Searching for clustering structure effects of reacting partners through competing fast and thermal emission processes

Daniela Fabris
INFN- Padova

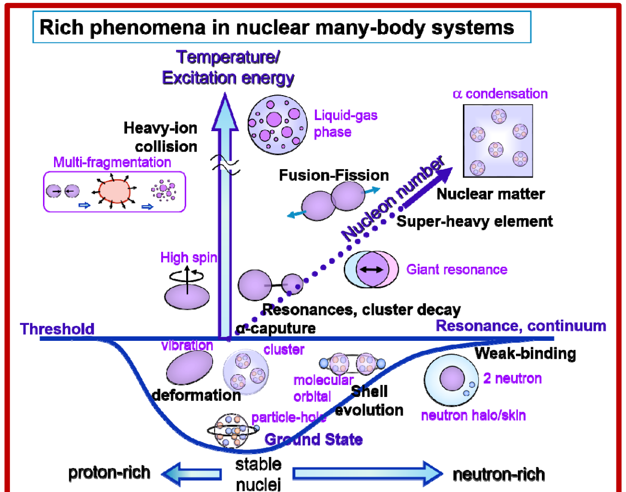
on behalf of NUCLEX collaboration

COMEX6

29 October - 2 November 2018
Cape Town, South

INFN Istituto Nazionale di Fisica Nucleare
Sezione di Padova

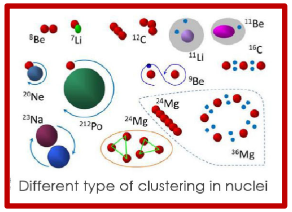
Study of Nuclear Clustering effects



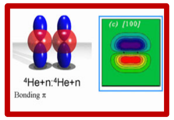
Y. Kanada-En'yo, International School of Physics "Enrico Fermi", course 201 (Nuclear Physics with Stable and Radioactive Beams), 14-19 July 2017

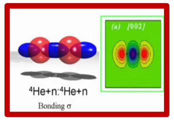
<u>Light Nuclei</u>

Coexistence of cluster and mean-fields aspects: connection between cluster emission and nuclear structure.



2N=2Z nuclei: α**-cluster structure** at **E*** close to the α**-decay threshold**





Neutron-rich nuclei: **molecular structures of clusters** bound by valence neutrons

<u>Medium Mass Nuclei</u>

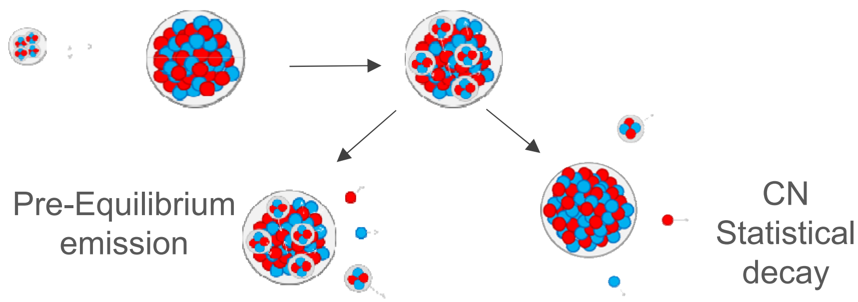
Clustering effects on reaction dynamics can be **related** either to their **preformation** or to their **dynamical formation**.

Analyze pre-equilibrium particles emission

- W. Von Oertzen et al. Phys. Rep. 432 (2006) 43
- M. Freer et al. , Rep. Progr. Phys. 70 (2007) 2149
- J. P. Ebran et al. , Nature 487 (2012) 341
- W.N. Catford J. Phys. Conf. Series 436, 012095
- P.E. Hodgson, E. Běták, Phys. Rep. 374 (2003) 1-89

…Using Reaction Dynamics

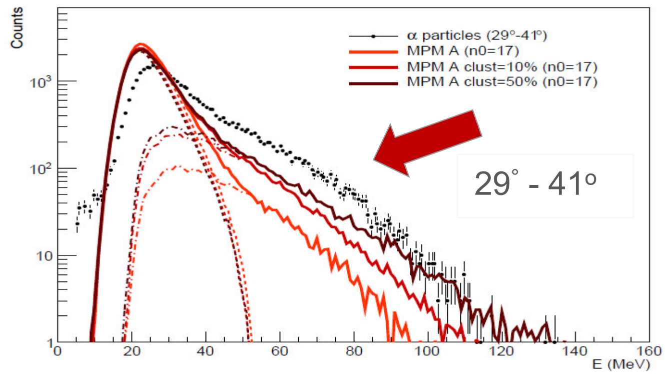
Possible effects of
α-cluster structure in the projectile



Study the competition between evaporation (surface) and fast (volume) emission of LCP.

Studying *pre-equilibrium particles emission*

T. Marchi et al., Inter. Journ. of Modern Phys. E – Special Topics
A. Corsi et al., PLB 679 (2009) 197.



^{16}O + ^{116}Sn @ 8, 12, 16 MeV/A

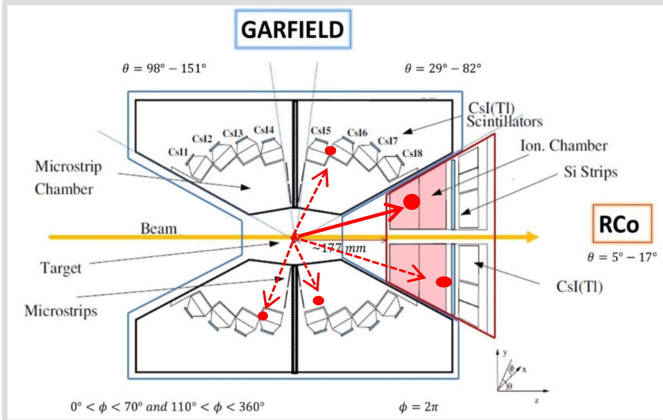
Over-production of α-particle emitted during non-equilibrium stage → possible effect of α-cluster structure in ^{16}O

The Experiment

	"FNi"	"OCu"
Projectile	^{19}**F**	^{16}**O**
Target	^{62}**Ni**	^{65}**Cu**
E_{beam} (MeV)	304	256
E/A (MeV/u)	**16**	**16**
η	0,531	0,605
B_{α} (MeV)	4,01	7,20
CN	^{81}**Rb**	^{81}**Rb**
E* (MeV)	240	209
v_{CN} (cm/ns)	1.304	1.098
L_{cr} ($\hbar$)	60.32	54.12
E_{surf} (MeV)	12,8	11,2

Comparing LCP emission from fusion reactions with different N/Z projectiles.

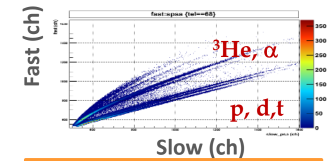
Set-up: GARFIELD 4π array at LNL



M. Bruno, F. Gramegna et al., EPJ A 49 (2013) 128

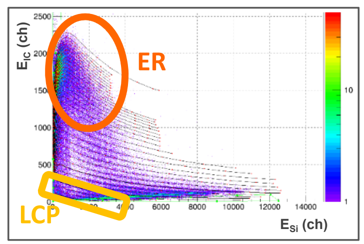
Evaporation Residues are detected in coincidence with **Light Charged Particles**

LCP in GARFIELD



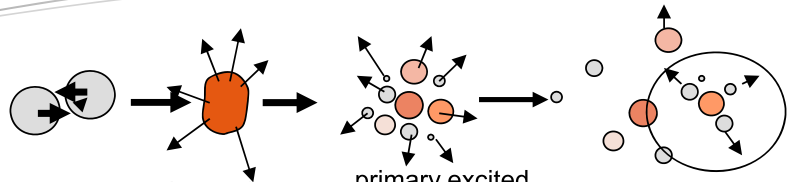
- Z identification
- A identification (1≤Z≤3)

LCP+ER in RCo



identified in RCo IC vs Si:
$\Delta\theta = 8.6° \div 17°$

Theoretical Codes



Statistical Code

GEMINI++

Monte Carlo code to simulate the decay of hot nuclei formed in fusion/quasi-fusion reactions.

- **Standalone** when a good selection of central events can be performed
- **Afterburner** (after a dynamical code) to produce secondary particles distributions from primary fragments -> to be compare with experimental data.

An event file is generated which can be <u>filtered</u> through a software replica of the exp. set-up.

R. J. Charity, Phys Rev C 82 (2010) 014610

Dynamical Codes

AMD

The dynamics is considered by eq. of motion of Gaussian wave packets representing the colliding nucleons.

- It describes the cluster structure of the interacting particles.
- It takes into account the particle-particle correlations.

A. Ono, PRC 59 (1999) 853

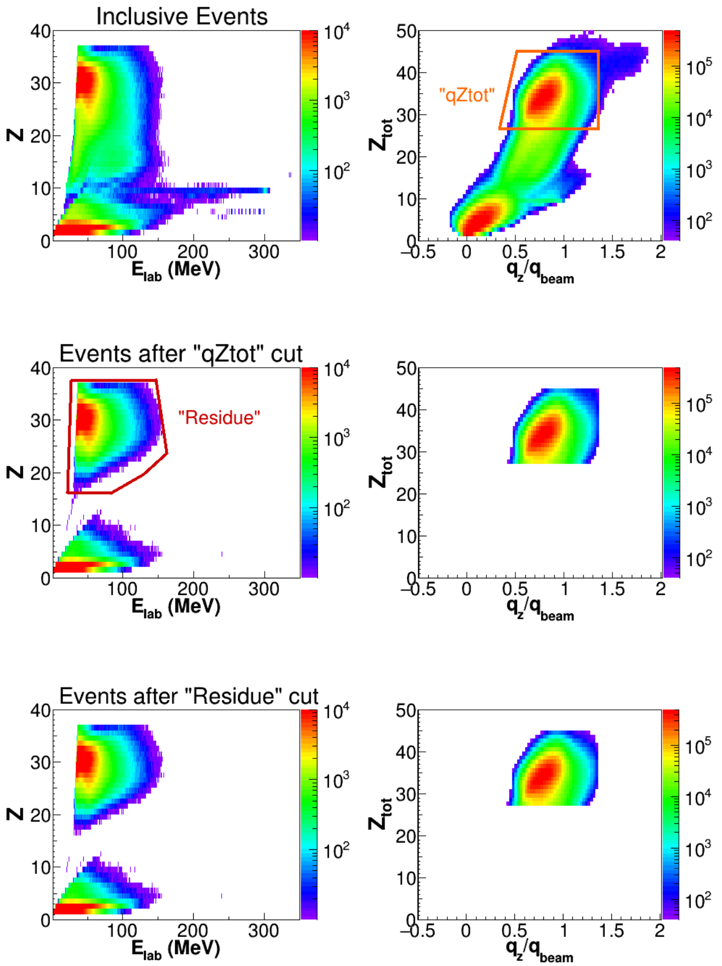
HIPSE

Phenomenological model based on sudden approximation.

