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Secondary Emission Models in E-Cloud Buildup Simulations: from the Lab to the Code

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Outline

- Introduction
- Simulations with SEY Table
- Heat Load
- Surface Properties and Secondary Energy
- Conclusions and Future Development

Outline

- **Introduction**
  - SEY: Elastic and True
  - True Secondary Electrons:
    - ✓ Energy spectrum
    - ✓ Dependence on the angle of incidence
- Simulations with SEY Table
- Heat Load
- Surface Properties and Secondary Energy
- Conclusions and Future Development

Introduction

Secondary Electron Yield (SEY) characterise a surface and is defined:

corresponding emitted current

$$\delta(E) = \frac{I_{emit}}{I_{imp}(E)} \quad (1)$$

electron current impinging the wall

SEY depends on the impinging electron energy.

Introduction: SEY (Cimino et al. model)

The SEY can be decomposed in two main components:

$$\delta(E) = \delta_{elas}(E) + \delta_{true}(E) \quad (2)$$

Electrons interact elastically by the chamber's wall (same energy, no deposition of energy in the surface)

true secondary electrons created by inelastic scattering (photoemission) with a fraction of the impacting energy

R. Cimino, I. R. Collins, M. A. Furman, M. Pivi, F. Ruggiero, G. Rumolo, and F. Zimmermann, "Can Low-Energy Electrons Affect High-Energy Physics Accelerators?," Phys. Rev. Lett., vol. 93, p. 014801, Jun 2004.

Introduction: SEY Elastic

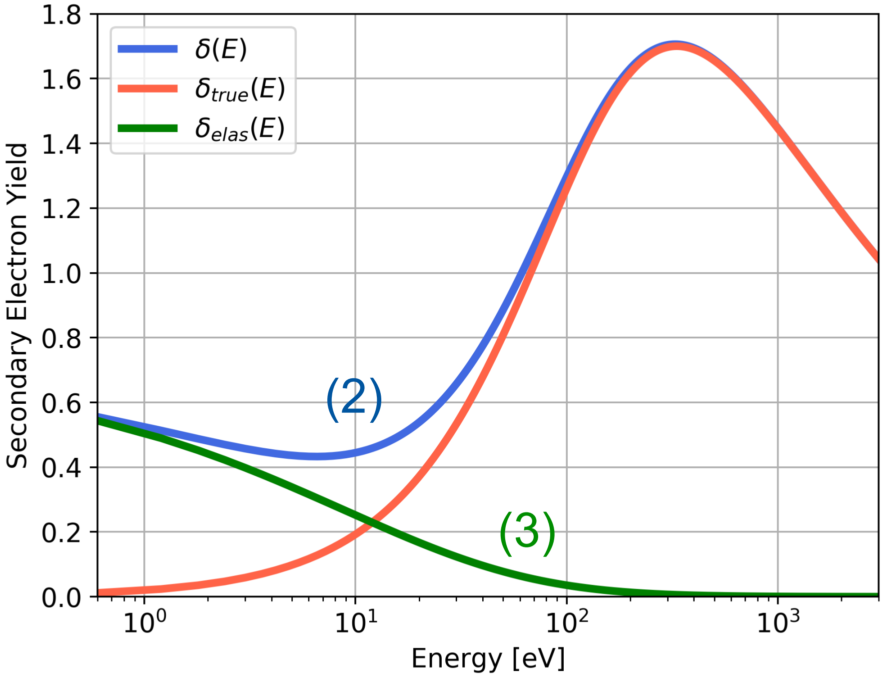
$$\delta(E) = \delta_{elas}(E) + \delta_{true}(E) \quad (2)$$

$$\delta_{elas}(E) = R_0 \left(\frac{\sqrt{E} - \sqrt{E+E_0}}{\sqrt{E}+\sqrt{E+E_0}}\right)^2 \quad (3)$$

E_0 and R_0: shape parameters.

For the LHC beam chambers:

- E_0 = 150 eV
- R_0 = 0.7

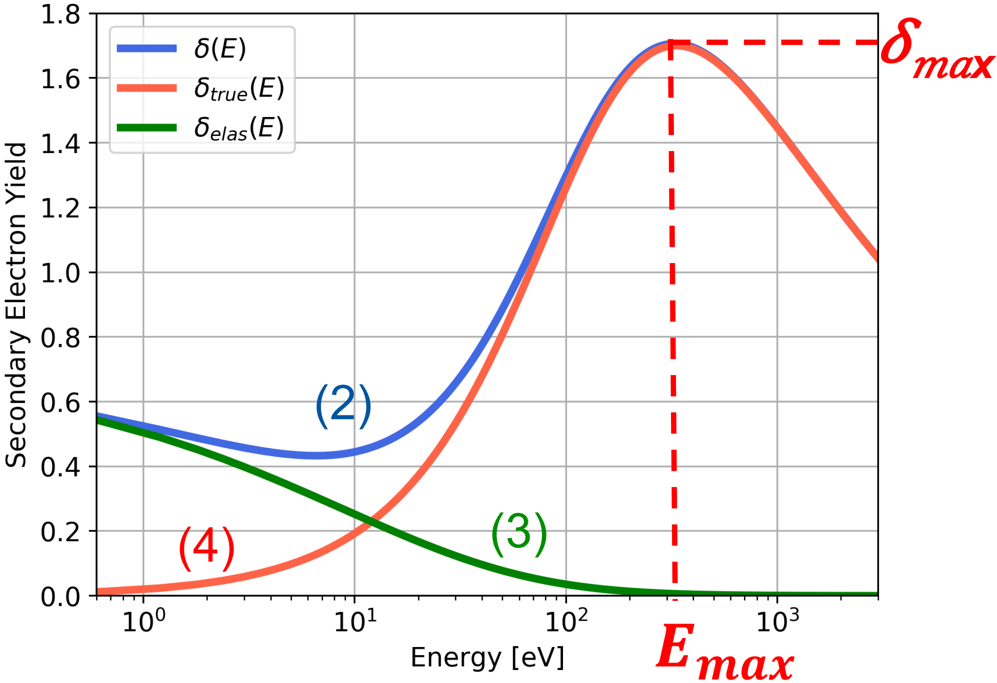


Introduction: SEY True

$$\delta(E) = \delta_{elas}(E) + \delta_{true}(E) \quad (2)$$

$$\delta_{true}(E) = \delta_{max} \frac{s \frac{E}{E_{max}}}{s-1+\left(\frac{E}{E_{max}}\right)^{s}} \quad (4)$$

- s: shape parameter;
- δ_{max}: maximum of the SEY curve dependent on the surface material, roughness and history
- E_{max}: electron energy, where the SEY reach the maximum δ_{max}: $\delta(E_{max}) \cong \delta_{true}(E_{max}) = \delta_{max}$



For the LHC beam chambers:

- s = 1.35
- E_{max} = 332 eV

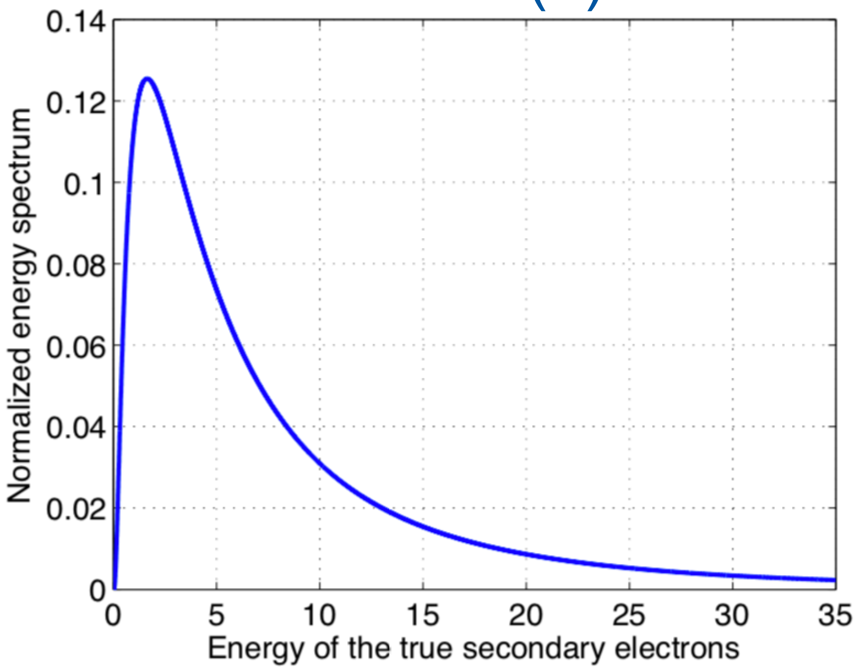
Introduction

The energy spectrum of the true secondary electrons is well fitted by a "lognormal" distribution:

$$\frac{dn_{true}}{dE} = \frac{1}{E\sigma_{true}\sqrt{2\pi}} e^{-\frac{(ln(E)-\mu_{true})^2}{2\sigma_{true}^2}} \quad (5)$$

For the LHC beam chambers:

- σ_{true} = 1.0828
- μ_{true} = 1.6636



Henrist, B., Vorlaufer, G., Scheuerlein, C., Hilleret, N., Taborelli, M., & Jiménez, M. (2002). Secondary electron emission data for the simulation of electron cloud.

