Experimental study of multinucleon transfer reactions in the interaction of heavy nuclei at CORSET setup

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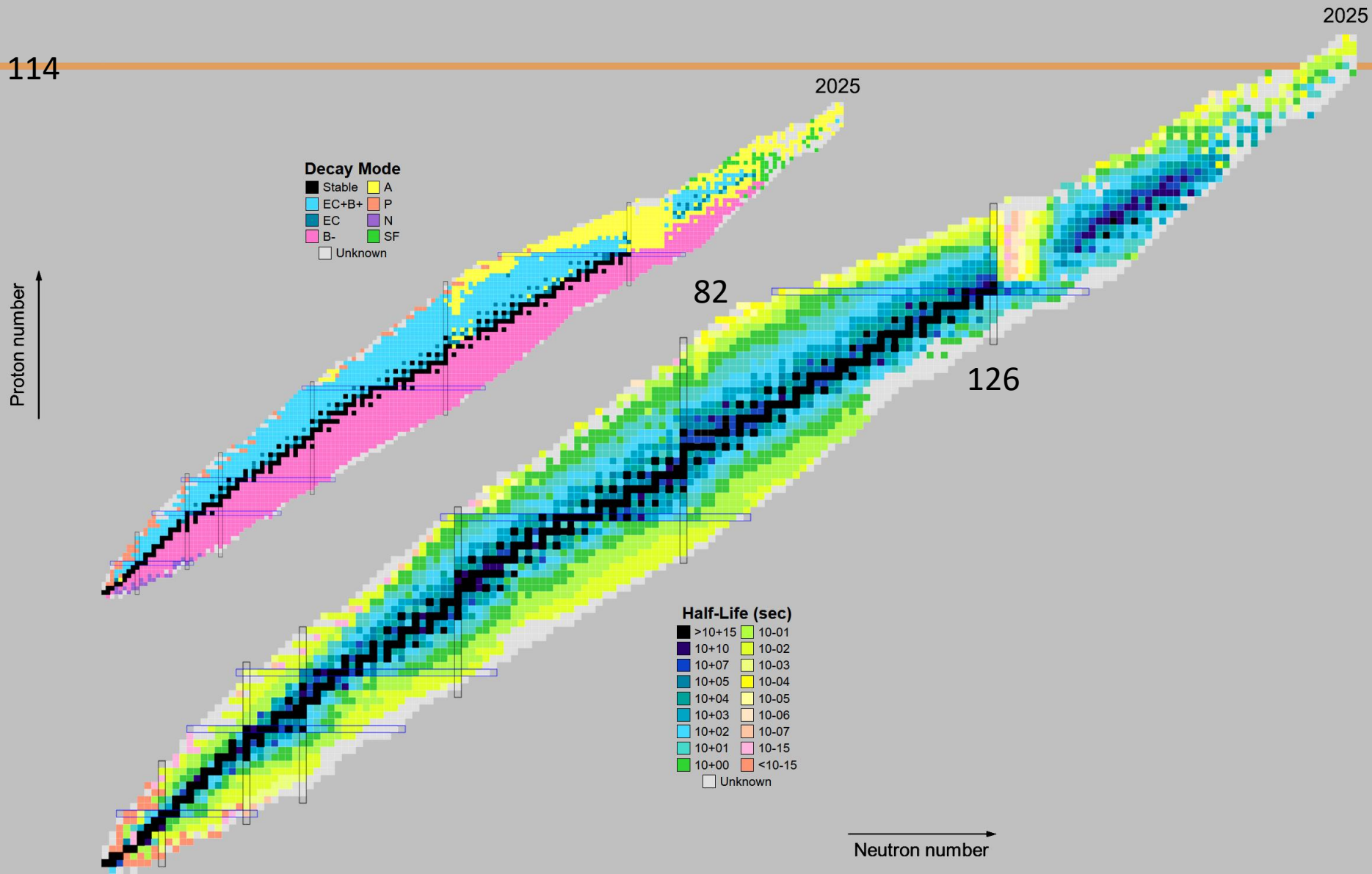
NISER Bhubaneswar

Synthesis of new nuclei



https://www.nndc.bnl.gov/nudat3/

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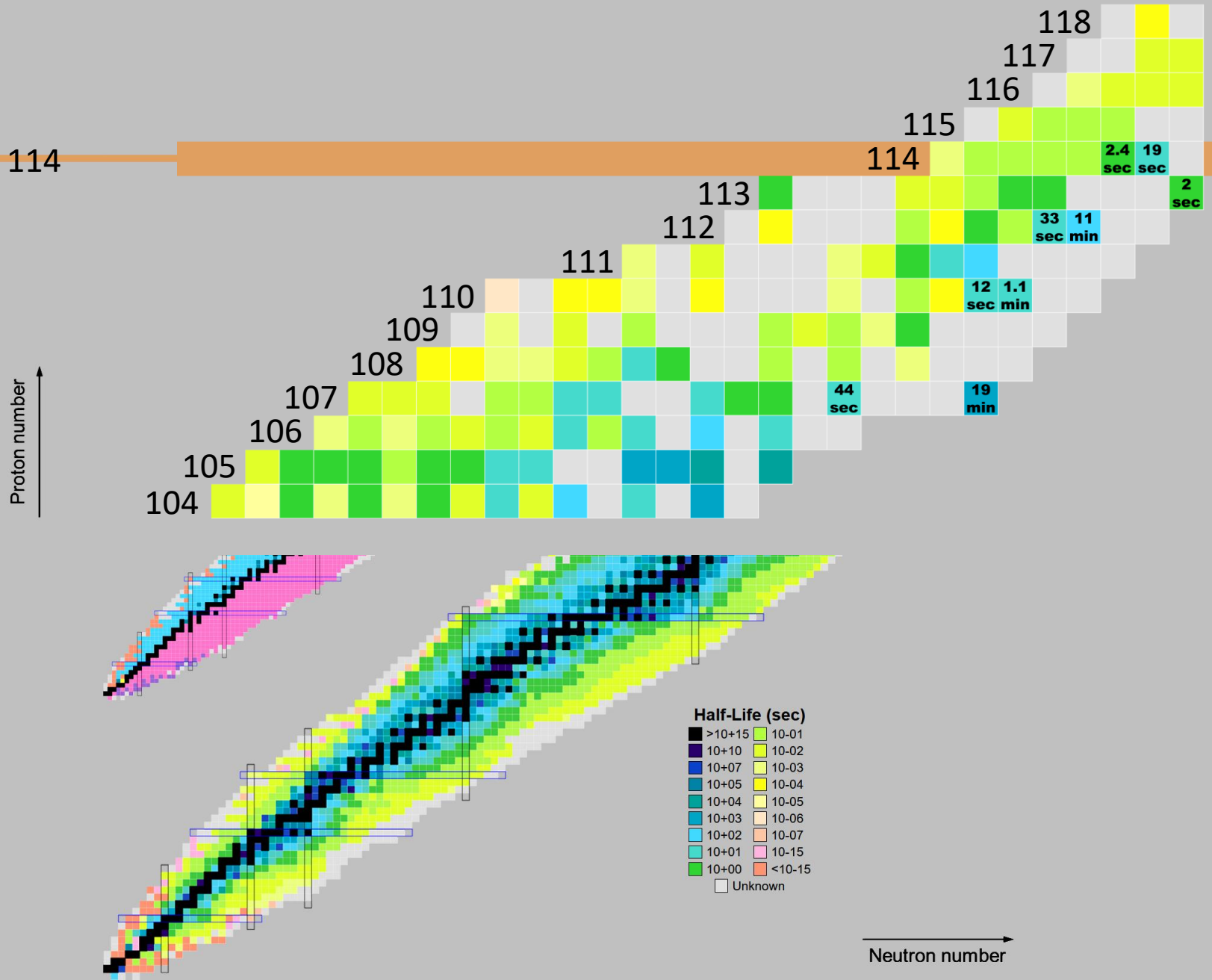

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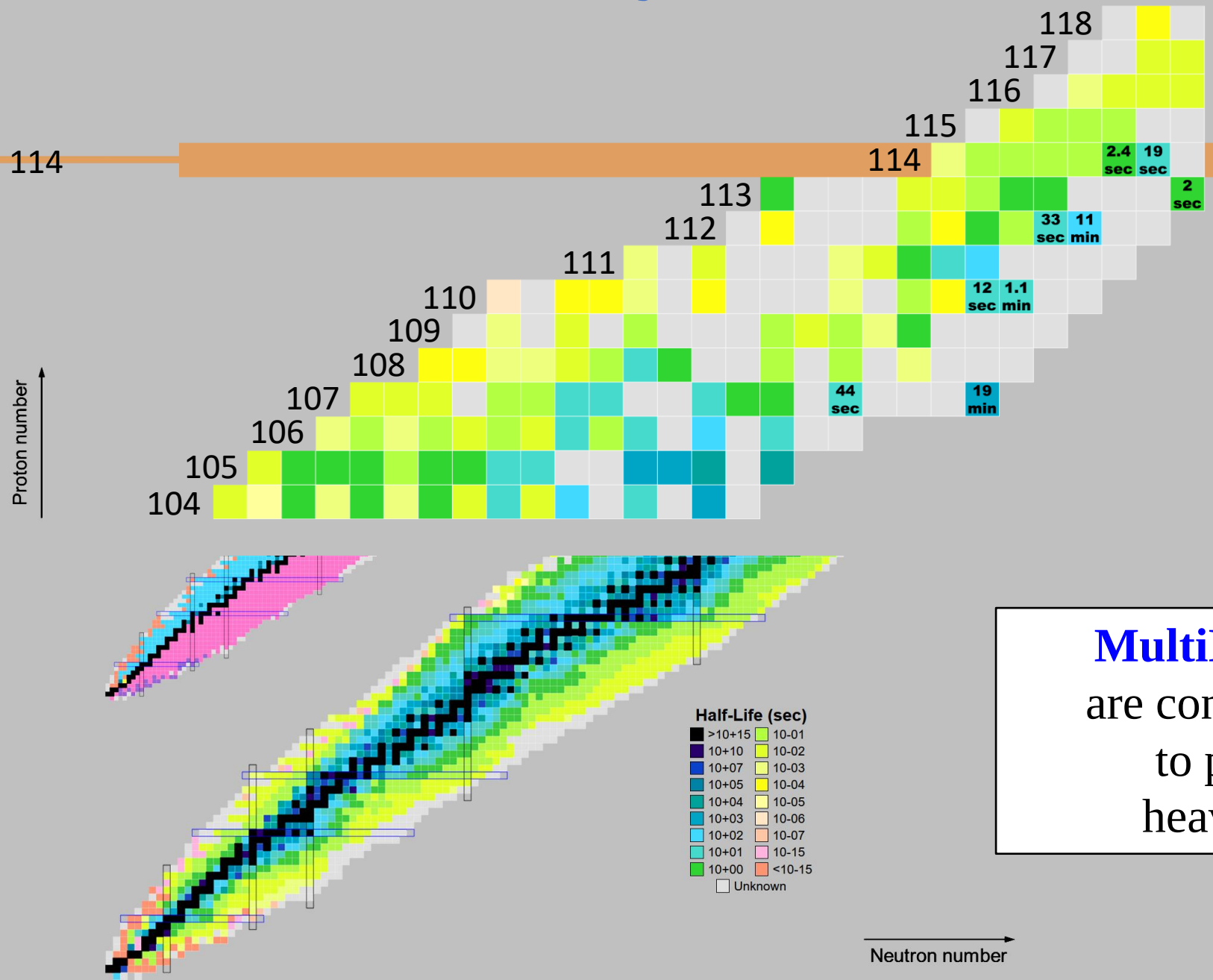
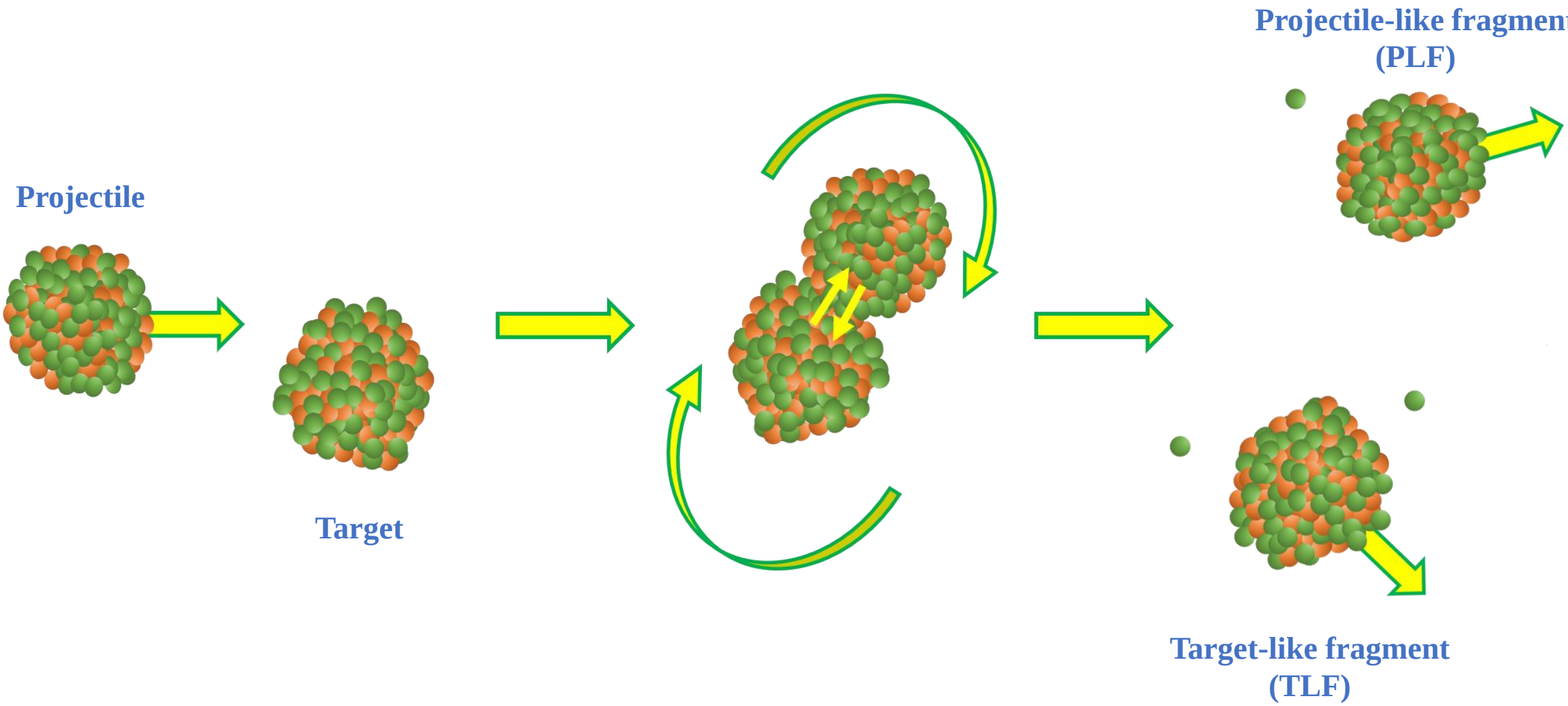


MultiNucleon Transfer reactions
are considered as a perspective way
to produce new neutron-rich
heavy and superheavy nuclei!

