The Primordial Lithium Problem

Can We Avoid New Physics ?

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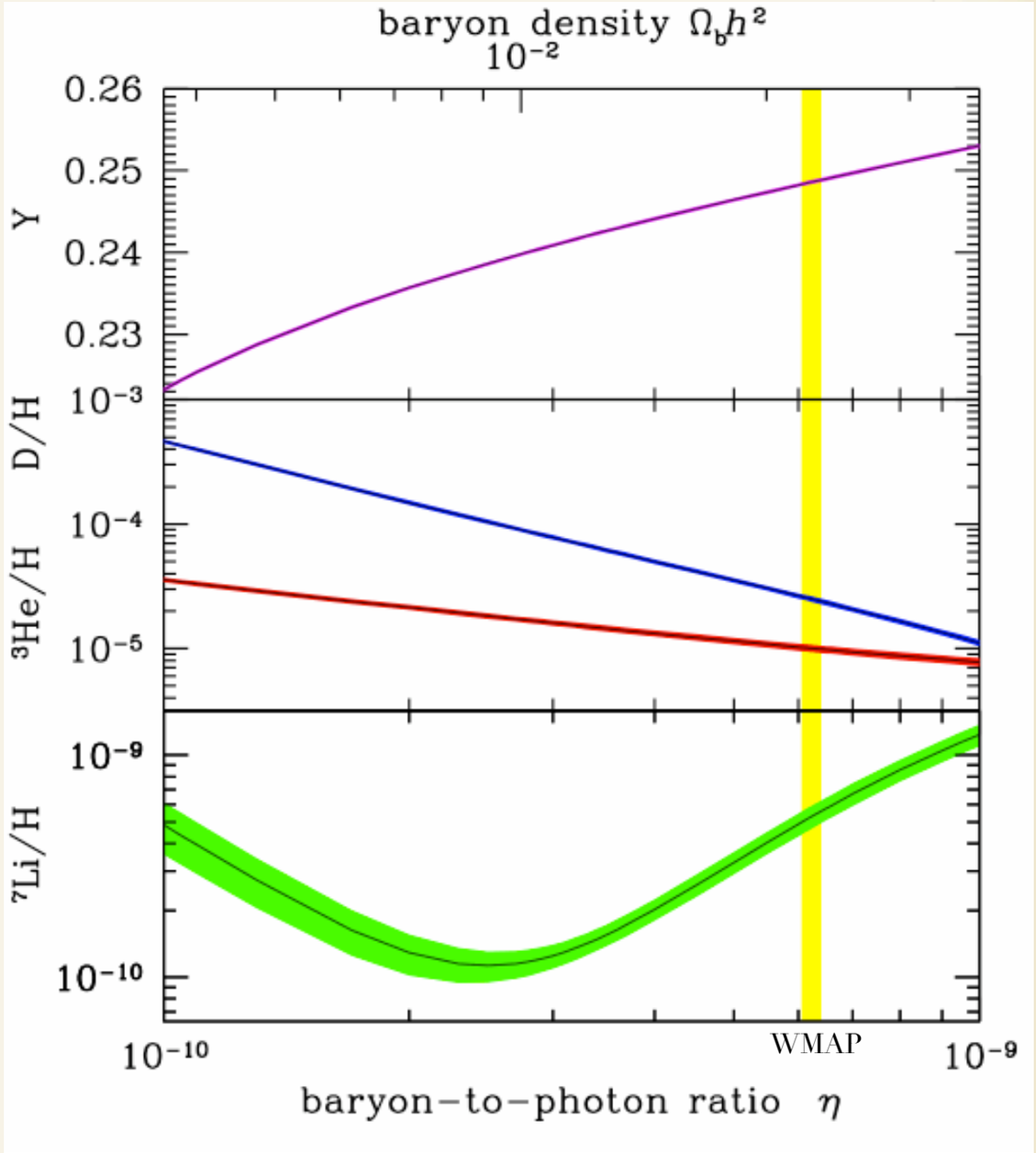
Great Lakes Cosmology Workshop 2010

What's the problem ?

- Light elemental abundances constrain Big Bang cosmology
  (Wagoner, Fowler and Hoyle, 1967 ; Steigman, Schramm and Gunn, 1977 ; Schramm and Turner, 1998)
- Abundances set by

  $n_B/n_\gamma = \eta \propto \Omega_b$
- WMAP gives η
- Discrepancy between theory (Cyburt, Fields and Olive, 2008) and observation of ^{7}Li (Spite and Spite, 1982 ; Smith et al., 1998)
- "Law of trichotomy"
  - Theory wrong
  - Observation wrong (Richards et al., 2005 ; Melendez et al., 2010)
  - Both wrong



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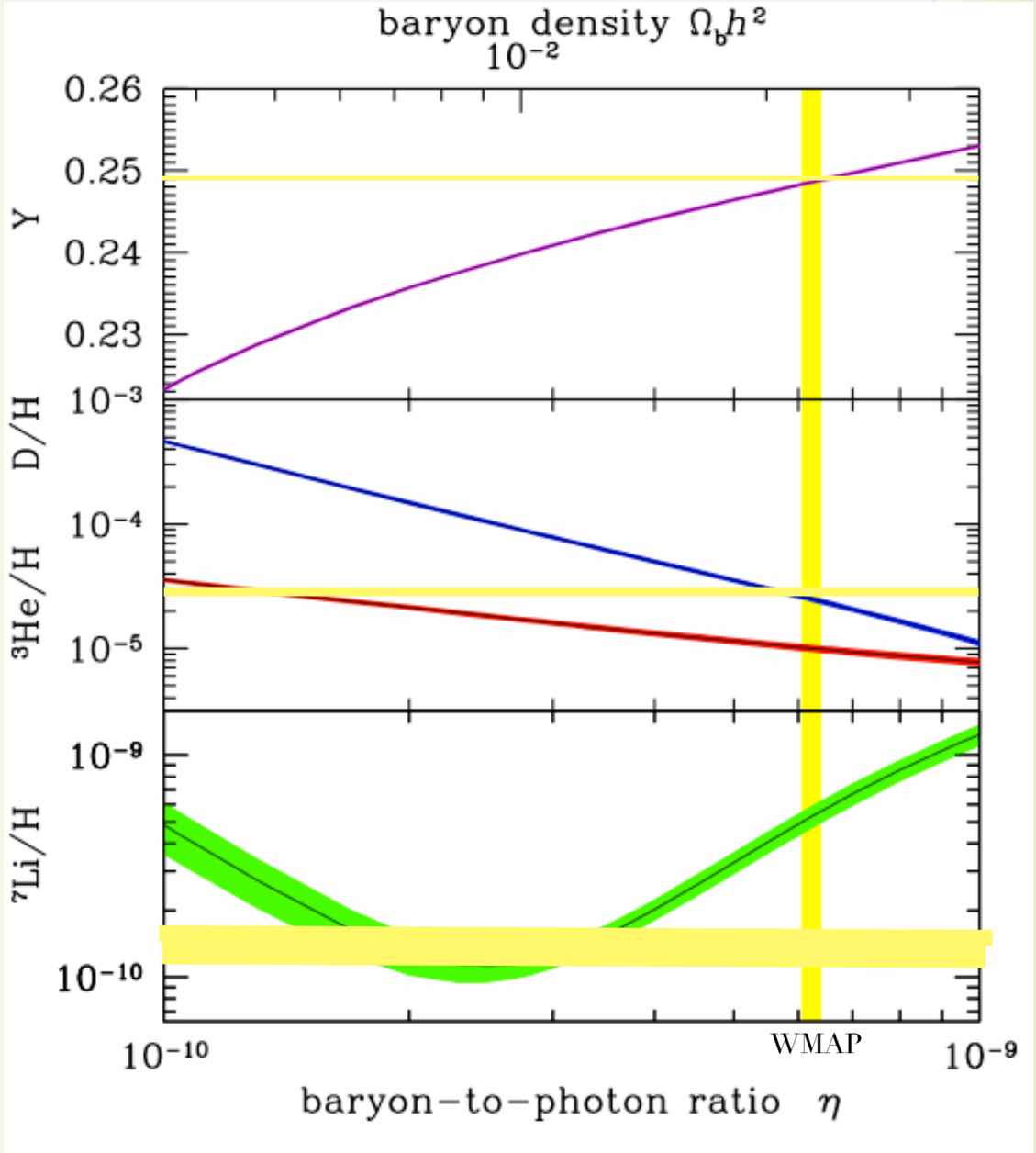

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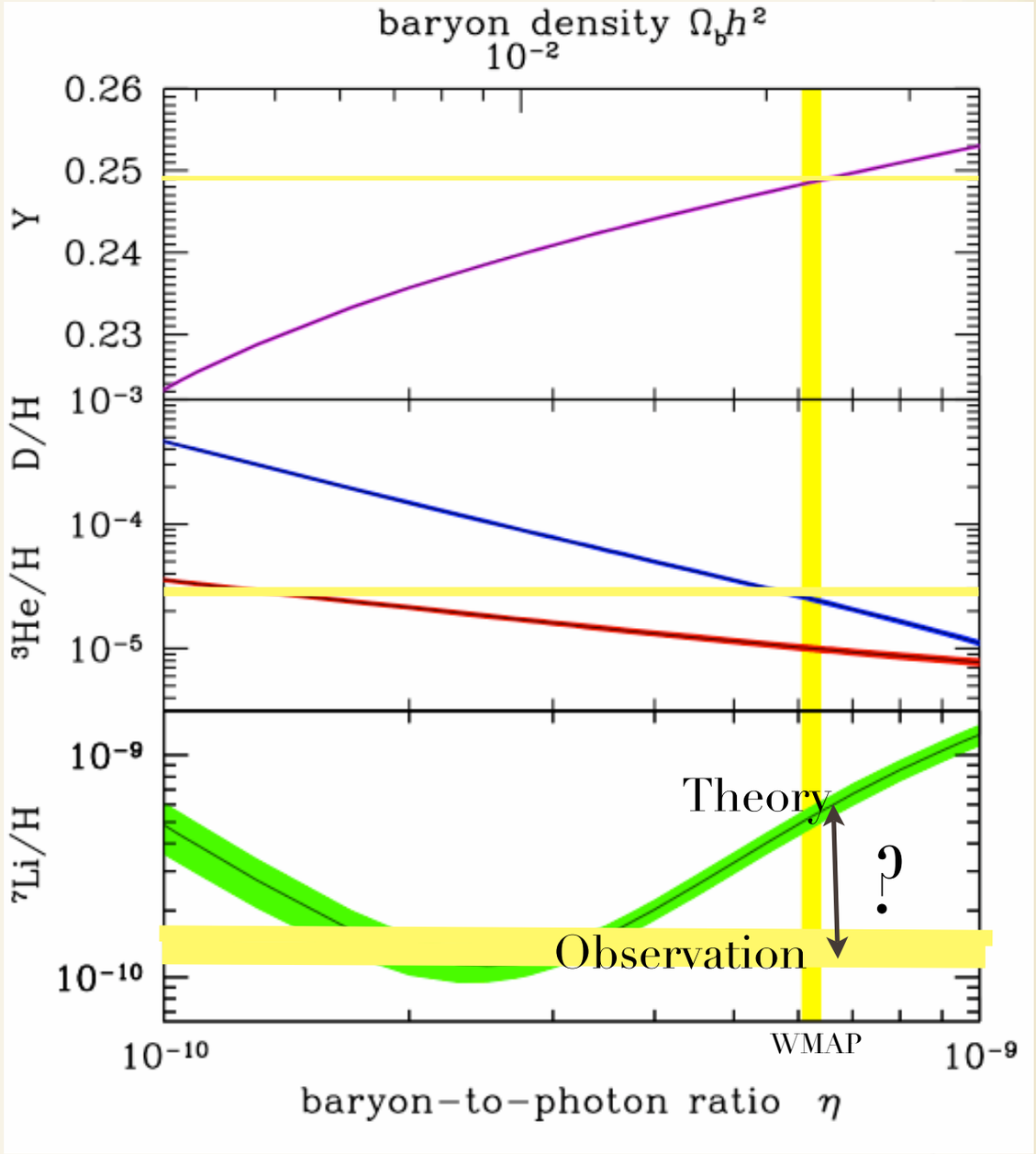

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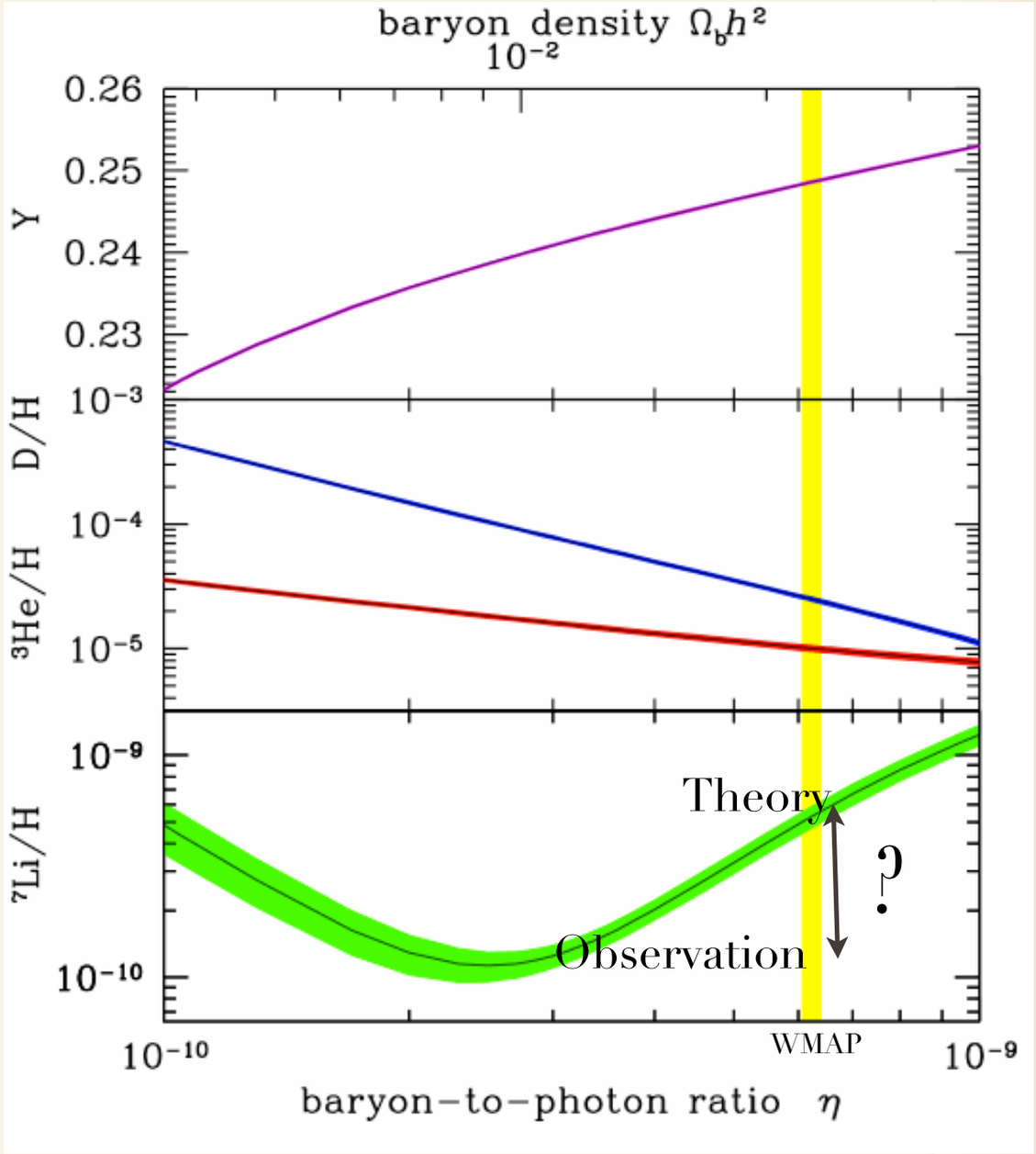

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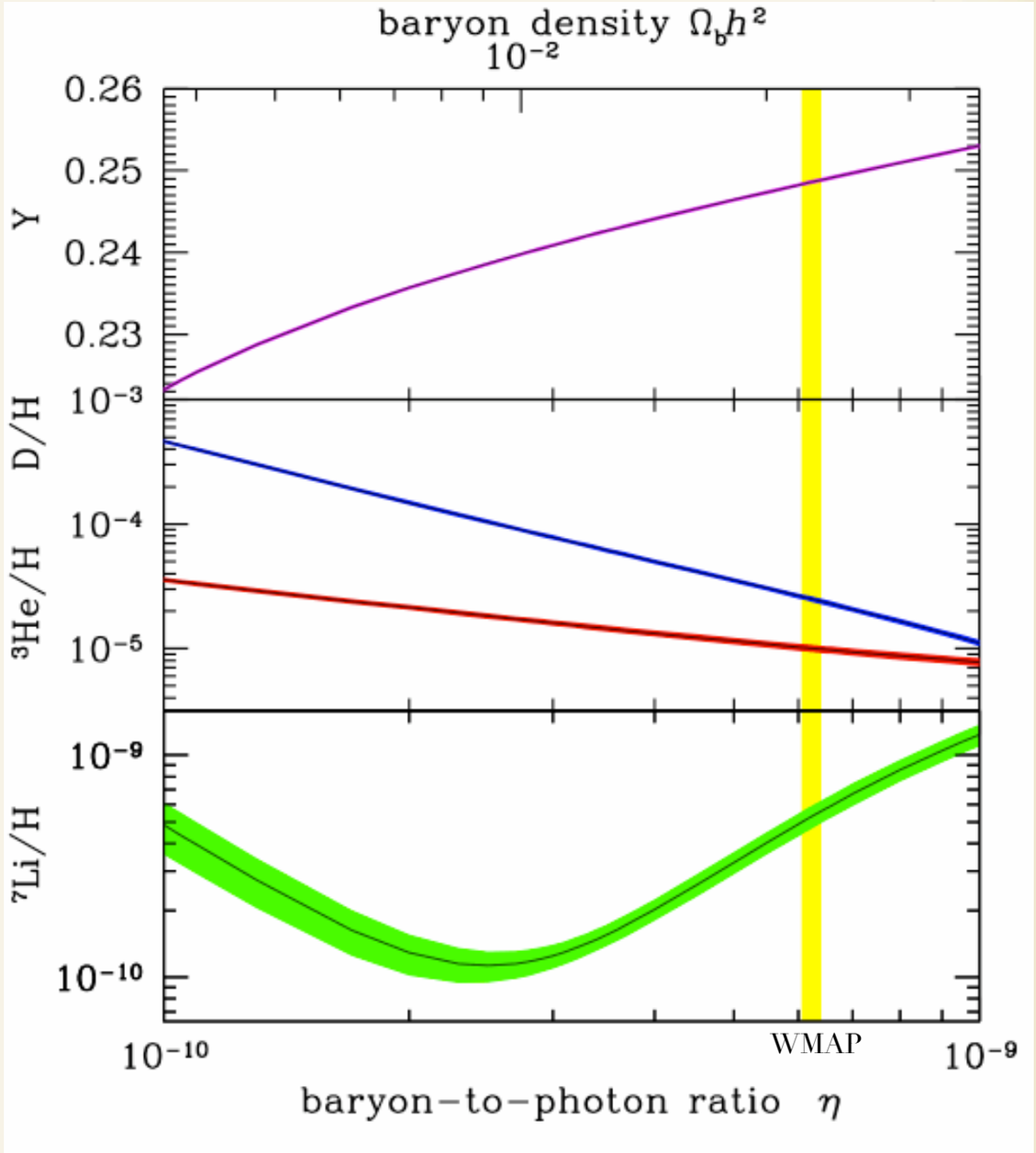

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Theory Solutions

- Assume observations right
  $\Rightarrow$ Reduce ^{7}Li or ^{7}Be
- Beyond Standard Model
  - Dark matter decay (Bailly et al., 2009 and others)
  - Bound states (Jittoh et al., 2010, Cyburt et al., 2006 and others)
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CERN

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CERN

Fermilab

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OR

- Within Standard Model
  - Enhance nuclear reactions

(Cyburt and Pospelov, 2009), Chakraborty, Fields and Olive (in prep)

