A model of x ray tungsten sources

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I Jornadas RSEF / IFIME de Física Médica

Who we are

- Grupo de Física Nuclear

VNiVERSiDAD D SALAMANCA
CAMPUS DE EXCELENCIA INTERNACIONAL

GFN
Salamanca

- Hadron-hadron interaction
- Hadron spectroscopy
- Electroweak form-factors
- Neutrino reactions
- Few hadron systems
- Multiquark states
- Heavy quark physics
- **X ray generation with lasers and their application to radiation therapy**

How did we get there

- Radiological protection in high-intensity laser facilities

@ Servicio láser de la Universidad de Salamanca

GENERACIÓN DE ELECTRONES Y RAYOS X

A PARTIR DE PULSOS LÁSER DE GW Y ALTA TASA DE

REPETICIÓN, Y SU PROTECCIÓN RADIOLÓGICA

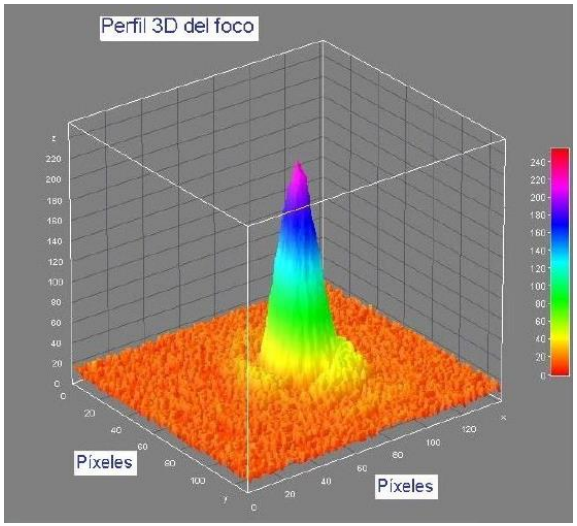
CARMEN FONSECA CUENCA

UNIVERSIDAD DE SALAMANCA

DEPARTAMENTO DE FÍSICA FUNDAMENTAL

OCTUBRE 2011

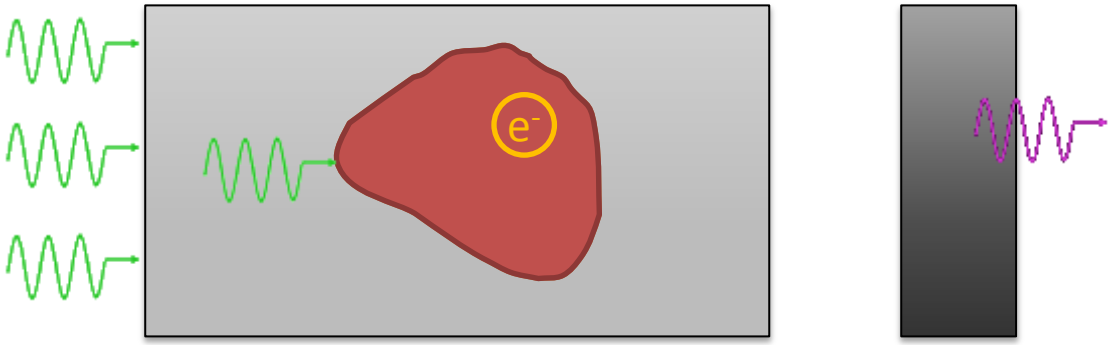
- 10 GW
- 0.8 mJ
- 120 fs
- 793 nm
- 990 Hz
- Focal spot: 4.5 mm



Radiation protection ~ Radiation therapy

What we [expect to] do

- X ray generation with lasers… (overdense media)

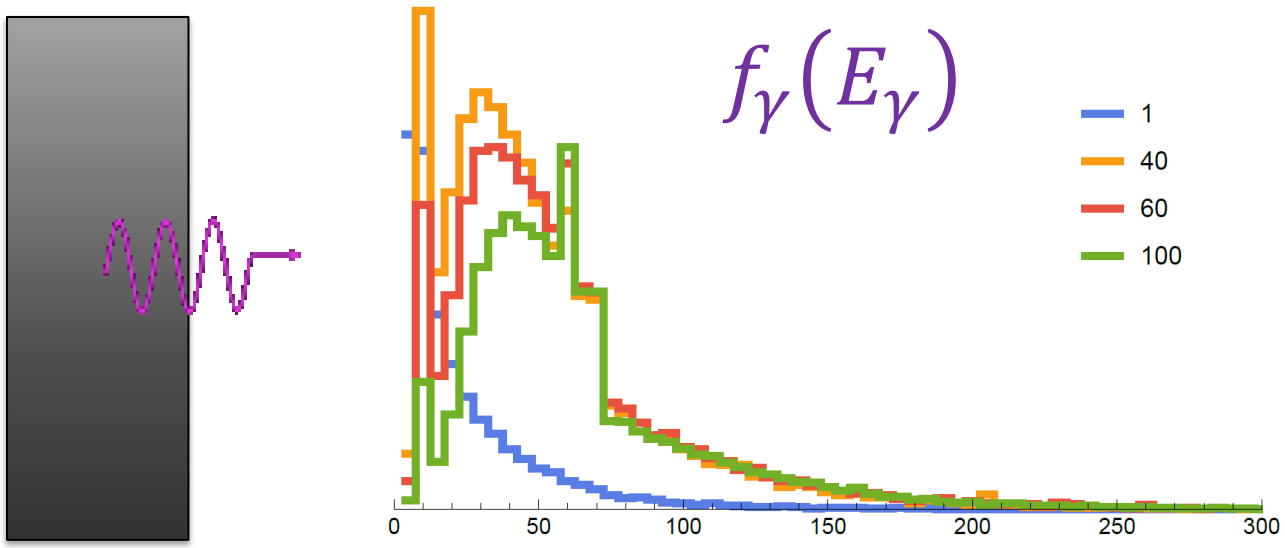


  - Sources with[1]:
    - High power
    - Short pulse duration
    - Cost-efficient (compared to syncrotrons)

[1] Cf. e.g. Giulietti & Gizzi, Riv. Nuovo Cimento 21 (1998) 1

What we [expect to] do

- … and their application to radiation therapy



The model of r-ray tungsten sources

- Model $\gamma = \gamma(e^{-}, \text{Geometry})$

Semiempirical models
- Birch & Marshall (1979)
- Poludniowski & Evans (2007) (SpekCalc)

