kakizaki et al., Phys. Rev. B 55, 6678 (1997).

新しいスピン検出法、3Dスピン検出、光源の進化＞＞＞スピン分解光電子分光の新しい展開

Spin-ARPES in the world

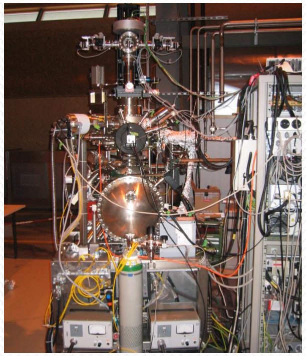
SOLEIL CASIOPEE beamline(10-1000 eV)

2D detector

SCIENTA R2002

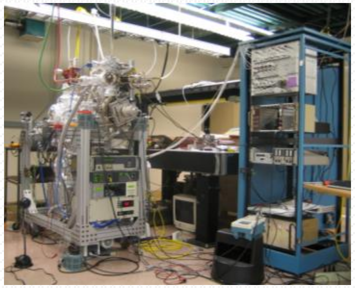
Rice Univ. type Mott detector(30-35kV)

SLS COPHEE (10-1000 eV)



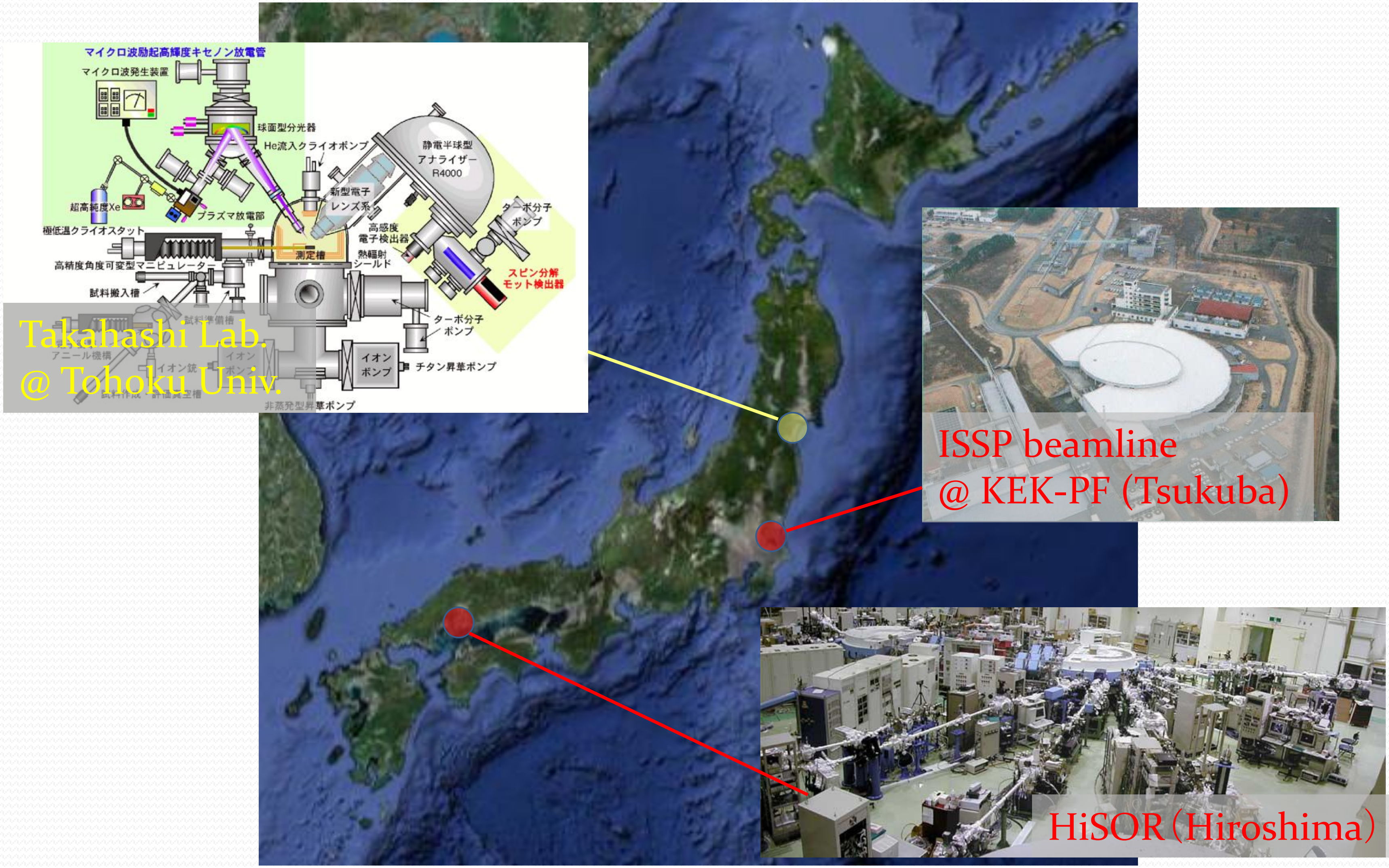
Two Mott detectors

LBNL, ALS (TOF+VLEED)



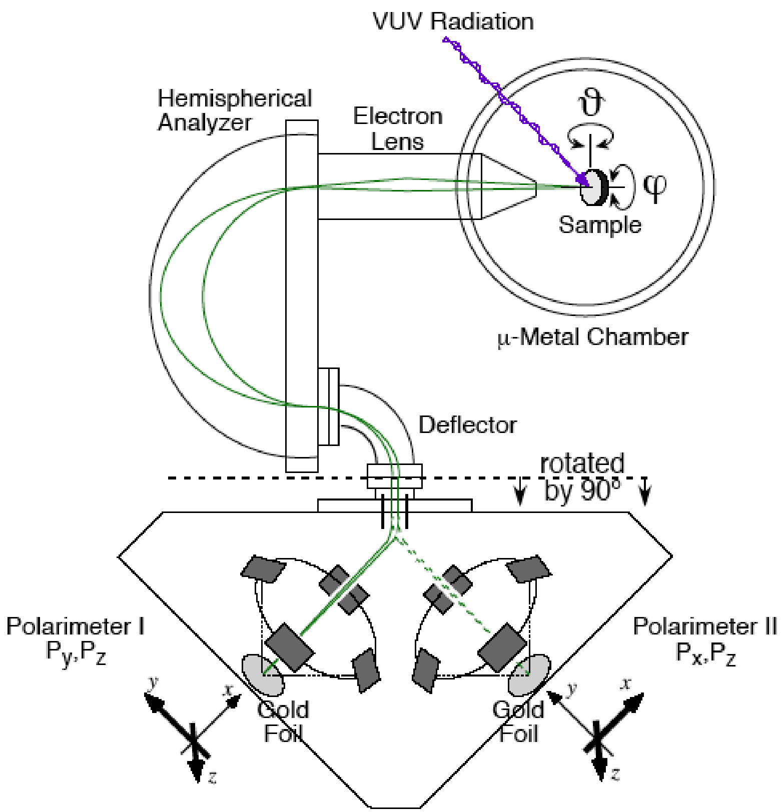
ΔE~5-10 meV?

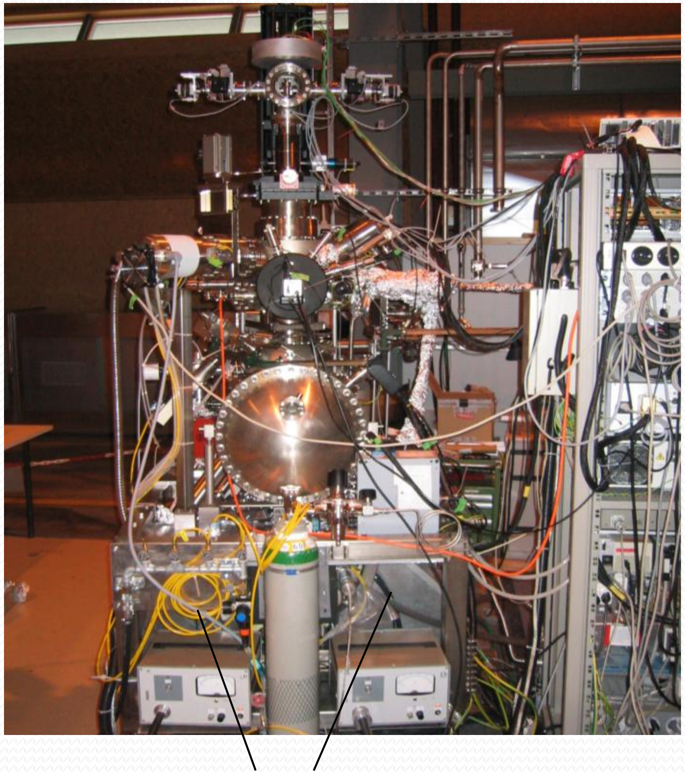
Spin-ARPES in Japan



COPHEE(COmplete PHotoEmission Experiment) machine at Swiss Light Source (SLS): 3D spin analysis

