Photoemission electron microscopy: Pump-probe experiments

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E4 - Phase solide

4 complementary end-stations share the solid state beamline at ATTOLab:

Spin-ARPES
Karol HRICOVINI
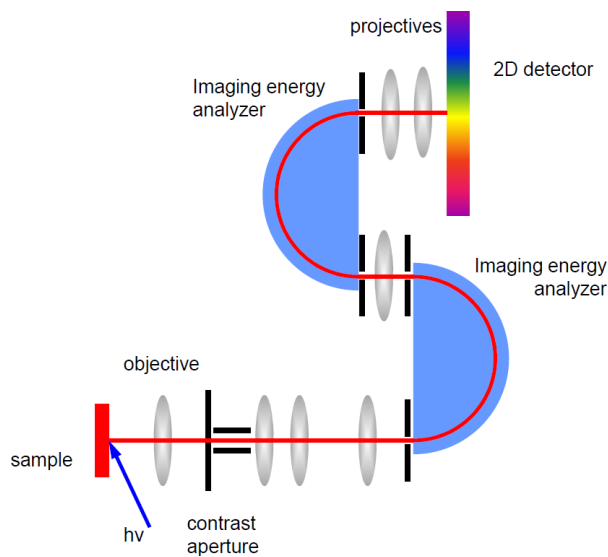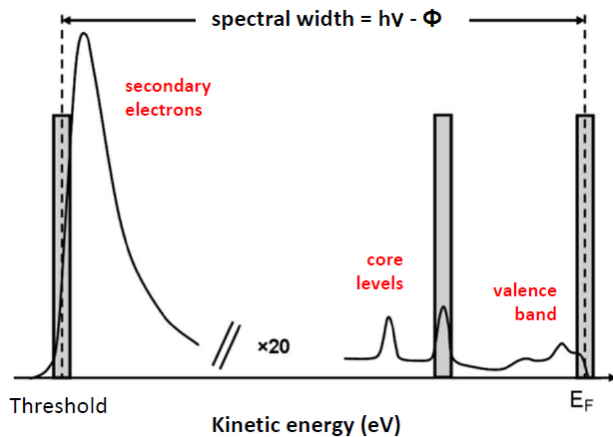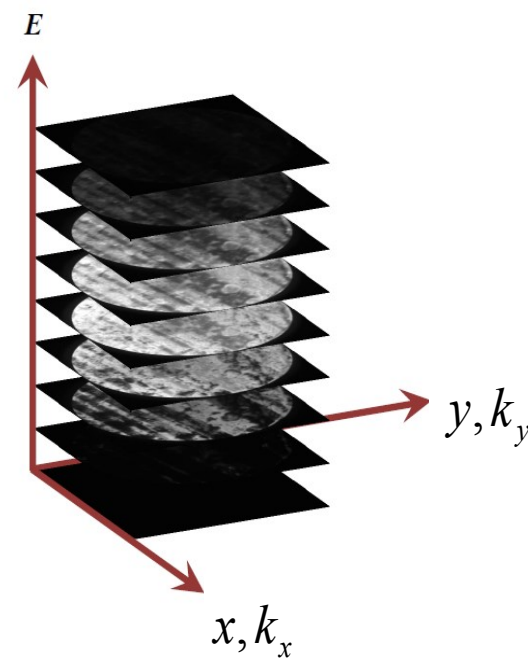
Laser-Solide
Stéphane GUIZARD

TR-ARPES
Marino MARSI

TR-PEEM
Nick BARRETT

PEEM pump-probe

spectral width = hν - Φ

secondary electrons

core levels

valence band

×20

Threshold

E_F

Kinetic energy (eV)

