Comparative study of 4 reactions at onset of pre-equilibrium

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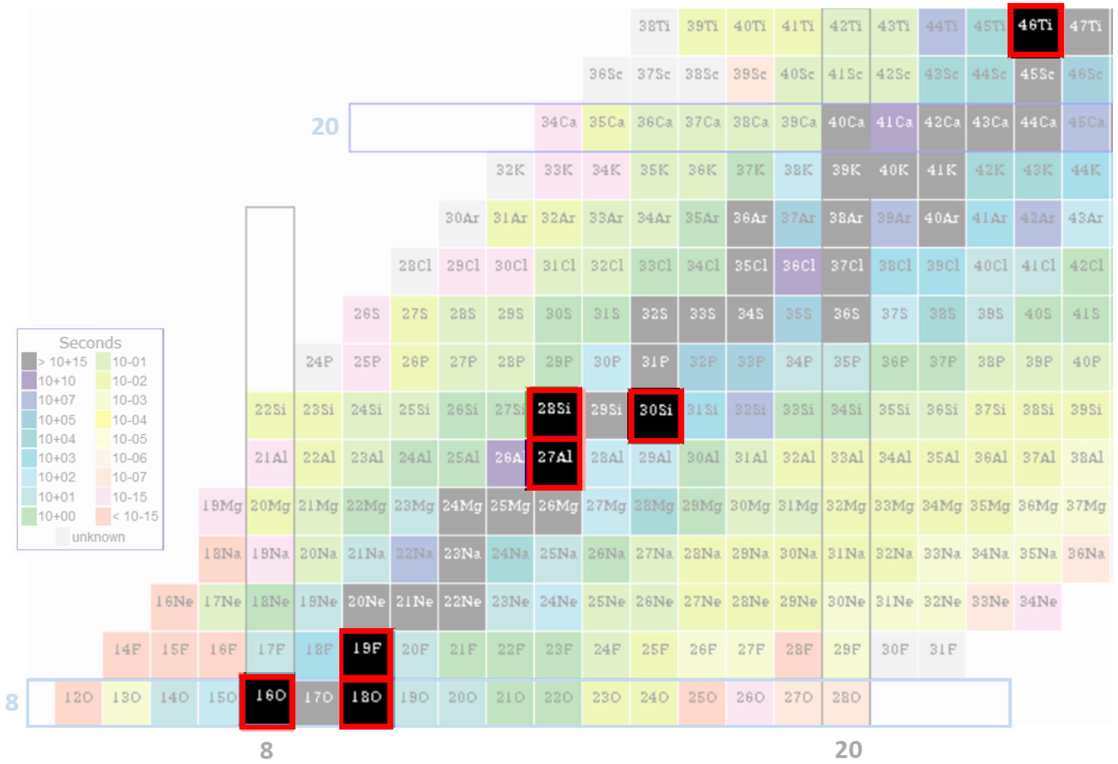
on behalf of NUCL-EX Collaboration



OUTLINE:

- Scientific motivation
- The experiment
- Analysis results:
  - Same beam velocity;
  - Same CN excitation energy.

Scientific Motivation

dissipation

- ELASTIC (or **EXCLUSIVE**) **BREAKUP**:

$$a + A \longrightarrow b + x + A_{gs}, where\ a = b + x$$

- NON-ELASTIC (or INCLUSIVE) BREAKUP:
  - **INELASTIC BREAKUP**:

$$a + A \longrightarrow b + x + A^{*}$$
$$a + A \longrightarrow b^{*} + x + A_{gs}$$

  - **PARTICLE TRANSFER**:

$$a + A \longrightarrow b + B, where\ B \equiv A + x \equiv bound\ system$$

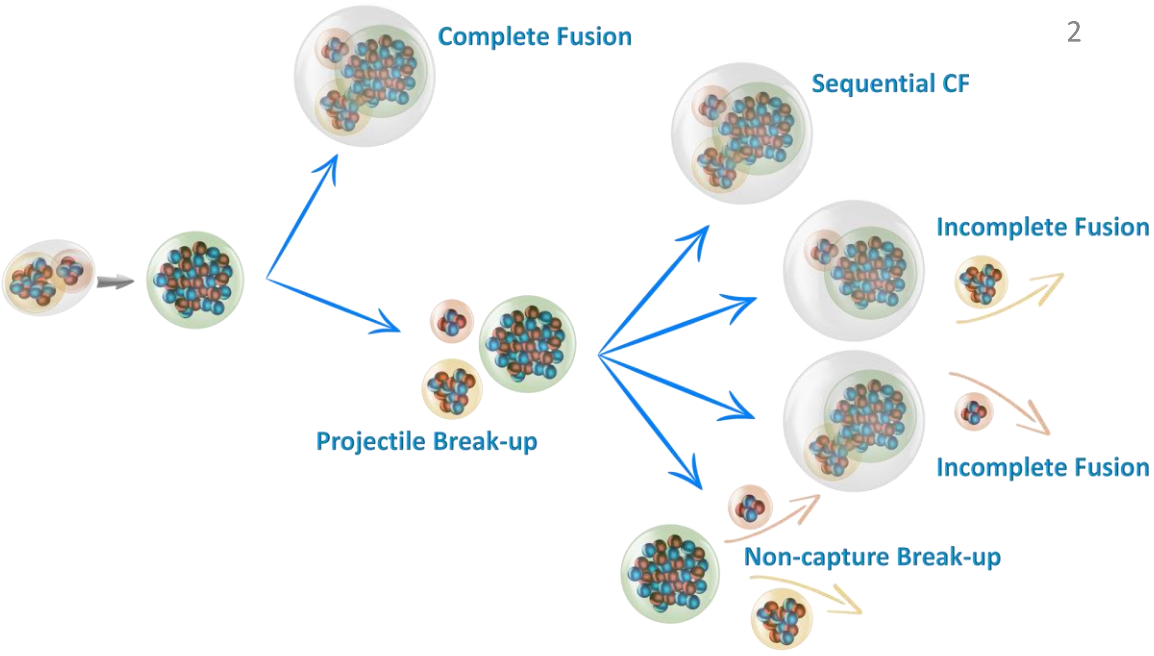
  - **INCOMPLETE FUSION:**

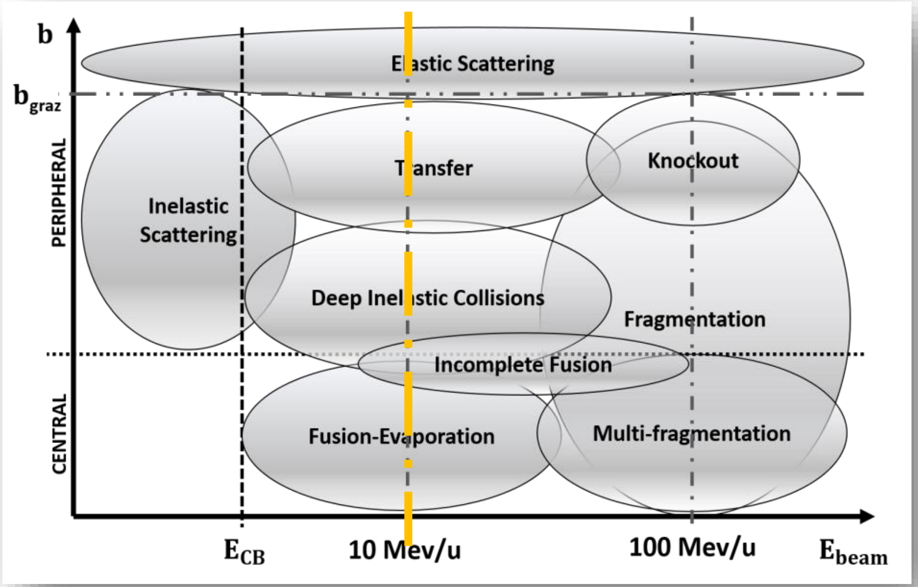
$$a + A \longrightarrow b + C, where\ C \Longrightarrow decay\ emitting\ \gamma\ or\ particles$$

- **COMPLETE FUSION**:

$$a + A \longrightarrow CN \Longrightarrow decay\ emitting\ \gamma\ or\ particles$$

$$a + A \longrightarrow preequilibrium\ particles + ICN \Longrightarrow decay\ emitting\ \gamma\ or\ particles$$





J. Cabrera, Phys. Rev. C 68 (2003) 034613-1. - - - X. Campi et al., Phys. Lett. B 142 (1984) 8. --- J. Pouliot et al., Phys. Lett. B 299 (1993) 210. --- W. D. M. Rae et al., Phys. Rev. C 30 (1984) 158.

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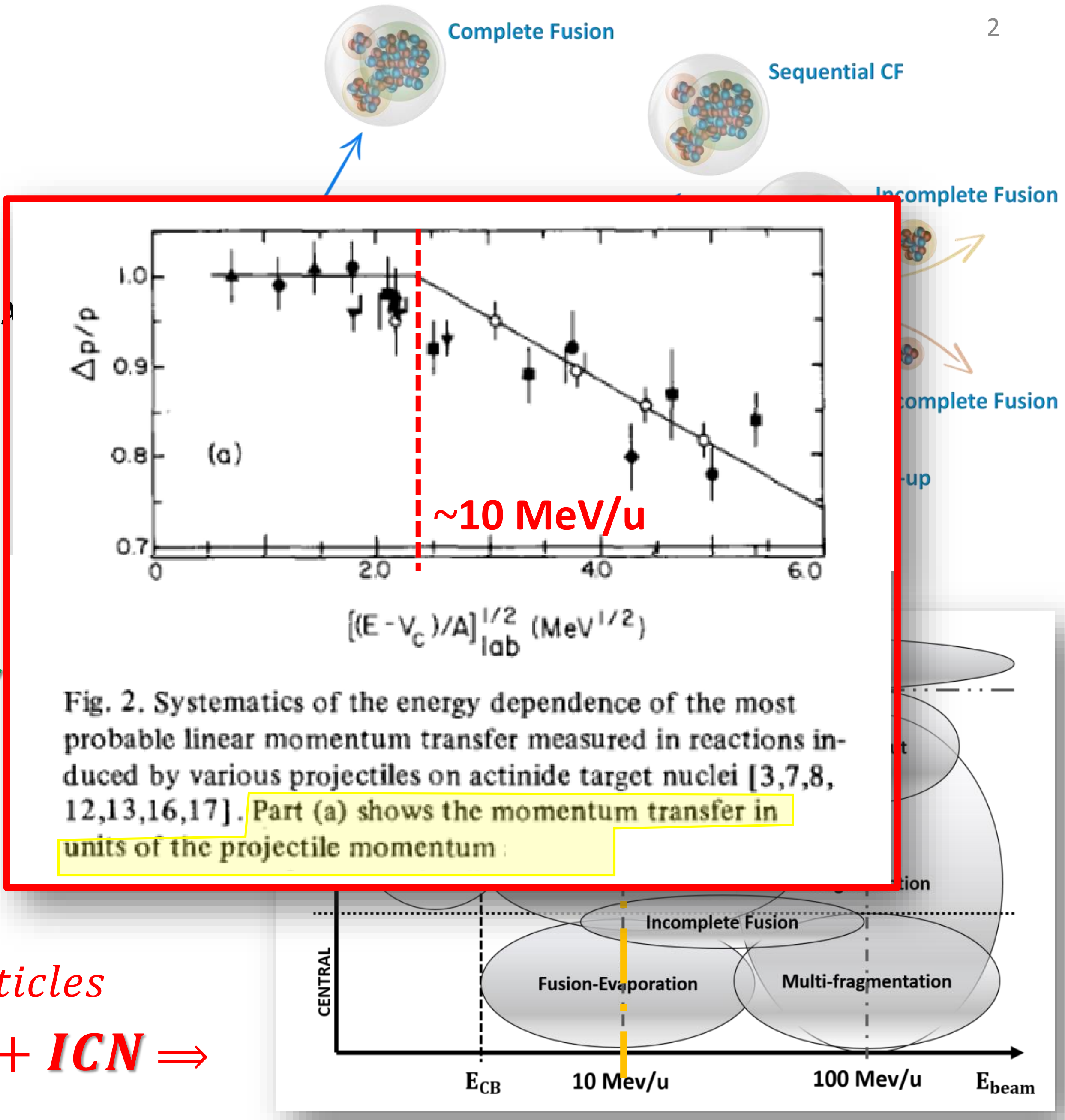

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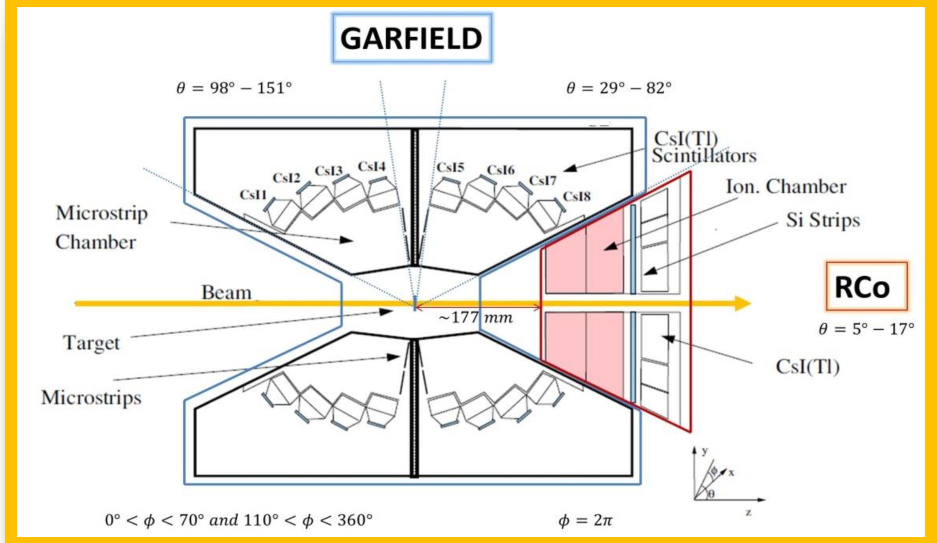
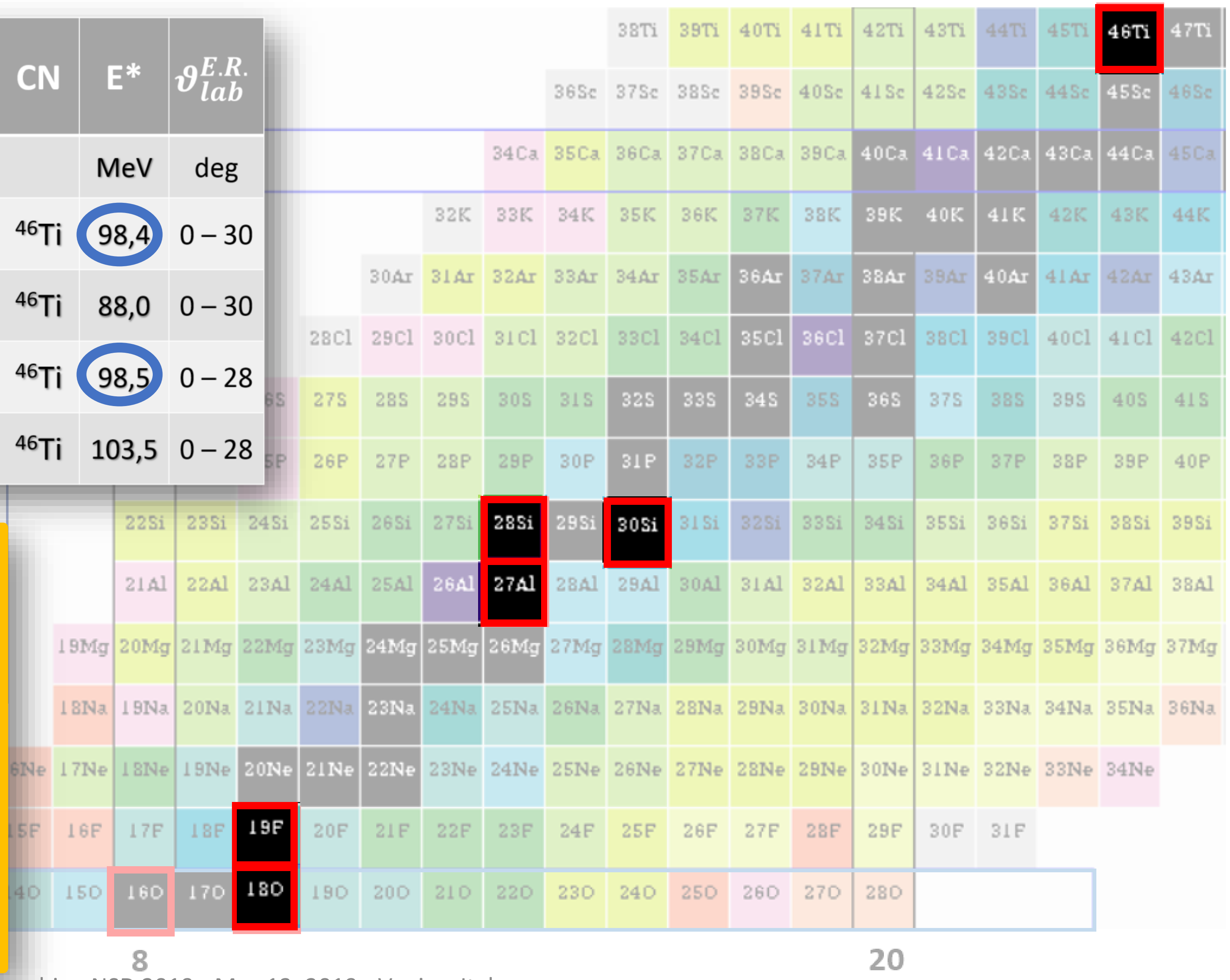
ACLUST2 experiment

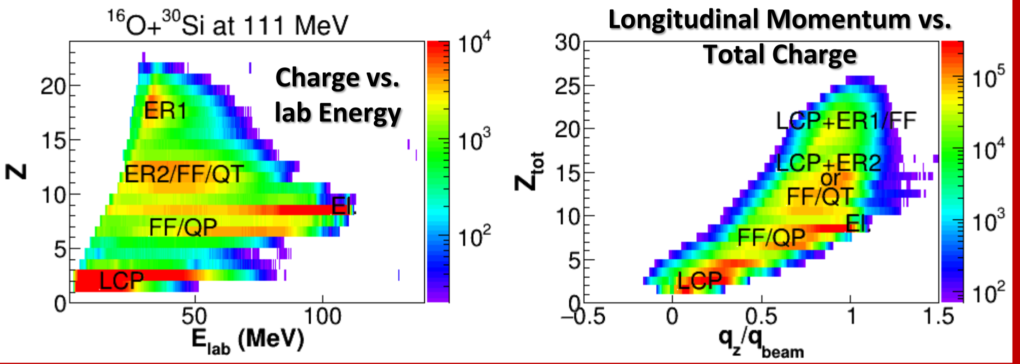
Entrance channel	$E_{beam,\,lab}$		v_{lab}	η	ϑ_{graz}	σ_{fus}	CN	E*	$\vartheta_{lab}^{E.R.}$
Beam + Target	MeV	MeV/u	cm/ns		deg	mb		MeV	deg
$^{16}O + ^{30}Si$	128	8	1,37	0,30	8,8	1070	^{46}Ti	98,4	0 – 30
$^{16}O + ^{30}Si$	111	7	1,28	0,30	10,1	1081	^{46}Ti	88,0	0 – 30
$^{18}O + ^{28}Si$	126	7	1,44	0,22	9,0	1110	^{46}Ti	98,5	0 – 28
$^{19}F + ^{27}Al$	133	7	1,52	0,17	8,9	1100	^{46}Ti	103,5	0 – 28



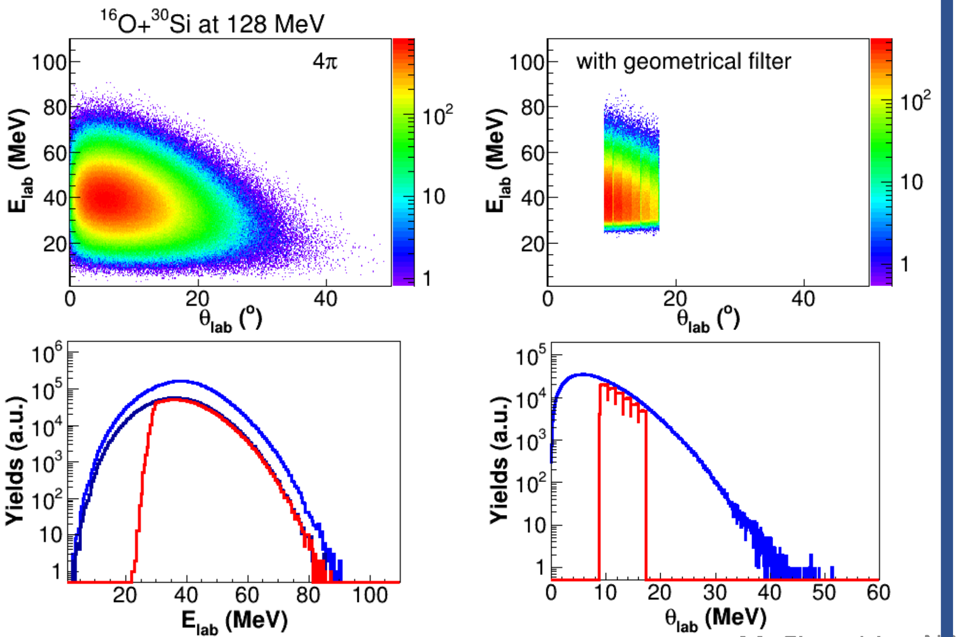


ACLUST2 data selection

Experimental Data: TOTAL EVENTS



Simulated Data: RESIDUES



- **TARGET CONTAMINATION**

  $\sim$**50%** ^{A}O in **Si**-target

  $\sim$**30%** ^{A}O in **Al**-target

- **COMPLETE EVENTS SELECTION**

$$Z^{tot}_{detected} = Z_{proj} + Z_{Targ} = 22$$

uncontaminated events **0.8%** of the total events

- **COMPARISON with MODELS**

Statistical (**GEMINI^{++}**) & Dynamical (AMD & HIPSE) codes

Simulated events are:

- **filtered** with a software replica of the experimental setup;
- selected in the same way of the experimental data.