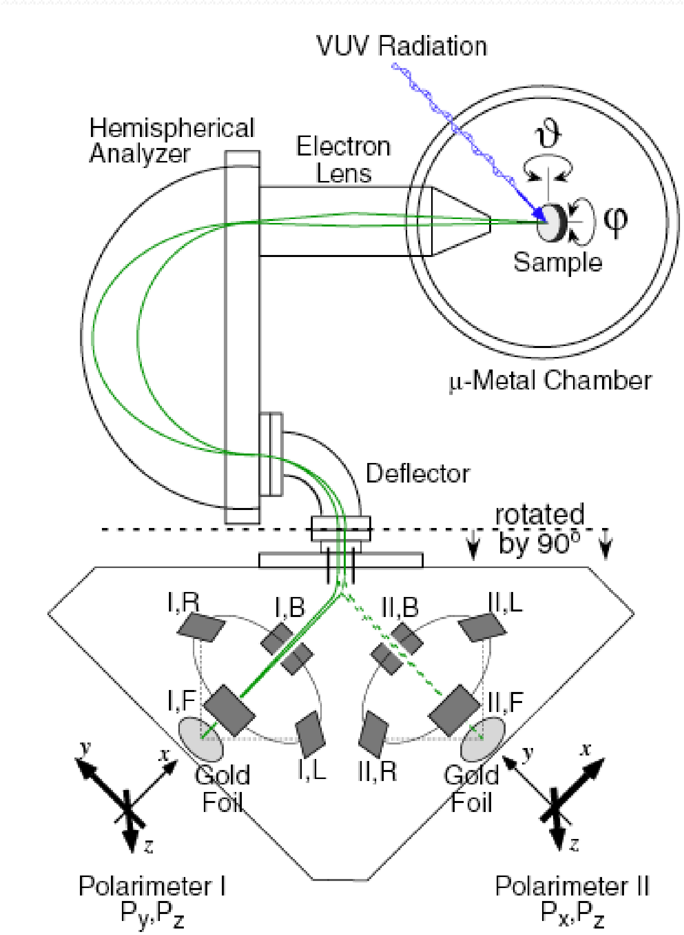
system : Omicron EA 125 + double 50 kV mini- Mott

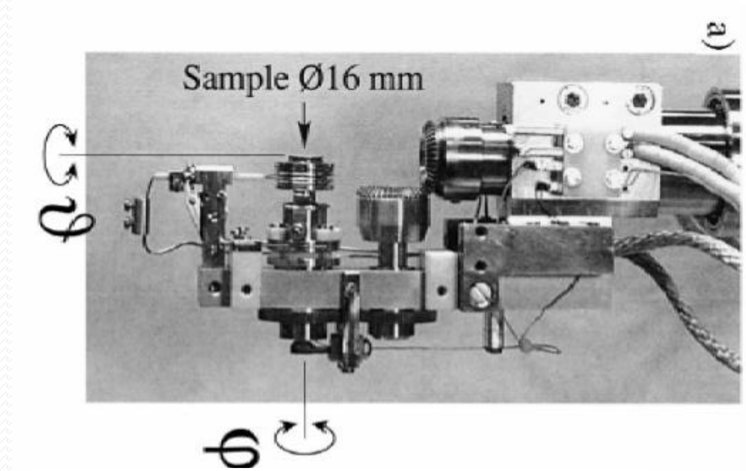




Two Mott detectors

COPHEEによる3Dスピン解析



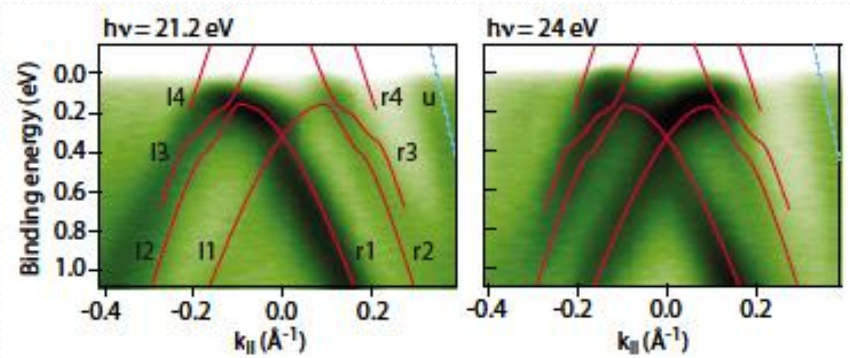


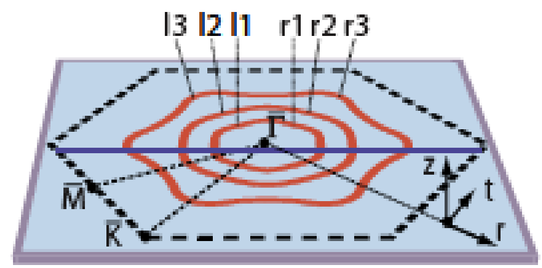
$$\begin{pmatrix} P_x^{(s)} \\ P_y^{(s)} \\ P_z^{(s)} \end{pmatrix} = \begin{pmatrix} \frac{\cos\vartheta\cos\varphi - \sin\varphi}{\sqrt{2}} & \frac{-\cos\vartheta\cos\varphi - \sin\varphi}{\sqrt{2}} & \sin\vartheta\cos\varphi \\ \frac{\cos\vartheta\sin\varphi + \cos\varphi}{\sqrt{2}} & \frac{-\cos\vartheta\sin\varphi + \cos\varphi}{\sqrt{2}} & \sin\vartheta\sin\varphi \\ \frac{-\sin\vartheta}{\sqrt{2}} & \frac{\sin\vartheta}{\sqrt{2}} & \cos\vartheta \end{pmatrix} \times \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$$

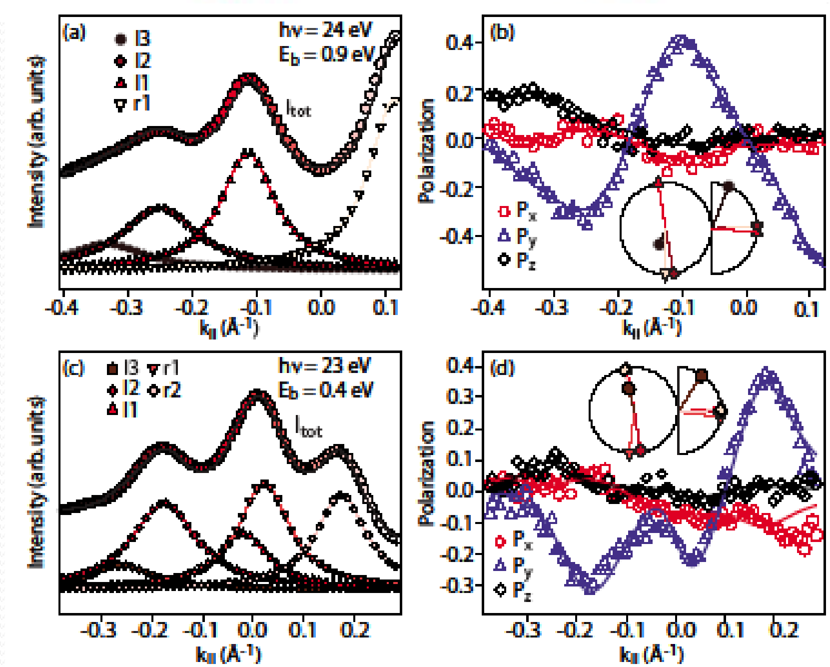
M. Hoesch et al. J. Electron Spectrosc. Relate. Phenom.124,263 (2002).

