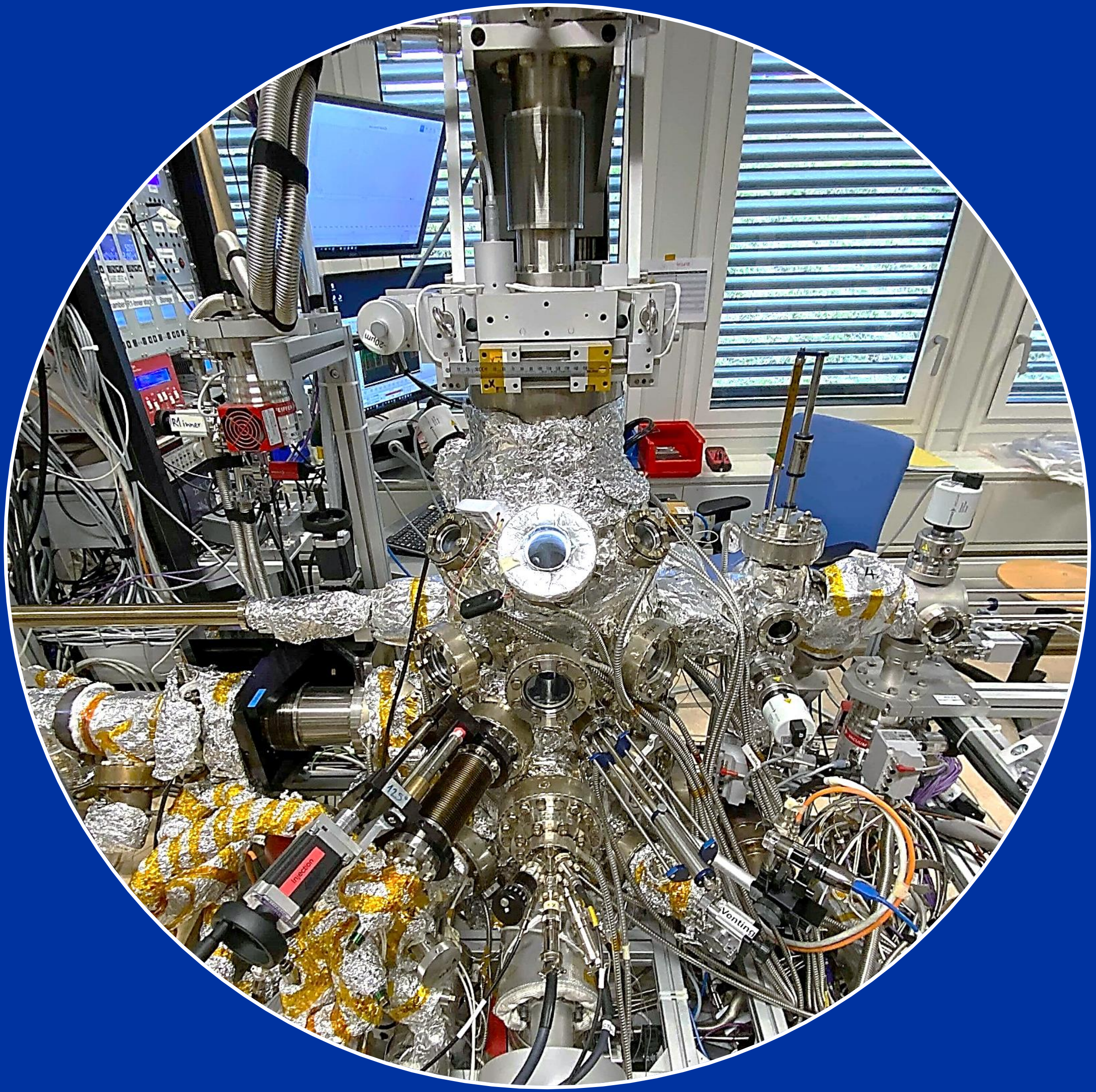
SEY and ESD of ices and technical surfaces at cryogenic temperatures



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TE-VSC-VSM, CERN
CTU in Prague, CZ

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Research motivation

Technical-grade metal surfaces

Polycrystalline, oxidized, porous, contaminated

Electron irradiation

Thermionic e^-

Multipacting e^-

Runaway e^-

Cosmic radiation

…

Cryogenic temperatures

Low diffusion rates

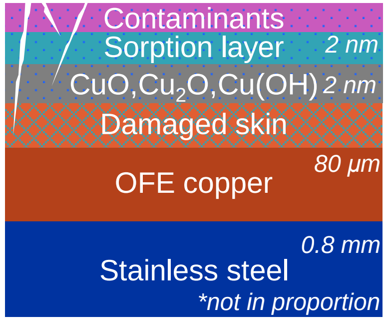
Cryosorbed gases

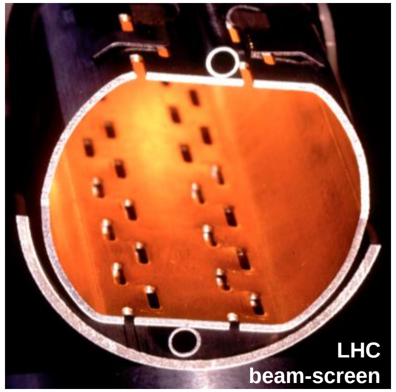
Cross-disciplinary interest

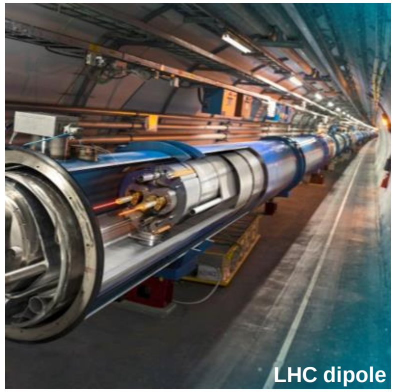
LHC-oriented

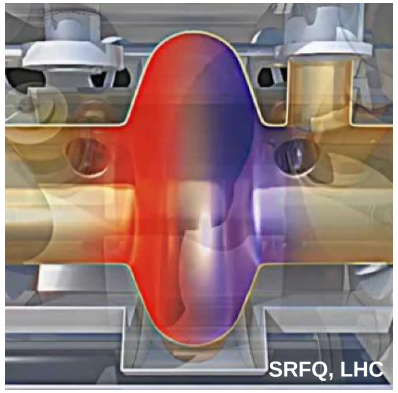
Other machines & applications

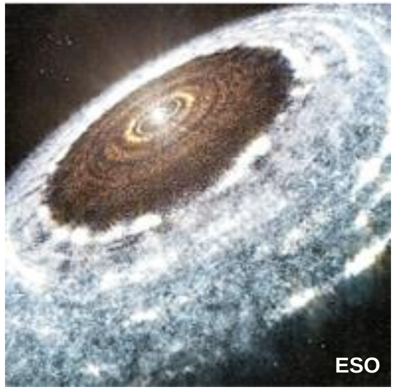
As received:



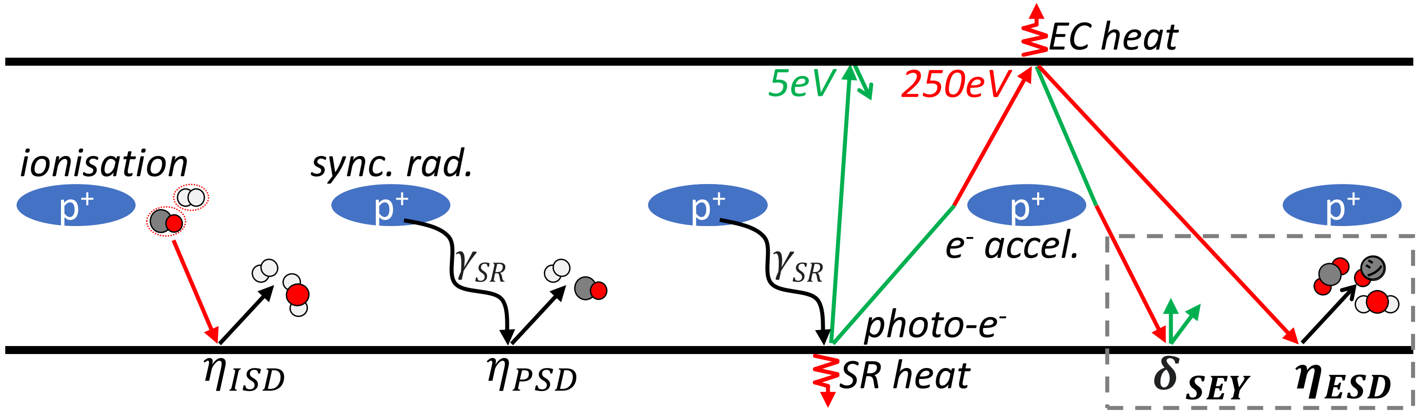


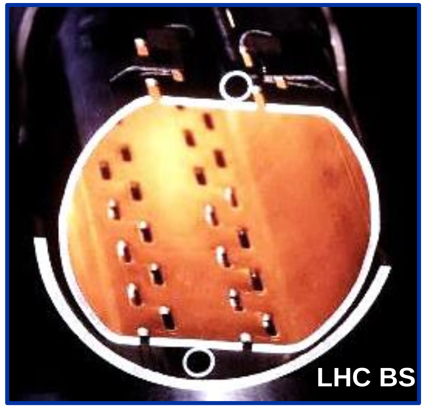






Dynamic vacuum effect in LHC





Electron cloud

Photoelectrons

Multipacting

Electrodesorption

Electrodesorption (ESD) yield: η_{e-}

Pressure rise: $\Delta p_{dyn.} \propto \frac{\eta_{e-} \cdot \dot{\Gamma}_{e-}}{S_{eff}}$

Consequences

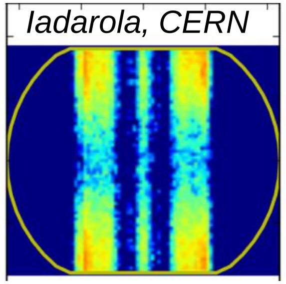
Beam instabilities, lifetime decrease

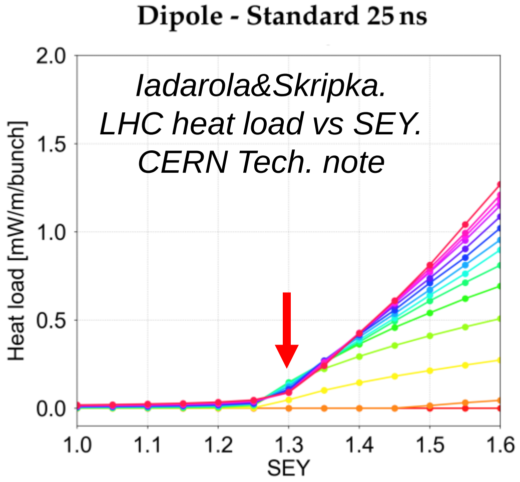
Heat load → temperature, pressure rise

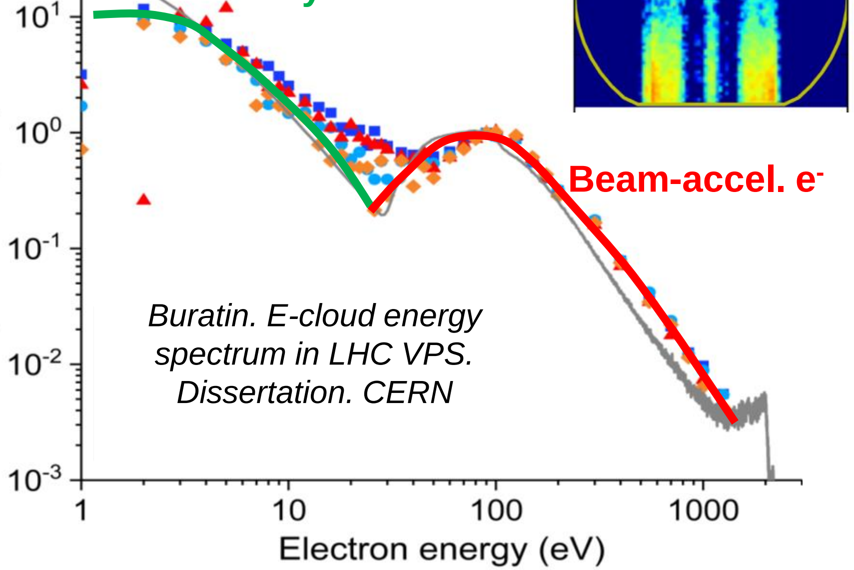
Electrical breakdown in RF devices

BG in detectors, Material activation

Performance limitation



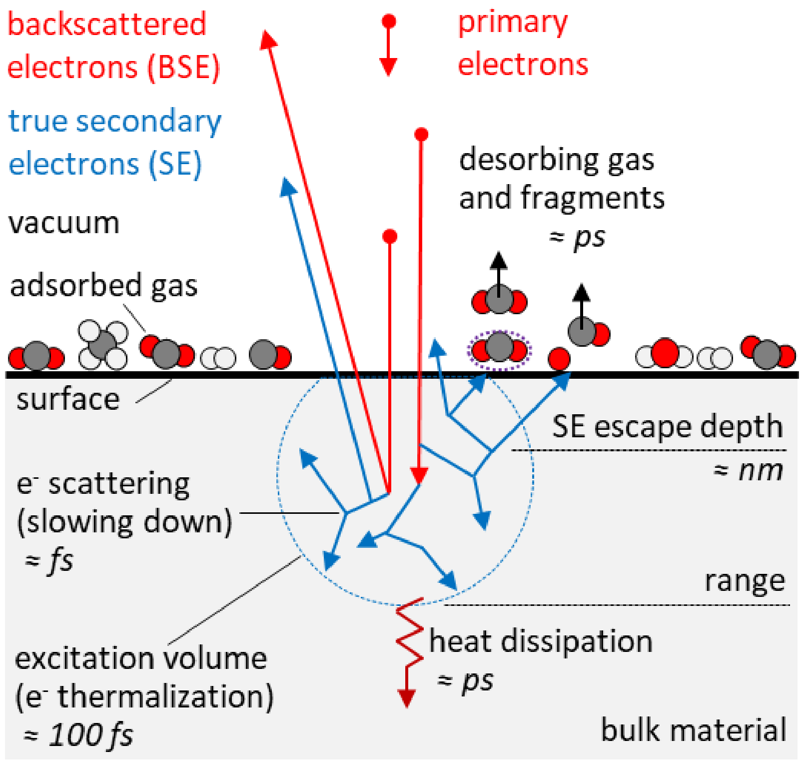




Parameters influencing the SEY and ESD

Material surface state:

