Understanding the structure of ^{56}Ni through one- and two-nucleon transfer reactions: shell gaps and np-pairing

Anastasia Georgiadou
Marlène Assie, Yorick Blumenfeld

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY
cnrs dépasser les frontières
UNIVERSITÉ PARIS SUD Comprendre le monde, construire l'avenir
université PARIS-SACLAY

- N=28 shell closure
- Pairing by transfer

- One neutron pick-up
- Two-nucleon transfer

Understanding the structure of ^{56}Ni through one- and two-nucleon transfer reactions: shell gaps and np-pairing

Anastasia Georgiadou
Marlène Assie, Yorick Blumenfeld

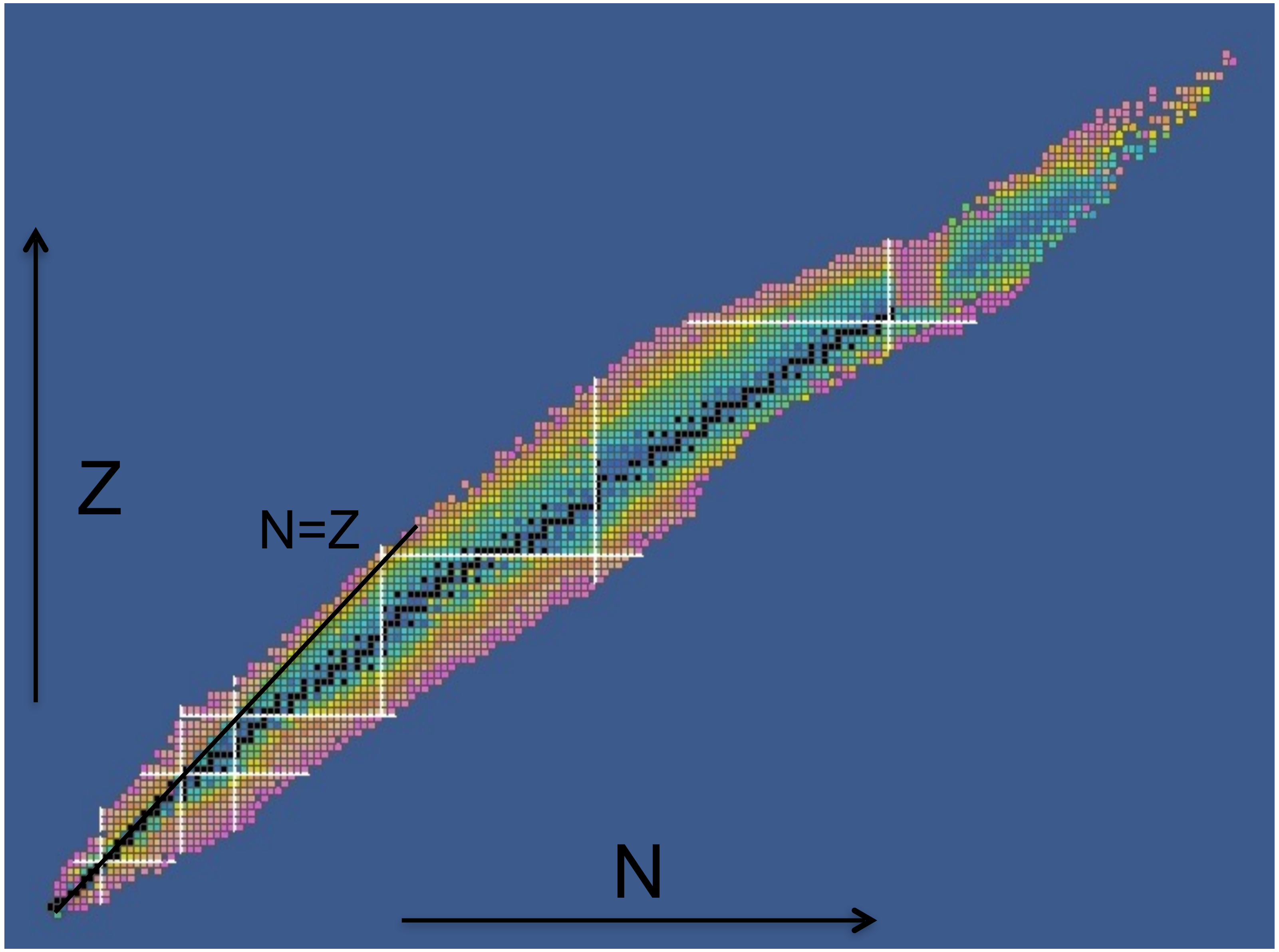
INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY
CNRS dépasser les frontières
UNIVERSITÉ PARIS SUD Comprendre le monde, construire l'avenir
université PARIS-SACLAY

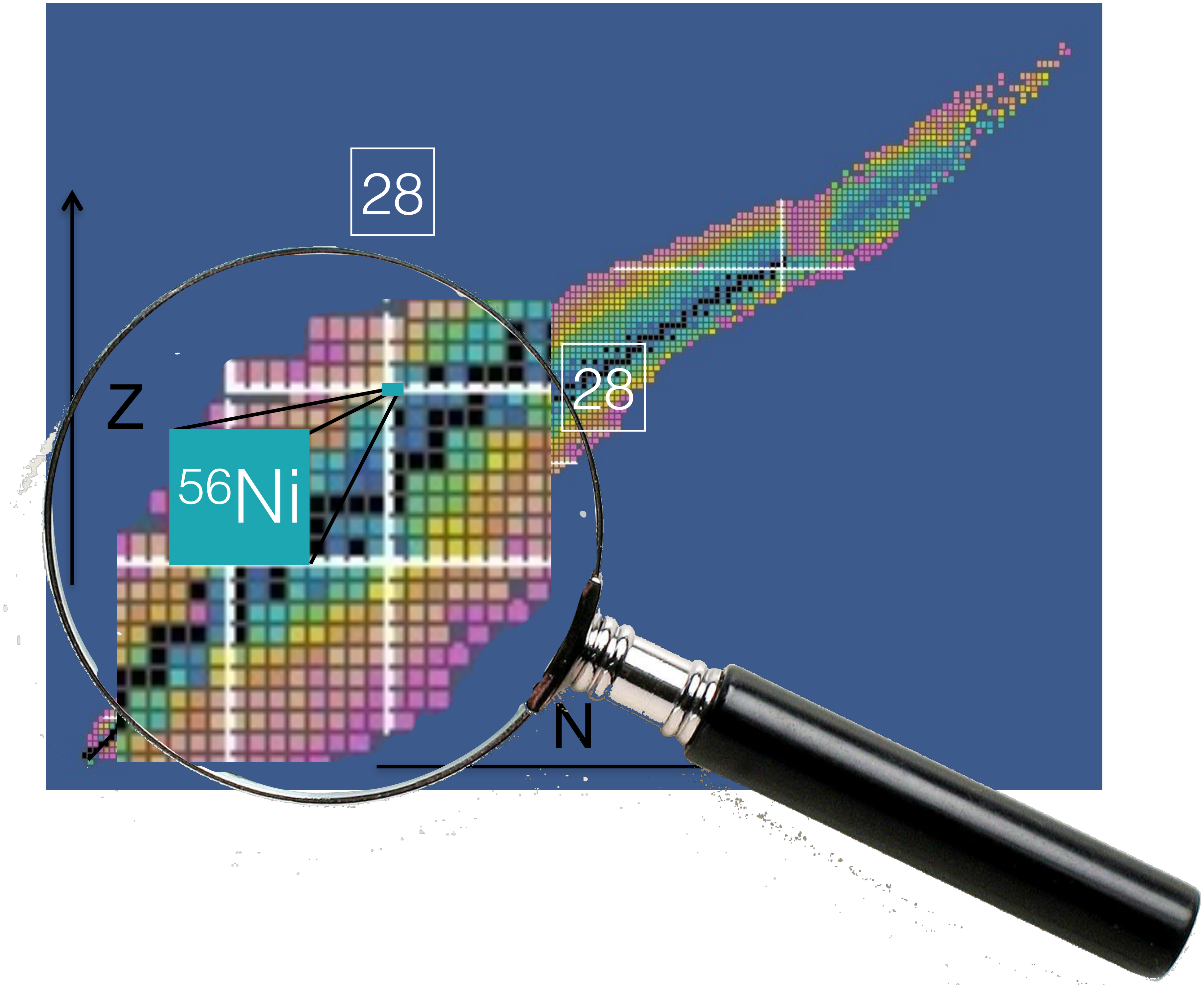
- N=28 shell closure
  - Pairing by transfer
- One neutron pick-up
  - Two-nucleon transfer

Understanding the structure of ^{56}Ni through one- and two-nucleon transfer reactions: shell gaps and np-pairing

Anastasia Georgiadou
Marlène Assie, Yorick Blumenfeld

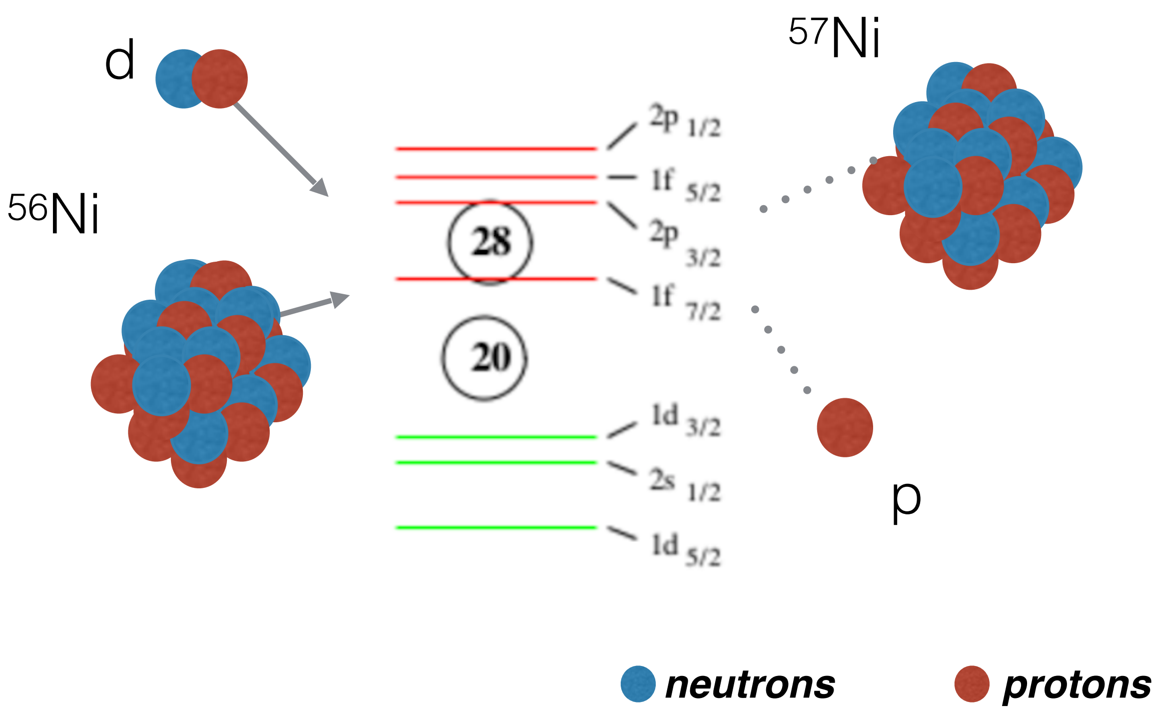
- N=28 shell closure
- Pairing by transfer
- One neutron pick-up
- Two-nucleon transfer


Z
N=Z
N


28
Z
28
56Ni
N

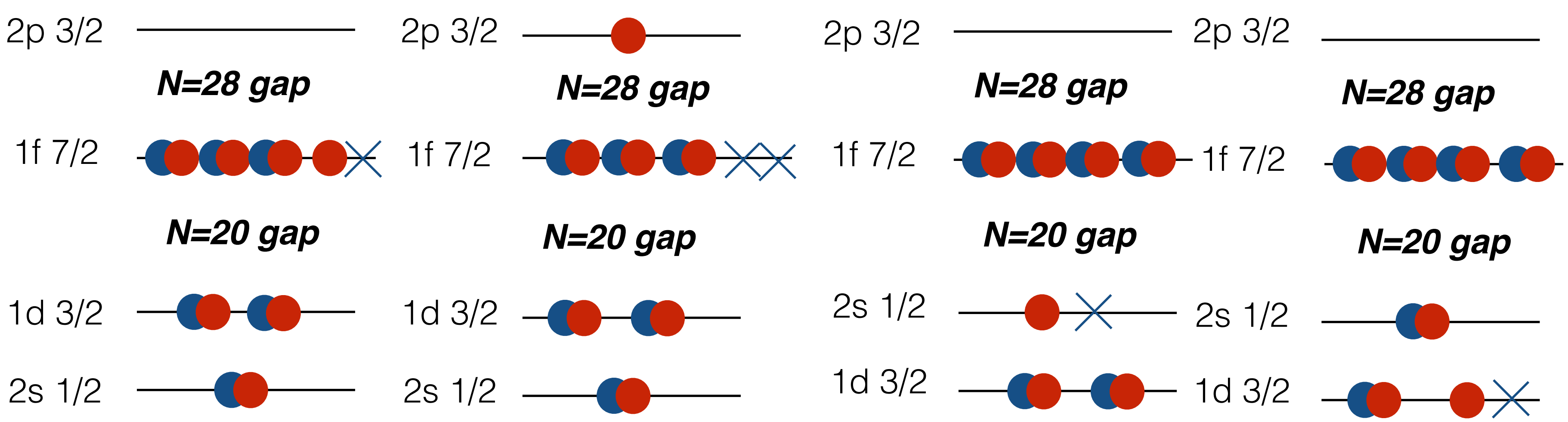
I. One nucleon transfer reaction

Transfer reactions continue to play **major role** in our understanding of the nuclear elementary modes of excitation, particularly in the **characterisation of the single particle** degrees of freedom and their correlations.



Neutron **pick-up reactions** gives information about the N=27 isotones.

Extraction of the neutron **Spectroscopic Factor (SF)**, is a measure of the overlap between the initial and final state.