RESULTS for the 3 reactions @ 7 AMeV

$^{16}O+^{30}Si$ @ 7 MeV/u (η=0.30; E^*_{CN}=88.0 MeV)
$^{18}O+^{28}Si$ @ 7 MeV/u (η=0.22; E^*_{CN}=95.5 MeV)
$^{19}F+^{27}Al$ @ 7 MeV/u (η=0.17; E^*_{CN}=103.5 MeV)

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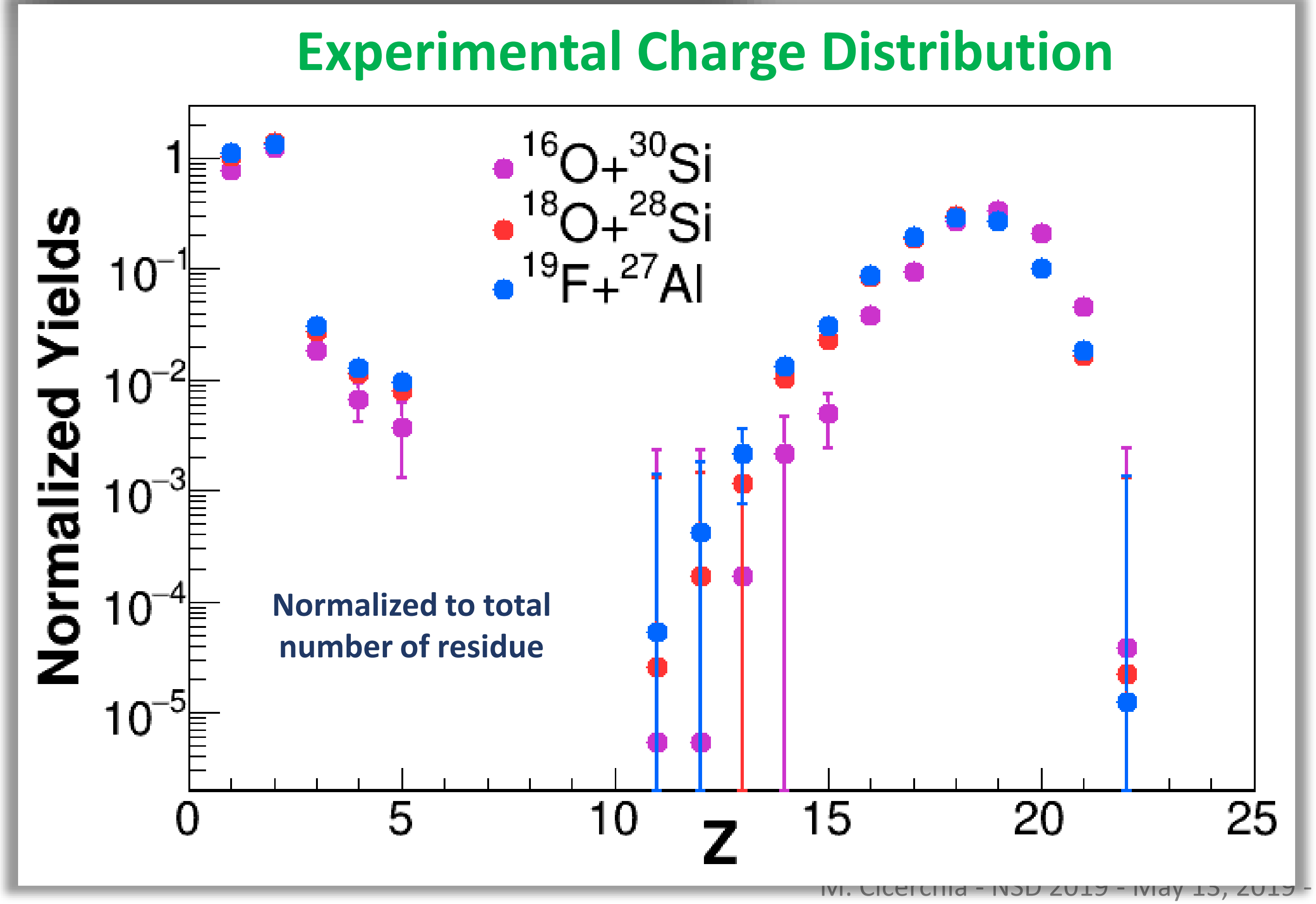

Percentage of each residue respect total number of residues

RESIDUE	^{16}O EXP	^{16}O G^{++}	^{18}O EXP	^{18}O G^{++}	^{19}F EXP	^{19}F G^{++}
Al	0,2%	0,06%	1,1%	0,4%	2%	0,8%
Si	0,7%	0,9%	3%	2%	4%	3%
P	4%	3%	11%	6%	12%	9%
S	13%	10%	27%	20%	28%	25%
Cl	36%	27%	49%	44%	48%	50%
Ar	61%	65%	58%	65%	55%	62%
K	55%	68%	38%	49%	37%	40%
Ca	**25%**	**23%**	**12%**	**13%**	**12%**	**10%**
Sc	5%	2%	2%	0,7%	2%	0,4%

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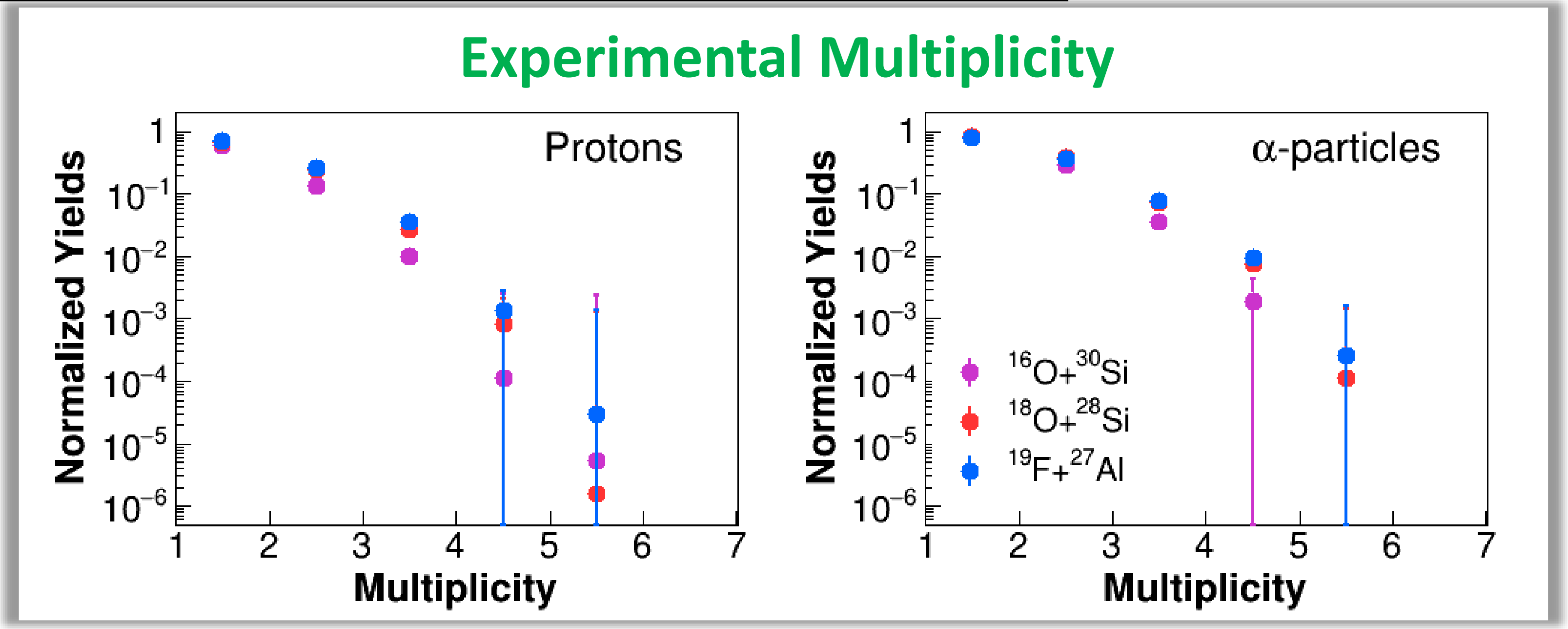

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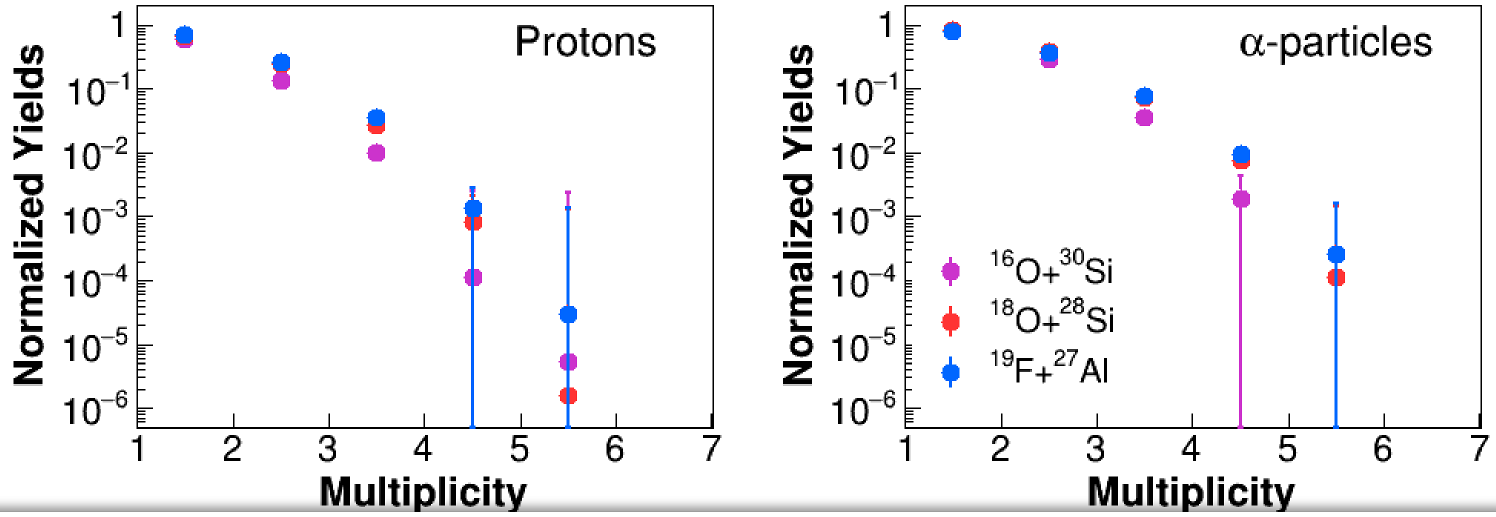
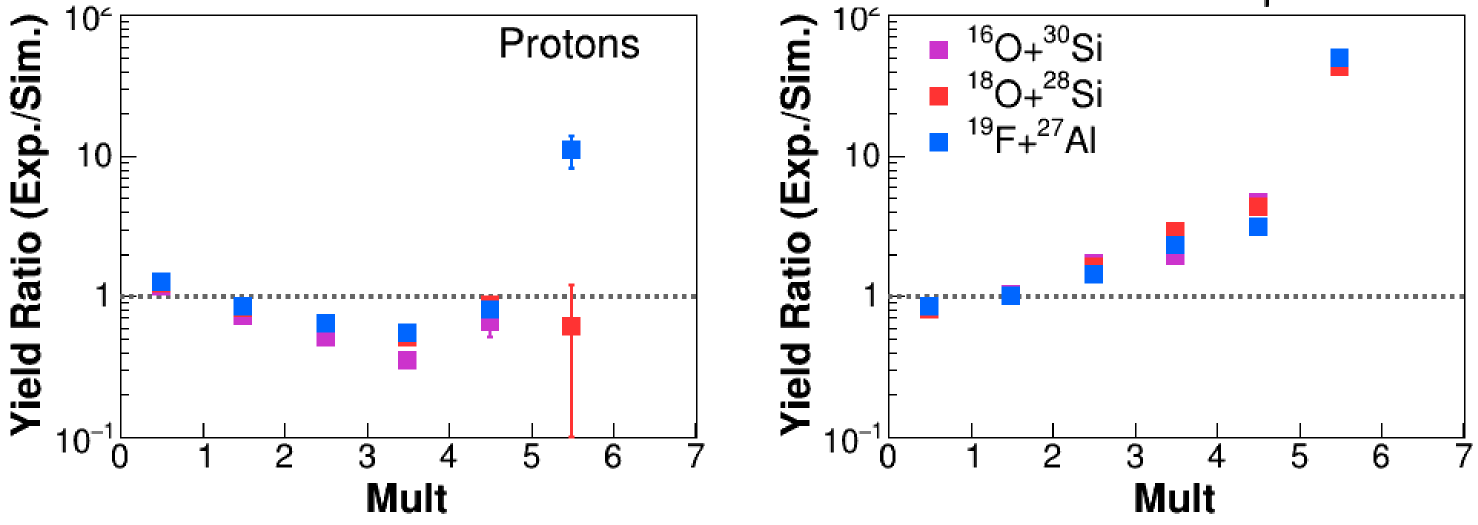
Experimental Multiplicity



RATIO (EXP/G++) of Yields vs. Multiplicity



p-α complementary behavior in agreement with found Branching Ratios in exclusive channels

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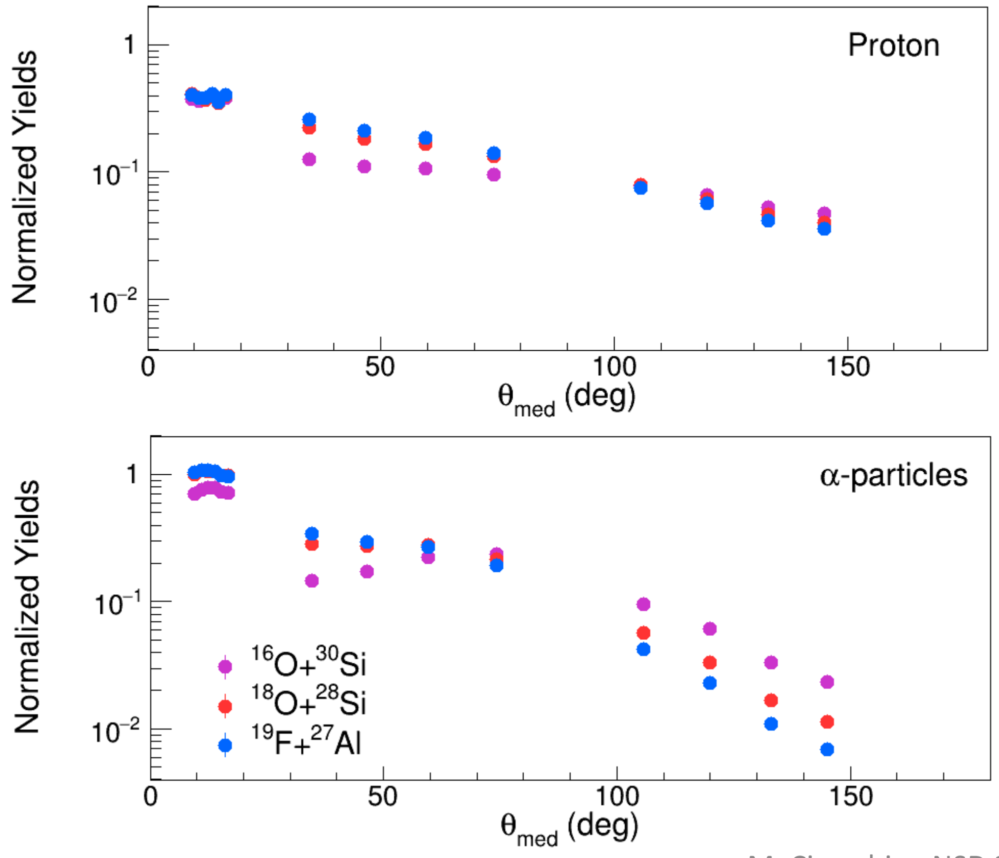
Experimental Angular Distribution



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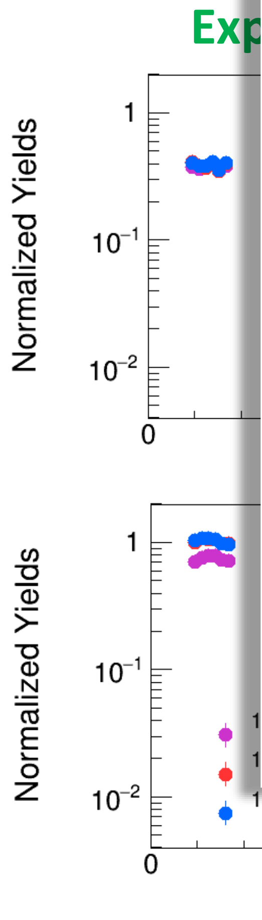

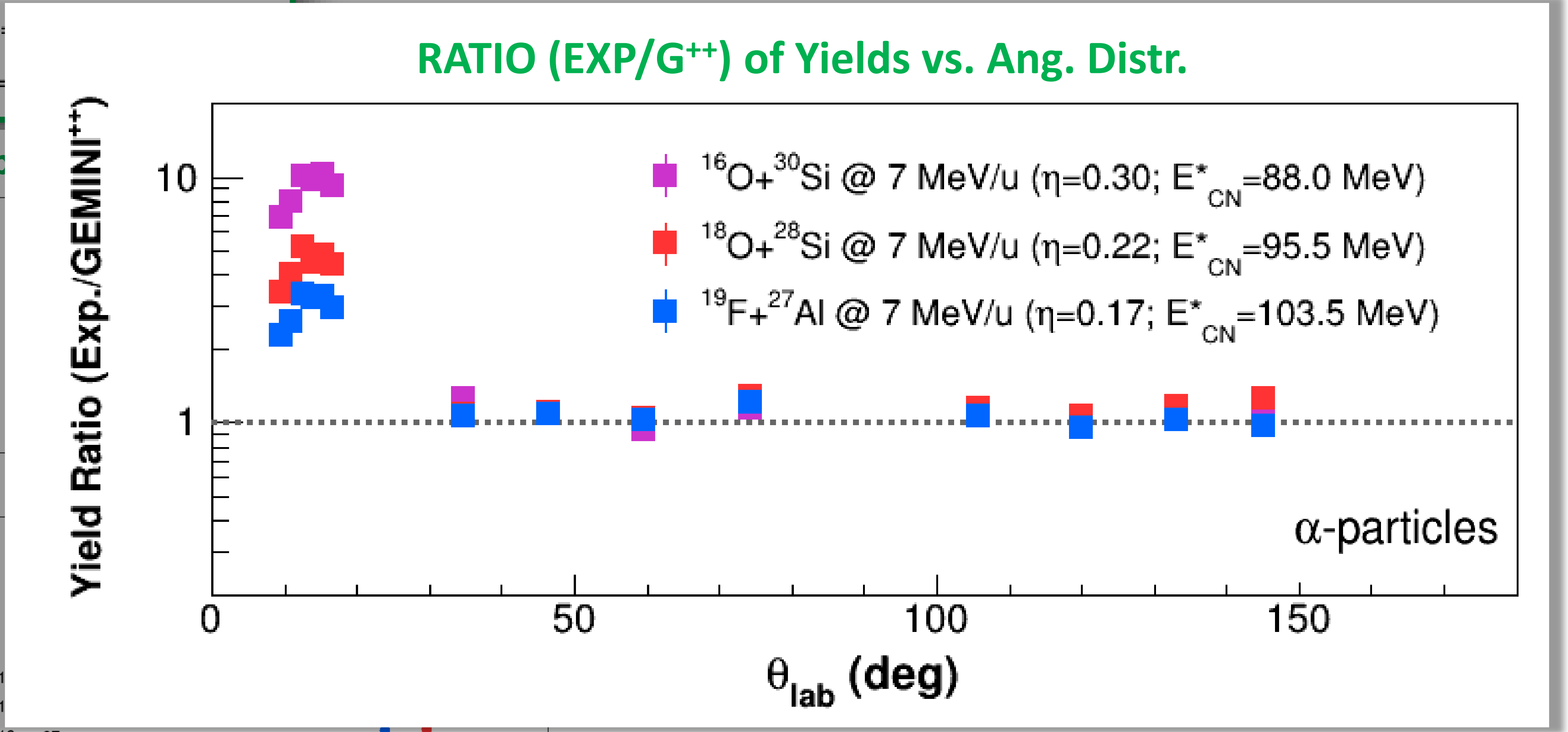

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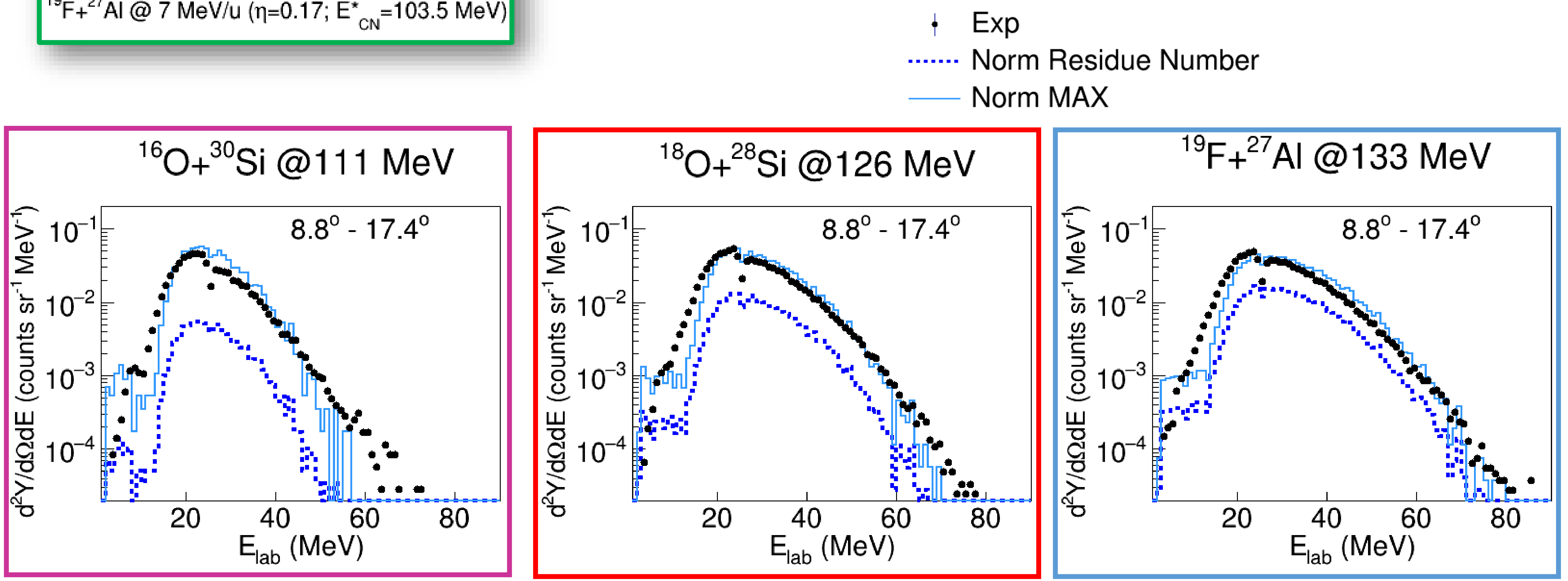
α-particles Energy Spectra: Exp. vs. G^{++}