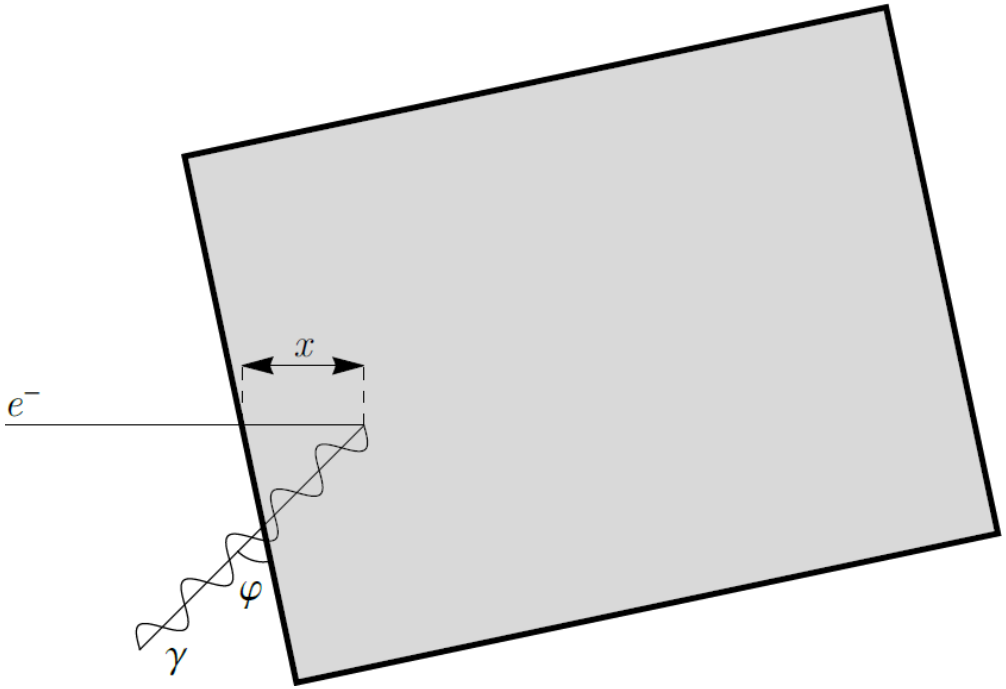
Monte Carlo methods
- The many Monte Carlo simulation tools (FLUKA, Penelope, Geant4, MCNPX, …)

Empirical methods
- TASMIP (1997)
- TASMICS (2014)

References:
R. Birch, M. Marshall, *Physics in Medicine and Biology* **24** (1979) 505
G. G. Poludniowski, P. M. Evans, *Med. Phys.* **34** (2007) 2164
G. G. Poludniowski, *Med. Phys.* **34** (2007) 2175
J. M. Boone, J. A. Seibert, *Med. Phys.* **24** (1997) 1661
A. M. Hernandez, J. M. Boone, *Med. Phys.* **41** (2014) 042101

A semiempirical model framework

- Thick target geometry



1. Describe **electron penetration**
2. Describe **bremsstrahlung production**
3. Add **characteristic radiation**

1 – Electron penetration

- Differential fluence $\psi(x,u)$

$$u := \frac{E}{E_0} \in [0,1]$$

Sum of path lengths per unit volume[♯]

Per unit of energy

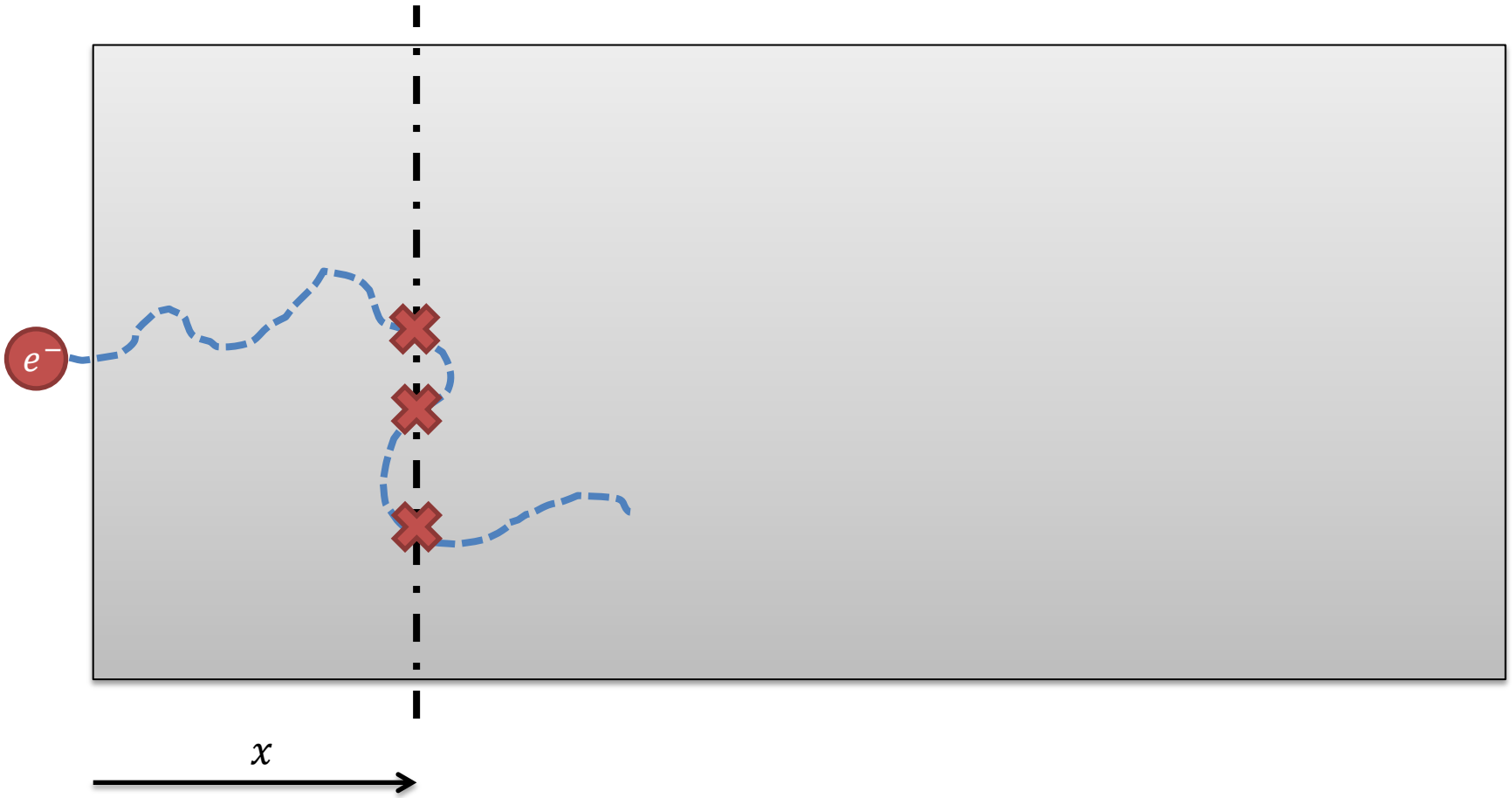
$$\psi(x,u) = \underbrace{\eta(x)}_{1}\ \underbrace{f_U(x;u)}_{2}\ \underbrace{d(x,u)}_{3}$$

1. $\eta(x)$: Crossing fraction (number of crossings)
2. $f_U(x;u)$: Marginal energy distribution (how crossings are distributed in energy)
3. $d(x,u)$: Mean diversion (relates crossing with path-length).

[♯] For the equivalence with the *usual* definition cf. Papiez & Battista (1993). Phys. Med. Biol. **39**, 1053.

