Measurement of Prompt Fission Neutron Spectrum using a Double Time-of-Flight Setup

E. Blain, Y. Danon

Outline

- Gamma tagging method
- Experimental setup
- Results
  - ^{252}Cf Spontaneous fission
  - ^{238}U neutron induced fission
- Conclusions
- Future work

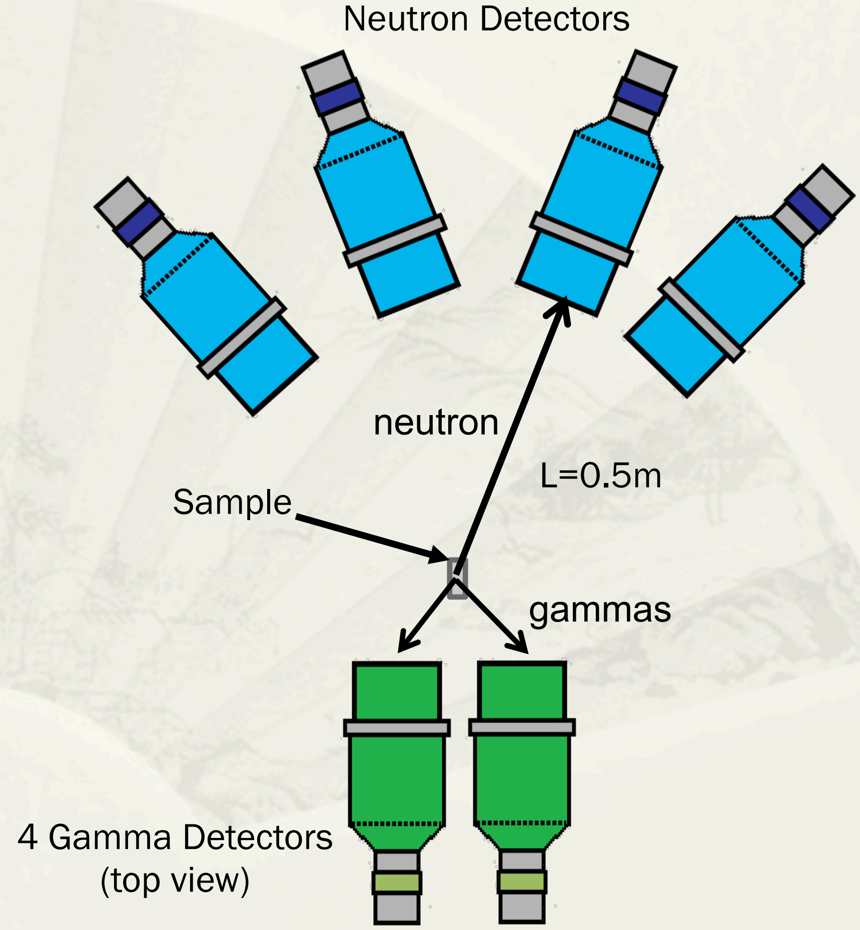
Fission Neutron Spectroscopy

- Methods of Fission Detection
  - Fission Chamber (Chi Nu at LANL[1])
    - Advantages - High Efficiency
    - Disadvantages - Very Thin Samples
  - Gamma Tagging
    - Advantages
      - Does not require complicated multiplate fission chamber
      - Much larger sample sizes
    - Disadvantages
      - Reduced fission detection efficiency (compensated by large sample size)
      - Sources of false coincidence
- Neutron Detection
  - High Energy Detectors – EJ301 Liquid Scintillator (Measurments down to 0.5 MeV)
  - Low Energy Detectors
    - EJ204 Plastic Scintillator (High efficiency, no gamma discrimination)
    - 6Li Glass Detector (Low efficiency, minimal gamma contamination)

[1]Robert C Haight, et al. "Progress in the Measurement of Prompt Neutron Output in Neutron-Induced Fission of 239Pu: The Chi-Nu Project", LA-UR-12-25233 (2012)

Gamma Tagging Method

- Utilizes fission gamma multiplicity to determine if a fission event has occurred
- Coincidence requirement on an array of BaF_2 gamma detectors
- Sources of false coincidence
  - Capture (Gamma detector number and size have been optimized to reduce this)
  - Radioactive Decay (Energy threshold has been set to reduce this)
  - Inelastic Scattering



