Program Degrad.2.4

Auger cascade model for electron thermalisation in gas mixtures produced by photons or particles in electric and magnetic fields

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For Particle and photon radiation the program calculates (using x-section data) the observables:

Position and time of each thermalised electron.

Includes all Physical processes.

Outputs raw data for users own analysis programs.

Present status

Some results

Comparison to older simulations

Upgrade path and schedule

Physics

Atomic/molecular cascade :

- Auger and Coster-Kronig decay
- Fluorescence
- Outer shell electron shake off

Coupled cascade model

Photon absorption:

- Photoelectric effect
- Compton and Rayleigh scattering with shell form factors.
- Pair Production

Electron scattering:

- Rotational, vibrational, excitation , attachment and ionisation.
- Bremstrahlung
- Relativistic kinematics and density effect on ionisation and excitation
- Penning transfers can be included (as in Magboltz)

Aims:

Accurate auger cascade model for ionisation of inner shells to give:

1 Calculation of fano factors W , F1 ,F2 ,F3 for photons and electron beam.

W=ev/ion pair F1 = width F2=skew F3=kurtosis

2 Single or double beta decay calculation to give electron cloud size, shape and numbers of electrons and photons (excimers)

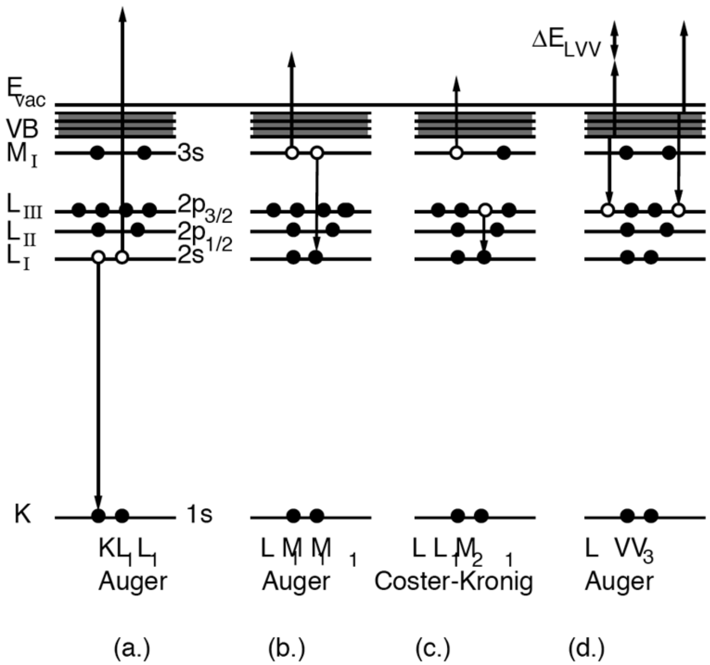
3 Calculation of number of clusters/cm and cluster size for particle tracks and de/dx. (Uses infinitely thin gas plane).

Can be of use in TPC analysis/simulation to give Neff.

Neff ~ number of clusters/cm * cluster size

Auger

Coster-Kronig



used first 17 atomic shells in Xenon

K,L1,L2,L3,M1,M2,M3,M4,M5,N1,N2,N3,N4,N5,O1,O2,O3

Fluorescence emission of photon rather than electron

Shake off outer shell electron emission from sudden change in potential

Photoelectric absorption

Cross-sections for each shell (17 in Xenon)

Bremsstrahlung

Cross-sections of Berger and Seltzer from 1kev

gamma angular distribution from :

C.Kohn and U.Ebert Atmospheric Research 135(2014)432

Electron angular distribution from conserved transverse momentum (approximation)

Compton Scattering

Inelastic form factor has been split into atomic shells

Pair production

Only important above 2.4 Mev . (double escape peak calculated)

Electron scattering

INCLUDES CROSS-SECTIONS FOR ROTATION VIBRATION ATTACHMENT AND EXCITATION FROM MAGBOLTZ

New ionisation model

NEW IONISATION MODEL : UPDATED MAGBOLTZ 10.1

SPLIT IONISATION CROSS-SECTION INTO INNER AND OUTER SHELLS.

e.g XENON INNER SHELLS - K,L1,L2,L3,M1,M2,M3,M4,M5

OUTER SHELLS - Charge States 1,2 and sum of 3,4,5,6

ARGON INNER SHELLS - K,L1,L2,L3

OUTER SHELLS - Charge states 1,2 and 3

Gases updated and included : He Ne Ar Kr Xe H_2 N_2 CH_4 CF_4 CO_2 C_4H_{10} .

Other gases will be updated and included later.

The new ionisation model is essential as it allows inner shell ionisations caused by electron scattering to be included in the cascade analysis by the emission of fluorescence x-rays and auger electrons

ATOMIC DE-EXCITATION

Penning effect

Transfer probabilities need to be entered in the gas subroutines

Probabilities depend on energy difference between excitation levels in gas1 and ionisation energy in gas 2

Hornbeck-Molnar (gas1=gas2)

Associative ionisation can occur for high lying levels in the noble gases

e.g. Ar** +Ar --- Ar2+ + e-

Less than 1% in Argon but may be larger in Xenon (work continuing). Reduces yield of excimer formation.

The calculated range of electron thermalised cloud sizes for incident electrons and photons between 100 ev and 3Mev is in agreement with the review of Kobetich and Katz for all the gases included in the prog.

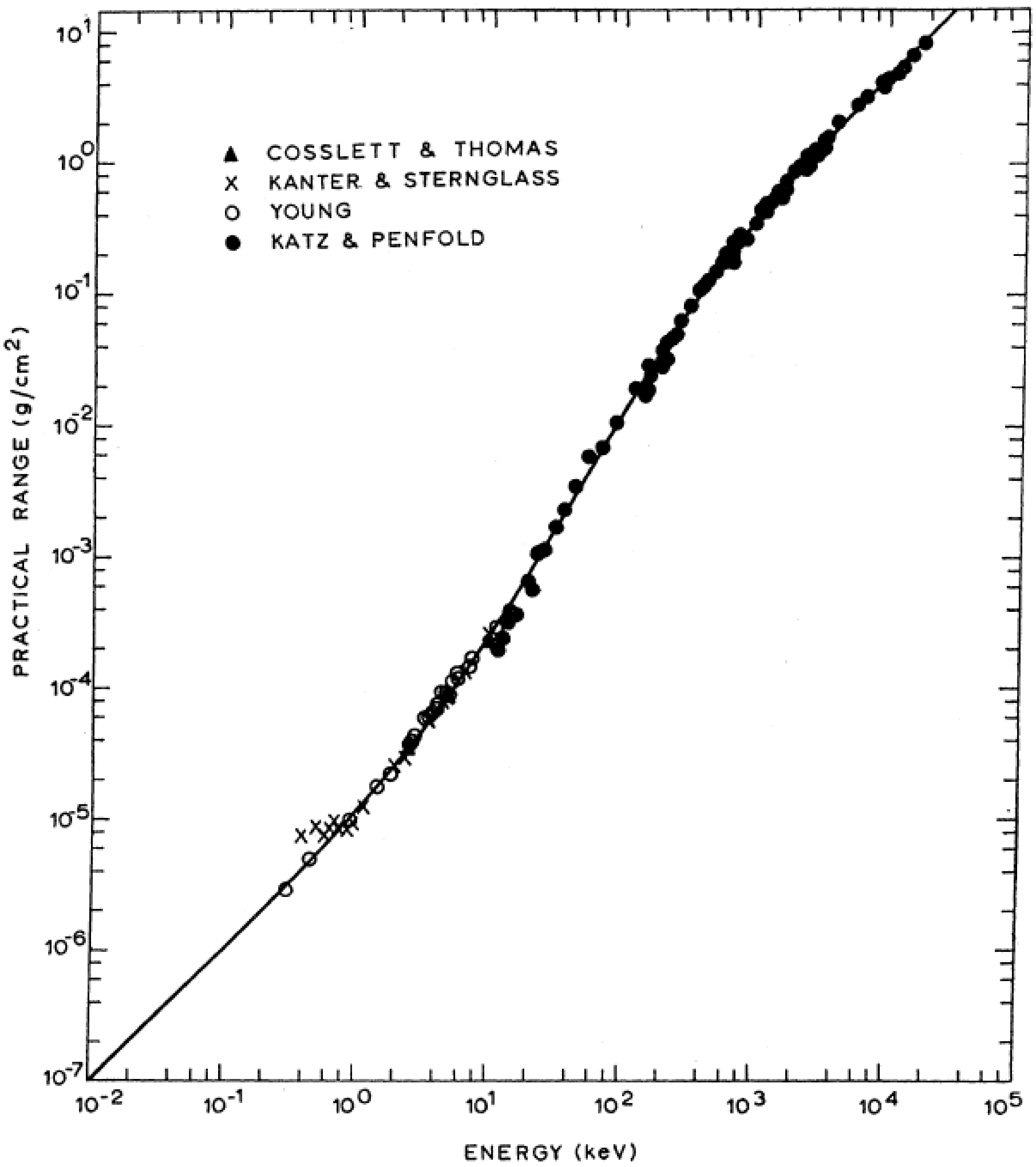
Kobetich and Katz Phys Rev 170(1968)391 >>>

Beta decay option tested and gives consistent ranges to the electron beam option.

MIPS

The simulation of track clusters assumes an infinitely thin gas plane.

The primary cluster frequency is given by the interaction of the track with the thin plane. The cluster size distribution is then developed during the thermalisation of the primary (including inner shell cascades) in a thick gas plane . The primary electron energy can be up to 10Mev (beta*gamma=20).


▲ COSSLETT & THOMAS
X KANTER & STERNGLASS
○ YOUNG
● KATZ & PENFOLD
PRACTICAL RANGE (g/cm²)
ENERGY (keV)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻²
10⁻¹
10⁰
10¹
10²
10³
10⁴
10⁵

Program Status

Program is fast: 6 Kev. 10k events in few minutes

1Mev 2.5k events in 1 hour (Intel Core Pc)

Good agreement with experimental W factors. ICRU Report 31

Icru : Xenon W= 22.1 +- 0.4ev. Argon W = 26.4 +- 0.4ev.

Calc: Xenon W= 22.6 +- 0.2ev. Argon W = 26.3 +- 0.2ev.

Published asymptotic Fano factors :

Xenon in range from 0.12 to 0.2 in Argon from 0.13 to 0.19

Calc: Xenon: gammas F = 0.185 electrons F= 0.180

Argon: gammas F= 0.145 electrons F= 0.142

Noble Gas asymptotic Fano factors

Gas	We	Fe	Wexc	Fexc	sqrt(Fe/Fexc)	experiment(icru)
He	47.1	0.235	68.8	0.68	0.59	41.3
Ne	37.4	0.135	76.8	0.68	0.44	35.4
Ar	26.3	0.144	60.1	0.71	0.45	26.4
Kr	24.8	0.158	46.8	0.72	0.47	24.4
Xe	22.6	0.184	37.7	0.76	0.49	22.1
error	1%		2%			2%

The difference between the calculation and the experiment in Helium and Neon is caused by gas impurities in the measurements which give Penning contributions to the total ionisation.

Molecular Gas asymptotic Fano factors

Gas	We	Fe	Wexc	Fexc	Experiment(ICRU)
CF4	28.1	0.15	59	0.77	
CH4	28.1	0.227	44.6	0.75	27.3
C4H10	22	0.245	58	0.81	23.4
CO2	31	0.28	30.3	0.59	33
N2	33.9	0.24	31.4	0.54	34.8
H2 (1)	36.1	0.374	27.5	0.55	36.5
H2 (2)	37.5	2.1	27.7	1.8	
error	2%		3%		2%

Comments: All gases except Hydrogen give converged We values at up to 3Mev
Hydrogen requires further investigation ….
CO2 and N2 also require improvement of data base at high energy.

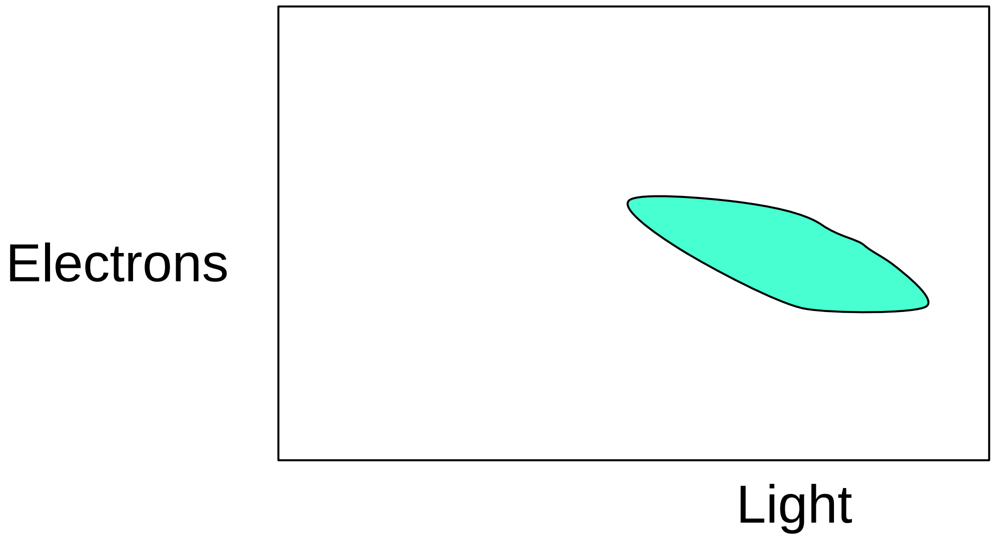
Dark Matter and Double beta decay experiments

Observe both light and charge in Noble gases/liquids.

To correct for anti-correlation use weighting of light emission .

The optimum weighting factor is given by sqrt(Fe/Fexc)

calculation shows this is almost a constant between 10Kev and 3Mev



The weighting factor may be used as a check on the calibration

of the light and electron collection efficiency.

