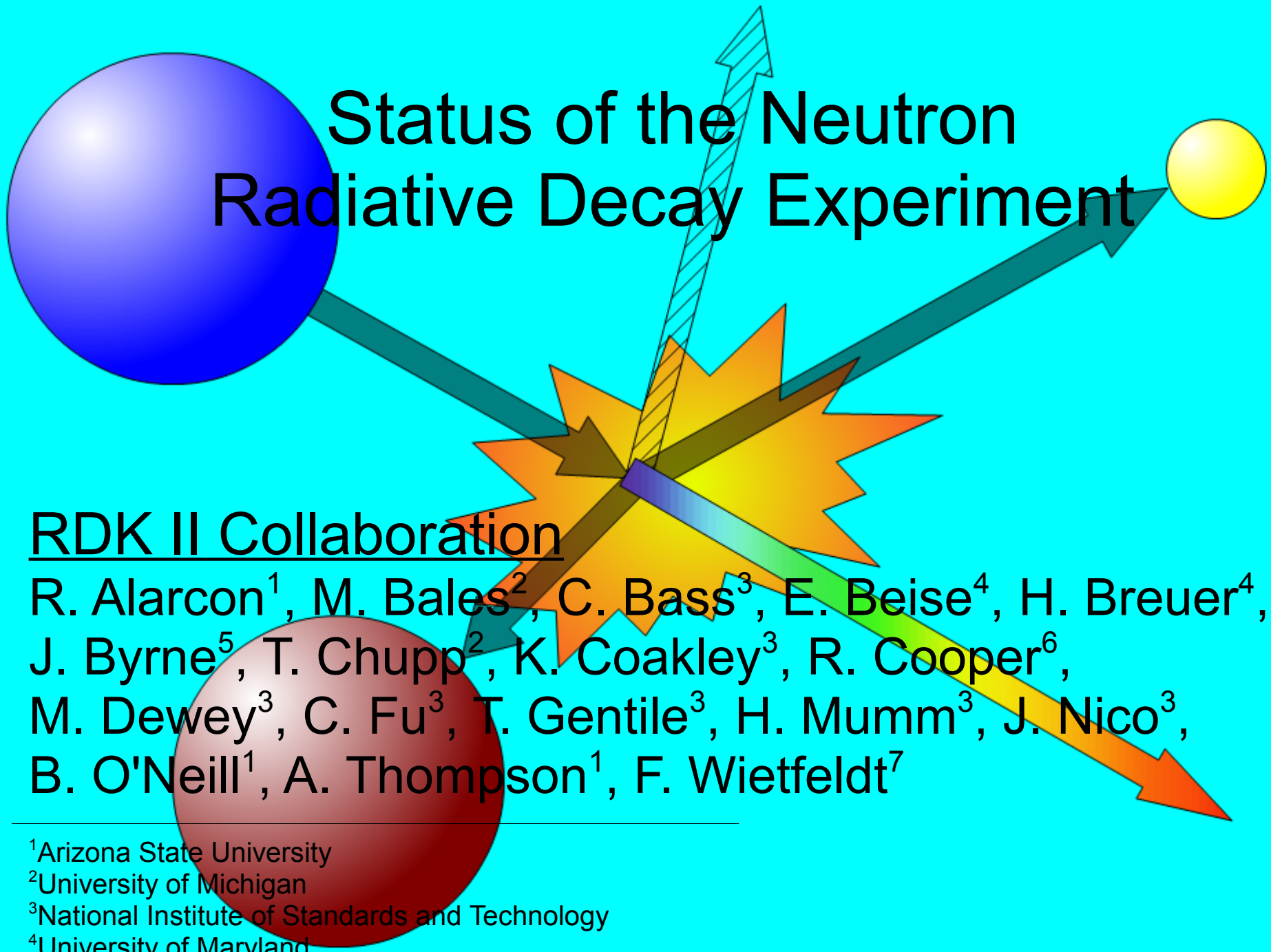
Status of the Neutron Radiative Decay Experiment



RDK II Collaboration

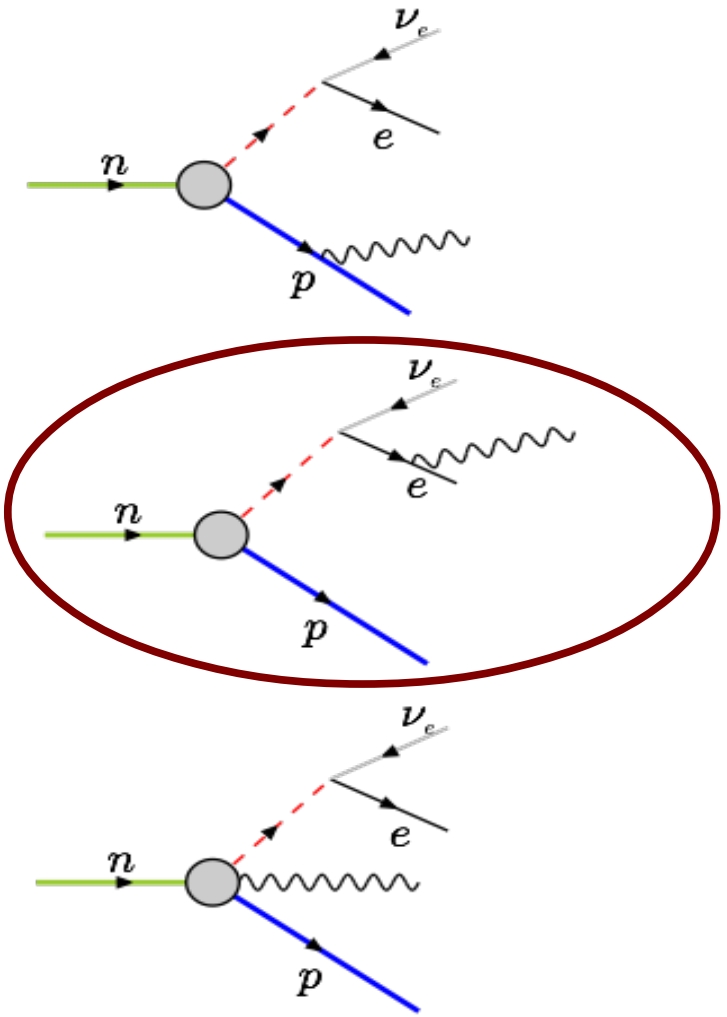
R. Alarcon[1], M. Bales[2], C. Bass[3], E. Beise[4], H. Breuer[4], J. Byrne[5], T. Chupp[2], K. Coakley[3], R. Cooper[6], M. Dewey[3], C. Fu[3], T. Gentile[3], H. Mumm[3], J. Nico[3], B. O'Neill[1], A. Thompson[1], F. Wietfeldt[7]

[1]Arizona State University
[2]University of Michigan
[3]National Institute of Standards and Technology
[4]University of Maryland
[5]University of Sussex
[6]Indiana University
[7]Tulane University

Radiative Decay Measurement

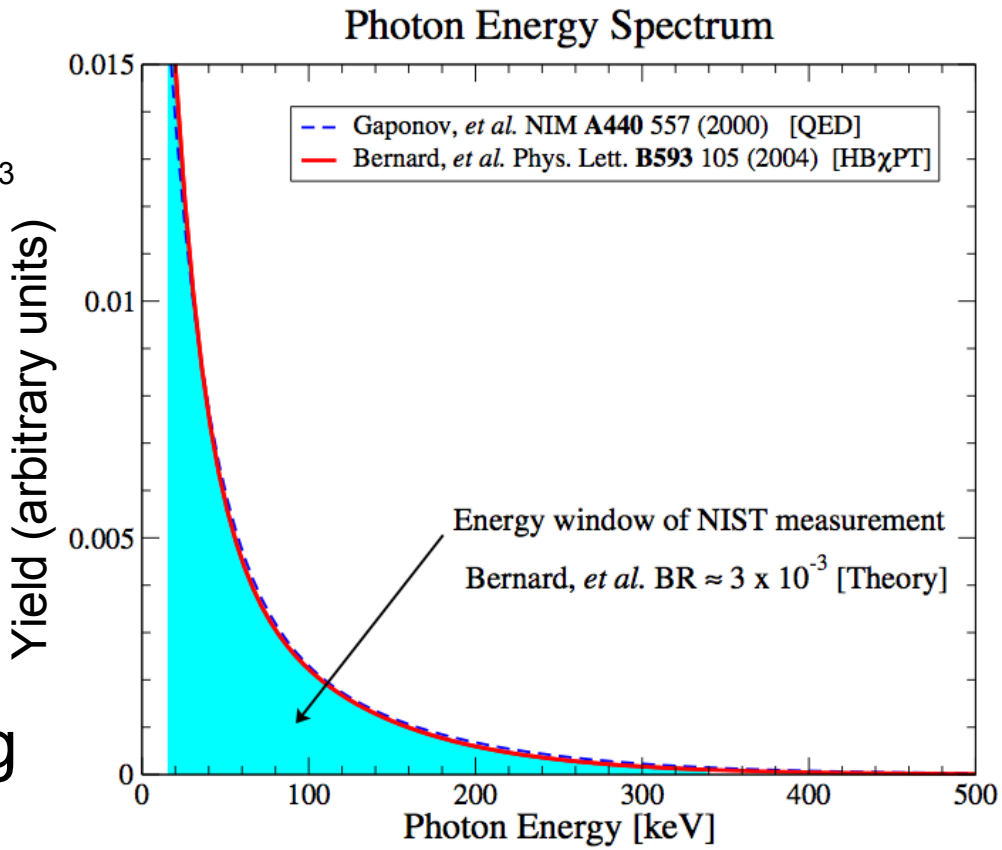
- Measure neutron radiative decay branching ratio and energy sprectrum to 1% uncertainty
  - 10% uncertainty in RKD I
- Test QED neutron radiative corrections
- Challenges
  - Long lifetime τ_n=(881.5±1.5)s
  - Small branching ratio
  - Large γ background

$n \rightarrow p^+ + e^- + \bar{\nu}_e + \gamma + 782keV$



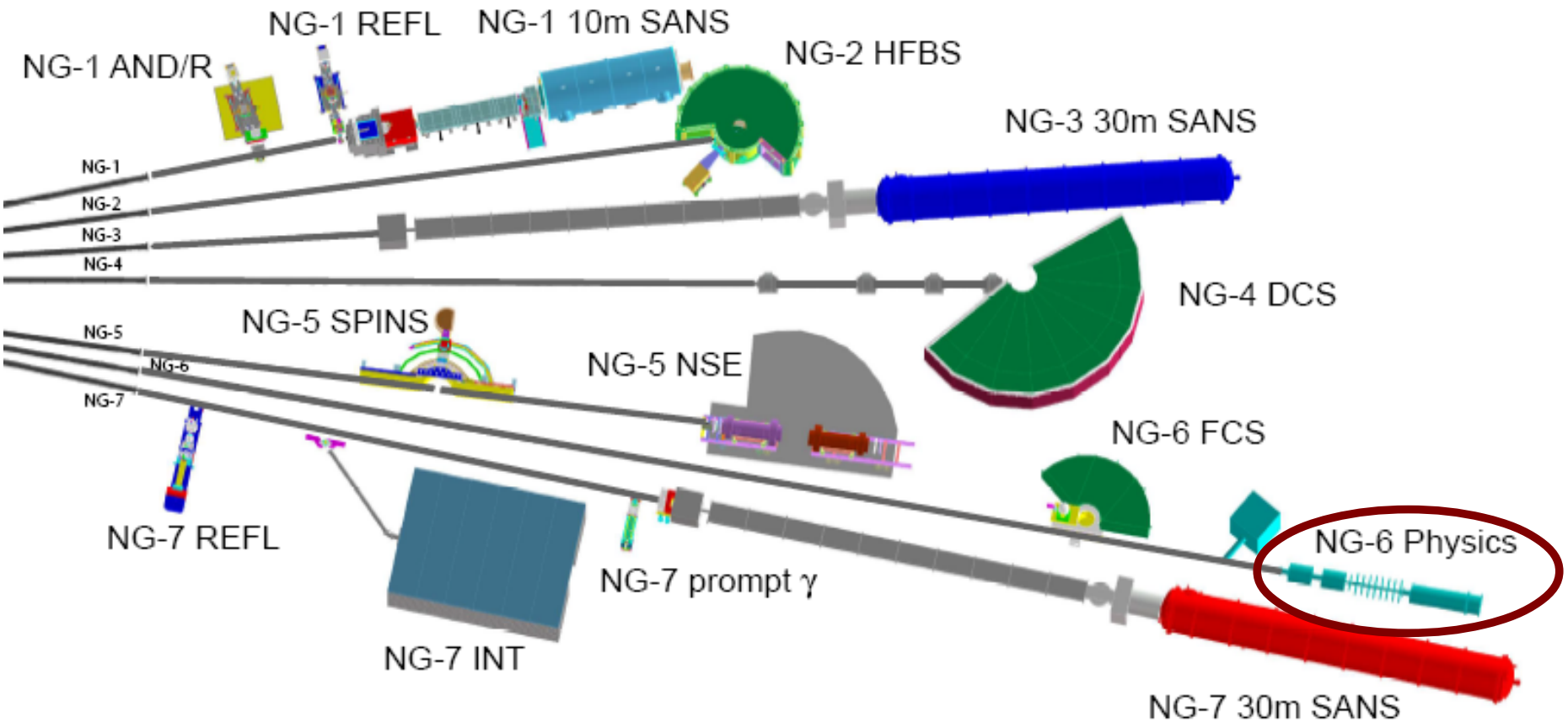
Motivation

- RDK I[1,2]
  - (3.09±0.30[syst.]±0.11[stat.])×10^{-3}
- RDK II
  - Goal 1% uncertainty
- Beyond 0.5%
  - Non-leading order terms
    - Proton bremsstrahlung
    - Recoil corrections
  - Polarization (*n*, γ, etc.)
  - Gardner & He^3

