Direct Observation of Proton Emission in ^{11}Be: experimental evidence and future developments

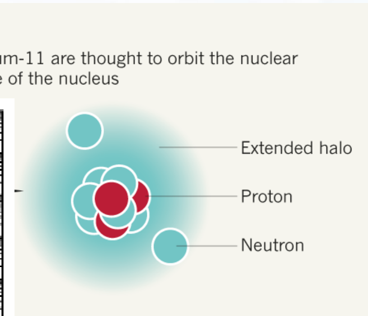
Y. Ayyad

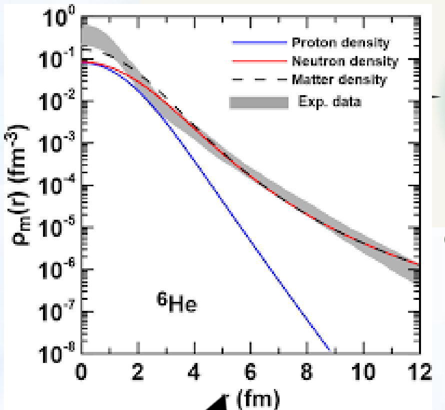
U.S. National Science Foundation (NSF) Cooperative Agreement No. PHY-1565546 and GrantNo. PHY-1713857

28/06/2021

From nuclear structure to dark matter

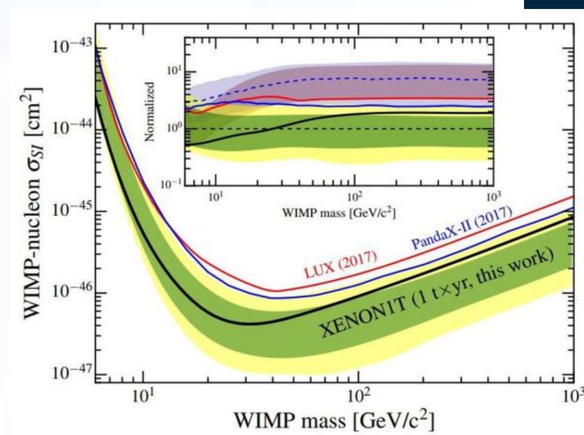
Nuclear structure and halo nuclei

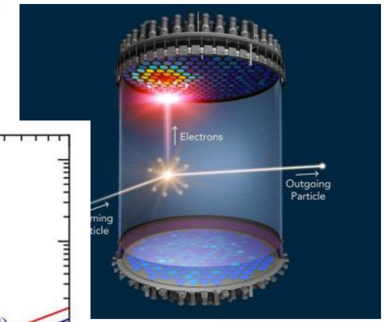


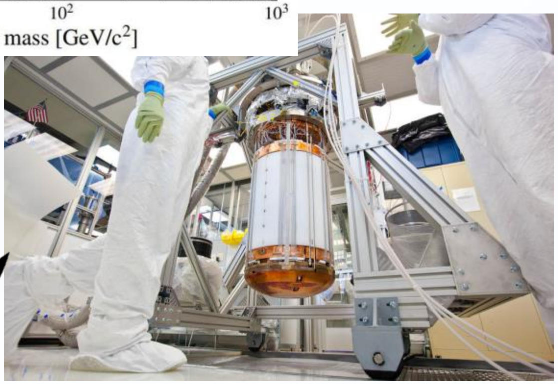


Credit: Nature, February 20, 2018, doi: 10.1038/d41586-018-02221-9

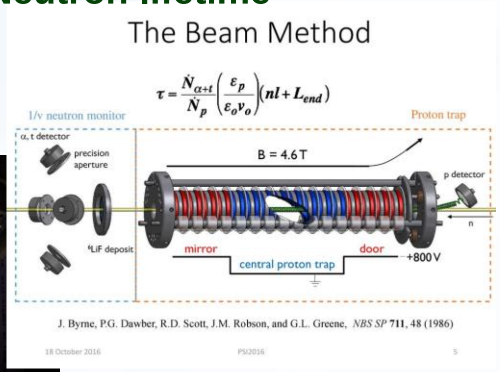
Dark matter

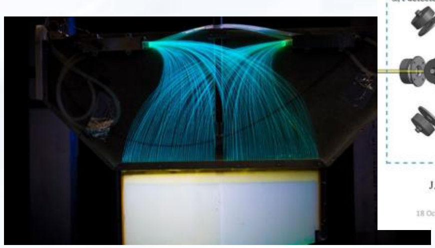






Neutron lifetime





Neutron lifetime puzzle

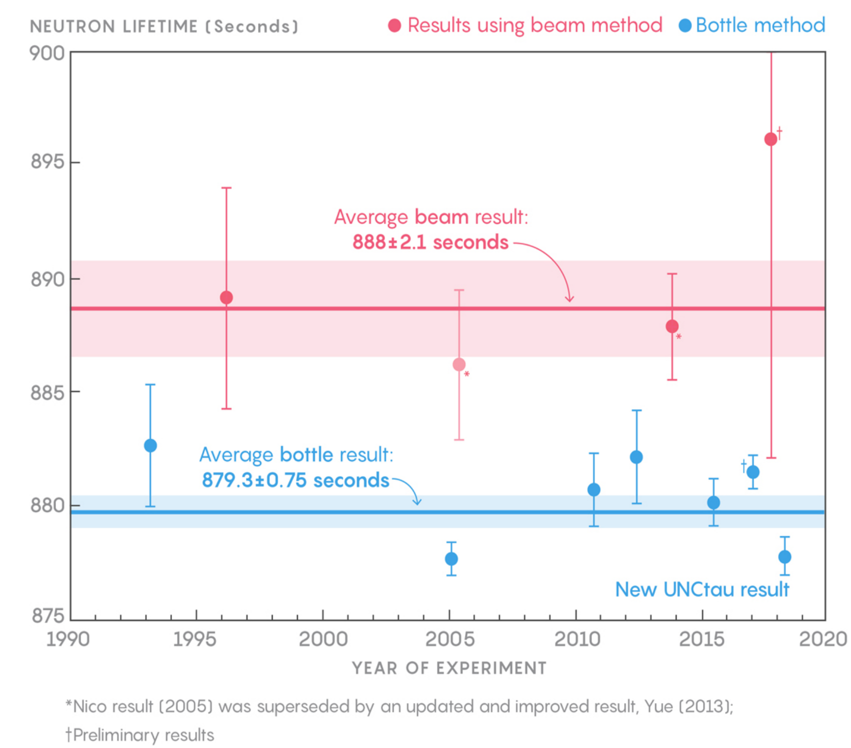
Free neutron can β^- into a proton

In beam method counts number of protons created

In bottle method counts number of neutrons disappearing

Both results are ~4σ away

Different observables measuring different decay modes?

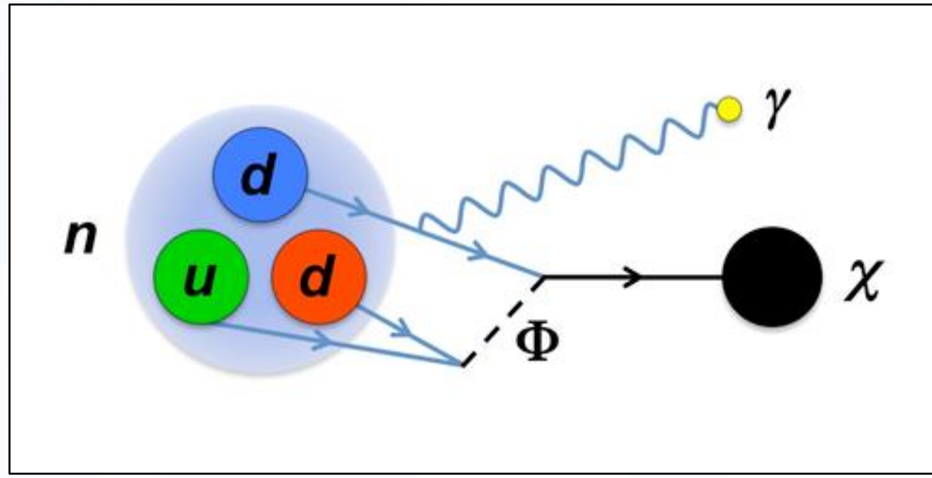


Adapted from www.quantama

Neutron dark decay

Recently, Fornal and Grisntein suggested that the neutron could decay to a dark matter particle