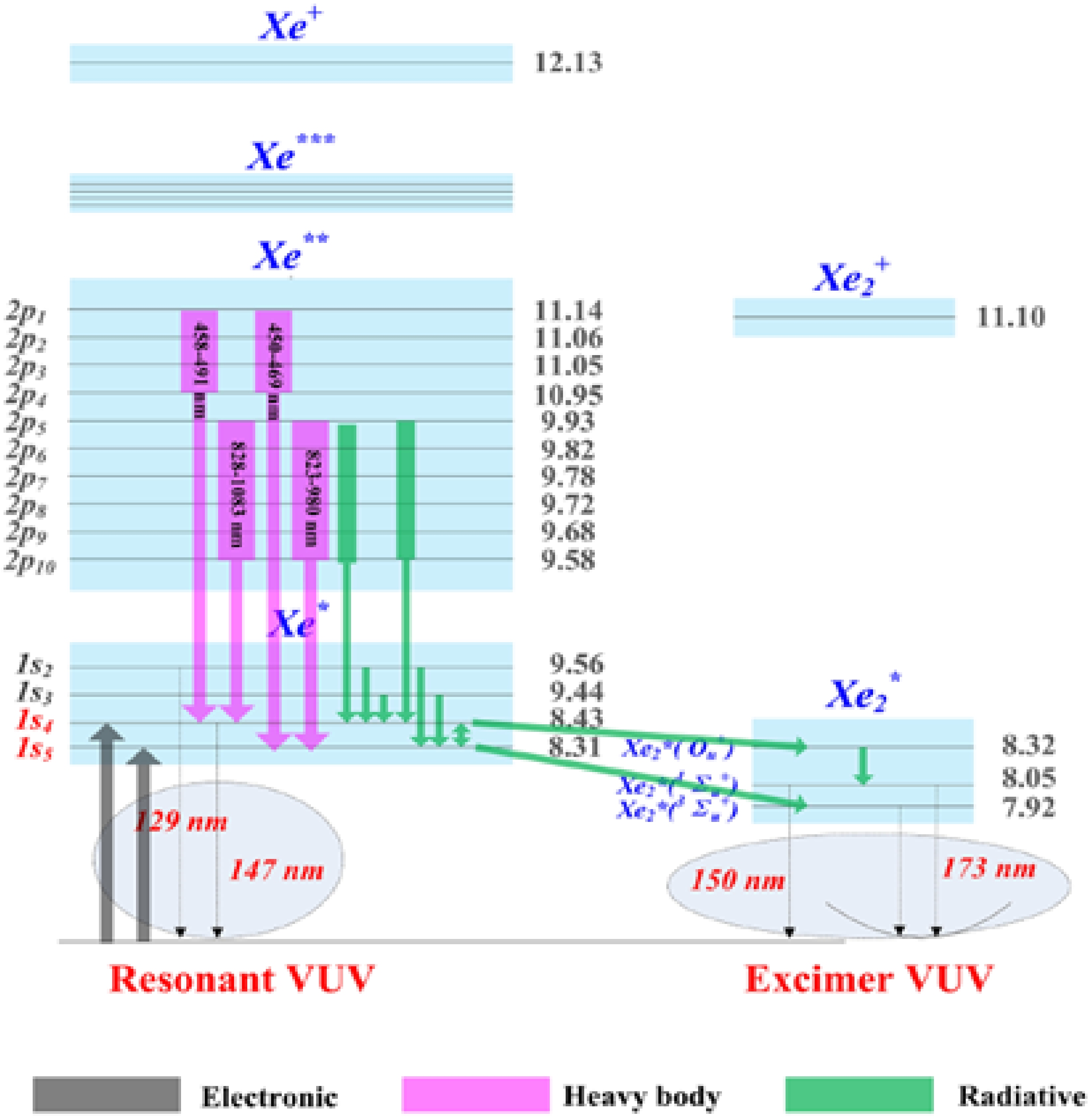
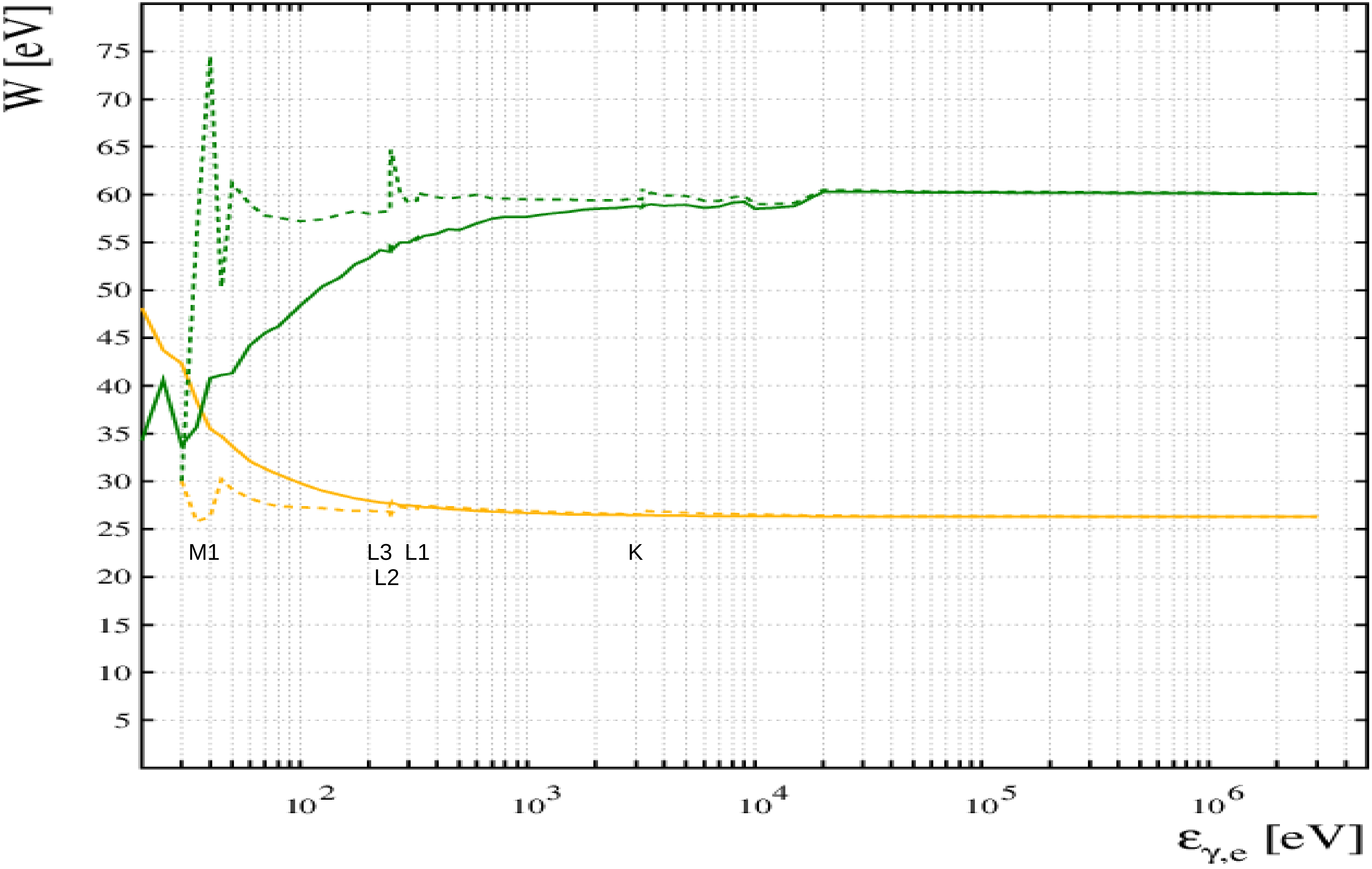


FIG. 10. The most important reaction equations about Xe*(1s$_4$) and Xe*(1s$_5$).

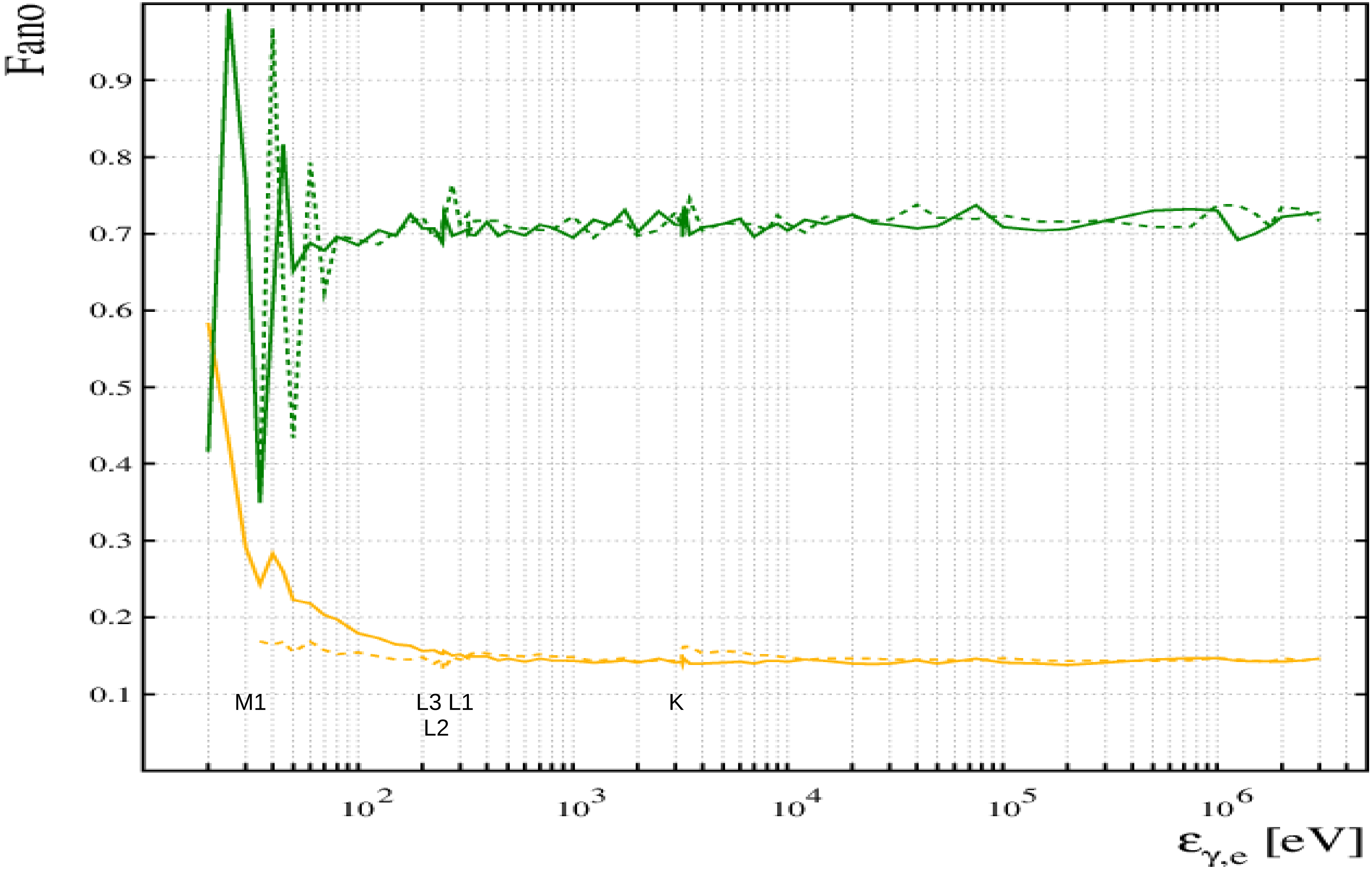
Argon

Dashed line : x rays   Solid Lines : electrons   Green : Excitation Yellow : ionisation



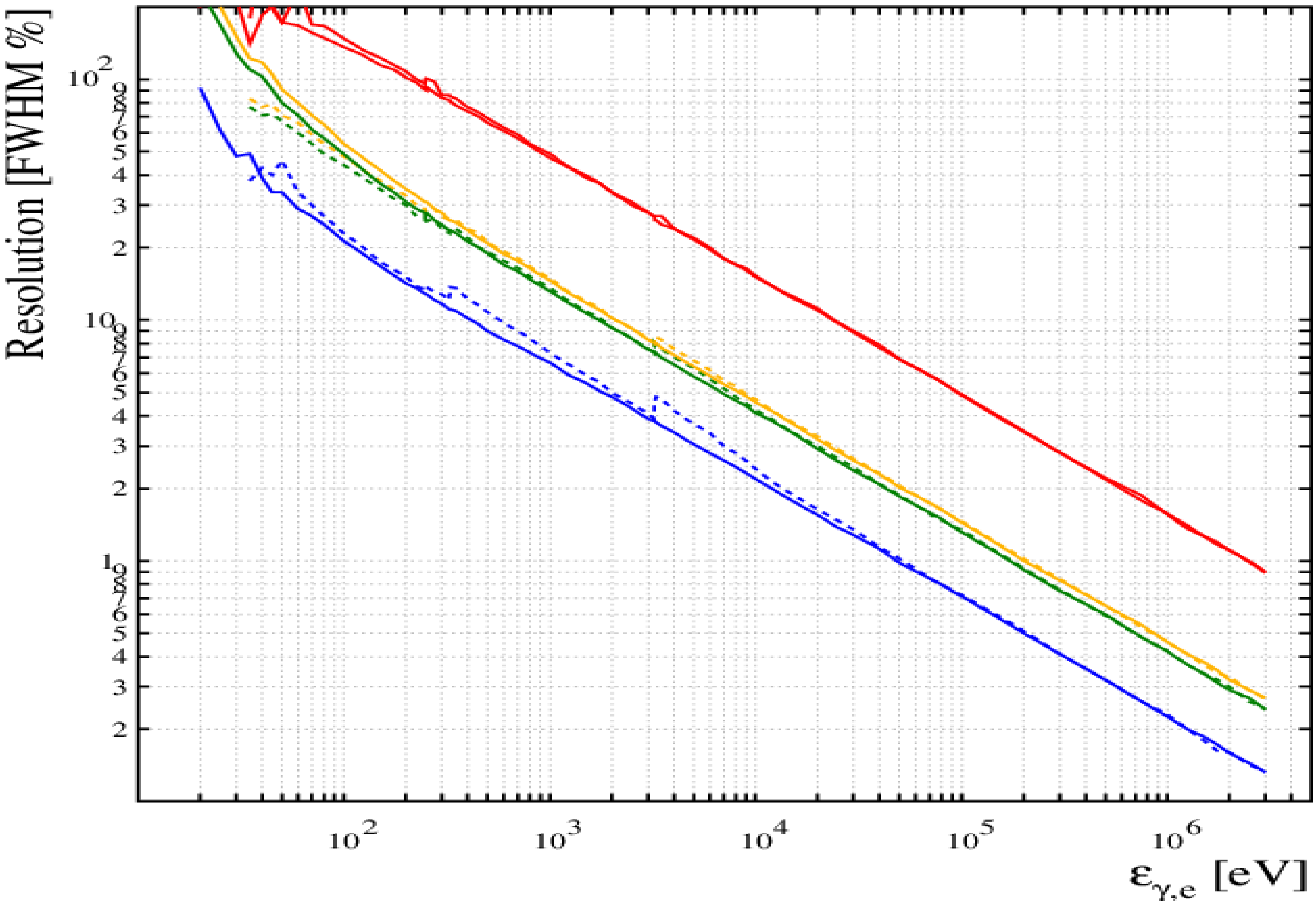
Argon

Dashed lines : x rays   Solid lines : electrons   Green : excitation   Yellow : ionisation