Ground State: f7/2	*1st Excited State:2p3/2-*	*2s1/2+*	*d3/2+*

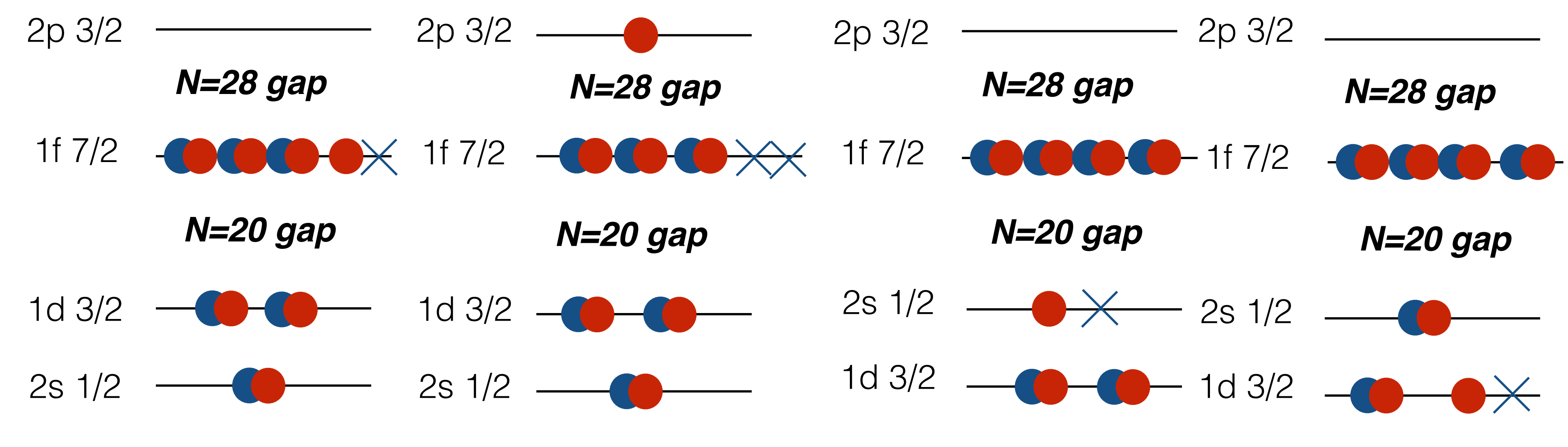
neutrons ***protons***

“Holes” probed in N=27 isotones

---

proton and neutron “Fermi surface” of ^{56}Ni

N=28 Shell Closure

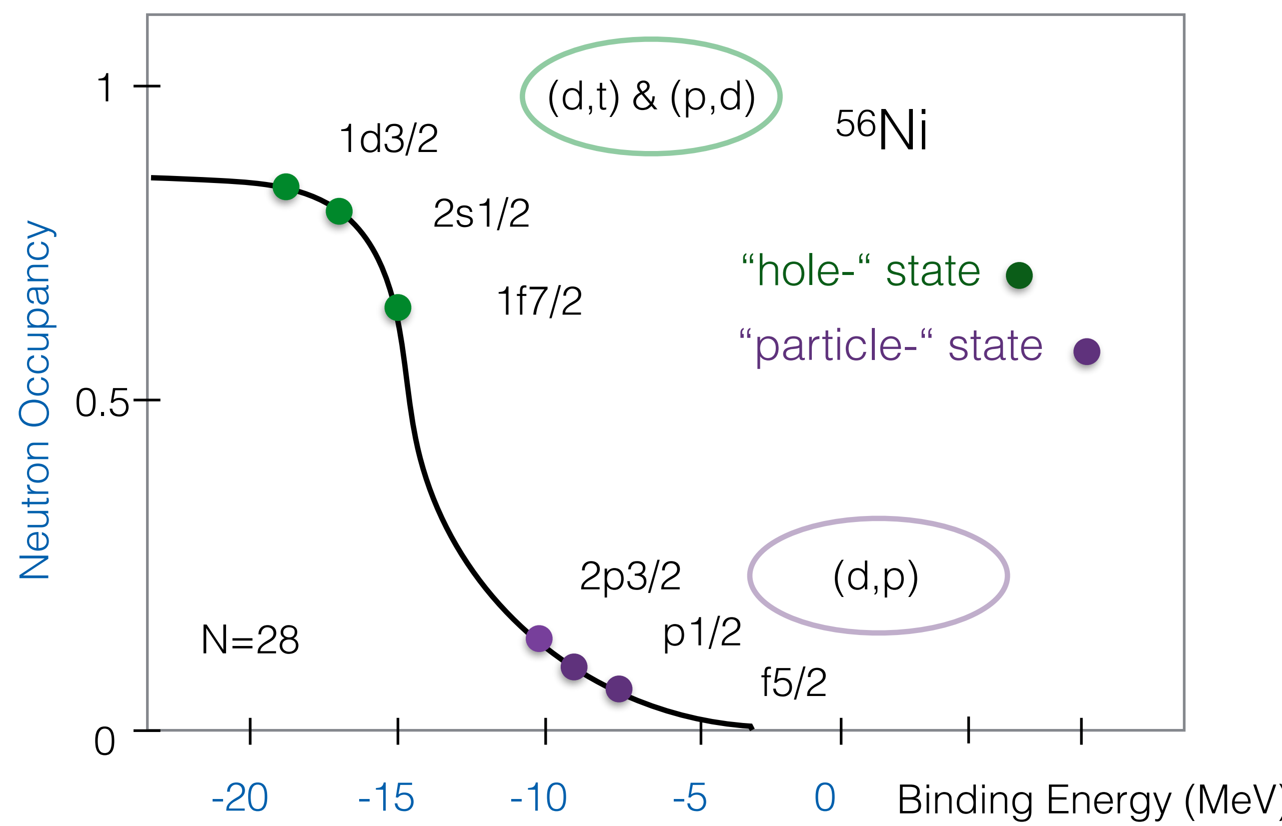


Ground State: f7/2	1st Excited State:2p3/2-	2s1/2+	d3/2+

neutrons ***protons***

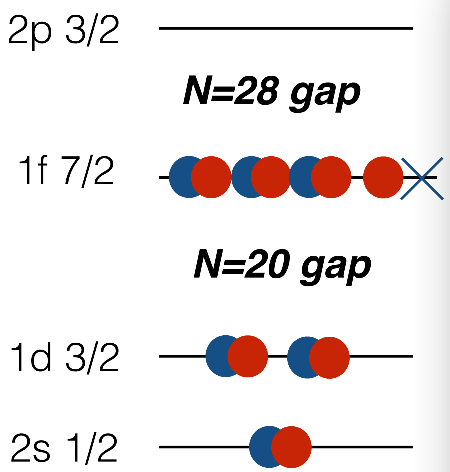
"Holes" probed in N=27 isotones

proton and neutron "Fermi surface" of ^{56}Ni



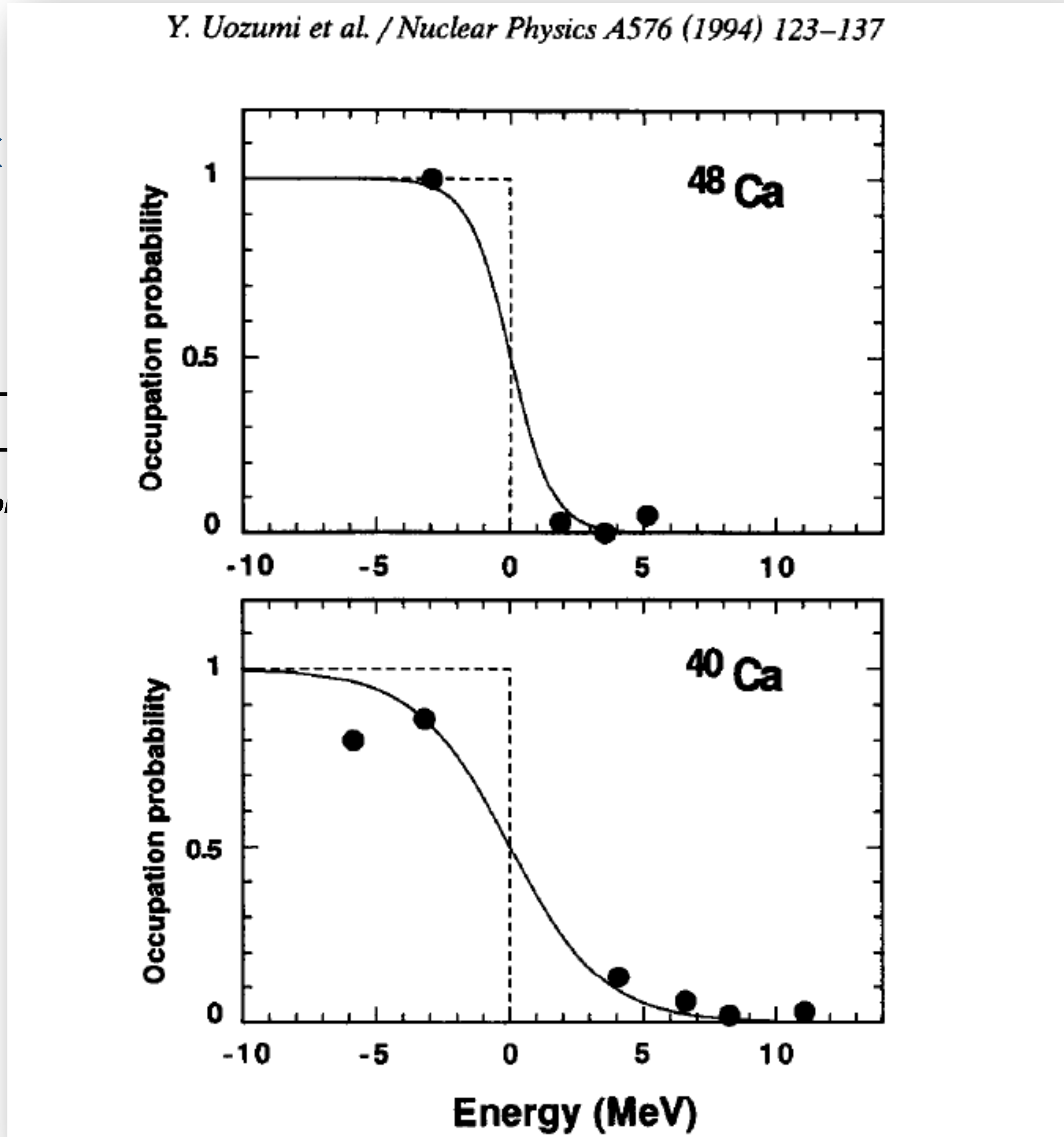
*Adapted from O.Sorlin

N=28 Shell Closure



Ground State: f7/2

neutrons pr

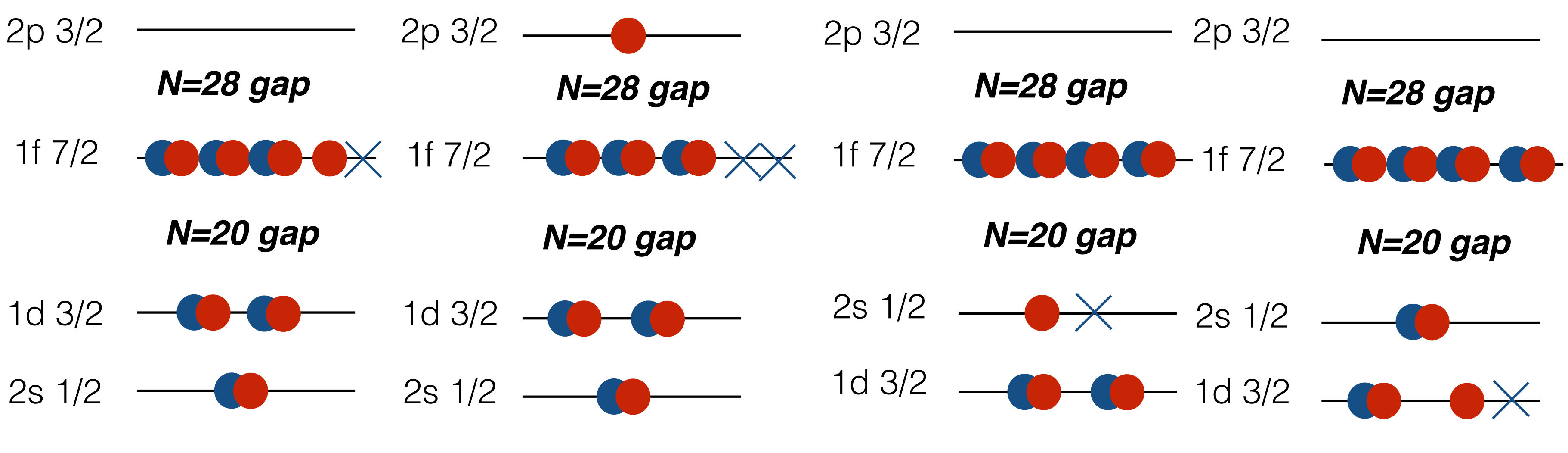


oles” probed in
N=27 isotones

oton and neutron
ermi surface” of
^{56}Ni

ed from O.Sorlin

N=28 Shell Closure

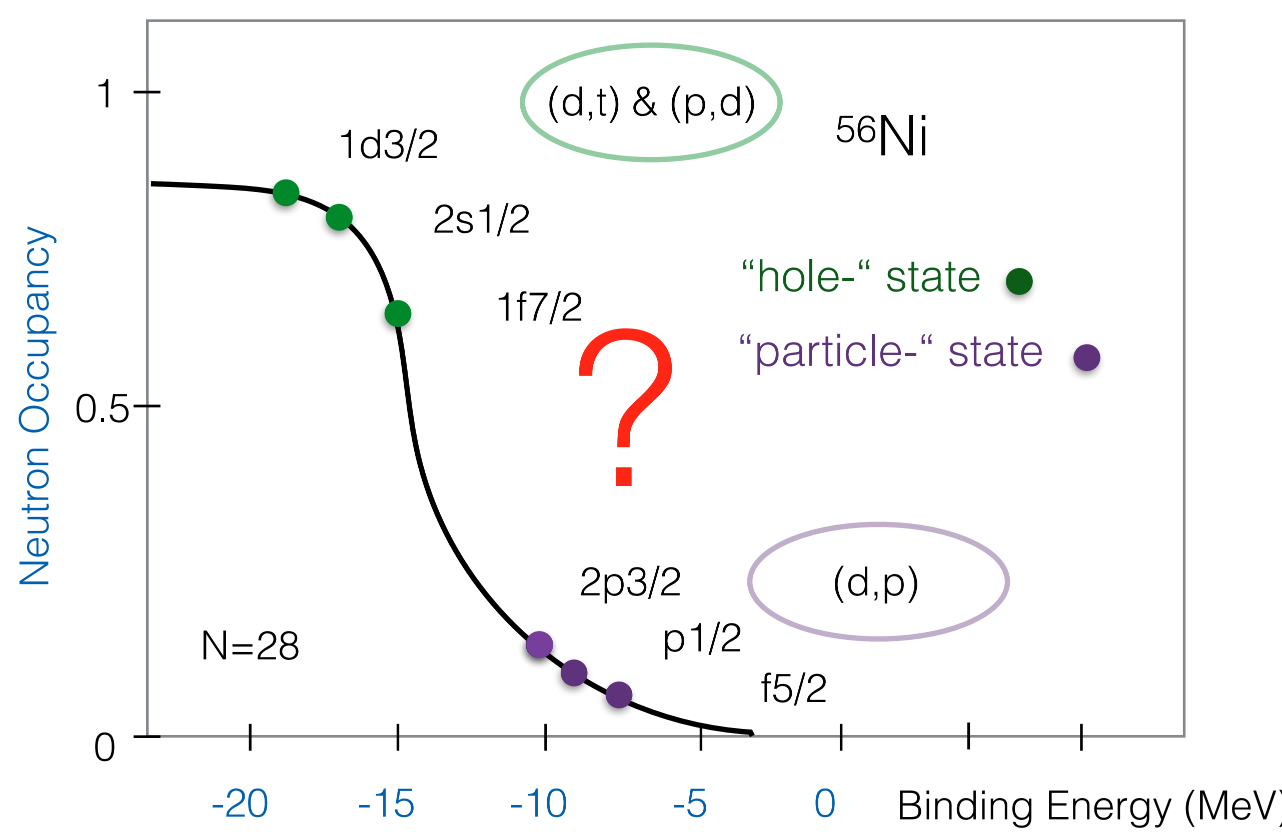


Ground State: f7/2	*1st Excited State:2p3/2-*	*2s1/2+*	*d3/2+*

neutrons ***protons***

"Holes" probed in N=27 isotones

proton and neutron "Fermi surface" of ^{56}Ni



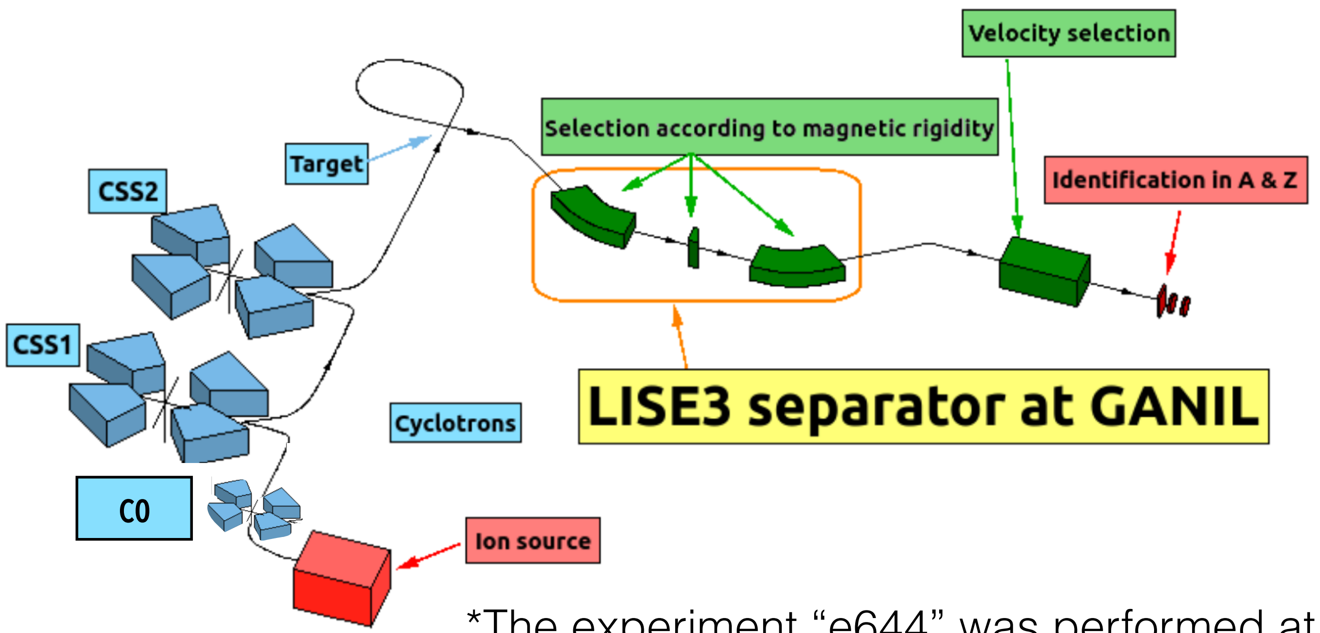
*Adapted from O.Sorlin

Primary beam : ^{58}Ni at 74,5 A MeV

Rotating target (CLIM) : ^{9}Be(1 mm)

Secondary beam : ^{56}Ni at 30A MeV

Reaction Targets: CH_2, CD_2, ^{12}C



*The experiment "e644" was performed at GANIL,CAEN at Spring 2014.

One nucleon transfer

^{56}Ni(p,d)^{55}Ni

^{56}Ni(d,t) ^{55}Ni

^{56}Ni(d,p) ^{57}Ni

Experimental Set Up

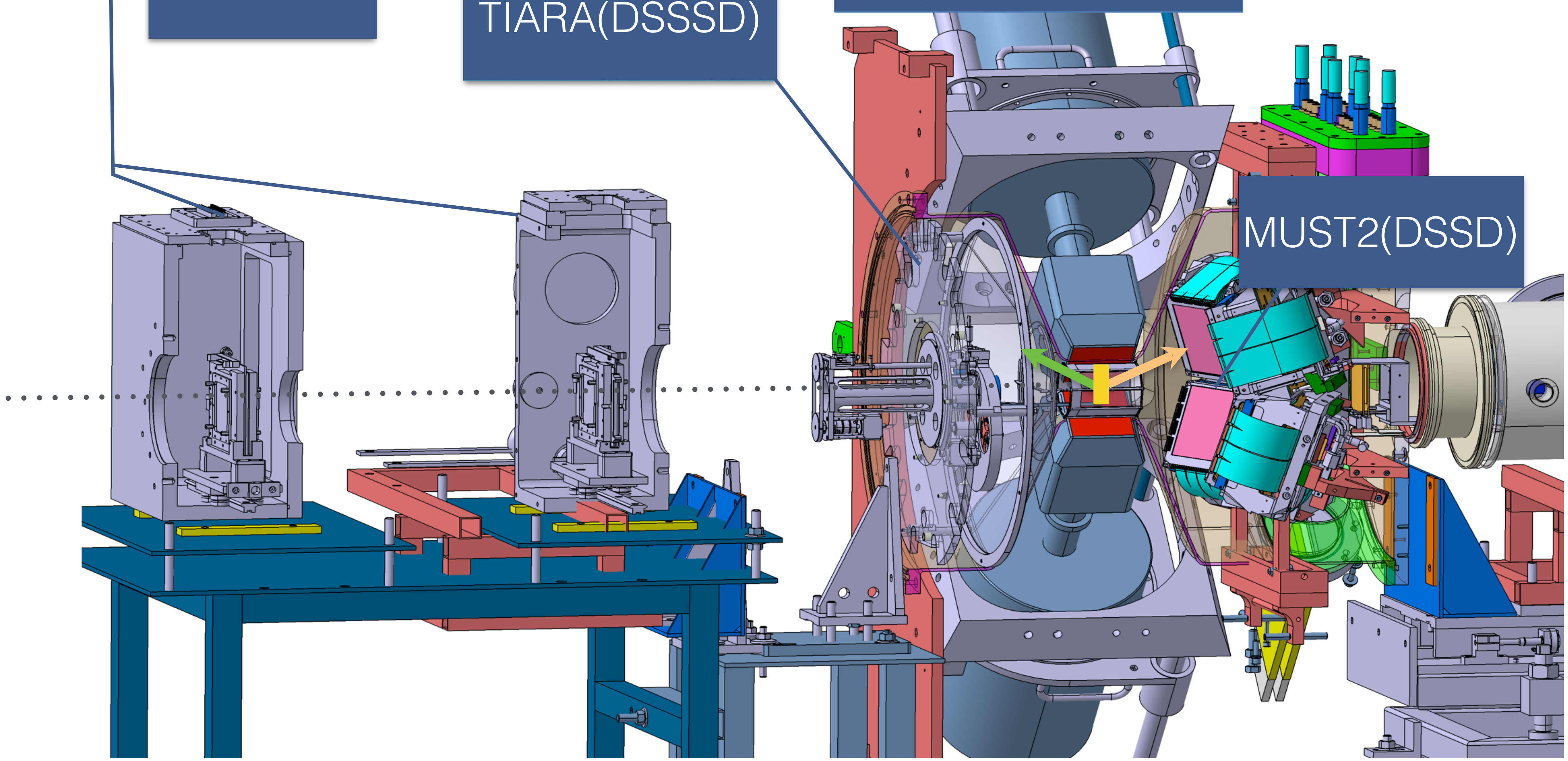
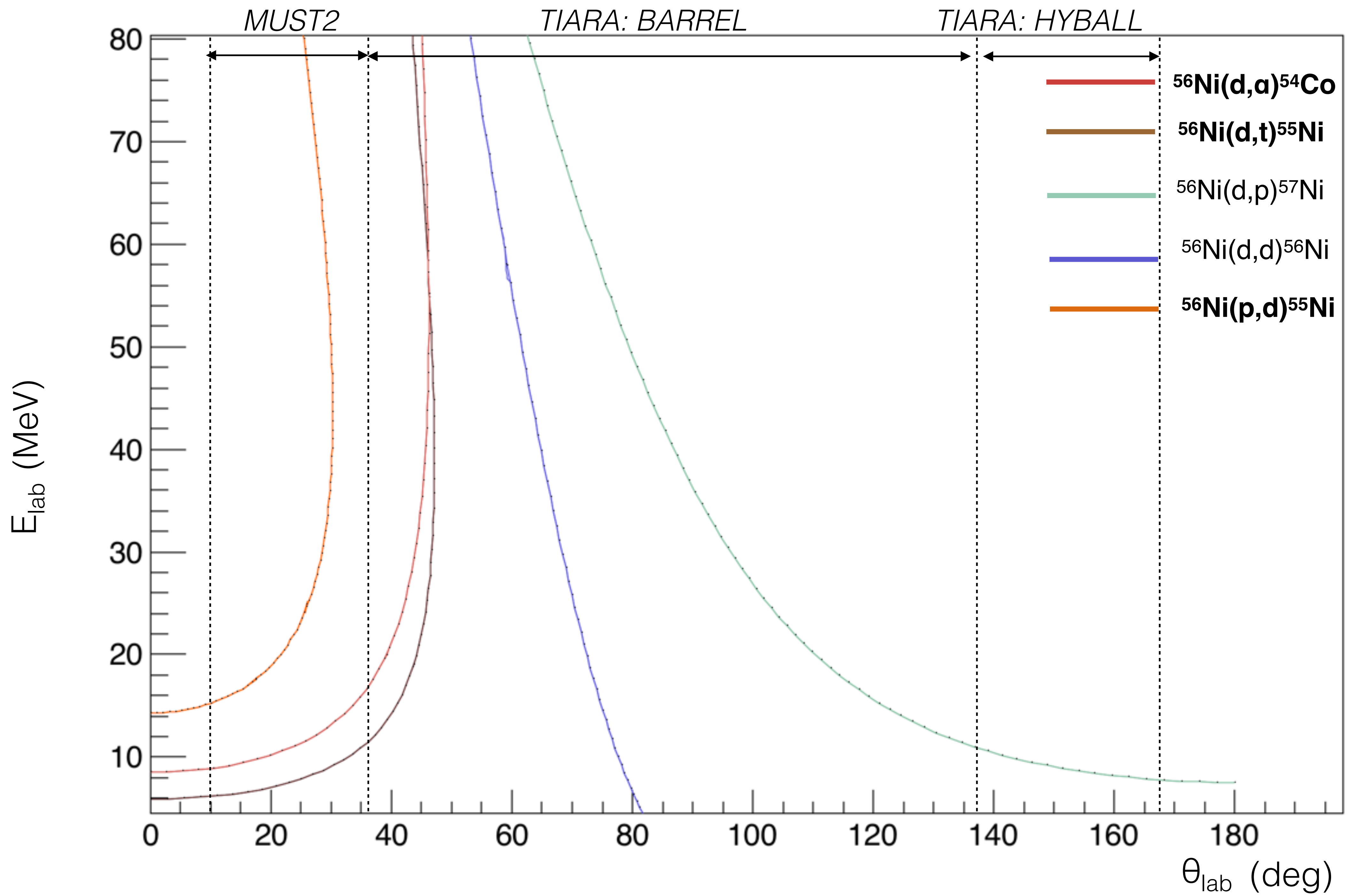


