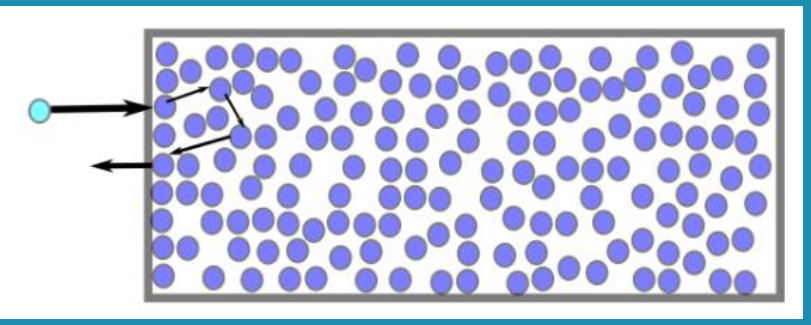
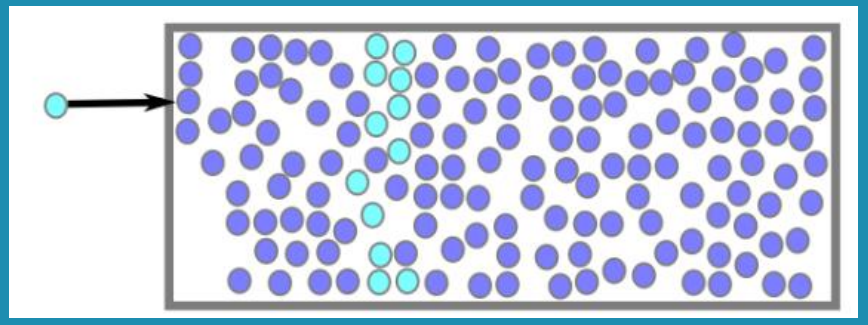
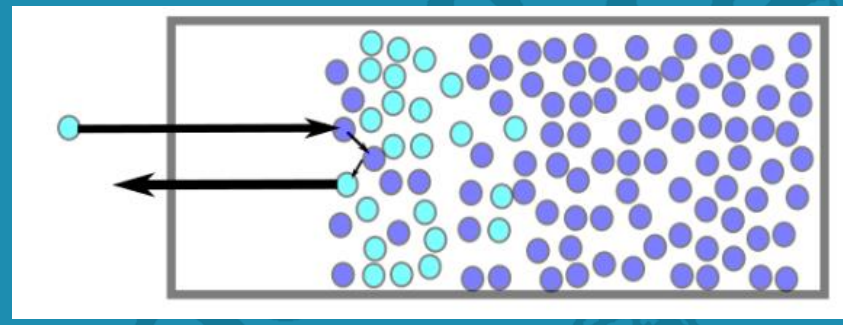
KU LEUVEN

11P6V24N –
fundamental research
fellowship Marie Deseyn

PRISMAP
Medical Radionuclides
EU 27



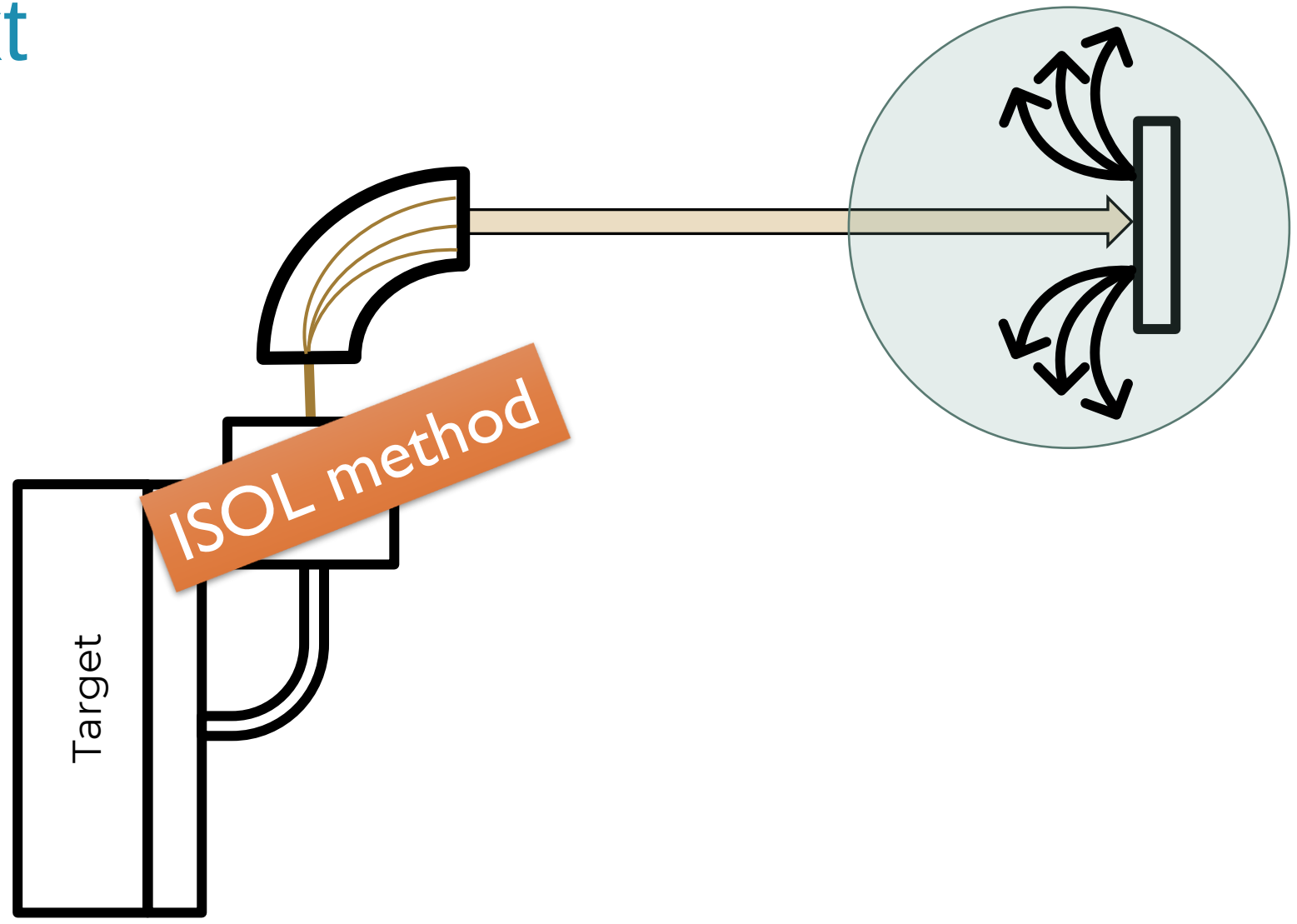




Self-Sputtering: An Overlooked Key in Implantations

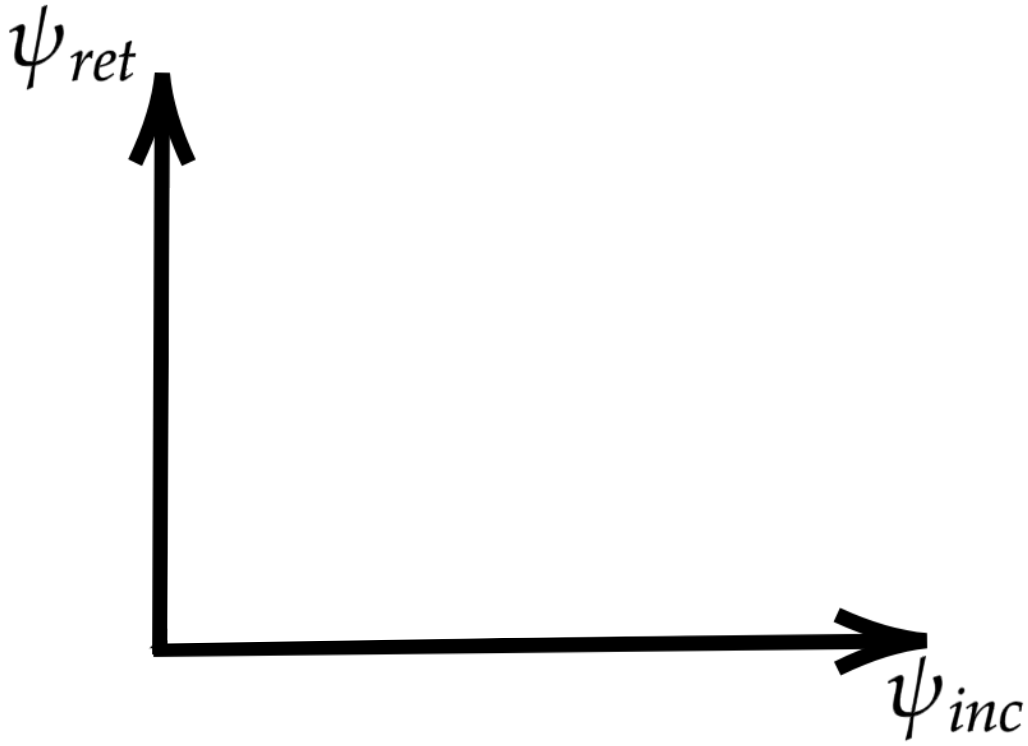
Marie Deseyn & Michael Heines

Context

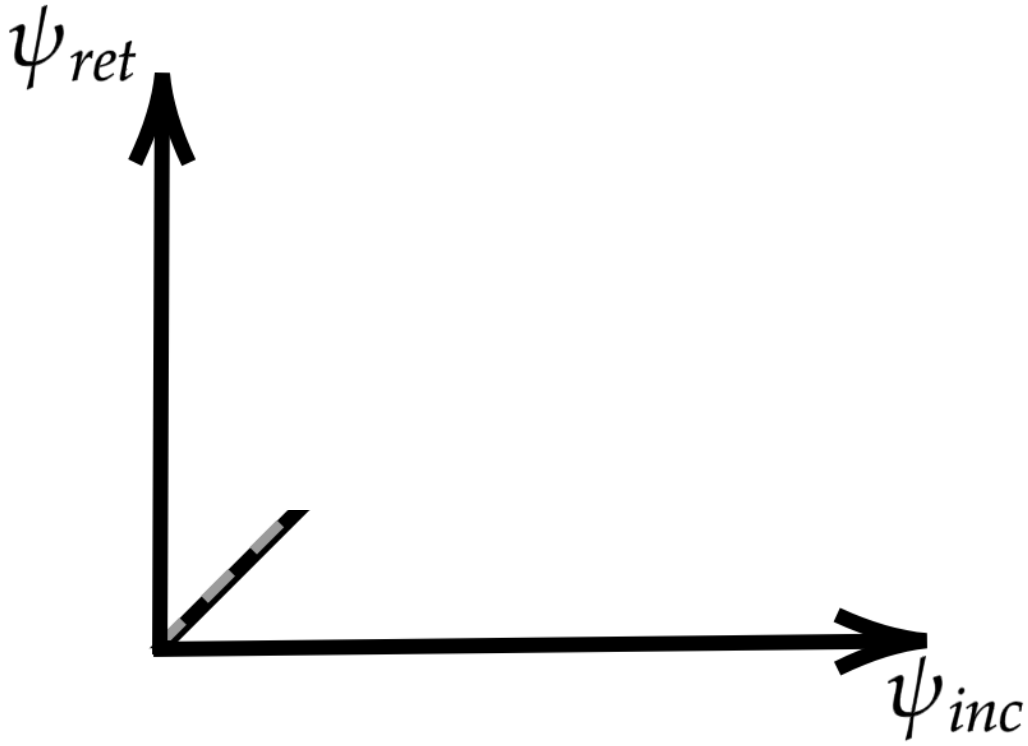


What is self-sputtering?