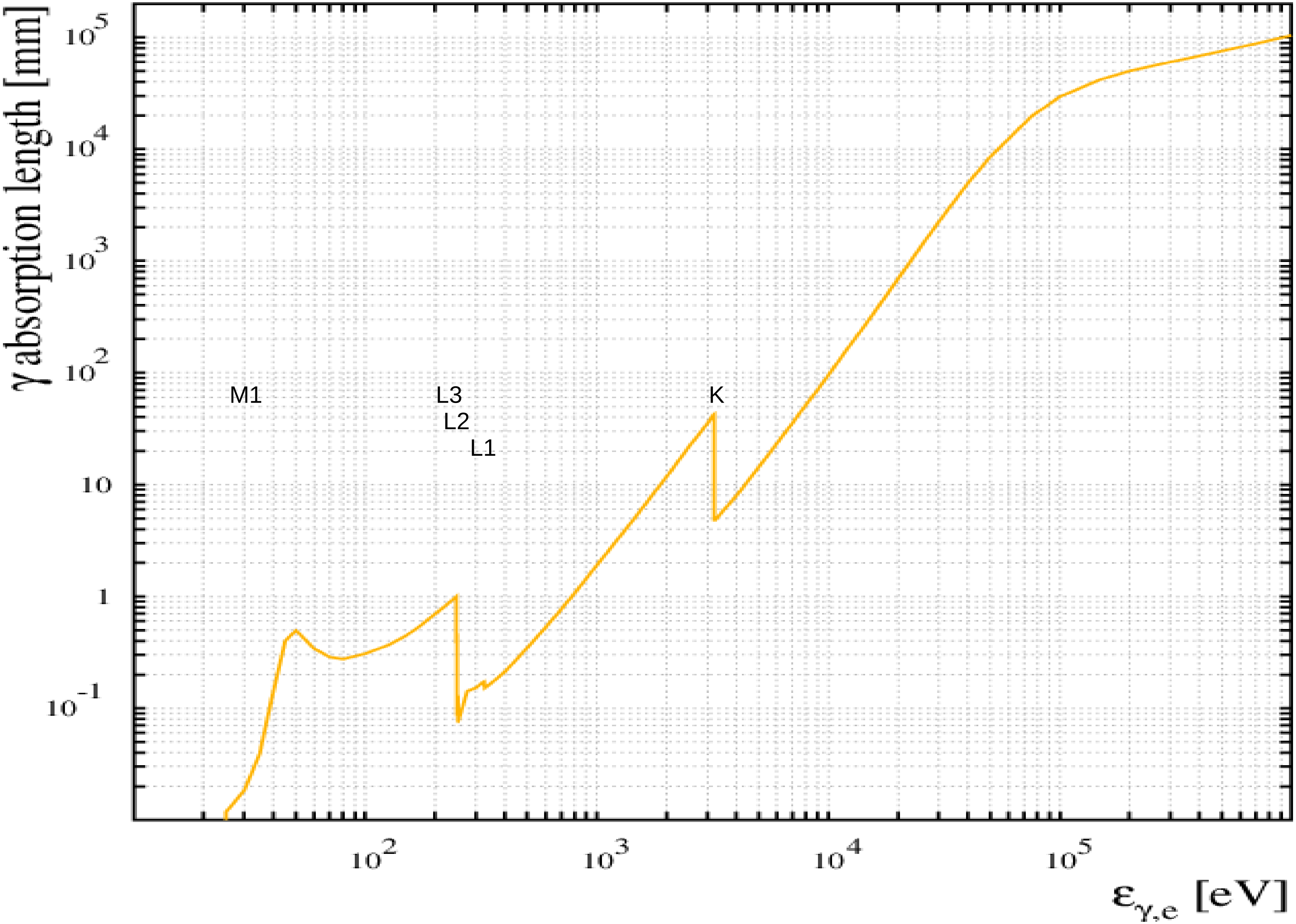
ARGON

Dotted Lines : x rays Solid Lines : electrons
Red : Excitation Yellow : ionisation Green : Ion +20% exc Blue : ion + 100% exc



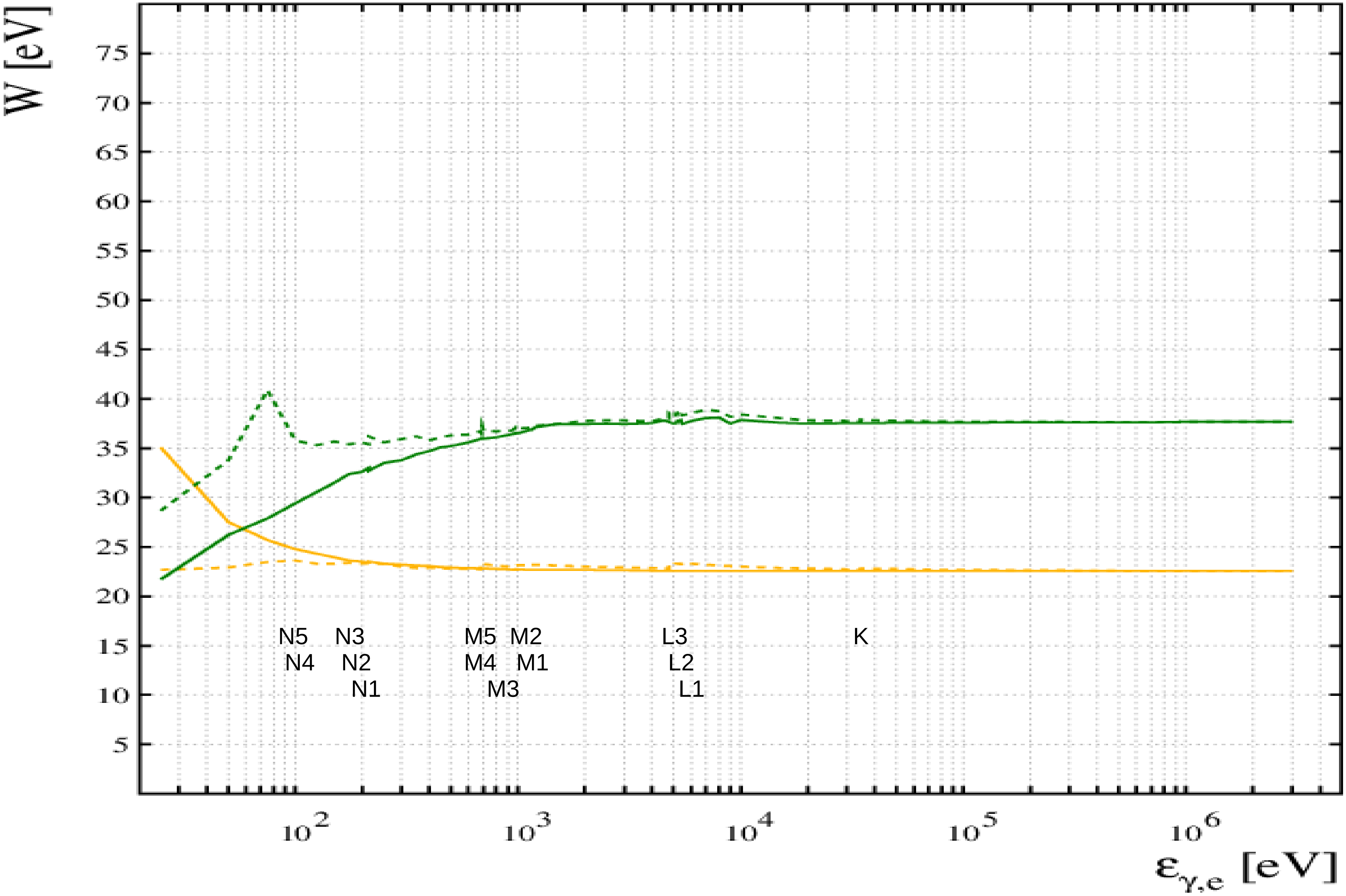
ARGON

Photon interaction length at 20 C 1 Bar



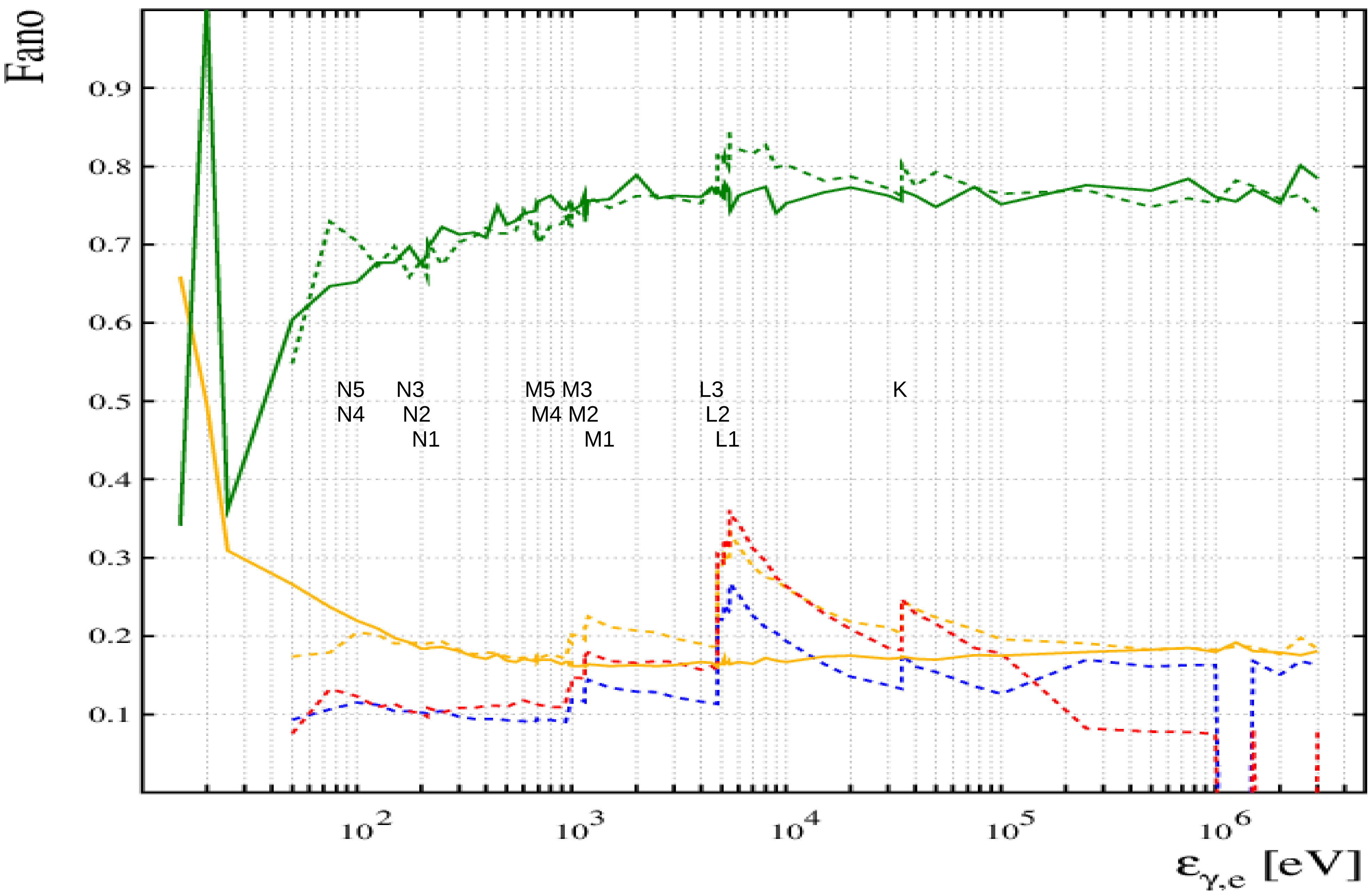
XENON

Dashed Lines : x rays   Solid Lines : electrons   Green : excitation Yellow : ionisation



XENON

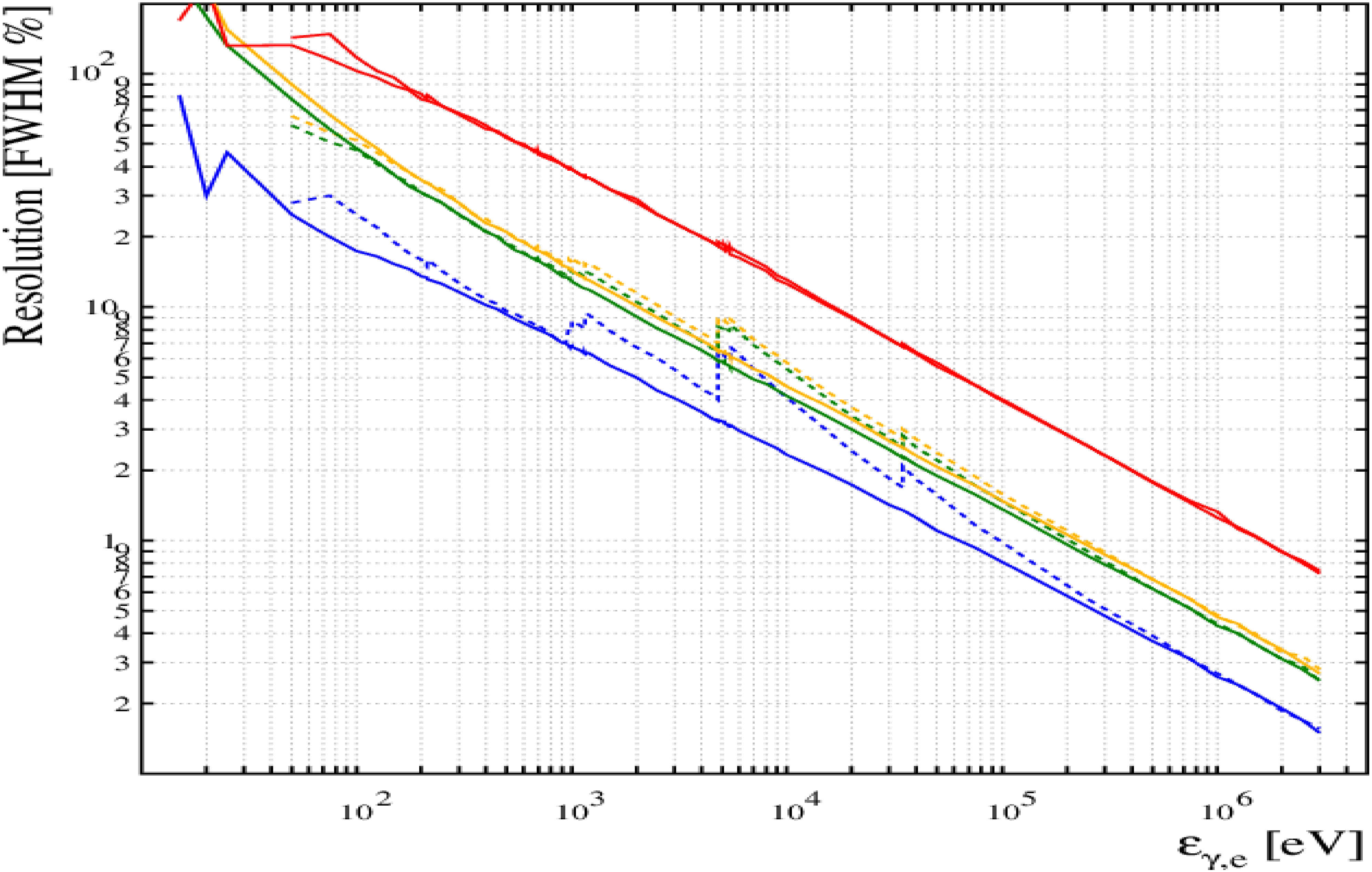
Dashed Lines : x rays   Solid Lines : electrons
Green : excitation   Yellow : ionisation   Blue : ion + 20% exc   Red : ion + 100%exc