- Surface composition
- Treatments & Coatings
- Cleaning
- Contamination
- Storage
- …



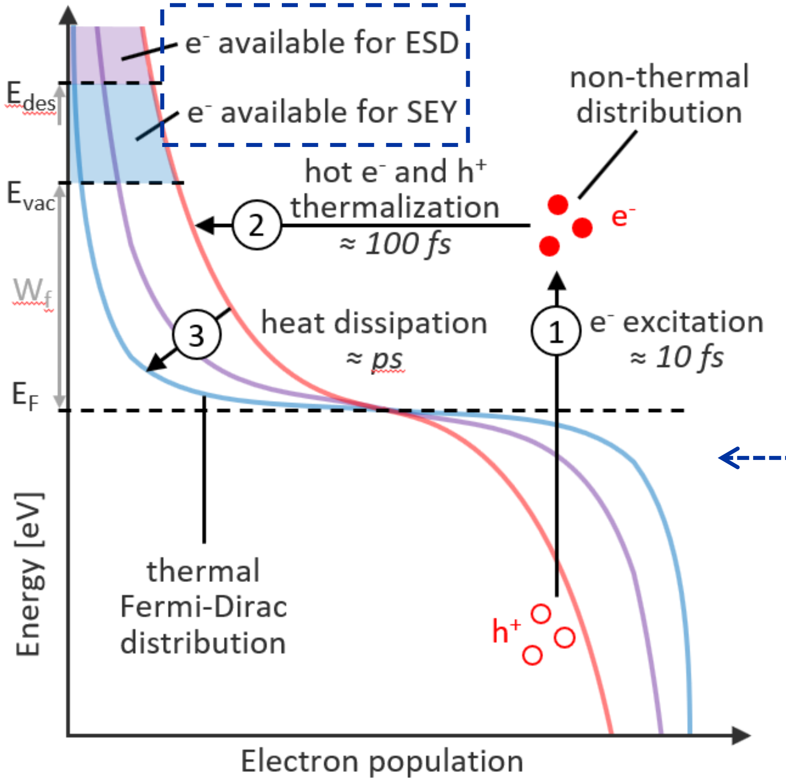
Electron irradiation:

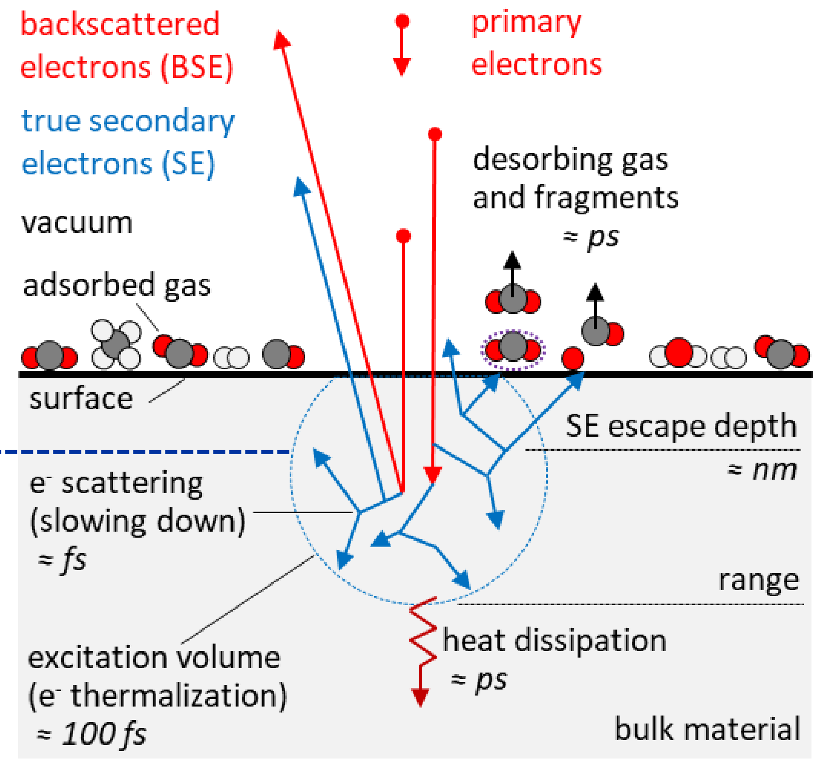
- Energy
- Dose
- Angle

Environment:

- Temperature
- Adsorbed gases

Electron and molecule emission





e^- impact energy is quickly redistributed:

first to e^- Fermi gas, then atoms

Born-Oppenheimer

Indirect energy transfer mechanism

from primary e^- to secondary particles

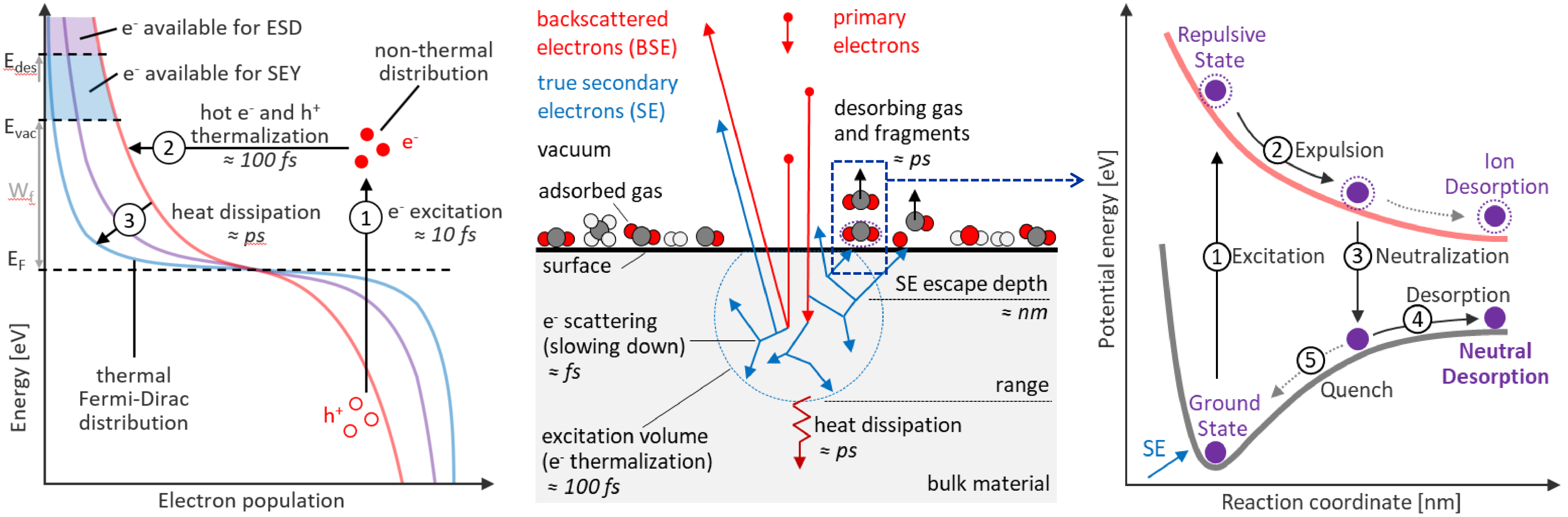
Energy invariance of emitted particles

Only fraction of e^- (over E_{vac},E_{des} tresholds)

can possibly contribute to SEY and ESD

$$\eta_{e-} \propto 1 / E_{BOND}$$

Electron and molecule emission



Experimental setup description

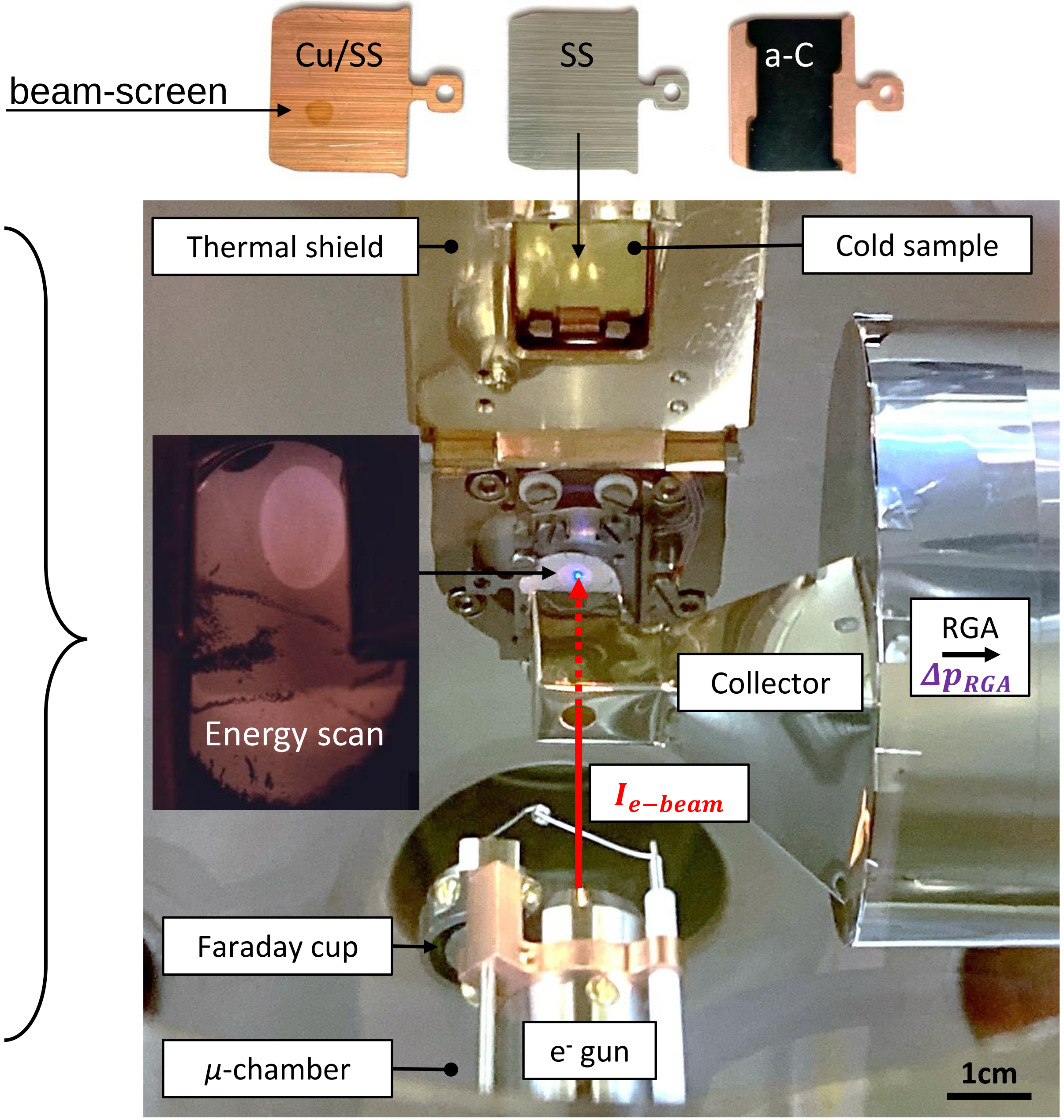
SEY, ESD, TPD capability at cold

Controllably reproduce LHC-like conditions:

10 K - 300 K	*T_{BS} = 5 - 20 K*
10^{-11} mbar	*hours till 1 Langmuir (10^{-6} Torr.s)*
0 - 1.5 keV	*E-cloud spectrum*
no B-field	*μ-metal chamber*

Experimental targets:

10^{-6} - 10^{3} molecule/e^-	*ESD sensitivity*
Cu, SS, Al, ...	*Unbaked metals*
a-Carbon, LESS, NEG	*Coatings and treatments*
N_2, CO, CO_2, CH_4, Ar,…	*Cryosorbed gases*

