NRV

LISE++

Calculators of two-body kinematics

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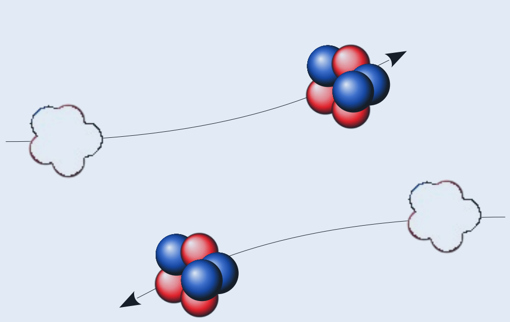
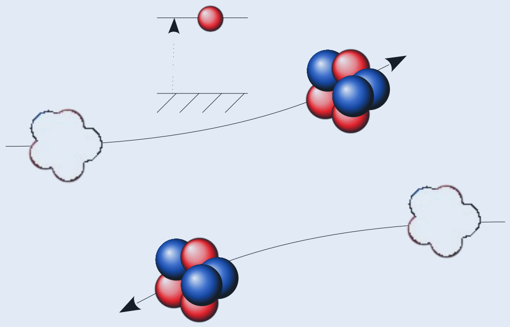
[NRV] I. Zagrebaev et al. , JINR Dubna
[LISE++] O.B Tarasov, D. Bazin , MSU East Lansing

Scattering and reactions of two nuclei (lower energies)

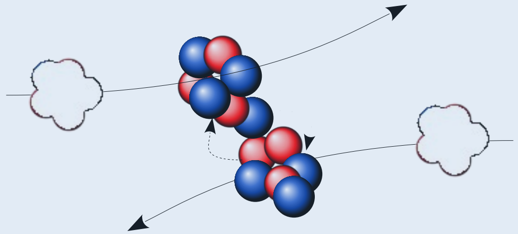
- Two nuclei in the outgoing channel



Elastic scattering

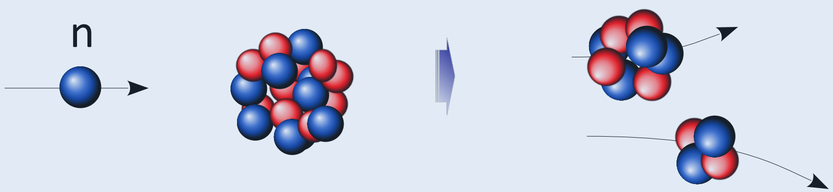


Inelastic scattering
with excitation

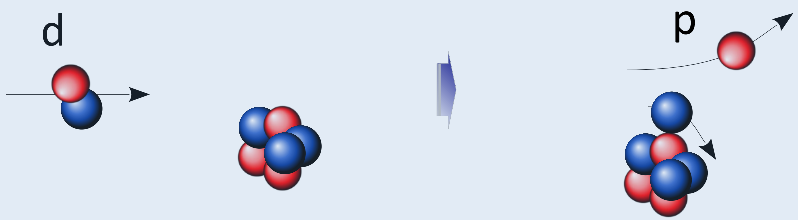


Transfer of nucleons
during contact

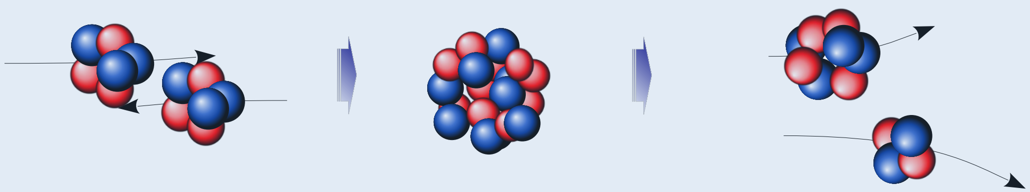
- Two / more nuclei in the outgoing channel + possible further emission of γ / n