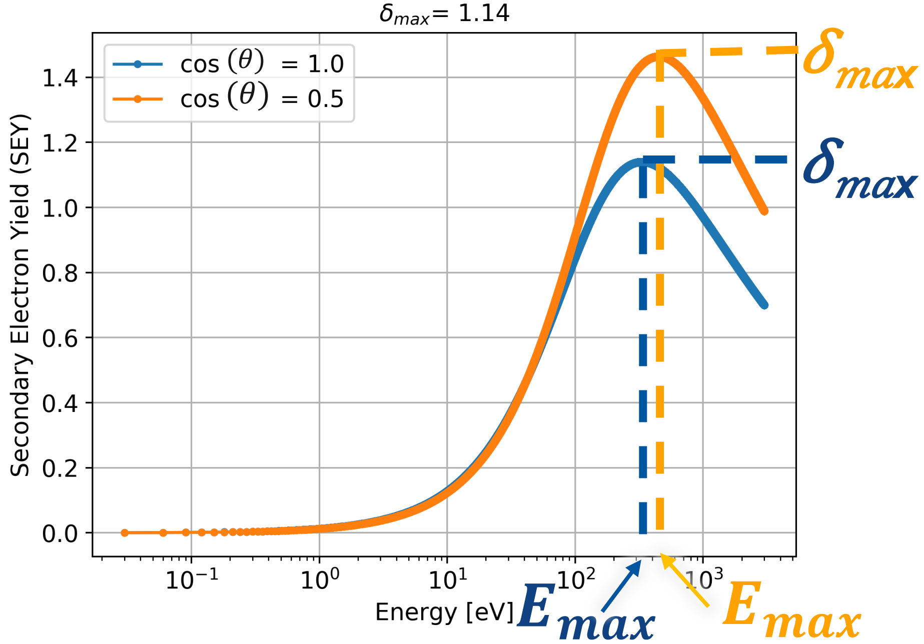
Introduction

E_{max} and δ_{max} of true secondary are rescaled as a function of the angle of incidence:

$$E_{max}(\theta) = E_{max}(\theta = 0)\left(1 + 0.7\,(1\ - \cos\theta\,)\right) \qquad (6)$$

$$\delta_{max}(\theta) = \delta_{max}(\theta = 0)e^{\frac{1-\cos\theta}{2}} \qquad (7)$$

θ: angle of impinging electron with respect of the normal to the surface.



Outline

- Introduction
- **Simulations with SEY Table**
  - Code development
  - Experimental Data and missing information
  - Assumptions
- Heat Load
- Surface Properties and Secondary Energy
- Conclusions and Future Development

Simulations with SEY Table: Code Development

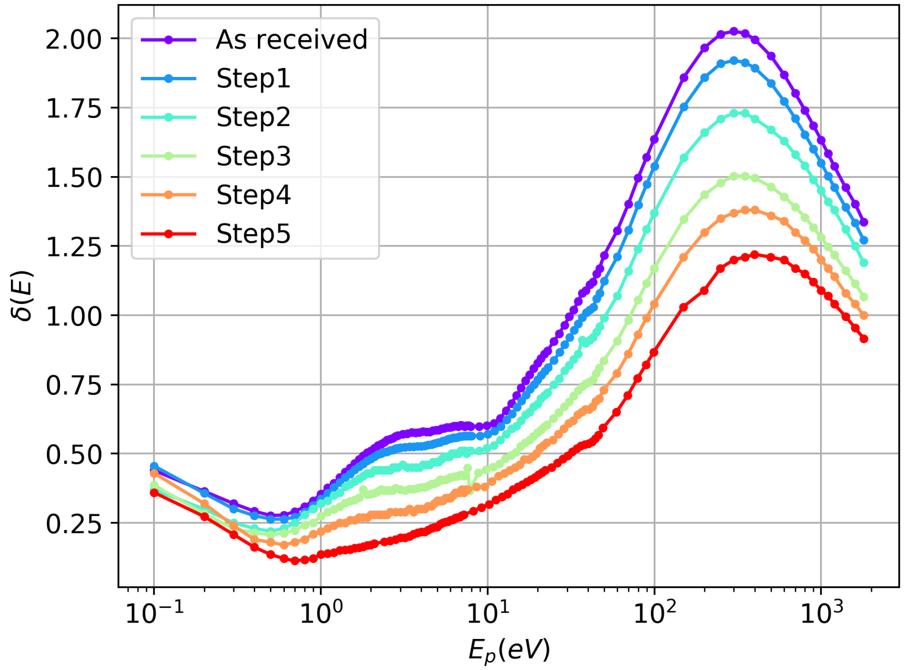
- Computational power of modern computers enables us to use directly tables of measurements for SEY curves instead of analytical models;

- This feature was implemented in PyECLOUD;
  - The SEY curves can be provided by .mat files

- First study recently conducted using data provided by the CERN surface team (TE-VSC)

Simulations with SEY Table: Experimental Data

- LHC Cu Beam screen
- SEY is measured after conditioning the sample with increasing electron dose
- SEY: as received $\delta_{max} \approx 2.0$, fully conditioned $\delta_{max} = 1.15$
- E_{max} shifts from 300 eV to 400 eV

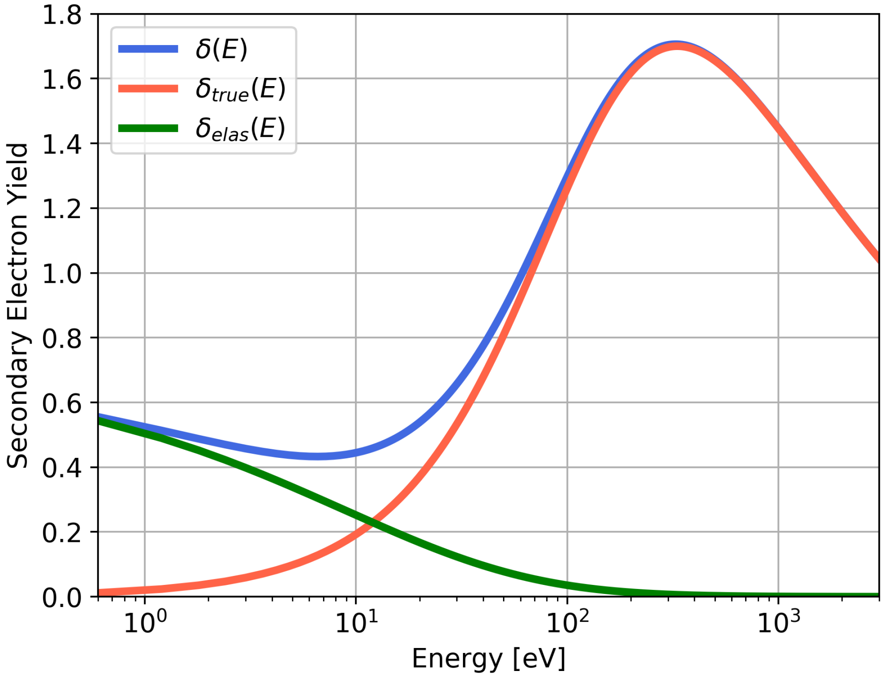


Courtesy of
Valentine Petit
CERN, TE-VSC

Simulations with SEY Table: Missing Information

The present setup used in the laboratory does not provide:

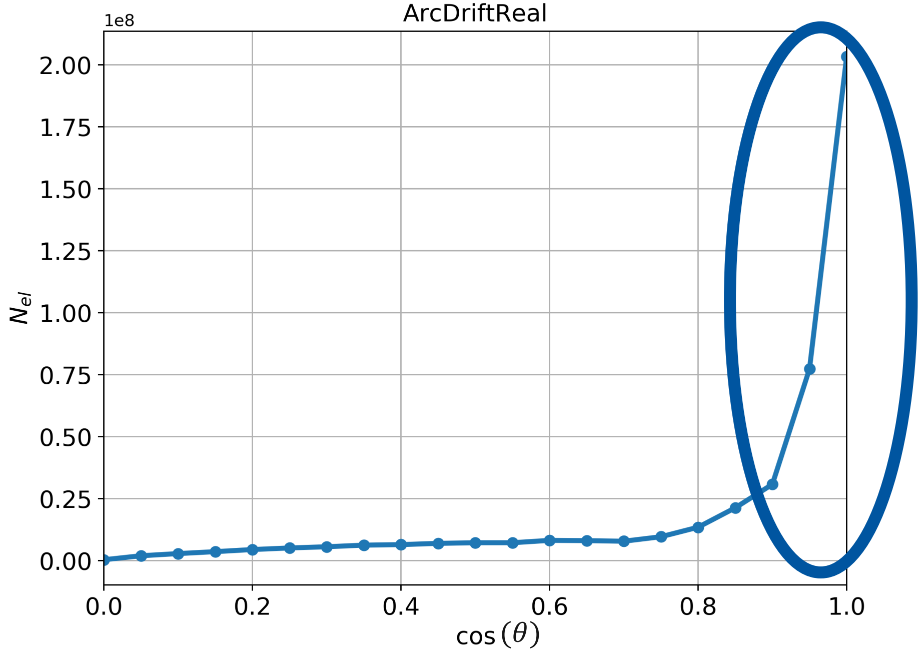
1. Dependence of the SEY on the angle of incidence
2. Energy spectrum of the secondary electrons
   - Magnitude of the elastic component w.r.t. the total



