

# SAMPLE HISTORIES FROM CARBON THERAPY OF A HUMAN BRAIN

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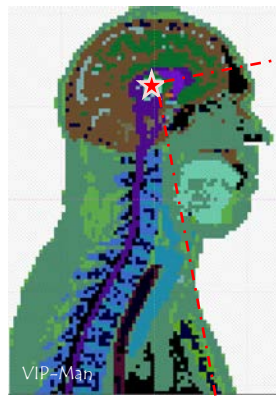
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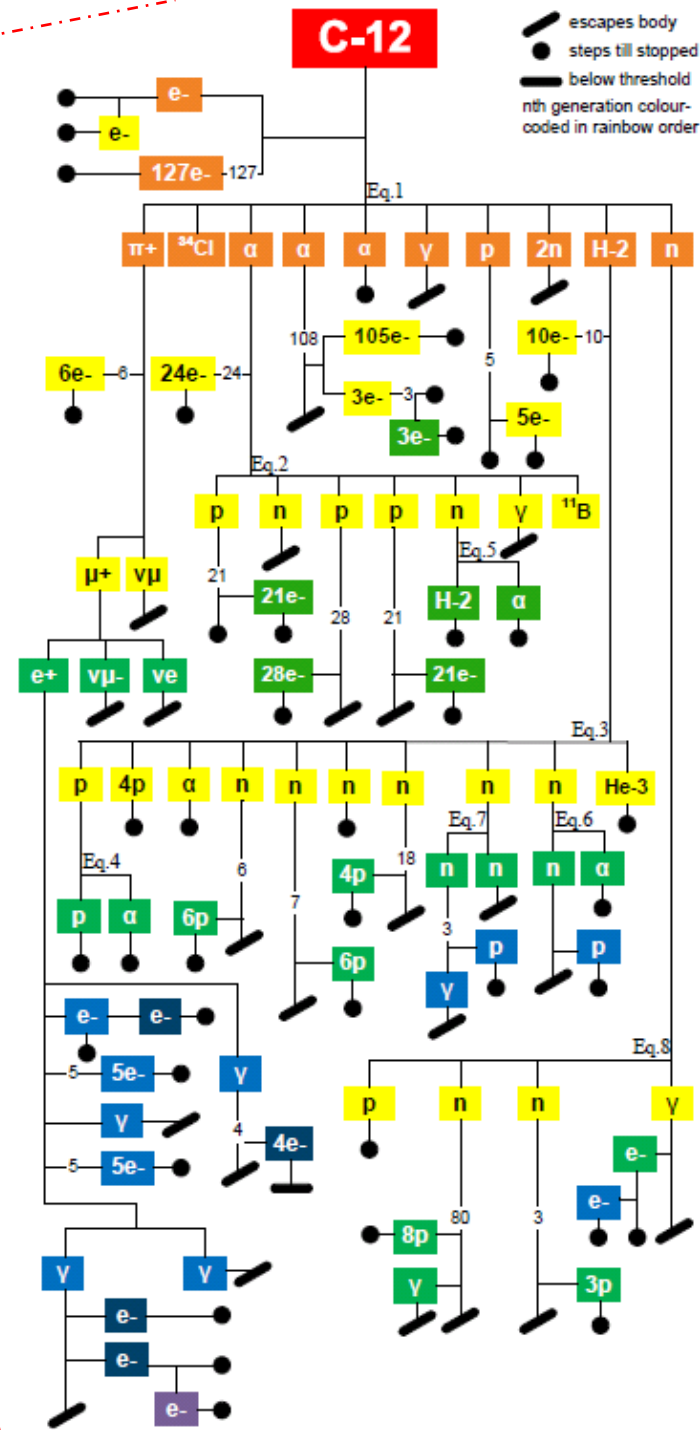


1 source ion started

506 collisions

454 secondary particles + 2 heavy ions

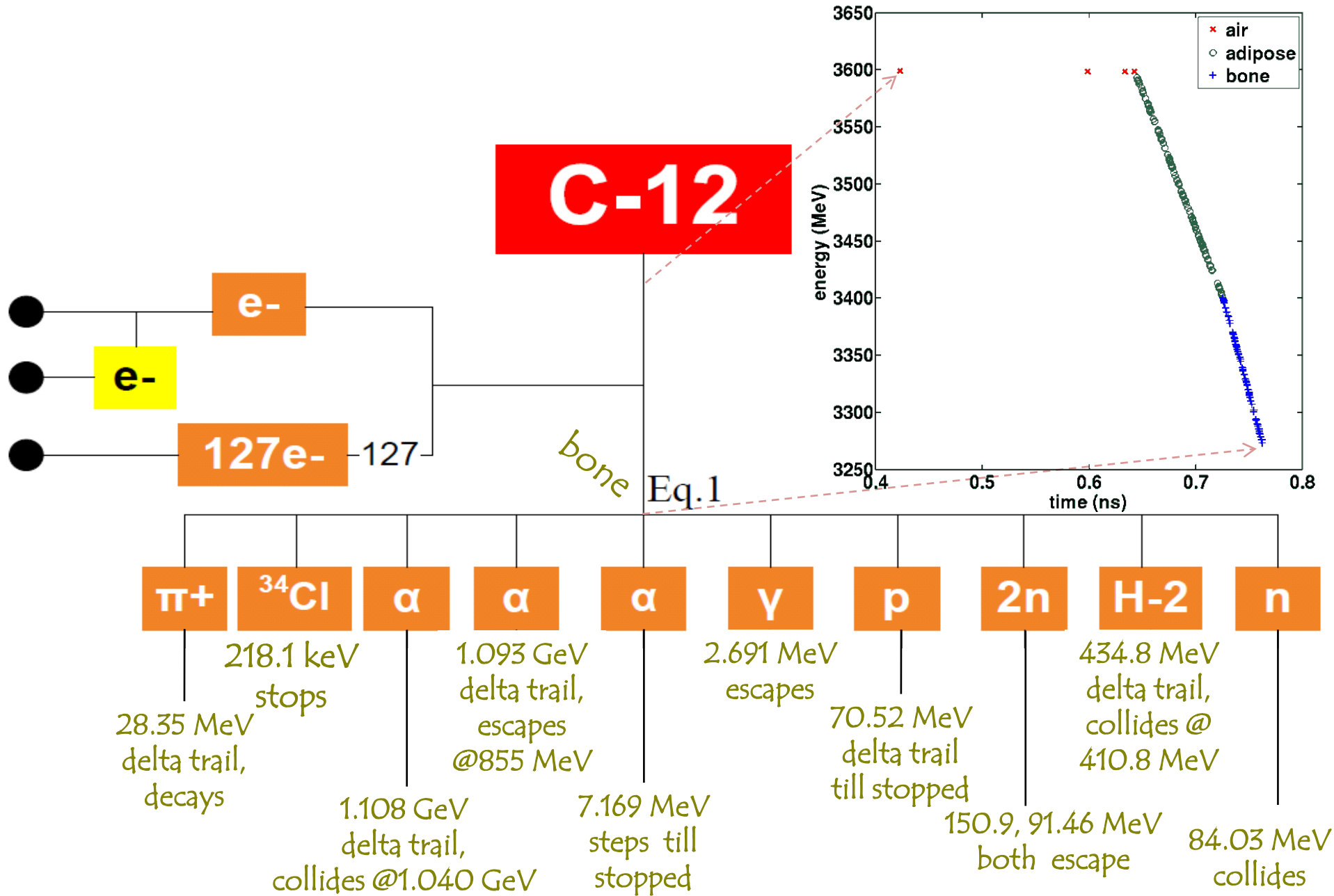
7 generations



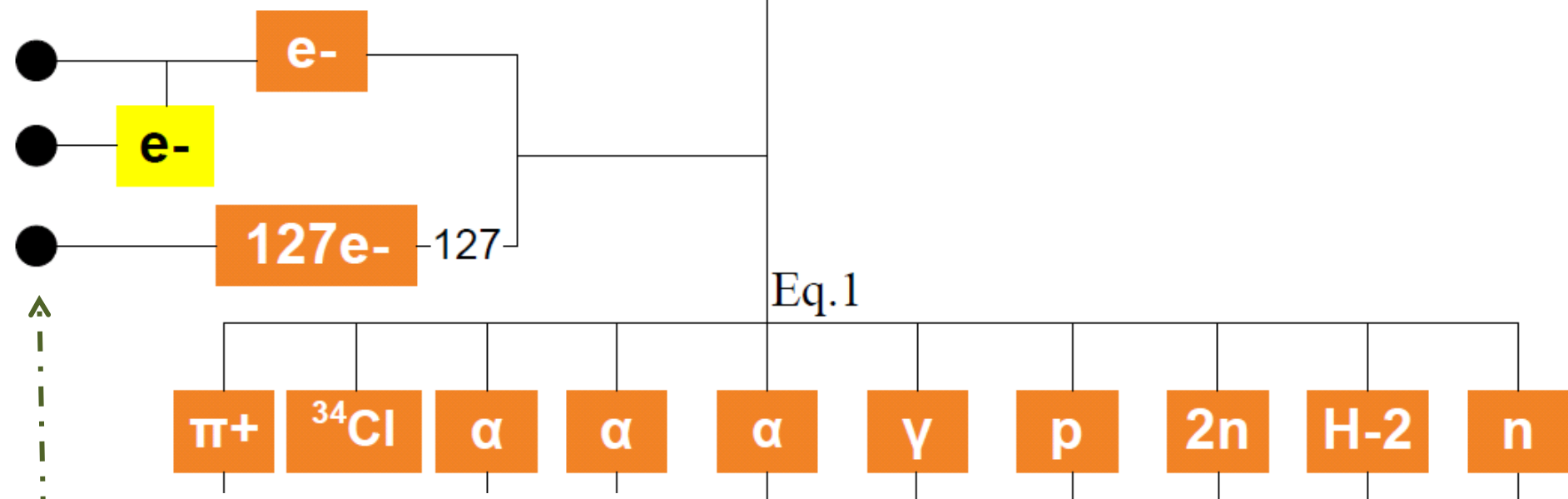
Particle count	Channel of creation	Fate
373 electrons	129 deltas from 2 alphas 128 deltas from $^{12}\text{C}$ source 75 deltas from 4 protons 10 deltas from 1 deuteron 7 Møller, 11 Bhabhas, 7 Comptons 6 deltas from 1 positive pion	all <b>step till stopped</b>
40 protons	29 from (n,np) 5 from inelastic collision of deuteron 3 from inelastic collision of alpha 1 from inelastic collision of $^{12}\text{C}$ source 1 each from (n,nnp $\gamma$ ) and inelastic (p,p')	37 <b>step till stopped</b> 2 <b>escape</b> 1 <b>collides inelastically</b>
16 neutrons	6 from inelastic collision of deuteron 3 from inelastic collision of $^{12}\text{C}$ source 2 from inelastic collision of alpha 2 each from (n,2n) and (n,nnp $\gamma$ ) 1 from inelastic (n,n')	10 <b>escape</b> 4 <b>collide inelastically</b> 1 <b>enters gamma capture</b> 1 <b>enters (n,n')</b>
9 gammas	2 from positron annihilation 2 bremsstrahlungs 1 from inelastic collision of $^{12}\text{C}$ source 1 from inelastic collision of alpha 1 each from (n, $\gamma$ ), (n,n $\gamma$ ), (n,nnp $\gamma$ )	all <b>escape</b>
7 alphas	3 from inelastic collision of $^{12}\text{C}$ source 1 from inelastic collision of deuteron 1 each from (n, $^2\text{H}\alpha$ ), (n,n $\alpha$ ), (p,p $\alpha$ )	5 <b>step till stopped</b> 1 <b>collides inelastically</b> 1 <b>escapes</b>
2 deuterons	1 from inelastic collision of $^{12}\text{C}$ source 1 from (n, $^2\text{H}\alpha$ )	1 <b>steps till stopped</b> 1 <b>collides inelastically</b>
1 helium-3	from inelastic collision of deuteron	<b>steps till stopped</b>
1 positive pion	from inelastic collision of $^{12}\text{C}$ source	<b>decays</b>
1 positive muon 1 muon neutrino	decay products of positive pion	<b>decays</b> <b>escapes</b>
1 positron 1 electron neutrino 1 muon antineutrino	decay products of positive muon	<b>annihilates in-flight</b> <b>escapes</b> <b>escapes</b>



