International Workshop on Multi facets of EoS and Clusters
Catania 22-25 May

IWM-EC 2018

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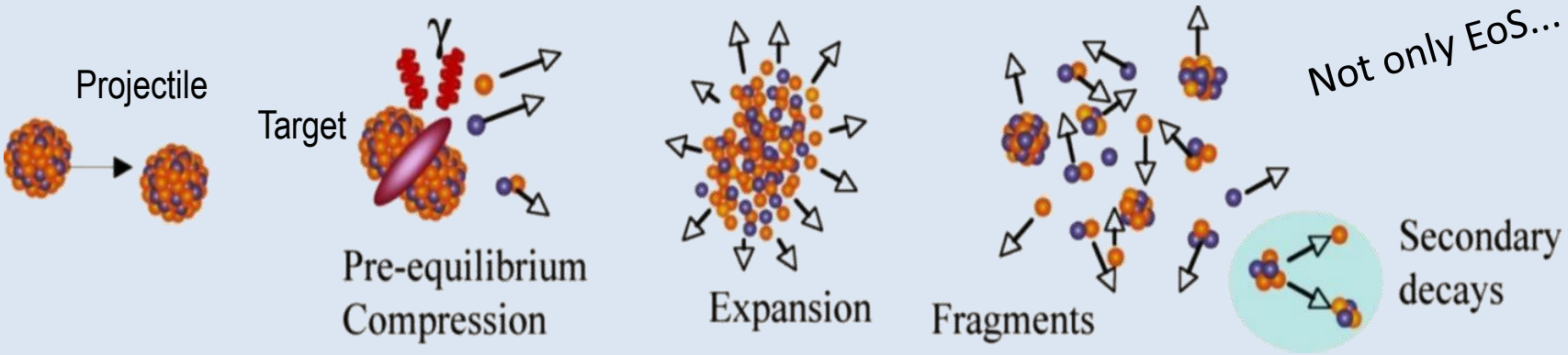
Decay of ^{12}C excited states produced in Heavy Ion Collisions at intermediate energies

Two and multi- particle correlations in Heavy Ion Collisions



Correlation techniques

Nuclear Dynamics

✓Femtoscopy: space-time properties of light particle emitting source

✓Nuclear Equation of State

Structure <-> Dynamics

✓Reconstruct of unbound states from correlation of two and multi particle decay

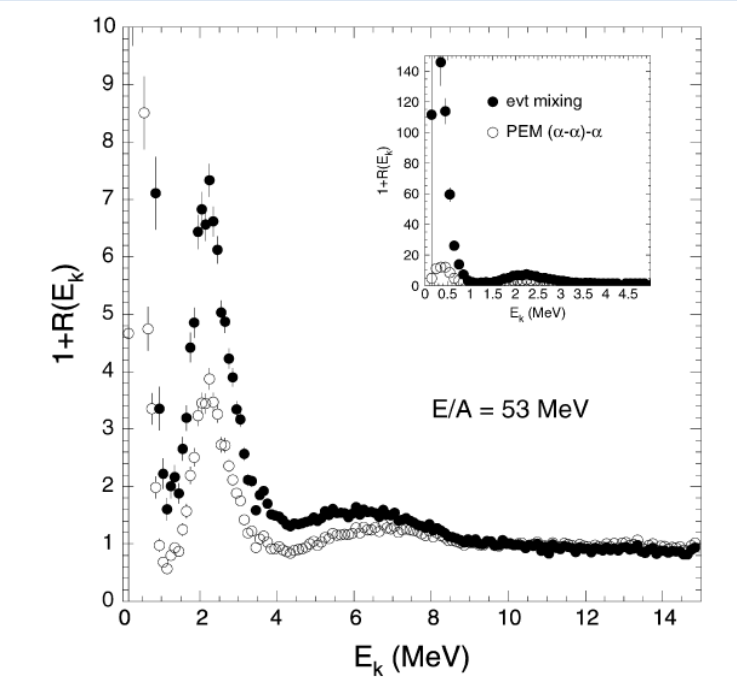
✓Spin of states, branching ratio for simultaneus and sequential decay

Multi- particle correlations in Heavy Ion Collisions

Study of 3 body decay :branching ratio- direct vs sequential

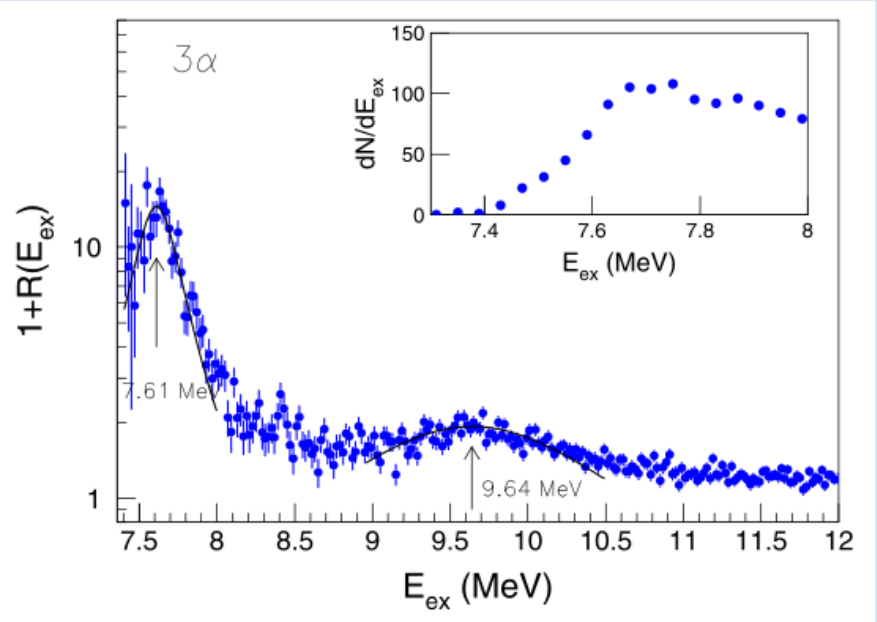
^{12}C->3α

$^{12}C+^{24}Mg$ E=53 e 95 AMeV with INDRA



F. Grenier et al., Nucl. Phys. A811, 233 (2008).

$^{40}Ca+^{12}C$ E=25 AMeV with CHIMERA



Raduta et al., Phys. Lett. B 705, 65 (2011)

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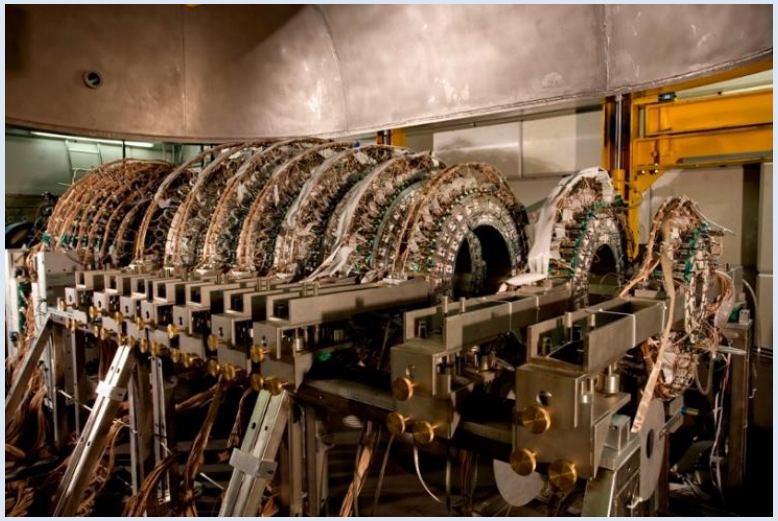
Correlation experiment at LNS

Quasi- projectile decay in peripheral collisions

$^{12}C+^{24}Mg$ @ 35 AMeV

CHIMERA Charged Heavy Ion Mass and Energy Resolving Array



Angular range 1 < θ < 30

Granularity	1192 modules Si (300 μm)+ CsI (Tl)
Geometry	RINGS: 688 modules 100-350 cm SPHERE: 504 modules 40 cm
Angular coverage	RINGS: 1 < θ < 30 SPHERE: 30 < θ < 176, 94% 4π

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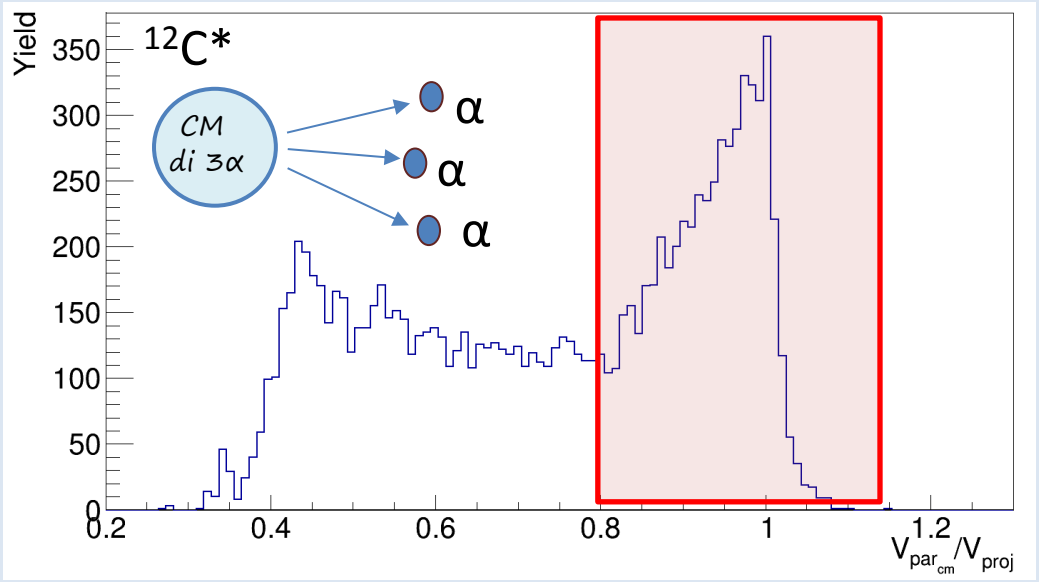
3α correlations in $^{12}C+^{24}Mg$ reaction