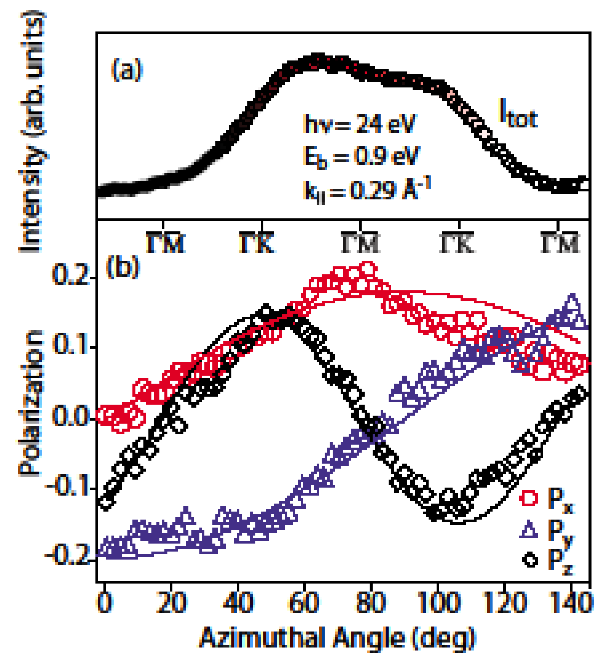
Example

3D ARPES on Ag/Bi surface alloy





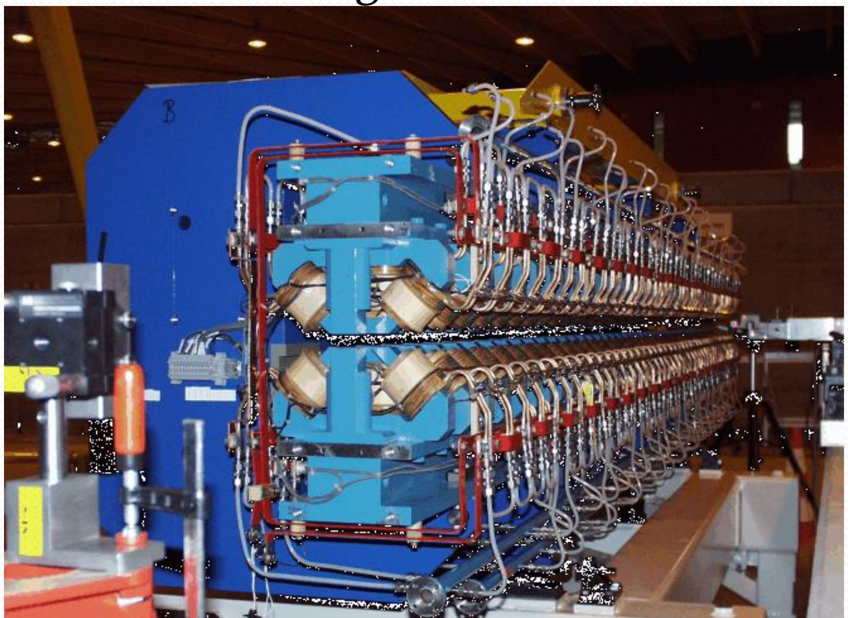




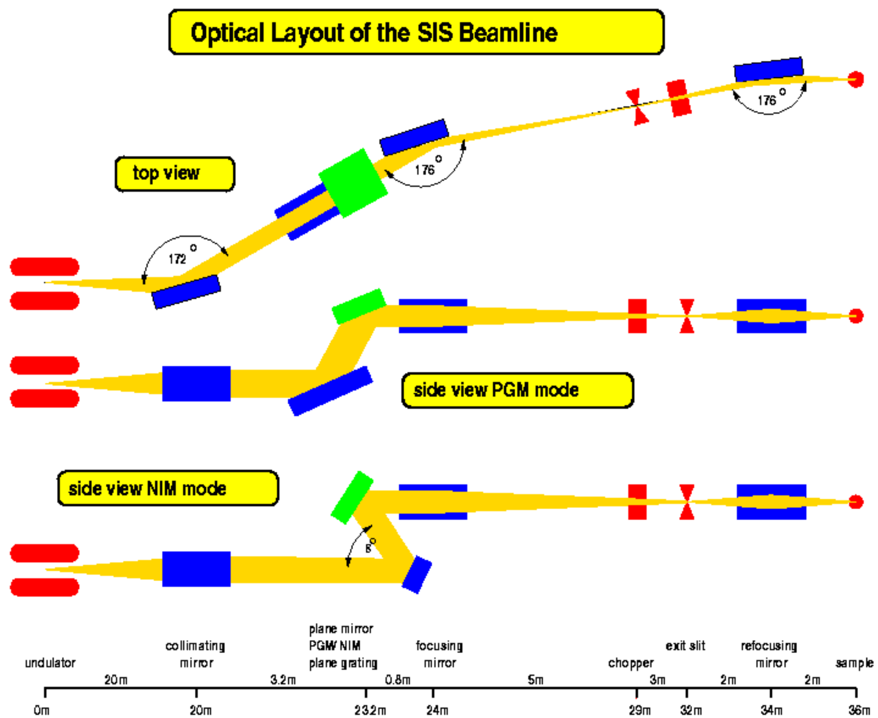
F. Meier et al. PRB 77, 165431 (2008).

Sources of SIS beamline

Electric magnet undulator



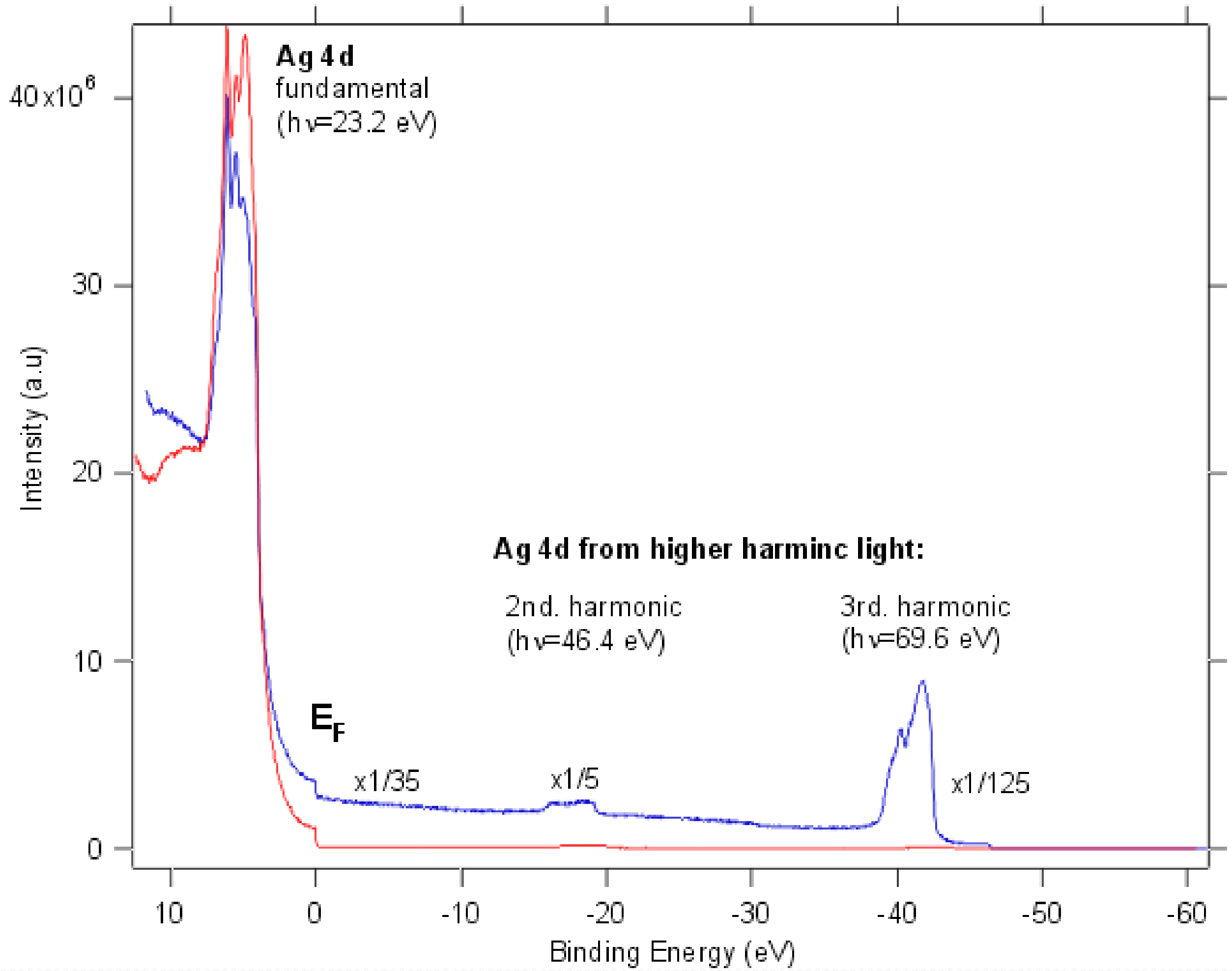
Type:	EM crossed field undulator
Length:	2 x 4.4 m
Period length:	212 mm
Number of poles:	2 x 21
Fundamental energy @ max. K:	10 eV
Flux @ 20 eV:	2 x 10^{15} ph/s/0.1%BW
Brightness @ 20 eV:	3 x 10^{17} ph/s/mm^2/mrad^2/0.1%BW
Photon source size @ 10 eV:	256 x 227 mm^2(s)
Photon source divergence @10 eV:	71 x 65 mrad^2(s)



