Transfer reactions on high-spin nuclear isomer

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Outline

- Introduction to nuclear isomers
- Case study: the single-particle aspect of the band-terminating $13/2^+$ state in ^{19}F
- Exp. results on first transfer reaction on high-spin isomer $^{18m}F(d,p)^{19}F$
- Other examples (including ^{26}Al, ^{42}Sc)
- Conclusions

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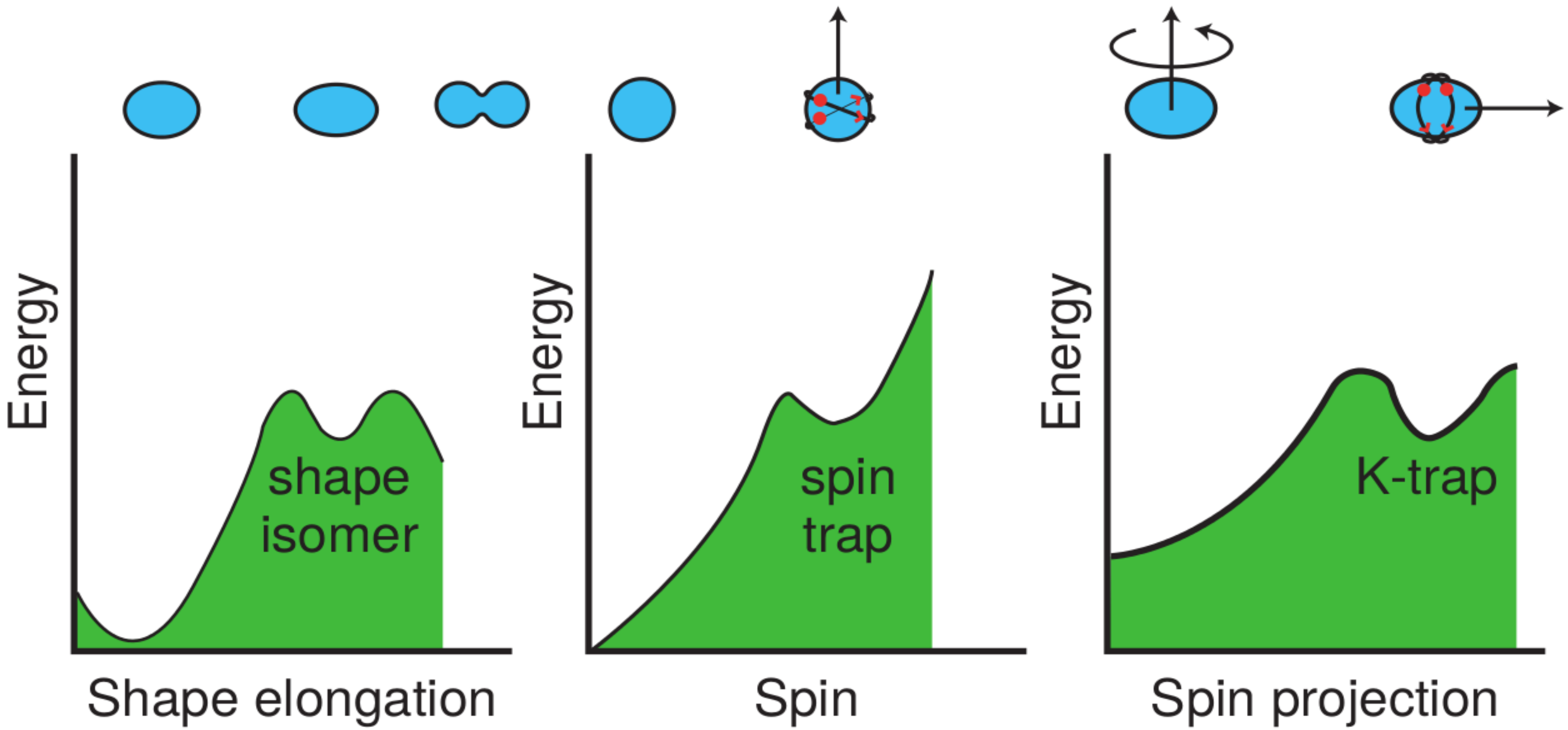
Nuclear Isomers (1 slide refresher)

- Nuclear isomers are meta-stable states ($T_{1/2}$ > few ns)
- Classification [Walker & Dracoulis, Nature 399, 35-40 (1999)]



- Nuclear isomers can be indicative of unusual/unexpected nuclear structure [Dracoulis, Phys. Scr. T152 014015 (2003)]
- May play an important role in nuclear astrophysics reactions

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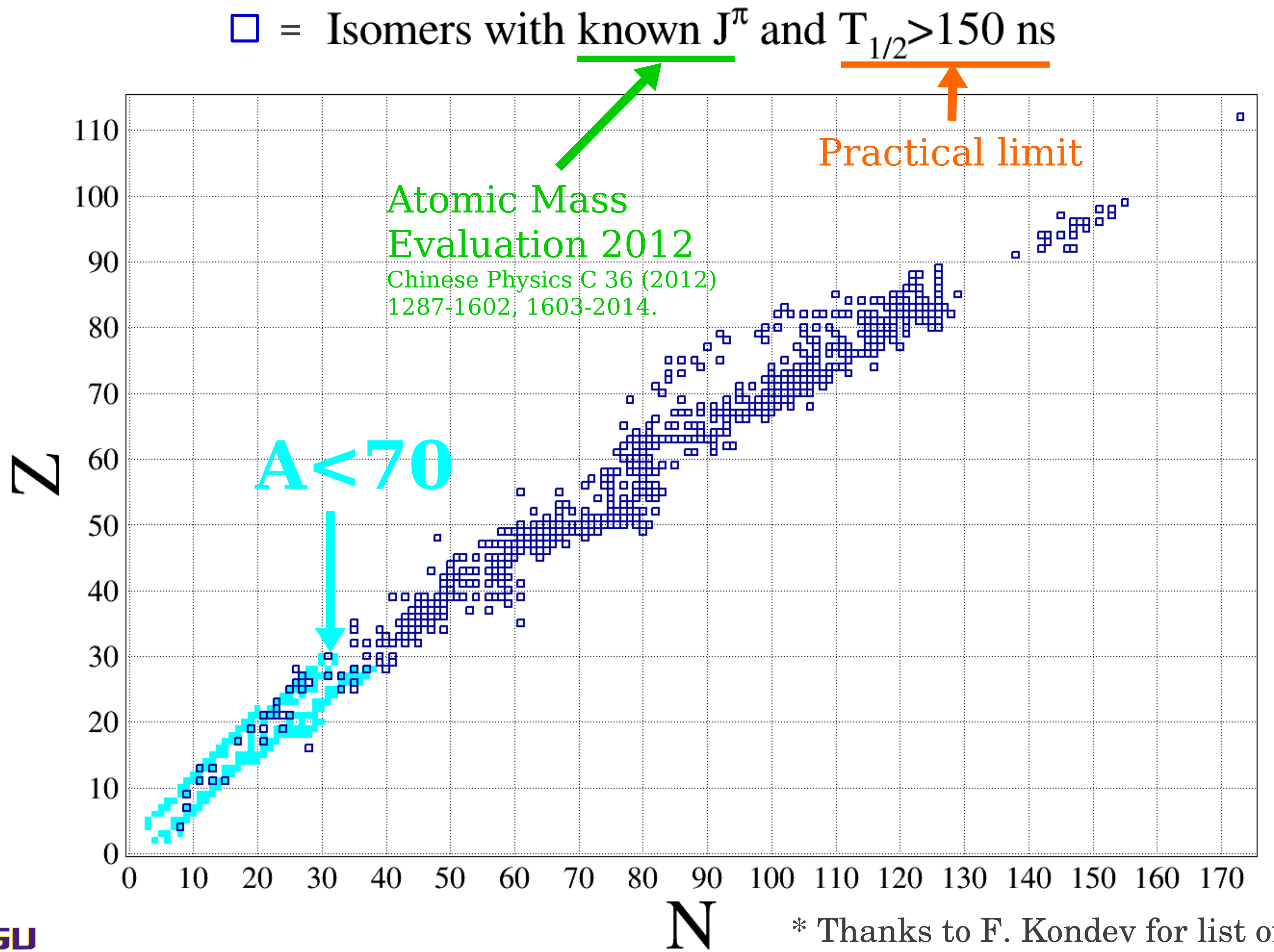
Isomers are common



