

## LISE++ development: Fusion-Fission

- \* LISE++ new reaction mechanism: Fusion-Fission
- \* LISE++: combination of consecutive transmission product calculation for several reactions

Version 7.8.87 beta from 6/6/6 available  
through LISE sites

# LISE++ new reaction mechanism: Fusion-Fission

Production Mechanism

Reactions | Energy Loss, Straggling | Charge states | Databases: Masses, Isomers

238U(20.0 MeV/u) + Be -> 182Yb

Reactions

Settings |  Projectile Fragmentation  additionally calculate yields for the next reactions

Settings |  Fusion -> Residual

**Settings |  Fusion -> Fission**

Settings |  Coulomb fission

Settings |  Abrasion-Fission

Settings |  Two Body Reactions

ISOL mode

Make default

Fusion from "Fusion-Residual"

Fission from "Abrasion-Fission"

Fusion -> Fission

Evaporation settings | Fission properties

Transmission probability for a one-dimensional potential barrier

Classical

Quantum-mechanical

$h_{\omega}$  - Curvature parameter of the parabolic potential describing the barrier (default value 5 MeV)  MeV

Make default

1. No angular momentum contribution
2. Fission cross section is taken without pre-fission neutrons

# Fusion-Residue (Fission) information window

**Fusion-Residue information window**

208Pb(50.0 MeV/u) + C -> 220Ra\* -> 53Ti

Q-value of reaction = -32.022 MeV  
 Fusion max.barrier = 58.87 MeV  
 Fusion radius = 8.70 fm

Depending on a place of reaction in the target

	beginning	middle	end
Beam energy (Lab) [MeV/u]	50.00	44.90	39.54
Beam energy (Lab) [MeV]	10398.8	9337.8	8224.3
Center of mass energy [MeV]	567.18	509.31	448.57
Excitation energy [MeV]	535.16	477.29	416.55
Compound recoil energy [MeV]	9831.7	8828.5	7775.7
Fusion cross section [mb]	2.22e+03	2.2e+03	2.17e+03
<b>Fusion-Fission CS [mb]</b>	<b>583</b>	<b>1.61e+3</b>	<b>1.65e+3</b>
<b>Fusion-Breakup CS [mb]</b>	<b>1.43e+3</b>	<b>58.2</b>	<b>0.3</b>

for setting residue after the stripper

Energy diapason (MeV/u) 40.242 :- 35.344  
 Corresponding ion charge state 21.95 :- 21.92

Plot the residue excitation function

**incomplete fusion (quasi-fusion, transfer reactions)**

All fusion characteristics are calculated with BASS model

Fusion-Residue calculator

Quit

**Projectile** 208Pb<sup>82+</sup> FuFis 2668  
 50 MeV/u 1 pA

**Compound** 220Ra

**Fragment** 53Ti<sup>22+</sup>

**Target** C 12.0328 mg/cm<sup>2</sup>

Calculated fusion-fission cross sections are kept in memory

**Fusion-Residue calculator**

208Pb(50.0 MeV/u) + C -> 220Ra\* -> 53Ti

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Beam energy (Lab)  50 MeV/u  
 Beam energy (Lab)  10398.8 MeV  
 Center of mass energy  567.18 MeV  
 Excitation energy  535.16 MeV  
 Compound recoil energy  9831.7 MeV  
 Fusion cross section 2216.9 mb

Residue

Energy (Lab)  44.688 MeV/u  
 Corresponding ion charge state 21.96

Calculations suppose the target thickness is negligibly small

If the stripper thickness is not equal to 0 then the stripper material is used to calculate a residue charge state

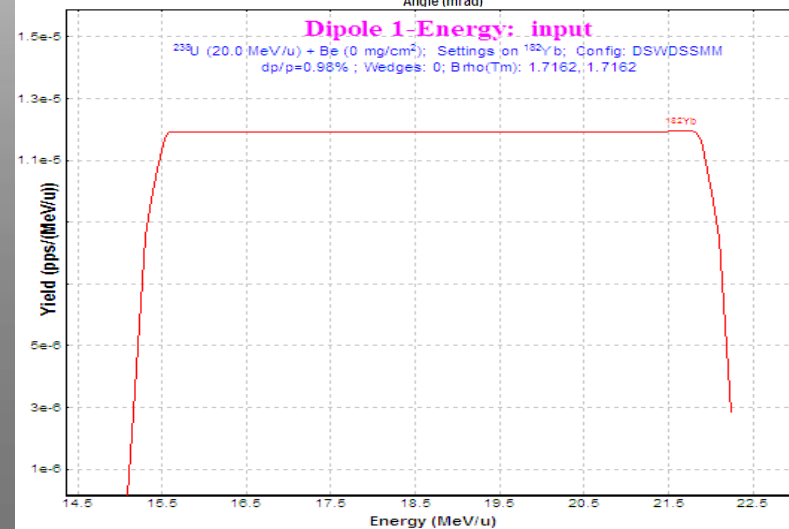
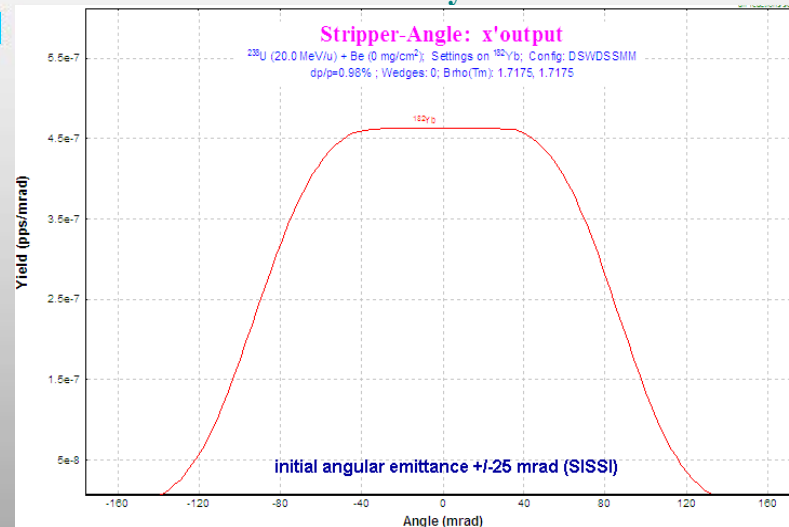
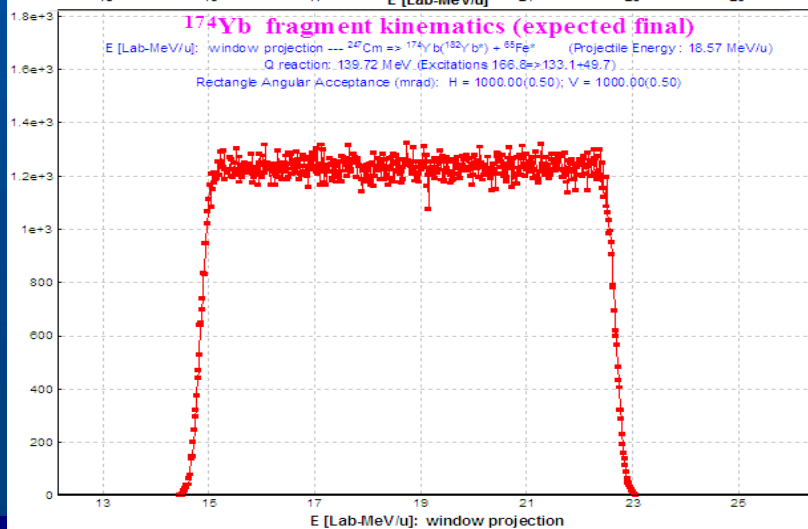
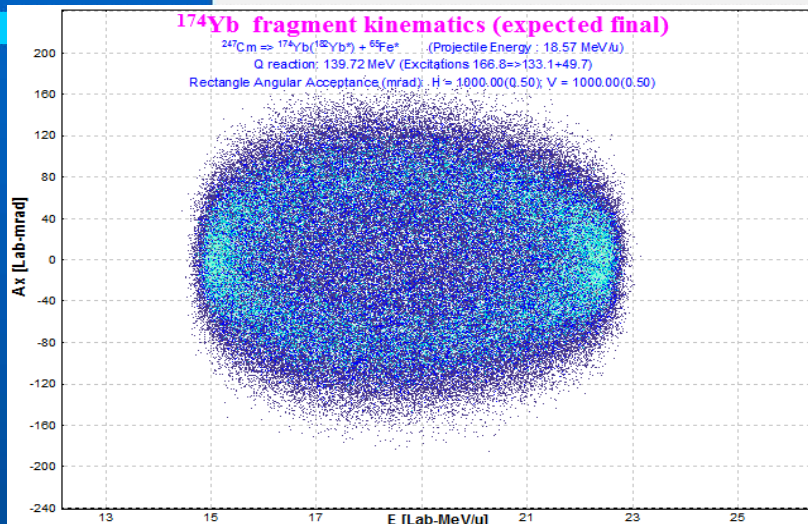
Quit

Break-up and fission channel cross sections in the Fusion information dialog (Fusion-Residual reaction)

