Experimental studies of exotic nuclear structure

J. Díaz Ovejas[1] for the MAGISOL collaboration.

[1]Instituto de Estructura de la Materia – CSIC, Serrano 113bis, E28006, Madrid, Spain.

Introduction

The structure of the atomic nucleus is a many body problem where many interactions take part. Several exotic phenomena appear throughout the nuclear chart, like for instance the halo structure, which occurs in some light nuclei close to the driplines. This structure consists in one or more nucleons spatially distributed at a big distance from the remaining tight core, and can be understood as a result of the finite range of the strong force plus the tunneling effect of the nucleons wave-functions.

The possibility of accelerating exotic radioactive beams as e.g. at HIE-ISOLDE at CERN, has opened a new possibility to the study of this phenomenon. An example of this is the IS561 experiment on *Transfer reactions at the neutron dripline with triton target,* carried out in October 2017 at HIE-ISOLDE. This experiment aimed to populate excited states of ^{11}Li, which has a 2n-halo configuration, by the ^{9}Li(t,p)^{11}Li* reaction.

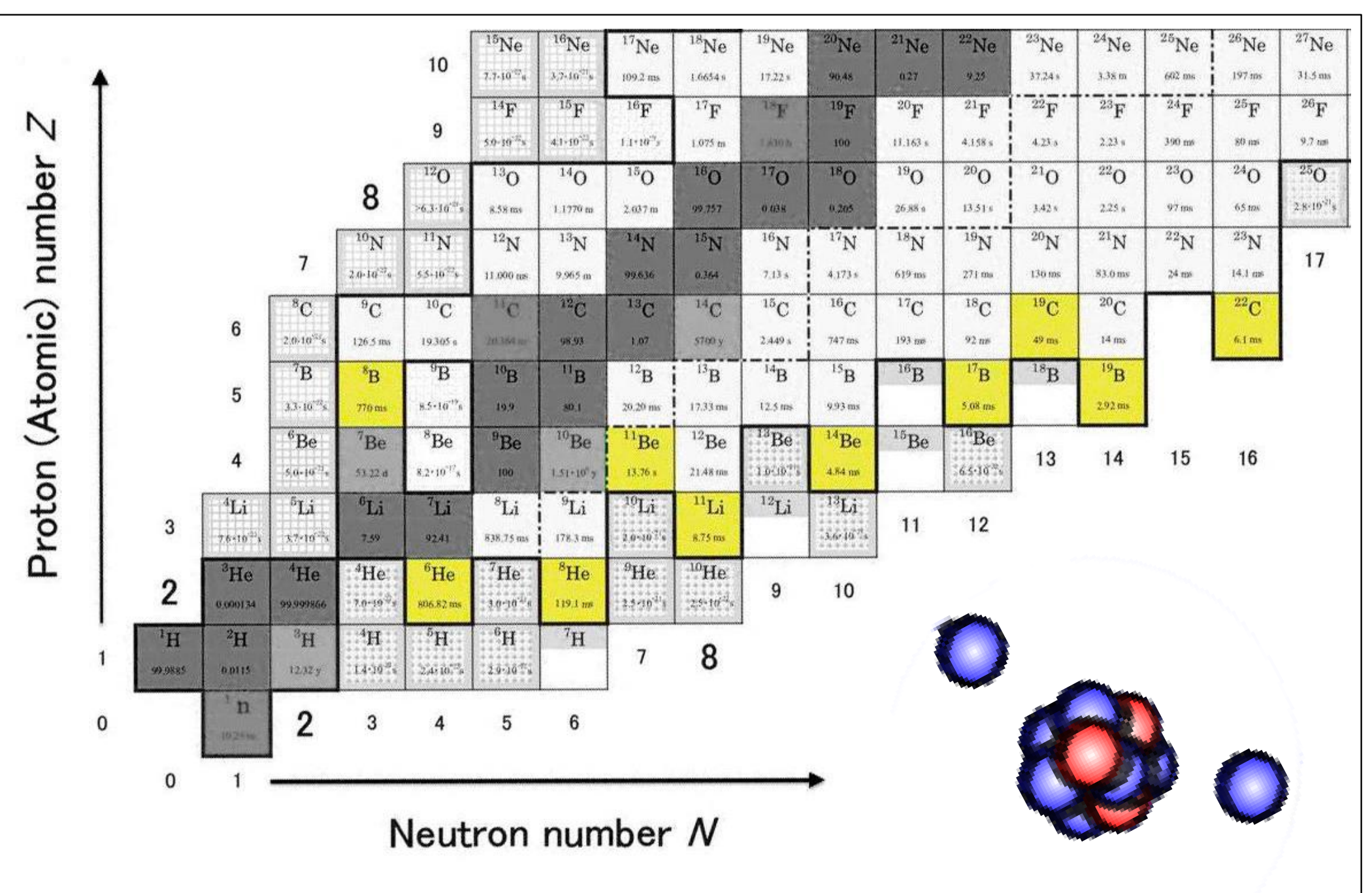

Fig 1. Light region of the nuclear chart with halo nuclei highlighted in yellow and illustrative representation of the 2n halo in ^{11}Li.

Experimental set-up

