STUDY OF THE TENSOR FORCE CONTRIBUTION IN THE OXYGEN ISOTOPES USING QFS REACTIONS

Barrière Antoine, Mozumdar Nikhil, Sorlin Olivier
and the R3B Collaboration

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laboratoire commun CEA/DRF CNRS/IN2P3

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R3B

Study of the evolution of proton $p_{3/2}$ - $p_{1/2}$ SO splitting between ^{16}O and ^{22}O

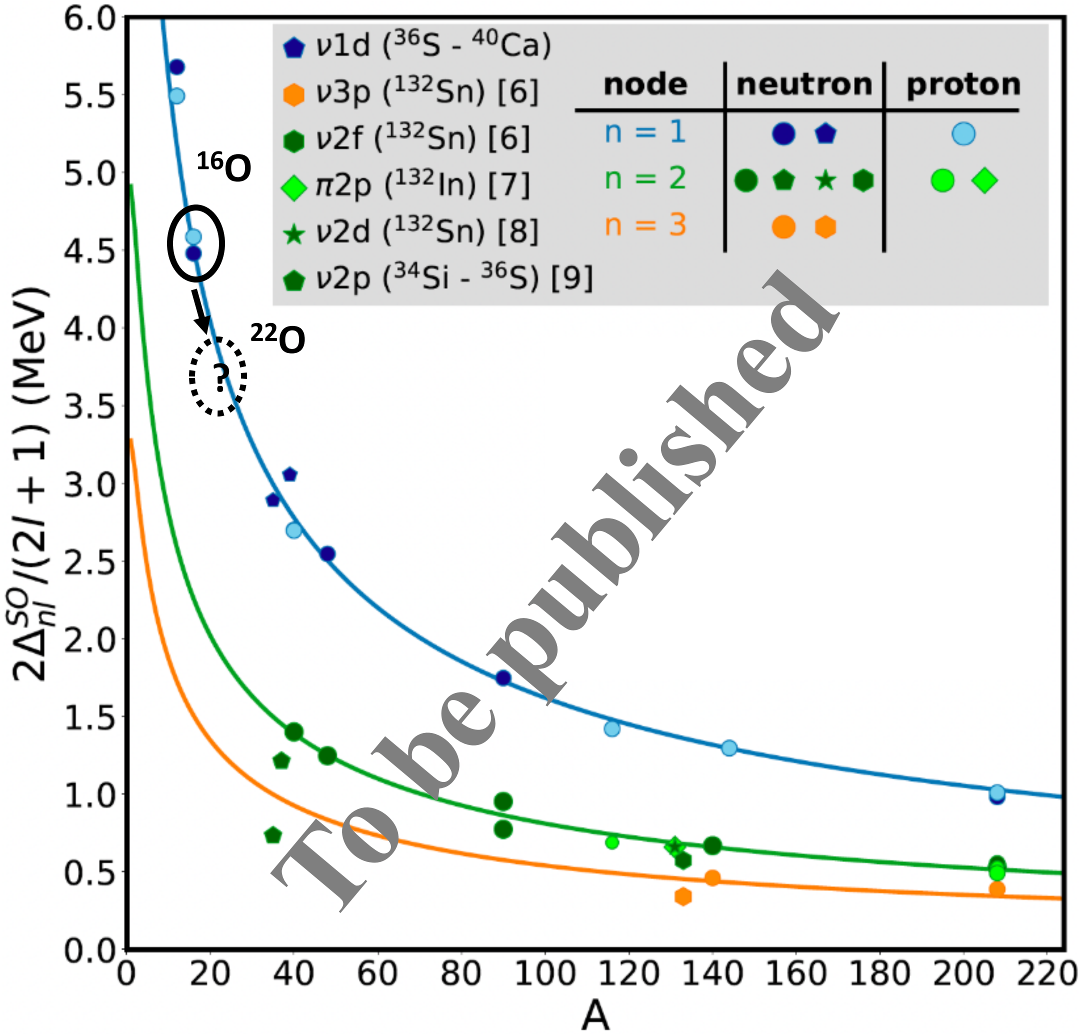
In the shell model framework, the nuclear interaction can be divided in several parts:

- Central
- Spin-orbit
- Tensor

A review[1] and global fit based mostly on stable nuclei data reproduces the SO splitting with the following function :

$$\Delta_{SO} = \frac{24.5}{n}(l+1/2)A^{-0.597}$$

The factor ~ $A^{-2/3}$ is the fingerprint of the role of the SO interaction in this trend (surface term).



Trend of Mairle[1] and review of new physics cases

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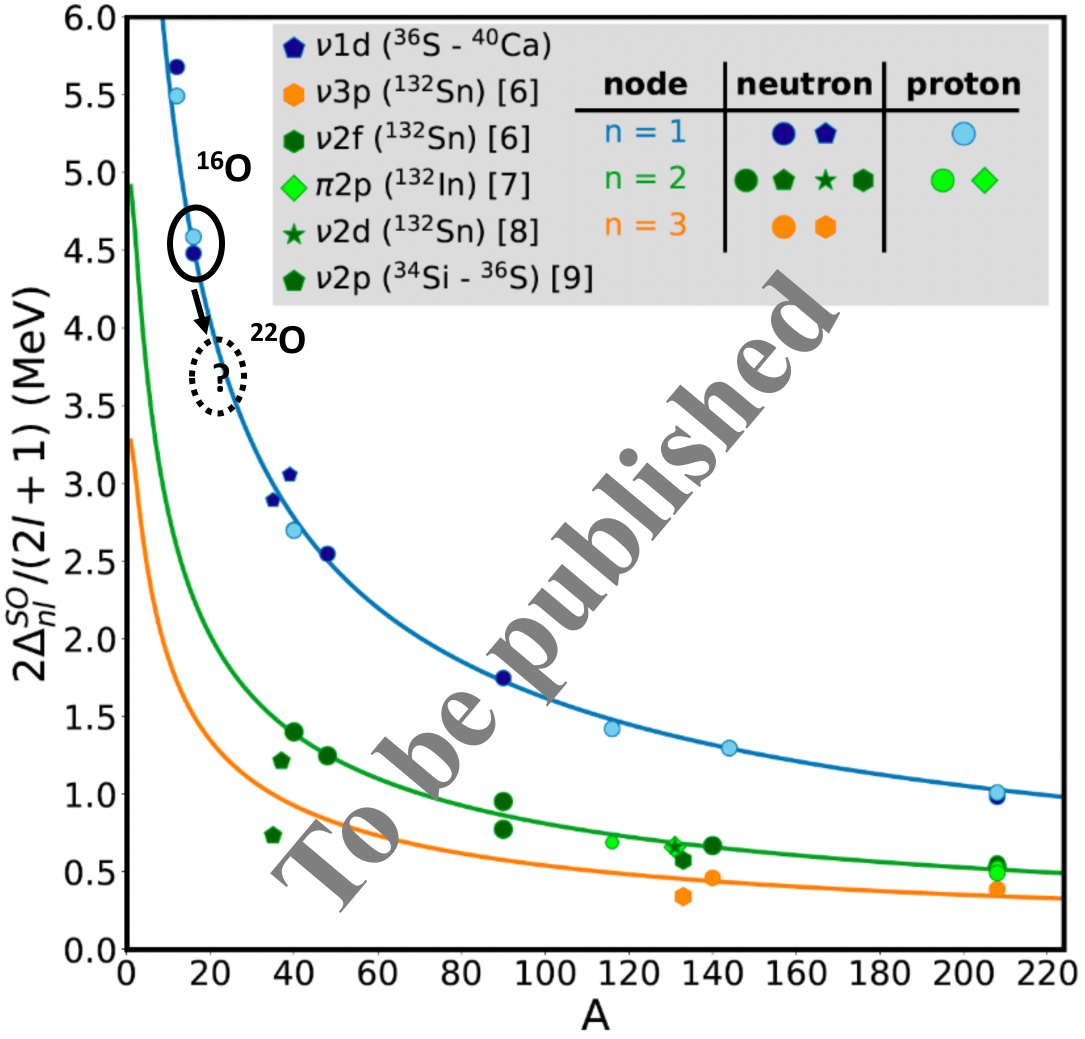
Estimation of the proton gap $0p_{1/2}$ - $0p_{3/2}$:
in ^{16}O --> 7.02 MeV
in ^{22}O --> 5.81 MeV

Deviations from this trend may be due to the tensor force contribution



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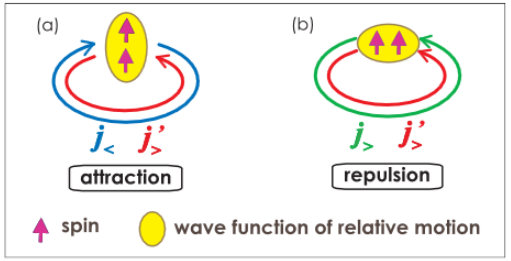
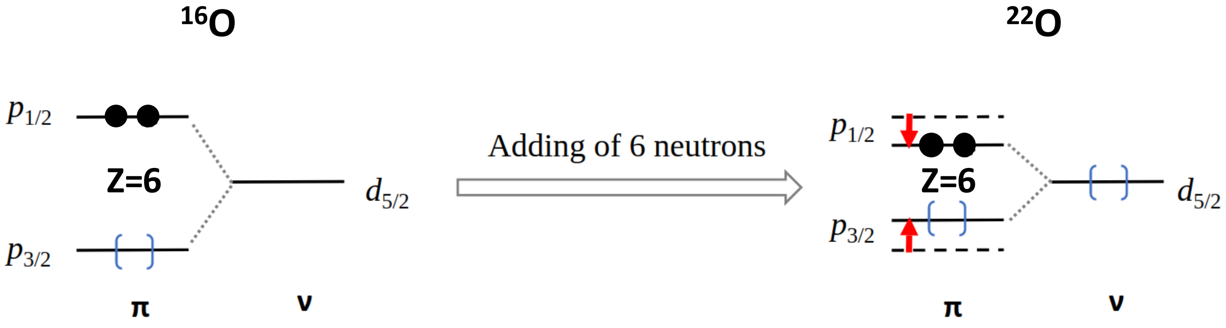
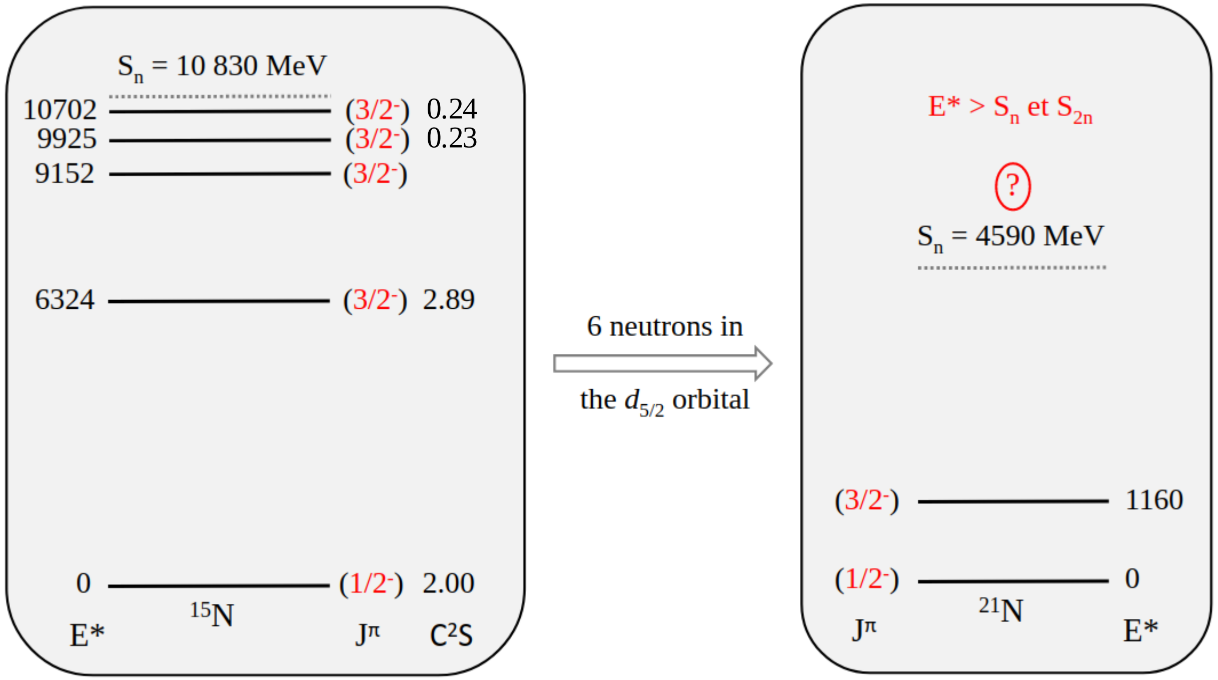
Role of tensor force in the O isotopic chain

Tensor interaction [3]:



The tensor force should then reduce the spin-orbit splitting $0p_{1/2}$ - $0p_{3/2}$ (proton) in the O isotopic chain, when the $0d_{5/2}$ (neutron) is filled.





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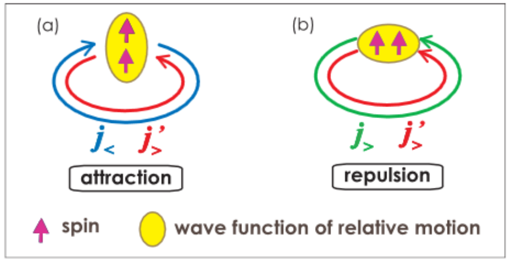

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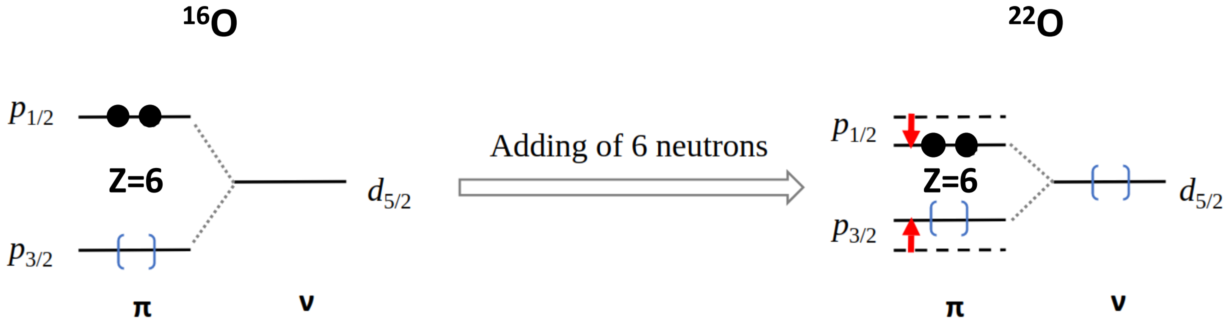

