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Title: An Overview of DANCE: A 4Π BaF_2 Detector for Neutron Capture Measurements at LANSCE

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Los Alamos NATIONAL LABORATORY

An overview of DANCE: A 4π BaF_2 detector for neutron capture measurements at LANSCE

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The Detector for Advanced Neutron Capture experiments (DANCE) is a 162-element, 4π BaF_2 array designed to make neutron capture cross-section measurements on rare or radioactive targets with masses as little as 1 mg. Accurate capture cross sections are needed in many research areas, including stellar nucleosynthesis, advanced nuclear fuel cycles, waste transmutation, and other applied programs. These cross sections are difficult to calculate accurately and must be measured. Up to now, except for a few long-lived nuclides there are essentially no differential capture measurements on radioactive nuclei. The DANCE array is located at the Lujan Neutron Scattering Center at LANSCE, which is a continuous-spectrum neutron source with useable energies from below thermal to about 100 keV. Data acquisition is done with 320 fast waveform digitizers. The design and initial performance results, including background minimization, will be discussed.

Many people have contributed to the DANCE experimental effort

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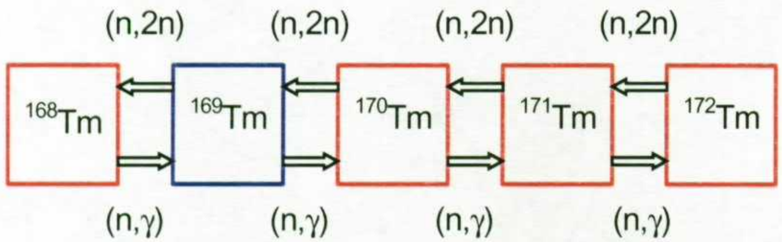
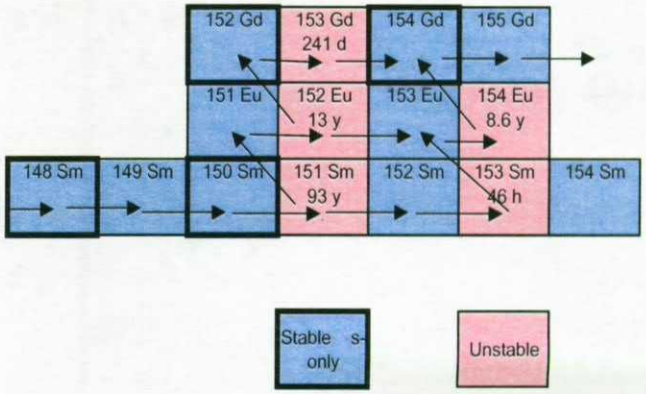
Why study neutron capture today?

- Energy range: 1 eV to 100 keV
- All easy targets measured
- Few measurements on unstable targets
- Cross sections on unstable targets needed for:
  - Defense programs (Stockpile Stewardship)
  - Nuclear Astrophysics
    - (s-process nucleosynthesis)
  - Accelerator Transmutation of Waste
  - Nuclear Physics
- Cross sections difficult to calculate
- Goal (demonstrated) : Measure 1 mg of material

