The Structure of the Hoyle State and its 2^+ Partner State in ^{12}C

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1. **Why 2^+_2 in ^{12}C?**
   The Structure of the Hoyle State
   Stellar Helium Burning (Formation of ^{12}C)

2. **The HIγS Facility: Real Photons $2 < E\gamma < 40$ MeV**
   $I\gamma \sim 5\text{x}10^8$ γ/sec
   $\Delta E \sim 2\%$

3. **The Detector: Optical Readout TPC (O-TPC)**

Beauty in Physics, May 14, 2012

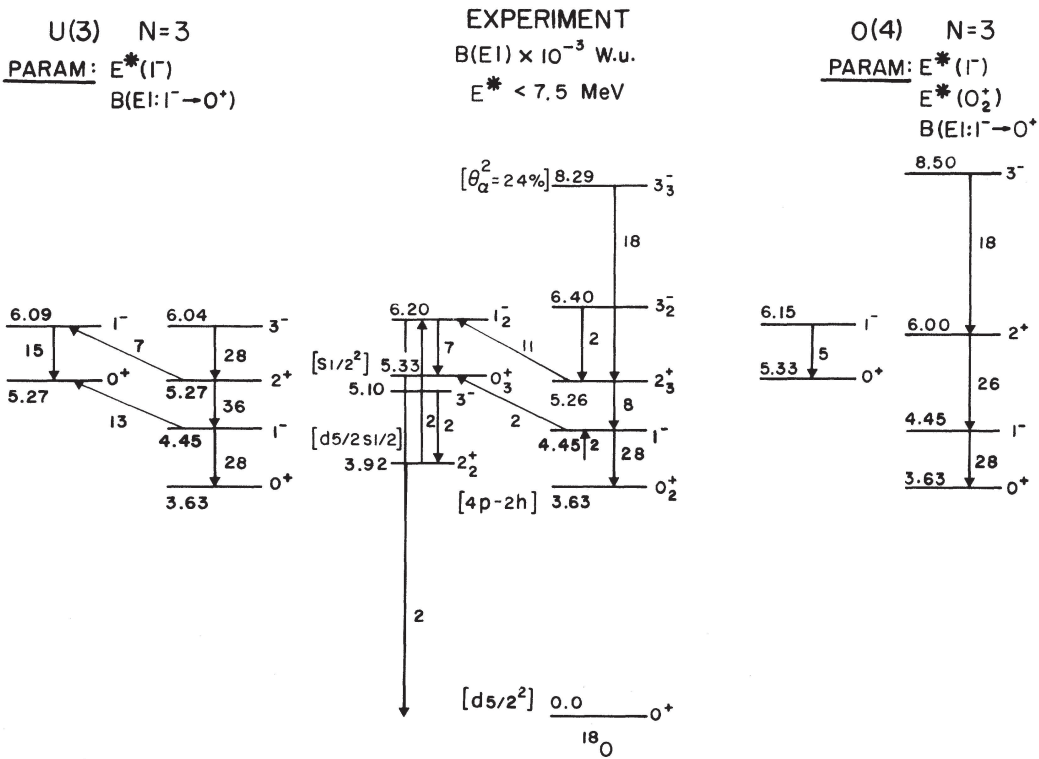
Happy Birthday Franco

Beware of What
We Wish For You
As it May (Still) Happen

M. Gai, M. Ruscev, D.A. Bromley and J.W. Olness; Phys. Rev. C43(1991)2127

(Low Lying) Dipole Collectivity

Vibron Model



Name: Gerald Brown
(please print)

1. I will/will not attend the May 13-14, 1989 Reunion. *(will circled)*
2. I will require hotel accommodations (please check):
   May 12 ___ May 13 ✓ May 14 ___ Other (specify)
   Single ___ Twin ___ Double ✓ Other (specify)
3. I will/will not be accompanied by my spouse. *(will circled)*
4. I/We will/will not attend the dinner on Saturday night. *(I/We will circled)*
   Seating Limited
5. I should like to learn more about (Gai) the following aspects of Yale physics
   a) Is the 1− transition in ^{18}O really weaker than the coexistence model predicted? (Gai + Bromley PRL)

PLEASE RETURN THIS CARD BY FEBRUARY 1st IF POSSIBLE

I still miss the days
of the colorful papers
of Brown & Green.

Moshe Gai

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Stony Brook,
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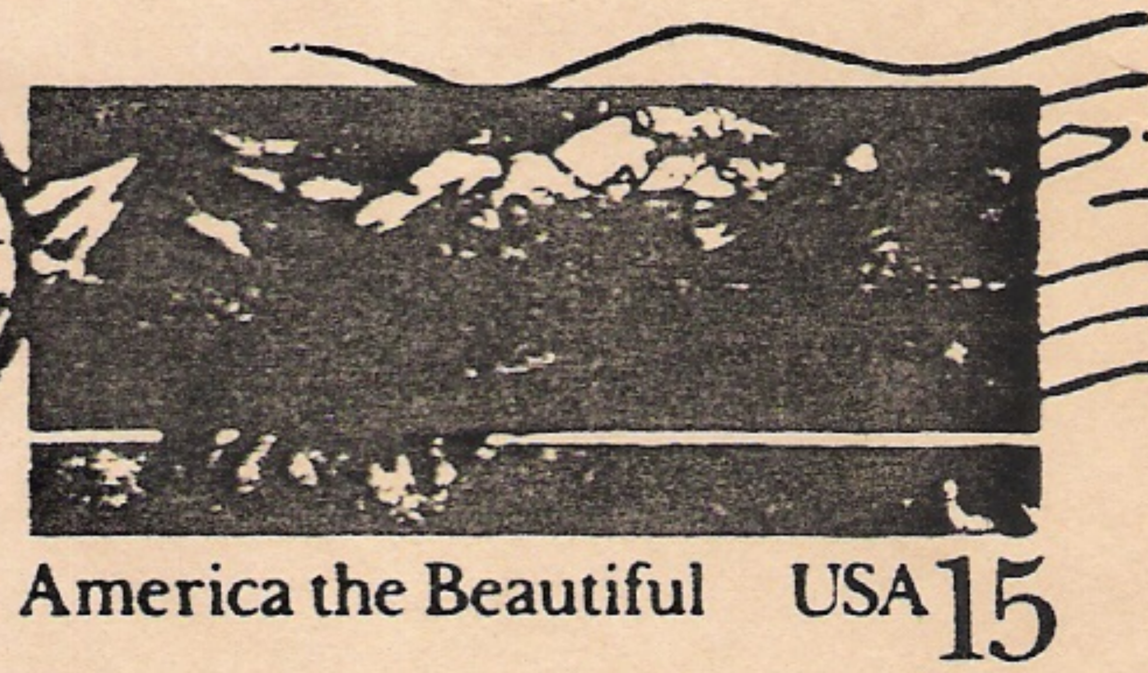
LONG ISLAND NY 117
PM
FEB
1989



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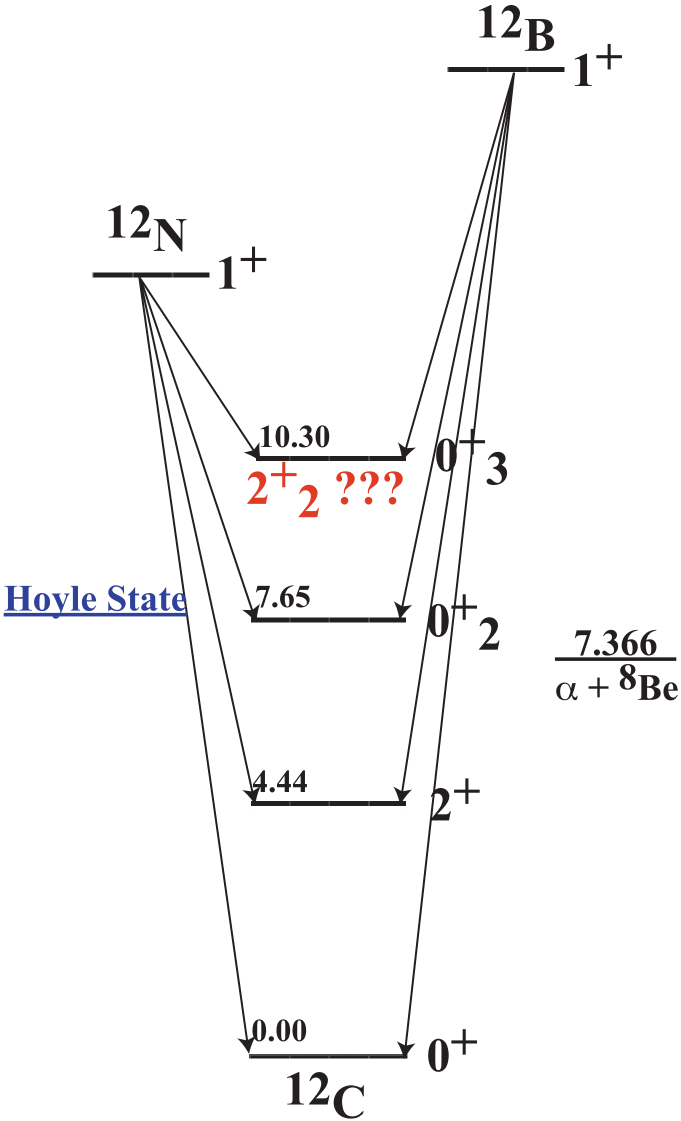
New Haven, Connecticut 06511-8167