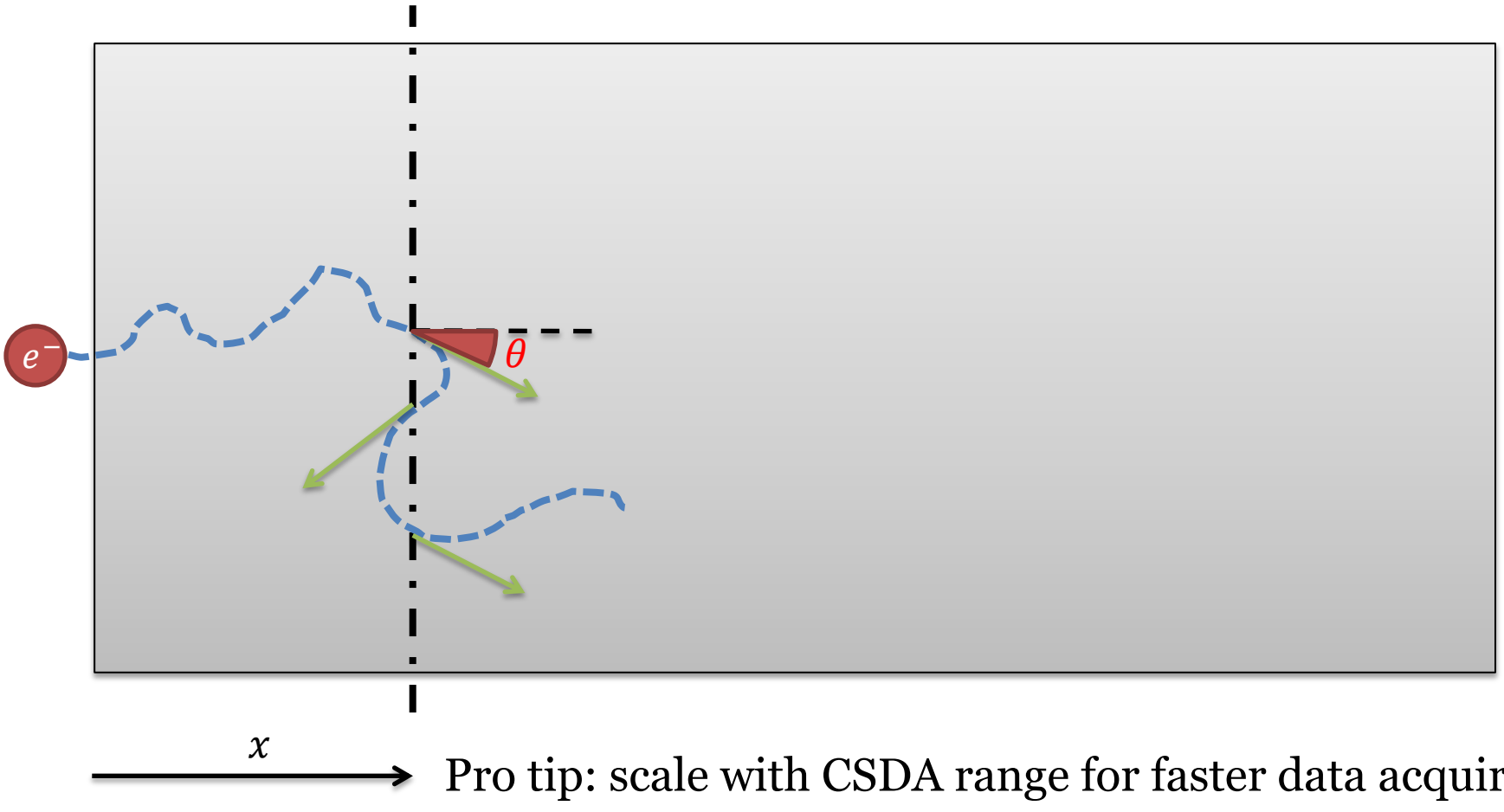
1 – Electron penetration

- Measure $\eta(x)\, f_U(x;u)$



1 – Electron penetration

- Measure $\eta(x) f_U(x;u) d(x,u)$



Pro tip: scale with CSDA range for faster data acquiring

1 – Electron penetration

- Simulation:

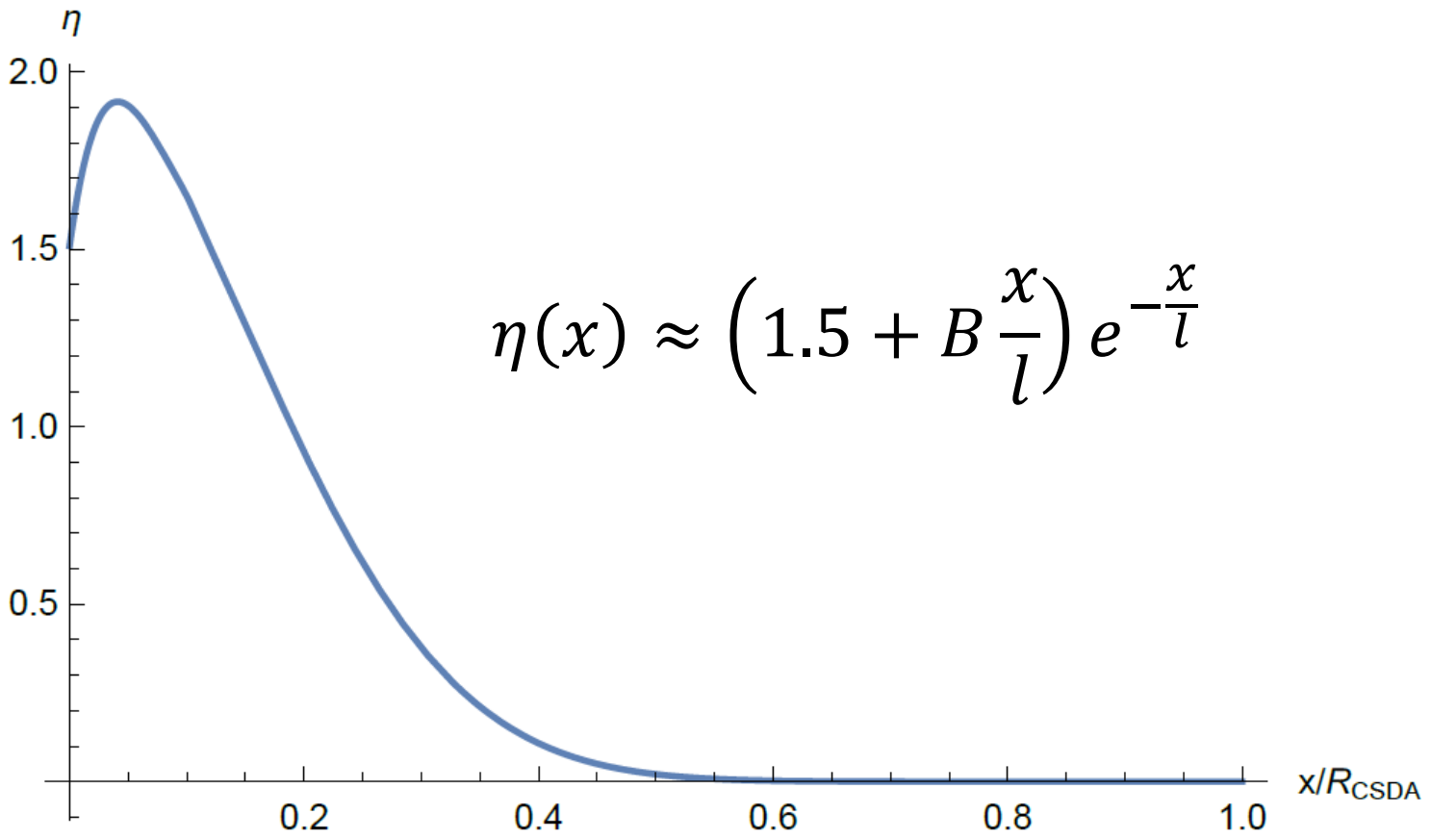
  - General purpose interaction and transport Monte Carlo code.
  - Key points:
    - Microscopic models-based
    - Ensured consistency and conservation laws
    - Exhaustive experimental checking
    - ~60 different particles in wide energy ranges

