Transmission through graphene of electrons in the 30 - 900 eV range

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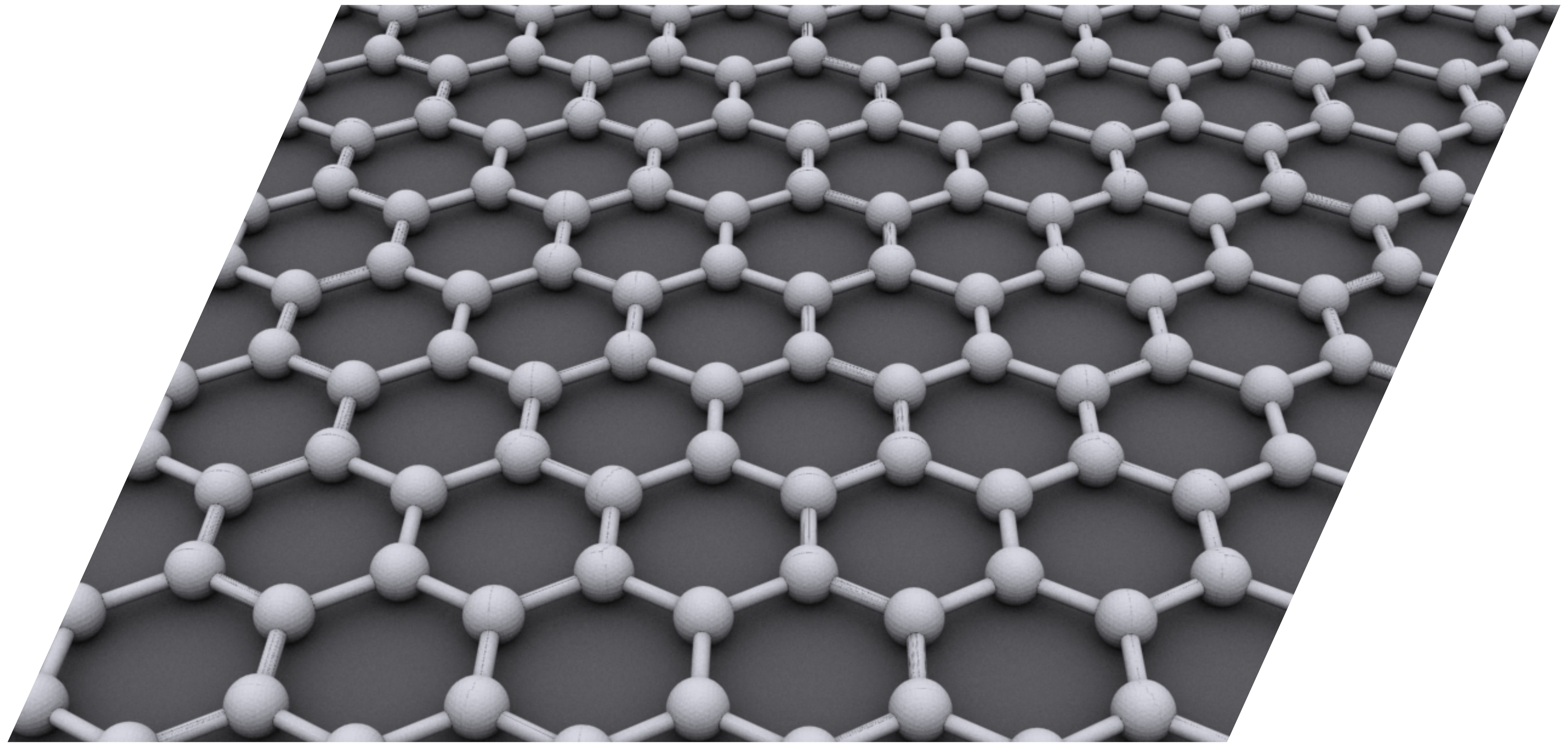
Graphene transparency: a growing topic of interest

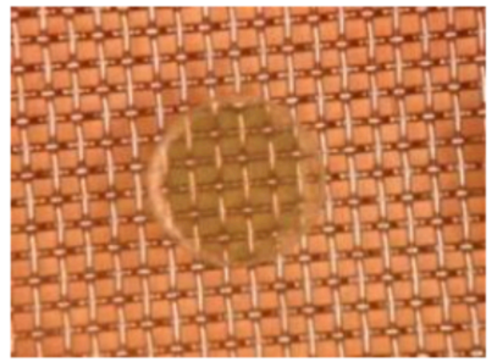
Graphene:

- Single sheet 1 atom thick
- C atoms sp_2 hybridised (planar, 120°) arranged in hexagons

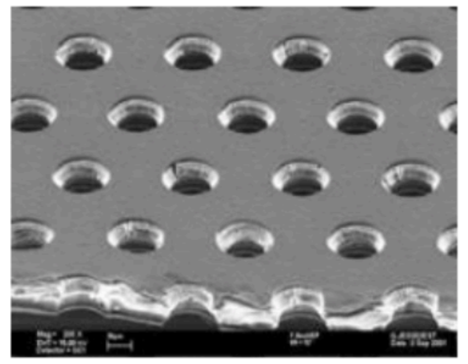


Transmission of low-energy electrons through graphene:

- Many experiments several electron energy ranges
- Only a few below 1 keV
- Discussion still open
- Interesting for novel detectors



MicroMegas



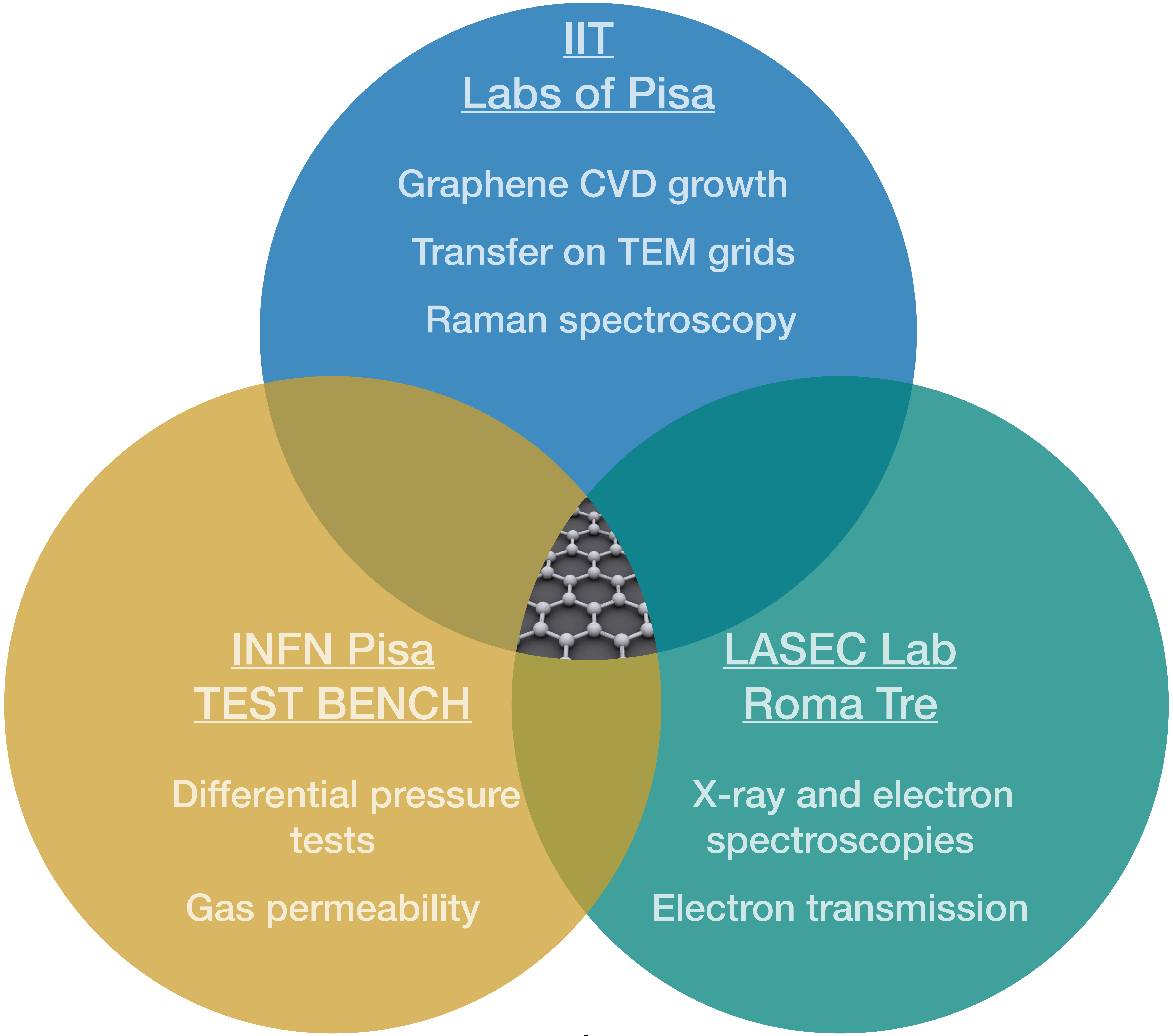
GEM

Integration of graphene in MPGD
Transparency to electrons
Impermeability to atoms

PTOLEMY

Tritiated graphene target
Measure the β-electrons

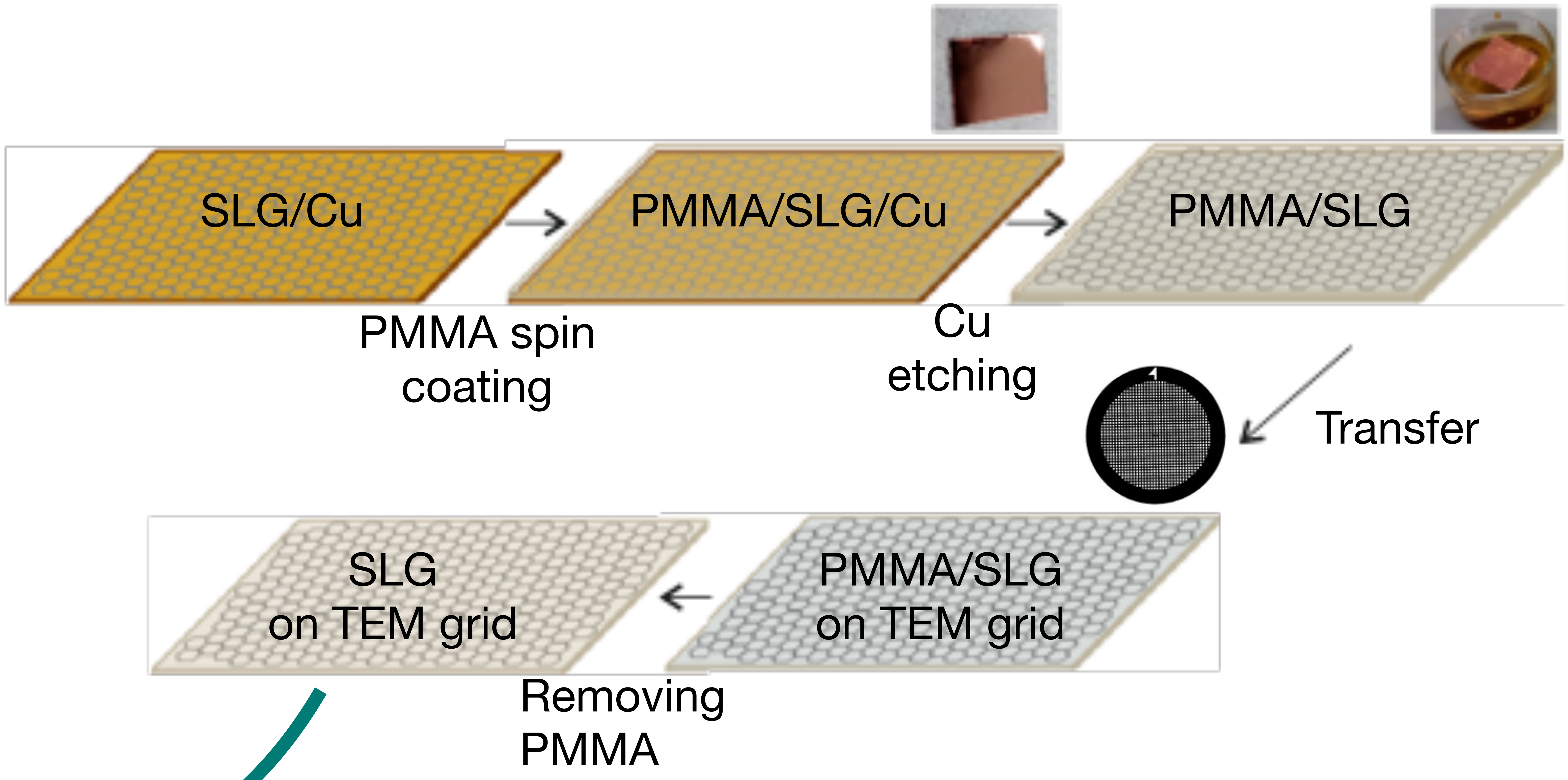
Graphene On meSH collaboration - GOSH

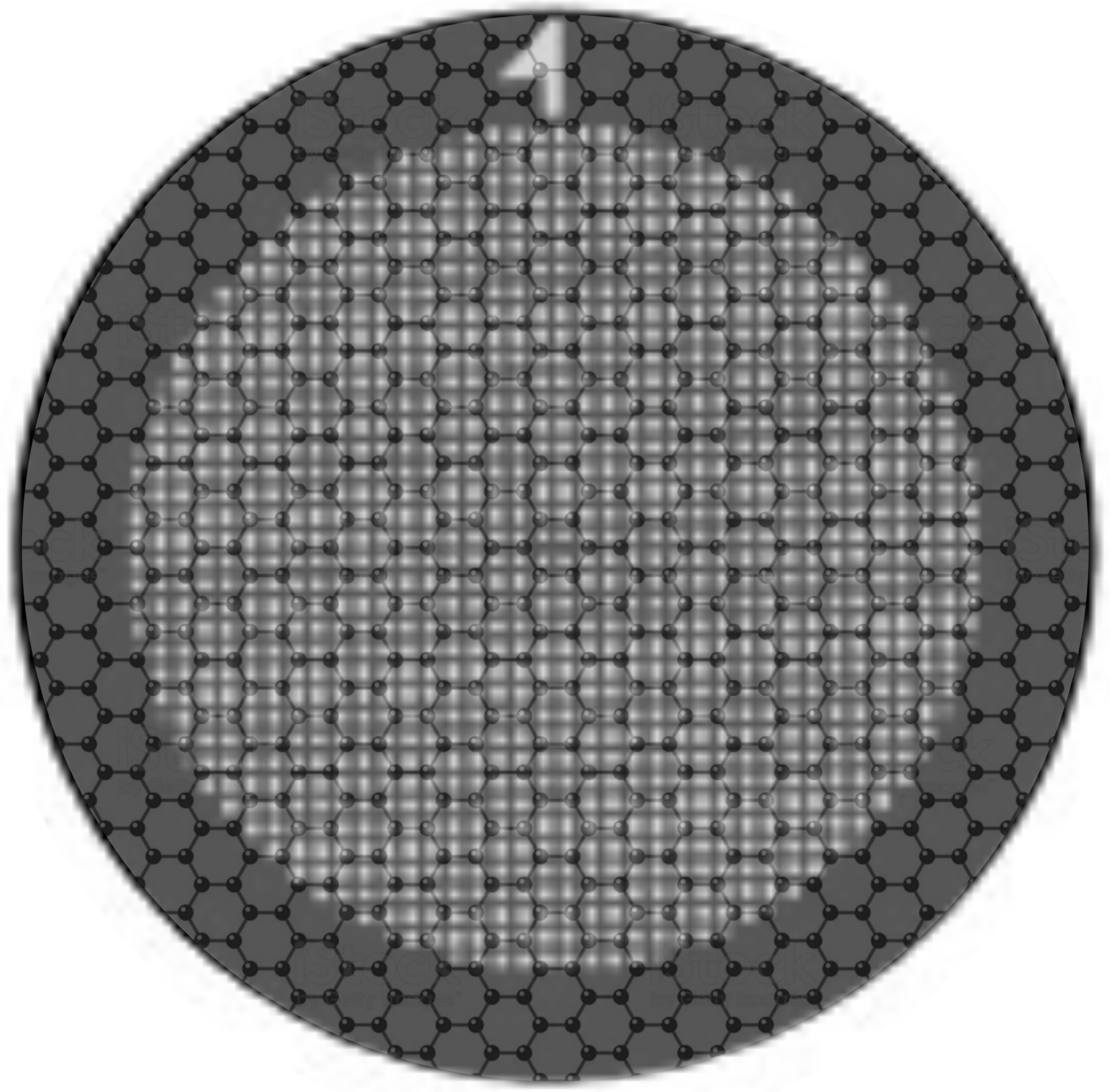


Sample preparation: graphene growth and transfer on TEM grid

Mono-/tri- layer graphene on nickel TEM grid:

- G2000HAN - Ted Pella Inc.
- 2000 mesh per inch → 12.5 μm pitch
- Hole width 6.5 μm
- Nominal geometrical transmission 41%





PMMA = Poly-methyl-methacrylate $(C_5O_2H_8)_n$

Measurements of graphene on TEM grids

Graphene characterisation with spectroscopy:

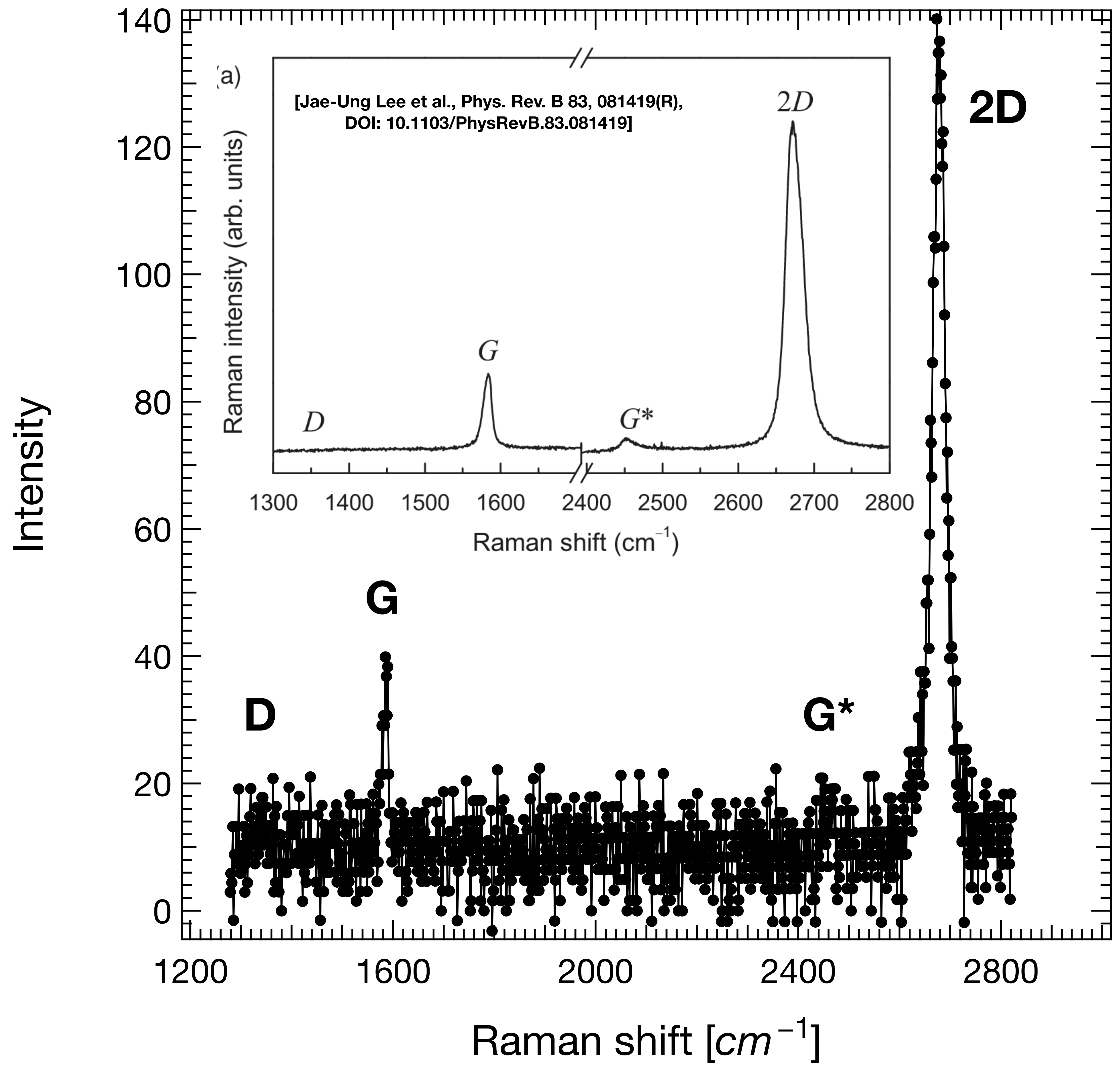
- Micro-Raman
- X-rays Photoemission Spectroscopy (XPS)
- Electron Energy Loss Spectroscopy (EELS)