Neutron Capture on Unstable Nuclei





Stockpile Stewardship

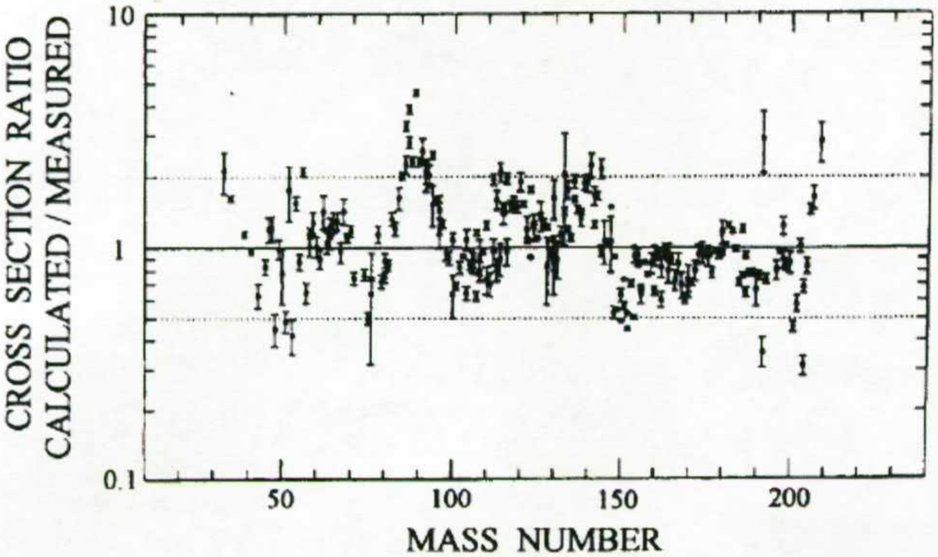
- Stable isotopes were inserted in weapons tests as diagnostics
- Accurate cross sections needed to infer device performance
- Cross sections for unstable isotopes mostly obtained from calculation-neutron capture has large uncertainties

Stellar Nucleosynthesis

- "s-process" takes place in medium-mass AGB stars, produces half of elements heavier than iron
- Unstable nuclei are branch points in s-process flow, provide critical information on stellar *neutron density* and *temperature*

LANSCE and C divisions have a unique capability to fabricate samples and measure capture reactions on unstable targets

Calculations do not provide accurate neutron capture cross sections



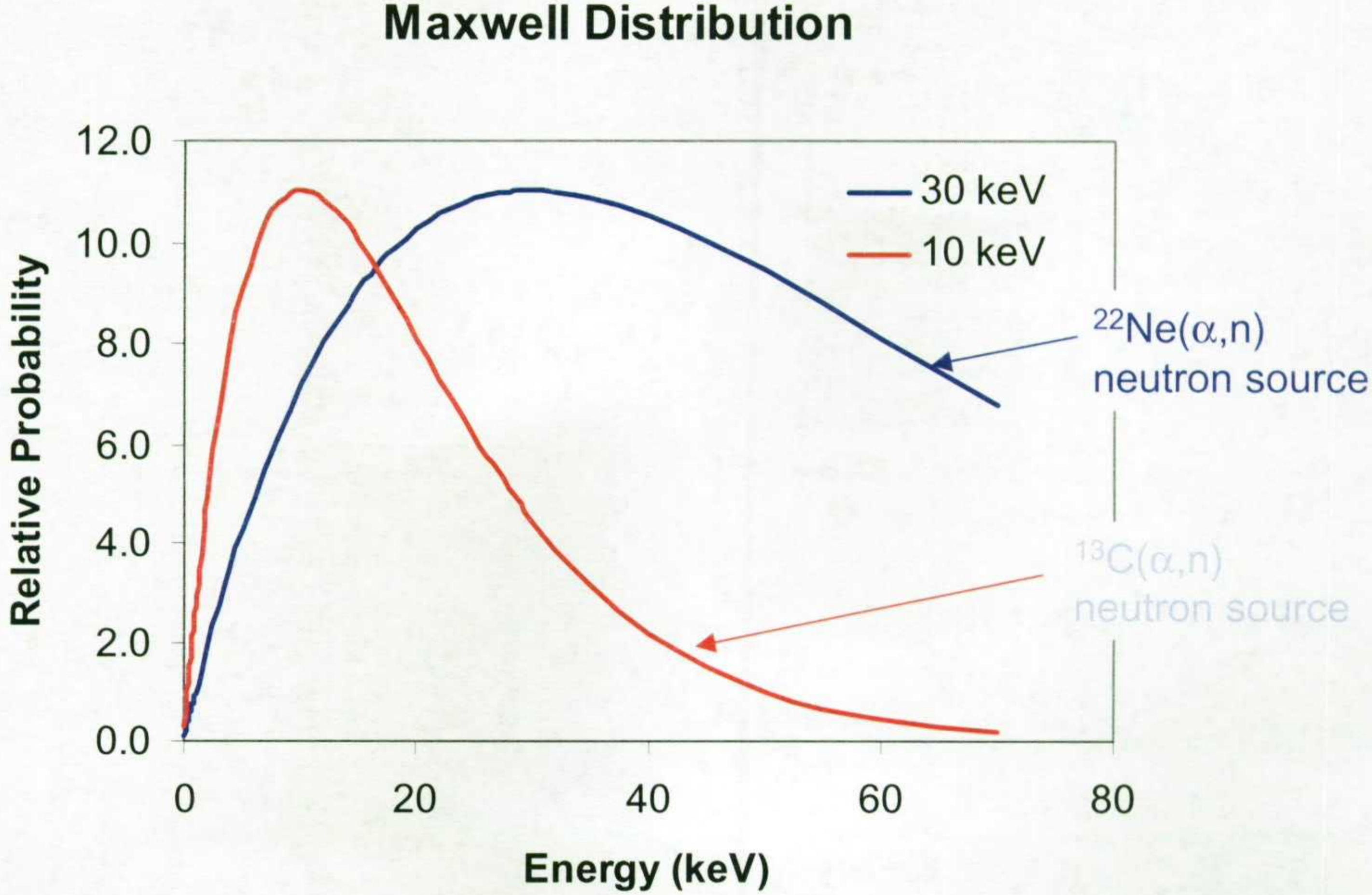
Measured capture cross sections differ from recent calculated estimates by +/- a factor of 2

