Measurement of the Superallowed Strength of ^{10}C

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Cabibbo-Kobayashi-Maskawa Weak Quark Mixing Matrix

$$\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & U_{ub} \\ V_{cd} & V_{cs} & U_{cb} \\ V_{td} & V_{ts} & U_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$|V|^2 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1?$$

- $G_V = G_F$ from $\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$
- $G_V = G_F|V_{ud}|$ from $\pi^+ \to \pi^0 + e^+ + \nu_e$
- $G_V = G_F|V_{us}|$ from $K^+ \to \pi^0 + e^+ + \nu_e$
- $G_V = G_F|V_{ub}|$ from $B^+ \to \pi^0 + e^+ + \nu_e$

$$\frac{\Gamma(\pi^+ \to \pi^0 + e^+ + \nu_e)}{\Gamma(\pi^+ \to \text{all})} = (1.040 \pm 0.006) \times 10^{-8}$$

Allowed Nuclear Beta Decay

$$\Gamma = \frac{1}{\tau} = \frac{\ln 2}{t} = \frac{m_e^5 c^4}{2\pi^3 \hbar^7} \left(G_V^2 |M_V|^2 + G_A^2 |M_A|^2 \right) f$$

$$f = \int_{m_e}^{E_0} F(Z, E) p E (E_0 - E)^2 dE$$

$$G_V^2 = G_F^2 |V_{ud}|^2$$

Superallowed Beta Decay

$0^+ \rightarrow 0^+$

$$\Gamma = \frac{1}{\tau} = \frac{\ln 2}{t} = \frac{m_e^5 c^4}{2\pi^3 \hbar^7} G_V^2 |M_V|^2 f$$

$T = 1$ Isotriplet

$$(T = 1, T_3 = \pm 1) \rightarrow (T = 1, T_3 = 0)$$

Conserved Vector Current (CVC) Hypothesis

$$|M_V(q^2 = 0)|^2 = 2$$

Corrections

Isospin Breaking Corrections

$$|M_V(q^2 = 0)|^2 = 2(1 - \delta_C)$$

Outer Radiative Corrections

$$f \to f(1 + \delta_R)$$

Inner Radiative Corrections

$$G_V^2 \to G_V^2(1 - \Delta_R^V)$$

Measure

1. Total Half Life $t_{\frac{1}{2}}$

2. $0^+ \rightarrow 0^+$ Branching Ratio ($\frac{1}{t} = BR \times \frac{1}{t_{\frac{1}{2}}}$)

3. $E_0 = Q + m_e$

Calculate

1. Inner Radiative Corrections Δ_R^V

2. Outer Radiative Corrections δ_R

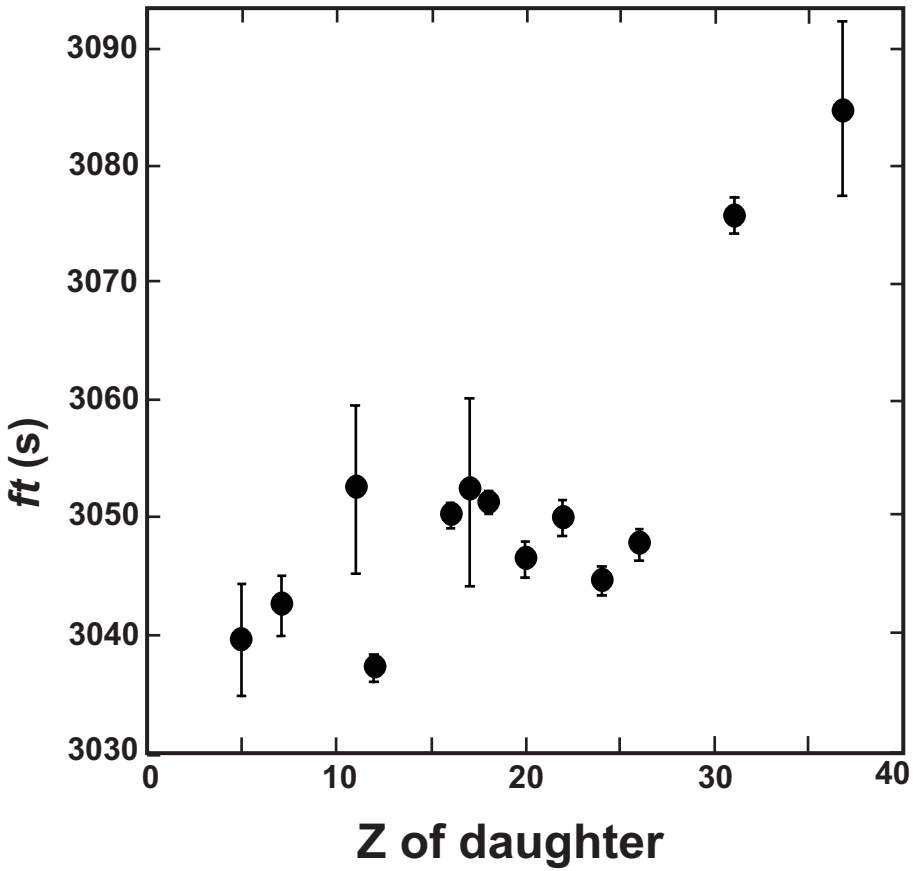
3. Isospin Breaking Corrections δ_C

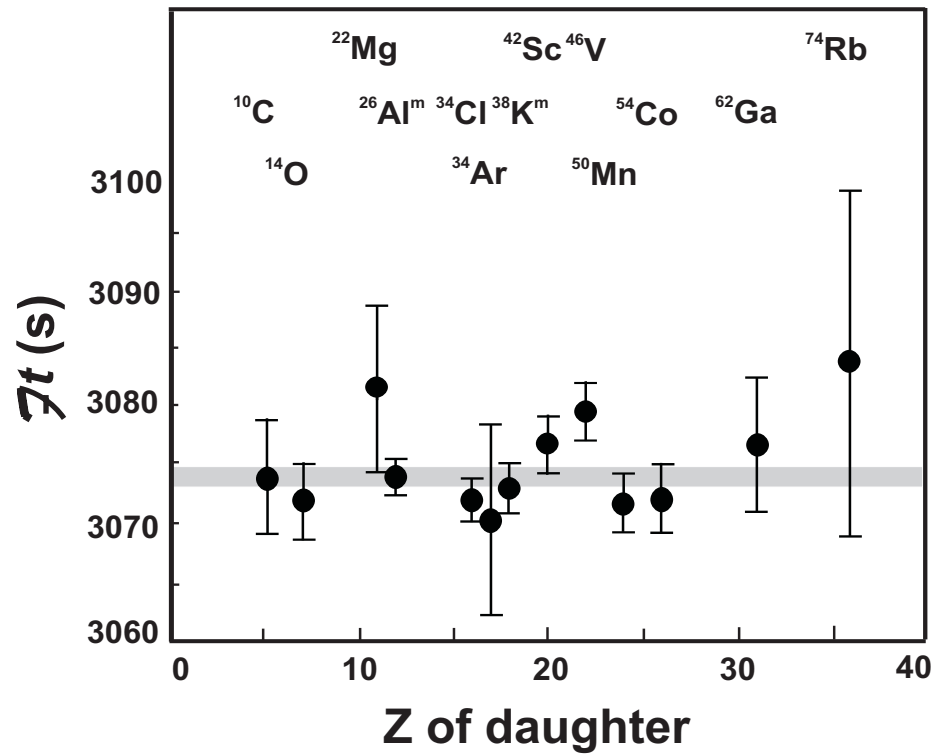
$$\mathsf{F}t \equiv ft(1+\delta_R)(1-\delta_C)$$

$$G_V^2 = \frac{K}{2\mathsf{F}t}$$

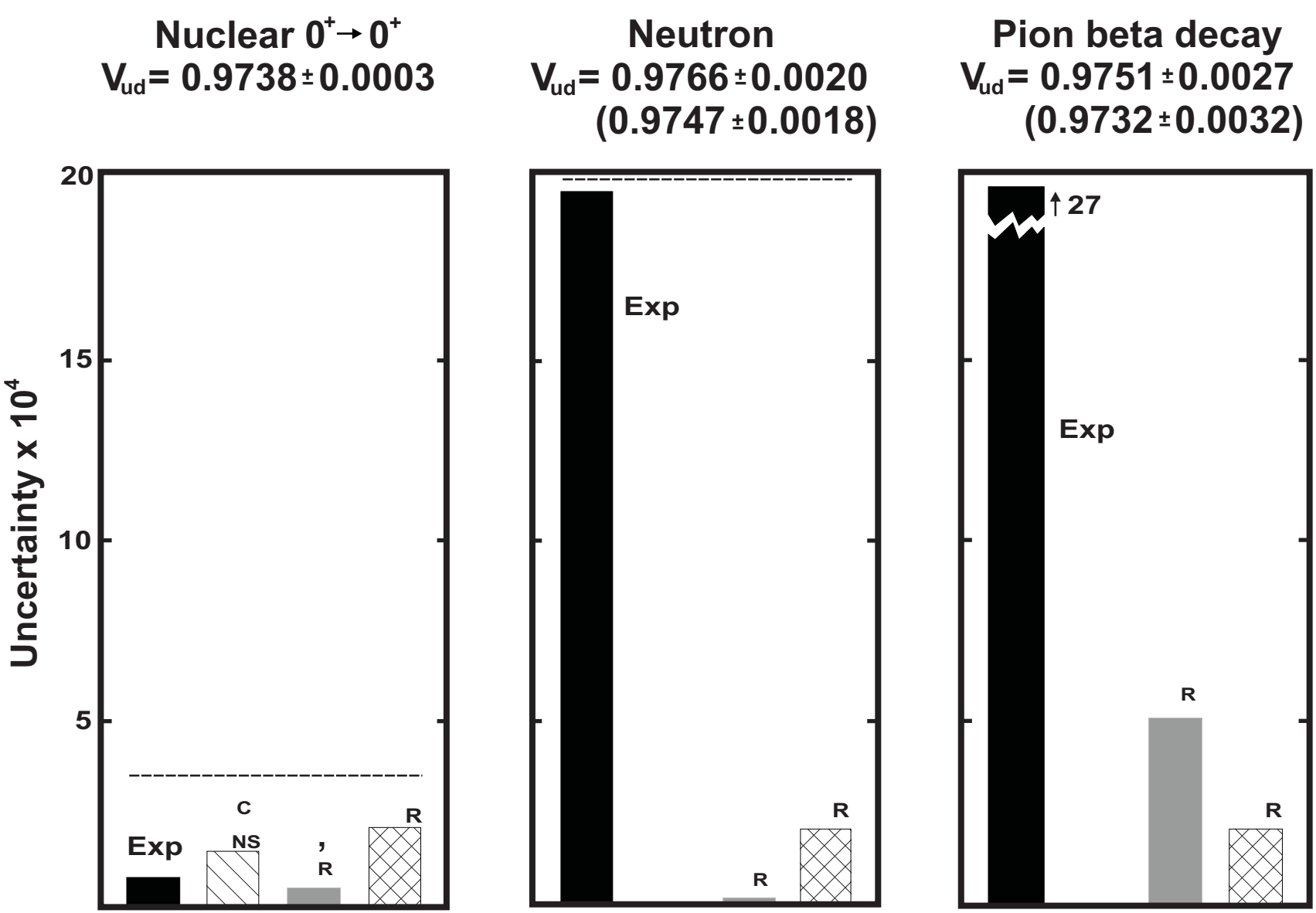
$$|V_{ud}|^2 = \frac{G_V^2(1-\Delta_R^V)}{G_F^2}$$

$$\frac{K}{(\hbar c)^6} = \frac{2\pi^3\hbar}{(m_e c^2)^5} = (8.120270 \pm 0.000012) \times 10^{-7} GeV^{-4} s$$





