ZAKOPANE CONFERENCE on Nuclear Physics 2026
Extremes of the Nuclear Landscape

Search for the γ decay from near-threshold states in ^{11}B and ^{14}C

Fabio Conca
Università degli Studi di Milano & INFN

On behalf of the ^{11}B collaboration:

F. Conca[1,2], G. Corbari[1,2], S. Bottoni[1,2], S. Leoni[1,2], G. Benzoni[2], C. Boiano[2], S. Brambilla[2], F. Camera[1,2], S. Capra[1,2], F.C.L. Crespi[1,2], D. Genna[1,2], A. Giaz[2], M. Luciani[1,2], B. Million[2], G. Secci[1,2], O. Wieland[2], B. Fornal[3], M. Ciemała[3], A. Maj[3], P. Bednarczyk[3], N. Cieplicka-Oryńczak[3], K. Gajewska[3], Ł. Iskra[3], M. Kmiecik[3], M. Matejska-Minda[3], K. Mazurek[3], D. Mengoni[4], F. Galtarossa[4], J.J. Valiente-Dobón[5,6], A.Gottardo[5], A. Goasduff[5], M. Balogh[5,7], A. Gadea[6], J.A. Dueñas[8], A.M. Sánchez-Benítez[8], C. Mihai[9], S. Pascu[9], R. Liçă[9], R. Mărginean[9]

[1]Università degli Studi di Milano, Milan, Italy, [2]INFN Sezione di Milano, Milan, Italy, [3]IFJ PAN, Krakow, Poland, [4]Università degli studi di Padova and INFN Sezione di Padova, Padua, Italy, [5]INFN Sezione di Legnaro, Legnaro, Italy, [6]IFIC, CSIC, Valencia, Spain, [7]Slovak Academy of Science, Bratislava, Slovakia, [8]Huelva University, Huelva, Spain, [9]IFIN-HH, Măgurele, Romania

and the AGATA collaboration

On behalf of the ^{14}C collaboration:

G. Corbari[a,b], S. Bottoni[a,b], M. Ciemała[c], F.C.L. Crespi[a,b], B. Fornal[c], S. Leoni[a,b], R.V.F. Janssens[d,e], S.D. Pain[f], M. Siciliano[g], E. Albanese[a,b], A.D. Ayangeakaa[d,e], G. Benzoni[b], S. Carmichael[h], M. Carpenter[g], K. Chipps[f], N. Cieplicka-Oryńczak[c], J.A. Cizewski[i], P. Copp[g], M. Febbraro[f], J. Forson[j], E. Gamba[a,b], H. Garland[i], G. Gilardy[i], J. Hooker[j], Ł. Iskra[c], H. Jayatissa[g], F. Kondev[g], K. Jones[j], M.D. Jones[d], T. Lauritsen[g], J. Li[g], D. Little[d], B. Million[b], C. Müller-Gatermann[g], A. Palmisano[j], M. Polettini[a,b], C. Porzio[a,b], A. Ratkiewicz[k], W. Reviol[g], N. Sensharma[d,e], D. Seweryniak[g], H. Sims[i], S. Stolz[g], R. Toomey[i], C. Ummel[i], O. Wieland[b], G. Wilson[g,l], J. Wu[g], S. Zhu[m], S. Ziliani[a,b]

[a]Università degli Studi di Milano, Milan, Italy, [b]INFN Sezione di Milano, Milan, Italy, [c]IFJ PAN, Krakow, Poland, [d]University of North Carolina at Chapel Hill, North Carolina, USA, [e]Triangle Universities Nuclear Laboratory, Duke University, North Carolina, USA, [f]Oak Ridge National Laboratory, Tennessee, USA, [g]Argonne National Laboratory, Illinois, USA, [h]Notre Dame University, Indiana, USA, [i]Rutgers University, New Jersey, USA, [j]University of Tennessee-Knoxville, Tennessee, USA, [k]Lawrence Livermore National Laboratory, California, USA, [l]Louisiana State University, Louisiana, USA, [m]Brookhaven National Laboratory, New York, USA

Istituto Nazionale di Fisica Nucleare

Outline

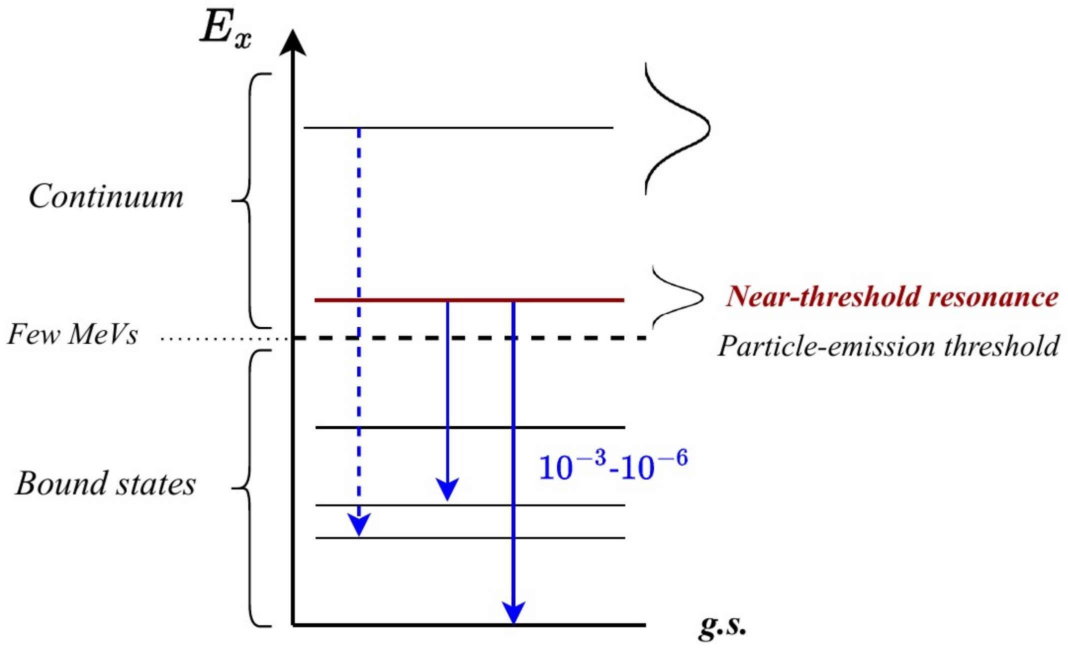
- Light nuclei as open quantum systems
- The ^{11}B case: existence of a near-threshold proton resonance?

- ^{11}B: the ^{6}Li(^{6}Li, pγ) experiment at LNL-INFN with GALILEO+TRACE
- ^{14}C: the ^{9}Be(^{6}Li, pγ) experiment at ANL with GRETINA+ORRUBA

- The new ^{6}Li(^{6}Li, pγ) experiment at LNL-INFN with AGATA+TRACE

- Preliminary analysis and results of the new experiment
- Summary and future perspectives

Near-threshold states in light nuclei



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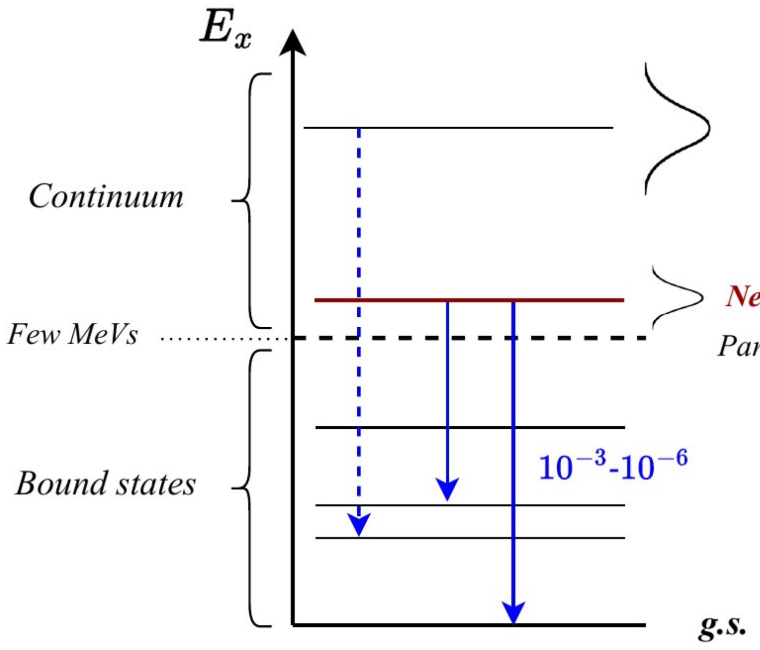

Relevant for understanding:

- Collectivization
- Nuclear clustering
- Nucleosynthesis (e.g., ^{12}C Hoyle state)

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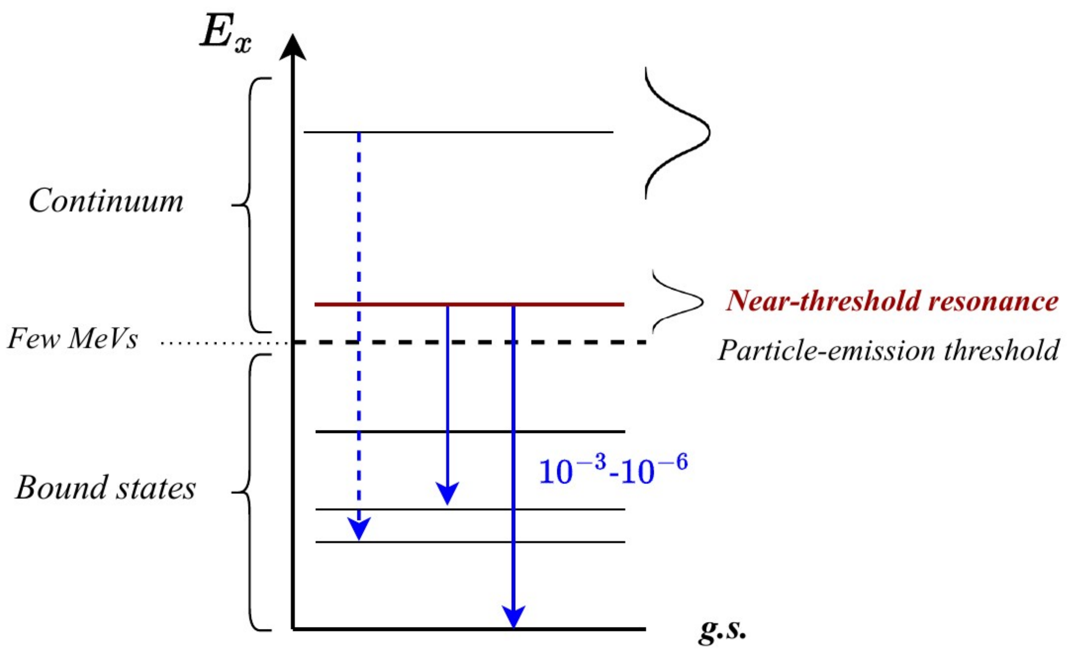

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Shell Model Embedded in the Continuum (SMEC):
- Coupling with continuum
- Core ⊗ particle/cluster
- Enhanced γ-ray branches (10^{-3}-10^{-6})

J. Okołowicz, M. Płoszajczaka and I. Rotter, Phys. Rep. **374**, 271 (2003)

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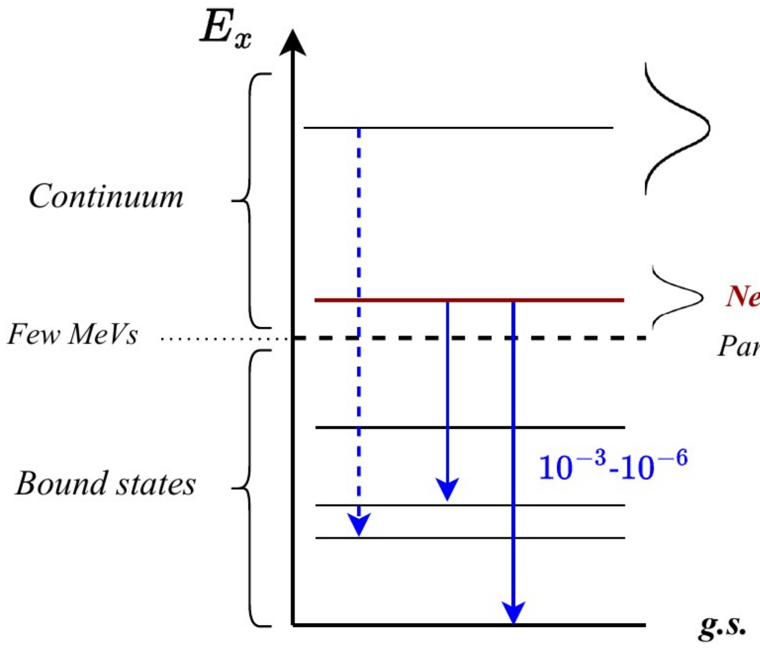