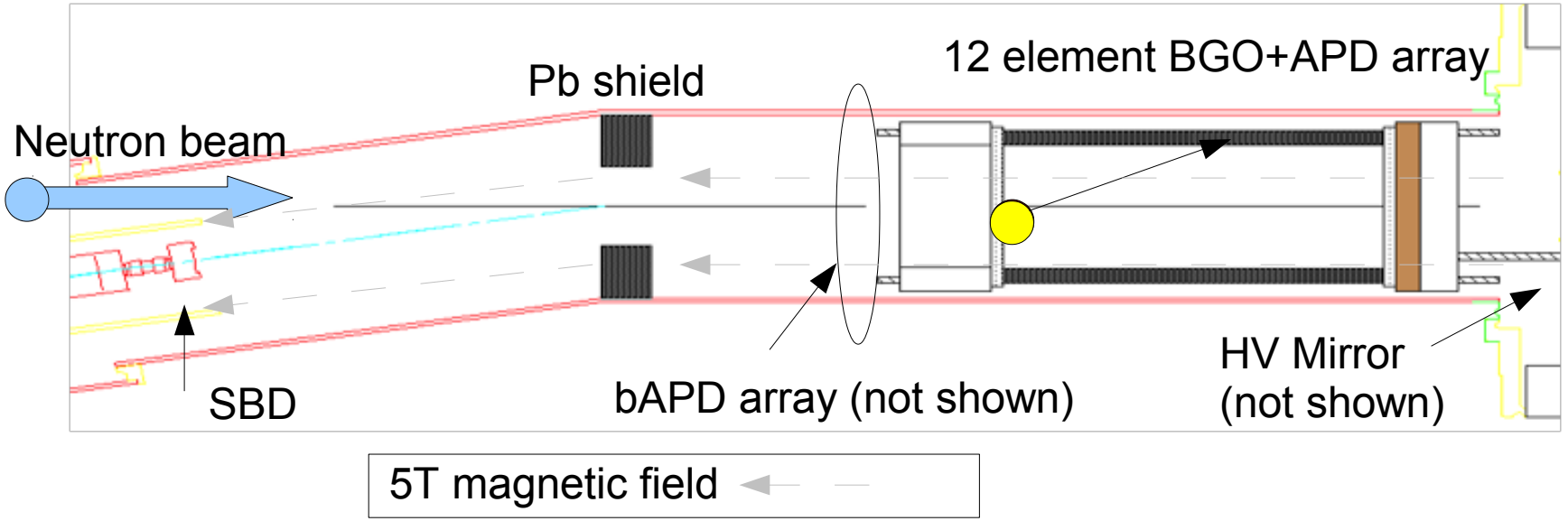


[1]Cooper, R. *et al.* PRC 81, 035503 (2010)
[2]Nico, J. S. *et al*. *Nature* 444, 1059–1062 (2006)
[3]arXiv:1101.1128v1

NIST Beam Line



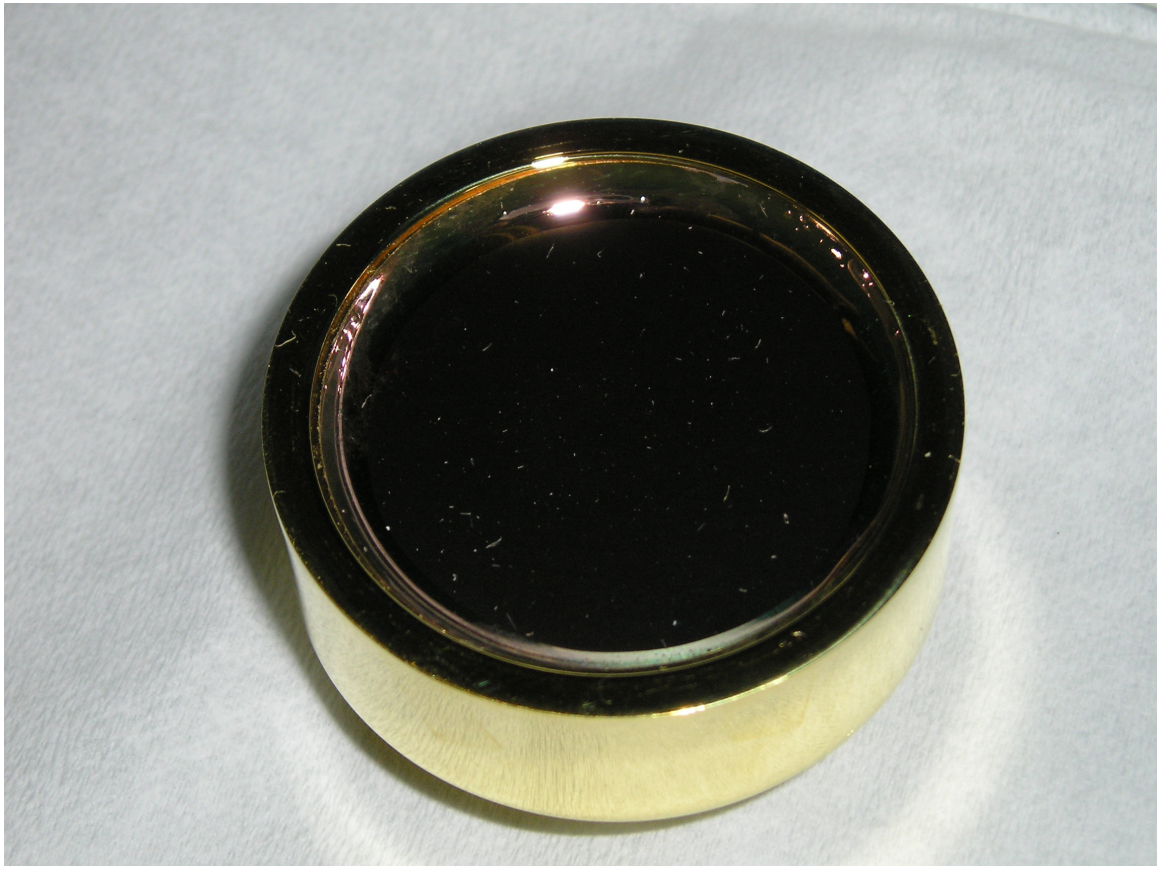
Experimental Setup



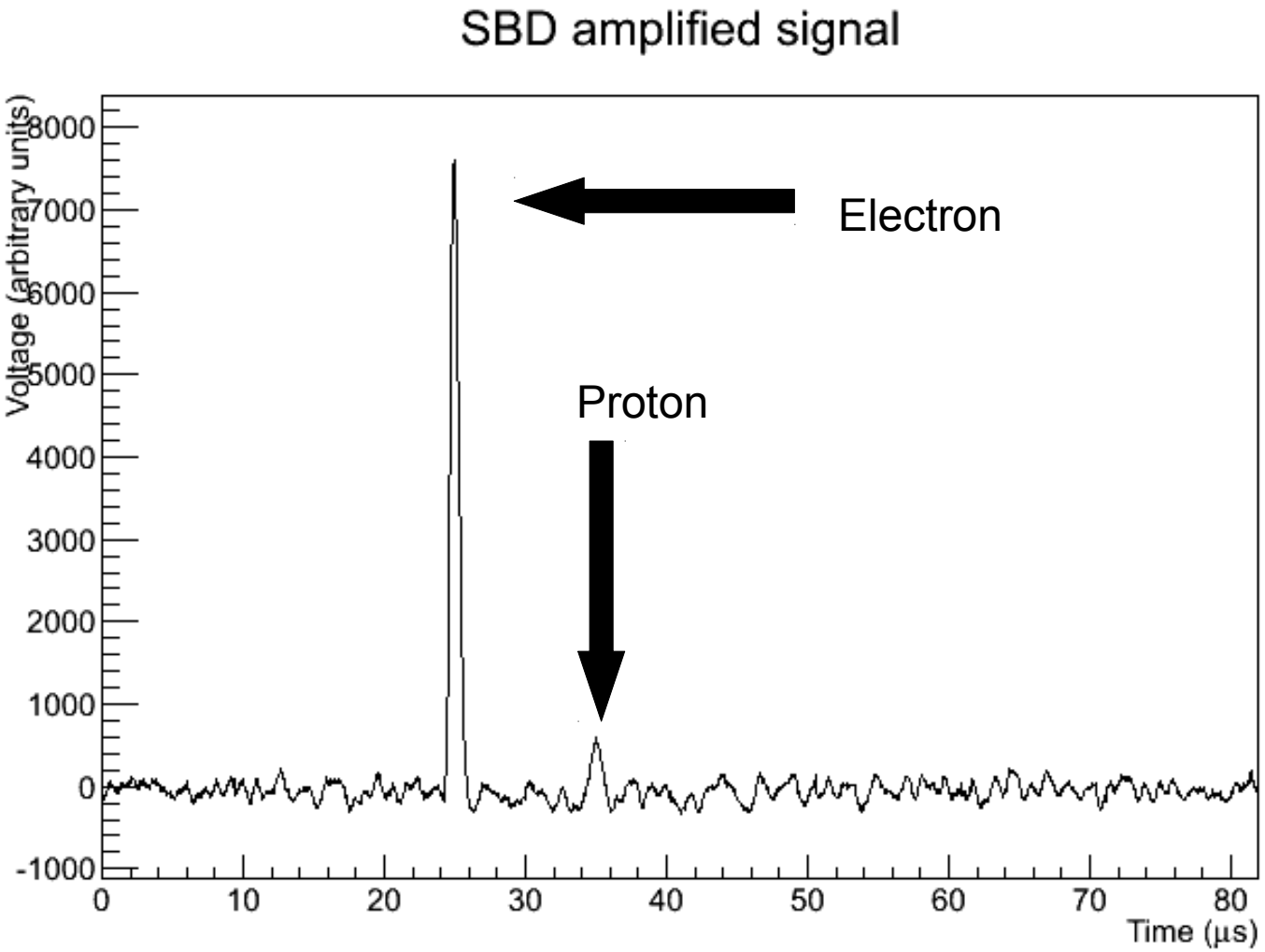
- Neutrons decay along beam
- Protons and electrons are confined in cyclotron orbits by magnetic field and guided into silicon detector
- Electrostatic mirror turns around “wrong-way” protons
- Protons are accelerated into the silicon detector
- Waveform base data acquisition

Electron-Proton Detector

- Surface Barrier Detector (SBD)
  - 1-1.5mm thick
  - 600mm^2 area
  - At -25kV bias

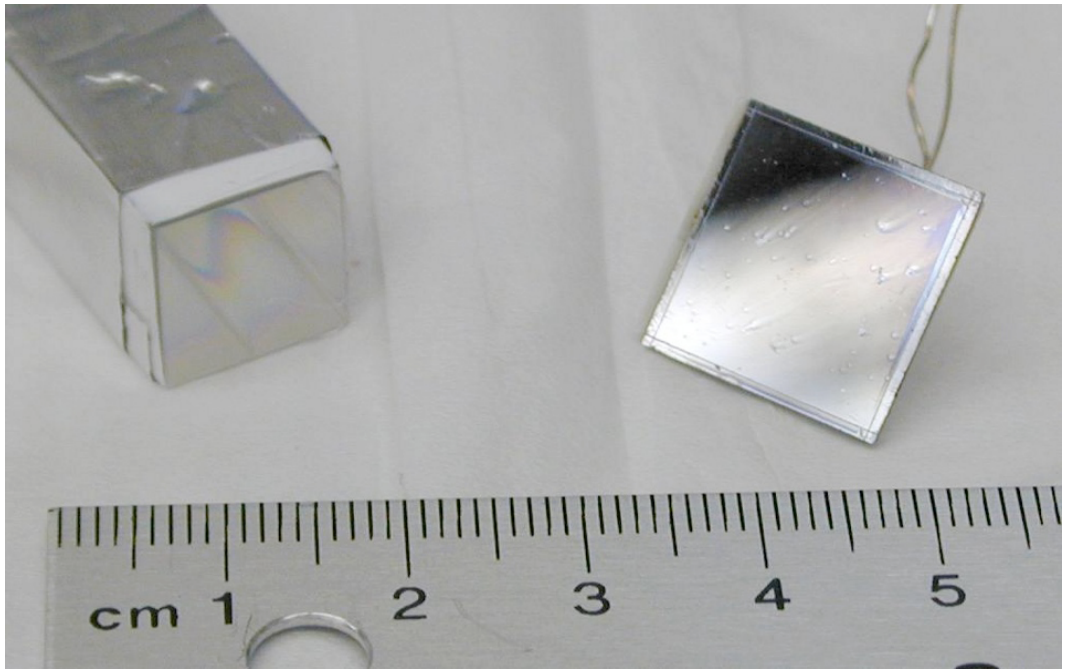


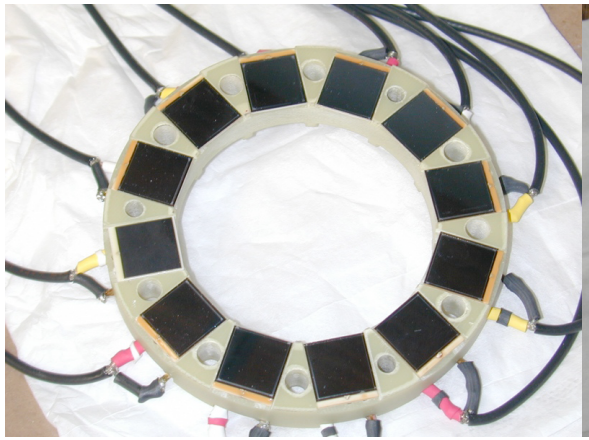
Electron-Proton Detector

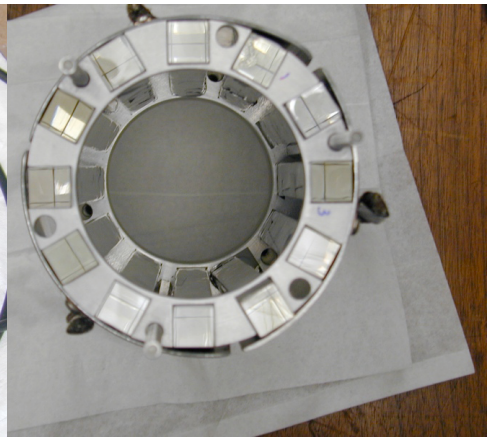


Scintillator Detector

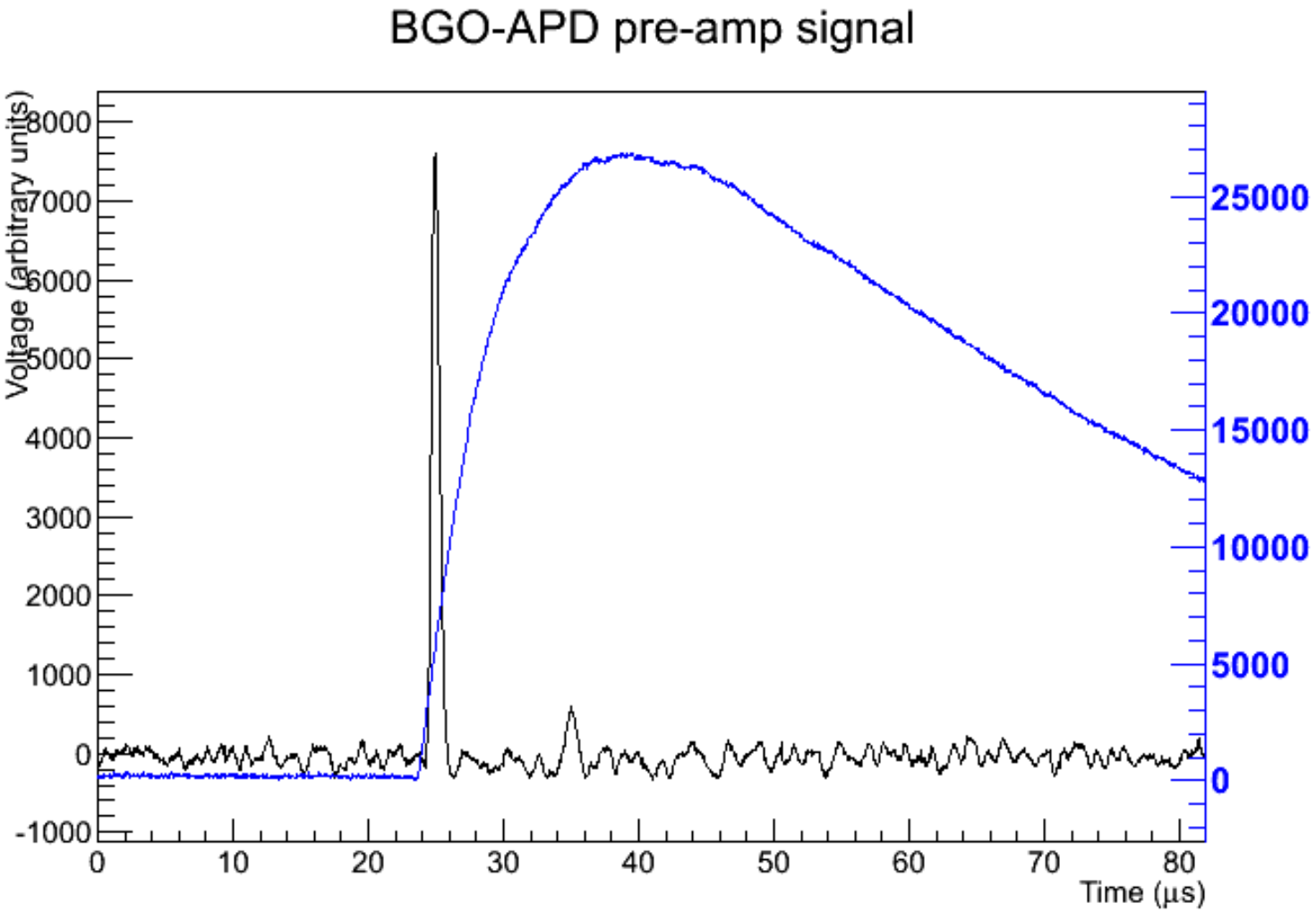
- Bismuth germanate (BGO) scintillator crystals coupled to avalanche photo-diodes (APD)
  - 12 Detectors
  - 200x12x12mm^3 BGOs
  - 14x14mm^2 APDs
  - ~10keV – endpoint