J.C. Hardy, CKM2006, hep-ph/0703165



J.C. Hardy, CKM2006, hep-ph/0703165

- $|V_{ud}| = 0.97378 \pm 0.00027$ from Superallowed Beta Decay
- $|V_{us}| = 0.2200 \pm 0.0026$ from PDG2004
- $|V_{ub}| = 0.00367 \pm 0.00047$ from PDG2004

$$|V|^2 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9966 \pm 0.0014$$

- Use only the two most recent $|V_{us}|$ measurements

- $|V|^2 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9993 \pm 0.0012$

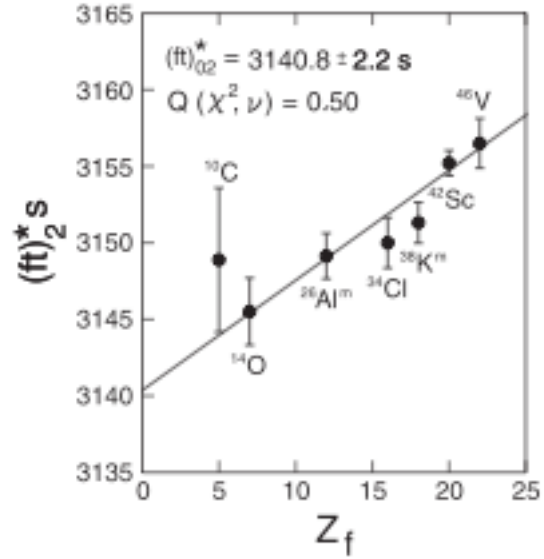


Fig. 1. The $(ft)^*_2 = ft(1 + \Delta^R)(1 - \delta_C)$, Δ^R being the overall radiative correction as defined in Ref. [2] and δ_C the nuclear mismatch following Ormand and Brown [6]. $(ft)^*_{02}$ is defined at $Z_f = 0.5$.

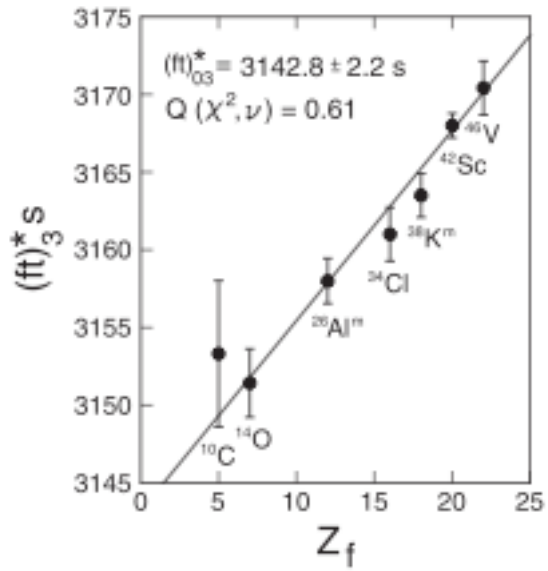
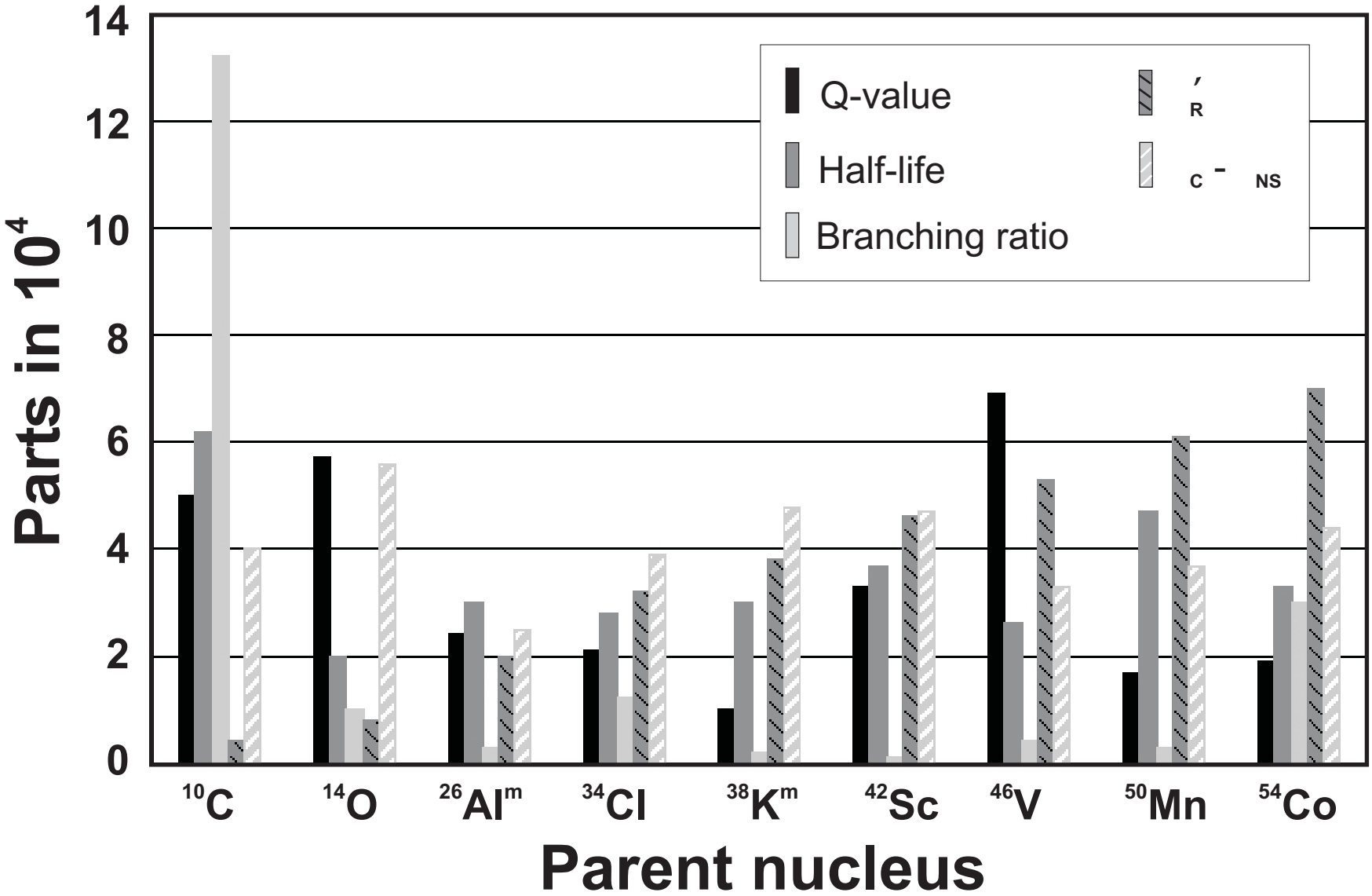
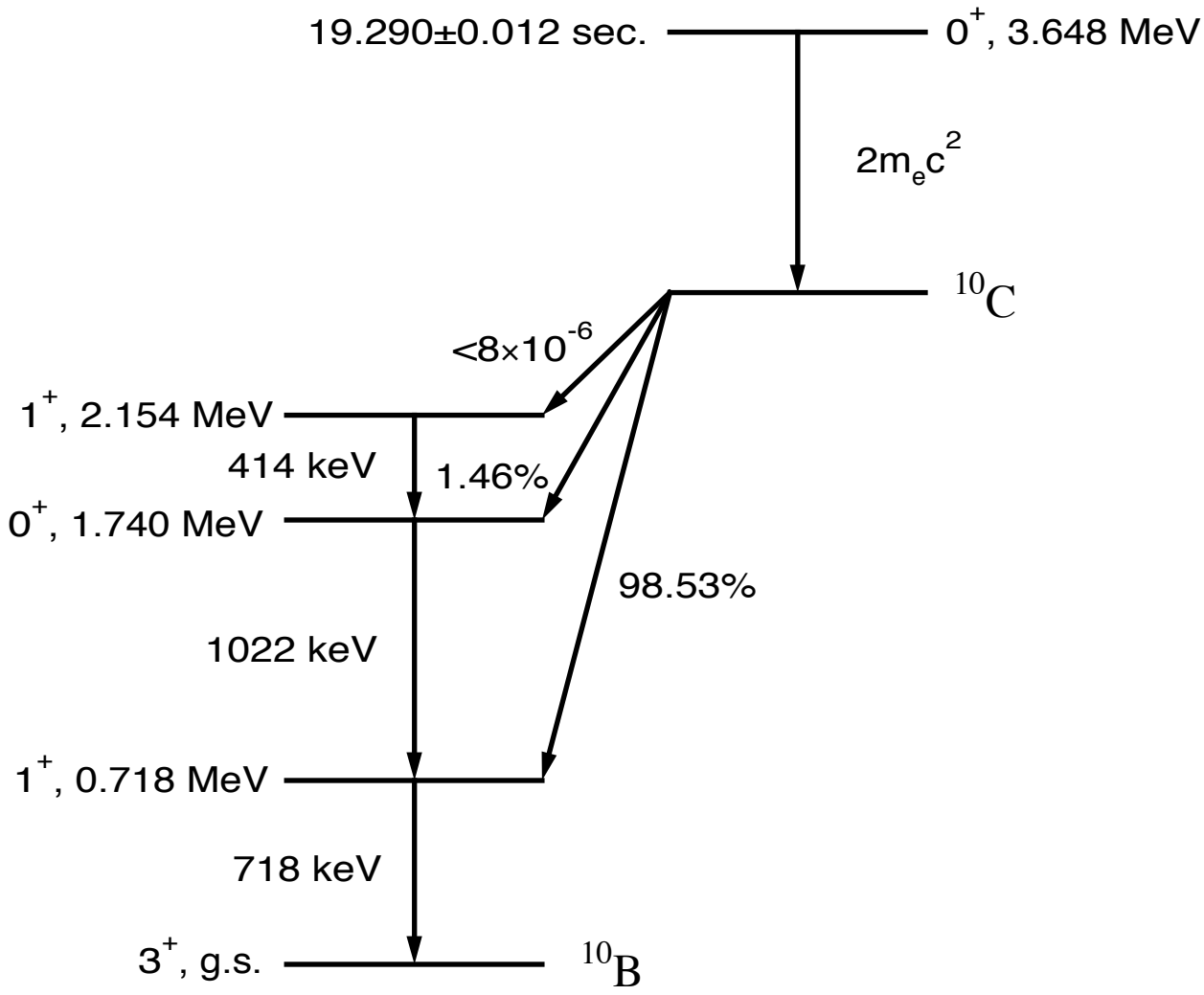


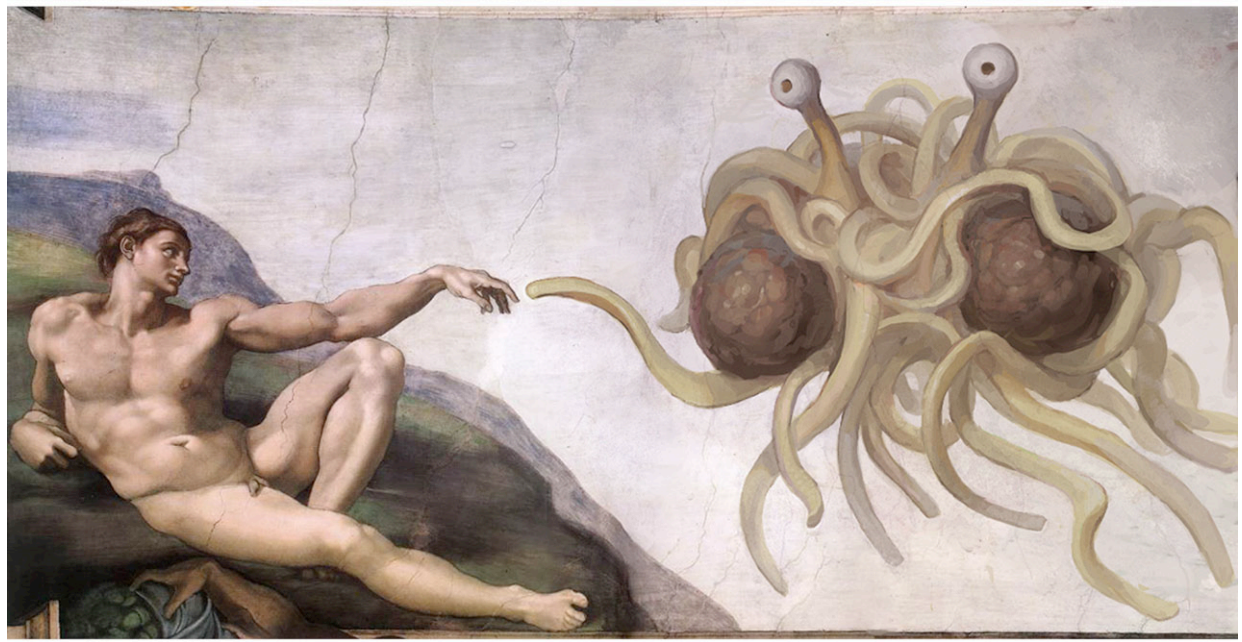
Fig. 2. The $(ft)^*_3 = ft(1 + \Delta^R)(1 - \delta_{Cf})$, Δ^R being the overall radiative correction as defined in Ref. [2] and δ_{Cf} the *fluctuation* of the mismatch from a smooth line through the δ_C of Fig. 1. $(ft)^*_{03}$ is defined at $Z_f = 0.5$.