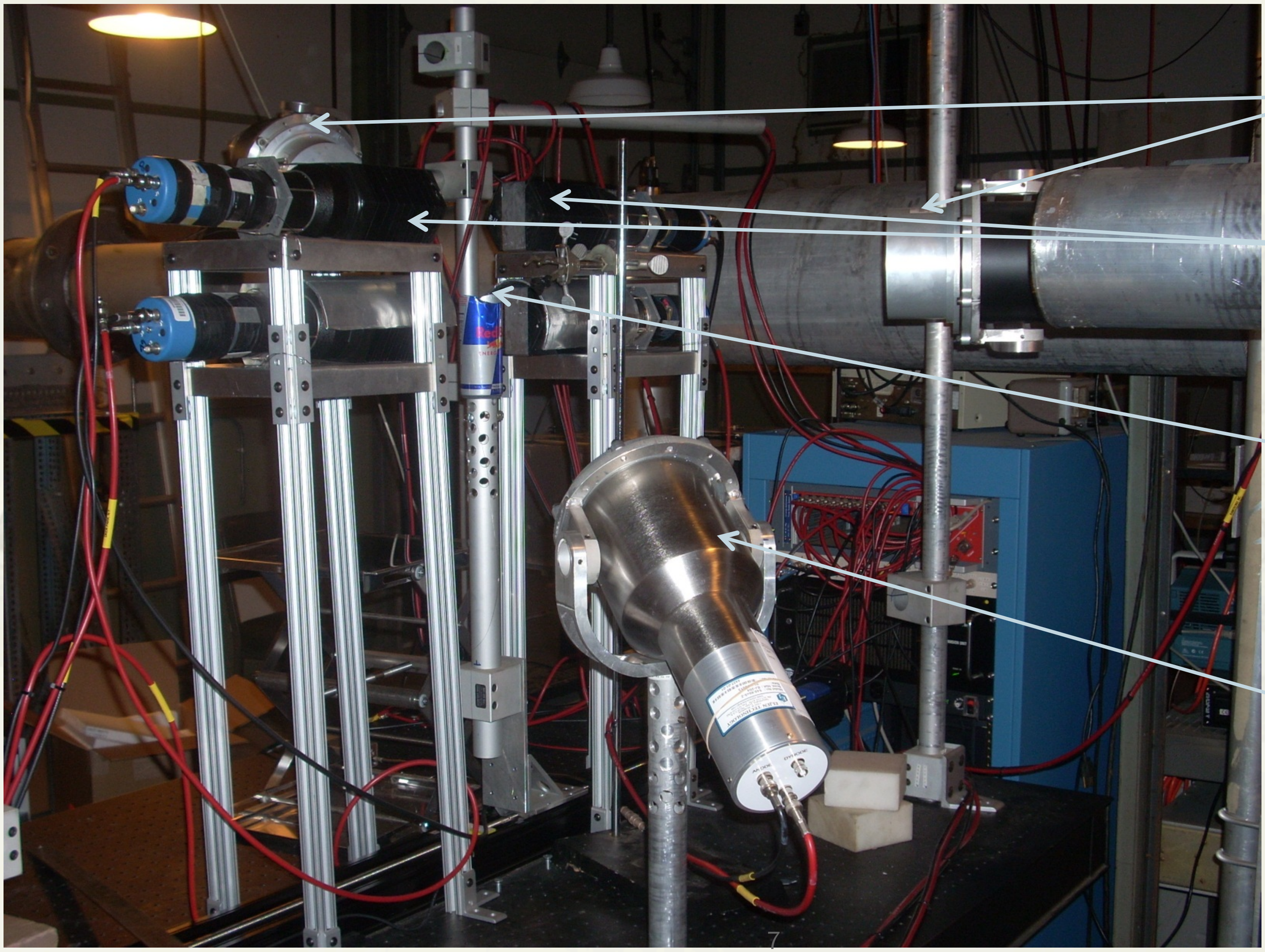
Prompt Fission Gamma Average Parameters

Isotope	Total energy (MeV)	Average number	Average energy (MeV)	Reference
^{233}U	6.69±0.3	6.31±0.3	1.06±0.07	Pleasonton (1973)
^{235}U	6.43±0.3	6.51±0.3	0.99±0.09	Pleasonton et al. (1972)
	6.70±0.4	6.69±0.3	0.97±0.05	Verbinski et al. (1973)
	7.2±0.3	7.45±0.32	0.96±0.05	Pelle and Maienschein (1971)
	6.53±0.2	6.60±0.2	0.97±0.04	Average
^{239}Pu	6.73±0.35	6.88±0.35	0.98±0.07	Pleasonton (1973)
	6.82±0.3	7.23±0.3	0.94±0.05	Verbinski et al. (1973)
	6.78±0.2	7.06±0.2	0.95±0.04	Average
^{252}Cf	7.06±0.35	8.32±0.4	0.85±0.06	Pleasonton et al. (1972)
	6.84±0.3	7.80±0.3	0.88±0.04	Verbinski et al. (1973)
	8.6	10	0.90±0.06	Bowman and Thompson (1958)
	6.7±0.4	n/a	n/a	Nardi et al. (1973)
	n/a	7.5±1.5	0.96±0.08	Val'skii et al. (1969)
	6.95±0.2	7.98±0.2	0.87±0.03	Average

Valid Fission Selection Criteria

- Coincidence of at least 2 on an array of 4 BaF_2 detectors
- 300 keV Energy threshold on each gamma detector
- Neutron event occurring on at least 1 of 3 neutron detectors
- Time between gamma and neutron events less than 600 ns
- Simulated fission detection efficiency 36.8%
  - False detection probability 3.9% (mostly from capture)
    - Correction for false detection will be implemented in final analysis

