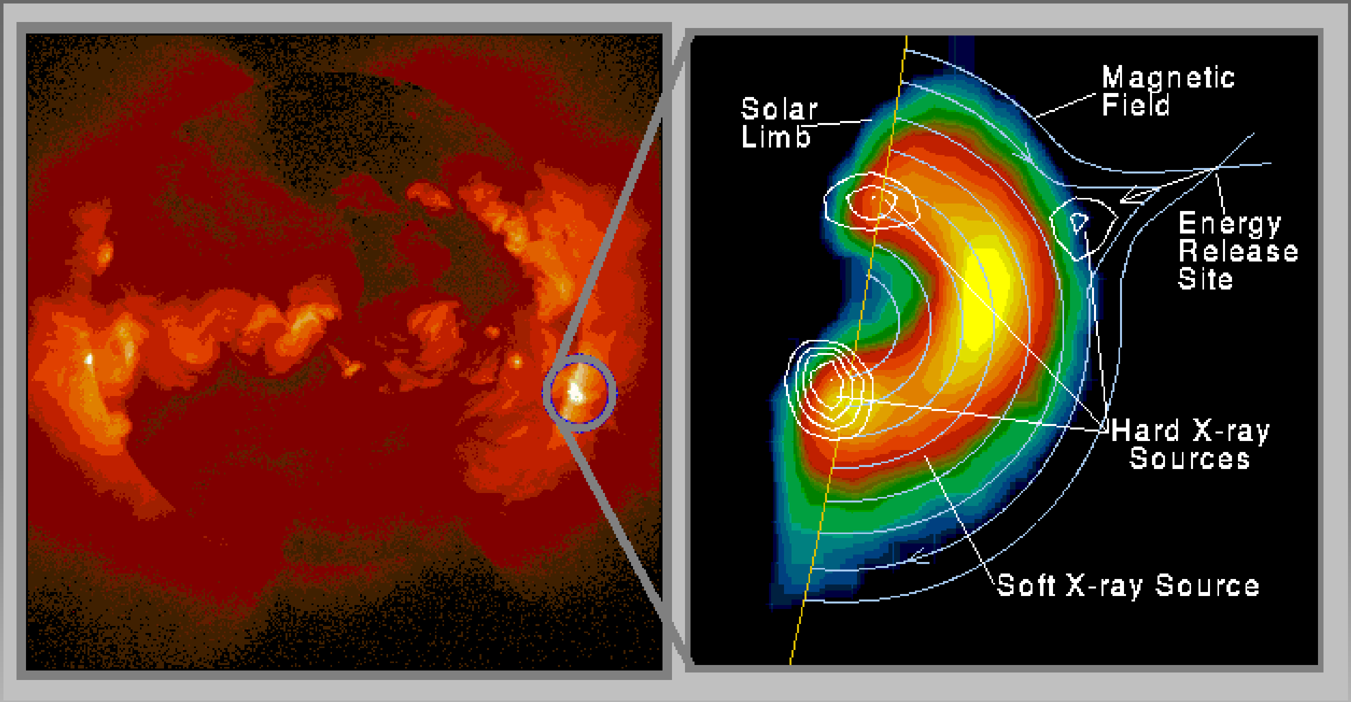
PARTICLE ACCELERATION IN TURBULENT SOLAR ACTIVE REGIONS



Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contour (right. Jan 13, 1992.)

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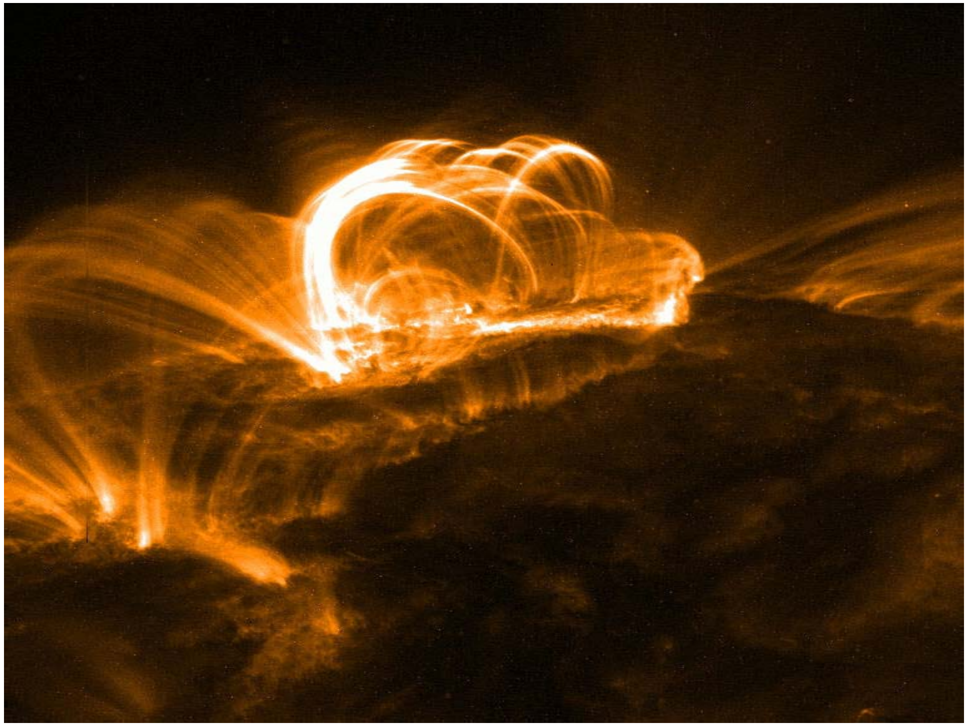
SOLAR FLARES AND RECONNECTION SITES

X – ray & Microwave
***Electron** associated emission*
Gamma – ray
***Ion** associated emission*

Solar Active Region formation:
Large-scale magnetic topology driven by ***strong turbulent flows*** *evolves forming* ***magnetic discontinuities*** *which* ***dissipate*** *the excess* ***magnetic energy*** *via* ***reconnection***



2005, TRACE (X-ray), NASA/LMSAL

Current Sheets
Magnetic energy ***dissipation regions*** *host* ***strong electric fields***
*(also shocks **& turbulent flows**)*
Acceleration sites

