The Triangular $\mathcal{D}_{3h}$ Symmetry of ^{12}C

Moshe Gai
UConn and Yale
http://astro.uconn.edu
moshe.gai@yale.edu

1. Happy (Semi) Retirement Peter
2. The Algebraic Cluster Model (ACM)
3. $\mathcal{D}_{3h}$ Symmetry of ^{12}C
3. The O-TPC Detector
4. Measurements With Gamma-Beams (HIγS at Duke, ELI-NP in Bucharest)
5. Outlook

Reflections on the atomic nucleus, Liverpool, July 29, 2015

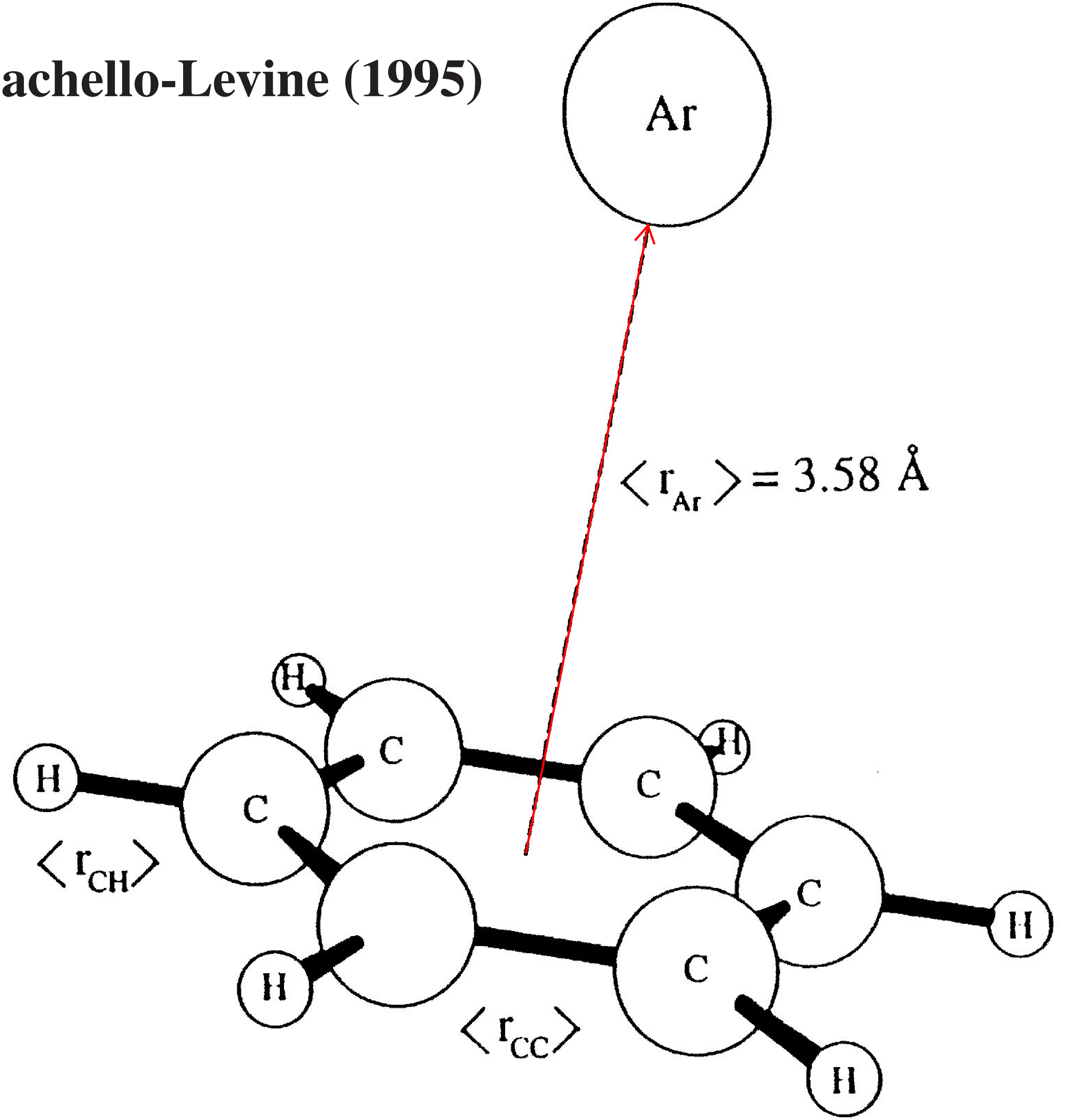
A (Personal) Brief Review of The Cluster Model

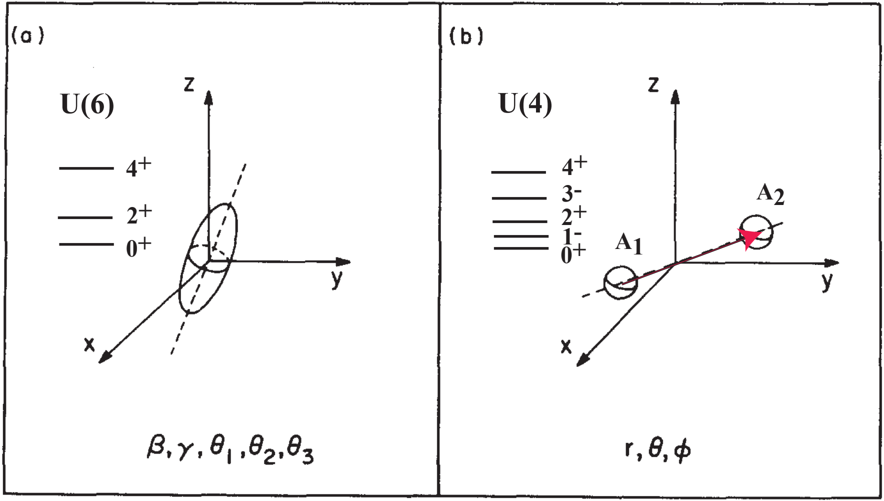
Did the era of Nuclear Physics Start in 1932?

(James Chadwick discovery of the neutron)

1930	Gamow's Theory of Alpha-Decay
1931	Gamow's Apha-Cluster Model of Nuclei
1937	Hafstadt and Teller
	John Wheeler
…	
1953	Fred Hoyle (^{12}C)
1959	Wildermuth (^{8}Be)
	D. Allan Bromley ($^{12}C + {}^{12}C$)
	"Nuclear Molecule"
…	
1966	David Brink (^{20}Ne…)
2000	Bijker and Iachello/
	"New Chapter of the Cluster Model"/ anonymous

Iachello-Levine (1995)





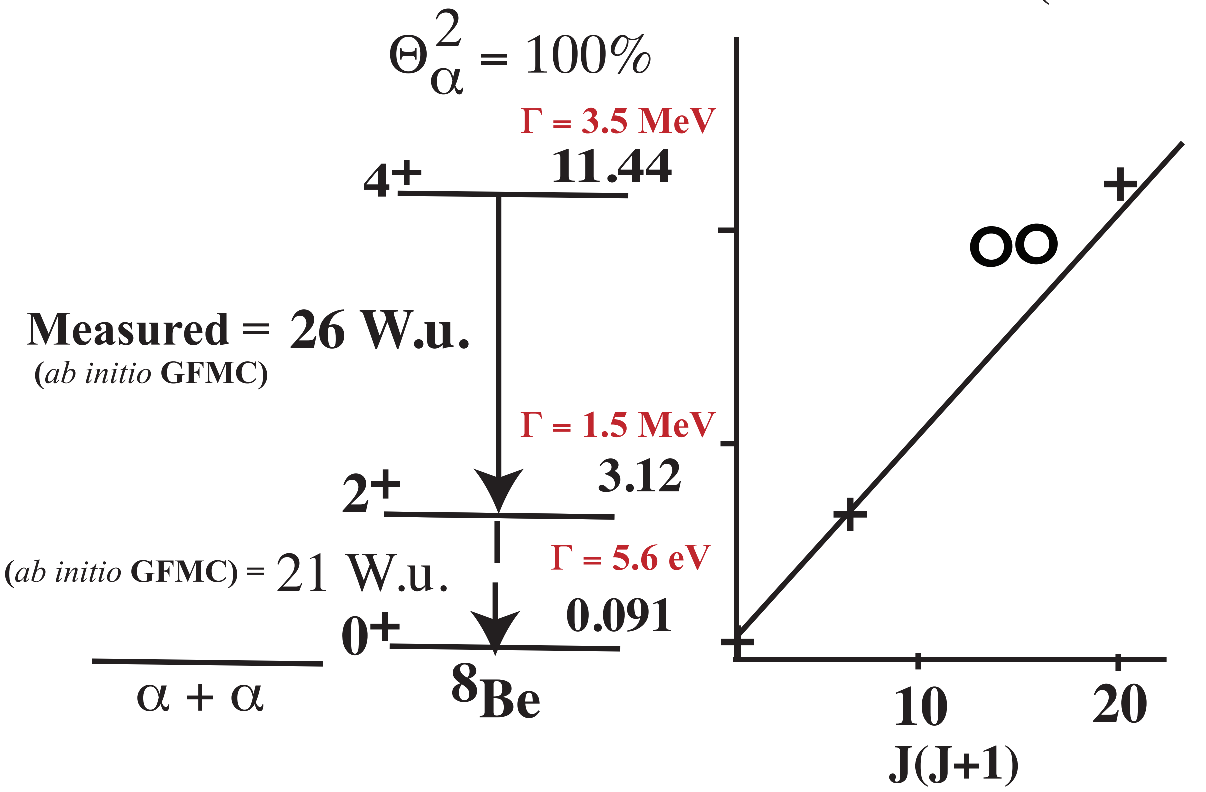
J. Chem. Phys., Vol. 77, No. 6, 15 September 1982