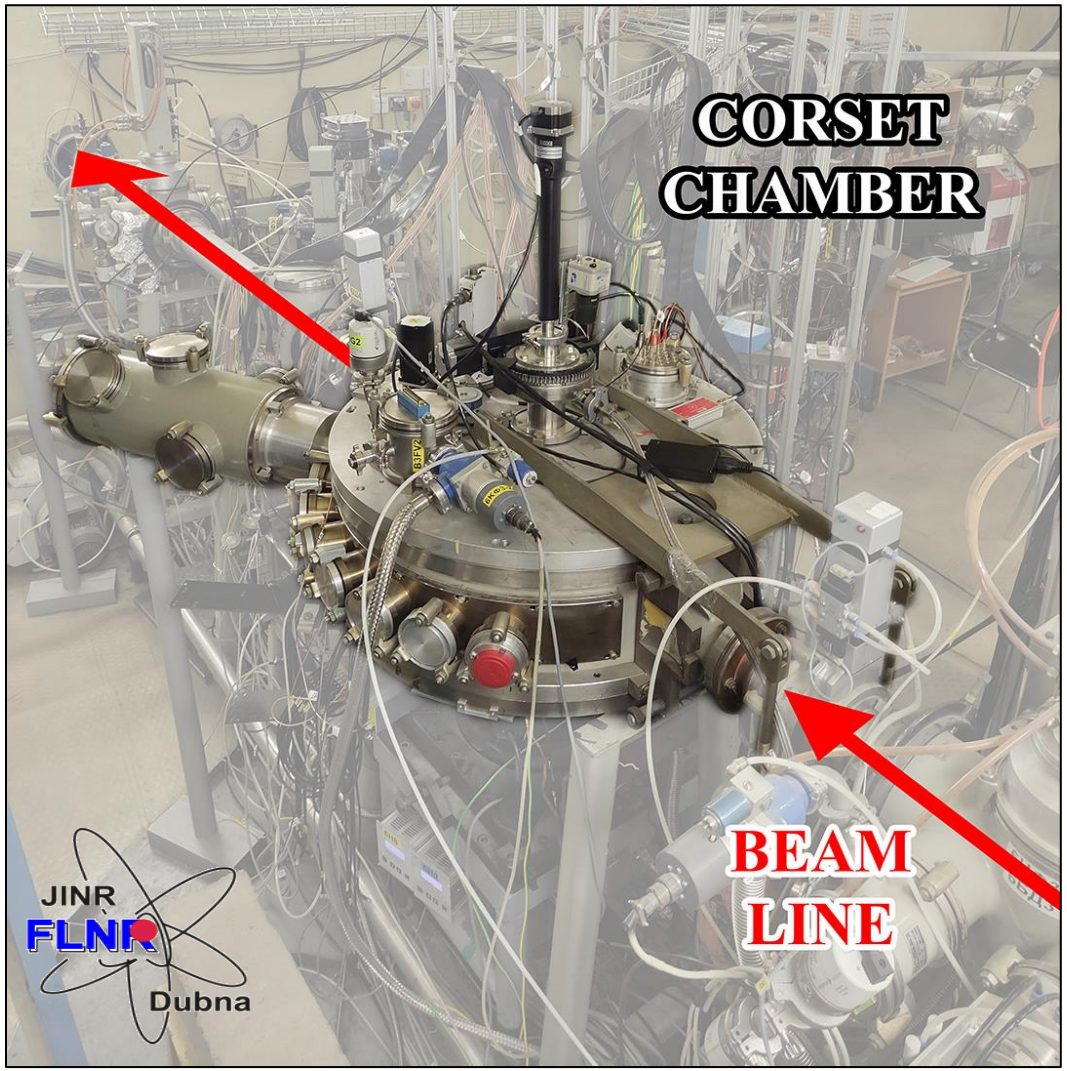
https://www.nndc.bnl.gov/nudat3/

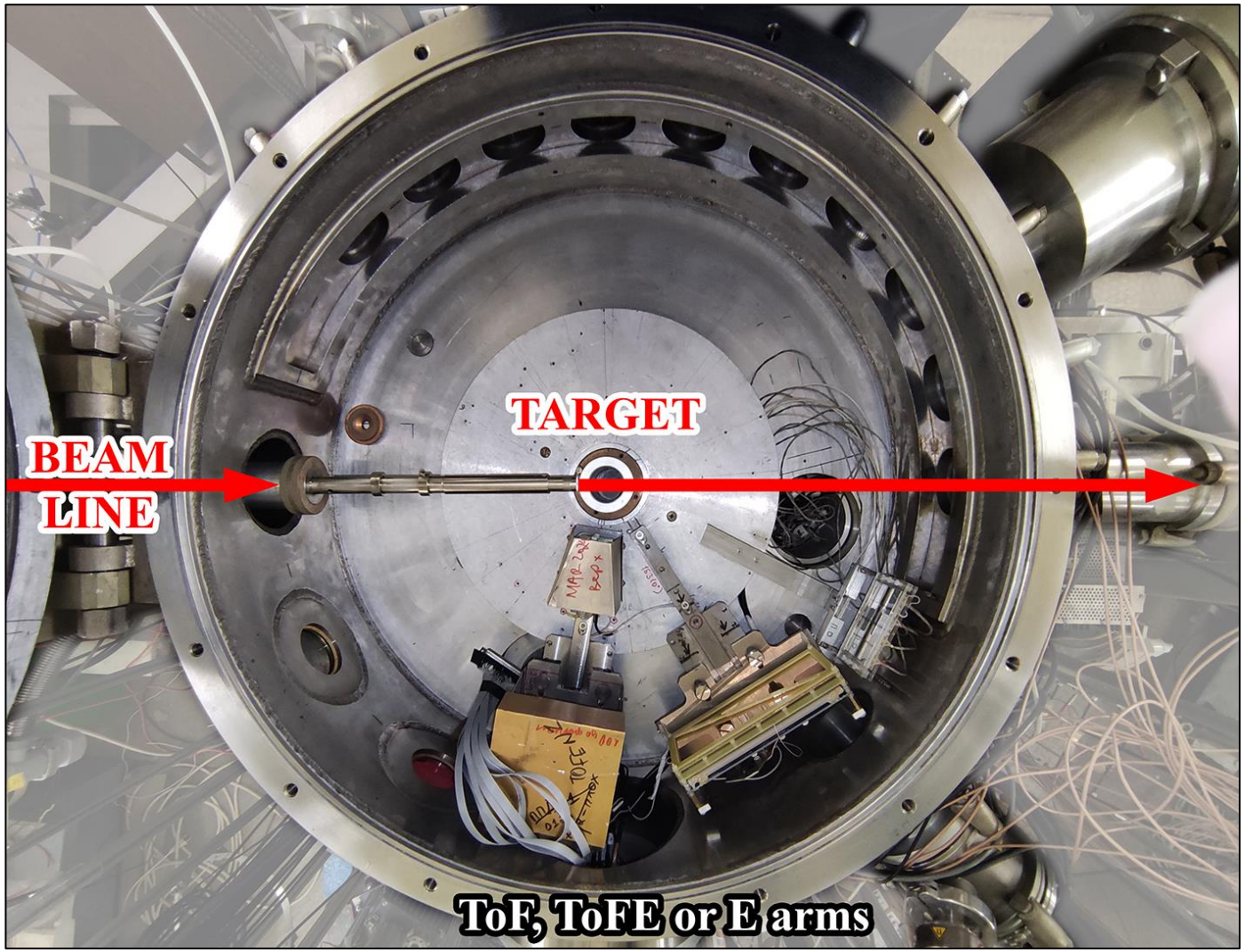
MultiNucleon Transfer reaction



MultiNucleon Transfer (MNT) reaction is a binary process with full momentum transfer. Masses of projectile-like (PLF) and target-like (TLF) fragments are near masses of projectile and target nuclei respectively.

Experimental study of MNT reactions at CORSET setup





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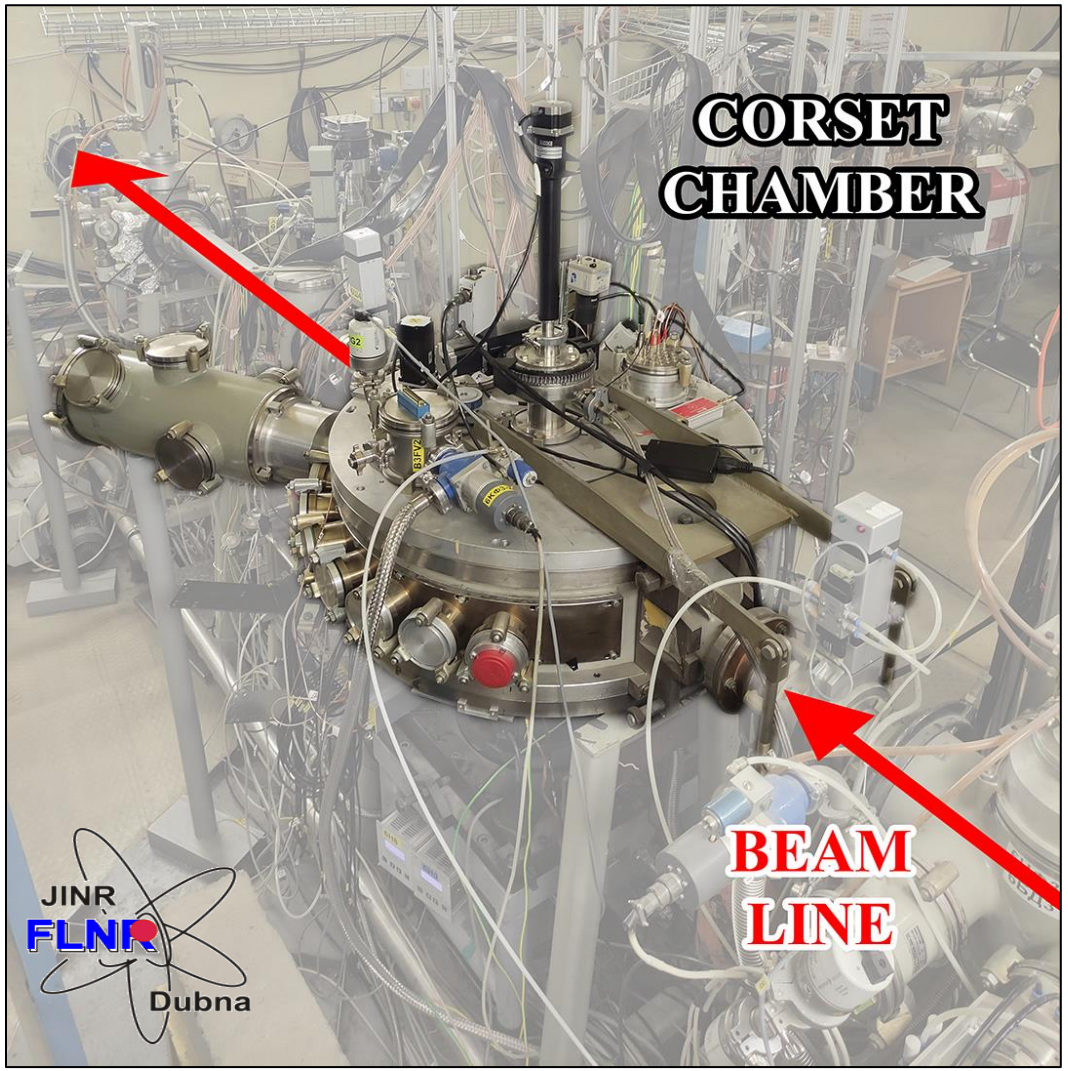

Measured reaction	E_{lab}
$^{136}Xe + ^{238}U$	1.11 GeV
$^{209}Bi + ^{238}U$	1.85 GeV
$^{209}Bi + ^{197}Au$	1.48 GeV
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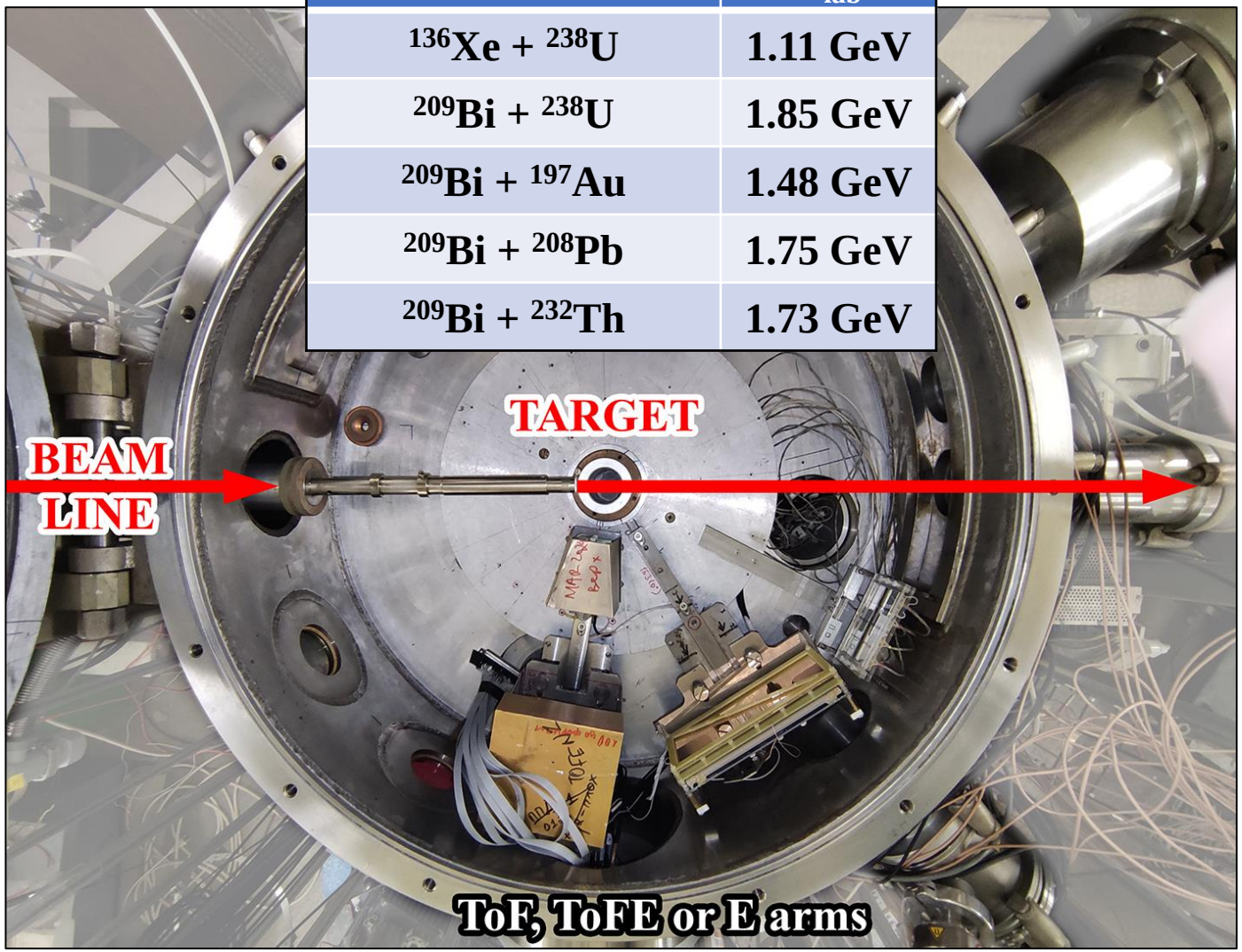
$^{209}Bi + ^{232}Th$	1.73 GeV



