The 75th Meeting of the INTC:

Mapping single-particle neutron strength towards the mid-shell in semi-magic lead isotopes

Spokepersons:

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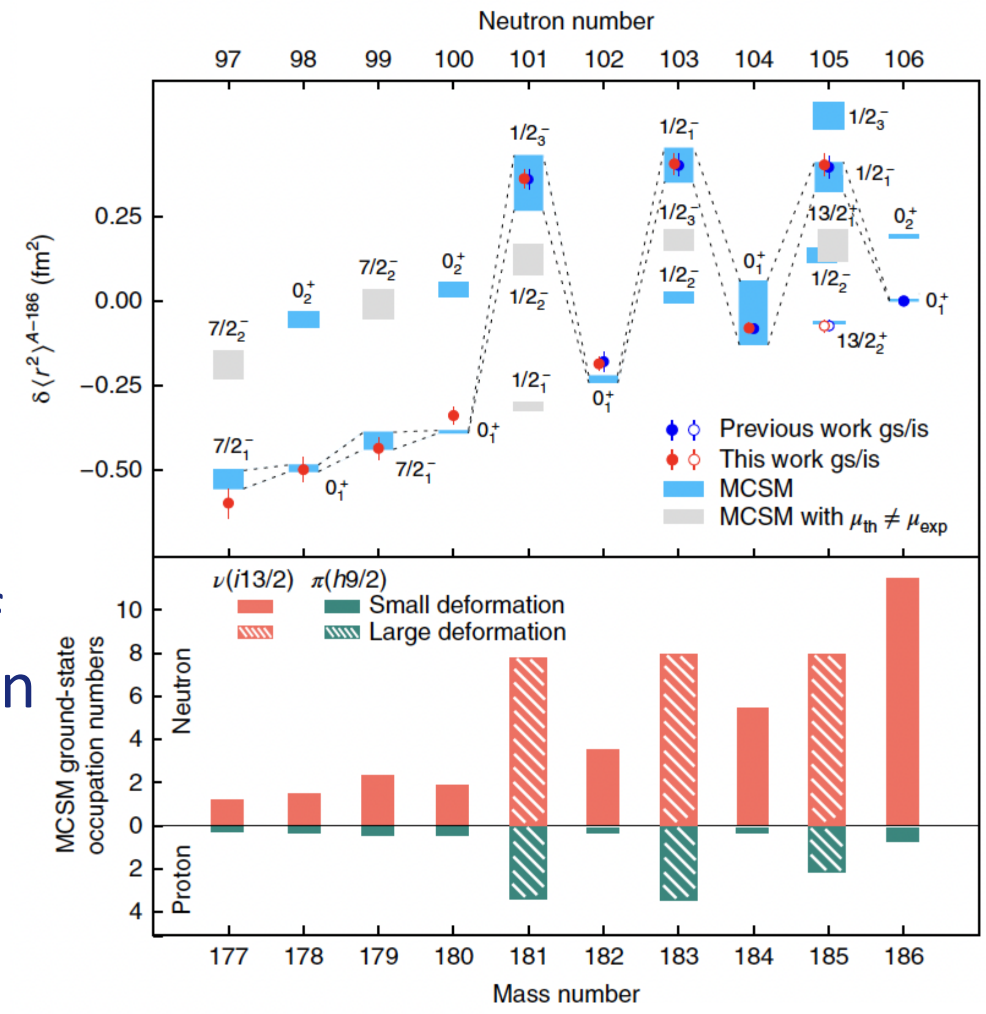
07.02.2024

Motivation

- Study the single-particle neutron states in neutron-deficient ^{197,199}Pb isotopes
- Understand the neutron particle occupancy development for $\nu 1i_{13/2}$ state
- Changing neutron occupancy in $\nu 1i_{13/2}$ orbital has been identified as driving the evolution of deformed intruder configurations in this region
- In Monte Carlo Shell Model calculations performed by Otsuka et al. to Hg isotopes, is shown



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B. Marsh et al., Nature Physics 14 (2018)

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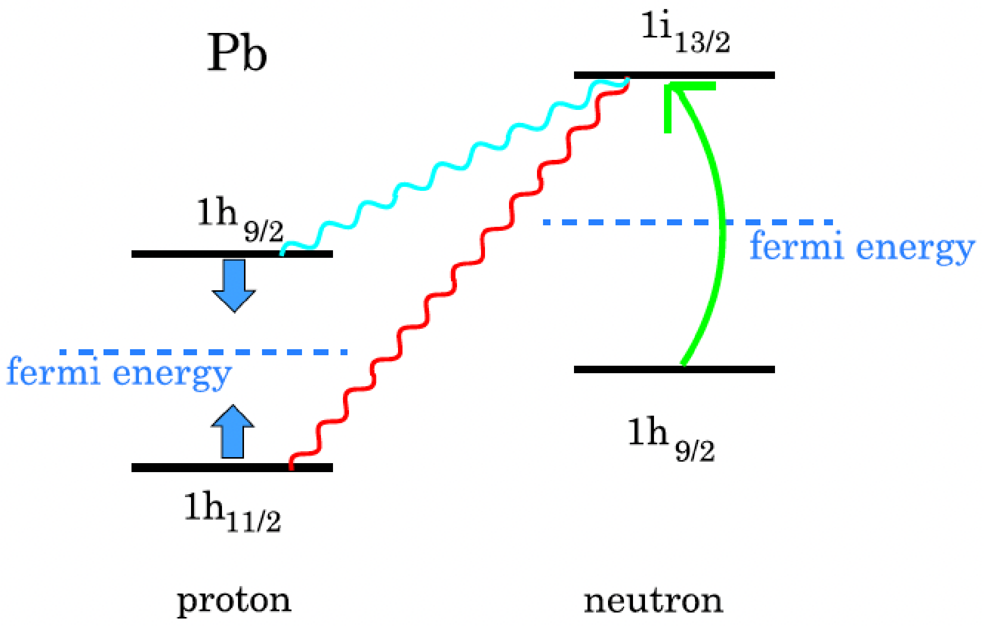
Motivation

