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ICTP-IAEA Joint Workshop on Nuclear Data for Science and Technology: Medical Applications

30 September - 4 October, 2013

Internal radionuclide therapy: Part II

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Internal radionuclide therapy: Part II (α, β, Auger therapy; dose quantification)

The wapons: particles ...
about their origin, character, and fate

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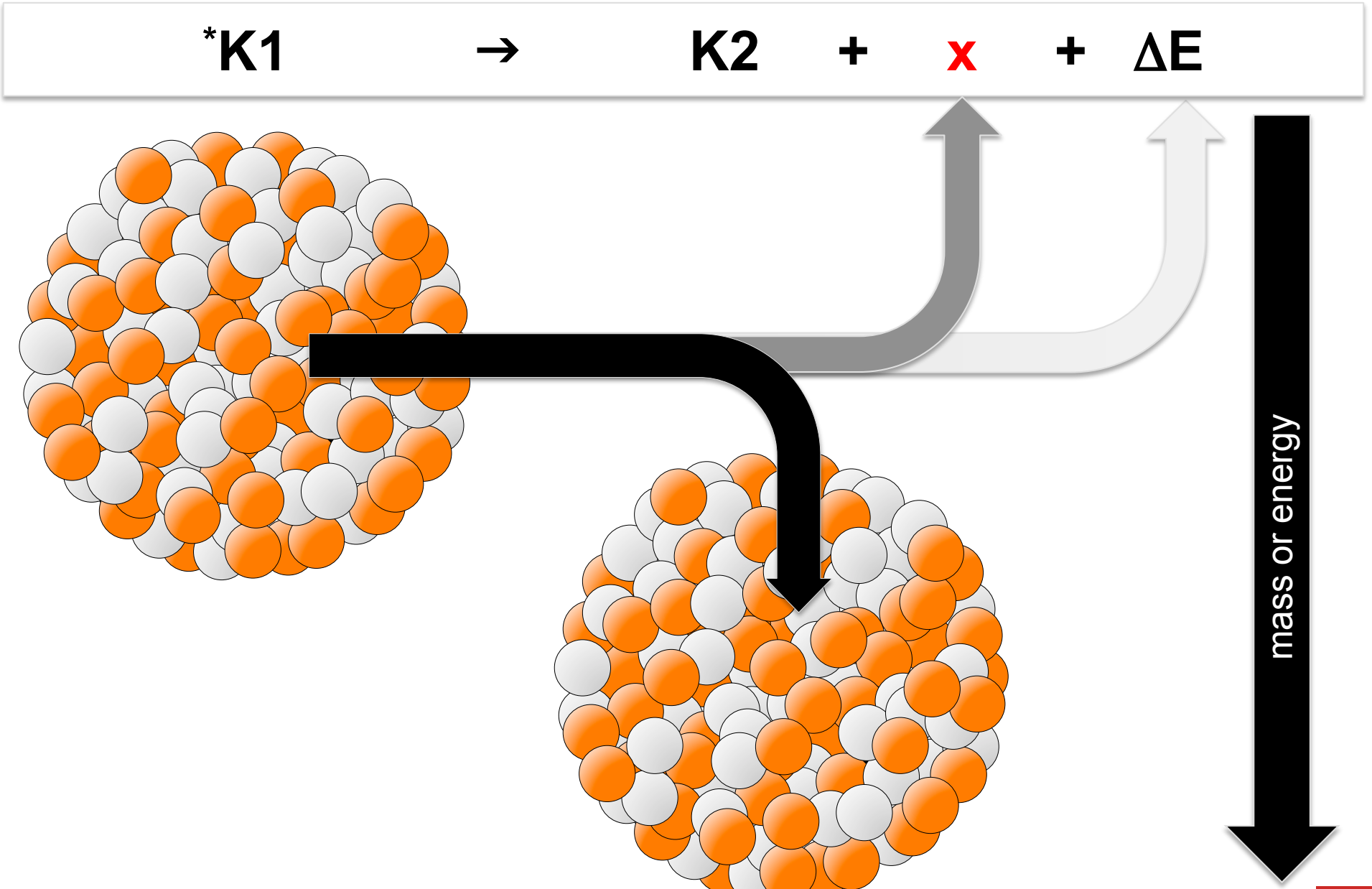
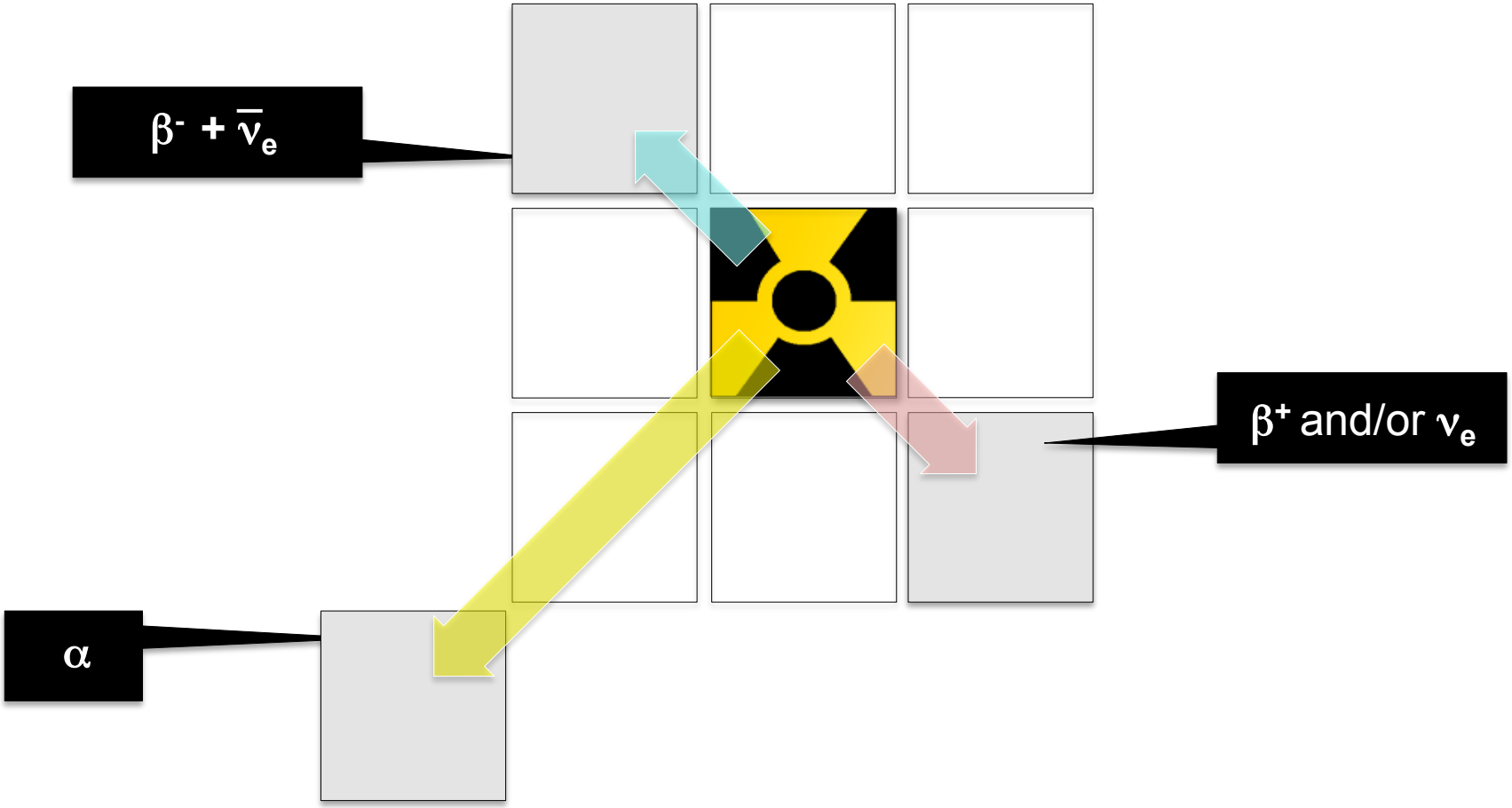
Workshop on Nuclear Data for Science and Technology: Medical Applications
30 September to 04 October 2013
Miramare – Trieste, Italy