*Illustration by Emmanuel Rindel

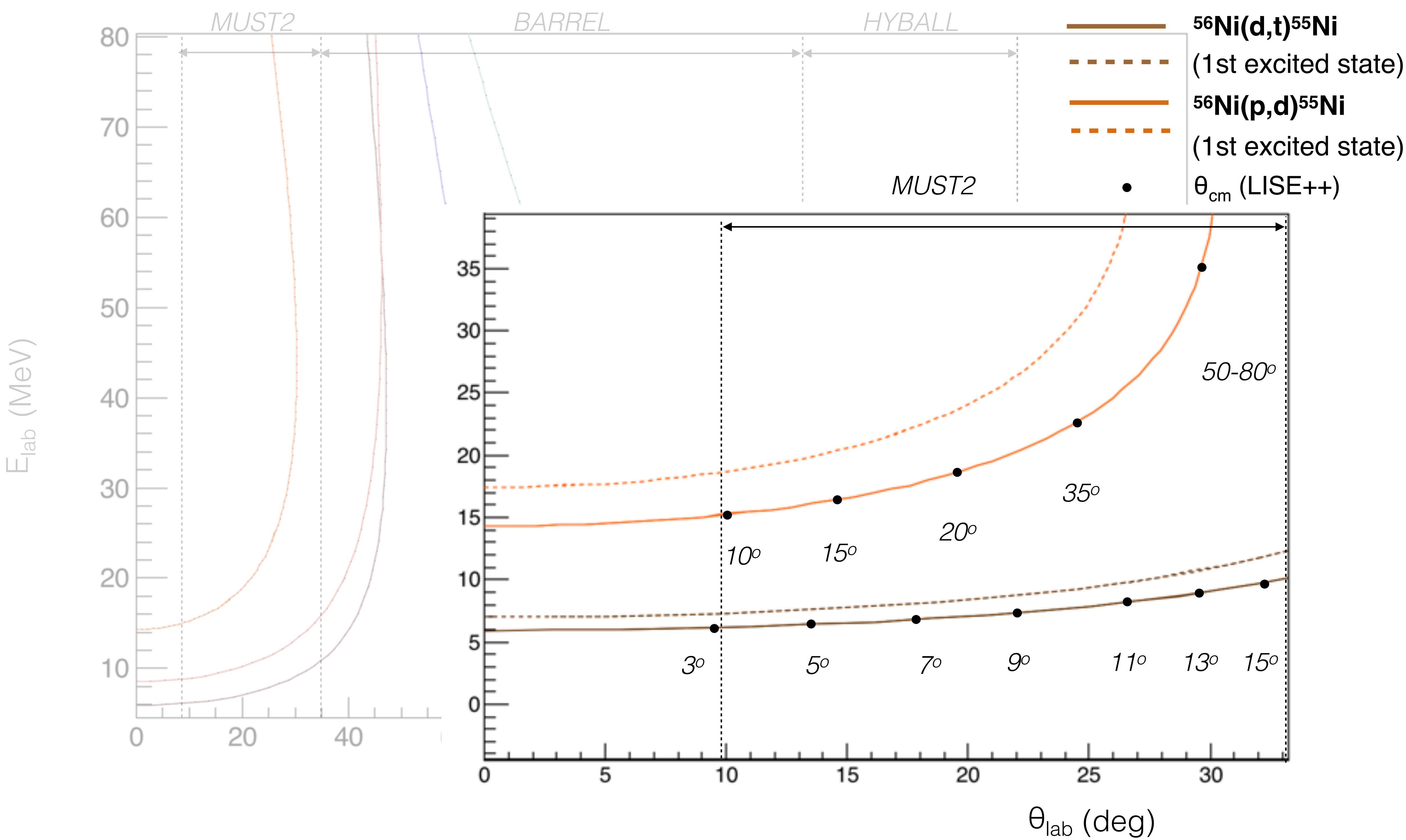
Beam ^{56}Ni
tritons
protons

Targets: CD_2, CH_2, ^{12}C

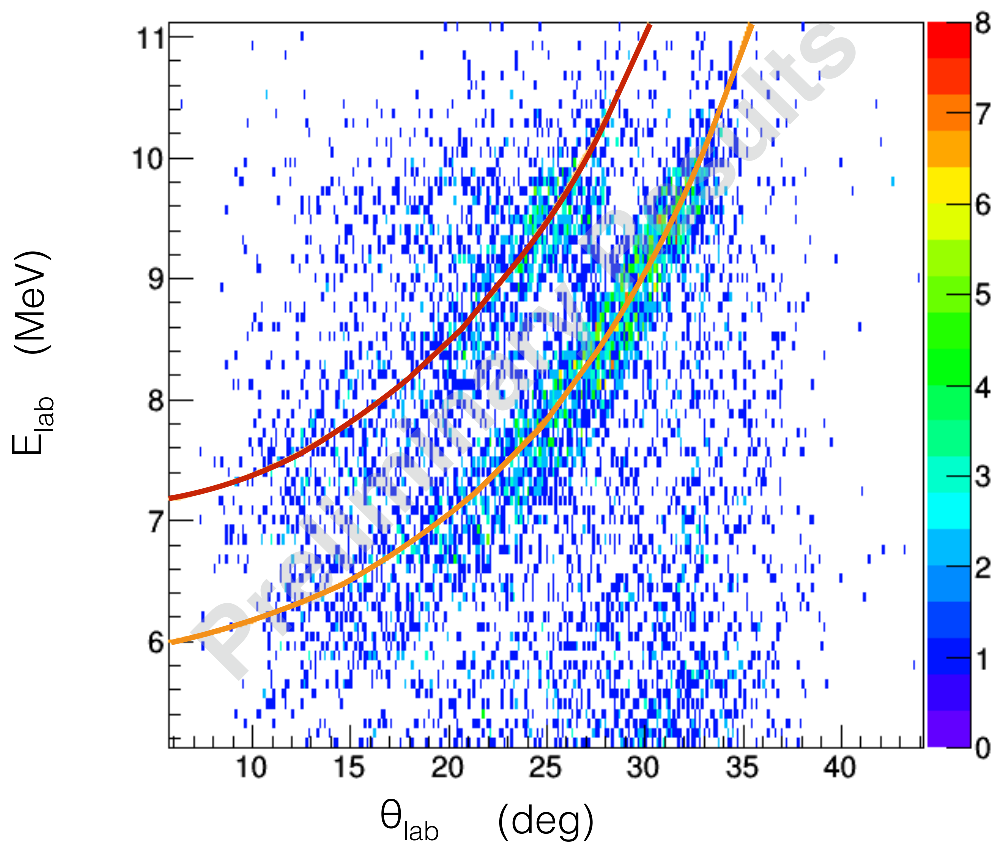
Analysis: The reaction Kinematics



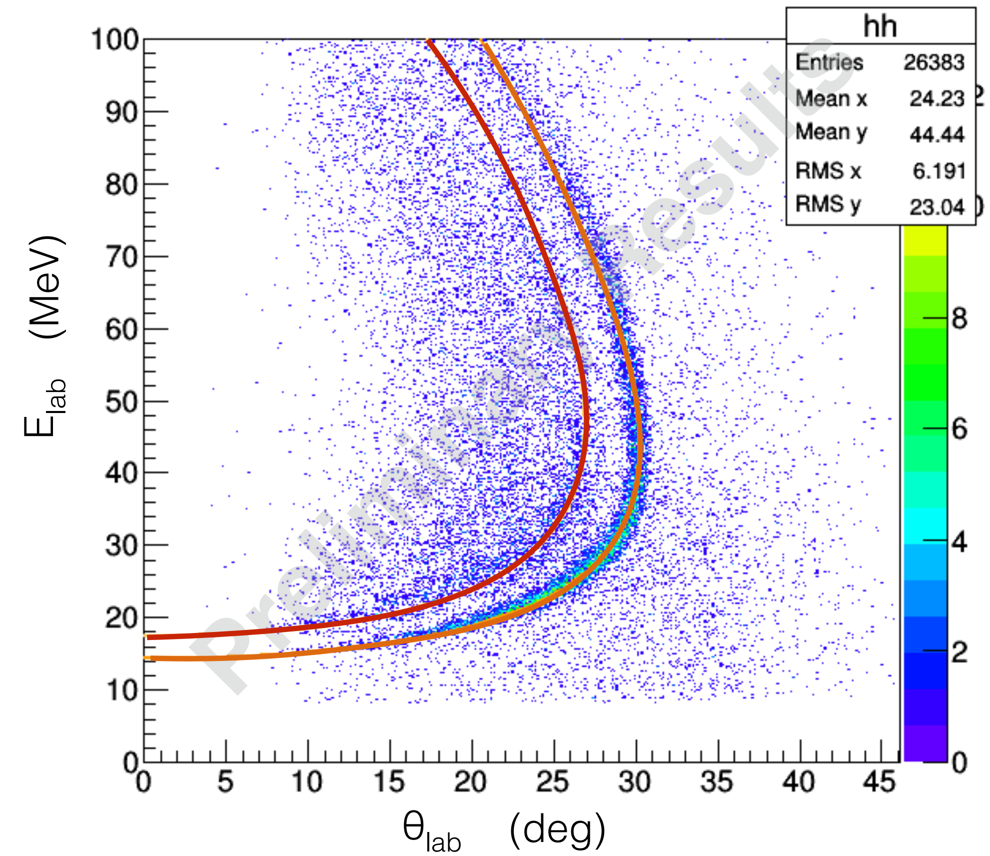
Analysis: The reaction Kinematics



$^{56}Ni(d,t)^{55}Ni$

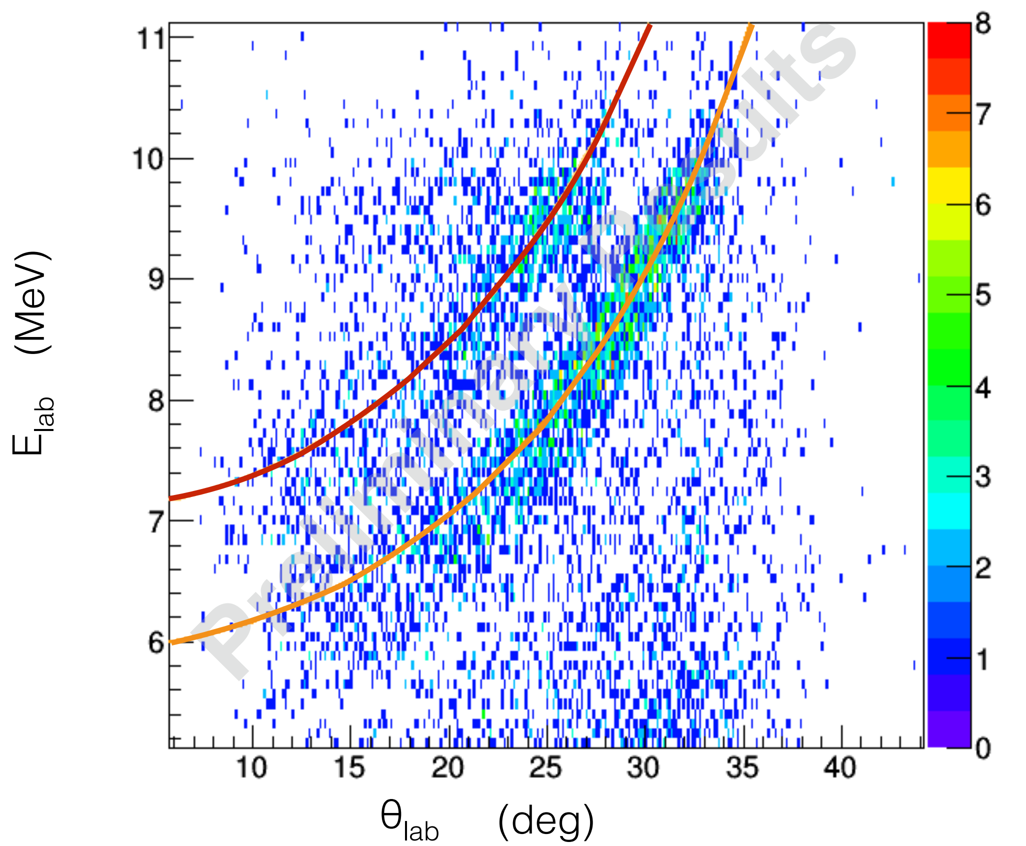


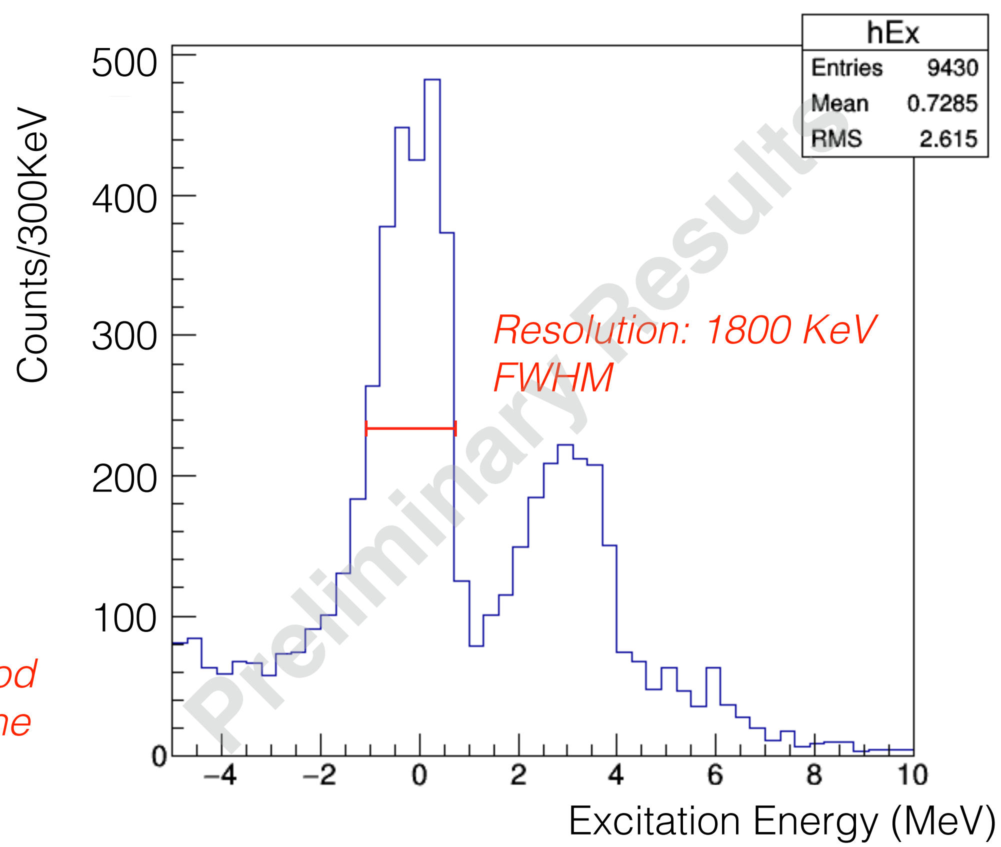
$^{56}Ni(p,d)^{55}Ni$



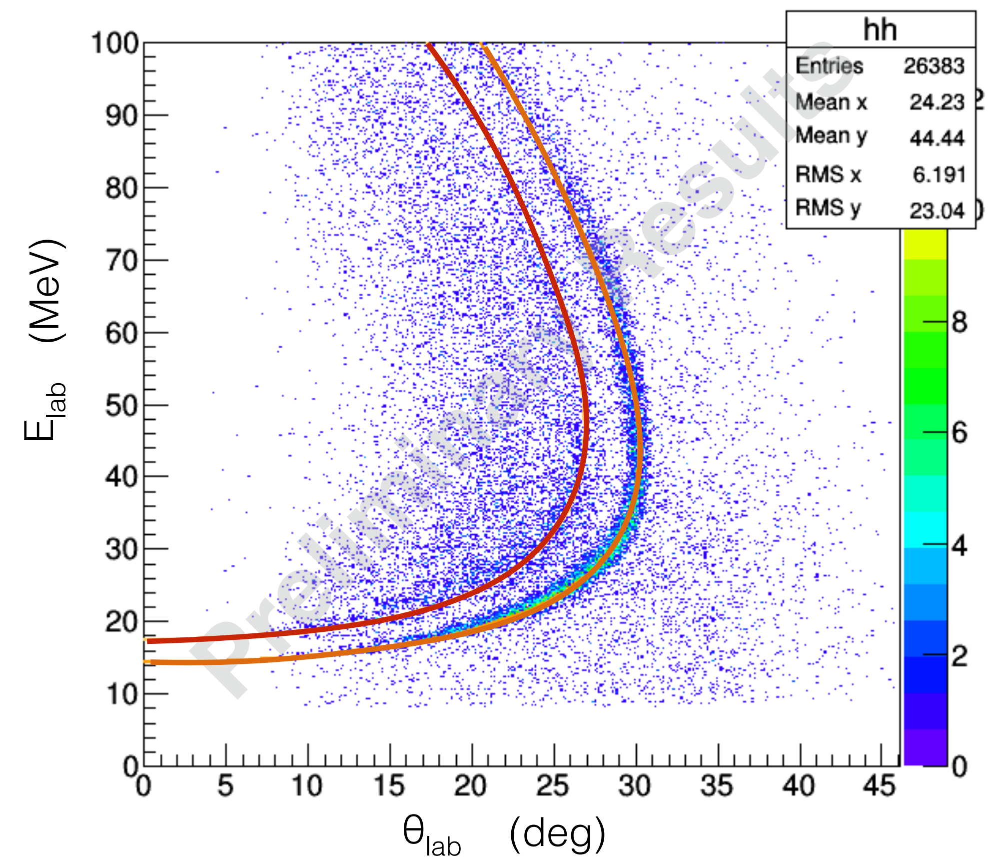
Ground State
(Excited States)

