E818

E818: Ar+Ni 74 A MeV Methodology & first results (proposed article)

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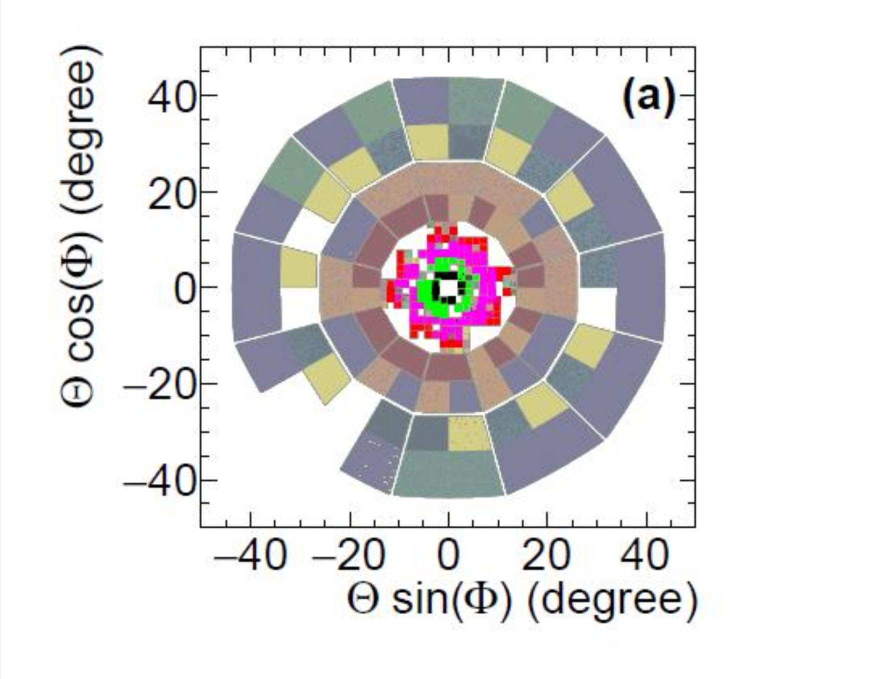
ARTICLE

- « long » section concerning experimental situation. « Long » because of some complex identification problems.
- The aim is that this article can be used for future articles without having to go through all that tedious experimental description.
- Physics: reaction mechanisms and isotope production.

EXPERIMENTAL SITUATION



- Rings 10 to 17 of the multidetector INDRA (Laboratory polar angles greater than 45 degrees) are not energy calibrated for this study. Therefore they are discarded in the analysis. We will see later that this point is not penalizing, since this study concerns the forward part of the centre-of-mass reference frame (hereinafter referred to as c.m.).
- The white parts of the figure 1-a correspond to the blind parts of the experimental set-up. In particular six INDRA telescopes were not working during the experiment.

FAZIA selection

Ecode>0 && Ecode<3

IDcode>11

INDRA selection

Rings 6-9

Ecode>0 && Ecode<3

In addition elimination of few particles:

Event selection (to remove « noise »)

Ztot4pi<56

M4pi<46

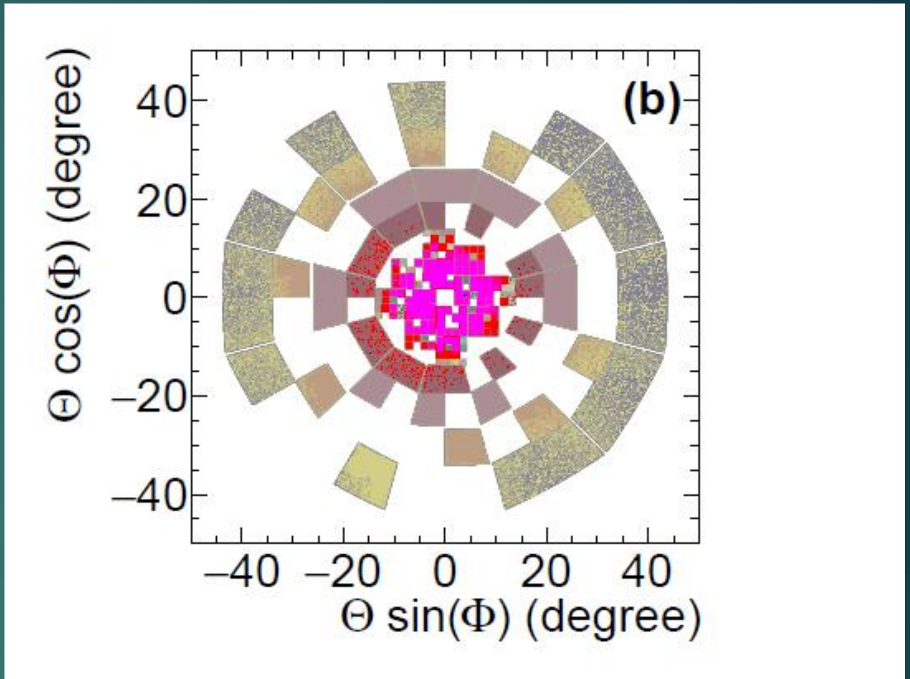
Particle selection (to remove “noise”)

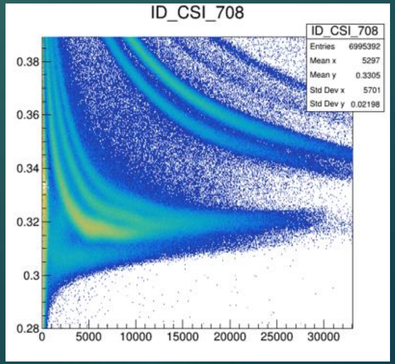
Z==1&&A==2&&Elab>260 MeV Eliminated

Z==1&&A==1&&Elab>199 MeV Eliminated

EXPERIMENTAL SITUATION

- During the experiment, several INDRA telescopes showed a loss of isotopic resolution for Z=1. This effect does not affect the other detected elements. This loss of resolution occurs above a certain value of the produced amount of light detected by the CsI(Tl). Because the Z identification is correct, these telescopes will be used initially to assess the charge completeness of detection in the forward part of the c.m. frame. An analysis of INDRA's first campaign on the same system indicates that these Z=1 particles corresponding to a high value of the produced light in the CsI(Tl) are emitted forward in the c.m. frame. In a second step, because for those telescopes the Z=1 energy is not measured properly above a certain threshold, these detectors will be entirely declared Z=1 blind. Thanks to INDRA's azymuthal symmetry, it will be possible to take into account for this blindness. The white part of figure 1-b takes up the previous problems and the choice of eliminating telescopes that are partially blind to the isotopic separation of Z=1. The colored part of figure 1-b thus indicates all detectors suitable for ^{1}H, ^{2}H and ^{3}H analysis.





Mass identification

Table 1. Percentage of mass identified particles for each element compared with the element's total detected production for INDRA. This concerns telescopes shown in Figure 1-a except for H where the percentage relates to the telescopes shown in Figure 1-b. The low isotopic resolving power beyond oxygen is caused by a small population that don't allow mass identification.

H	He	Li	Be	B	C	N	O	F	>F
100%	100%	100%	100%	98.8%	98%	89.7%	71.5%	5.3%	0%

Table 2. Percentage of mass identified particles for each element compared with the element's total detected production for FAZIA. This concerns telescopes shown in Figure 1-a. Isotopic resolution beyond Chlorine element suffers from the presence of a spot of quasi-elastic events.

H	He	Li	Be	B	C	N	O	F
99.2%	99.8%	99.3%	99.8%	99.4%	99.4%	99.4%	99.6%	99.6%
Ne	Na	Mg	Al	Si	P	S	Cl	Ar
97.2%	97.8%	98.8%	99.2%	99.5%	99.2%	99.2%	98.1%	47.5%

Data: forward part of c.m. frame

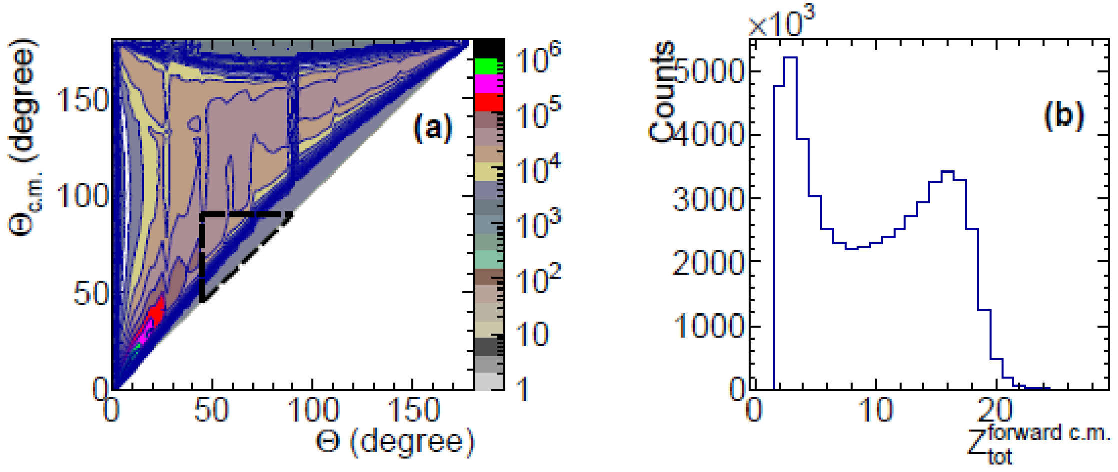
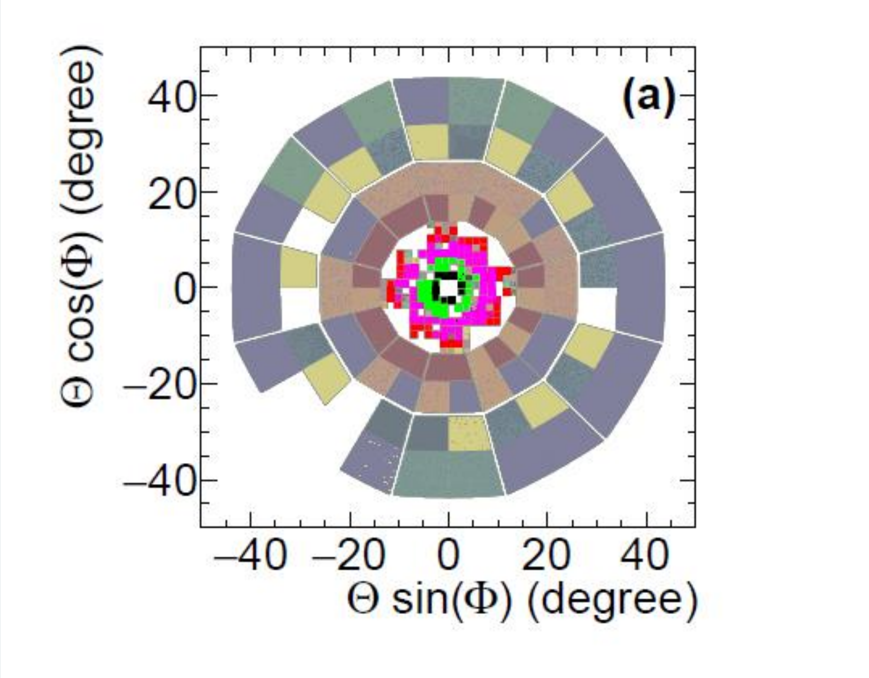


Figure 2. (Color online) **(a)**: Data from first INDRA campaign (1993), relationship between the c.m. frame polar angle and the Laboratory frame polar angle. Particles contained within the triangle area are not detected by the present selected detection system. **(b)**: total atomic number detected in the forward part of the c.m. frame (present experiment).

SELECTION



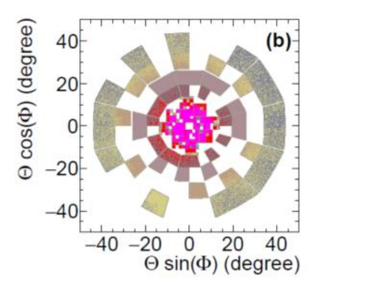
Ztot forward c.m. > 15
Mtot forward c.m. > 1

Correction for Z=1 efficiency

Table 4. Review of the number of problematic INDRA telescopes per ring and associated corrective factor for Z=1.

INDRA ring number	6	7	8	9
Polar angle coverage (^{o})	14-20	20-27	27-35	35-45
Number of telescopes	24	24	24	24
Number of not working telescopes (figure 1-a)	0	0	4	2
Number of telescopes Z=1 declared blind	7	10	10	6
Correction factor	24/17	24/14	20/10	22/16

This is not 24/10 (24/16) because Z_{tot} forward c.m. has been calculated with 20 (22) telescopes.