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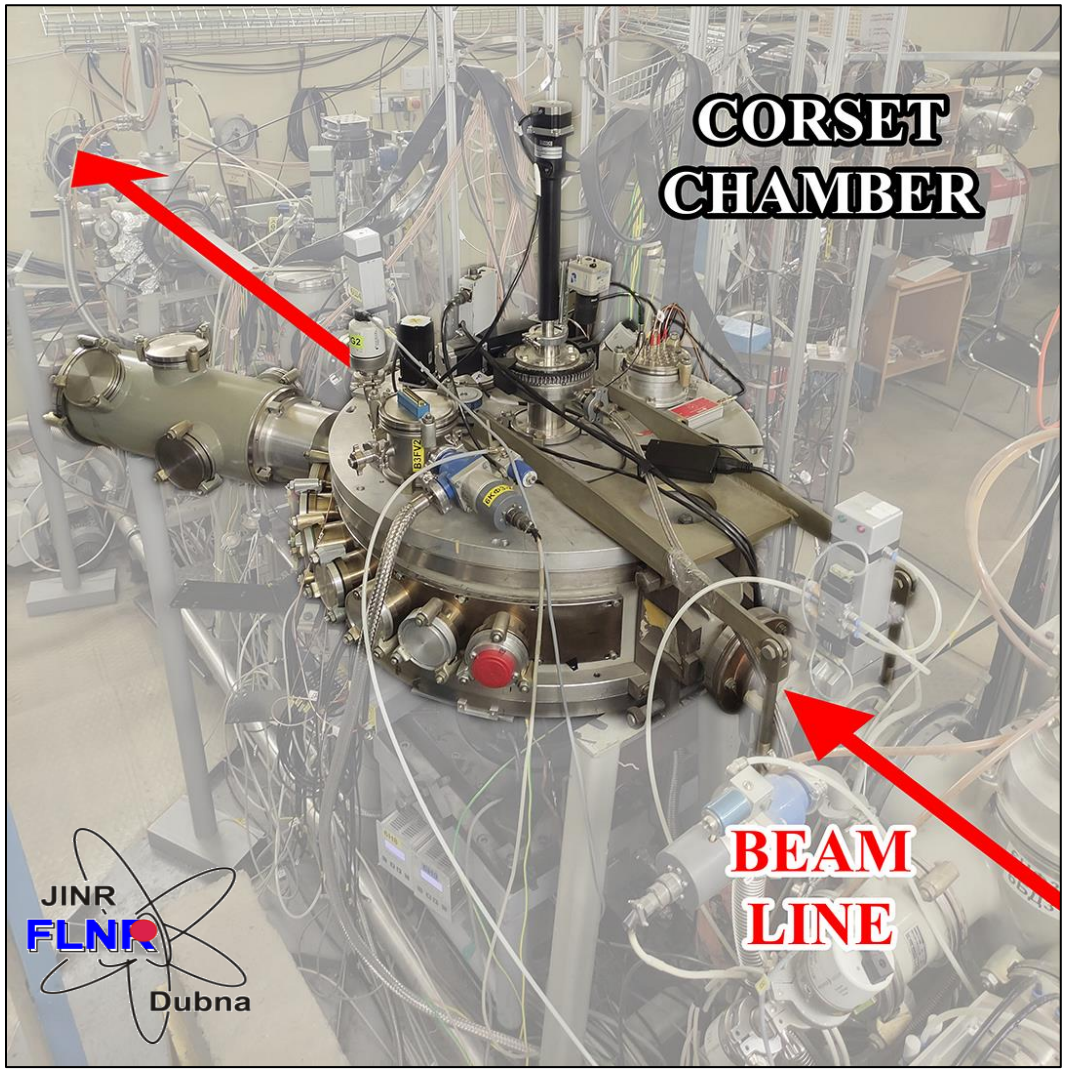

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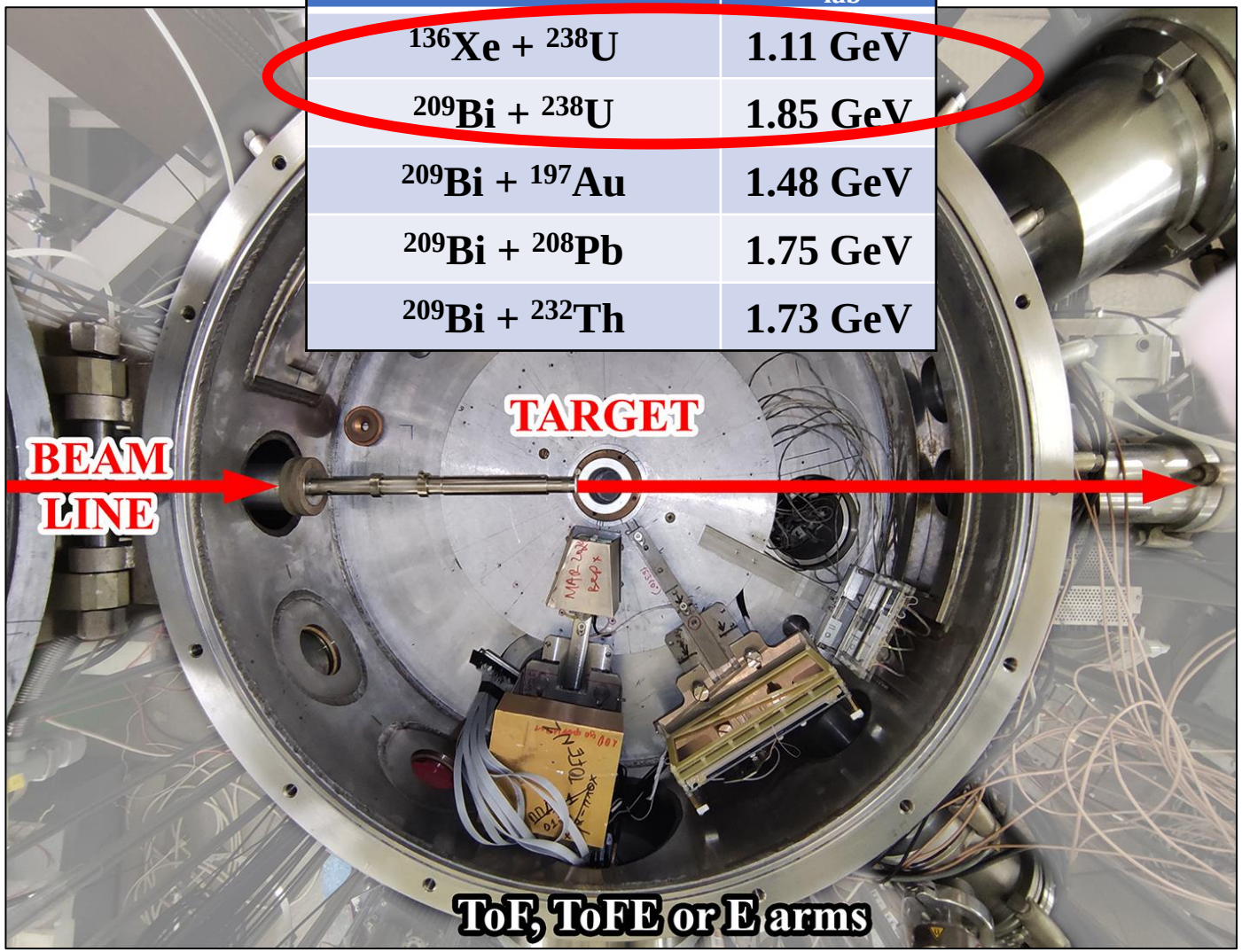
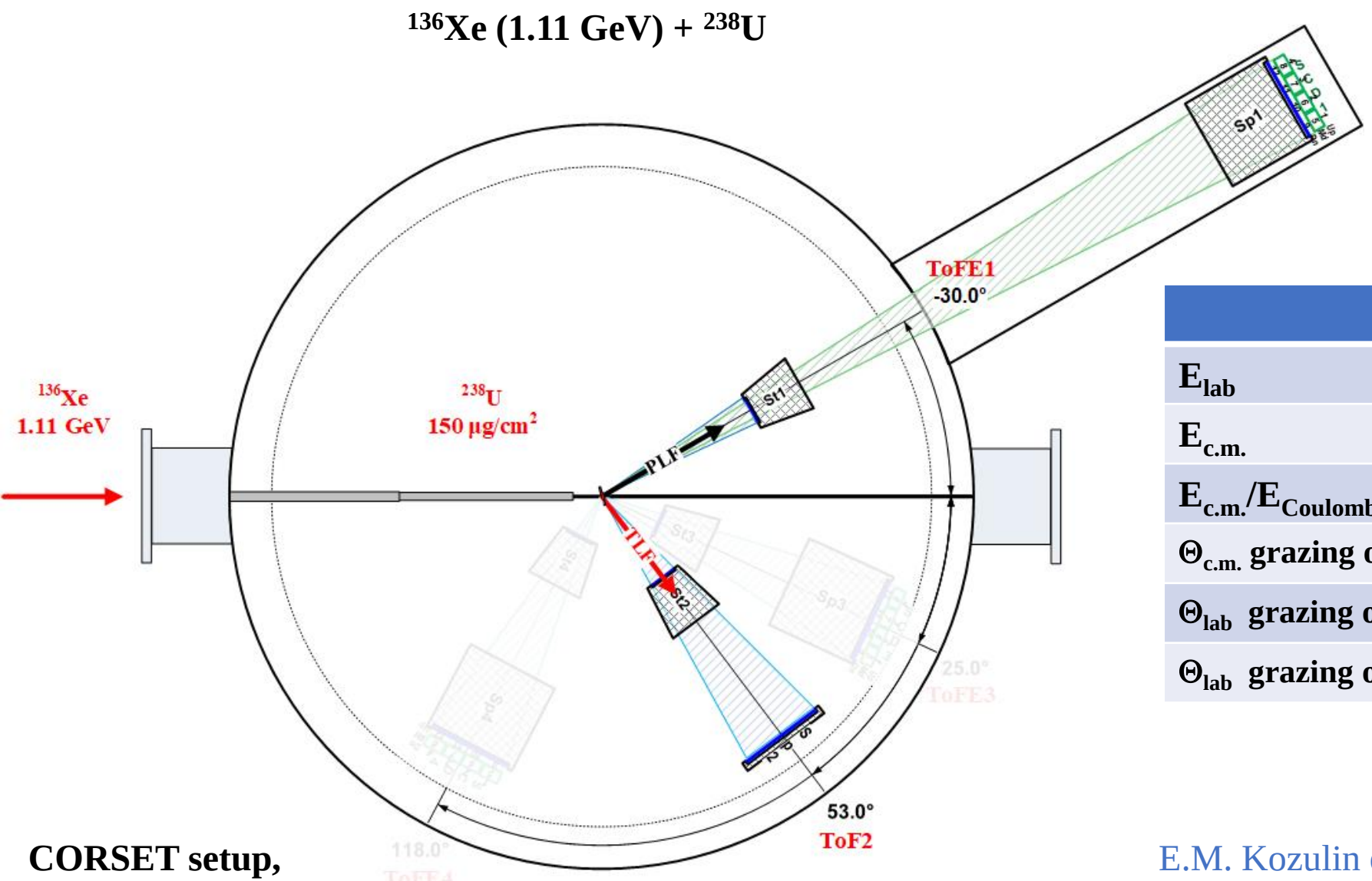


Experiments ^{136}Xe, ^{209}Bi + ^{238}U at energy ≈ 1.45 $E_{Coulomb}$



JINR FLNR Dubna

	^{136}Xe + ^{238}U	^{209}Bi + ^{238}U
E_{lab}	1.11 GeV	1.85 GeV
$E_{c.m.}$	706 MeV	985 MeV
$E_{c.m.}/E_{Coulomb}$	1.48	1.42
$\Theta_{c.m.}$ grazing of Ion	57°	61°
Θ_{lab} grazing of Ion	37°	33°
Θ_{lab} grazing of ^{238}U	61.5°	59.5°

CORSET setup, FLNR

Time resolution: 150 - 200 ps

E.M. Kozulin et al., Phys. Rev. C 109, 034616 (2024)
I.V. Vorobiev et al., Phys. Rev. C 112, 014625 (2025)

Mass-energy distributions of survived primary TLFs

(before deexcitation process)

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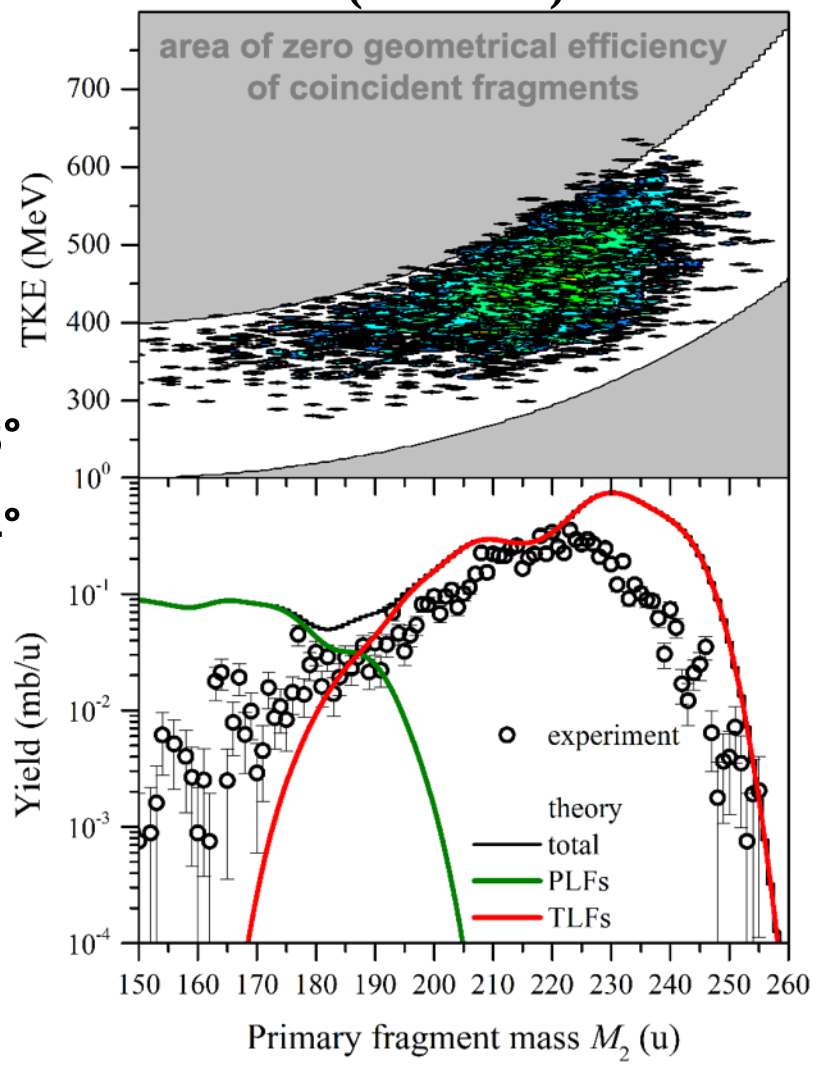