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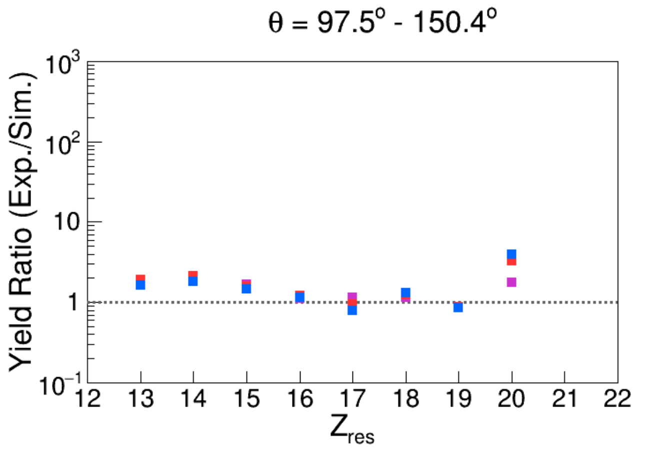
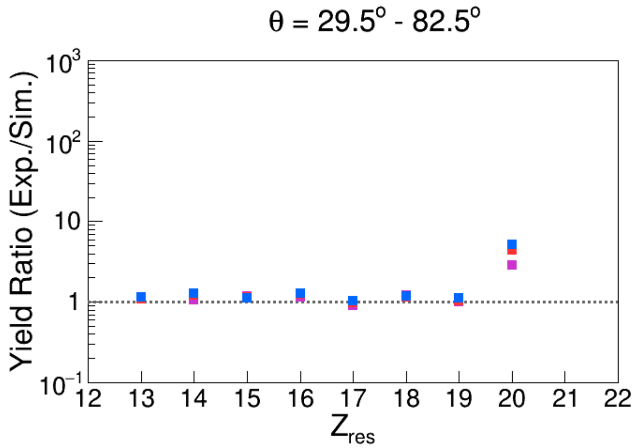
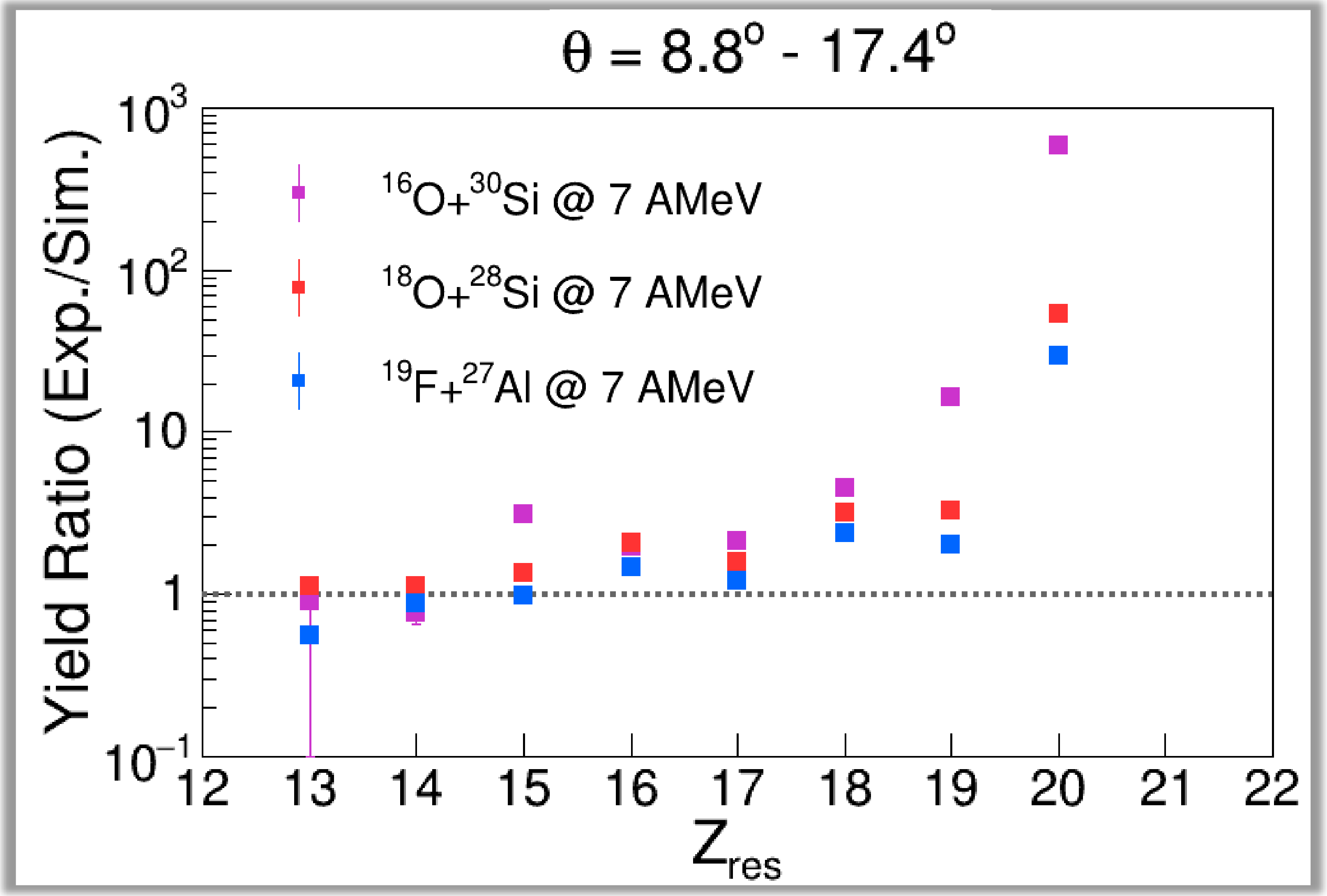




Ratio of α-particles yields in exclusive channels



RESULTS for the last reaction: $^{16}O+^{30}Si$@8 AMeV

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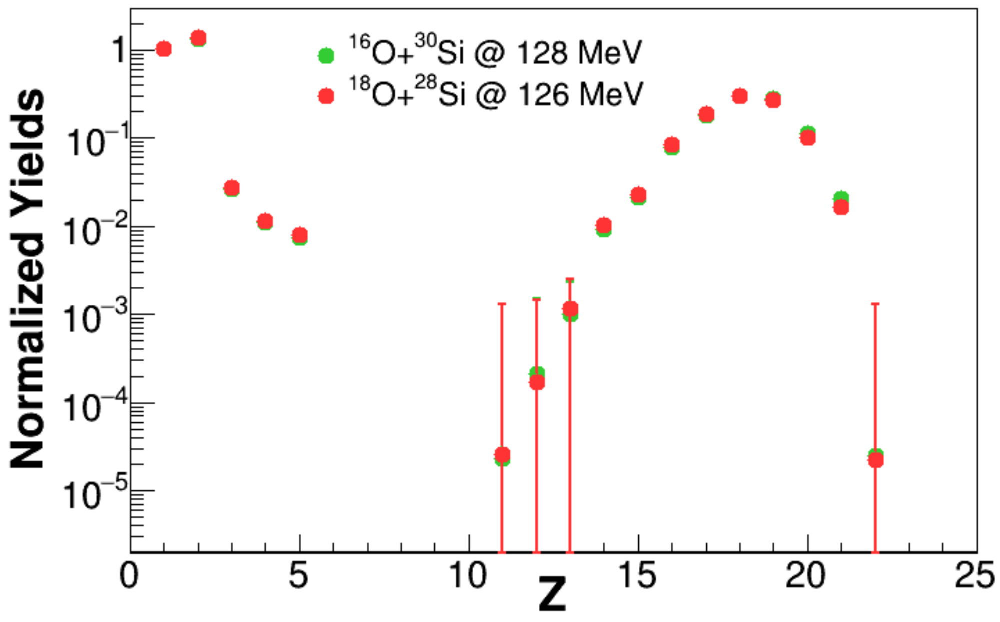
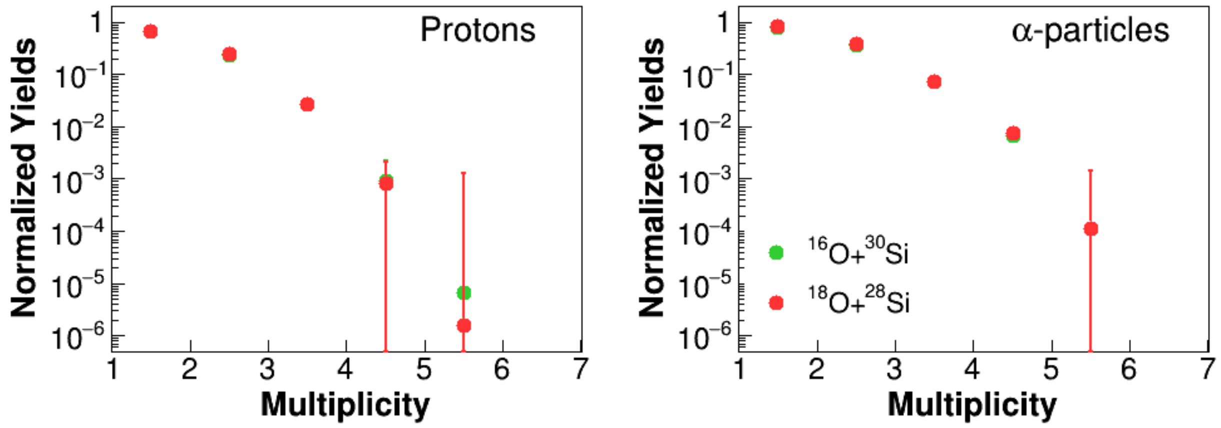
Experimental Charge Distribution



Experimental Multiplicity



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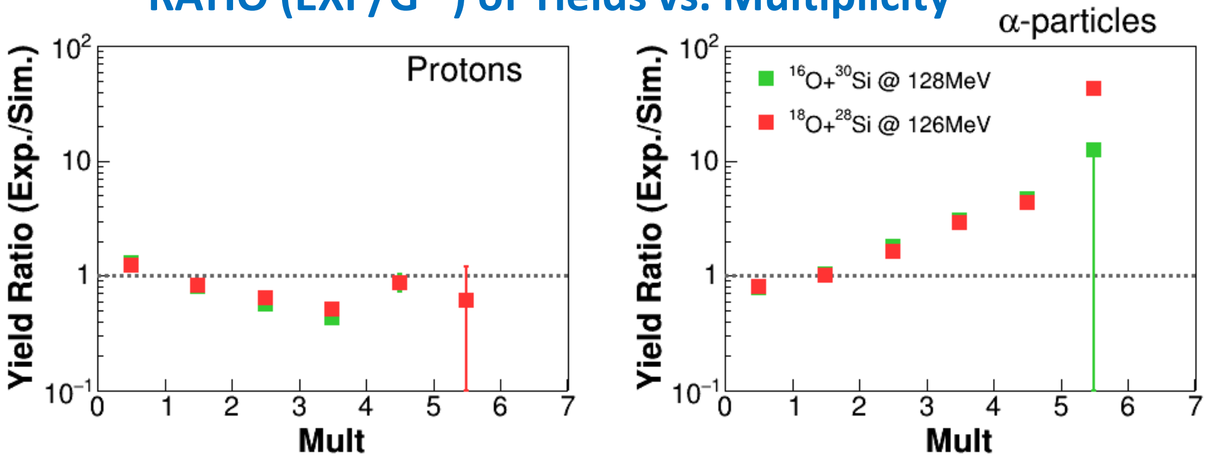

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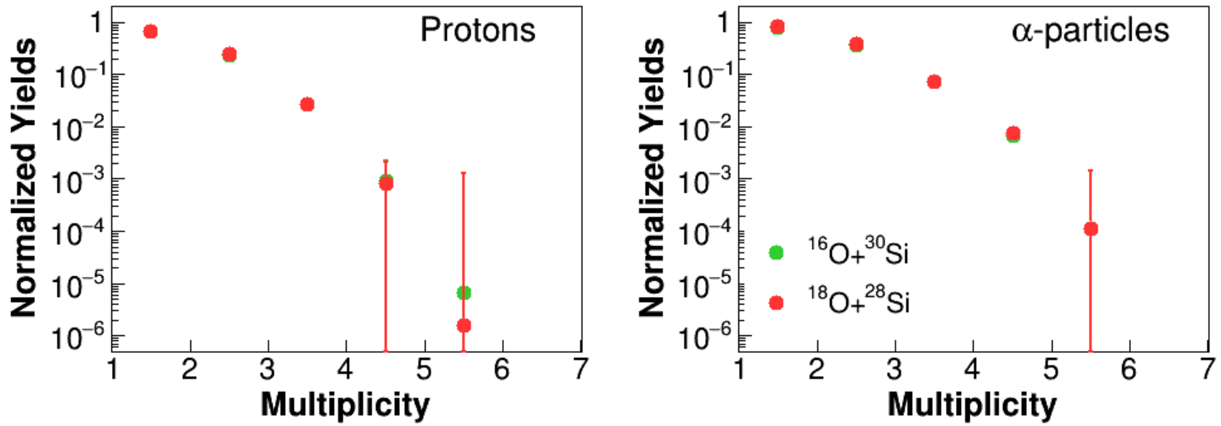

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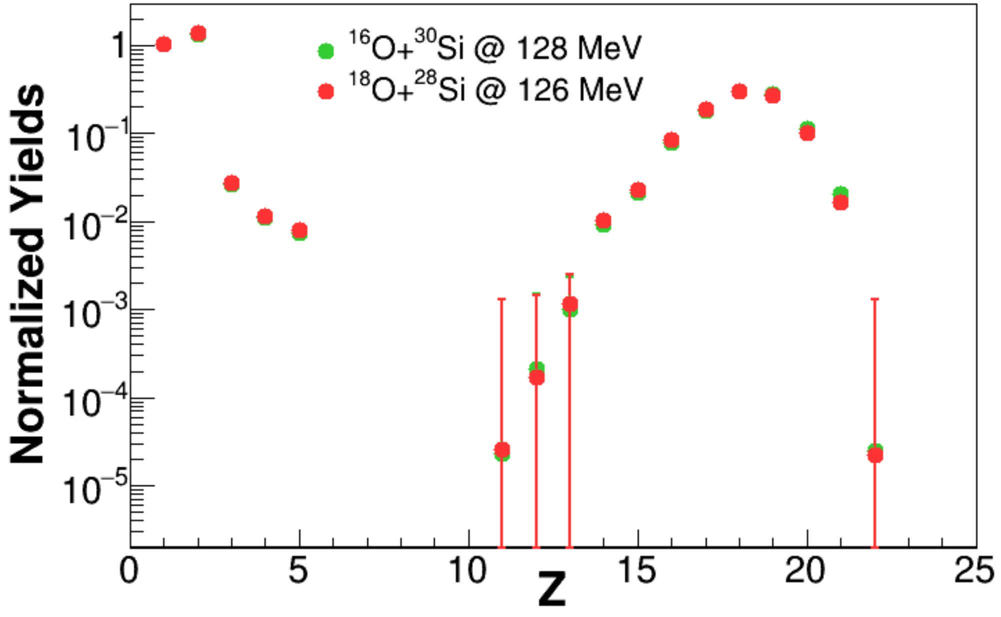

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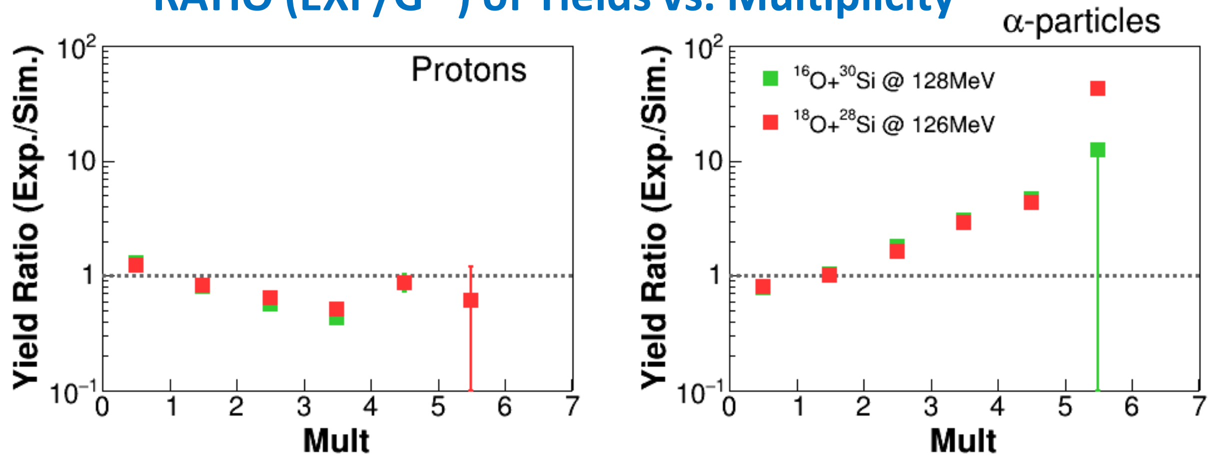

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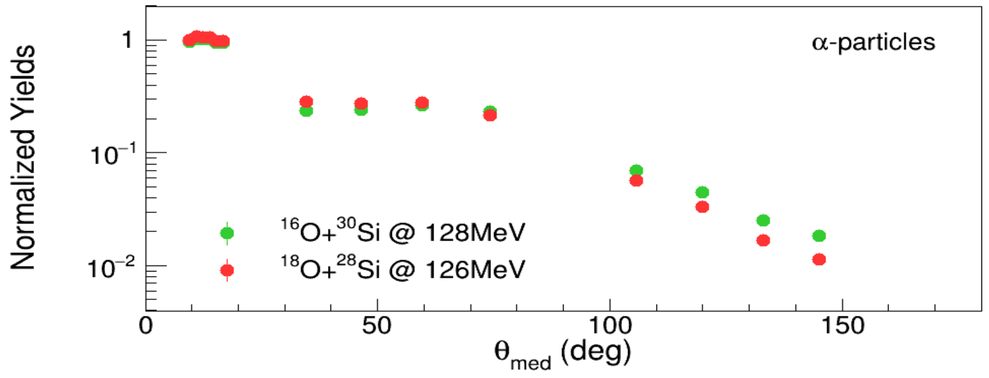
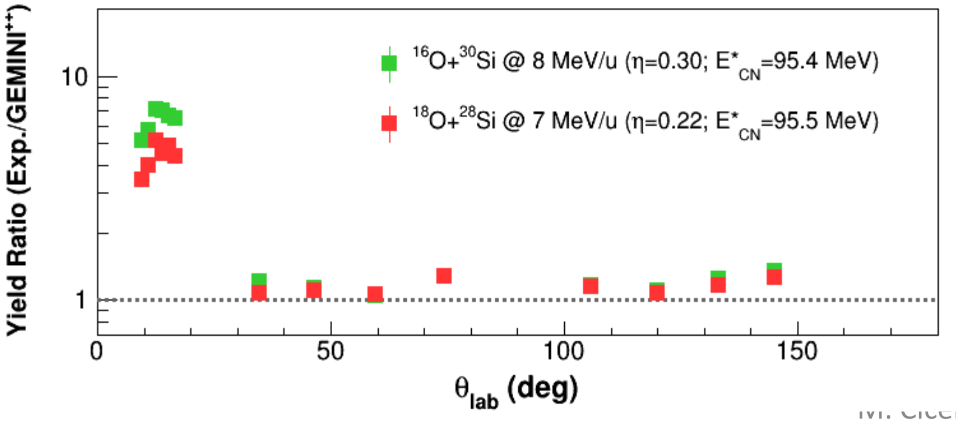
Experimental α Angular Distribution



RATIO (EXP/G++) of α Yields vs. Ang. Distr.