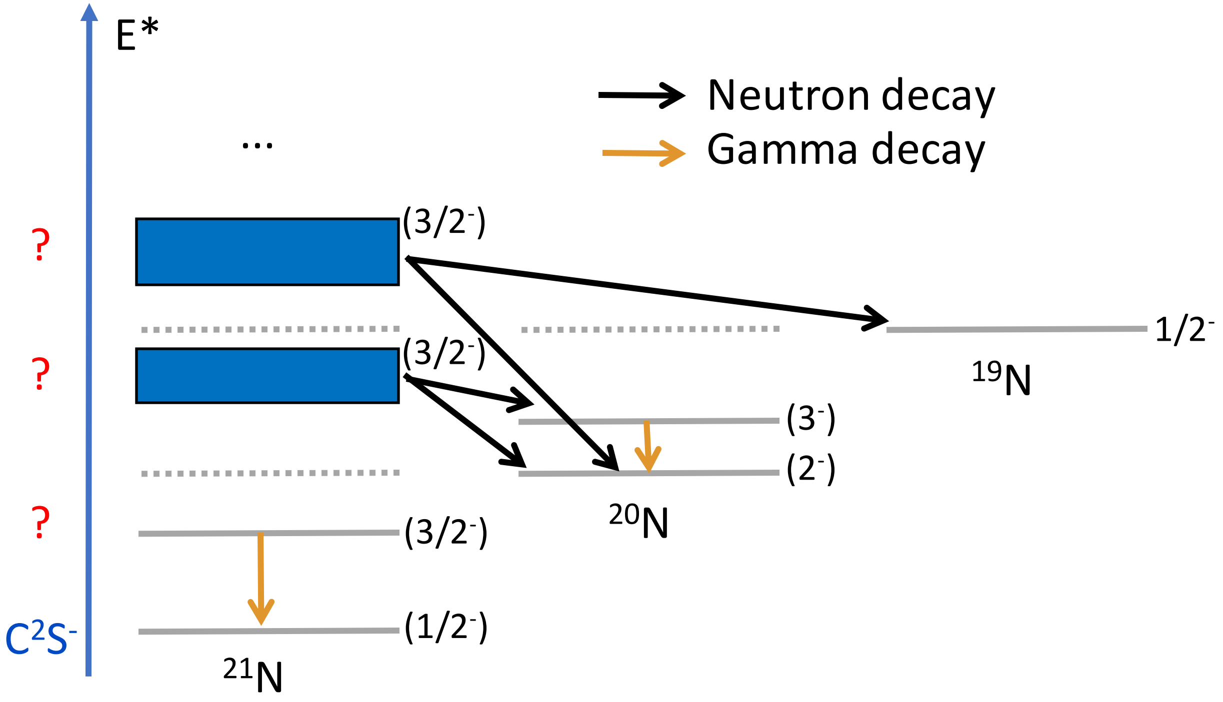

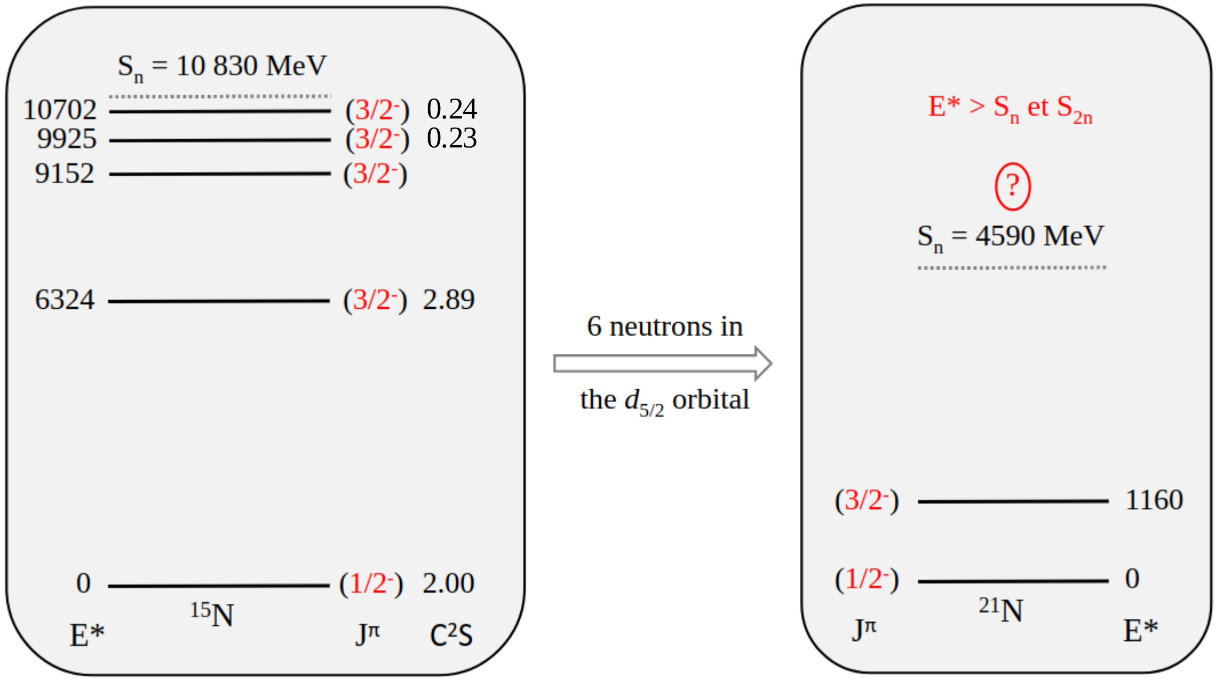

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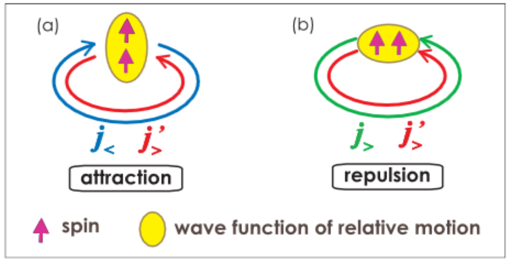

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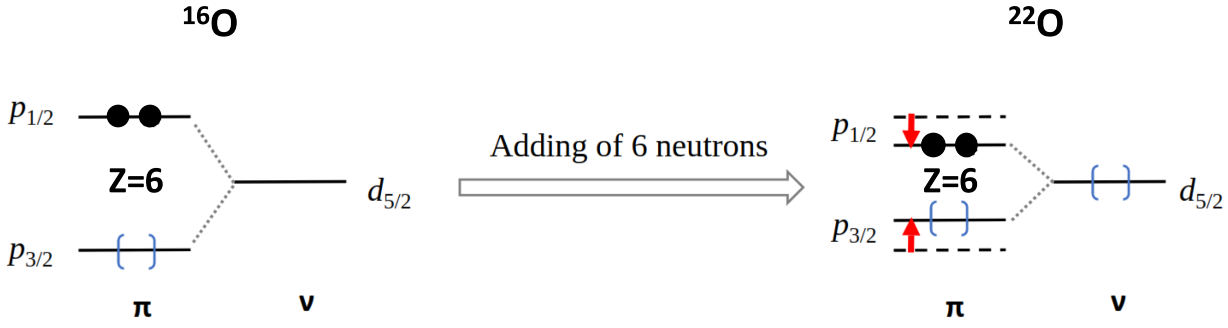

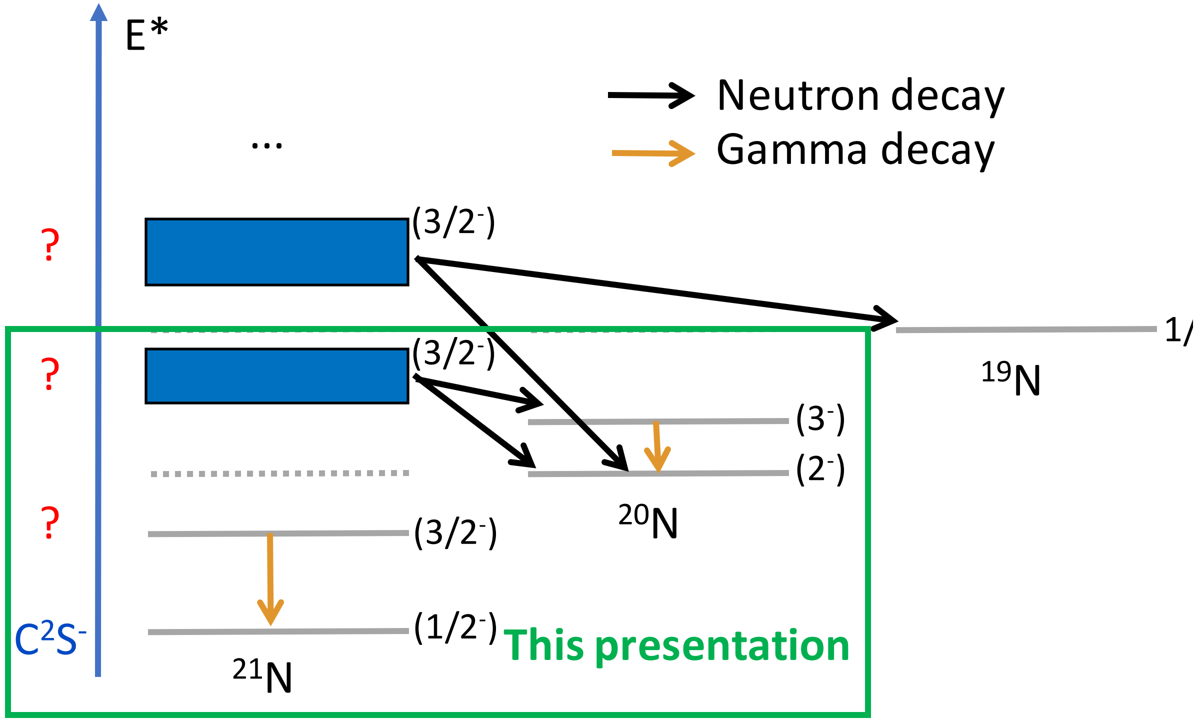

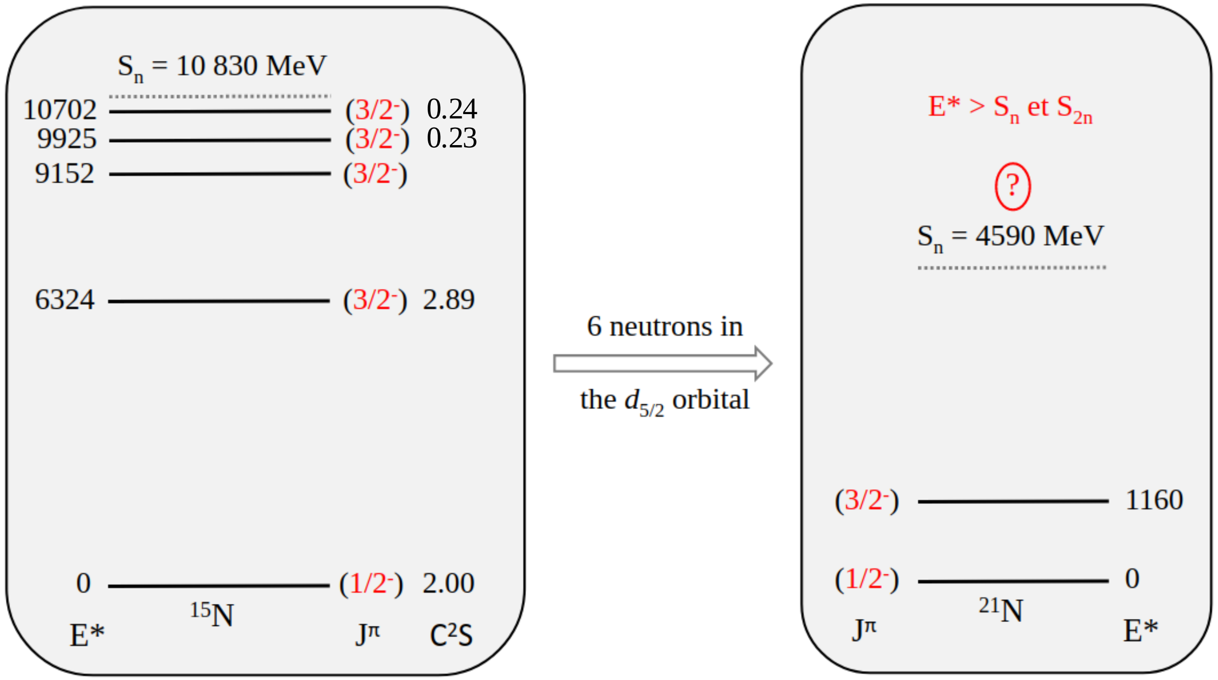

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Experimental setup

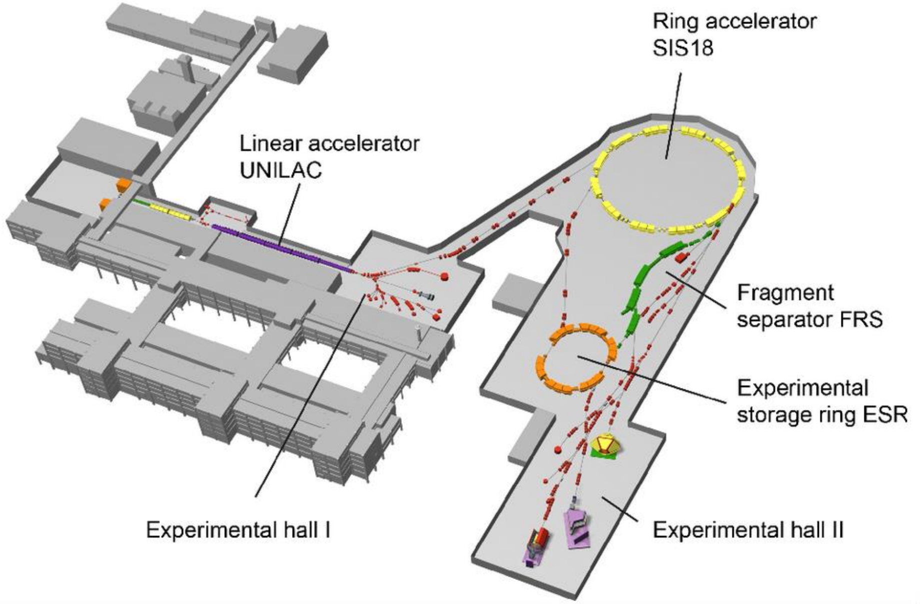
R^{3}B setup at GSI

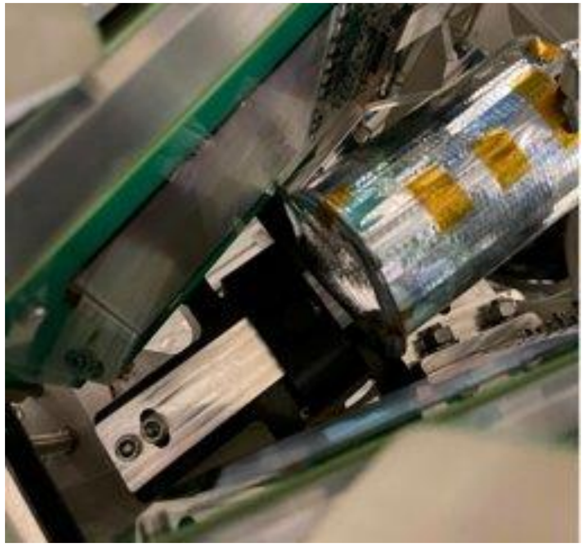
Cocktail beam from FRS (2 beam settings)

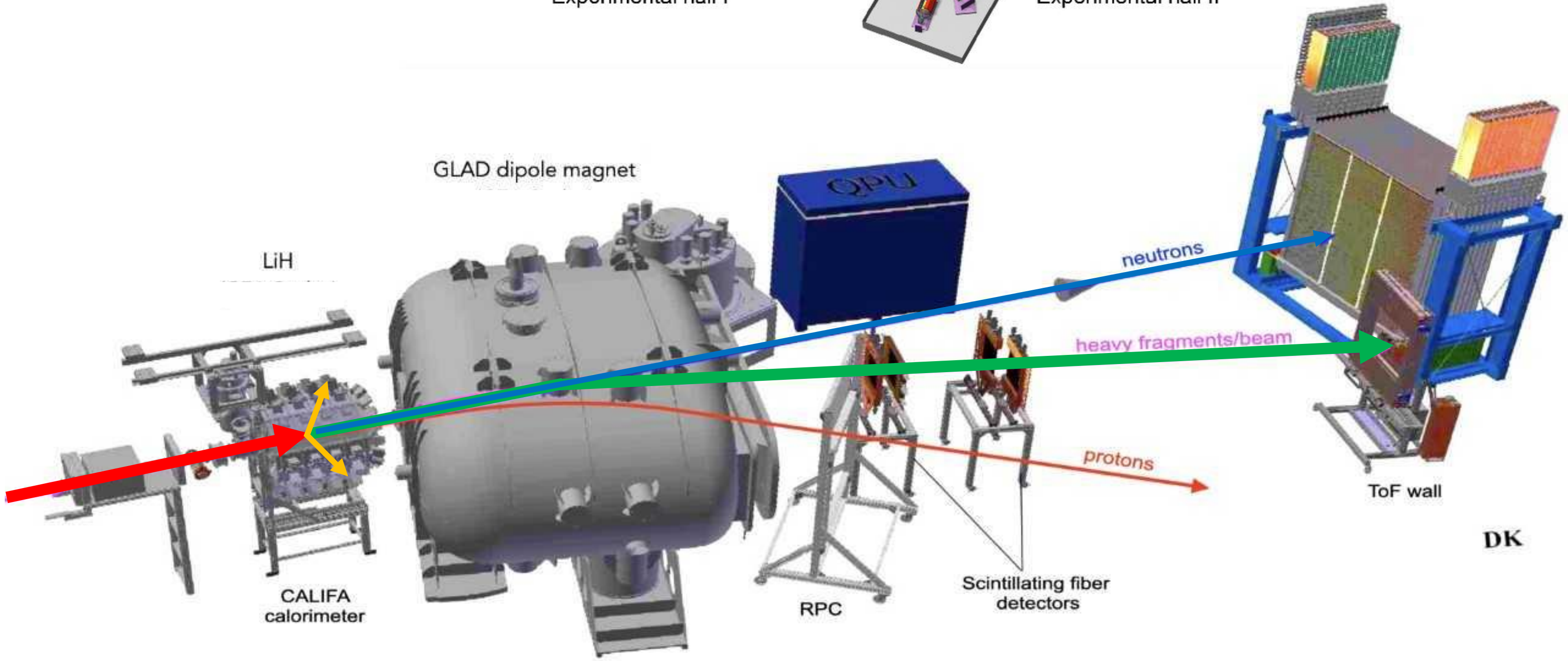
Beam energy: ~550MeV/A

QFS reaction e.g. (*p,pn*) and (*p,2p*) in LiH

Complete measurement in inverse kinematics:







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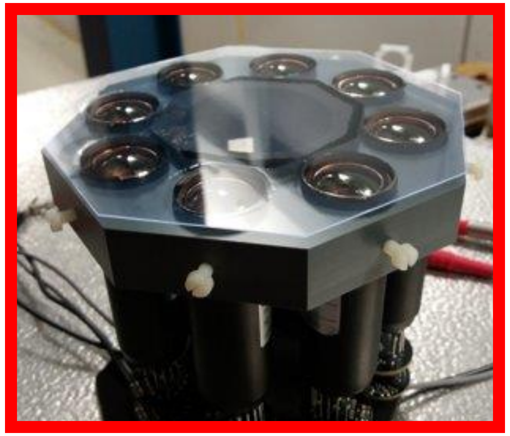
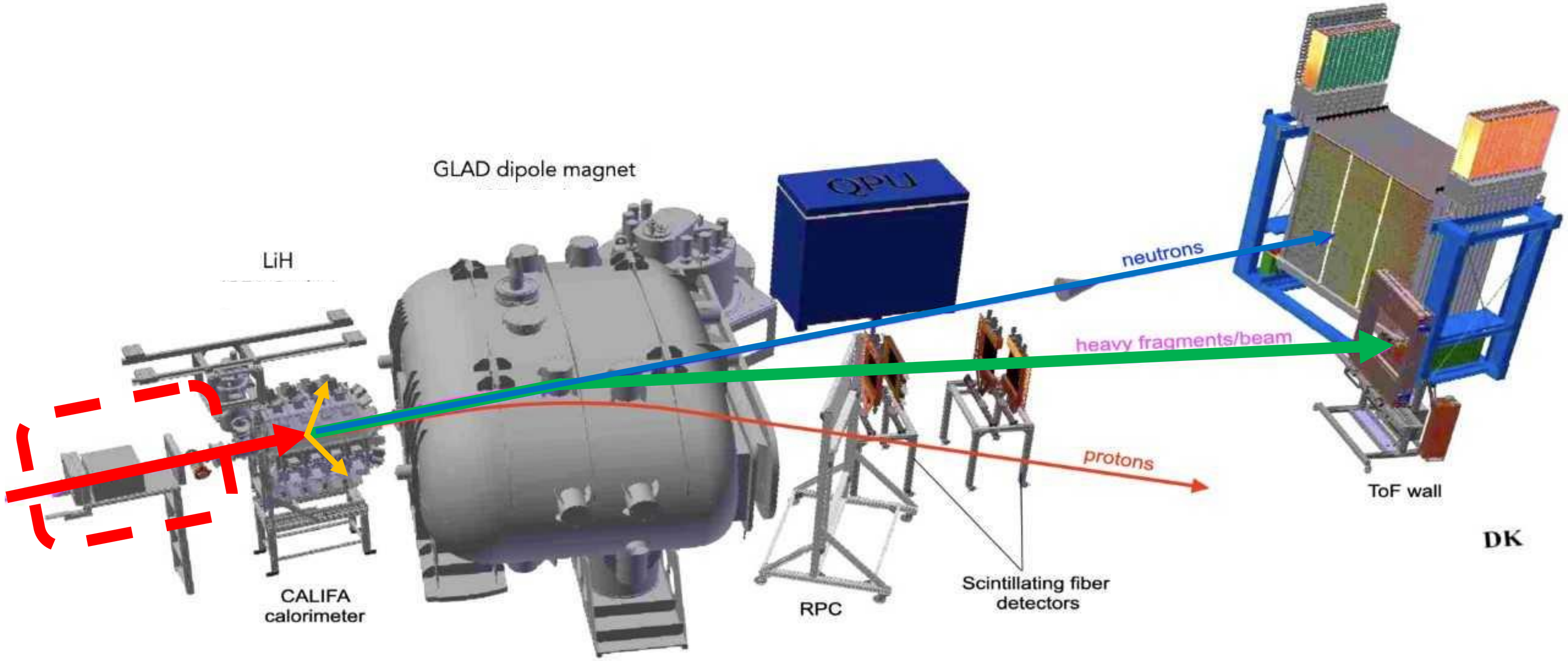


LOS (t)

MusLi (ΔE) + MWPC (x,y)



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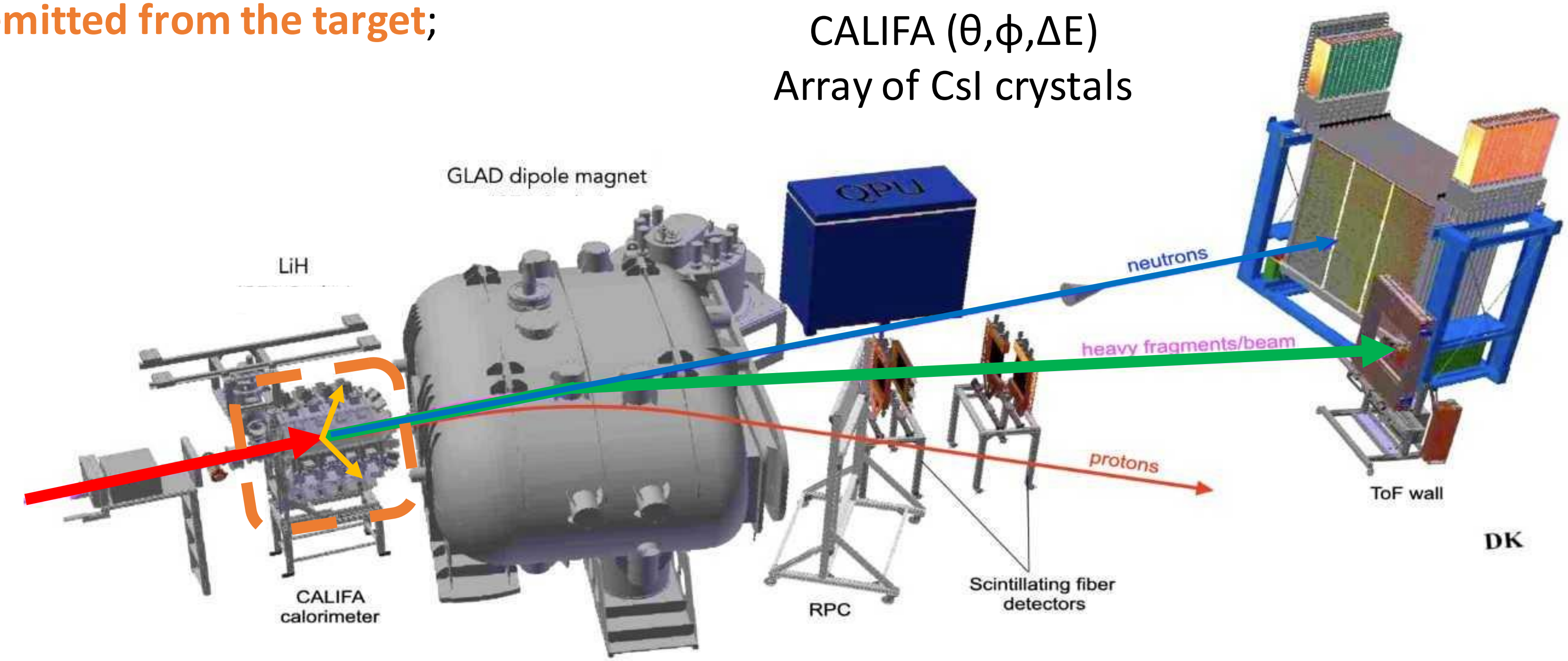
Complete measurement in inverse kinematics:
- **Incoming nucleus**;
- **Light particles and gammas emitted from the target**;

CALIFA (θ,ϕ,ΔE)
Array of CsI crystals



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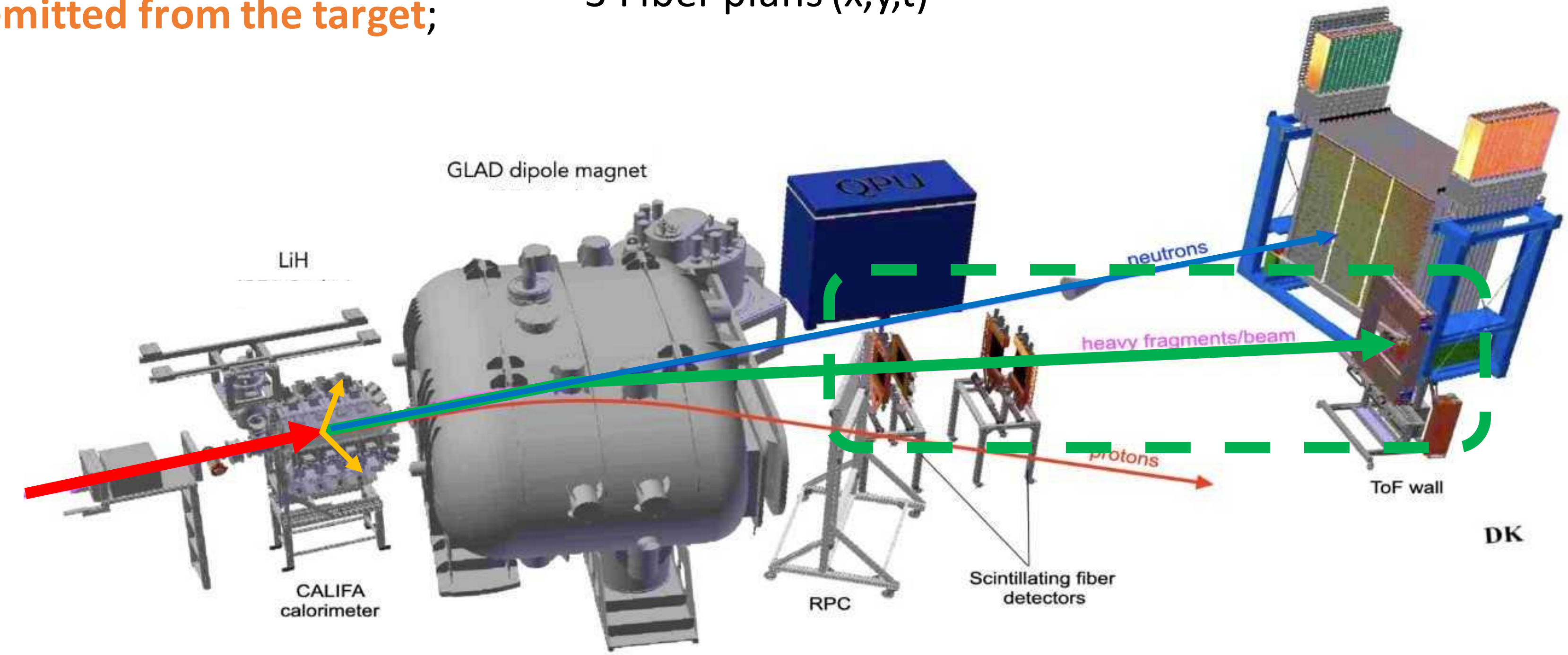
Complete measurement in inverse kinematics:
- **Incoming nucleus**;
- **Light particles and gammas emitted from the target**;
- **Outgoing fragment**;


3 Fiber plans (x,y,t)


ToFD (x,y,t,ΔE)



Experimental setup

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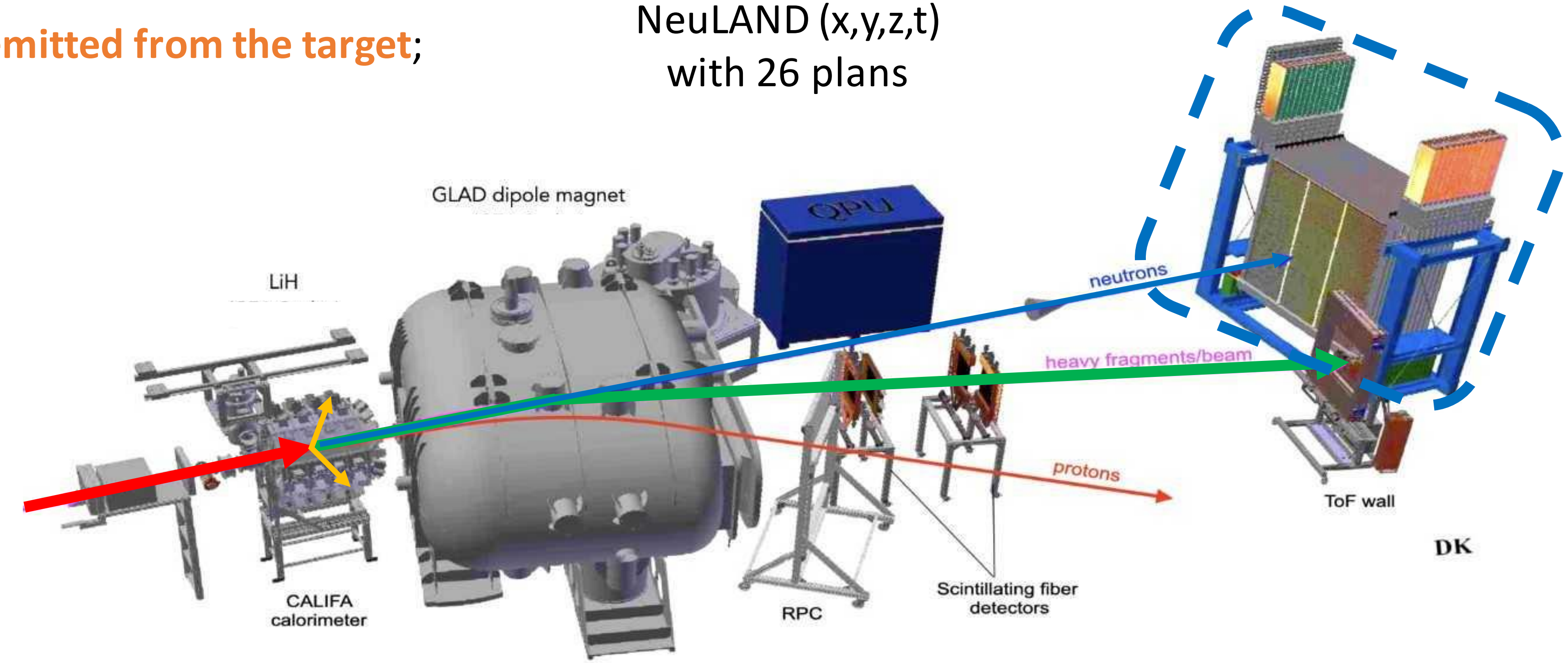
Cocktail beam from FRS (2 beam settings)

Beam energy: ~550MeV/A

QFS reaction e.g. (*p,pn*) and (*p,2p*) in LiH

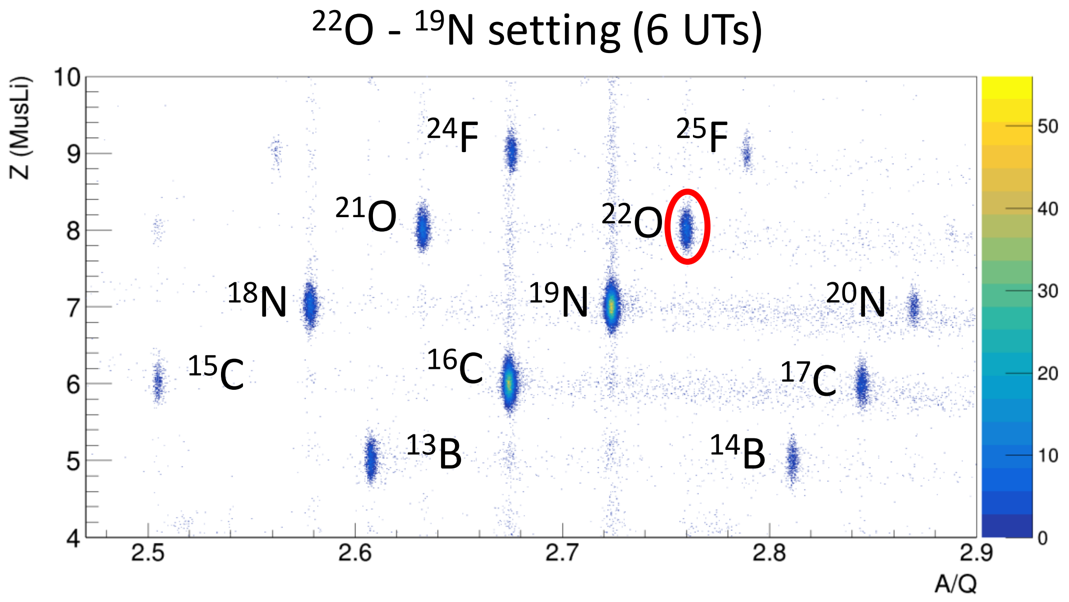
Complete measurement in inverse kinematics:
- **Incoming nucleus**;
- **Light particles and gammas emitted from the target**;
- **Outgoing fragment**;
- **Neutrons**.