D.H. Wilkinson
NIM A 543, 497 (2005)



J.C. Hardy and I.S. Towner, nucl-th/0412056


19.290±0.012 sec.
0+, 3.648 MeV
2mec2
10C
<8×10-6
1+, 2.154 MeV
414 keV
1.46%
0+, 1.740 MeV
98.53%
1022 keV
1+, 0.718 MeV
718 keV
3+, g.s.
10B



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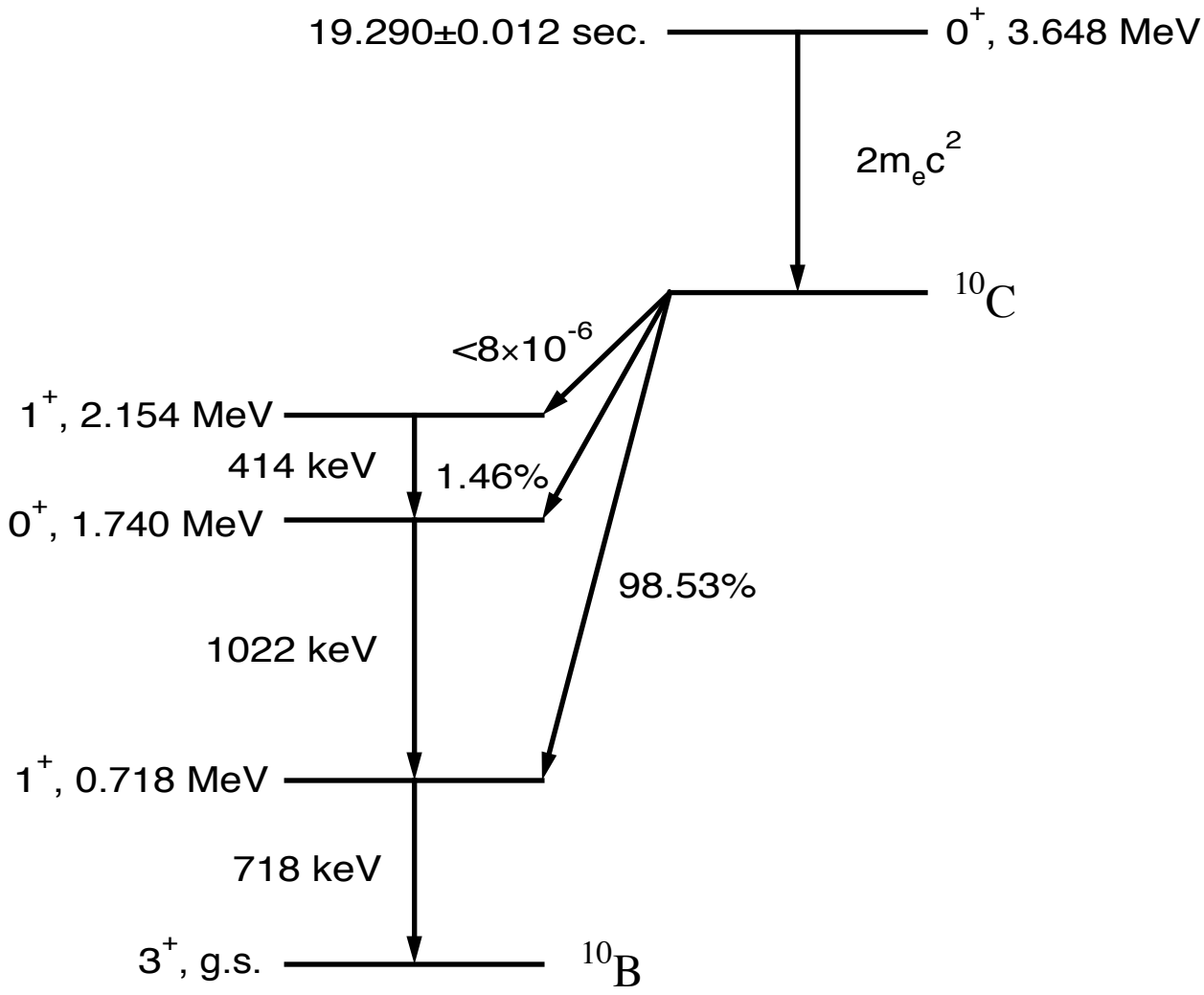
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1+, 2.154 MeV
414 keV
1.46%
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1022 keV
1+, 0.718 MeV
718 keV
3+, g.s.
10B

Measurement of the Strength of the Superallowed Fermi Branch in the Beta Decay of ^{10}C with GAMMASPHERE

Brian Fujikawa (LBNL), Steve Astalos (LLNL), Tom Banks (UCB), Jason Burke (LLNL), Stuart Freedman (UCB/LBNL), John Greene (ANL), Nick Scielzo (LLNL), Paul Vetter (LBNL), and Wes Winter (UCB/LBNL)

Experiment 1: Measurement of $R = \frac{Y(^{10}\text{C:}1022\,\text{keV})}{Y(^{10}\text{C:}718\,\text{keV})}$

$$^{10}\text{B(p, n)}^{10}\text{C}$$

Experiment 2: Measurement of $\epsilon = \frac{Y(^{10}\text{B:}1022\,\text{keV})}{Y(^{10}\text{B:}718\,\text{keV})}$

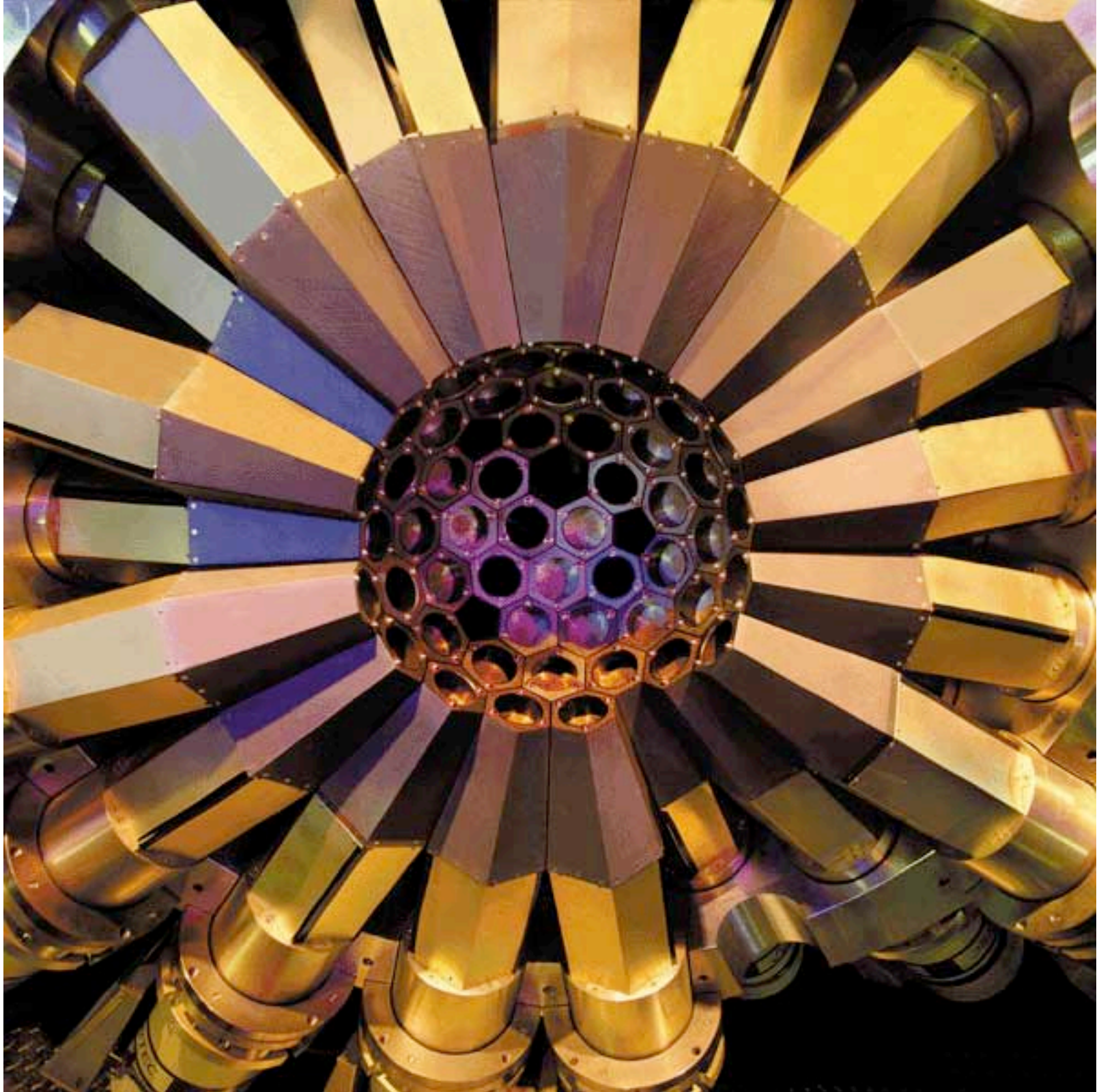
$$^{10}\text{B(p, p}\acute{}\text{)}^{10}\text{B}(1^{+}, 2.15\,\text{MeV})$$