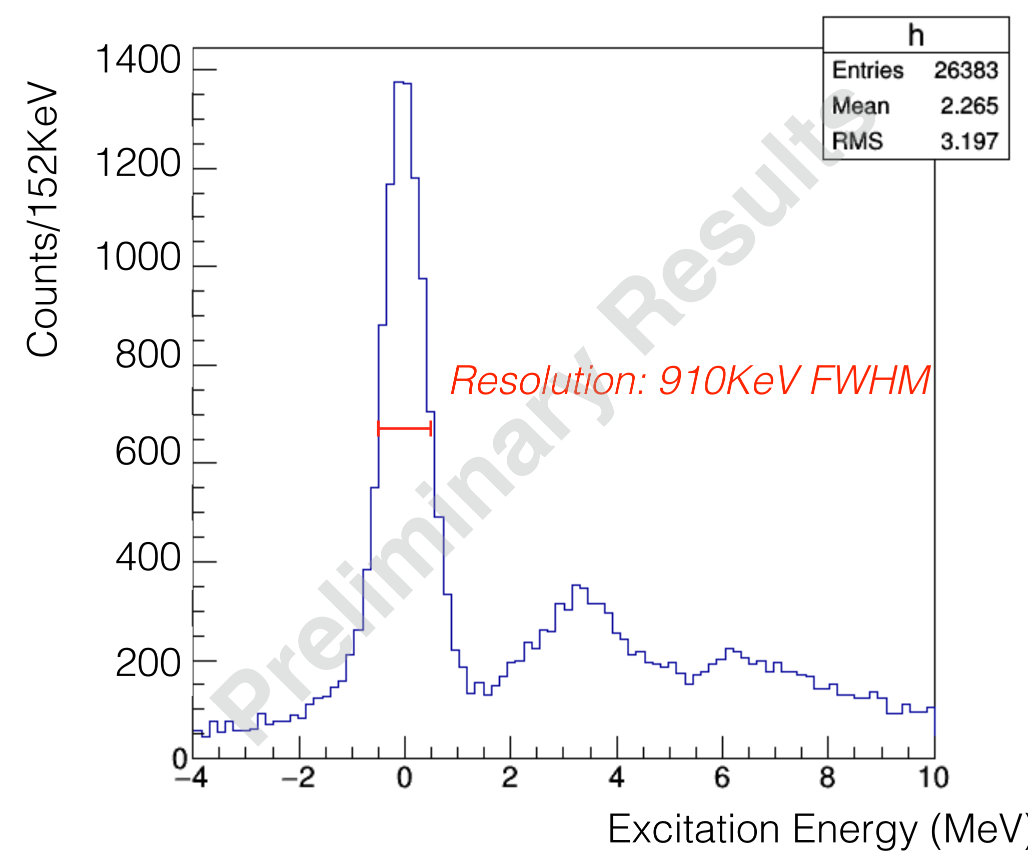
$^{56}Ni(d,t)^{55}Ni$





$^{56}Ni(p,d)^{55}Ni$

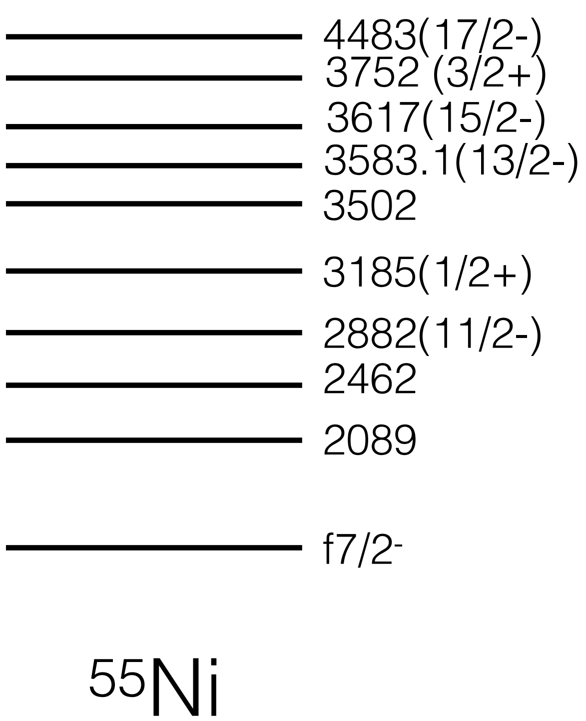


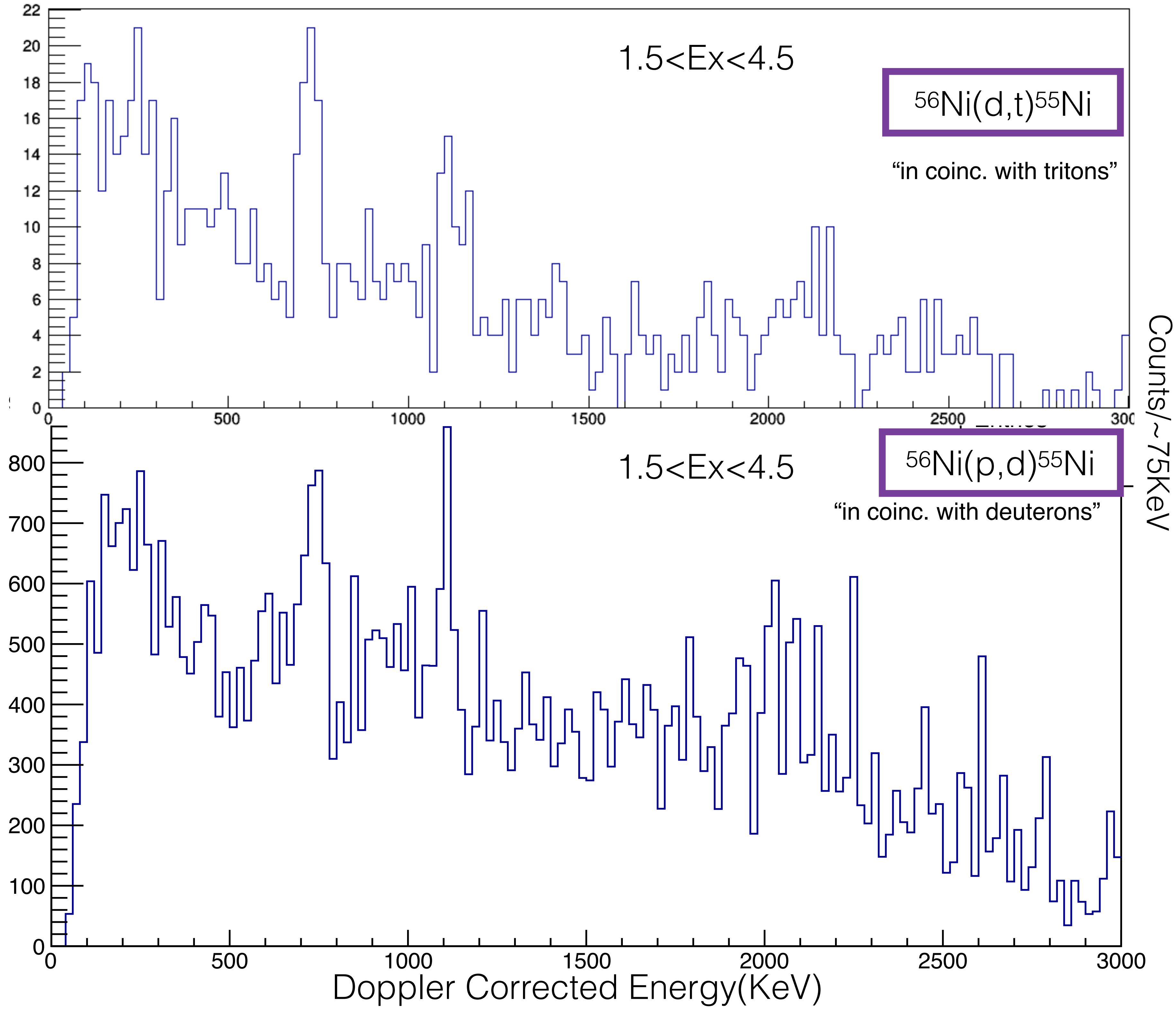


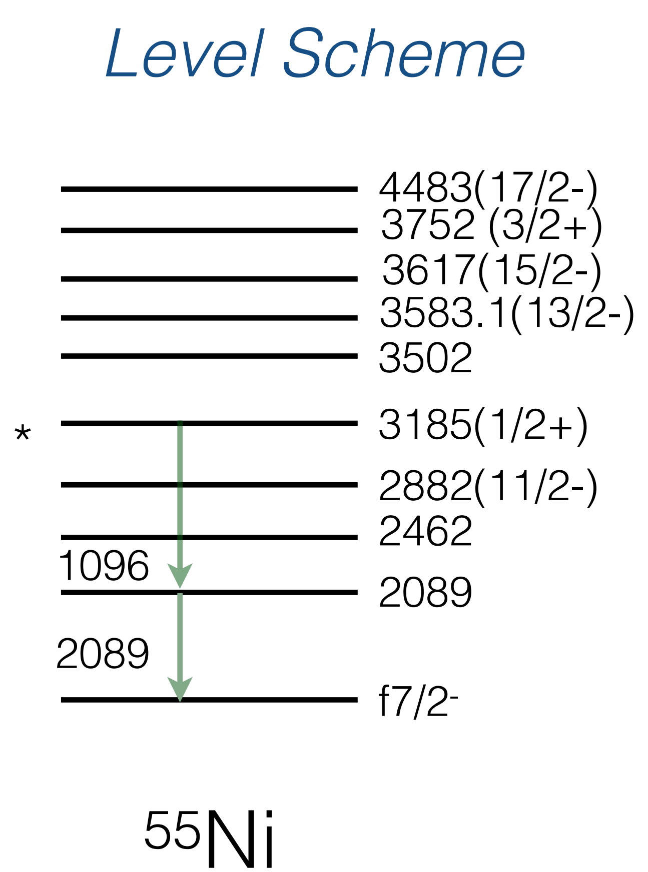
Resolution: In good agreement with the simulation!