The Laboratory for Nuclear Science At Avery Point



Why Search For 2^+_2 in ^{12}C

The Structure of the Hoyle State, 1953?

1. Deformed three alpha state?
   Rotational band built on it, Morinaga, 1956?
   Linear Alpha Chain, Brink 1966?
2. Spherical, Low N limit of BEC?
   Alpha Condensate?
   Efimov State?

3. 2^+_2 Predicted e.g. Descouvemont & Baye at 9.11 MeV; B(E2: $2^+ \rightarrow$ gs) = 2 Wu

4. 2^+_2 Included in NACRE compliation x15 at T > 3 GK (Beyond Hoyle)

5. 2^+_2 Not Observed in beta-decay

6. 2^+_2 Observed in $^{12}C(p,p')$ and $^{12}C(\alpha,\alpha')$

Hoyle State (7.654 MeV): Low N Limit of Alpha-Condensate in ^{12}C

T. Yamada, Y. Funaki, H. Horiuchi, G. Röpke, P. Schuck, and A. Tohsaki

arXiv.org > nucl-th > arXiv:1103.3940v1

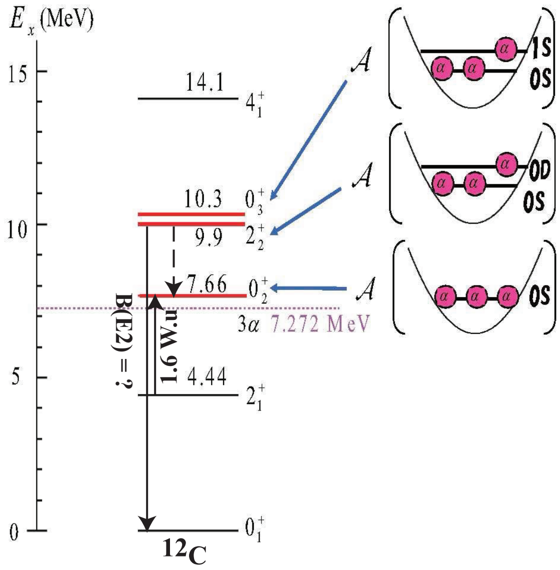


Fig. 15 (Color online) Theoretical interpretation of the 0_2^+, 2_2^+ and 0_3^+ states.

Descouvemont and Baye; PRC36(1987)54

Deforemed 2^+_2 at 9.11 MeV in ^{12}C

B(E2: $2^+_2 \rightarrow$ gs) = 0.5 - 2.6 W.u.

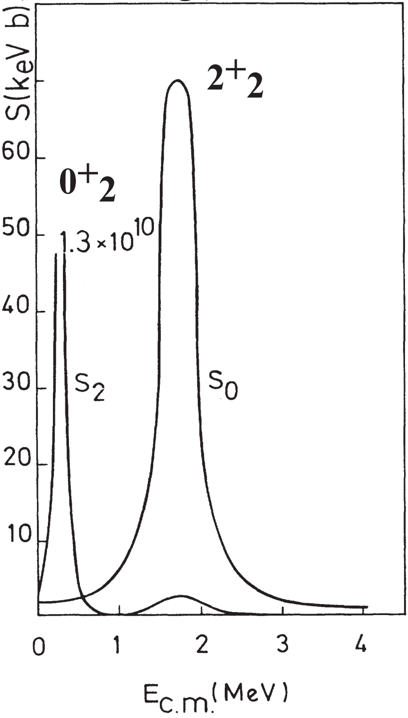
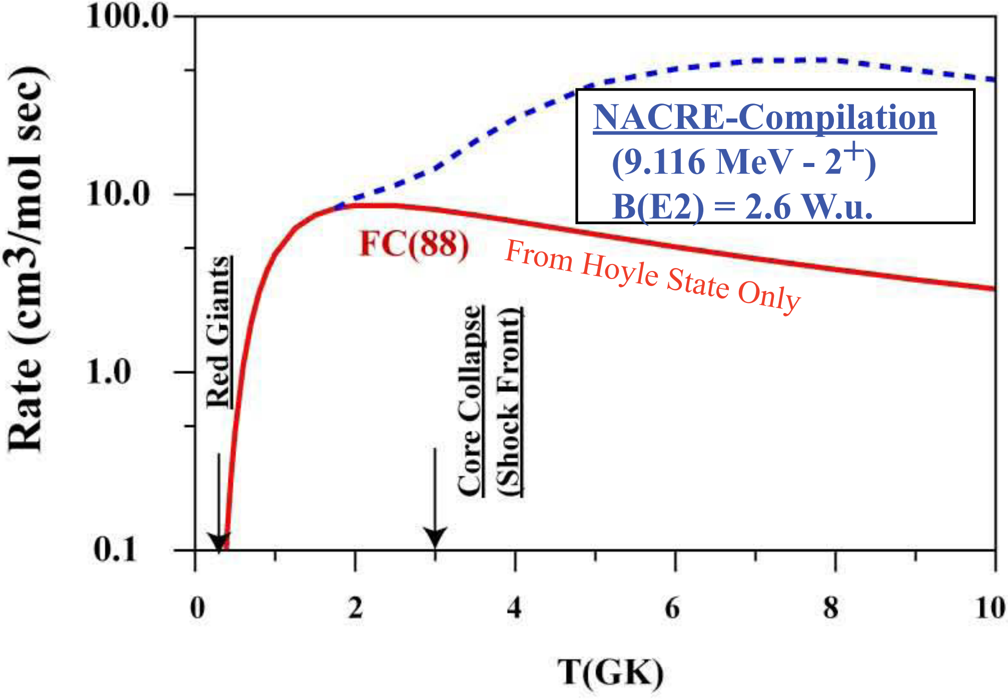
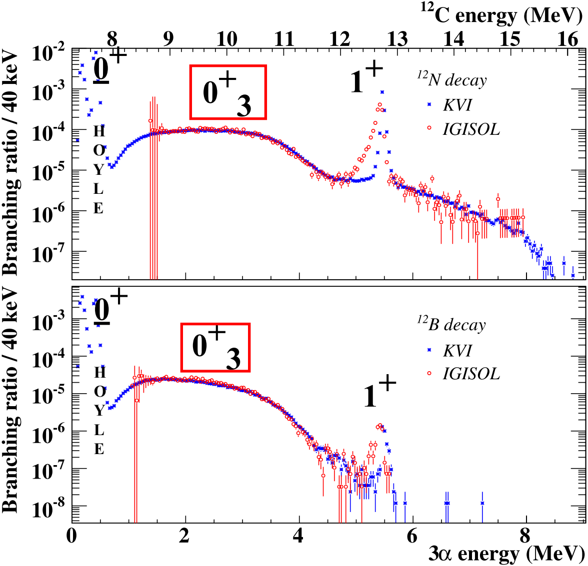


FIG. 2. $^8Be(\alpha,\gamma)^{12}C$ astrophysical S factors for transitions towards the 0_1^+ and 2_1^+ states of ^{12}C.