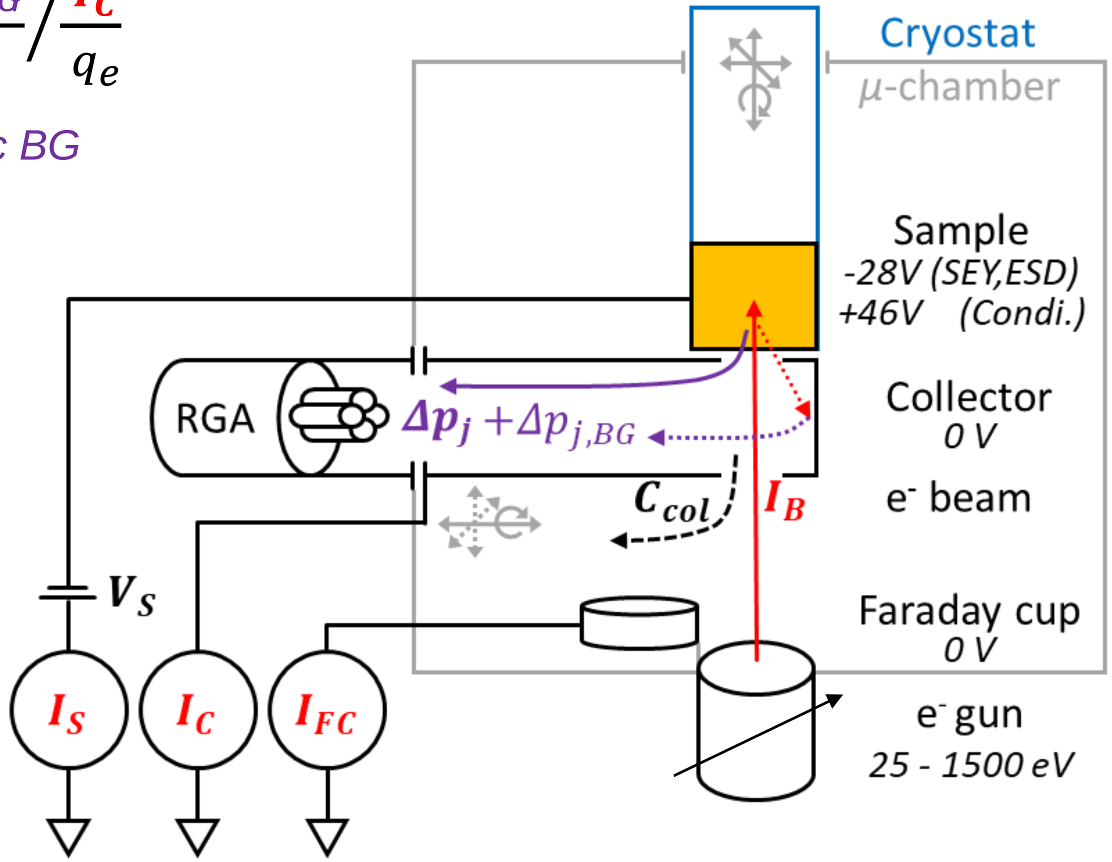


ESD and SEY measurement

ESD yield: $$\eta_{e,j}(E,D) = \frac{C_j.\Delta p_j}{k_B.T} \Big/ \frac{I_B}{q_e} + \frac{C_j.\Delta p_{j,BG}}{k_B.T} \Big/ \frac{I_C}{q_e}$$

Signal + *Dynamic BG*

SEY: $$\delta(E,D) = \frac{I_{SE}}{I_B} = \frac{I_C}{I_C + I_S}$$



Collector

- Closed geometry to capture molecules and e⁻
- Simultaneous SEY and ESD measurement
- Conductance-limited pumping, defined by geometry
- *Gas dosing possibility*

Low-energy

- Retarding sample bias to reach 0 eV

SEY measurement

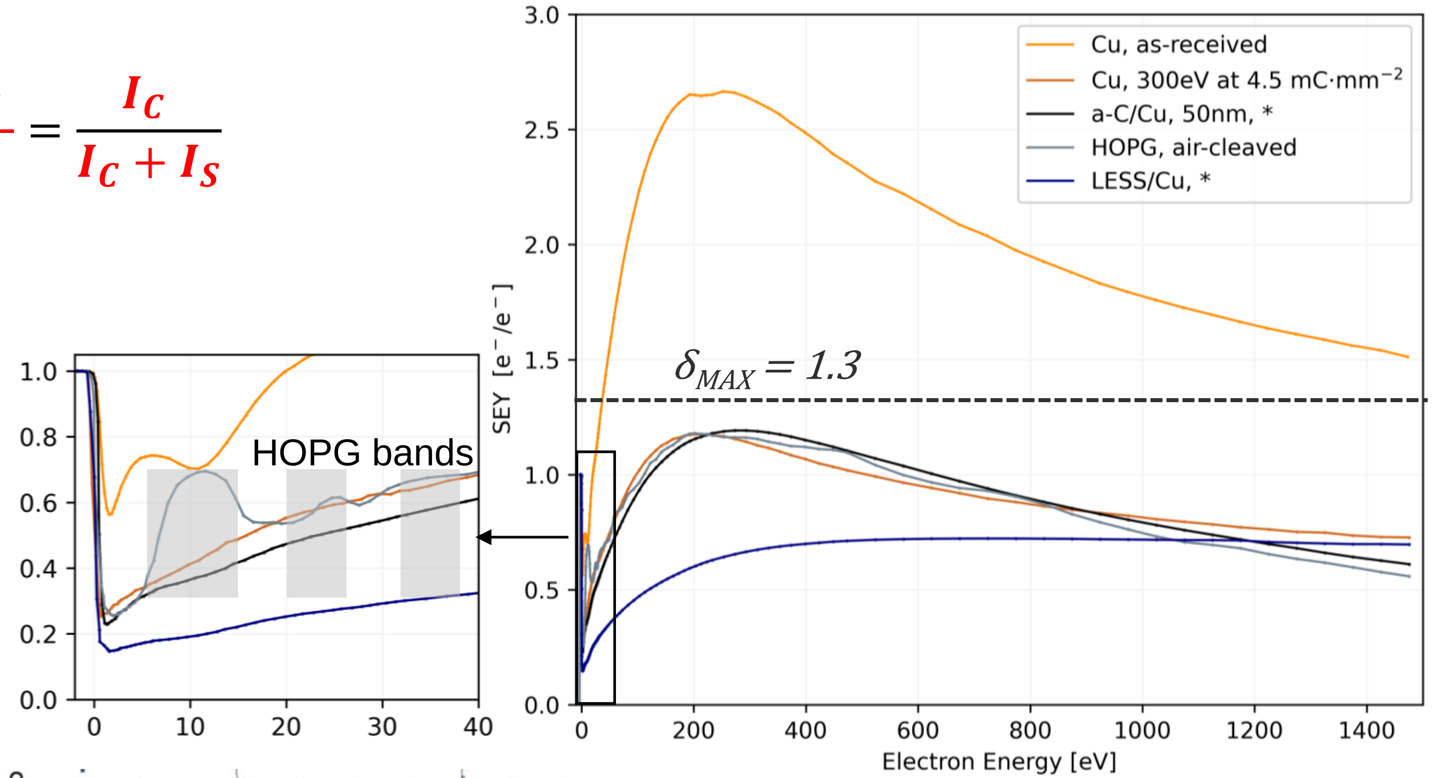
Secondary electron yield: $$\delta(E,D) = \frac{I_{SE}}{I_B} = \frac{I_C}{I_C + I_S}$$

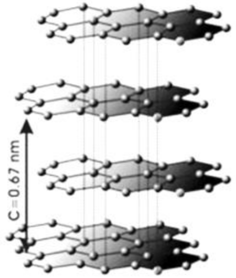
Engineering relevance

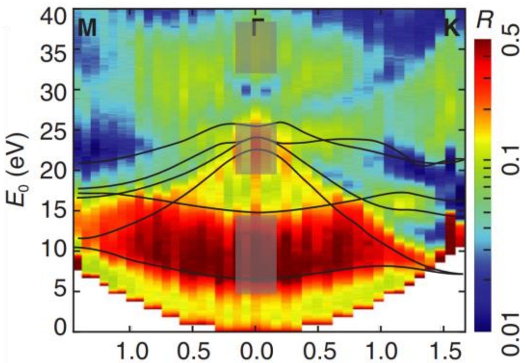
- LHC e$^-$ multipacting limit
- Similar SEY shape between conditioned Cu, a-C & HOPG

Mean of calibration

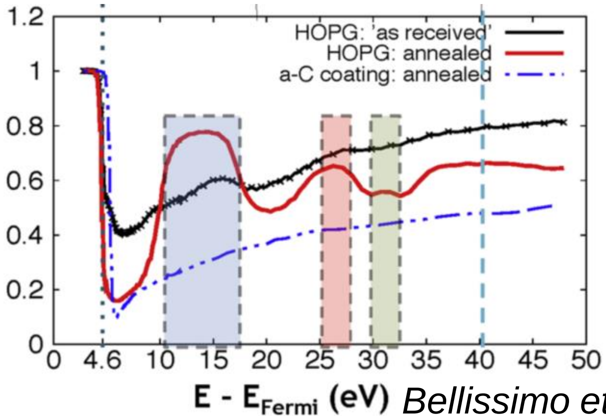
- Set energy scale, verify resolution
- HOPG reference – Checks with other labs
- HOPG bands imprint onto the LE-SEY







Geelen et al.



Bellissimo et al.

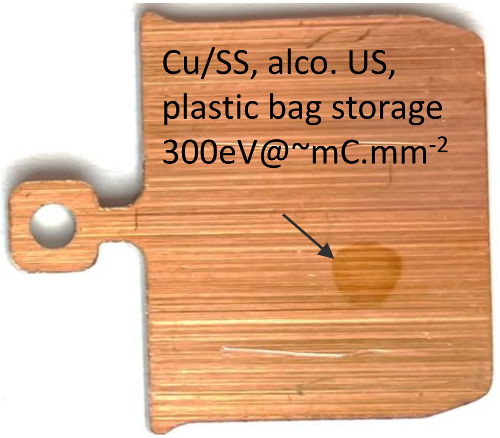
SEY: Cold Cu conditioning at low and high energy

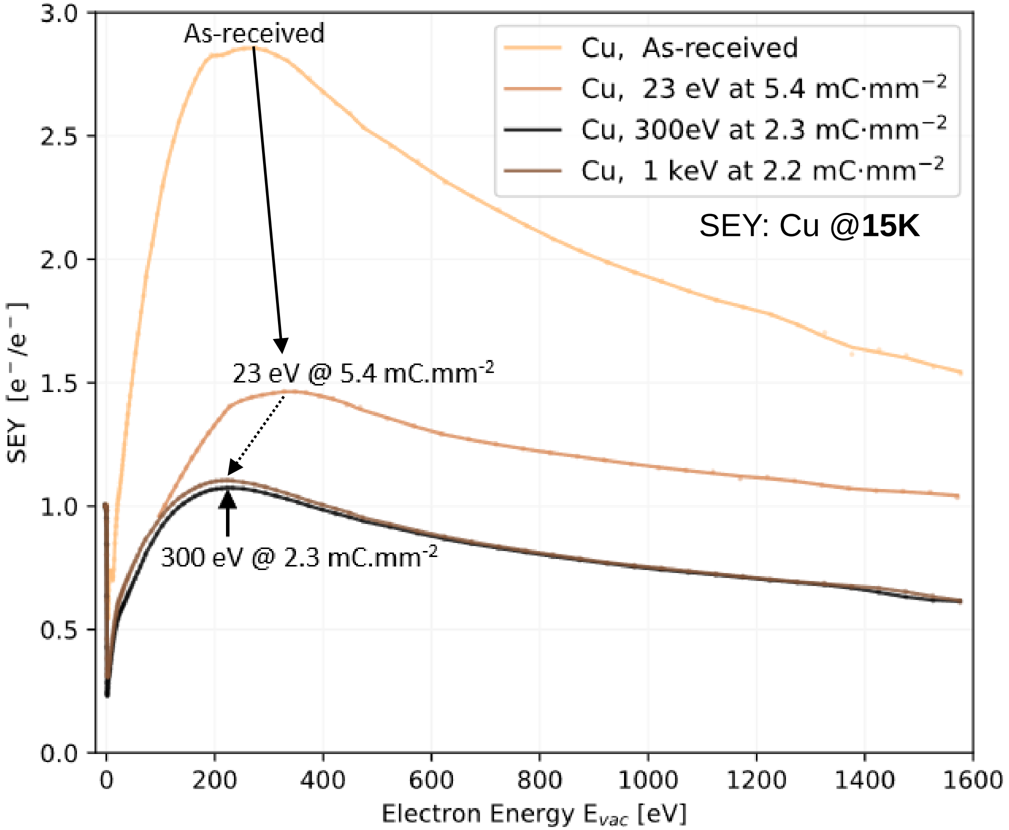
Conditioning Decrease of SEY and ESD with e^- dose

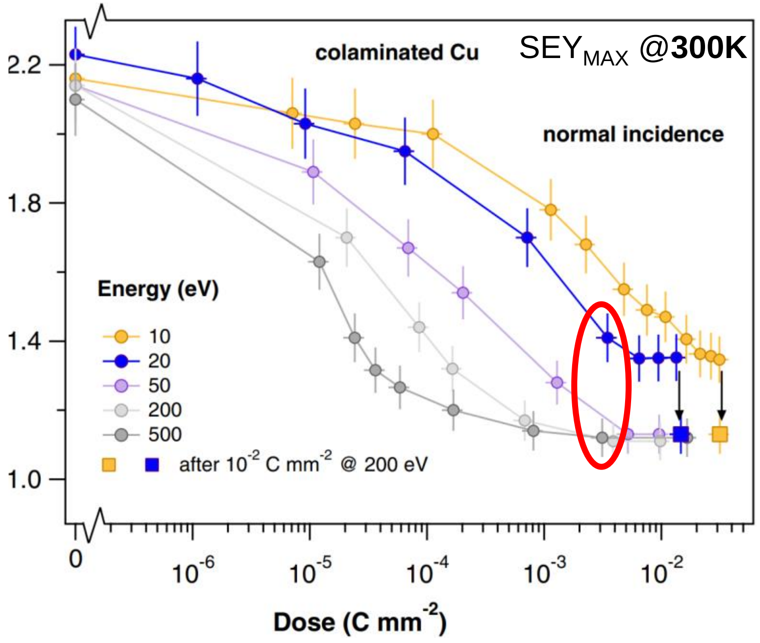
SEY scrubbing: Depletion of adsorbed gas & **formation of a graphitic layer**

High energy electrons are necessary for graphitization.

