Solving the puzzle of quadrupole strength in ^{8}Li to benchmark *ab initio* predictions in few-body nuclei

EXP 25.018 – December 2025

Simone Bottoni
Università degli Studi di Milano
INFN Sezione di Milano

Franco Galtarossa
INFN Sezione di Padova

Marco Rocchini
INFN Sezione di Firenze

THE 26TH AGATA WEEK
AND ACC MEETING
7-11 SEPTEMBER 2026
HEAVY ION LABORATORY, WARSAW, POLAND

AGATA ADVANCED GAMMA TRACKING ARRAY

EXOTIC Radioactive Nuclear Beams

Collaboration

S. Bottoni[1,2], F. Galtarossa[3], M. Rocchini[4], M. Mazzocco[5,3], S. Pigliapoco[5,3], A. Goasduff[6], P. Aguilera[5,3], G. Andreetta[5,6], F. Angelini[5,6], M. Balogh[6], J. Benito[6], G. Benzoni[2], V. Bildstein[7], A. Bracco[1,2], D. Brugnara[6], F. Camera[1,2], S. Carollo[5,3], M. Ciemała[8], N. Cieplicka-Oryńczak[8], G. Corbari[1,2], F.C.L. Crespi[1,2], G. de Angelis[6], B. Fornal[8], P.E. Garrett[7], D. Genna[1,2], A. Giaz[2], B. Góngora-Servín[6], A. Gottardo[6], K. Hadyńska-Klęk[9], D. Kalaydjieva[7], G. King[10], R. Kjus[9], M. Komorowska[9], Ł. W. Iskra[8], S. M. Lenzi[5,3], S. Leoni[1,2], M. Luciani[1,2], N. Marchini[4], M. Matejska-Minda[8], R. Menegazzo[3], D. Mengoni[5,3], B. Million[2] A. Nannini[4], P.J. Napiorkowski[9], D. R. Napoli[6], R. Nicolás del Álamo[5,3], S. Pastore[11], J. Pellumaj[2], M. Piarulli[11], I. Pietka[9], E. Pilotto[5,3], F. Recchia[5,3], K. Rezynkina[3], J. Srebrny[9], D. Stramaccioni[5,3], J. J. Valiente-Dobón[6], O. Wieland[2], K. Wrzosek-Lipska[9], L. Zago[1,6], M. Zielińska[12]

[1] *Dipartimento di Fisica, Università degli Studi di Milano, Milano, Italy.*
[2] *INFN Sezione di Milano, Milano, Italy*
[3] *INFN Sezione di Padova, Padova, Italy*
[4] *INFN Sezione di Firenze, Firenze, Italy*
[5] *Dipartimento di Fisica, Università degli Studi di Padova, Padova, Italy*
[6] *INFN Laboratori Nazionali di Legnaro, Legnaro, Italy.*
[7] *Department of Physics, University of Guelph, Guelph, Canada.*
[8] *Institute of Nuclear Physics PAN, Krakow, Poland.*
[9] *HIL, University of Warsaw, Warsaw, Poland.*
[10] *Los Alamos National Laboratory, Los Alamos, USA.*
[11] *Department of Physics, Washington University, St. Louis, Missouri, USA*
[12] *Irfu/DPhN, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.*

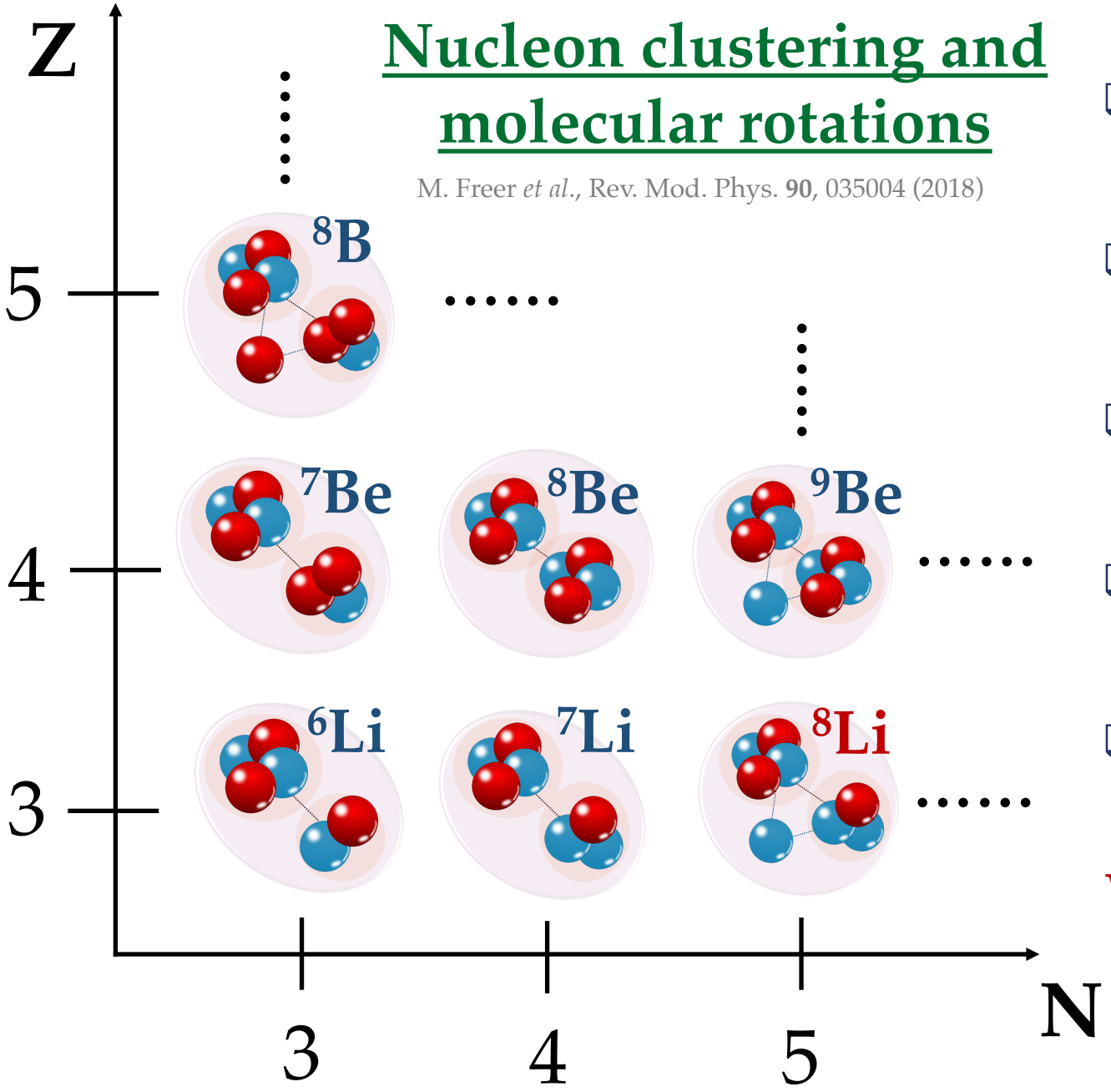
AGATA
ADVANCED GAMMA TRACKING ARRAY

EXOTIC
Radioactive Nuclear Beams

Simone Bottoni

Nucleon clustering and molecular rotations

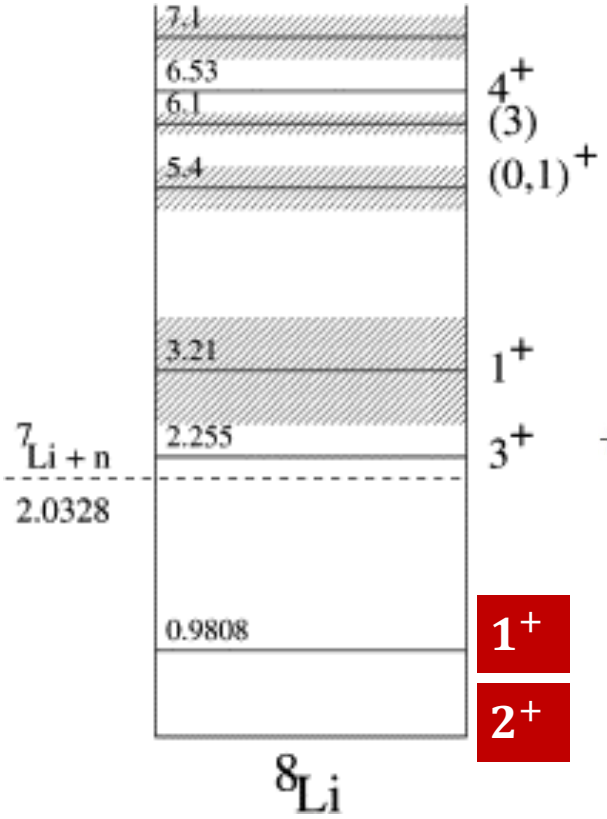
M. Freer *et al.*, Rev. Mod. Phys. **90**, 035004 (2018)