Transmission of low-energy electrons (30-900 eV):

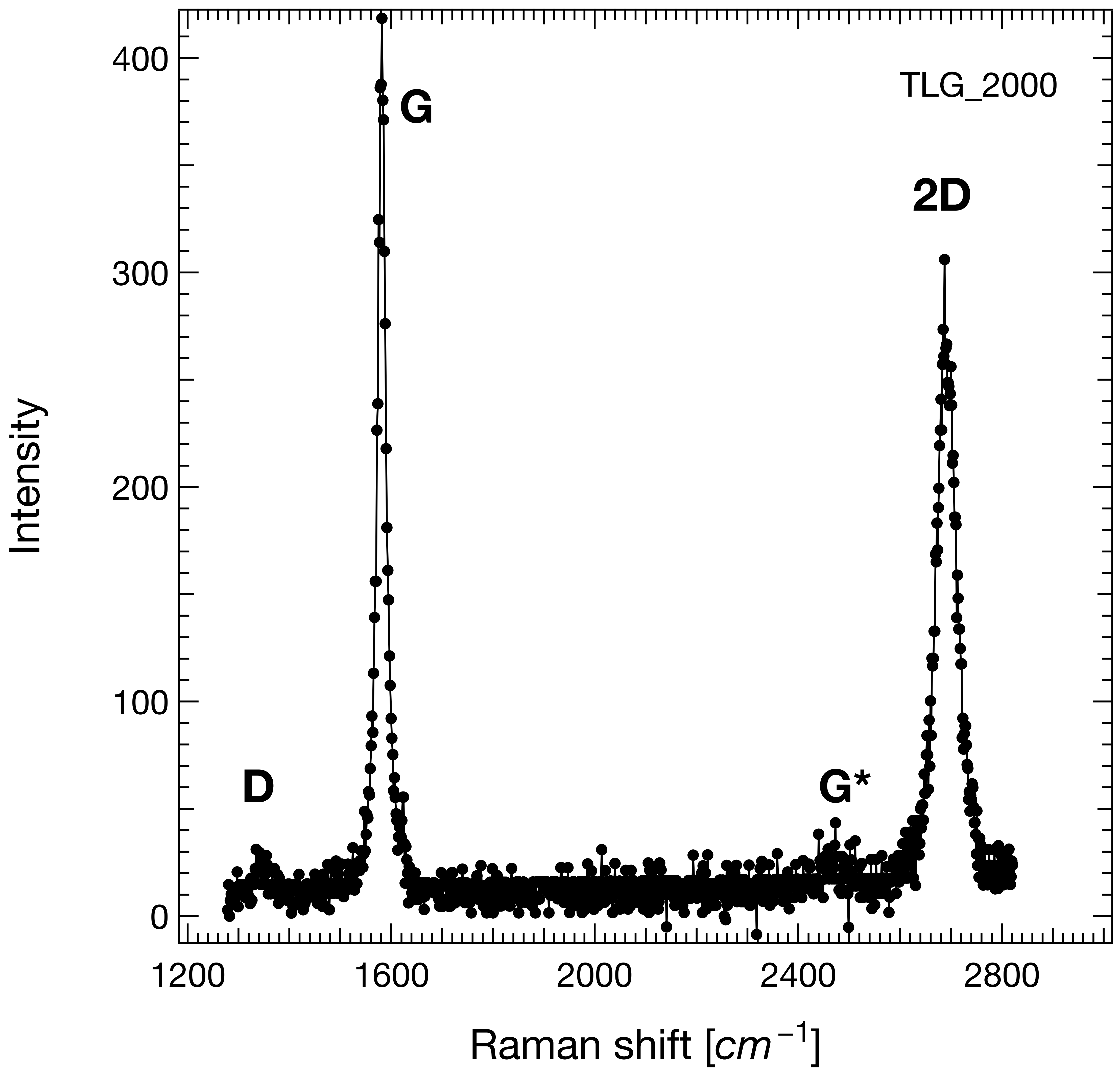
- Fixed point measurement as a function of the energy
- 2D maps of the grids at fixed energies

Raman spectra: full coverage good quality graphene

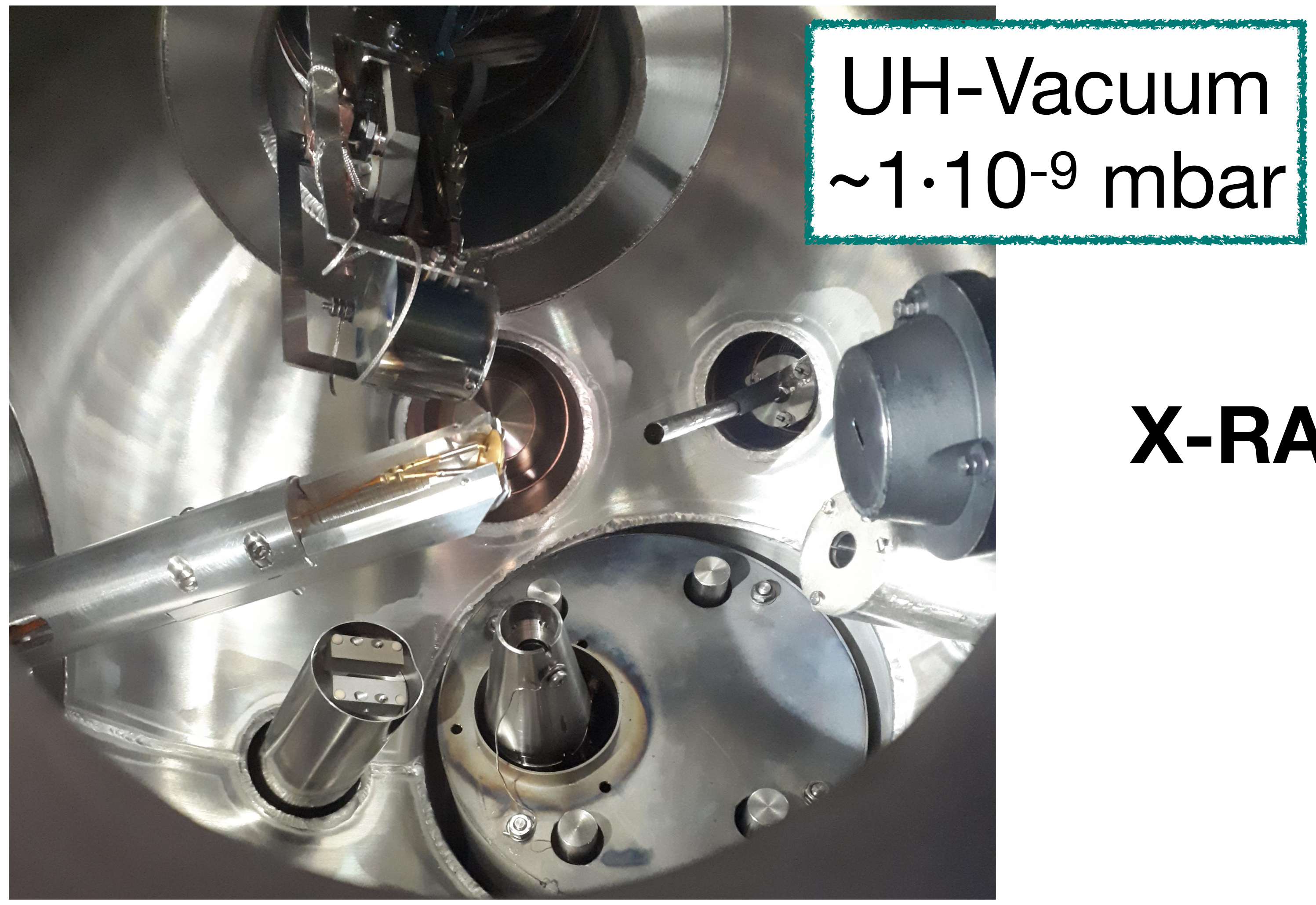
MONO-layer full coverage

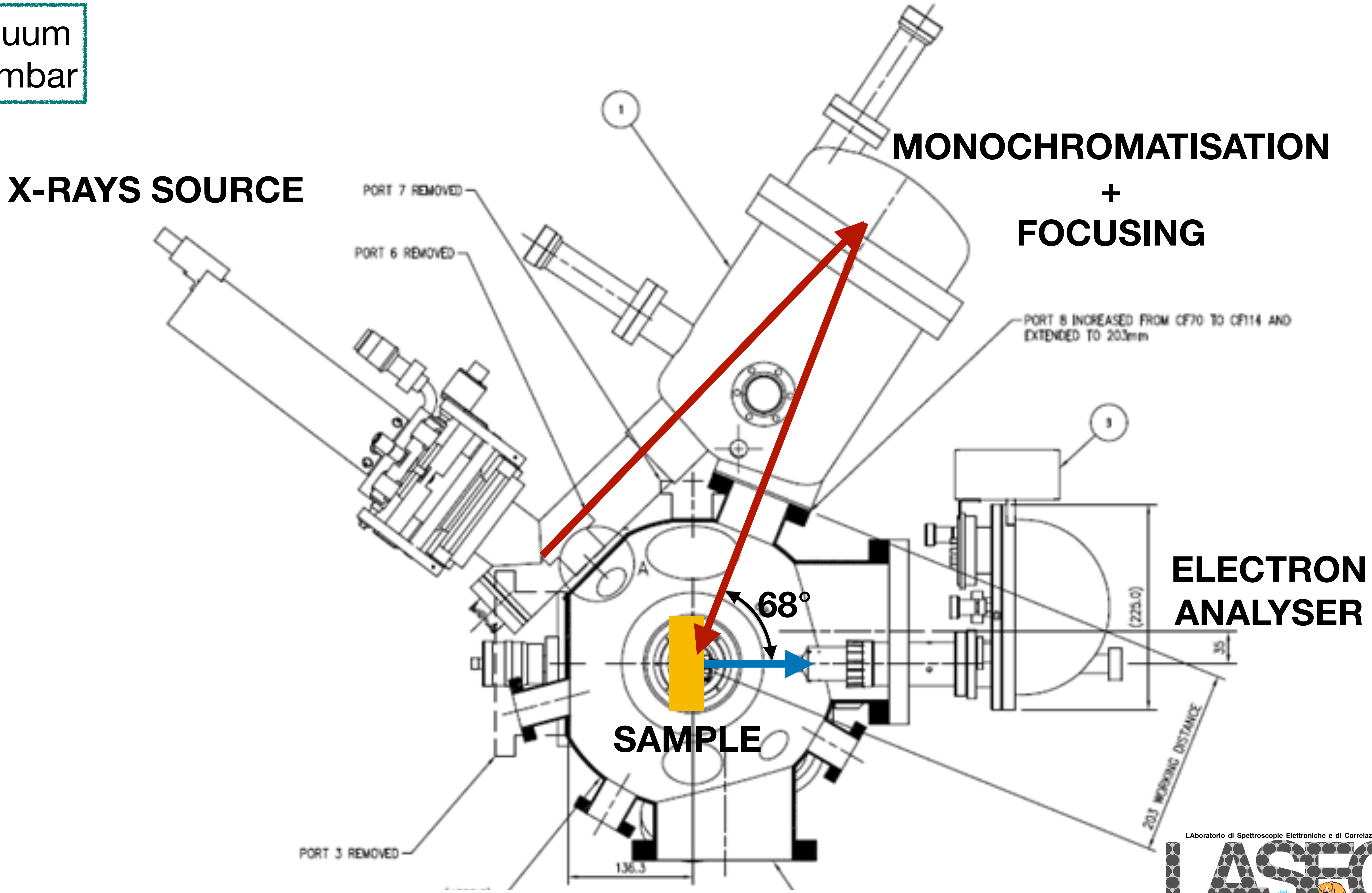


TRI-layer full coverage



The XPS layout

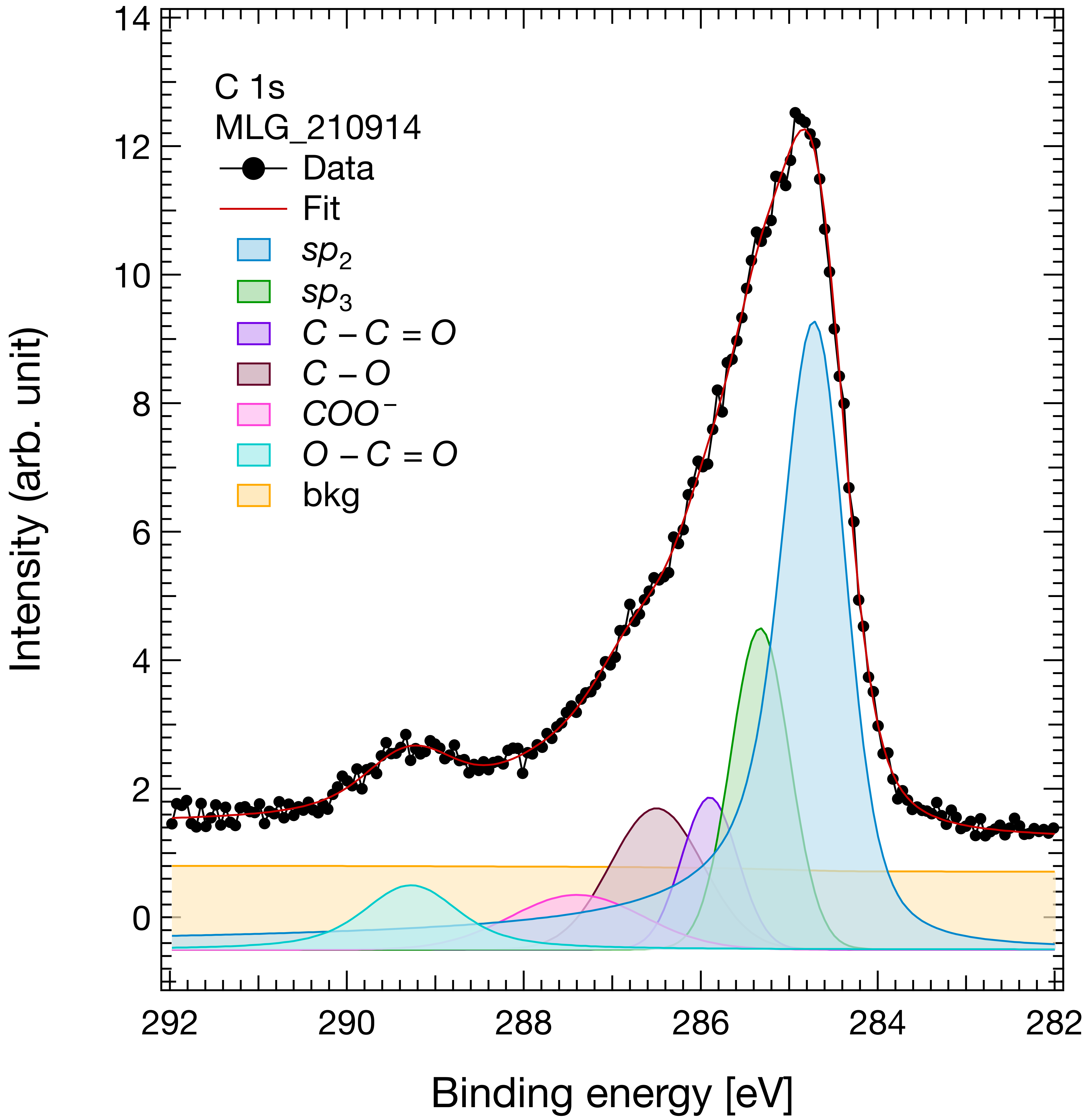




Al Kα source:

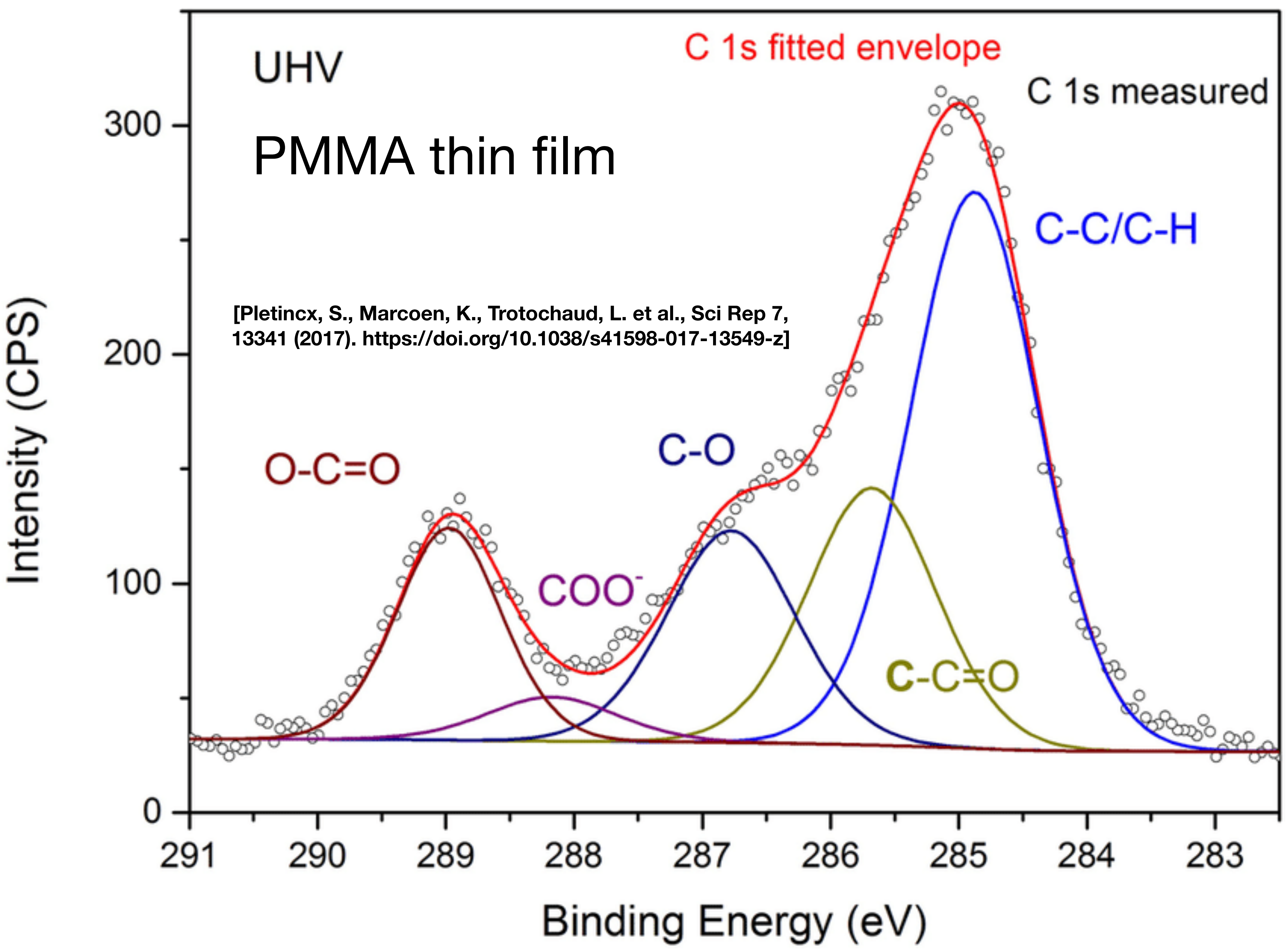
- hv = 1486.7 eV
- Resolution 0.35 eV
- Analyser wf = 4.3 eV
- Tot resolution = 0.46 eV

