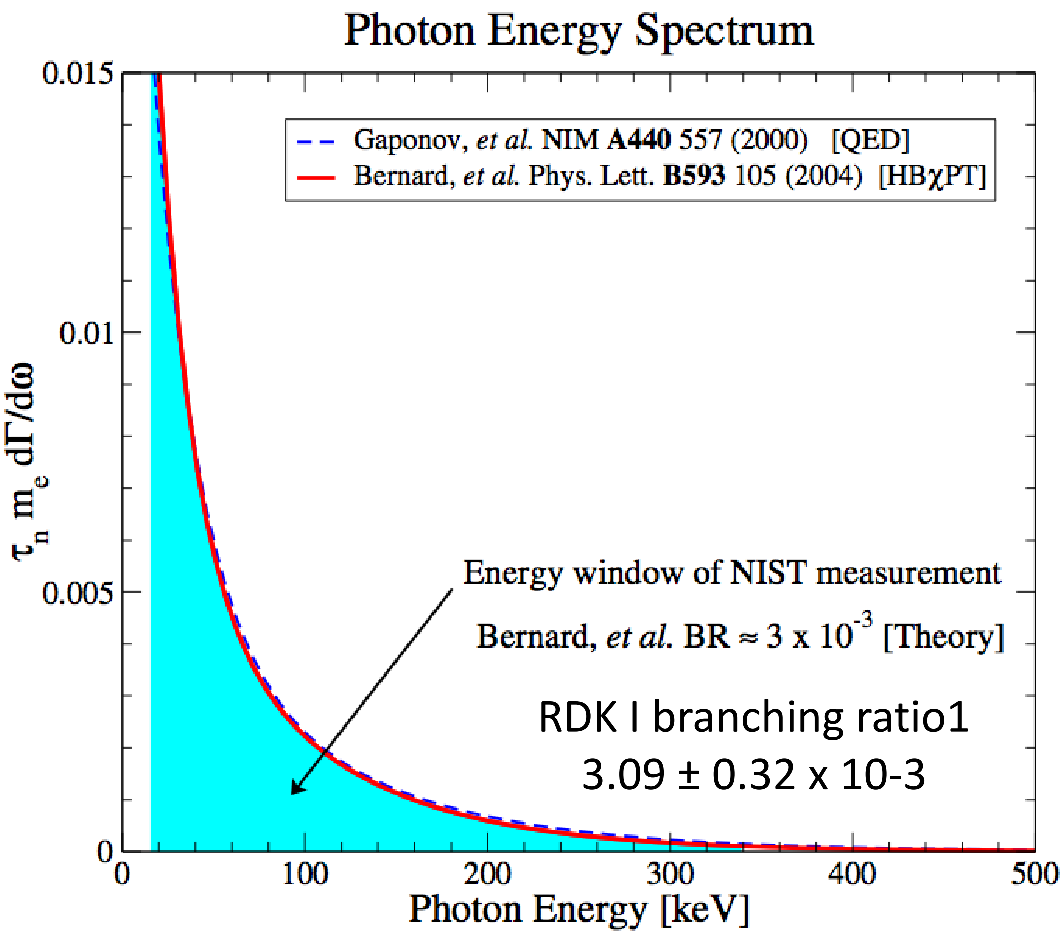
Precision Measurement of the Radiative Decay Mode of the Neutron

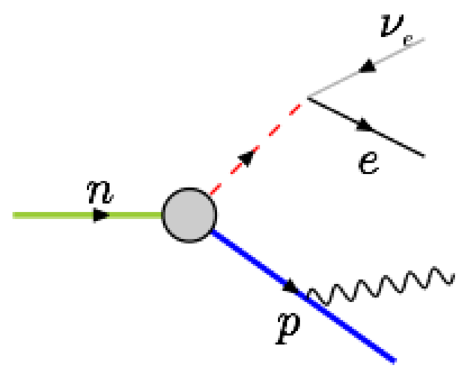
RDK II Collaboration

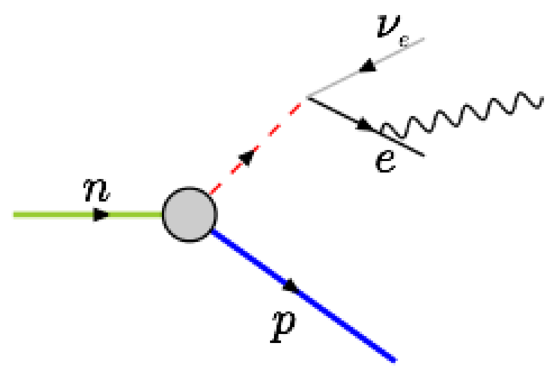
Arizona State University
R. Alarcon, B. O'Neill
University of Maryland
E. Beise, H. Breuer
University of Michigan
M. Bales, T. Chupp, R. Cooper
National Institute of Science & Technology (NIST)
C. Bass, K. Coakley, S. Dewey, C. Fu, T. Gentile, P. Mumm, J. Nico, A. Thompson
University of Sussex
J. Byrne
Tulane University
F. Wietfeldt, K. Pulliam