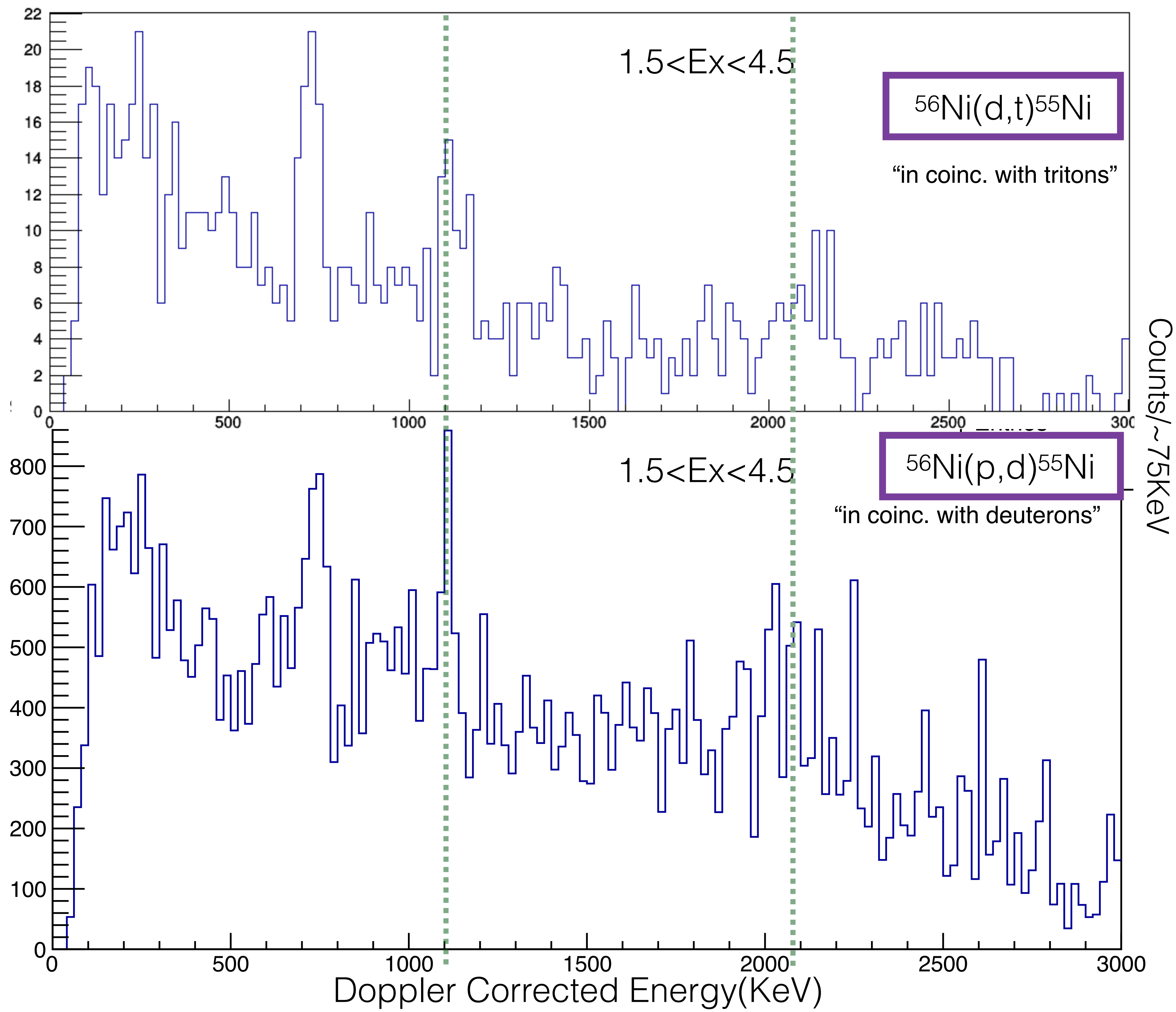
Analysis: Particle-Gamma Coincidence

Level Scheme





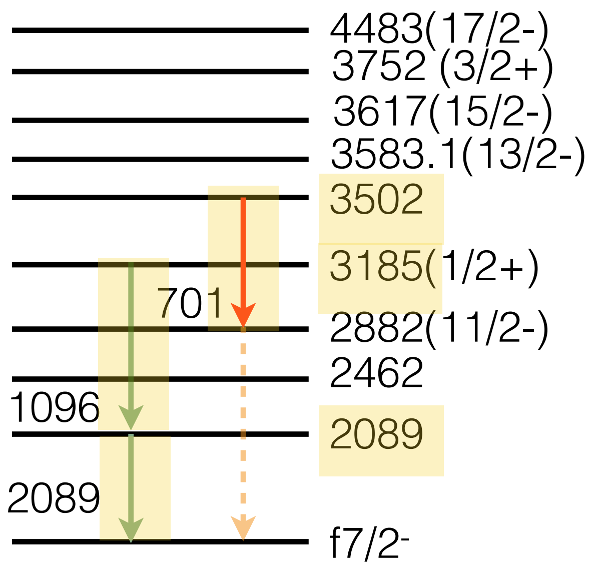




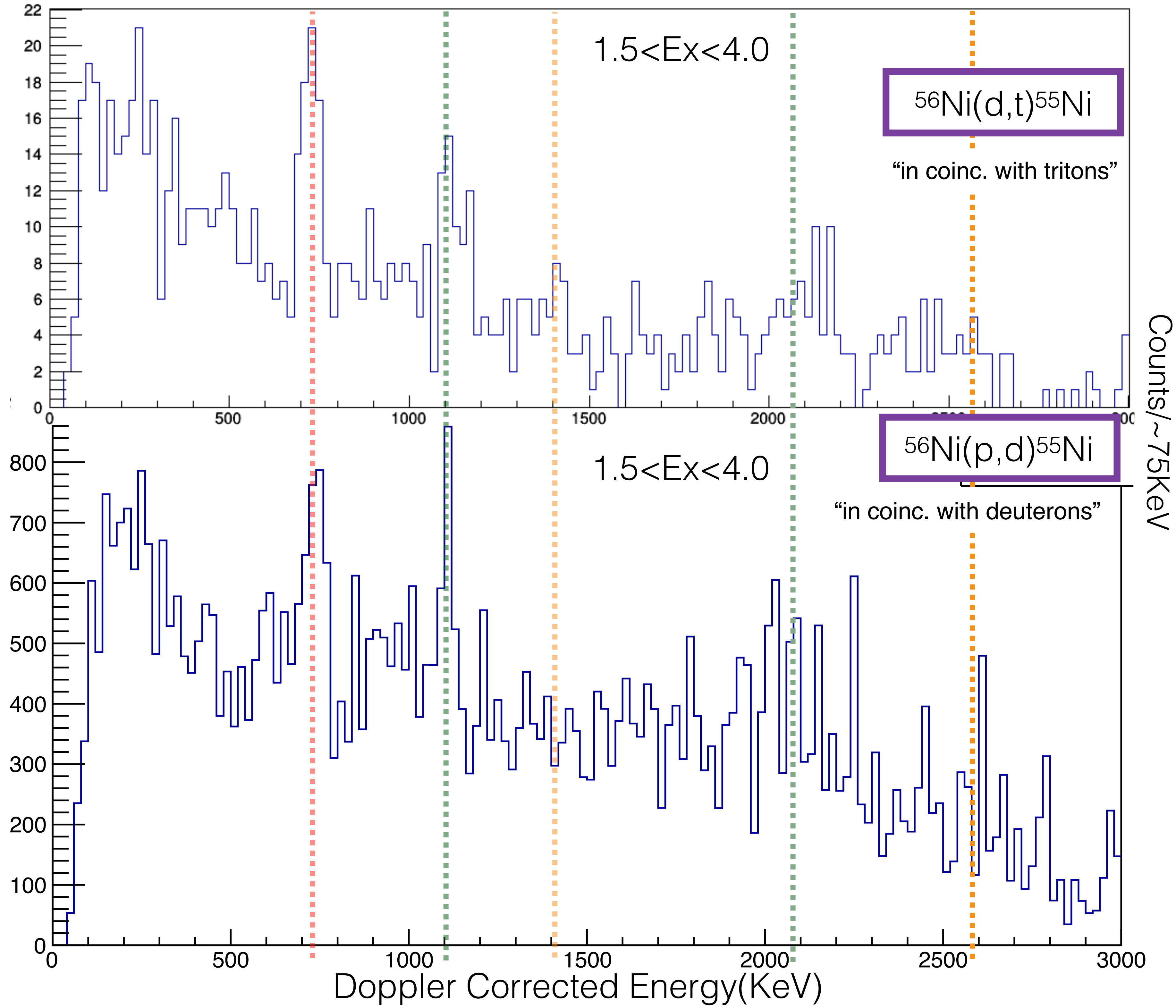
* *A. Sanetullaev, PLB, 236 (2014)*

Analysis: Particle-Gamma Coincidence

Level Scheme



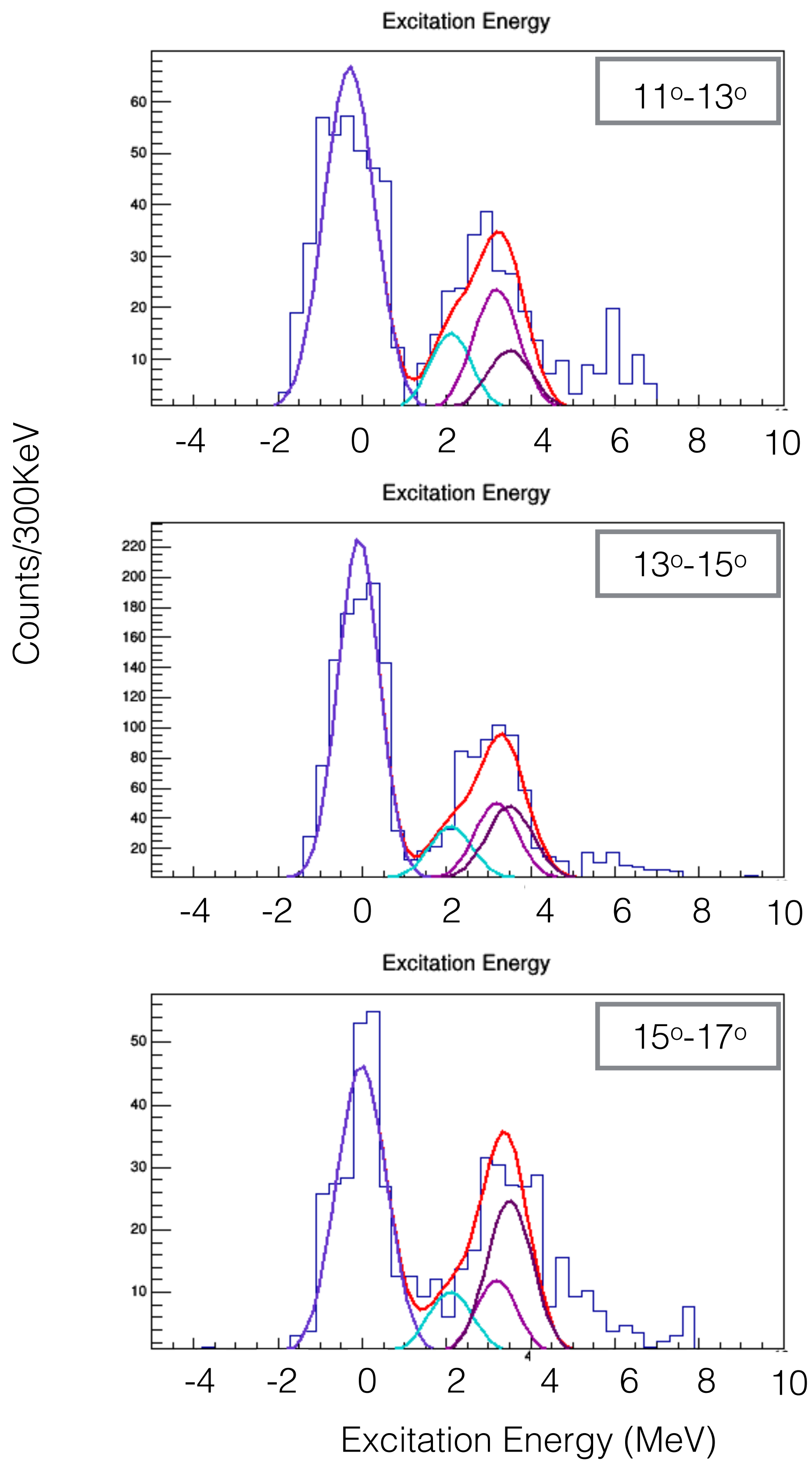
^{55}Ni

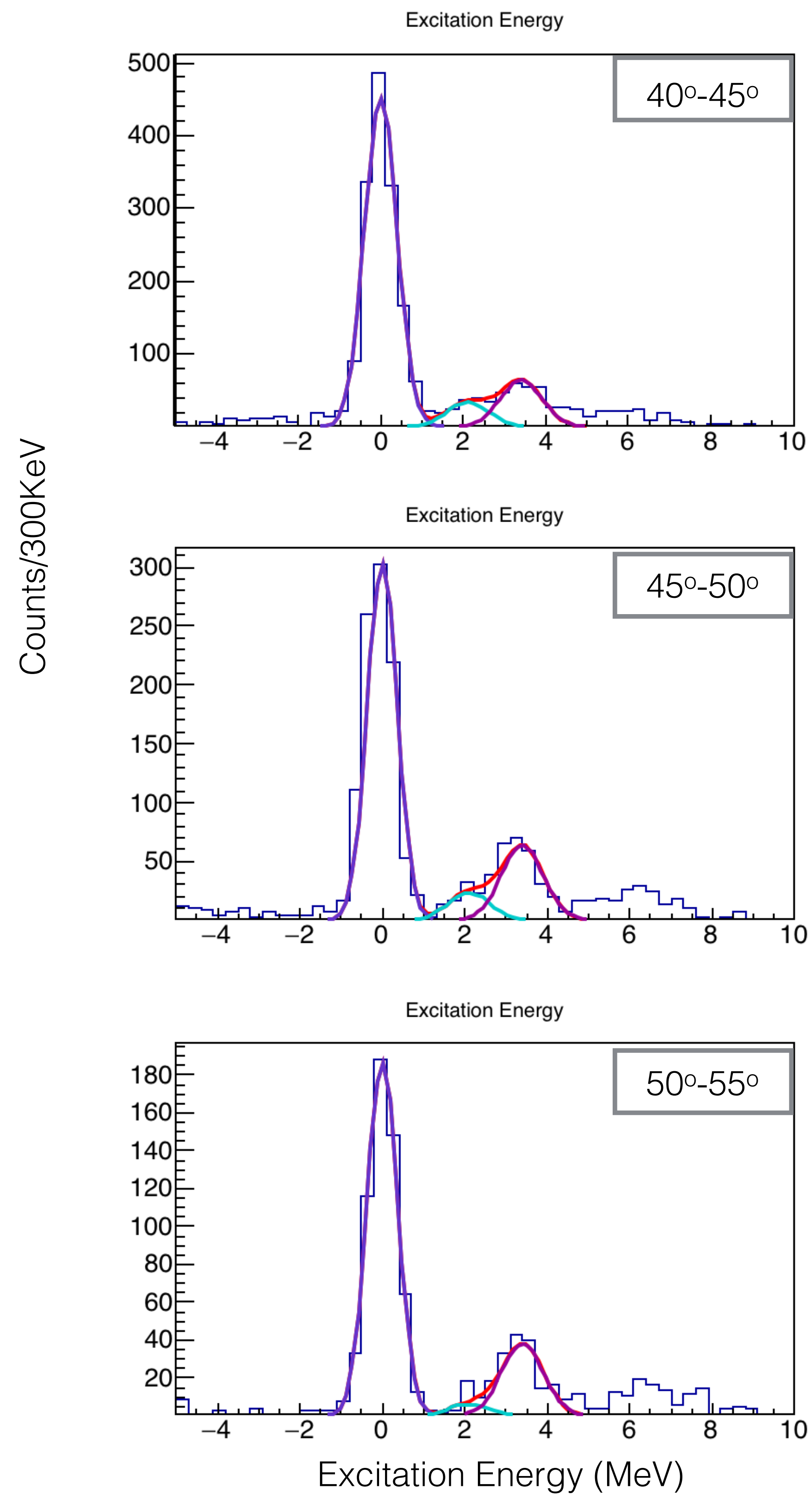


$^{56}Ni(d,t)^{55}Ni$

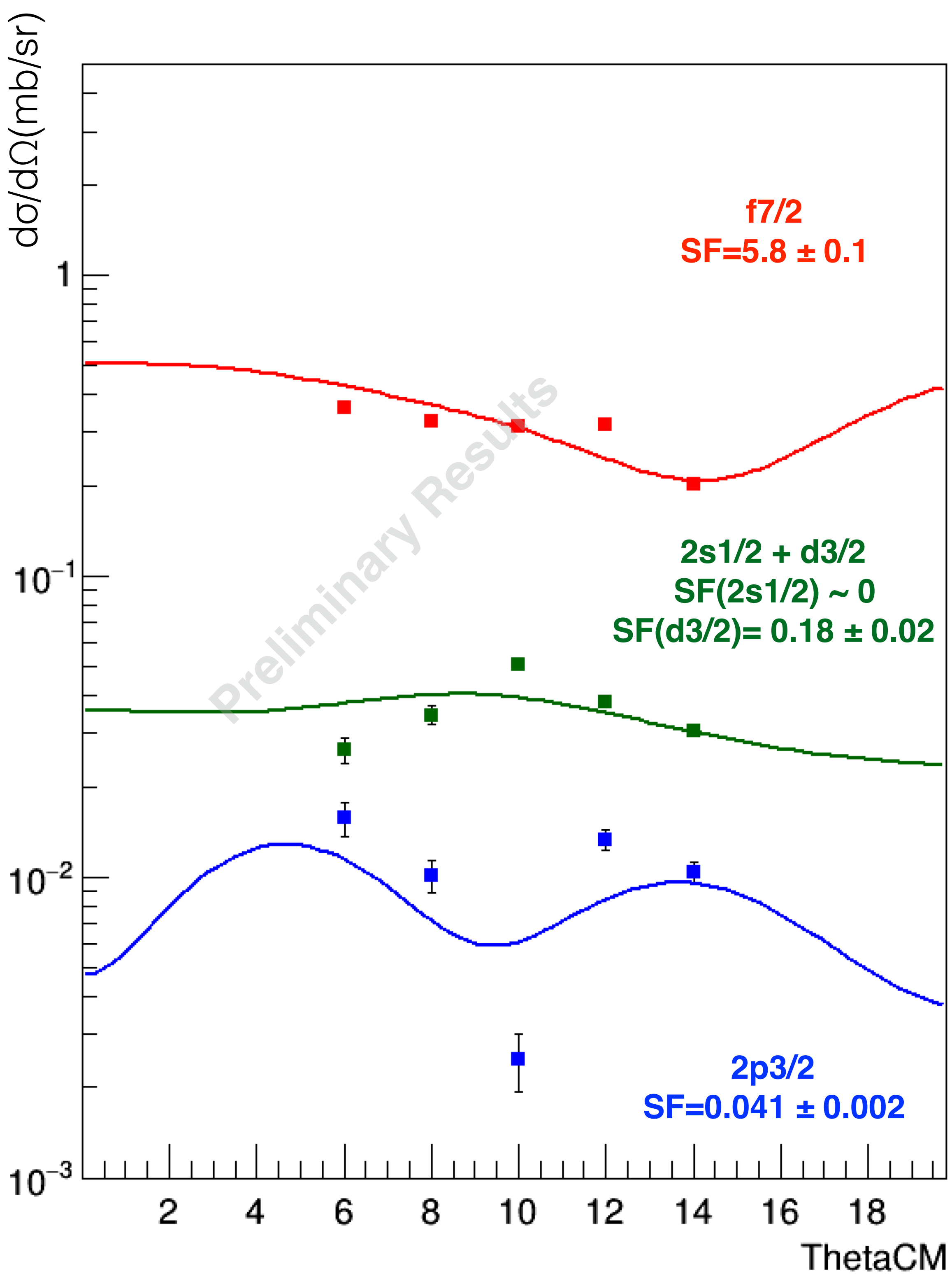
$^{56}Ni(p,d)^{55}Ni$

Particle-Gamma coincidences for different angles in the theta in centre of mass

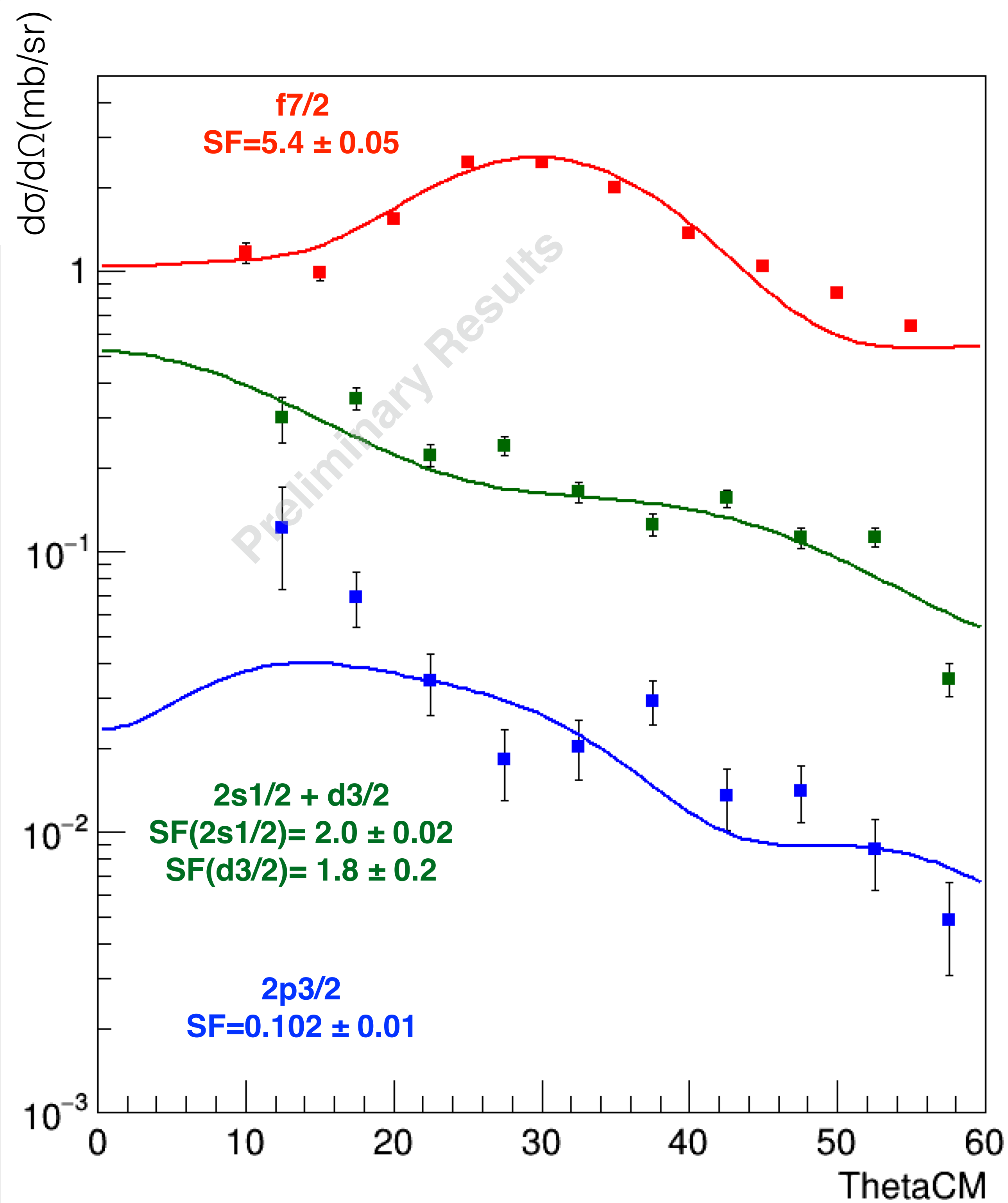




^{56}Ni(d,t)^{55}Ni



^{56}Ni(p,d)^{55}Ni



Calculation with DWBA: A.Georgiadou, J.Guillot

Potential for t used by Pang et al.

Potential for d used by Daehnik et al.