Impact parameter estimator

$$V_{front}^{Z>1} = \left(\frac{|\sum_{i(Z>1)} M_i \vec{V}_i^{c.m.}|}{\sum_{i(Z>1)} M_i} \right)_{forward\ c.m.}$$

Z=1 are not used

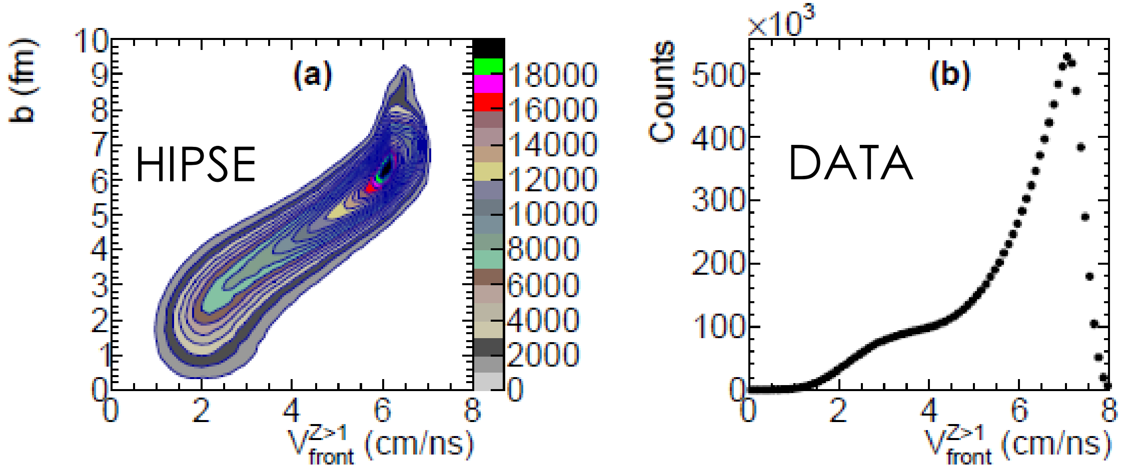


Figure 3. (Color online) **(a)**: correlation between the true model impact parameter and the impact parameter estimator (HIPSE event generator). **(b)**: impact parameter estimator distribution (present experiment).

V_{front}

N.b.: idem (without Z=1) E_{diss} (E. Galichet et al. PRC 79 (2009) 064614)

$$E_{diss} = E_{c.m.} - \frac{1}{2}\mu V_{rel}^2,$$

$$V_{rel} = V_{QP}^{rec} \times \frac{A_{tot}}{A_{target}},$$

Overview of reaction mechanisms

Data detected from 1.9° to 45° (Lab. Frame)

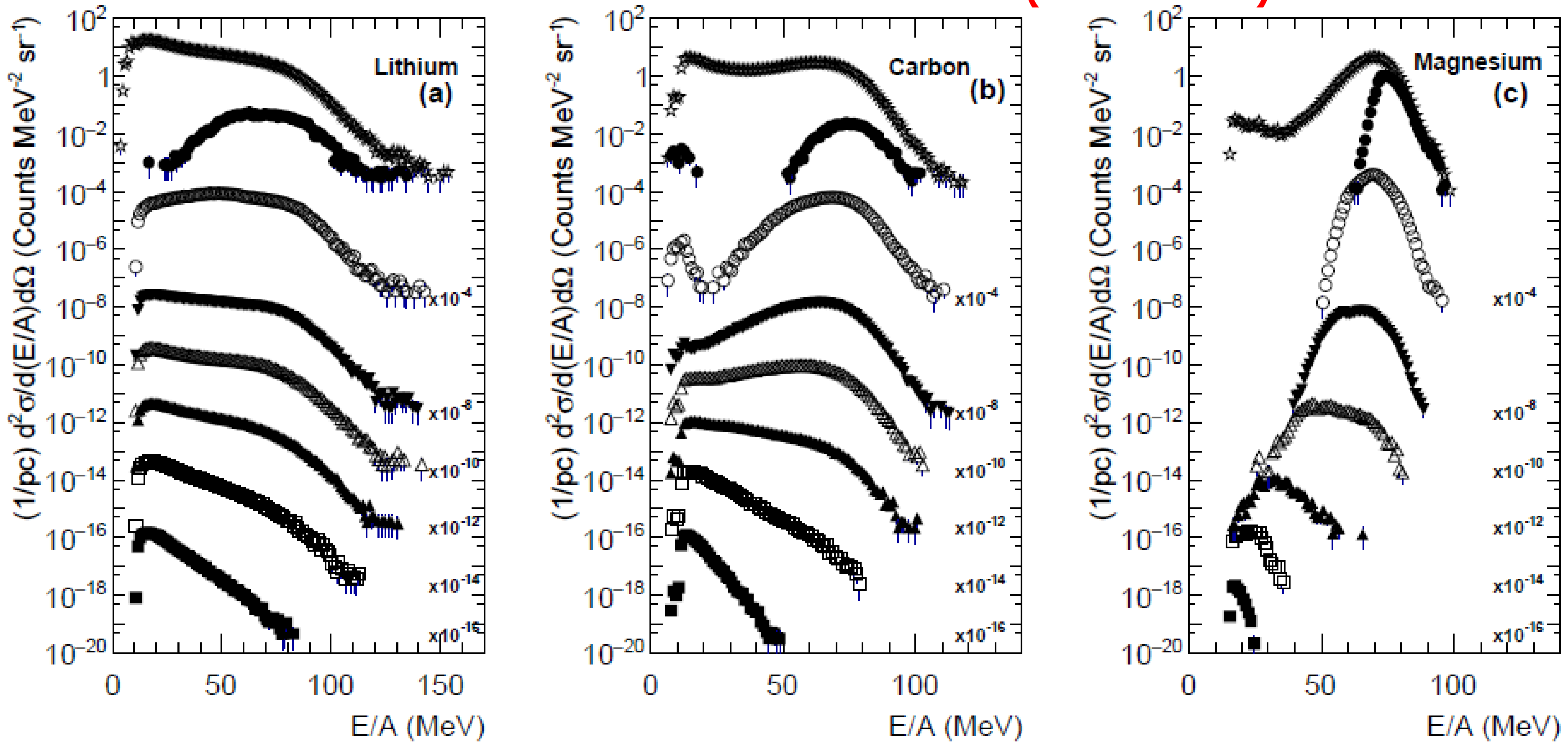


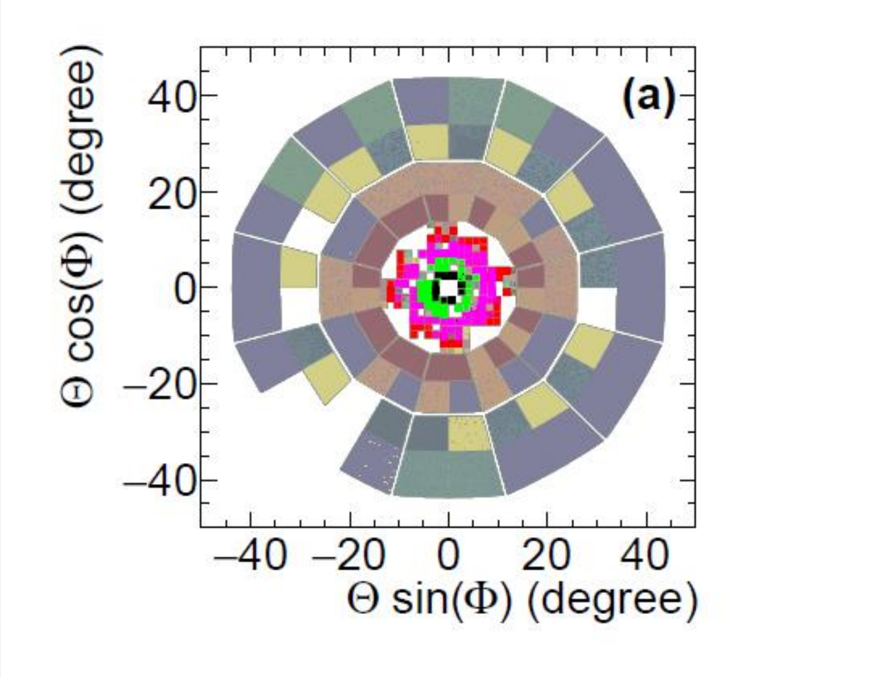
Figure symbol	■	□	▲	△	▼	○	●
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

Star: total

Invariant cross-section in the Laboratory frame.

Target fragments are eliminated when selecting forward part of c.m. frame.

SELECTION

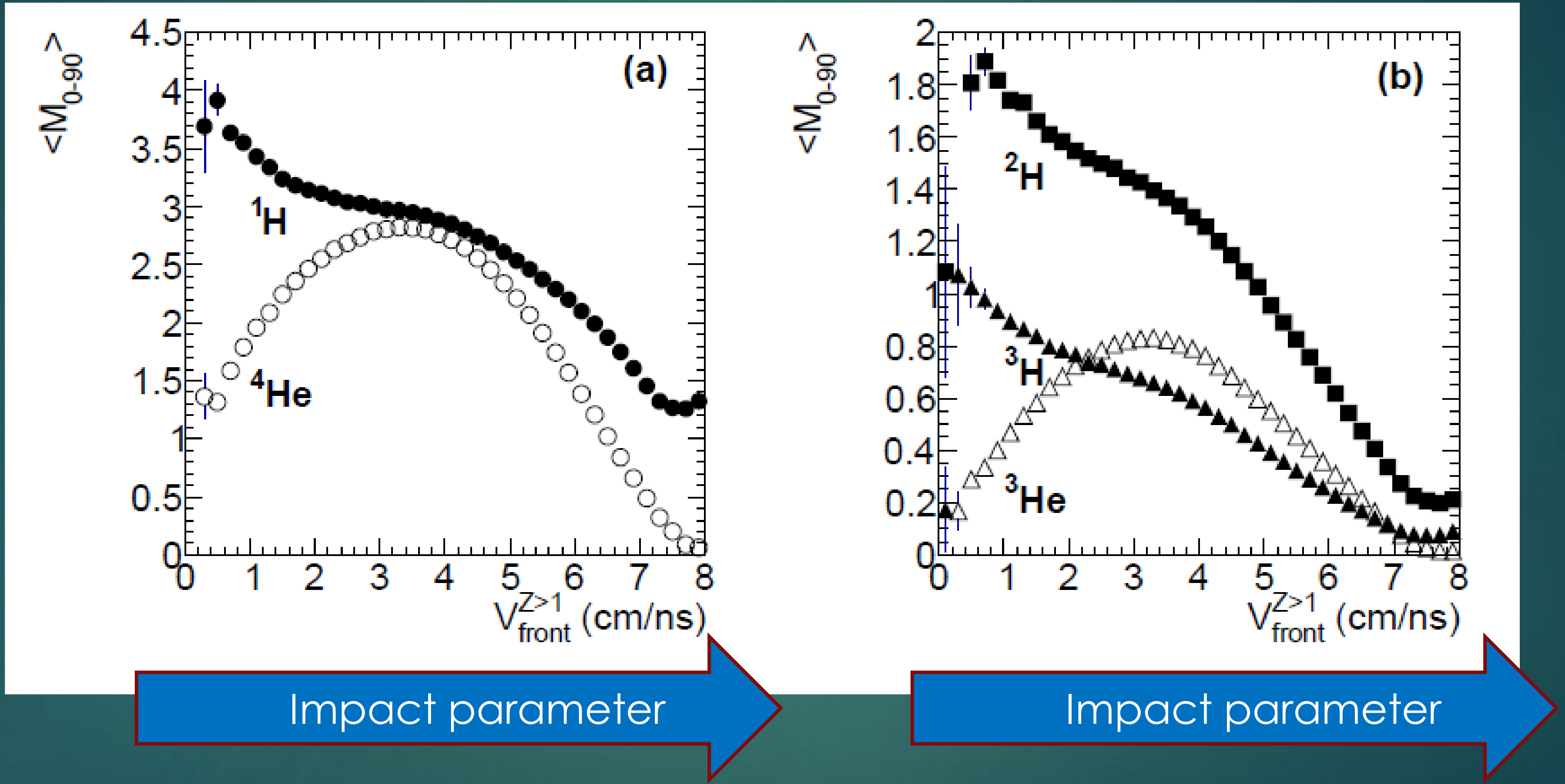


Ztot forward c.m. > 15
Mtot forward c.m. > 1

In the following only the particles detected in the forward part of the c.m. frame are presented

Overview of reaction mechanisms

Light charged particle multiplicities in the forward part of c.m.