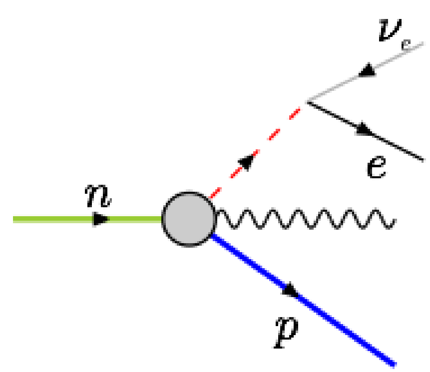
Theory



RDK I branching ratio[1]
3.09 ± 0.32 x 10-3

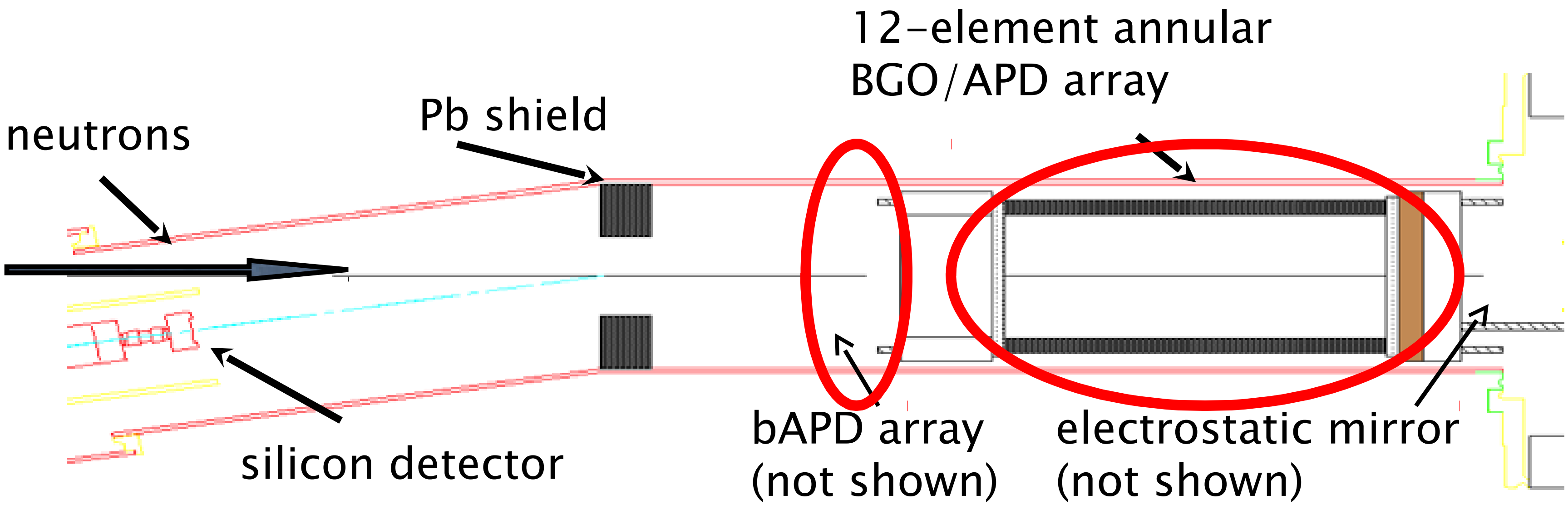






[1]Nico, J. S. *et al*. *Nature* 444, 1059–1062 (2006)

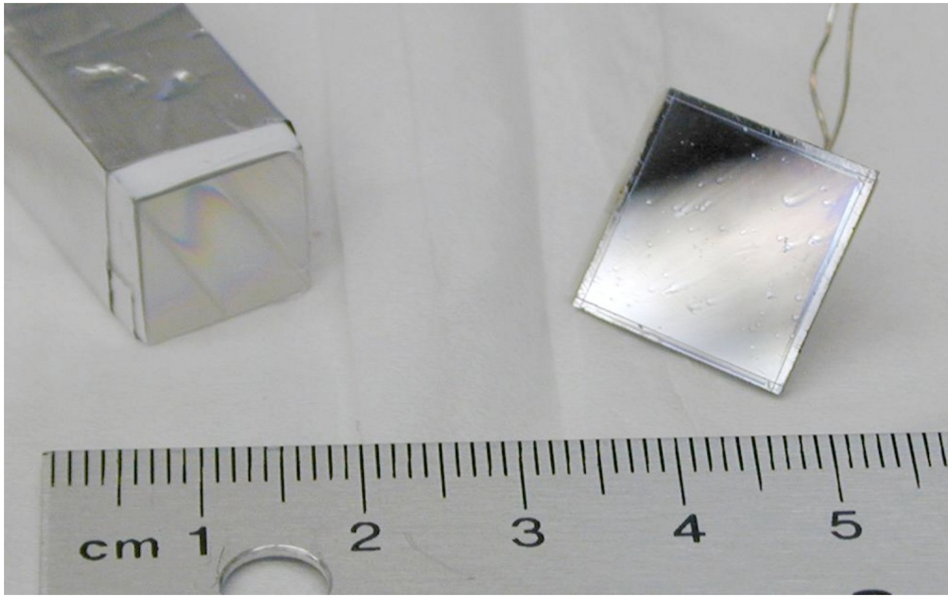
Overview

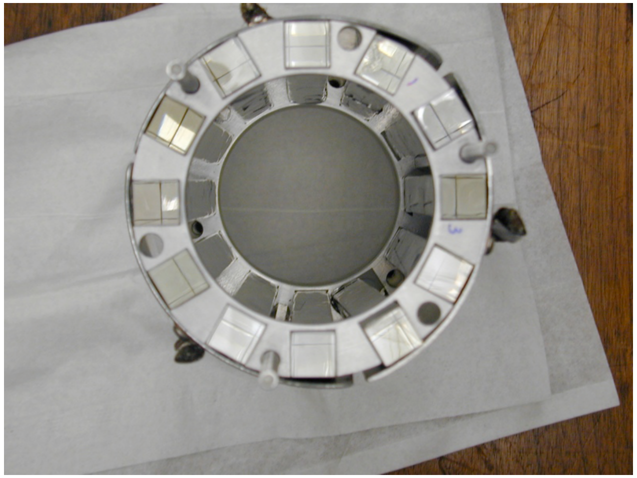


- National Institute of Standards & Technology (NIST) NG6 cold neutron beam
- On beam from July 2008 to Nov 2009
- 4.6 T magnetic field traps charged decay products to tight orbits giving large solid angle coverage
- Electrostatic mirror turns around “wrong-way” protons
- Delayed electron-proton coincidence trigger
- Waveform-based data acquisition