Monolayer C 1s: high contamination

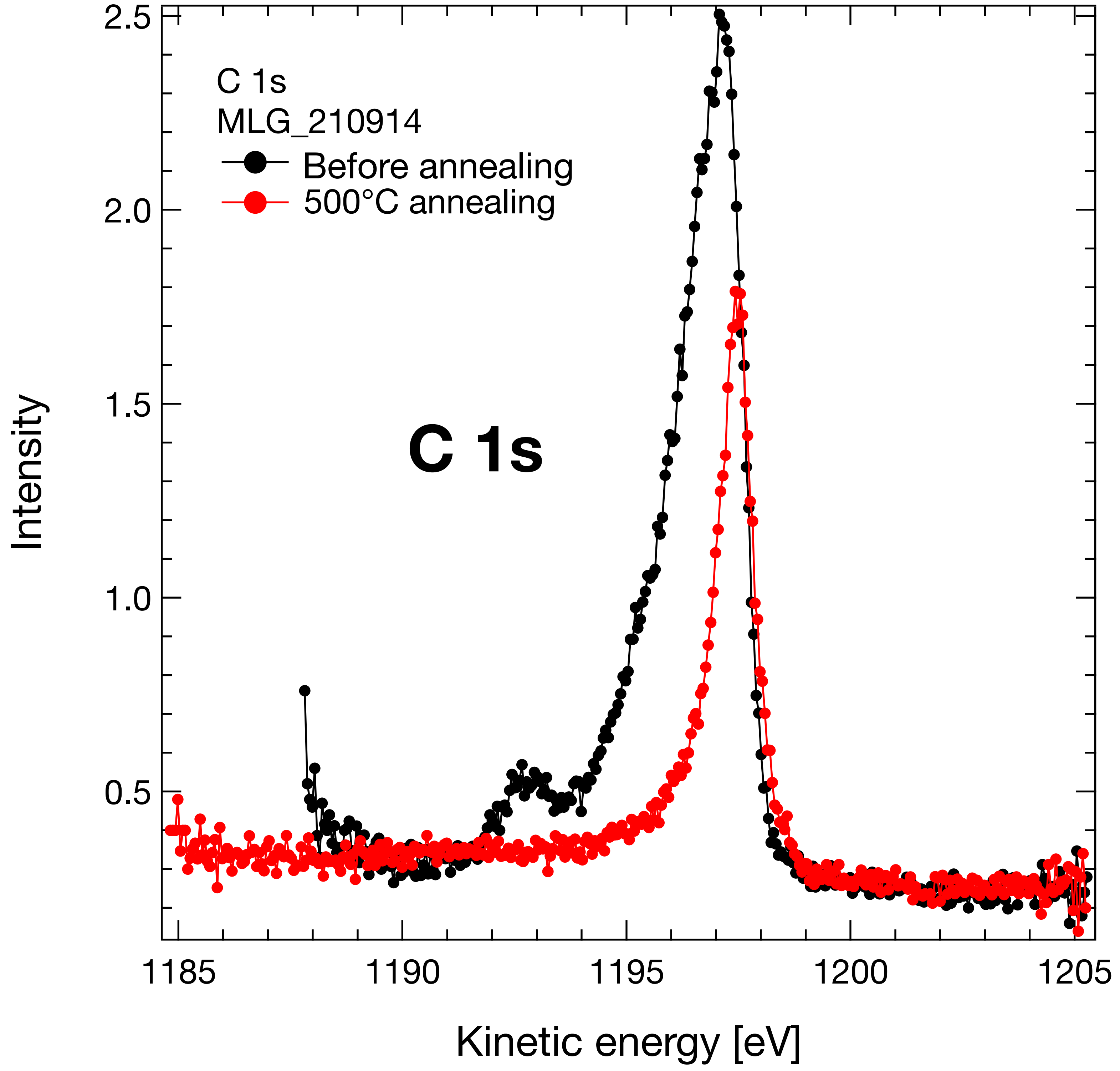


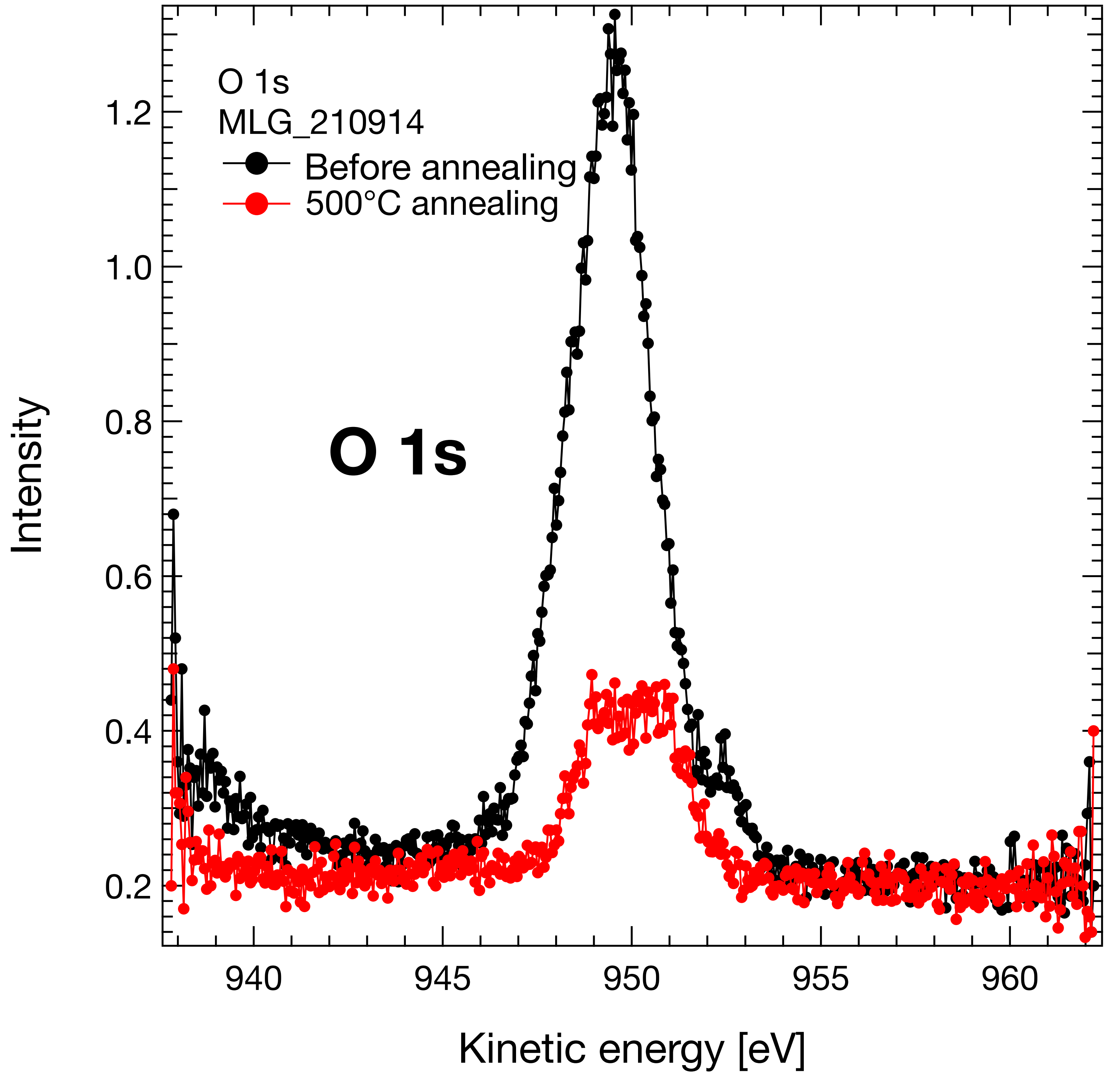
Monolayer sample measured before annealing:

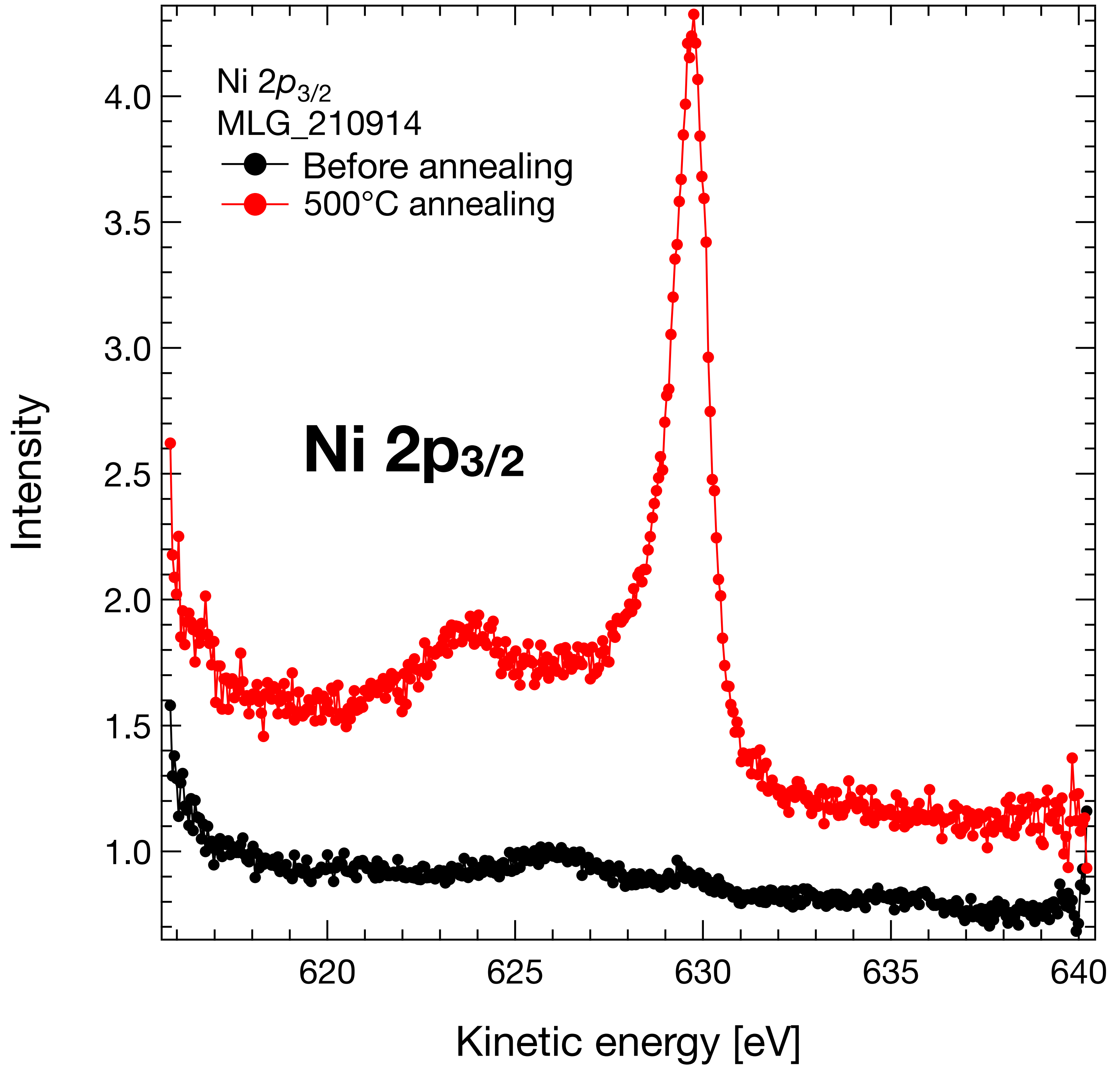
- High contamination
- PMMA residues due to graphene transfer
- Clean the sample is necessary



500°C in vacuum annealing removes contamination







C 1s spectra:

- Contaminants removed
- Mainly sp_2 component

O 1s spectra:

- Oxygen significantly removed

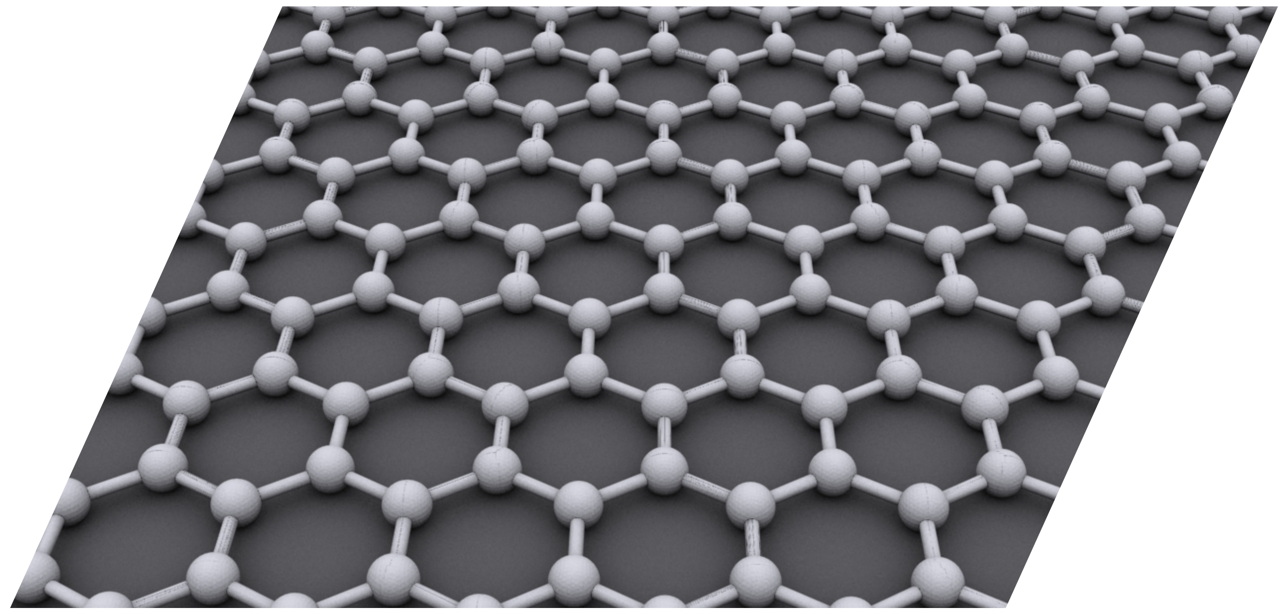
Ni $2p_{3/2}$ spectra:

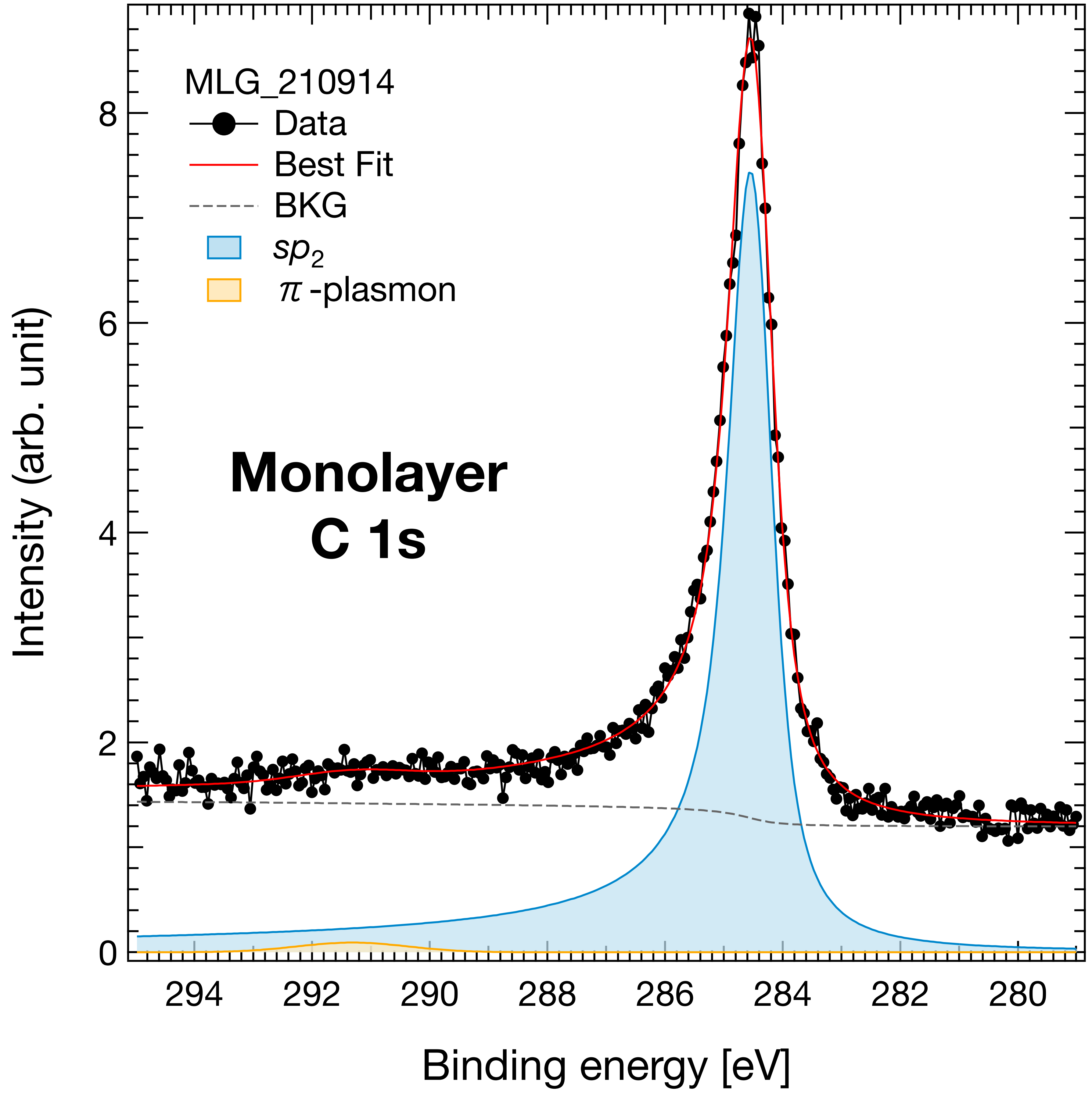
- Ni oxide reduced
- Metallic Ni increased
- Metallic Ni satellite appears

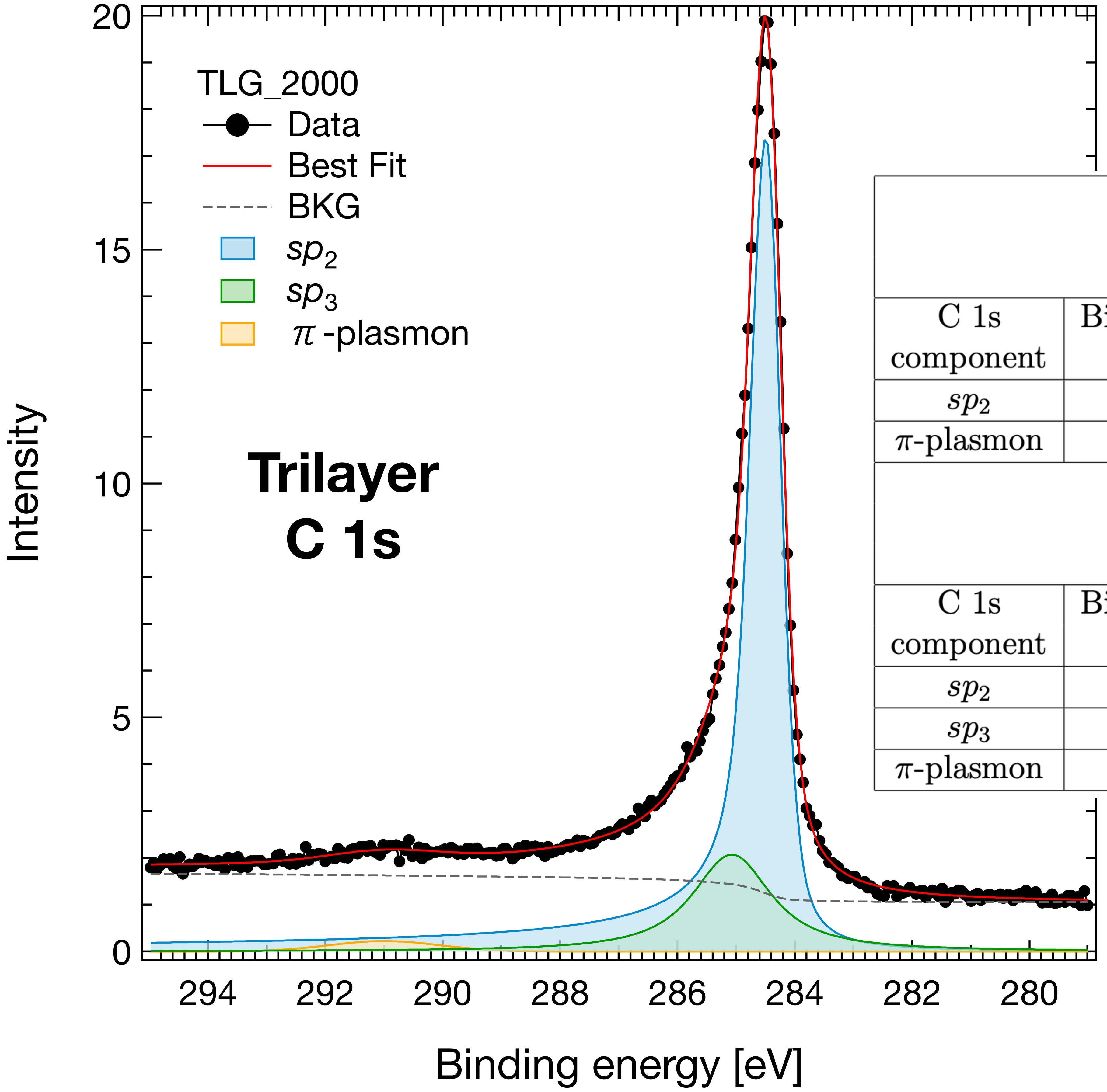
XPS: good quality graphene

Both C 1s spectra reveal a good quality graphene:

- Main contribution due to sp_2
- Slight amount (~10%) of sp_3 in the trilayer
- Lorentzian width of sp_2 higher in the monolayer







Monolayer graphene

C 1s component	Binding energy [eV]	Area	Gaussian width [eV]	Lorentzian width [eV]	Asymmetry
sp_2	284.45	204	0.45	0.58	0.1
π-plasmon	290.9	4	1.9	0	0

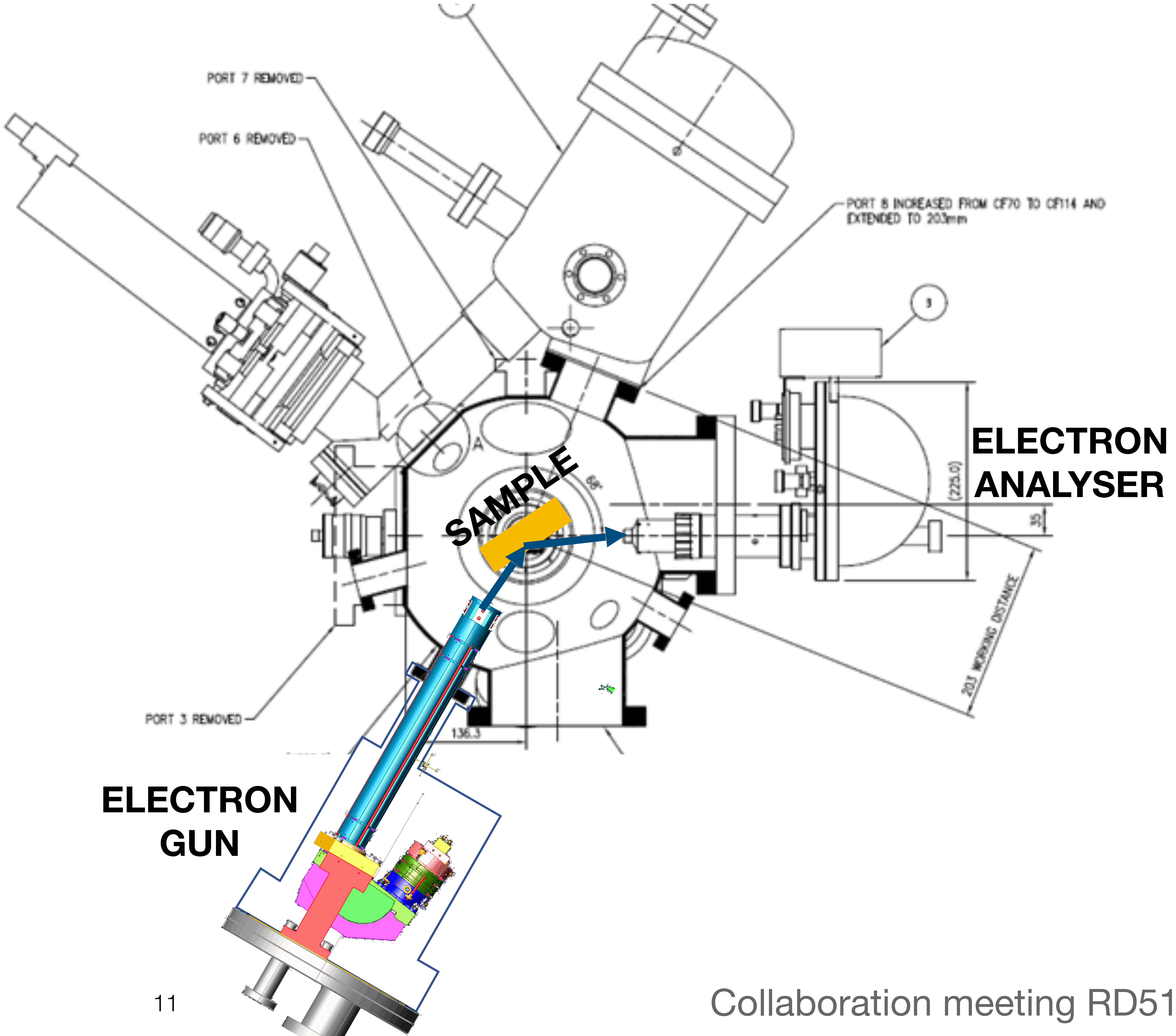
Trilayer graphene

C 1s component	Binding energy [eV]	Area	Gaussian width [eV]	Lorentzian width [eV]	Asymmetry
sp_2	284.47	311	0.46	0.24	0.1
sp_3	285.1	84	0.5	1.5	0
π-plasmon	291.0	10	2.2	0	0

The EELS layout

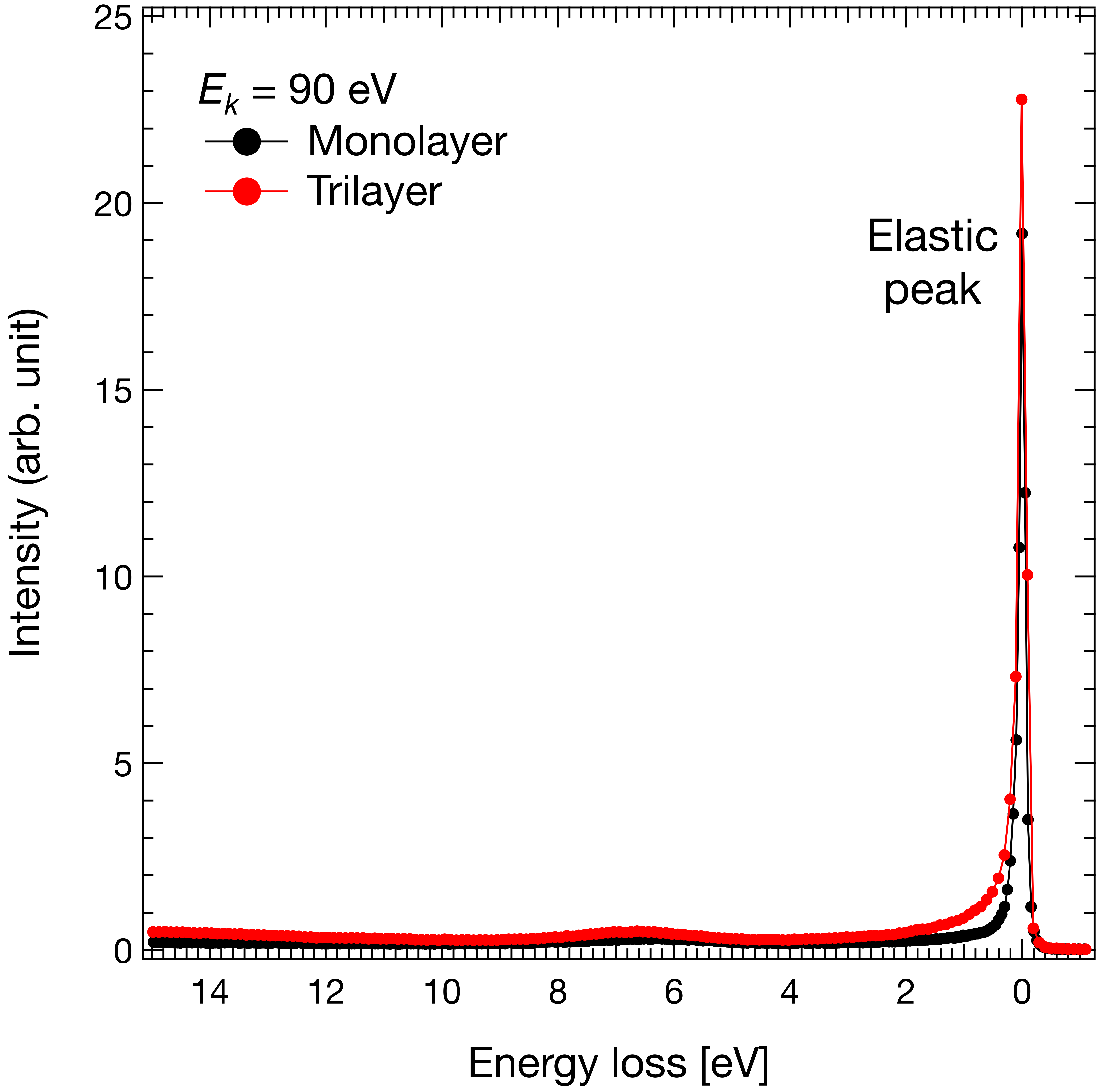
Custom-made monochromatic electron gun:

- Continuous electron beam
- Tuneable energy 30 - 900 eV
- Resolution = 45 meV



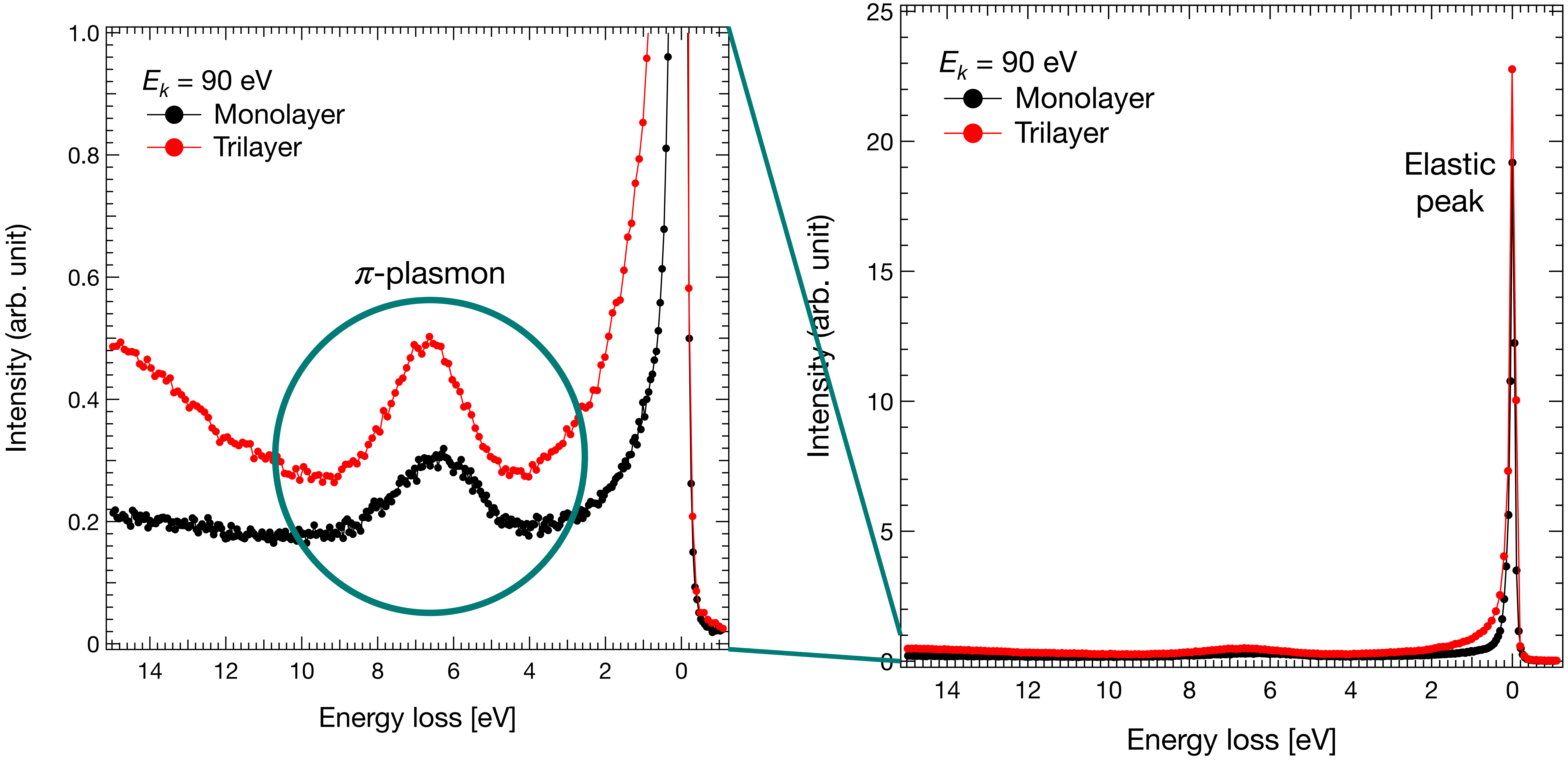
Comparison of the EELS spectra

Primary electron energy 90 eV

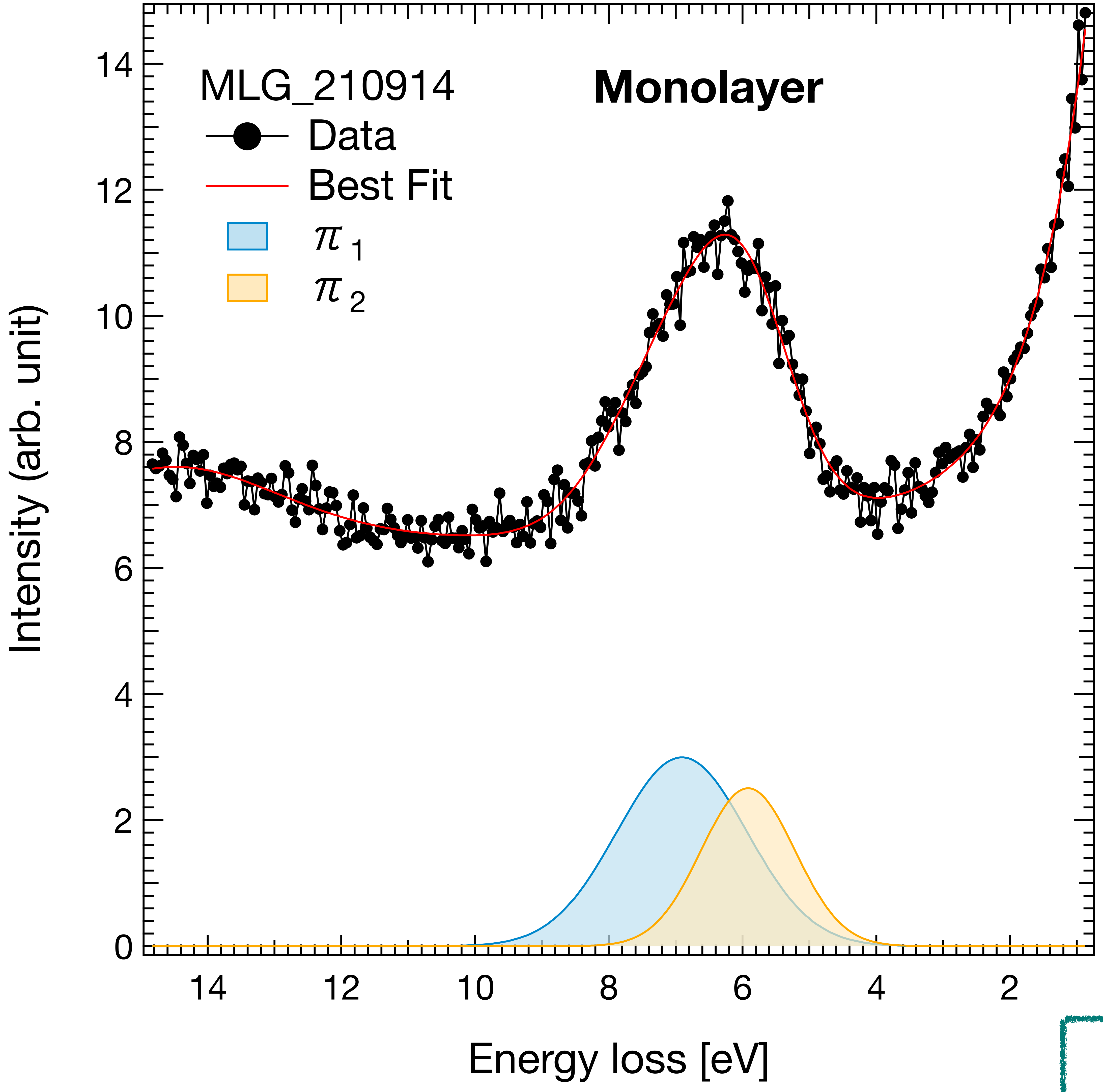


Comparison of the EELS spectra

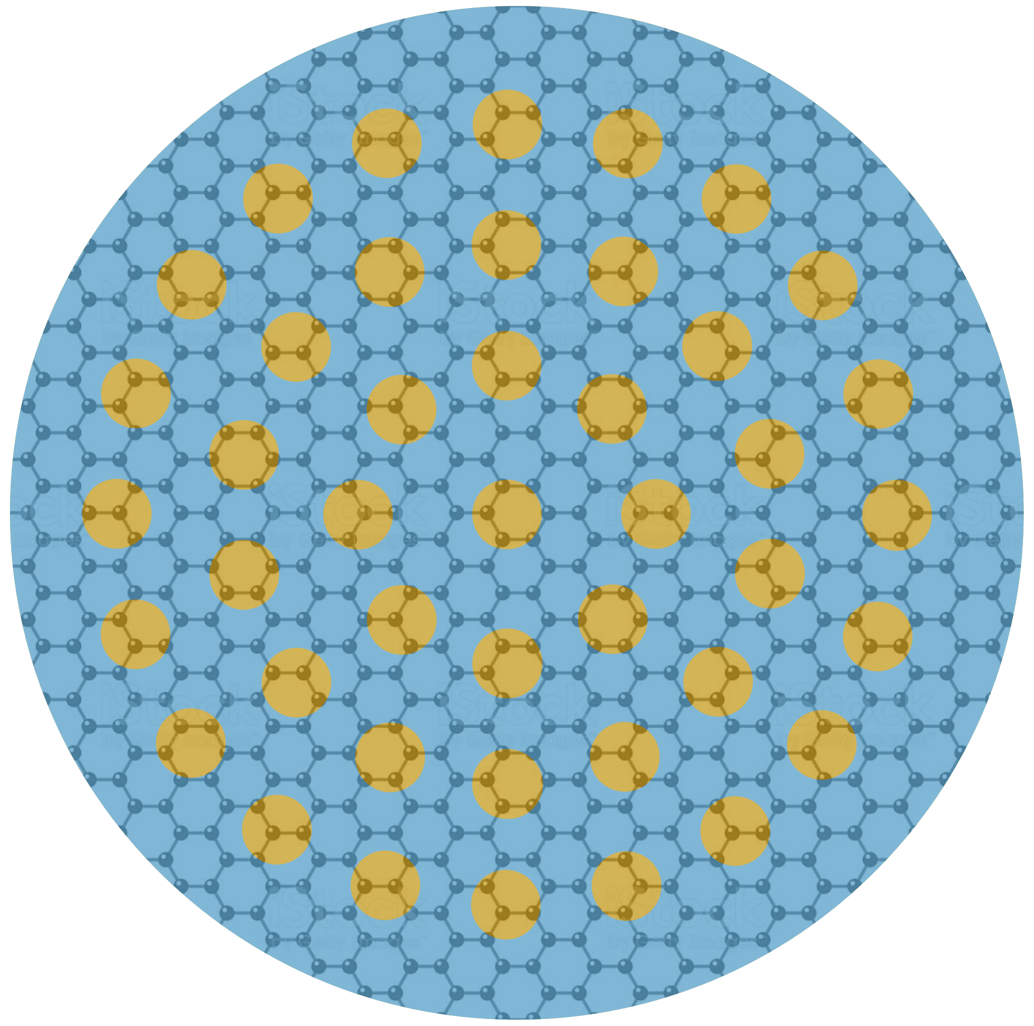
Primary electron energy 90 eV

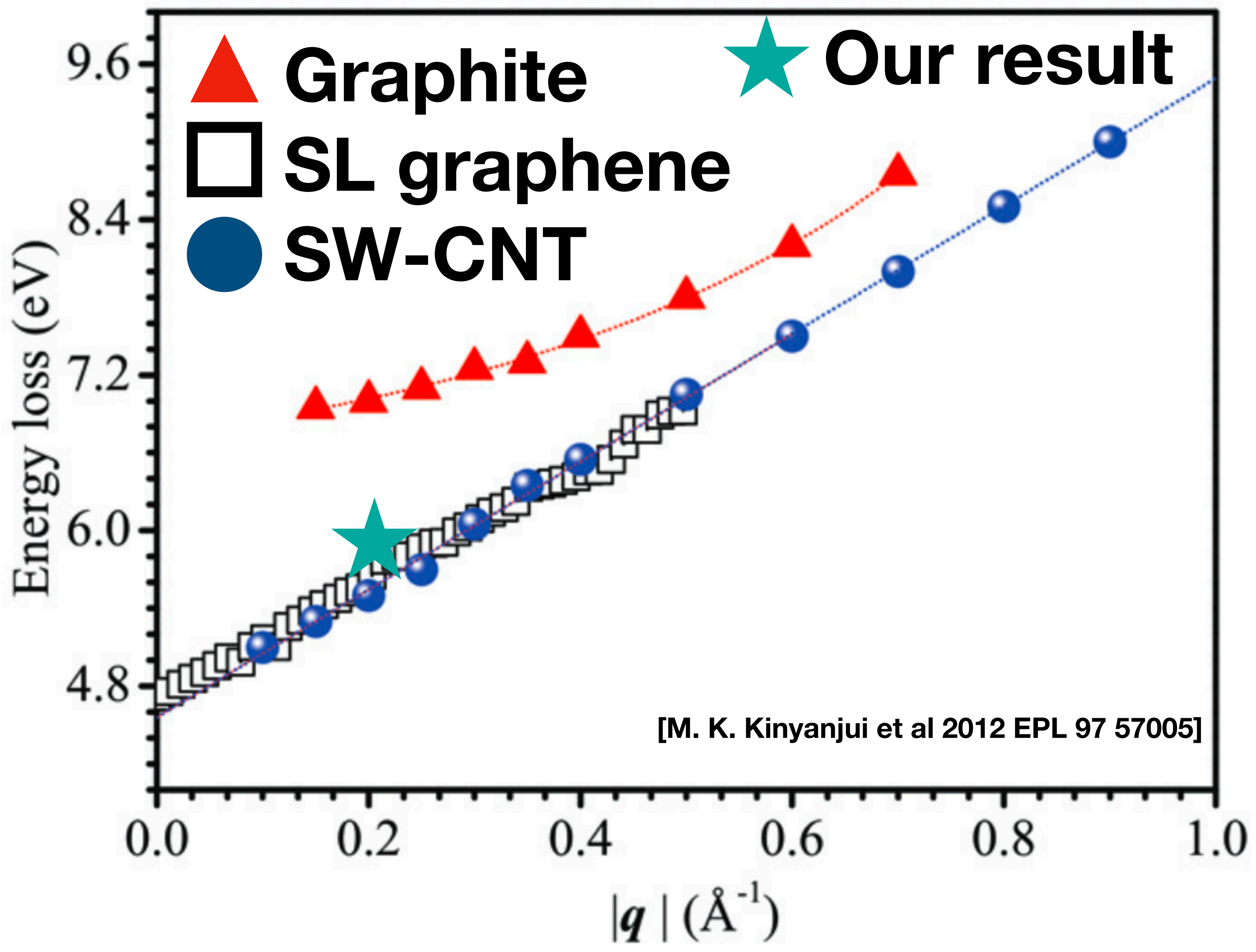


EELS on monolayer: suspended graphene



Monolayer graphene			
Component	Energy loss [eV]	Area	FWHM [eV]
π_1-plasmon	6.9	143	2.3
π_2-plasmon	5.9	87	1.7

