Electron Emission in Photoinjector Simulation Codes

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Introduction

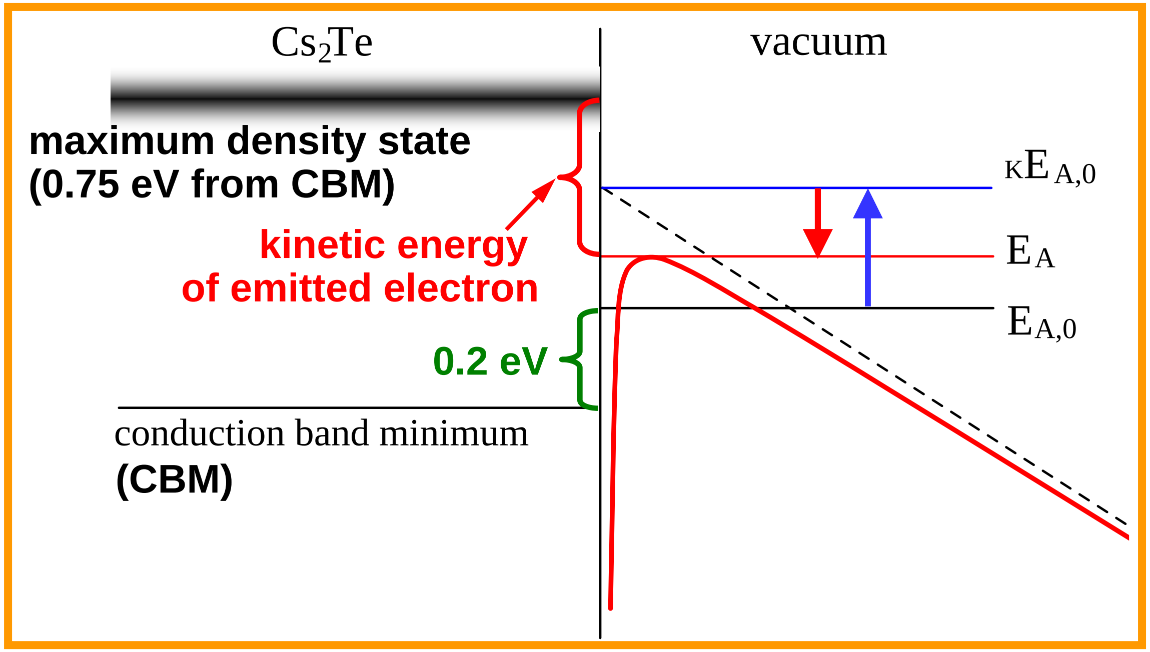
- In photoinjectors, electron beams are in an ultra-high density.
- A tiny variation of initial beam parameters (like rise/fall time of the drive laser and inhomogeneity) changes the beam quality dramatically. → <u>photoemission</u>

- High-quality photoinjectors require high accelerating field and results in high <u>field emission</u>.
- Dark current as well as electron beams need to be tracked.

- For high QE cathodes <u>secondary emission</u> may take place.

General review of photoinjector simulation codes: C. Limborg et al, PAC2003, p. 3528.

Photoemission – QE and Energy



electron affinity increase due to surface contamination

$$E_A = \kappa\, E_{A,0} - \sqrt{\frac{e^3}{4\pi\varepsilon_0}\,\beta_{ph}\, E_{emit}}$$

electron affinity decrease due to the Schottky effect

Potential barrier decrease by the electric field

Electron affinity variation results in

1. Bunch charge change
2. Kinetic energy change of emitted electrons (thermal emittance)

κ : surface contamination factor
β_{ph}: field enhancement factor
E_{emit}: electric field at emission