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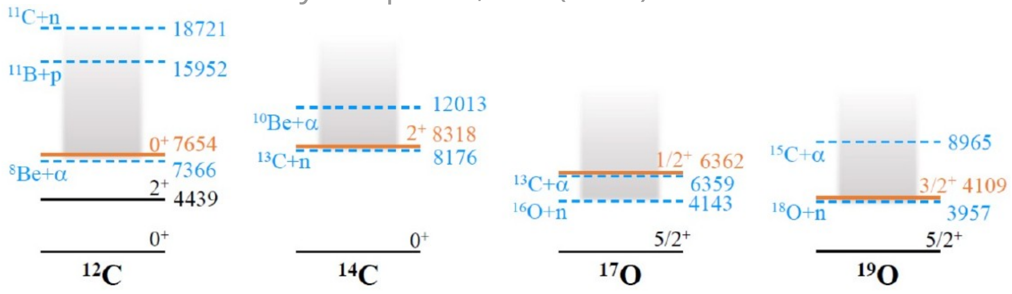
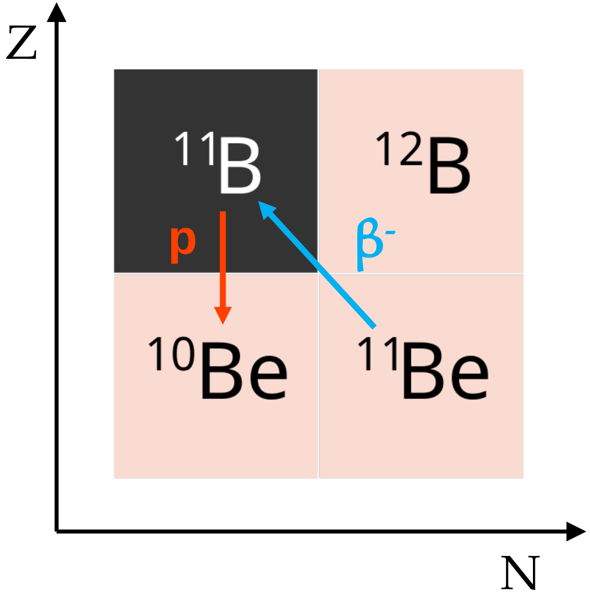
γ-ray as probes to investigate their wave functions



The rare β⁻p decay of ^{11}B



A n-rich nucleus emitting a proton: an **extremely rare decay**

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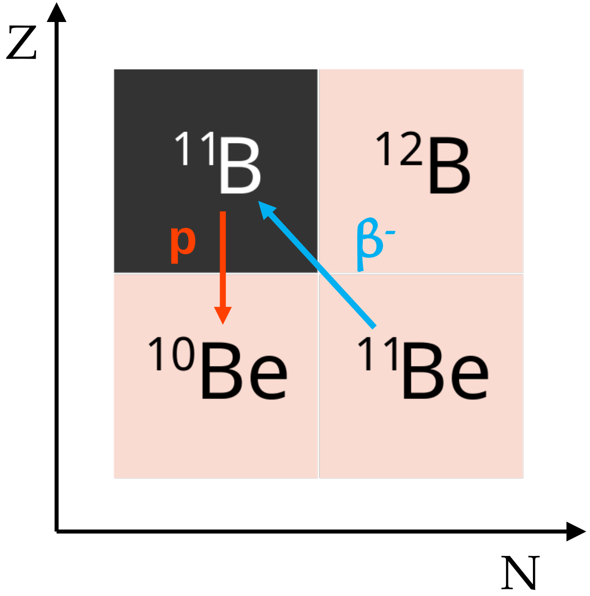

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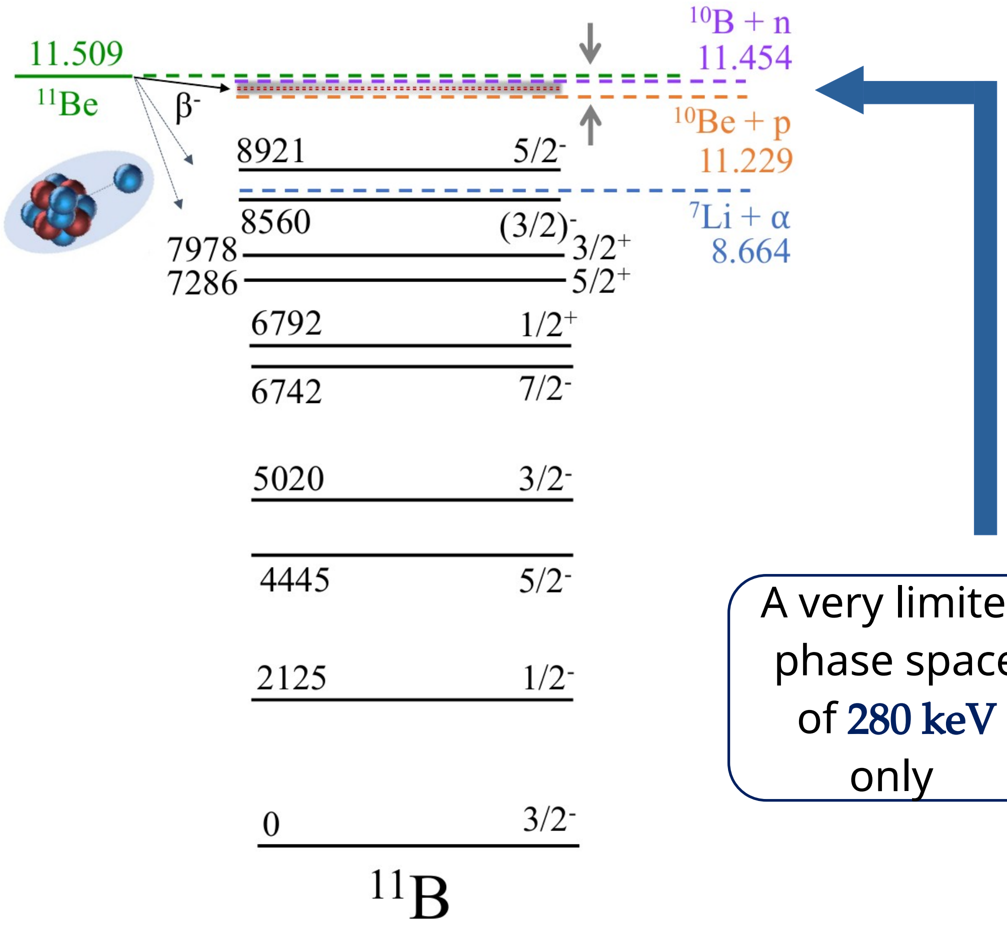
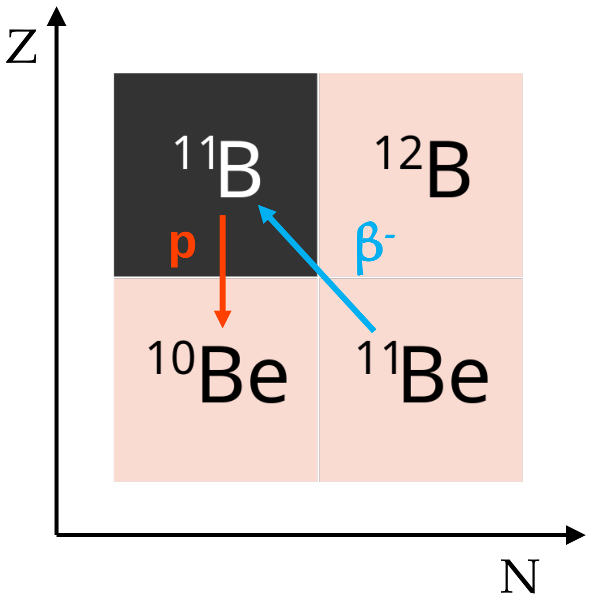


A very limited phase space of **280 keV** only

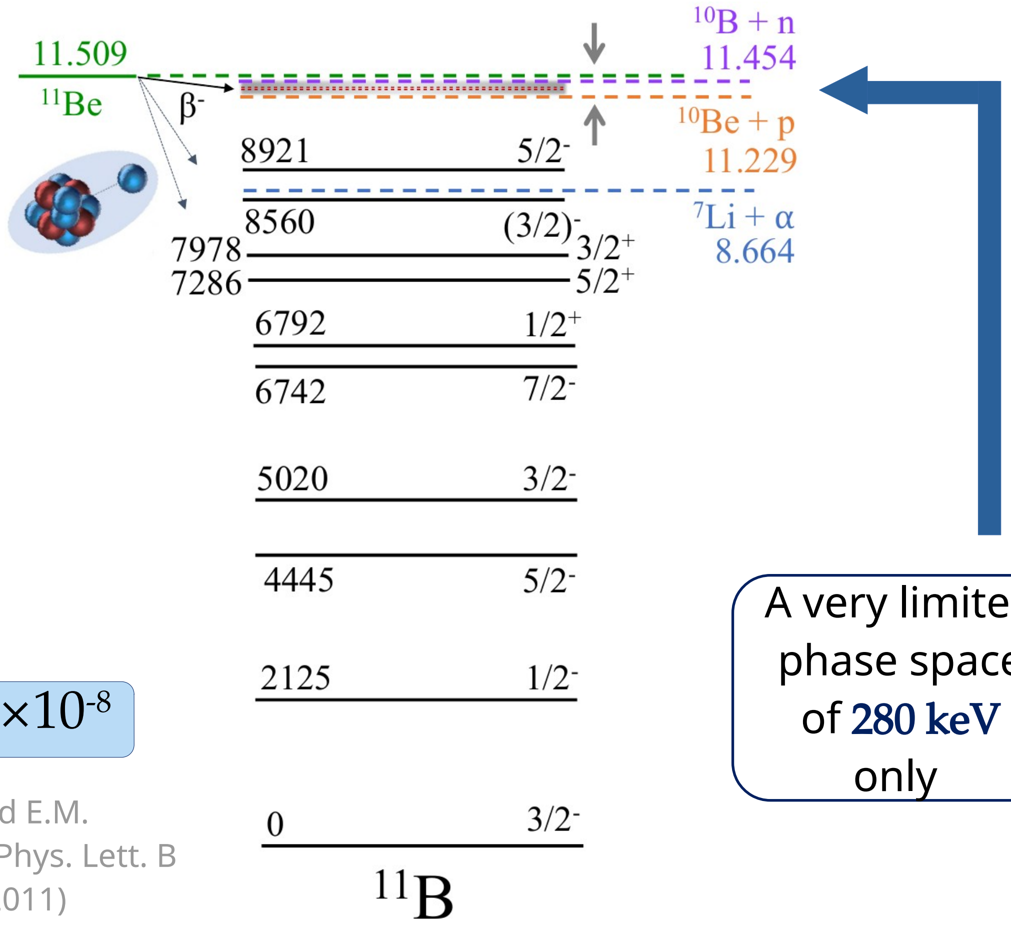
The rare β⁻p decay of ¹¹B



A n-rich nucleus emitting a proton: an **extremely rare decay**

$b_{\beta p}=3\times10^{-8}$

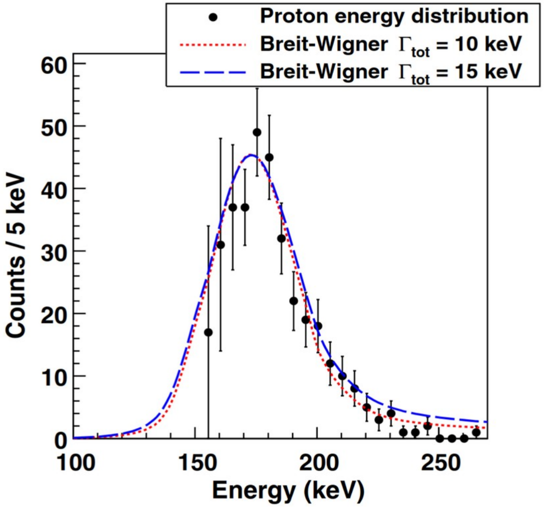
D. Baye and E.M. Tursunov, Phys. Lett. B **696**, 464 (2011)