Primary detector

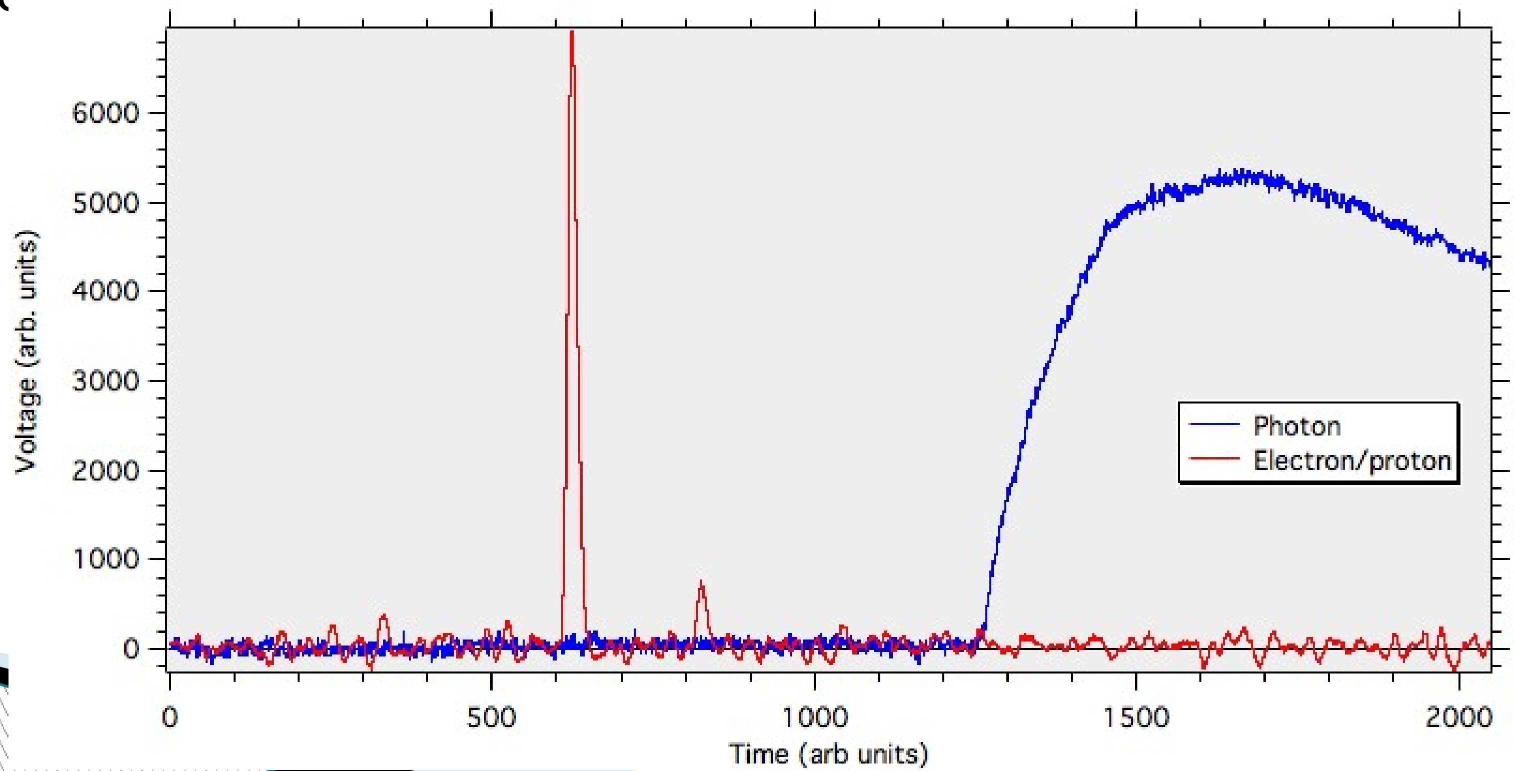
- Bismuth germanate (BGO) scintillator crystals coupled to avalanche photo-diodes (APD)
  - 12 detectors
  - 200x12x12mm3 BGOs
  - 14x14mm2 APDs
  - <10keV-endpoint





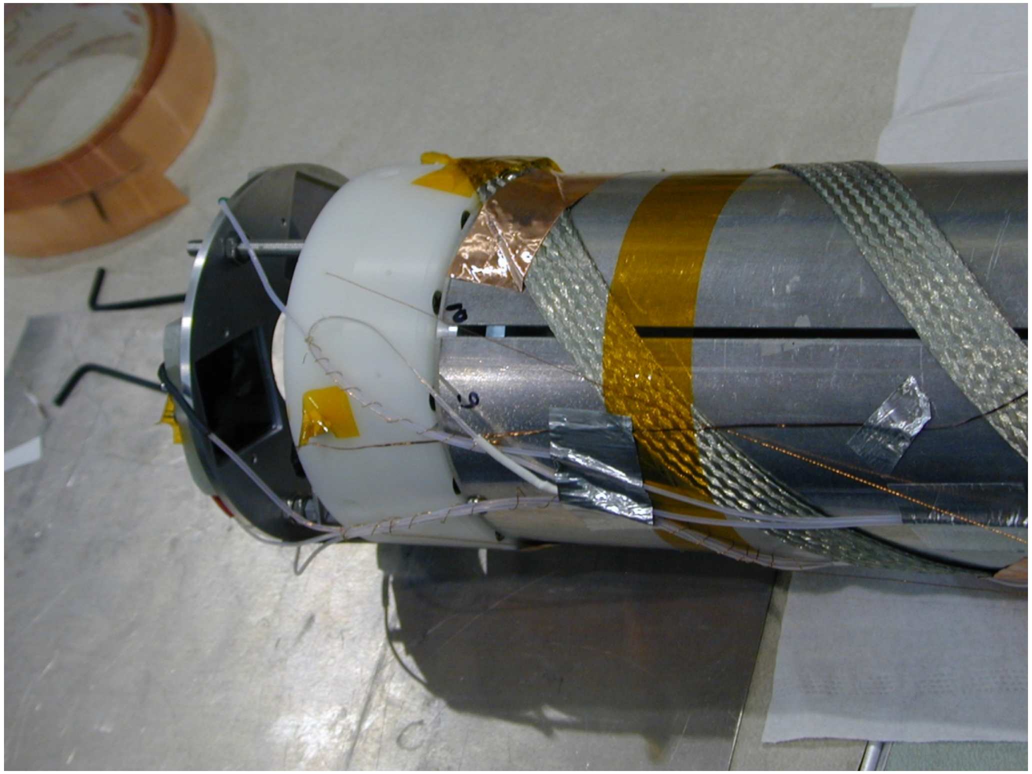
Primary detector

- APDs operate in vacuum and high magnetic field (~5 T)
- APD gain increases and noise decreases with cooling
- Light yield of BGO increases with cooling
- Large crystals available at reasonable cost
- Stable operation over weeks of operation



