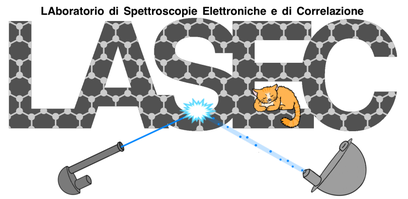
Transmission through graphene of electrons in the 30 - 900 eV range

Alice Apponi, Domenica Convertino, Neeraj Mishra, Camilla Coletti, Mauro Iodice, Franco Frasconi, Federico Pilo, Gianluca Cavoto, Alessandro Ruocco



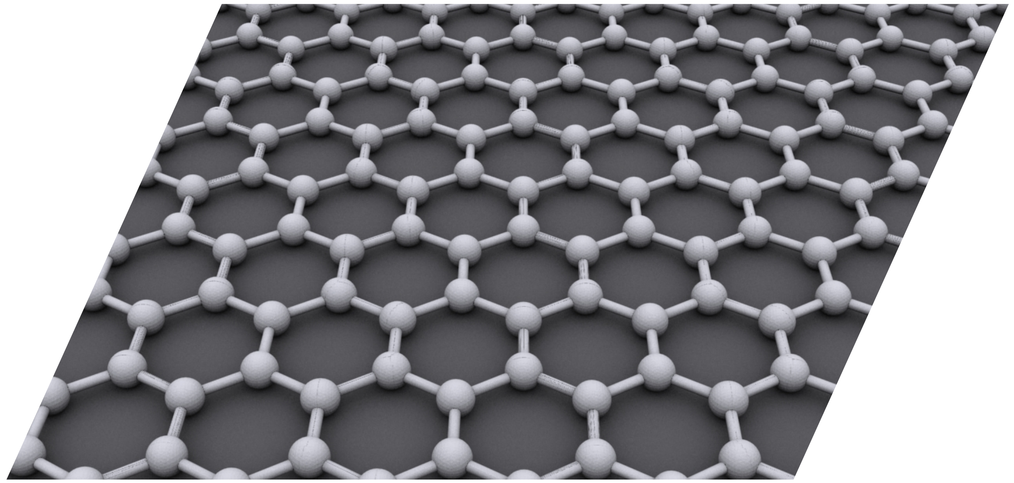
Ptolemy collaboration meeting

06 - 07 October 2022 / Zandvoort, NL

Graphene transparency: a growing topic of interest

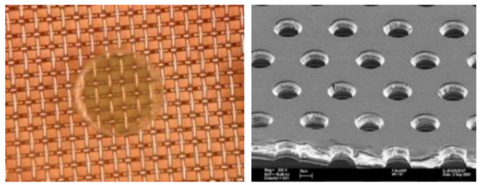
Graphene:

- 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

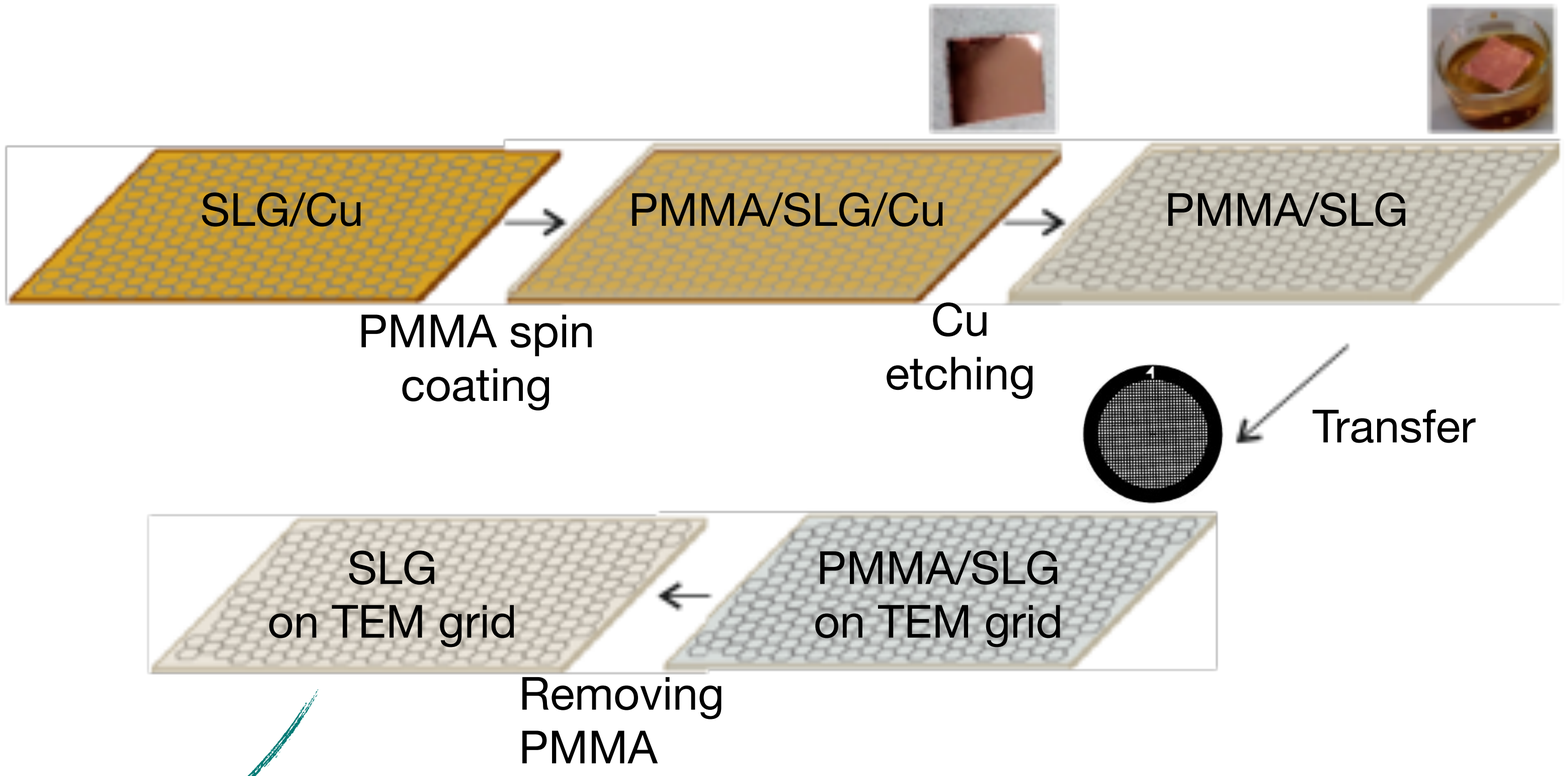
PTOLEMY

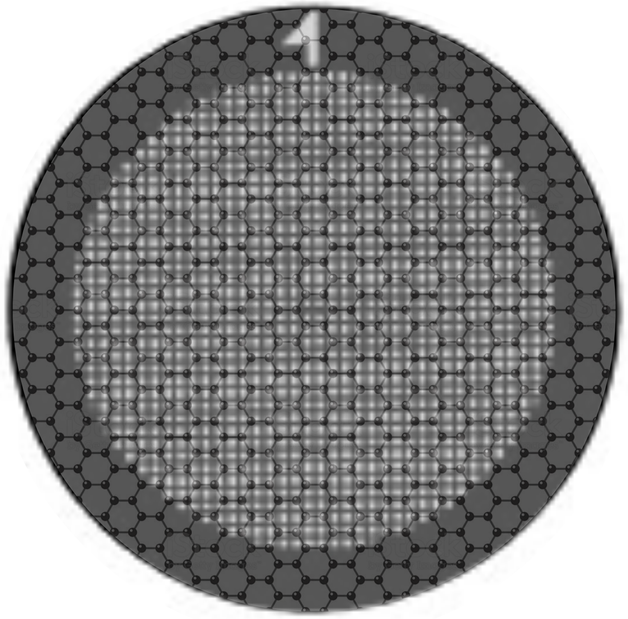
Tritiated graphene target
Measure the β-electrons

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%





Camilla Coletti talk tomorrow

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):

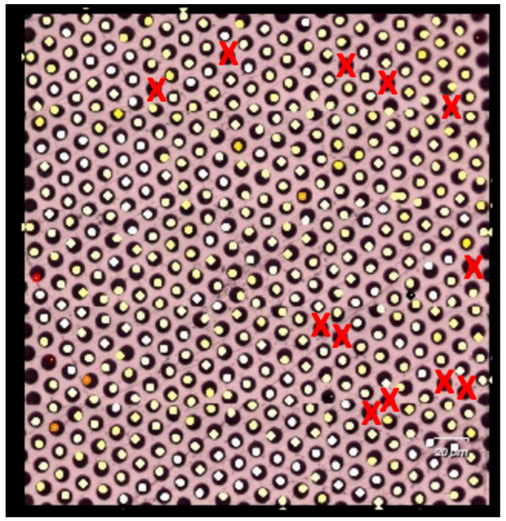
- Fixed point measurement as a function of the energy

Raman spectra: full coverage good quality graphene

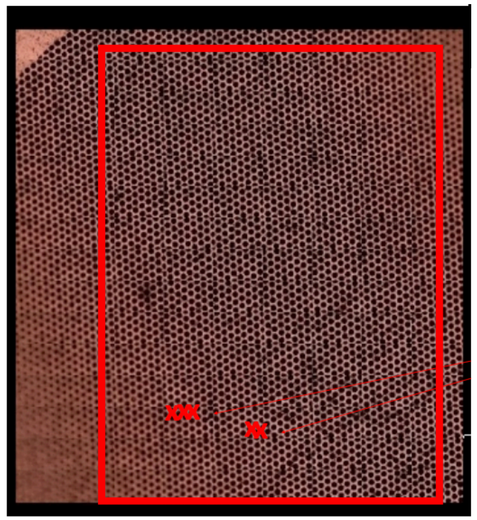
Micro-Raman maps:

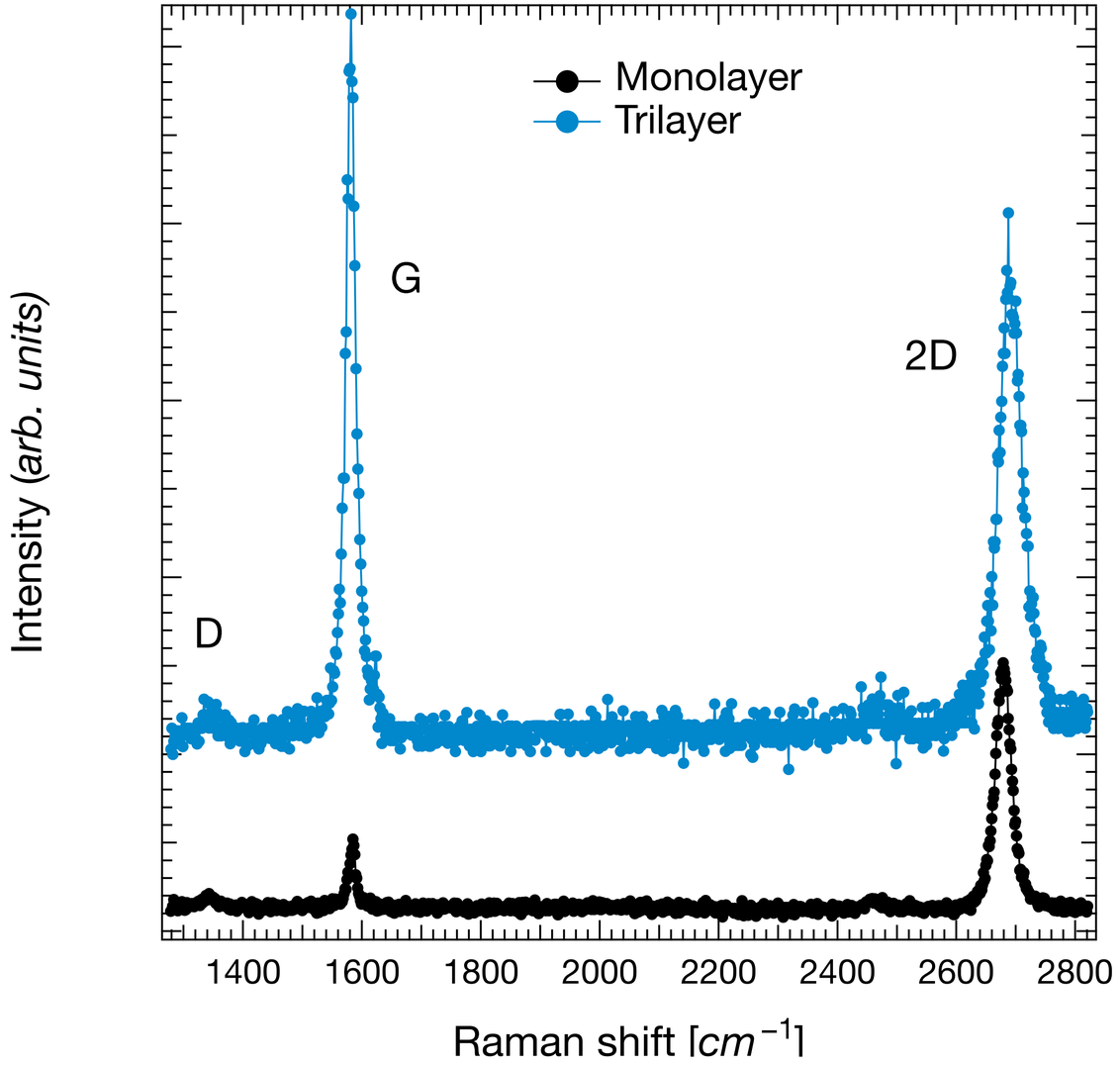
- Full coverage achieved
- Few spots without graphene X

Monolayer



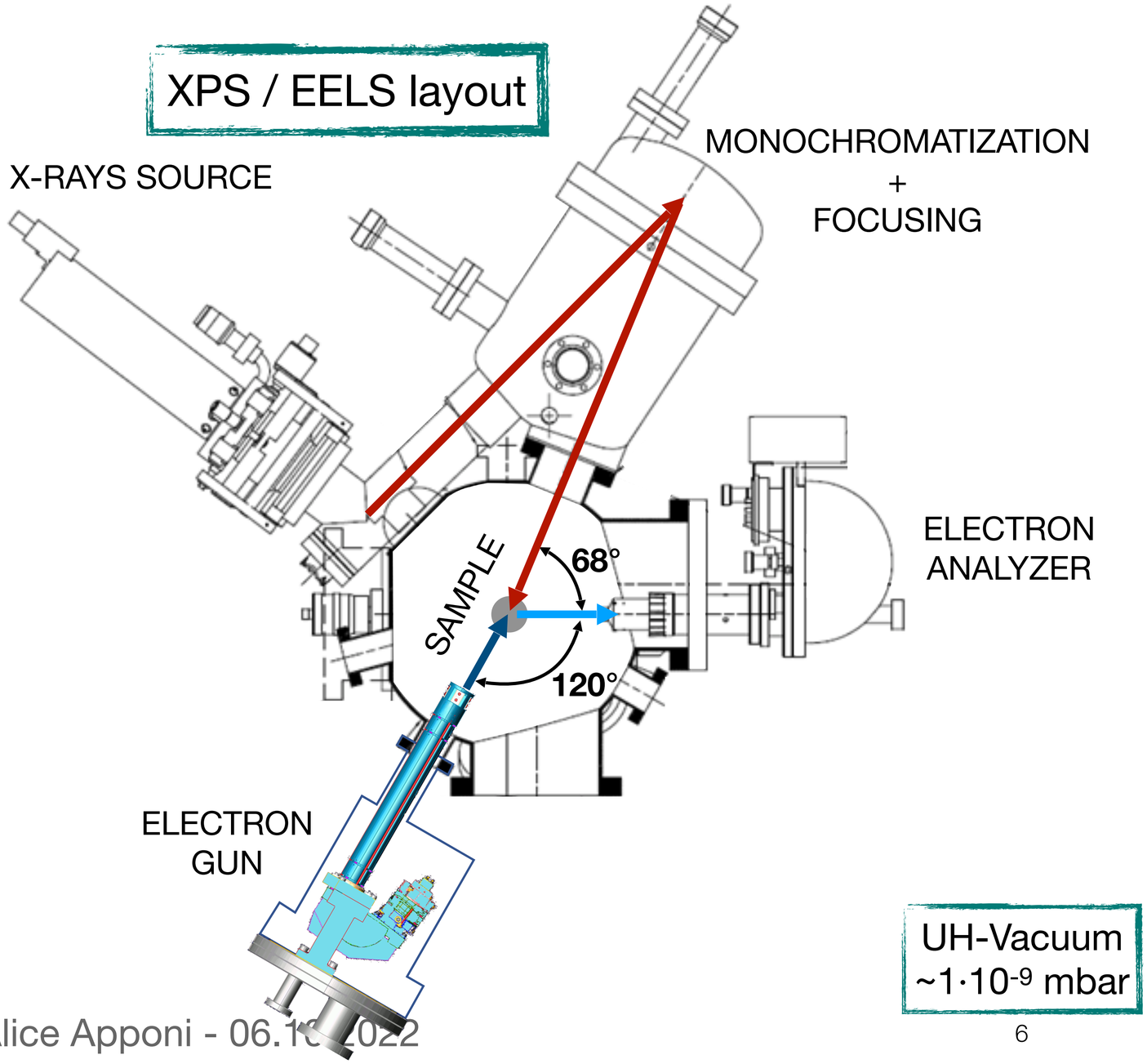
Trilayer





The LASEC experimental layout

XPS / EELS layout



UH-Vacuum
~1·10^{-9} mbar

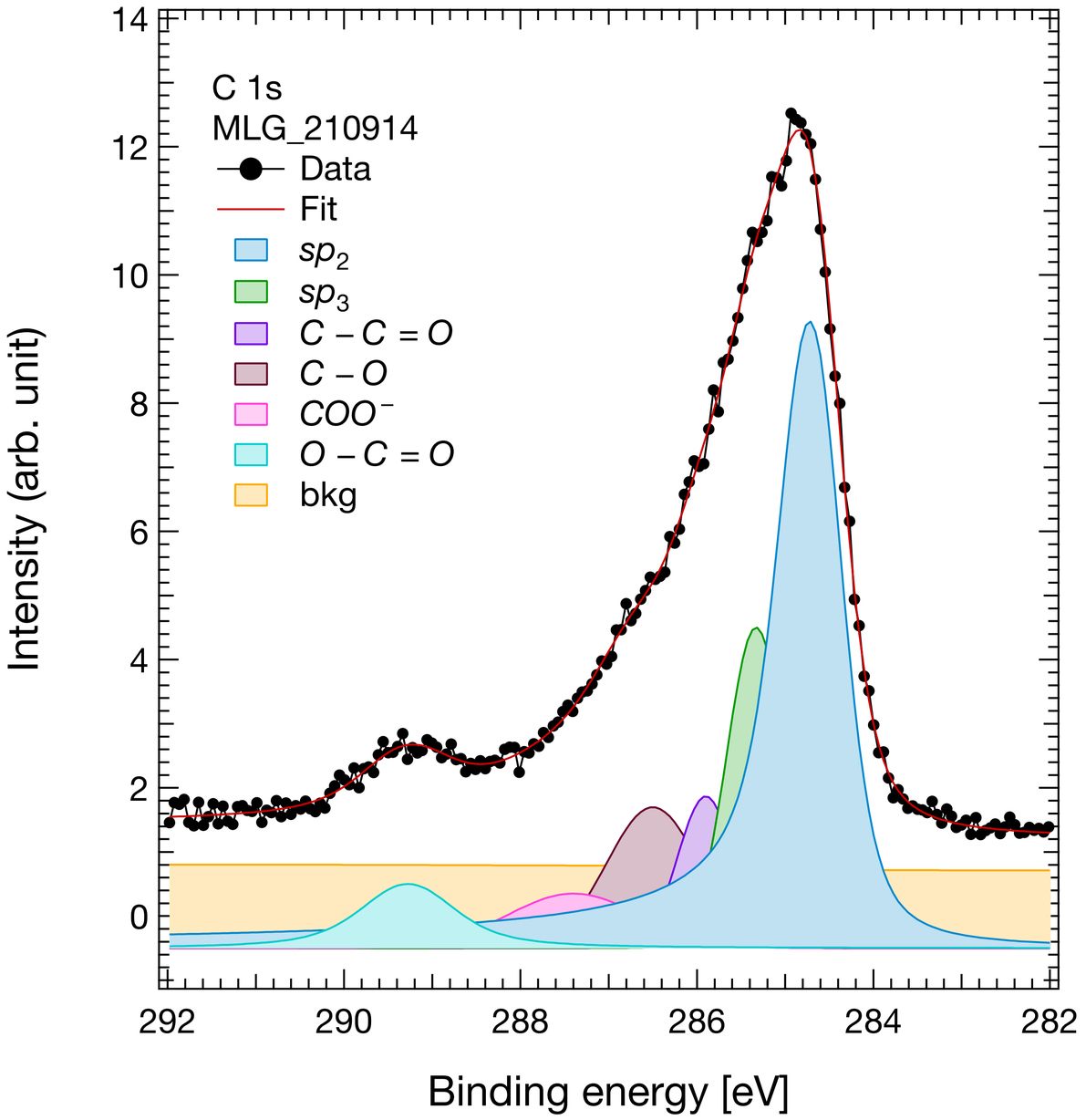
Al Kα source:

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

Custom-made monochromatic electron gun:

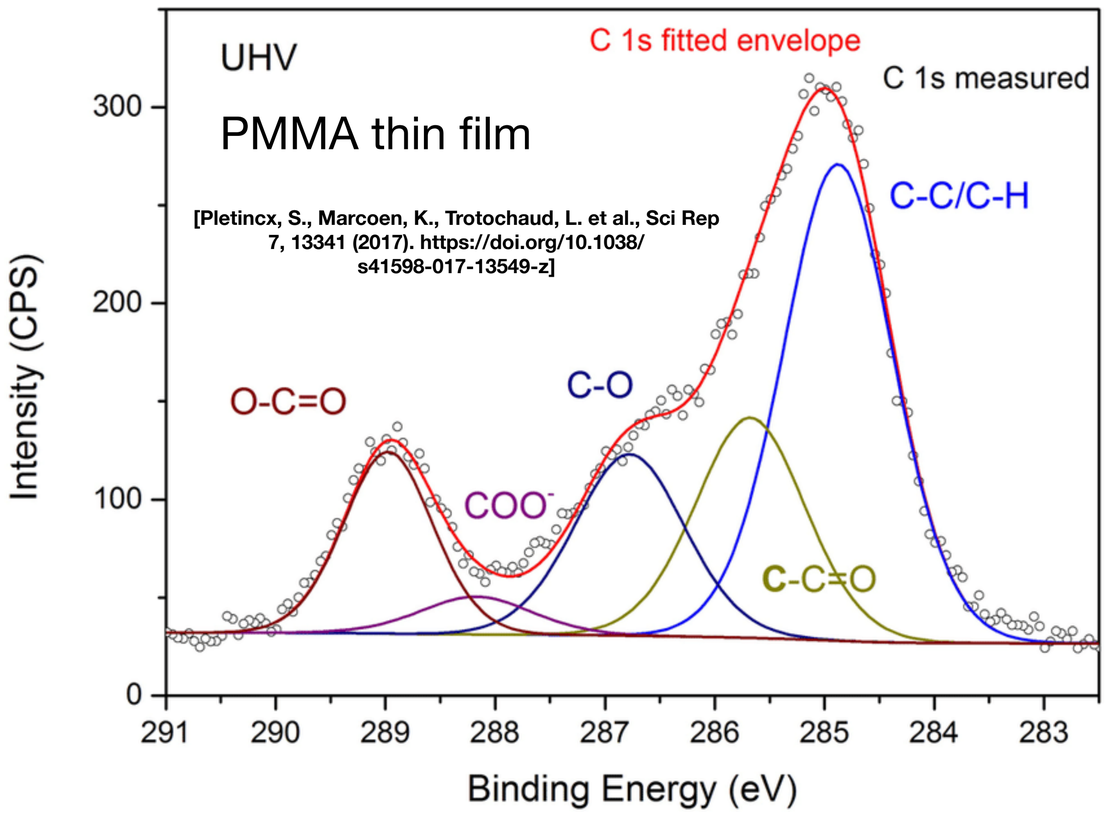
- Continuous electron beam
- Tuneable energy 30 - 900 eV
- Resolution = 45 meV

Monolayer C 1s: high contamination



Monolayer sample measured before annealing:

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

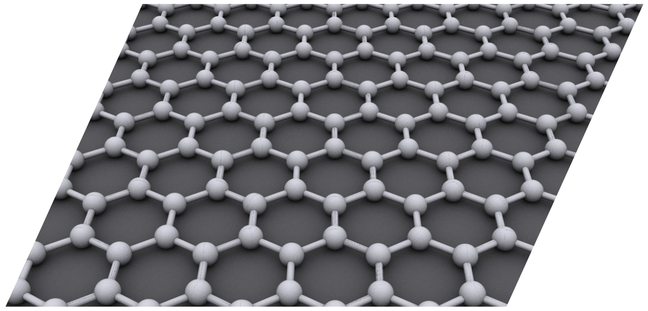


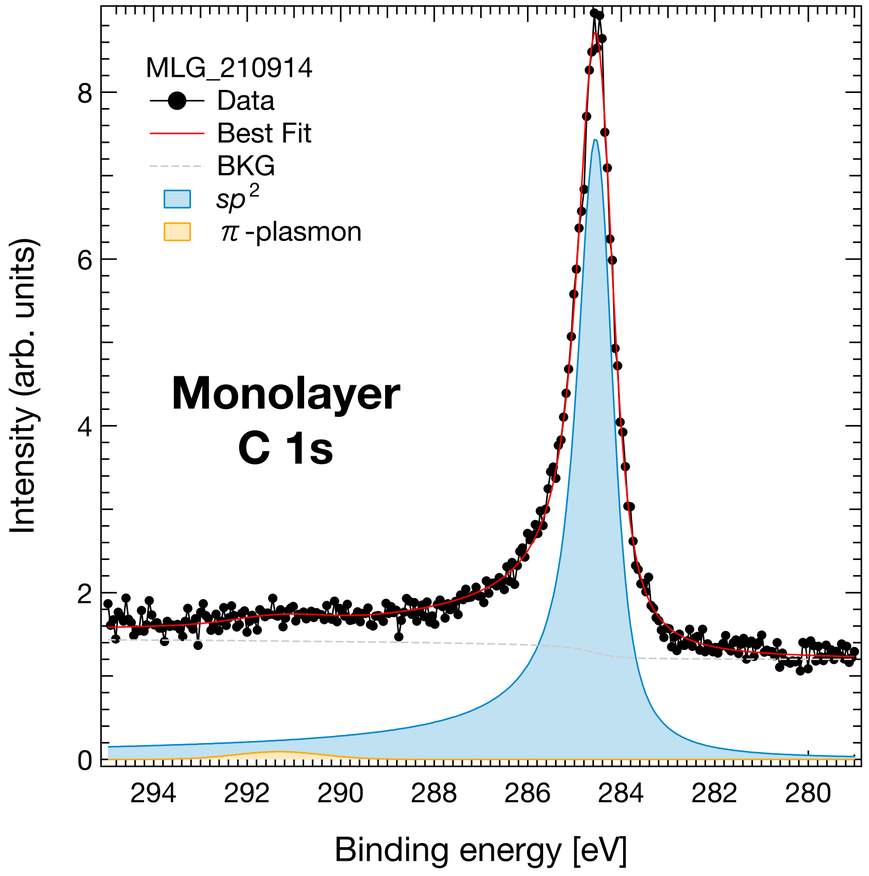
XPS: good quality graphene

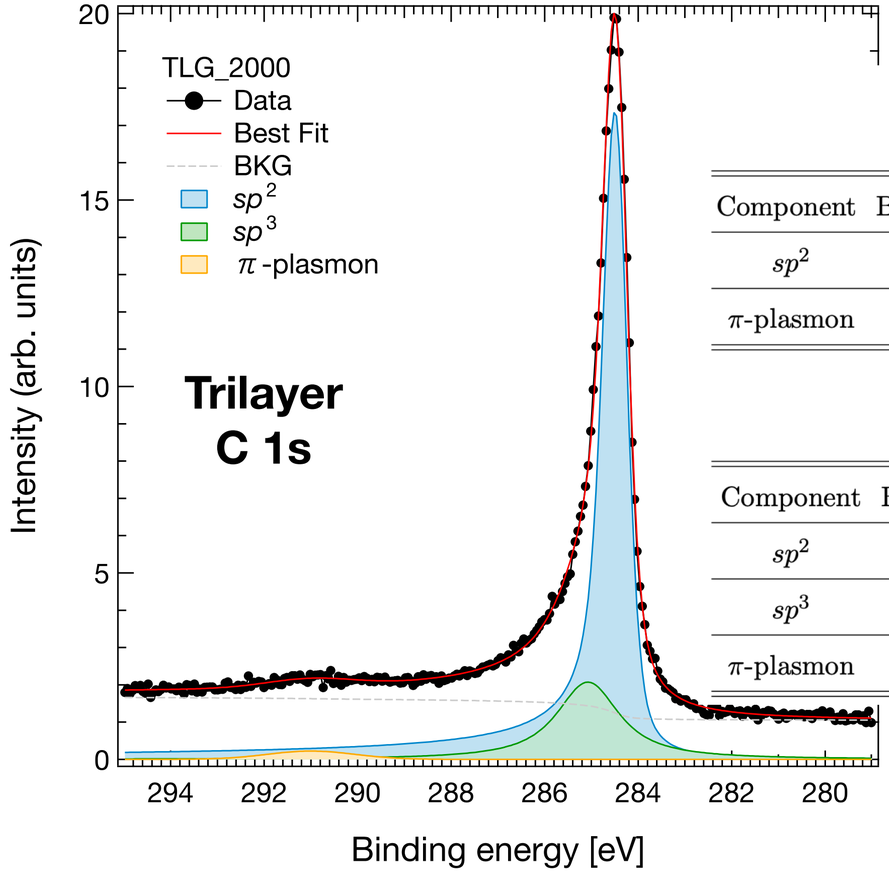
500°C annealing in vacuum

Both C 1s spectra reveal a good quality graphene:

- Main contribution due to sp_2
- Slight amount (~20%) of sp_3 in the trilayer
- Lorentzian width of sp_2 higher in the monolayer







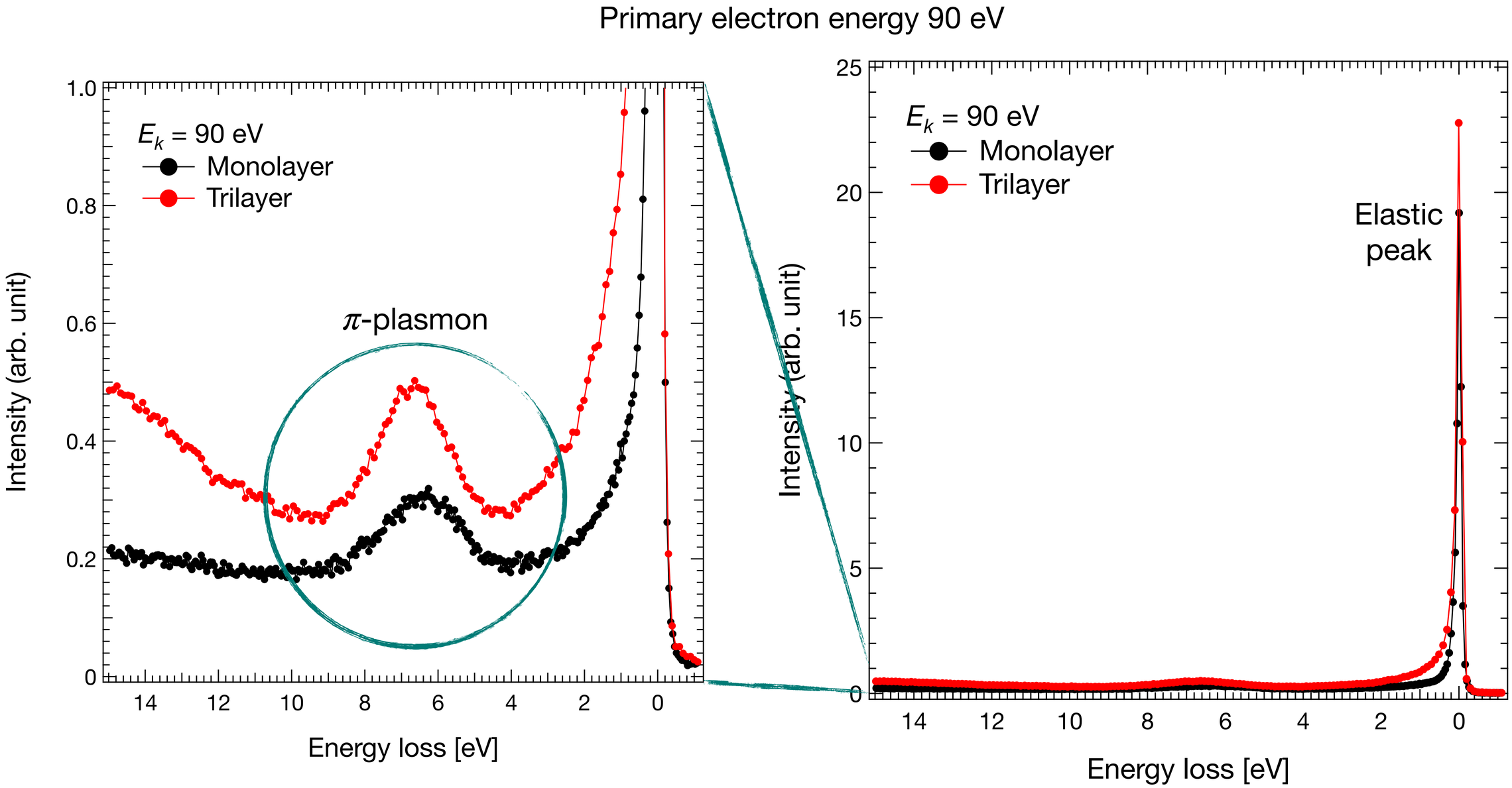
Monolayer graphene

Component	Binding energy [eV]	Area	GW [eV]	LW [eV]	Asymmetry
sp^2	284.45	204	0.45	0.58	0.1
π-plasmon	290.9	4	1.9	0	0

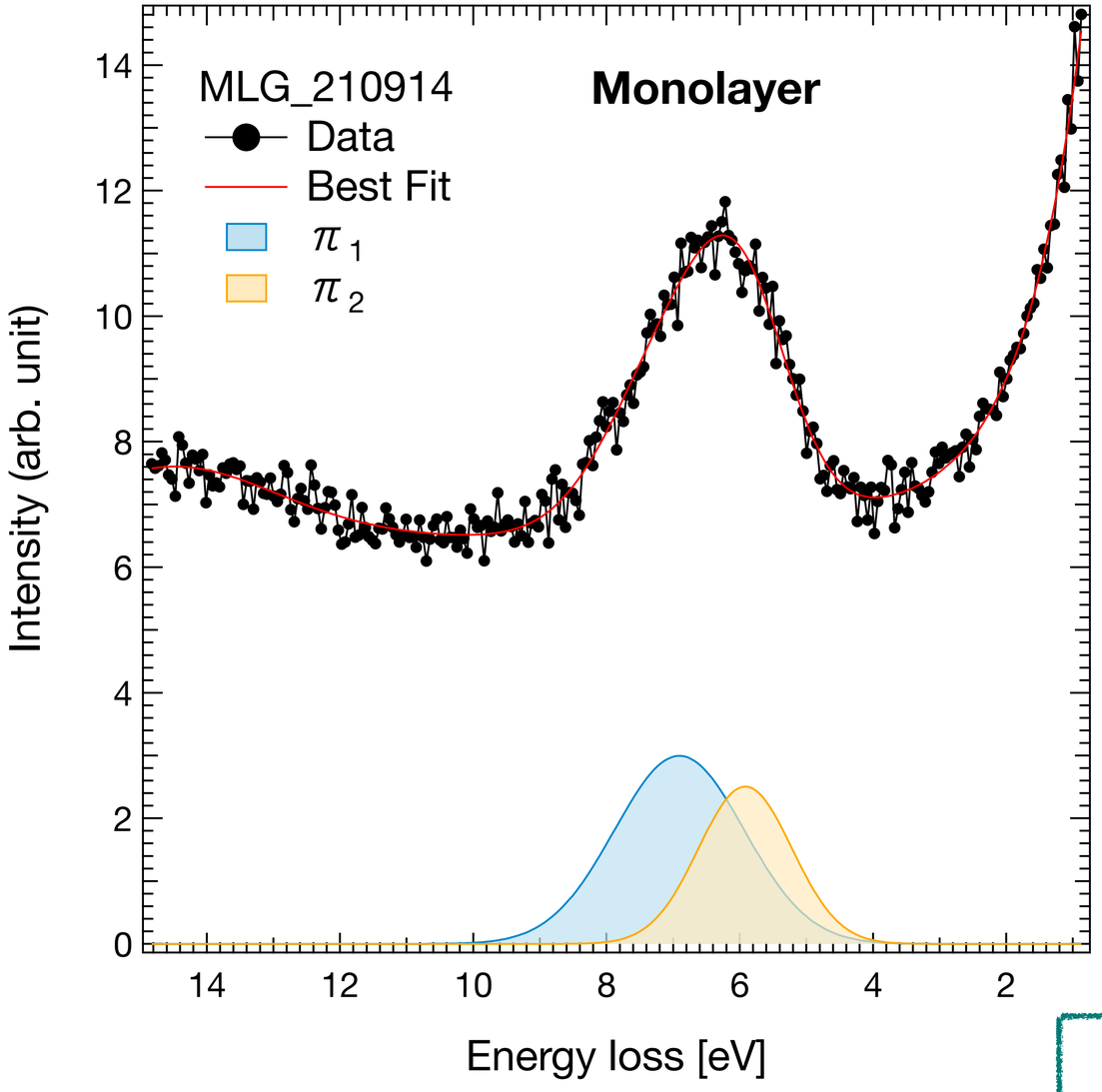
Trilayer graphene

Component	Binding energy [eV]	Area	GW [eV]	LW [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