Fission into fragments

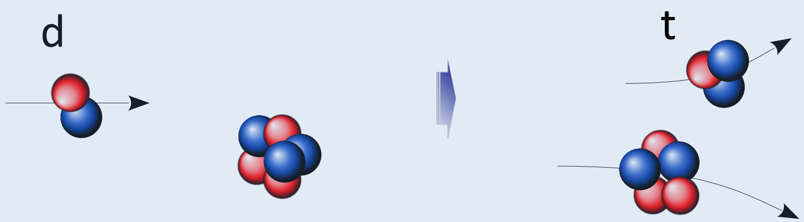


Breakup / Stripping



Fusion into
Compound nucleus

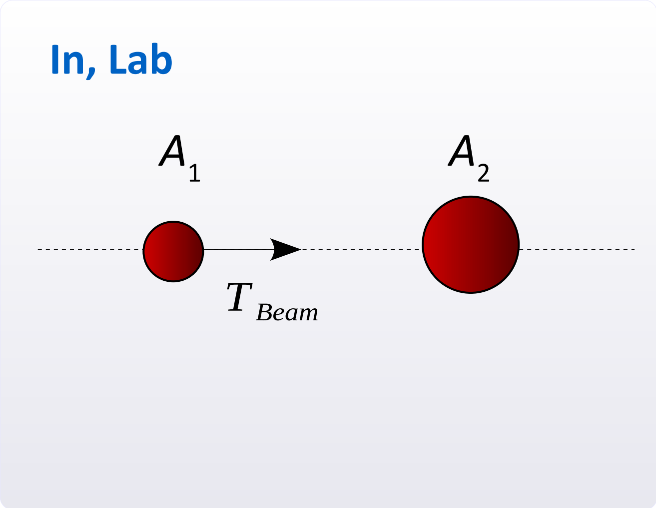
Possibly:
Fission into fragments

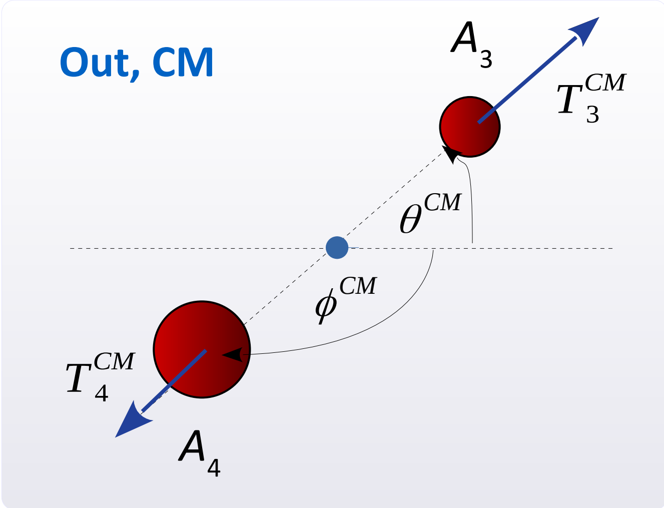


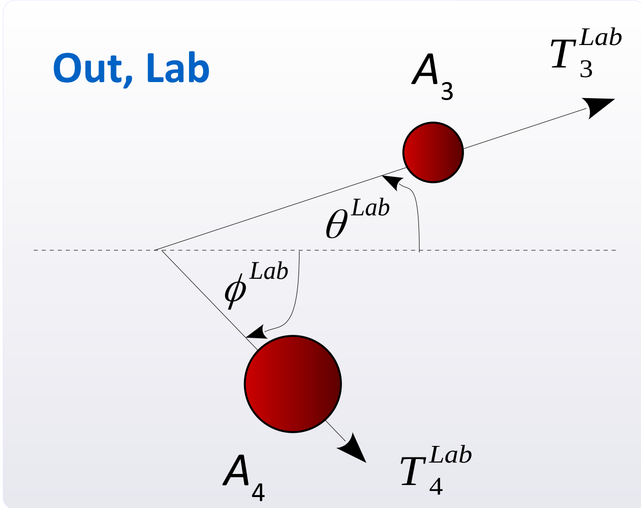
Pickup

Some facts on non-relativistic kinematics of elastic collision

- The beam nucleus A_1 is accelerated to kinetic energy T_{Beam} and hits the stationary target nucleus A_2.