Experimental Setup

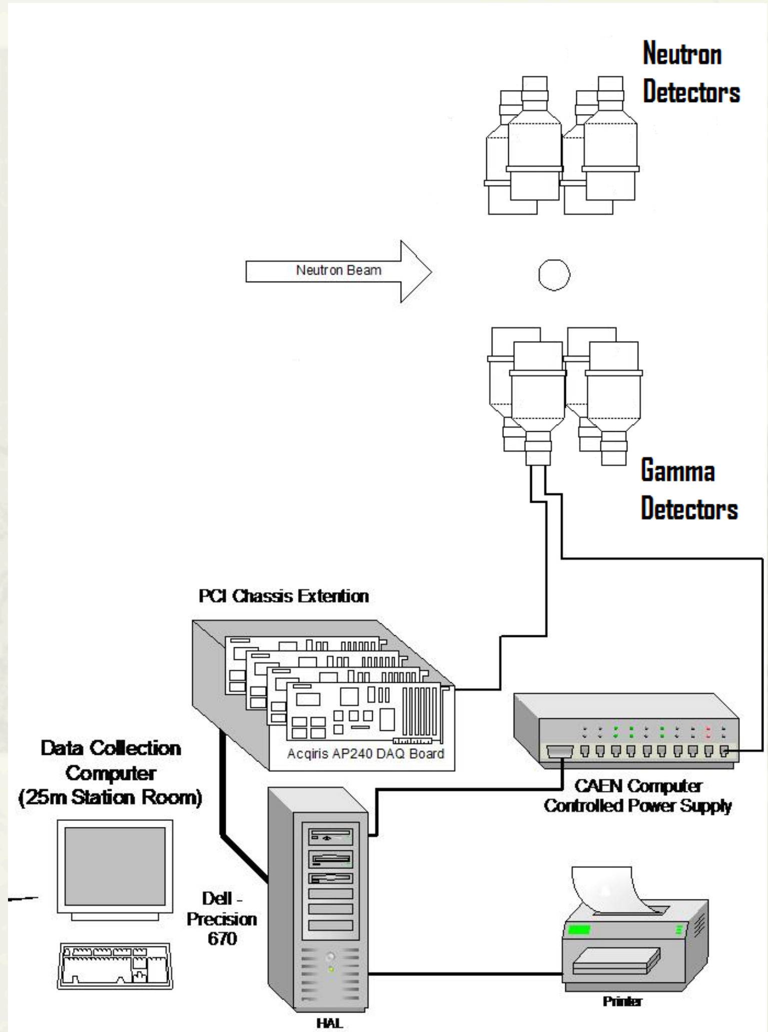


Neutron/Gamma Detectors

- Neutron Detectors
  - 1 EJ-204 Plastic Scintillator
    - 0.5” thick x 5” diam.
    - 48 cm away from center of sample
  - 2 EJ-301 Liquid Scintillators
    - 3” thick x 5” diam.
    - 50 cm away from center of sample
- Gamma Detectors
  - 4 BaF_2 detectors on loan from ORNL
    - Hexagonal detectors 2” x 5” thick
  - 10 cm from sample center
  - ¼” lead shield between detectors reducing scattering between detectors

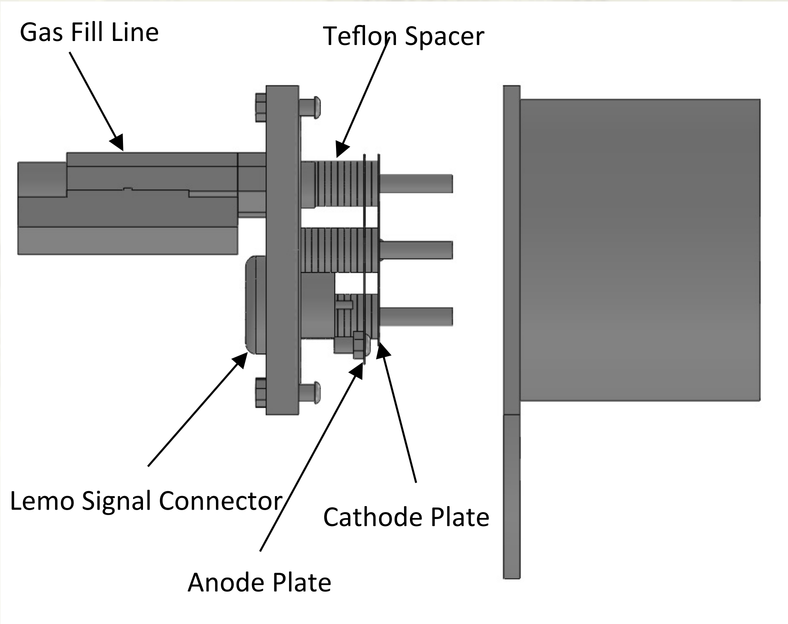
Digital Data Acquisition

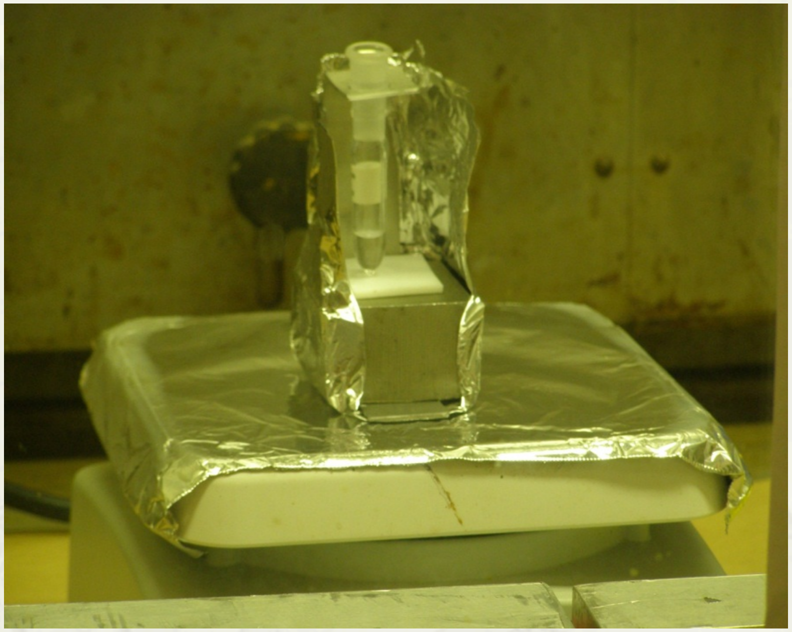
- PCI Chasis Extention
  - 4 Acqiris AP240 DAQ boards
  - (2 channels per board)
- Computer controlled power supply
  - Chassis - SY 3527
  - Board - A1733N
- 1 Gsample/sec acquisition rate giving 1 ns timing resolution
- 125k events/sec acquisition rate allows for coincidence analysis in post processing