A very limited phase space of 280 keV only

The rare β⁻p decay of ^{11}B

β⁻ decay of ^{11}Be with TPC @TRIUMF

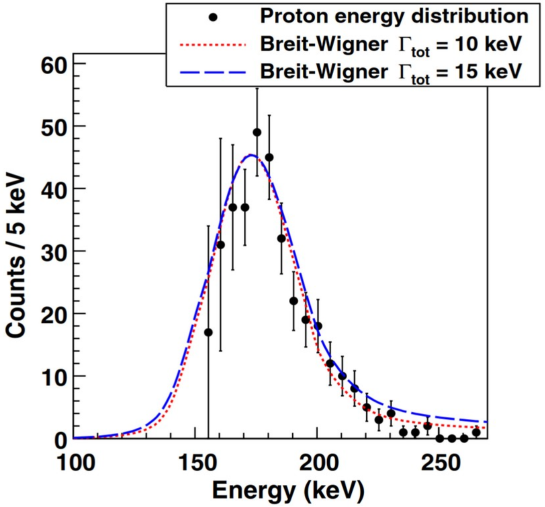


$b_{\beta p} = 1.3\times10^{-5}$

Y. Ayyad et al., Phys. Rev. Lett. **123**, 082501 (2019)

The rare $\beta^{-}p$ decay of ^{11}B

β^{-} decay of ^{11}Be with TPC @TRIUMF



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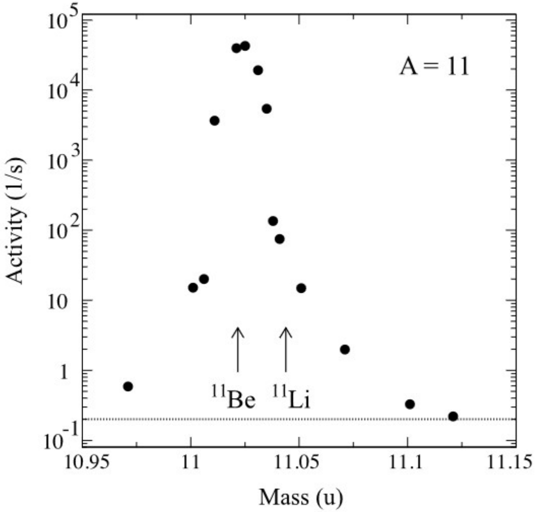
Y. Ayyad et al., Phys. Rev. Lett. **123**, 082501 (2019)

^{11}Be production and AMS @ISOLDE

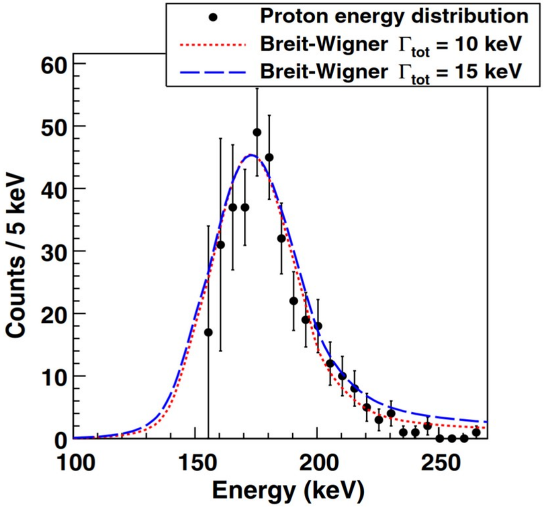


$$b_{\beta p} = (8.3 \pm 0.9)\times10^{-6}$$

K. Riisager et al., Phys. Lett. B **732**, 305 (2014)

The rare β⁻p decay of ^{11}B

β⁻ decay of ^{11}Be with TPC @TRIUMF



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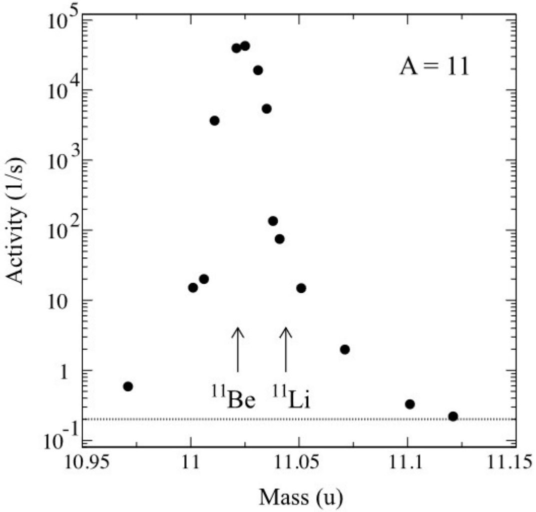


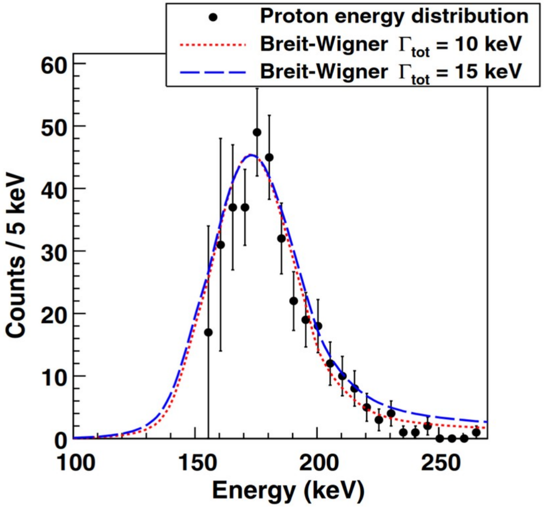
$b_{\beta p} < 2.2\times10^{-6}$

REVISED

K. Riisager et al., Eur. Phys. J. A **56**, 100 (2020)

The rare β⁻p decay of ^{11}B

β⁻ decay of ^{11}Be with TPC @TRIUMF



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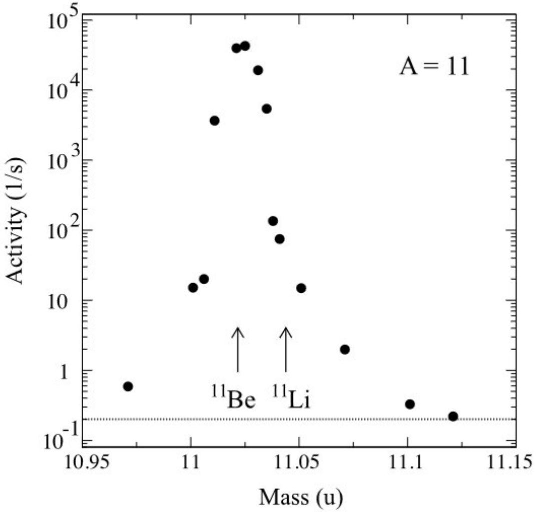

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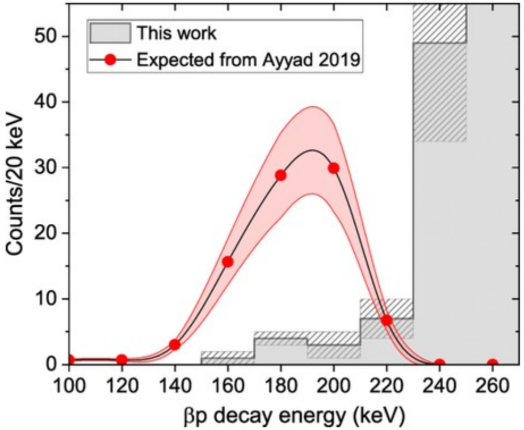
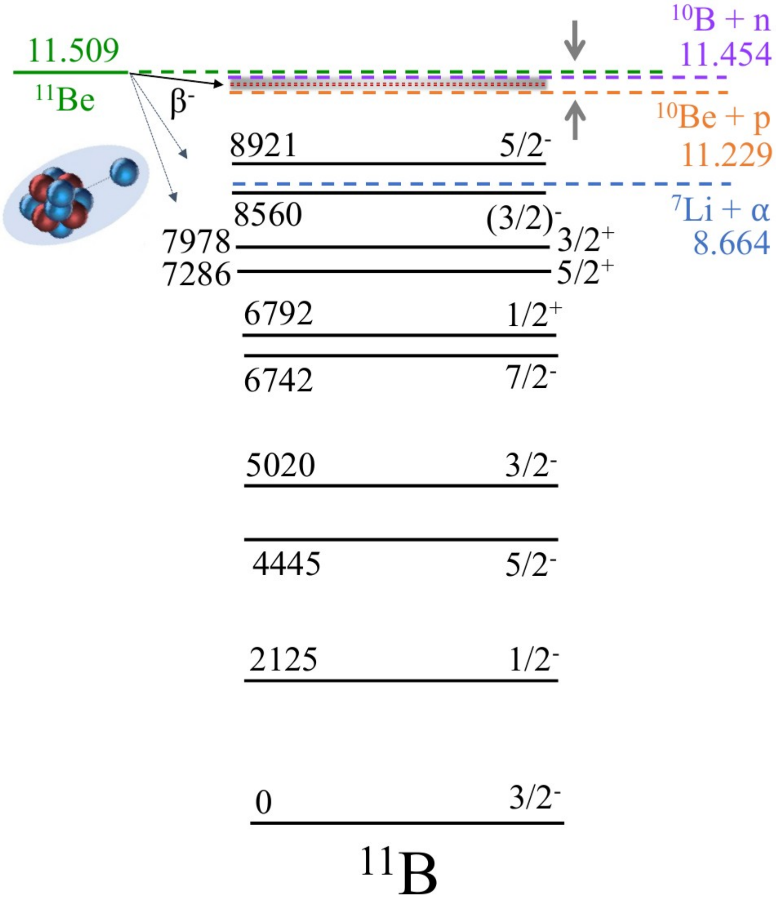


$b_{\beta p} < (2.2 \pm 0.8)\times10^{-6}$

N. Sokołowska et al., Phys. Rev. C **110**, 034328 (2024)

A near-threshold resonance in ^{11}B?



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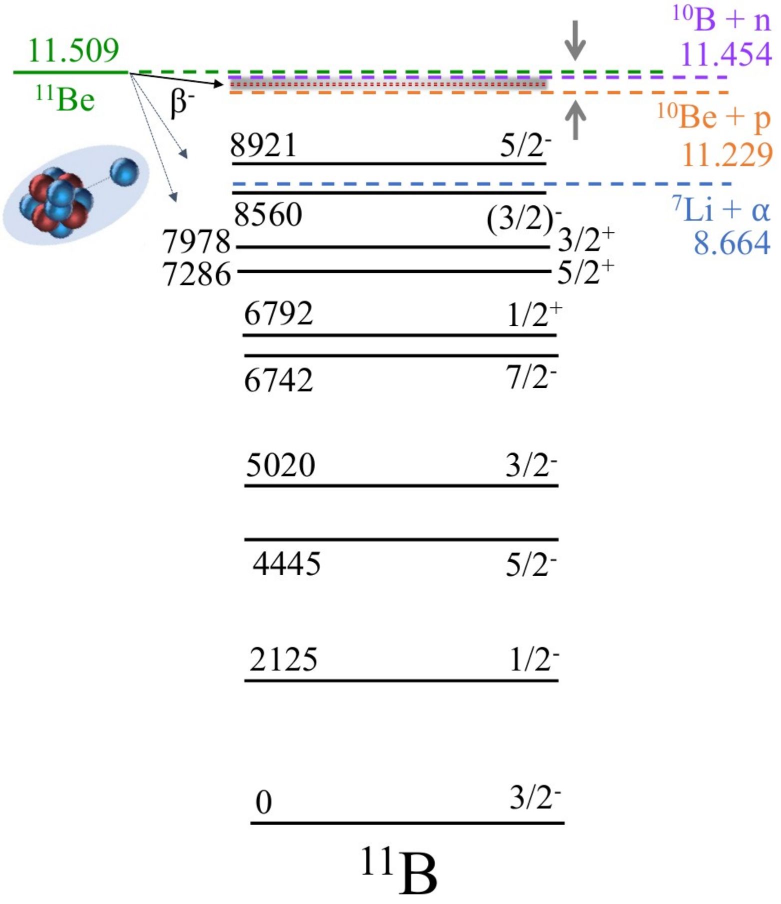
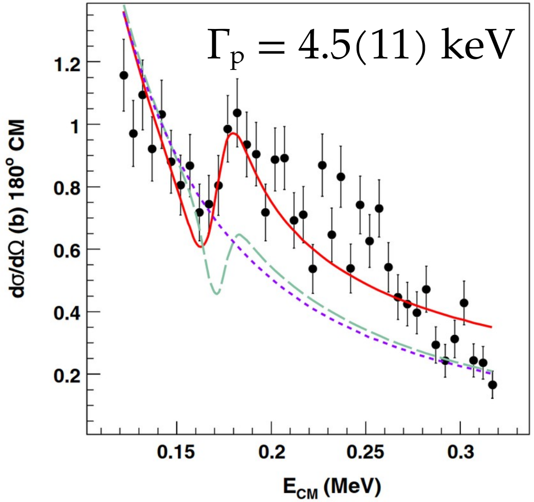