# CARBON STEPS HEADING TOWARDS ABSORPTION

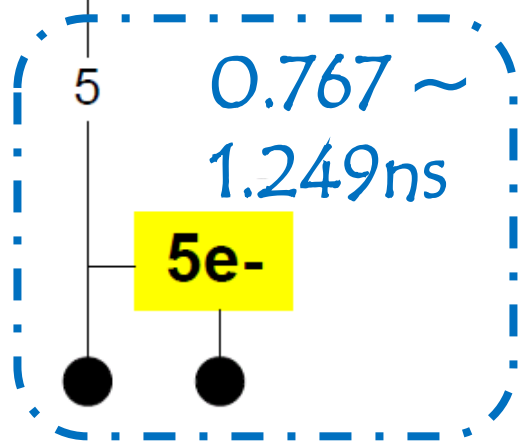


# C-12



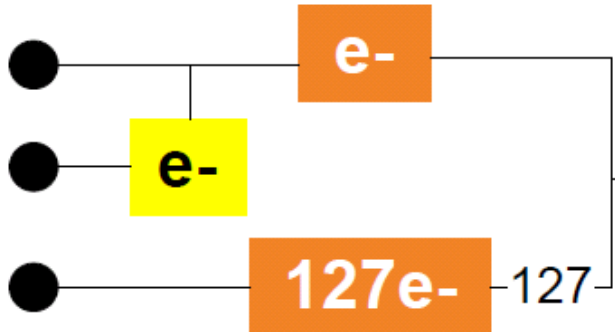
energy deposition  
tailored during  
treatment planning

escapes  
prospect for  
treatment monitoring

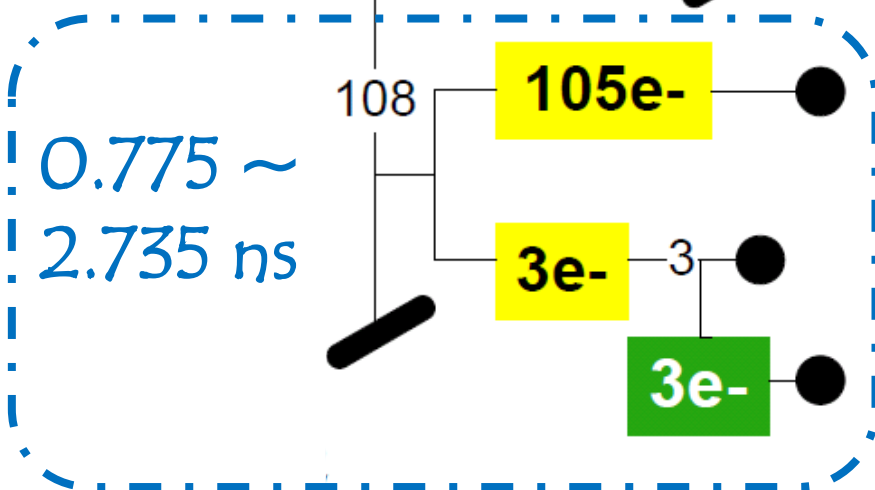
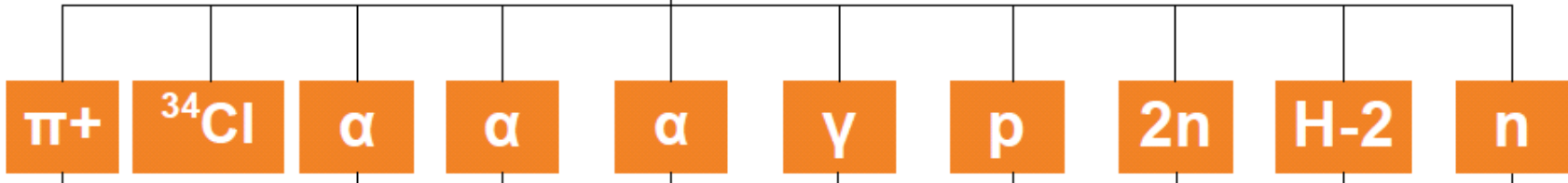