projectives

2D detector

Imaging energy analyzer

Imaging energy analyzer

objective

sample

hν

contrast aperture

Real & reciprocal space imaging
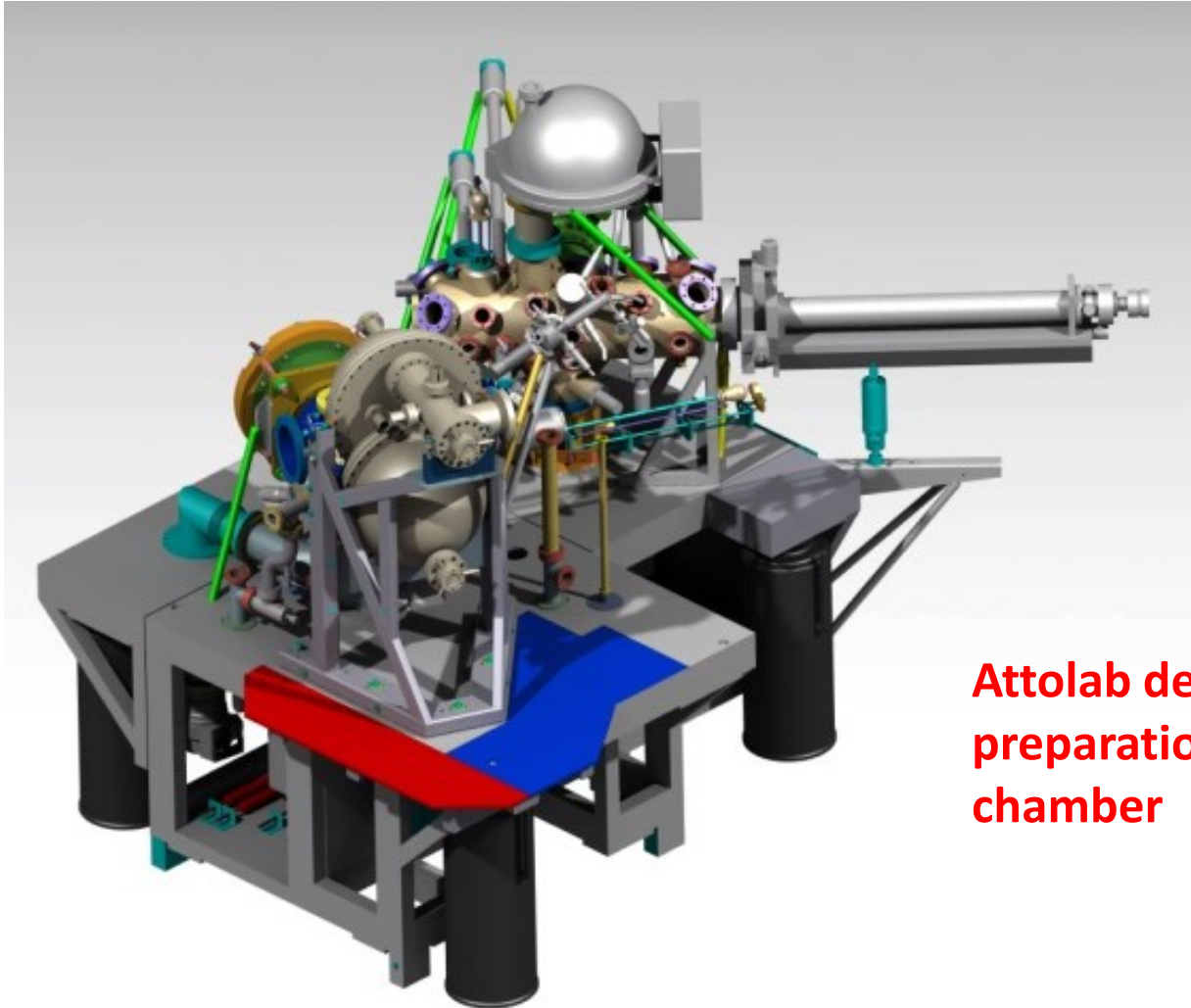

E

y, k_y

x, k_x

Pump-probe PEEM
IR+VUV/XUV

Technical beamline requirements