- It describes nuclear collisions of heavy-ions in the intermediate energy range,
- It takes into account dynamical and statistical effects.

D. Lacroix, et al., Phys. Rev. C69 (2004) 054604

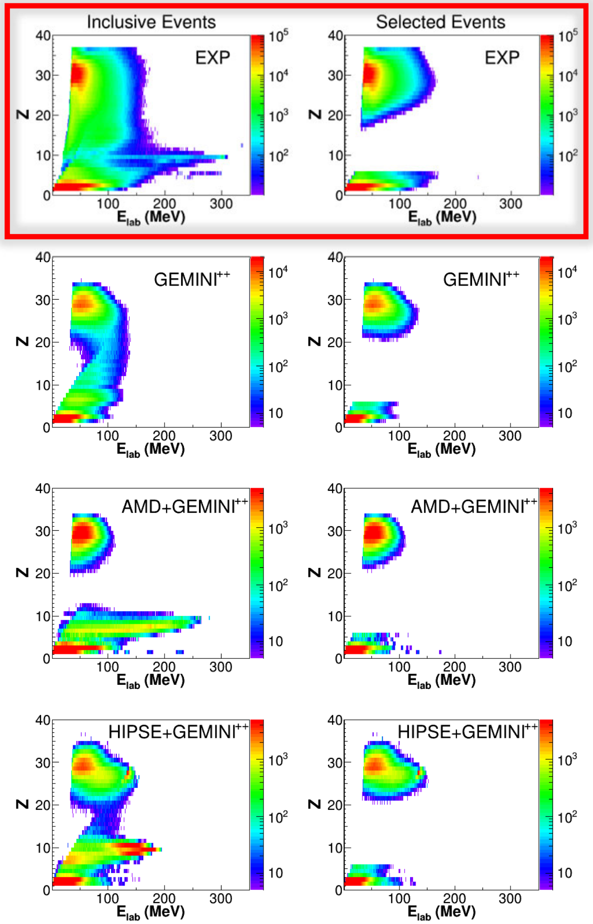
Events Selection

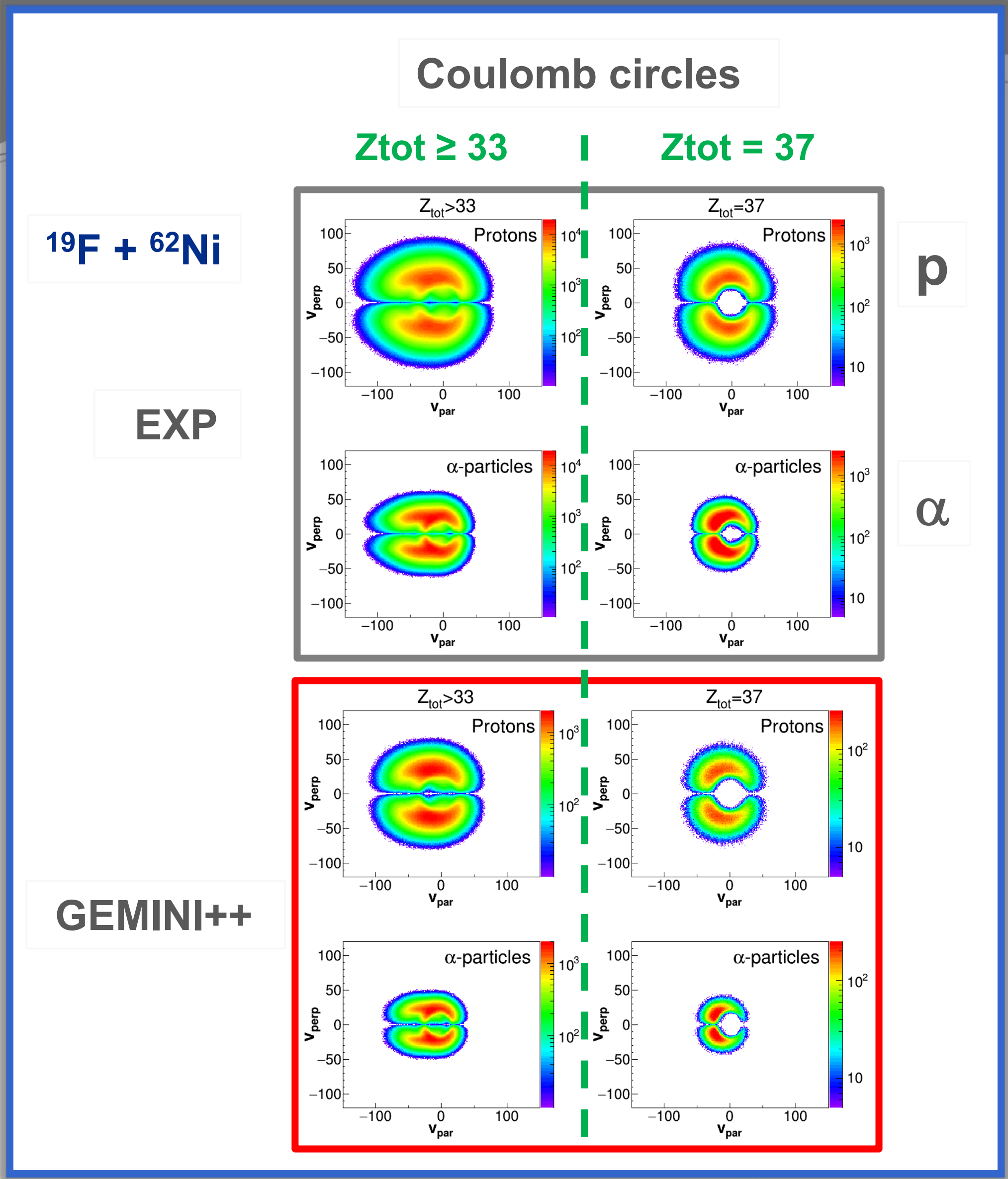


- ❑ Cut **"qZtot"** on longitudinal momentum vs Total charge
  - $Z_{tot} > 26 \longleftrightarrow \frac{Z_{tot}}{ZP+ZT} > 0.7$
  - $q/q_{beam} < 1.3$

- ❑ Cut **"Residue"** on Laboratory Energy vs Charge
  - ***At least*** **1 fragment** with Z **inside** the cut **"Residue"**

