An investigation of light neutron-rich nuclei around N=14

Paloma Díaz Fernández

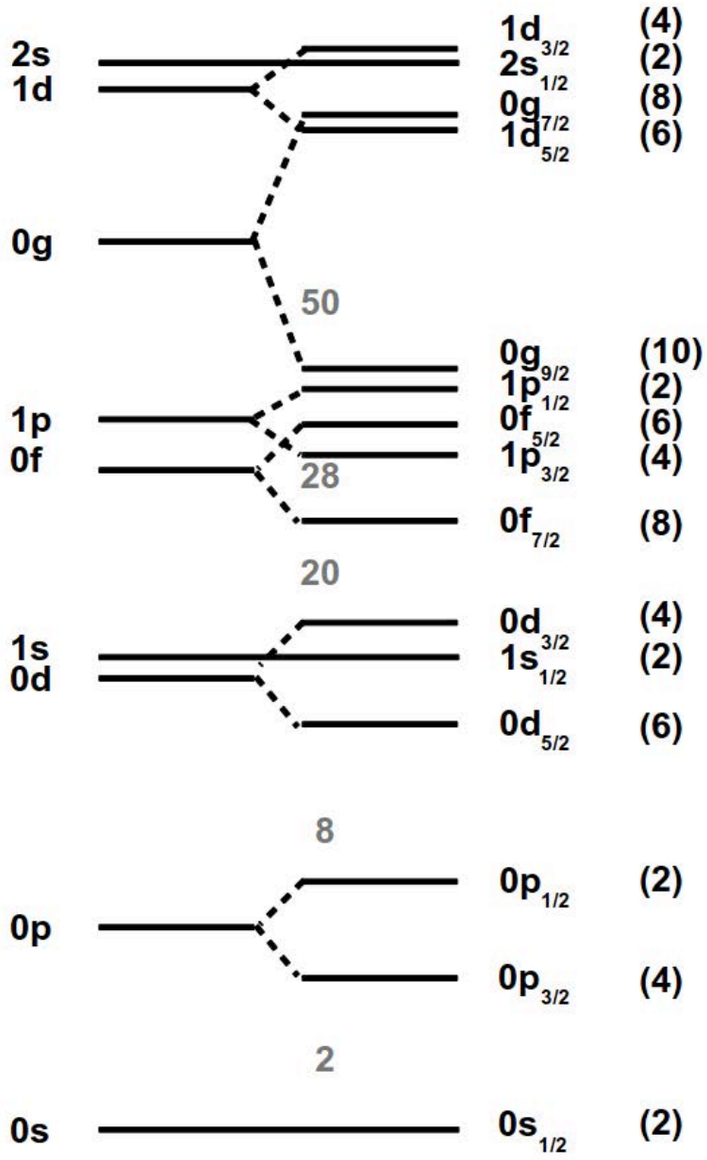
for the R^3B collaboration

NUSTAR week 2013

UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

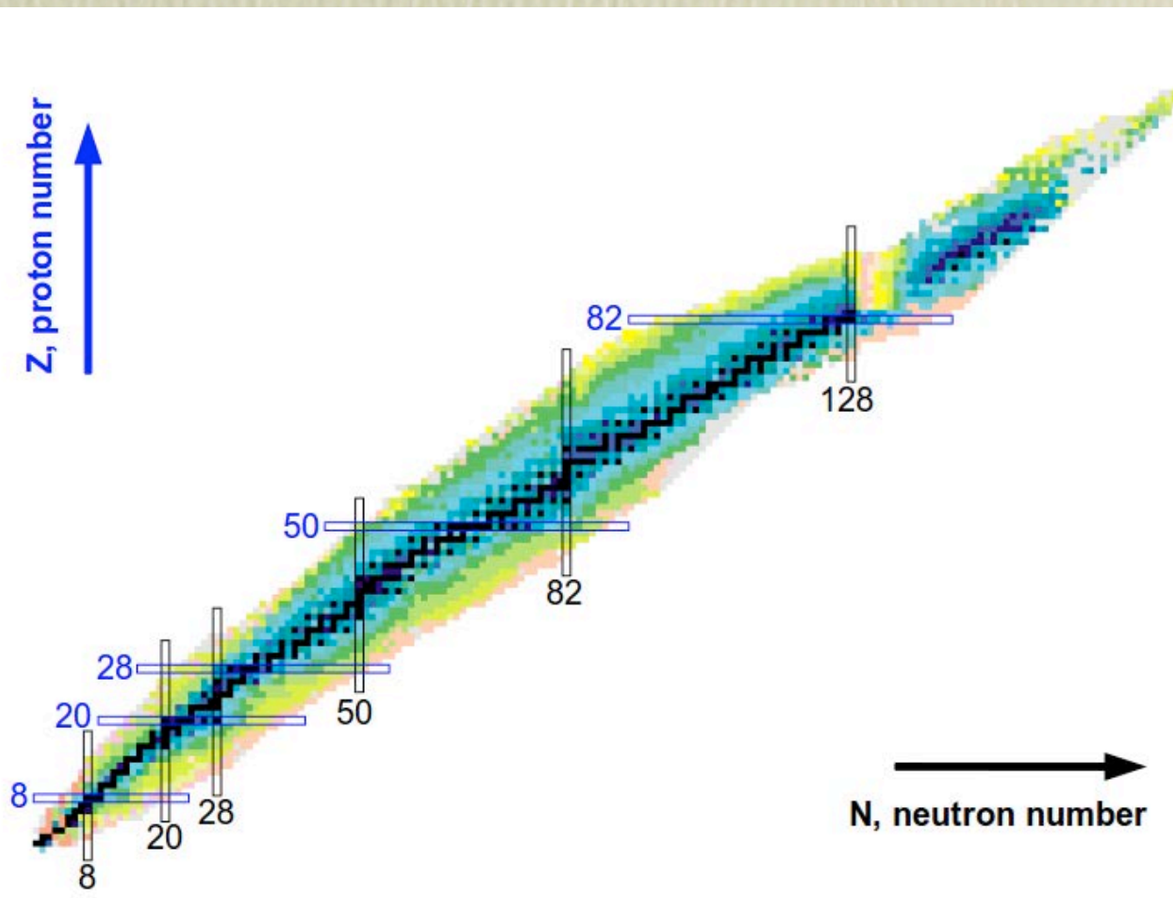
GENP Grupo Experimental de Núcleos y Partículas

Motivation



Mayer & Jensen

The nuclear shell structure evolves when we move to nuclei which have an important asymmetry in the number of neutrons and protons



http://www.nndc.bnl.gov/chart

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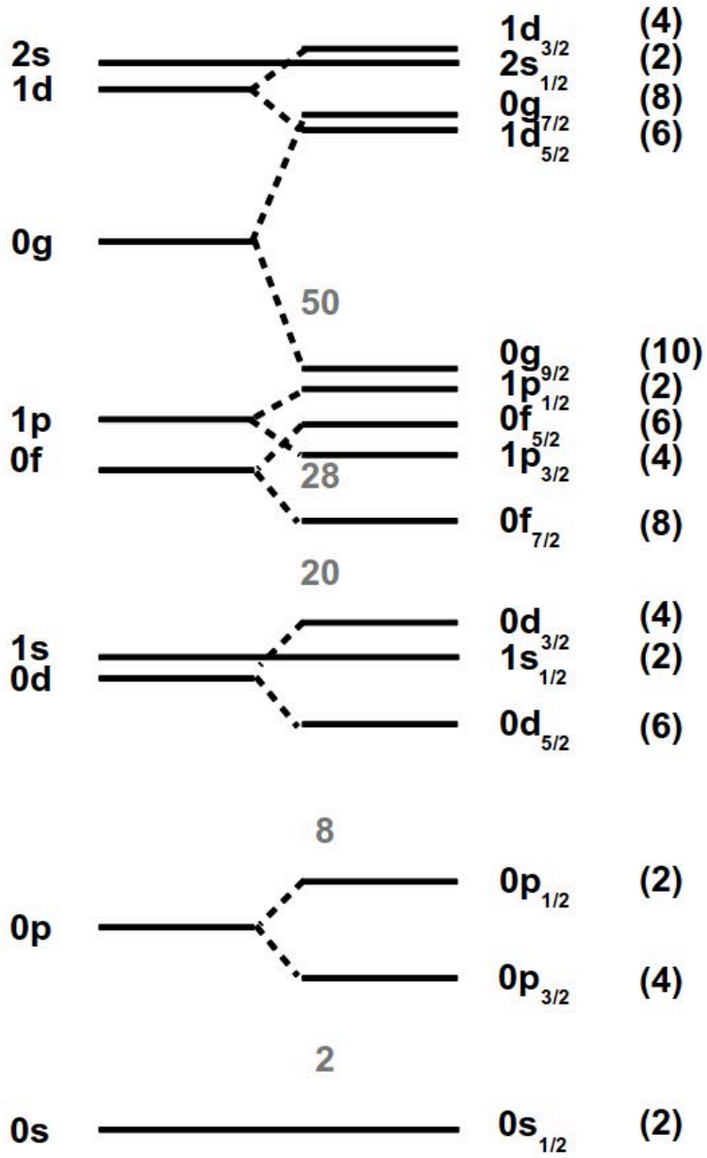

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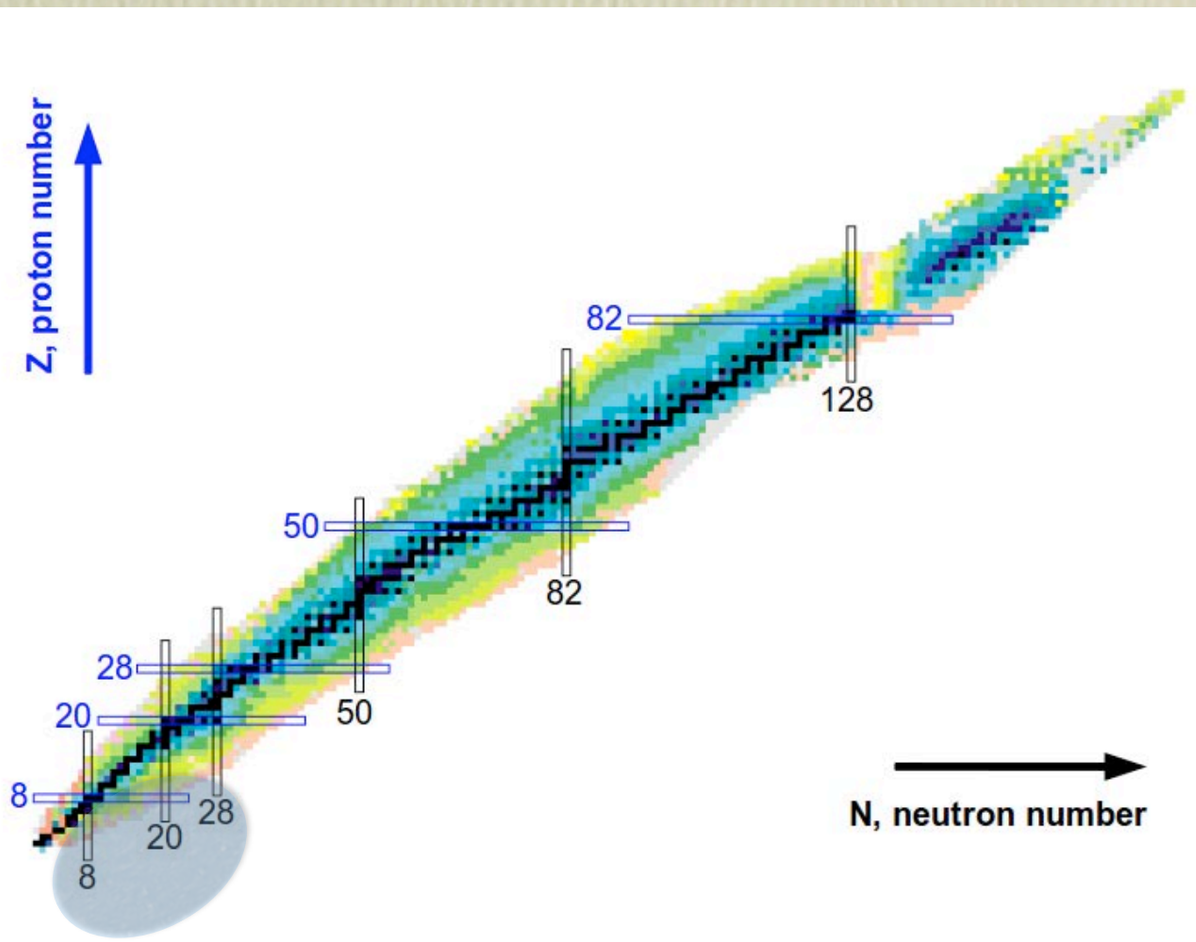

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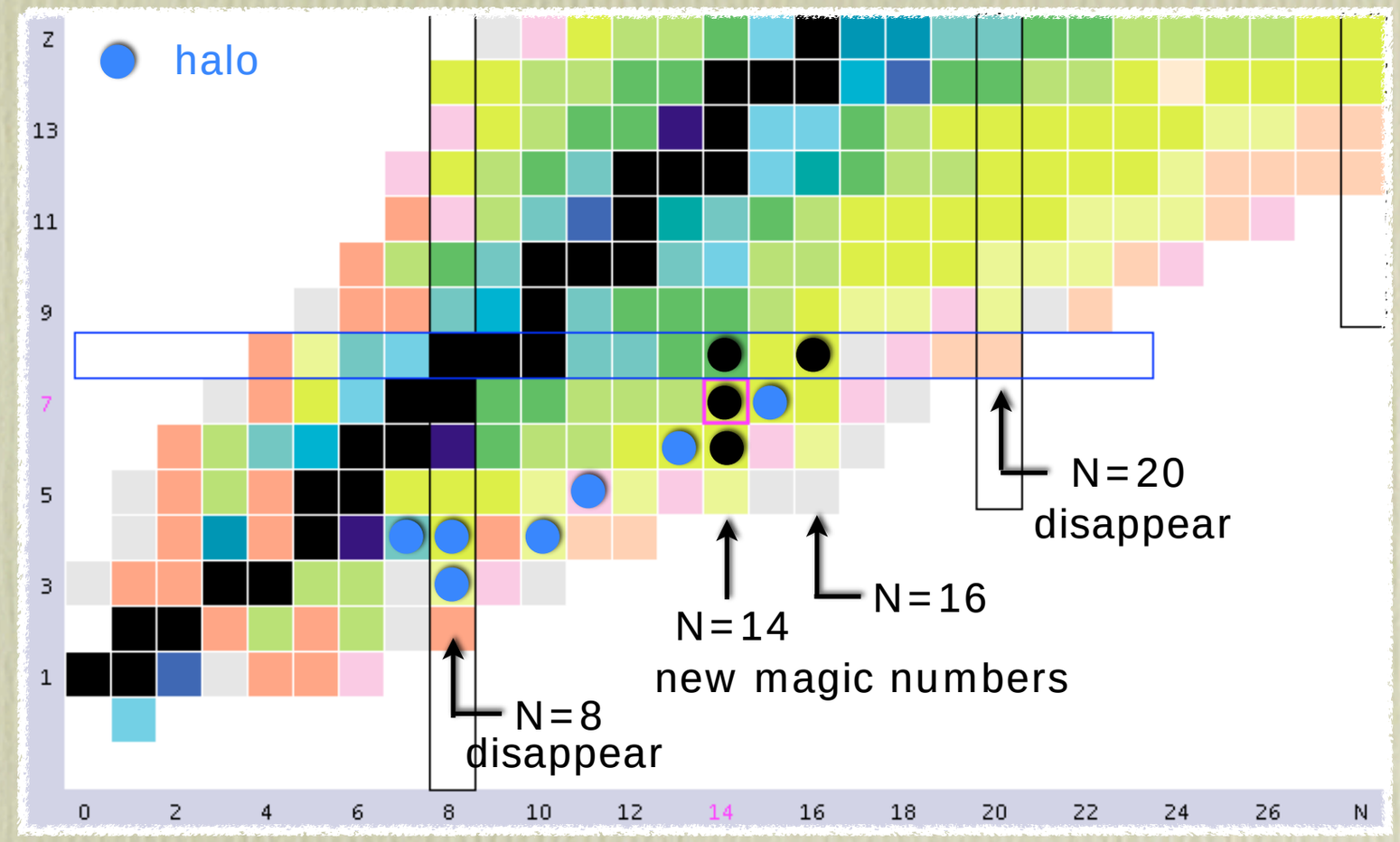
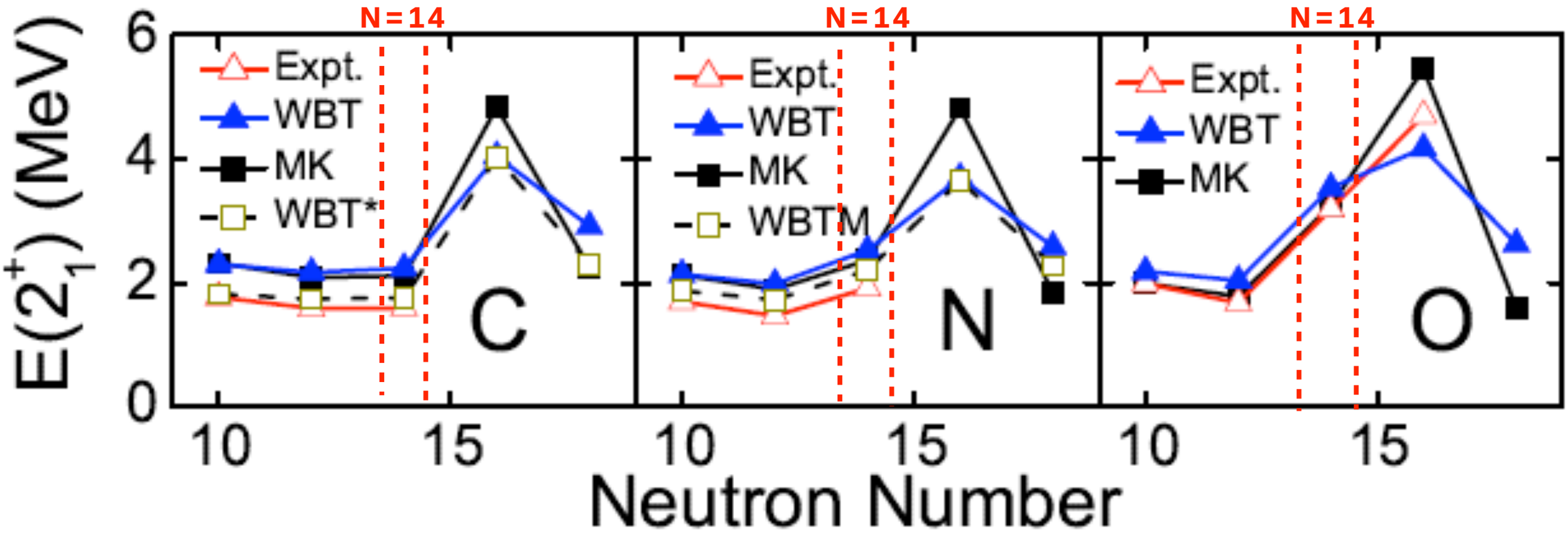


- Disappearence of the N = 8: ^{11}Li, ^{12}Be
- Halo nuclei: ^{11}Li, ^{11}Be, ^{14}Be, ^{17}C, ^{19}C, ^{22}N
- New shell closures at N = 14 and N =16: ^{22}O, ^{24}O
- Disappearence N = 20: ^{26}O and ^{25}O unbound

Motivation

The N = 14 sub-shell closure

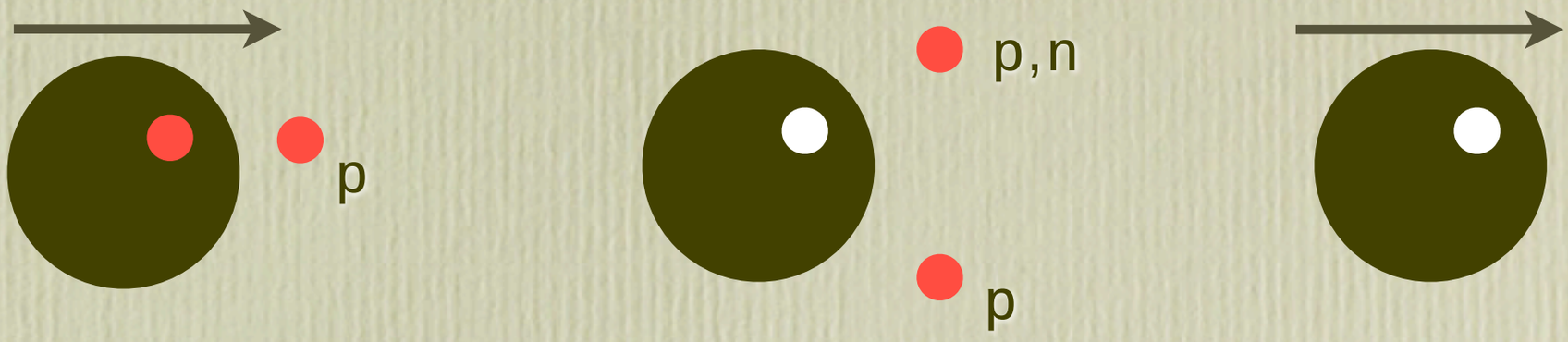


DISAPPEARENCE **SOFT** **STRONG**

C. X. Yuan
Nuc. Phys. A.
Vol 883 25-34 (2012)

Reaction mechanism

Quasi-free scattering: (p,2p) and (p,pn)



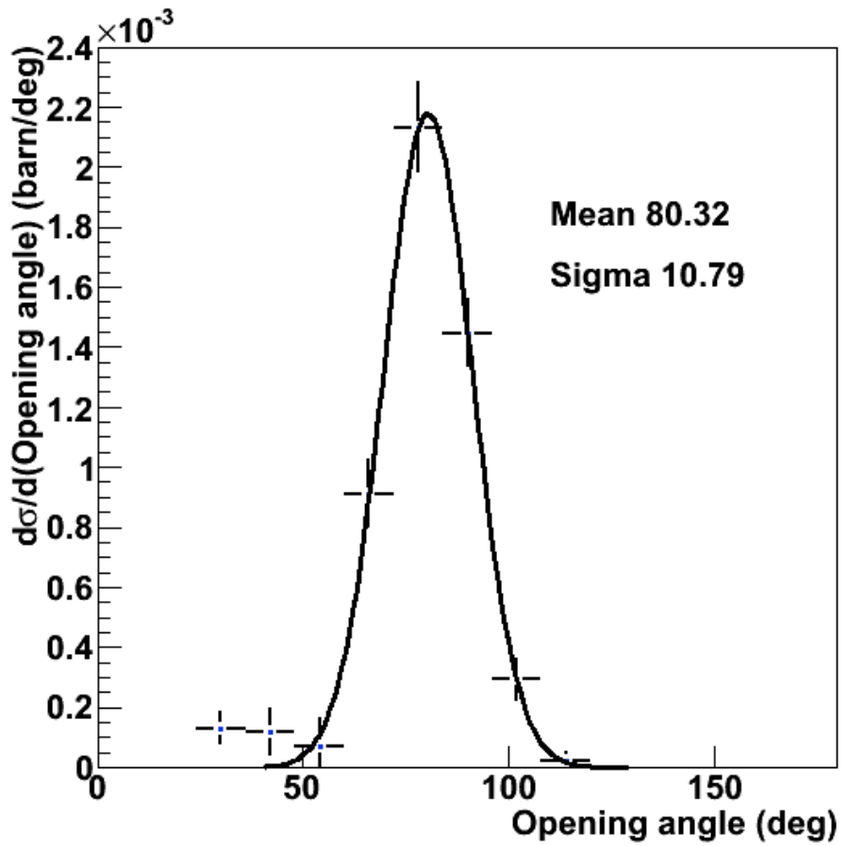
Incoming projectile CH_2 target Outgoing fragment