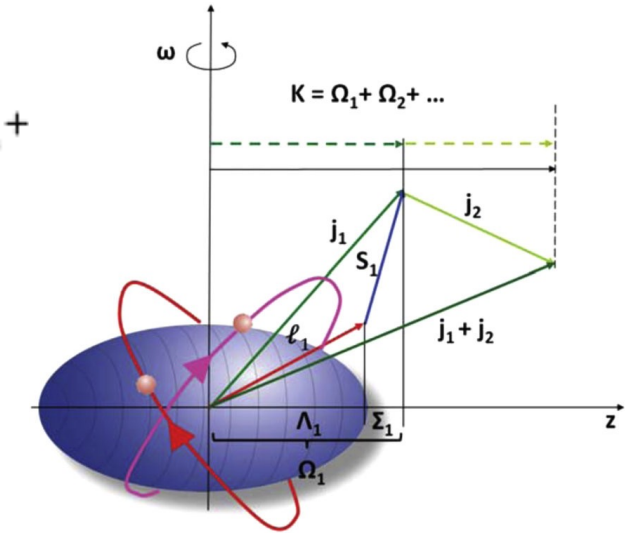


- Low nucleon density and **clusterization**
- Sizable **deformation** and molecular **rotations**
- **Large E2** transition strengths
- Structure captured by ***ab initio*** calculations
- Nucleon **dynamics** with 2- and 3-body **forces**

What happens in ^{8}Li?

Classic axially symmetric rotations





$$I = K, K+1, K+2, \ldots$$

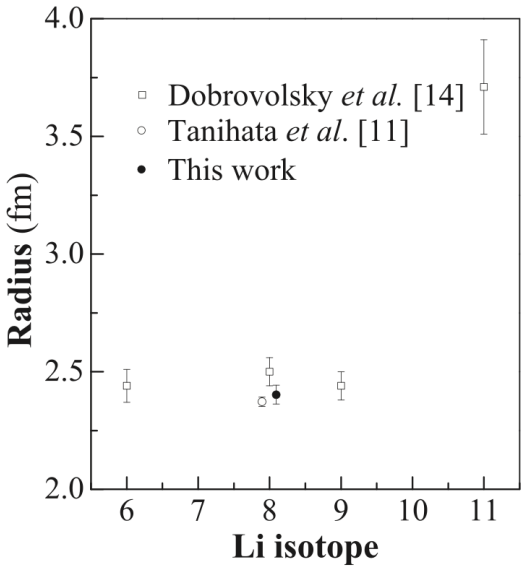
No 1^+ member of a K=2 rotational band

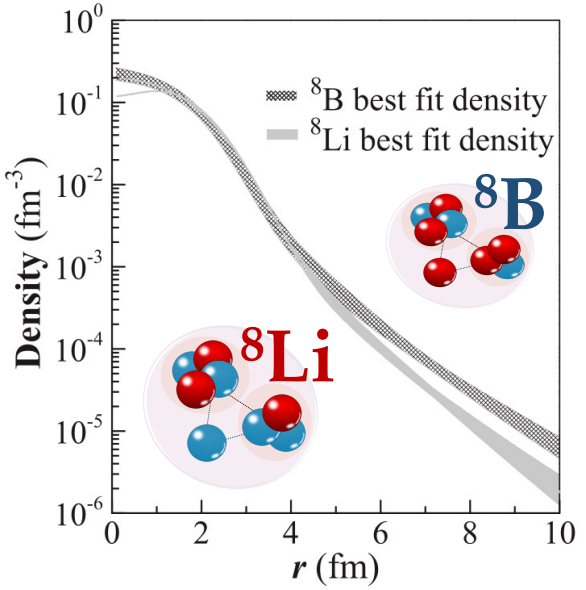
Matter density distribution

PHYSICAL REVIEW C **90**, 044321 (2014)

Structure of ^{8}Li from a reaction cross-section measurement

G. W. Fan,[1] M. Fukuda,[2] D. Nishimura,[2] X. L. Cai,[3] S. Fukuda,[4] I. Hachiuma,[5] C. Ichikawa,[5] T. Izumikawa,[6] M. Kanazawa,[4] A. Kitagawa,[4] T. Kuboki,[5] M. Lantz,[7] M. Mihara,[2] M. Nagashima,[6] K. Namihira,[5] Y. Ohkuma,[6] T. Ohtsubo,[6] Zhongzhou Ren,[8] S. Sato,[4] Z. Q. Shen,[1] M. Sugiyama,[5] S. Suzuki,[6] T. Suzuki,[5] M. Takechi,[7] T. Yamaguchi,[5] B. J. Xu,[3] and W. Xu[3]





No halo structure and short density tail

1 **but very large B(E2) values exist in the literature…**

Without γ rays

VOLUME 66, NUMBER 19 PHYSICAL REVIEW LETTERS 13 MAY 1991

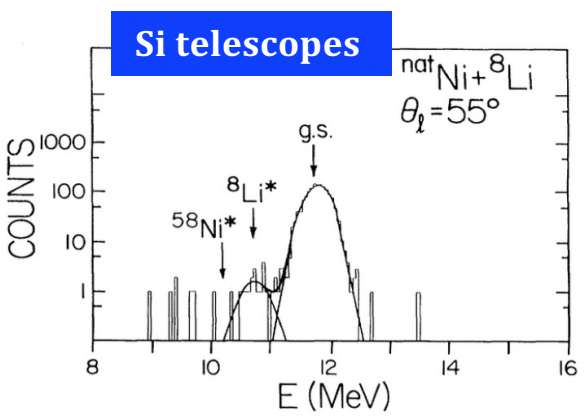
Coulomb Excitation of ^{8}Li

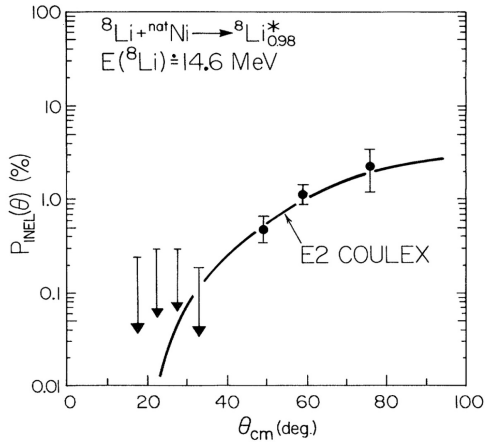
J. A. Brown, F. D. Becchetti, J. W. Jänecke, K. Ashktorab, and D. A. Roberts
Physics Department, University of Michigan, Ann Arbor, Michigan 48109-1090

J. J. Kolata, R. J. Smith, and K. Lamkin
Physics Department, University of Notre Dame, Notre Dame, Indiana 46556

R. E. Warner
Physics Department, Oberlin College, Oberlin, Ohio 44074
(Received 3 December 1990; revised manuscript received 22 March 1991)

Si telescopes





$$B(E2; 2^+ \rightarrow 1^+) = 55(15)\ e^2fm^4$$

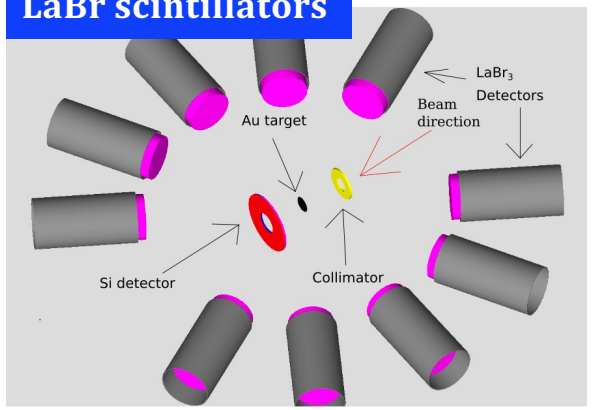
With γ rays

PHYSICAL REVIEW C **109**, 064304 (2024)

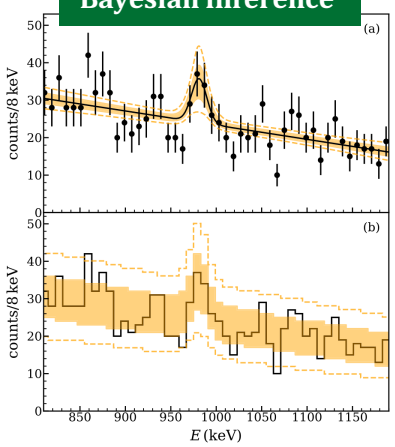
Remeasuring the anomalously enhanced $B(E2; 2^+ \rightarrow 1^+)$ in ^{8}Li