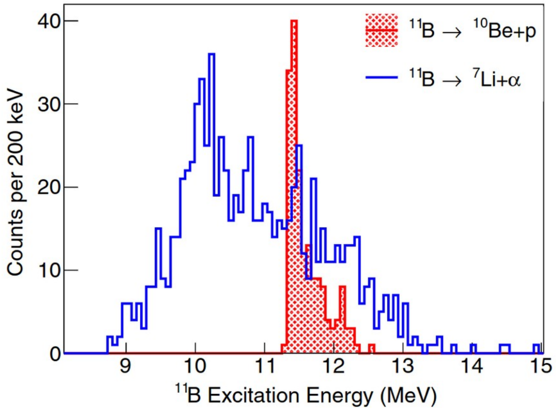
$^{10}Be(p,p')$ @NSCL



$$E_{res} = 11.400(20)\ \mathrm{MeV}$$

Y. Ayyad et al., Phys. Rev. Lett. **129**, 012501 (2022)

$^{10}Be(d,n)$ @FSU



$$E_{res} = 11.440(40)\ \mathrm{MeV}$$

E. Lopez-Saavedra et al., Phys. Rev. Lett. **129**, 012502 (2022)

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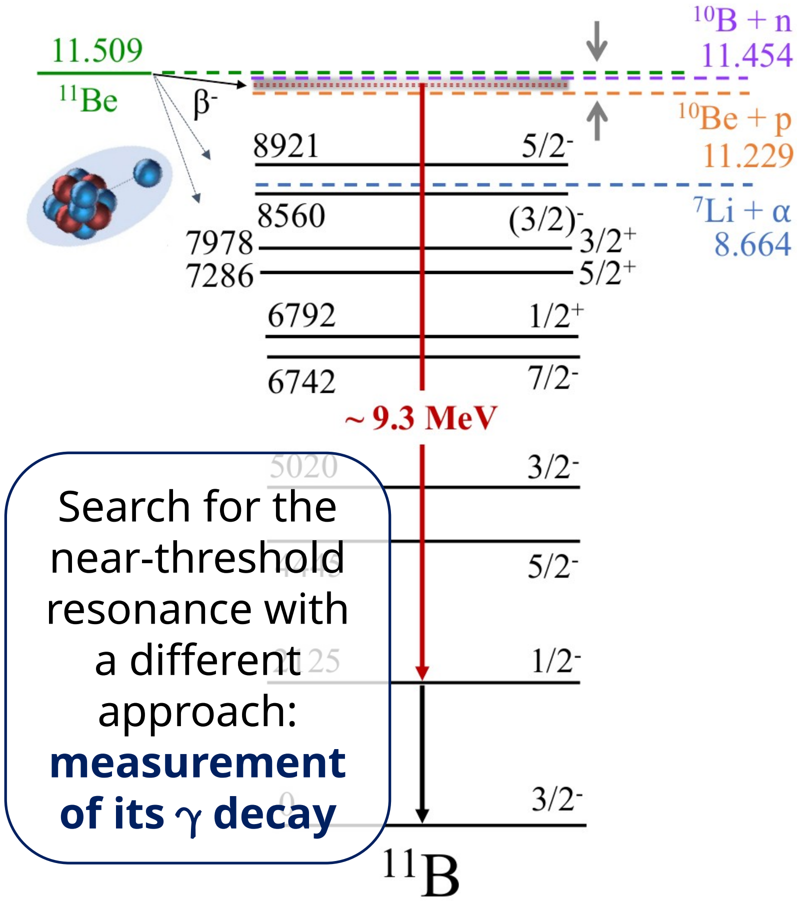
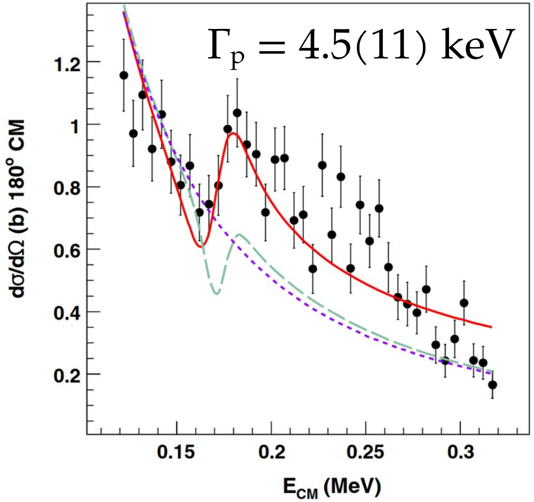


Search for the near-threshold resonance with a different approach: **measurement of its γ decay**

^{10}Be(p,p') @NSCL



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Y. Ayyad et al., Phys. Rev. Lett. **129**, 012501 (2022)

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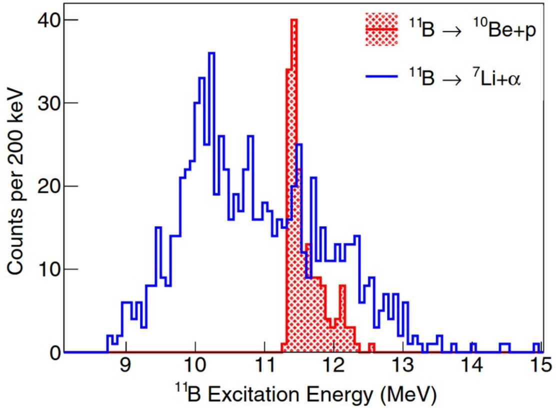

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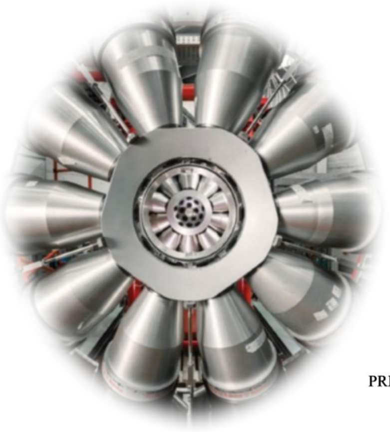
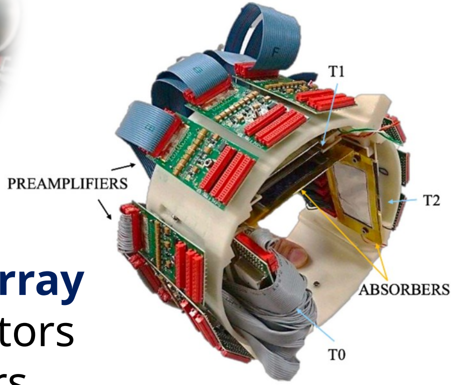
E. Lopez-Saavedra et al., Phys. Rev. Lett. **129**, 012502 (2022)

Search for the γ decay at LNL with GALILEO



^{6}Li(^{6}Li,pγ) **fusion-evaporation** reaction
@LNL with GALILEO+TRACE setup



GALILEO HPGe array
- 20 single detectors
- 10 triple clusters
- BGO AC shields

TRACE Si detector
- 3 ΔE-E telescopes
- 60 pads each
- PSA

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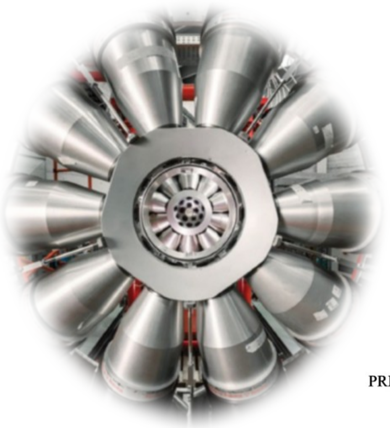

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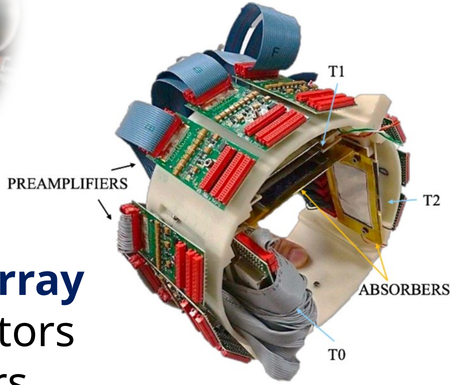

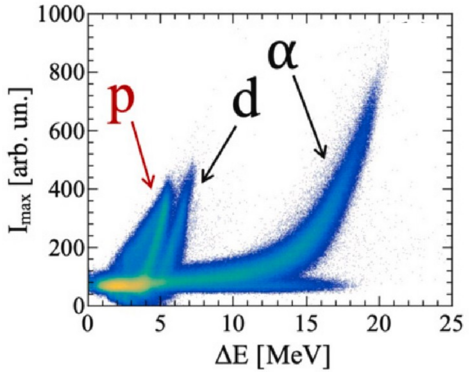

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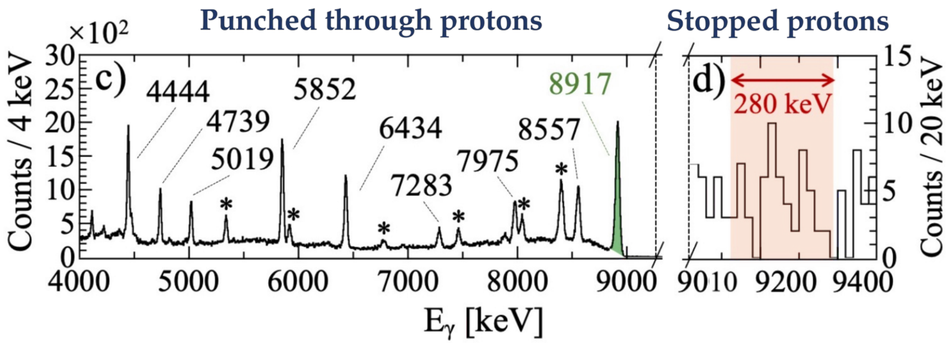

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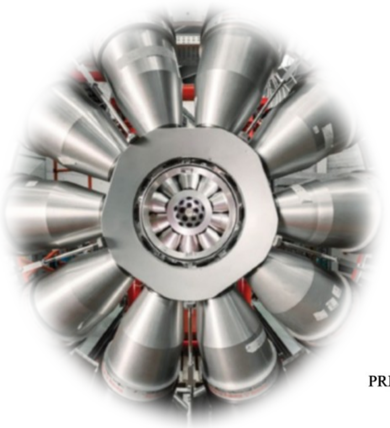

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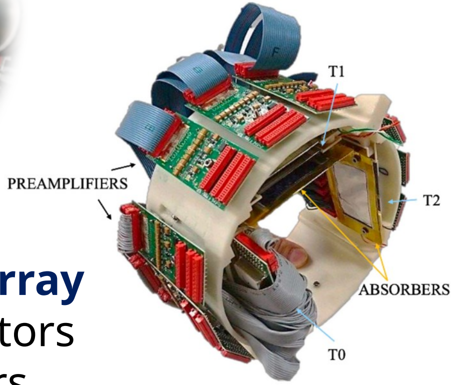

