Isomer beams and transfer reactions

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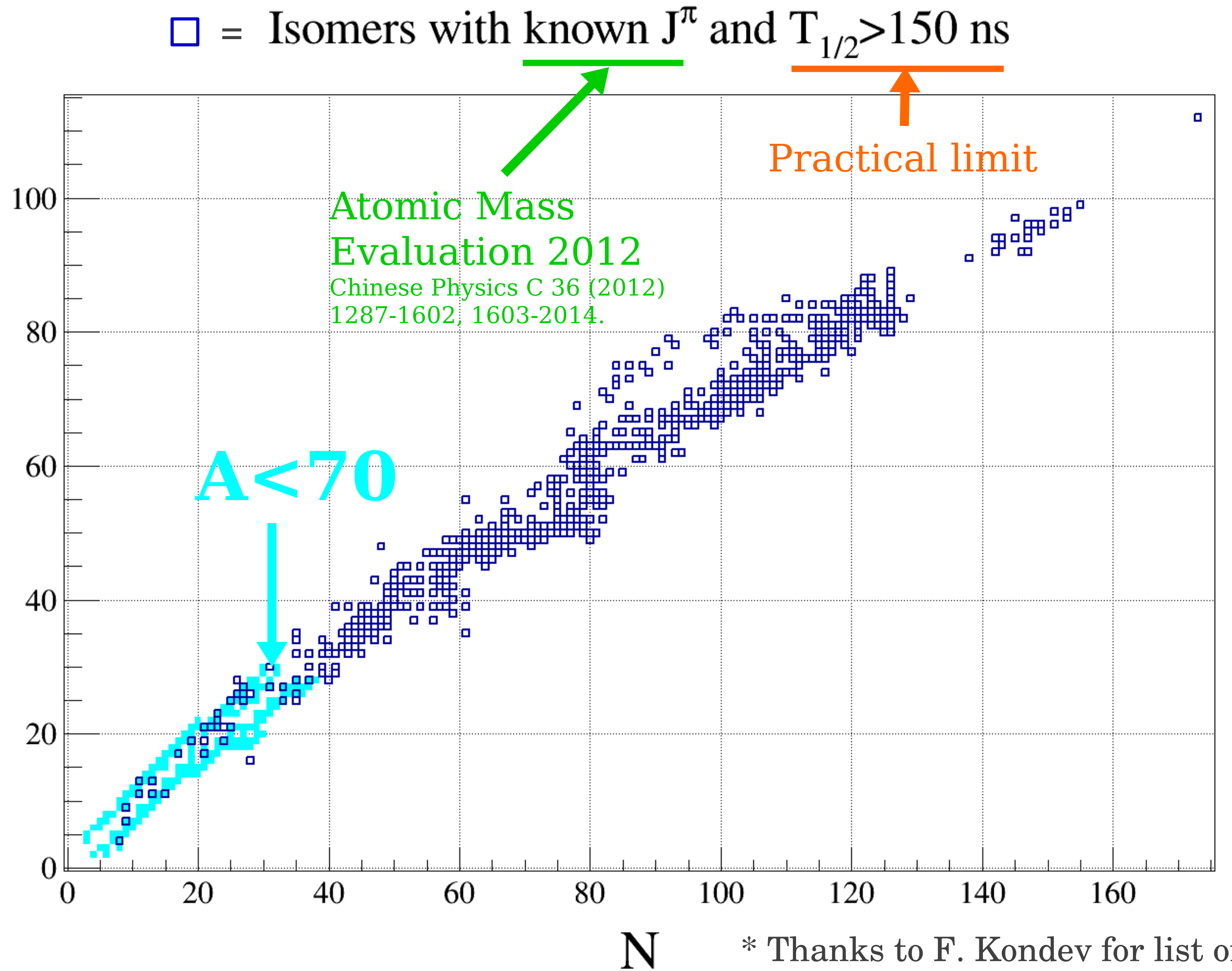
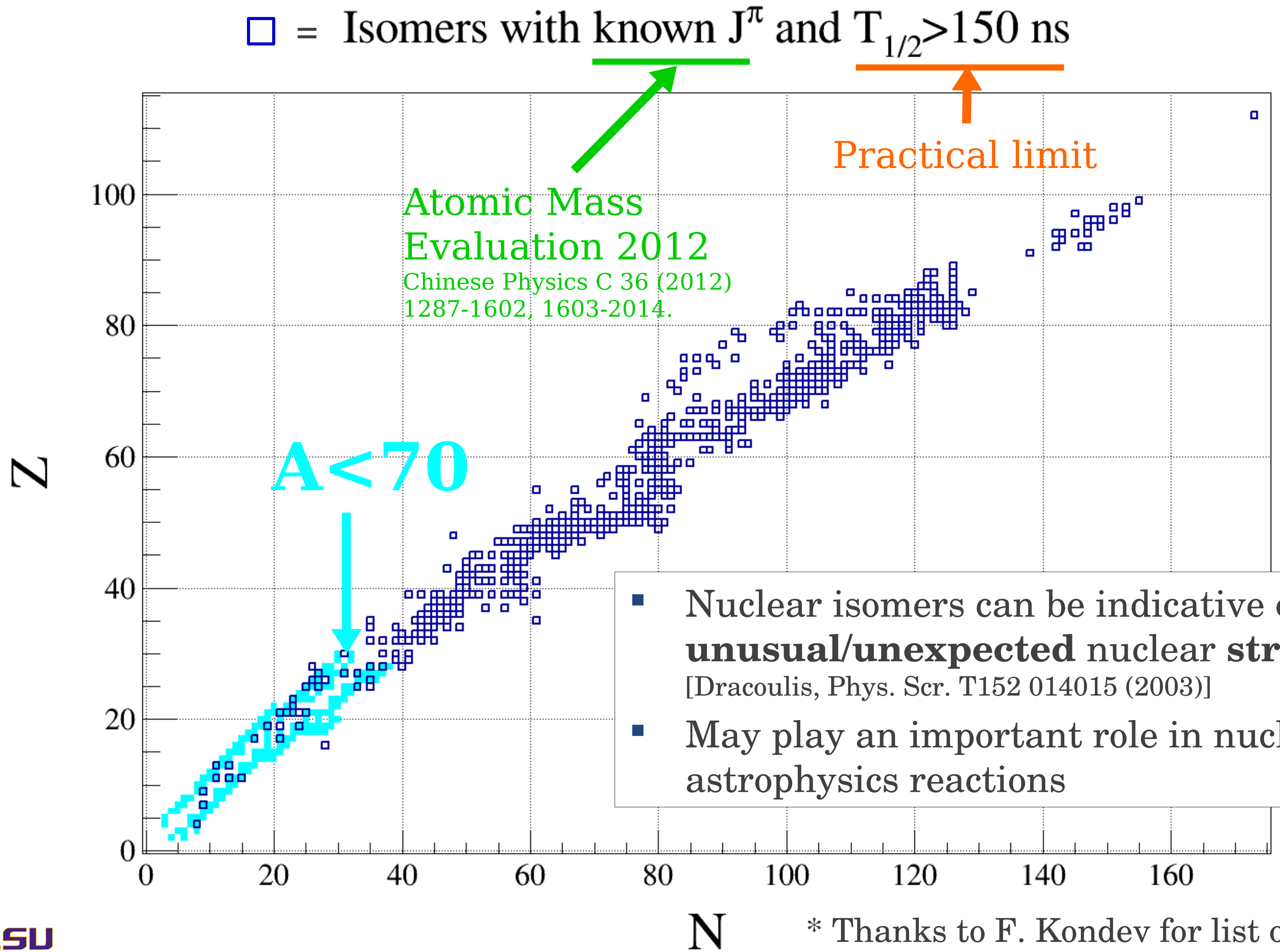
ReA Solenoidal Spectrometer Projects Meeting

