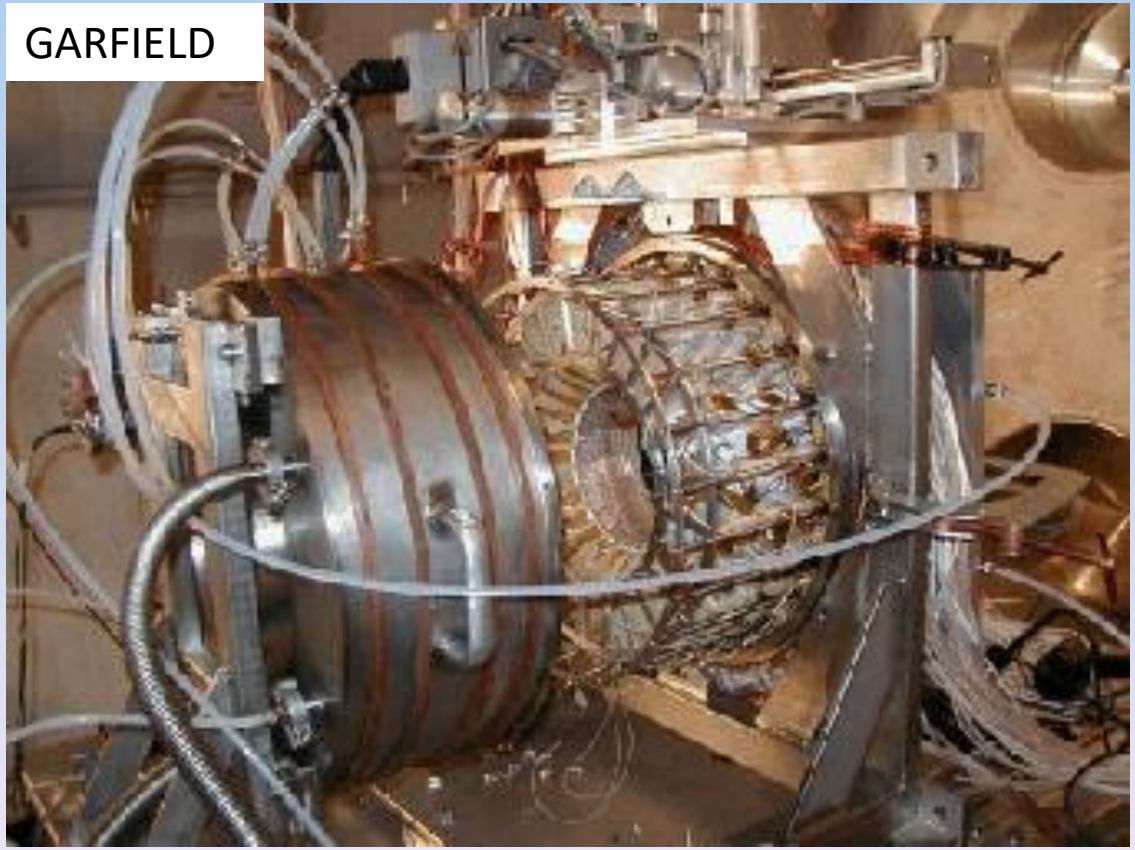
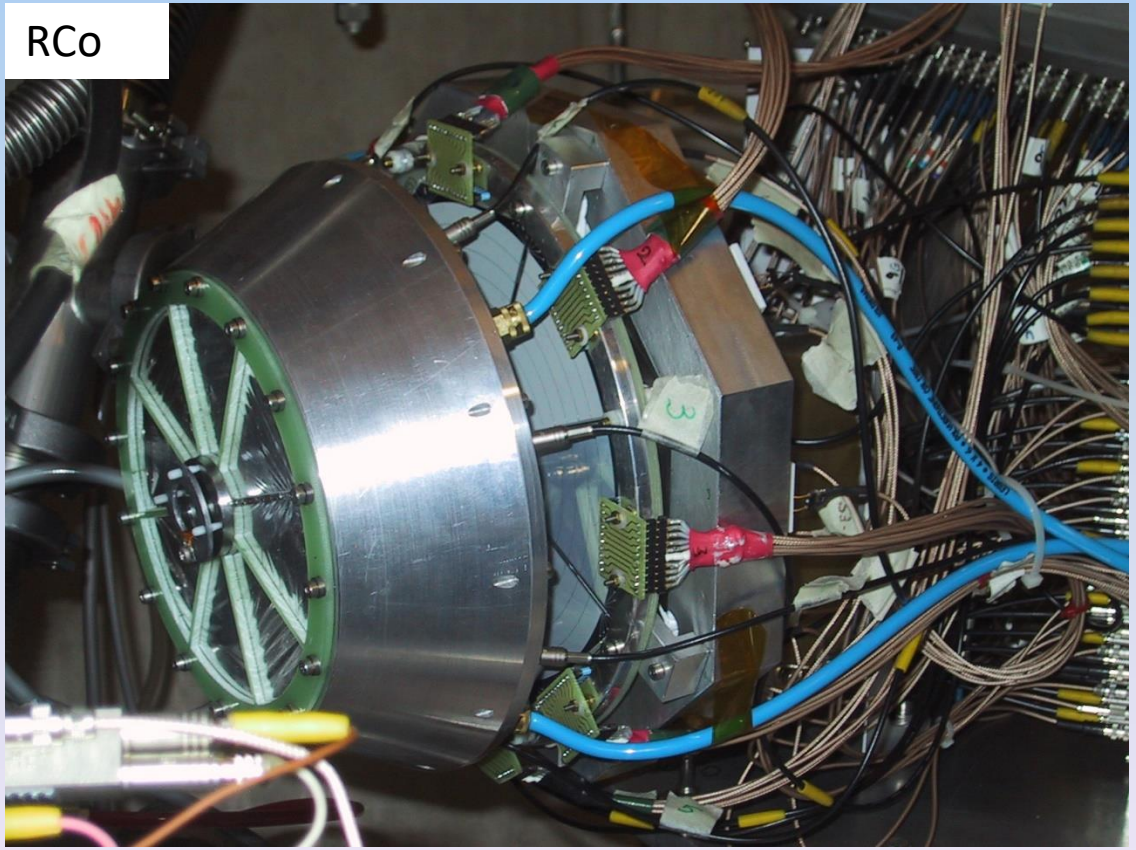
Looking for non-statistical effects in the decay of ^{36,37}Ar*: first results