Triple Alpha Burning Rate: $^{8}Be(\alpha,\gamma)^{12}C$

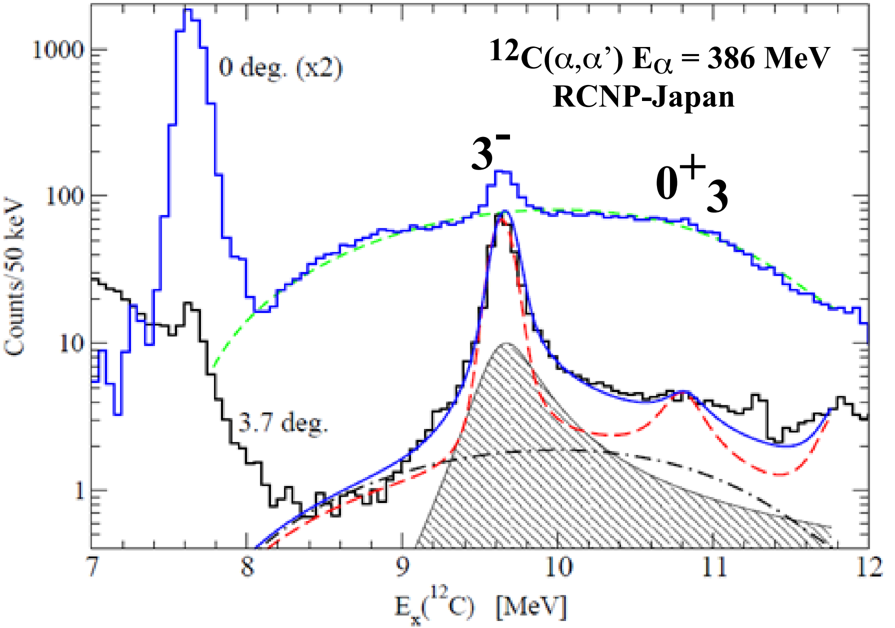


S. Hyldegaard *et al.;* Phys. Let B678(2009)459.



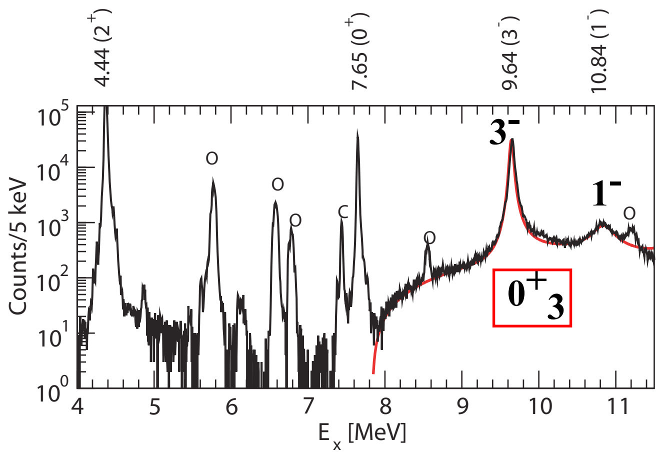
Identification of the 2^+ excitation of the ^{12}C Hoyle-state

M. Itoh,[1] M. Freer,[2,*] T. Kawabata,[3] H. Fujita,[4] H. Akimune,[5] Z. Buthelezi,[6] J. Carter,[7] R. W. Fearick,[8] S. V. Förtsch,[6] M. Fujiwara,[4] U. Garg,[9] K. Kawase,[10] T. Murakami,[3] B. K. Nayak,[9] R. Neveling,[6] S. M. Perez,[6] P. Papka,[11] H. Sakaguchi,[4] Y. Sasamoto,[12] F. D. Smit,[6] J. A. Swartz,[11] S. Terashima,[13] M. Uchida,[14] I. Usman,[7] Y. Yasuda,[4] M. Yosoi,[4] and J. Zenihiro[4]



^{12}C(p,p')

M. Freer *et al*



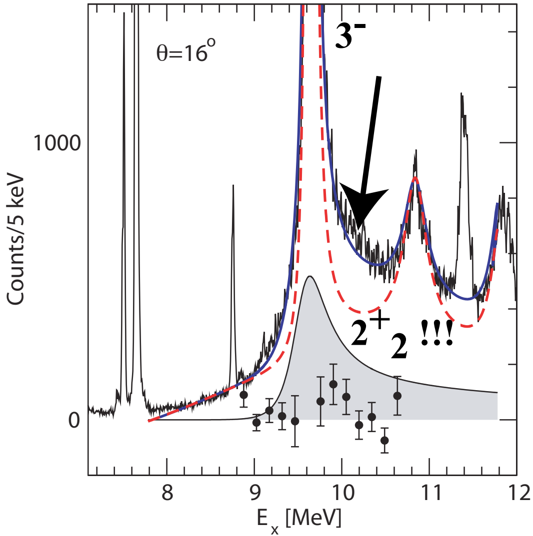
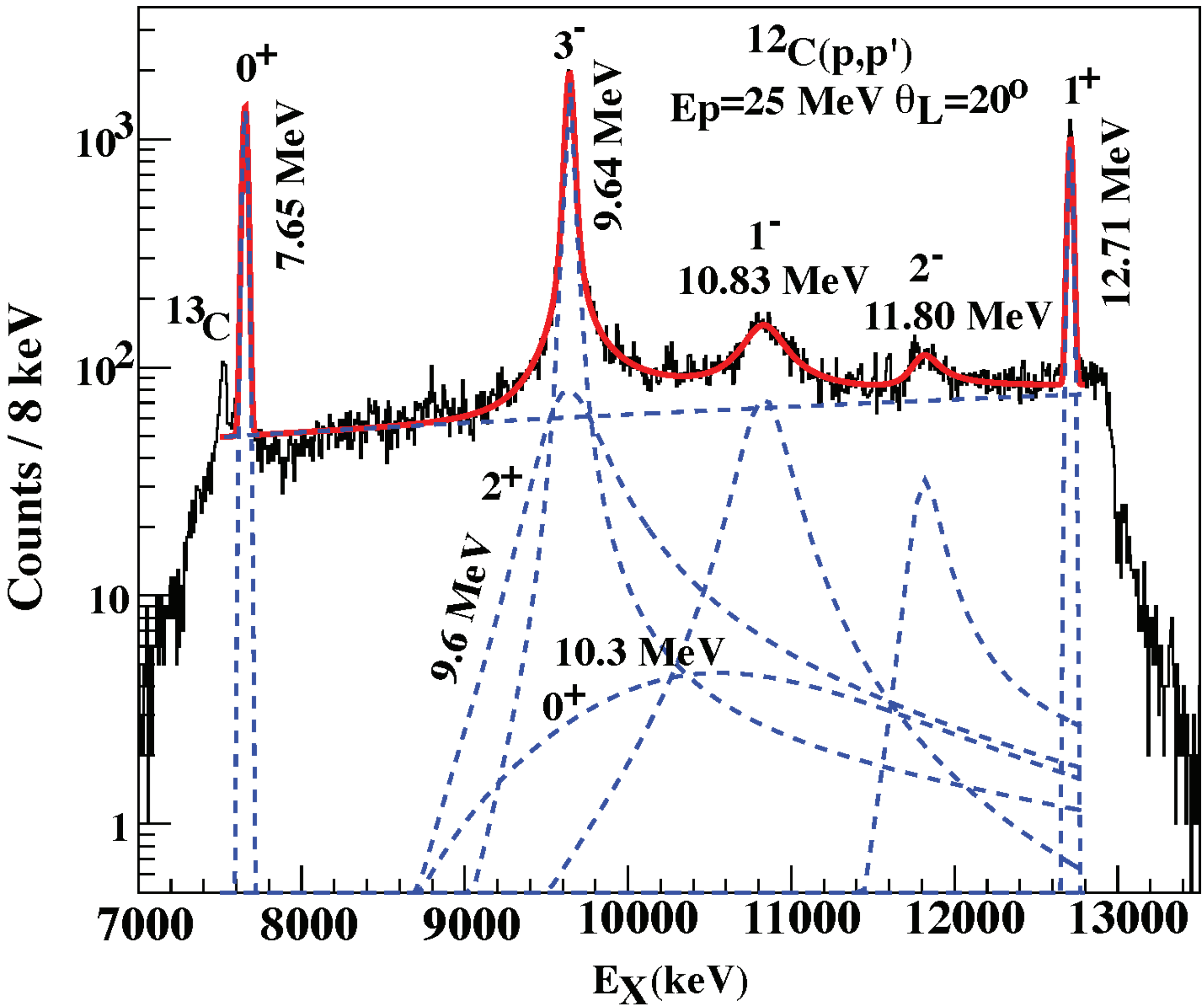