* Thanks to F. Kondev for list of isomers

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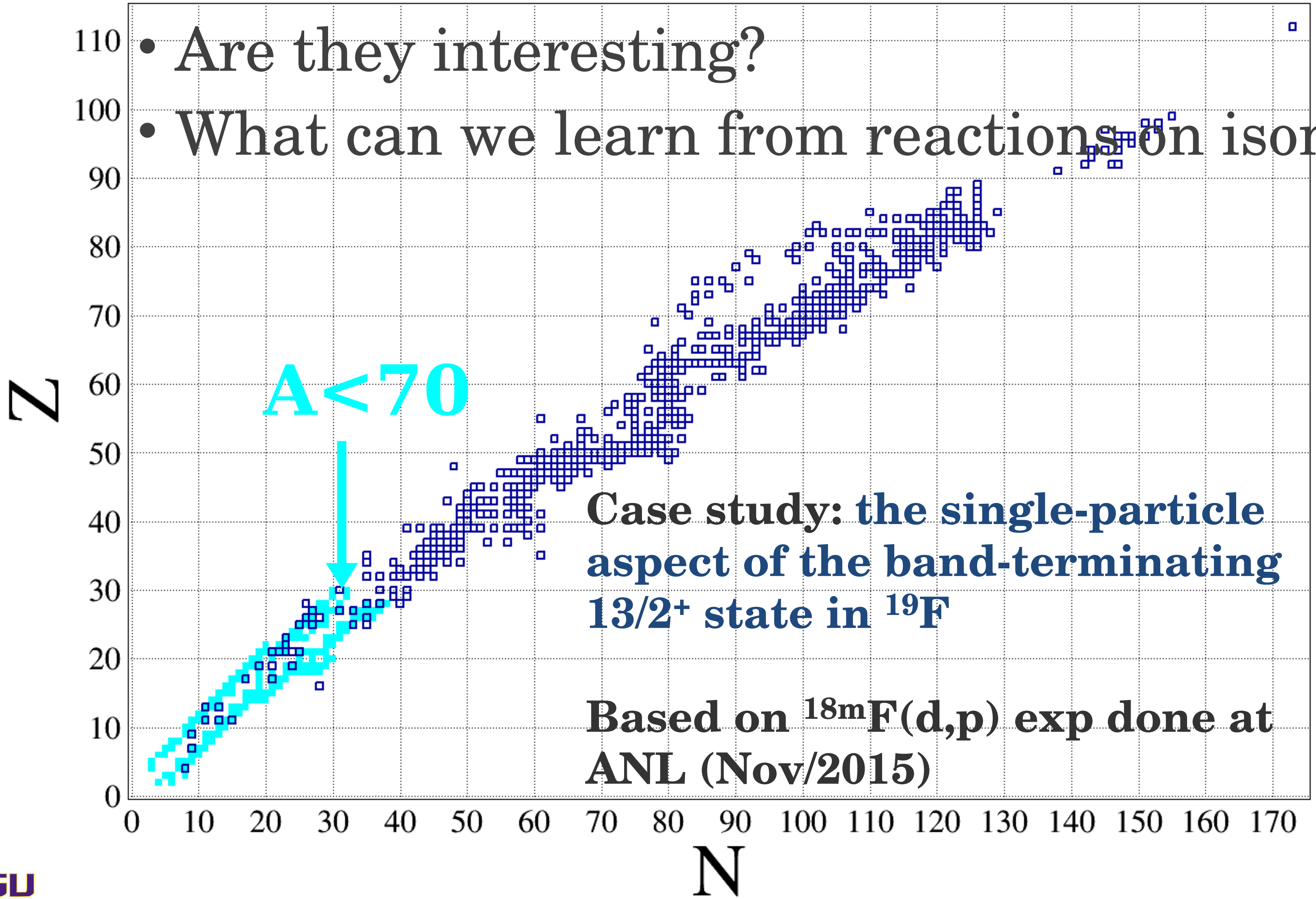
Isomers are common, but ...

□ = Isomers with known J^{π} and $T_{1/2}$>150 ns

- Are they interesting?
- What can we learn from reactions on isomers?



Case study: the single-particle aspect of the band-terminating 13/2+ state in ^{19}F

Based on ^{18m}F(d,p) exp done at ANL (Nov/2015)

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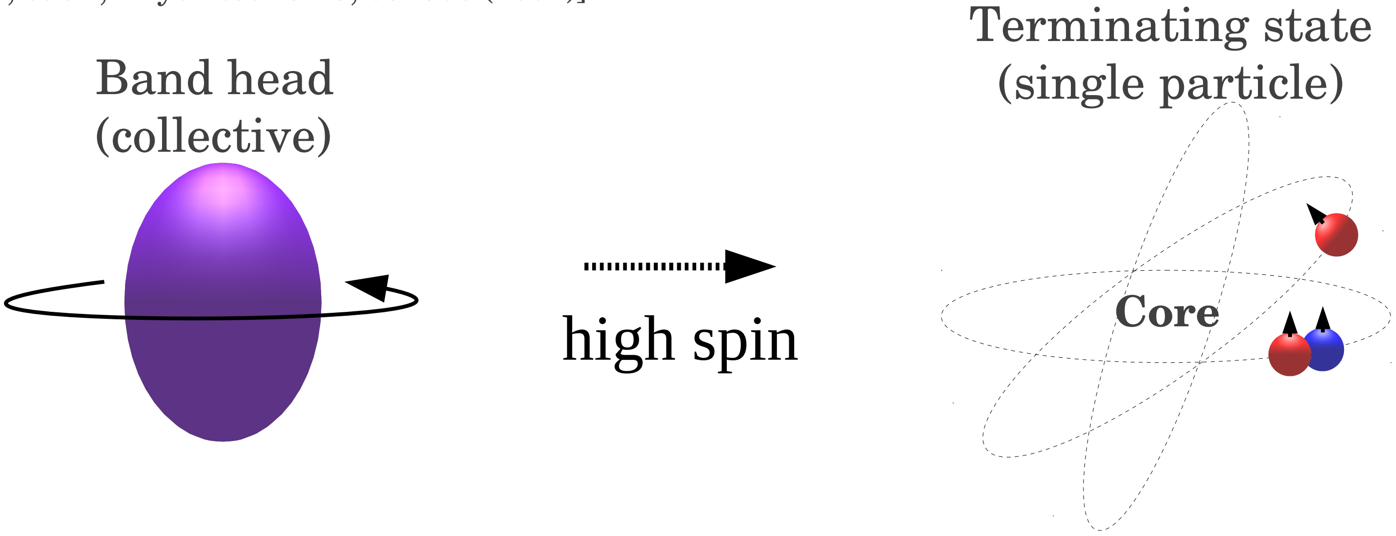
Case study: the single-particle aspect of the band-terminating 13/2$^+$ state in ^{19}F

- **Band termination**, process by which states in a rotational band gradually lose their collective character and terminate in a single-particle state

  [Afanasjev, et al., Physics Reports 322, 1 (1999)]

  [Zalewski, et al., Phys. Rev. C 75, 054306 (2007)]



- **Experimental investigations** on band termination have relied on **comparisons** of the excitation energies of the band member states with the predictions of the **rigid rotor model**, as well as on **lifetime measurements**

  ^{158}Er: [Simpson, et al., Physics Letters B 327, 187 (1994)]

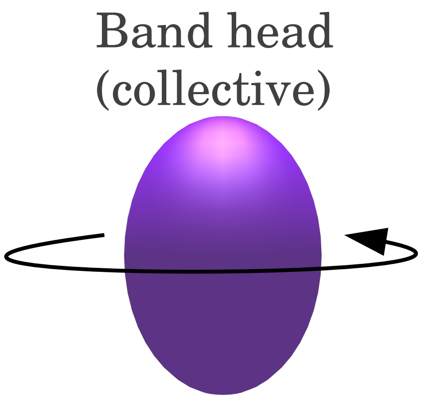
  ^{109}Sb: [Schnare, et al., Phys. Rev. C 54, 1598 (1996)]

  ^{102}Pd: [Gizon, et al., Physics Letters B 410, 95 (1997)]

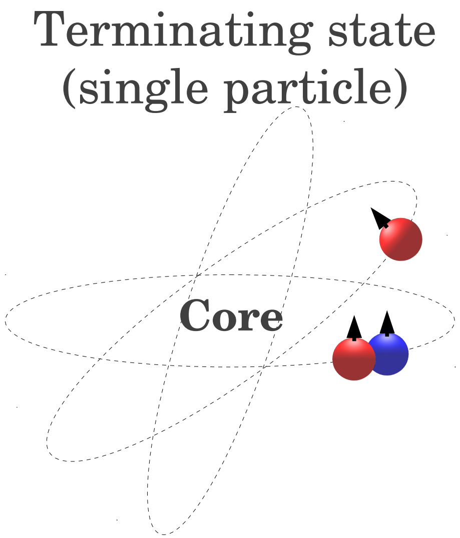
  For A<30 [Headly, et al.,, Phys. Rev. C 49, 222 (1994)]