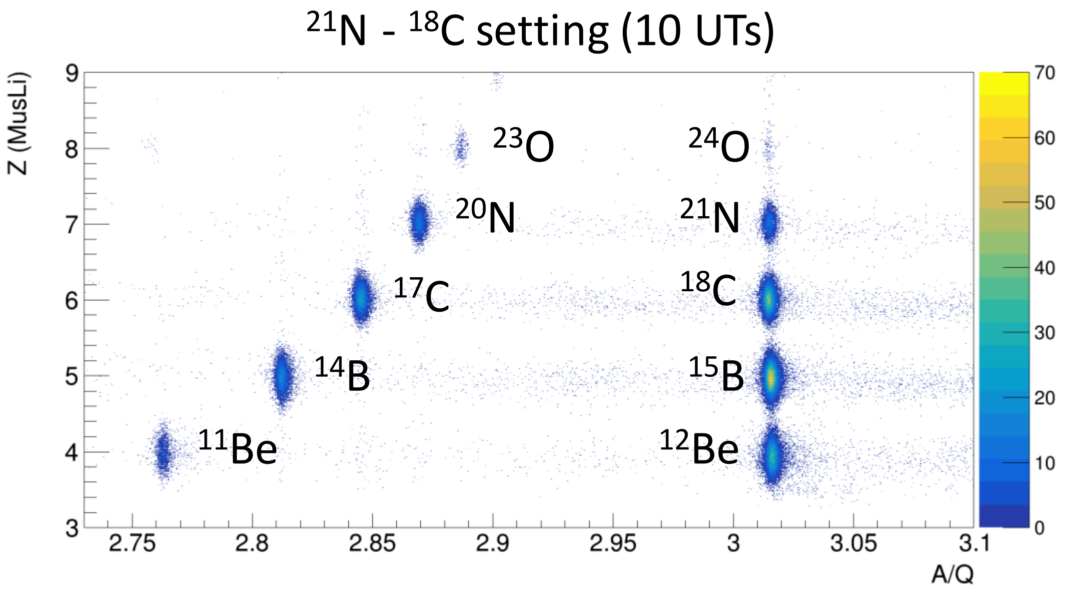
NeuLAND (x,y,z,t)
with 26 plans



Identification of the incoming nuclei

2 settings were used :



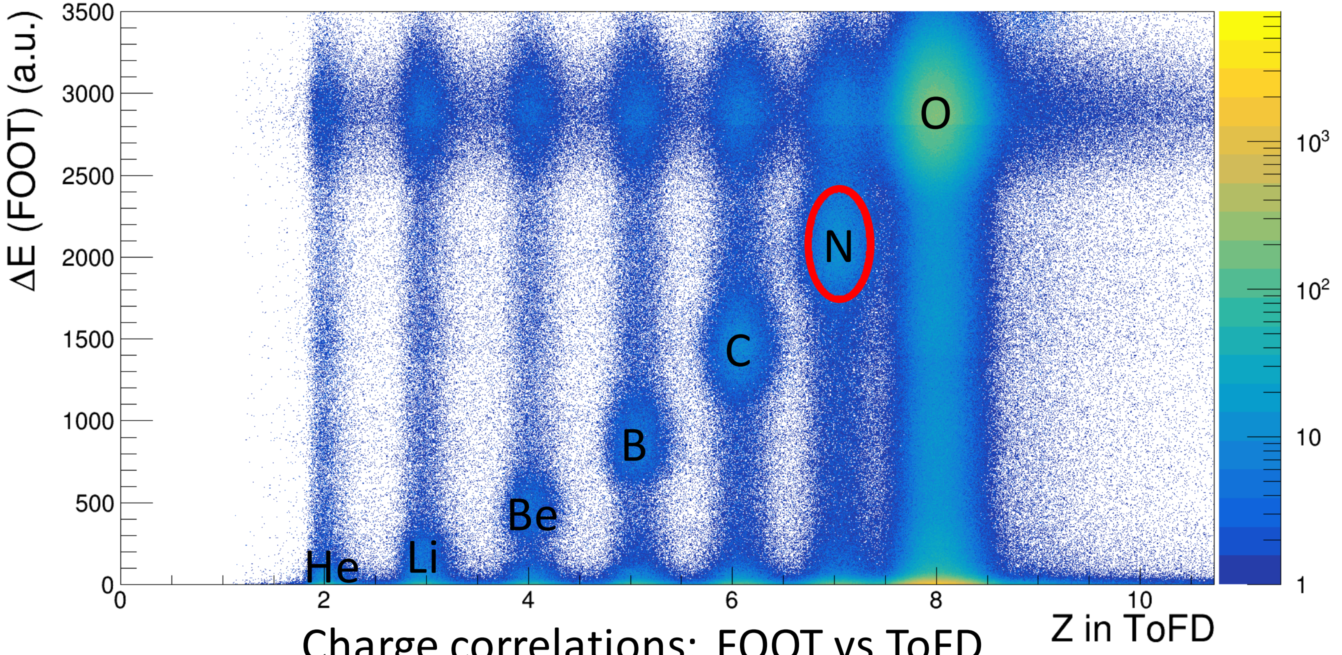


ΔE(MusLi) --> Z
(Bethe-Bloch)

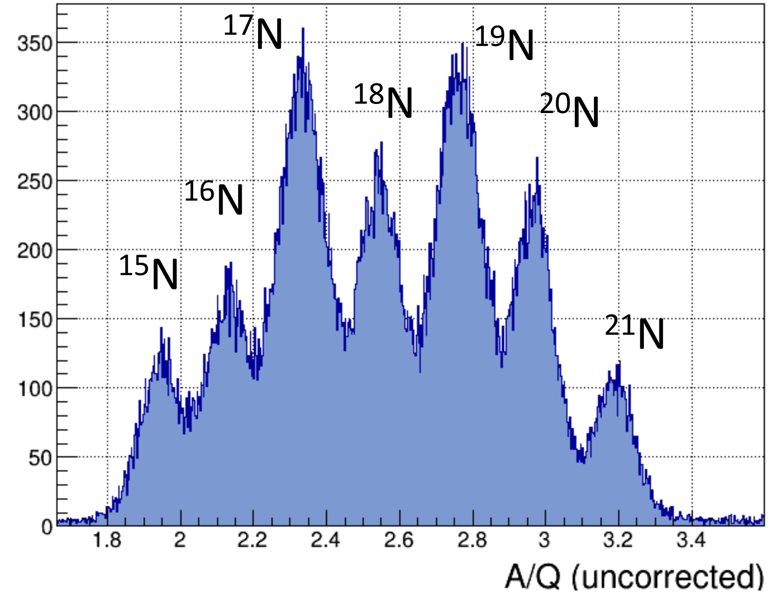
ToF (S2-LOS) --> $\beta \cdot \gamma$

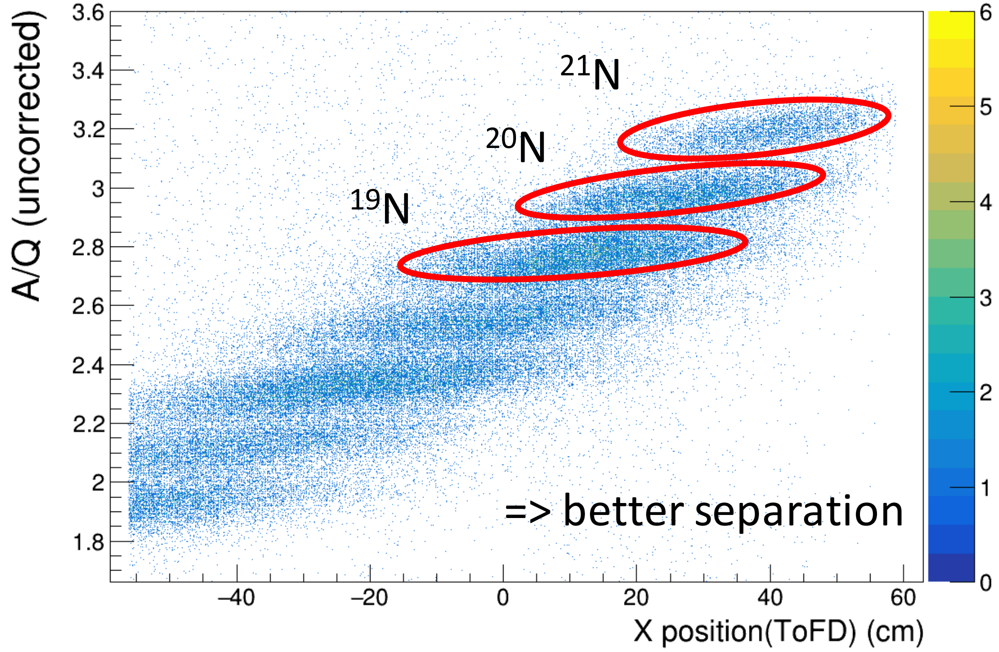
$$A/Q = \frac{B\rho_0 \cdot (1 - PosS2/D_{S2-CC})}{3.10716 \cdot \beta \cdot \gamma}$$

Identification of the N isotopes from the $^{22}O(p,2p)^{21}N$ reaction



Charge correlations: FOOT vs ToFD

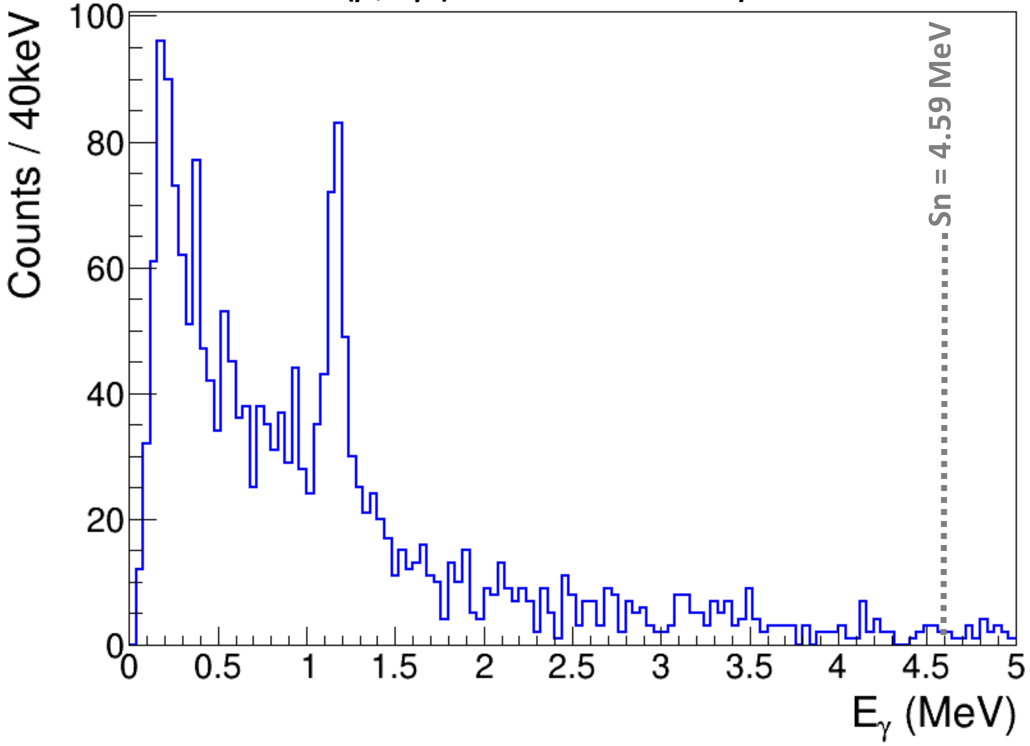


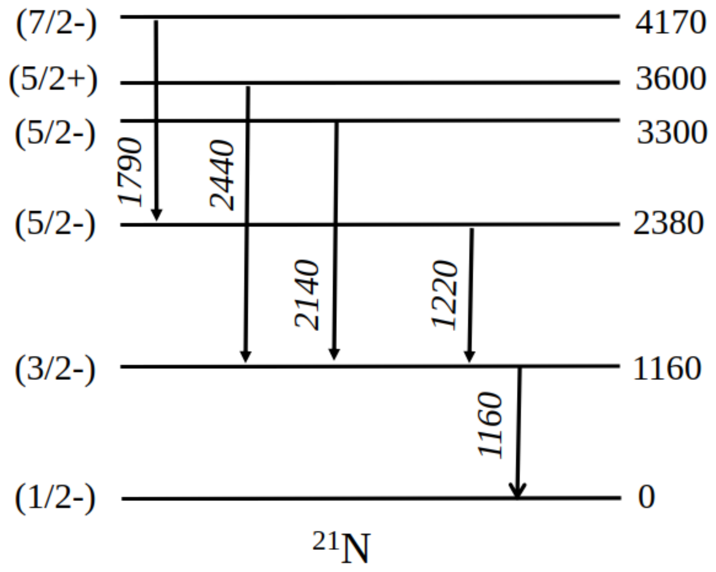


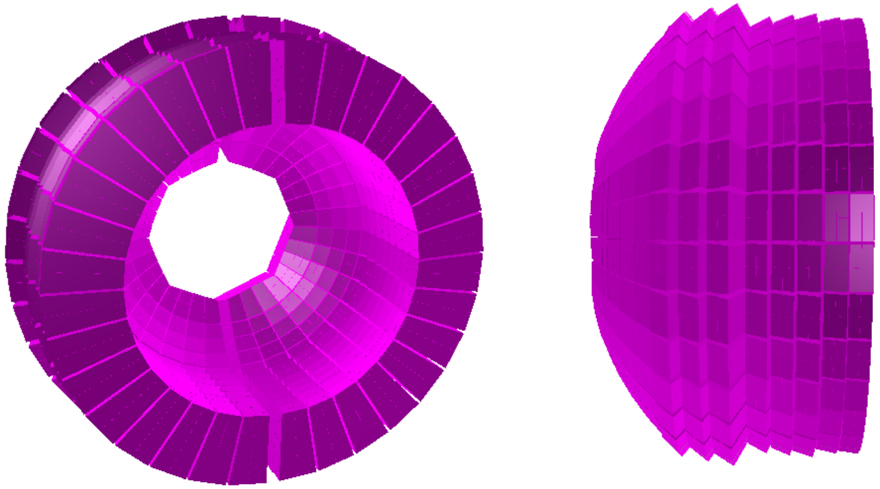
- Use of the energy losses in FOOTs and ToFD to reject events with a change of the Z in the air (reaction).
- To get the mass, a tracking algorithm allows to link positions before and after GLAD, with the propagation in the magnetic field (=> flight path).
- The inclusive cross section is then obtained by counting the ^{21}N (bound states).

Population of bound states in the $^{22}O(p,2p)^{21}N$ reaction

$^{22}O(p,2p)^{21}N^{*}$ => $^{21}N + \gamma$

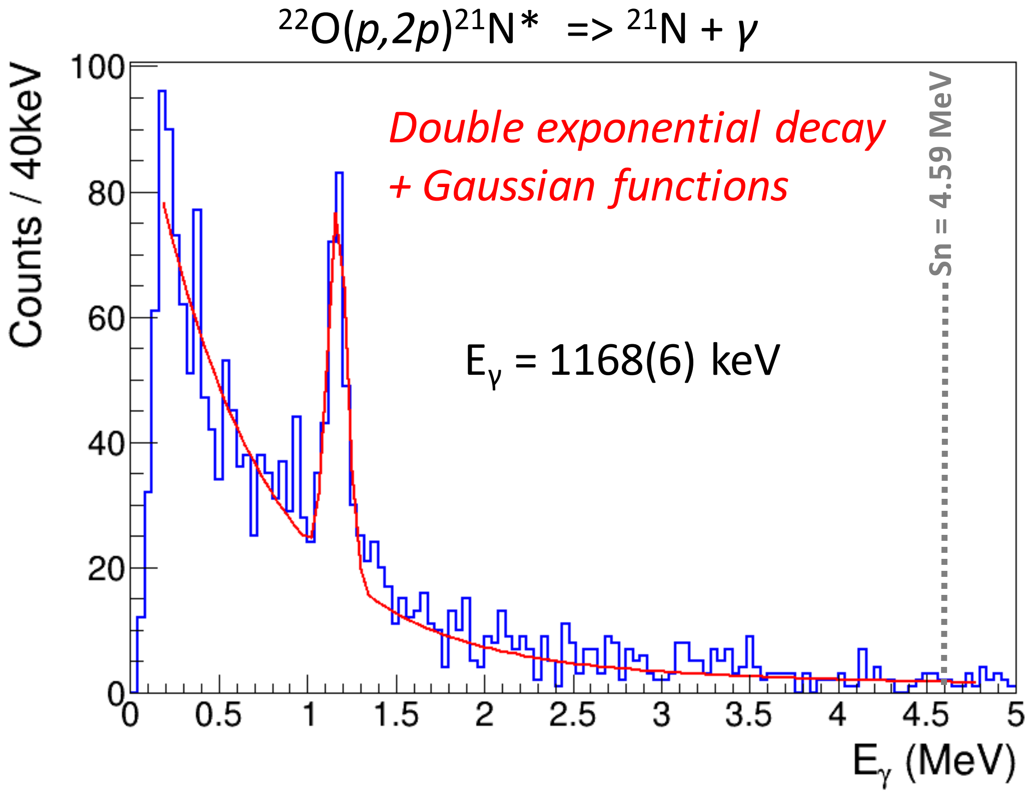


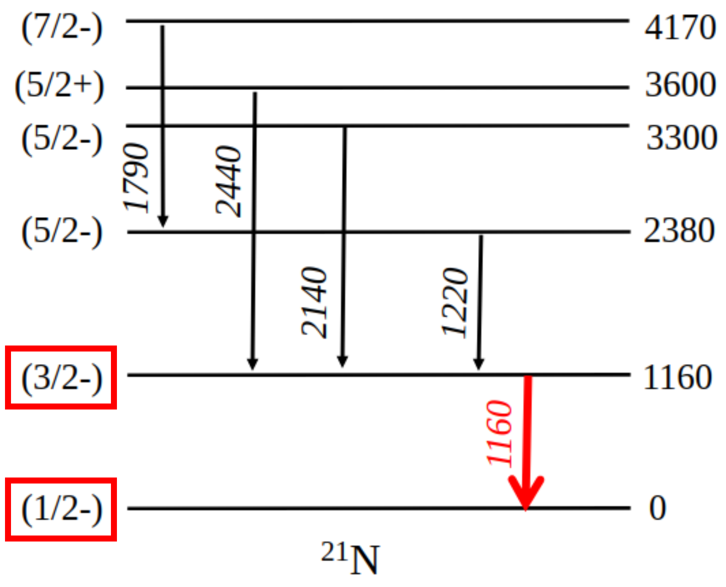




CALIFA (Barrel + Endcap) : 1504 crystals, including 480 with 2 electronic gains (Endcap)