Focusing optics into PEEM field of view
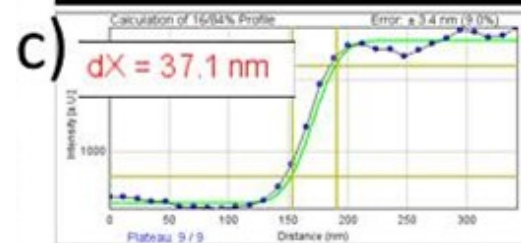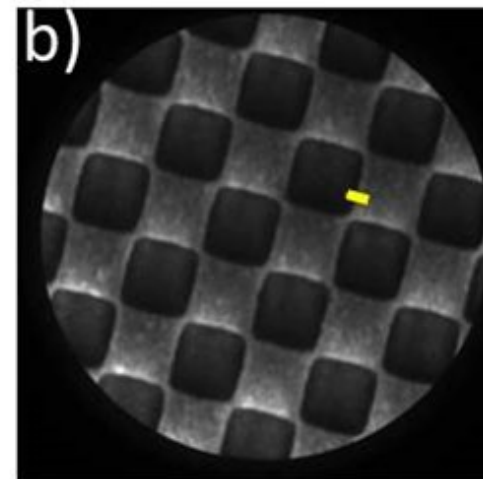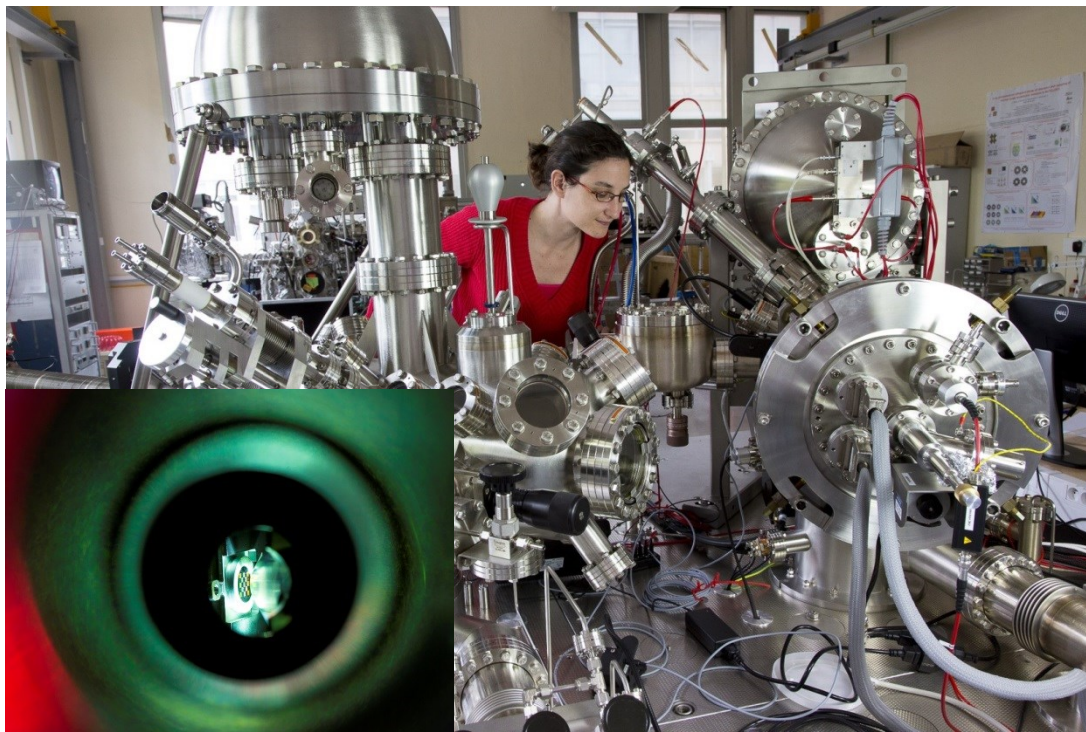Monochromator OPT2X narrow band line
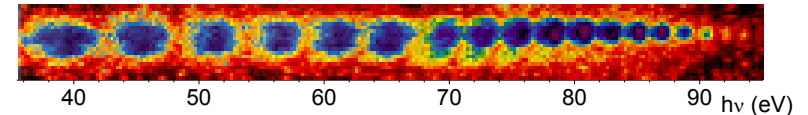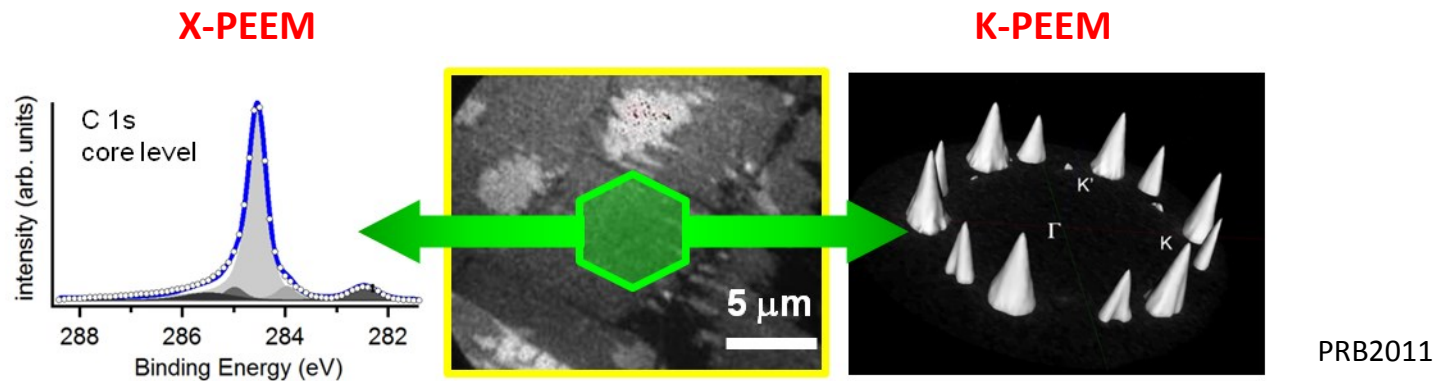
Mesoxcope

