Optical Readout Time Projection Chamber (O-TPC) for Studies in Nuclear Astrophysics

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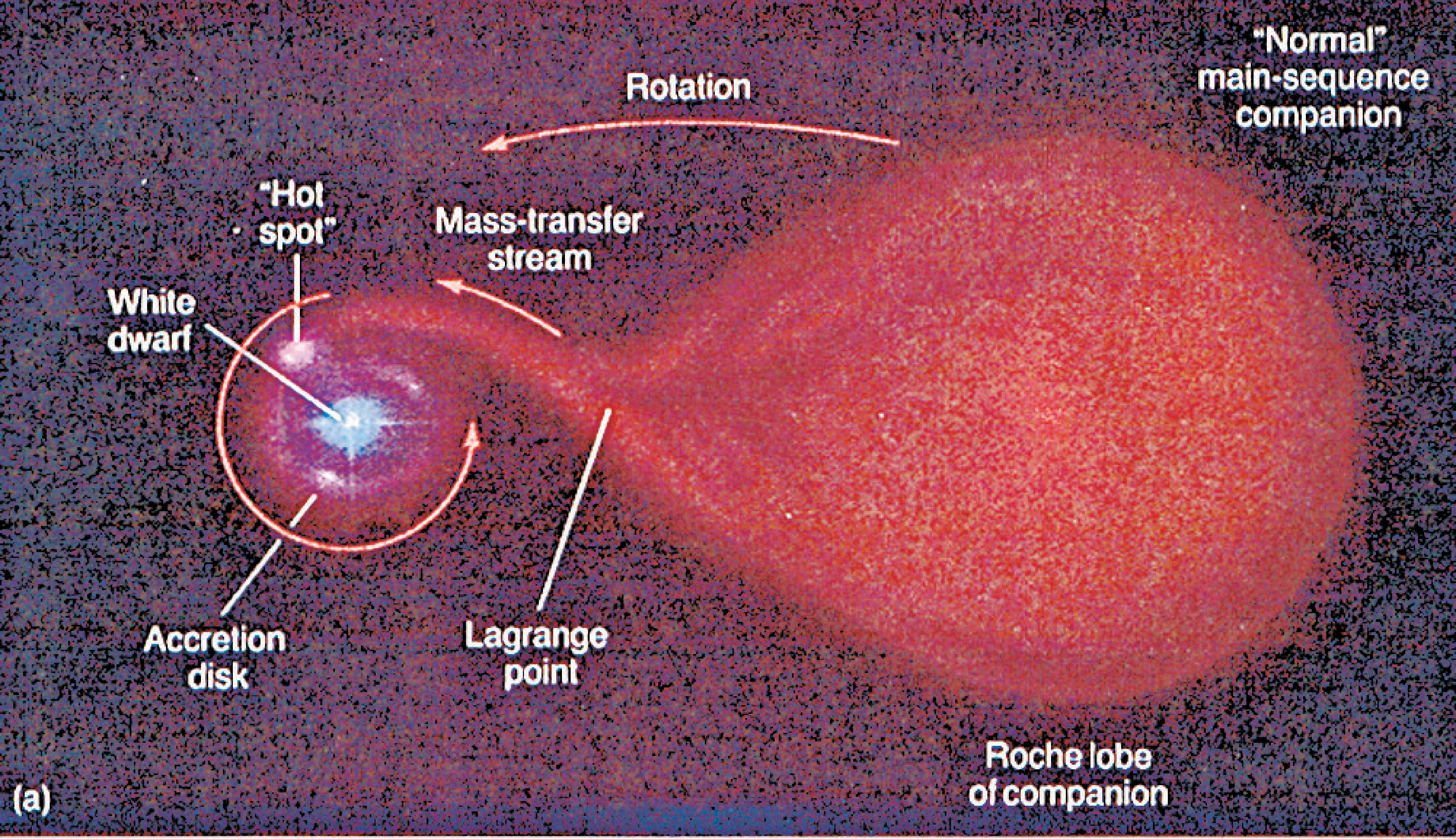
Laboratory for Nuclear Science at Avery Point

1. **The Problem: C/O ratio in Helium Burning**
   (Who cares? the shattered hopes/illusions)

2. **The Solution: O-TPC**
   (Who will do it? and where?)

Breckenridge, 11 Februray 2005

The Laboratory for Nuclear Science At Avery Point



"Normal" main-sequence companion
Rotation
"Hot spot"
Mass-transfer stream
White dwarf
Accretion disk
Lagrange point
Roche lobe of companion
(a)

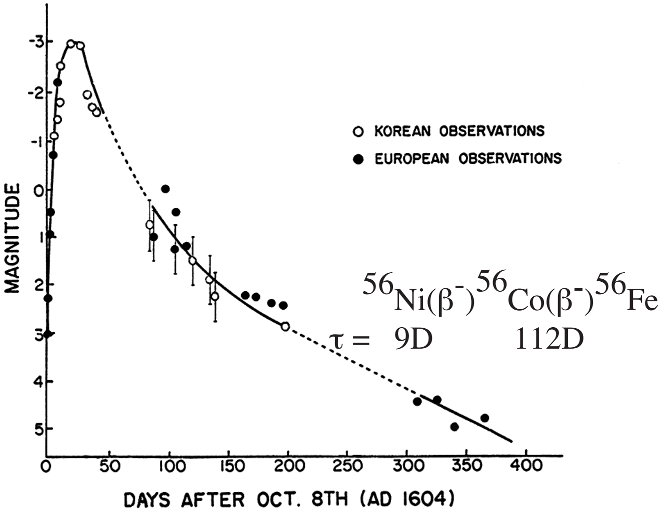
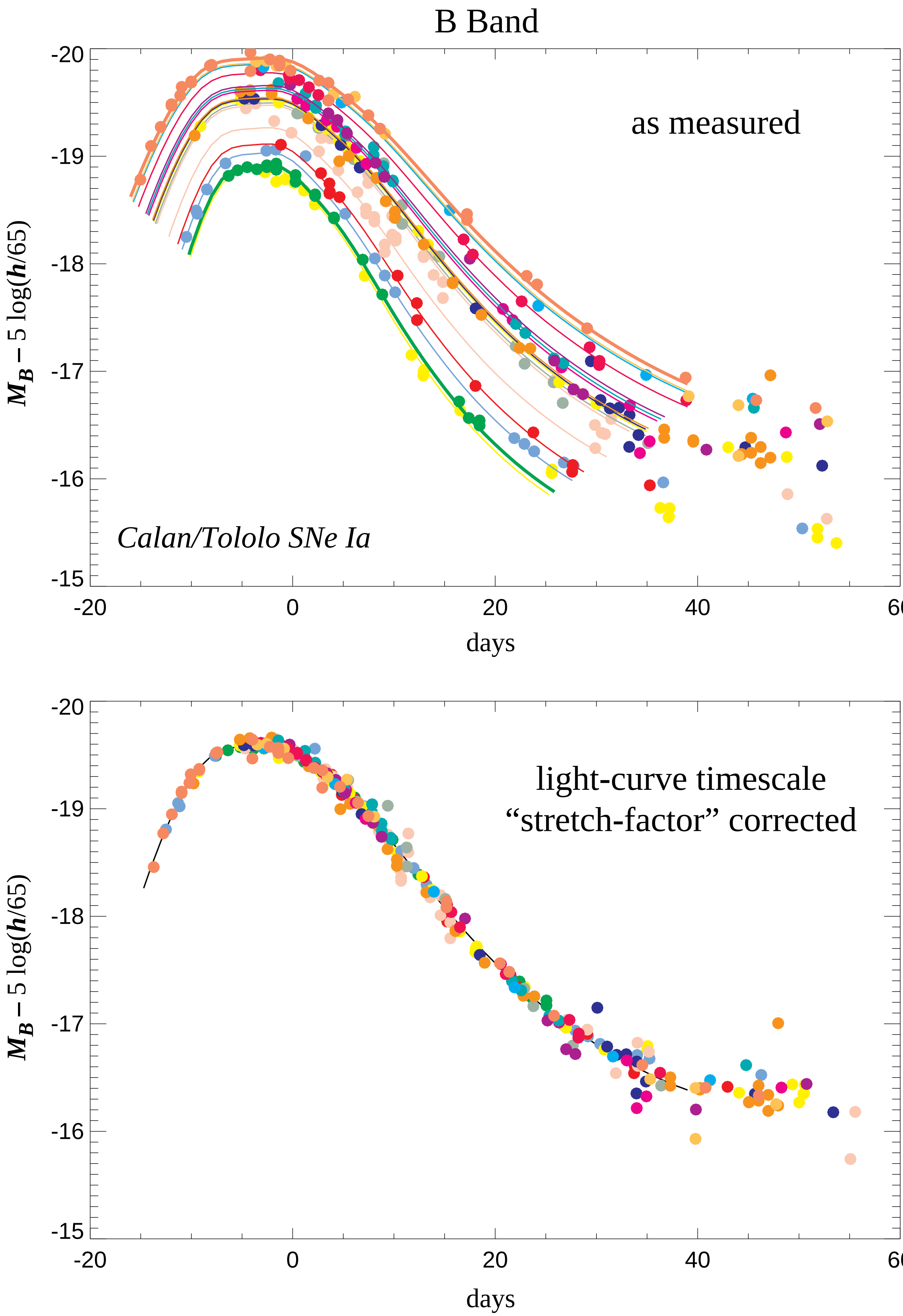