Isomers are common



* Thanks to F. Kondev for list of isomers

Isomers are common



- 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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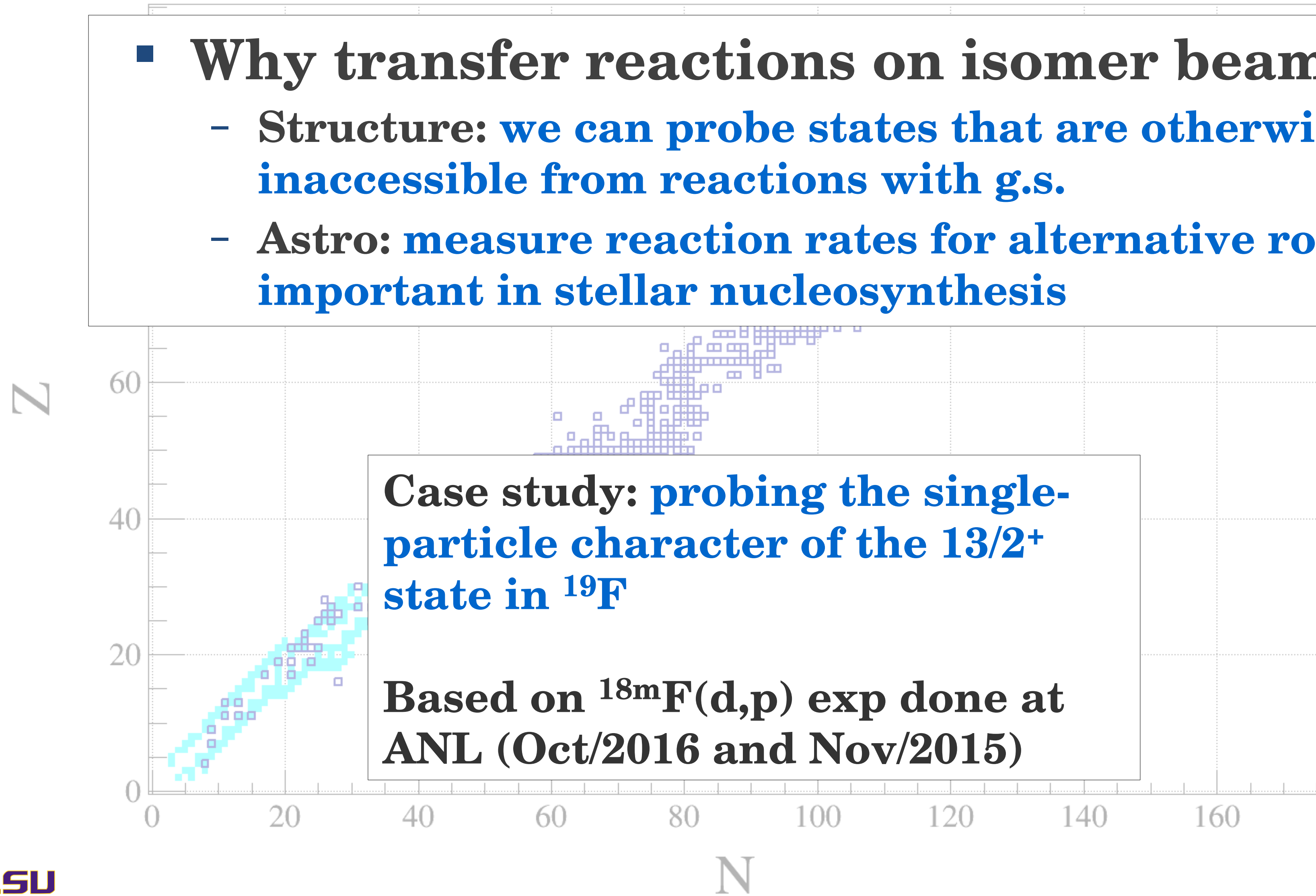
Isomers are common, so what …

- **Why transfer reactions on isomer beams?**
  - Structure: we can probe states that are otherwise inaccessible from reactions with g.s.
  - Astro: measure reaction rates for alternative routes important in stellar nucleosynthesis