S. Barlini –INFN and University of Florence- for the NUCLEX collaboration

GARFIELD

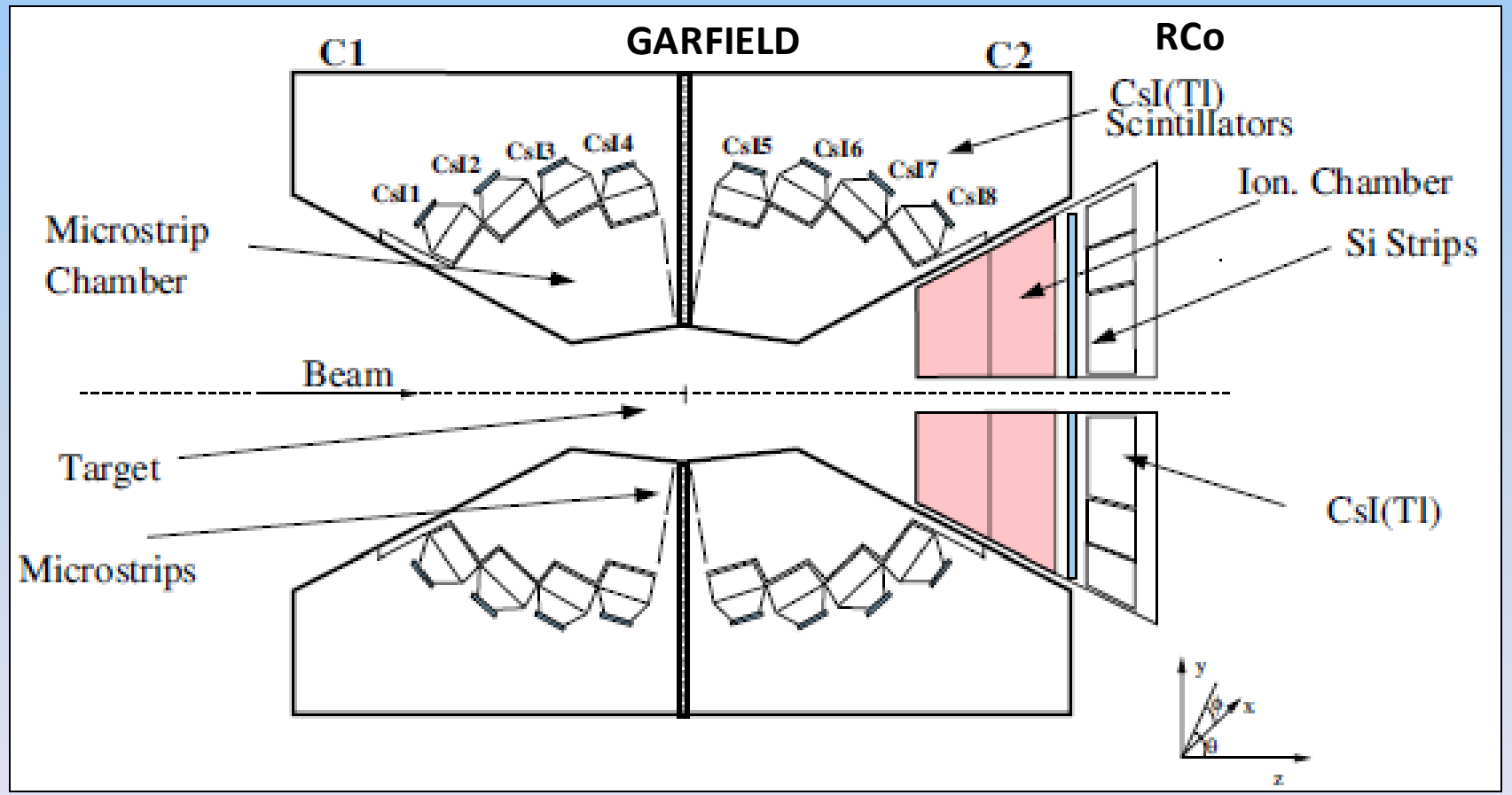


RCo



Eunpc 2018, Bologna 2-7 September 2018

The Experimental Apparatus: GARFIELD+RCo



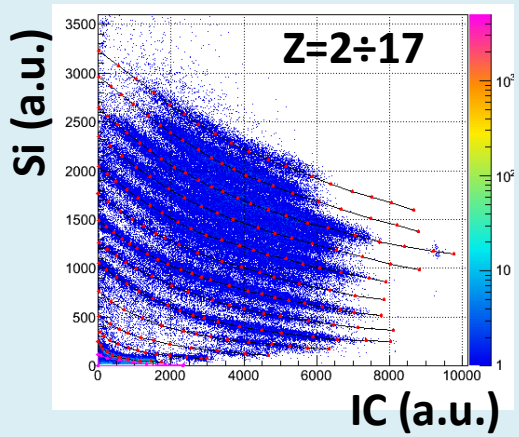
RCo

- 3 stages telescope (IC+Si+Csi(Tl))
- $5 \leq \theta_{RCo} \leq 17$ with 8 Si strips
- Fully digital electronics
- Detection of ER and FF

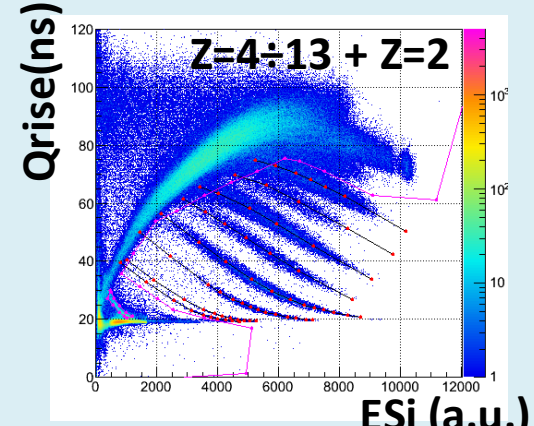
GARFIELD

- 2 stages telescope
- $95° \leq \theta_{c1} \leq 150°$ and $30° \leq \theta_{c2} \leq 85°$
- Digital electronics (CsI) and analogic (µstrip)
- Detection of ONLY LCP