# Fusion-Fission kinematics (after target)

## Monte Carlo

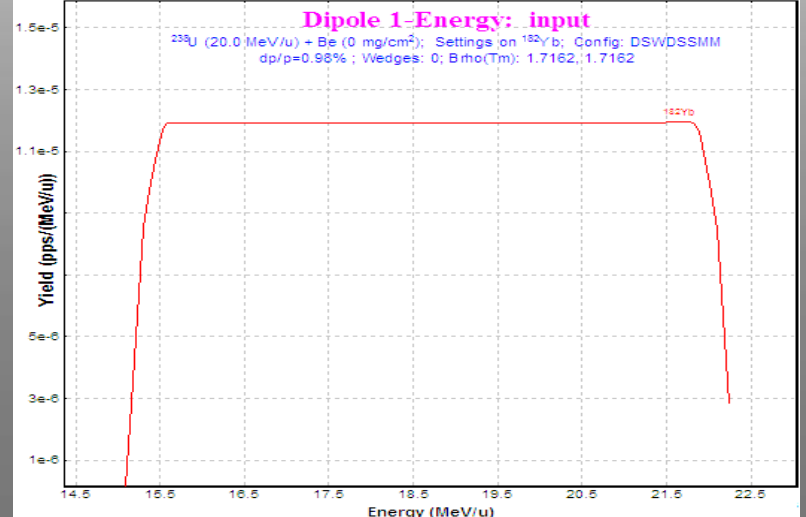
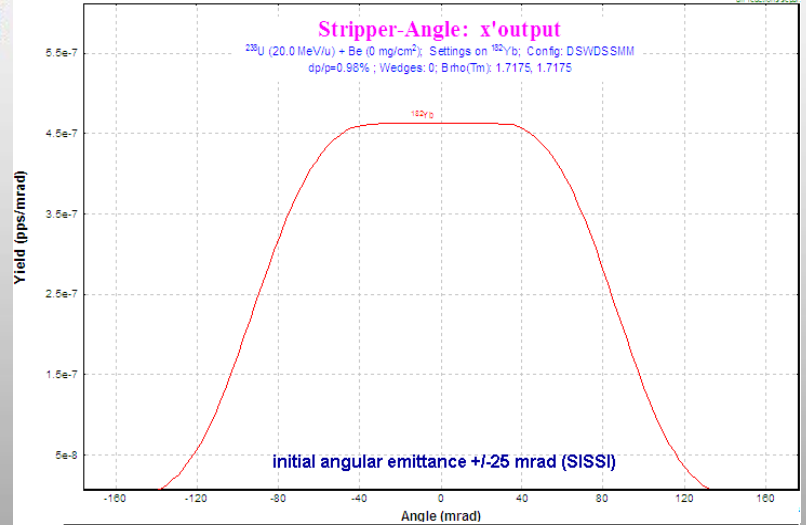
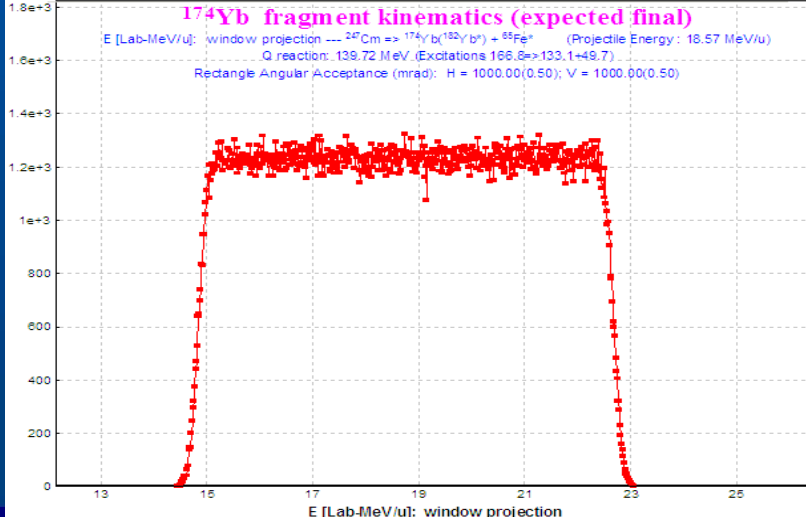
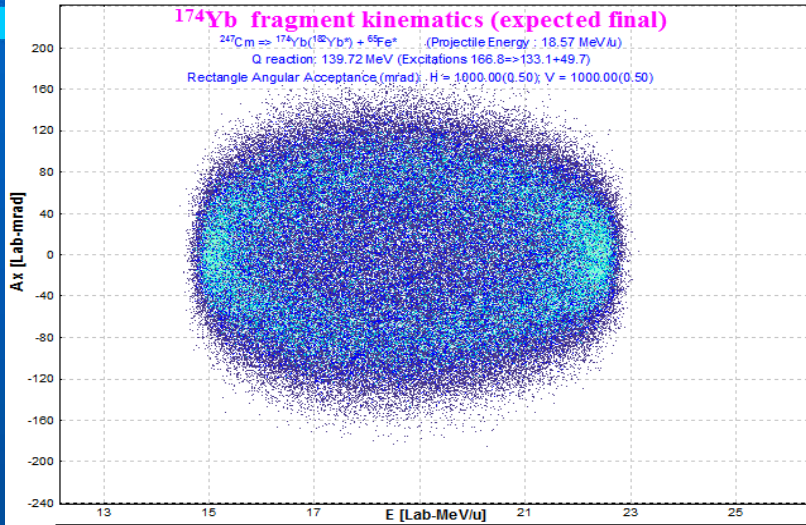
## LISE analytical



# Fusion-Fission kinematics (after target)

## Monte Carlo

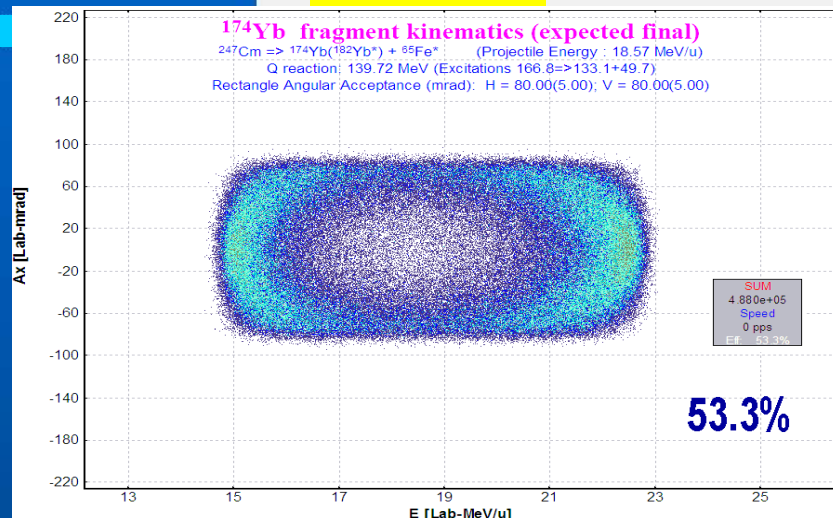
## LISE analytical



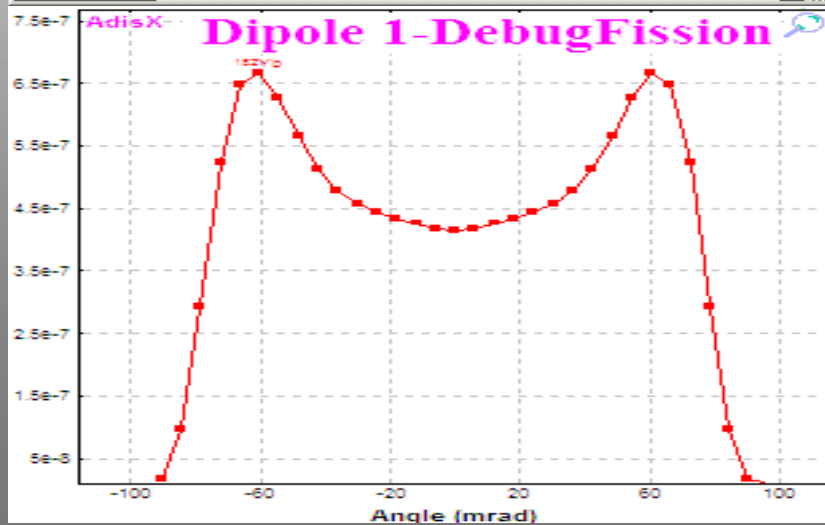
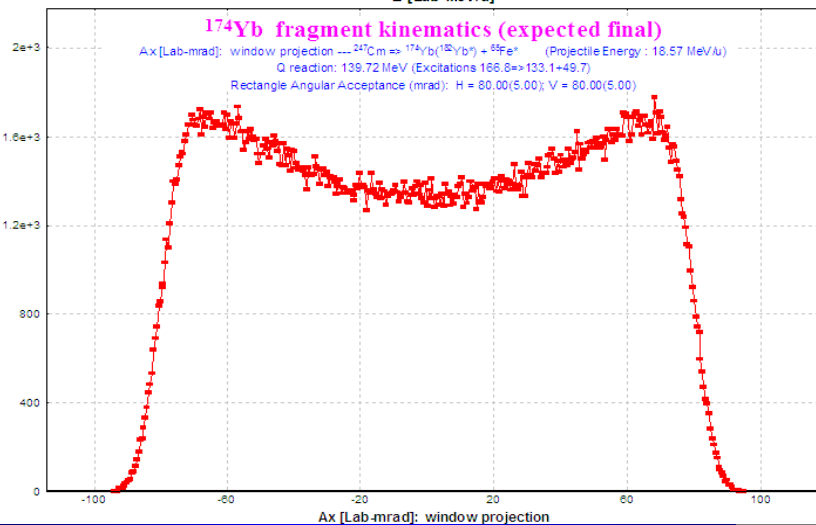
# Angular acceptance

## Monte Carlo

## LISE analytical



statistics 182Yb		
182Yb		Unknown (Z=70, N=112)
Q1 (Dipole 1)		70
Q2 (Dipole 2)		70
Production Rate	(pps)	3.51e-6
Reaction		FusFis
Sum of reactions	(pps)	3.51e-6
CS in the target	(mb)	1.98e-5
Total transmission	(%)	4.251
Target	(%)	100
Unreacted in mater.	(%)	100
Unstopped in mater.	(%)	100
Dipole 1	(%)	<b>58</b>
X angular transmiss.	(%)	77.09
Y angular transmiss.	(%)	75.24
SlitsDisp	(%)	8.71
X space transmission	(%)	8.75
Y space transmission	(%)	99.6
Dipole 2	(%)	84.1