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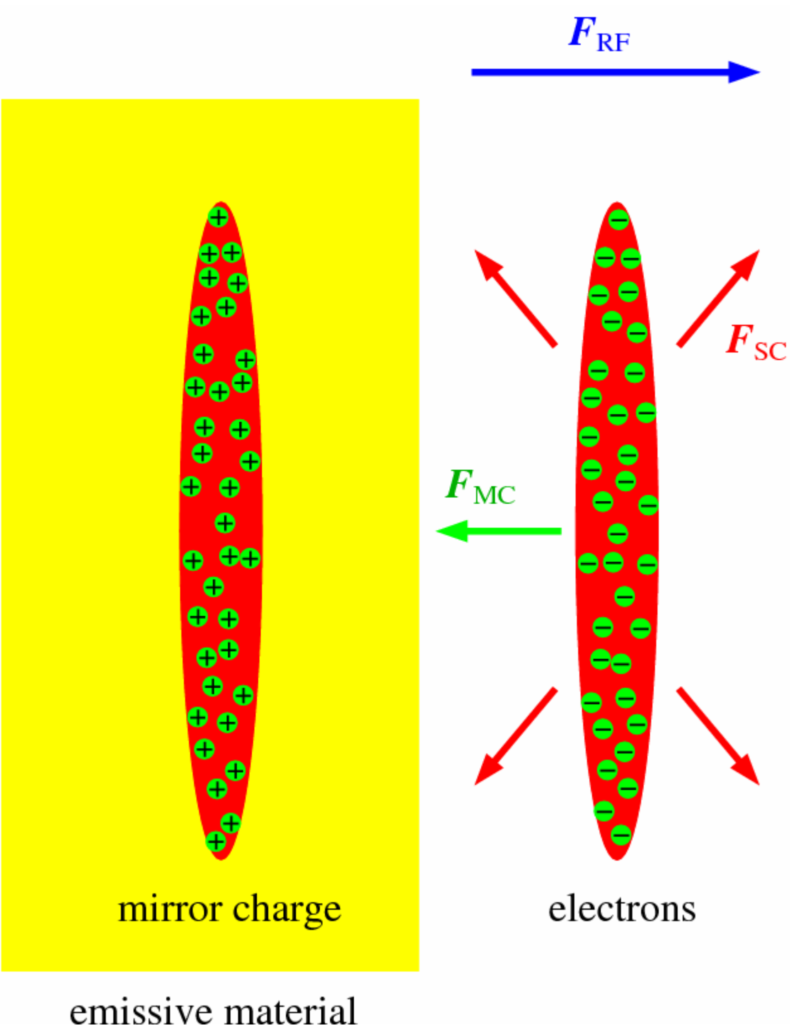
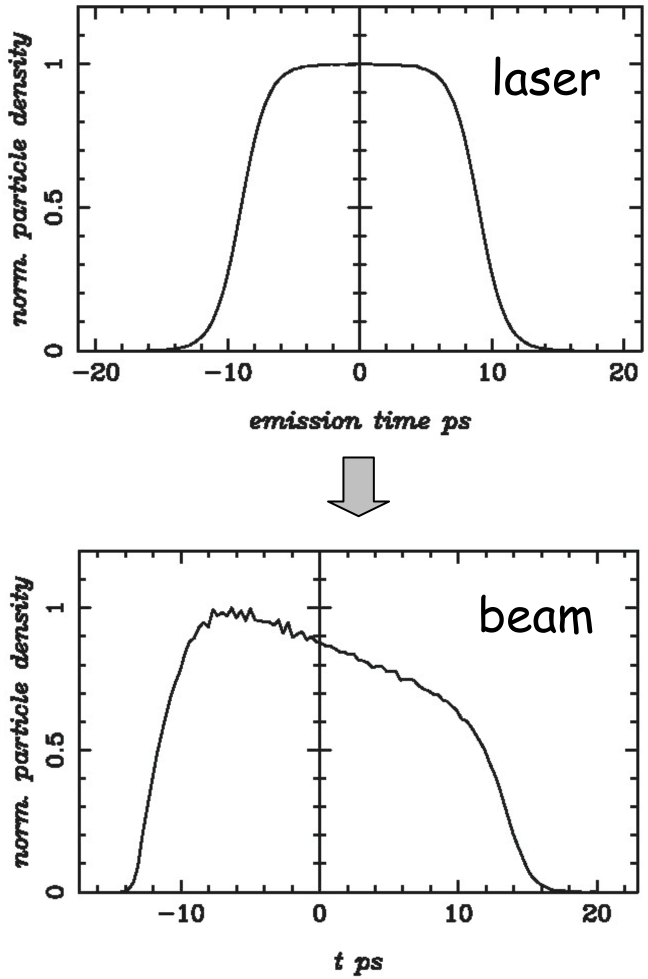
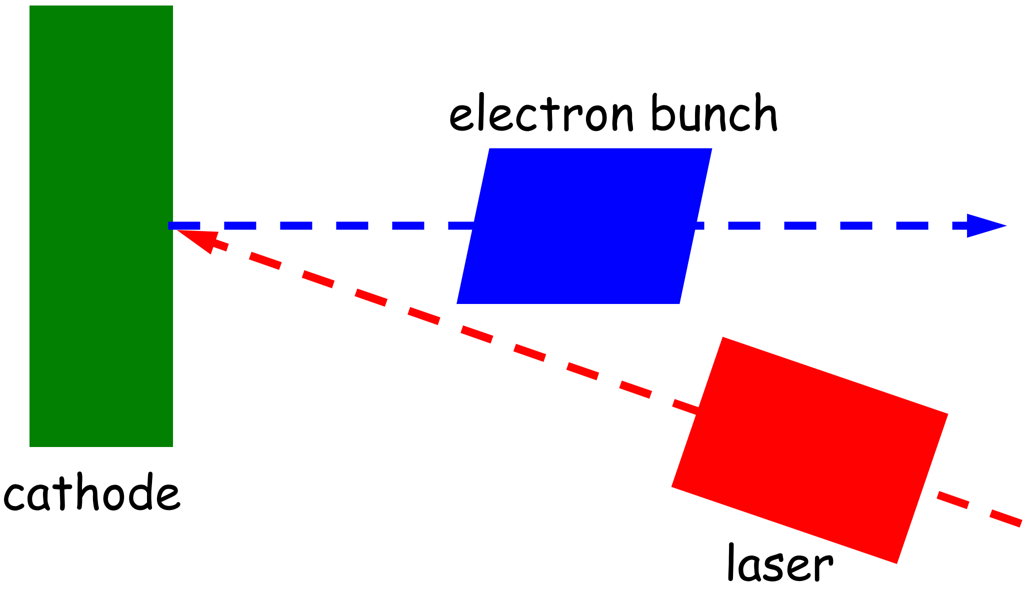
Photoemission – Mirror Effect