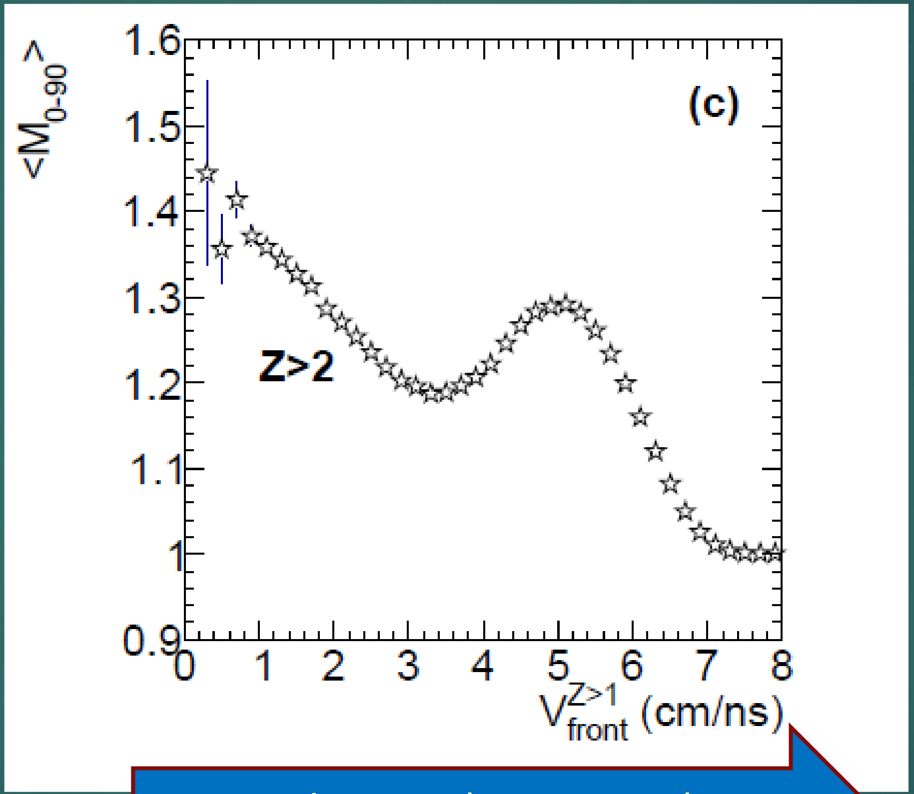


Z=1 (1H, 2H, 3H) multiplicities: change of slope around $V_{front}^{Z>1}$ =3.5 cm/ns.

Z=2 (3He, 4He) multiplicities: maximum production around $V_{front}^{Z>1}$ =3.5 cm/ns.

Overview of reaction mechanisms

Z>2 multiplicity in the forward part of c.m.



Impact parameter

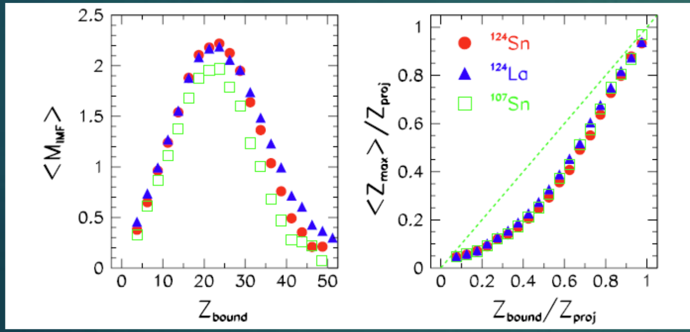
Impact parameter

Z>2 multiplicity: « rise and fall » for $V^{Z>1}_{front}$ =8.0 - 3.5 cm/ns.
Z>2 multiplicity: change of behaviour for $V^{Z>1}_{front}$ < 3.5 cm/ns.

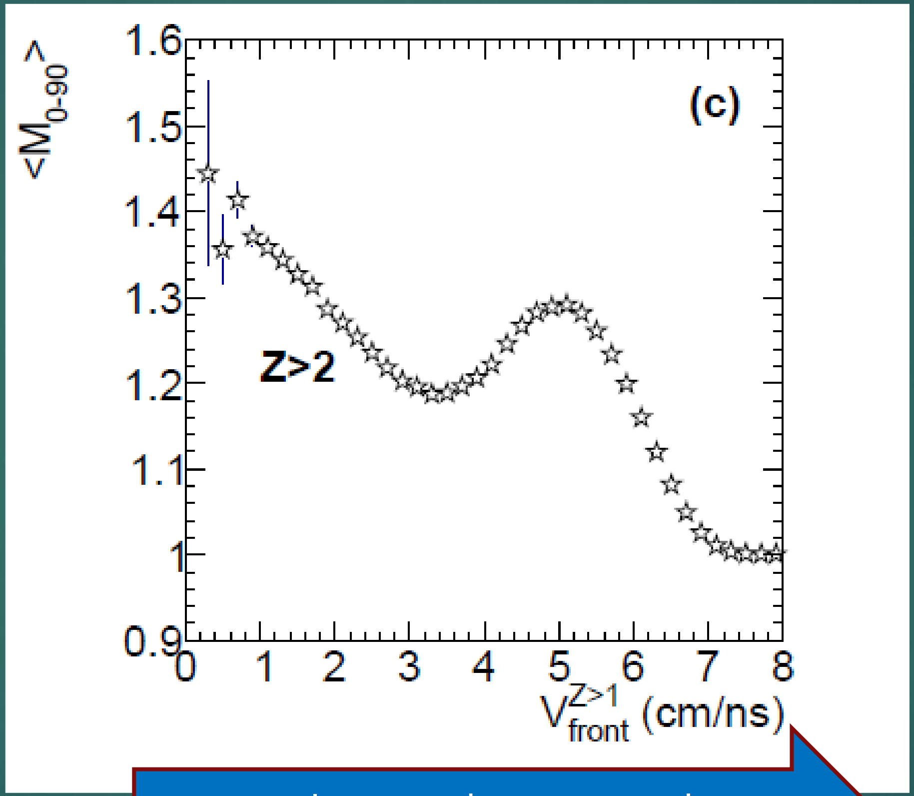
Overview of reaction mechanisms

Z>2 multiplicity in the forward part of c.m.

Multifragmentation of projectile spectator 124Sn, 124La and 107Sn at 600 A MeV. Intermediate Mass Fragment multiplicity



C. Sfienti et al. PRL 102 (2009) 152701 (ALADIN)



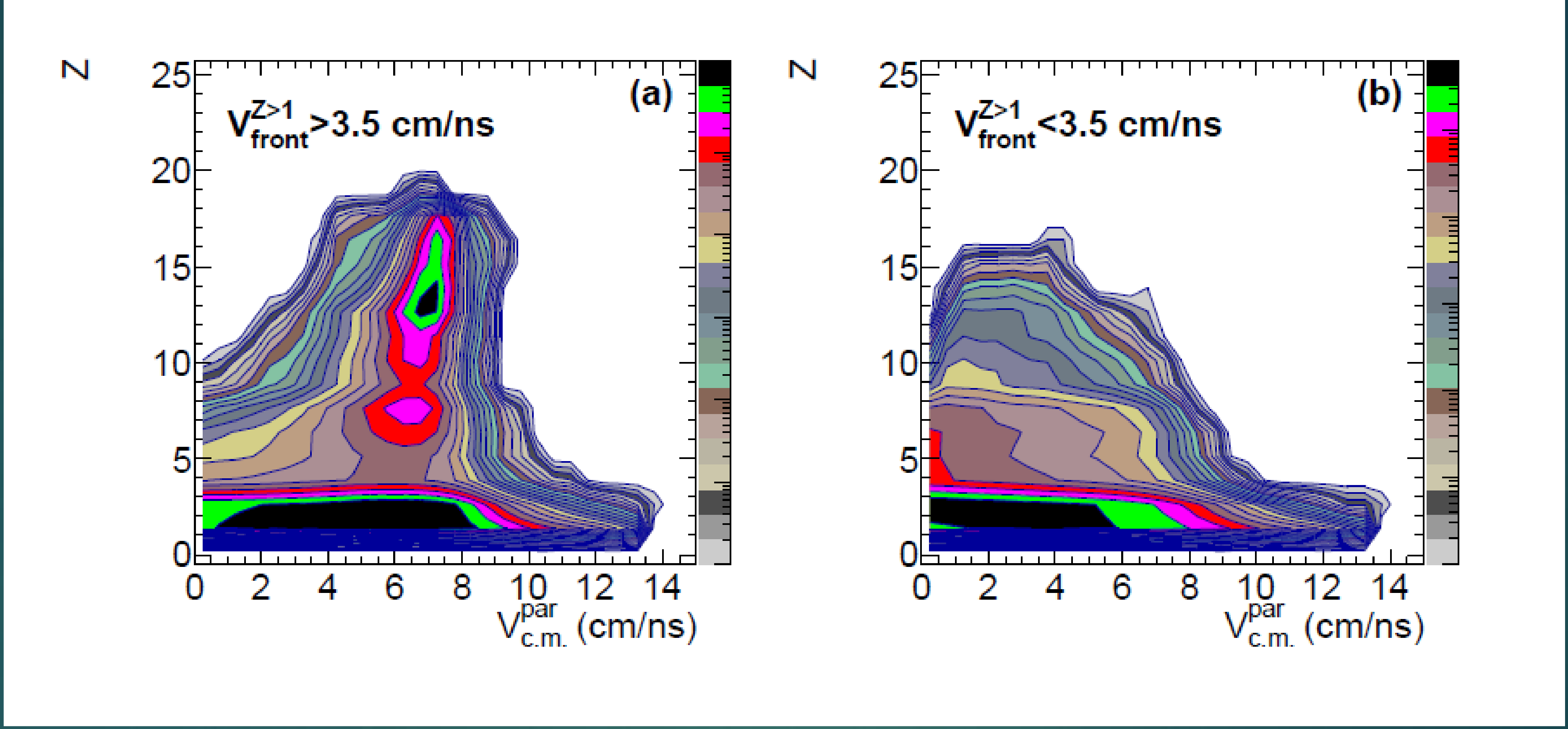
Impact parameter

Impact parameter

Z>2 multiplicity: « rise and fall » for $V_{front}^{Z>1}$ =8.0 - 3.5 cm/ns.

Z>2 multiplicity: change of behaviour for $V_{front}^{Z>1}$ < 3.5 cm/ns.