Population of bound states in the ^{22}O(p,2p)^{21}N reaction





Resolution:
σ = 40keV at E_γ = 1.170 MeV
=> FWHM / E_γ = 8%

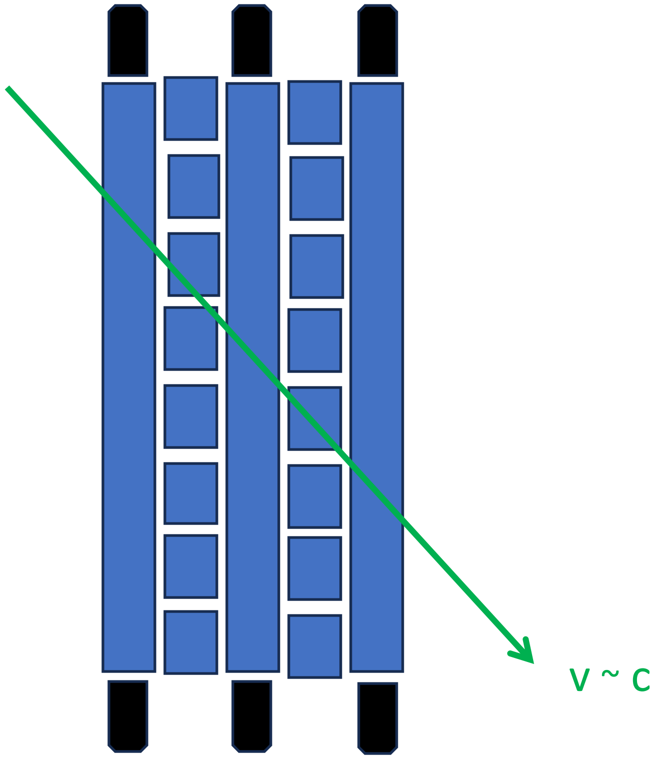
Efficiency:
ε_γ(1.170MeV) = 26 %

Results : $\frac{N(3/2_1^-)}{N(1/2_{GS}^-)} = \frac{N(3/2_1^-)}{N_{incl} - N(3/2_1^-)} = 19.0(31)\%$

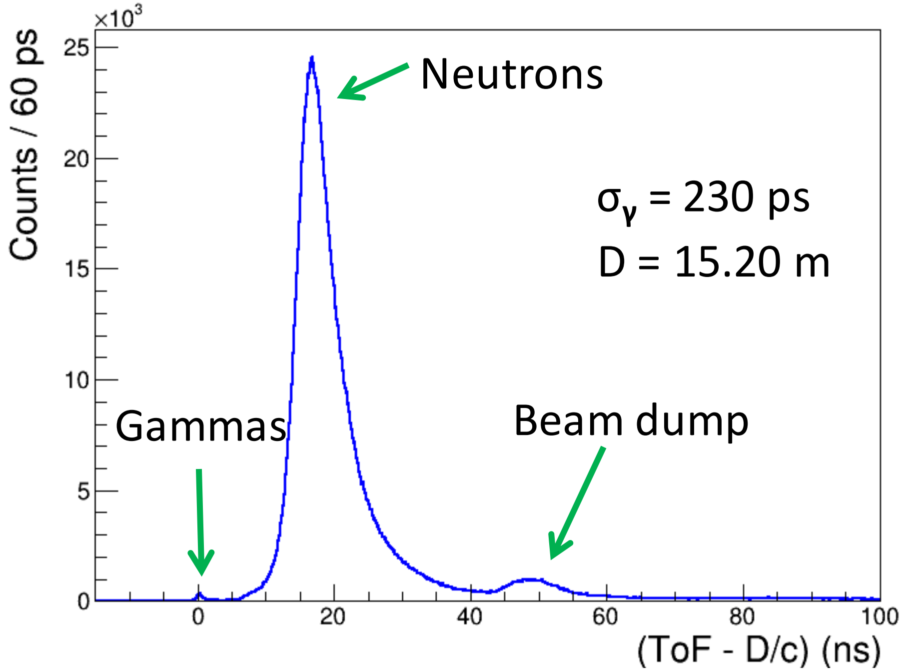
=> Among the bound states, the $1/2^-_{GS}$ is the most populated by the (*p,2p*) reaction.

NeuLAND and the invariant mass method

Alignment of the time difference of the two PMTs for each bar, using cosmic rays (muons) and a tracking algorithm.



Portion of NeuLAND crossed by a cosmic ray particle.

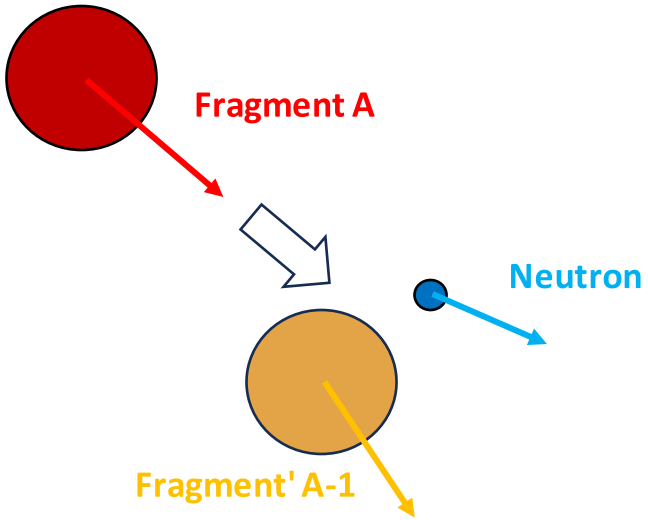


Use of the invariant mass method:

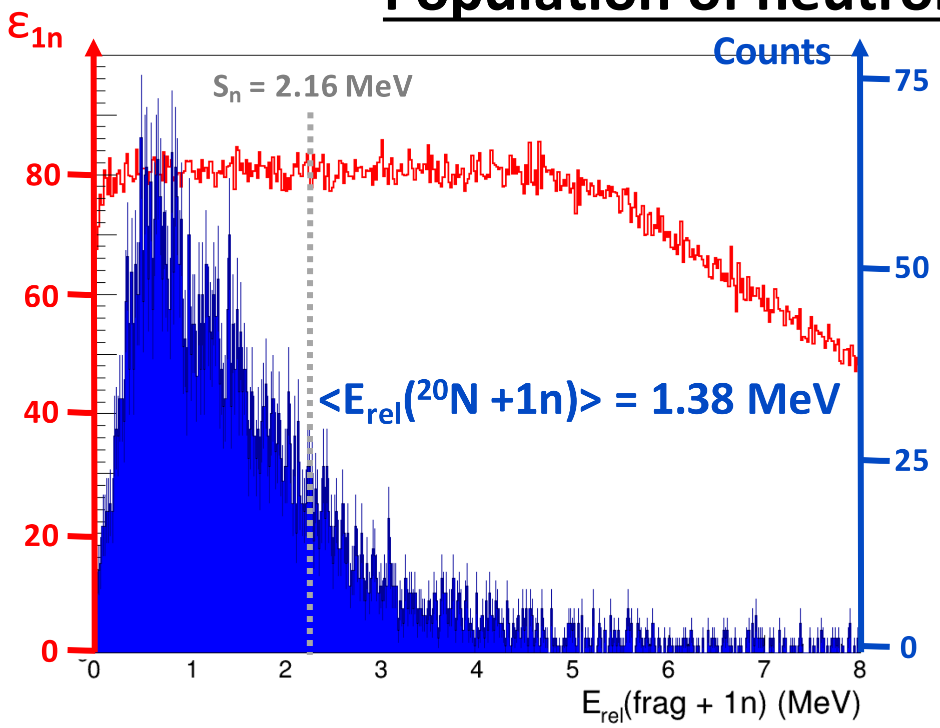
$$M_{inv} = \sqrt{\left(\sum_{i=0}^{N} E_i\right)^2 - \left(\sum_{i=0}^{N} p_i\right)^2}$$

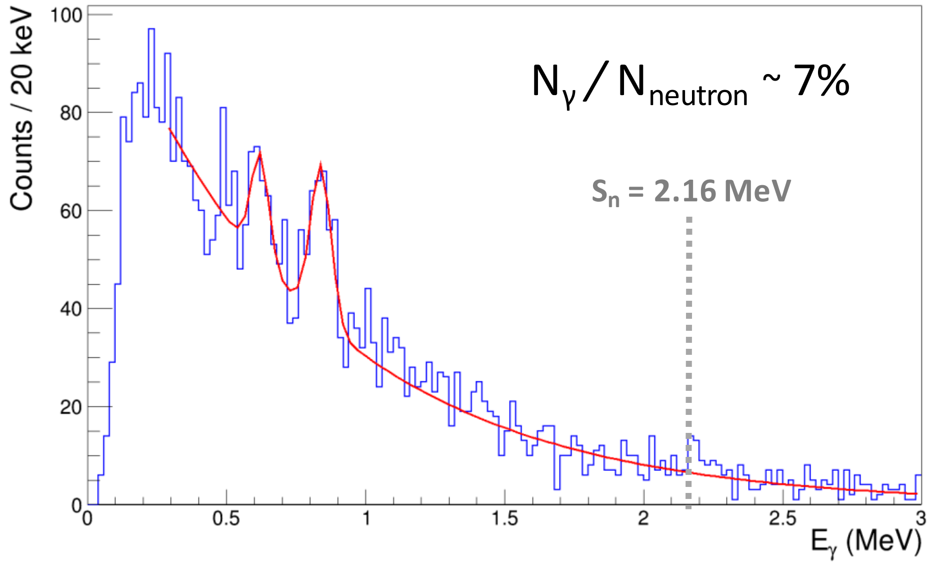
with the energy and momentum of the fragment and neutron(s)

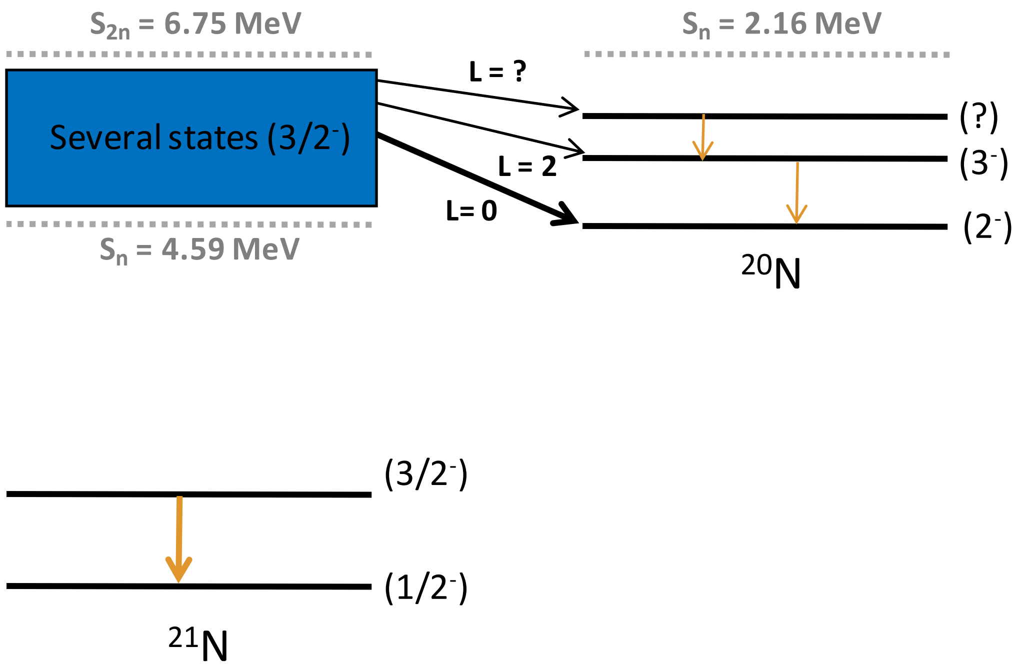
$$E_{rel} = M_{inv} - \sum_{i=0}^{N} m_i$$



Population of neutron unbound states in the $^{22}O(p,2p)^{21}N$ reaction



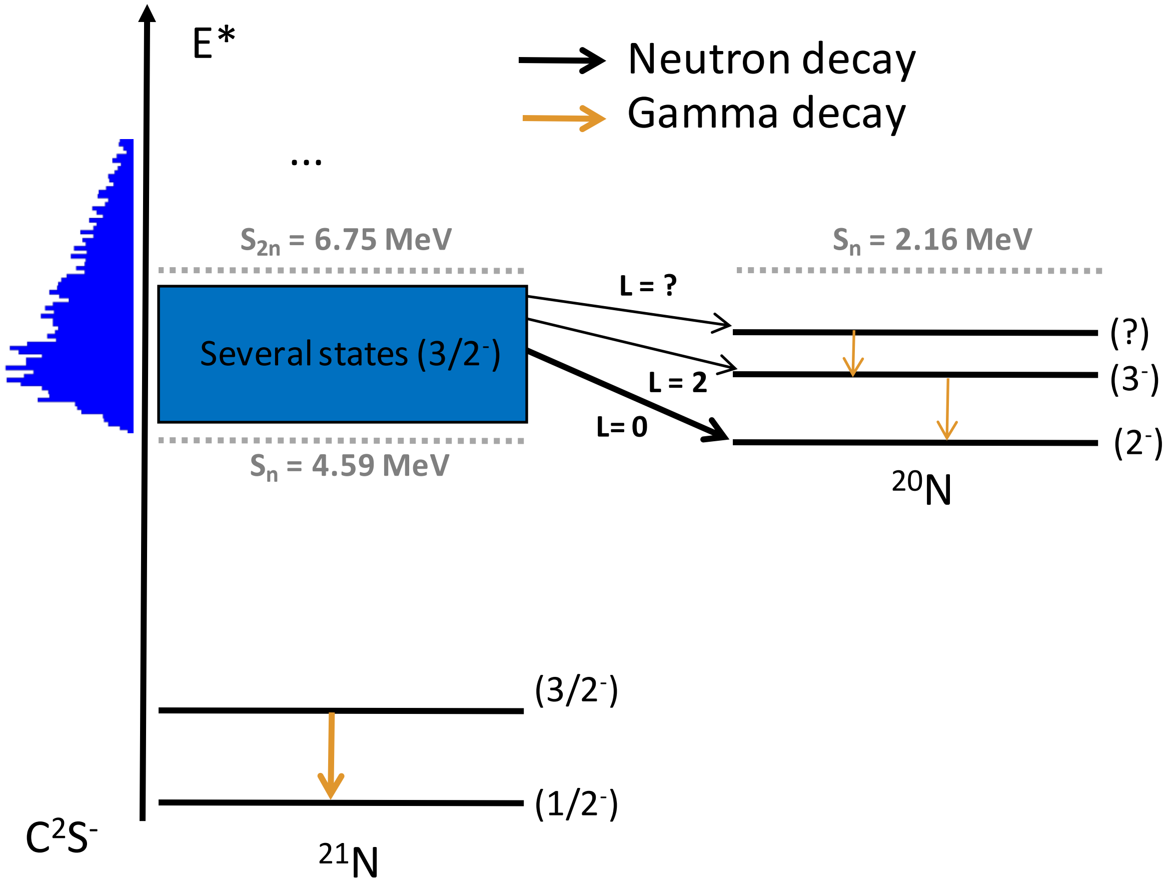




Fit of the E_{rel} distribution requires to take into account:

- Time resolution of NeuLAND --> already done;
- Effective resolution of the beta(fragment)
  --> straggling + detector resolution --> still ongoing.