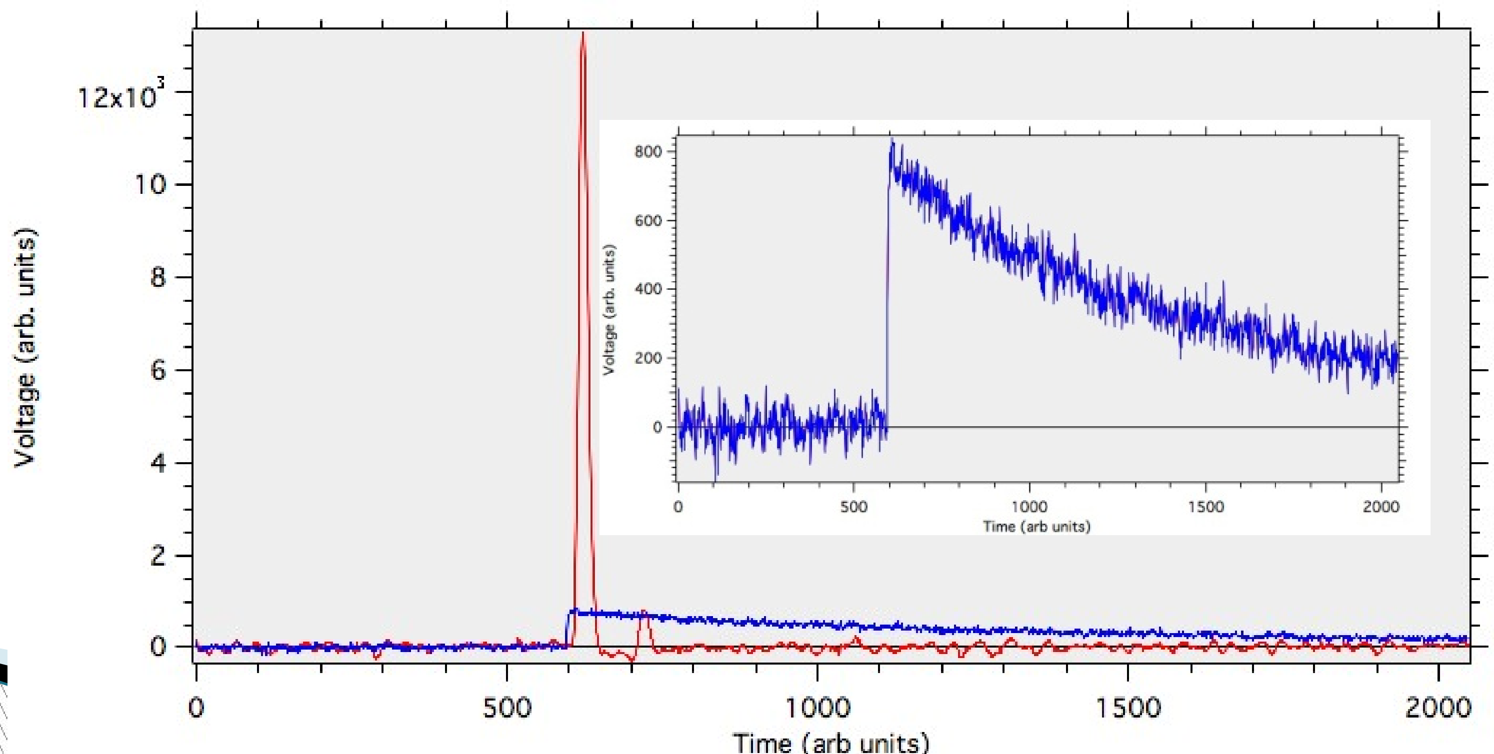
Direct detector

- Large area bare avalanche photo-diode (bAPD)
  - 3 detectors
  - 28x28mm2
  - ~500eV-20keV



Direct detector

- Lower energy range
- Lower background
- Narrower timing peak
- Smaller cross section



Analysis

	All voltages	Full Mirror
Run time	164.4d	97.8d
Live time	147.1d	87.5d
Total triggers	9.7x107	6.8x107
Run data	6.4Tb	4.4Tb
Total data	22Tb	

- Parameters to extract from waveforms
  - Energy
    - Electron
    - Proton
    - Photon
  - Time of Flight
    - Electron-proton
    - Electron-photon

Curve fitting

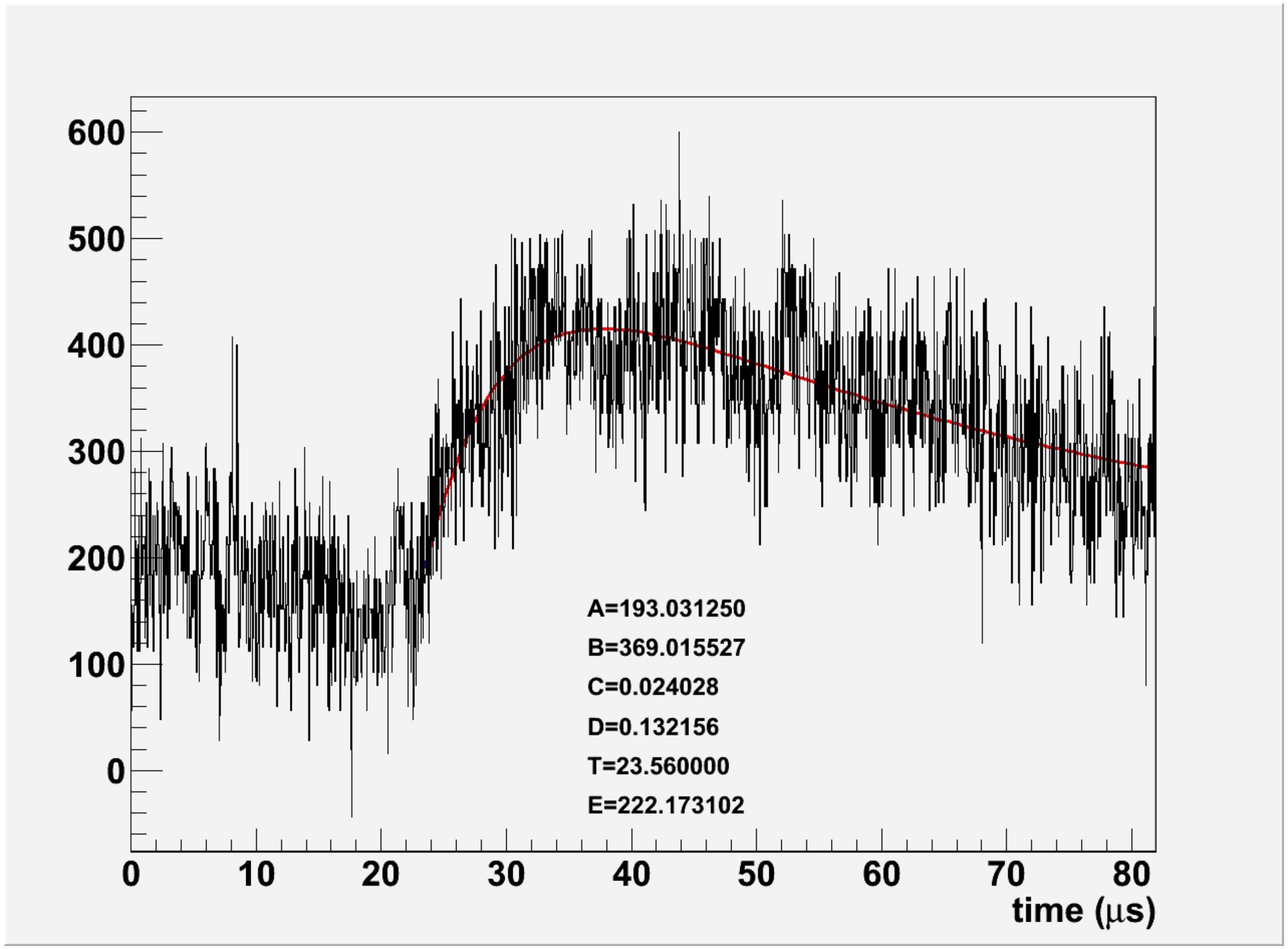
- Fit function
  - A+Be−C(x−t)(1−e−D(x−t))
  - A = signal drift (electronics)
  - B = intensity
  - C = falling rate (electronics)
  - D = rising rate (BGO to APD)
  - t = time
  - E = energy