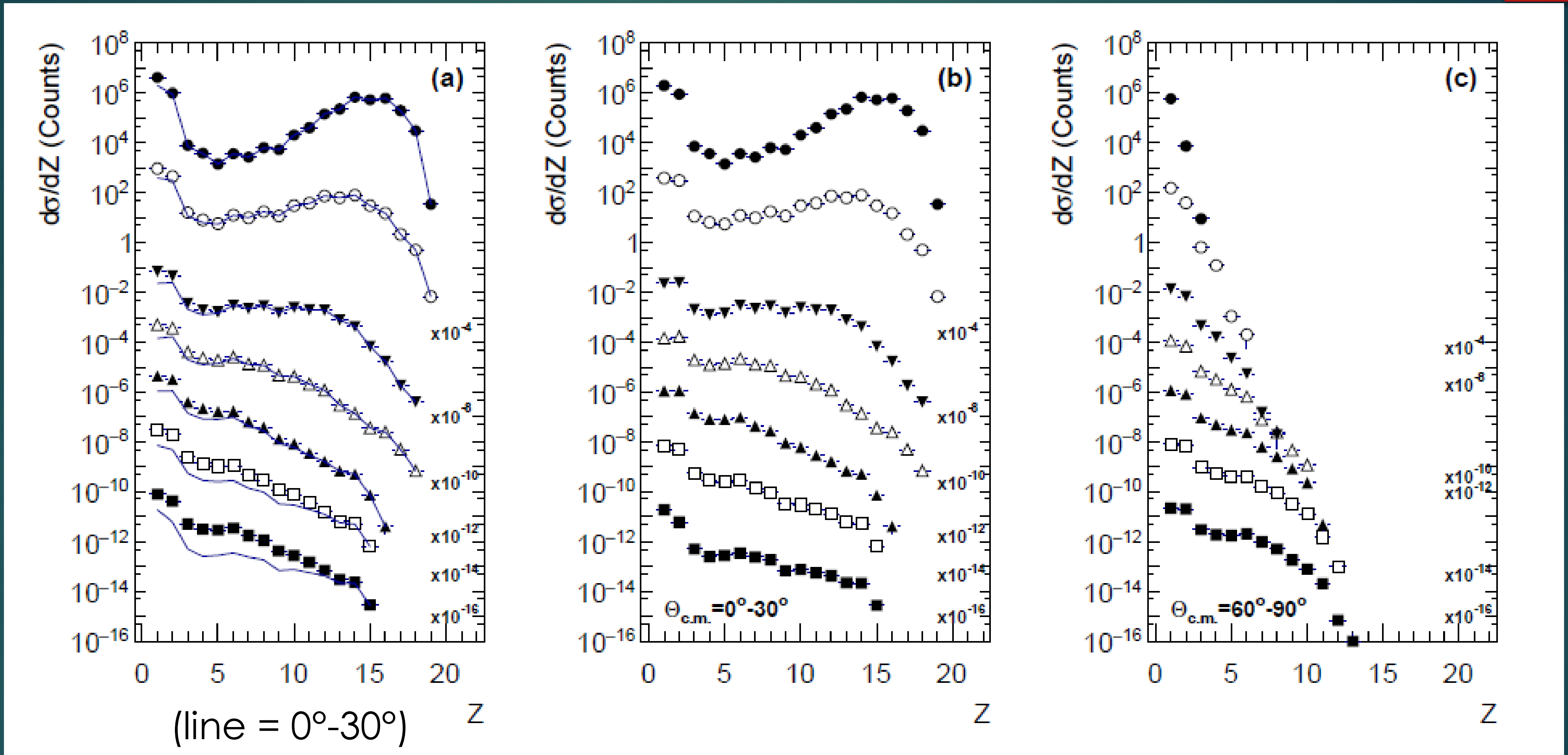
Overview of reaction mechanisms



Peripheral events:
Projectile like fragment physics and ½ rapidity/neck emission.

Central events:
Multifragmentation of short live projectile+target combined system.

Forward part of the c.m. frame



0°-90°

0°-30°

60°-90°

Table 3. Symbols used for figures and labels used in the text for the seven intervals of impact parameter estimator ($V^{Z>1}_{front}$) .

Figure symbol	■	□	▲	△	▼	○	●
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

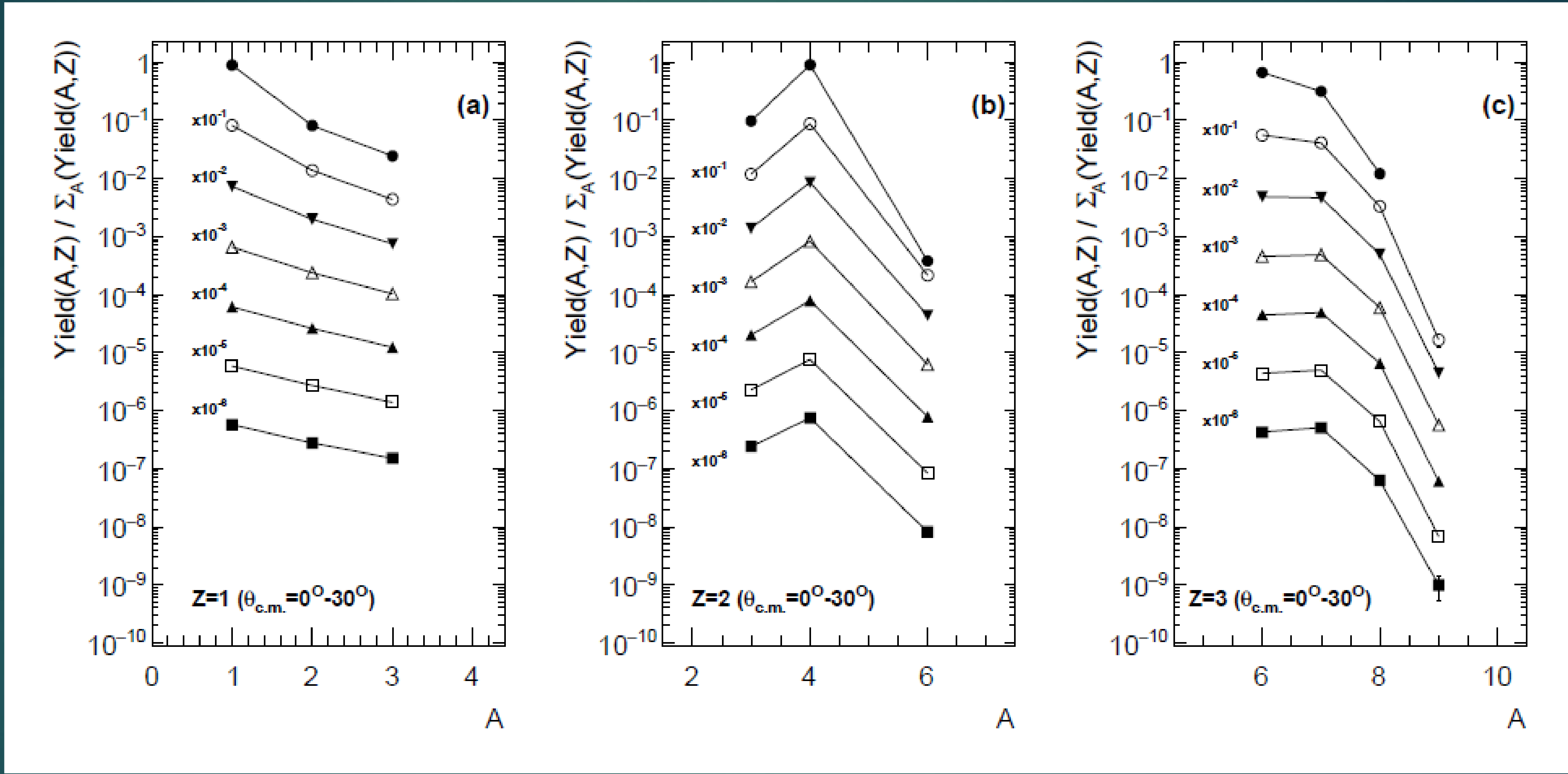
Atomic number distributions for several c.m. angular ranges

1) Normalized Yields 0°-30° c.m.

$$Normalized\,Yield(A,Z) = \frac{Yield(A,Z)}{\sum_A Yield(A,Z)}$$

From Hydrogen to Chlorine

1) Normalized Yields 0°-30° c.m.



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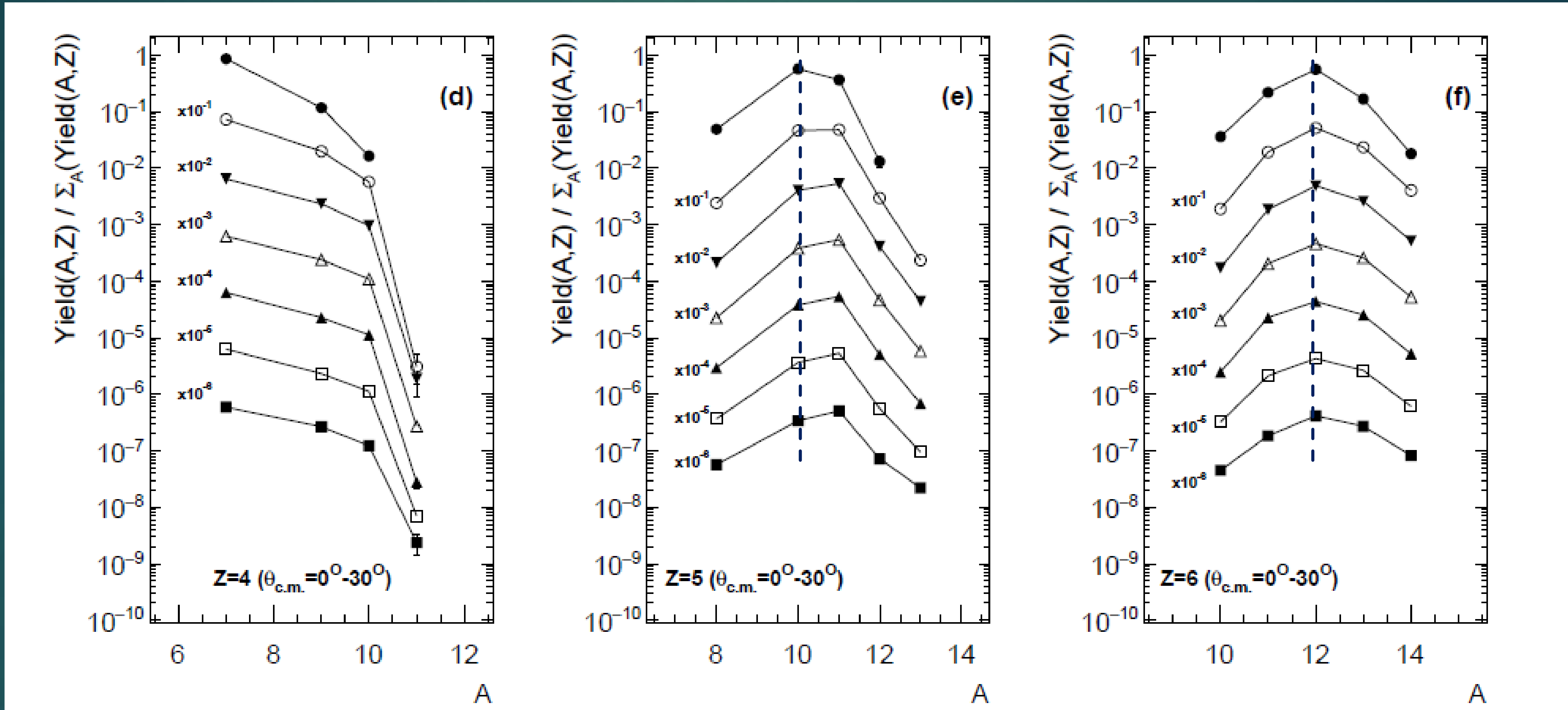
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

Most probable value:
for peripheral events ^{1}H, ^{4}He and ^{6}Li productions are enhanced as compared to more central events.

1) Normalized Yields 0°-30° c.m.



Black dashed line: N=Z

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Figure symbol	■	□	▲	△	▼	○	●
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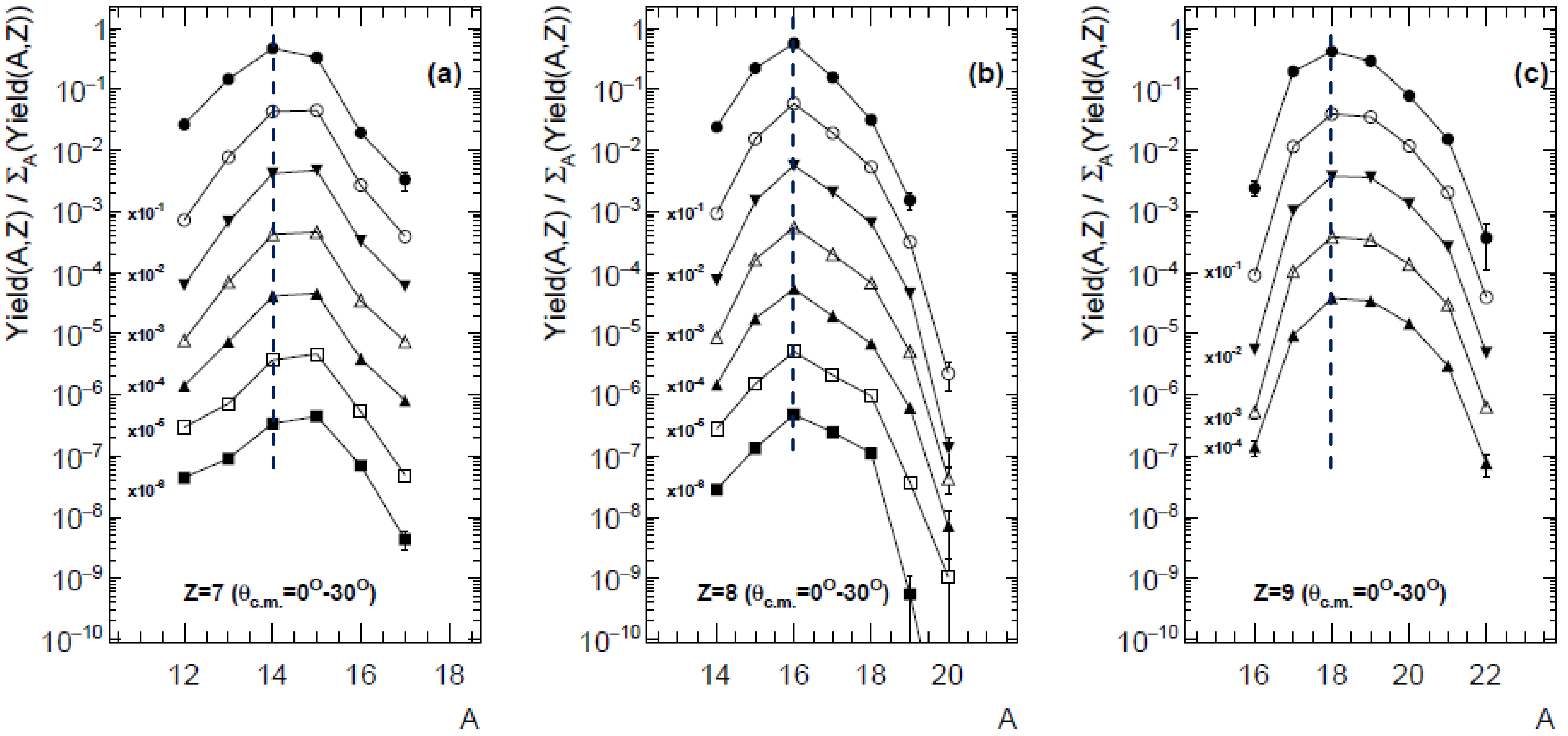
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

Most probable value:

For peripheral events ^{7}Be production is enhanced as compared to more central events. Carbon: N=Z, Boron: N=Z towards N>Z with decreasing impact parameter

1) Normalized Yields 0°-30° c.m.