The Broad State Issue

$\hbar^2/2I = 0.53$ MeV

$\mu c^2 R^2 = 197.63^2$ MeV fm^2

$R = 4.6$ fm $= 1.4\,(4^{1/3} + 4^{1/3})$ fm



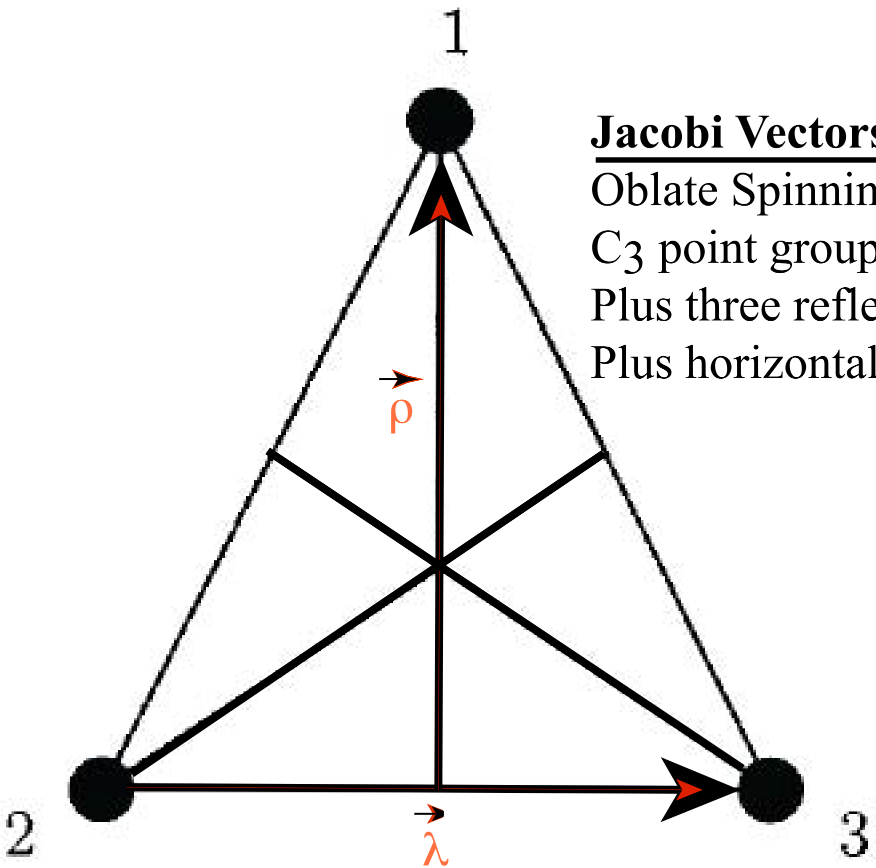
Also note *ab initio* EFT calculations on the lattice of 10 MeV Broad 2^+ in ^{12}C

Spectrum of the (Symmetric) Triangular Spinning Top:

Molecular Physics: H_3^+ Molecule

Hadron Structure: Three Quark Model

Nuclear Structure: ^{12}C Three Alpha-Particles



Jacobi Vectors: $\vec{\lambda}$, $\vec{\rho}$

Oblate Spinning Top: U(6+1)

C_3 point group symmetry

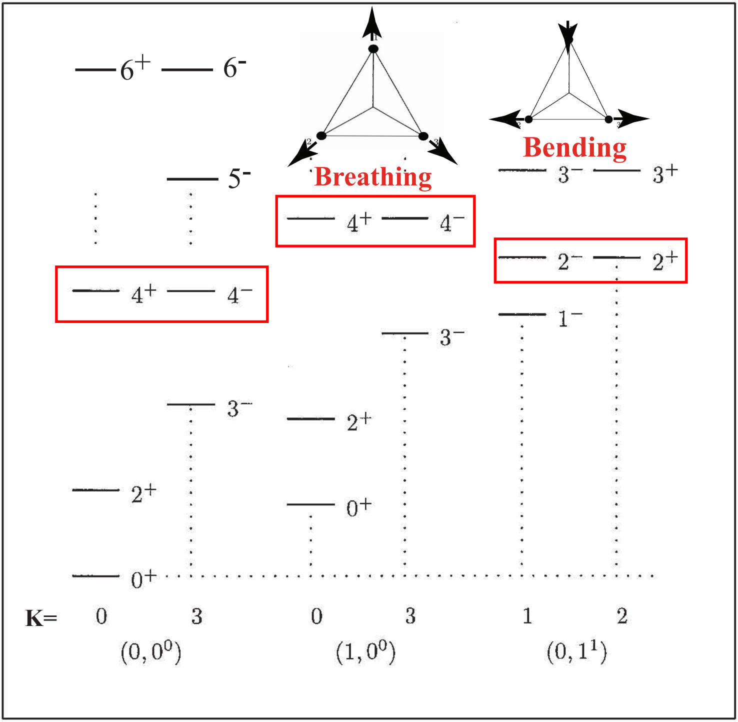
Plus three reflections

Plus horizontal: D_{3h} Symmetry

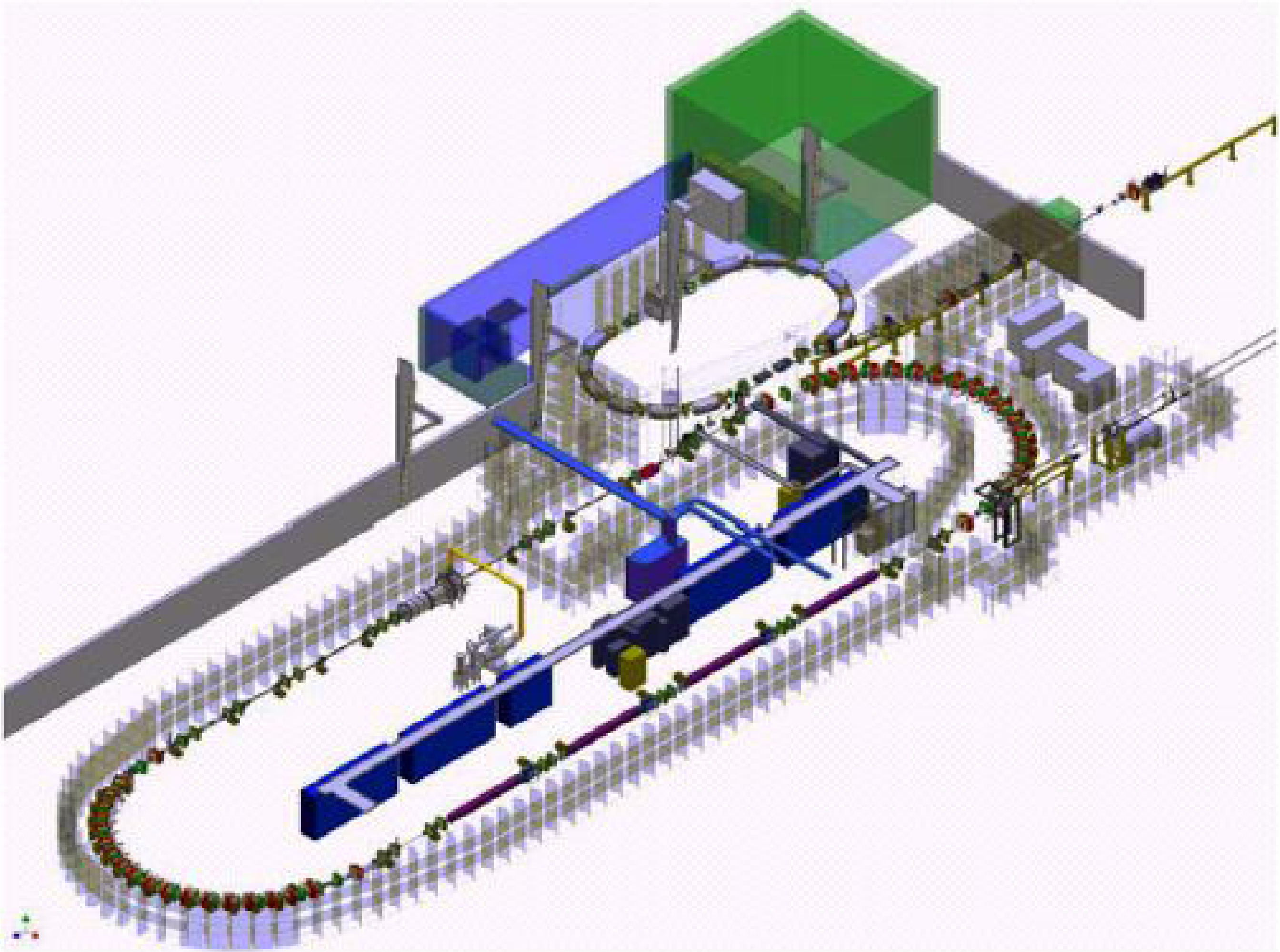
Rotation-Vibration Spectrum of the Three Alpha Triangular Spinning Top