- Data on single-particle states strongly coupled to the $\pi(0p\text{-}0h)$ band configuration are currently lacking neutron-deficient Pb isotopes
- There is no information on how the single-particle strength is distributed
- This experiment would be the first step towards systematic studies of evolving single-particle strength along the semi-magic lead isotopic chain



T. Otsuka et al., J. Phys. G: Nucl. Part. Phys. 43 (2016)

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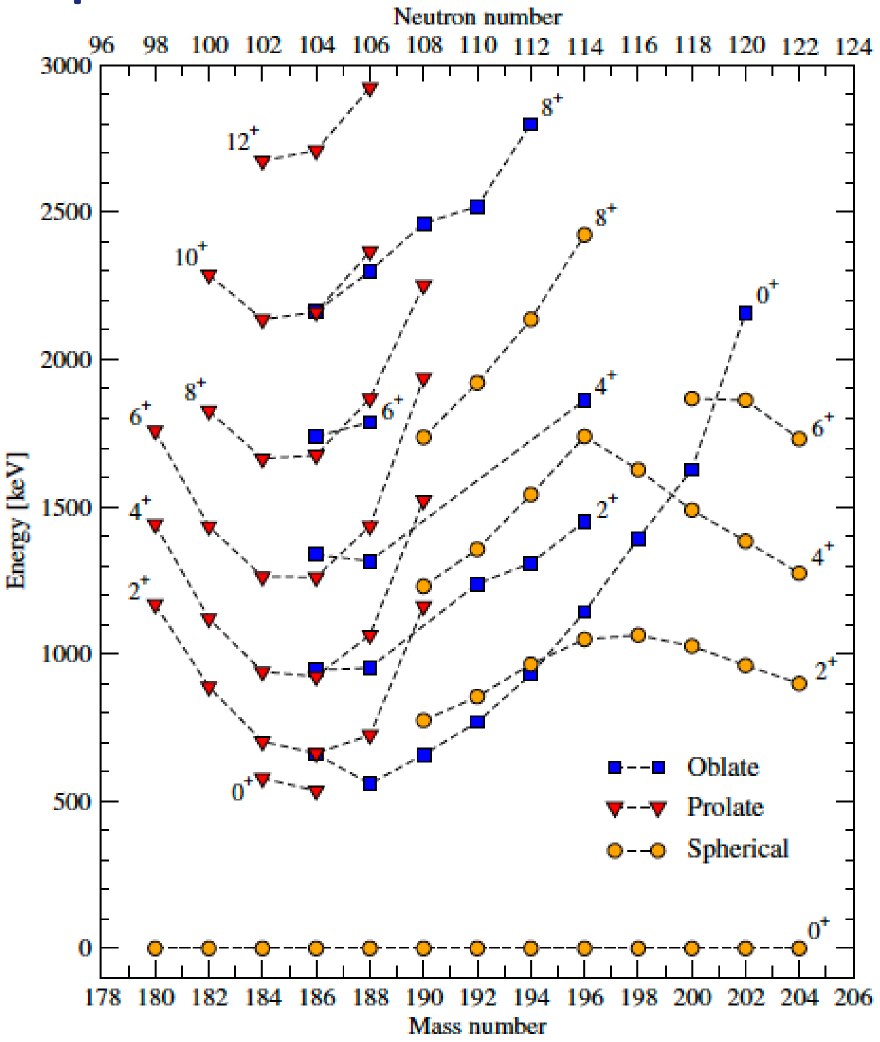
Shape coexistence in Pb isotopes

- Shape coexistence in Pb nuclei has been the subject of intense study for several decades
- The $\pi(2p\text{-}2h)$ and $\pi(4p\text{-}4h)$ intruder configurations are associated with oblate and prolate deformed structures, respectively
- The minima of these can be found in the neutron mid-shell



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J. Ojala, J. Pakarinen et al., Communications Physics 5 (2022)