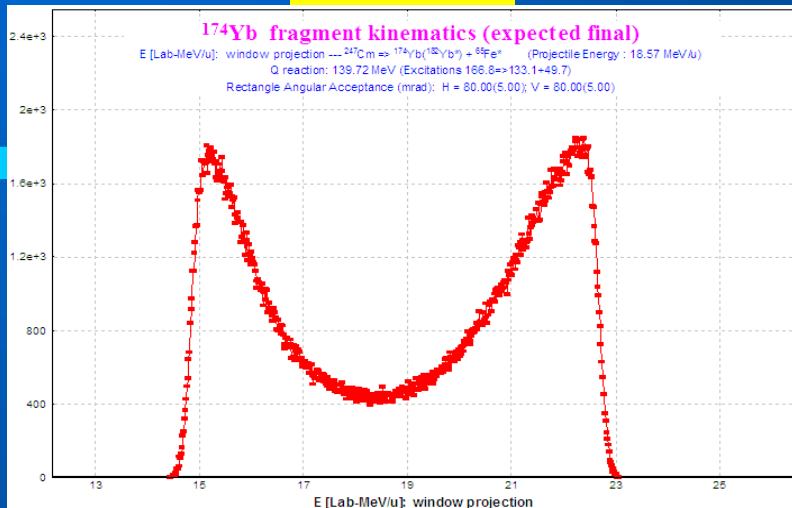




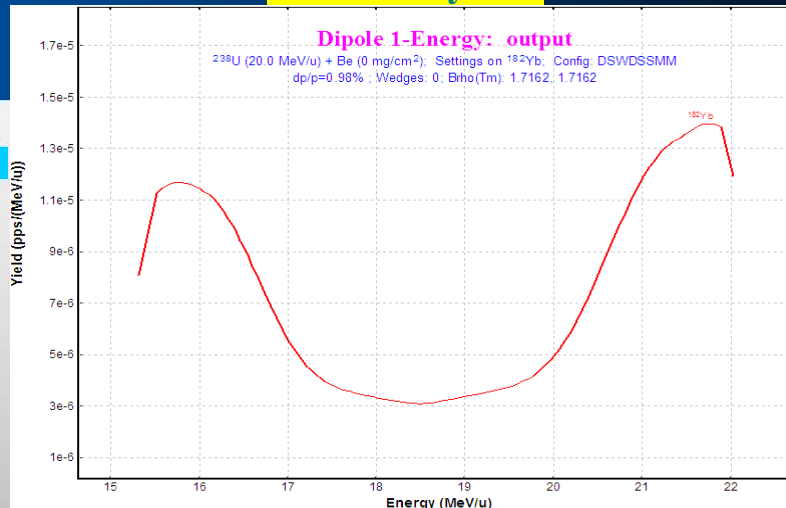
# Angular and Momentum acceptances

## Angular acceptance (2)

### Monte Carlo

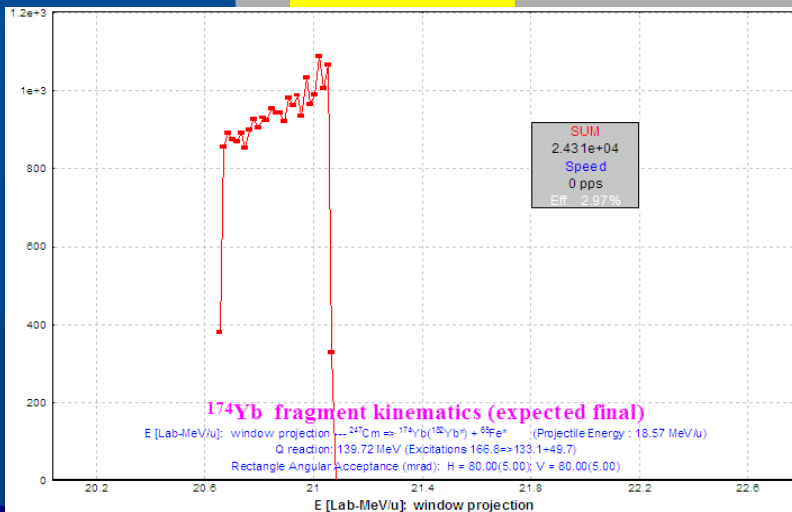


### LISE analytical



## Momentum acceptance

### Monte Carlo



### LISE analytical



# Fusion-Fission plots

**Fusion-Fission cross section plot**

Plot type:  
 Energy dependence  
 Fixed energy from reaction

Plot : Energy dependence  
 Fission fragment excitation function  
 No (faster)  Show fission & breakup channels  
 Yes   
 Suggest for the fission fragment ex.function that Fusion CS always equal to 1 barn  
 Number points for the plot   
 min Ecm =   
 max Ecm =

Plot : Fixed energy from reaction  
 Cross sections & Excitation energy  
 Average Fusion-Fission excitation energy =  MeV    Fission barrier =  MeV  
 Fusion-Fission CS =  mb    Fusion CS =  mb

Modes:  
 Plot type:  
 Isotopes, Z=const  
 Isobars, A=const  
 Isotones, N=const  
 Isospin, N-Z =const  
 Isospin, N-2Z=const  
 <N>/Z  
 sum(CS); Z=const  
 sum(CS); A=const  
 sum(CS); N=const

Cross sections are :  
 Final (after deexcitation)  
 Initial (before light particle emission)

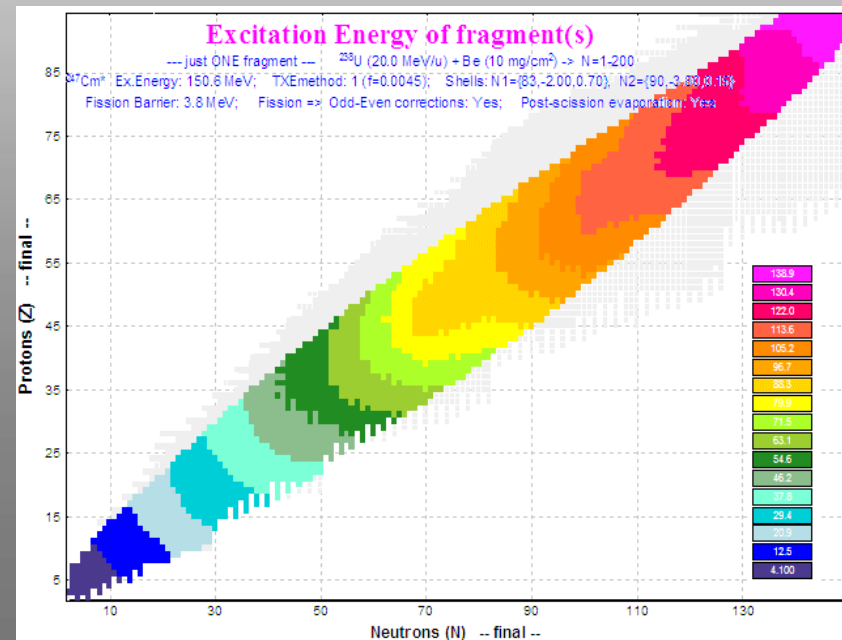
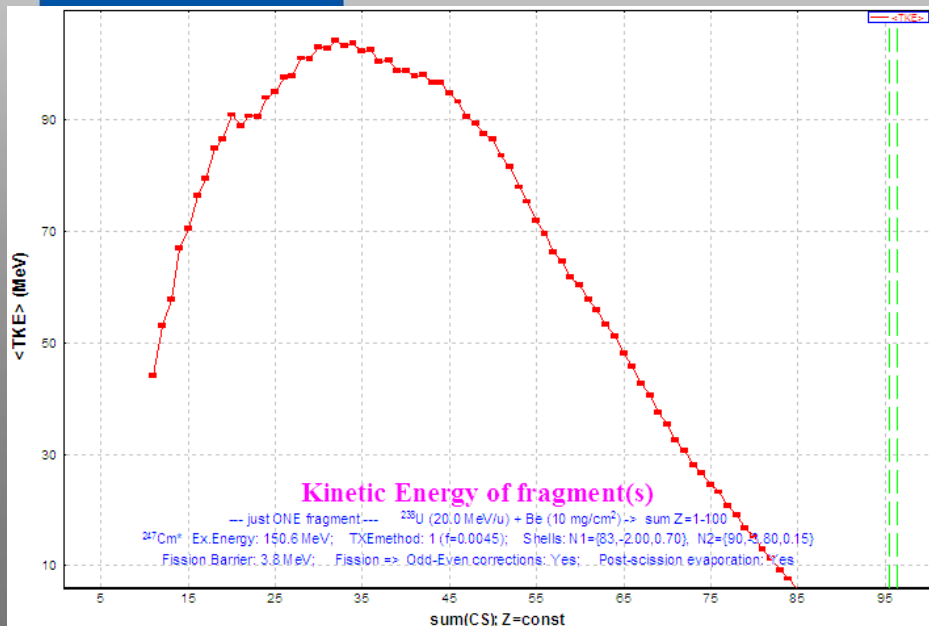
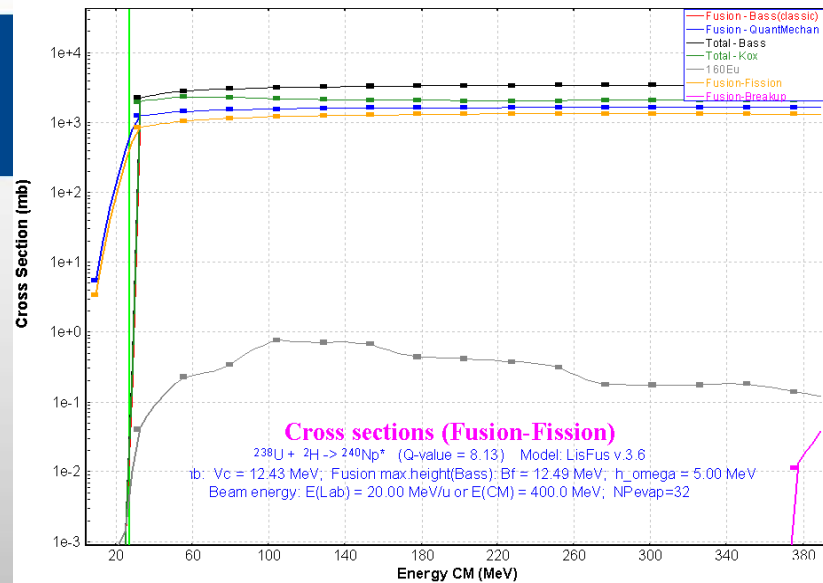
Dimension of the plot:  
 ONE-dimensional  
 TWO-dimensional