- If the scattering or collision is elastic, $A_3 = A_1$ and $A_2 = A_4$. Applying *E* and *p* conservation laws gives:

$$T_3^{Lab} = T_{Beam} \frac{\left(A_1 + A_2 \cos\theta^{CM}\right)^2 + \left(A_2 \sin\theta^{CM}\right)^2}{\left(A_1 + A_2\right)^2}$$

where

$$\tan\theta^{Lab} = \frac{\sin\theta^{CM}}{\cos\theta^{CM} + \frac{A_1}{A_2}}$$

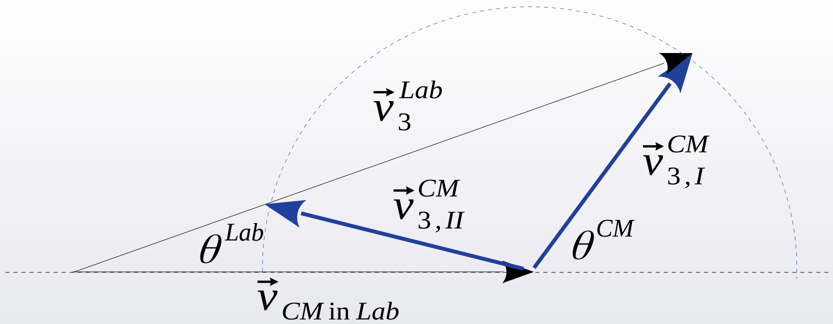
$$T_4^{Lab} = T_{Beam} \frac{A_1 A_2}{\left(A_1 + A_2\right)^2} \left(2\sin\phi^{Lab}\right)^2$$

$$\phi^{Lab} = \frac{\pi}{2} - \frac{\phi^{CM}}{2}$$

- ***Caution***: if $A_1 > A_2$, then:

1) one θ^{Lab} is realized by two θ^{CM}
2) θ^{Lab} has an upper limit.

This situation is called **reverse kinematics**.



Heat of reaction Q

- **Energy balance** for a two-body process (not necessarily elastic one), in the CM frame:

Input channel = **Output channel**

$$m_1 c^2 + m_2 c^2 + T_{Beam} = m_3 c^2 + m_4 c^2 + T_3^{CM} + T_4^{CM} + \epsilon_3^* + \epsilon_4^*$$

- $m_1 c^2 + m_2 c^2$: Masses of input nuclei
- T_{Beam}: Kin. energy of beam nucleus
- $m_3 c^2 + m_4 c^2$: Masses of output nuclei
- $T_3^{CM} + T_4^{CM}$: Kin. energies of output nuclei
- $\epsilon_3^* + \epsilon_4^*$: Excitation energies of output nuclei

- Imagine a specific output channel (nuclei of masses m_3, m_4 in excited states of energies ϵ_3^*, ϵ_4^*).
Can this reaction undergo freely? Does it release (kinetic) energy spontaneously?
Or should energy be pumped (via beam kinetic energy) ?