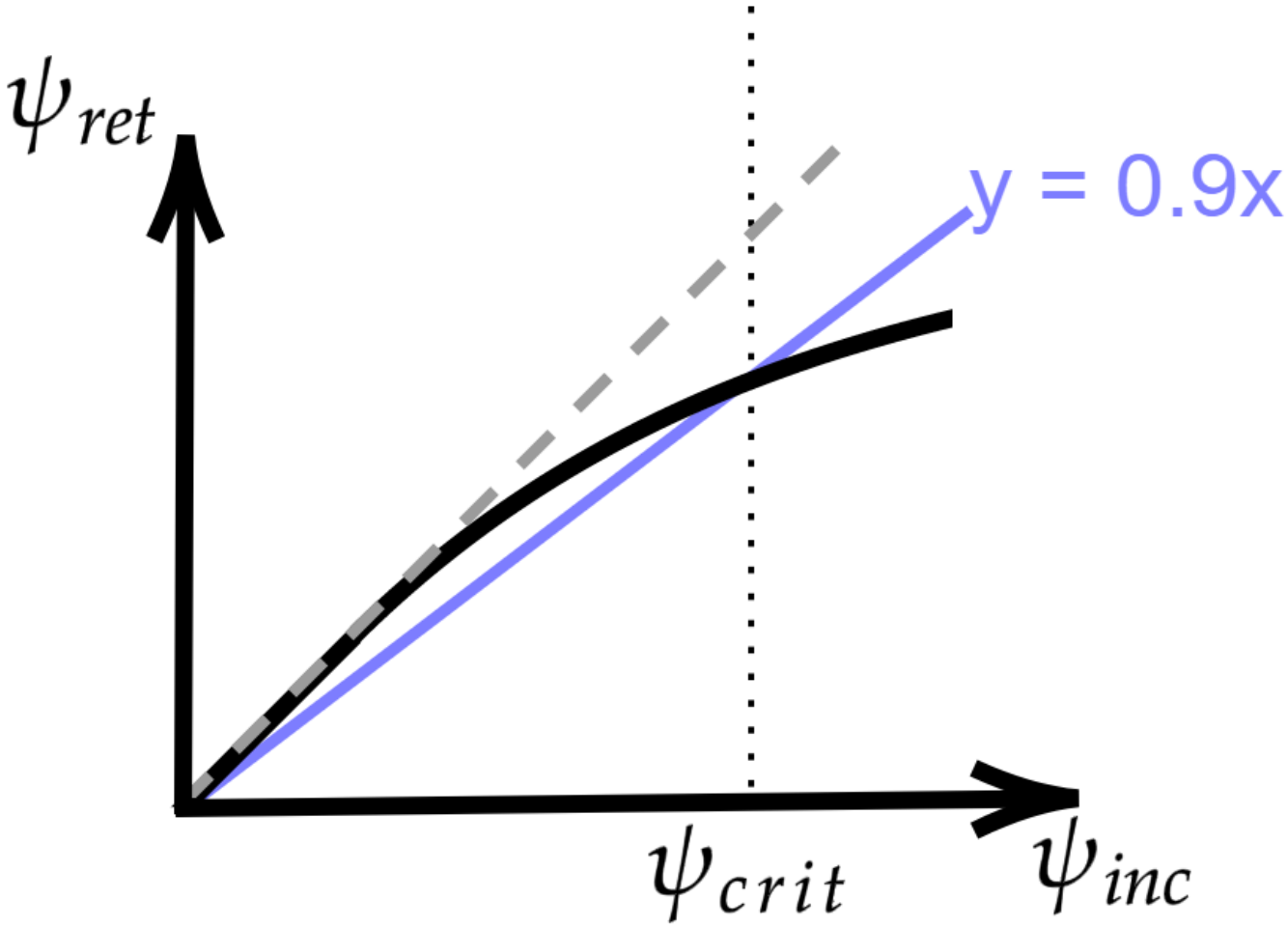
https://www.youtube.com/watch?v=ksrfzzpuKdc



What is self-sputtering?



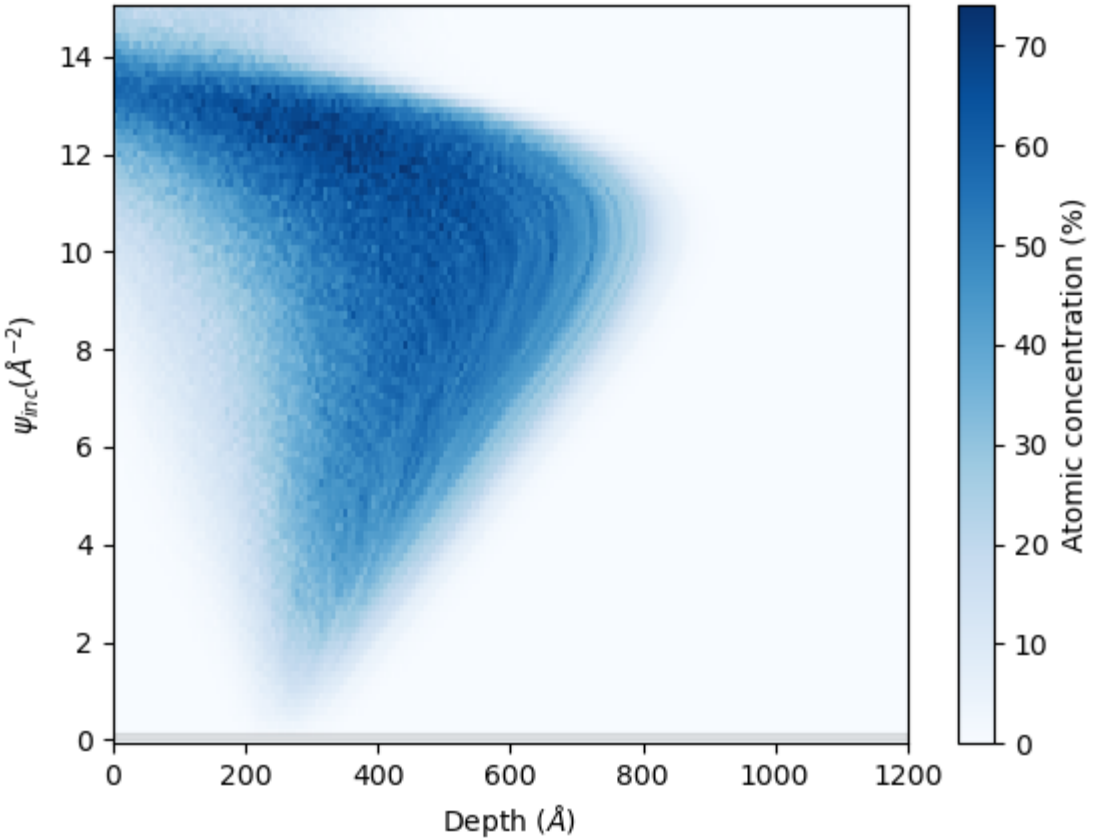
What is self-sputtering?