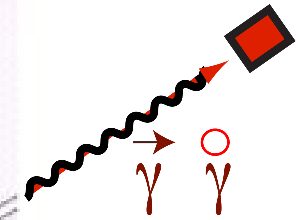
U(7) Model

R. Bijker and F. Iachello; Ann. Phys. **298**(2002)334

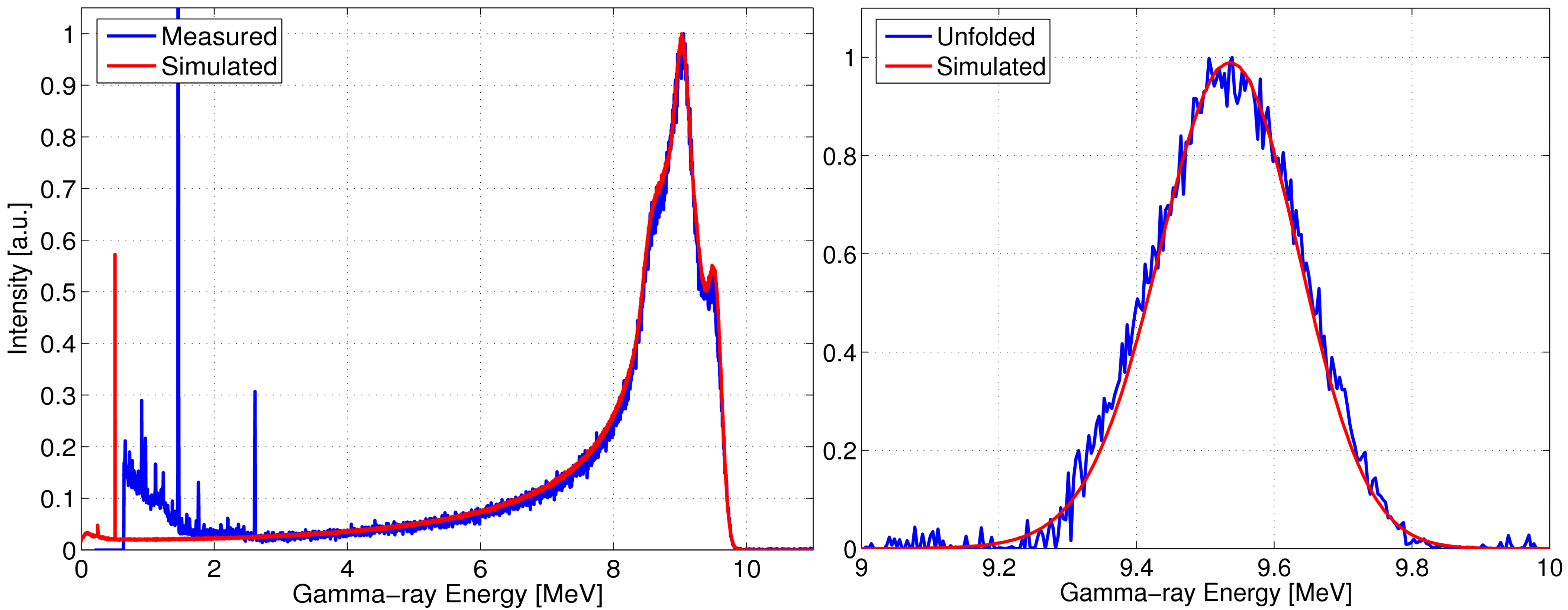


DFELL & HIGS





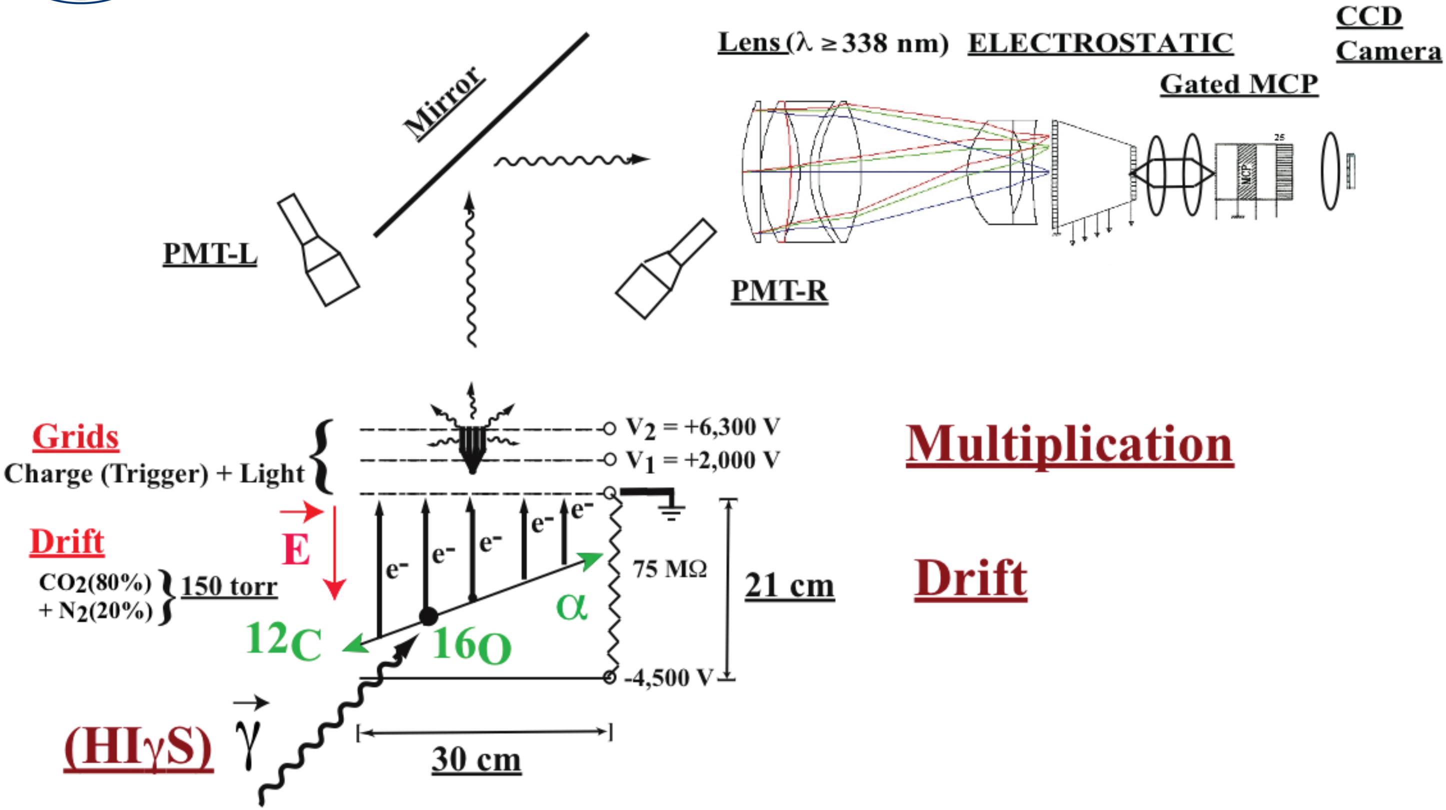
9.55 MeV


Measured
Simulated
Intensity [a.u.]
Gamma–ray Energy [MeV]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
Unfolded
Simulated
0
0.2
0.4
0.6
0.8
1
9
9.2
9.4
9.6
9.8
10
Gamma–ray Energy [MeV]

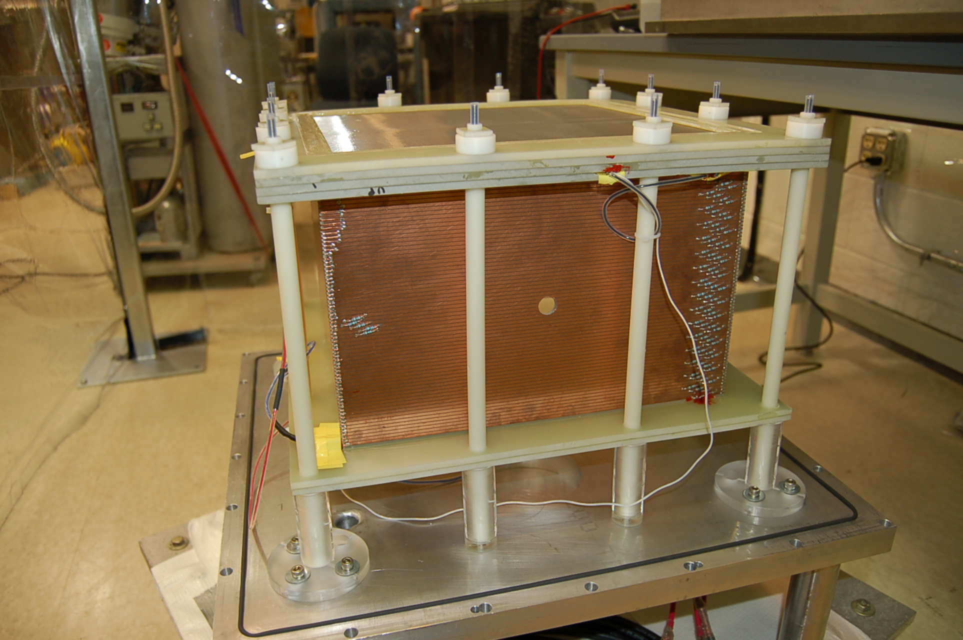
ELI-NP, July 18, 2014, Magurele, Bucharest, Romania