S. L. Henderson,[1,*] T. Ahn,[1,†] P. J. Fasano,[1,‡] A. E. McCoy,[2,3,‡] S. Aguilar,[1] D. T. Blankstein,[1] L. Caves,[1] A. C. Dombos,[1] R. K. Grzywacz,[4] K. L. Jones,[4] S. Jin,[1] R. Kelmar,[1] J. J. Kolata,[1] P. D. O'Malley,[1] C. S. Reingold,[1,*] A. Simon,[1] and K. Smith[4,*]
[1]*Department of Physics and Astronomy, University of Notre Dame, 225 Nieuwland Science Hall, Notre Dame, Indiana 46556, USA*
[2]*Facility for Rare Isotope Beams, Michigan State University, Michigan 48824, USA*
[3]*Department of Physics, Washington University in Saint Louis, Saint Louis, Missouri 63130, USA*
[4]*Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA*

LaBr scintillators



Bayesian inference



$$B(E2; 2^+ \rightarrow 1^+) = 19^{+7}_{-6}(2)\ e^2fm^4$$

2 but *ab initio* calculations predict very small values…

Green's Function Monte Carlo

PHYSICAL REVIEW C **87**, 035503 (2013)

Quantum Monte Carlo calculations of electromagnetic moments and transitions in $A \leqslant 9$ nuclei with meson-exchange currents derived from chiral effective field theory

S. Pastore,[1,*] Steven C. Pieper,[1,†] R. Schiavilla,[2,3,‡] and R. B. Wiringa[1,§]
[1]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[2]*Theory Center, Jefferson Laboratory, Newport News, Virginia 23606, USA*
[3]*Department of Physics, Old Dominion University, Norfolk, Virginia 23529, USA*

$$H = T + V = \sum_{i=1}^{A} t_i + \sum_{i<j} v_{ij} + \sum_{i<j<k} V_{ijk} + \dots$$

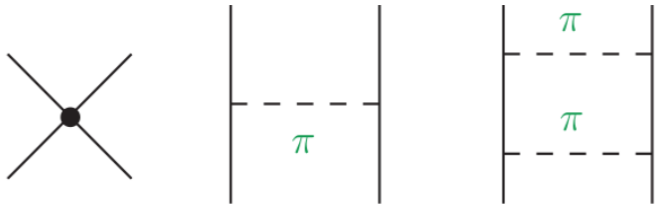
AV18 — R. B. Wiringa *et al.*, Phys. Rev. C **51**, 38 (1995)

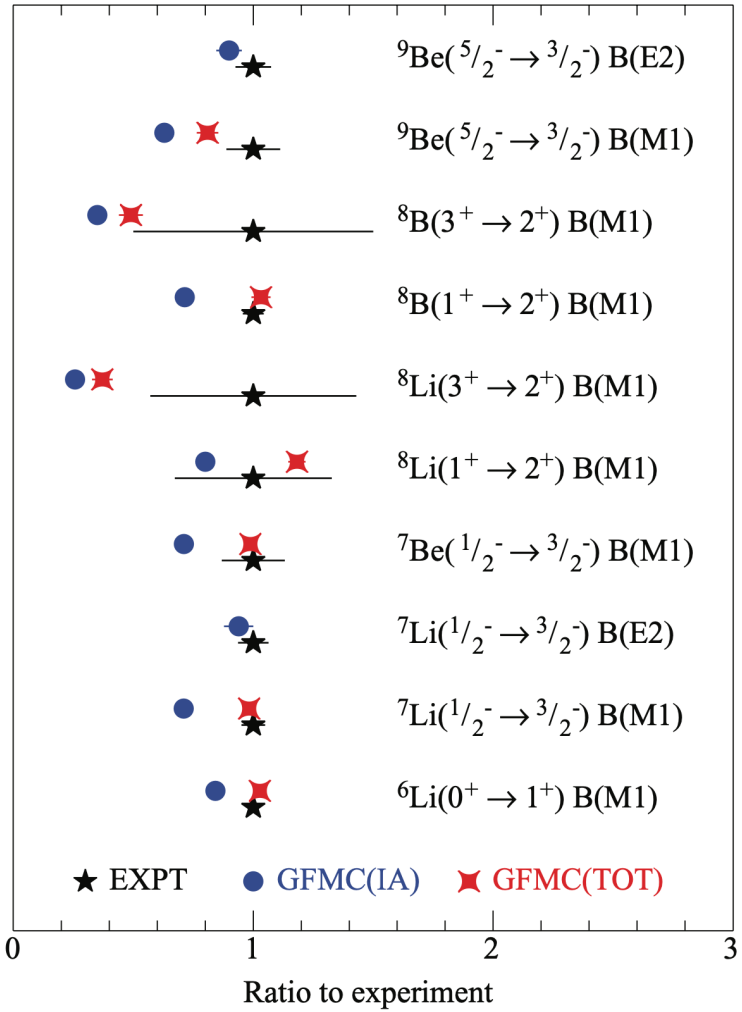
IL7 — S. C. Pieper, AIP Conf. Proc. **1011**, 143 (2008)

Variational approach

$$E_V = \frac{\langle \Psi_V | H | \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle} \geq E_0 \qquad \Psi(\tau) = \exp[-(H - E_0)\tau]\Psi_V$$

χEFT electromagnetic operators





Results for ^{8}Li

$B(E2; 2^+ \to 1^+) = 0.8\ e^2fm^4$

No-Core Configuration Interaction calculations (NCCI)

Simone Bottoni

PHYSICAL REVIEW C **106**, 034320 (2022)

***Ab initio* estimation of $E2$ strengths in ^{8}Li and its neighbors by normalization to the measured quadrupole moment**

Mark A. Caprio and Patrick J. Fasano
Department of Physics and Astronomy, University of Notre Dame, Notre Dame, Indiana 46556-5670, USA

$$H_A = T_{\text{rel}} + \mathcal{V} = \frac{1}{A}\sum_{i<j}\frac{(\vec{p}_i - \vec{p}_j)^2}{2m} + \sum_{i<j}^{A} V_{\text{NN},ij} + \sum_{i<j<k}^{A} V_{\text{NNN},ijk}$$

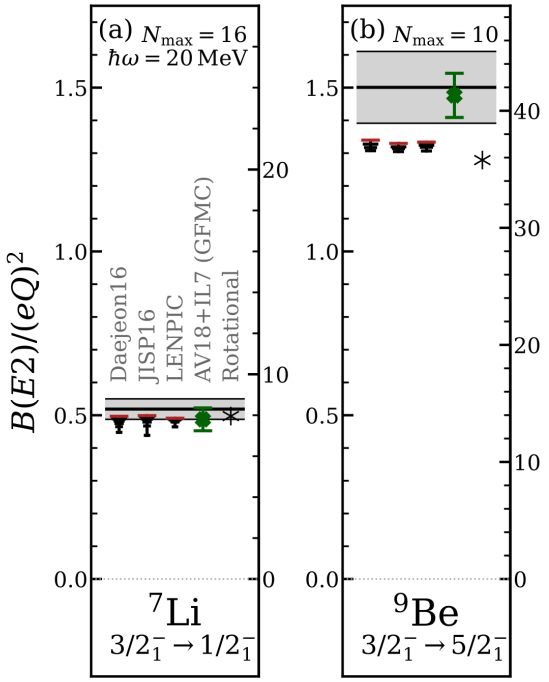
R. Barret *et al.*, Prog. Part. Nucl. Phys. **69**, 131 (2013)

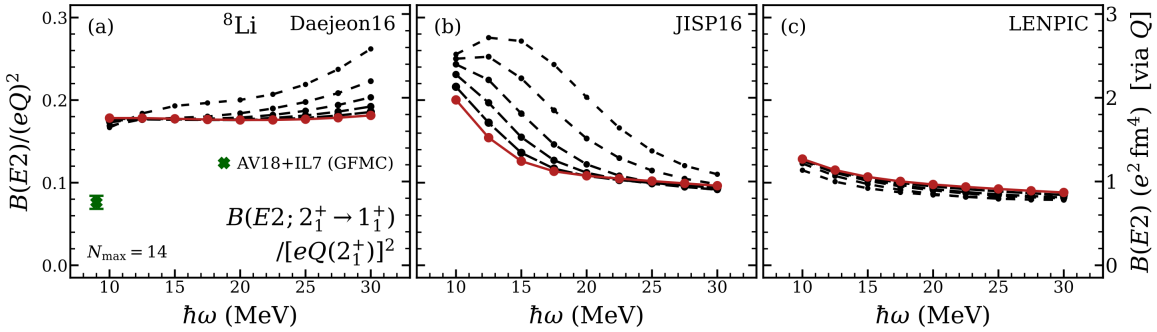
- Truncated HO basis and excitations
- Slow convergence of B(E2)
- Approximated B(E2) values