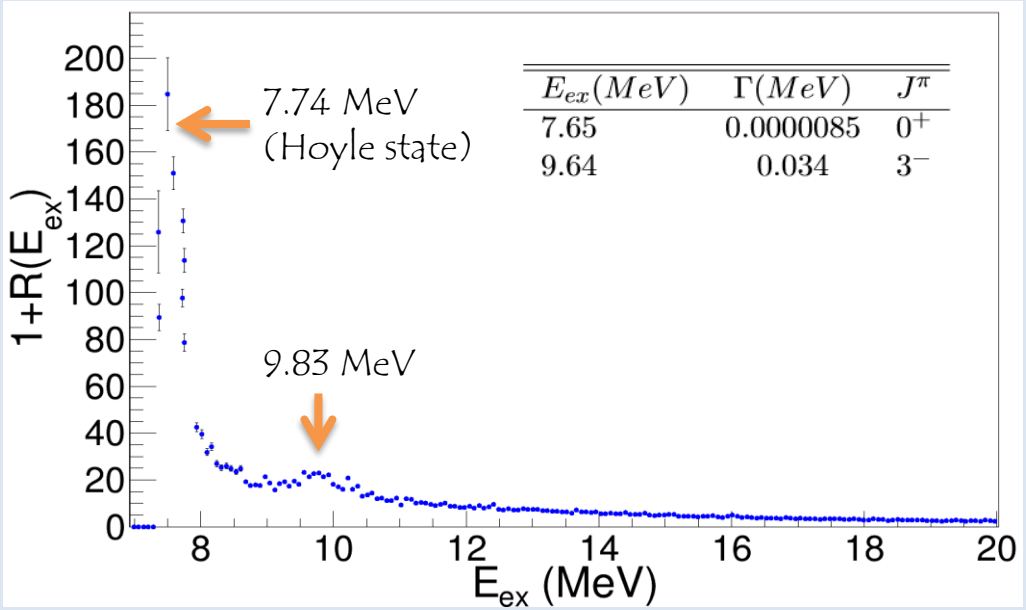
Event selection



$$\frac{V_{par}}{V_{proj}} > 0.8 \qquad (V_{proj} = 7.99\,cm/ns)$$

Confirmed by comparison with HIPSE model prediction

D. Lacroix et al. ,Phys. Rev. C69 054604



$E_{ex}(MeV)$	$\Gamma(MeV)$	J^π
7.65	0.0000085	0^+
9.64	0.034	3^-

Correlation Function

$$1+R(E_{ex}) = \frac{Y_{coinc}(E_{ex})}{Y_{uncorr}(E_{ex})}$$

$$E_{ex} = E_{tot} - Q$$

3α threshold=7.27MeV

Random extraction from single particle spectra

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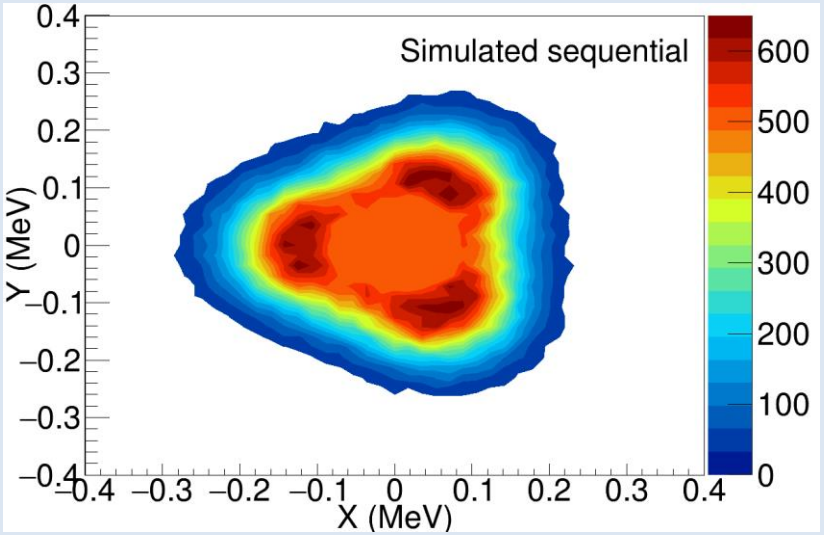
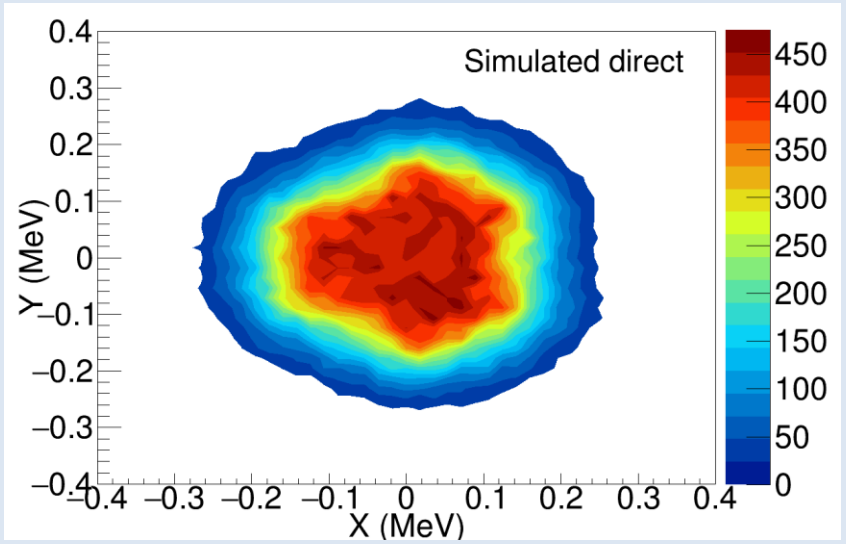
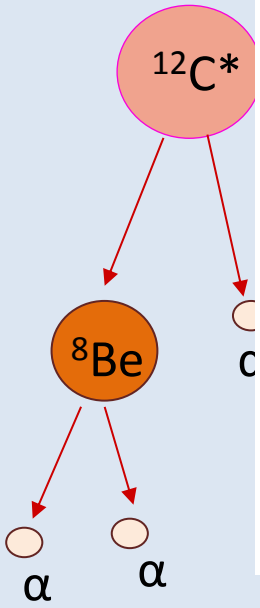
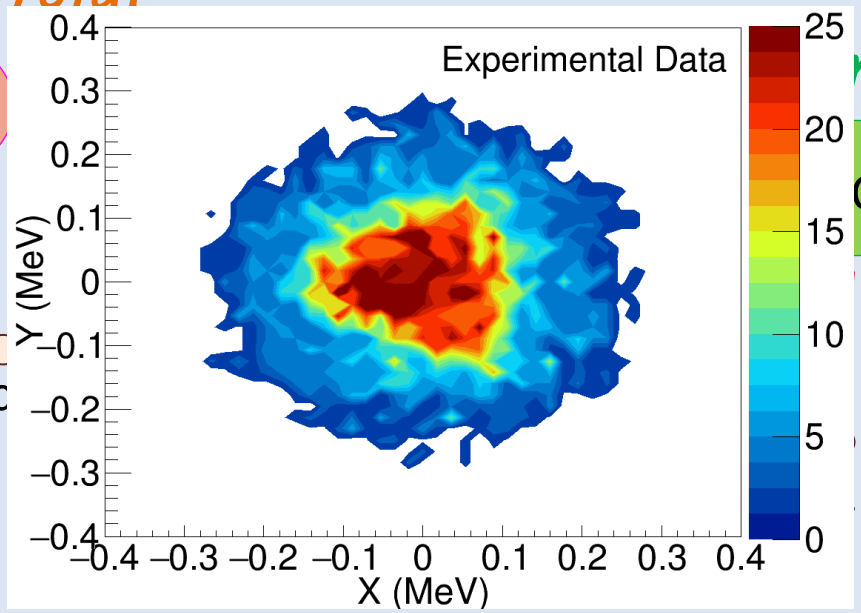
Hoyle state: Dalitz Plots





