Resonances in ^{19}Ne with relevance to the astrophysically important ^{18}F(p,α)^{15}O reaction

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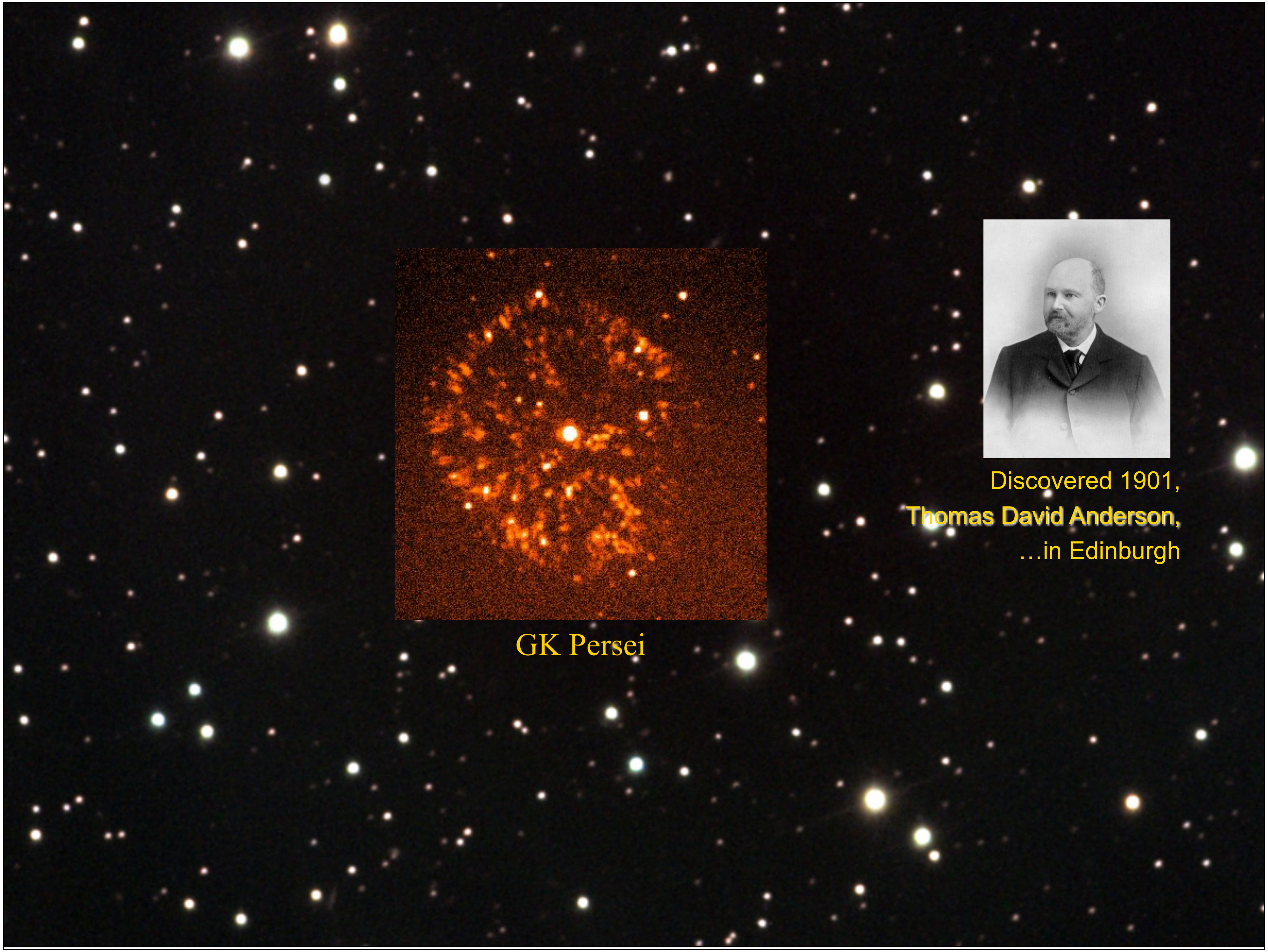
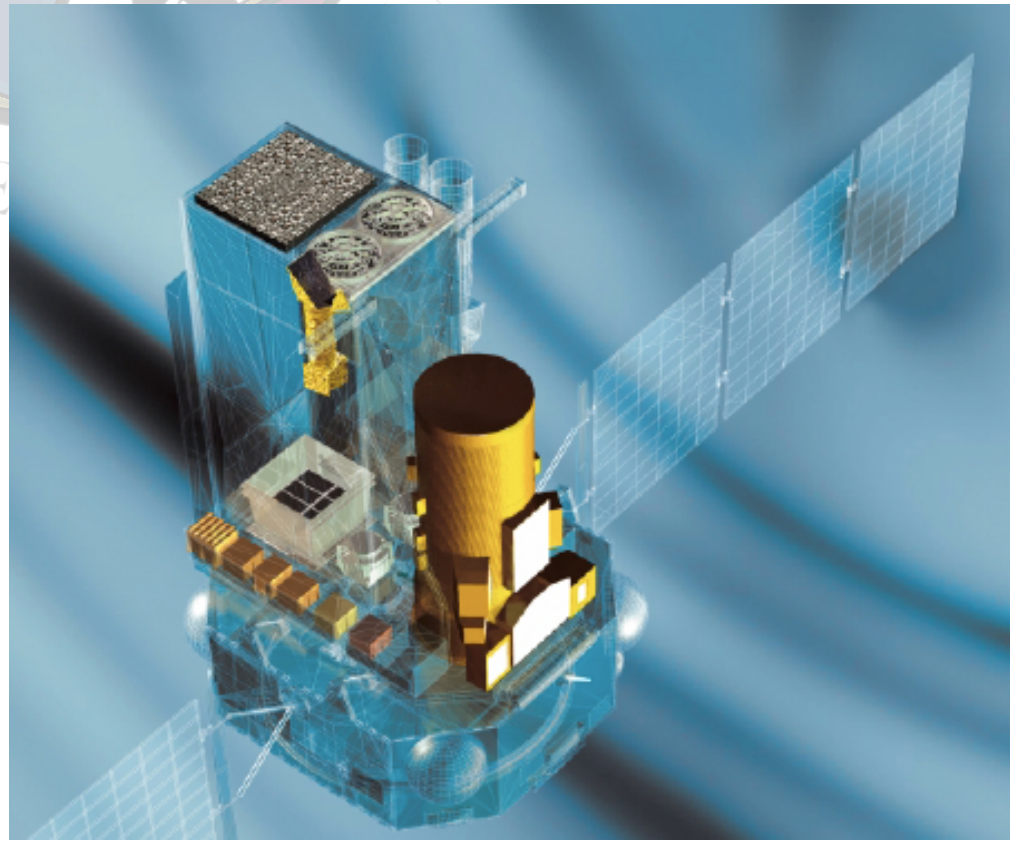
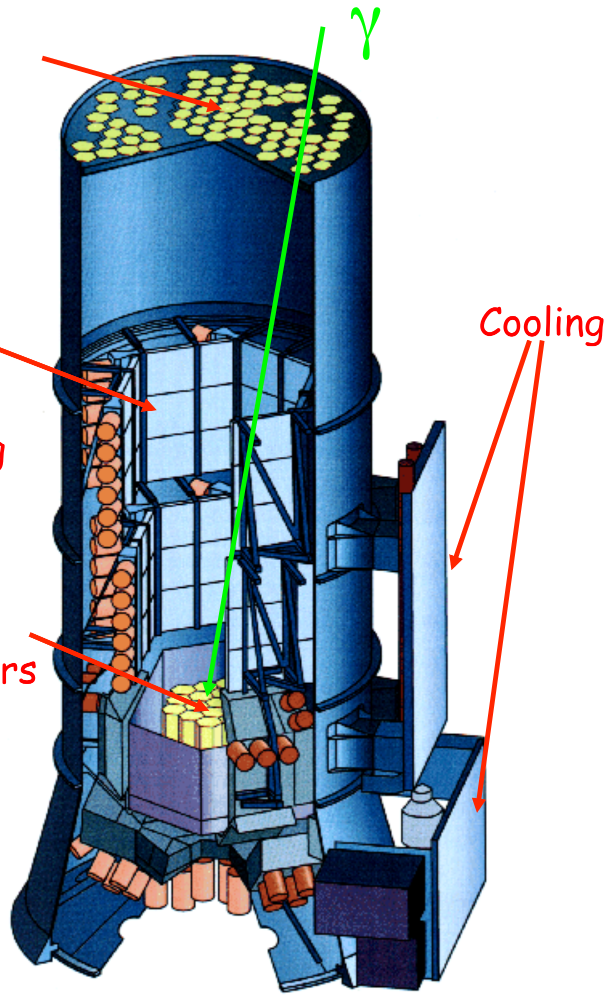
Motivation


GK Persei
Discovered 1901,
Thomas David Anderson,
…in Edinburgh


esa
integral
European Space Agency

INTEGRAL SPI





Astronomy & Astrophysics manuscript no. arxiv
January 10, 2010

New estimates of the gamma-ray line emission of the Cygnus region from INTEGRAL/SPI observations

Pierrick Martin[1,2], Jürgen Knödlseder[1,2], Roland Diehl[3], and Georges Meynet[4]

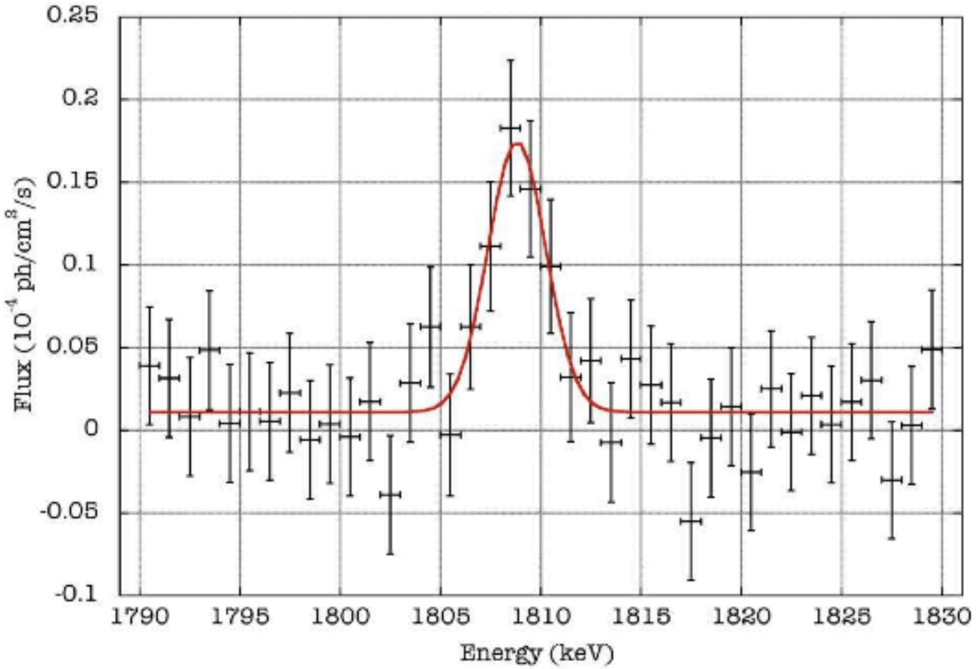


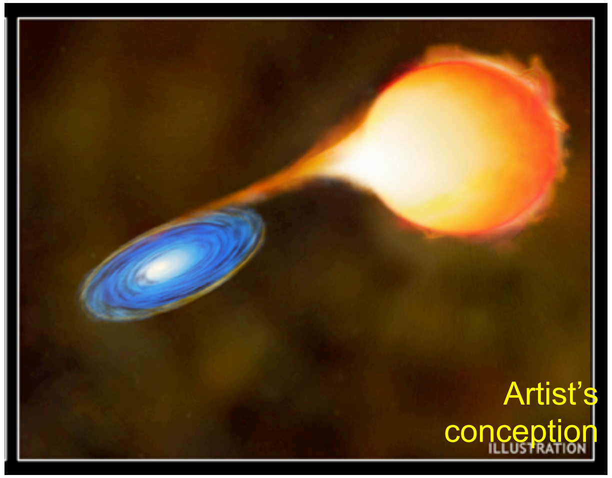
Fig. 1. Spectrum of the 1809 keV emission from the Cygnus region, from about 4 years of INTEGRAL/SPI observations. The red line represents the best Gaussian fit to the data points.