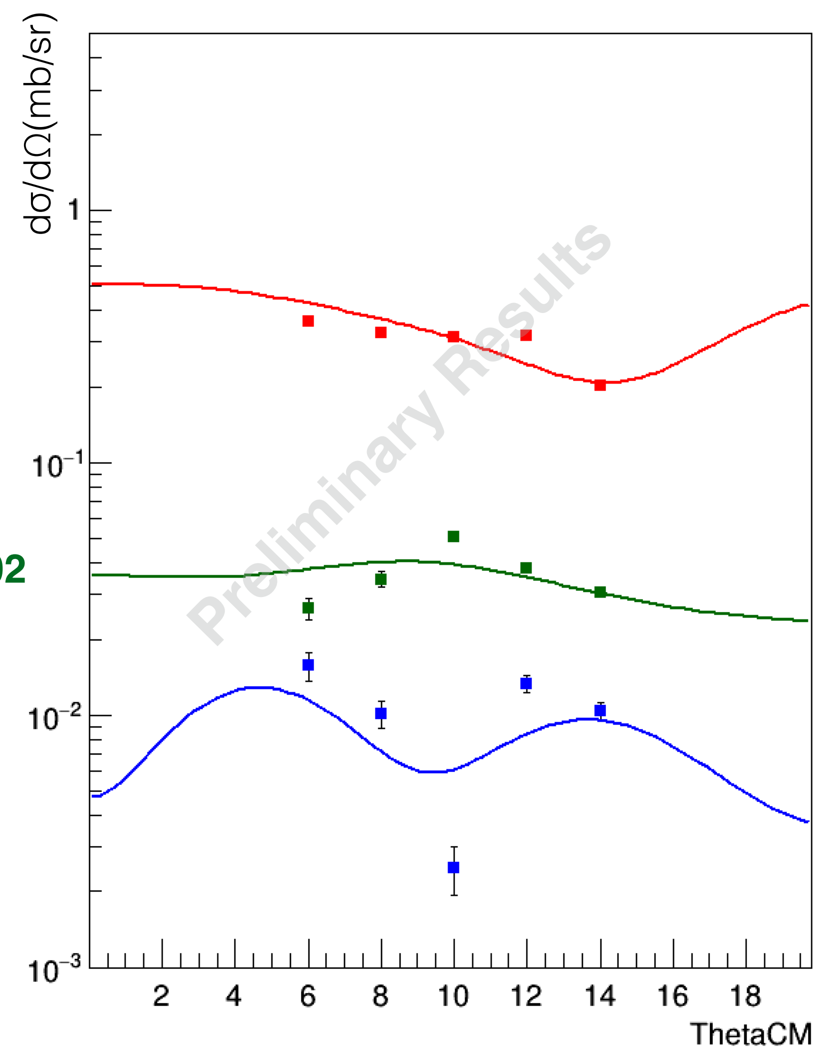
$^{56}Ni(d,t)^{55}Ni$

$^{56}Ni(p,d)^{55}Ni$

f7/2
SF=5.8 ± 0.1

2s1/2 + d3/2
SF(2s1/2) ~ 0
SF(d3/2)= 0.18 ± 0.02

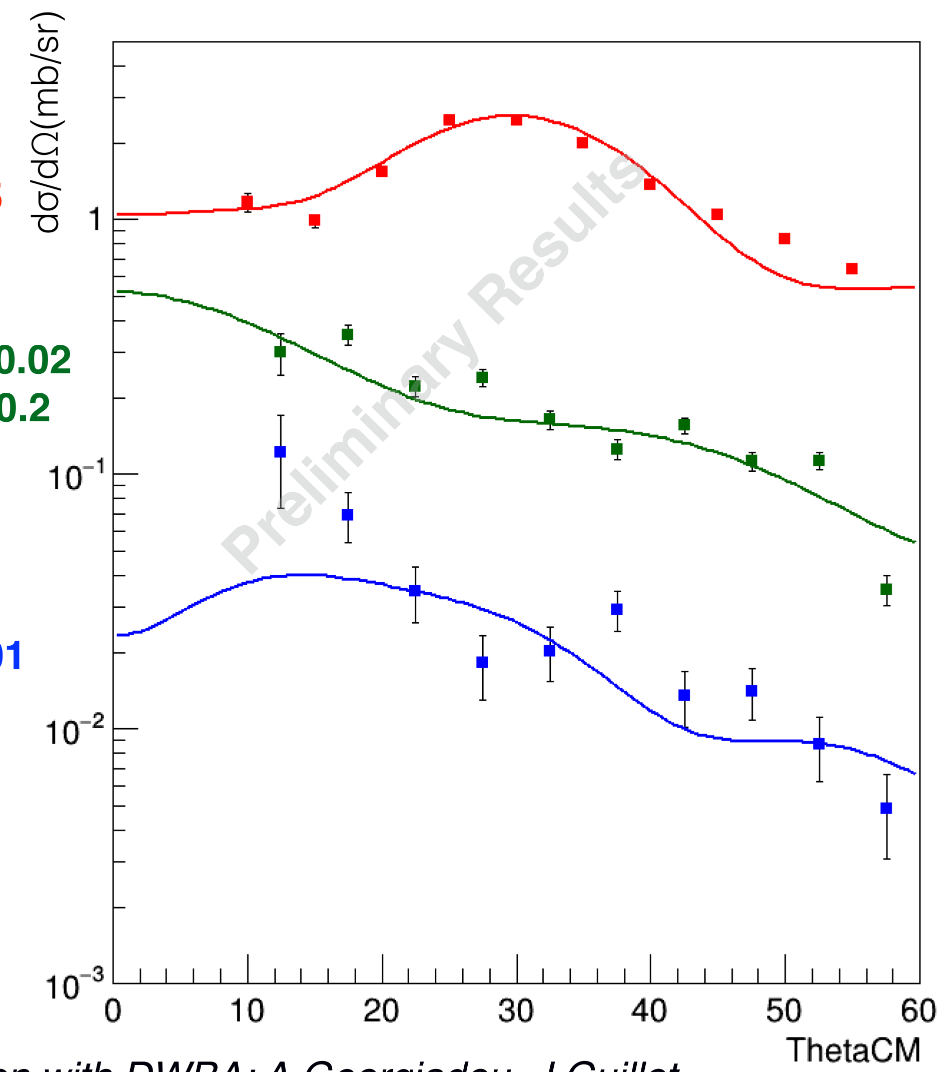
2p3/2
SF=0.041 ± 0.002

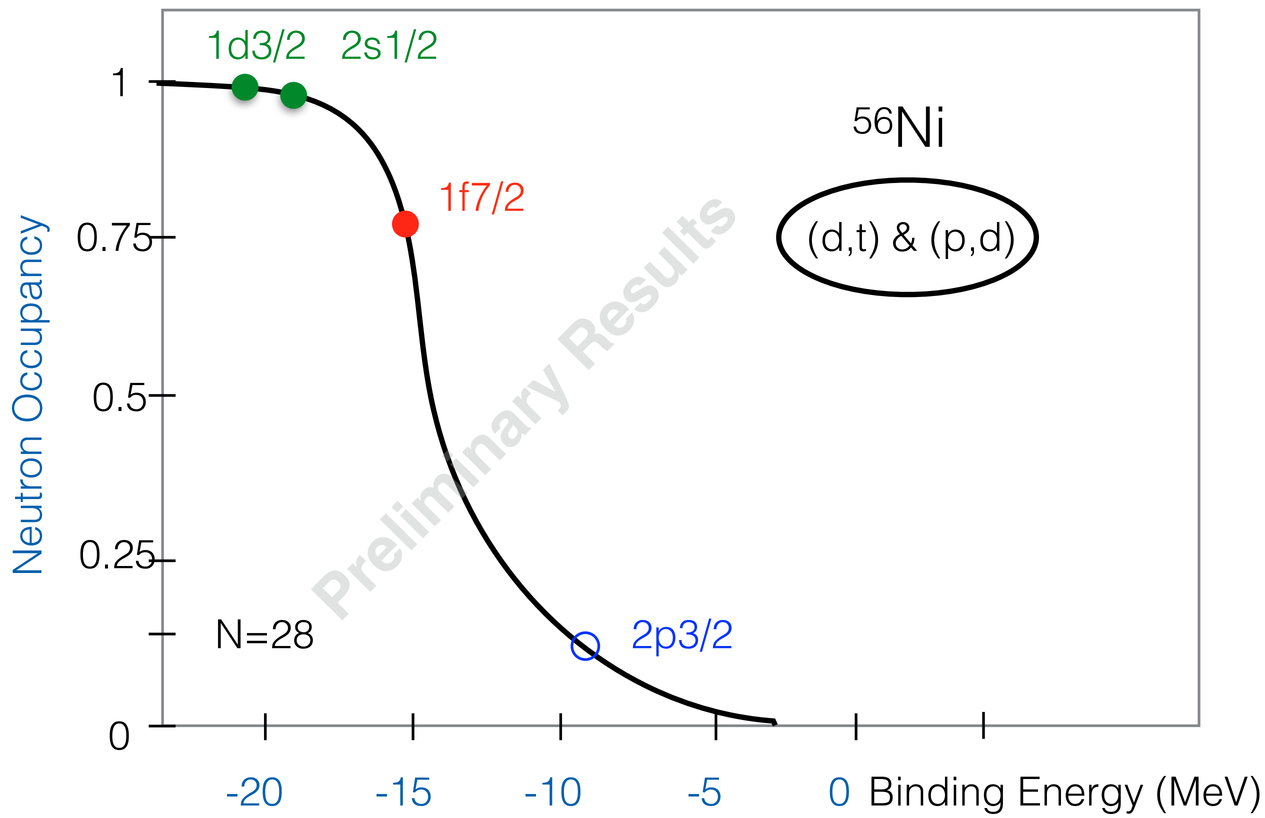


f7/2
SF=5.4 ± 0.05

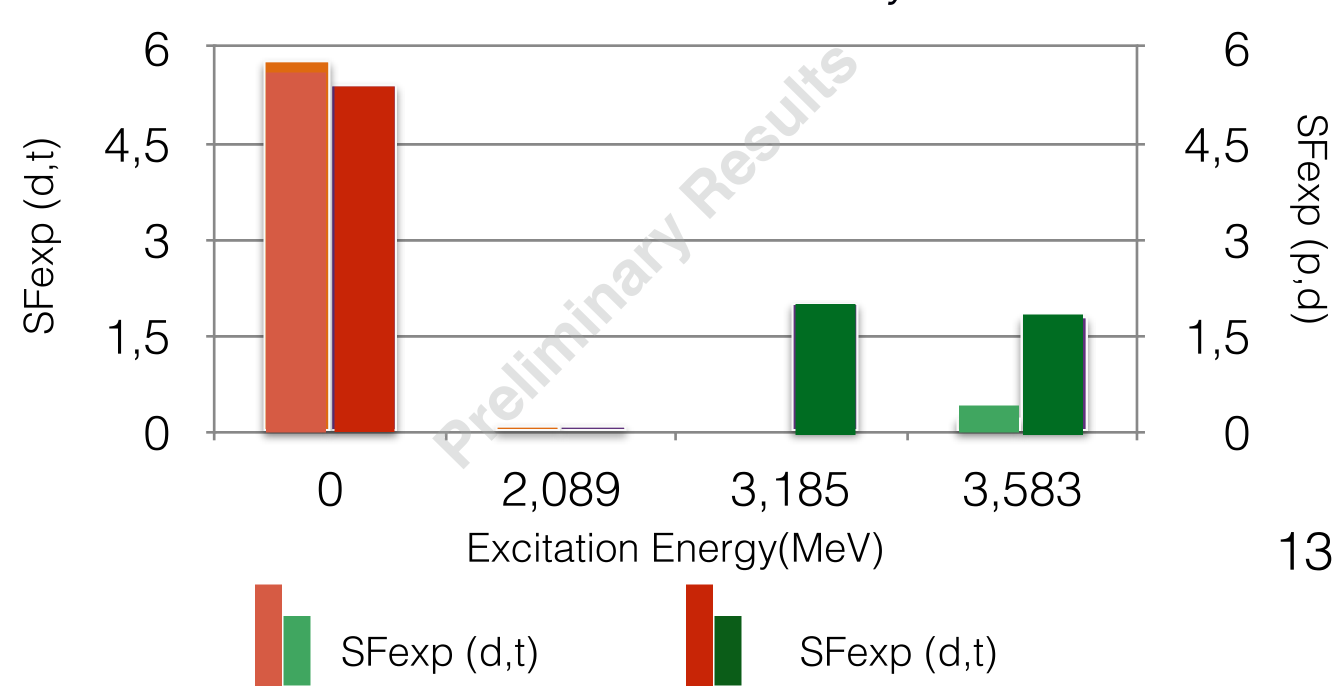
2s1/2 + d3/2
SF(2s1/2)= 2.0 ± 0.02
SF(d3/2)= 1.8 ± 0.2

2p3/2
SF=0.102 ± 0.01





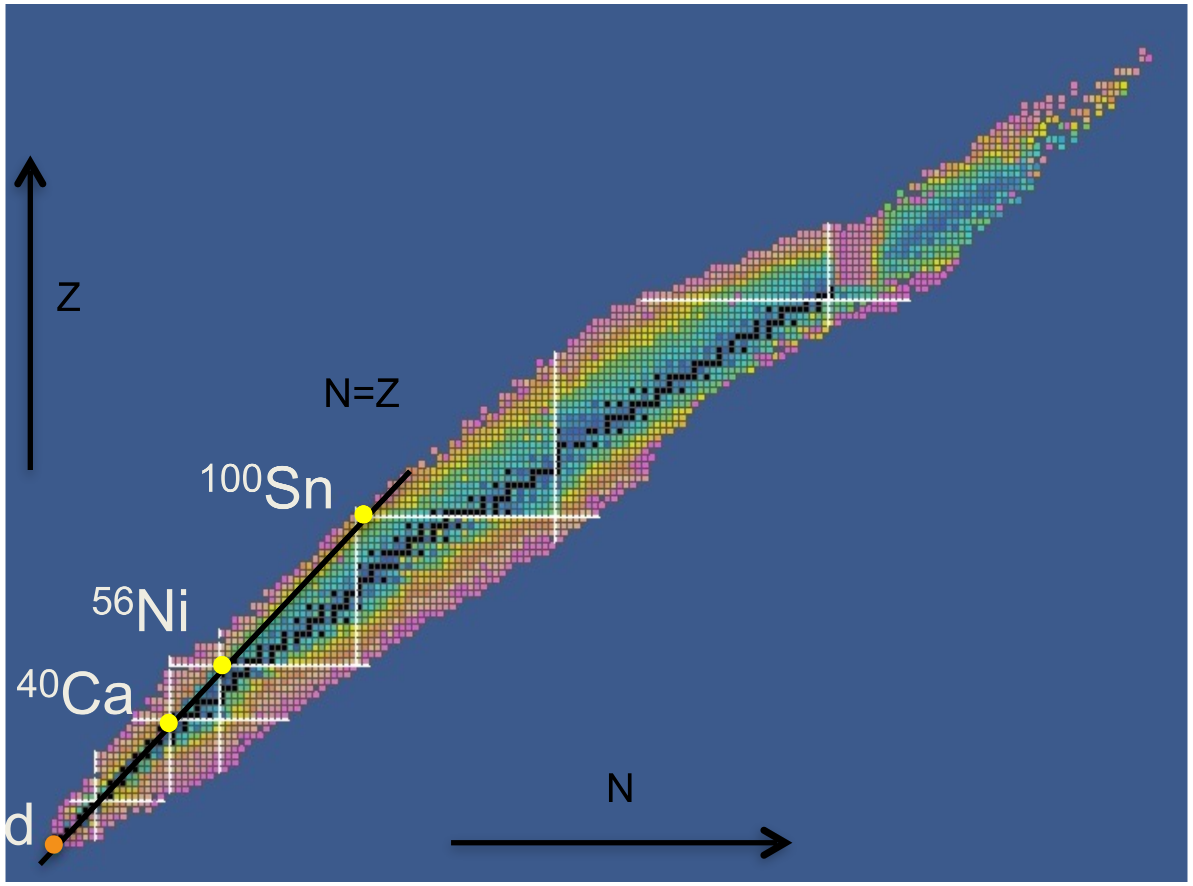
Calculation with DWBA: A.Georgiadou, J.Guillot
Potential for t used by Pang et al.
Potential for d used by Daehnik et al.



II. Two nucleon transfer reaction

Pairing in the nuclei?

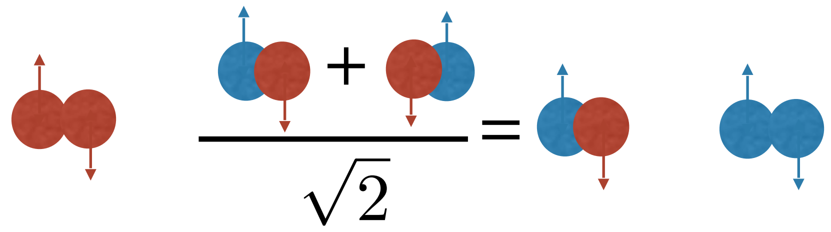
From Theory: n-p pairing may be important in N=Z nuclei with high J valence. ^{56}Ni : the N=Z nucleus for which we can do transfer and study np pairing



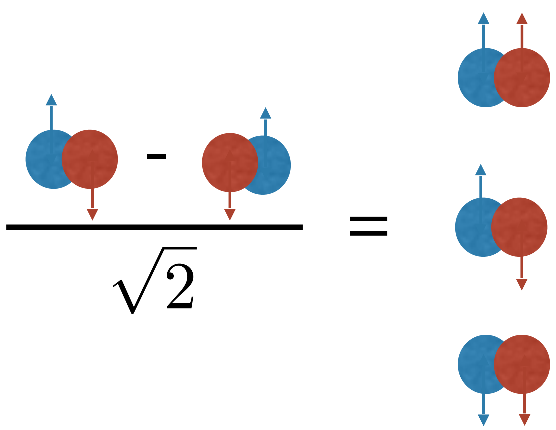
- For nuclei with N≠Z, nn and pp pairs are favoured.
- In the case of nuclei with N≈Z, n and p occupy the same shell model orbit.

Large spatial overlap of the wave functions of proton and neutron in N=Z nuclei.

Neutron-Proton Pairing via Transfer Reaction



Isovector
T=1, J=0, S=0

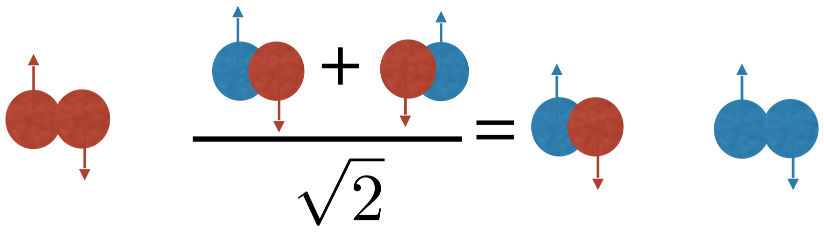


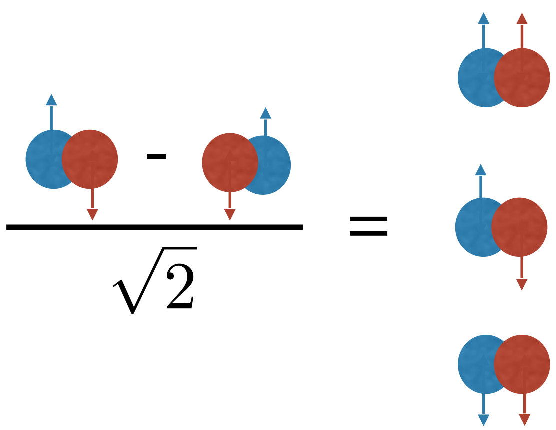
Isoscalar
T=0, J=1, S=1

● ***neutrons*** ● ***protons***

While T=1 np pairing should be similar to nn and pp pairing due to charge independence, the characteristics of T=0 pairing are largely unknown.

In the T=0 channel the interaction is stronger than in the T=1 channel, the proof is the existence of the bound A=2 nucleus (deuteron).





While T=1 np pairing should be similar to nn and pp pairing due to charge independence, the characteristics of T=0 pairing are largely unknown.

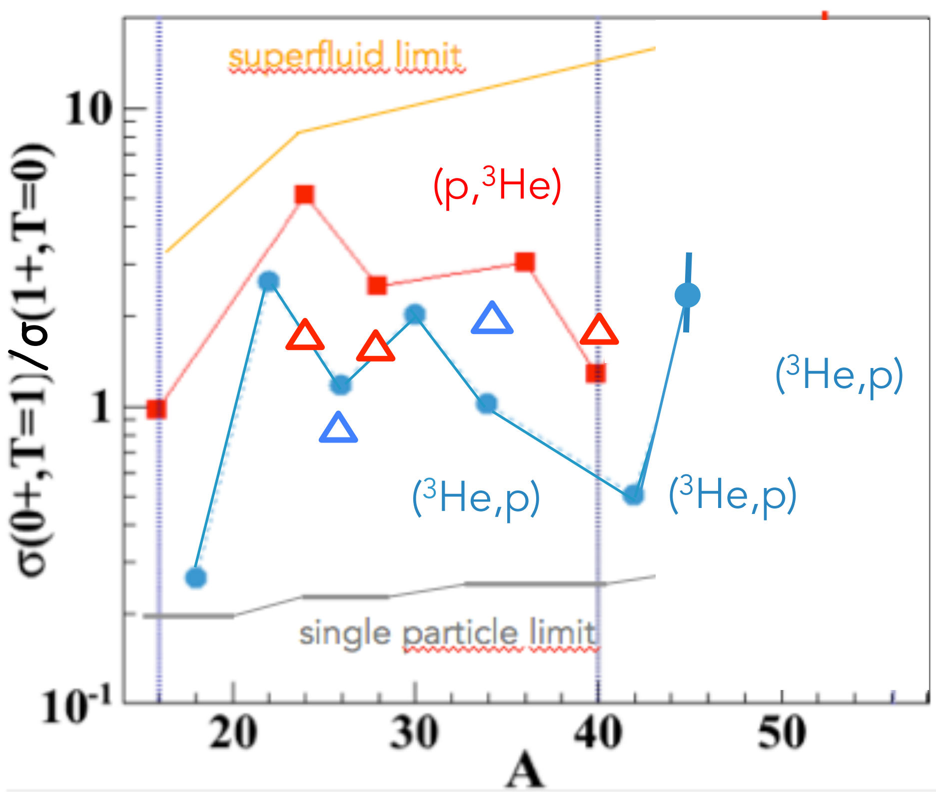
In the T=0 channel the interaction is stronger than in the T=1 channel, the proof is the existence of the bound A=2 nucleus (deuteron).

Why transfer?

- **transfer is proportional to the number of pairs**
- **σ (0+)/σ (1+)** gives the relative strength of **T=1/T=0** pairing
- Role of isoscalar (T=0) and isovector (T=1) pairing
  - **Pairing vibrations** (normal system)
  - **Pairing rotations** (superfluid system)
  - **Isoscalar pairing** and **collective modes**

σ (0+)/σ (1+) gives the relative strength of T=1/T=0 pairing

sd Shell	fp Shell

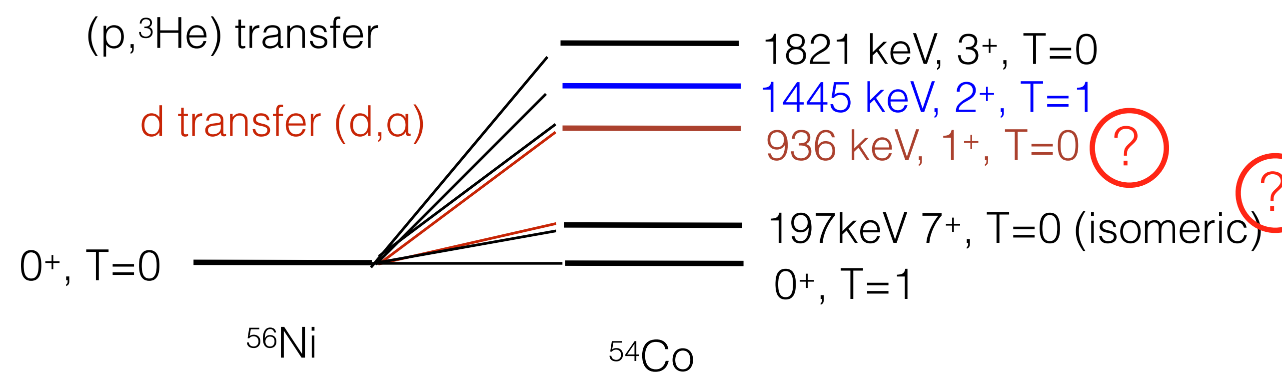


closed shells closed shells

- Experimental data
- △△ *Y. Ayyad, J. Lee, et al.*
- Single particle estimate
- Isovector superfluid limit

Diagram depicting the 2-nucleon transfer cross-sections ratio measured until today.

fp Shell



^{56}Ni (p,^{3}He) ^{54}Co, ΔT=0,1

(p,^{3}He): ^{56}Ni+p -> ^{3}He+^{54}Co

^{56}Ni (d,α) ^{54}Co, ΔT=0

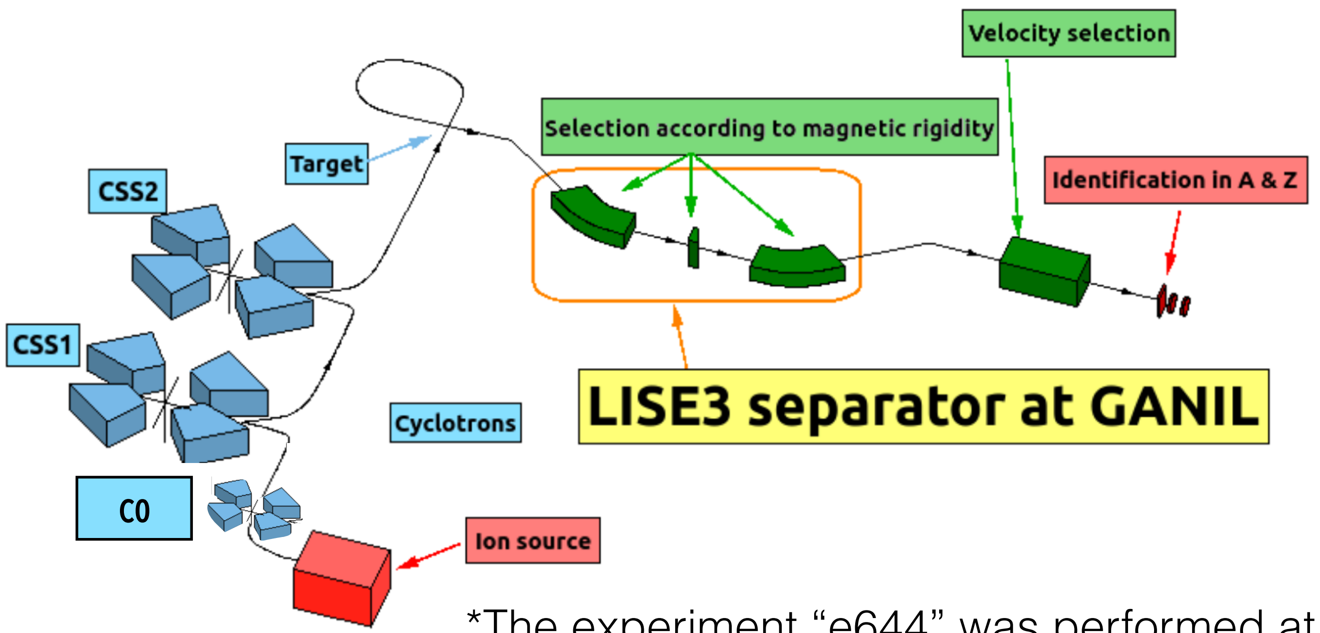
(d,α): ^{56}Ni+d -> α+^{54}Co

Primary beam : ^{58}Ni at 74,5 A MeV

Rotating target (CLIM) : ^{9}Be(1 mm)

Secondary beam : ^{56}Ni at 30A MeV

Reaction Targets: CH_2, CD_2, ^{12}C



*The experiment "e644" was performed at GANIL,CAEN at Spring 2014.