- **Heat of reaction, Q:**

$$Q \overset{df}{=} (m_1 + m_2) - (m_3 + m_4) - (\epsilon_3^* + \epsilon_4^*)$$

$$\Rightarrow \quad Q \overset{numerically}{=} T_3^{CM} + T_4^{CM} - T_{Beam}$$

If $Q \geq 0$, this process can occur spontaneously

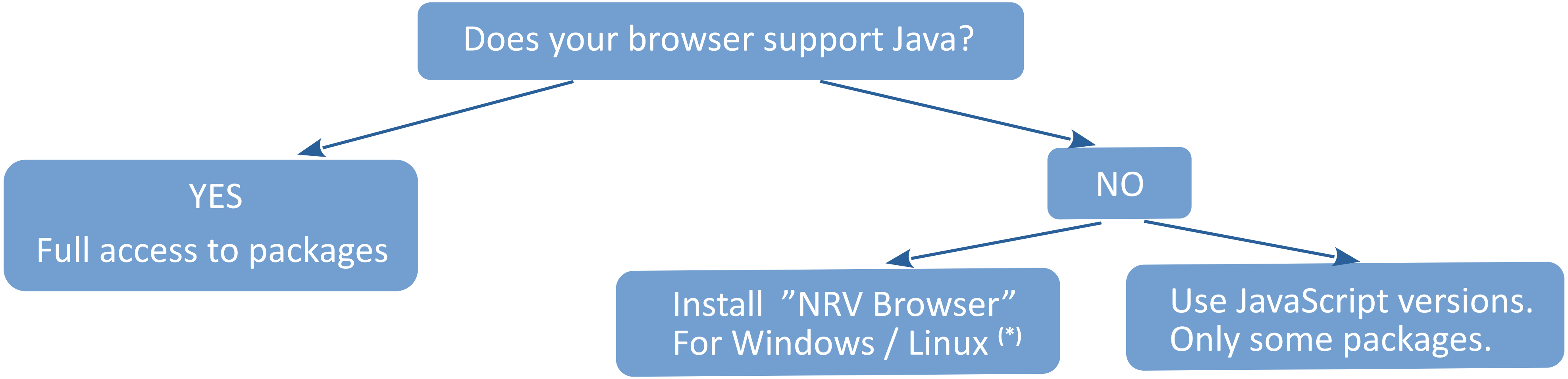
If $Q < 0$, it cannot. We must supply this amount of energy (via beam kinetic energy)

If the collision is elastic, then $Q = 0$.

- **Nuclear Reactions Video** by V. Zagrebaev's group @ JINR Dubna around 1999.

  It is a "low-energy knowledge base" with nuclide chart, data on nuclei, nuclear processes, kinematics calculator.

  Flagship paper: A.V. Karpov *et al.*, "NRV web of knowledge base on low-energy nuclear physics", Nuclear Instruments and Methods A 859, 112 (2017)



- **Nuclear properties** – chart of nuclides. Data for each nuclide: binding energies, deformations, excited states (E, spins) and decay properties (BR, Q-values).

- **Systematics** – provide graphs of: separation / binding energy, size, half-life, deformation, fission barriers as function of A / Z / N for a selected one of these values.

- **Kinematics calculator** – provides translations between energies and emission angles of nuclei emitted in 2-body nuclear collisions:
  - elastic scattering (from Coulomb or nuclear interaction)
  - inelastic scattering (with excitation of any of nuclei; via Coulomb or nuclear forces)
  - transfer of some nucleons between nuclei during the collision

(*) On NPD training computer, type: ① `cp -r ~kpiasecki/soft/nrv/ctnp/* .` ② `./run.sh`

Two-body kinematics: user interface

Kinetic energy of beam nucleus
Caution: press enter!

PLF = Projectile-like fragment

TLF = Target-like fragment

Not secure | nrv.jinr.ru/nrv/mobilenrv/kinematics/Kinematics2Body.html

Projectile			Target			Projectile-like fragment			Target-like fragment		
Mg	24	+	Zr	90	→	Mg	24	+	Zr	90	+ Q_{tot}(= 0.0 MeV) [1]