FIG. 2. (Color online) ^{12}C excitation energy spectrum measured at θ_{lab} = 28?. Contaminants from ^{16}O (O) and ^{13}C (C) are indi-

UConn-Yale, M.W. Zimmerman *et al.* Phys. Rev. C 84, 027304 (2011)



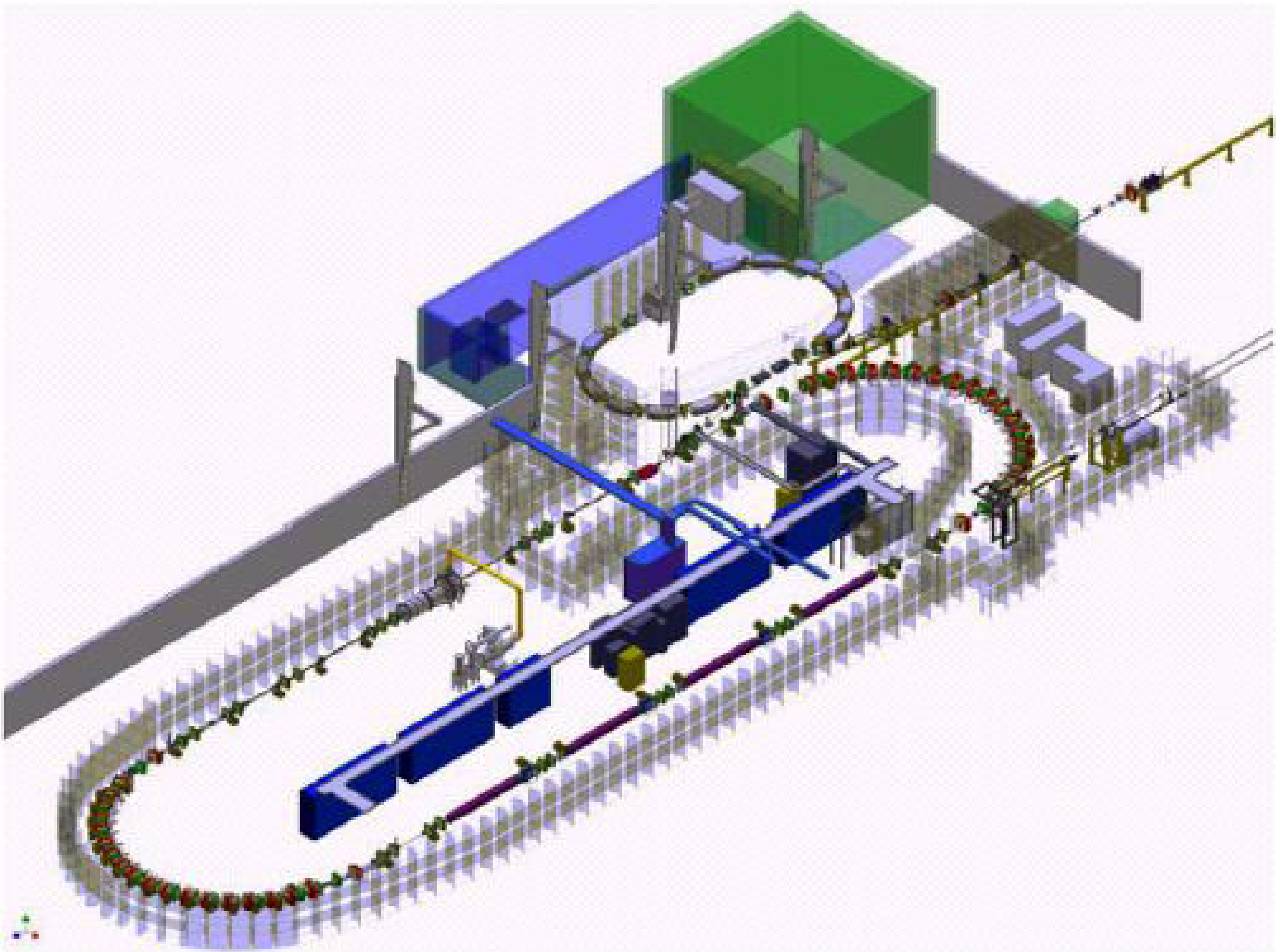
Beta Decay Experiments
$^{12}C(p,p')$ Experiments