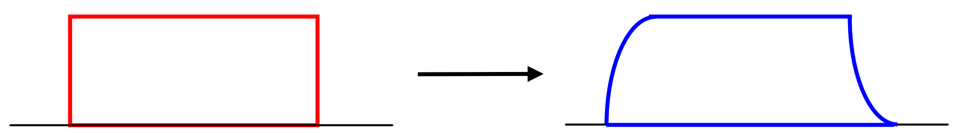
Photoemission – Simplest

- No QE inhomogeneity
- No Schottky effect
- No mirror charge + SC
- No ……



tilting due to incident angle: angle x beam size (2° x 1 mm → 0.1 ps)

$l_{bunch} \sim l_{laser}$ * response time



Important for special cases: ultra-short pulse generation, GaAs cathode …

Photoemission Features for Simulation (1)

- Initial distribution of an electron beam
  - Spatial and temporal shape of the cathode laser:
    Most simulation codes: ASTRA (generator), PARMELA (EGUN), TREDI, IMPACT, GPT …
  - QE variation in space (QE inhomogeneity):
    QE map should be integrated
  - QE variation due to Schottky effect: ASTRA (astra)
  - Mirror charge effect:
    Most simulation codes with a space charge routine
  - Response time of photoemission (cathode material):
    No code
  - Bunch tilting due to incident angle: No code

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Photoemission Features for Simulation (2)

- Energy distribution of electrons → thermal emittance
  - Cathode material, contamination, roughness, laser wavelength, accelerating field