Simulations with SEY Table: Assumptions

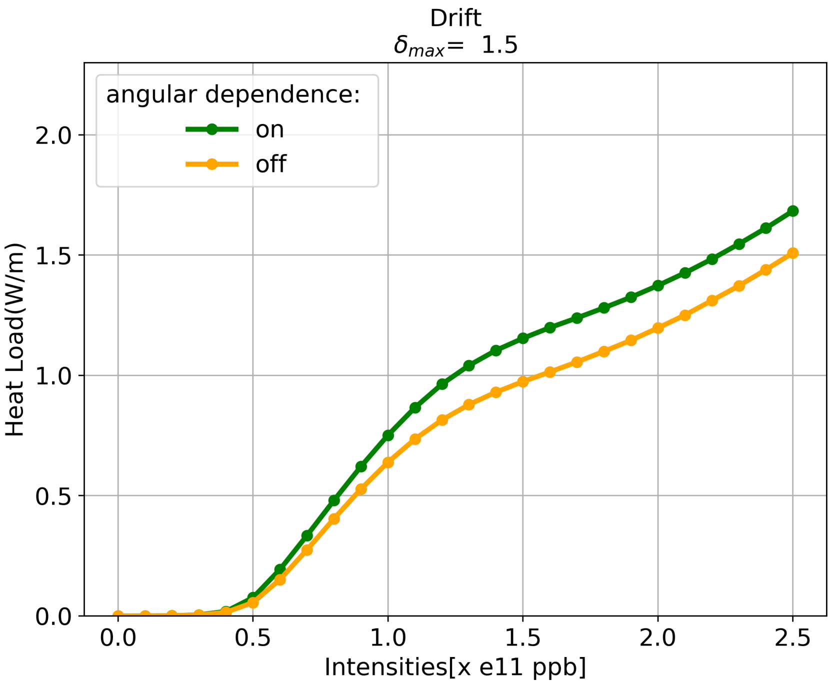
- None of these aspects is crucial for LHC dipole and drift simulations
  1. **In the following angular dependence is neglected**

The majority of electron impinging angles are normal to the surface



Tested using the model

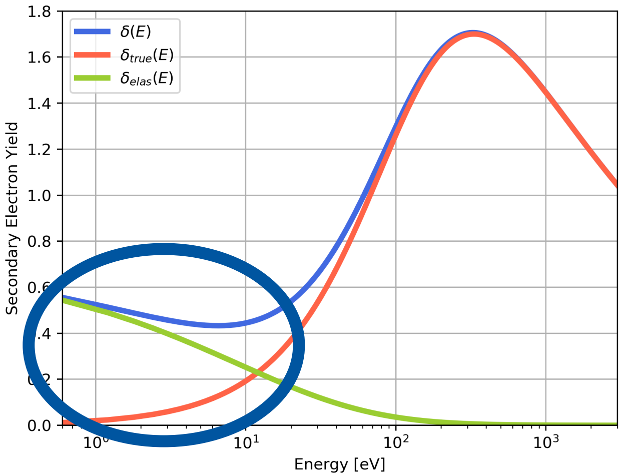
→ Good agreement for the heat load

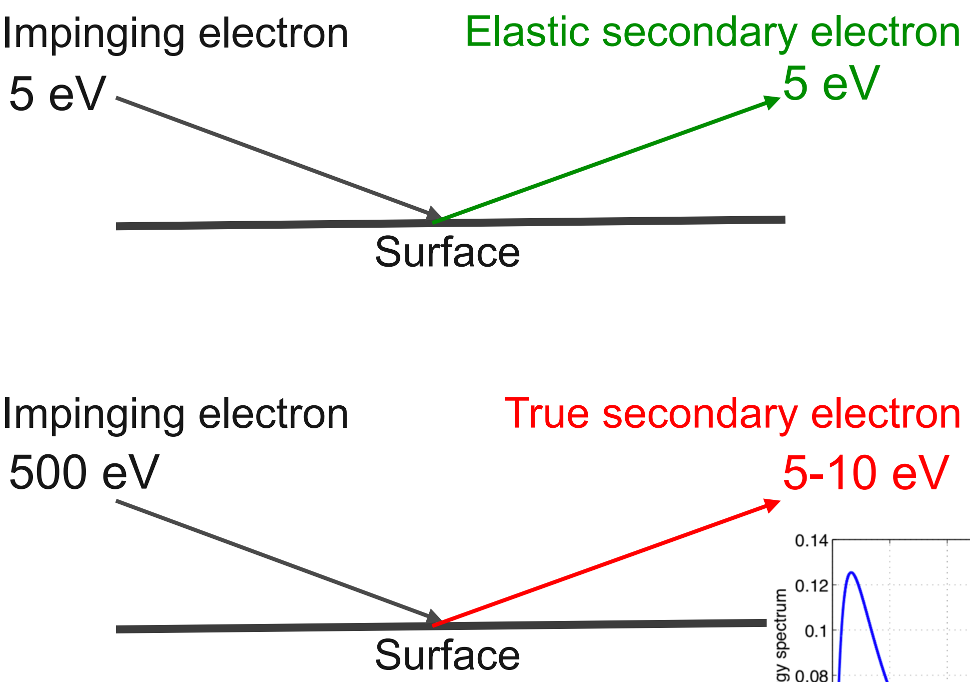


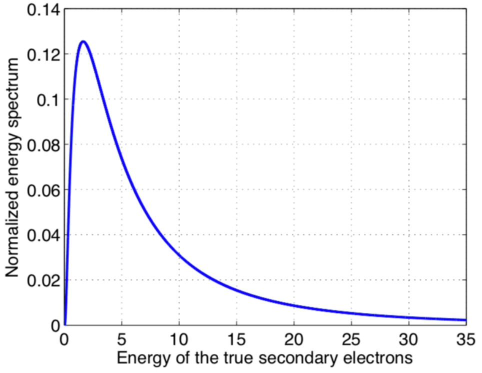
Simulations with SEY Table: Assumptions

- Elastic secondary electrons are mostly low energy electrons, therefore they can be confused with true secondary electrons which are also low energy electrons:

  all emitted electrons are generated with the true-secondary energy distribution

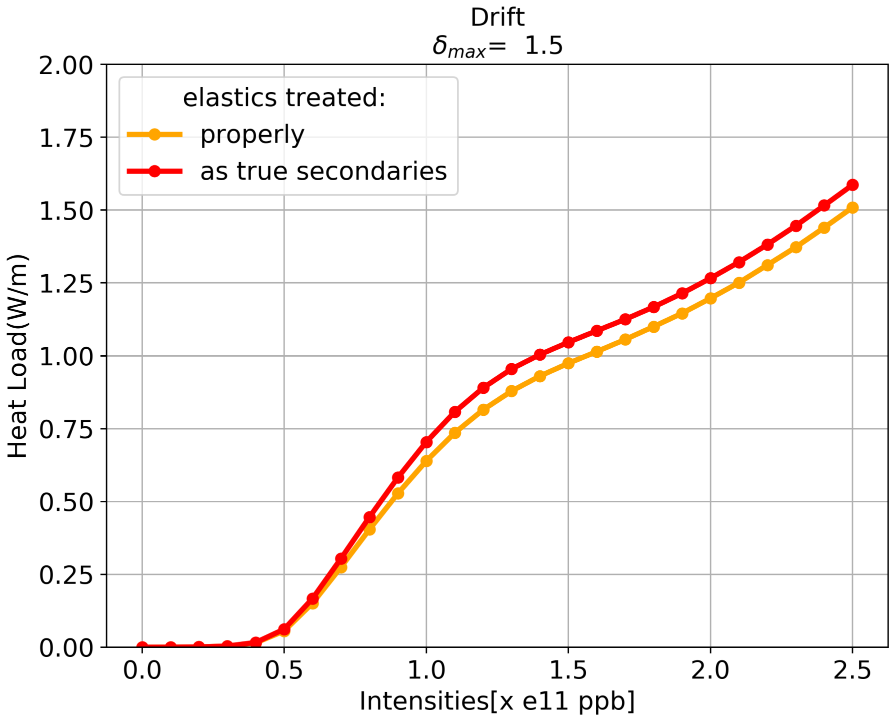






Input SEY of the Model: Assumptions

- None of these aspects is crucial for LHC dipole and drift simulations
  1. In the following angular dependence is neglected
  2. **All secondary electrons are generated as true secondary**



Tested using the model:
→ The approximation is good

Input SEY of the Model: Assumptions

- None of these aspects is crucial for LHC dipole and drift simulations
  1. In the following angular dependence is neglected
  2. All secondary electrons are generated as true secondary

- **These approximations should be removed when more complete data from the lab will be available**