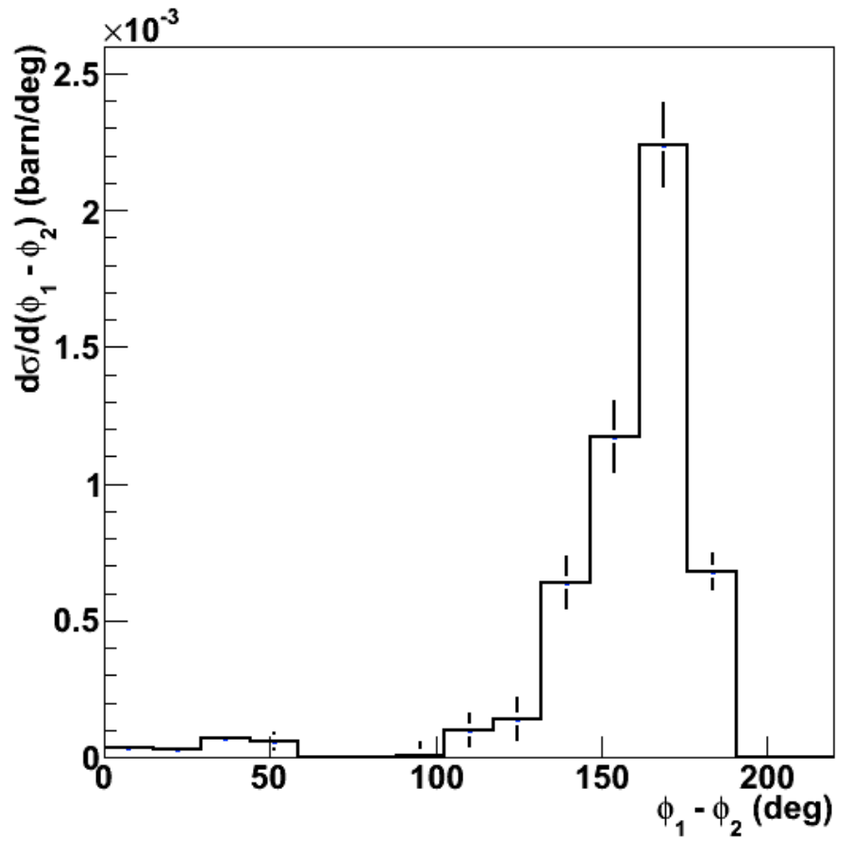
QFS selection: incoming + outgoing + two high energy particles at Crystal Ball

Angular signature for the emitted nucleons:

- ✓ Opening angle ~80º
- ✓ Back to back in φ

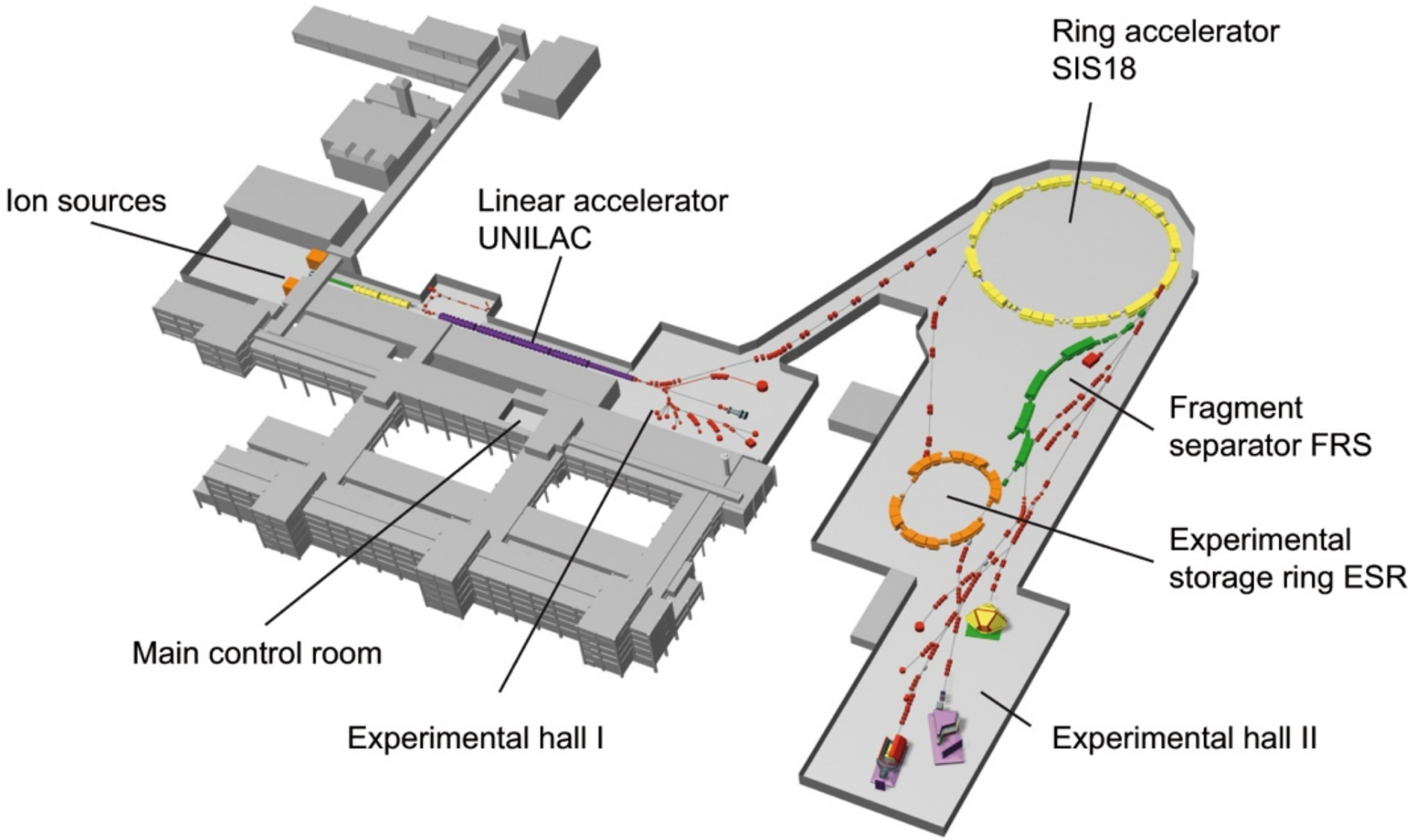
$^{22}O(p,2p)^{21}N$





S393 Experiment at GSI (2010)

- $^{40}Ar^{11+}$ primary beam from SIS
- Fragmentation on ^{9}Be target
- Selection of the secondary beam at the FRS
- Beam delivered to Cave C, R^3B/LAND setup



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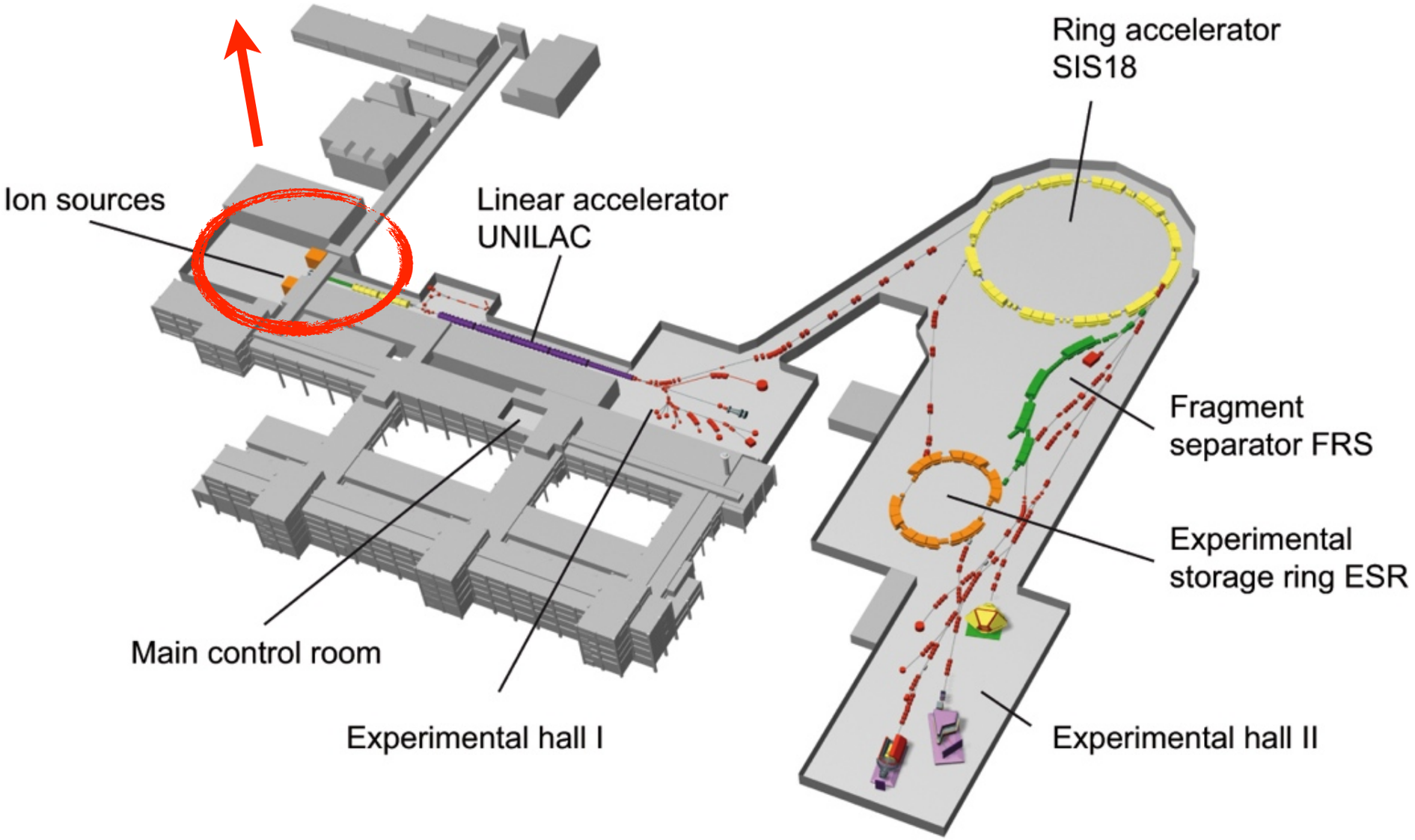
Primary beam ^{40}Ar



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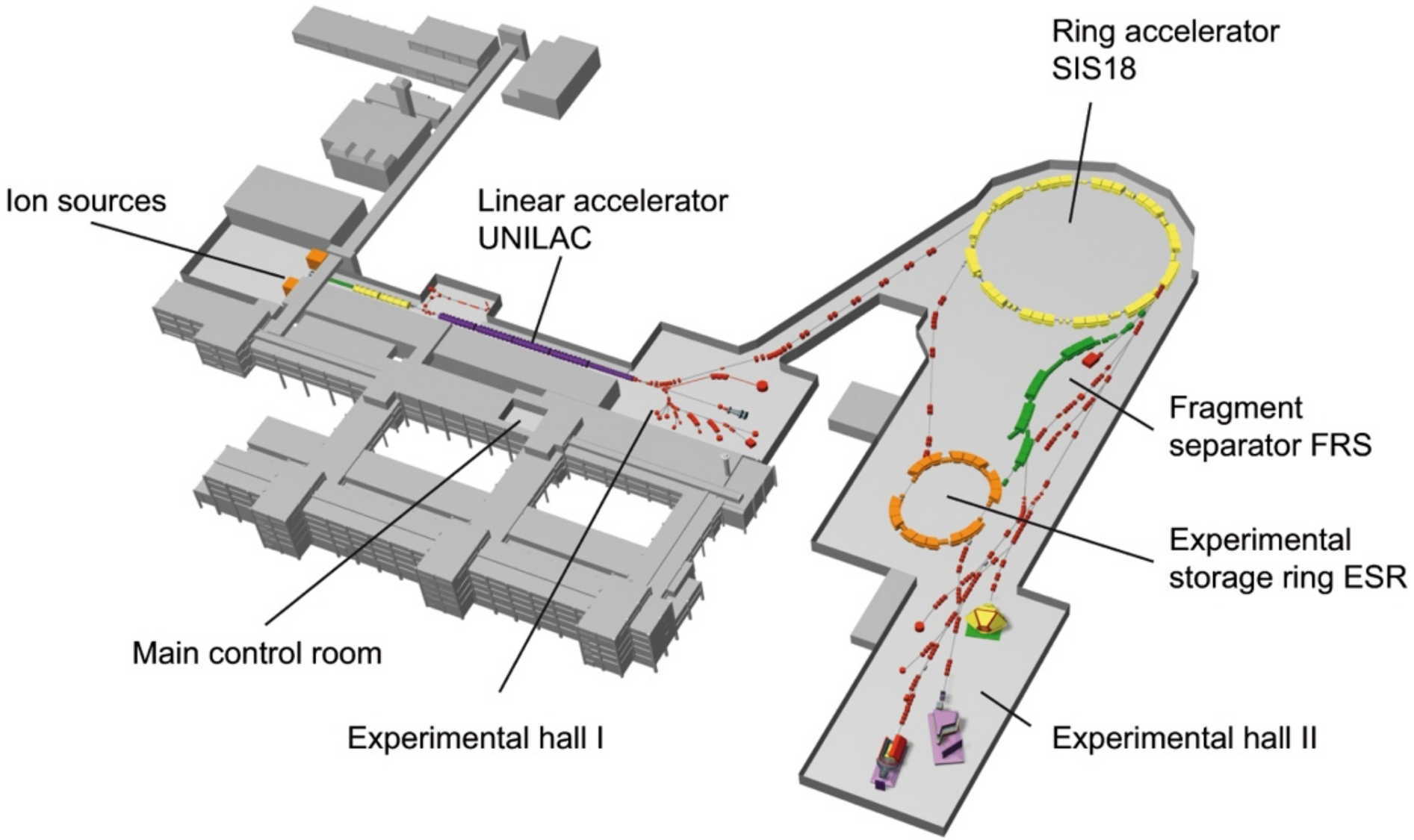

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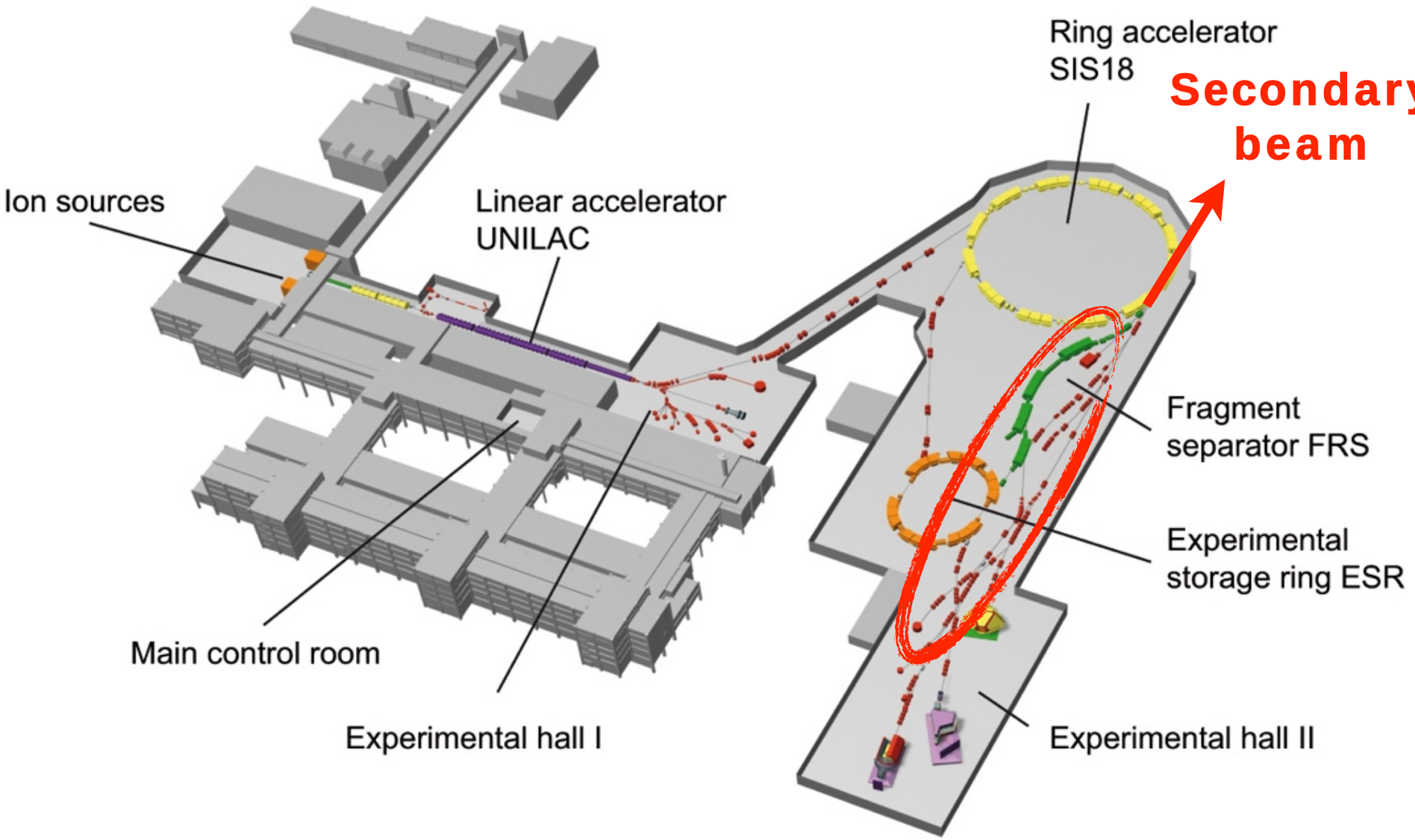

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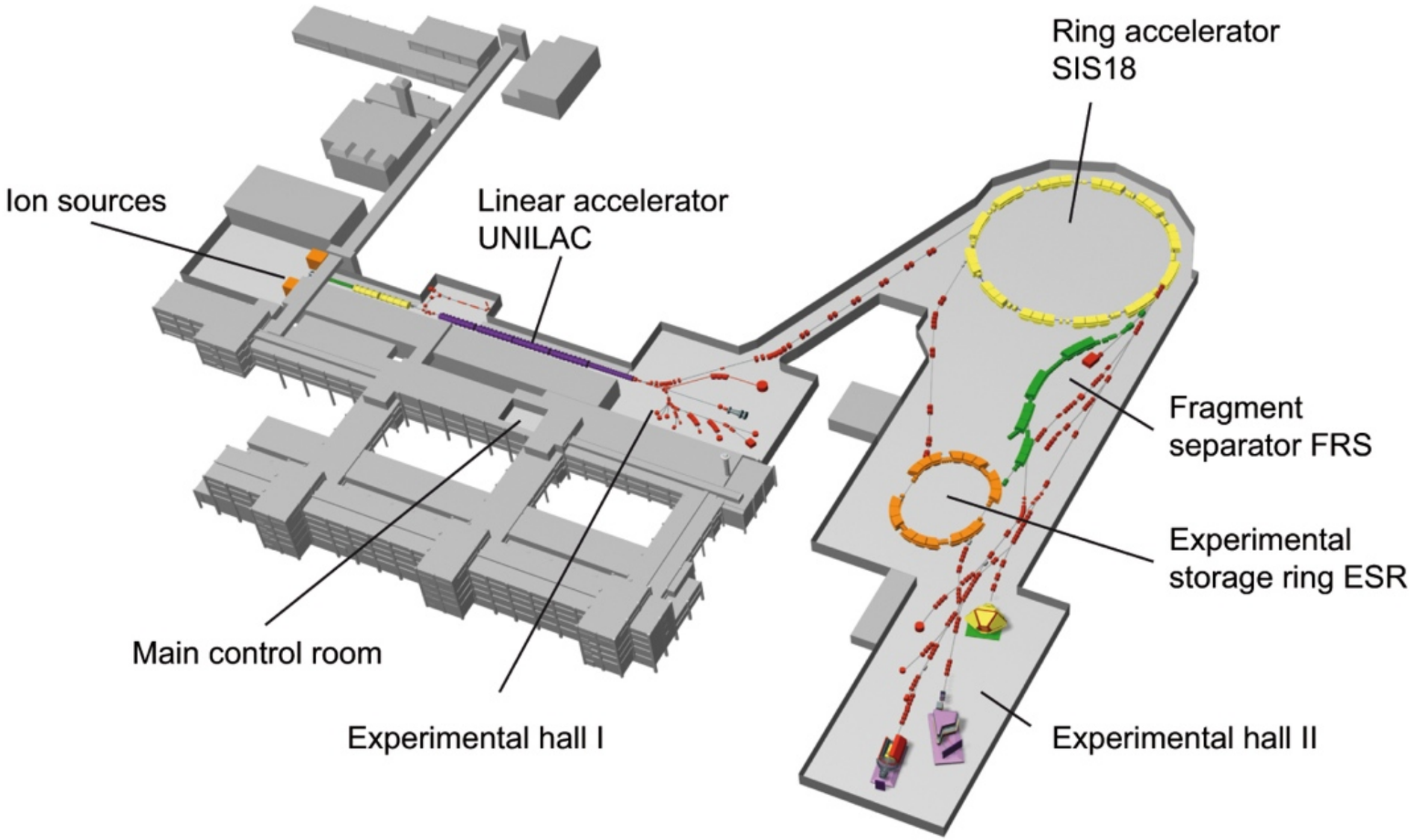

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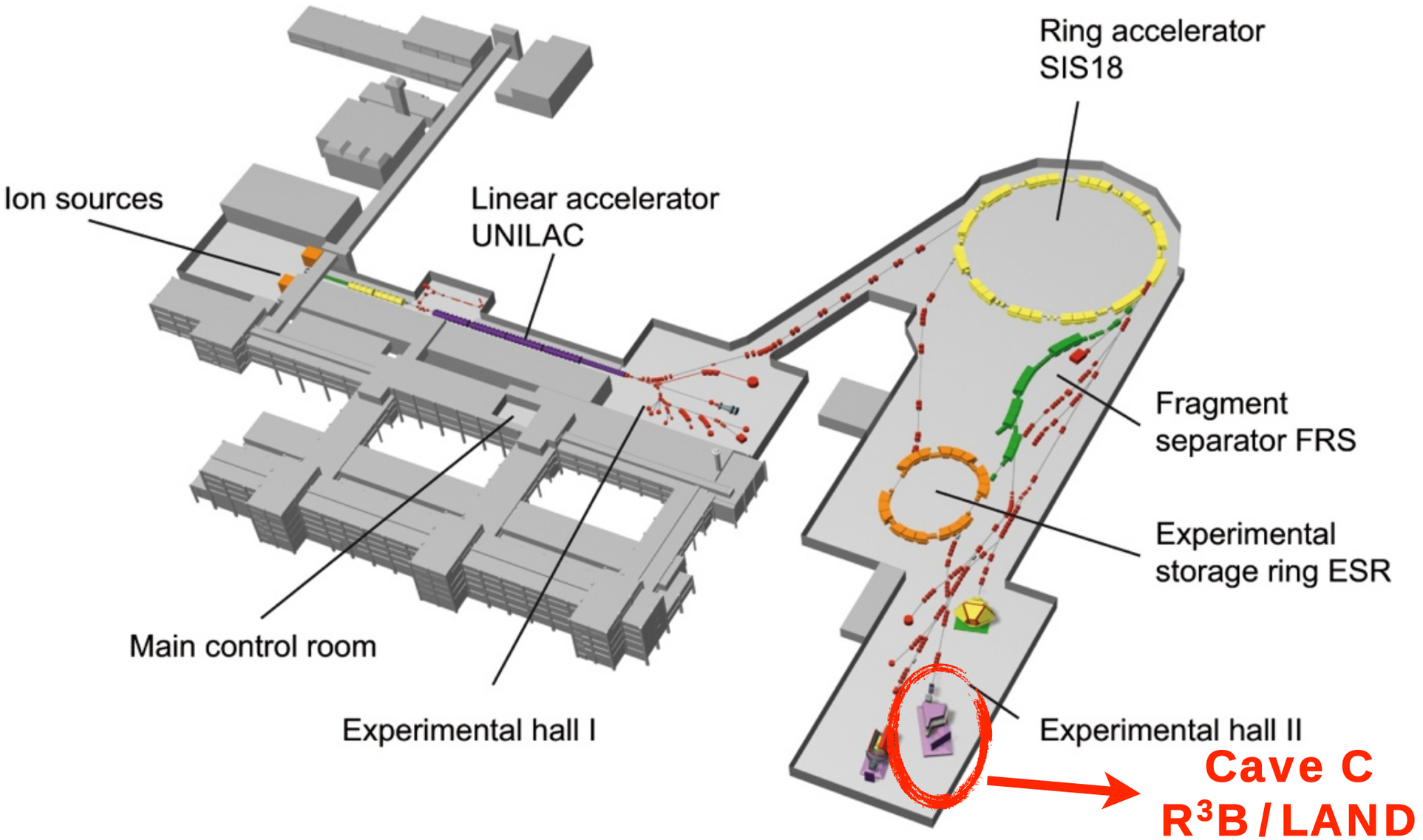