- ❑ Additional conditions:
  - ***Only*** **1 fragment with Z ≥ 6**

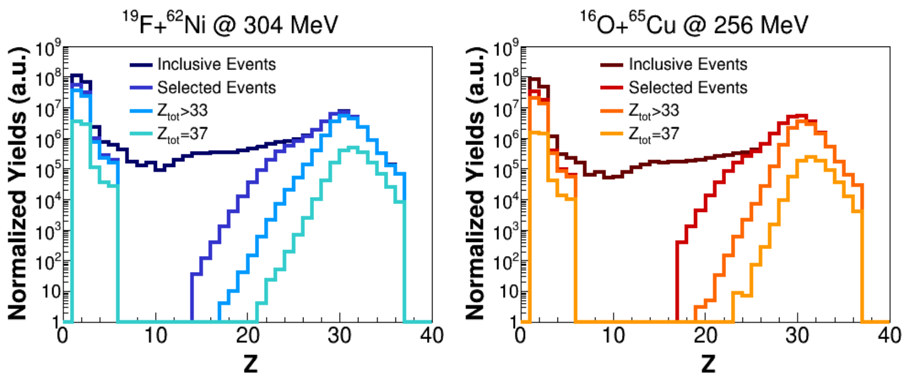




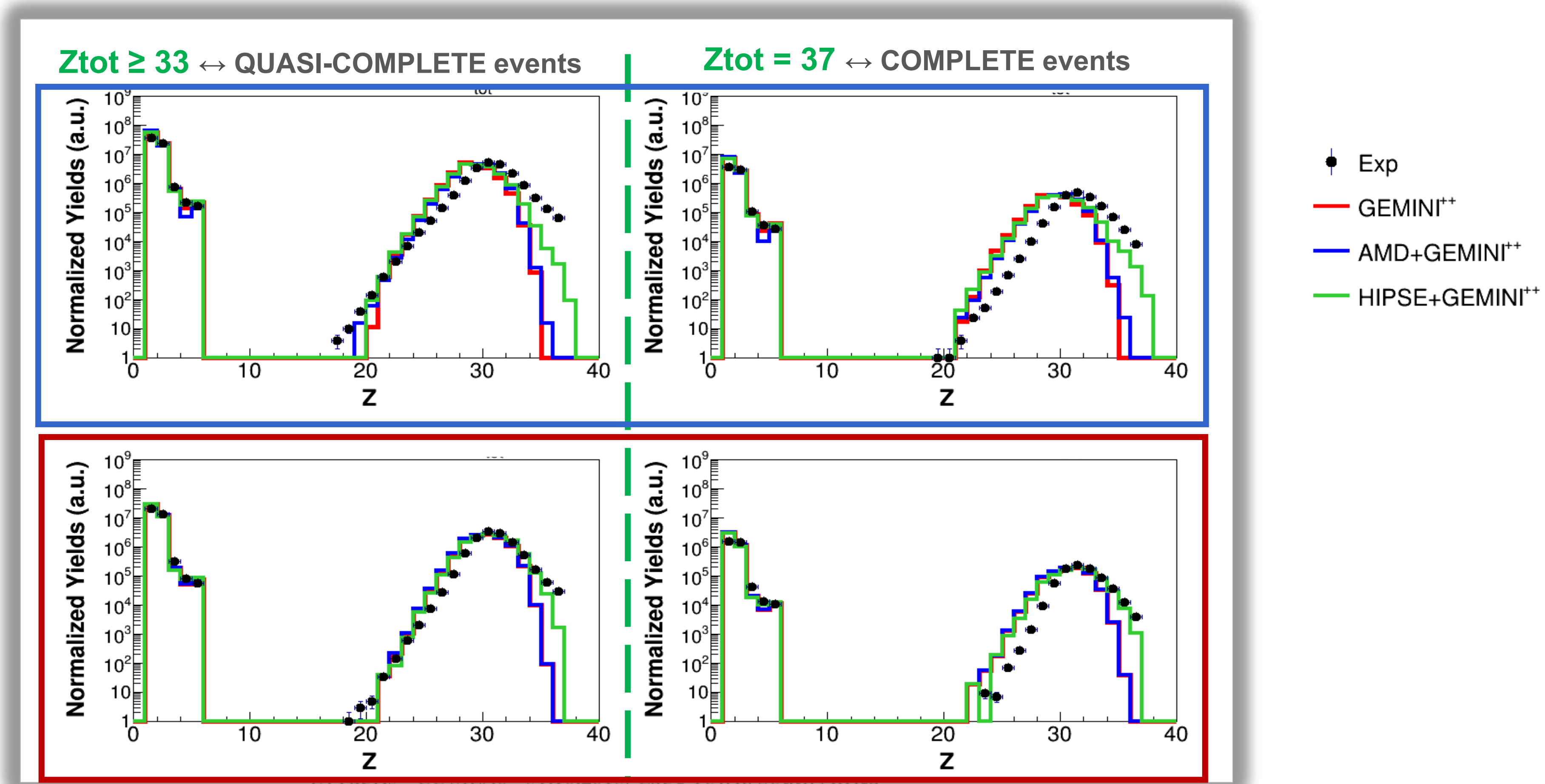
Events Selection (II)

- **Ztot ≥ 33 ↔ QUASI-COMPLETE events**
- **Ztot = 37 ↔ COMPLETE events**

Charge Distributions



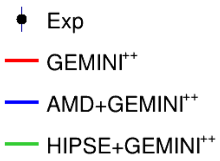
Comparison with Simulations: Z-distribution



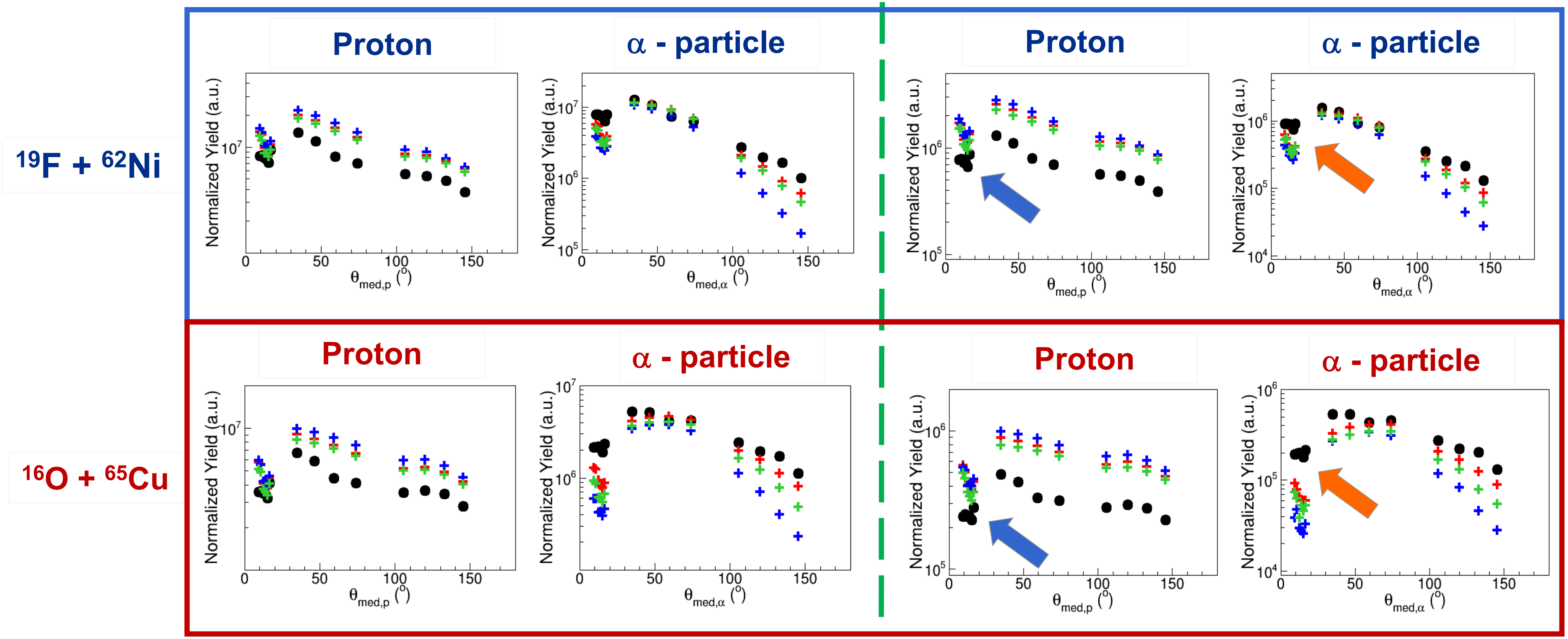
$^{19}F + ^{62}Ni$

$^{16}O + ^{65}Cu$

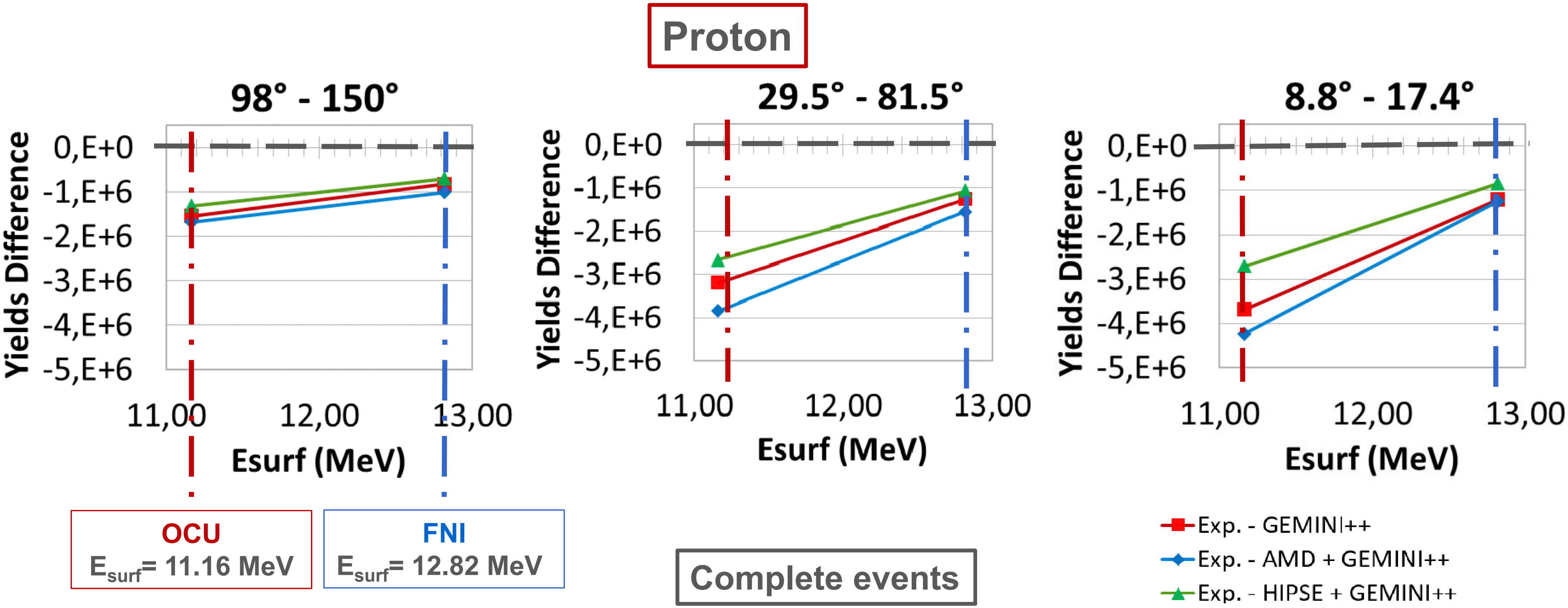
Angular Distributions vs Simulations



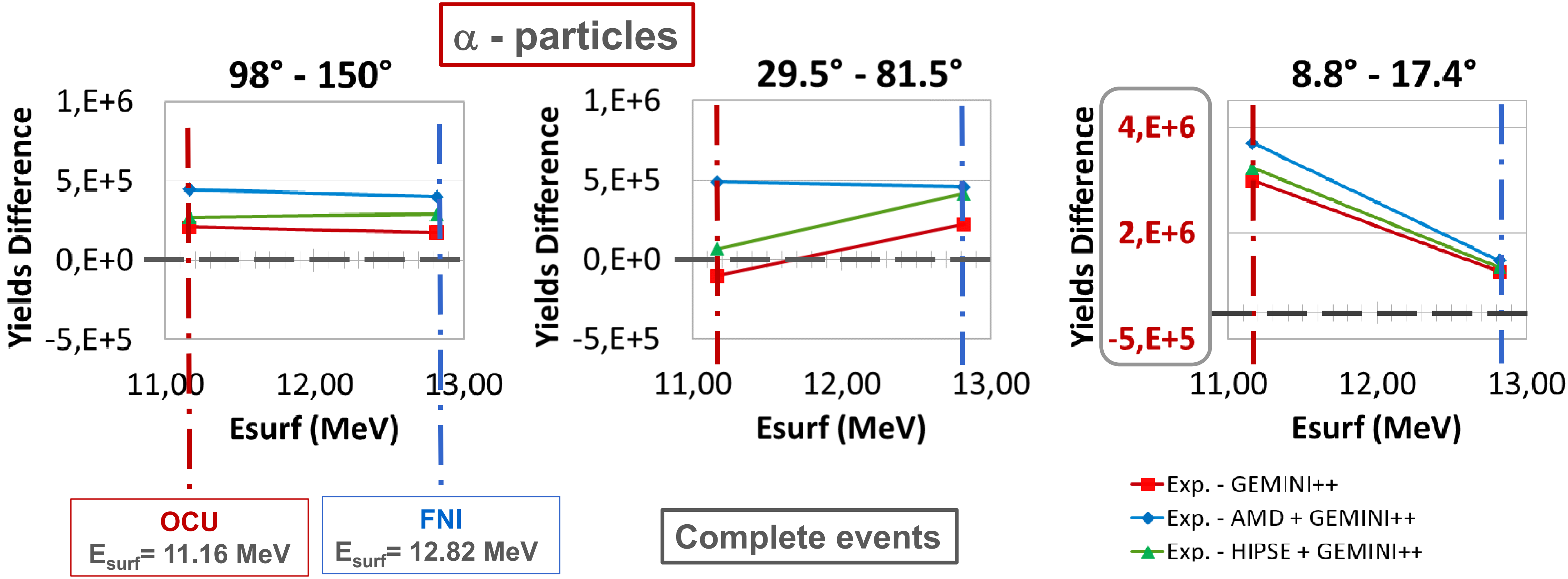
Ztot ≥ 33 ↔ QUASI-COMPLETE events | **Ztot = 37 ↔ COMPLETE events**