A branching ratio of ~1% would explain the neutron lifetime puzzle



PHYSICAL REVIEW LETTERS **120,** 191801 (2018)

Editors' Suggestion   Featured in Physics

Dark Matter Interpretation of the Neutron Decay Anomaly

Bartosz Fornal and Benjamín Grinstein

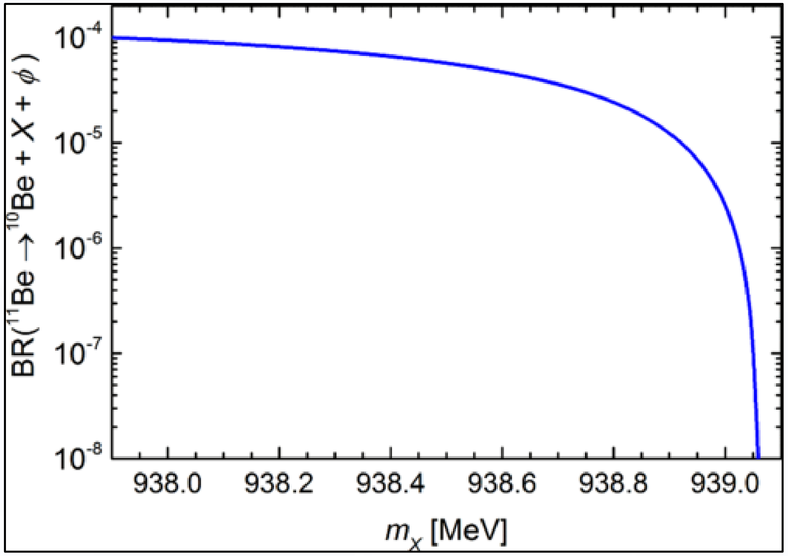
Department of Physics, University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093, USA

(Received 19 January 2018; revised manuscript received 3 March 2018; published 9 May 2018)

Fornal and Grisntein PRL **120**, 191801(2018)

Neutron dark decay in nuclei

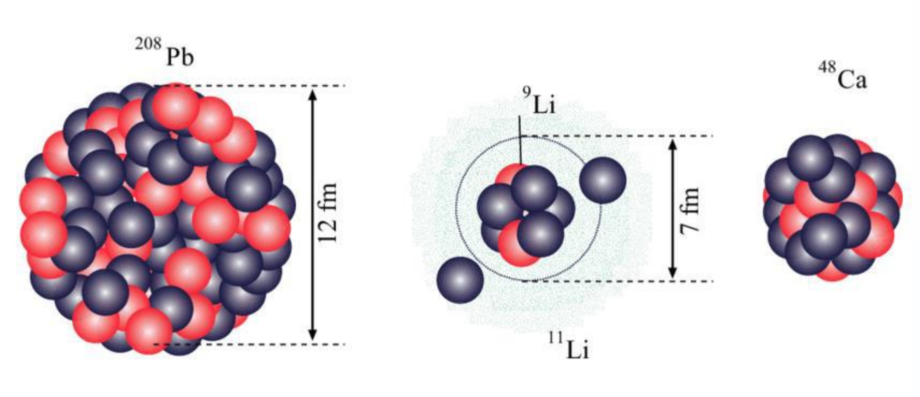
- Fornal and Gristein already suggested that neutron dark decay could occur in nuclei with S_n<1.572 MeV
- **^{11}Be is the best candidate**
- $^{11}Be \rightarrow {}^{10}Be + \chi$
- Branching ratio upper limit of 10^{-4}, depending on the dark particle mass

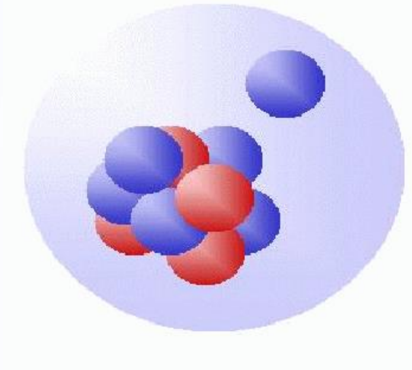


Pfutzner, PRC **97**, 042501 (2018)

β⁻-delayed proton emission

- ^{11}Be is a halo nucleus
- Wave functions of the halo neutron and core can be treated independently
- The neutron can decay into a proton above the ^{11}B binding energy.
- Beta-delayed proton emission is possible if Sn<(mn−mp−me)c2≈0.782 MeV. Qbp = 280 keV.
- ^{11}Be → ^{10}Be + p



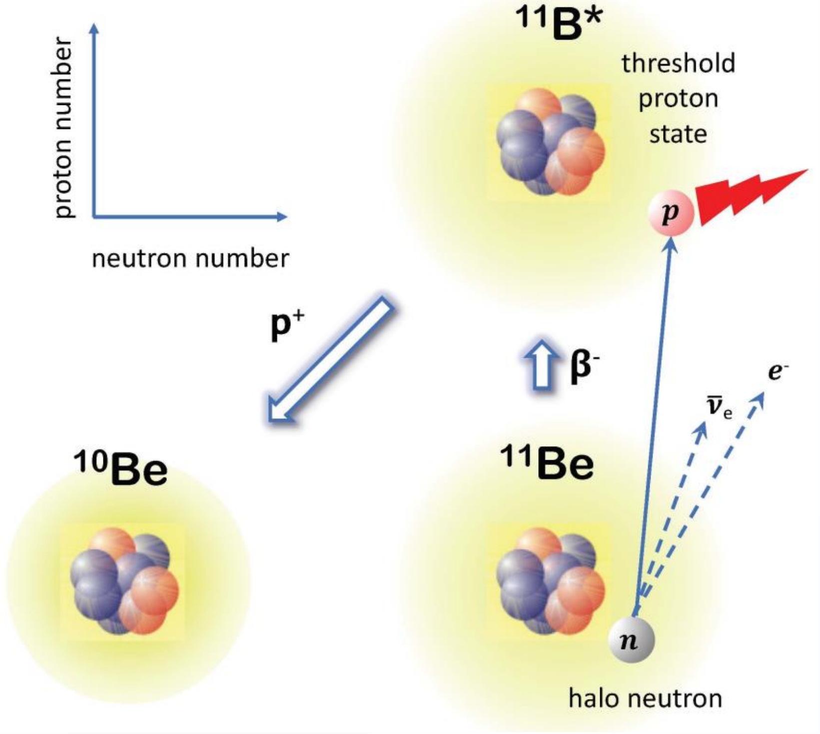


^{11}Be

Riisager, Phys. Scr. **T152,** 014001 (2013)

β⁻-delayed proton emission

- ^{11}Be is a halo nucleus
- Wave functions of the halo neutron and core can be treated independently
- The neutron can decay into a proton above the ^{11}B binding energy.
- Beta-delayed proton emission is possible if $S_n<(m_n-m_p-m_e)c^2\approx 0.782$ MeV. Qbp = 280 keV.
- ^{11}Be → ^{10}Be + p (Very low energy!)