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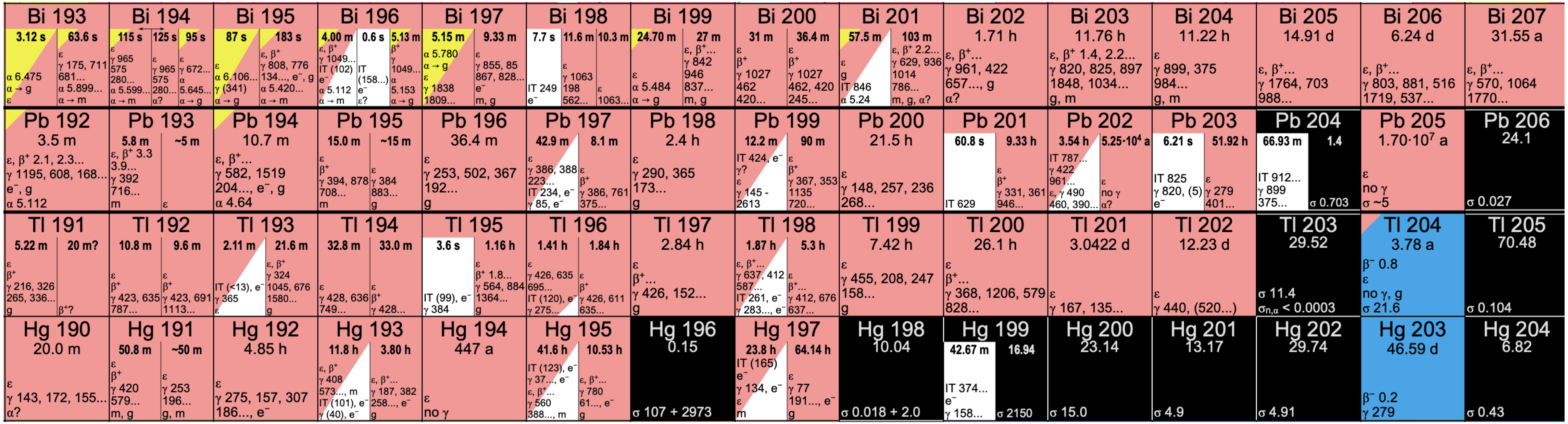
Pb isotopes



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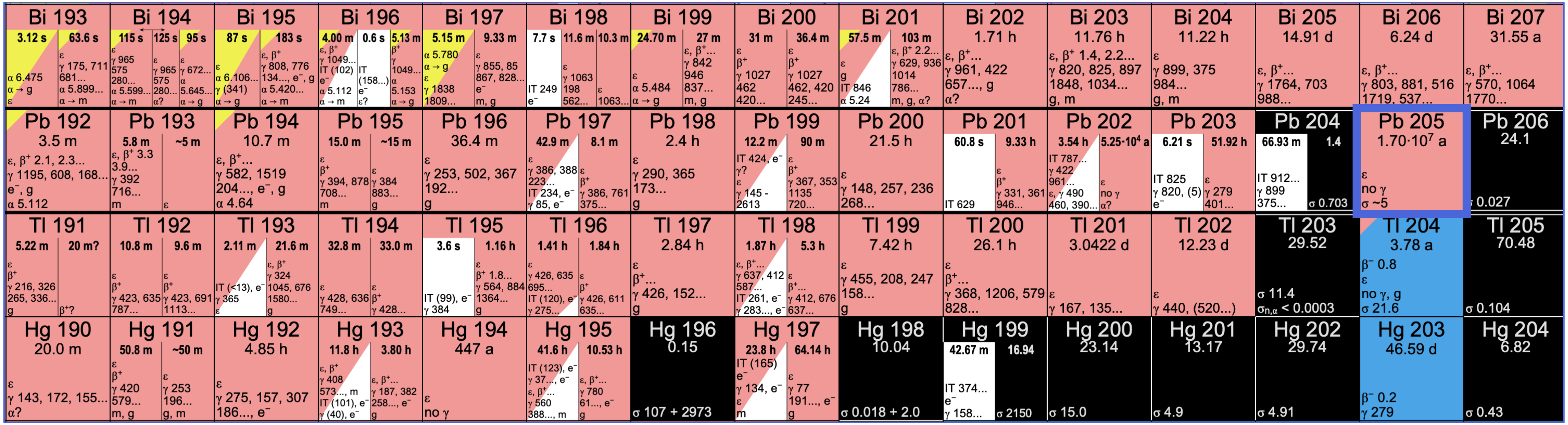
Pb isotopes