Mode	Energy range
NIM	10-30 eV
PGM	20-800 eV

＋可变偏光

Suppress of higher order light by Quasi periodic mode

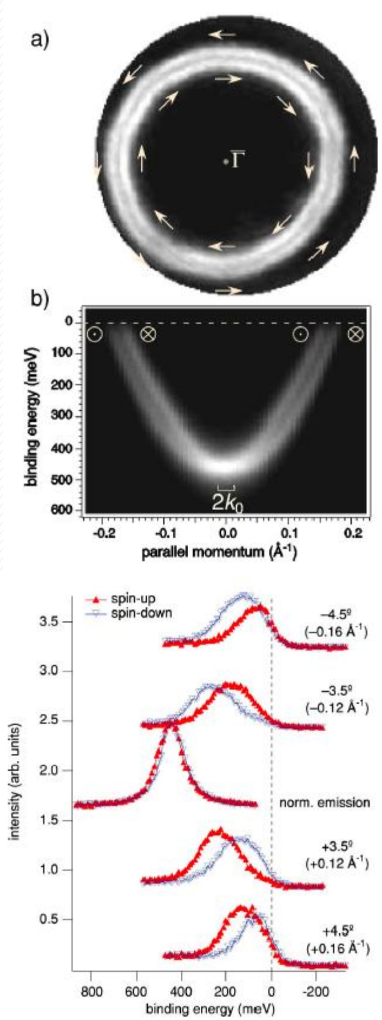


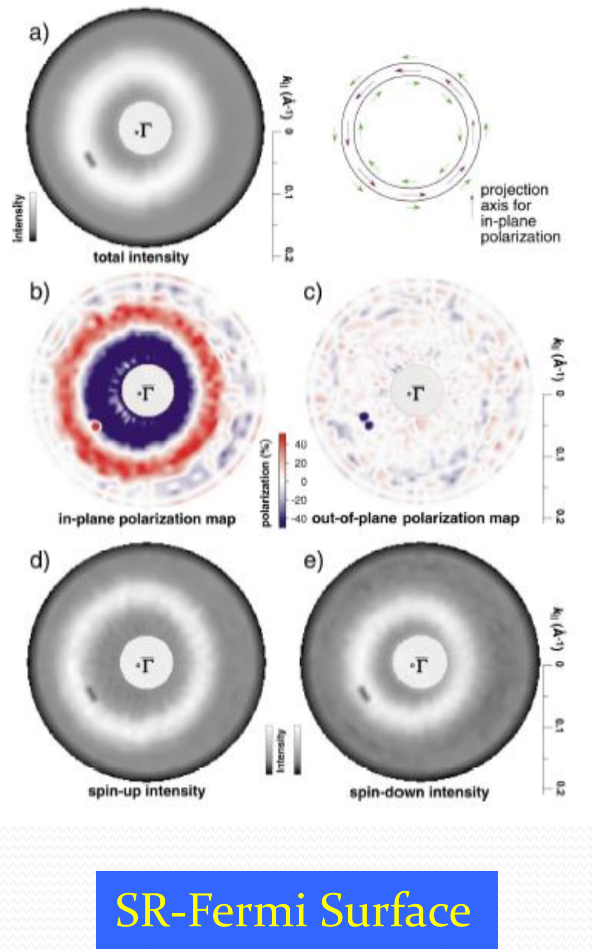
COPHEE+SIS beamline

“STRONGEST” SPIN resolved ARPES station in the world at present.

Results from COPHEE machine 1

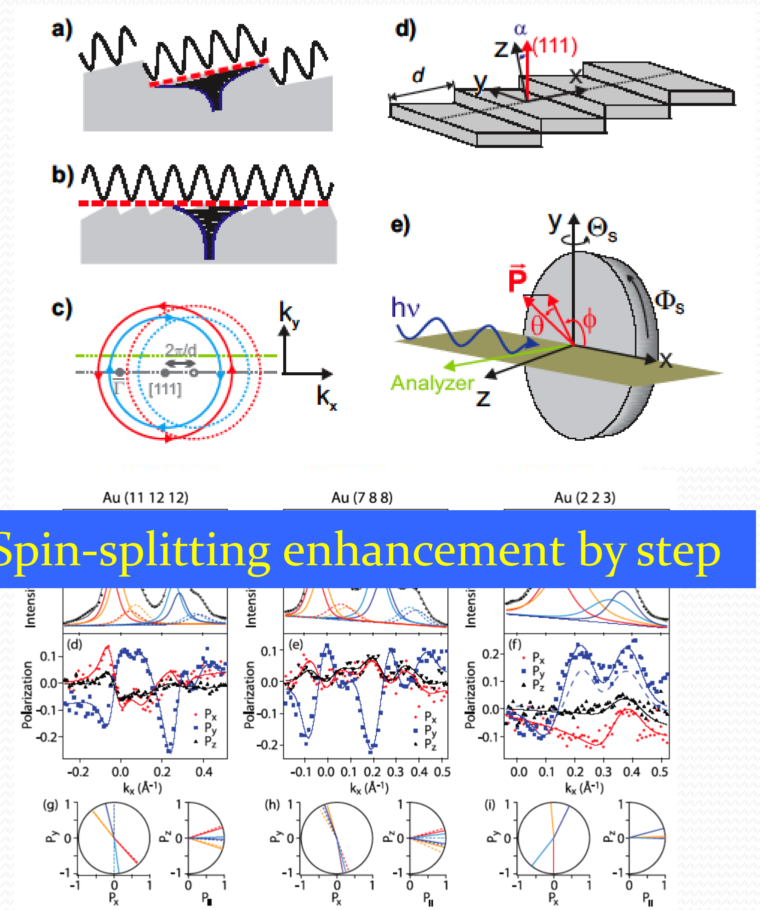
SP-Fermi Surface Mapping of Au(111), vicinal Au(111)





SR-Fermi Surface

M. Hoesch et al. PRB69, 241401(R)(2004).

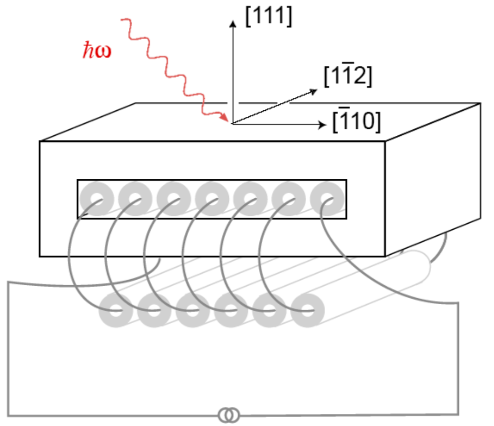


Spin-splitting enhancement by step

J. Lobo-Checa et al., PRL submitted.

Results from COPHEE machine 1

SP Surface State of Ni(111)