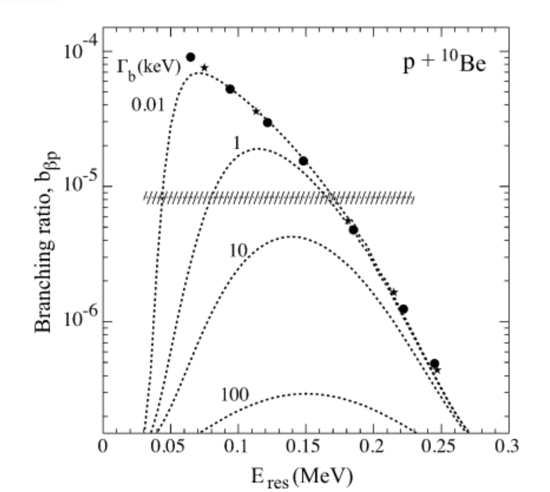


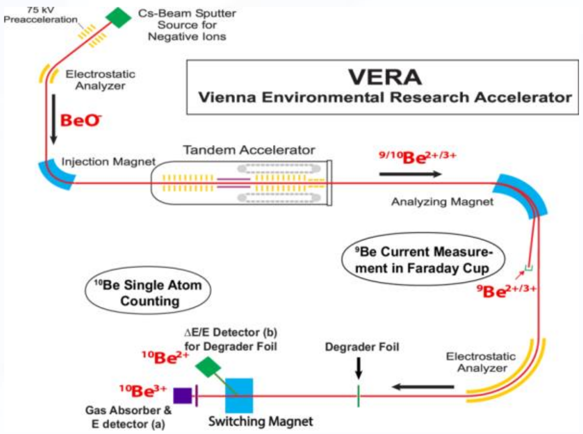
Phys. Rev. Lett. **124**, 042502

^{11}Be β$^-$-delayed proton emission

- Riisager *et al.* implanted ^{11}Be in a catcher and let it decay
- Then analyzed the ratio of ^{10}Be/ ^{11}B in the catcher with the accelerator mass spectrometry technique
- Deduced that the ^{11}Be → ^{10}Be branching ratio was $8.3(9)\cdot10^{-6}$
- This value is orders of magnitude higher than theoretical predictions
- An unobserved resonance in ^{11}B could explain it
- Or another ^{11}Be → ^{10}Be unknown branch…

Riisager, Phys. Scr. **T152,** 014001 (2013)
Riisager, PLB **732** 305 (2014)





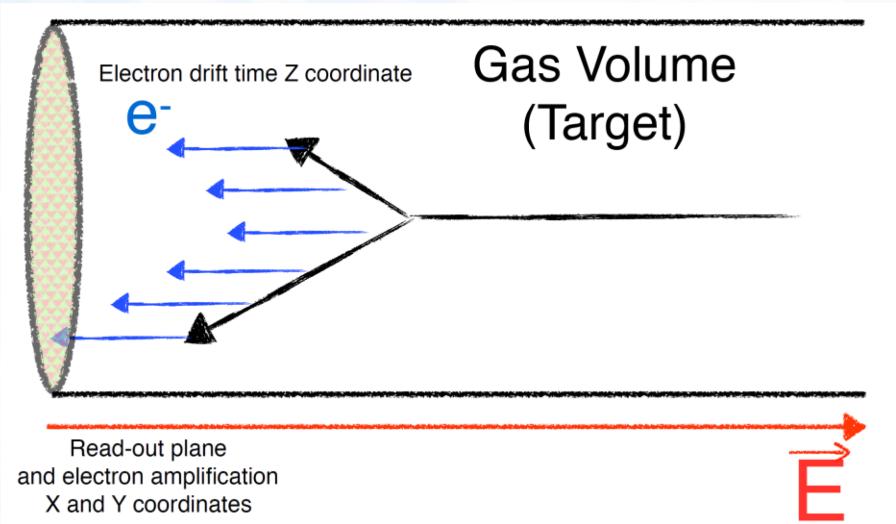
Neutron dark decay in nuclei

Riisager *et al.* measured the combination of all decay branches leading to $^{11}Be \rightarrow {}^{10}Be$ (*n* disappearing)

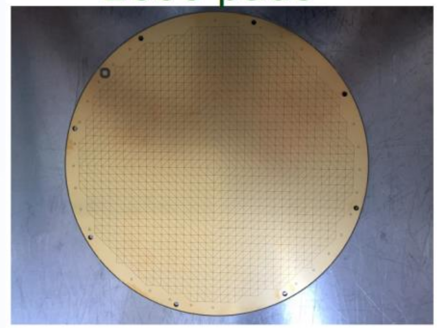
This experiment specifically measured the $^{11}Be \rightarrow {}^{10}Be + p^+$ branch (p^+ appearing)

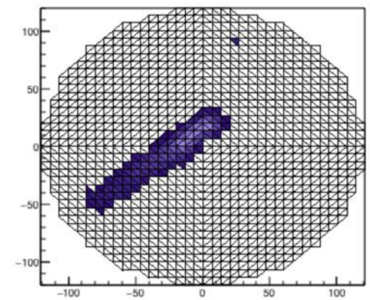
Any discrepancy between both results would be an indication of unaccounted decay branches, with the dark decay as a very likely candidate