ISOLDE facility provides a wide range of more than 1000 radioactive isotopes with half-lives longer than 10 ms, production intensities up to the 10^{11} ions/s and energies that recently reached 8 MeV/u, thanks to the brand new HIE superconducting post-accelerator Linac. For the IS561 experiment a ^{9}Li beam at the maximum energy was required.

The ionised, separated and accelerated beam is led to the *Scattering Experiment Chamber* (SEC), inside which silicon detectors are arranged. The set-up consists of five 60 µm thick *Double Sided Silicon Stripped Detectors* (DSSDs) stacked with 1.5 mm thick silicon pads each one (i.e. telescope configuration, to allow for particle identification) in a pentagon array covering forward angles after target position; two more symmetric telescopes covering backwards angles; and two tilted 1 mm thick DSSDs up and down the beam to catch reaction fragments. There are also a Faraday cup and a beam-dump telescope for beam diagnostic placed at the end of the chamber in the beam line. Outside the chamber, 30 plastic scintillators+PMTs are set to detect neutrons at forward directions.

Choosing ^{3}H as reaction target allows for the 2n pick-up by ^{9}Li due to its neutron to proton ratio (2/1). Its gaseous state force to use a backing material in which it can be contained so a Ti sheet with an initial loading of ^{3}H/Ti≥1 was utilized. This amount of tritium and its relatively short half-life (12.3 y) result in an extremely high activity of the target piece; 6.7 GBq in October 2017.