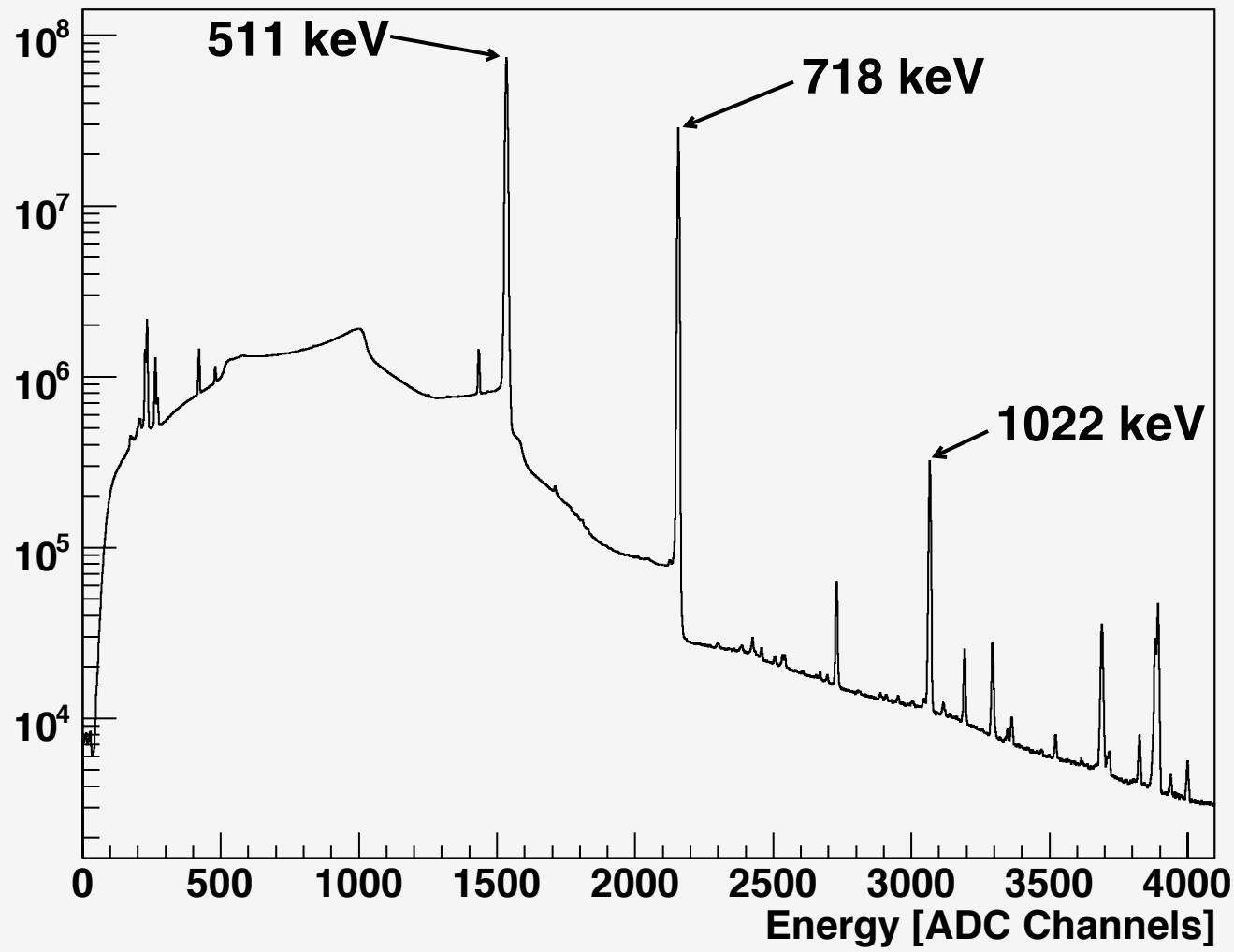
Experiment 3: Measurement of $Y(2 \times 511\,\text{keV})$

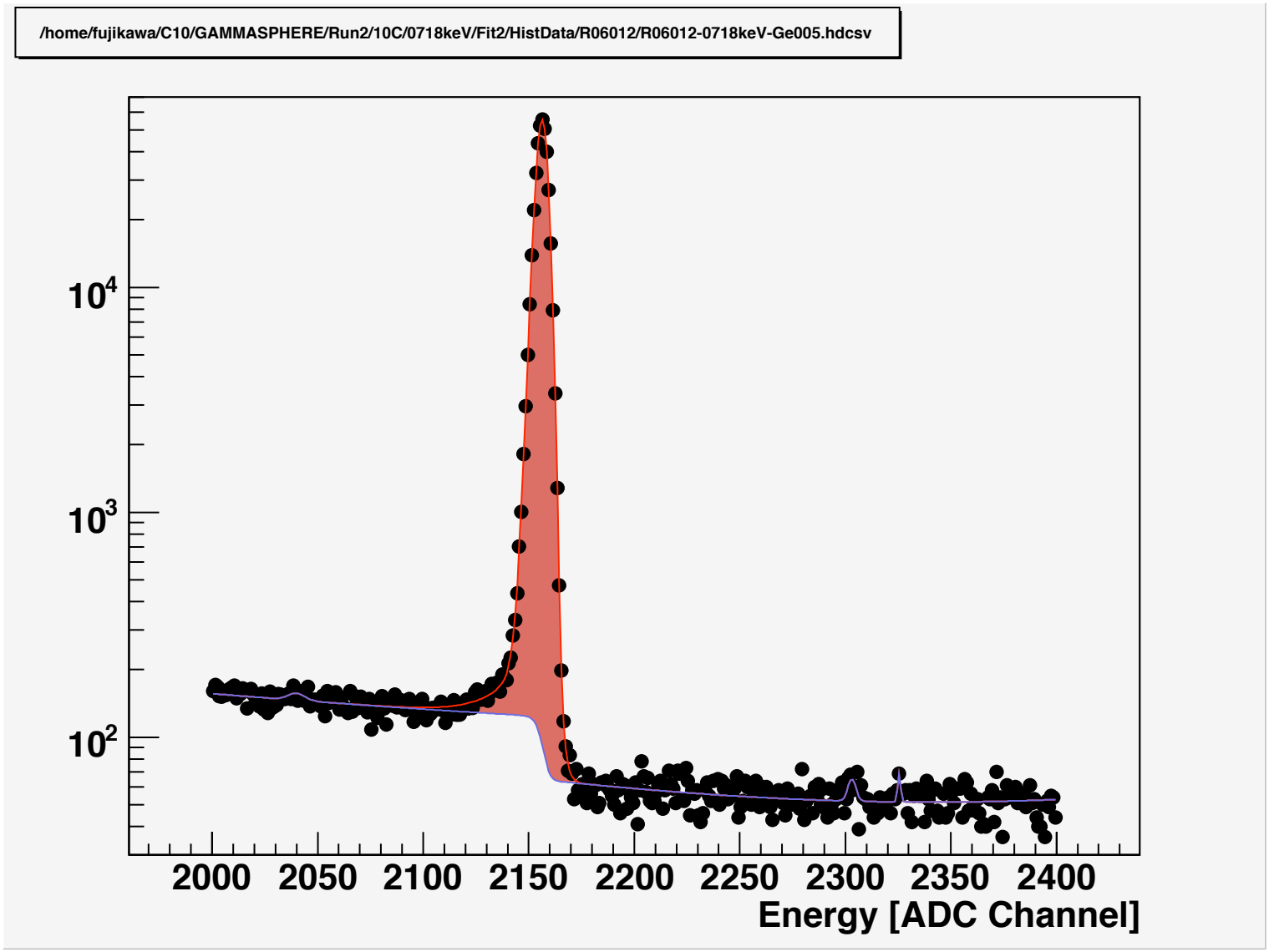
$$^{19}\text{F(p, n)}^{19}\text{Ne, } ^{68}\text{Ge}$$

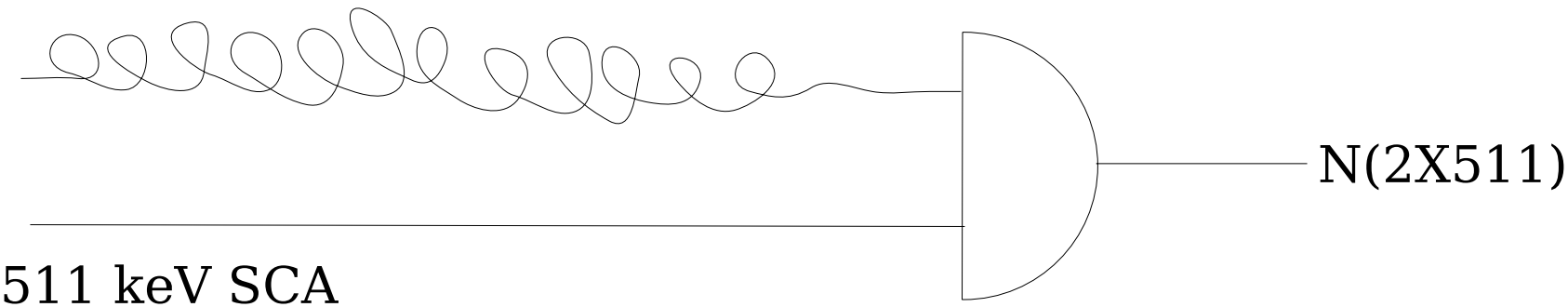
Result:

$$BR = \frac{\frac{Y(^{10}\text{C:}1022\,\text{keV}) - Y(2\times 511\,\text{keV})}{Y(^{10}\text{C:}718\,\text{keV})}}{\frac{Y(^{10}\text{B:}1022\,\text{keV})}{Y(^{10}\text{B:}718\,\text{keV})}}$$




511 keV
718 keV
1022 keV
10^8
10^7
10^6
10^5
10^4
0
500
1000
1500
2000
2500
3000
3500
4000
Energy [ADC Channels]


/home/fujikawa/C10/GAMMASPHERE/Run2/10C/0718keV/Fit2/HistData/R06012/R06012-0718keV-Ge005.hdcsv
10^4
10^3
10^2
2000
2050
2100
2150
2200
2250
2300
2350
2400
Energy [ADC Channel]