$$x_{\max} = t + \frac{1}{D}\ln\left(1 + \frac{D}{C}\right)$$

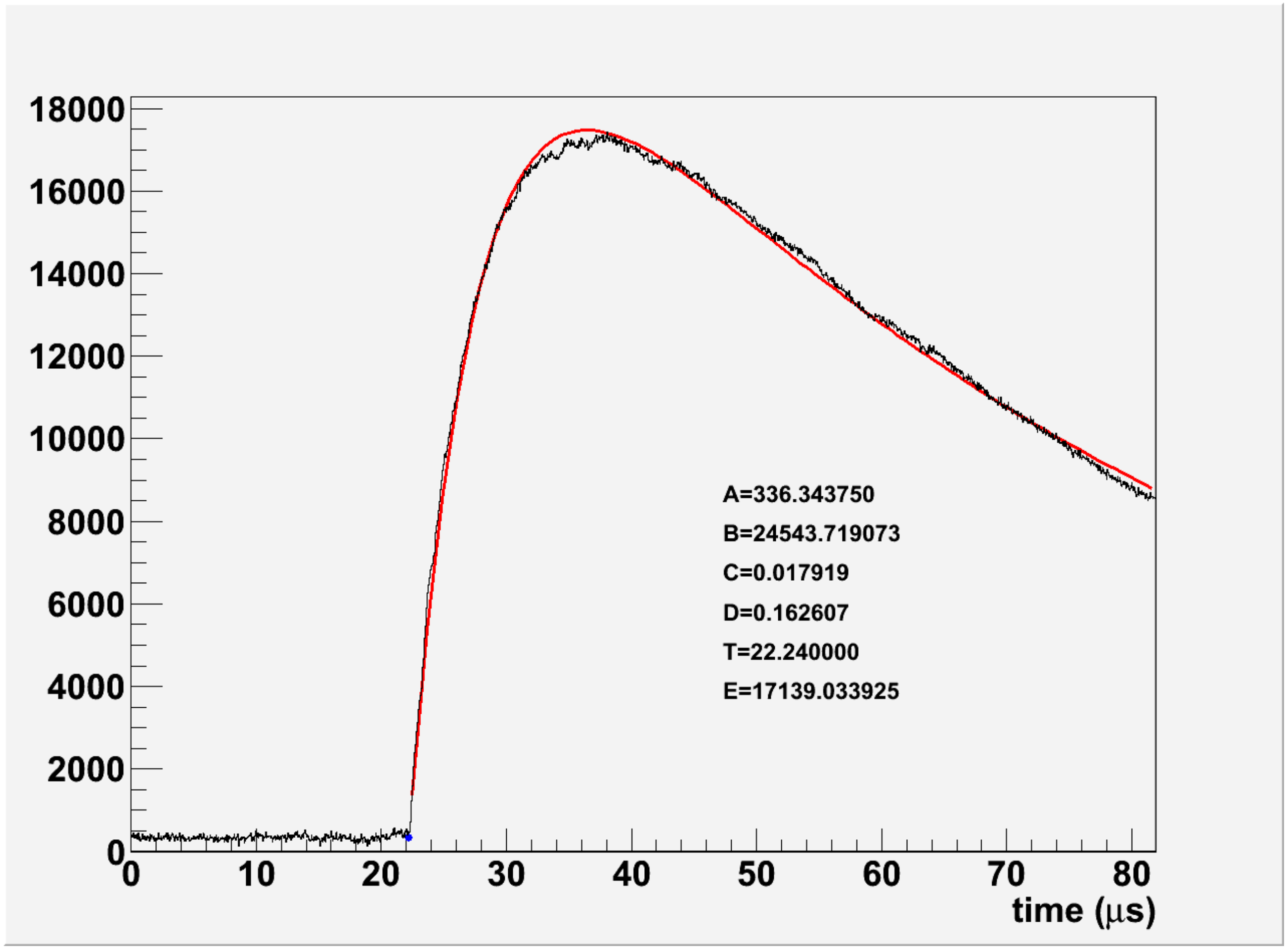
$$E = \frac{BD}{C + D}\left(1 + \frac{D}{C}\right)^{-\frac{C}{D}}$$

- Hybrid linear/non-linear regression
- Allows measurement of additional parameters
- Poor fits with some signals