Sequential





rect

Dalitz parameter

$$x = \sqrt{3}(E_{1CM} - E_{2CM})/3$$

$$y = (2E_{3CM} - E_{1CM} - E_{2CM})/3$$

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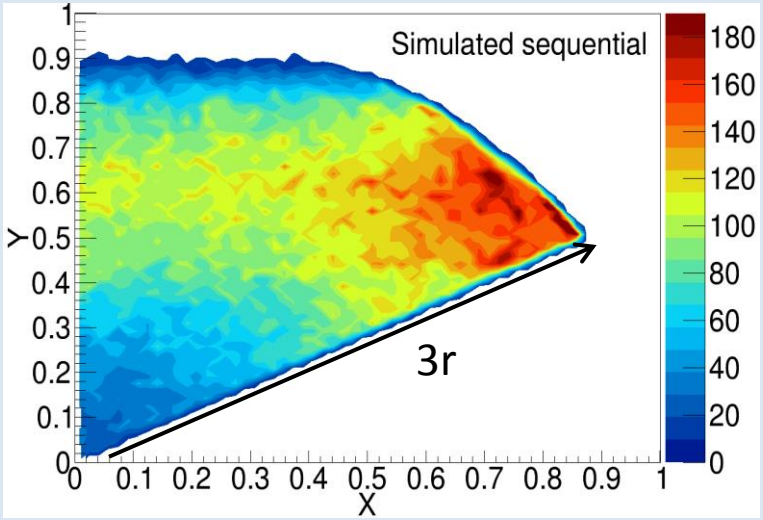
Stato di Hoyle: Symmetric Dalitz Plots

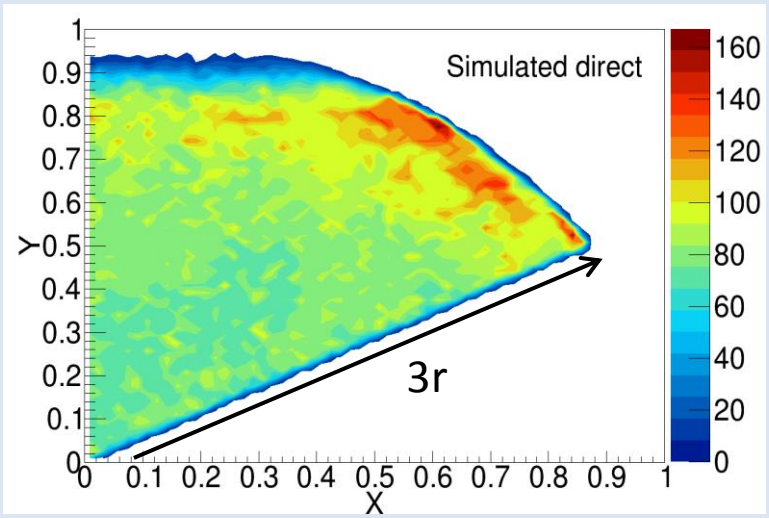
Itoh et al., PRL 113, 102501 (2014)

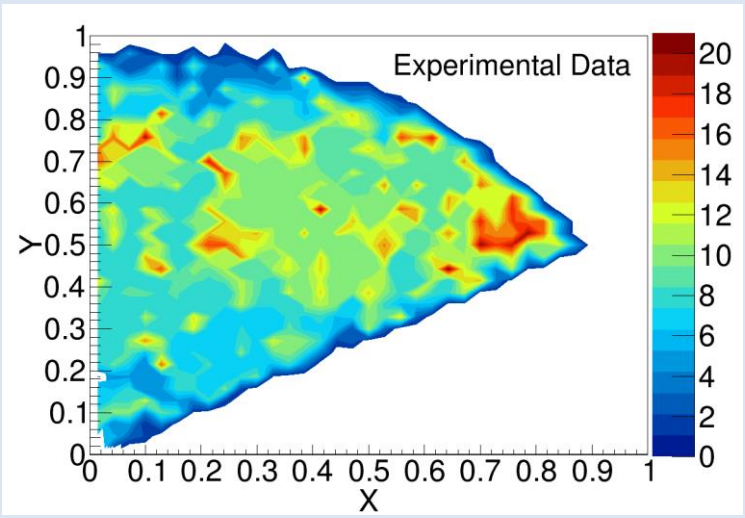
$$x = \sqrt{3}(\varepsilon_j - \varepsilon_k) \qquad \varepsilon_{i,j,k} = E_{i,j,k}/(E_i + E_j + E_k)$$

$$y = 2\varepsilon_i - \varepsilon_j - \varepsilon_k \qquad (3r)^2 = 3(\varepsilon_j - \varepsilon_k)^2 + (2\varepsilon_i - \varepsilon_j - \varepsilon_k)^2$$

Particles energies in $^{12}C^*$ frame normalized to the total energy of 3α decay







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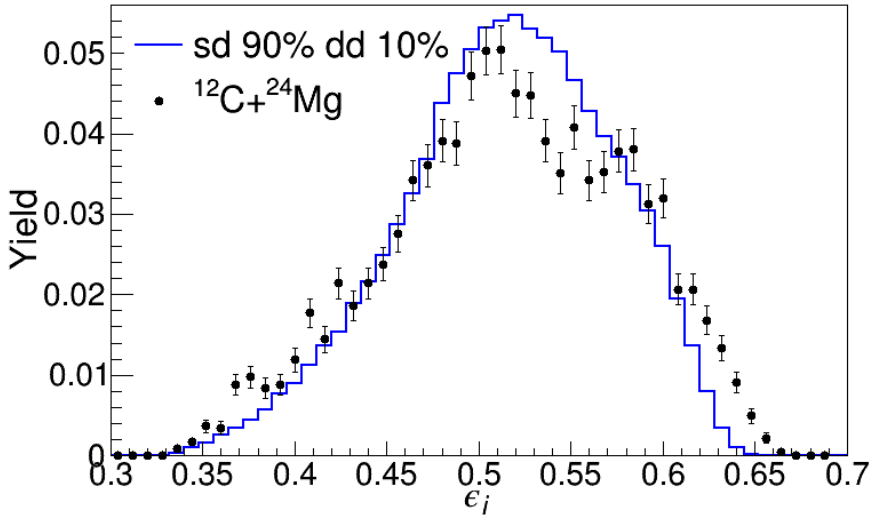
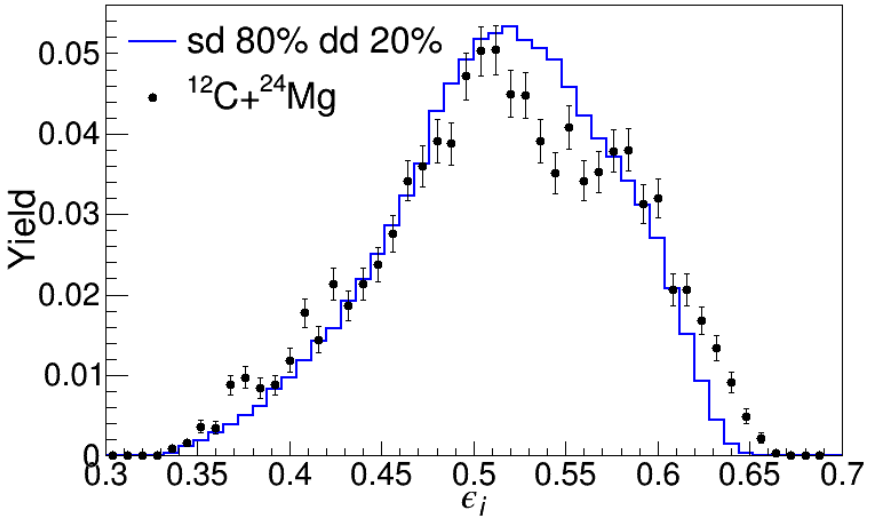
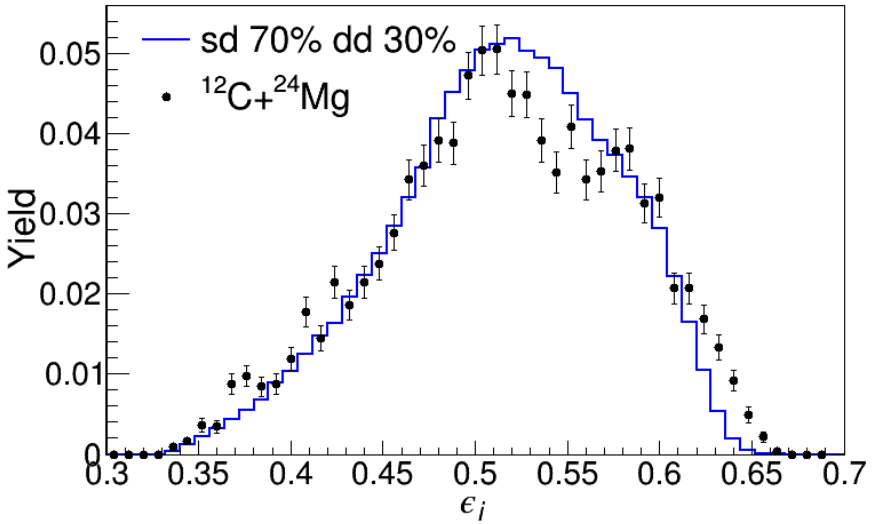
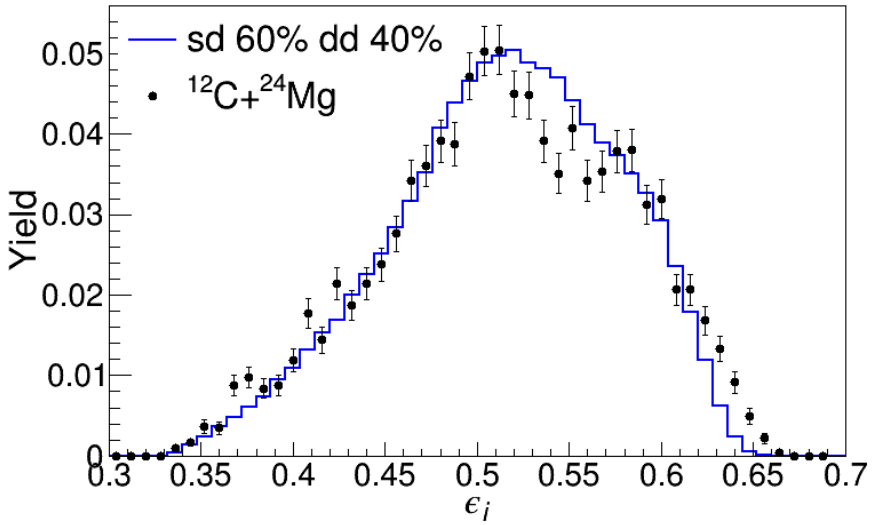
Hoyle state: Symmetric Dalitz Plots