0.767 ~  
1.249ns

# C-12

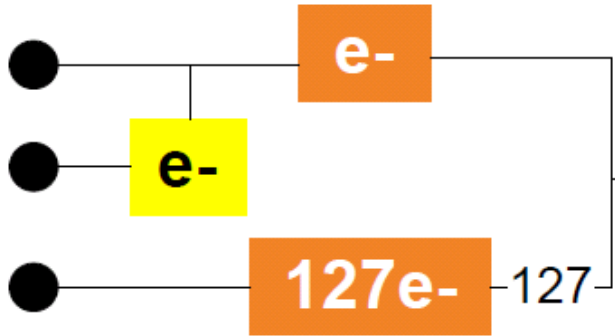


Eq.1

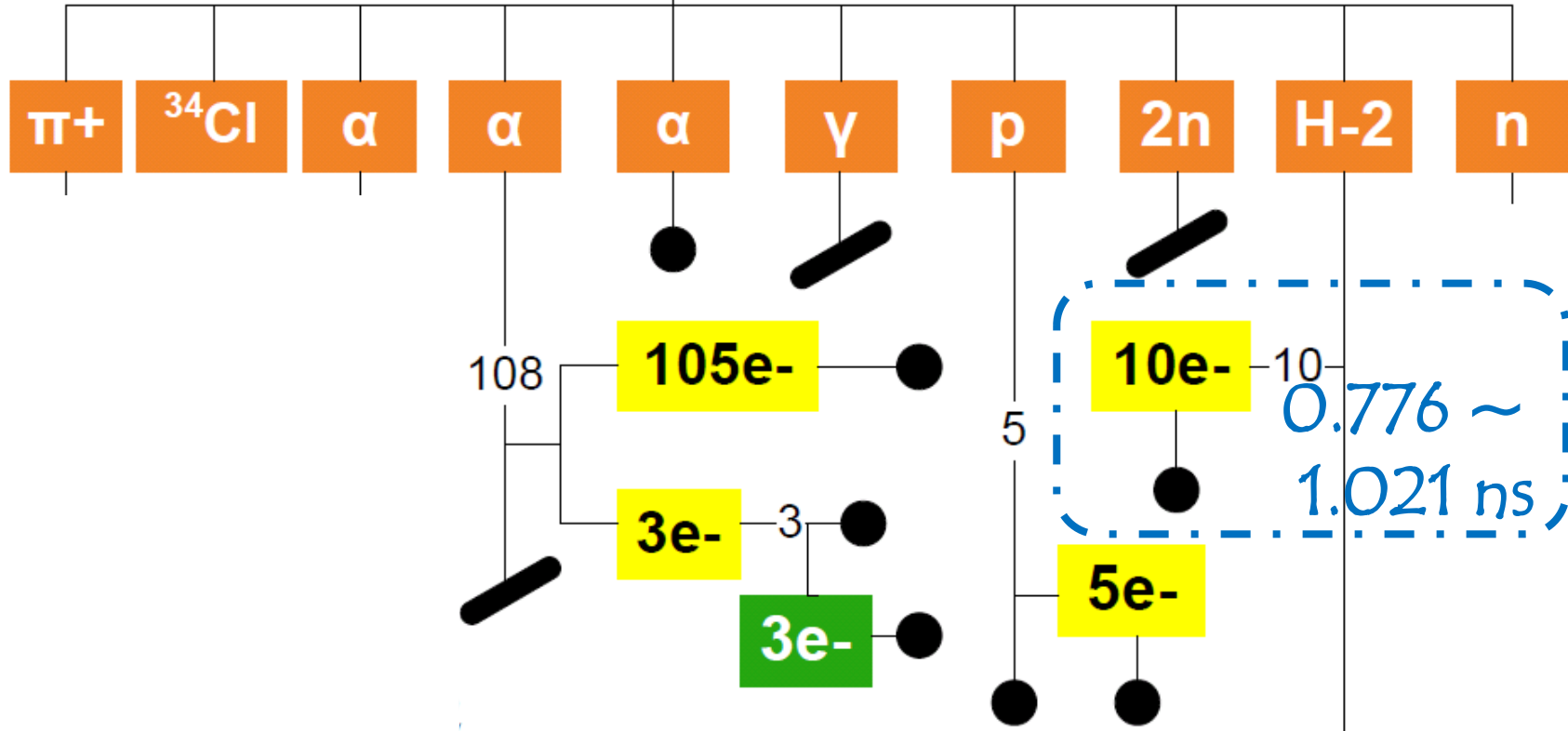


$0.775 \sim 2.735 \text{ ns}$

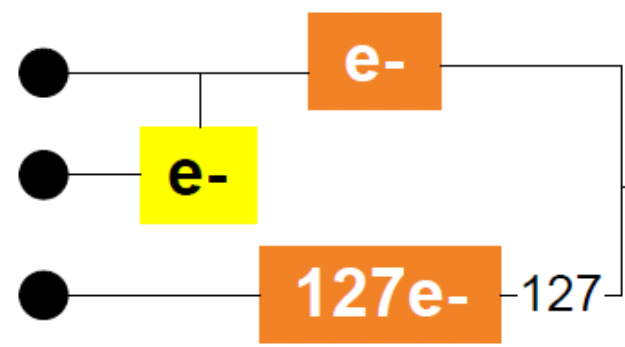
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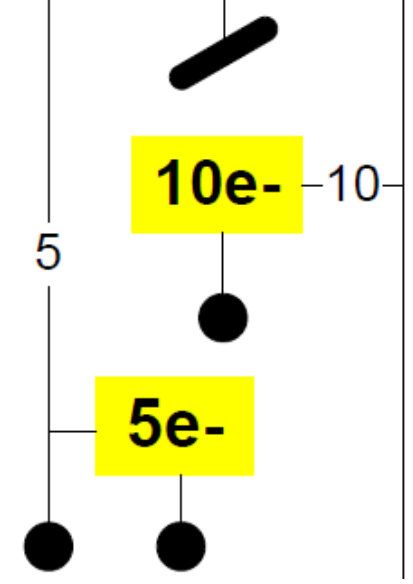
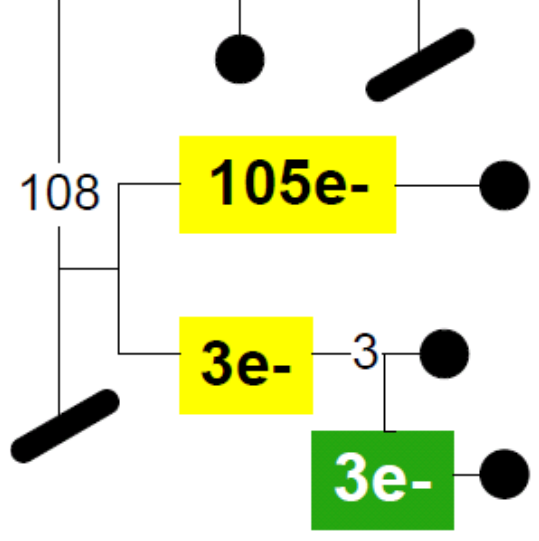
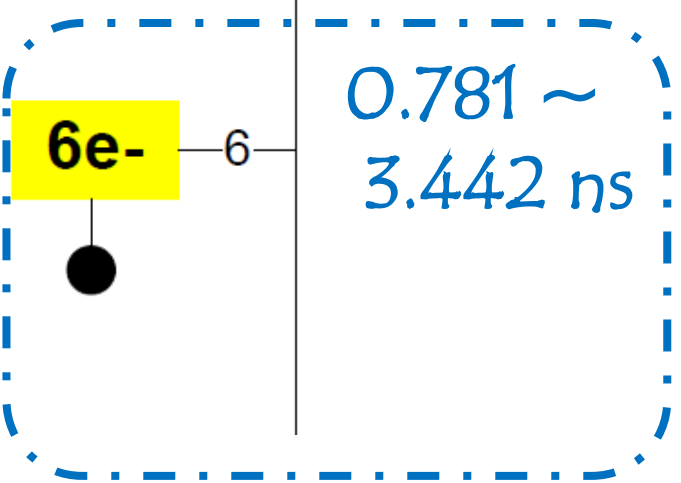
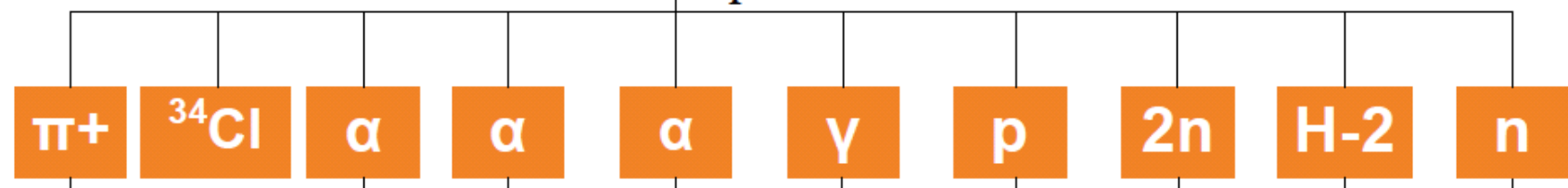
Eq.1



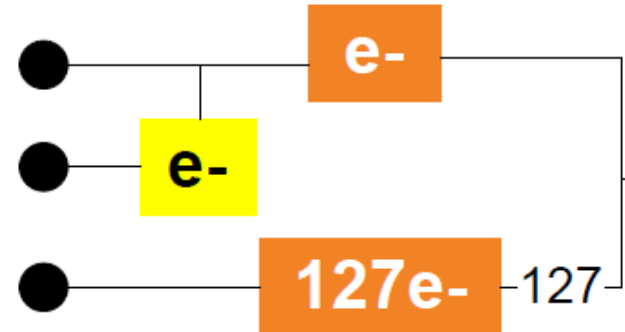
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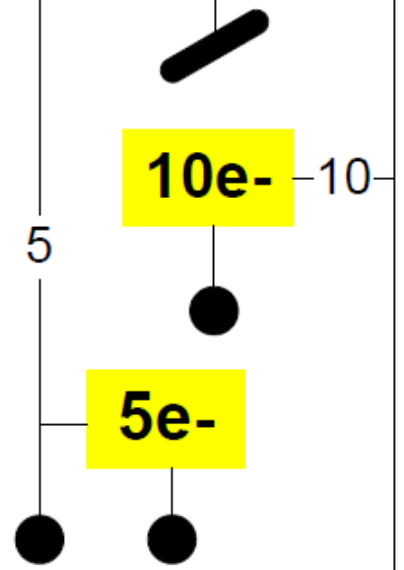
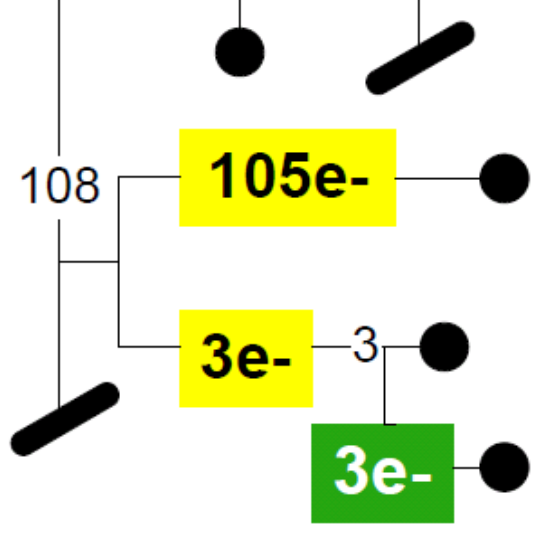
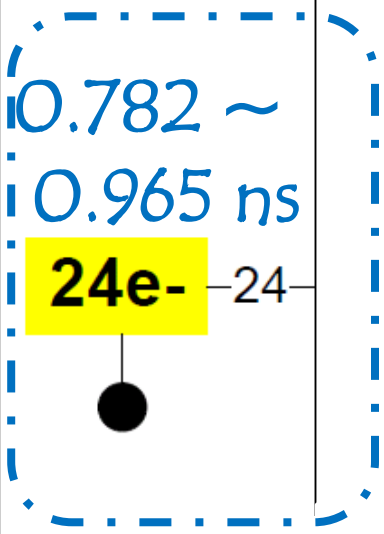
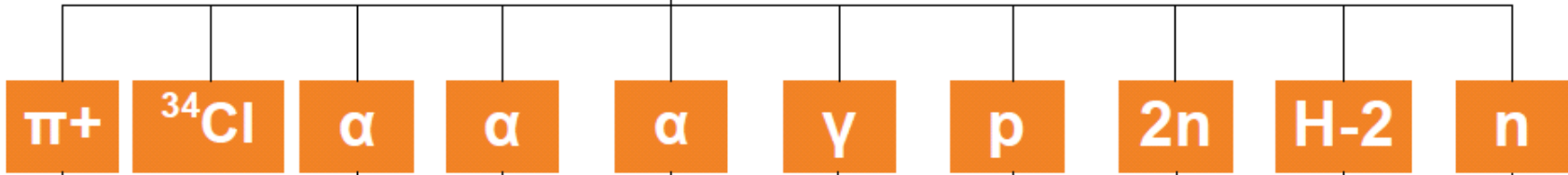
Eq.1