Attolab dedicated preparation chamber

MesoXcope

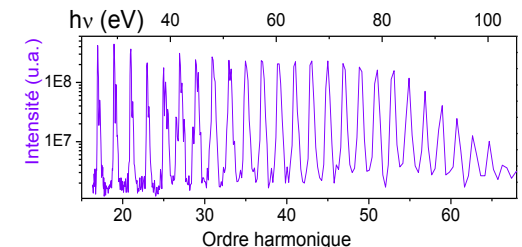**Dedicated to high resolution band structure imaging of functional oxides & 2D materials**

b)

c) dX = 37.1 nm

Real & Reciprocal Space Imaging

MesoXcope : ΔE = 50-100 meV, Δx = 50 nm, Δk = 0.02 Å^{-1}, T = 30-600 K

X-PEEM   **K-PEEM**

PRB2011

PEEM with laser

- ❖ band structure 2D materials, oxides
- ❖ Valence band edges
- ❖ shallow core levels
- ❖ Count-rate issues

Electron dynamics in BiFeO$_3$

Ultra fast optical spectroscopy

Ti-sapphire 100 fs 250 kHz 4 μJ/pulse BBO frequency doubled 383-398 nm

Pump: O 2p – Fe 3d
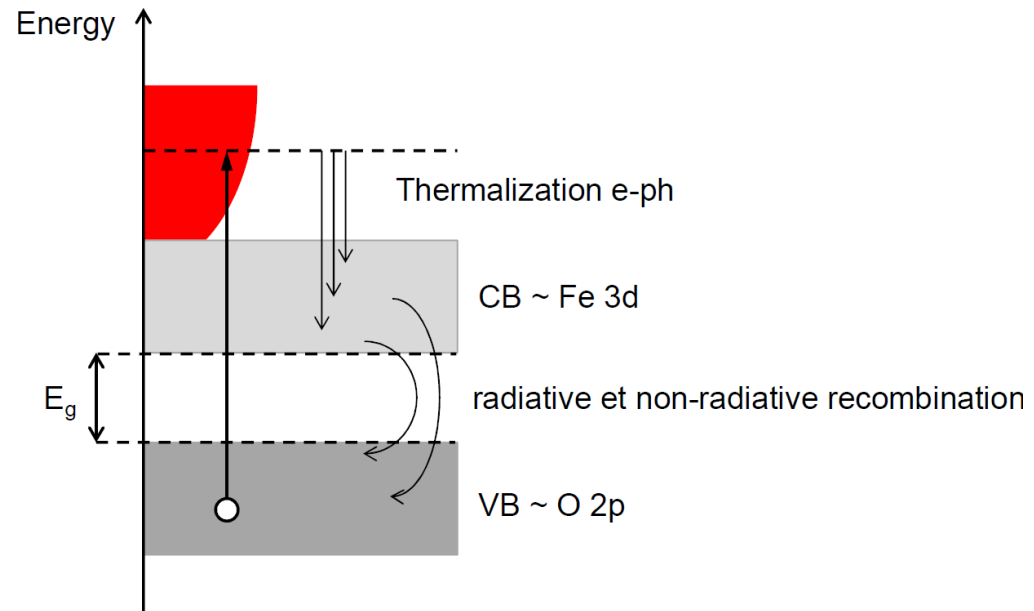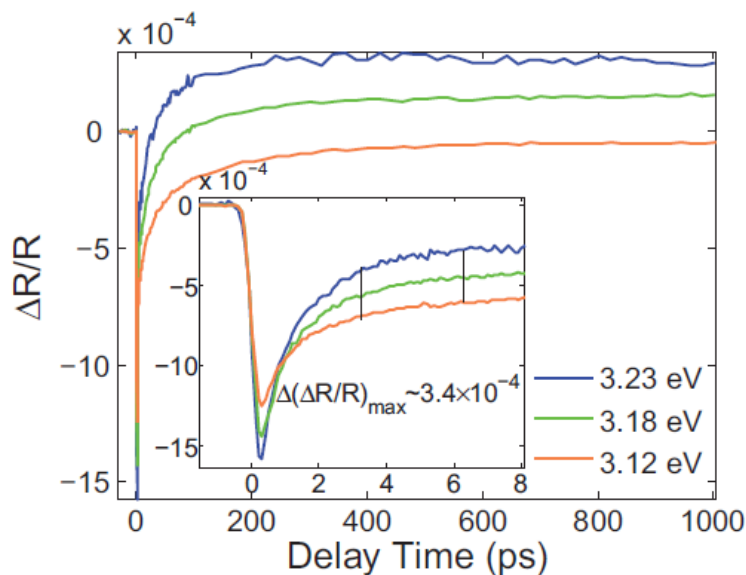Probe: Reflectivity ΔR/R

3 time constants
~1 ps phonon scattering
~10 ps radiative
~1 ns recombination

Energy

Thermalization e-ph

CB ~ Fe 3d

E_g

radiative et non-radiative recombination

VB ~ O 2p

x 10^{-4}

ΔR/R

x 10^{-4}

Δ(ΔR/R)$_{max}$ ~3.4×10^{-4}

— 3.23 eV
— 3.18 eV
— 3.12 eV

Delay Time (ps)