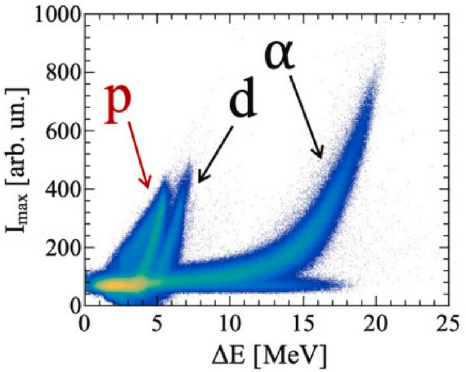

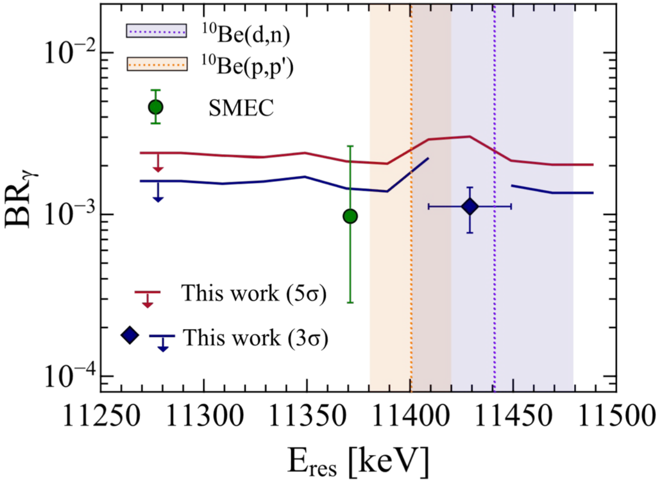

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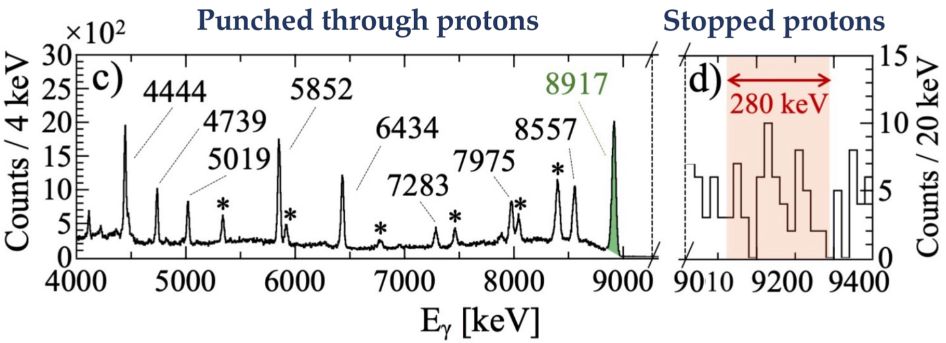

Exp: $b_\gamma < 2.37 \times 10^{-3}$

SMEC: $b_\gamma = 0.98 \times 10^{-3}$

J. Okołowicz, M. Płoszajczak, and W. Nazarewicz J. Phys. G: Nucl. Part. Phys. 49, 10LT01 (2022)

Search for the γ decay at LNL with GALILEO

Phys. Lett. B 855 (2024) 138851

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Letter

Search for the γ decay of the narrow near-threshold proton resonance in ^{11}B

S. Bottoni [a,b,*], G. Corbari [a,b], S. Leoni [a,b], B. Fornal [c], A. Goasduff [d], S. Capra [a,b], D. Mengoni [e,f], E. Albanese [a,b], S. Ziliani [a,b], G. Benzoni [b], A.M. Sánchez-Benítez [g], A. Bracco [a,b], D. Brugnara [d], F. Camera [a,b], M. Ciemała [c], N. Cieplicka-Oryńczak [c], F.C.L. Crespi [a,b], J.A. Dueñas [h], A. Gadea [i], F. Galtarossa [f], E. Gamba [a,b], A. Gottardo [d], A. Gozzelino [d], J. Ha [e,f], Ł.W. Iskra [c], T. Marchi [d], R. Menegazzo [f], B. Million [b], D.R. Napoli [d], G. Pasqualato [e,f], J. Pellumaj [d,j], R.M. Pérez-Vidal [d,i], S. Pigliapoco [e,f], M. Polettini [a,b], C. Porzio [a,b,1], F. Recchia [e,f], K. Rezynkina [e,f], J.J. Valiente-Dóbon [d], O. Wieland [b], I. Zanon [d], G. Zhang [e,f]

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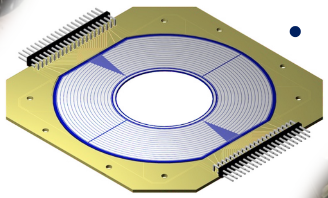
0.98 × 10^{-3}

J. Okołowicz, M. Płoszajczak, and W. Nazarewicz J. Phys. G: Nucl. Part. Phys. 49, 10LT01 (2022)

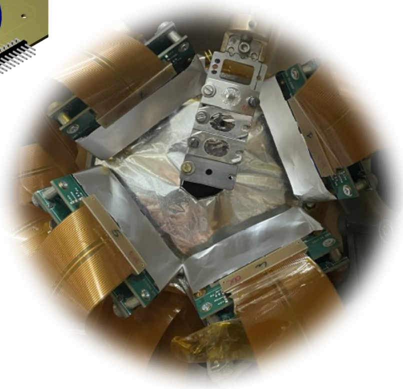
The new AGATA+TRACE experiment at LNL

^{6}Li(^{6}Li,pγ) **fusion-evaporation** reaction @LNL
with AGATA+SAURON+TRACE setup

AGATA
- 10 triple clusters (ATC)
- 1π coverage
- ~5 mm position resolution



SAURON
- DSSSD detector
- 16 pads – 64 strips



TRACE
- 4 ΔE-E Si detectors
- 60 4mm x 4mm pads on each layer
- new electronics

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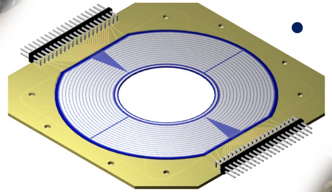

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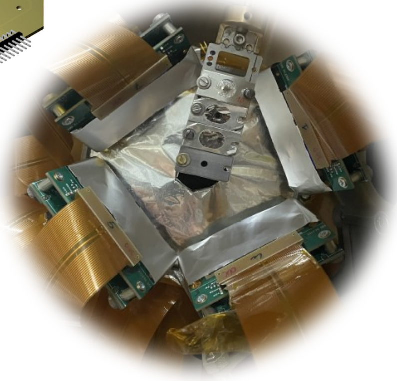

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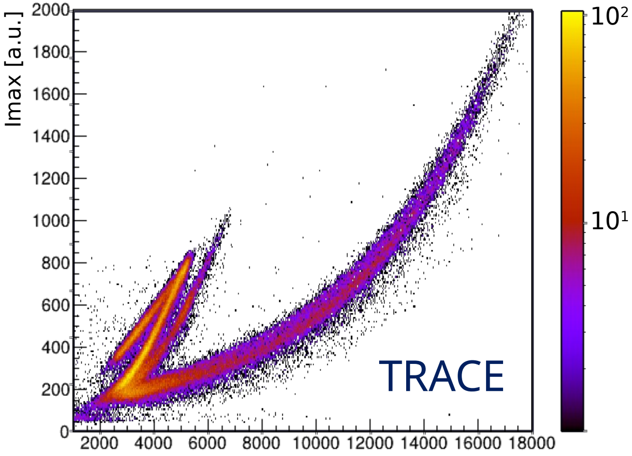
- 60 4mm x 4mm pads on each layer
- new electronics

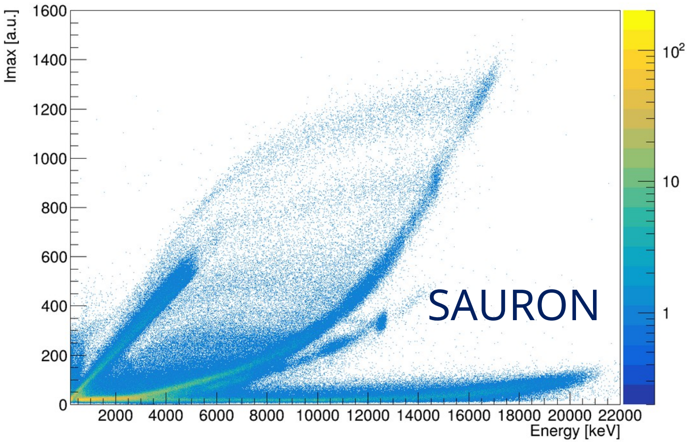
~150 PB storage
~30000 CPU cores

Data storage and analysis
@INFN-CNAF Tier1 (Bologna)

Batch Job Management
via HTCondor

Preliminary results





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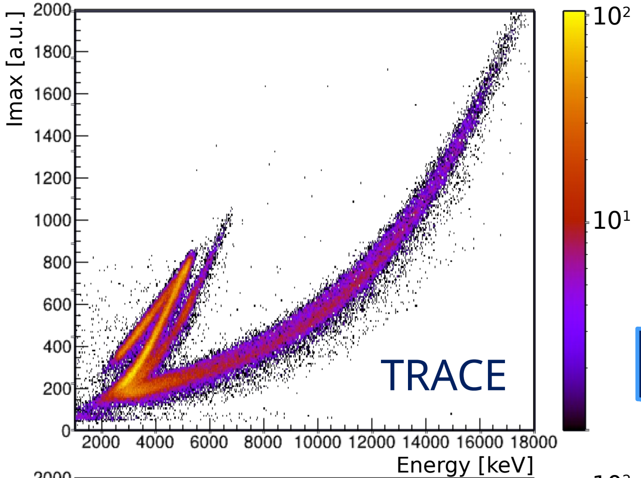
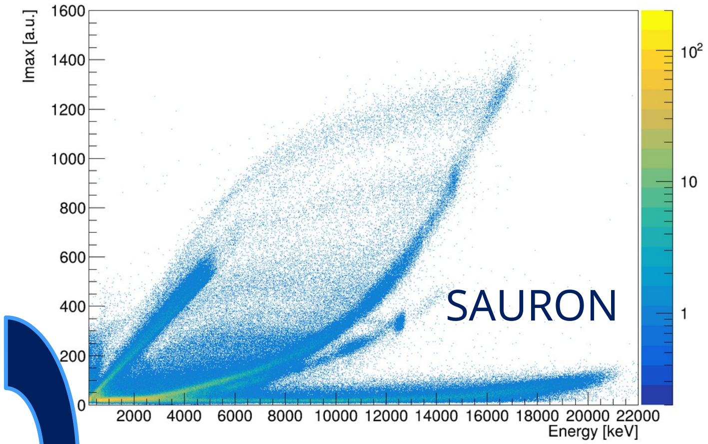
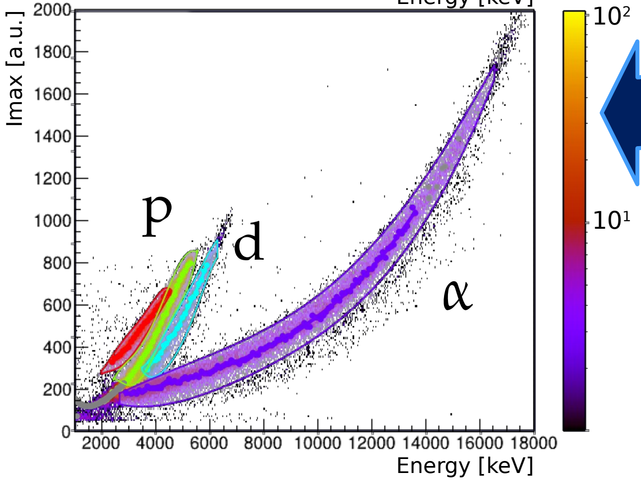
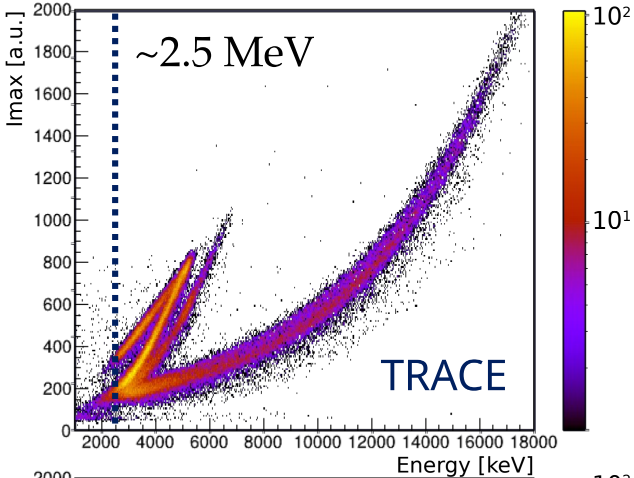