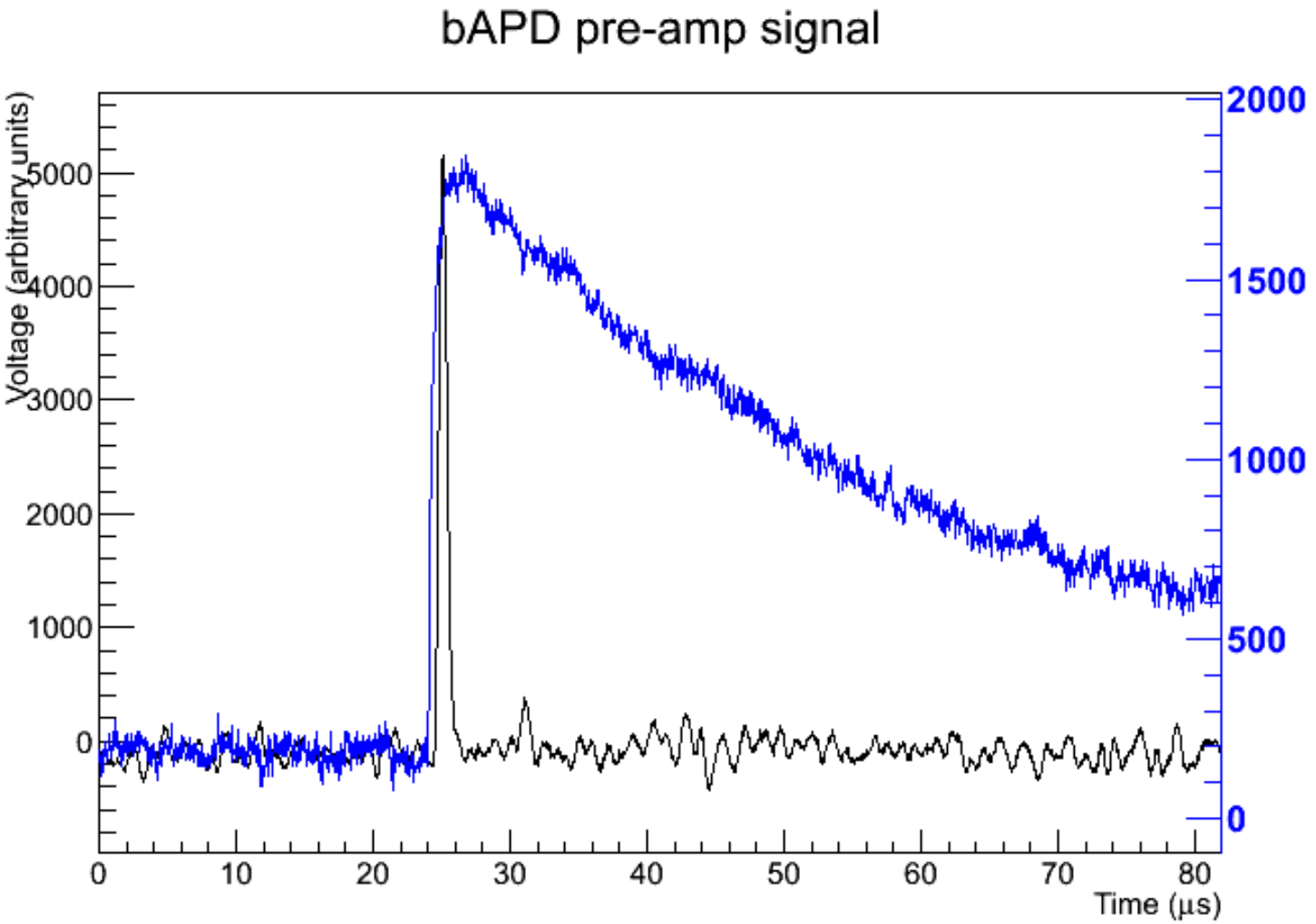
Scintillator Detector



Direct Detector

- Large area bare (non scintillating) avalanche photo-diode (bAPD) to extend the energy range
  - 3 detectors
  - 28x28mm^2
  - ~500eV – ~20keV

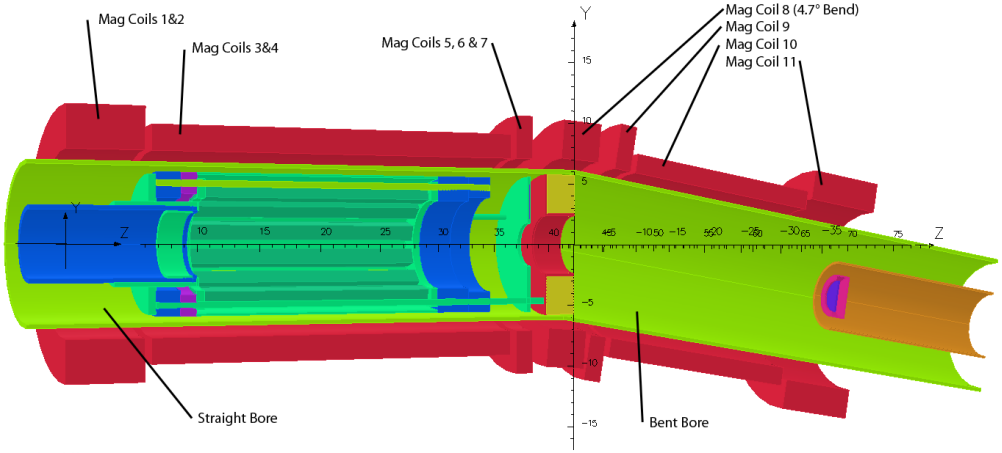
Direct Detector

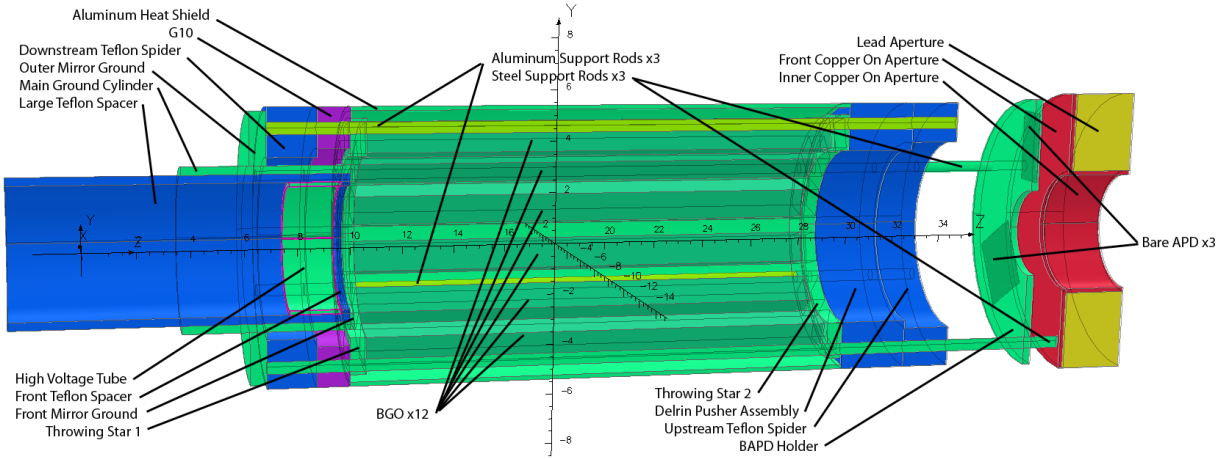


Simulation

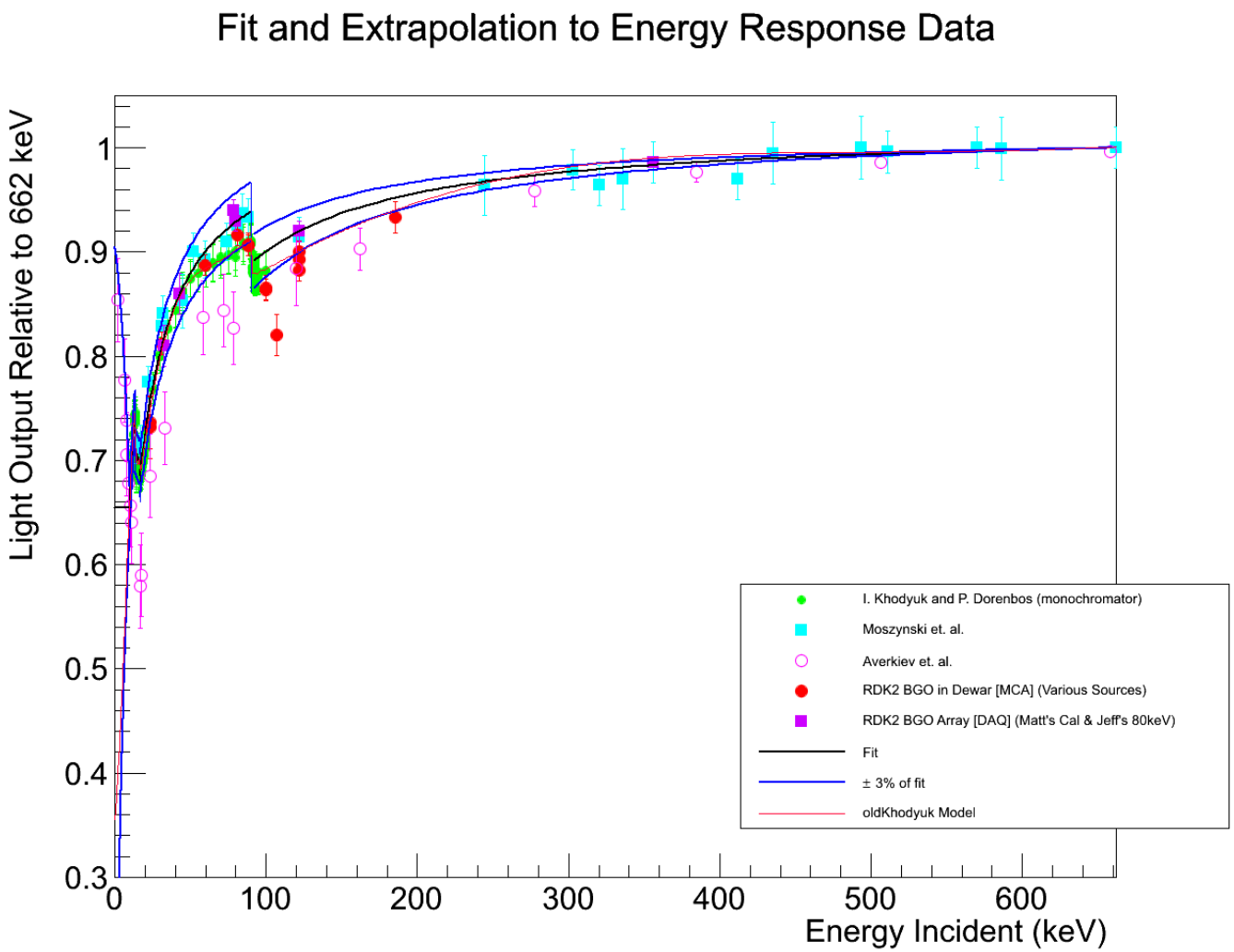
Critical to extracting results:

- Monte Carlo
  - Geant4
  - MCMP
- EM Field
  - Biot-Savart
  - TOSCA

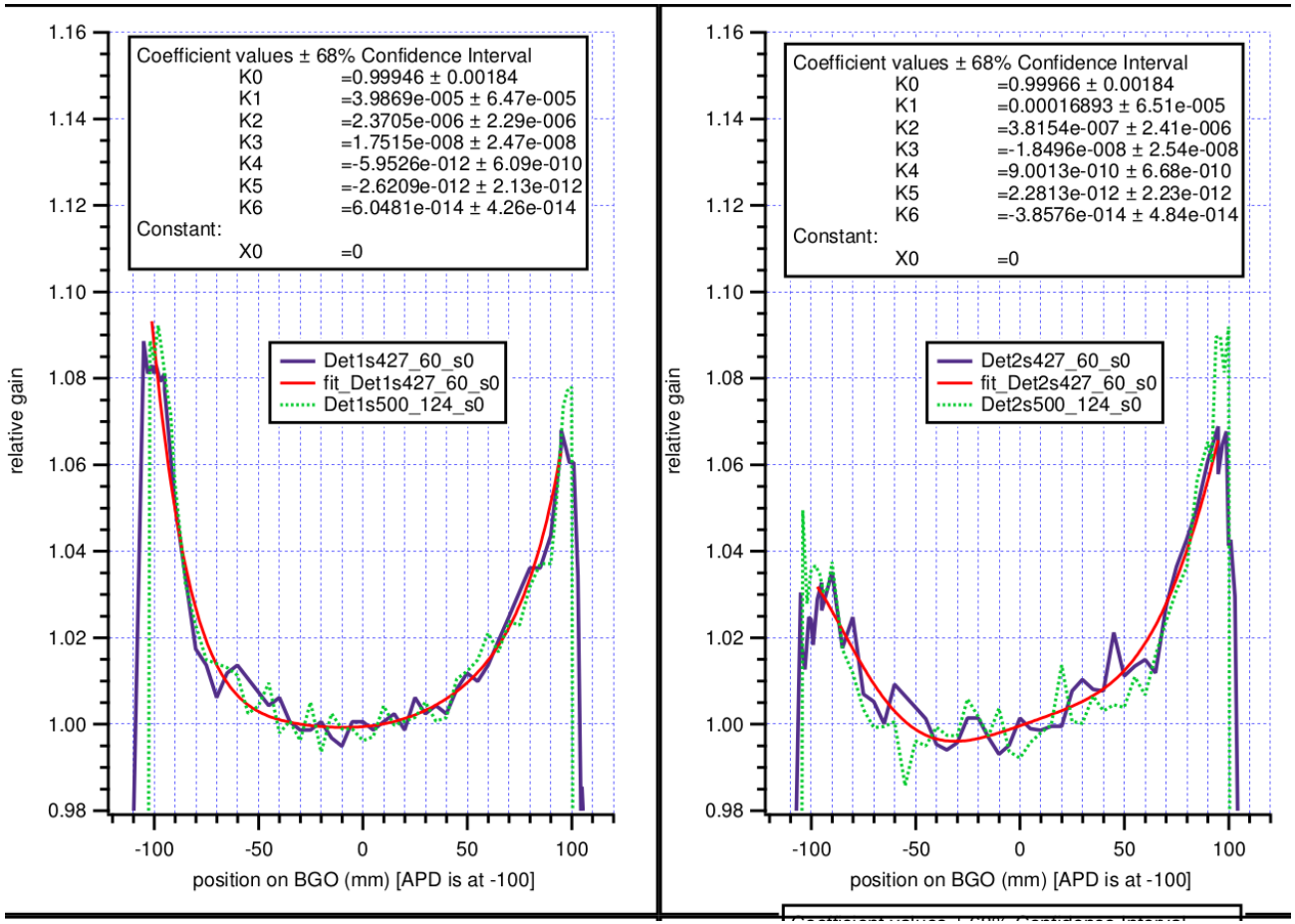




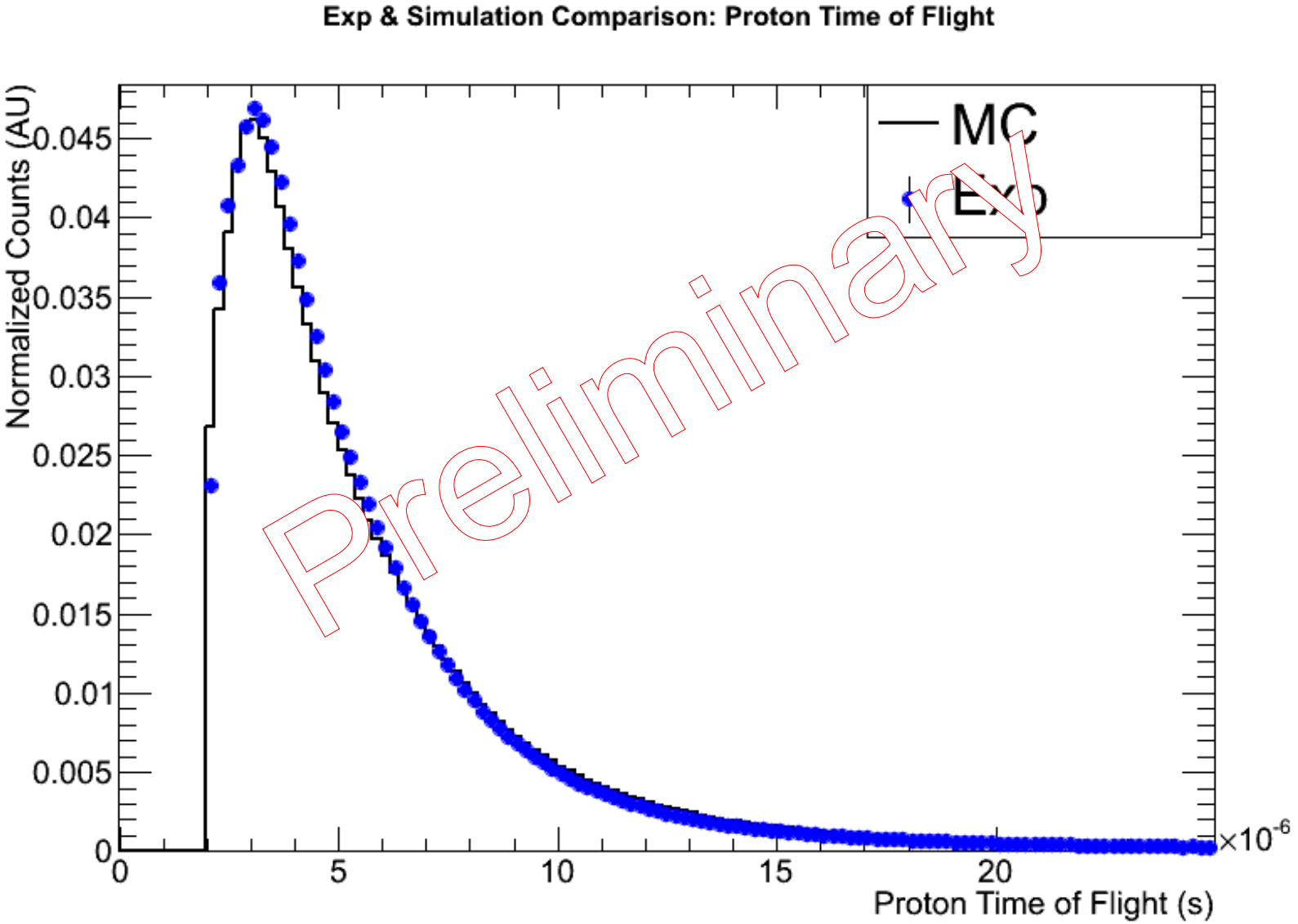
BGO Light Output



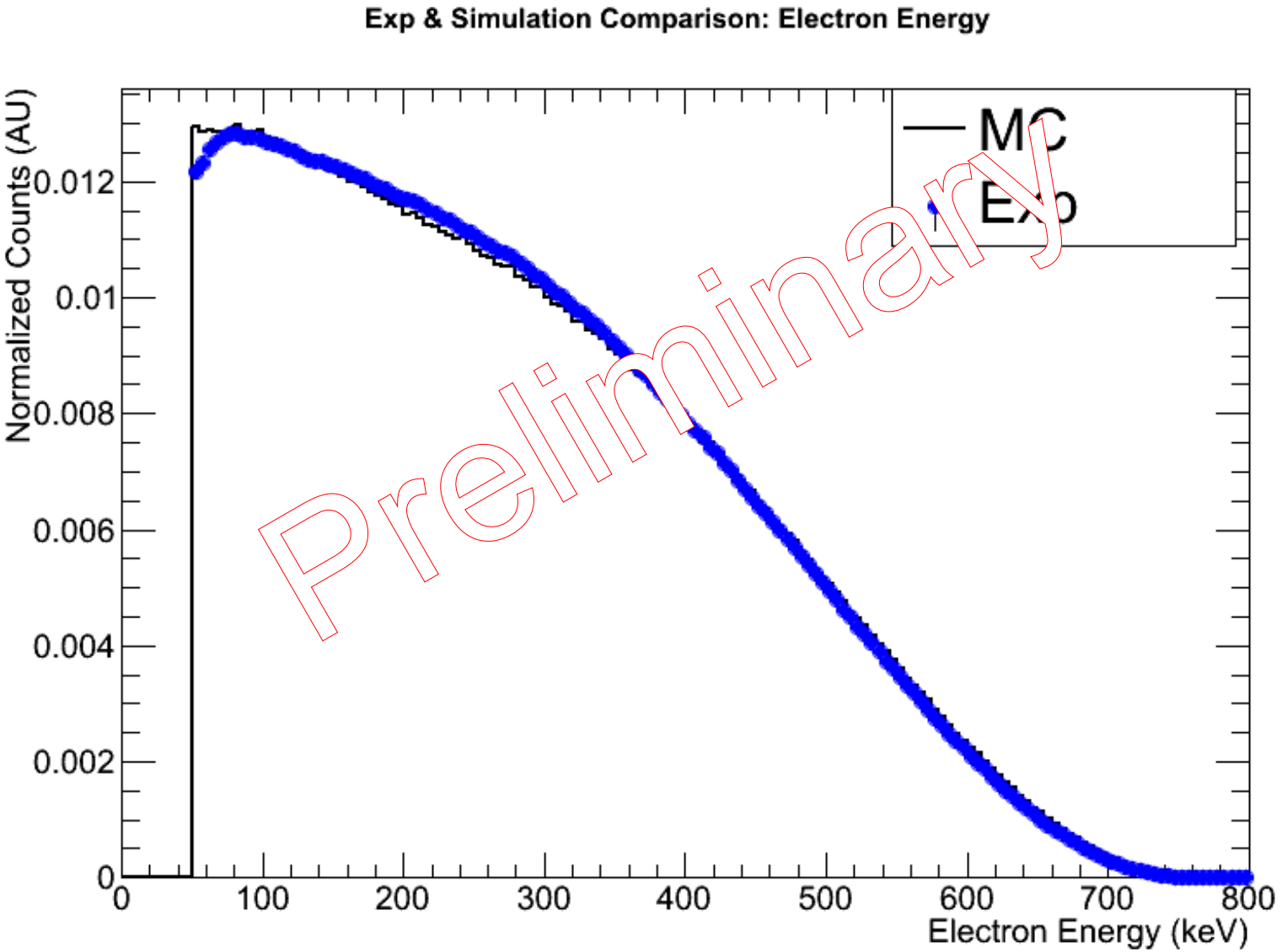
BGO Light Output



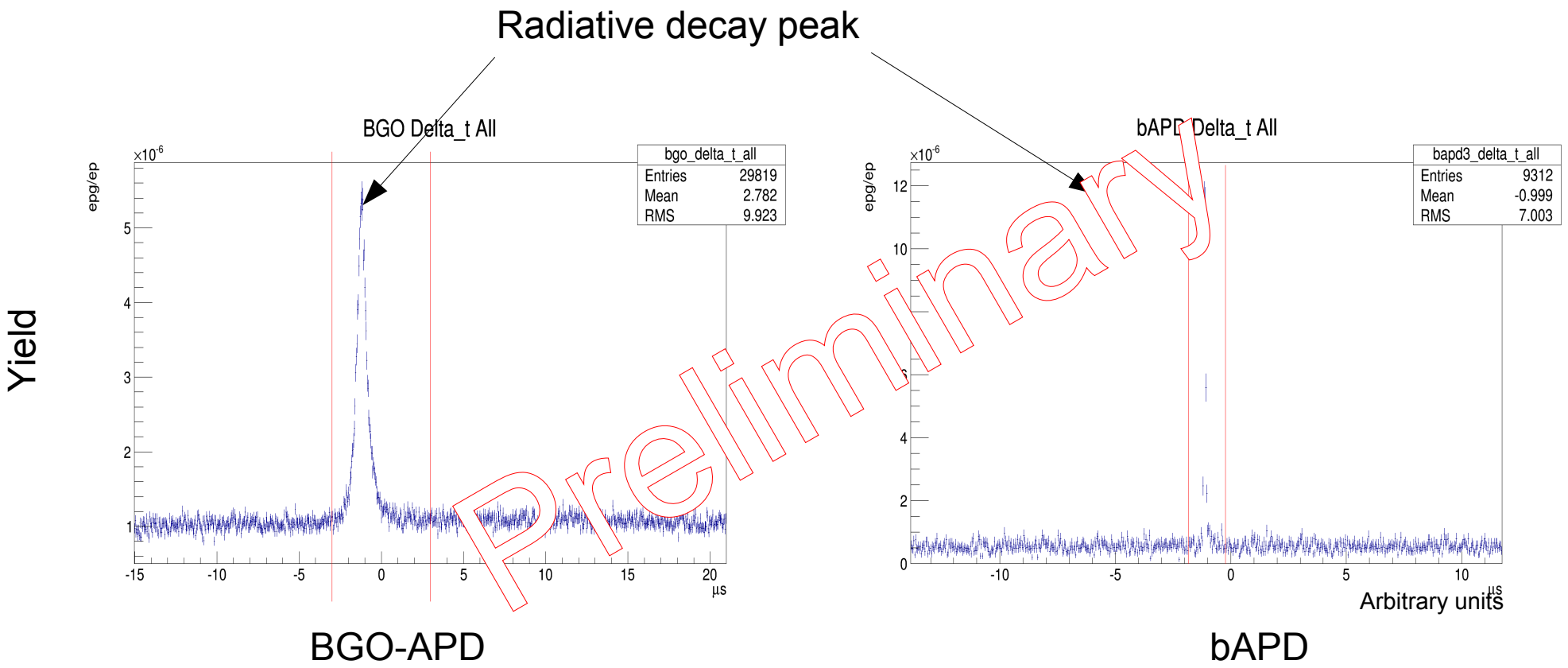
Electron-Proton ToF



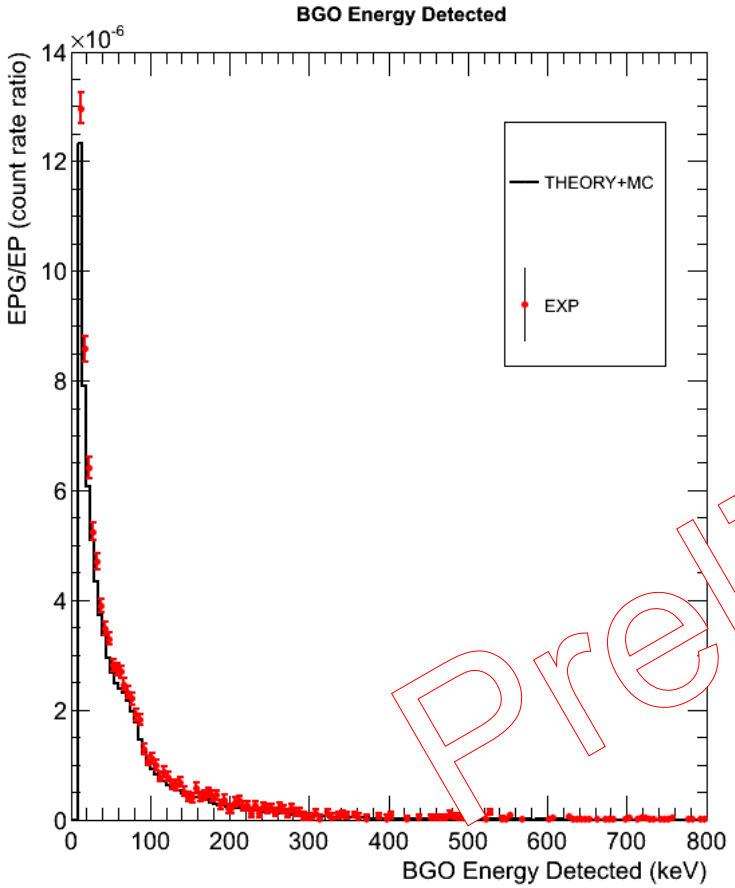
Electron Energy

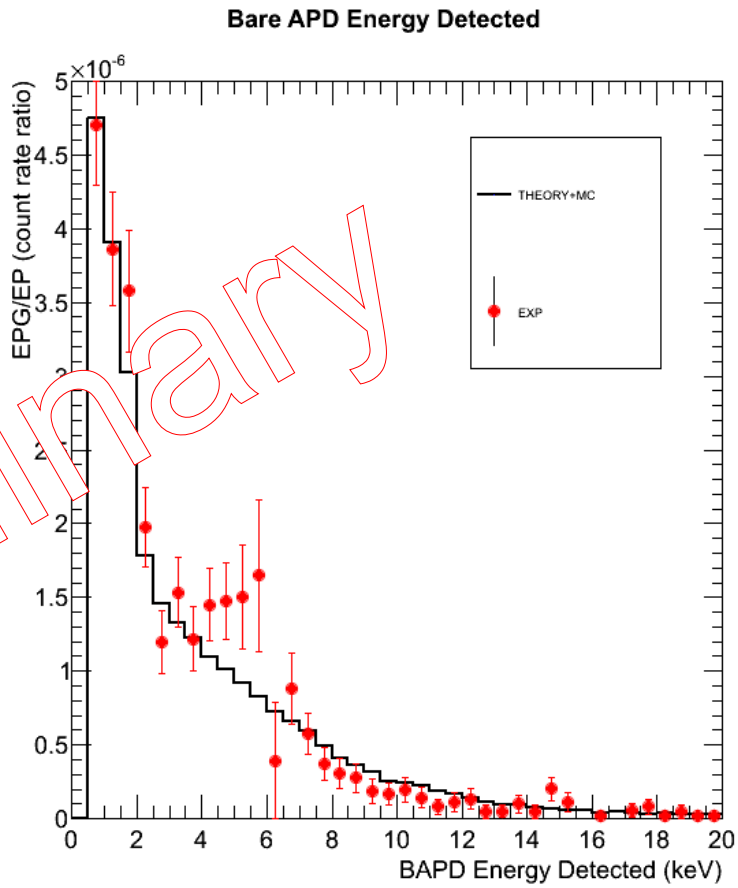


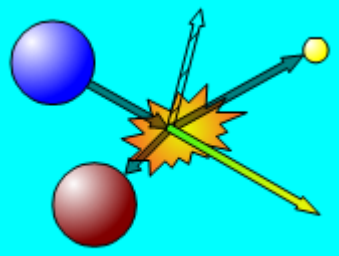
Photon Timing



Photon Energy

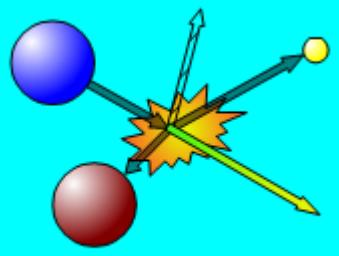


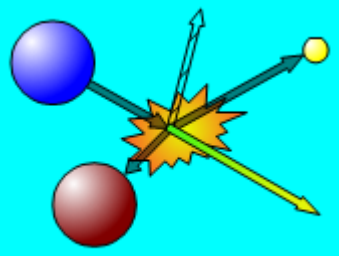




Conclusion

- Achieved high statistical precision on EPG/EP
  - BGO: $(8.826 \pm 0.081) \cdot 10^{-5}$
  - BAPD: $(3.07 \pm 0.38) \cdot 10^{-5}$
- Expanded energy range below 1keV and up to the endpoint (approx 780keV)
- Work continues on systematic errors
  - Monte Carlo
- Goal of ~1% total uncertainty on branching ratio and energy spectrum

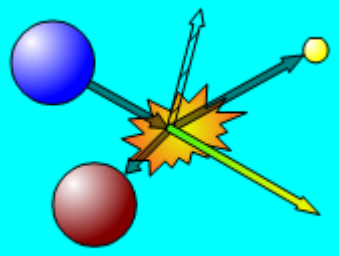




Runtime Metrics