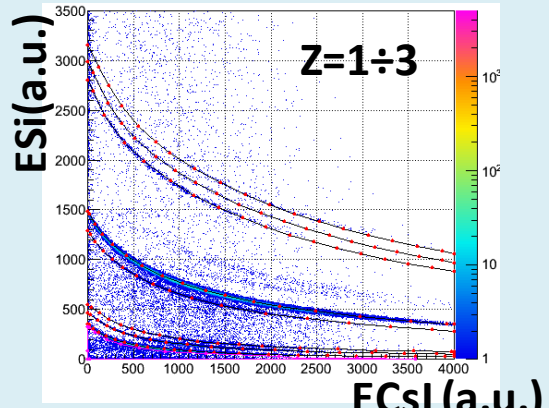
RCo IC vs Si



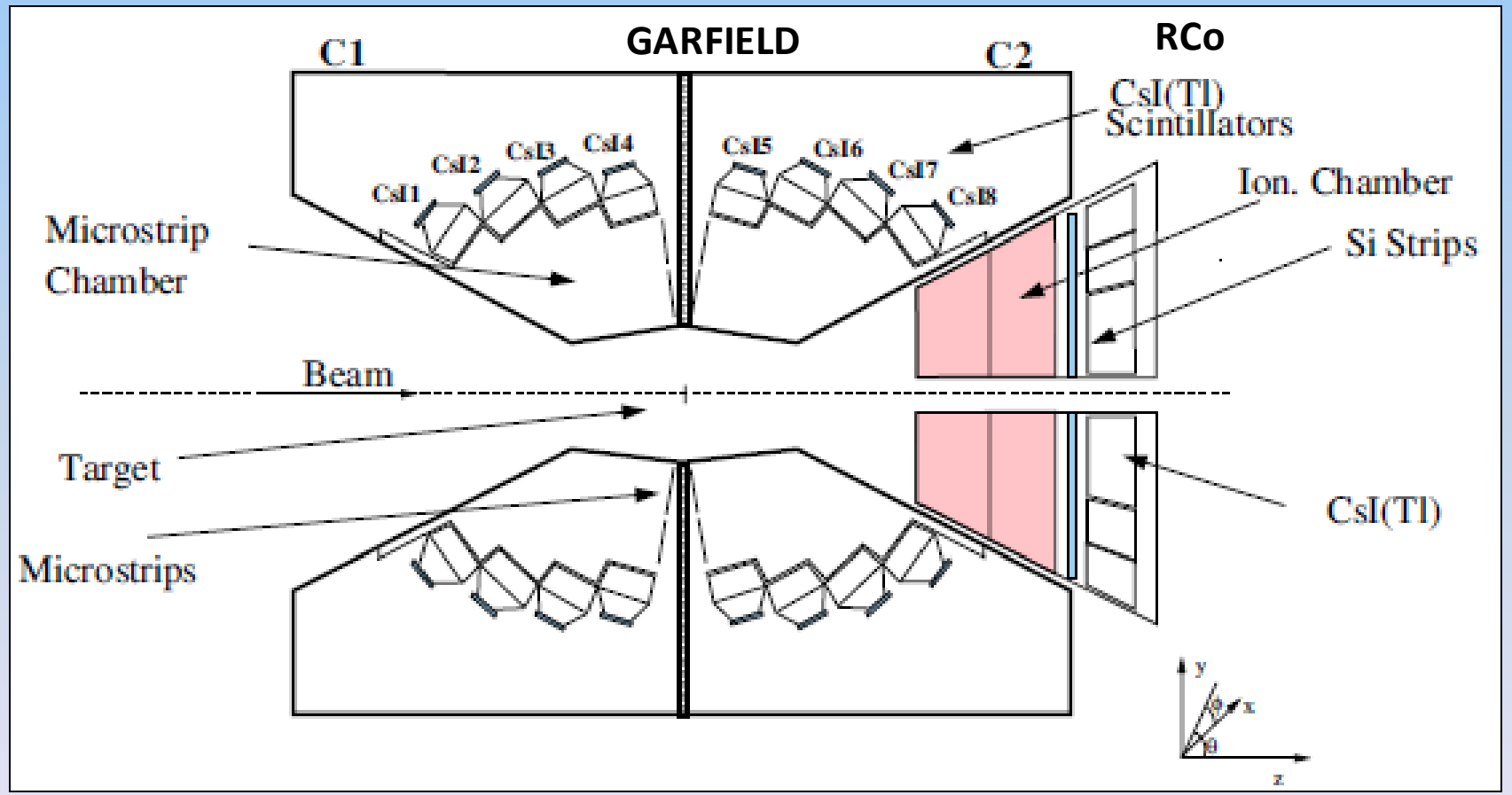
RCo SiPSA

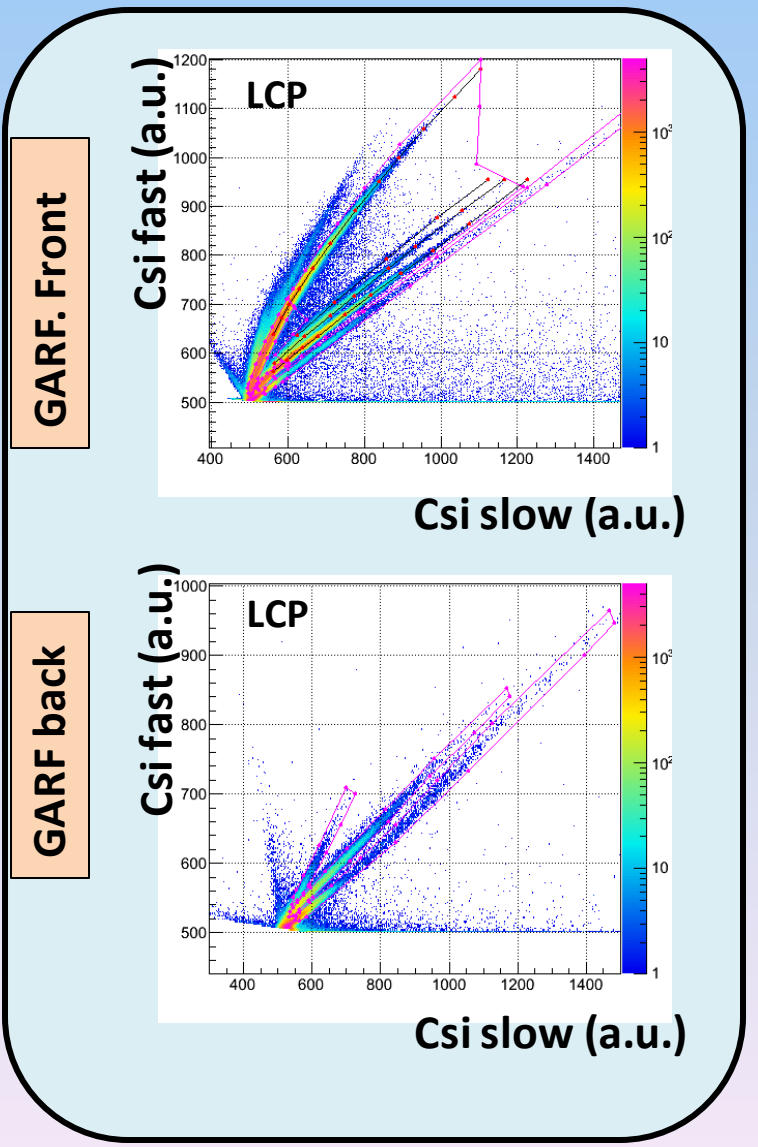


RCo Si vs CsI



The Experimental Apparatus: GARFIELD+RCo





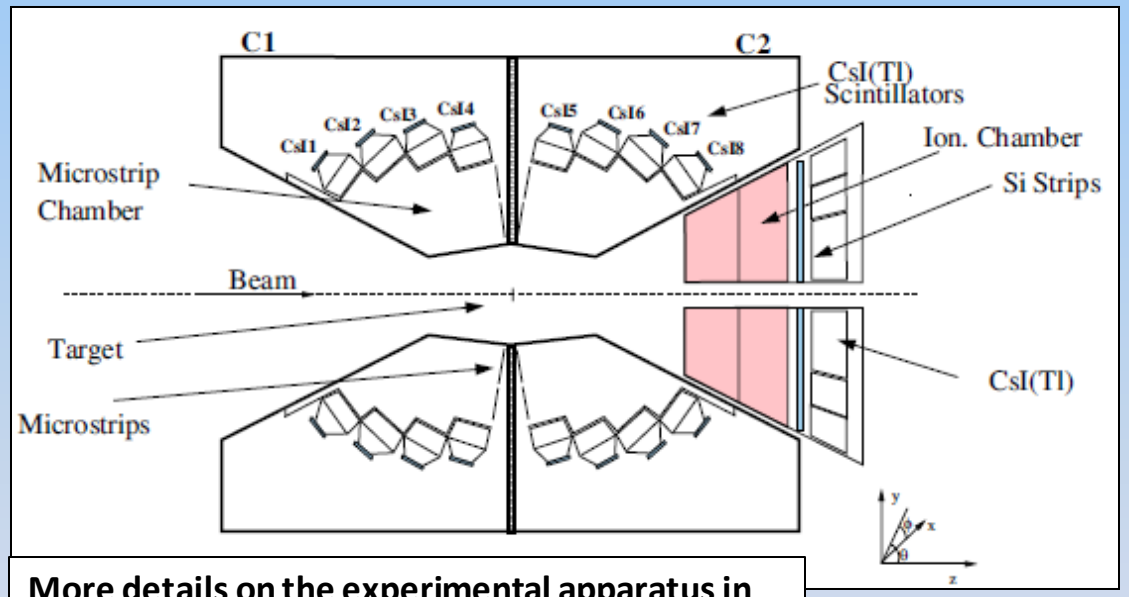
RCo

- 3 stages telescope (IC+Si+Csi(Tl))
- $5 \leq \theta_{RCo} \leq 17$ with 8 Si strips
- Fully digital electronics
- Detection of ER (and FF)

GARFIELD

- 2 stages telescope
- $95° \leq \theta_{c1} \leq 150°$ and $30° \leq \theta_{c2} \leq 85°$
- Digital electronics (CsI) and analogic (μstrip)
- Detection of ONLY LCP

GARFIELD+Rco: previous experiments



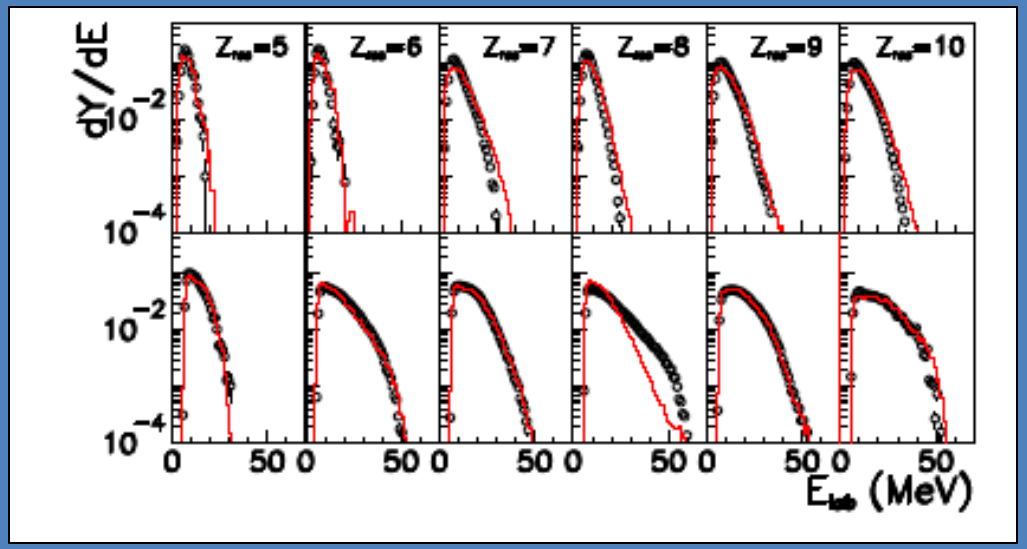
More details on the experimental apparatus in
M.Bruno et al, Europ. Phys. J. A49 (2013), 1

Light systems with GARFIELD+RCo apparatus: a long story…..

- $^{12}C+^{12,13}C$@95 MeV (see **A.Camaiani talk**)
- $^{14}N+^{10}B$@80.7 MeV
- $^{16}O+^{12}C$@90,110,130 meV (see **C.Frosin talk**)

G.Baiocco et al, PRC87 (2013), 064607
L.Morelli et al., J.of Phy.G 41(2014), 075107
L.Morelli et al., J.of Phy.G 41(2014), 075108
L.Morelli et al., J.of Phy.G 43(2016), 045110
A.Camaiani et al., PRC 97 (2018), 044607

- Use of a «dedicate» Hauser-Feshbac evaporation code with the introduction of the discrete decay level
- Study of the «complete» events (Ztot=Zp+Zt)
- From the comparison between data and model, an extra alfa emission appears in the alfa-cluster channels (mainly Z_{ER}=8)
- Not so much differences between $^{24}Mg^*$ and $^{25}Mg^*$ decay

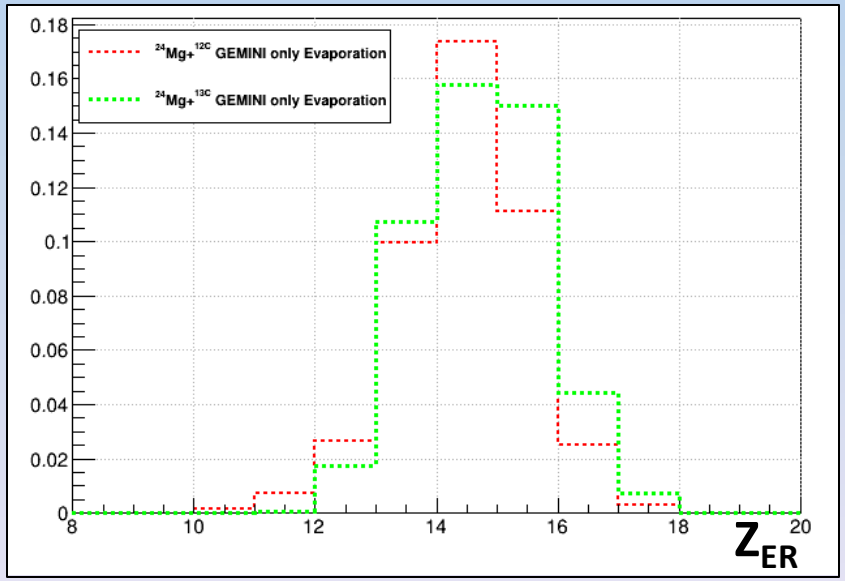


Selection of the Fusion-Evaporation events:

Reaction	Energy (MeV)	Vp (cm/ns)	CN	E^*_{CN} (MeV)	v_{CN} (cm/ns)	$L_{grazing}$ (ħ)
$^{24}Mg+^{12}C$	162	3.61	$^{36}Ar^*$	70.3	2.41	24.3
$^{24}Mg+^{13}C$	142	3.38	$^{37}Ar^*$	70	2.19	24.8