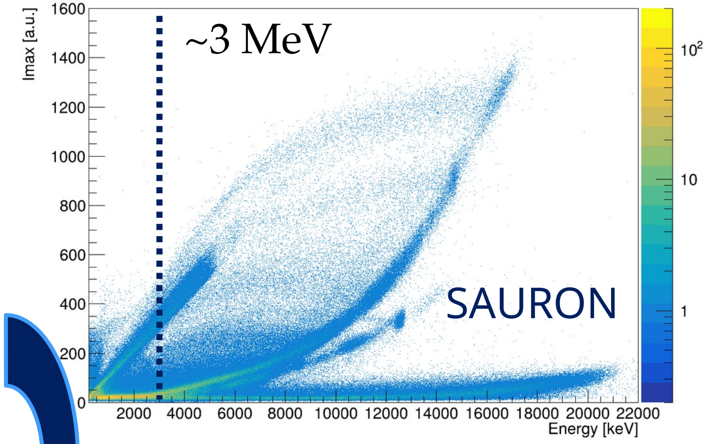


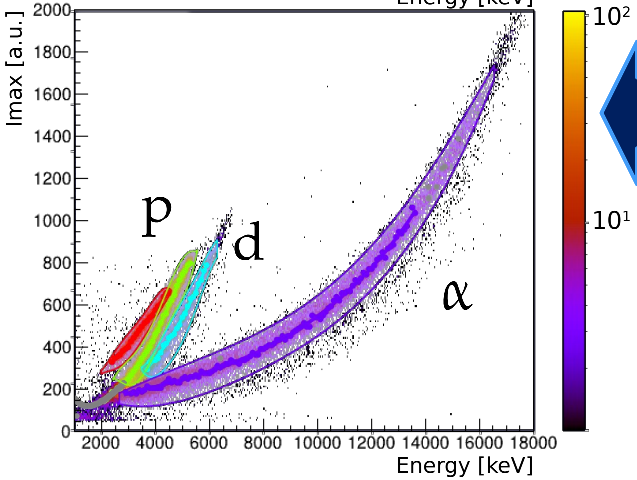


Semi-automatic PID on PSA matrices with clustering algorithm

Preliminary results



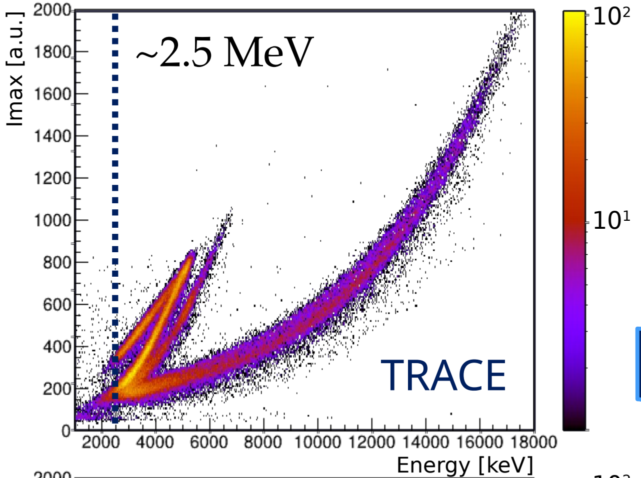


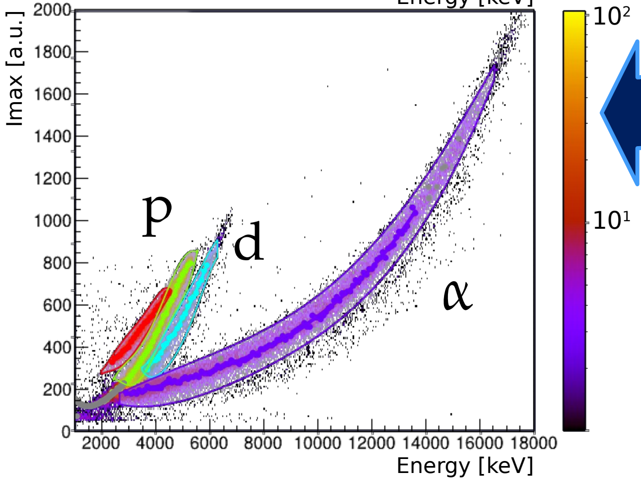


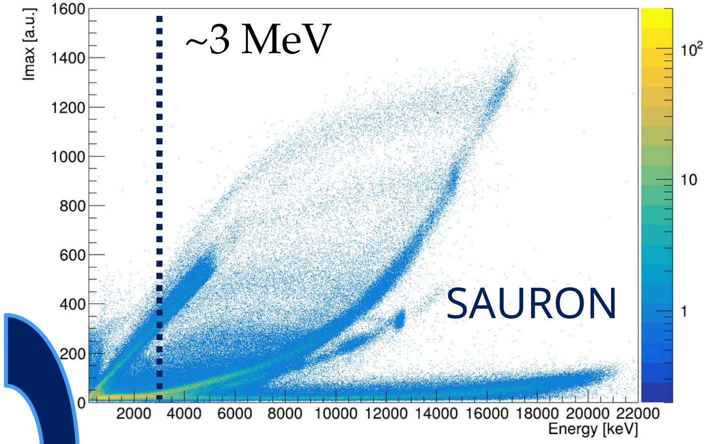
Semi-automatic PID on PSA matrices with clustering algorithm

$4\ \mathrm{MeV} < E_p < 6\ \mathrm{MeV}$ protons: above PSA thresholds

Preliminary results



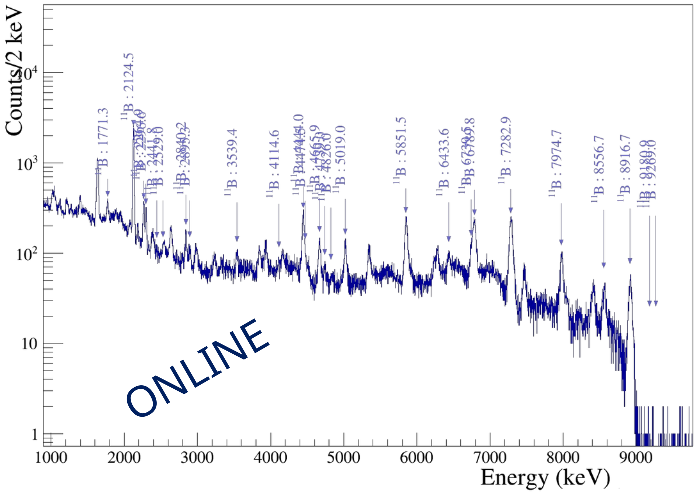




Semi-automatic PID on PSA matrices with clustering algorithm

$4\ \mathrm{MeV} < E_p < 6\ \mathrm{MeV}$ protons: above PSA thresholds

γ-ray Doppler-corrected spectrum gated on SAURON

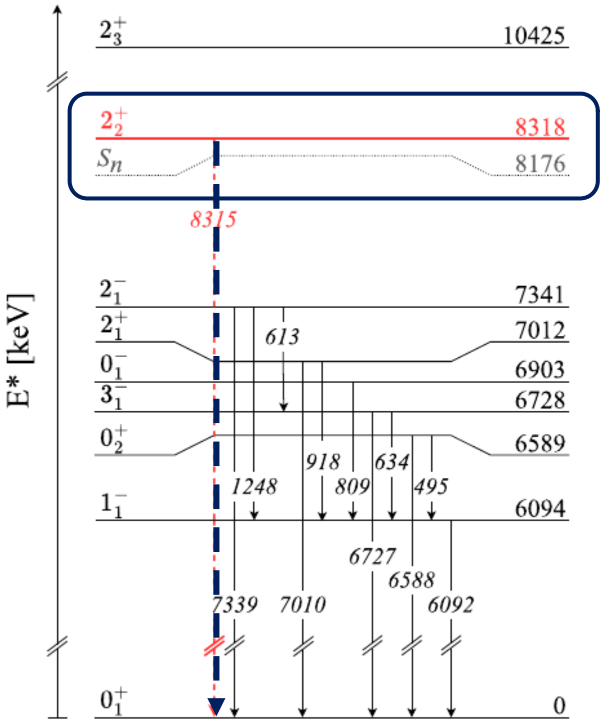


γ decay from near-threshold resonance

expected $b_\gamma \lesssim 10^{-4}$

Impact of the continuum in a similar case: ^{14}C

$^{9}Be(^{6}Li,p\gamma)$ fusion-evaporation reaction @ANL with GRETINA+ORRUBA setup



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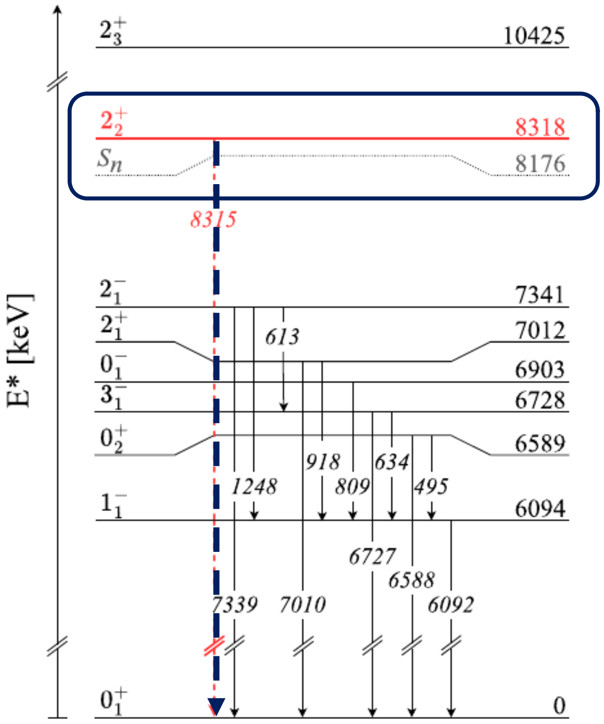
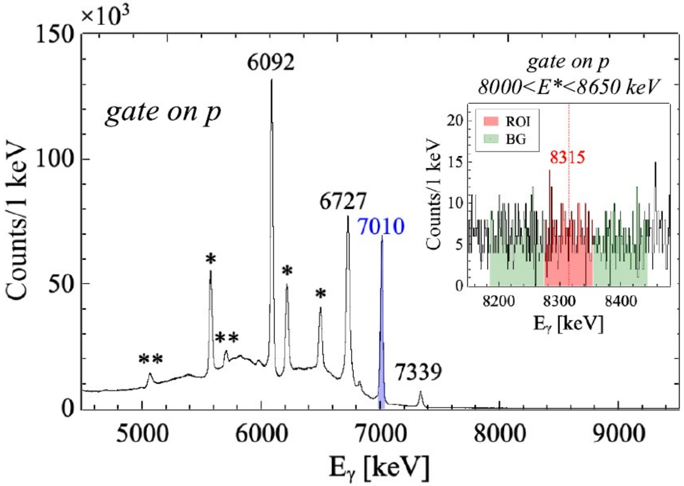


Upper limit on the γ-decay branch of the 2_2^+ **resonance**:

$$b_\gamma < 4.0 \times 10^{-5}$$



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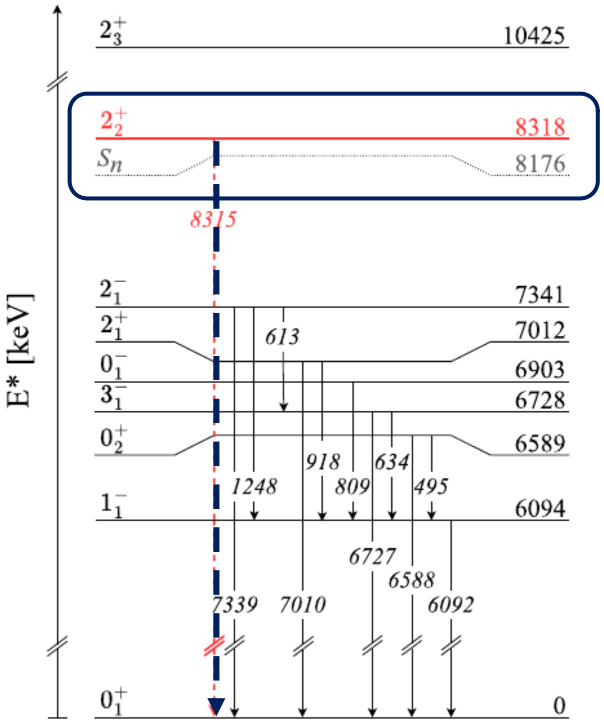