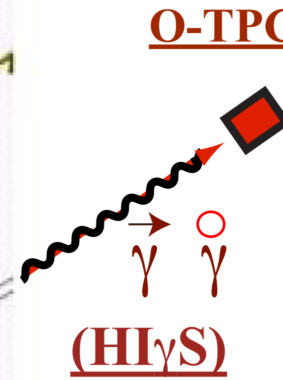
Plagued with Background from 0^+_3

Gamma Beams are Ideal: No $0^+(gs) \rightarrow 0^+$

O-TPC Ideal Detector for Gamma Beams

DFELL & HIGS





WEIZMANN INSTITUTE OF SCIENCE

PTB

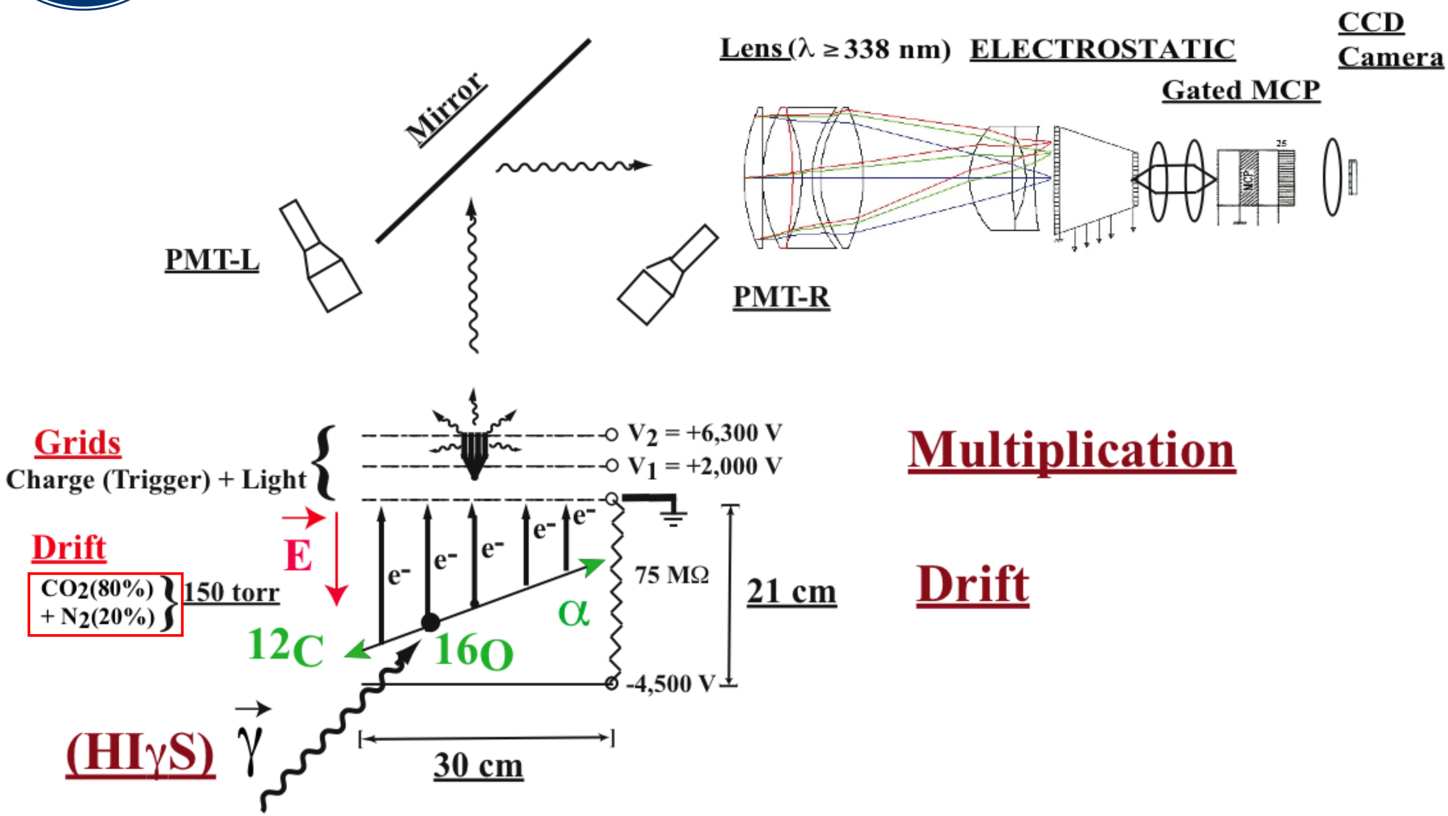
YALE

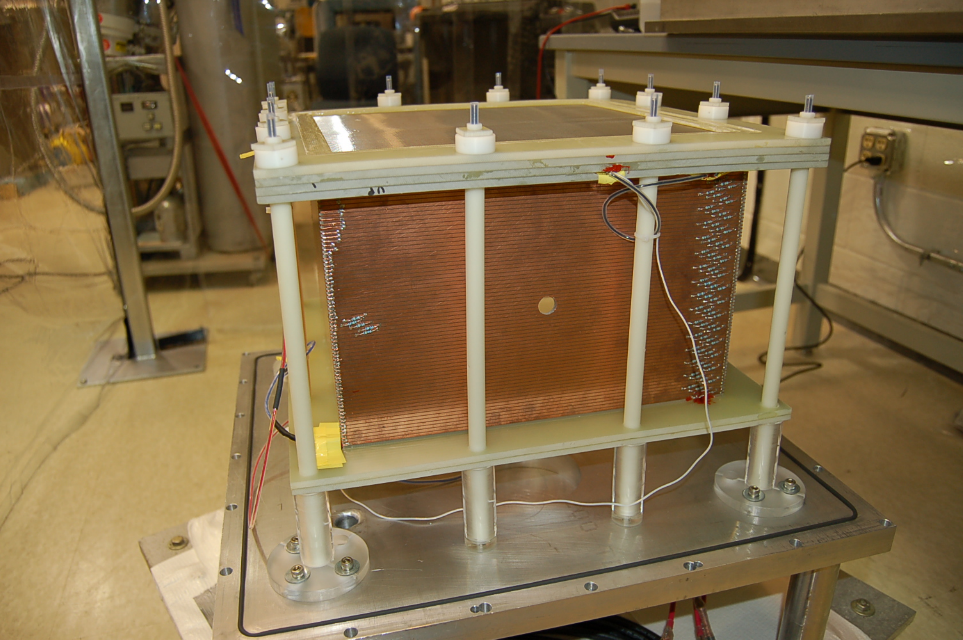
UCL

UNIVERSITY OF CONNECTICUT 1881

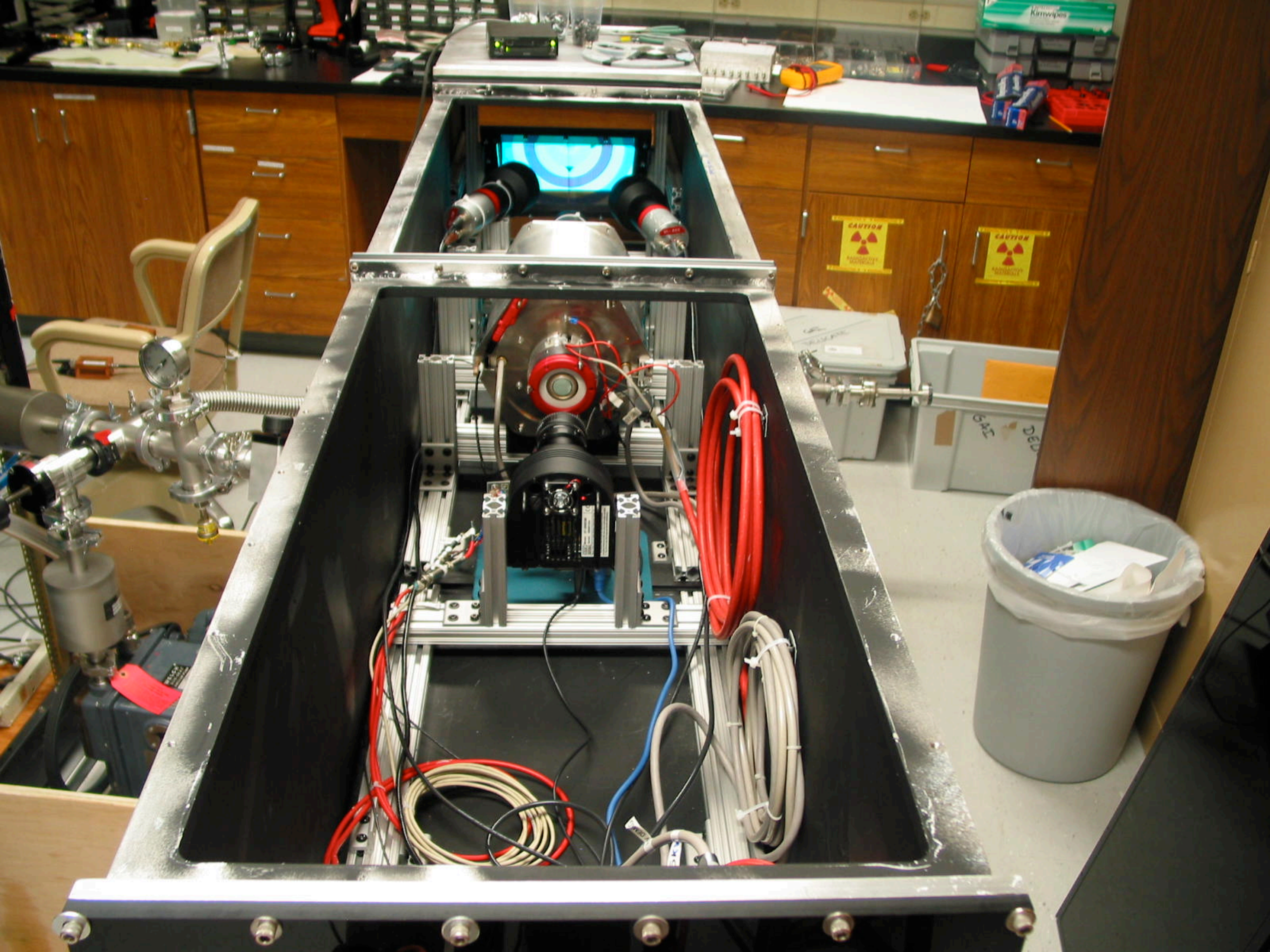
TUNL