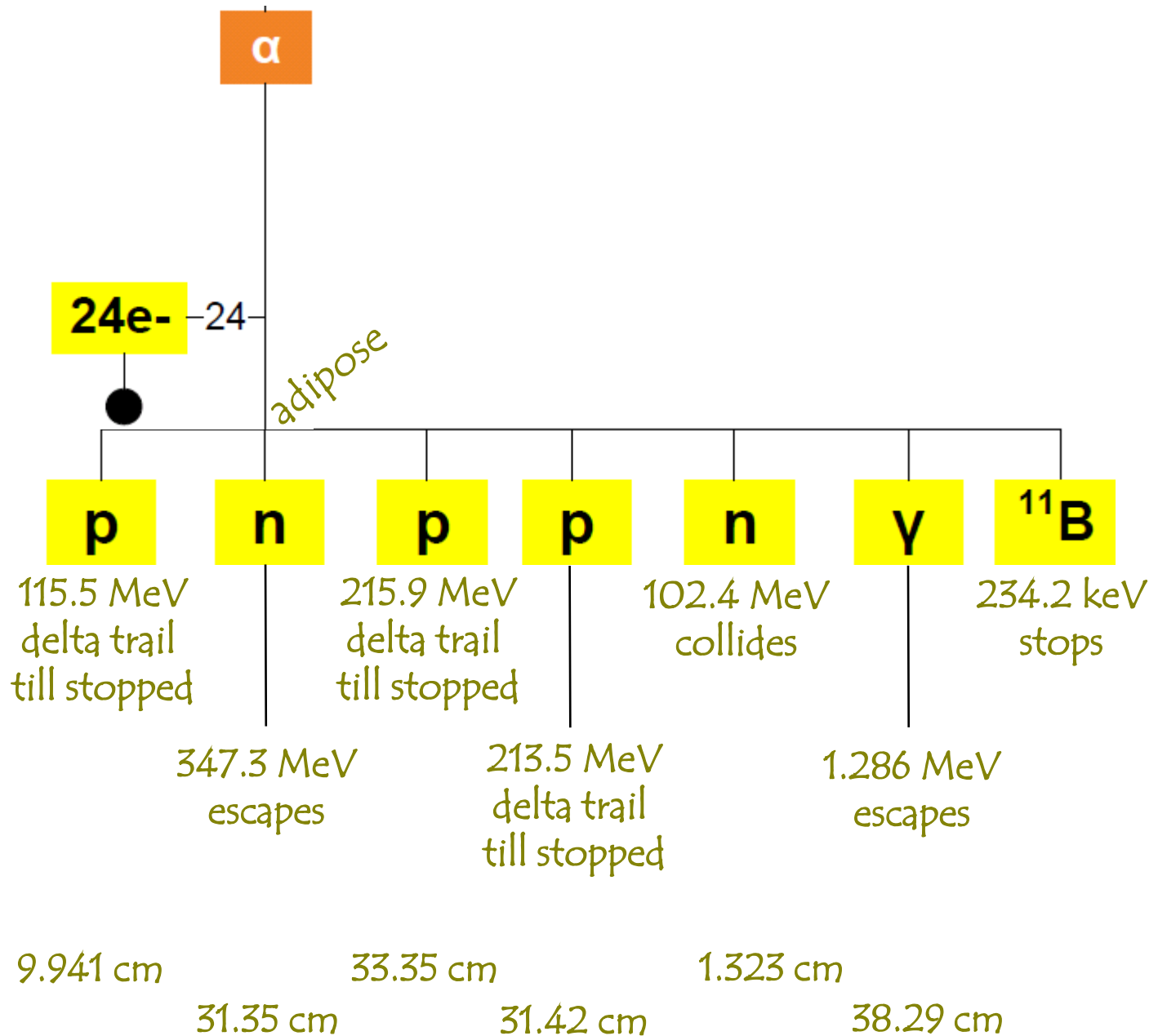


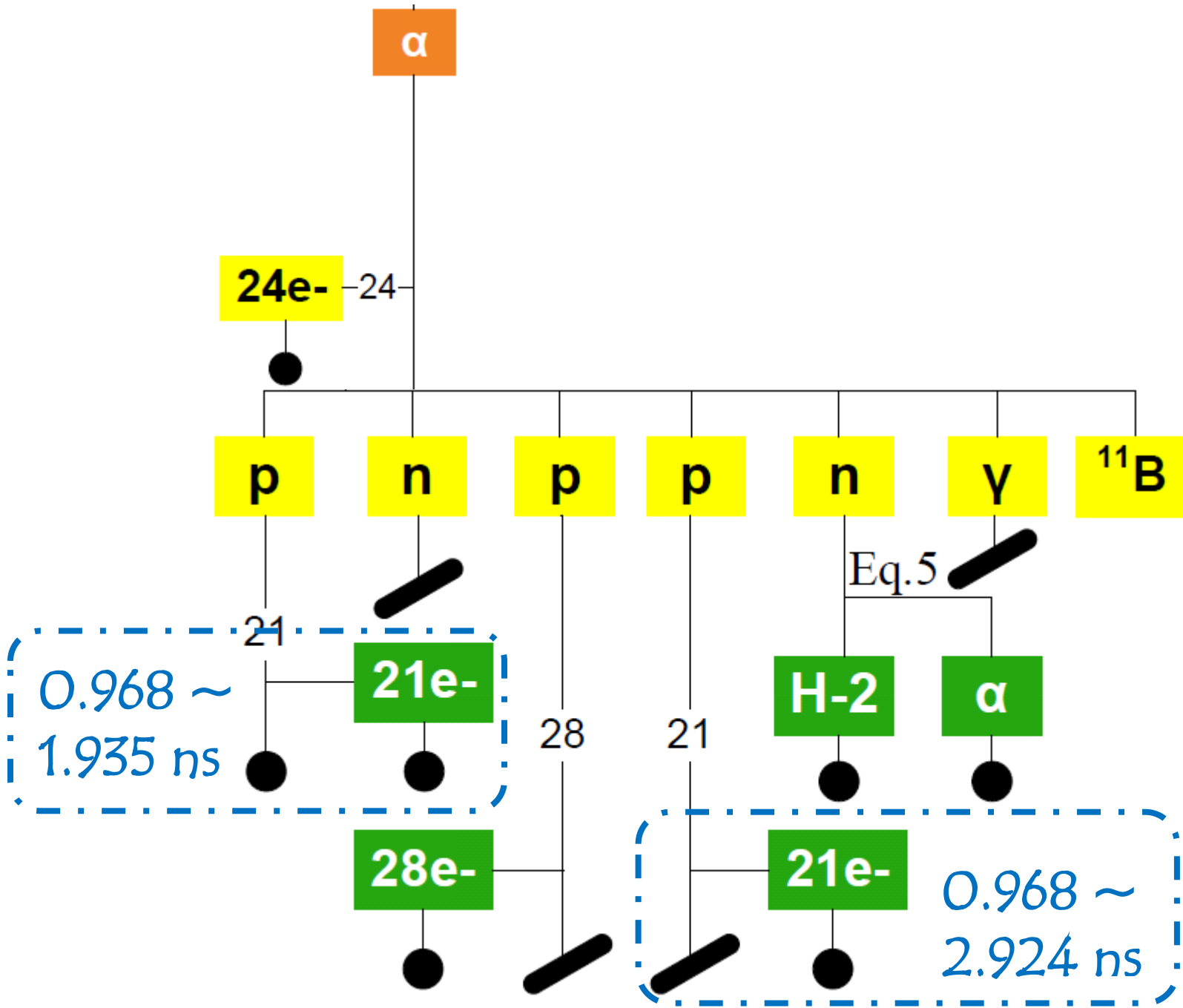
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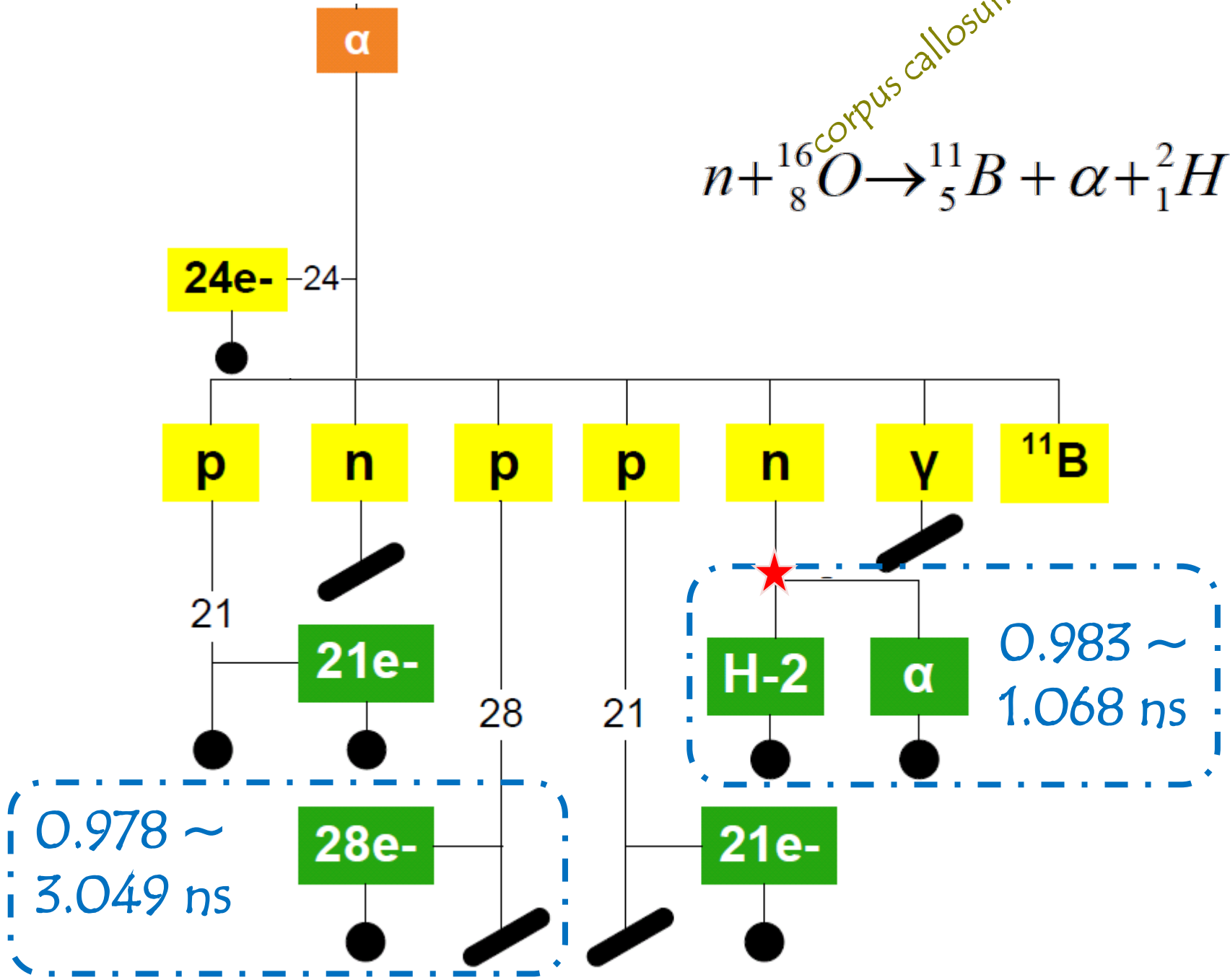
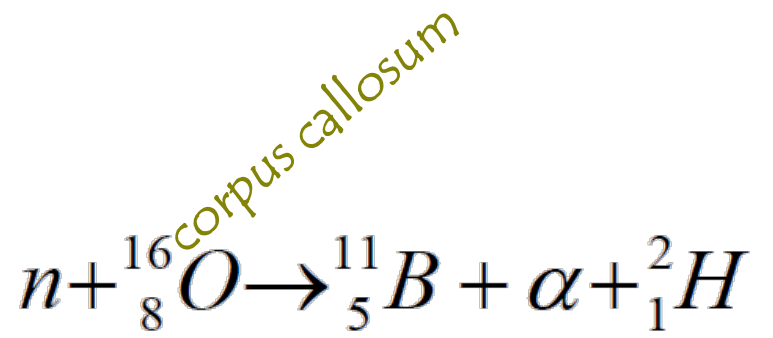