Black dashed line: N=Z

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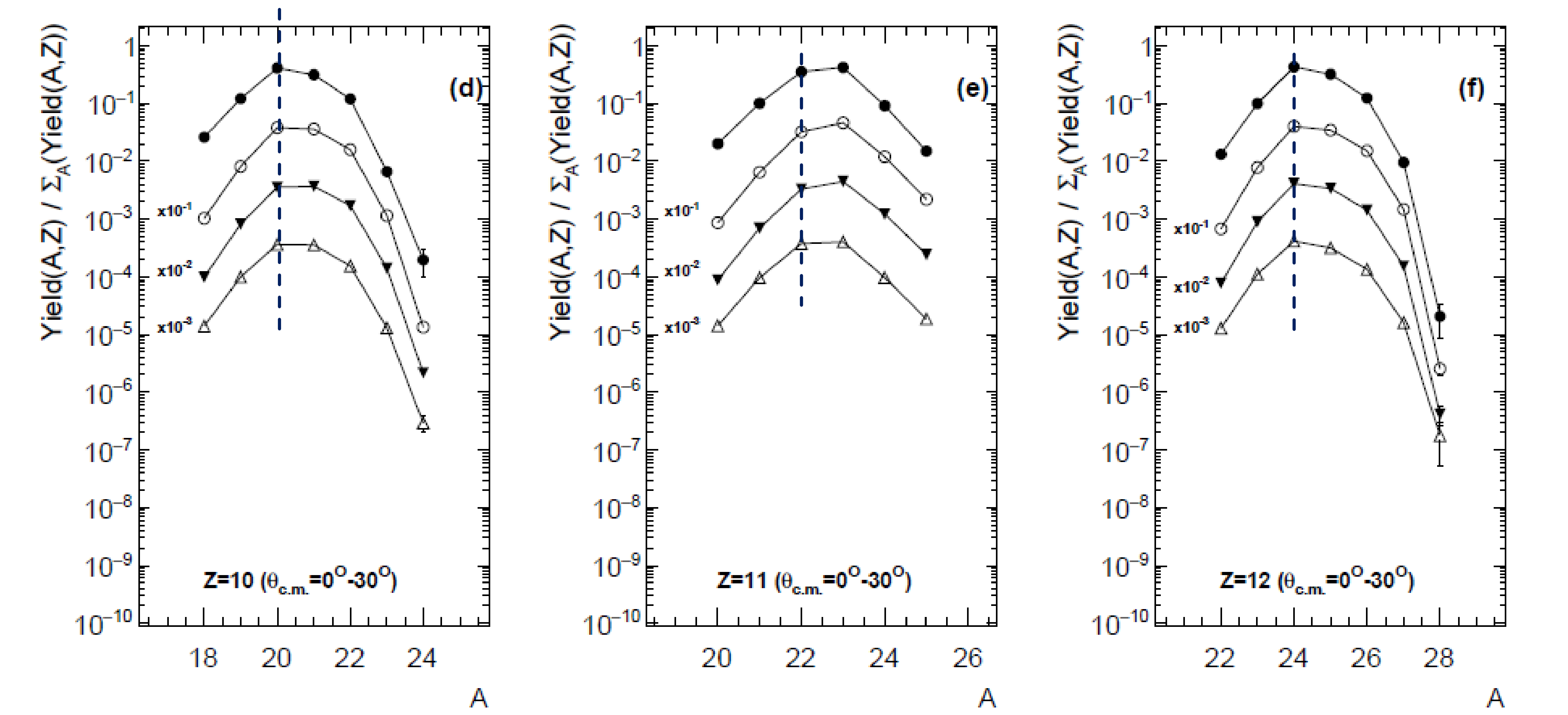
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

Most probable value:
Nitrogen: N=Z towards N>Z with decreasing impact parameter.
Oxygen and Fluor: N=Z.

1) Normalized Yields 0°-30° c.m.



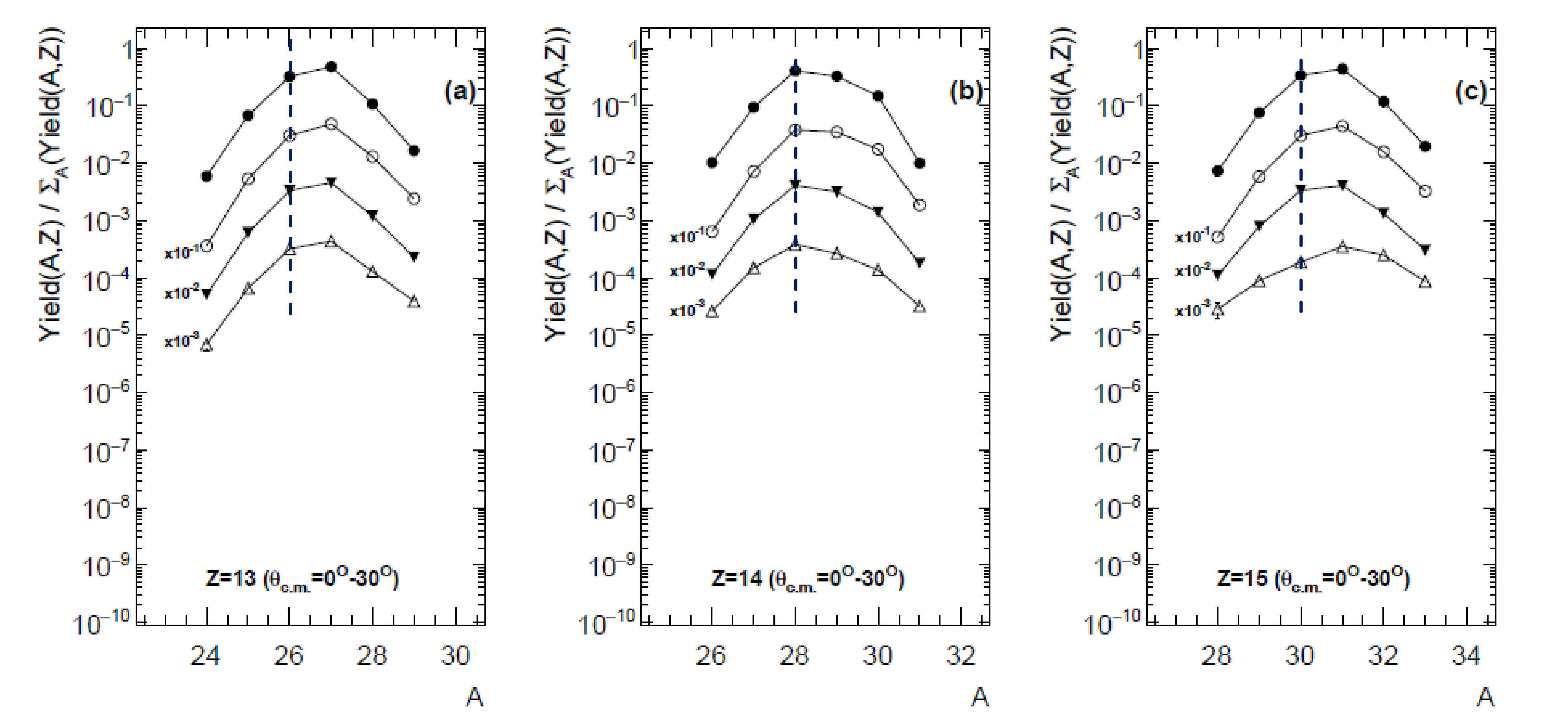
Black dashed line: N=Z

Table 3. Symbols used for figures and labels used in the text for the seven intervals of impact parameter estimator ($V_{front}^{Z>1}$) .

Figure symbol	■	□	▲	△	▼	○	●
Text label	1	2	3	4	5	6	7
$V_{front}^{Z>1}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

Most probable value:
Neon: N=Z towards N>Z with decreasing impact parameter.
Sodium: N-Z=+1, Magnesium: N=Z.

1) Normalized Yields 0°-30° c.m.



Black dashed line: N=Z

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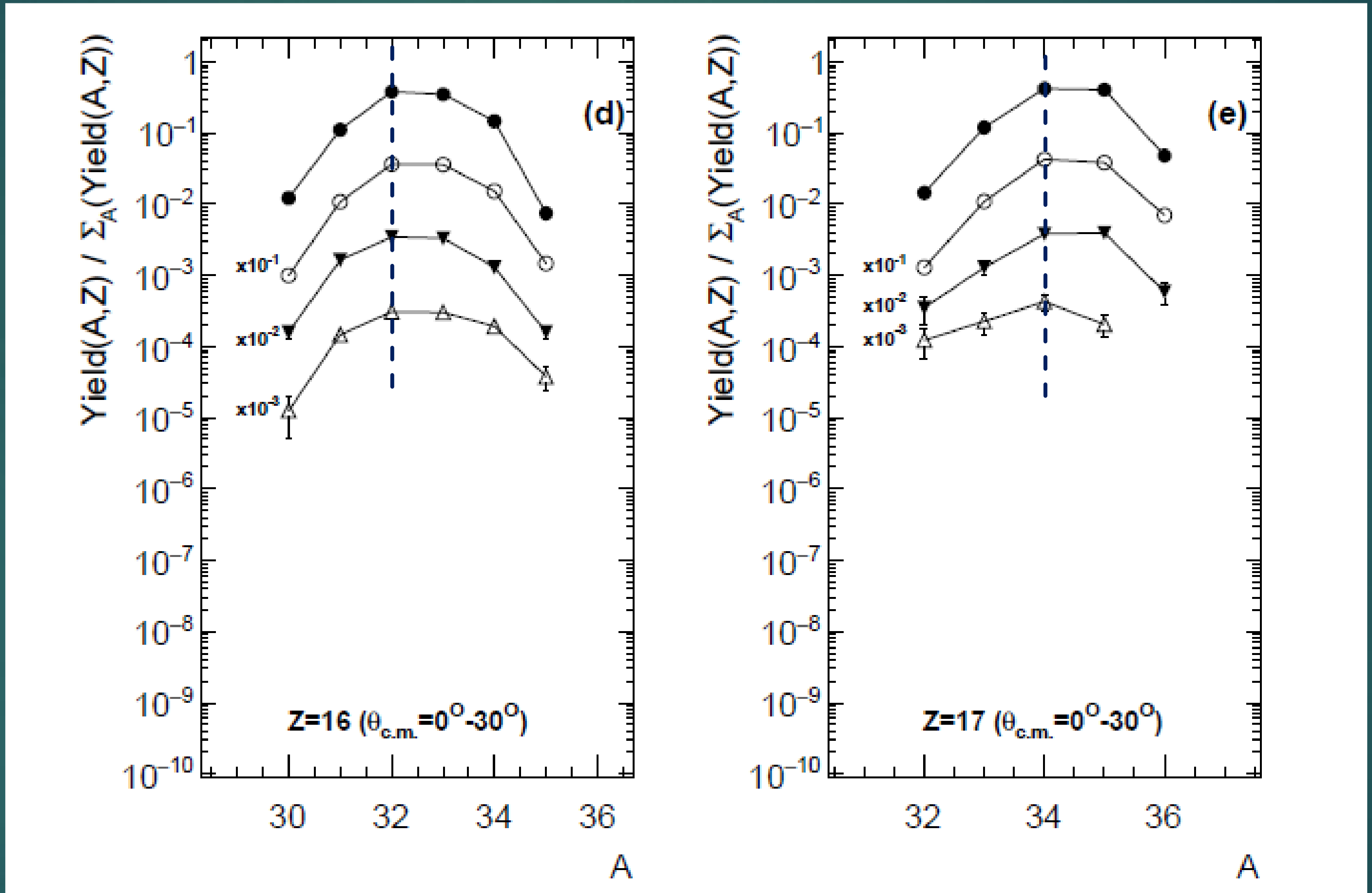
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

Most probable value:
Aluminium and Phosphorous: N-Z=+1.
Silicium: N=Z.