MAGNITUDE
DAYS AFTER OCT. 8TH (AD 1604)
KOREAN OBSERVATIONS
EUROPEAN OBSERVATIONS
-3
-2
-1
0
1
2
3
4
5
0
50
100
150
200
250
300
350
400
$^{56}Ni(\beta^-)^{56}Co(\beta^-)^{56}Fe$
$\tau =$ 9D 112D

그림 3



Kim, *et al.* (1997)

Peter Hoeflich (2002)

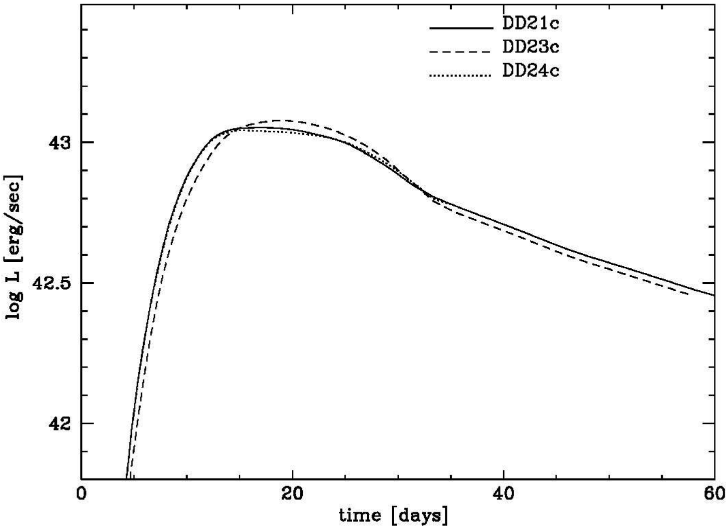
INFLUENCE ON LIGHT CURVES (0-60 Days)

DD21c: C/O=1/1; Z=0.02 (solar)

DD23c: C/O=2/3; Z=0.02 (solar)

DD24c: C/O=1/1; Z=0.0067 (solar/3)

Bolometric Light Curves



C/O Ratio of the WD

- Maxima ≈ 2-3 days later (i.g. 1-5 days)
- Peak to 'Tail' ratio changes by ≈ 0.3^m

Metalicity Z - negligible

OFF SET in M(dM15)

dM(V) $\simeq$ 0.1 dt(rise)

Helium Burning:

$3\alpha \rightarrow {}^{12}C$ Known

$\alpha + {}^{12}C \rightarrow {}^{16}O$???

C/O = ?

${}^{12}C(\alpha,\gamma){}^{16}O$ (E_{cm} = 300 keV)

$$\sigma(\alpha,\gamma) = S/E \times e^{-2\pi\eta}$$

$$(\eta = e^2 Z_1 Z_2 / \hbar \upsilon = Z_1 Z_2 \alpha / \beta)$$

Astrophysical Cross Section Factor (P and D waves)

$S_{E1}(300)$

$S_{E2}(300)$

±15%

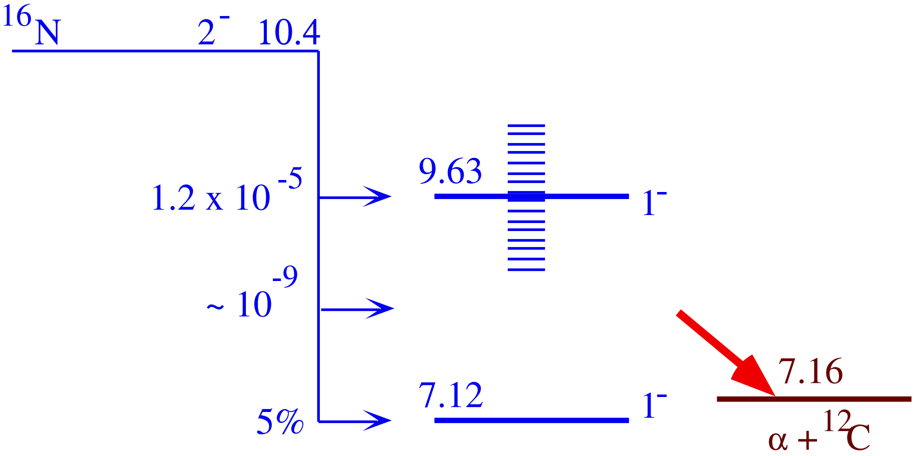
The chlorine detector must be maintained in low-level operation until the chlorine and gallium detectors can be operated at full level simultaneously. Otherwise endless conjecture concerning time variations in the solar neutrino flux will ensue. Moreover, the results of the gallium observations may uncover information that has been overlooked in the past chlorine observations.

The CNO cycle operates at the higher temperatures which occur during hydrogen burning in main sequence stars somewhat more massive than the sun. This is the case because the CNO cycle reaction rates rise more rapidly with temperature than do those of the *pp* chain. The cycle is important because ^{13}C, ^{14}N, ^{15}N, ^{17}O, and ^{18}O are produced from ^{12}C and ^{16}O as seeds. The role of these nuclei as sources of neutrons during helium burning is discussed in Sec. V.

V. THE SYNTHESIS OF ^{12}C AND ^{16}O AND NEUTRON PRODUCTION IN HELIUM BURNING

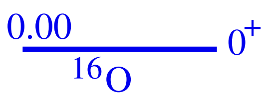
The human body is 65% oxygen by mass and 18% carbon, with the remainder mostly hydrogen. Oxygen (0.85%) and carbon (0.39%) are the most abundant elements heavier than helium in the sun and similar main sequence stars. It is little wonder that the determination of the ratio ^{12}C/^{16}O produced in helium burning is a problem of paramount importance in Nuclear Astrophysics. This ratio depends in a fairly complicated manner on the density, temperature, and duration of helium burning, but it depends directly on the relative rates of the $3\alpha \rightarrow {}^{12}$C process and the ^{12}C$(\alpha,\gamma)^{16}$O process. If $3\alpha \rightarrow {}^{12}$C is much faster than ^{12}C$(\alpha,\gamma)^{16}$O, then no ^{16}O is produced in helium burning. If the reverse is true, then no ^{12}C is produced. For the most part the subsequent reaction ^{16}O$(\alpha,\gamma)^{20}$Ne is slow enough to be neglected.