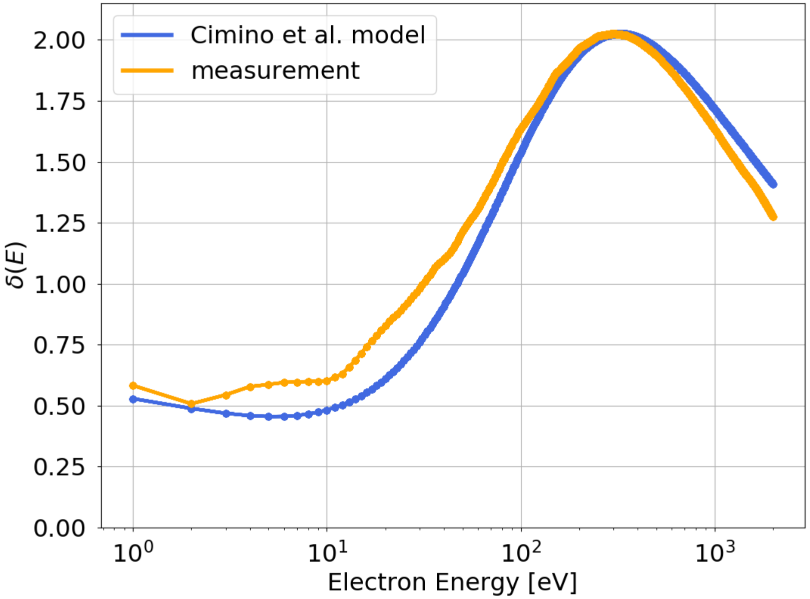
Outline

- Introduction
- Simulations with SEY Table
- **Heat Load**
  - Parameters
  - Heat load versus intensities simulations in both the cases
    - ✓ using analytical model of SEY
    - ✓ tables of measurements of SEY
- Surface Properties and Secondary Energy
- Conclusions and Future Development

Heat Load

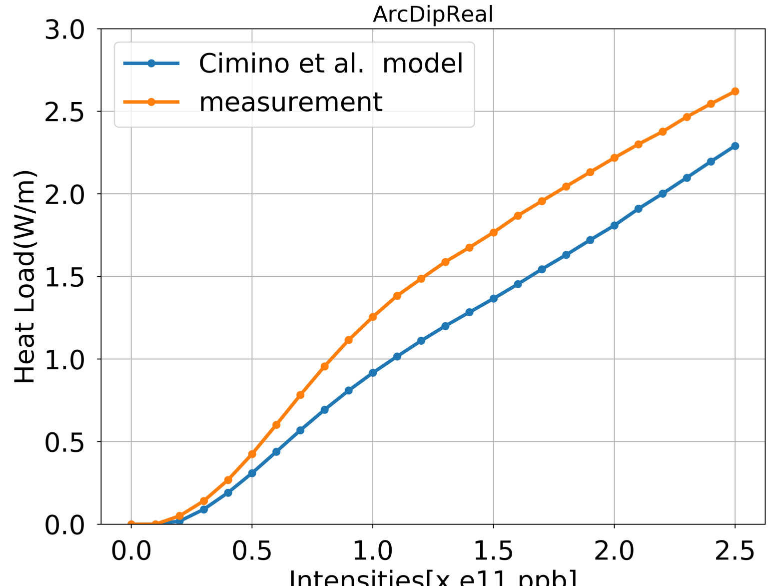
- Simulate EC buildup with the measured SEY curves and the Cimino et al. model to compare.
- Parameters:
  - δ_{max} scan → Graphically inferred from measurements
  - Intensity Scan: 0.0 - 2.5 e11 ppb
  - Angular dependence OFF
  - Elastics treated as true secondaries in both cases

Heat Load

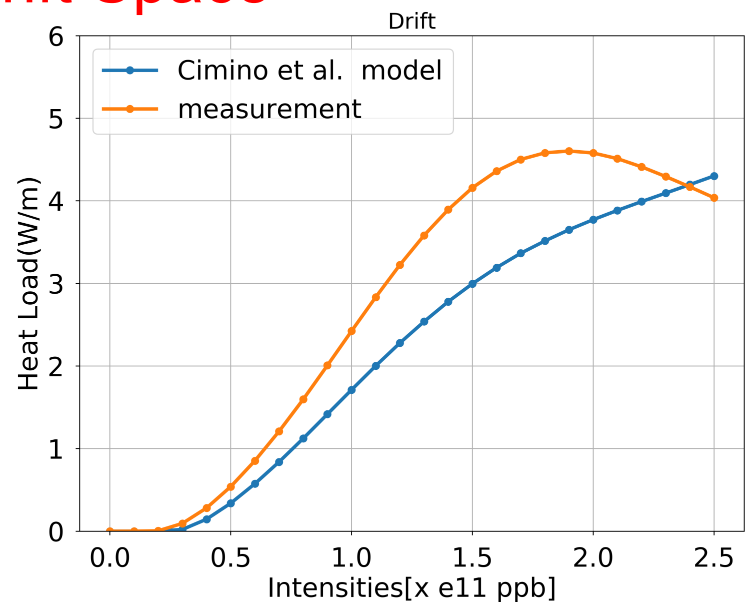


Dipole

δ_{max} = 2.02

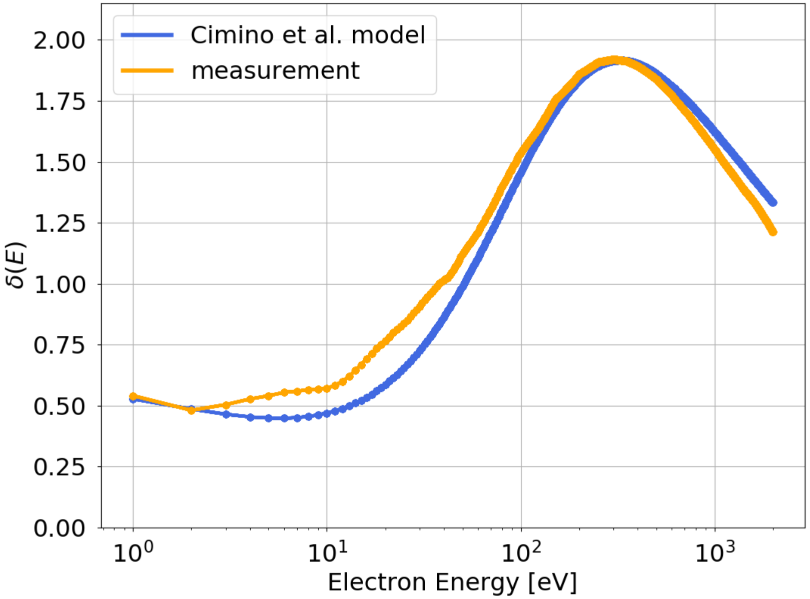


Drift Space



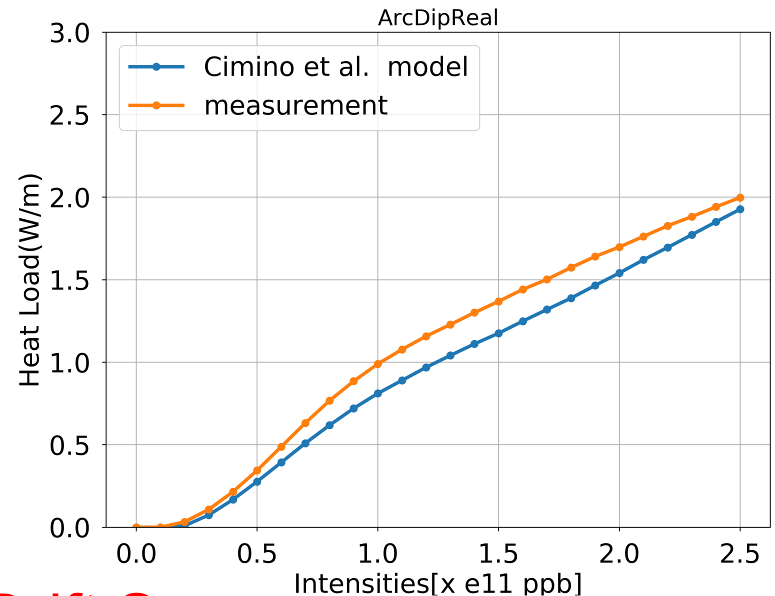
1. For high δ_{max}:
   - Visible difference between SEY curves in the low and high energy regions
   - Visible difference between Heat loads
2. Heat load dependence with bunch intensity changes the slope, not foreseen by the model