Known at 300K → **Same story at 15K**, confirmed by C_{1s} peak on XPS







Cimino et al. Nature of the Decrease of SEY by Electron Bombardment and its Energy Dependence. 2012

SEY: Warm Cu conditioning vs initial surface state

Conditioning Decrease of SEY and ESD with e^- dose

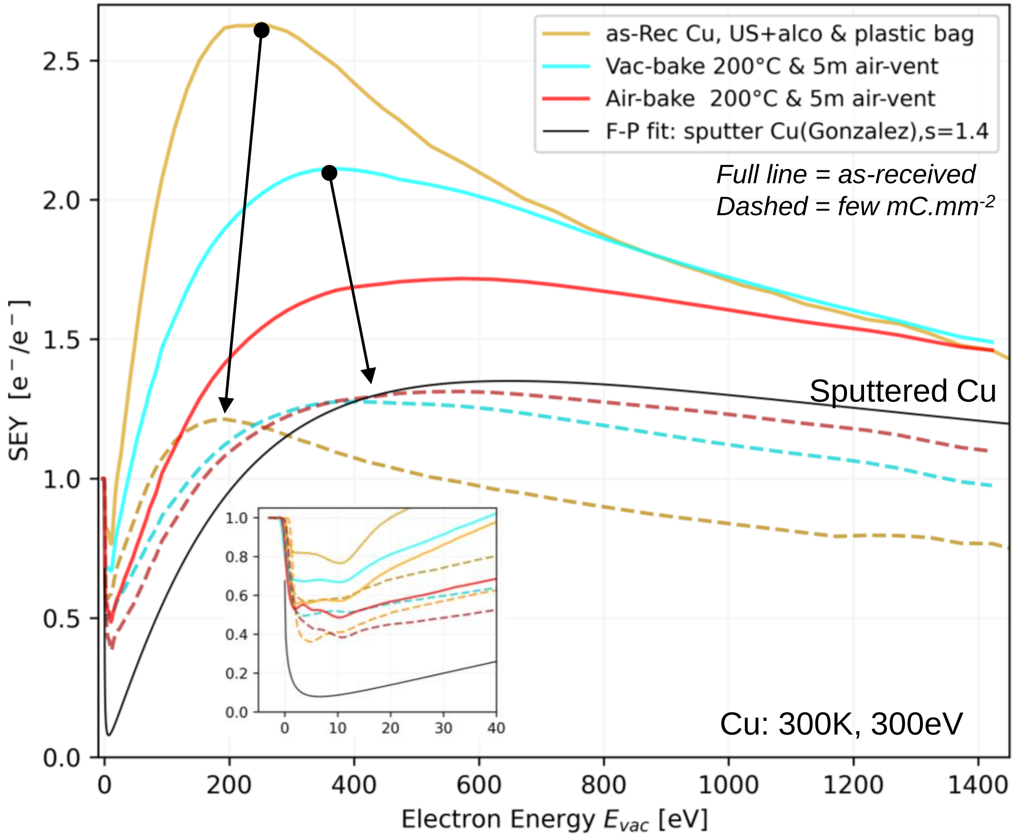
SEY scrubbing: Depletion of adsorbed gas **& formation of a graphitic layer**

Surface-bound carbon is necessary for graphitization

As-received shape indicates a graphitization potential, $E_{MAX} \approx 200$ eV

"Carbon c'est bon" Nishiwaki & Kato. (2009). Graphitization of inner surface of copper beam duct of KEKB positron ring. Vacuum.

Scheuerlein et al. 2002. An AES study of the room temperature conditioning of technological metal surfaces by electron irradiation. Applied Surface Science.



SEY: Cold Cu conditioning vs residual gas composition

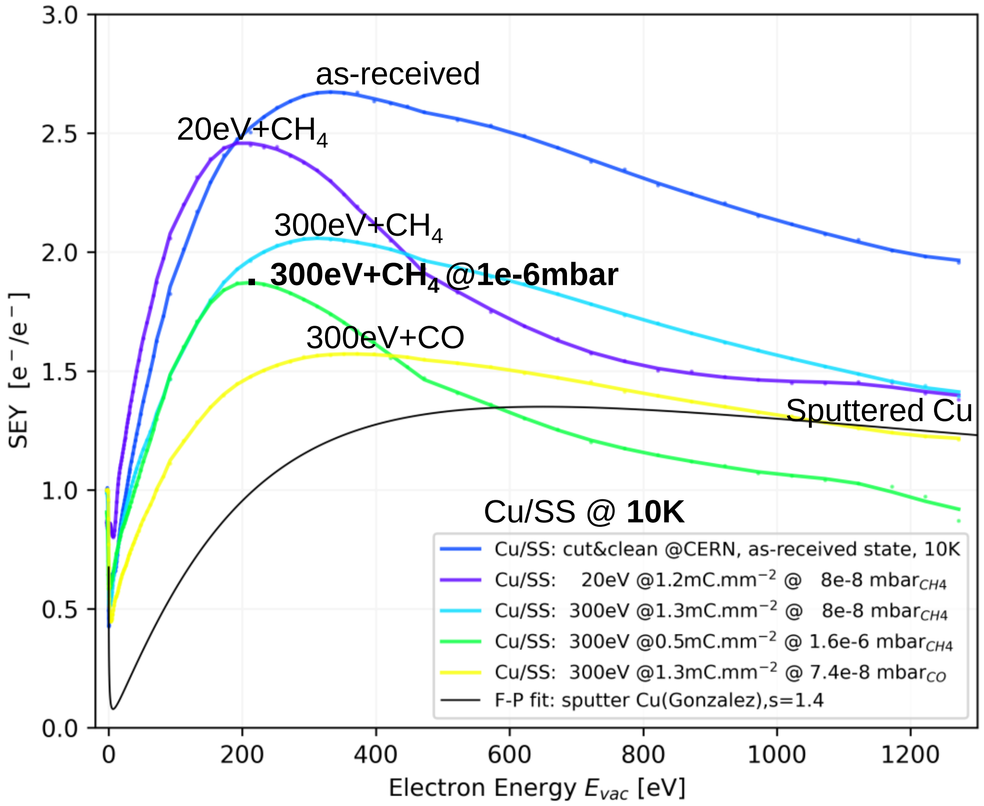
Conditioning Decrease of SEY and ESD with e$^-$ dose

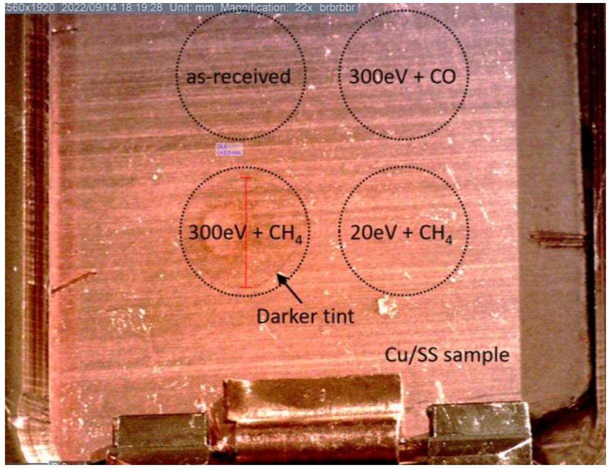
SEY scrubbing: Depletion of adsorbed gas & **formation of a graphitic layer**

The carbon-rich residual gas is insufficient to aid graphitization at this setting (at UHV and 10K)

"Carbon c'est bon" Nishiwaki & Kato.. (2009). Graphitization of inner surface of copper beam duct of KEKB positron ring. Vacuum

Scheuerlein et al. 2002. An AES study of the room temperature conditioning of technological metal surfaces by electron irradiation. Applied Surface Science





Loose follow-up on a 300K study:
Scheuerlein & Taborelli. Electron stimulated carbon adsorption in ultrahigh vacuum monitored by AES. *JVST-A,* 2002.

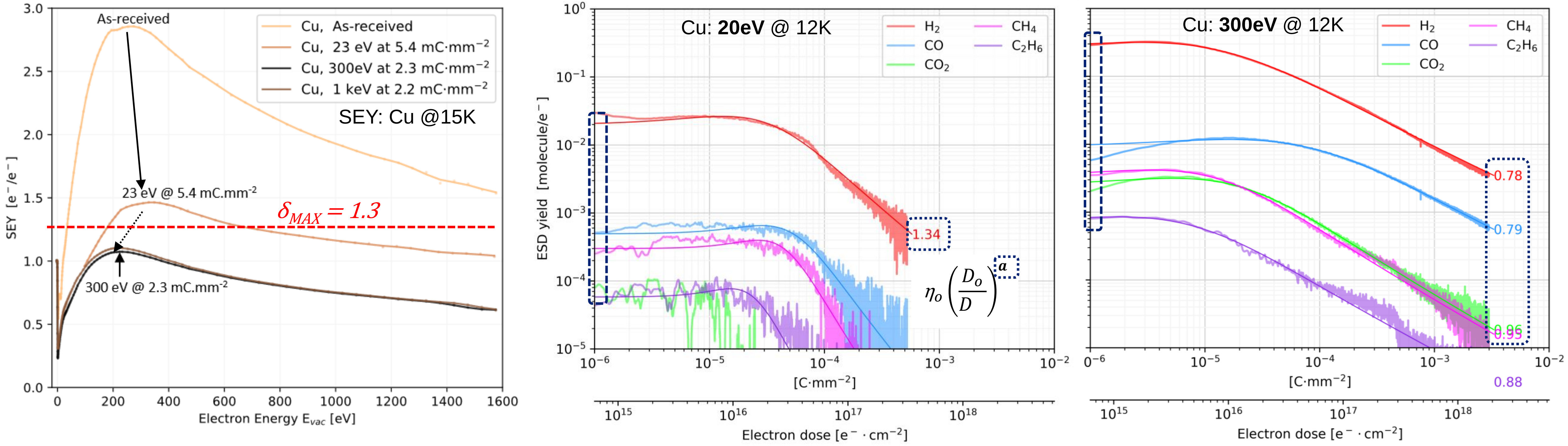
ESD: Cold Cu conditioning at low and high energy

Conditioning Decrease of SEY and ESD with e^- dose

SEY scrubbing Depletion of adsorbed gas & formation of graphitic layer

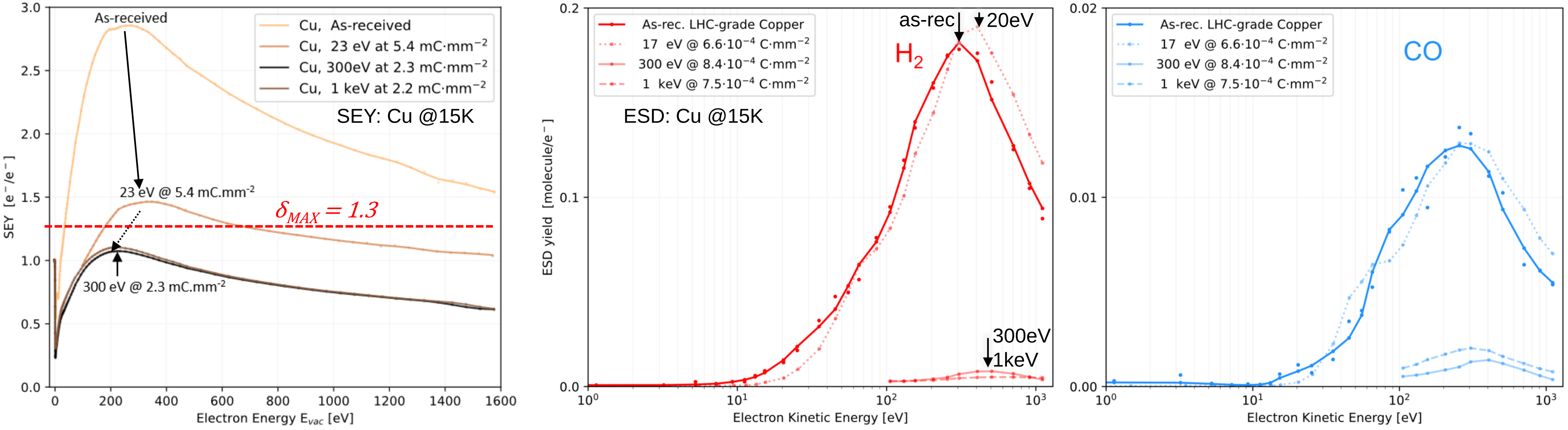
ESD conditioning: **Depletion of adsorbed gas**

Lower ESD yield at high e^- dose → Lower pressure rise due to e-cloud



ESD: Cold Cu conditioning at low and high energy

Conditioning	Decrease of SEY and ESD with e⁻ dose
SEY scrubbing	Depletion of adsorbed gas & formation of graphitic layer
ESD conditioning:	**Depletion of adsorbed gas**
	Lower ESD yield at high e⁻ dose → Lower pressure rise due to e-cloud
	20 eV do little - 300 eV conditions best - 1 keV is not proportionally more efficient