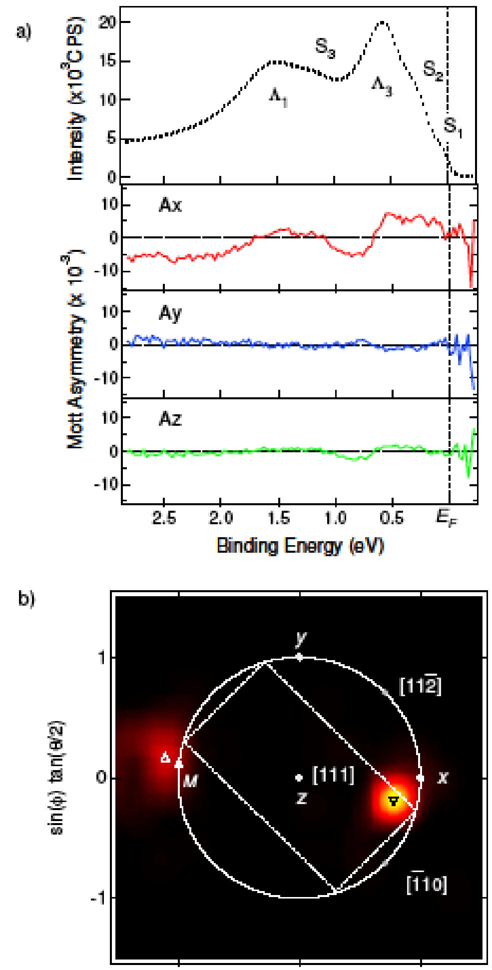
$\Delta\theta = \pm 1^\circ$

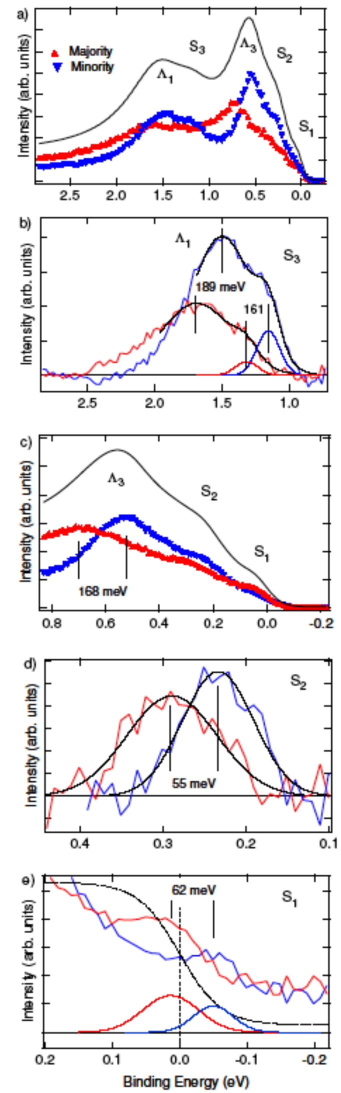
$\Delta E = 78$ meV

Δ_{ex}(Shockley)=62±15 meV

Δ_{ex}(Tamm)=55±10 meV

Δ_{ex}(3^{rd} SS)=161±20 meV



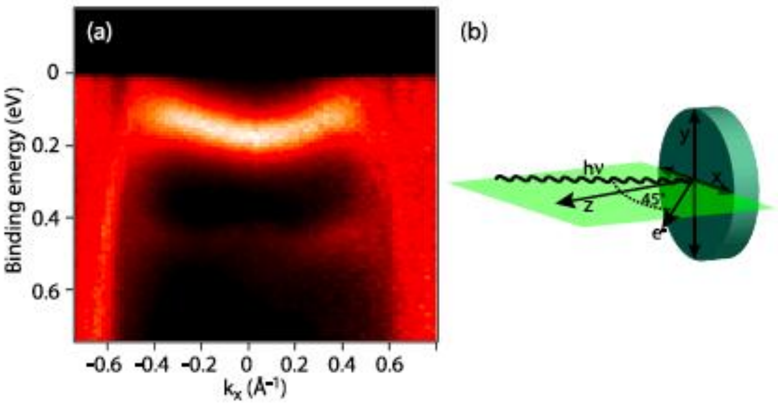


T. Okuda et al. PRB 80, 180404(R) (2009).

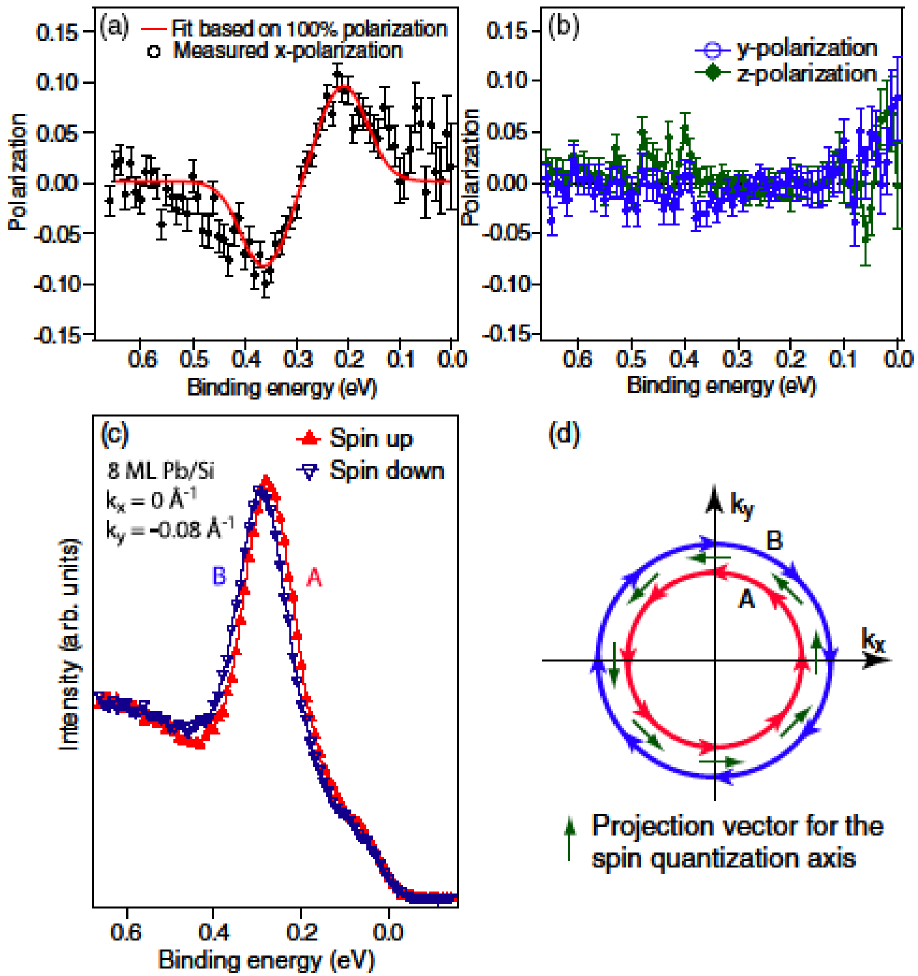
Spin splitting smaller than intrinsic line width is observed.
SRPES above Fermi level.

Results from COPHEE machine 2

Pb film on Si(111)



Spin splitting smaller than intrinsic line width is observed.



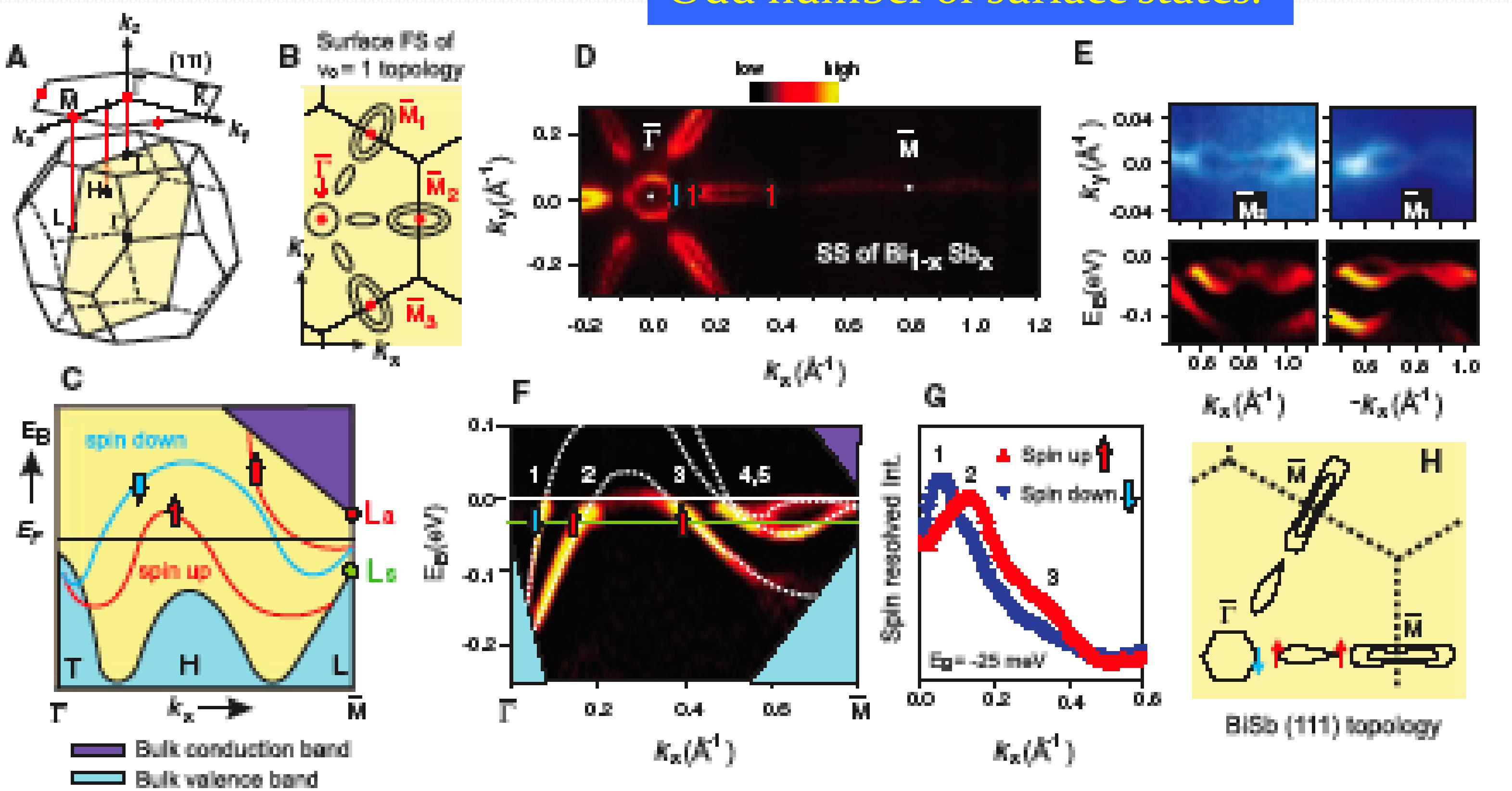
J. Hugo Dil et al. PRL101, 266802 (2008).