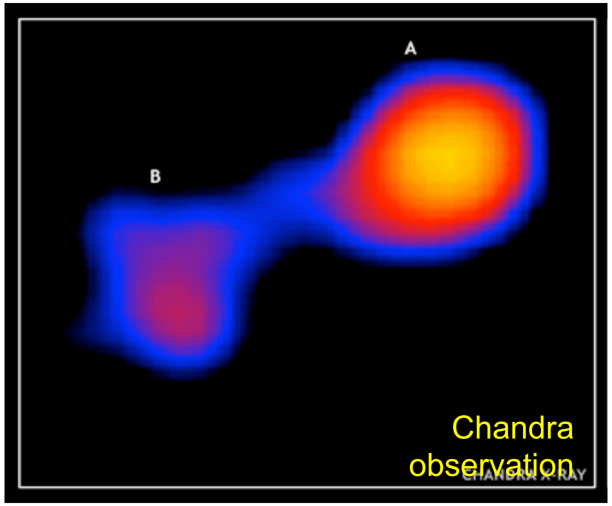
Astrophysical Gamma Ray Emitters

Nucleus	lifetime	Emission	Source
^{13}B	862 s	511 keV	CO Novae ONe Novae
^{18}F	158 m	511 keV	CO Novae ONe Novae
^{7}Be	77 d	478 keV	CO Novae
^{22}Na	3.75 yr	1275 keV	ONe Novae
^{26}Al	1.0 Myr	1809 keV	WR, CC SNe?
^{44}Ti	87 yr	1157 keV	CC SNe
^{60}Fe	2.2 Myr	1173,1333 keV	CC SNe

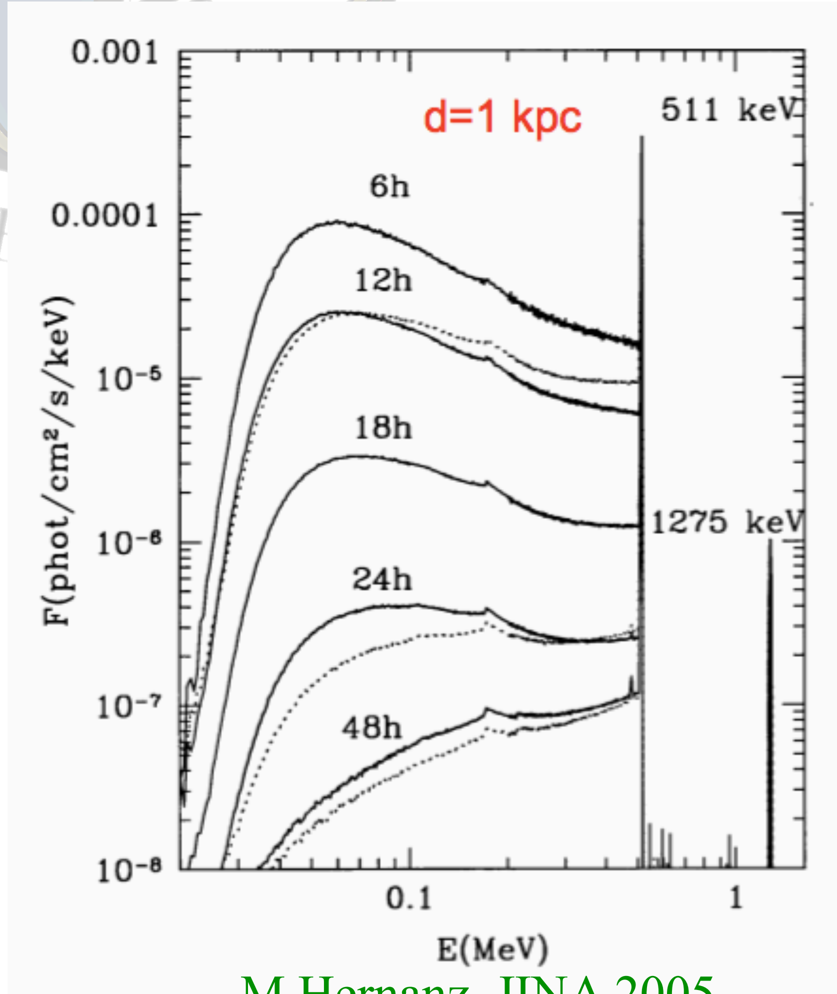
Motivation

- Classical Novae
  - accretion of H on CO or ONe WD
- Our understanding to date is based on…
  - Light curves
  - Spectra
  - Meteoritic data
- Problems…
  - Limited information in light curves
  - Spectra give *chemical* abundances
  - Spectra give ~*final* abundances
  - Meteoritic data also is ‘delayed’ & complex
- A better probe would be gamma-rays





Gamma ray probes of Novae



M Hernanz, JINA 2005

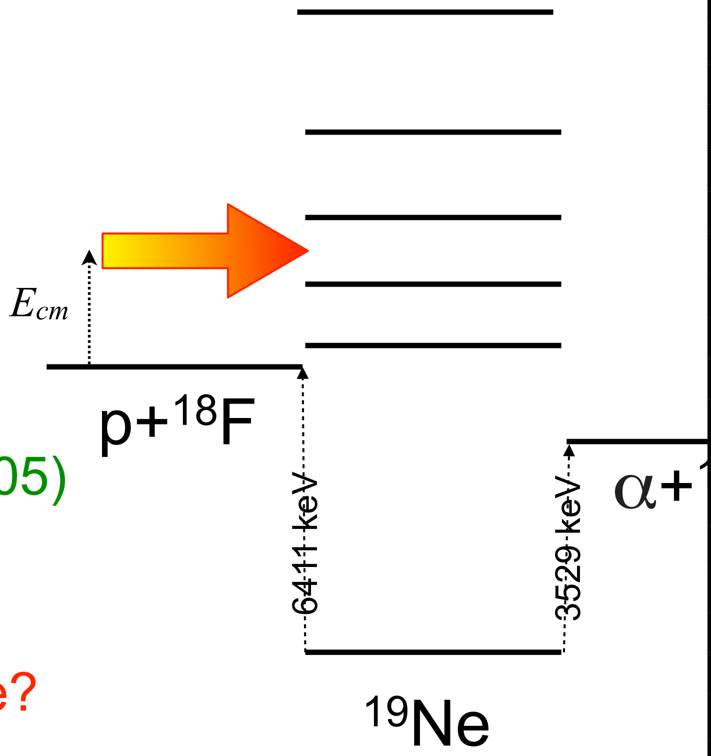
Overall novae gamma-ray line emission is ***dominated by 511 keV γ-rays from ^{18}F β^+ decay***

- Need to know rates of reactions creating and destroying ^{18}F
- Large Uncertainties remain, especially in **$^{18}F(p,\alpha)^{15}O$**
- Rate is determined by resonant contributions from states in **^{19}Ne**

Why is the rate so uncertain?

Problems...

- There are many states
  - Nesaraja PRC 75 (2007) 055809
  - ...and most level data is extremely uncertain
  - 'Known' key states
    - *ℓ=0* at 8, 38, 665 keV
    - *ℓ=1* at 26, 330
- Signs of interference terms
  - de Sereville NPA **758** (2005)
  - Beer PRC(R) **83** (2011)
- Additional states?
  - Broad sub-threshold state?
  - THIS WORK

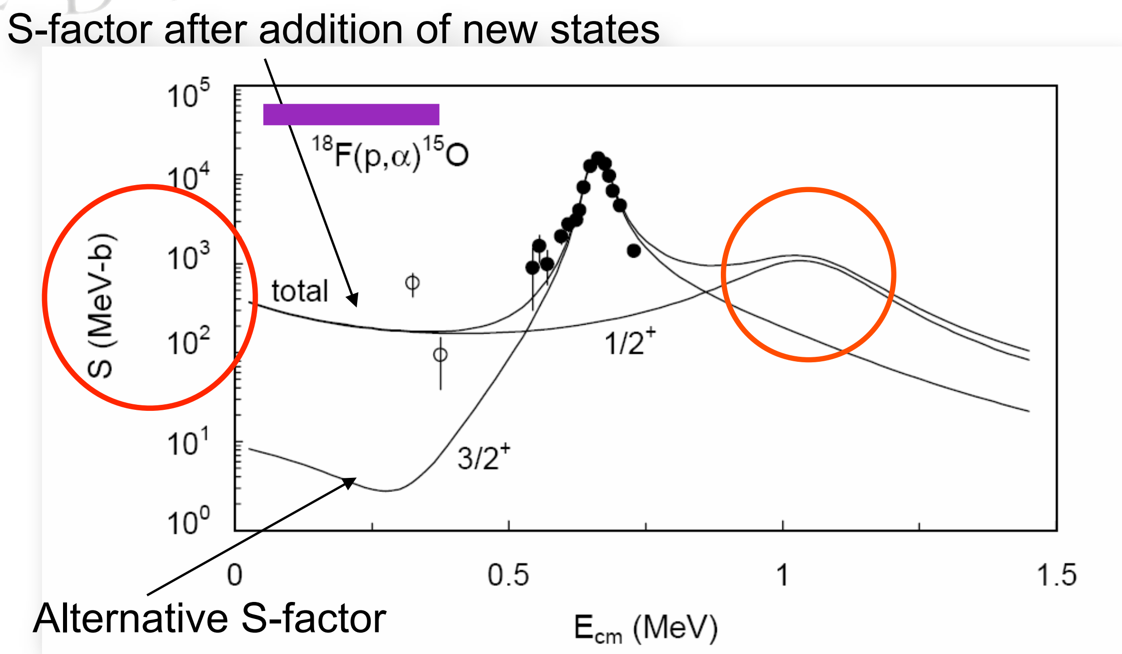


E_R (keV)	Jπ
8	3/2+
11	11/2+
26	1/2-
38	3/2+
93	7/2+
131	9/2+
287	5/2+
330	3/2-
430	3/2-
450	7/2-
528	1/2-
643	5/2+
665	3/2+
762	11/2-
827	3/2+
842	1/2+
1009	7/2+
1089	5/2+
1120	5/2-
1147	5/2-
1197	3/2+
1233	1/2-
1289	5/2-
1408	7/2+
1415	11/2+
1533	5/2+
1603	5/2+
1658	1/2+