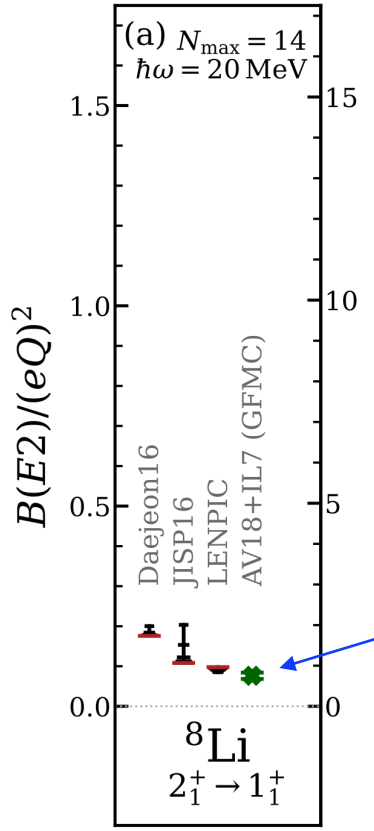
$$\frac{B(E2)}{(eQ)^2} \propto \left|\frac{\langle J_f||Q_2||J_i\rangle}{\langle J||Q_2||J\rangle}\right|^2$$

Systematic truncation errors are cancelled in the ratio of diagonal and non-diagonal E2 matrix elements

Benchmark







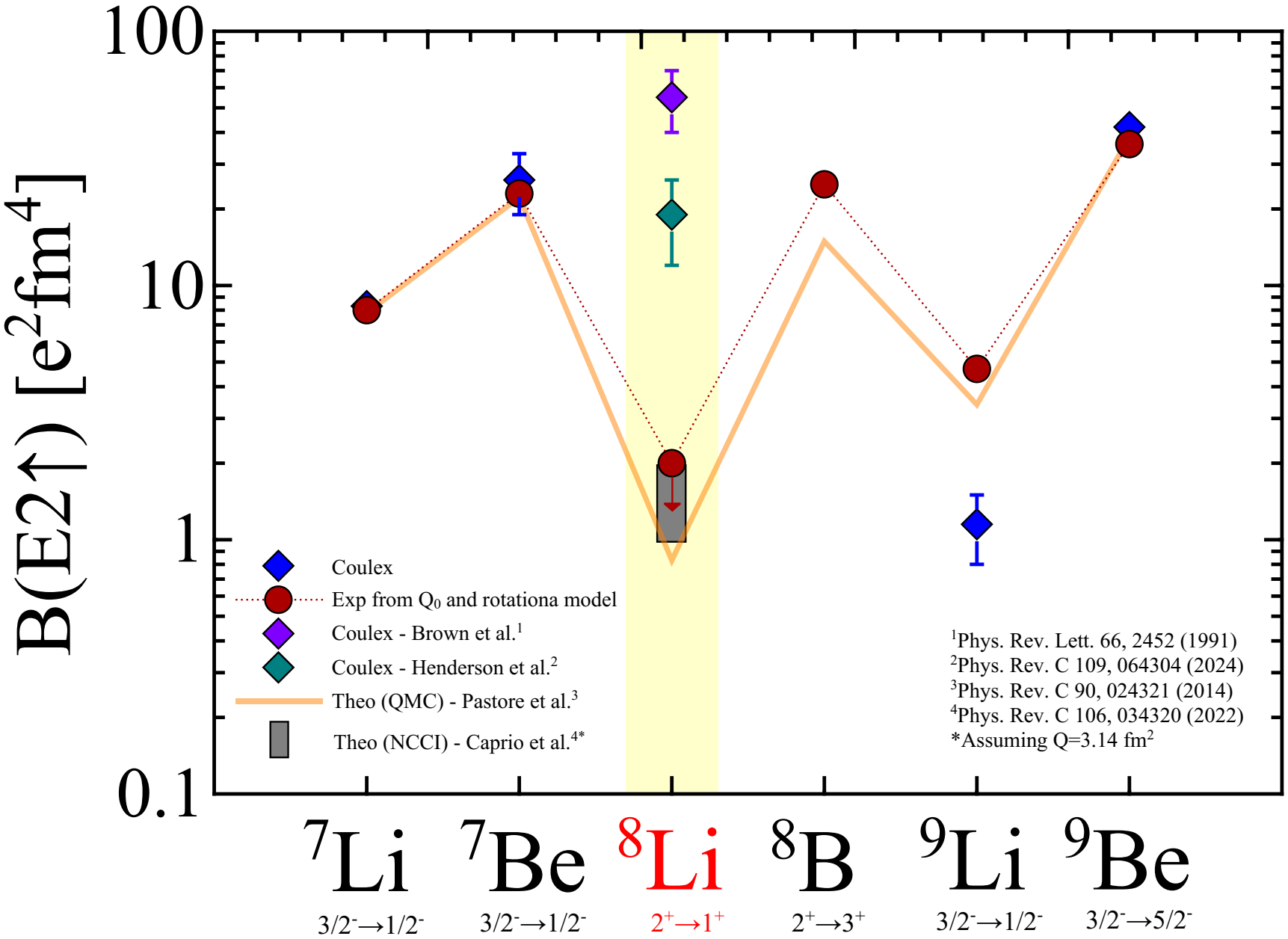
Results for ^{8}Li

assuming Q_0=3.14 fm²

$B(E2; 2^+ \to 1^+) = 1 - 2\ e^2fm^4$

compatible with QMC

ACC meeting
Warsaw, 7-8 Sept. 2026



ab initio calculations

Predictions of large B(E2) classically interpreted as **molecular rotations**

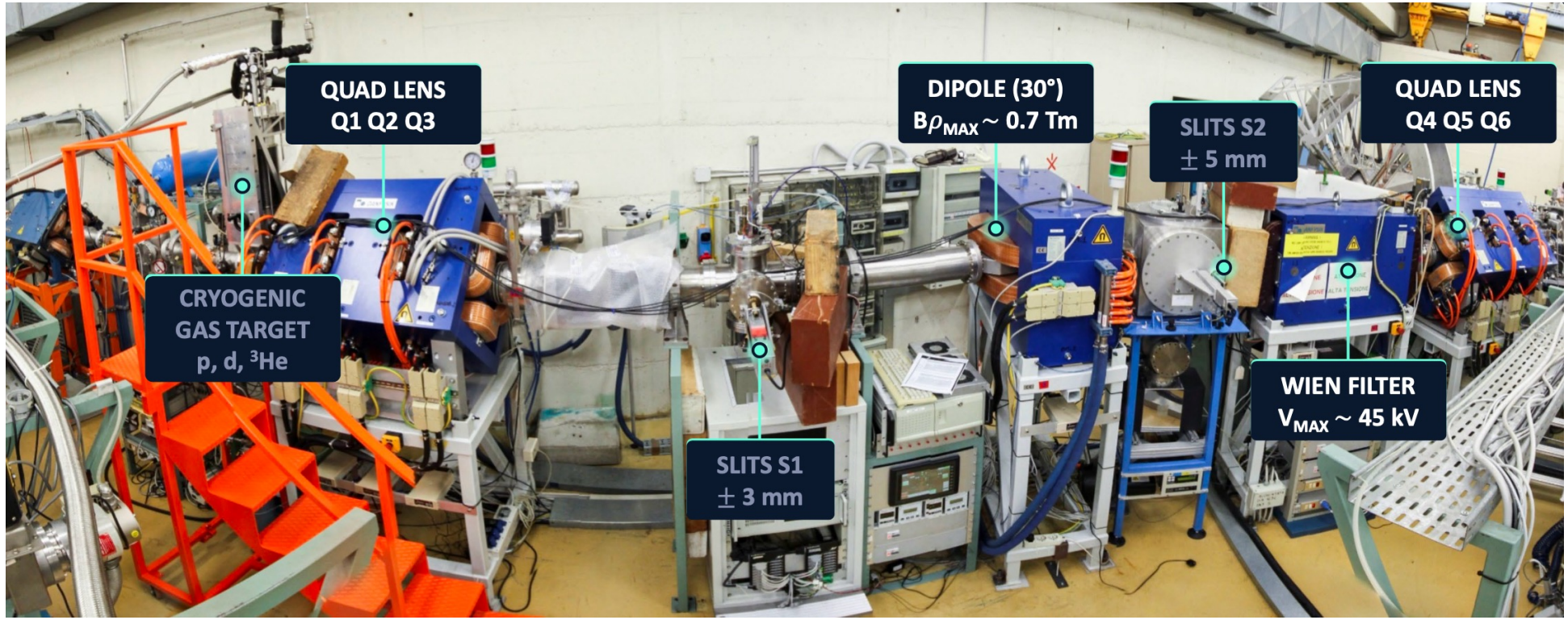
Predictions of B(E2) as deduced from ground-state **quadrupole moments**