Optical Readout TPC (O-TPC)

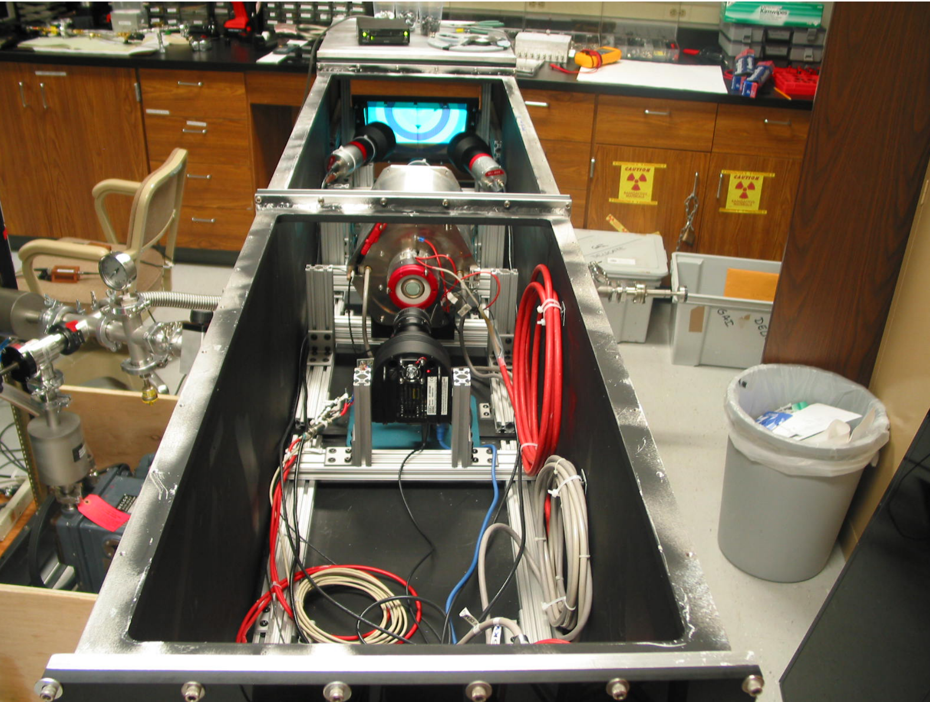
Opto-Electronic Chain



October 7, 2006/ Avery Point



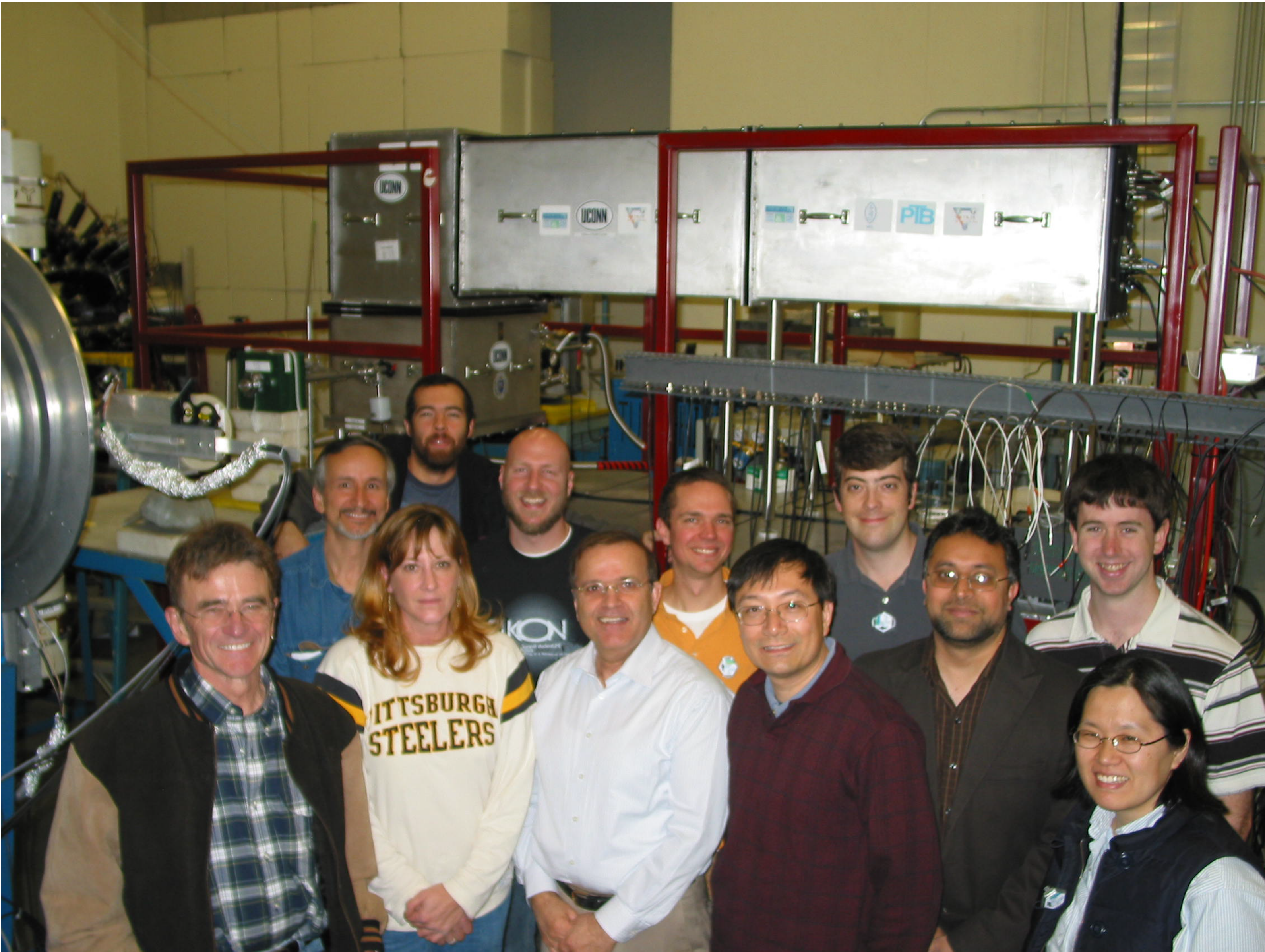
O-TPC at the LNS at Avery Point



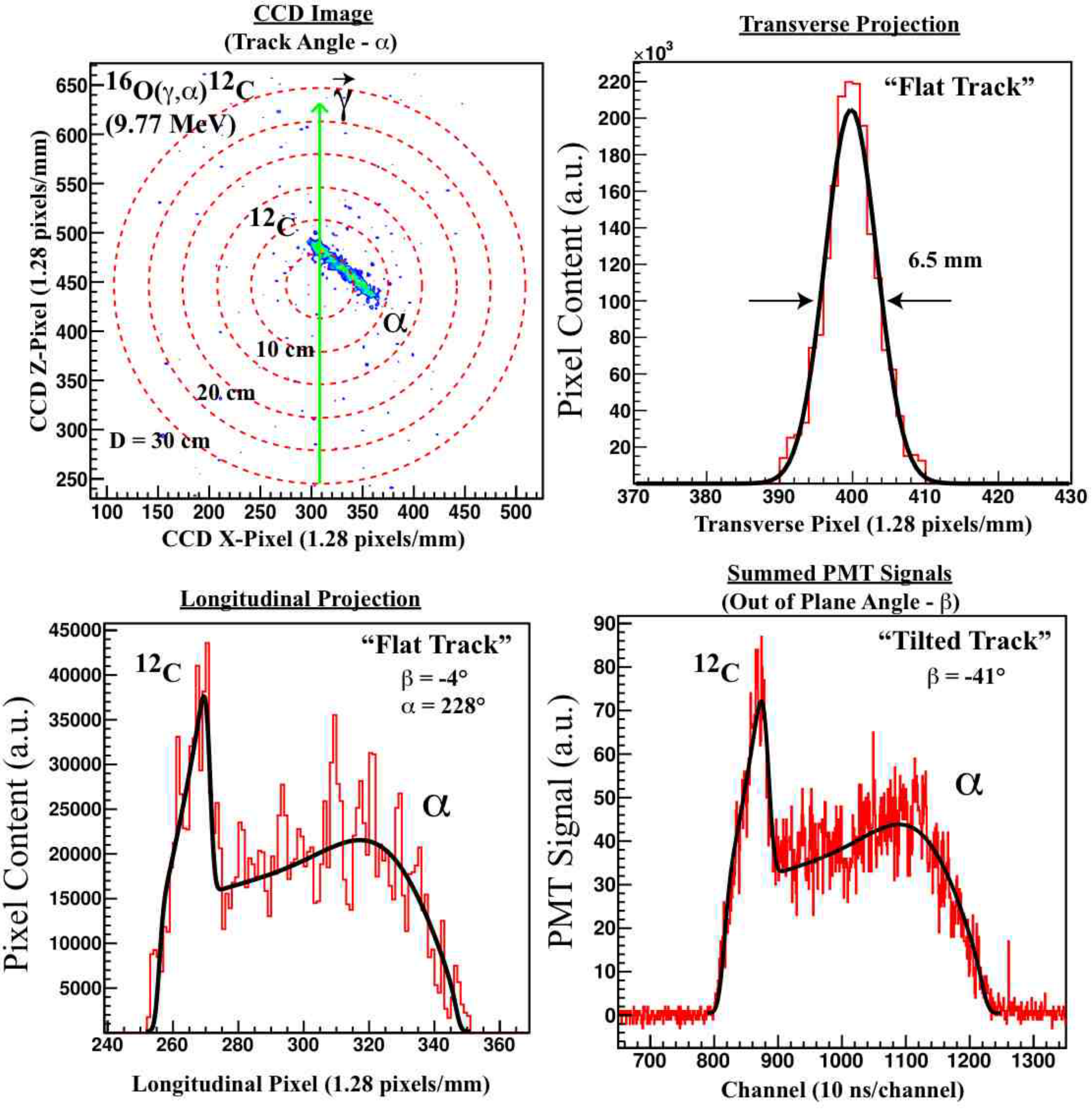

UCONN
Ziploc
MANUALS
Kimberly Clark

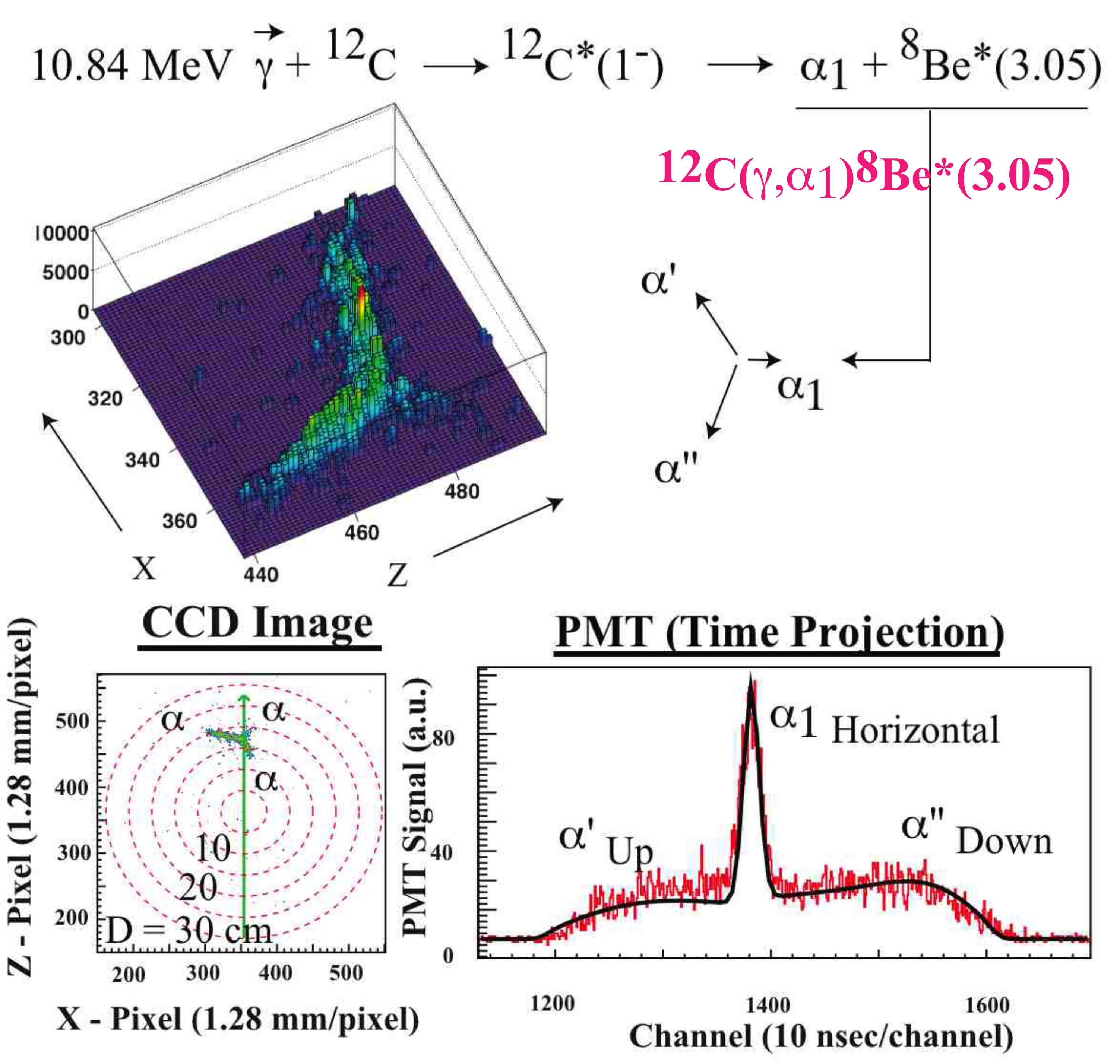
O-TPC at HIγS at TUNL/ Duke

April 3, 2008/ HIγS at TUNL, Duke University