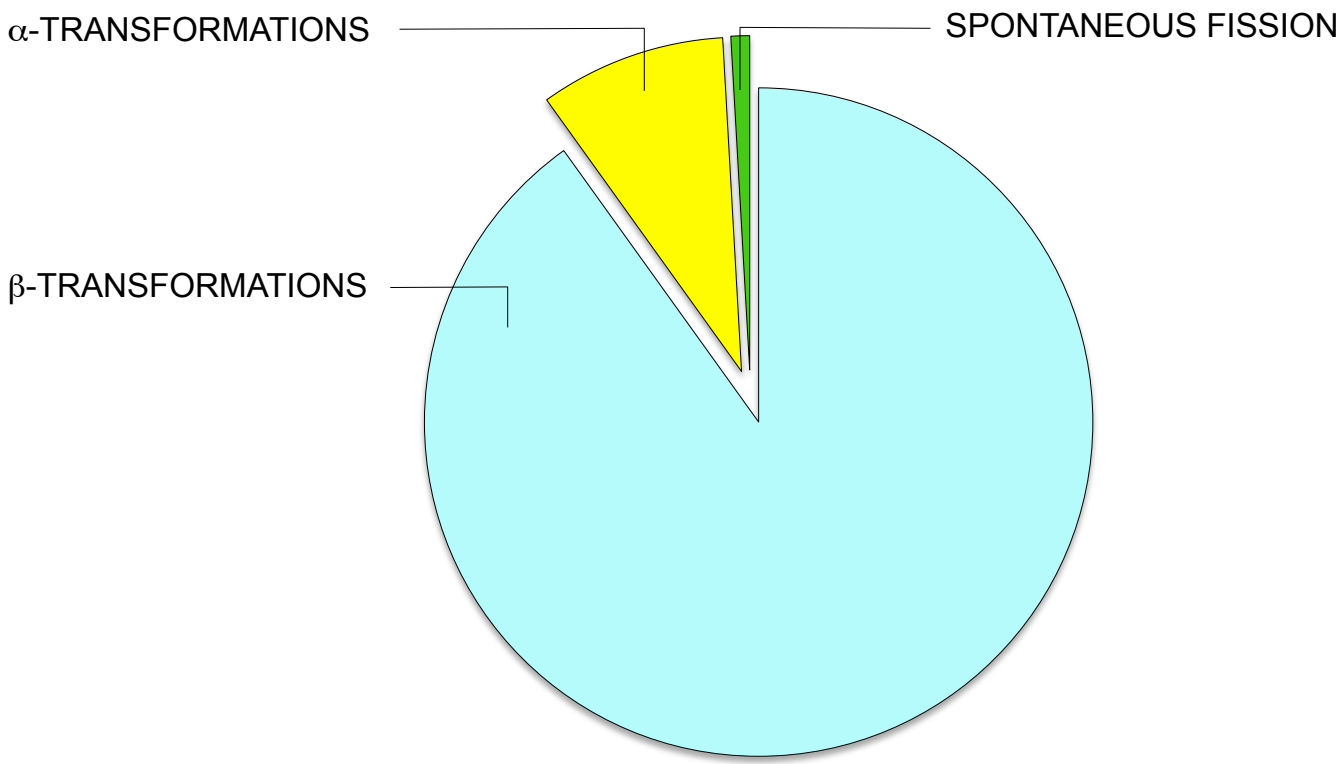
PRIMARY & SECONDARY TRANSFORMATIONS + POST-EFFECTS



PRIMARY TRANSFORMATIONS

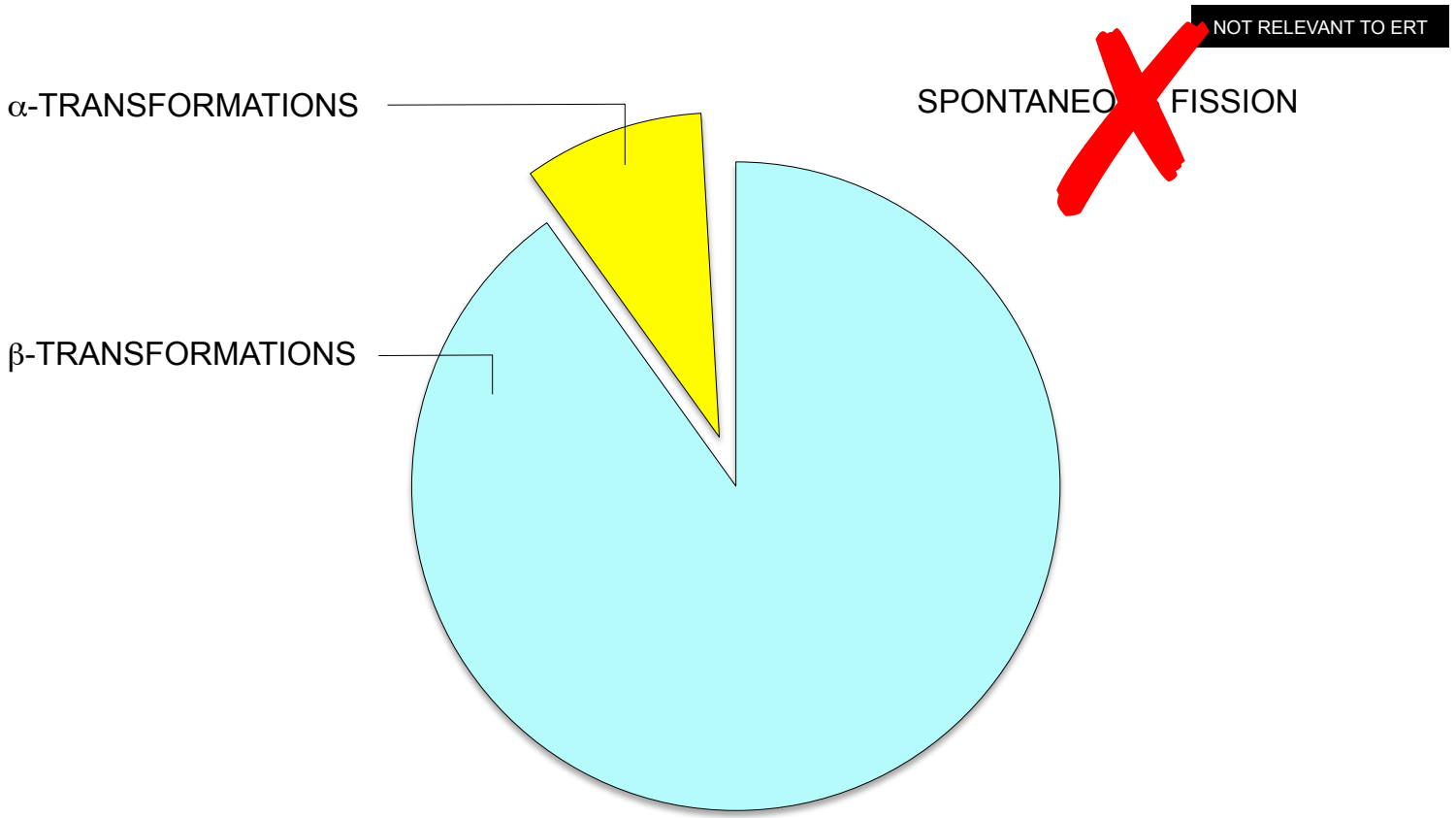


PRIMARY TRANSFORMATIONS



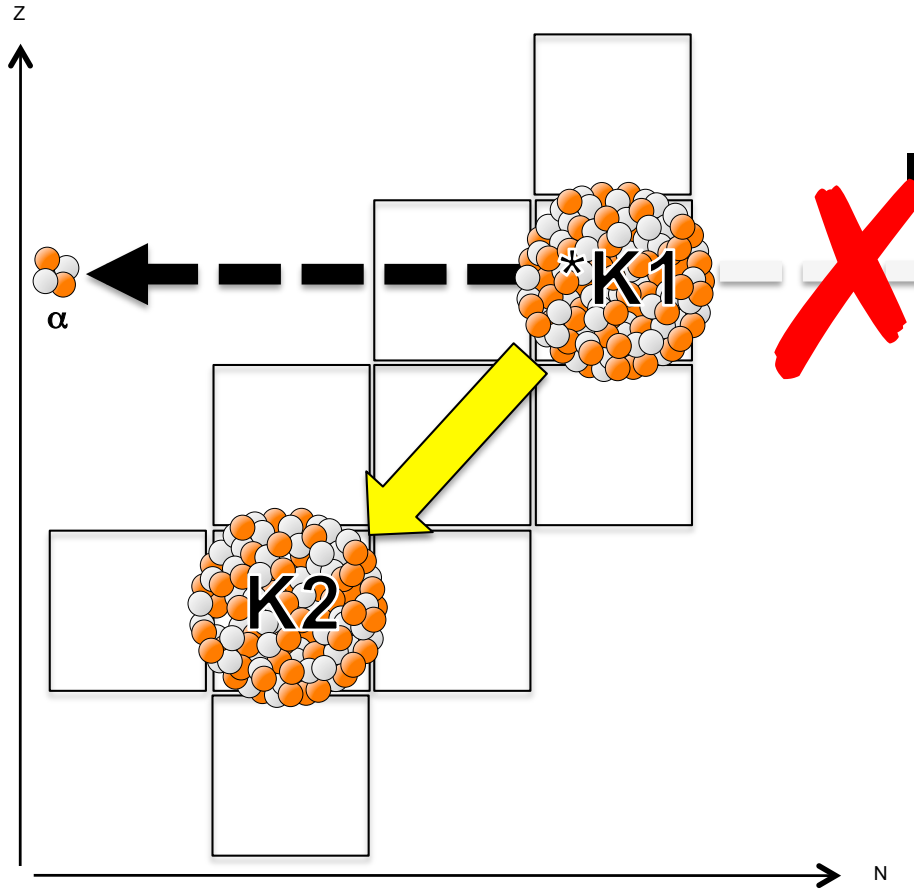
PRIMARY TRANSFORMATIONS

RELEVANT TO ENDORADINUCLIDE THERAPY



α PRIMARY TRANSFORMATIONS

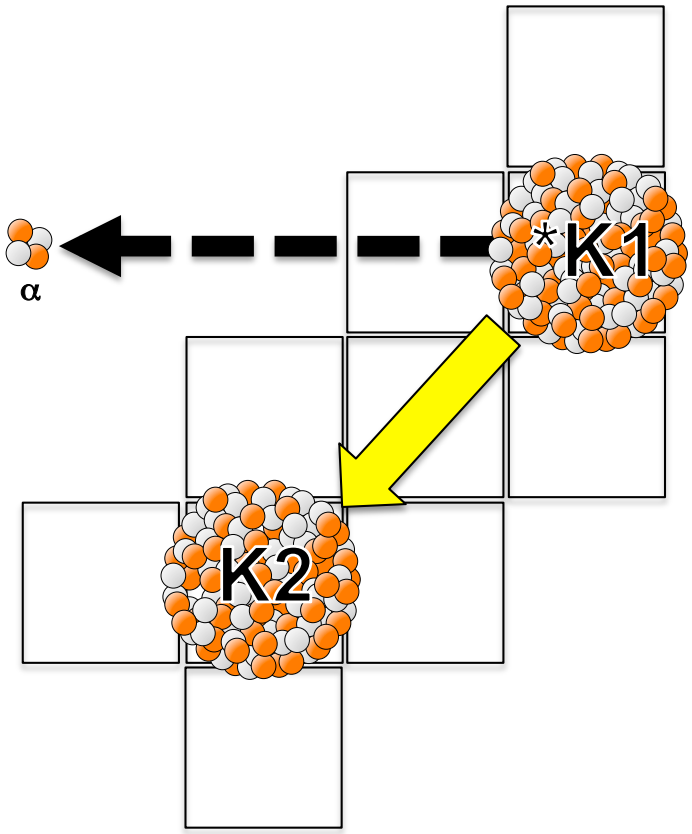
$$K1 \longrightarrow K2 + \alpha + \Delta E$$

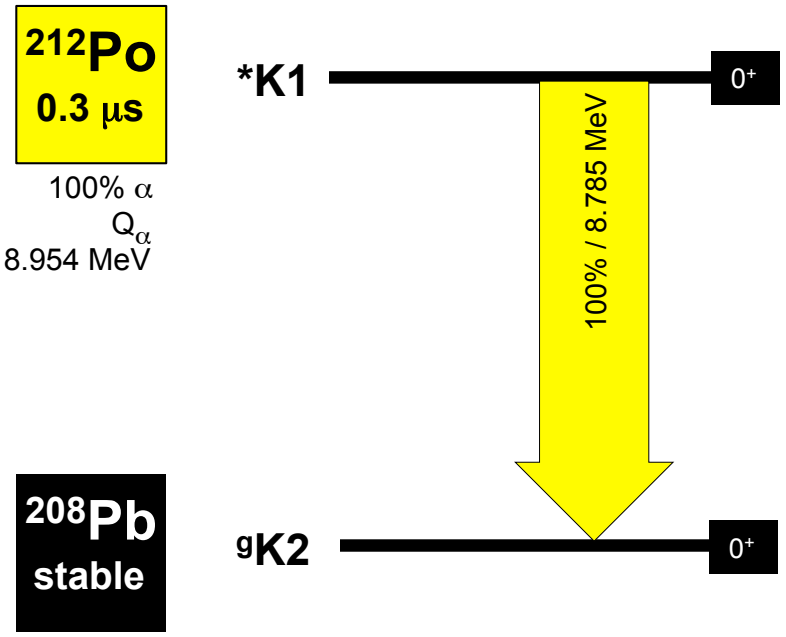


Q_α	$= \Delta E = \Delta m^{excess}{}_{*K1} - (\Delta m^{excess}{}_{K2} + \Delta m^{excess}{}_{\alpha})$	MeV
	= 47.3091 - (40.6140 + 2.4249) MeV	4.270
E_α	$= Q_\alpha / (1 + m_\alpha / m_{K2}) = 4.270$ MeV / 1 + 4/234)	4.198
	$= Q_\alpha (/ m_{K2} / m_{*K1}) = 4.270$ MeV (234/238)	
$^{RECOIL}E$ (^{234}Th)	$= Q_\alpha - E_\alpha$	
	= 4.270 MeV - 4.198 MeV	0.072

α PRIMARY TRANSFORMATIONS

$$K1 \longrightarrow K2 + \alpha + \Delta E$$





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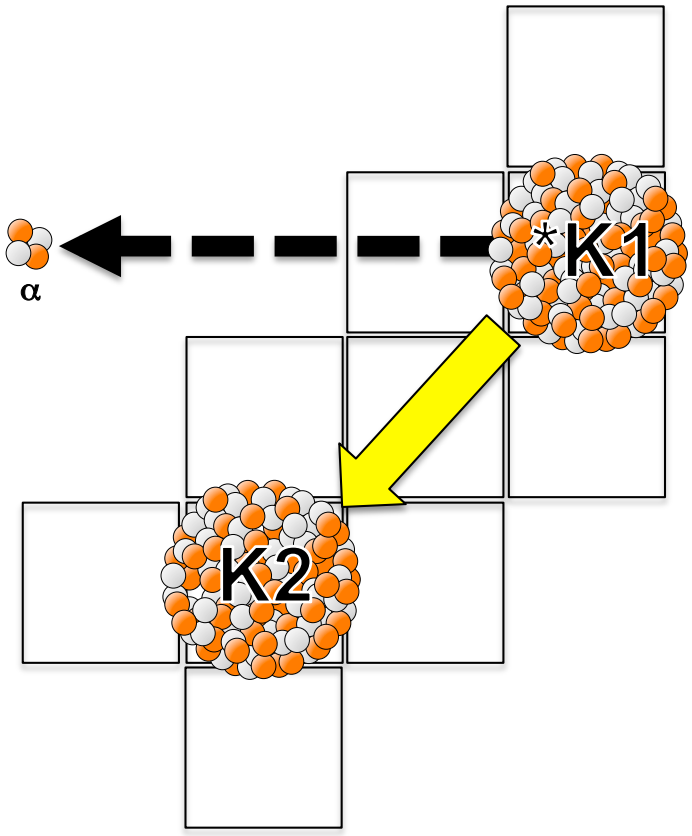

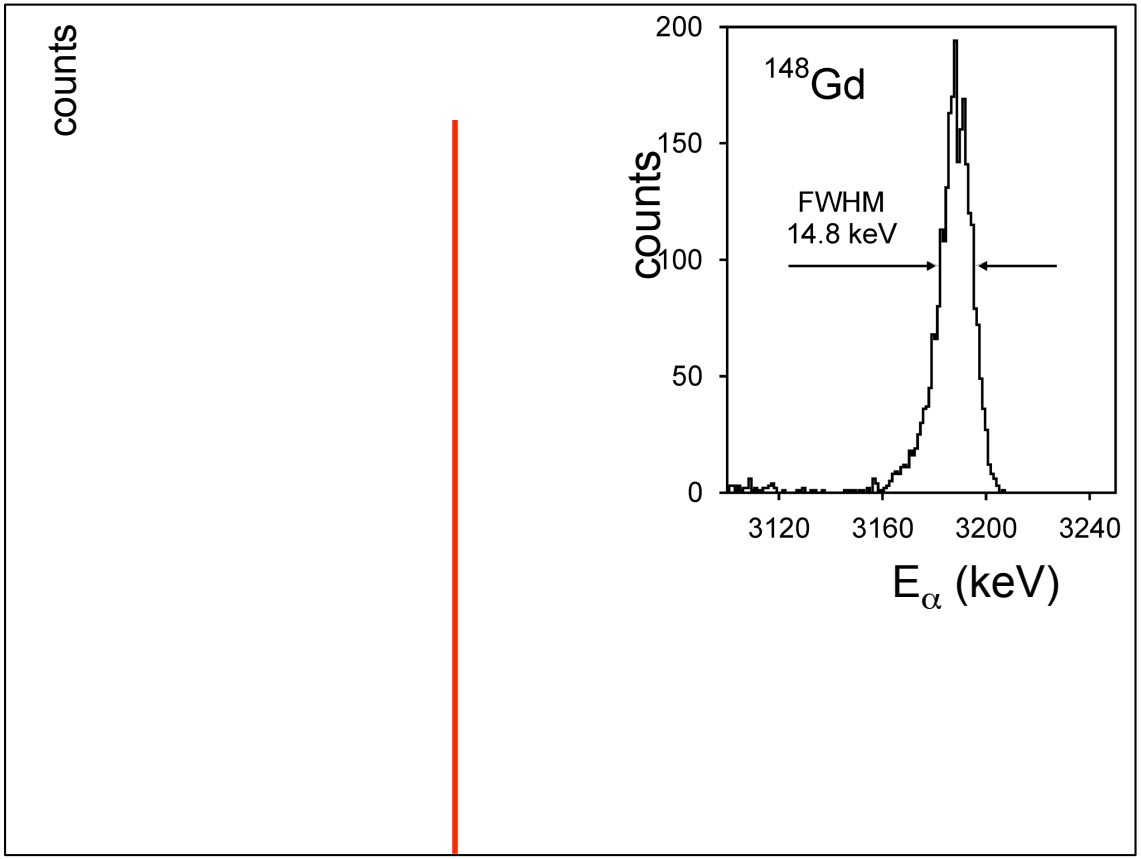

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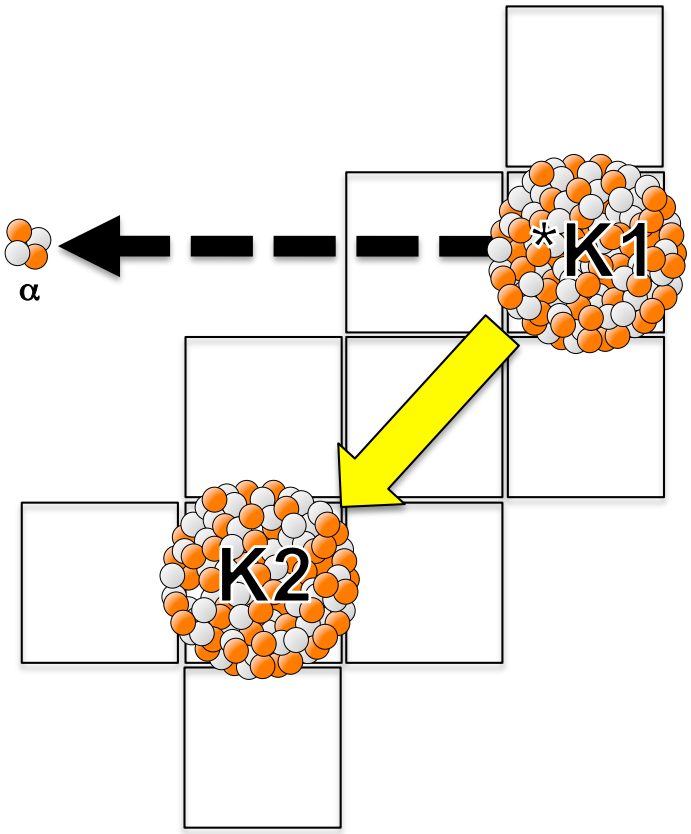