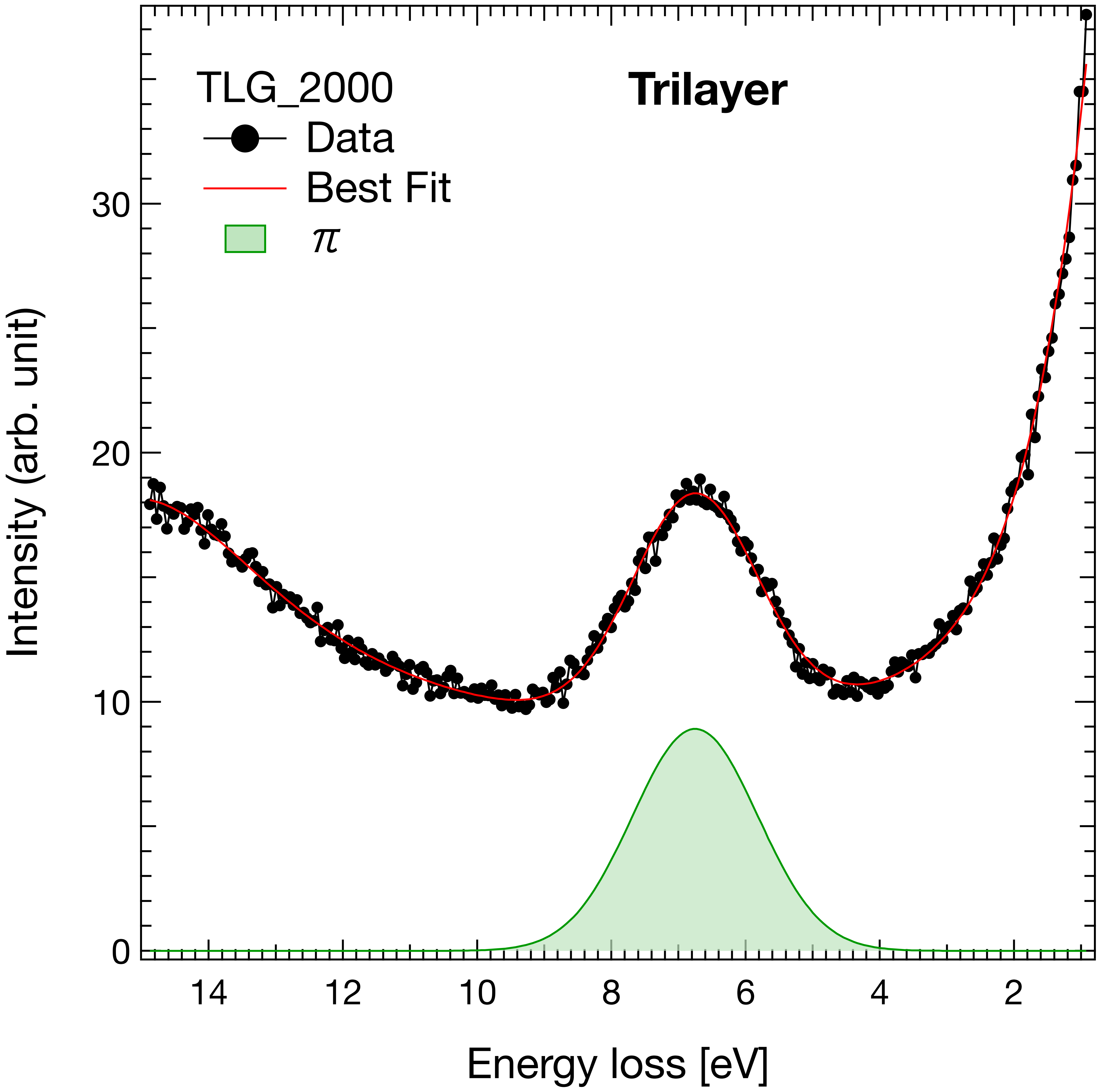




$$\frac{A_{\pi_2}}{A_{\pi_1} + A_{\pi_2}} = 38\ \%$$

Keep in mind this number, we'll see later on!

EELS: suspended graphene



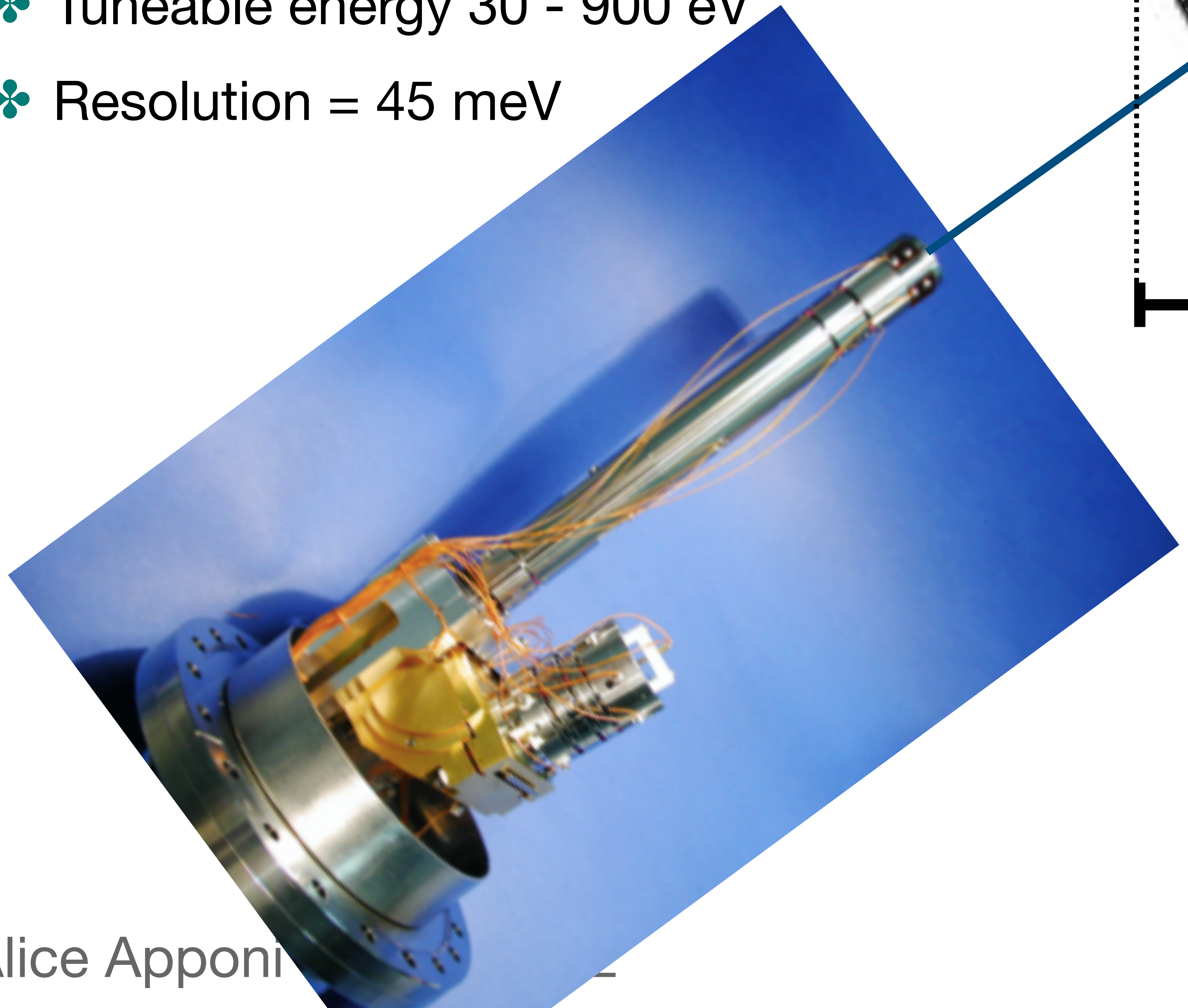
Trilayer graphene			
Component	Energy loss [eV]	Area	FWHM [eV]
π-plasmon	6.8	410	2.2

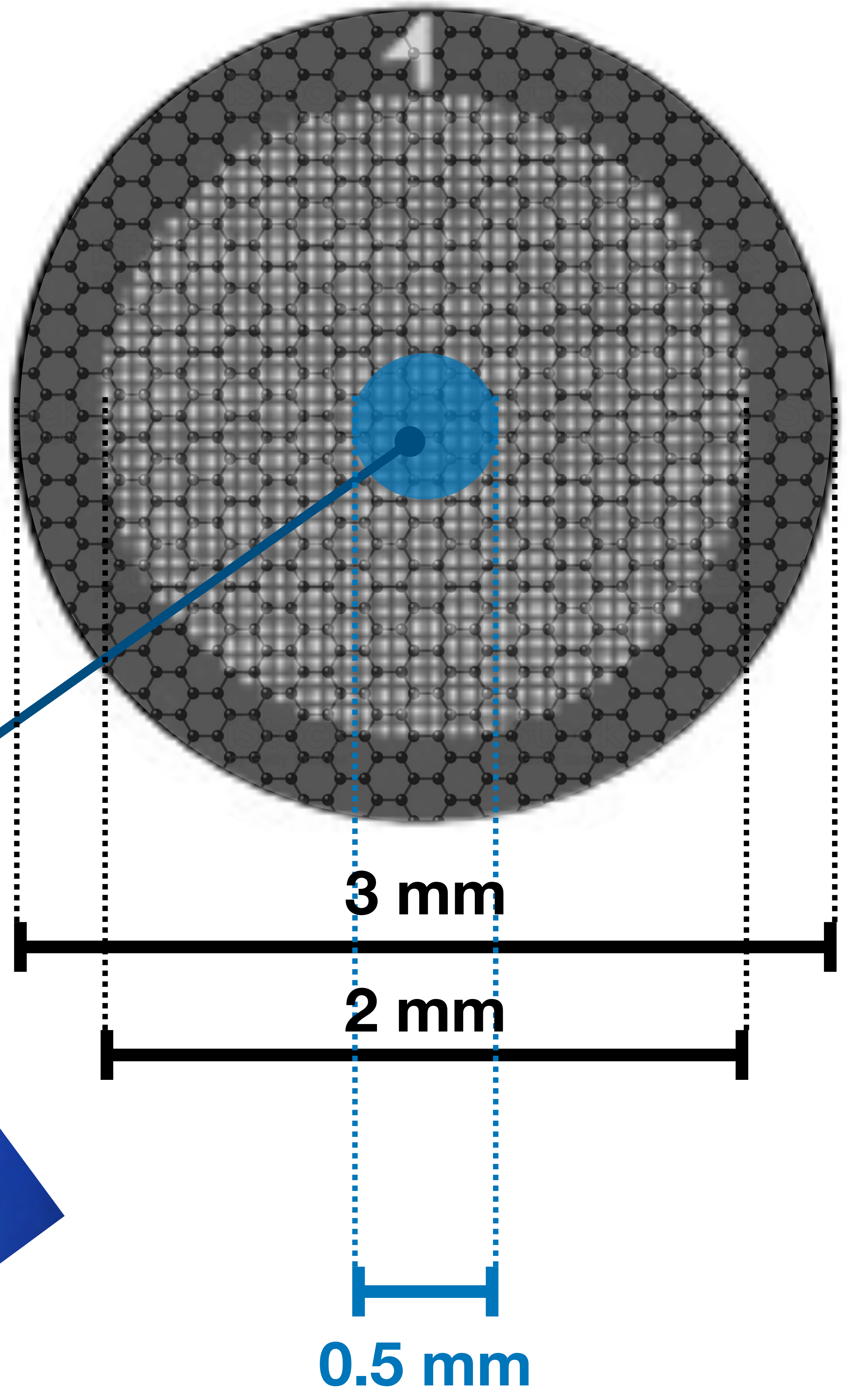
π-plasmon energy shifted increasing the number of graphene layers ~1 eV wrt monolayer

Transmission measurement: average on several grid holes

Monochromatic electron gun:

- Continuous electron beam
- Tuneable energy 30 - 900 eV
- Resolution = 45 meV

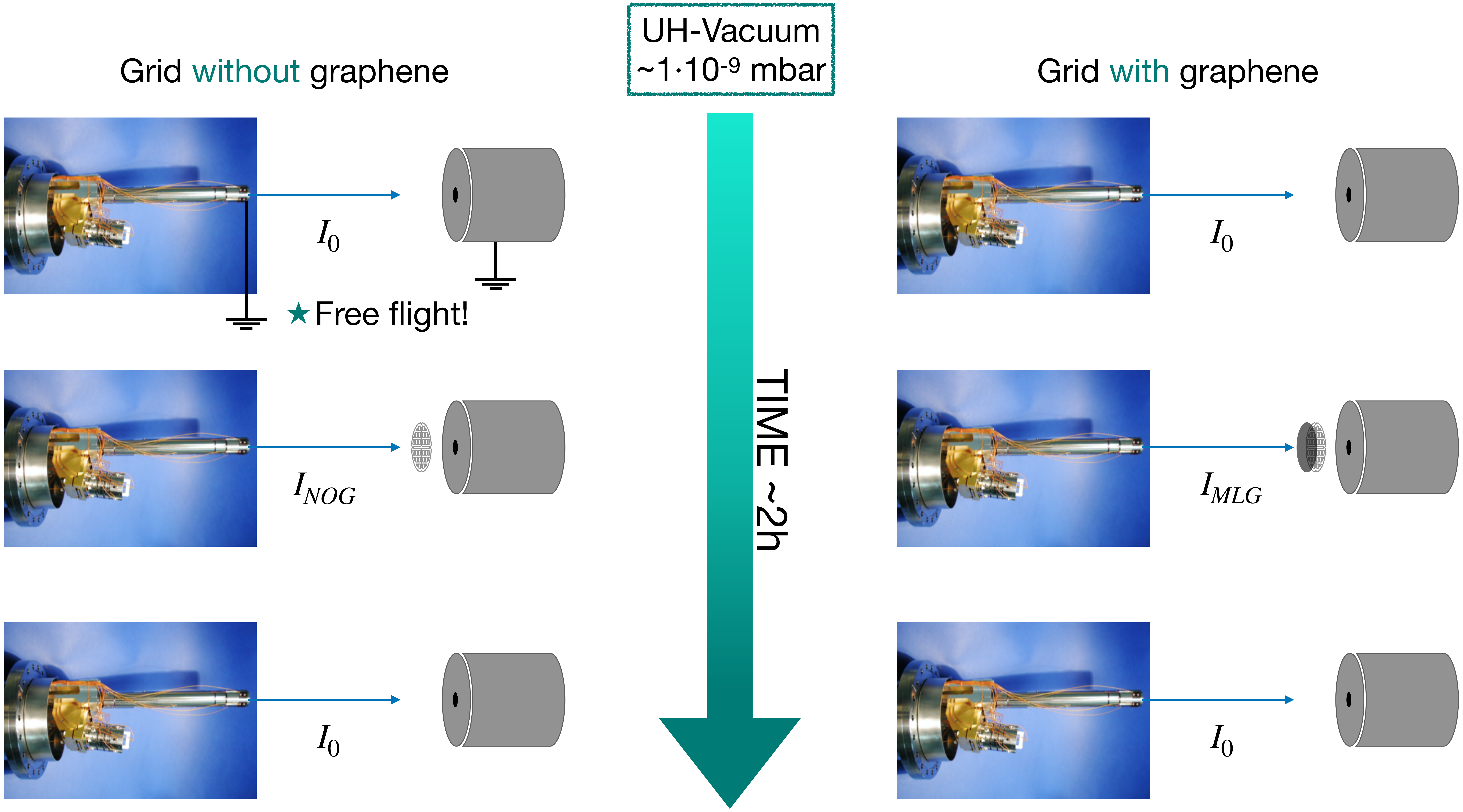




Dimension outline:

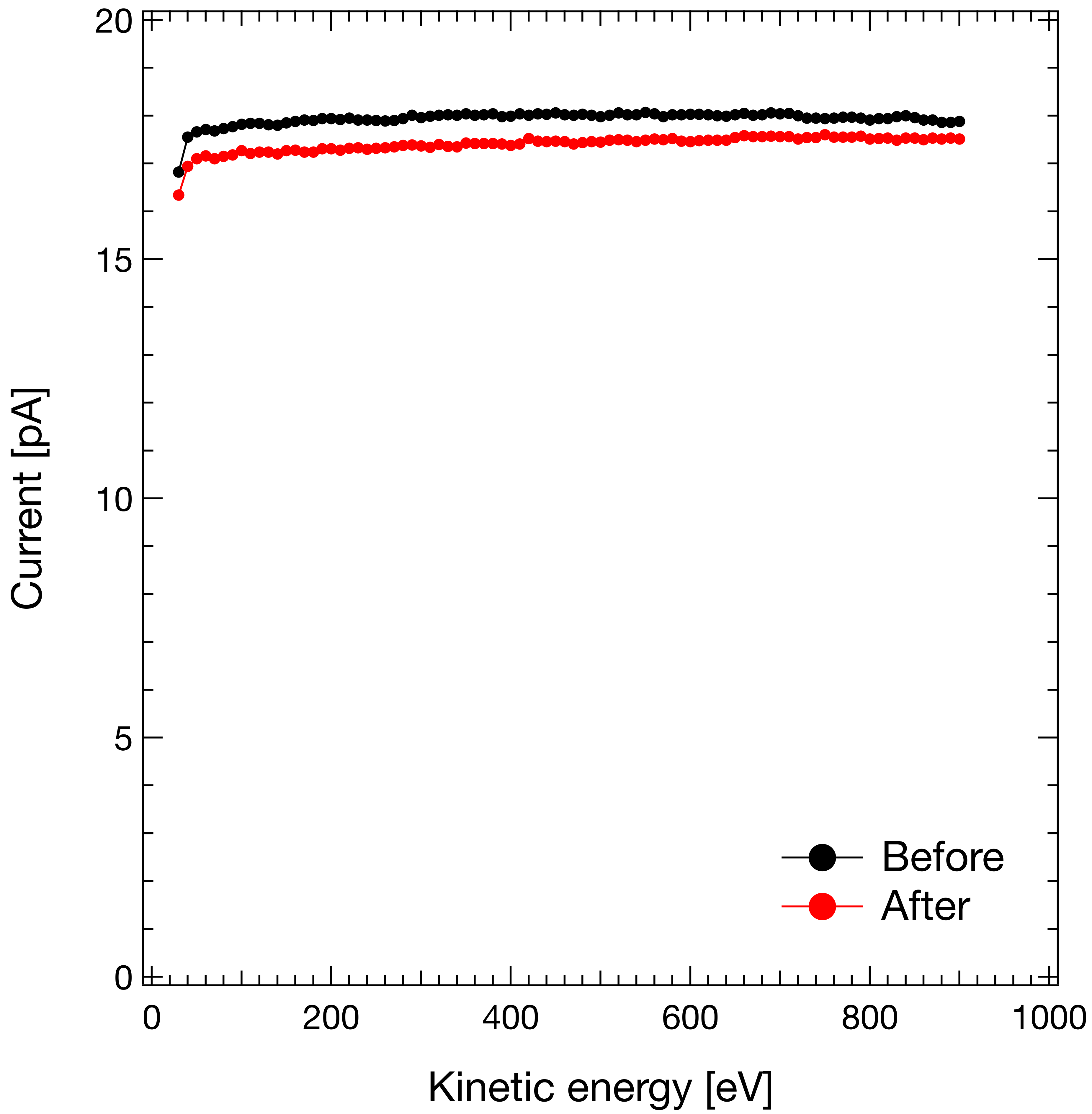
- Diameter 3 mm
- Effective diameter 2 mm
- 2000 mesh per inch → 12.5 μm pitch
- Hole width 6.5 μm
- Beam size ~ 0.5 mm