1) Normalized Yields 0°-30° c.m.



Black dashed line: N=Z

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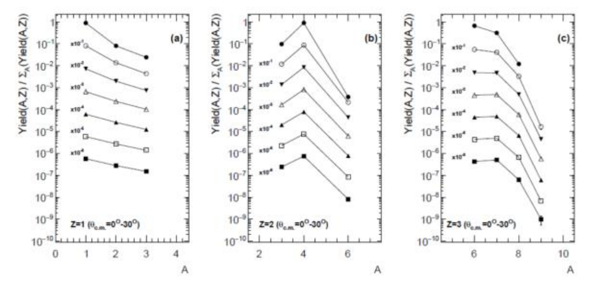
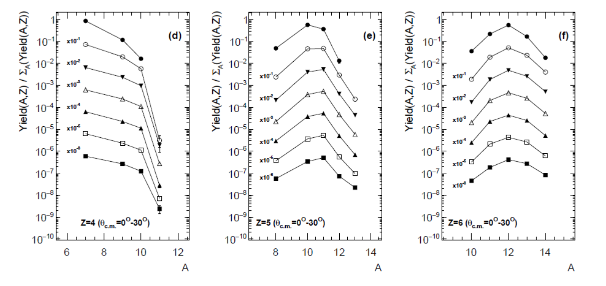
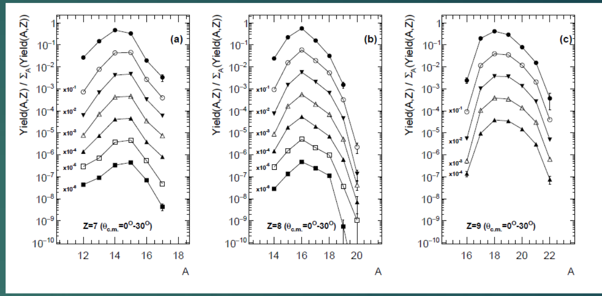
$V_{front}^{Z>1}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

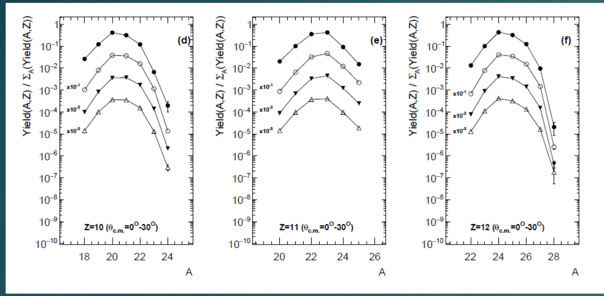
Most probable value:
Sulfur and Chlorine: N=Z.

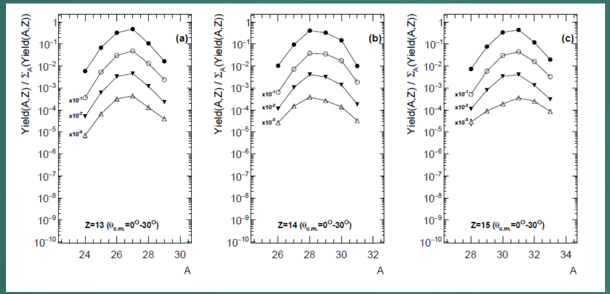
1) Normalized Yields 0°-30° c.m.

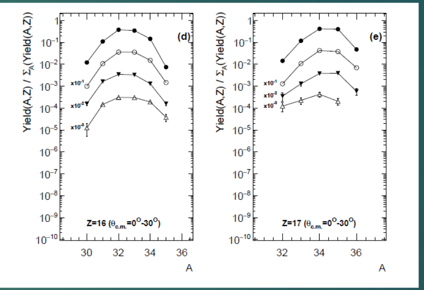












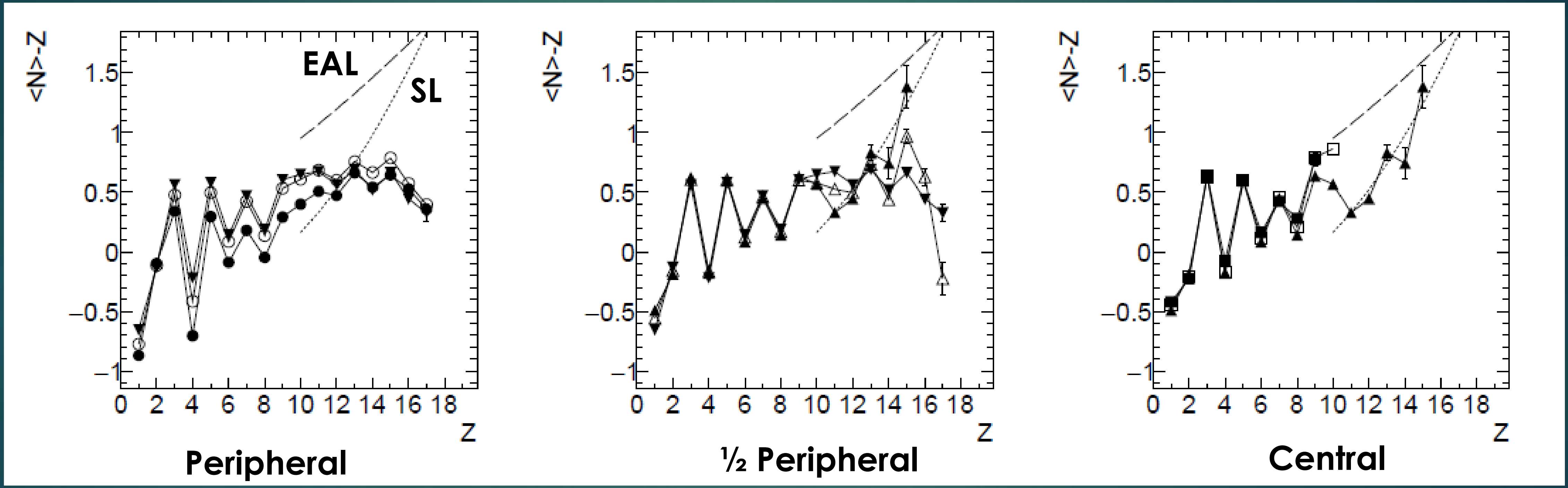
In the 0°-30° zone, all charged particles are identified in Z and A in this experiment.

This opens up many new avenues of study.

1) Normalized Yields 0°-30° c.m.

To summarize: Mean value of N-Z for each element for impact parameter bins

Warning: multiplicity of charged particles forward c.m. >1 !



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$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

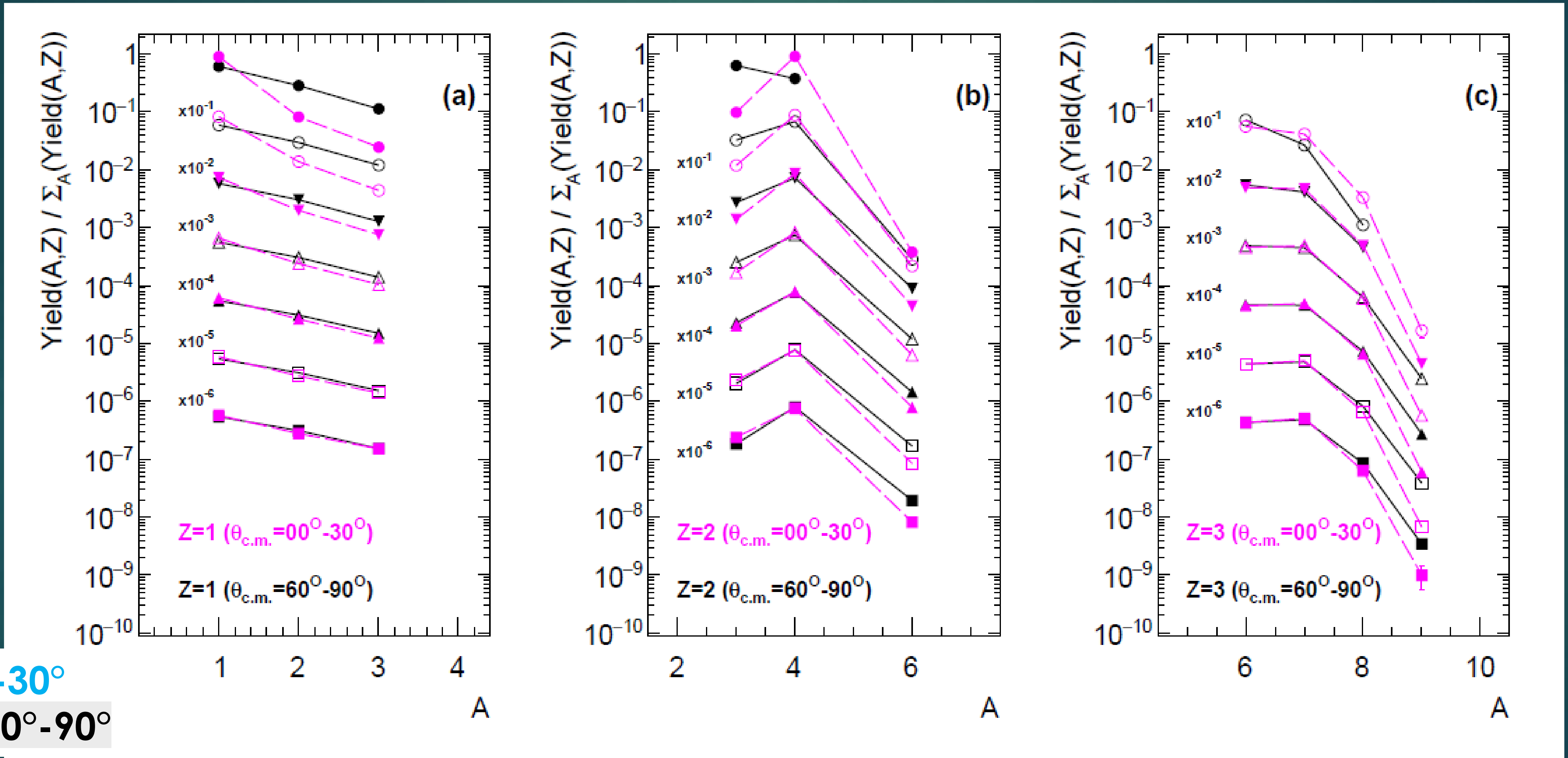
2) Normalized Yields 60°-90° c.m.

$$Normalized\, Yield(A, Z) = \frac{Yield(A, Z)}{\sum_A Yield(A, Z)}$$

From Hydrogen to Carbon

2) Normalized Yields 60°-90° c.m.