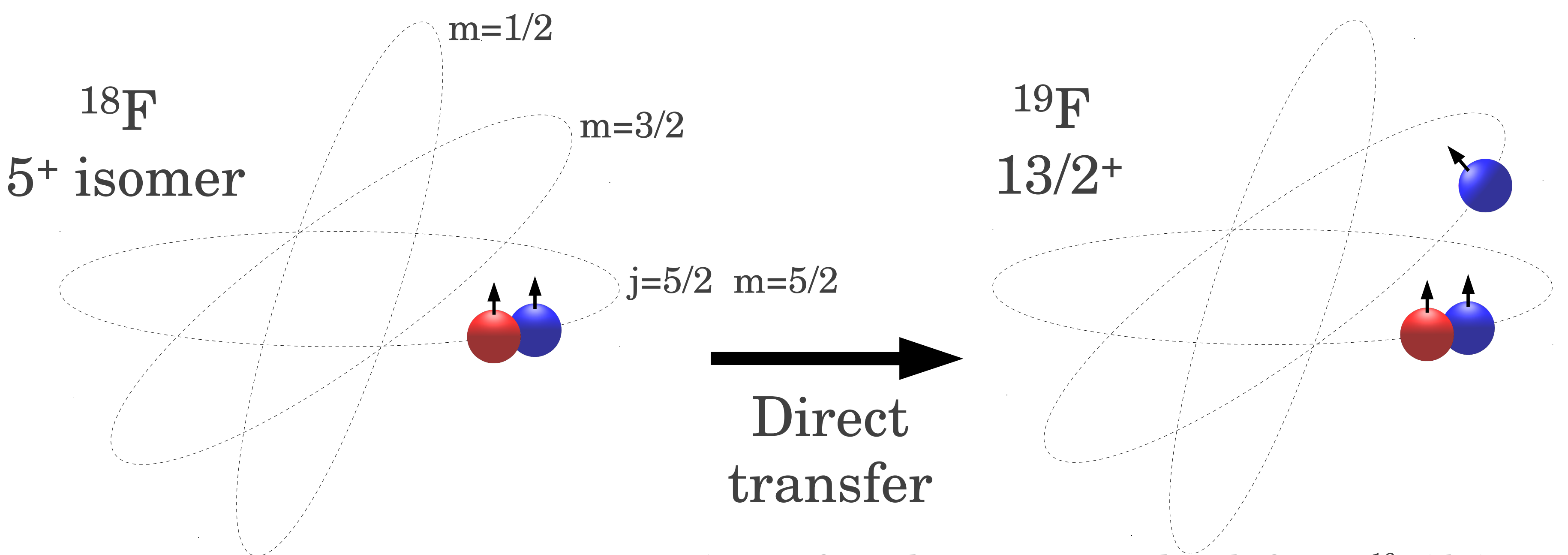


Case study: probing the single-particle character of the $13/2^+$ state in ^{19}F

Based on $^{18m}F(d,p)$ exp done at ANL (Oct/2016 and Nov/2015)

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

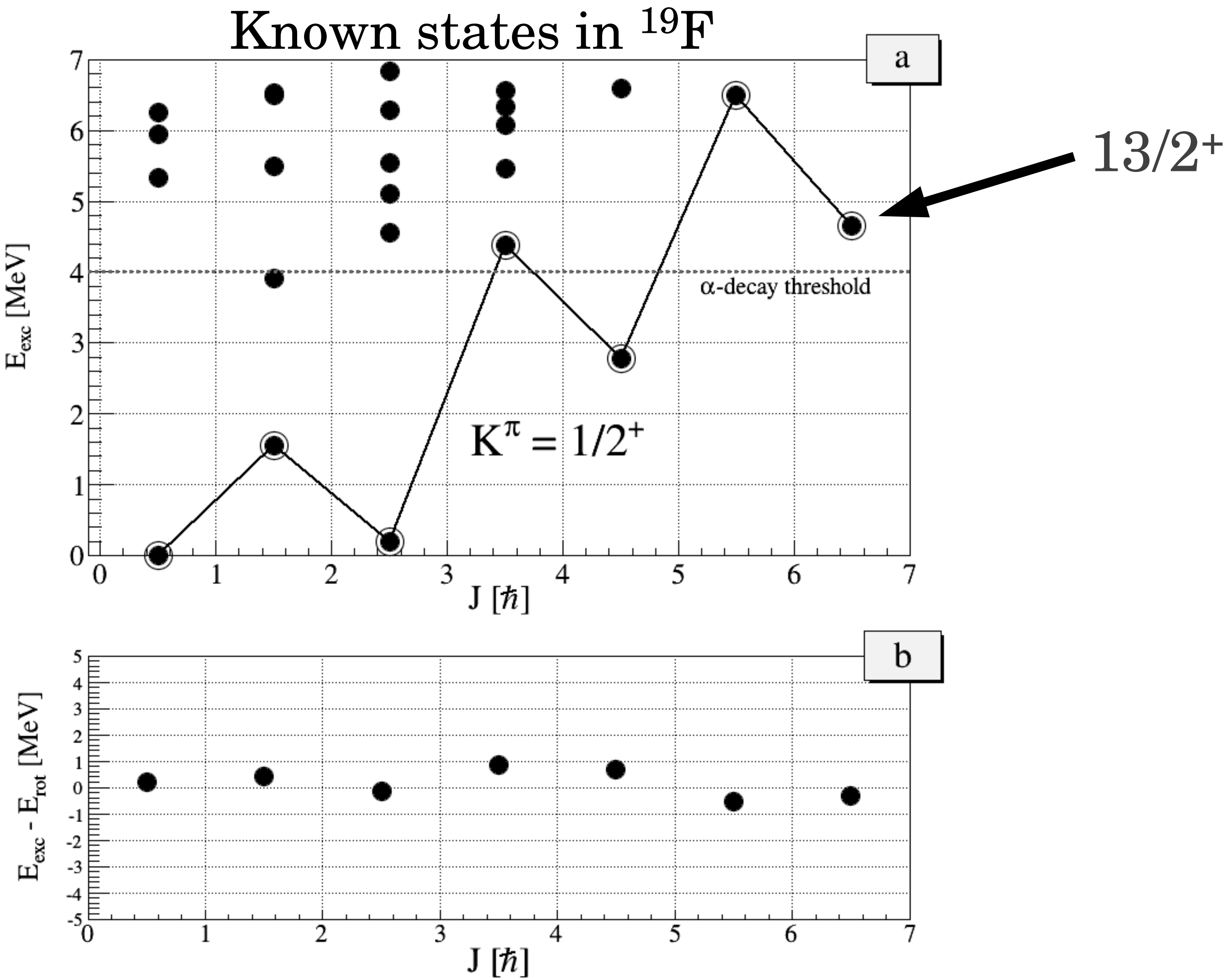
- In ^{19}F, we can **probe** the **single-particle character** of the proposed terminating state of the ground-state rotational band, the **$13/2^{+}$** state
- **How?** By making a **high-spin isomer beam** and **transferring a neutron**[1,2]