- On beam from July 2008 to November 2009
- Off beam calibrations from January 2010 to July 2010

	All voltages	Full mirror
Run time	164.4d	97.8d
Live time	147.1d	87.5d
Total triggers	$9.7 \cdot 10^7$	$6.8 \cdot 10^7$
Run data	6.4TB	4.4TB
Total data	25TB	



Improvements in RDK II

- Twelve BGO+APD detectors
- Three bare APD (bAPD) detectors
- Neutron counter
- In situ calibration runs
- Improved statistics: O(0.1%) for BGOs
- Greater energy range
  - <10keV to the endpoint on BGO
  - <1keV to ≈10keV for bAPD

NIST Beam Line

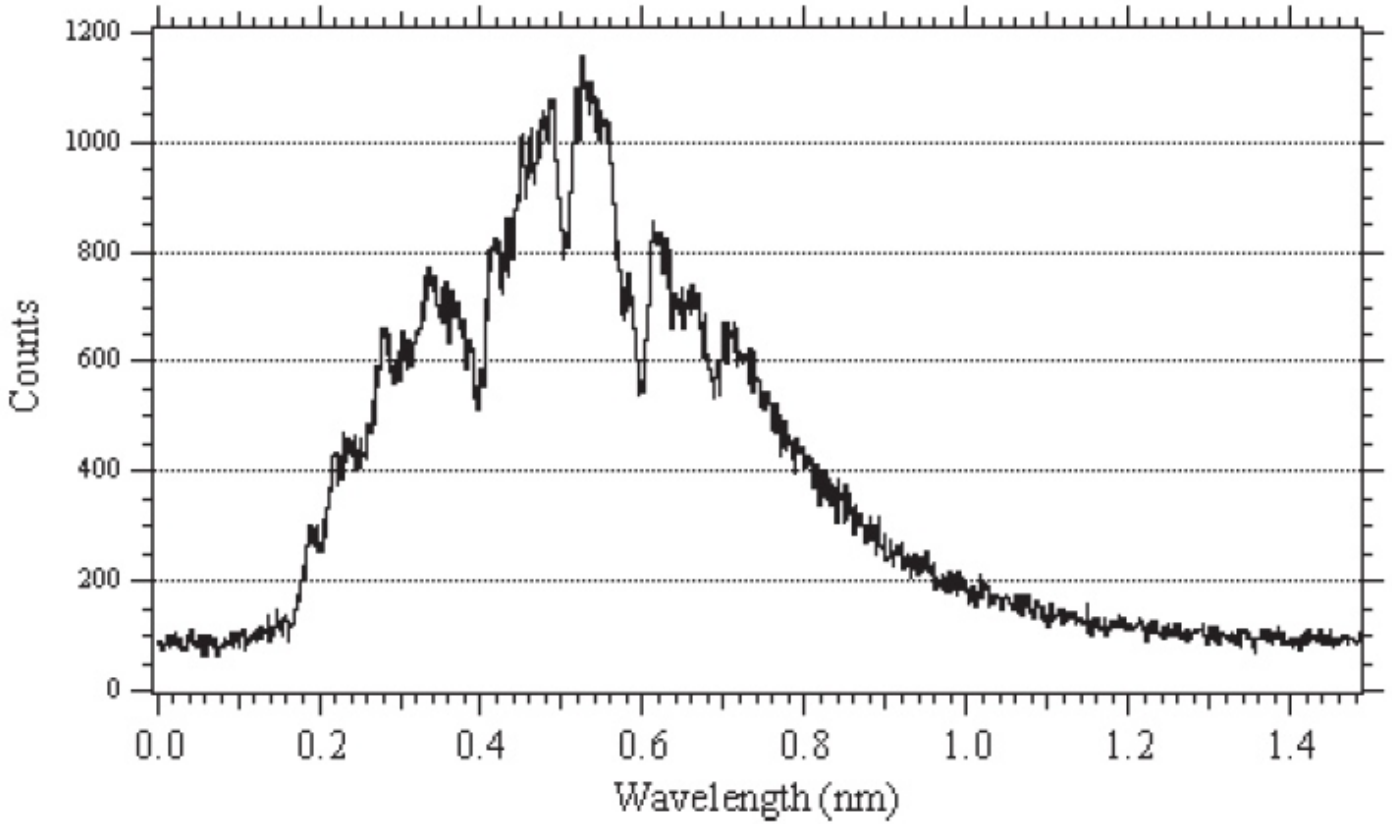
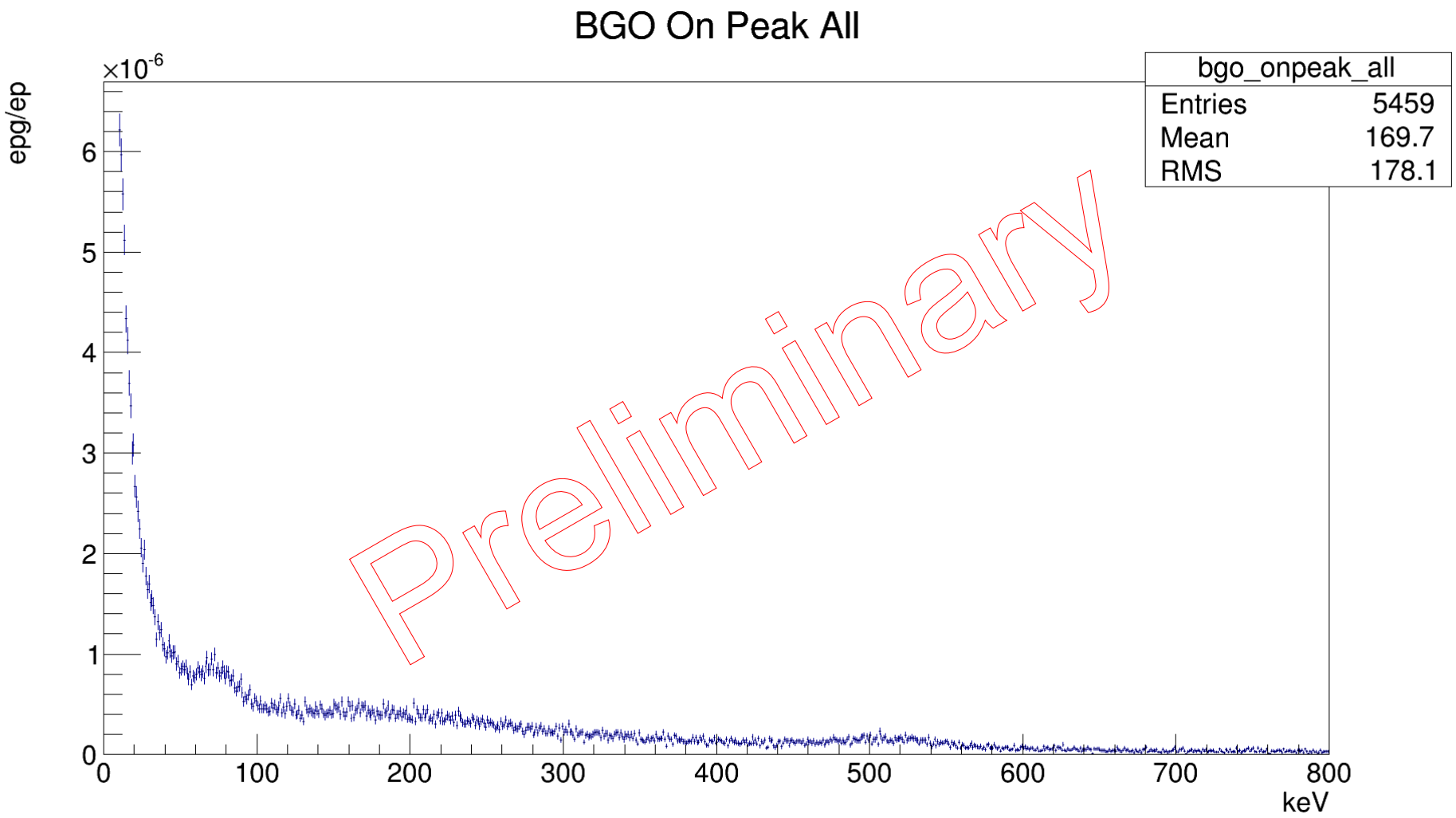
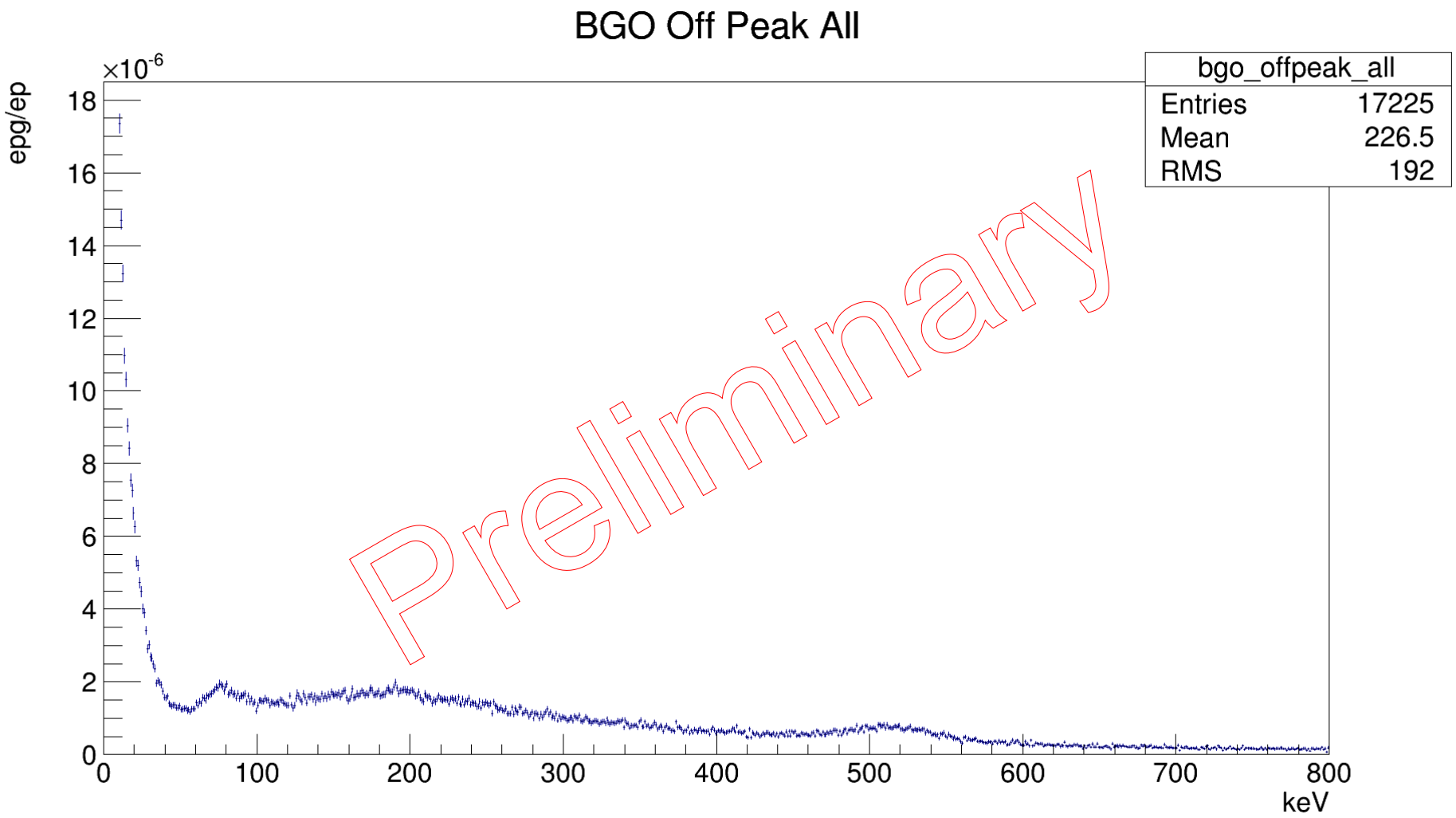


Fig. 2. Wavelength spectrum of the NG-6 polychromatic beam. The dips in the spectrum correspond to Bragg-edges from materials upstream, typically aluminum and bismuth. The dip at 0.6 nm appears due to an upstream monochromator. The data were obtained with a 15 cm bismuth filter, polarizing supermirror, and neutron collimation in the beam.