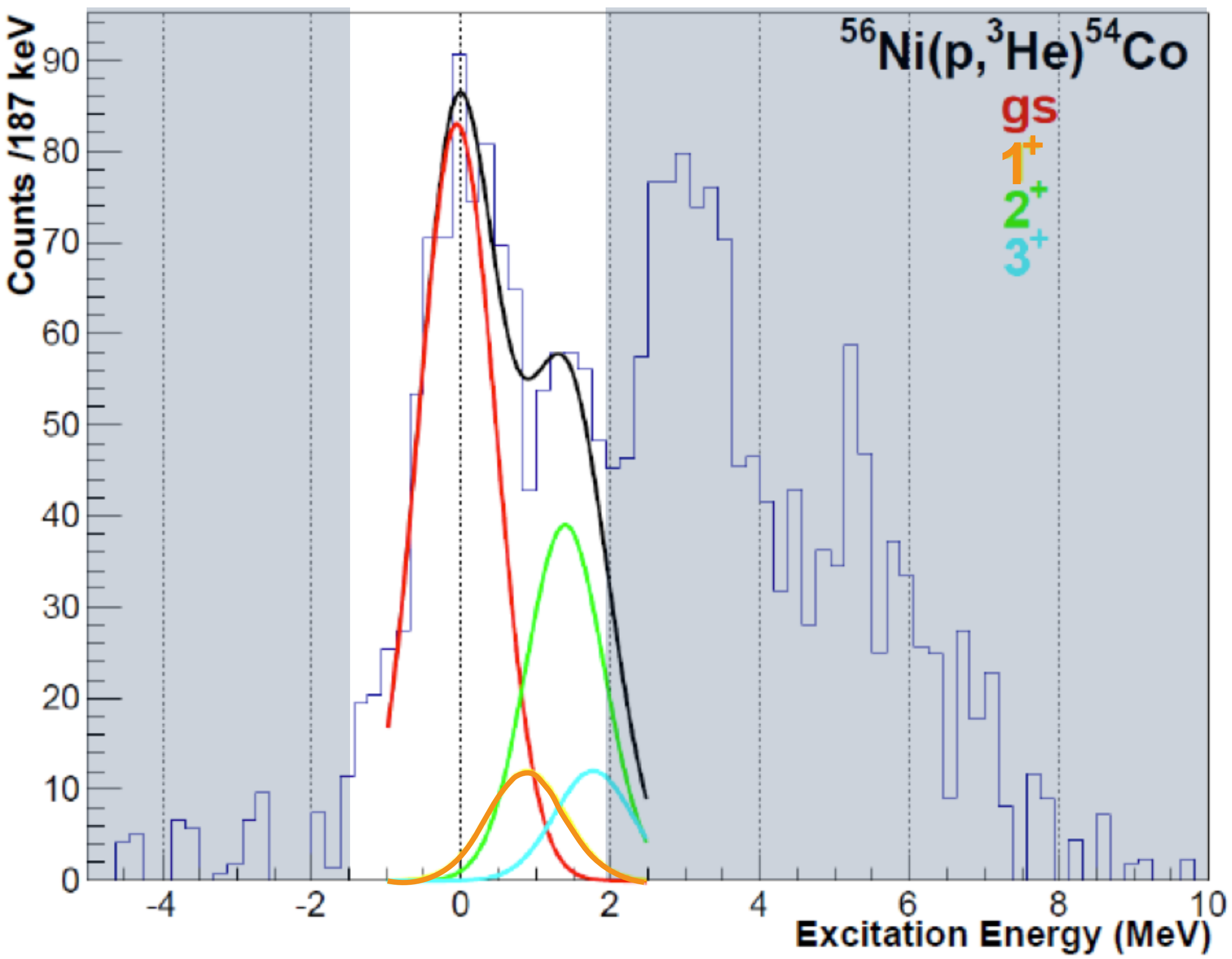
One nucleon transfer

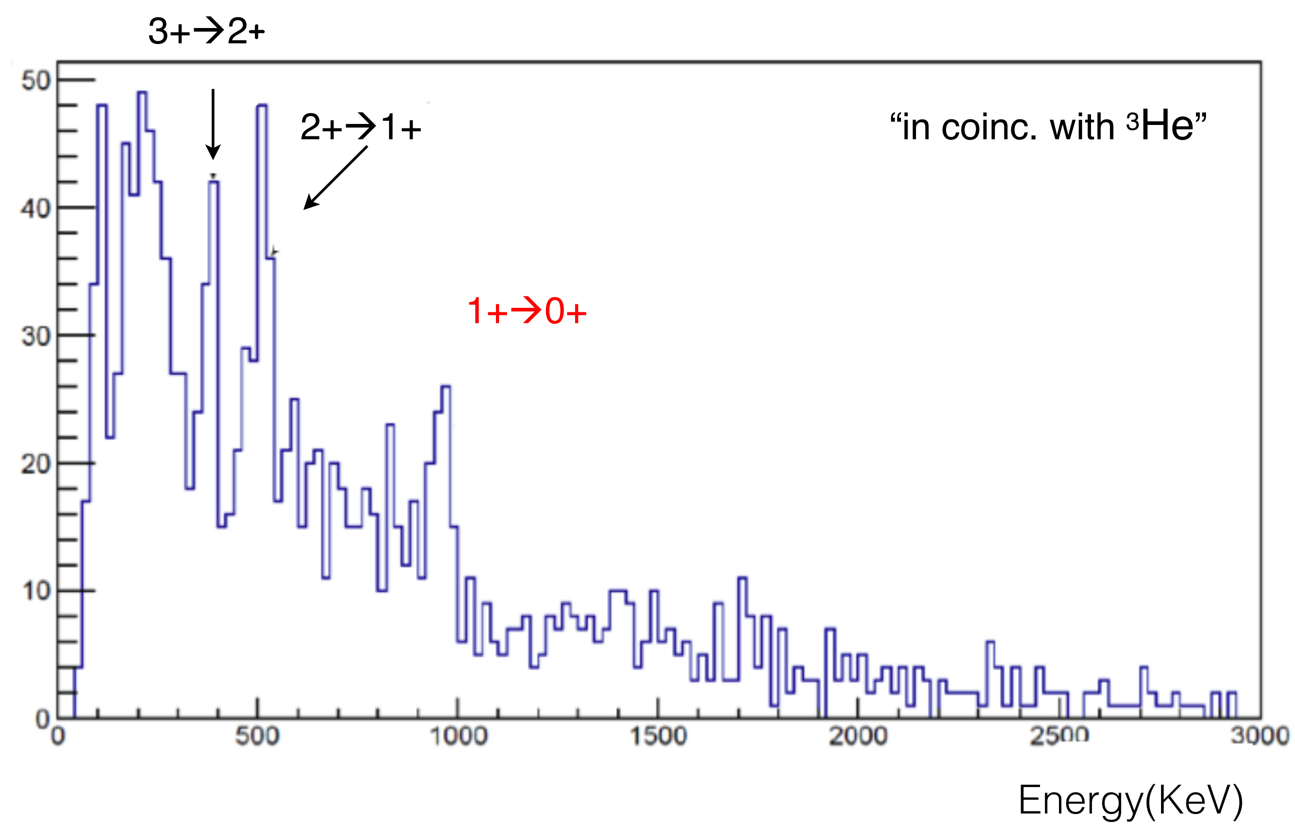
^{56}Ni(p,^{3}He)^{54}Co

^{56}Ni(d,α)^{54}Co

σ (0+)/σ (1+) gives the relative strength of T=1/T=0 pairing

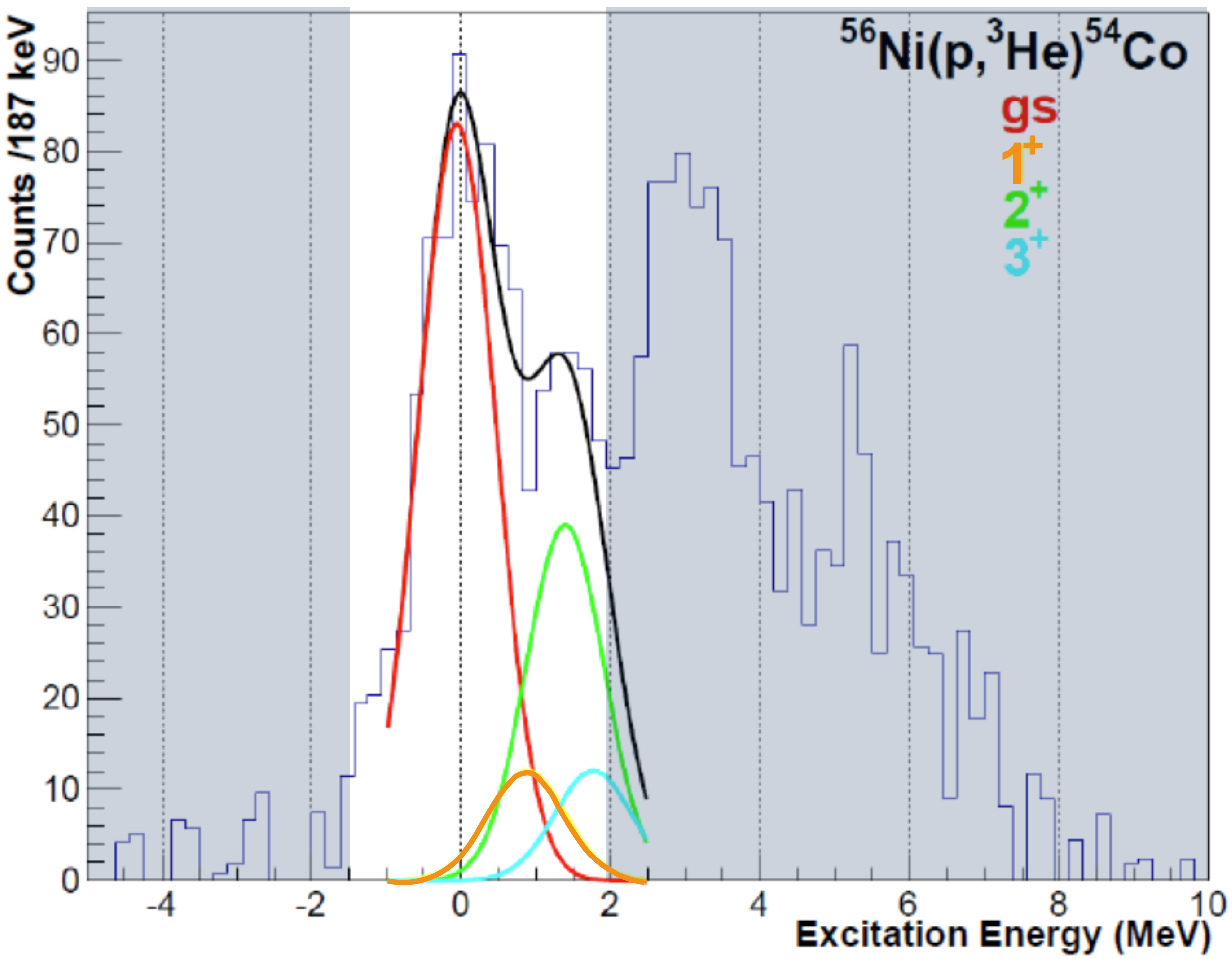
**B. Le Crom, Thesis,Université Paris-Saclay, 2016.*

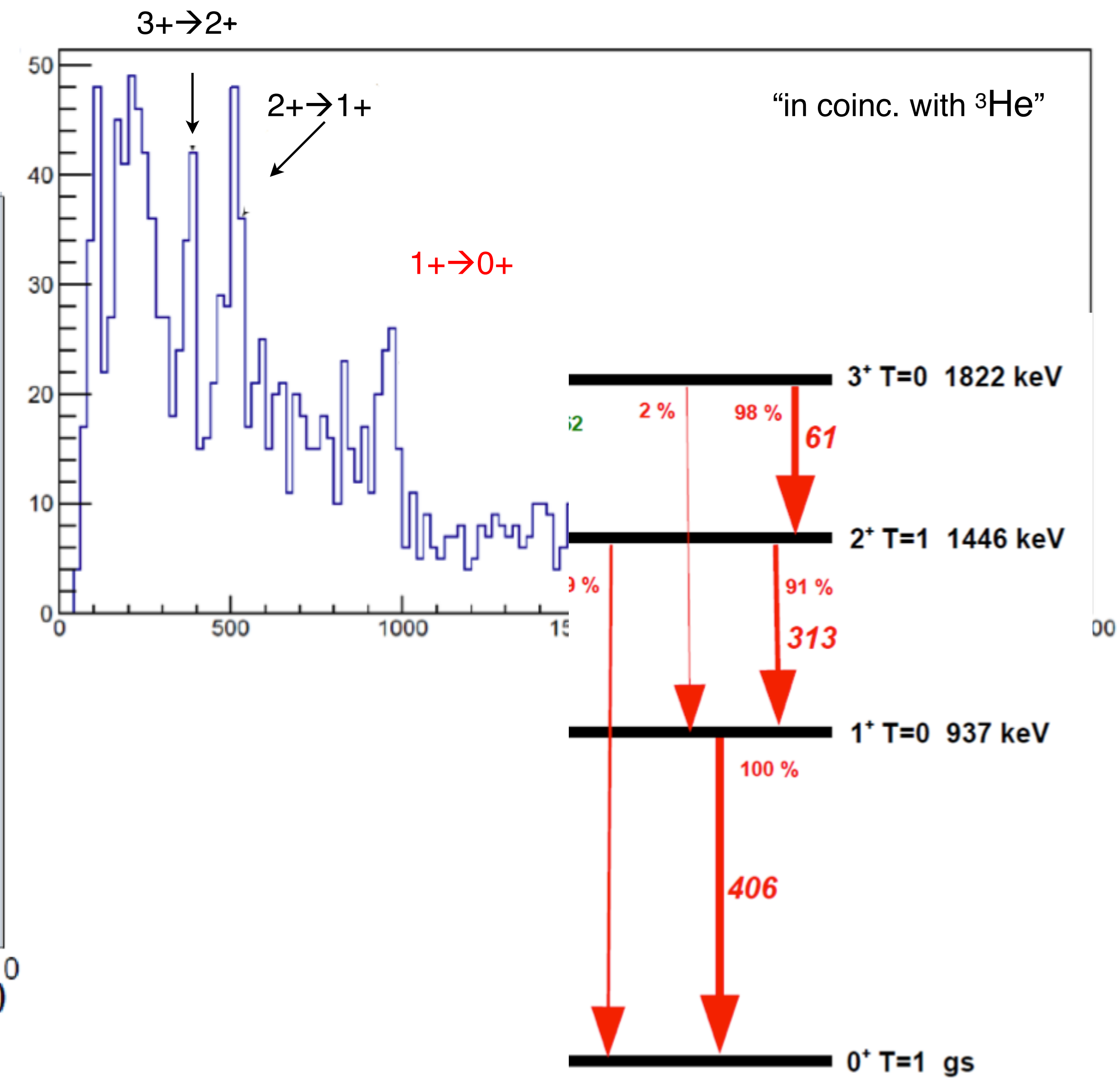




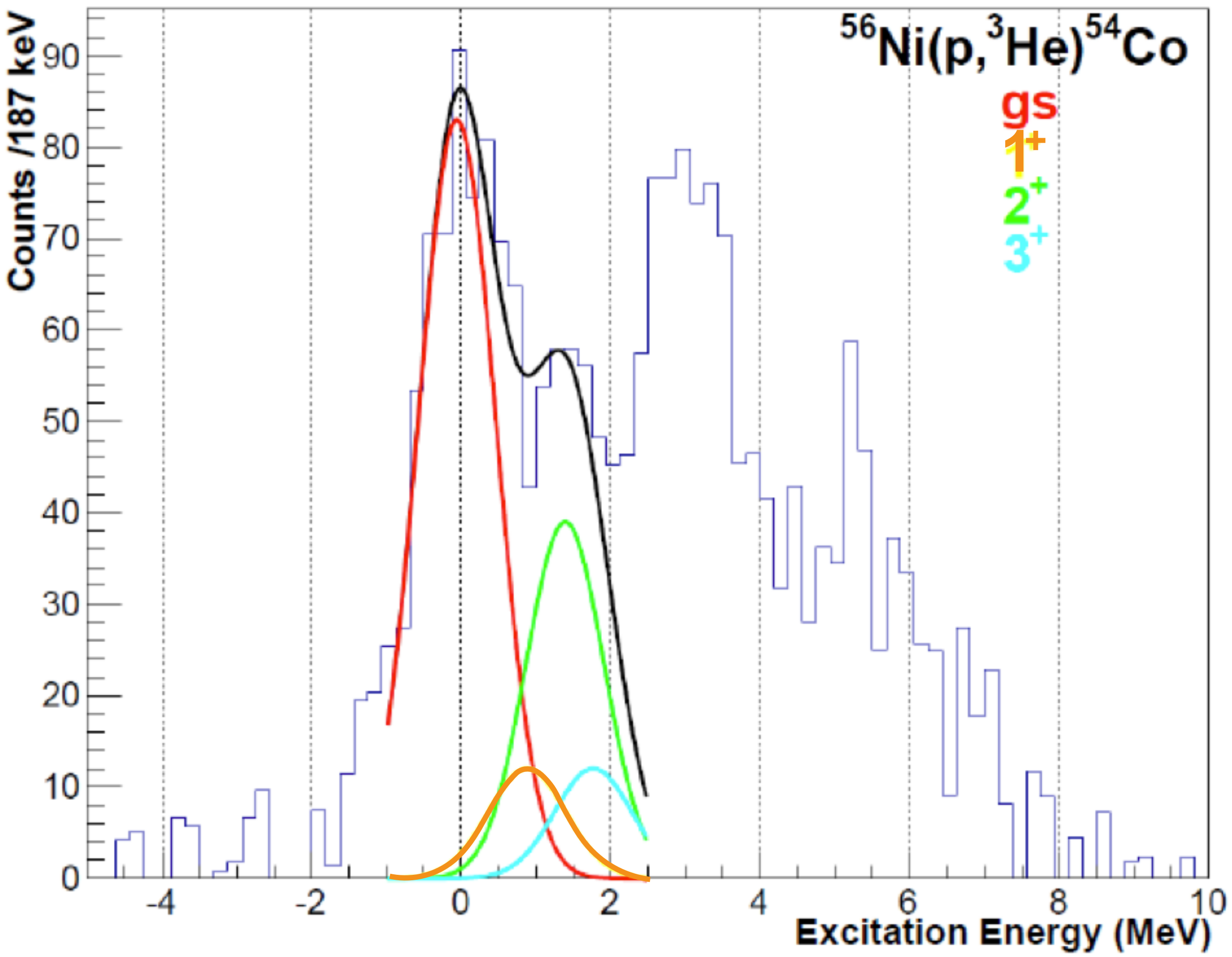
σ (0+)/σ (1+) gives the relative strength of T=1/T=0 pairing