Fission Chamber

- Parallel Plate Fission Chamber designed at RPI
- 2 mm plate spacing allowing for fast timing response
- Methane fill gas at 1 atm



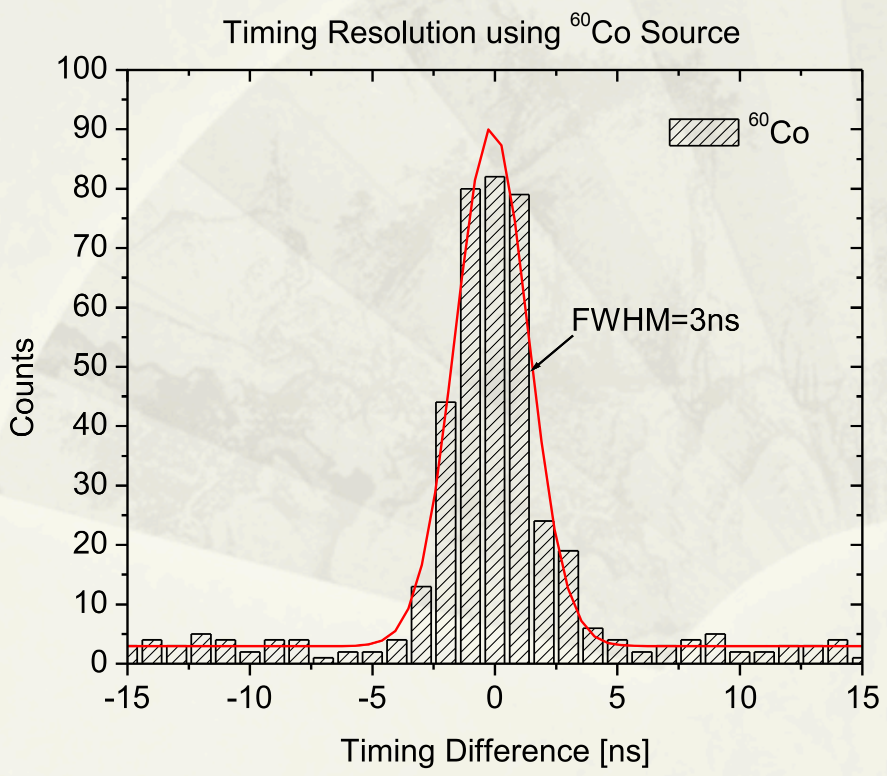


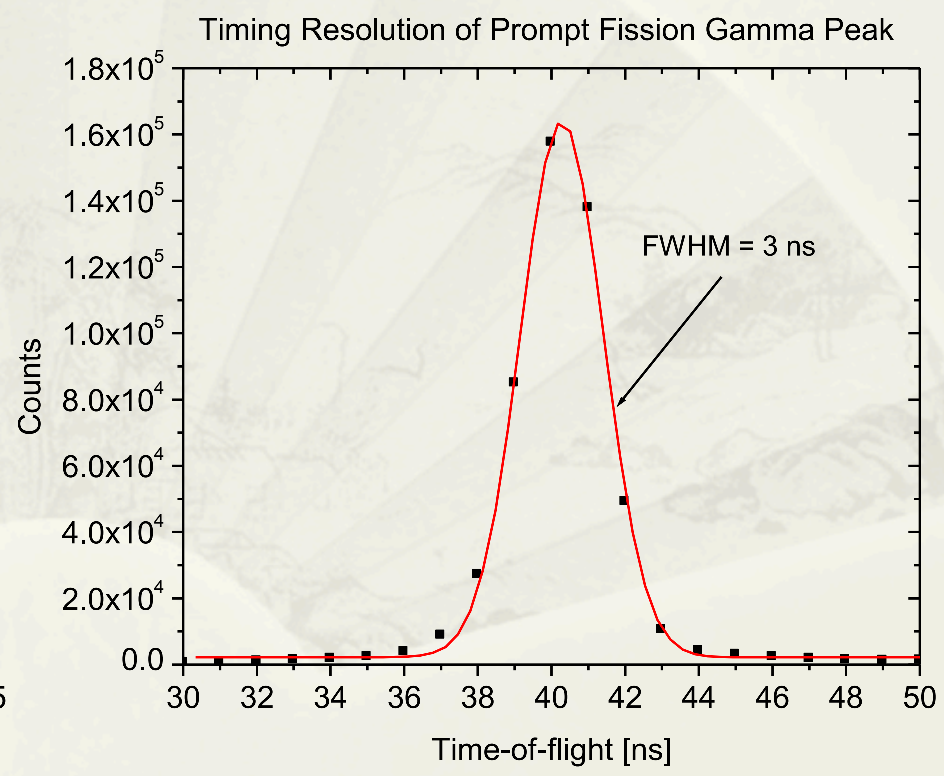
^{252}Cf sample mixed with HCl evaporating on hotplate

- 20 ng ^{252}Cf sample obtained from ORNL
- Deposited onto sample plate through stippling 25 depositions of 2 μL
- 1” final spot size of deposition
- 87% final deposition (~17.4ng)

System Timing Resolution

- The timing resolution with the ^{60}Co source was taken with 2 EJ-301 detectors
- The timing resolution for the prompt gamma peak is the time between the BaF_2 detectors and the EJ-301 detectors