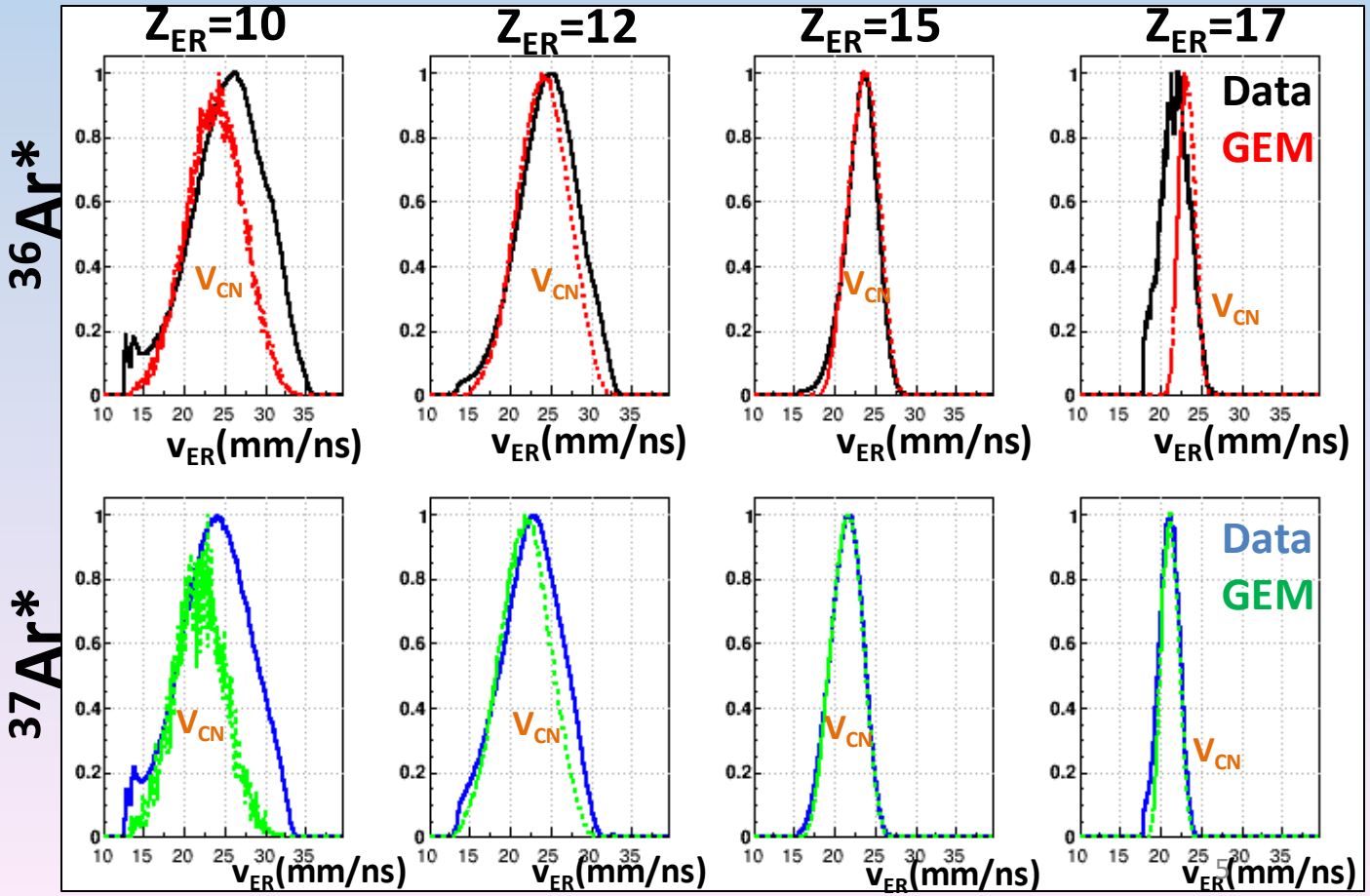
Statistical model: GEMINI++(R.J.Charity et al., PRC82(2010), 014610)

- Compound Nucleus decay via Fusion-Evaporation or Fusion-Fission processes
- MC simulation is filtered via software replica of the apparatus.
- Selection of MC directly using the reaction mechanism (Evaporation or Fission), or us the same conditions of the exp. data

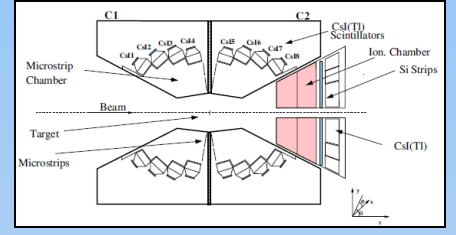


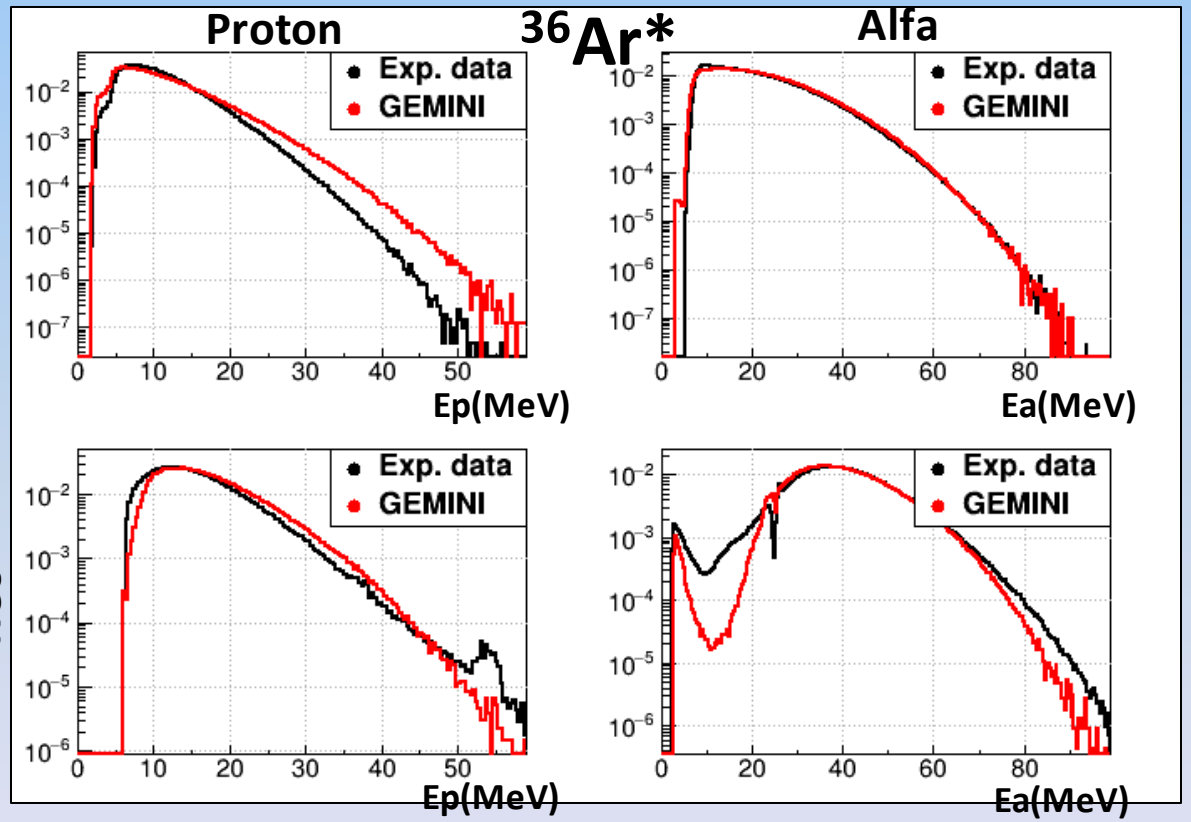
Conditions to select Evaporation Residue events:

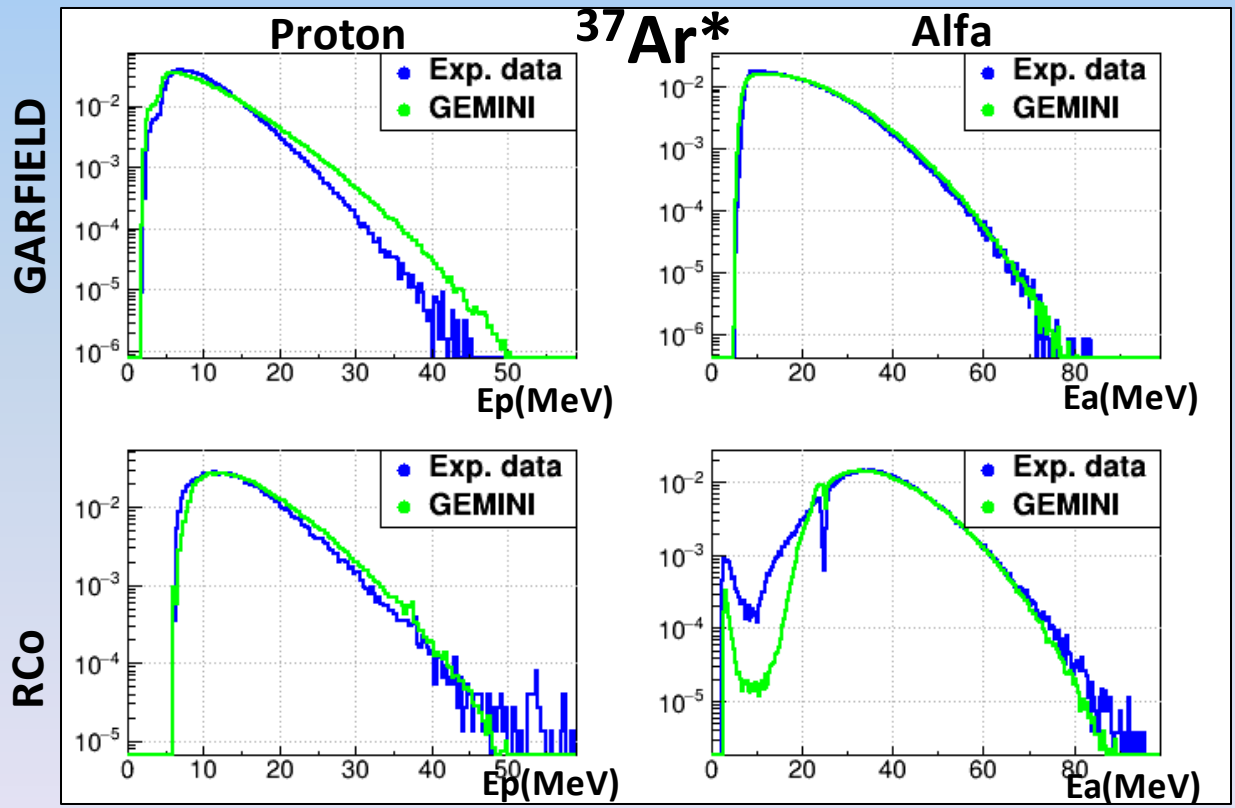
- Only one fragment (Z>3) detected in RCo
- $Z_{ER} \geq 11$
- Selection on the vER