Case study: the single-particle aspect of the band-terminating 13/2$^+$ state in ^{19}F

- The final nucleon configurations (spectroscopic factors) have never been **directly *observed***



high spin



- Direct reactions, like (*d*,*p*), do not populate high-spin states (low momentum transfer)
- E.g. ^{17}O(*d*,*p*) can populate states in ^{18}O with J^{π}=0$^+$ to 4$^+$ (^{17}O g.s. = 5/2$^+$)

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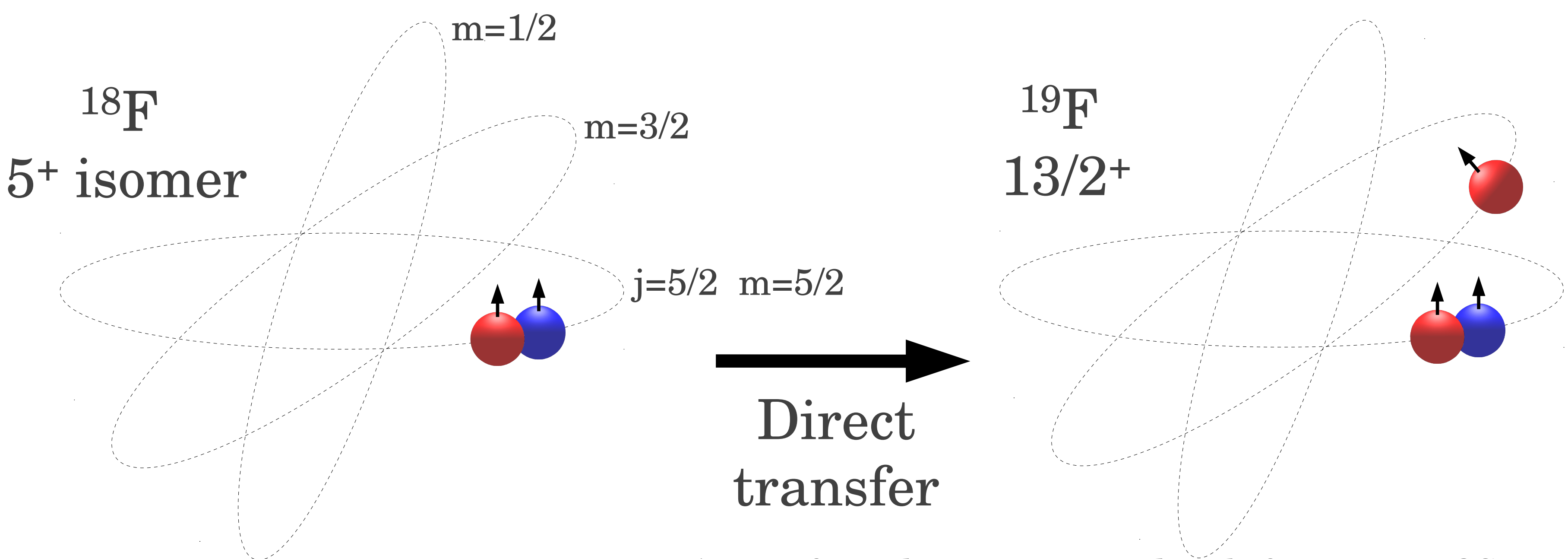
Case study: the single-particle aspect of the band-terminating 13/2⁺ state in ^{19}F

- In ^{19}F, we can **directly probe** the **nucleon configuration** of the proposed terminating state of the ground-state rotational band, the yrast $13/2^+$
- **How?** By making a **high-spin isomer beam** and **transferring a neutron** (**new experimental technique!*,****)



(E_{exc} = 1.12 MeV, $T_{1/2}$ = 162(7) ns)

* Transfer on low-spin isomer done before in HELIOS exp. $^{16}N(d,p)$ “by accident” (GS=2^-, Iso=0^-). Reactions with isomer were regarded as contamination.
** Roberts and Becchetti, have done Coulomb exc. studies using 18mF beam