Broad sub-threshold state? Prediction

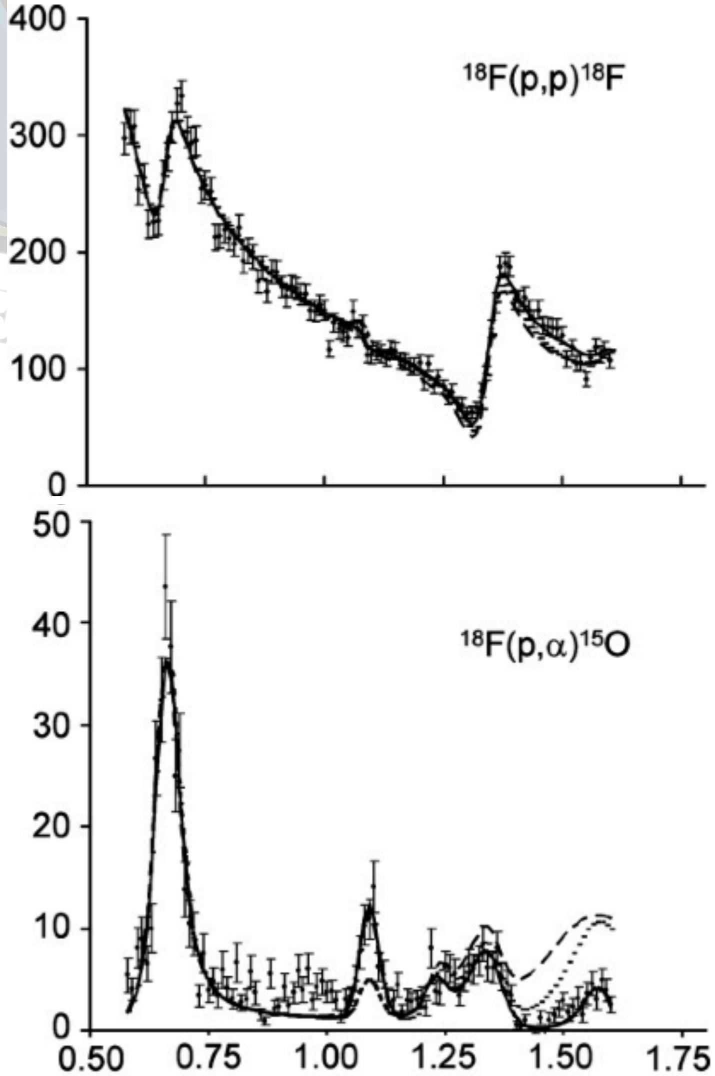
Dufour & Descouvemont, NPA 785 (2007)

Broad $\ell = 0$ states at $E_r \approx -0.4$ & 1.5 MeV?



Presence of a broad sub-threshold state limits the amount of destructive interference in the Gamow window.

Broad sub-threshold state? Non-observation



Murphy *et al.* PRC 79 (2009)

Searched for higher energy state: Existence of state would infer existence of sub-threshold state.

State at about the correct energy seen, but appears to lack sufficient strength (i.e. width)

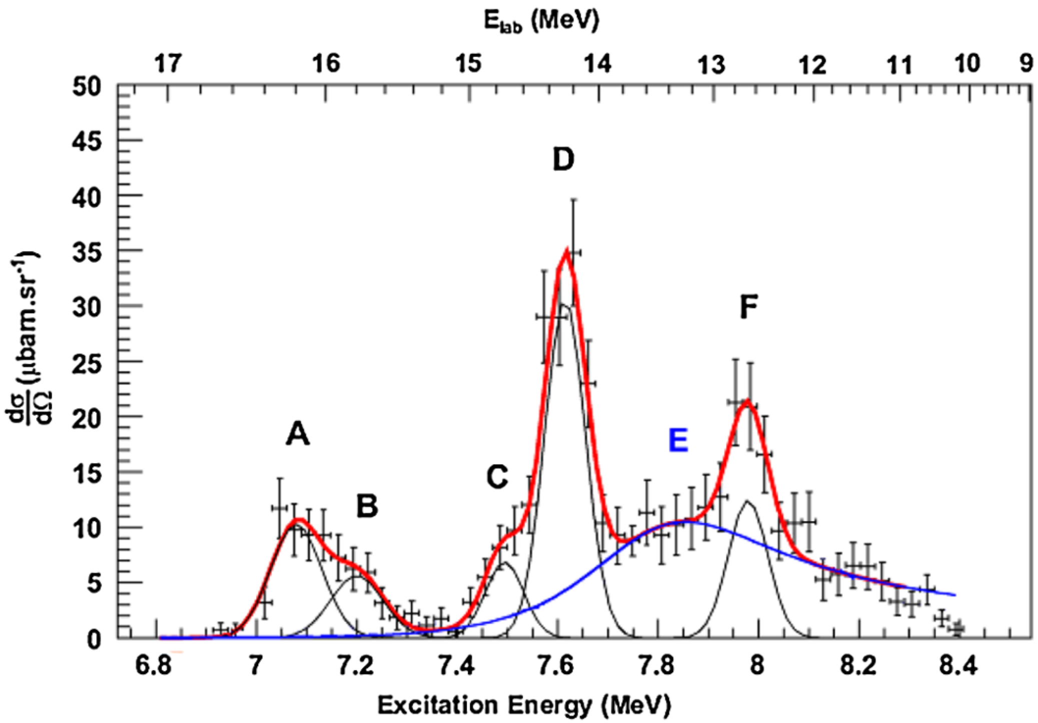
Relevant data were very close to high energy limit of the experiment - possibly compromised by target edge effects?

Broad sub-threshold state? Observation!

Dalouzy et al. PRL 102 (2009)

$$^{1}H(^{19}Ne,p)^{19}Ne^{*}(p)^{18}F$$

$\hookrightarrow \alpha$



Broad underlying state seen at correct energy

Width in agreement with prediction

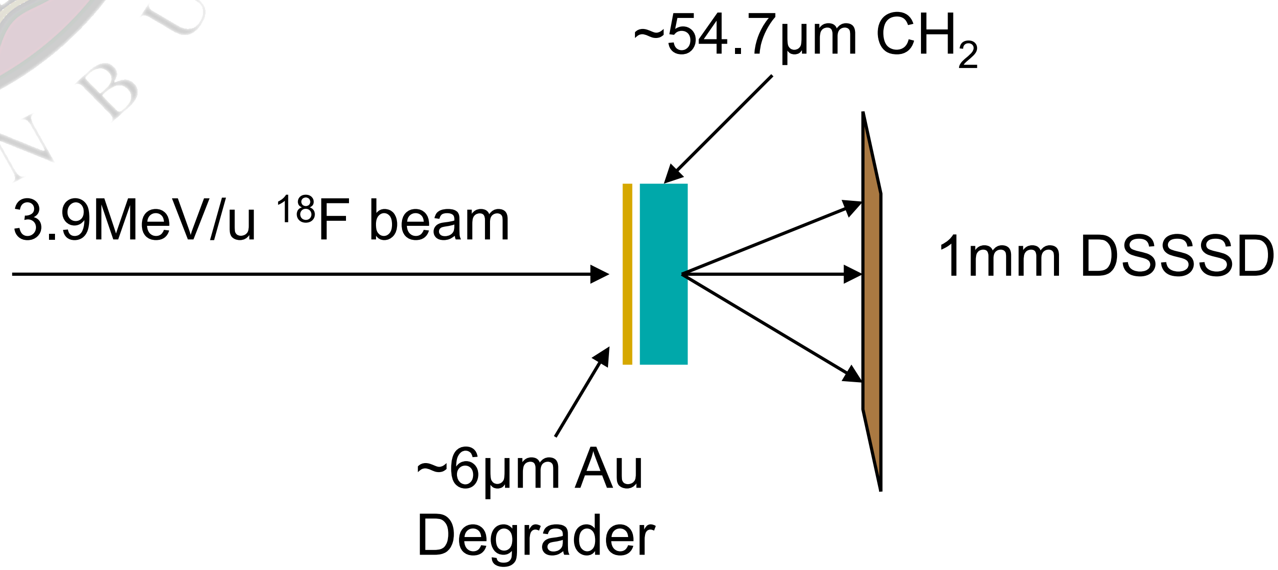
Angular distribution looks like ℓ=0

Experiment had quite a bit of contamination (scattered protons & kinematic ambiguity)

New p+^{18}F data

- April 2010
- 95 MeV/A ^{20}Ne on C
- ECR ion source
- CIME acceleration
- 3.9 MeV/A ^{18}F
- High energy stripping to generate 9^+ beam
- 2×10^4 pps delivered on target
- ECLAN chamber in G2 Cave

Set up



Beam energy degraded to ~2 MeV/A
Beam stops in target
Protons and alphas detected in DSSD

Lab to cm energy, & Resolution

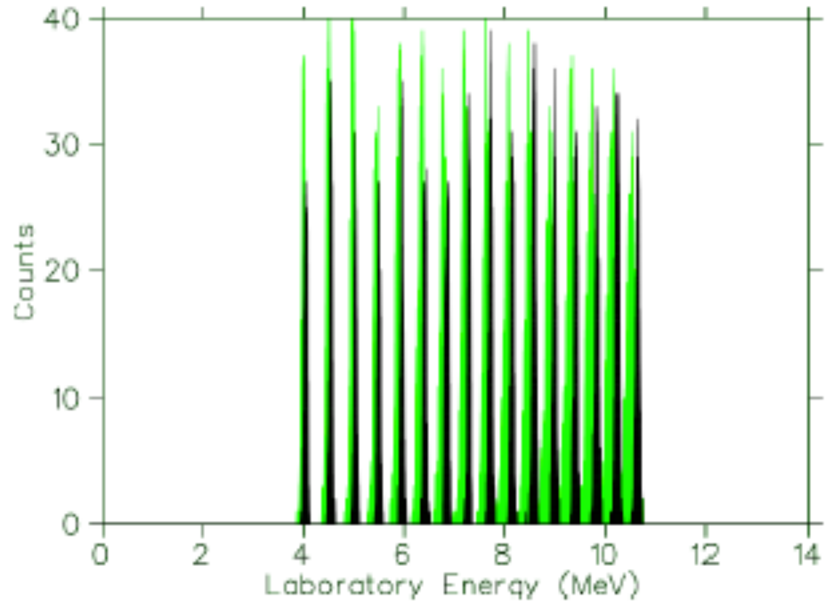


FIG. 1: (Color online.) Monte Carlo simulated energy spectra of two detector pixels for alpha particles from the $^{18}F(p,\alpha)^{15}O$ reaction, assuming reactions occur only at discrete center of mass energies (100 keV steps over the range 0.6 to 2.1 MeV). There is a unique mapping of detected laboratory energy to center of mass reaction energy. See text for discussion.