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

1) Transfer on low-spin isomer done before in ^{16}N(*d*,*p*) HELIOS exp. "by accident" (GS=2^{-}, Iso=0^{-}). Reactions with isomer were regarded as contamination.
2) Roberts and Becchetti, have used ^{18m}F beams since 1990! Although not for transfer studies

Which states can be populated?



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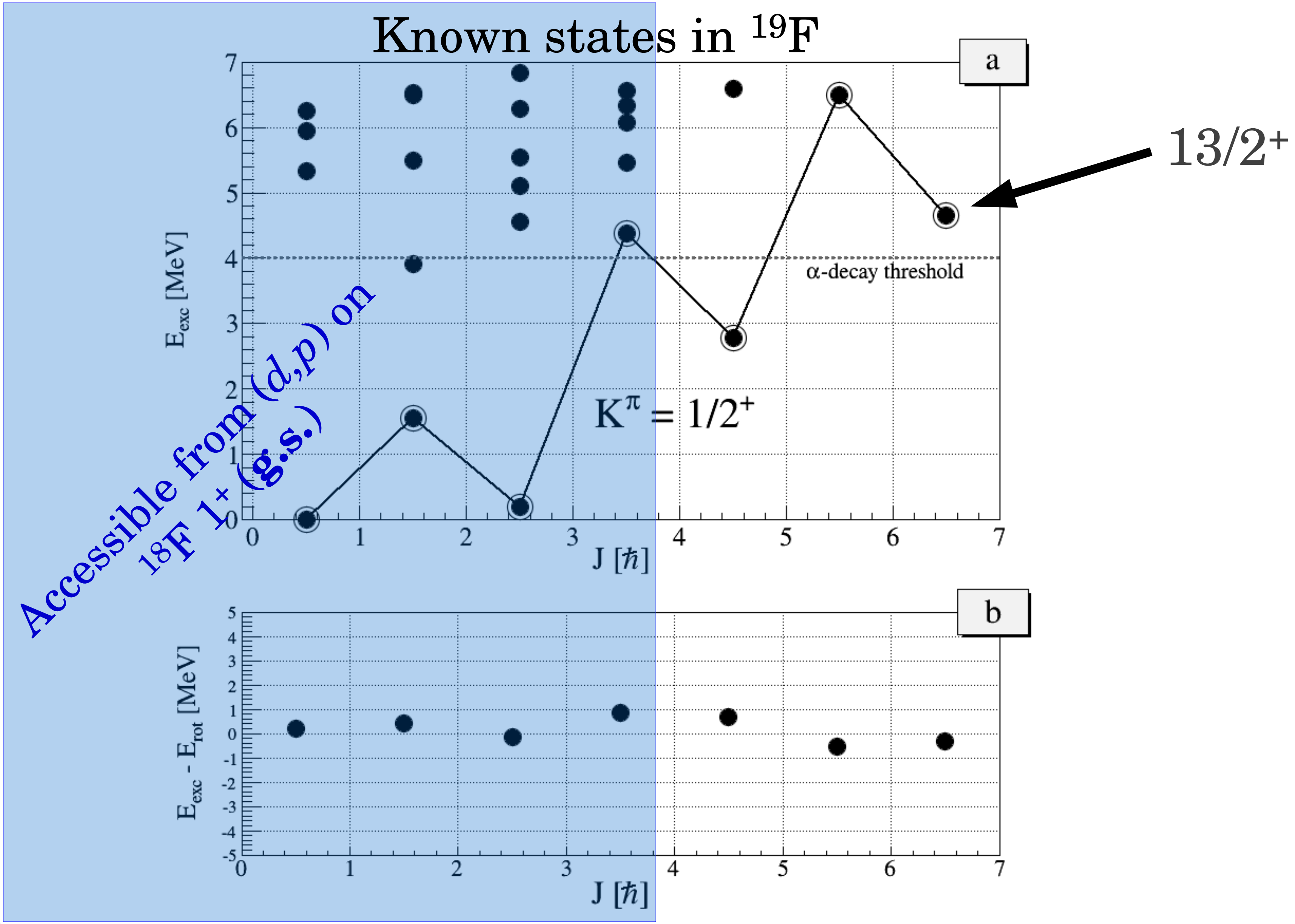