XENON

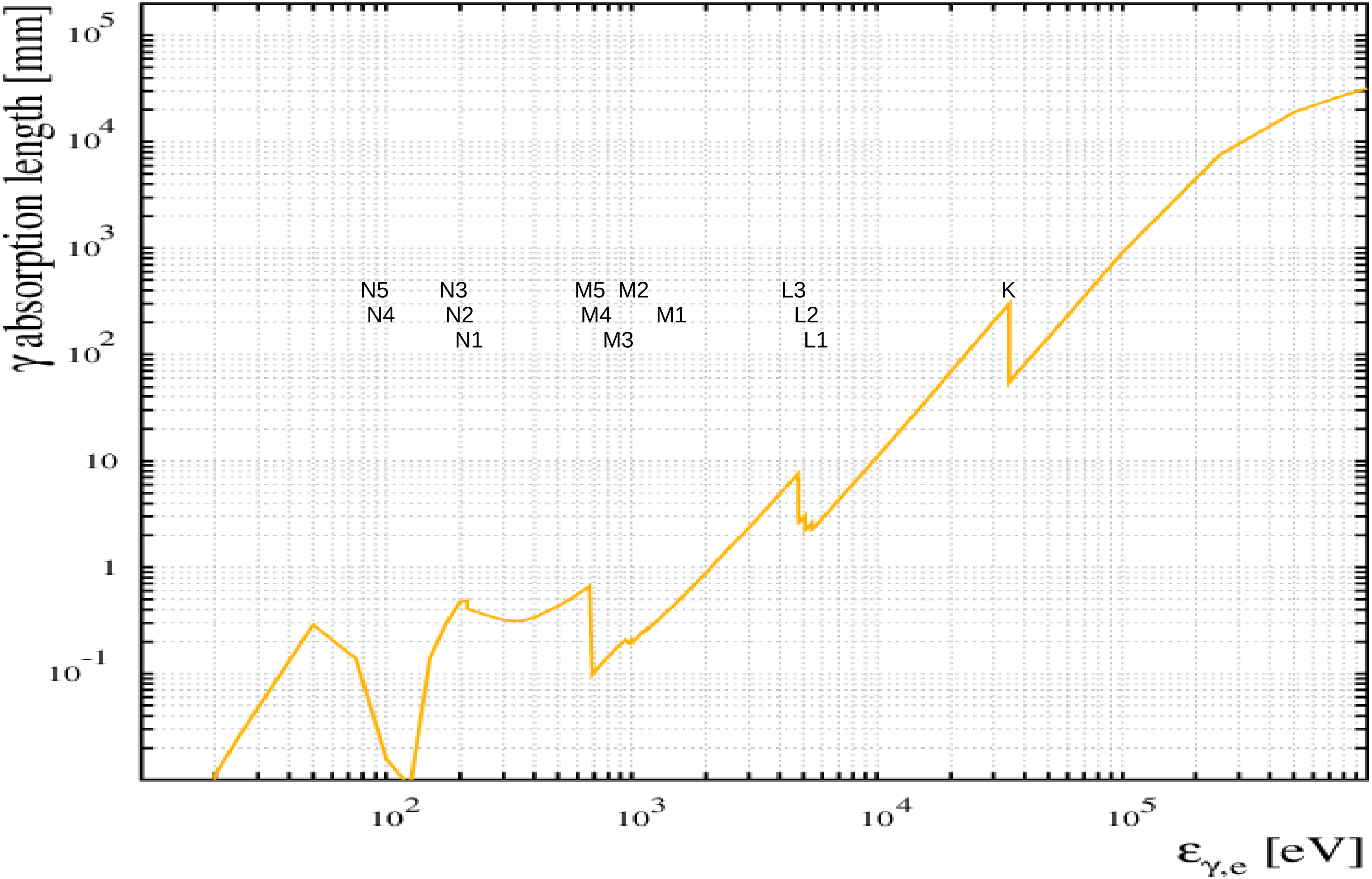
Dashed Lines : x rays   Solid Lines : electrons

Red : excitations   Yellow : Ionisation   Green : ion + 20% exc   Blue : ion + 100% exc



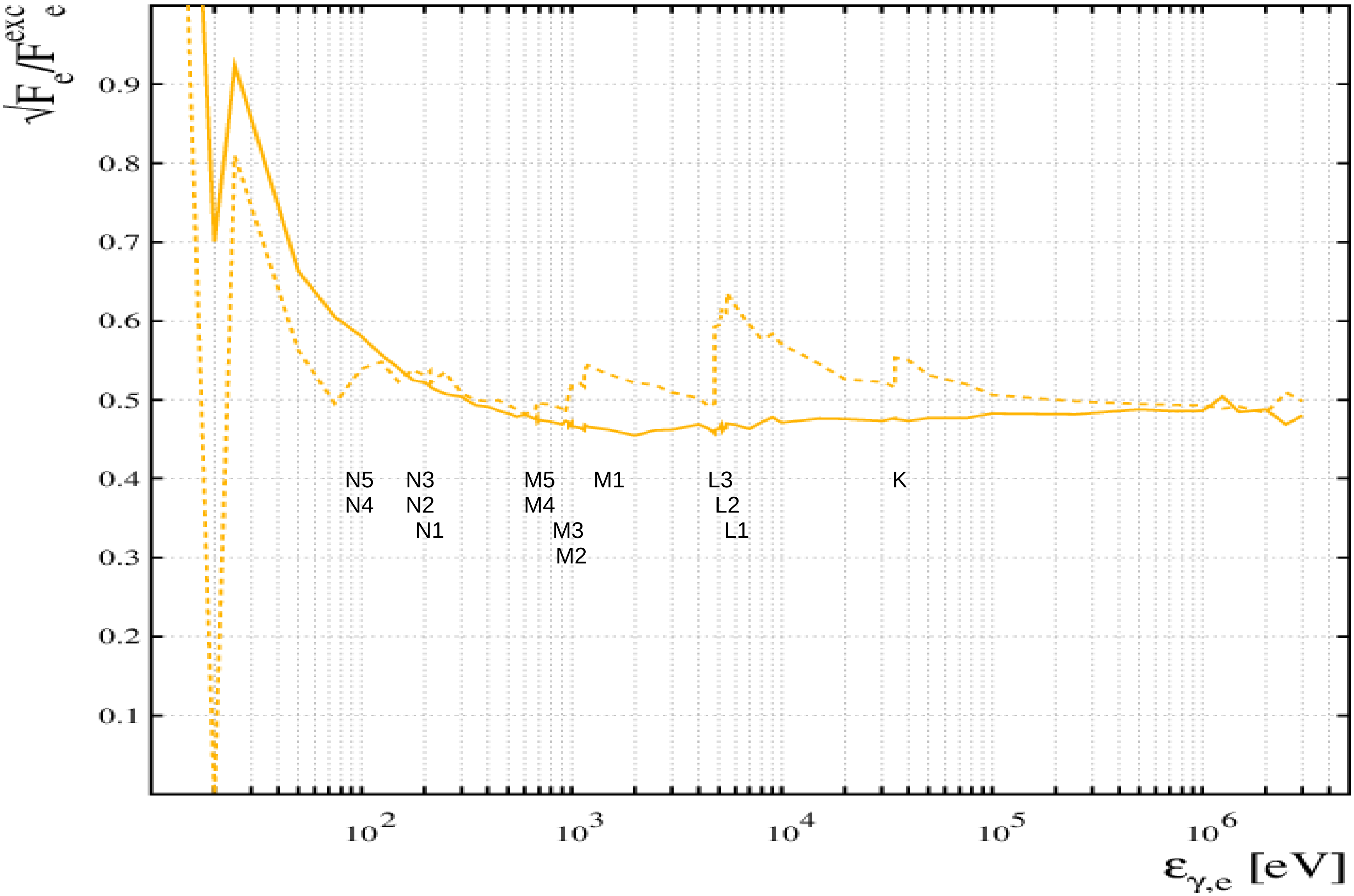
XENON

Photon interaction length 20 C 1 bar



XENON

Optimum weighting factor for light/charge



Comparison to previous calculations and some experiments:

Dias et al   J. Appl. Phys. 82(1997)2742

Non-linearity at shell edges: only comparison in Xenon possible

Discontinuity from linearity: all in ev.

Kshell :   Calc. :   157
Dias :   206
Exp.   :   165 + -10

	L1 shell	L2 shell	L3 shell	Total L1-L3
Calc. :	19	18	76	113
Dias :	20	15	90	135
Exp. 1 :	16+-2	26 +-2	55 +-2	96 +-6
Exp. 2 :				128+-15

Light yield from S1 signal : calculation :   Xenon 38.5 ev/photon
Experiment: range from 78 to 140 ev/photon

Effect of Drift field at High electron energy

For Beta decay in Xenon :

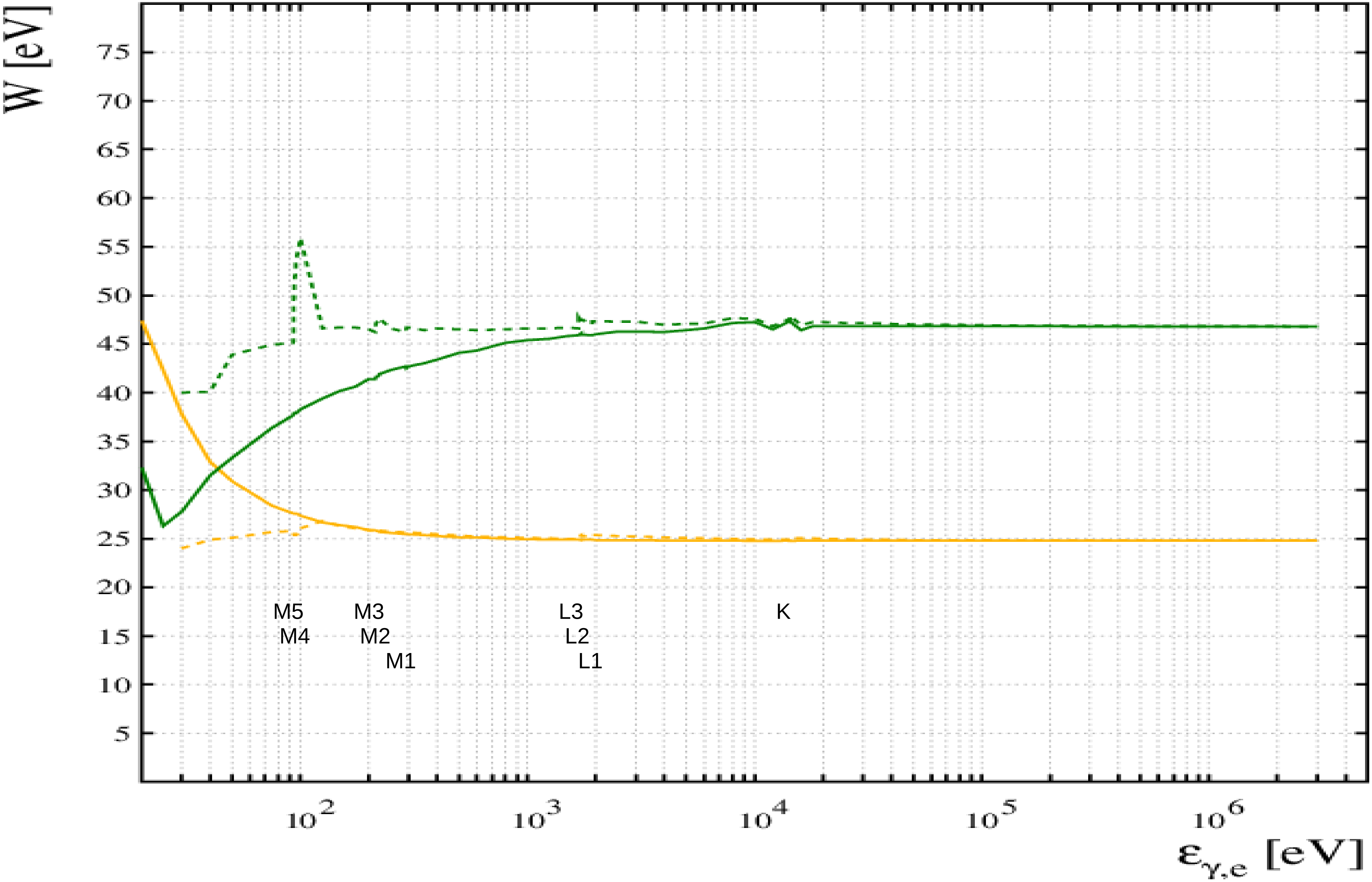
electric field in range 25 to 100v/cm/atmosphere

Electric Field	Resolution % FWHM at 1Mev
0.01	0.46
25	0.48
50	0.52
100	0.66

May be possible to correct the events by correlation with electron cloud size along electric-field direction .