"The FLUKA Code: Developments and Challenges for High Energy and Medical Applications" T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis, **Nuclear Data Sheets 120, 211-214 (2014)**

"FLUKA: a multi-particle transport code" A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, **CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773**

1 – Electron penetration

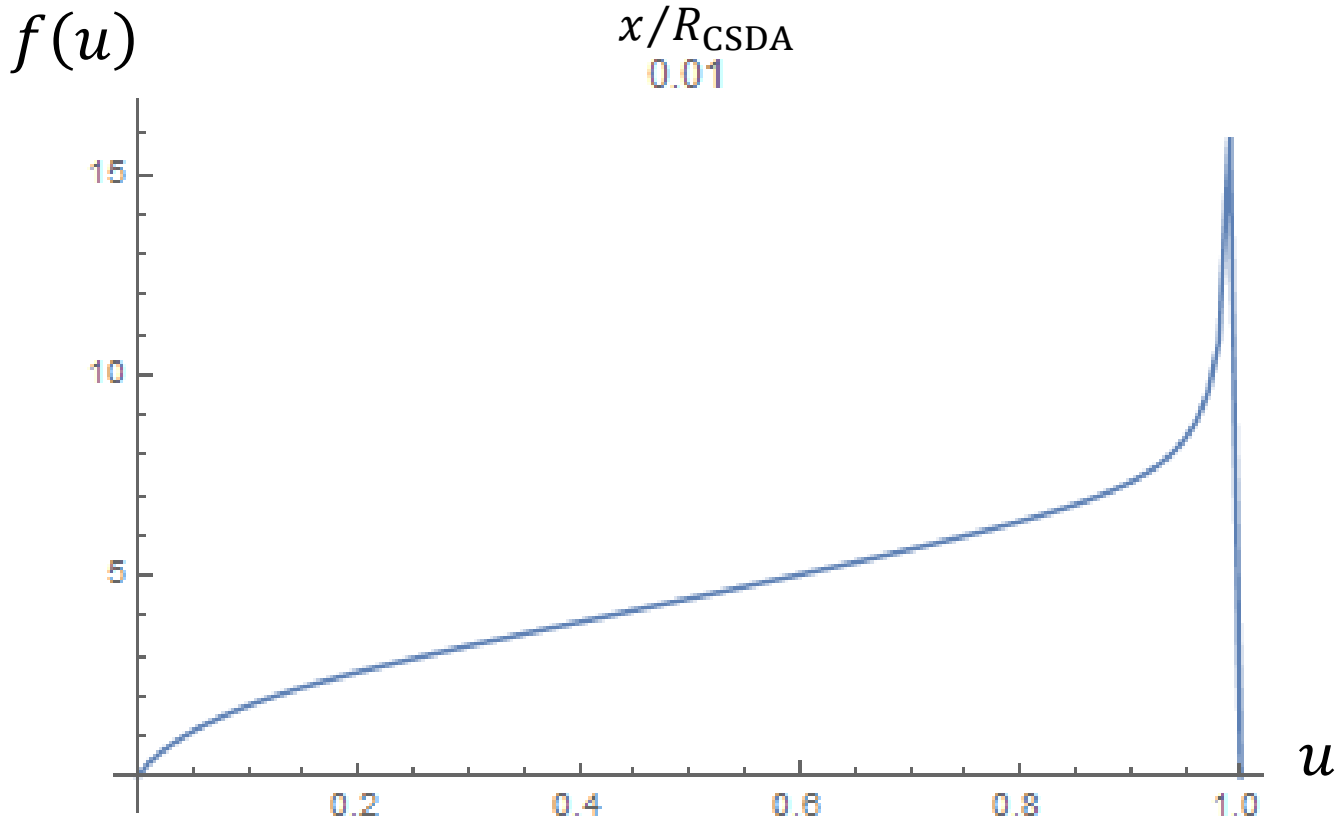
- Results: Crossing fraction



$$\eta(x) \approx \left(1.5 + B\frac{x}{l}\right) e^{-\frac{x}{l}}$$

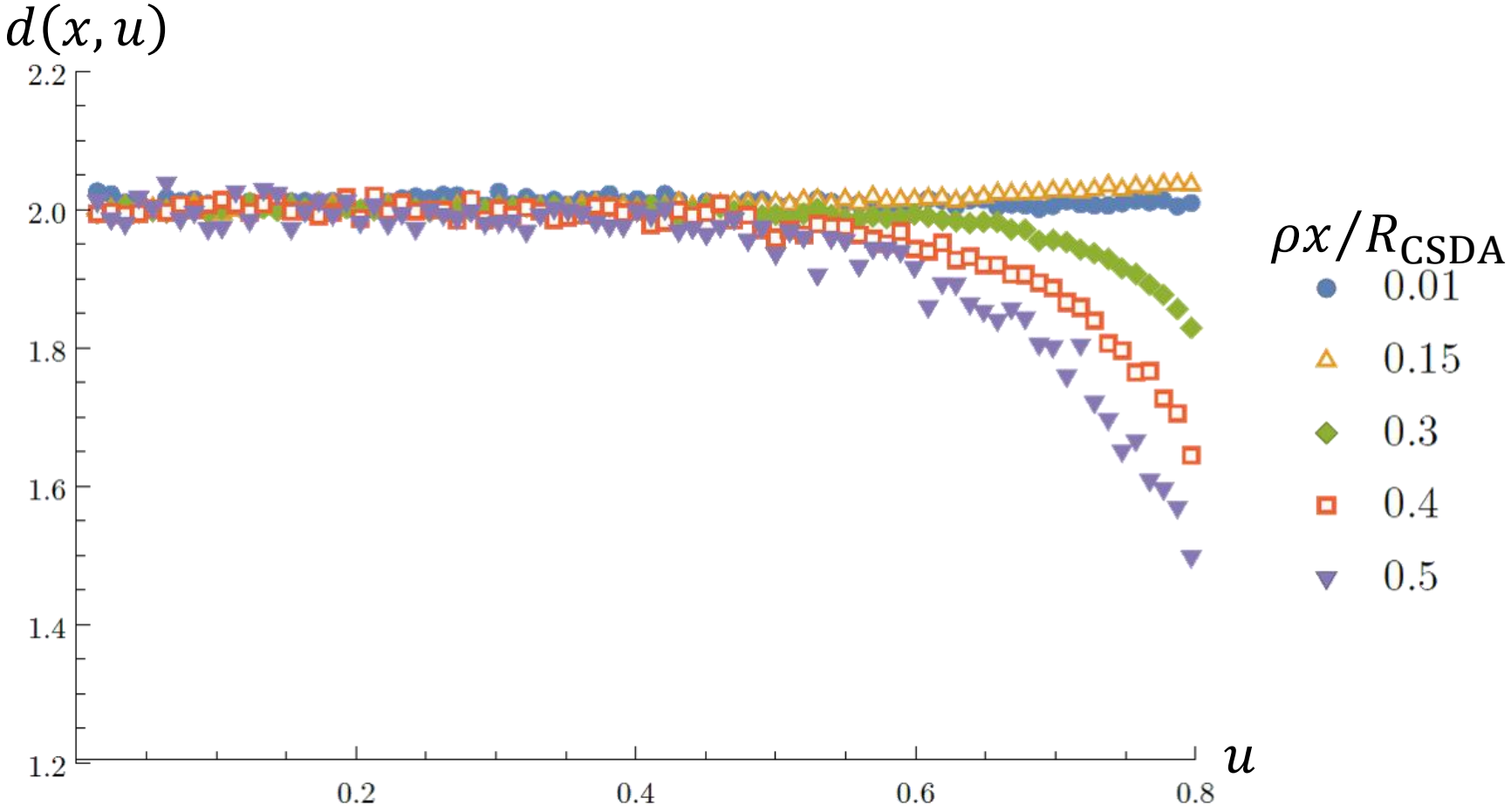
1 – Electron penetration

- Results: straggling distribution



1 – Electron penetration

- Results: Mean diversion



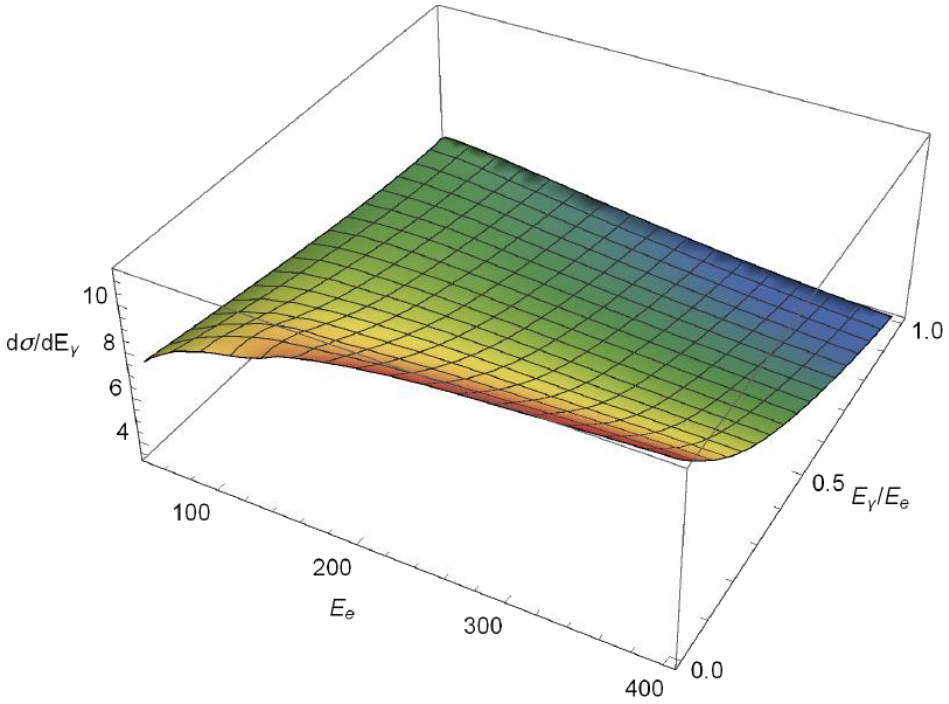
2 – Bremsstrahlung production

Nuclear Instruments and Methods in Physics Research B12 (1985) 95–134
North-Holland, Amsterdam