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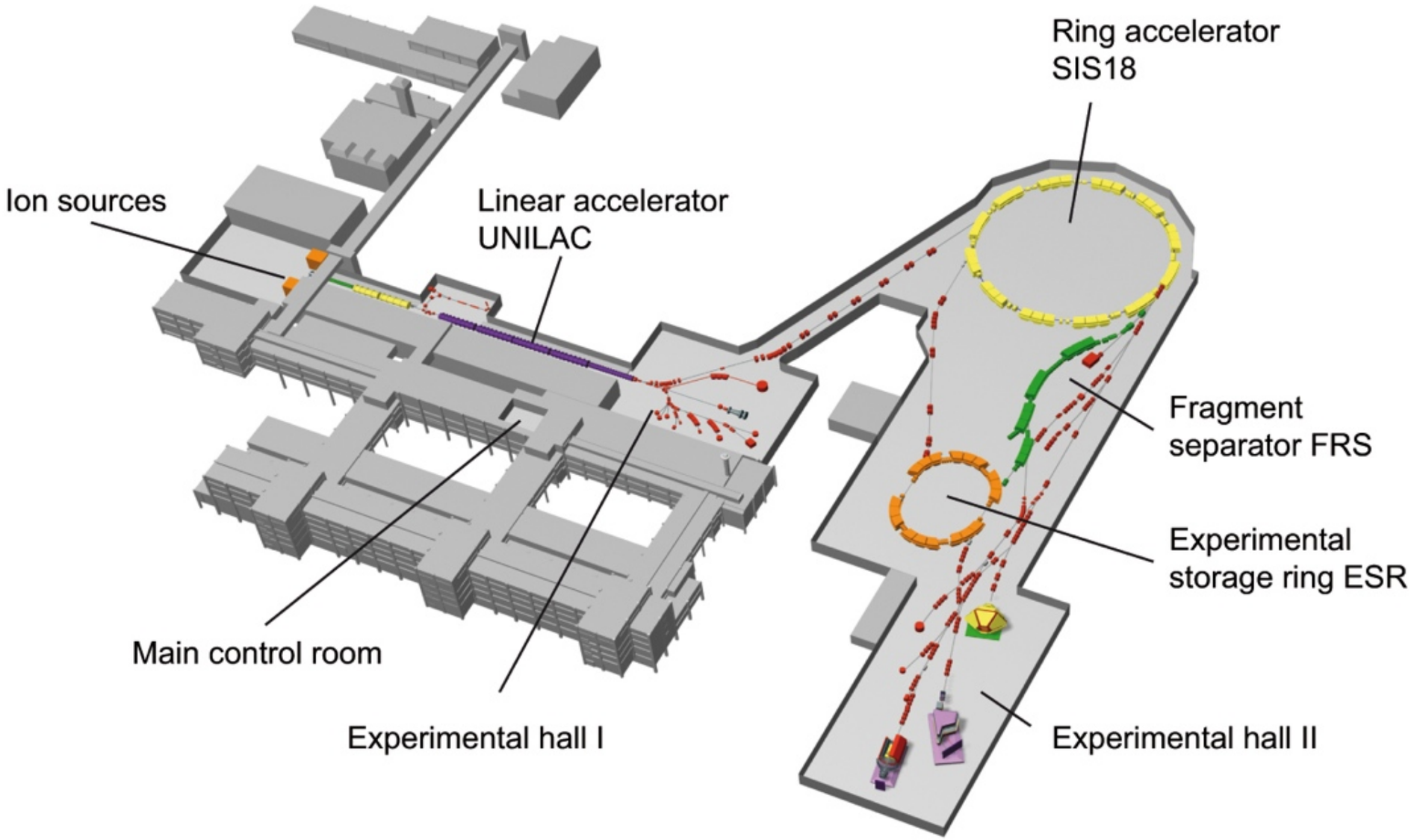

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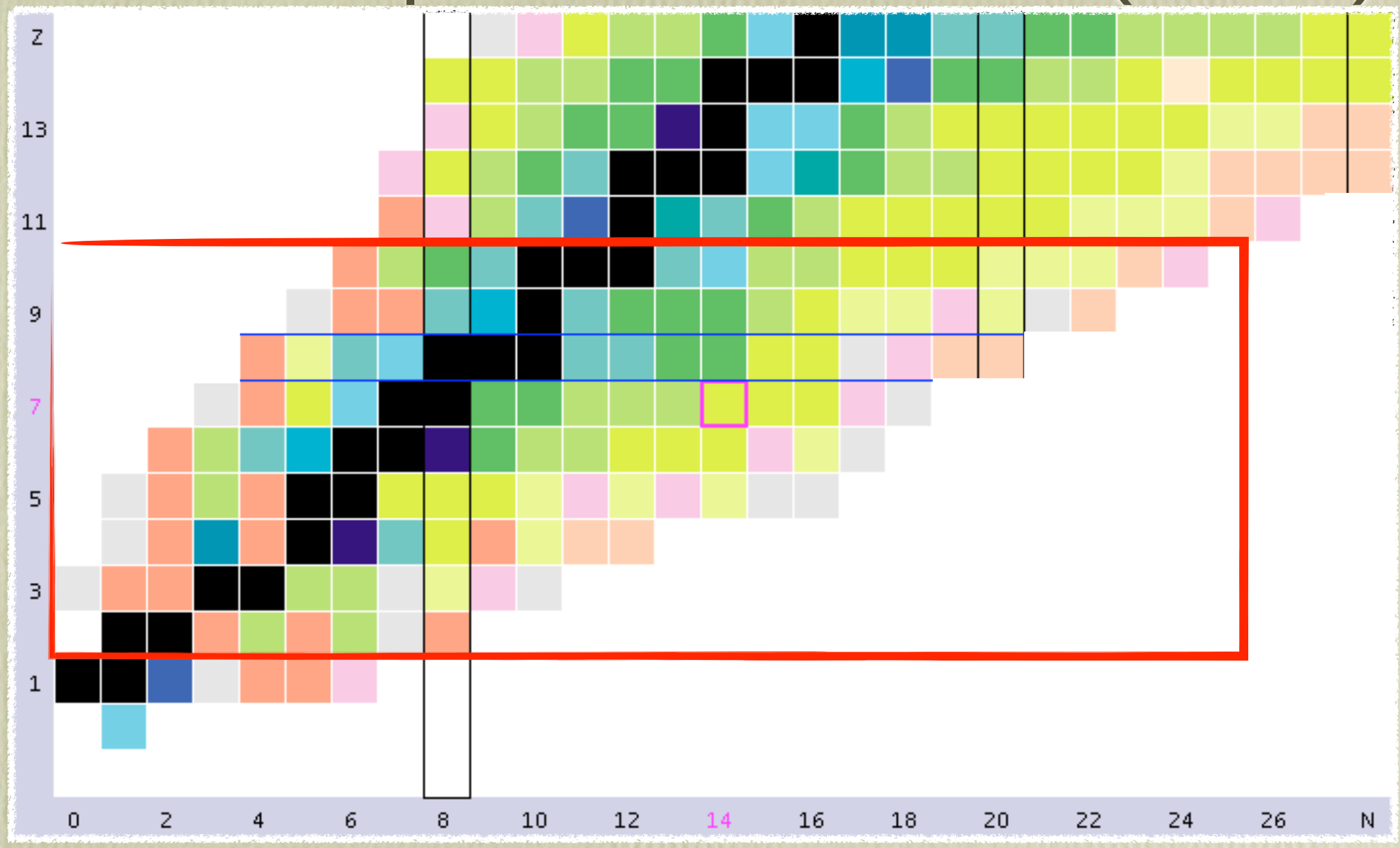

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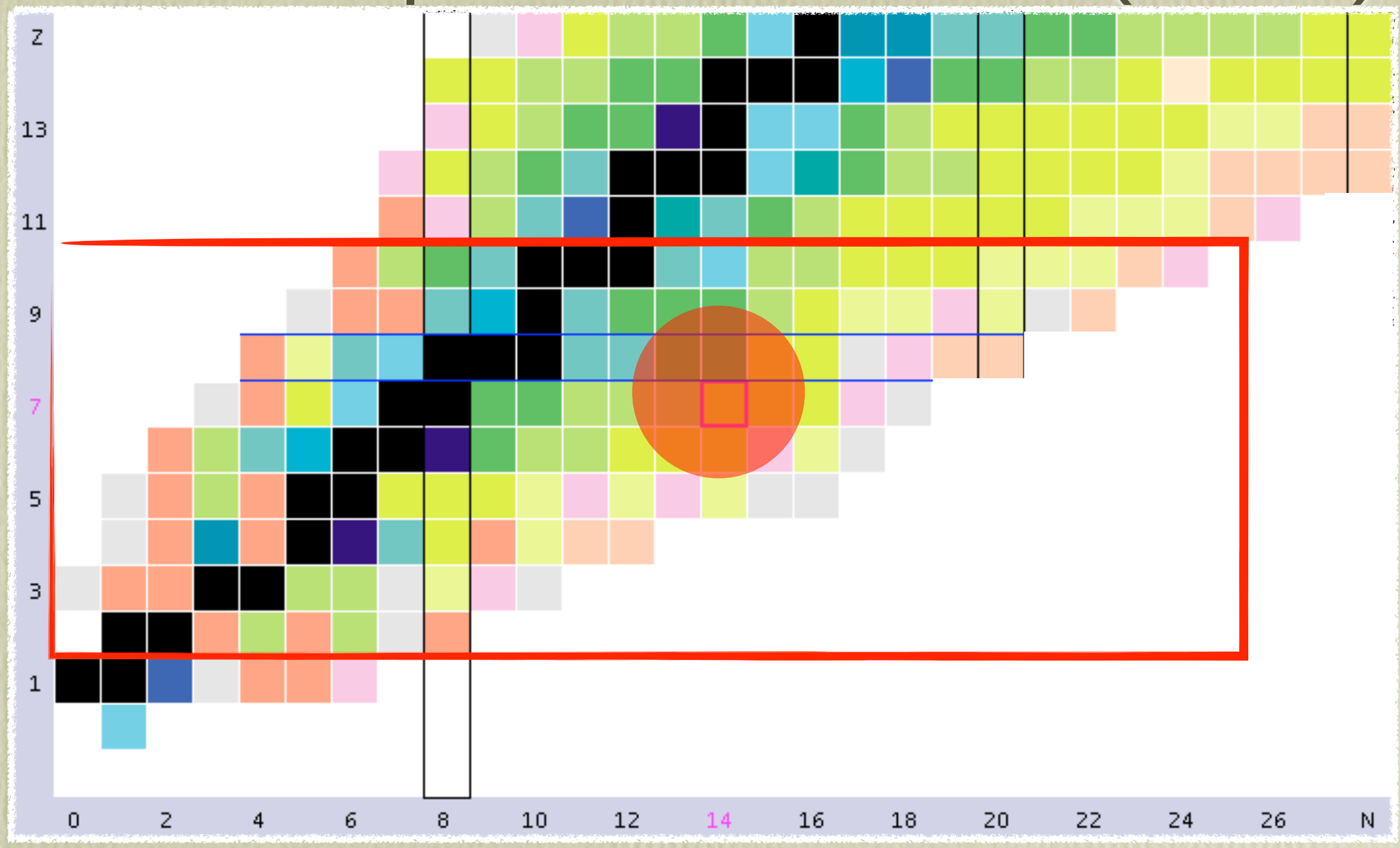

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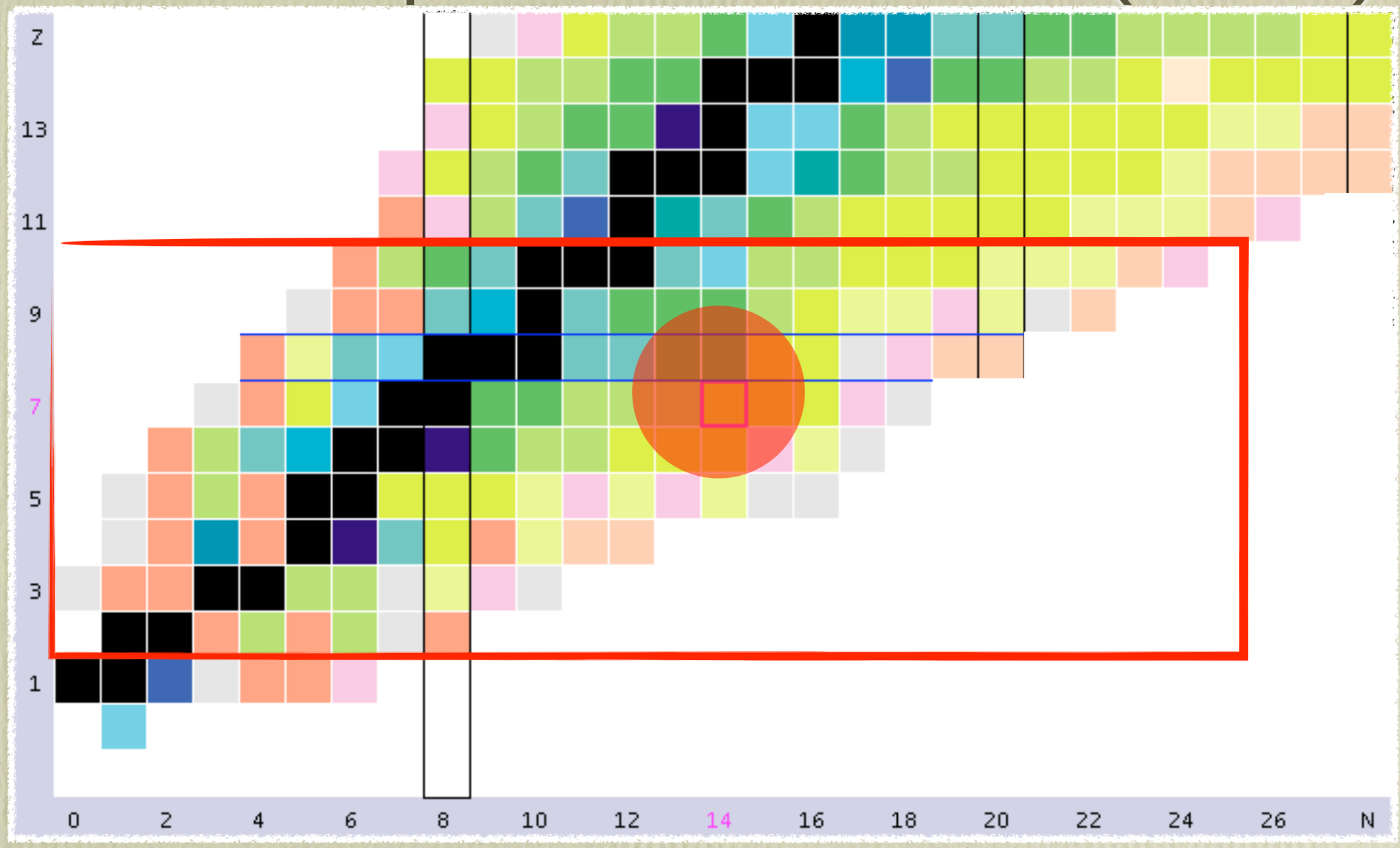
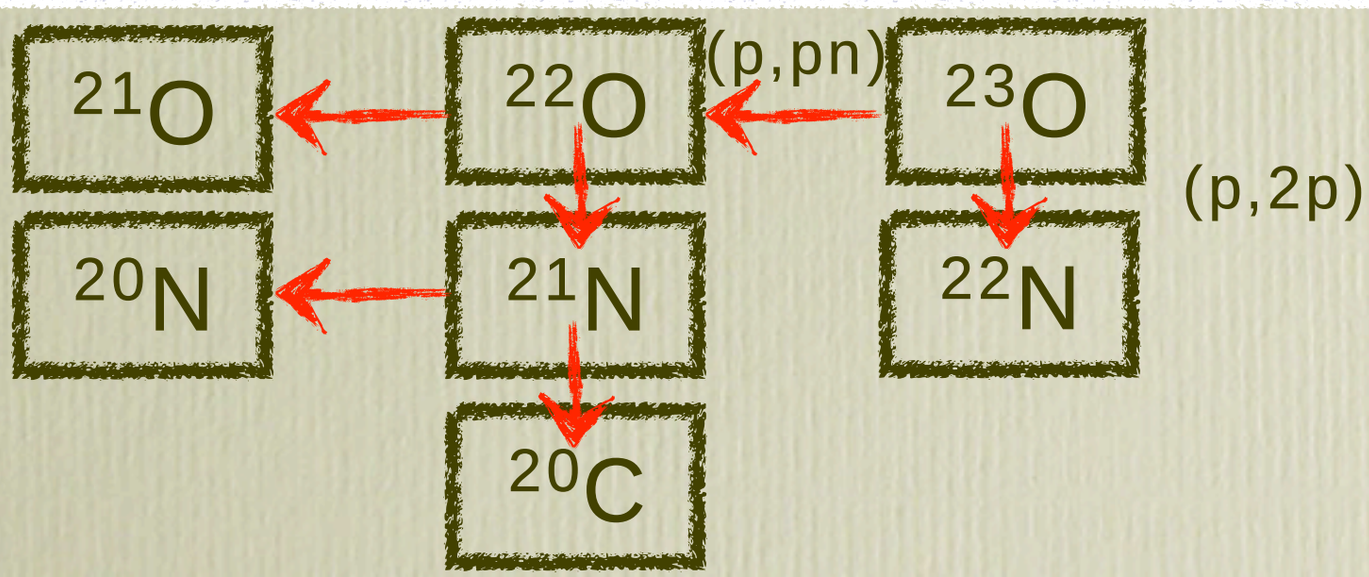
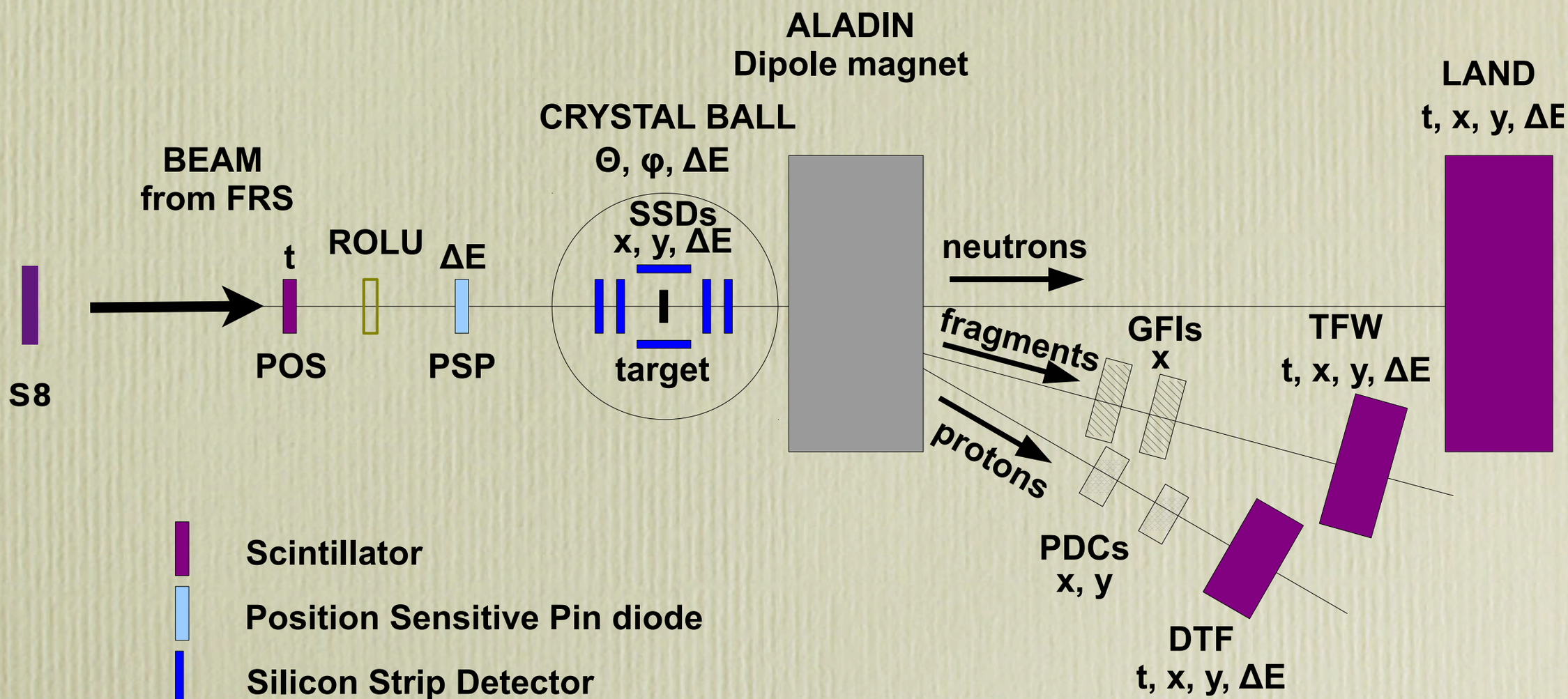