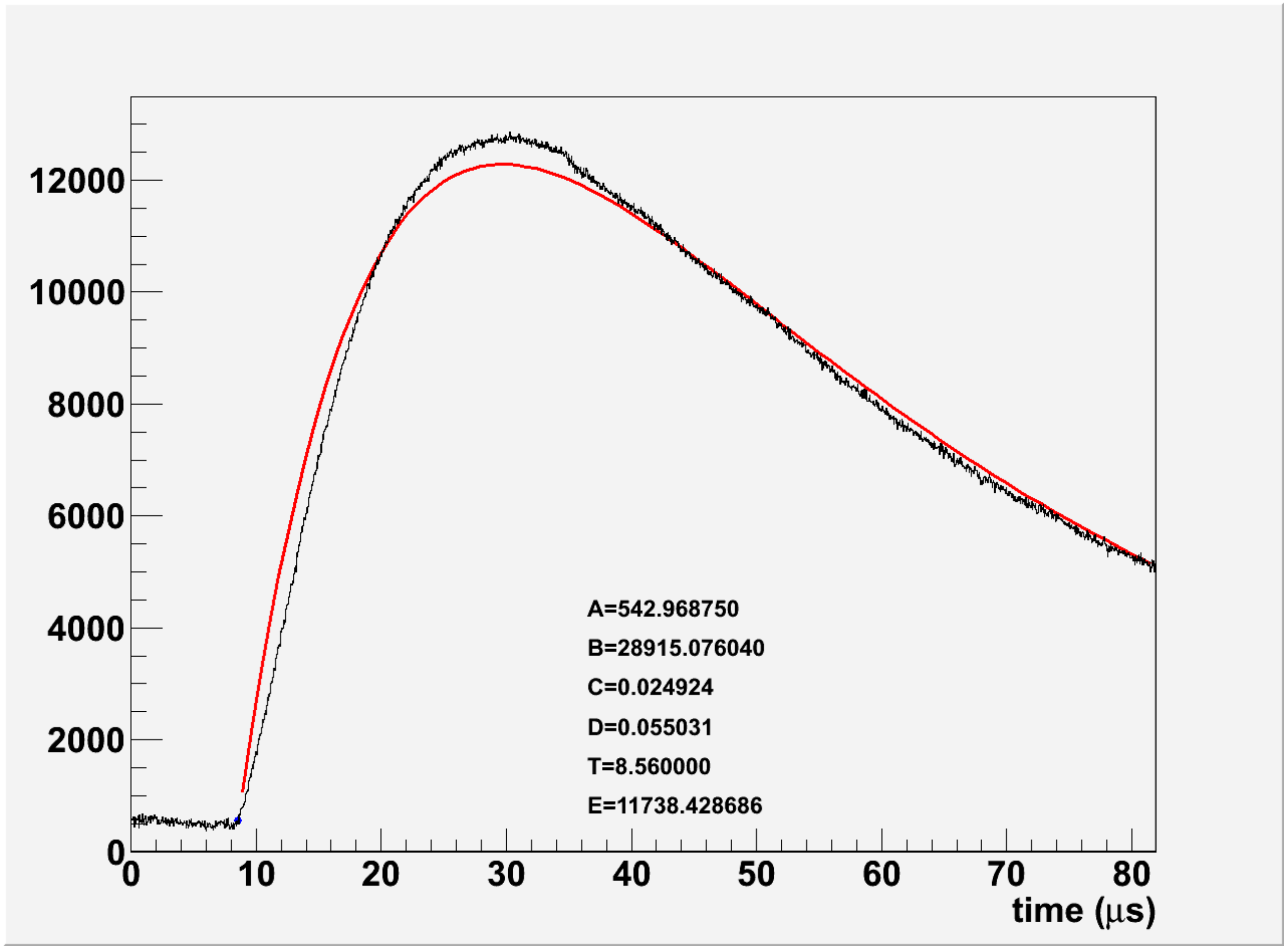
Curve fitting



Curve fitting



Curve fitting



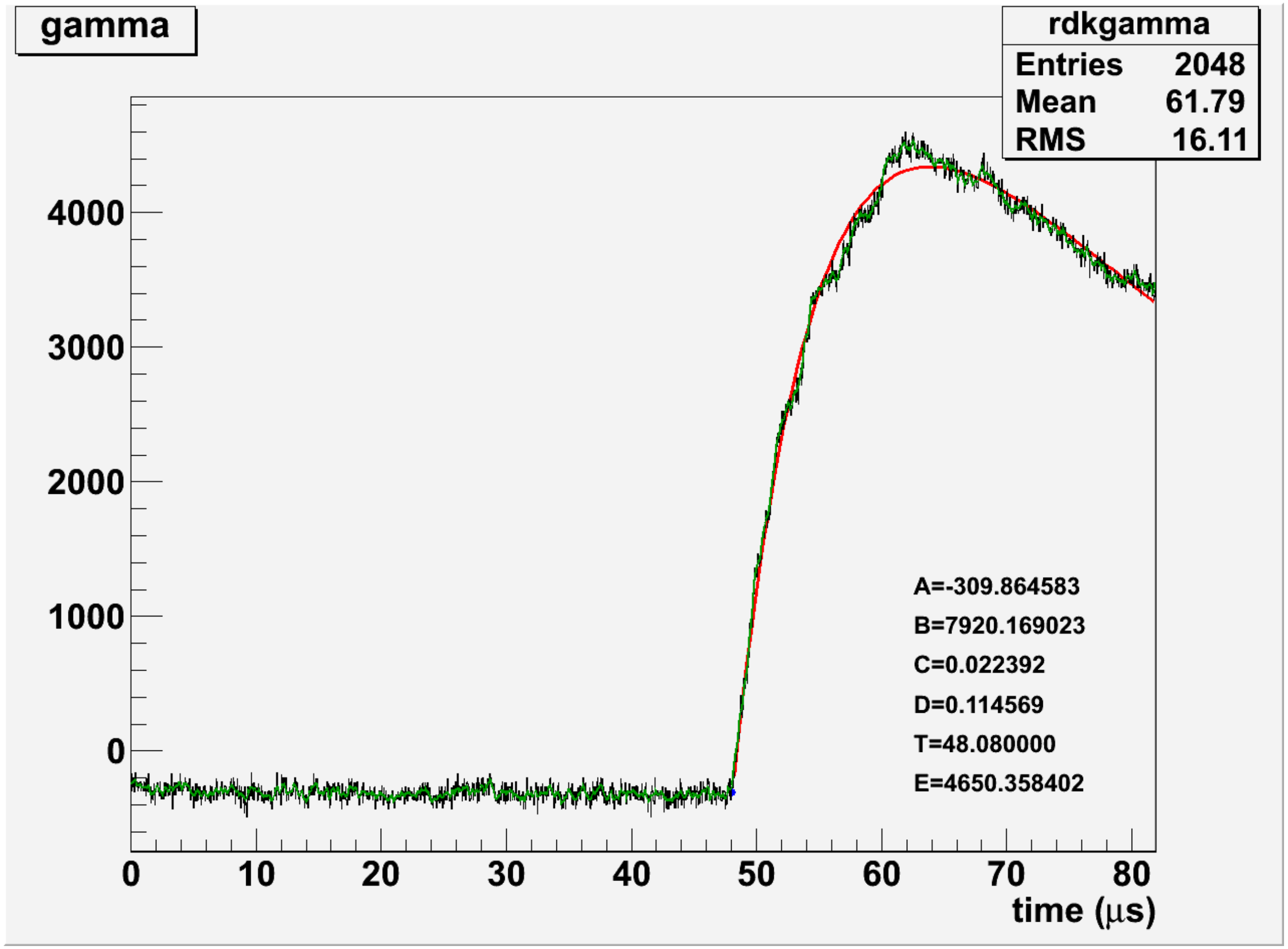
Smoothing

- Adaptation of locally weighted scatterplot smoothing (LOWESS) algorithm
- Uniform spacing of points allows the use of a simple transformation matrix
- Adjustable smoothing radius R
- Tradeoff between timing resolution and noise reduction

$$X = \begin{bmatrix} 1 & -R \\ 1 & -R+1 \\ \vdots & \vdots \\ 1 & R-1 \\ 1 & R \end{bmatrix} \qquad W_{ii} = 1 - \left| \frac{X_{i1}}{R+1} \right|^3$$