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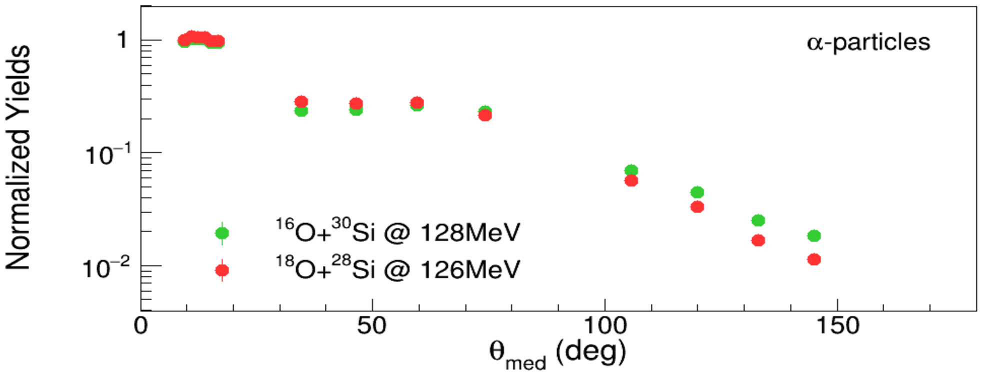

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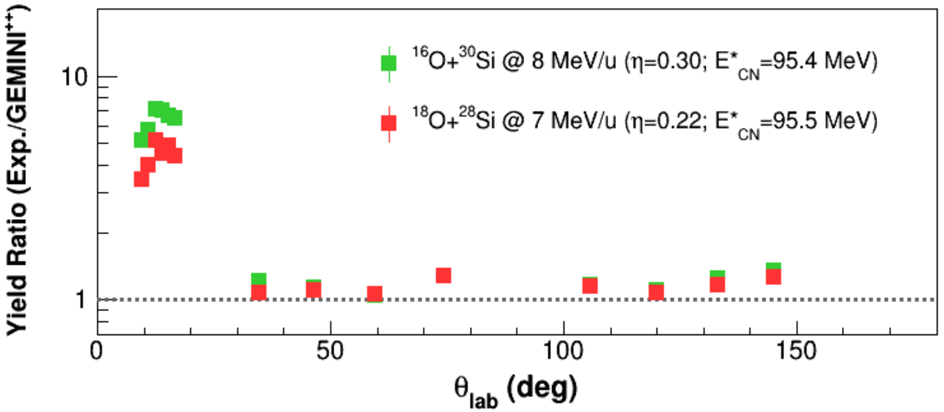

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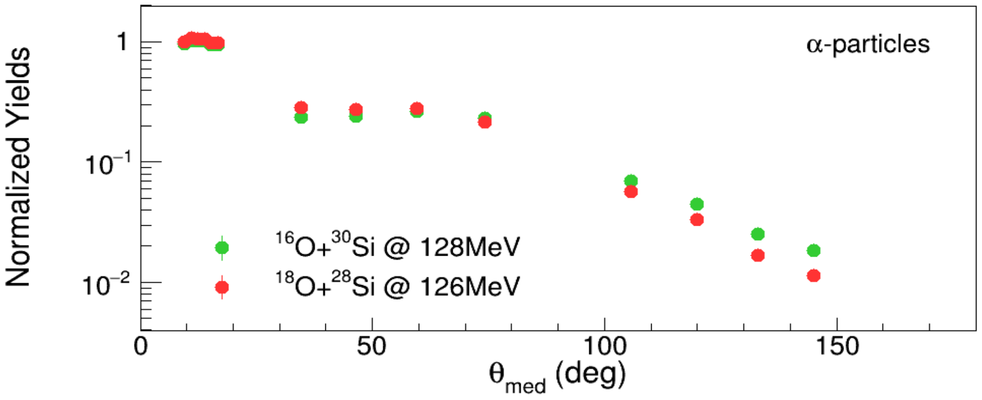

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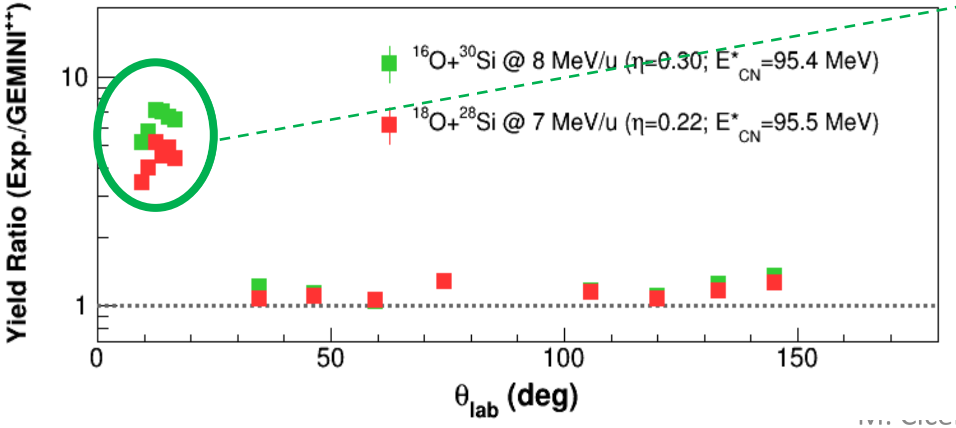
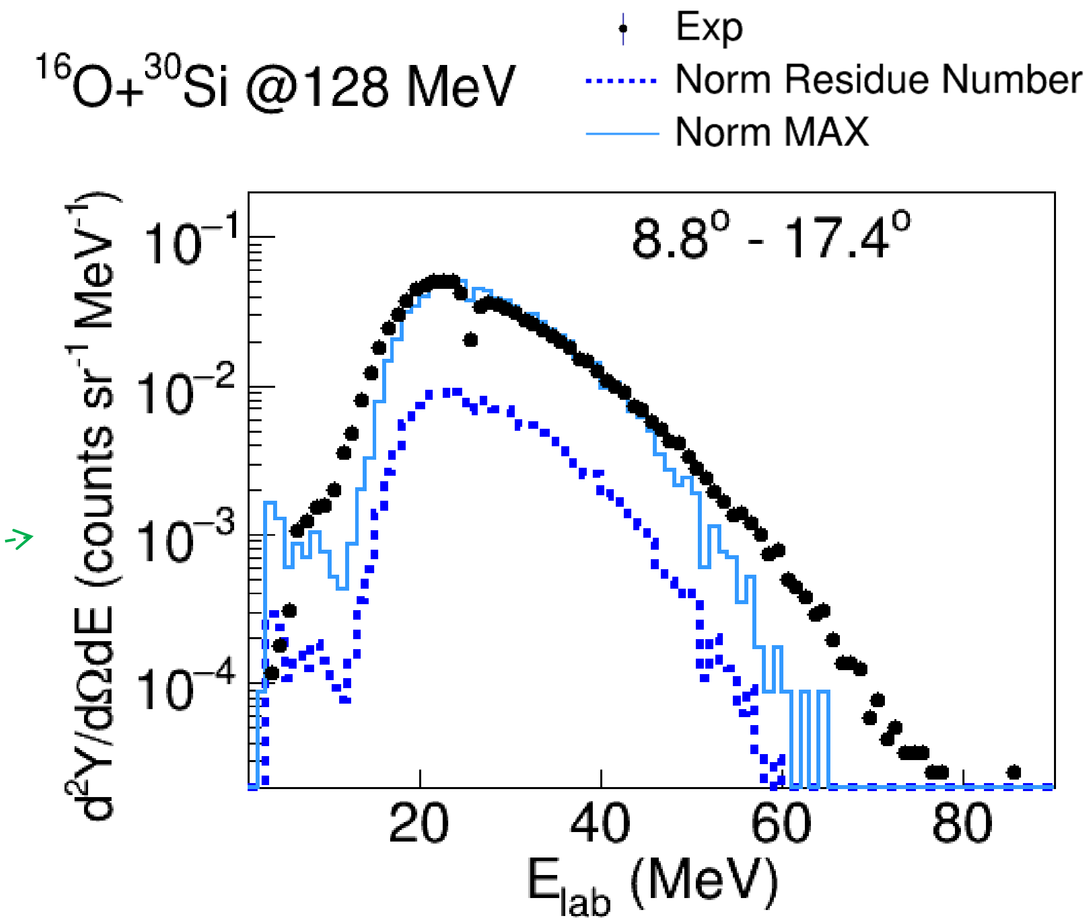


α-particles Energy Spectra: Exp. vs. G++



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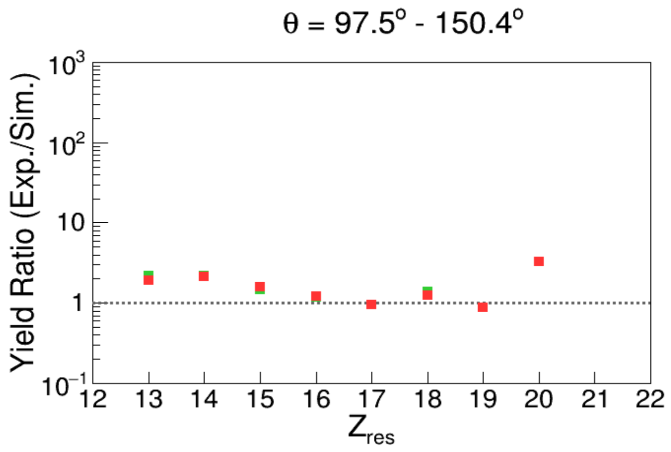
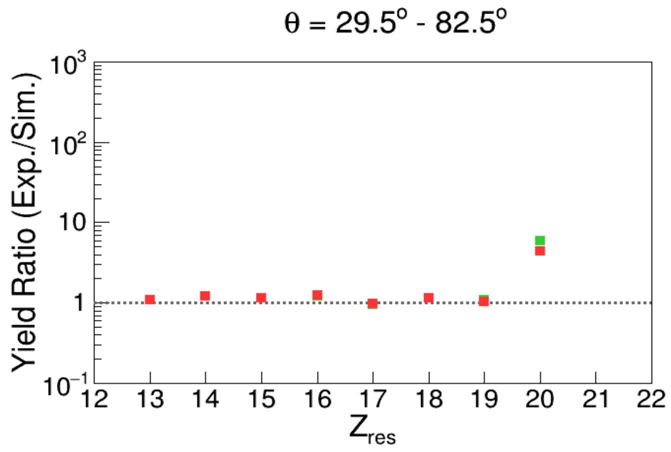
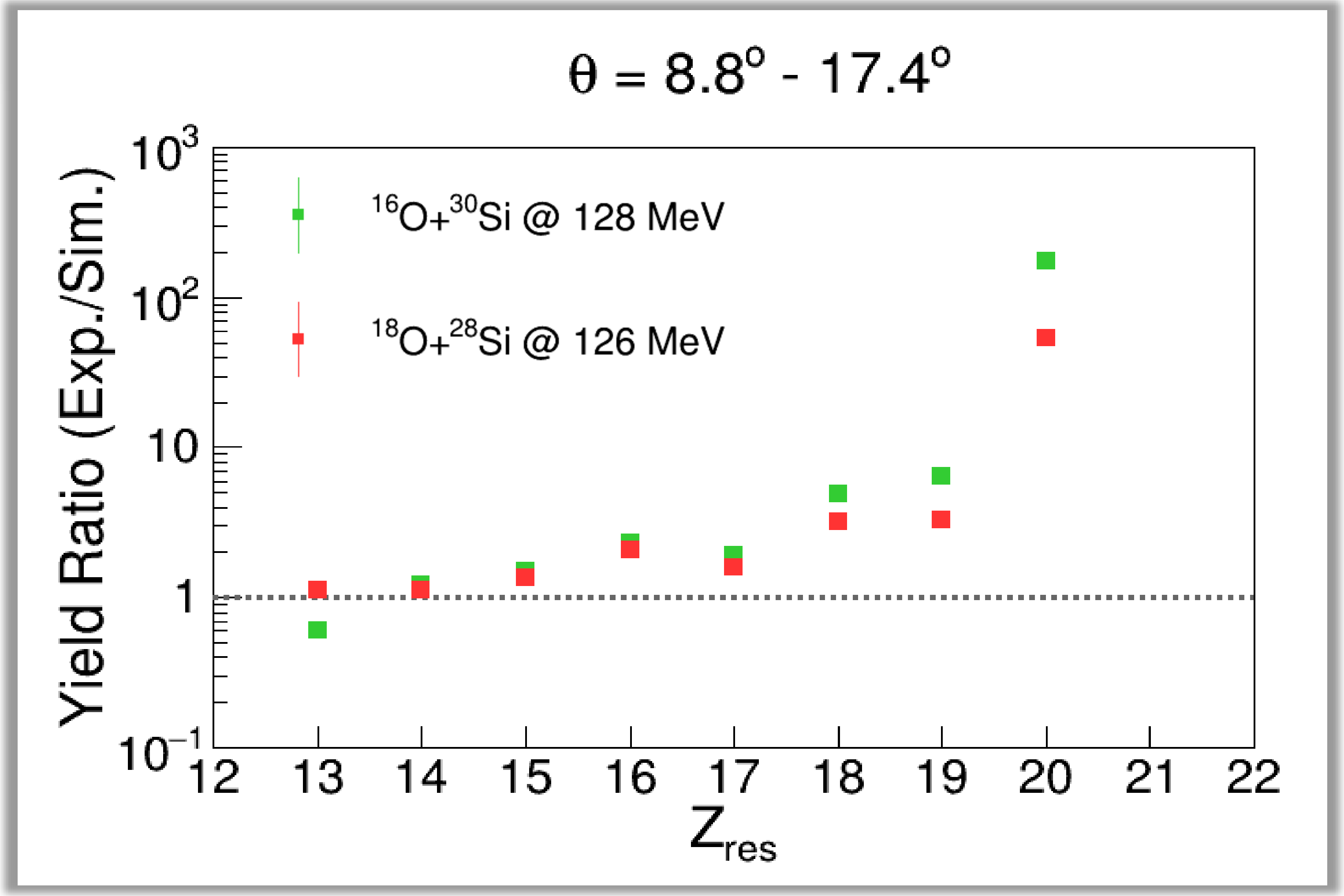
Ratio of α-particles yields in exclusive channels



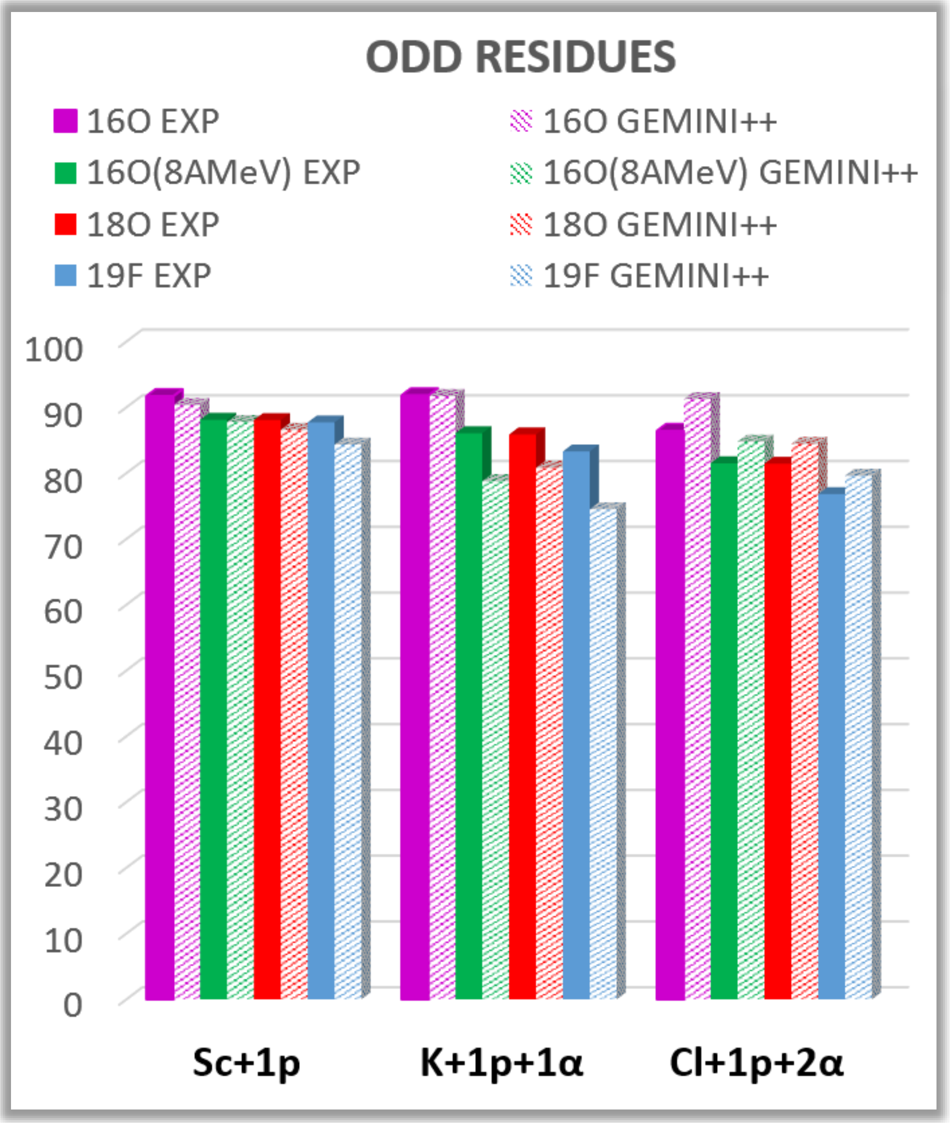


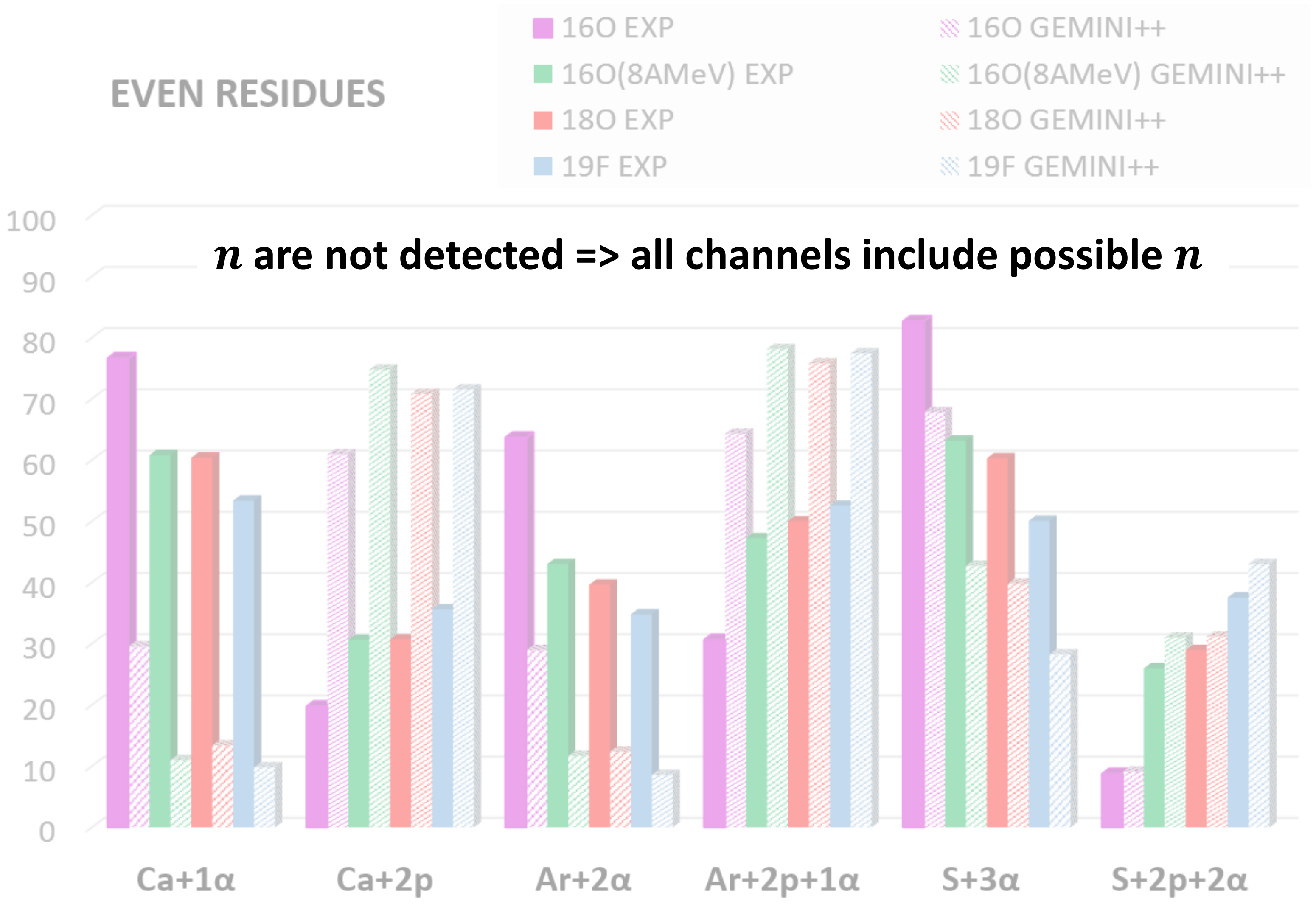


Summary

	reactions at same v_{beam} (7AMeV): $^{16}O+^{30}Si$ $^{18}O+^{28}Si$ $^{19}F+^{27}Al$ @7AMeV	reactions at same E^*_{CN} (98,5MeV): $^{16}O+^{30}Si$@8AMeV $^{18}O+^{28}Si$@7AMeV
EXP. GLOBAL VARIABLES:		
• Z distribution • Multiplicity	Expected behavior	
• Angular Distribution	Dependence on v_{CN} of the A.D. behavior	
	Strong over-production of α at very forward angles	
COMPARISON WITH STATISTICAL MODEL (RATIO):		
• Multiplicity	Underestimation of high multiplicity α	
• Angular Distribution	Dependence on E^*_{CN} and/or η of α forward overproduction	Dependence on η and/or v_{beam} overproduction
	Forward α over-production for $Z_{residue} > 17$	
• Energy Spectra	Yields underestimation (higher as E^*_{CN} decreases)	
	Shape reproduction	^{16}O → signature of pre-equilibrium onset

BRANCHING RATIO of the most populated exit channels





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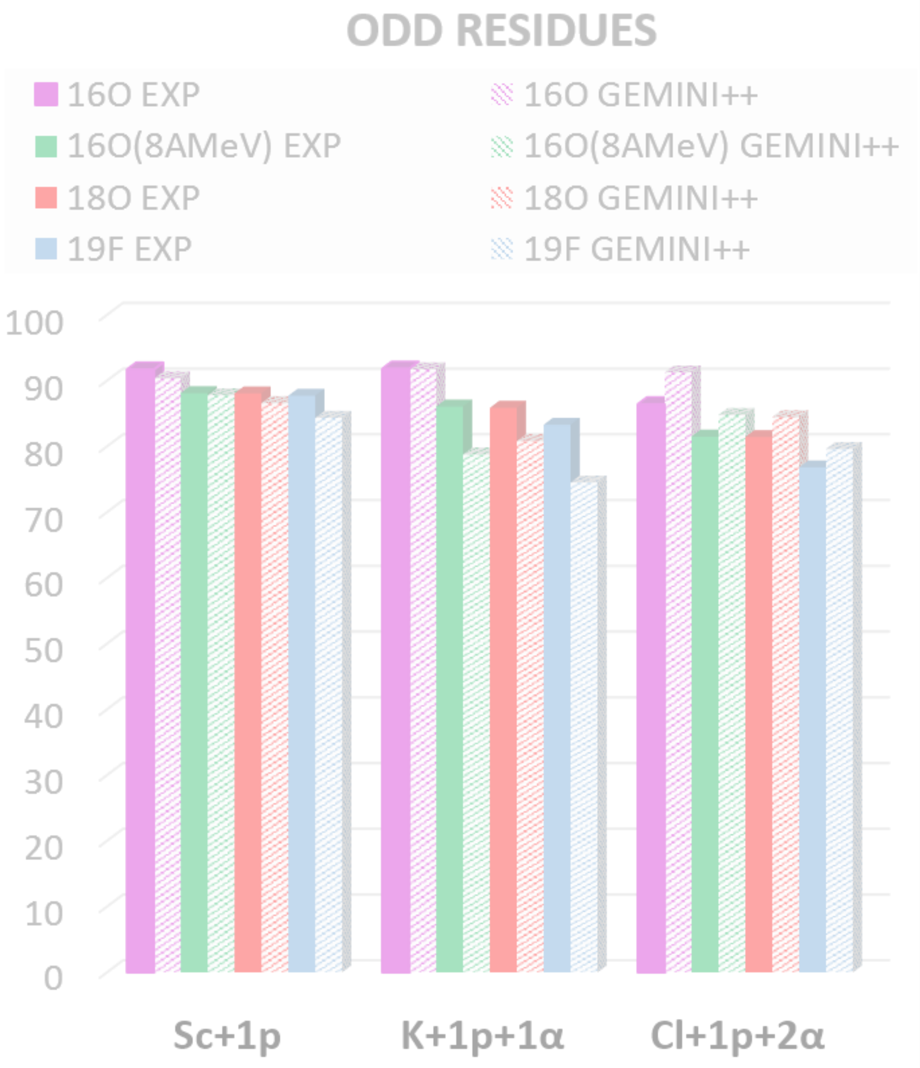