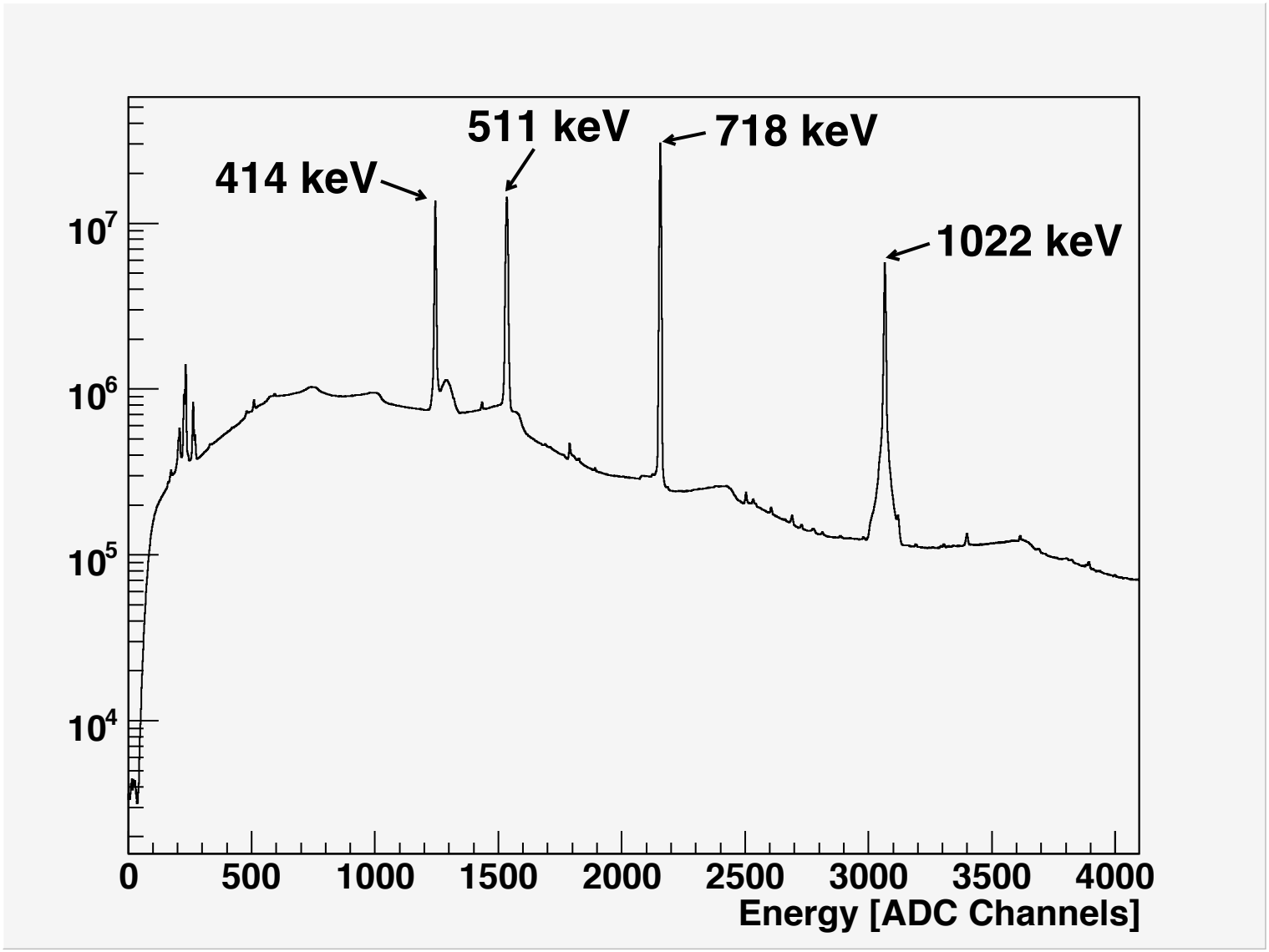


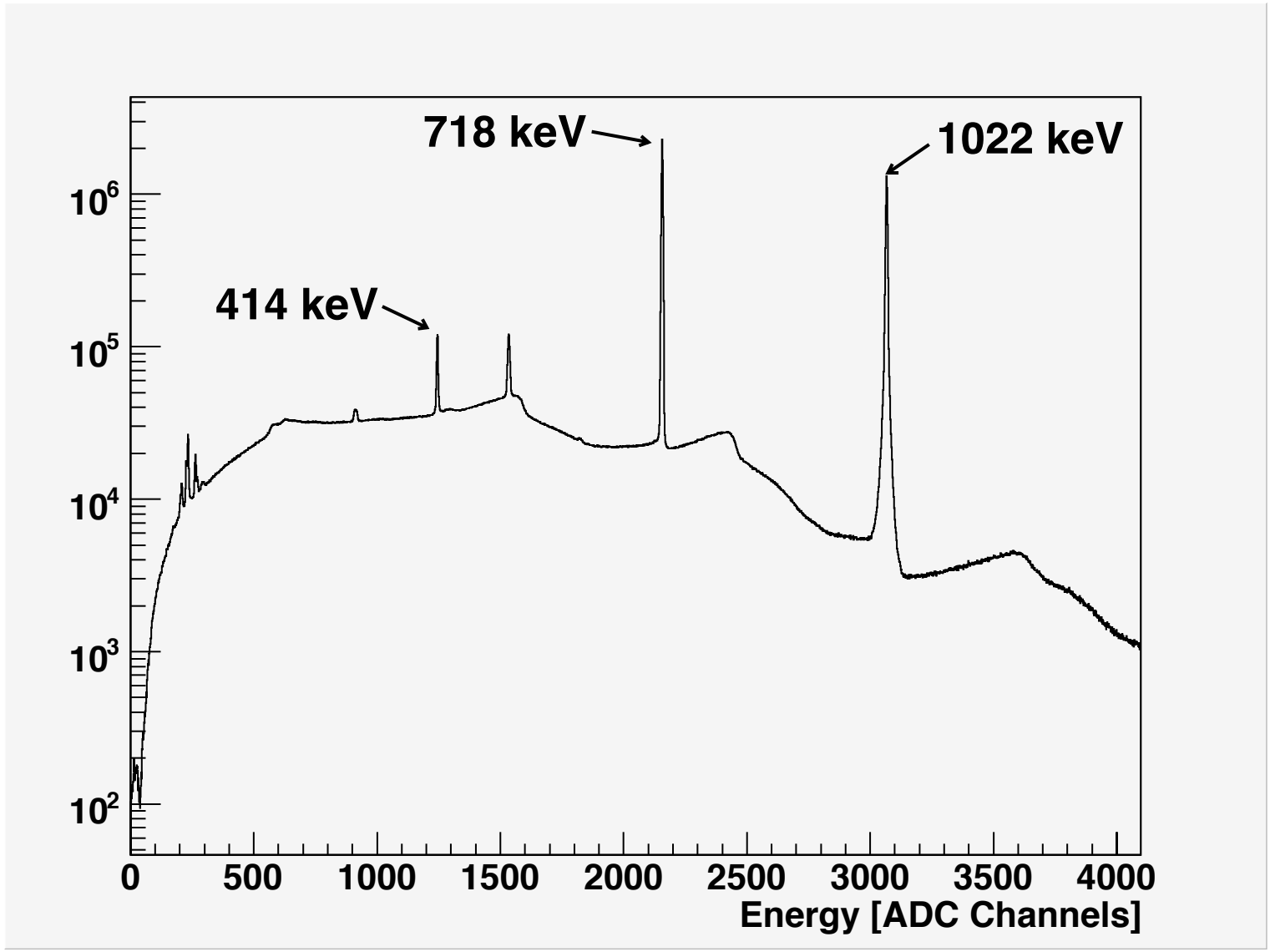
Fake Pileup Circuit: $N(2 \times 511\,\text{keV}) = (r_{511}T)(r_{511}\tau_F)$

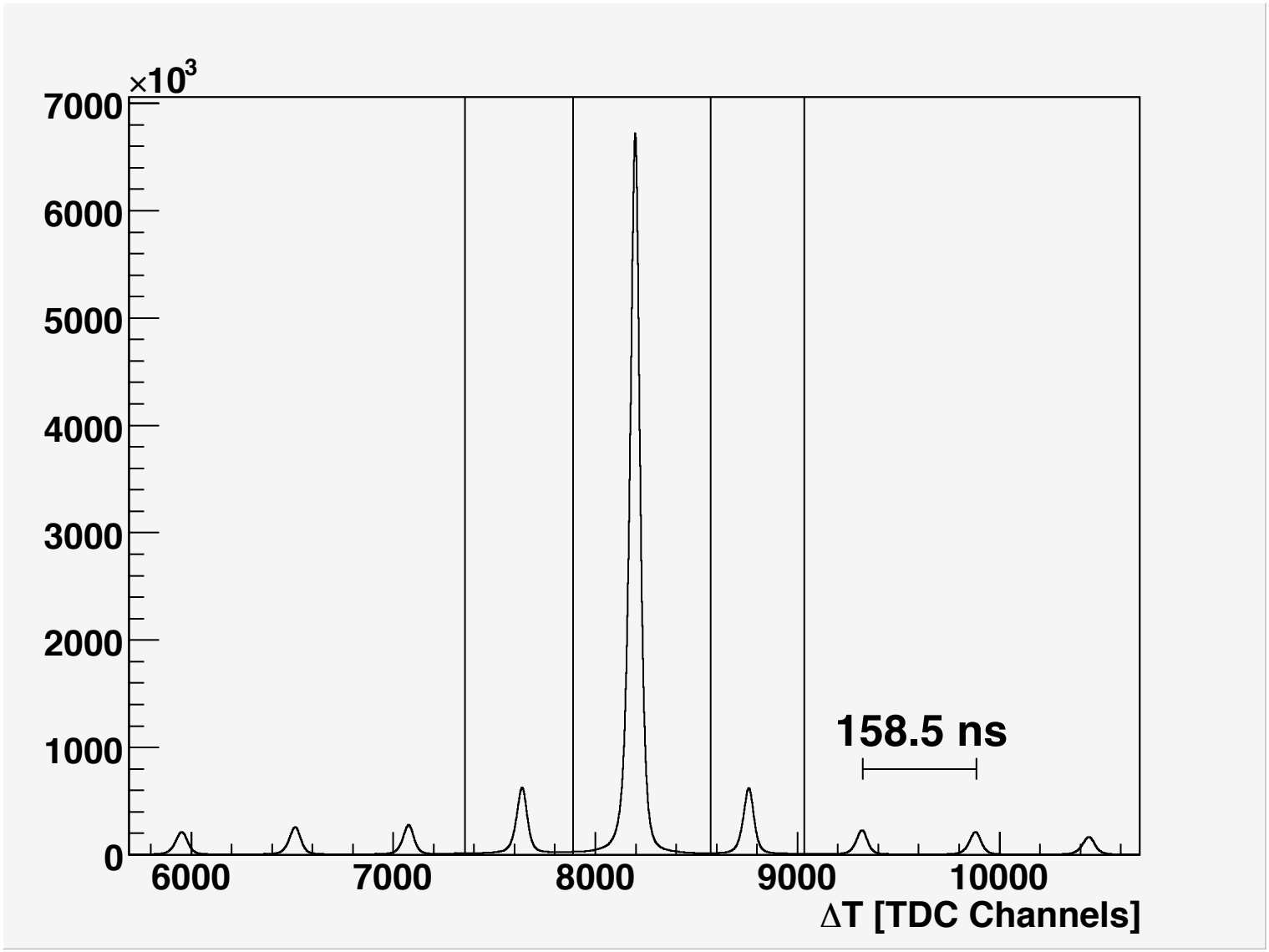
Amplifier Circuit: $Y(2 \times 511\,\text{keV}) = (r_{511}T)(r_{511}\tau_A)$

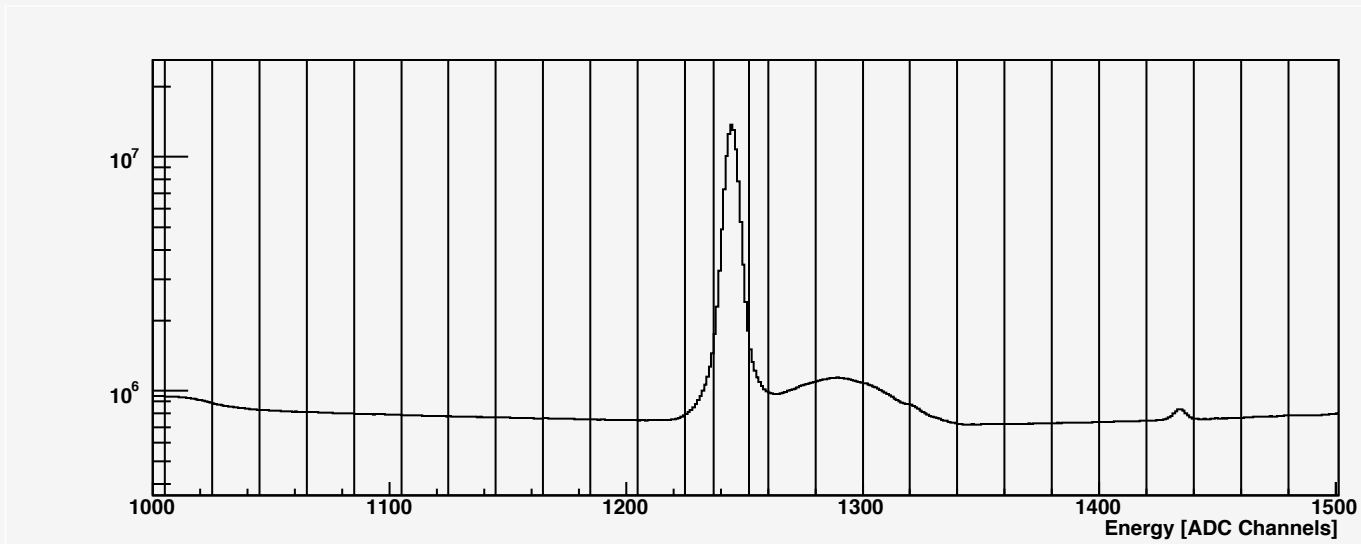
$$\frac{Y(2 \times 511\,\text{keV})}{N(2 \times 511\,\text{keV})} = \frac{\tau_A}{\tau_F} = const.$$