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Heavy Ion Collisions

Evidence of direct decay

$^{12}C + ^{24}Mg$, 35 AMeV

$^{40}Ca + ^{12}C$, 25 AMeV

Raduta et al. ,Phys. Lett. B 705, 65 (2011)

Direct reaction anelastic scattering

Negligible direct contributions

$^{12}C + ^{12}C$, 54 MeV

M. Freer et al., PRC 49 (1994) R1751

$\alpha + ^{12}C$,60 AMeV

T.K. Rana et al., PRC 88 021601 (2013)

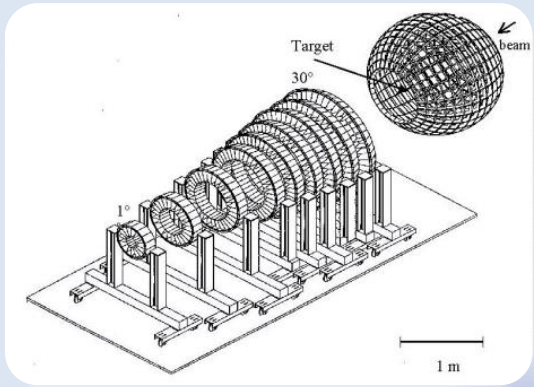
$^{14}N(d,\alpha)^{12}C(7.654)$

D. Dell'Aquila et al., Phys. Rev. Lett. 119 132501 (2017)

EQUILIBRATION experiment at LNS

M. Papa et al. PHYSICAL REVIEW C91, 041601 (2015)

$^{48}Ca + ^{27}Al$ @ 40 AMeV



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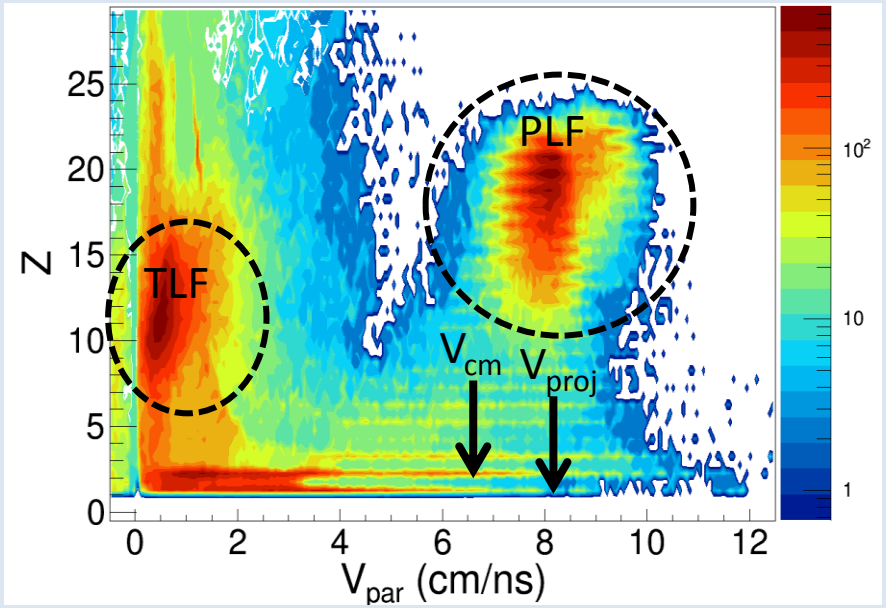
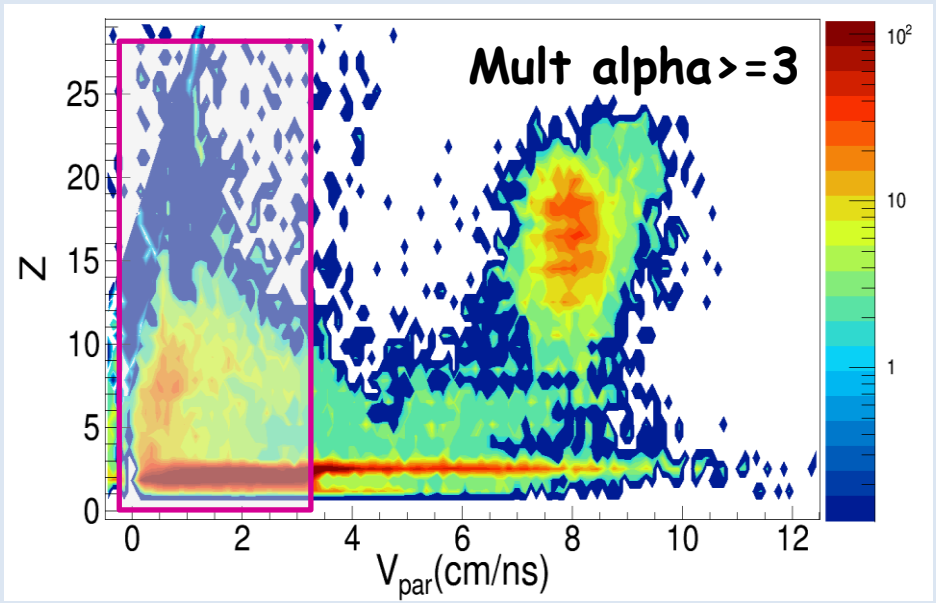
Z-V_{par} Plot

$^{48}Ca+^{27}Al$ @ 40 AMeV

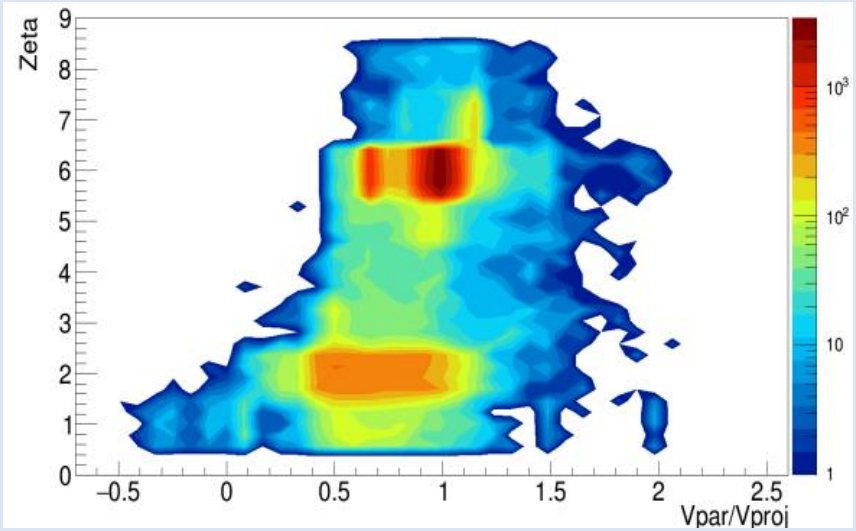


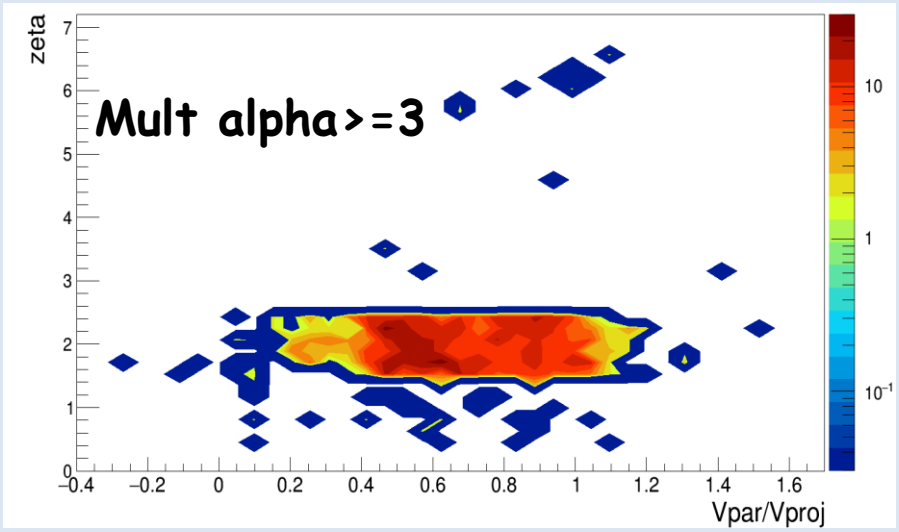


Displacement of bump corresponding to TLF through lower values of Z.