(From Rauscher and Thielemen, *Atomic and Nuclear Astrophysics*, IOP, 1998)

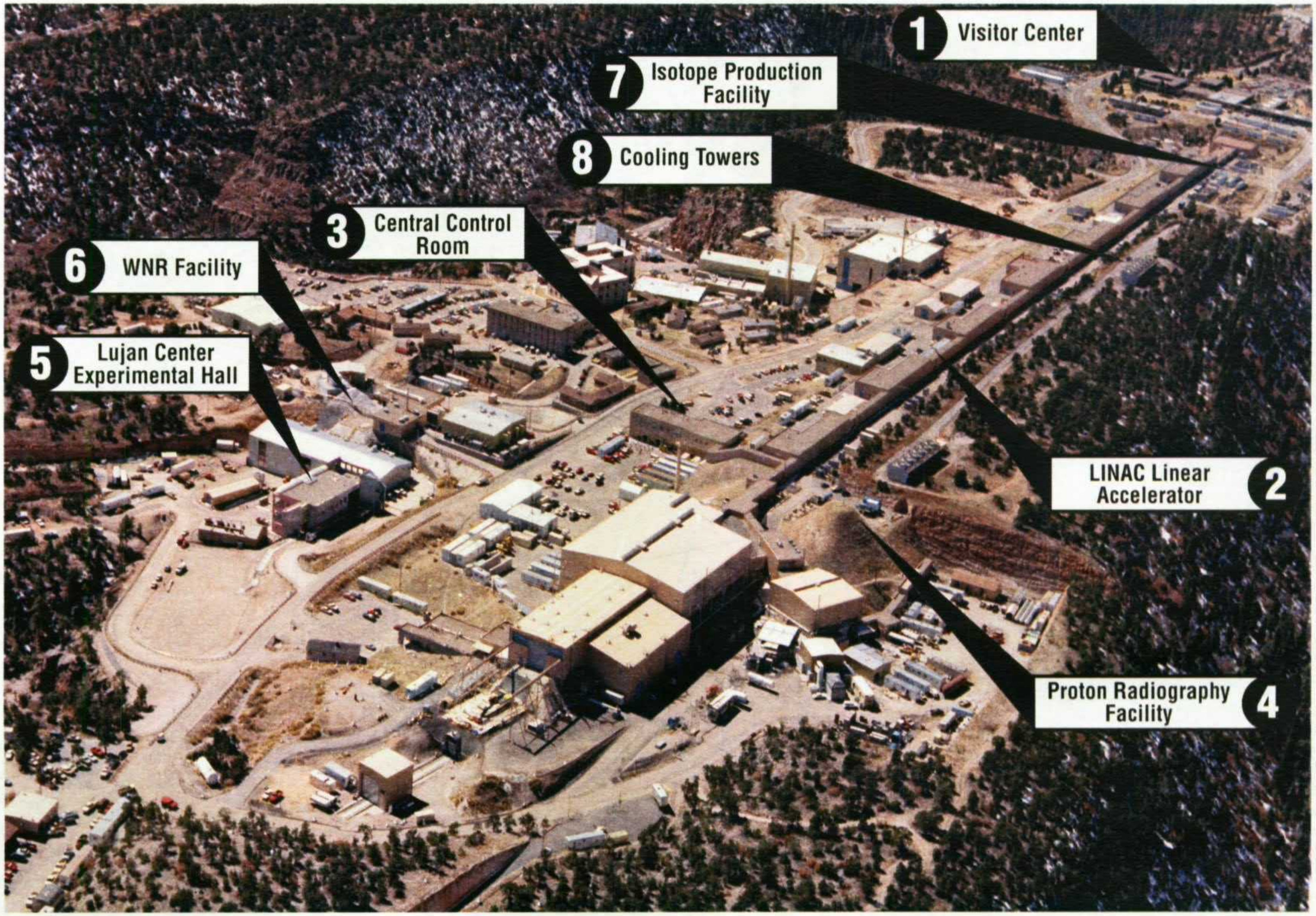
Fig. 12. Stellar (n,γ) cross sections calculated with the statistical model code NON-SMOKER are compared with the available experimental data [108].