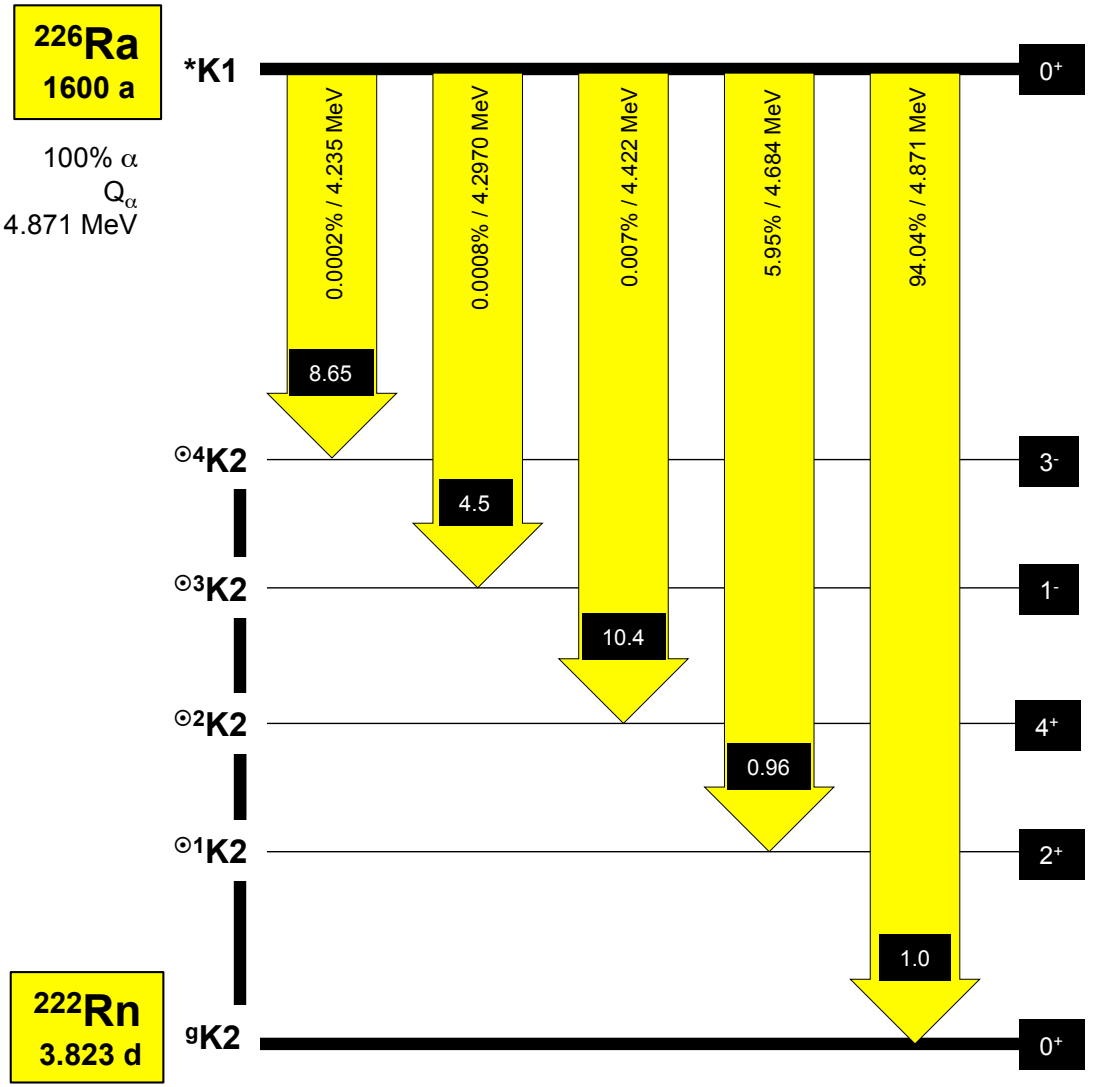

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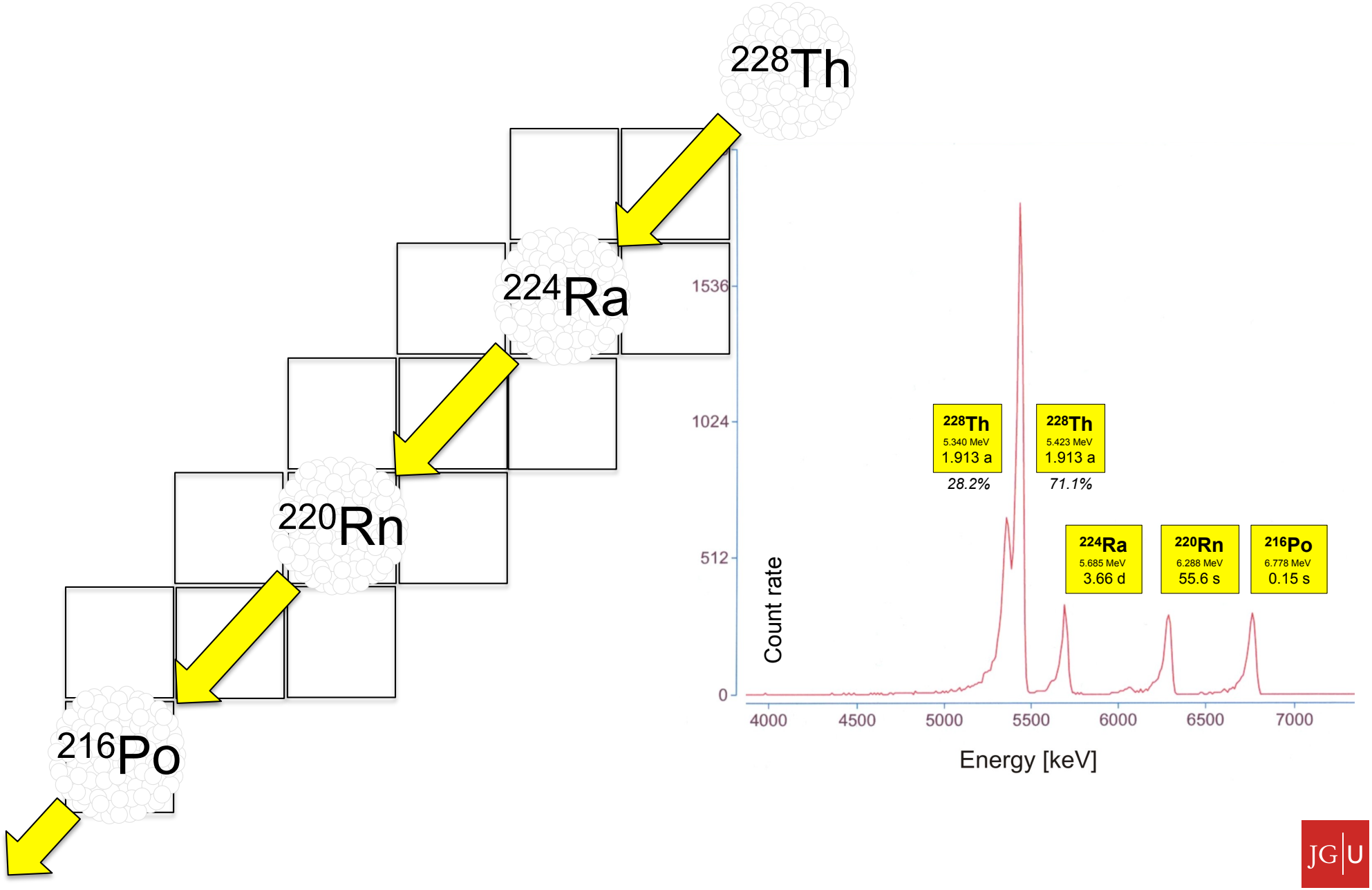


α PRIMARY TRANSFORMATIONS

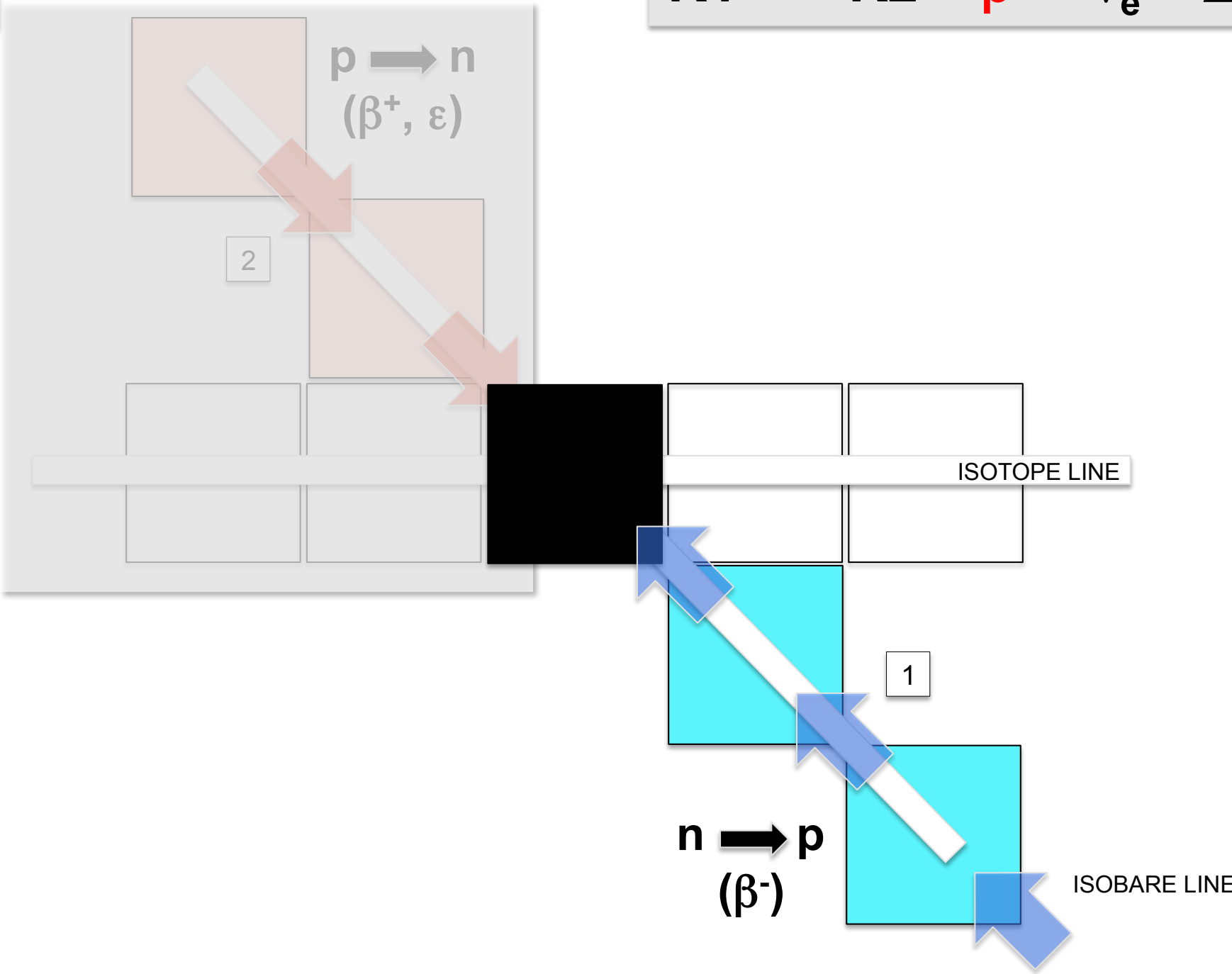
$$K1 \longrightarrow K2 + \alpha + \Delta E$$

Nuclide	t½	Production	E_α (MeV)
^{225}Ac	10 d	^{233}U-chain, ^{229}Th-chain, ^{226}Ra(p,2n)^{225}Ac	5.830, 5.793, 5.732, ...
^{224}Ra	3.66 d	^{228}Th	5.686, 5.449, ..
^{223}Ra	11.4 d	^{227}Ac-chain, ^{227}Th-chain, ^{226}Ra(n,γ)^{227}Ac	5.716, 5.607, ...
^{213}Bi	45.6 m	^{225}Ac-chain, ^{225}Ac/^{213}Bi-generator	5.87, ...
^{212}Bi	60 m	^{224}Ra-chain, ^{212}Bi/^{212}Pb-Generator	6.051, 6.090 ...
^{211}At	7.2 h	^{209}Bi(α,2n)^{211}At	5.867, ...
^{149}Tb	4.1 h	Ta(p,spall), ^{152}Gd(p,4n)^{149}Tb	3.49