BREMSSTRAHLUNG SPECTRA FROM ELECTRON INTERACTIONS WITH SCREENED ATOMIC NUCLEI AND ORBITAL ELECTRONS *

Stephen M. SELTZER and Martin J. BERGER
*National Bureau of Standards **, Gaithersburg, MD 20899, USA*

$$\psi(x,u) \quad \frac{\mathrm{d}\sigma_{\mathrm{br}}}{\mathrm{d}E_\gamma}$$



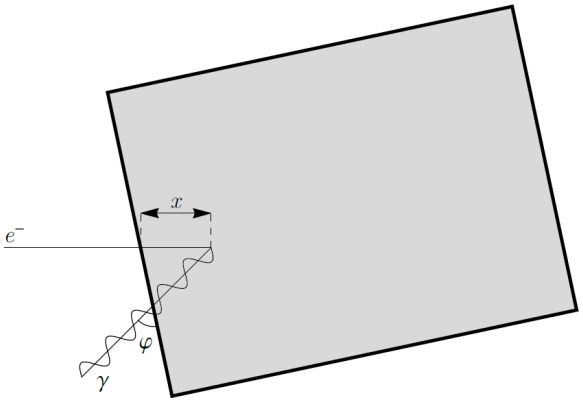
2 – Bremsstrahlung production

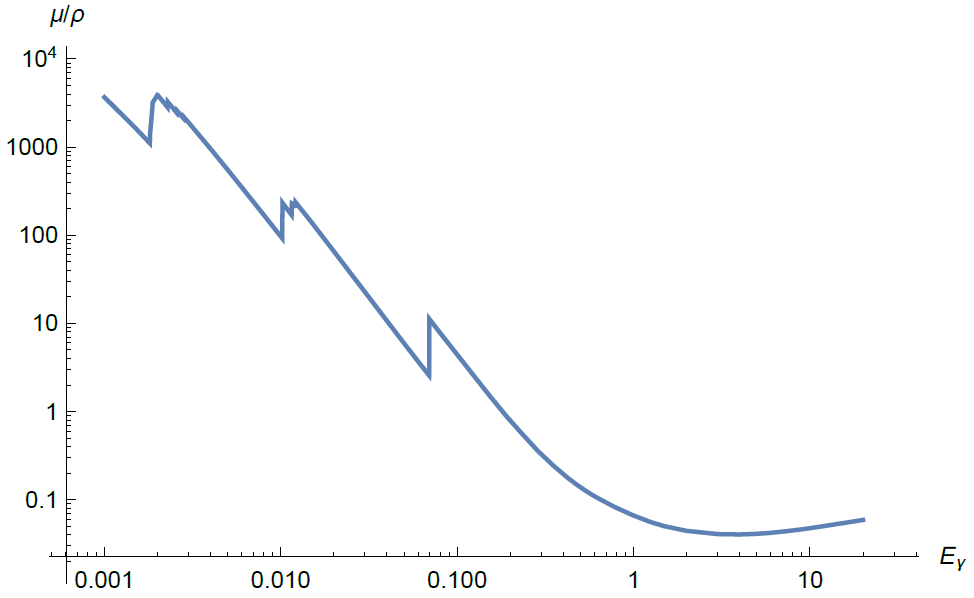
NISTIR 5632 | Version History | Disclaimer

Tables of X-Ray Mass Attenuation Coefficients
and Mass Energy-Absorption Coefficients
from 1 keV to 20 MeV for Elements Z = 1 to 92
and 48 Additional Substances of Dosimetric Interest*

J. H. Hubbell[+] and S. M. Seltzer
Radiation Physics Division, PML, NIST

$$\psi(x,u) \quad \frac{\mathrm{d}\sigma_{\mathrm{br}}}{\mathrm{d}E_\gamma} \quad e^{-\mu x \cdot \csc(\varphi)}$$