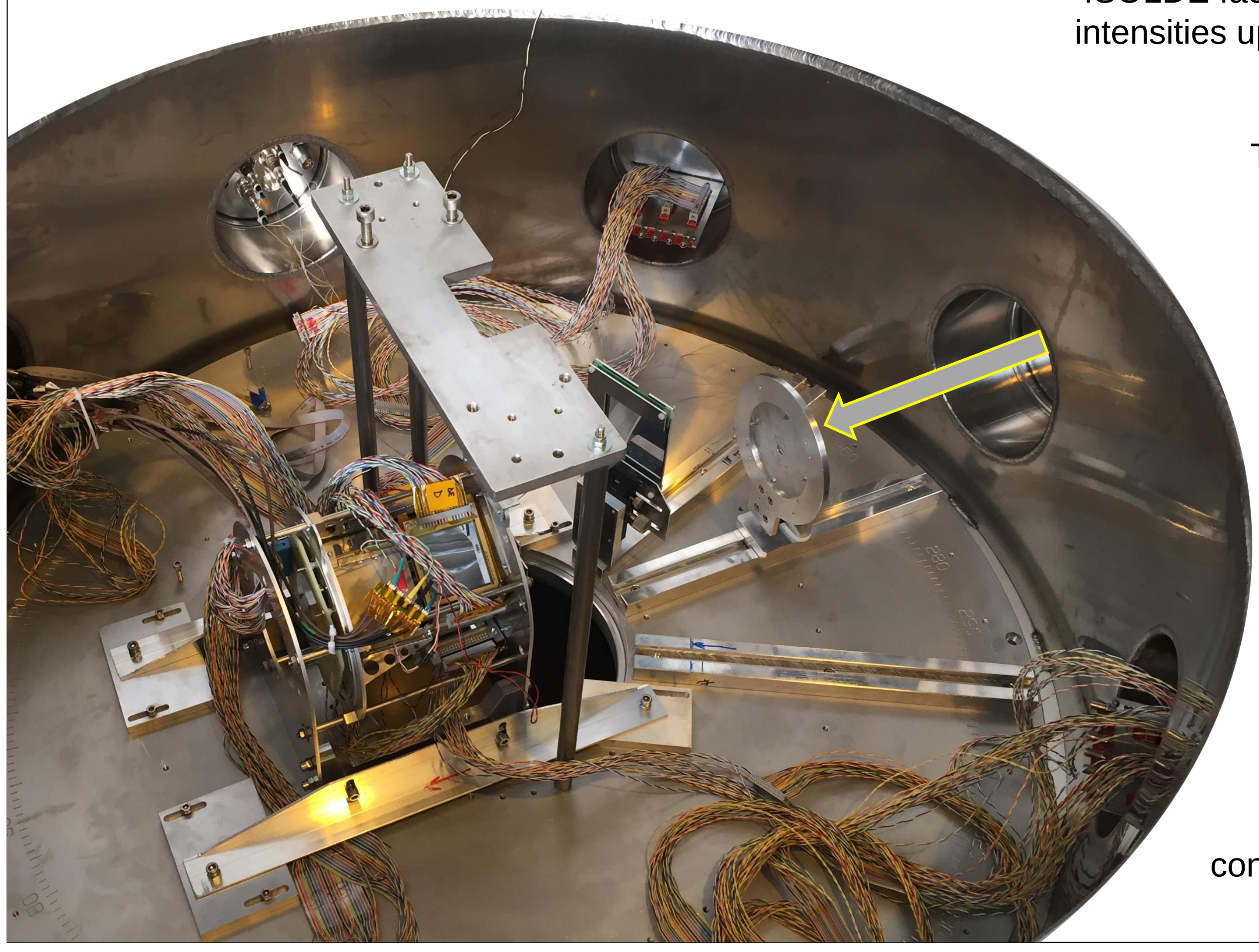

Fig 2. Insight of the SEC vacuum chamber with the silicon detectors placed and connected. Incoming beam direction is indicated.

Physics case & preliminary results

Telescope detectors allow for isotopic identification and the electronic outputs consist of events with several particles in coincidende for every 4 µs time window, so reaction channel selection is feasible. 2n transfer to ^{11}Li consists of [1,4]:

$$ {}^{9}Li + {}^{3}H \rightarrow {}^{11}Li + p \qquad {}^{11}Li\,(g.s.)\left\{\begin{matrix} T_{1/2} = 8.75\,ms \\ Q_{\beta^-} = 20.55\,MeV \end{matrix}\right\} to\,{}^{11}Be\,(>94\%) $$ [3]

Due to half-life reasons, a reaction in inverse kinematics [4] is required experimentally, with the heavy and most unstable particle as projectile. Energy and momenta conservation lead to the resulting proton to recoil at very backward angles after the reaction (in lab. system i.e. 138-160 degrees expected). Its detection is the main sign of ^{11}Li population and its energy would show the excited state from which it was produced.

Previous works [1] have observed this kind of transfer reaction to study lighter Li isotopes and now tritium target implies a new step in this research line. The first rough analysis evidence the 2n pick-up in the expected energy range of the ^{11}Li excited states.