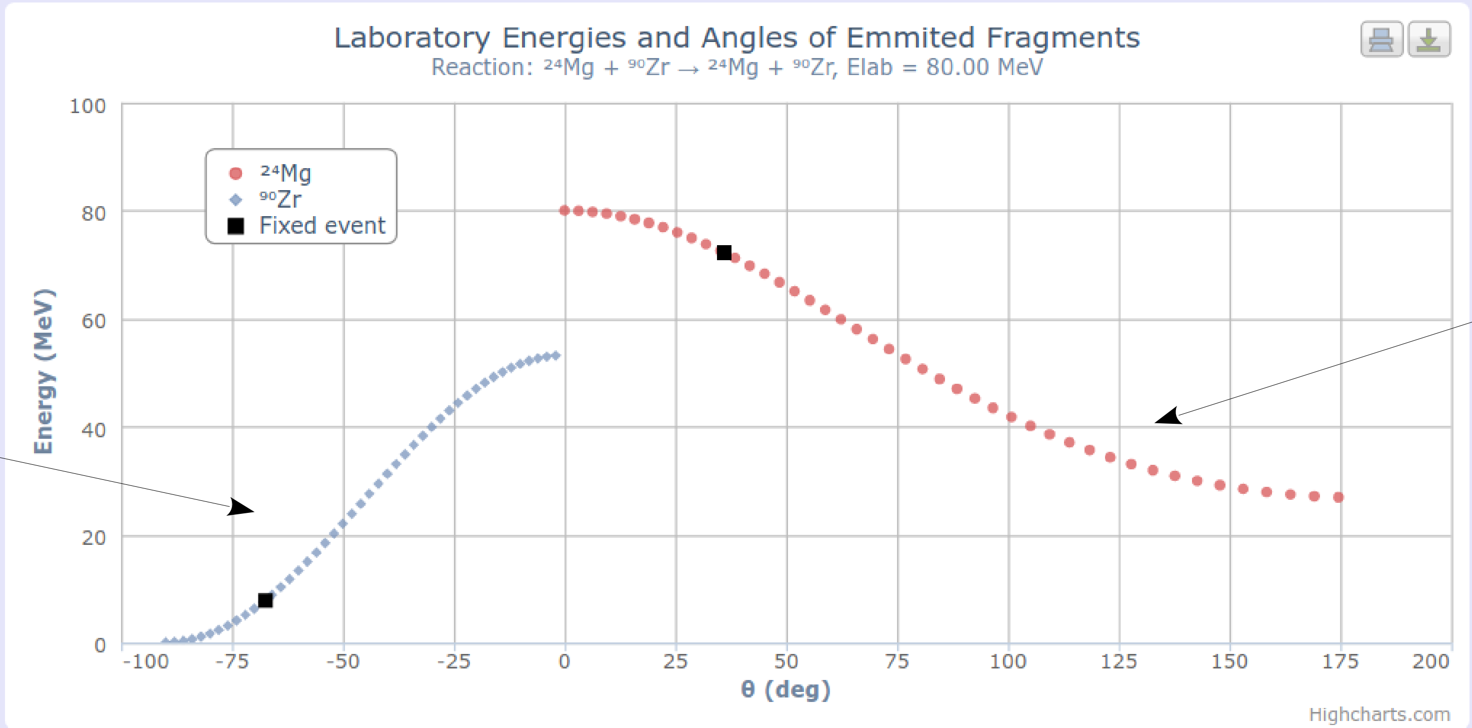
E_{lab} = 80.00 MeV ε_{PLF}= 0.0 MeV ε_{TLF}= 0.0 MeV E_{cm}(out)= 63.16 MeV

Calculate $\Delta\theta_{cm}$ = 4.00 deg

After typing nuclei and *E*, Q is shown automatically.

Excitation energies of PLF and TLF

Energy vs. Angle | Energy vs. Energy | Angle vs. Angle



TLF

PLF

Kinematically allowed values

	θ_{lab} (deg)	E_{lab} (MeV)
^{24}Mg	0.0° < θ_{lab} < 180.00°	26.81 < E_{lab} < 80.00
^{90}Zr	0.0° < θ_{lab} < 90.00°	0.0 < E_{lab} < 53.19

Fixed event parameters

E_{PLF}= 72.21 MeV θ_{PLF}= 35.99 deg

E_{TLF}= 7.79 MeV θ_{TLF}= -67.50 deg

☑ Show/Hide θ_{cm}= 45.00 deg

Save data as ASCII file

Give some input values and you'll get output & black point on the plot.