  Most simulation codes offer as initial emittance and/or initial electron energy

ASTRA Input for an Electron Beam

Generator input

```
&INPUT
 Fname='laser_profile.ini'
 …
 IPart=200000
 …
 Cathode=T
 Q_total=1.0E0
 Dist_z='p'
 Lt=0.016,   rt=0.004
 Dist_pz='i',   LE=0.00075
 Dist_x='r',   sig_x=0.47E0
 Dist_y='r',   sig_y=0.47E0
 Nemit_x=0.0E0
 /
```

Astra input

```
&NEWRUN
 ...
 Distribution = 'laser_profile.ini'
 ...
 Q_Schottky=0.01
/

&CHARGE
 LSPCH=T
 ...
 Lmirror=.T
/
```

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PARMELA Input

cathode temperature (eV)

CATHODE 0, R_a, *output flag*, $R_{cathode}$, kT

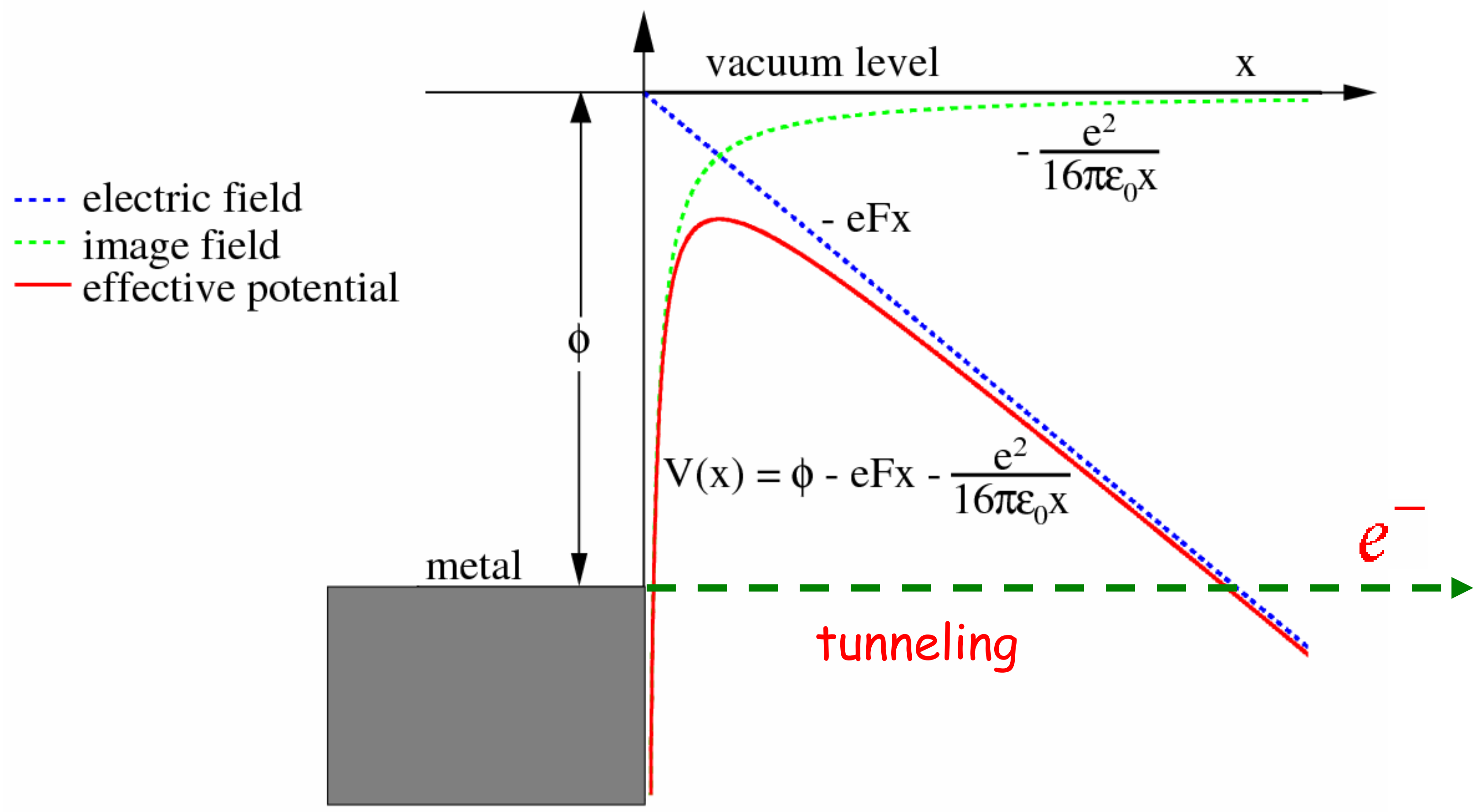
option for image charge calculation

SCHEFF I_T, ΔR_{SC}, ΔZ_{CS}, N_R, N_Z, N_{Bunch}, L_{Bunch}, *RingOption*, ……

type of electron dustribution

INPUT *Type*, N_A, σ_r, r_{max}, σ_ϕ, ϕ_{max}, ……

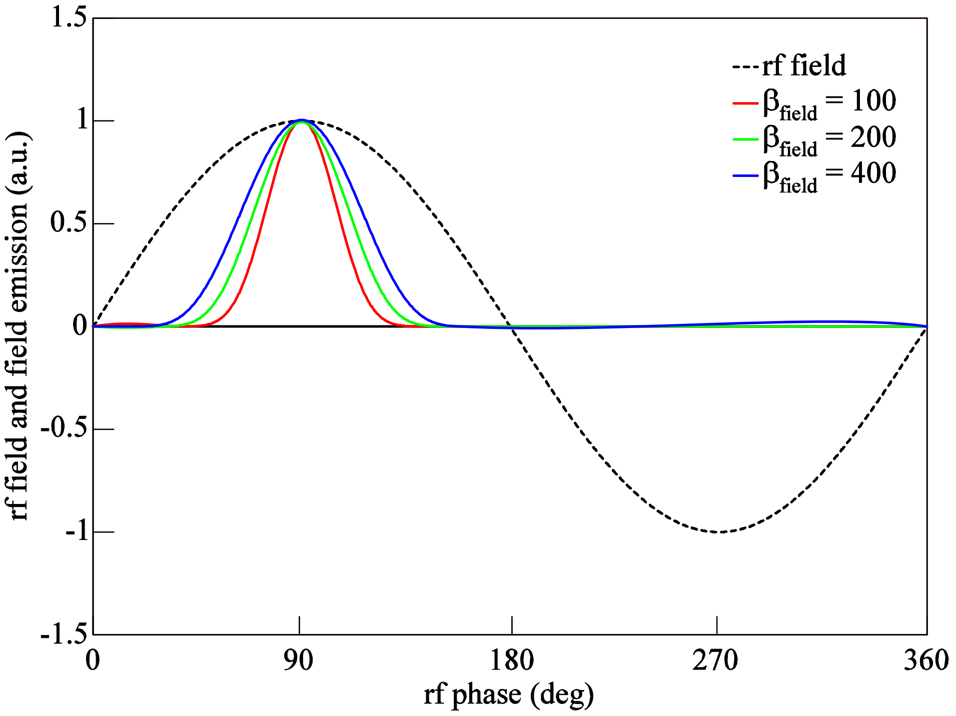
Field Emission - Phenomena



$$\boxed{\bar{I}_{\mathrm{FE}} = C_1 E^2 \exp(-C_2 / E)}$$ Fowler-Nordheim

Field emission - Model

- Generate electrons depending on the applied E-field strength at the surface
  - $I_{FE} = C_1 E^2 \exp(-C_2/E)$



  - C_1 and C_2 can be empirically found with measurement of field-emitted current as a function of applied field strength