Angular Distributions Differences: Exp – Simulations

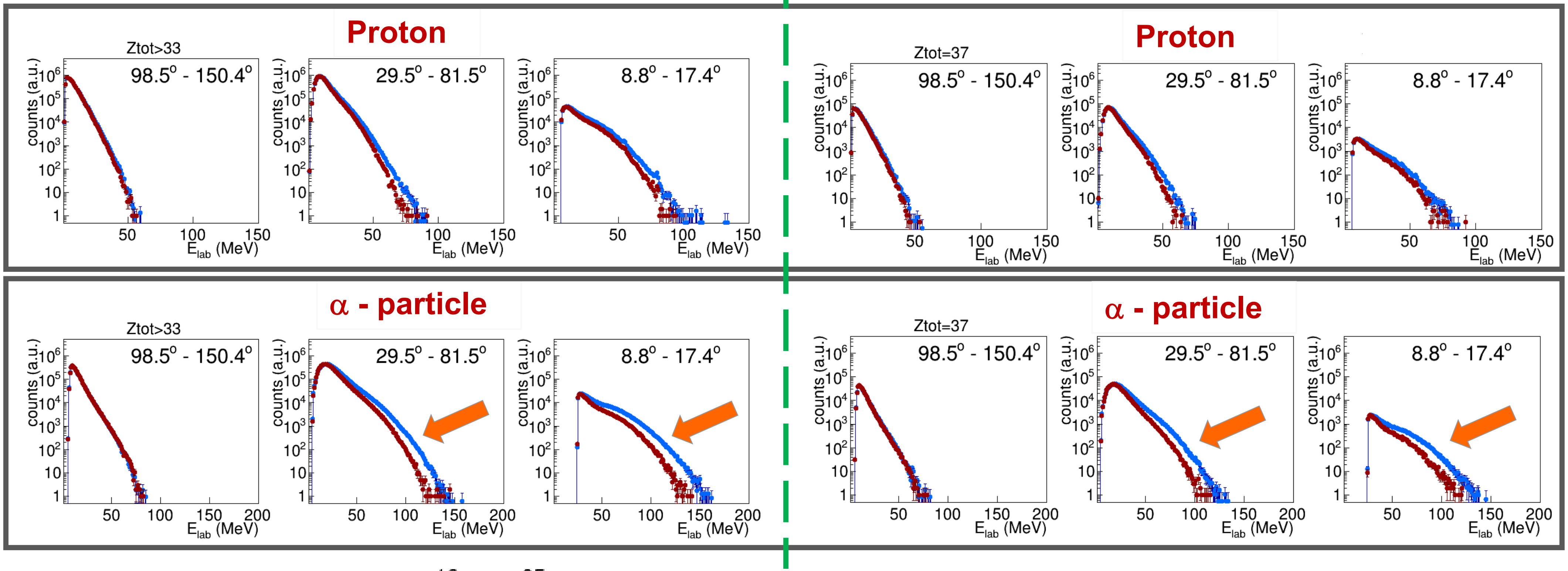


Angular Distributions Differences: Exp – Simulations



Experimental Energy spectra: FNi vs OCu

Ztot ≥ 33 ↔ QUASI-COMPLETE events | **Ztot = 37 ↔ COMPLETE events**



$^{16}O + ^{65}Cu$ @256 MeV → **E* = 209 MeV**

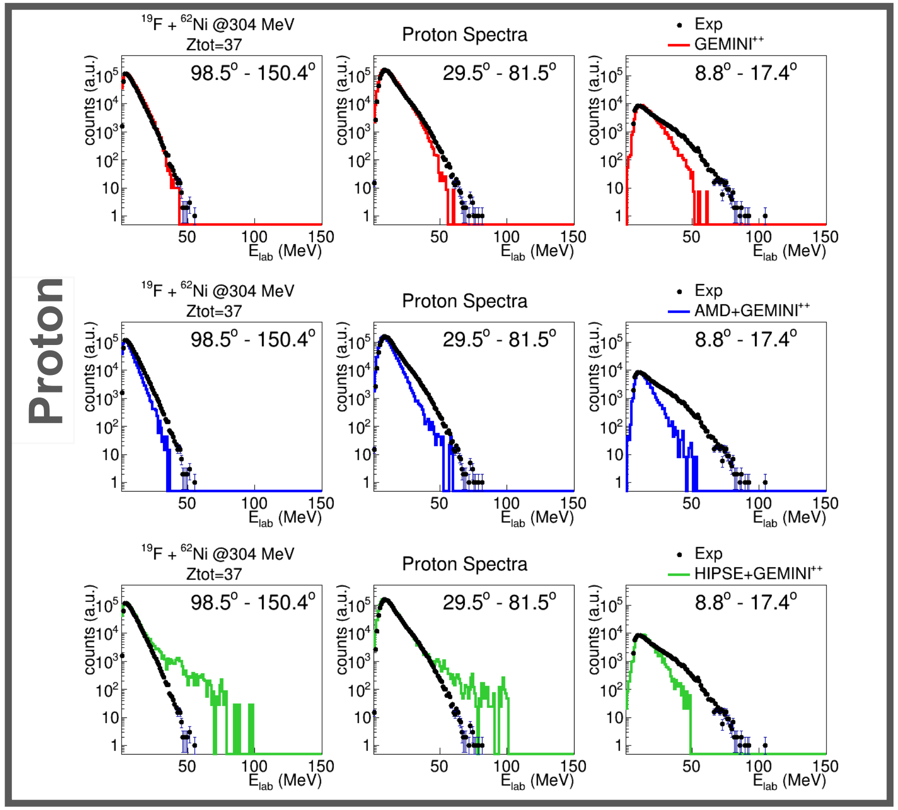
$^{19}F + ^{62}Ni$ @304 MeV → **E* = 240 MeV**