Large discrepancy in ^{8}Li

no theoretical interpretation of such a large E2 strength

Proposed experiment

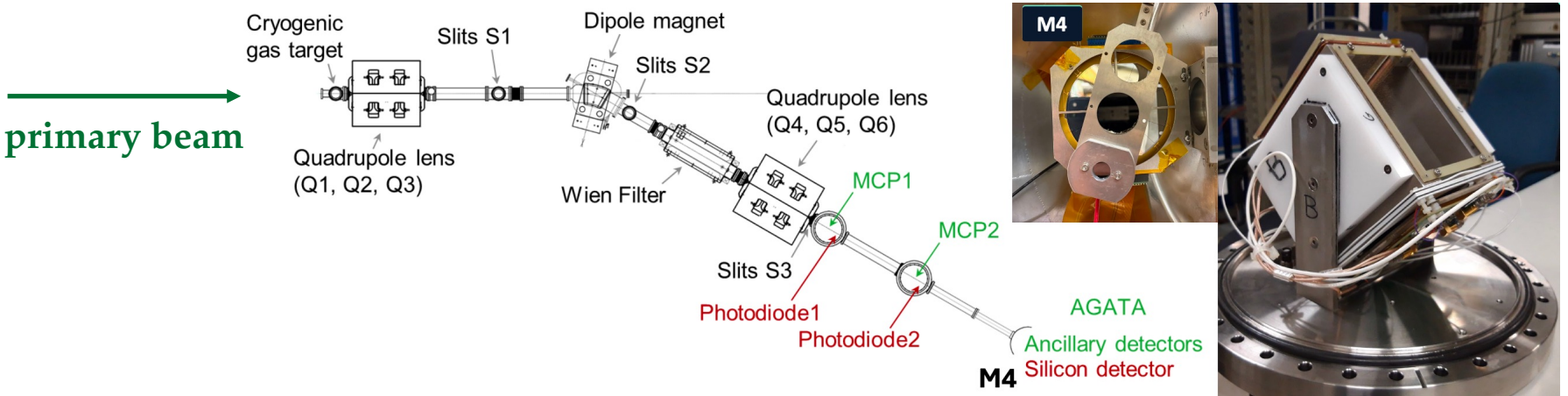
investigation of the possible ^{8}Li anomaly via Coulex



^{8}Li beam production

^{7}Li (d,p) @ 28 MeV
from Tandem

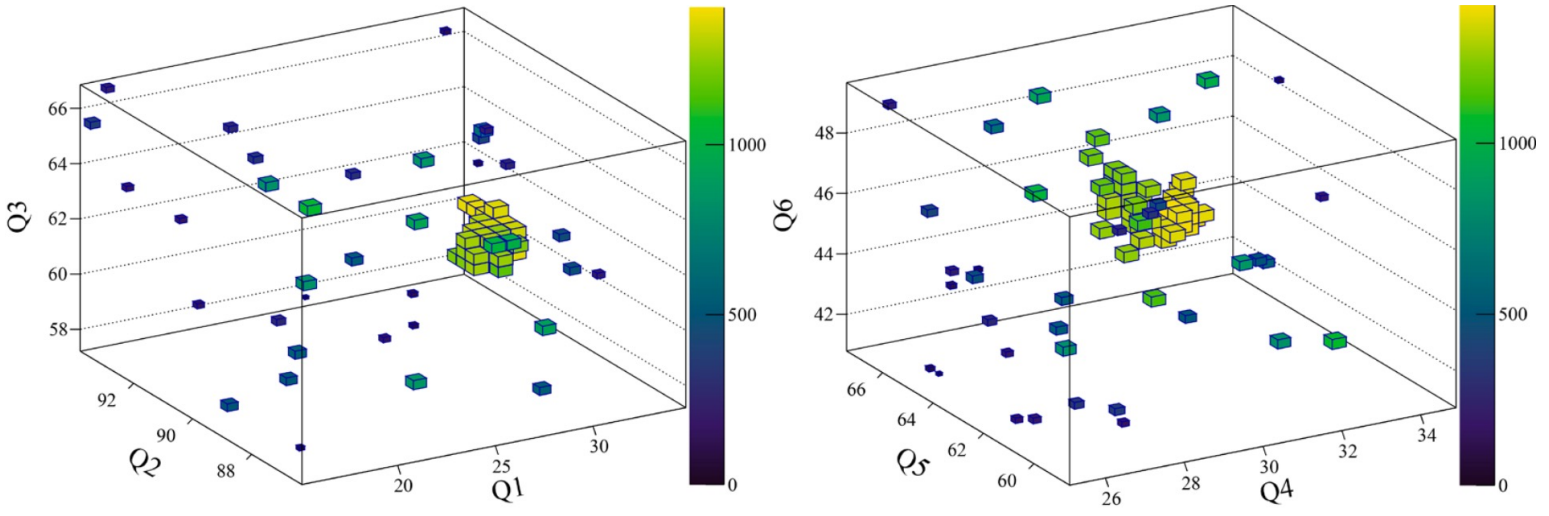
Primary intensity
up to 300 enA

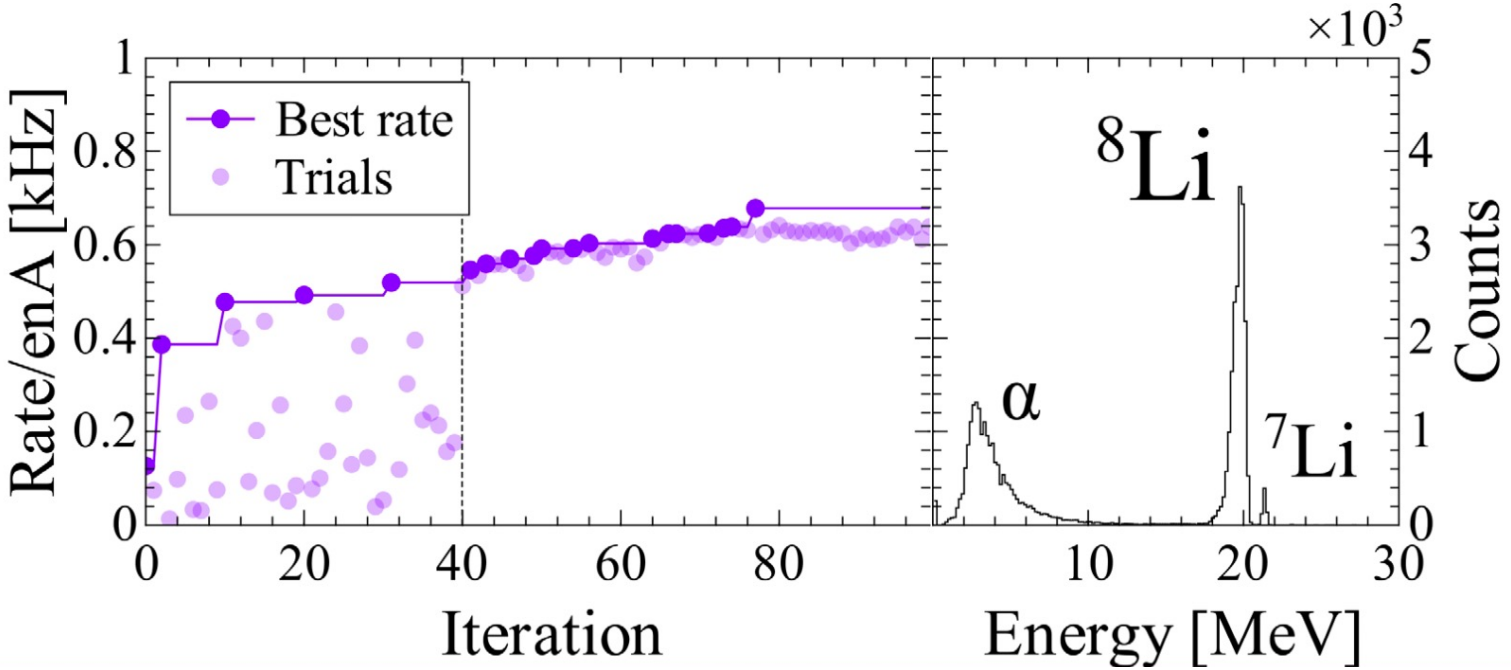


Courtesy of M. Mazzocco, S. Pigliapoco, A. Togni, D. Genna

^{8}Li beam production and transport optimization

Simone Bottoni

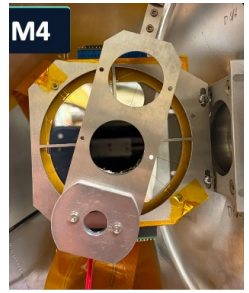




Courtesy of D. Genna

Bayesian Optimization

- Simultaneous modification of 8 optical parameters
- Rate measured at target position