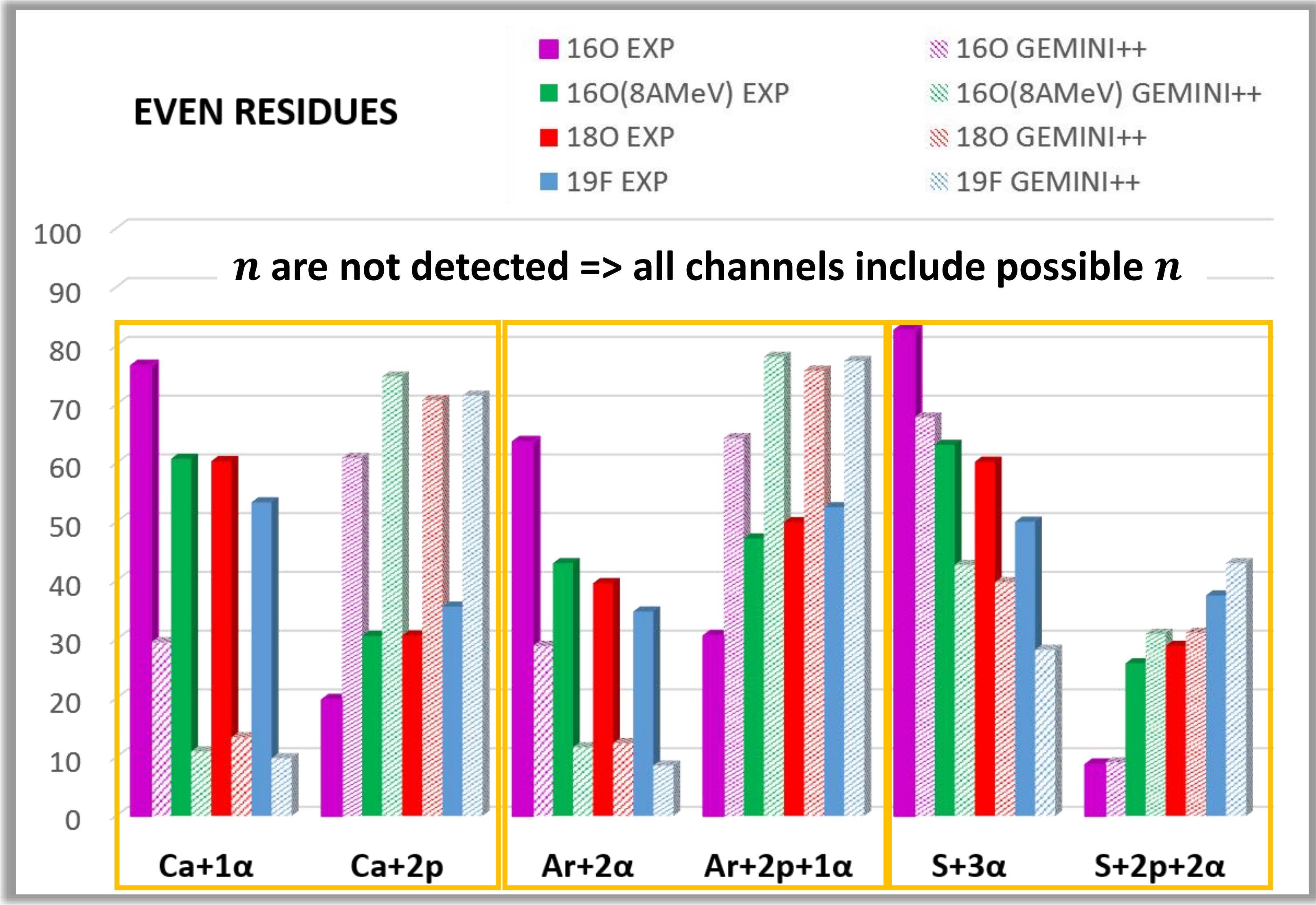

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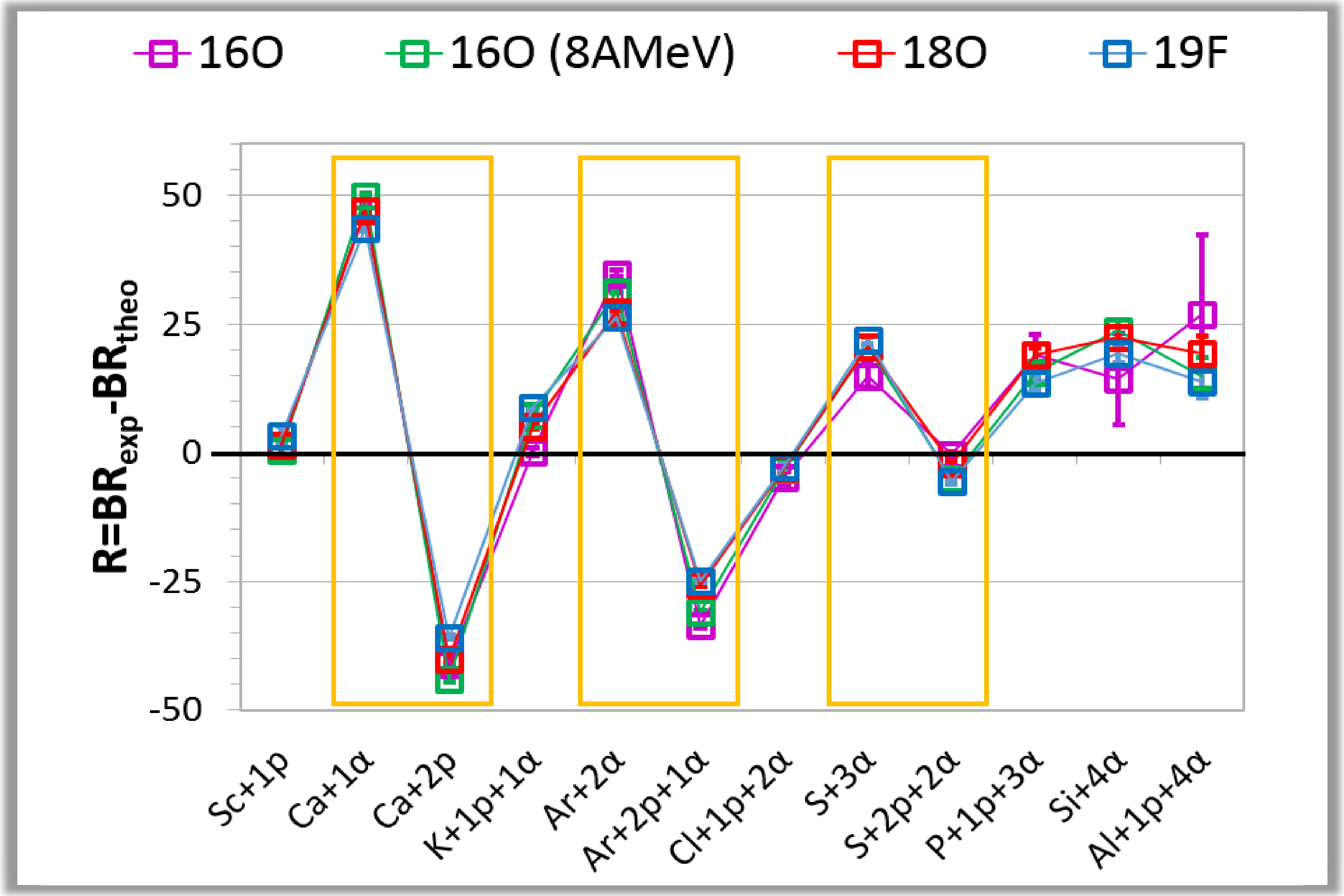

Conclusions

Analysis and comparison of 4 reactions	
3 at same v_{beam} (7AMeV): ^{16}O+^{30}Si ^{18}O+^{28}Si ^{19}F+^{27}Al @7AMeV	2 at same $\mathrm{E}^*_{\mathrm{CN}}$ (98,5MeV): ^{16}O+^{30}Si@8AMeV ^{18}O+^{28}Si@7AMeV

Experimental α-overproduction at forward angles (yields) respect statistical predictions	
The highest is for ^{16}O @ 7 AMeV.	^{16}O @ 8 AMeV onset of pre-equilibrium

$\mathrm{E}^*_{\mathrm{CN}}$ dependence of the B.R. trend.

EXP. vs. GEMINI++:

- **ODD RESIDUES: trends and yields are well reproduced by statistical model;**
- **EVEN RESIDUES:**
  - **trends are reproduced;**
  - **HIGH DISCREPANCIES in the reproduction of yields in pure α ($+xn$) exit channels.**

seems to be higher for ^{16}O @ 7 AMeV, but in comparison with model the discrepancies have the same trend for all the reactions.

Statistical model DON'T REPRODUCE light nuclei => may be due to the important rule of the structure.

Thank you for the attention!!

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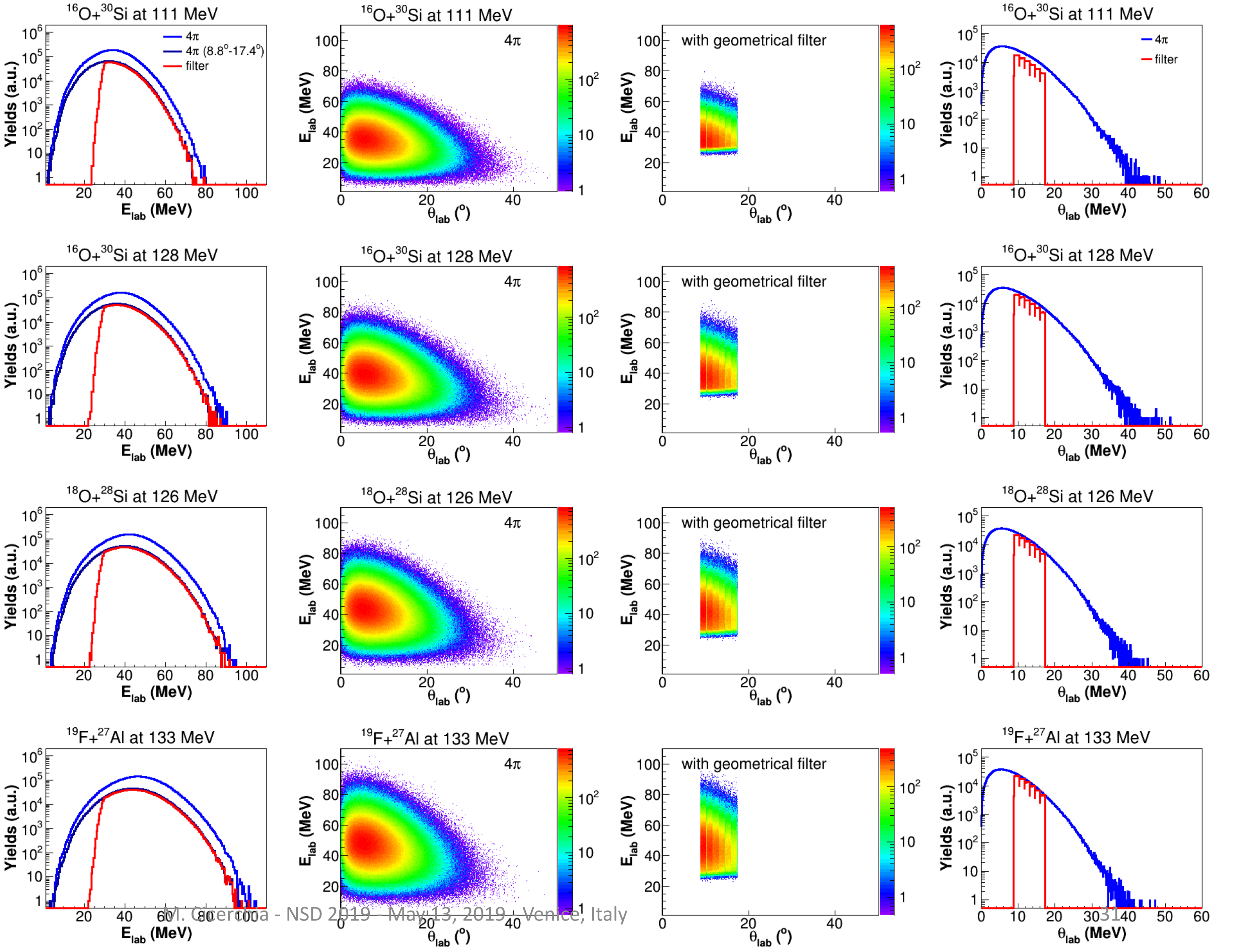
Spares

RESIDUES

GEMINI^{++}
filtered with a software replica of the experimental setup

Entrance channel	ϑ_{graz}	σ_{fus}
Beam + Target	deg	mb
$^{16}O + ^{30}Si$	8,8	1070
$^{16}O + ^{30}Si$	10,1	1081
$^{18}O + ^{28}Si$	9,0	1110
$^{19}F + ^{27}Al$	8,9	1100



RESIDUES

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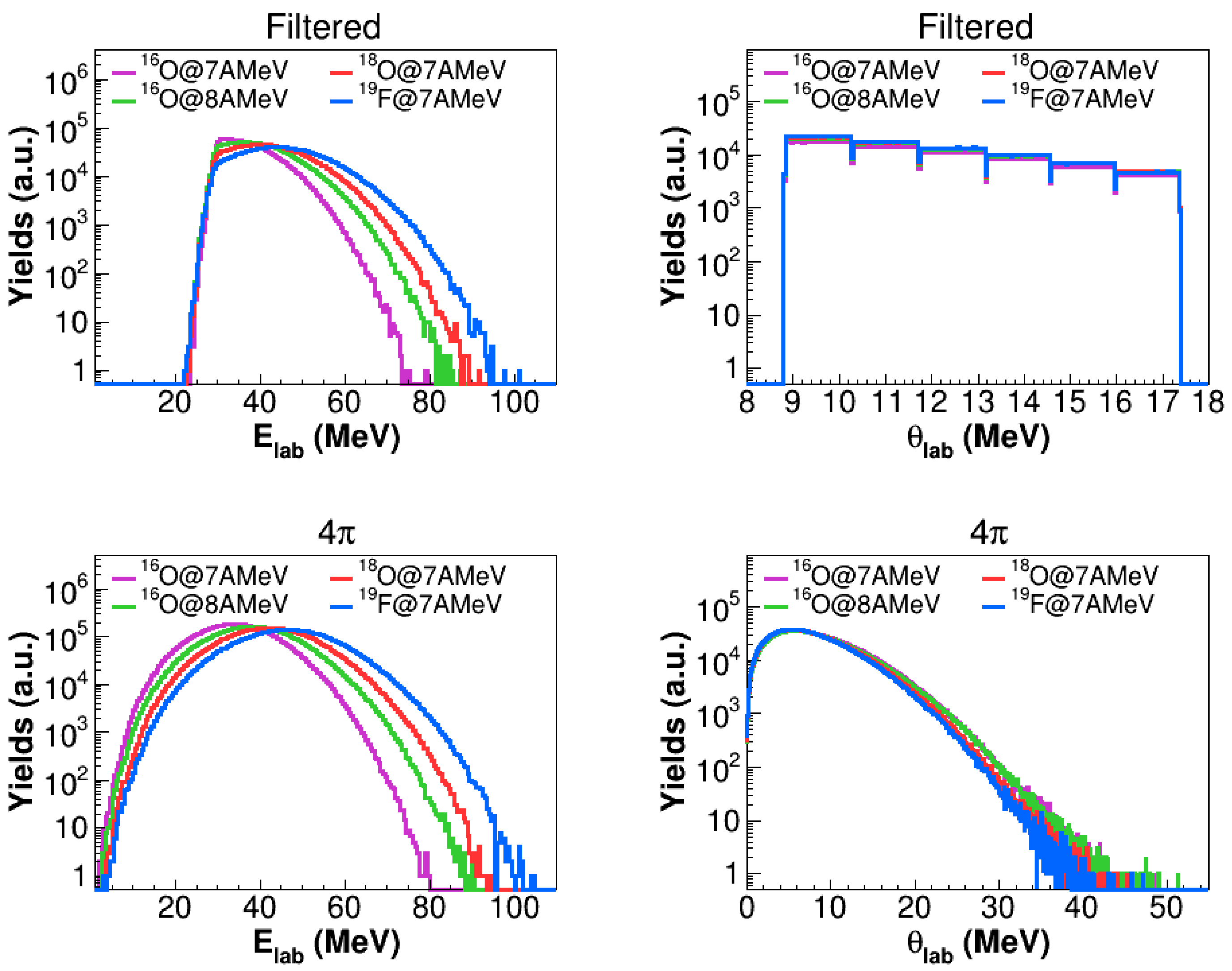
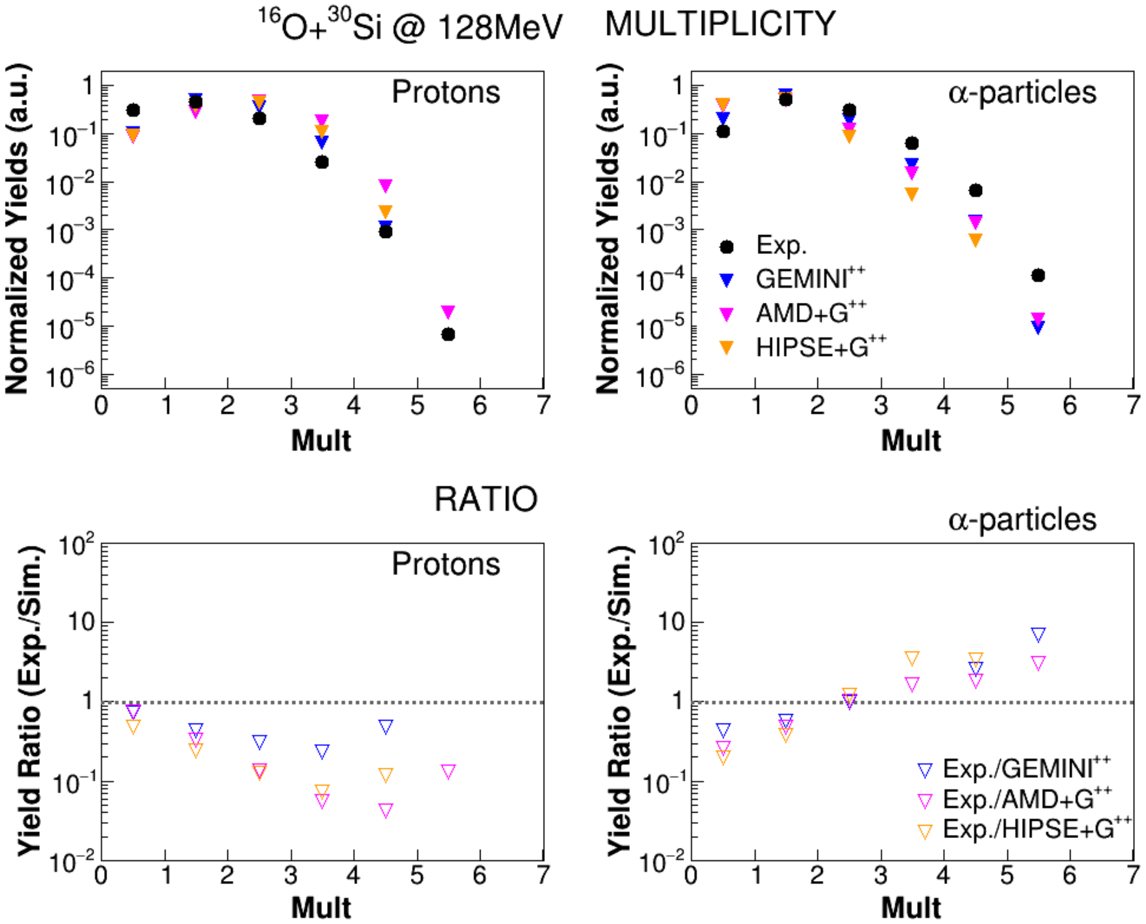
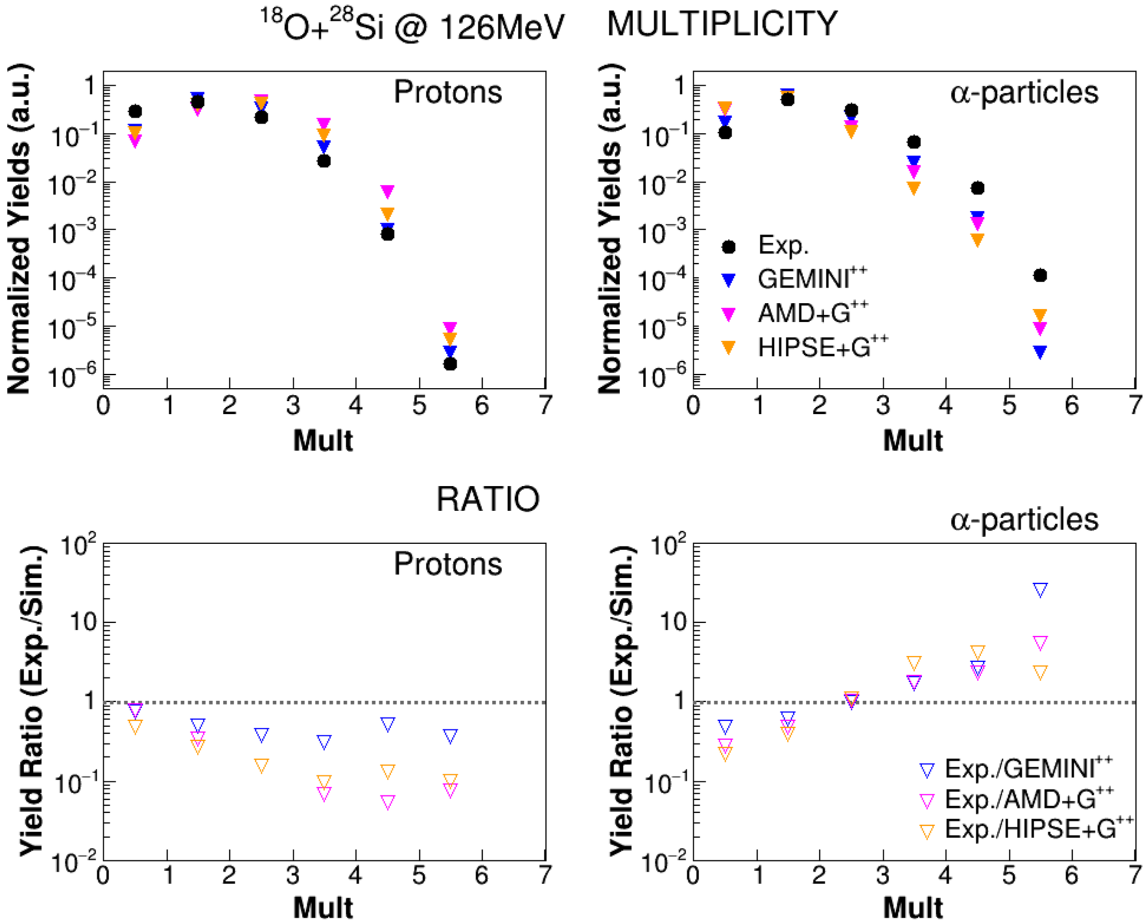