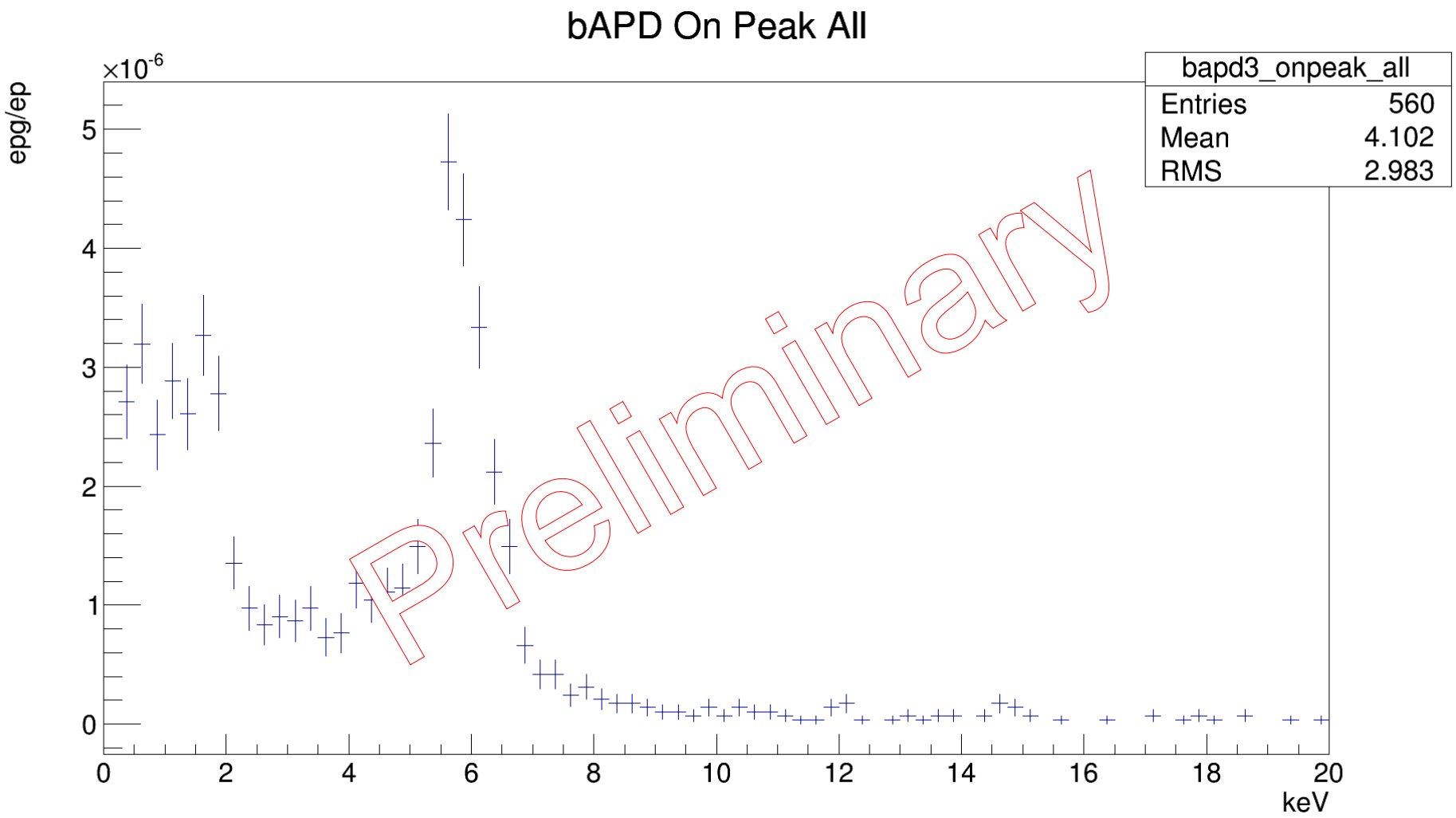
RDK II Results



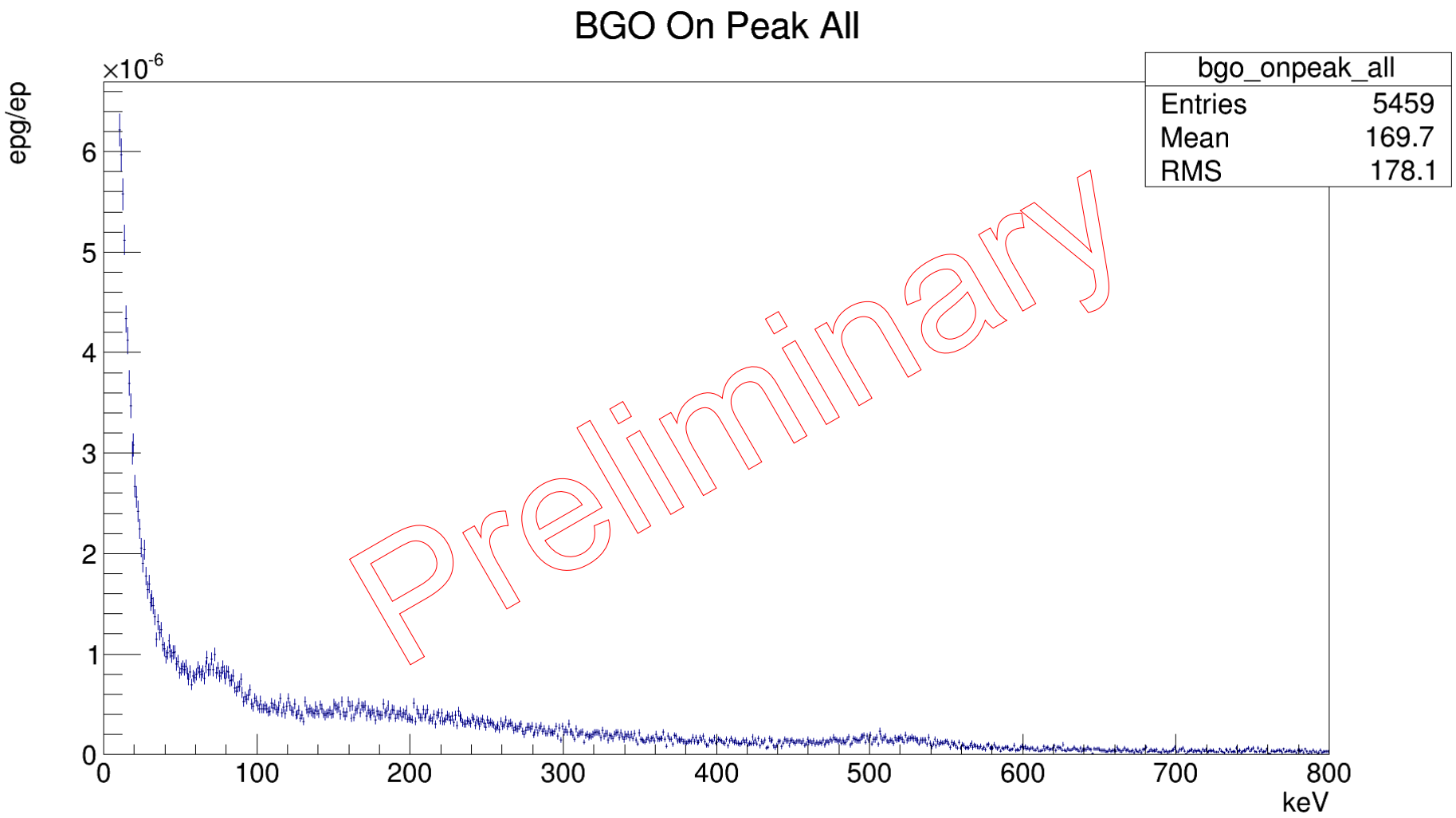
RDK II Results



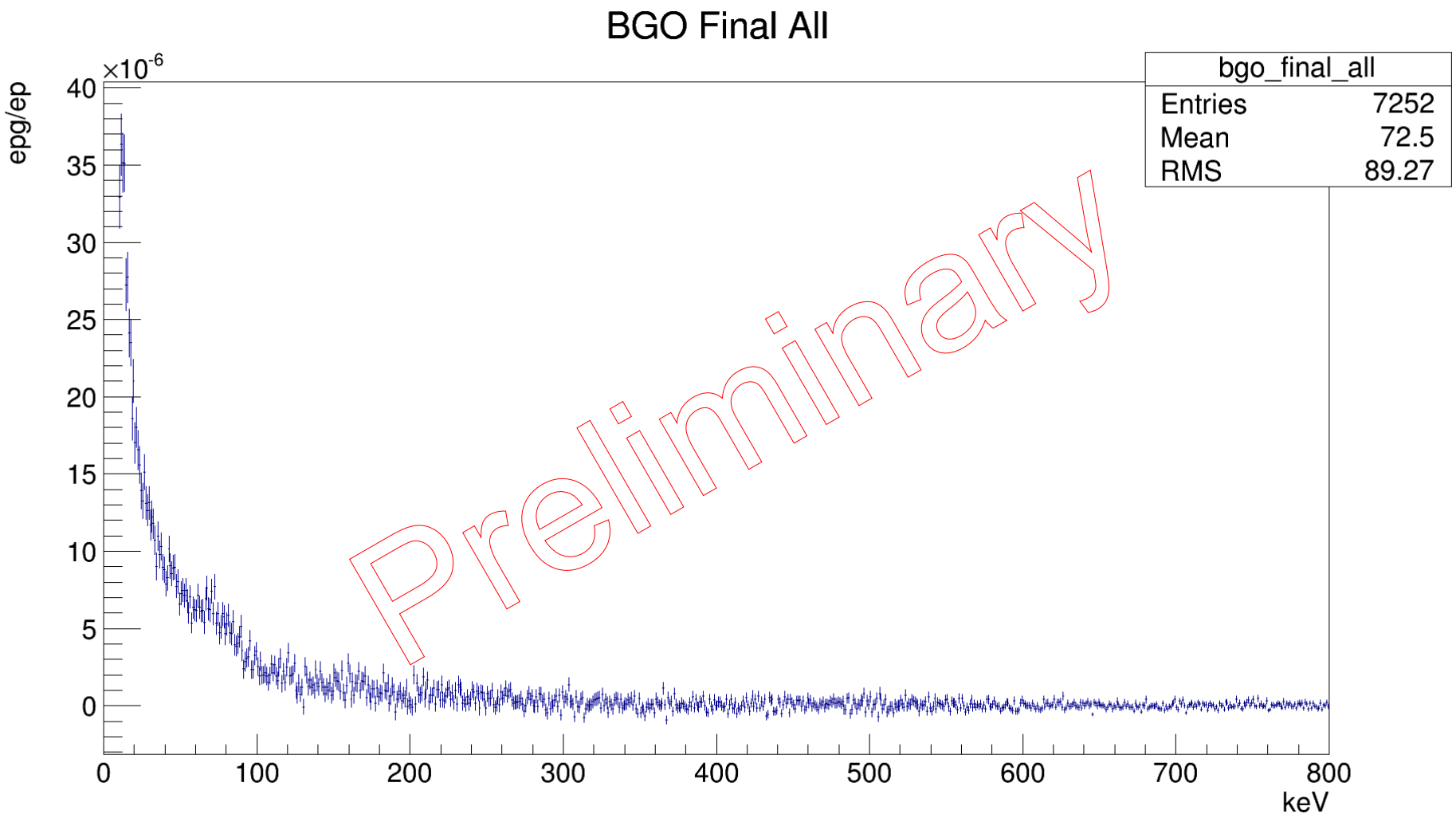
RDK II Results



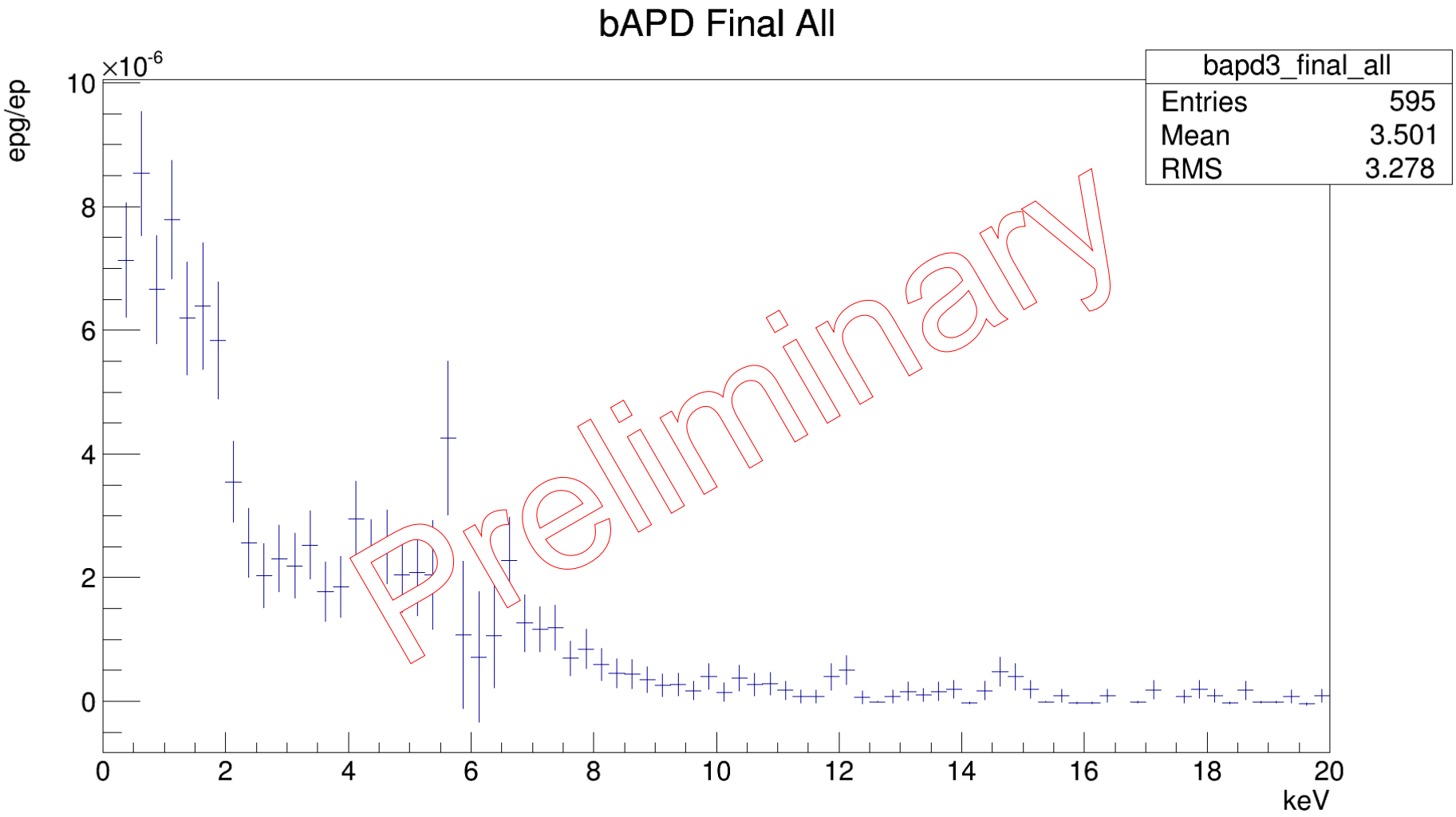
RDK II Results

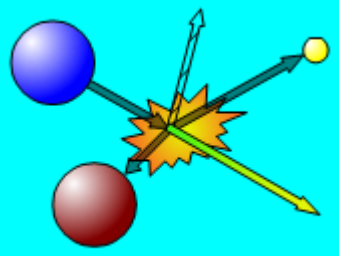


RDK II Results



RDK II Results



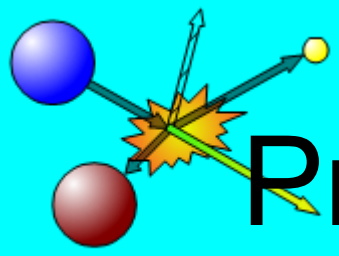


Motivation

Measurement and year	Neutron lifetime (s)	Measurement type
Byrne 1996	889.2±3.0[syst.]±3.8[stat.]	Beam, Penning trap
Arzumanov 2000	885.4±0.9[syst.]±0.4[stat.]	Bottle, UCN gravitational trap
Nico 2005	886.3±1.2[syst.]±3.2[stat.]	Beam, Penning trap
PDG World Average	885.7±0.8	
Seberov 2005	878.5±0.7[syst.]±0.3[stat.]	Bottle, UCN gravitational trap