Z-V_{par} Plot

$^{12}C+^{24}Mg$ @ 35 AMeV

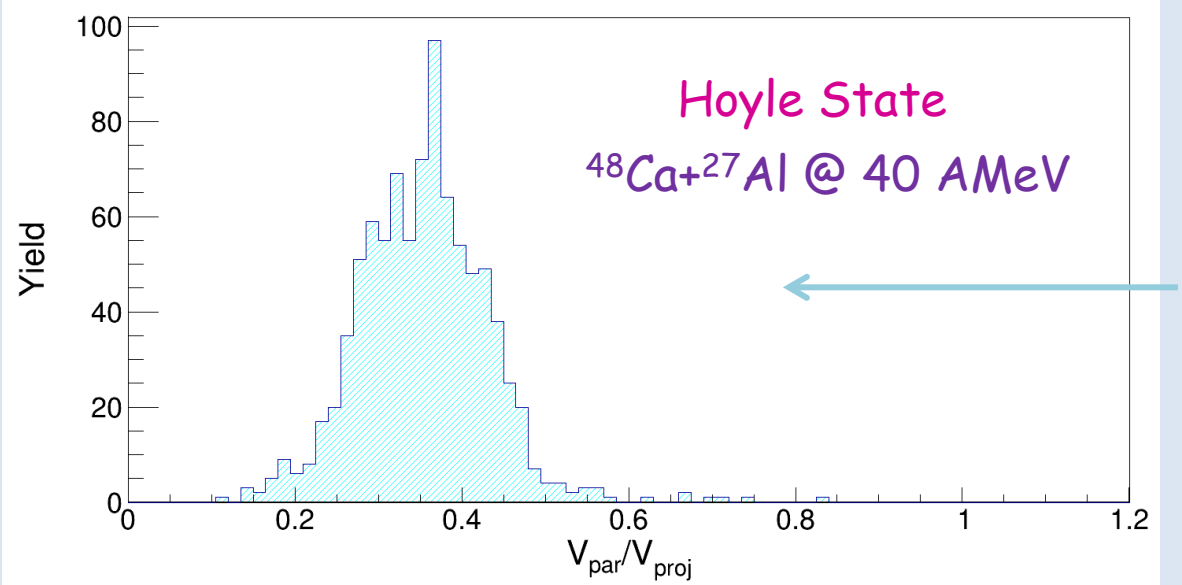




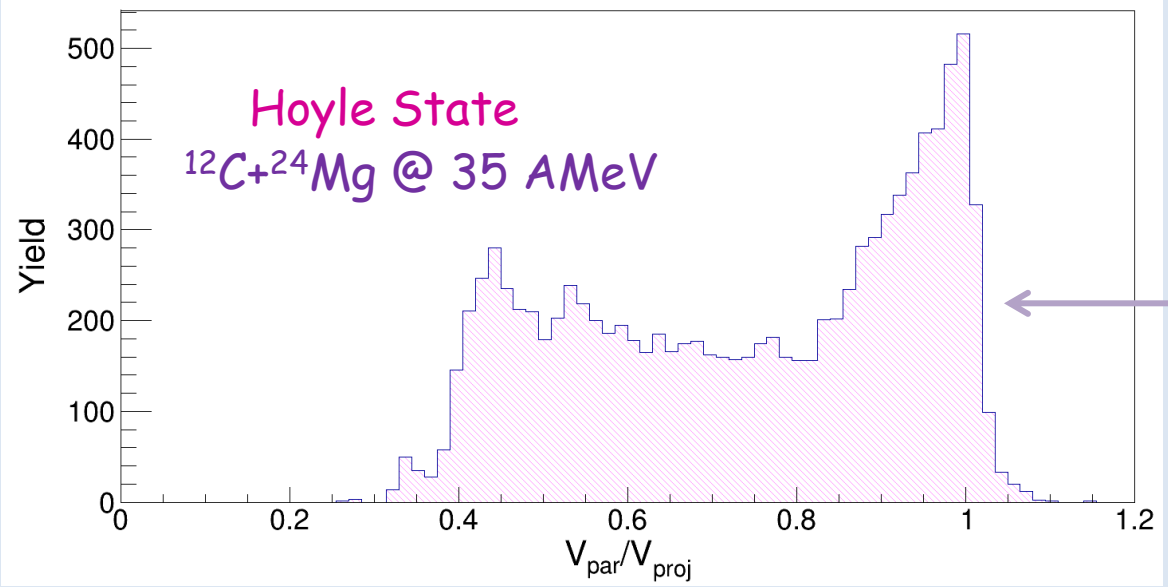
Many more events associated to disappearances of PLF

EQUILIBRATION experiment at LNS

Reconstructed parallel velocity of ^{12}C, obtained from the center of mass of 3α detected in coincidence



Hoyle state is produced from breaking of ^{27}Al in rather dissipative collisions



Hoyle state is essencially produced from ^{12}C in less dissipative processes

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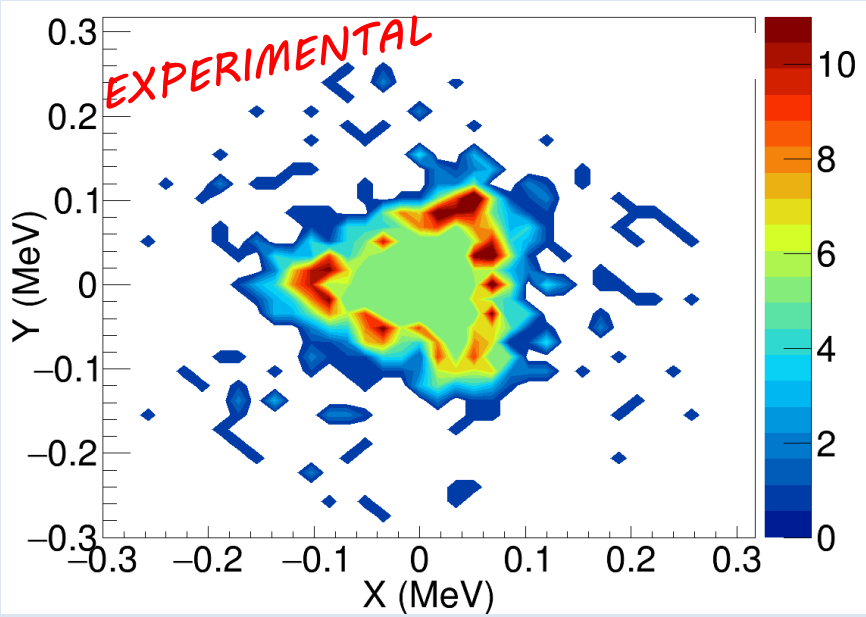
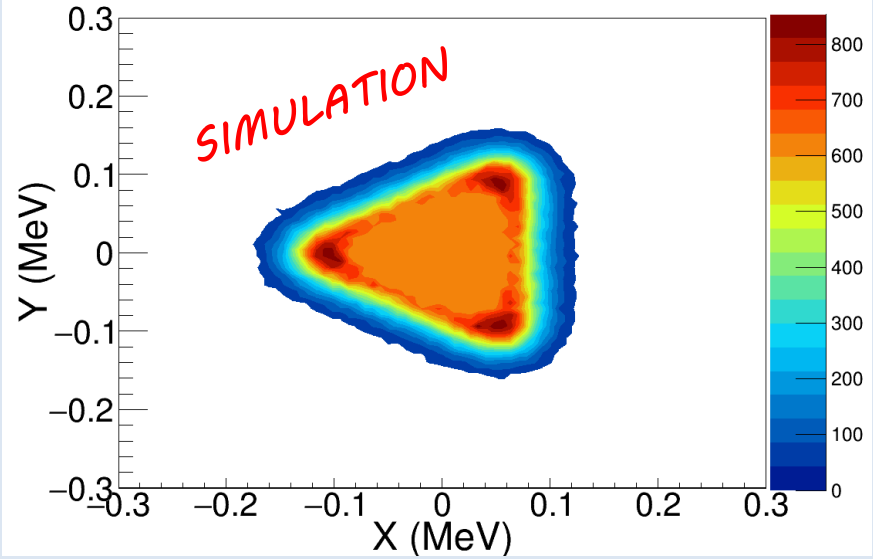
Dynamics of three body decay : Dalitz Plots

$^{48}Ca+^{27}Al$ @ 40 AMeV





Hoyle State

In contrast to previous results, in $^{48}Ca+^{27}Al$ system the Hoyle state seems to decay entirely passing though the ground state of ^{8}Be.