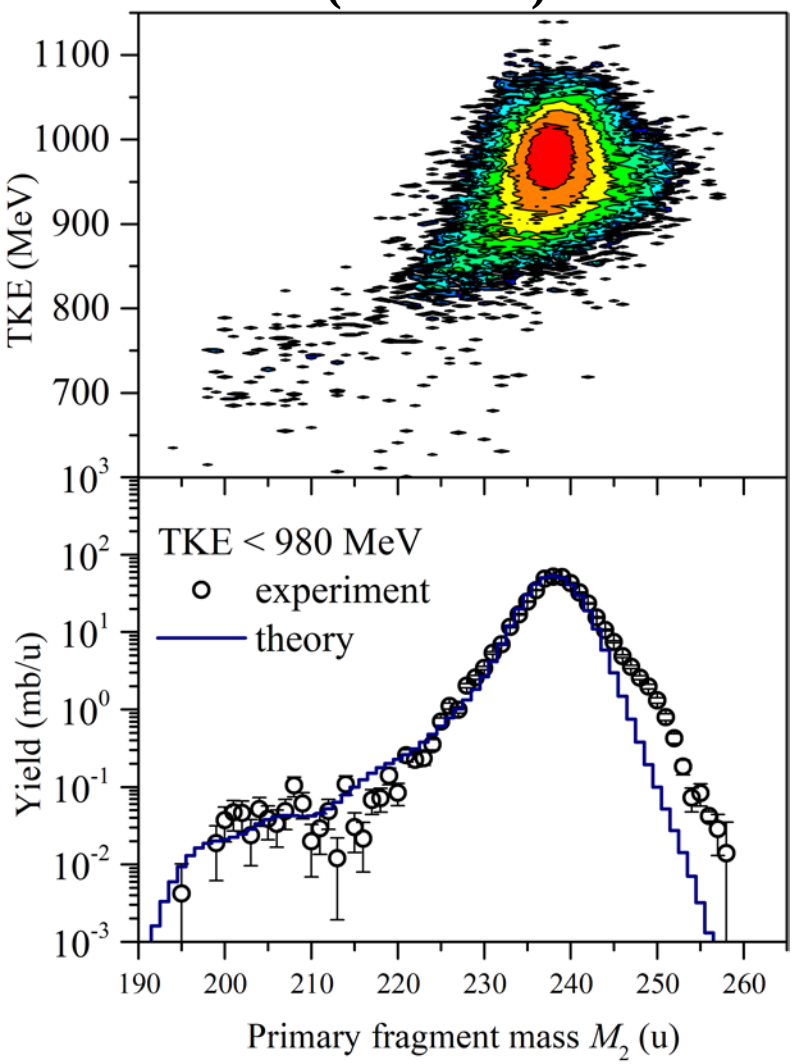

$\Theta_{lab\ 1} = 30° \pm 2.8°$

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Solid lines are the theoretical calculations by A. Karpov and V. Saiko

A.V. Karpov, V.V. Saiko, Phys. Rev. C 96, 024618 (2017)

The heaviest primary fragment mass found in the mass distribution for survived primary TLFs is:

255 u (+ 17 u, Z ≈ 99–100, Es–Fm isotopes) with the cross section of about 2 μb.

258 u (+ 20 u, Z ≈ 101, Md isotopes) with the cross section of about 10 μb.

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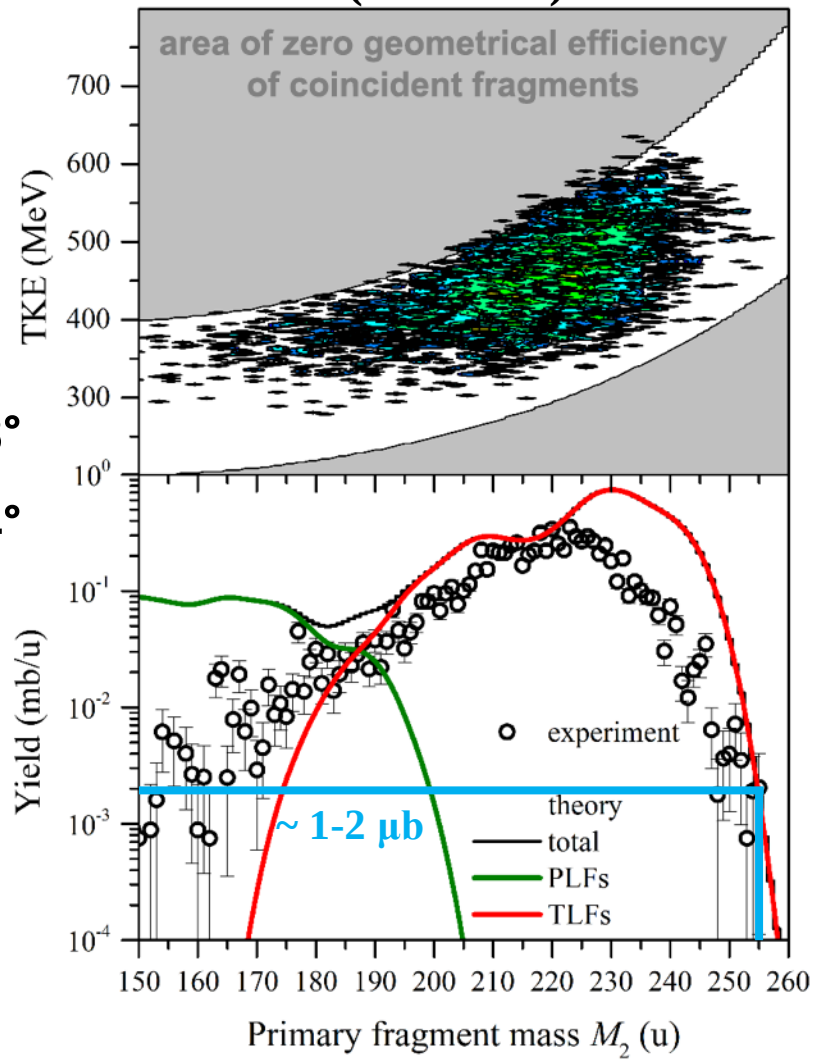

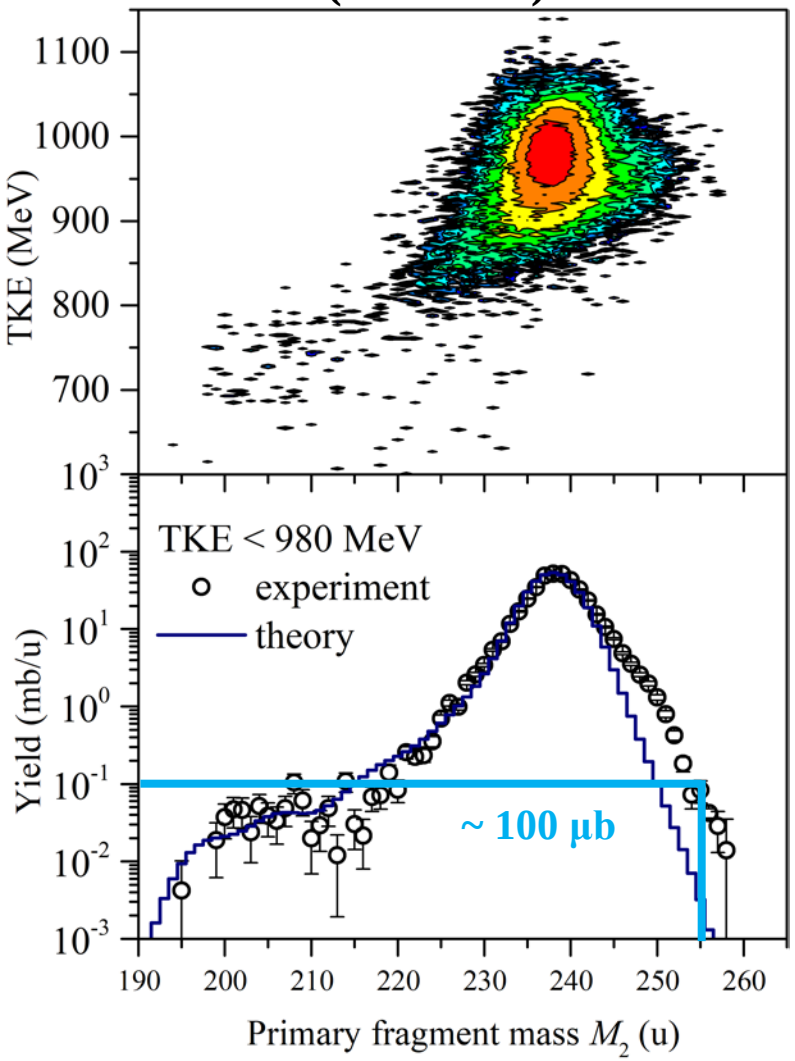

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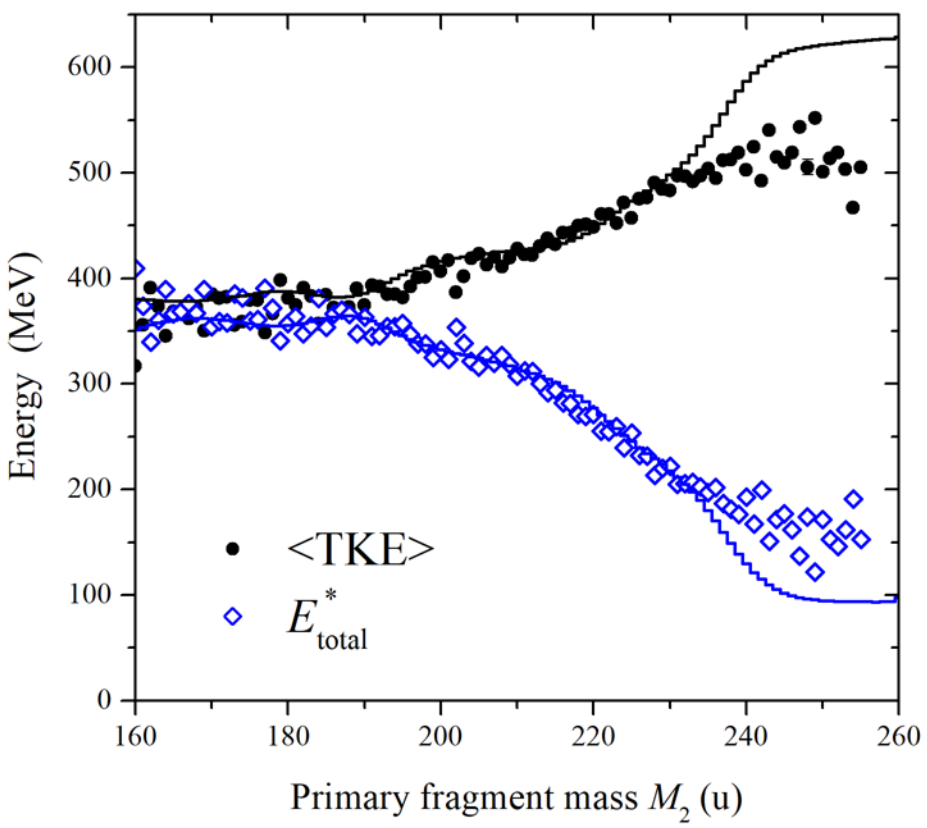

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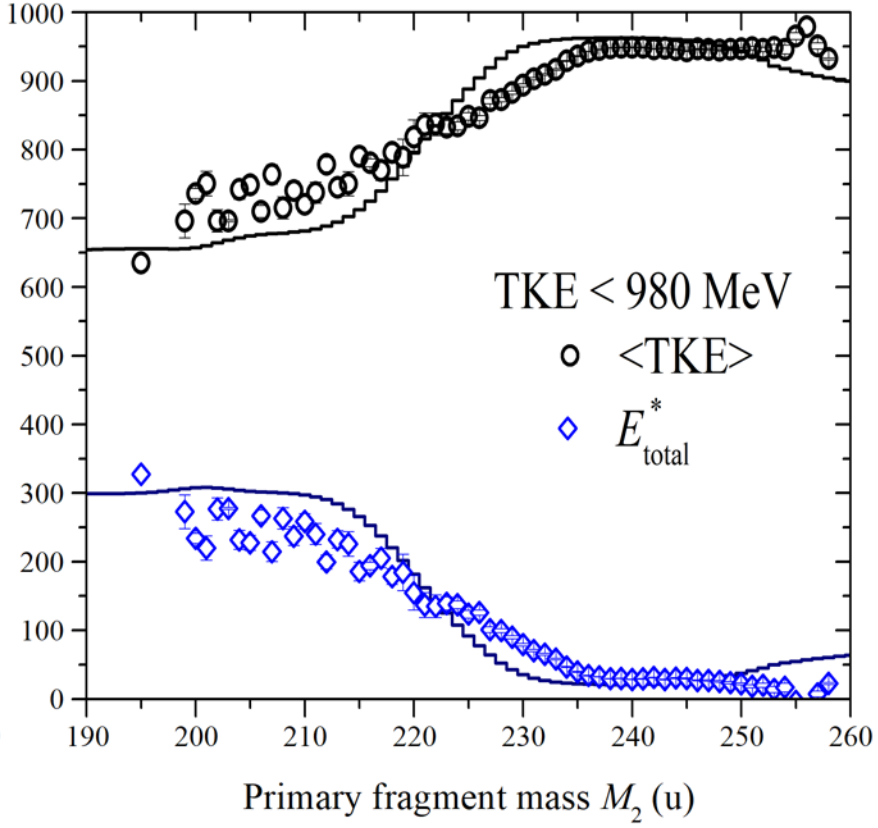
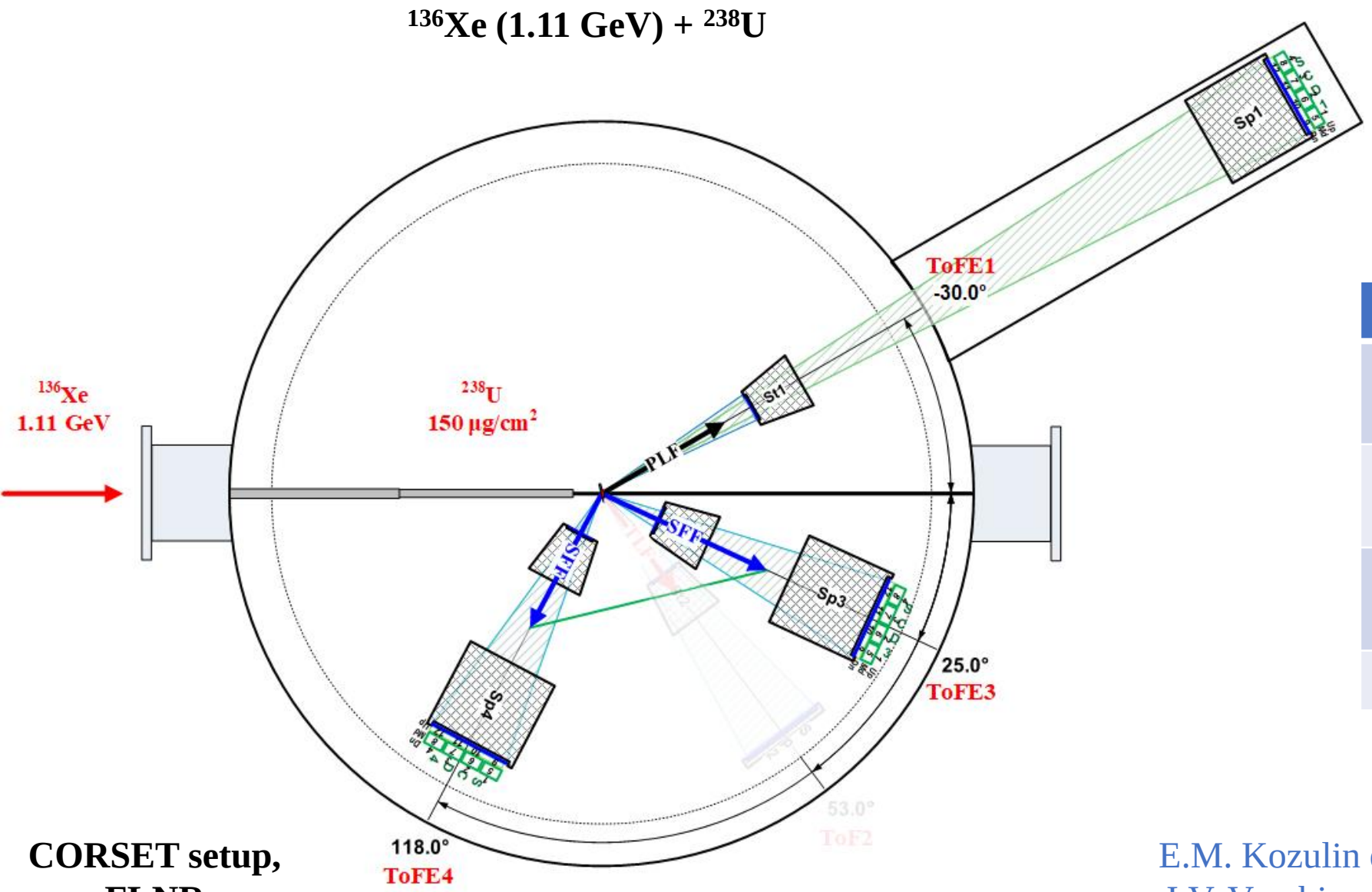