ESD energy dependence: Warm Cu

Main desorbing gases: H_2, CO, CO_2, CH_4, C_2H_6, Ar, H_2O

Threshold around 10eV

zero for: $E_{KIN,\,e-} < E_{THR}$

Linear until ~200 eV

$D_{DEPO} << D_{ESC}$

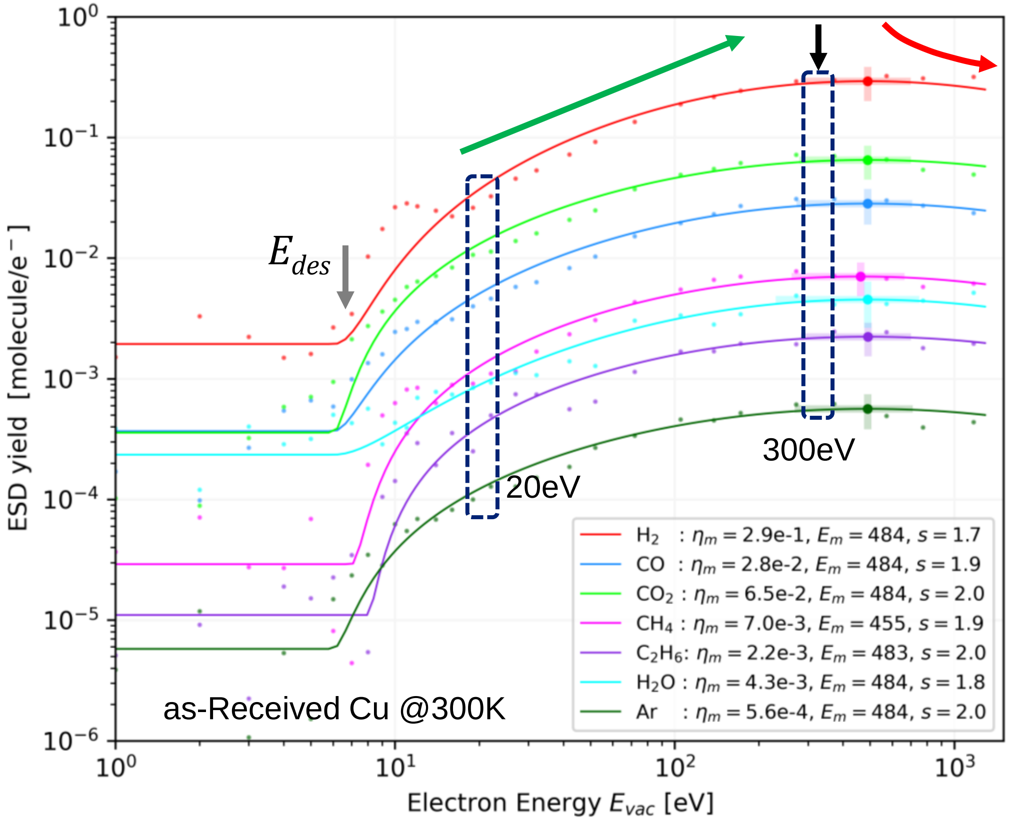
Peak at few hundred eV

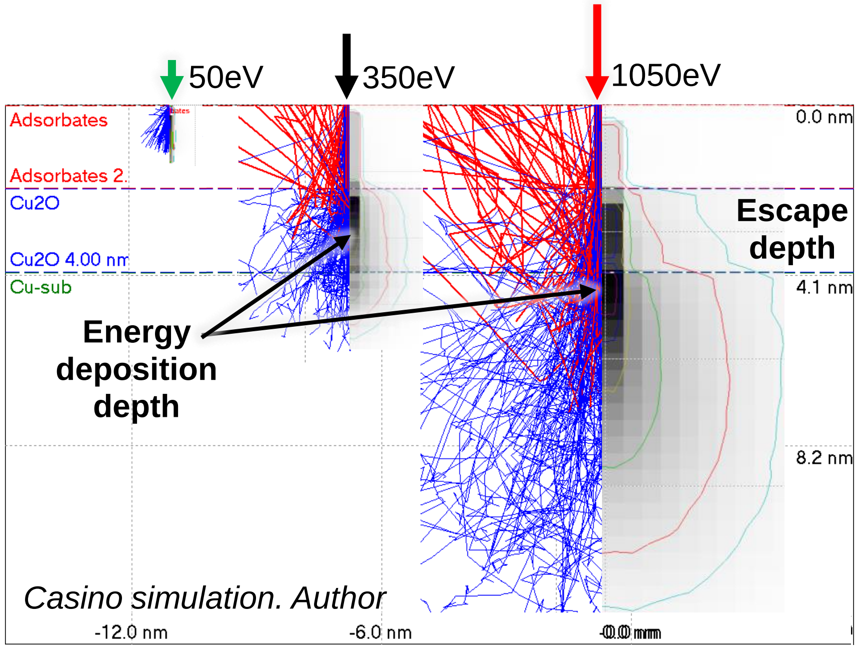
$D_{DEPO} \approx D_{ESC}$

Decay above ~1 keV

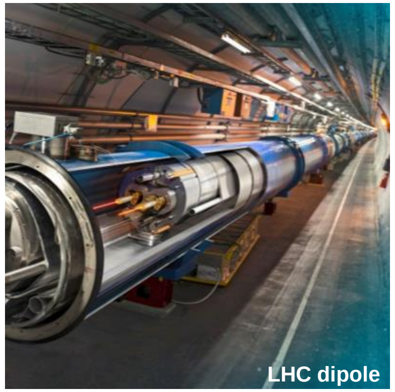
$D_{DEPO} >> D_{ESC}$

Follows the DIET theory





From SEY & ESD to Δp_j



Knowing the SEY ↔ EC ↔ ESD interplay allows calculating the dynamic pressure rise due to ESD

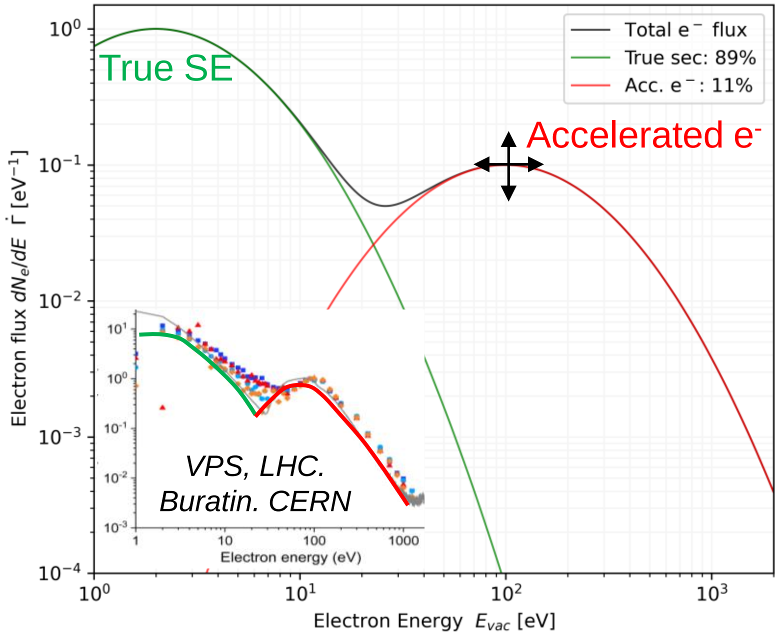
Most of $\boldsymbol{\Delta p_j}$ is caused by the beam-accelerated e⁻

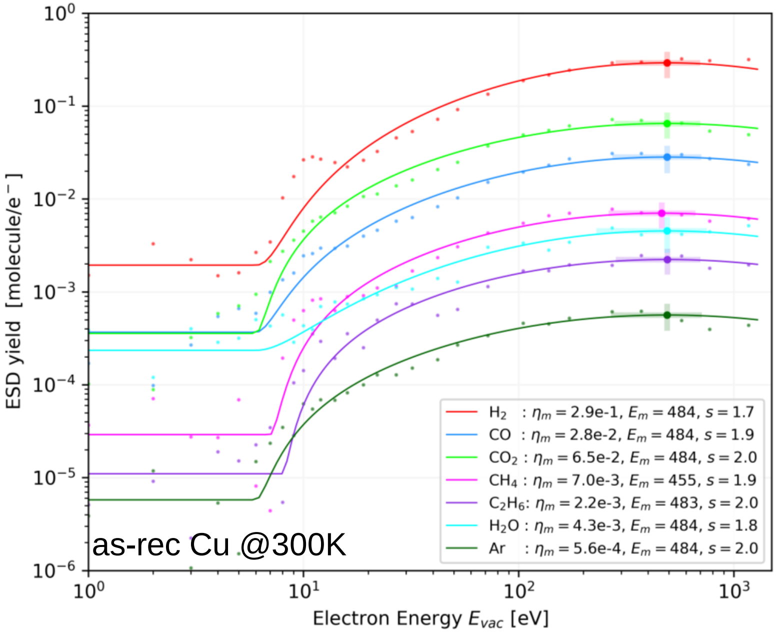
$$\dot{r}_{e-}(E,D) \quad * \quad \eta_{e-,j}(E,D) \quad \propto \quad Q_j/S_j = \Delta p_j$$

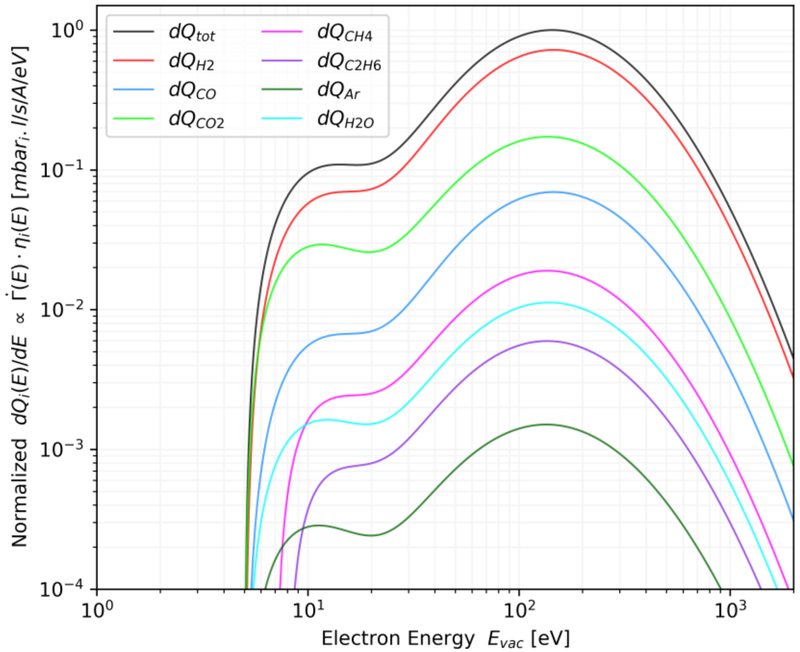
2x: $\dot{r}_{e-}(E) = \dot{r}_{max}.\exp(\frac{-\ln^2(E/E_{max})}{2\sigma^2})$

$\eta(E) = \eta_{max}.\exp(\frac{-\ln^2((E-E_{thr})/E_{max})}{2\sigma^2}) + \eta_{BG}$