Eq.1

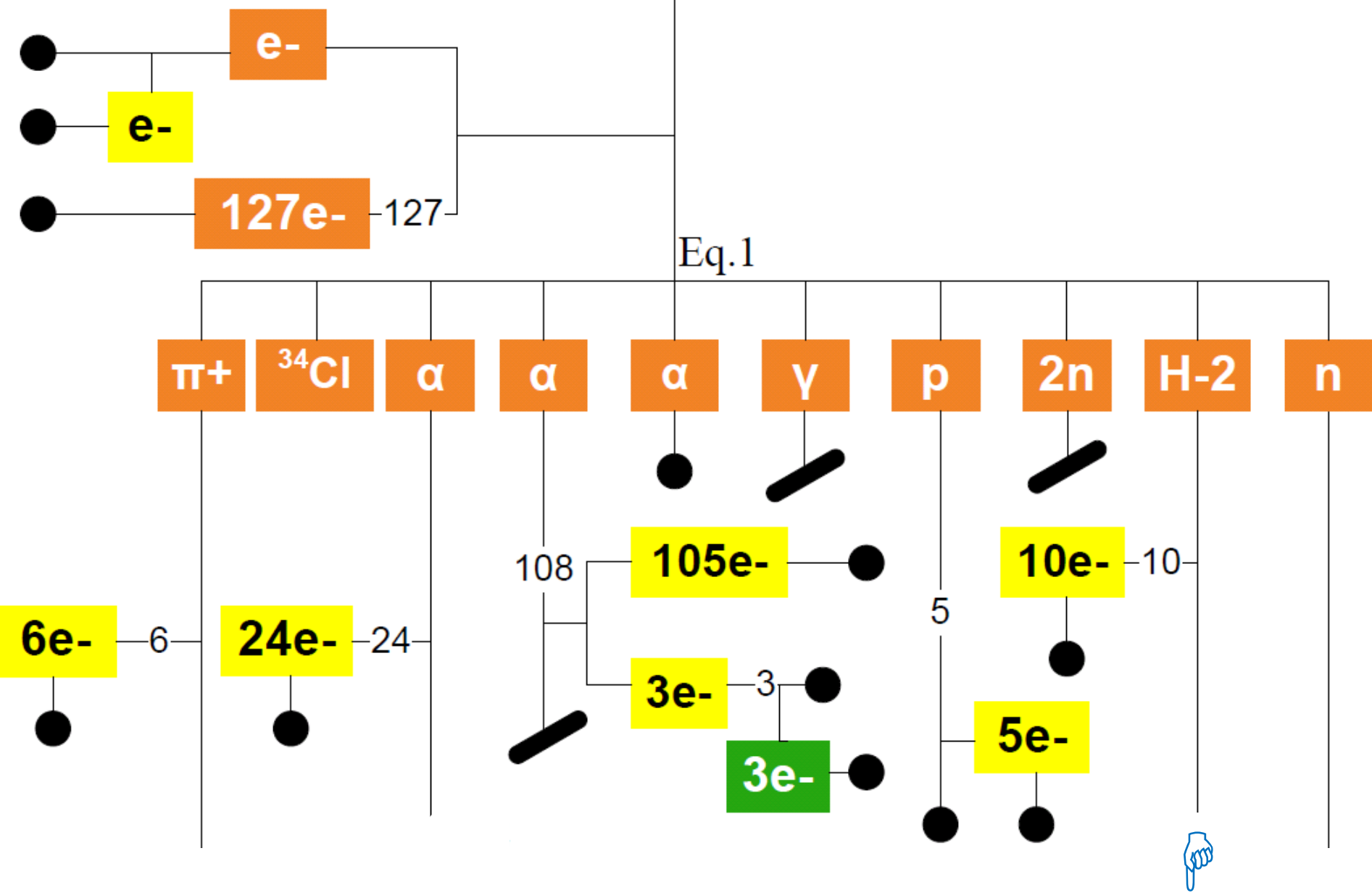


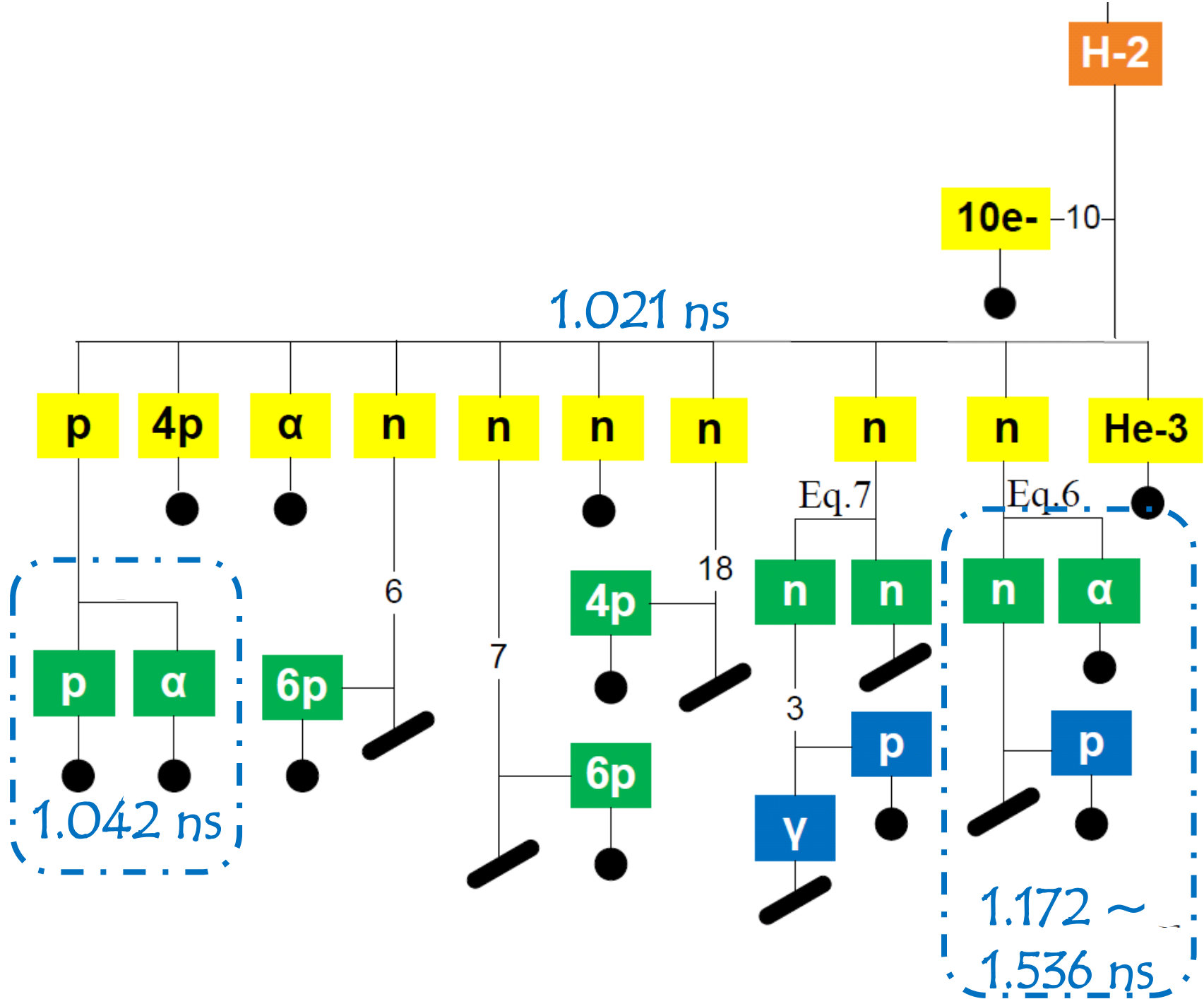


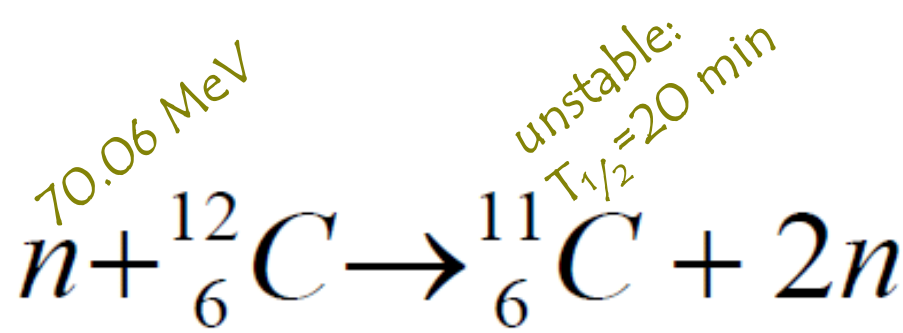




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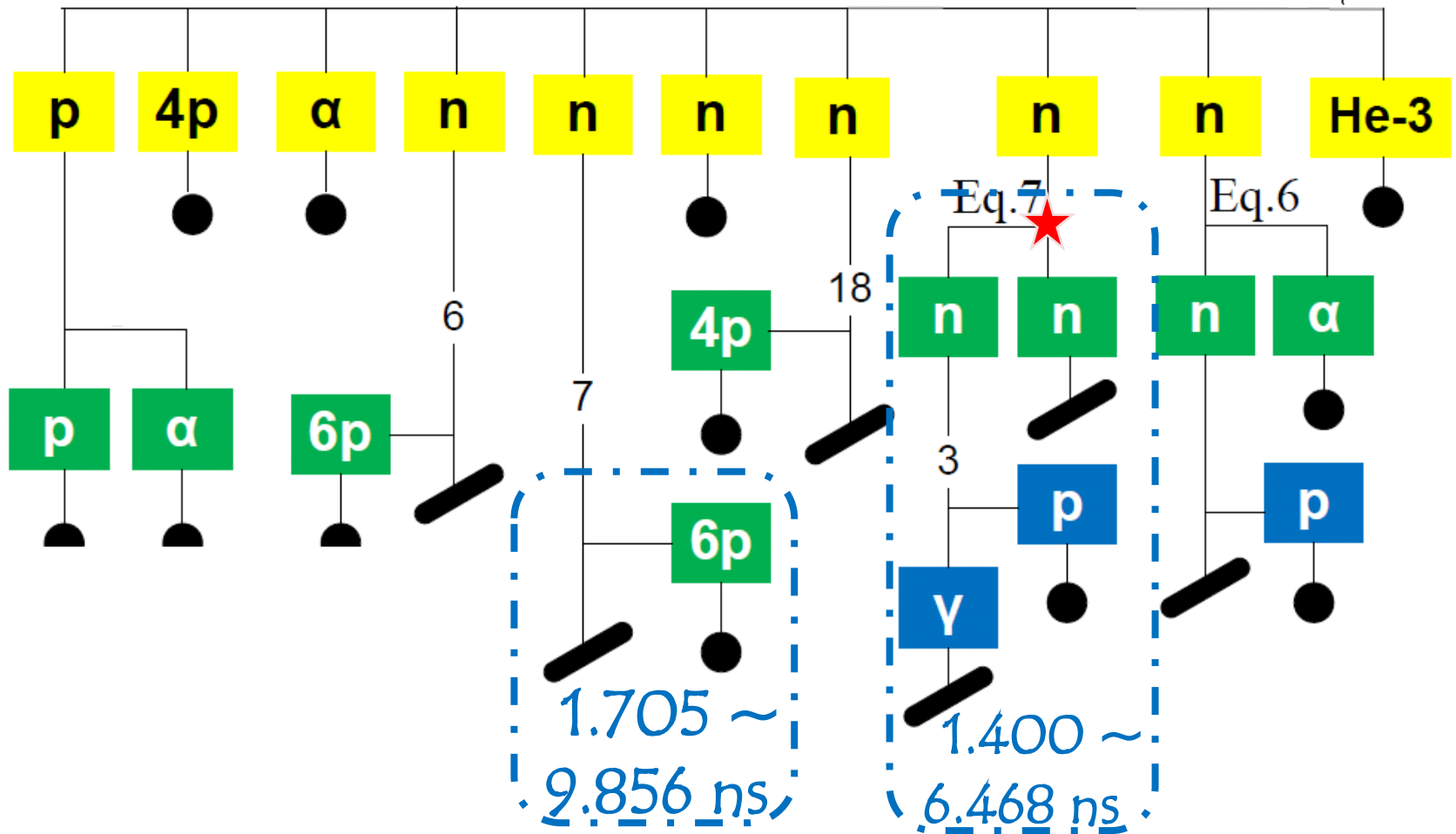