Active Target Time Projection Chamber

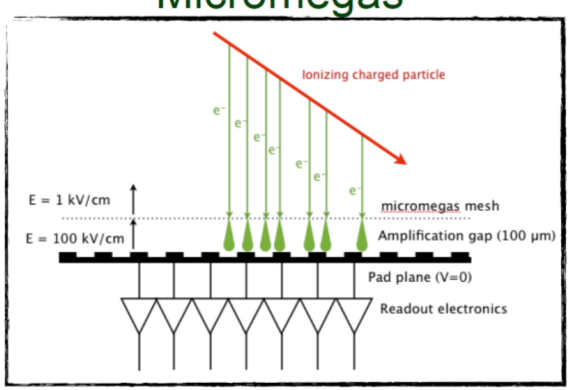


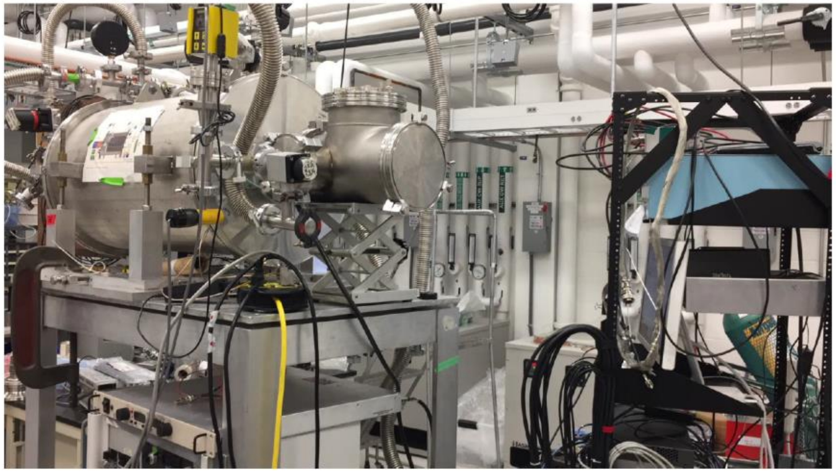
2000 pads





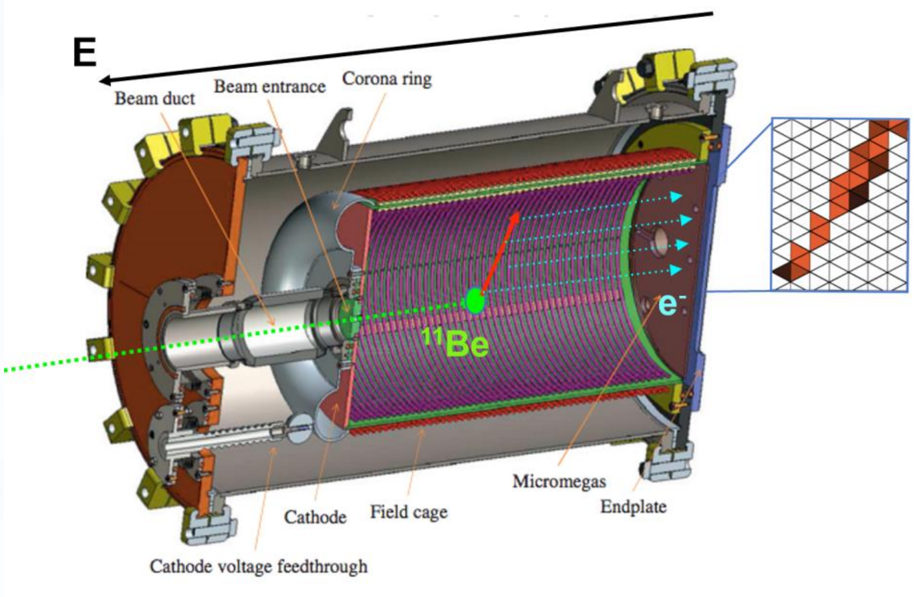
Micromegas





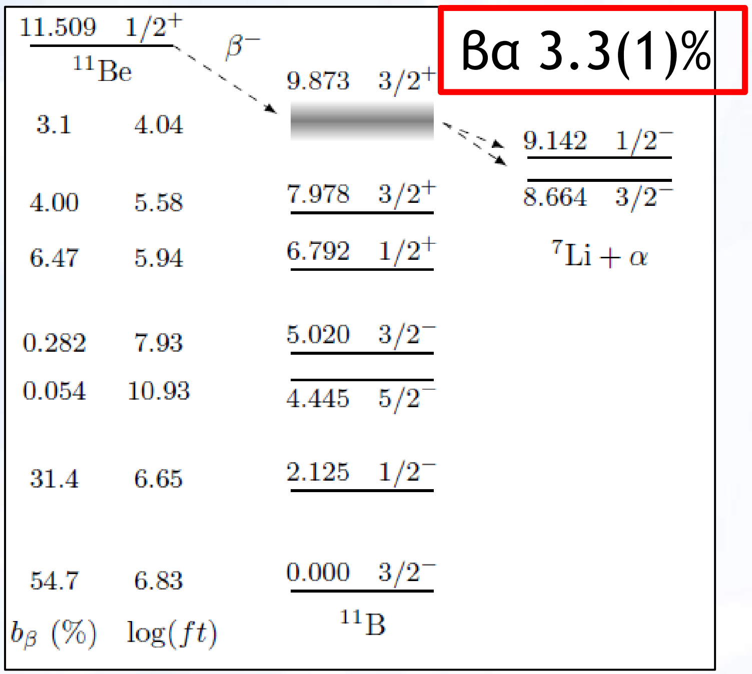
Experiment at TRIUMF (ISAC-I)

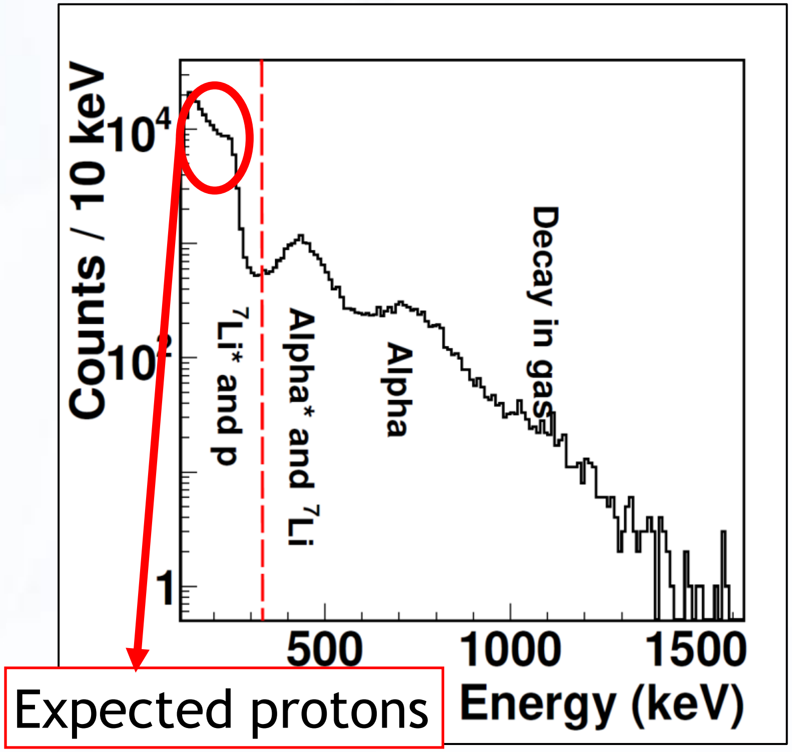
- Implant-decay on the pAT-TPC
- High detection efficiency (80%) and resolution ($\sigma(E)$~5%, $\sigma(\theta)$=1 deg)
- Full reconstruction and identification of p and α
- He(+10% CO_2) as thin tracking medium: low straggling and β-blind
- ^{11}Be ions drifted to the cathode
- Protons of ~180 keV stopped in 10 cm tracks



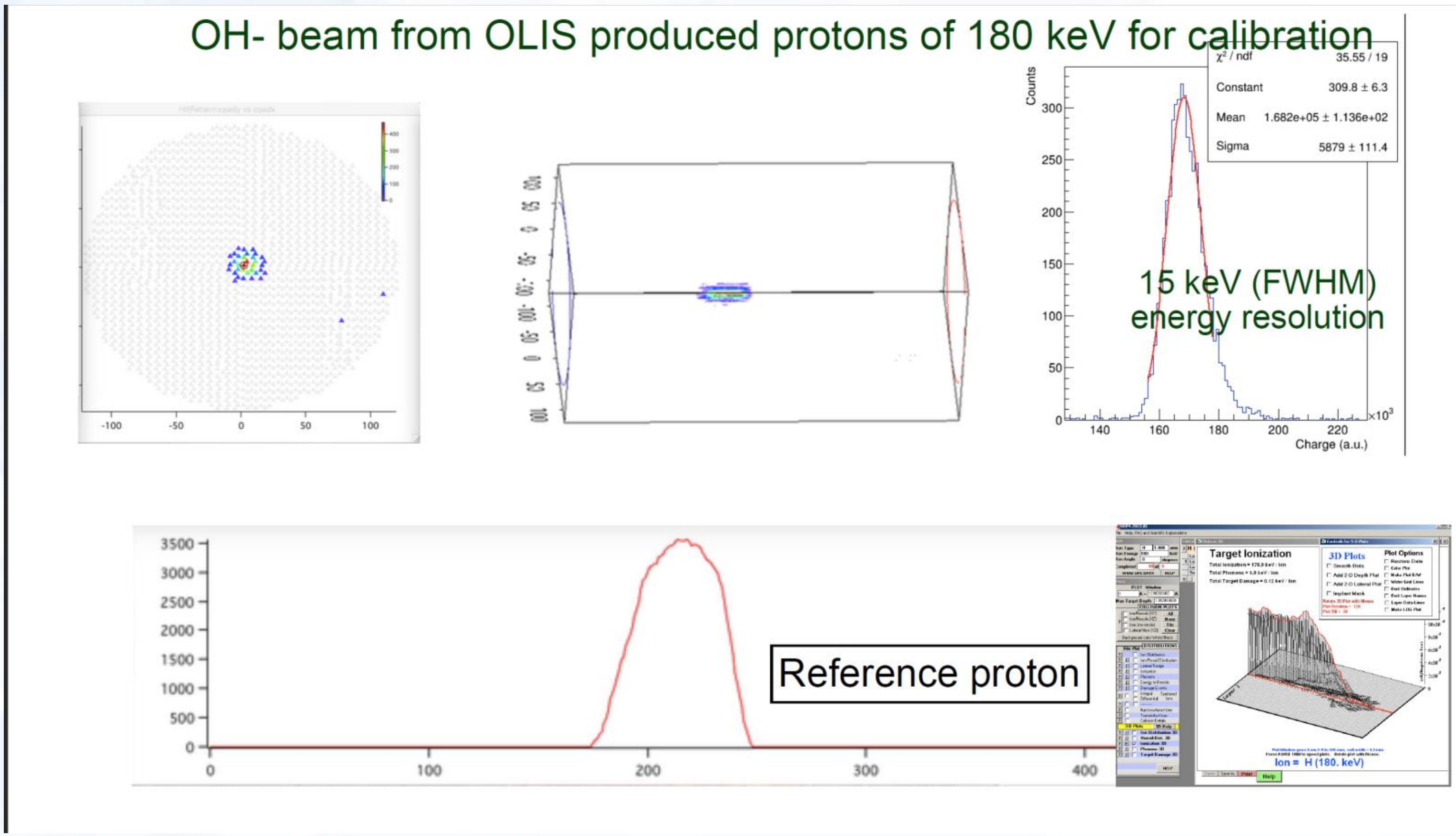
Suzuki, NIMA **691**, 39-54 (2012)