- **Very few measurements of neutron capture have been made on unstable nuclei.**
- **Difficult to precisely extrapolate cross sections measured on stable targets**
- **Precise cross section measurements on unstable nuclei needed for:**
  - **Defense programs (stewardship science)**
  - **Nuclear astrophysics (s-process nucleosynthesis)**
  - **Advanced accelerator applications - waste transmutation**
  - **Nuclear Physics**

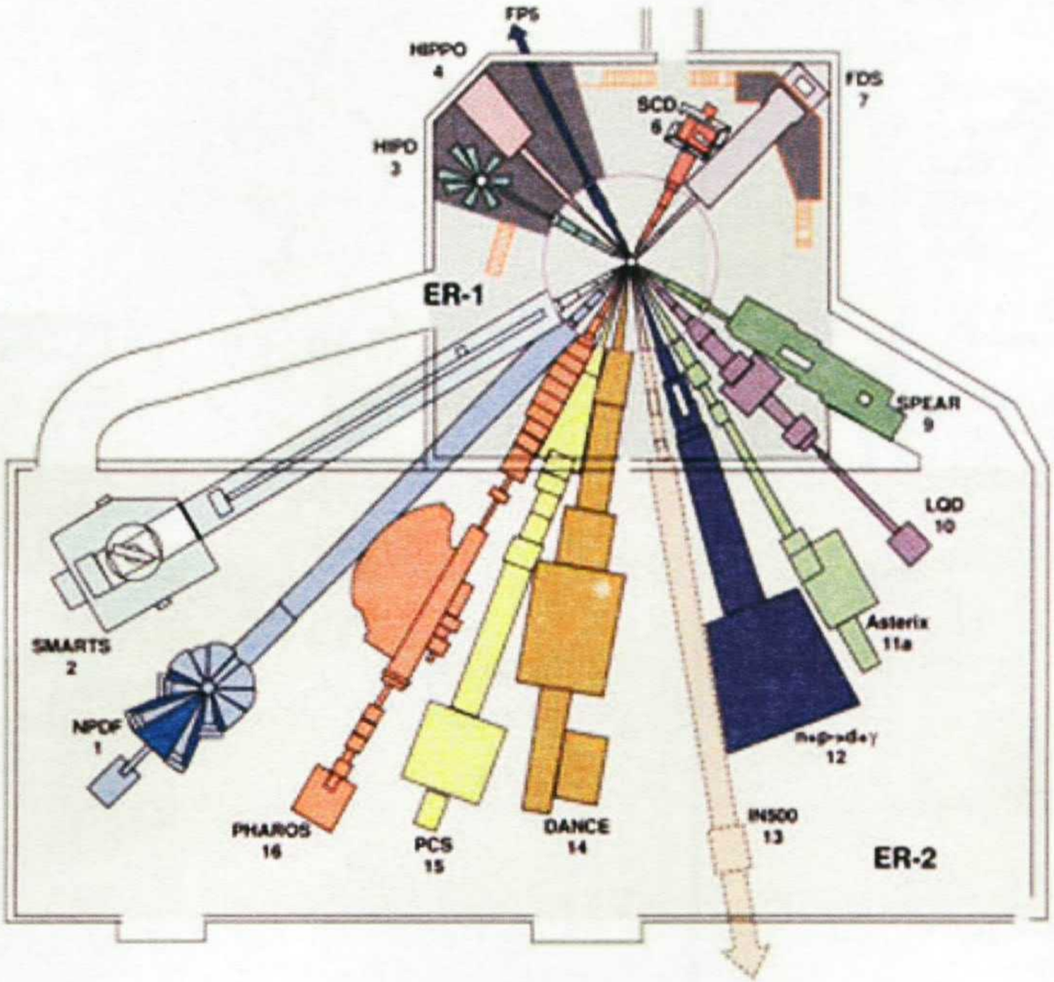
Stellar reaction rates are integrated over a Maxwell