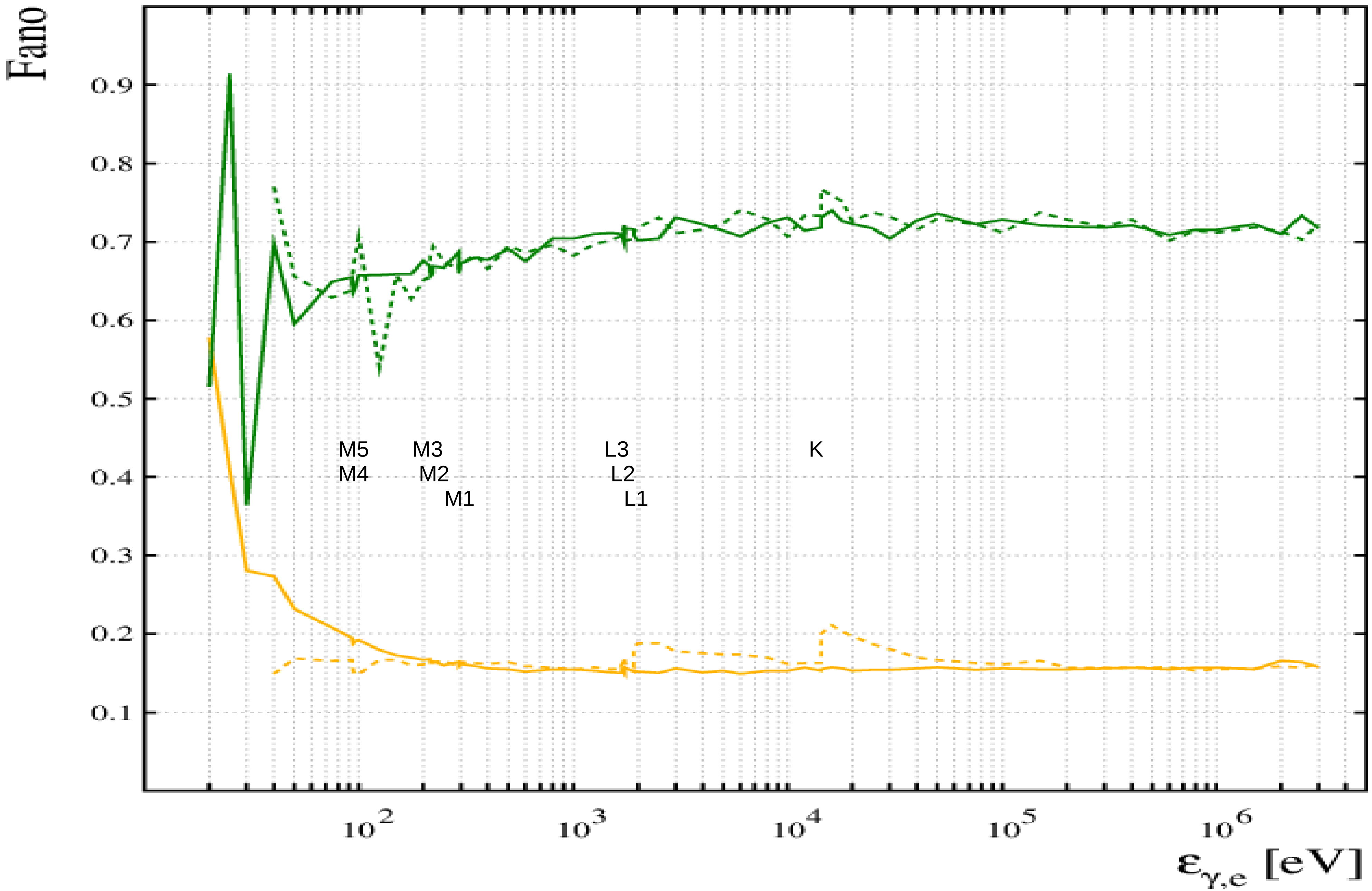
KRYPTON

Dashed Lines : x rays Solid lines : electrons Green : excitation Yellow : ionisation



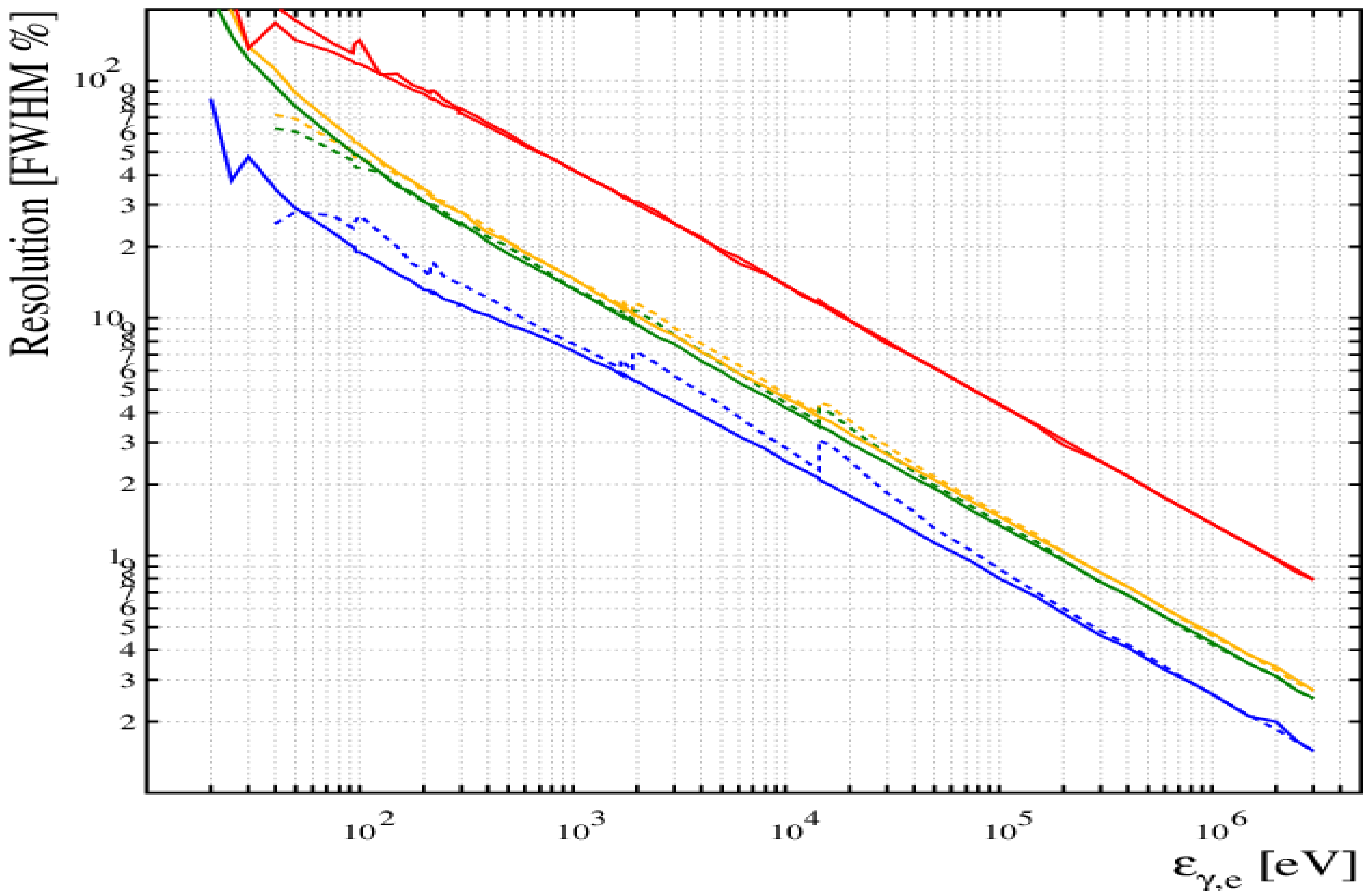
KRYPTON

Dashed lines : x rays   Solid Lines : electrons   Green : excitation   Yellow : electrons



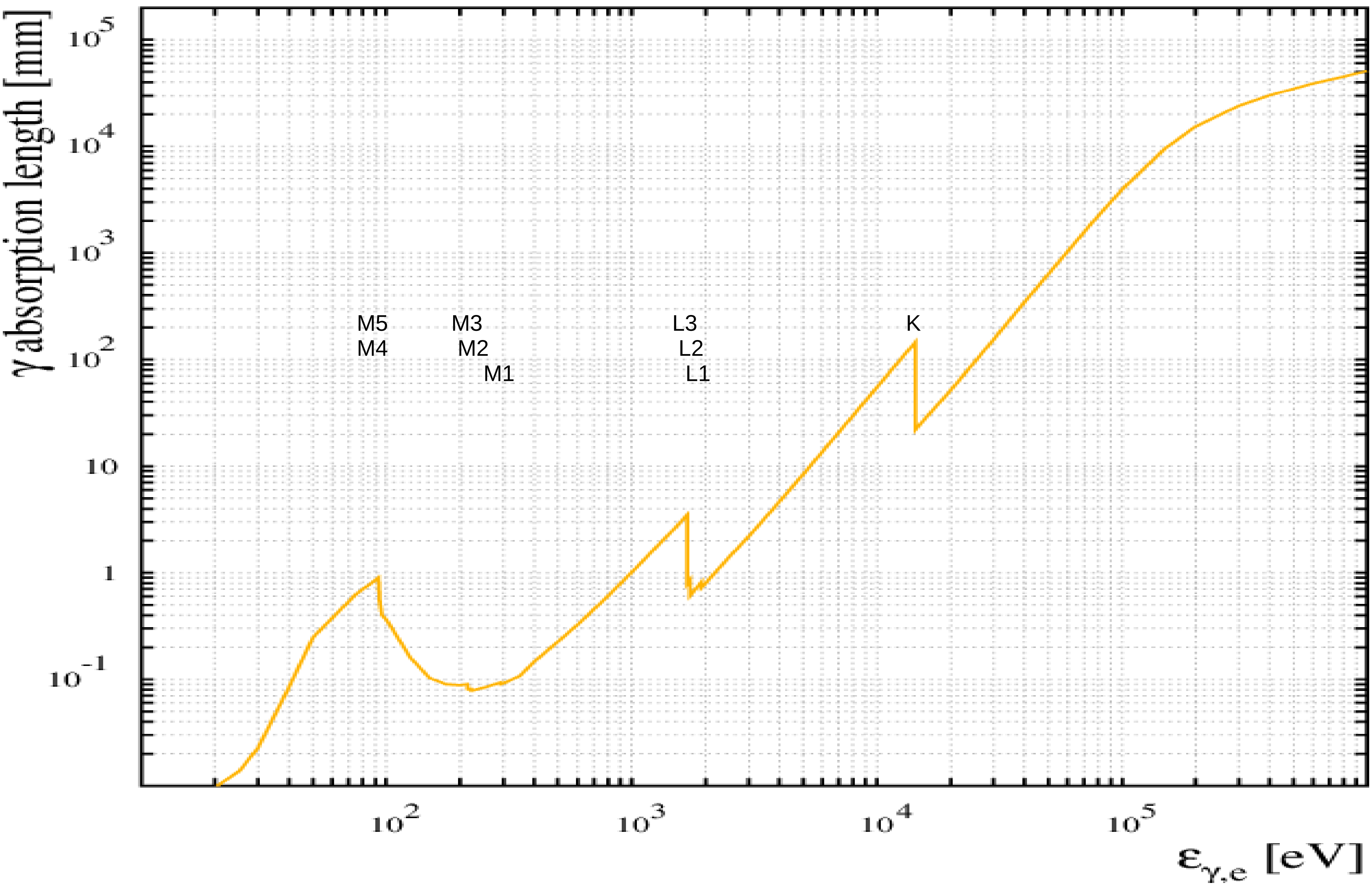
KRYPTON

Dashed Lines : x rays   Solid Lines : electrons   Red : excitation   Yellow : ionisation
Green : ion+20% exc   Blue : ion +100% exc