Energy spectra

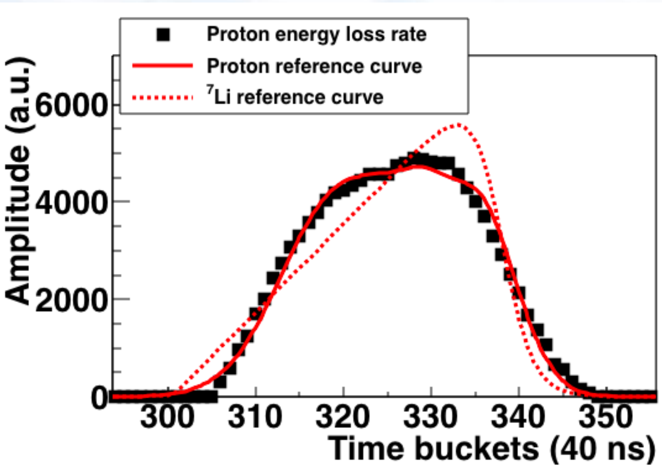


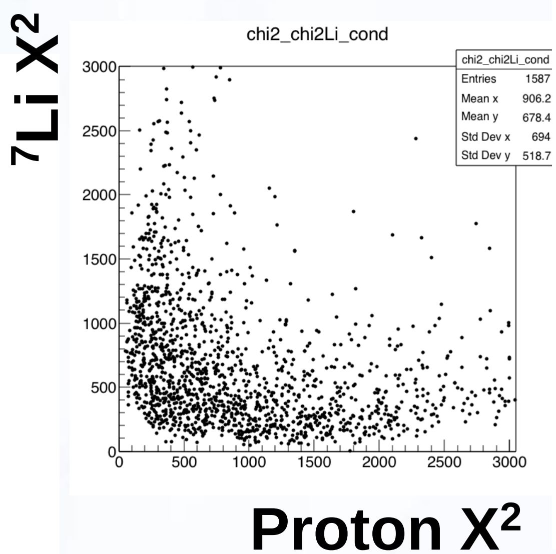


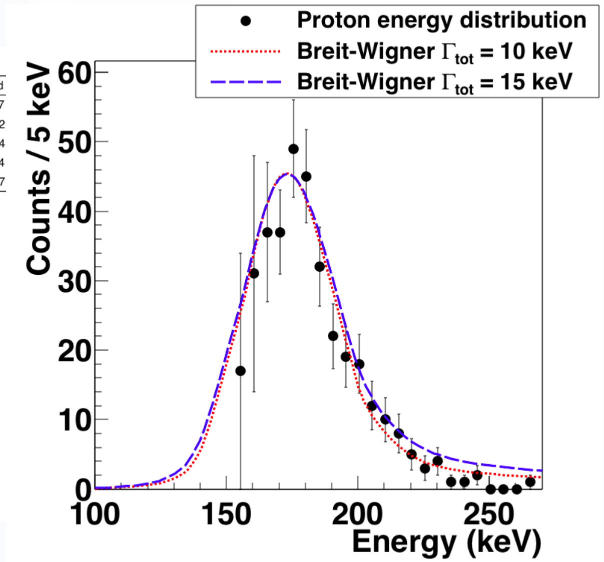
Proton beam calibration

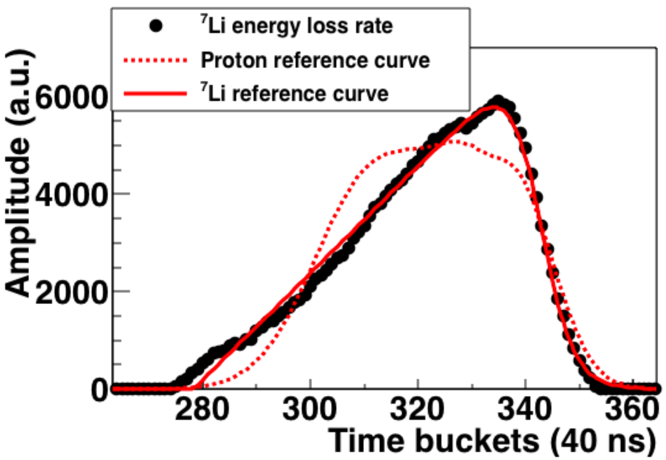


Y. Ayyad *et al*.
Phys. Rev. Lett. 123, 082501 – Published 22 August 2019;
Erratum Phys. Rev. Lett. 124, 129902 (2020)









- First direct observation of β^-p in a neutron-rich nuclei.
- Branching ratio is 1.2×10^{-5} , with 30% uncertainty… Theoretical calculations yield 8.0×10^{-6}.
- A narrow resonance (12 keV) in ^{11}B was inferred. E = 11425(20)keV, Γ=12(5) keV, Jπ = 1/2;3/2+
- Decay into the continuum would be characterized by a much shorter branching ratio (10^{-10}).

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Unha maneira de facer Europa

Theory tries to reproduce the result

PHYSICAL REVIEW LETTERS **124**, 042502 (2020)

Convenient Location of a Near-Threshold Proton-Emitting Resonance in ^{11}B

J. Okołowicz,[1] M. Płoszajczak,[2] and W. Nazarewicz[3]
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[2]*Grand Accélérateur National d'Ions Lourds (GANIL), CEA/DSM—CNRS/IN2P3, BP 55027, F-14076 Caen Cedex, France*
[3]*Department of Physics and Astronomy and FRIB Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*

(Received 10 October 2019; published 29 January 2020)

The presence of clusterlike narrow resonances in the vicinity of reaction or decay thresholds is a ubiquitous phenomenon with profound consequences. We argue that the continuum coupling, present in the open quantum system description of the atomic nucleus, can profoundly impact the nature of near-threshold states. In this Letter, we discuss the structure of the recently observed near-threshold resonance in ^{11}B, whose very existence explains the puzzling beta-delayed proton emission of the neutron-rich ^{11}Be.

DOI: 10.1103/PhysRevLett.124.042502

2020 Fall Meeting of the APS Division of Nuclear Physics
Thursday–Sunday, October 29–November 1 2020; Time Zone: Central Time, USA

Session DD: Nuclear Theory I: Structure and Reactions
8:30 AM–10:18 AM, Friday, October 30, 2020

Chair: Charlotte Elster, Ohio University

Abstract: DD.00008 : Ab-initio analysis of β-delayed proton emission in ^{11}Be*
9:54 AM–10:06 AM

Preview Abstract ← Abstract →

Authors:
Mack Atkinson
(TRIUMF)

Petr Navratil
(TRIUMF)

The exotic β-delayed proton emission is calculated in ^{11}Be from first principles using chiral two- and three-nucleon forces. To investigate the unexpectedly large branching ratio measured in [PRL 123, 082501 (2019)] we calculate the proposed $1/2^+$ proton resonance in ^{11}B using the no-core shell model with continuum (NCSMC). This timely calculation helps to resolve whether this large branching ratio is caused by unknown dark decay modes or an unobserved proton resonance.

In favor

epl A Letters Journal Exploring the Frontiers of Physics
April 2020
EPL, **130** (2020) 12001 www.epljournal.org
doi: 10.1209/0295-5075/130/12001

Assessment of the beta-delayed proton decay rate of ^{11}Be

A. Volya

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Cyclotron Institute, Texas A&M University - College Station, TX 77843, USA

received 24 February 2020; accepted in final form 24 April 2020
published online 13 May 2020

PACS 21.10.Tg – Lifetimes, widths
PACS 23.50.+z – Decay by proton emission
PACS 21.60.Cs – Shell model

Abstract – The ^{11}Be neutron halo nucleus appears to decay into ^{10}Be with a rate that exceeds expectations. Neutron disappearance into dark matter, beta decay of a halo neutron, or beta-delayed proton decay have been offered as explanations. In this work we study the latter option; we carry out shell model calculations and sequential decay analysis examining the beta-delayed proton decay going through a resonance in ^{11}B. The narrow energy window, lack of states with sufficient spectroscopic strength, overwhelming alpha decay branch, all make reconciling the observed rate with beta-delayed proton decay difficult.

editor's choice

Against

Criticisms

Comment on "Direct Observation of Proton Emission in ^{11}Be"

H.O.U. Fynbo,[1] Z. Janas,[2] C. Mazzocchi,[2] M. Pfützner,[2,*] J. Refsgaard,[3,4] K. Riisager,[1] and N. Sokołowska[2]

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[4]*TRIUMF, 4004 Wesbrook Mall, Vancouver BC, V6T 2A3 Canada*

We argue that conclusions of [PRL 123, 082501 (2019)] are incorrect. The authors present the direct observation of beta-delayed proton emission in the beta decay of ^{11}Be. From the determined branching ratio for this process and from the energy spectrum of emitted protons the existence of a so
in ^{11}B was deduced. The given beta strength for the transition to this state is
show that the combination of peak position and branching ratio is in strong
sidered by the authors. Furthermore, we identify several deficiencies in the a
sources of background, that could explain the error.