Vertical Axis:  
 Z (protons)  
 A (nucleons)  
 N (neutrons)  
 N-Z (isospin)  
 N-2Z

Nmin =   
 Nmax =

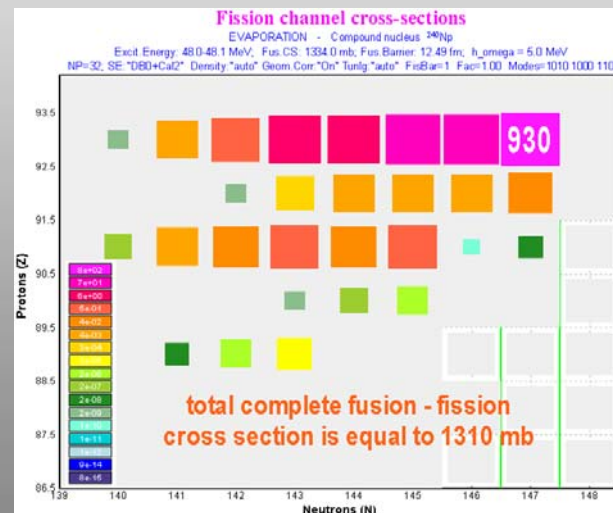
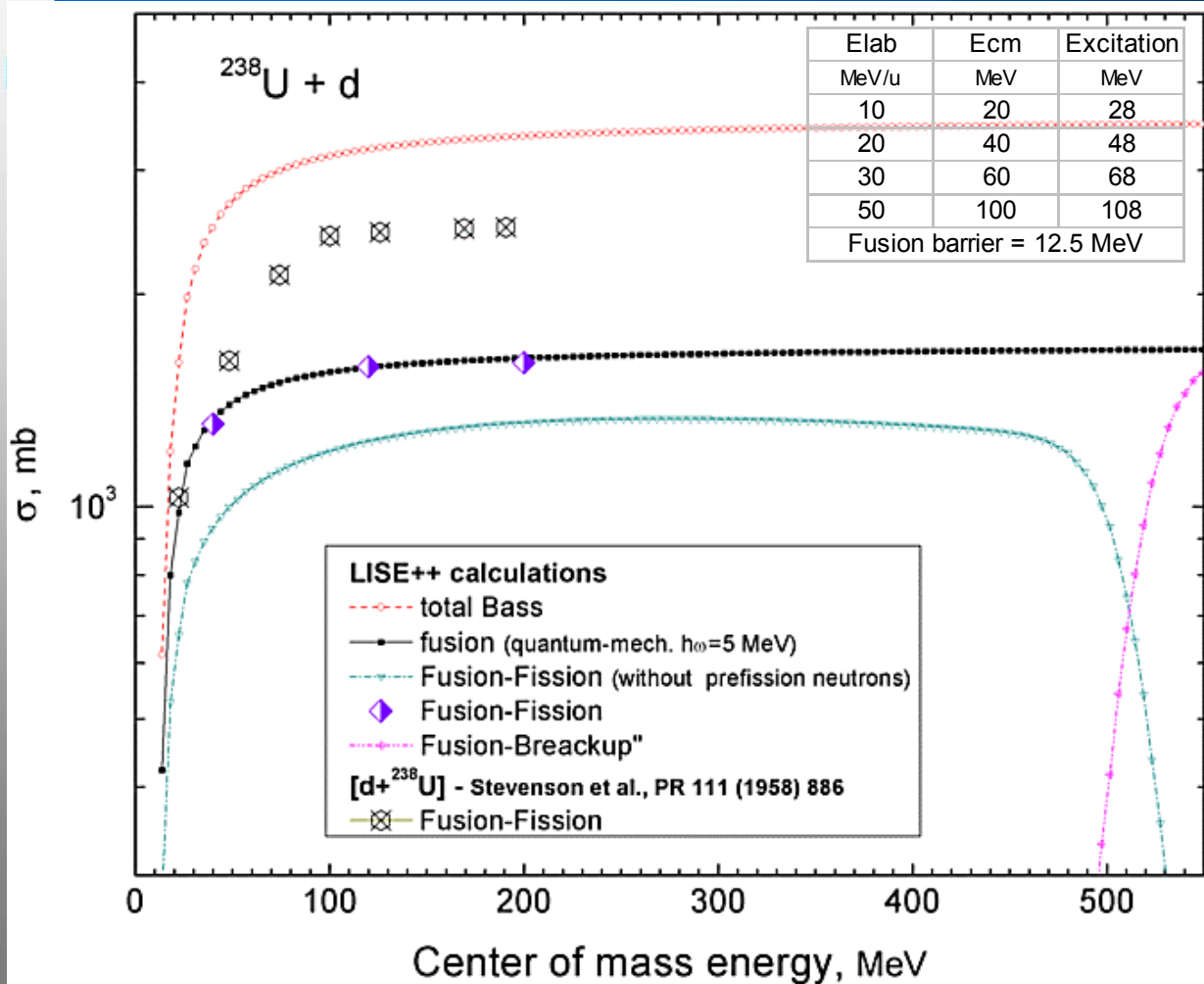
All     Odd     Even