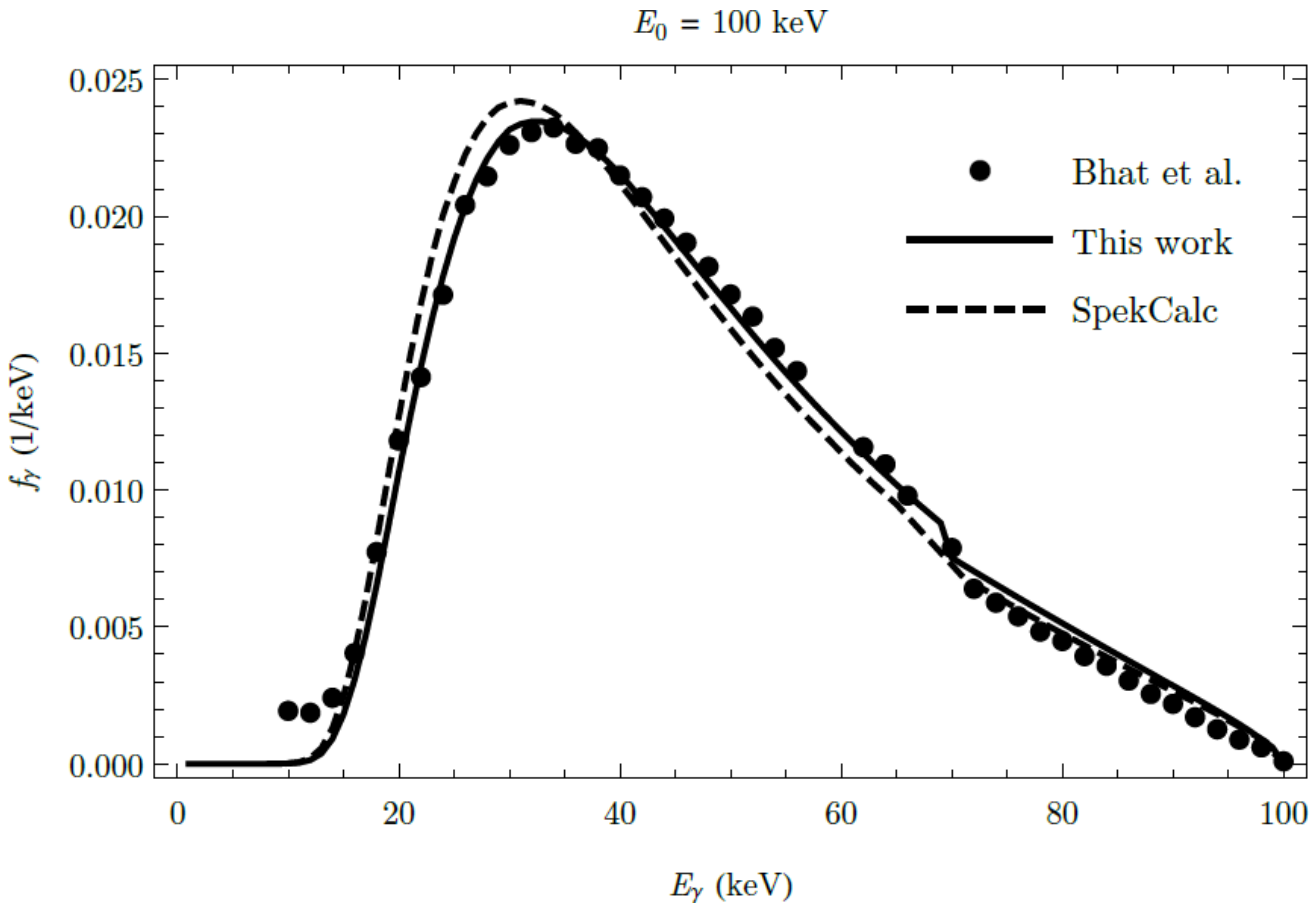
2 – Bremsstrahlung production

$$f_\gamma(E_\gamma) = \iint_{\substack{x\in\mathbb{R}^+ \\ u\in[0,1]}} \psi(x,u)\ \frac{\mathrm{d}\sigma_{\mathrm{br}}}{\mathrm{d}E_\gamma}\ e^{-\mu x\cdot\csc(\varphi)}\ \mathrm{d}x\mathrm{d}u$$