Opto-Electronic Chain






UCONN
Ziploc
MANUALS
Kimberly Clark


Kimwipes
CAUTION
CAUTION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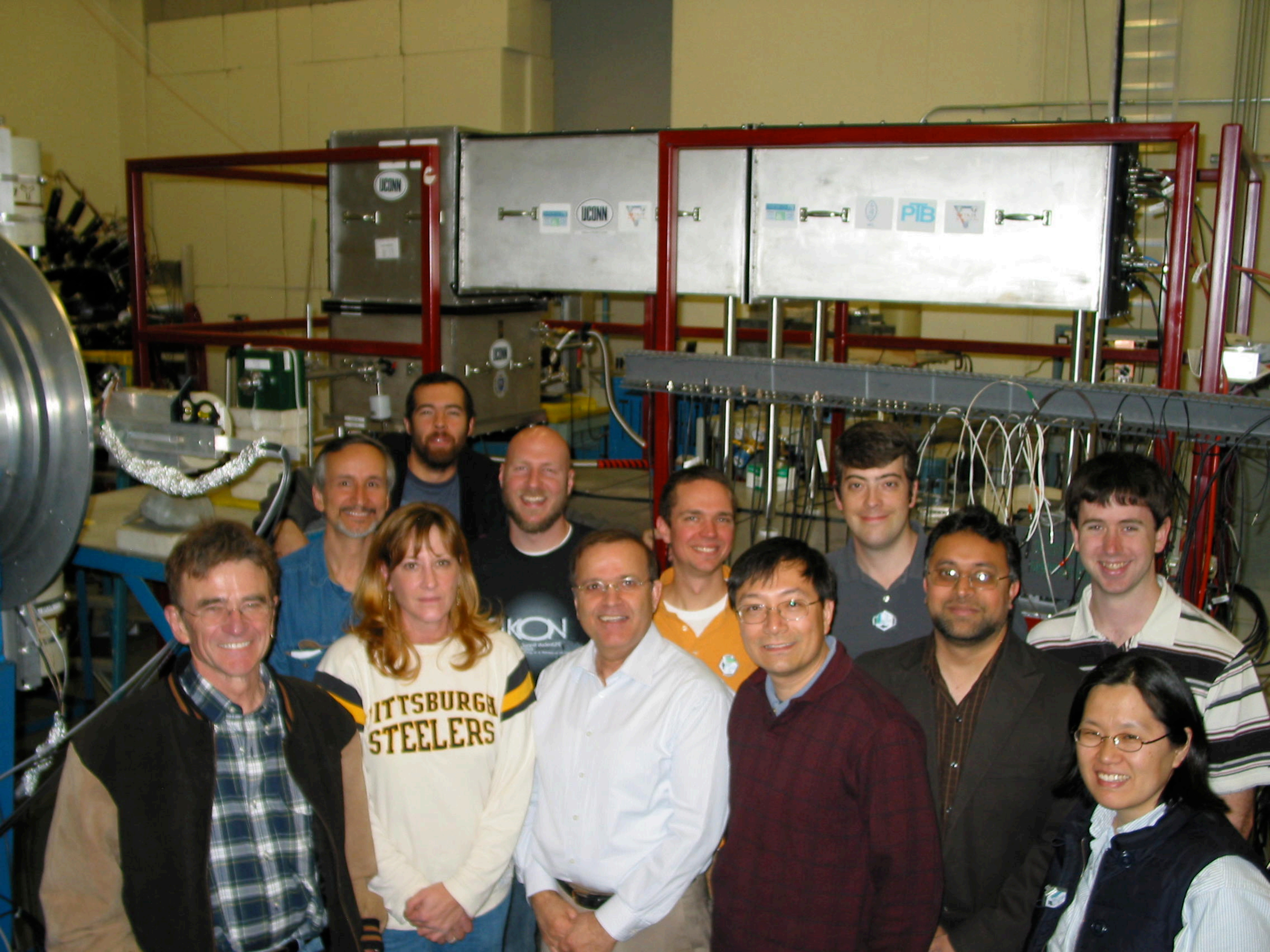
UCONN
HUSKY
UCONN
TOPCO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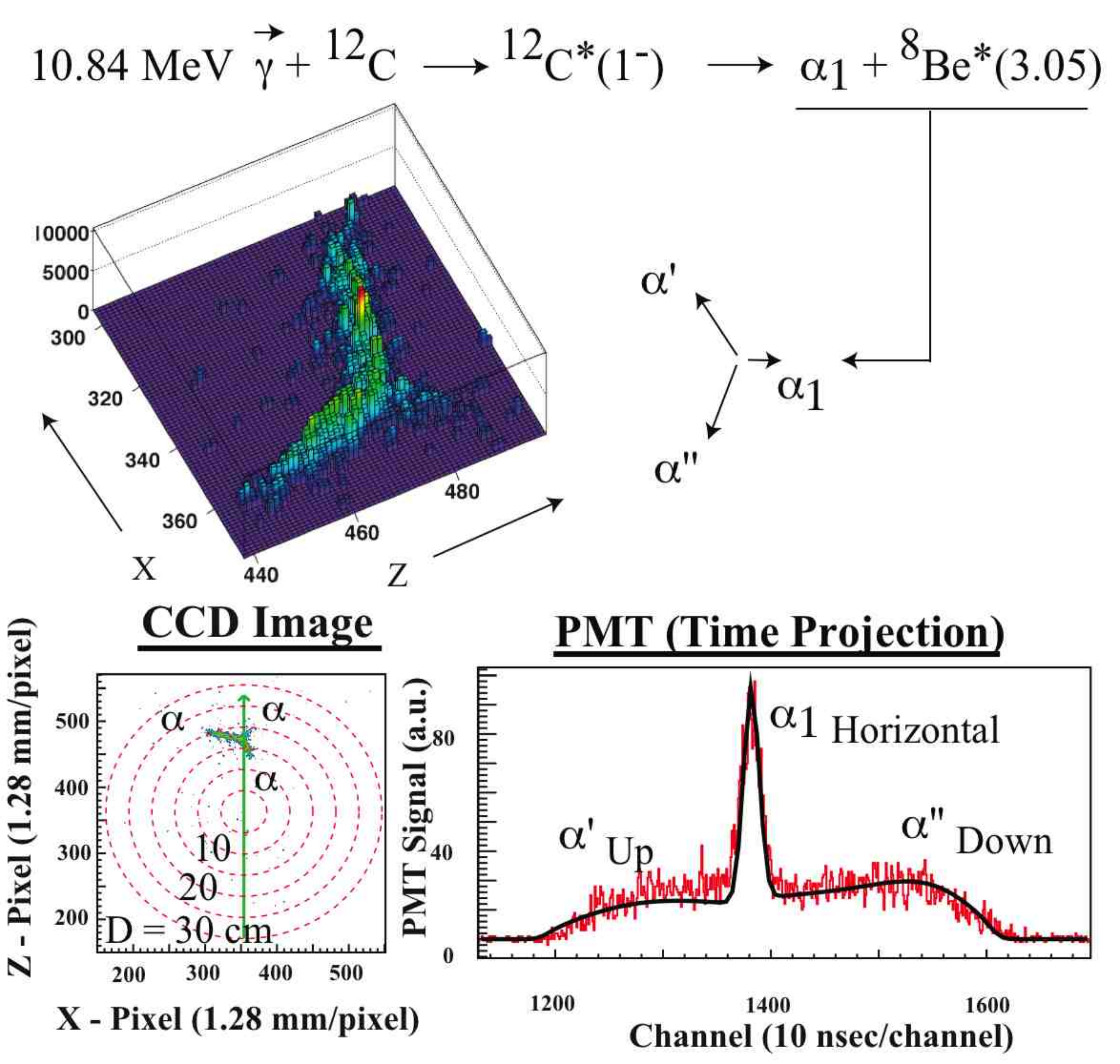
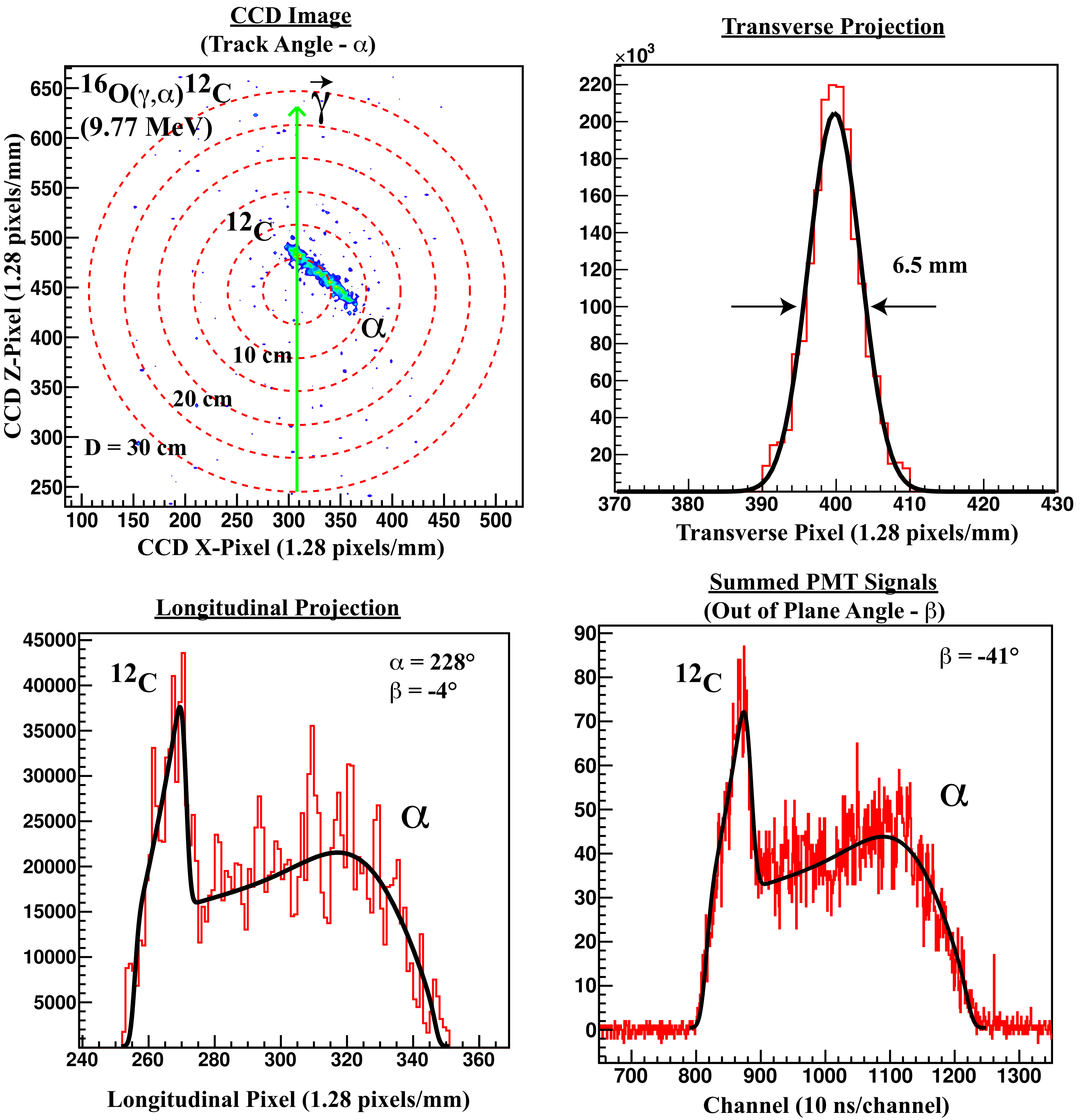
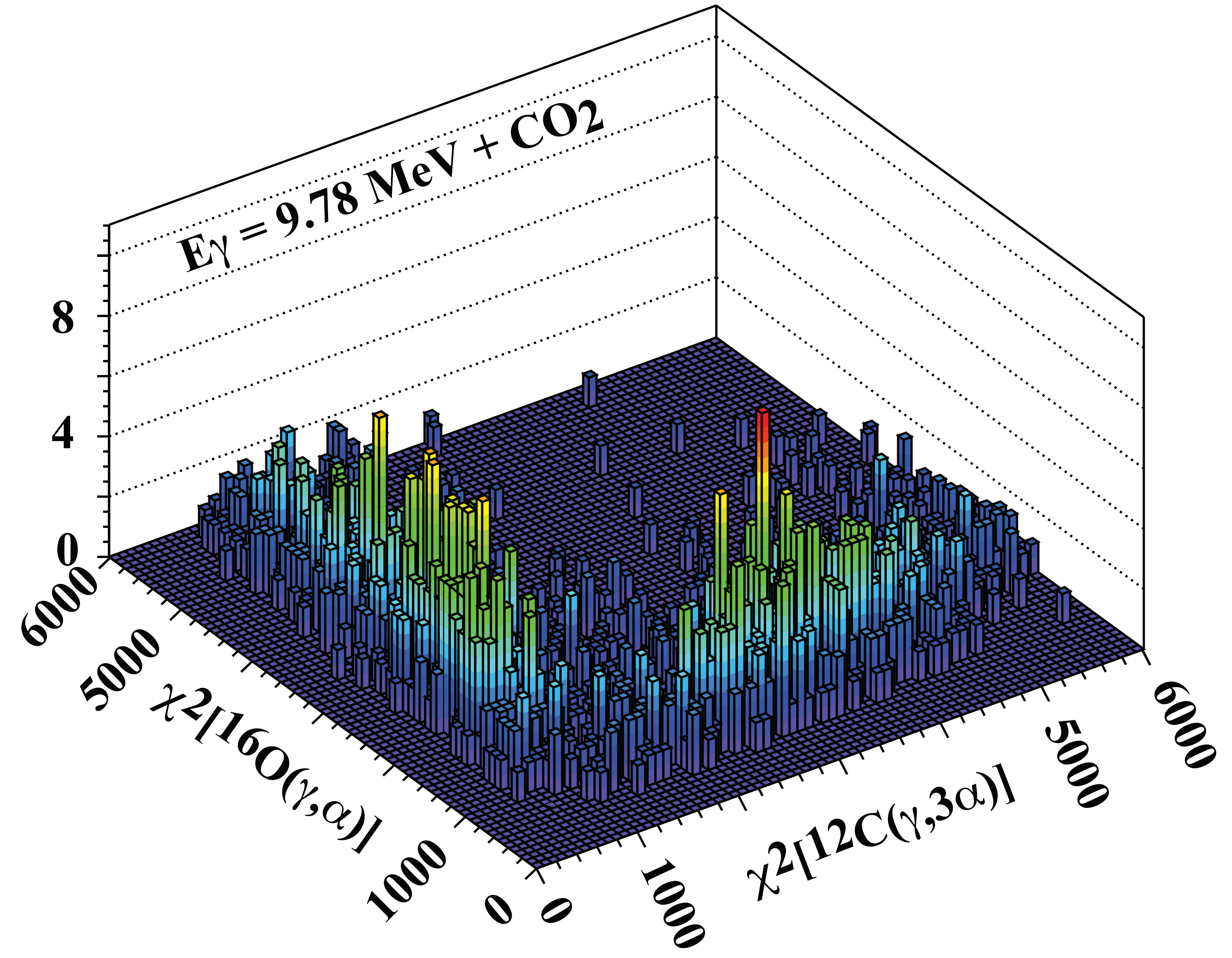
UCONN
PTB
ITTSBURGH
STEELERS