OK     Cancel



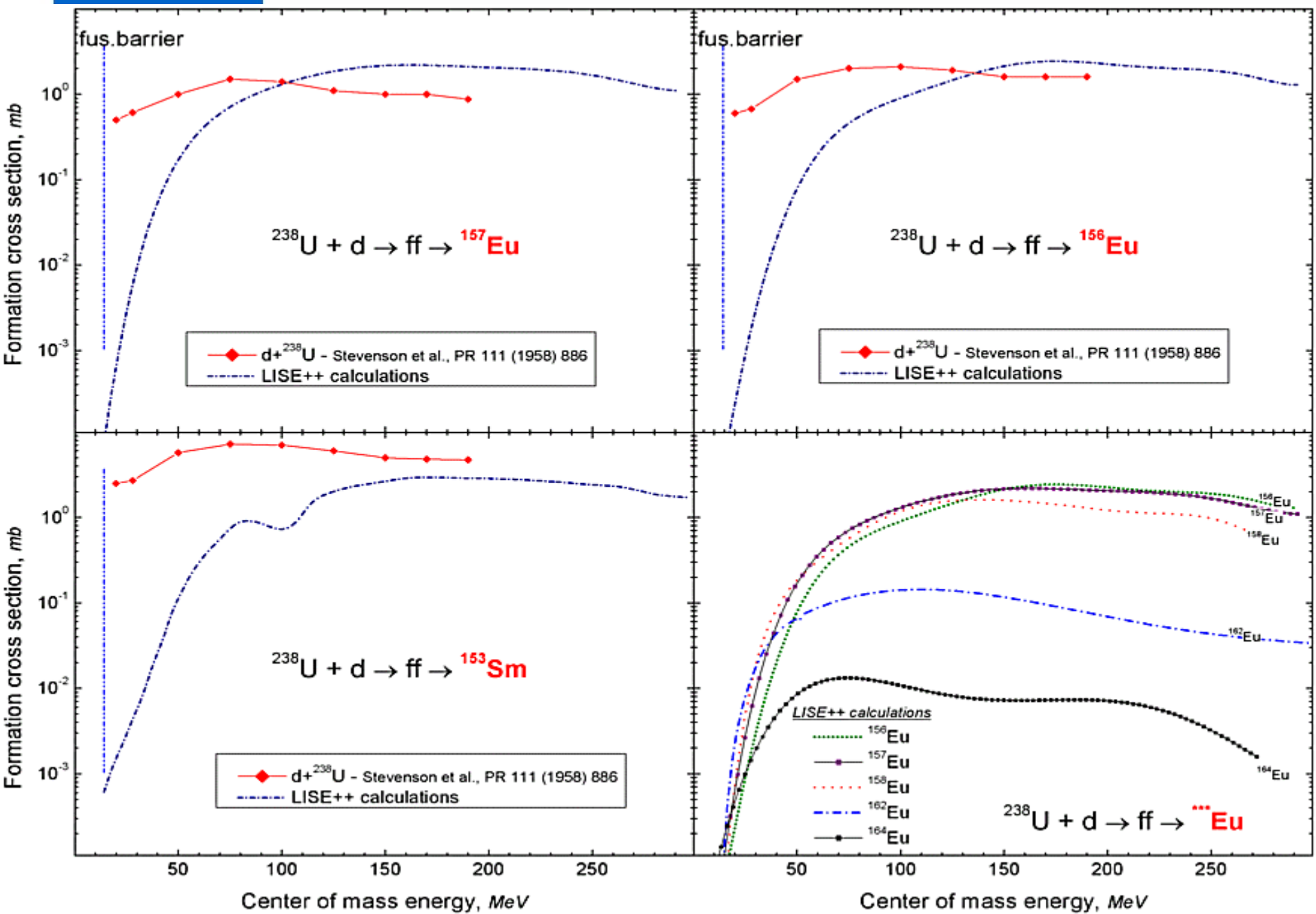


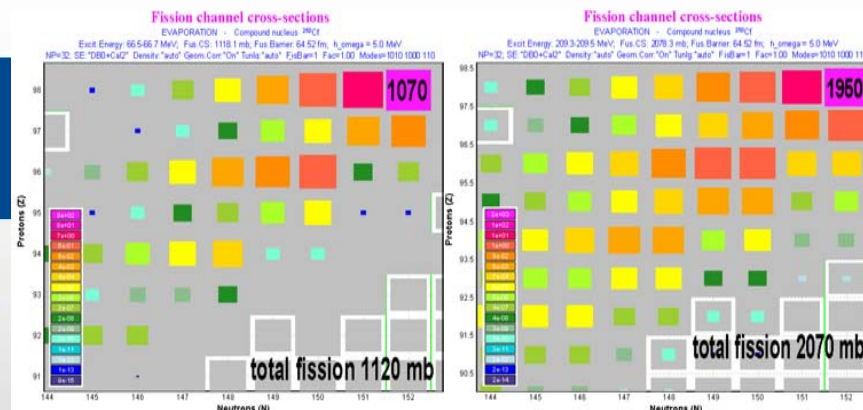
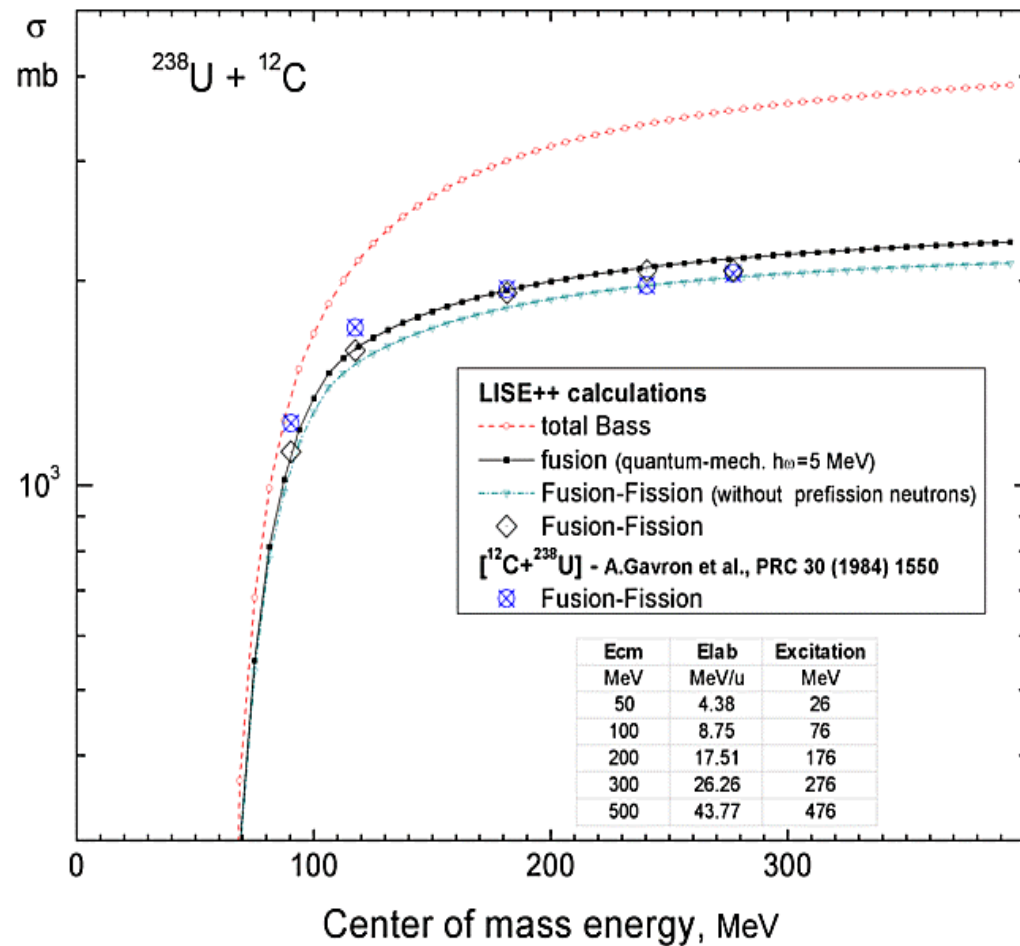
# $^{238}\text{U} + d$ : data and LISE calculations (1)





# $^{238}\text{U} + \text{d}$ : data and LISE++ calculations (2)





**Fusion and fusionlike process**  
 A.Gavron et al., PRC30 (1984) 1550

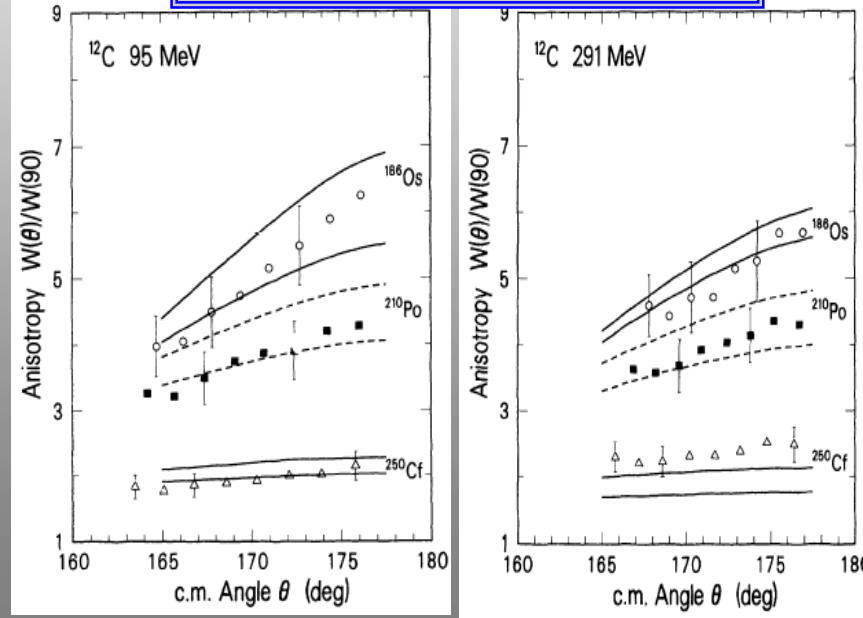
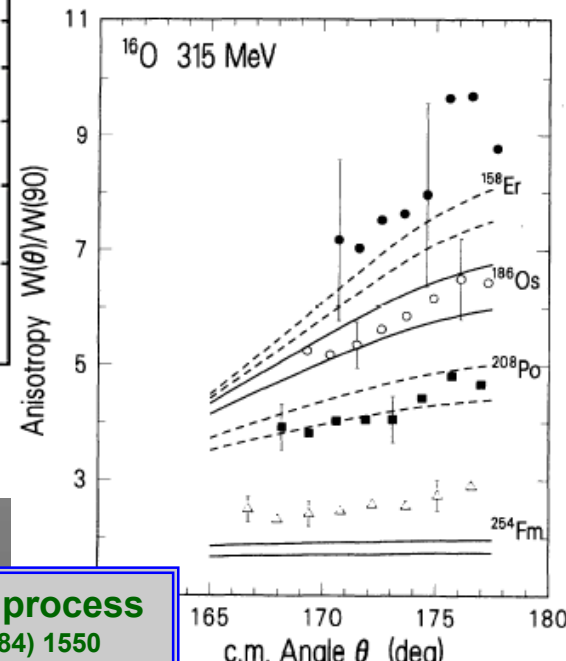
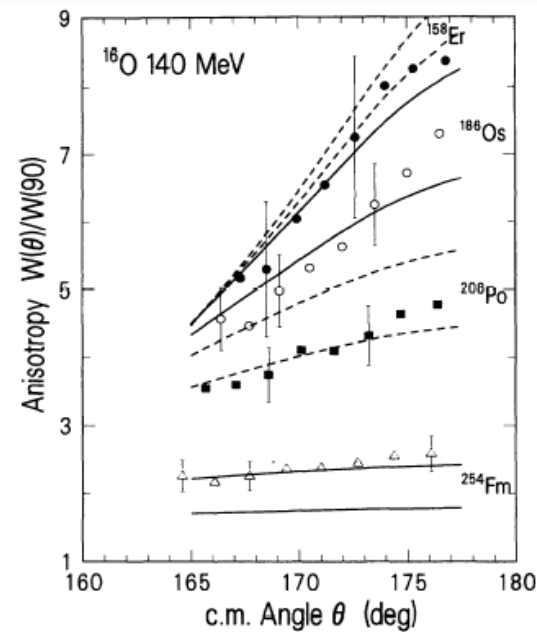
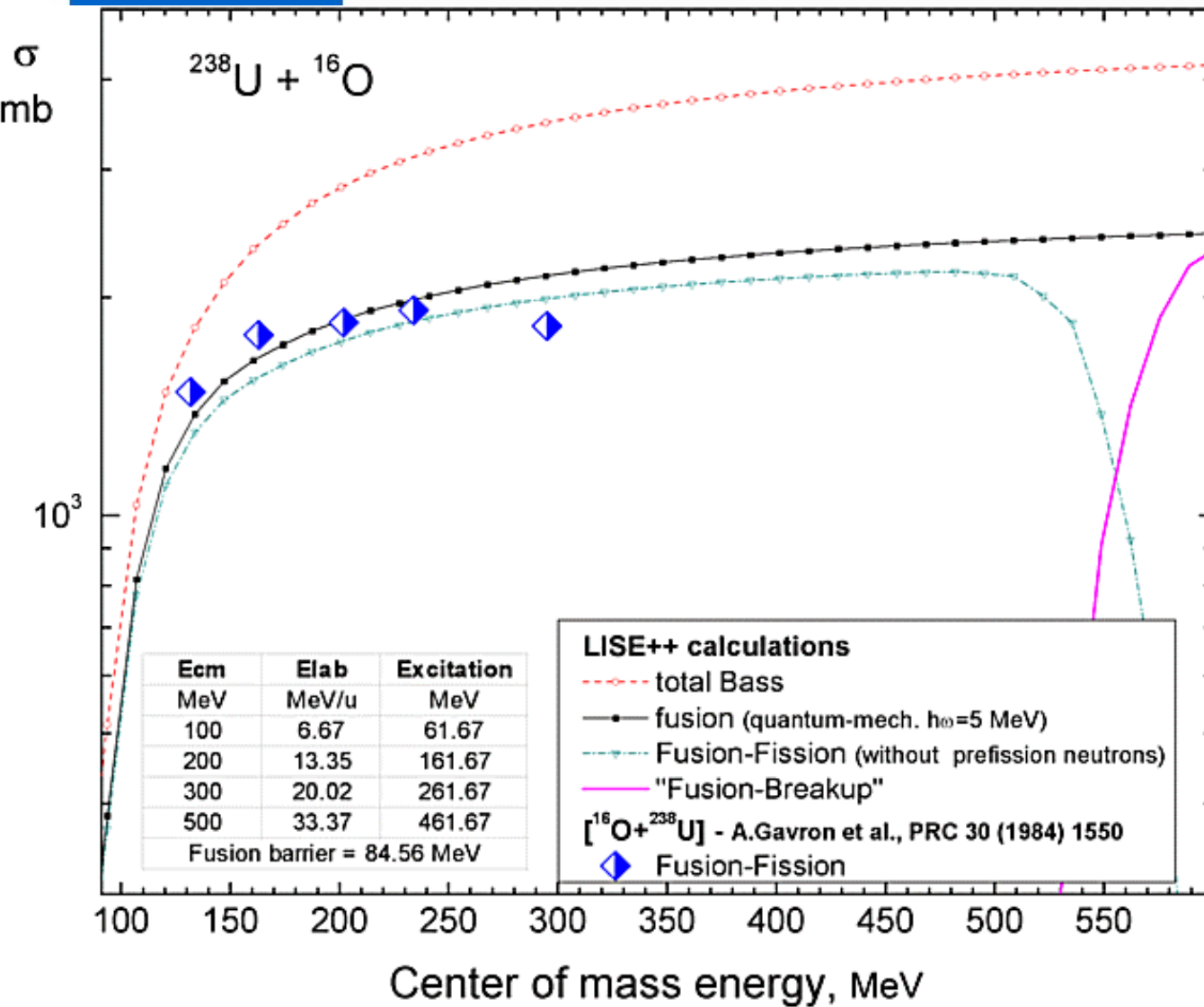