Comparison of the EELS spectra

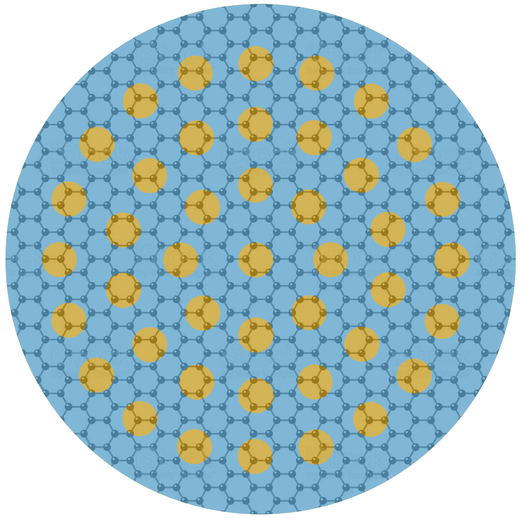


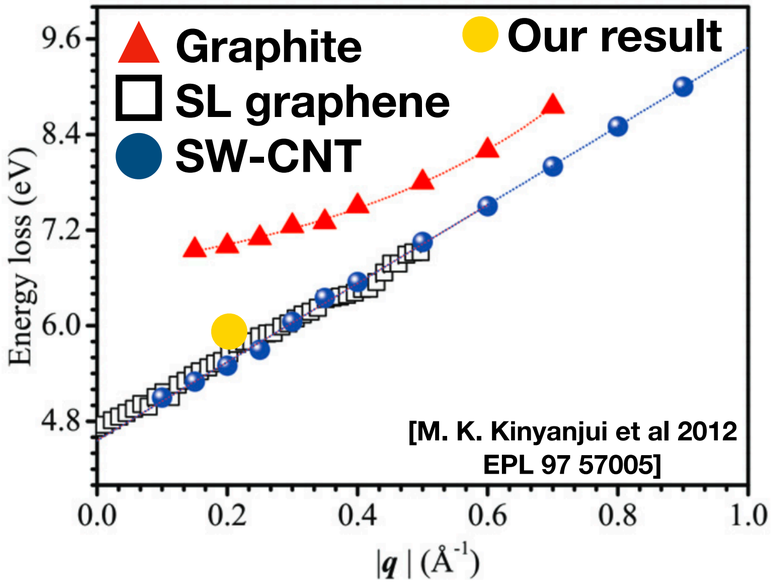
EELS on monolayer: suspended graphene



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

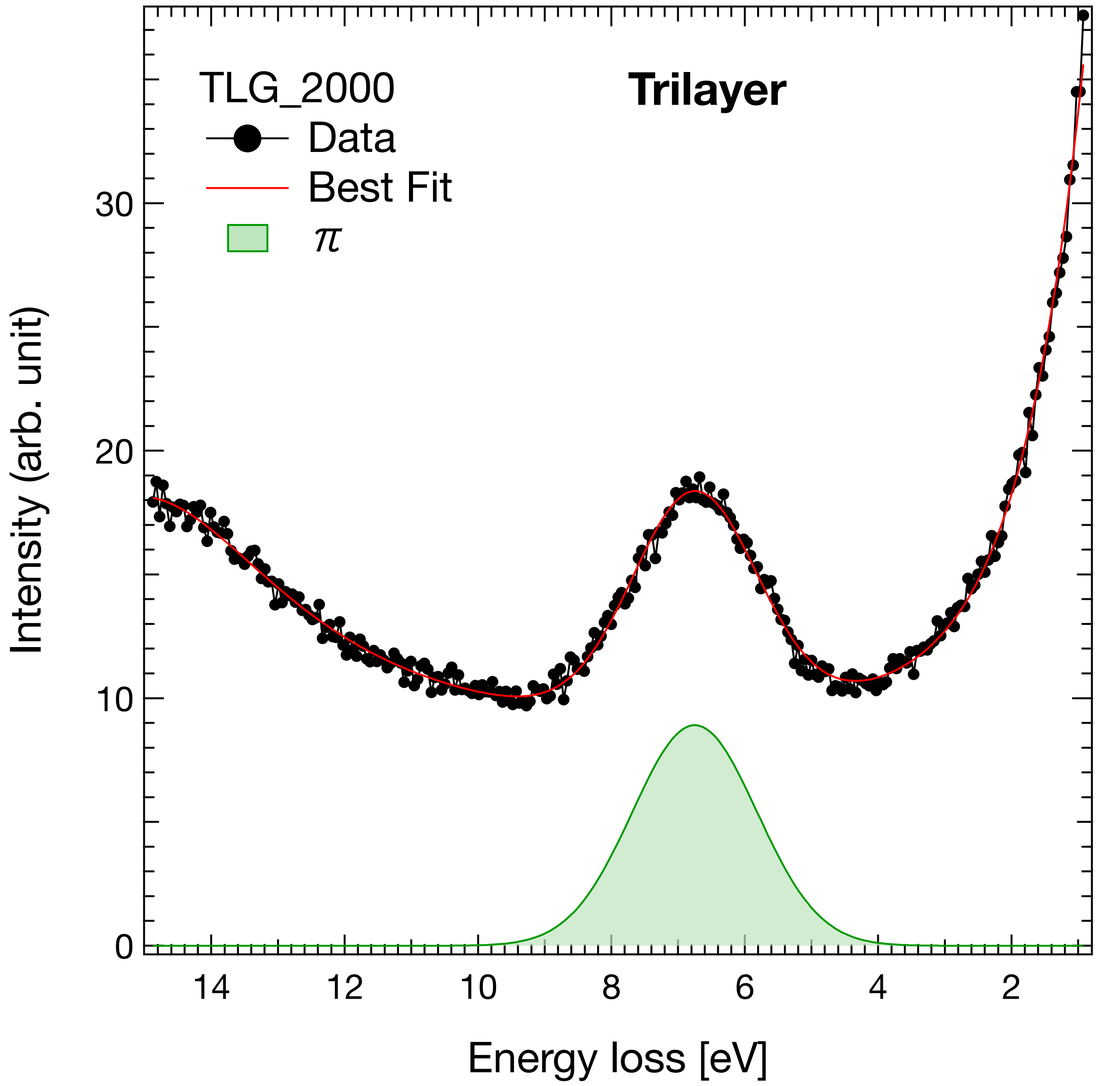




$$\frac{A_{\pi_2}}{A_{\pi_1} + A_{\pi_2}} = 38\,\%$$

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

EELS on trilayer: π-plasmon energy shifted



Trilayer graphene

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

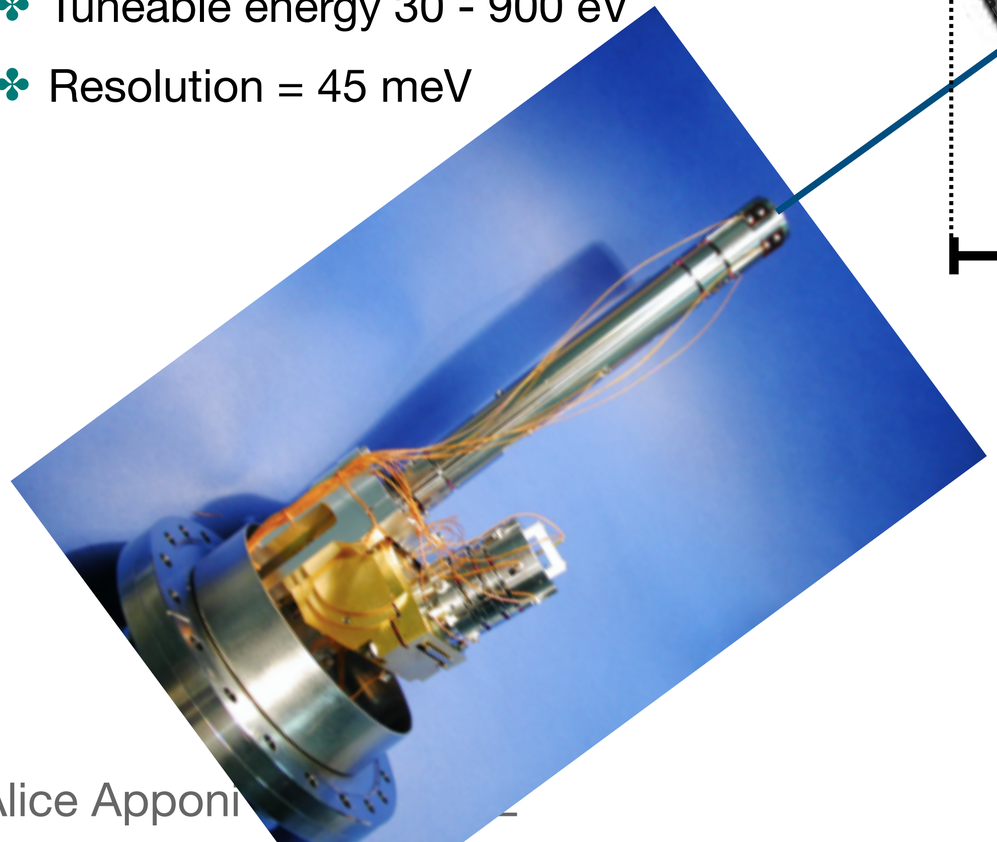
π-plasmon energy shifted increasing the number of graphene layers

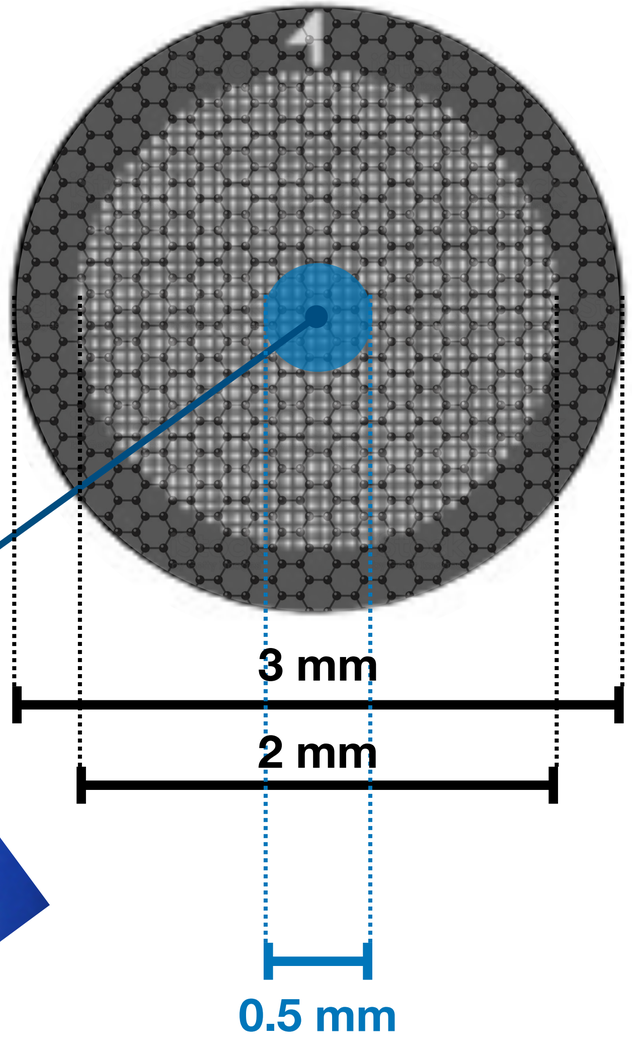
~1 eV wrt monolayer

Transmission measurement: average on several grid holes

Monochromatic electron gun:

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

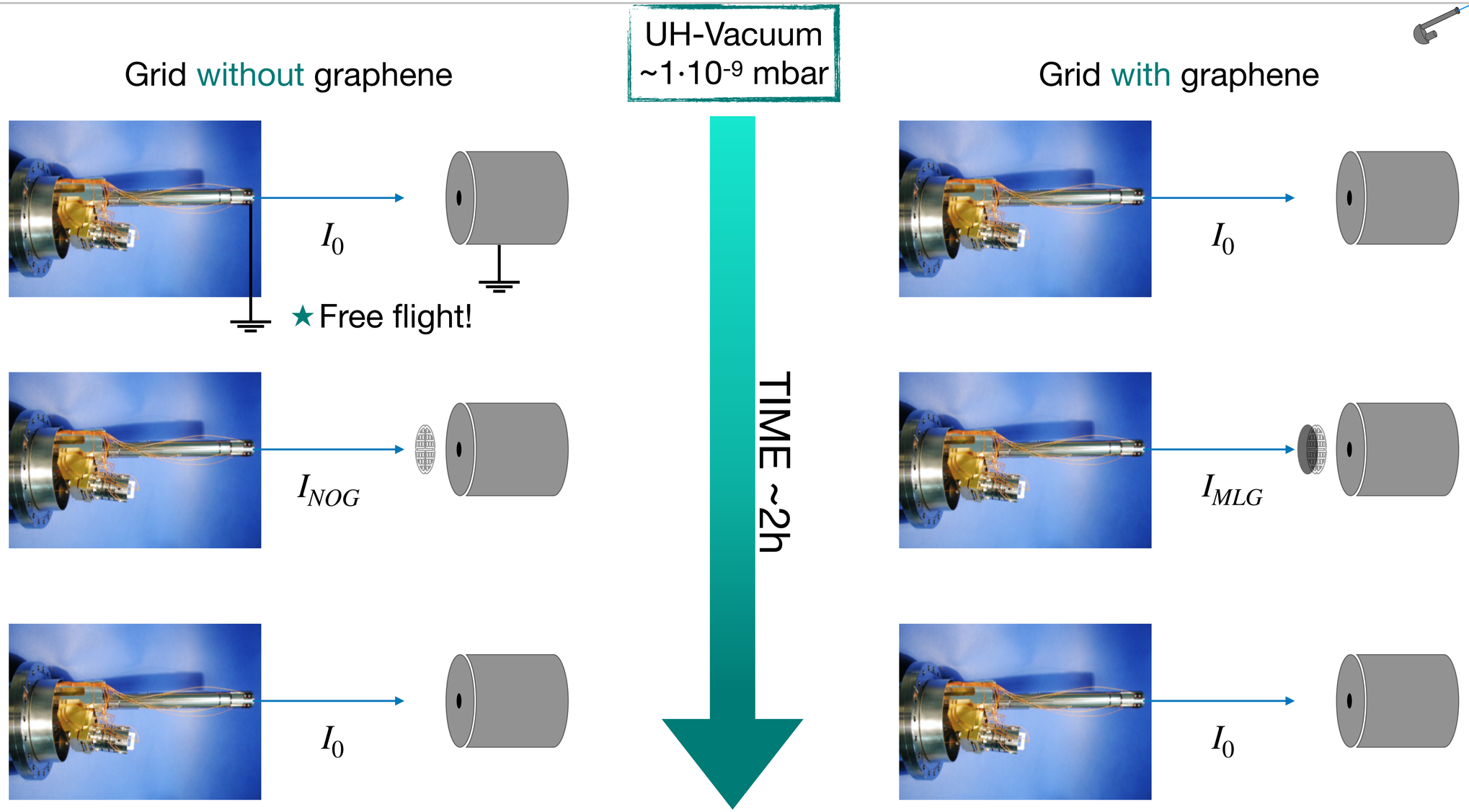




Dimension outline:

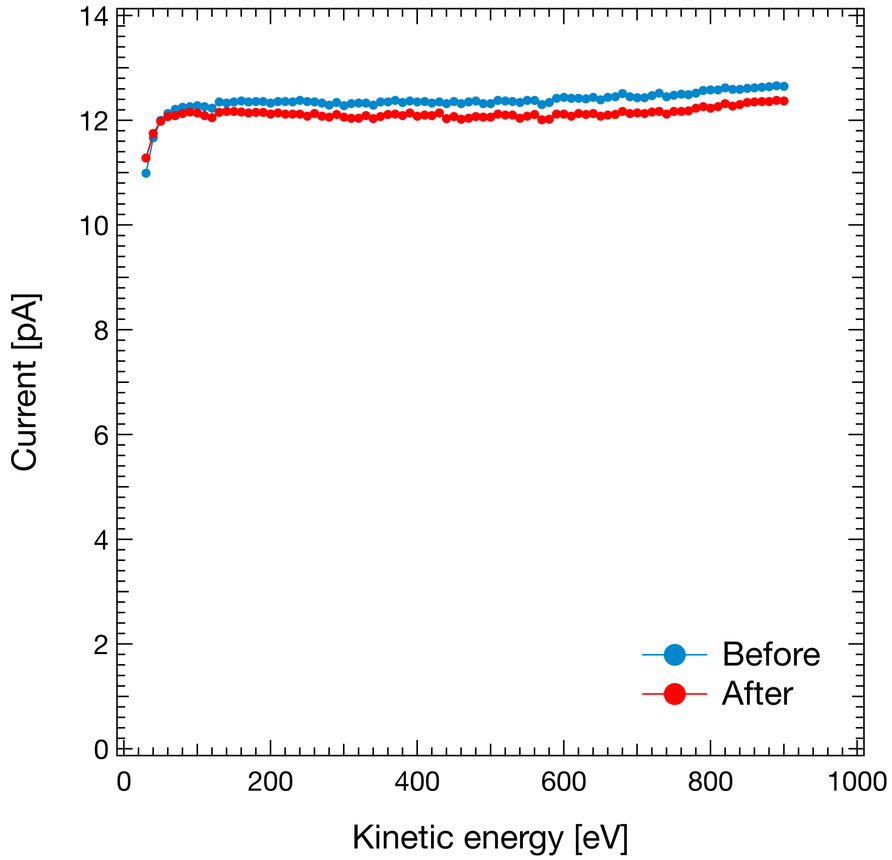
- Diameter 3 mm
- Effective diameter 2 mm
- 2000 mesh per inch → 12.5 μm pitch
- Hole width 6.5 μm
- Beam size ~ 0.5 mm