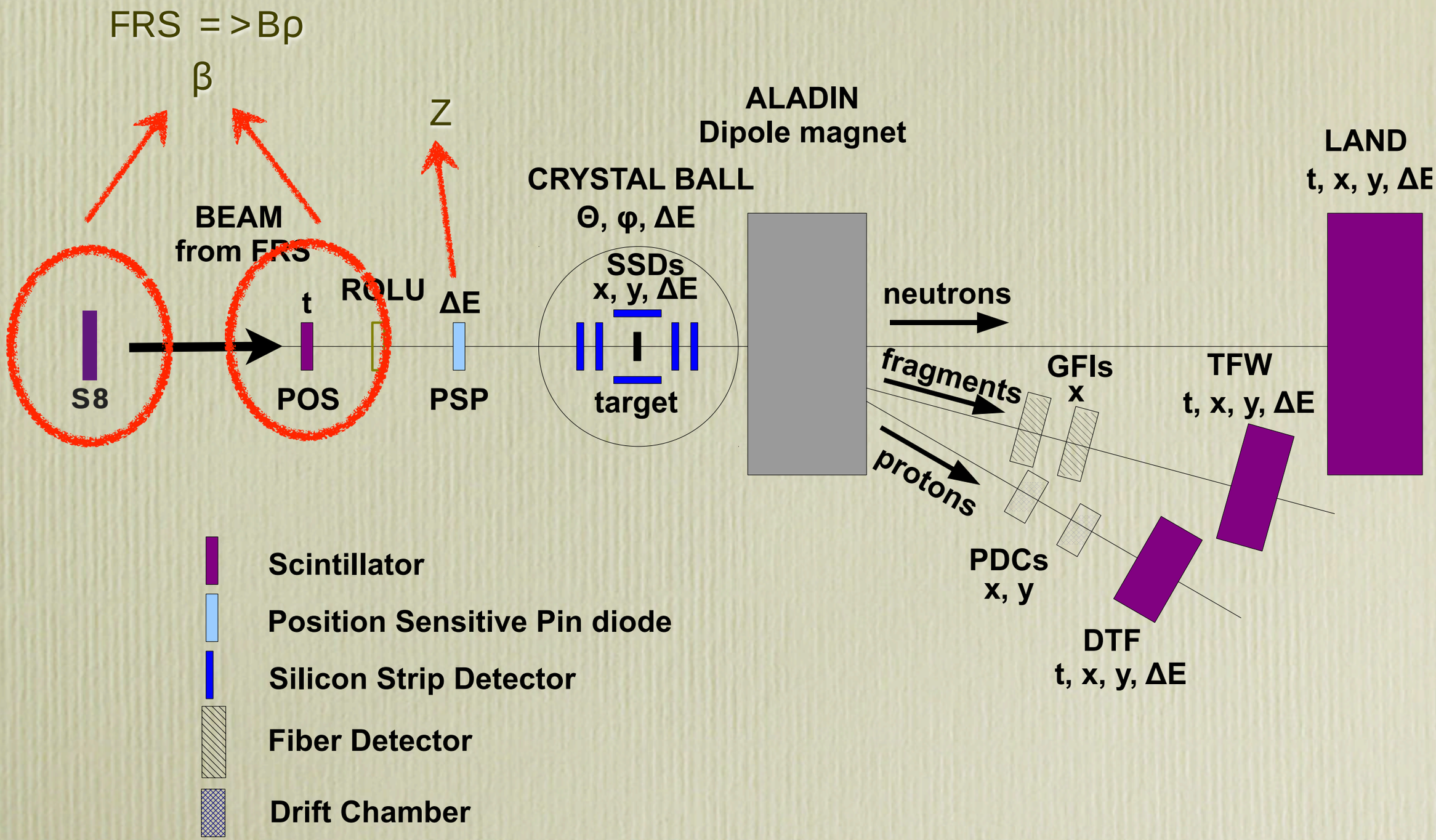


R3B/LAND setup



Incoming identification

$B\rho/\beta\gamma \alpha A/Z$



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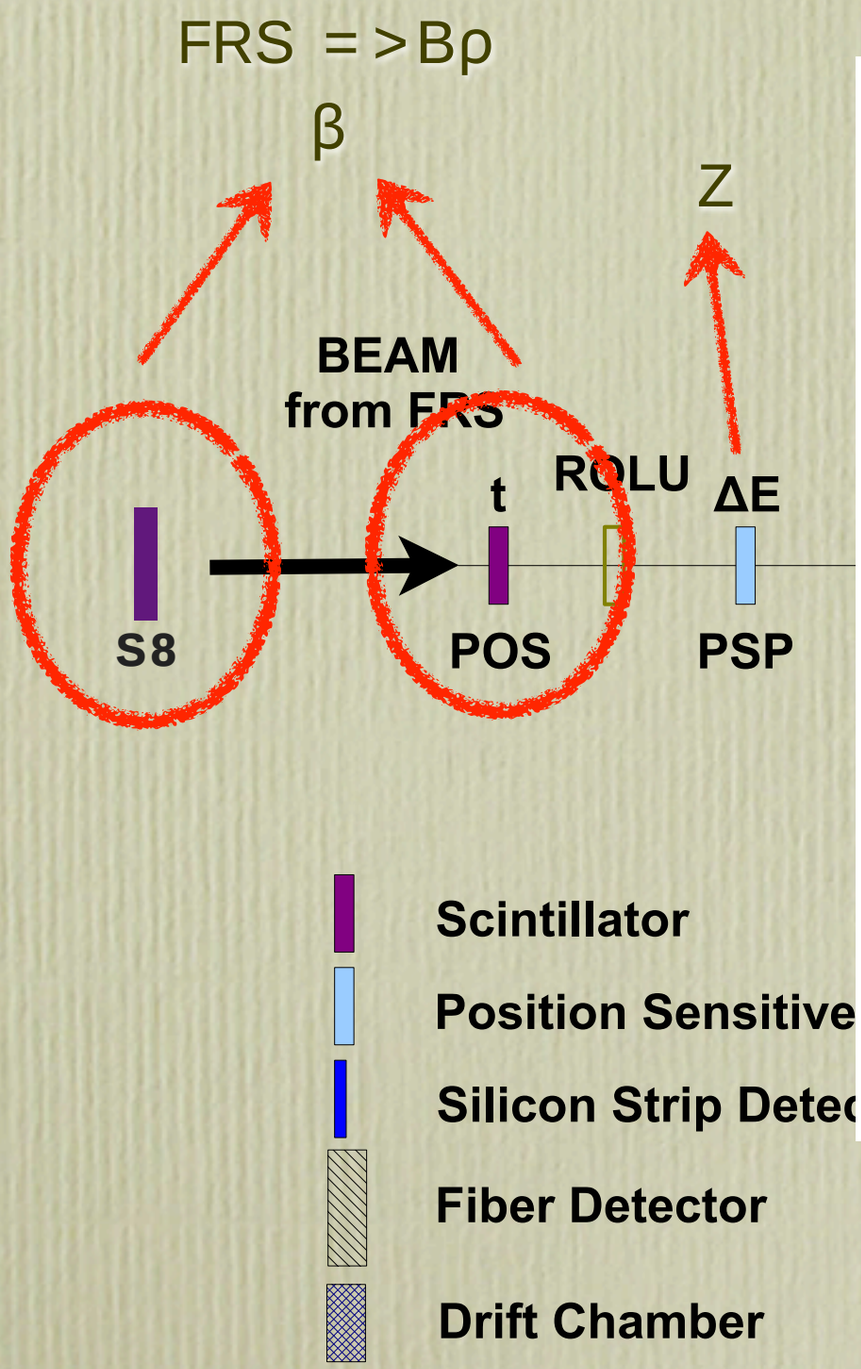

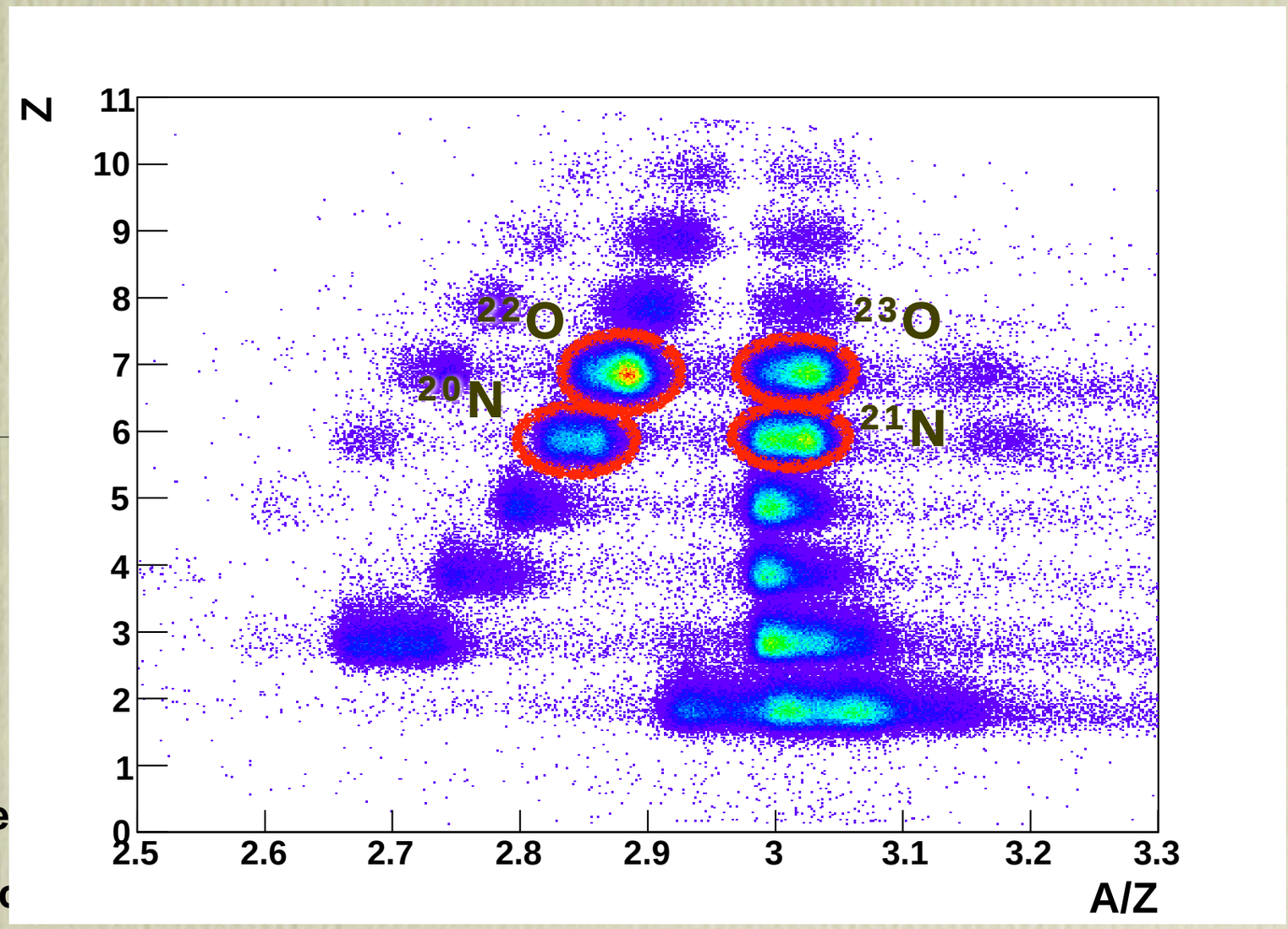

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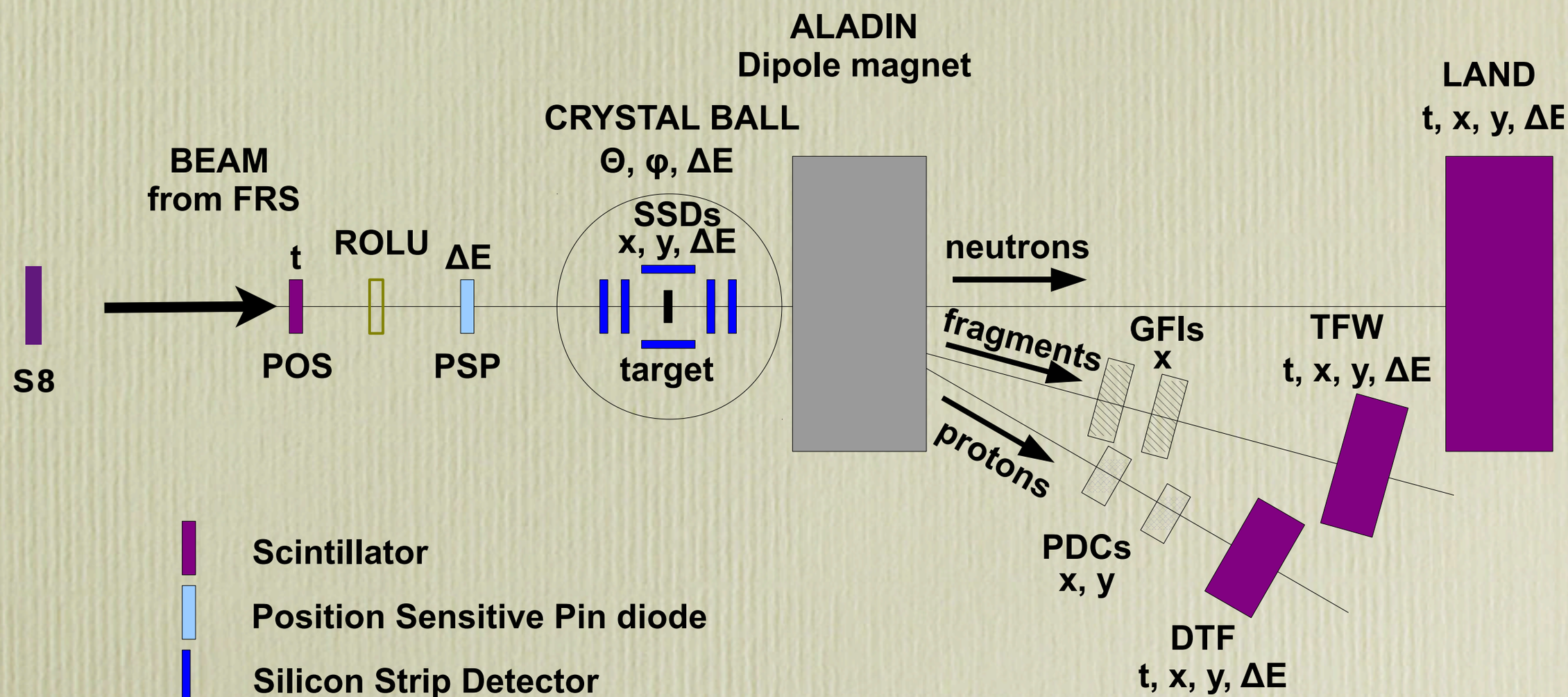

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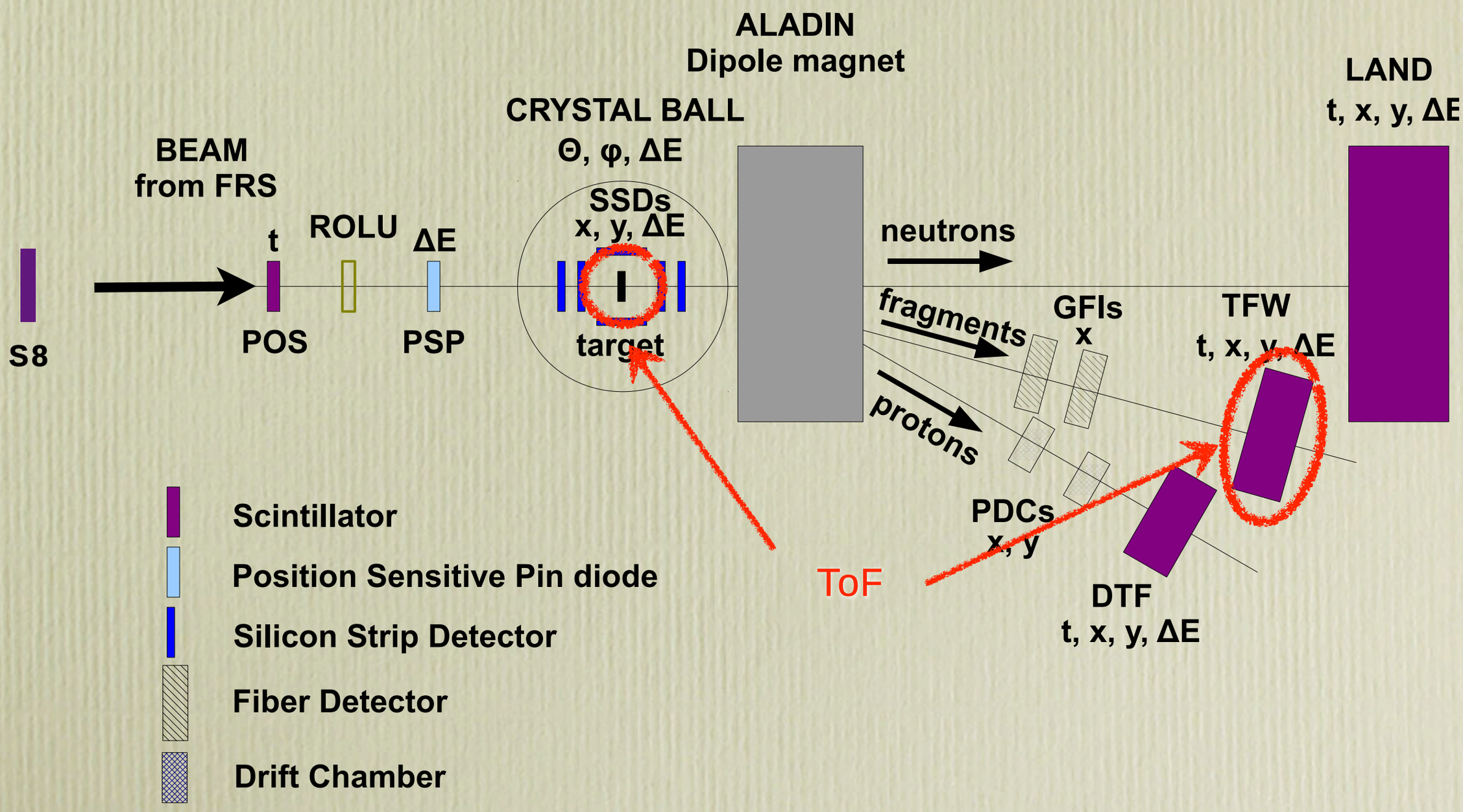

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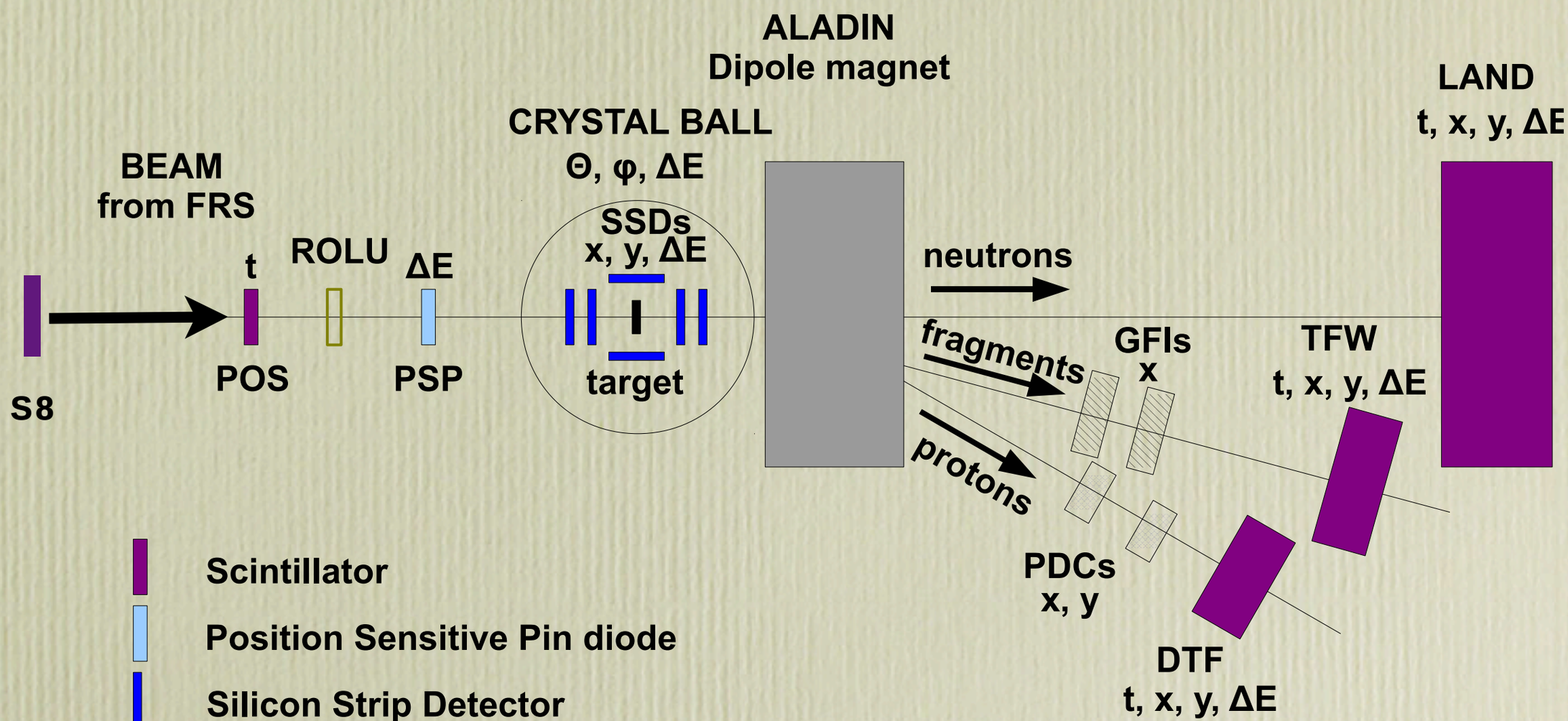

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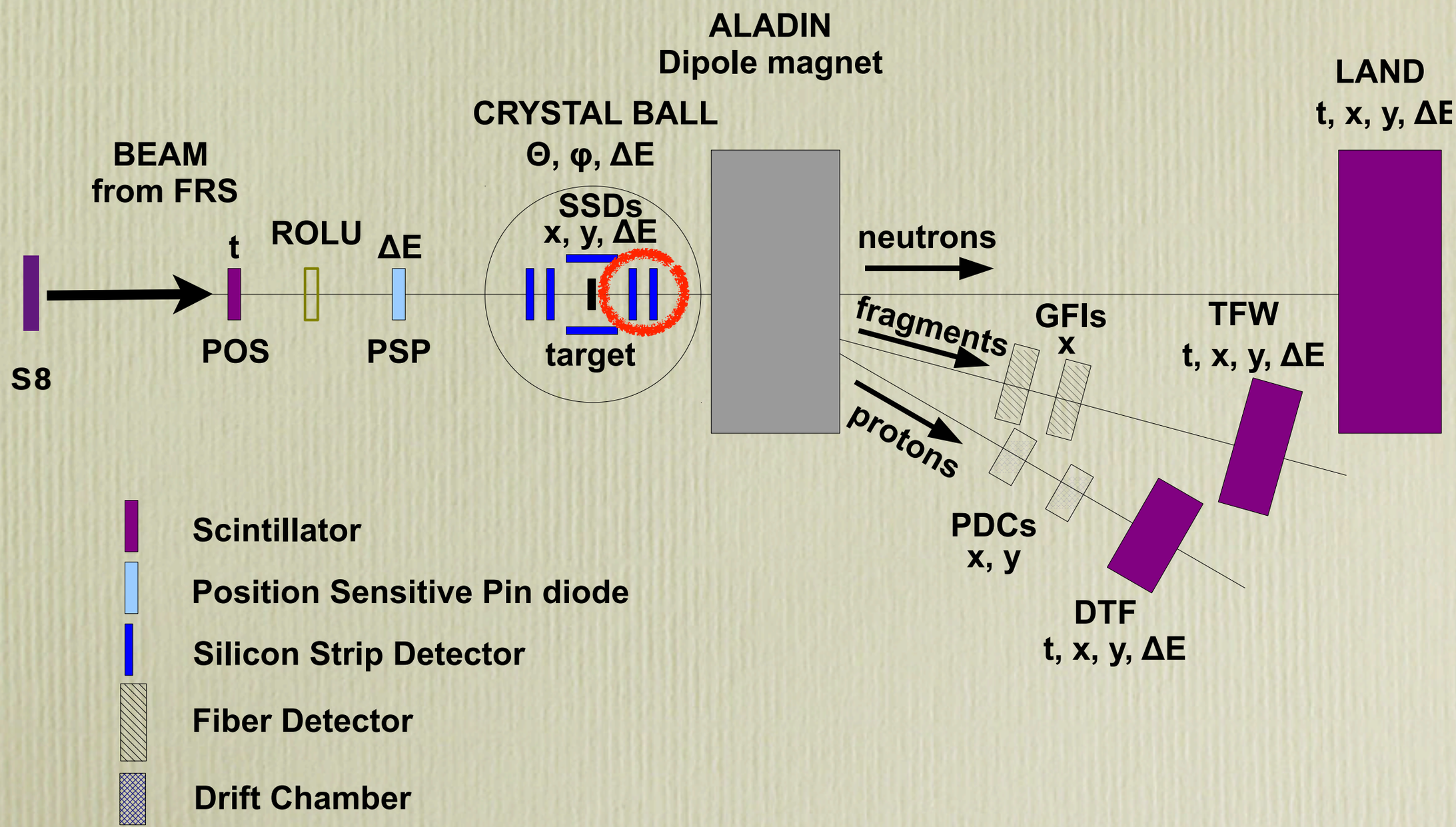