ASTRA Input for Dark Current

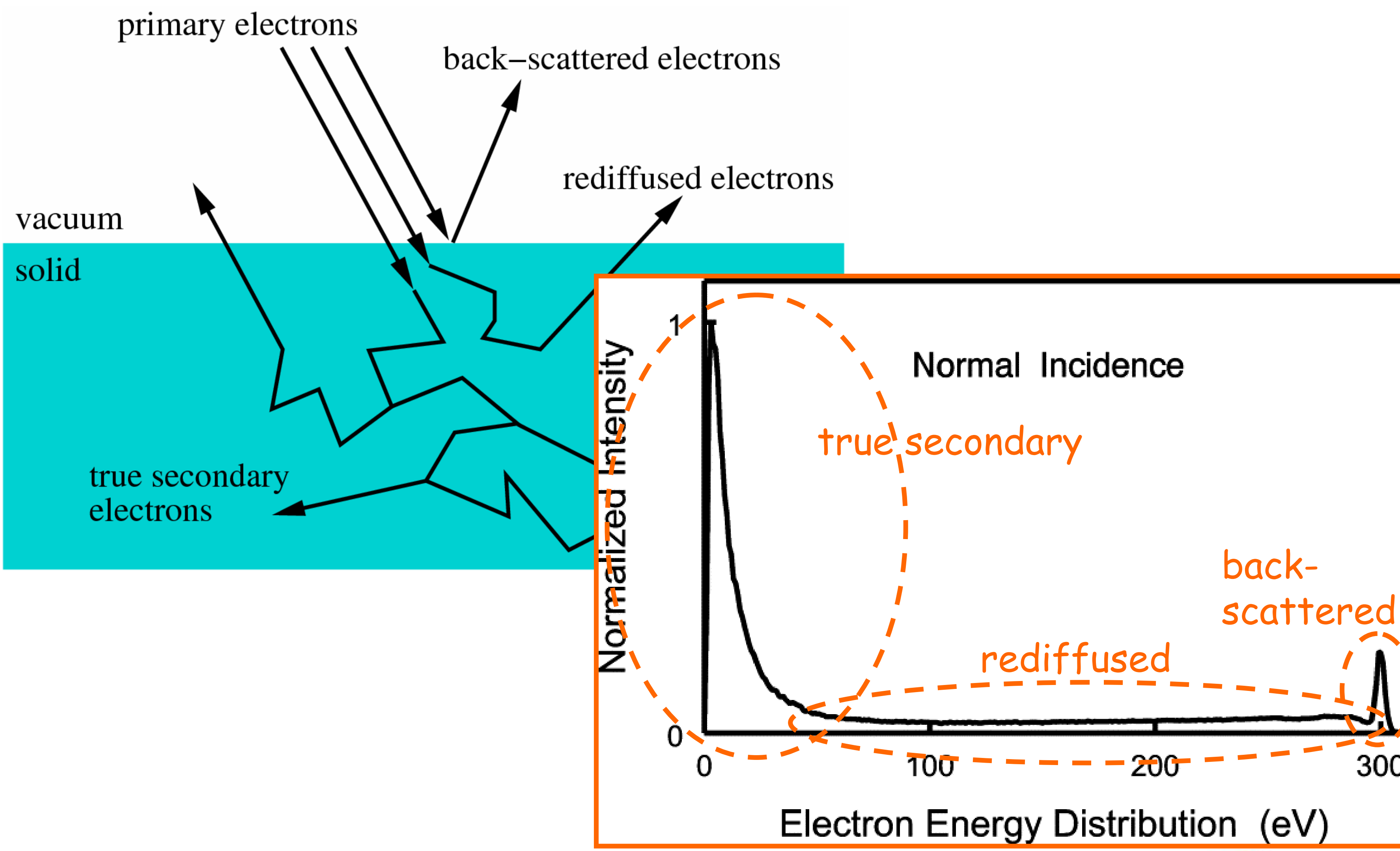
Generator input

```
&INPUT
 Fname='dark_current.ini'
   …
 IPart=10000
 …

 Dist_z='g'
 Sig_clock=0.032
 /
```

Astra input

```
&NEWRUN
 …
 Distribution = 'dark_current.ini'
 Xoff=0.0, Yoff=0.0
 Zoff=0.0
 …
/


&APERTURE
 Lapert=T
 File_Aperture(1)='beam_pipe.dat"
/
```

Secondary Emission - Phenomena



R.E. Kirby and F.K. King, NIMA 469 ,1 (2001)