- No reliable particle identification
- B(GT)>3 (above free single nucleon decay limit)

Eur. Phys. J. A (2020) 56:100
https://doi.org/10.1140/epja/s10050-020-00110-2

THE EUROPEAN PHYSICAL JOURNAL A

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Regular Article - Experimental Physics

Search for beta-delayed proton emission from ^{11}Be

K. Riisager[1,a], M. J. G. Borge[2,3], J. A. Briz[3], M. Carmona-Gallardo[4], O. Forstner[5], L. M. Fraile[4], H. O. U. Fynbo[1], A. Garzon Camacho[3], J. G. Johansen[1], B. Jonson[6], M. V. Lund[1], J. Lachner[5], M. Madurga[2], S. Merchel[7], E. Nacher[3], T. Nilsson[6], P. Steier[5], O. Tengblad[3], V. Vedia[4]

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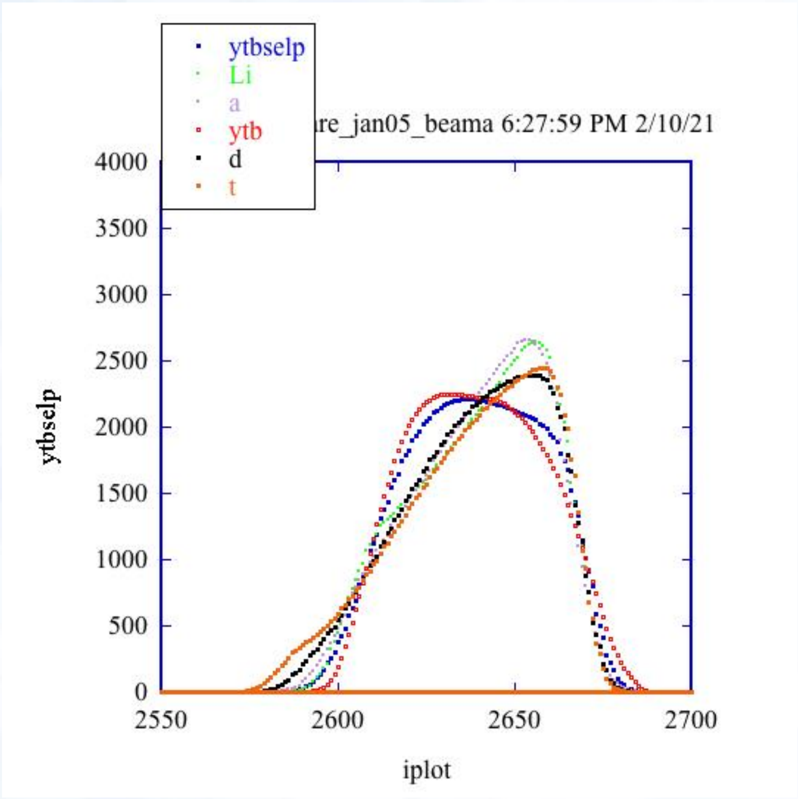
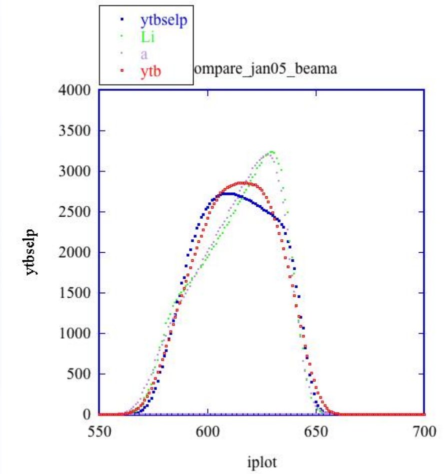
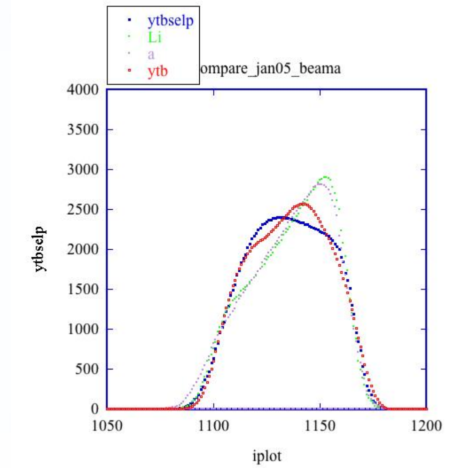
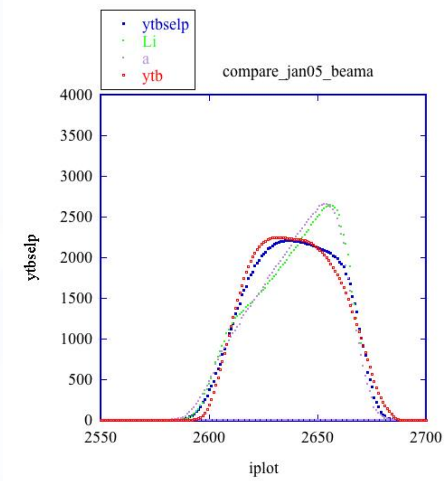
Communicated by Klaus Blaum

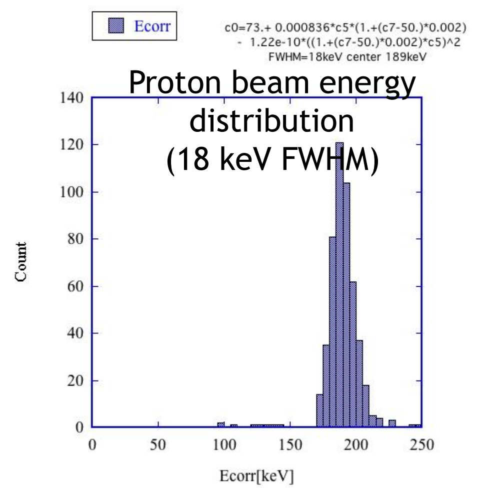
Particle identification: p,d,t,alpha and ^{7}Li









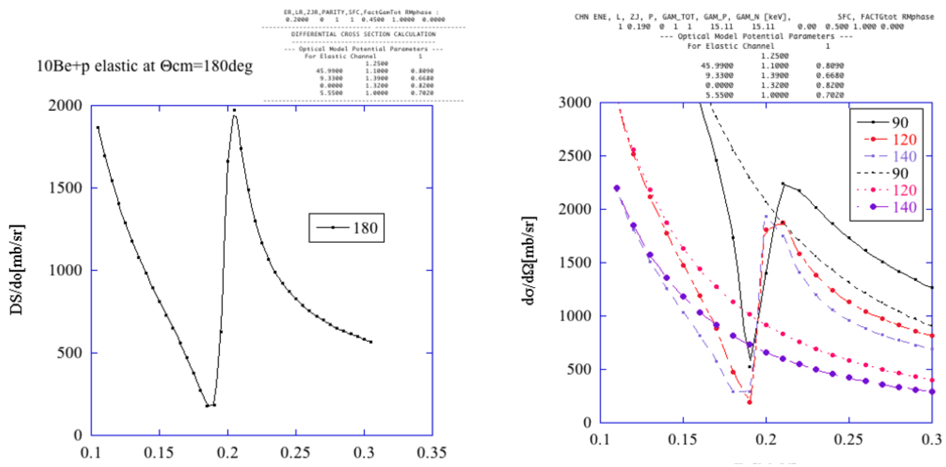


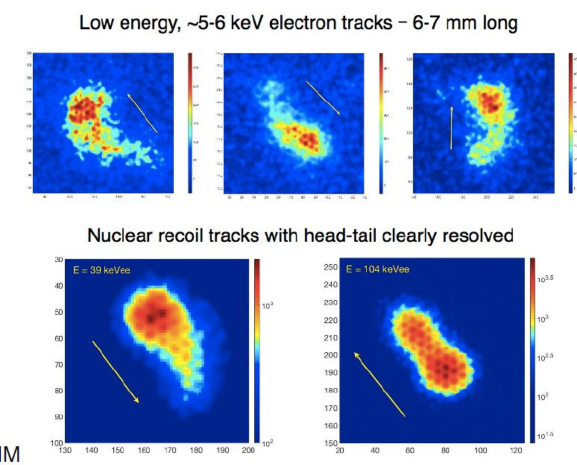
Beta-delayed proton emission in ^{11}Be: reanalysis and outlook