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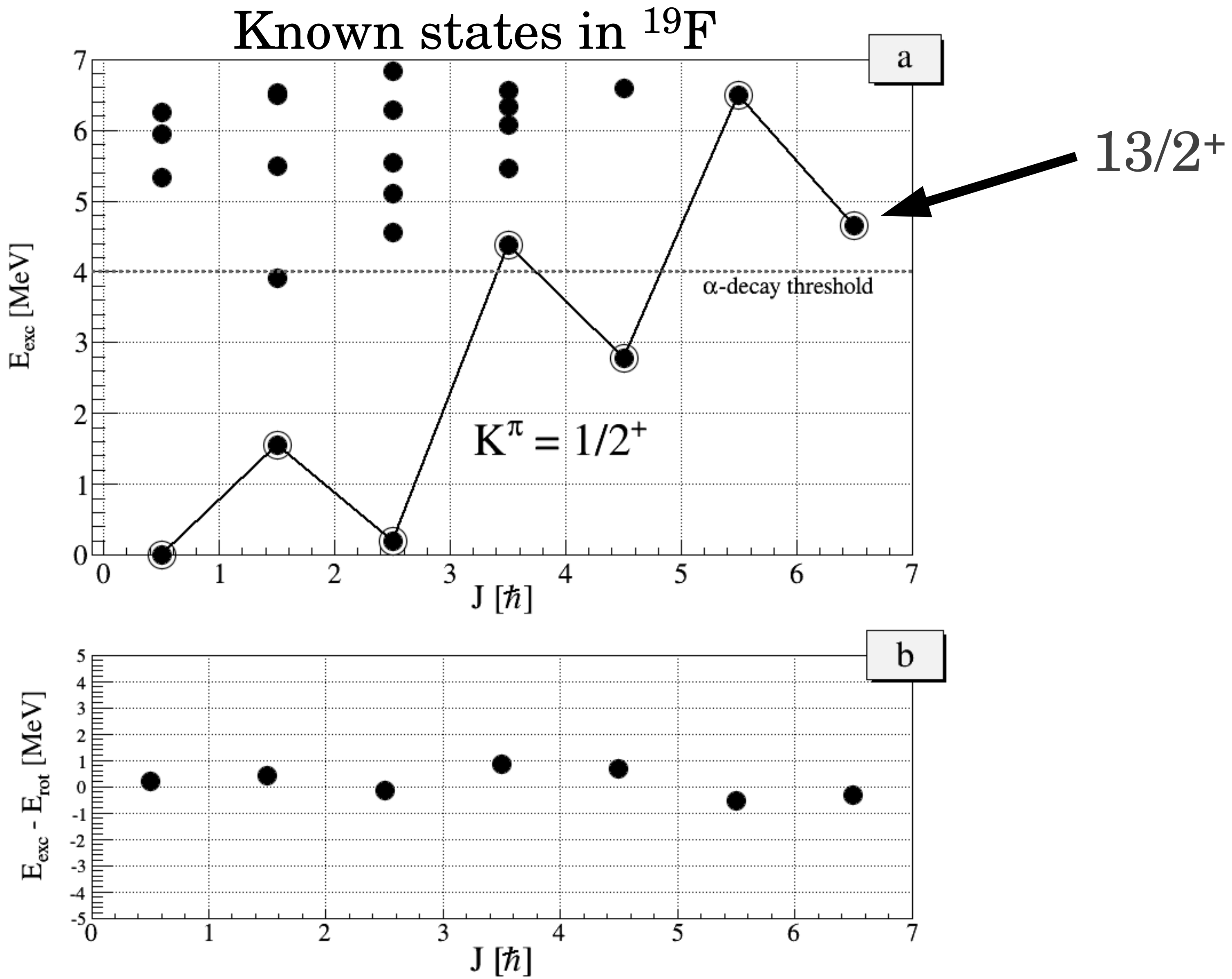
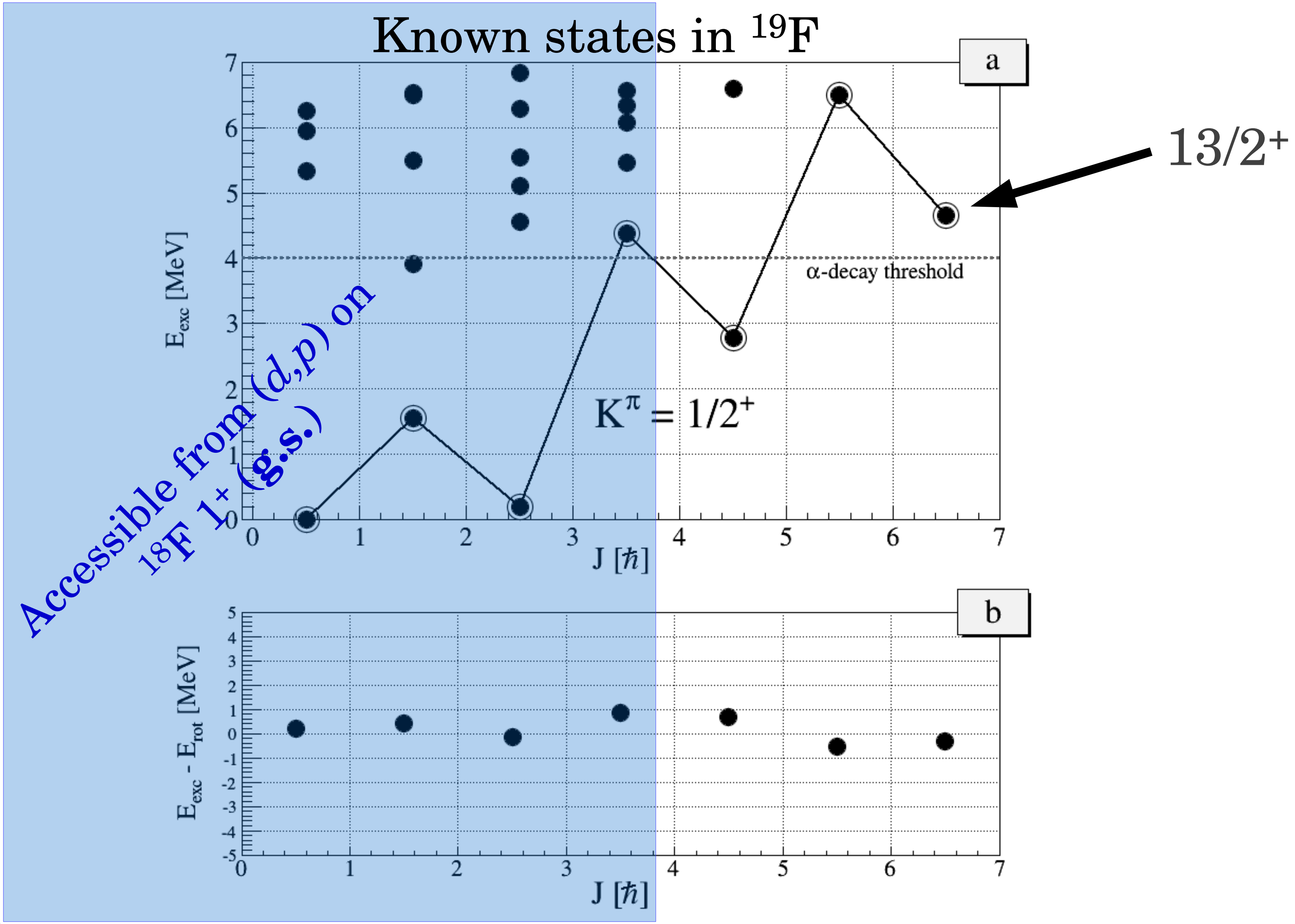
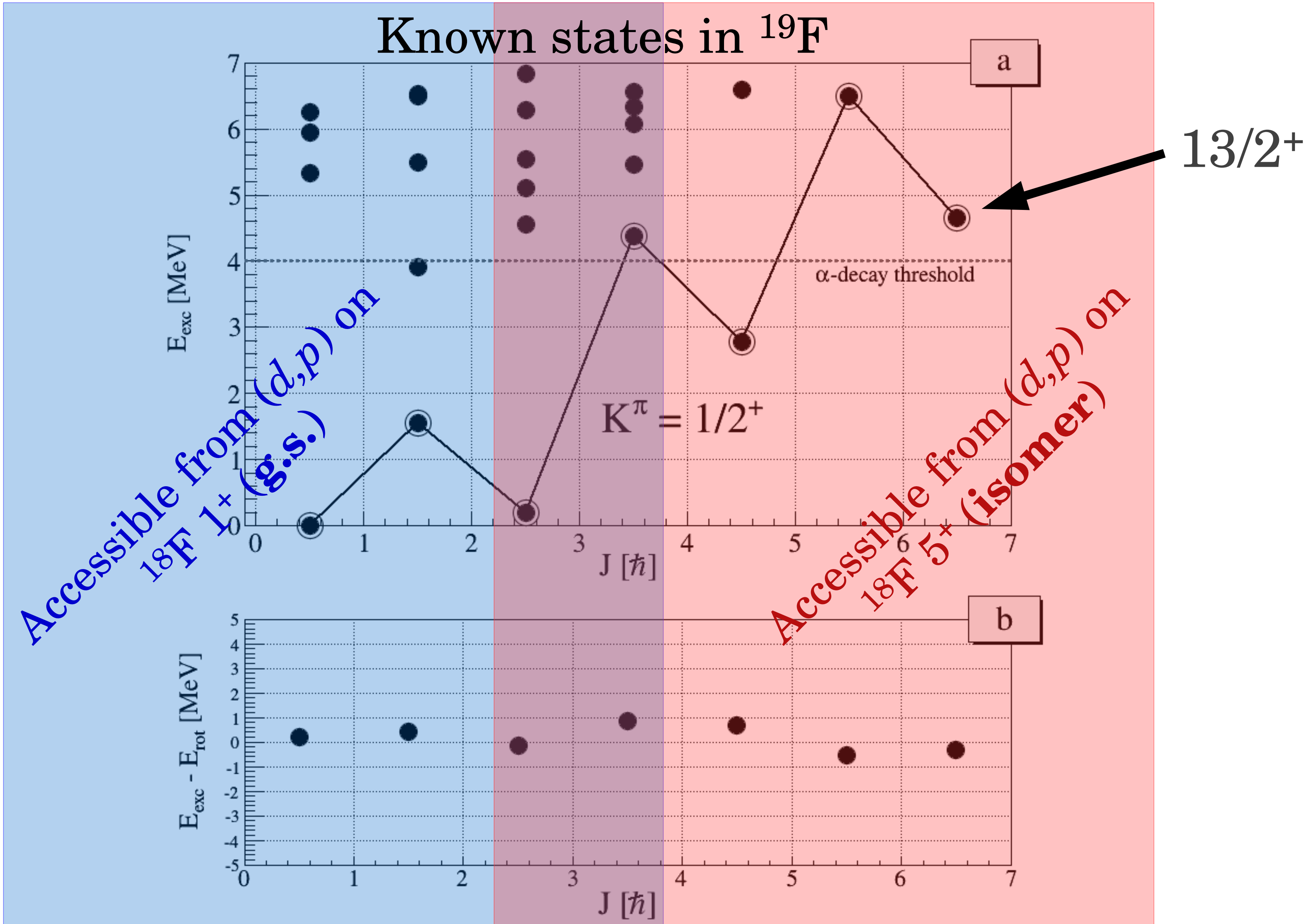
Which states can be populated?



Which states can be populated?

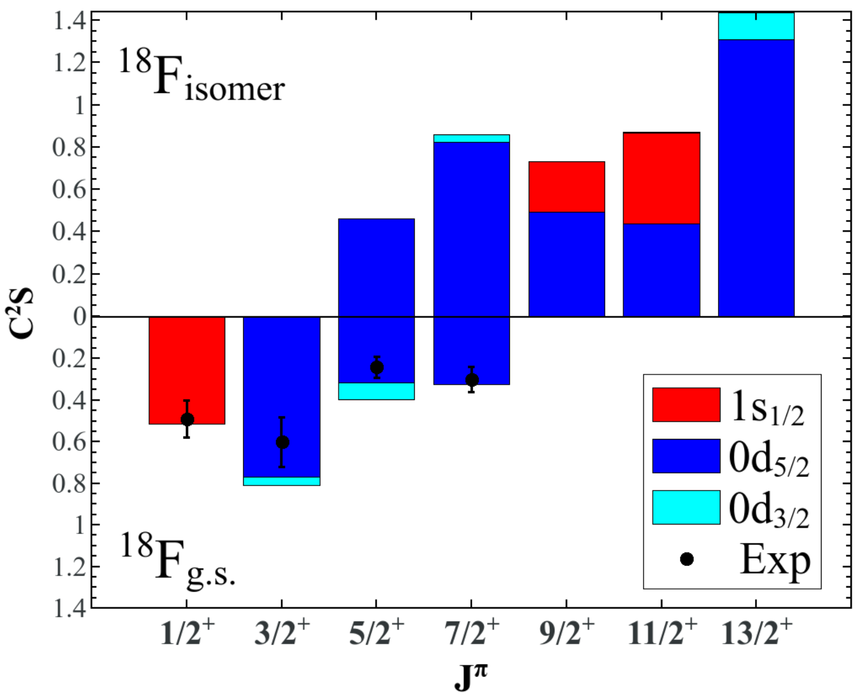


Which states can be populated?