Conclusions and perspectives



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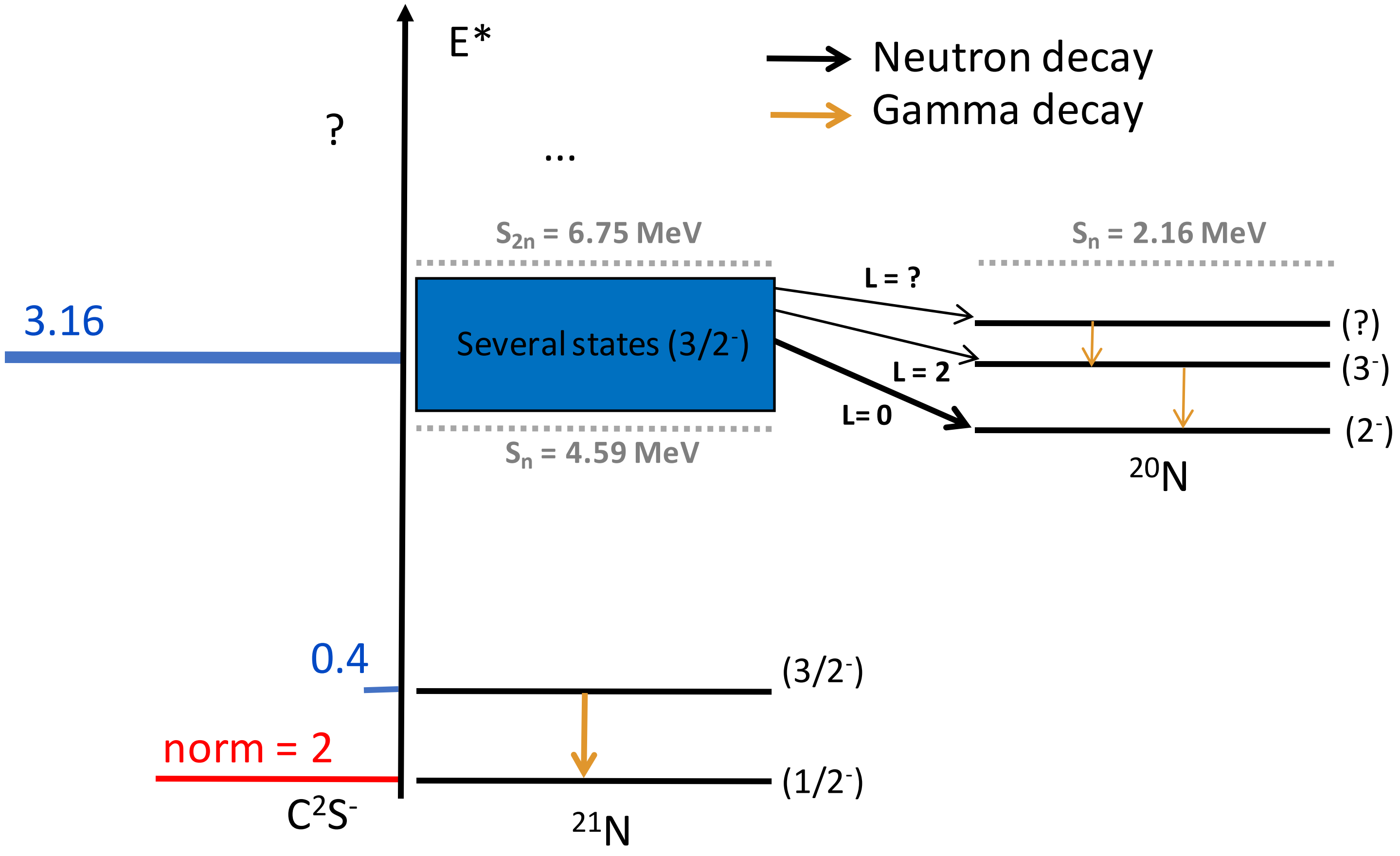
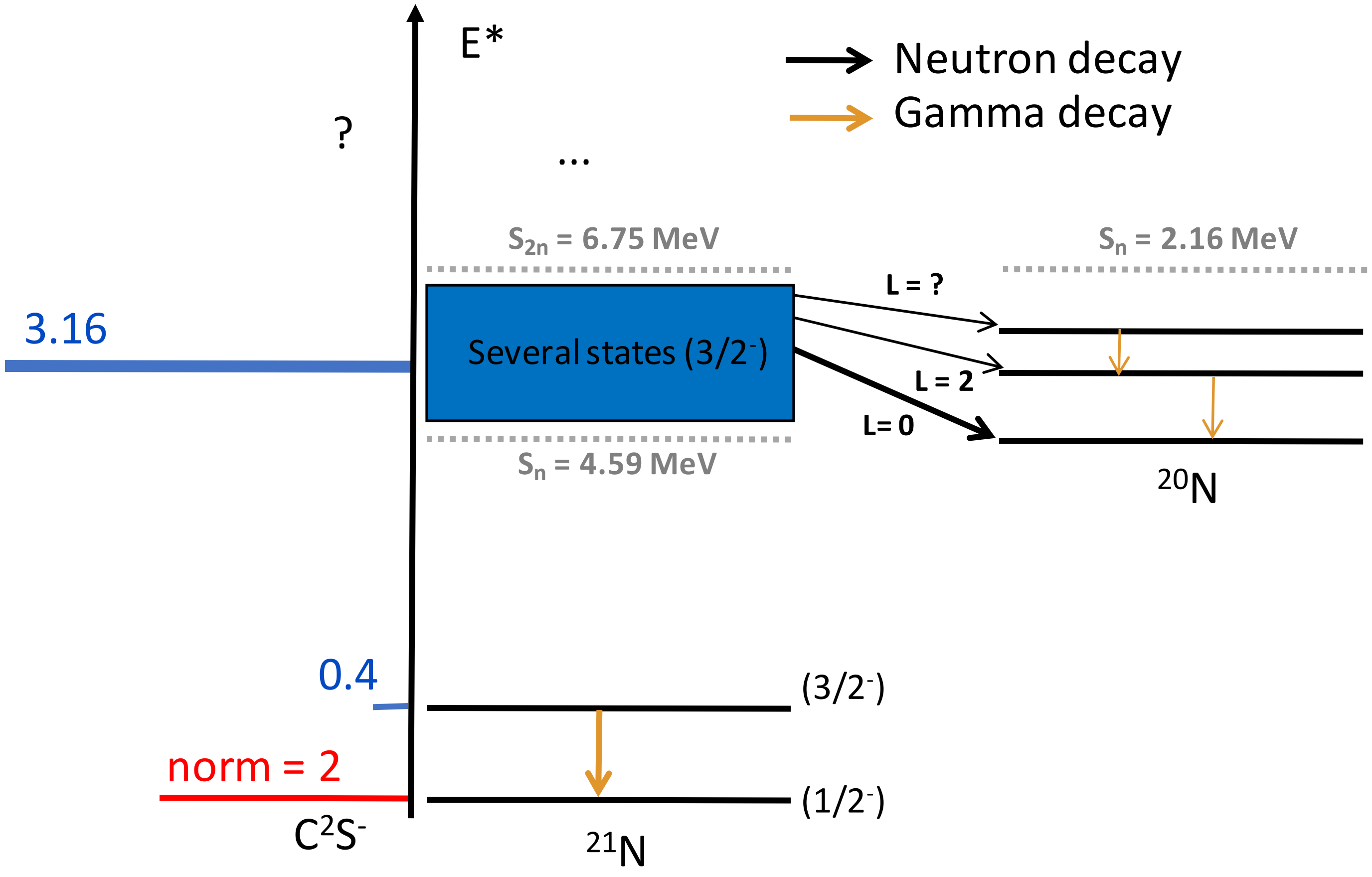


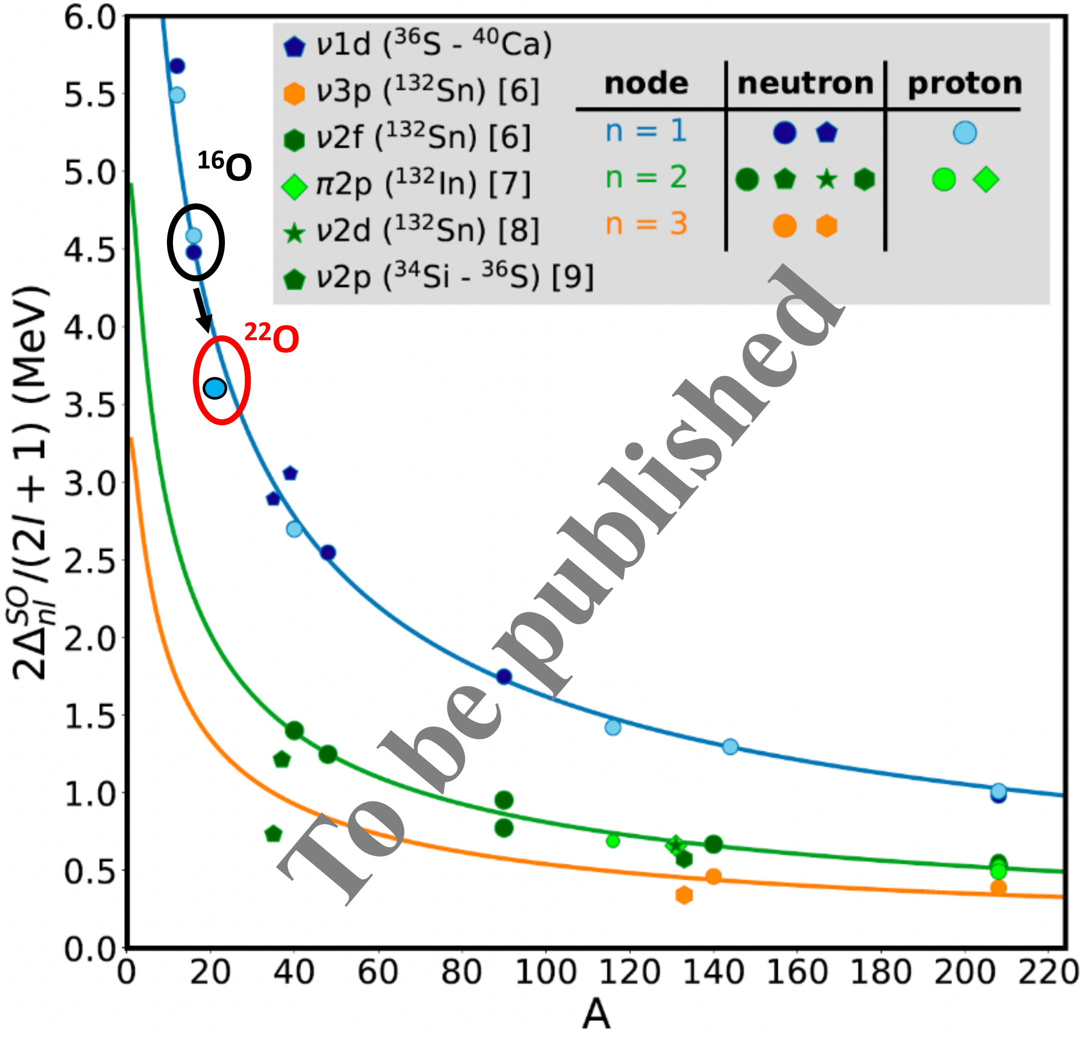
Fraction of the strength recovered:

$$\frac{N_{tot}(3/2^-)}{N(1/2^-_{GS})} \geq \frac{N(3/2^-_1)+N_{1n}}{N_{incl}-N(3/2^-_1)} = 1.77(13)$$

A small fraction may be located above the S_{2n}

Conclusions and perspectives





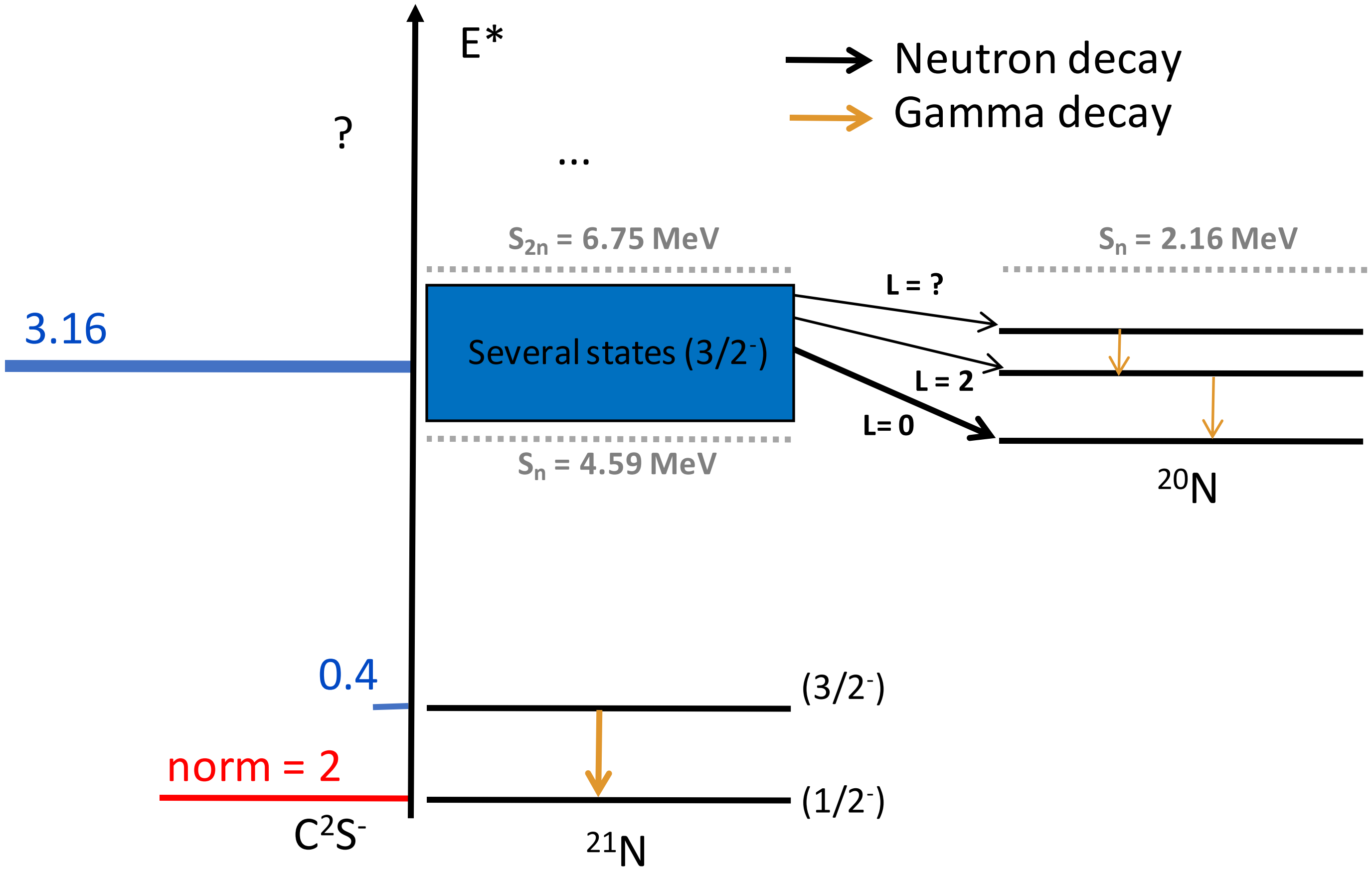
First estimation of the proton gap in ^{22}O:

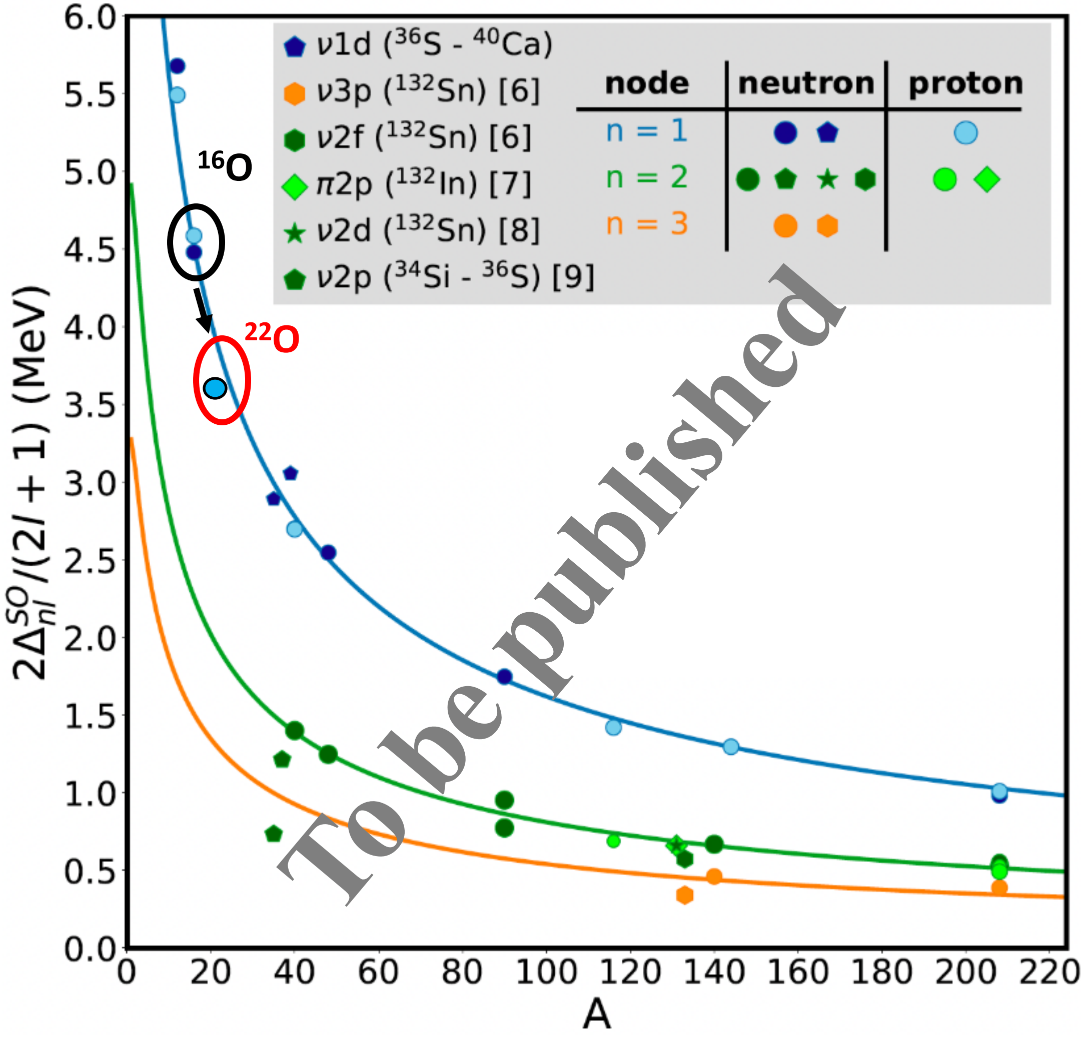
$$< 0p_{3/2} >_{s.p.} \geq \frac{E^*(3/2^-_1)N(3/2^-_1) + N_{1n}E^*_{1n}}{N(3/2^-_1) + N_{1n}}$$

$$< 0p_{3/2} >_{s.p.} - < 0p_{1/2} >_{s.p.} \geq 5.46 MeV$$

⇨ Deviation from the Mairle's trend about 350 keV

Conclusions and perspectives



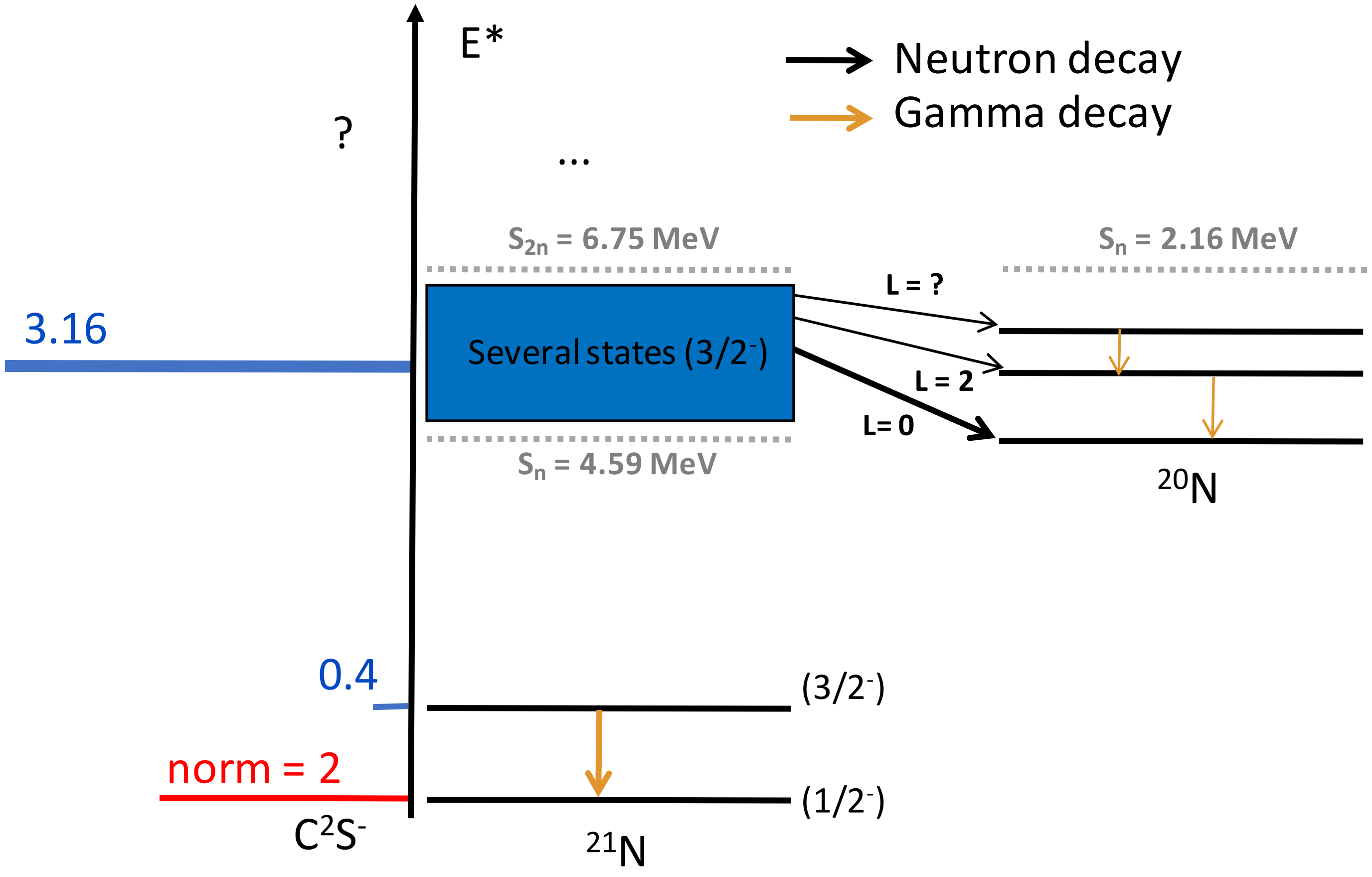


Perspectives :

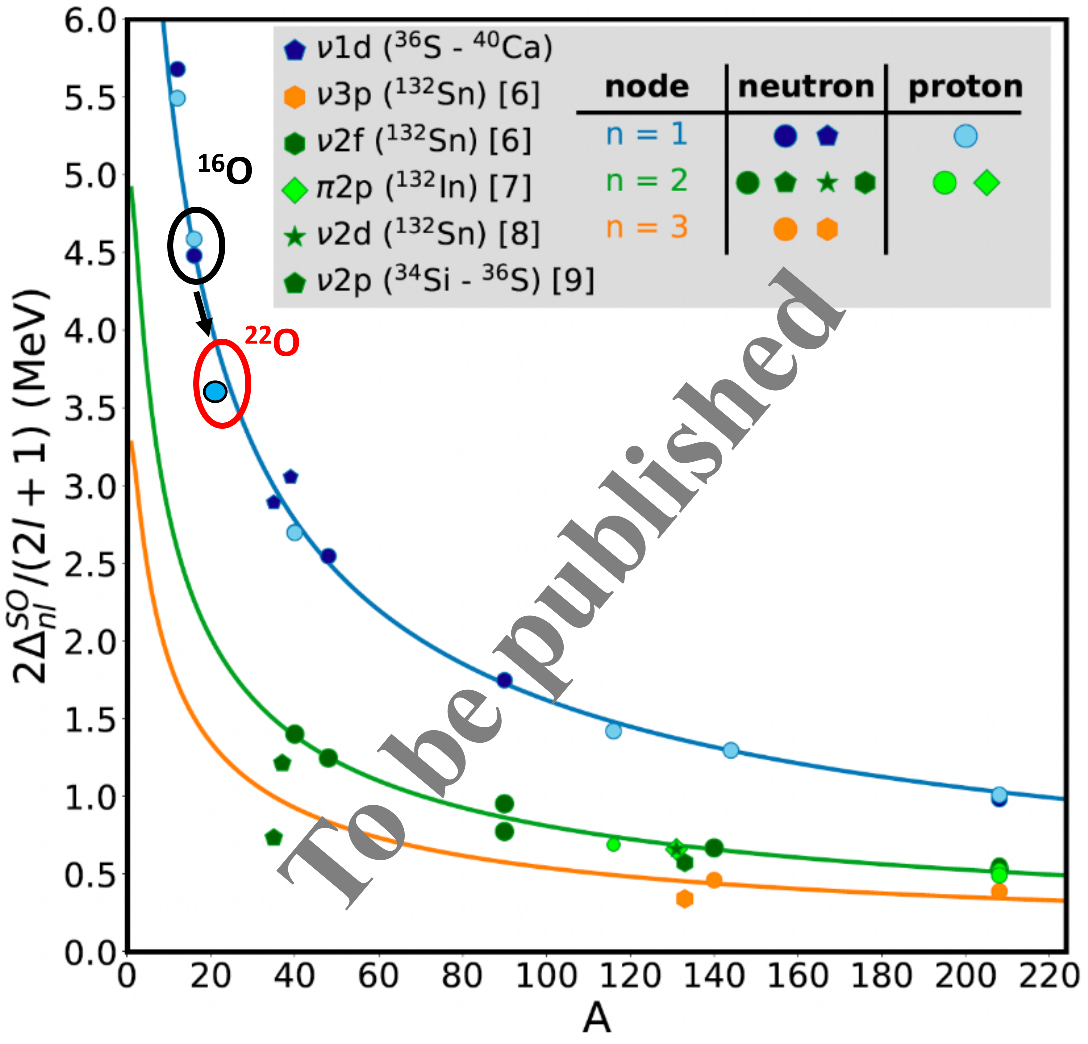
- Study of the ^{21}O momentum via ^{22}O(p,pn)
(6 neutrons in the neutron orbital $0d_{5/2}$?);
- 1n spectroscopy, w. gamma-neutron coincidences;
- Analysis of unbound states decaying by 2n emission.

⇨ Deviation from the Mairle's trend about 350 keV

Conclusions and perspectives



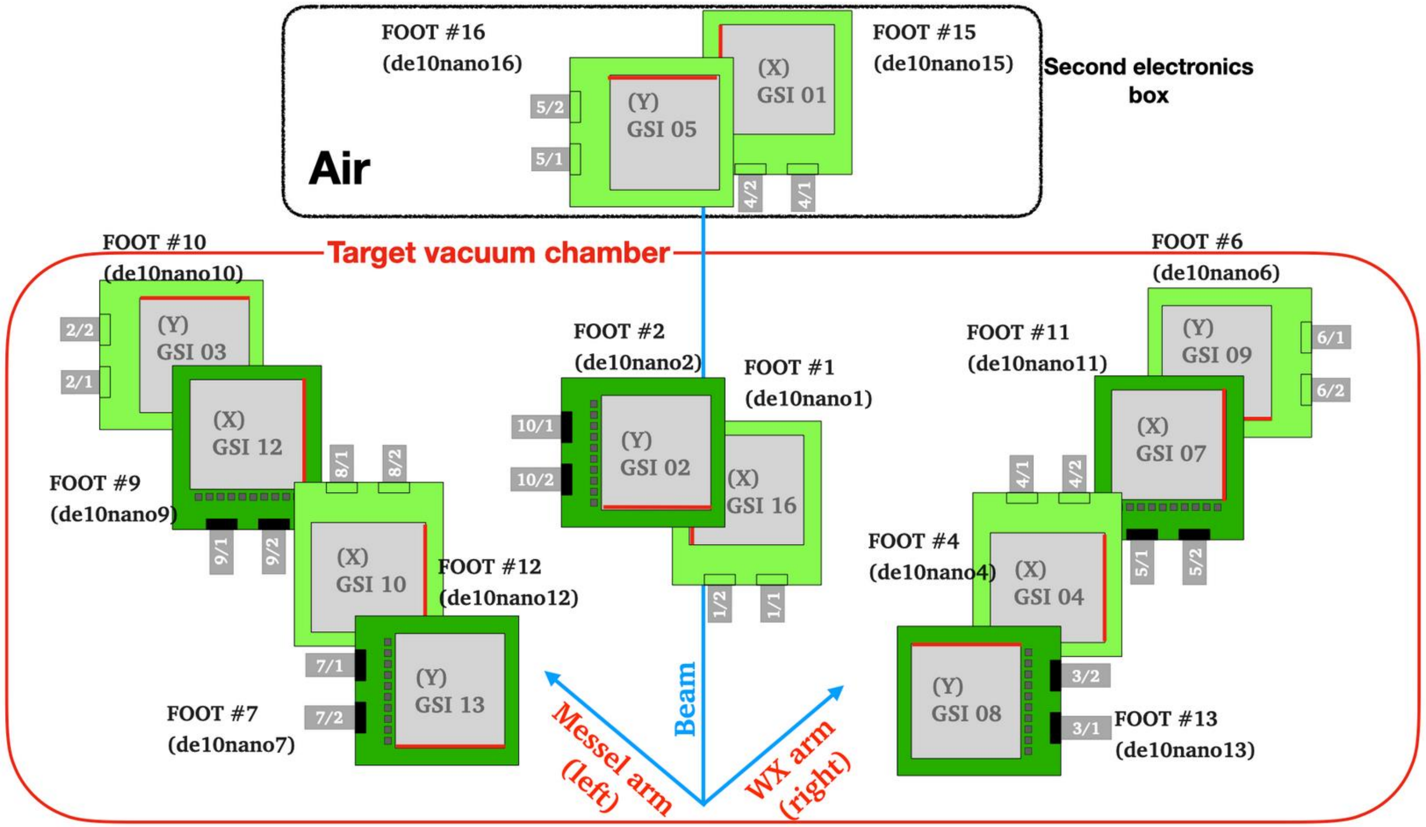
Thank you for your attention !



Deviation from the Mairle's trend about 350 keV

Backup Slides

Tracking around the target

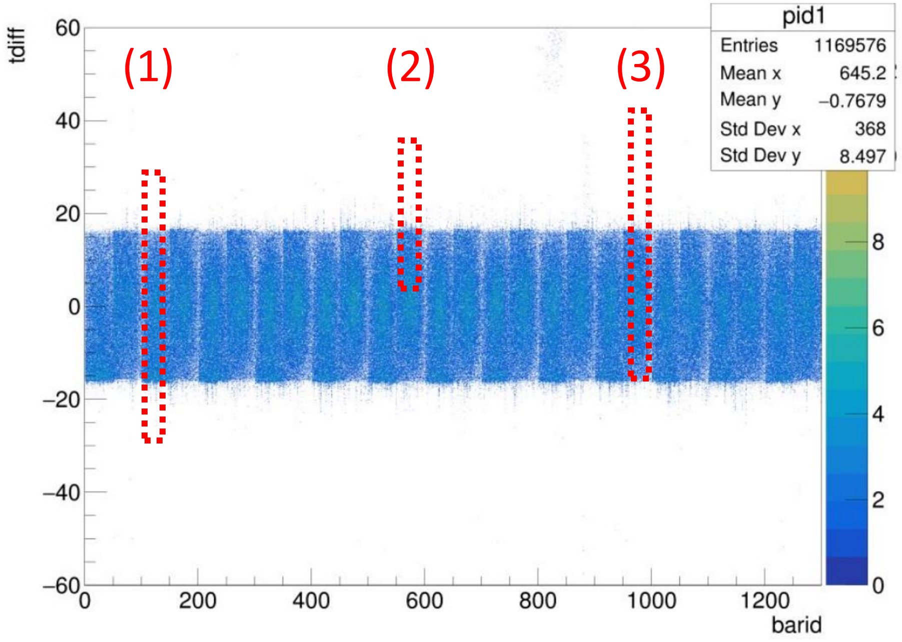


FOOTs mapping : 4 on each side + 4 in-beam

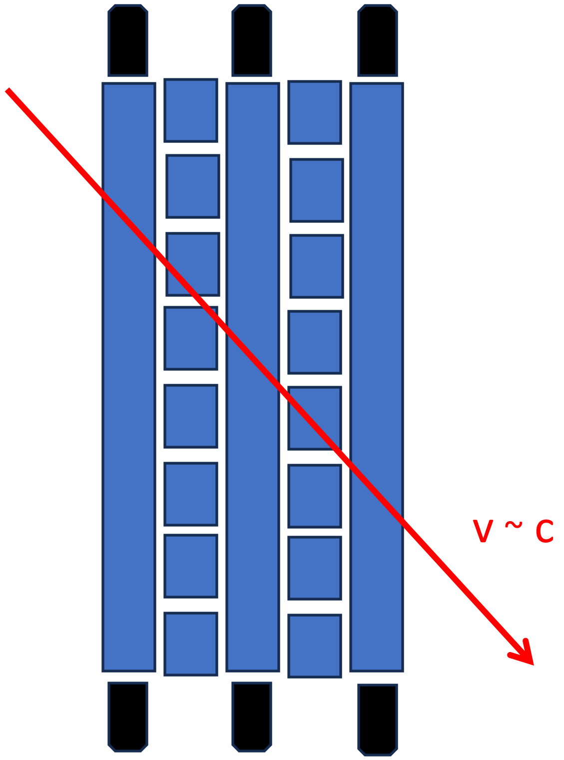
NeuLAND calibration

PMTs time for one bar -> position within the bar + ToF (target-bar)

1) Alignment of the time difference of the two PMTs for each bar, using cosmic rays and a tracking algorithm



Time difference left/right or bottom-top PMTs vs Bar Id, for on-spill events



Portion of NeuLAND crossed by a cosmic ray particle.