Results from COPHEE machine 3

SARPES on Topological Insulator

$Bi_{1-x}Sb_x$, Bi(114)

Odd number of surface states.



D.Hsieh et al. Science, 323, 919 (2009).

From COPHEE to ESPRESSO

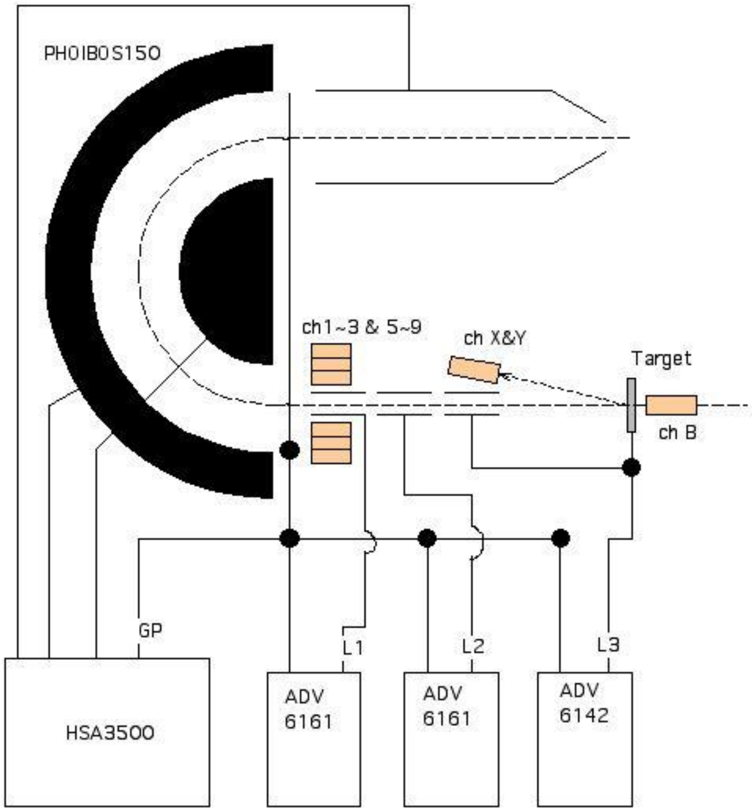
COmplete PHotoEmission Experiment

Extreme SPin REolved SpectroScopy Observation

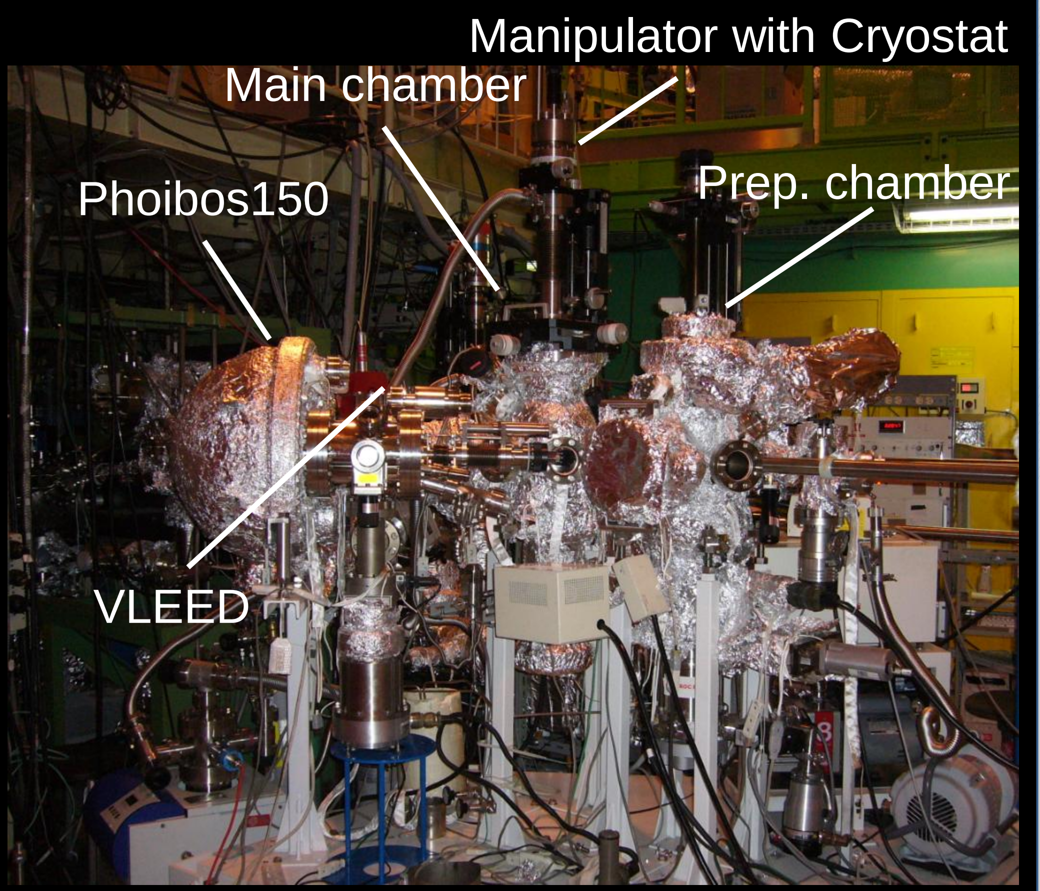
<

Espresso is much stronger than Coffee !!

VLEED at ISSP beamline 19A



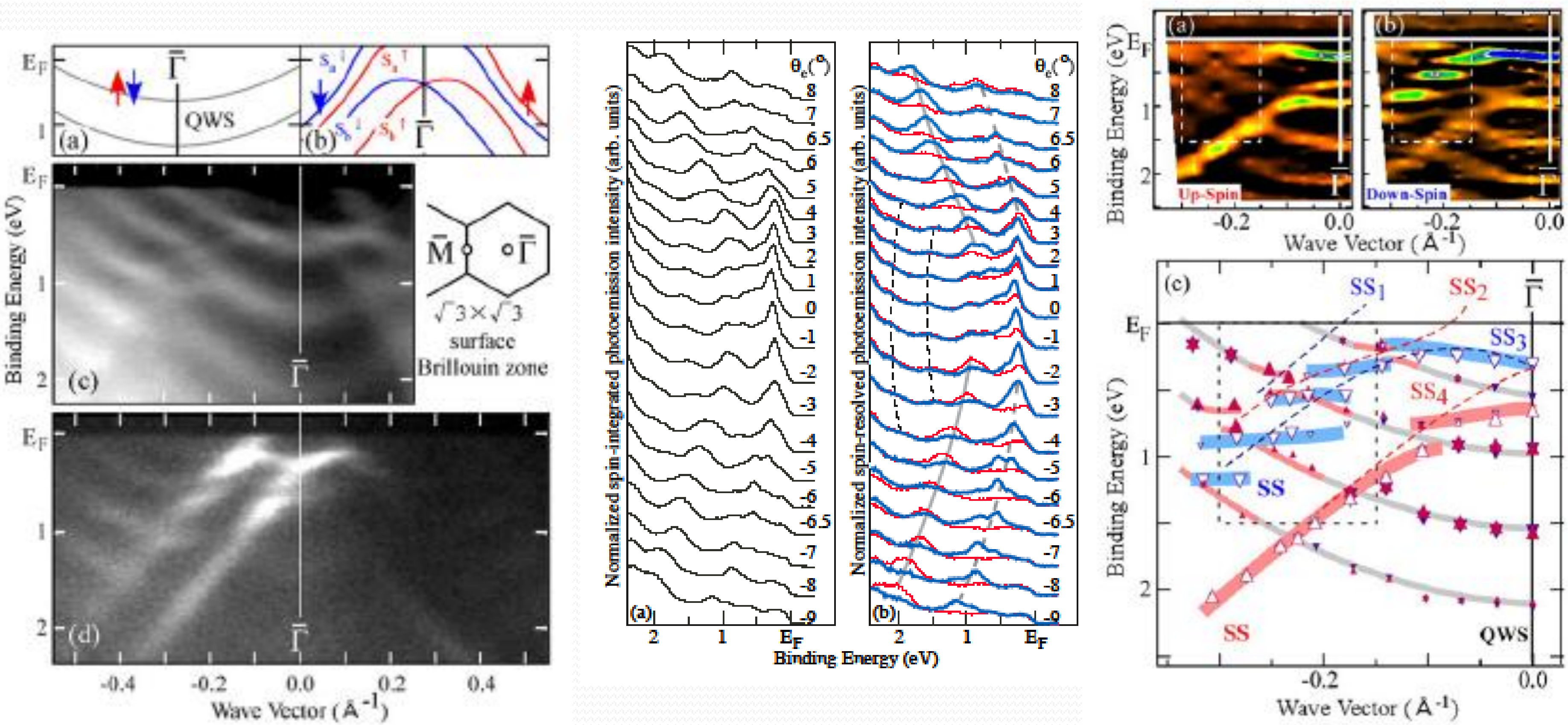
T. Okuda & Y. Takeichi et al. Rev. Sci. Instrum. 79,123117(2009).