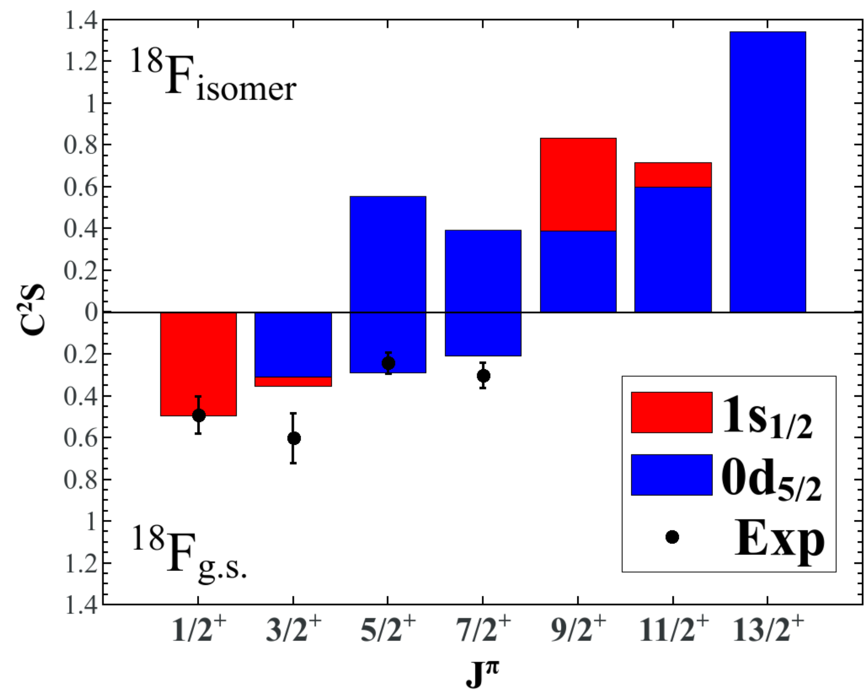


Core excitations

Shell model calculation using USDA interaction (no core excitations)



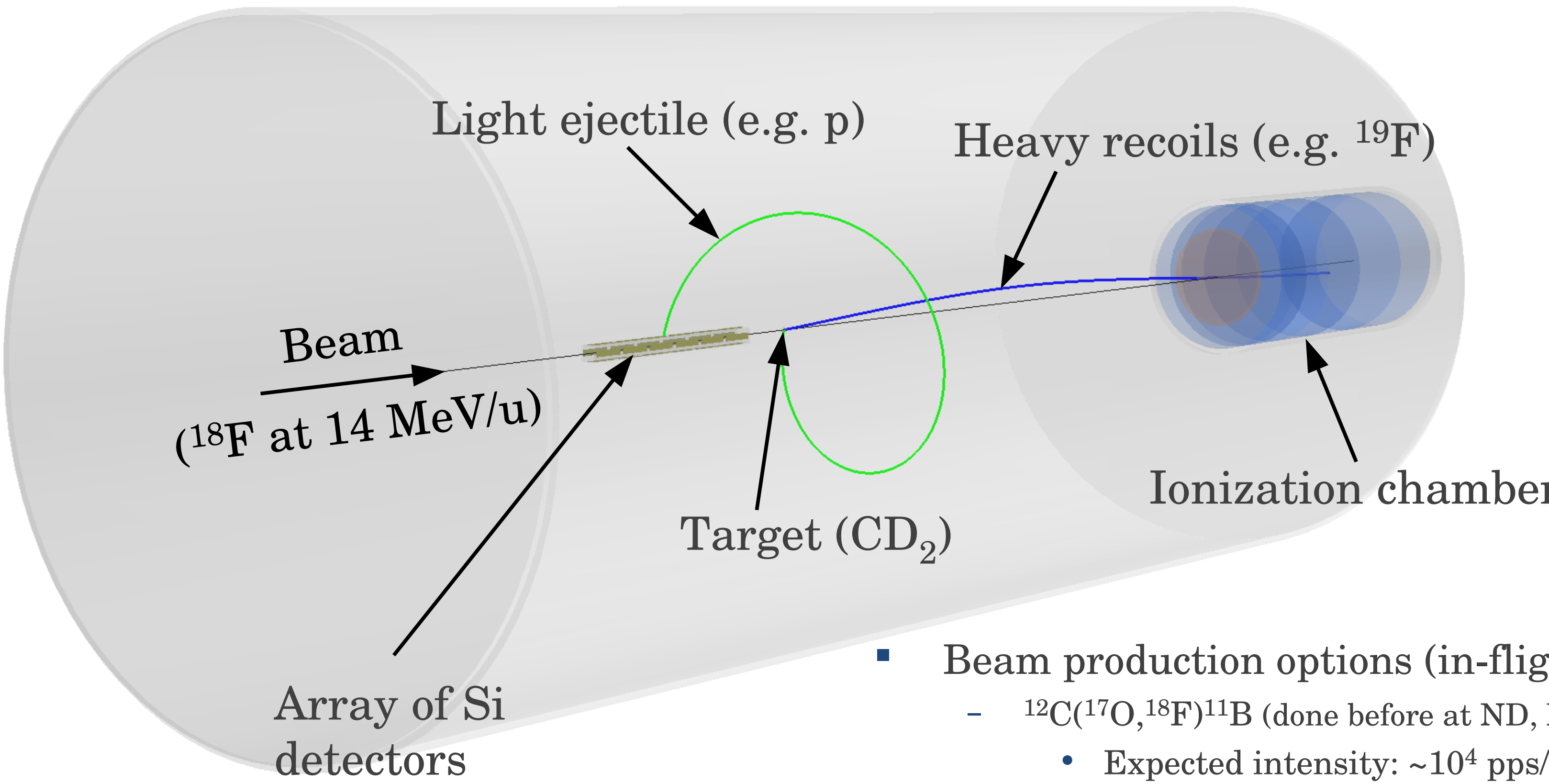
Shell model calculation using p+sd valence space (core excitations allowed)



NOTE: Quick-and-dirty SM calculations

Need state-of-the-art SM calculations

Experiment at the HELIcal Orbit Spectrometer (HELIOS)



- Beam production options (in-flight):
  - ^{12}C(^{17}O,^{18}F)^{11}B (done before at ND, NSCL)
    - Expected intensity: ~10^4 pps/pnA [Roberts PRC **65**, 044605 (2002)]
    - Isomer/ground state ratio (at production target): ~70%
  - ^{2}H(^{17}O,^{18}F)n (similar beams prod. at ANL)
    - Expected intensity: ~10^4 pps/pnA [Harss Rev. Sci. Inst. **71** 2 380 (2000)]