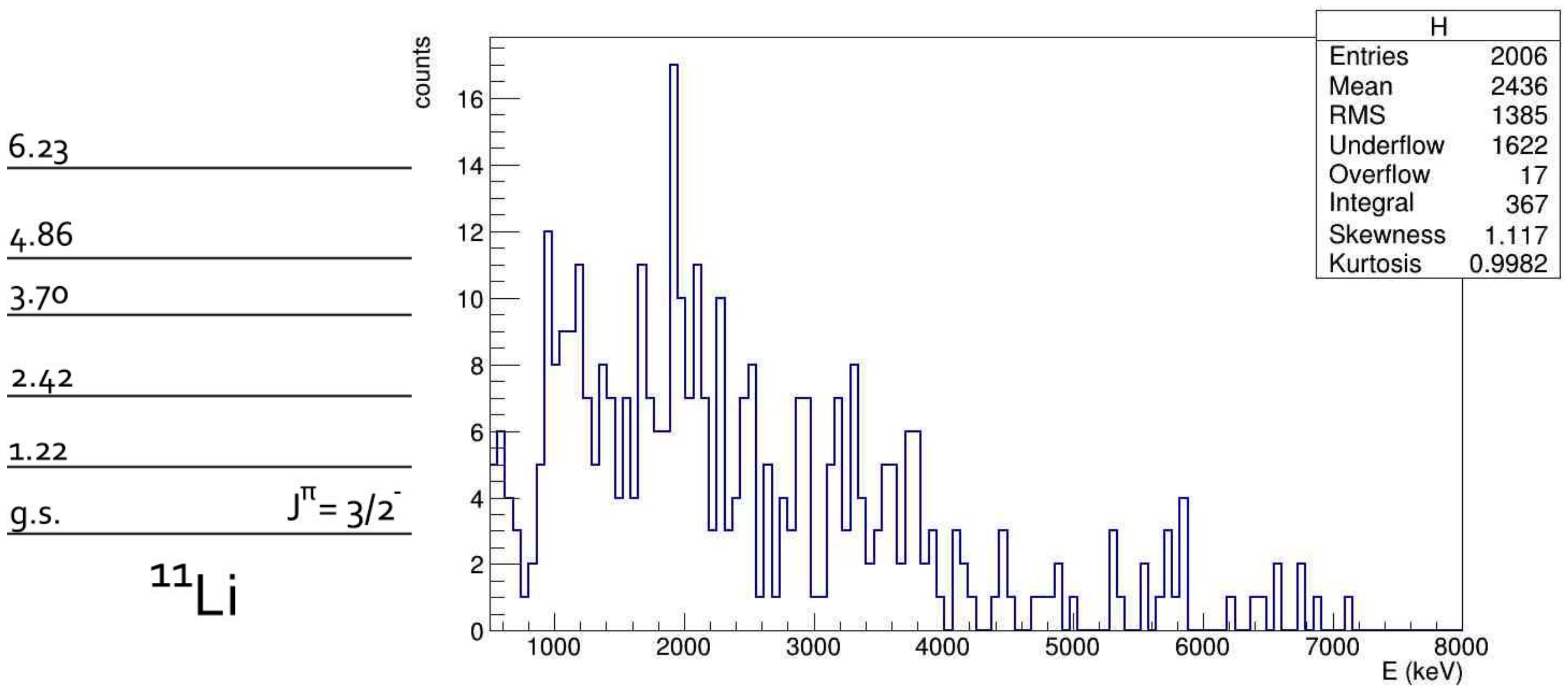

Fig 3. Left: Known excited structure of ^{11} Li [3].
Right: Hits recorded in a DSSD at backward angles in anti-coincidence with its pad. Counts due to the reaction of interest with ^{3}H are directly observed in the expected range of energy of the excited states of ^{11}Li.