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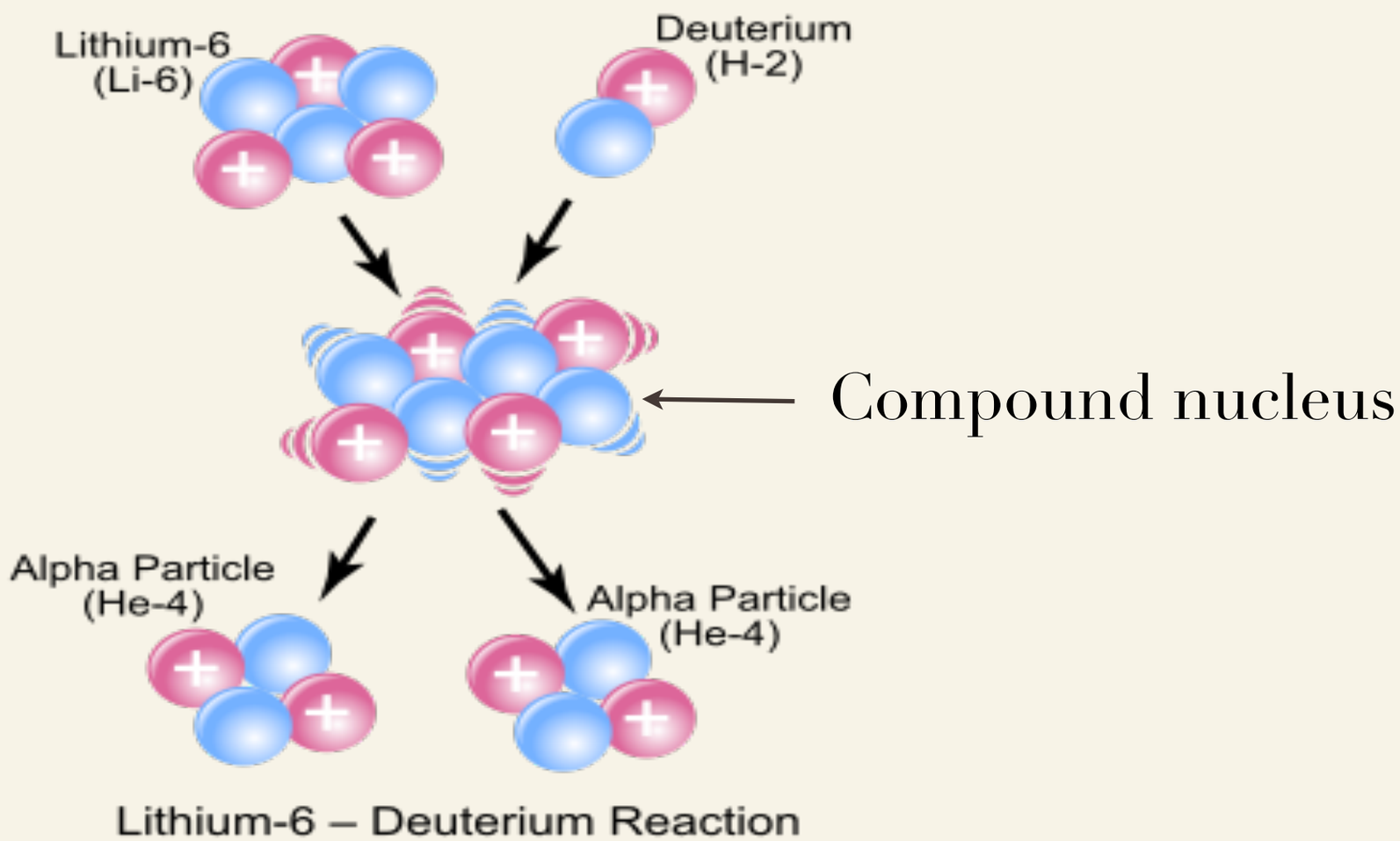
Fermilab

Resonances

Resonances



- A + B --> C + D vs A + B --> X* --> C + D

Resonance parameters

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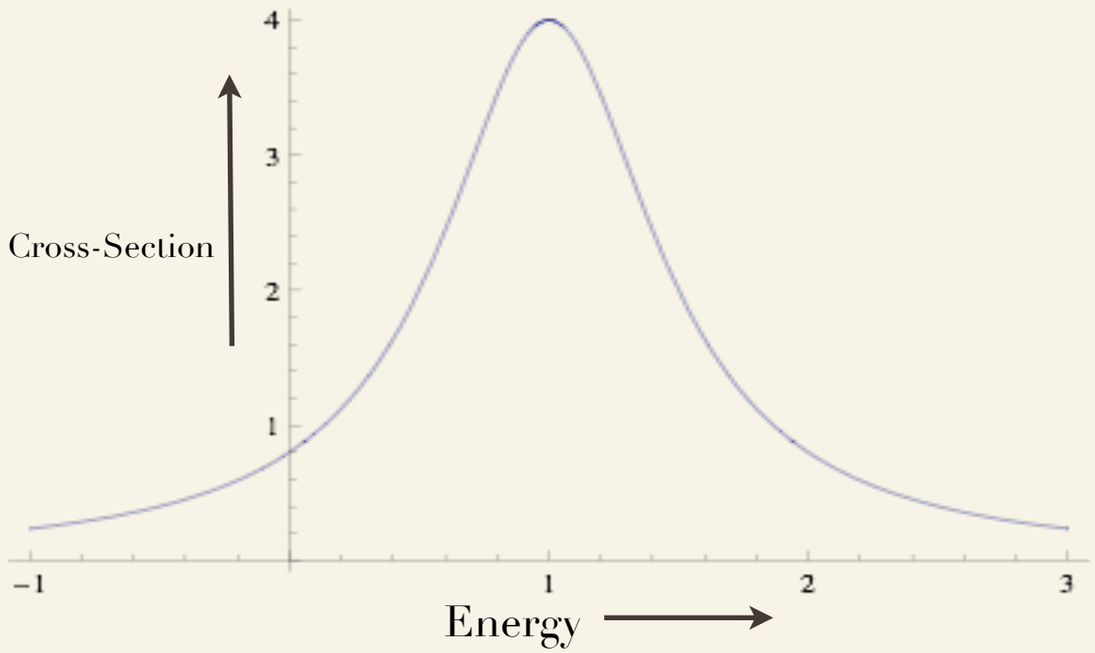

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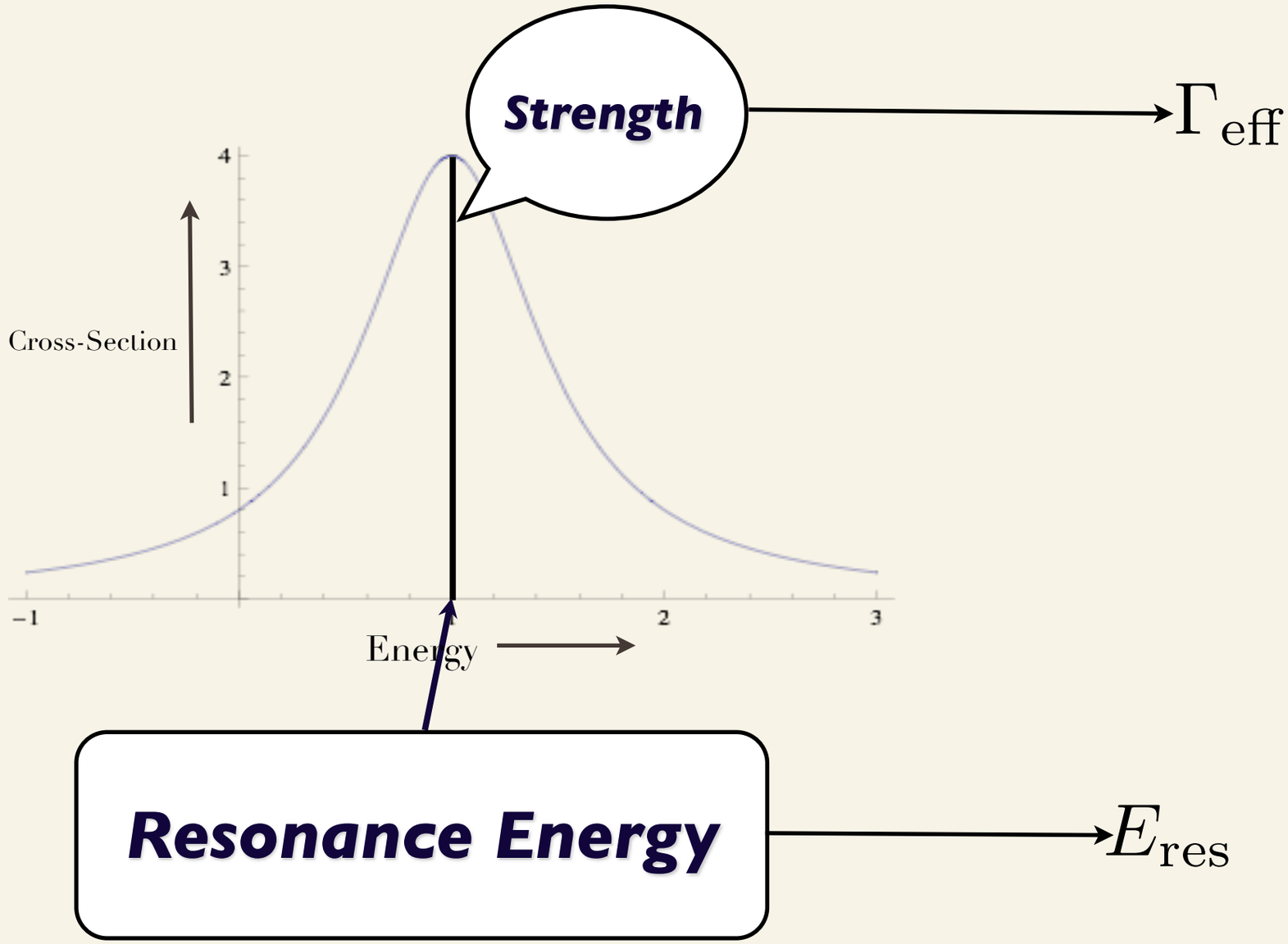

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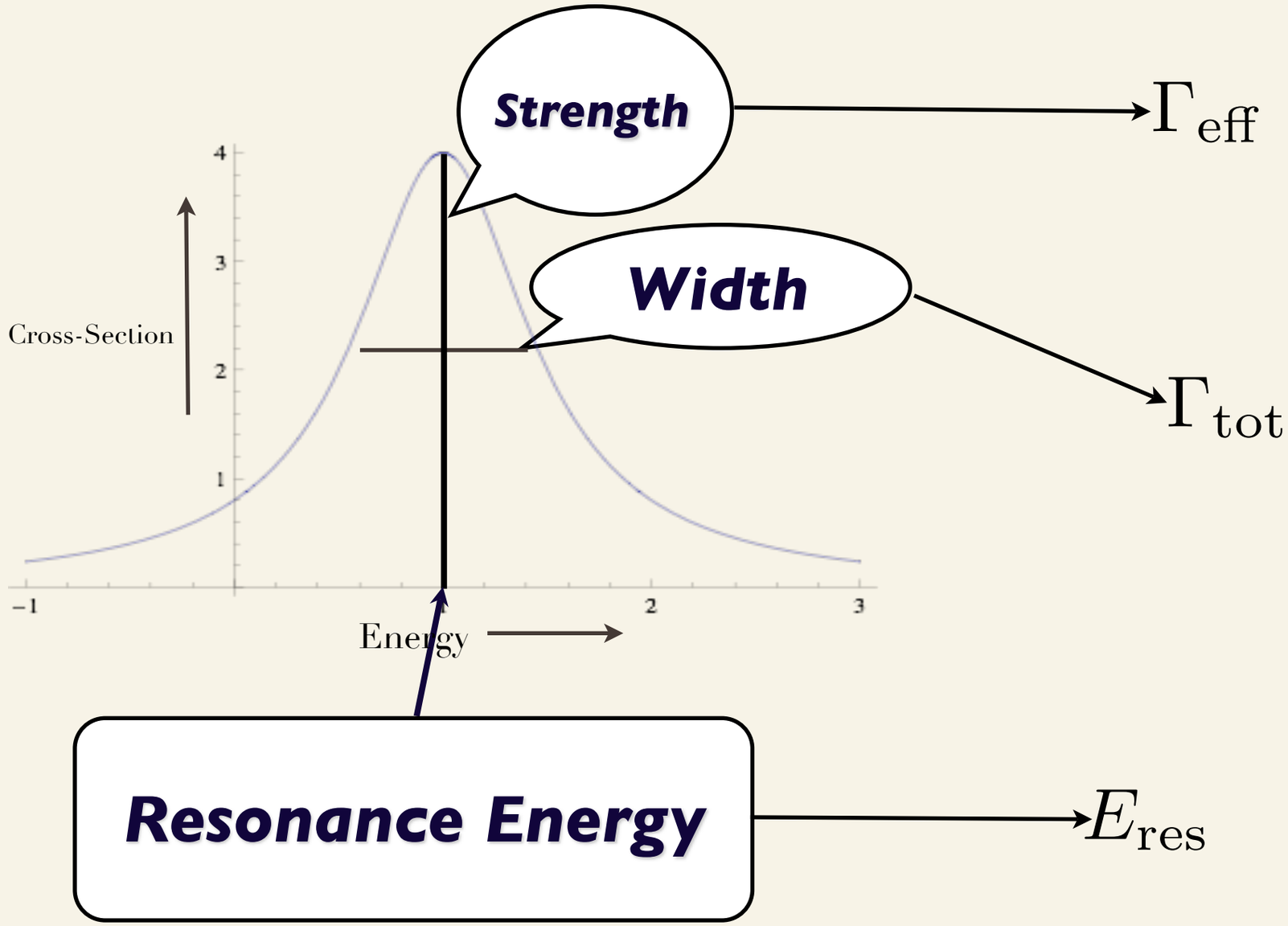

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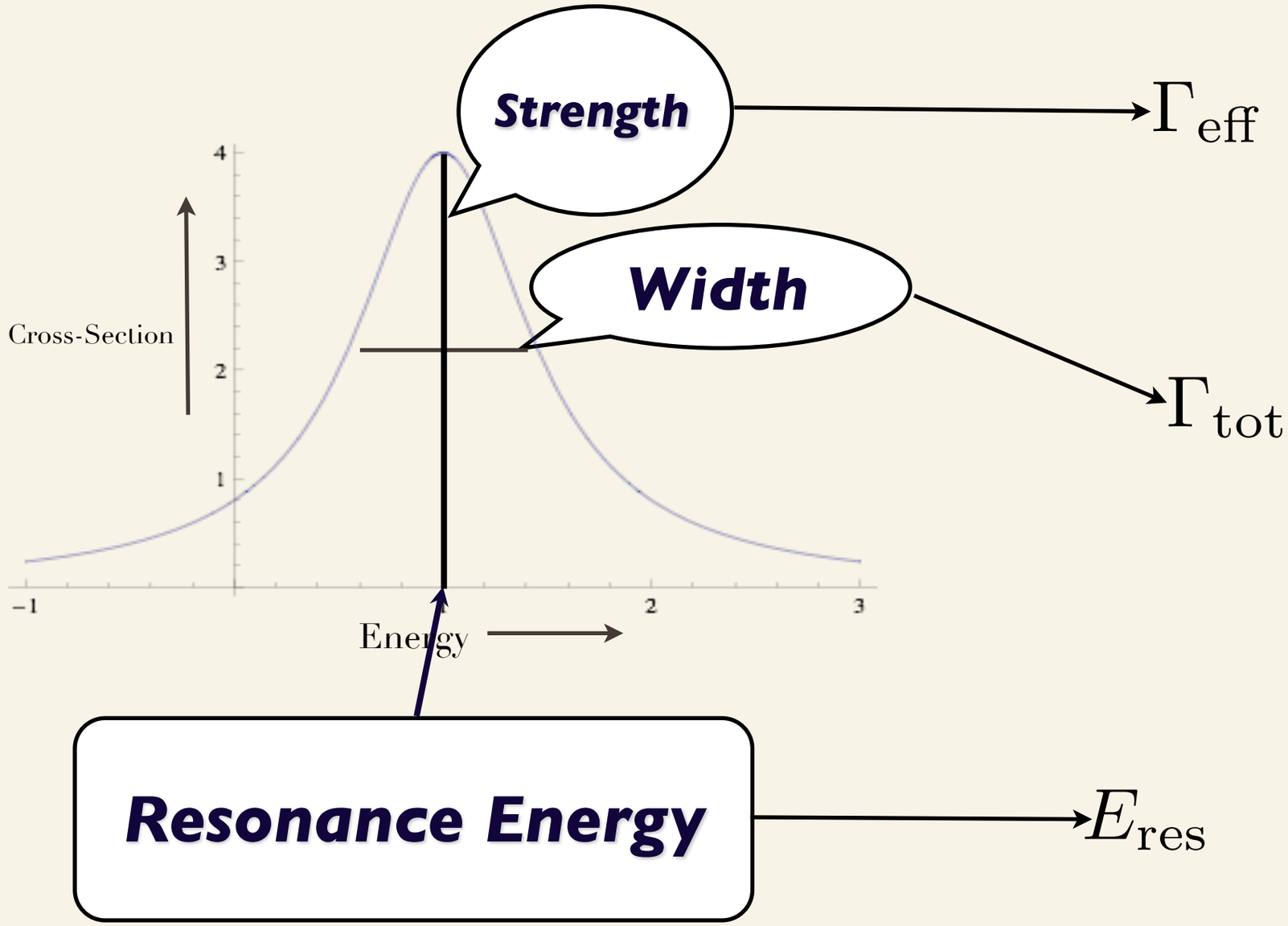

Narrow Resonance Approximation

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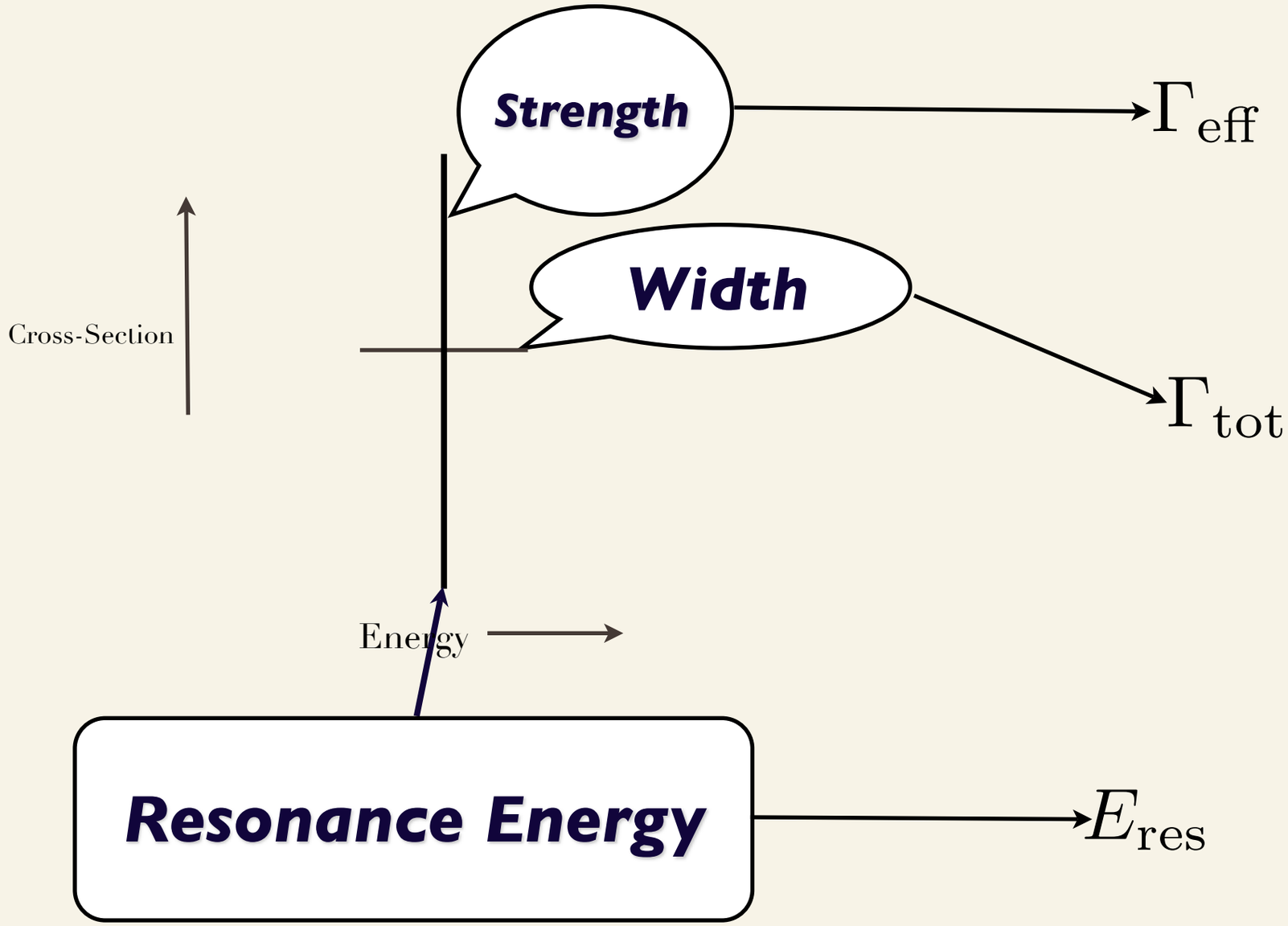