Exp
GEMINI++
AMD+GEMINI++
HIPSE+GEMINI++

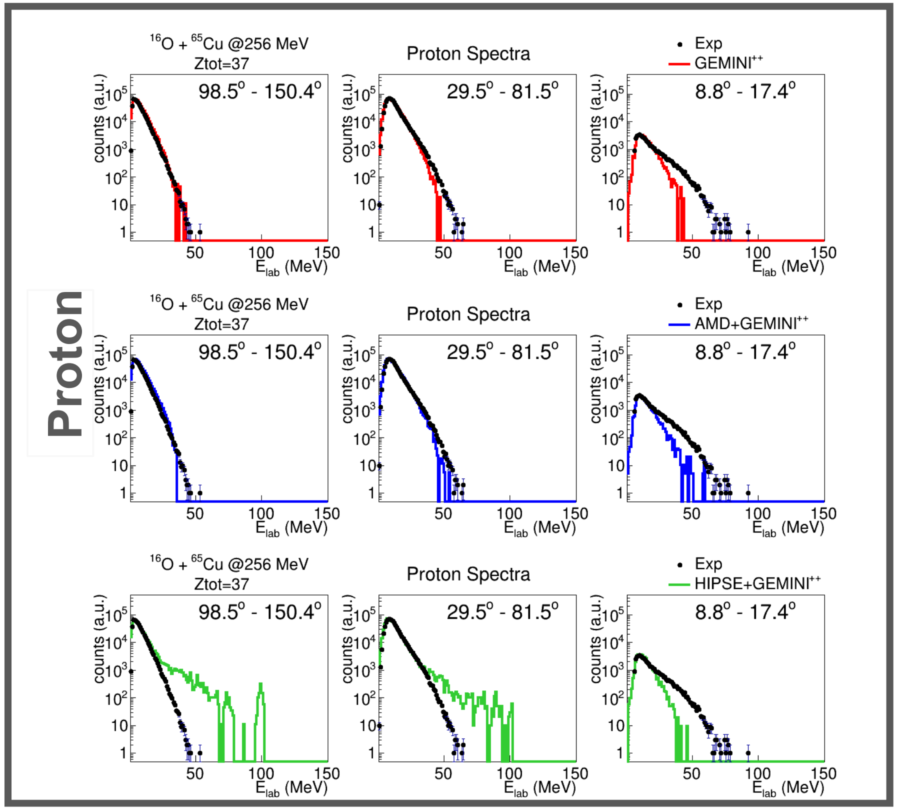
Proton Energy Spectra vs Simulations

Complete events

$^{19}F + ^{62}Ni$



$^{16}O + ^{65}Cu$

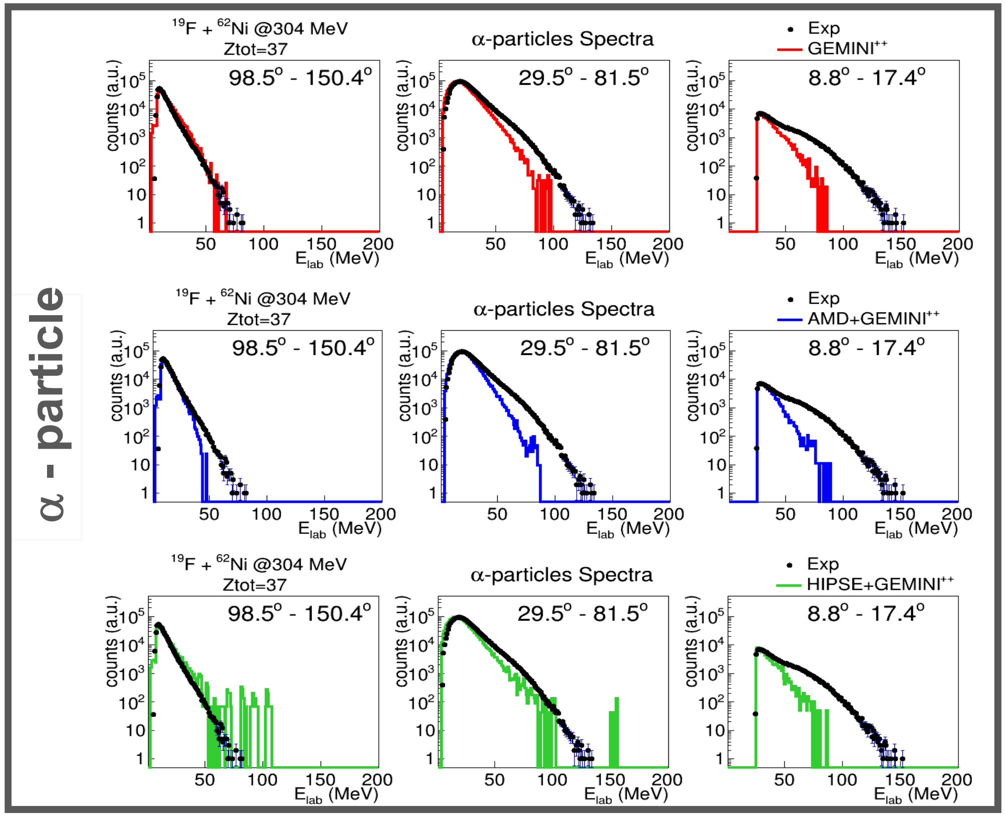


α-particles Energy Spectra vs Simulations

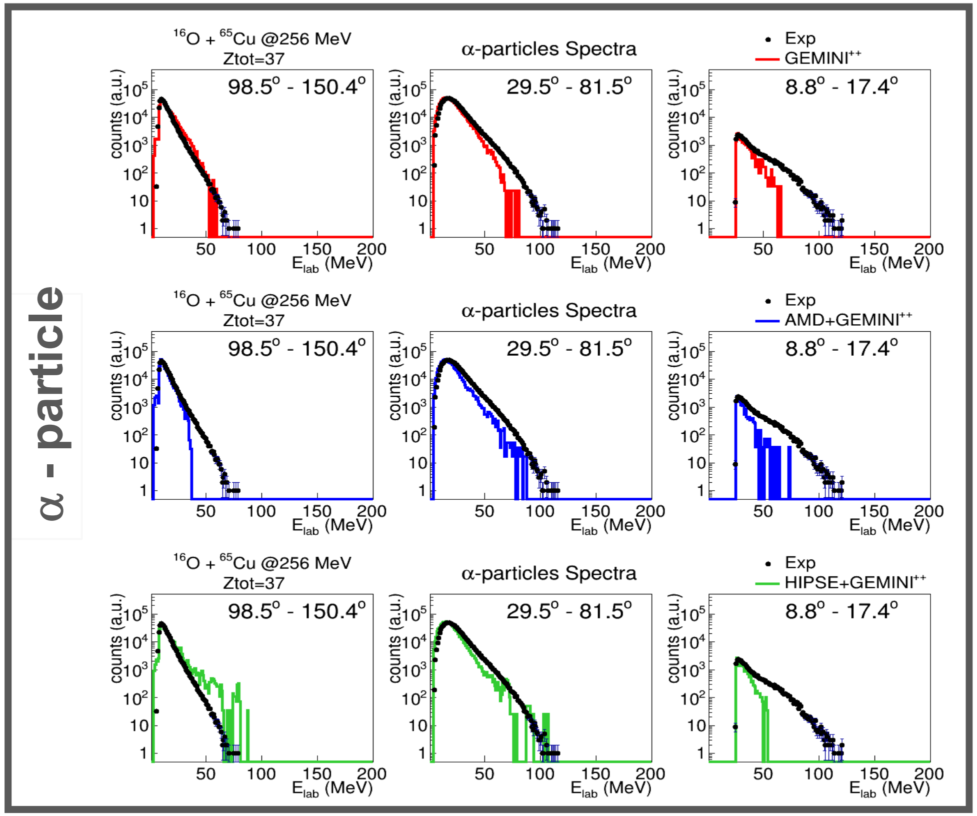
- Exp
- GEMINI++
- AMD+GEMINI++
- HIPSE+GEMINI++

Complete events

$^{19}F + ^{62}Ni$



$^{16}O + ^{65}Cu$



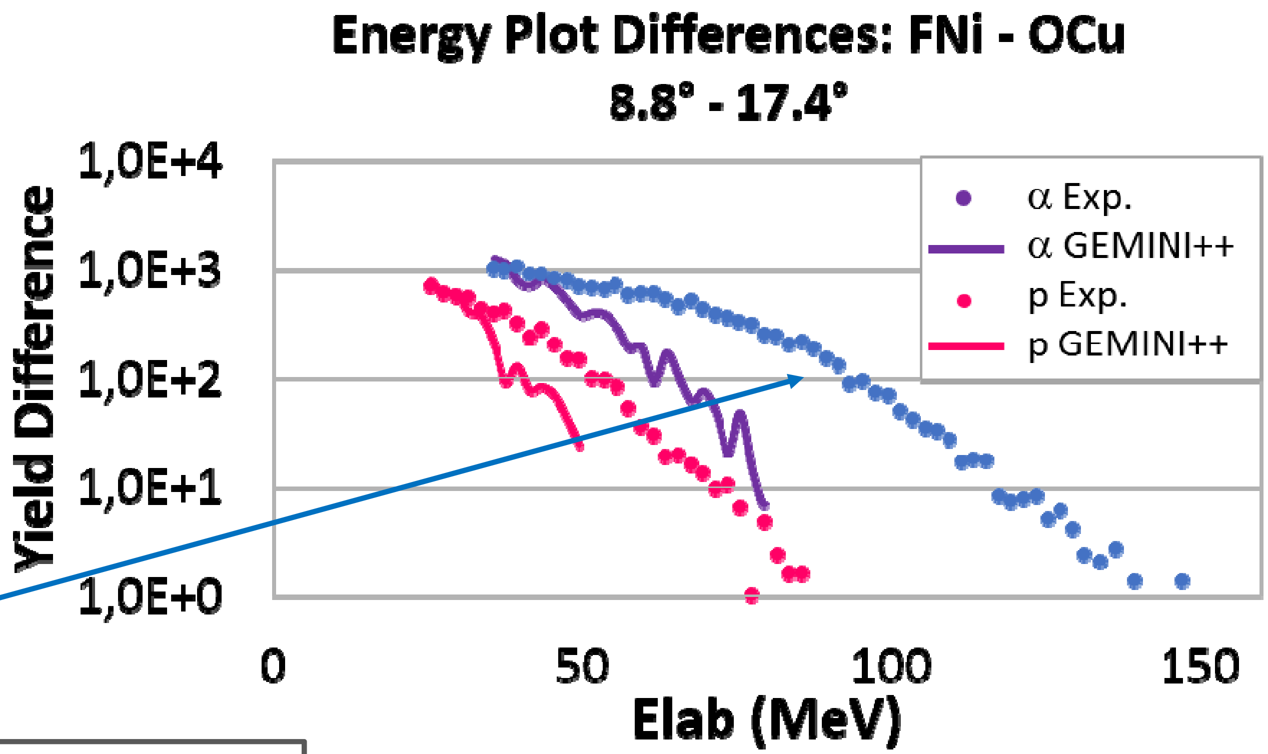
Energy spectra Difference: FNi - OCu

$^{16}O + ^{65}Cu$ @256 MeV → E* = 209 MeV
$^{19}F + ^{62}Ni$ @304 MeV → E* = 240 MeV