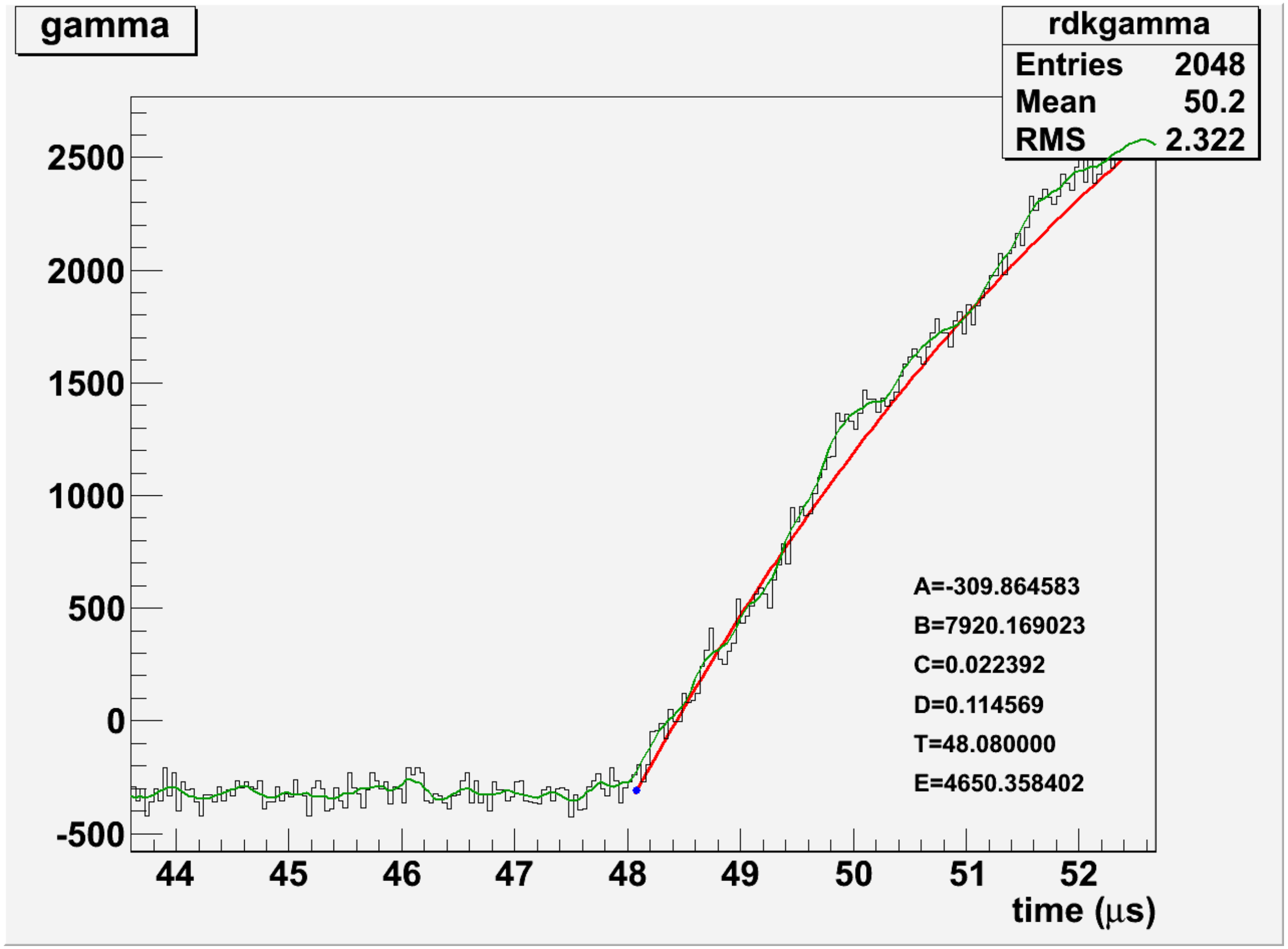
$$T = \begin{bmatrix} 1 & 0 \end{bmatrix} \cdot \left(X^T W X \right)^{-1} X^T W \qquad y'_x = T \cdot y_{x-R,x+R}$$

Smoothing



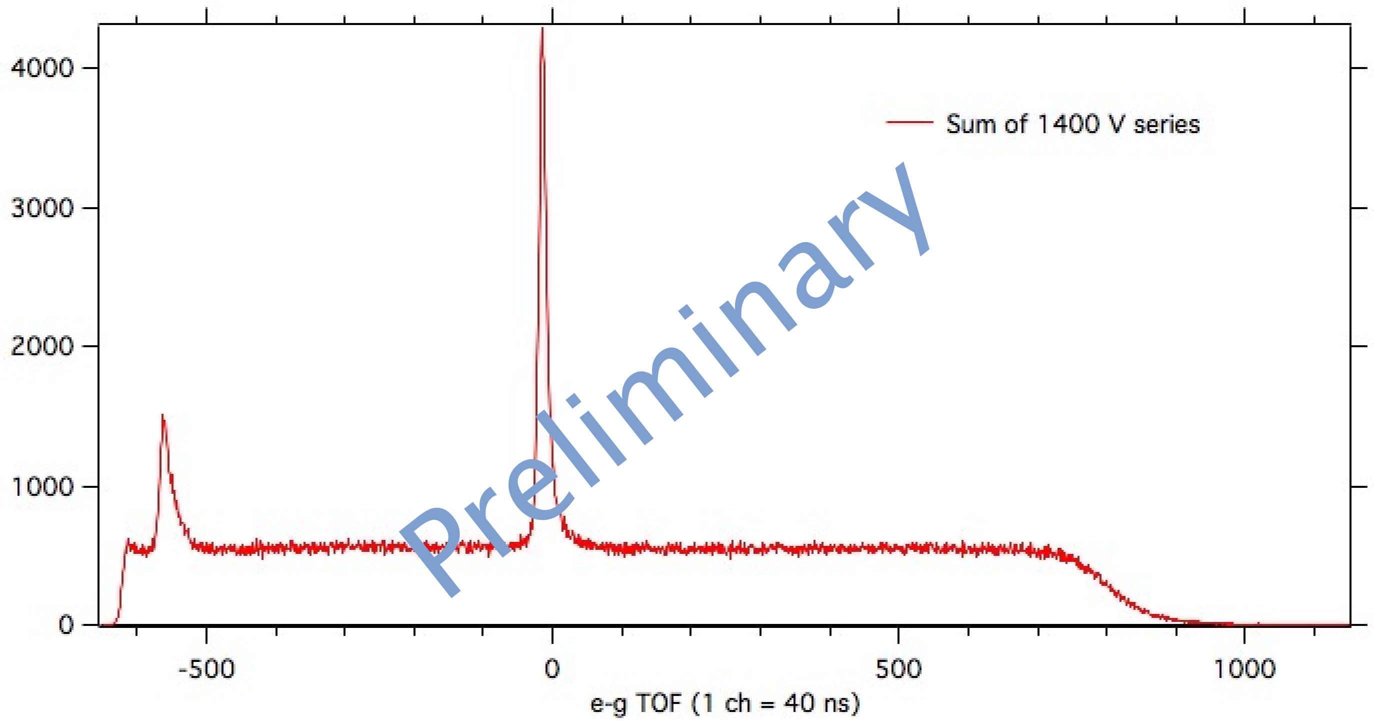
gamma
rdkgamma
Entries 2048
Mean 61.79
RMS 16.11
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
time (μs)
A=-309.864583
B=7920.169023
C=0.022392
D=0.114569
T=48.080000
E=4650.358402