Multiplicity





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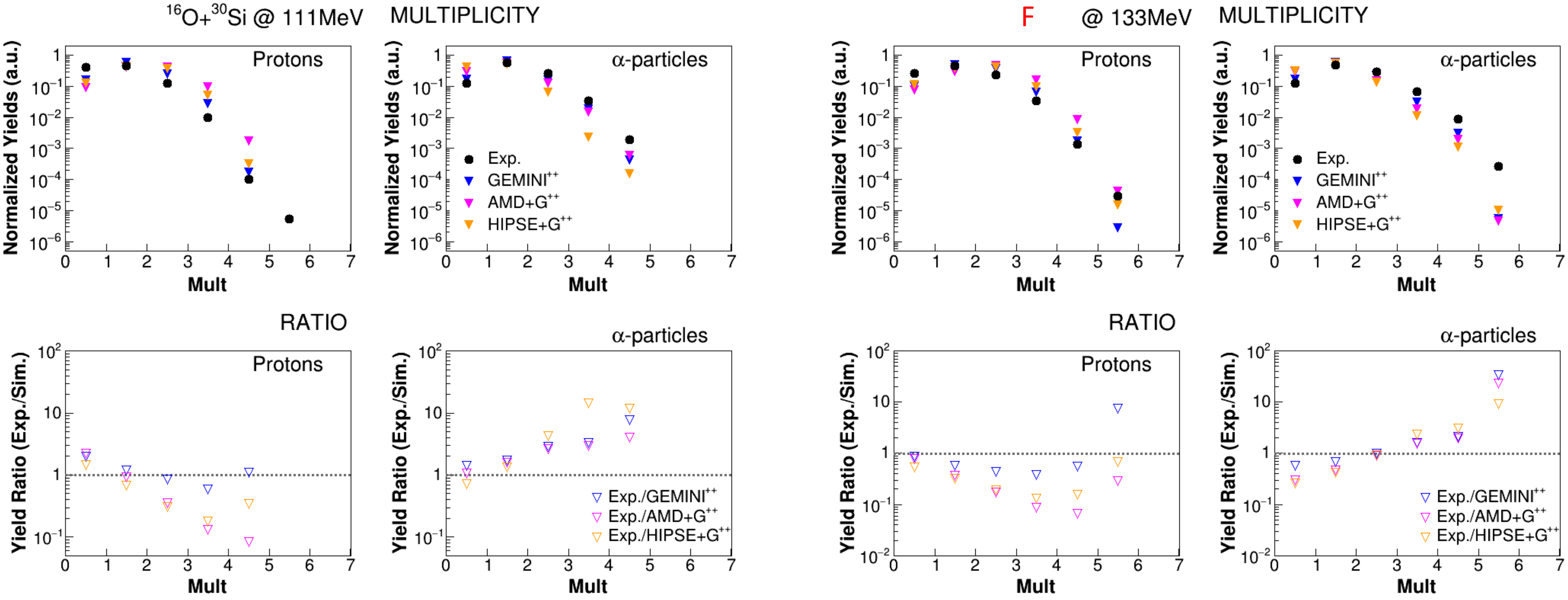
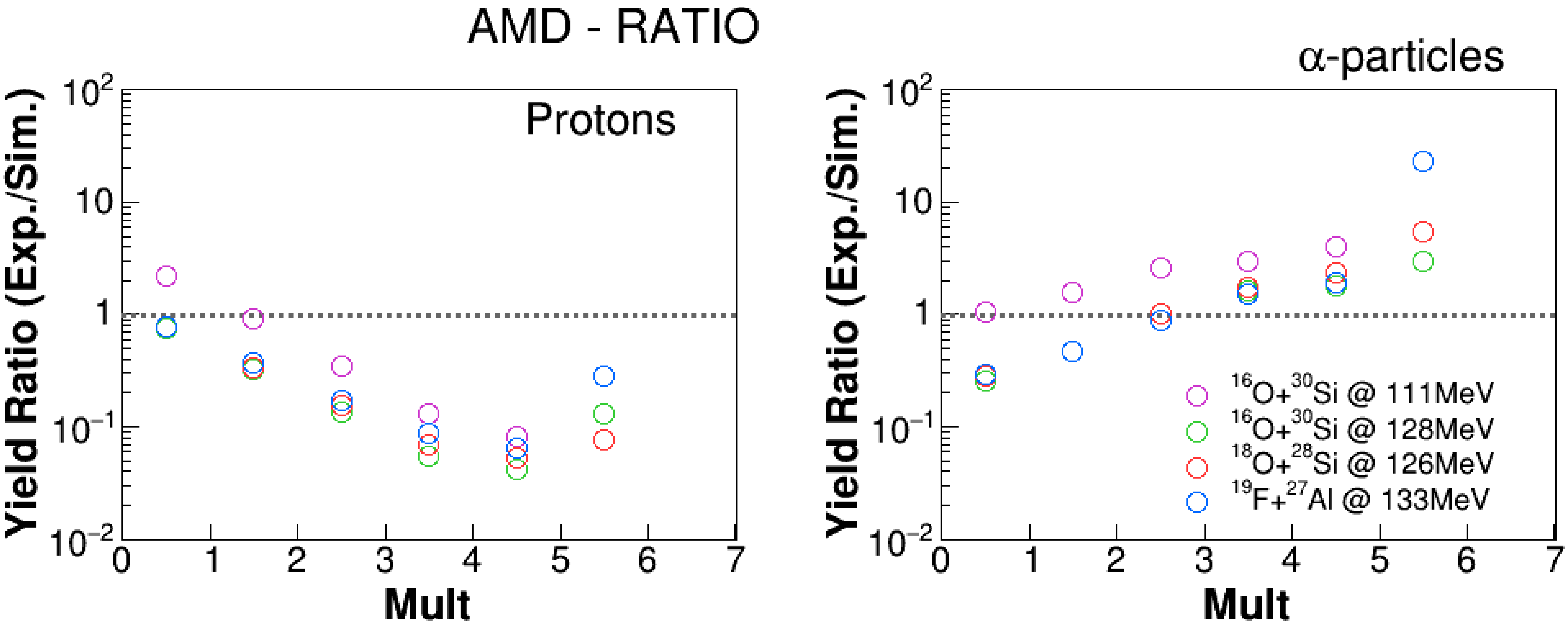
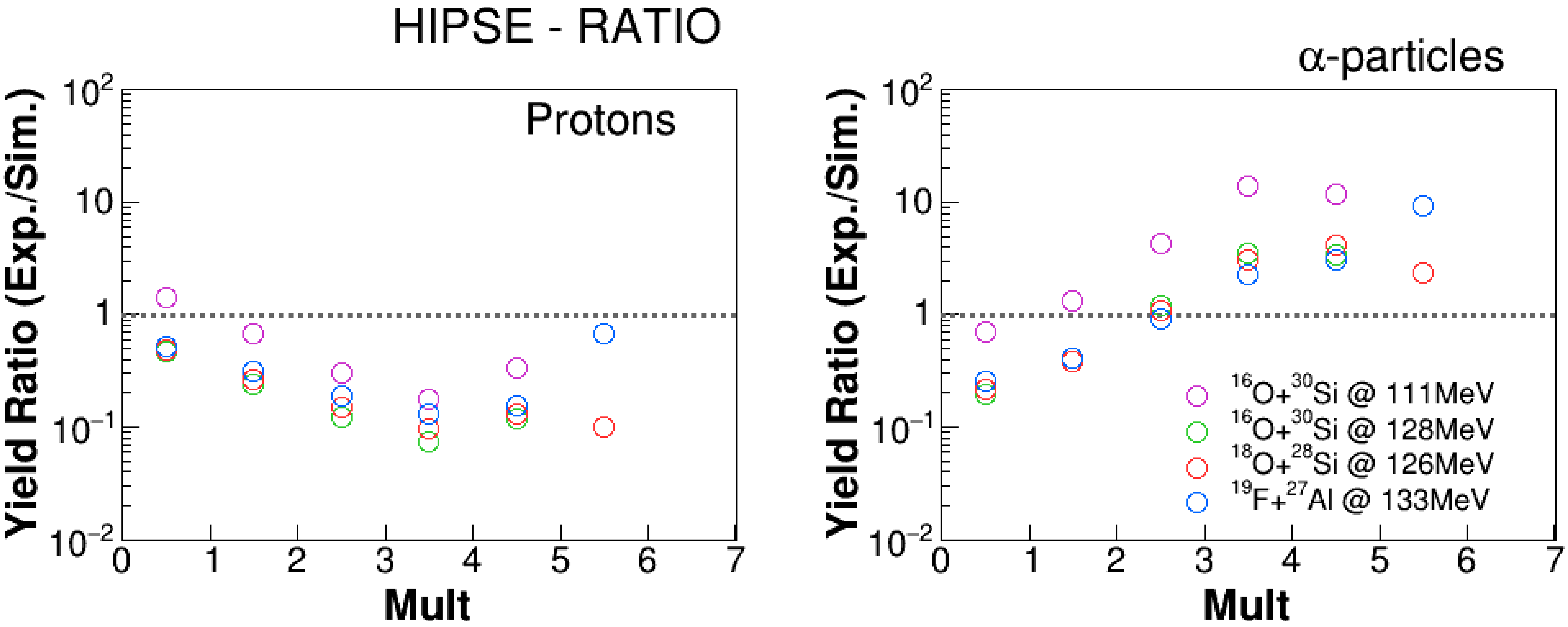


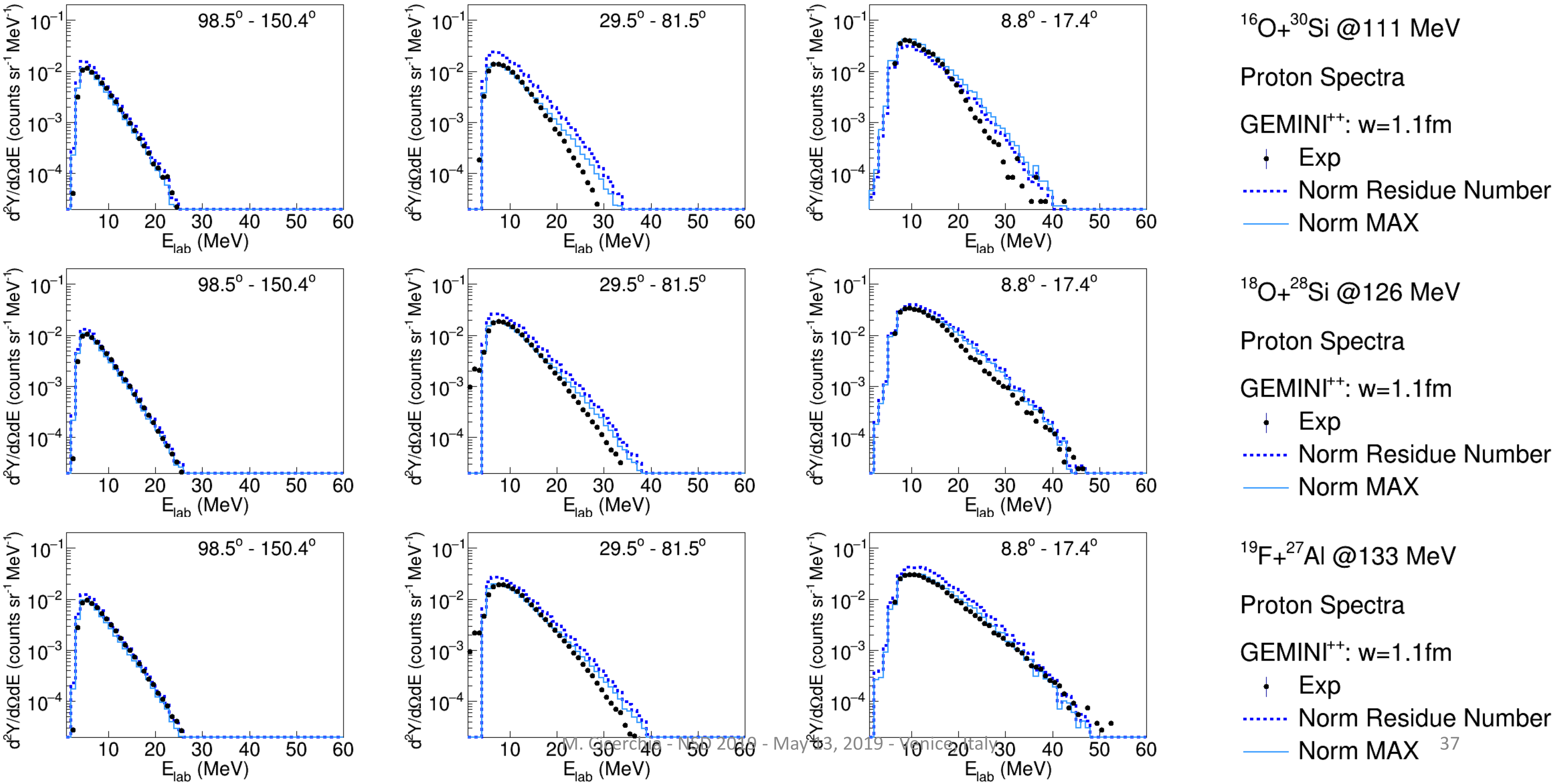
RATIO EXP AMD



RATIO EXP HIPSE

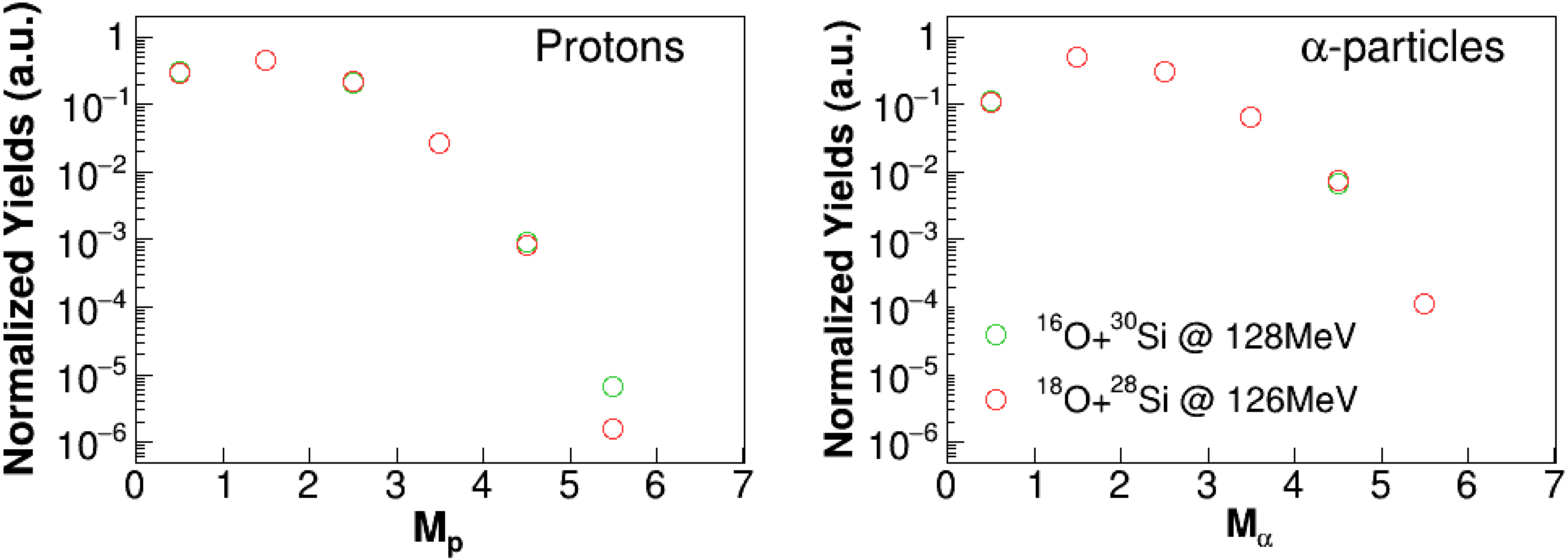


Energy spectra

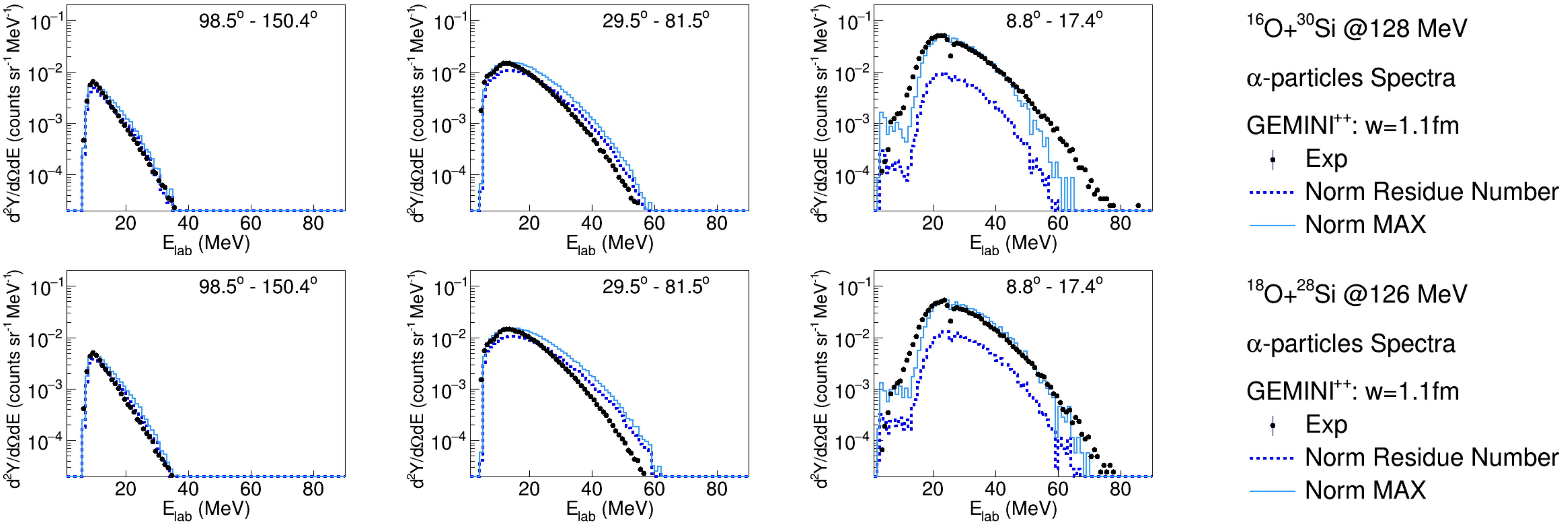


multiplicity

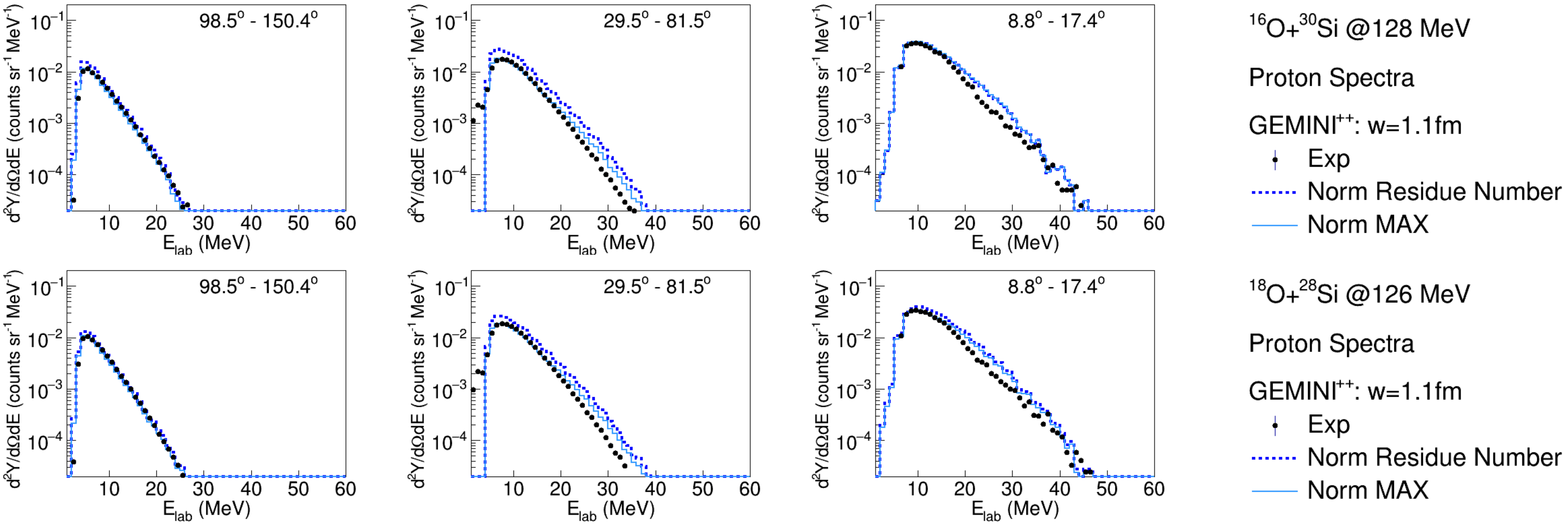
Comparison of MULTIPLICITY for reactions with same E^*_{CN}=98.5 MeV