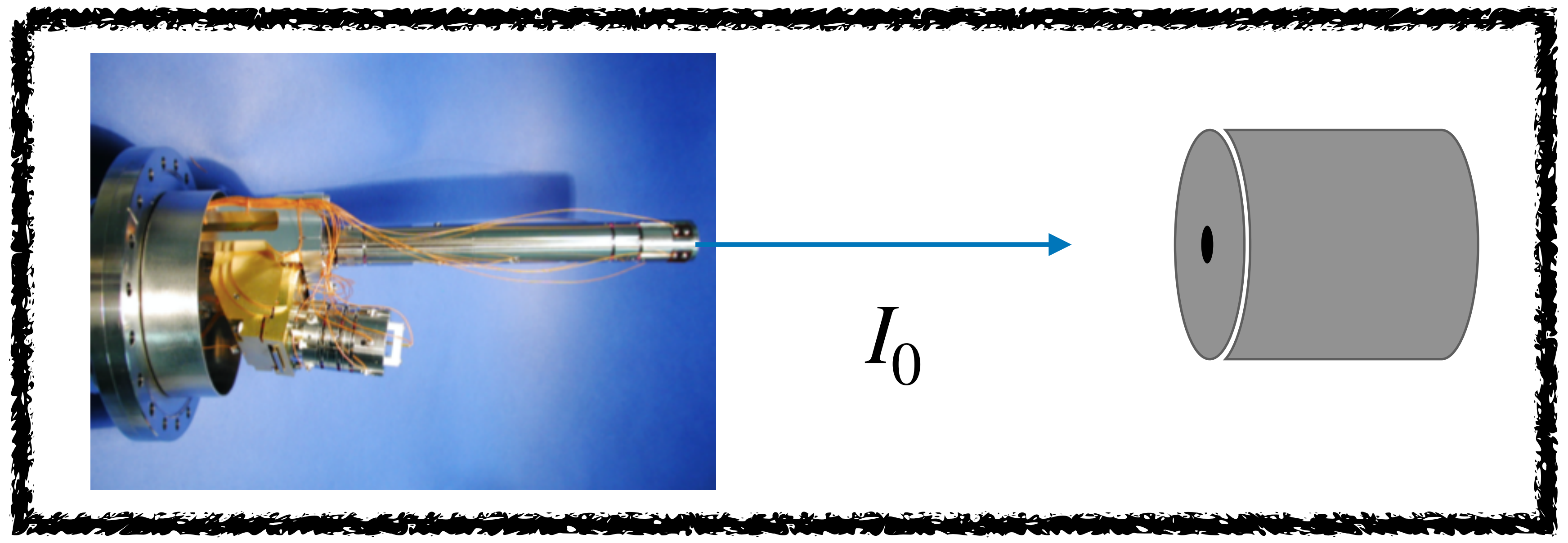
Transmission measurement: the method

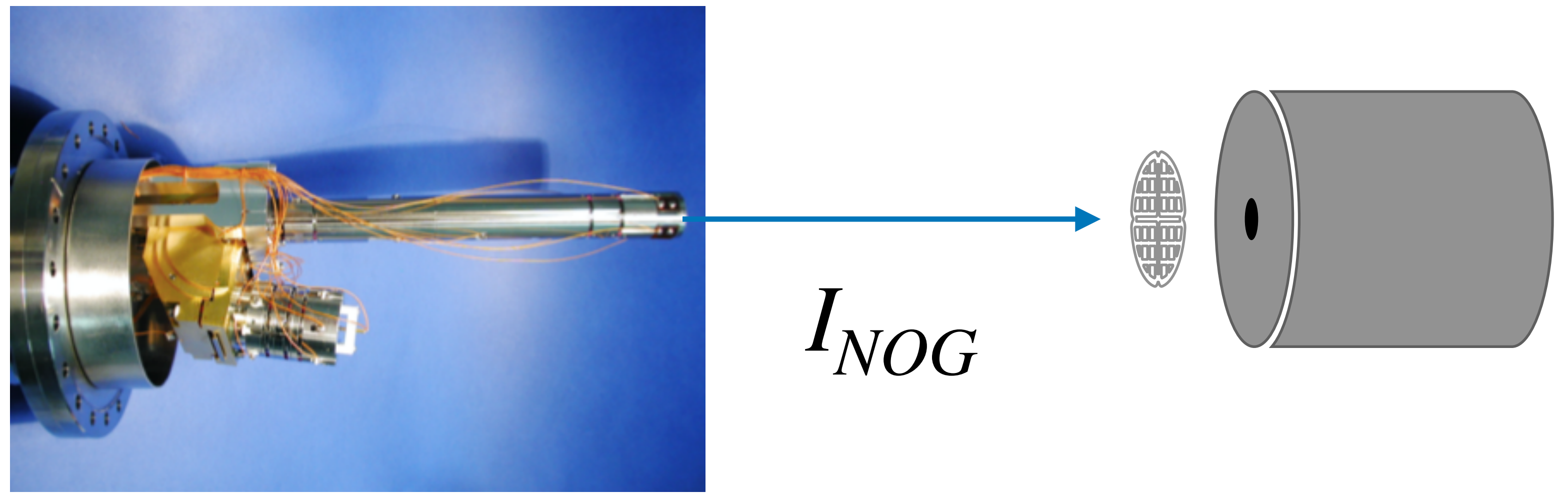


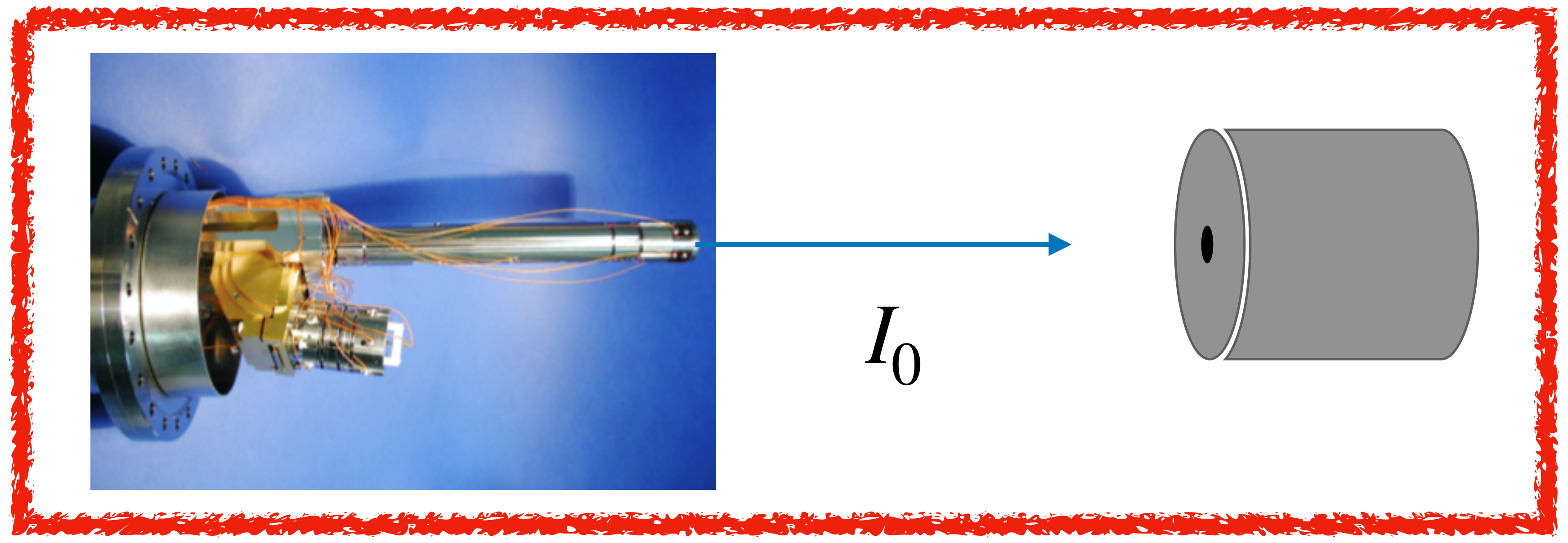
✤Check stability with current measurement before and after

Absolute current measurement before and after the grid

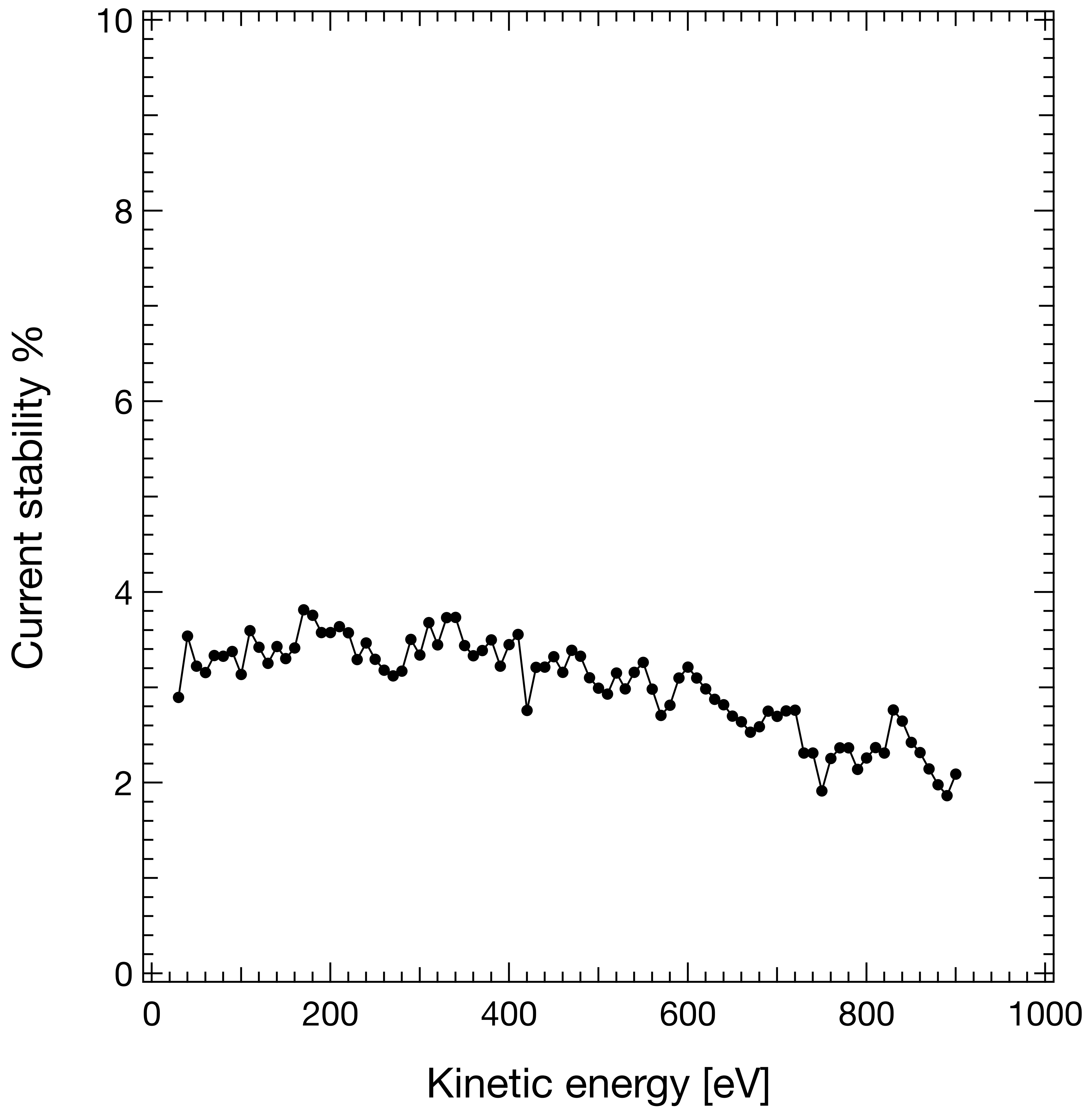


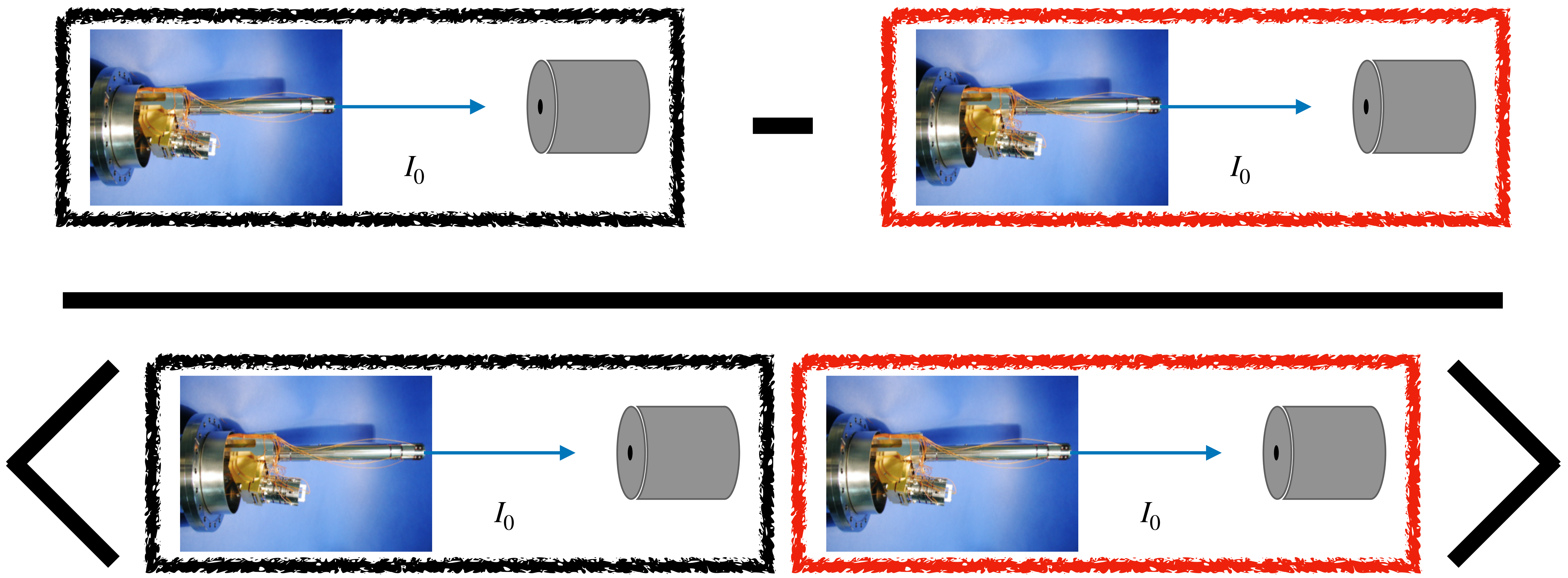






Current stability ~ 3%



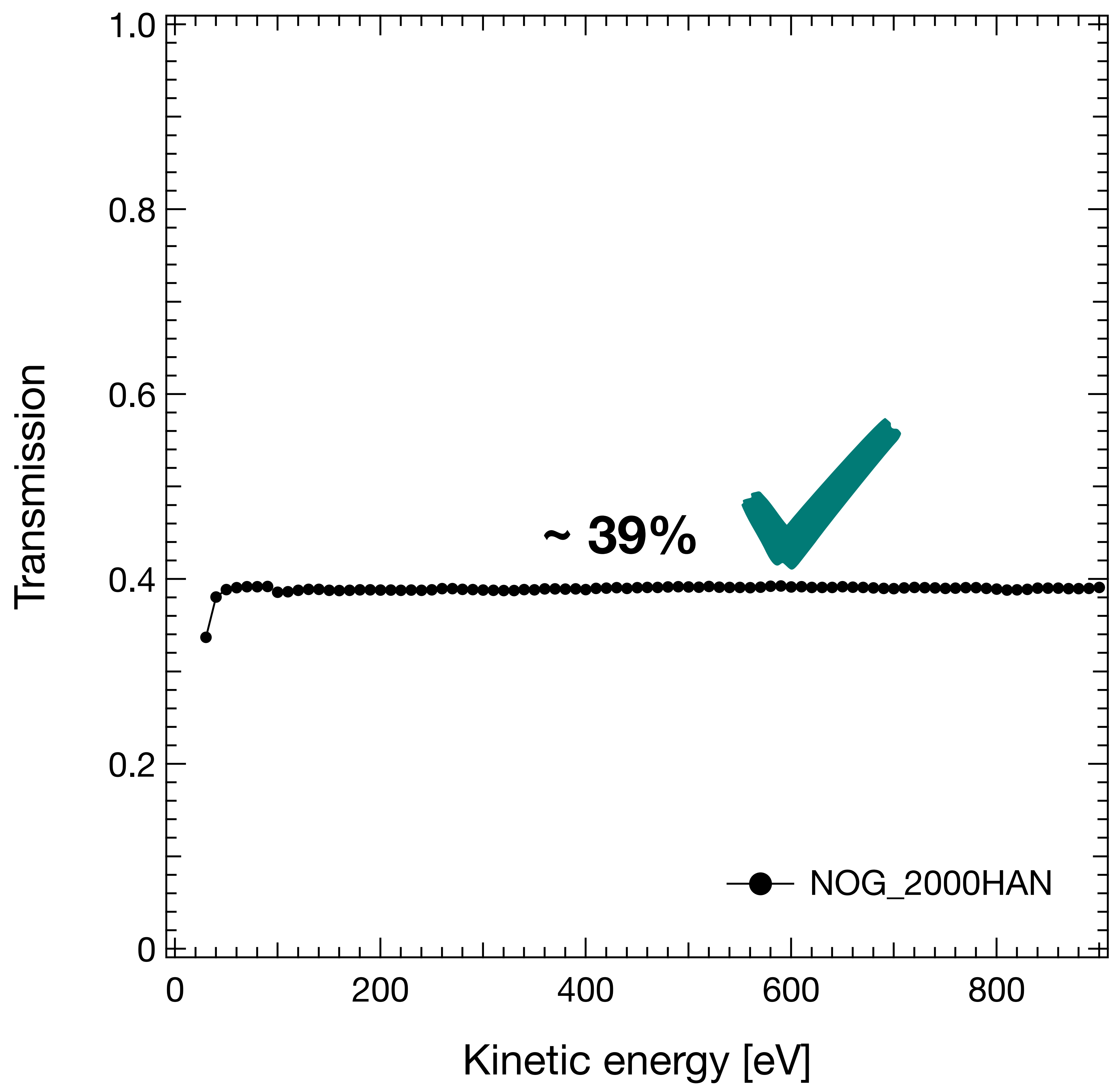


- Current stability → before - after difference / average
- Picoammeter accuracy 0.5%
- Uncertainty essentially due to current stability

Transmission of grid without graphene ~ 39%

$$\frac{I_{NOG}}{I_0} \longrightarrow$$ grid without graphene (i.e. geometrical transmission)

- 2000 mesh per inch → 12.5 μm pitch
- Hole width 6.5 μm
- Nominal geometrical transmission 41%
- Uncertainty 1.7% (not shown ~same size of the dots)