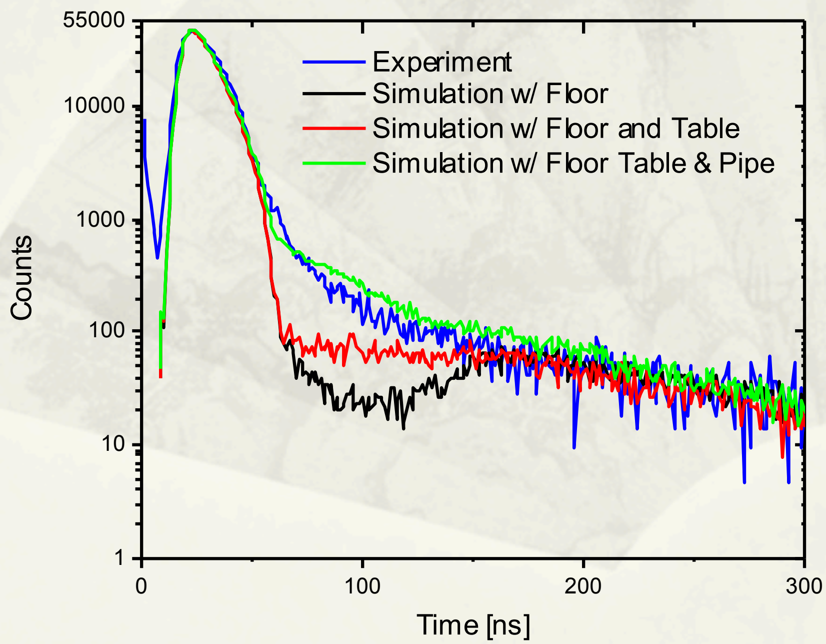




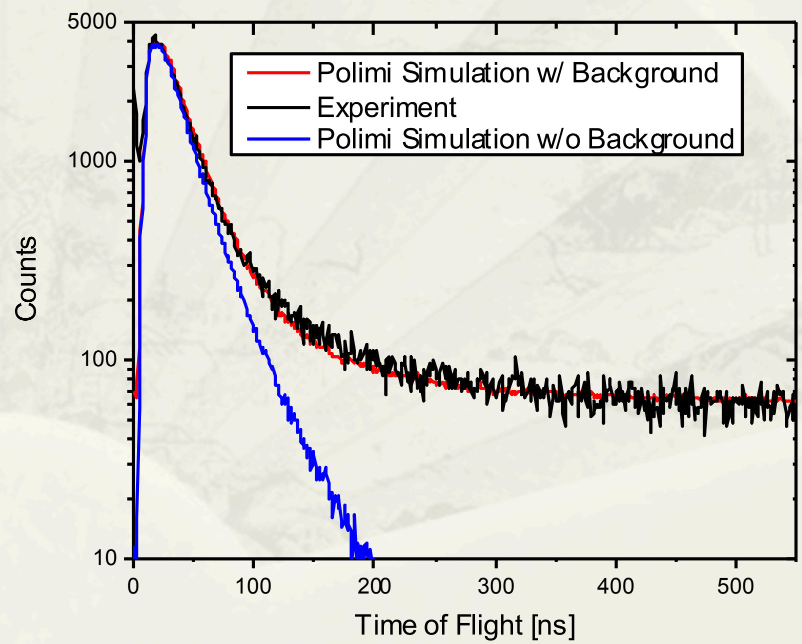
Background Considerations

- Three sources of background
  - Time independent background (random coincidence, neutrons and gammas)
  - Time dependent neutron background (neutron scattering)
  - Time dependent gamma background (neutron scattering, prompt fission neutrons)