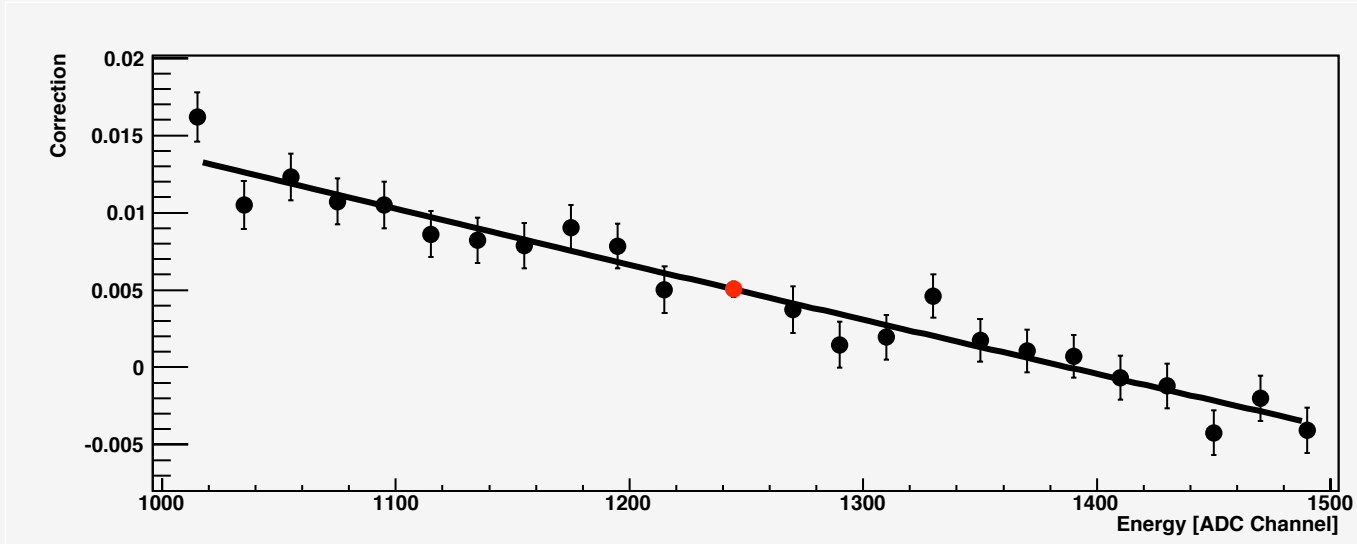
Method	2×511 keV Pileup Correction
^{19}Ne	-3.34(6)%
^{68}Ge	-3.37(3)%


414 keV
511 keV
718 keV
1022 keV
10^7
10^6
10^5
10^4
0
500
1000
1500
2000
2500
3000
3500
4000
Energy [ADC Channels]


718 keV
1022 keV
414 keV
10^6
10^5
10^4
10^3
10^2
0
500
1000
1500
2000
2500
3000
3500
4000
Energy [ADC Channels]


×10^3
7000
6000
5000
4000
3000
2000
1000
0
6000
7000
8000
9000
10000
158.5 ns
ΔT [TDC Channels]

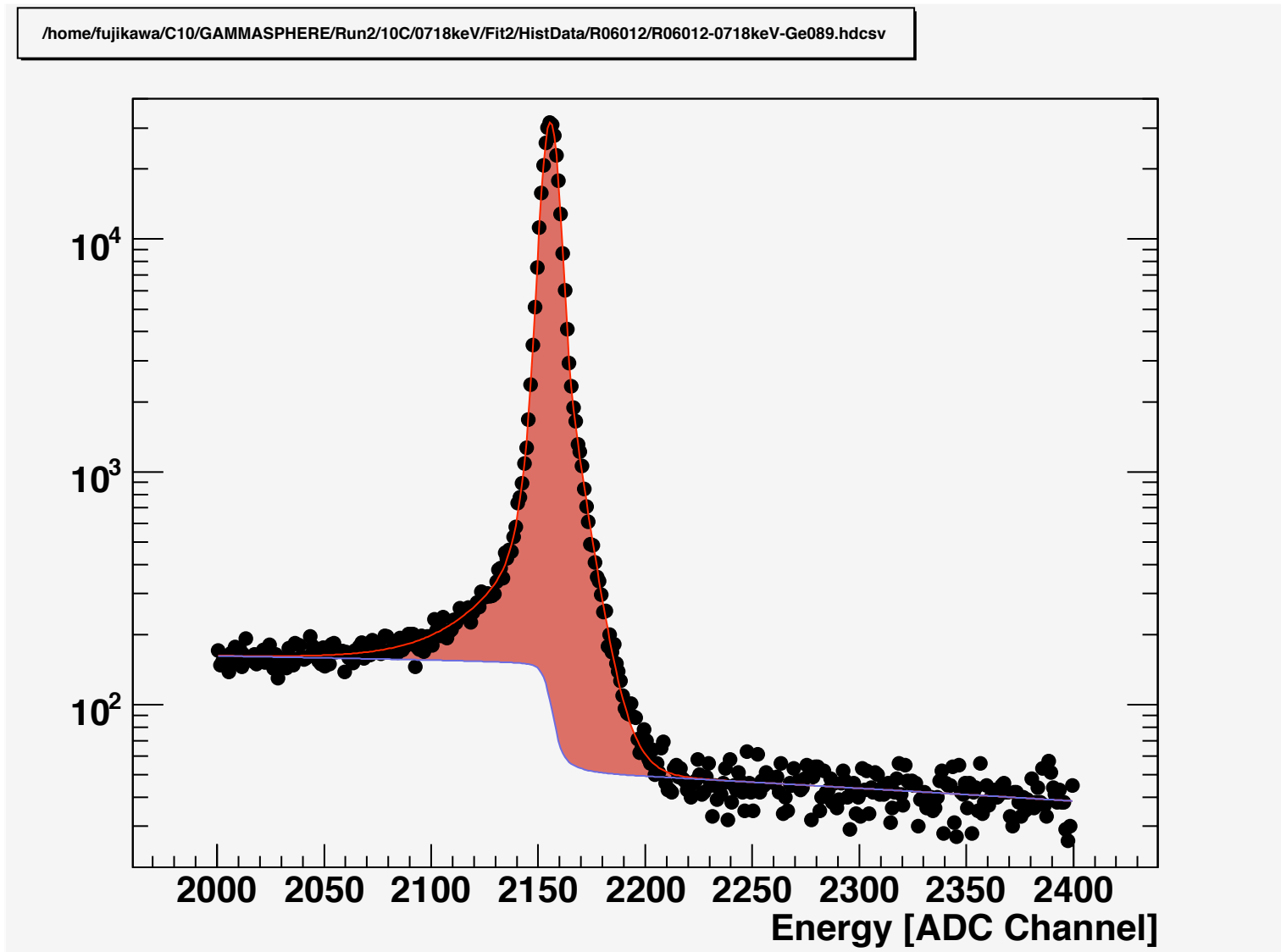

10^7
10^6
1000
1100
1200
1300
1400
1500
Energy [ADC Channels]


Correction
0.02
0.015
0.01
0.005
0
-0.005
1000
1100
1200
1300
1400
1500
Energy [ADC Channel]

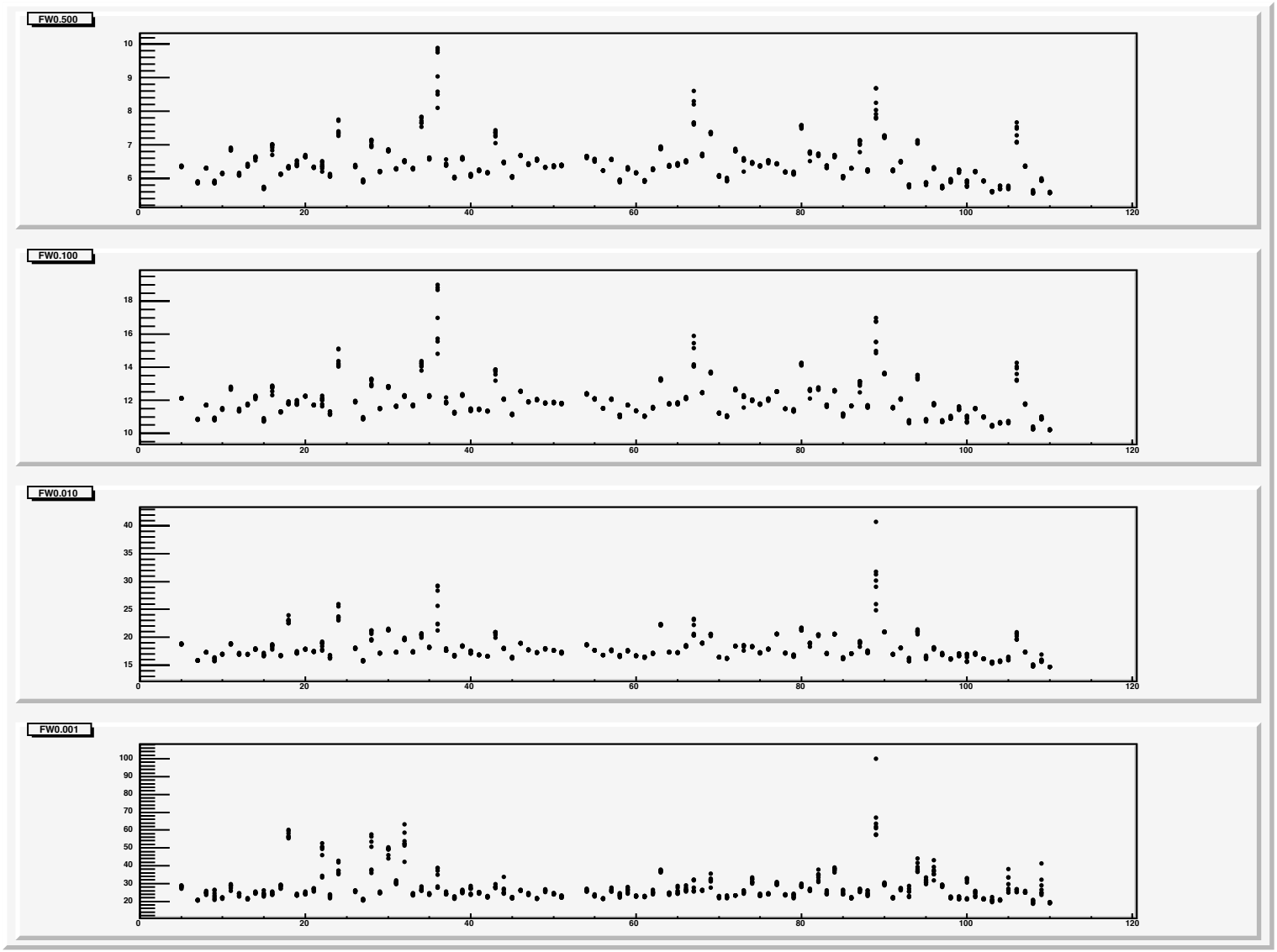
GAMMASPHERE has 110 Ge Detectors

- 8 detectors were missing
- 2 detectors were removed from the analysis for having unstable time peaks
- 2 detectors were removed from the analysis for having bad energy peak positions
- 2 detectors were removed from the analysis for having bad energy peak shapes
- 12 detectors removed from the analysis for having broad energy peaks
- 1 detector removed from the analysis for having bad pile-up rejection