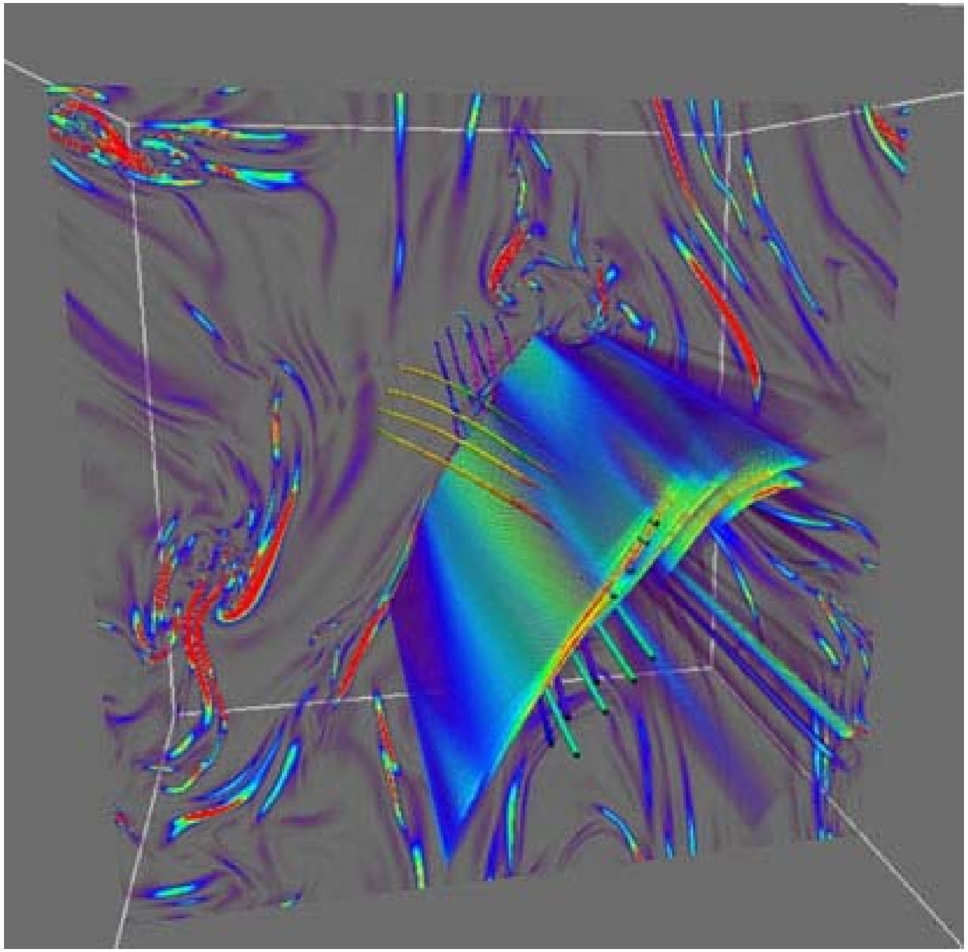
RECONNECTION SITES' STRUCTURE

- ***Single elongated***
  current sheet
  (mostly large flare attribute)

- ***Multiple small-scale***
  current sheets
  (typical flares)

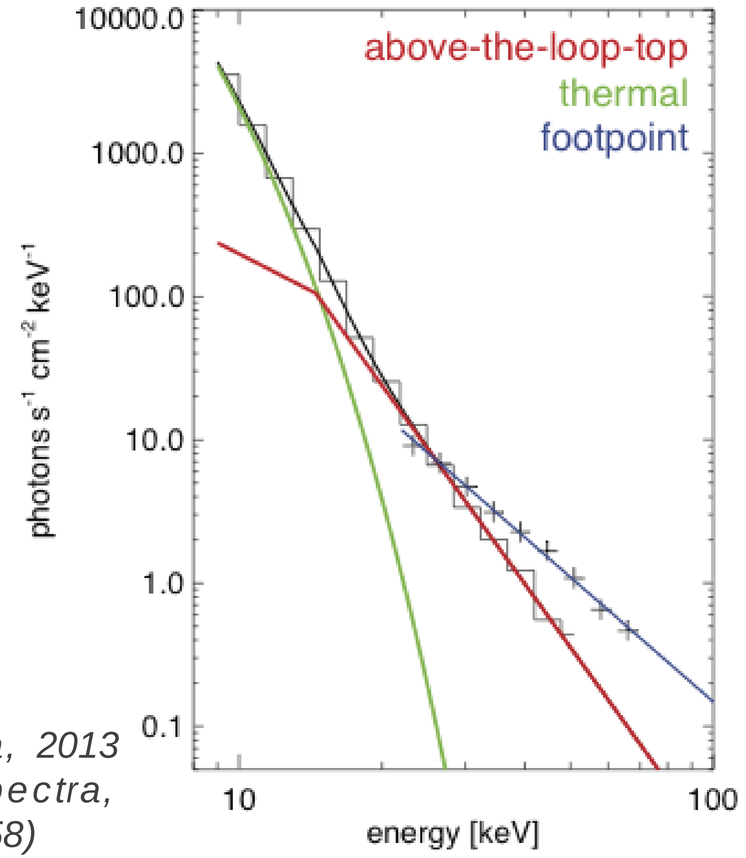
*The **hierarchical fragmentation** of UCSs has been demonstrated with*