Mass identification up to Carbon with a high %



Blue: 0°-30°

Black: 60°-90°

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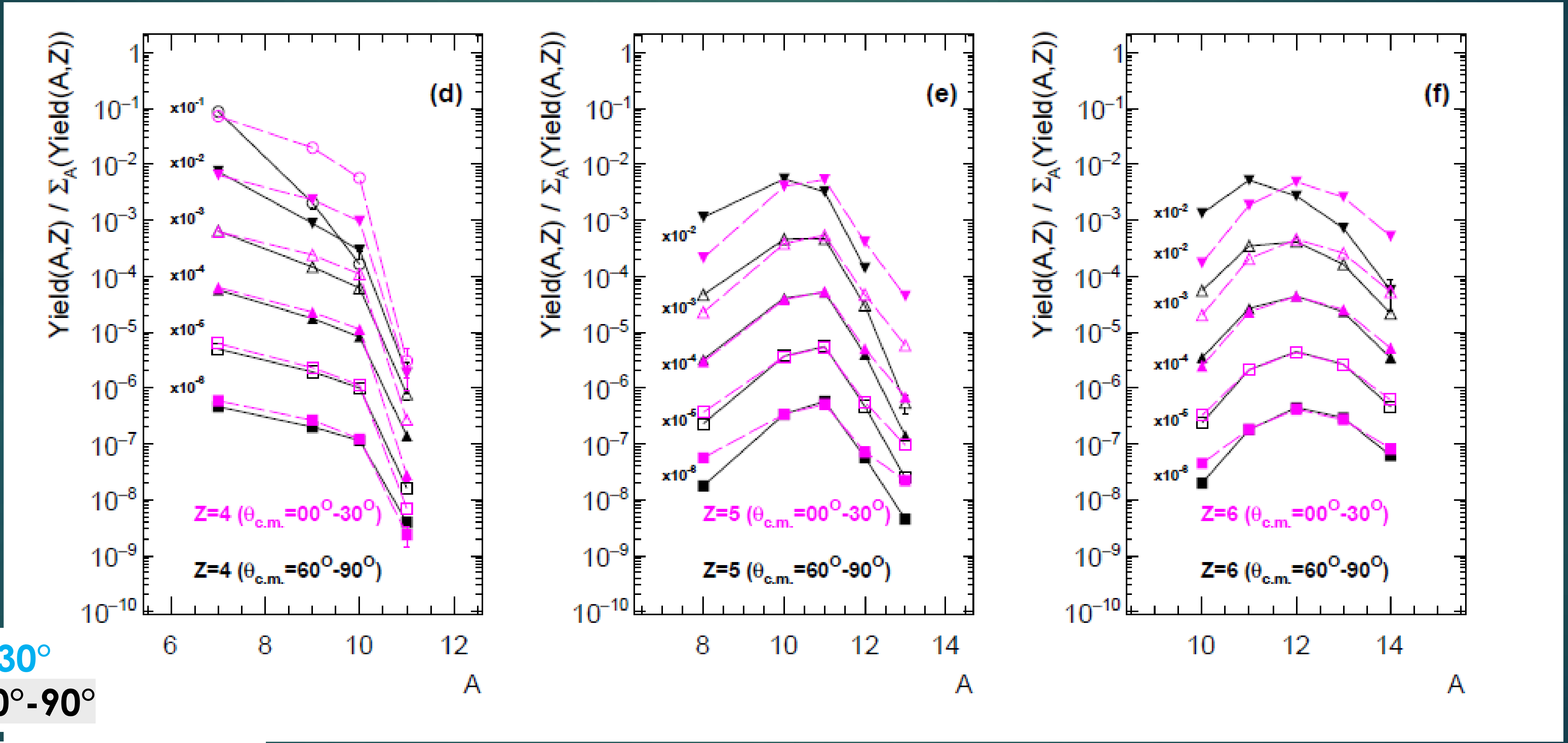
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

For peripheral events: 60°-90° 3He more abundant than 4He

For central events: same chemical composition for 0°-30° and 60°-90°

2) Normalized Yields 60°-90° c.m.

Mass identification up to Carbon with a high %



Blue: 0°-30°

Black: 60°-90°

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Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

For peripheral events: 60°-90° 11C more abundant than 12C

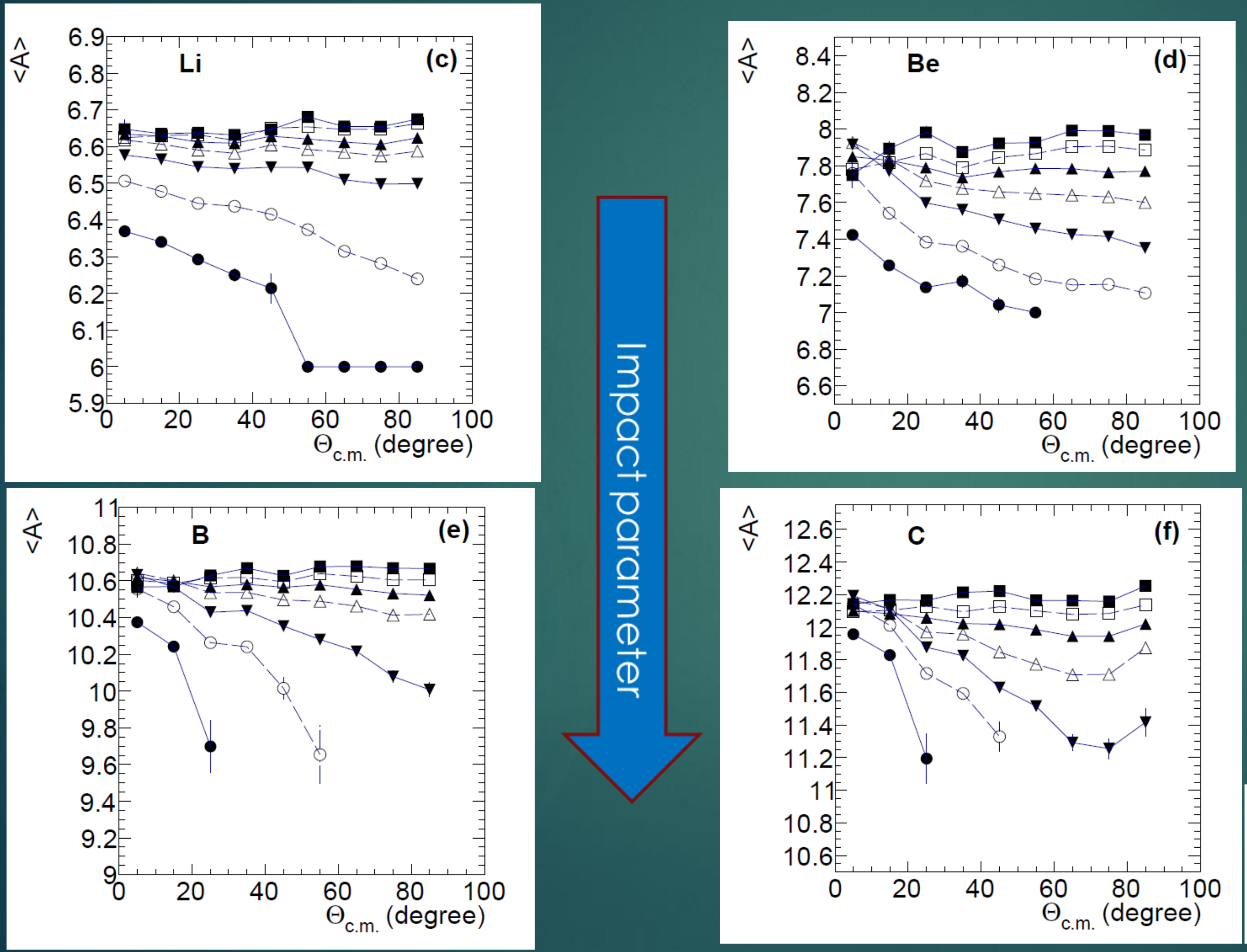
For central events: same chemical composition for 0°-30° and 60°-90°

3) Normalized Yields 60°-90°/0°-30°

For peripheral events:
fragments produced at mid-rapidity are « neutron-poor » or, in other words, are less neutron-rich than the fragments produced in the QP zone.

For central events:
same chemical composition for 0°-30° and 60°-90°.

4) Normalized Yields 0°-90° c.m.: Li-C



Mean mass vs c.m. angle for Z>2:

- in central events the chemical composition of each element is the same relative to the angle.
- In peripheral events, there is an evolution of the n-richness with the angle: neutron richness decreases with increasing angle.

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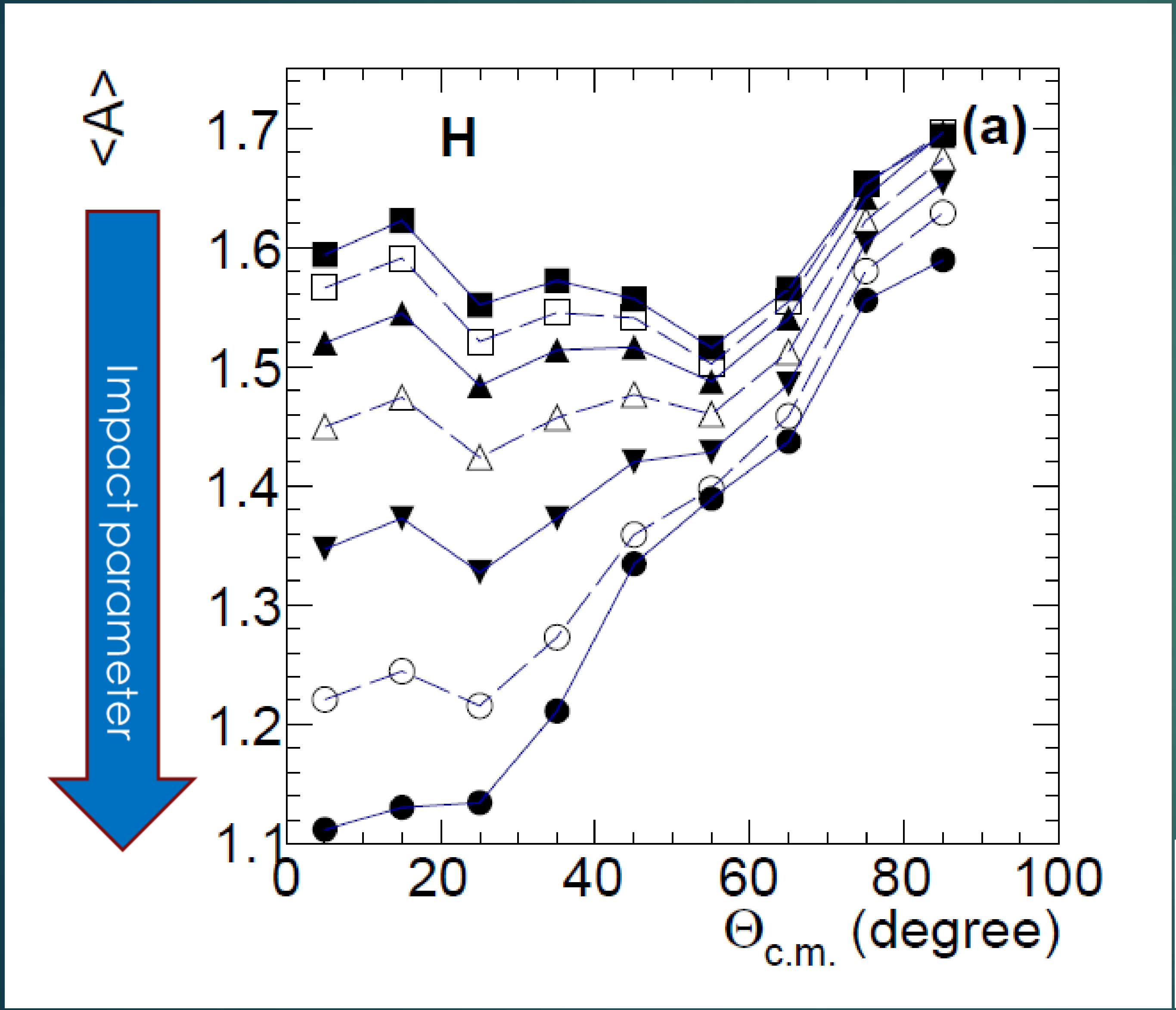
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

4) Normalized Yields 0°-90° c.m.: H



Mean mass vs c.m. angle for Z=1:

- In peripheral events, there is an evolution of the n-richness with the angle: neutron richness increases with increasing angle (inverse with respect to Z>2).
- At mid-rapidity, the mean mass is almost constant (n-rich).
- For central events the mean mass value is evolving with angle but within a fairly narrow range (10%).