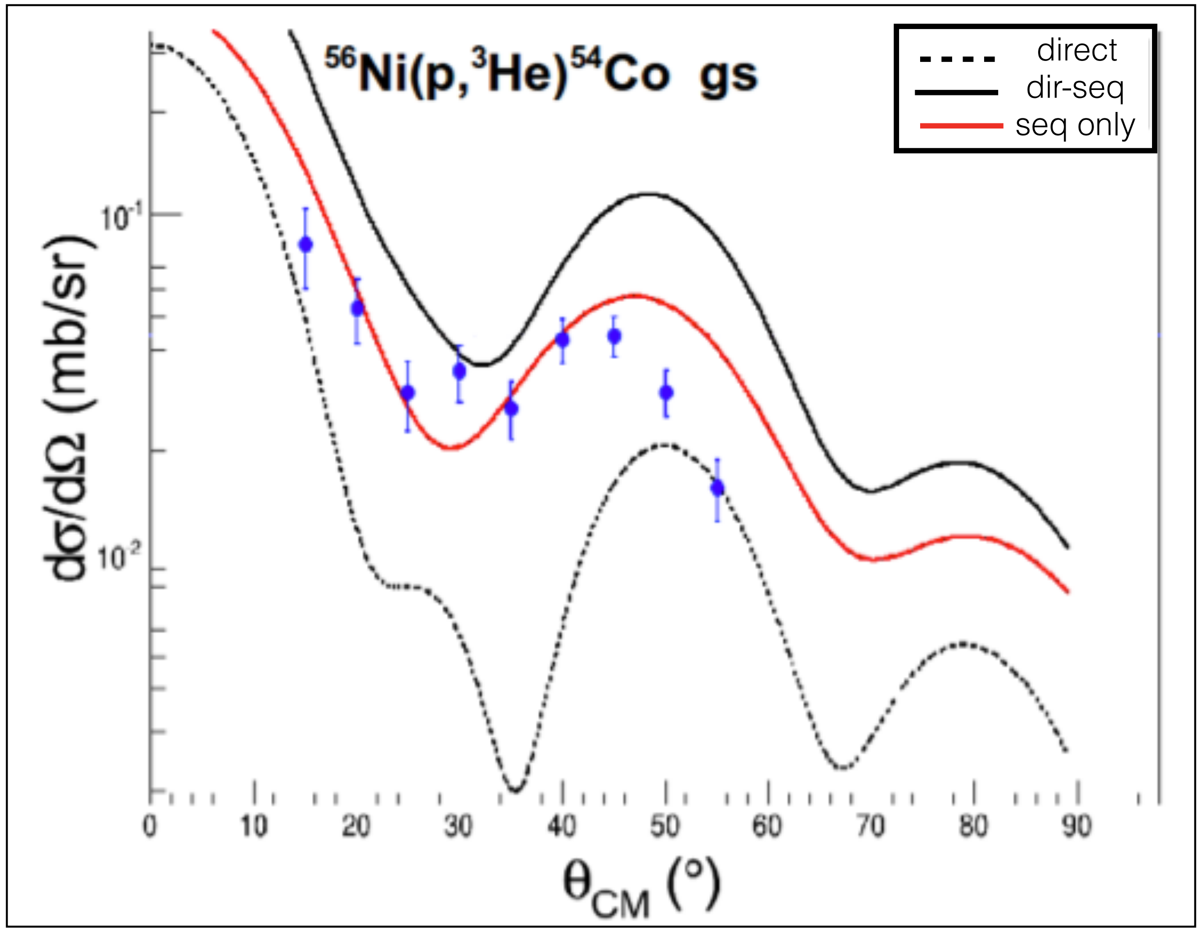
**B. Le Crom, Thesis, Université Paris-Saclay, 2016.*





^{54}Co

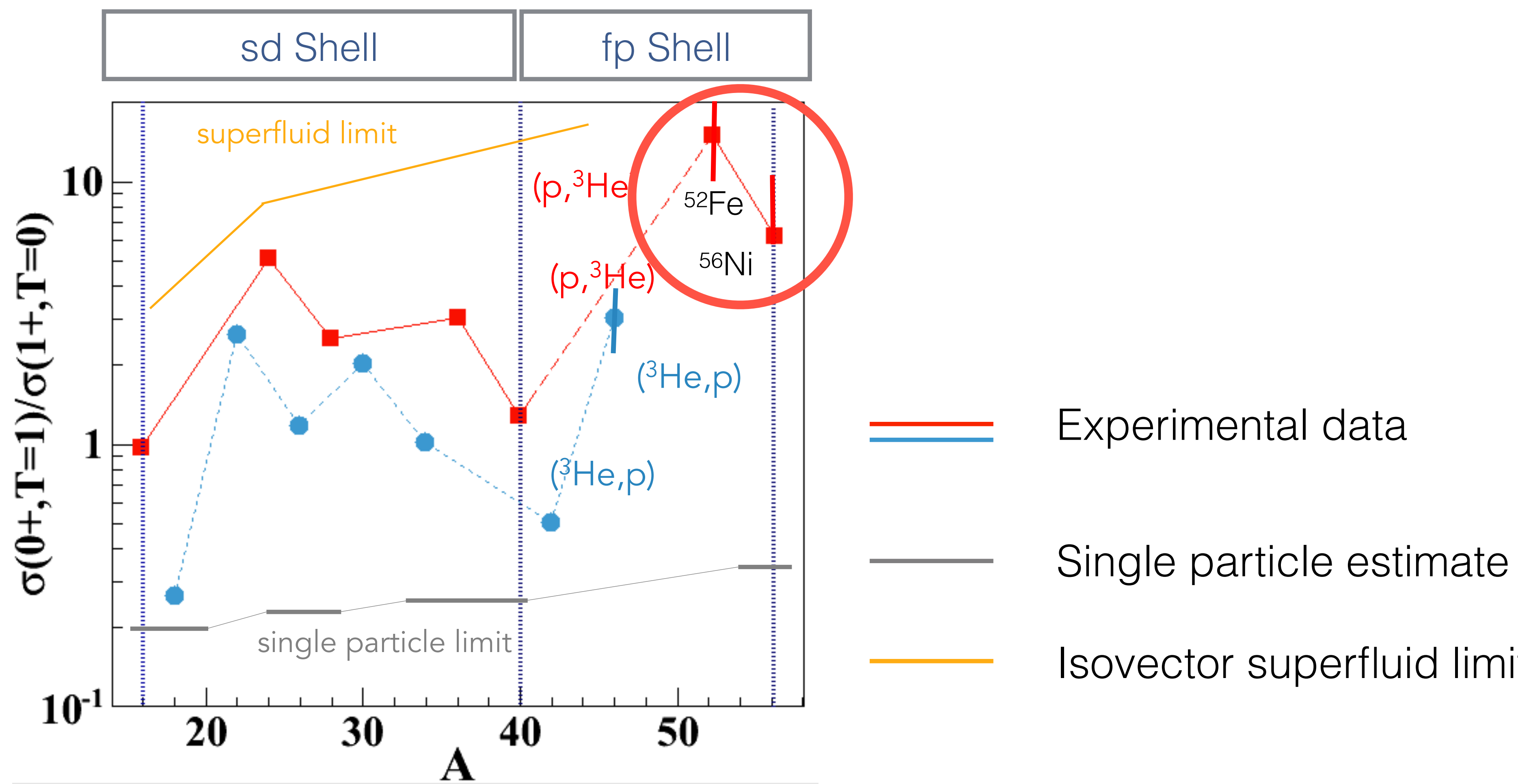


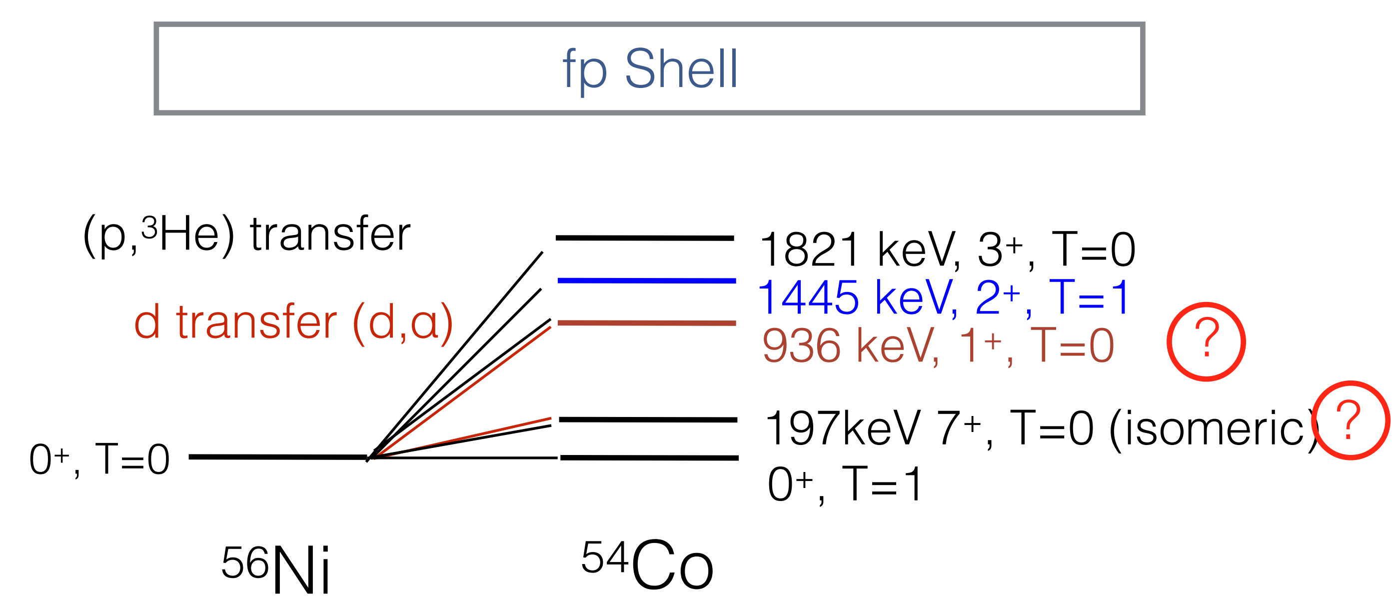


**B. Le Crom, Thesis,Université Paris-Saclay, 2016.*

Calculation with DWBA : J. Guillot

^{56}Ni(p,^{3}He)^{54}Co | ^{56}Ni(d,α)^{54}Co





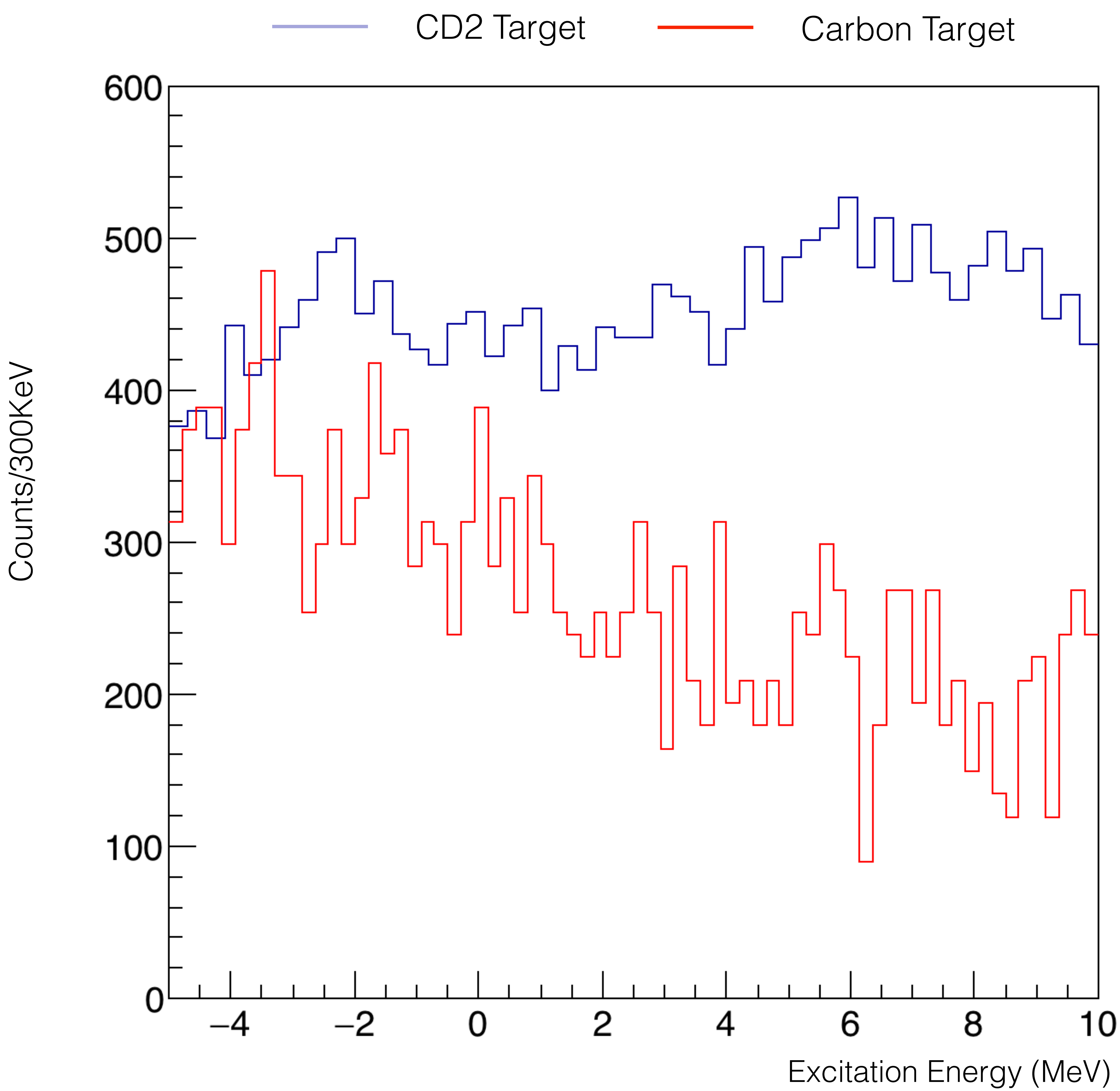
^{56}Ni (p,^{3}He) ^{54}Co, ΔT=0,1 *

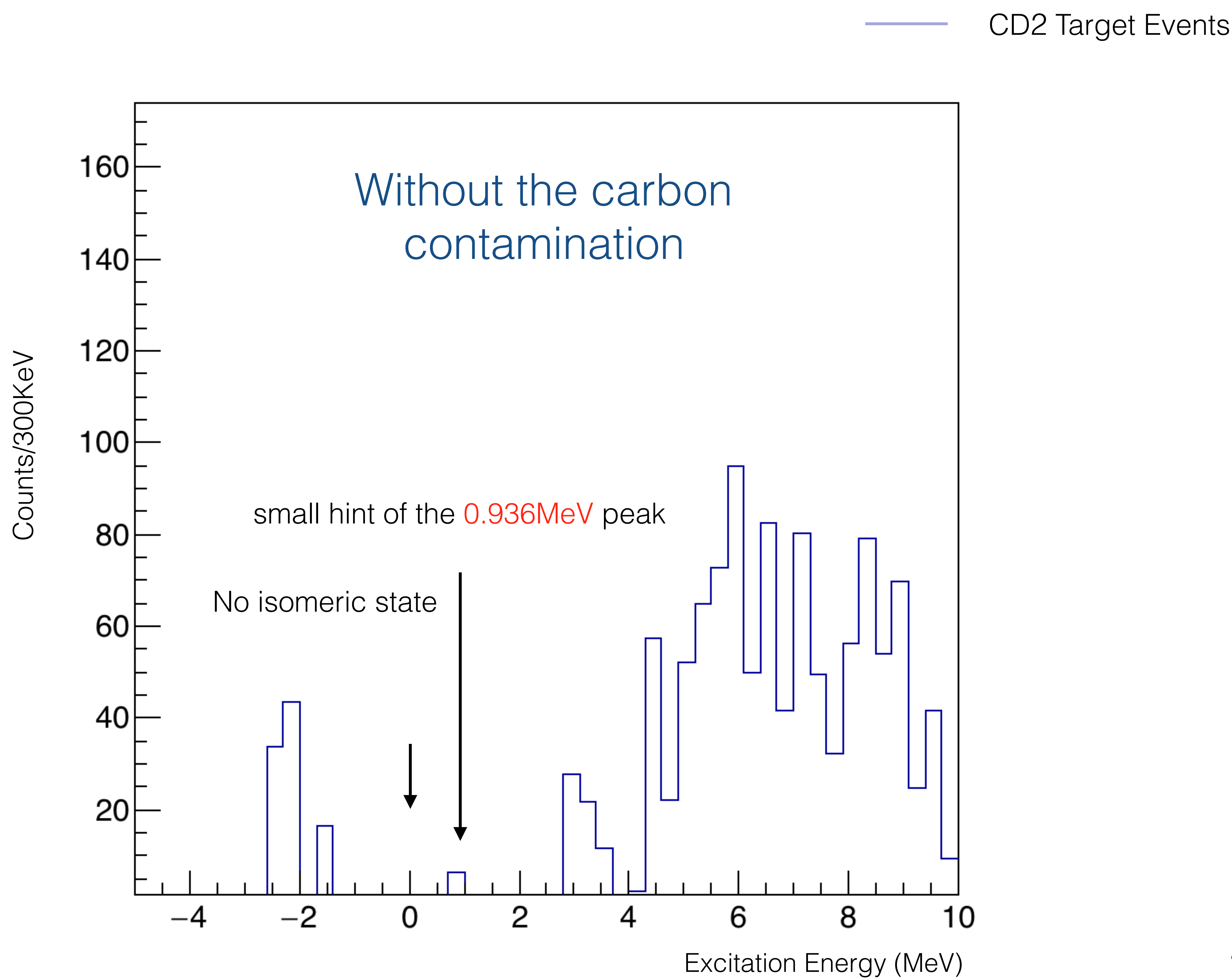
gives the ratio $\frac{T=1}{T=0} = 6.3\ ^{+2.8}_{-0.8}$ *

^{56}Ni (d,α) ^{54}Co, ΔT=0

*To be published, Thesis: B.Le Crom.

$^{56}Ni(d,\alpha)^{54}Co$




CD2 Target Events
Without the carbon contamination
small hint of the 0.936MeV peak
No isomeric state
Counts/300KeV
160
140
120
100
80
60
40
20
−4
−2
0
2
4
6
8
10
Excitation Energy (MeV)

One-nucleon Transfer

- The *(d,t)* & *(p,d)* reaction adds information about the shell closure *in the N=28 region.*
- In addition we *enrich the level scheme of* ^{55}*Ni.*

Two-nucleon Transfer

- For both the ^{56}*Ni and* ^{52}*Fe* we add *new measurements in the fp shell*.
- The *(d,α)* gives very low statistics around the expected 0.936MeV peak that would reveal the T=0 isoscalar pairing. Nevertheless, it *adds new information about higher energies* that used to be explained as T=1 isovector state, and might reveal a mixture of isospin states.

THANK YOU

ANASTASIA GEORGIADOU

"E644 COLLABORATION"

A.Georgiadou, M. Assié, Y. Blumenfeld, B. Le Crom, F. Flavigny, L. Achouri , M. Aouadi, B. Bastin, A. Benitez, R. Borcea, W. Catford, E. Clement, A. Corsi, G. Defrance, M-C. Delattre, F. Delaunay, N. De Séréville, Q. Deshayes, B. Fernandez, M. Fisichella, S. Franchoo, J. Gibelin, A. Gillibert, J. Guillot, F. Hammache, O. Kamalou, A. Knapton, V. Lapoux, S. Leblond, M. Marques, A. Matta, P. Morfouace, N. Orr, J. Pancin, X. Pereira, L. Perrot, E. Pollacco, D. Ramos, T. Roger, F. Rotaru, J-A. Scarpaci, M. Sénoville, O. Sorlin, M. Stanoiu, I. Stefan, D. Suzuki, J-C Thomas, M. Vandebrouck, G. Verde[a]

A. Sanetullaev et al. / Physics Letters B 736 (2014) 137–141

Table 1
Experimental and calculated information on the $f_{7/2}$, $p_{3/2}$ and $s_{1/2}$ states. The notation of "SF_{SM1}", "SF_{SM2}", and "SF_{SCGF}" refers to the shell-model calculations using a modified SDPFM interaction, those with the SDPF-MU interaction, and those with self-consistent Green's functions theory respectively.

State	E^*_{expt} (MeV)	E^*_{SM1} (MeV)	E^*_{SM2} (MeV)	E^*_{SCGF} (MeV)	SF_{expt}	SF_{SM1}	SF_{SM2}	SF_{SCGF}
$f_{7/2}$	0	0	0	0	6.7 ± 0.7	6.75	6.94	5.78
$p_{3/2}$	2.09	1.895	2.281	4.34	0.19 ± 0.03	0.189	0.13	0.06
$s_{1/2}$	3.18	3.039	3.755	11.48	1.0 ± 0.2	1.57	1.21	1.10
$d_{3/2}$	(3.752)	3.309	4.453	12.47	NA	2.88	1.68	2.16