  - ***MHD***
  - ***SOC** (Self – Organized Criticality)*

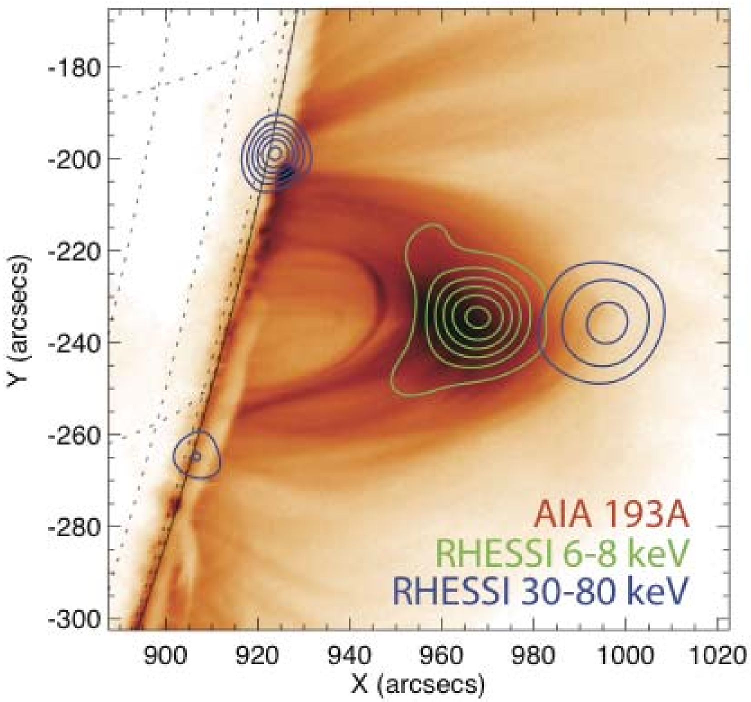


Nordlund and Galsgaard, 2012
(MHD high – resolution braiding simulation)

PARTICLE ACCELERATION IN SOLAR FLARES



One *of the requirements for an*
efficient particle acceleration mechanism
is to be able to
reproduce the observational emission spectra
that is, yield
kinetic energy distributions
with certain properties



Krucker and Battaglia, 2013
(RHESSI hard X – ray spectra,
SOL 2012 – 07 – 19 T05:58)

This task has so far been performed using

- ***MHD*** *(particle trajectories in frozen structures)*
- ***Kinetic*** *(direct energy distributions)*

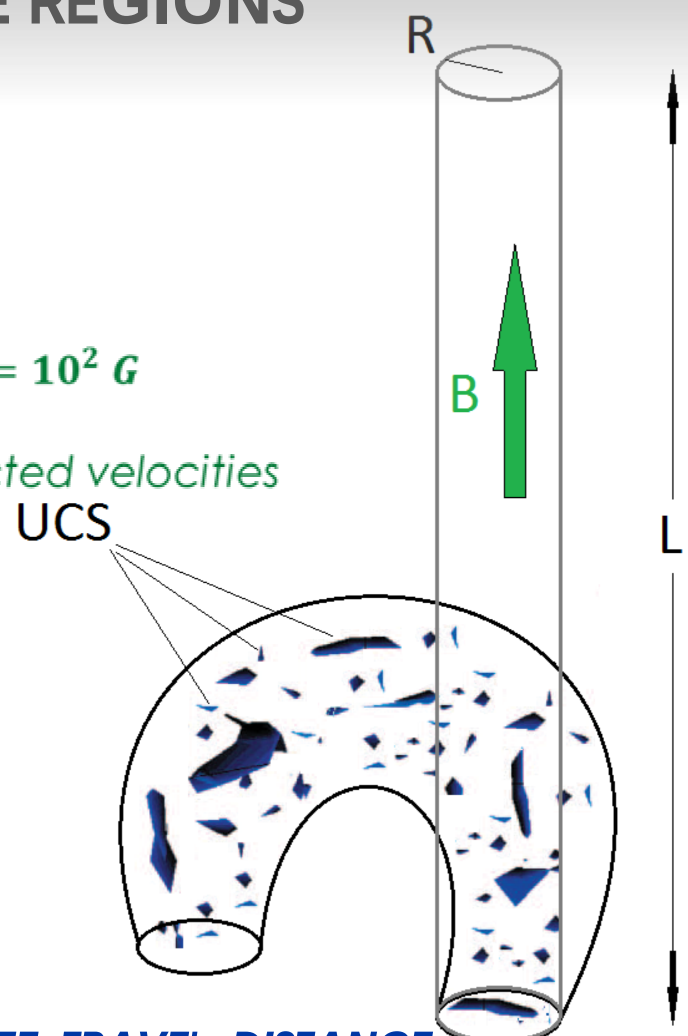
models

PARTICLE ACCELERATION IN TURBULENT SOLAR ACTIVE REGIONS

Toutountzi et al. Hel.A.S. 11th Conference, 2013

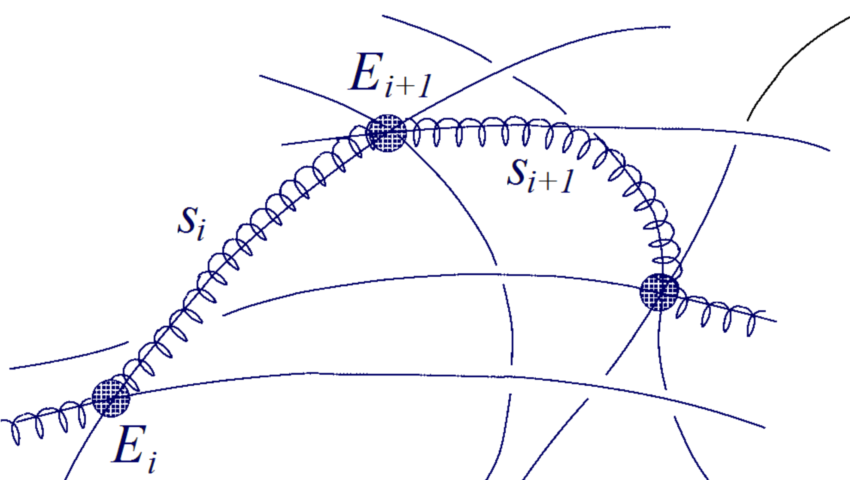
SETTING A.

- *Cylindrical volume simulating a* ***flux tube***
- *Initially occupied by* ***maxwellian plasma***
- *Of* ***uniform density*** *and temperature* $T = 10^6\ K$
- ***Uniform and stationary*** *magnetic field of magnitude* $B = 10^2\ G$ *directed upwards along the axis*
- ***Test-electrons*** *randomly distributed with randomly directed velocities*
- *A* ***particle code*** *traces their* ***guiding center*** *trajectories*



SETTING B.