In geom. model maximal (output) scattering angle before nuclei touch each other →

Grazing collision([4], p.7): θ_{gr}(cm) ≈ 143.3 deg, θ_{gr}(lab) ≈ 131.9 deg, b_{gr} ≈ 1.7 fm, L_{gr} ≈ 13 ħ

Coulomb barrier([4], p.326, 332): V_C ≈ 62.2 MeV, R_C ≈ 10.3 fm

- **LISE++** by O.B Tarasov and D. Bazin @ Michigan State University (MSU)

  Its main goal concerns **fragment separators** (transmission and yields of fragments produced / collected there). However, it offers several calculators, including the **Relativistic Kinematics Calculator**.

  WWW: **https://lise.nscl.msu.edu**

  Papers: [2008], [2016], [2023] .

  Installation:

  - Download: [**HERE**]
  - NPD training computer: first install on your account:

    ① `mkdir lise; cd lise`
    ② `cp ~kpiasecki/soft/lise++/ctnp/lise_setup.sh`
    ③ `./lise_setup.sh`

    Then run using wine:

    ④ `nice wine ./LISE++.exe`

- **Instructions** on **Relativistic Kinematics calculator:** [**HERE**] and [**HERE**]

- **How to open Calculator**:

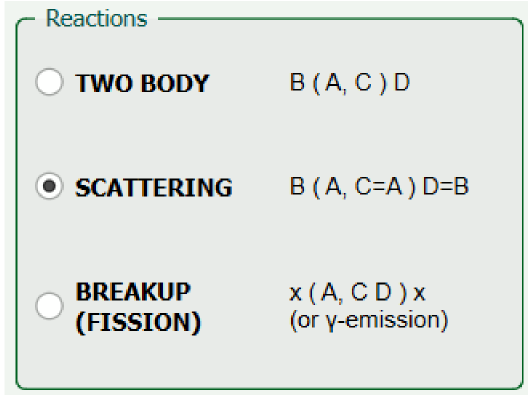
  ▸ From the upper toolbar, choose:

- Different **types of processes**:

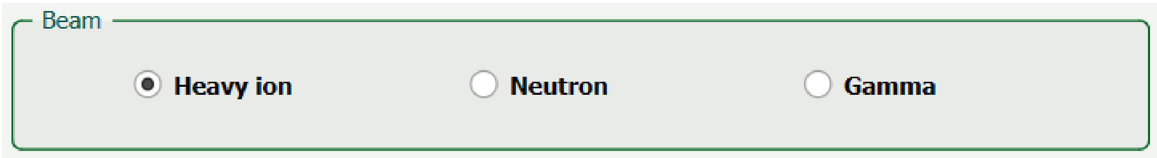
  Scattering: A + B → A + B , nuclear convention: B (A, A) B

  Two body: A + B → C + D , nuclear convention: B (A, C) D

  Breakup (**fission**) , but also: decay.
  Understood as „spontaneous" process, i.e. symbol x means none.
  Either fission of nucleus (A → B C), or decay from excited state (A* → B C)



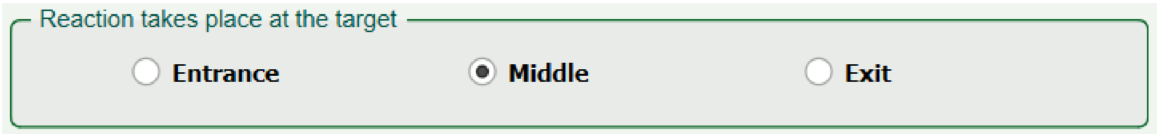
- Different **types of beam**:

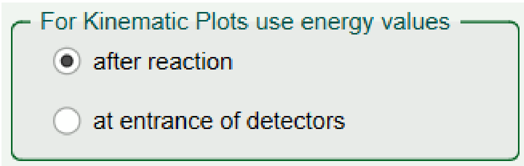


- Target has **thickness**
  ⇒ substrates and products **lose energy**.

  Lise needs to be told,
  where in the target the reaction occurs.

  Also, if energy of products should be given
  just after reaction, or after crossing the target.