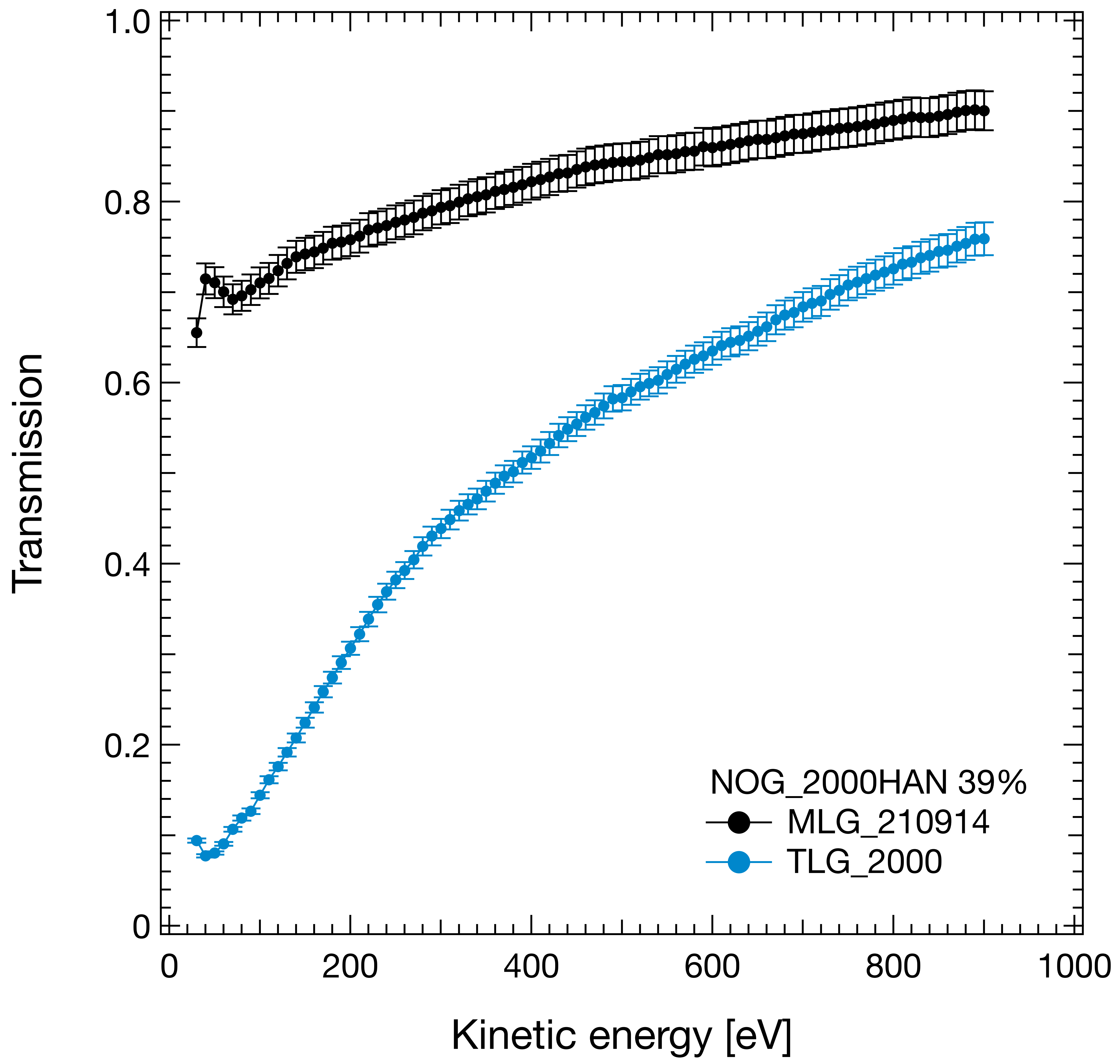
Transmission through full coverage mono- and tri- layer

$$\frac{I_{xLG}}{I_0 \cdot 0.39} \longrightarrow$$ grid with graphene (net of the 39% grid transparency)

- ✤ Uncertainty 2.4%
- ✤ Fixed positions of grid and gun
- ✤ Slight shift of the beam with energy variation

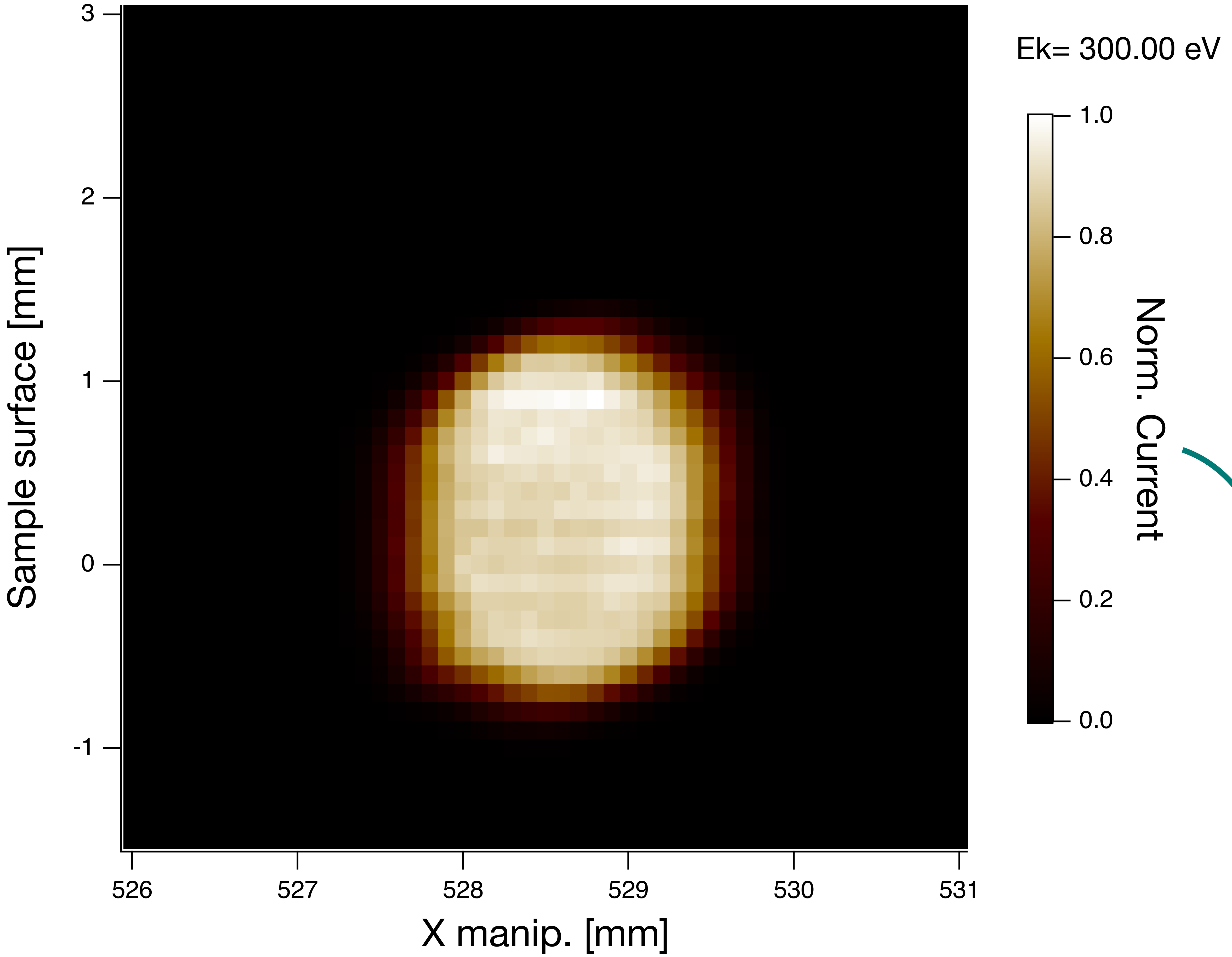
  - ✤ Homogeneous sample 
  - ✤ Inhomogeneous sample 

2D MAP!

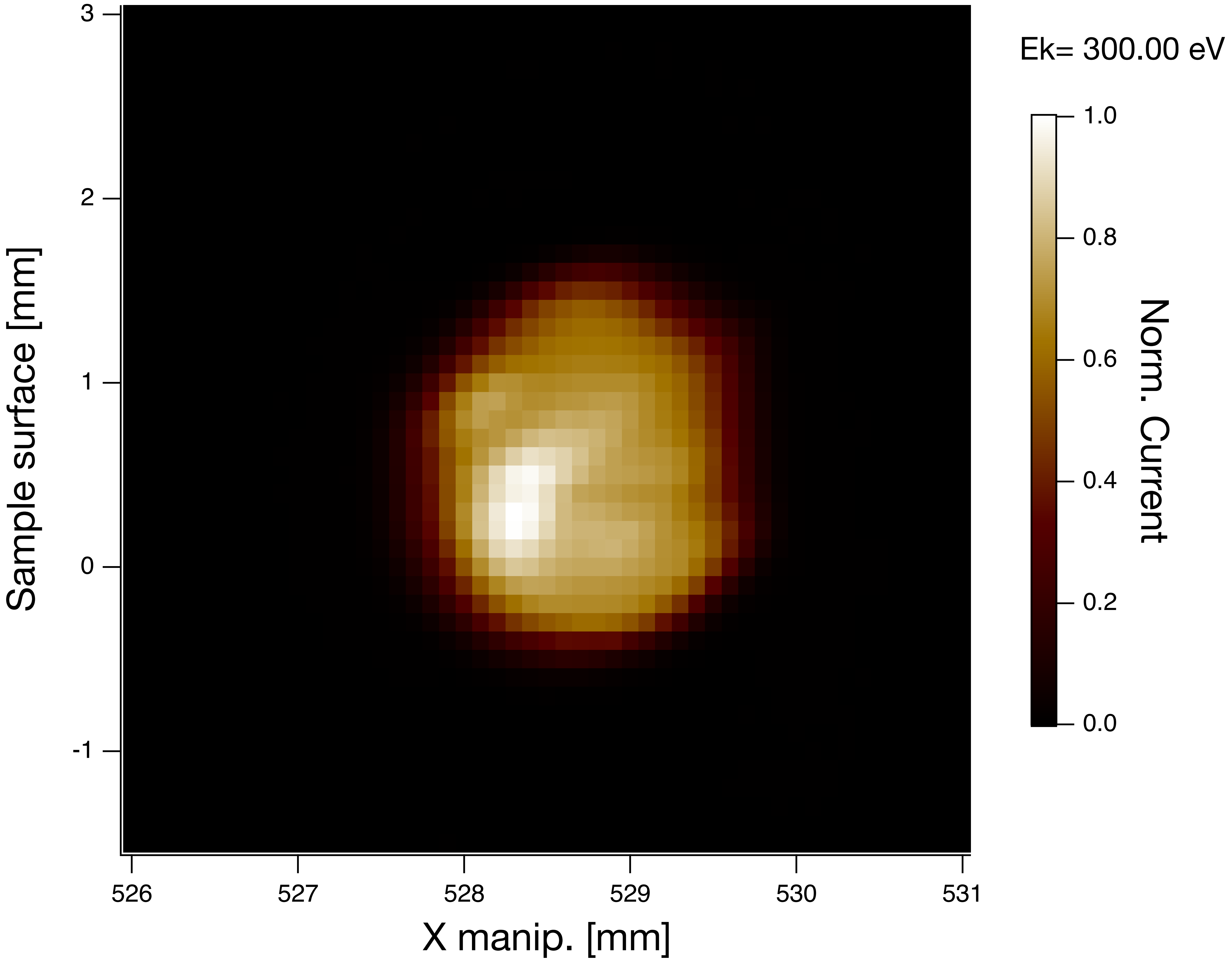


2D maps at fixed electron energy to check homogeneity

Monolayer



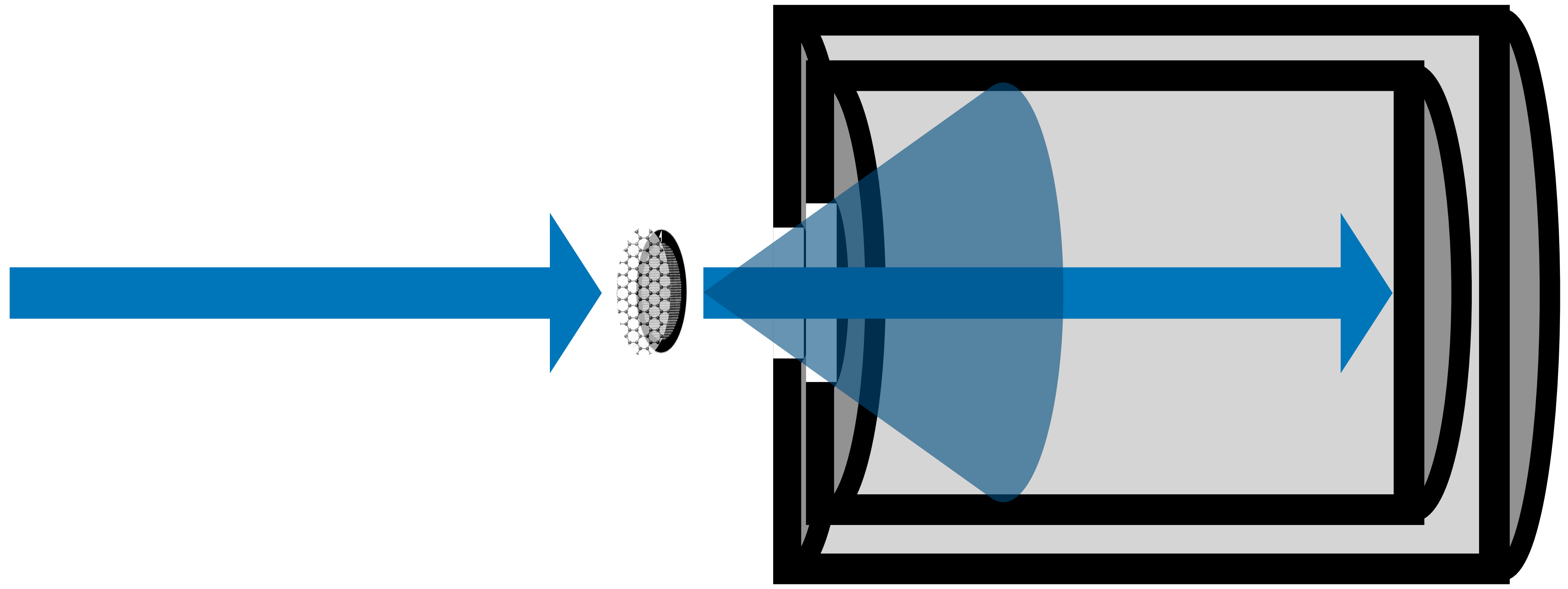
Trilayer



Current normalised to the maximum

The nature of the measured electrons

Elastically scattered electrons contribute less than 10%



N_s = # elastically scattered electrons

N_i = # incident electrons

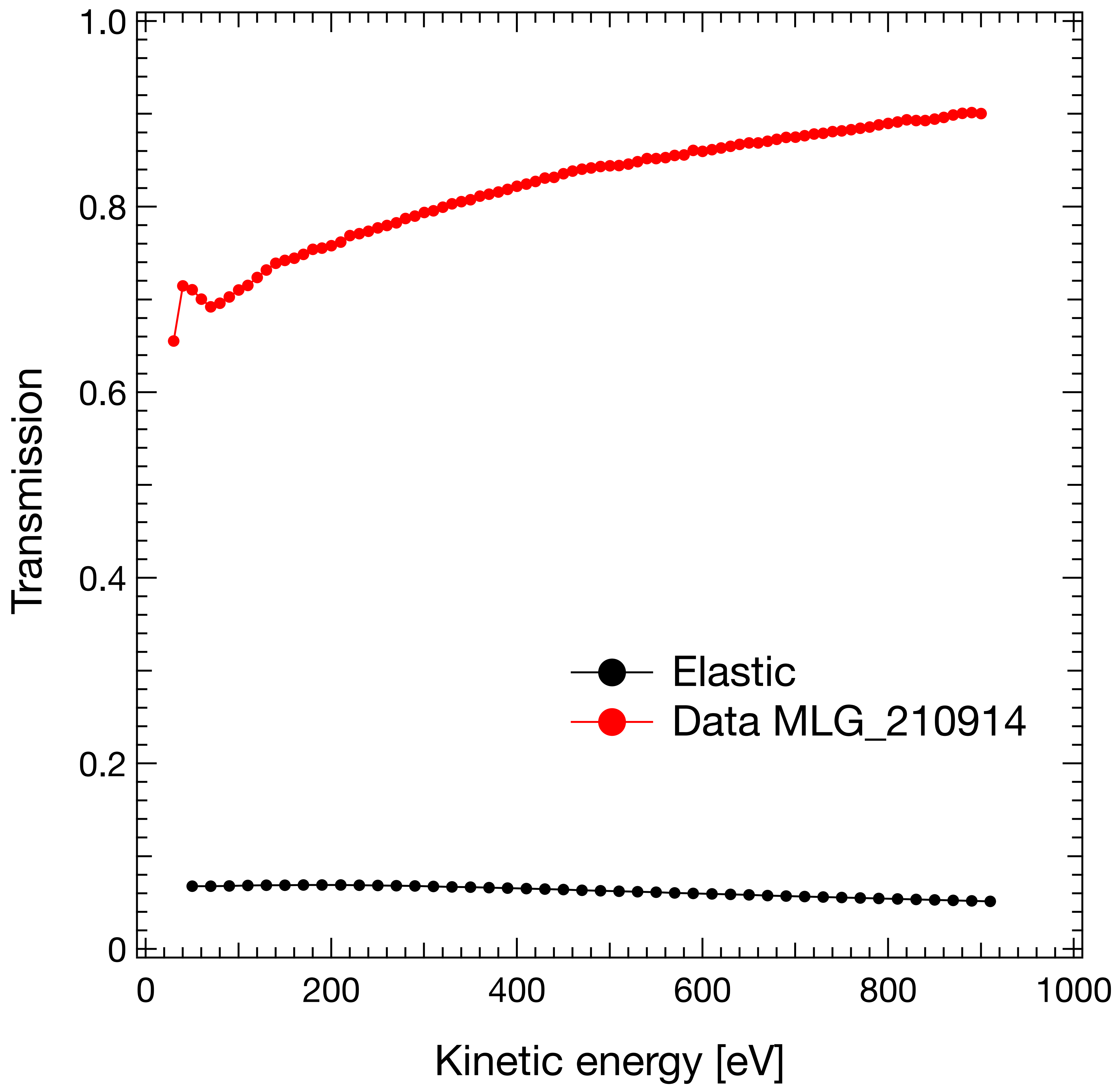
$$\frac{N_s}{N_i} = n_a \; f_g \; 2\pi \int_\theta \frac{d\sigma}{d\Omega}(\theta) \; \sin\theta \; d\theta$$

Carbon atom density
$39 \; nm^{-2} = 0.11 \; a_0^{-2}$

Geometrical factor
39%

Taken from NIST database

[A. Jablonski, F. Salvat, C. J. Powell and A. Y. Lee, NIST Electron Elastic-Scattering Cross-Section Database Version 4.0. NIST Standard Reference Database Number 64, National Institute of Standards and Technology, Gaithersburg, MD, 20899, 2016]



To conclude

Sample preparation:

- Full coverage mono- and tri- layer graphene reached

Graphene characterisation with spectroscopy:

- Contaminants removed with 500°C annealing
- Good quality graphene, C 1s mainly sp_2
- Footprint of suspended monolayer graphene (38% π-plasmon ratio, 39% measured open area!)
- Energy shifted π-plasmon for trilayer graphene

Transmission of low-energy electrons (30-900 eV):

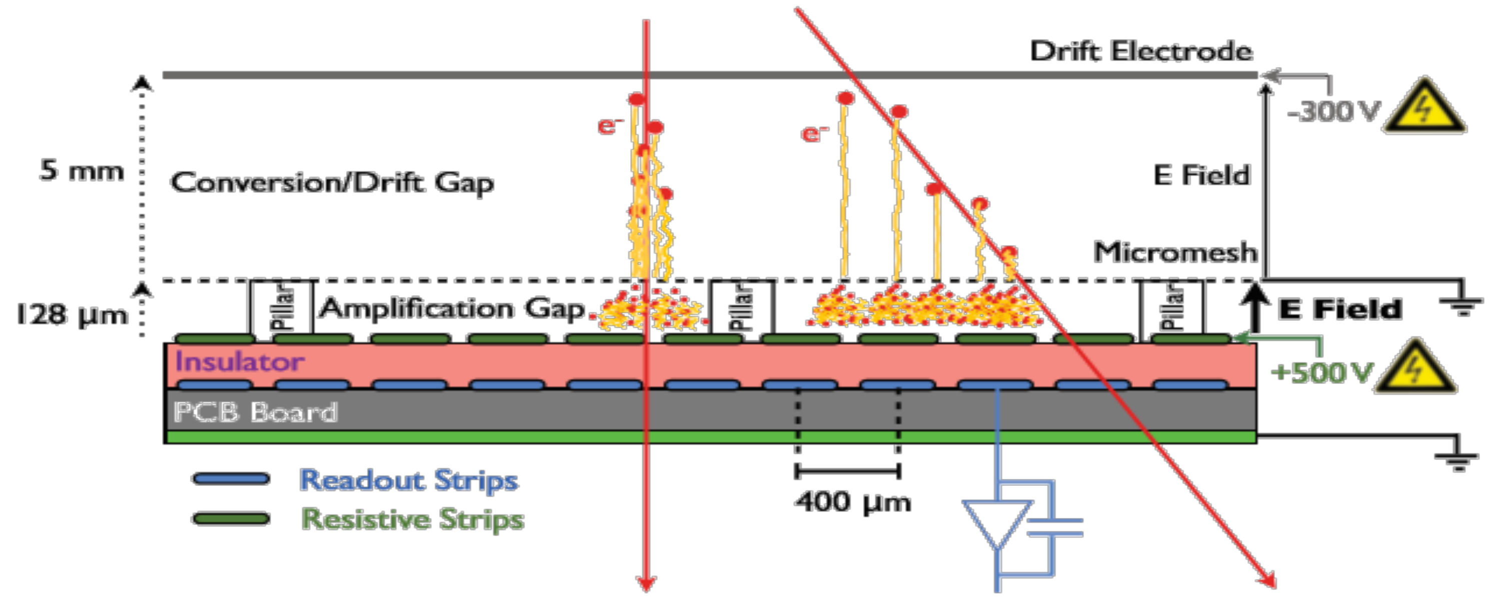
- 70% to 90% transmission through monolayer graphene
- 10% to 80% transmission through trilayer graphene
- Main contribution due to the transmitted beam due to non-scattered electrons