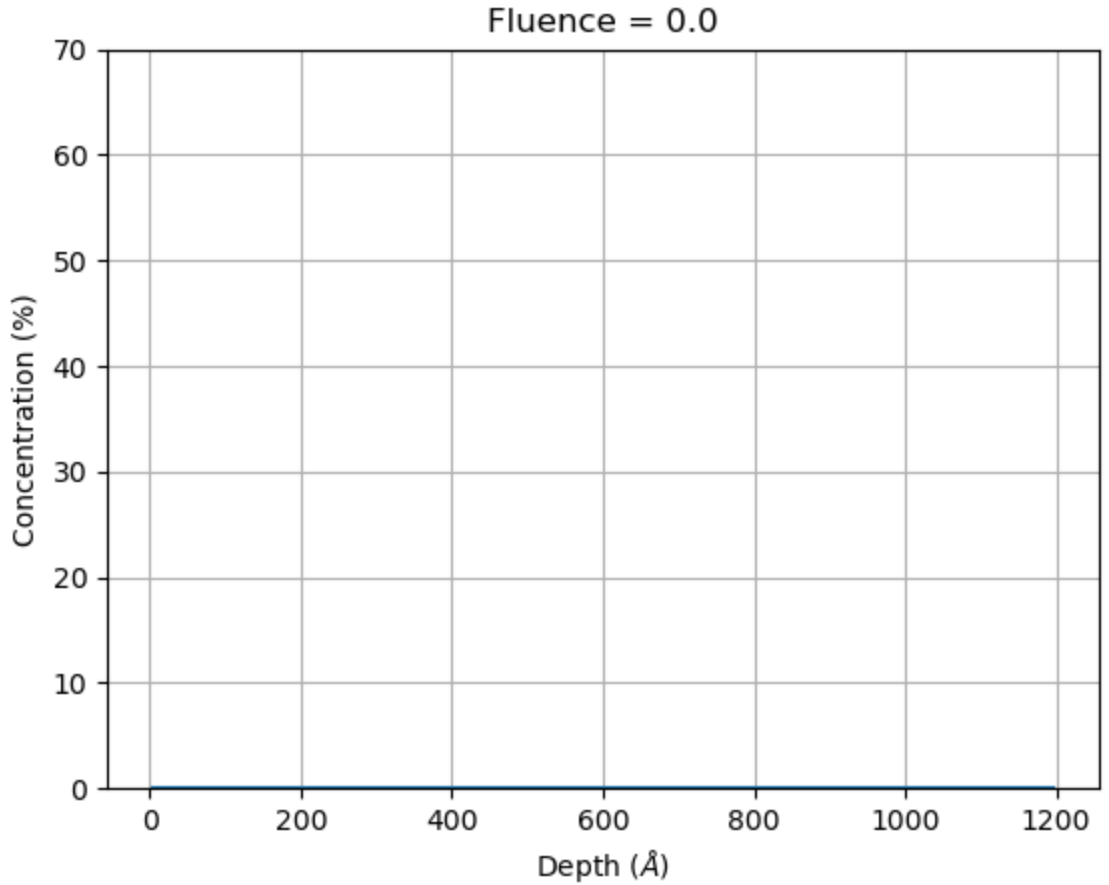


AIM: investigate ψ_{crit}
- Know when to replace foils
- Maximize ψ_{crit}

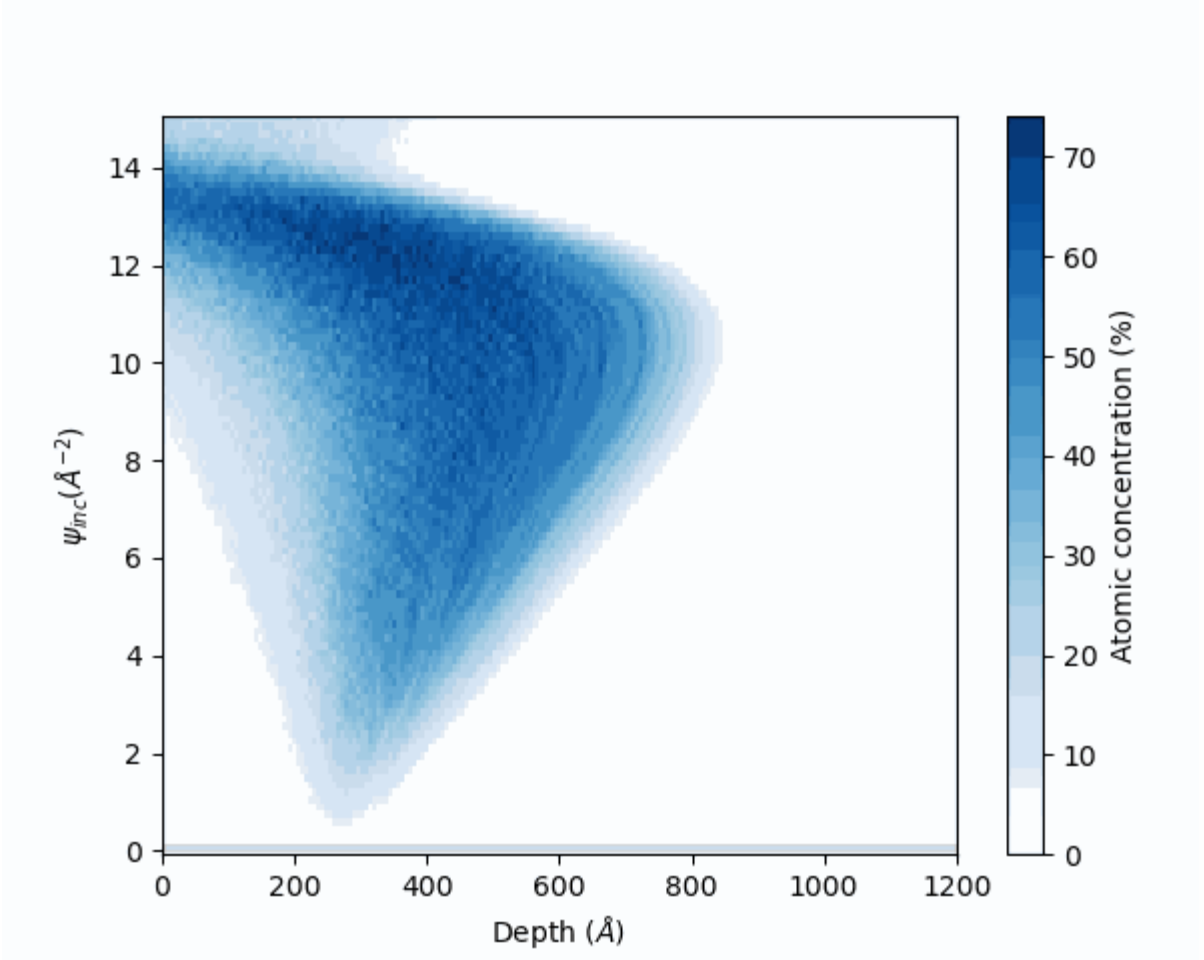
→ With the use of TRIDYN

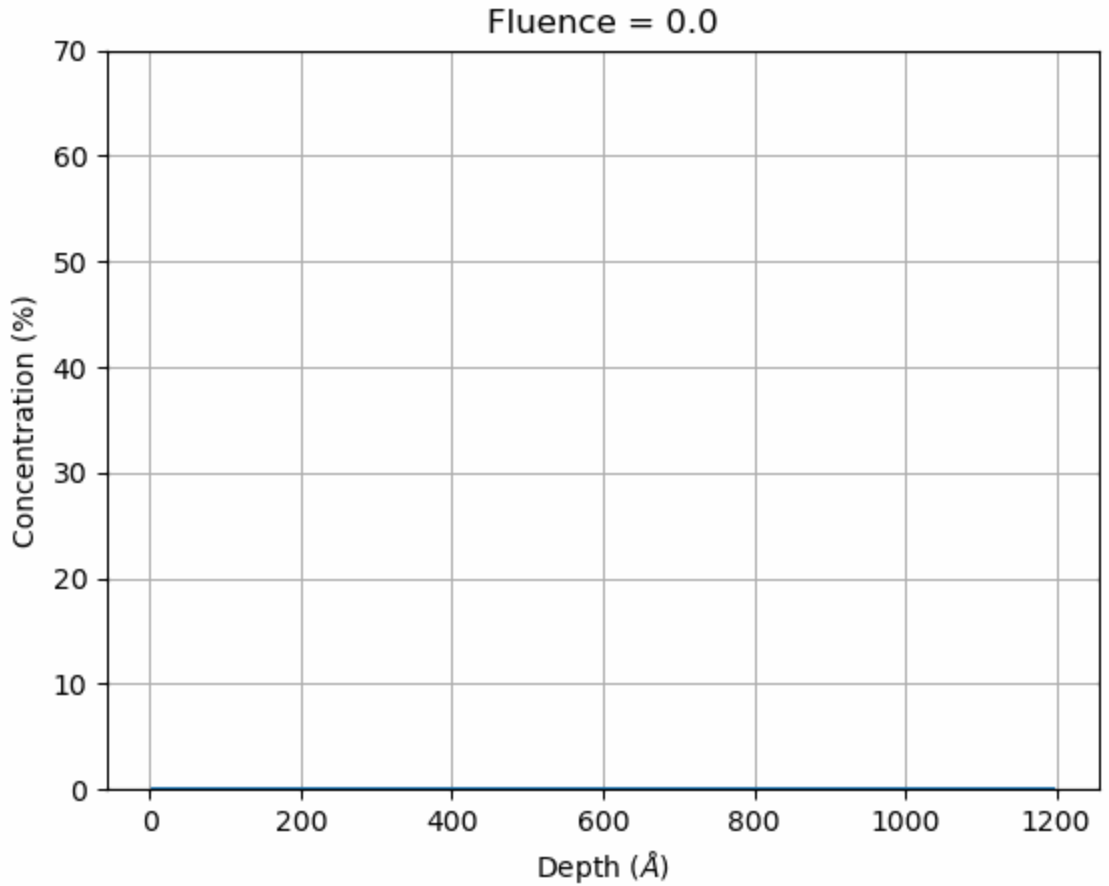
The dynamics inside the sample





The dynamics inside the sample





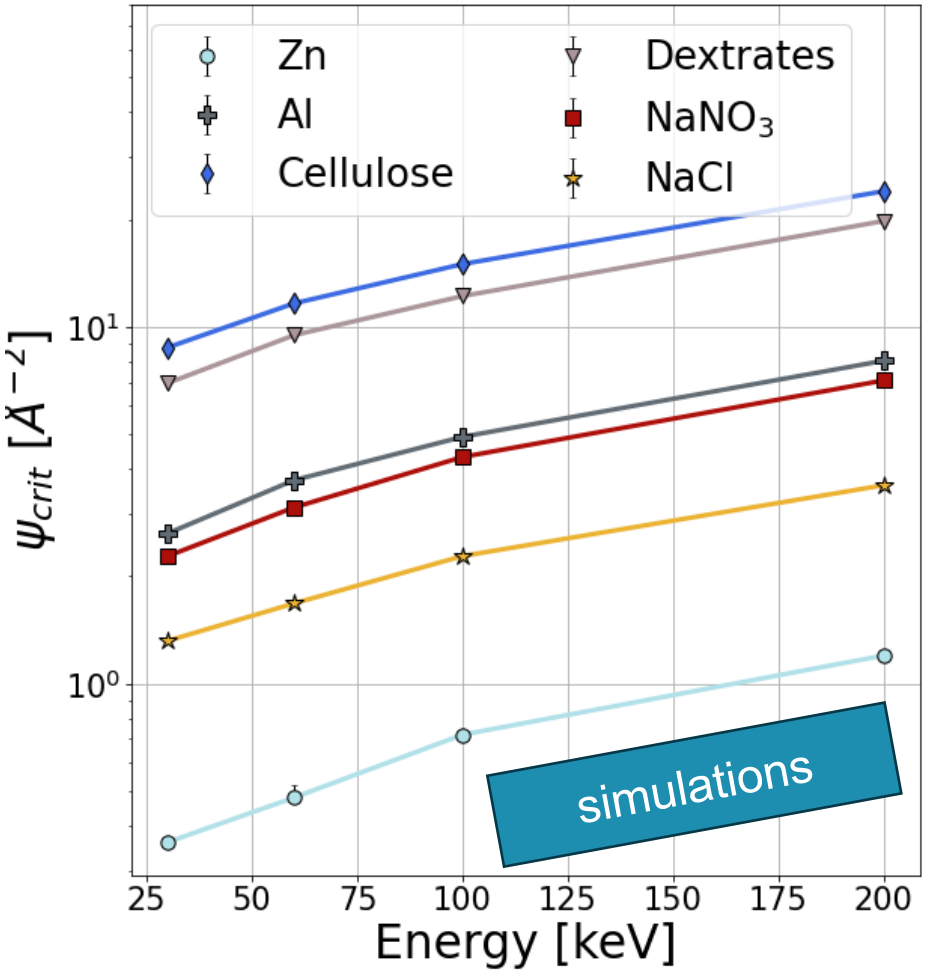
Foil & energy of the beam

Implantation in:

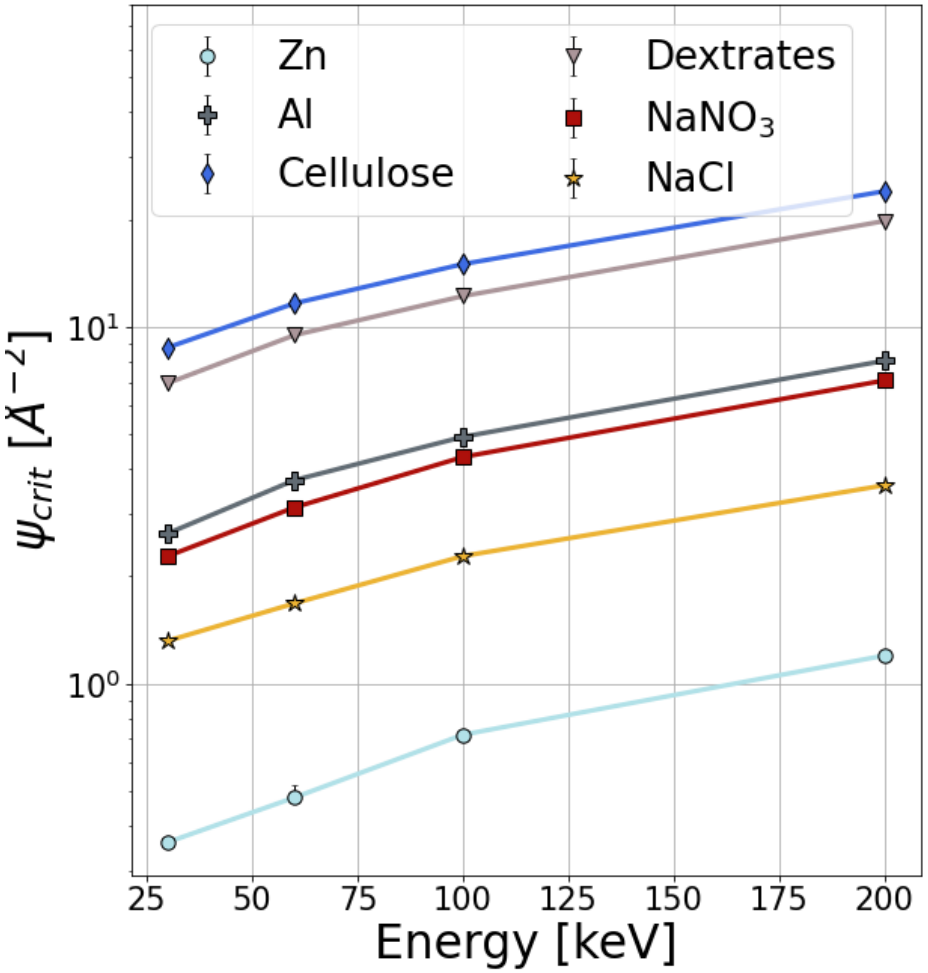
- Al
- Zn
- Salt
- Sugar

At:

- 30keV
- 60keV
- 100keV
- 200keV



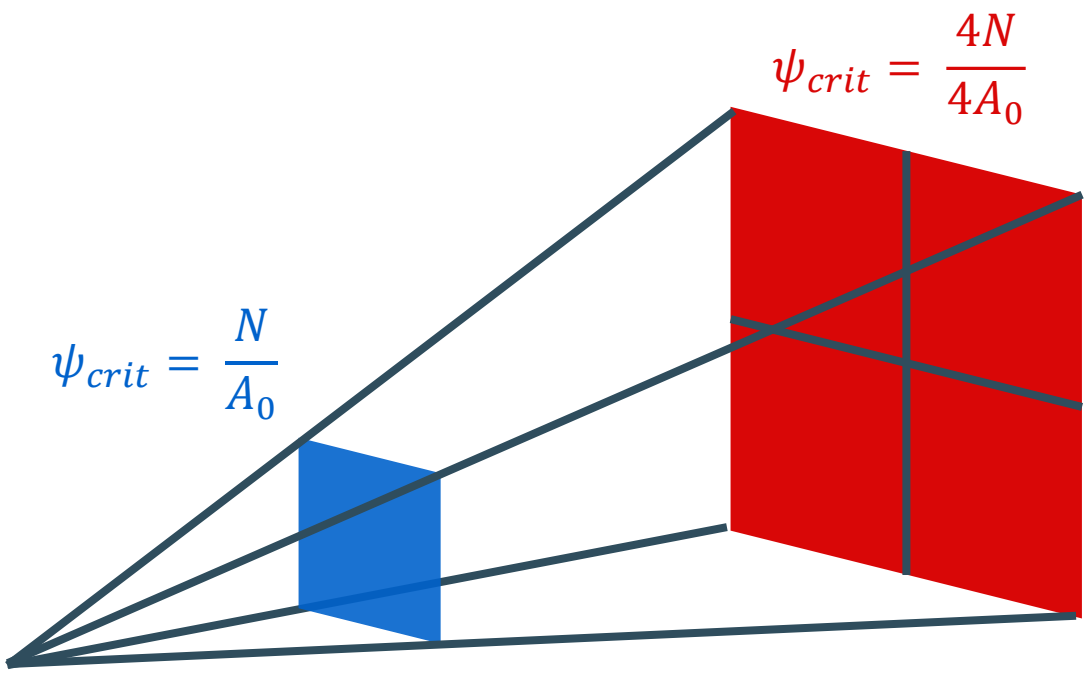
Foil & energy of the beam



MAXIMIZE ψ_{crit}

- Decrease Z of foil
  - Al instead of Zn @ CERN-MEDICIS
  - Implantation of K, Ag, La in glassy carbon for nuclear charge radius determination
- Maximize the energy of the ions