There is general agreement about the rate of the $3\alpha \rightarrow {}^{12}$C process, as reviewed by Barnes (1982). However there is a lively controversy at the present time about the laboratory cross section for ^{12}C$(\alpha,\gamma)^{16}$O and about its theoretical extrapolation to the low energies at which the reaction effectively operates. The situation is depicted in Figs. 4, 5, and 6, taken with some modification from Langanke and Koonin (1983), Dyer and Barnes (1974), and Kettner *et al.* (1982). The Caltech data obtained in the Kellogg Laboratory is shown as the experimental points in Fig. 4, taken from Dyer and Barnes (1974), who compared their results with theoretical calculations by Koonin, Tombrello, and Fox (1974). The Münster data are shown as the experimental points in Fig. 5, taken from



Enhancement: (I) W_0^5

(II) Matrix Elements

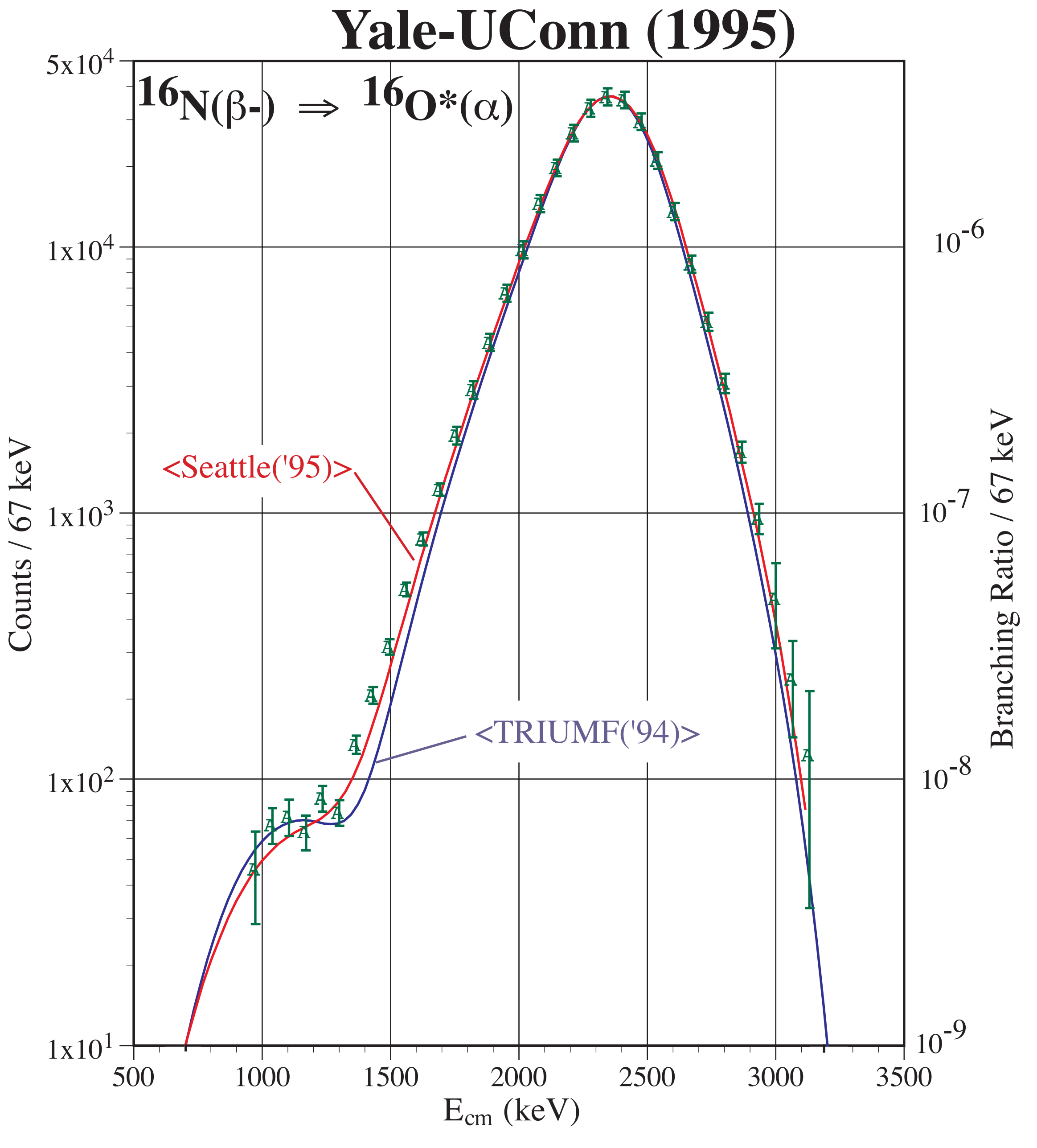


$^{12}C(\alpha,\gamma)^{16}O$: $\sigma = \sigma_{E1} + \sigma_{E2}$

$^{16}N(\beta^-)^{16}O^*$: $\sigma = \sigma_{E1} + \sigma_{E3}$

β^- Selection Rules: $\Delta J = 0,1 \quad \Delta\pi = +$

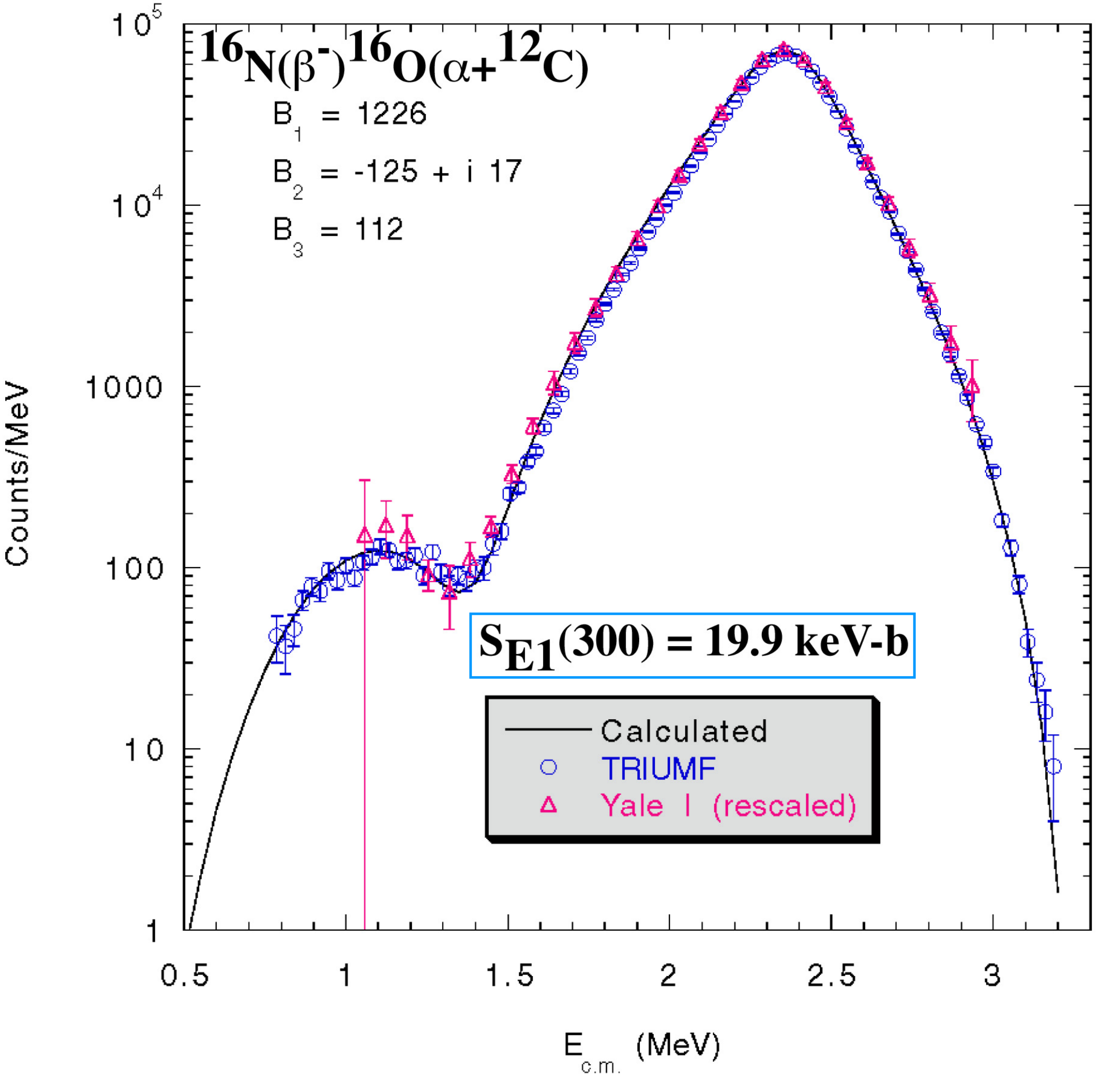
$2^- \longrightarrow 1^-$ or 3^-



Yale-UConn (1995)
$^{16}N(\beta-) \Rightarrow {}^{16}O^*(\alpha)$
<Seattle('95)>
<TRIUMF('94)>
Counts / 67 keV
Branching Ratio / 67 keV
E_{cm} (keV)
5x10^4
1x10^4
1x10^3
1x10^2
1x10^1
10^-6
10^-7
10^-8
10^-9
500
1000
1500
2000
2500
3000
3500