I.V. Vorobiev et al., Phys. Rev. C 112, 014625 (2025)

The total excitation energy may be estimated from TKE measurements: $E^*_{\text{total}} \approx E_{c.m.}\text{-TKE} + Q_{\text{gg}}$

For survived primary transuranium fragments the total excitation energies of composite nuclear systems for the reaction ^{209}Bi (1.85 GeV) + ^{238}U are less than **50 MeV** =>
sufficiently good conditions for survival of such MNT fragments!

Experiments ^{136}Xe, ^{209}Bi + ^{238}U at energy ≈ 1.45 $E_{Coulomb}$



CORSET setup, FLNR

^{136}Xe + ^{238}U (150 μg/cm^2)	
ToFE1 acceptance angle	X: ±2.8° Y: ±2.1°
ToFE3 acceptance angle	X: ±7.3° Y: ±5.5°
ToFE4 acceptance angle	X: ±7.6° Y: ±5.7°
Time resolution	150-200ps

E.M. Kozulin et al., Phys. Rev. C 109, 034616 (2024)
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Mass distributions of primary TLFs for 2- and 3-body events

(before deexcitation process)

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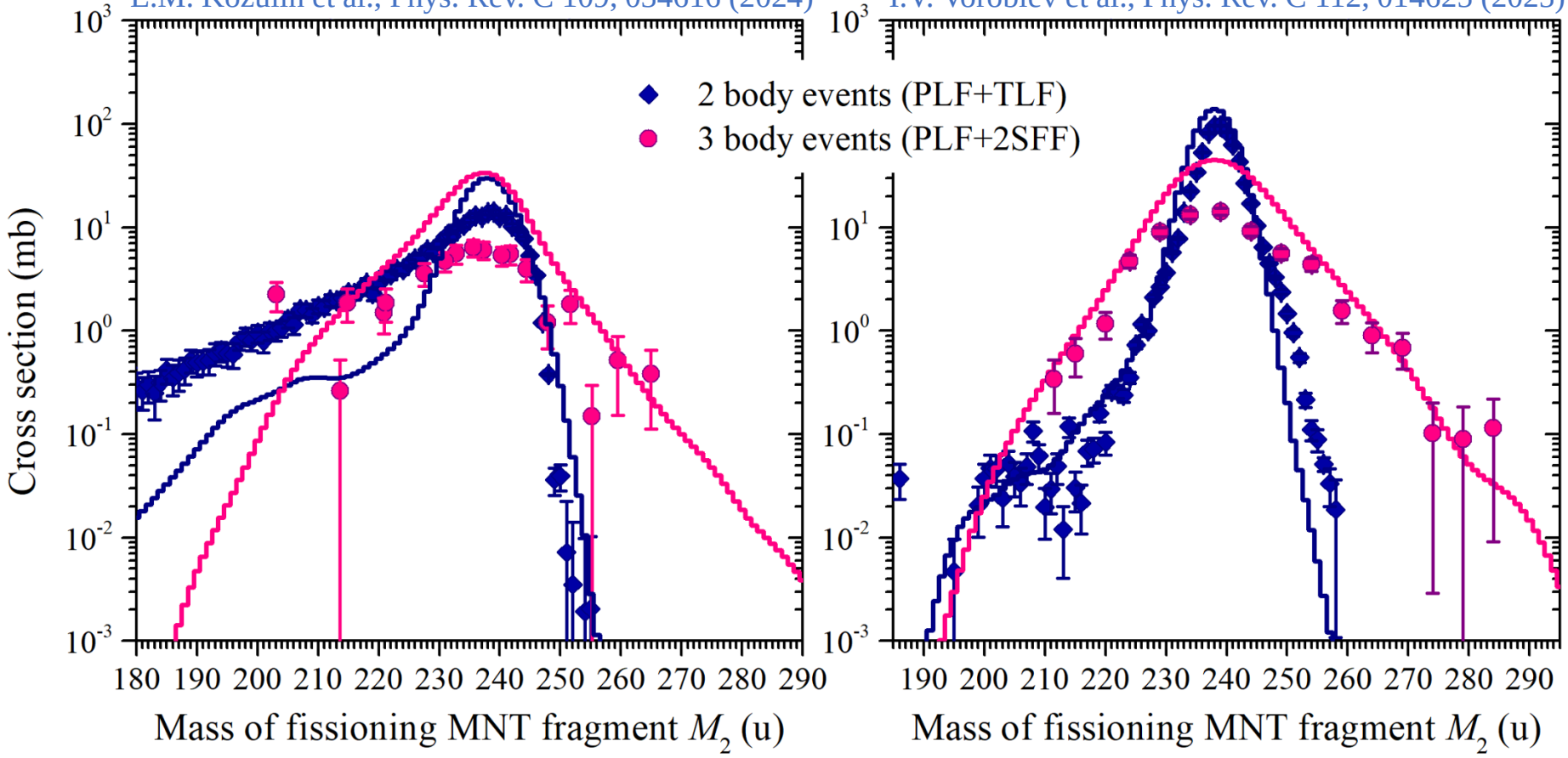

The heaviest primary fragment mass found in the mass distribution for 3-body events for primary TLFs is:

265 u (+ 27 u, Z ≈ 103, Lr isotopes) with the cross section of a few hundred μb.

284 u (+ 46 u, Z ≈ 111, Rg isotopes) with the cross section of a few hundred μb.

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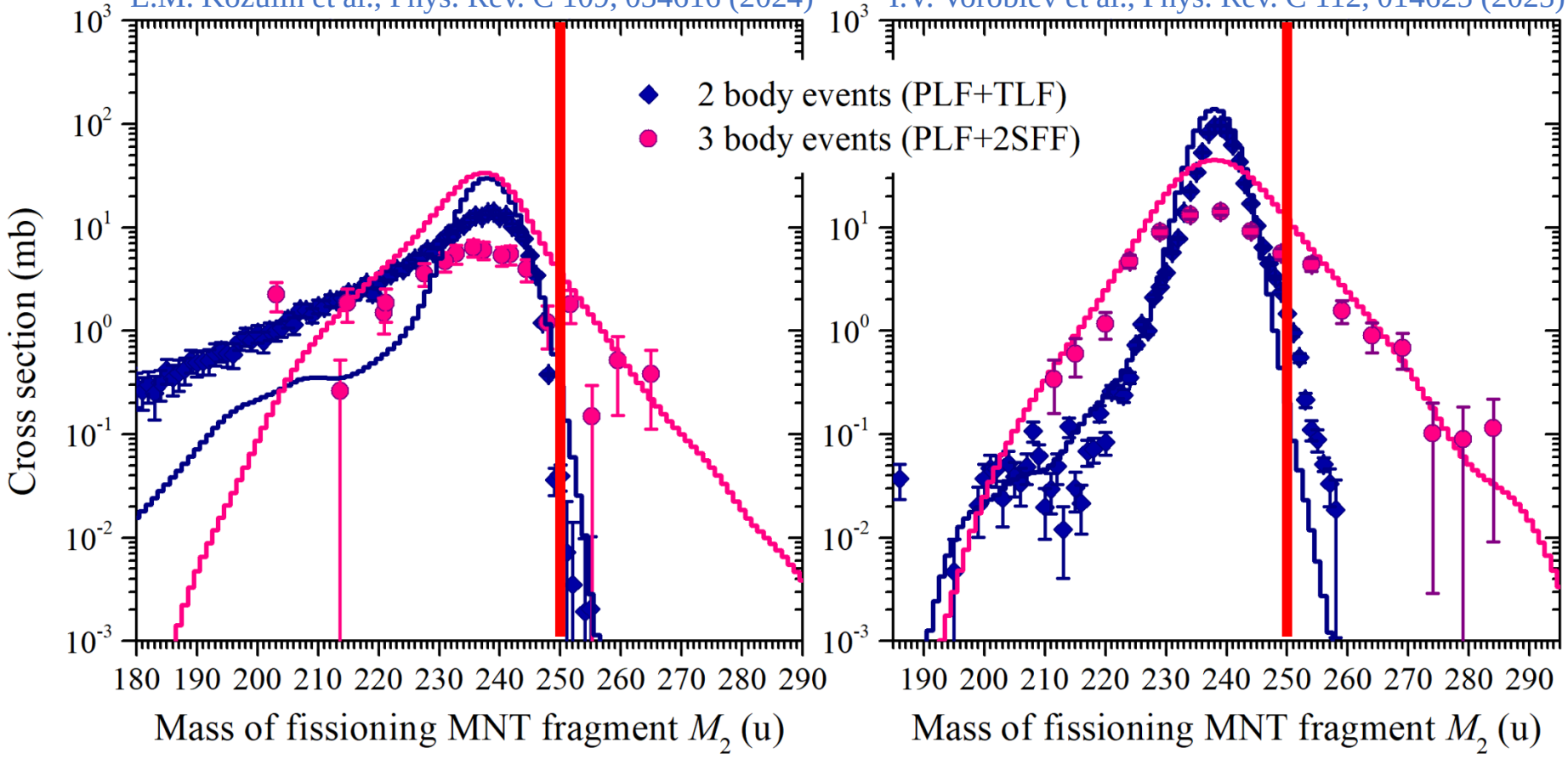

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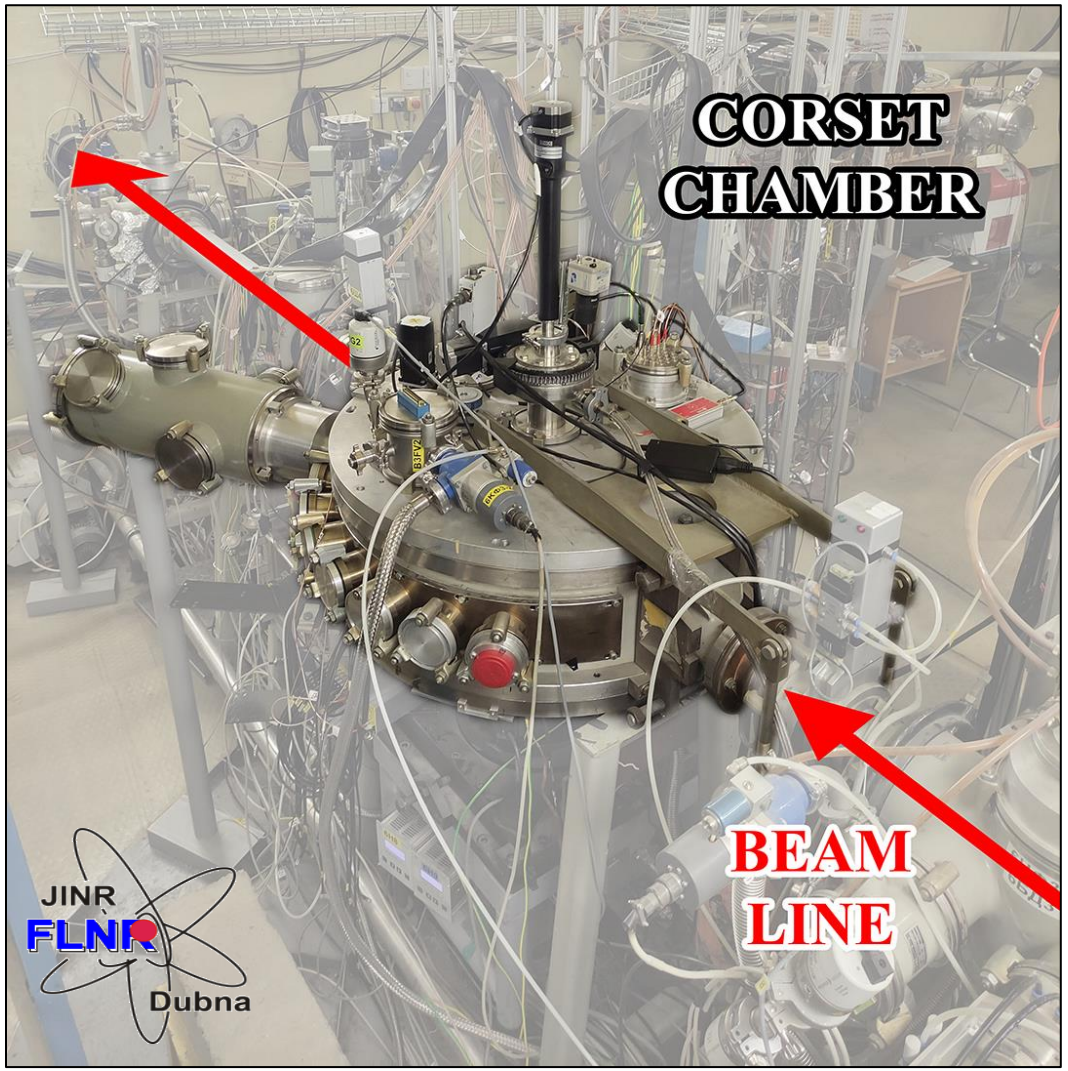