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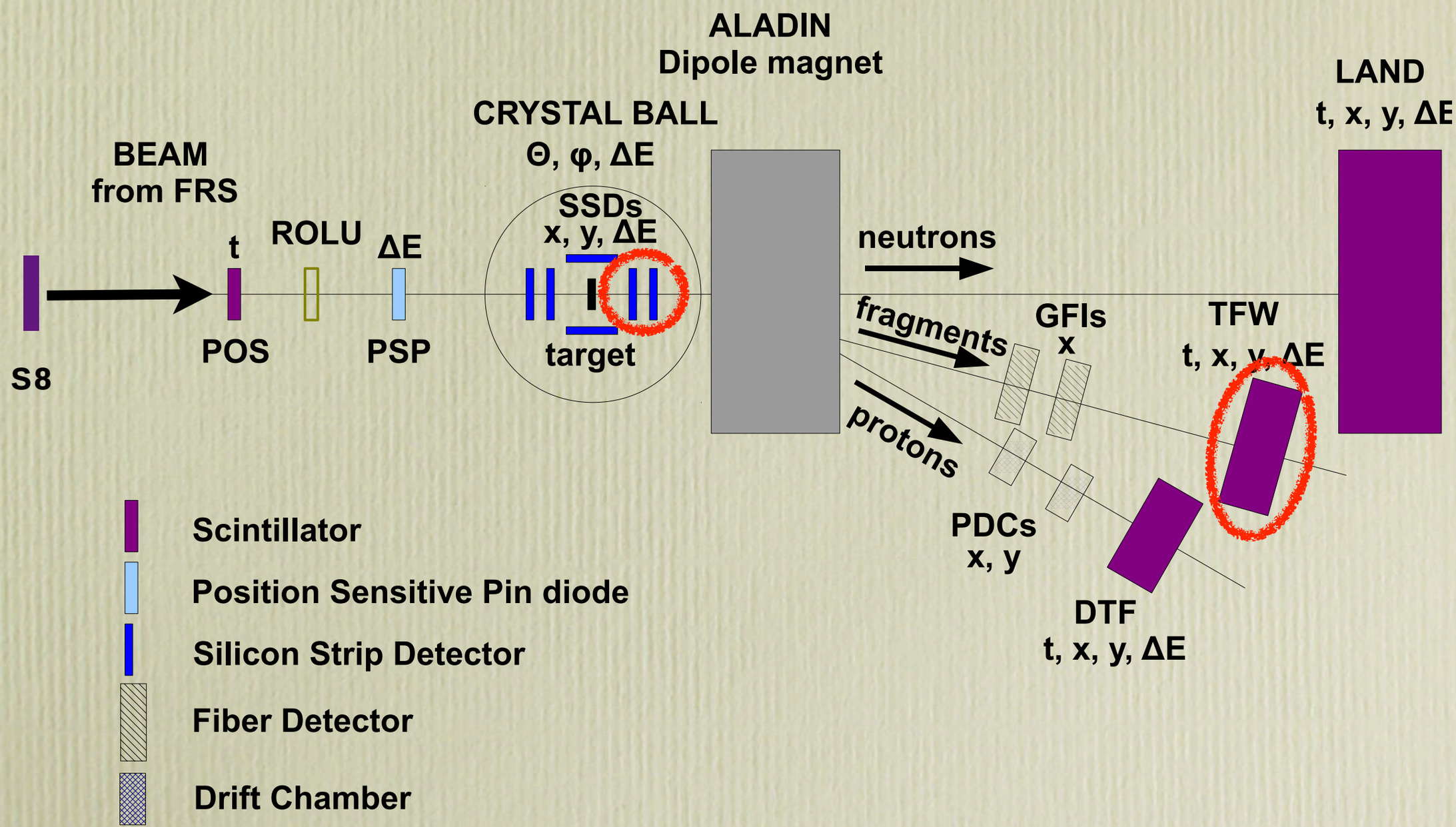

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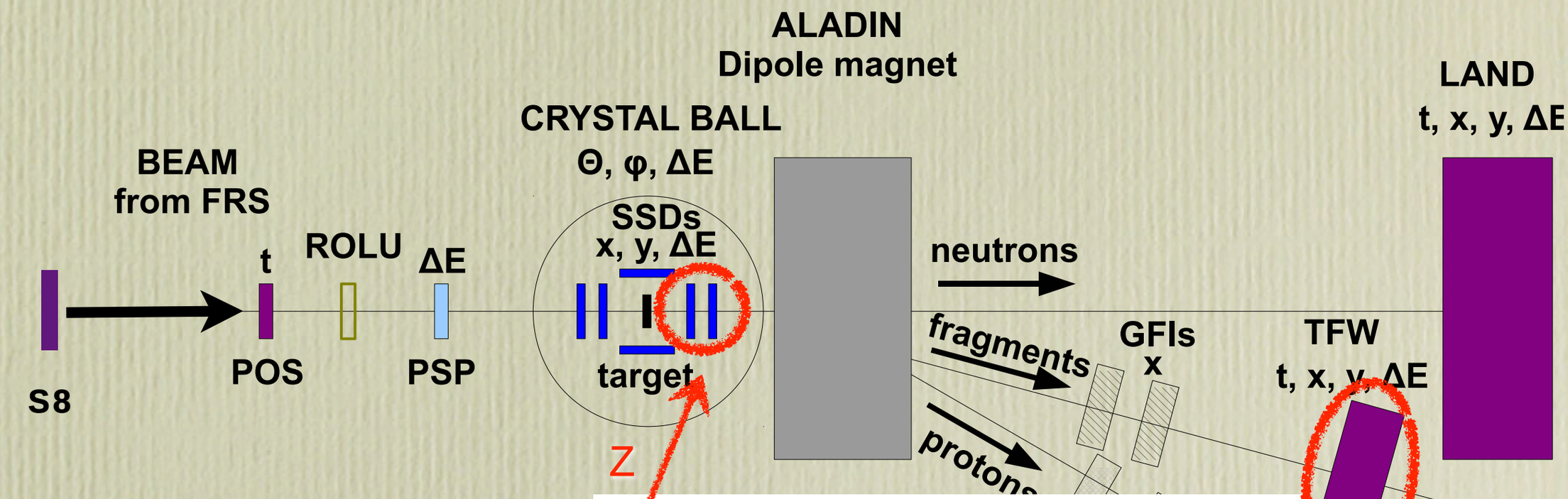


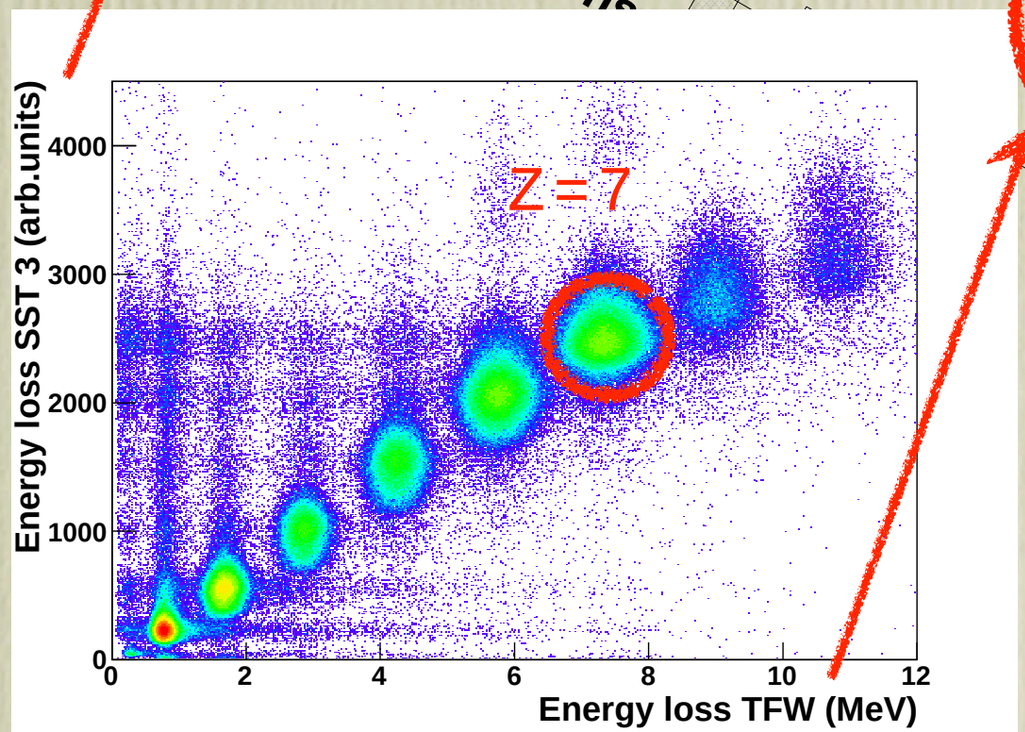
Scintillator

Position Sensitive Pin

Silicon Strip Detector

Fiber Detector

Drift Chamber



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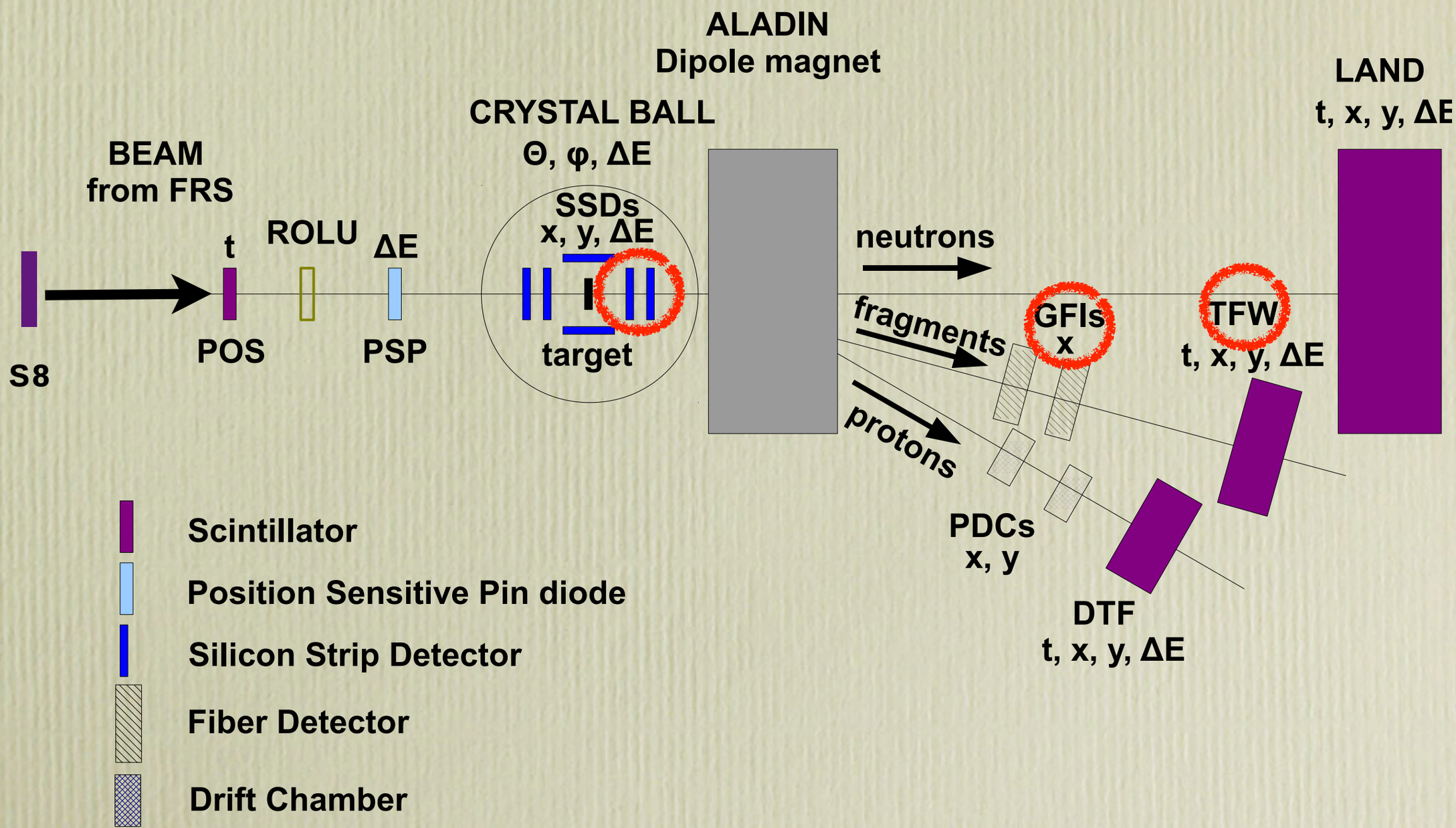

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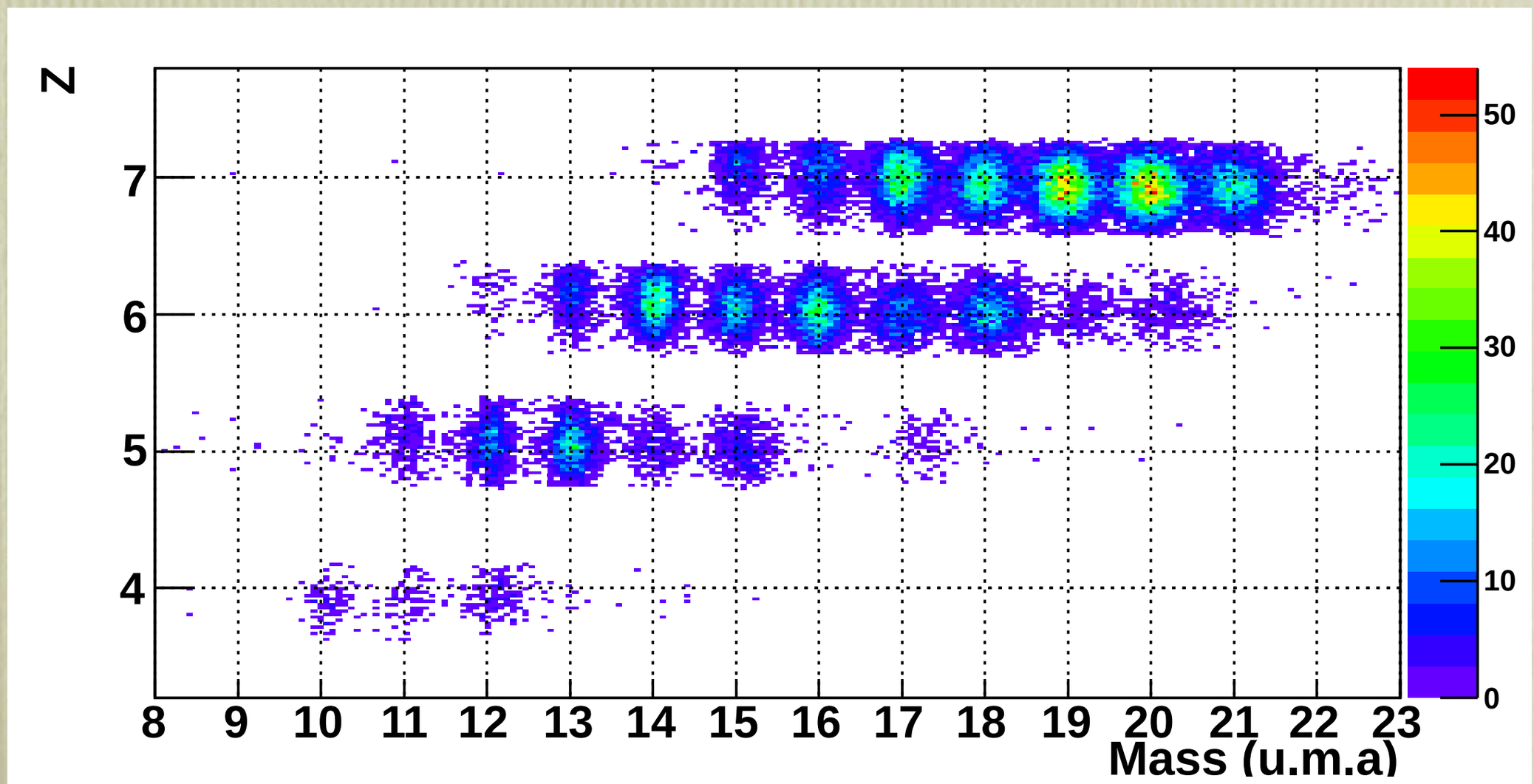
OUTGOING IDENTIFICATION
FOR INCOMING ^{21}N



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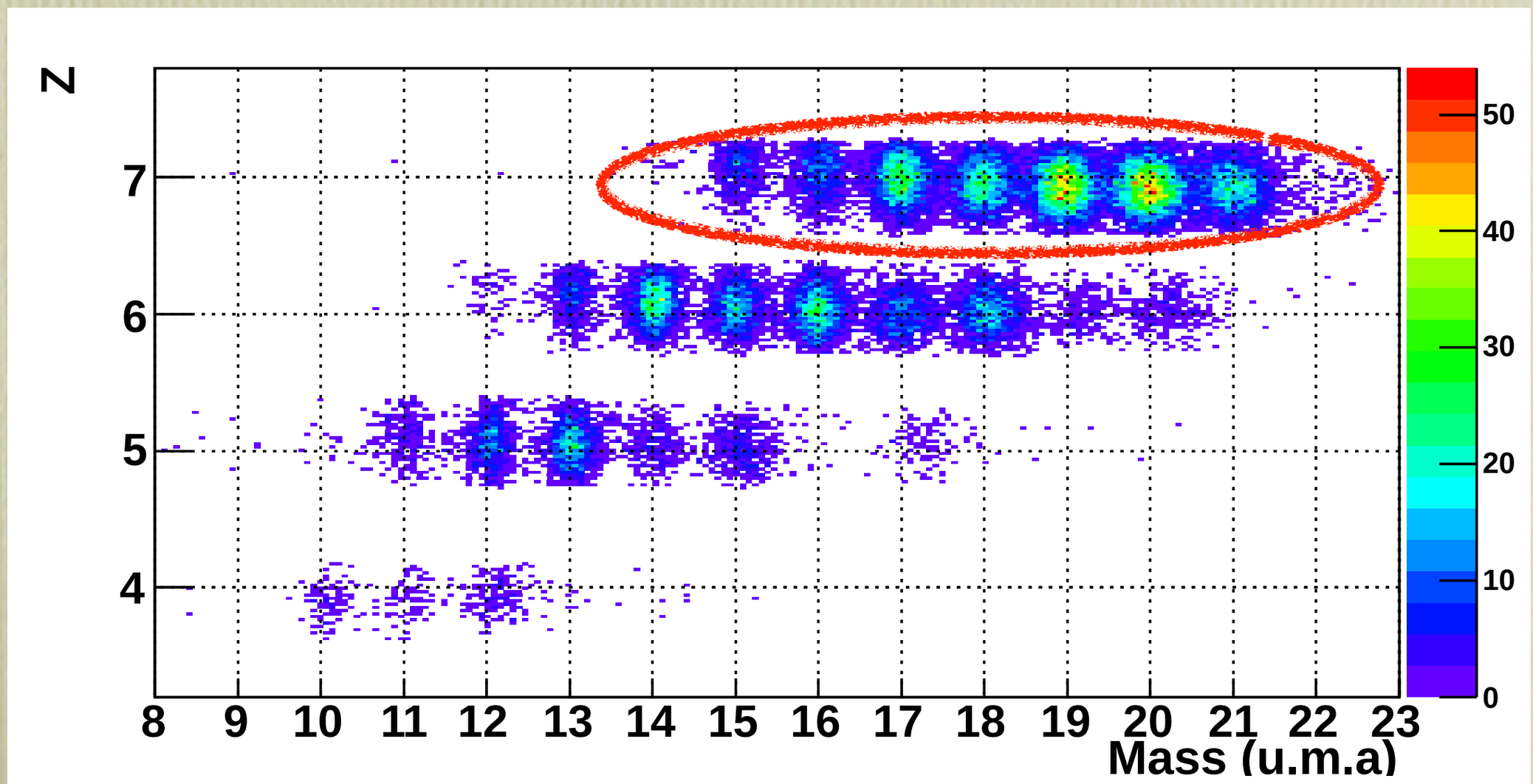