Secondary Emission - Model

- When a primary electron hit the surface, define the number of secondary electrons and emits to the vacuum.
  - Energy of the primary electron
  - Bombardment angle to the surface

- Properties of the emitted electrons

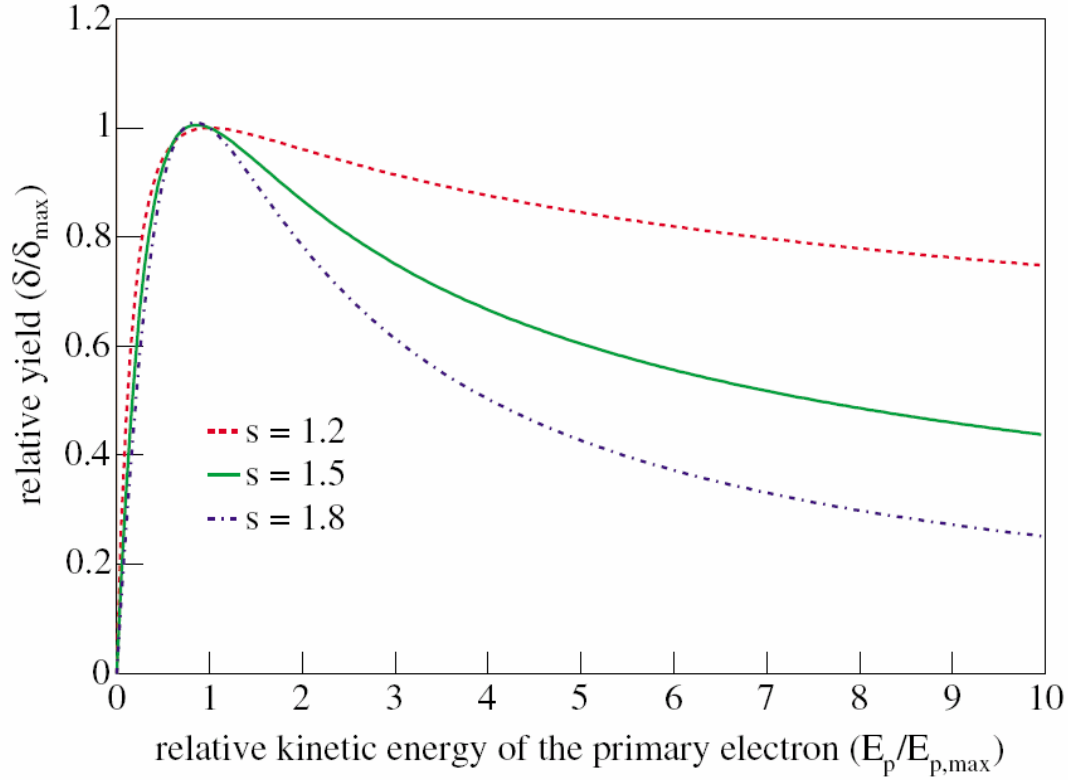
- Continue to track the new emitted electrons

Secondary Emission in ASTRA

$$\delta(E_p) = \delta_{\max} \frac{E_p}{E_{p,\max}} \frac{s}{s - 1 + (E_p/E_{p,\max})^s}$$

Astra input

```
&APERTURE
 File_Aperture(1)= 'Rad'
 Ap_z1(1)= –0.1
 Ap_z2(1)= 0.0
 Ap_r(1)= –2.5
 SE_d0(1)= 20.0
 SE_Epm(1)= 2.2    ! KeV
 SE_fs(1)= 1.5
 SE_Esc(1)= 2.0     ! eV
 Max_secondary=100000
/
```



Summary

- Most simulation codes can generate a realistic initial beam profile and calculate mirror charge effect. <u>But, bench marking study is necessary for different codes.</u>
- Some codes have extra functions (ex: ASTRA for Schottky effect, PARMELA, GPT … for spherical cathode)
- Missing functions
  - Photoemission response time
  - Bunch tilting due to incident angle

- Dark current can be tracked with beam simulations codes if the codes can control initial emitting point

- Some codes (ASTRA, GPT, MAFIA, …) offer secondary electron generation