LISE++ Relativistic Kinematics Calculator

- **Example**

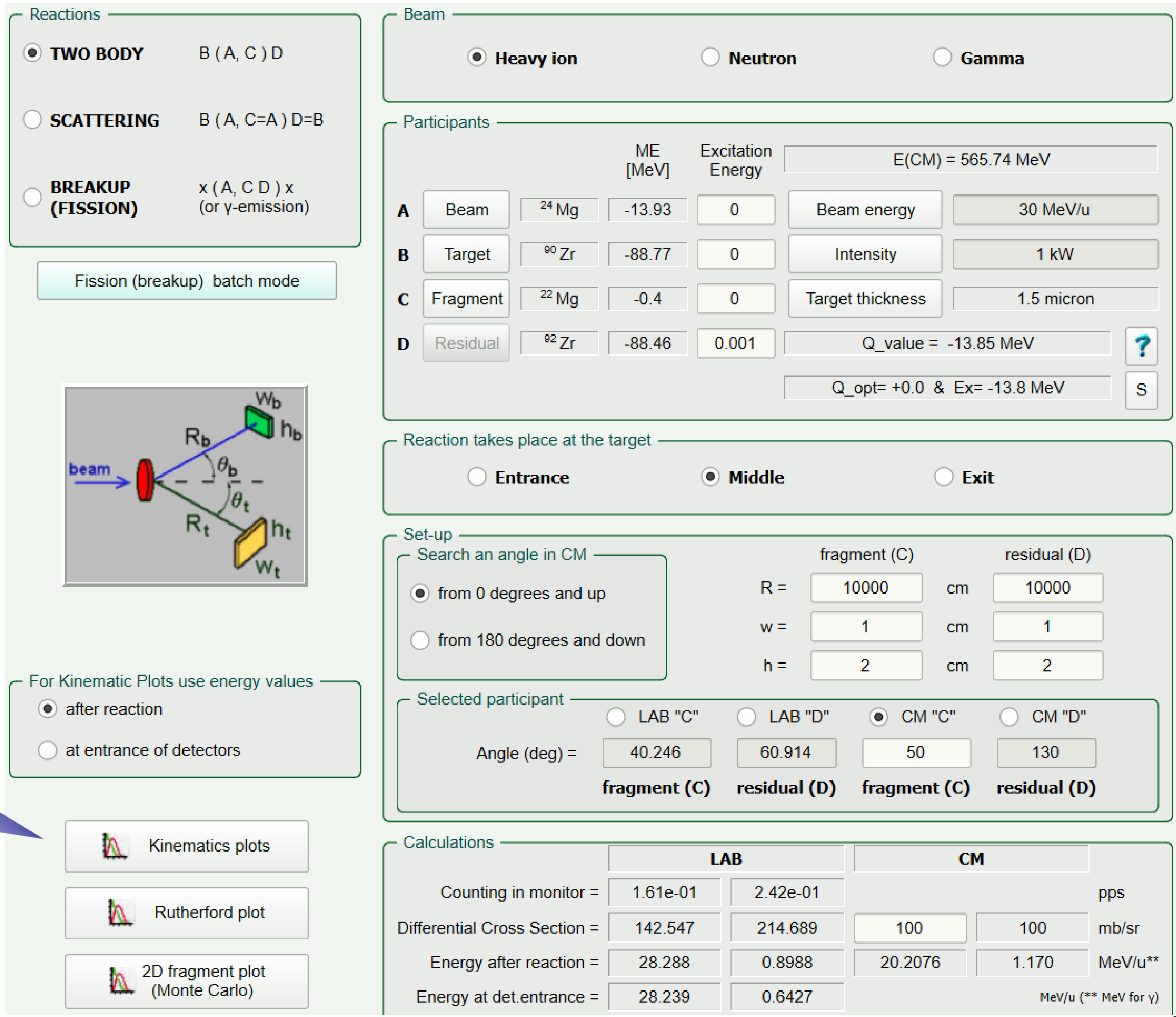
$^{24}Mg + ^{90}Zr \rightarrow ^{22}Mg + ^{92}Zr$