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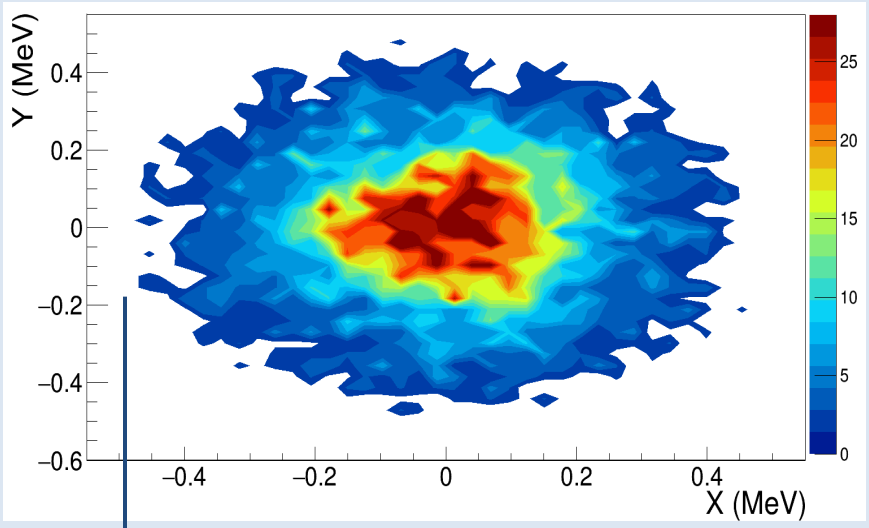
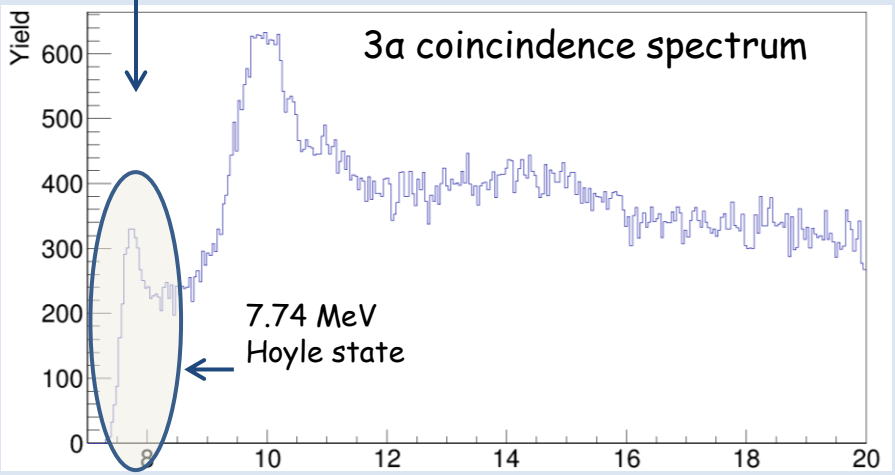
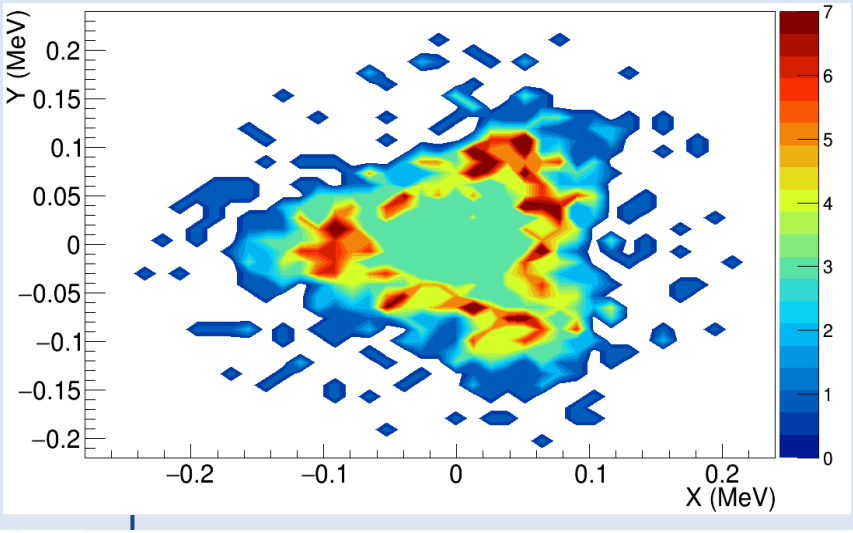
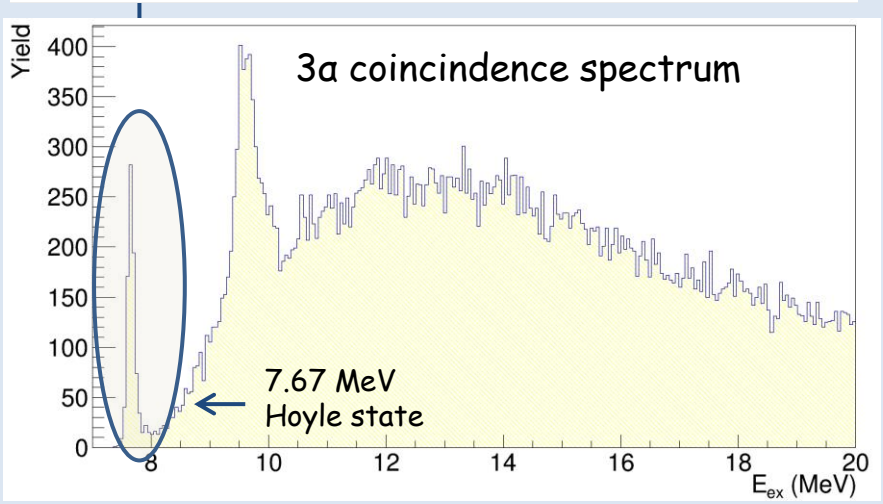
$^{12}C+^{24}Mg$ @ 35 AMeV





$^{48}Ca+^{27}Al$ @ 40 AMeV





The observed differences could depend on alpha particles background due to the α -like structure of ^{12}C and ^{24}Mg ???

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$^{12}C+^{24}Mg$ simulation with HIPSE + GEMINI