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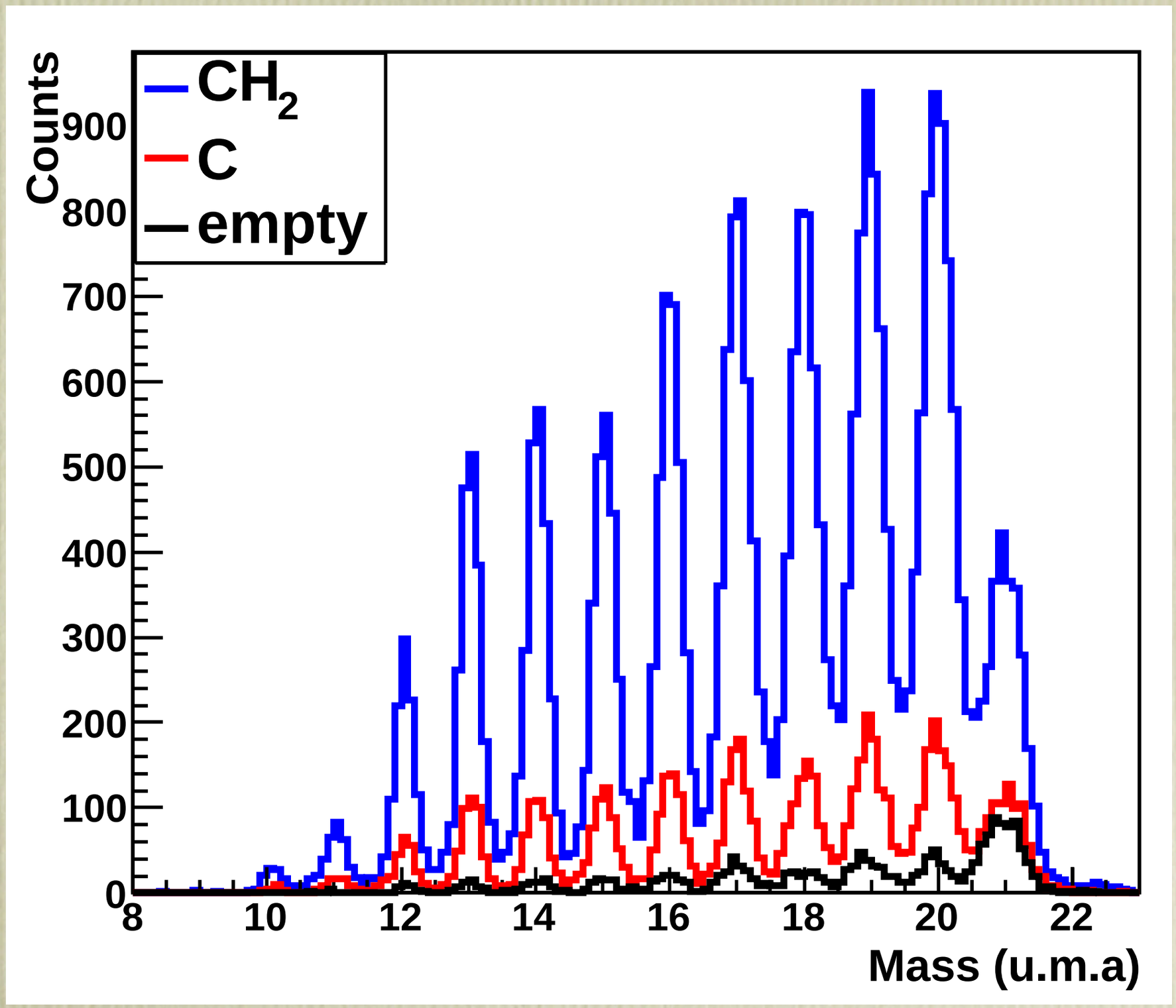
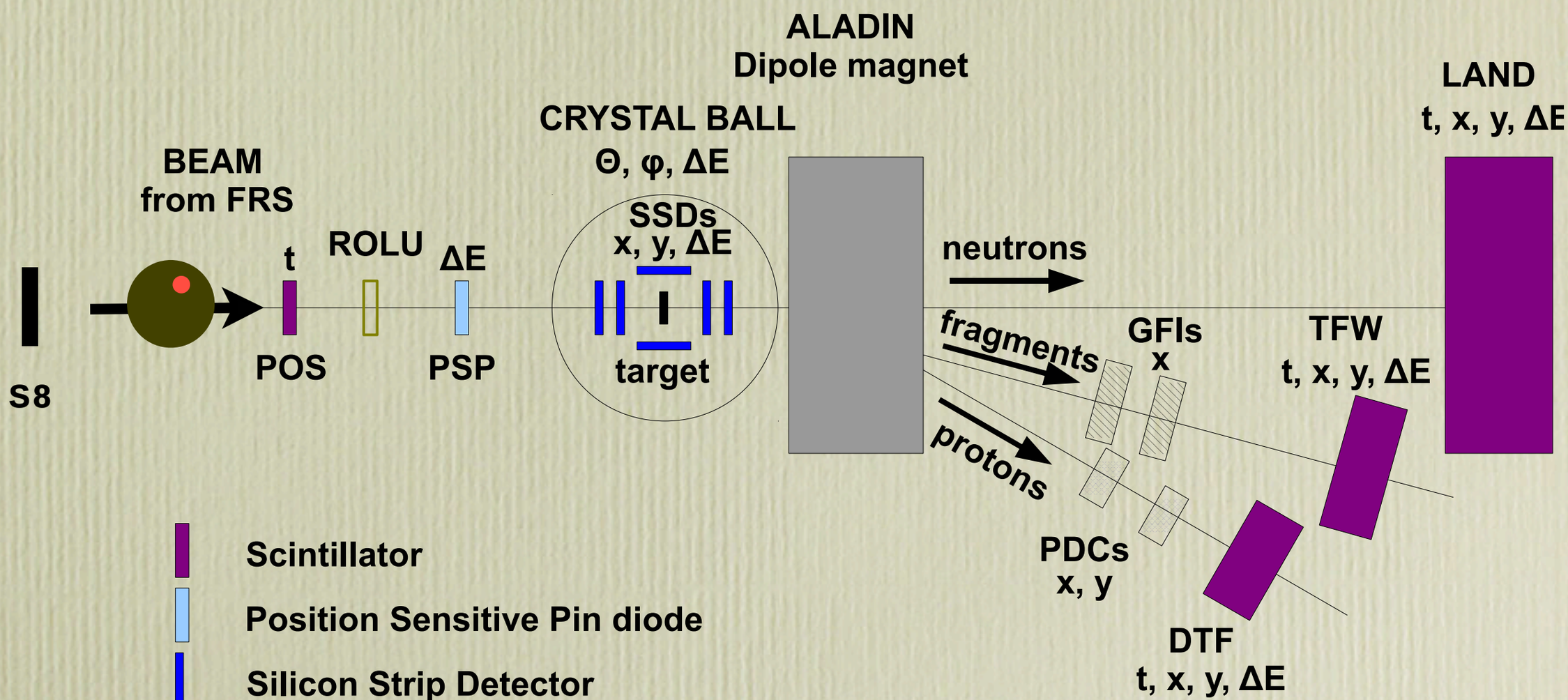


(p,pn) and (p,2p)channels

$^{21}N(p,pn)^{20}N$ $^{22}O(p,pn)^{21}O$ $^{23}O(p,pn)^{22}O$

$^{21}N(p,2p)^{20}C$ $^{22}O(p,2p)^{21}N$ $^{23}O(p,2p)^{22}N$



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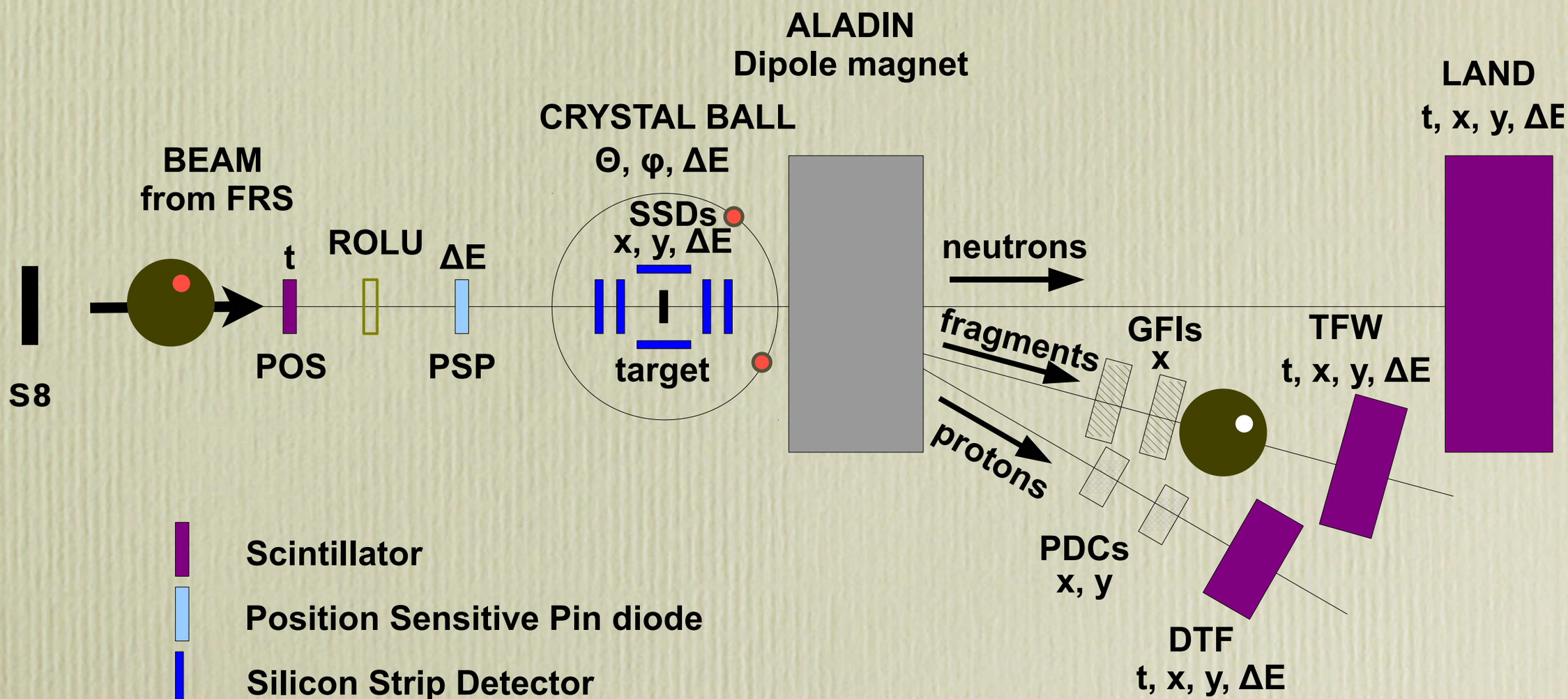
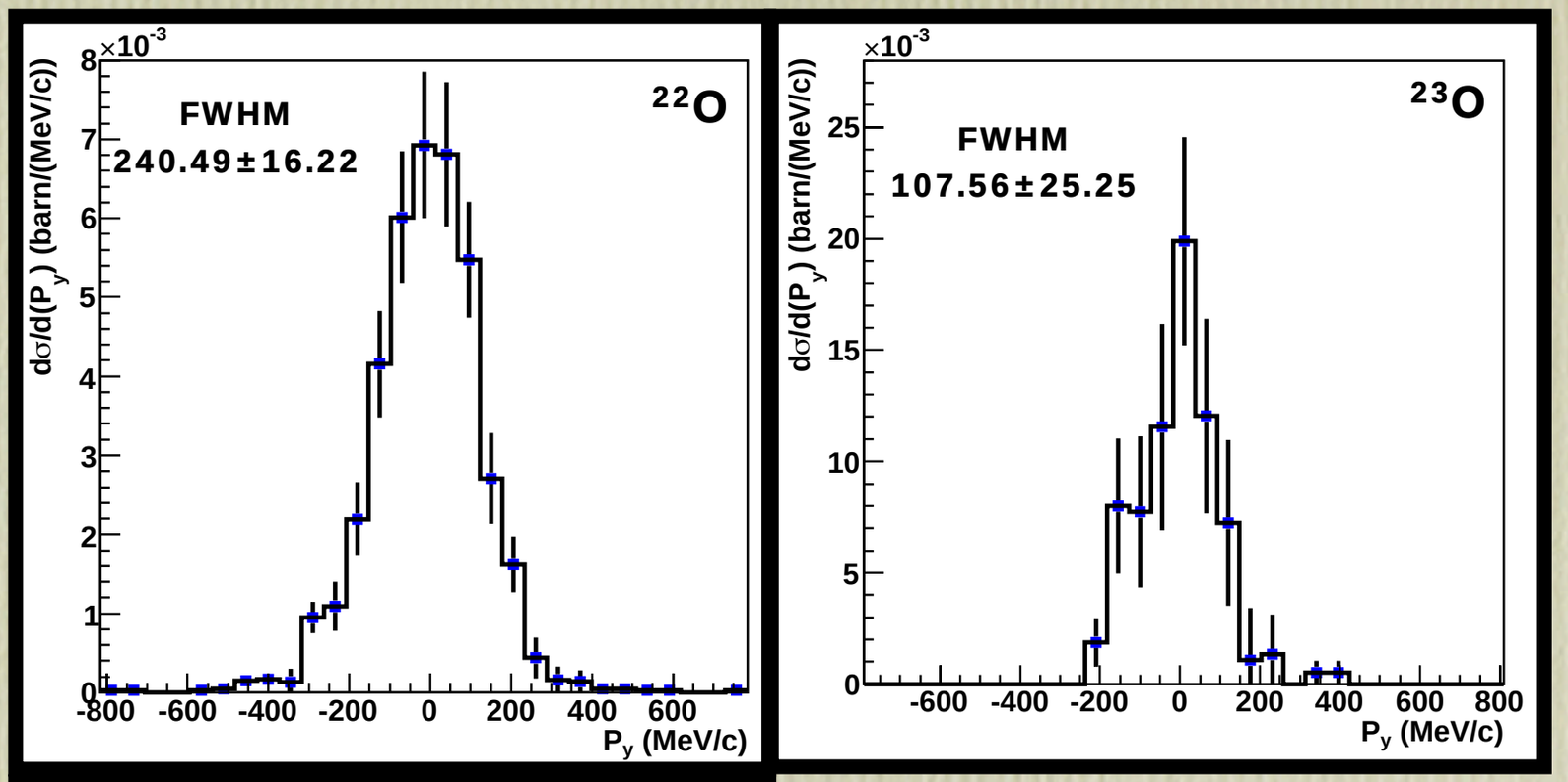


Results for (p,pn)

Preliminary results!!



Inclusive transversal momentum

QFS one-neutron knockout channels

0

N

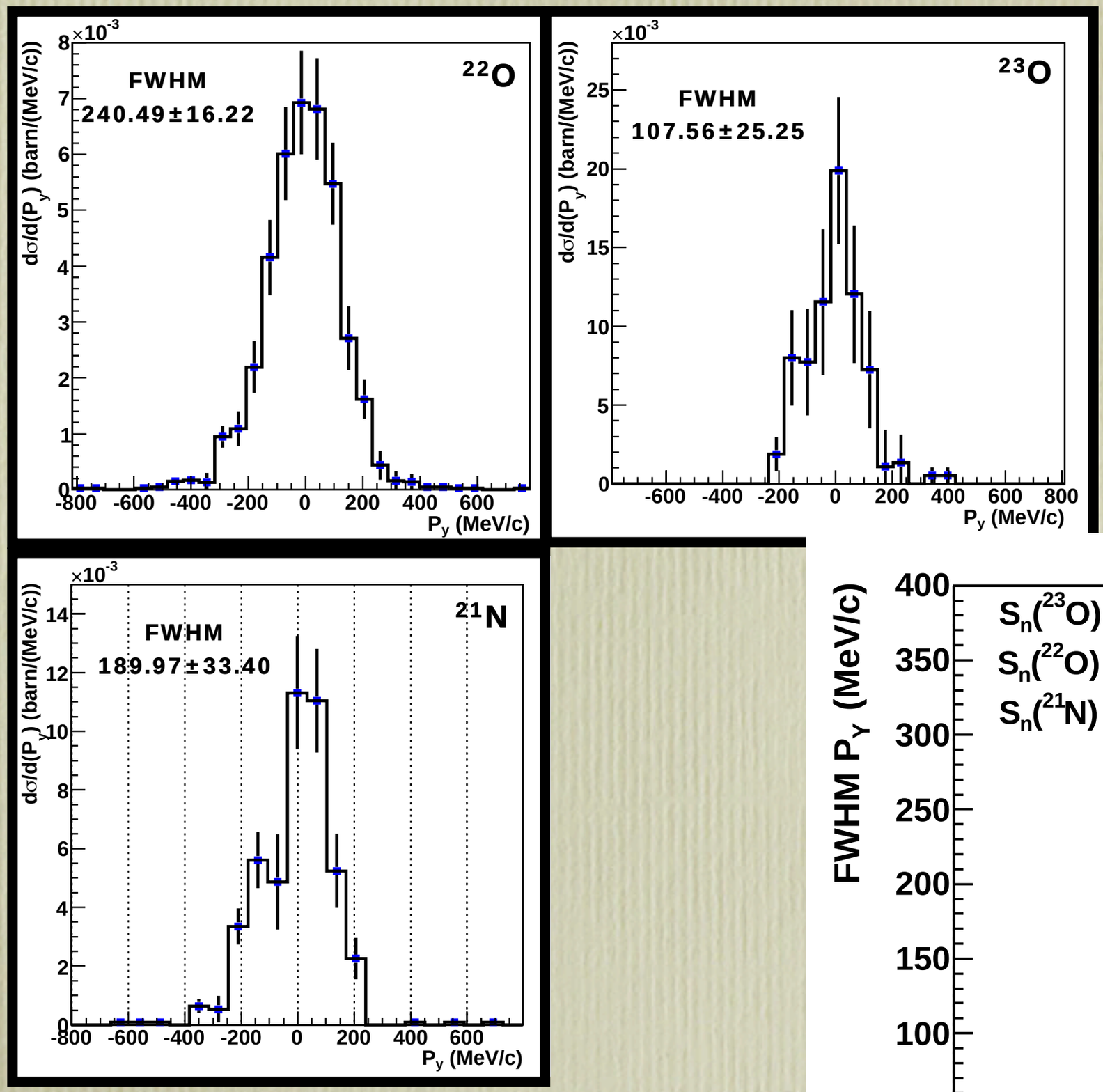
14

15

Number of neutrons in the projectiles

Results for (p,pn)

Preliminary results!!



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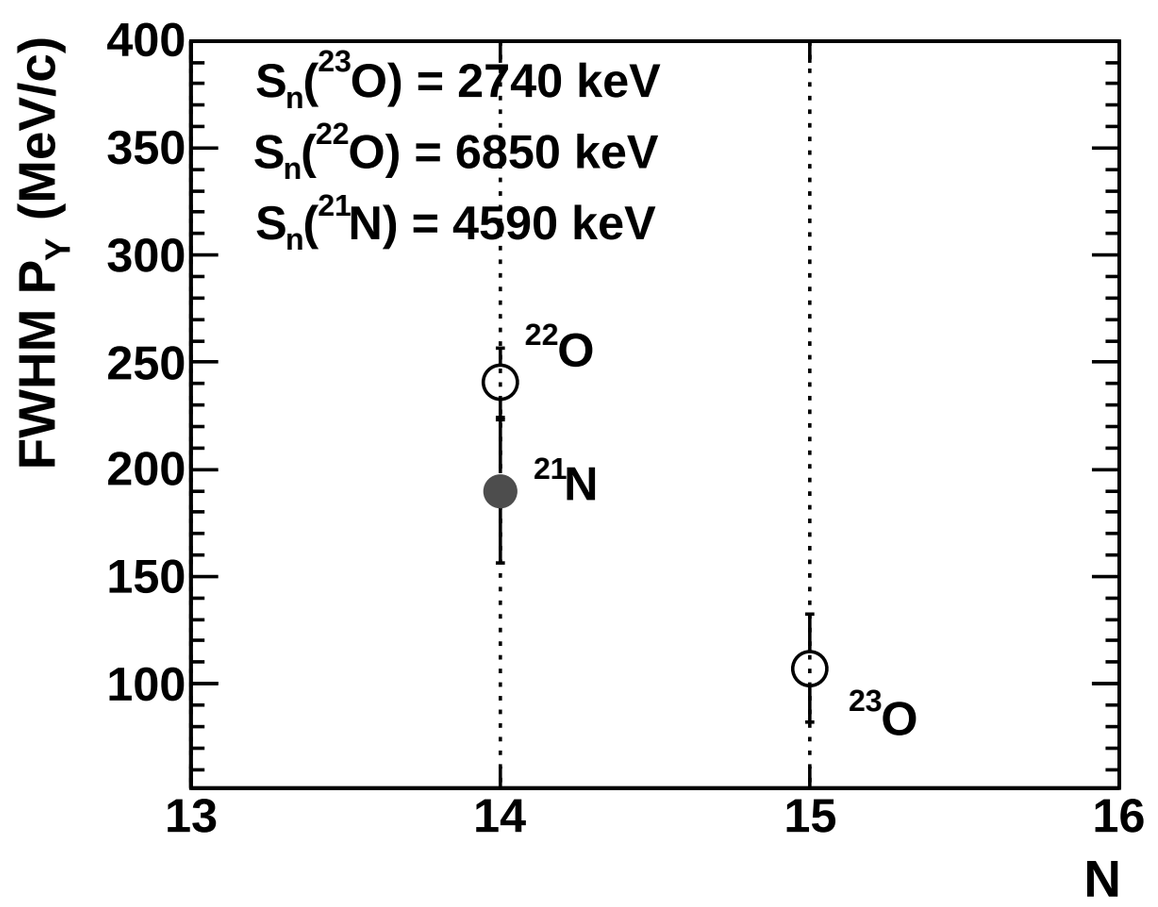
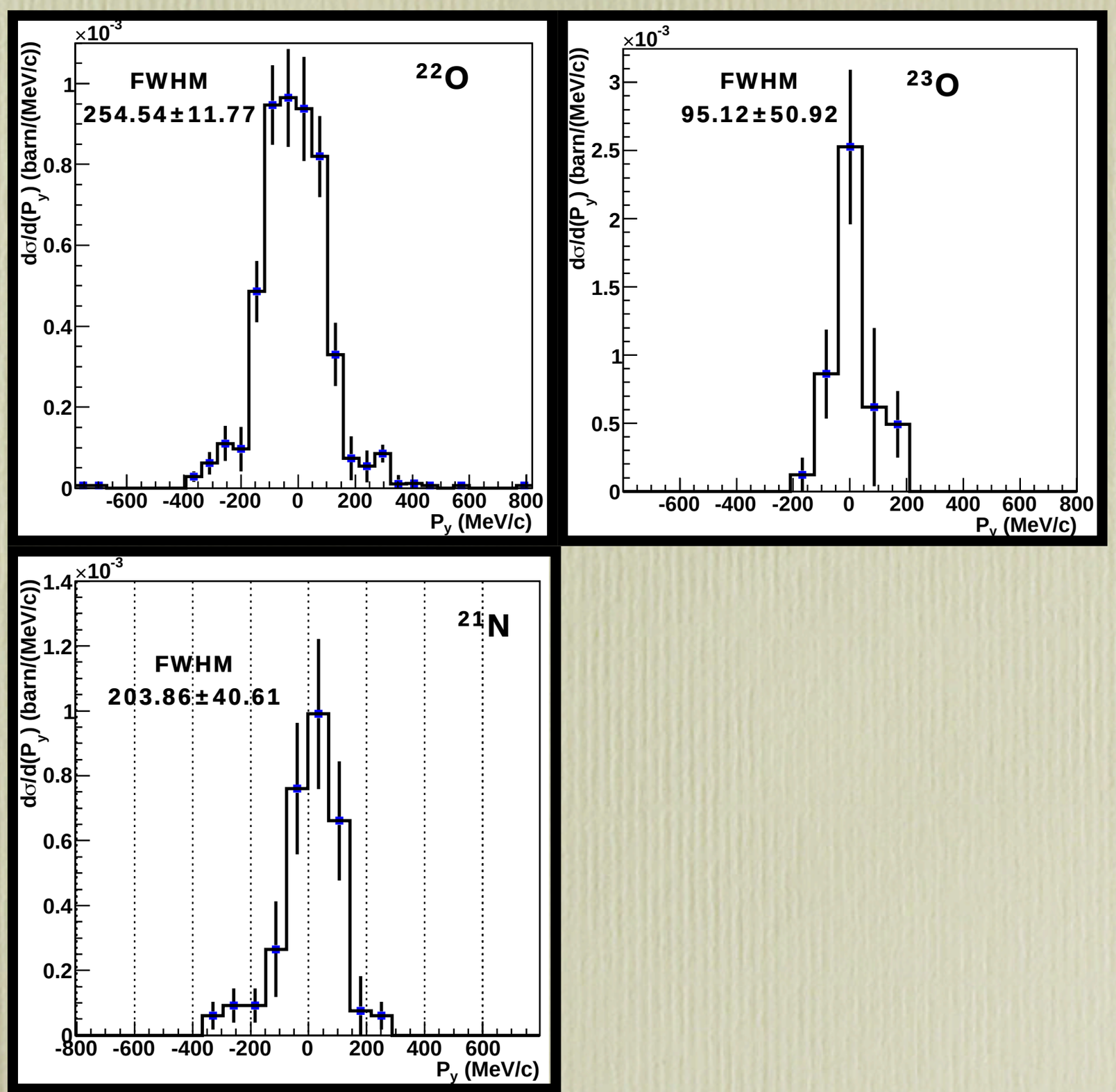


Results for (p,2p)

Preliminary results!!