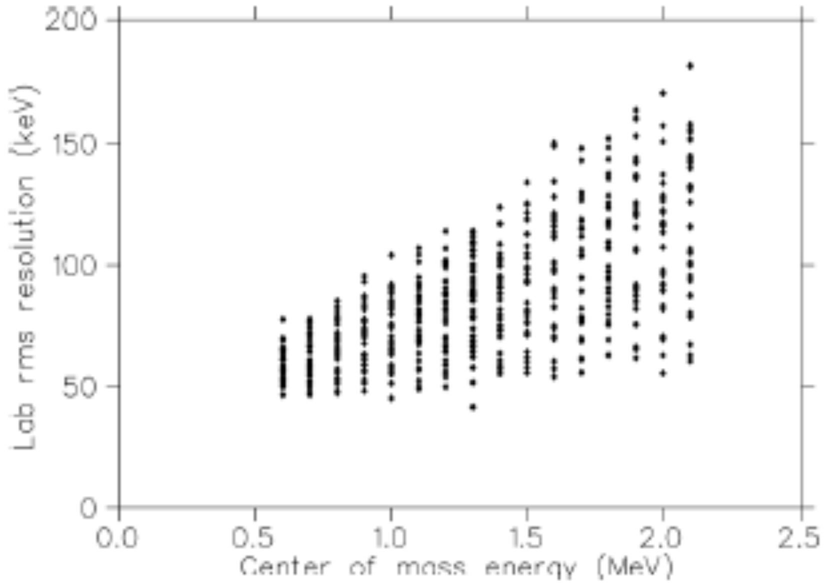
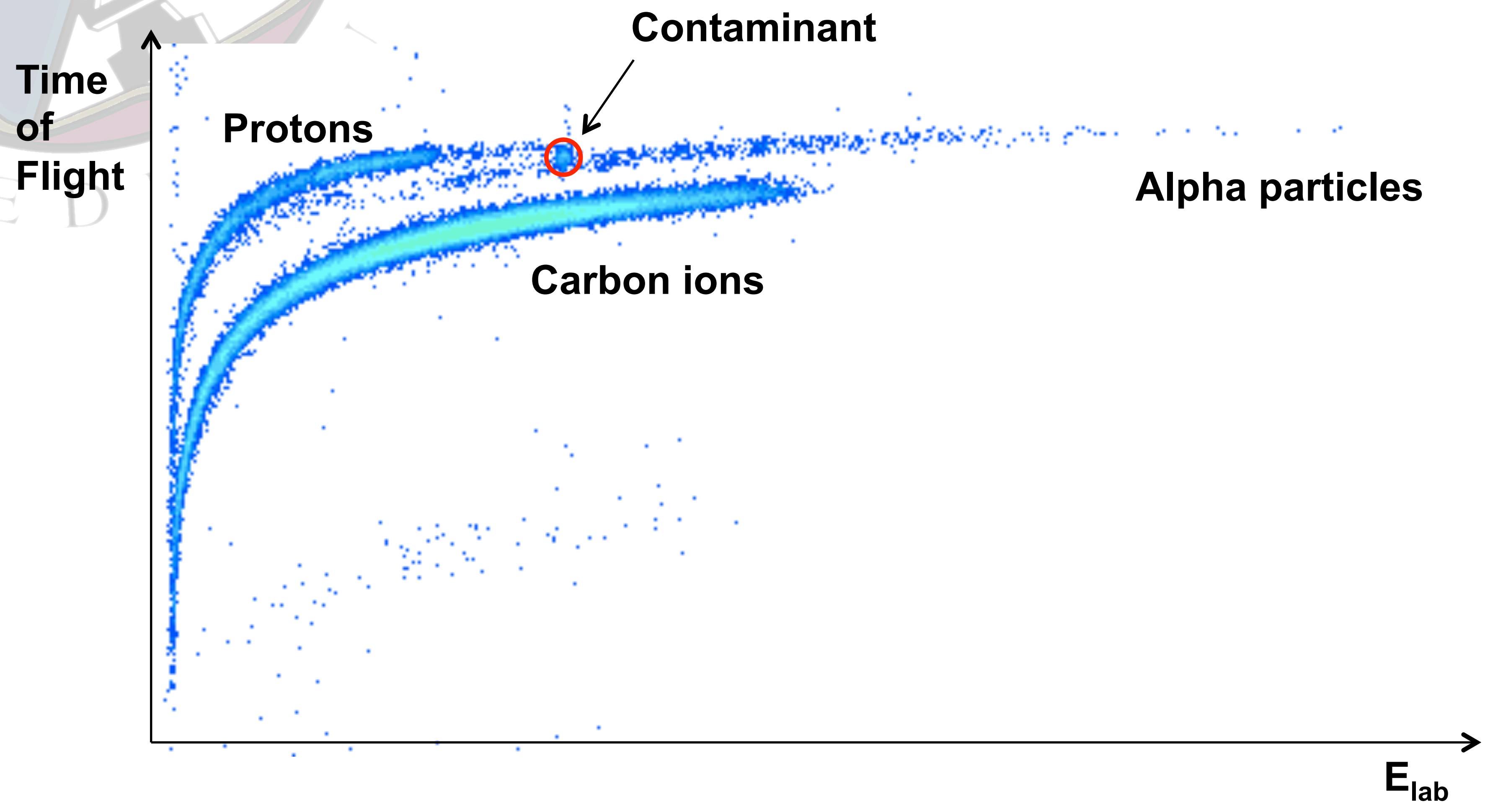
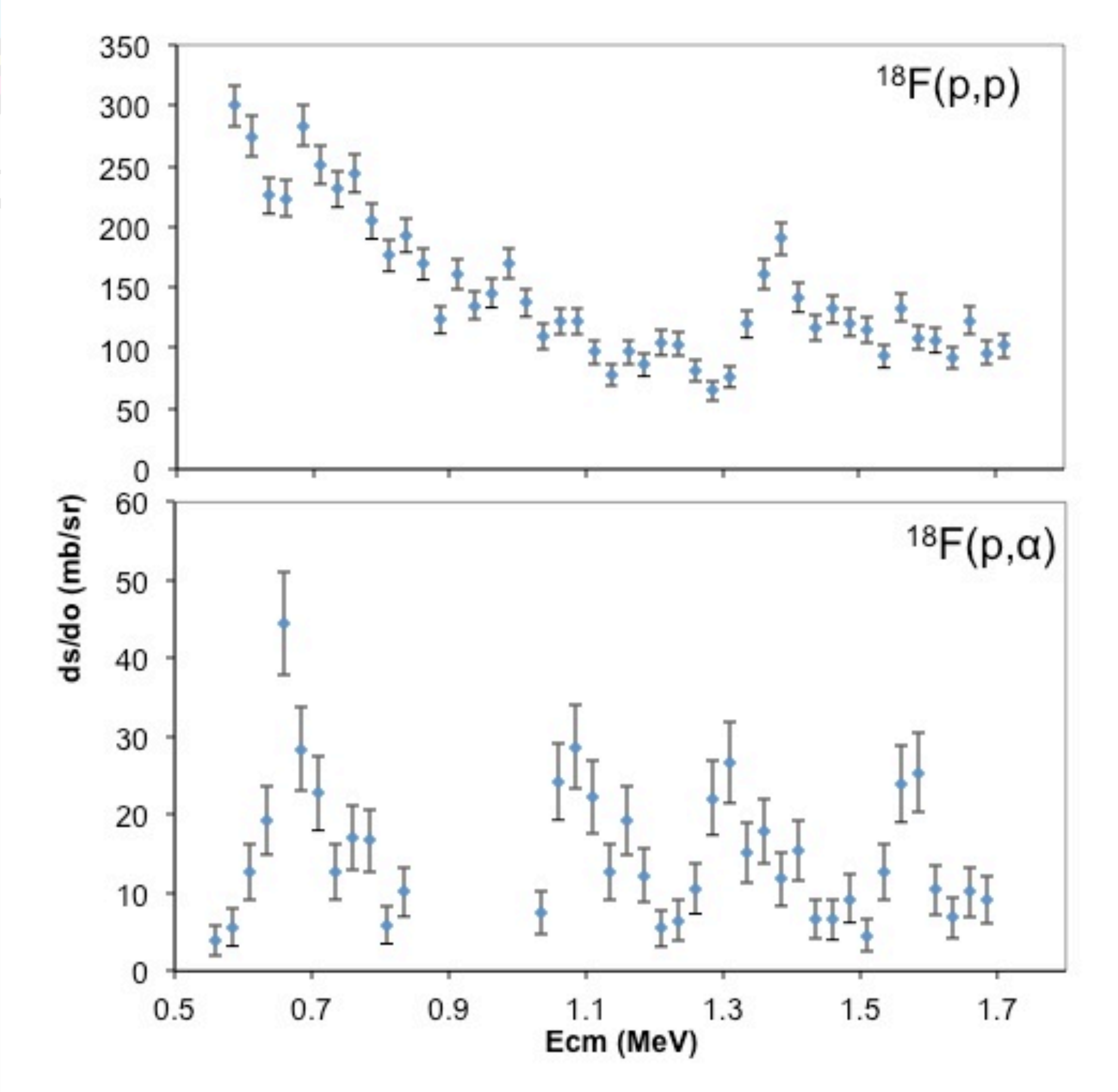


FIG. 2: Monte Carlo simulated rms energy resolutions for alpha particles from the $^{18}F(p,\alpha)^{15}O$ reaction, as a function of the center of mass energy. See text for discussion.