Smoothing



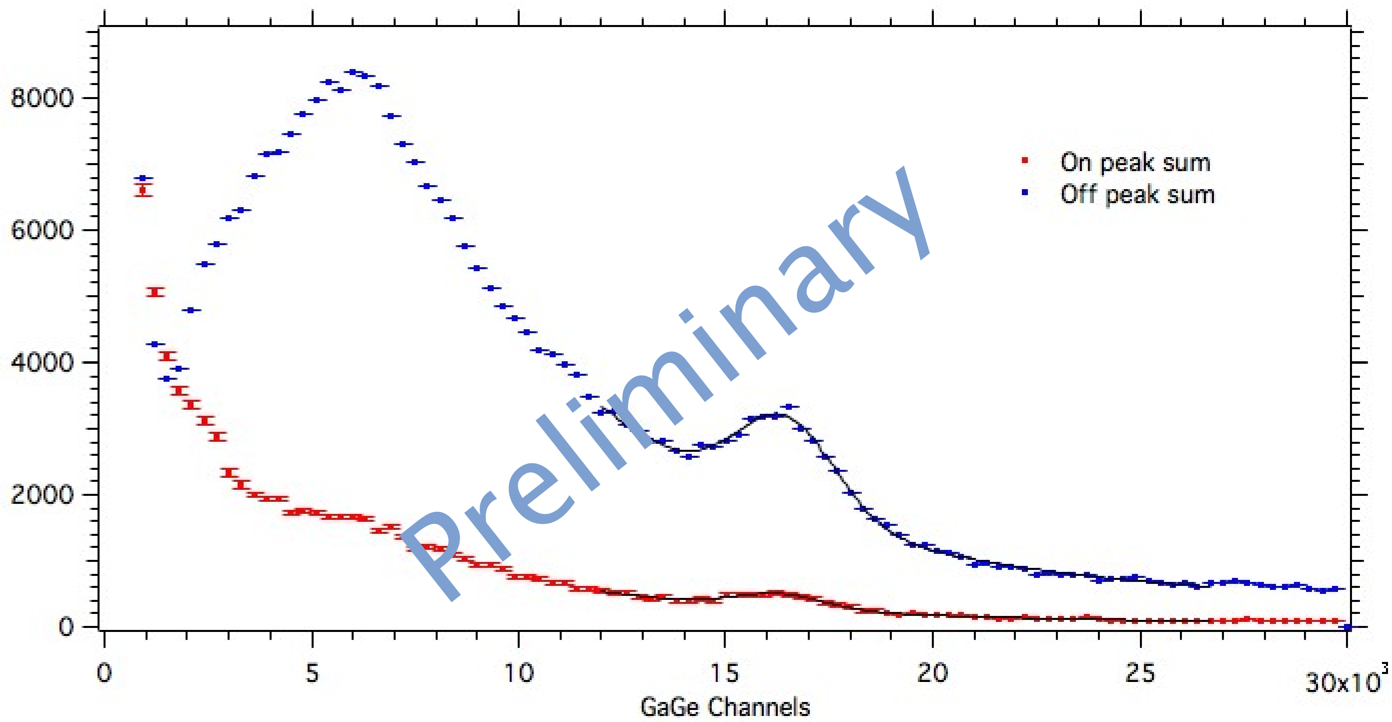
gamma
rdkgamma
Entries 2048
Mean 50.2
RMS 2.322
2500
2000
1500
1000
500
0
-500
44
45
46
47
48
49
50
51
52
time (μs)
A=-309.864583
B=7920.169023
C=0.022392
D=0.114569
T=48.080000
E=4650.358402

Results



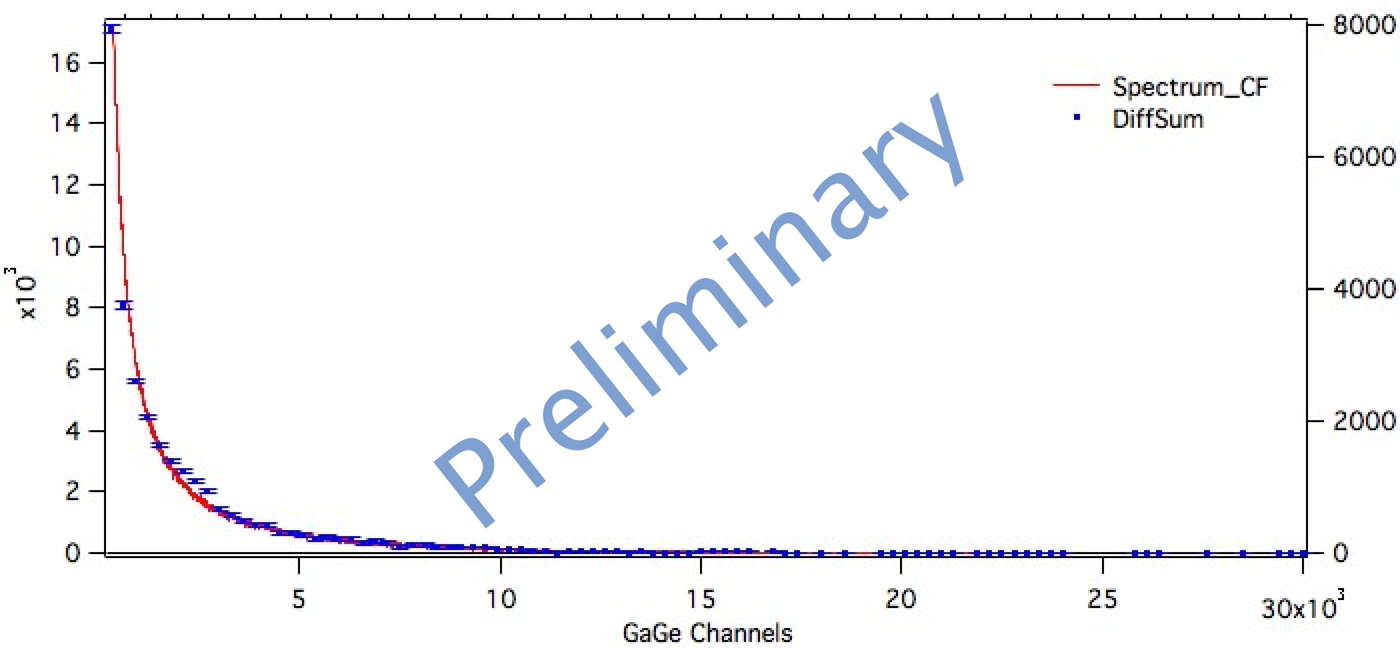
4000
3000
2000
1000
0
-500
0
500
1000
e-g TOF (1 ch = 40 ns)
Sum of 1400 V series
Preliminary

Results



8000
6000
4000
2000
0
0
5
10
15
20
25
30x10³
GaGe Channels
On peak sum
Off peak sum
Preliminary

Results



Spectrum_CF
DiffSum
Preliminary
x10^3
16
14
12
10
8
6
4
2
0
8000
6000
4000
2000
0
5
10
15
20
25
30x10^3
GaGe Channels