EJ-301

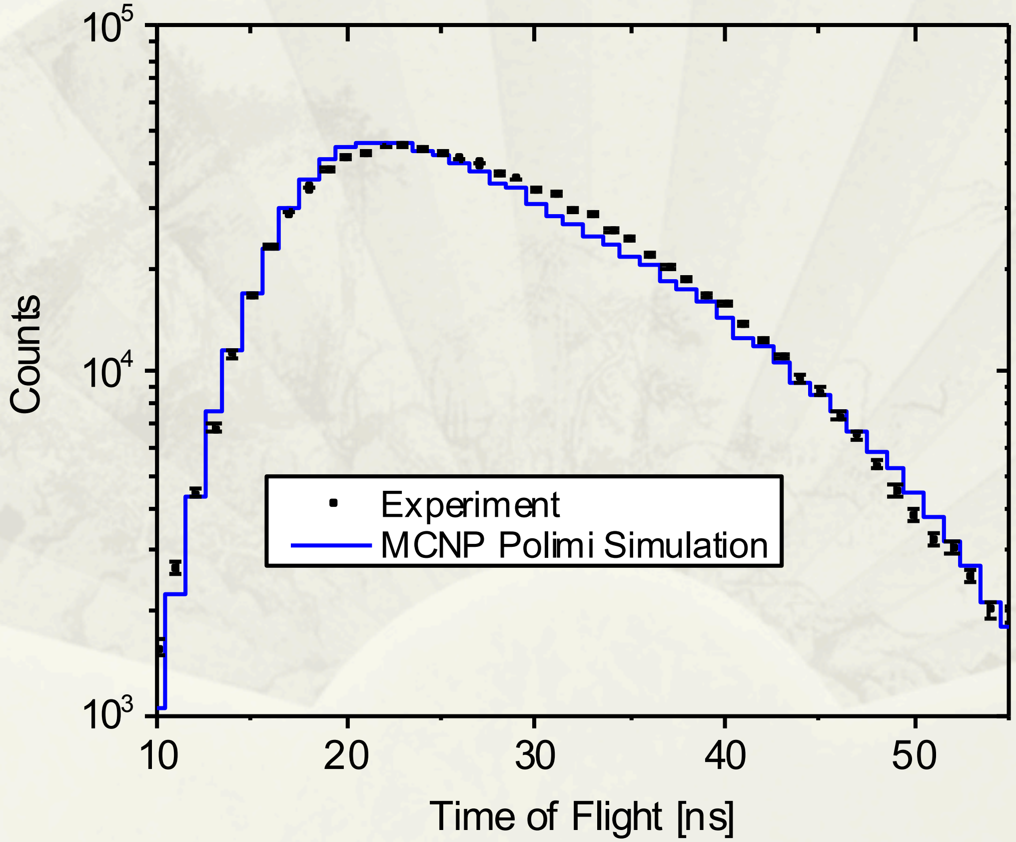


EJ-204

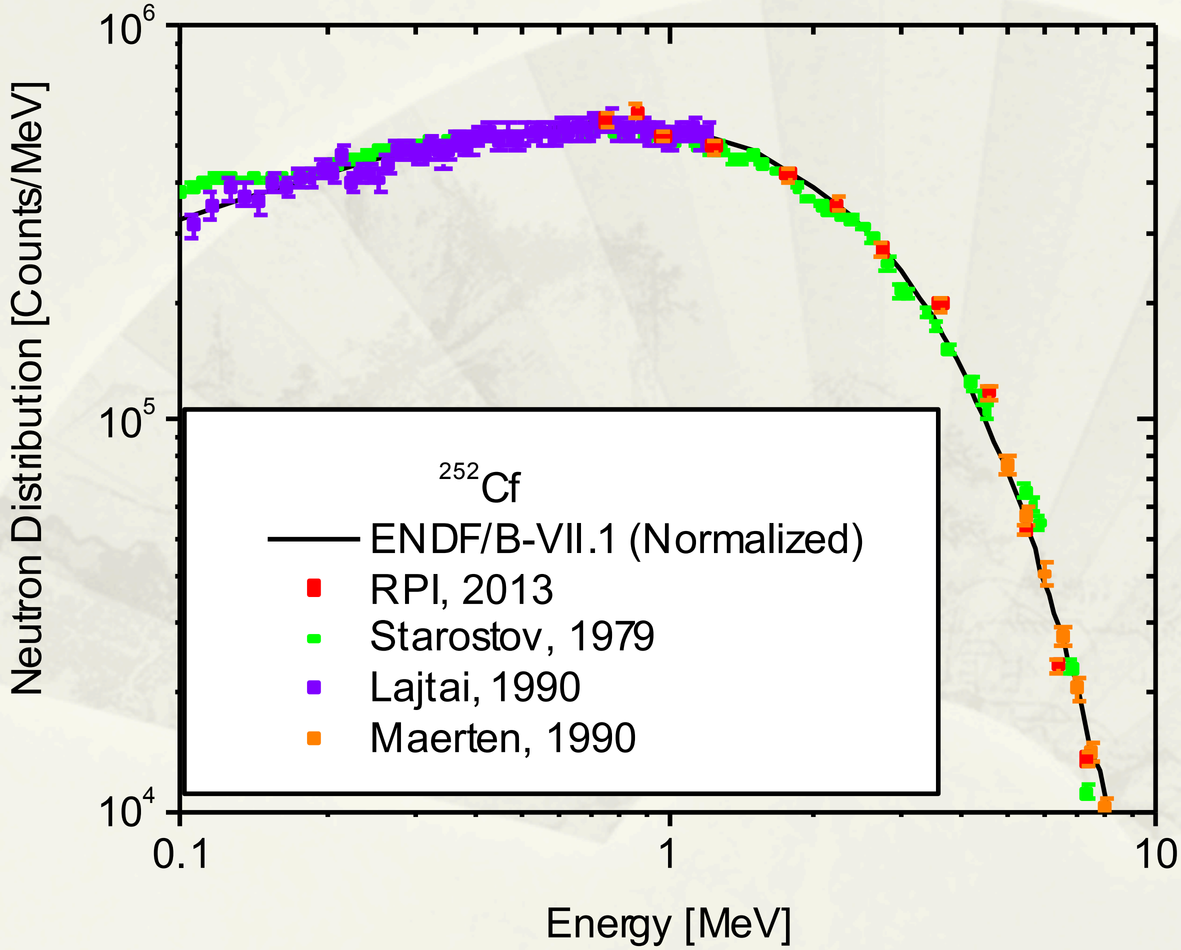


Comparison to Simulation

An MCNP Polimi simulation was performed and the PFNS for spontaneous fission of ^{252}Cf was compared with experiment. The simulation used the PFNS from the Manhart evaluation. A Gaussian time distribution was used to simulate the detector time response