LCP spectra and molteplicity in Fusion-Evaporation reactions:





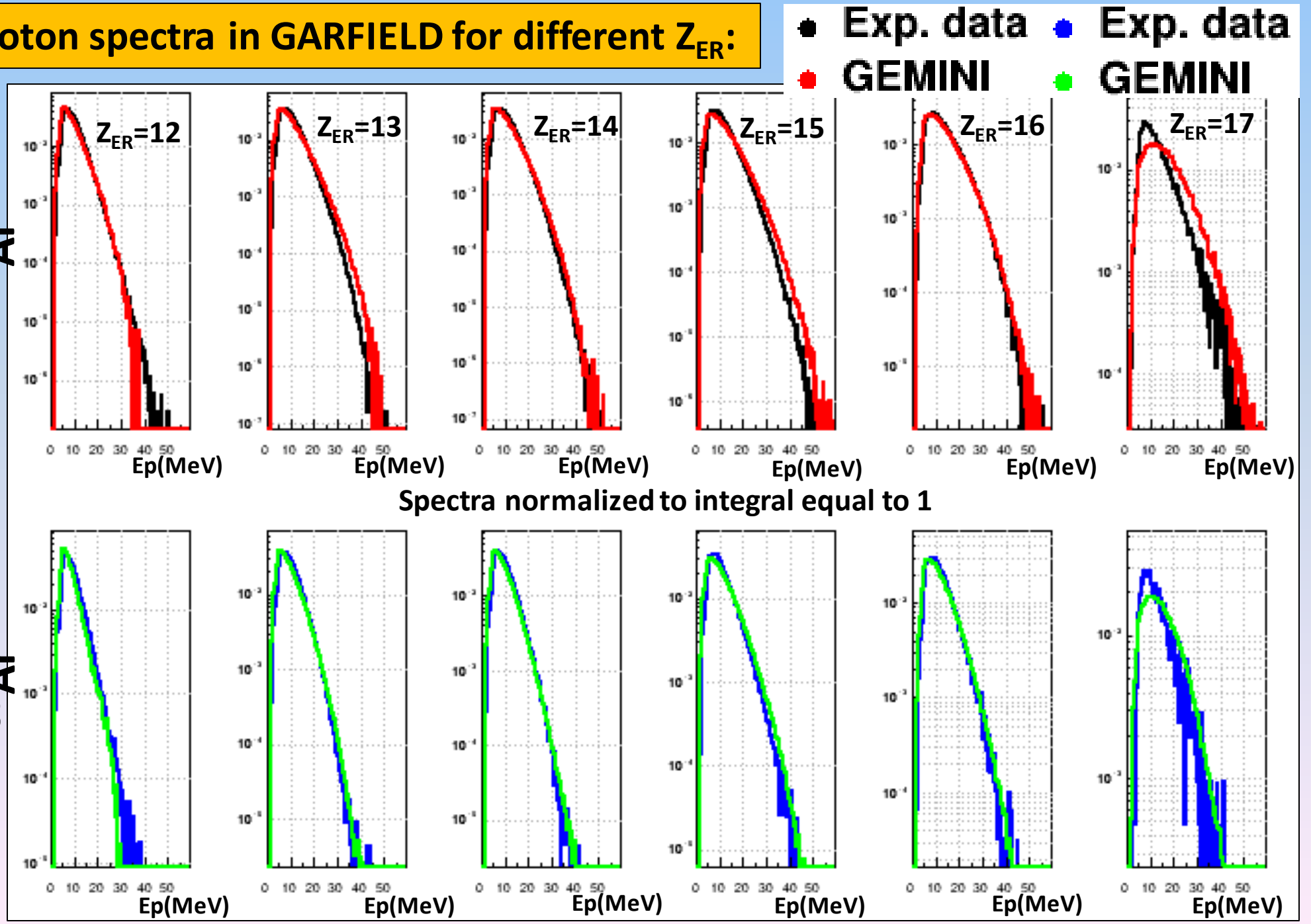


Measured LCP multiplicity (Relative Estimated error ±)

	GARF. proton		GARF. Alfa		RCo proton		RCo Alfa	
	Exp.	GEM.	Exp.	GEM.	Exp.	GEM	Exp.	GEM.
^{36}Ar*	0.49	0.62	0.72	0.64	0.07	0.10	0.17	0.15
^{37}Ar*	0.42	0.48	0.76	0.69	0.05	0.07	0.18	0.15

- Proton energy spectra not well reproduced expecially for GARFIELD
- Good alfa energy spectra reproduction
- The model understimated the alpha production and overstimated the proton

Proton spectra in GARFIELD for different Z_{ER}:



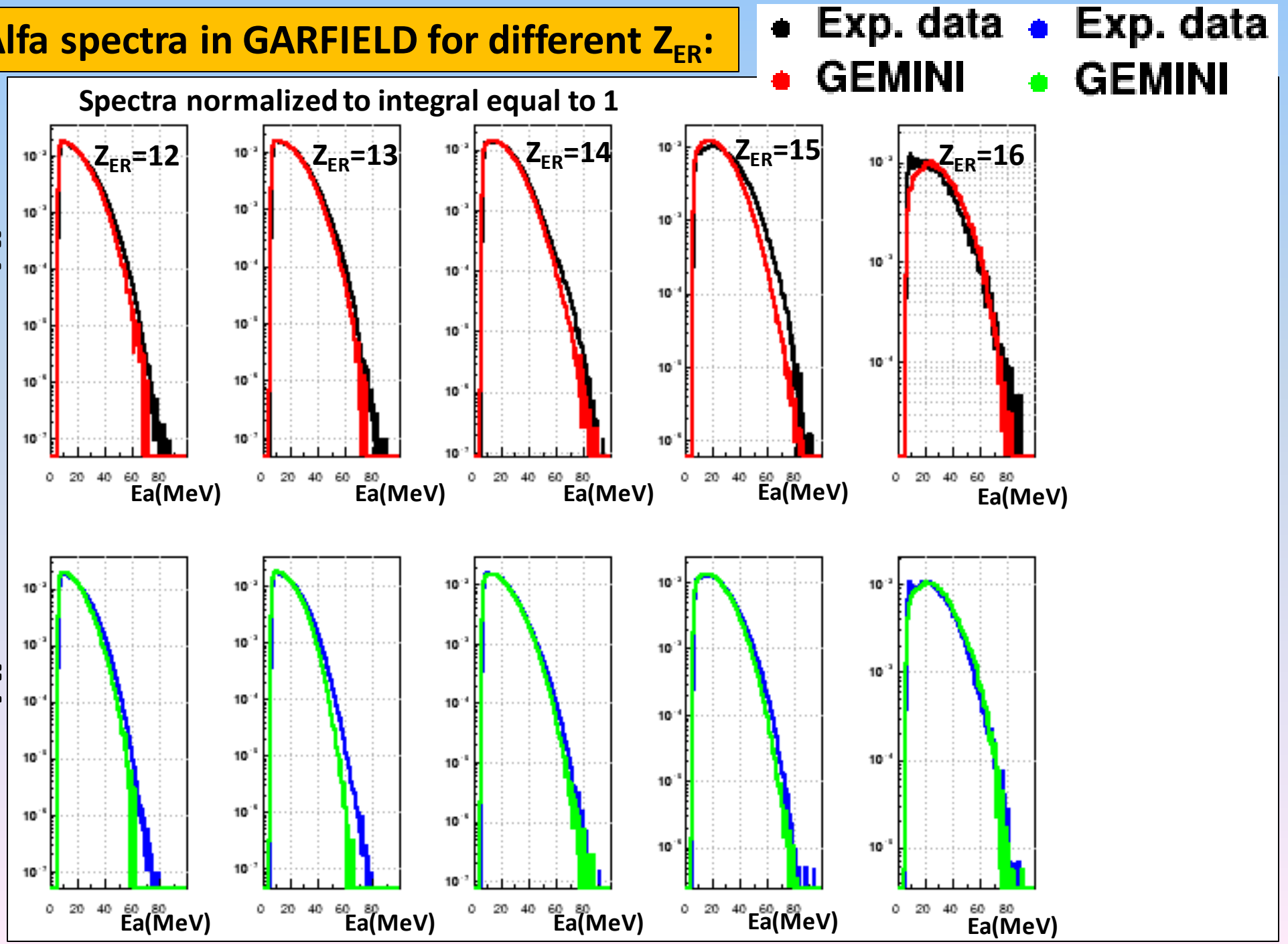
^{36}Ar*

The shape of the GARFIELD proton energy spectra for Z_{ER}=13,15,17 are not well reproduced

^{37}Ar*

The shape of the GARFIELD proton energy spectra for well reproduced, including the Z_{ER}=17 case.