❑ Conduction band structure (« static » experiment)
❑ Depolarising dynamics
❑ Relaxation & recombination dynamics
❑ Charge carrier lifetimes

Sheu et al. APL 2012

Photoferroelectricity in BiFeO$_3$

Open circuit voltages >> Si band gap
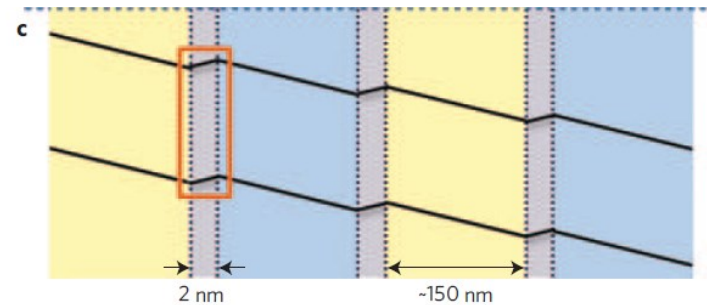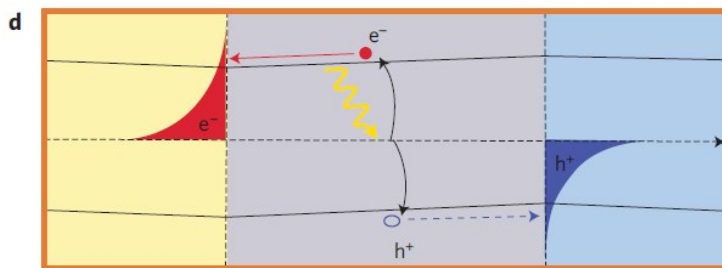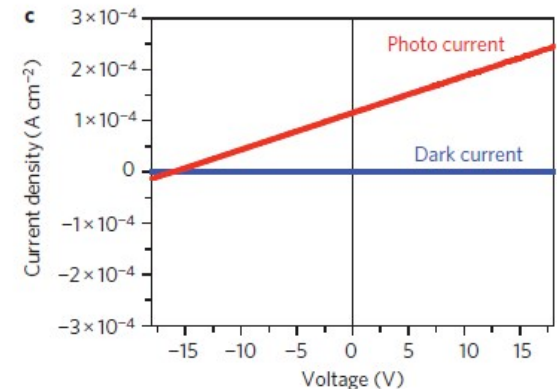Domain wall vs bulk photovoltage
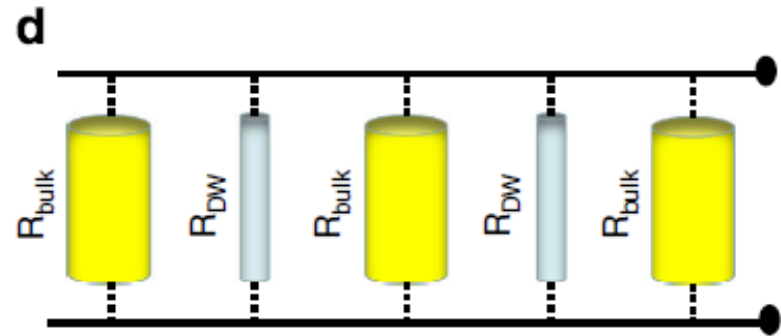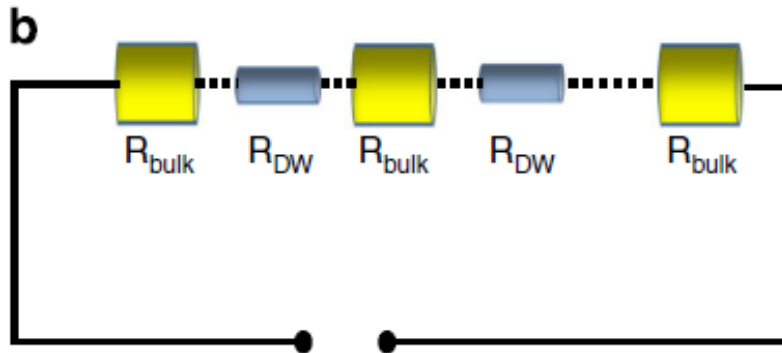
With attolab:
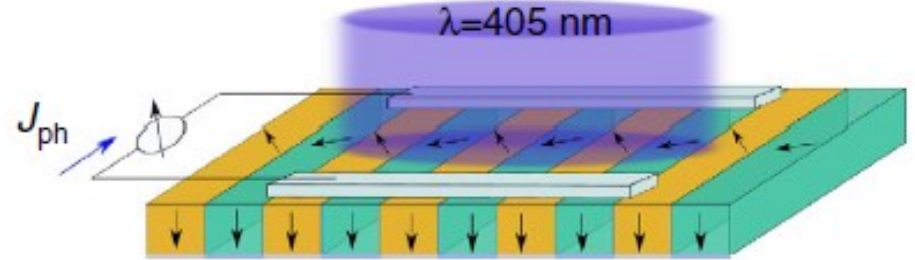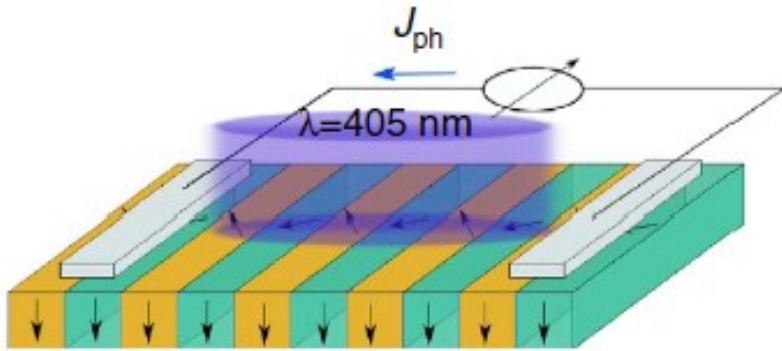Pump: UV pulse (frequency doubled)
Probe: HHG PEEM
Informations:
Electron-hole pair separation @ domain walls