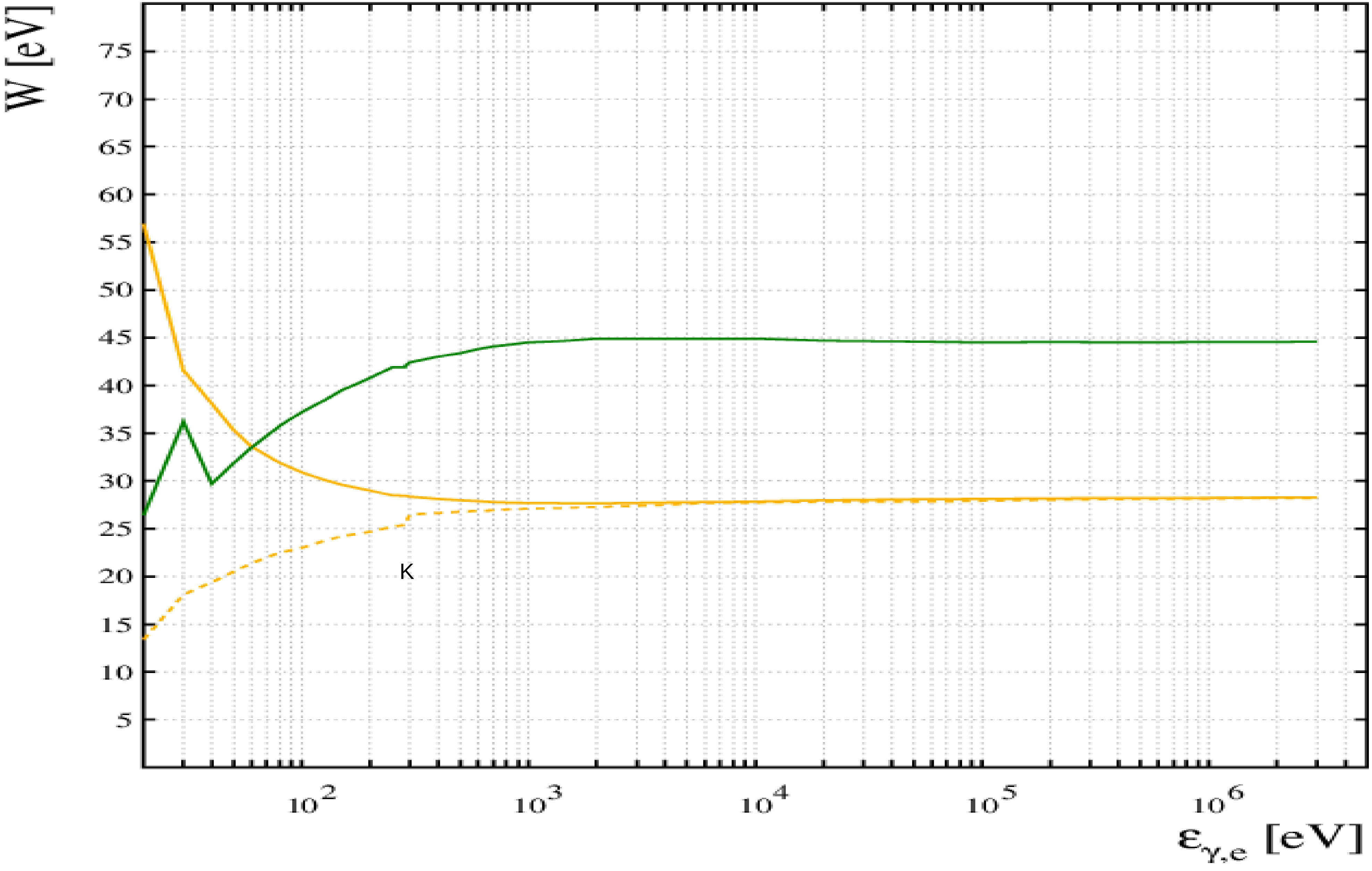
KRYPTON

Photon interaction length 20C 1 bar



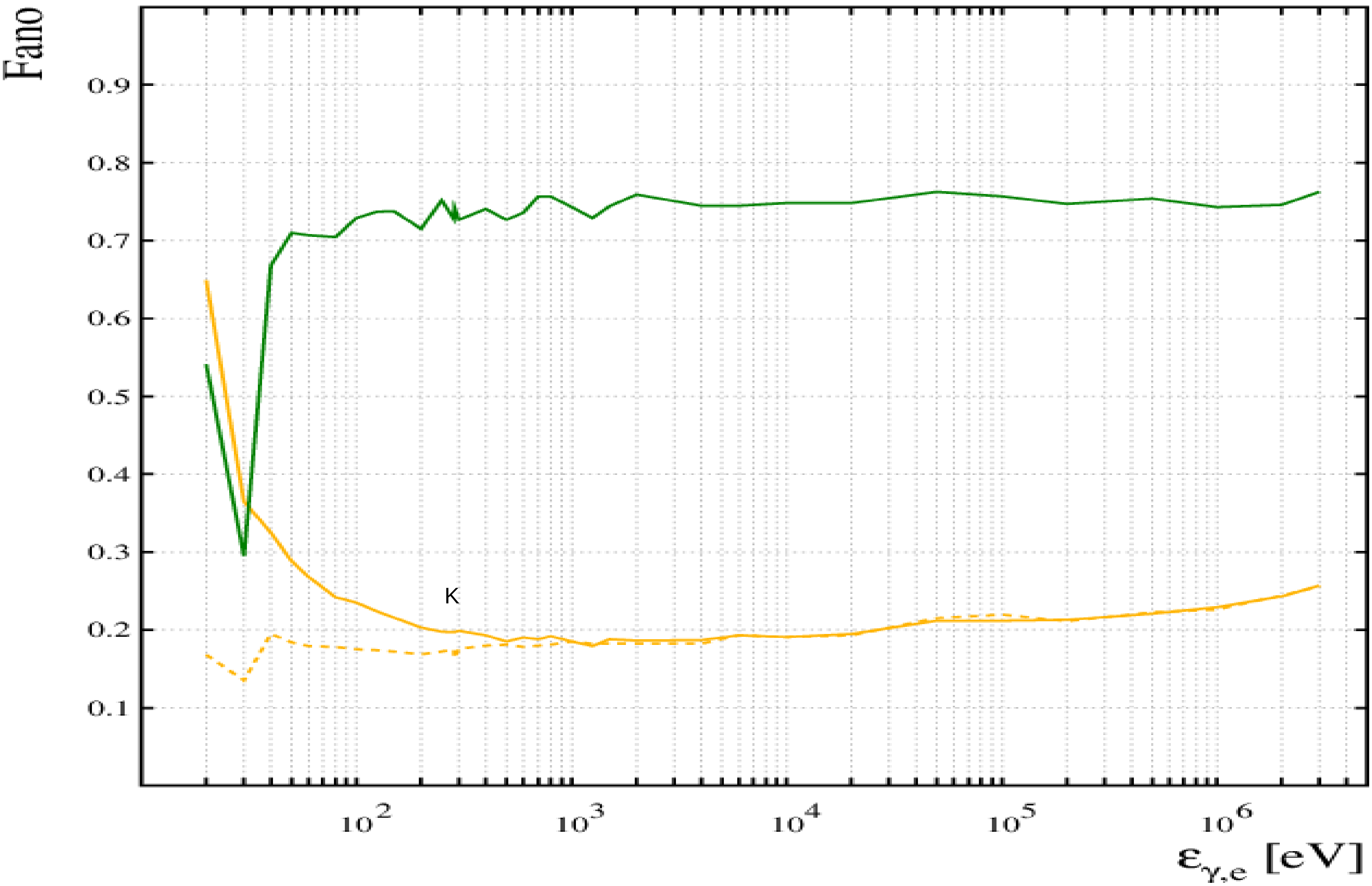
CH4

Dashed Lines : x rays Solid Lines : electrons Green : excitation Yellow : ionisation



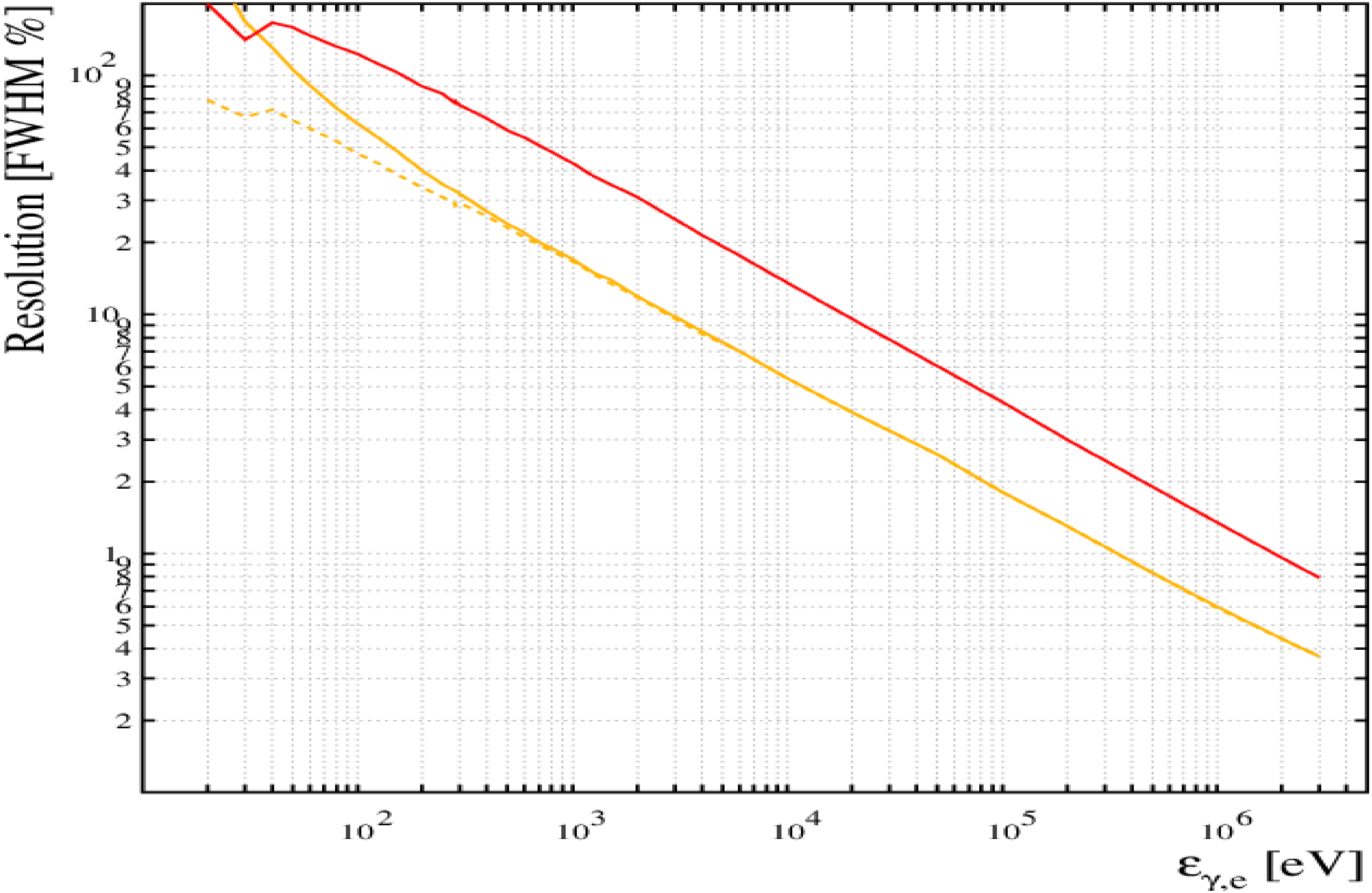
CH4

Dashed Lines : x rays   Solid Lines : electrons   Green : excitation   Yellow : ionisation



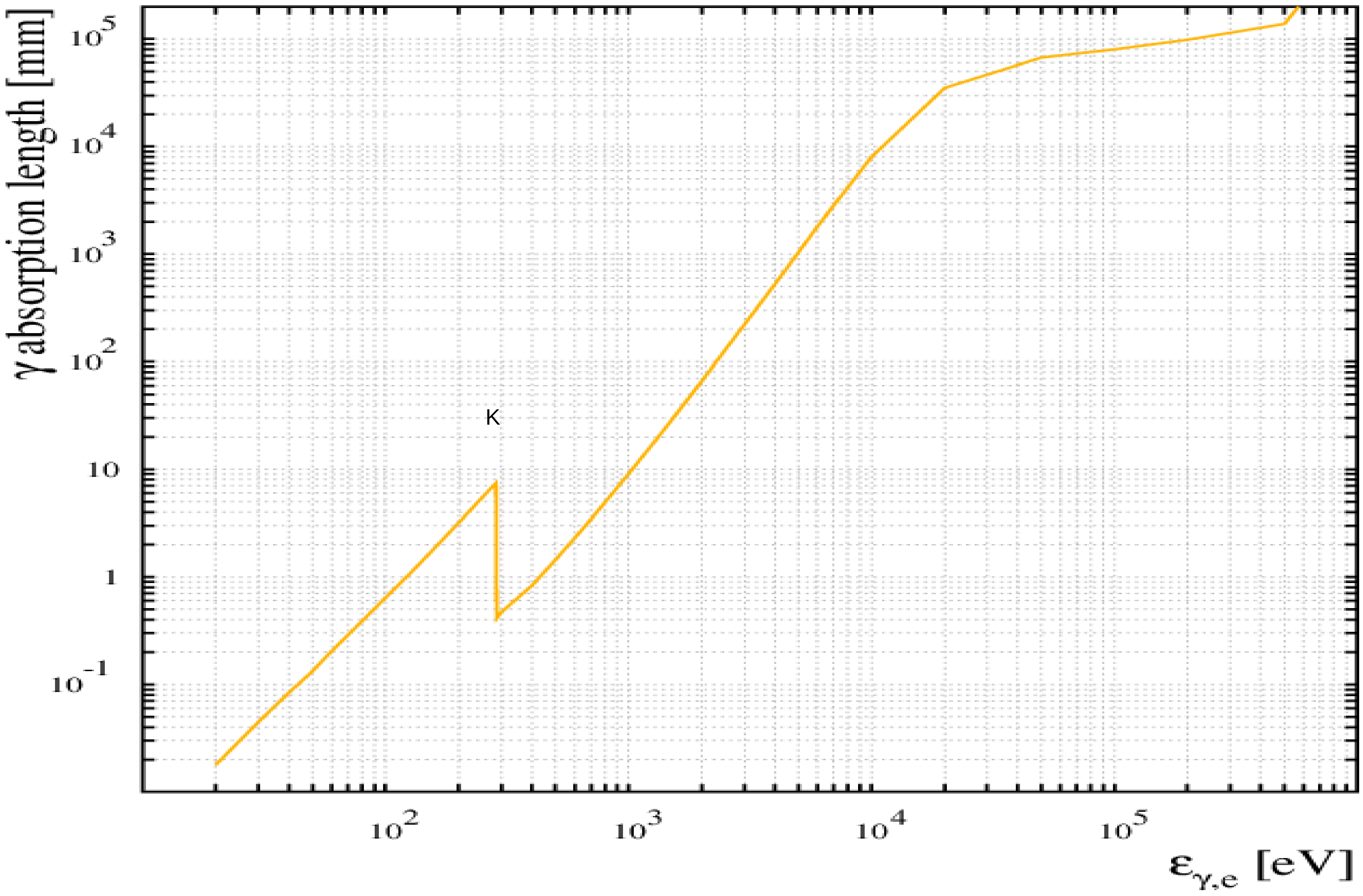
CH4

Dashed Lines : x rays   Solid Lines : electrons   Red : excitation   Yellow :ionisation