Heat Load

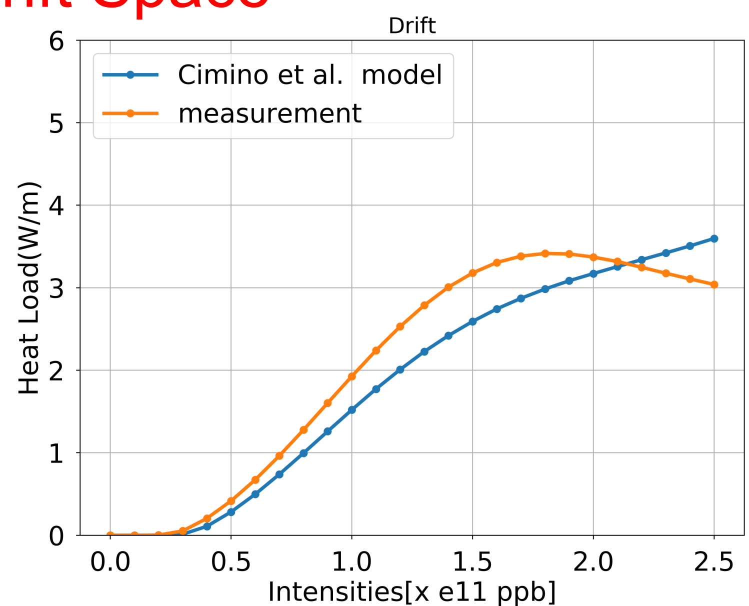


Dipole

δ_{max} = 1.91

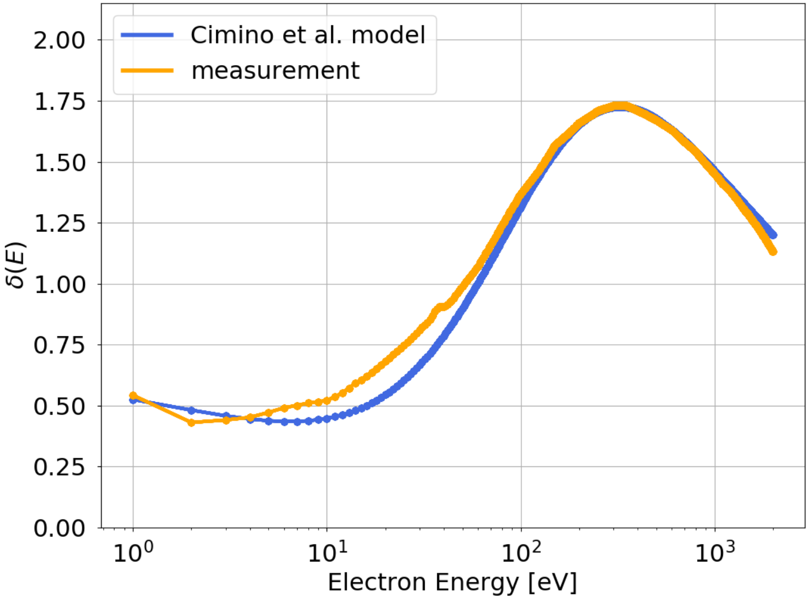


Drift Space



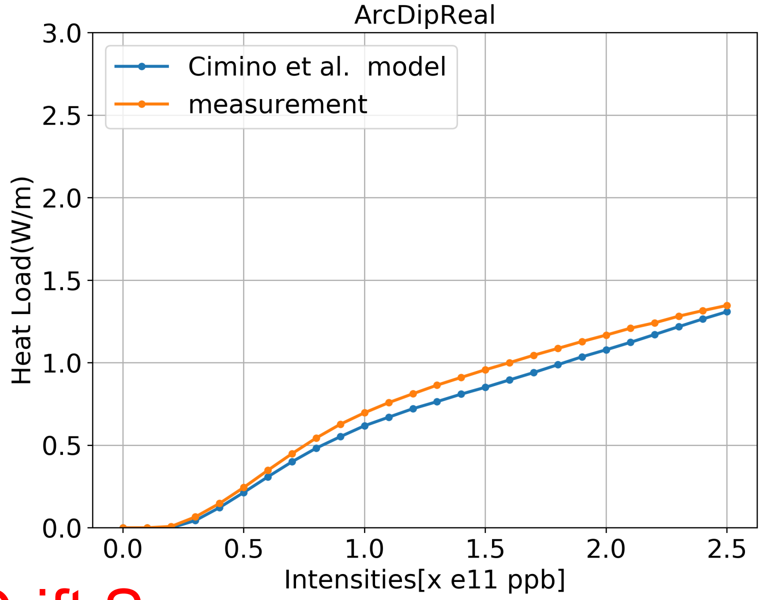
Smaller δ_{max} → Smaller difference

Heat Load

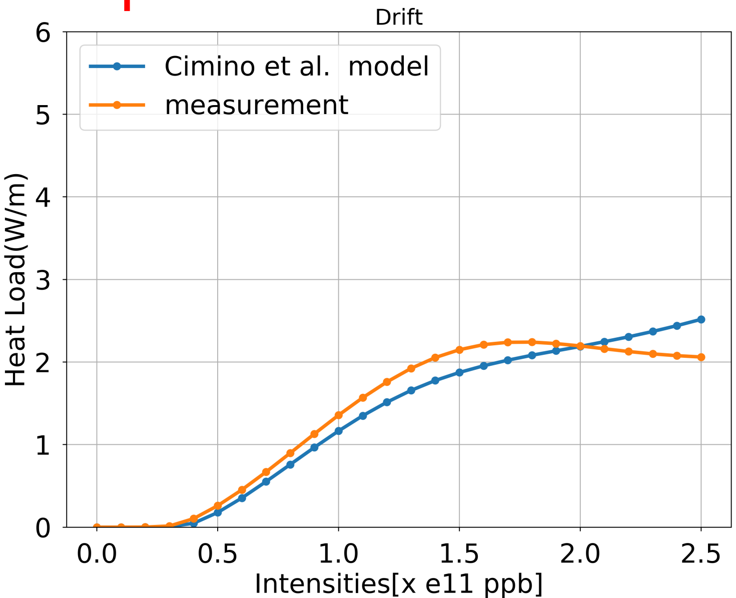


Dipole

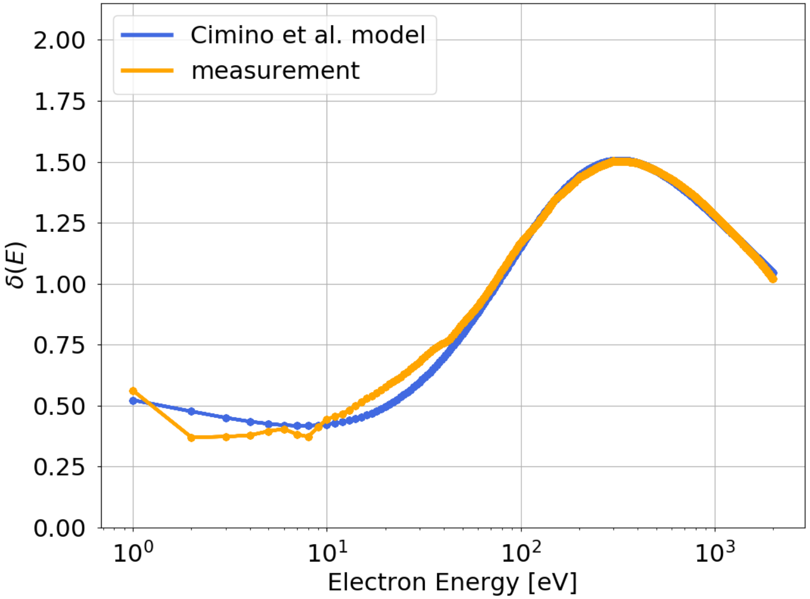
δ_{max} = 1.72



Drift Space



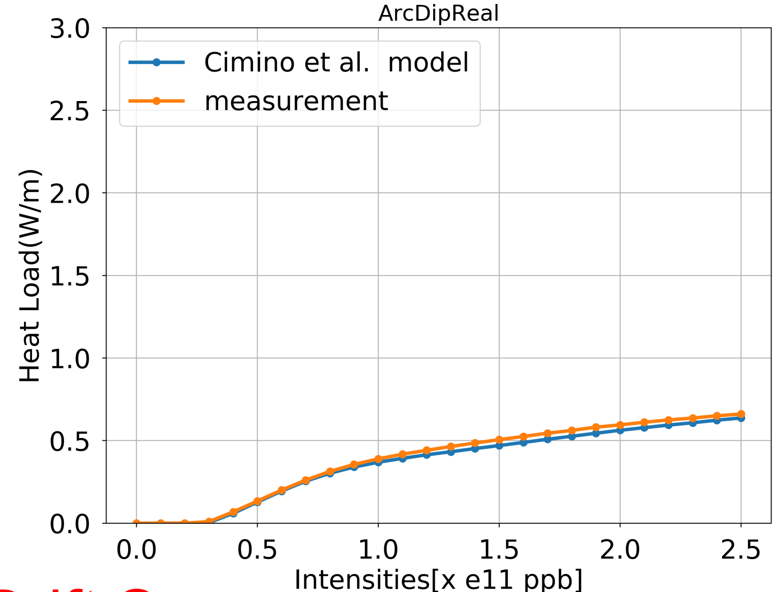
Heat Load



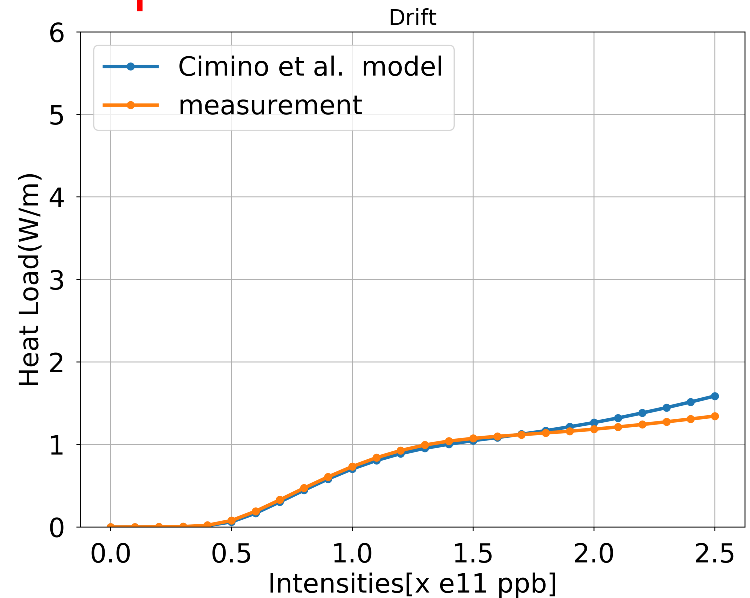
For low δ_{max} heat load dependence on intensity flattens above 0.5e11 (both for SEY model and measurements)