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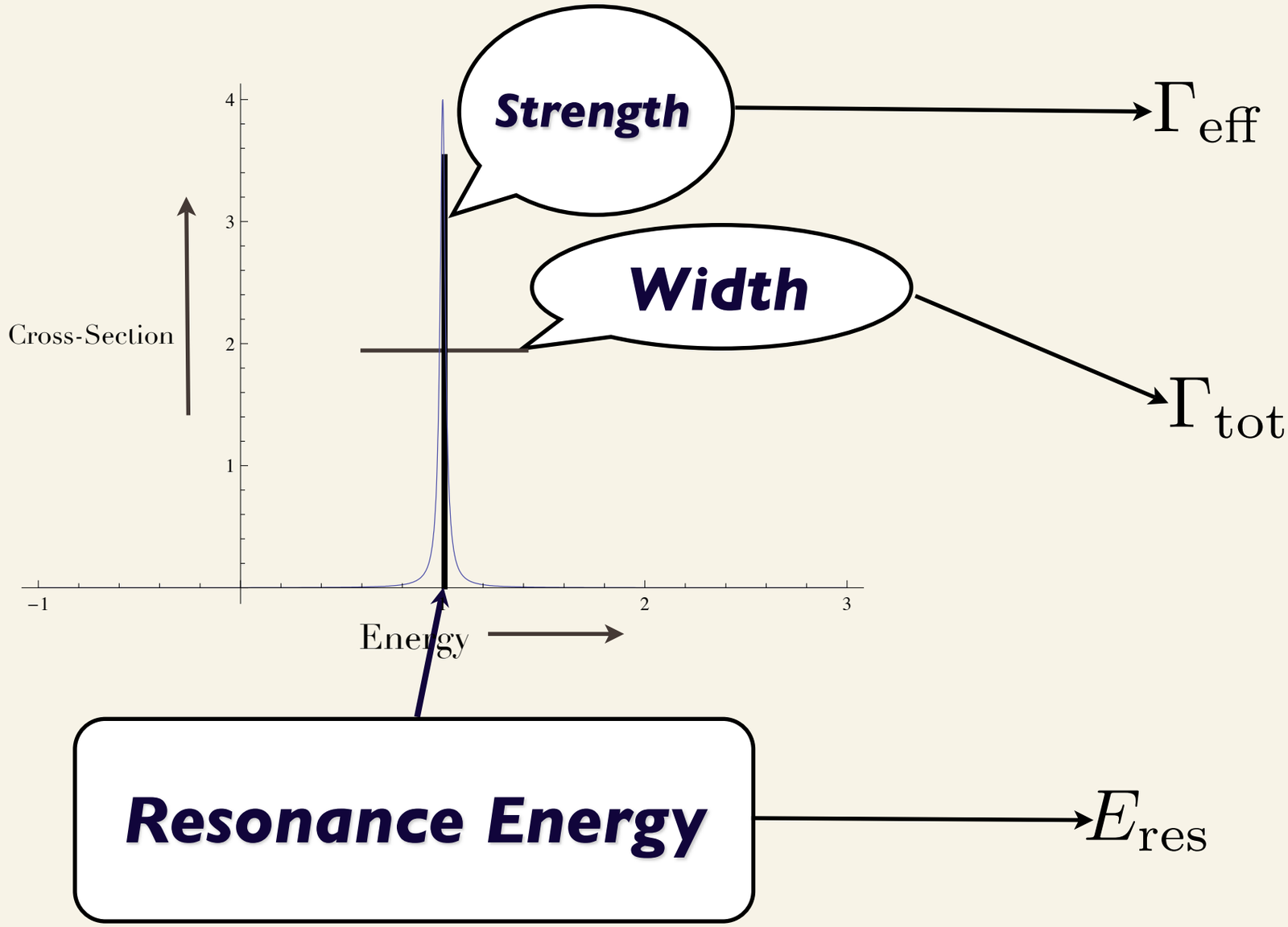

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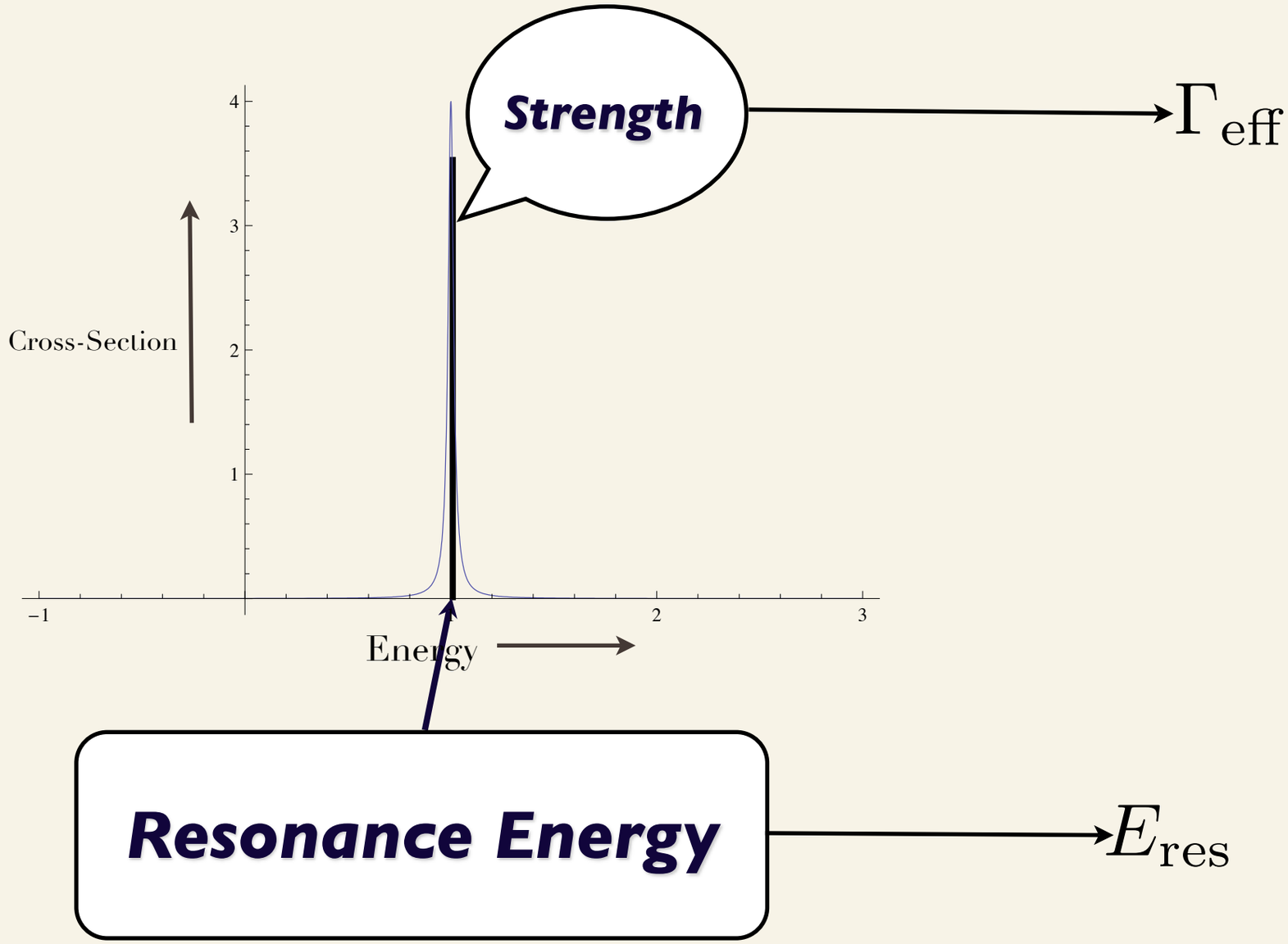

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- Cyburt and Pospelov, (2009)

  - Recognised existing level
  (16.7 MeV in ^{9}B)
  - ^{7}Be + d → p + 2 α
  - Strength unknown
  - Big error bars in E_{res}
  - Potential solution ?
  - We agree

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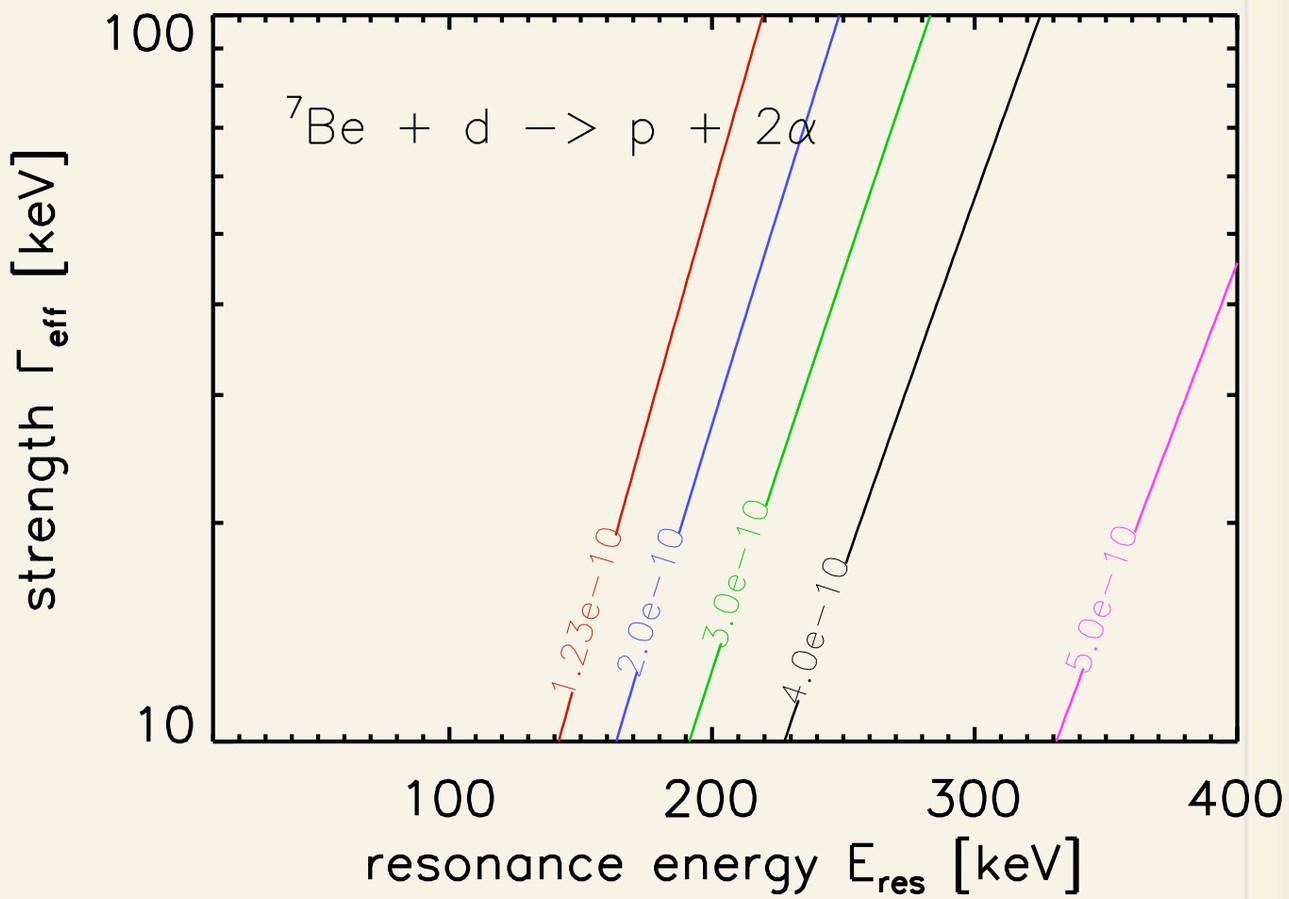

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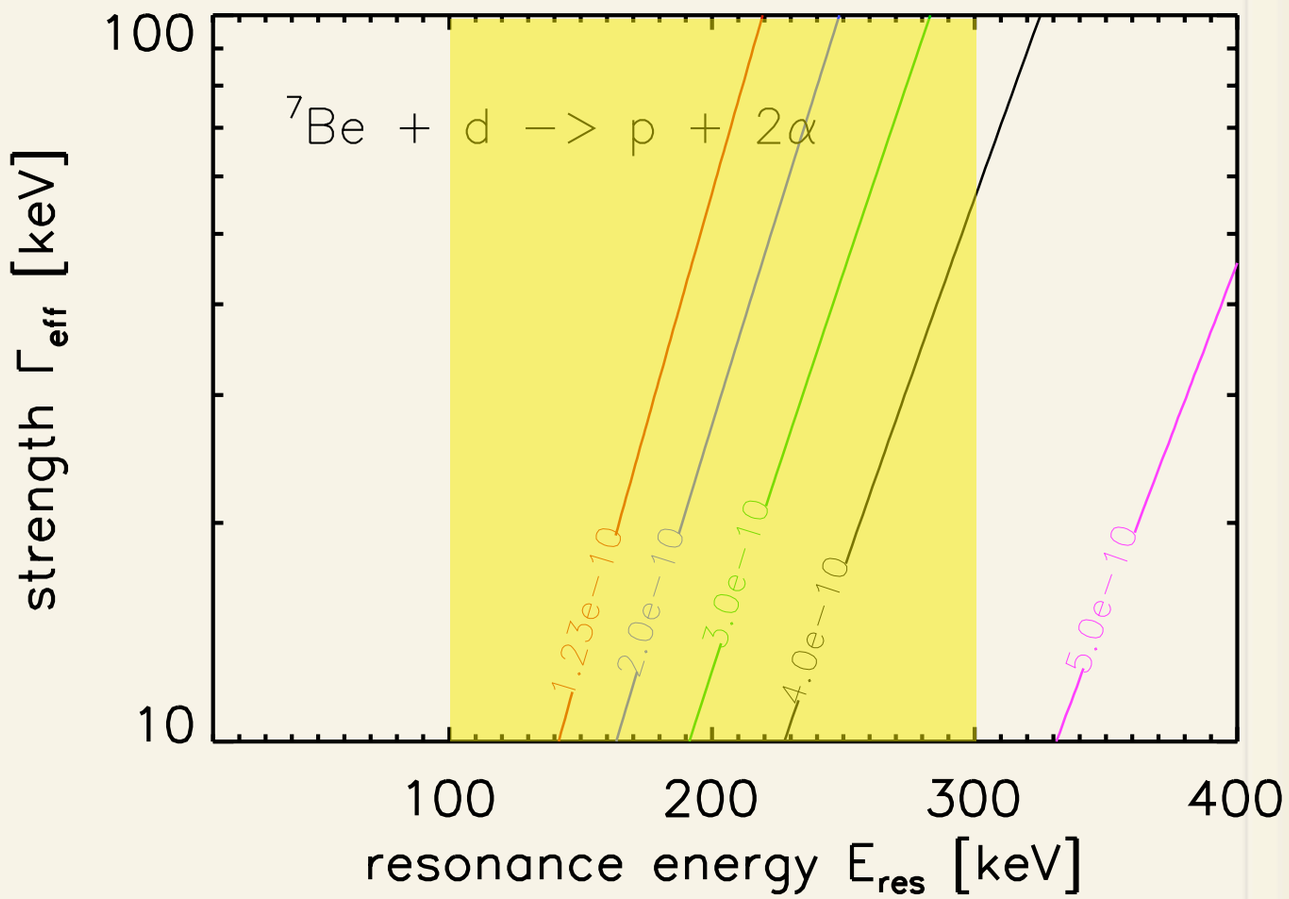

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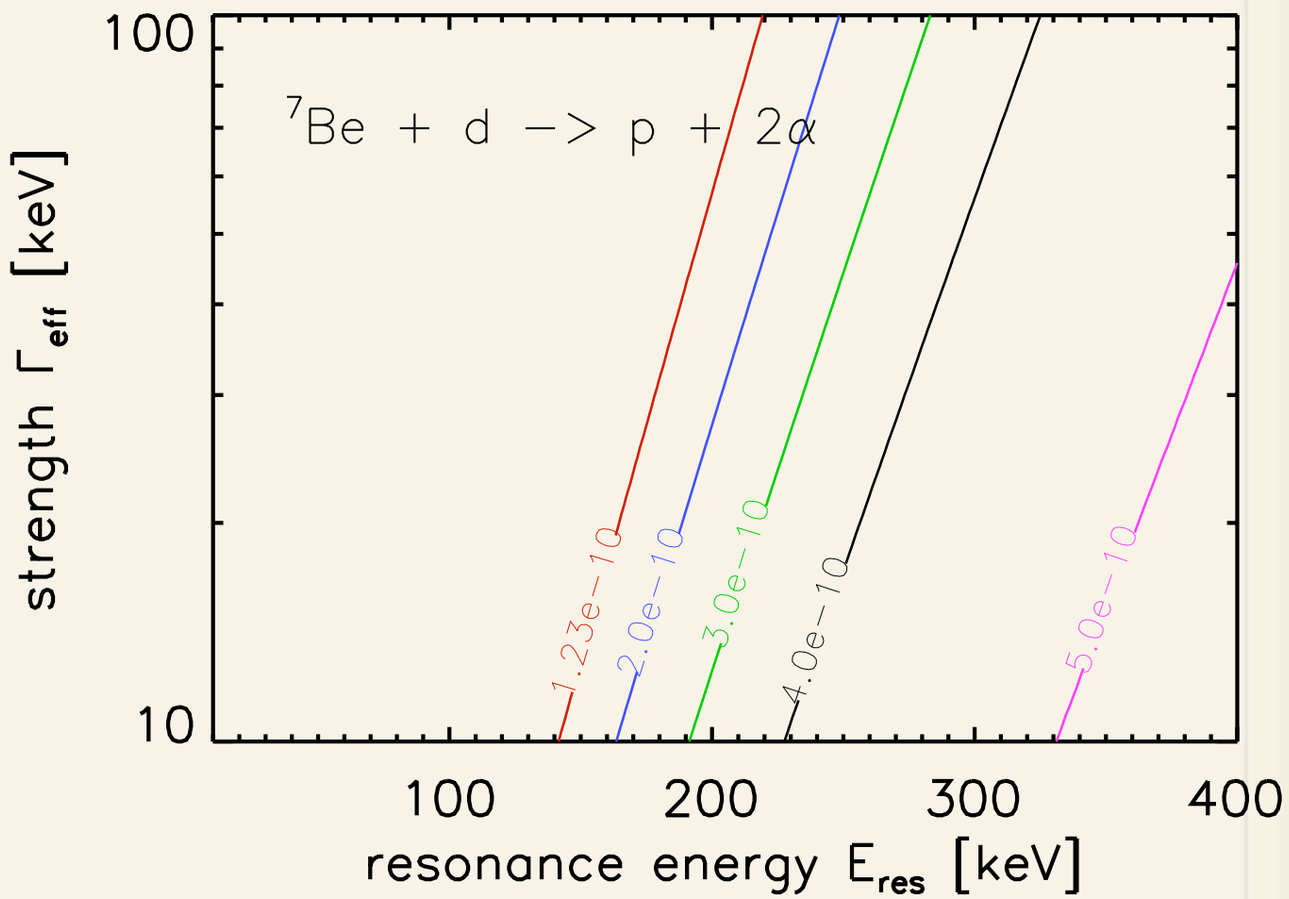