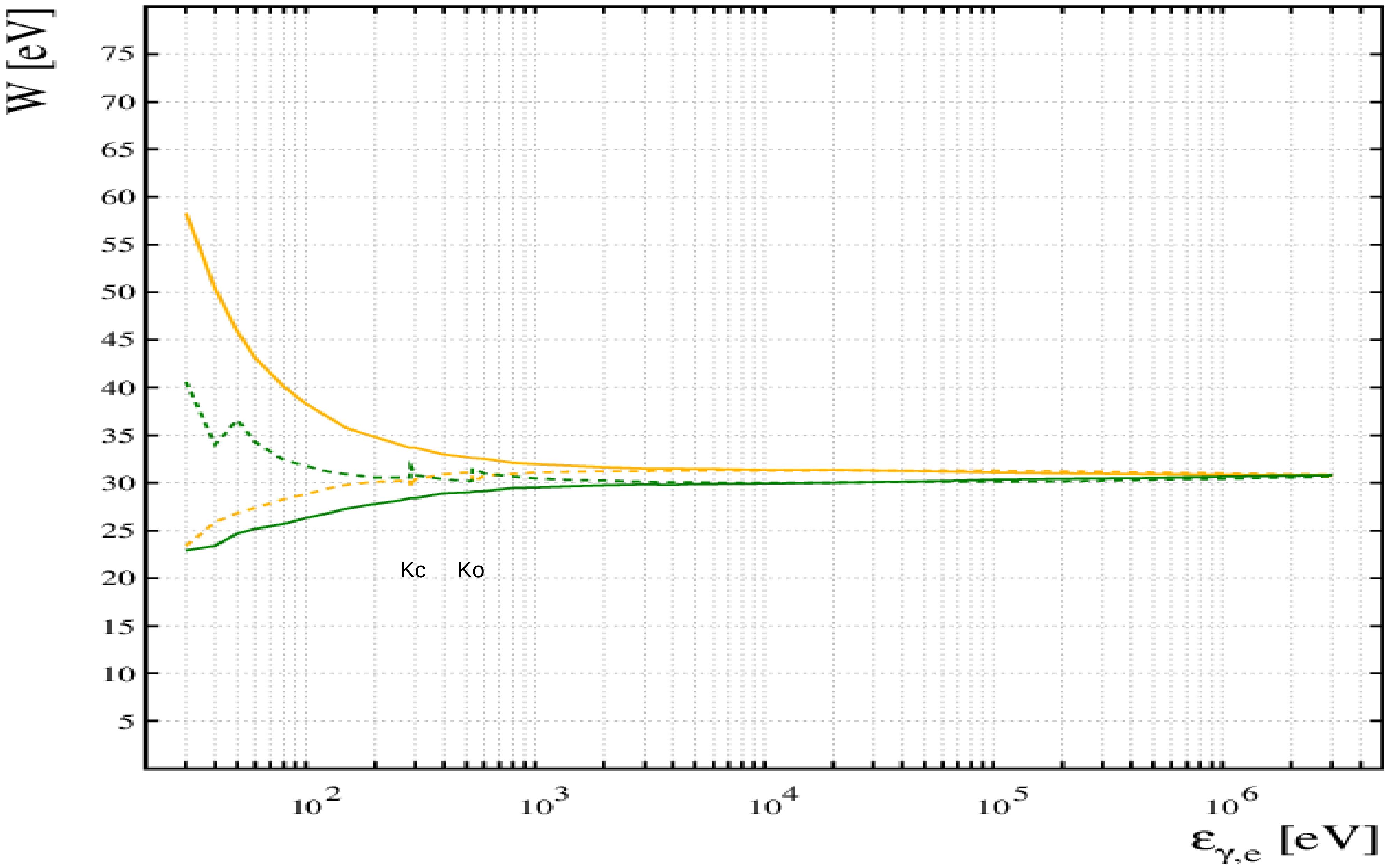
CH4

Photon interaction length 20 C 1 bar



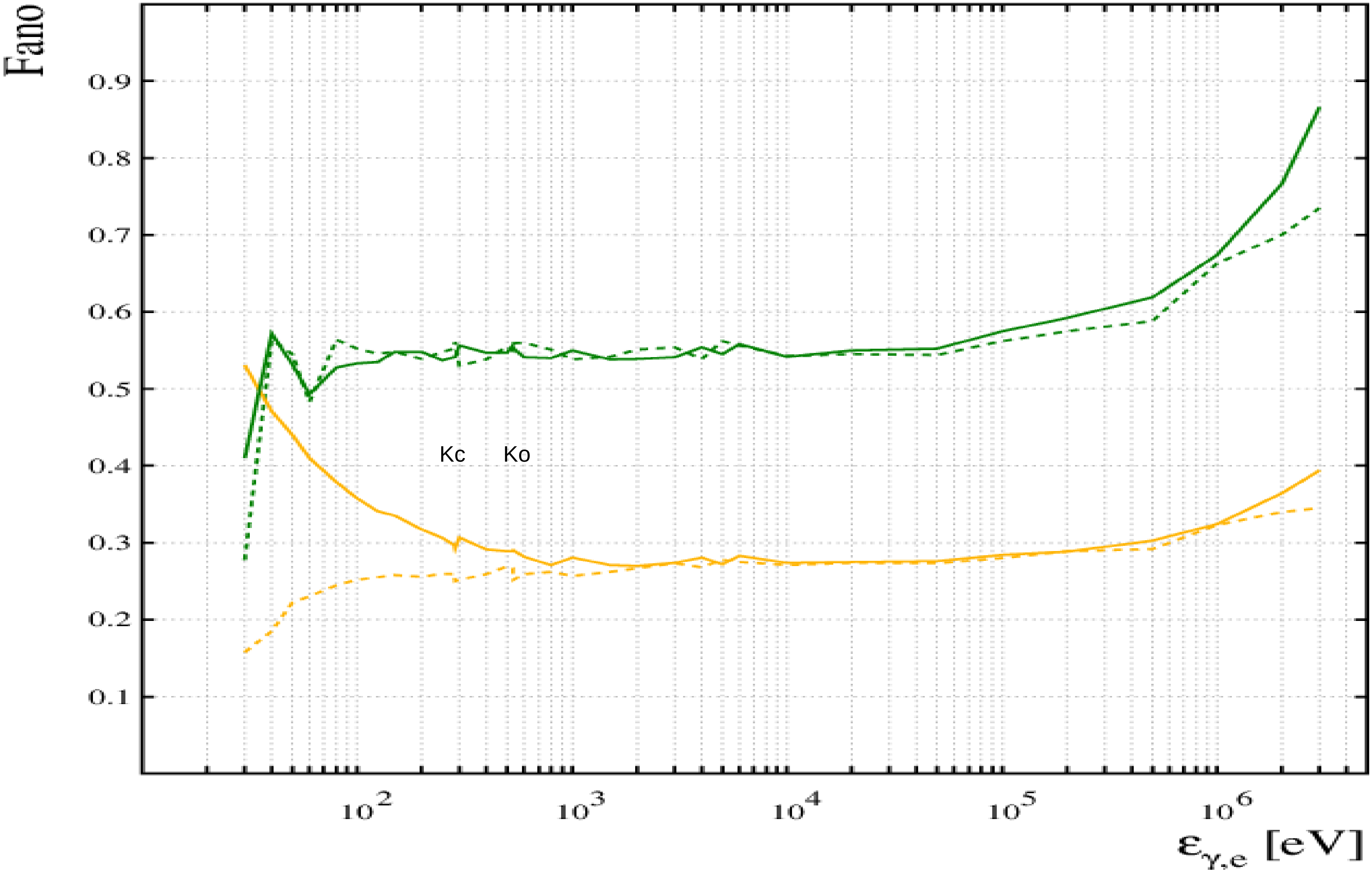
CO2

Dashed Lines : x rays　Solid Lines : electrons　Green : excitation　Yellow : ionisation



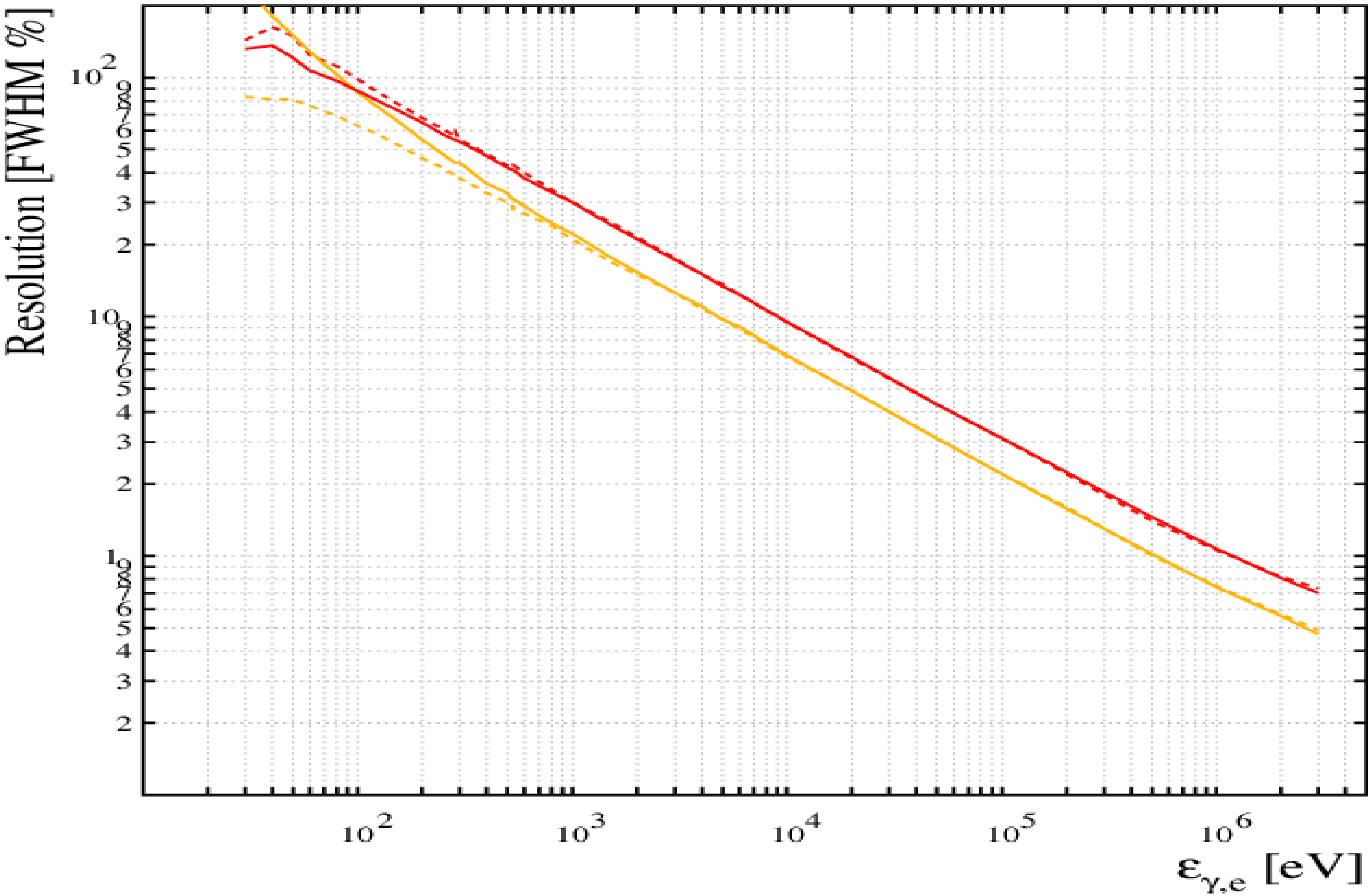
CO2

Dashed Lines : x rays　Solid Lines : electrons　Green : excitation　Yellow : ionisation



CO2

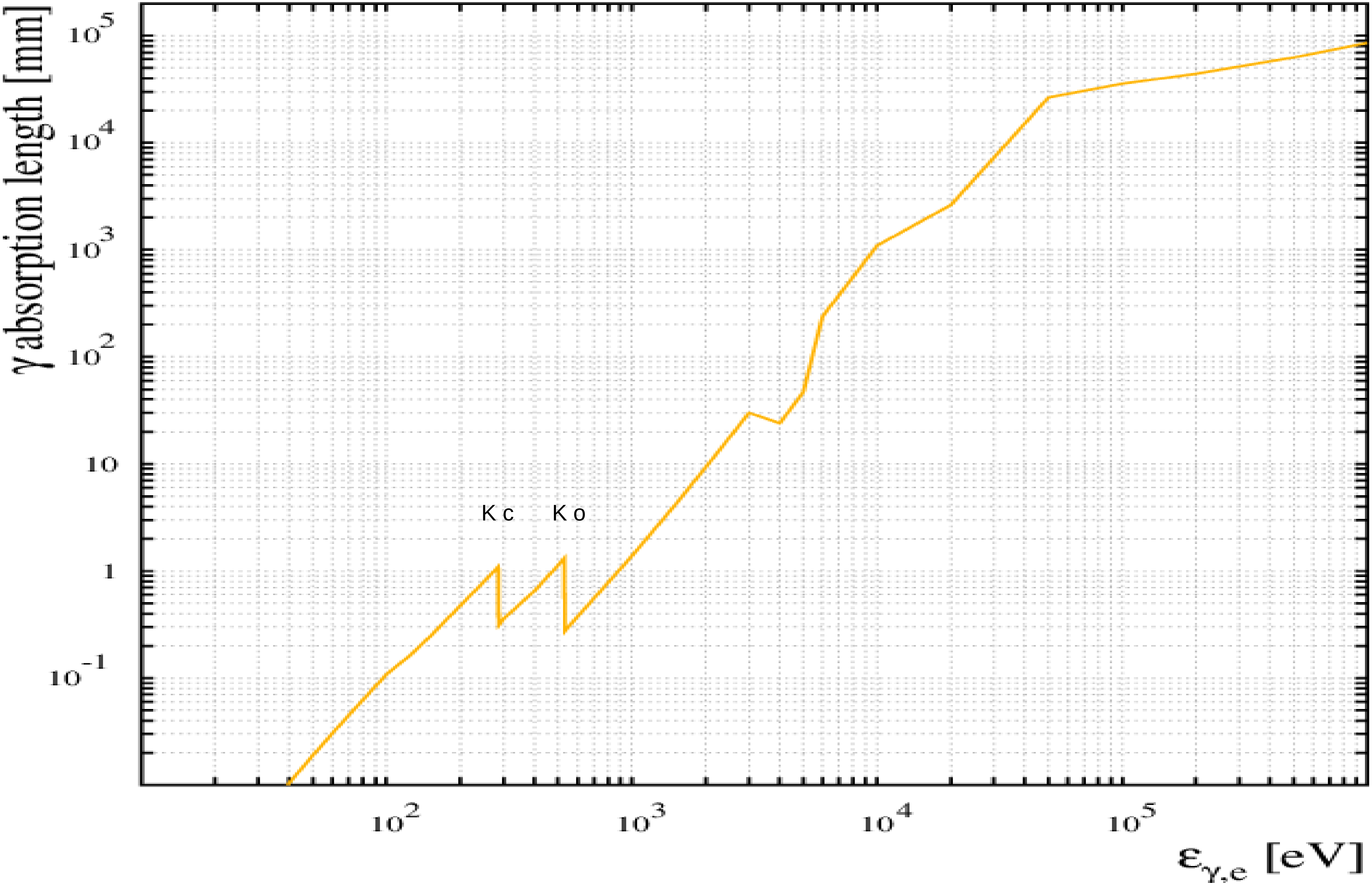
Dashed Lines : x rays   Solid Lines : electrons   Red : excitation   Yellow : ionisation



CO2

There may be problem in
data base > 3kev photon
Absorption length

Photon interaction length 20 C 1 Bar



Charged particle simulation

Program calculates: de/dx , primary cluster density and cluster size distribution
option to output raw thermalised cluster space and time points.