Particle identification



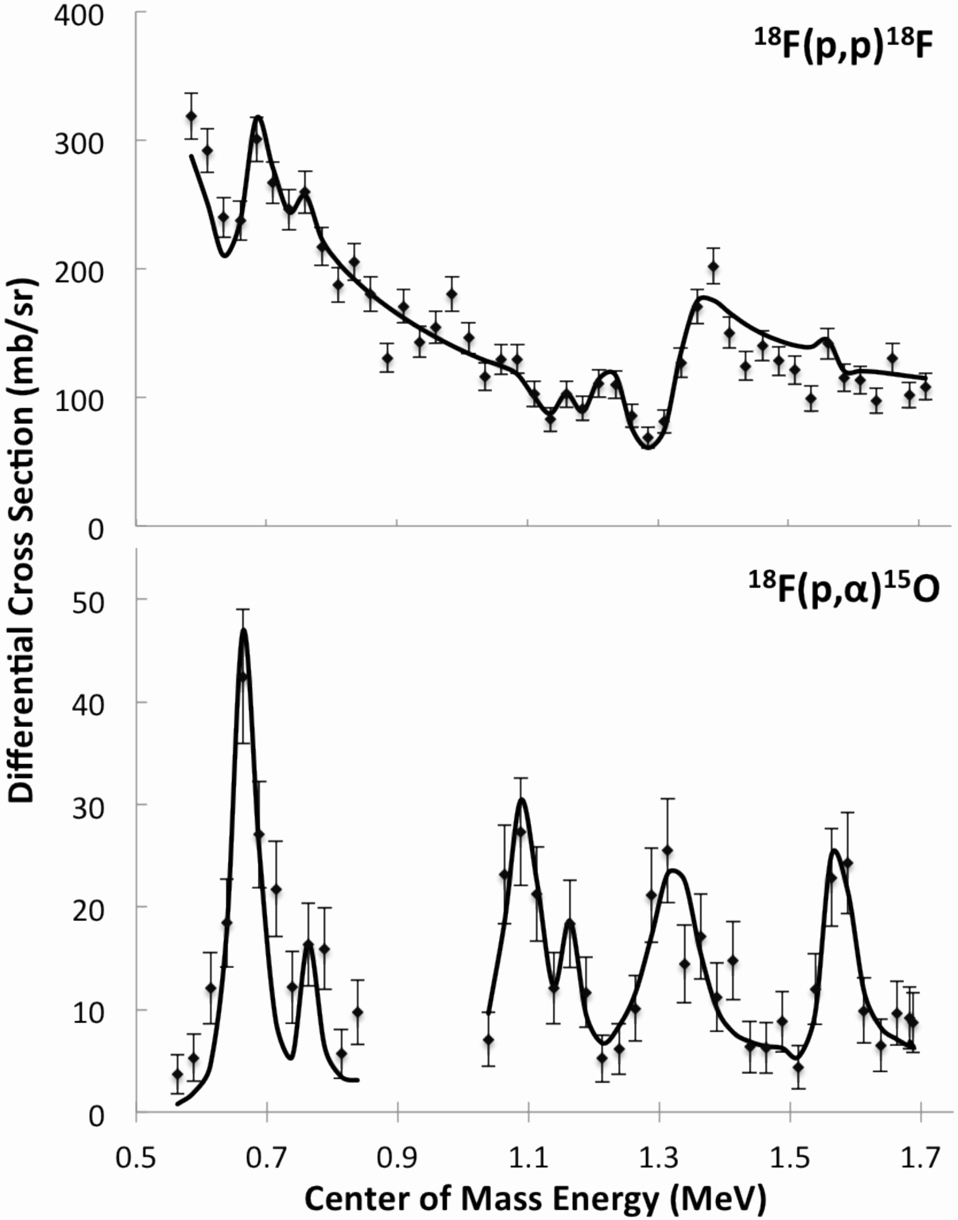
Preliminary Results



Preliminary Results

	Ecm (MeV)	J^π	Γp(keV)	Γα(keV)	Int
A	0.665	3/2+	15	24	+
B	0.759(20)	3/2+	1.6(5)	2.4(6)	
C	1.096(11)	5/2+	3(1)	54(12)	
D	1.160(34)	3/2+	2.3(6)	1.9(6)	
E	1.219(22)	3/2-	21(3)	0.1(1)	
F	1.335(6)	3/2+	65(8)	26(4)	-
G	1.455(38)	1/2+	55(12)	347(92)	
H	1.571(13)	5/2+	1.7(4)	12(3)	

- Results of R Matrix analysis carried out using DREAM code from P. Descouvemont
- Comparison references:
    1. Nesaraja *et al.* PRC 75, 055809 (2007)
    2. Murphy *et al.* PRC 79, 058801 (2009)
    3. Dalouzy *et al.* PRL 102, 162503 (2009)



Preliminary Results (A)

	Ecm (MeV)	J^{π}	Γp(keV)	Γα(keV)	Int
A	0.665	3/2+	15	24	+
B	0.759(20)	3/2+	1.6(5)	2.4(6)	
C	1.096(11)	5/2+	3(1)	54(12)	
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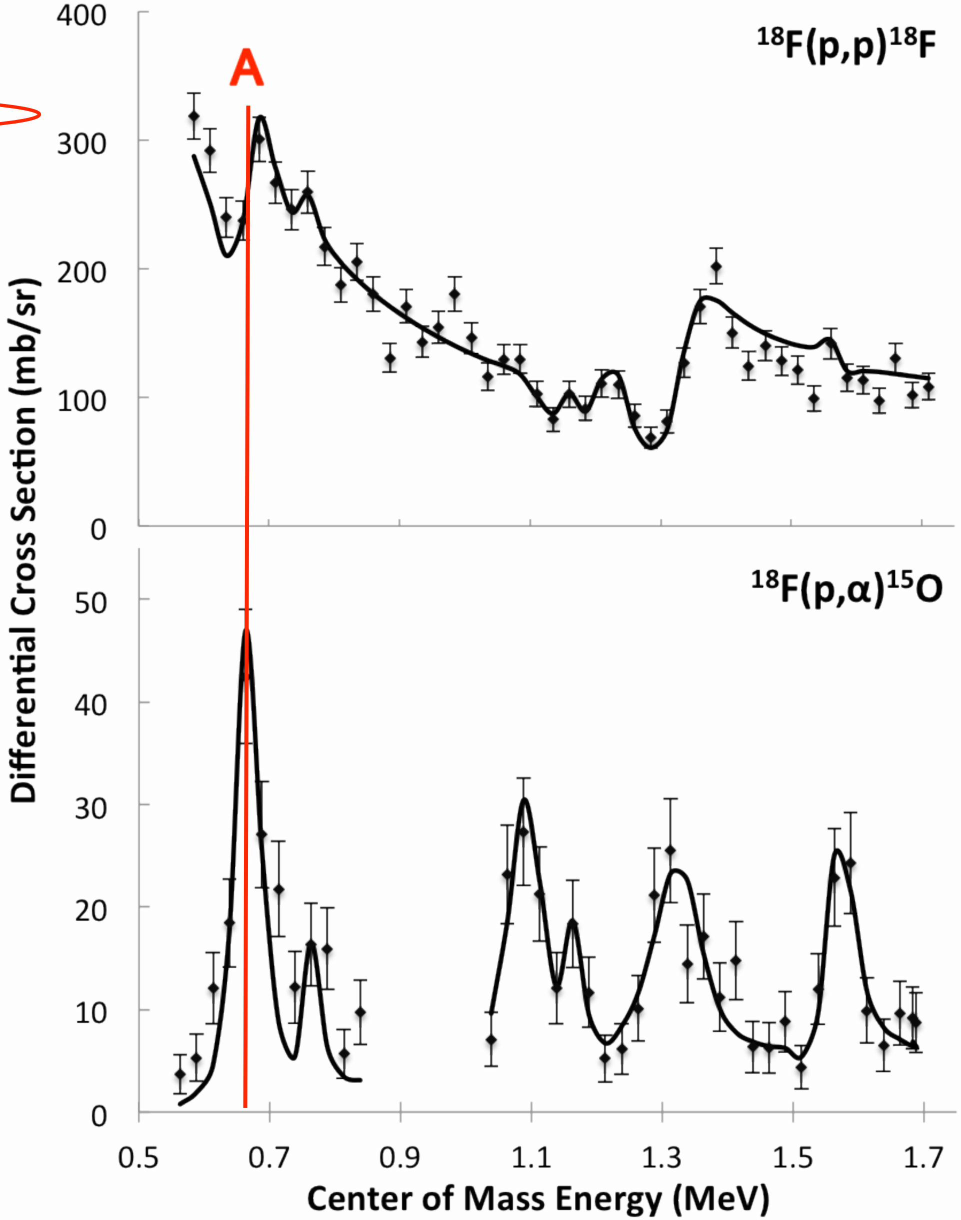
F	1.335(6)	3/2+	65(8)	26(4)	-
G	1.455(38)	1/2+	55(12)	347(92)	
H	1.571(13)	5/2+	1.7(4)	12(3)	

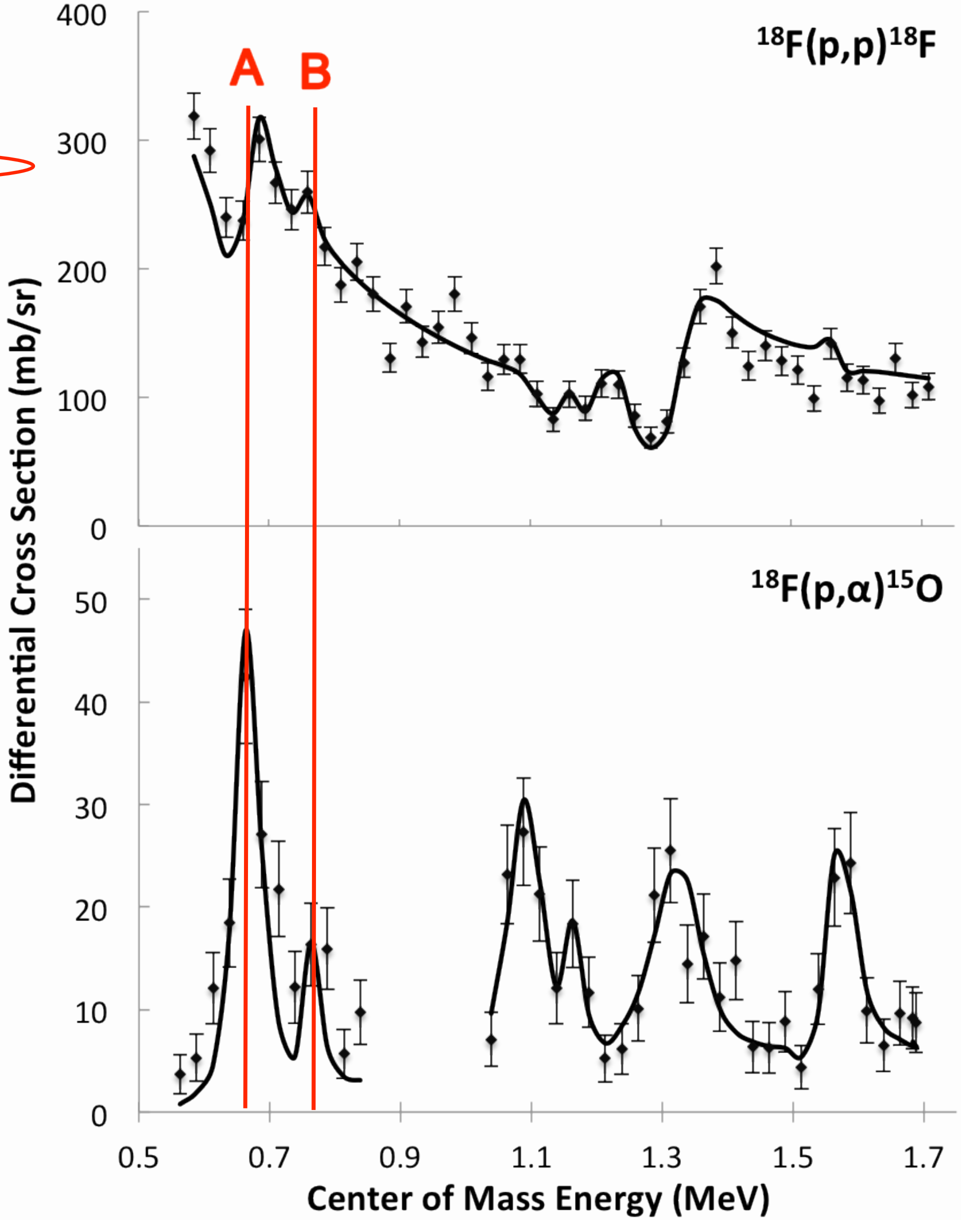
- Well known '665keV' state
- Cross sections scaled to this state