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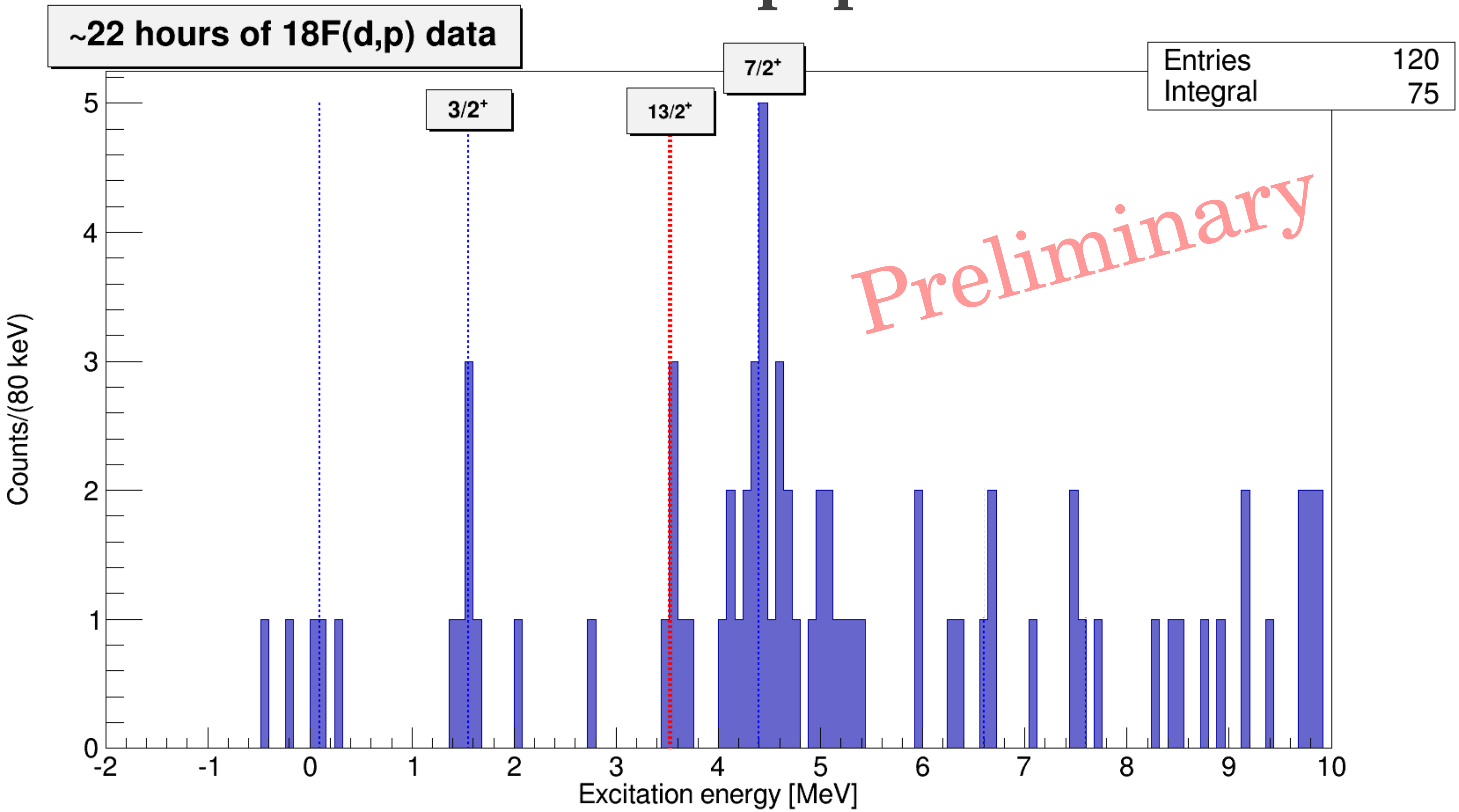
$^{18}F(d,p)^{19}F$ experiment (excitation energy spectrum)

* ^{18}F beam intensity ~ 3x10^4 pps from 100 pnA of ^{17}O

First time a band-terminating state is populated via transfer!



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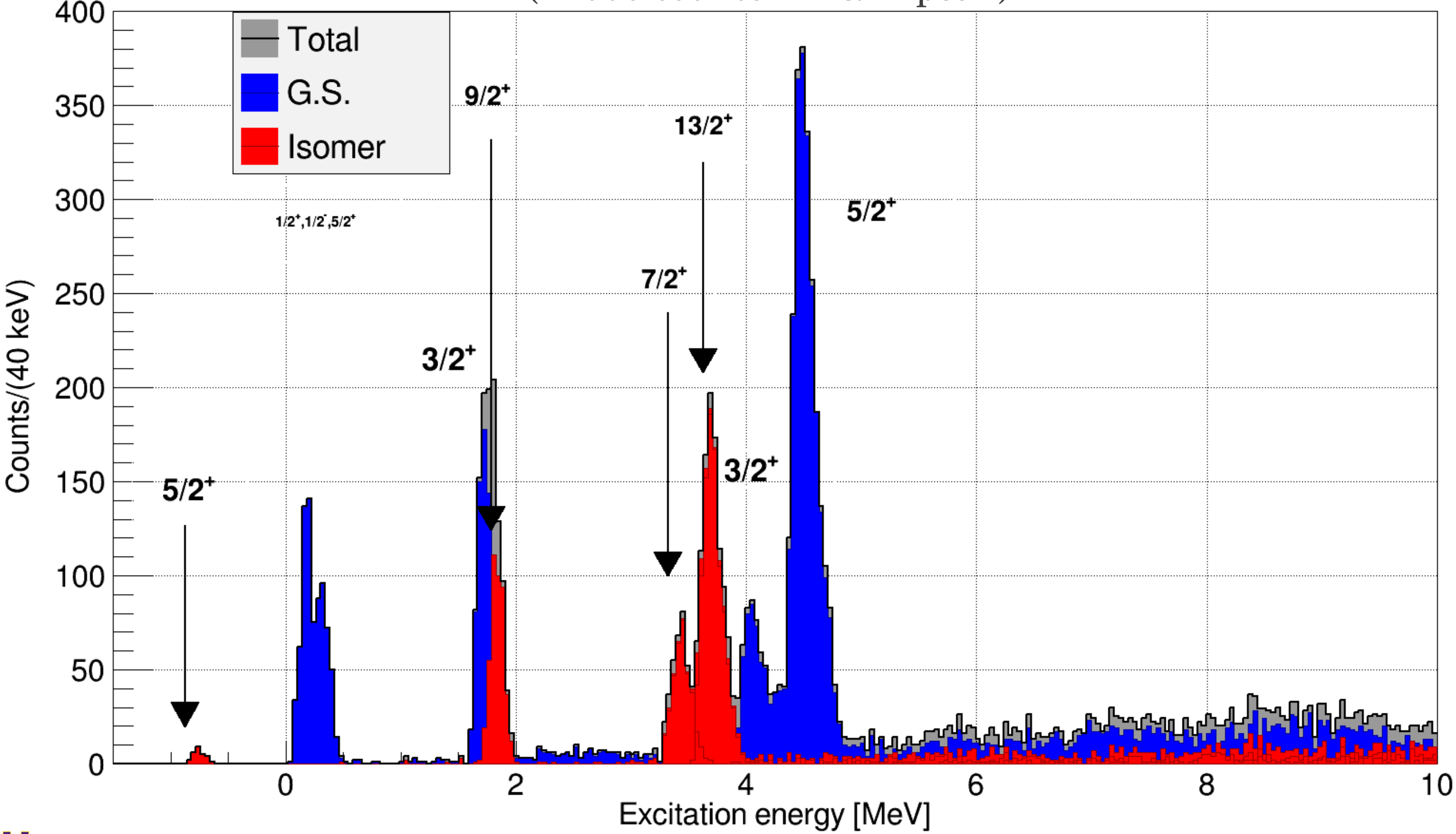
^{18}F(*d*,*p*)^{19}F simulation (excitation energy spectrum)

* From 5 days with a ^{18}F beam intensity of 1x10^{6} pps

Expected ^{18}F(*d*,*p*)^{19}F spectrum
assuming 20% ^{18m}F, 80% ^{18}F on HELIOS target

(~1000 counts in 13/2^{+} peak)



Based on (*d*,*p*) reactions with ^{18}F g.s. Kozub, et al., PRC 73 044307 (2006)