The program uses the Opal Beaty parameterisation for the primary/secondary ionisation energy splitting. J.Chem. Phys. 55(1971)4100

However the Opal Beaty parameters were originally applied assuming a single ionisation level. The program uses multiple ionisation levels and the parameterisation has been modified to accommodate the many levels.

We compare the results with the de/dx from ESTAR and the recent analysis by Groom with more modern oscillator strengths

The conclusion is that the ESTAR de/dx are low by between 10 and 18% , the Groom values are in better agreement with calculation.

The cluster size distribution is sensitive to the energy splitting..

The error in our calculation is in the range 5 to 8% limited by knowledge of the energy splitting. It may be possible to improve this to better than 4% if accurate values of the cluster size distribution are measured for the cluster sizes 1 2 3 and 4.

Opal Beaty

Used probability of secondary energy ,Es as a function of primary energy Ep:

F(Es/Ep) = 1/(1+(Es/Eobty)**2)

where Eobty = constant * ionisation energy.

We now know the ionisation x-section for multiple levels and shells .

The formula to fit with multiple levels is now the above function weighted with the shell x-sections.

In the program we assume a constant common to all the ionisation energies and so have only the one parameter in the fit.

The cluster size distribution for mips. Is very sensitive to the splitting function.

The constraint on the cluster sizes from Fiscle et al NIM A3011991)202 along with a constraint to agree with de/dx from Groom is used to fix the constant Eobty. However a more direct and accurate route would be to fit the Opal Beaty secondary electron distributions (published in Nuclear Data Tables).

Charged particle track cluster size distribution for Noble gases

Cluster Size	He	Ne	Ar	Kr	Xe
1	81	68.8	67.8	64.4	57.4
2	10.2	15.3	13.7	14.5	16.4
3	3.25	5.41	4.88	6.02	8.79
4	1.56	2.64	2.27	3.25	4.65
5	0.89	1.54	1.28	2.01	2.62
6	0.569	1	0.813	1.32	1.62
7	0.397	0.718	0.568	0.968	1.06
8	0.294	0.547	0.466	0.76	0.791
9	0.231	0.396	0.532	0.652	0.578
10	0.184	0.311	0.681	0.538	0.448
11	0.153	0.252	0.804	0.477	0.367
12	0.119	0.206	0.781	0.419	0.297
13	0.103	0.173	0.682	0.384	0.255
14	0.084	0.155	0.563	0.321	0.204
15	0.076	0.13	0.455	0.271	0.177
16	0.067	0.116	0.379	0.251	0.148
17	0.055	0.1	0.315	0.22	0.143
18	0.044	0.091	0.265	0.194	0.117
19	0.042	0.081	0.217	0.173	0.094
20	0.038	0.072	0.185	0.147	0.09
21		0.073			
22		0.075			
23		0.08			
24		0.08			
25		0.074			
26		0.071			
>20	0.665	1.97	2.3	2.71	3.8
Shell		K	L3,L2,L1	M5 to M1	N1

Charged particle track cluster size distribution for molecular gases

Cluster size	CF4	CH4	C4H10	CO2	N2	H2
1	67.2	82.3	79.9	78.2	80.2	83.9
2	15.7	9.18	9.72	10.88	9.37	8.65
3	5.63	2.82	3.45	3.5	3.07	2.68
4	2.72	1.34	1.65	1.68	1.53	1.25
5	1.66	0.758	0.939	0.98	0.9	0.75
6	1.08	0.473	0.598	0.616	0.6	0.506
7	0.75	0.322	0.404	0.43	0.4	0.353
8	0.548	0.239	0.299	0.317	0.3	0.255
9	0.436	0.189	0.222	0.265	0.247	0.202
10	0.344	0.168	0.189	0.243	0.205	0.157
11	0.299	0.16	0.161	0.212	0.19	0.126
12	0.259	0.162	0.147	0.177	0.191	0.105
13	0.22	0.161	0.148	0.161	0.201	0.088
14	0.184	0.139	0.146	0.137	0.199	0.078
15	0.161	0.135	0.144	0.129	0.196	0.064
16	0.139	0.118	0.132	0.117	0.164	0.062
17	0.129	0.109	0.126	0.11	0.158	0.054
18	0.118	0.09	0.111	0.103	0.141	0.044
19	0.096	0.081	0.095	0.102	0.119	0.045
20	0.091	0.076	0.089	0.099	0.11	0.035
>20	2.24	0.99	1.29	1.62	1.46	0.6
Shell	C K	C K	C K	C K O K	N K	

Helium De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	5.627	3.982	3.248	3.025	3.107	3.315	
De/Dx elastic	0.05822	0.0425	0.03649	0.03834	0.04073	0.04331	0.04436
De/Dx exc	58.38	41.56	34.13	32.1	33.34	35.99	39.08
De/Dx ion	477.3	353.1	300.1	291.2	309	339.3	373
De/Dx brem	0.2306	0.3077	0.4429	0.9189	2.109	4.891	11.01
De/Dx tot	536	395	334.7	324.2	344.5	380.2	423.1
De/Dx cut(9kev)	418.2	296	241.4	224.7	230.8	246.3	264.7
% pass cut	99.8	99.8	99.8	99.8	99.8	99.8	99.8

Minimum ionising (without brem) : Estar =295.7
Groom =322.2
Degrad =323.3

Neon De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	19.08	13.56	11.1	10.43	10.72	11.49	12.4
De/Dx elastic	0.2692	0.1988	0.1714	0.1729	0.1963	0.2127	0.2195
De/Dx exc	40.69	28.96	23.77	22.35	23.19	25	27.12
De/Dx ion	2251	1693	1462	1444	1558	1737	1936
De/Dx brem	5.686	7.102	9.499	18.37	39.98	89.08	194.2
De/Dx tot	2297	1729	1496	1485	1621	1851	2157
De/Dx cut(9kev)	1896	1352	1111	1043	1080	1161	1256
% pass cut	99.1	99	99	99	99	99	99

Minimum ionising (without brem) : Estar =1313
Groom =1446
Degrad =1467

Argon De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	42.73	30.28	24.72	23.05	23.71	25.33	27.25
De/Dx elastic	0.4175	0.3965	0.2717	0.2896	0.2891	0.3012	0.3062
De/Dx exc	123.6	87.99	72.24	67.85	70.31	75.69	81.97
De/Dx ion	4278	3216	2770	2736	2948	3288	3667
De/Dx brem	19.42	24.01	31.24	58.92	125.3	275.3	592
De/Dx tot	4422	3328	2874	2863	3144	3639	4342
De/Dx cut(9kev)	3635	2598	2137	2013	2087	2248	2435
% pass cut	97.3	97.2	97.1	97	97	97.1	97.1

Minimum ionising (without brem) : Estar = 2297
Groom = 2452
Degrad = 2805

Krypton De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	56.75	40.15	32.74	30.46	31.27	33.36	35.84
De/Dx elastic	0.7887	0.6052	0.5375	0.5239	0.5667	0.587	0.5849
De/Dx exc	161.3	114.7	94.12	88.31	91.41	98.3	106.4
De/Dx ion	6736	5152	4510	4516	4929	5560	6265
De/Dx brem	84.24	104.9	133.8	243	495.9	1059	2226
De/Dx tot	6982	5373	4739	4848	5517	6718	8598
De/Dx cut(9kev)	5255	3744	3071	2879	2975	3194	3451
% pass cut	87	86.8	86.7	86.6	86.6	86.6	86.6

Minimum ionising (without brem)   :   Estar   = 4254
Groom = 4731
Degrad = 4605

Xenon De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	80.63	57.76	47.71	45.08	46.93	50.72	55.1
De/Dx elastic	1.149	0.8908	0.8055	0.7936	0.8433	0.9064	0.971
De/Dx exc	244	174.1	142.7	133.2	137.9	148.1	160.1
De/Dx ion	10110	7822	6928	7030	7761	8848	10070
De/Dx brem	91.75	163.2	279	565.2	1153	2394	4926
De/Dx tot	10450	8160	7350	7729	9653	11390	15160
De/Dx cut(9kev)	7890	5699	4746	4524	4747	5167	5653
% pass cut	77.4	77.1	76.9	76.8	76.8	76.8	76.8

Minimum ionising (without brem) : Estar = 6146
Groom = 6882
Degrad = 7164

CF4 De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	101.1	71.02	57.48	52.99	53.94	57.07	60.82
De/Dx elastic	0.2206	0.1633	0.1404	0.1443	0.1714	0.1676	0.5777
De/Dx exc	282.8	198.6	160.7	148.1	150.8	159.5	170
De/Dx ion	9890	7385	6322	6186	6607	7301	8067
De/Dx brem	19.79	24.82	33.41	64.96	141.8	318.2	689
De/Dx tot	10190	7609	6516	6399	6900	7779	8927
De/Dx cut(9kev)	8283	5846	4752	4412	4516	4805	5146
% pass cut	98.9	98.9	98.8	98.8	98.8	98.8	98.8

Minimum ionising (without brem) : Groom =6382
Degrad =6334

CH4 De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	46.25	32.72	26.68	24.83	25.49	27.19	29.28
De/Dx elastic	0.1348	0.09859	0.08424	0.08531	0.08728	0.1022	0.1162
De/Dx exc	229	164.3	133.9	123.3	127.6	137.1	147.8
De/Dx ion	2700	1997	1695	1647	1750	1927	2123
De/Dx brem	2.251	2.89	3.992	7.968	17.8	40.61	89.13
De/Dx tot	2932	2164	1833	1778	1896	2105	2360
De/Dx cut(9kev)	2380	1687	1378	1286	1324	1416	1523
% pass cut	99.6	99.6	99.6	99.6	99.6	99.6	99.6

Minimum ionising (without brem) : Estar = 1479
Groom = 1613
Degrad = 1771

C4H10 De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	171.1	121.8	99.88	93.62	96.74	103.8	112
De/Dx elastic	0.1428	0.1046	0.0893	0.08957	0.09638	0.1131	0.1211
De/Dx exc	693.6	491.6	401.5	374.4	385.1	411.6	442.5
De/Dx ion	8918	6666	5710	5604	5999	6644	7345
De/Dx brem	2.619	3.401	4.767	9.654	21.78	50.1	110.6
De/Dx tot	9614	7161	6117	5988	6406	7106	7898
De/Dx cut(9kev)	7735	5501	4488	4212	4353	4675	5048
% pass cut	99.5	99.5	99.4	99.4	99.4	99.4	99.4

Minimum ionising (without brem)   :   Estar   = 5110
Groom = 5670
Degrad = 5978

CO2 De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	63.32	45.06	36.96	34.65	35.81	38.45	41.53
De/Dx elastic	0.2005	0.1471	0.1269	0.1264	0.136	0.1498	0.1121
De/Dx exc	437	319.7	241.4	219.4	218.2	226.5	237.7
De/Dx ion	4960	3734	3224	3189	3440	3837	4277
De/Dx brem	8.979	11.33	15.32	29.95	65.76	148.1	324.6
De/Dx tot	5406	4065	3481	3439	3724	4212	4840
De/Dx cut(9kev)	4198	2998	2467	2323	2409	2595	2812
% pass cut	98.9	98.9	98.8	98.8	98.8	98.8	98.8

Minimum ionising (without brem) : Estar = 3053
Groom = 3351
Degrad = 3409

N2 De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	41.06	29.04	23.67	22.02	22.6	24.11	25.87
De/Dx elastic	0.1898	0.139	0.1194	0.1201	0.1272	0.1381	0.1219
De/Dx exc	327.6	289	211.9	111.5	111.5	111.4	111.3
De/Dx ion	3356	2510	2154	2114	2266	2511	2780
De/Dx brem	5.481	6.924	9.388	11.4	40.52	91.26	198.9
De/Dx tot	3690	2806	2376	2244	2418	2714	3090
De/Dx cut(9kev)	2858	2032	1663	1556	1605	1720	1853
% pass cut	99.3	99.3	99.2	99.2	99.2	99.2	99.2

Minimum ionising (without brem) : Estar = 1947
Groom = 2127
Degrad = 2233

H2 De/Dx and primary cluster density

Energy Mev	0.15	0.3	0.6	1.3	2.6	5.2	10
Beta*Gamma	0.825	1.24	1.944	3.427	6.057	11.23	20.74
Np 1/cm	9.026	6.339	5.129	4.729	4.813	5.092	5.427
De/Dx elastic	0.05994	0.04319	0.0366	0.03616	0.03883	0.04384	0.04626
De/Dx exc	133.3	95.13	78.27	73.64	76.35	82.21	88.92
De/Dx ion	481.7	352.6	296.3	283.7	297.4	322.4	350.1
De/Dx brem	0.1261	0.1755	0.2659	0.5782	1.368	3.263	7.403
De/Dx tot	615.1	447.9	374.9	358	375.1	408	446.5
De/Dx cut(9kev)	426.3	299.5	242.2	223.3	227.3	240.5	256.3
% pass cut	98.9	99.9	99.9	99.9	99.9	99.9	99.9

Minimum ionising (without brem) : Estar = 317.4
Groom = 343.7
Degrad = 357.4

Upgrade schedule

1) Extend data base for particle track solution further into fermi plateau

   up to 100Mev , Beta*gamma=200 October 2014

2) Optimise Opal Beaty fit with constraints from Groom (de/dx)

   October 2014

3) Include more gases in degrad . 2015

4) Produce write up/guide for beginners

5) Possible student project :

   Find optimum Eobty by fiting formulae to Opal Beaty experimental data (in nuclear data tables) ?????

Conclusion

Program now works well for xrays , electron beams and beta decay

all relevant physical processes included.

Work remains to improve the energy splitting model , Opal beaty

or other models. With better energy splitting simulation it may be

possible to get 2% accuracy on de/dx.

Experimental measurements of 1,2,3 and 4 electron clusters may

allow better tuning of the energy splitting model.

Thanks to Rob Veenhof for coding some fast random number

generators for Compton scattering and Carlos Azevedo for

the patience to put up with constant upgrades and error fixes

during the debug cycle (60k lines of fortran)..