JG|U

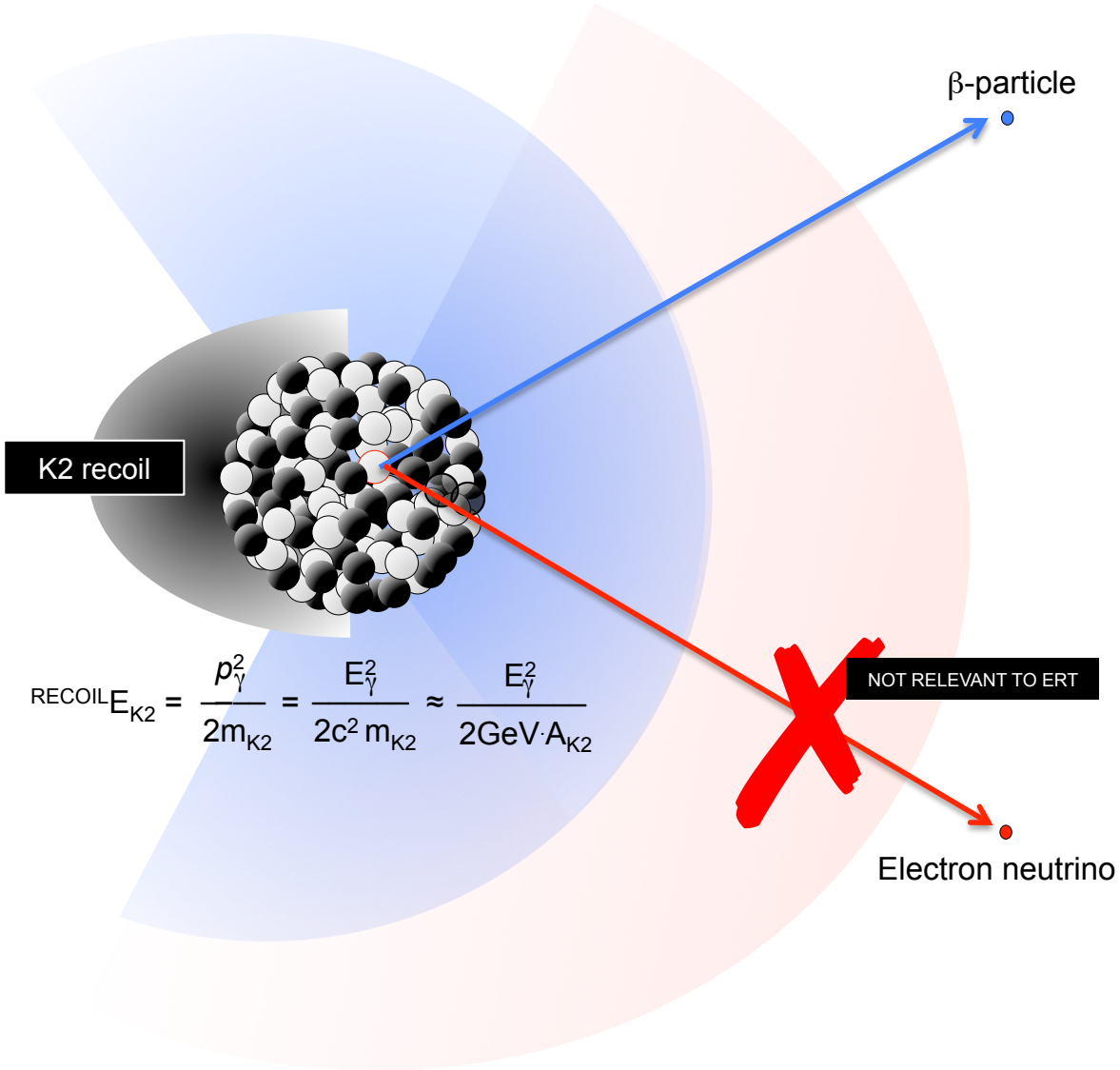
β⁻ PRIMARY TRANSFORMATIONS

$$K1 \longrightarrow K2 + \beta^- + \bar{\nu}_e + \Delta E$$



β- PRIMARY TRANSFORMATIONS

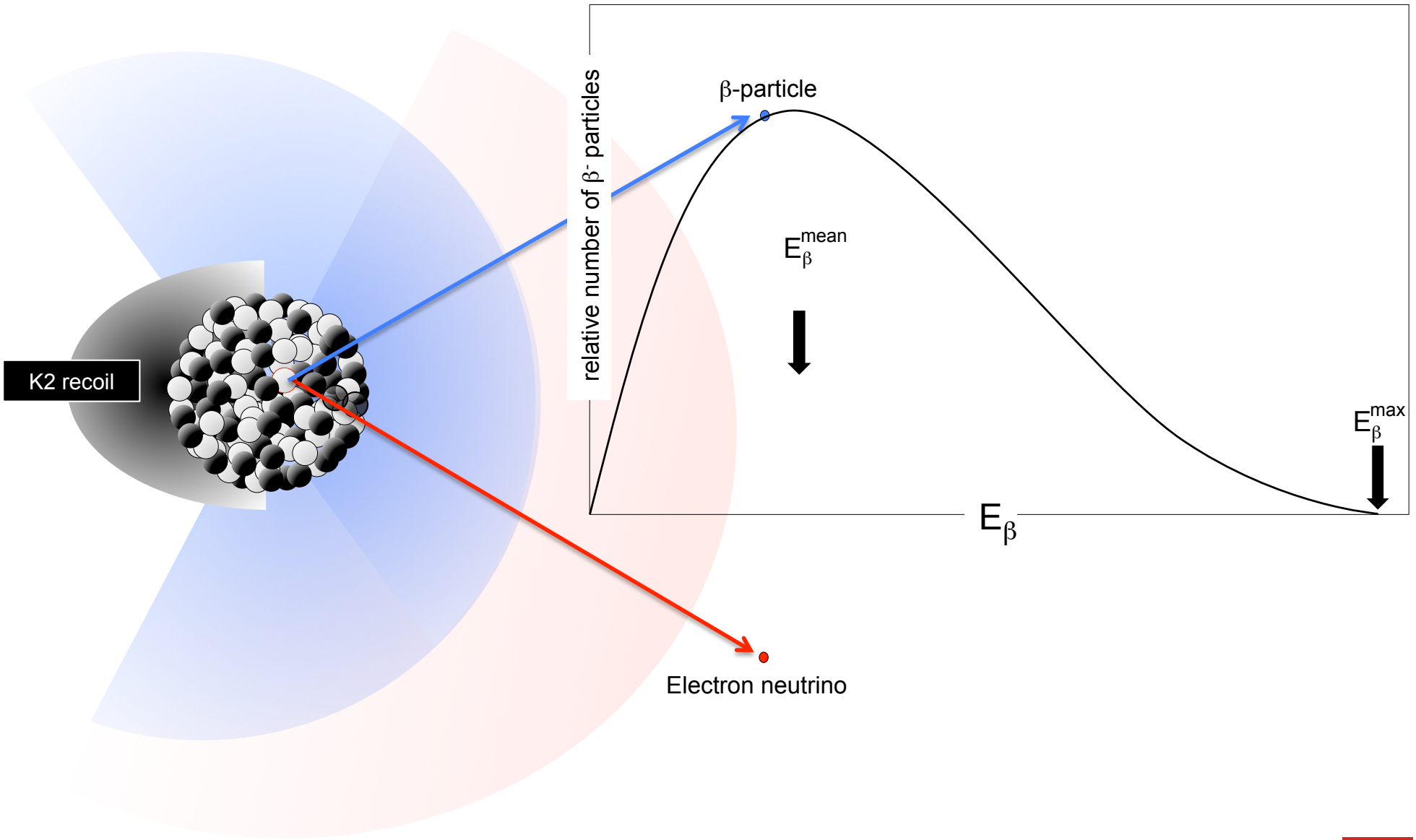
$$K1 \longrightarrow K2 + \beta^- + \bar{\nu}_e + \Delta E$$



$$^{RECOIL}E_{K2} = \frac{p_\gamma^2}{2m_{K2}} = \frac{E_\gamma^2}{2c^2\, m_{K2}} \approx \frac{E_\gamma^2}{2GeV \cdot A_{K2}}$$

β⁻ PRIMARY TRANSFORMATIONS

$$K1 \longrightarrow K2 + \beta^- + \bar{\nu}_e + \Delta E$$



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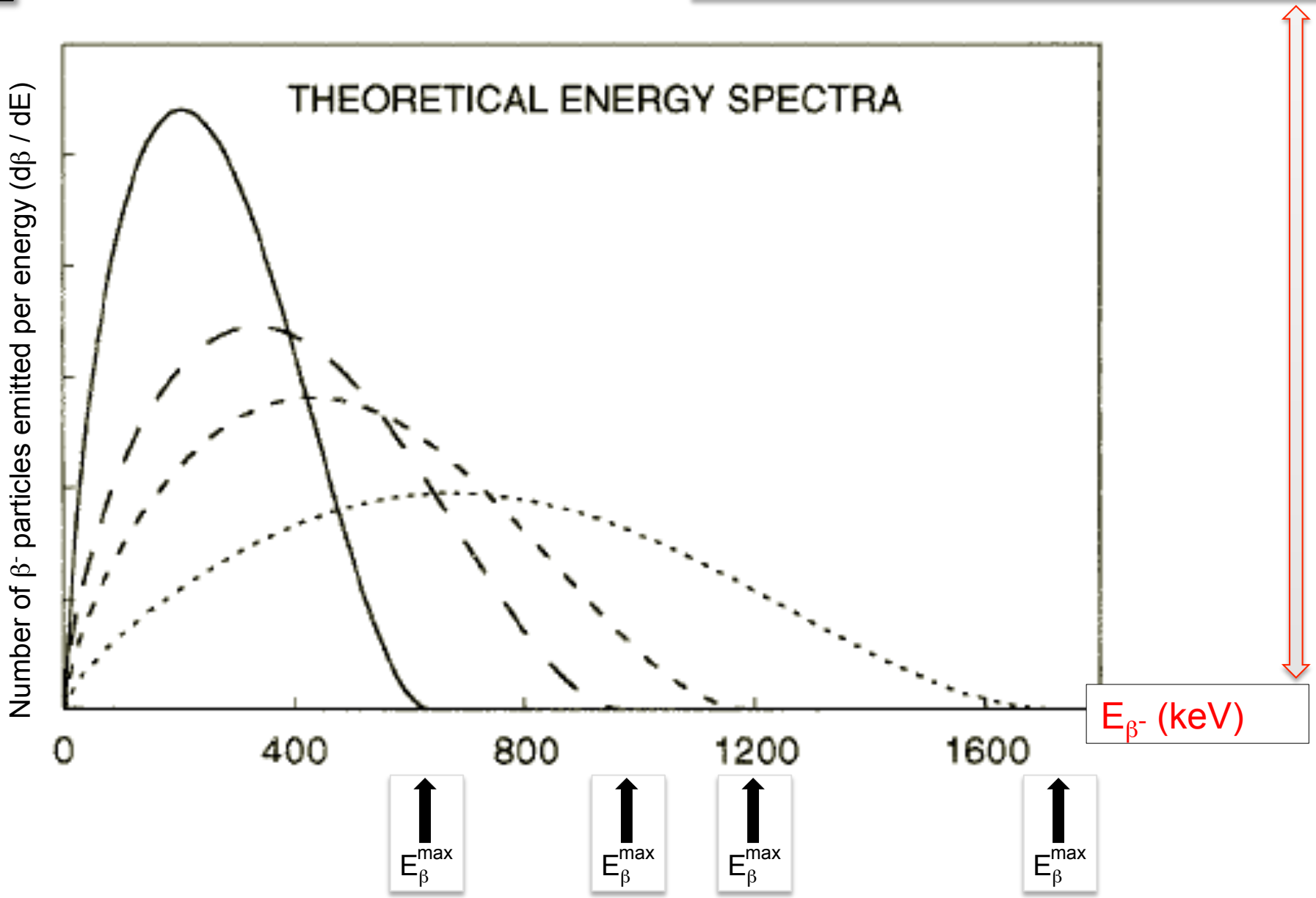
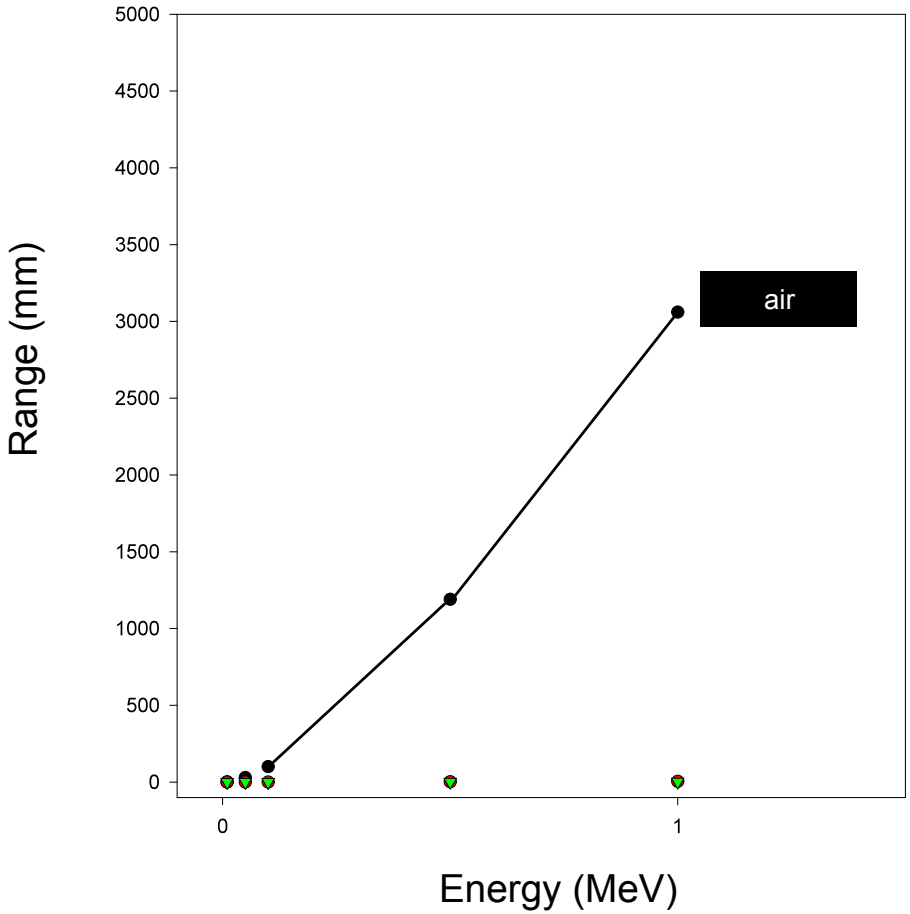
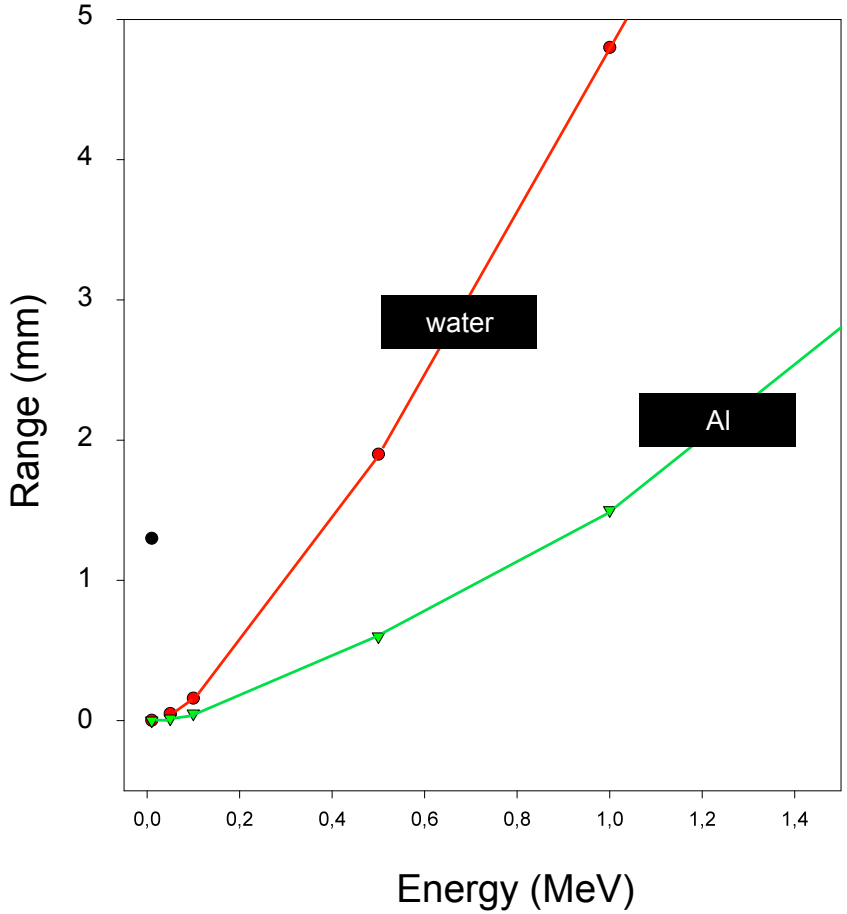