- A new particle ID has been developed including d, t and ^{4}He energy loss curves.
- The Chi-squared test has been redefined: normalization to the number of points (it didn't actually change anything).
- Instead of projecting the calculated energy loss curves, we have projected the one of the particle to analyze into its direction.
- We have obtained a very similar branching ratio.
- This does NOT rule out the possibility of populating the IAS of ^{11}B.
- Manuscript in preparation (W. Mittig, Y. Ayyad and D. Bazin)

IGFAE Instituto Galego de Física de Altas Enerxías · USC Universidade de Santiago de Compostela · XUNTA DE GALICIA

- **Direct measurement of 10Be+p at 400 keV/u at ReA3 (Y. Ayyad. Search for near-threshold narrow resonances. July 2021)**
- Possibility of measuring the ^{10}Be recoil (20 keV) with a Optical TPC for directional dark matter search.
- Development of a MTHGEM with finer pitch to increase primary luminescence in CF_4. This will enhance electron-heavy recoil rejection capabilities (production started by CERN MPGD team).
- Other opportunities: Combined measurement of heavy recoil and neutron in beta-delayed neutron emission.
- Other proton/neutron emission studies at ReA (NSCL) and at GEEL (^{10}Be+n)





D Loomba, UNM

- We have observed the emission of protons in neutron-rich nuclei after β-decay.
- The particle identification was done using the characteristic Bragg curves for decaying particles detected in a Time Projection Chamber.
- We have obtained consistent results using two complementary methods.
- Future experiments to improve the sensitivity of our detection setup are planned.

Thank you for your attention!

galicia
Xacobeo 2021
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Unha maneira de facer Europa
UNIÓN EUROPEA
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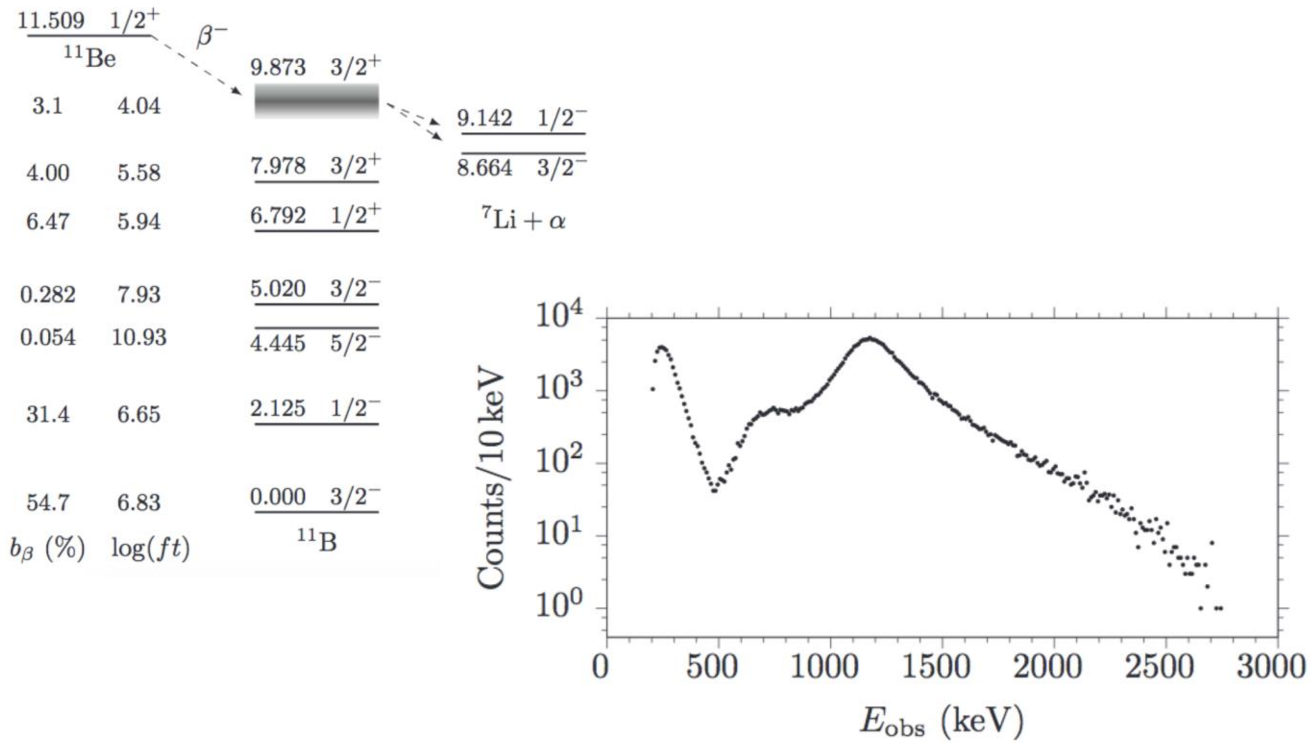
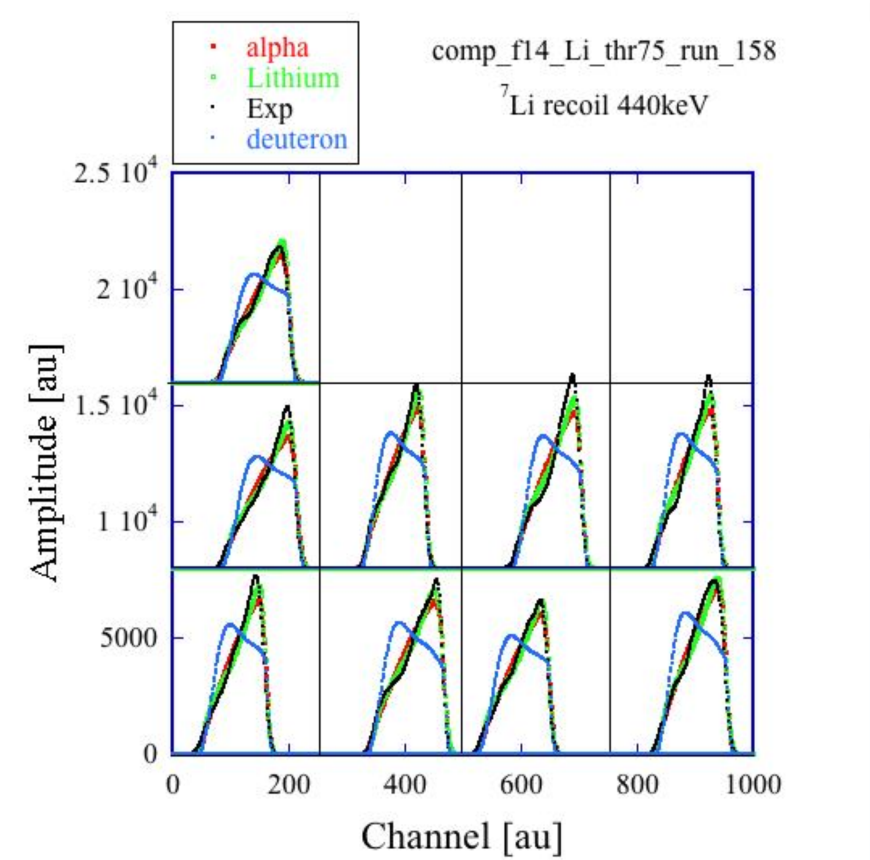