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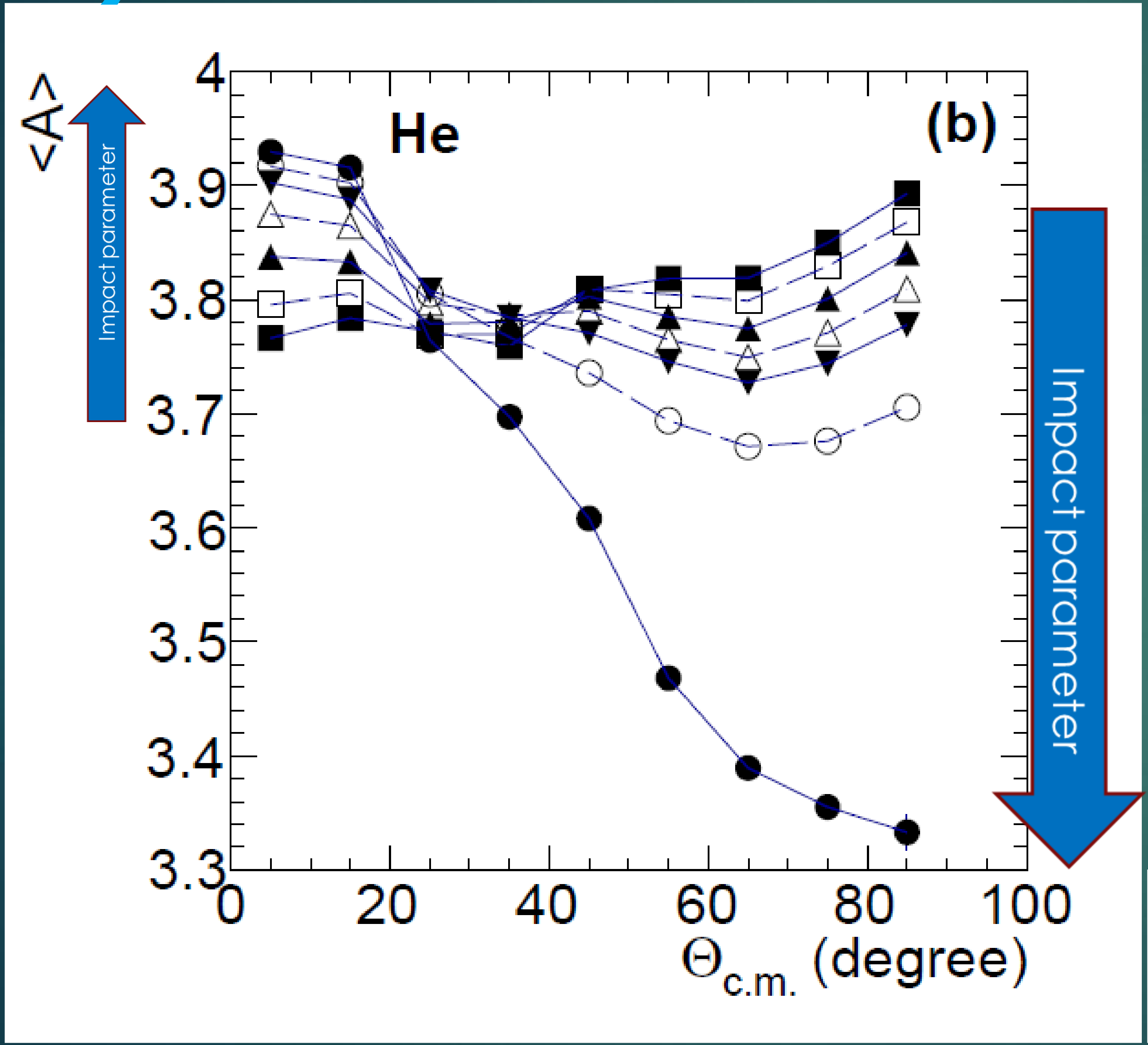
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

4) Normalized Yields 0°-90° c.m.: He



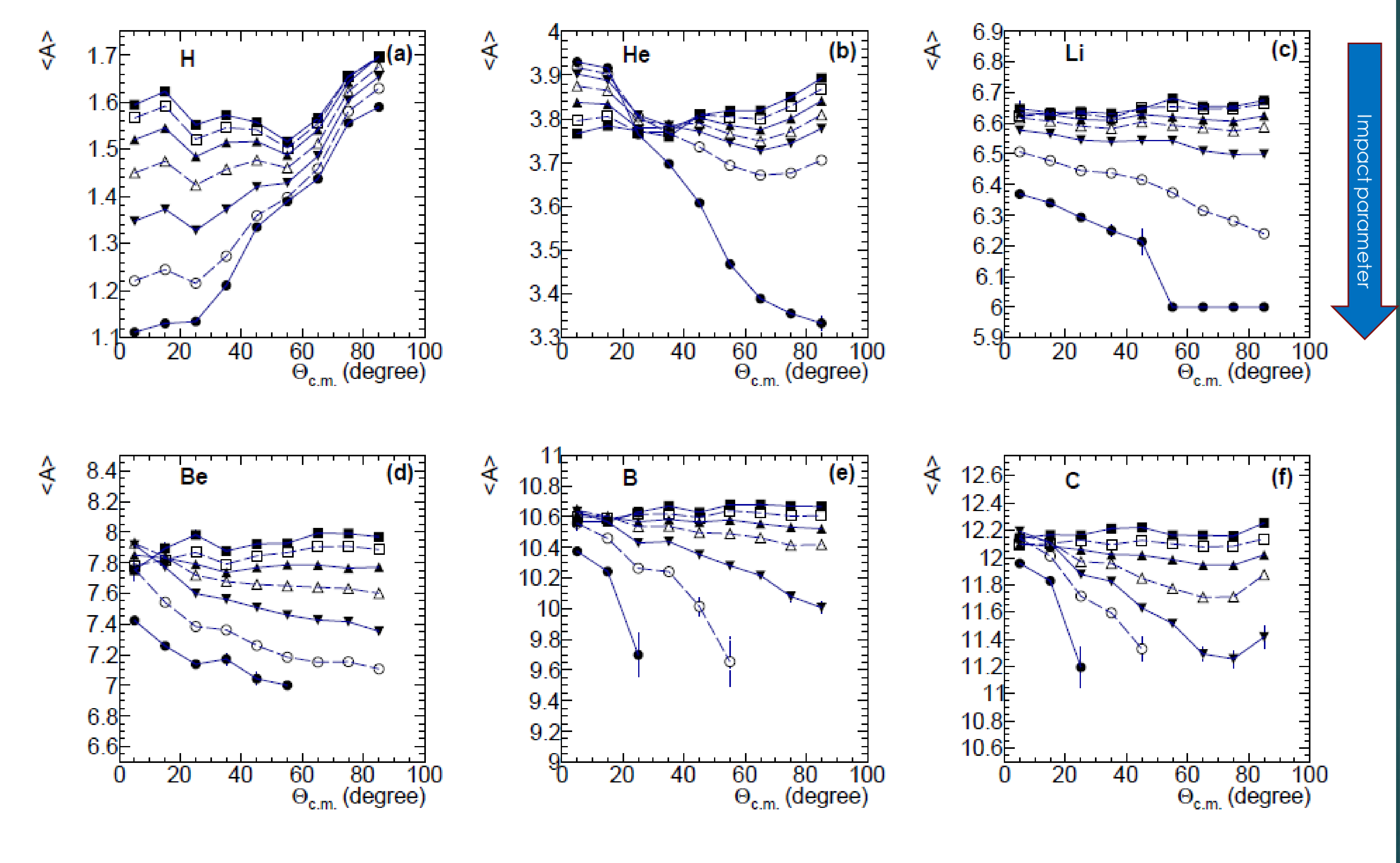
Mean mass vs c.m. angle for Z=2:

- Heliums behave like Z>2 and NOT like Z=1.
- A difference between He and Z>2: for the very forward angles, the n-richness decreases with decreasing impact parameter (increasing E* opening of 3He production channel).

Table 3. Symbols used for figures and labels used in the text for the seven intervals of impact parameter estimator ($V^{Z>1}_{front}$) .

Figure symbol	■	□	▲	△	▼	○	●
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

4) Normalized Yields 0°-90° c.m.: H-C



Some conclusions:

- For mid-rapidity in peripheral events: Z>1 are « neutron poor » while Z=1 are « neutron rich ». The mid-rapidity neutron enrichment is thus caused by neutrons and Hydrogens.

- CHEMICAL EQUILIBRIUM IS ACHIEVED IN CENTRAL EVENTS.

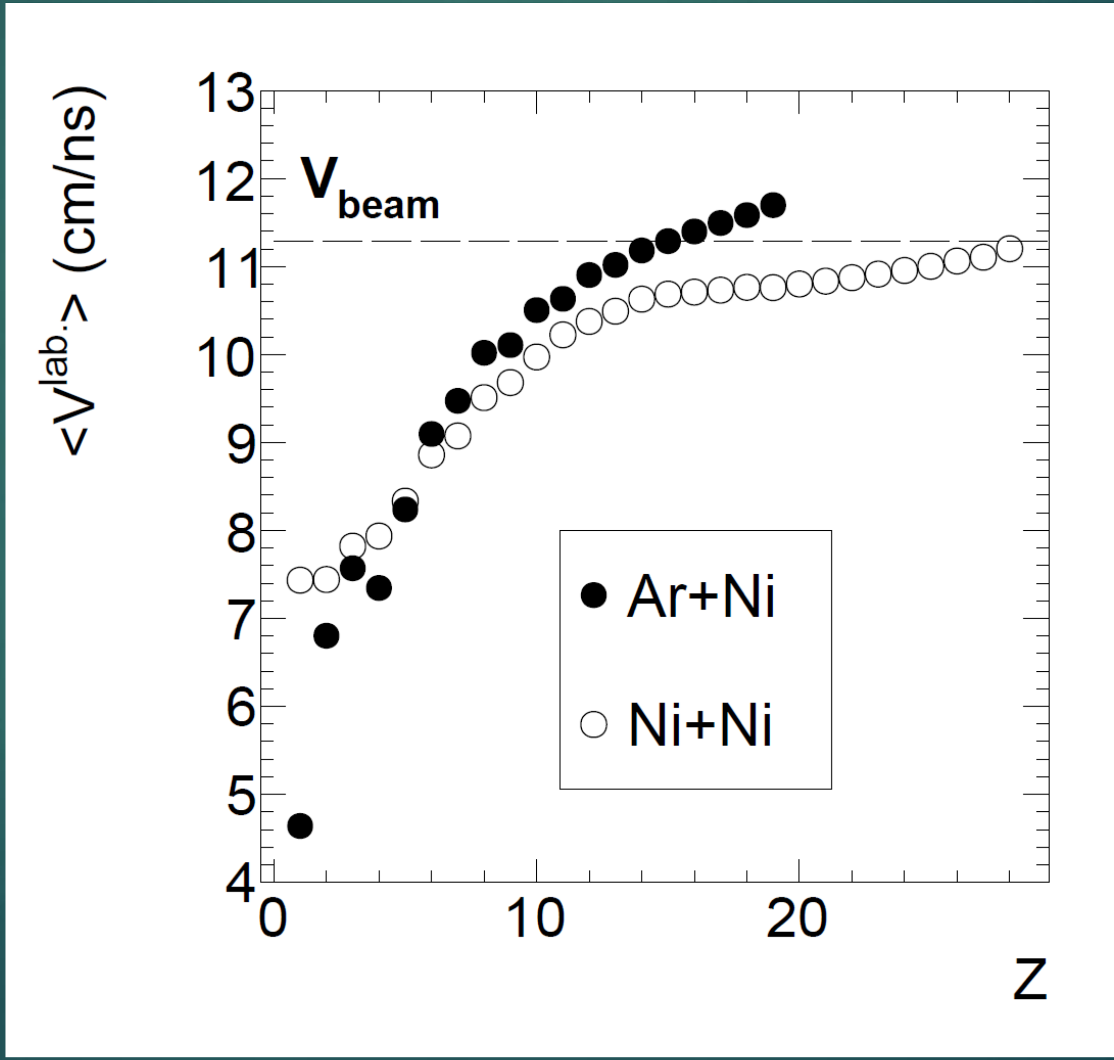
Table 3. Symbols used for figures and labels used in the text for the seven intervals of impact parameter estimator ($V^{Z>1}_{front}$) .

Figure symbol	■	□	▲	△	▼	○	●
Text label	1	2	3	4	5	6	7
$V^{Z>1}_{front}$ interval (cm/ns)	0-2	2-3	3-4	4-5	5-6	6-7	7-8

Merci de votre attention.

An article is in preparation.

Problem concerning energy calibration for Ar+Ni



1) Normalized Yields 0°-30° c.m.

In the 0°-30° zone, all charged particles are identified in Z and A in this experiment.
Exemple:
Light Charged Particles detected in the forward part of the c.m. frame with different isotopes of Sulfur (peripheral events).
Evaporation/mid-rapidity/Deuteron production.