TRIUMF(94): $S_{E1}(300) = 81 \pm 21$ keV-b

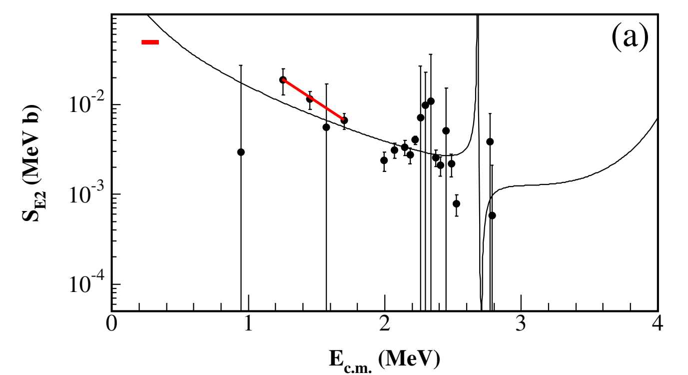
G.M. Hale; Nucl. Phys. A621(1997)177c



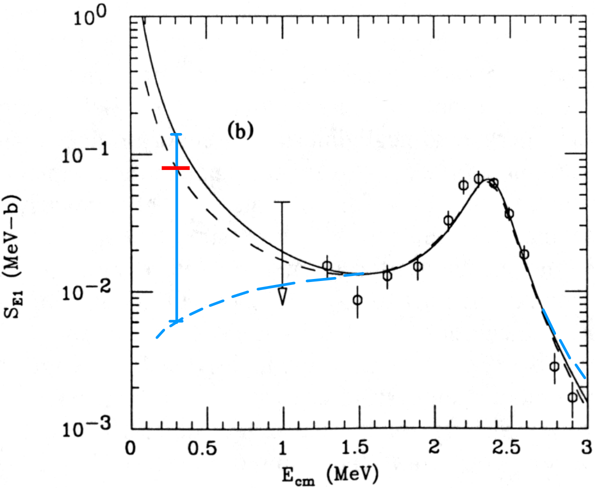
Notre Dame - 2002

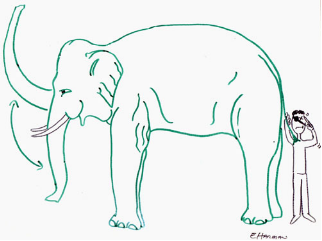
ratios of the excitation function for $\theta_{lab} = 84.0°$ relative to the one at $\theta_{lab} = 58.9°$ and a fit to this function.

The best fit for the reduced width amplitude of the 2^+ subthreshold state occurred for $\gamma_{12} = 0.47$ MeV$^{1/2}$, with $\gamma_{11} = 0.27$ MeV$^{1/2}$ for the subthreshold 1^- state for the single channel program. Identical results were obtained in the multichannel program (both $a = 5.5$ fm). To obtain an error estimation, fits were obtained for values of γ_{12} from 0.2 to 0.60 MeV$^{1/2}$, with all other parameters being allowed to vary. The resulting χ^2 curve is shown in Fig. 2(a). The same approach was used to scan γ_{11} from 0 to 0.60 MeV$^{1/2}$ for the 1^- state. A 1σ uncertainty of $\gamma_{12} = 0.47 \pm 0.06$ MeV$^{1/2}$, and $\gamma_{11} = 0.27^{+0.11}_{-0.27}$ MeV$^{1/2}$ was calculated with the previously established [2] guideline $\chi^2 < \chi^2_{min} \pm 9\chi^2_\nu$. A list of the best fit parameters is presented in Table I. The best fit has a χ^2_ν of approximately 1.66. Deviations from an ideal fit occur at resonances with widths in the keV range where the sensitivity to target effects and beam energy calibration is from $^{12}C(\alpha,\gamma)^{16}O$ and ^{16}N data [2]. This analysis leads to a value of $S_{E1}(300) = 80 \pm 20$ keV b, and $S_{E2}(300) = 49^{+7}_{-9}$ or 58^{+8}_{-11} keV b, depending on the sign of the $E = 4.39$ MeV 2^+ resonance γ width amplitude relative to that for direct capture and the subthreshold resonance. As this interference sign is unknown, the two results are averaged and errors include the limits on both measurements, yielding $S_{E2}(300) = 53 \pm 13$ keV b. With the full range of a allowed here, the final result is $S_{E2}(300) = 53^{+13}_{-18}$ keV b. In this analysis destructive interference between the ground state direct capture and the tail of the subthreshold 2^+ resonance has been employed. This is justified by a total decrease in χ^2 of nearly 300 between the destructive and constructive options, largely due to the γ-angular distributions of Refs. [5] and [7]. However, additional angular distributions would be desirable, as the constructive option leads to 92 and 102 keV b, respectively, for $S_{E2}(300)$. The data set of Ref. [25] is unfortunately not available to the authors.



(a)
S_{E2} (MeV b)
10^{-2}
10^{-3}
10^{-4}
0
1
2
3
4
$E_{c.m.}$ (MeV)


(b)
S_{E1} (MeV−b)
E_{cm} (MeV)
10^0
10^{-1}
10^{-2}
10^{-3}
0
0.5
1
1.5
2
2.5
3



Eric T. Harman

Physics Today 55:12(2002)26

UConn - HIγS/Duke - Weizmann PTB - UHartford - GCSU - LLN Collaboration

Optical Readout Time Projection Chamber (TPC)

$$^{16}\mathrm{O} + \gamma \rightarrow \alpha + {}^{12}C$$

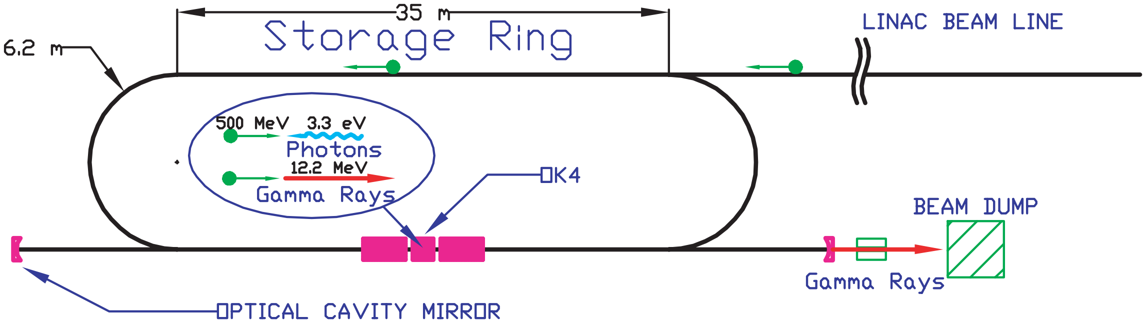
$$\mathrm{E}_\gamma \quad = 8.0 \text{ - } 10.0 \text{ MeV}$$

$$\sigma(\gamma,\alpha) = \frac{(2S_1+1)(2S_2+1)}{2(2S_4+1)} \times \frac{k_\alpha^2}{k_\gamma^2} \times \sigma(\alpha,\gamma)$$