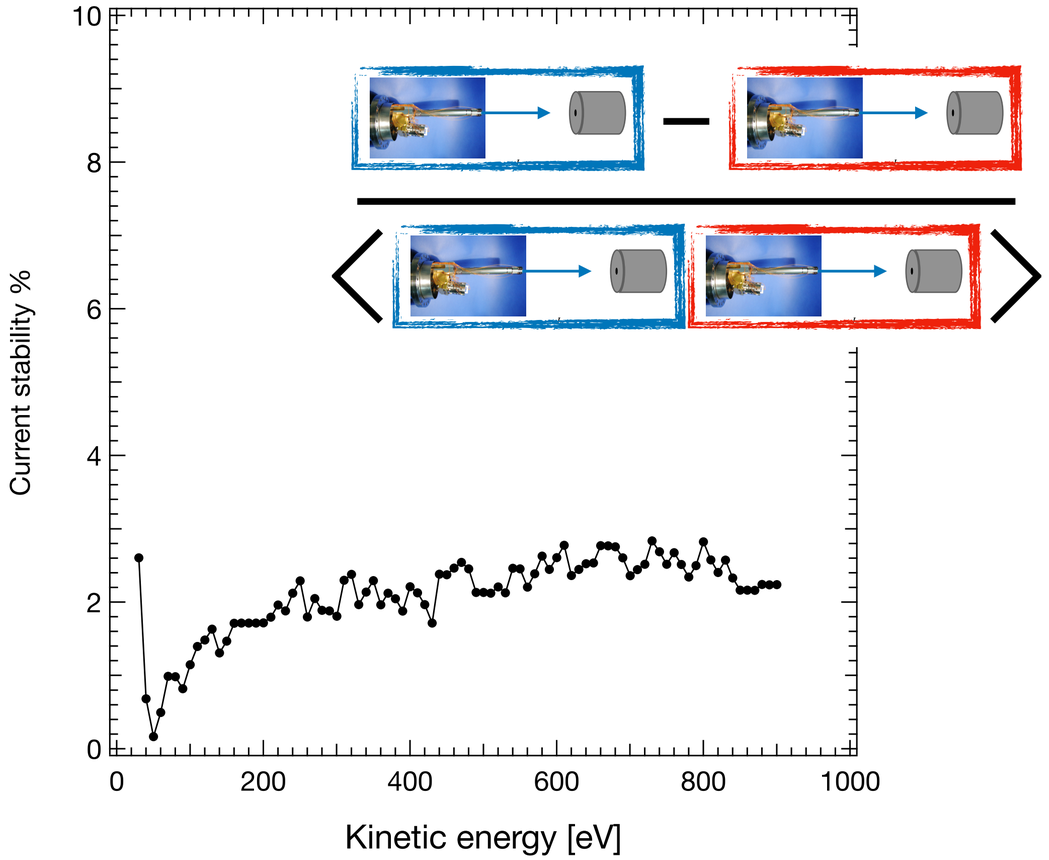
Transmission measurement: the method



✤Check stability with current measurement before and after

Current stability < 3%



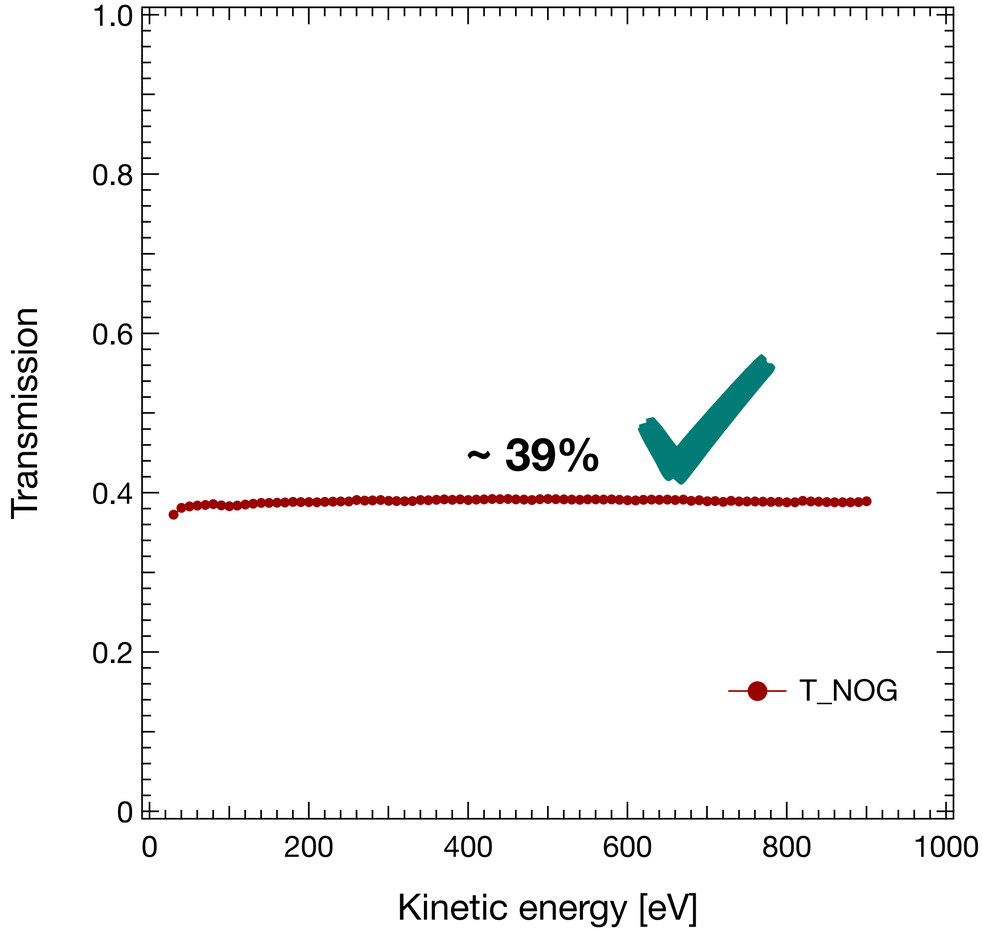


- Current stability → before - after difference / average
- Picoammeter accuracy 0.5%
- Uncertainty essentially due to current stability

Transmission of grid without graphene ~ 39%

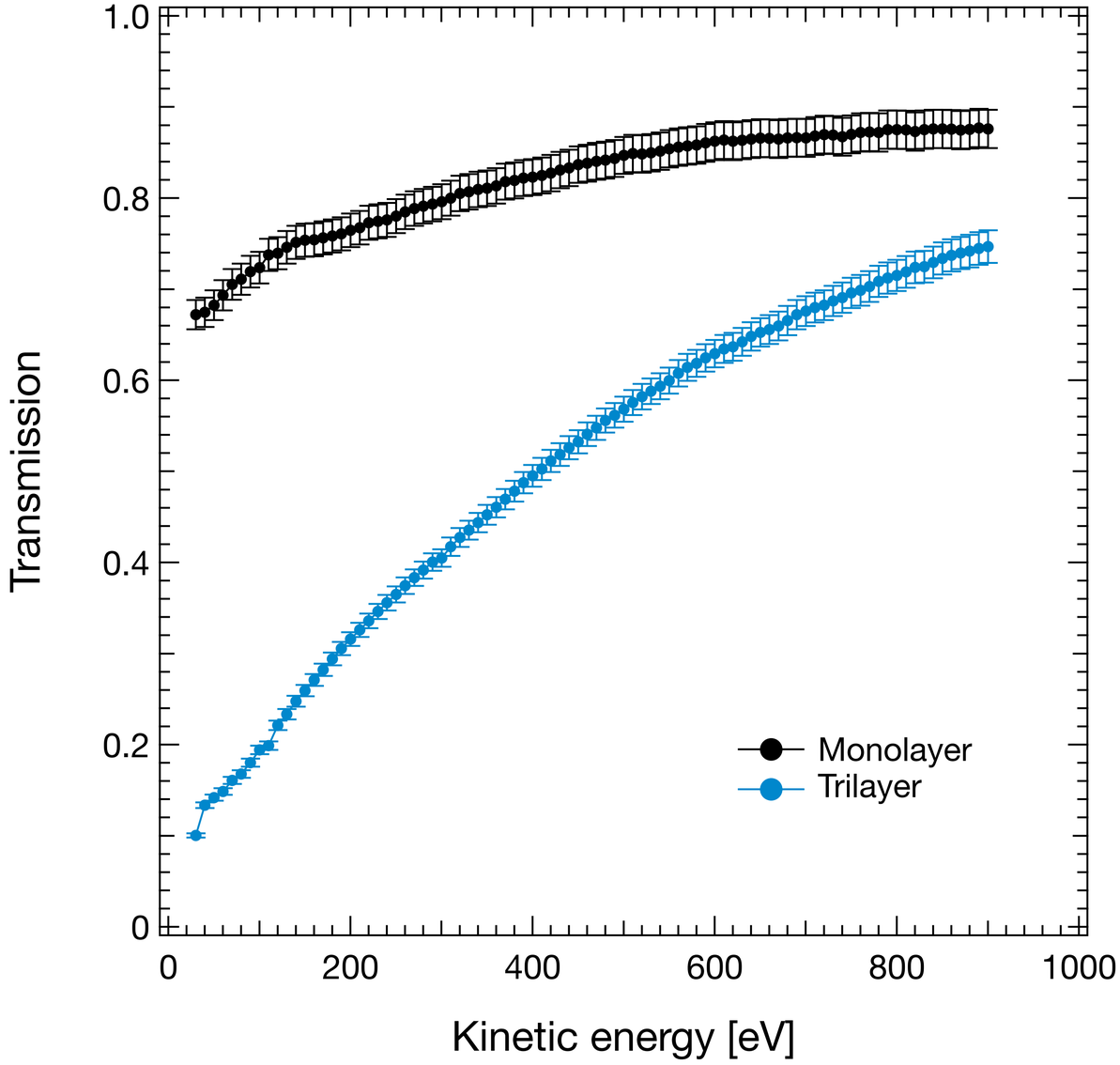
$\frac{I_{NOG}}{I_0}$ ⟶ grid without graphene (i.e. geometrical transmission)

- Nominal geometrical transmission 41%
- Uncertainty 1.7% (not shown ~same size of the dots)