Foil & energy of the beam

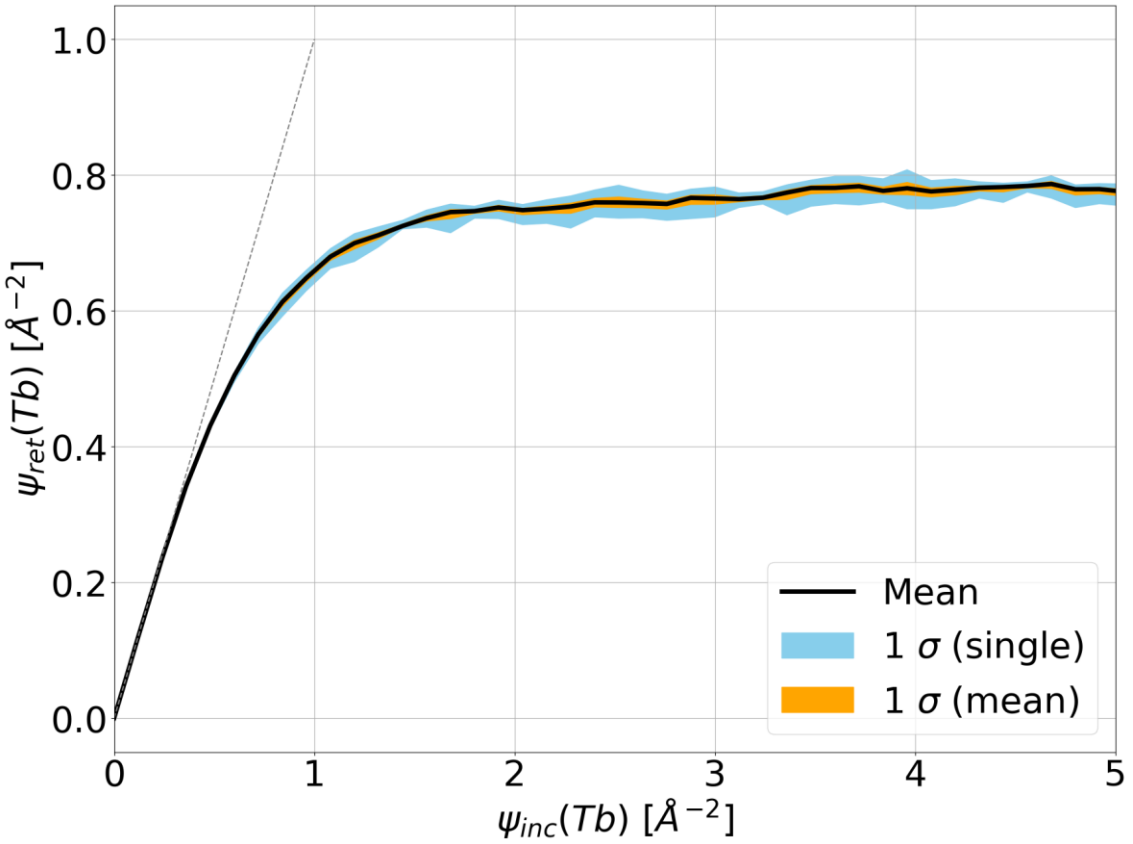


MAXIMIZE ψ_{crit}

- Decrease Z of foil
  - Al instead of Zn @ CERN-MEDICIS
  - Implantation of K, Ag, Au, La in glassy carbon for nuclear charge radius determination
- Maximize the energy of the ions
- Broaden the implantation spot

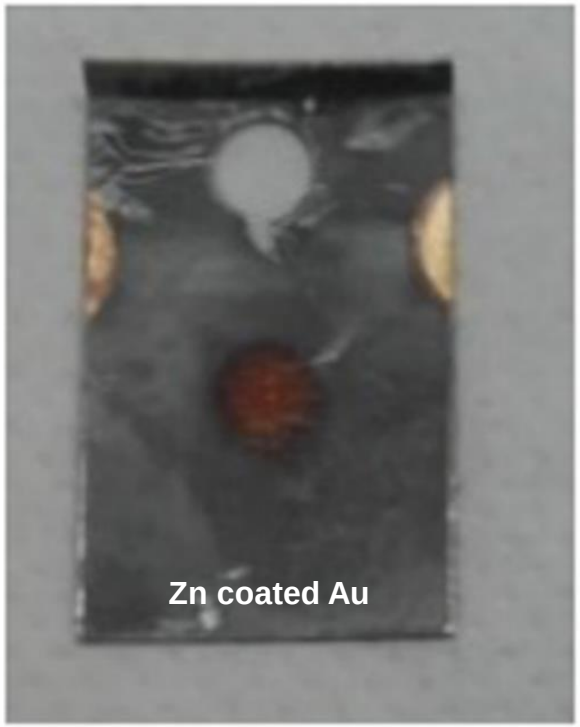
Estimating errors on the analysis

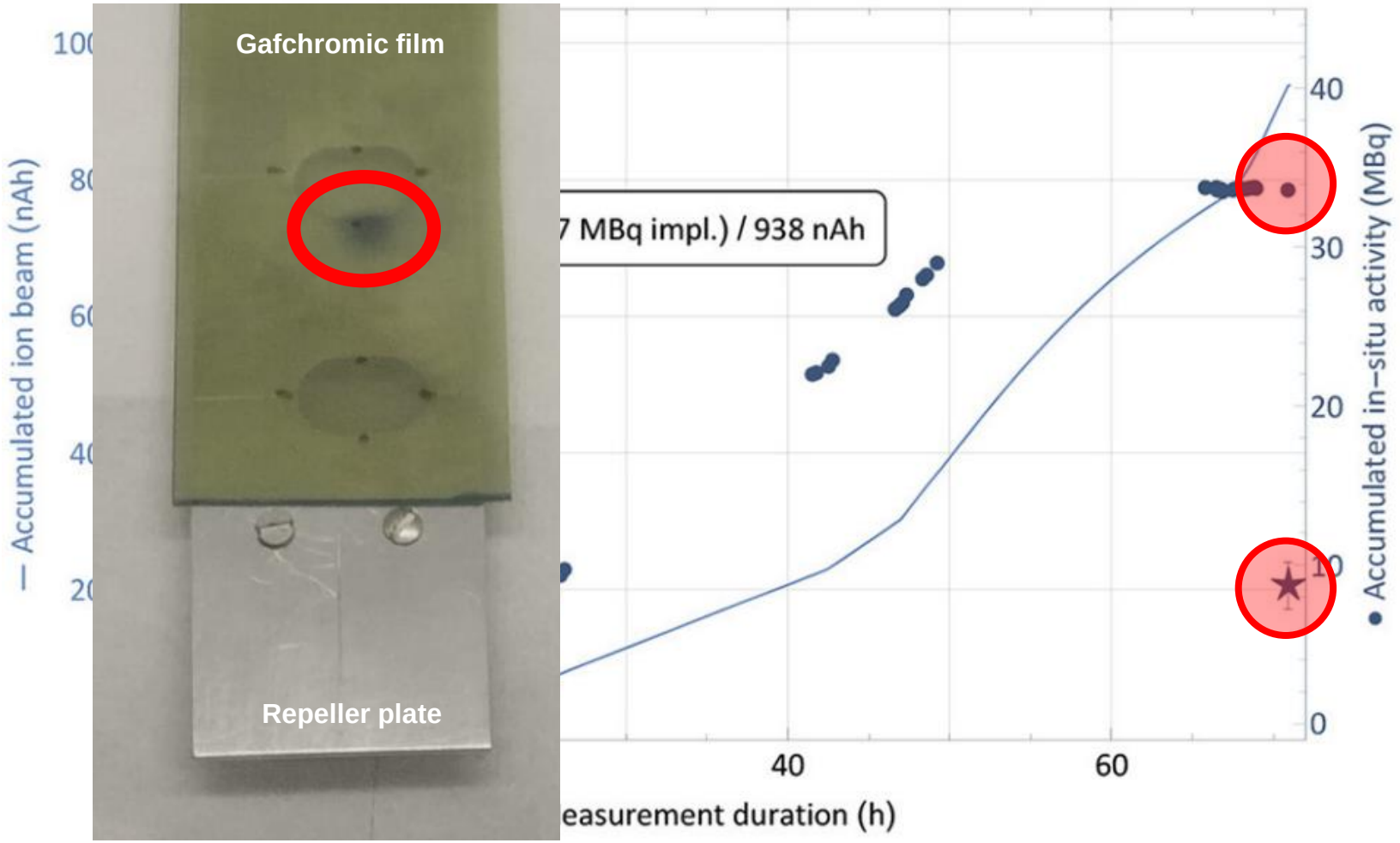
- No way to guess errors coming from:
  - Crystal structure
  - Surface binding energy
  - …
- Statistical uncertainty: Multiple simulations with different seeds



“Real-life” examples – medical isotope collections

- ^{167}Tm collection





Heinke, Reinhard et al. “Efficient Production of High Specific Activity Thulium-167 at Paul Scherrer Institute and CERN-MEDICIS.” Frontiers in medicine vol. 8 712374. 12 Oct. 2021, doi:10.3389/fmed.2021.712374

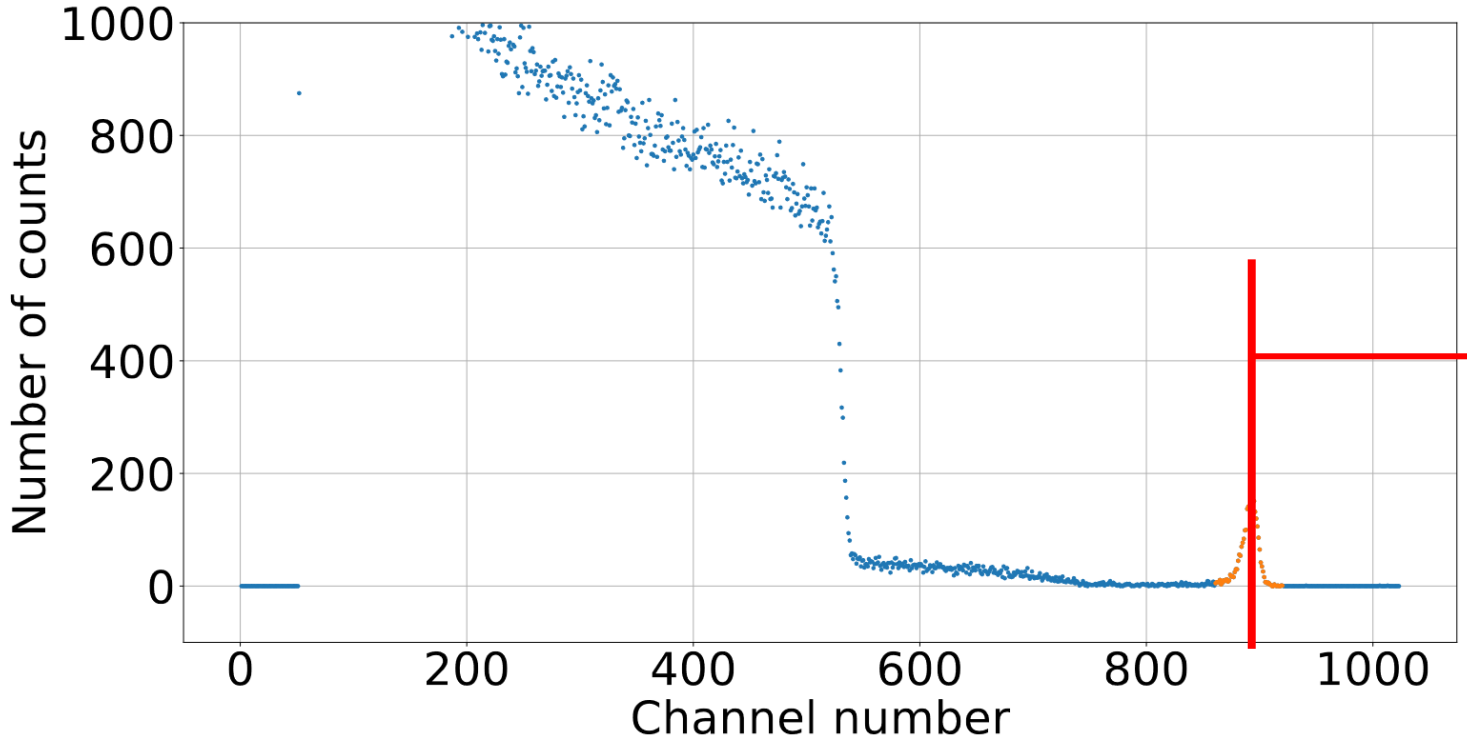
“Real-life” examples – medical isotope collections