ESD gas load per eV



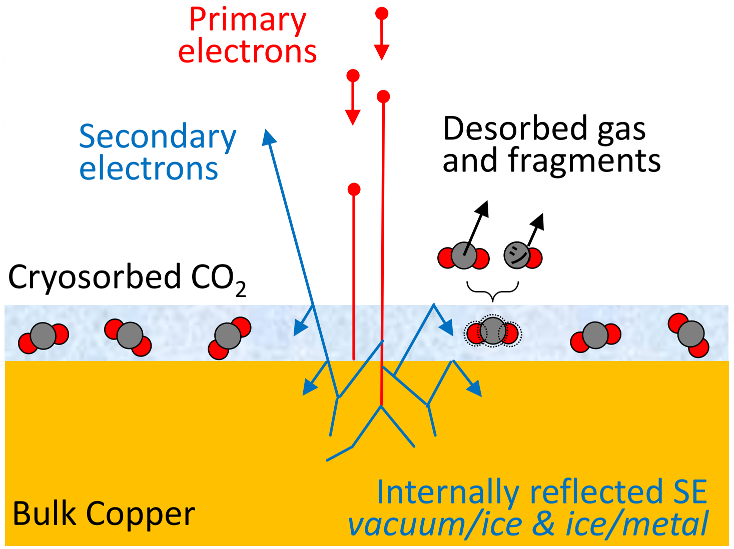


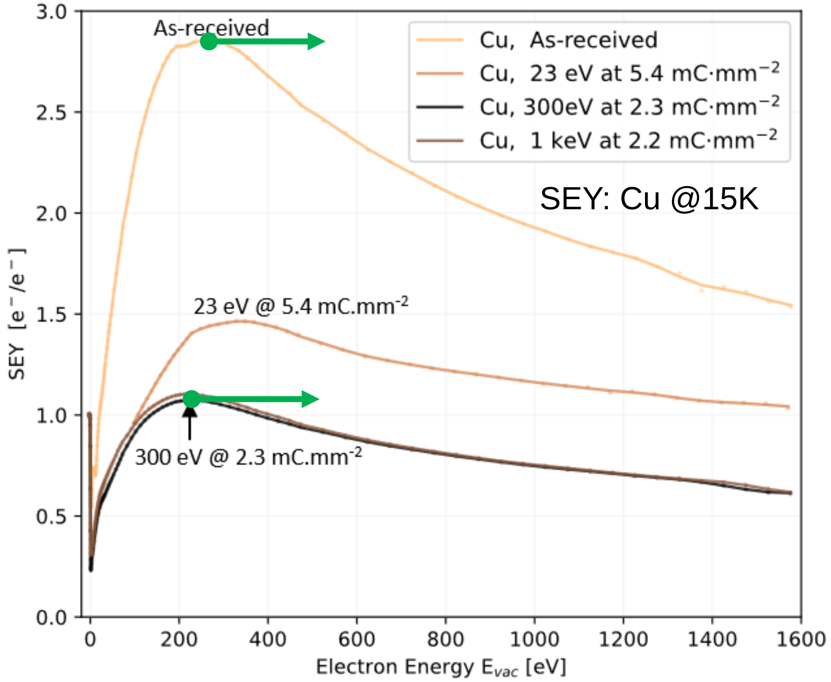


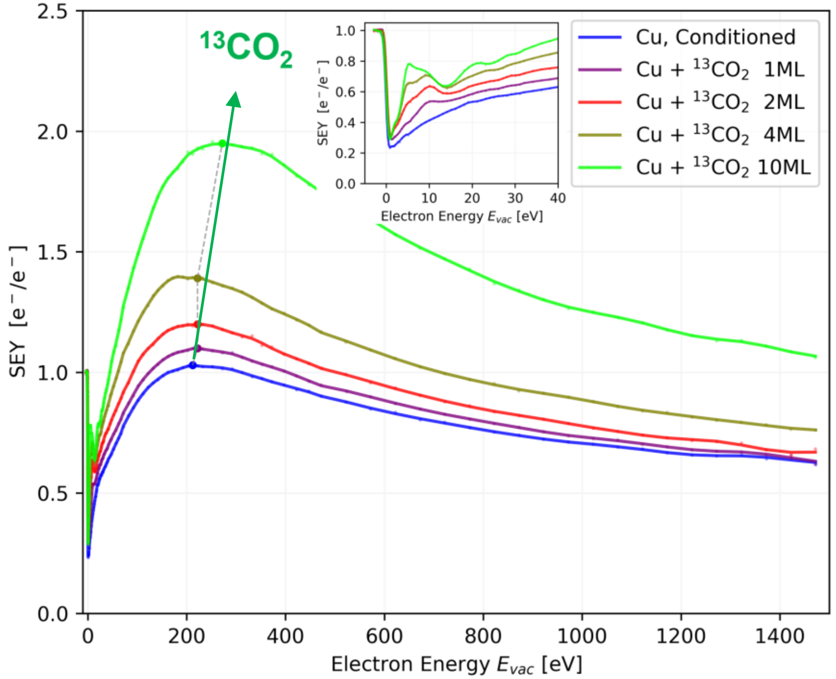
SEY: gas on conditioned Cu

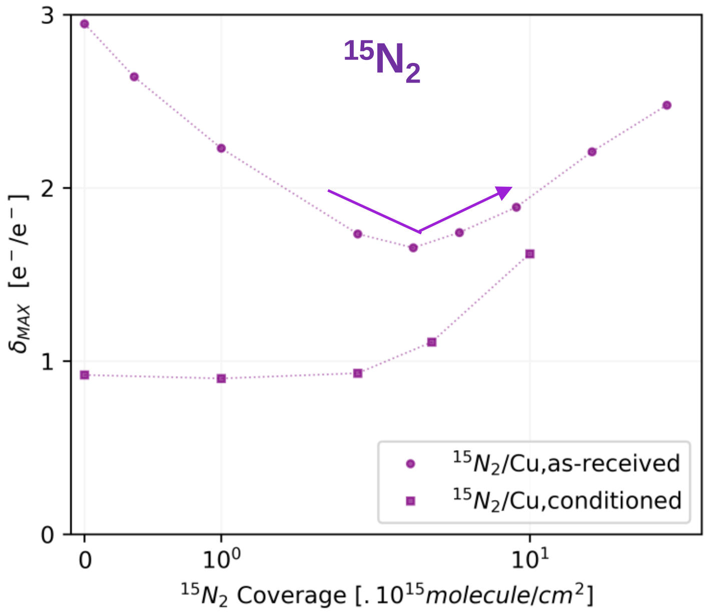
Ice = cryosorbed gas, weakly-bound

SEY is substrate-agnostic @10ML (non-porous)









SEY: gas on conditioned Cu

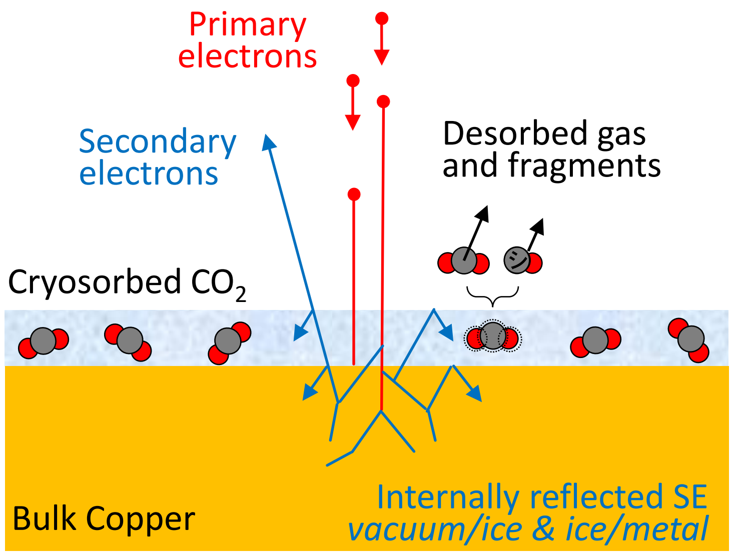
Ice = cryosorbed gas, weakly-bound

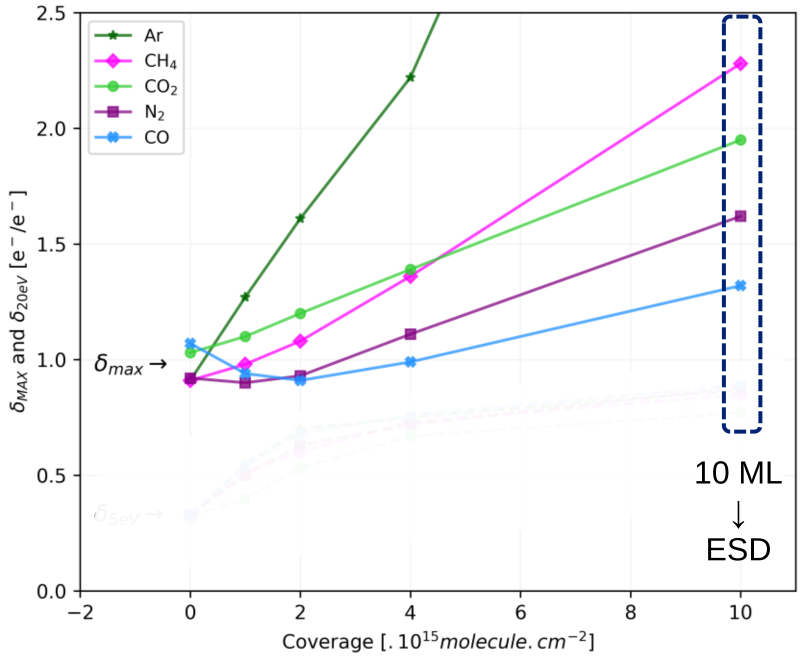
SEY is substrate-agnostic @10ML

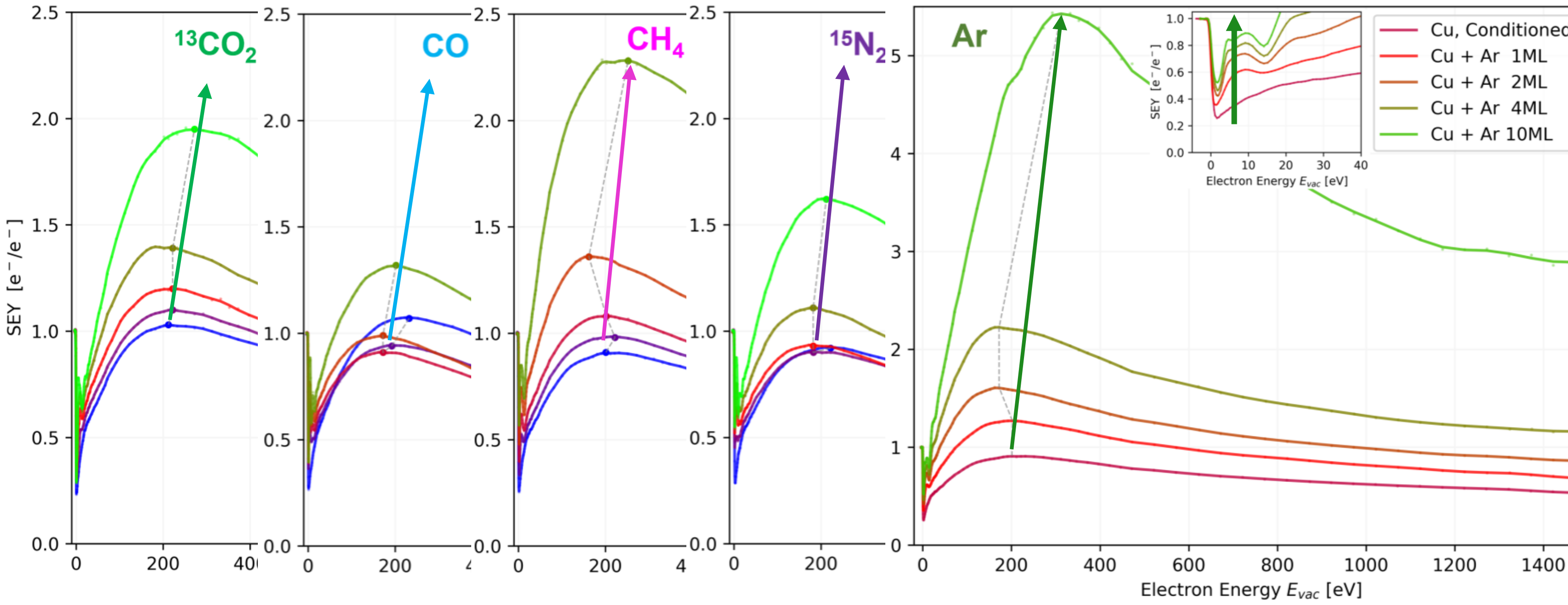
LE-SEY is particularly sensitive, even low coverages