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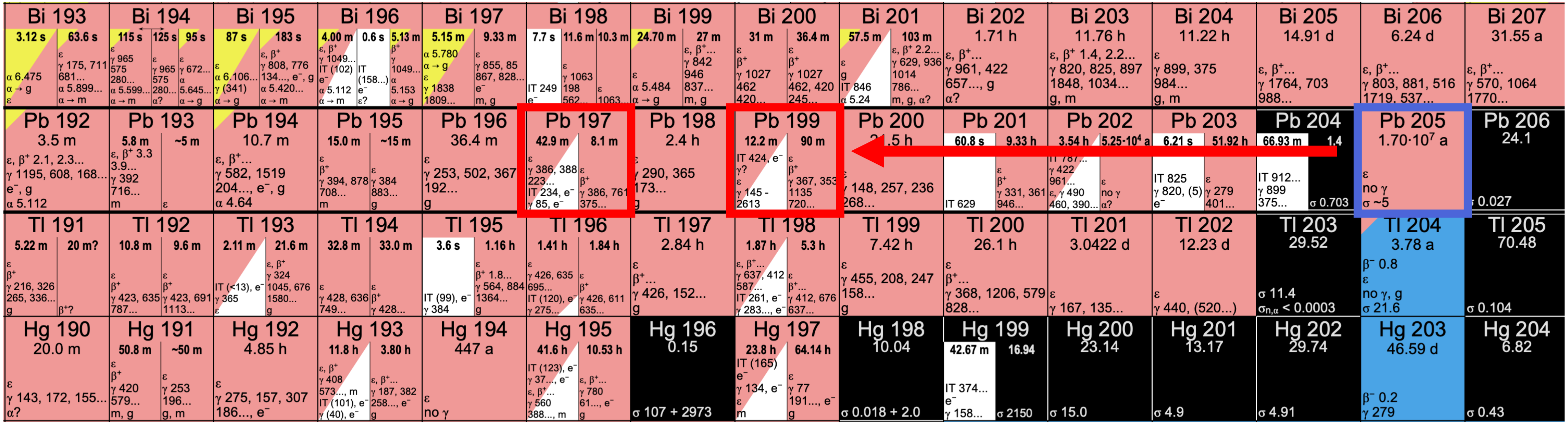
Pb isotopes



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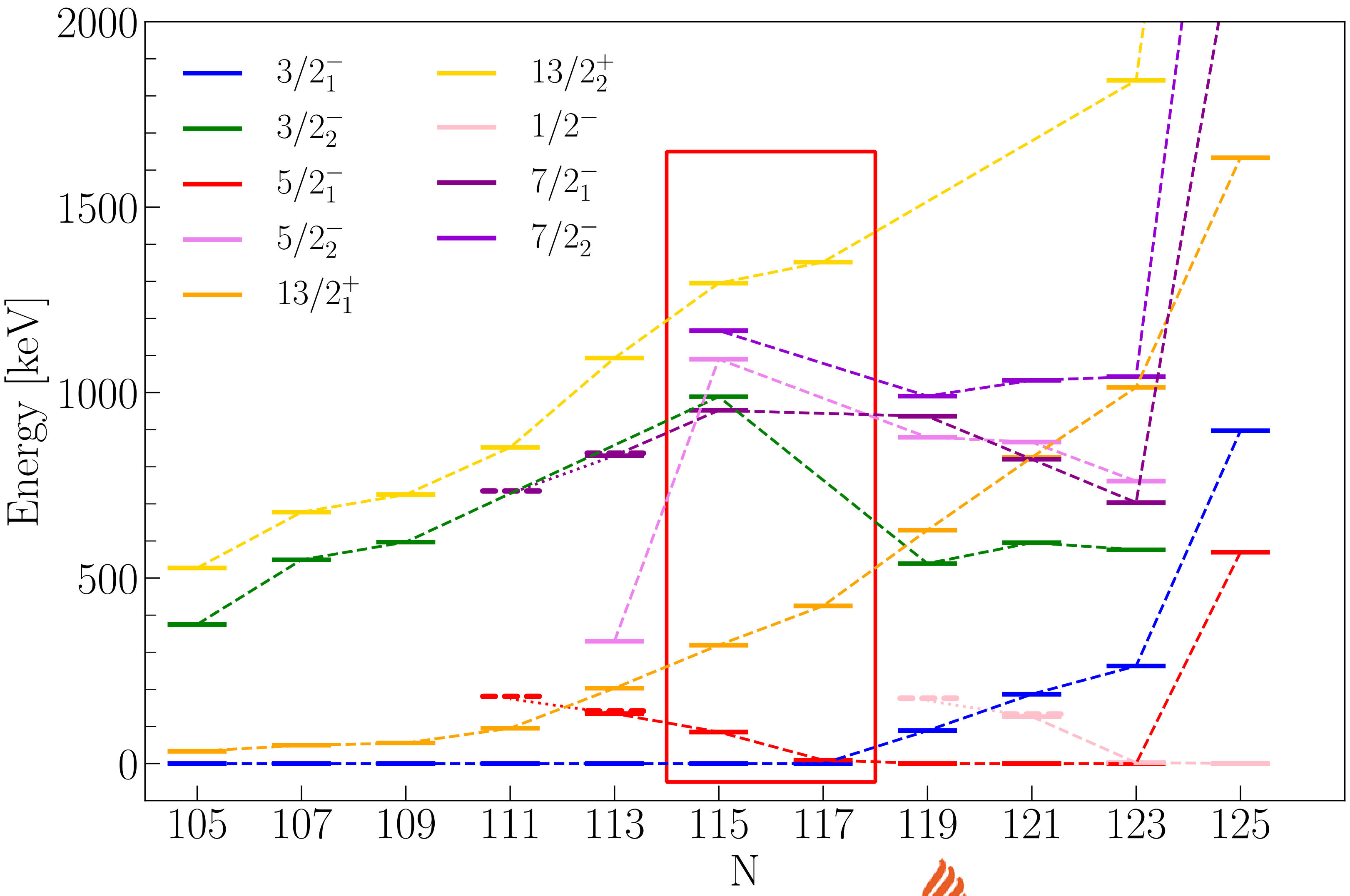
Systematics

- Assumed single-particle states are shown in the figure
- The level energies are based on the α- and β-decay studies
- Is the first excited 13/2⁺ state coupled with the *π*(0*p*-0*h*) spherical configuration?