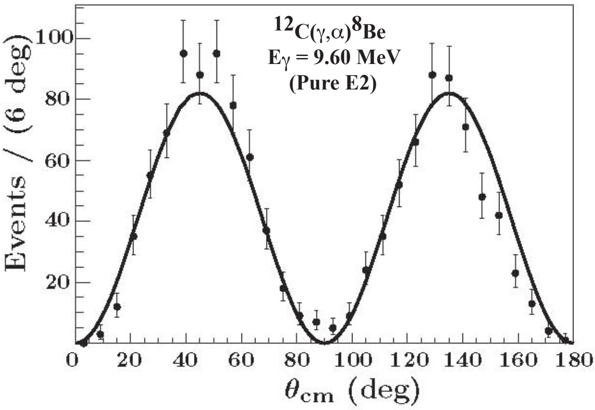
10.84 MeV $\vec{\gamma}$ + ^{12}C → ^{12}C*(1$^-$) → α_1 + ^{8}Be*(3.05)
10000
5000
0
300
320
340
360
440
460
480
X
Z
α'
α1
α''
CCD Image
Z - Pixel (1.28 mm/pixel)
500
400
300
200
α
α
α
10
20
D = 30 cm
200
300
400
500
X - Pixel (1.28 mm/pixel)
PMT (Time Projection)
PMT Signal (a.u.)
80
40
0
α1 Horizontal
α' Up
α'' Down
1200
1400
1600
Channel (10 nsec/channel)