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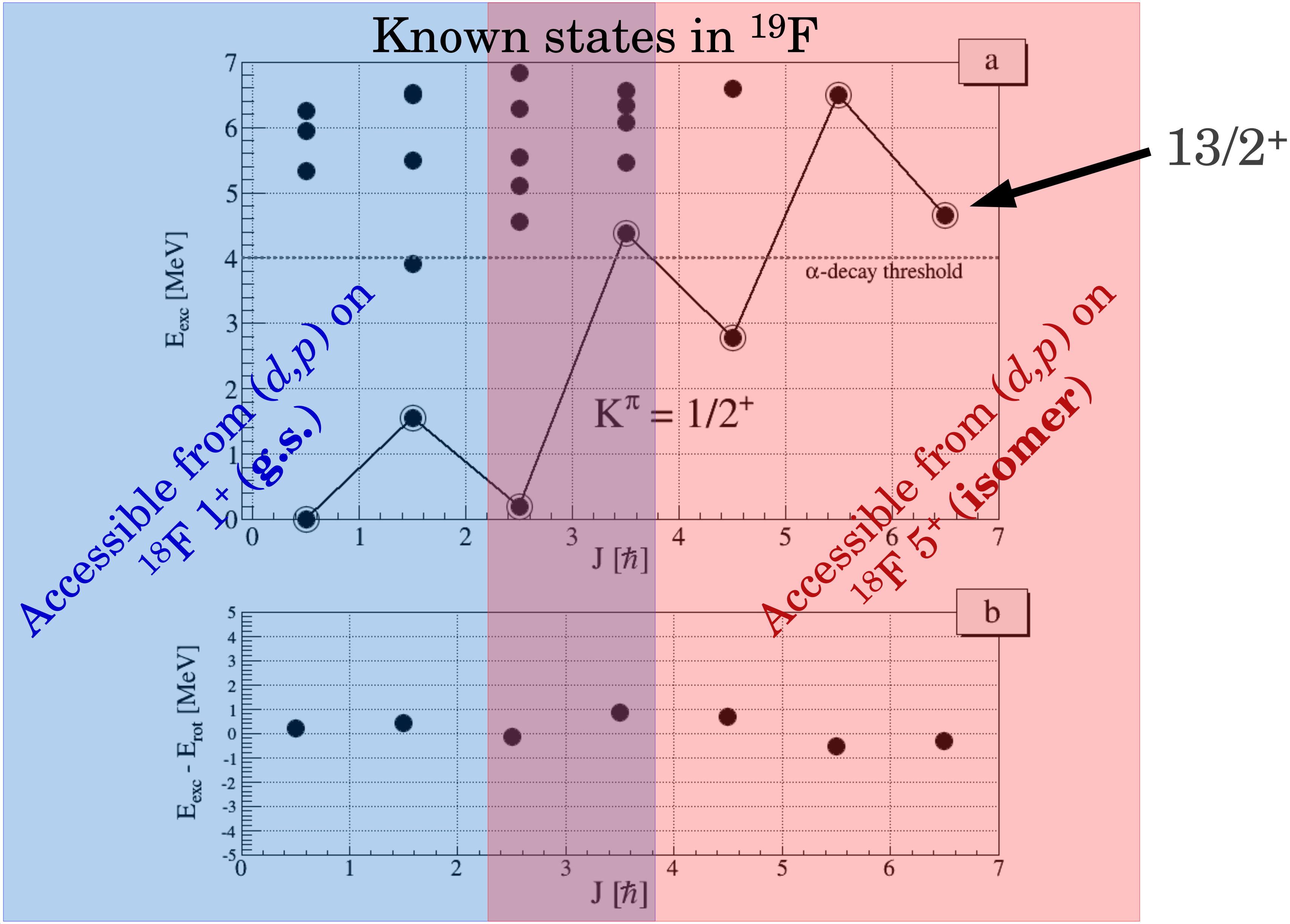

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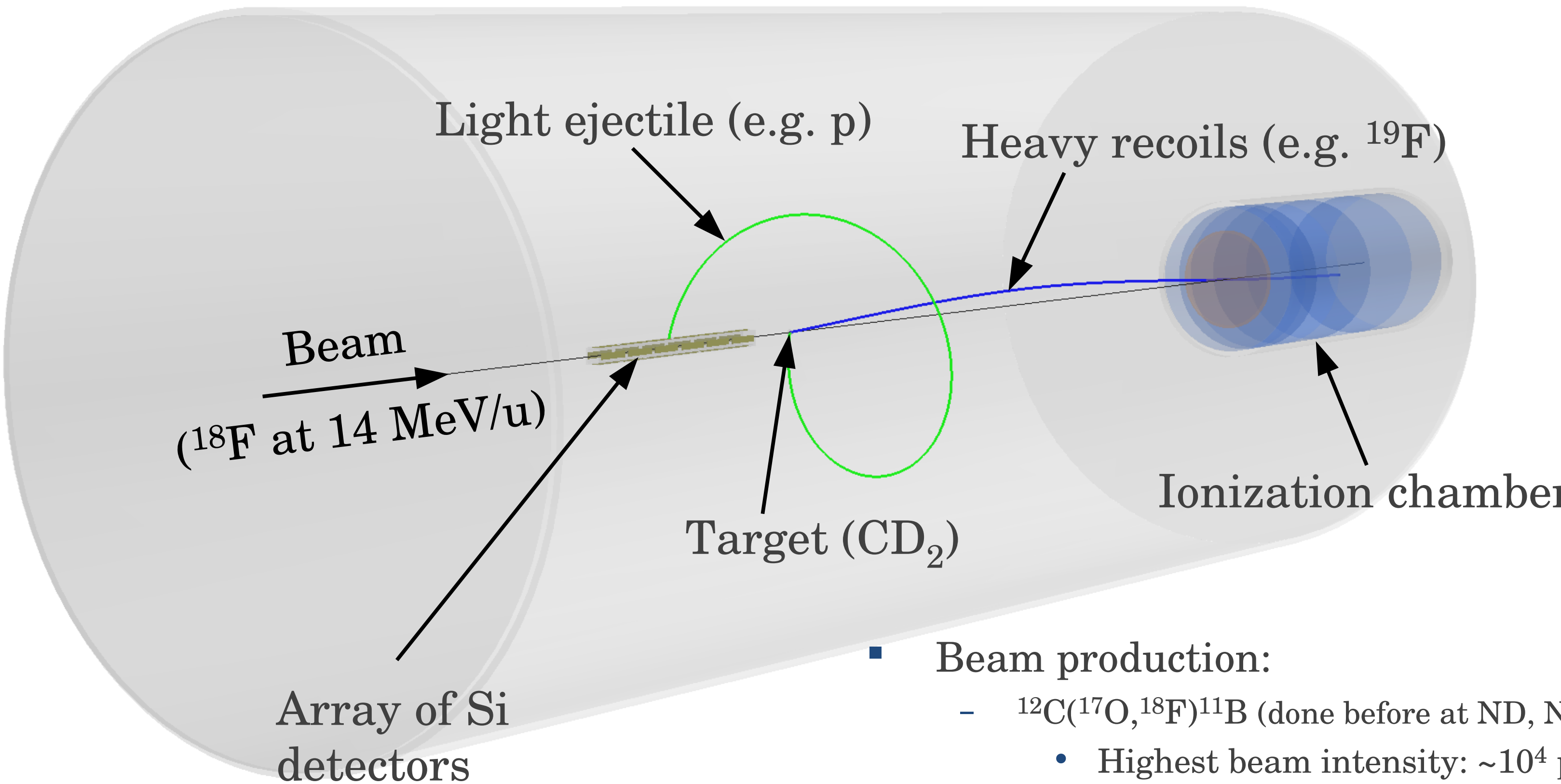
Experiment at the HELIcal Orbit Spectrometer (HELIOS)