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Why to perform this experiment

- This experiment would allow us to obtain single-particle strength for the $i_{13/2}$ state, which is possible with ISS, unlike with MINIBALL as it is an isomeric state
- The needed beam is feasible only in ISOLDE (FRIB beam intensity is one order of magnitude lower)
- The experiment would provide a testing ground for theory calculations, which suffer from lack of the spectroscopic information in neutron-deficient Pb nuclei

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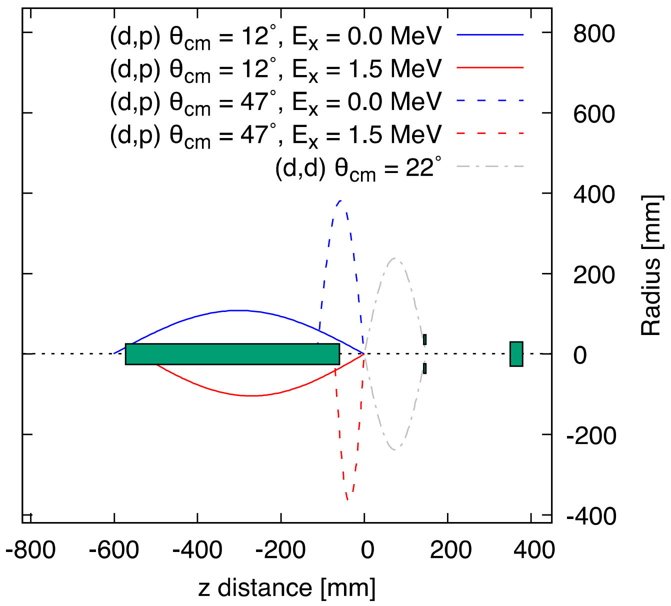
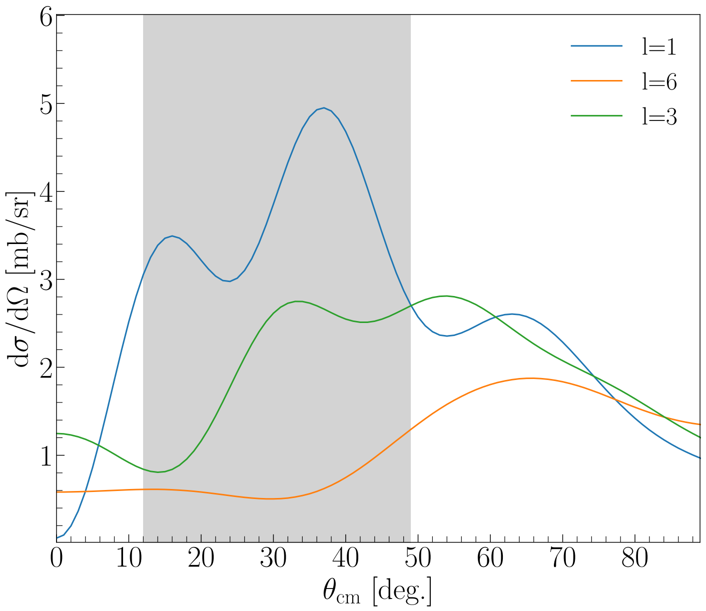
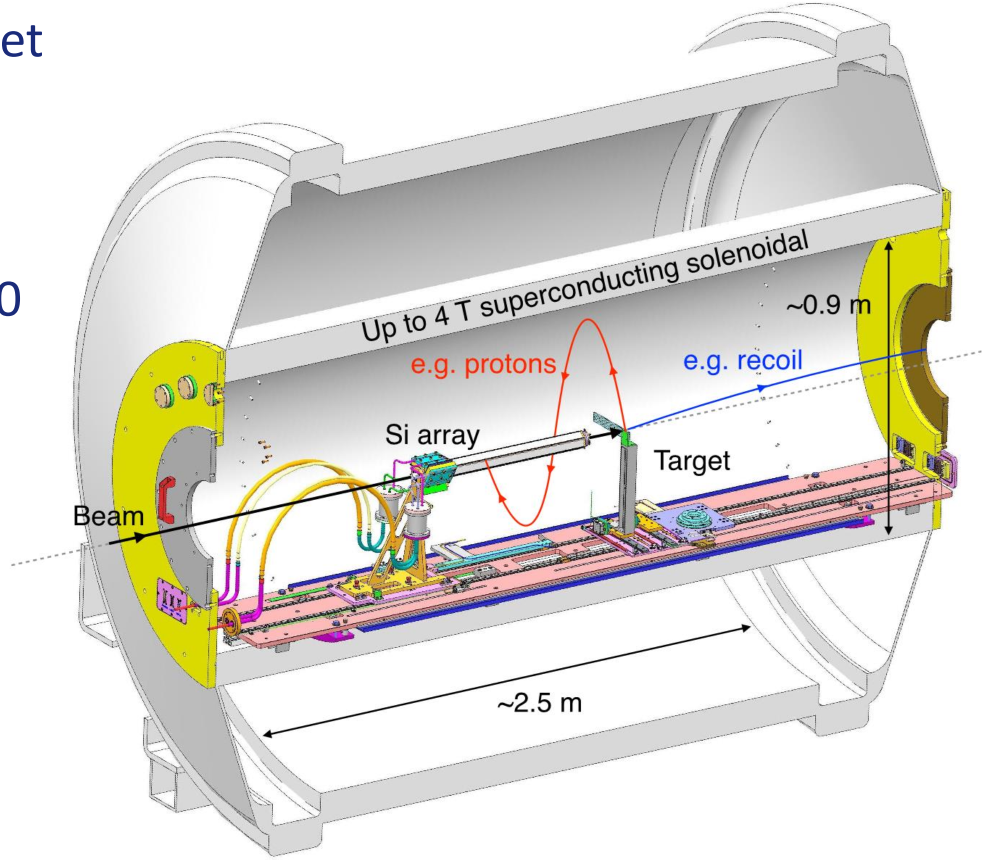
Transfer reaction at ISS - d(^{196,198}Pb,p) ^{197,199}Pb