S_{eff}~0.4, FOM~10^{-2} **ΔE~30 meV, Δθ~±0.7°**

Results from VLEED 1

spin-dependent hybridization on Bi/Ag surface alloy

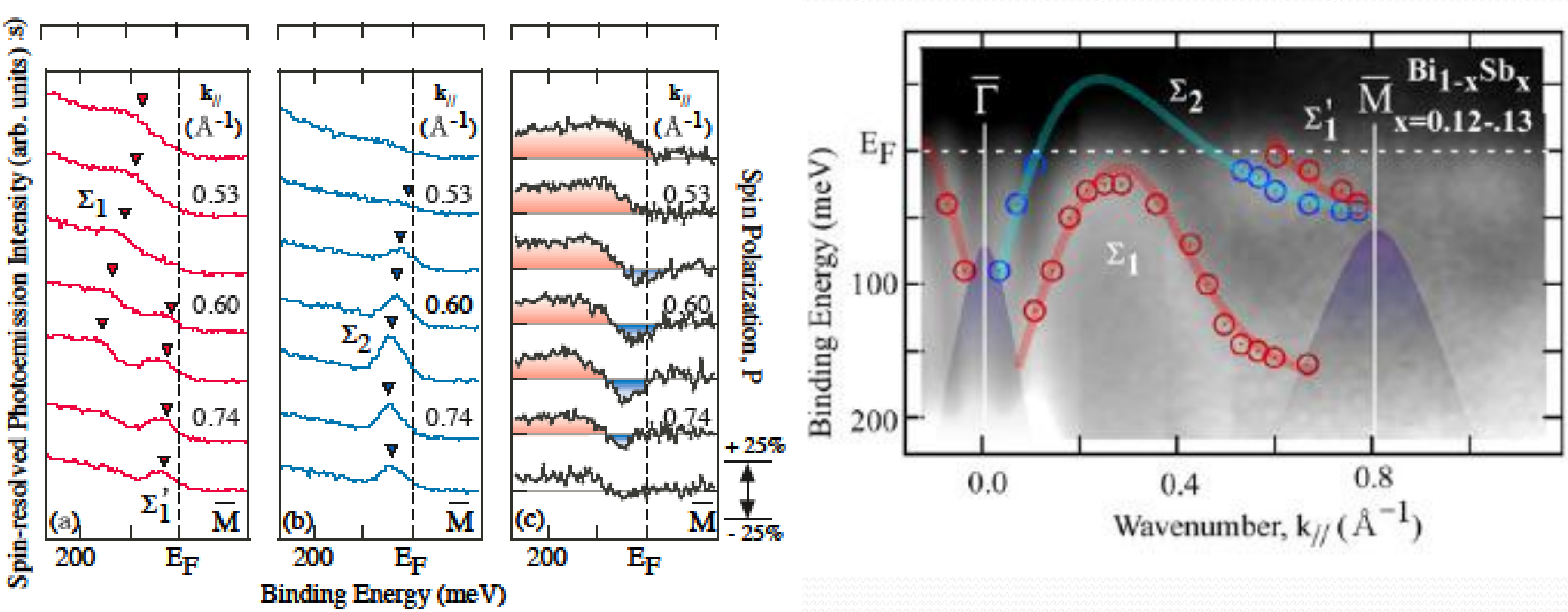


Spin dependent hybridization between SS and QWS

K. He et al. Phys. Rev. Lett. submitted.

Results from VLEED 2

High-resolution SARPES on $Bi_{1-x}Sb_x$



$\Delta\theta = \pm 0.7^\circ$
ΔE=70 meV

The 5 th SS could be resolved at M bar point.

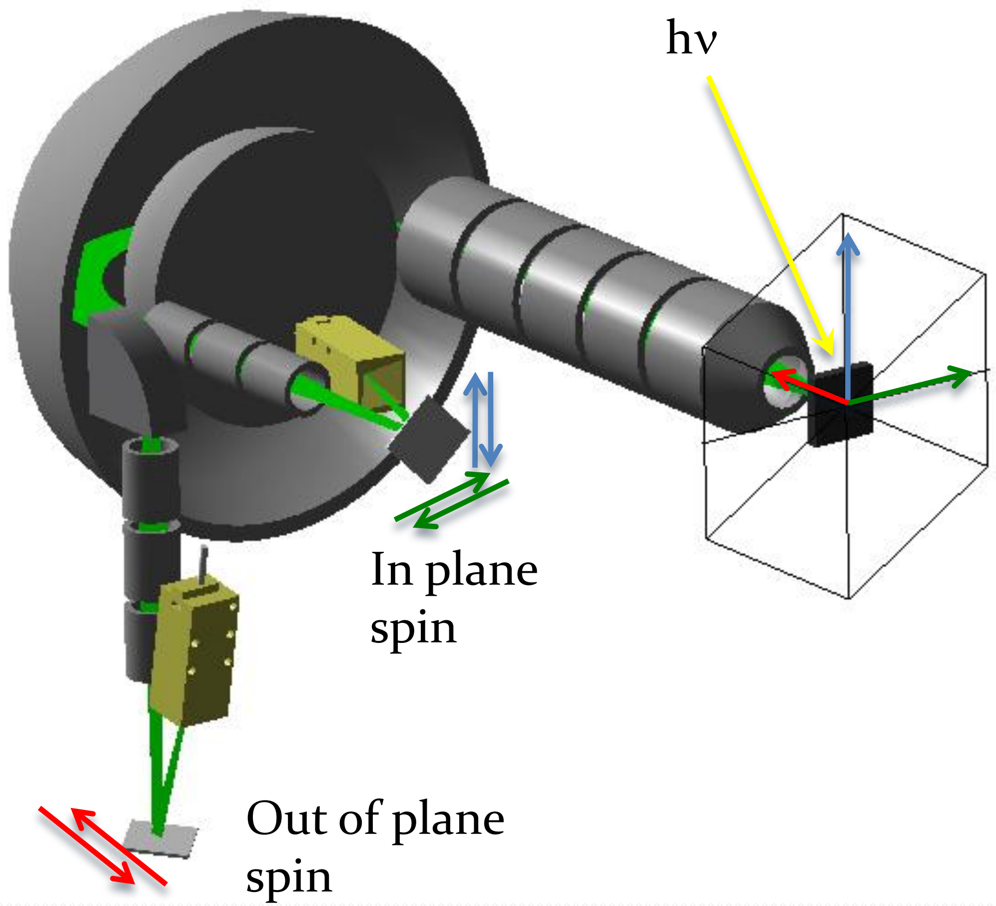
A. Nishide, Y.Takeichi et al., New J. Phys. to be published.

ESPRESSO project

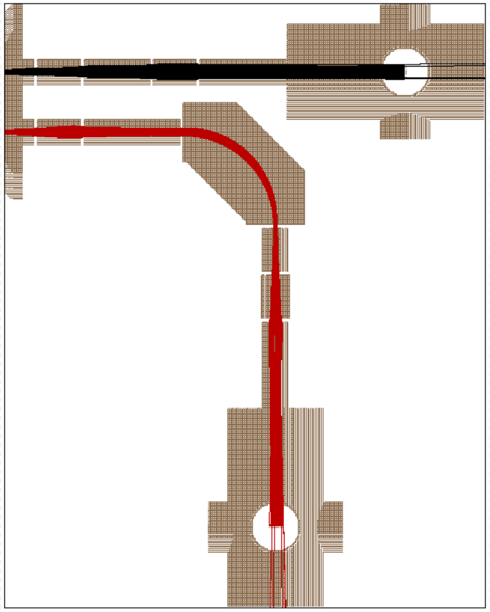
Extreme SPin REolved SpectroScopy Observation