Preliminary Results (B)

	Ecm (MeV)	J^π	Γp(keV)	Γα(keV)	Int
A	0.665	3/2+	15	24	+
B	0.759(20)	3/2+	1.6(5)	2.4(6)	
C	1.096(11)	5/2+	3(1)	54(12)	
D	1.160(34)	3/2+	2.3(6)	1.9(6)	
E	1.219(22)	3/2-	21(3)	0.1(1)	
F	1.335(6)	3/2+	65(8)	26(4)	-
G	1.455(38)	1/2+	55(12)	347(92)	
H	1.571(13)	5/2+	1.7(4)	12(3)	

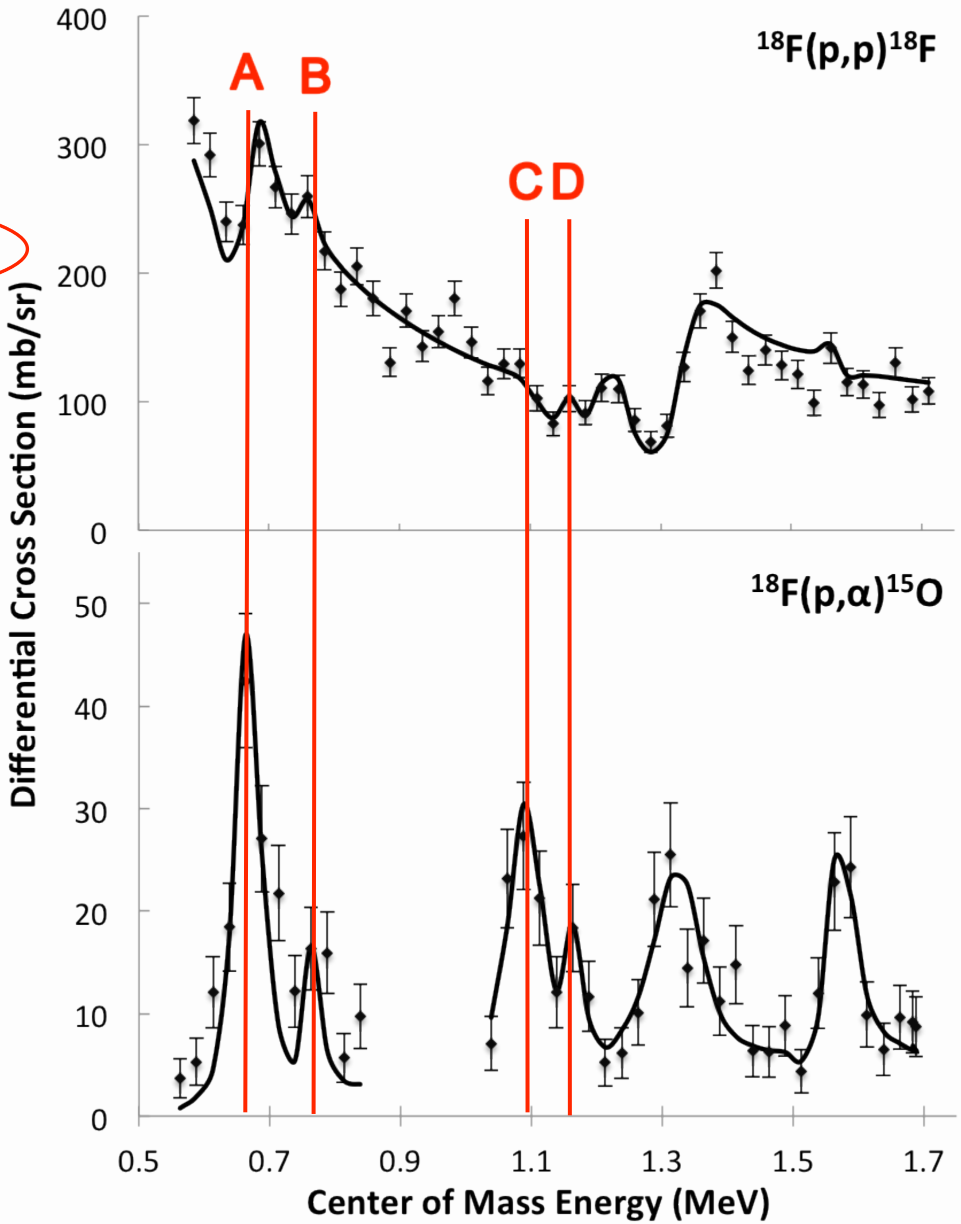
- Reported by Nesaraja/ Dalouzy
- Significantly weaker than Dalouzy
- Consistent in strength with Nesaraja



Preliminary Results (C & D)

	Ecm (MeV)	J^{π}	Γp(keV)	Γα(keV)	Int
A	0.665	3/2+	15	24	+
B	0.759(20)	3/2+	1.6(5)	2.4(6)	
C	1.096(11)	5/2+	3(1)	54(12)	
D	1.160(34)	3/2+	2.3(6)	1.9(6)	
E	1.219(22)	3/2-	21(3)	0.1(1)	
F	1.335(6)	3/2+	65(8)	26(4)	-
G	1.455(38)	1/2+	55(12)	347(92)	
H	1.571(13)	5/2+	1.7(4)	12(3)	

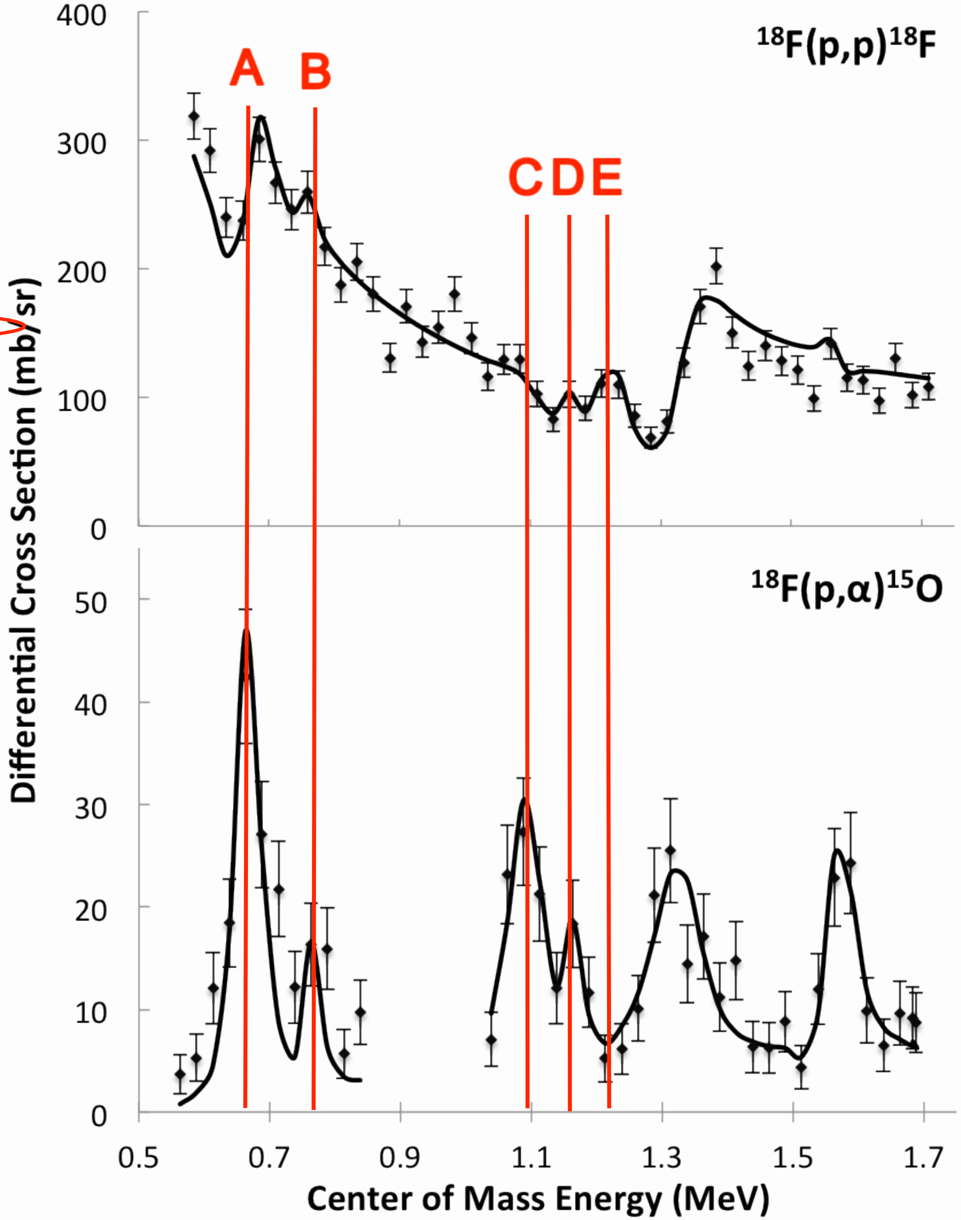
- C reported by Murphy – narrower but current result relatively consistent
- C and D reported by Dalouzy/Nesaraja at different strengths
- C in good agreement in energy



Preliminary Results (E)

	Ecm (MeV)	J^π	Γp(keV)	Γα(keV)	Int
A	0.665	3/2+	15	24	+
B	0.759(20)	3/2+	1.6(5)	2.4(6)	
C	1.096(11)	5/2+	3(1)	54(12)	
D	1.160(34)	3/2+	2.3(6)	1.9(6)	
E	1.219(22)	3/2-	21(3)	0.1(1)	
F	1.335(6)	3/2+	65(8)	26(4)	-
G	1.455(38)	1/2+	55(12)	347(92)	
H	1.571(13)	5/2+	1.7(4)	12(3)	