Simulated by GEMINI++

16 MeV/u -> same projectile velocity

$B_\alpha (^{16}O) = 7.16$ MeV
$B_\alpha (^{19}F) = 4.01$ MeV

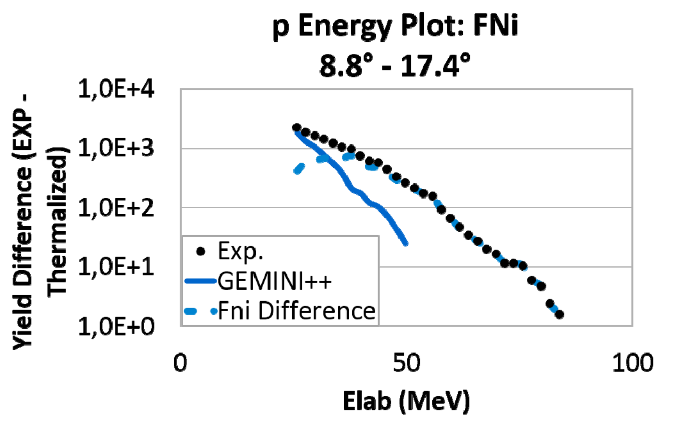


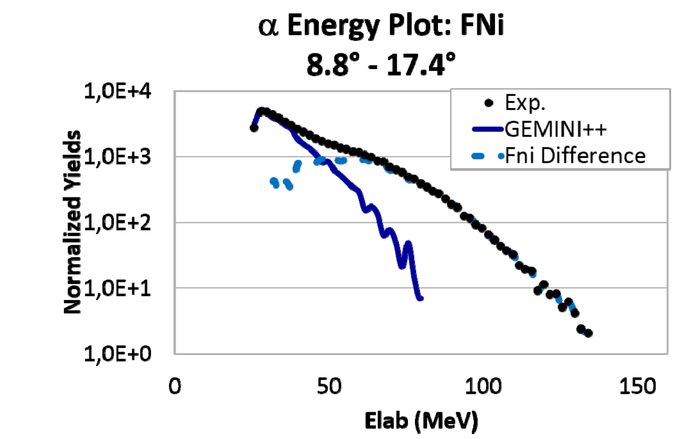
Complete events

Complete events

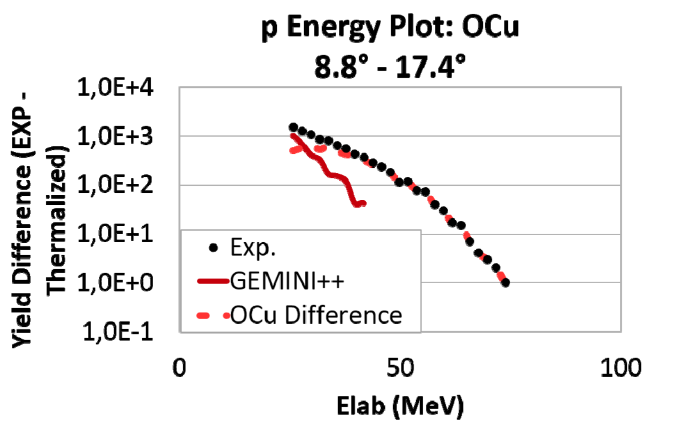
Energy Spectra vs Simulations

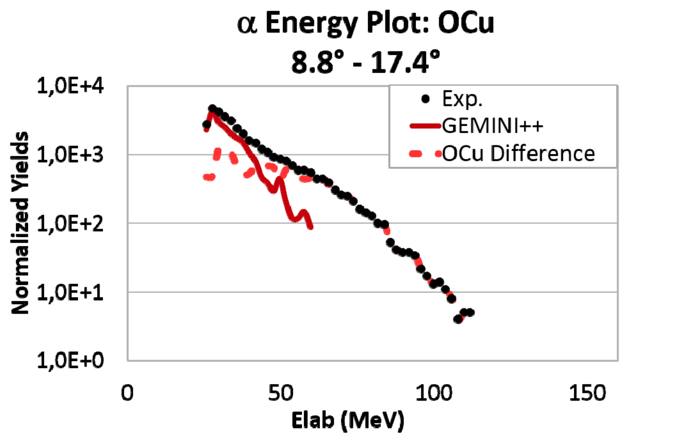
$^{19}F + ^{62}Ni$ @ 304 MeV

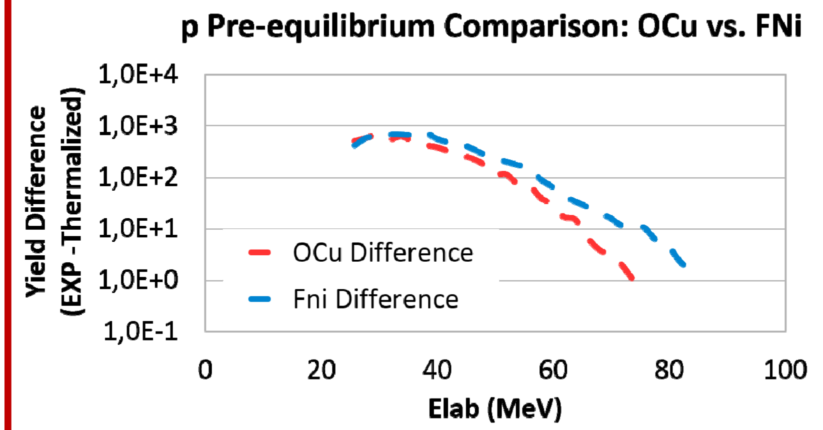


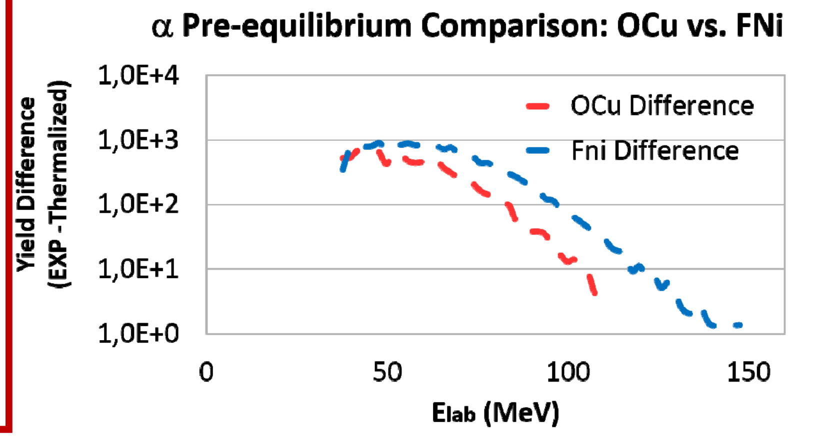


$^{16}O + ^{65}Cu$ @ 256 MeV









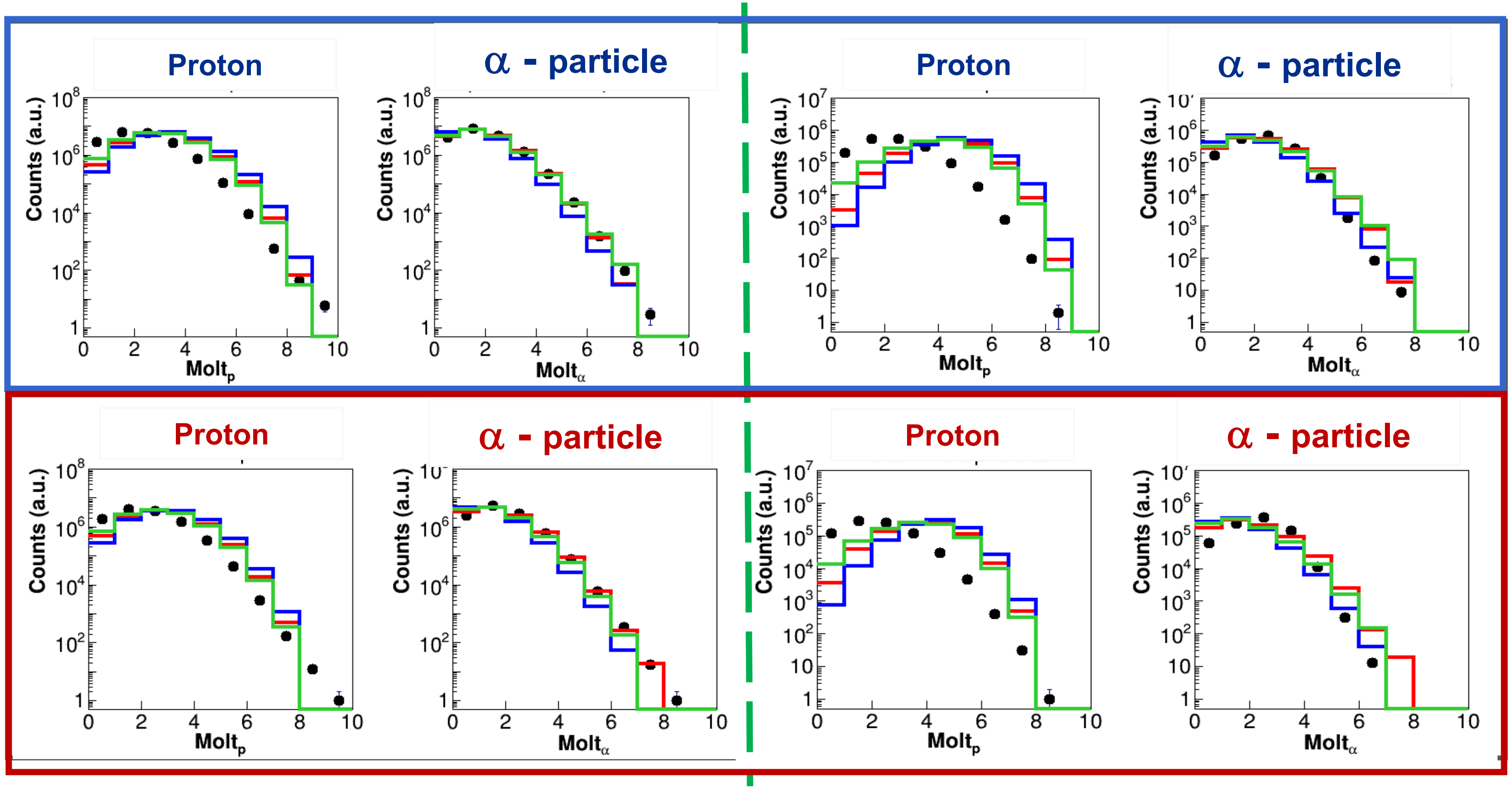
Comparison with Simulations: Proton and α Multiplicity