- ^{167}Tm collection
- ^{155}Tb collection
  - 5.4(3)MBq impinging on the foil ↔ 2.69(10)MBq retained on the foil
  - TRIDYN simulation: 2.60(15)MBq retained

Experimental verification of TRIDYN

Experimental verification of TRIDYN

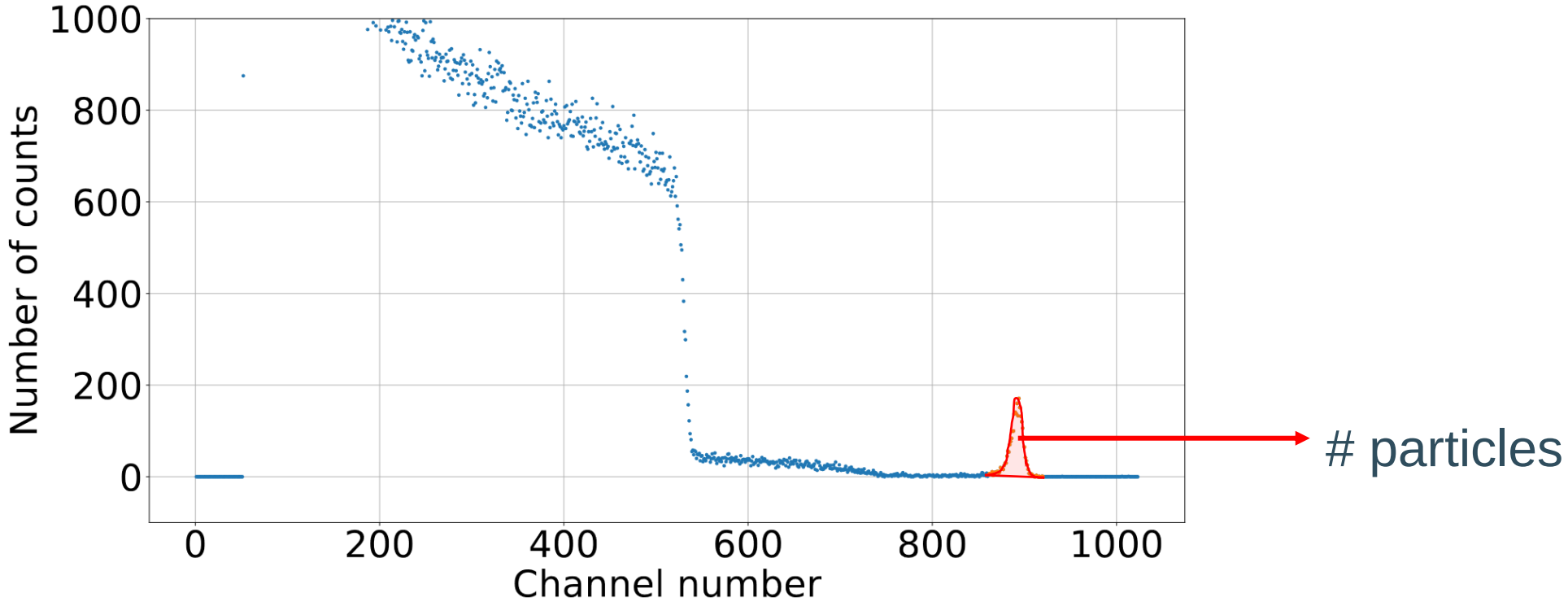
- Implantation of Yb in Zn and Al (high current implanter at IMBL)
- RBS (Rutherford Backscattering Spectrometry)



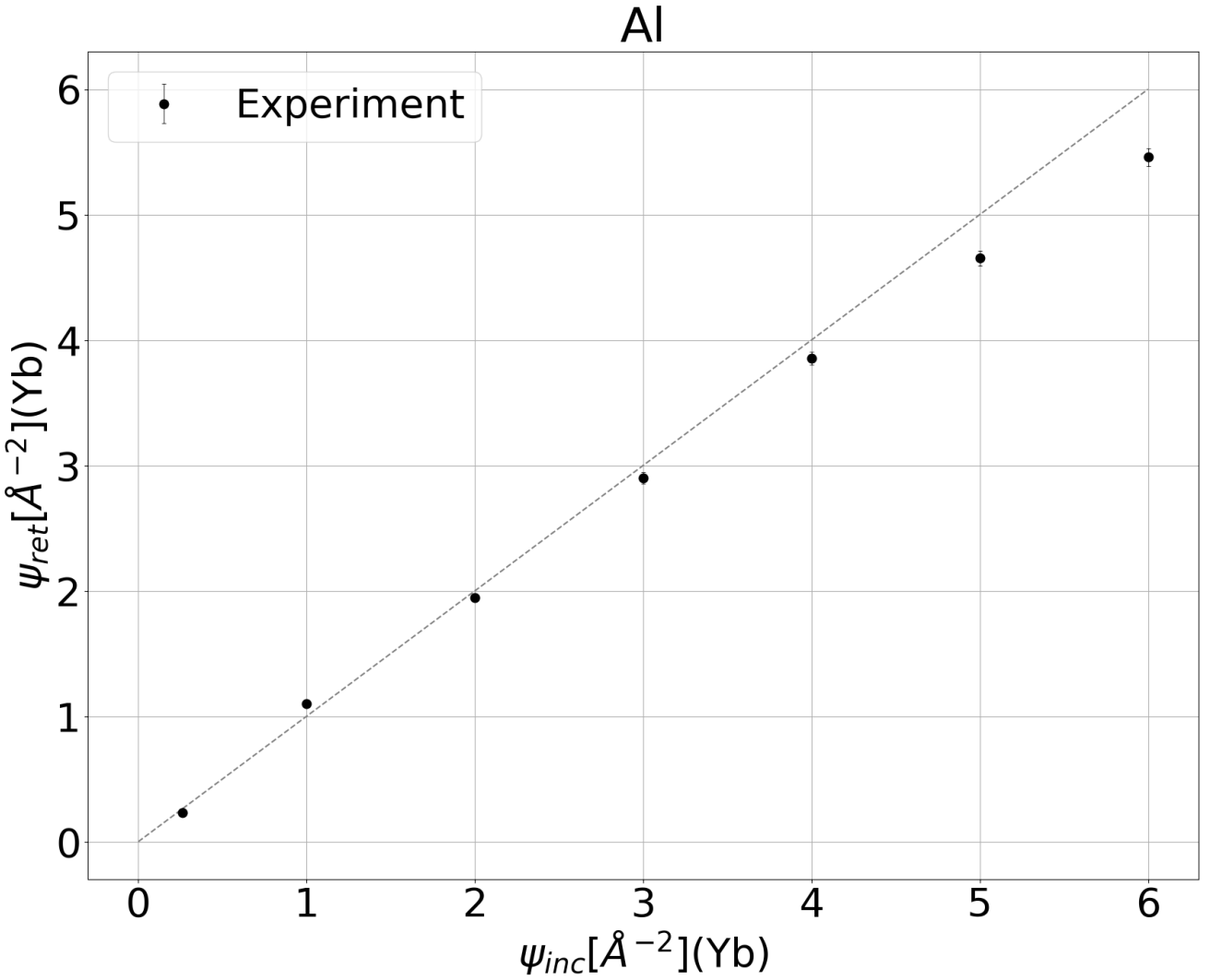
Depth and element

Experimental verification of TRIDYN

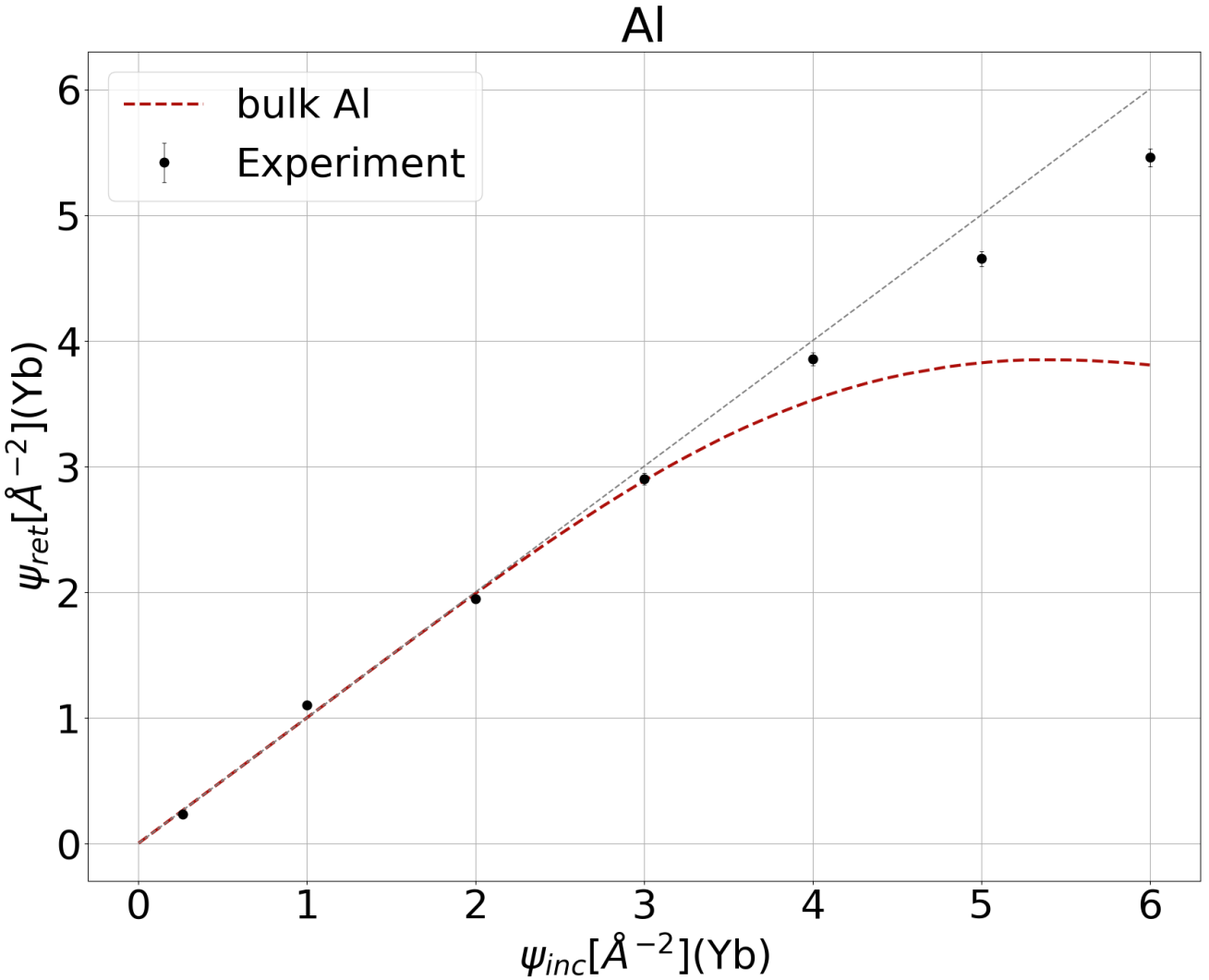
- Implantation of Yb in Zn and Al (high current implanter at IMBL)
- RBS (Rutherford Backscattering Spectrometry)