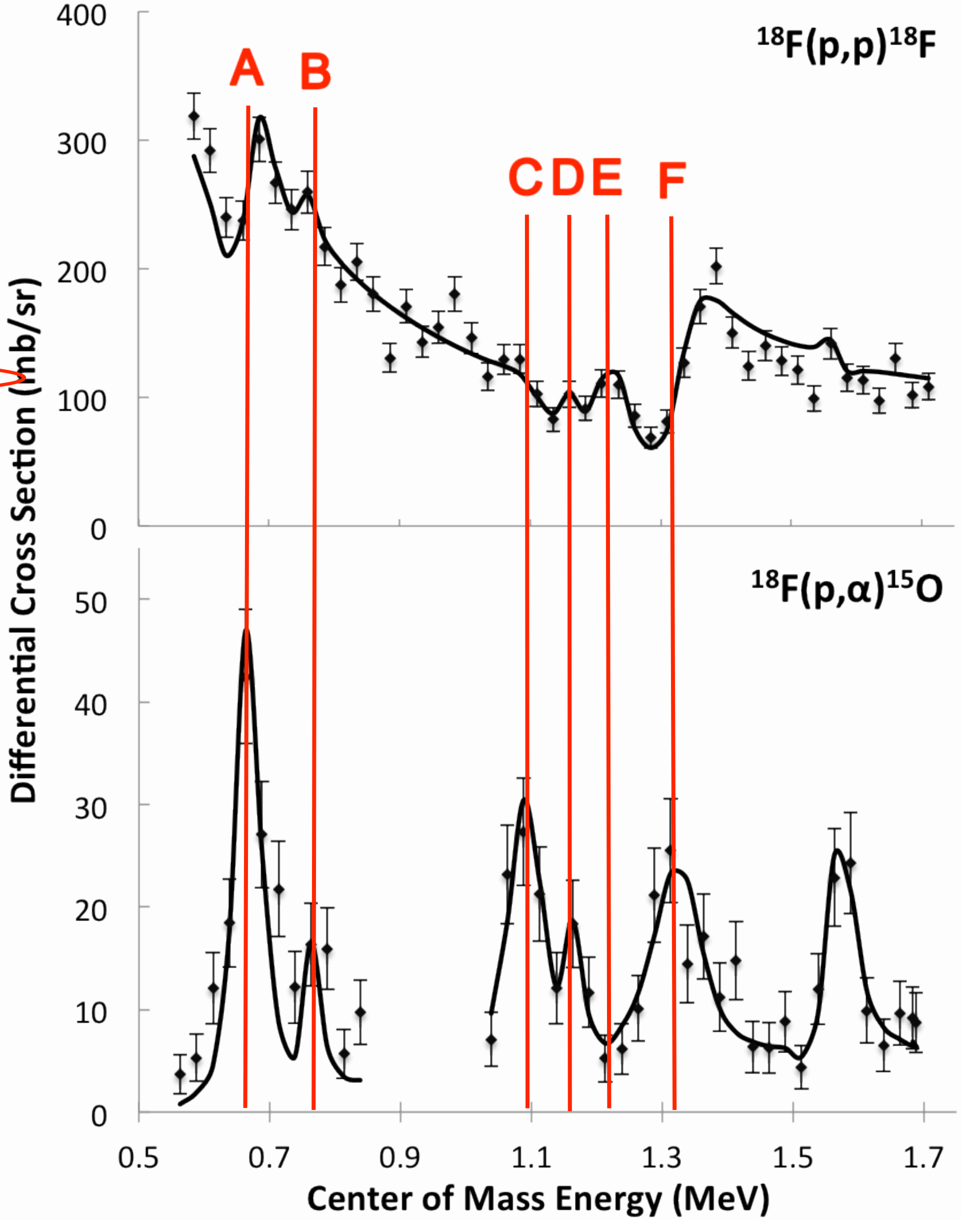
- Previously reported by Nesaraja and Murphy
- Agreement in spin with Murphy
- No agreement in strength
- Required to fit bottom of state F



Preliminary Results (F)

	Ecm (MeV)	Jπ	Γp(keV)	Γα(keV)	Int
A	0.665	3/2+	15	24	+
B	0.759(20)	3/2+	1.6(5)	2.4(6)	
C	1.096(11)	5/2+	3(1)	54(12)	
D	1.160(34)	3/2+	2.3(6)	1.9(6)	
E	1.219(22)	3/2-	21(3)	0.1(1)	
F	1.335(6)	3/2+	65(8)	26(4)	-
G	1.455(38)	1/2+	55(12)	347(92)	
H	1.571(13)	5/2+	1.7(4)	12(3)	

- Observed by Murphy with less strength
- New strength due to strong correlation with state G



Preliminary Results (G)

	Ecm (MeV)	Jπ	Γp(keV)	Γα(keV)	Int
A	0.665	3/2+	15	24	+
B	0.759(20)	3/2+	1.6(5)	2.4(6)	
C	1.096(11)	5/2+	3(1)	54(12)	
D	1.160(34)	3/2+	2.3(6)	1.9(6)	
E	1.219(22)	3/2-	21(3)	0.1(1)	
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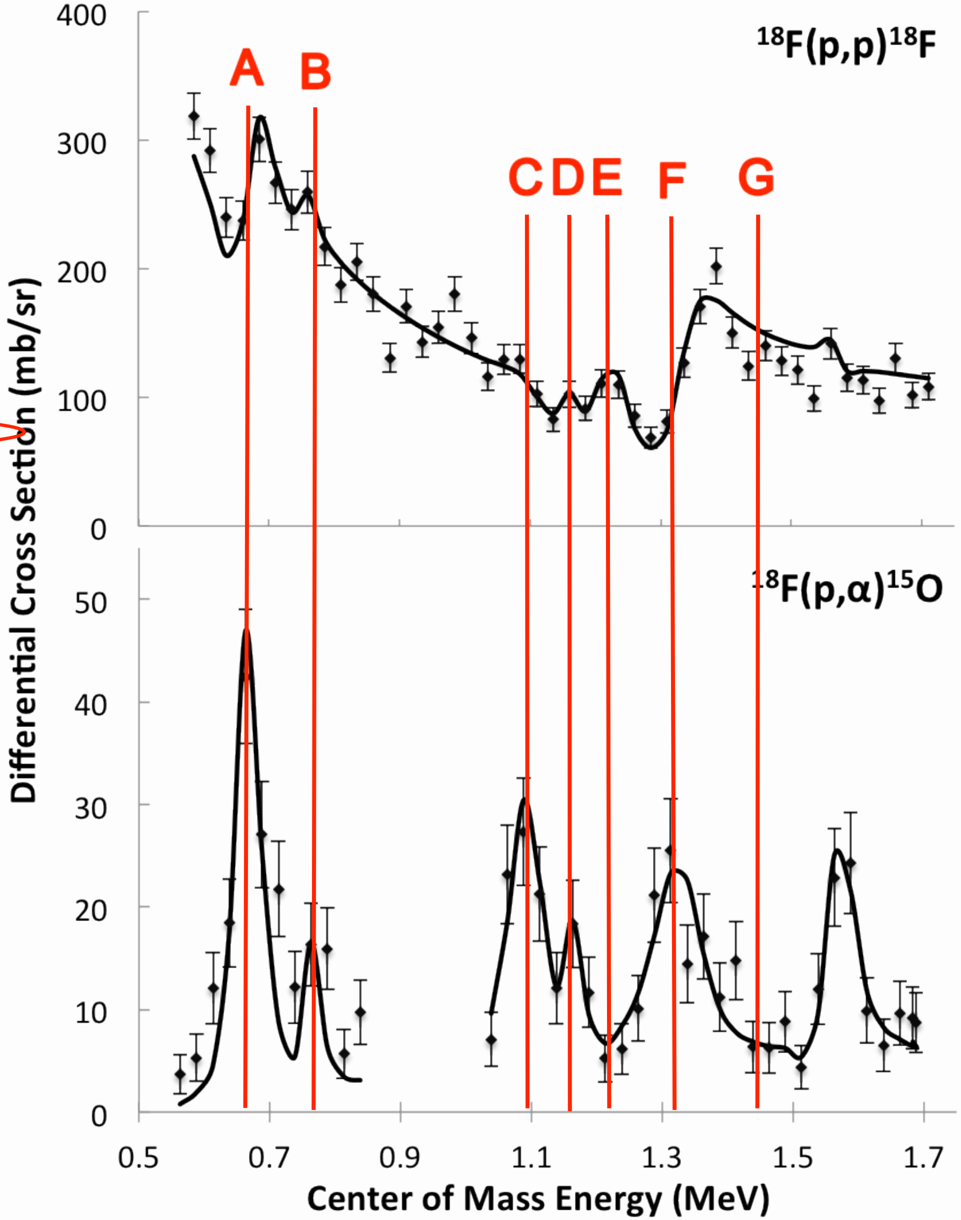
G	1.455(38)	1/2+	55(12)	347(92)	
H	1.571(13)	5/2+	1.7(4)	12(3)	

- Predicted broad $1/2^+$ state?
- Stay tuned…



Preliminary Results (H)