Statistical description of the ***electric field****'s fractal structure*



Vlahos, Isliker & Lepreti, 2004

3 PDFs

$P_1 = P_1(s)$ ***FREE TRAVEL DISTANCE***

$P_2 = P_2(E)$ ***ELECTRIC FIELD STRENGTH***

$P_3 = P_3(d)$ ***ACCELERATION LENGTH***

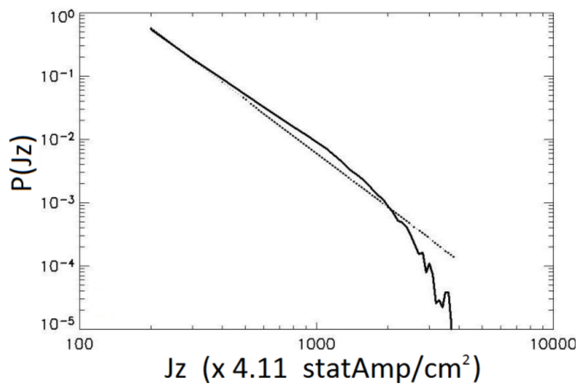
A STATISTICAL STUDY OF CURRENT-SHEET FORMATION ABOVE SOLAR ACTIVE REGIONS BASED ON SELF-ORGANIZED CRITICALITY

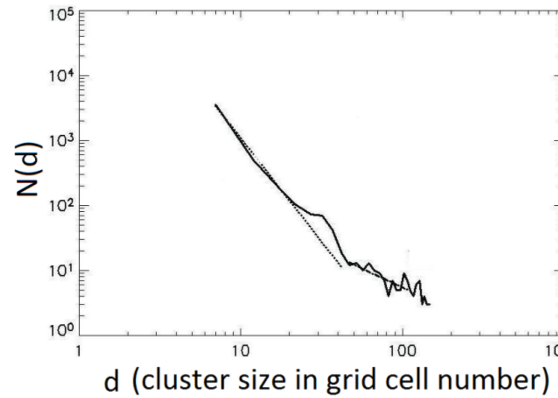
Dimitropoulou et al. Hel.A.S. 11th Conference, 2013

BASIC PROCESS STEPS

- *Pre – process 2D vector magnetograms from IVM*
- *3D magnetic field extrapolation*
- *Unstable site identification*
- *Force the system into the SOC state*

The formation of unstable clusters is triggered by an avalanche which, as a whole, simulates a solar flare





FREE TRAVEL DISTANCE

$$P_1(s) = \begin{cases} A_1\, s^{D_F-3} & D_F \le 2 \\ A_2\, \exp[a_2 s^{D_F-2}]\, s^{D_F-3} & D_F > 2 \end{cases}$$