- Beam production:
  - ^{12}C(^{17}O,^{18}F)^{11}B (done before at ND, NSCL)
    - Highest beam intensity: ~10^4 pps/pnA [Roberts PRC **65**, 044605 (2002)]
    - Iso/g.s. ratio (at production target): ~70%
  - ^{2}H(^{17}O,^{18}F)n (**present experiment**)
    - ^{18}F beam intensity: ~7-8x10^3 pps/pnA
    - Purity ~30%
    - Iso/g.s. ratio (at production target): ~55%

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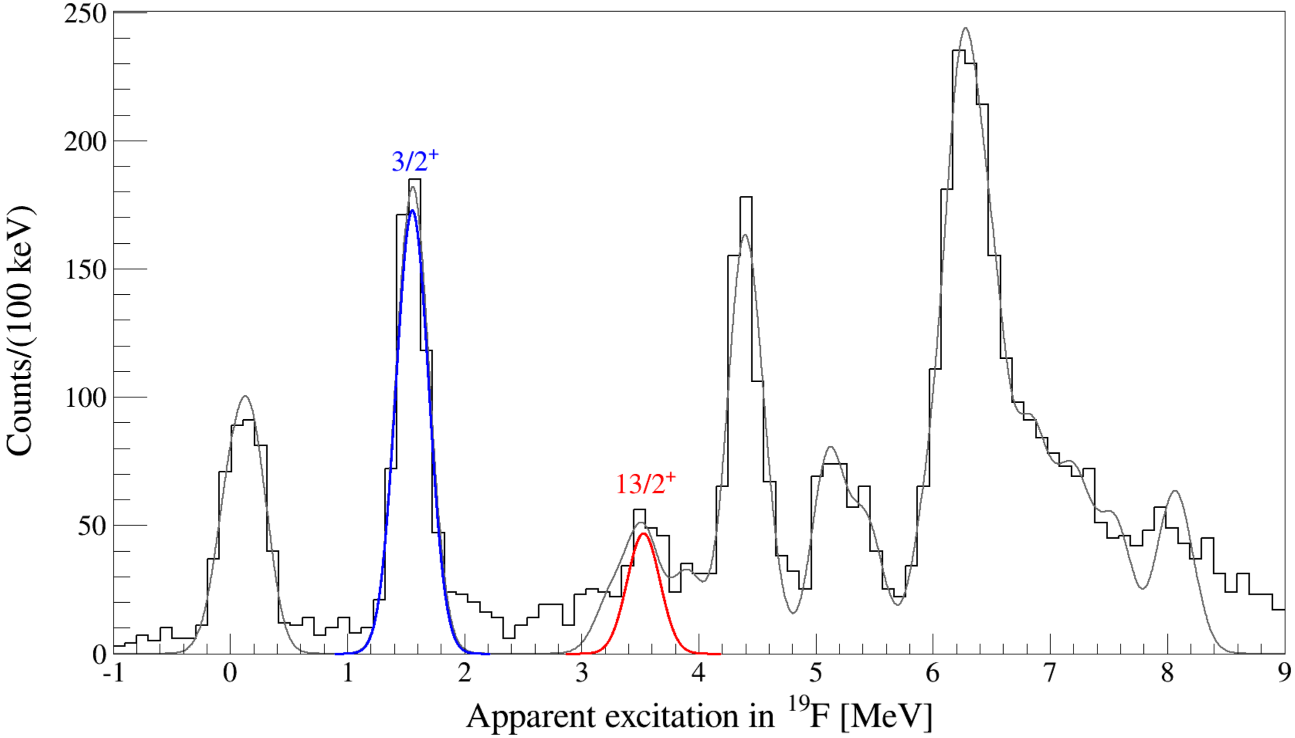
$^{18}F(d,p)^{19}F$ experiment: results

Apparent excitation energy

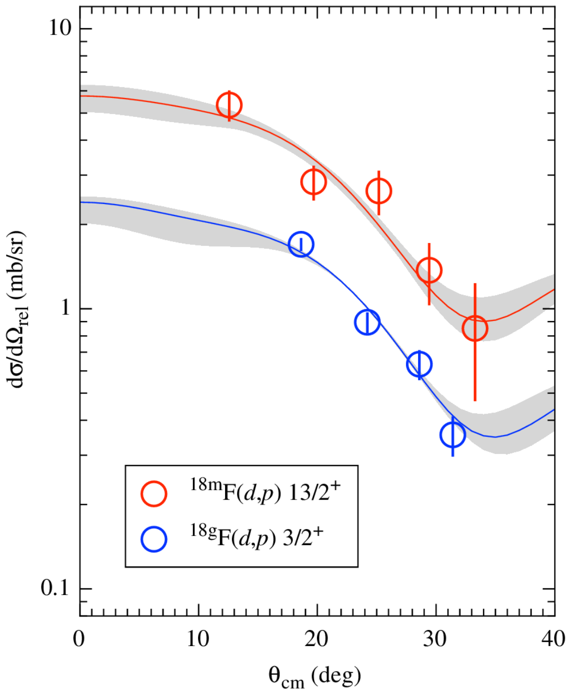
1.1-MeV shift for reactions with isomer

Fit using known states in ^{19}F (fixed E_x and FWHM, 12 states in E_x<6 MeV)
$3/2^+$ state from reactions on ground state
$13/2^+$ state from reactions on isomer



Resolution ~ 330 keV (FWHM)

Relative angular distributions (L=2)



Shaded region represents the variation of DWBA calculations with different optical-model parameters and the solid lines is the weighted average distribution

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^{18}F(d,p)^{19}F experiment: results