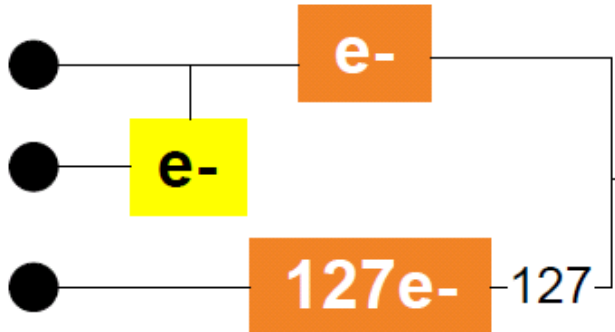
10e-<sup>-10</sup>

H-2

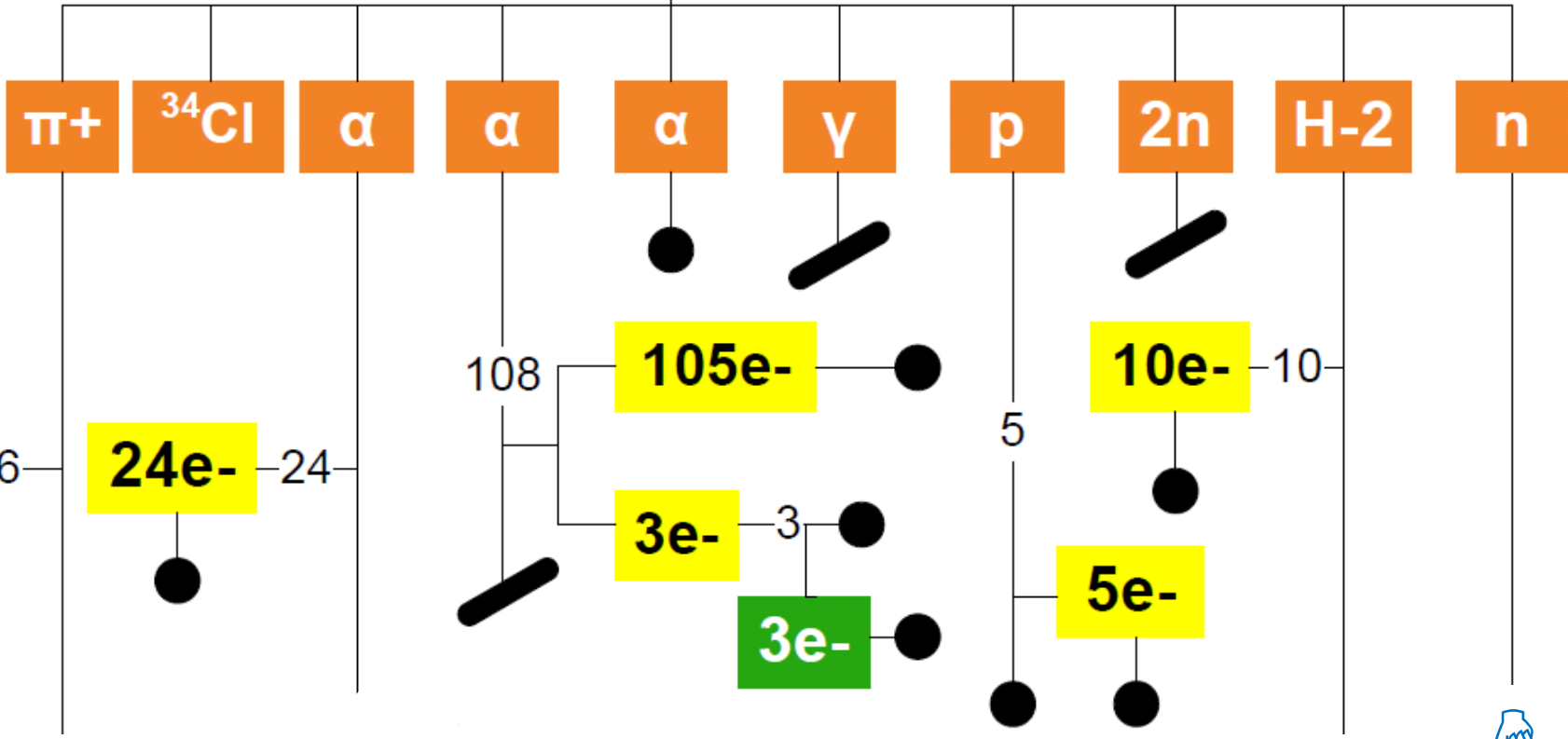


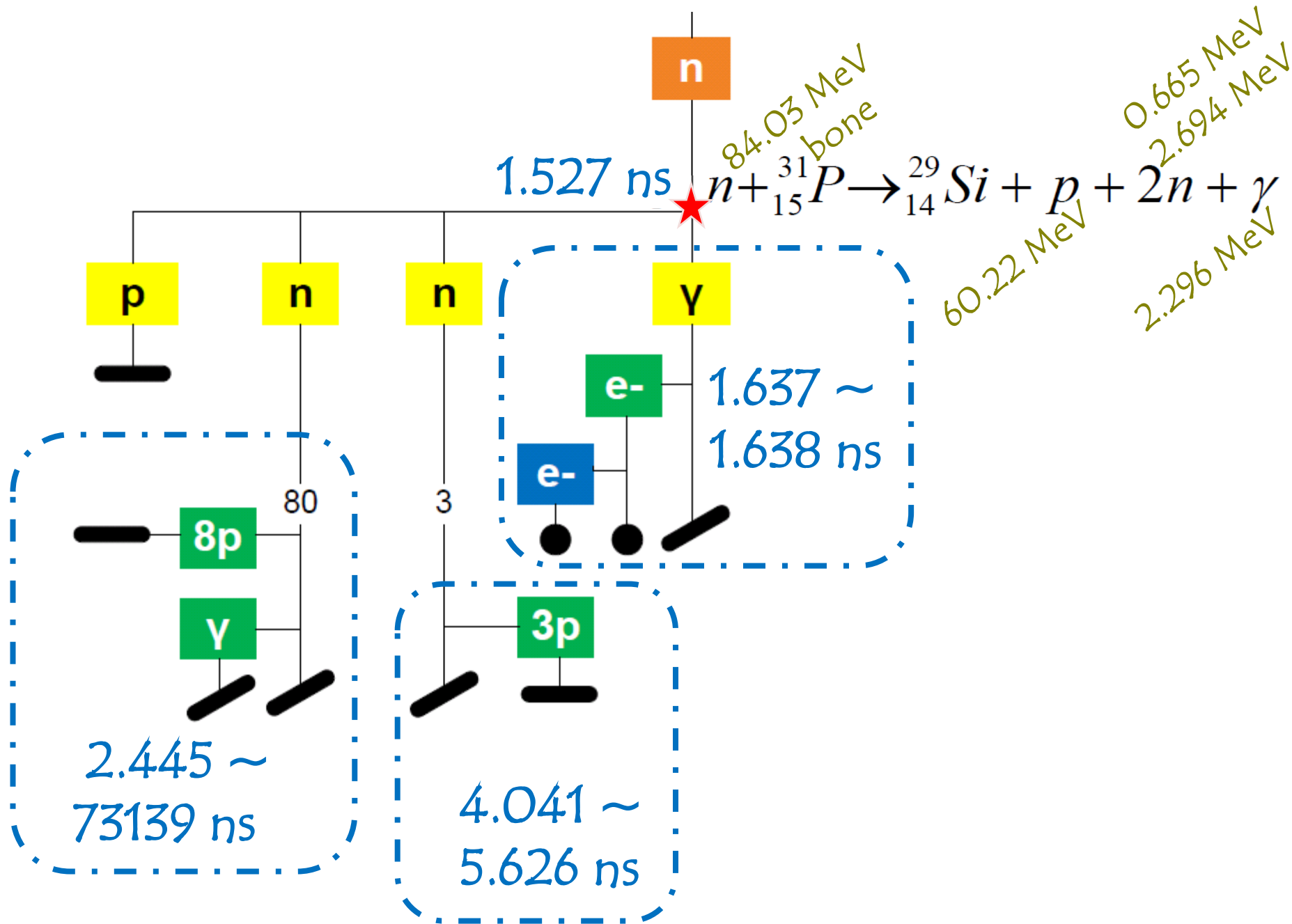


# C-12

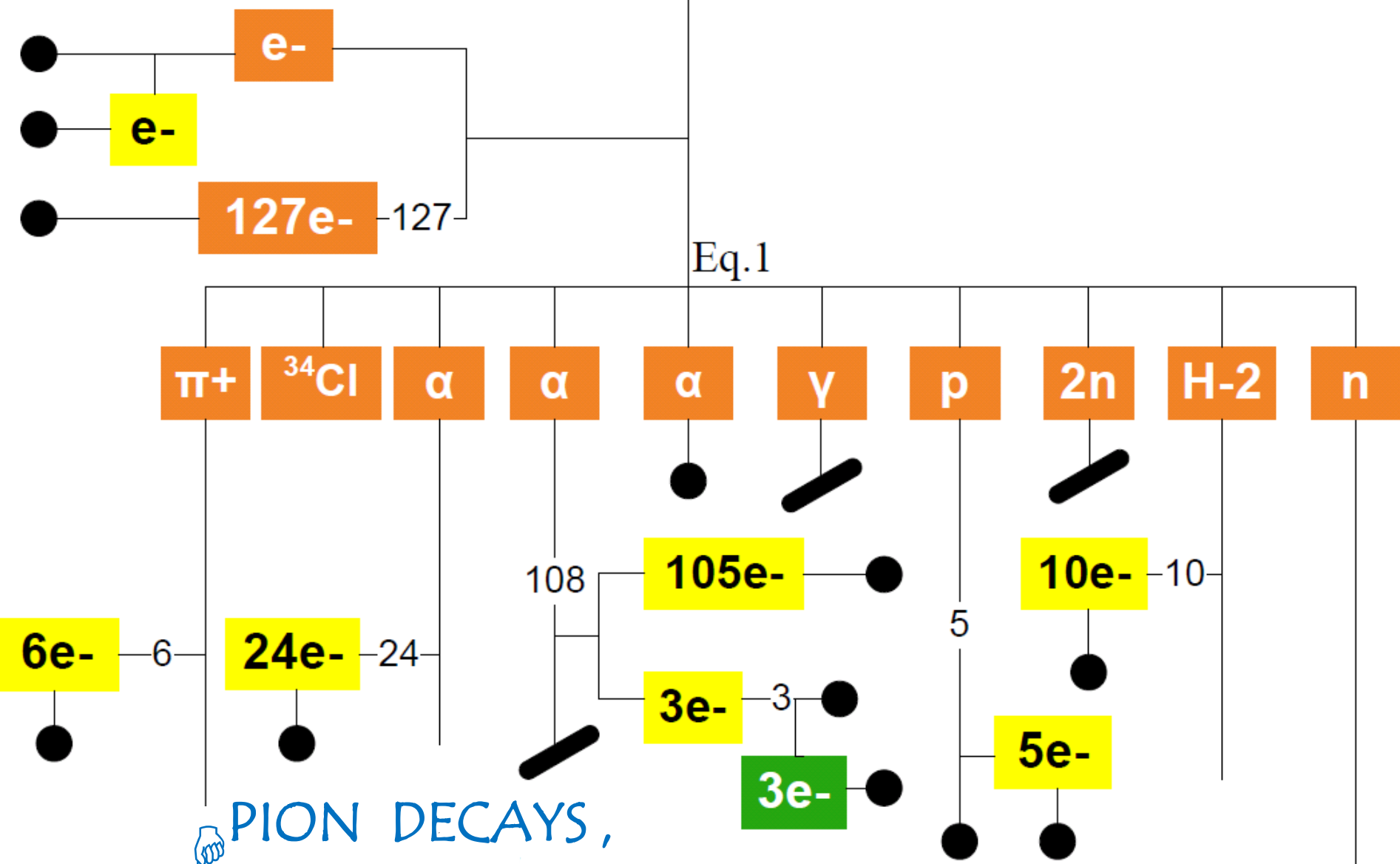


Eq.1

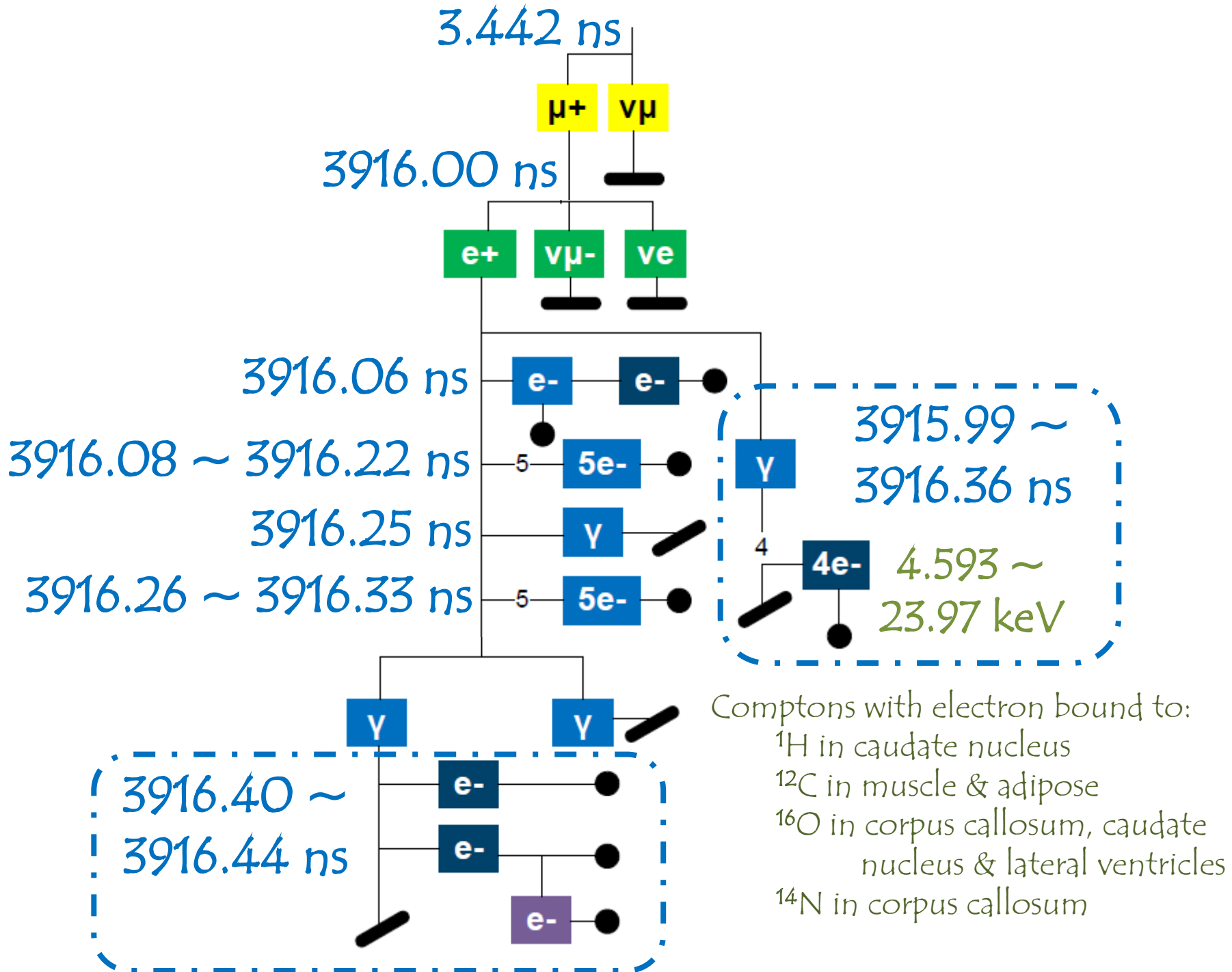