Isliker & Vlahos, 2003

ELECTRIC FIELD STRENGTH

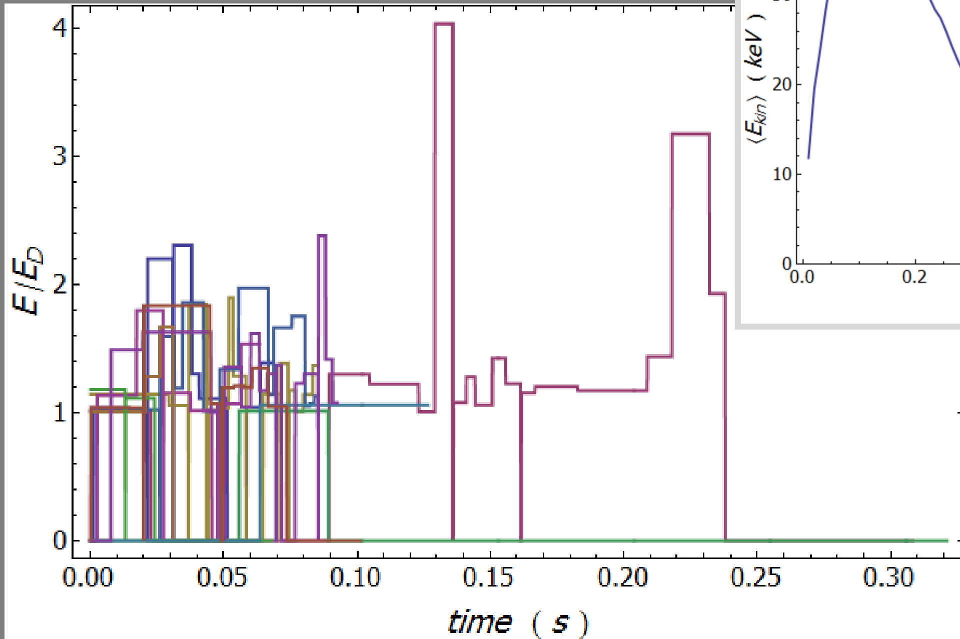
$$P_2(E) = B\, E^{-b}$$

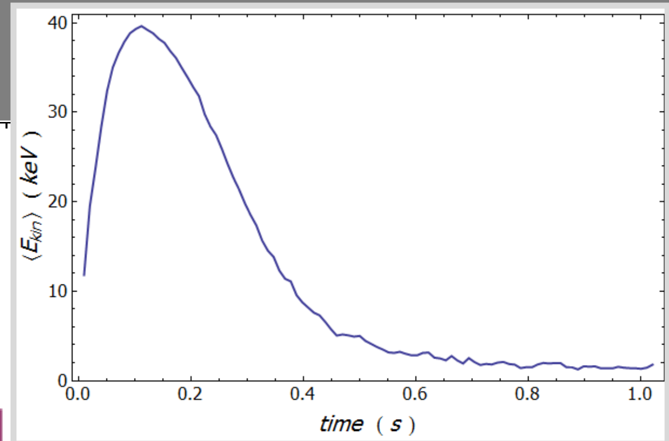
ACCELERATION LENGTH

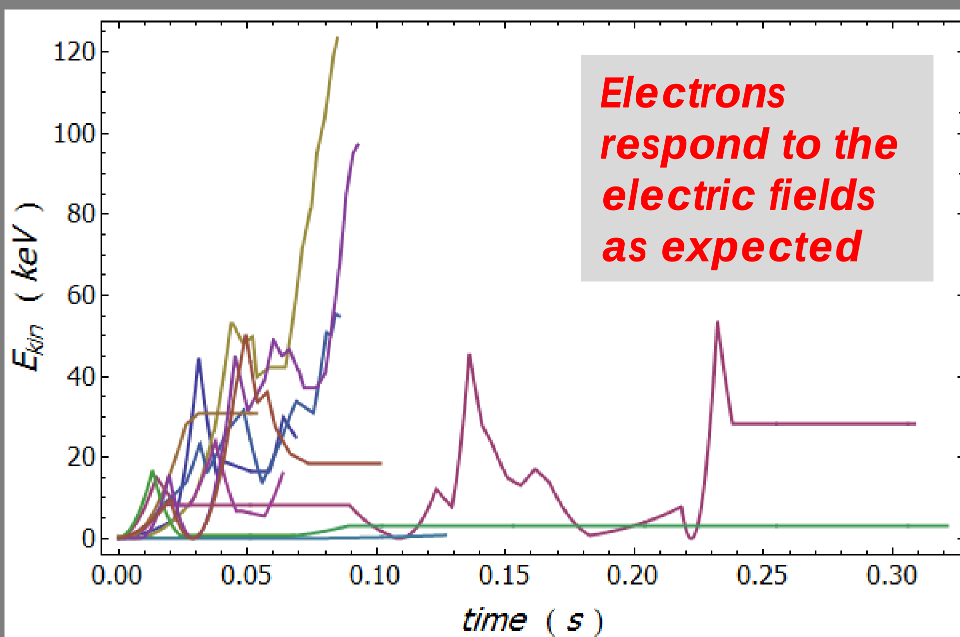
$$P_3(d) = \begin{cases} C_1\, d^{-c_1} & d \le d_{th} \\ C_2\, d^{-c_2} & d > d_{th} \end{cases}$$