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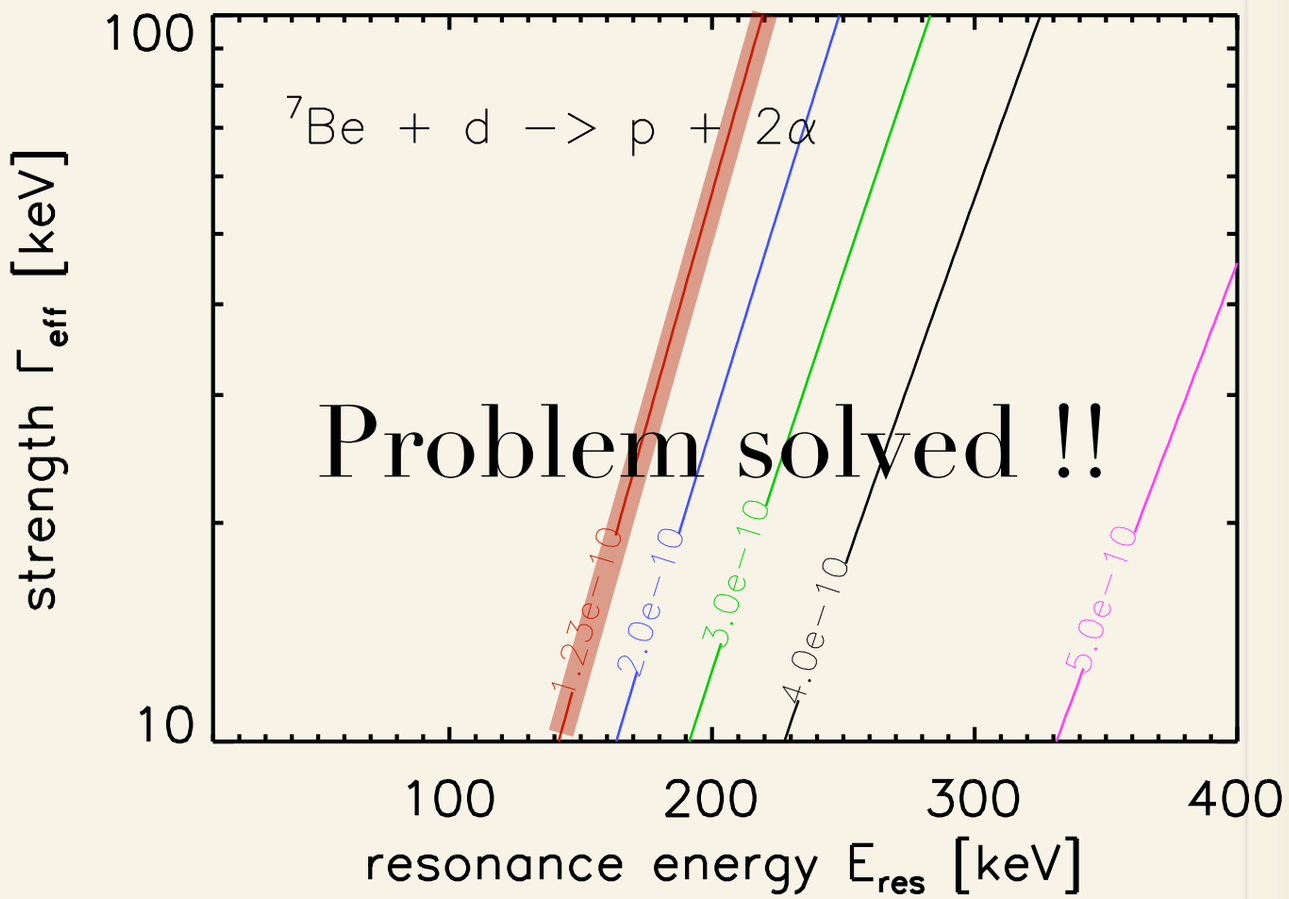

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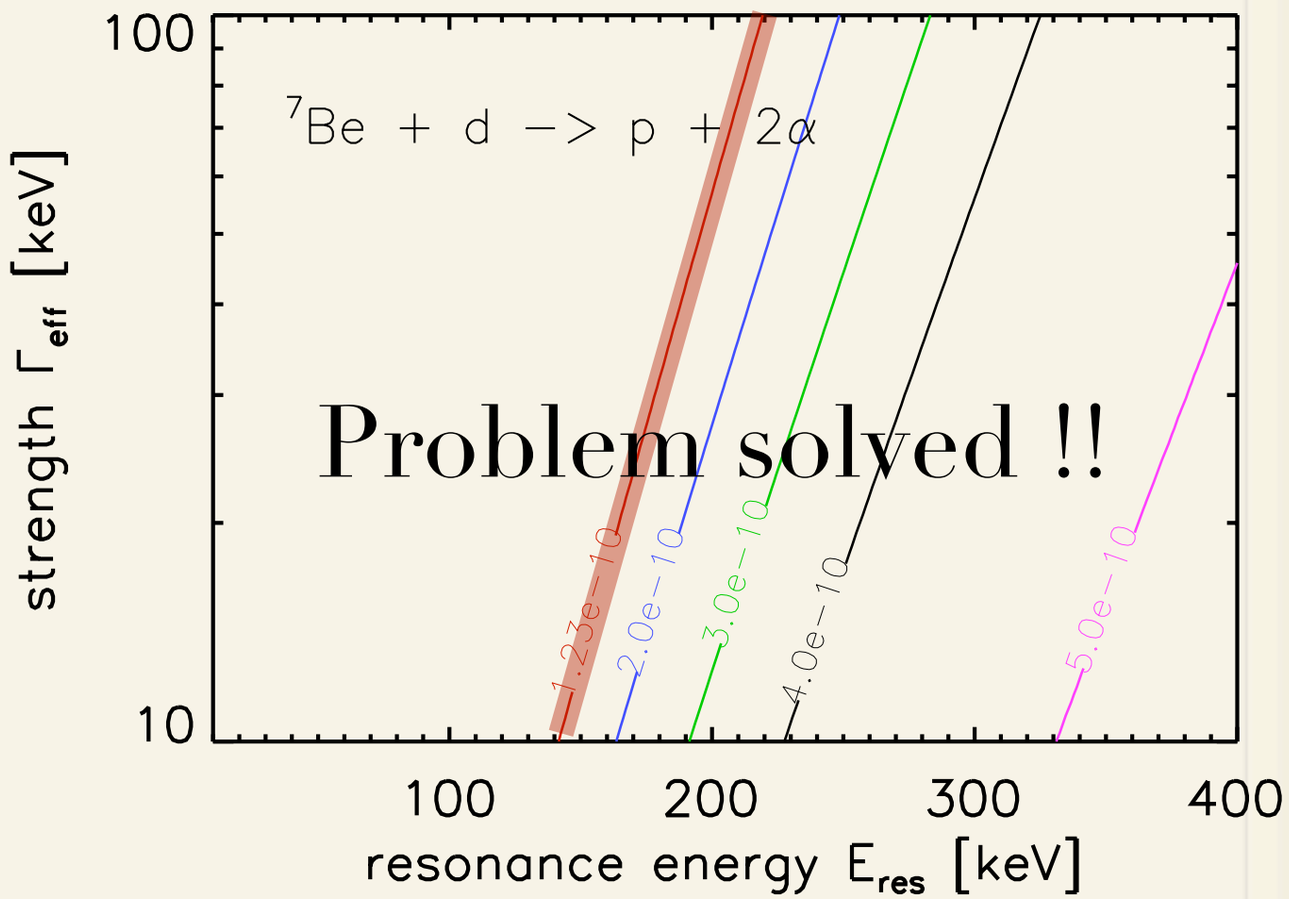

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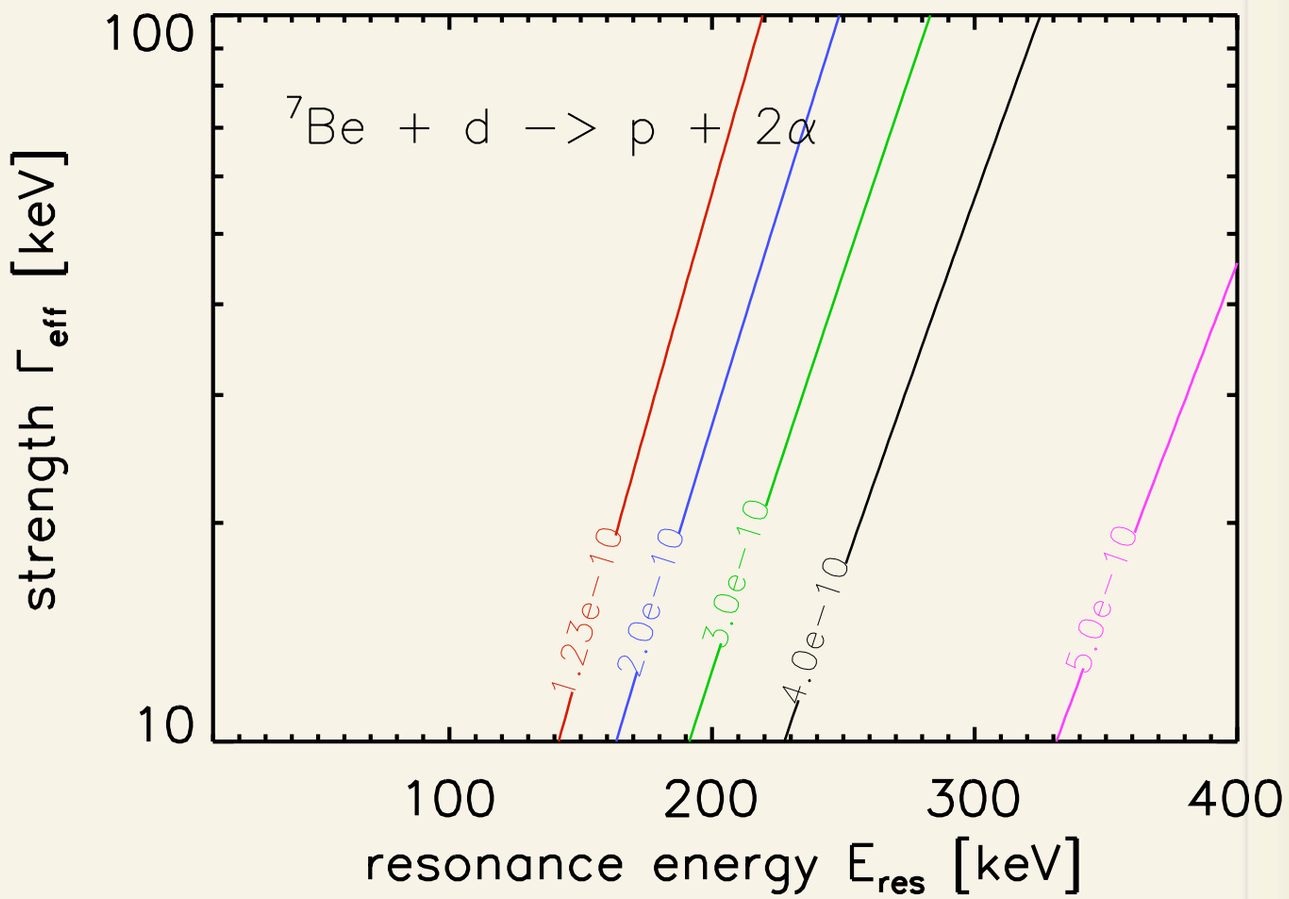

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Fear not.....there's more options

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- Chakraborty, Fields and Olive (In prep)
  - ^{7}Li or ^{7}Be can be destroyed with n, p, t, d, ^{3}He, α and γ
  - Resonances in compound nuclei with mass 8 to 11
  - Systematically list them
  - Parametrize solution space for any resonance

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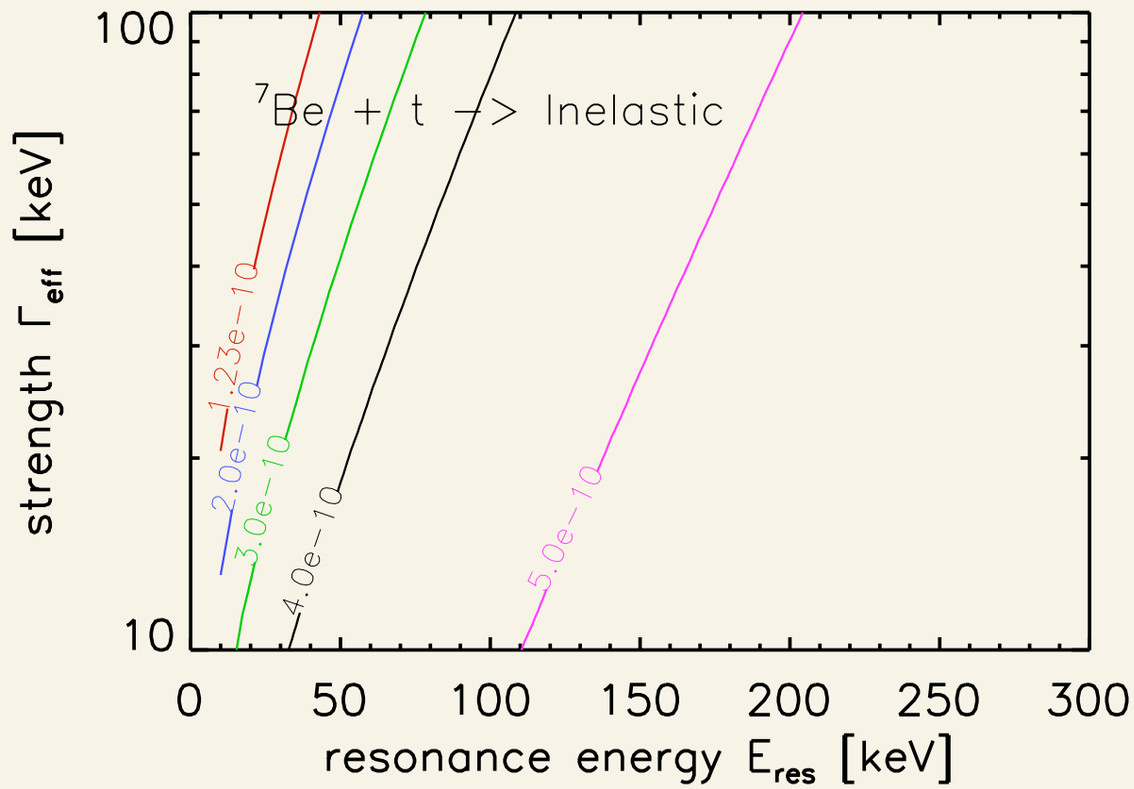

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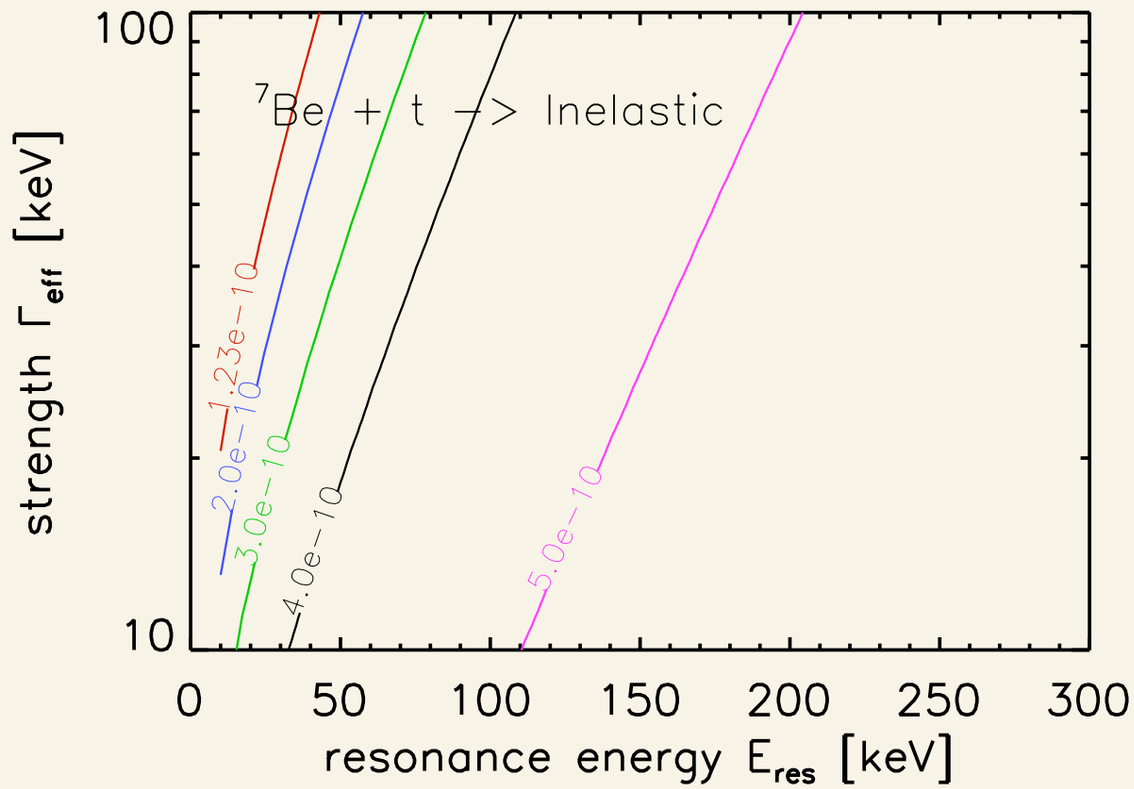