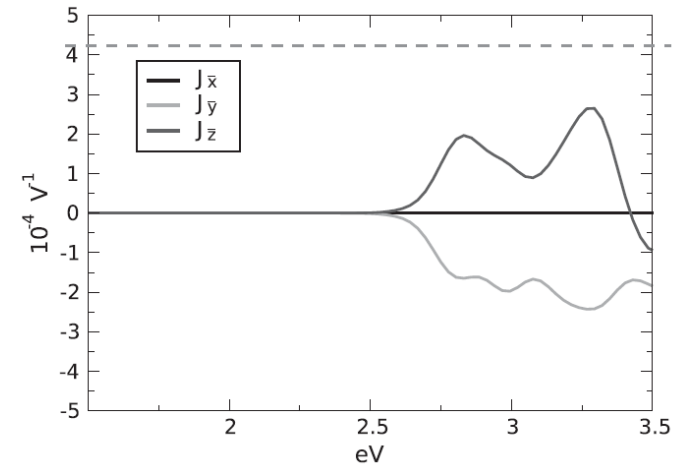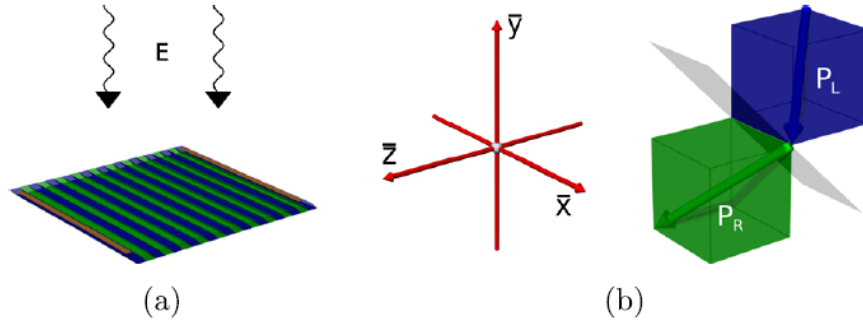

Yang *Nature Nanotech* 2010

Parallel/Perpendicular J_{PV}

Shift current origin
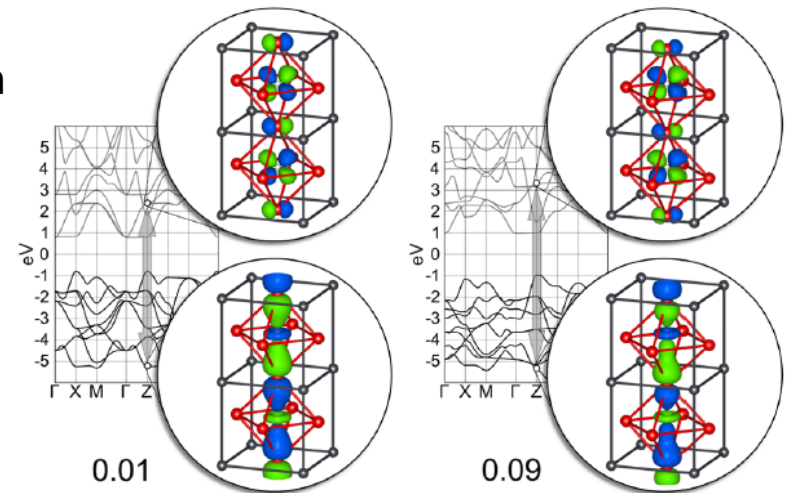

(a)   (b)