Higher δ_{MAX} and E_{MAX} → e^- multipacting

Higher reflectivity at LE-SEY → e^- survival → faster EC build-up transients







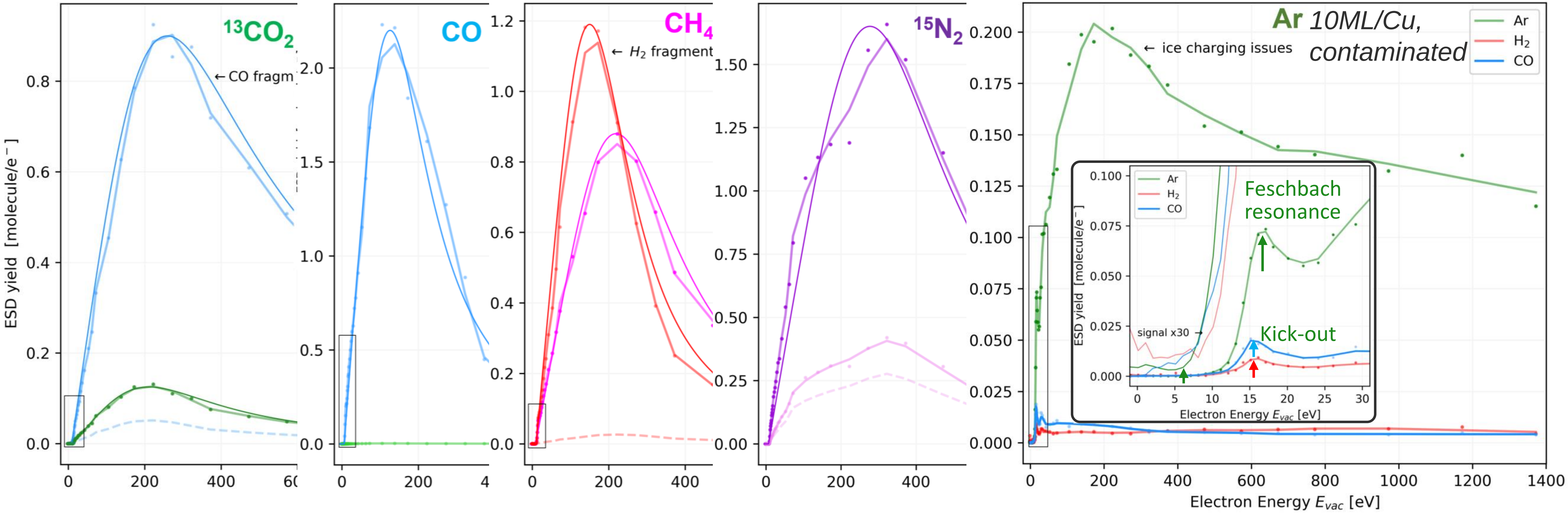
ESD of ices at 10ML

Ice = cryosorbed gas, weakly-bound

→ high ESD yields

→ significant cracking, induced by SE

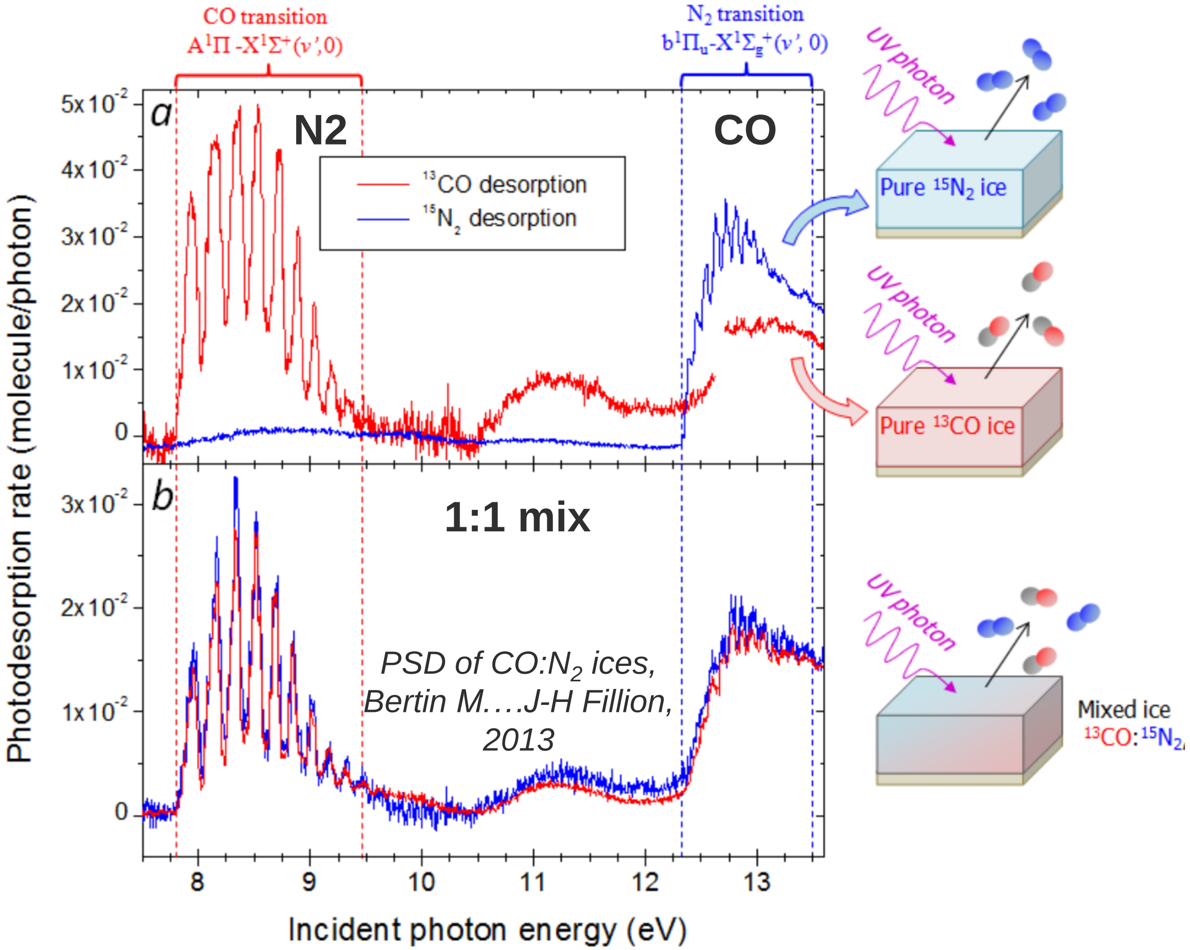
$$\eta(E) = \boldsymbol{\eta_{max}} \cdot \exp\left(\frac{-\ln^2((E - \boldsymbol{E_{thr}})/\boldsymbol{E_{max}})}{2\boldsymbol{\sigma}^2}\right)$$

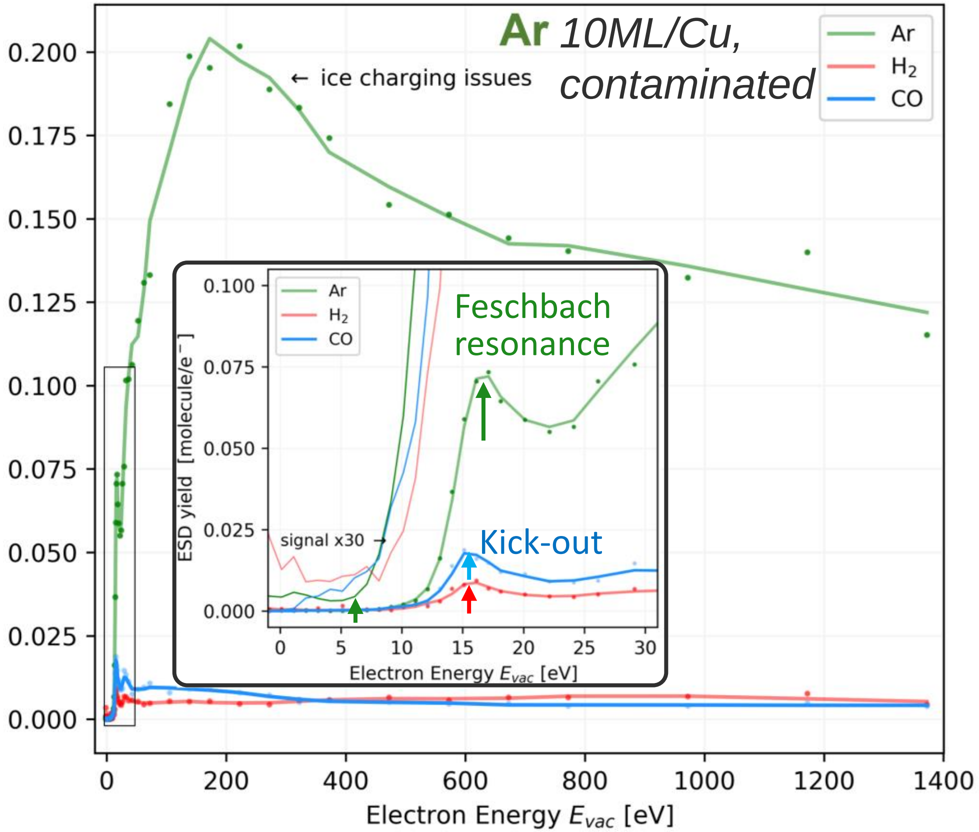


ESD of ices at 10ML

Mutual ESD yield influence in a mixture

Both enhancement and quench are possible





Binary ices: SEY & ESD at 10ML

Non-linear mapping of SEY & ESD with composition

Linear averaging leads to factor ~2 errors

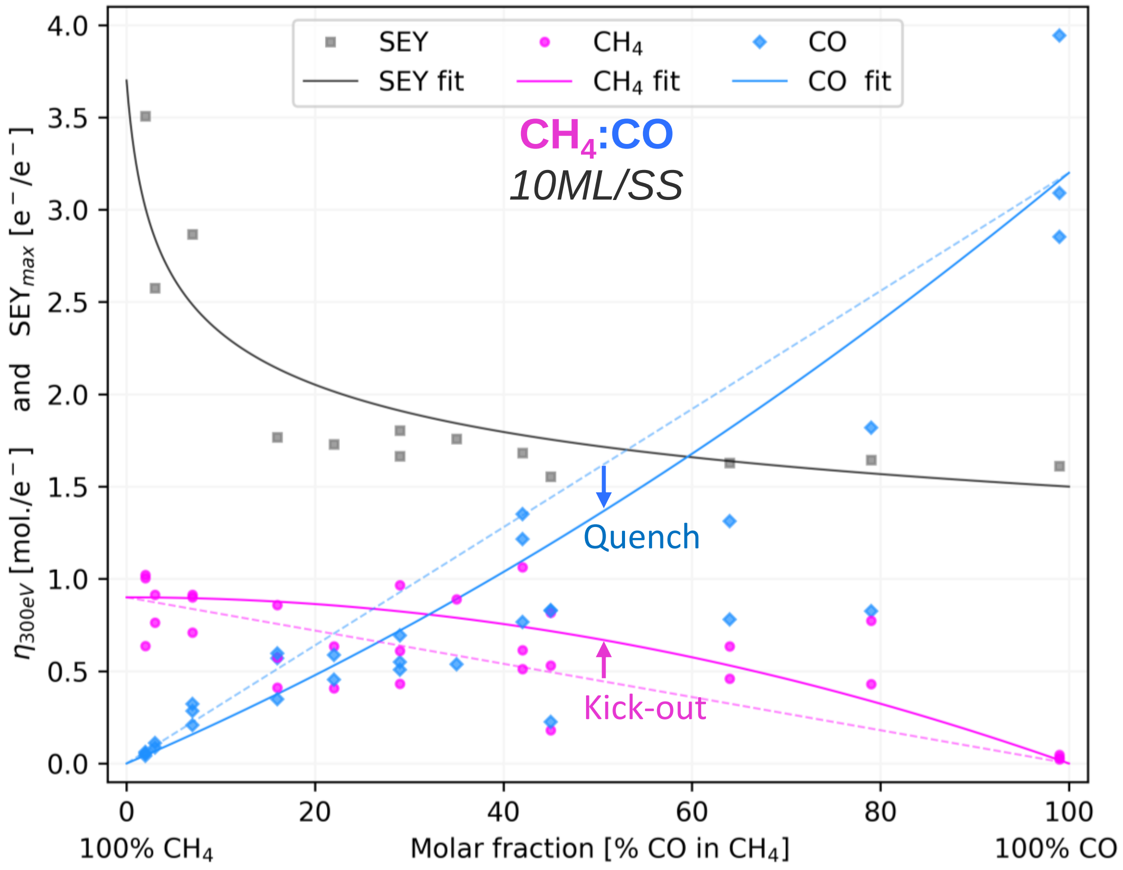
Mutual influence of desorption yields also observed in PSD:

- Bertin, M., Fayolle, E. C., Romanzin, C., Poderoso, H. A., Michaut, X., Philippe, L., ... & Fillion, J. H. (2013). Indirect Ultraviolet Photodesorption From CO: N2 Binary Ices—an Efficient Grain-gas Process. *The Astrophysical Journal*, *779*(2), 120.

Quenching behaviour is also known:

- Dupuy, R., Haubner, M., Henrist, B., Fillion, J. H., & Baglin, V. (2020). Electron-stimulated desorption from molecular ices in the 0.15–2 keV regime. Journal of Applied Physics, 128(17), 175304.
- Reimann, C. T., W. L. Brown, and R. E. Johnson. Electronically stimulated sputtering and luminescence from solid argon. *Physical Review B* 37.4 (1988): 1455.

ESD and SEY often anticorrelate in thick ices (!)