HIPSE

D. Lacroix et al. ,Phys. Rev. C69 054604

Event generator

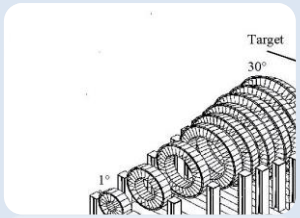
+

GEMINI

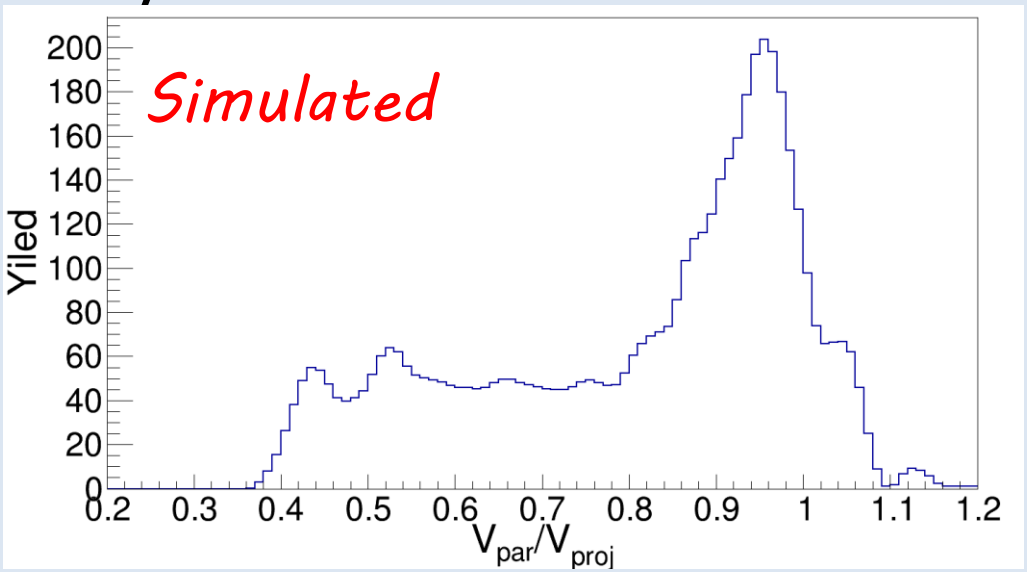
Statistical desexitation

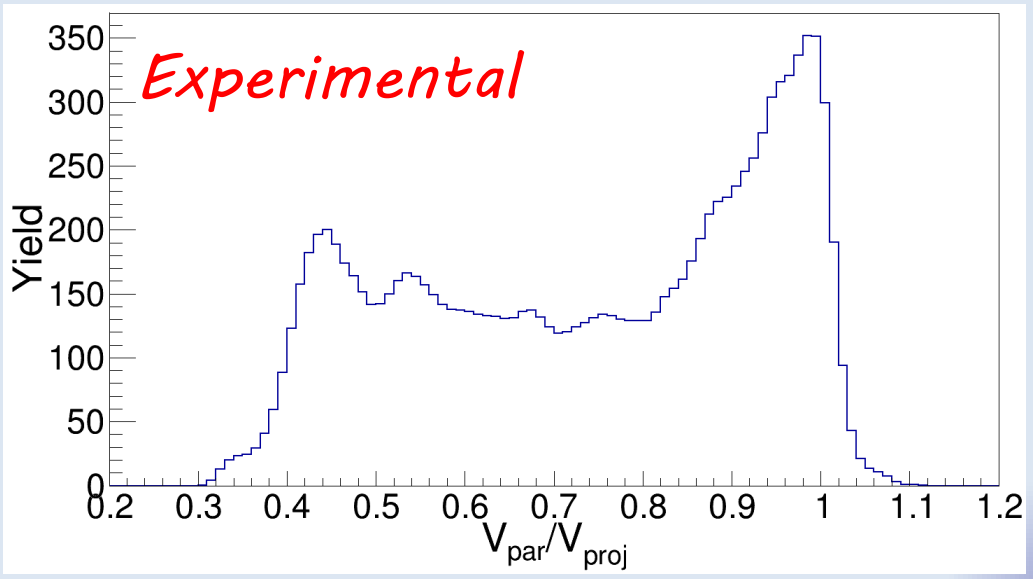
+

Filter



Velocity of CM associated to the 3α





$^{12}C+^{24}Mg$ simulation with HIPSE + GEMINI

HIPSE

D. Lacroix et al. ,Phys. Rev. C69 054604

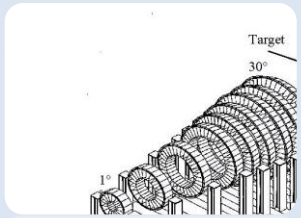
Event generator

+

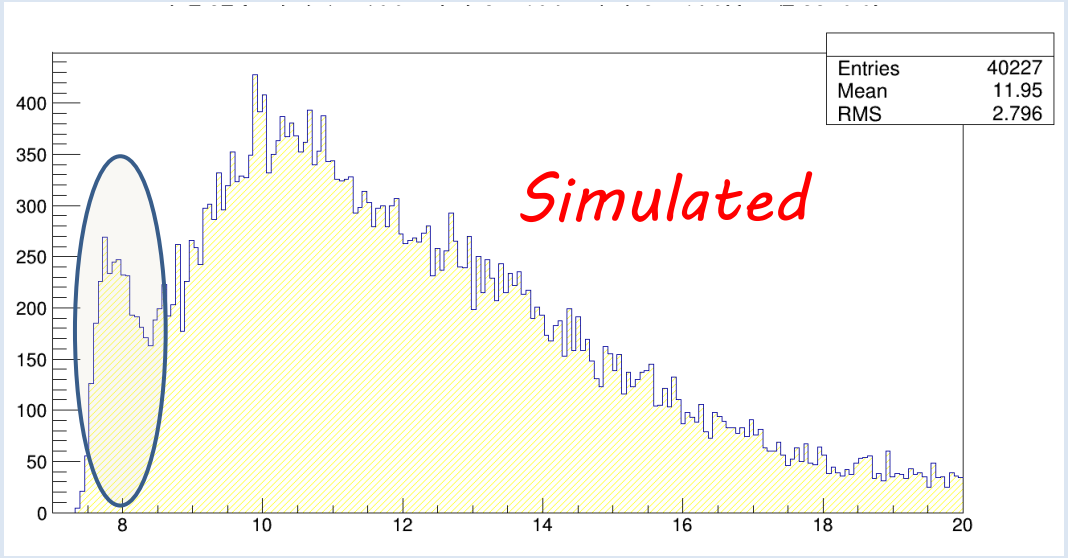
GEMINI

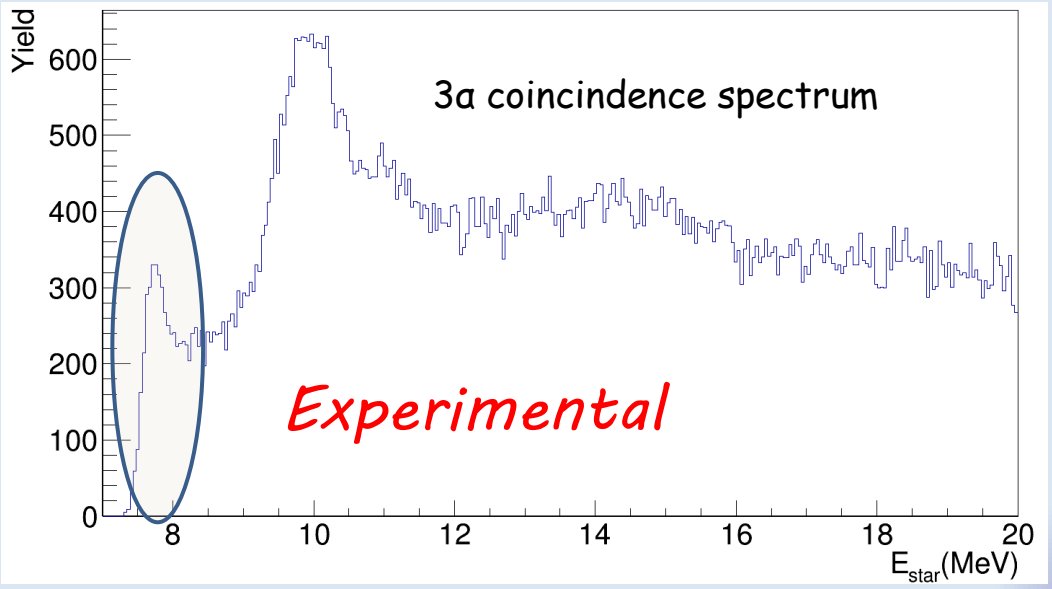
Statistical desexitation

+



3α coincindence spectra





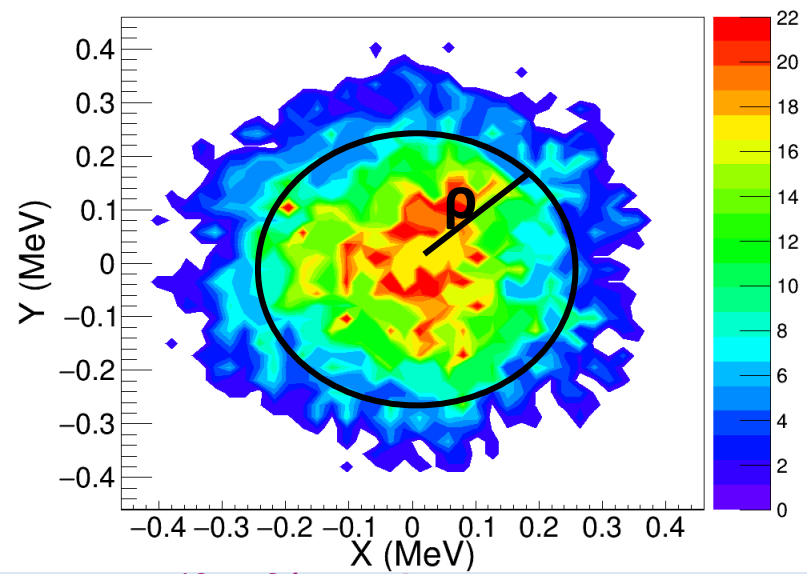
Simulation $^{12}C+^{24}Mg$ HIPSE + GEMINI

Preliminary

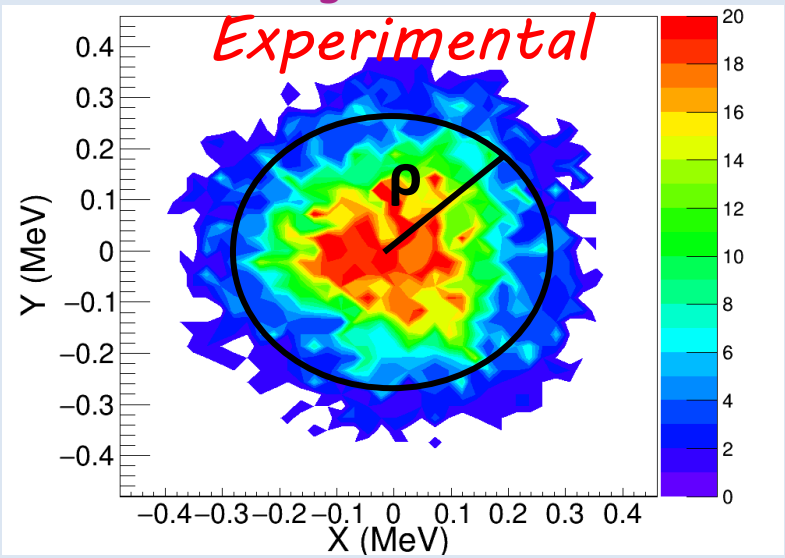
Simulated

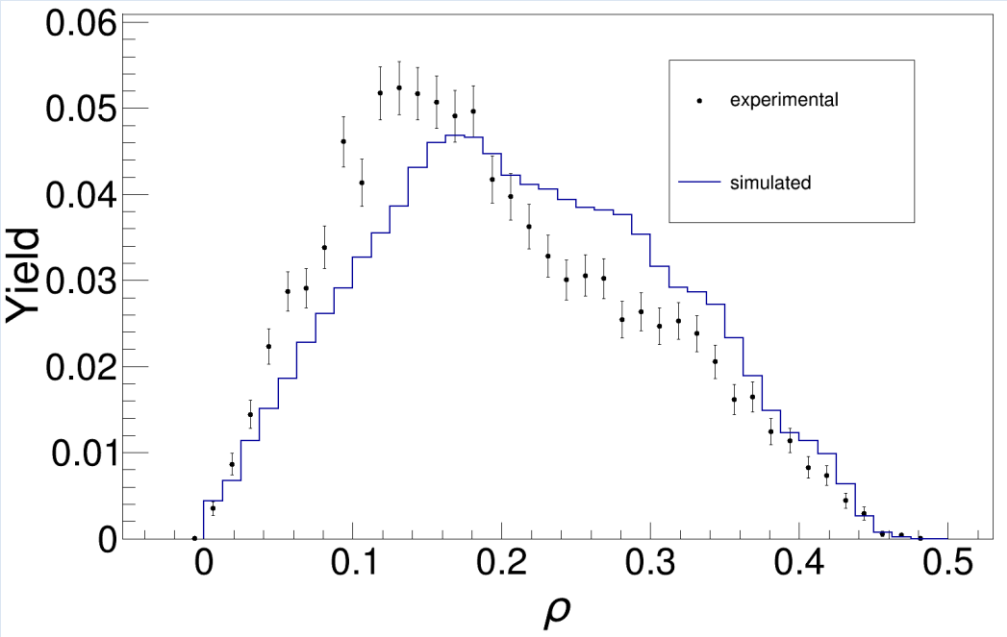
$^{12}C \rightarrow {}^{8}Be+\alpha \rightarrow 3\alpha$+BACKGROUND