Dipole

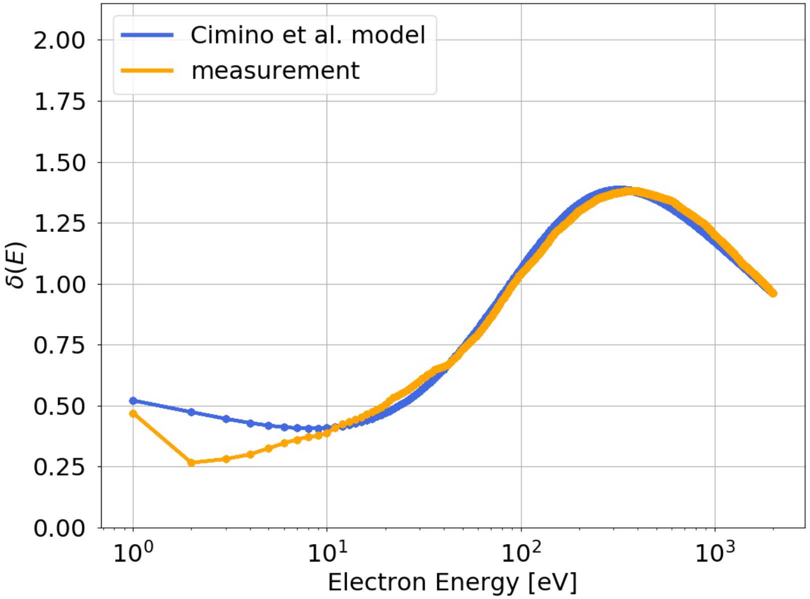
δ_{max} = 1.5



Drift Space

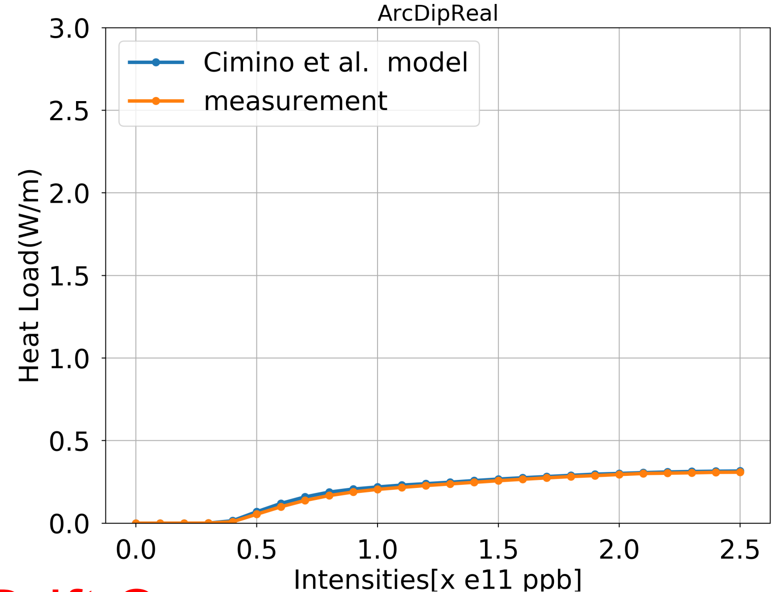


Heat Load

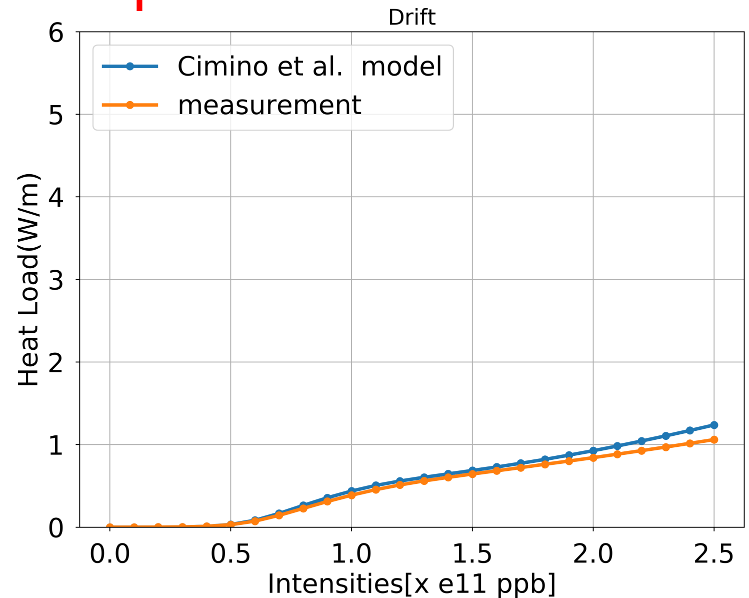


Dipole

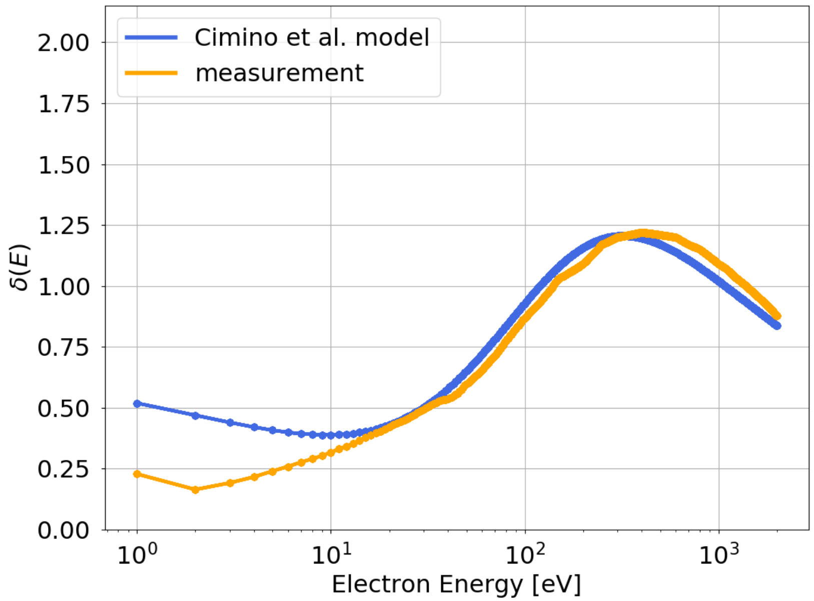
δ_{max} = 1.38



Drift Space

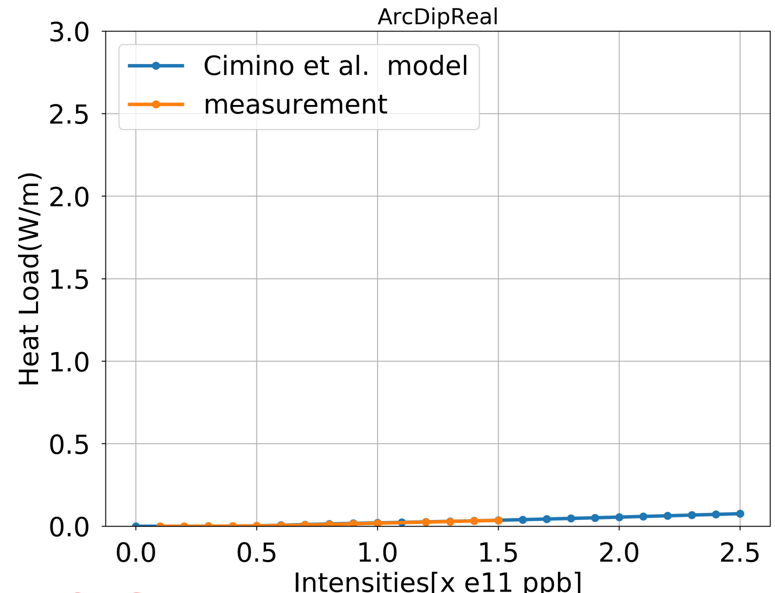


Heat Load

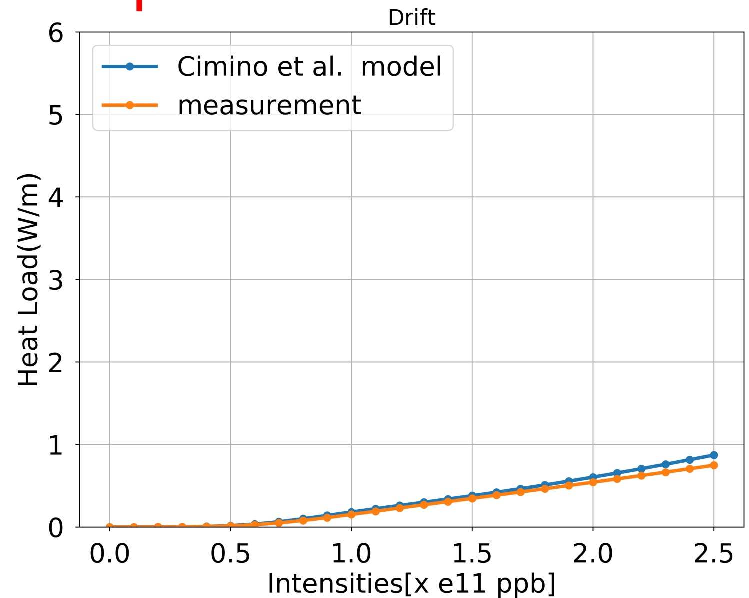


Dipole

δ_{max} = 1.20

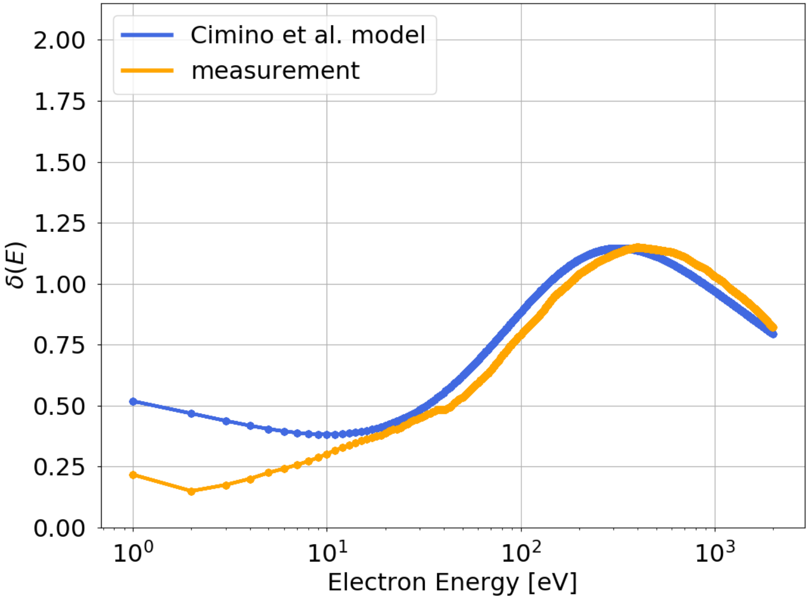


Drift Space



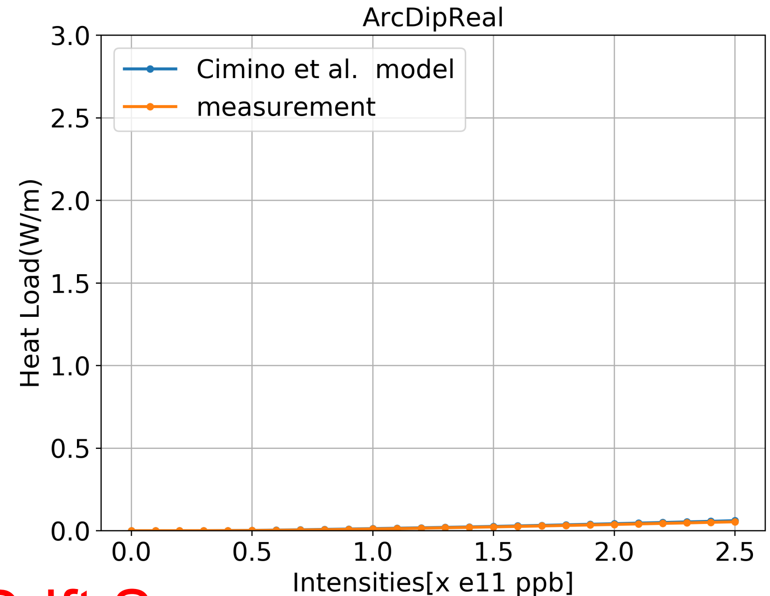
- Low heat loads (above mutipacting threshold)