Alfa spectra in GARFIELD for different Z_{ER}:



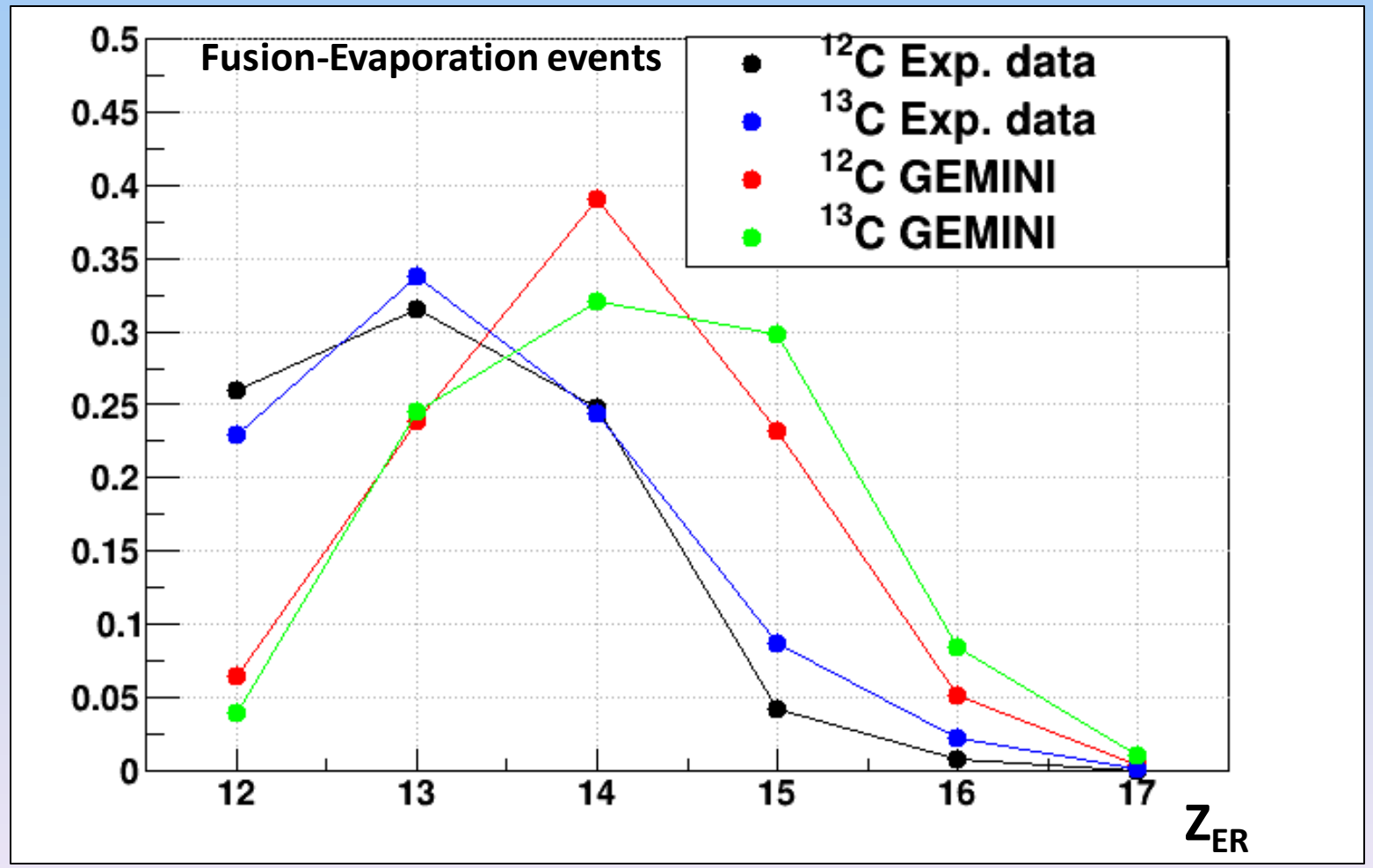
$^{36}Ar^*$

Good general behaviour. Some problems at Z_{ER}=15

$^{37}Ar^*$

Good general behaviour.

Charge distribution of the Z_{ER}



	Exp. data	GEMINI
^{36}Ar*	13.3	14.4
^{37}Ar*	13.6	14.7

The GEMINI model seems to favorite larger Evaporation Residue, similary to the Z_{ER} general distribution.

^{37}Ar*

The small differences in the LCP energy spectra can be due to the fact that Z_{ER} distribution is not reproduced

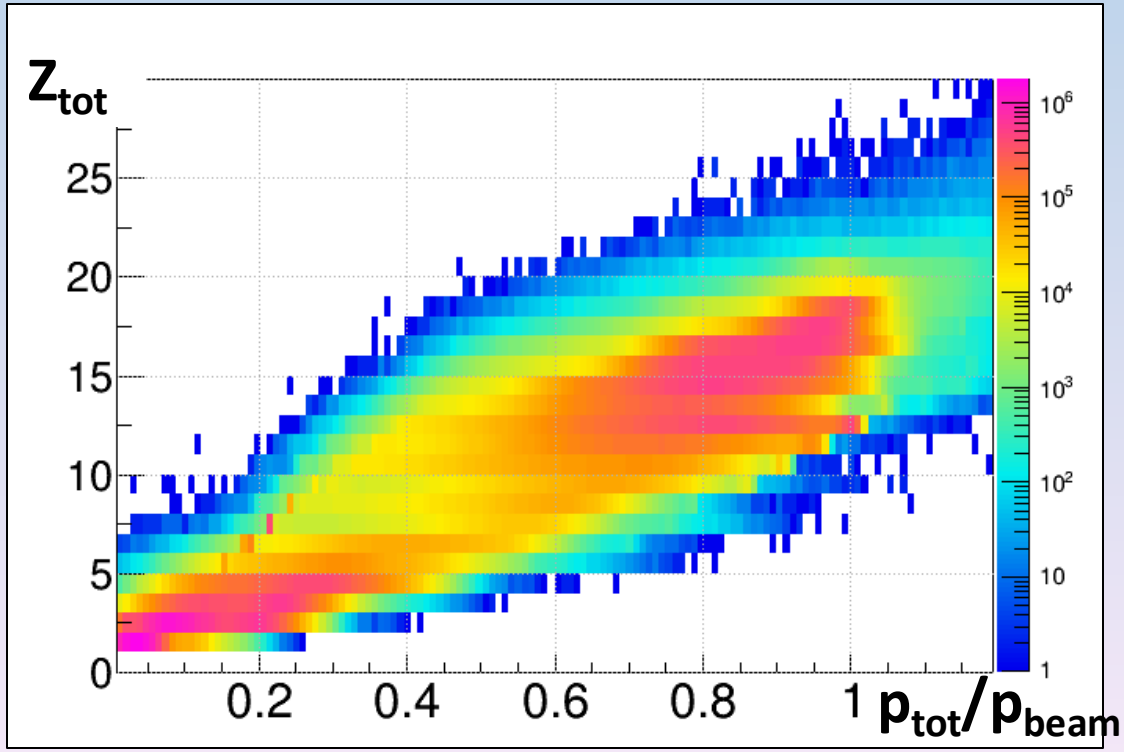
^{36}Ar*

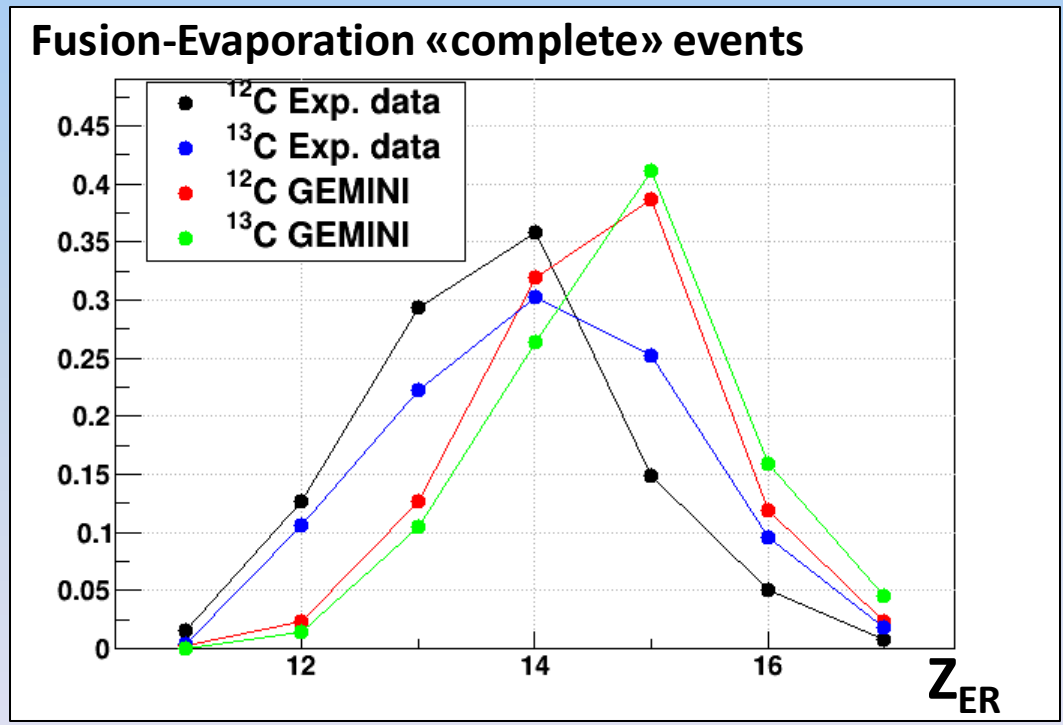
The differenced in the LCP energy spectra can be due to the Z_{ER} distribution non reproduced, but also the Branching Ratio of some channels.