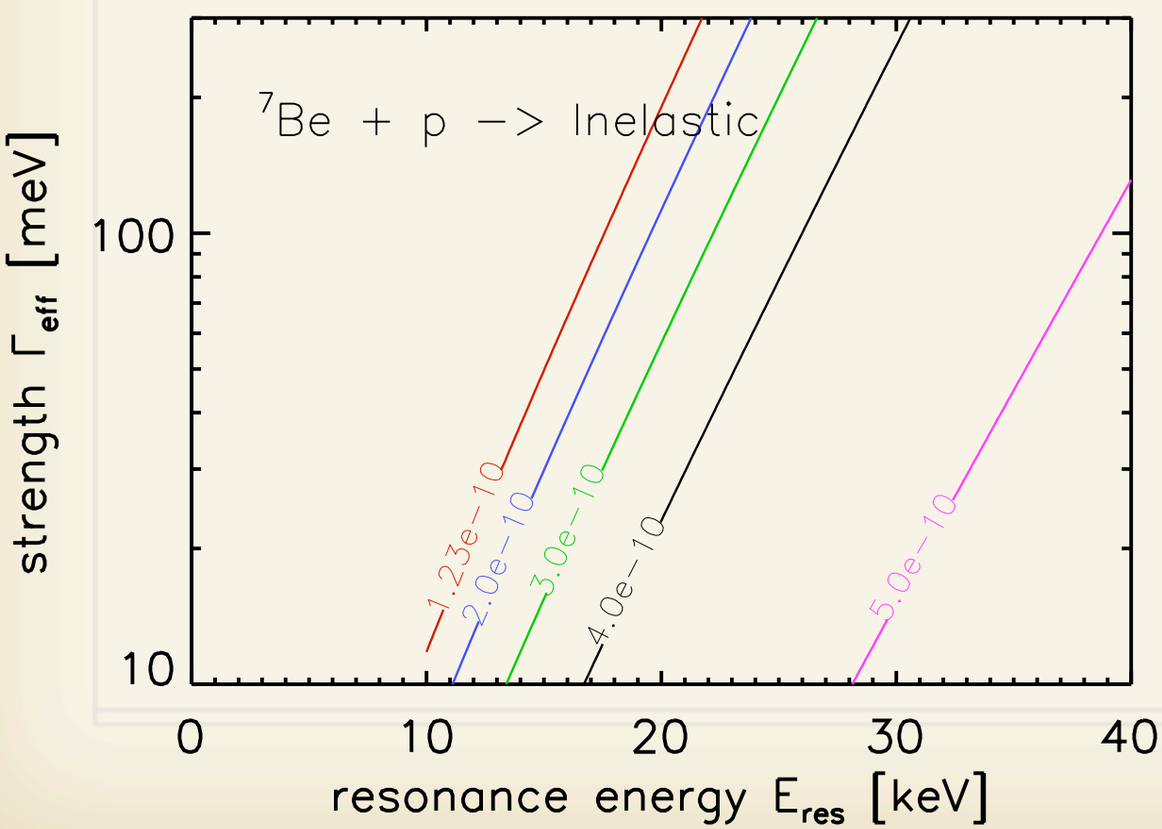

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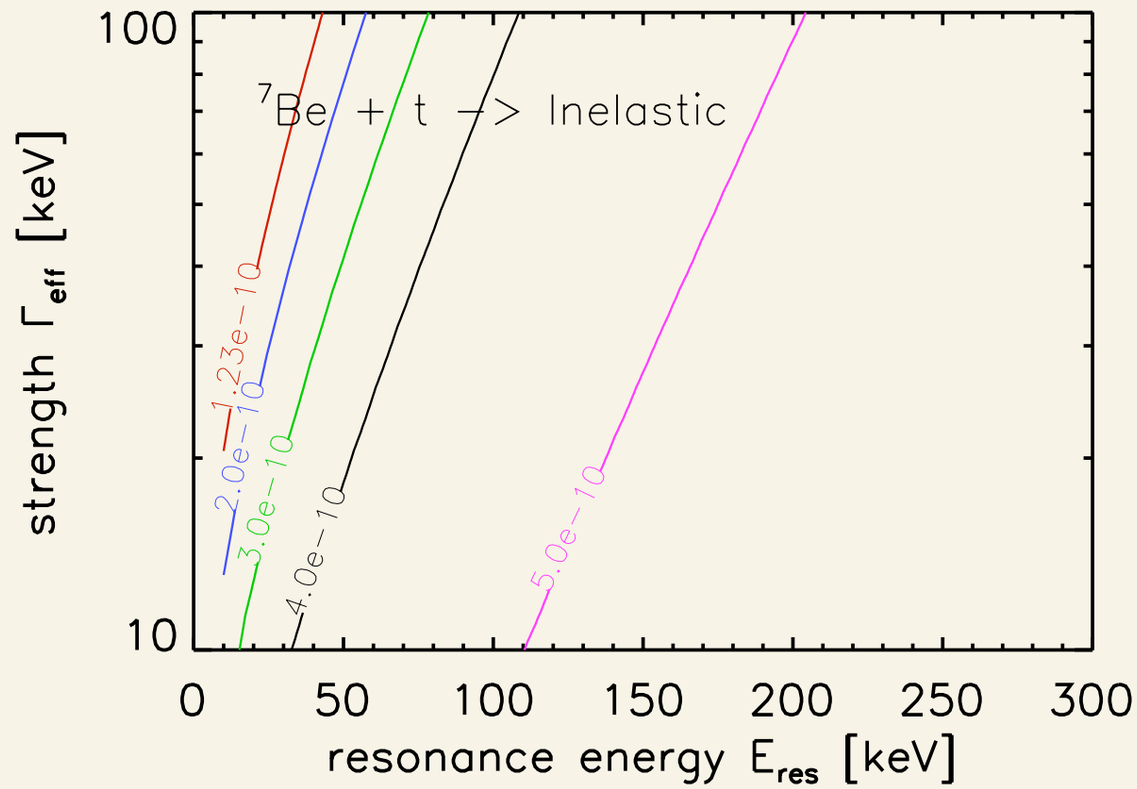
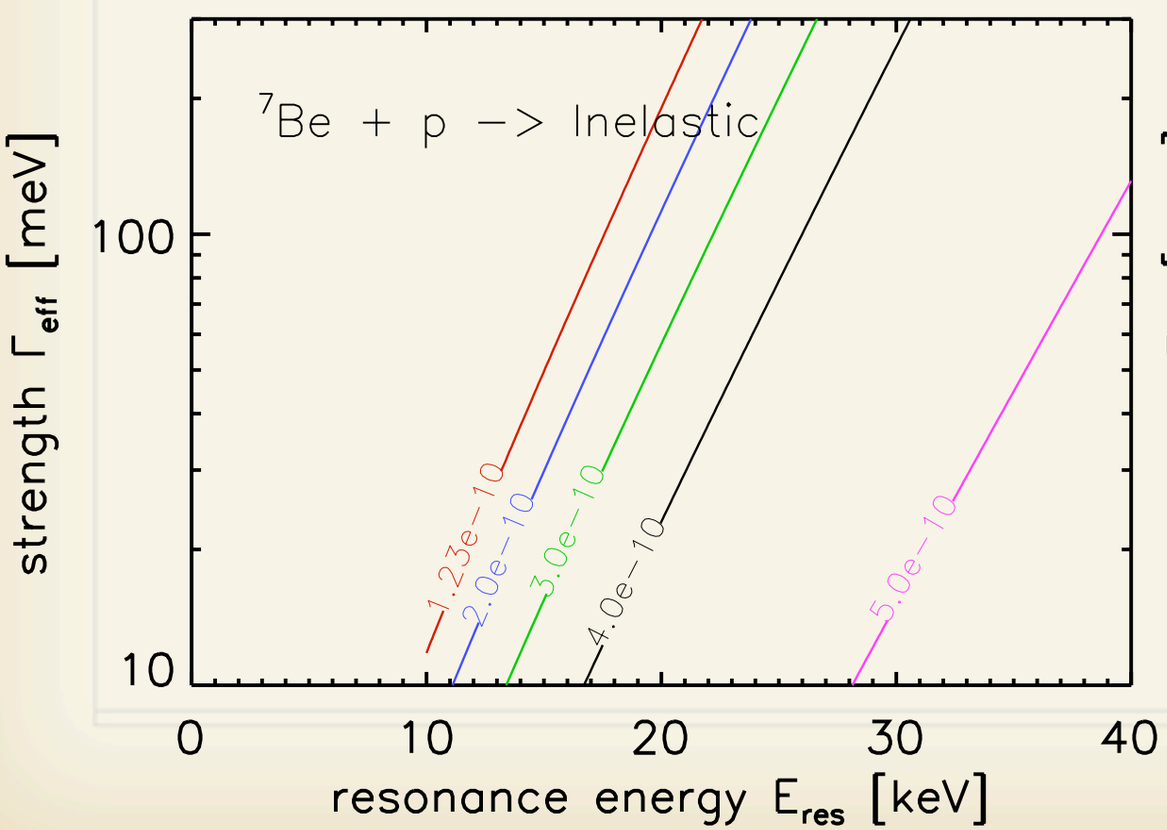
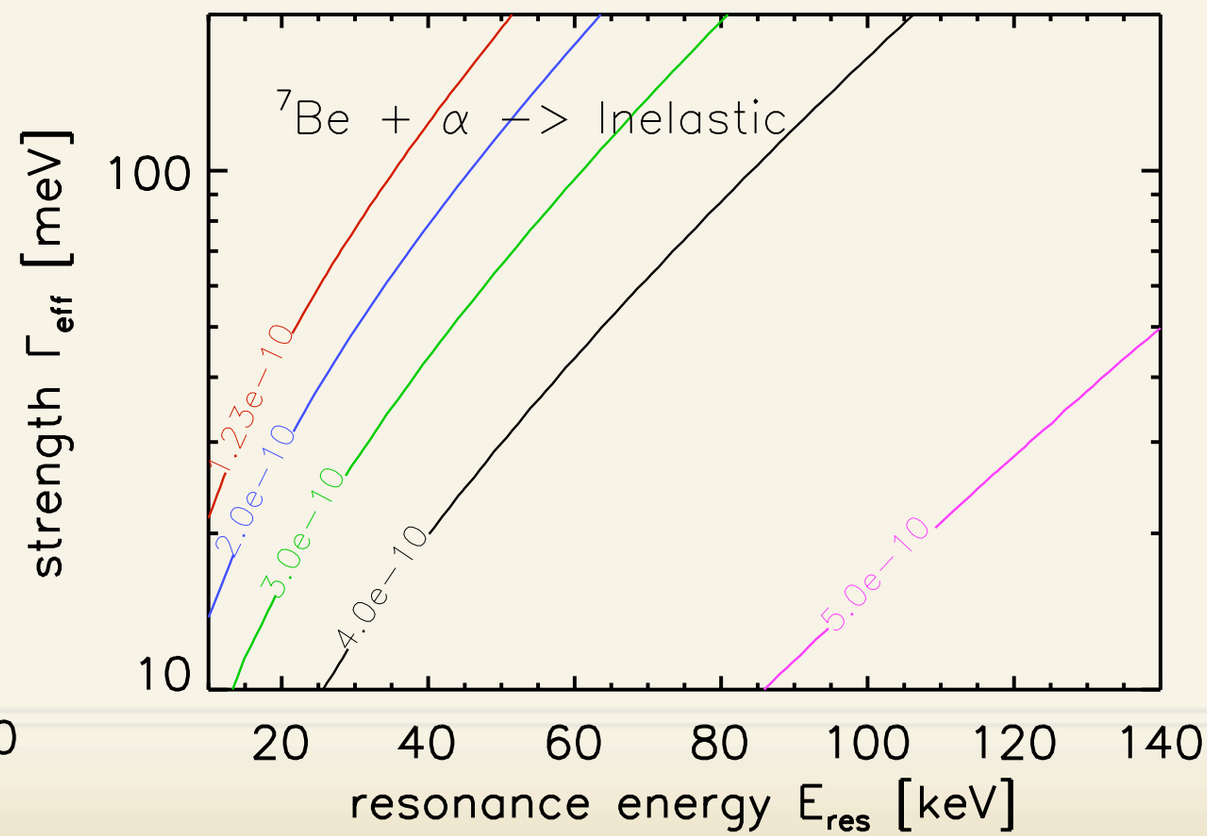




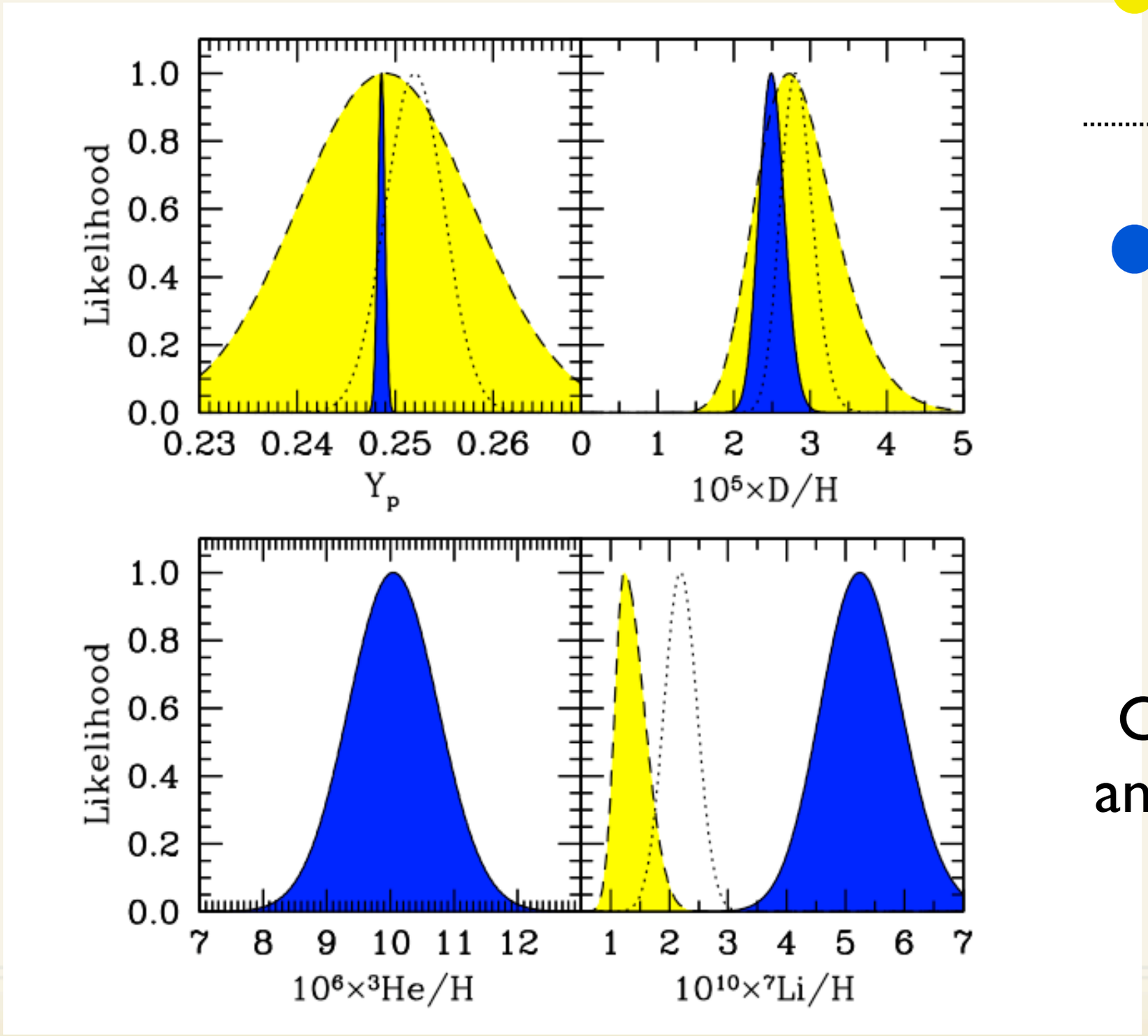


Do we have any Standard Model solutions ?

- Potentially yes → Nuclear resonances
- Complete or partial match
  - $^7Be + d \rightarrow p + 2\,\alpha$ (Cyburt and Pospelov, (2009) and competing channels)
  - $^7Be + t \rightarrow$ Inelastic (Chakraborty, Fields and Olive, (In prep)
  - Missed resonances / levels
- Testable by current nuclear experiments
- We may be able to avoid new physics

Thank you !!

Theory vs Observations - The Lithium problem



Observations

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Theory

Cyburt, Fields and Olive, 2008

Nucleosynthetic History

Mukhanov (2004)

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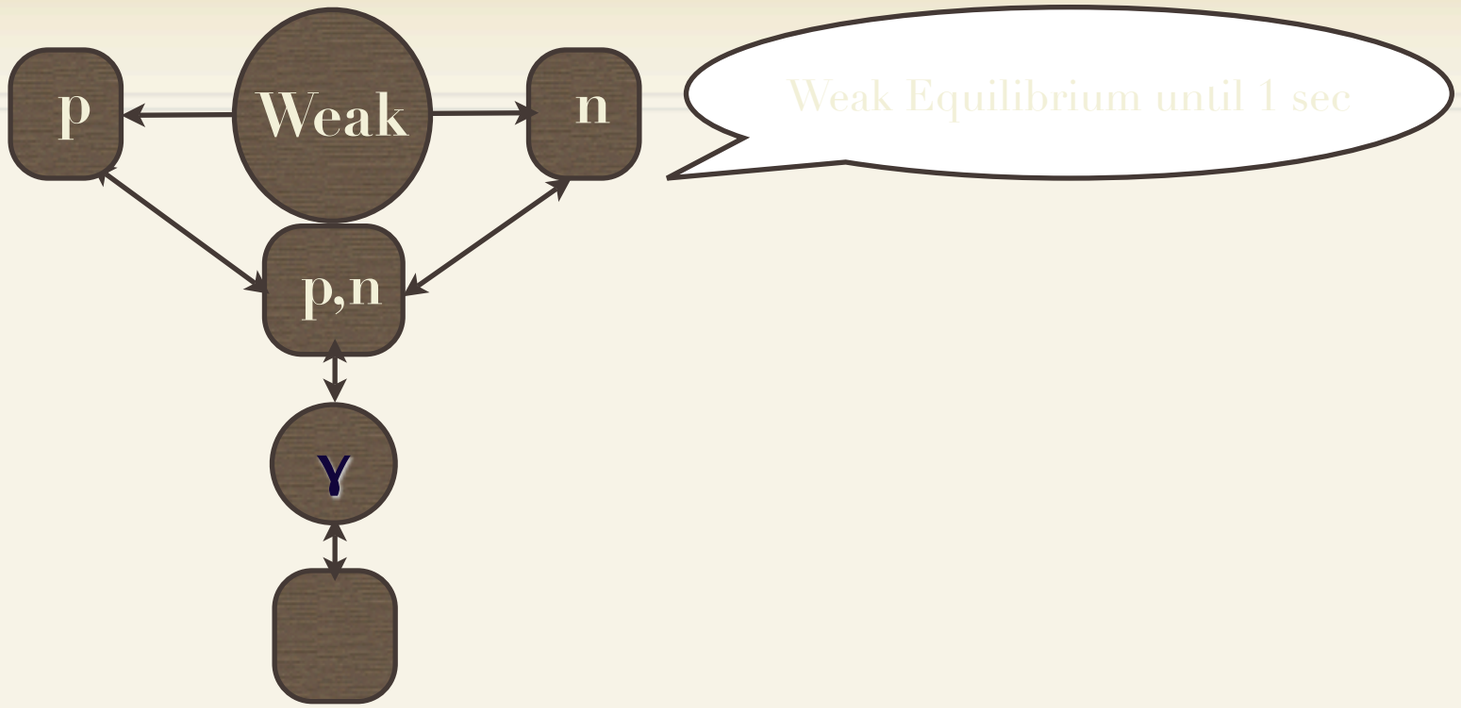

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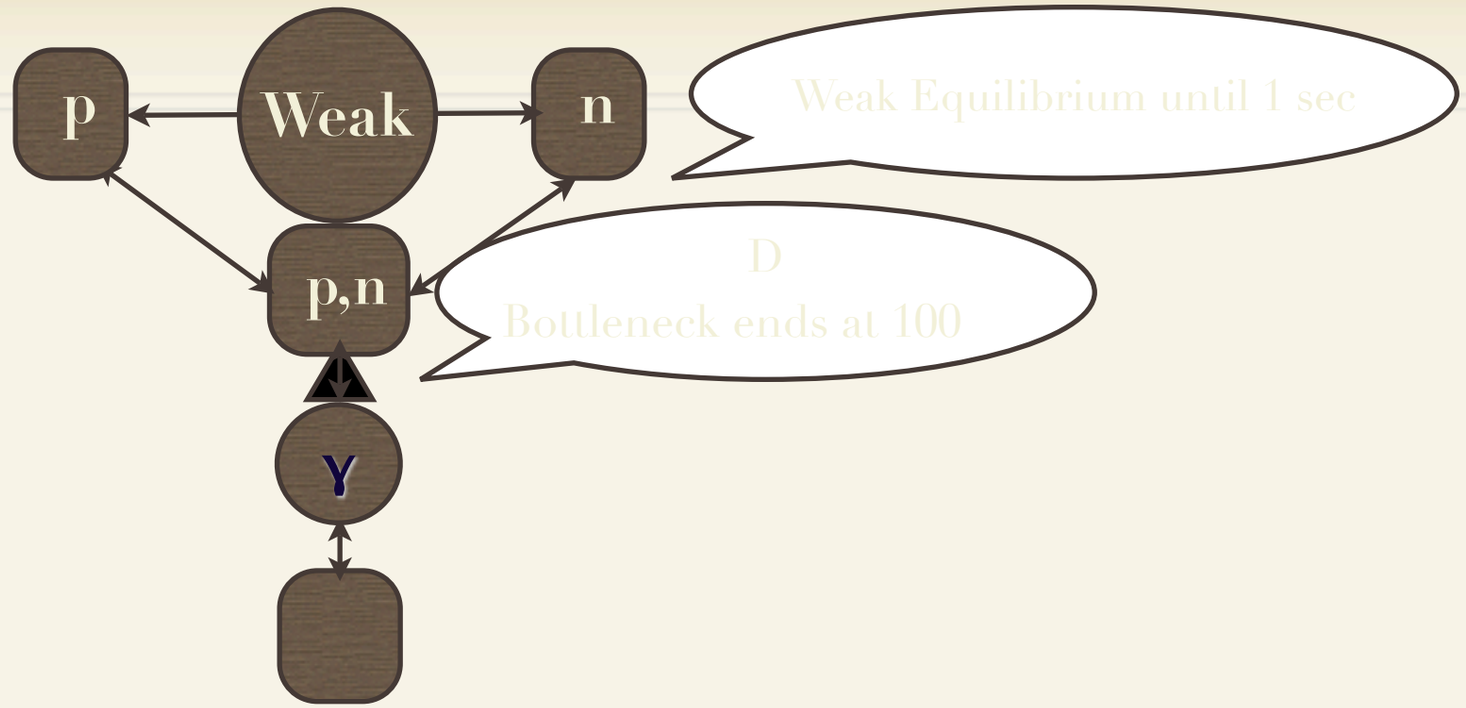