- ❑ DW related photocurrent
- ❑ Bulk Photovoltaic current opposite to J_{DW}
- ❑ Zero current parallel to DW
- ❑ Significant photocurrent perpendicular to film

- ❑ Bonding – Anti-bonding transition
- ❑ Polarization dependent shift vector

Young *Phys. Rev. Lett.* 2012 x2

Moving the MesoXcope

Installation at Elettra synchrotron (Trieste) 06 May - 16 June 2015
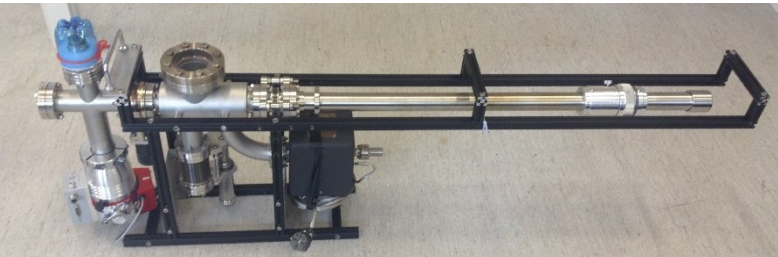
Departure
Saclay

*Specialist
removals
company*

Arrival
Elettra

First results with UHV suitcase

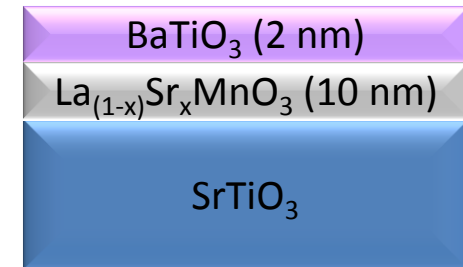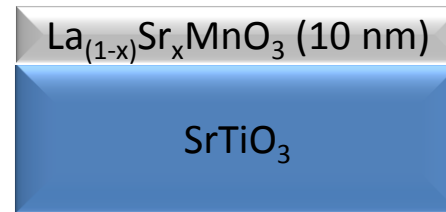**UHV suitcase**
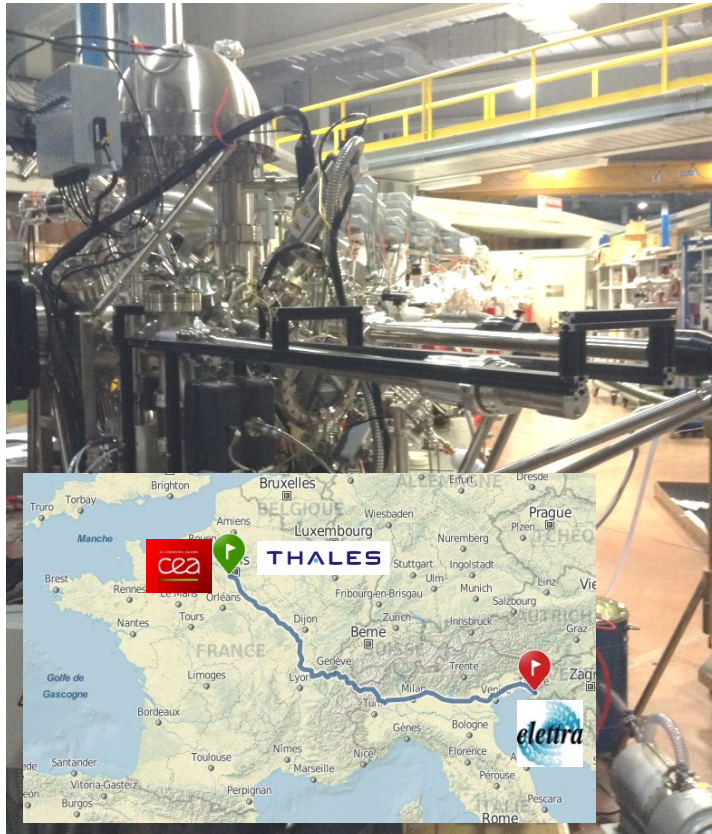Oxy-Clean (Labex NanoSaclay)
$P \sim 1 \times 10^{-9}$ mbar
Up to 4 samples

Transfer Thales / Elettra
Sample $\sim$ 4 days in suitcase

NanoSaclay
Laboratoire d'Excellence
en Nanosciences et Nanotechnologies

BaTiO$_3$ (2 nm)

La$_{(1-x)}$Sr$_x$MnO$_3$ (10 nm)

La$_{(1-x)}$Sr$_x$MnO$_3$ (10 nm)