RESULTS 1/5

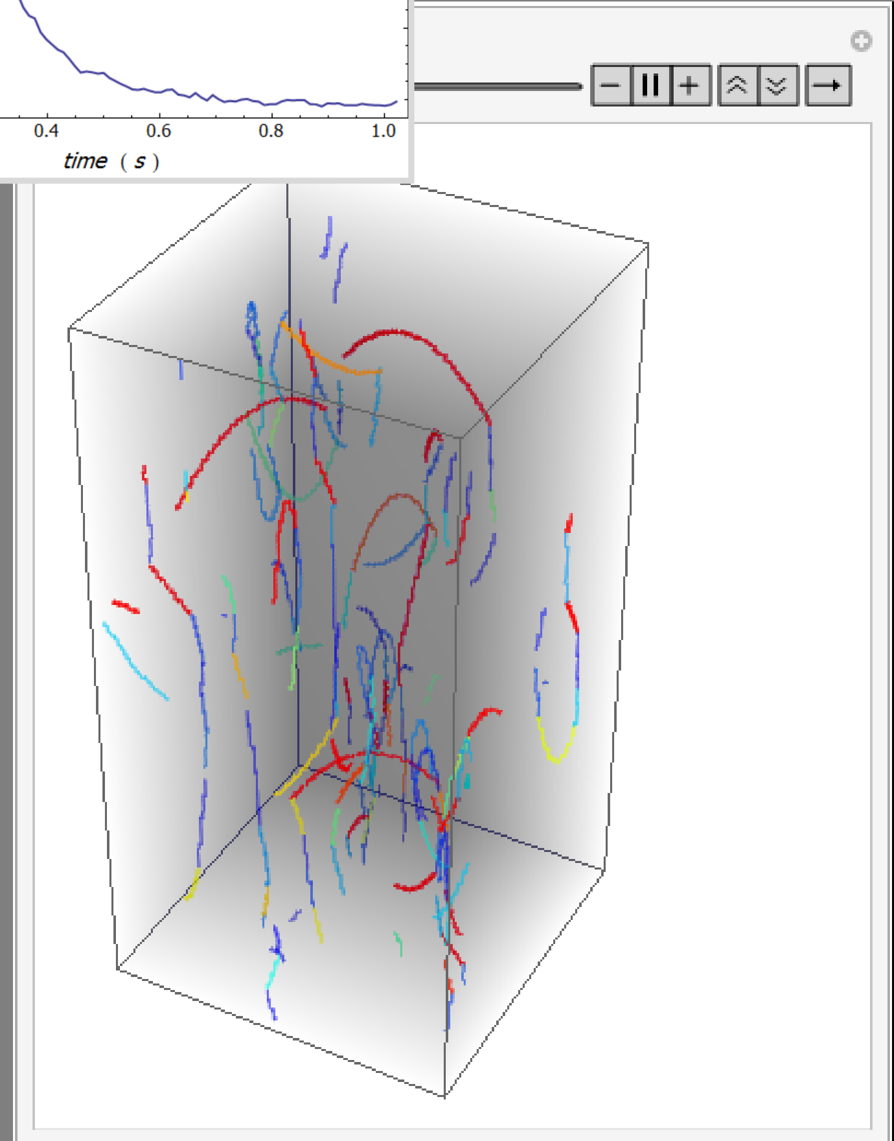
A FIRST LOOK ON HOW THINGS WORK





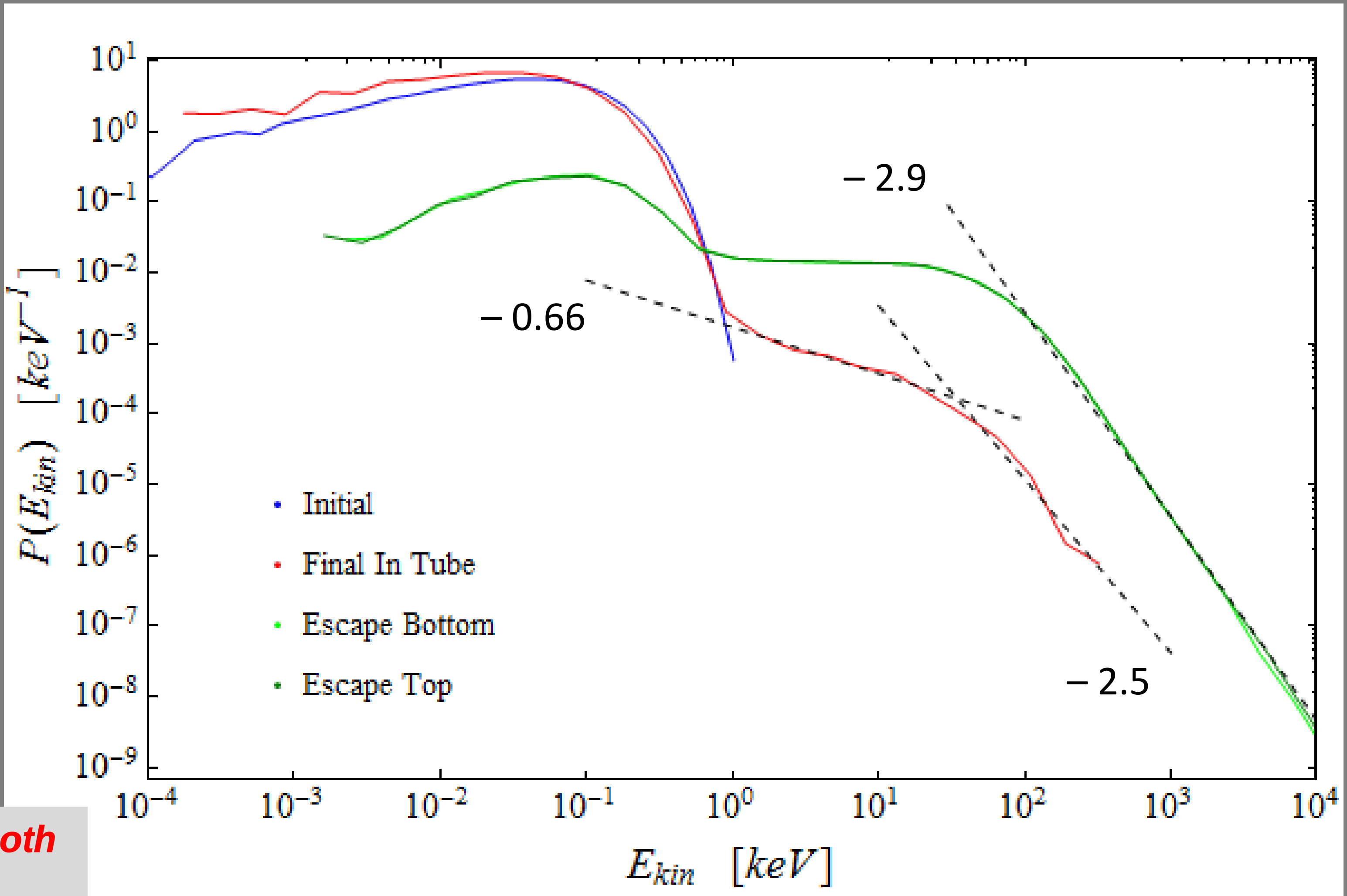


Electrons respond to the electric fields as expected



RESULTS 2/5

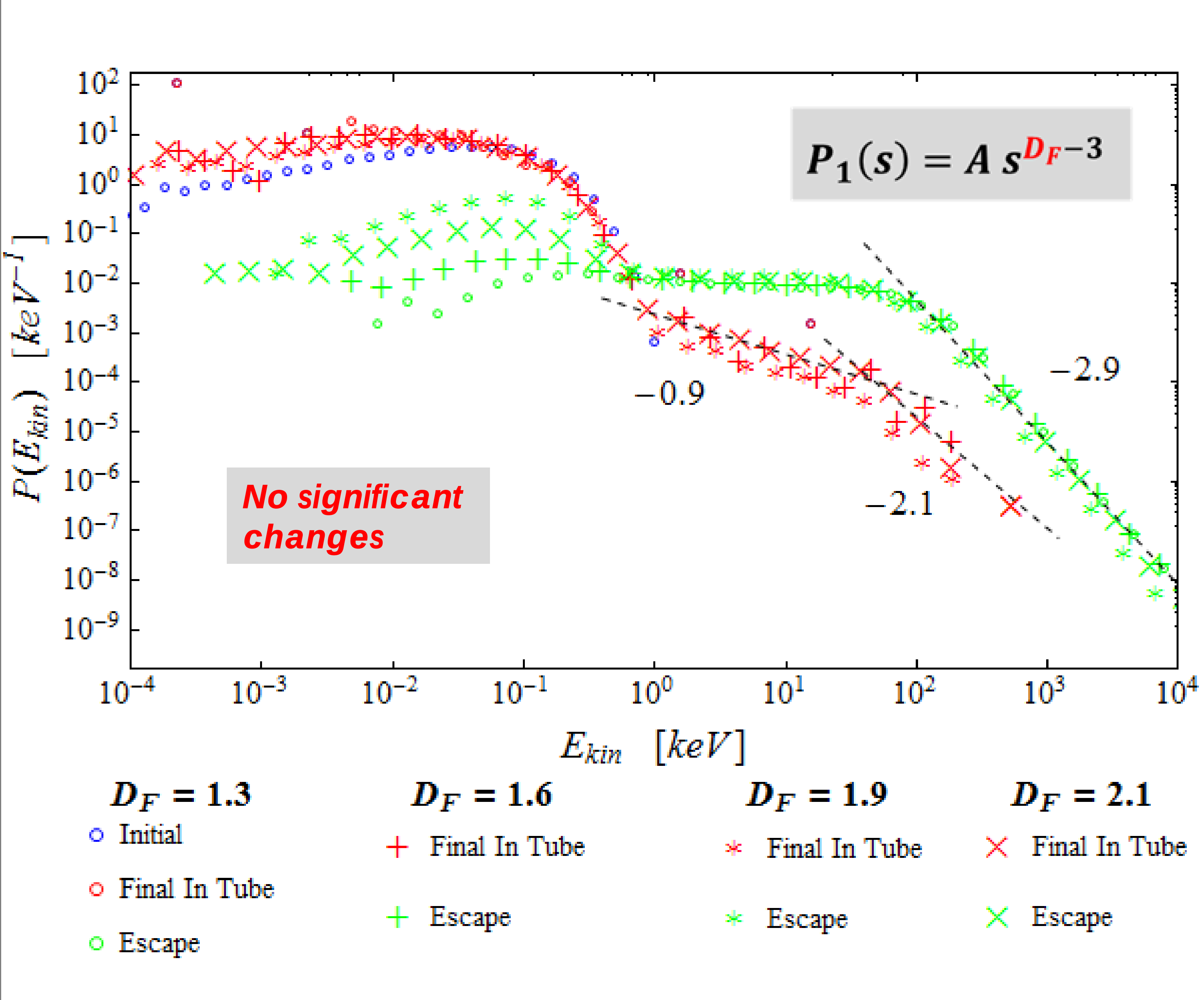