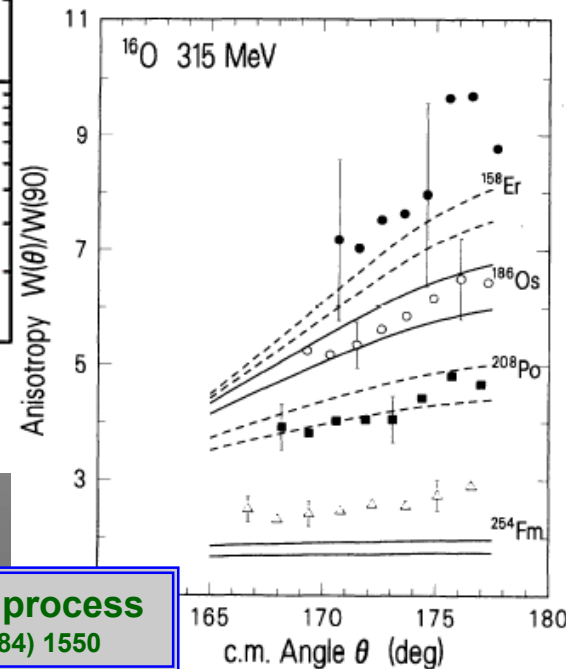
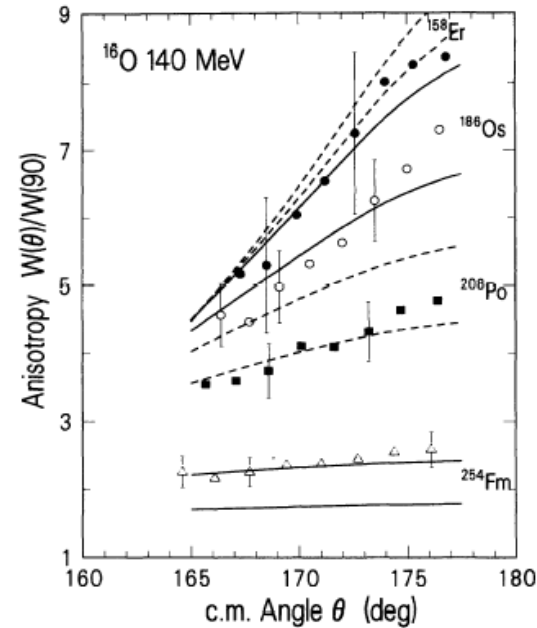
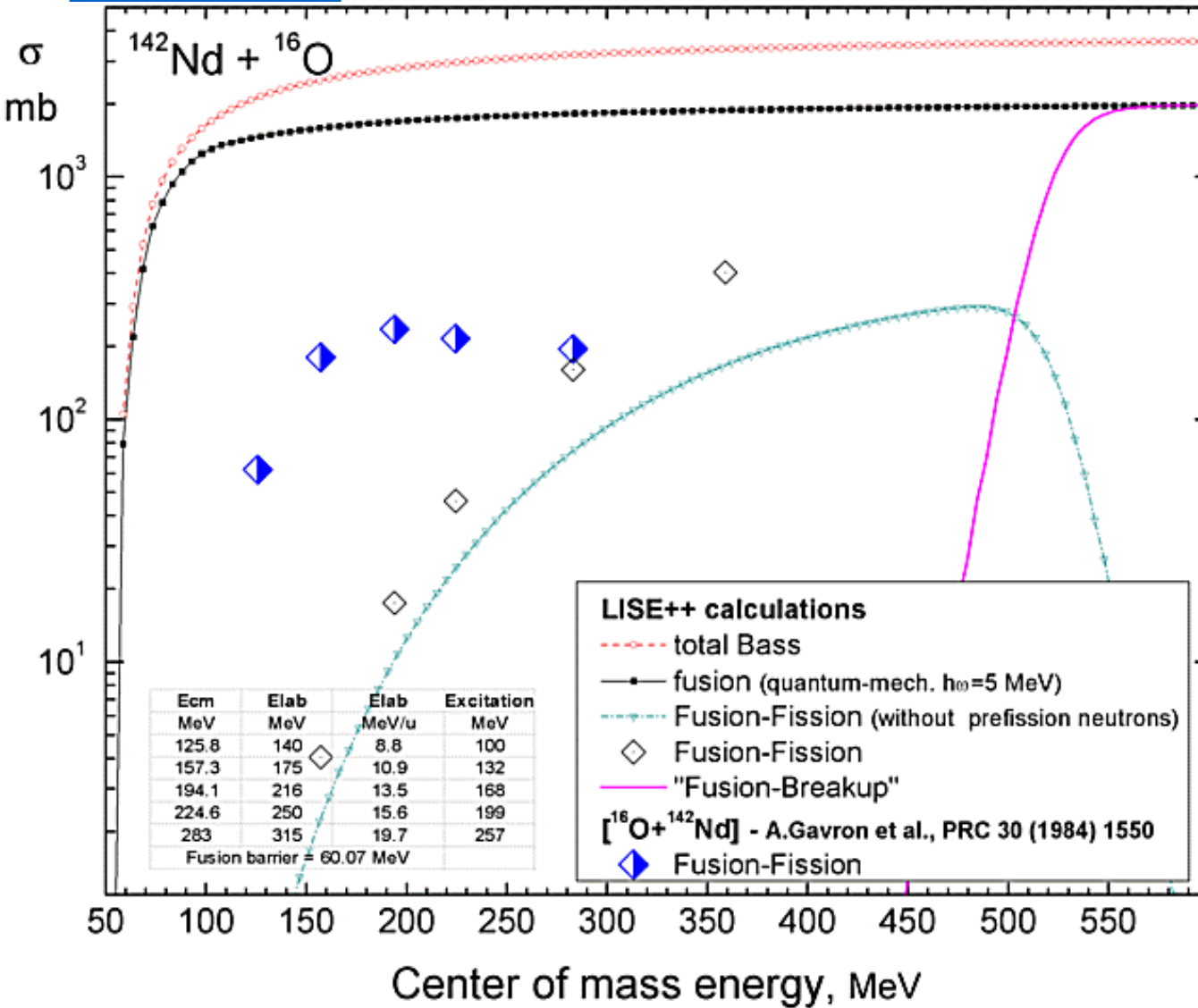
FIG. 8. Angular distribution of fission fragments for  $^{12}\text{C}$  at 95 MeV. Circles, on  $^{174}\text{Yb}$ ; squares, on  $^{198}\text{Pt}$ ; triangles, on  $^{238}\text{U}$ . Lines are results of calculations using the transition state model. Alternate systems have solid and dashed lines to improve readability.