SrTiO$_3$

SrTiO$_3$

FoV=3.9 Å^{-1} BE=1.1 eV, hv=84 eV

k_x (Å^{-1})

k_x (Å^{-1})

k_y (Å^{-1})

k_y (Å^{-1})
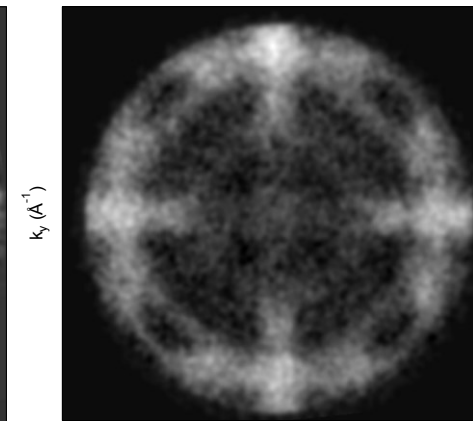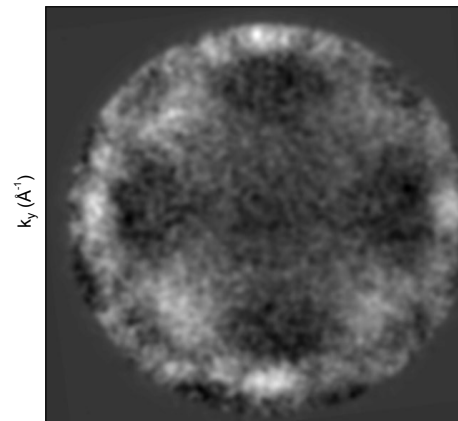
PEEM band structure: clean surface!

Space charge

Rule of thumb: Space charge limit 2e/μm² pulse

IR laser 800nm 35 fs 3.6mJ 1 kHz
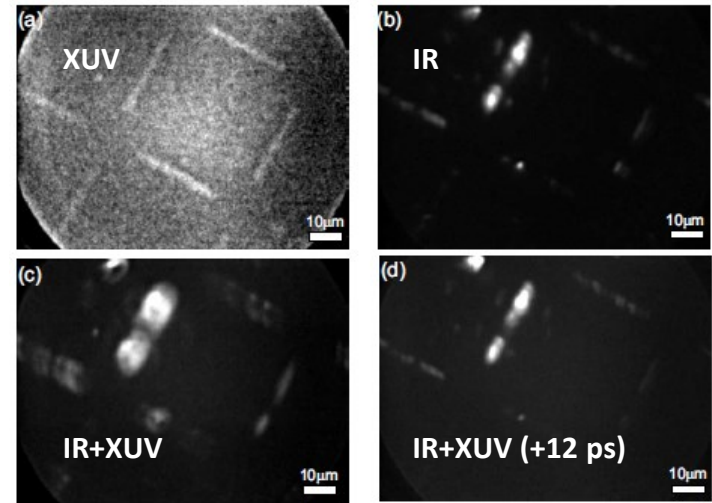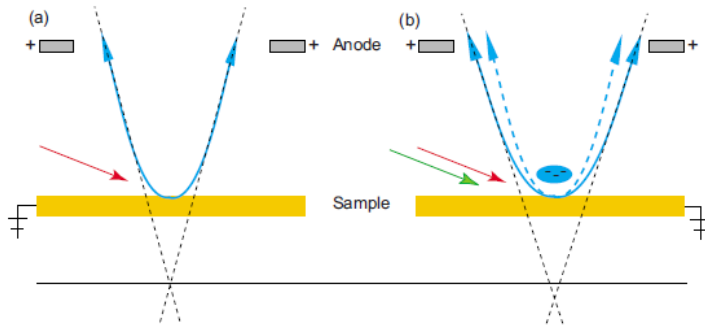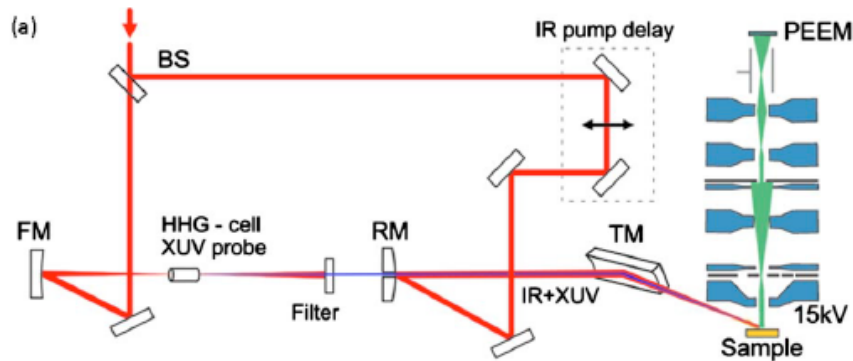
Pulse train 10x200 as, 1.3 fs separation, 10^7 electrons emitted per pulse train

ΔE = 1 eV @ 1 fs,
10-20 fs to minimize space-charge & optimize resolution

Mikkelson *RSI* 2009

Merci pour votre attention