11.509 1/2+
11Be
β−
9.873 3/2+
3.1 4.04
9.142 1/2−
8.664 3/2−
4.00 5.58 7.978 3/2+
6.47 5.94 6.792 1/2+
7Li + α
0.282 7.93 5.020 3/2−
0.054 10.93 4.445 5/2−
31.4 6.65 2.125 1/2−
54.7 6.83 0.000 3/2−
bβ (%) log(ft) 11B
Counts/10 keV
10^4
10^3
10^2
10^1
10^0
0 500 1000 1500 2000 2500 3000
Eobs (keV)

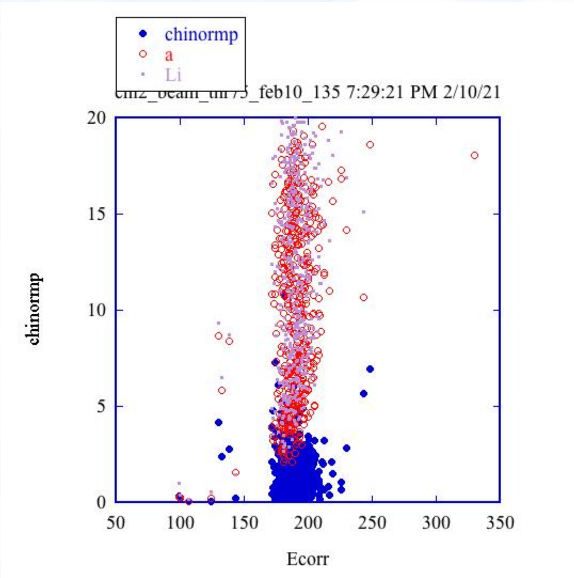
Particle identification: p,d,t,alpha and ^{7}Li



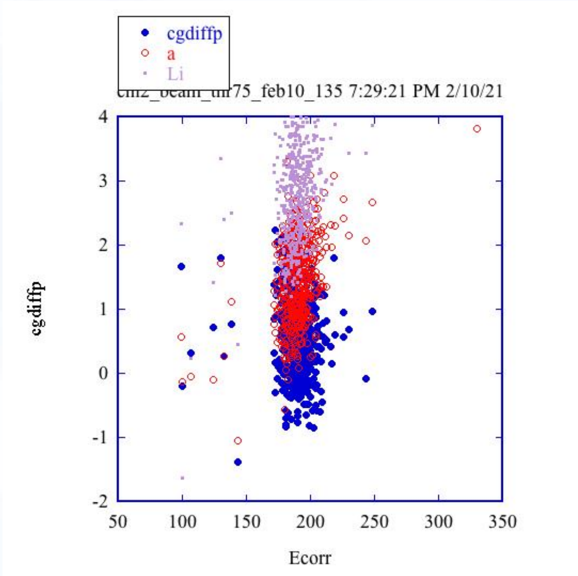
Criteria for proton event selection

- Proton beam events are used to assess the selection parameters.
- Chi2, center of gravity (shape of the pulse) and stretch factor.

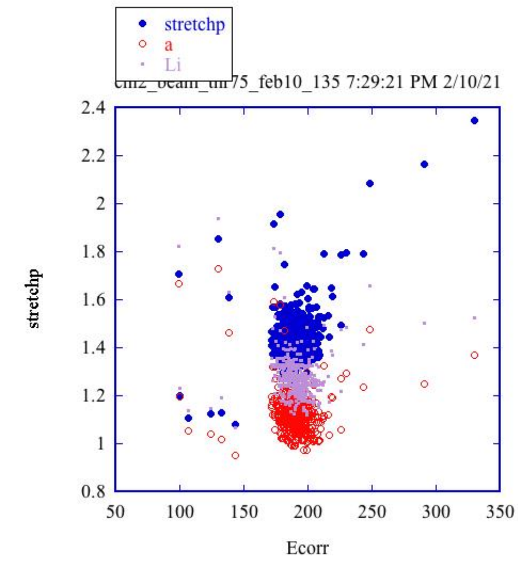
Chi2



Center of gravity

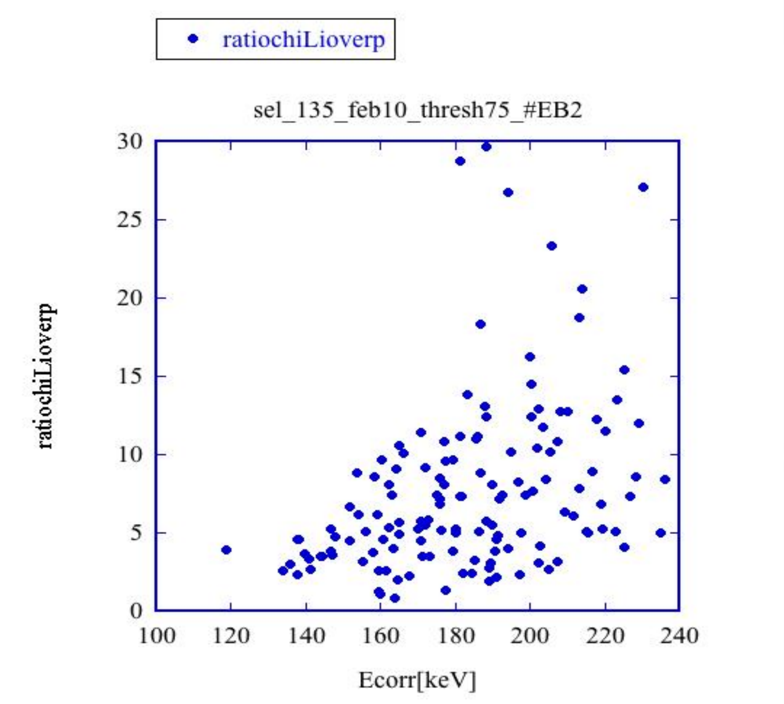


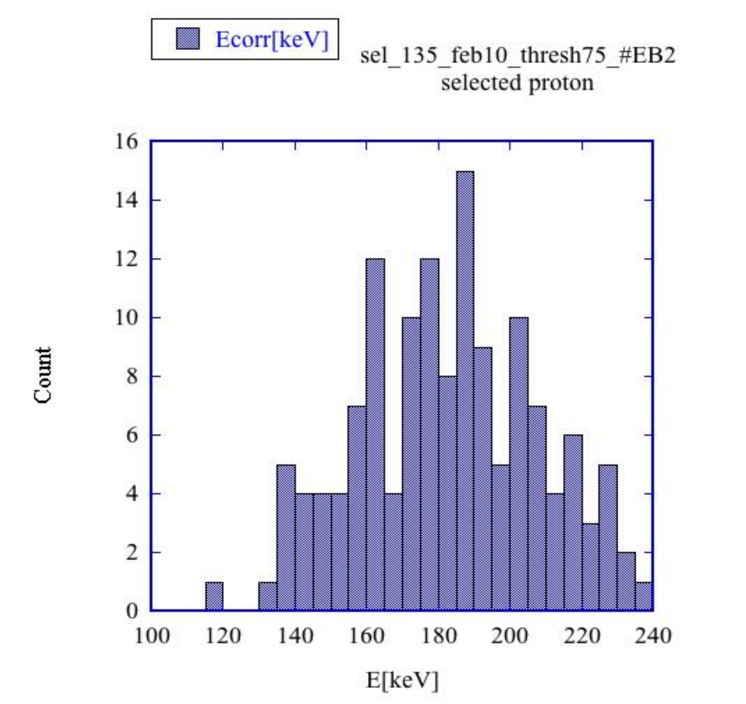
Stretch



Criteria for proton event selection

- Proton beam events are used to assess the selection parameters.
- Chi2, center of gravity (shape of the pulse) and stretch factor.
- This method is complementary to the one we used before: no selection in chi2.
- The energy distribution obtained in the last analysis is compatible with the published result.





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