- No difference despite the difference in the SEY curves, heat load dominated by photoelectrons

Heat Load

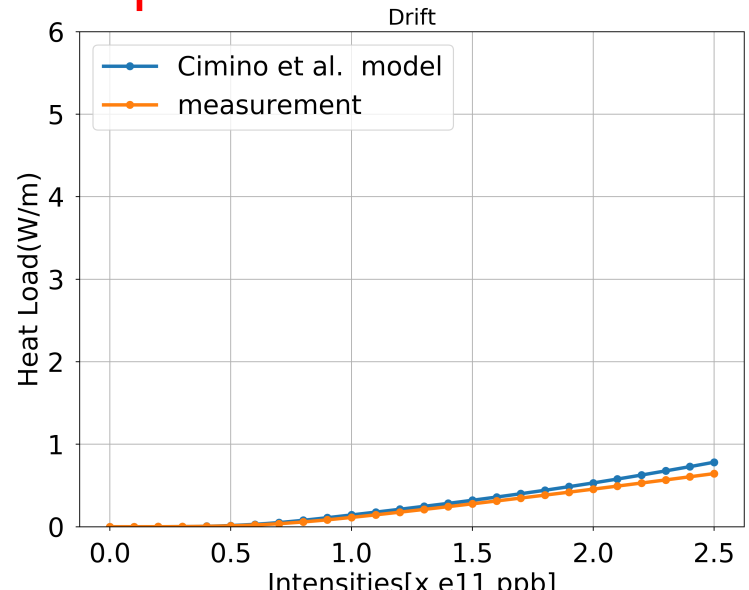


Dipole

δ_{max} = 1.14



Drift Space

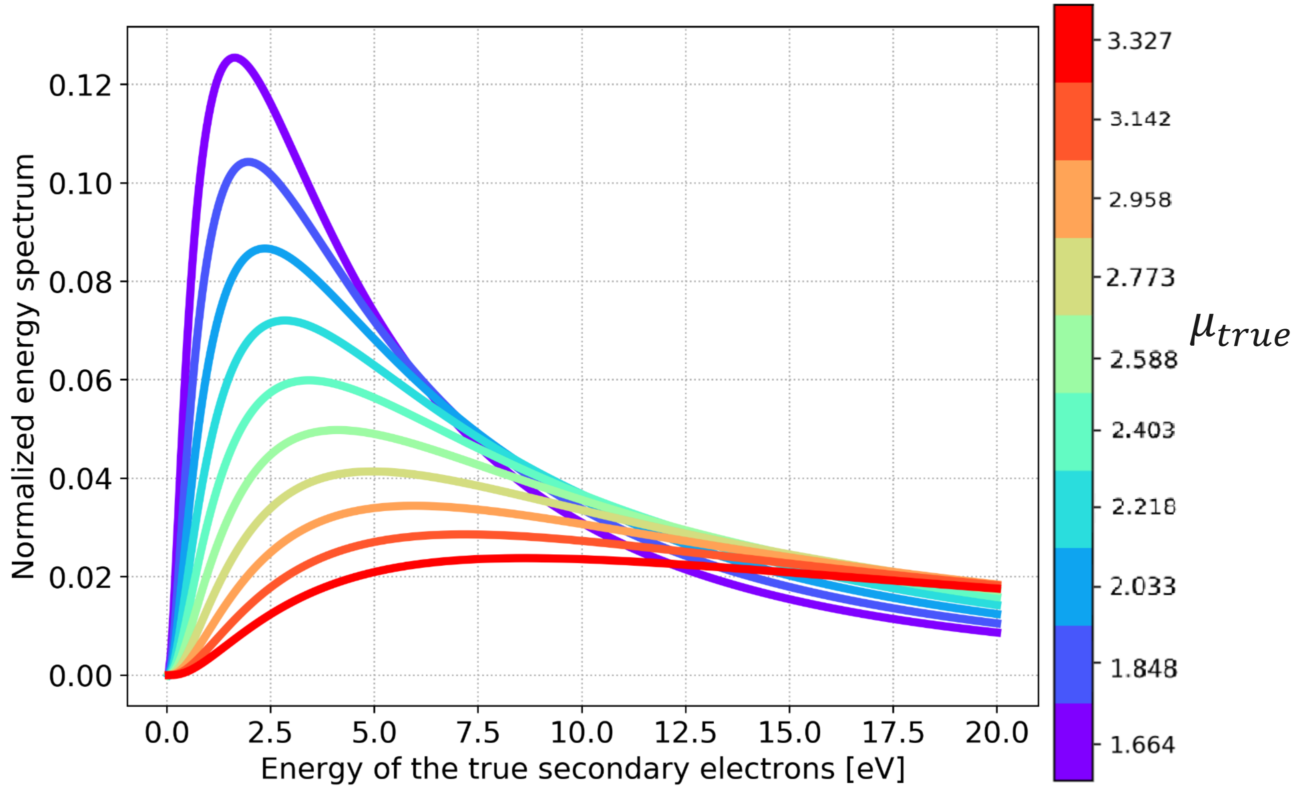


Outline

- Introduction
- Input SEY of the Model
- Heat Load
- **Surface Properties and Secondary Energy**
  - Energy spectrum and heat load at varying model parameter μ_{true}
  - Database of secondary emission models
- Conclusions and Future Development