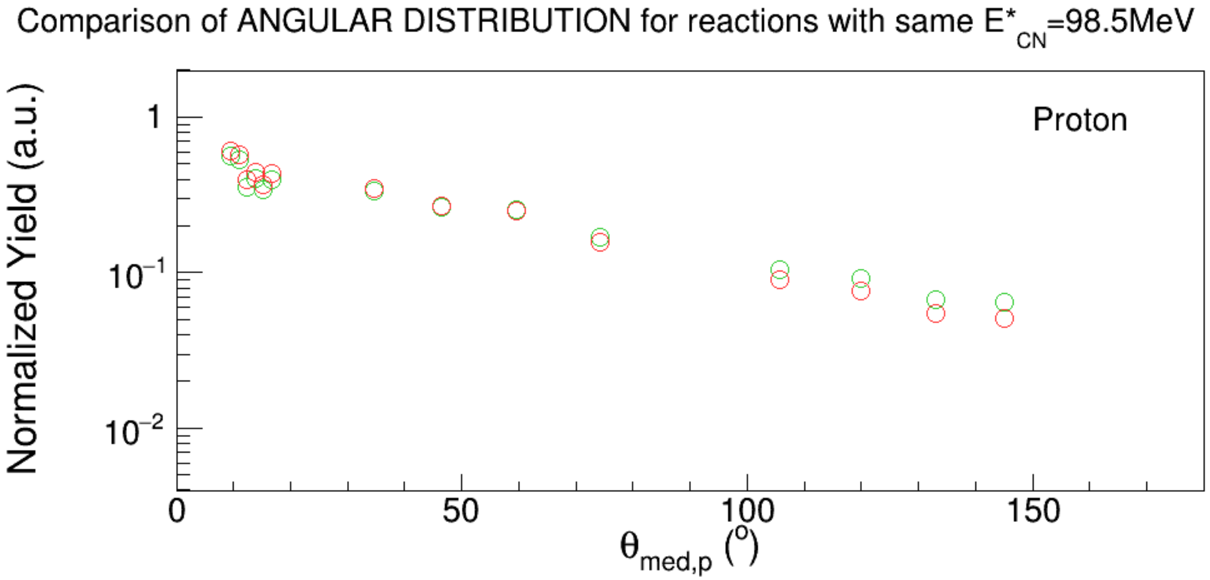
Energy spectra

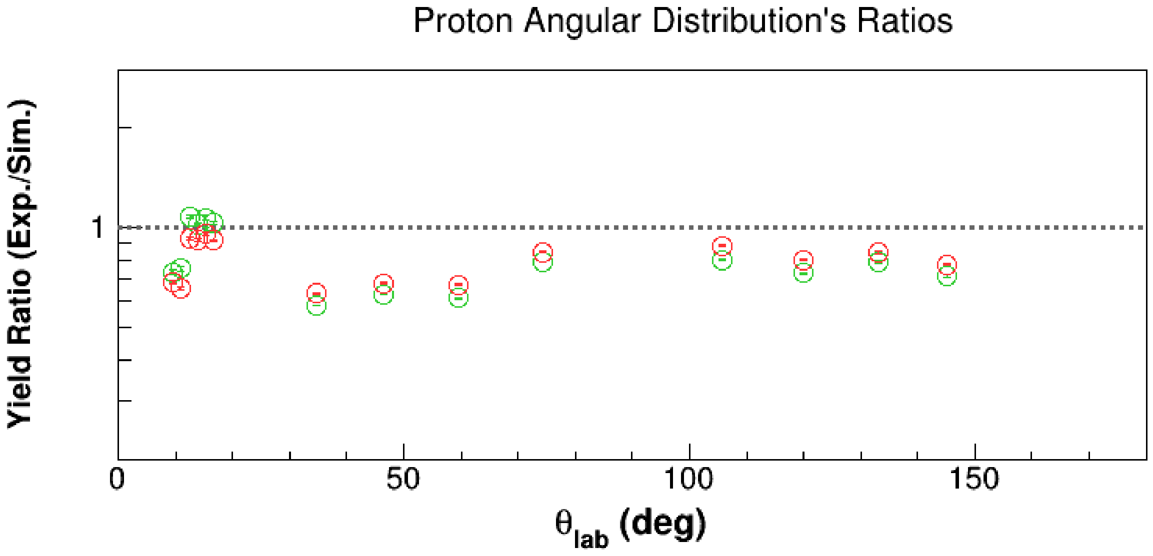


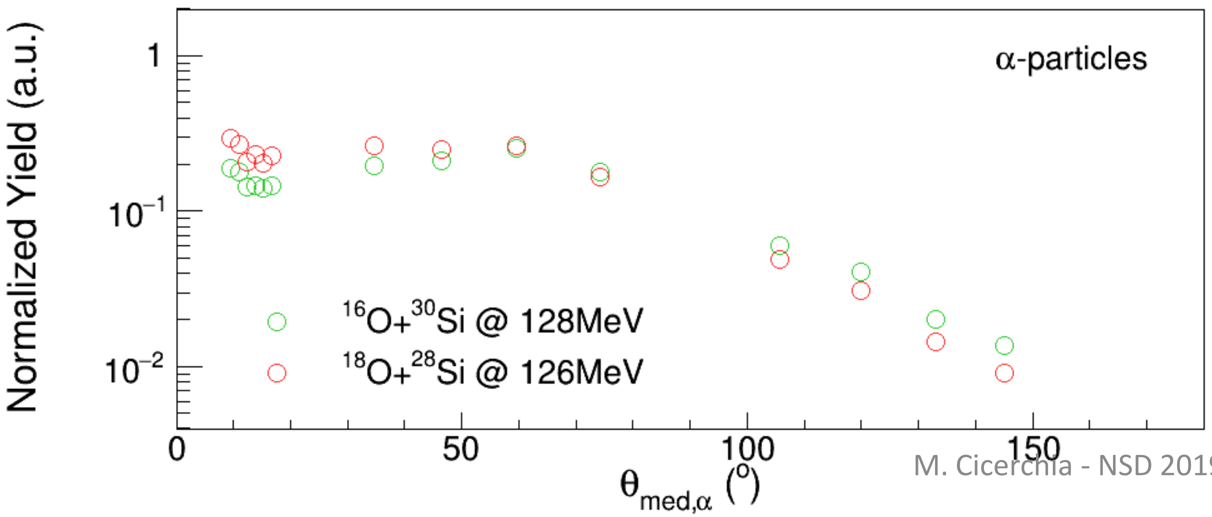
Energy spectra

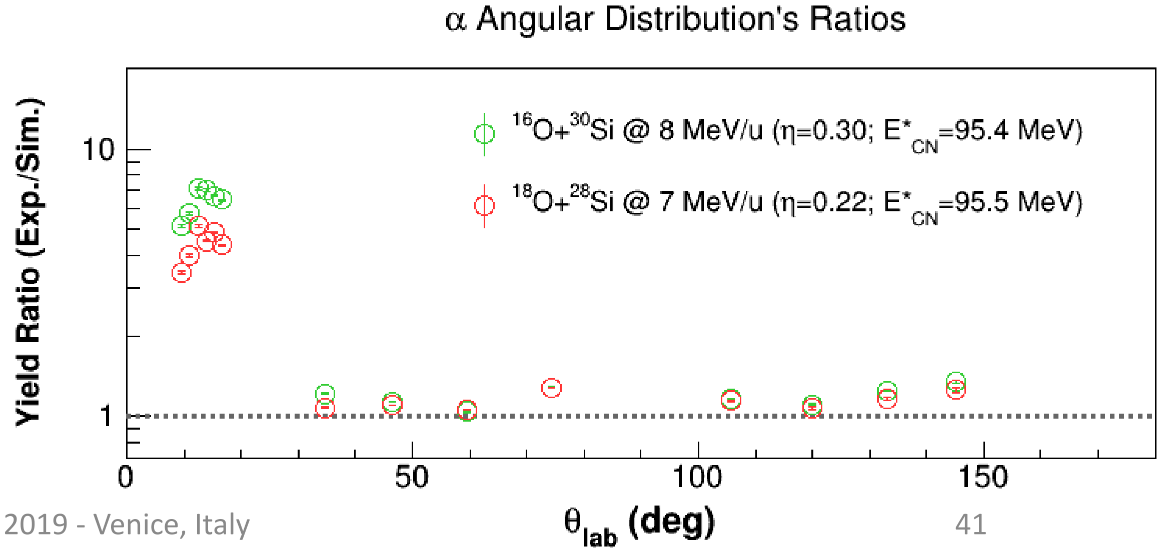


Ang Distr: G11

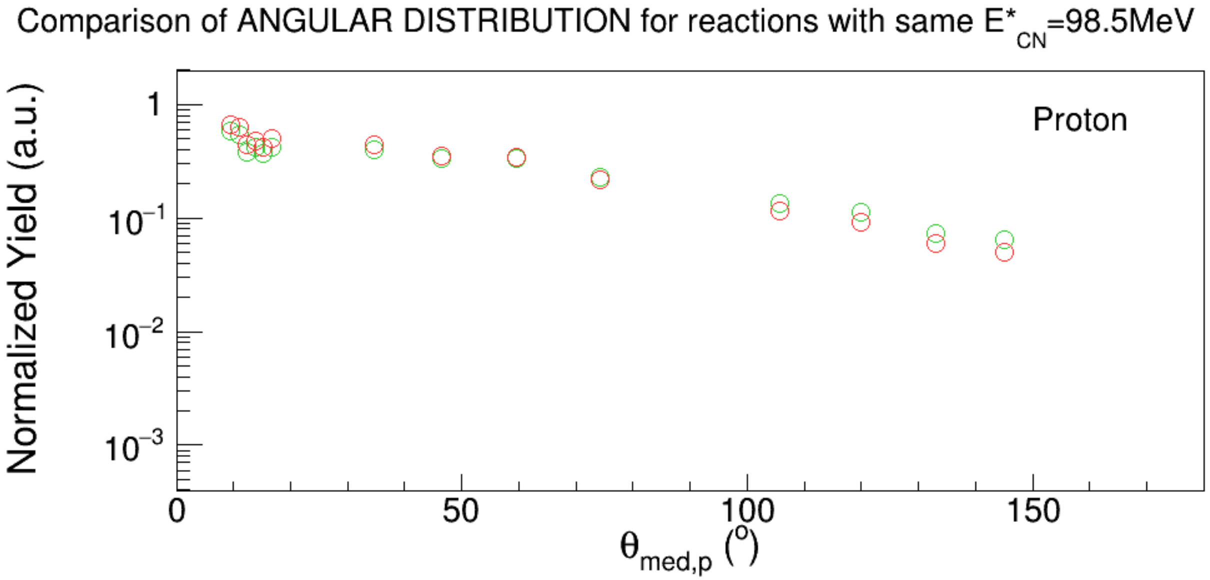


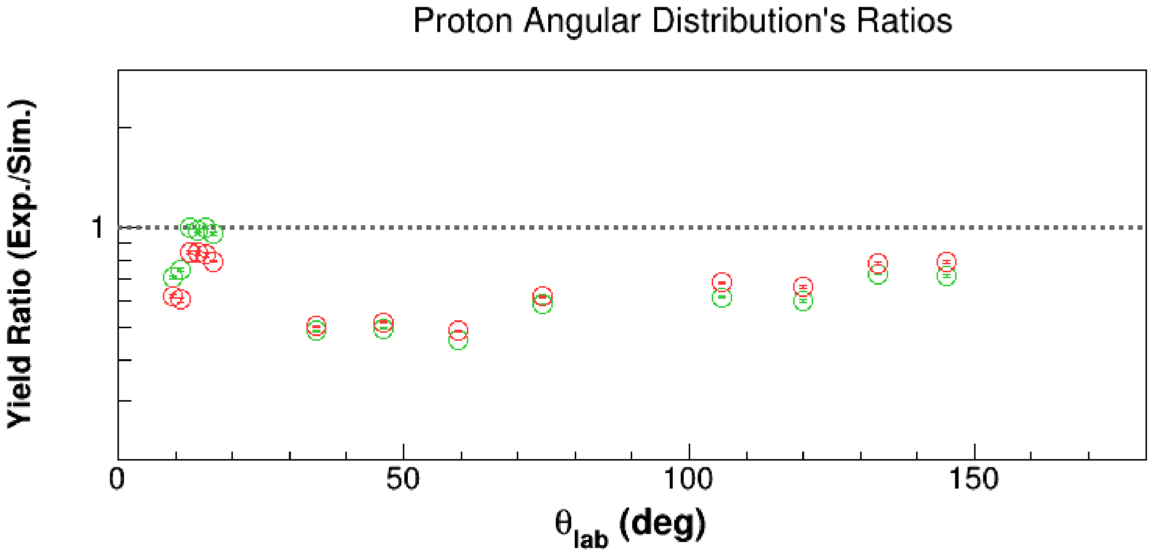


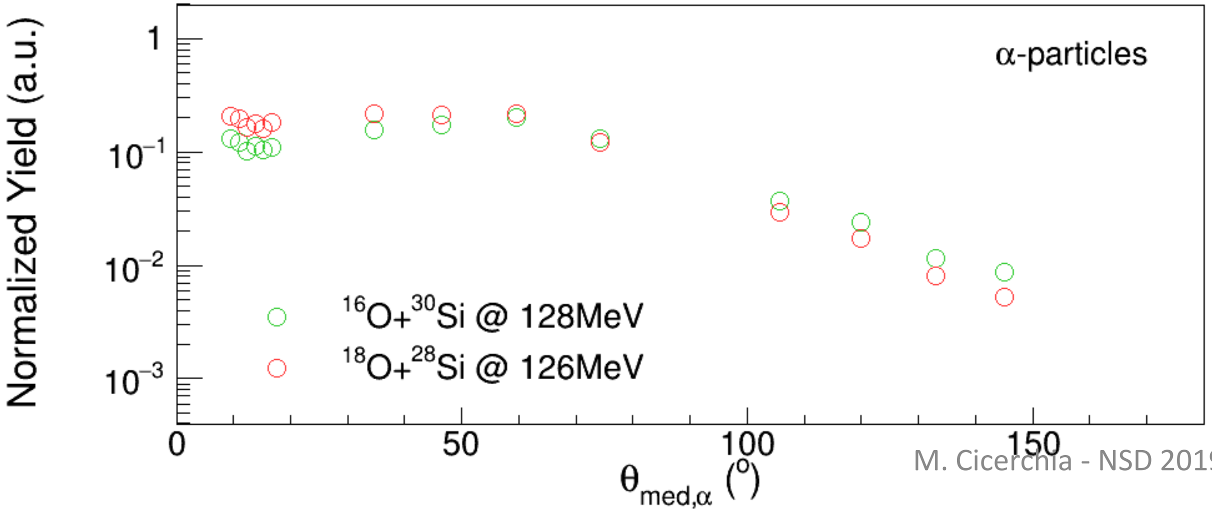


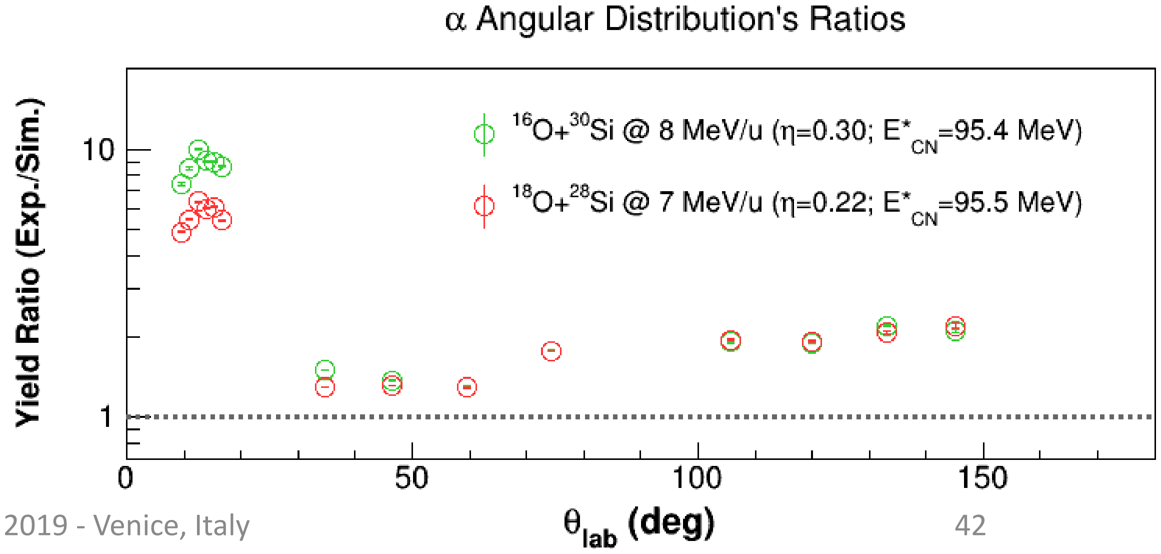


Ang Distr: AMD

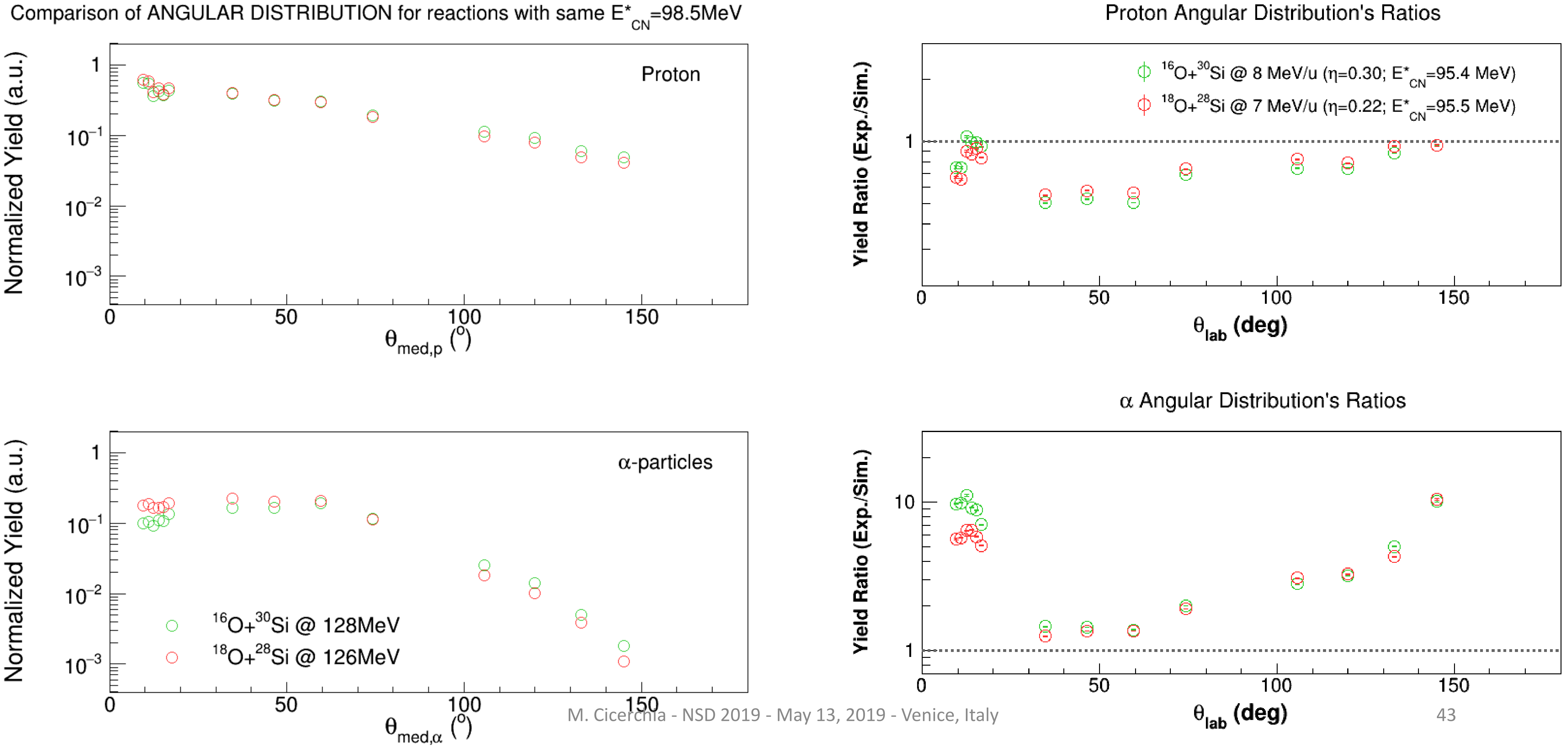






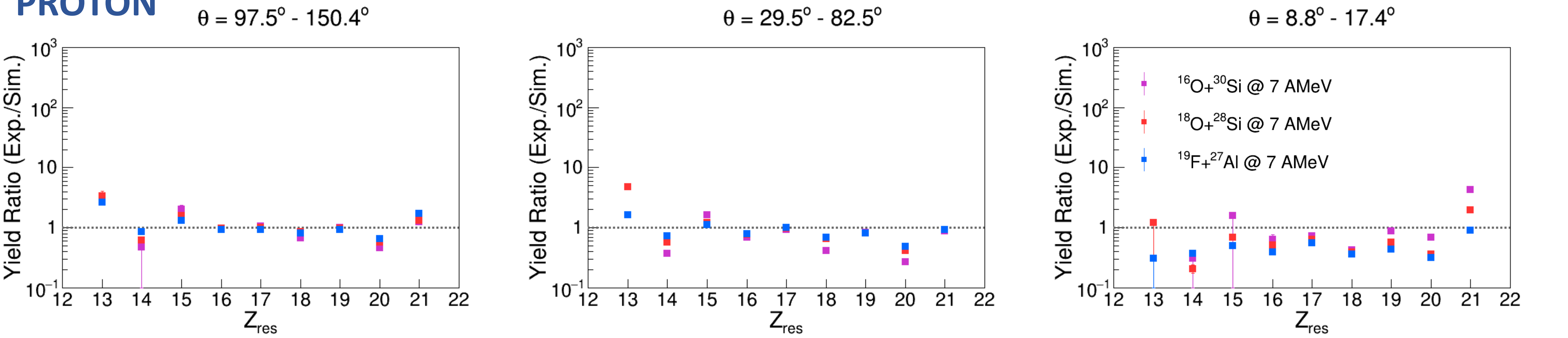


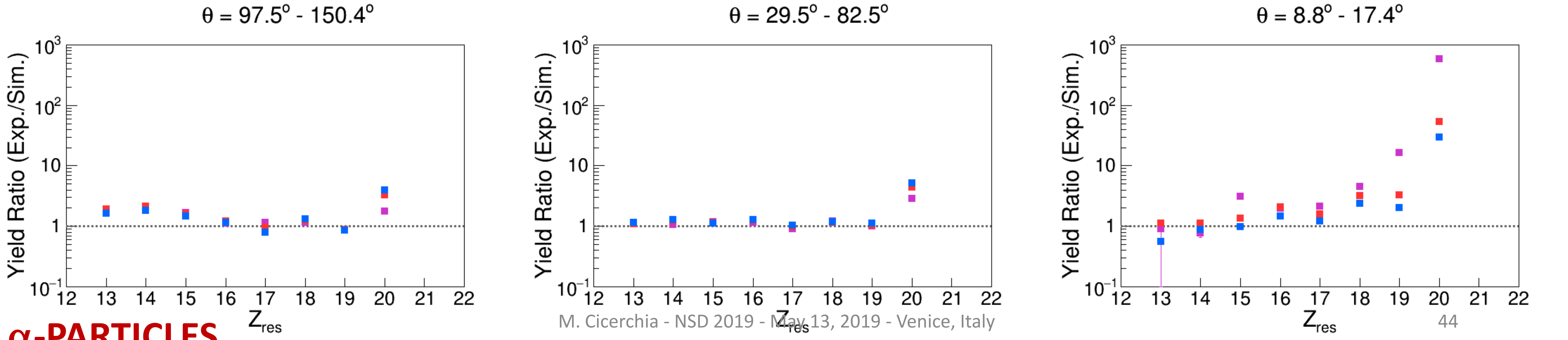
Ang Distr: HIPSE



Ratio Angular Distribution in exclusive channels

PROTON

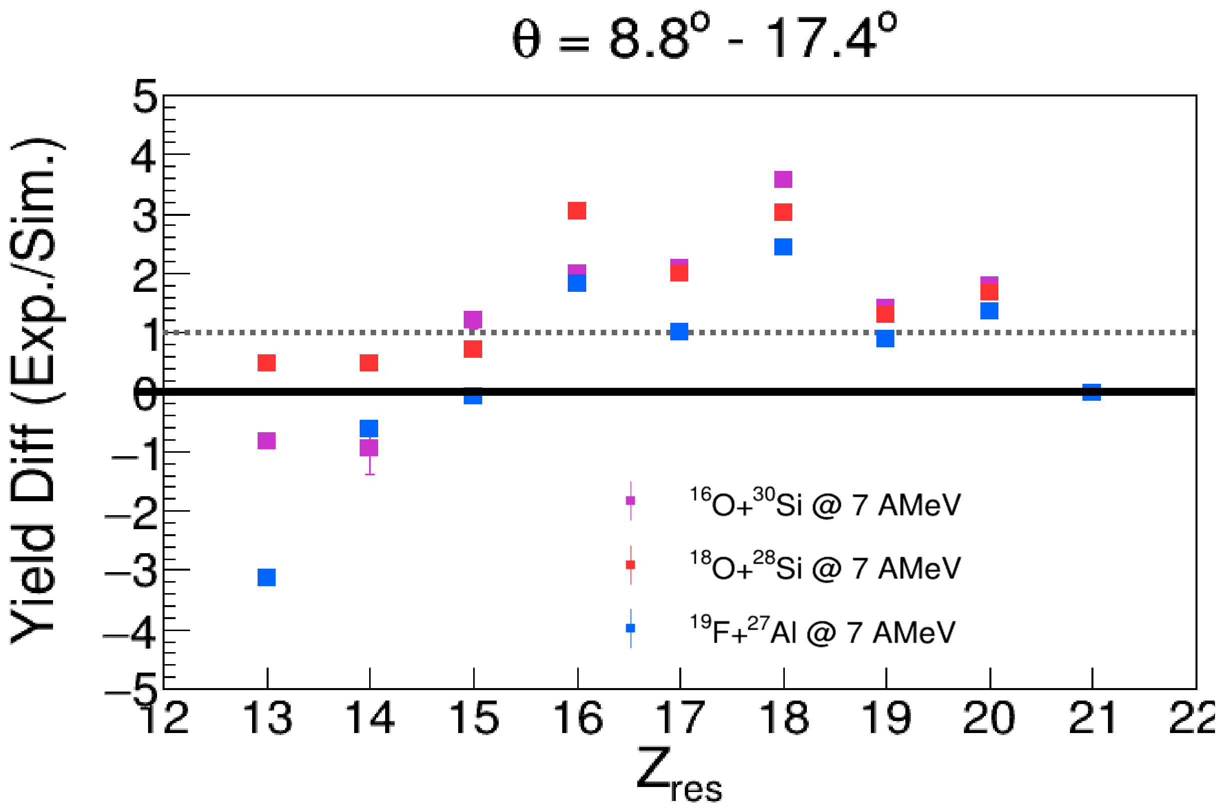




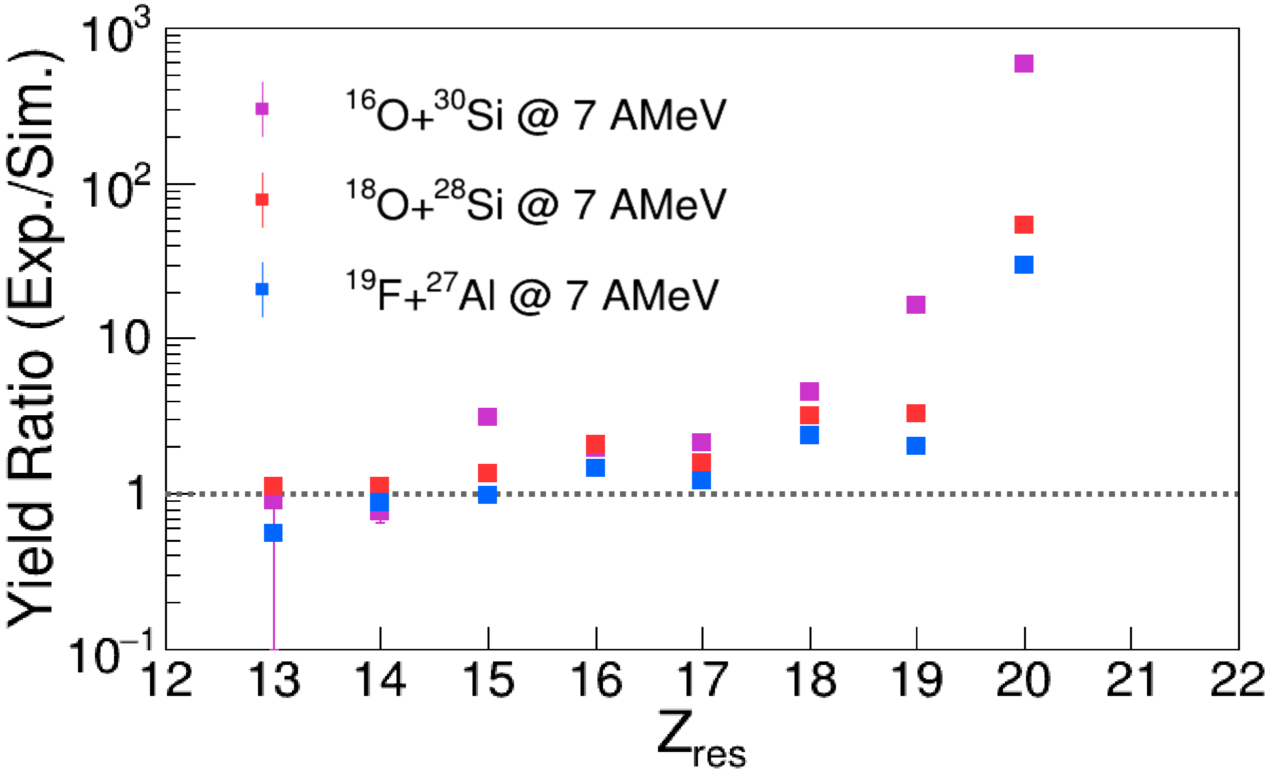
α-PARTICLES

RESULTS for the 3 reactions @ 7 AMeV

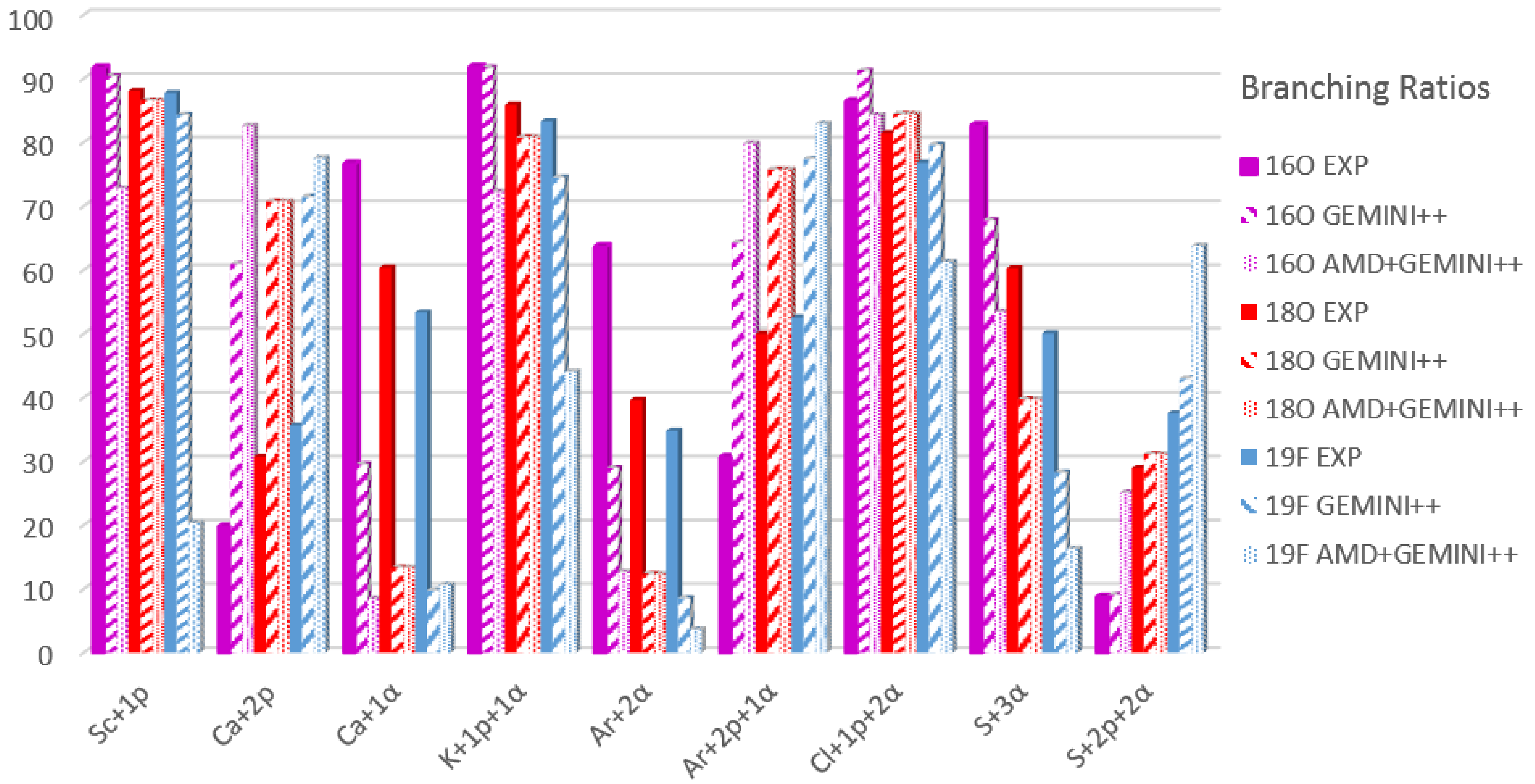
Difference of α-particles Angular Distribution in exclusive channels



Ratio of α-particles Angular Distribution in exclusive channels



BR @ 7 MeV exp and Ggeo and AMD



RESULTS for the 3 reactions @ 7 AMeV

$^{16}O+^{30}Si$ @ 7 MeV/u (η=0.30; E^*_{CN}=88.0 MeV)

$^{18}O+^{28}Si$ @ 7 MeV/u (η=0.22; E^*_{CN}=95.5 MeV)

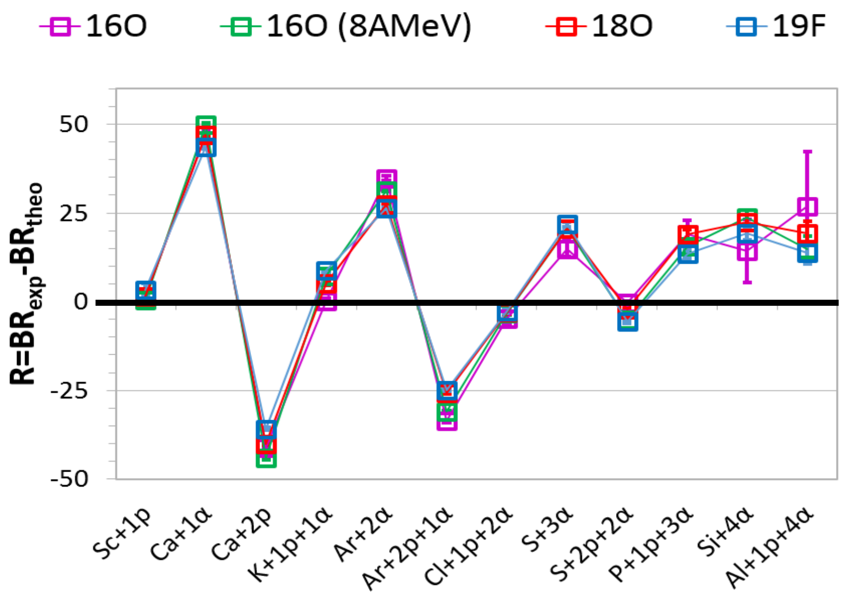
$^{19}F+^{27}Al$ @ 7 MeV/u (η=0.17; E^*_{CN}=103.5 MeV)

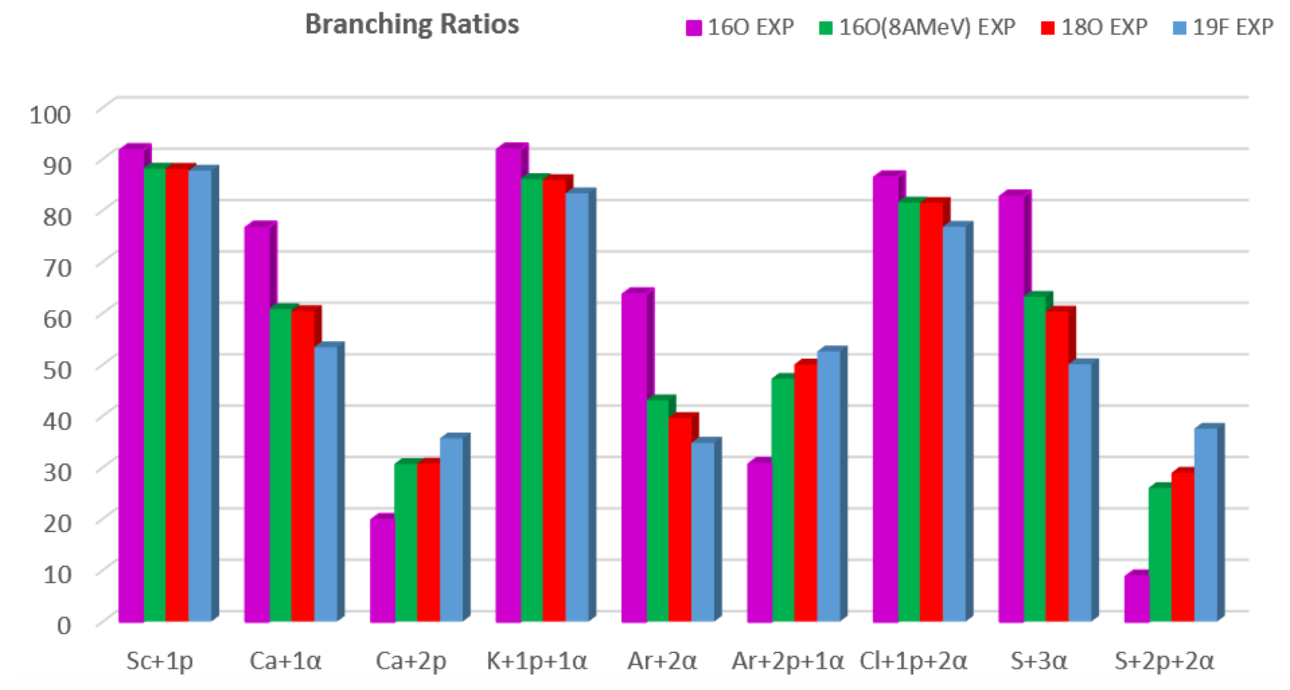
Branching Ratios of the most populated exit channels

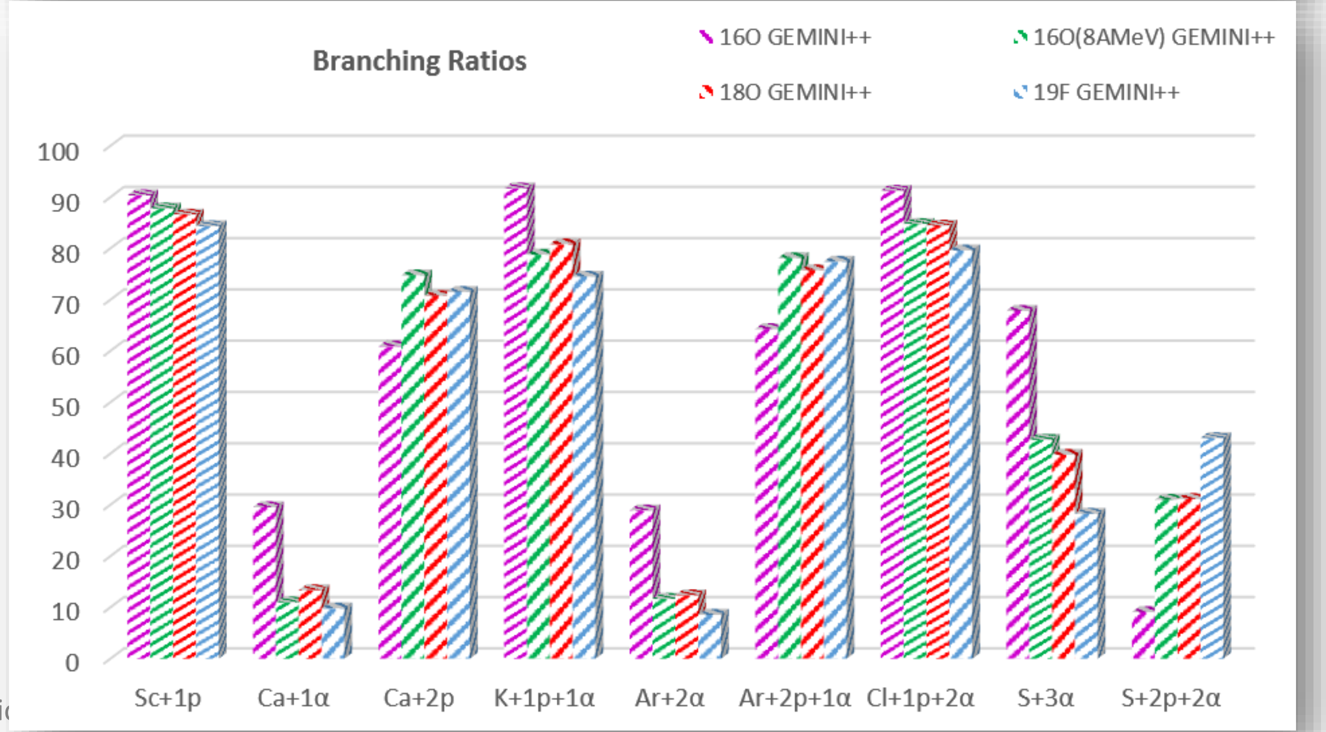
	^{16}O				^{18}O				^{19}F			