Summary & outlook

- ❑ Charged particles and neutrons resulting from the ^{9}Li + ^{3}H reaction at 8MeV/u (lab. energy) have been measured with silicon detectors and plastic scintillators+PMTs arrays in an optimized configuration.
- ❑ The 2-neutron transfer channel to populate ^{11}Li has been observed looking at the outgoing proton that remains from ^{3}H, which is ejected at backwards angles by conservation laws.
- ❑ A more precise calibration of the detectors is currently in progress to consider dead layer corrections and other effects.
- ❑ A background substraction and a fine channel selection are still to be done, as well as the ^{11}Li excited structure characterization.

References

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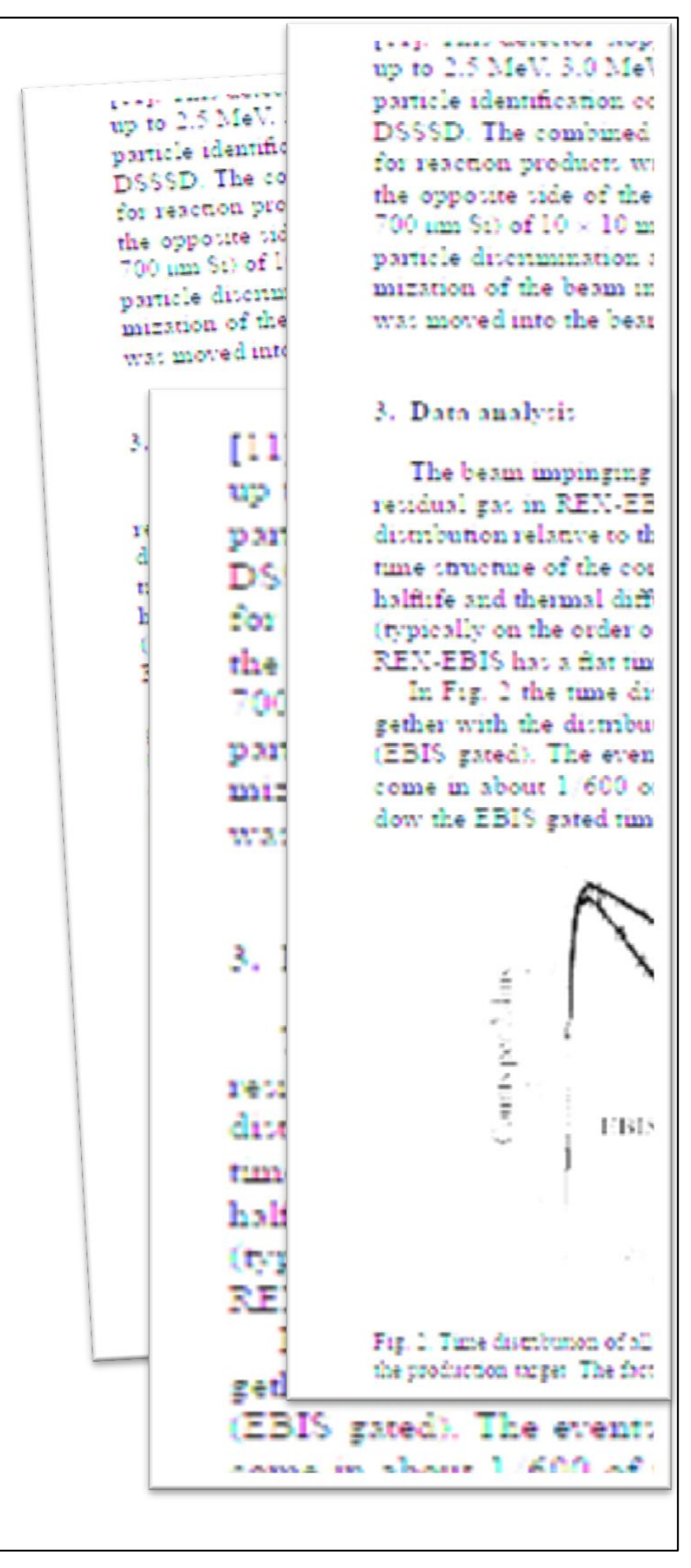

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Send e-mail to: j.diaz@csic.es