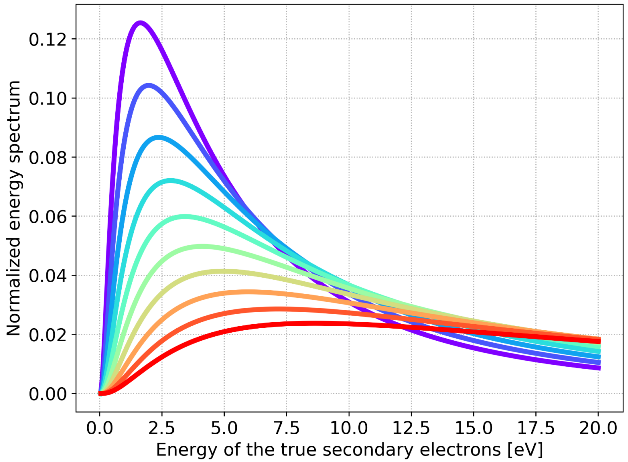
Surface Properties and Secondary Energy

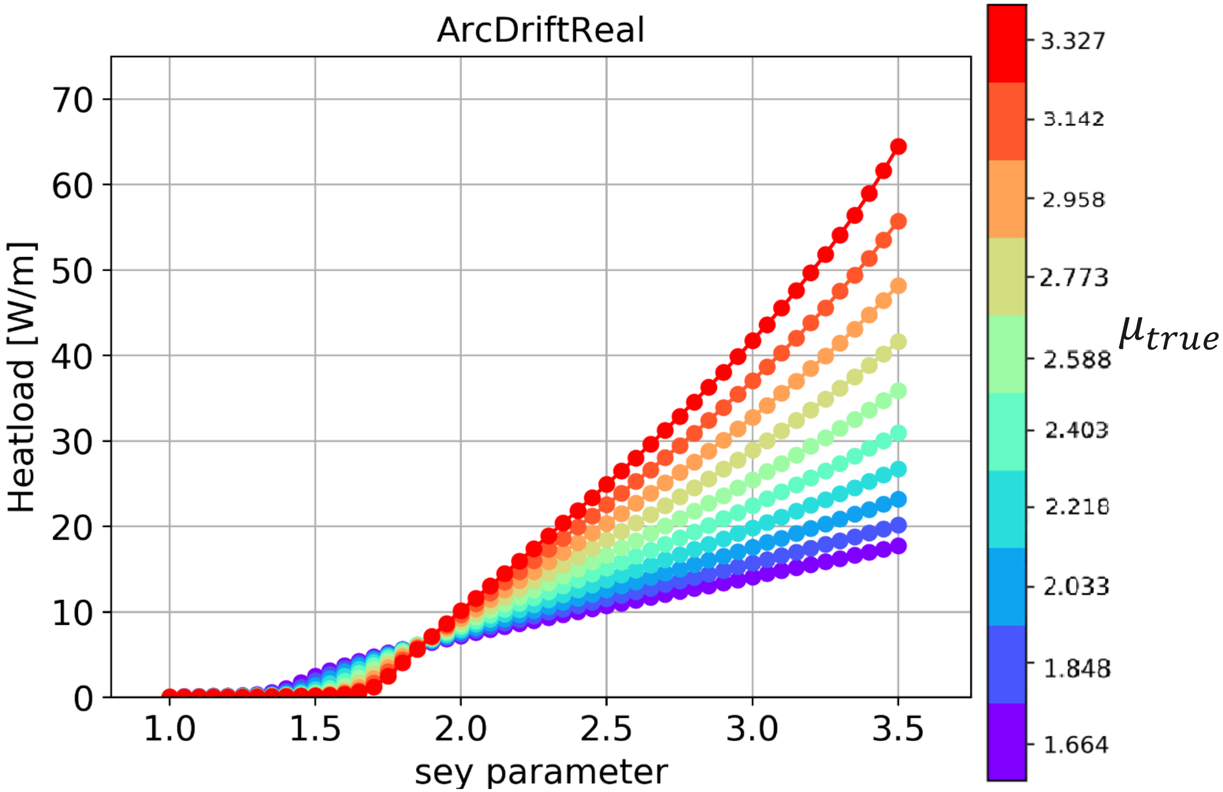
- However, there is more than just the SEY curve
- For example, the energy of the secondary electrons determines the probability of them being absorbed before the next bunch passage



Surface Properties and Secondary Energy

- Change μ_{true} parameter of the energy spectrum produces a significant impact in heat loads





Surface Properties and Secondary Energy

The ideal would be to have a database of secondary emission models including:

1. SEY curves
2. Energy spectra

For different:

- Material
- Accumulated scrubbing
- Other relevant parameters (temperature, condensed gases?)

- To be used directly in the simulator

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Conclusions and Future Development

- Computational power of modern computers enable us to use directly tables of measurements for the SEY curves instead of analytical models

- Visible difference between experimental data and simulation results of the SEY versus energy for high δ_{max}

- Heat loads versus bunch intensities in both the cases of using analytical model and tables of measurements of SEY were shown
  - visible difference especially for high δ_{max}

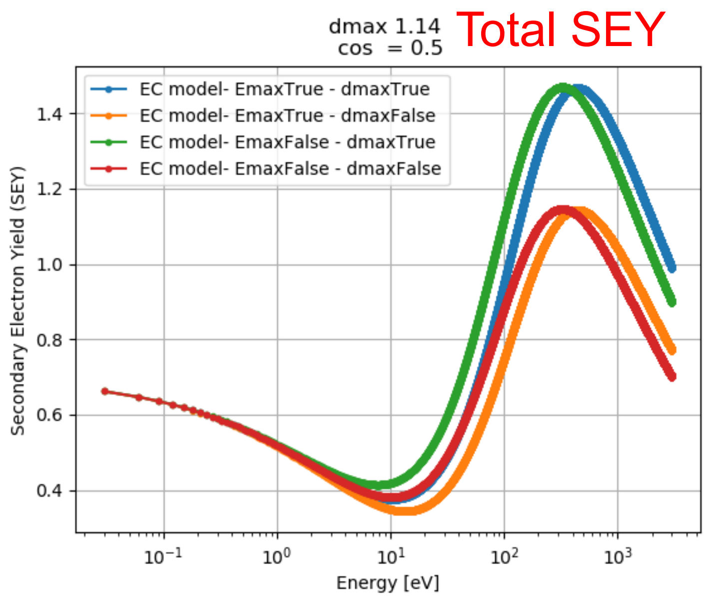
- With the available lab data, angular dependence had to be switched off and elastic secondary electrons had to be treated as true secondary electrons
  - These assumptions can be removed when more complete data from the lab will be available

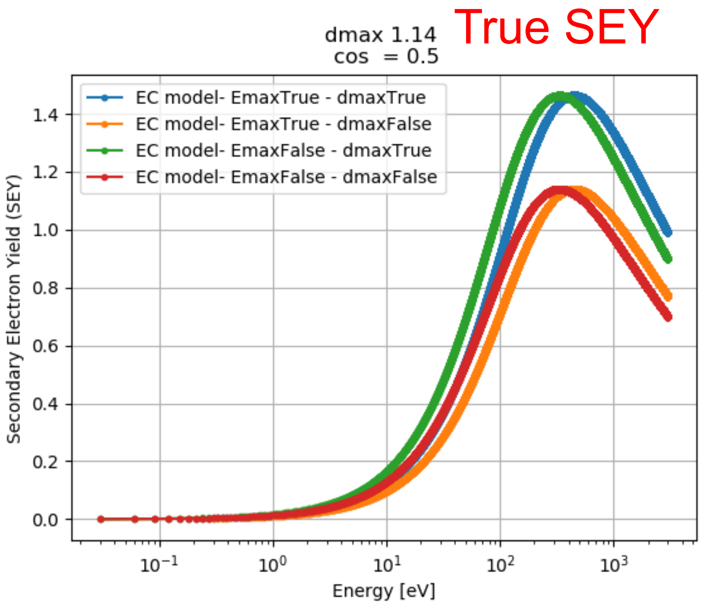
- It would be very useful to have more data on the energy spectrum of the secondary electrons, for different materials and conditioning states

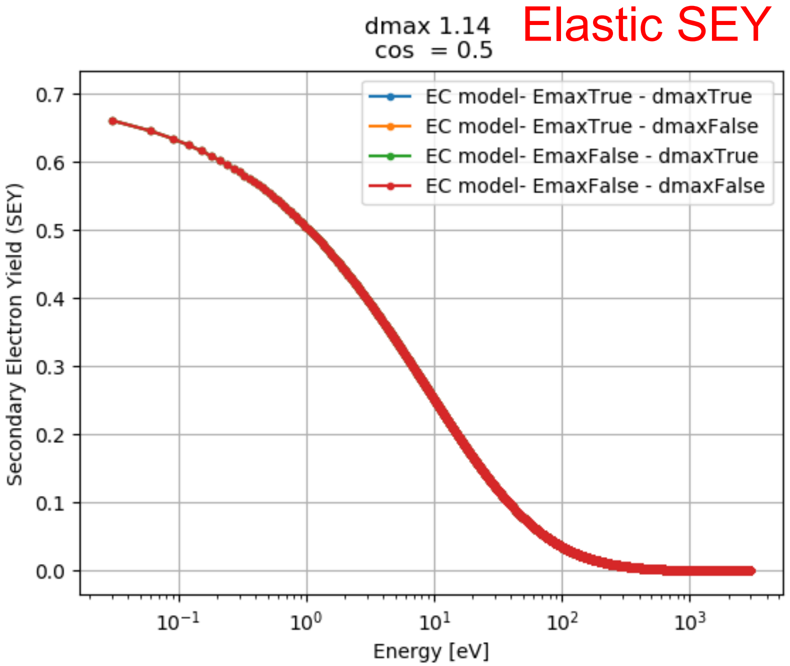
- These studies were carried out in the case of dipole magnets and drift spaces, and will be extended for quadrupole magnets

Thanks for your attention

Dependance on the angle of incidence







Input SEY of the Model: Assumptions

The elastic secondary electrons cannot be treated as true secondary electrons when the angular dependence is enabled: this is investigated for a drift space and a dipole