The study of the «complete» events

The selection «complete» events means:

- Selection of Fusion-Evaporation events
- Ztot=Zp+Zt=18
- 0.9 ≤ pz/pbeam ≤ 1.1

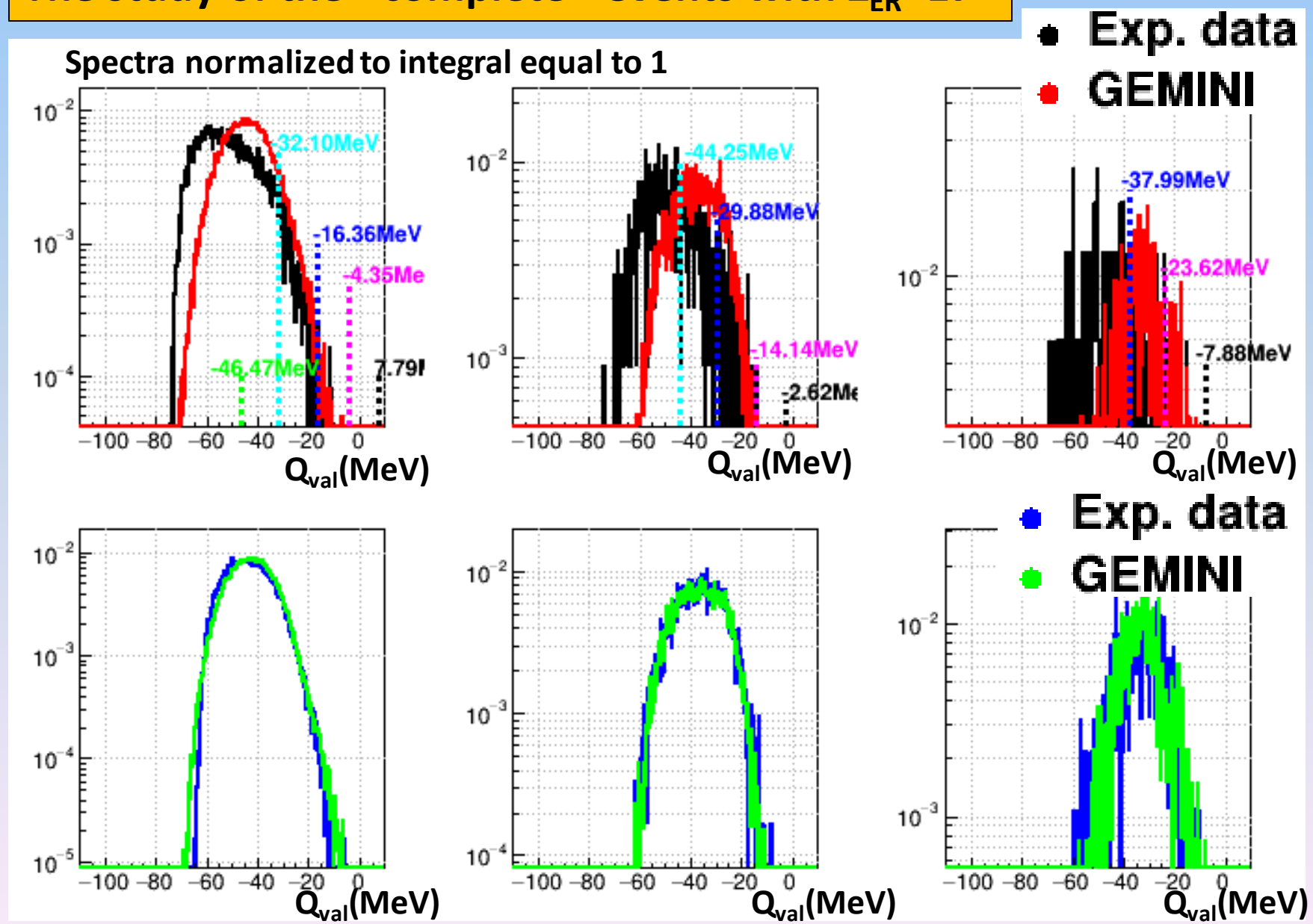




	Exp. data	GEMINI
^{36}Ar*	13.7	14.5
^{37}Ar*	14.1	14.7

The study of the «complete» events with Z_{ER}=17

$$Q_{val} = \left(\sum_{i=1}^{Mtot} E_i \right) - Eb_{eam}$$

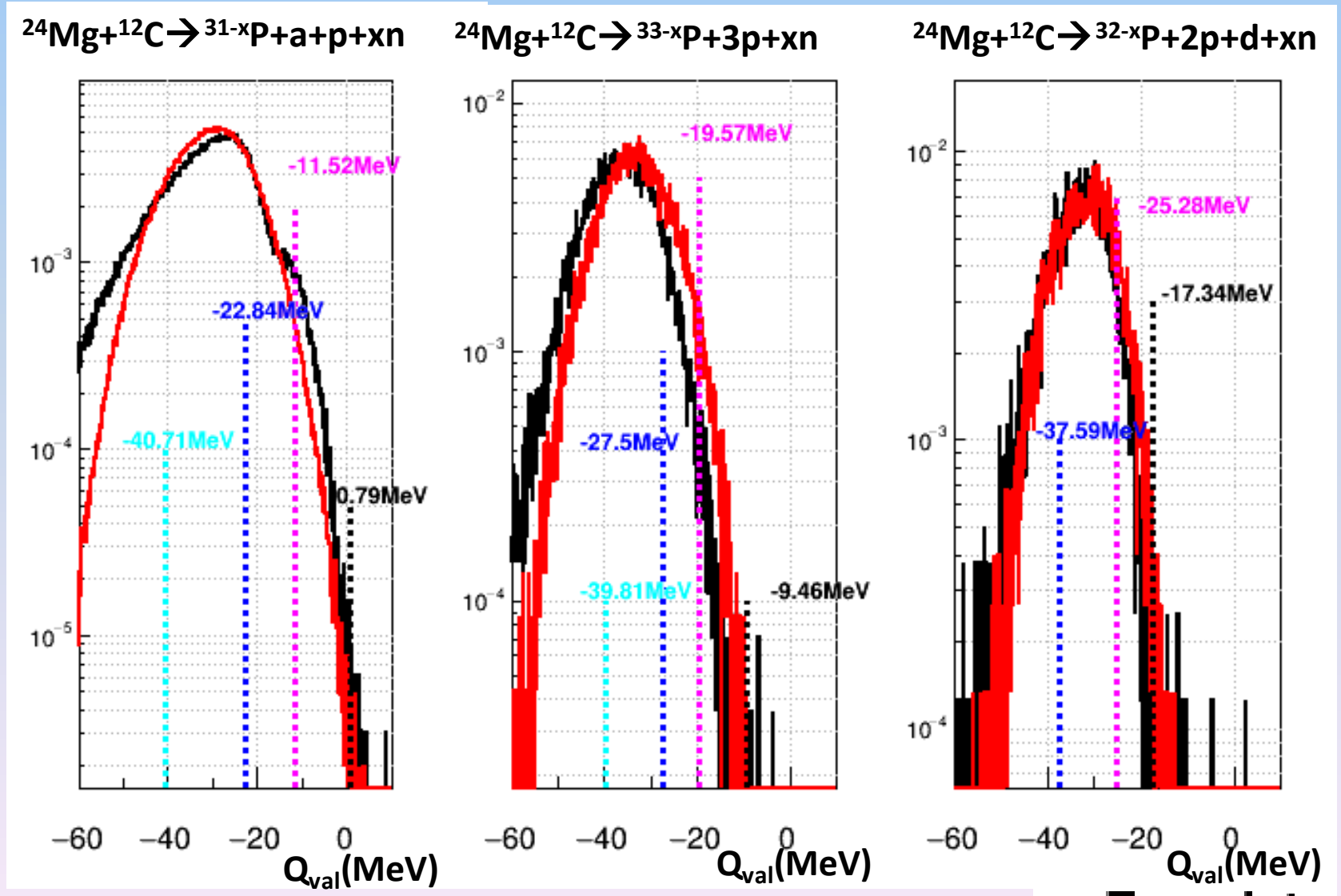


Z_{ER}=17	Dati (%)	GEM (%)
Cl +p + xn	92±4	90.5
Cl +d+xn	7.3±0.4	8.6
Cl +t + xn	1.0±0.04	0.9

Z_{ER}=17	Dati (%)	GEM (%)
Cl +p + xn	89±4	91.6
Cl +d+xn	9.5±0.4	7.7
Cl +t + xn	1.4±0.06	0.8

The model reproduces the neutron evaporation **ONLY** in the ^{37}Ar* decay

The study of the «complete» events with Z_{ER}=15



Spectra normalized to integral equal to 1

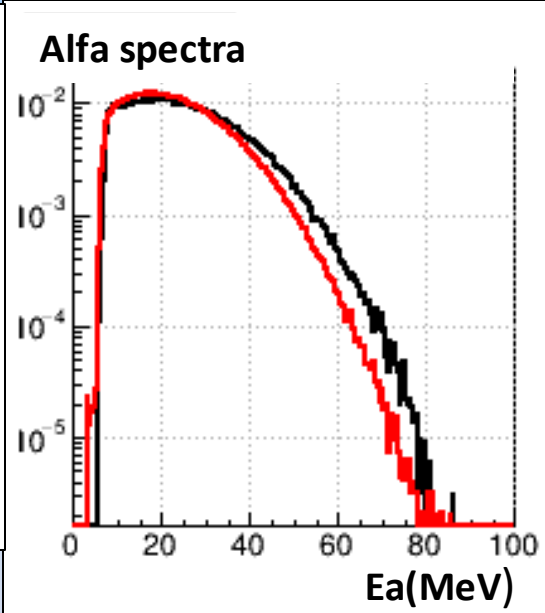
Z_{ER}=15	Dati (%)	GEM(%)
$^{33-x}$P+3p + xn	7,2±0.2	2,0
$^{32-x}$P +2p+d+xn	2,1±0.1	0,7
$^{31-x}$P +a +p+ xn	86±3	91
P+He+H	91±4	97
P+H	9,3±0.4	3