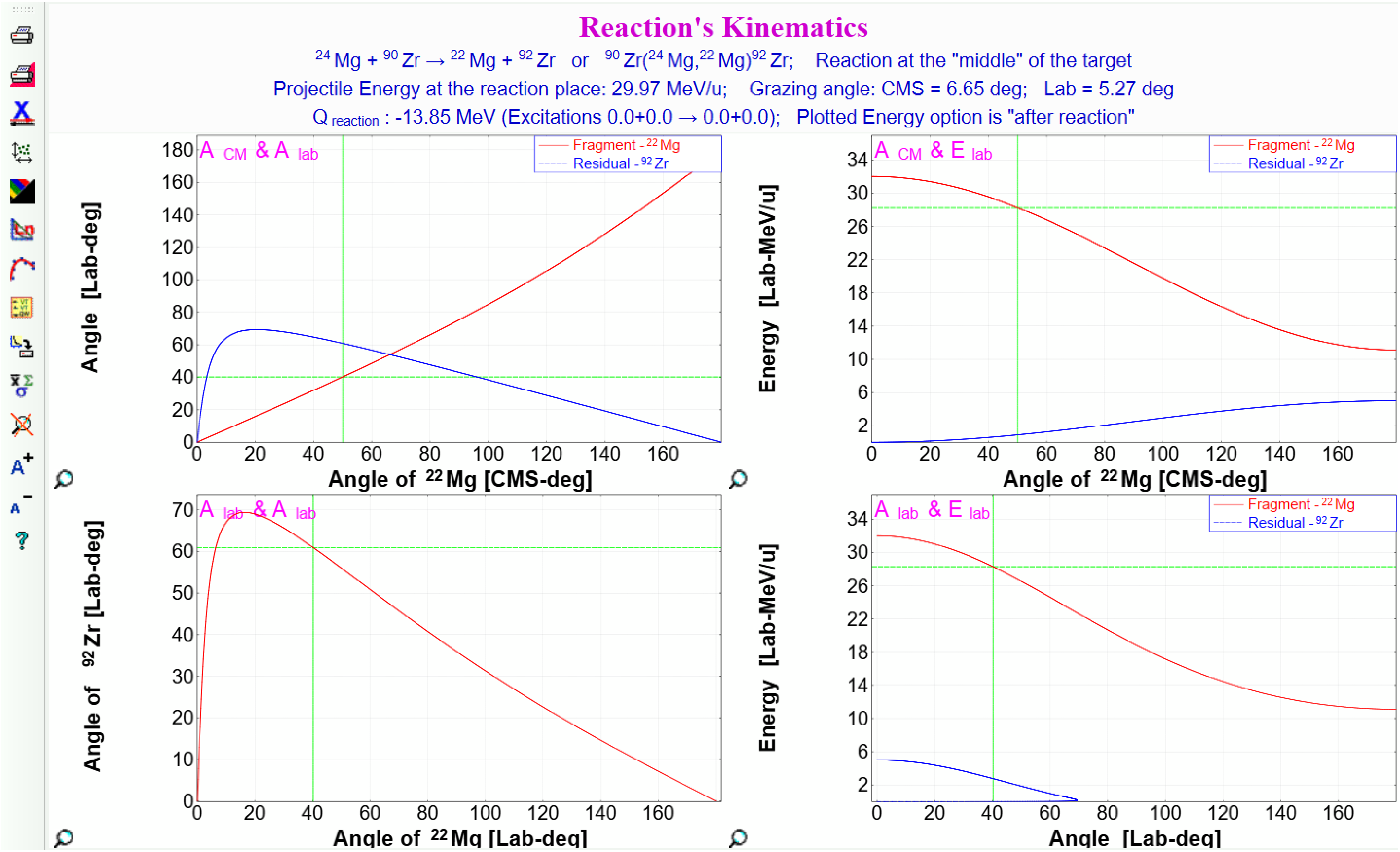
T_{Beam} = 30A MeV

Target thickness: 1.5 μm

Reaction: mid-target

Click





- Click [icon] to save data into text file.