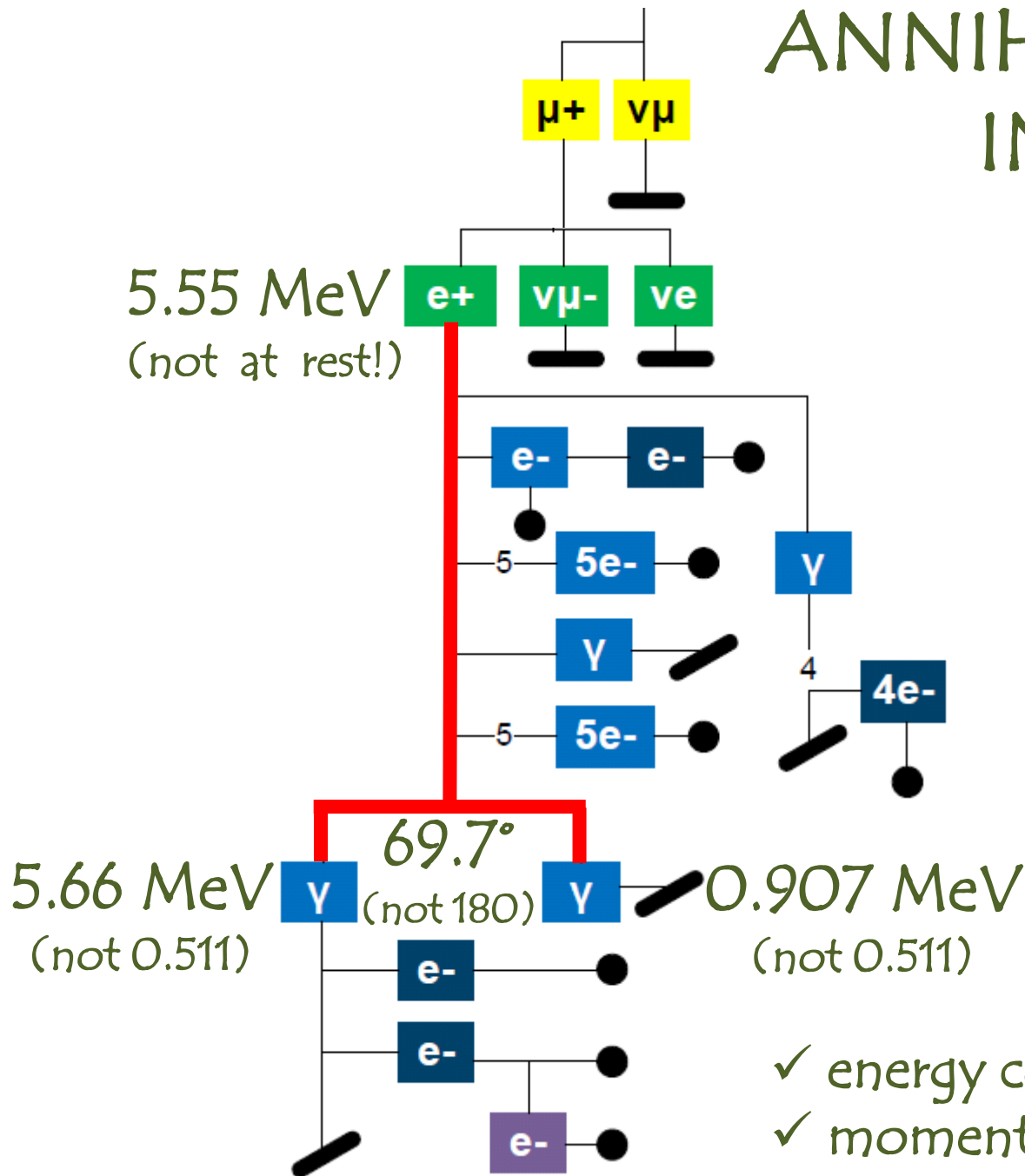
# C-12



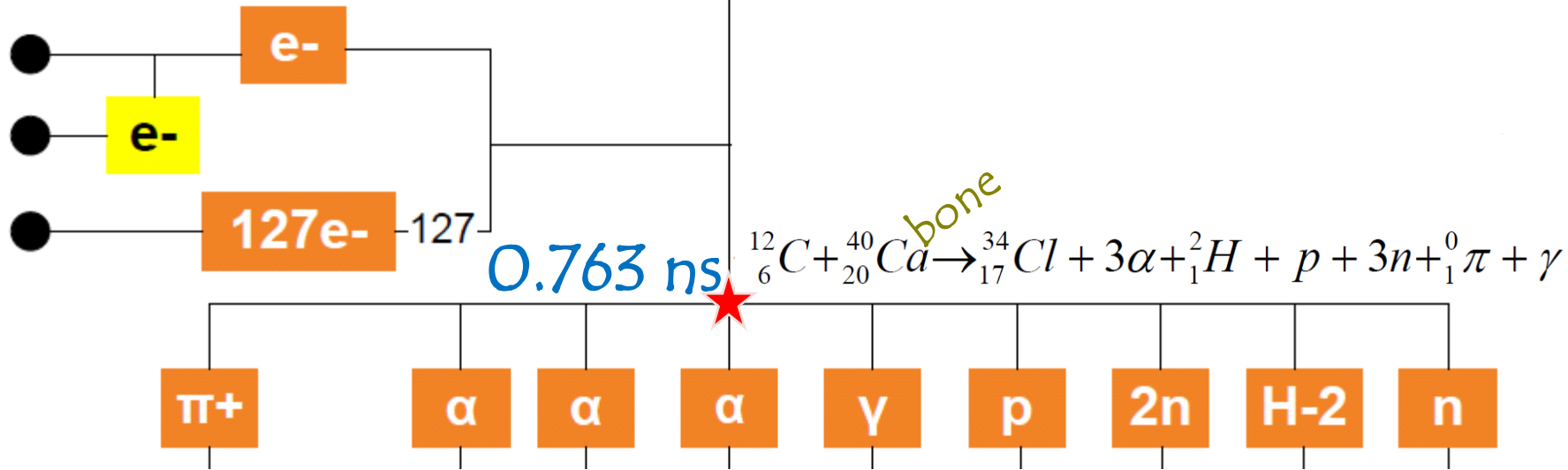
**PION DECAYS, ELECTROMAGNETIC SHOWER FOLLOWS**



# ANNIHILATION IN-FLIGHT



# C-12



CARBON STOPPED IN THE SKULL.  
2.72 cm UNDER THE SKIN.  
RATHER PREMATURE.

IS 300MeV/A TOO LOW THEN?