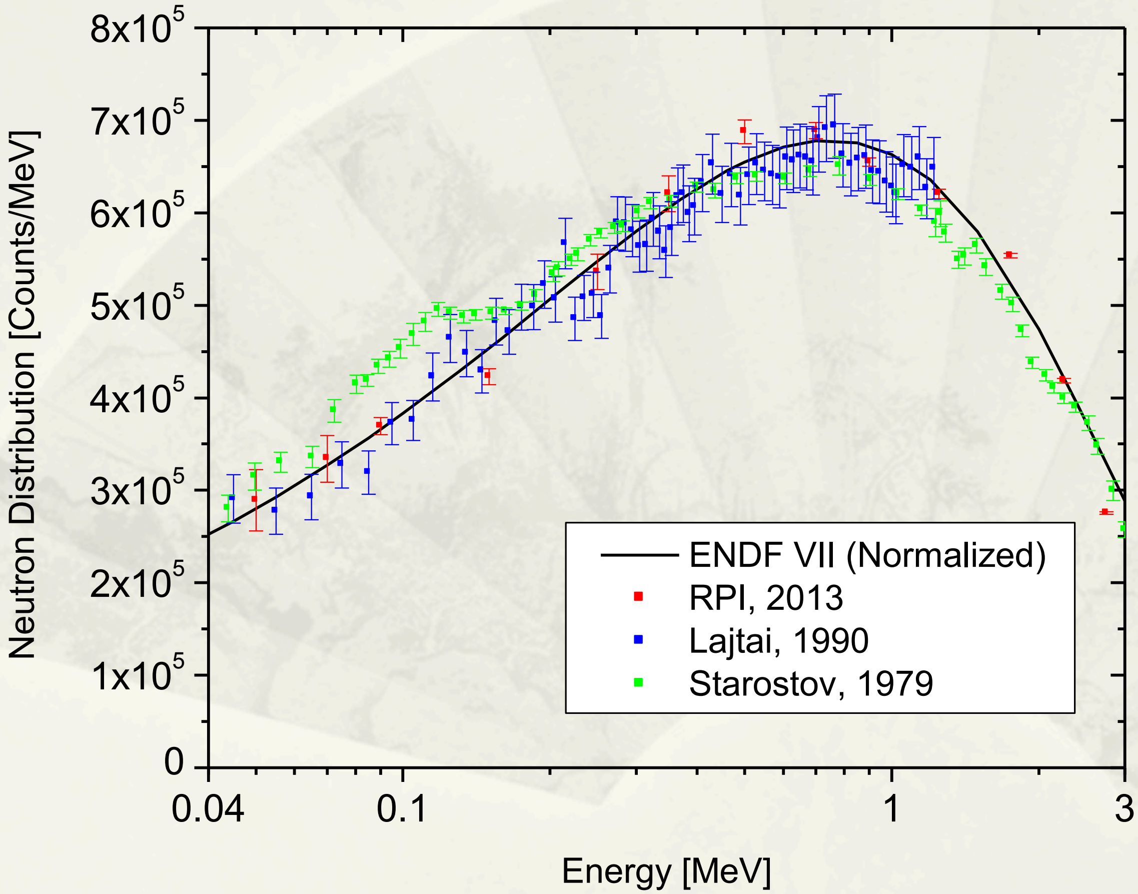


^{252}Cf Prompt Fission Neutron Spectrum High Energy



- High Energy spectrum taken with EJ-301 liquid scintillator
- The gamma tagging method shows good agreement to ENDF VII in the energy range from 0.7 MeV to 7.8 MeV
- Uncertainties include statistical, background correction and efficiency

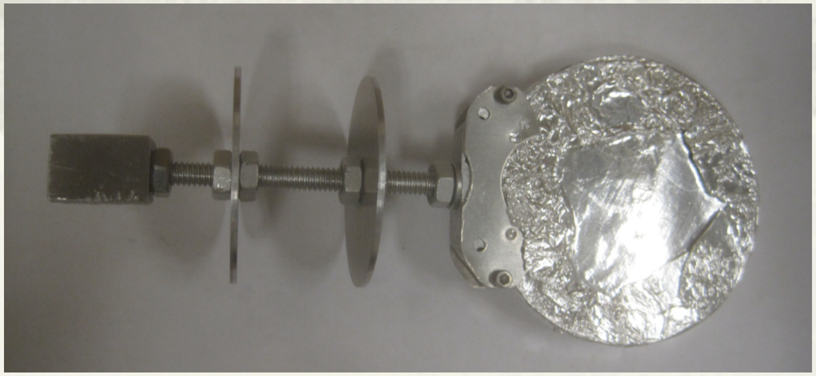
^{252}Cf Prompt Fission Neutron Spectrum Low Energy