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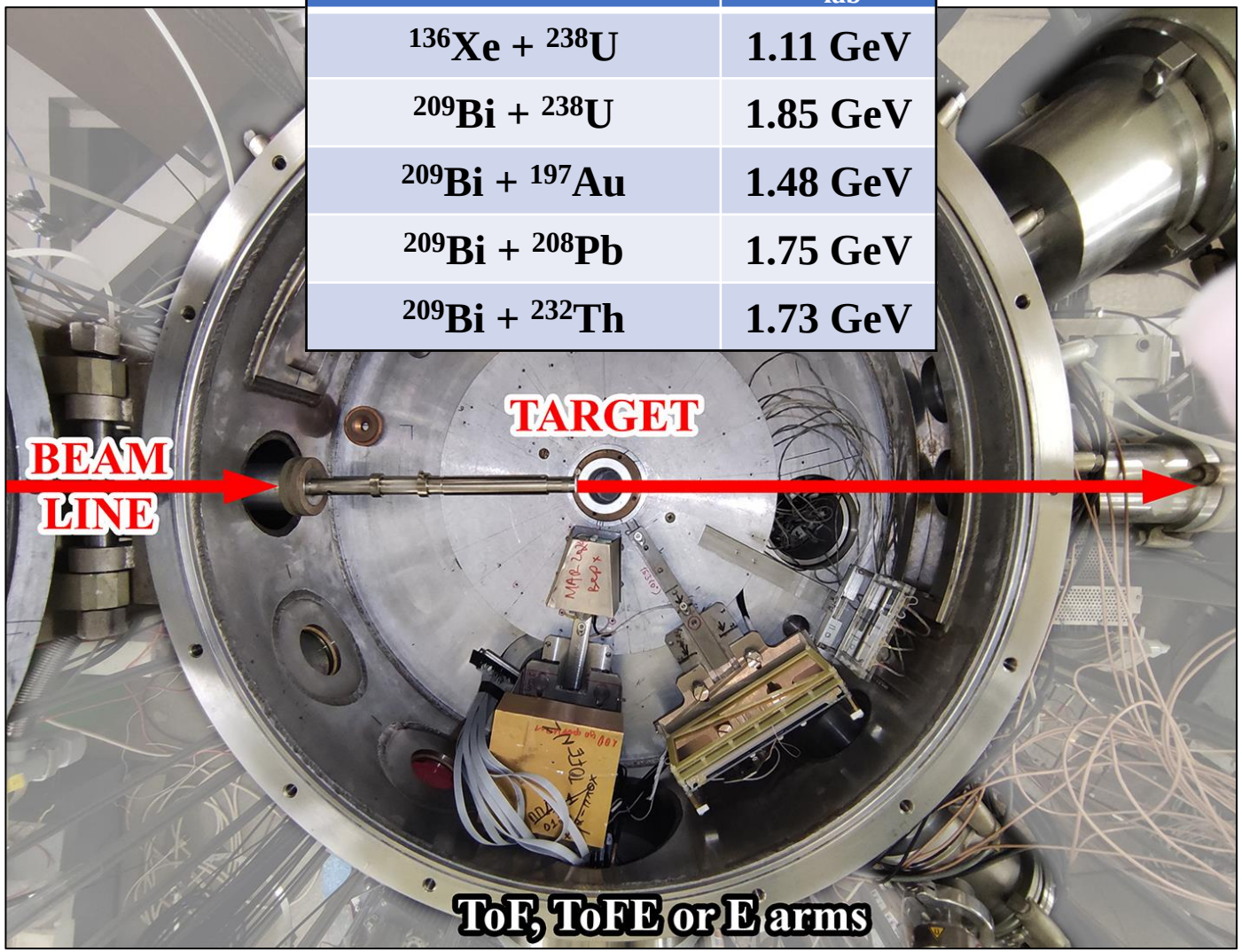

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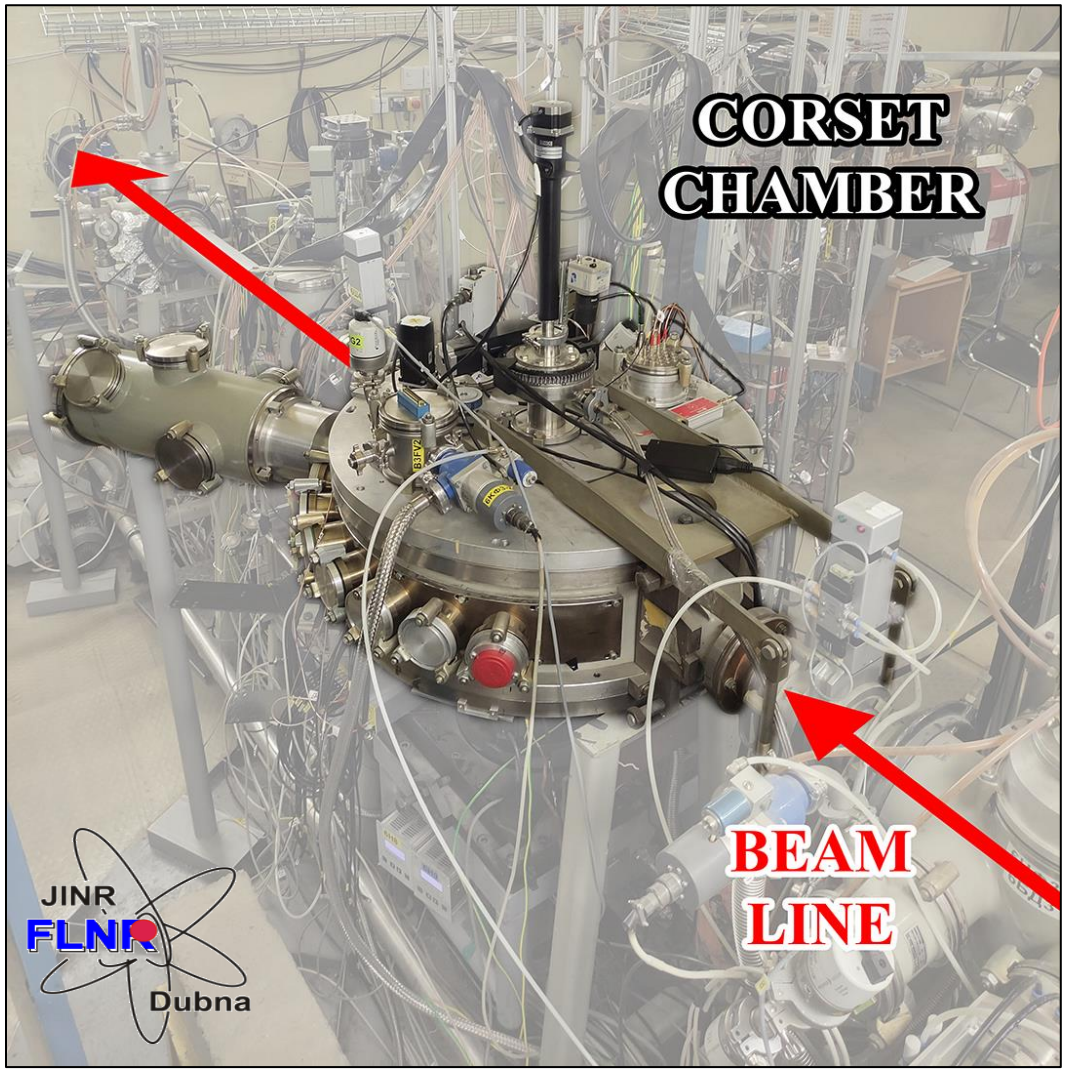

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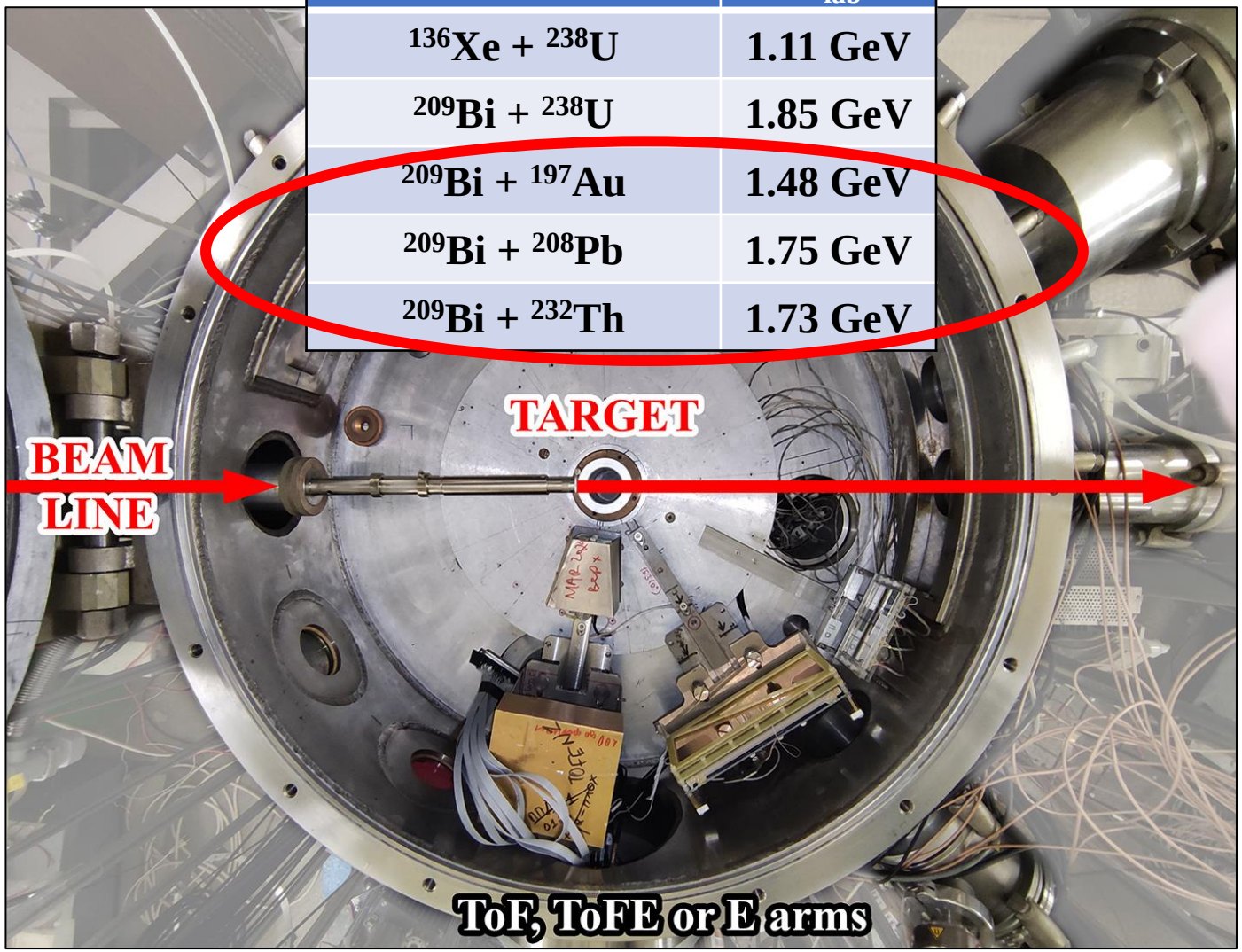
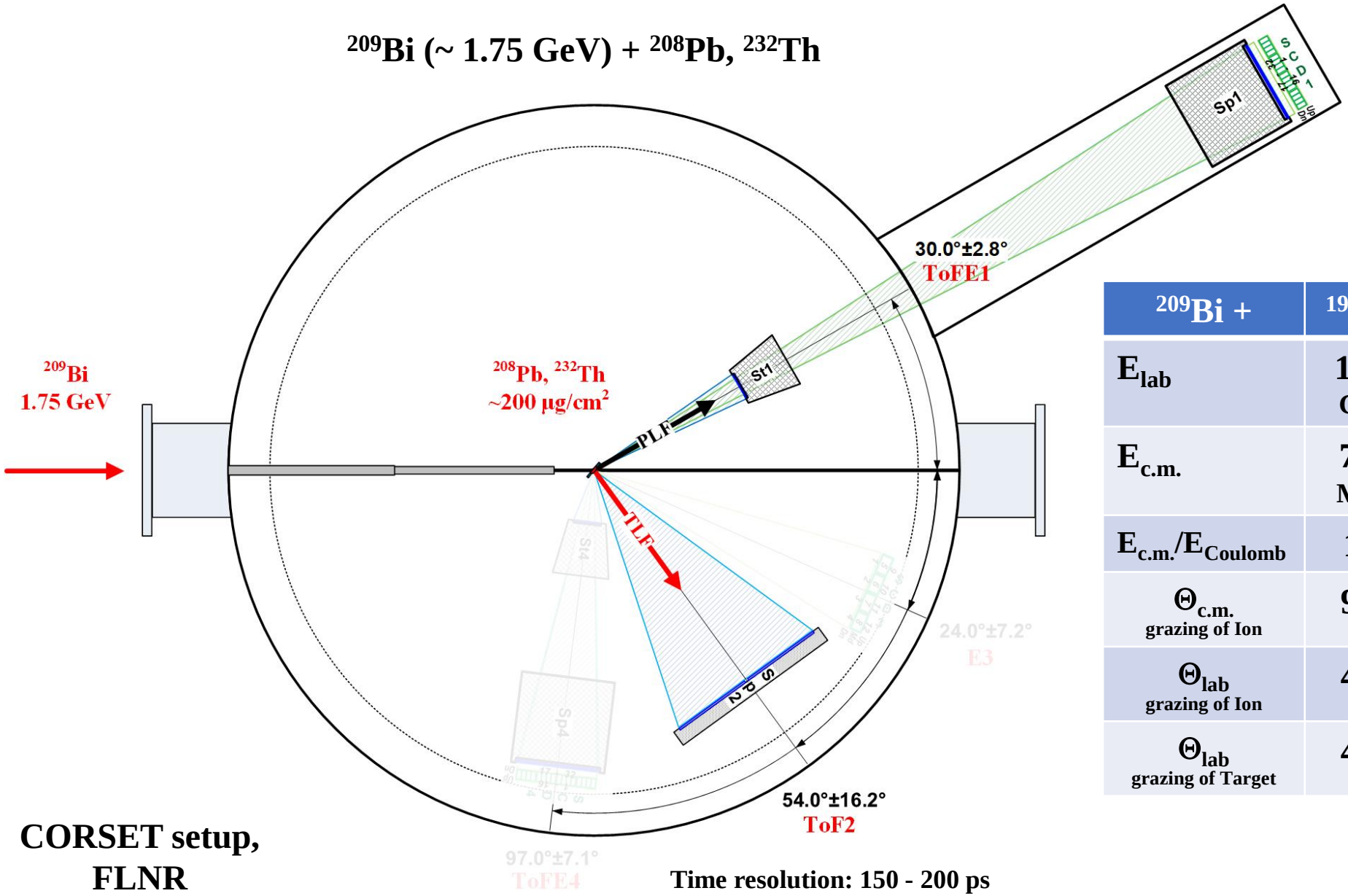