β- PRIMARY TRANSFORMATIONS

$$K1 \longrightarrow K2 + \beta^{-} + \bar{\nu}_e + \Delta E$$

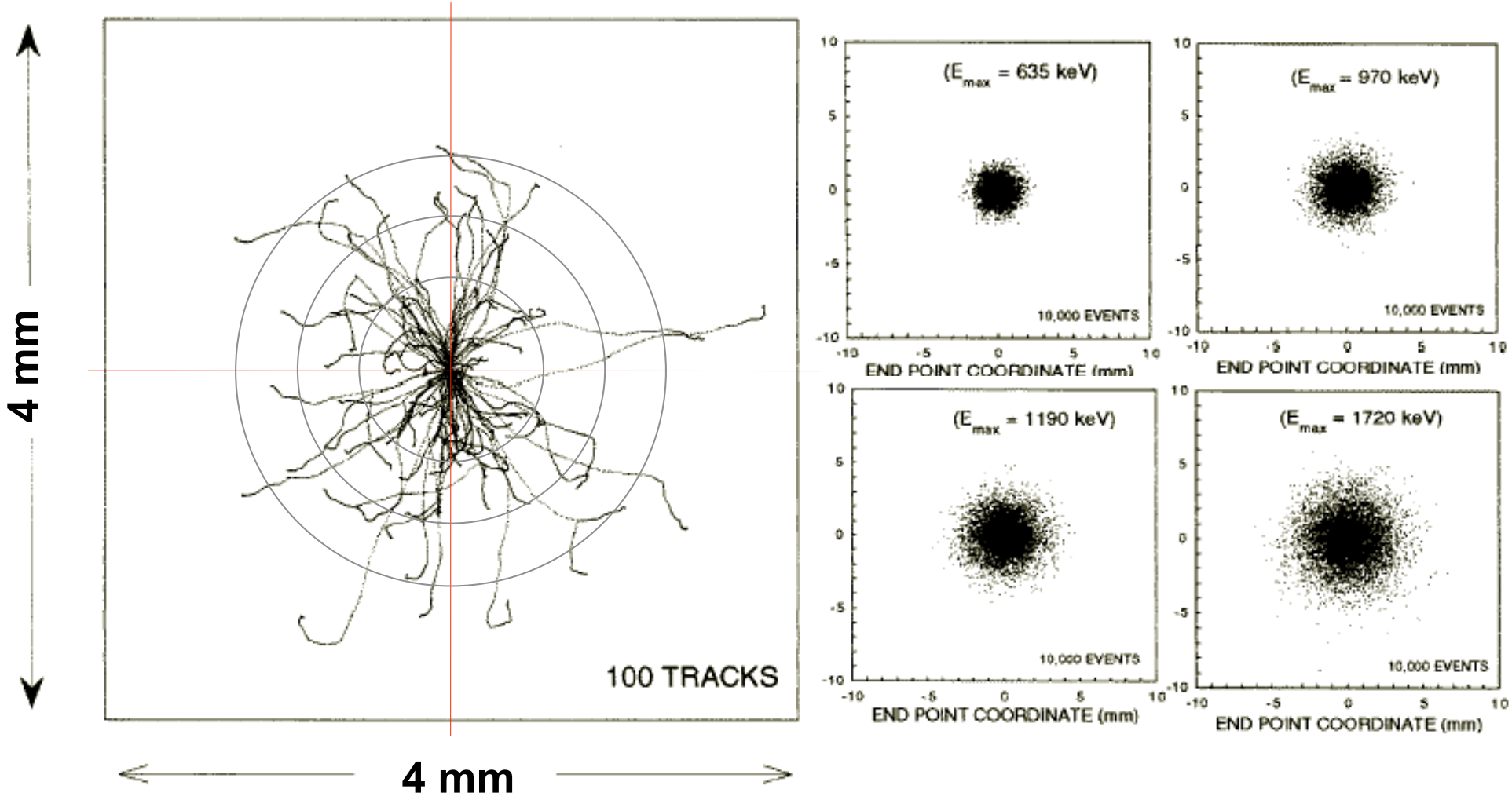
$E_\beta^{max\ (mean)}$ = 2.28 (0.9) MeV
Electron range (water) = 12 (5) mm





β- PRIMARY TRANSFORMATIONS

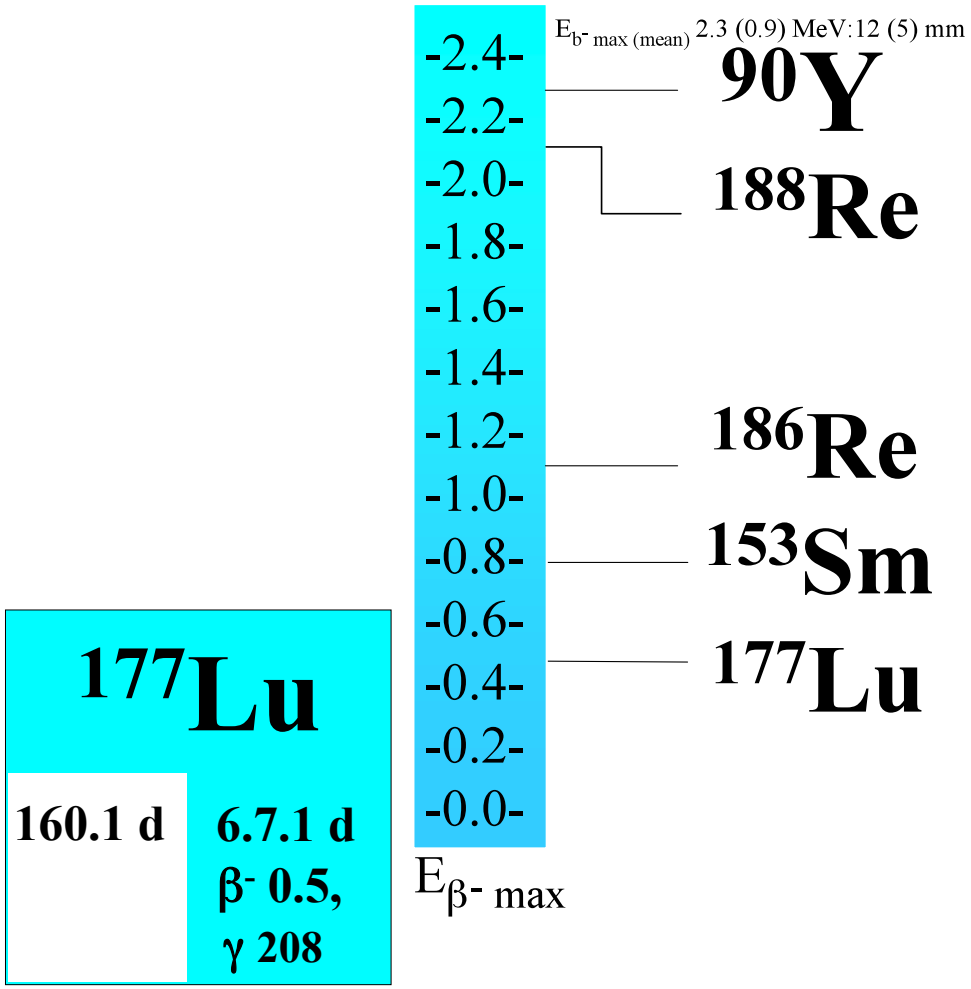
$$K1 \longrightarrow K2 + \beta^{-} + \bar{\nu}_e + \Delta E$$

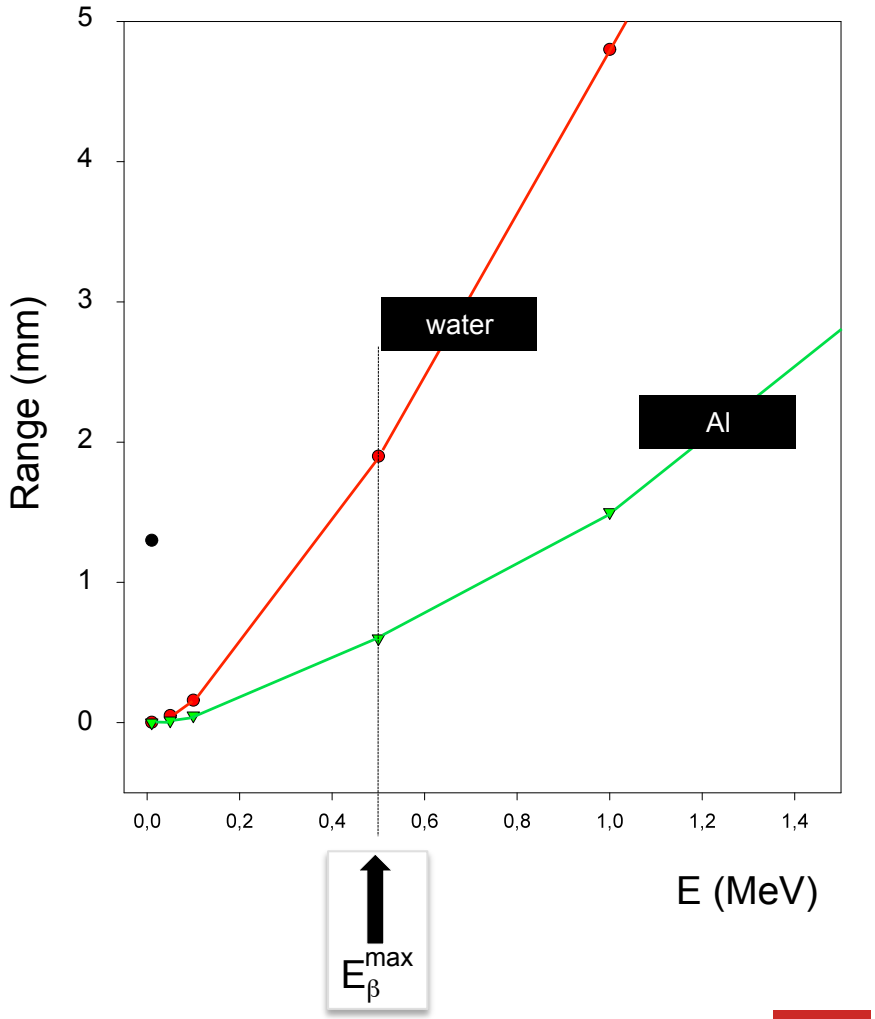


Craig S Levin and Edward J Hoffman,
Calculation of positron range and its effect on the fundamental limit of positron emission tomography system spatial resolution,
Phys. Med. Biol. 44 (1999) 781–799.