(relative) Spectroscopic factors

Preliminary, uncertainties to be determined

			S_{exp} [a]		S_{exp} [b]		S_{theo} [c]			S_{theo} [d]		
J_i^π	$2J_f^\pi$	E_f [keV]	$\ell = 2$	$\ell = 0$	$\ell = 2$	$\ell = 0$	$0d_{5/2}$	$0d_{3/2}$	$1s_{1/2}$	$0d_{5/2}$	$0d_{3/2}$	$1s_{1/2}$
1^+	1^+	0		0.09(X)		0.45(9)			0.42			0.53
1^+	5^+	197	0.28(X)			0.24(5)	0.28	0.06		0.32	0.08	
1^+	3^+	1554[e]	0.607(X)		0.60(12)		0.77	0.04		0.79	0.04	
1^+	7^+	4377[e]	0.70(X)		0.30(6)		0.12			0.32		
5^+	7^+	4377	0.88(X)				0.88			0.82	0.04	
5^+	13^+	4648	1.29(X)				1.28	0.12		1.29	0.14	
5^+	11^+	6500[e]	0.85(X)	0.10(X)			0.64		0.13	0.45		0.41
1^+	5_3^+	5107	0.11(X)		0.15(3)		0.14			0.16	0.01	
1^+	1_2^+	5938		0.12(X)				0.01	0.29			0.21

a Present. Based upon calculated ratio of ^{18}F isomer to ground state and magnitude of spec. factor of the $3/2^+$ state from reanalysis of Kozub's data

b Kozub et al.

c S.M. calculation using PSD interaction (^{12}C core)

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Conclusions from ^{18}F(*d*,*p*) experiment

- We have observed neutron-transfer reactions on the short-lived 5^+ isomeric state of ^{18}F, thereby populating high-spin states in ^{19}F that are **otherwise inaccessible** from (*d*,*p*) reactions on the ^{18}F ground state

- We have extracted a relative spectroscopic factor for the proposed band-terminating $13/2^+$ in ^{19}F that is **2 times larger** than the one for the $3/2^+$ state (a rel. pure single-particle state), in agreement with SM calc.

- The large value of the $13/2^+$ spec. factor is further confirmation that the **angular momentum of a band-terminating state** is generated from the alignment of the spins of the valence nucleons with negligible contribution from collective effects

- From SM calc. the **$11/2^+$** state seems to be a sensitive probe for **core-excitations** in ^{19}F (on-going data analysis)

- Paper in preparation

Future studies (at ANL, ReA, RCNP)

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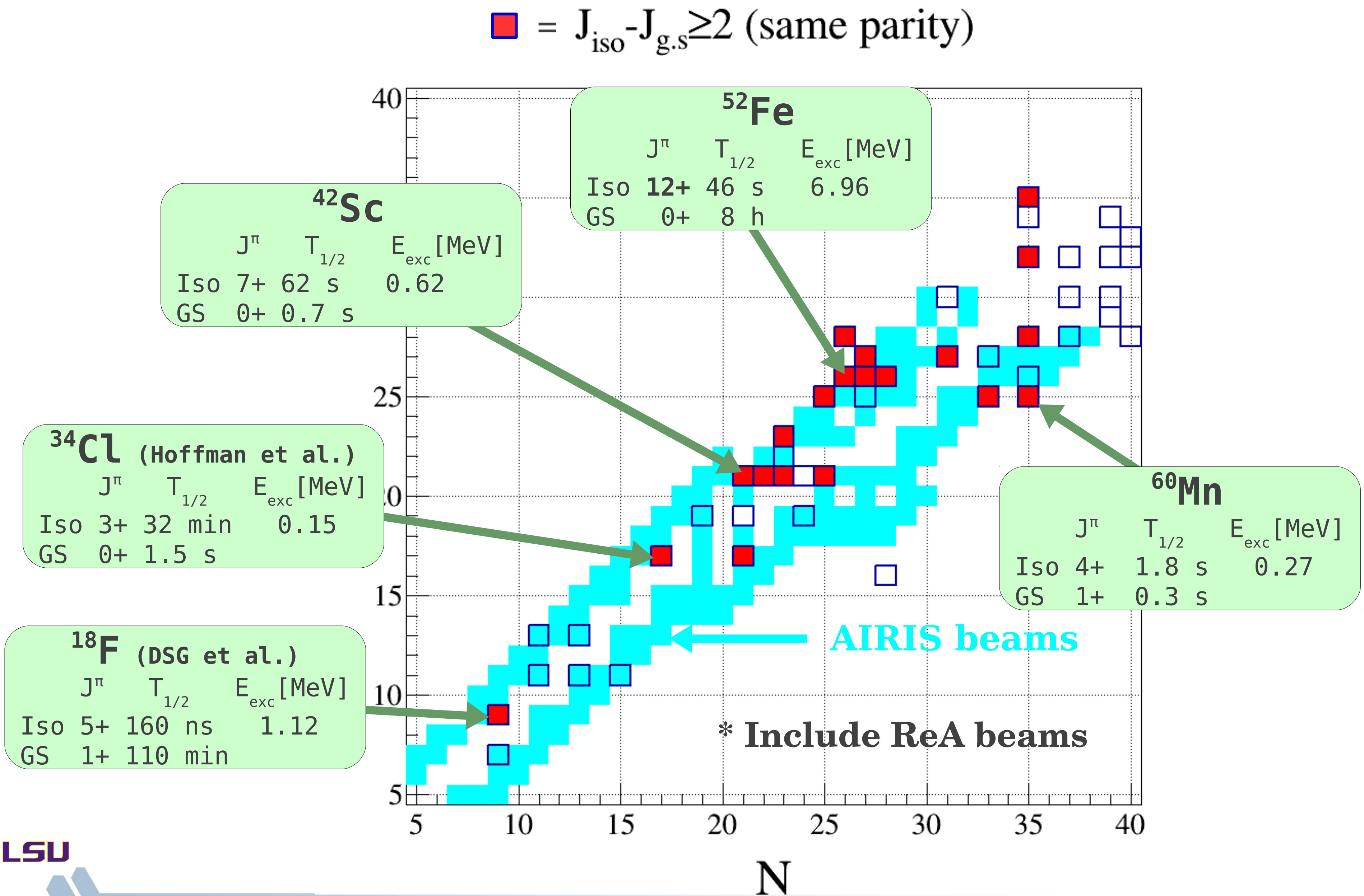
Other high-spin isomers (similar to ^{18}F)