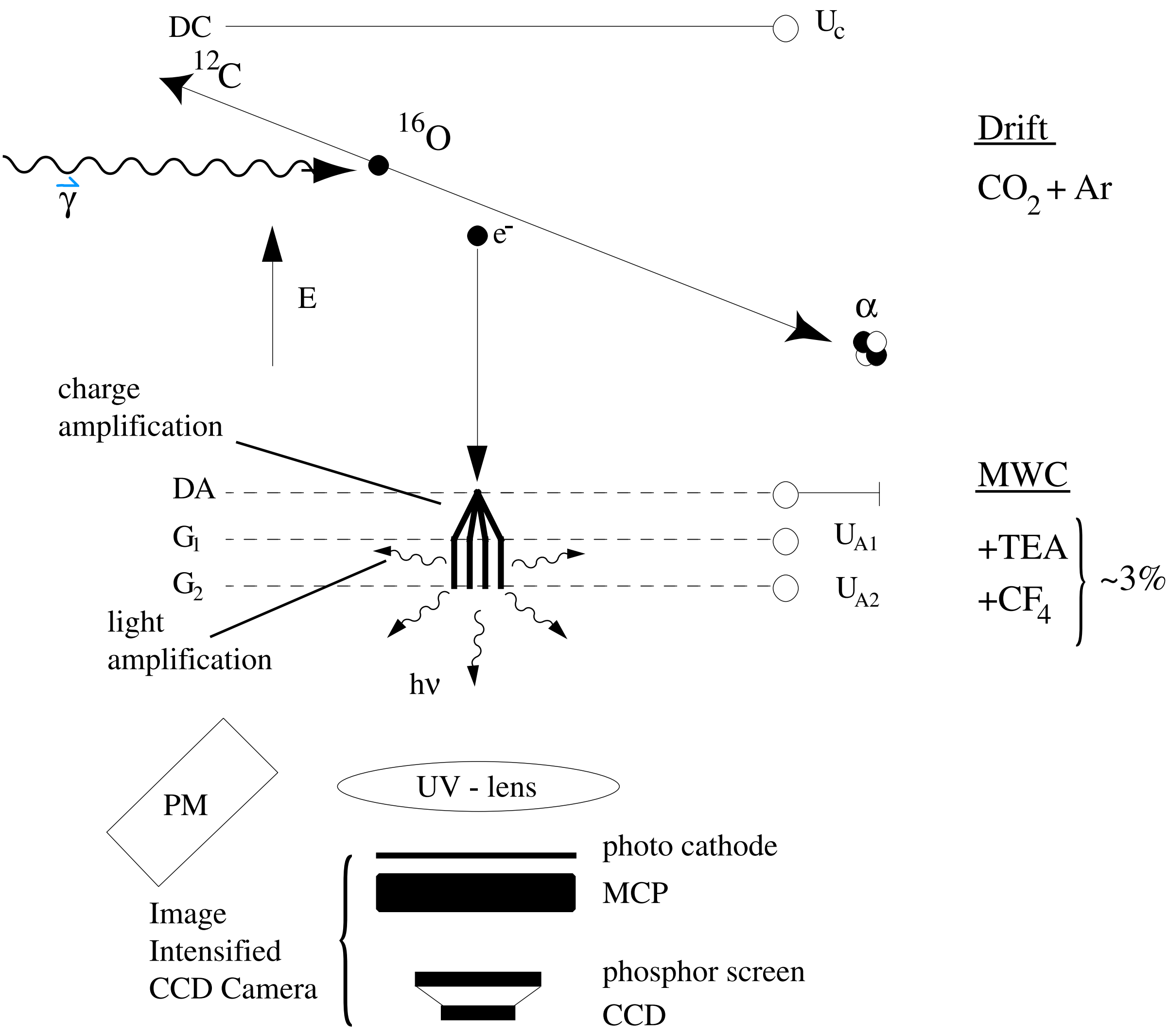
$$= \frac{1}{2} \times \frac{k_\alpha^2}{k_\gamma^2} \times \sigma(\alpha,\gamma)$$

$$= \frac{1}{2} \times (80 - 160) \times \sigma(\alpha,\gamma)$$

$$= \boxed{(80 - 160)} \times \sigma(\alpha,\gamma)$$


35 m
Storage Ring
LINAC BEAM LINE
6.2 m
500 MeV
3.3 eV
Photons
12.2 MeV
Gamma Rays
OK4
BEAM DUMP
Gamma Rays
OPTICAL CAVITY MIRROR

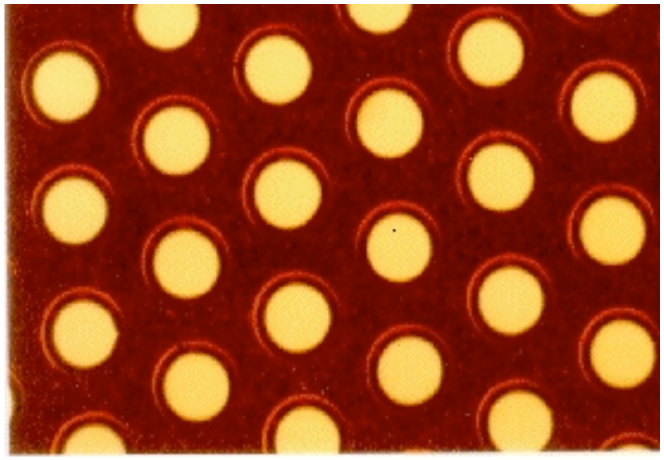
Optical Readout TPC

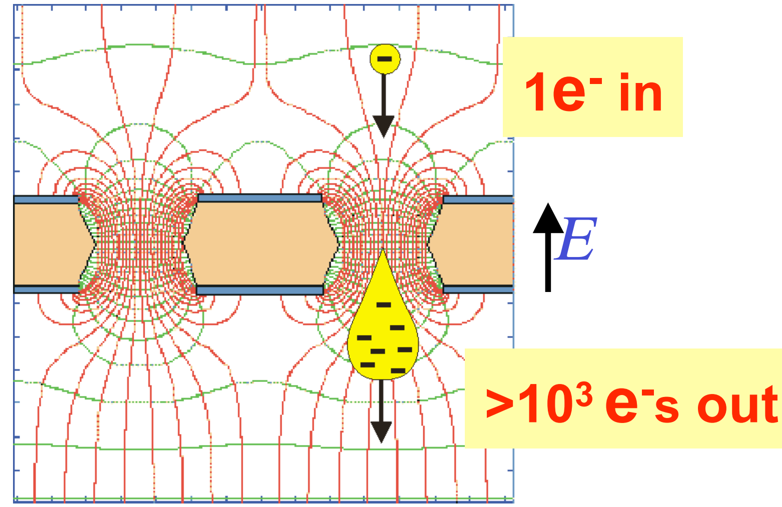


Gas Electron Multiplier (GEM)