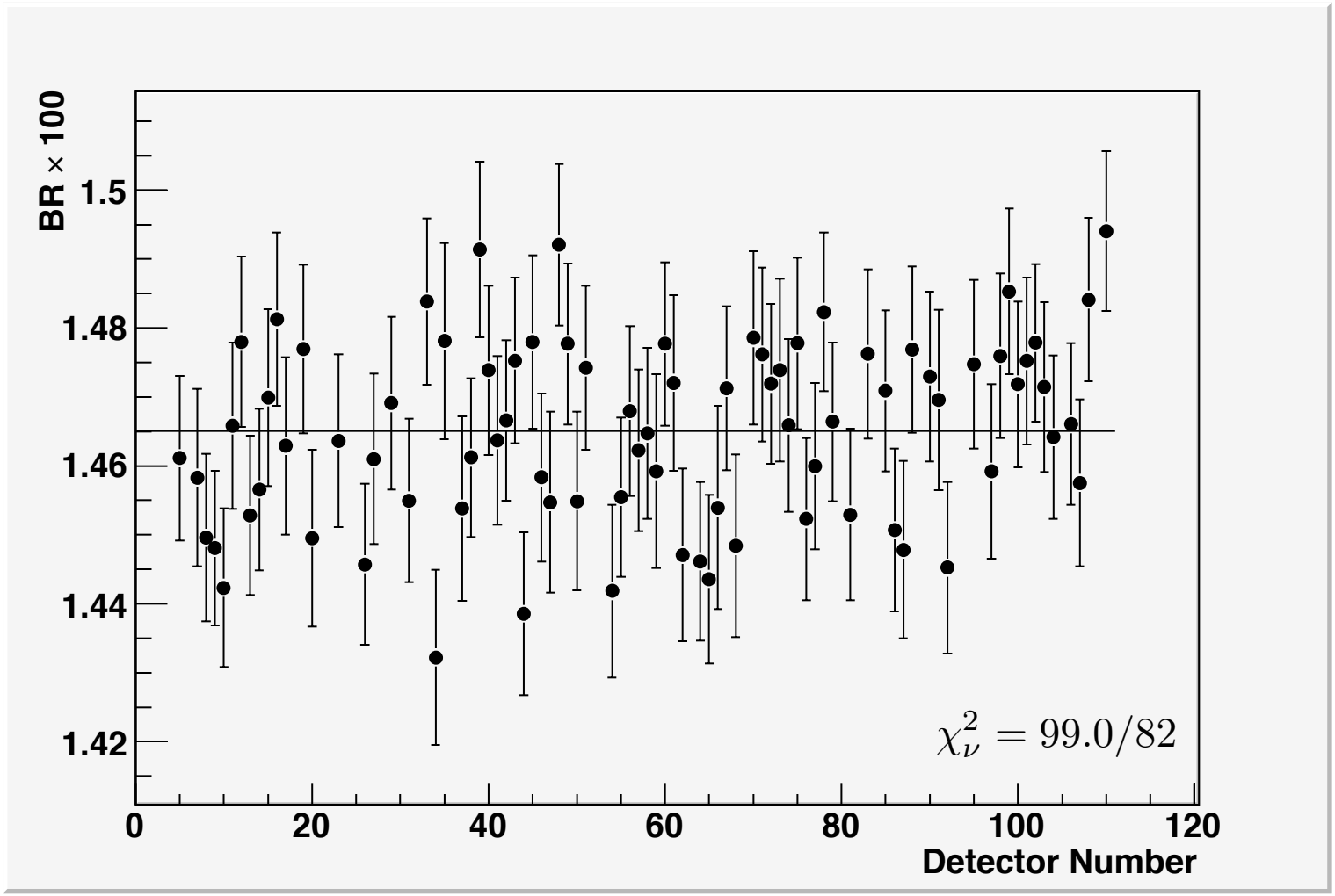
This analysis uses 83 Ge Detectors


/home/fujikawa/C10/GAMMASPHERE/Run2/10C/0718keV/Fit2/HistData/R06012/R06012-0718keV-Ge089.hdcsv
10^4
10^3
10^2
2000
2050
2100
2150
2200
2250
2300
2350
2400
Energy [ADC Channel]

Full Widths (718 keV Peak)

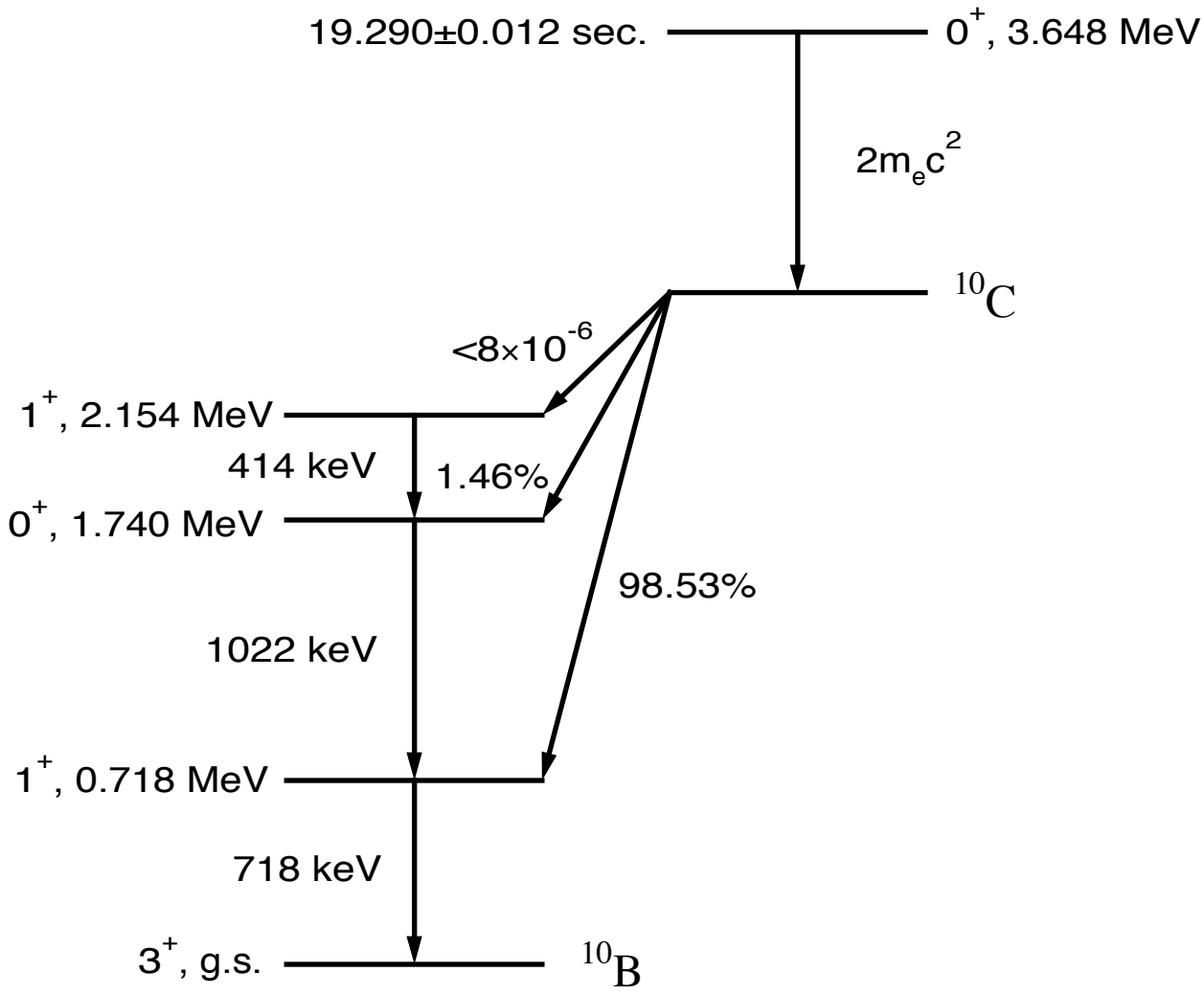


Detector Number


BR × 100
1.5
1.48
1.46
1.44
1.42
0
20
40
60
80
100
120
Detector Number
$\chi^2_\nu = 99.0/82$

Correction	Size	Affects
Accidental Coincidences	-1.753(9)%	Efficiency
Compton Background	-0.491(2)%	Efficiency
Double Escape Peak	-0.036(4)%	Efficiency
Kinematic Shift	-0.002(12)%	Efficiency
2×511 keV Pileup	-3.37(3)%	β Decay
Summing	-0.032(3)%	Efficiency
	+0.44(4)%	β Decay

$$R = (1.4641 \pm 0.0013_{stat} \pm 0.0004_{syst}) \times 10^{-2}$$


19.290±0.012 sec.
0+, 3.648 MeV
2mec2
10C
<8×10-6
1+, 2.154 MeV
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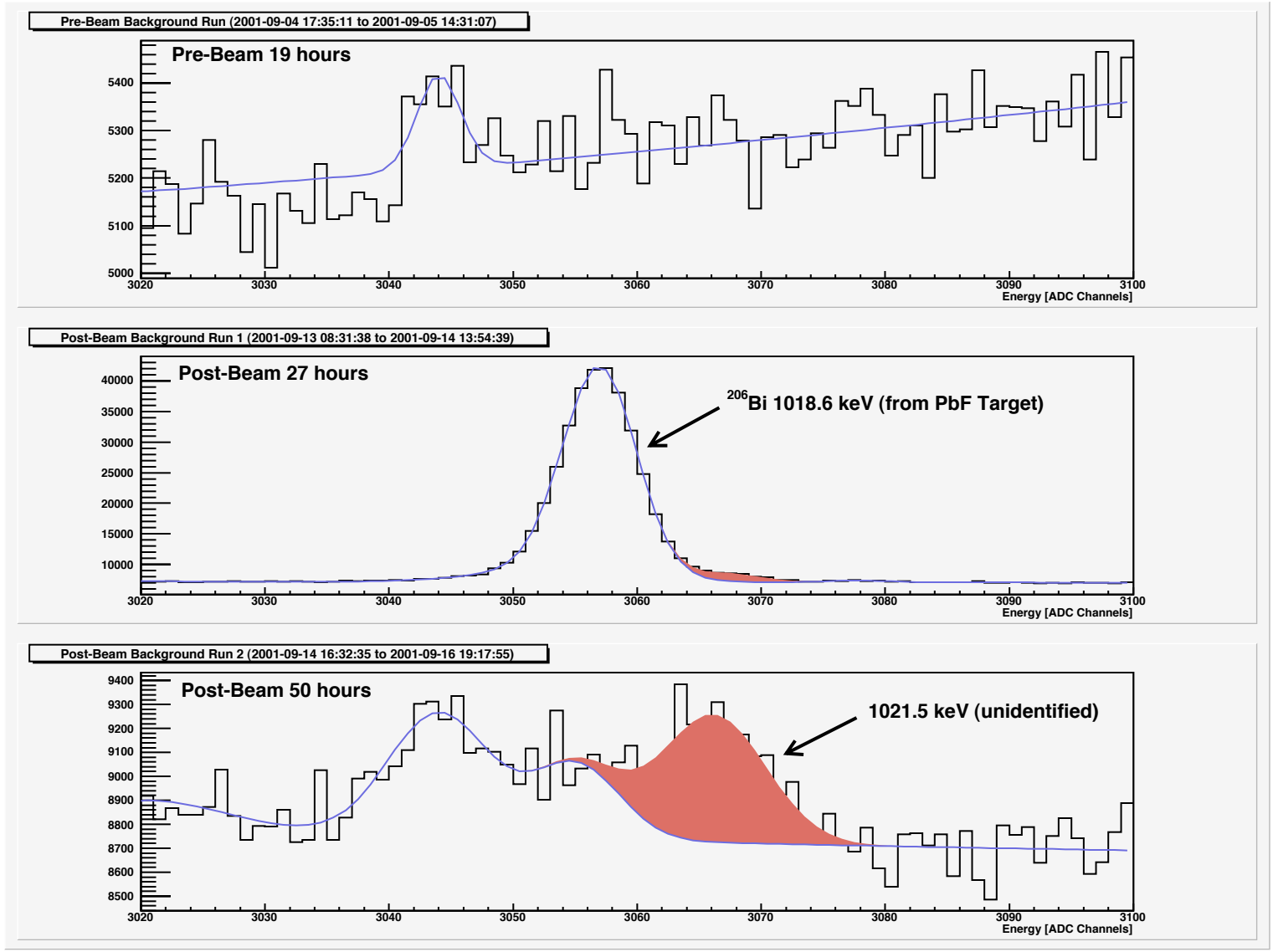
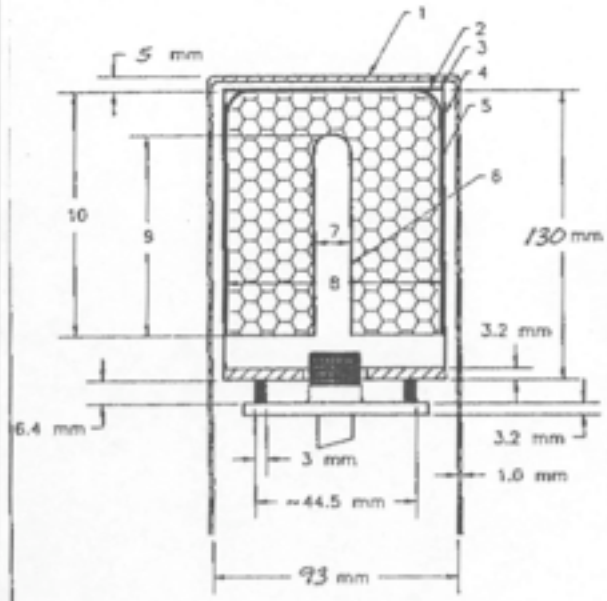