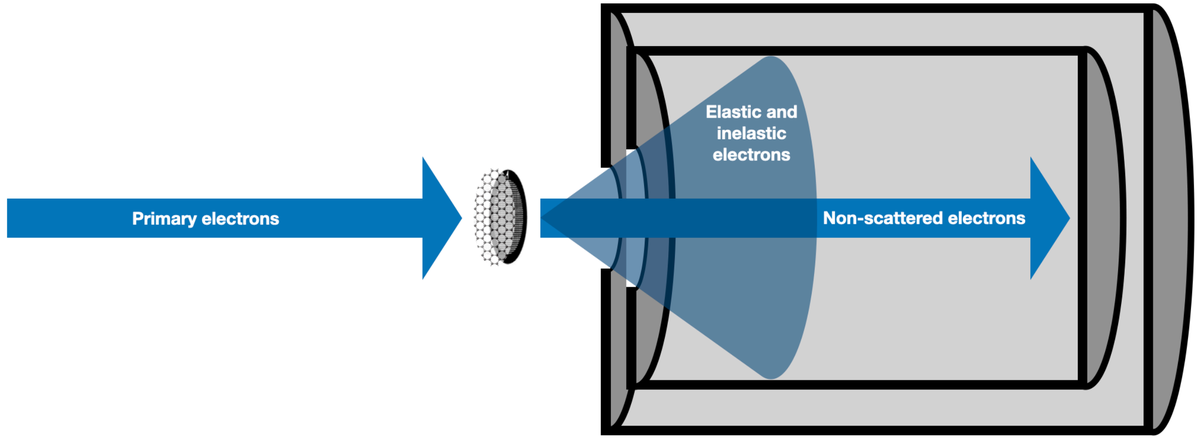


Transmission through mono- and tri- layer graphene

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



Monolayer: elastically scattered electrons less than 8%



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

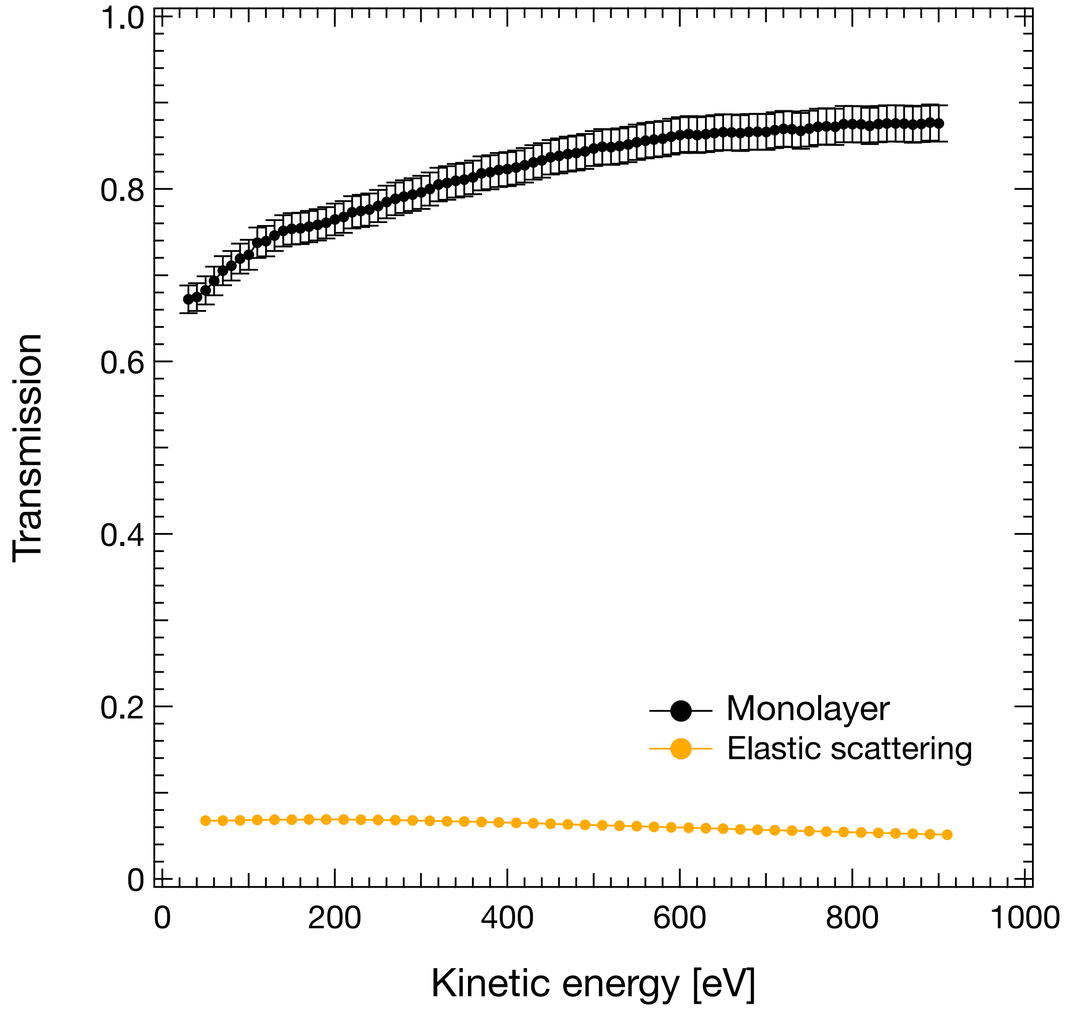
$39 \; nm^{-2} = 0.11 \; a_0^{-2}$

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]



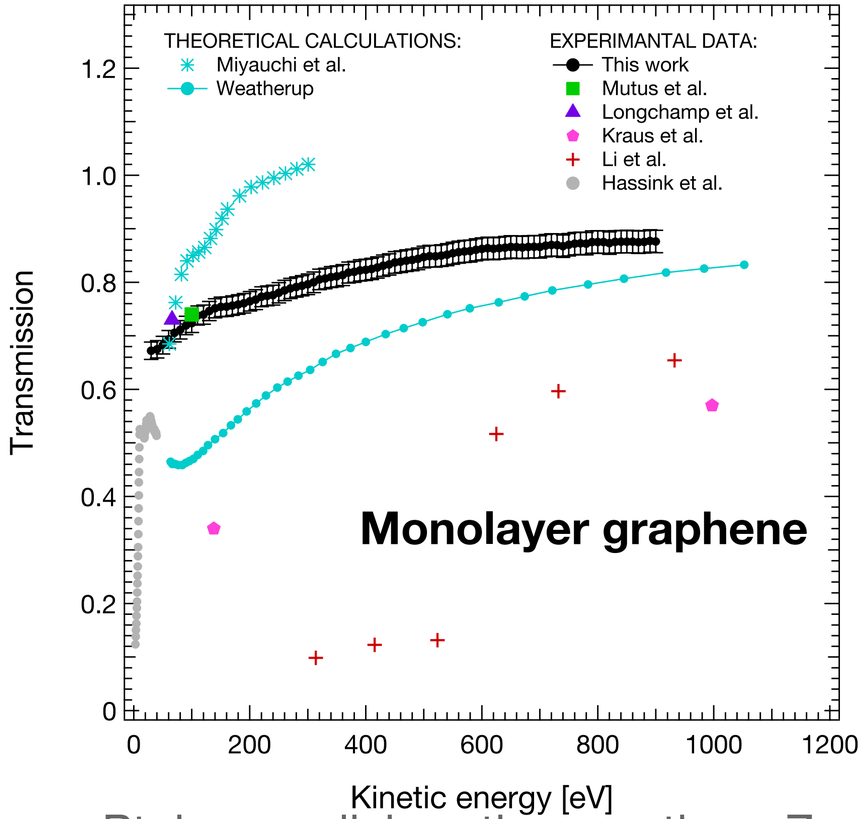
To conclude

Graphene characterisation with spectroscopy:

- Contaminants removed with 500°C in-vacuum annealing
- High quality graphene, C 1s mainly sp_2
- Evidence 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):

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



Graphene On meSH collaboration - GOSH

Alice Apponi, Università Roma Tre and INFN Roma3

Domenica Convertino, IIT Pisa

Neeraj Mishra, IIT Pisa

Camilla Coletti, IIT Pisa

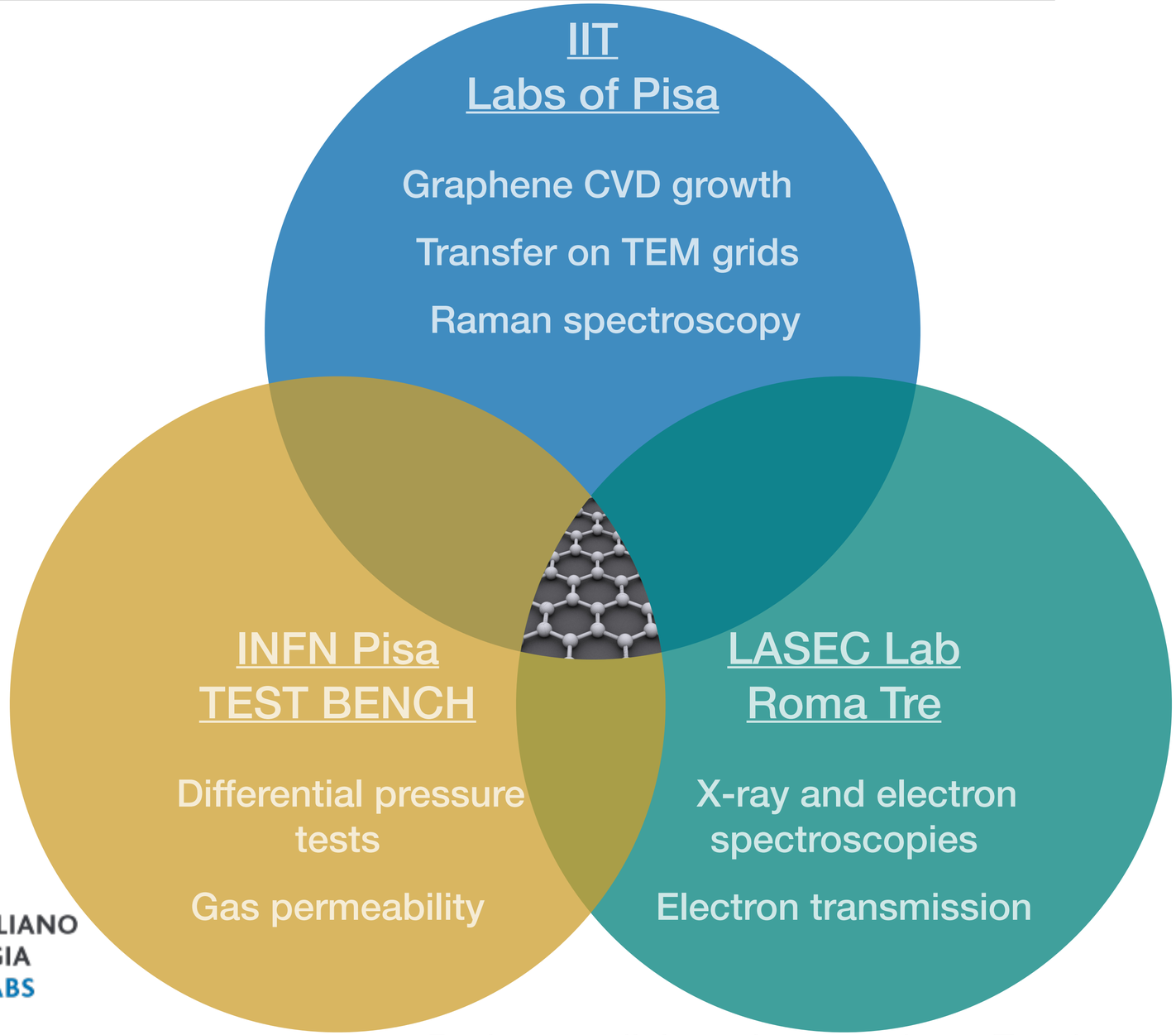
Mauro Iodice, INFN Roma3

Franco Frasconi, INFN Pisa

Federico Pilo, INFN Pisa

Gianluca Cavoto, Università Sapienza and INFN Roma

Alessandro Ruocco, Università Roma Tre and INFN Roma3



Backup slides