F. Sauli NIM A 433 (1997) 531

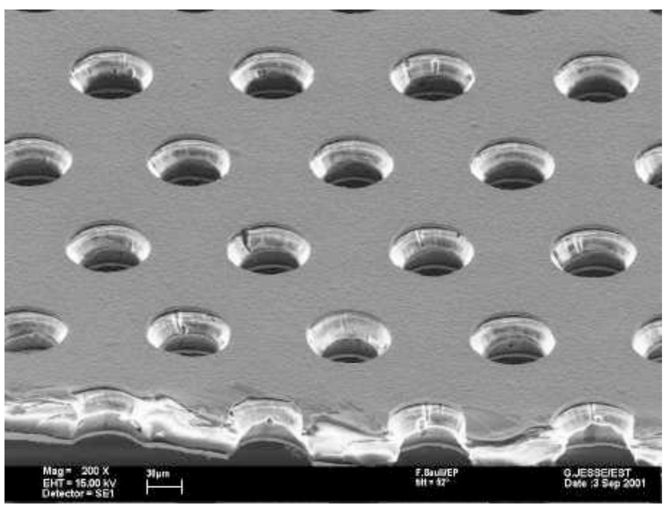
Photo of a GEM





Electric field in the holes >20kV/cm

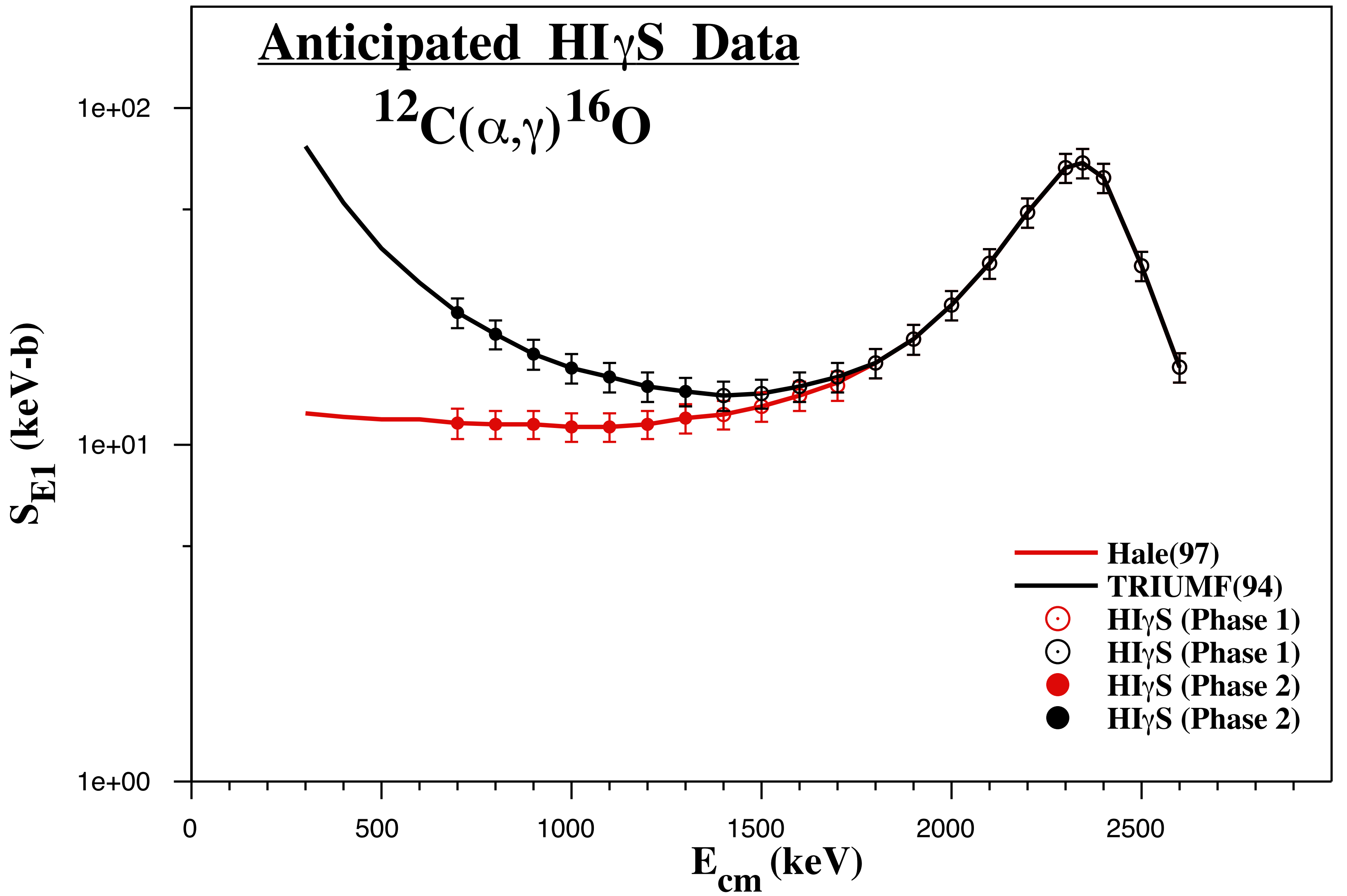
Electron Microscope view of a GEM



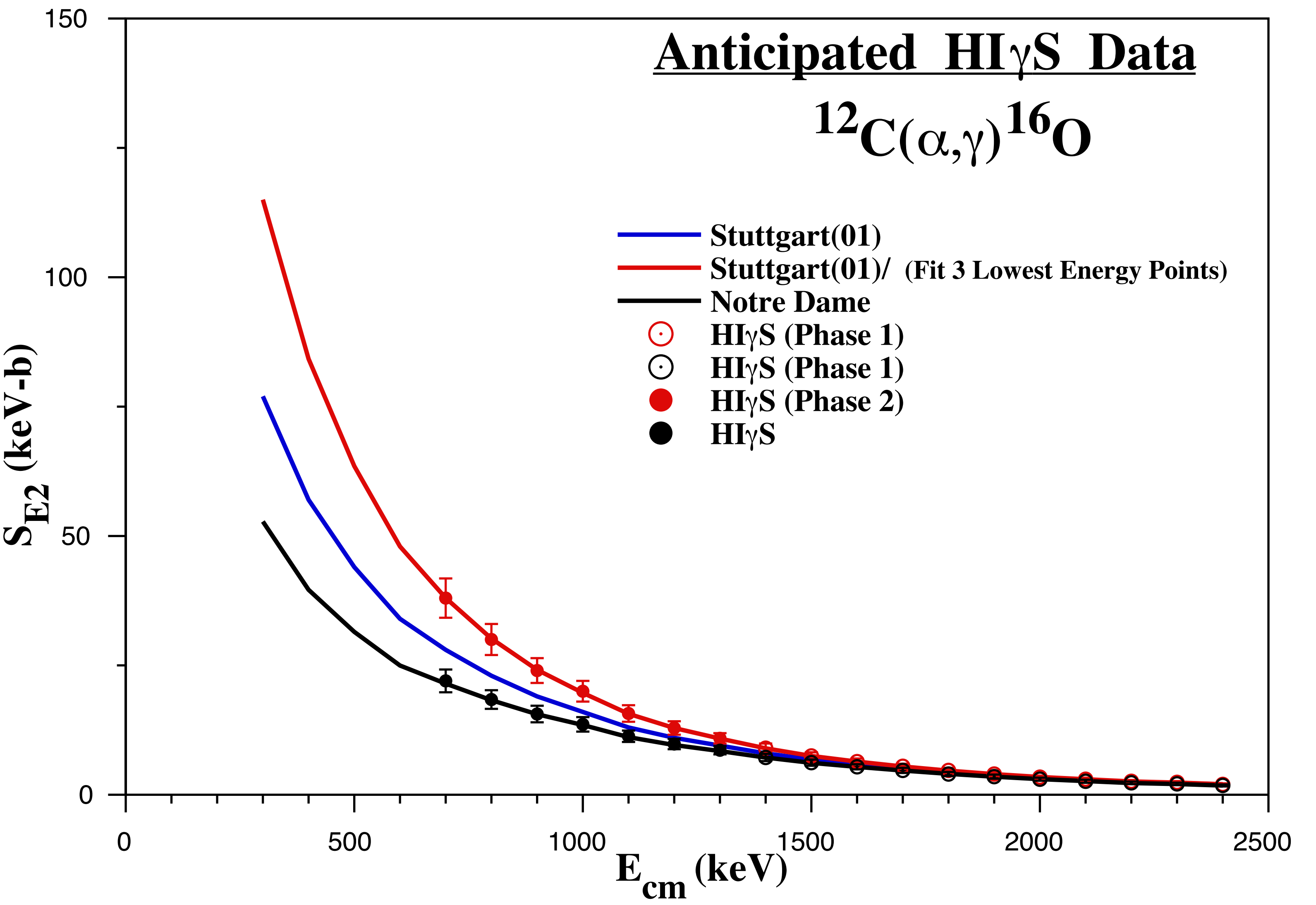
Typical parameters:

- 50μm Kapton
- metal coated
- Ø50-70μm holes
- 100-200μm pitch
- 80% opacity

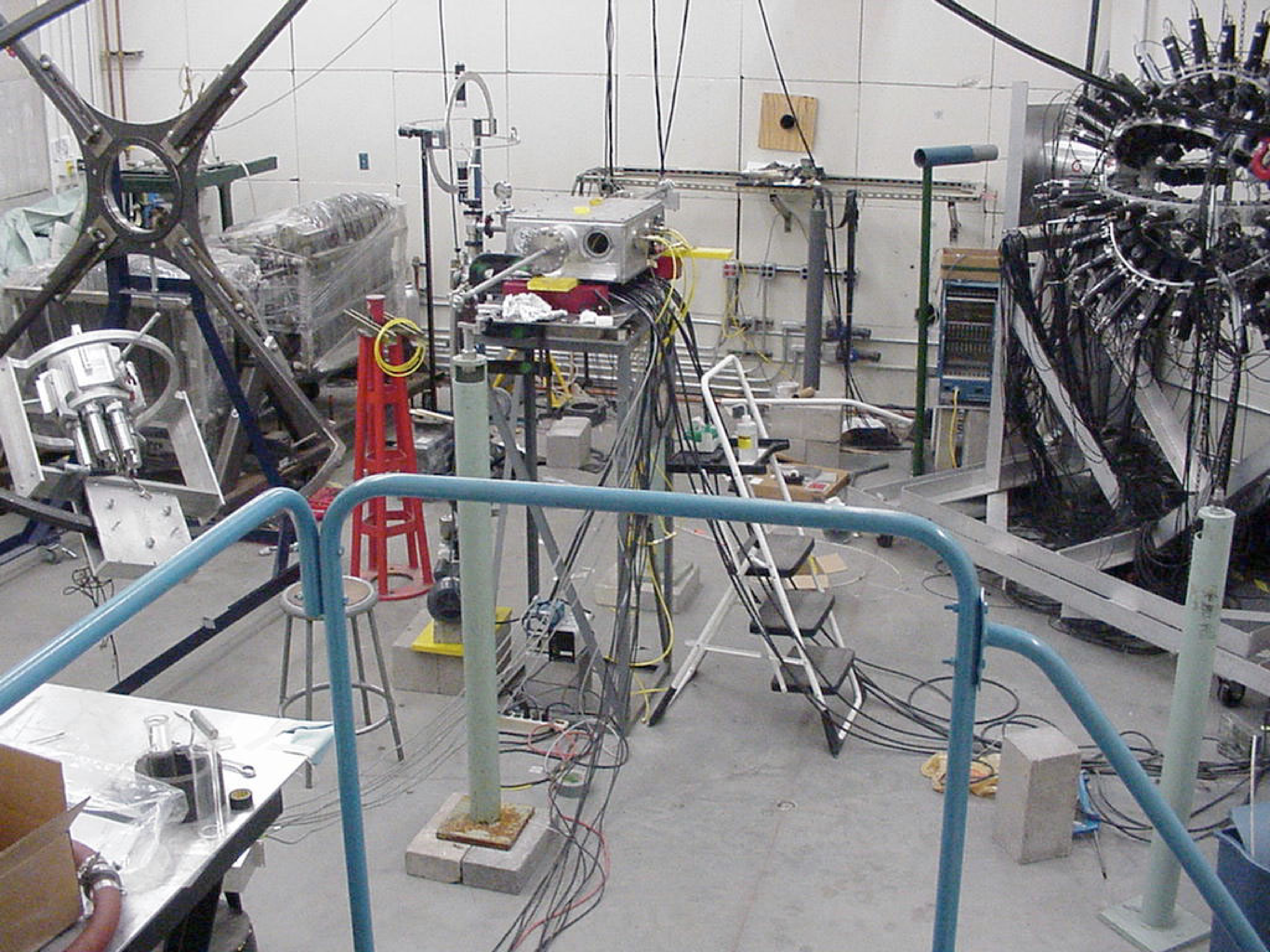
A. Breskin

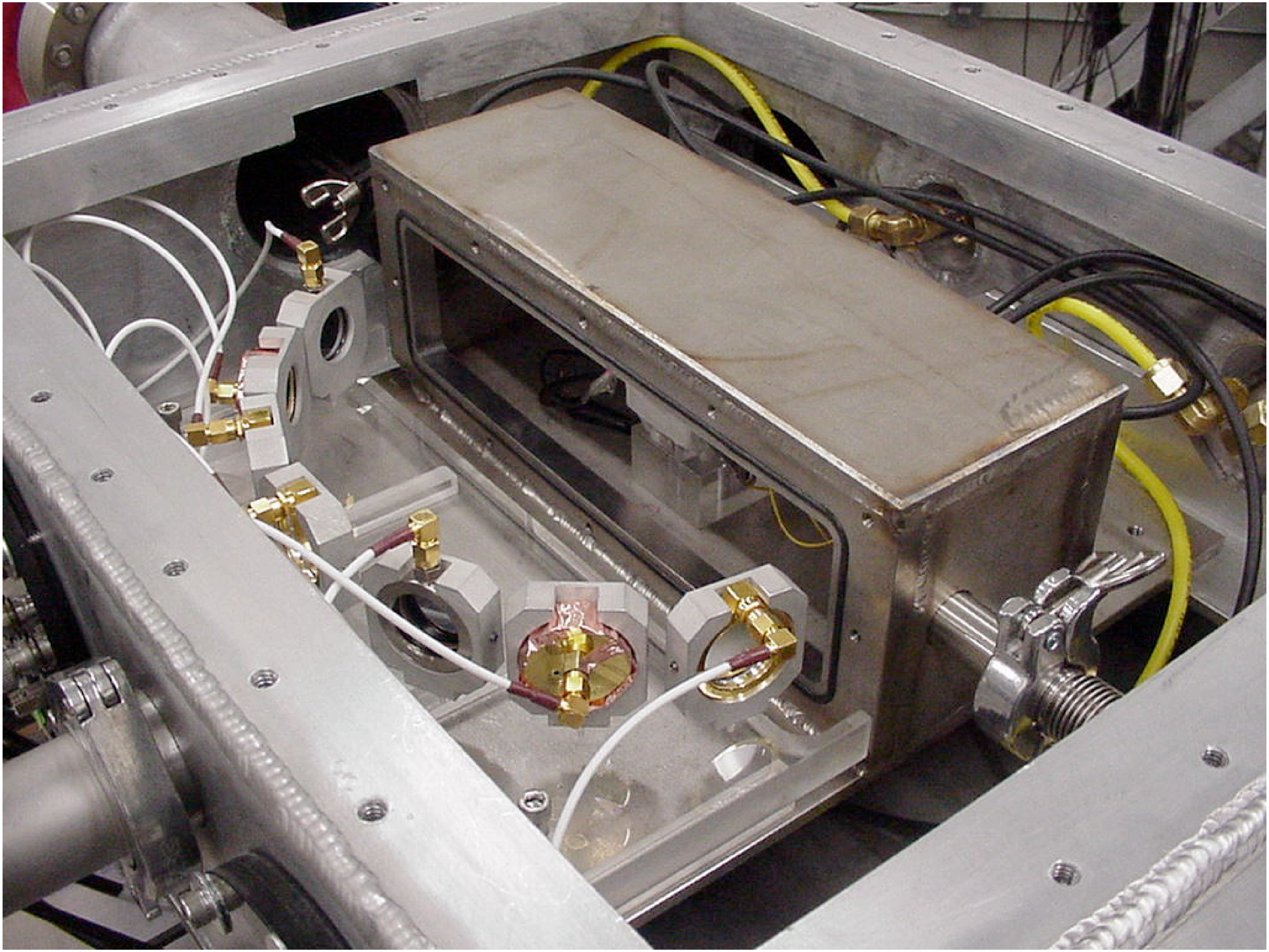


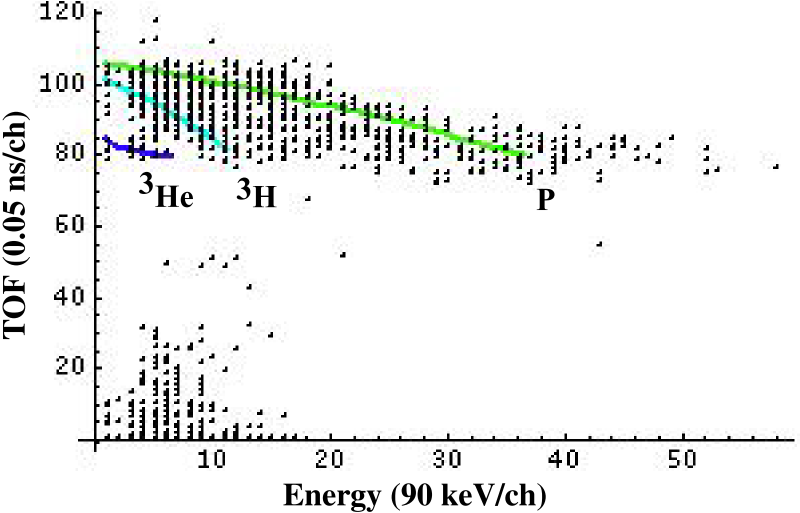
Anticipated HIγS Data
$^{12}C(\alpha,\gamma)^{16}O$
1e+02
1e+01
1e+00
S_{E1} (keV-b)
0
500
1000
1500
2000
2500
E_{cm} (keV)
Hale(97)
TRIUMF(94)
HIγS (Phase 1)
HIγS (Phase 1)
HIγS (Phase 2)
HIγS (Phase 2)