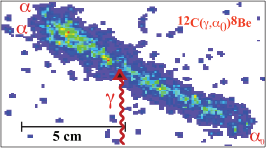
M. Gai *et al.;* JINST 5(2010)12004

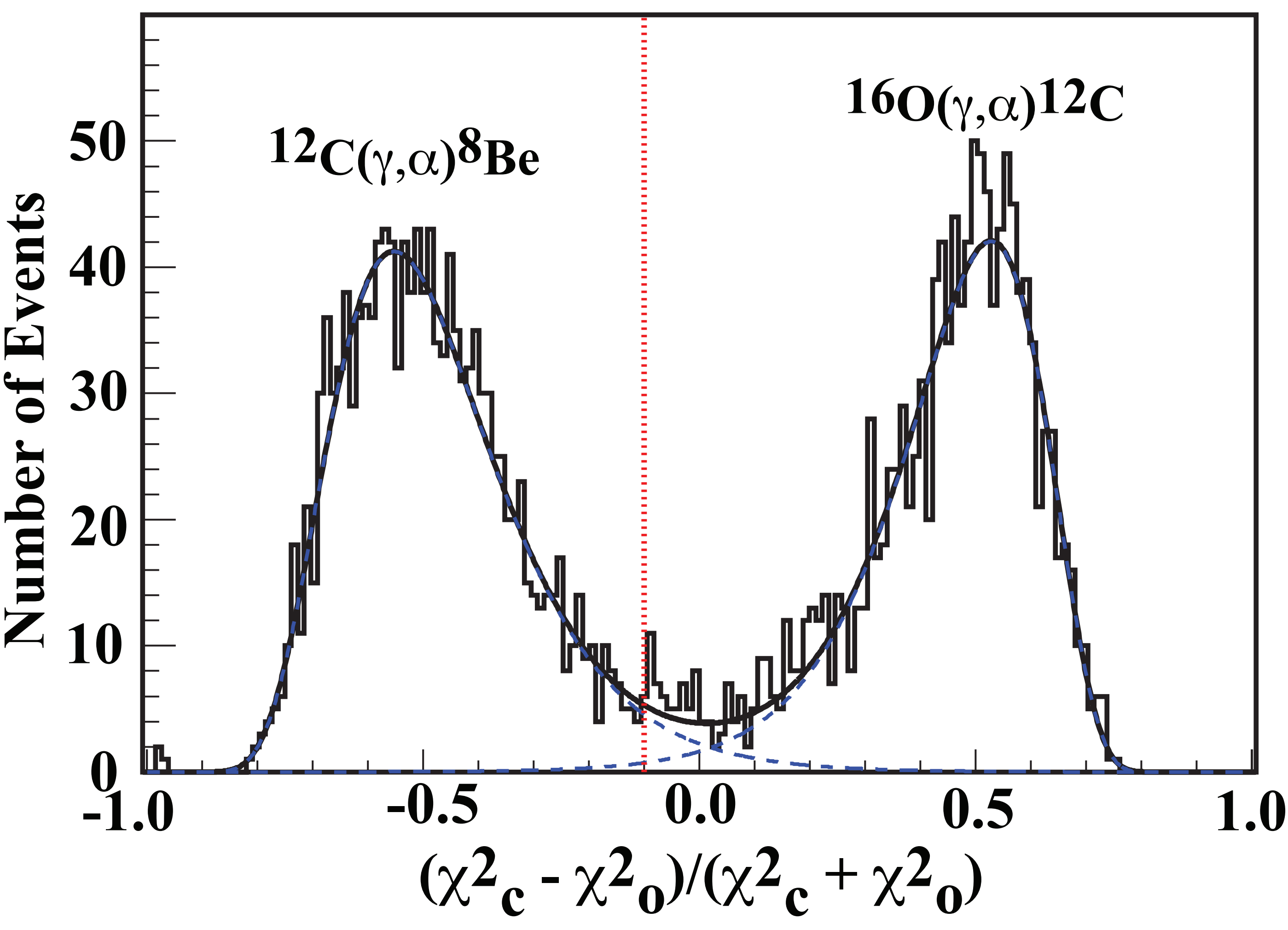




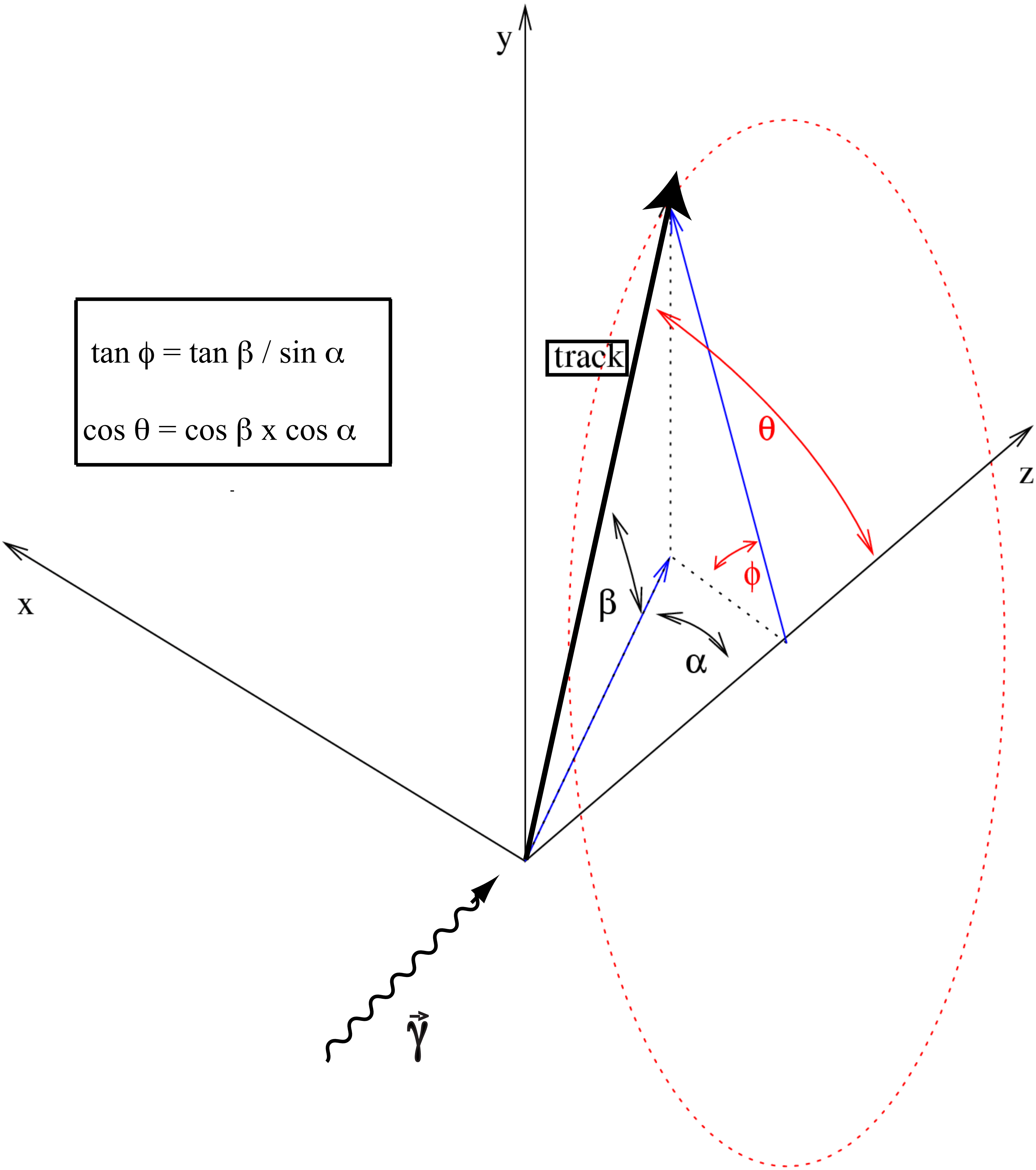
10.84 MeV γ + 12C → 12C*(1-) → α1 + 8Be*(3.05)
12C(γ,α1)8Be*(3.05)
α'
α1
α''
10000
5000
0
300
320
340
360
440
460
480
X
Z
CCD Image
α
α
α
10
20
D = 30 cm
500
400
300
200
200
300
400
500
Z - Pixel (1.28 mm/pixel)
X - Pixel (1.28 mm/pixel)
PMT (Time Projection)