Pre-Beam Background Run (2001-09-04 17:35:11 to 2001-09-05 14:31:07)
Pre-Beam 19 hours
5400
5300
5200
5100
5000
3020
3030
3040
3050
3060
3070
3080
3090
3100
Energy [ADC Channels]
Post-Beam Background Run 1 (2001-09-13 08:31:38 to 2001-09-14 13:54:39)
Post-Beam 27 hours
206Bi 1018.6 keV (from PbF Target)
40000
35000
30000
25000
20000
15000
10000
3020
3030
3040
3050
3060
3070
3080
3090
3100
Energy [ADC Channels]
Post-Beam Background Run 2 (2001-09-14 16:32:35 to 2001-09-16 19:17:55)
Post-Beam 50 hours
1021.5 keV (unidentified)
9400
9300
9200
9100
9000
8900
8800
8700
8600
8500
3020
3030
3040
3050
3060
3070
3080
3090
3100
Energy [ADC Channels]

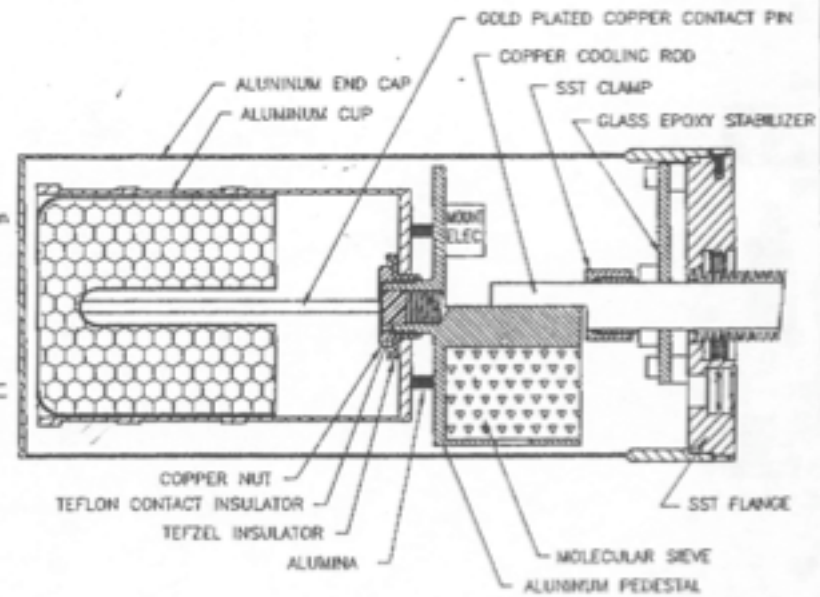
Parameters of 1022 keV Background

- Energy: $1021.0\,\text{keV} < E_\gamma < 1022.4\,\text{keV}$ (most likely region)
- Energy: $1020.3\,\text{keV} < E_\gamma < 1022.8\,\text{keV}$ (very conservative region)
- Short Component: $t_{\frac{1}{2}} \approx 10\,\text{hours}$
- Long Component: $t_{\frac{1}{2}} > 3\,\text{days}$

1022 keV Background

- ^{120}Sb (1023.3 ± 0.4 keV) unlikely
- Candidate search at `http://www.nndc.bnl.gov/`
- Candidate search at `http://ie.lbl.gov/`
- Escape peak unlikely (no peak at $1022 + 511$ keV)
- ^{64}Cu ($t_{\frac{1}{2}} = 12.7$ h) is a likely candidate for the short component





1.	ALUMINUM	1.0 mm
2.	MYLAR	0.025 mm
3.	ALUMINUM FOIL	0.025 mm
4.	ALUMINUM CUP	0.50 mm
5.	LITHIUM CONTACT	0.7 mm
6.	BORON CONTACT	~0.3 mg/cm²
7.	HOLE DIAMETER	10.3 mm
8.	CRYSTAL DIAMETER	72 mm
9.	HOLE LENGTH	82.7 mm
10.	CRYSTAL LENGTH	94.8 mm

EG&G ORTEC

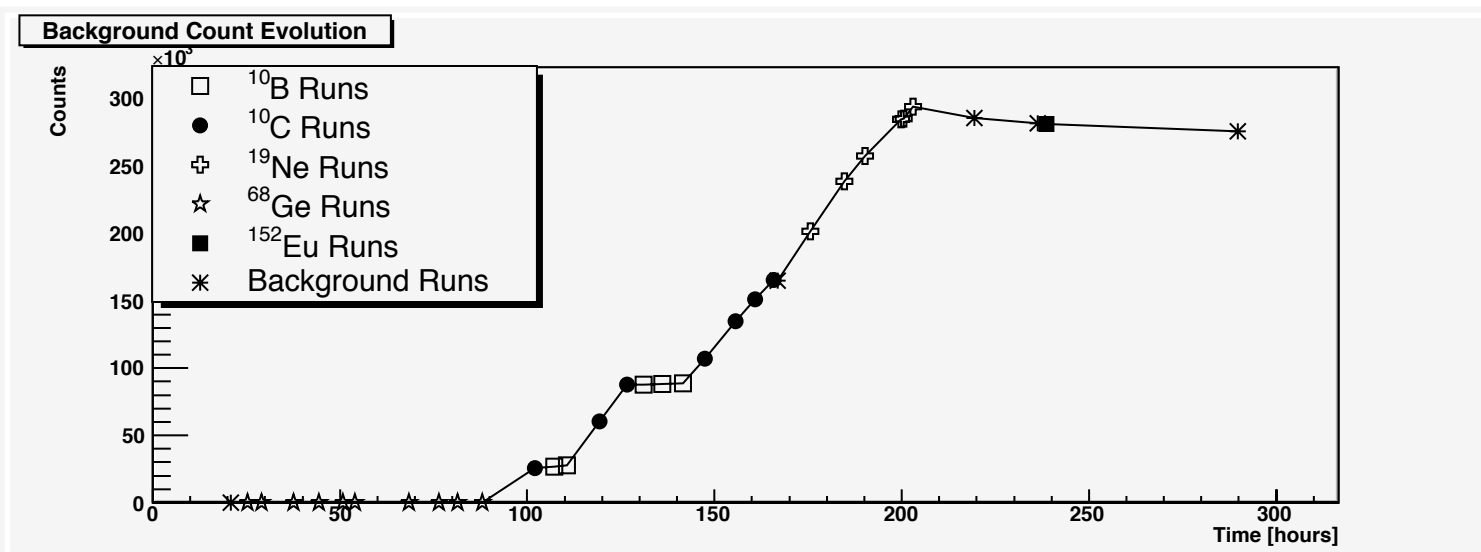
100 MIDLAND ROAD, OAK RIDGE, TENNESSEE 37830

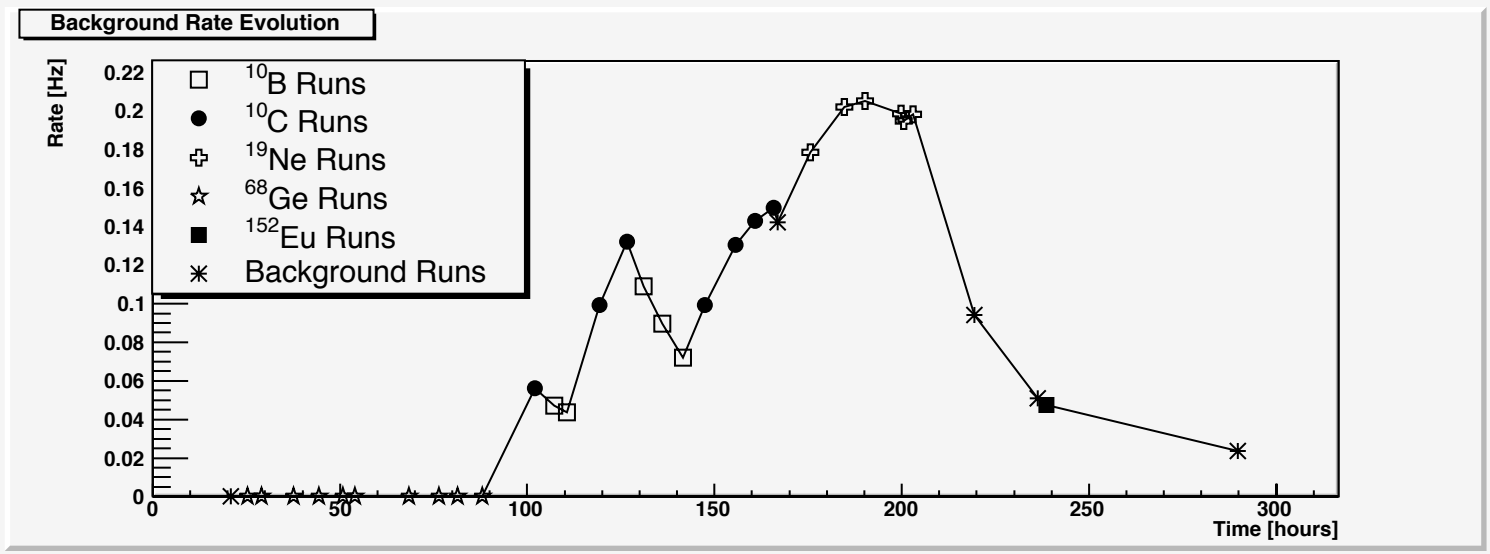
MATERIALS & DIMENSIONS
DETECTOR # P40242A

DWG. 3-30-87

073091G1 B

1/1





$$\frac{dN_s}{dt} = p_s \times I_{Beam} - \frac{N_s}{\tau_s}$$

$$\frac{dN_l}{dt} = p_l \times I_{Beam} - \frac{N_l}{\tau_l}$$

Work in Progress (Preliminary and Incomplete)

Correction	Size	Affects
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Summing	-0.032(3)%	Efficiency
	+0.44(4)%	β Decay
1022 keV Background	-0.13(2)%	β Decay

$$BR = (1.4622 \pm 0.0014_{stat} \pm 0.0004_{syst} \pm 0.00XX_{bkgdsyst}) \times 10^{-2}$$

Branching Ratio	Measurement
$(1.465 \pm 0.014) \times 10^{-2}$	Robinson 1972
$(1.473 \pm 0.007) \times 10^{-2}$	Nagai 1991
$(1.465 \pm 0.009) \times 10^{-2}$	Kroupa 1991
$(1.4625 \pm 0.0025) \times 10^{-2}$	Savard 1995
$(1.4665 \pm 0.0038) \times 10^{-2}$	Fujikawa 1999
$(1.4621 \pm 0.0014) \times 10^{-2}$	Preliminary Result