# $^{238}\text{U} + ^{16}\text{O}$ : data and LISE calculations



**Fusion and fusionlike process**  
 A.Gavron et al., PRC30 (1984) 1550

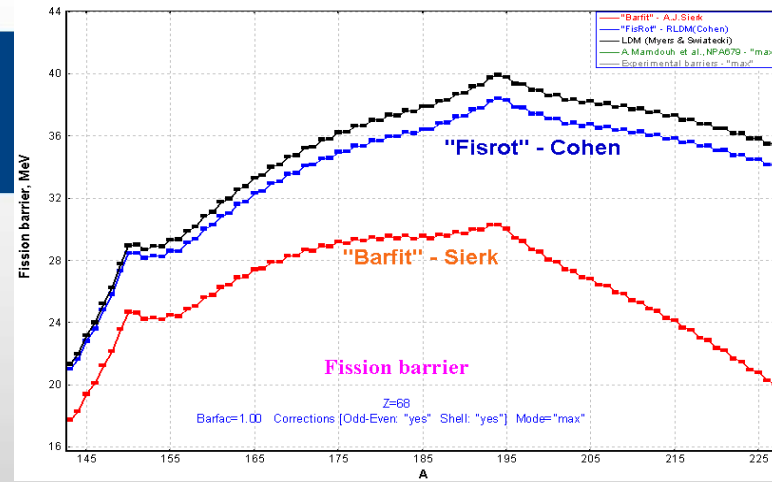
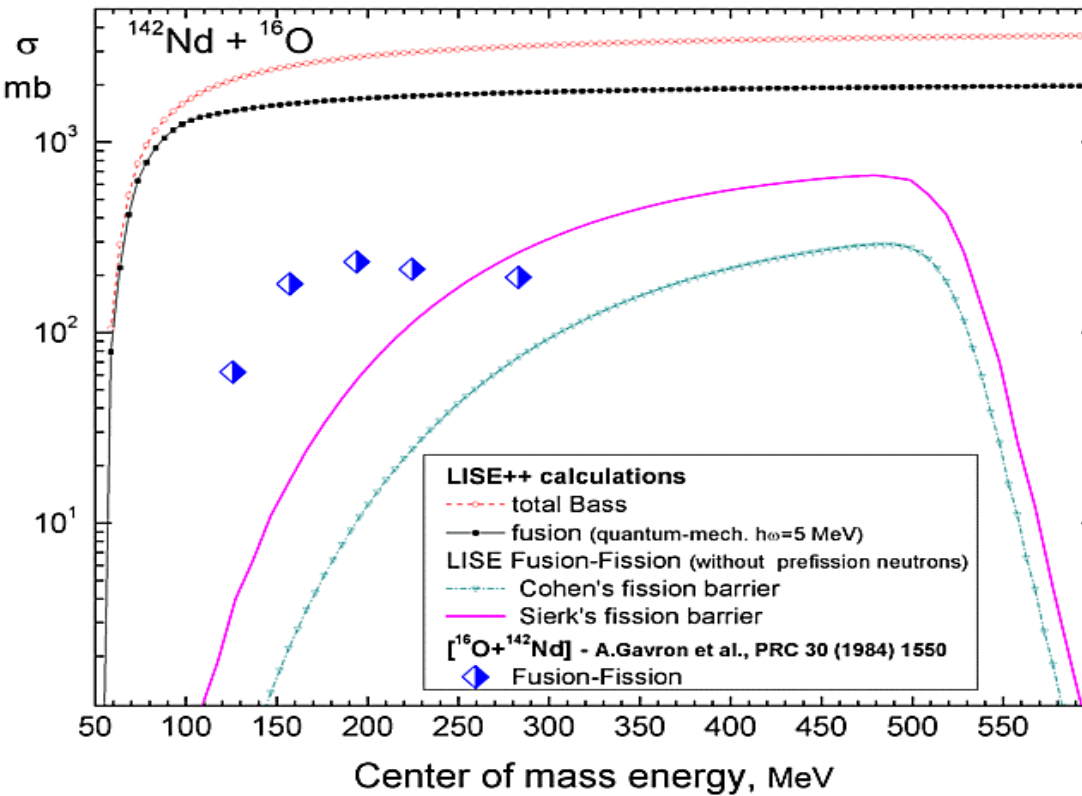
# $^{142}\text{Nd} + ^{16}\text{O}$ : data and LISE calculations (1)



Fission barrier? "FisRot"(Cohen) was used default

**Fusion and fusionlike process**  
A.Gavron et al., PRC30 (1984) 1550





Fission barriers at L=0 for Z=68 isotopes

LISE calculations without angular momentum contribution do not reproduce well this region !

**Fission Barrier**

A Element Z  
 158 er 68

Beta+ decay

Sierk barrier information  
 Barrier vanishes at = 80 hbar

Fission Barrier Plot

Use in the code	Fission Barrier at L=0	Fission Barrier at Lx = 60	G.S. Energy at Lx (MeV)
<input type="radio"/> 0 - "Barfit" - A.J.Sierk, PRC33(1986)2039	25.05	8.52	25.21
<input checked="" type="radio"/> 1 - "FisRot" - S.Cohen et al.An.P 82(1974)	29.39	10.95	25.12

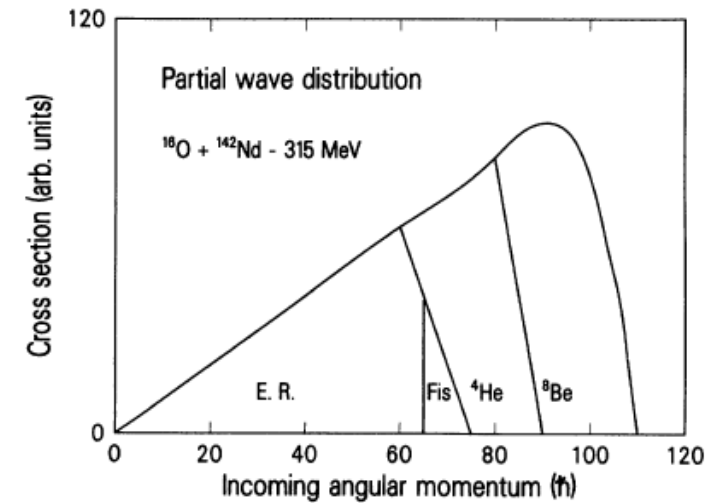
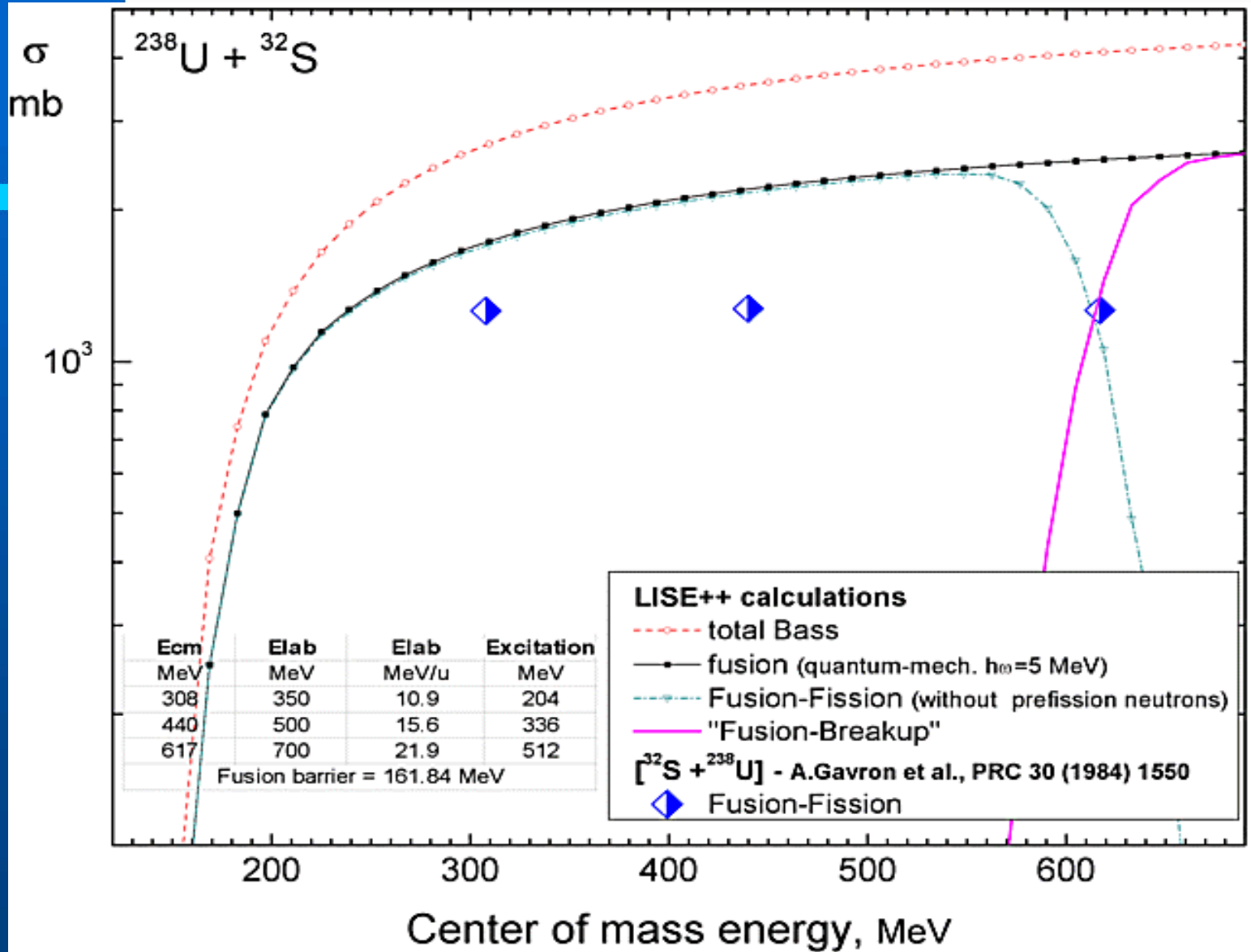


FIG. 17. Schematic partial wave distribution for the  $^{16}\text{O} + ^{142}\text{Nd}$  reaction. ER (evaporation residues) and FIS (fission) label regions of complete fusion which lead to evaporation residues and fission, respectively.  $^4\text{He}$  and  $^8\text{Be}$  label regions of incomplete fusion which, after emission of these particles, end up predominantly in the ER region.