Radiative corrections

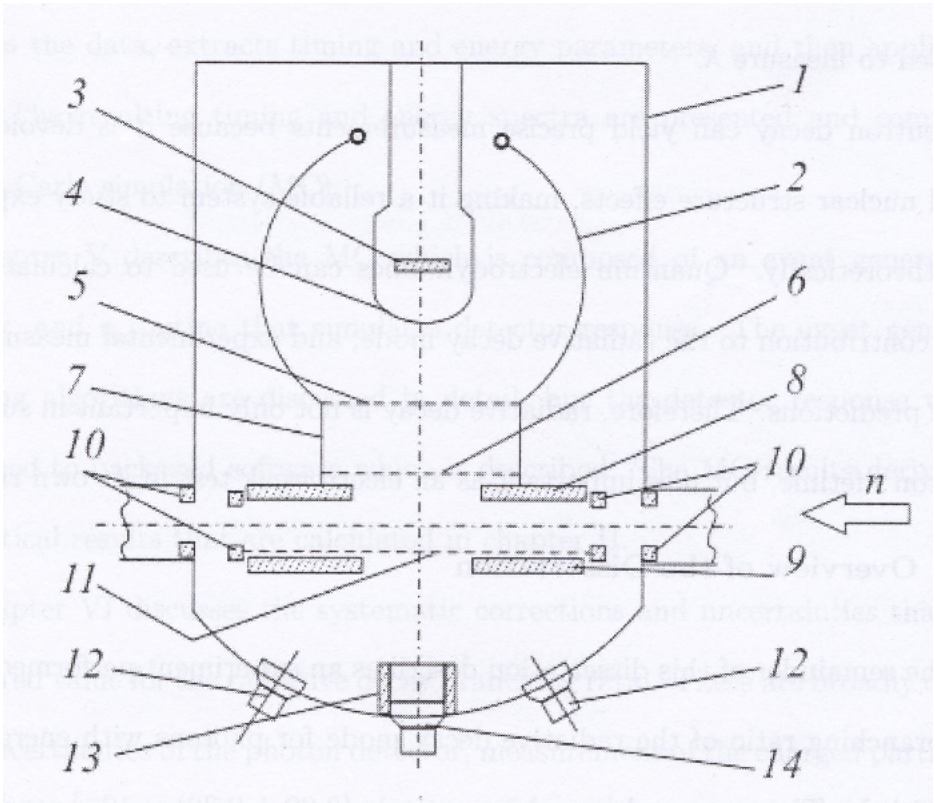
- Electron energy spectrum
- Angular correlation
- Correlated background

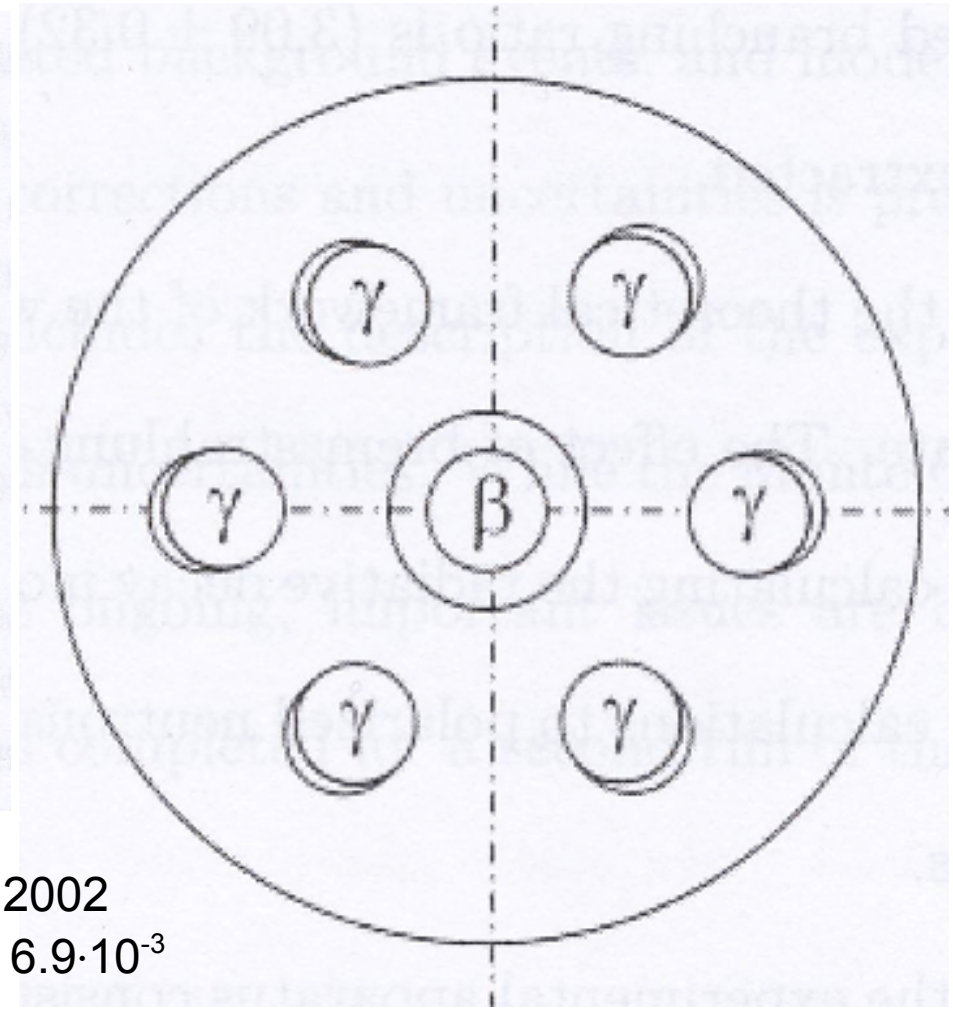


Previous Measurements: ILL

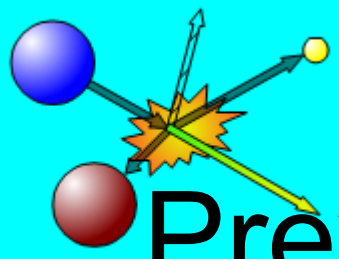
- Beck et al., Institut Laue-Langevin (ILL) 2002
- Electron-delayed proton-photon triple coincidence measurement
- Electron detector: plastic scintillator
- Proton detector: microchannel plate (MCP)
- Photon detector: Six CsI(T1) scintillators
- Result: BR for 35-100keV less than $6.9 \cdot 10^{-3}$
- Predicted: $1.1 \cdot 10^{-3}$

Previous Measurements: ILL





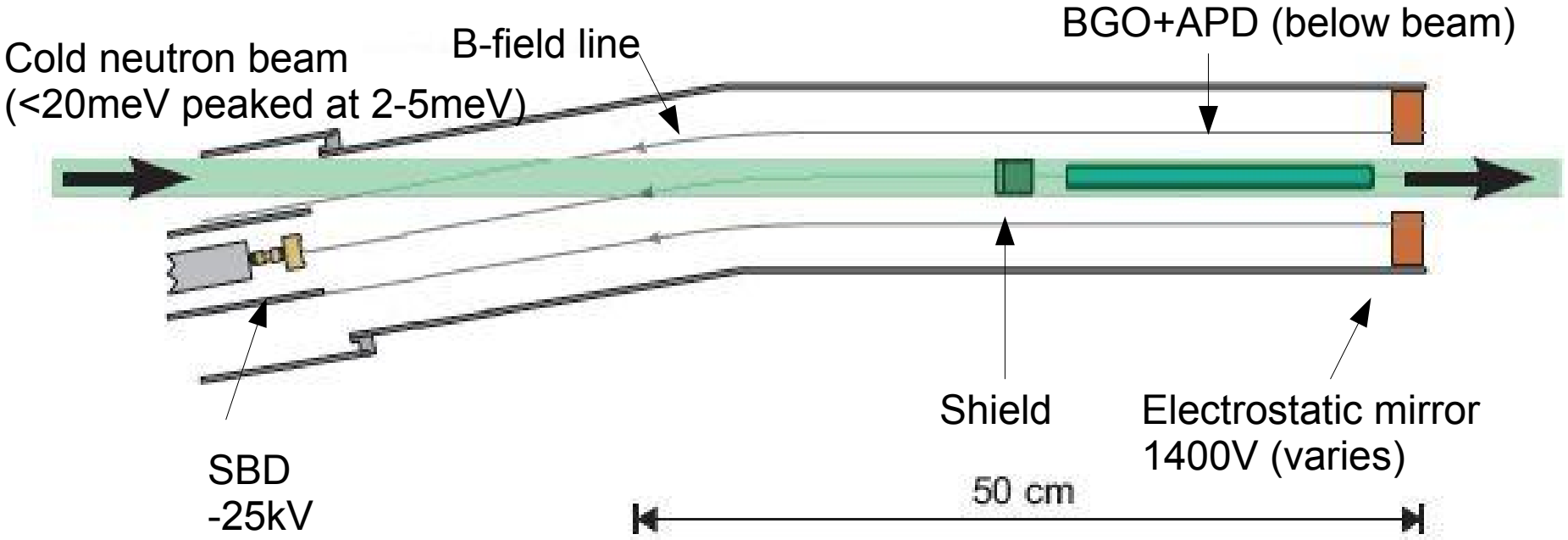
- Beck et al., Institut Laue-Langevin (ILL) 2002
- Branching ratio for 35-100keV less than $6.9 \cdot 10^{-3}$



Previous Measurements: RDK I

- Nico et al., National Institute of Standards and Technology (NIST) 2005
- Triple coincidence measurement
- Electron-proton detector: surface barrier detector (SBD)
- Photon detector: bismuth germanate (BGO) scintillator + avalanche photo-diode (APD)
- Result: BR for 15-340keV = $3.09 \pm 0.32 \cdot 10^{-3}$
- Predicted: $2.85 \cdot 10^{-3}$

Previous Measurements: RDK I



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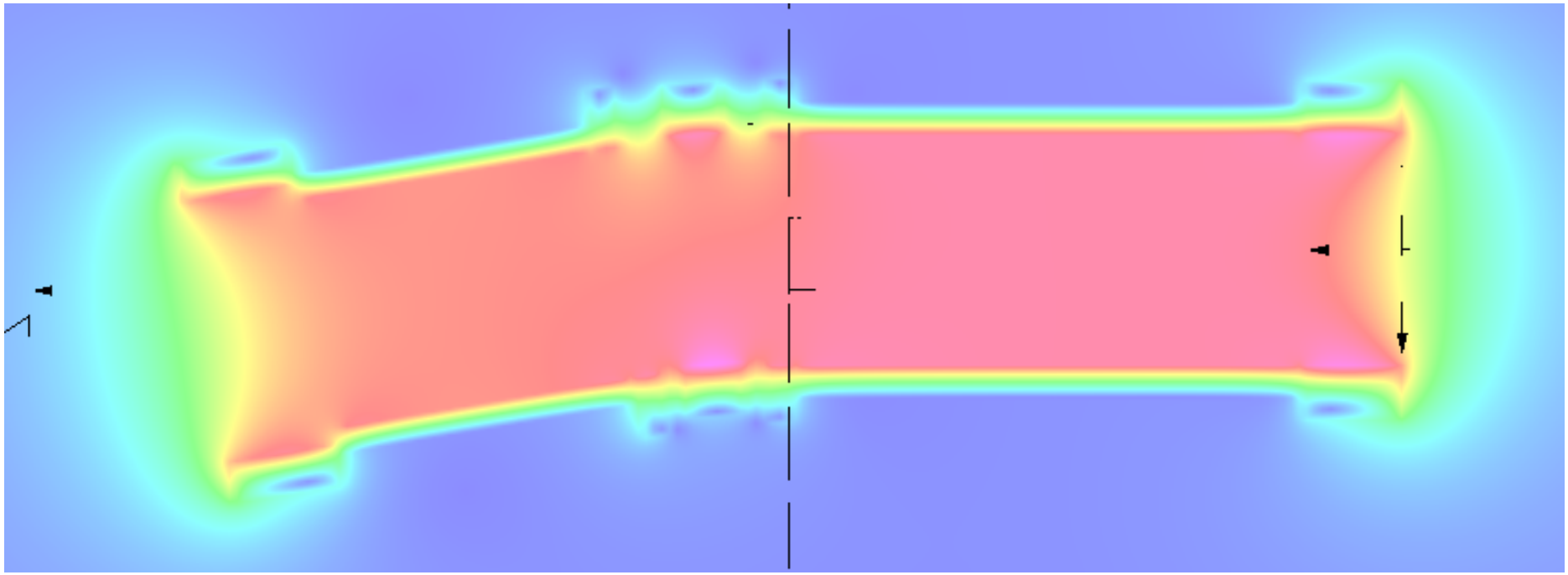
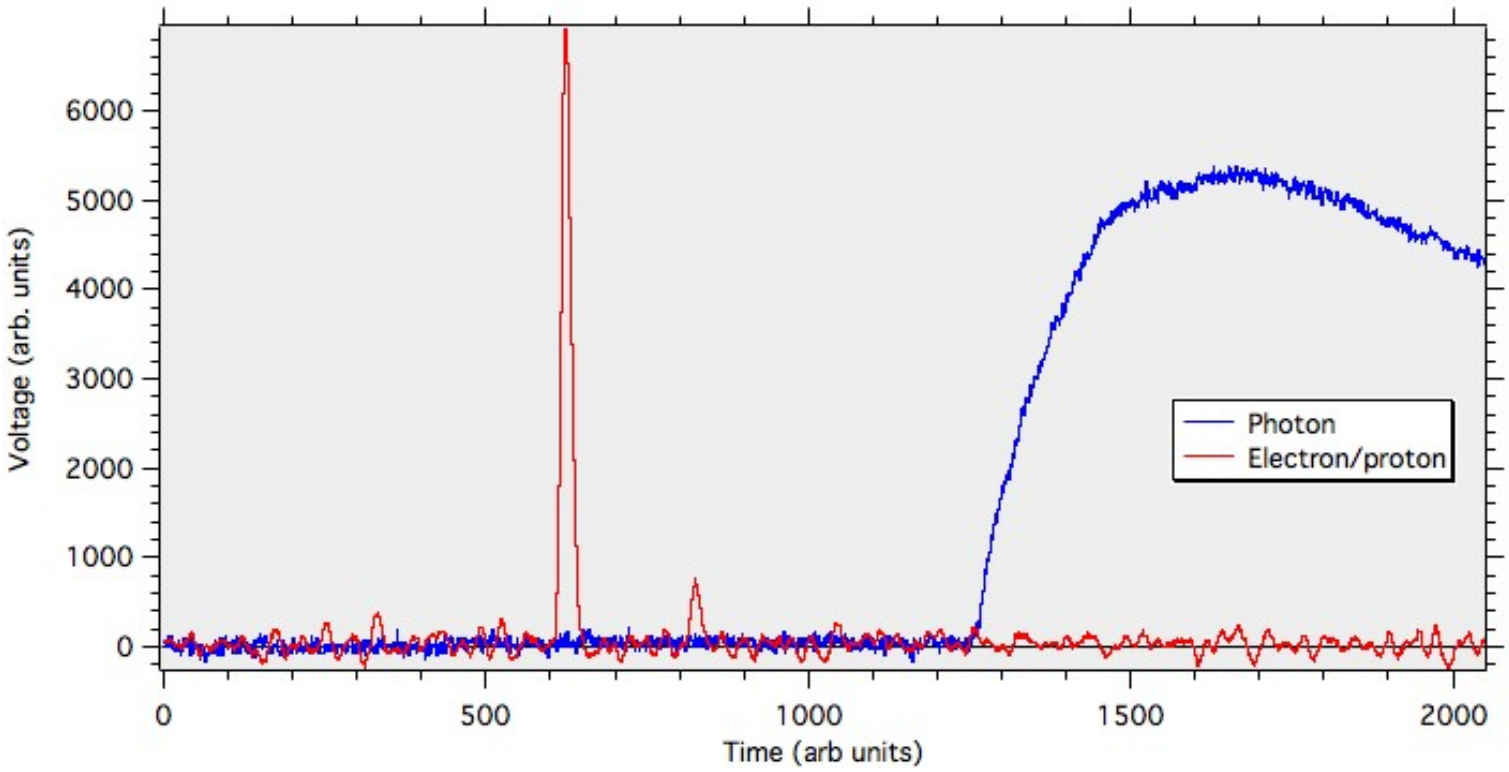
Previous Measurements: RDK I