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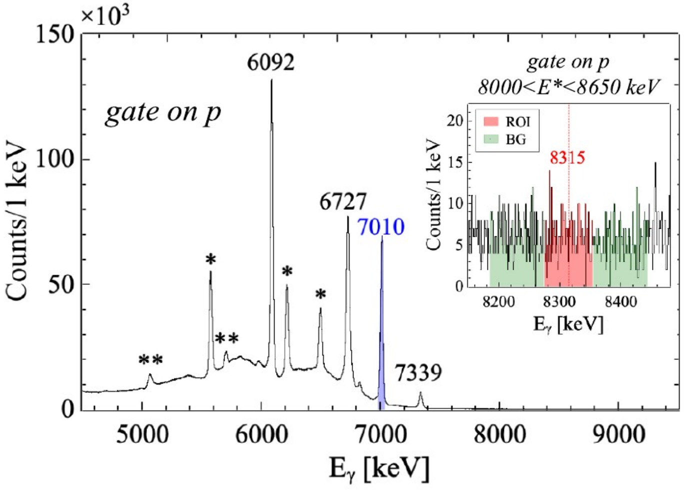
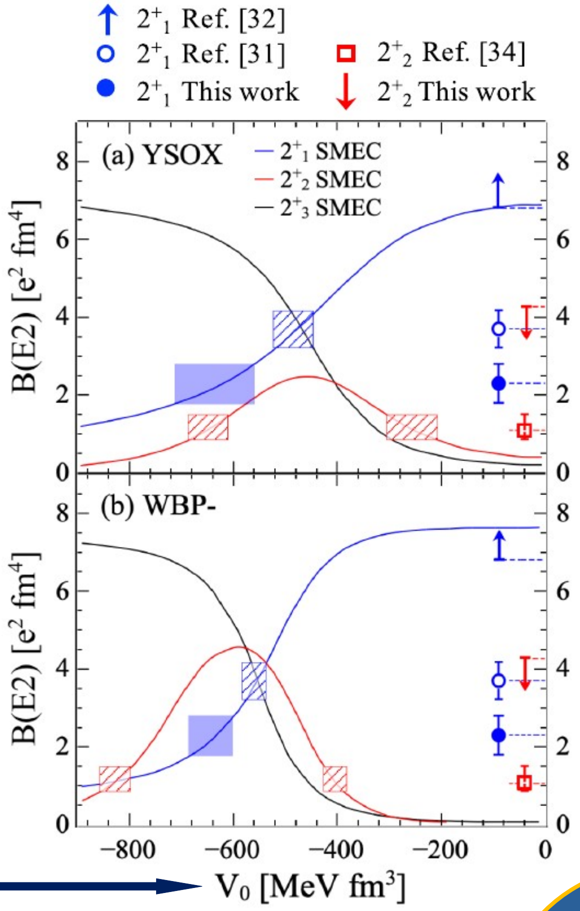
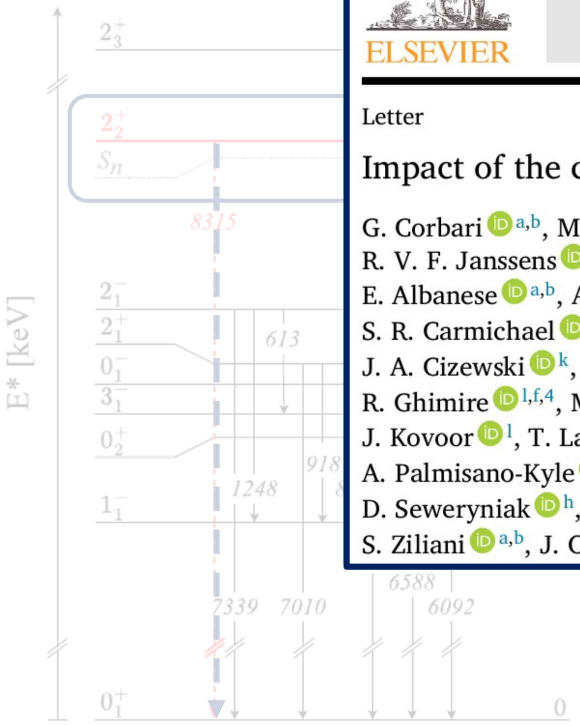


Constraining the V_0 continuum coupling strength parameter



Impact of the continuum in a similar case: ^{14}C

^{9}Be(^{6}Li,pγ) … **evaporation** rea… with GRETINA+O…



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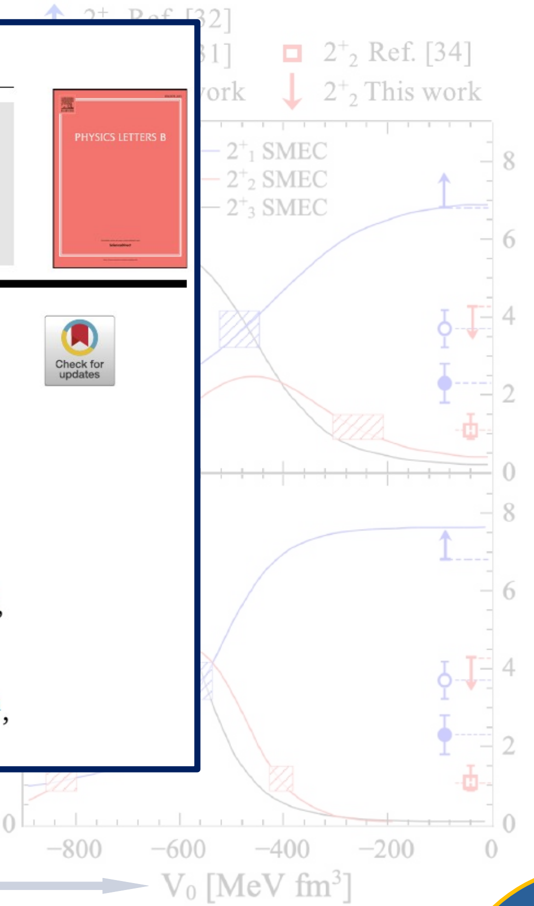
Letter

Impact of the continuum on the γ decay of the lowest 2^+ states in ^{14}C

G. Corbari [a,b], M. Ciemała [c], S. Bottoni [a,b], S. Leoni [a,b,*], B. Fornal [c,*], R. V. F. Janssens [d,e,*], S. D. Pain [f,*], A. Ratkiewicz [g], F. C. L Crespi [a,b], M. Siciliano [h], E. Albanese [a,b], A. D. Ayangeakaa [d,e], G. Benzoni [b], C. M. Campbell [i], S. R. Carmichael [j,1], M. P. Carpenter [h], K. A. Chipps [f], N. Cieplicka-Oryńczak [c], J. A. Cizewski [k], P. Copp [h,2], J. Forson [l], E. R. Gamba [a,b], H. I. Garland [k,3], R. Ghimire [l,f,4], M. R. Hall [f,5], Ł. W. Iskra [c], H. Jayatissa [h,2], K. Jones [l], F. Kondev [h], J. Kovoor [l], T. Lauritsen [h], A. Maj [c], B. Million [b], C. Mueller-Gatermann [h], A. Palmisano-Kyle [l], M. Polettini [a,b], C. Porzio [a,b,6], W. Reviol [h], N. Sensharma [d,e,1], D. Seweryniak [h], H. Sims [k], C. C. Ummel [k,4], O. Wieland [b], G. Wilson [h,m,7], S. Zhu [n], S. Ziliani [a,b], J. Okołowicz [o], M. Płoszajczak [o]



Constraining the V_0 continuum coupling strength parameter

Summary and future perspectives

- **Near-threshold resonances**: key role in clustering and collectivization phenomena, fundamental probe of nuclei as **open quantum systems** and to explain nucleosynthesis reactions

- A near-threshold proton resonance in ^{11}**B**?
  → ^{6}Li(^{6}Li,pγ) experiment with **AGATA**+SAURON+**TRACE** @LNL (2025)

- γ tracking algorithms, improved Doppler correction and clean particle identifications: **enhanced sensitivity on the γ branching** is expected
  → upper limit of 4×10^{-5} reached in ^{14}C with GRETINA

- Analysis is ongoing: fine-tuning of Si detectors calibration, AGATA neutron damage correction and test of γ tracking algorithms up to $9\ \mathrm{MeV}$.

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Thank you!

Backup slides

SMEC Theory

Continuum coupling

$$\mathcal{H}(E) = H_{\mathcal{Q}_0\mathcal{Q}_0} + W_{\mathcal{Q}_0\mathcal{Q}_0}(E)$$
$$W_{\mathcal{Q}_0\mathcal{Q}_0}(E) = V_0^2 h(E)$$

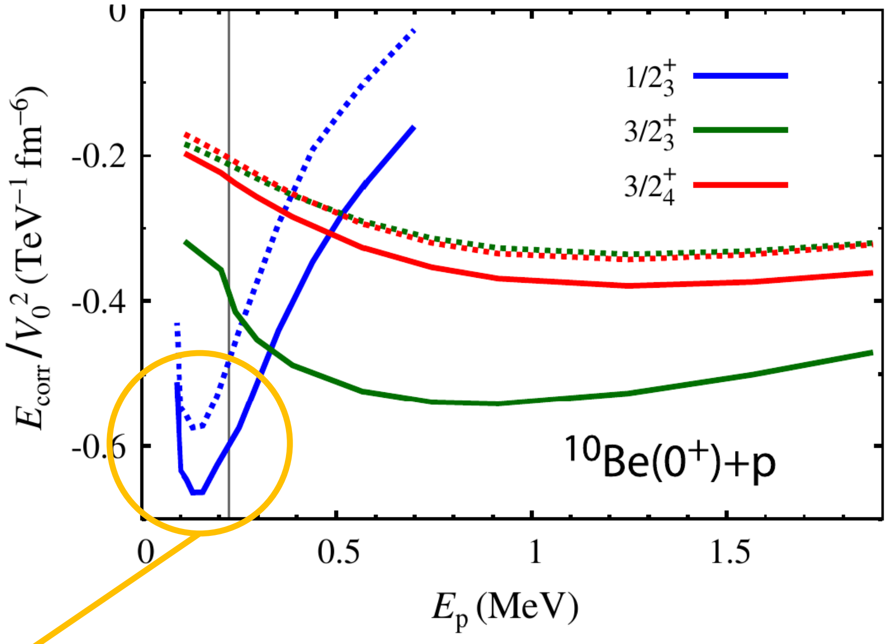
Shell Model Hamiltonian + energy-dependent continuum coupling

J. Okołowicz, M. Płoszajczak, and W. Nazarewicz J. Phys. Rev. Lett. **124**, 042502 (2020)

Correlation energy

$$E^{J^\pi}_{\mathrm{corr};\alpha}(E) = \langle \Psi^{J^\pi}_\alpha(E) | W_{\mathcal{Q}_0\mathcal{Q}_0}(E) | \Psi^{J^\pi}_\alpha(E) \rangle$$
$$|\Psi^{J^\pi}_\alpha(E)\rangle = \left| {}^{A-1}Z(K^{\pi'}) \otimes \ell_j \right\rangle^{J^\pi}$$

Shell Model states coupled to one-nucleon decay channel

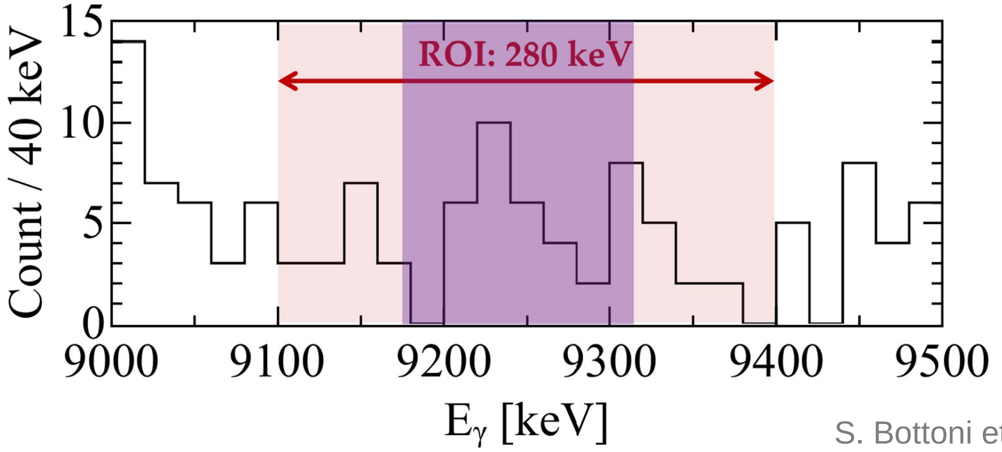


E_{res}=11371 keV

1p-channel $\left[{}^{10}\mathrm{Be}(0^+) \otimes p\left(s_{1/2}\right)\right]^{1/2^+}$