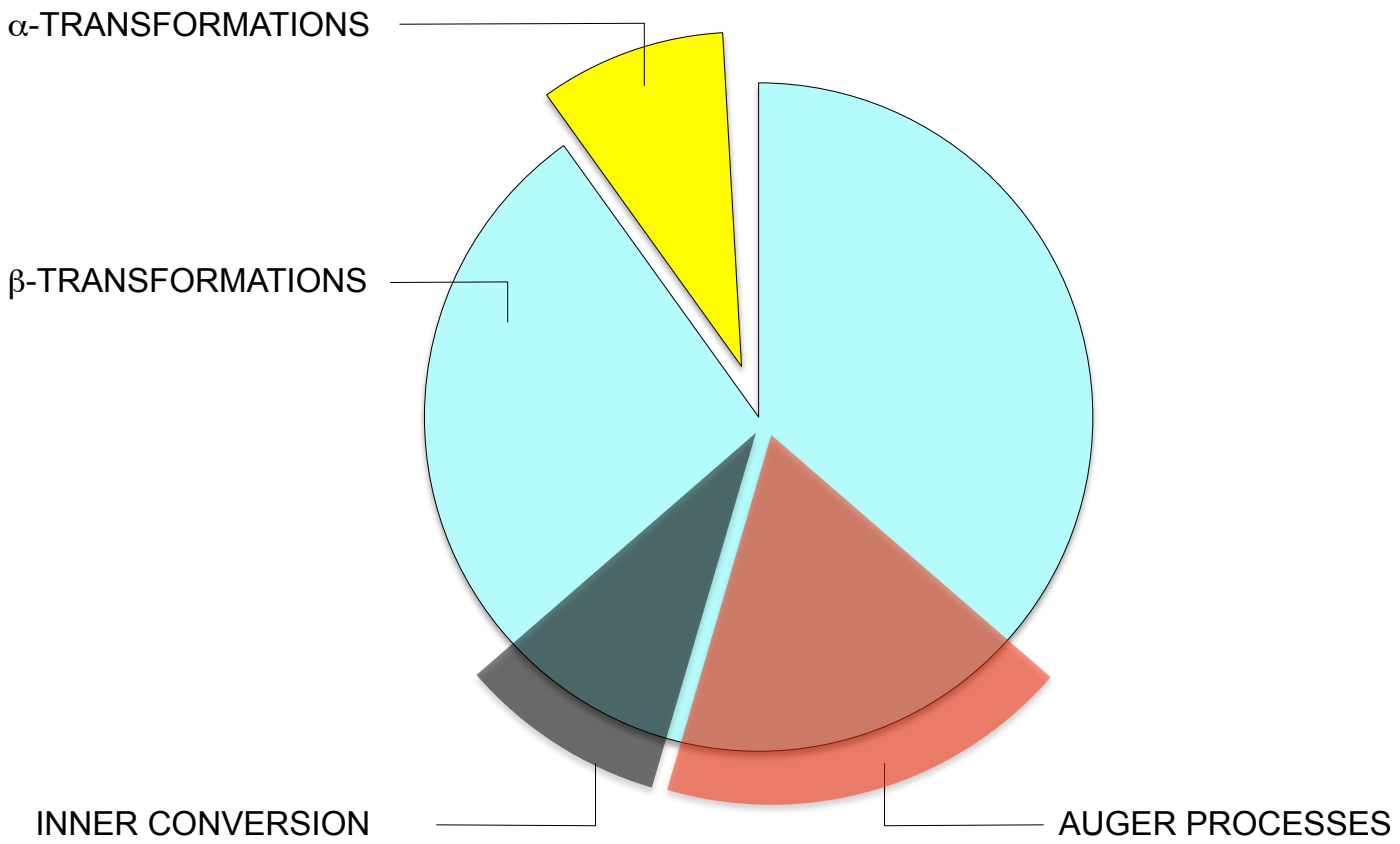
β- PRIMARY TRANSFORMATIONS

$$K1 \longrightarrow K2 + \beta^- + \bar{\nu}_e + \Delta E$$





ε PRIMARY & SECONDARY TRANSFORMATIONS + POST-EFFECTS



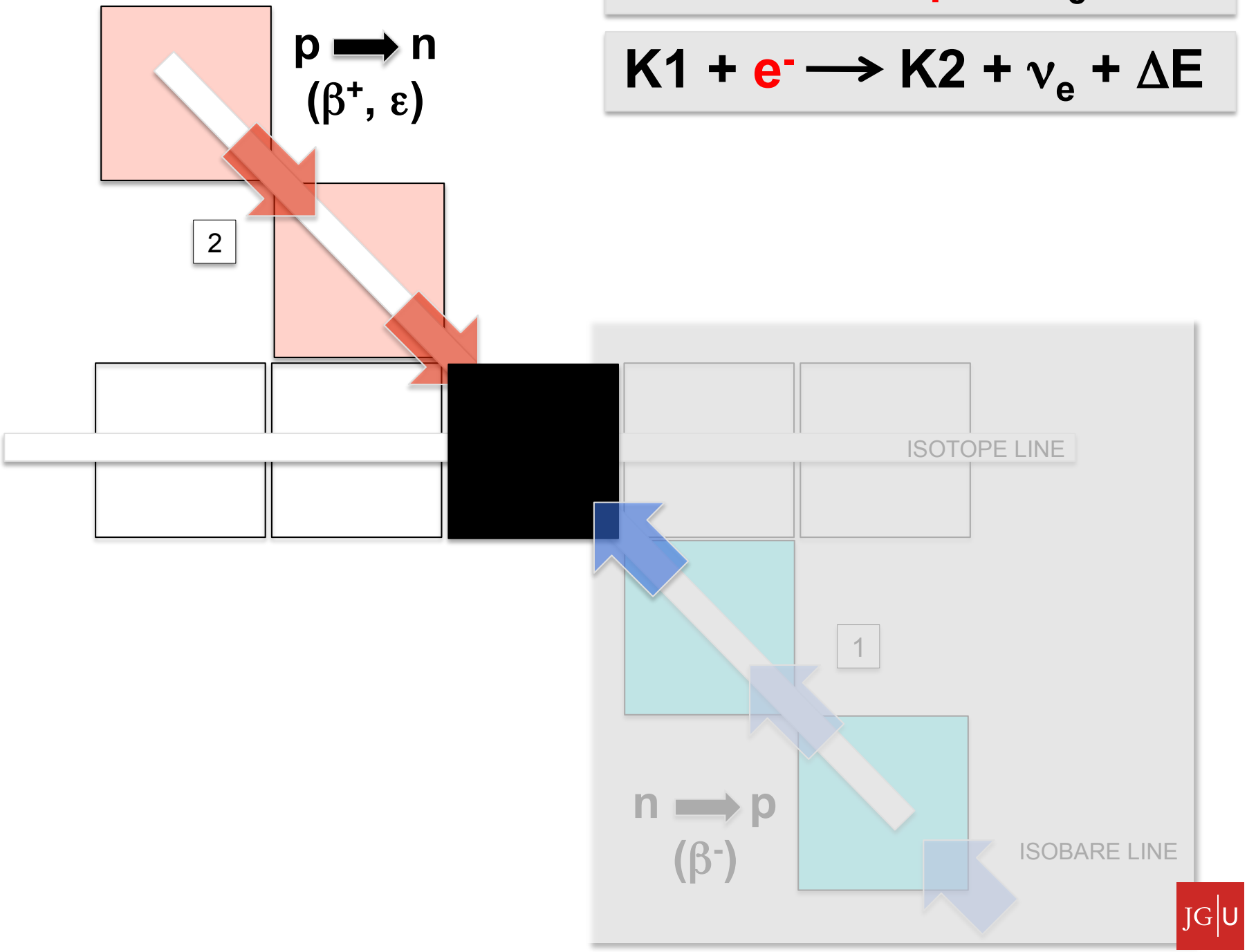
PRIMARY TRANSFORMATIONS

β^+

ε

$$K1 \longrightarrow K2 + \beta^+ + \nu_e + \Delta E$$

$$K1 + e^- \longrightarrow K2 + \nu_e + \Delta E$$

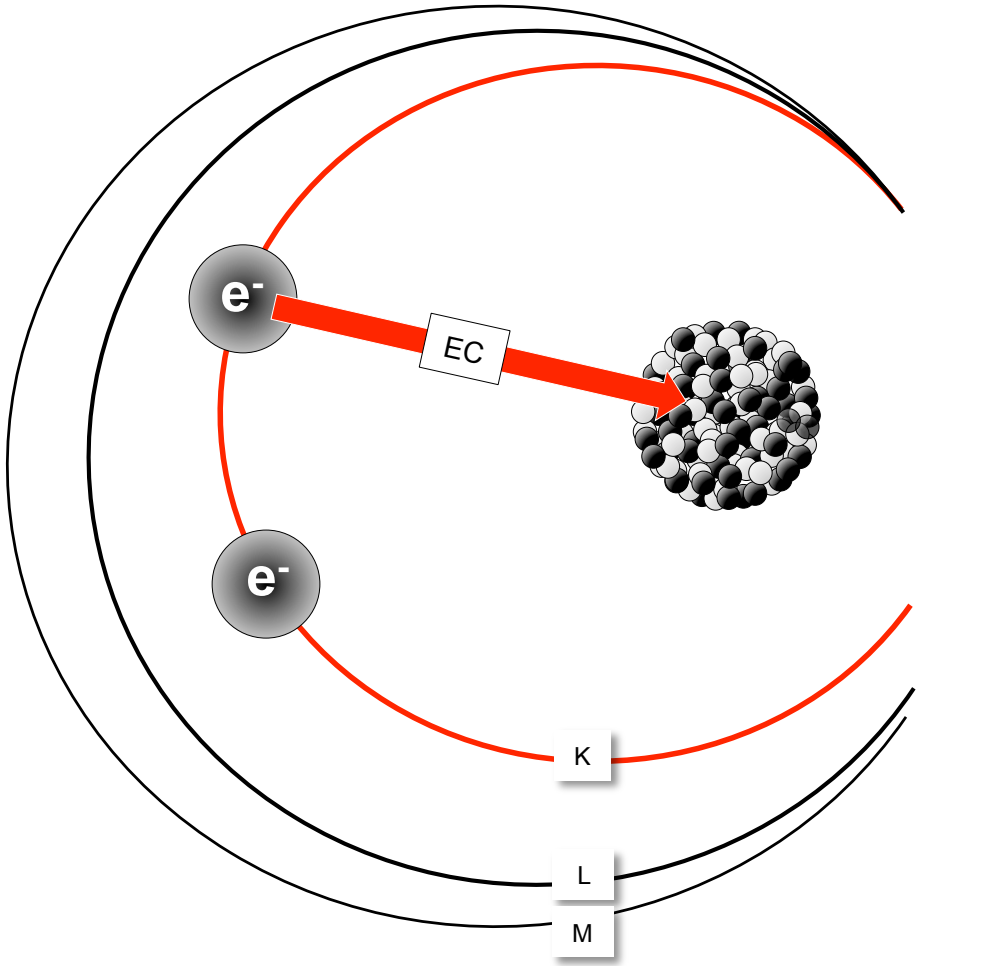


ε PRIMARY TRANSFORMATIONS AND POST-EFECTS

$$K1 + e^- \longrightarrow K2 + \nu_e + \Delta E$$

Electron capture …

KLM

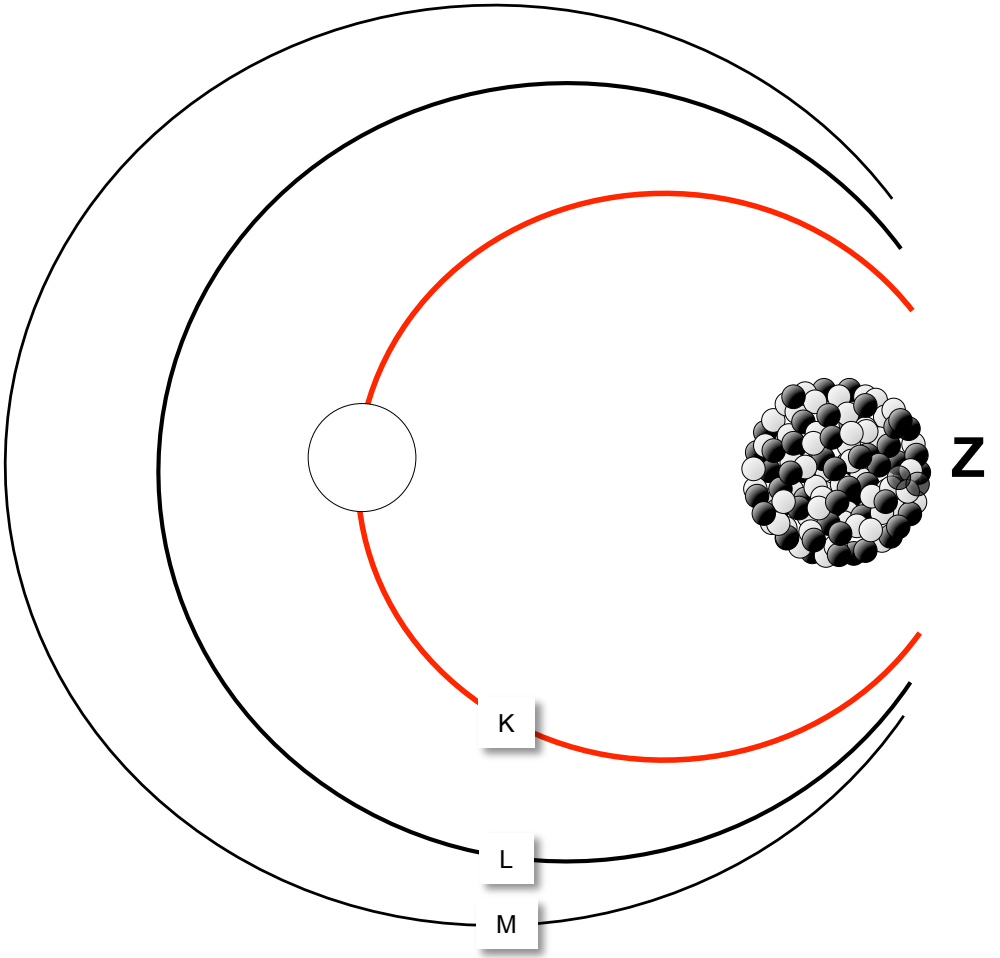


ε PRIMARY TRANSFORMATIONS AND POST-EFECTS

$$K1 + e^- \longrightarrow K2 + \nu_e + \Delta E$$

From electron capture …
to electron vacancies

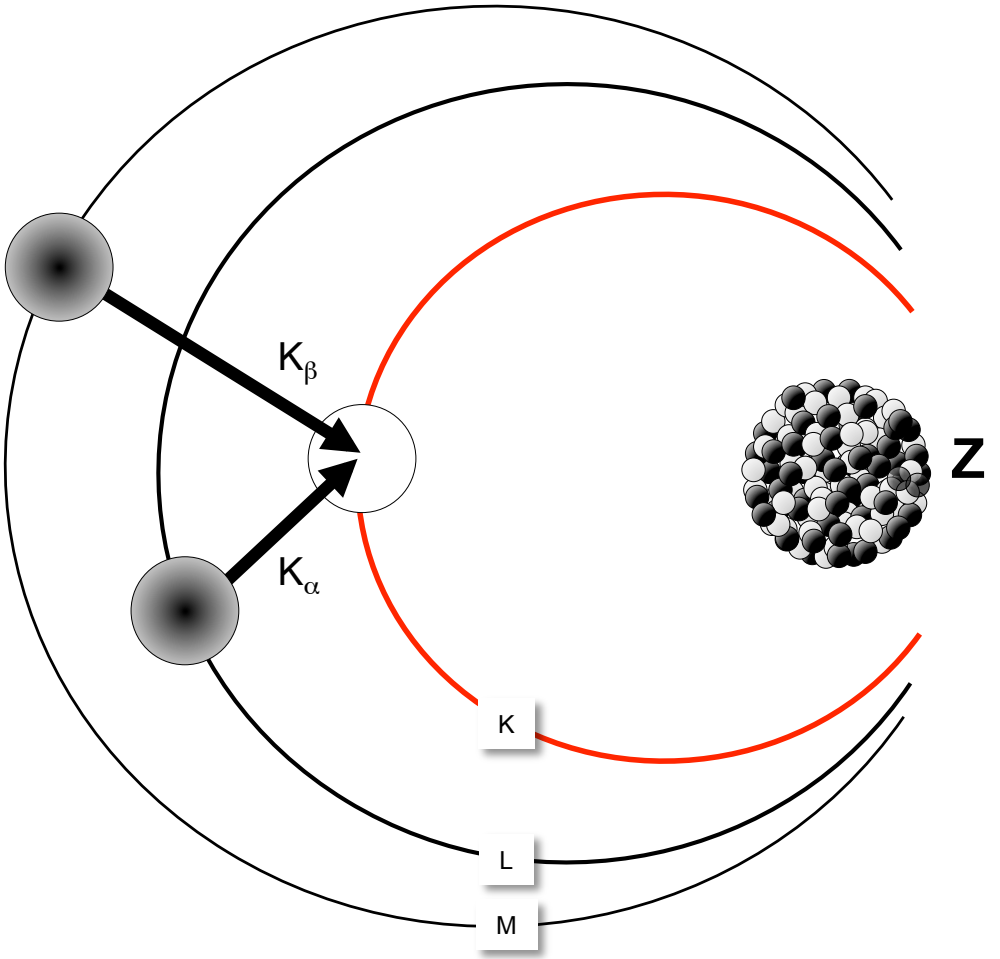
KLM



ε PRIMARY TRANSFORMATIONS AND POST-EFECTS

$$K1 + e^- \longrightarrow K2 + \nu_e + \Delta E$$

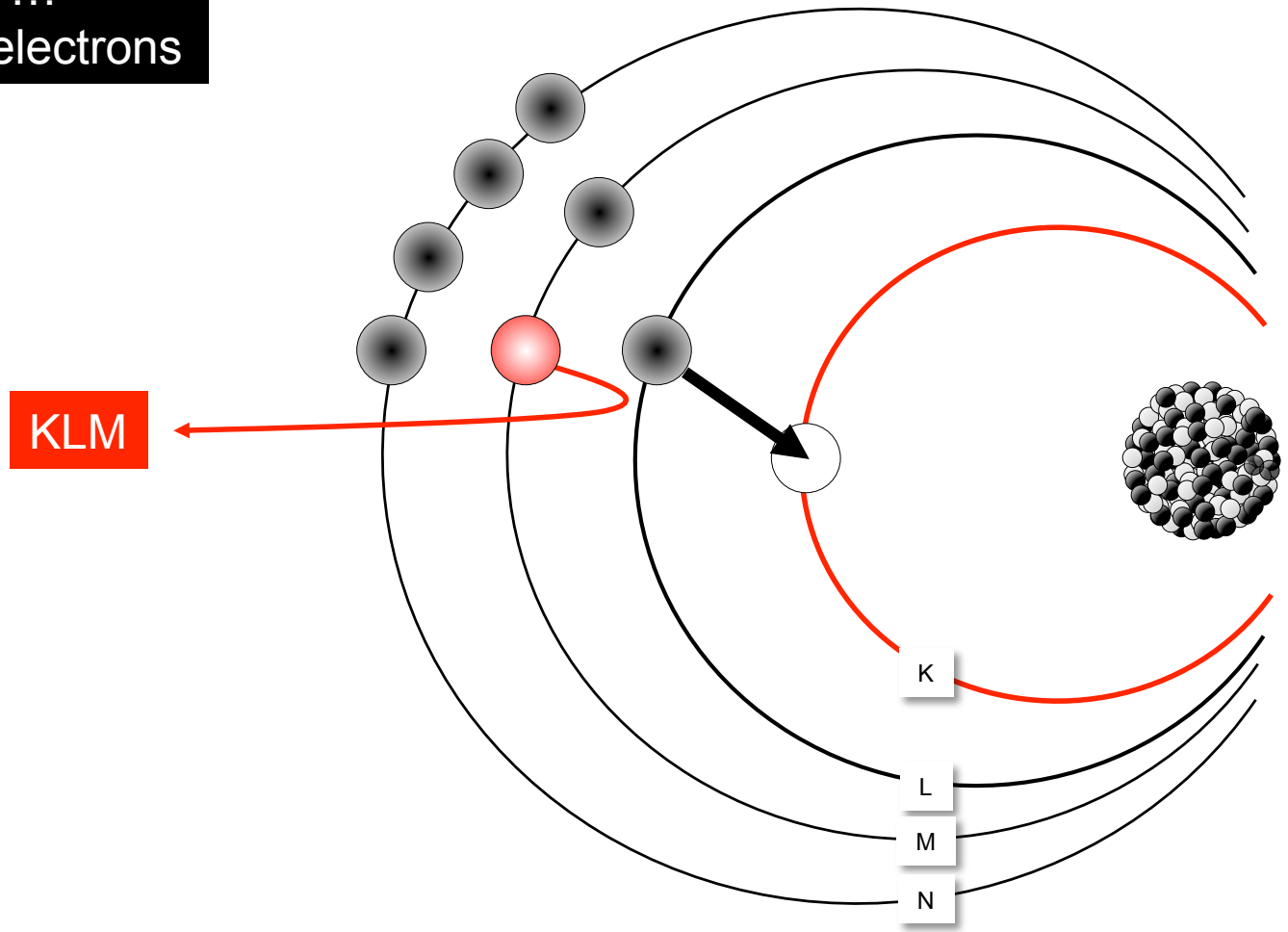
From electron vacancies …
to X-ray emission