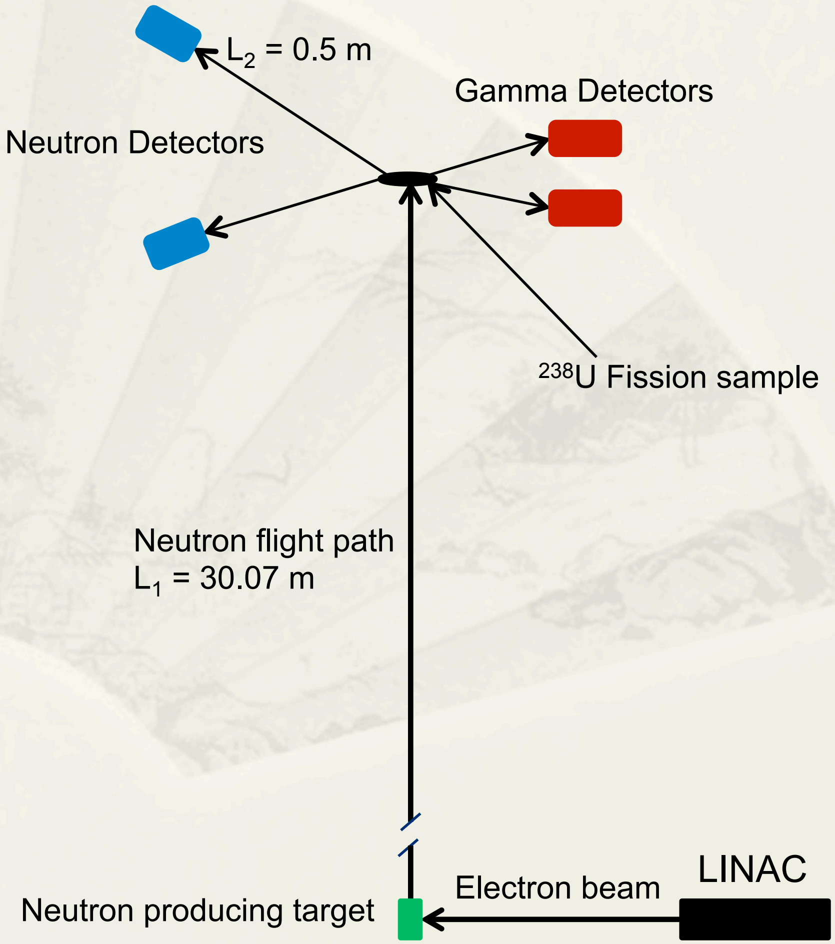


- Low energy data taken with 0.5” EJ-204 plastic scintillator
- RPI data shows good agreement to Lajtai data and ENDF evaluation
- Thin plastic detector allows for measurement down to 50 keV
- Gamma tagging method accurately reproduces PFNS for ^{252}Cf
- Only stastical error shown for RPI data

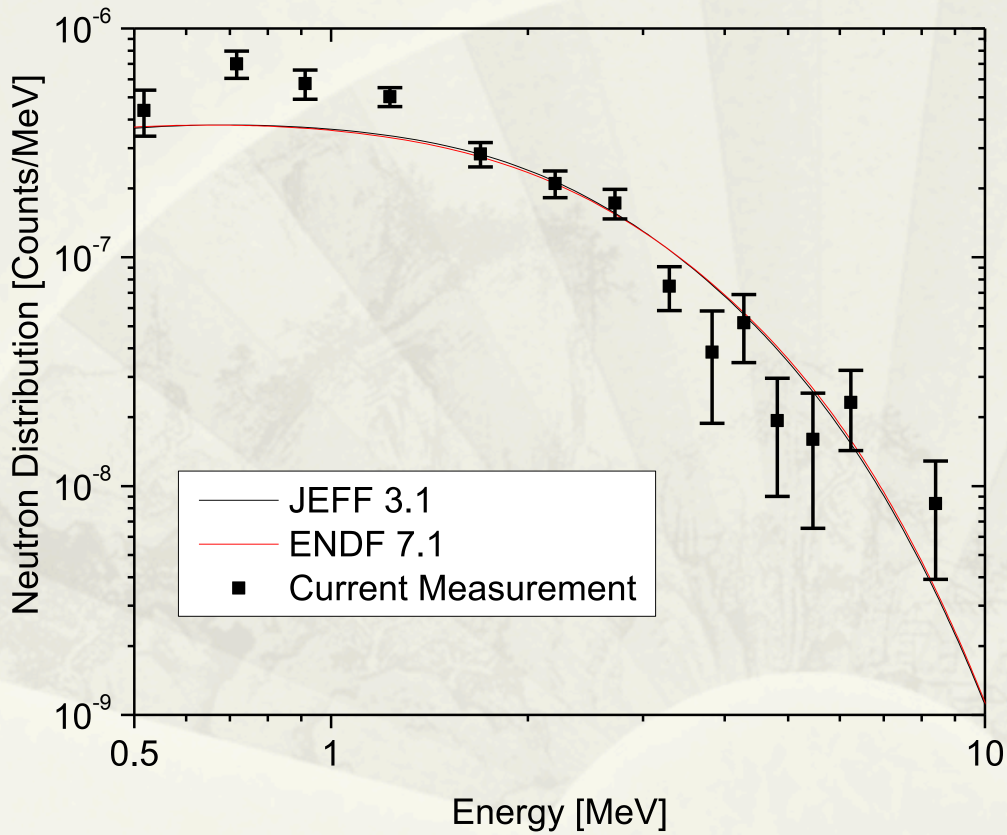
^{238}U Experimental Setup

- Neutrons generated from 60 MeV LINAC (white neutron source)
- 30.07 m flight path from neutron source to fission sample
- Double time-of-flight setup allows for simultaneous measurement of PFNS for several incident neutron energy ranges
- 1 EJ-301 detector, 3 EJ-204 detectors simultaneously measure high energy and low energy portion of PFNS
- 3/8" thick ^{238}U disc used for sample (highlights benefits of larger sample with gamma tagging method)





^{238}U Prompt Fission Neutron Spectrum High Energy



- Spectrum is normalized to ENDF at 1.2 MeV
- Spectrum is integrated over all incident time-of-flights
- Preliminary data shows good agreement with current evaluations
- Increase near 1 MeV agrees with new data by Sardet *et. al.*

Sources of Uncertainty

- Statistical uncertainty
- Uncertainty in timing (system resolution of 1.2ns)
- Uncertainty in flight-path (0.5” thick detector for EJ-204 3” thick detector for EJ-301)
- False coincidence events
  - Primarily caused by inelastic scattering from neutron beam experiments
- Uncertainty in the energy dependence of the neutron detection efficiency
  - In-beam experiments with neutron detectors were used to determine efficiency uncertainty

Conclusions

- The gamma tagging method has been shown to accurately reproduce the ^{252}Cf PFNS in the range from 50 keV to 7 MeV
- The gamma tagging method allows for more accurate timing resolution compared to fission chambers
- Thin plastic detectors have allowed for the measurement of the PFNS down to 50 keV neutron energy.

Future Work

- Determine total false coincidence rates using MCNP Polimi code
- Measure low energy fission spectrum for ^{238}U
- Develop methodology to correct for false fission contamination
  - Use MCNP Polimi to determine different non-fissioning materials which can be used to simulate scattering contribution e.g. Pb
  - Determine if sub-threshold data can be used to correct inelastic scattering contribution from ^{238}U

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Questions?