Some norm-related constant are omitted here

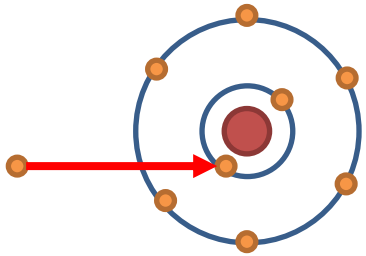
2 – Bremsstrahlung production

- Typical predictions

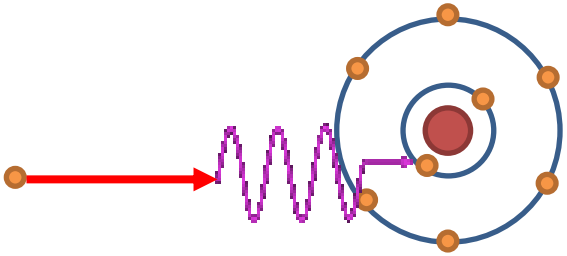


3 – Characteristic radiation

- Sources of shell vacancies
  - Electron impact



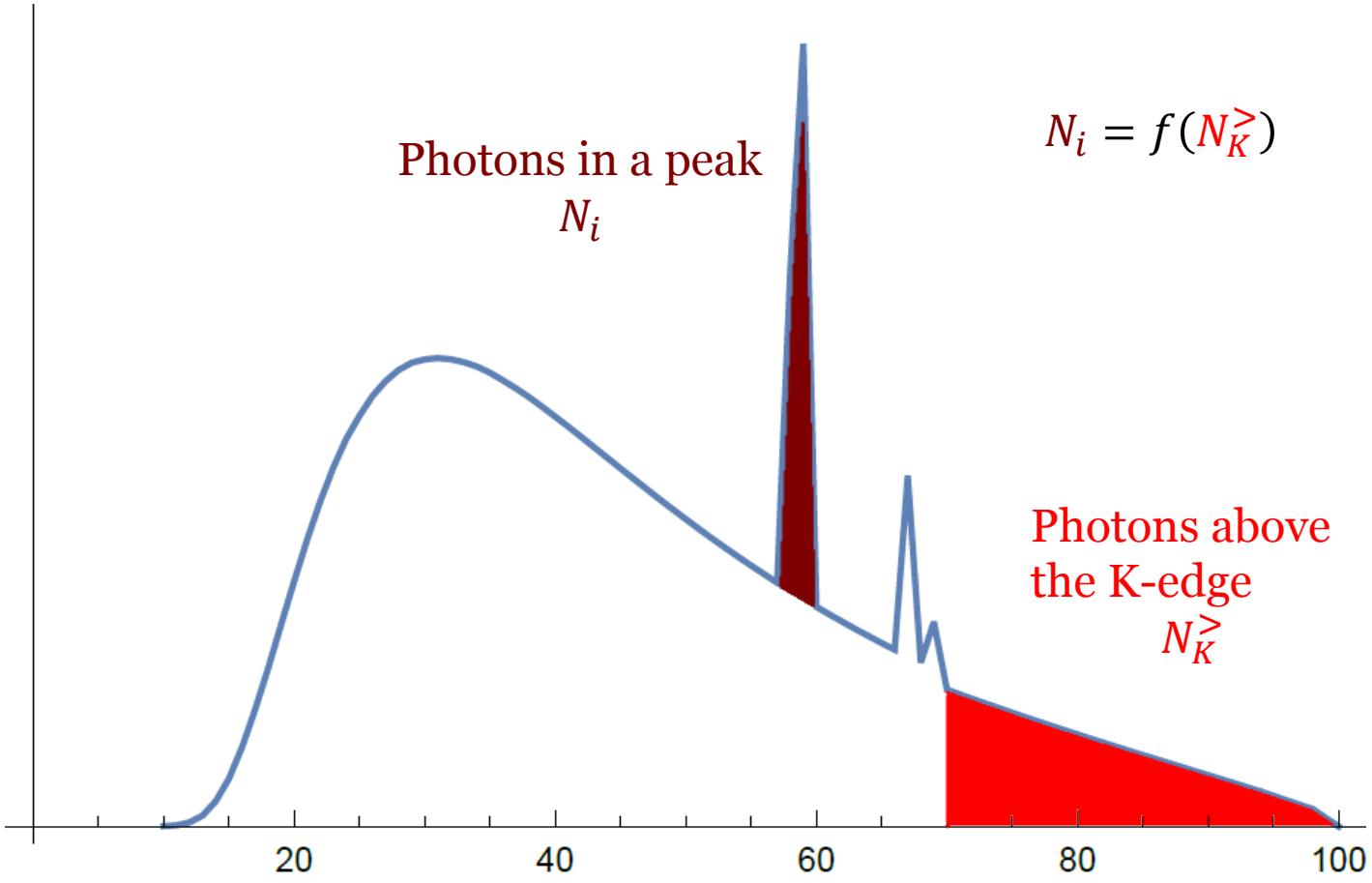
  - Photoelectric or Compton effects



Secondary radiation-induced, but important in high Z targets!!!
First-principle modelling is difficult

3 – Characteristic radiation

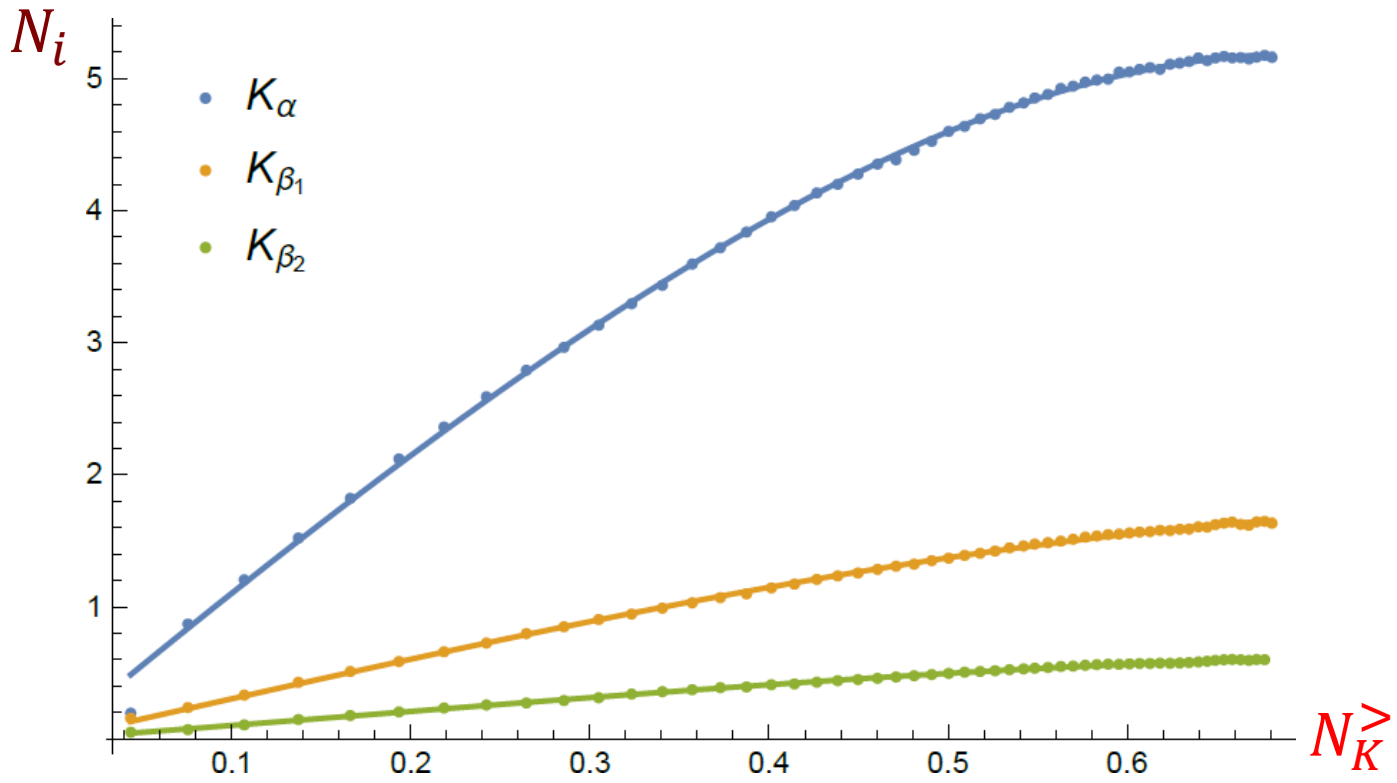
- Simple dependence model



3 – Characteristic radiation

- Test with TASMICS[#] spectra

A. M. Hernandez, J. M. Boone, *Med. Phys.* **41** (2014) 042101



~ linear regime in $N_K^> < 0.4 \Leftarrow E_e < 400$ keV

Conclusions

- A **semiempirical model improving** the previous ones (better agreement in shape and in HVL predictions) was built.
- A **graphical user interface** is being developed.

- Nevertheless…
  if one can afford it!

Thank you for your attention!

And thanks also to:

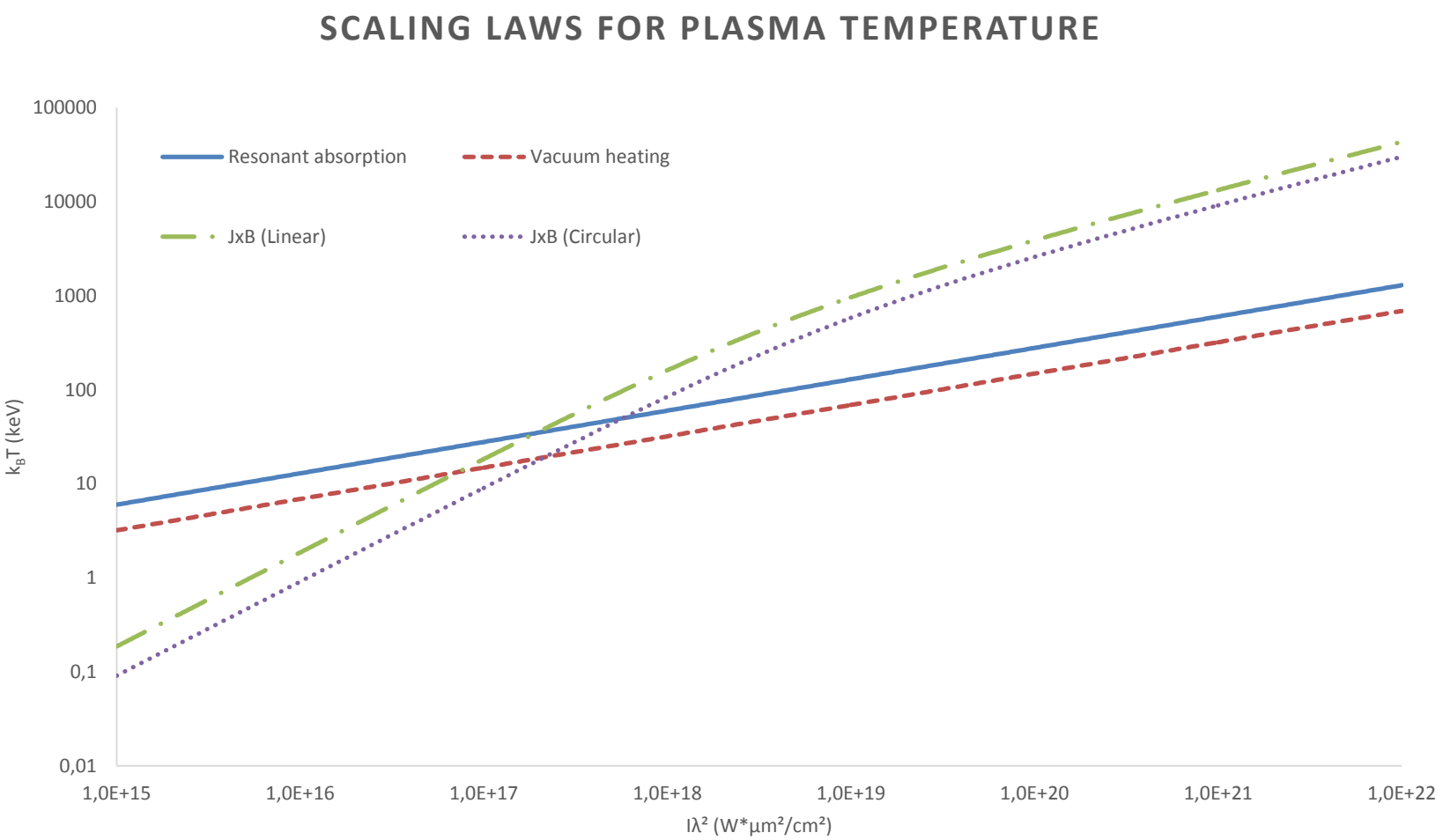
- Our hosts:

- Institutions supporting this research:

Correspondence: guillehg@usal.es

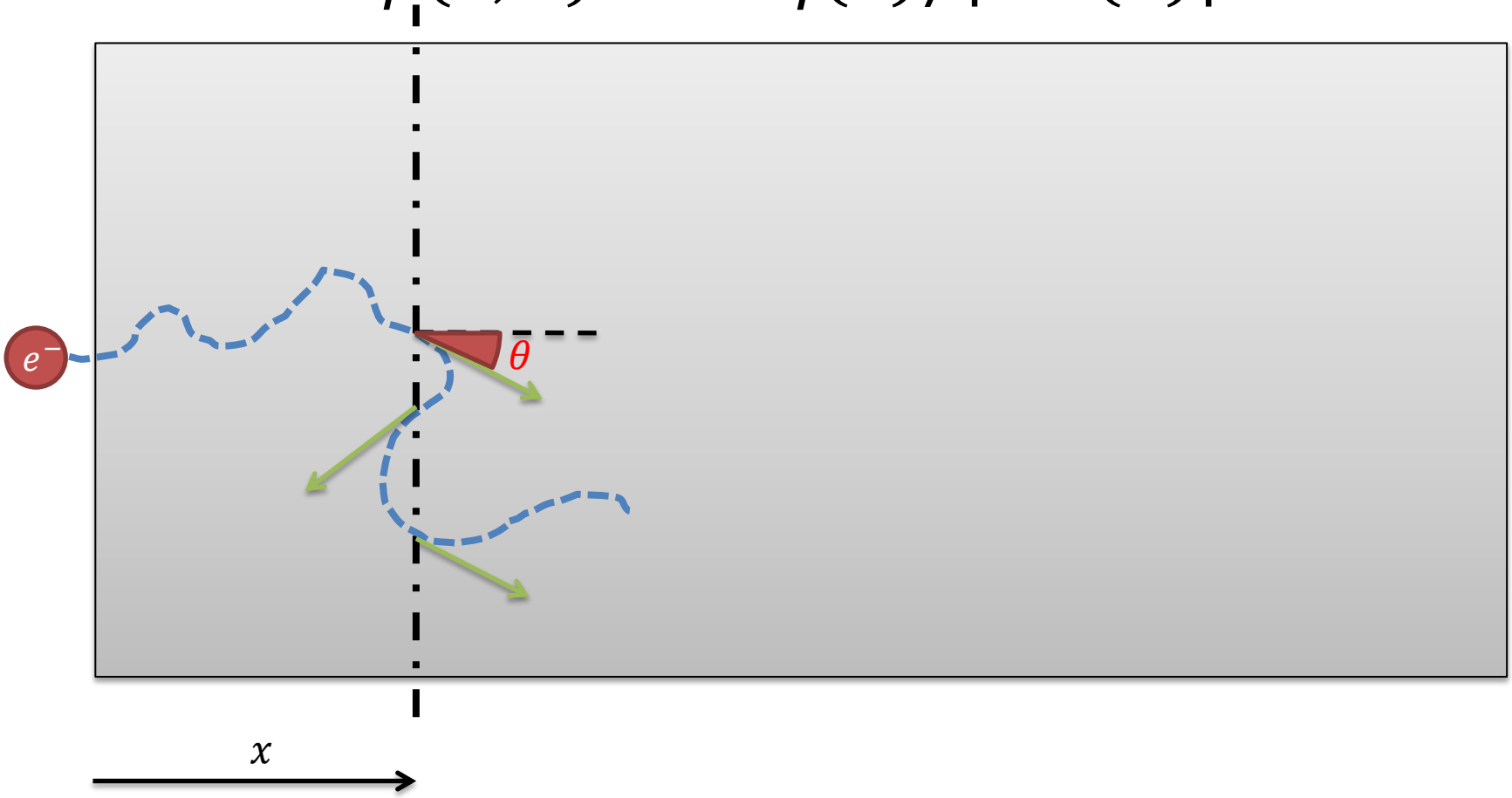
(Backup slides)

Plasma heating scaling



Fluence decomposition

- Fluence $\psi(x,u)\mathrm{d}x = \eta(x)/|\cos(\theta)|\,\mathrm{d}x$



Fluence decomposition

- Energy and angle are distributions at a crossing

$$U, \Theta \rightsquigarrow f_{U,\Theta}(u, \theta)$$

- Don't care about Θ (angle independent CS), fluence is then

$$\psi(x, u) = \eta(x) \int_0^{\pi} \frac{f_{U,\Theta}(x; u, \theta)}{|\cos(\theta)|} \mathrm{d}\theta$$

Straggling (.avi version)

- Distributions on U (marginal)
  - Straggling dependence on depth (.avi version)