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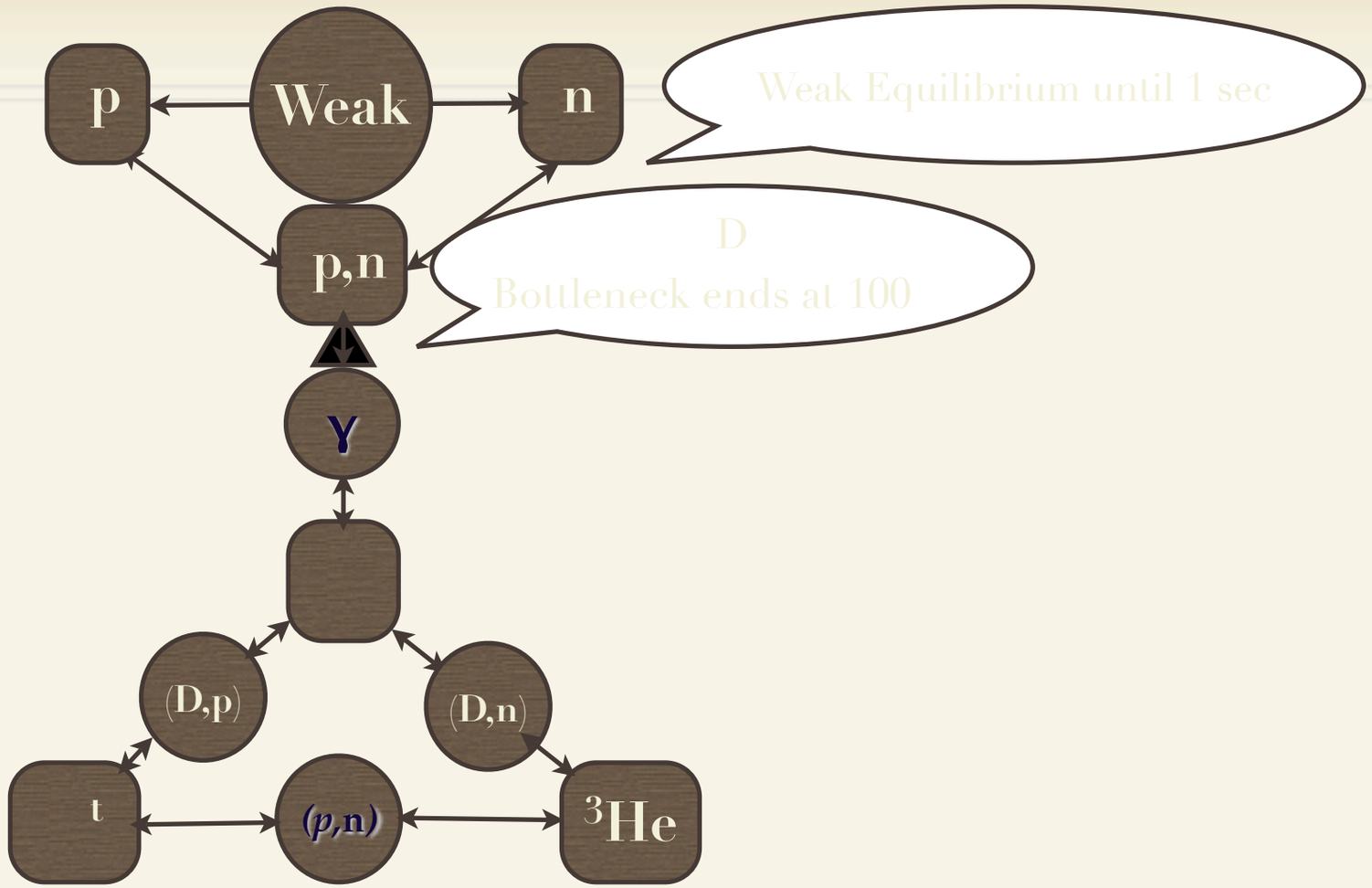

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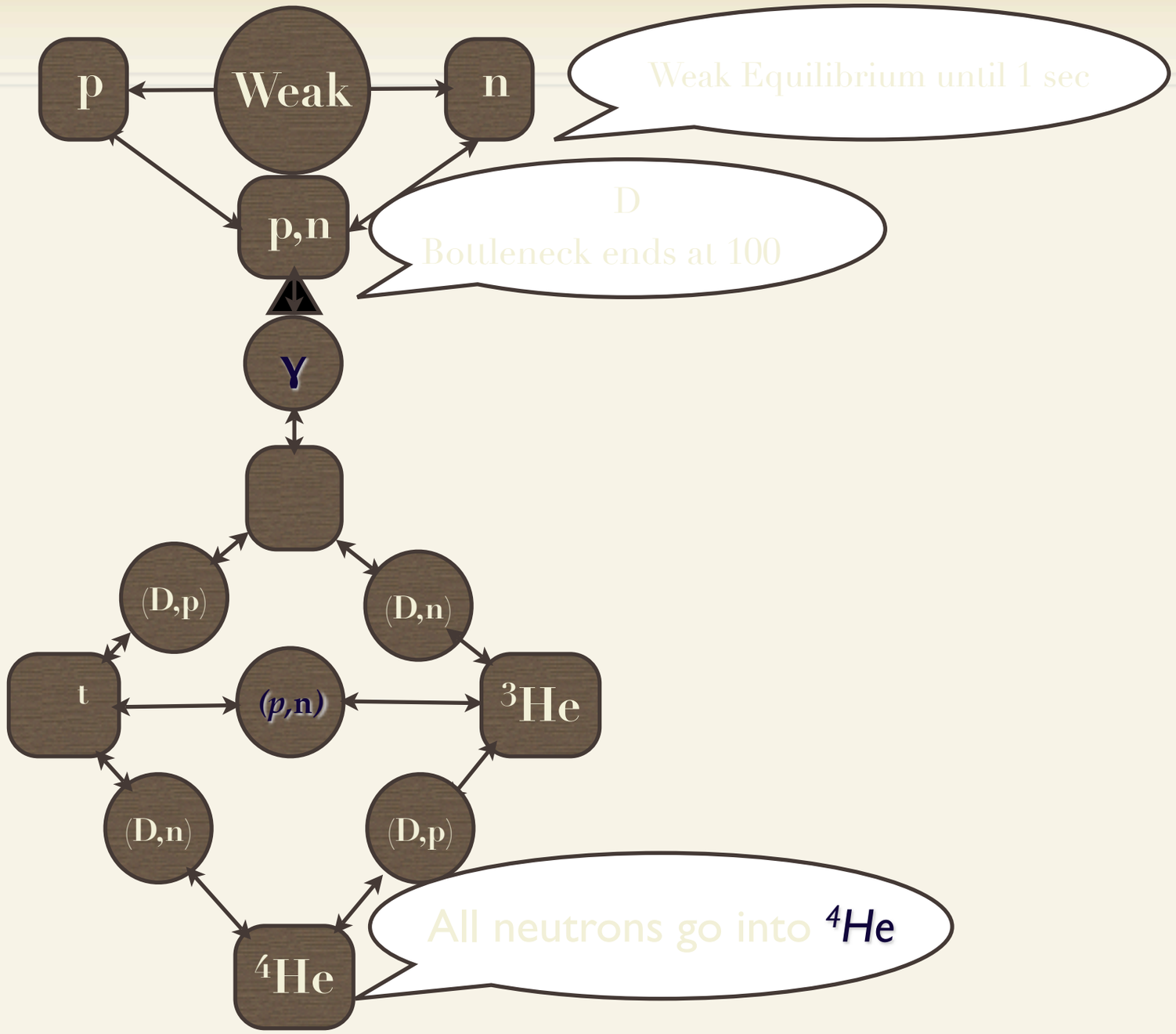

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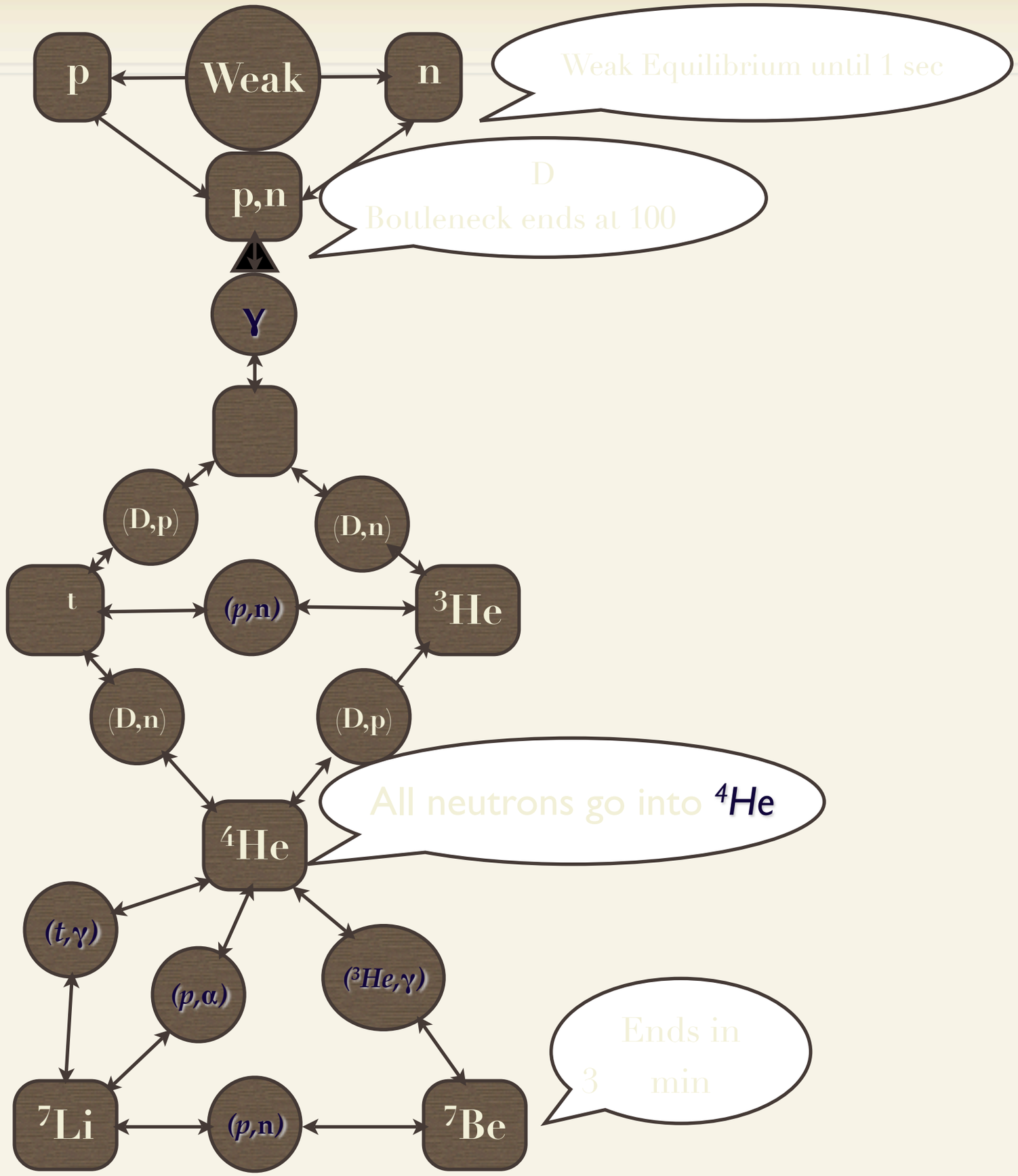

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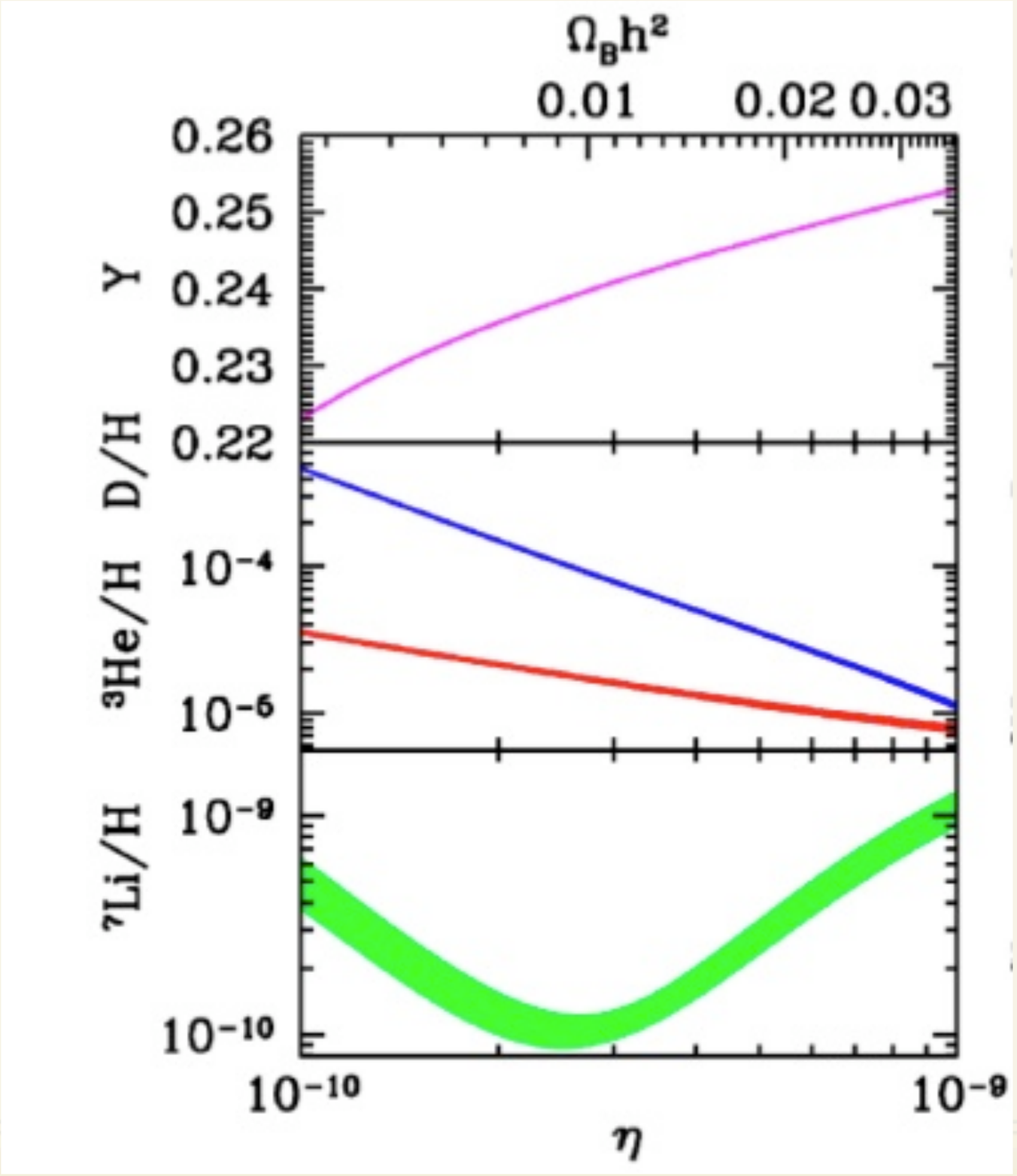
Theoretical Predictions



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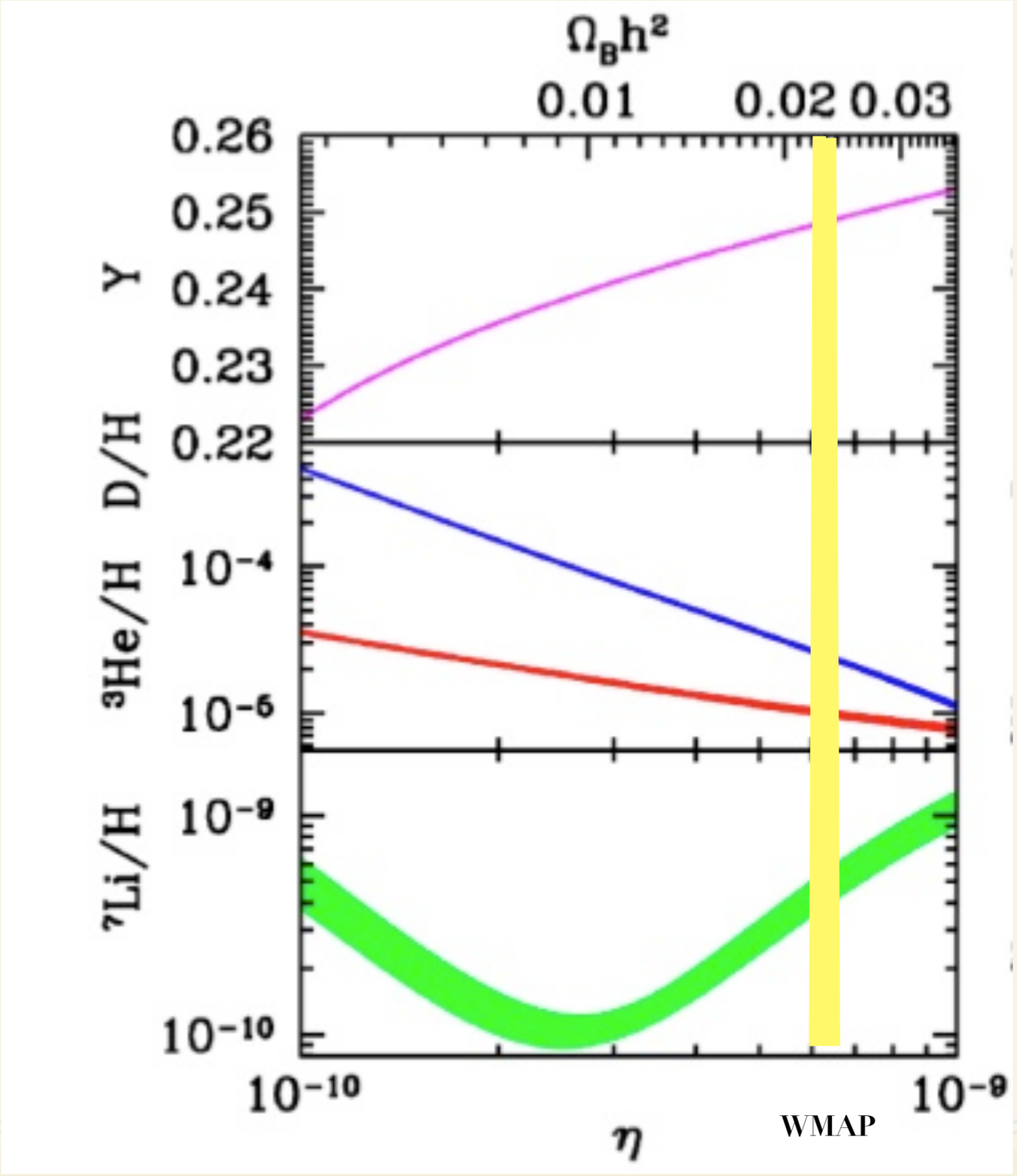

Cyburt , (2004)

Observations

- Need primordial abundance measurements
- Light elements also formed in other ways
- Look at low metallicity environments, avoid pollution

- ^{4}He - Metal poor compact dwarfs (Izotov and Thuan, 1999; Meurer et al., 1995)
  D - Quasar absorption lines (O'Meara, 2006,2001)
  ^{3}He - Galactic HII (ionised hydrogen) regions (Bania et al., 2002)

What's wrong ??

- We dont know for sure !!
- "Law of trichotomy"
  - either theory or observation is wrong or both !!
- Theory
  - Holes in nuclear reaction network (Cyburt and Pospelov, 2009)
  - New physics !! (Dark matter decay (Bailly et al., 2009 and others), Bound states (Jittoh et al., 2010, Cyburt et al., 2006 and others), varying fundamental constants (Berengut et al., 2010),....)
- Observations

Nuclear Physics Solution

- Two main checks
  1. Completeness of nuclear database or missing reactions
  2. Improved reaction rates
- Can't decrease production rates - well studied and constrained
- Increase destruction
- Resonances ?