SIMULATED PDFs



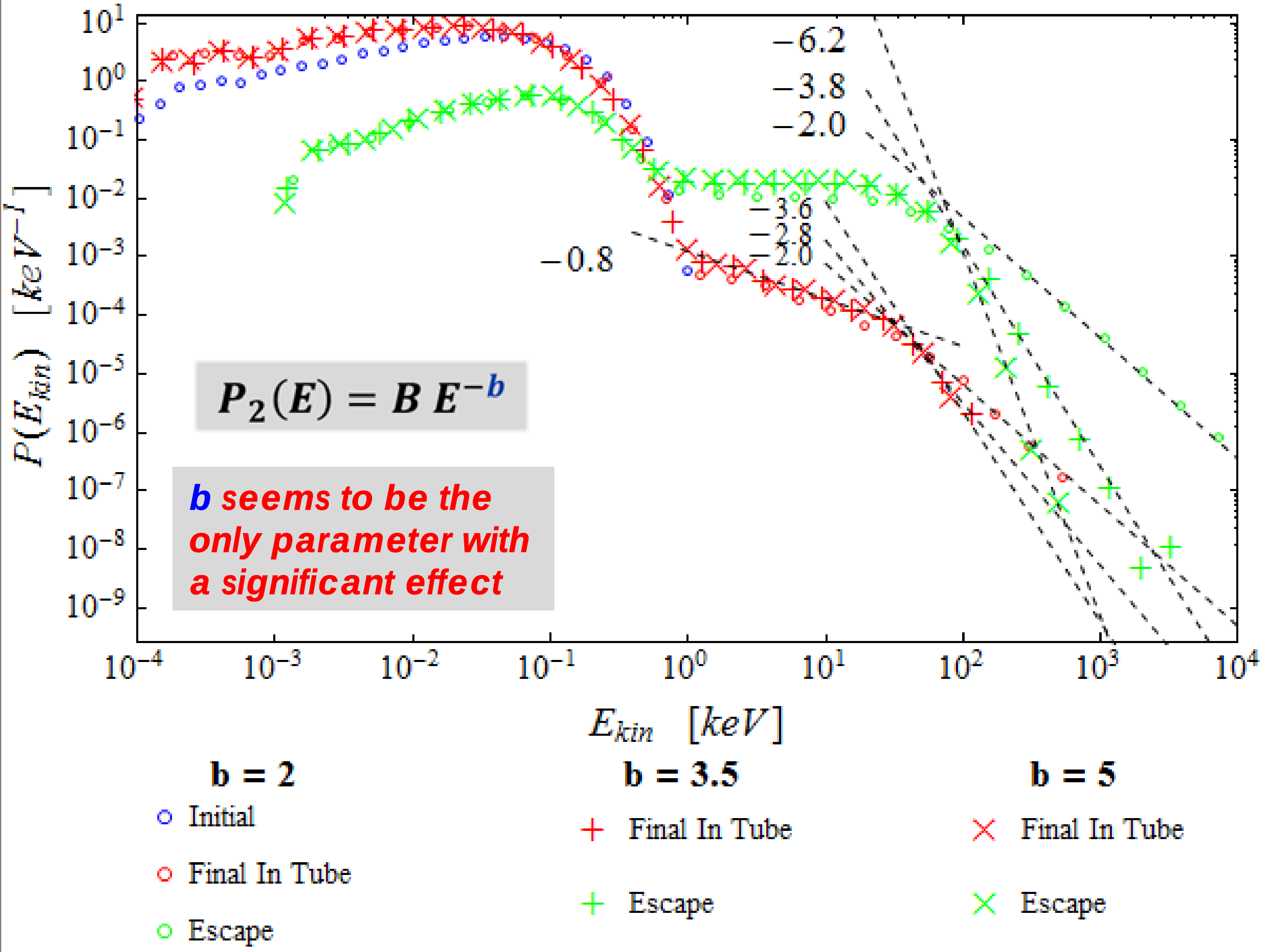
Note that both escaping populations have the same distributions

RESULTS 3/5

VARYING FRACTALITY



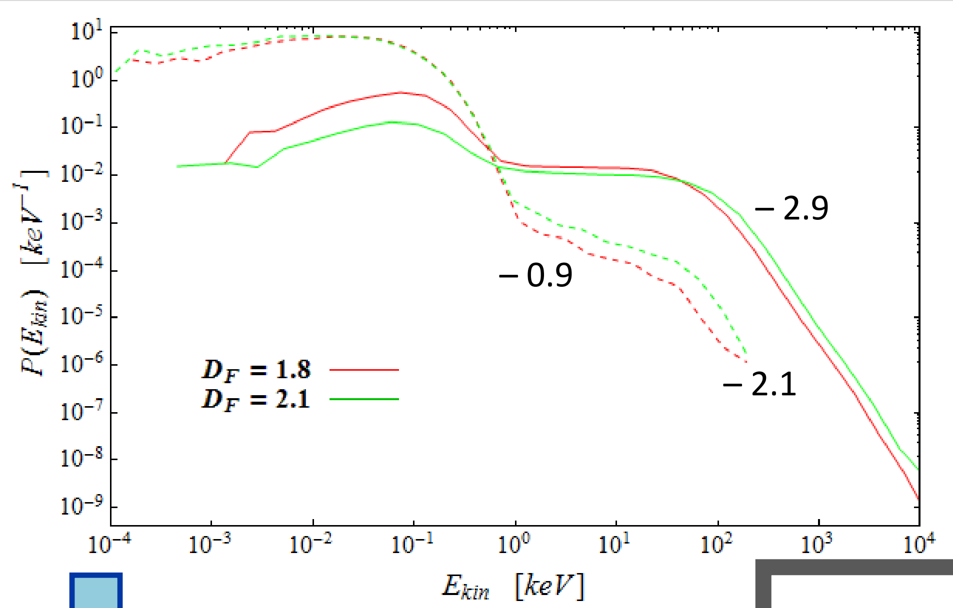
VARYING POWER-LAW INDEX OF ELECTRIC FIELD