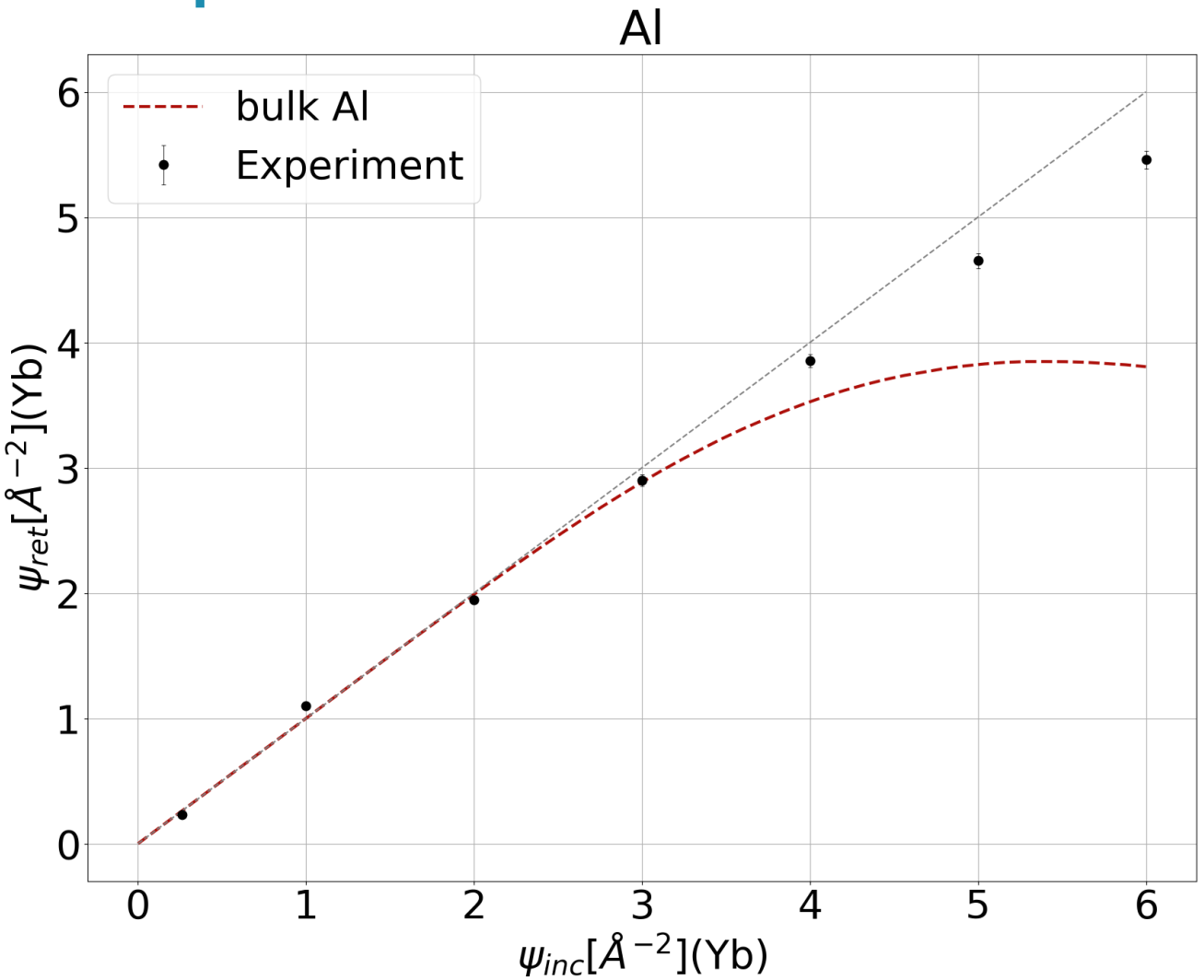
Experimental verification of TRIDYN

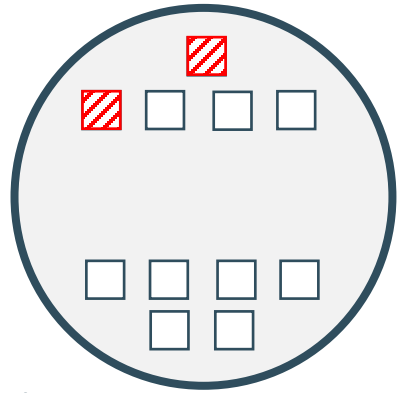


Experimental verification of TRIDYN



Experimental verification of TRIDYN



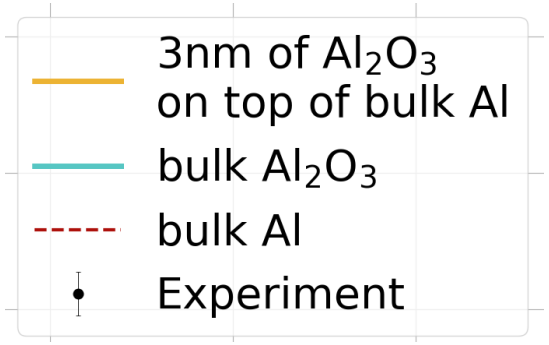


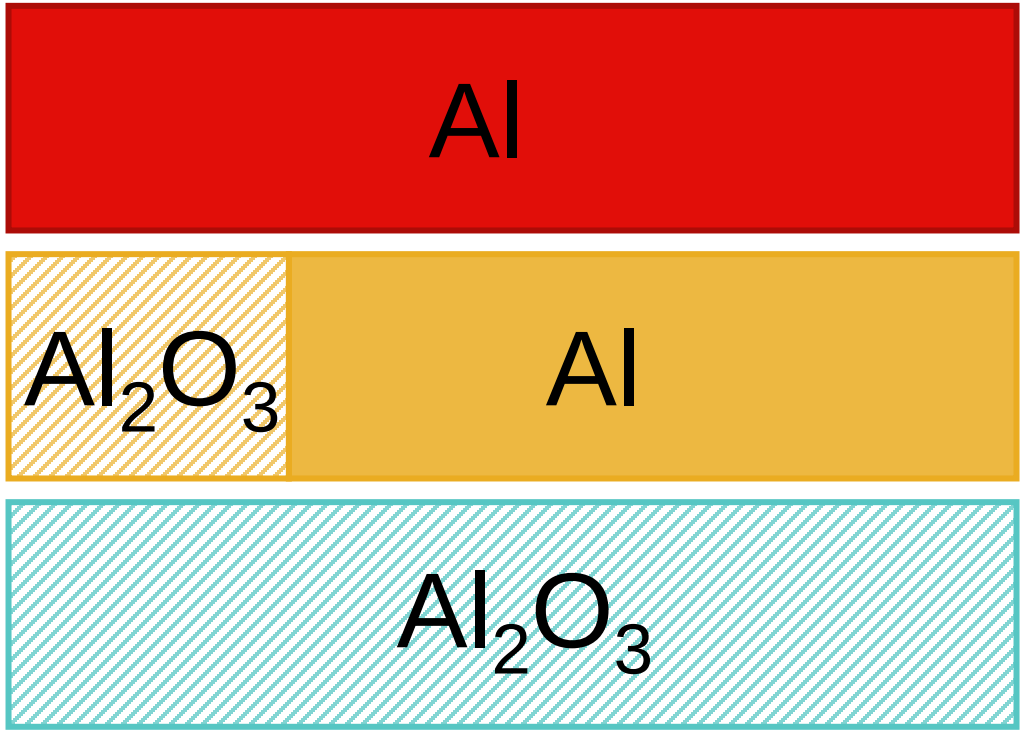
Implantation procedure:

- All foils implanted with $1Å^{-2}$
- All foils removed from vacuum to remove foil 1
- All foils except foil 1 put back to implant $1Å^{-2}$ (total implanted: $2Å^{-2}$)
- All foils removed from vacuum to remove foil 2
- …

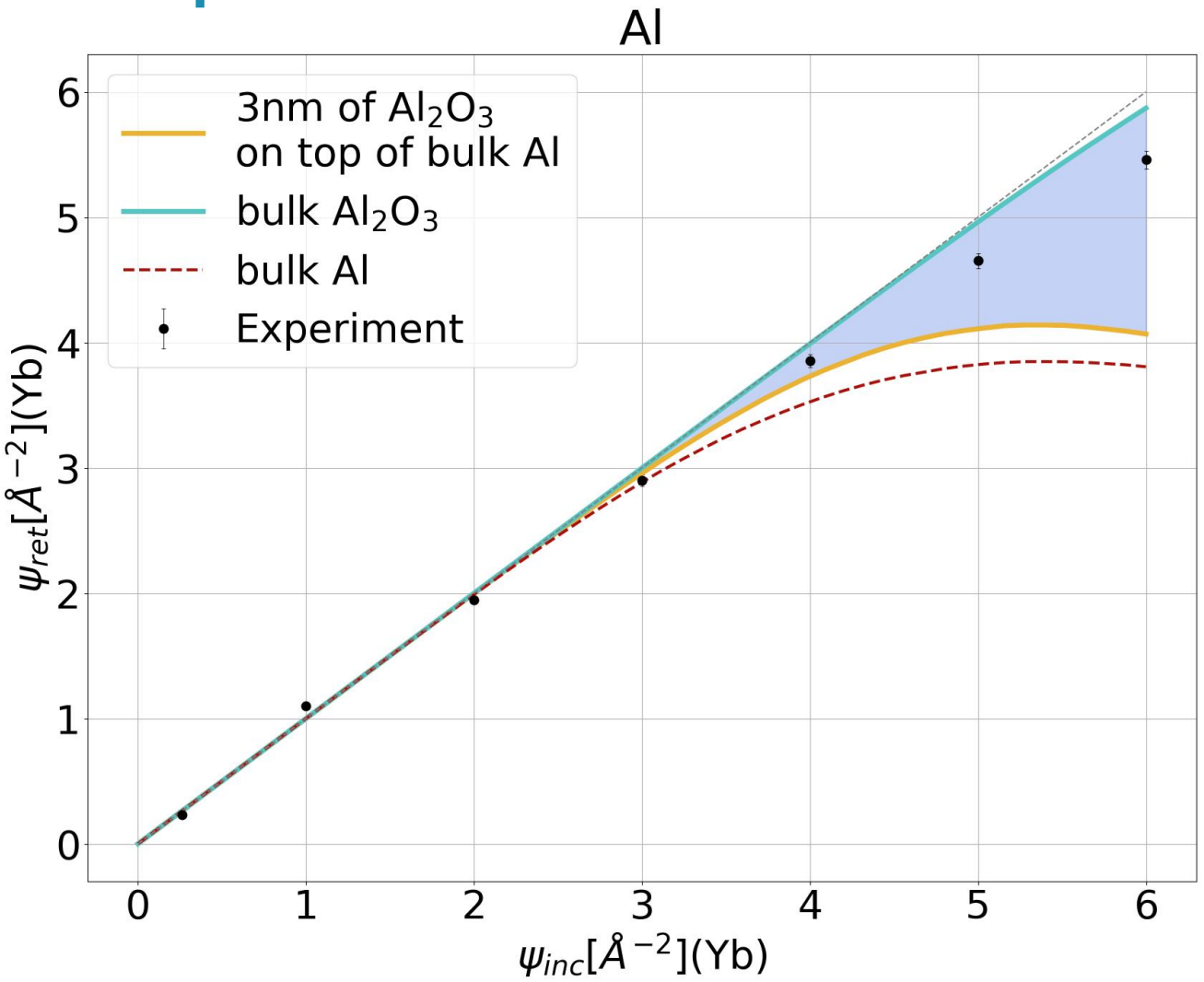
Importance of buildup of native layer of Al_2O_3