ε PRIMARY TRANSFORMATIONS AND POST-EFECTS

$$K1 + e^- \longrightarrow K2 + \nu_e + \Delta E$$

From electron vacancies …
to emissions of AUGER electrons



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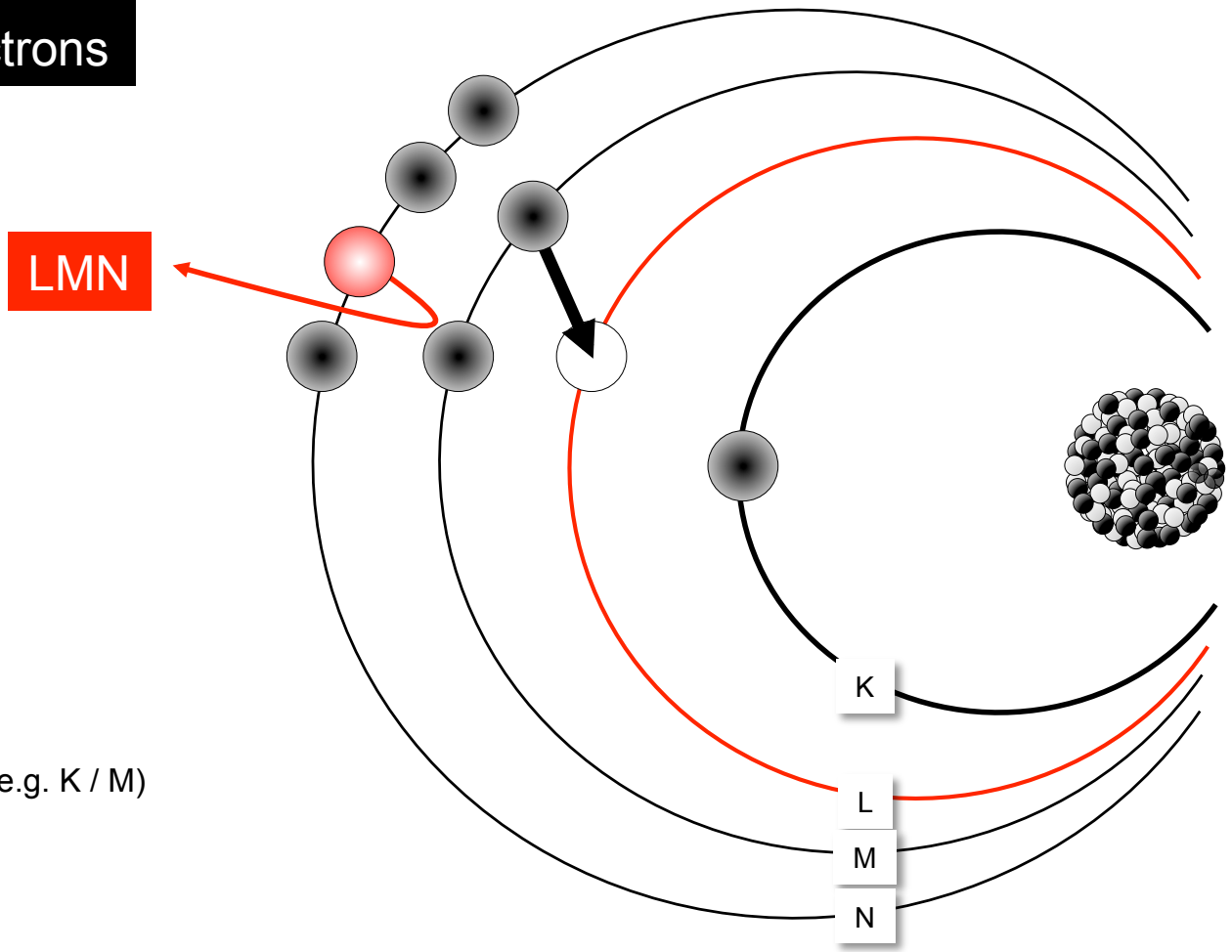


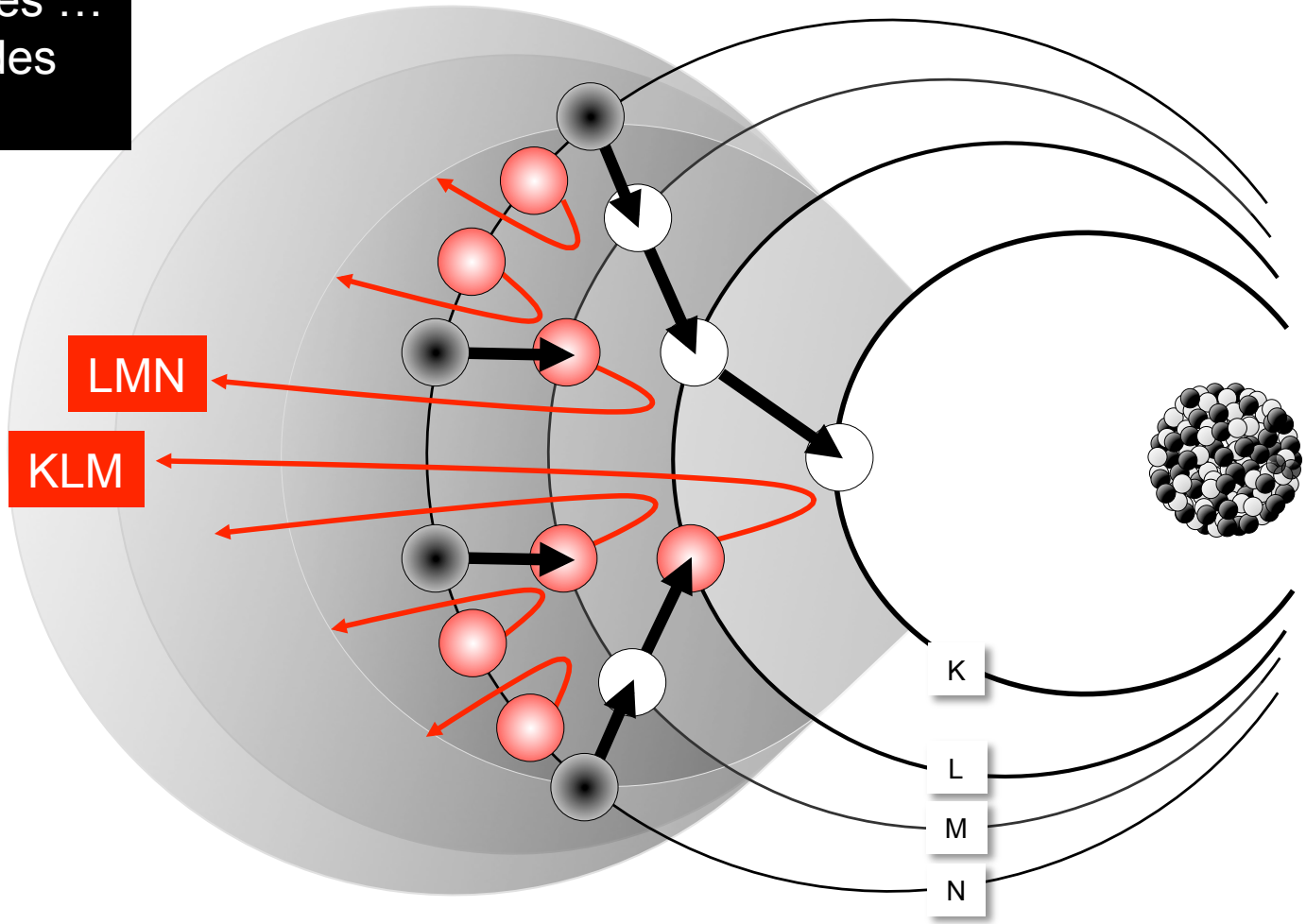
$E_{AUGER\text{-}e} = E_X - E_{B(e)}$
between different main electron shells (e.g. K / M)

$E_{KOSTER\text{-}KRONIG\text{-}e}$
within one main shell between sub-shells (z.B. L1 / L2 / ...)

ε PRIMARY TRANSFORMATIONS AND POST-EFECTS

$$K1 + e^- \longrightarrow K2 + \nu_e + \Delta E$$

From electron vacancies …
to emissions of cascades
of AUGER electrons



ε PRIMARY TRANSFORMATIONS AND POST-EFECTS

$$K1 + e^- \longrightarrow K2 + \nu_e + \Delta E$$

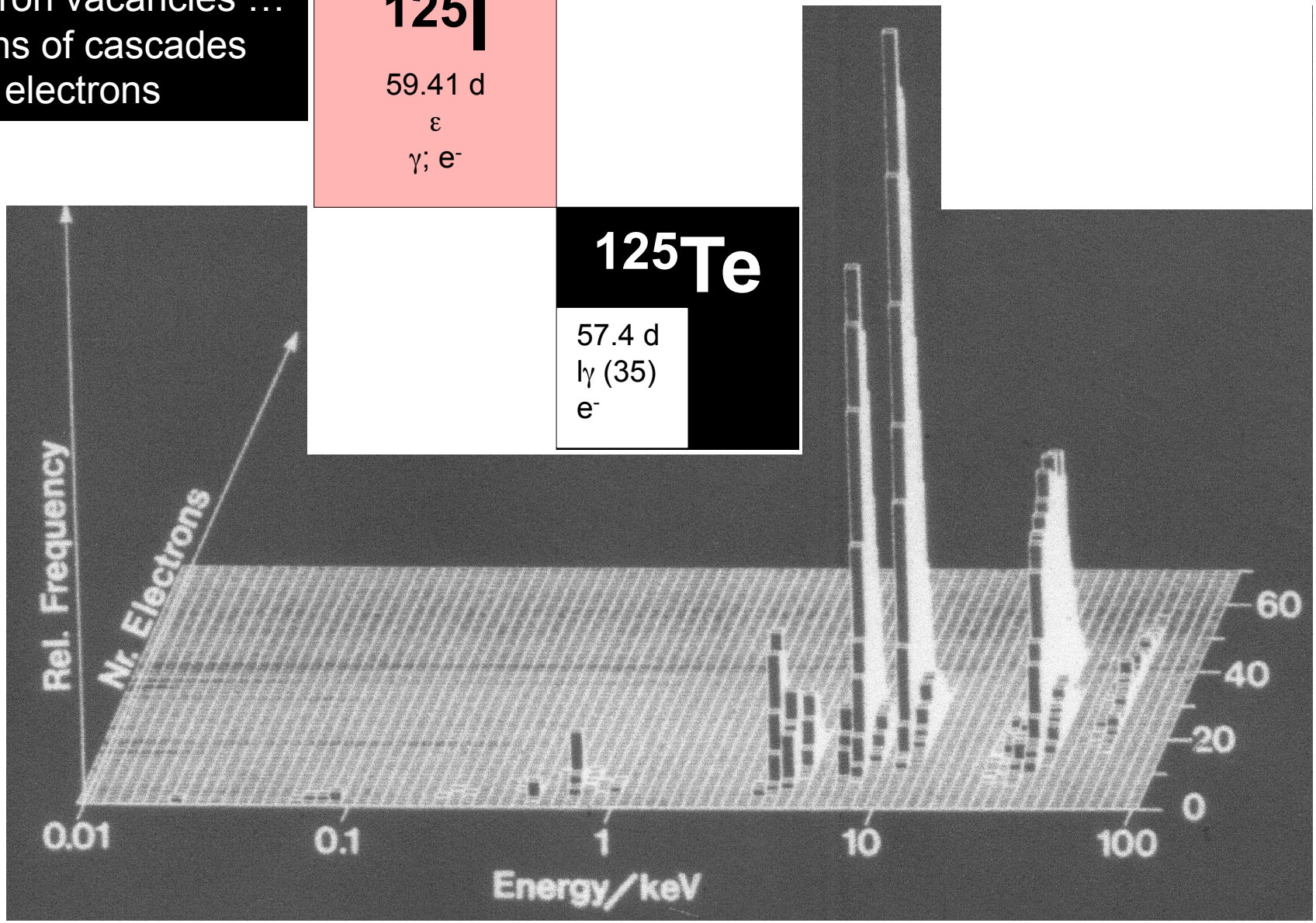
From electron vacancies …
to emissions of cascades
of AUGER electrons

^{125}I

59.41 d
ε
γ; e^-

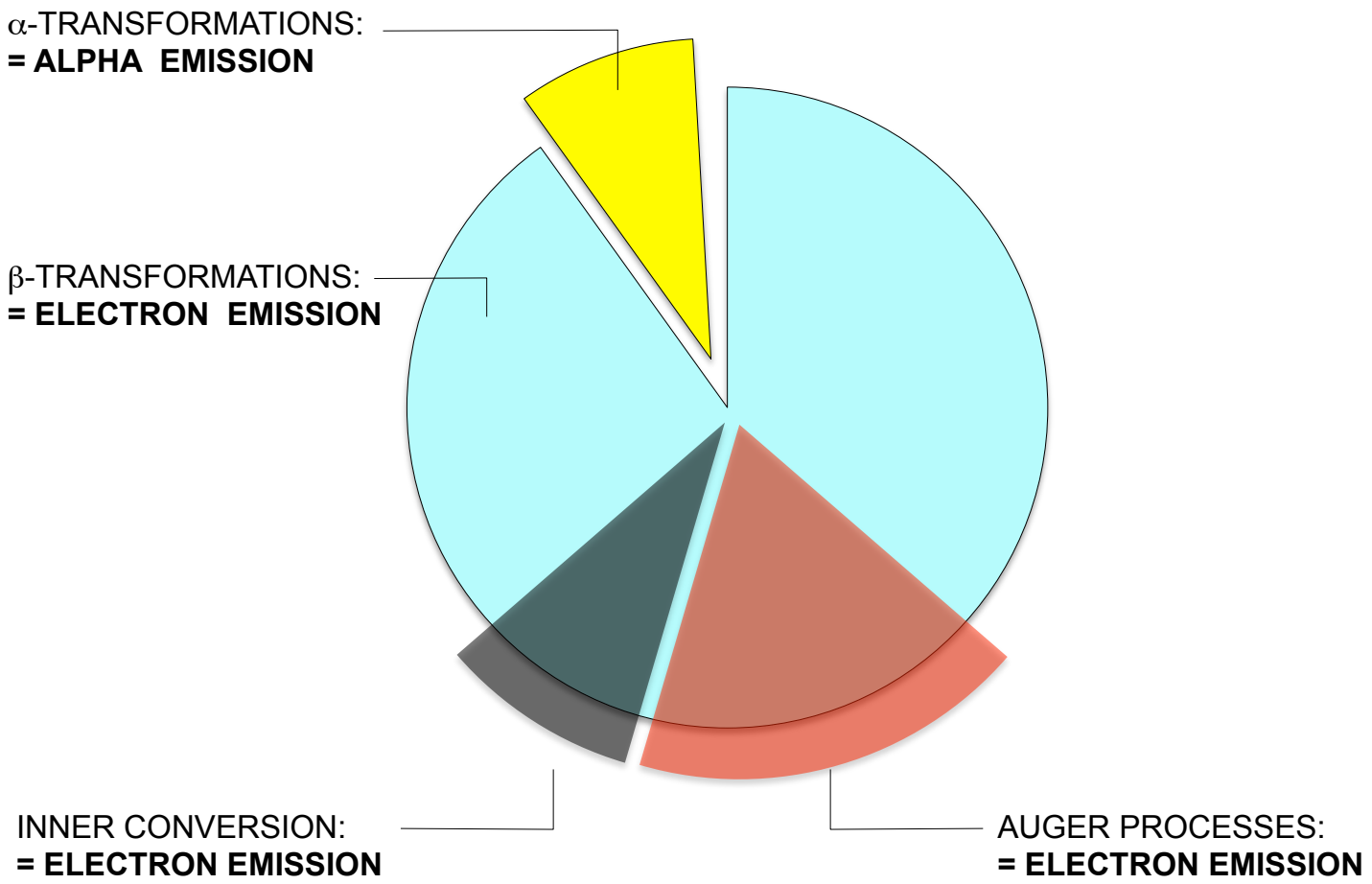
^{125}Te

57.4 d
Iγ (35)
e^-



Frequency of the overall (A) + (CK) electrons released per primary transformation step of ^{125}I and their individual energies (D. E. Charlton, J. Booz, KFA J 1979).