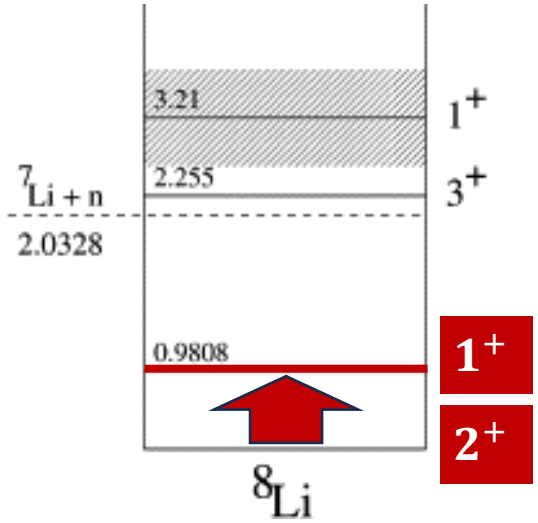
- Convergence time ~ 1 h
  (8-10 h with manual methods)

I_{beam} = 5E4 – 1E5 pps

Technical paper in preparation

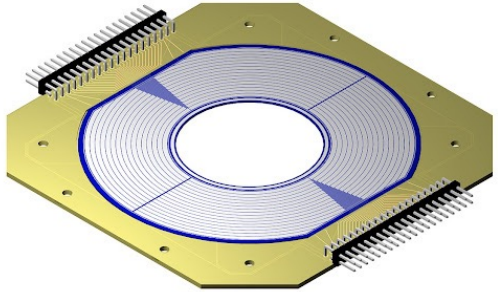
The ^{8}Li Coulex experiment

Simone Bottoni



AGATA

SAURON Si detector

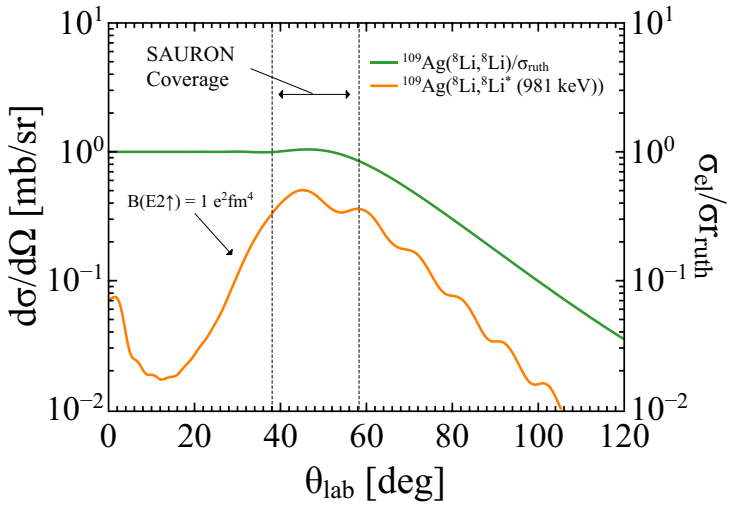


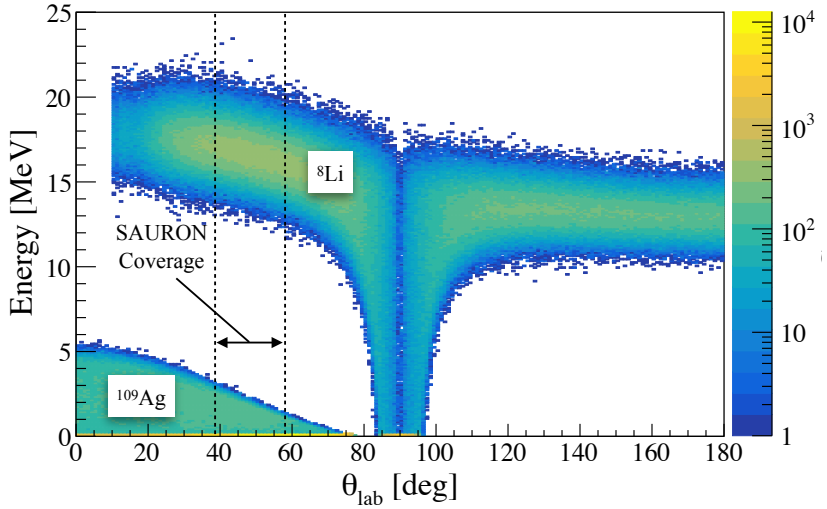
Superior resolving power of AGATA to reach B(E2) ~ 1 e^{2}fm^4

^{109}Ag target 3 mg/cm^2

mostly low-energy γ rays

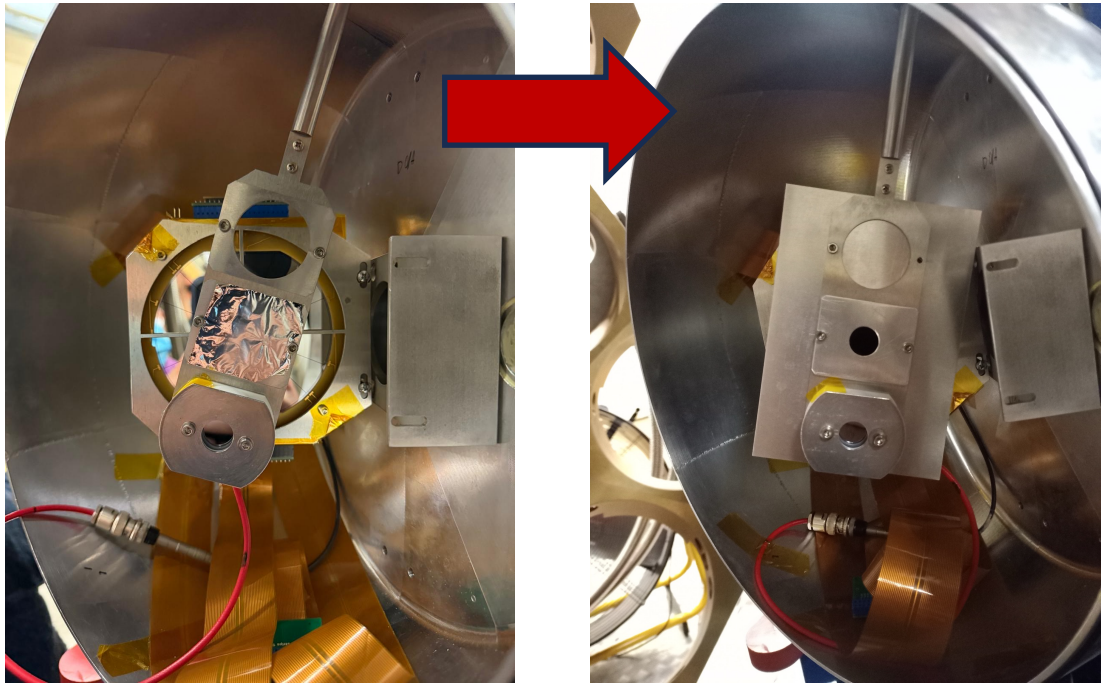
Safe Coulex





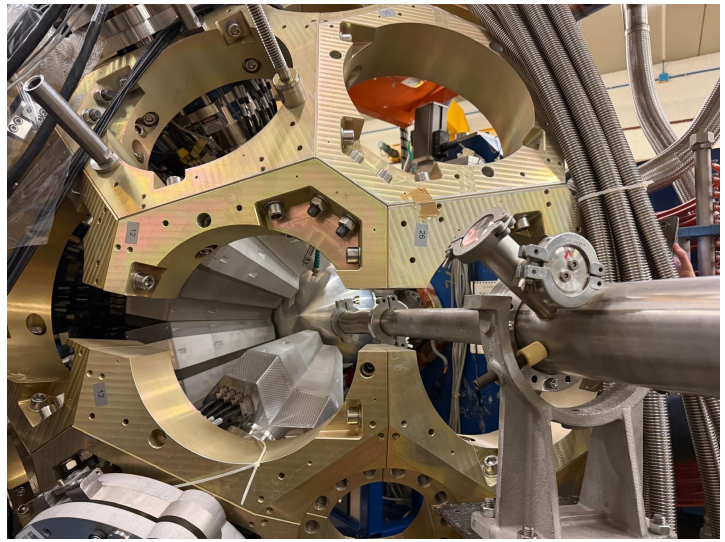
- Expected FWHM = 8 keV @ 1 MeV
- No γ-ray feeding
- No M1 contribution
- **Normalization:**
  - ^{109}Ag target