Experimental verification of TRIDYN

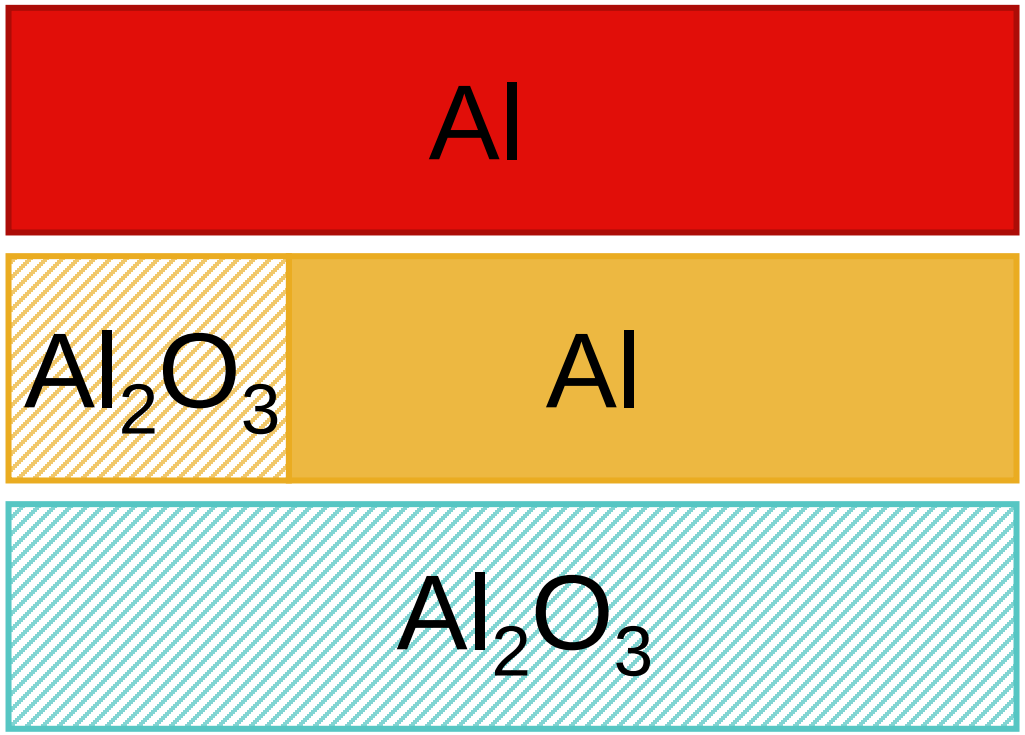




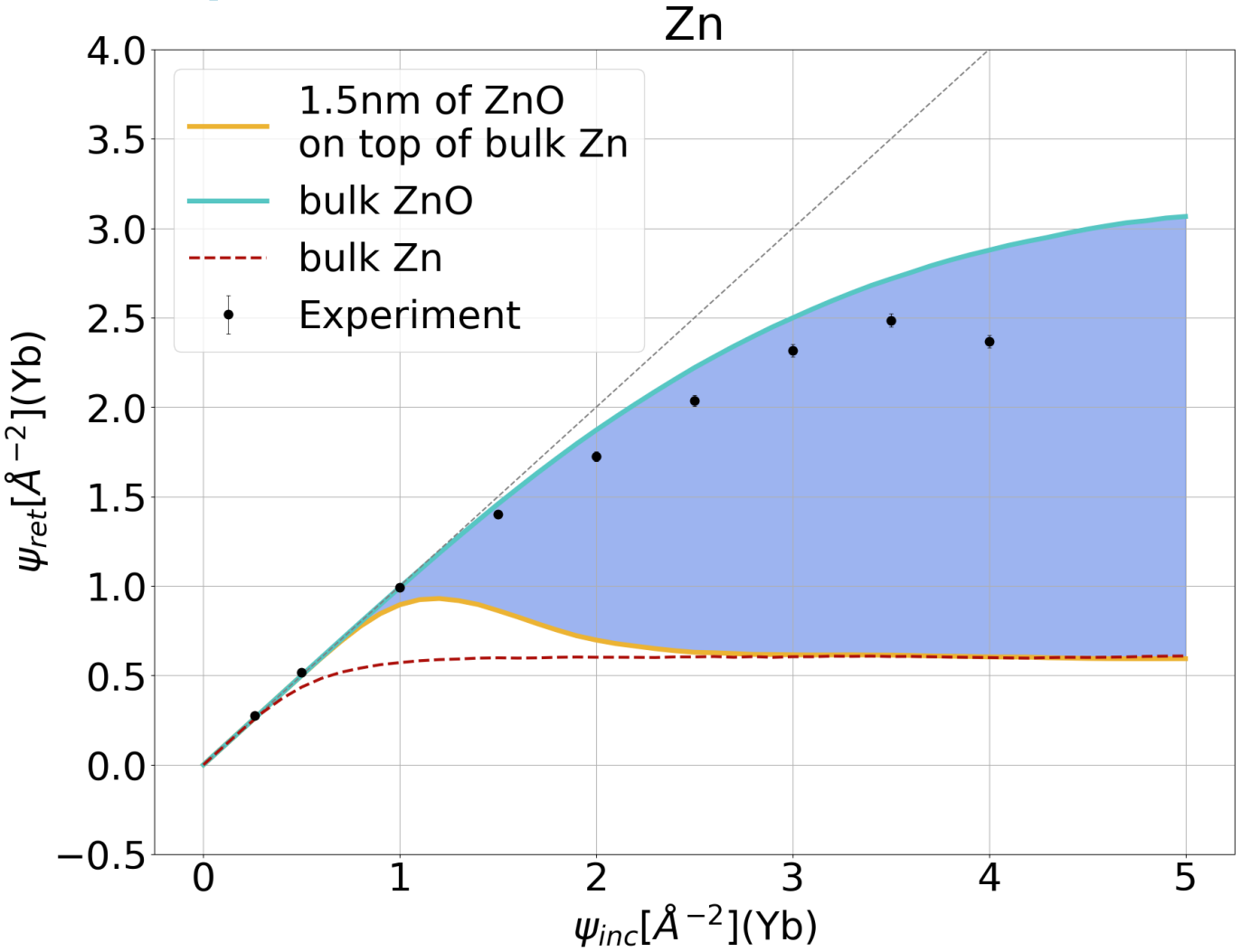
Experimental verification of TRIDYN

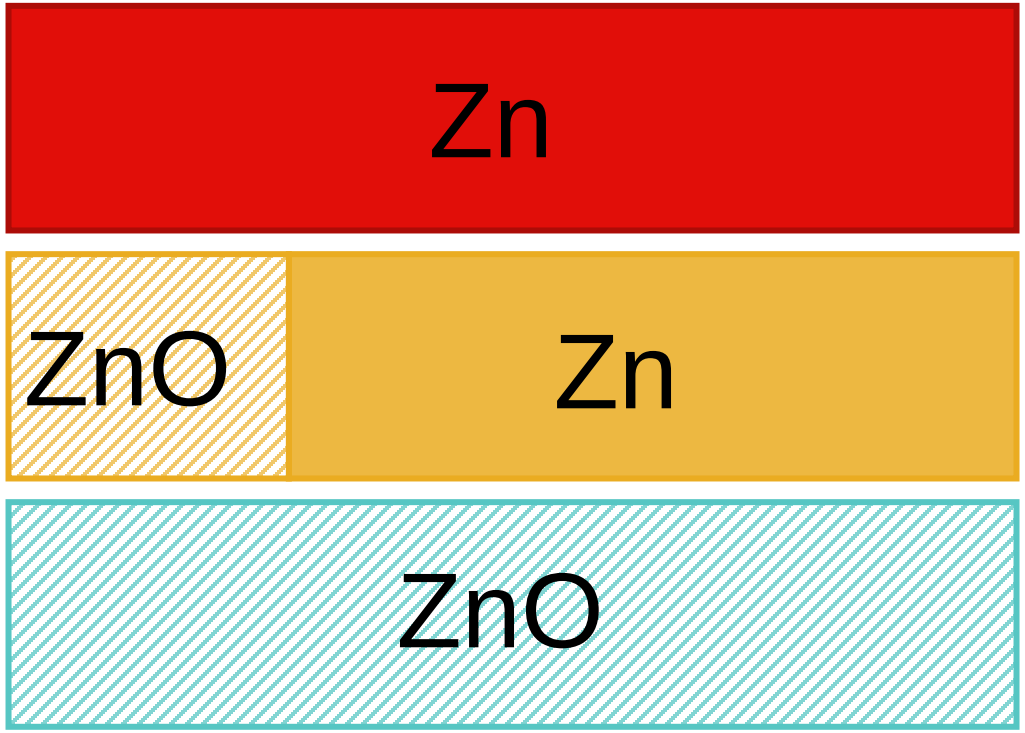


→ Experiment in between **bulk Al_2O_3** and **native layer of Al_2O_3 on bulk Al**