α1 Horizontal
α' Up
α'' Down
PMT Signal (a.u.)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

W.R. Zimmerman *et al.*; Phys. Rev. Lett. 110(2013)152502

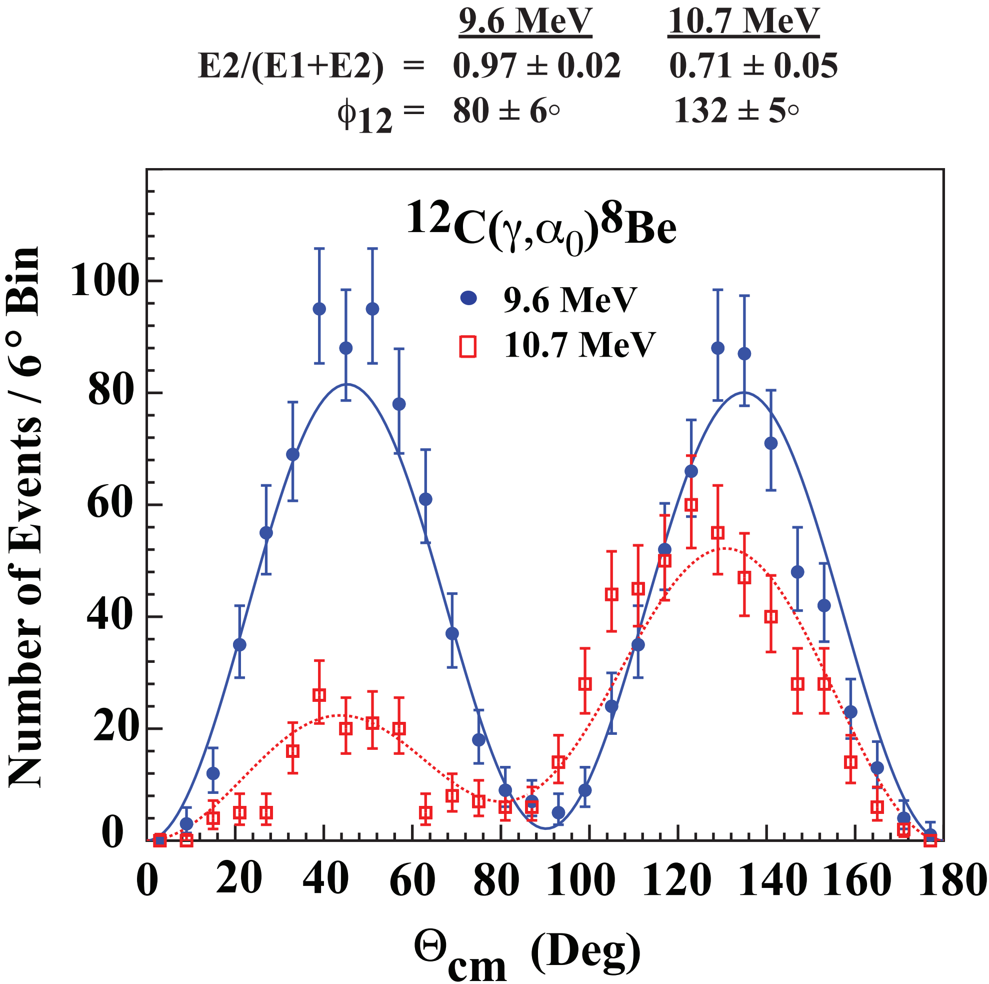




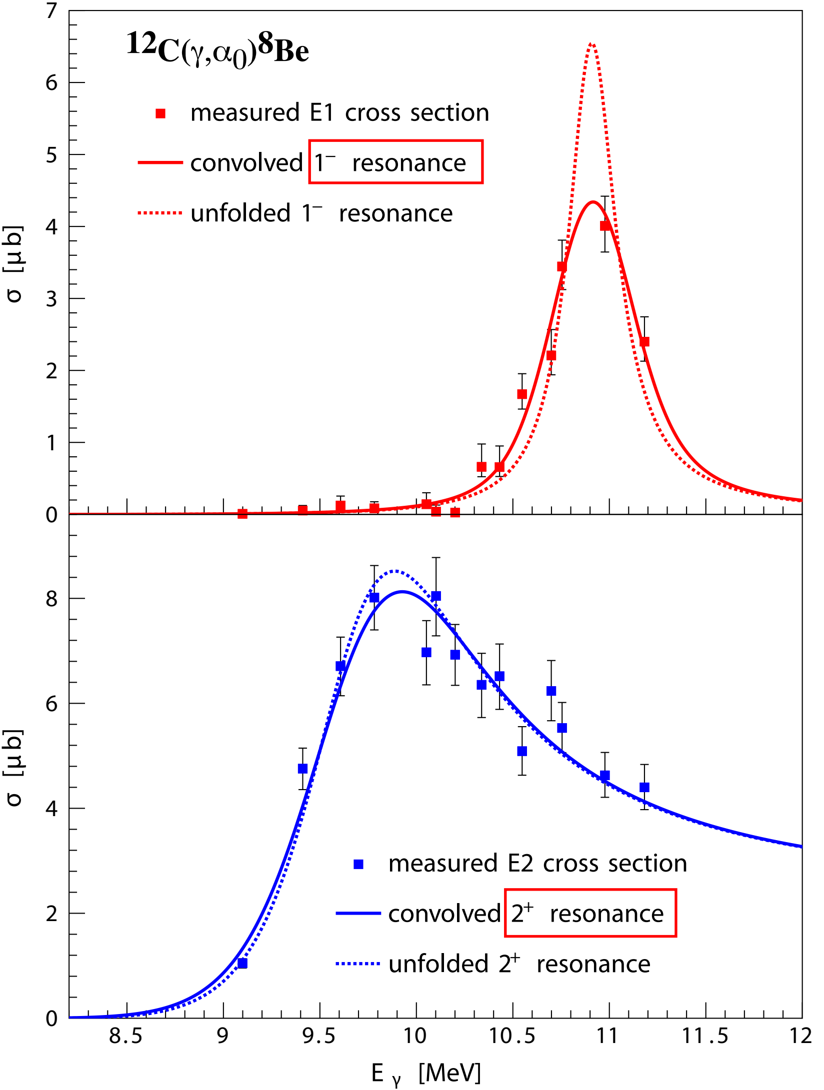
Number of Events
0
10
20
30
40
50
-1.0
-0.5
0.0
0.5
1.0
$(\chi^2_c - \chi^2_o)/(\chi^2_c + \chi^2_o)$
$^{12}C(\gamma,\alpha)^8Be$
$^{16}O(\gamma,\alpha)^{12}C$