- Exp
- GEMINI++
- AMD+GEMINI++
- HIPSE+GEMINI++

Ztot ≥ 33 ↔ QUASI-COMPLETE events | **Ztot = 37 ↔ COMPLETE events**

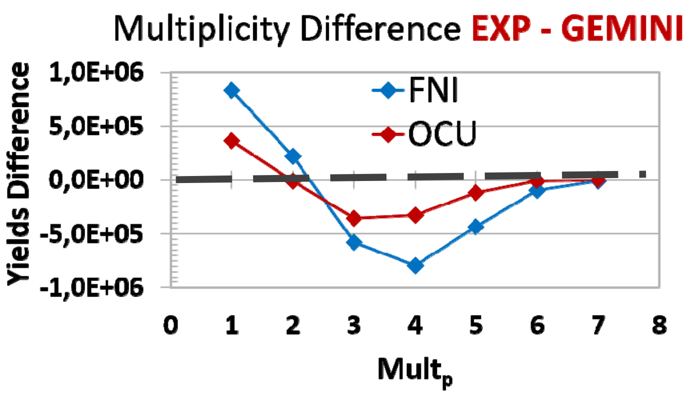
$^{19}F + ^{62}Ni$ @ 304 MeV

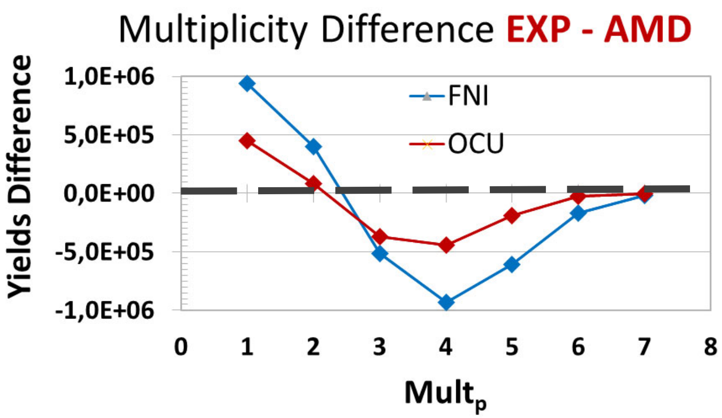
$^{16}O + ^{65}Cu$ @ 256 MeV

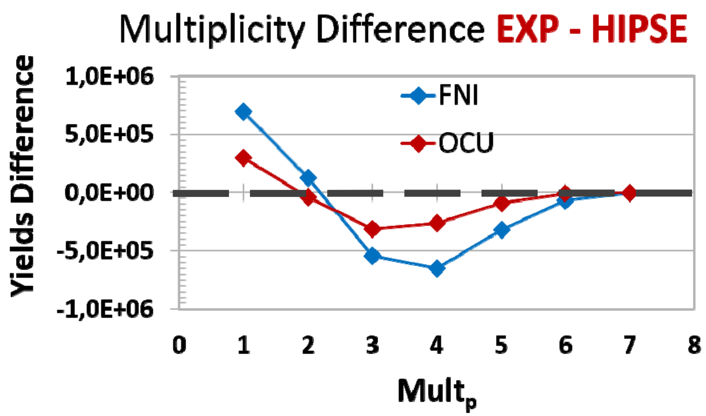


Proton Multiplicity Differences

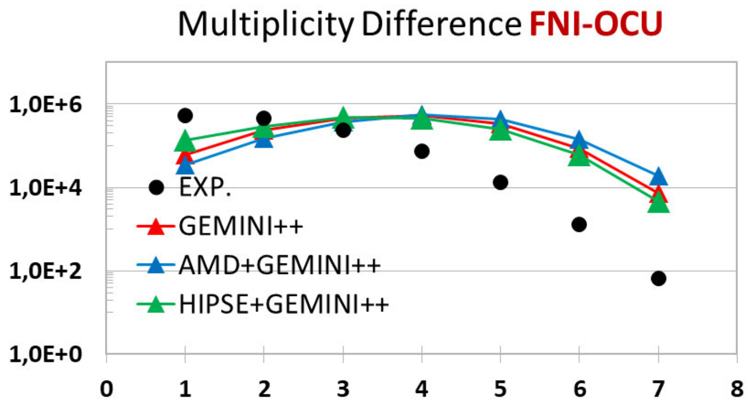
Differences with different **Simulations**







Difference between the **two systems**
FNI - OCU



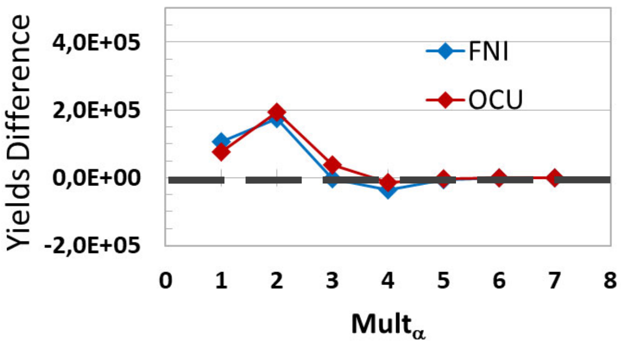
Proton

Complete events

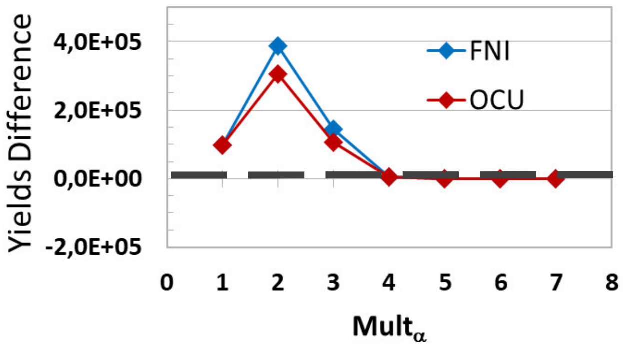
α–particles Multiplicity Differences

Differences with different **Simulations**

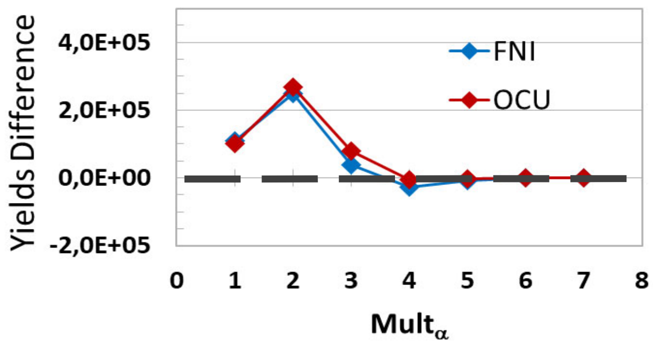
Multiplicity Difference **EXP - GEMINI**