	EXP		G11	AMD	EXP		G11	AMD	EXP		G11	AMD
	BR(%)	err BR	BR(%)	BR(%)	BR(%)	err BR	BR(%)	BR(%)	BR(%)	err BR	BR(%)	BR(%)
Sc+1p	92	2	90	73	88	2	87	29	88	2	84	20
Ca+1α	76,6	0,9	29,6	8,5	60,4	0,6	13,4	5,7	53,4	0,6	9,8	10,7
Ca+2p	19,8	0,3	60,9	82,6	30,7	0,4	70,8	83,6	35,6	0,4	71,5	77,6
K+1p+1α	91,8	0,8	91,7	72,3	85,9	0,5	80,8	49,6	83,3	0,5	74,5	44,1
Ar+2α	63,7	0,7	28,9	12,7	39,6	0,3	12,4	4,8	34,8	0,3	8,6	3,7
Ar+2p+1α	30,6	0,4	64,3	79,8	50,0	0,3	75,8	84,0	52,5	0,3	77,4	83,0
Cl+1p+2α	86,4	1,5	91,3	84,3	81,4	0,6	84,5	67,4	76,8	0,6	79,6	61,3
S+3α	83	2	68	53	60,3	0,7	39,8	24,3	50,1	0,6	28,3	16,3
S+2p+2α	8,7	0,5	9,1	25,2	28,9	0,4	31,2	55,5	37,5	0,5	43,0	63,8
P+1p+3α	49	4	30	37	71,0	1,4	51,9	57,1	73,5	1,3	60,1	63,1
P+3p+2α	0,4	0,2	0,0	0,3	0,49	0,07	0,17	2,47	1,10	0,09	0,70	42,37
P+2α+Li	12,6	1,7	0,5	1,5	7,7	0,3	1,5	1,7	6,8	0,3	1,6	3,2
P+1p+1α+Li	4,0	0,8	1,9	2,4	4,6	0,2	5,7	5,2	4,3	0,2	7,2	1,6
P+1α+B	33	3	67	58	11,0	0,4	36,1	27,6	7,5	0,3	23,3	4,3
Si+4α	81	9	67	56	71	2	49	45	62	2	43	20
Si+2p+3α	1,6	0,8	0,0	1,6	5,1	0,4	2,2	8,7	9,4	0,5	4,0	46,3
Si+2α+Be	9	2	9	9	7,6	0,5	6,1	7,0	7,0	0,4	6,8	11,9
Si+1p+1α+B	6	2	23	31	12,3	0,6	40,1	33,0	13,6	0,6	40,9	4,0
Al+1p+4α	27	15	0	8	32	3	12	29	39	3	25	45
Al+2α+B	50	24	100	92	47	5	84	65	36	3	63	46

Conclusions

- …







Conclusions

Alpha channels

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Beam + Target	cm/ns	deg	mb
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