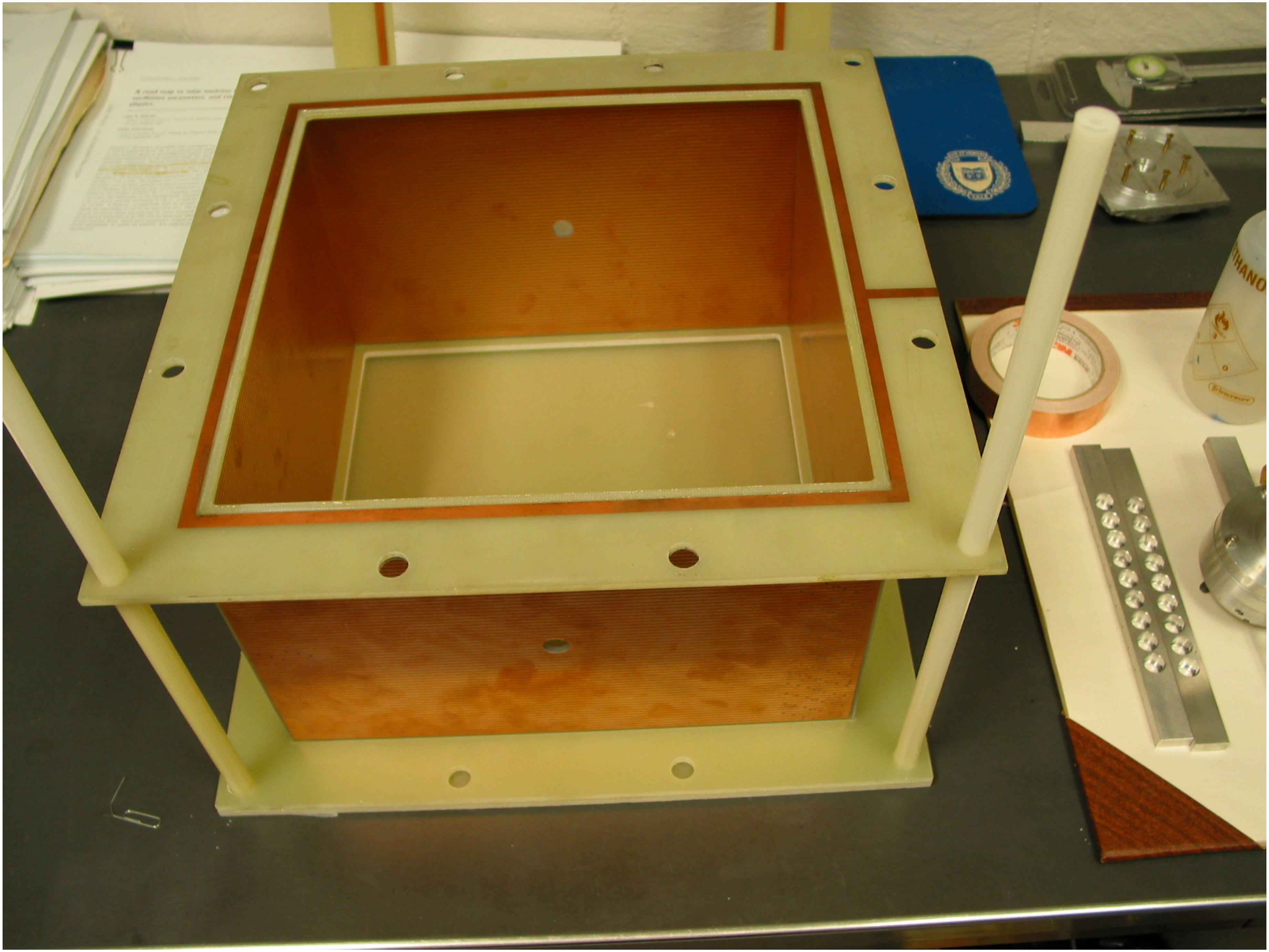
Anticipated HIγS Data
$^{12}C(\alpha,\gamma)^{16}O$
Stuttgart(01)
Stuttgart(01)/ (Fit 3 Lowest Energy Points)
Notre Dame
HIγS (Phase 1)
HIγS (Phase 1)
HIγS (Phase 2)
HIγS
S_{E2} (keV-b)
E_{cm} (keV)
0
50
100
150
0
500
1000
1500
2000
2500

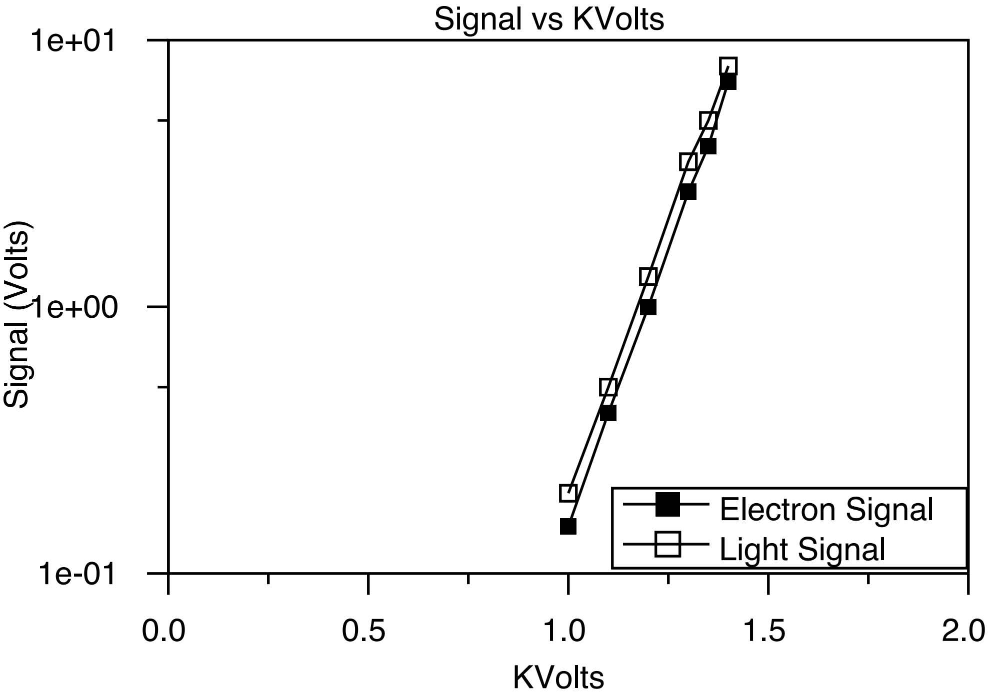


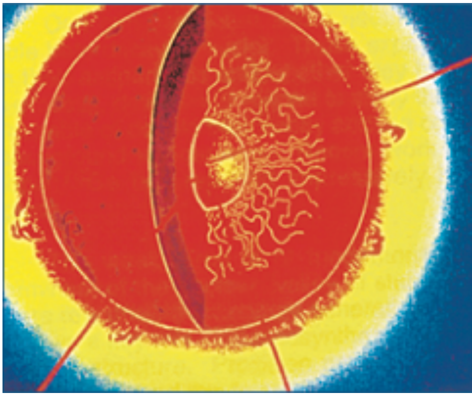




TOF (0.05 ns/ch)
120
100
80
60
40
20
^{3}He
^{3}H
P
10
20
30
40
50
Energy (90 keV/ch)




Signal vs KVolts
1e+01
1e+00
1e-01
Signal (Volts)
0.0
0.5
1.0
1.5
2.0
KVolts
Electron Signal
Light Signal



University of Connecticut
Laboratory for Nuclear Science
at Avery Point

1. **The Problem: C/O ratio in Helium Burning**
   (Who cares? the shattered hopes/illusions)

We Have a Major Problem
It is Not Solved After 30 Years
The Physics Community Cares

2. **The Solution: O-TPC**
   (Who will do it? and where?)

HIγS + O-TPC
UConn-Weizmann-PTB-Duke

Breckenridge, 11 Februray 2005