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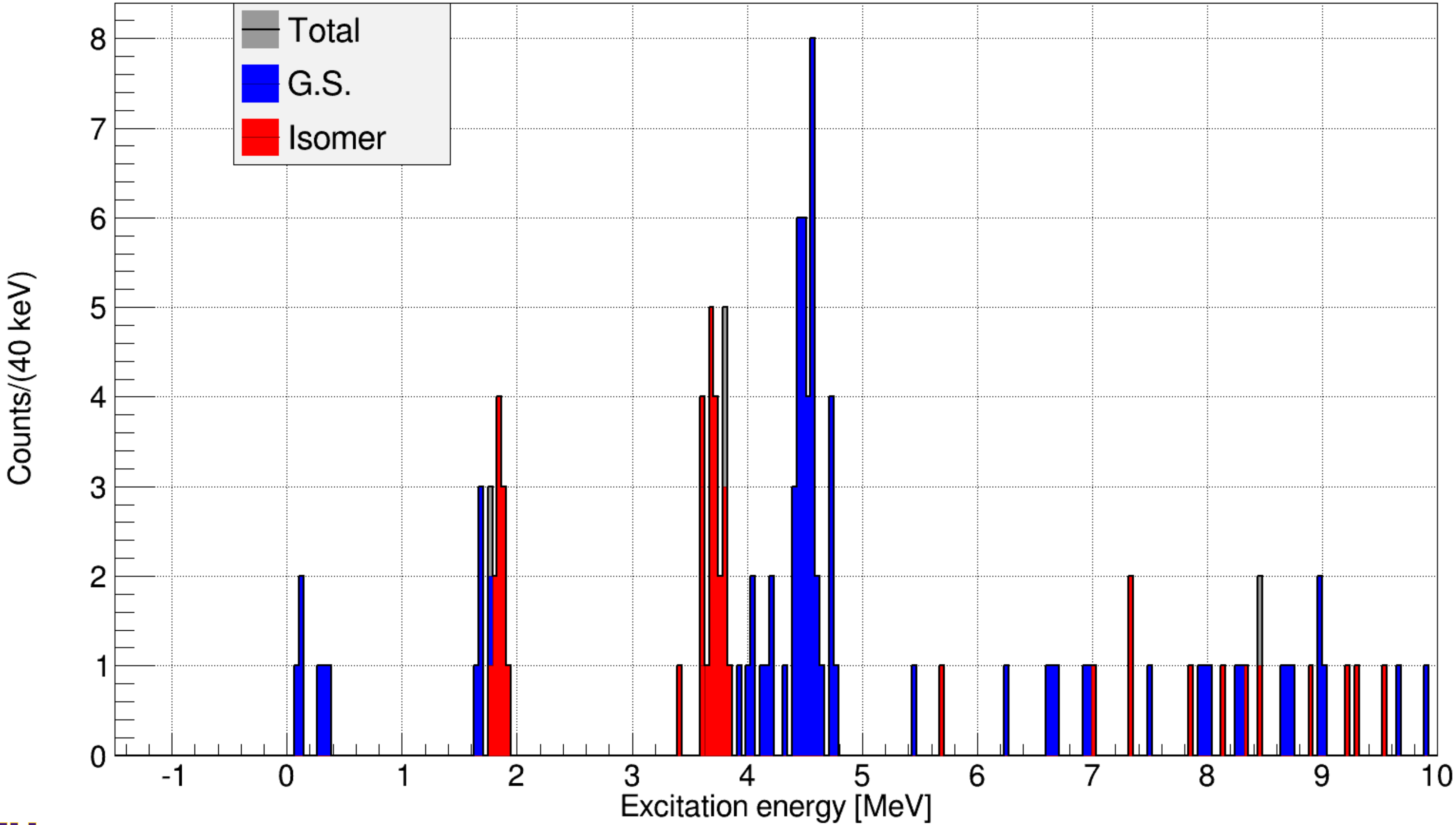
^{18}F(*d*,*p*)^{19}F simulation (excitation energy spectrum)

Expected ^{18}F(*d*,*p*)^{19}F spectrum
assuming 20% ^{18}F^{m}, 80% ^{18}F^{g} on HELIOS target

(~10 counts in 13/2+ peak)



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$^{18}F(d,p)^{19}F$ experiment (excitation energy spectrum)

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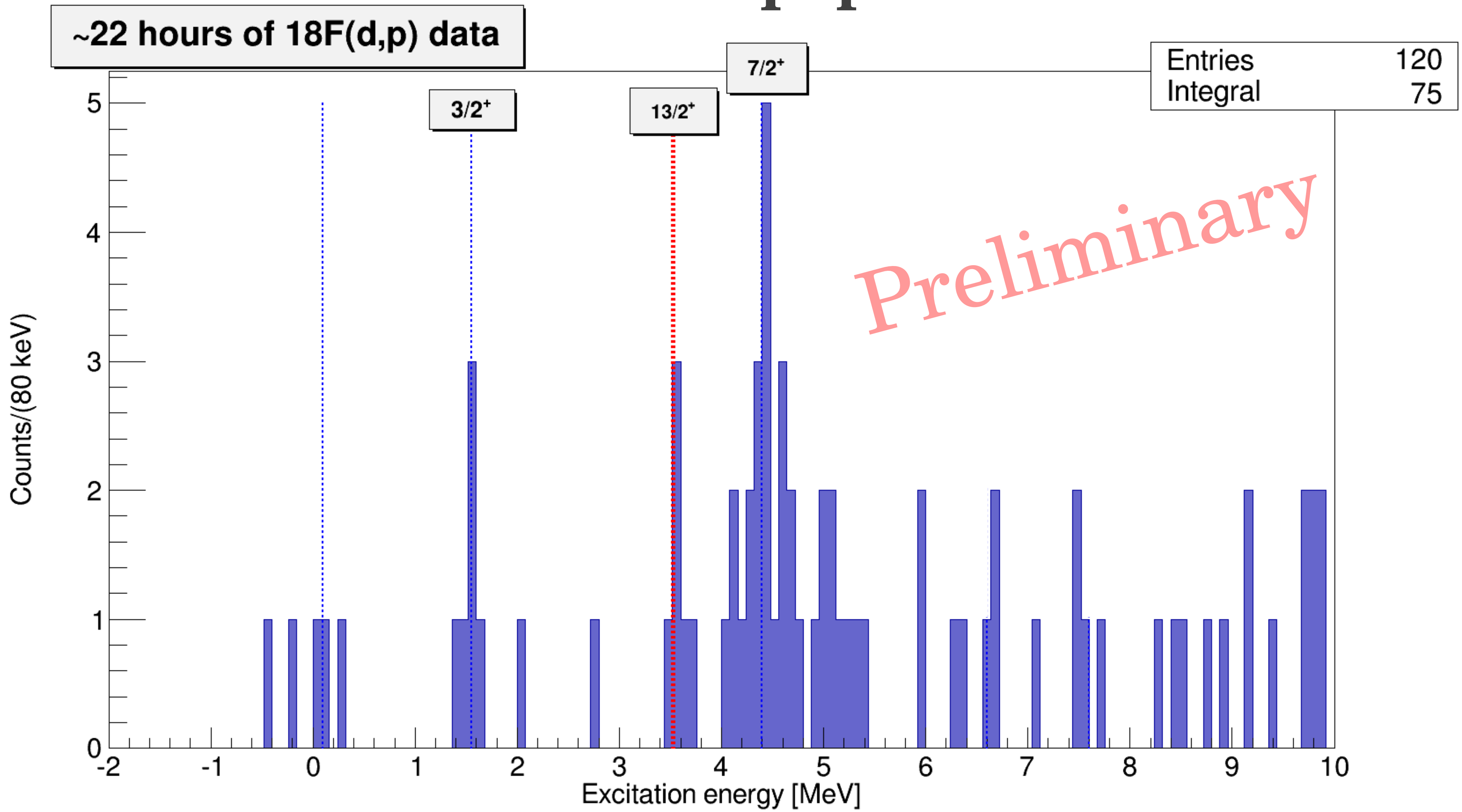

7-day run scheduled Oct/2016 (ATLAS)

Expecting ~15 times more statistics

Stay tuned ...