Inside the scattering chamber

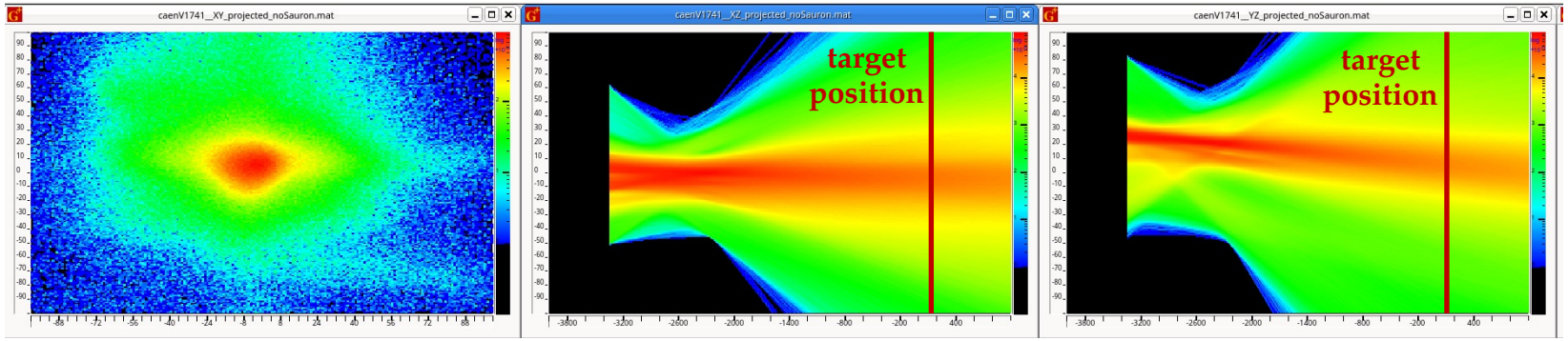


Neutron shielding

AGATA in close-up position



MCP beam tracking

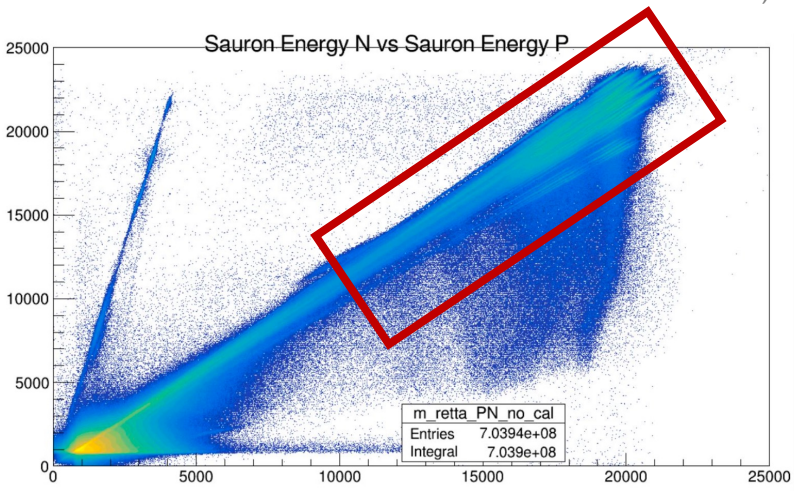


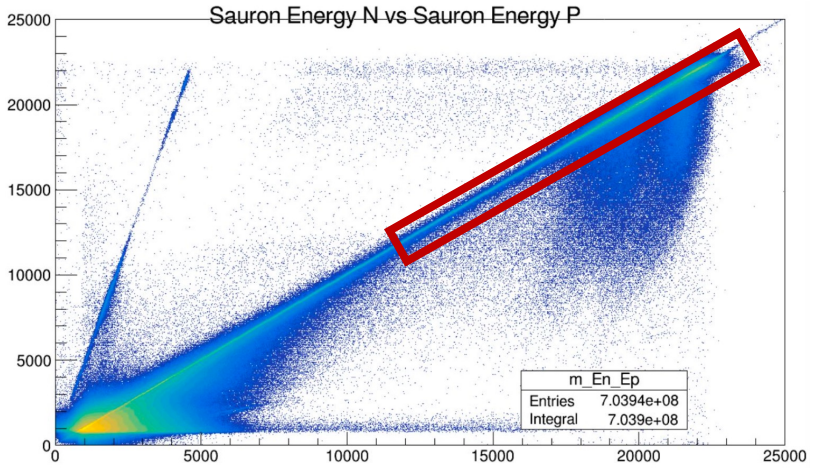
Beam spot and direction

ACC meeting
Warsaw, 7-8 Sept. 2026

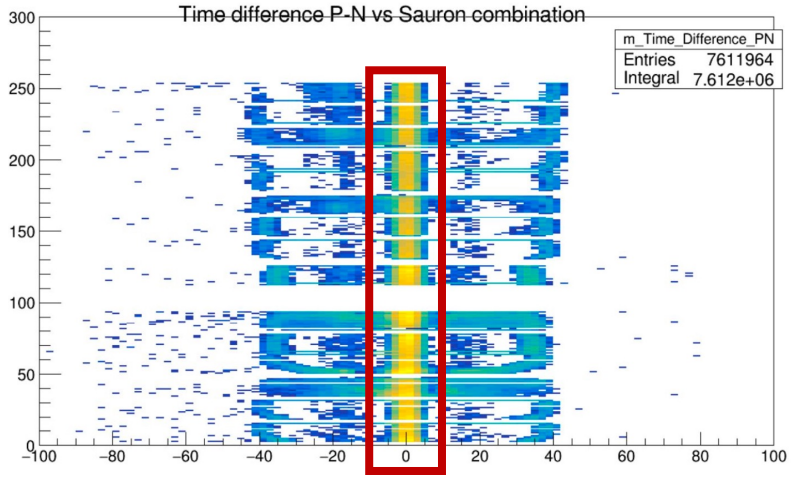
p-n energy correlation

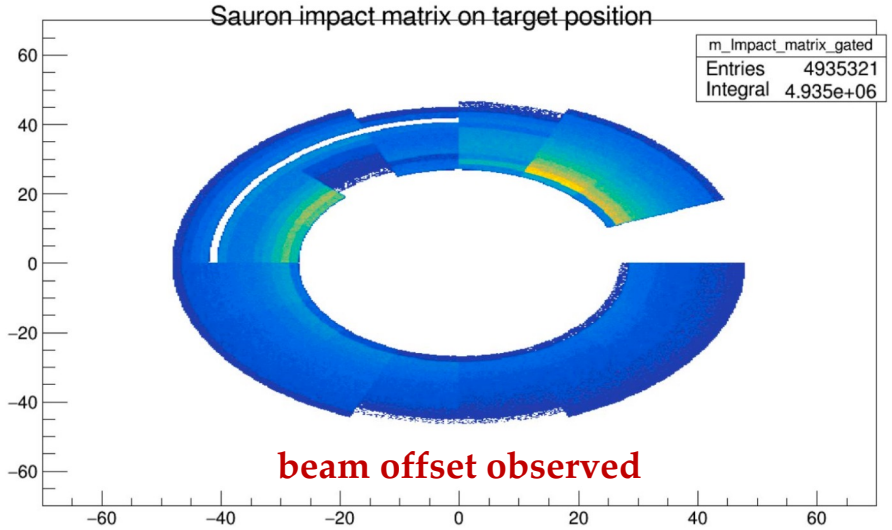
M. Reese et al., NIM A 779, 63 (2015)