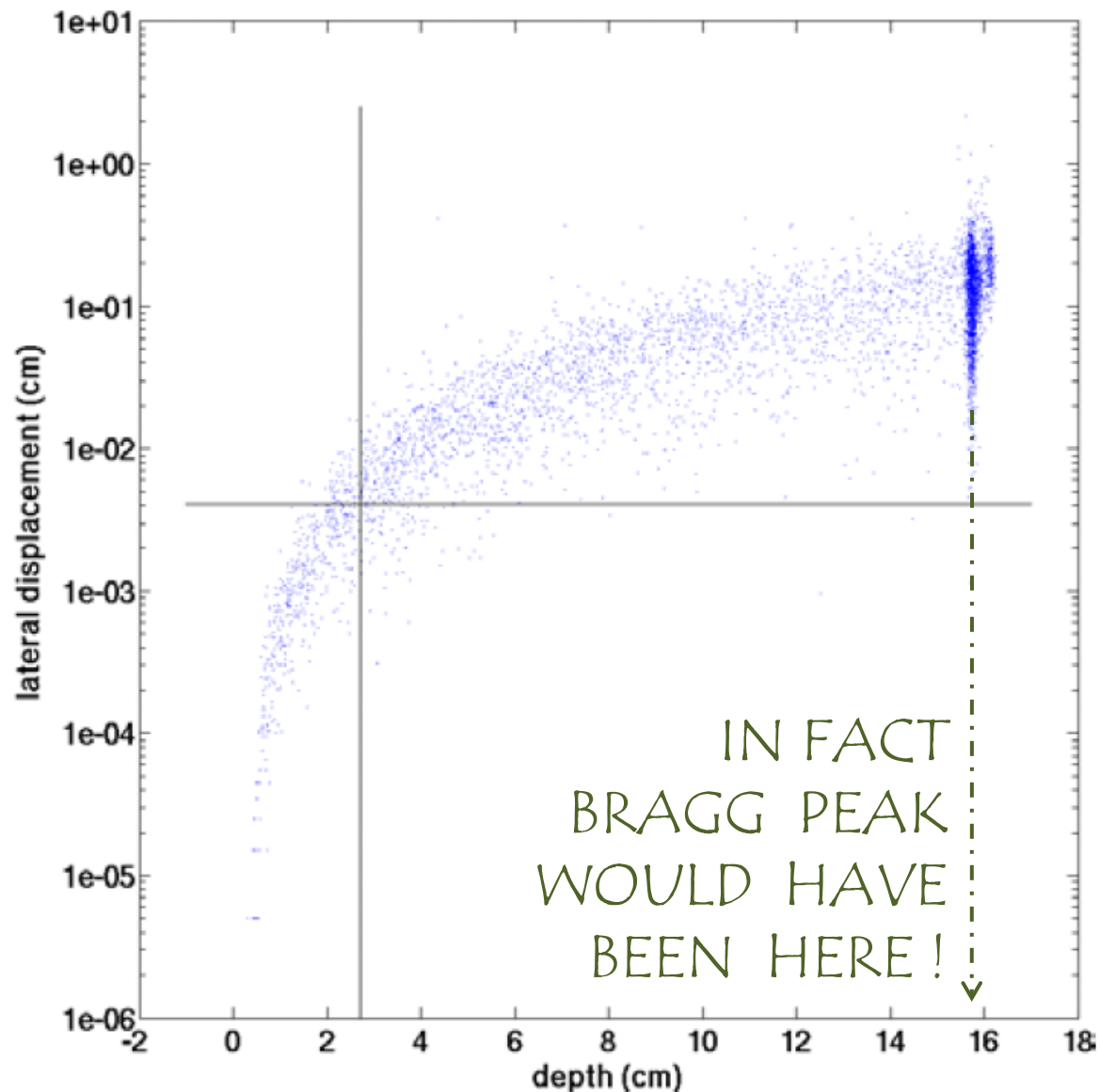
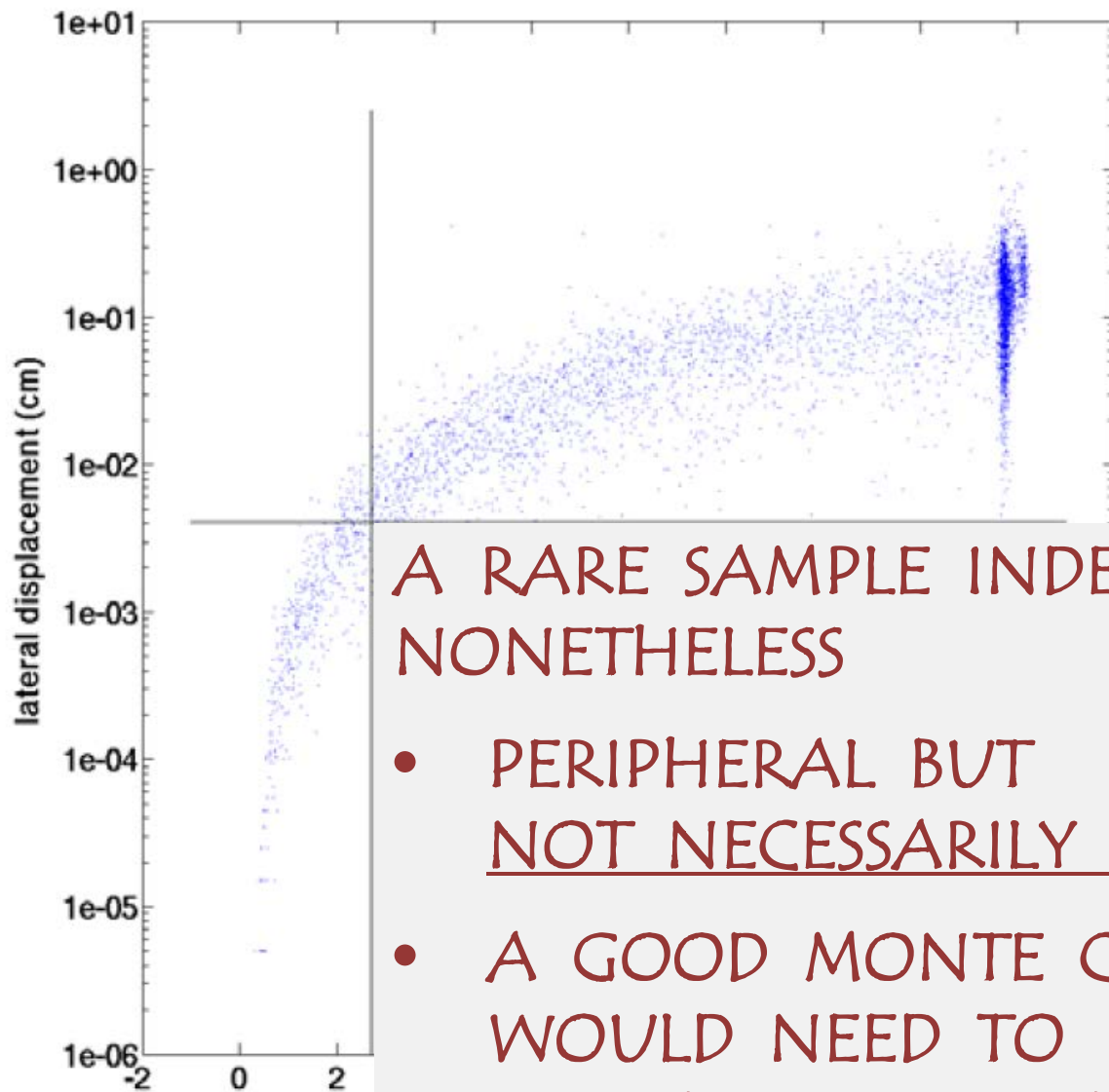


Fig. 2. Position where  $^{12}\text{C}$  track ended: the 3741th history (cross-hair) in the context of 5000 histories, of which 10 escaped.



A RARE SAMPLE INDEED,  
NONETHELESS

- PERIPHERAL BUT NOT NECESSARILY NEGLIGIBLE
- A GOOD MONTE CARLO CODE WOULD NEED TO GET THE TAIL RIGHT
- GOOD TRAINING SHOULD TELL THE FULL STORY

# MONTE CARLO

## ANALOG

$E, p, A, Z$  conserved at each point of interaction



Each particle has a uniquely-defined parent; each sibling (if any) is uniquely identified

## NON-ANALOG

Kinship is lost

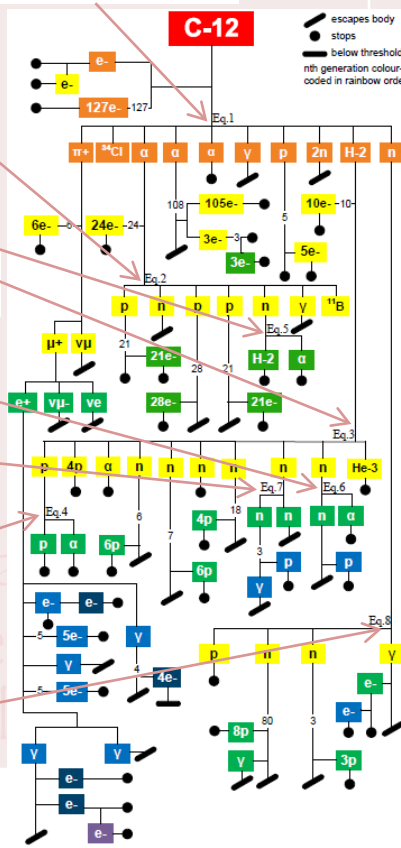
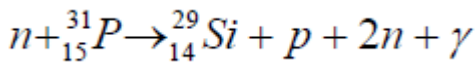
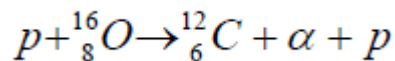
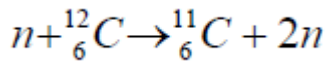
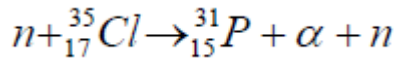
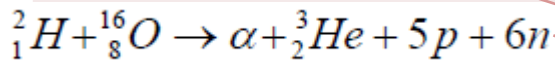
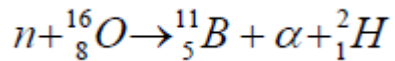
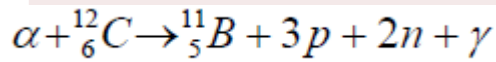
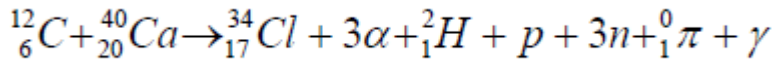


Doesn't matter if we want averaged estimations eg. dose or fluence – same results

# MONTE CARLO

## ANALOG

$E, p, A, Z$  conserved at each point of interaction



## NON-ANALOG

Kinship is lost

Doesn't matter if we want averaged estimations eg. dose or fluence - same results

# DISPLAYING PARTICLE TRACKS

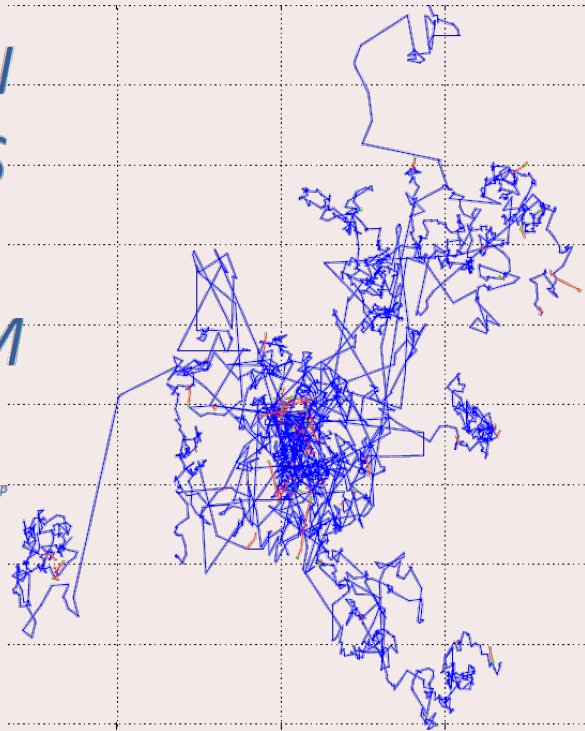
HOMOGENEOUS PHANTOM  
ala-cloud chamber  
2D: no problem

SOMEBODY'S HEAD  
not so easy to plot

**CARBON  
STORIES  
IN  
CALCIUM**

[mary.chin@cern.ch](mailto:mary.chin@cern.ch)

1<sup>st</sup> FLUKA Advanced Course & Workshop  
Ericeira 4-8 Oct 2010



No three points  
can be drawn  
on the same  
2D background

ANYWAY X,Y,Z ARE NOT THE MOST  
IMPORTANT PHASE-SPACE PARAMETERS

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