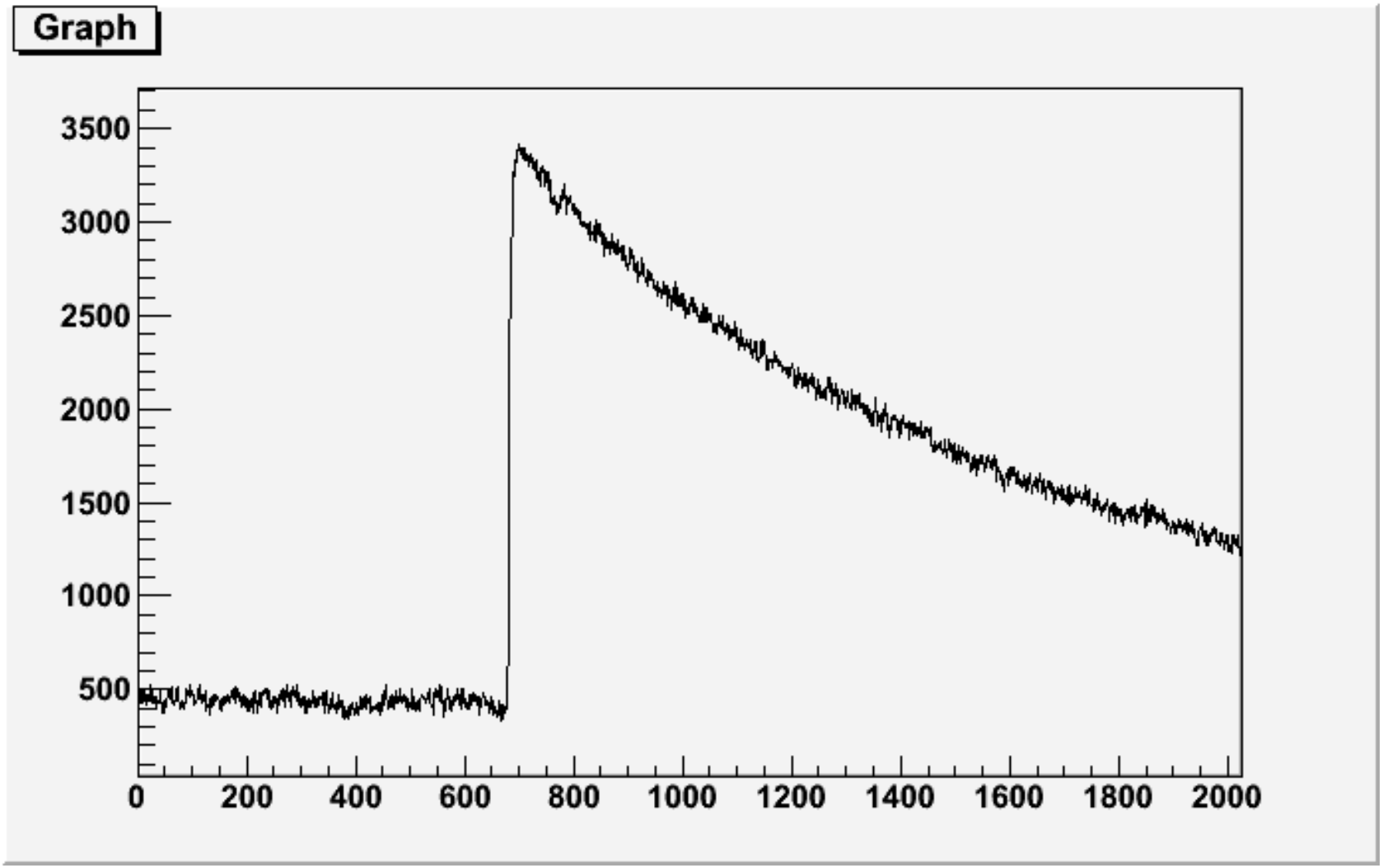


- 4.6T superconducting magnet
- 9.5° bend

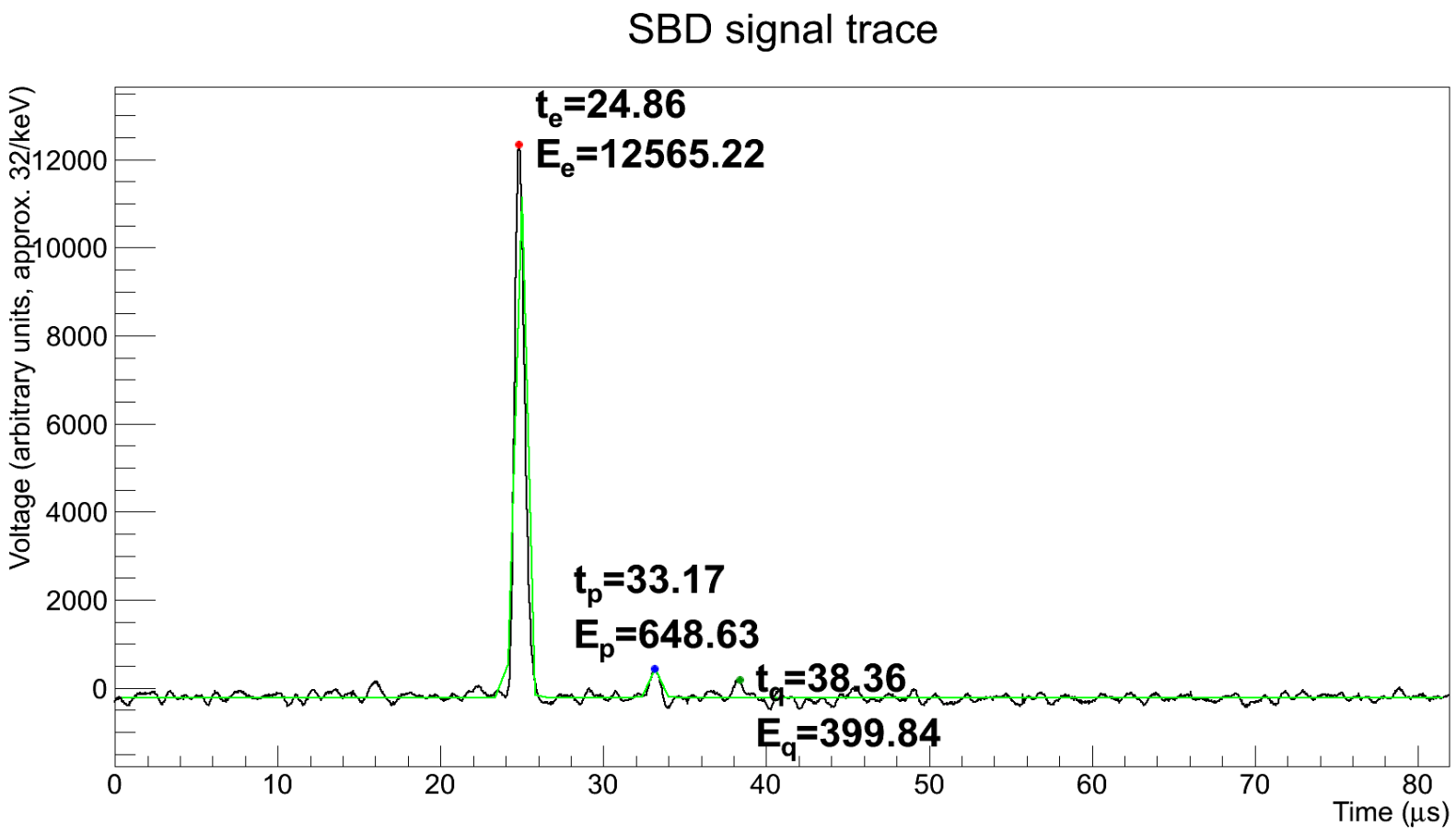
Primary Detector



Direct Detector

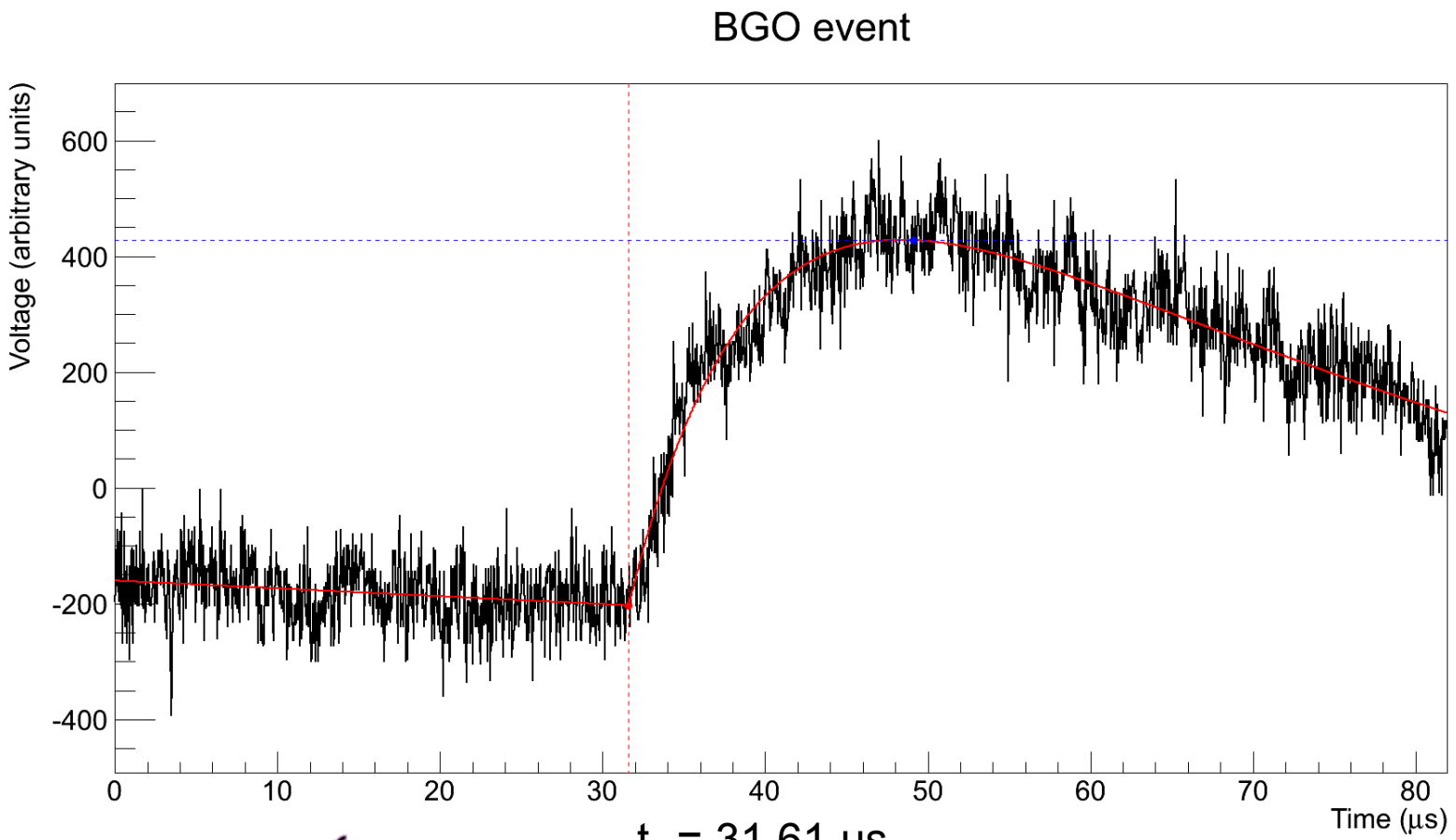


Electron-Proton Detector



$$V(t) = A + E_e e^{-(t-t_e)^2/\left(2\sigma_e^2\right)} + E_p e^{-\left(t-t_p\right)^2/\left(2\sigma_p^2\right)}$$

BGO – Full Signal Fit



E_γ = 654.6 ≈ 20 keV

t_0 = 31.61 μs

$$V(t) = \begin{cases} A + Ft & \text{if } t \leq t_0 \\ A + Ft + Be^{-C(t-t_0)}\left(1 - e^{-D(t-t_0)}\right) & \text{if } t > t_0 \end{cases}$$

$$\mathrm{E}_\gamma = \frac{BD}{C+D}\left(\frac{C+D}{C}\right)^{-C/D}$$