y
x
z
track
tan ϕ = tan β / sin α
cos θ = cos β x cos α
θ
ϕ
β
α
$\vec{\gamma}$



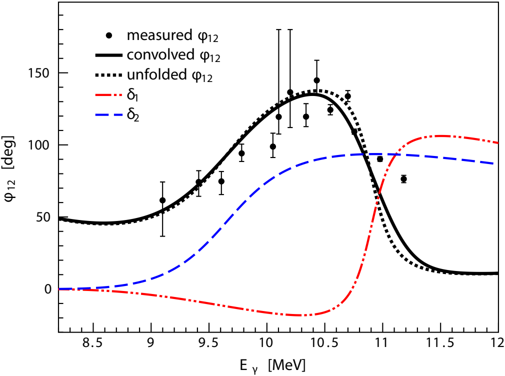
9.6 MeV
10.7 MeV
E2/(E1+E2) = 0.97 ± 0.02 0.71 ± 0.05
φ12 = 80 ± 6° 132 ± 5°
12C(γ,α0)8Be
9.6 MeV
10.7 MeV
Number of Events / 6° Bin
0
20
40
60
80
100
0 20 40 60 80 100 120 140 160 180
Θcm (Deg)



$^{12}C(\gamma,\alpha_0)^8Be$
measured E1 cross section
convolved 1^- resonance
unfolded 1^- resonance
measured E2 cross section
convolved 2^+ resonance
unfolded 2^+ resonance
σ [μb]
σ [μb]
E γ [MeV]

W.R. Zimmerman *et al.*; Phys. Rev. Lett. 110(2013)152502

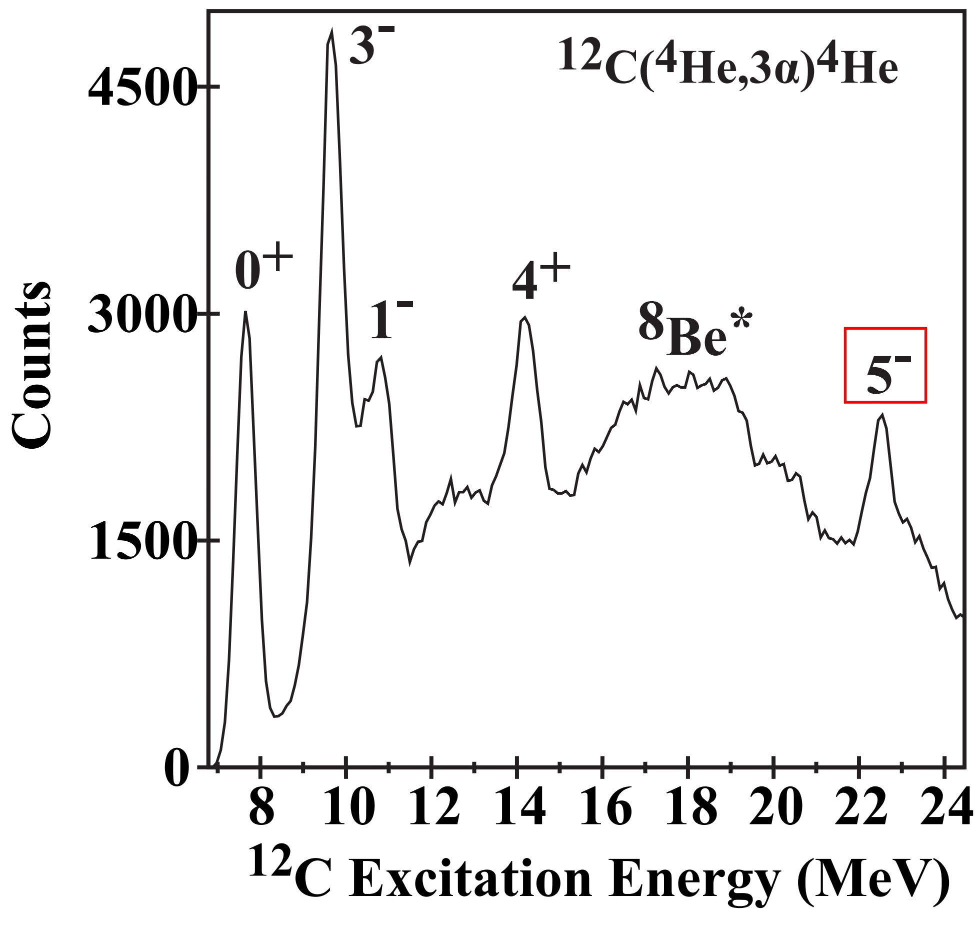
Unitarity: $\phi_{12} = \delta_2 - \delta_1 + \arctan(\eta/2)$



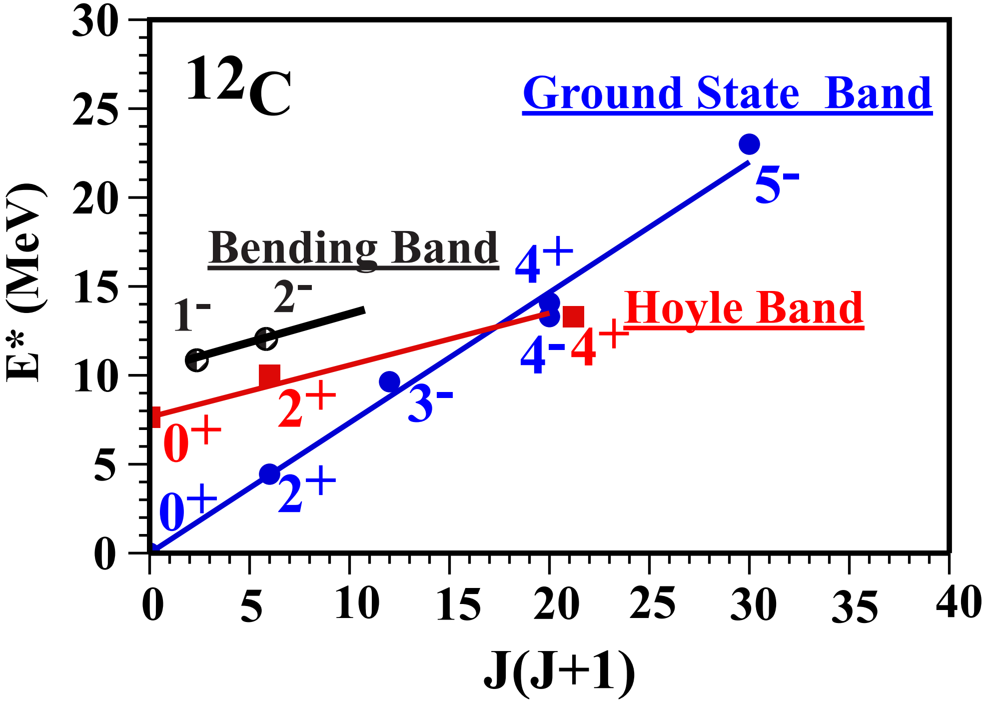
Birmingham Measurement:

D.J. Marin-Lambarri, R. Bijker, M. Freer, M. Gai, Tz. Kokalova, D.J. Parker, C. Wheldon

Phy. Rev. Lett. 113, 012502 (2014)



D.J. Marin-Lambarri, R. Bijker, M. Freer, M. Gai, Tz. Kokalova, D.J. Parker, C. Wheldon, Phys. Rev. Lett. 113, 012502 (2014)



Carbon nucleus seen spinning in triangular state

Jul 8, 2014 4 comments

The University of Birmingham's cyclotron

Physicists have obtained important new evidence showing that the structure of the carbon-12 nucleus – without which there would be no life here on Earth – resembles that of an equilateral triangle. The evidence was obtained by physicists in the UK, Mexico and the US by measuring a new rapidly spinning rotational state of the nucleus. The finding suggests that the "Hoyle state" of carbon-12, which plays an important role in the creation of carbon in red giant stars, has the same shape too. Recent theoretical predictions, in contrast, had suggested that the Hoyle state is more like an obtuse triangle or "bent arm".