Multiplicity Difference **EXP - AMD**



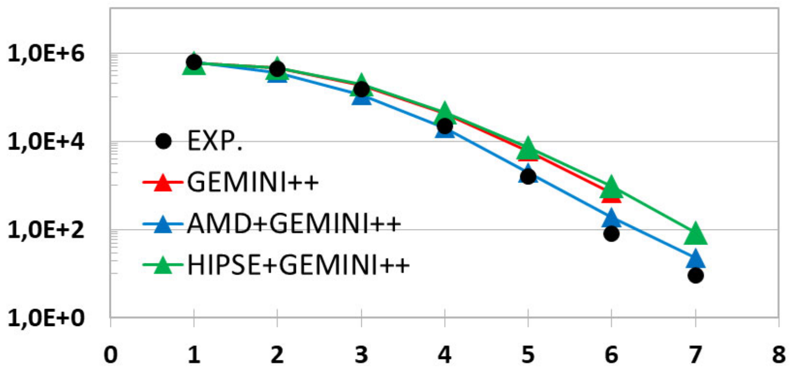
Multiplicity Difference **EXP - HIPSE**



Difference between the **two systems**

FNI - OCU

Multiplicity Difference **FNI-OCU**

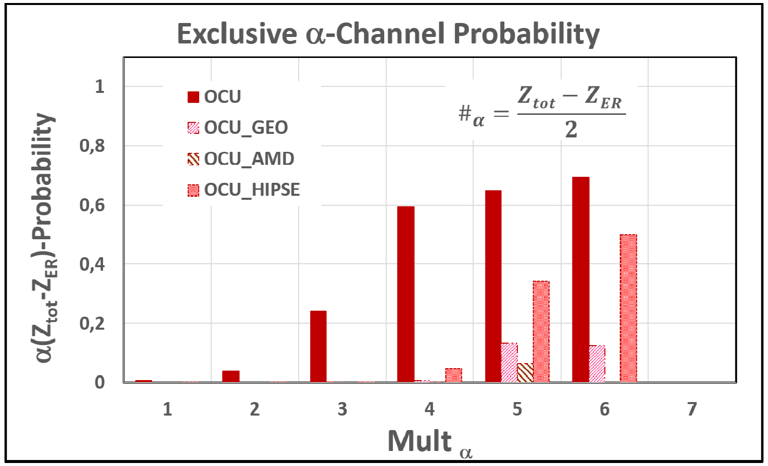


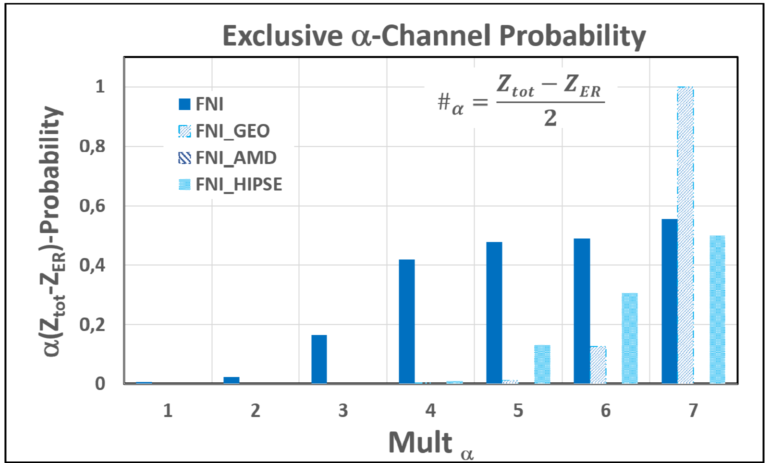
α–particles

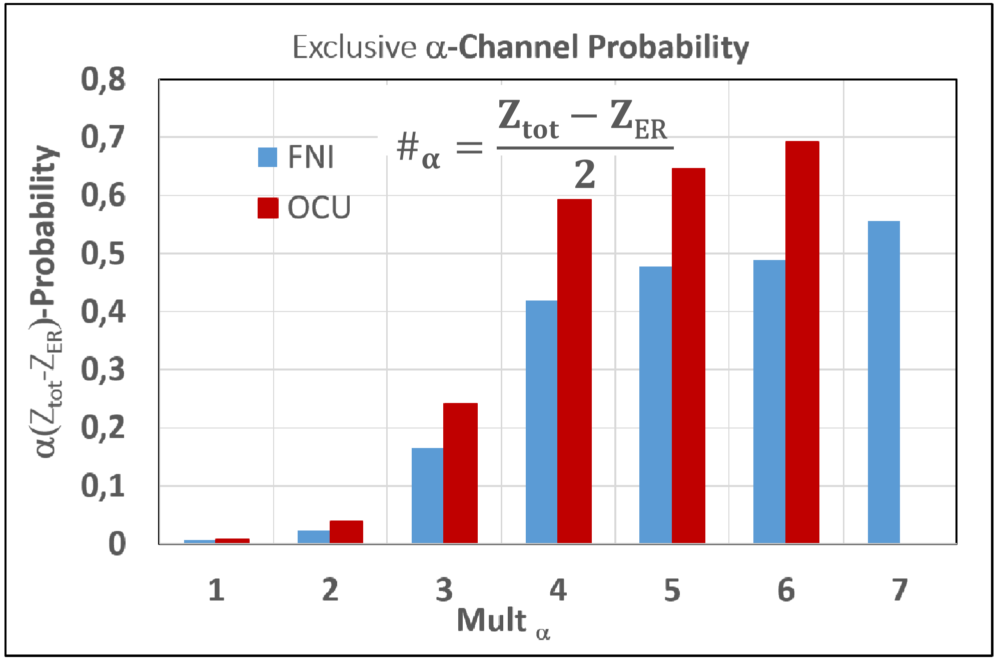
Complete events

Exclusive α-Channel Probability

Complete events





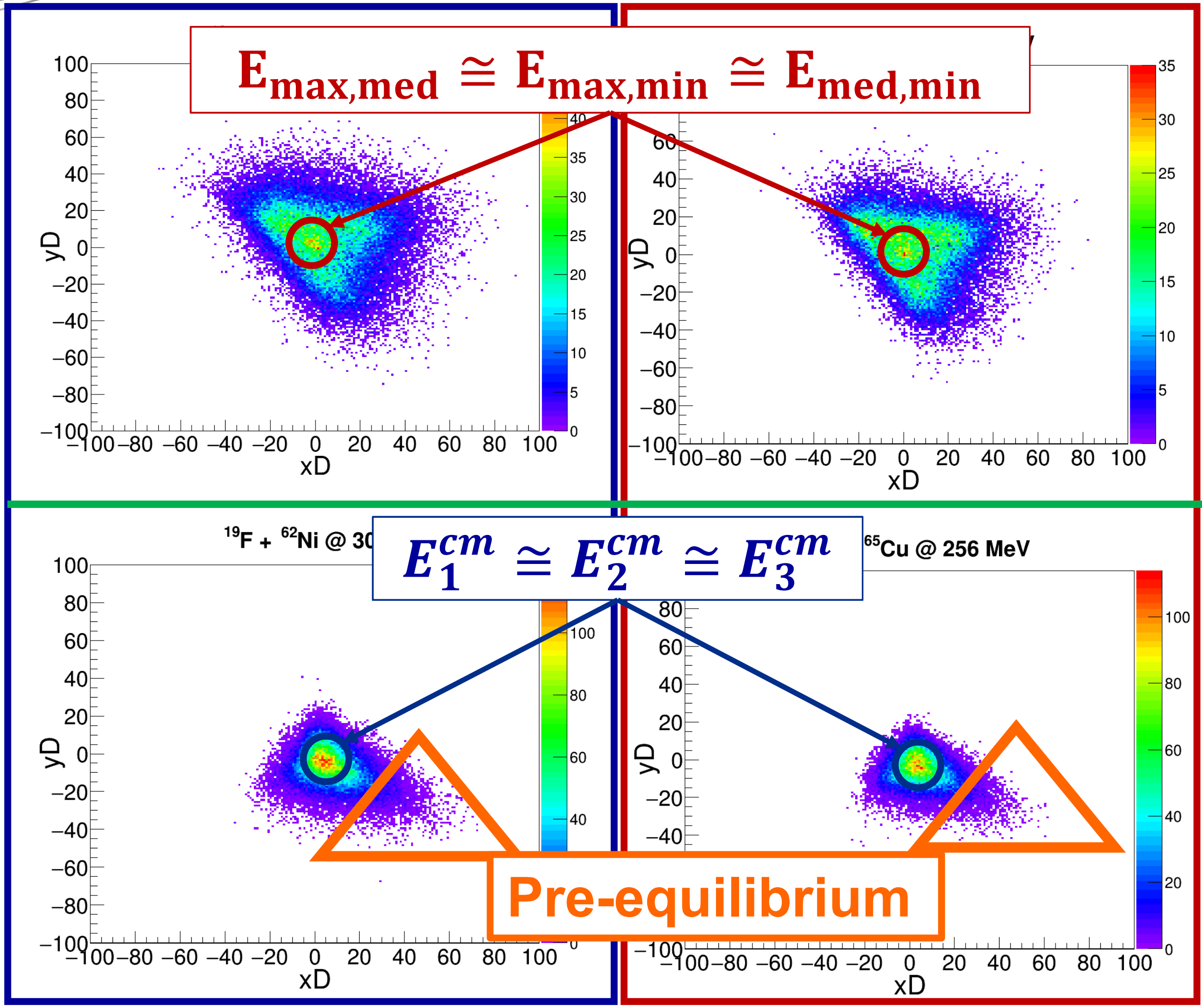


$$P = \frac{Yield\#\alpha\ pure}{Yield\#\alpha}$$

$$Z_{ER} = 37 - Mult_\alpha \times Z_\alpha$$

Dalitz Plot

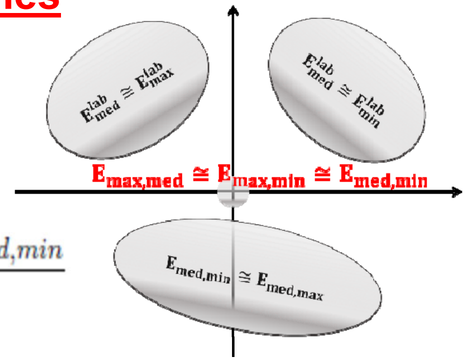
$^{19}F + ^{62}Ni$ | $^{16}O + ^{65}Cu$



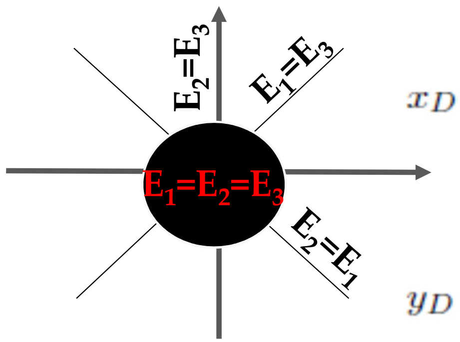
DALITZ 1: Relative Energies

$$x_D = \sqrt{3}\frac{E_{max,med} - E_{med,min}}{2}$$

$$y_D = \frac{2E_{max,min} - E_{max,med} - E_{med,min}}{2}$$



DALITZ 2: Absolute CM Energies



$$x_D = \sqrt{3}\frac{E_3^{cm} - E_2^{cm}}{2}$$

$$y_D = \frac{2E_1^{cm} - E_3^{cm} - E_2^{cm}}{2}$$

Summary

- The two reactions **$^{16}O + ^{65}Cu$** and **$^{19}F + ^{62}Ni$** have been studied at **same projectile energy** 16 MeV/u to search for clustering structure effects in the reacting partners.
- A selection events have been done to take *central collisions* with **Z_{tot}/Z_p+Z_t> 89%**
- **Complete events** (Z_{tot} = 37) have been analyzed:
  - the **$^{19}F + ^{62}Ni$** system shows an *angular distribution* **more similar** to calculations than **$^{16}O + ^{65}Cu$** ;
  - From the shape of the *Energy spectra* the **$^{19}F + ^{62}Ni$** system exibits a **larger pre-equilibrium** component with respect to **$^{16}O + ^{65}Cu$**, especially for **'pure' α channel** → **possible projectile α-cluster effects ???**
  - **Pure alpha decay channel** are **predominant** and **not** reproduced by the simulations for the two systems. The **$^{16}O + ^{65}Cu$** case shows a **larger probability** than **$^{19}F + ^{62}Ni$** for such channels.
  - Selected **exclusive 3 alpha decay channel** shows a predominance of **equal** **Relative Energy** α particles (Dalitz 1) and **equal** **CM Energy** α particle (Dalitz 2).
  - **Asymmetric Dalitz 2** plot is observed with a certain number of events with an elongate right bottom corner (E_3 max) → which may indicate the presence of **Fast particle emission** from **pre-equilibrium mechanis** even in this specific decay channel.

Outlook

- AMD and HIPSE new calculations with different input parameters
- Study of different exclusive decay channels

NUCL-EX Collaboration

D. Fabris[1], F. Gramegna[2], M. Cicerchia[2,11], V.L. Kravchuk[4], T. Marchi[2], S. Barlini[6], S. Piantelli[6], M. Bini[6], M. Bruno[5], G. Casini[6], M.Cinausero[2], M. D'Agostino[5], M. Degerlier[3], N. Gelli[6], G. Mantovani[2,11], L. Morelli[5] , A. Olmi[6], P. Ottanelli[6], G. Pasquali[6], G. Poggi[6], S. Valdrè[6], O.V. Fotina[7], J. Mabiala[10], C. Frosin[6], A. Camaiani[6], I. Lombardo[12]

[1] *INFN sezione di Padova, Padova, Italy*
[2] *Laboratori Nazionali di Legnaro, Legnaro (PD), Italy*
[3] *University of Nevsehir, Science and Art Faculty, Physics Department, Nevsehir, Turkey*
[4] *National Research Center "Kurchatov Institute", Moscow, Russia*
[5] *Dipartimento di Fisica, Universita' di Bologna and INFN sezione di Bologna, Bologna, Italy*
[6] *Dipartimento di Fisica, Universita' di Firenze and INFN sezione di Firenze, Firenze, Italy*
[7] *Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia*
[8] *Dipartimento di Scienze Fisiche, Università di Napoli "Federico II", Napoli, Italy*
[9] *Laboratori Nazionali del Sud, Catania, Italy*
[10] *Prairie View A&M University, Houston, Texas, USA*
[11] *Dipartimento di Fisica e Astronomia, Università di Padova, Padova, Italy*
[12] *INFN Sezione di Catania, Catania, Italy*

Akira Ono - *Department of Physics, Tohoku University, Sendai, Japan* -> AMD
Davide Mancusi – *CEA Saclay, France* -> Gemini++
Denis Lacroix – *IPN Orsay, France* -> HIPSE