- The Si array will be located as close as possible to the target
- The luminosity detector will be used to detect elastically scattered deuteron
- Magnetic field: 2.5 T
- A new 2-dimensional target ladder will allow more than 50 targets to be used
- Polyethylene target thickness: 150 µg/cm²







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Proton yields for different states

- Calculated with an assumption C^2S=0.2
- DWBA calculations were performed with Ptolemy
- The requested 10 shifts would allow to have large enough statistics for i13/2 state
- Similar yields are expected for ^{199}Pb

Energy (keV)	I^π	σ_{DWBA}	Counts per shift
0	$3/2_1^-$	7.8	350
85	$5/2_1^-$	4.5	203
319	$13/2_1^+$	1.4	65
952	$7/2_1^-$	7.7	346
989	$3/2_2^-$	9.4	423
1089	$5/2_2^-$	5.4	243
1167	$7/2_2^-$	8.0	361
1295	$13/2_2^+$	1.6	71

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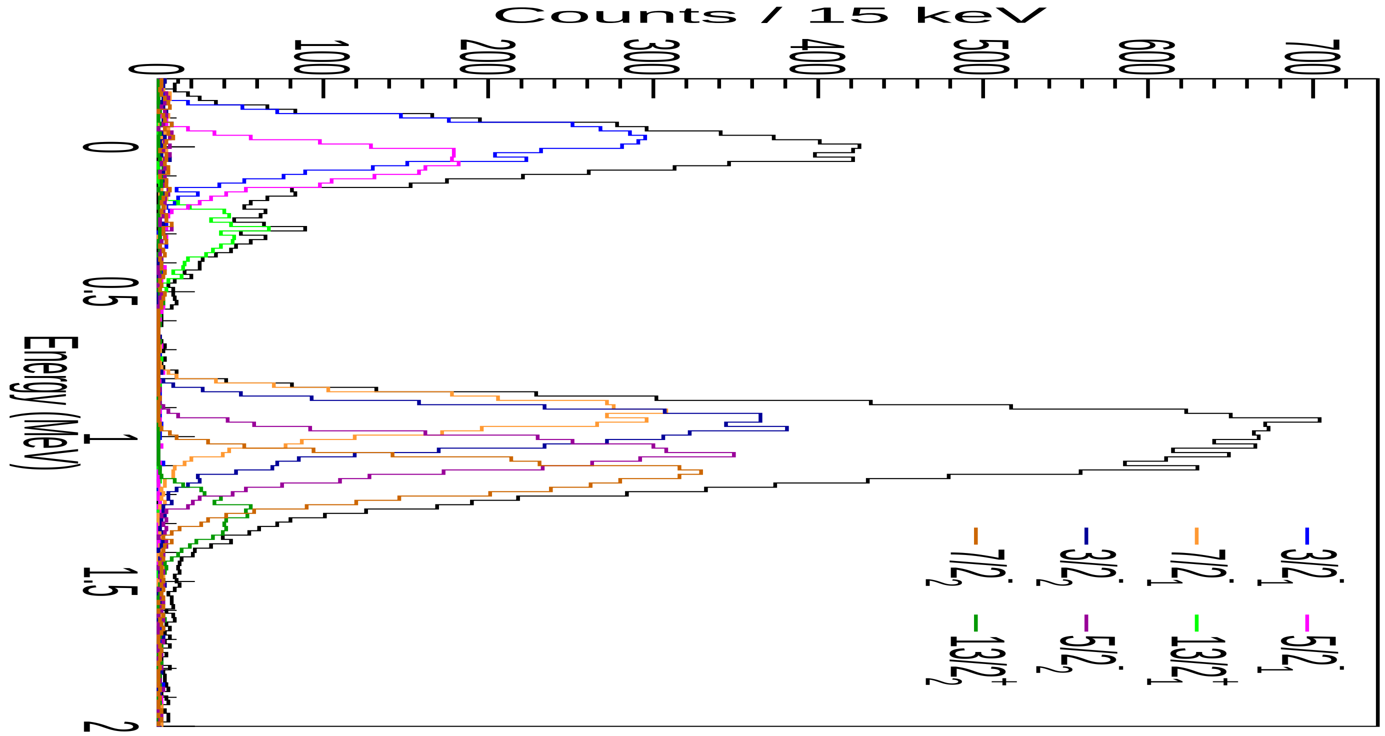
Simulation of d(^{196}Pb,p) ^{197}Pb