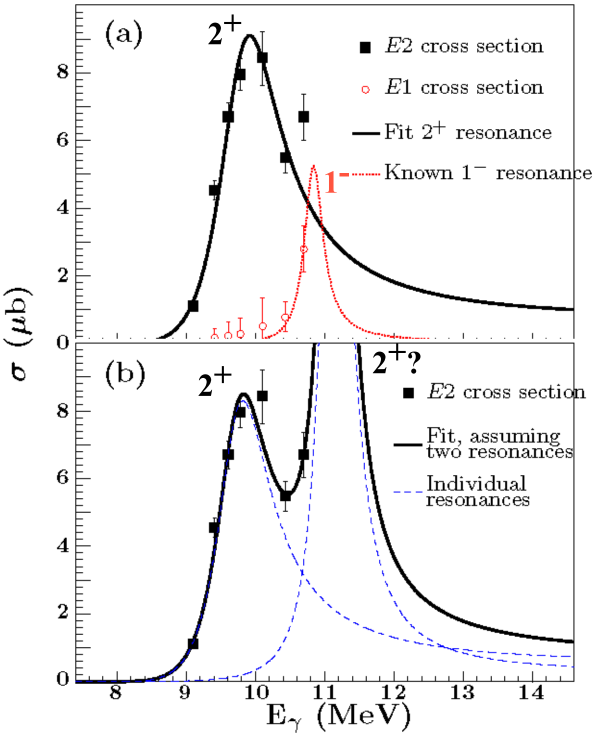
CCD Image
(Track Angle - α)
16O(γ,α)12C
(9.77 MeV)
γ
12C
α
10 cm
20 cm
D = 30 cm
CCD Z-Pixel (1.28 pixels/mm)
CCD X-Pixel (1.28 pixels/mm)
Transverse Projection
×10^3
6.5 mm
Transverse Pixel (1.28 pixels/mm)
Longitudinal Projection
12C
α = 228°
β = -4°
α
Longitudinal Pixel (1.28 pixels/mm)
Summed PMT Signals
(Out of Plane Angle - β)
12C
β = -41°
α
Channel (10 ns/channel)



Eγ = 9.78 MeV + CO2
8
4
0
6000
5000
1000
0
χ2[16O(γ,α)]
0
1000
5000
6000
χ2[12C(γ,3α)]



$^{12}C(\gamma,\alpha)^{8}Be$
E_γ = 9.60 MeV
(Pure E2)
Events / (6 deg)
θ_{cm} (deg)
0
20
40
60
80
100
120
140
160
180

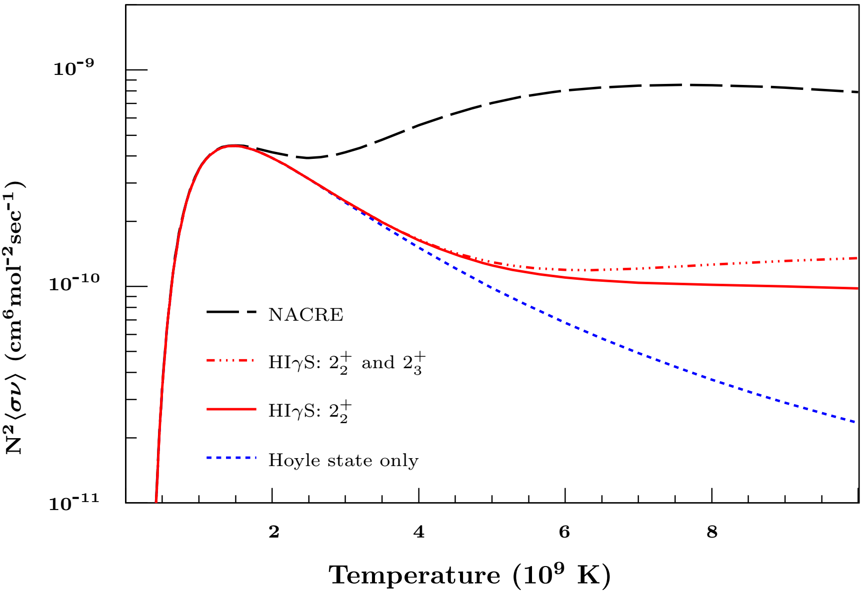


(a)
2+
E2 cross section
E1 cross section
Fit 2+ resonance
1-
Known 1− resonance
(b)
2+
2+?
E2 cross section
Fit, assuming two resonances
Individual resonances
σ (μb)
Eγ (MeV)

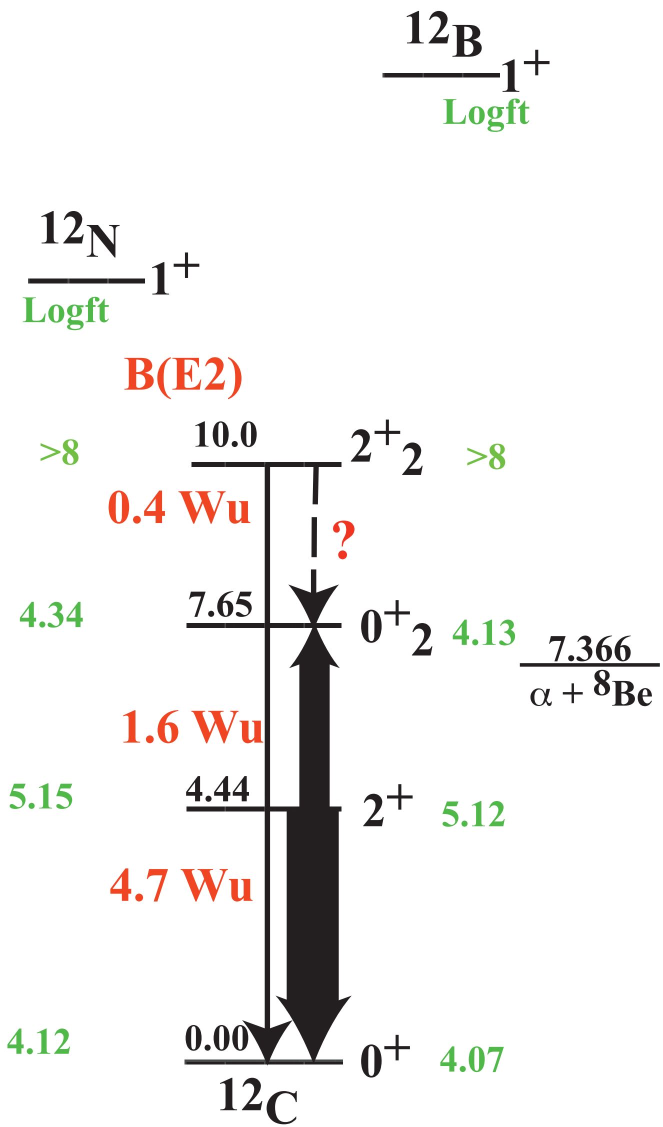
TABLE I. HIγS measurements of 2^+ resonance parameters. Results are shown from fits to both a single resonance as well as two 2^+ resonances. $\gamma_\alpha^2/\gamma_W^2$ is the ratio of the reduced alpha width to the Wigner limit [39]. B($E2$) values are for transitions from the 2^+ state to the ground state.

	$E_{\rm res}$ (MeV)	Γ_α(res) (keV)	$\Gamma_{\gamma 0}$(res) (meV)	$\gamma_\alpha^2/\gamma_W^2$	B($E2$) (W.u.)
Single Res.	10.11(4)	907(58)	63(5)	0.72(7)	0.44(4)
Two Res.	9.98(5)	759(61)	47(5)	0.67(10)	0.35(4)
	11.16[a]	430[a]	103(31)	0.16[a]	0.44(14)

[a] Resonance parameters for a possible 2^+ at 11.16 MeV were taken from [27].



10^{-9}
10^{-10}
10^{-11}
$N^2\langle\sigma\nu\rangle$ ($cm^6 mol^{-2} sec^{-1}$)
2
4
6
8
Temperature (10^9 K)
NACRE
HIγS: 2_2^+ and 2_3^+
HIγS: 2_2^+
Hoyle state only



Conclusions

1. Is Logft Correct?
   (2^+_2 missed in β - decay?)
2. B(E2: $2^+_2 \rightarrow 0^+_2$) = ?
   100 W.u. BR ~ 10^{-7}

The O-TPC at HIγS Collaboration:

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A.H. Young
W.R. Zimmerman

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G.F. Burkhard
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UHartford:
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GCSU:
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NGCSU:*
R.M. Prior
M.C. Spraker

* Supported by US Department of Energy

** Supported by the American Committee on Weizman Yale-Weizmann Collaboration

*** In Kind Contribution, Optical Readout System