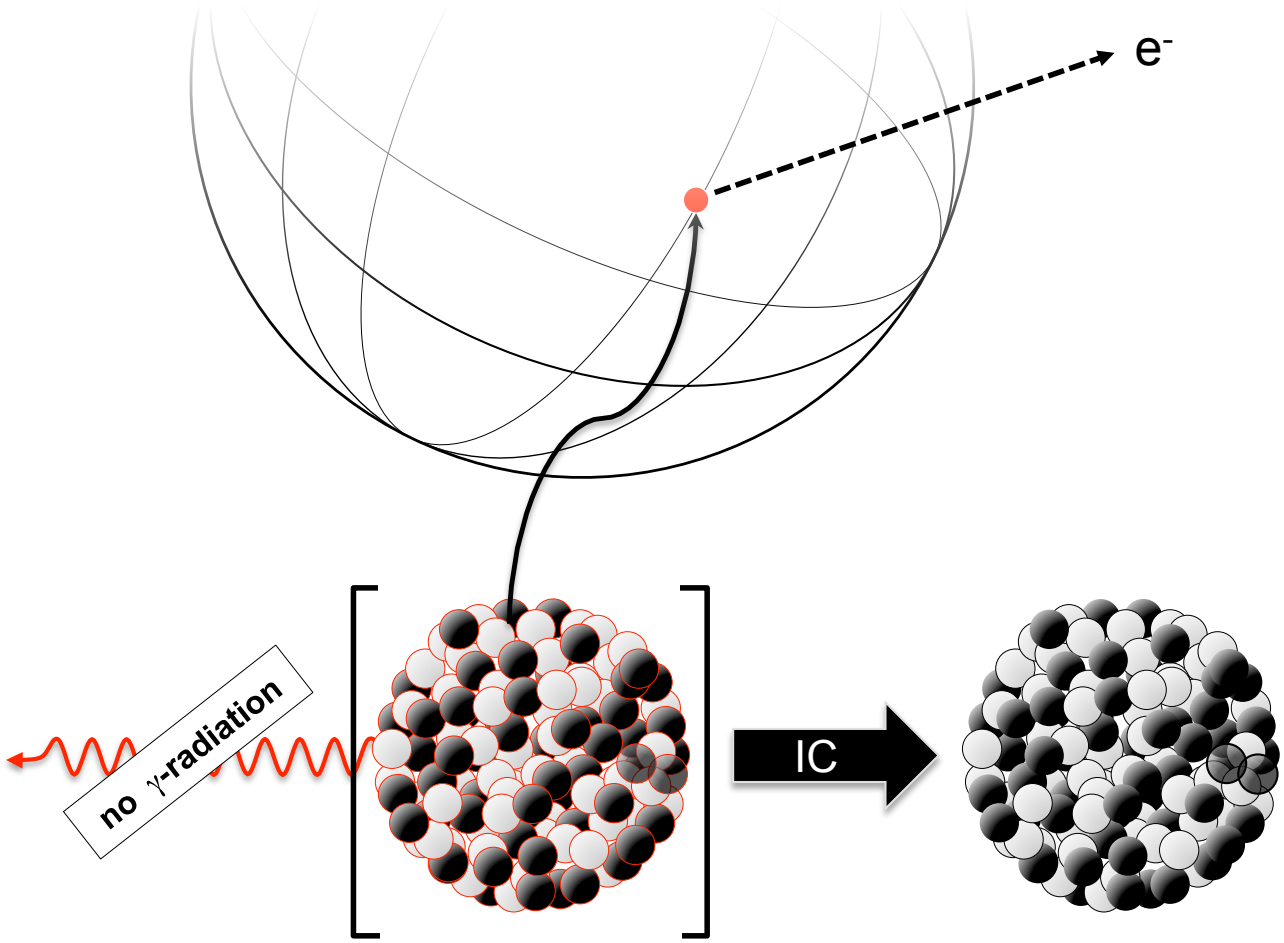
PRIMARY & SECONDARY TRANSFORMATIONS + POST-EFFECTS



SECONDARY TRANSFORMATIONS AND POST-EFECTS

$$^{*}K2 \longrightarrow {}^{\odot i}K2 + y + \Delta E^{*}$$

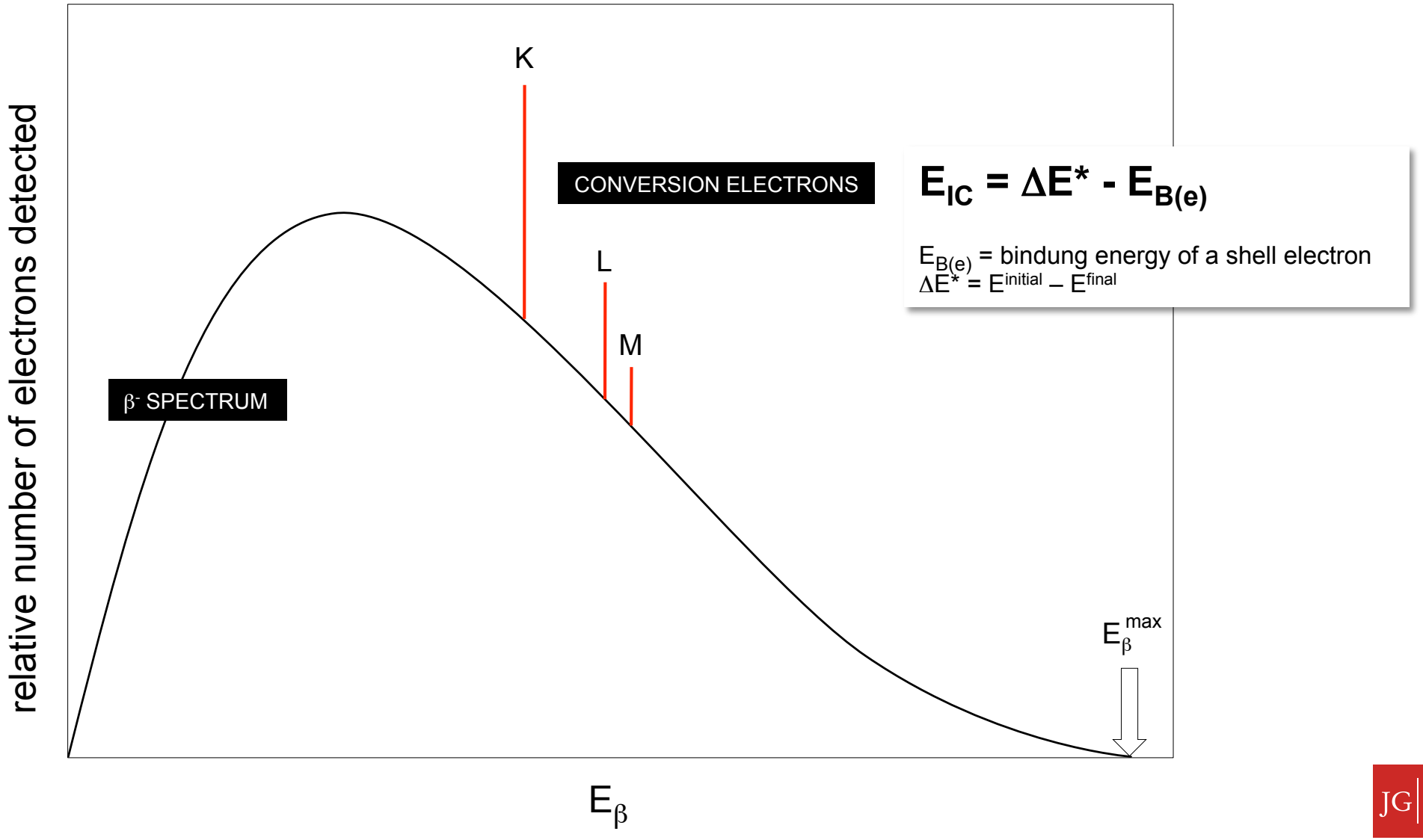
From excited nuclear states ….
to inner conversion (IC)



SECONDARY TRANSFORMATIONS AND POST-EFECTS

$$^{*}K2 \longrightarrow {}^{\odot i}K2 + y + \Delta E^{*}$$

From inner conversion (IC)
to emission of “conversion electrons”

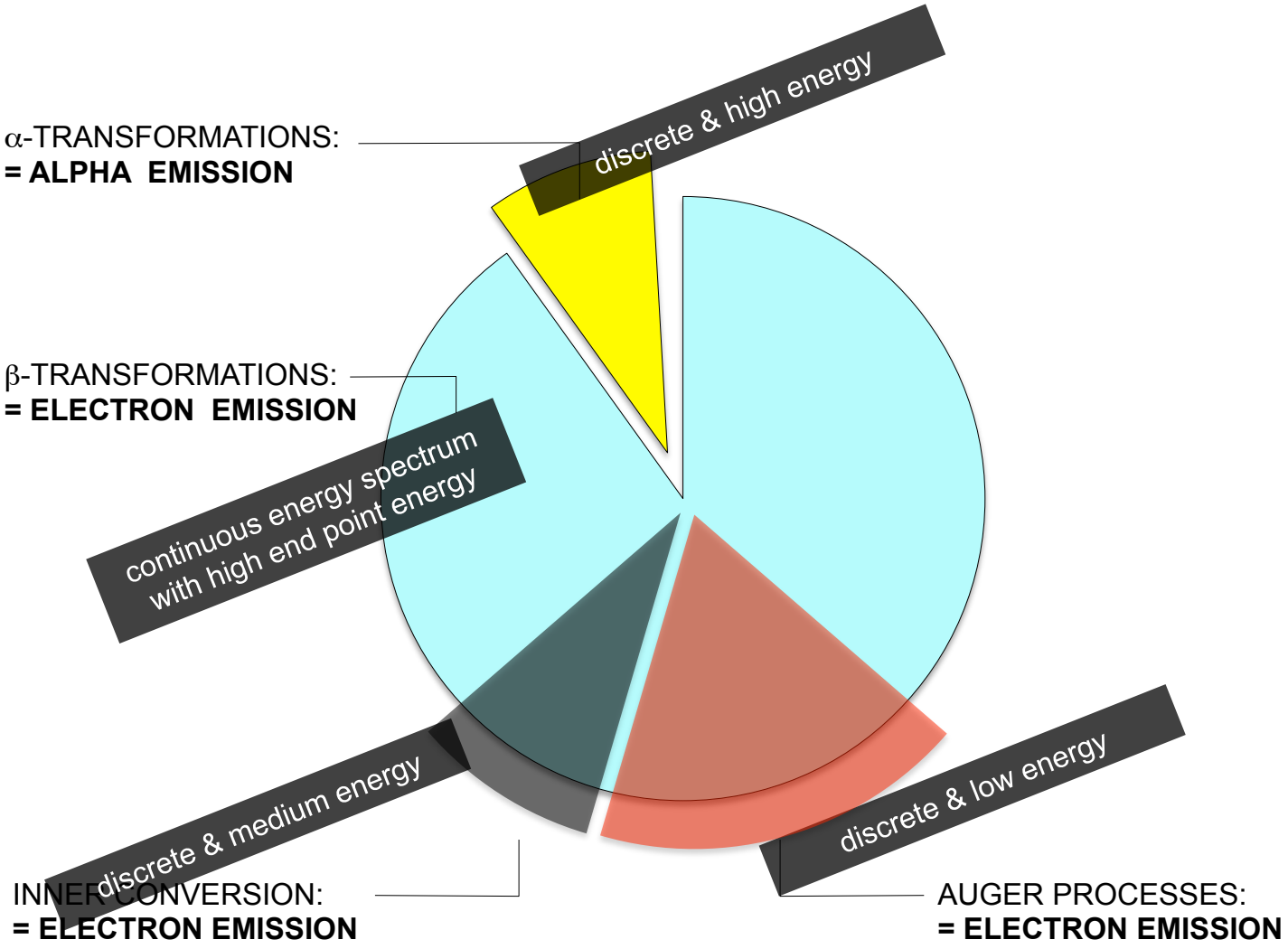


$$E_{IC} = \Delta E^{*} - E_{B(e)}$$

$E_{B(e)}$ = bindung energy of a shell electron
$\Delta E^{*} = E^{initial} - E^{final}$

PRIMARY & SECONDARY TRANSFORMATIONS + POST-EFFECTS

The wapons: particles ...
about their origin, character, and ...



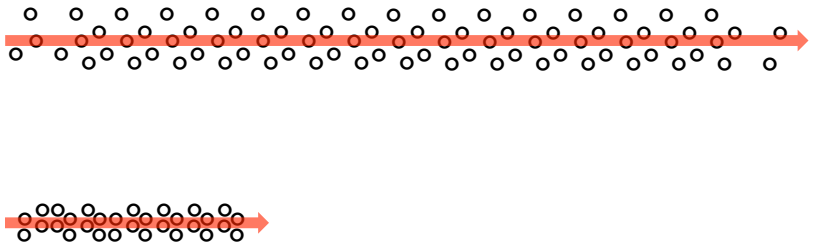
Internal radionuclide therapy: Part II
(α, β, Auger therapy; dose quantification)

The wapons: particles ...
about their origin, character, and fate

Their fate:

1. PARTICLE INTERACTION WITH MATTER (WATER)

2. IONIZATING WATER MOLECULES,
   THERBY CREATING REACTIVE RADICALS:
   H_2O ->->->-> OH°, H°, etc.



$$\frac{\text{energy}}{\text{distance}} = \textbf{LET}$$

linear energy transfer

Internal radionuclide therapy: Part II
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The wapons: particles ... about their origin, character, and fate

PARTICLE	ENERGY MAX (MeV)	ENERGY MEAN (MeV)	RANGE MEAN (mm)	LET (keV/μm)
α	≈ 4-8	-	< 0.01 – 0.1	≈ 100
β^-	≈ 0.2 -2.5	0.1 -1.0	0.4 - 4	≈ 0.1-0.2
IC-electrons	≈ 0.1	-	< 0.1	≈ 1-2
AUGER electrons	< 0.0005 (< 0.5 keV)	-	< 0.000025 (< 28 nm)	≈ 20

INNER CONVERSION:
= ELECTRON EMISSION

AUGER PROCESSES:
= ELECTRON EMISSION

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2. IONIZATING WATER MOLECULES,
   THERBY CREATING REACTIVE RADICALS:
   H_2O ->->->-> OH°, H°, etc.

3. RADICALS “ATTACK” DNA-BASE PAIRS
   TO BREAK BONDS BETWEEN THEM