Experiments ^{209}Bi + ^{197}Au, ^{208}Pb, ^{232}Th, ^{238}U at energies above $E_{Coulomb}$

^{209}Bi (~ 1.75 GeV) + ^{208}Pb, ^{232}Th



CORSET setup, FLNR

Time resolution: 150 - 200 ps

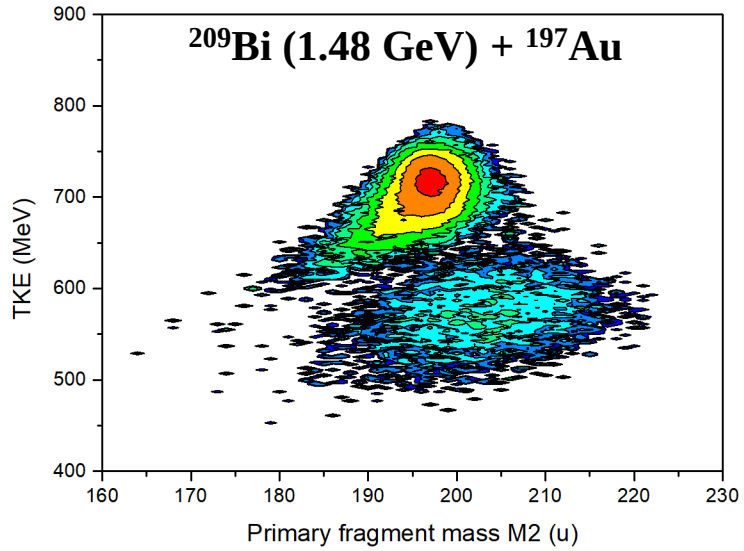
^{209}Bi +	^{197}Au	^{208}Pb	^{232}Th	^{238}U
E_{lab}	1.48 GeV	1.75 GeV	1.73 GeV	1.85 GeV
$E_{c.m.}$	718 MeV	873 MeV	910 MeV	985 MeV
$E_{c.m.}/E_{Coulomb}$	1.2	1.42	1.37	1.45
$\Theta_{c.m.}$ grazing of Ion	90°	66°	70°	61°
Θ_{lab} grazing of Ion	43°	33°	37°	33°
Θ_{lab} grazing of Target	45°	57°	55°	59.5°

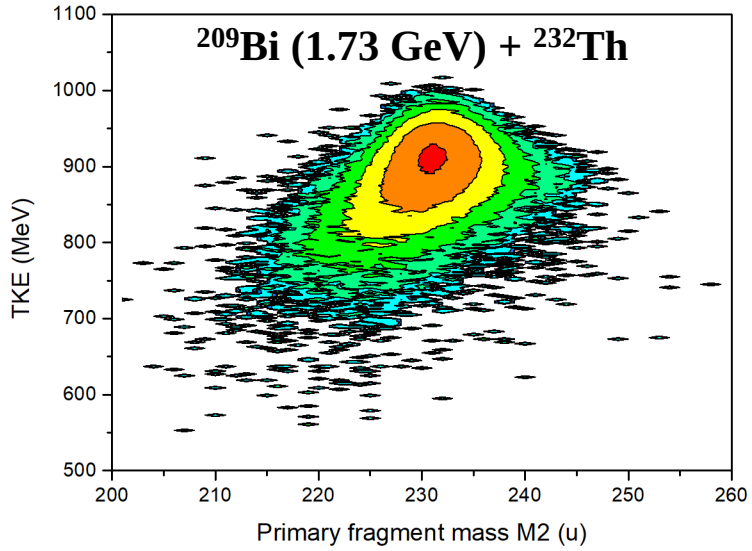
Mass-energy distributions of survived primary TLFs

(before deexcitation process)

$\Theta_{lab\ 1} = 30° \pm 2.8°$

$\Theta_{lab\ 2} = 56° \pm 7.4°$





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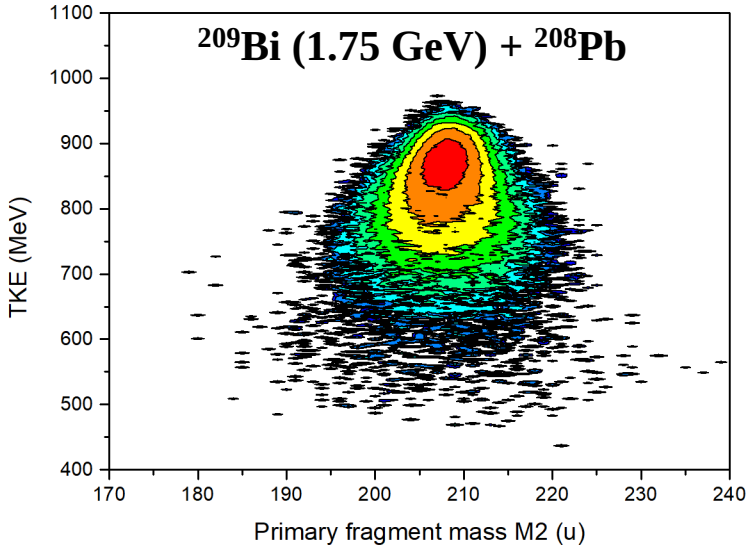

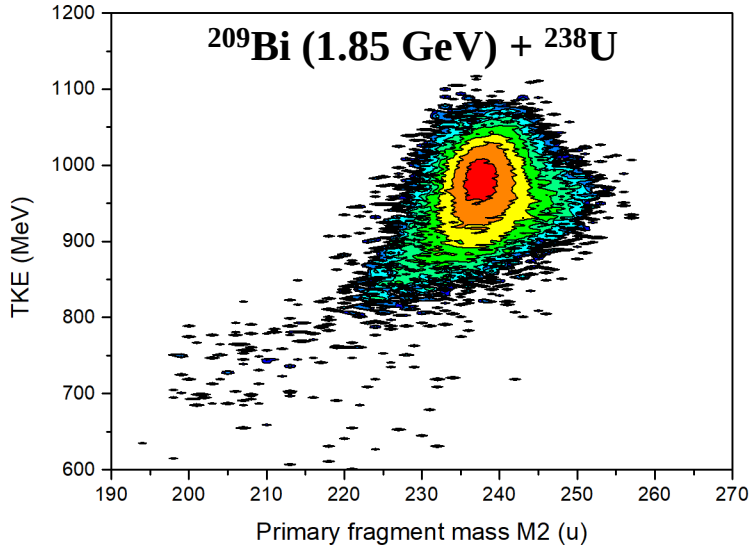

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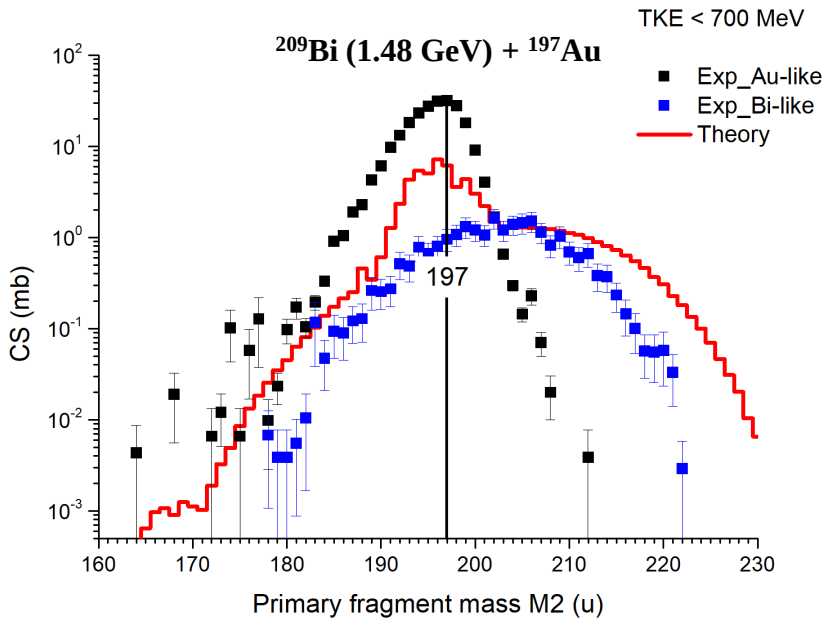
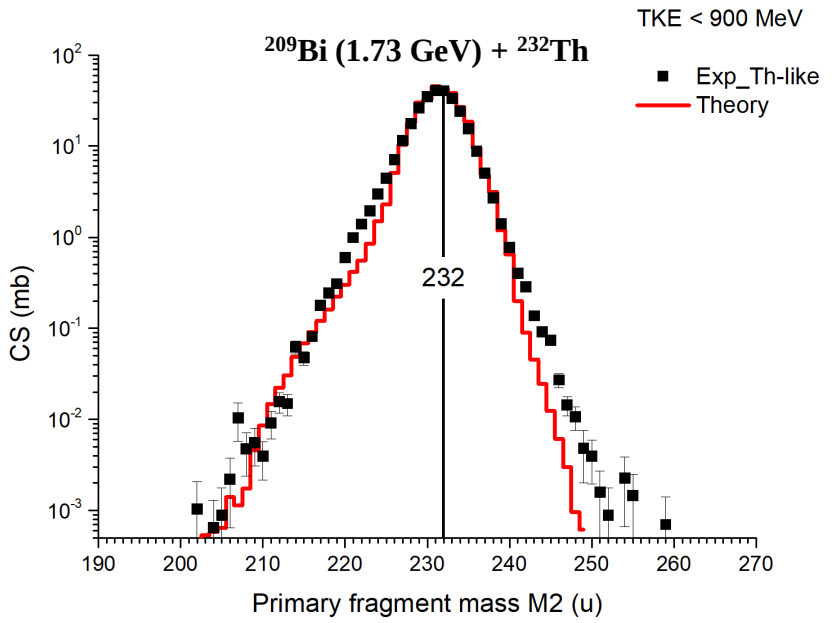
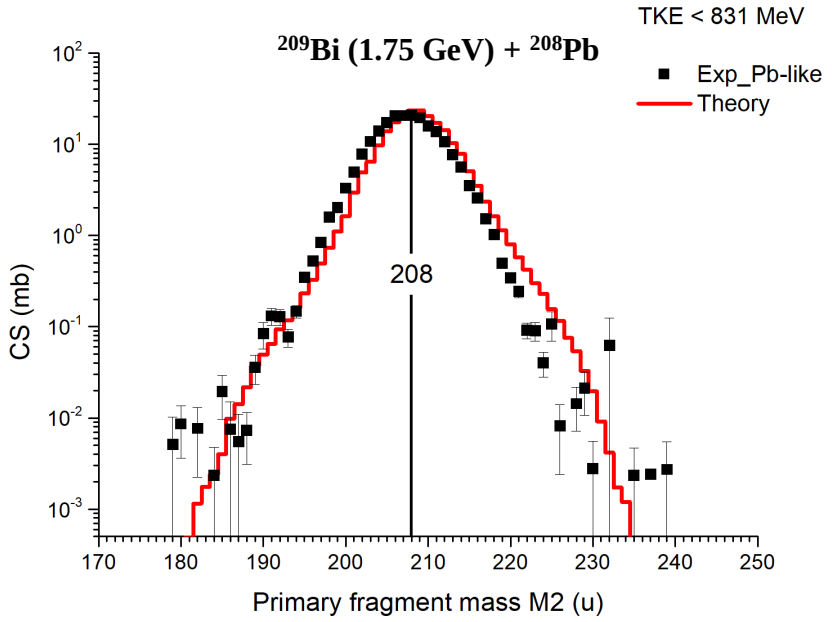
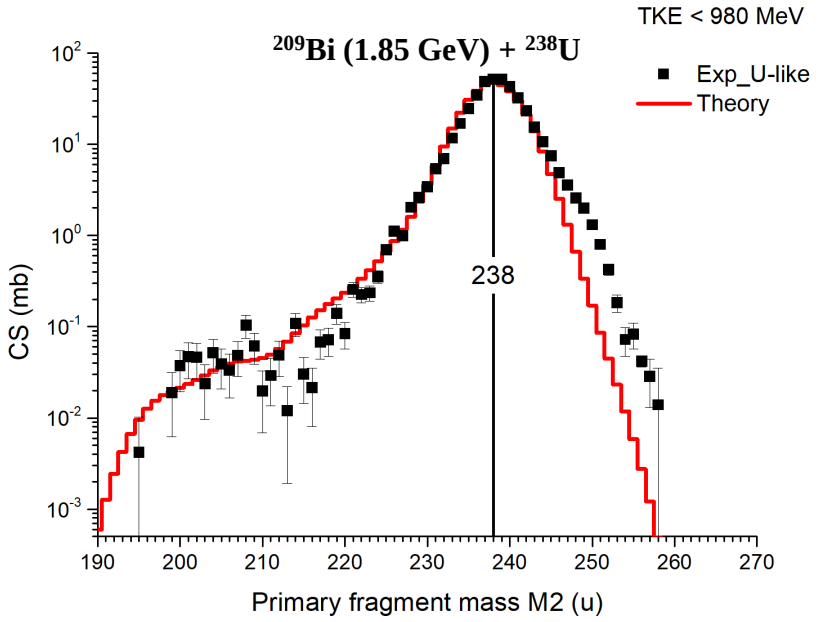
Mass distributions of survived primary TLFs









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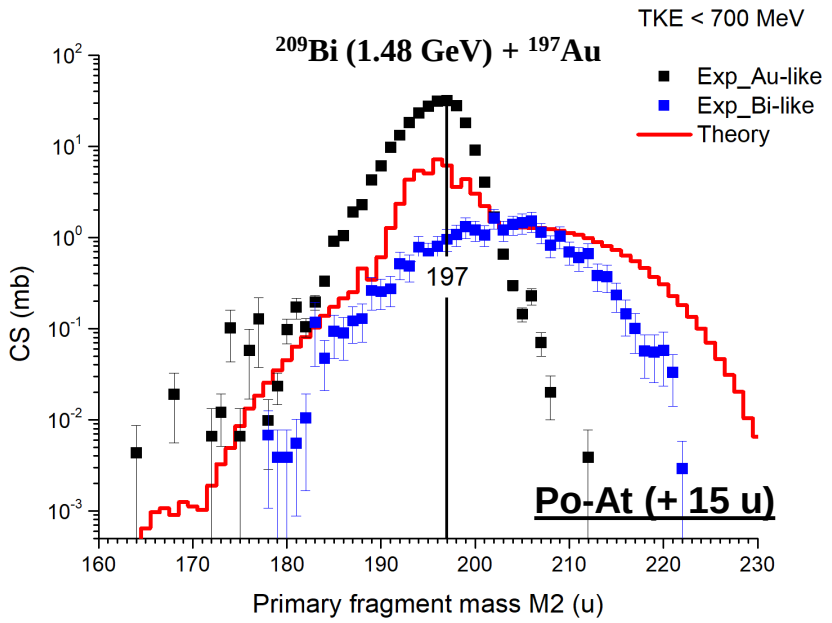