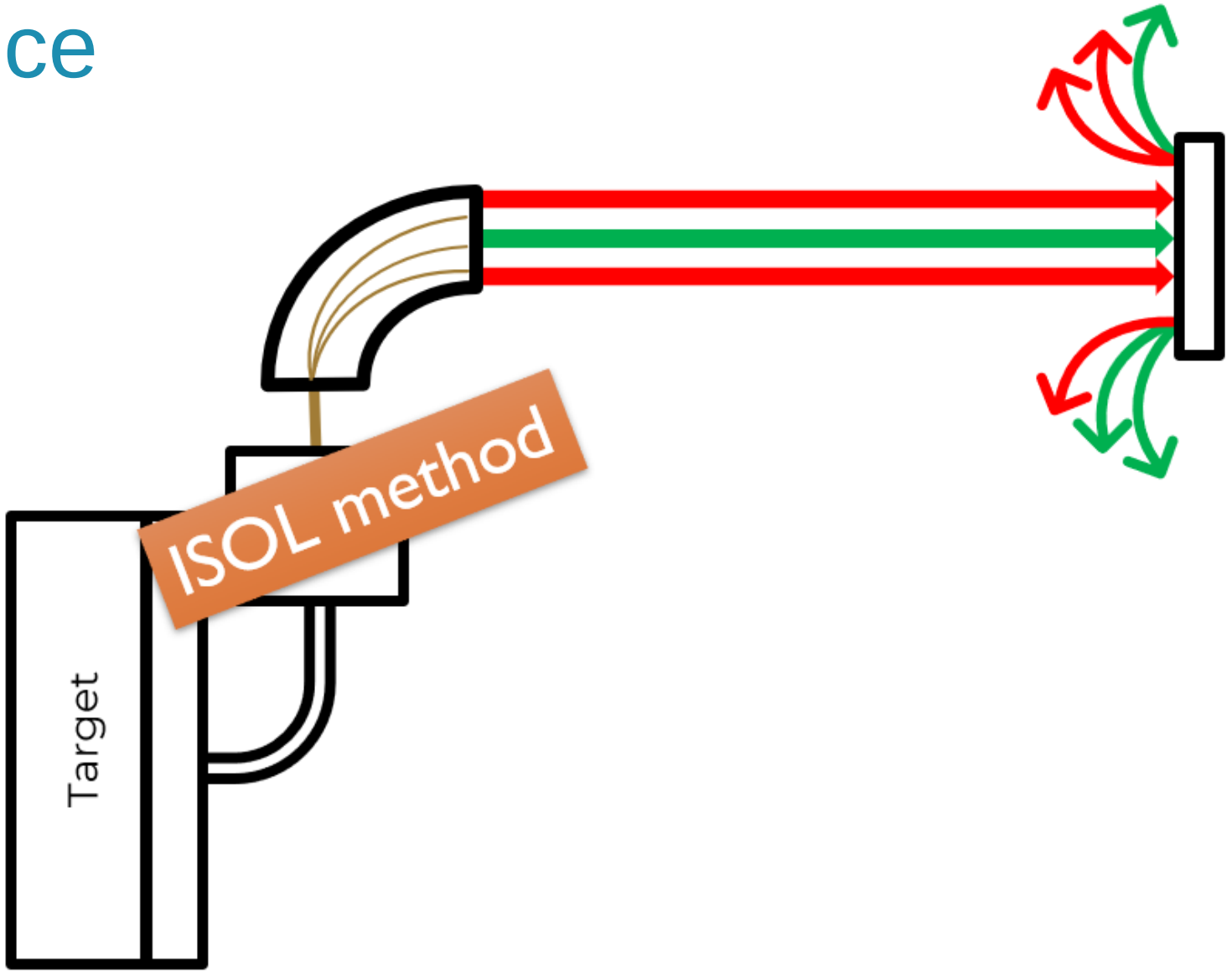
Experimental verification of TRIDYN



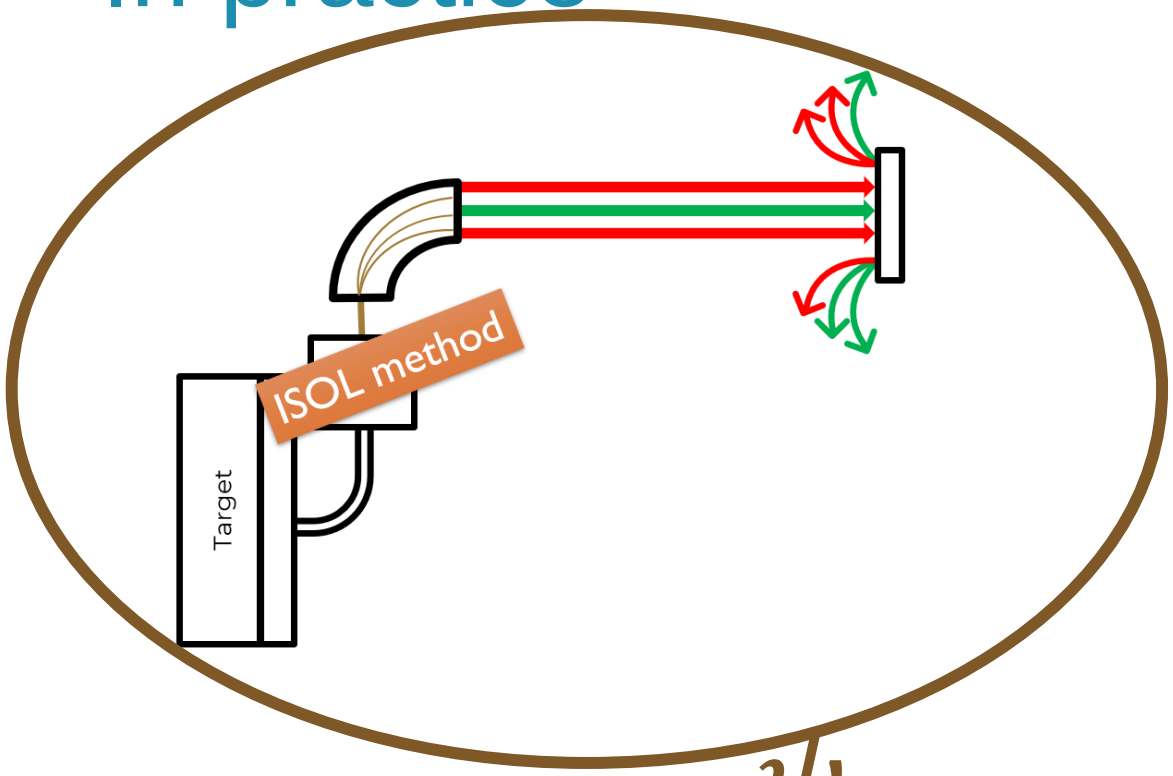


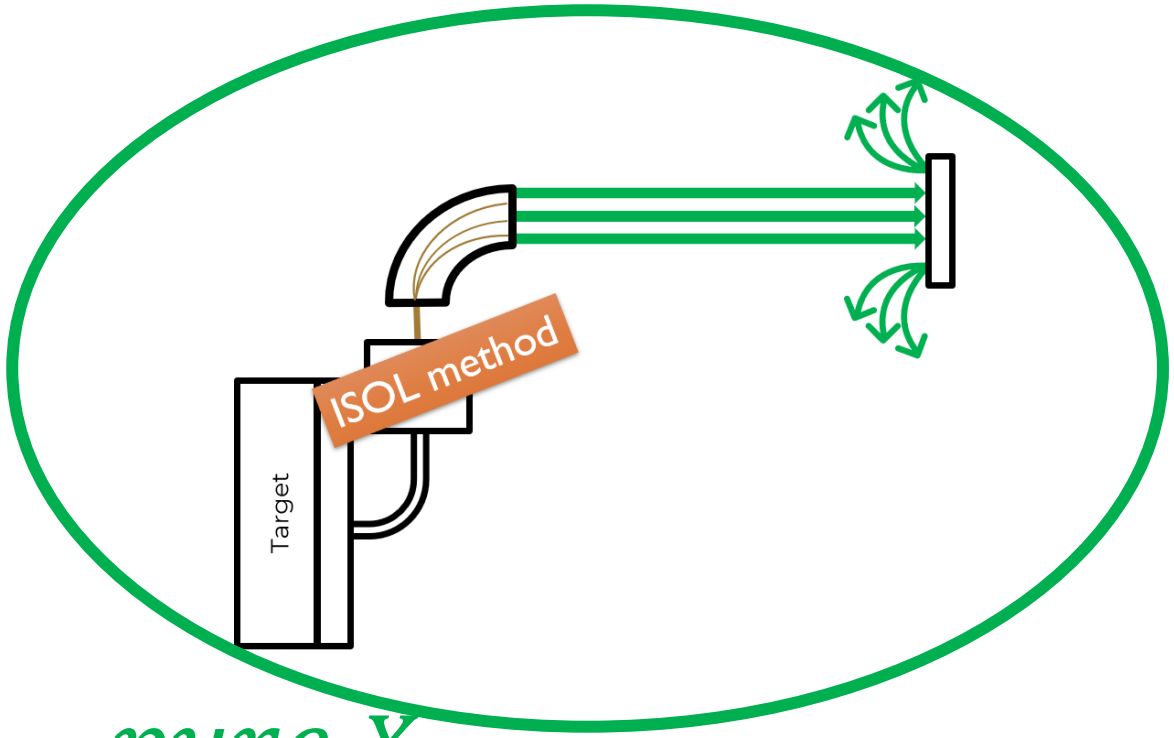
In practice

In practice



In practice



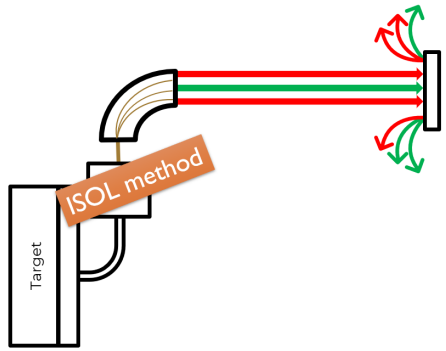


$$\psi_{tot,\,crit} \approx \psi_{tot,crit}^{pure\ X}$$

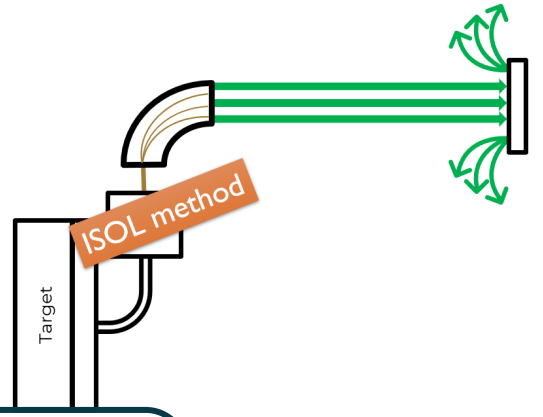
$$c_{int.}^{crit} = 2\pi e \psi_{tot,\,crit} \sigma_r^2 \approx 2\pi e\, \psi_{tot,crit}^{pure\ X} \sigma_r^2$$

In practice

Collection of X + y



TRIDYN simulation for implantation of X



$$\psi_{tot,crit}^{pure\ X}$$

$$c_{int.}^{crit} \approx 2\pi e\, \psi_{tot,crit}^{pure\ X} \sigma_r^2$$

In practice

$$c_{\text{int.}}^{crit} \approx 2\pi e \psi_{tot,crit}^{\text{pure X}} \sigma_r^2$$

ψ^{crit} [Å^{-2}]	$C_5H_5O_6$ 30keV	$C_5H_5O_6$ 60keV	$C_6H_{10}O_5$ 30keV	$C_6H_{10}O_5$ 60keV
Sc	$11.280^{+(60)}_{-(130)}$	$12.000^{+(60)}_{-(60)}$	$12.000^{+(60)}_{-(60)}$	$12.000^{+(60)}_{-(60)}$
Cu	$7.560^{+(60)}_{-(130)}$	$12.000^{+(60)}_{-(60)}$	$9.240^{+(60)}_{-(130)}$	$12.000^{+(60)}_{-(60)}$
Sm	$5.160^{+(130)}_{-(60)}$	$7.440^{+(60)}_{-(60)}$	$6.600^{+(60)}_{-(60)}$	$9.480^{+(60)}_{-(60)}$
Tb	$5.760^{+(130)}_{-(60)}$	$8.280^{+(60)}_{-(60)}$	$7.440^{+(60)}_{-(130)}$	$10.320^{+(60)}_{-(60)}$
Tm	$5.400^{+(60)}_{-(130)}$	$7.560^{+(60)}_{-(60)}$	$6.720^{+(60)}_{-(60)}$	$9.480^{+(60)}_{-(60)}$
Ac	$7.800^{+(130)}_{-(60)}$	$10.200^{+(60)}_{-(130)}$	$10.200^{+(60)}_{-(60)}$	$12.000^{+(60)}_{-(60)}$

ψ^{crit} [Å^{-2}]	Al 30keV	Al 60keV	Zn 30keV	Zn 60keV
Sc	$4.32^{+(13)}_{-(13)}$	$10.080^{+(60)}_{-(130)}$	$0.600^{+(60)}_{-(130)}$	$1.440^{+(60)}_{-(130)}$
Cu	$3.000^{+(60)}_{-(130)}$	$5.520^{+(60)}_{-(130)}$	$0.360^{+(60)}_{-(60)}$	$0.840^{+(60)}_{-(60)}$
Sm	$2.040^{+(60)}_{-(130)}$	$2.88^{+(13)}_{-(13)}$	$0.240^{+(60)}_{-(60)}$	$0.480^{+(60)}_{-(60)}$
Tb	$2.160^{+(60)}_{-(60)}$	$3.120^{+(130)}_{-(60)}$	$0.360^{+(60)}_{-(60)}$	$0.480^{+(60)}_{-(60)}$
Tm	$2.040^{+(130)}_{-(60)}$	$2.880^{+(130)}_{-(60)}$	$0.240^{+(130)}_{-(60)}$	$0.480^{+(60)}_{-(130)}$
Ac	$2.040^{+(60)}_{-(130)}$	$2.640^{+(60)}_{-(130)}$	$0.240^{+(60)}_{-(60)}$	$0.360^{+(60)}_{-(130)}$

ψ^{crit} [Å^{-2}]	NaCl 30keV	NaCl 60keV	$NaNO_3$ 30keV	$NaNO_3$ 60keV
Sc	$2.400^{+(60)}_{-(60)}$	$5.040^{+(60)}_{-(130)}$	$4.080^{+(130)}_{-(60)}$	$8.640^{+(60)}_{-(130)}$
Cu	$1.680^{+(60)}_{-(60)}$	$3.000^{+(60)}_{-(60)}$	$2.760^{+(60)}_{-(130)}$	$5.160^{+(60)}_{-(130)}$
Sm	$1.080^{+(60)}_{-(60)}$	$1.560^{+(60)}_{-(60)}$	$2.160^{+(60)}_{-(130)}$	$3.000^{+(60)}_{-(60)}$
Tb	$1.200^{+(60)}_{-(60)}$	$1.680^{+(60)}_{-(60)}$	$2.160^{+(60)}_{-(60)}$	$3.000^{+(130)}_{-(60)}$
Tm	$1.080^{+(130)}_{-(60)}$	$1.560^{+(60)}_{-(60)}$	$2.160^{+(60)}_{-(130)}$	$3.000^{+(60)}_{-(60)}$
Ac	$1.200^{+(60)}_{-(130)}$	$1.440^{+(130)}_{-(60)}$	$2.280^{+(130)}_{-(60)}$	$3.120^{+(60)}_{-(130)}$

Conclusion

- Self-sputtering is not neglectable for collection of many particles (~ 10^{12} – 10^{14} particles depending on Z values and beam spot)
- Self-sputtering minimized by:
  - Increasing implantation surface
  - Increasing implantation energy
  - Investigating foil material
  - Foil replacement
- TRIDYN simulations = good first estimate BUT be mindful of the input:
  - Oxide layer
  - Crystal structure
  - Surface binding energy matrix

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fundamental research
fellowship Marie Deseyn

PRISMAP
Medical Radionuclides

Thank you!