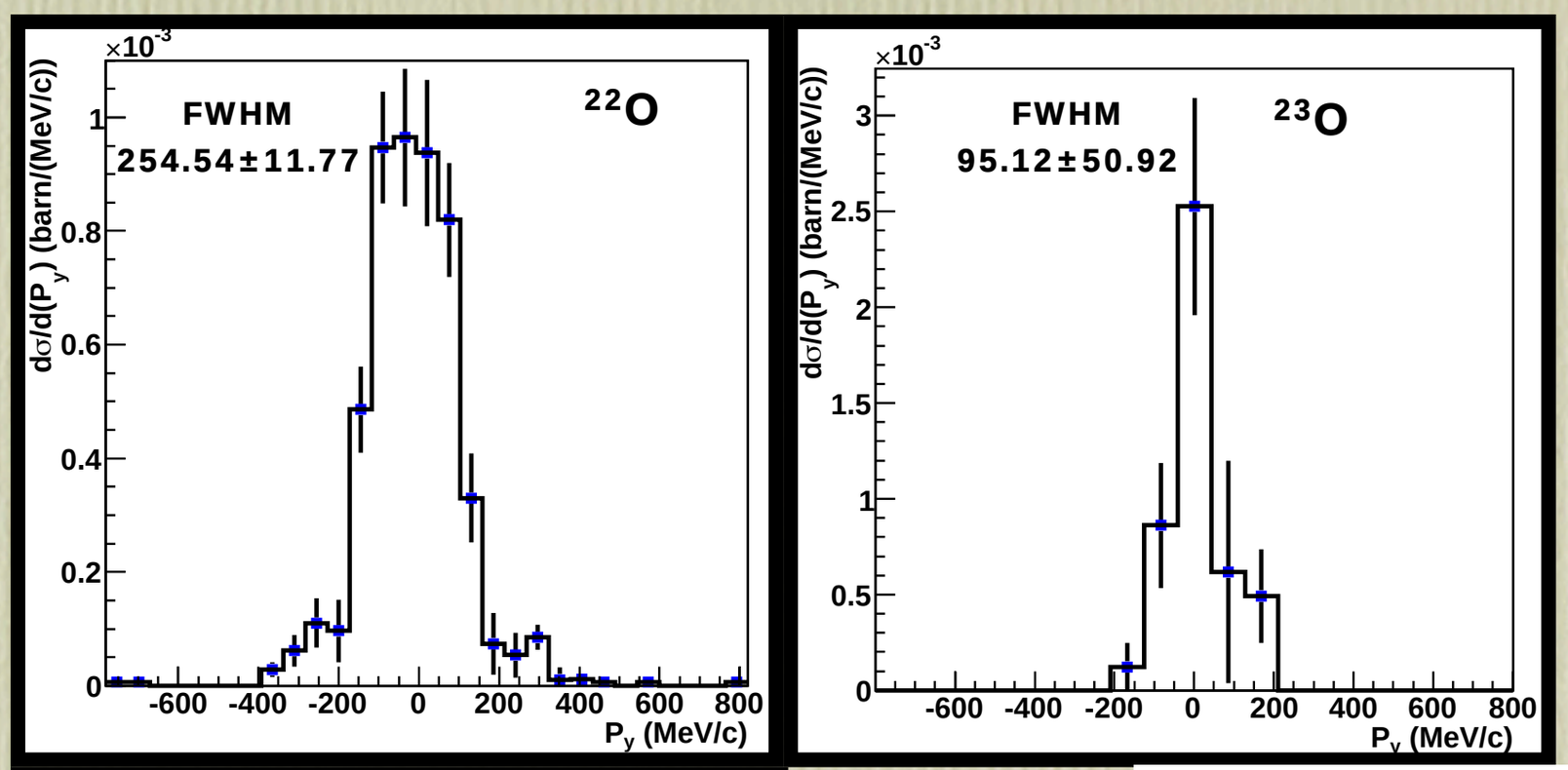


Inclusive transversal momentum

QFS one-proton knockout channels

Results for (p,2p)

Preliminary results!!



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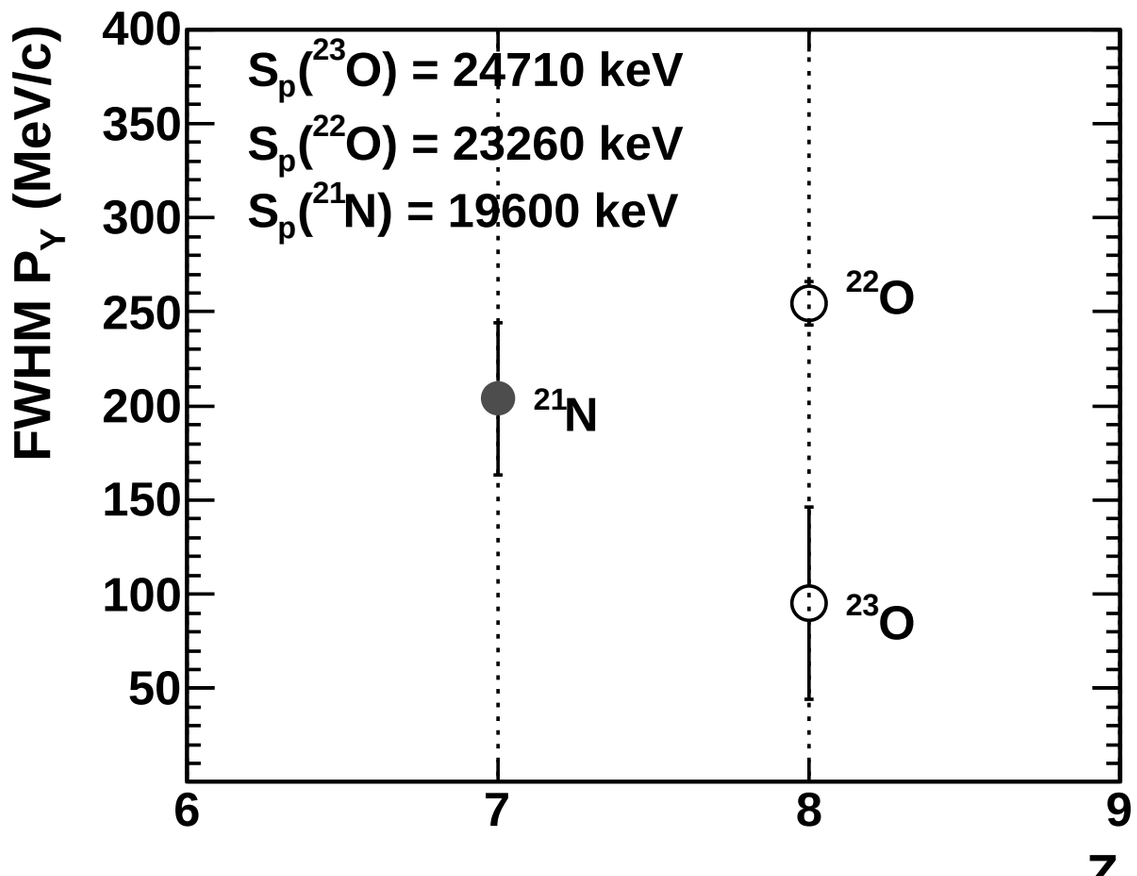
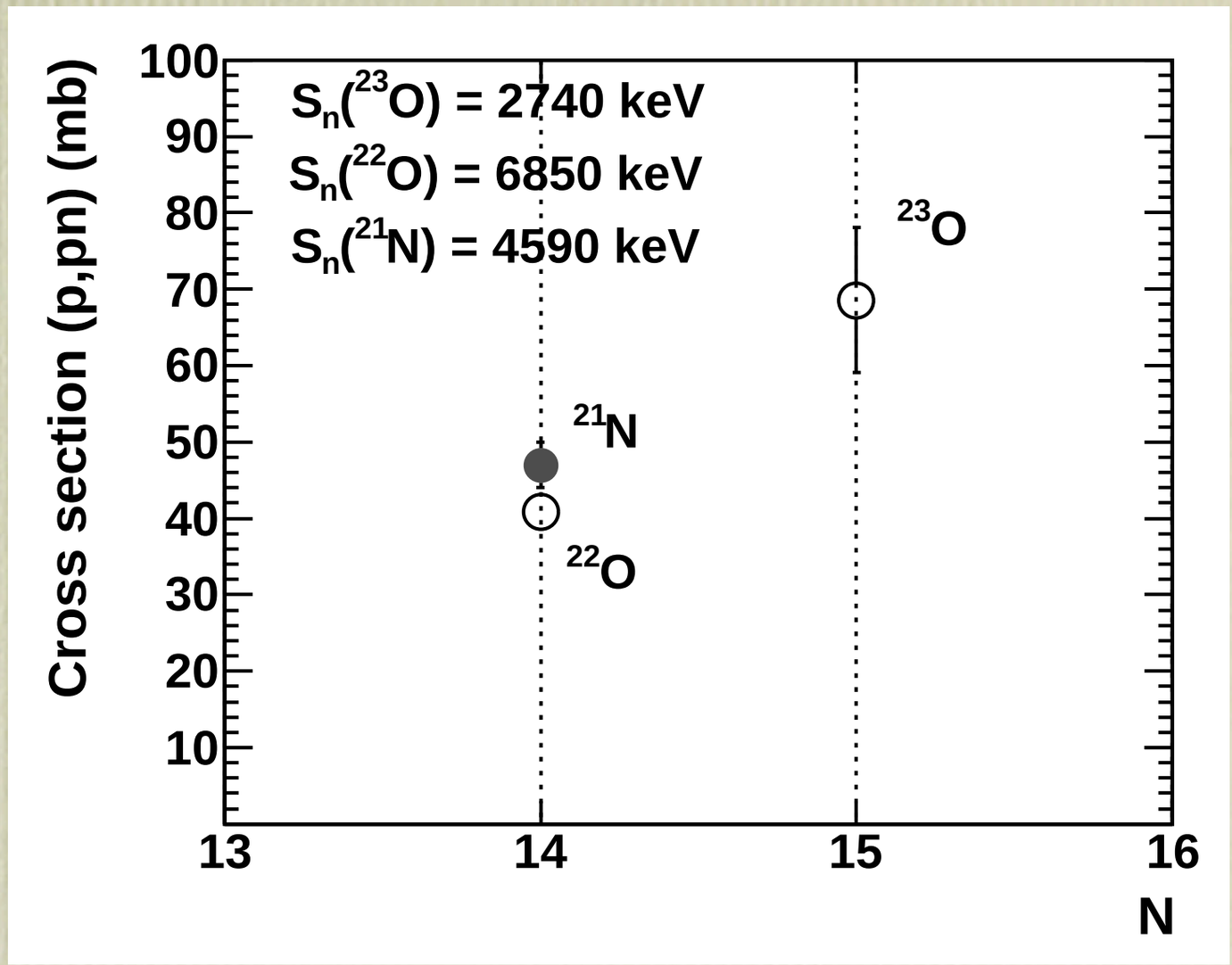


Results for (p,pn) (p,2p)

Preliminary results!!

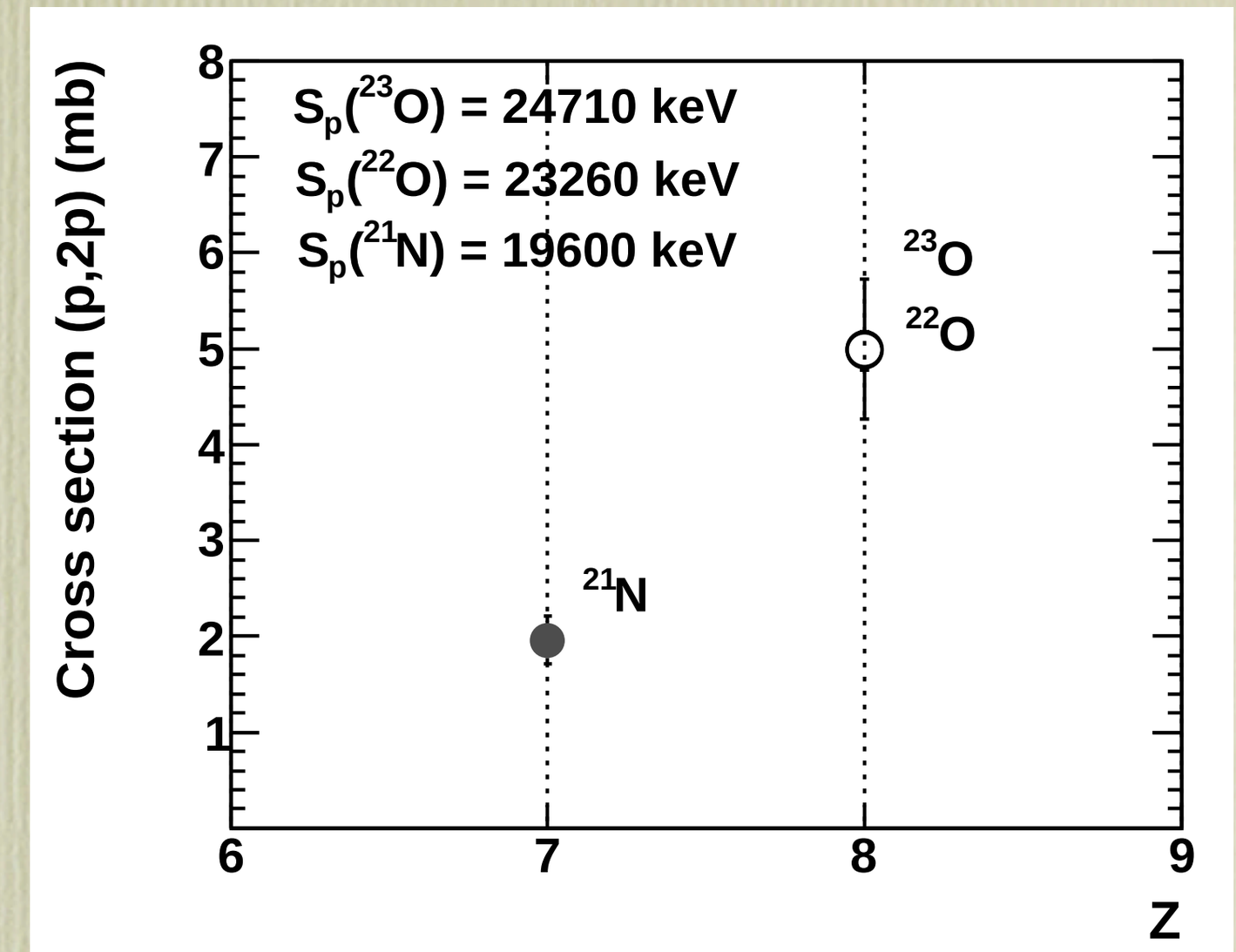
Reaction	σ(mb)
^{21}N(p,pn)^{20}N	46.8±3.4
^{23}O(p,pn)^{22}O	68.6±8.7
^{22}O(p,pn)^{21}O	40.8±1.8

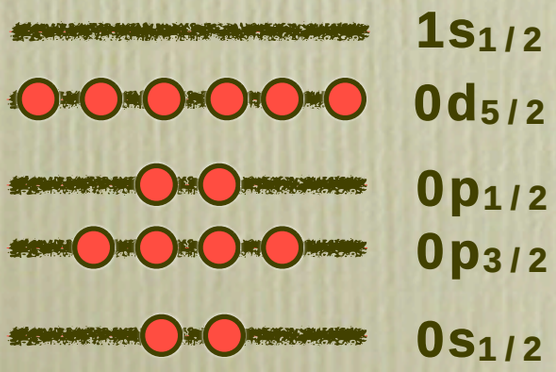


Results for (p,pn) (p,2p)

Preliminary results!!

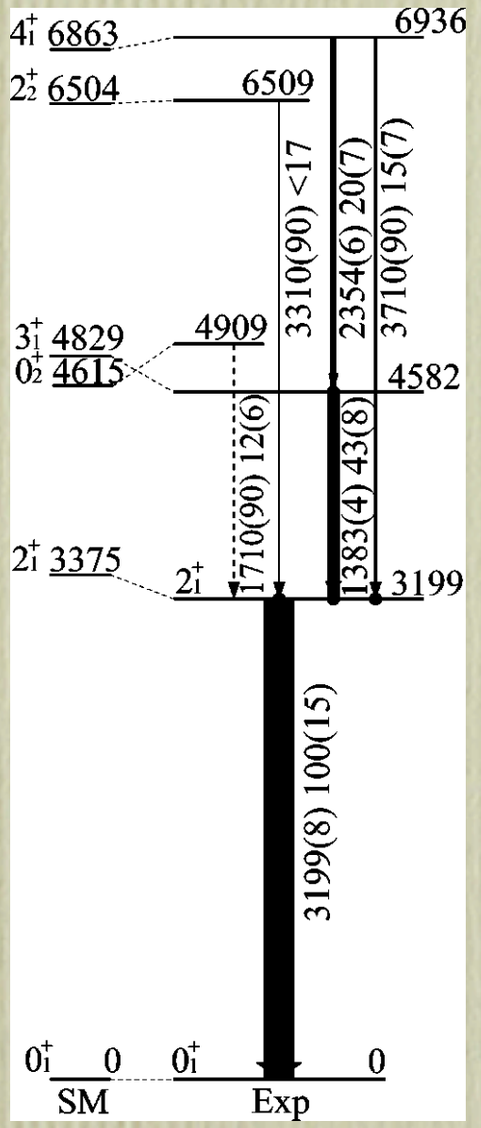
Reaction	σ(mb)
^{21}N(p,2p)^{20}C	1.96±0.24
^{23}O(p,2p)^{22}N	5.02±0.72
^{22}O(p,2p)^{21}N	4.98±0.20

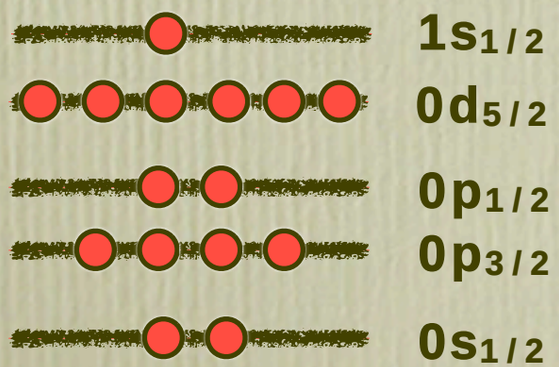




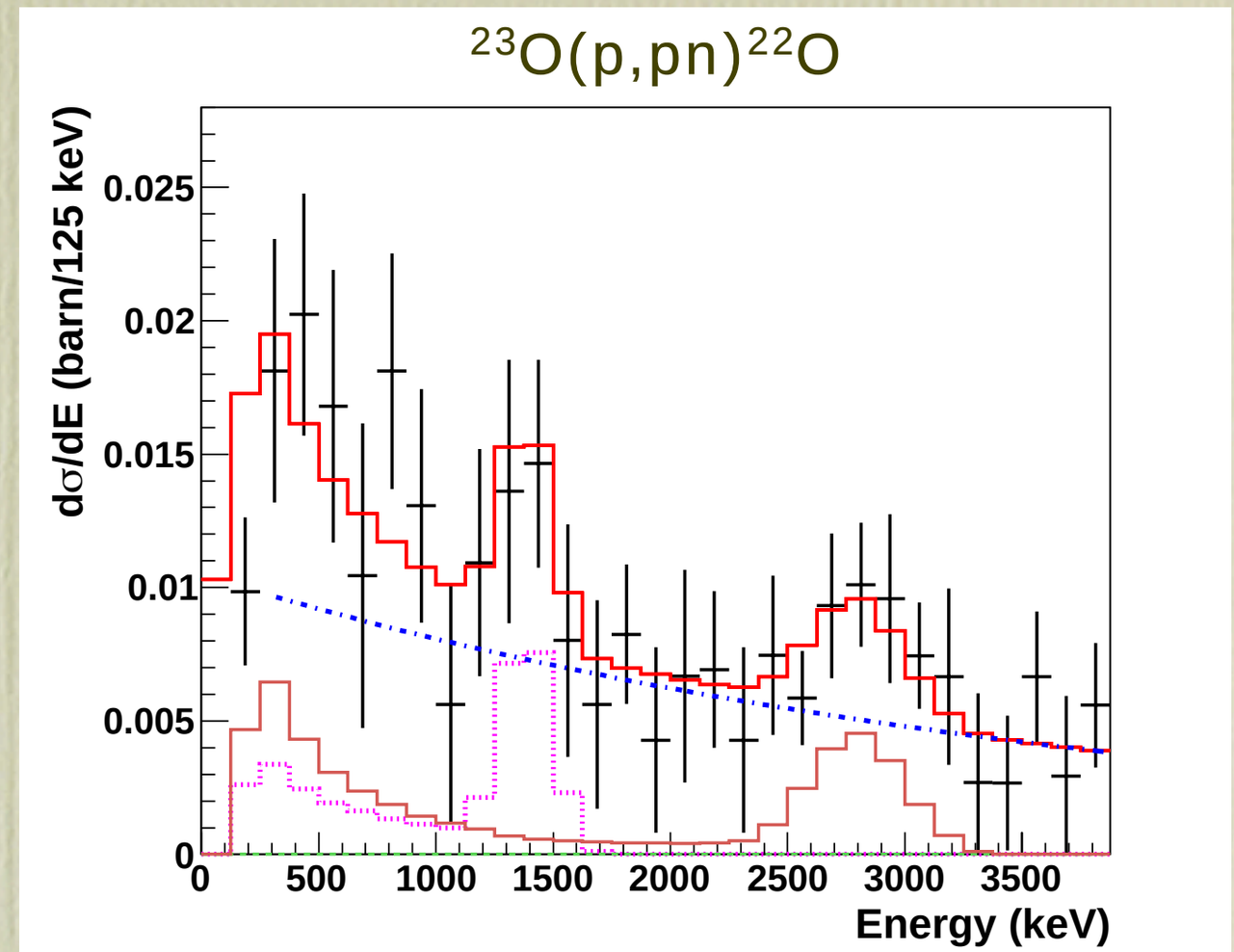
Exclusive measurements

M. Stanoiu et al.
Phys. Rev.C. 69, 034312 (2004)





Gamma rays

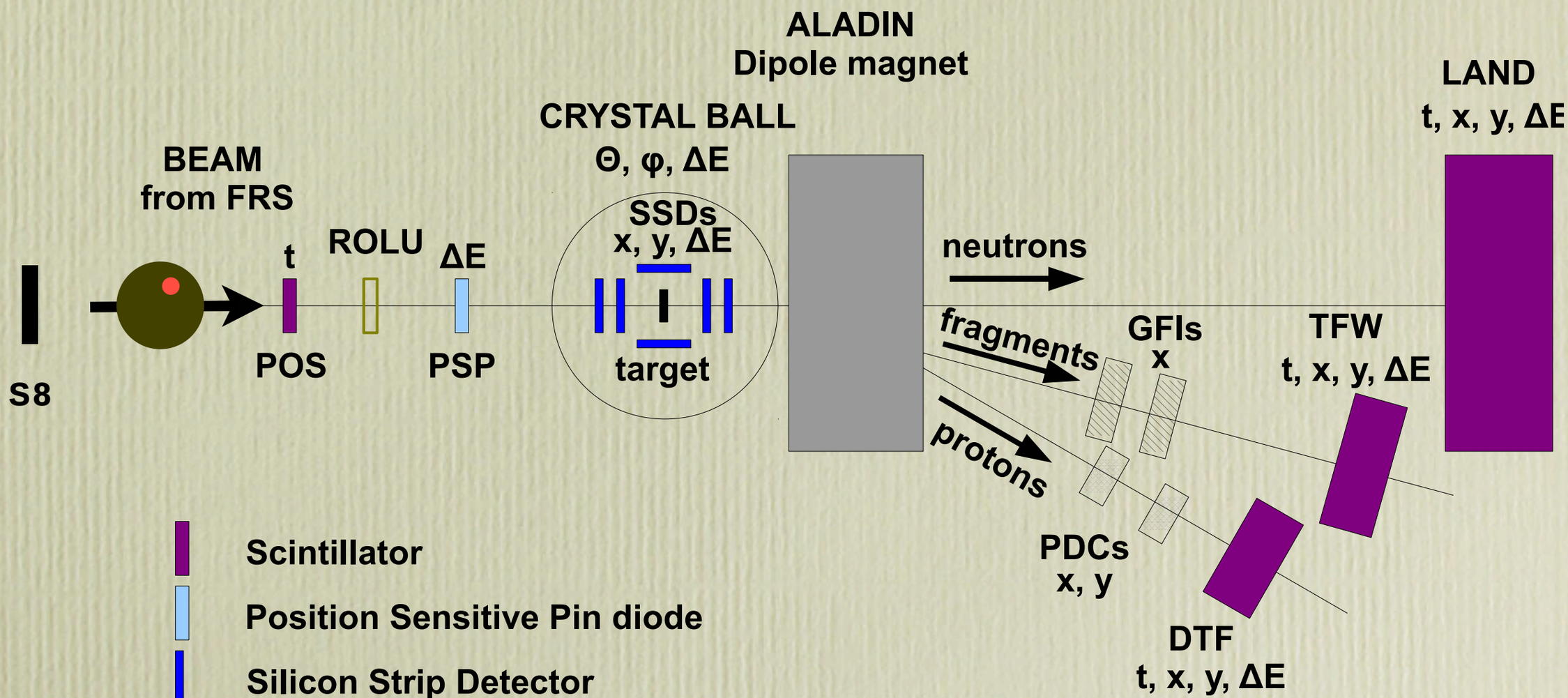


	Results from this work	Results from [18]
E_γ (keV)	I_γ (%) (2800)	I_γ (%)
1383	59 ±11	43 ±8
2800	100 ±16	100 ±15