$$P_2(E) = B\,E^{-b}$$

***b* seems to be the only parameter with a significant effect**

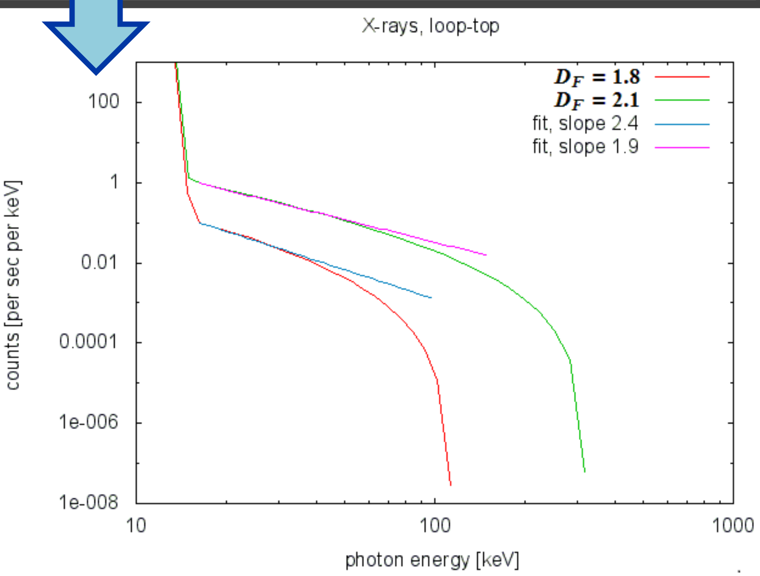
RESULTS 5/5

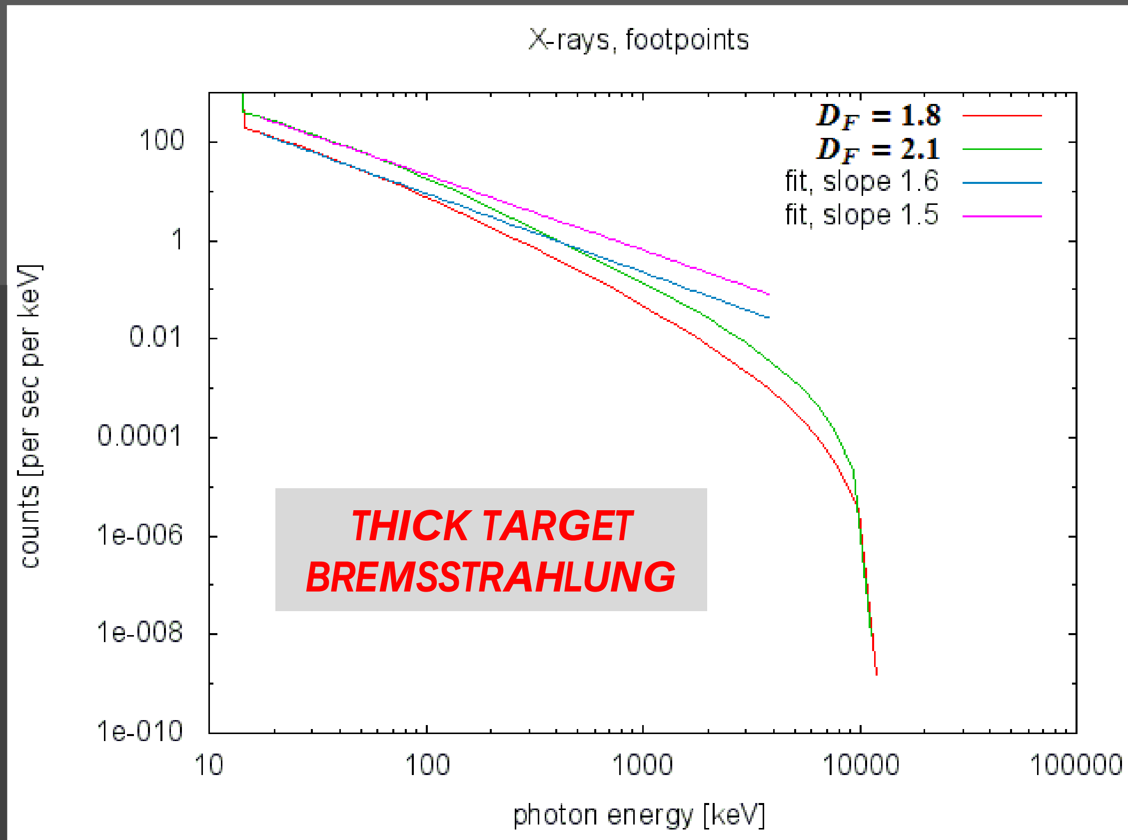


kinetic energy distribution of a footpoint source emitting Hard X-rays

HARD X-RAY EMISSION SPECTRA

kinetic energy distribution of a loop-top source emitting "Softer" Hard X-rays





THICK TARGET BREMSSTRAHLUNG

SUMMARY / CONCLUSIONS

- ***A** non-collisional **particle code***
- *traces **500,000 test – electrons'***
- ***guiding center** trajectories*
- *for a time **t = 2 sec** inside a simulated flux – tube with*
- ***a uniform & stationary magnetic field** and*
- ***a fragmented electric field***
- *collecting the particles' **energies at various instants***

- *Electrons seem to **respond** to the imposed fields as expected*
- ***Acceleration** actually does take place*
- *A **parametric study** is performed, revealing that while the*
    - *total time of integration*
    - *maximum electric field strength*
    - *fractality of the electric field structure*

  do not affect the particle acceleration,
    - *the **power-law index of the electric field** appears to have a **non negligible effect***
- *The results concerning the simulated **hard X-ray emission spectra**, even though **preliminary**, they do reveal a power law in the range 20KeV-1MeV for the footpoints and 20 -100KeV for the trapped particles*