ESPRESSO machine at ISSP

3D SARPES with double-VLEED



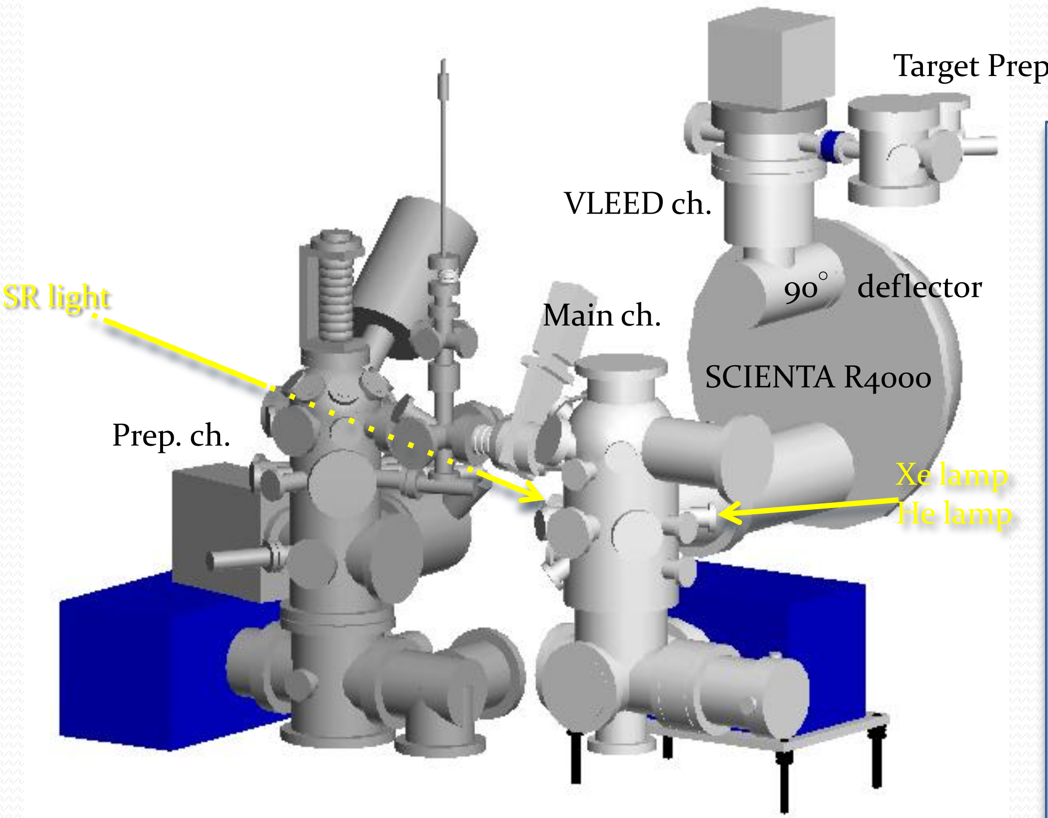
By installing deflector out of plane spin can be observed simultaneously with in plane spins.



Simulation results by SIMION

ESPRESSO machine at BL-9 in HSRC

High- throughput and High-resolution SARPES by VLEED



An
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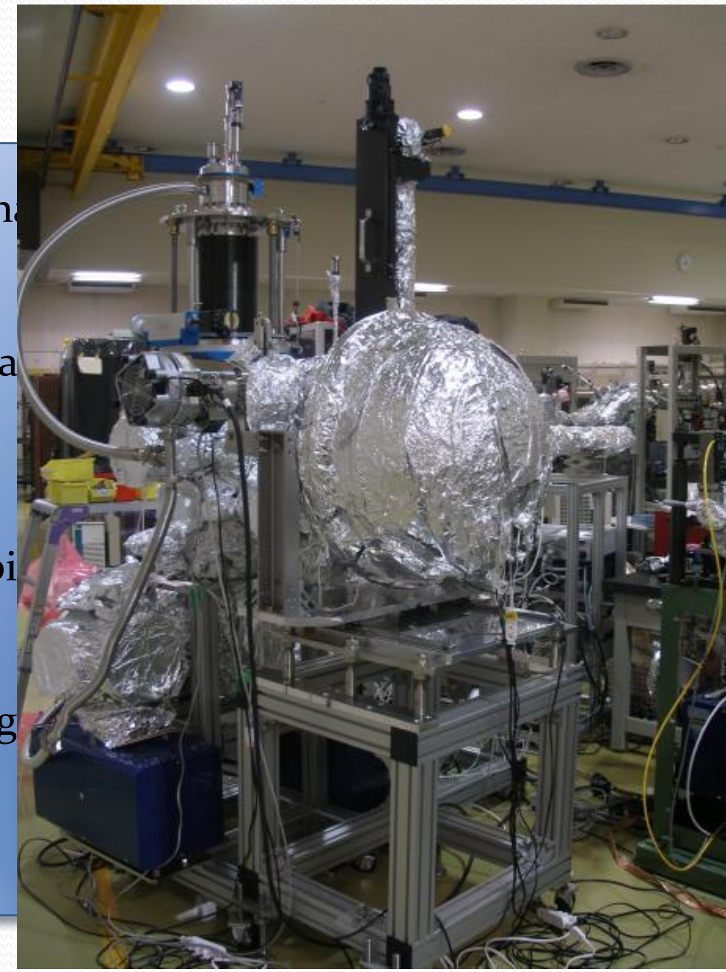
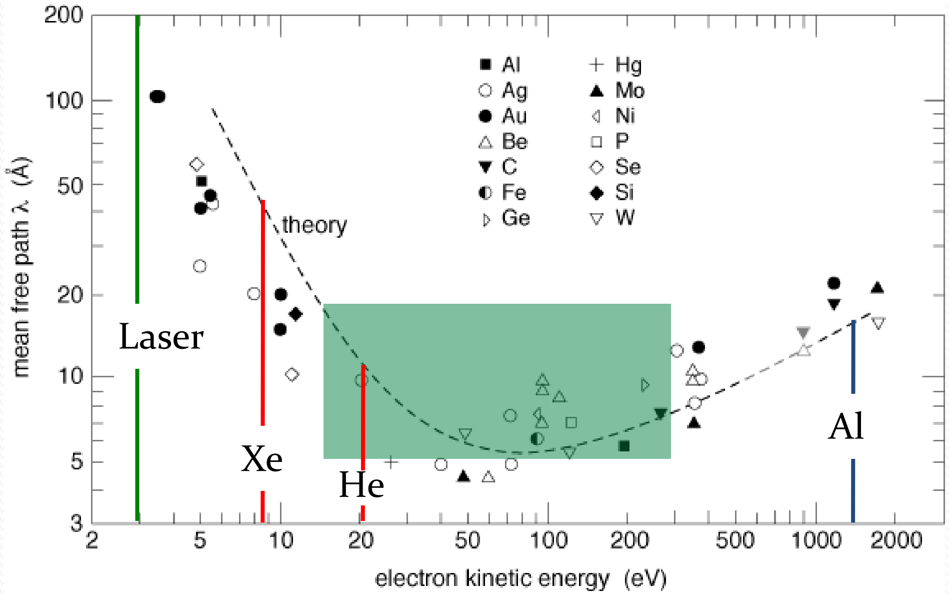


2D high resolution ARPES can be performed.
SR-FS mapping can be done with i-gonio manipulator
Goal: SARPES with ΔE~10 meV and $\Delta\theta < \pm 0.5^{\circ}$

Future prospect
HAXSPES, LASER-SPES….

- Bulk sensitive SRPES
- SR-XRD
- Ultra high-resolution SRPES



Source	hν (eV)	ΔE (meV)
Laser(Nd:YVO_4)	6.99	0.26
Xe (Ar, Kr) lamp	8.4 (11.7, 10.1)	0.6
He lamp	21.22	1
SR	15-1000	1<
X-ray tube (Al)	1486.7	1000<

Summary　新BL19を更新する意義と新BL19に望むこと

- 低エネルギー（10 eV　or 少なくとも20 eVから）を利用できるビームラインに。＞角度分解能をカバー

- (SXまでカバーしていると尚良い＞＞＞SXSPES, SP-XRDなど＞＞＞SP-8?）

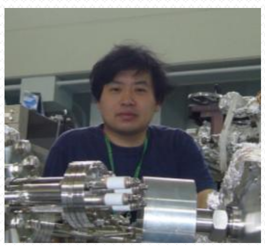
- PFのTopUp　VUV光源は、スピン分解光電子（特にVLEED)にとっては大きなアドバンテージ。

- （円）偏光切り替えが出来ると尚良い。＞＞＞非磁性体表面スピンの精密測定に非常に有効　＞＞＞電磁石アンジュレータの方がよい？

Collaborators

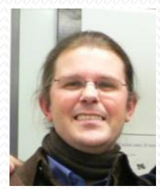
ISSP

- Y. Takeichi
- Y. Maeda
- K. He
- A. Nishide
- A. Harasawa
- I. Matsuda
- T. Kinoshita
- A. Kakizaki



UniZH

- T. Greber
- J. Lobo-Checa
- M. Hoesch
- J. Osterwalder



HRSC

- K. Miyamoto
- K. Kanomaru
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- M. Arita
- H. Namatame
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Thank you for your attention