- Simulation performed with NPTool
- Aim to be sensitive to $C^2S \geq 0.2$ for $13/2^+$ state
- Some fragmentation of the low-*l* strength is expected.
- A similar excitation spectrum is expected for ^{199}Pb



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NPTool: A. Matta et al. J. Phys. G **43**, 045113 (2016)

Beam request

- There is experience in producing these beams
- Beam energy: 7.5 MeV/u (as high as possible)
- Beam purity: 98.7%
- Beam intensity and target condition can evaluated in combination with a FC and luminosity monitor

Isotope	E_{Beam} [MeV/u]	Average yield [pps]	Purity [%]
^{188}Pb	2.82	3.2E+05	55.1±5.5
^{190}Pb	2.82	2.2E+05	86.3±2.0
^{192}Pb	2.84	5.0E+05	96.9±0.8
^{194}Pb	2.82	7.8E+05	97.0±0.7
^{196}Pb	2.82	5.0E+05	98.7±0.5
^{198}Pb	2.82	2.5E+05	98.6±0.7

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J. Pakarinen et al JPS Conf. Proc. 6 02001 (2015)

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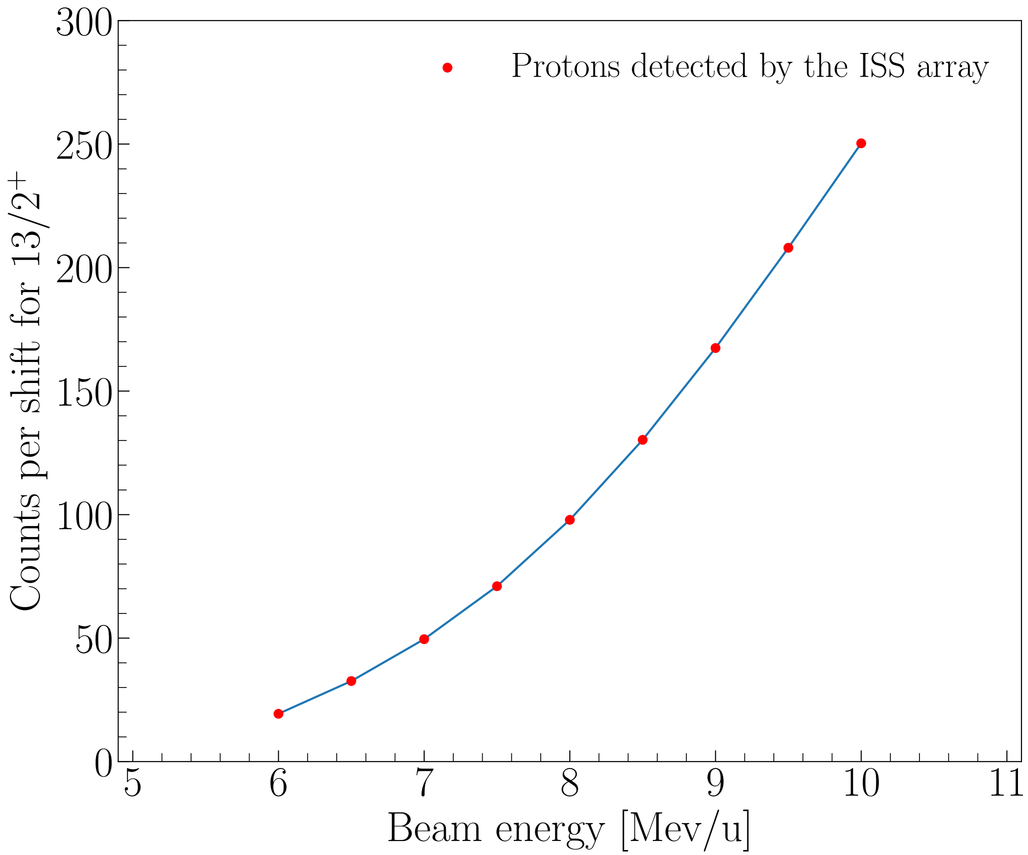
TAC Recommendation

TAC recommendation	**The TAC notes that the requested energy is at the edge of the feasibility and that the rate at the experiment might be 50% lower than requested.**

- The energy will have an effect on transferring cross-sections. The higher beam energy is preferred as the $13/2^+$ state would have a higher cross-section
- The effect of beam energy is low for statistics.
- A thicker target can be used to recover some loss of beam intensity, with a compromise on energy resolution



Summary and beam time request

- 10 shifts for both $^{197,199}Pb$
- 3 shift C-foil to assess fusion-evaporation background
- 1 shift each isotope for laser on/off running
- 1 shift is required for beam tuning and preparation of the experimental setup
- **Total 26 shifts**

Energy (keV)	I^π	σ_{DWBA}	Counts per shift
0	$3/2^-_1$	7.8	350
85	$5/2^-_1$	4.5	203
319	$13/2^+_1$	1.4	65
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Thank you!