Let's try resonances

http://pntpm3.ulb.ac.be/Nacre/barre_database.htm

- http://en.wikipedia.org/wiki/Nuclear_reaction

- A + B --> C + D vs A + B --> X* --> C + D

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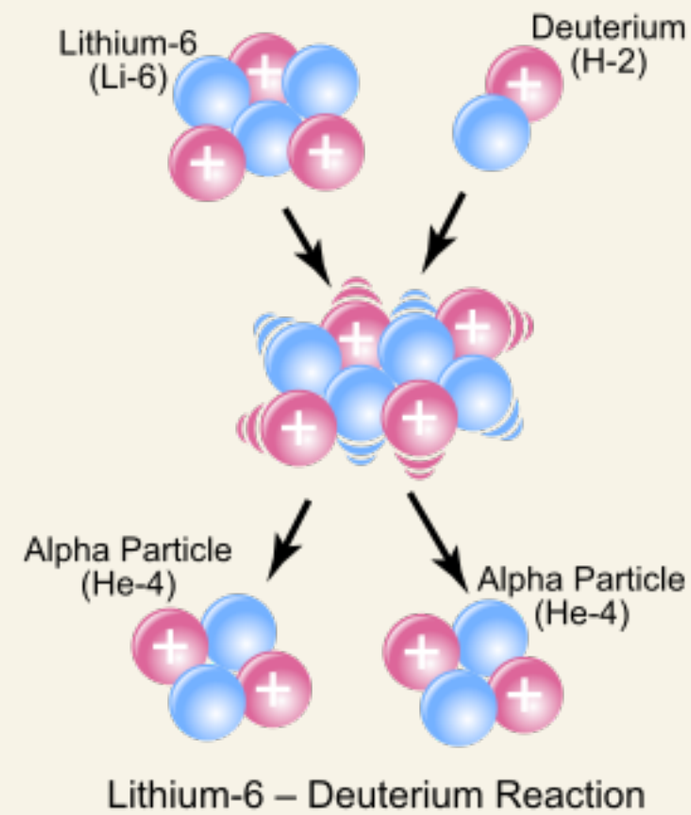

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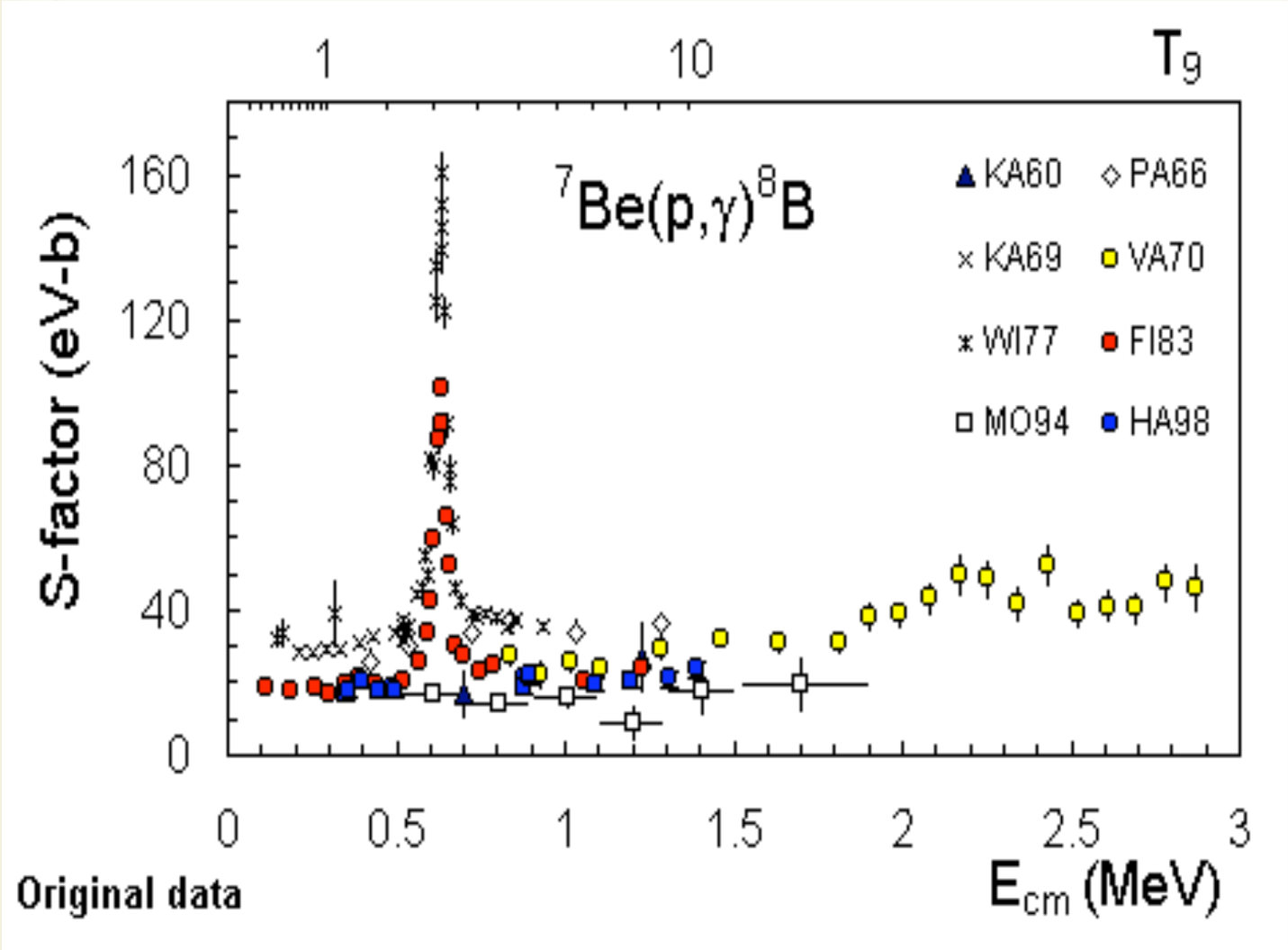
$$S(E) = \sigma(E) E \exp(2\pi\eta)$$



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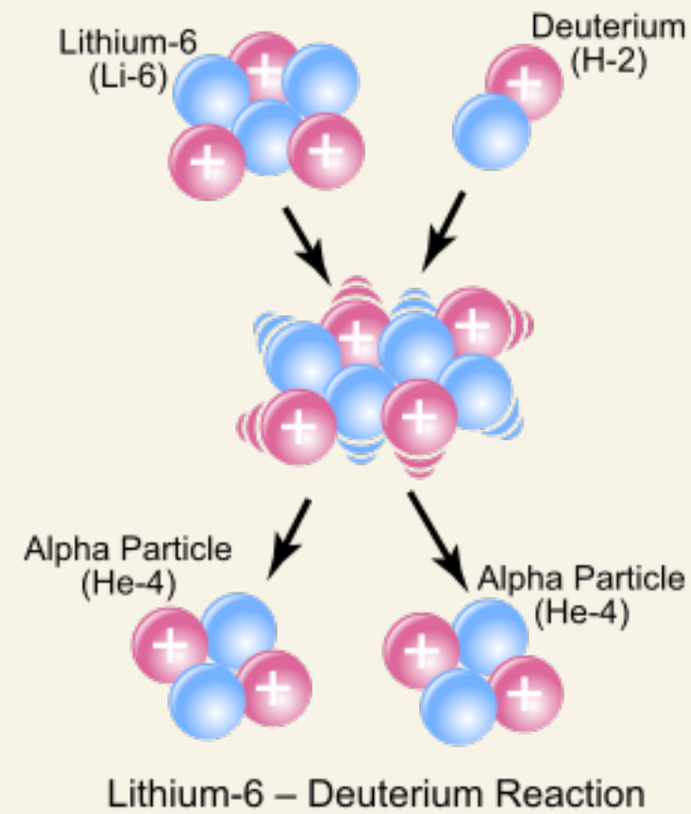


http://en.wikipedia.org/wiki/Nuclear_reaction

- A + B --> C + D vs A + B --> X* --> C + D

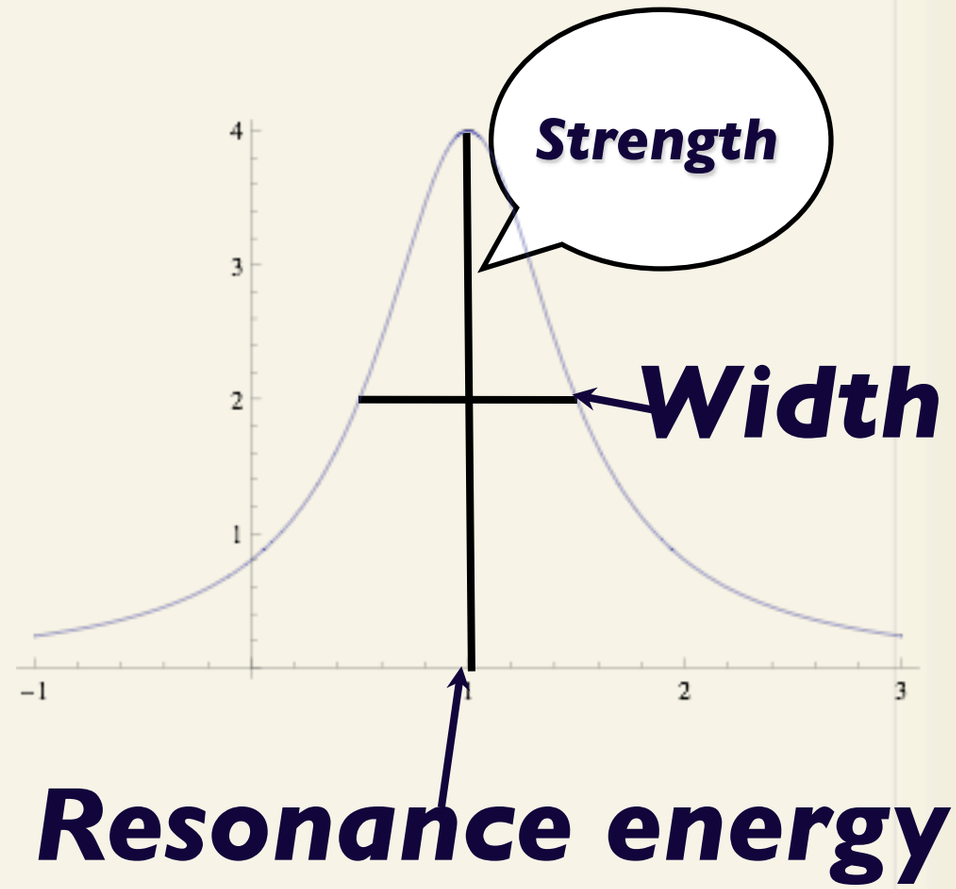
Resonant Cross-section

- In nuclear physics,

$$\sigma \propto \frac{\Gamma_1 \Gamma_2}{(E - E_R)^2 + (\Gamma_{tot}/2)^2}$$

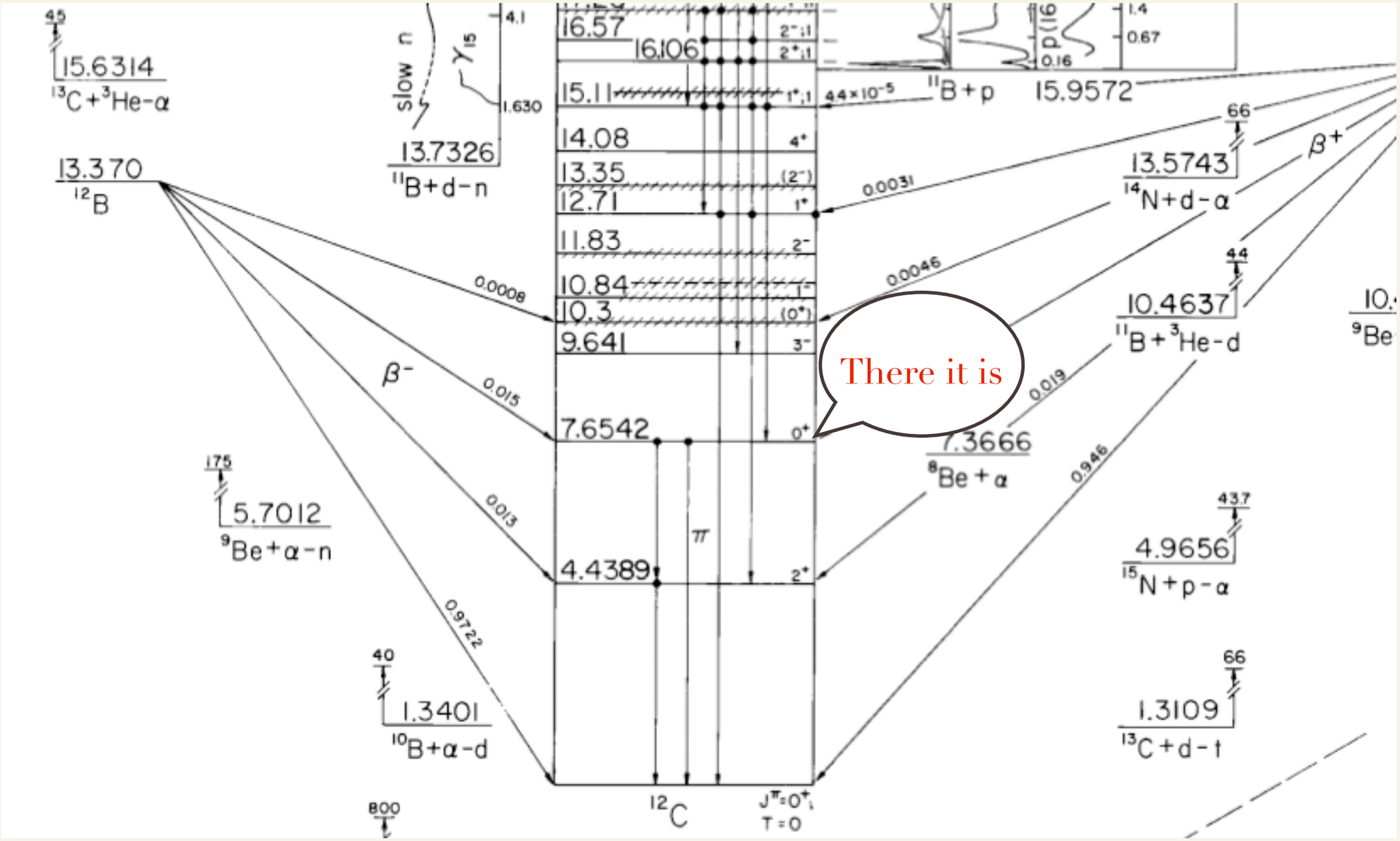
- (Breit-Wigner single level formula)

- Rate of reaction ~ n_A n_B $< \sigma \ v >$



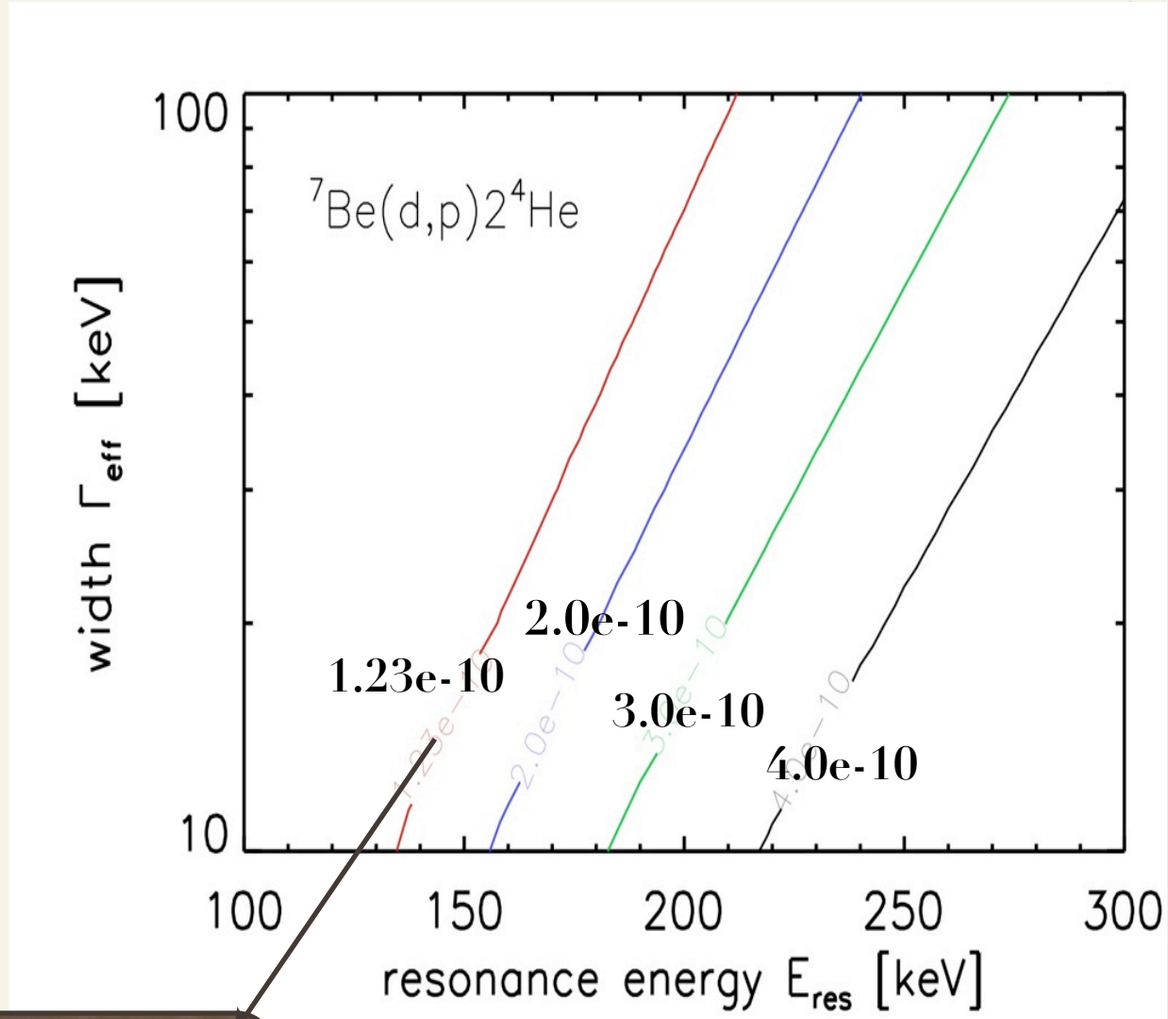
T Not position of the energy level in the compound nucleus, but extra energy required by reactants to get there over Q-value

Carbon 12


15.6314
13C+3He-α
13.370
12B
slow n
γ15
4.1
1.630
13.7326
11B+d-n
16.57
16.106
15.11
14.08
13.35
12.71
11.83
10.84
10.3
9.641
7.6542
4.4389
12C
π
β-
0.0008
0.015
0.013
0.9722
5.7012
9Be+α-n
1.3401
10B+α-d
11B+p
15.9572
0.0031
0.0046
13.5743
14N+d-α
β+
10.4637
11B+3He-d
0.019
7.3666
8Be+α
0.946
4.9656
15N+p-α
1.3109
13C+d-t
There it is

Cyburt and Pospelov

- Identified a narrow level in ^{9}B at 16.7 MeV
- Width of energy level unknown
- Enhancement of reaction ^{7}Be(d,γ)^{9}B and ^{7}Be(d,p)α α
- (E_R,Γ_d) ~ (170-220, 10-40) keV , ^{7}Li/H = (2.5 - 6) 10^{-10}



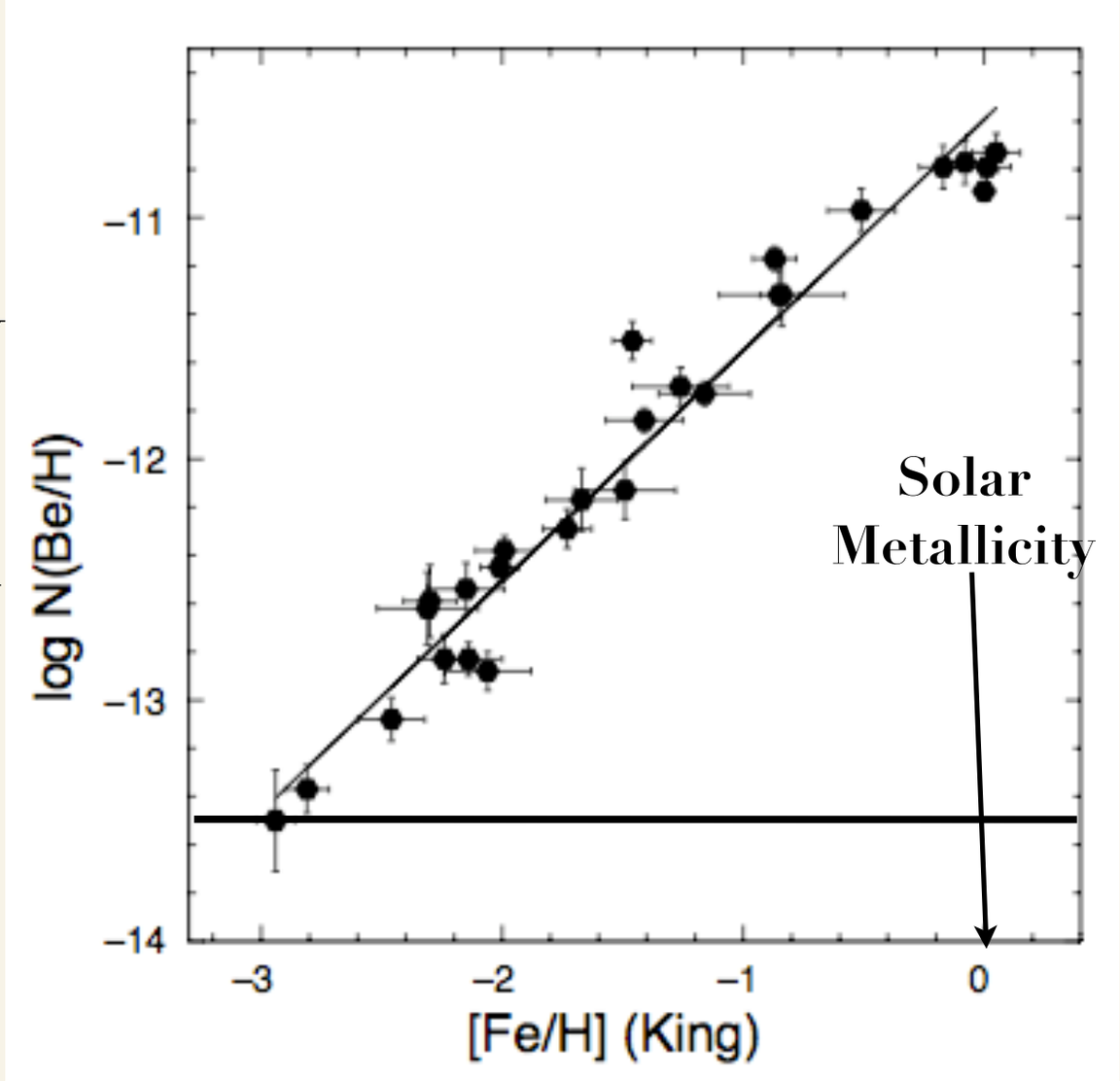
Observations

Looks encouraging but.....