1n-channel $\left[{}^{10}\mathrm{B}(3^+) \otimes n\left(d_{5/2}\right)\right]^{1/2^+}$

Statistical analysis of GALILEO experiment

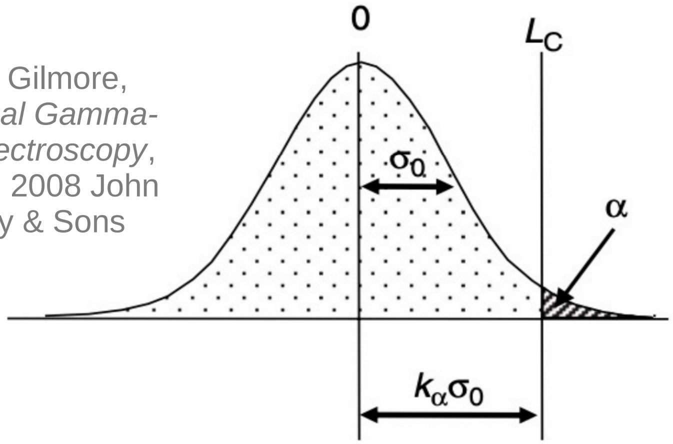


S. Bottoni et al., Phys. Lett. B **855**, 138851 (2024)

- Region of interest: **280 keV**
- **120-keV** moving window (3σ)
- **20-keV** steps (1σ)

Look-Elsewhere Effect: $CL_{loc}=CL_{glob}^{1/M}$

G.R. Gilmore, *Practical Gamma-ray spectroscopy*, 2nd ed., 2008 John Wiley & Sons

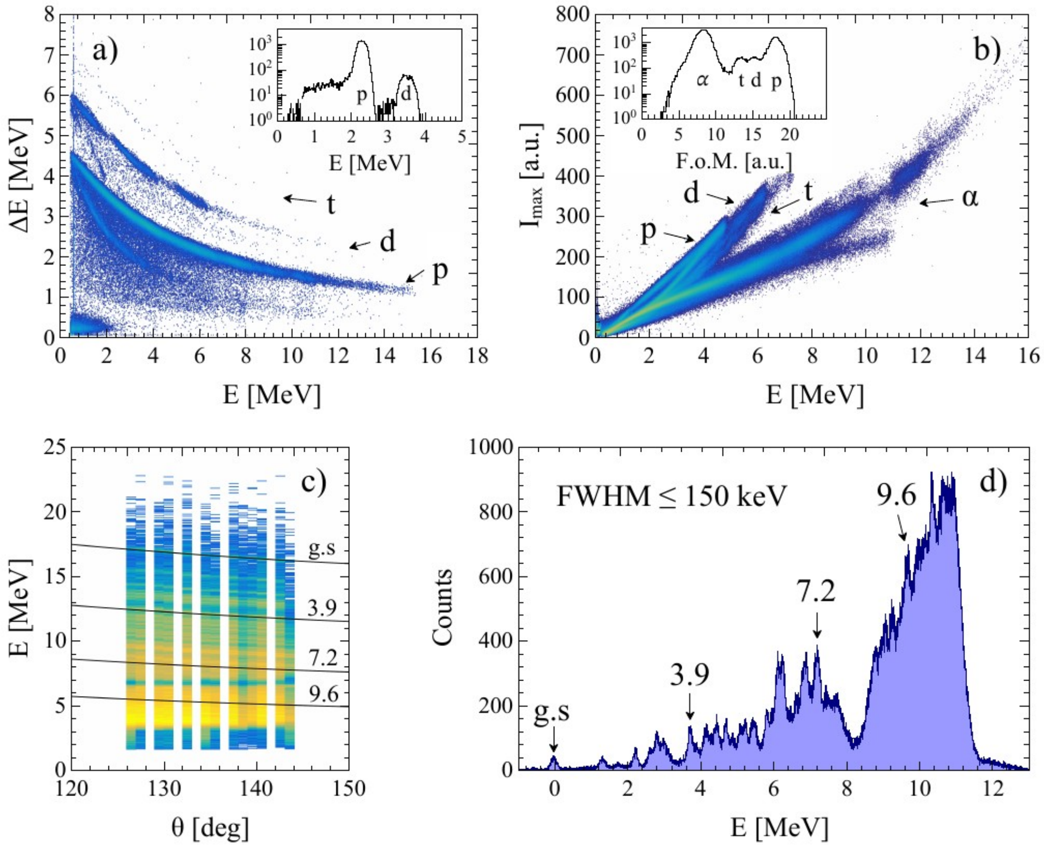


$$L_C = k_\alpha \sqrt{[B(1+n/2m)]}$$

Significant excess of counts (C) in the considered region if:

$C\text{-}B > L_C$

TRACE commissioning in 2024



Commissioning: **^{7}Li(^{13}C,p)^{19}O @12 MeV** in **PISOLO** chamber @LNL

Pixel-type matrices of 12×5 4×4 mm^2 on both ΔE and E layers

Thicknesses: **200 μm** and **1500 μm**

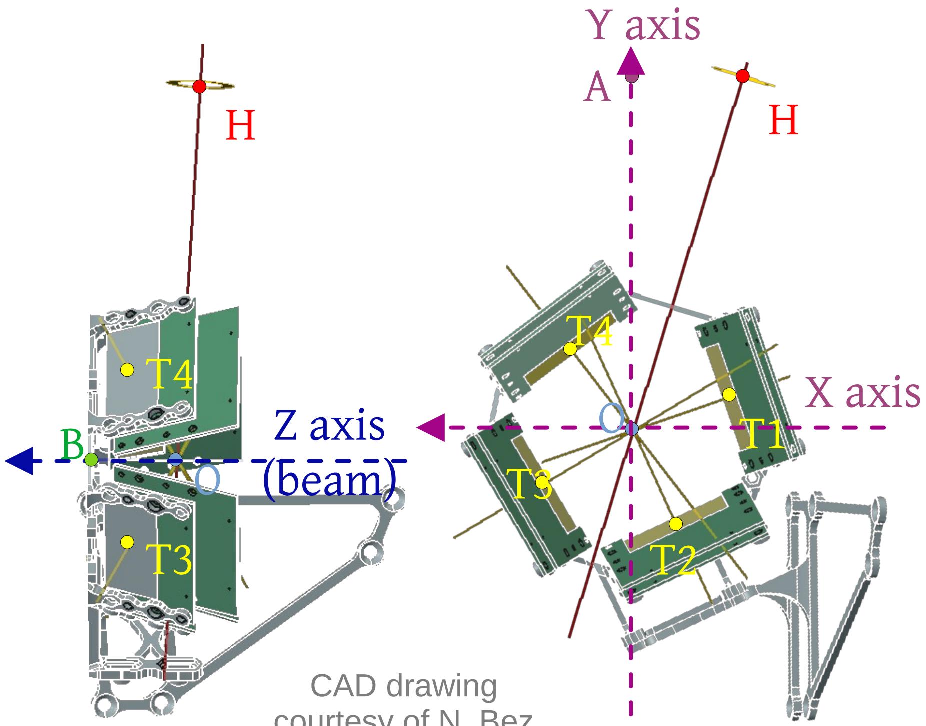
Readout: channel by channel or grouping scheme (rows and columns)

Tested **new components** (preamplifiers, kapton cables, etc.)

Tested **PID capabilities**

Tested **readout techniques**

TRACE readout



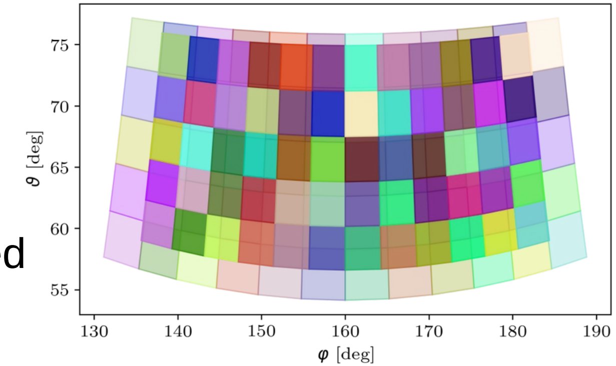
CAD drawing
courtesy of N. Bez

55	50	45	40	35	30	25	20	15	10	5	0
56	51	46	41	36	31	26	21	16	11	6	1
57	52	47	42	37	32	27	22	17	12	7	2
58	53	48	43	38	33	28	23	18	13	8	3
59	54	49	44	39	34	29	24	19	14	9	4
PCB		CONNECTOR									

5×12 layout mapped
into 6×10 layout
(E layer)

55	50	45	40	35	30
56	51	46	41	36	31
57	52	47	42	37	32
58	53	48	43	38	33
59	54	49	44	39	34
25	20	15	10	5	0
26	21	16	11	6	1
27	22	17	12	7	2
28	23	18	13	8	3
29	24	19	14	9	4

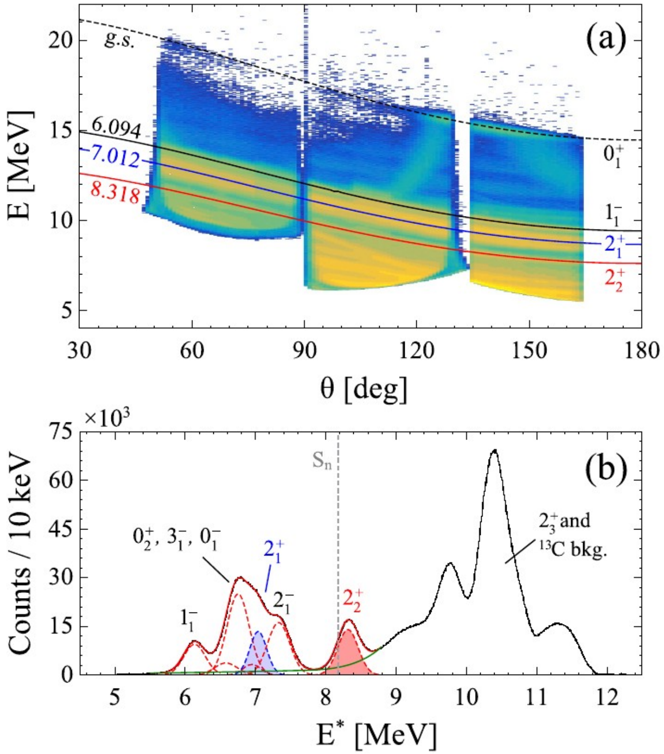
column - row
readout logic
(60 ch. → 16 ch.)



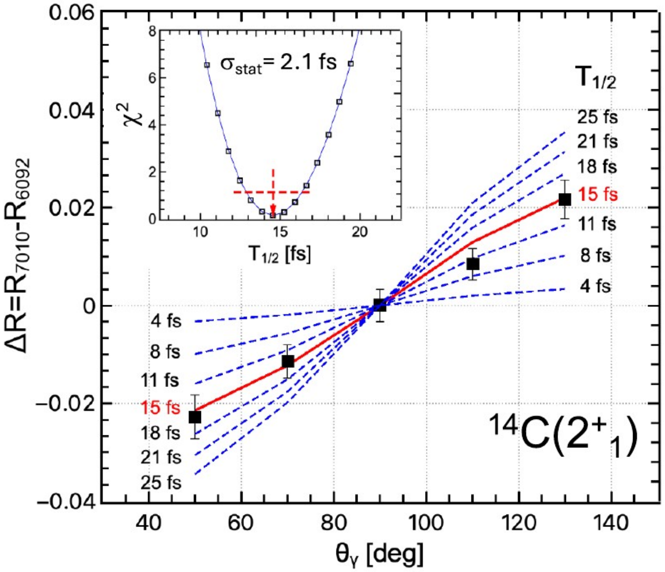
Planar geometry mapped
into (θ,φ) plane

^{14}C experiment

^{9}Be(^{6}Li,pγ) fusion-evaporation reaction @**ANL** with **GODDESS (GRETINA+ORRUBA)** setup



G. Corbari et al., Phys. Lett. B **879**, 140630 (2026)



Fractional Doppler-Shift Attenuation Method:

$$R(\theta_\gamma) = \frac{E_\gamma(90^\circ) - E_\gamma(\theta_\gamma)}{E_\gamma(90^\circ)}$$