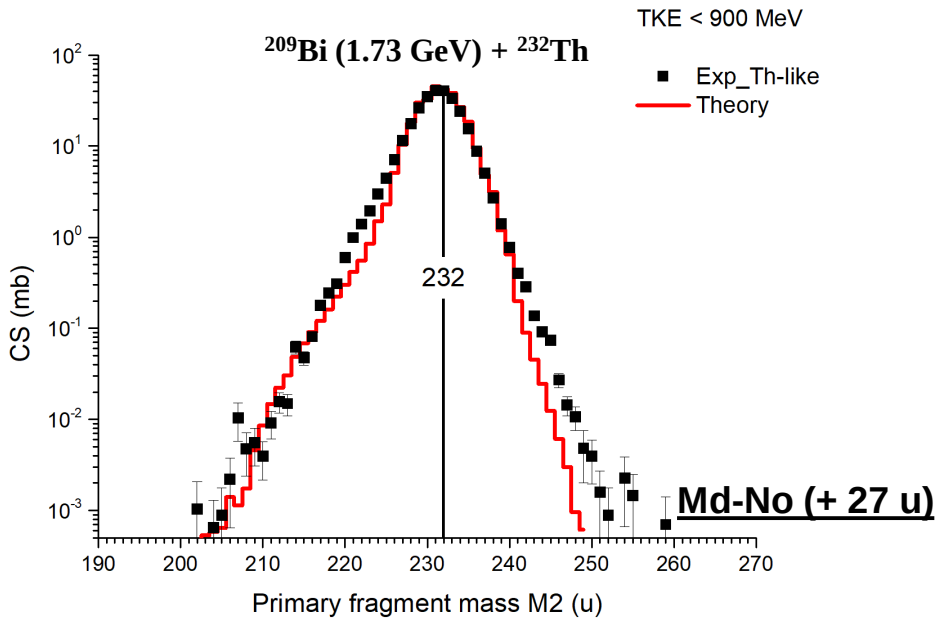

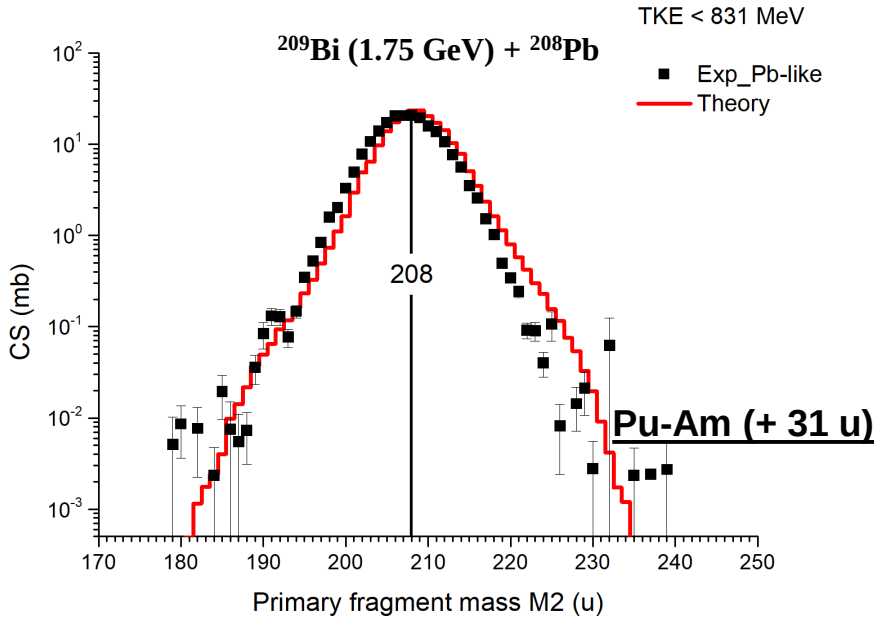

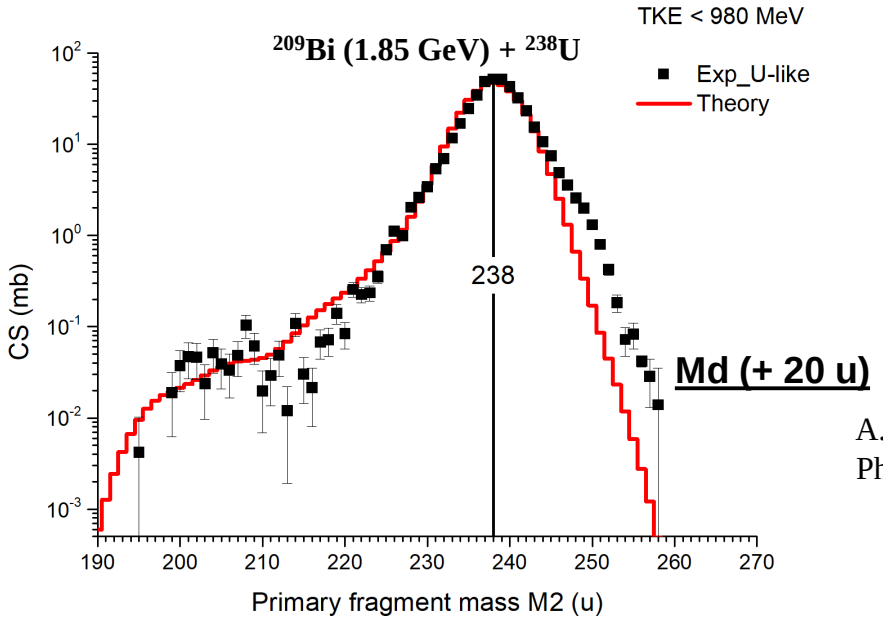

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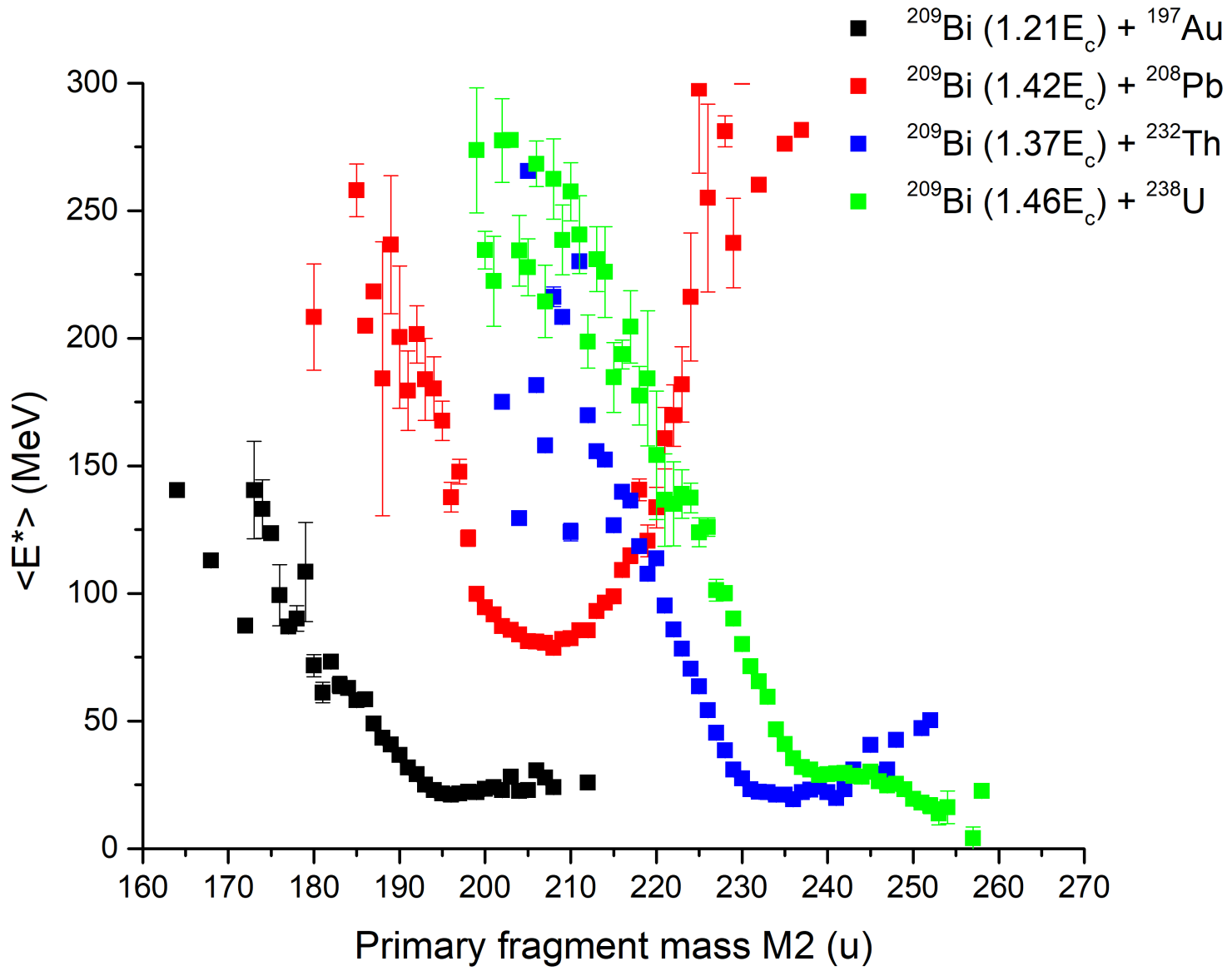
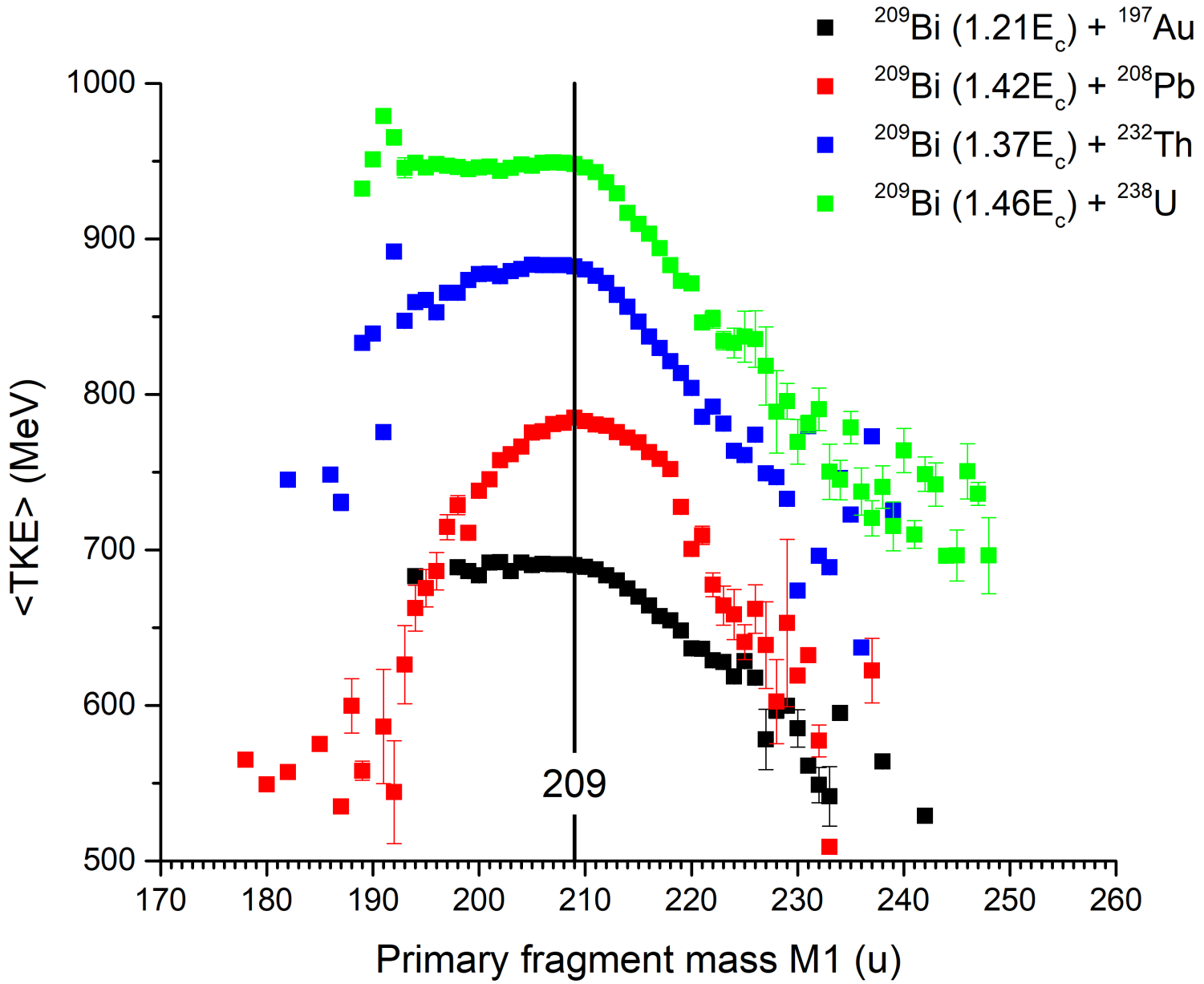
Total excitation energies for survived primary TLFs



The total excitation energy can be estimated from the TKE measurements: $E^*_{\text{total}} \approx E_{c.m.}\text{-TKE} + Q_{\text{gg}}$

Total kinetic energies for survived primary PLFs (Bi-like)



Conclusion

- In the investigation of MNT reactions as a possible tool to produce new isotopes of heavy and superheavy elements, the measurements of mass and energy distributions of binary survived primary fragments formed in the $^{136}Xe + ^{238}U$ and $^{209}Bi + ^{197}Au$, ^{208}Pb, ^{232}Th, ^{238}U reactions above the Coulomb barrier have been performed at modified CORSET setup. Also for now modified CORSET setup allows to study binary processes, as well as 3-body events (projectile-like fragment + sequential fission of heavy MNT fragment).

- For binary events the largest nucleon transfers from projectile nucleus to target nucleus have been observed in the $^{209}Bi + ^{208}Pb$ and $^{209}Bi + ^{232}Th$ reactions: 31 and 26 nucleons respectively with the cross-sections of a few microbarns. To produce transuranium nuclei it's preferable to use the $^{209}Bi + ^{238}U$ reaction. Due to registration of 3-body events the massive nucleon transfers from projectile to target nucleus of about **46 u** have been observed in the $^{209}Bi + ^{238}U$ reaction.

- The measurements of TKE of binary reaction fragments (via ToF-ToF method) allow to estimate their total excitation energy. When trans-target fragments are formed, the total excitation energies are less than 50 MeV in the $^{209}Bi + ^{197}Au$, ^{208}Th, ^{238}U reactions, what creates sufficiently good conditions for survival of such MNT fragments.

- In the $^{209}Bi + ^{208}Pb$ reaction the nucleon transfers are on average accompanied by greater kinetic energy losses compared to other reactions, but this doesn't reduce the yields of formed fragments even at high excitation energies. This may probably indicate the influence of the closed shells Z = 82 and/or N = 126 of Pb nuclei in such dissipative collisions.

Thank you for your attention!

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