	Ecm (MeV)	J^π	Γp(keV)	Γα(keV)	Int
A	0.665	3/2+	15	24	+
B	0.759(20)	3/2+	1.6(5)	2.4(6)	
C	1.096(11)	5/2+	3(1)	54(12)	
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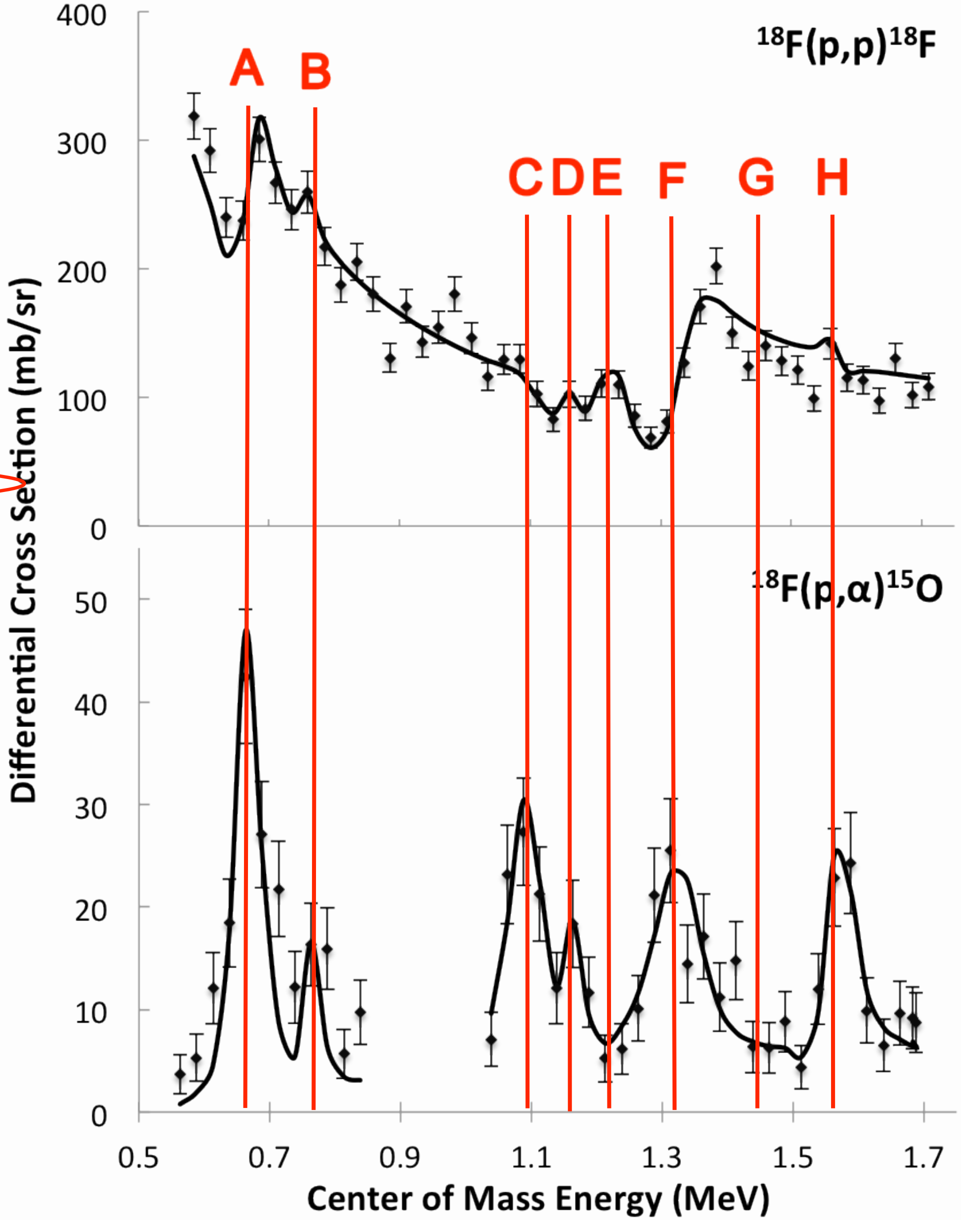
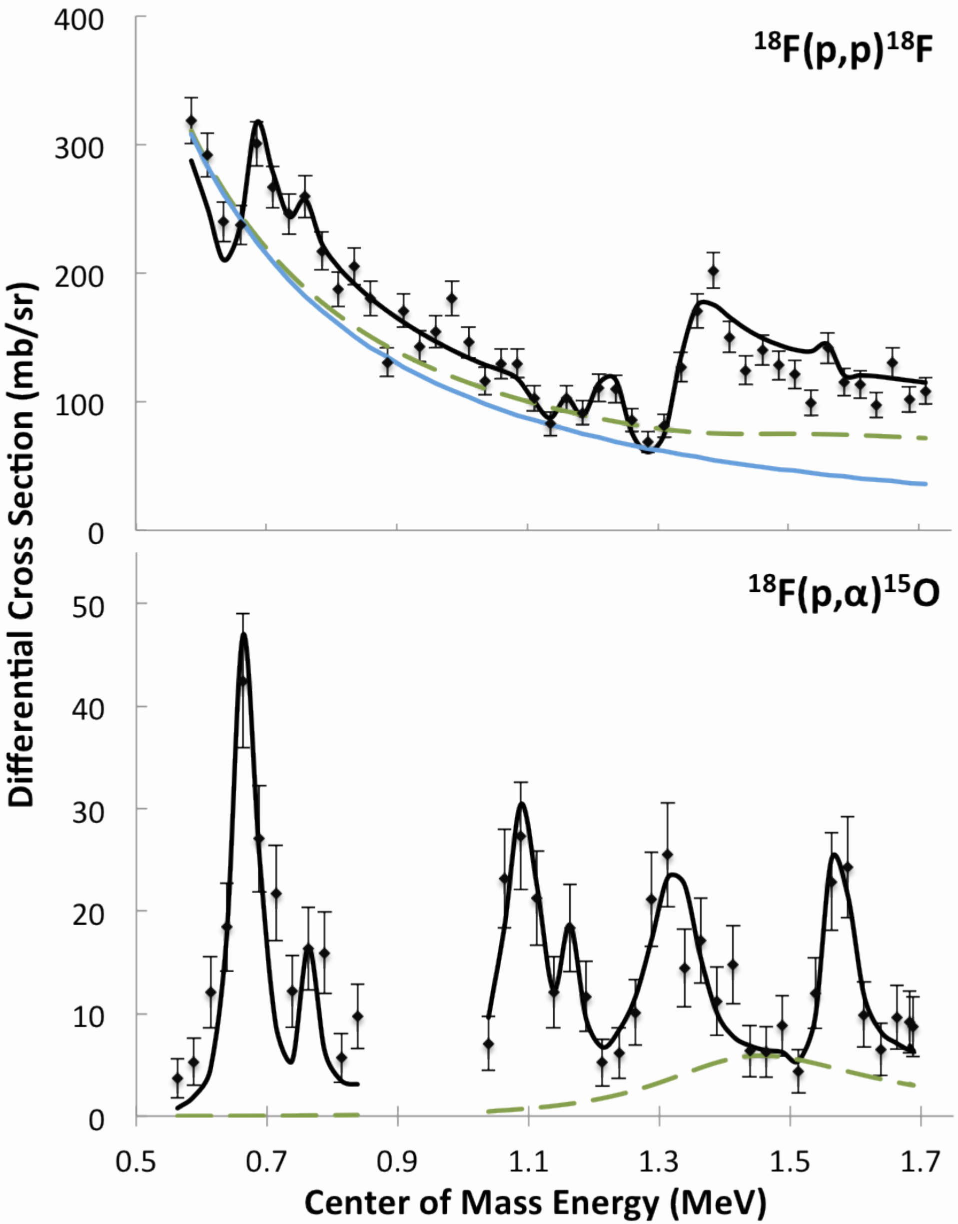
- Observed by Dalouzy (alternative π) and Murphy (alternative J)
- Dalouzy J unambiguous but π inferred
- Current data strongly favours $J^\pi=5/2^+$ at consistent strengths

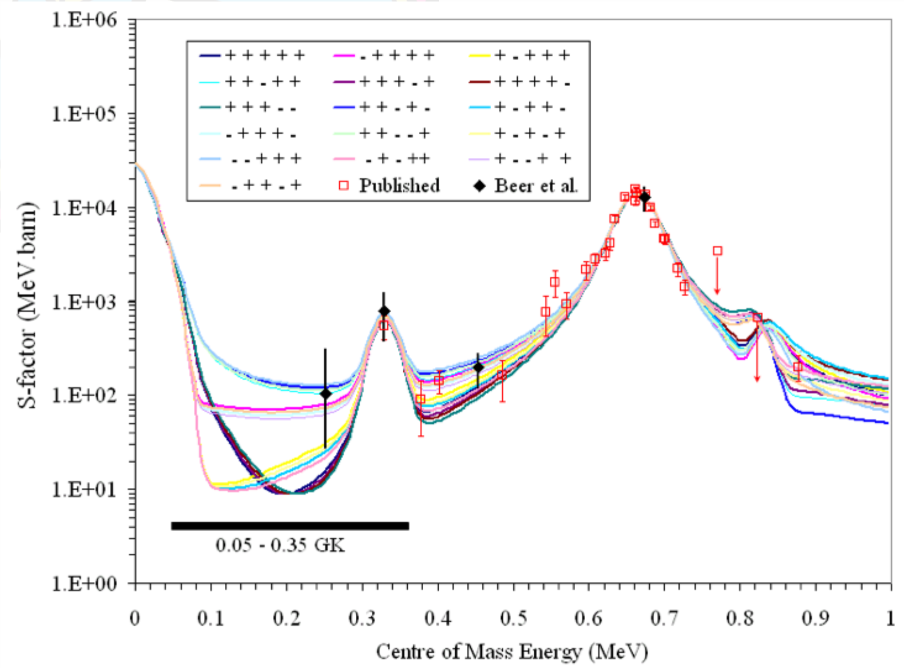


Dufour/Descouvemont State??

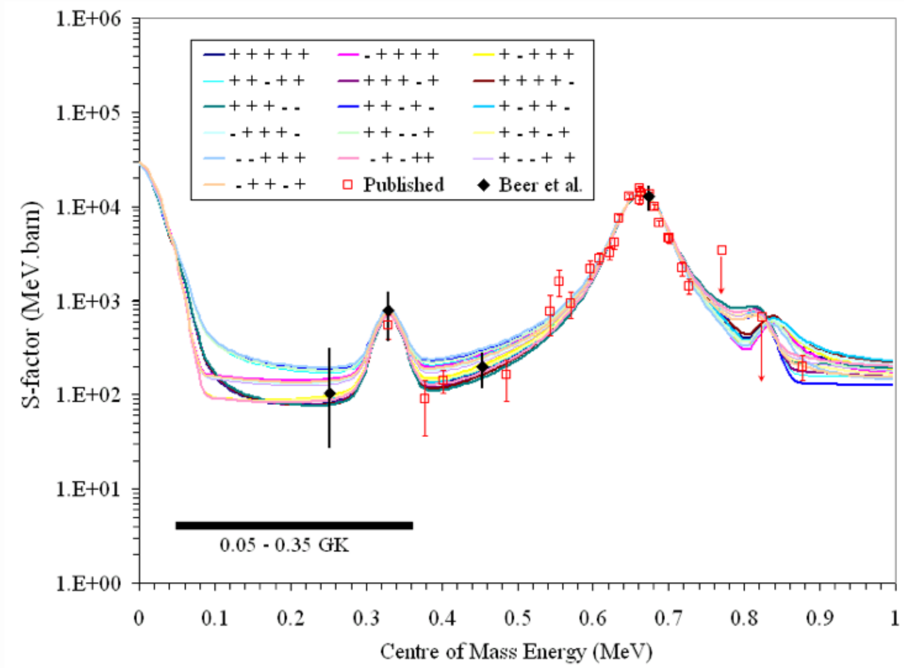
- Candidate observed at E_{CM}=1.455MeV (G)
- ~ factor of 2 *narrower* than predicted in proton channel
- ~ a factor of 2 *broader* than predicted in alpha channel
- But consistent in total width (402(93)keV) with Dalouzy (292(107)keV
- Broad state **<u>is 'required'</u>** to fit to data



Impact



Beer PRC(R) 2011 *et al.* Fig 3.
(not incl. predicted $1/2^+$ states)



Including $1/2^+$ states (parameters from Dufour & Descouvemont)

Narrows uncertainty in astrophysical S-Factor

Conclusions

- New data obtained in study of astrophysically important $^{18}F(p,\alpha)^{15}O$ reaction

- New work finds candidate for a recently predicted $1/2^+$ state, consistent with previous measurement

- Precision of extracted parameters is constrained by limited statistics

- Strongly support the proposal of F. de Olivera Santos for repeat of Dalouzy experiment, with scattered protons detected in VAMOS

Collaborators

- University of Edinburgh:
  - A. S. Murphy
  - T. Davinson
  - P. J. Woods
- University of York:
  - A. M. Laird
  - J. R. Brown
- Orsay:
  - N. de Sereville
- Tractebel:
  - C. Angulo
- LPC Caen
  - N. L. Achouri
- GANIL
  - F. de Oliveira Santos
  - P. Ujic
  - O. Kamalou
- ORNL:
  - S. T. Pittman
- ULB:
  - Pierre Descouvemont

References

Dufour and Descouvemont, Nucl. Phys. A 785 (2007) 381–394

Dalouzy *et al.*, Phys. Rev. Lett. 102, 162503 (2009)

Murphy *et al.*, Phys. Rev. C 79, 058801 (2009)

Nesaraja *et al.* Phys. Rev. C 75, 055809 (2007)

C.E.Beer *et al.*, Phys. Rev. C**83**, 042801(R) (2011)

Thank you