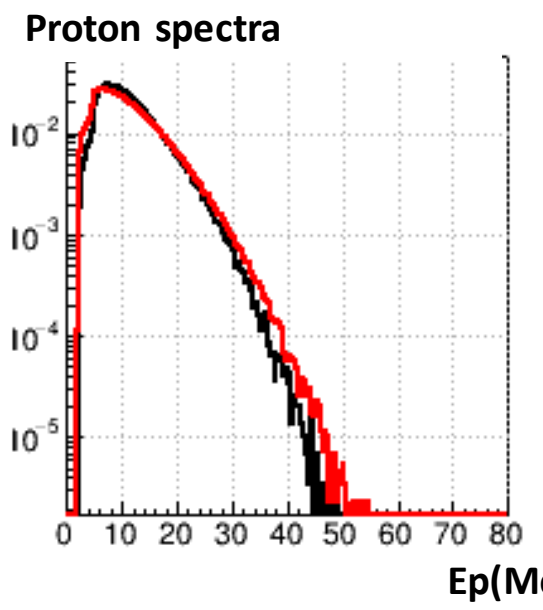
Estimated error ±5%

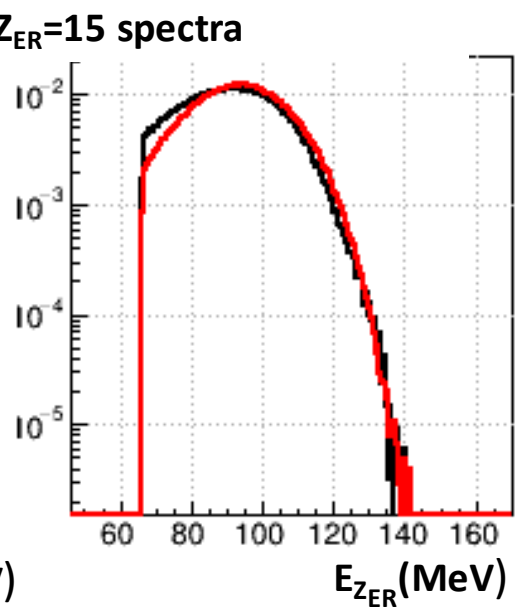
- BR are not perfectly reproduced: The channel with 3p (or 2p and d) is understimated in the GEMINI model while the channel with at least one alfa is overstimated.
- The Q_{value} distributions are well reproduced in all the cases.

The study of the «complete» events with Z_{ER}=15

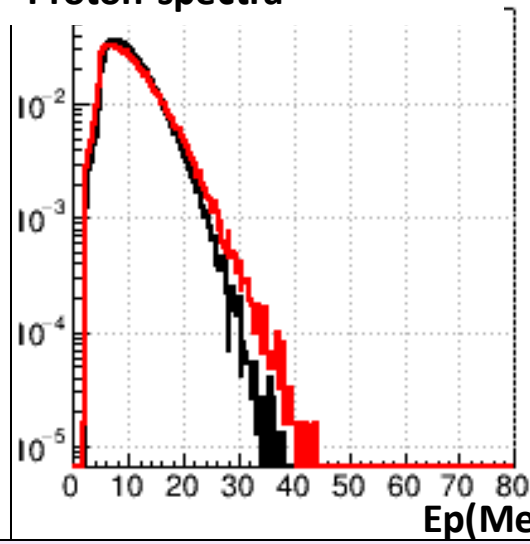
$^{24}Mg+^{12}C \rightarrow ^{31-x}P+a+p+xn$

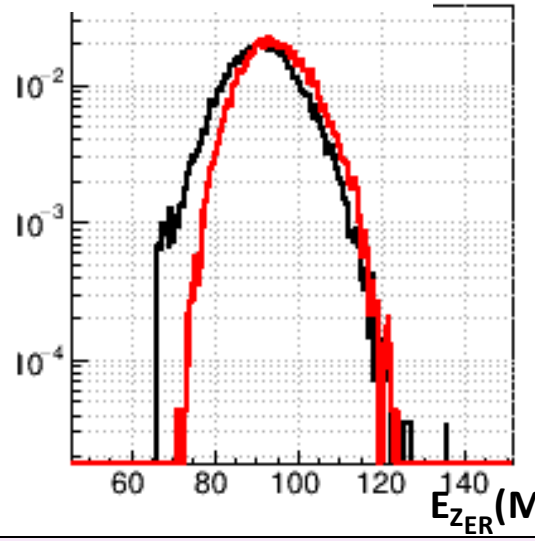






$^{24}Mg+^{12}C \rightarrow ^{33-x}P+3p+xn$





Spectra normalized to integral equal to 1

- **Exp. data**
- **GEMINI**

For Z_{ER}=15 in the $^{36}Ar^*$ decay, we can note some differences in the shape of the energy spectra and in the BR of the two main decay channels.
This can explain the not correct reproduction of the spectra.

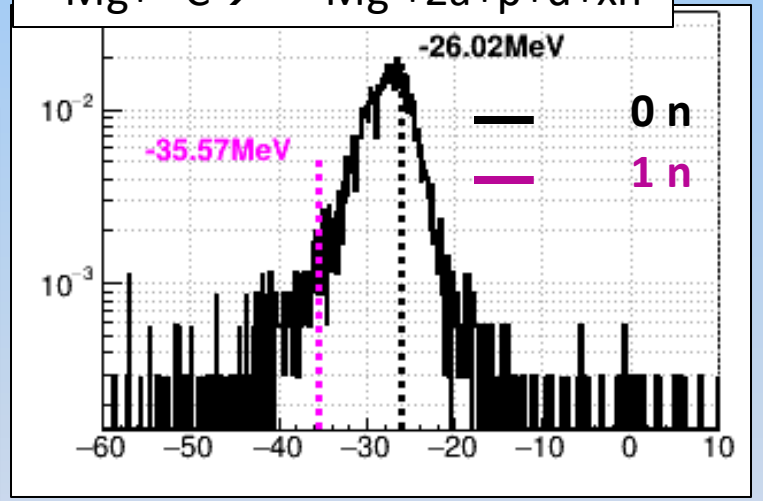
The BR of the «complete» events with Z_{ER}=12,14,16

$^{36}Ar^*$

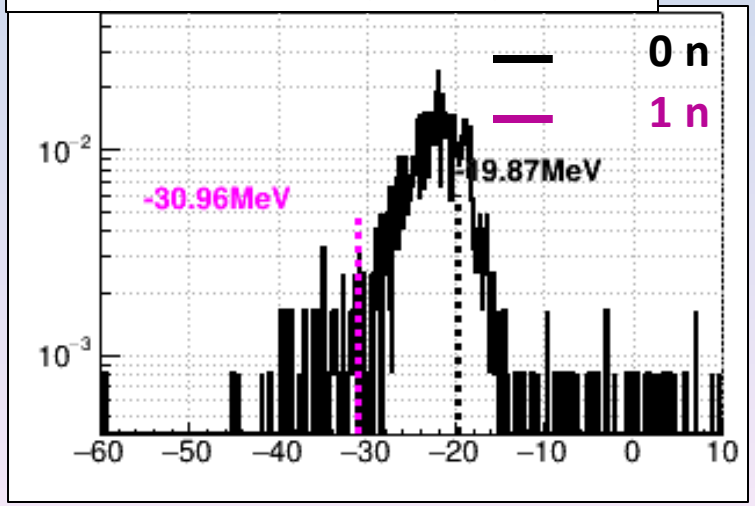
Z_{ER}=12	Exp. (%)	GEM (%)
$^{24-x}$Mg+3a+xn	85±3	80
$^{26-x}$Mg +2a+2p+xn	12±1	17
$^{25-x}$Mg +2a+p+d+xn	0,90±0.04	0,8
Mg+He+H+Li	0,9±0.04	0,8

Z_{ER}=14	Exp. (%)	GEM (%)
$^{30-x}$Si+a+2p + xn	**60±2**	**44,7**
$^{29-x}$Si +a+1p+d+xn	7.0±0.3	7,2
$^{28-x}$Si +2a + xn	**30±1**	**43,4**

$^{24}Mg+^{12}C \rightarrow {}^{25-x}Mg$ +2a+p+d+xn



$^{24}Mg+^{13}C \rightarrow {}^{26-x}Mg$ +2a+p+d+xn



$^{37}Ar^*$

Z_{ER}=12	Exp. (%)	GEM (%)
$^{24-x}$Mg+3a+xn	97±4	94.9
$^{26-x}$Mg +2a+2p+xn	2.1±0.08	2.6
$^{25-x}$Mg +2a+p+d+xn	0.3±0.01	1.0
Mg+He+H+Li	0.5±0.02	0.8

Z_{ER}=14	Exp. (%)	GEM (%)
$^{30-x}$Si+a+2p + xn	**34±1**	**22**
$^{29-x}$Si +a+1p+d+xn	4.9±0.2	5.2
$^{28-x}$Si +2a + xn	**58±2**	**69**

CONCLUSIONS:

- The data analysis suggests that the event selection should be more accurate. Some contributions from Fusion-Fission and Break-up mechanism can still enter in the Fusion-Evaporation data set. Identification of low energy alfa particles can be improuved.

- The charge distribution of the Evaporation Residue is different between experimental data and GEMINI. The model seems to favorite heavier Evaporation Residue.

- The experimental proton multiplicity is less with respect to the simulation, while the alfa multiplicity is highier. In particular, the BR of the chian Z_{ER} =14 + 2 alfa is not well reproduced by the model. Unespectly, the 2alfa chain with Z_{ER} =14 is overstimated in the model with respect the Z_{ER}=14+a+2p channel. This is not completely coherent with the general picture of possible cluster effects which are not taken into account in the standard statistical model.

- ^{37}Ar * decay shows some interesting differences with respect to the ^{36}Ar* decay, expecially for Z_{ER} =17. In fact, the proton energy spectra is well reproduced by the model ONLY for ^{37}Ar *. The percentual of d,t emitted for Z_{ER} =17 complete events is greater for ^{37}Ar * system.

Thank you very much for the attention….