Binary ices: SEY & ESD at 10ML

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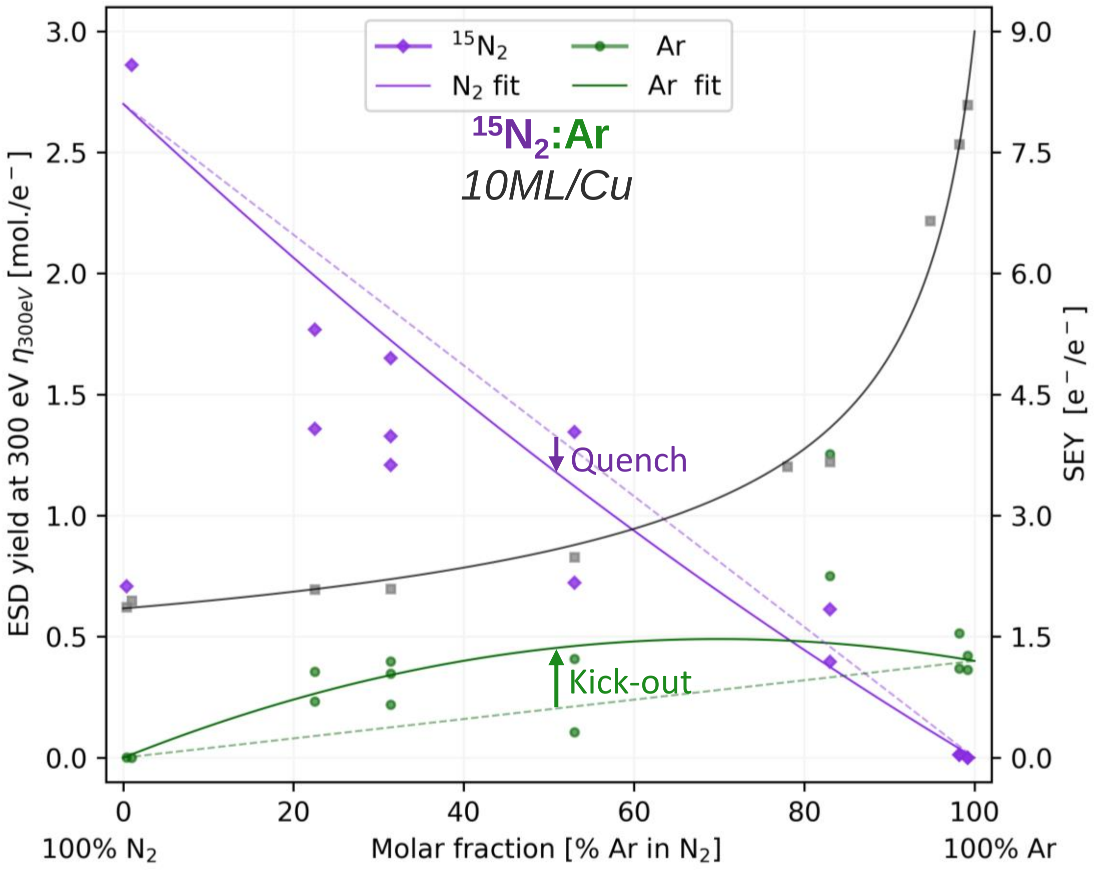
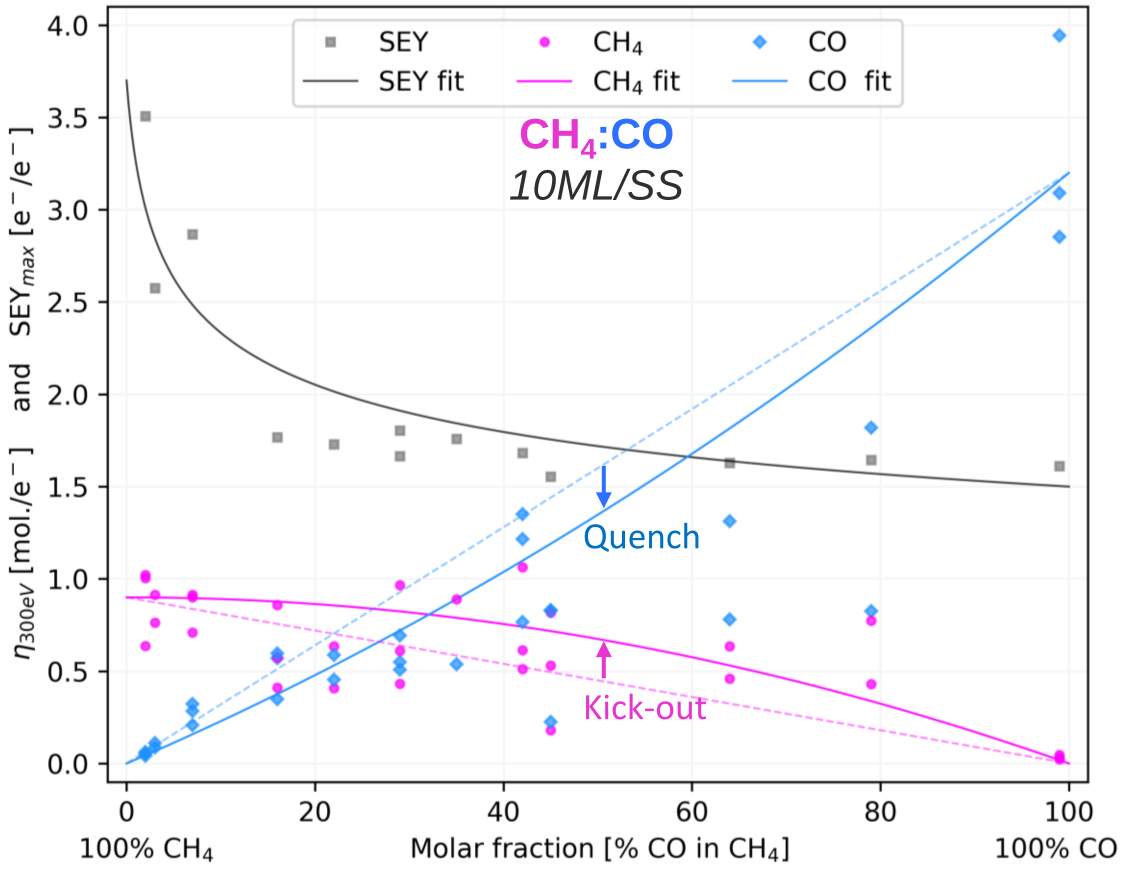




Binary ices: simple model for SEY & ESD

Simple model: *k≈0.5, n=3~5*

SEY: $\delta_{A:B,max}(x) = \sqrt[n]{(x-1).\eta^n_{A,max} + x.\delta^n_{B,max}}$

ESD: $\eta_{A:B\to A}(x) = (x-1)\ .\eta_A \ + \eta_B\ .x(x-1)\ .\frac{\eta_B - \eta_A}{\eta_A + \eta_B}\ .k^{sign(B-A)}$

$\eta_{A:B\to B}(x) = x\ .\eta_B \ + \eta_A\ .x(x-1)\ .\frac{\eta_A - \eta_B}{\eta_A + \eta_B}\ .k^{sign(A-B)}$

Possible generalization to n-components

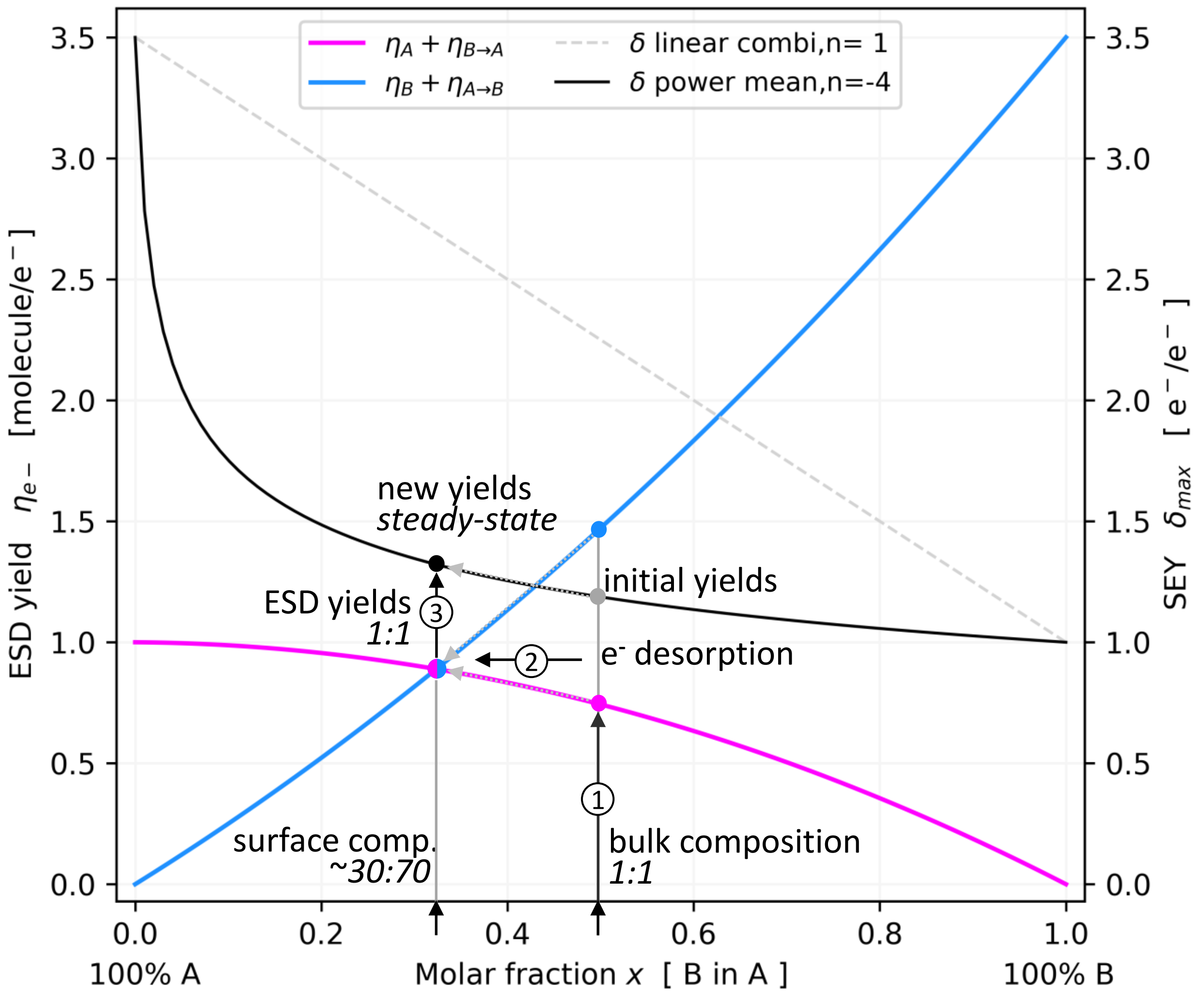
If similar to multicomponent sputtering:

(Ion Implantation and Synthesis of materials,Nastasi&Mayer,2006)

e- irradiation pushes the SEY and ESD to a new steady state,

where the ESD yield ratio = bulk composition ratio

New SEY appears, following the newly established ESD ratio on the e- irradiated thick ice surface.



Conclusions

New collector-based setup for cold ESD, SEY & TPD

Developed methods to probe low-energy region of ESD and SEY
in conditions relevant to HL-LHC and other cold machines & applications

New data for technical-grade surfaces & coatings

ESD yield, threshold, conditioning rate and SEY
as a function of energy, dose, temperature and cryosorbed gases
for Copper and other materials, coatings & treatments

Insights into LHC vacuum and EC-induced dynamic vacuum effect:
Conditioning is linked to ESD and SEY reduction, also at cold

Fraction of E-cloud effectively contributes to the conditioning

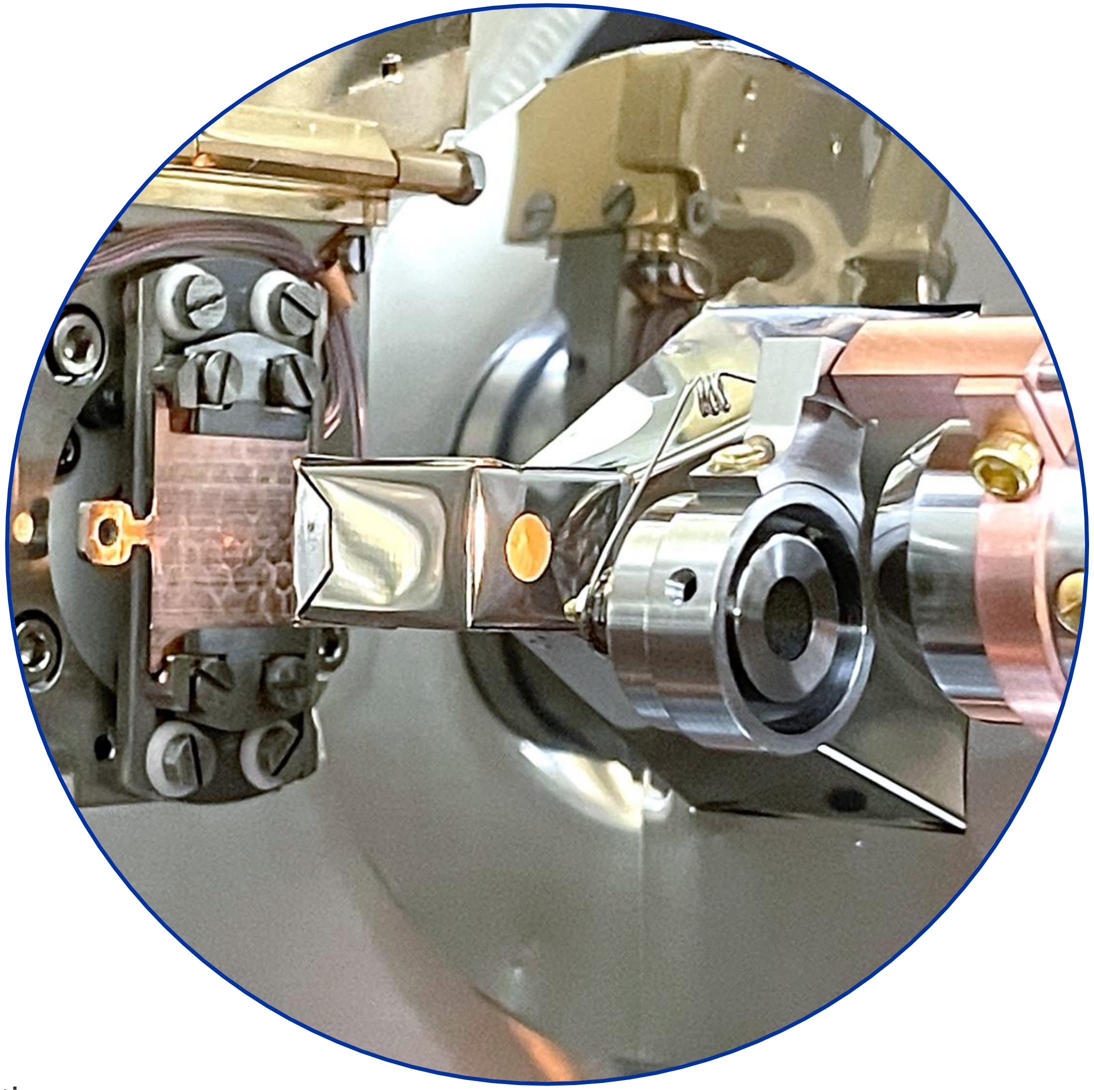
Electrons fragment molecules: different gas dynamics and chemistry

Mixed ices have a strongly nonlinear behavior

Next steps

Explore the parameter space and better understand the processes

Generalize the results for further use: semi-empirical fits to data for simulations



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Papers to read:

Technical paper: Haubner, Baglin, Henrist. (2022). Collector-based measurement of gas desorption and secondary electron emission induced by 0-1.4 keV electrons from LHC-grade copper at 15 K. *Accepted at NIM–B.*

First data paper: Haubner, Baglin, Henrist, (2022). Electron conditioning of technical surfaces at cryogenic and room temperature in the 0-1 keV energy range. *Accepted at Vacuum.*

Thick Ices: Dupuy, R., Haubner, M., Henrist, B., Fillion, J. H., & Baglin, V. (2020). Electron-stimulated desorption from molecular ices in the 0.15–2 keV regime. Journal of Applied Physics, 128(17), 175304..