Backup slides

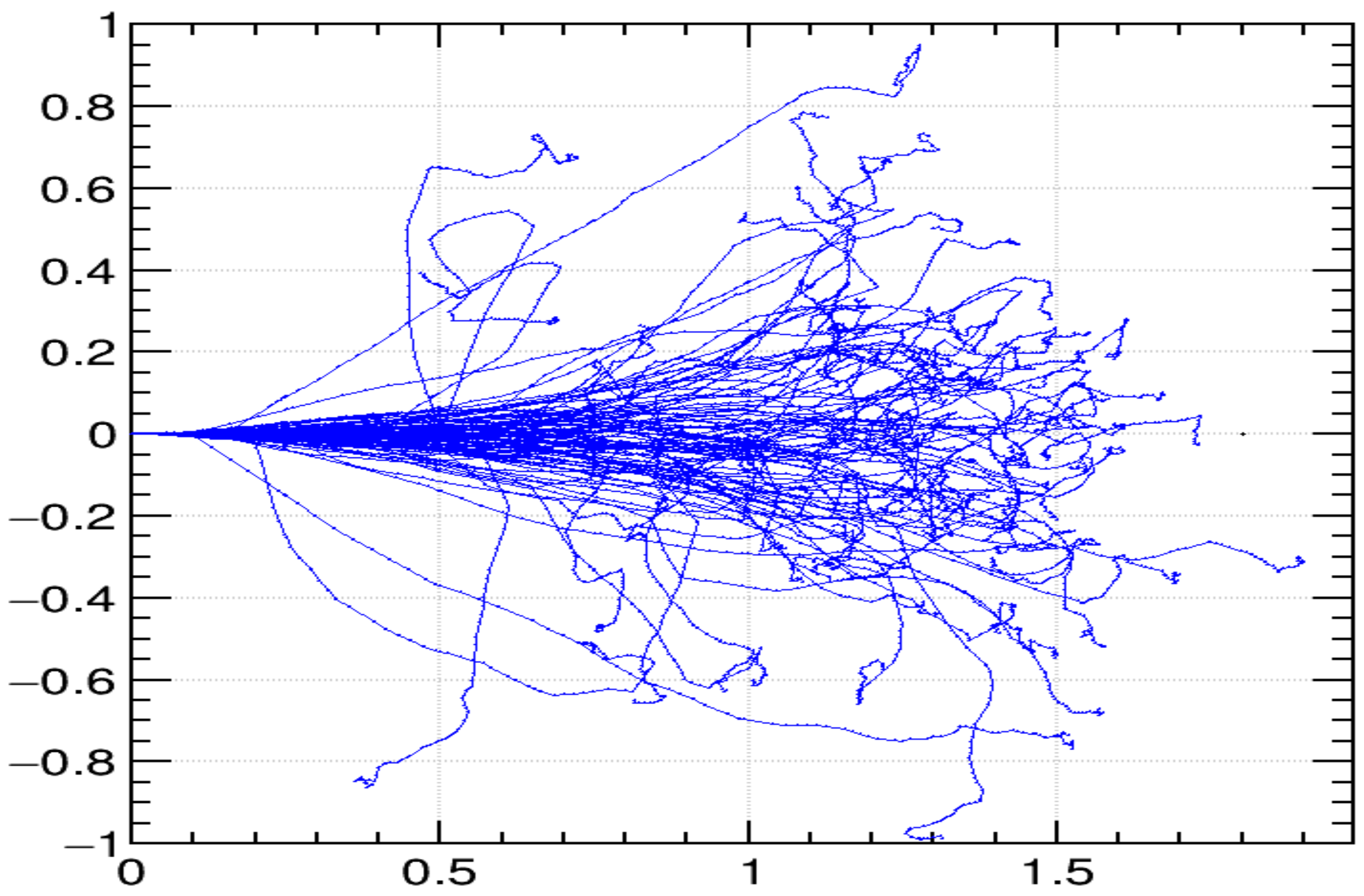
GRAPHENE ON MESH Collaboration

Is it possible to replace the “micromesh” of a Micro-megas with a (grid supported) graphene film?

- Operating a MPGD at low pressure is a key factor to reconstruct the tracks of very low energy particles (< 100 keV)
- Lowering the gas pressure in the amplification gap increase the discharge probability and limit the detector gain
- The graphene is considered to be completely impermeable to all gases. If the graphene transparency is enough high, we could replace the classical mesh with a graphene film and work with **differential** pressure between the DRIFT and the AVALANCHE region



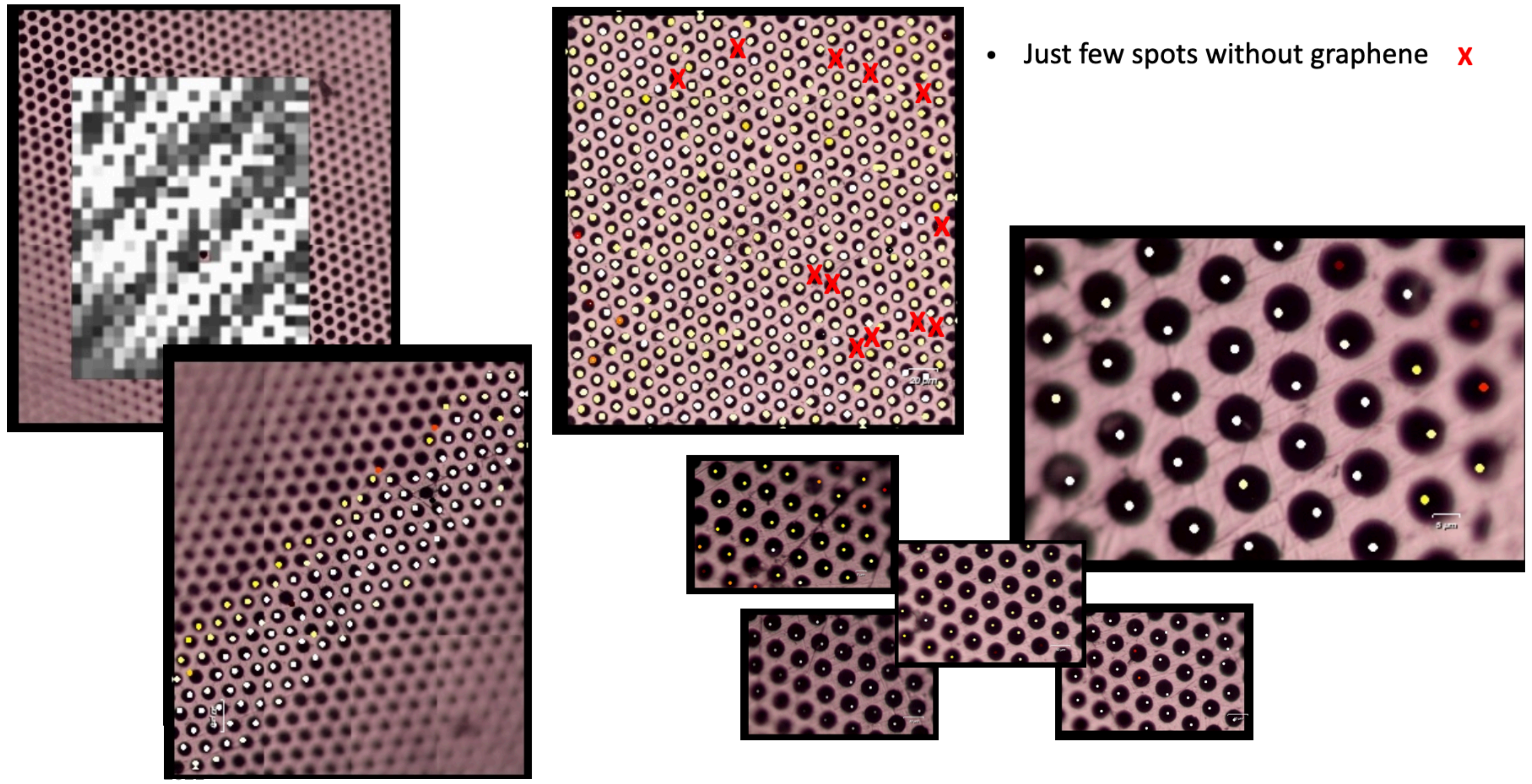
Bulk micromegas detector cross section



100 keV Helium in pure Argon at 20°C and 100 mbar

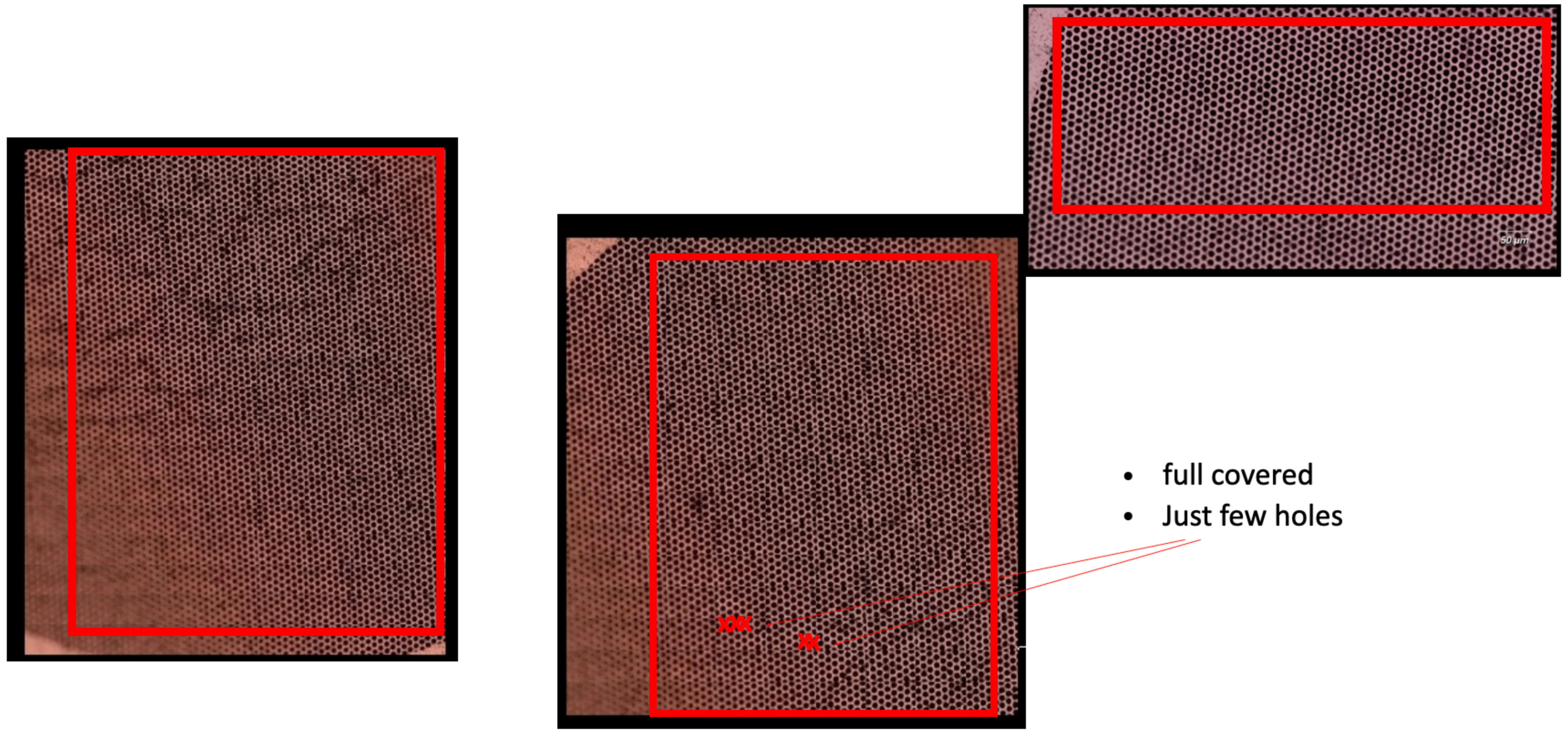
Full coverage achieved for mono- and tri- layer graphene

MONOLAYER



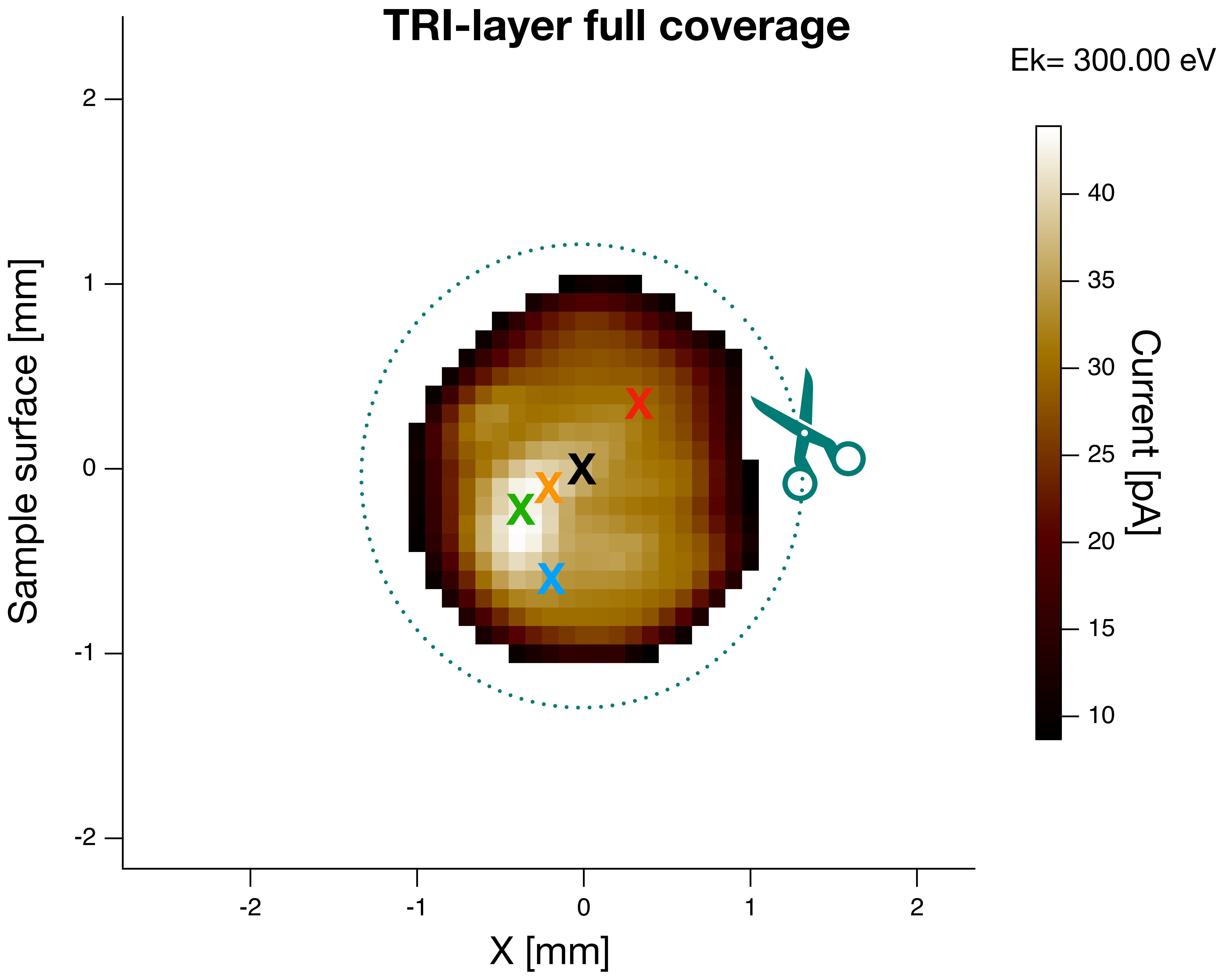
- Just few spots without graphene x

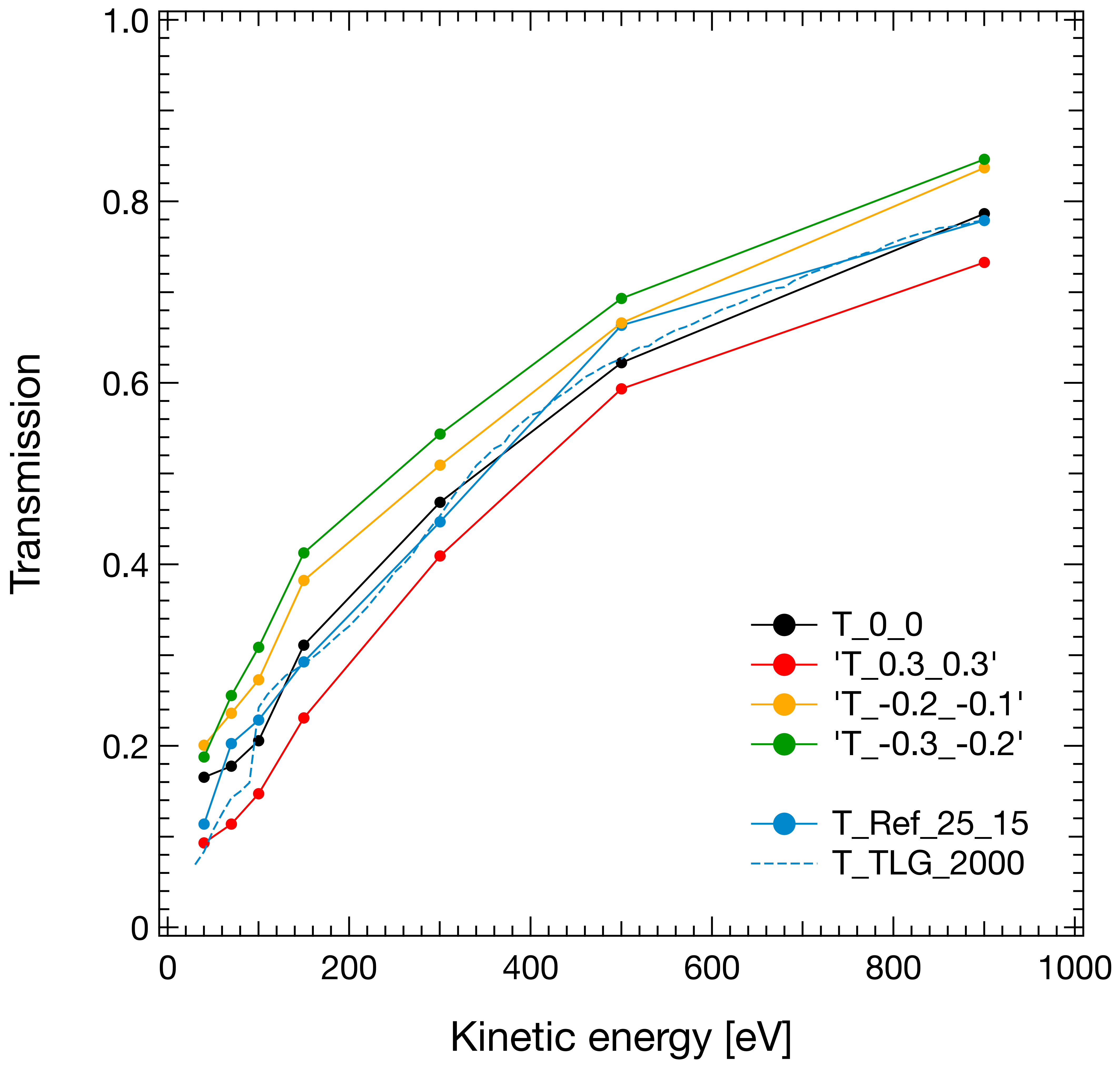
TRILAYER



- full covered
- Just few holes

Transmission evaluated in different points of the map





C 1s post-annealing: comparison with HOPG