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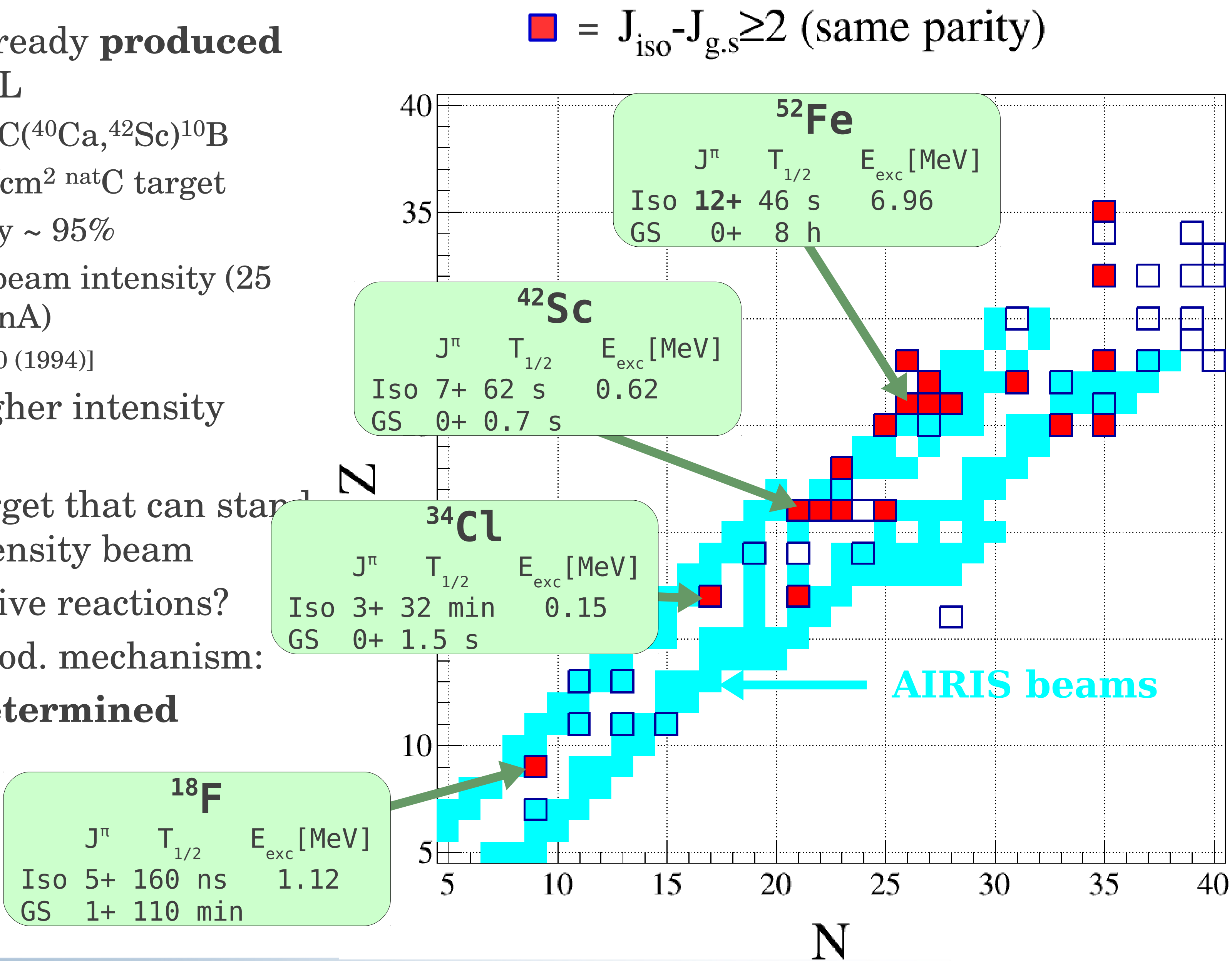
Future possibility ^{42}Sc (similar to ^{18}F)

- Beam already **produced** at GANIL
  - via ^{12}C(^{40}Ca,^{42}Sc)^{10}B
  - 5 mg/cm^2 ^{nat}C target
  - Purity ~ 95%
  - Low beam intensity (25 pps/pnA)

  [PLB **331** 280 (1994)]
- Need higher intensity beam!
- Need target that can stand high intensity beam
- Alternative reactions?
- Beam prod. mechanism: **to be determined**



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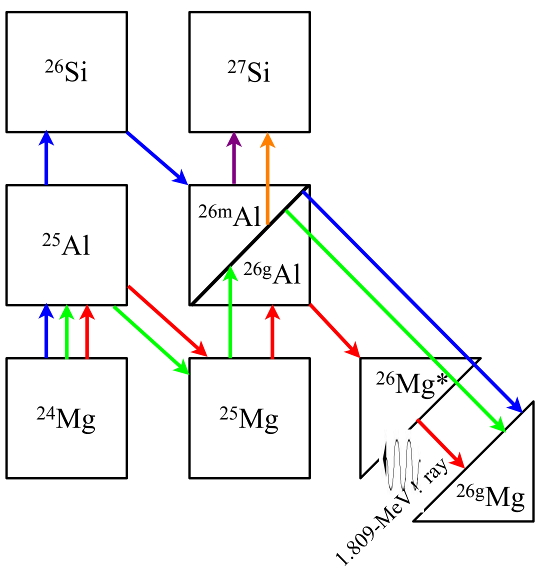
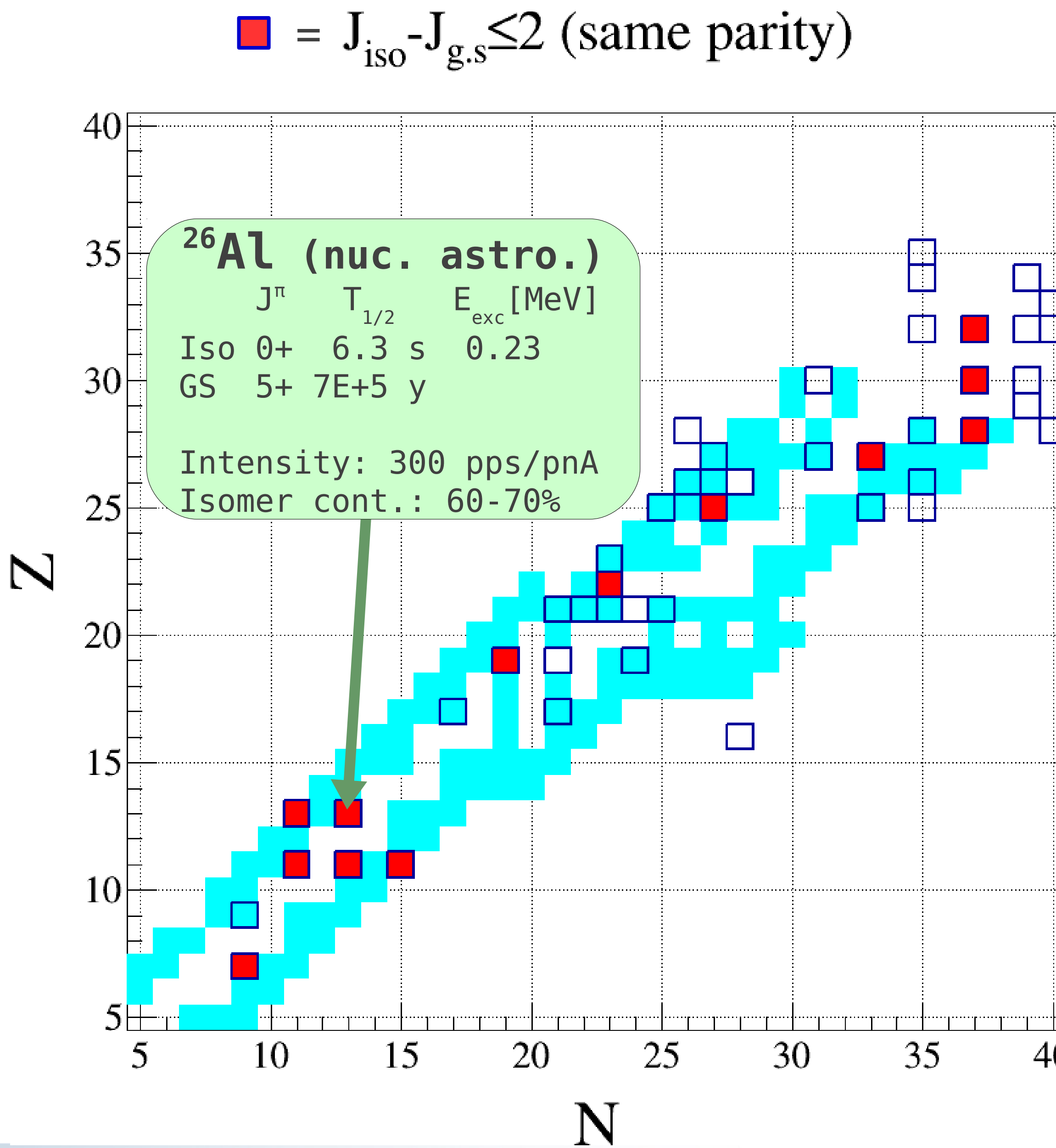
Nuc. Astro. example: ^{26}Al

- Beam already produced!
  - Isomer beam Energy: 5 MeV/u

  (ATLAS in-flight facility)

- Accepted proposal by Almaraz-Calderon, et al.: ^{26}Al^{m}(*d*,*p*)^{27}Al reaction populates isobaric analog states to ^{26}Al^{m}(*p*,γ)^{27}Si





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Conclusions

- We have potentially performed first transfer reaction on isomeric beam
- While isomers are abundant, beams of isomers are difficult to produce
- At the moment, each exp. with isomeric beam must be approached on a case-by-case basis
- When possible, this novel technique can probe aspects of nuclear structure which are otherwise unattainable
- Long-lived nuclear isomers may play important role in nucleosynthesis (nuclear astrophysics most famous example: ^{26}Al)
- Transfer reactions on isomeric beam is a promising technique with three on going experimental efforts (^{18m}F, ^{34m}Cl, ^{26m}Al)

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