A. Experimental verification

B. More importantly ^{9}B has other decay channels

^{9}B -> ^{9}Be



Boesgaard et al., 1999

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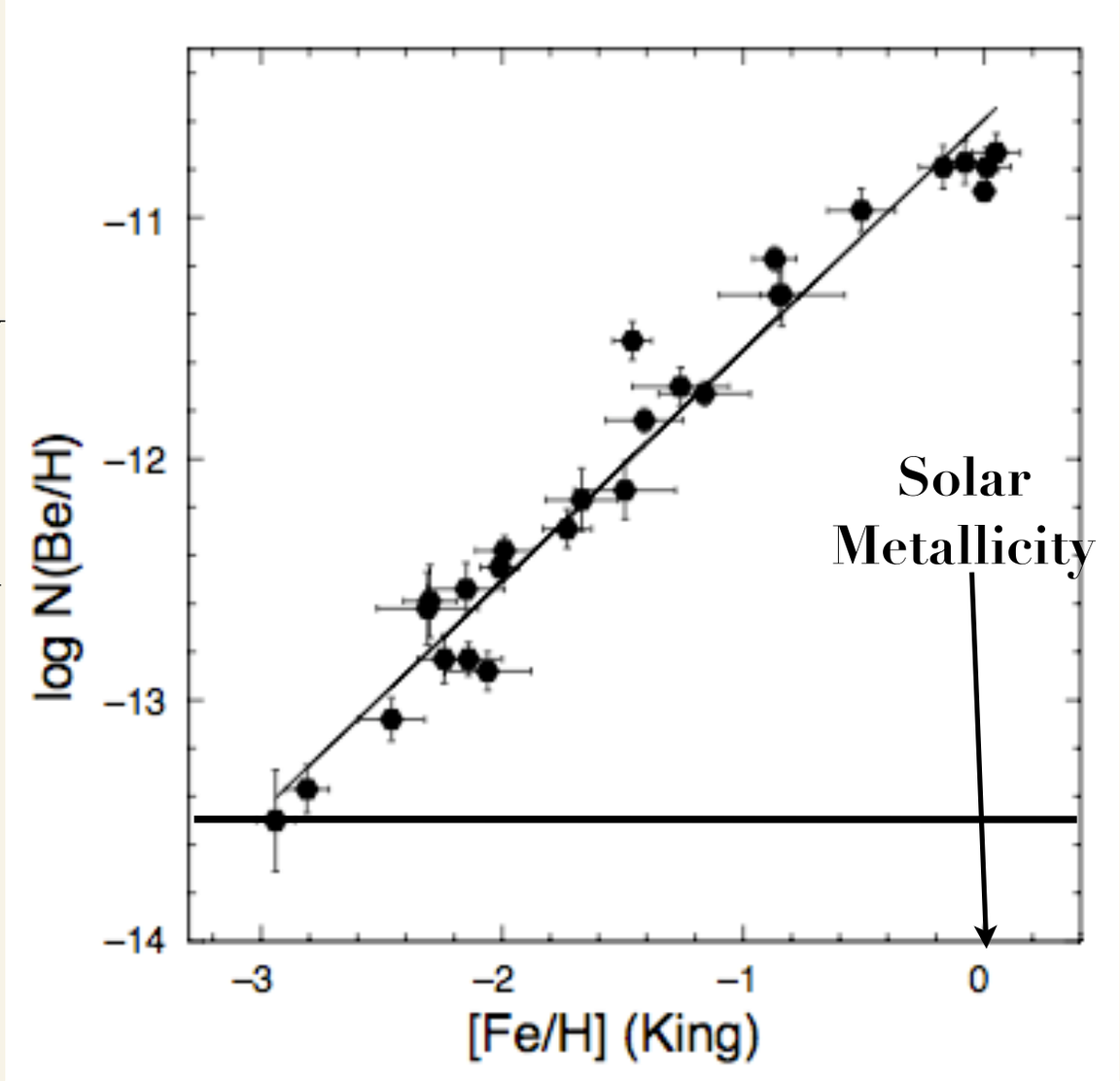
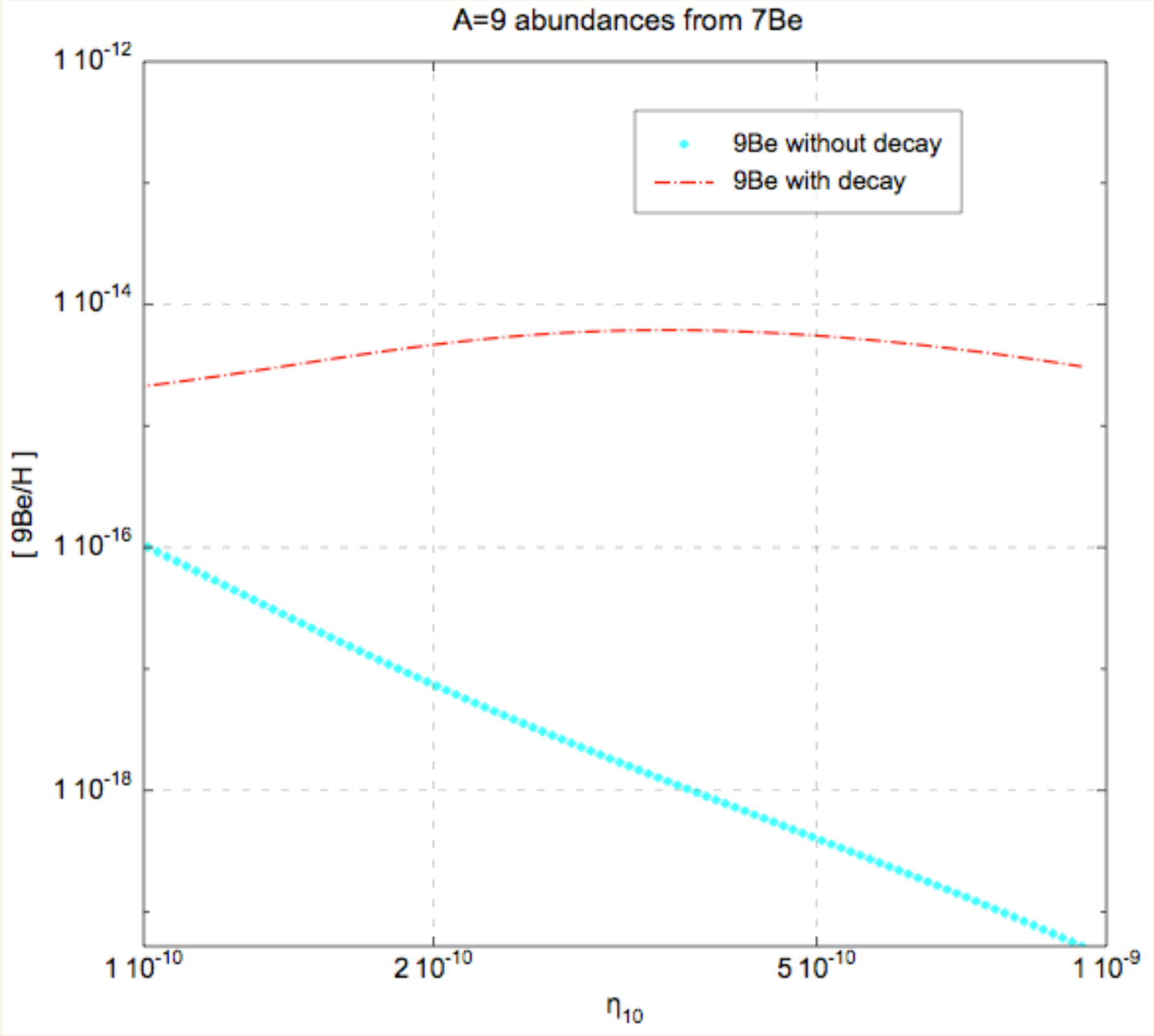
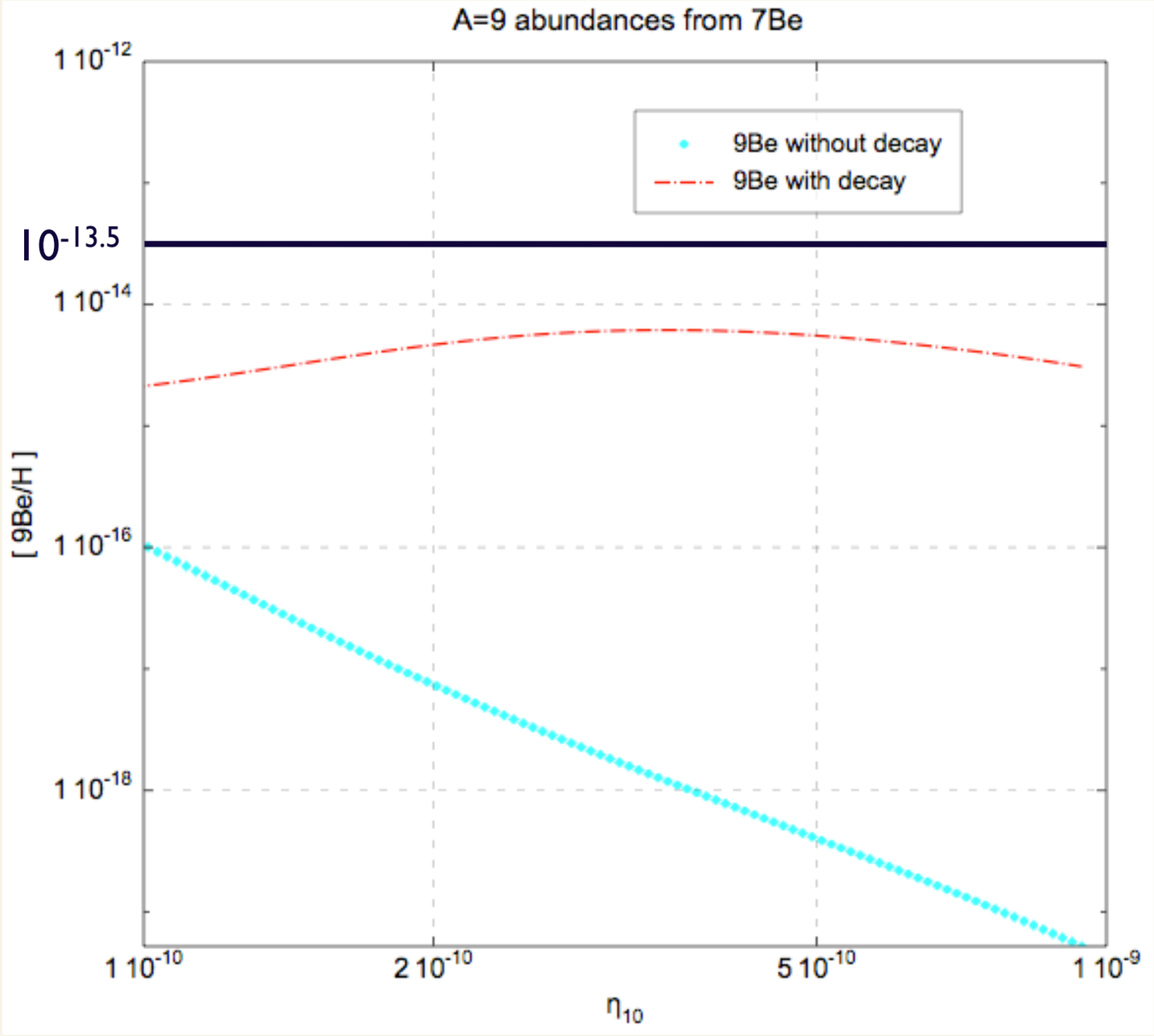


Boesgaard et al., 1999

They are fine



They are fine



Systematic Search

- Need other options ready
- Want to try all conceivable resonances
- Not infinite choices !!

- Lock on to our targets
  - ^{7}Li, ^{7}Be
- Ready our projectiles
  - n,p,t, ^{3}He, ^{4}He, and photons

Candidates allowed by selection rules

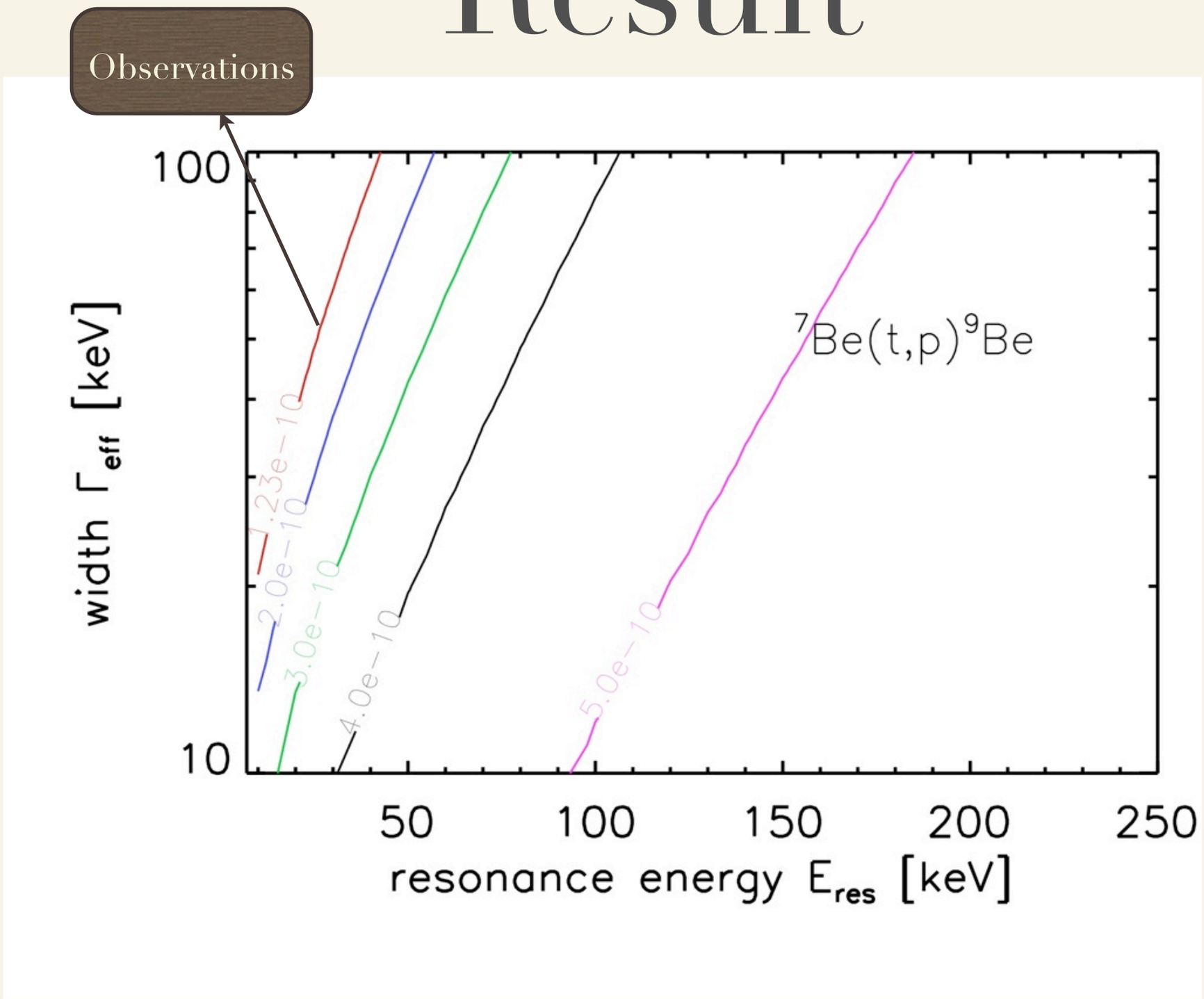
A.2. Table of resonances

Resonance in Compound State	Reaction	E_R	Γ_{rxn}	Γ_{tot}
^{8}Be, 1^+, 17.64 MeV	^{7}Li$(p,\gamma)\alpha\alpha$	385 keV	unknown	10.7 keV
^{8}Be, 2^+, 16.922 MeV	^{7}Li$(p,\gamma)\alpha\alpha$	-333 keV	unknown	74.0 keV
^{8}Be, 2^-, 18.91 MeV	^{7}Be$(n,\gamma)\alpha\alpha$	10.3 keV	0.168+0.099 eV	122 keV
^{8}Be, 3^+, 19.07 MeV	^{7}Be$(n,\gamma)\alpha\alpha$	170.3 keV	10.5 eV	270 keV
^{8}B, 2^+, Ground state	^{7}Be$(p,\gamma)^8$B	-137.5 keV	-	-
^{8}B, 1^+, 0.7695 MeV	^{7}Be$(p,\gamma)^8$B	49.5 keV	$\approx$ 35.6 keV	35.6 keV
^{9}Be, $(5/2^+)$, 16.671 MeV	^{7}Li$(d,\gamma)^9$Be	-24.9 keV	41 keV	41 keV
^{9}Be, $1/2^-$, 16.9752 MeV	^{7}Li$(d,\gamma)^9$Be	279.3 keV	62 eV	389 eV
^{9}Be, $1/2^-$, 16.9752 MeV	^{7}Li$(d,p)^8$Li	87.0 keV	$<$ 290 eV	389 eV
^{9}Be, $1/2^+$, 1.684 MeV	^{7}Li$(d,n)^8$Be	18.6 keV	$\approx$ 217 keV	217 keV
^{9}B, $(5/2^+)$, 16.71 MeV	^{7}Be$(d,{}^3$He$)^6$Li	107.7 keV	unknown	unknown
^{9}B, $(5/2^+)$, 16.71 MeV	^{7}Be$(d,\gamma)^9$B$(,e^+ + \nu\gamma)^9$Be	219.9 keV	unknown	unknown
^{10}Be, (2^-), 17.12 MeV	^{7}Li$(t,\gamma)^{10}$Be	-130.9 keV	$\approx$ 150 keV	unknown
^{10}Be, 17.79 MeV	^{7}Li$(t,n)^{10}$Be	539.1 keV	$\approx$ 112 keV	unknown
^{10}B, 2^+, 18.80 MeV	^{7}Be$(t,\gamma)^{10}$B	130.9 keV	$<$ 600 keV	unknown
^{10}B, 2^+, 18.80 MeV	^{7}Be$(t,p)^9$Be	130.9 keV	$<$ 600 keV	unknown
^{10}B, 2^+, 18.80 MeV	^{7}Be$(t,{}^3$He$)^7$Li	130.9 keV	$<$ 600 keV	unknown
^{11}B, $(3/2^-)$, 8.56 MeV	^{7}Li$(\alpha,\gamma)^{11}$B	-103.7 keV	0.94 eV	unknown
^{11}C, $3/2^+$, 7.50 MeV	^{7}Be$(\alpha,\gamma)^{11}$C	-43.0 keV	$> 7.37 \times 10^{-3}$eV	$> 7.37 \times 10^{-3}$eV

Table 2: This table lists the potential resonant reactions which may achieve required destruction of mass 7. These are all allowed by selection rules. The values of these parameters are taken from *http://www.tunl.duke.edu/nucldata/*

Chakraborty, Fields and Olive (in preparation)

Result



1.23e-10

2.0e-10

3.0e-10

4.0e-10

5.0e-10