$$\rho = \sqrt{x^2 + y^2}$$



$^{12}C+^{24}Mg$ @ 35 AMeV





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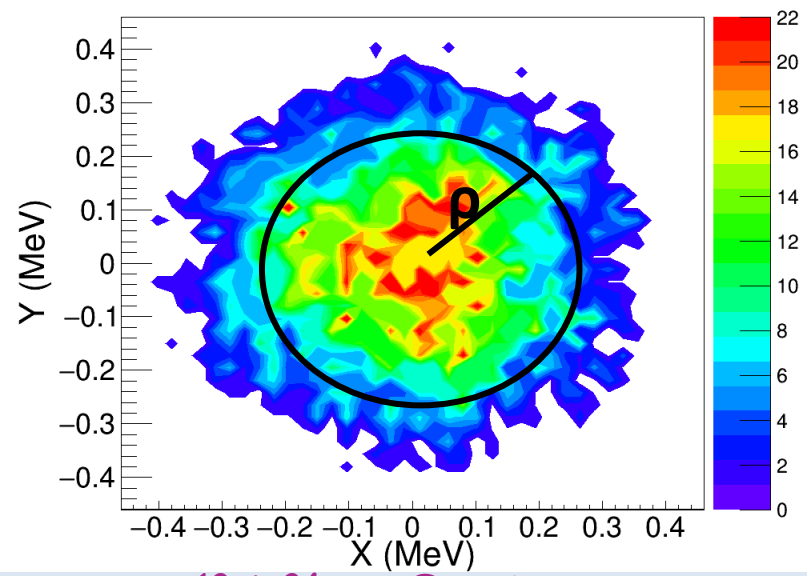
Simulation $^{12}C+^{24}Mg$ HIPSE + GEMINI

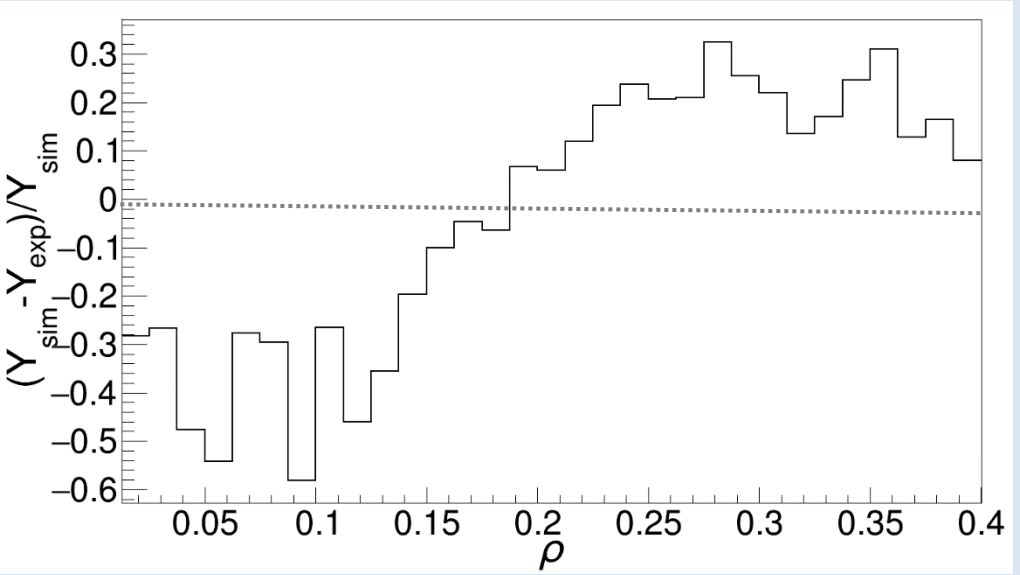
Preliminary

Simulated

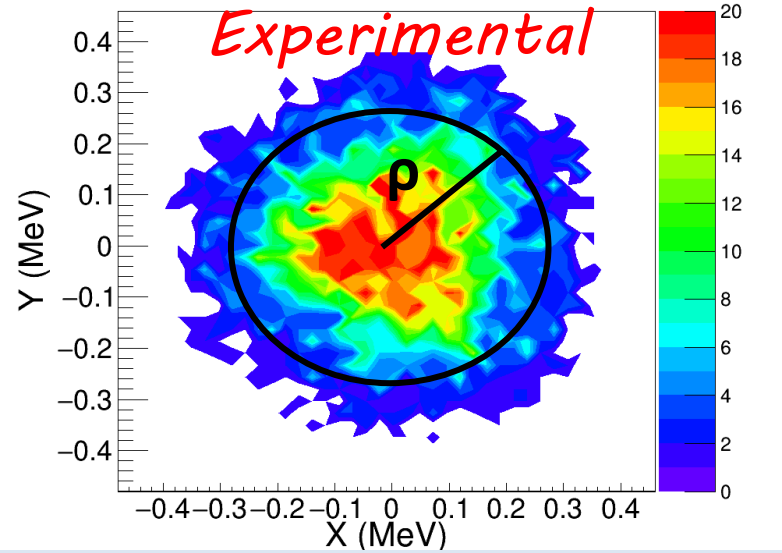
^{12}C->^{8}Be+α->3α+BACKGROUND



$^{12}C+^{24}Mg$ @ 35 AMeV



Experimental



Background cannot be enough to reproduce the spectrum typical of direct decay processes!!!!

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Dynamics of involved processes

$^{12}C+^{24}Mg$ @ 35 AMeV

Hoyle state is produced from Quasi-projectile dominated by fast processes

$^{48}Ca+^{27}Al$ @ 40 AMeV

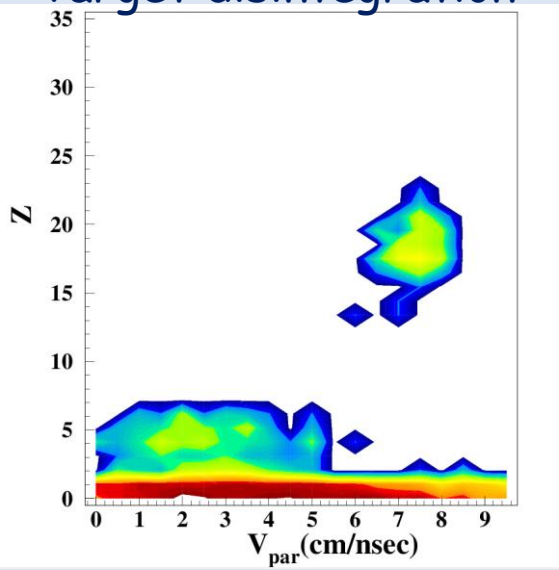
Hoyle state is produced from multi break up of target

Typical reaction times~150 fm/c

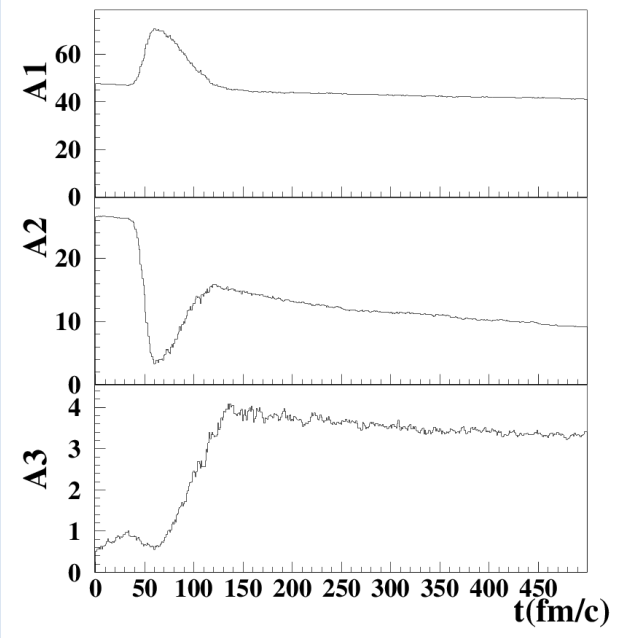
CoMD-III Simulations: $^{48}Ca+^{27}Al$ @ 40 AMeV

Preliminary

Target disintegration



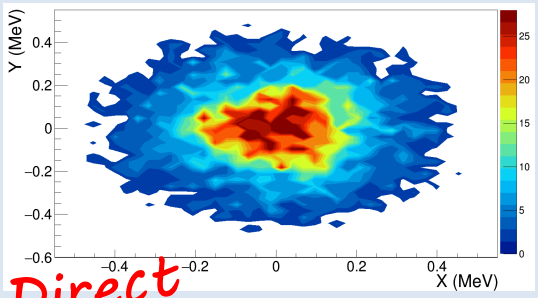
Time of fragments production



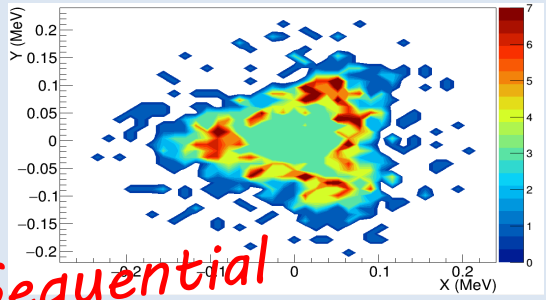
Conclusions and future perspective

Analysis of decay of ^{12}C excited states

$^{12}C+^{24}Mg$ @ 35 AMeV



$^{48}Ca+^{27}Al$ @ 40 AMeV



Simulations suggest that the background of α particles cannot be the only responsible for the observed differences. We are working to identify particular selections allowing us to reduce this backgrond

We are working to understand if the observed discrepancies of decay modes could be related to different dynamics of involved reactions

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Newchim Collaboration

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Thank you for your attention