# $^{238}\text{U} + ^{32}\text{S}$ : data and LISE calculations



# Combination of consecutive transmission product calculation for several reactions

Production Mechanism

Reactions Energy Loss, Straggling Charge states Databases: Masses, Isomers

238U(20.0 MeV/u) + H -> 172Tb

Fusion-Fission  
A0 + A1 = A2

Reactions

Settings  Projectile Fragmentation  additionally calculate yields for the next reactions

Settings  Fusion -> Residual

Settings  Fusion -> Fission

Settings  Coulomb fission

Settings  Abrasion-Fission

Settings  Two Body Reactions

ISOL mode

Make default

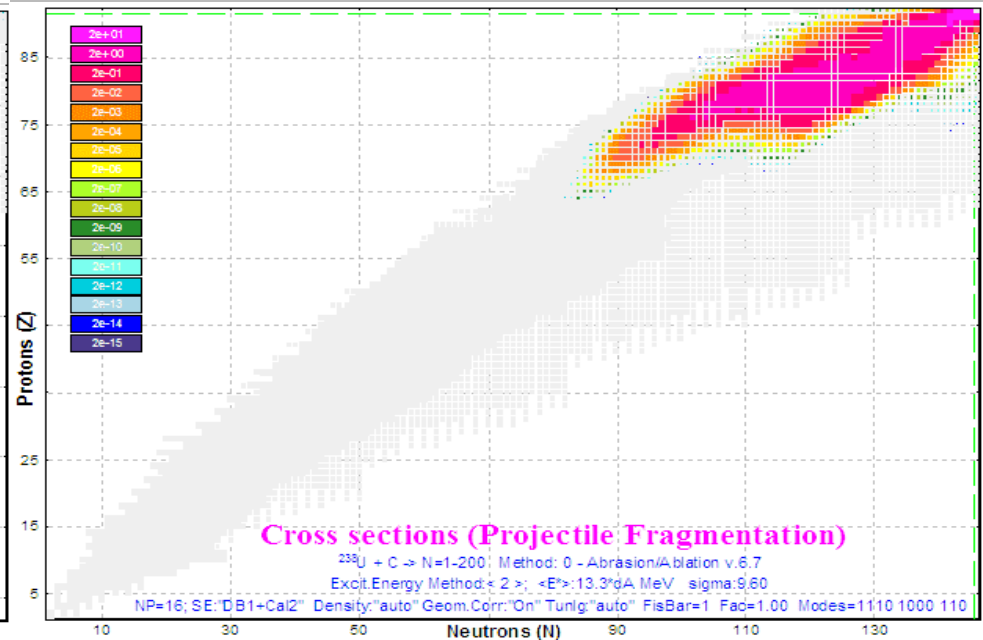
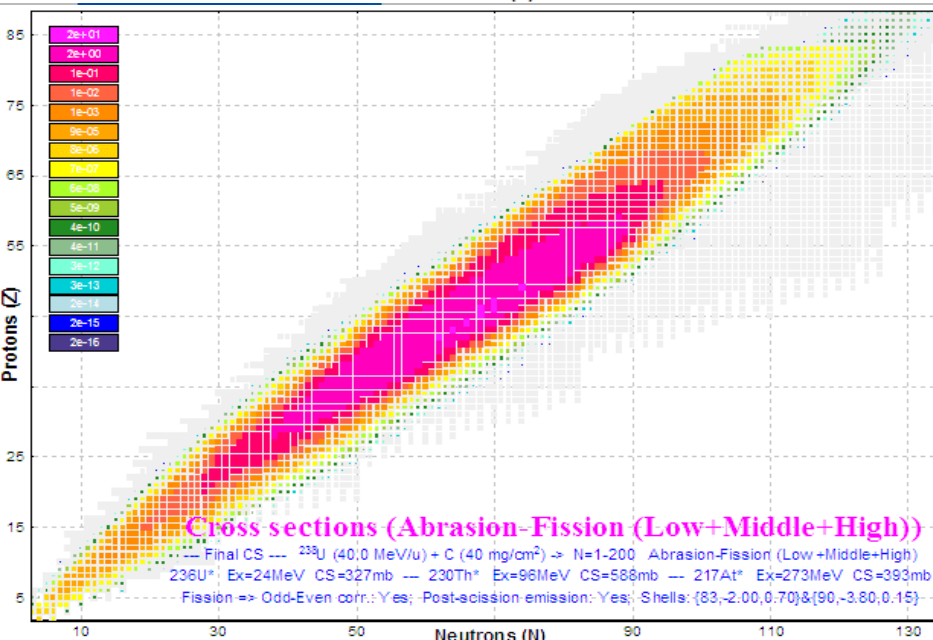
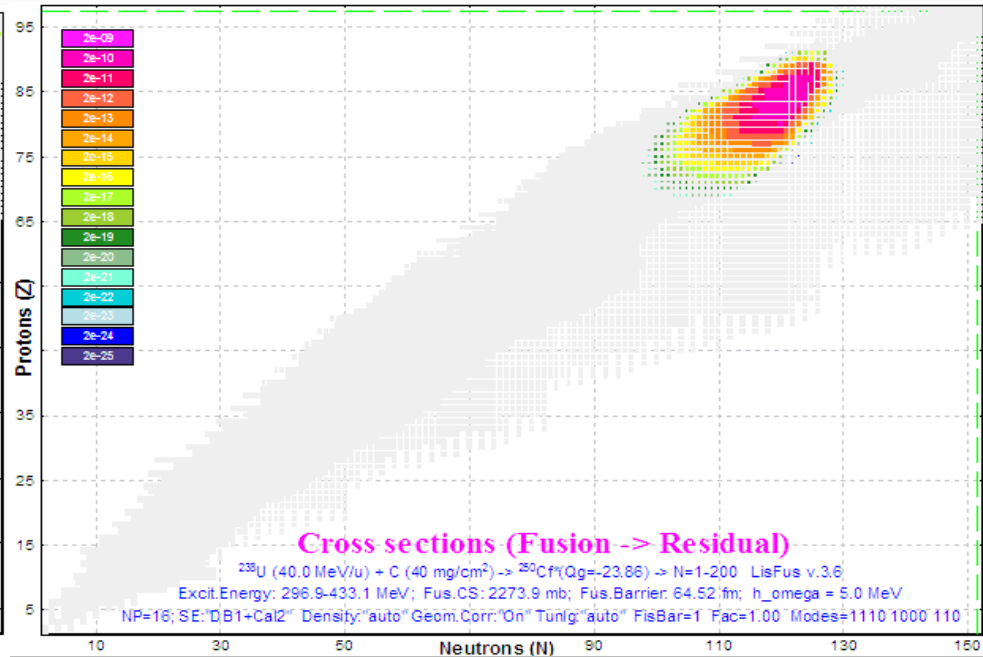
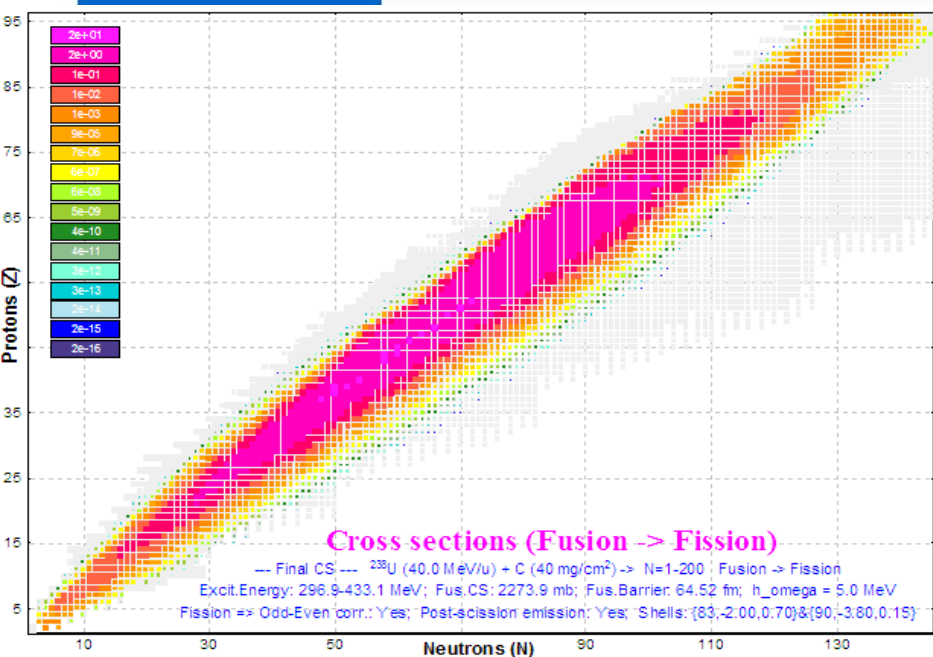
OK Cancel Help

## Notes

- Coulomb fission is included in Abrasion-Fission
- Use the Abrasion-Ablation model instead EPAX for the Projectile fragmentation mechanism in the case of consecutive calculations
- Preliminary check excitation energy region settings for Abrasion-Fission mode

# Combination of consecutive transmission product calculation

## $^{238}\text{U}(40\text{MeV/u}) + \text{C} \rightarrow \text{Fusion or Abrasion} ??$



# Combination of consecutive transmission product calculation $^{238}\text{U}(40\text{MeV/u}) + \text{C} \rightarrow \text{Angular acceptance}$