One neutron evaporation channels

Invariant mass

$$E^* = \sqrt{\sum_i^N m_i^2 + \sum_{i \neq j}^N \gamma_i \gamma_j m_i m_j \left(1 - \beta_i \beta_j cos\theta_{ij}\right)} - M_o$$



$^{22}O(p,pn)^{21}O^* -> ^{20}O + n$

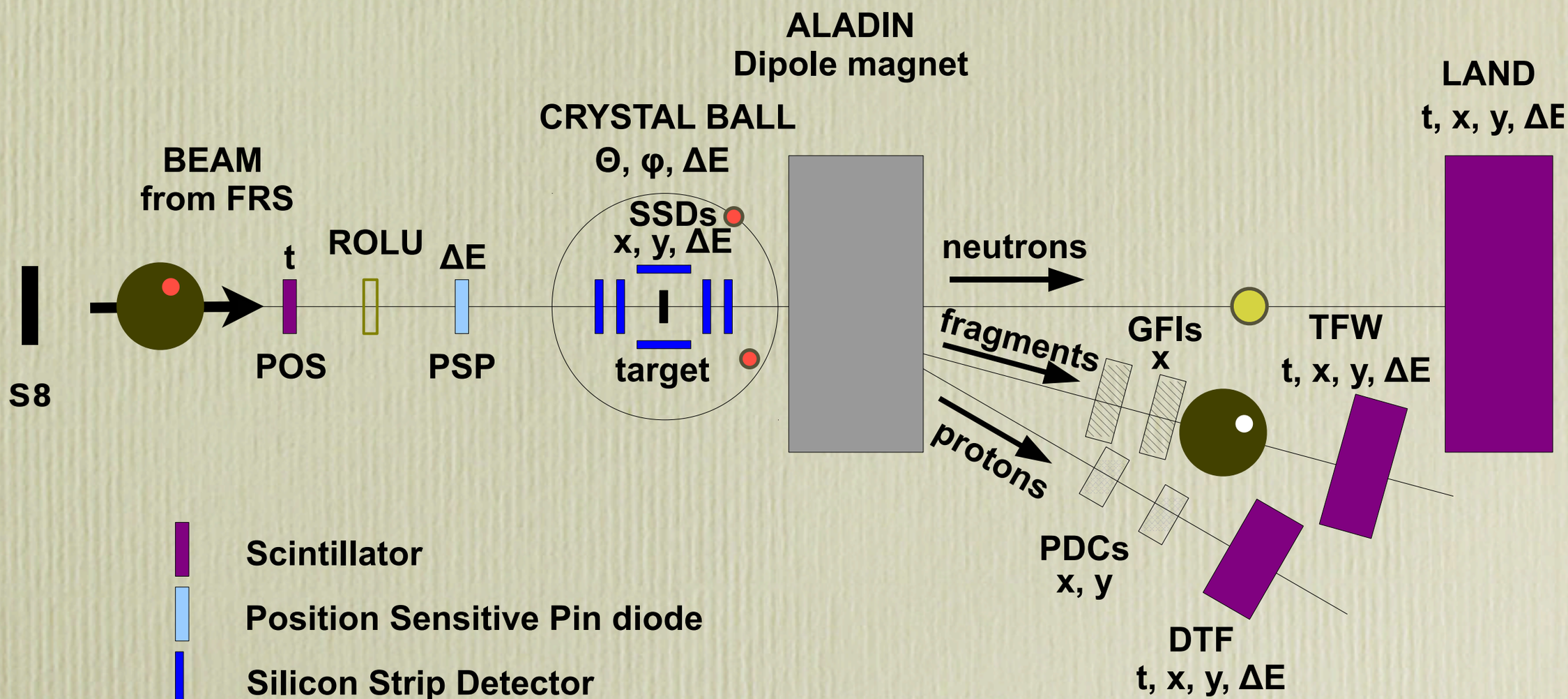
$^{23}O(p,pn)^{22}O^* -> ^{21}O + n$

$^{21}N(p,pn)^{20}N^* -> ^{19}N + n$

One neutron evaporation channels

Invariant mass

$$E^* = \sqrt{\sum_{i}^{N} m_i^2 + \sum_{i \neq j}^{N} \gamma_i \gamma_j m_i m_j \left(1 - \beta_i \beta_j cos\theta_{ij}\right)} - M_o$$



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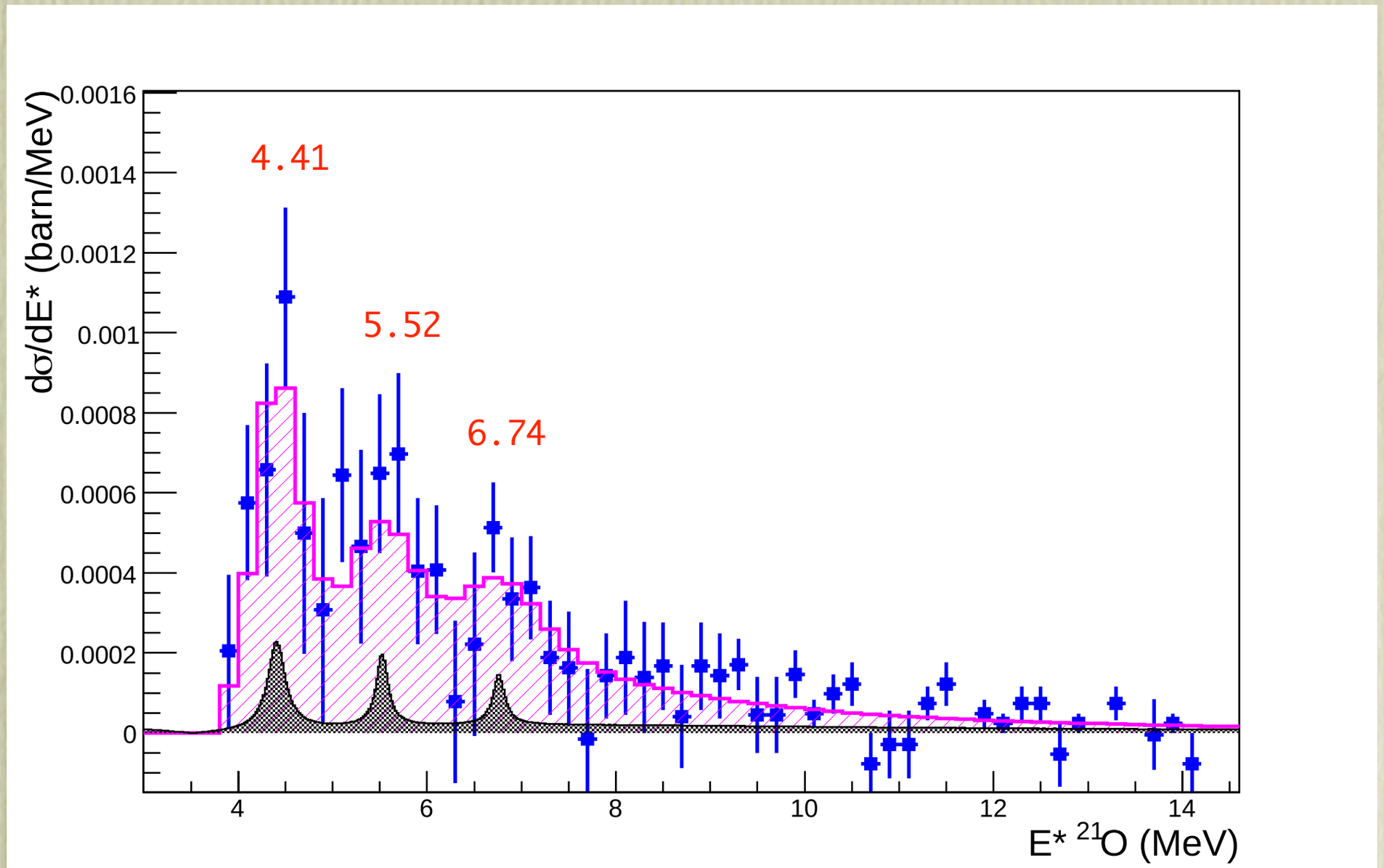
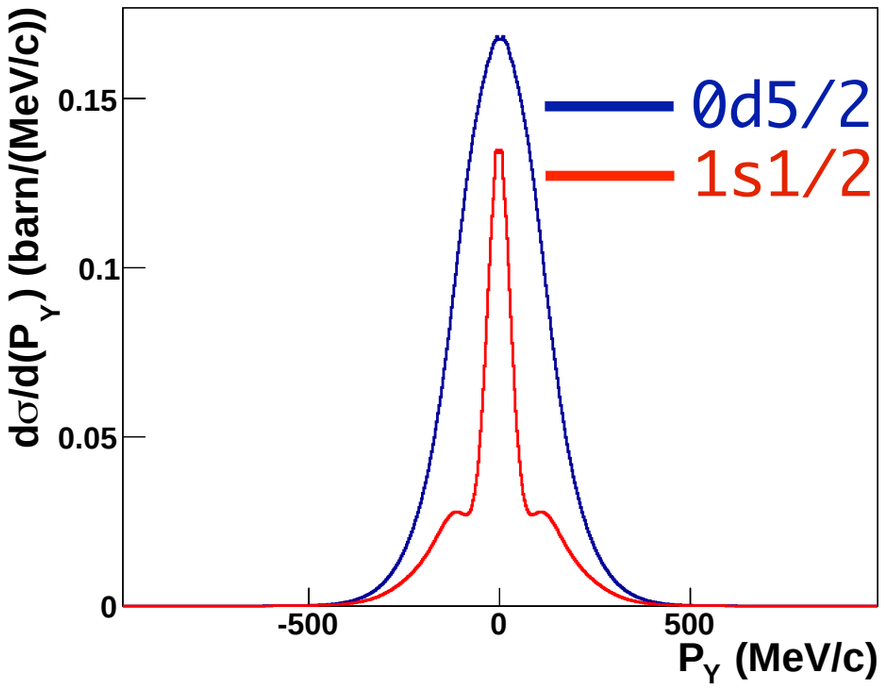
One neutron evaporation channels

$^{22}O(p,pn)^{21}O^{*}->^{20}O+n$



Theoretical calculations

Preliminary results!!

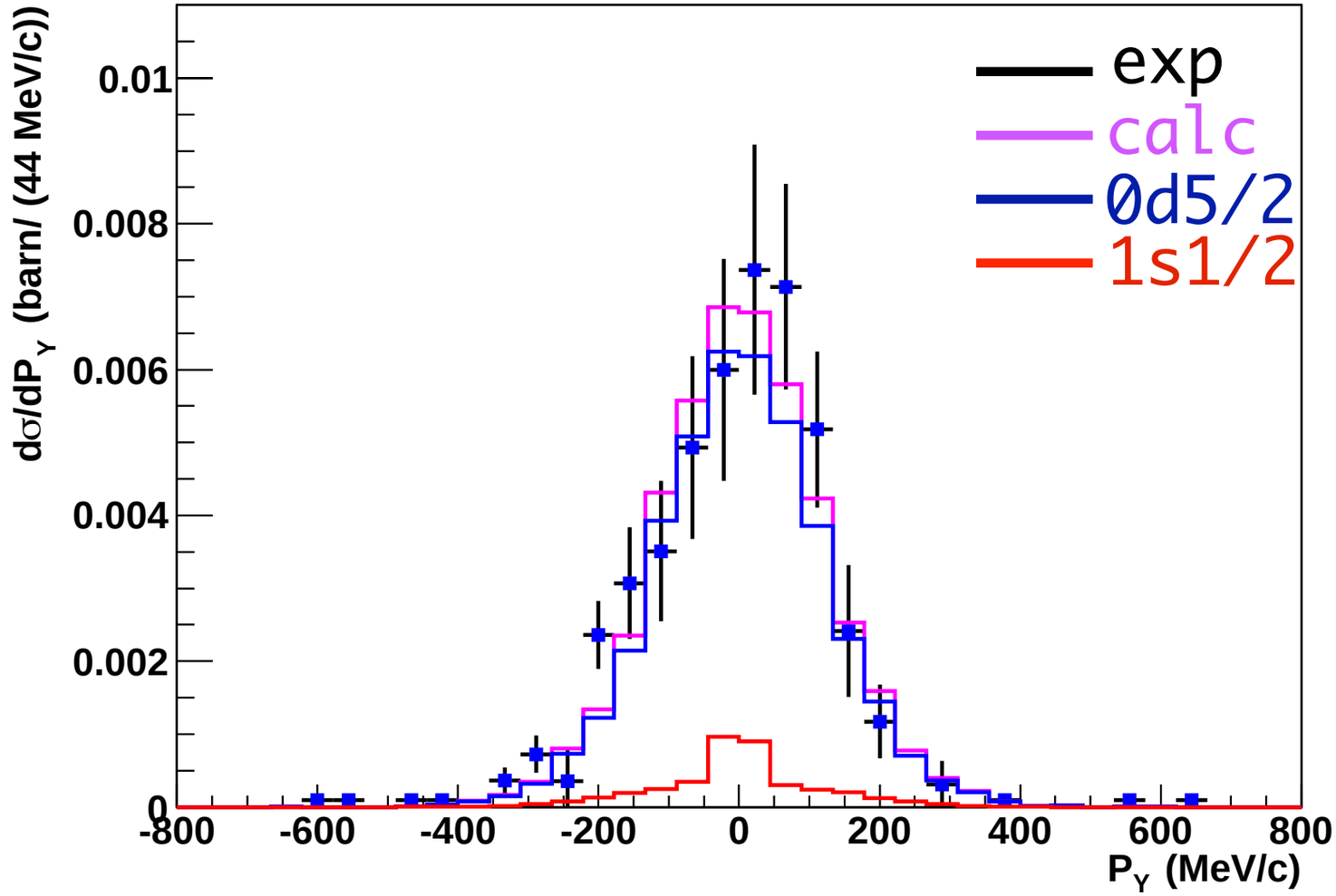


Transversal momentum calculated by Carlos Bertulani

T. Aumann, C. A. Bertulani, J. Ryckebusch *Quasi-free (p,2p) and (p,pn) reactions with unstable nuclei.* Submitted to Phys. Rev. C (2013)

weight d-wave: 0.91±0.18
weight s-wave: 0.09±0.18

$^{21}N(p,pn)^{20}N$

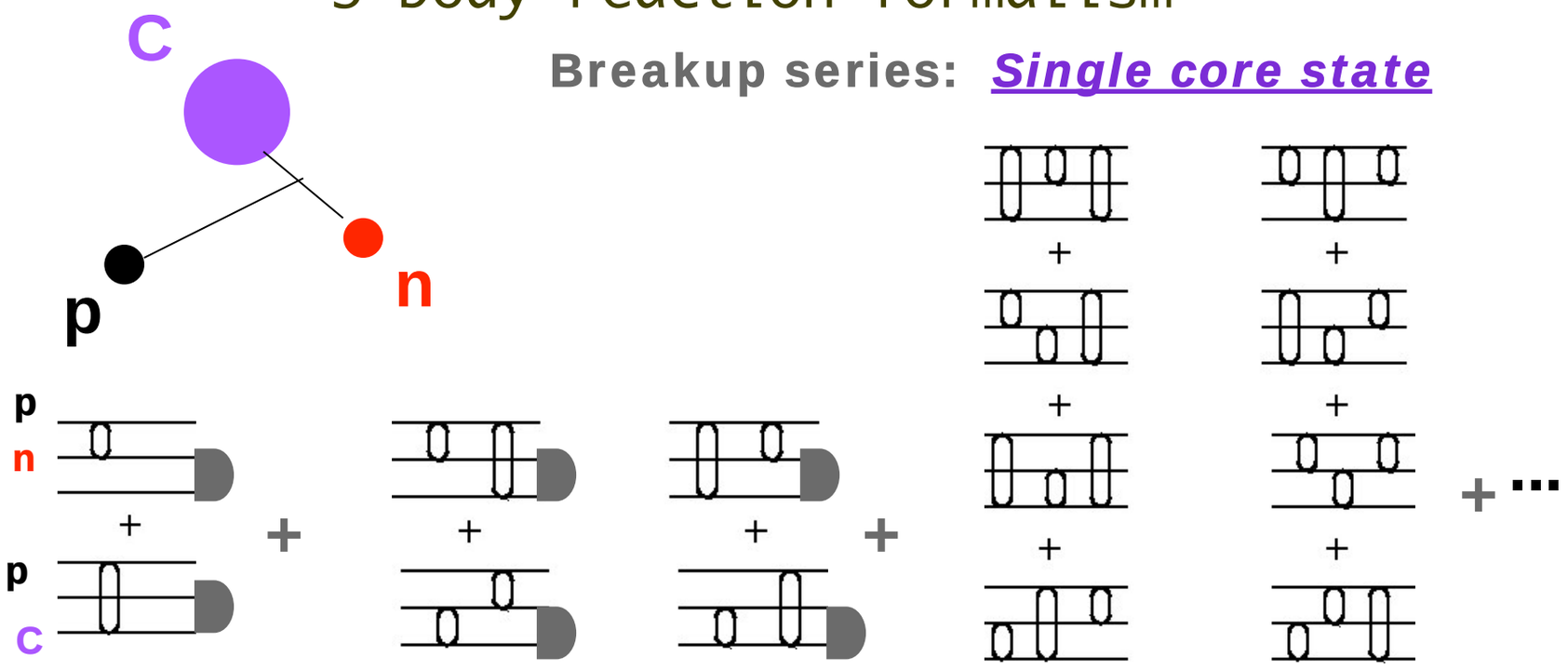


Theoretical calculations

Preliminary results!!

3-body reaction formalism

Breakup series: ***Single core state***



Single Scattering

SST

Double Scattering

Raquel Crespo

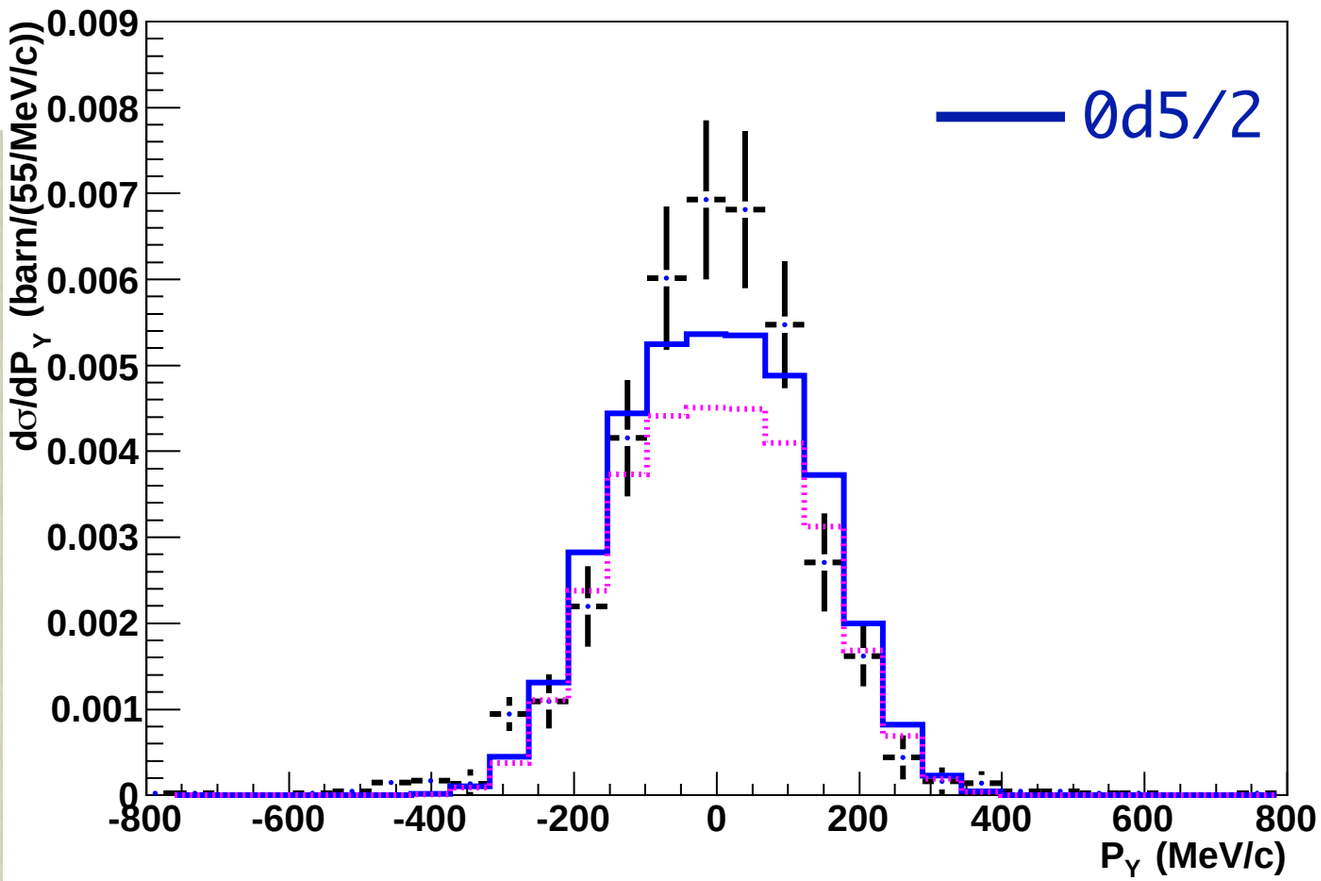
$^{22}O(p,pn)^{21}O$

^{22}O -> ^{21}O

inert core + valence neutron

few-body Faddeev

Calculations made by R. Crespo, E. Calvo, A. Deltuva



Conclusions

- Inclusive cross sections and momentum distributions have been measured via (p,pn) and (p,2p) QFS reactions for the projectiles ^{21}N, ^{23}O and ^{22}O

- The analysis of the same projectile via proton and neutron removal in QFS conditions, allowed to study the proton and neutron shell at the same time

- The comparison of inclusive momentum distribution and cross section with theoretical calculations would provide information to understand the shell gaps evolution and to disentangle between different configurations

- For ^{23}O(p,pn)^{22}O, ^{22}O(p,2p)^{21}N and ^{22}O(p,2p)^{21}O, the coincident measurement of the gamma fragment would allow to determine different contributions in the original projectile wave function that involved low-lying excited states in the fragment

- For some cases, the excitation energy after one nucleon removal was enough to populate unbound states in the fragment. These results would provide information on the inner region of the exotic projectiles