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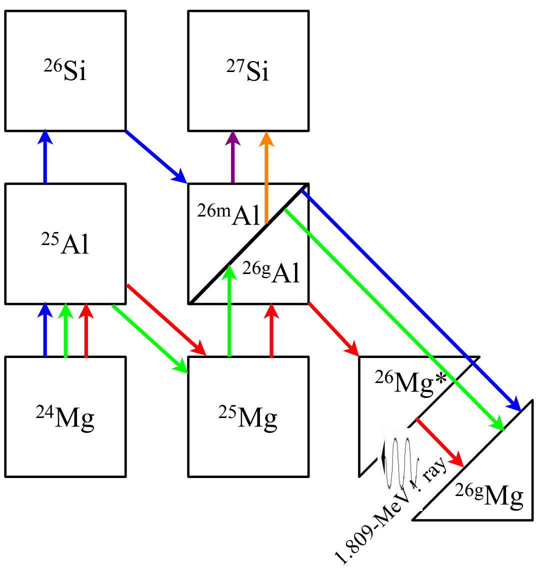
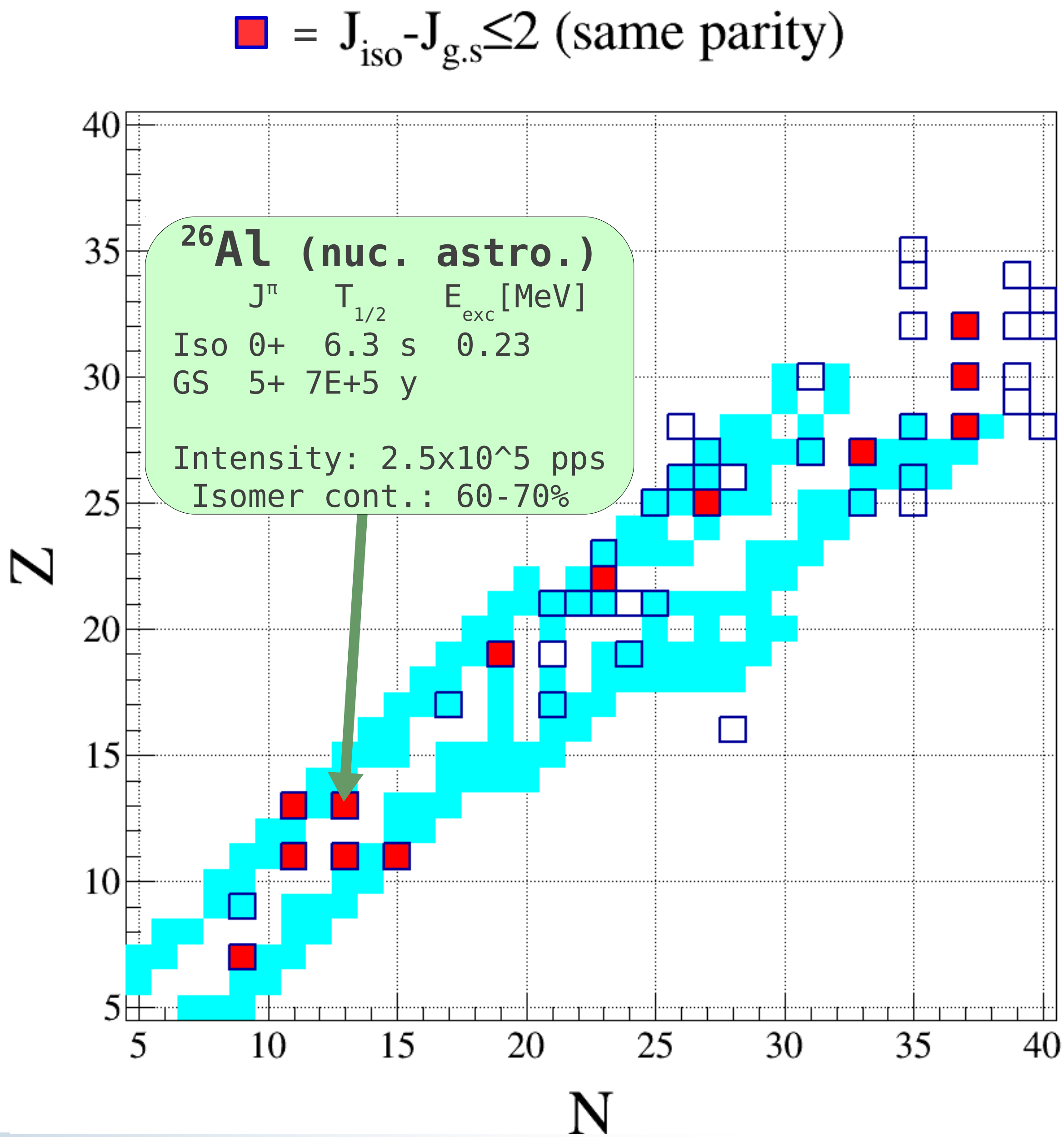
Nuc. Astro. example: ^{26}Al

- Beam already produced!
  (ATLAS in-flight facility)

- Experiment by Almaraz-Calderon, et al. (2016): $^{26}\mathrm{Al}^{m}(d,p)^{27}\mathrm{Al}$ reaction populates isobaric analog states to $^{26}\mathrm{Al}^{m}(p,\gamma)^{27}\mathrm{Si}$
  (not a HELIOS exp)

- Finalizing draft (PRL)





Conclusions on isomer beams and transfer reactions

- 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**
- Nuclear isomers may play important role in nucleosynthesis (nuclear astrophysics most famous example: ^{26}Al)
- Transfer reactions on isomeric beams is a promising technique with three on going experimental efforts (^{18m}F, ^{34m}Cl, ^{26m}Al) and clear near-future physics opportunities

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