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

(Following HIE-ISOLDE Letter of Intent I-110)

Mapping single-particle neutron strength towards the mid-shell in semi-magic lead isotopes

February 6, 2024

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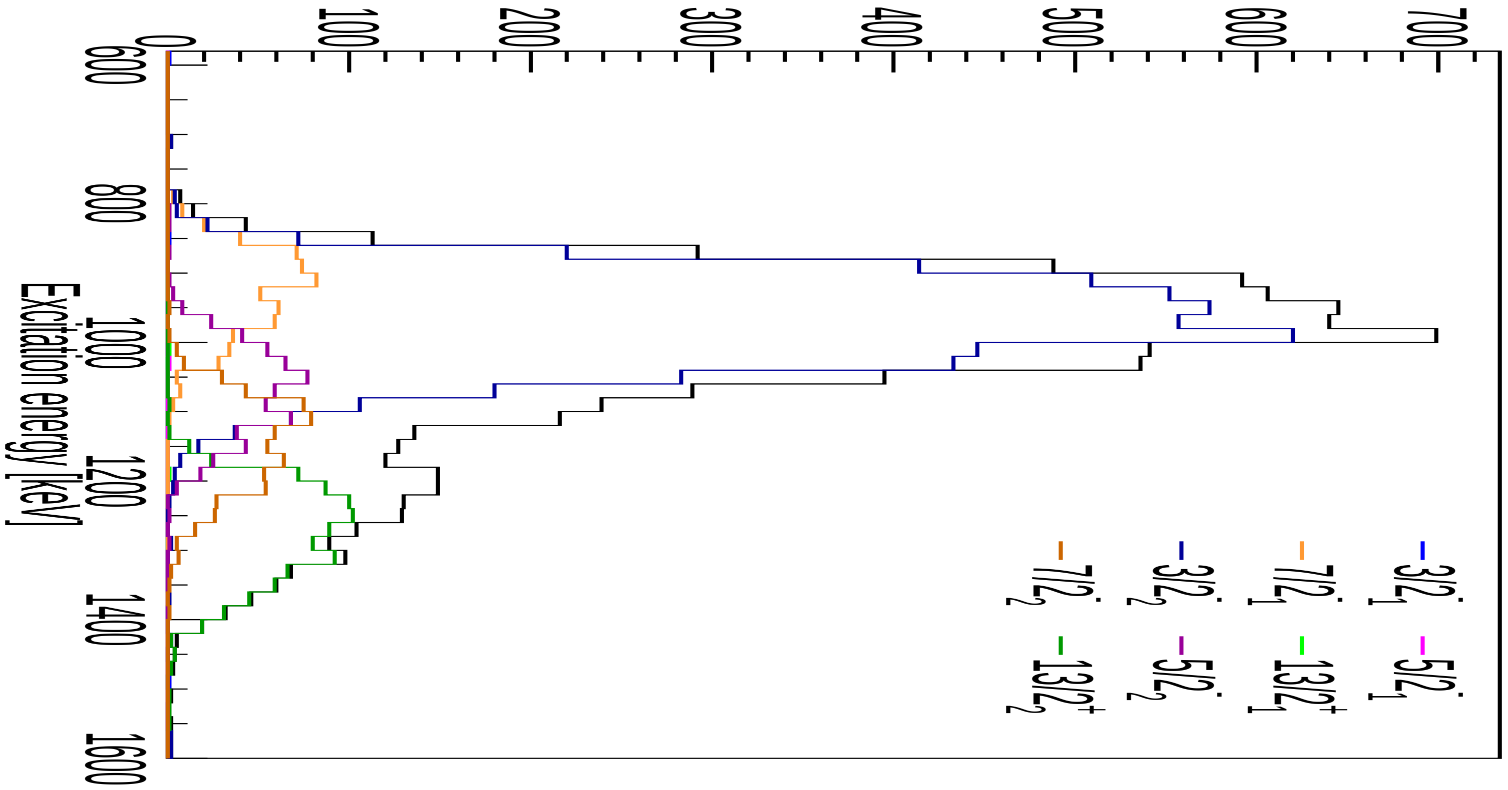
Excitation spectrum for identification $13/2_2^+$

- l=3 @ 952 keV; C^2S = 0.2 +
  l=1 @ 989 keV; C^2S = 0.8 +
  l=3 @ 1089 keV; C^2S = 0.2 +
  l=3 @ 1167 keV; C^2S = 0.2 +
  l=6 @ 1295 keV; C2S = 0.8



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Level schemes $^{197,199}Pb$

- Based on EC-decay of $^{197,199}Bi$ spectroscopy
- The spins of the ^{199}Pb are not well-known