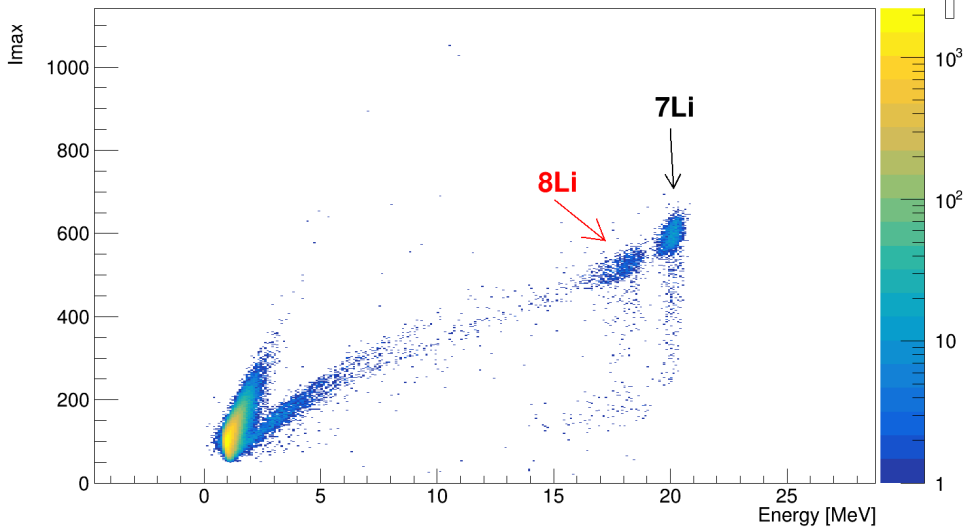




p-n time correlation







Ion identification through PSA in the Si detector

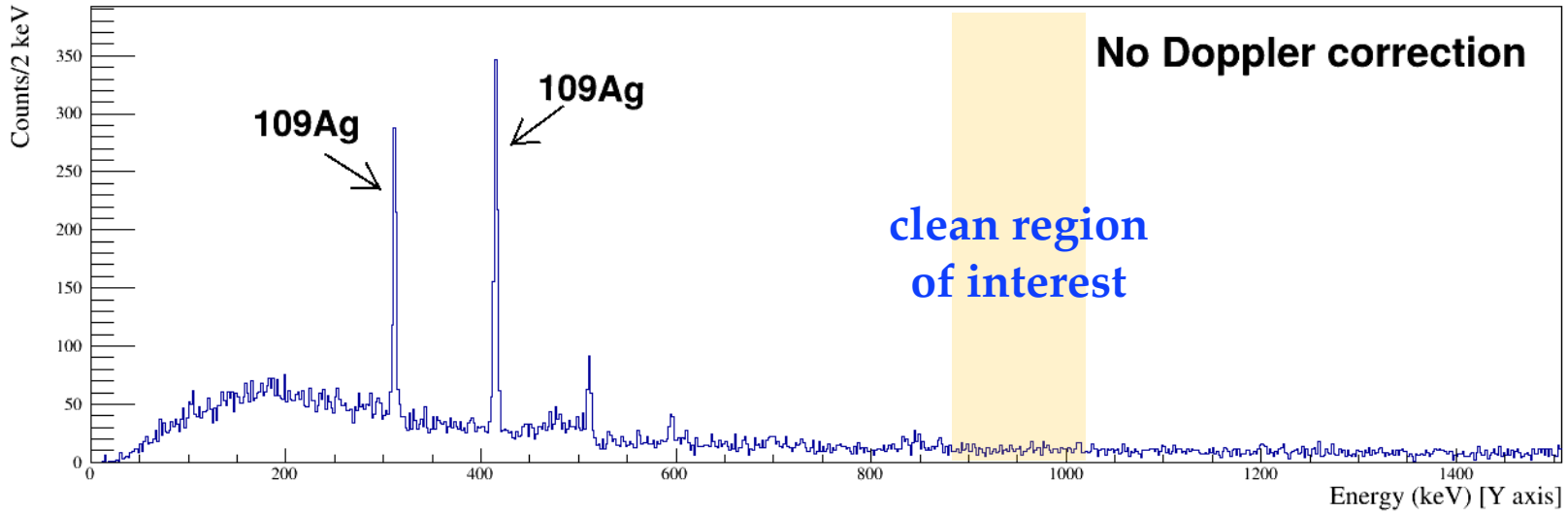
Bachelor's thesis by T. Ghiringhelli

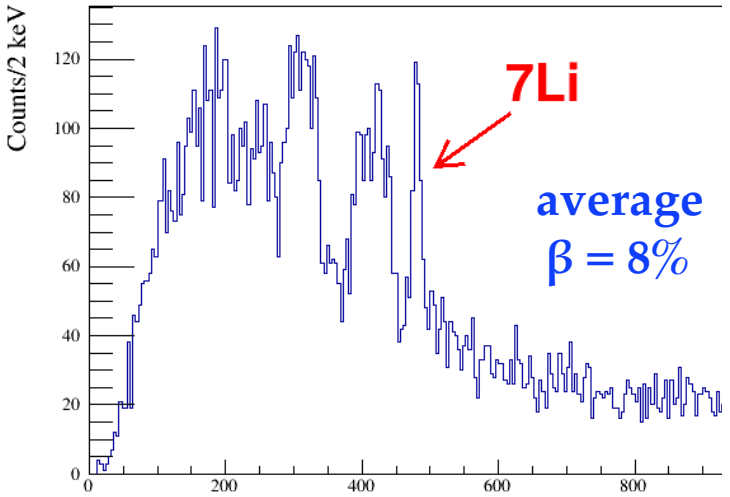
calibrations, PID, beam offset, and study of Rutherford scattering

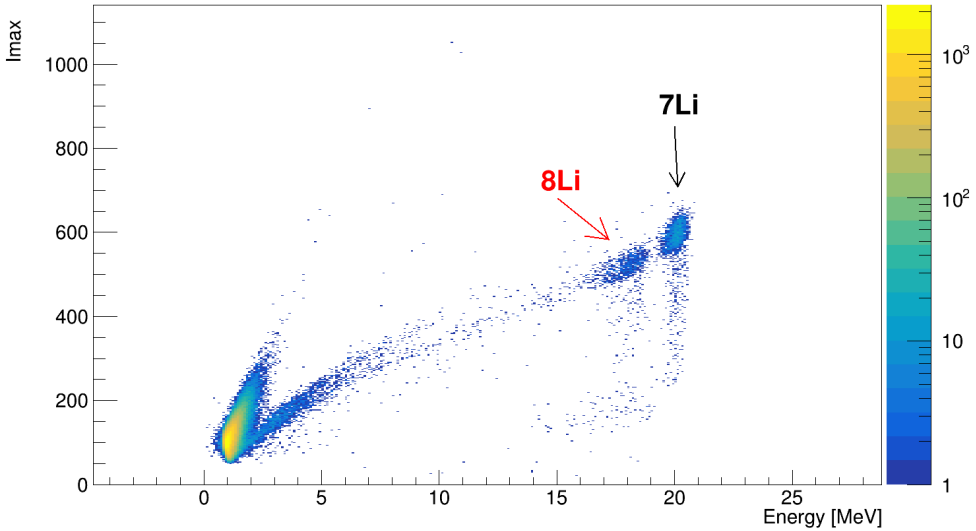
ACC meeting
Warsaw, 7-8 Sept. 2026

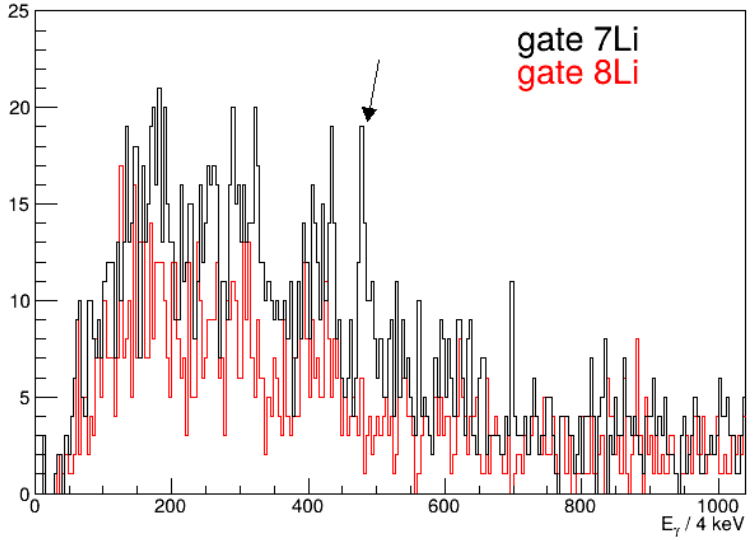
Online γ-ray spectra - partial statistics

Simone Bottoni









selectivity to different ion gates

No prominent ^{8}Li peak pointing to a small B(E2)

ongoing analysis

A collective effort and commitment

Special thanks to:

G. Andreetta, D. Brugnara, P. Figuera, D. Genna, A. Goasduff, A. Gottardo, M. Mazzocco, S. Pigliapoco, D. Stramaccioni, A. Togni, D. Torresi, L. Zago

Thank you!

Simone Bottoni
Università degli Studi di Milano
INFN Sezione di Milano

Franco Galtarossa
INFN Sezione di Padova

Marco Rocchini
INFN Sezione di Firenze

THE 26TH AGATA WEEK
AND ACC MEETING
7-11 SEPTEMBER 2026
HEAVY ION LABORATORY, WARSAW, POLAND

AGATA
ADVANCED GAMMA TRACKING ARRAY

EXOTIC
Radioactive Nuclear Beams