All the carbon in the universe is created in red giant stars by two

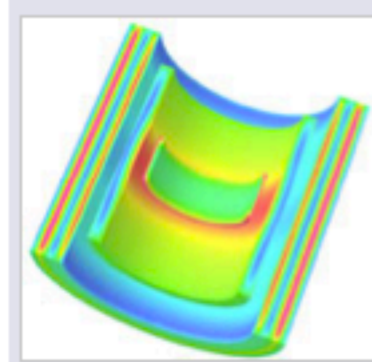
Related stories

- Testing the elements of the Big Bang
- Sir Fred Hoyle 1915–2001
- Carbon's Hoyle state calculated at long last
- The secret of life

Related links

Francesco Iachello

Latest webinar

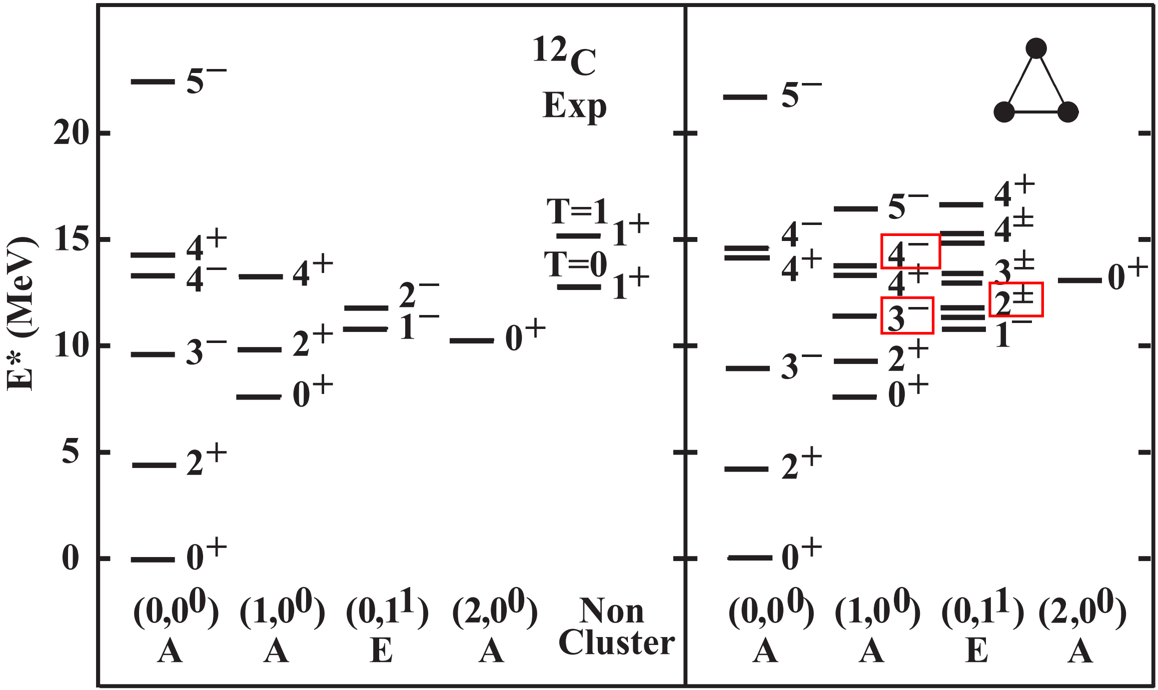


Virtual prototyping of superconducting devices

Sponsored by Cobham

Register for this free webinar

Featured video



E* (MeV)
0
5
10
15
20
12C
Exp
5−
4+
4−
3−
2+
0+
4+
2+
0+
2−
1−
0+
T=1
1+
T=0
1+
(0,0^0)
A
(1,0^0)
A
(0,1^1)
E
(2,0^0)
A
Non
Cluster
5−
4−
4+
3−
2+
0+
5−
4−
4+
3−
2+
0+
4+
4±
3±
2±
1−
0+
(0,0^0)
A
(1,0^0)
A
(0,1^1)
E
(2,0^0)
A

PHYSICAL REVIEW C **76**, 034320 (2007)

Reexamination of the excited states of ^{12}C

M. Freer,[1] I. Boztosun,[2,*] C. A. Bremner,[2] S. P. G. Chappell,[2] R. L. Cowin,[3] G. K. Dillon,[3] B. R. Fulton,[3] B. J. Greenhalgh,[3] T. Munoz-Britton,[1] M. P. Nicoli,[1] W. D. M. Rae,[2] S. M. Singer,[1] N. Sparks,[1] D. L. Watson,[3] and D. C. Weisser[4]

[1]*School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom*

[2]*Nuclear and Astrophysics Laboratory, University of Oxford, Keble Road, Oxford OX1 3RH, United Kingdom*

[3]*Department of Physics, University of York, Heslington, York YO10 5DD, United Kingdom*

[4]*Department of Nuclear Physics, The Australian National University, Canberra ACT 0200, Australia*

(Received 6 June 2007; revised manuscript received 31 July 2007; published 24 September 2007)

An analysis of the ^{12}C(^{12}C, 3α)^{12}C reaction was made at beam energies between 82 and 106 MeV. Decays to both the ground state and the excited states of ^{8}Be were isolated, allowing states of different characters to be identified. In particular, evidence was found for a previously observed state at 11.16 MeV. An analysis of the angular distributions of the unnatural parity states at 11.83 and 13.35 MeV, previously assigned $J^\pi = 2^-$, calls into question the validity of these assignments, suggesting that at least one of the states may correspond to $J^\pi = 4^-$. Evidence is also found for 1^- and 3^- strengths associated with broad states between 11 and 14 MeV.

DOI: 10.1103/PhysRevC.76.034320 PACS number(s): 25.70.Ef, 25.70.Mn, 27.20.+n

Viability of Carbon-Based Life as a Function of the Light Quark Mass

Evgeny Epelbaum,[1] Hermann Krebs,[1] Timo A. Lähde,[2] Dean Lee,[3] and Ulf-G. Meißner[2,4,5]
[1]*Institut für Theoretische Physik II, Ruhr-Universität Bochum, D-44870 Bochum, Germany*
[2]*Institut für Kernphysik, Institute for Advanced Simulation, and Jülich Center for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany*
[3]*Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA*
[4]*Helmholtz-Institut für Strahlen- und Kernphysik and Bethe Center for Theoretical Physics, Universität Bonn, D-53115 Bonn, Germany*
[5]*JARA—High Performance Computing, Forschungszentrum Jülich, D-52425 Jülich, Germany*
(Received 18 December 2012; published 13 March 2013)

The Hoyle state plays a crucial role in the helium burning of stars that have reached the red giant stage. The close proximity of this state to the triple-alpha threshold is needed for the production of carbon, oxygen, and other elements necessary for life. We investigate whether this life-essential condition is robust or delicately fine-tuned by measuring its dependence on the fundamental constants of nature, specifically the light quark mass and the strength of the electromagnetic interaction. We show that there exist strong correlations between the alpha-particle binding energy and the various energies relevant to the triple-alpha process. We derive limits on the variation of these fundamental parameters from the requirement that sufficient amounts of carbon and oxygen be generated in stars. We also discuss the implications of our results for an anthropic view of the Universe.

DOI: 10.1103/PhysRevLett.110.112502 PACS numbers: 21.10.Dr, 21.30.−x, 21.60.De

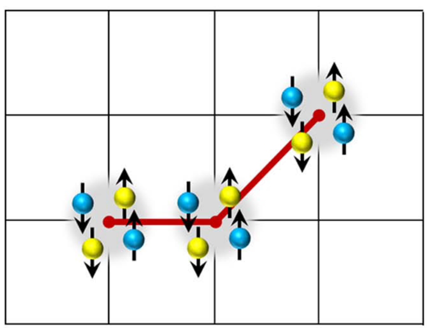
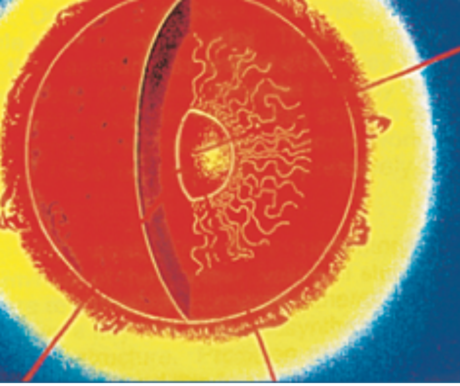


FIG. 3 (color online). Illustration of the initial state Λ. There are 24 equivalent orientations of this bent-arm or obtuse triangular configuration.



University of Connecticut
Laboratory for Nuclear Science
at Avery Point

Conclusions and Outlook/ Future

All observed ^{12}C states below 15 MeV
Are predicted by the U(7) Model/ $\mathcal{D}_{3h}$ Symmetry
(Except non-clusters 1^+ states)

Observed in ^{12}C:
Ground State Rotational Band: 0^+, 2^+, 3^-, $4^{\pm}$, 5^-
Parity doublet: $4^{\pm}$

Predicted ("Missing") in ^{12}C:
Hoyle Band: 3^- and 4^-
Will determine geometry of Hoyle State
(equilateral, obtuse, etc.)

$^{12}C(e,e')$ Measurement at the S-DALINAC
"The Missing 3^- State"