For each bar, we can define:

Time diff : T1 – T2
-> Effective speed of light

Time synch : T1 + T2
-> Global offset

(1) => diff correction
(2) => synch correction
(3) => both of them

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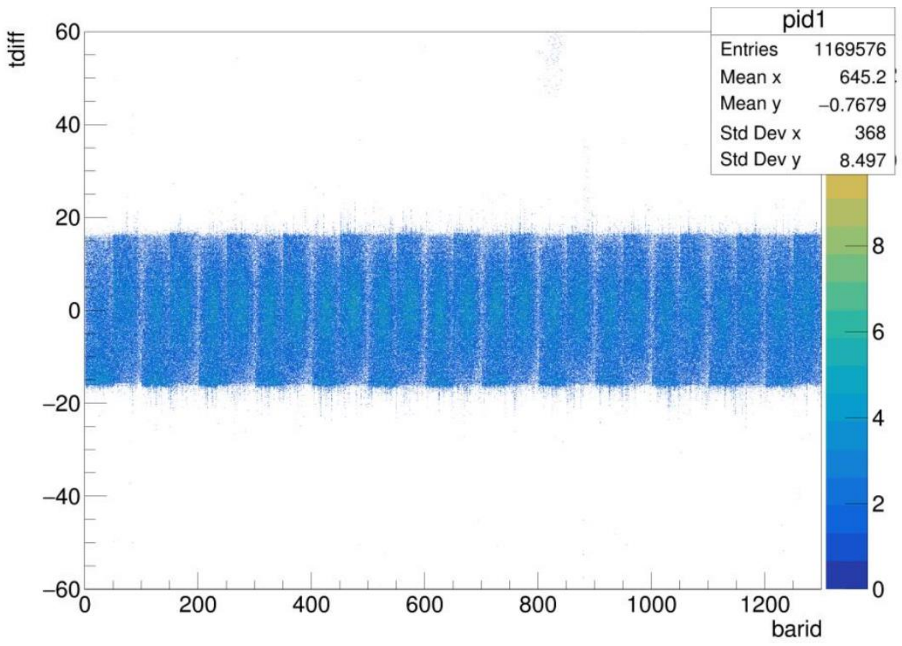
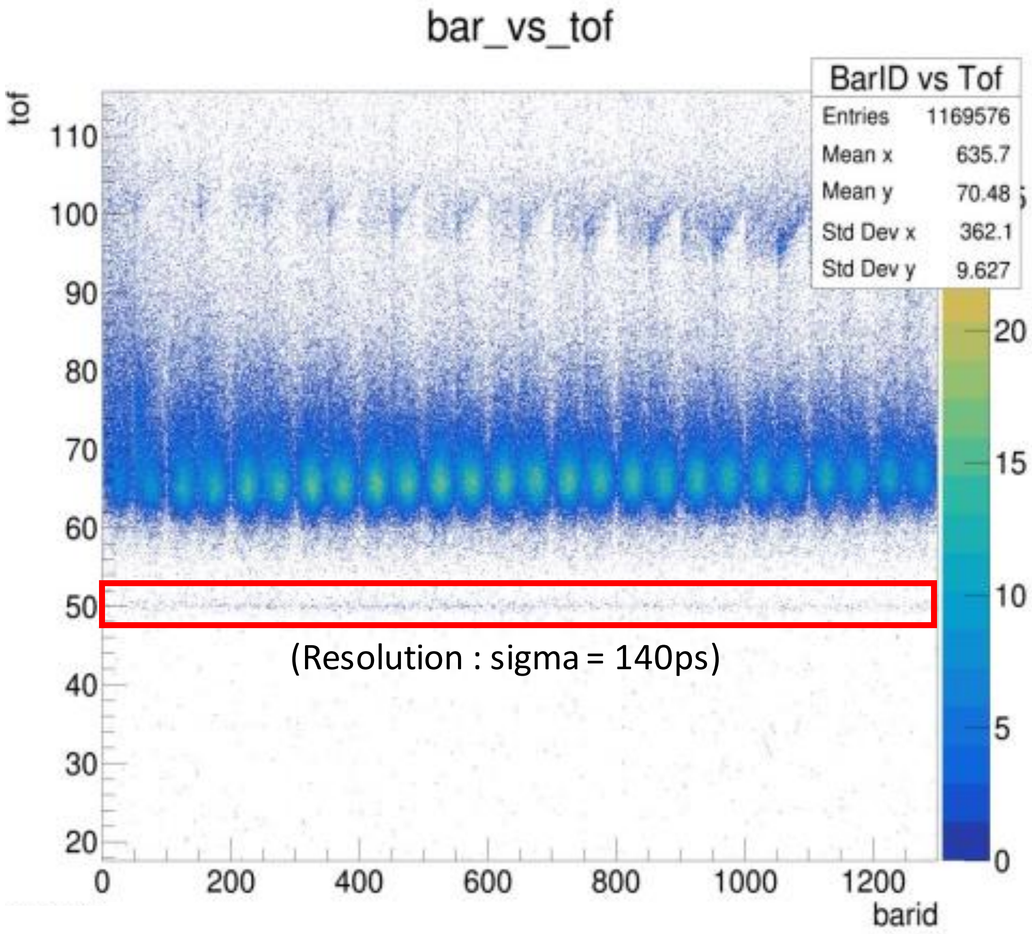


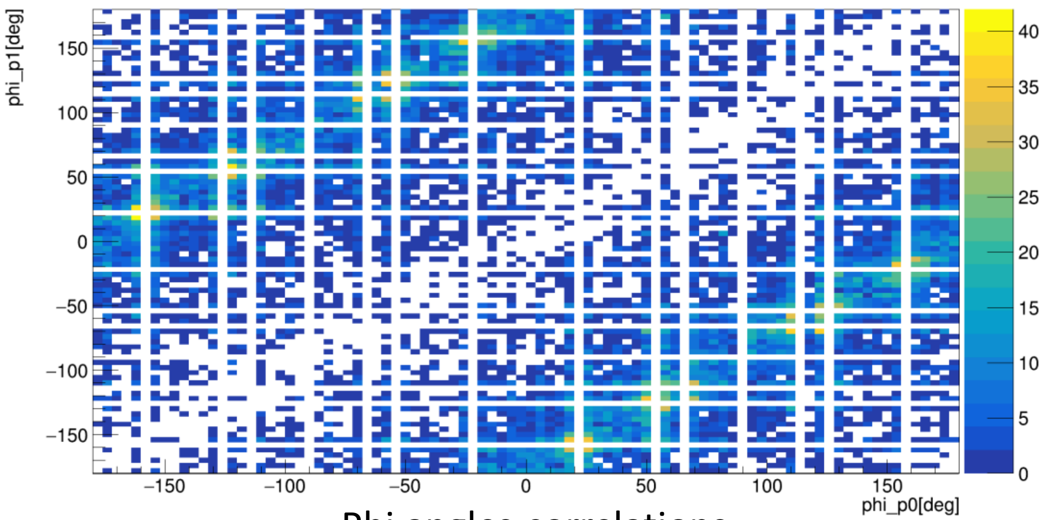
Time difference left/right or bottom-top PMTs vs Bar Id, for on-spill events

2) Fine tuning with the gamma peak

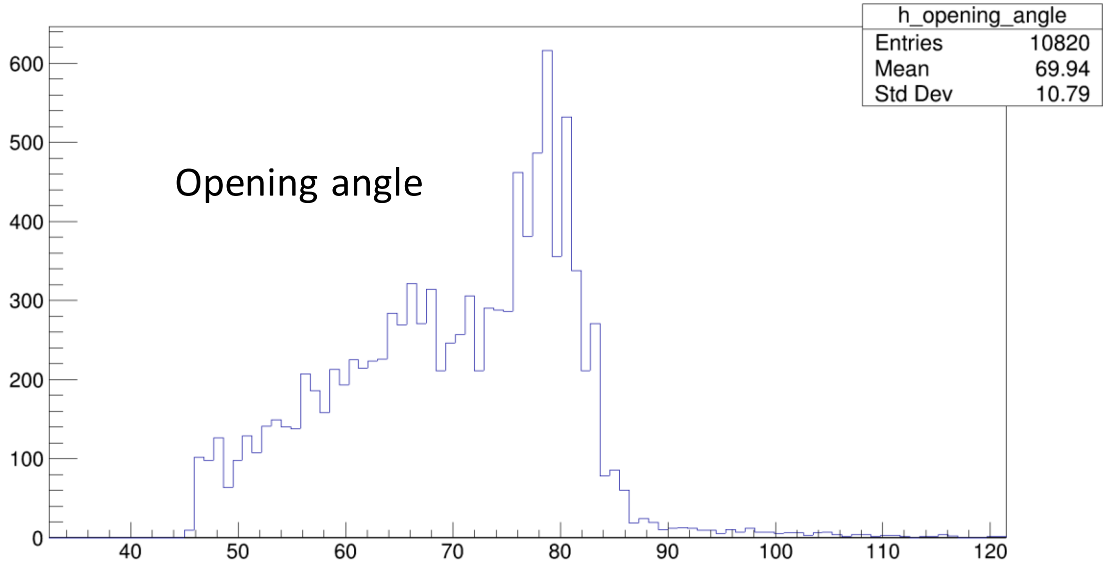


ToF (NeuLAND Bar – LOS) vs Bar Id for on-spill events

Califa and the QFS reactions

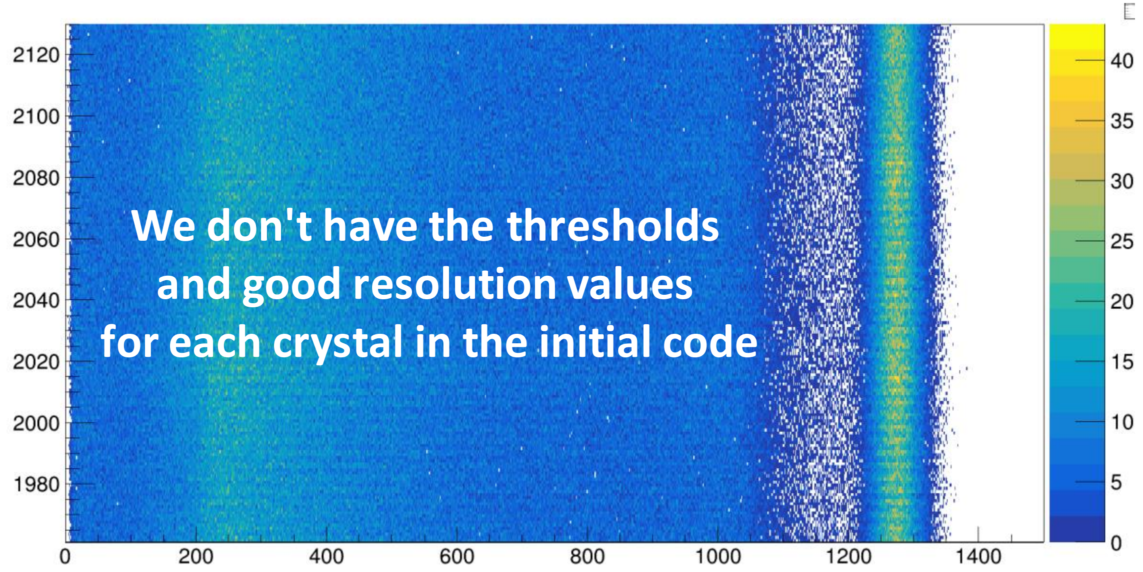


Phi angles correlations

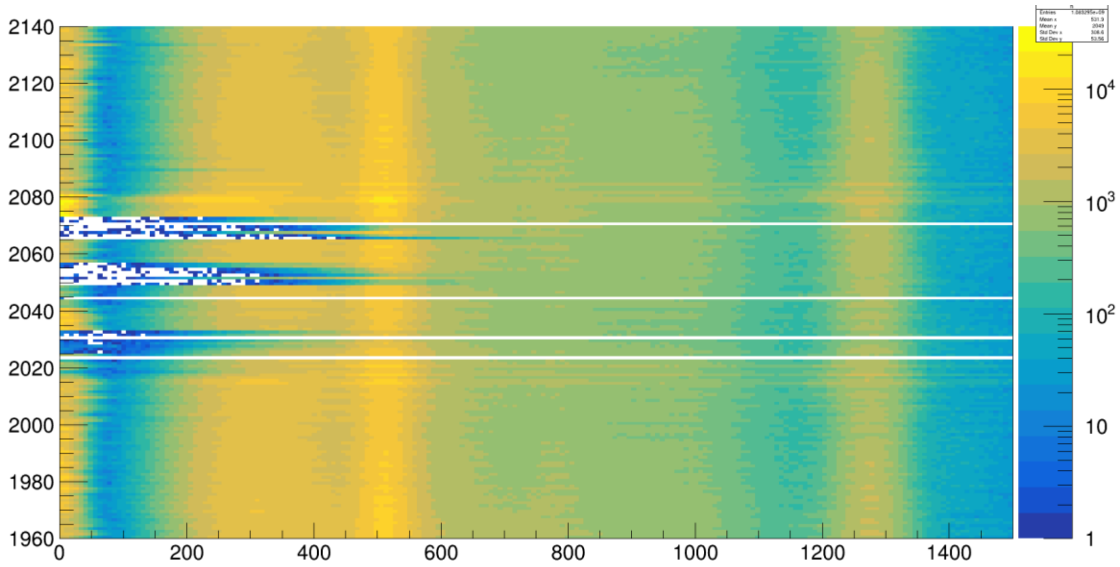


^{19}N cut + coplanar condition : delta phi (2 protons) <40°

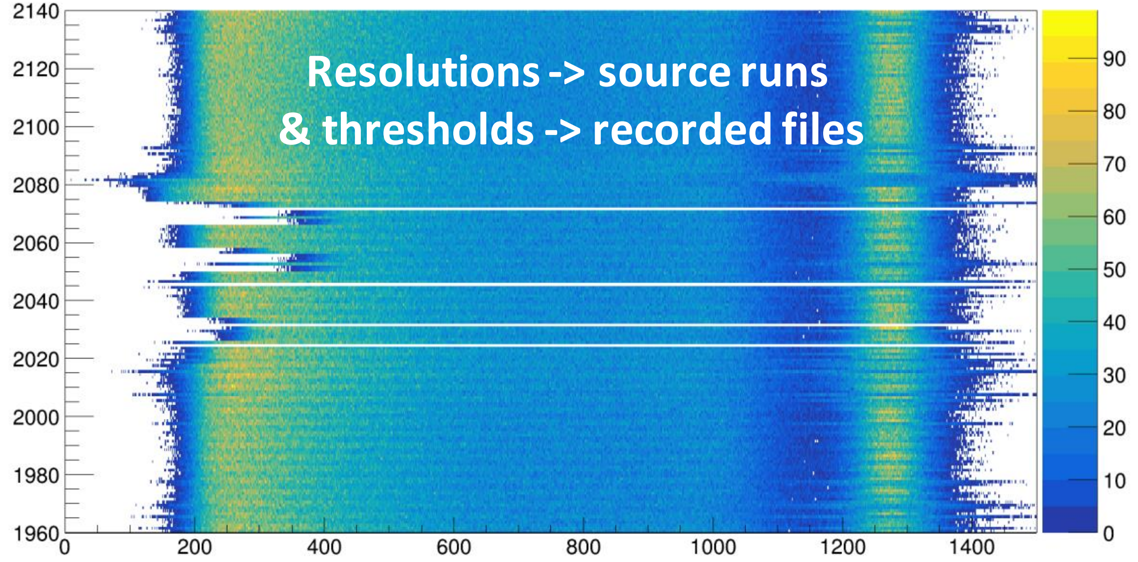
Modifications of the gamma simulations



Crystal Id vs energy (simulation): 1274keV peak



Crystal Id vs energy (^{22}Na source)



Crystal Id vs energy (simulation): 1274keV peak

Use of simulations in gamma analysis:

-> To get the energy of the transitions

-> To obtain the associated cross section