Los Alamos Neutron Science Center *(LANSCE)*

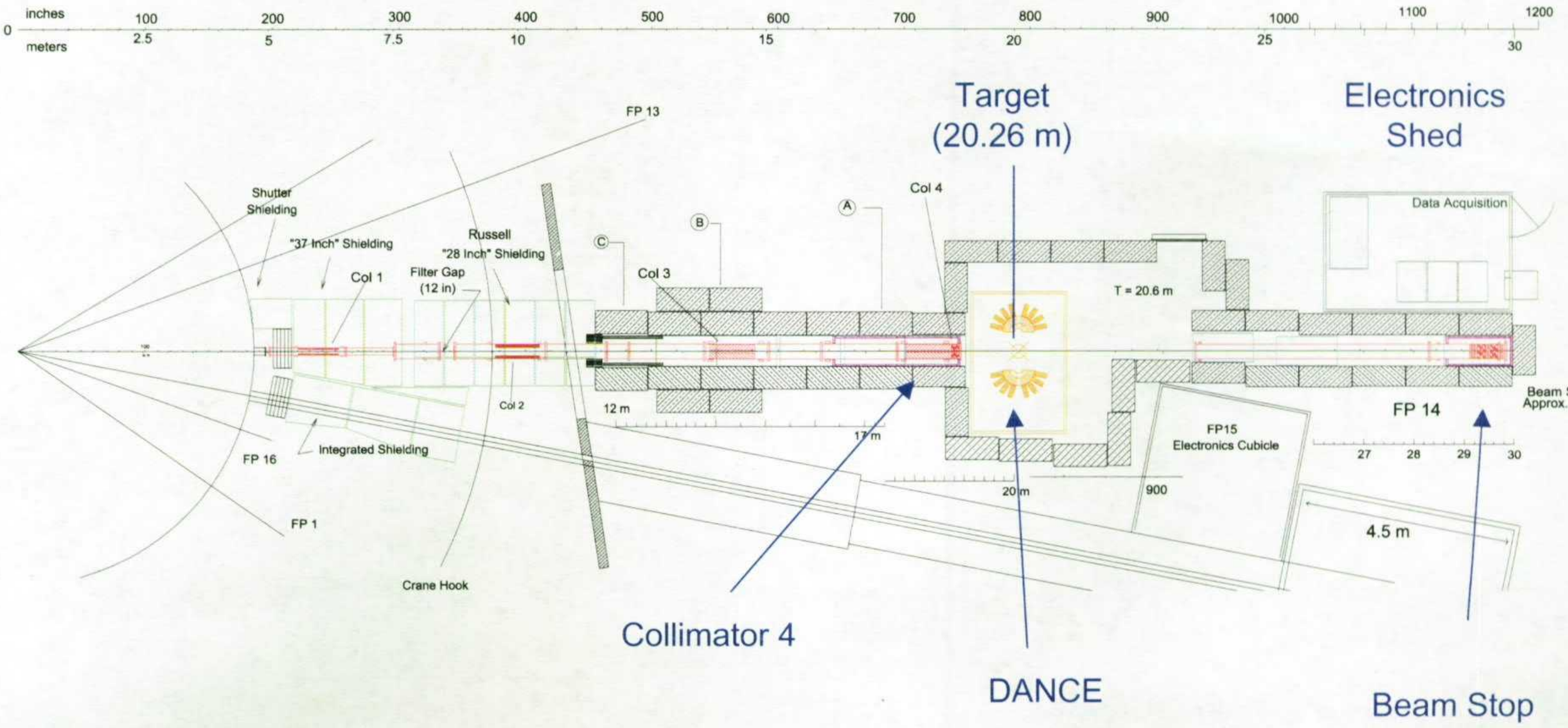


DANCE is located on Flight Path 14 at the Lujan Center.



FP 14 views the second-tier coupled water moderator.

DANCE / Flight Path 14 at the Lujan Center

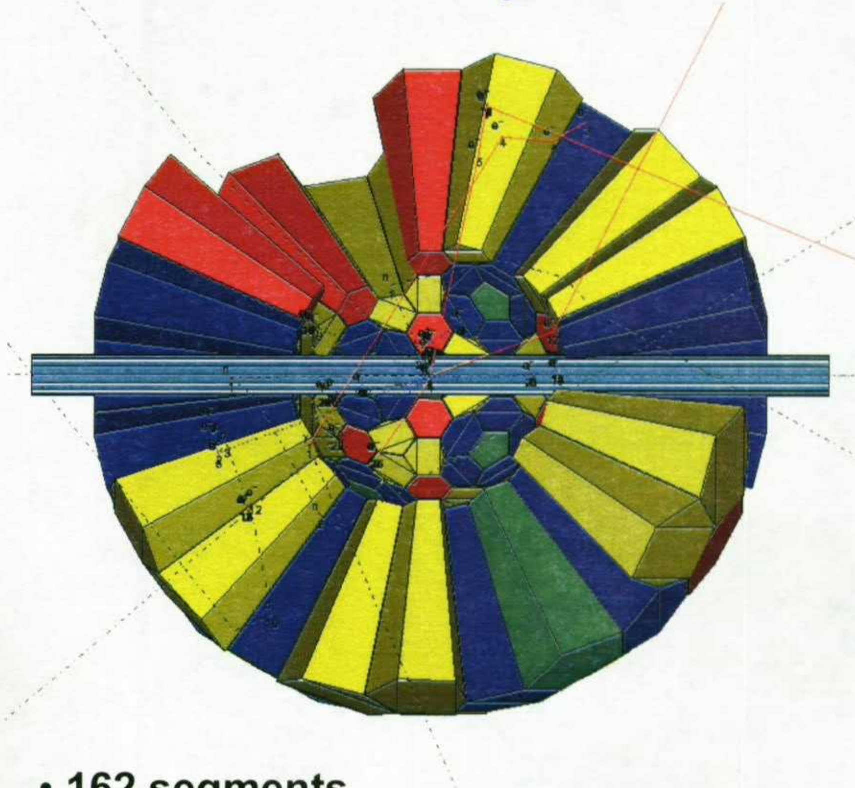


DANCE: General principles

- Calorimeter
  - identifies capture by total energy in gamma rays
- Insensitive to neutrons
  - because scattering cross section > capture in our energy range of interest (1 keV < En < 300 keV)
- Fast
  - 1 Ci is 37 decays/nanosecond
  - 10^{12} MeV/sec (?) of radioactive decay (30 Ci)
- Segmented

The DANCE barium fluoride array

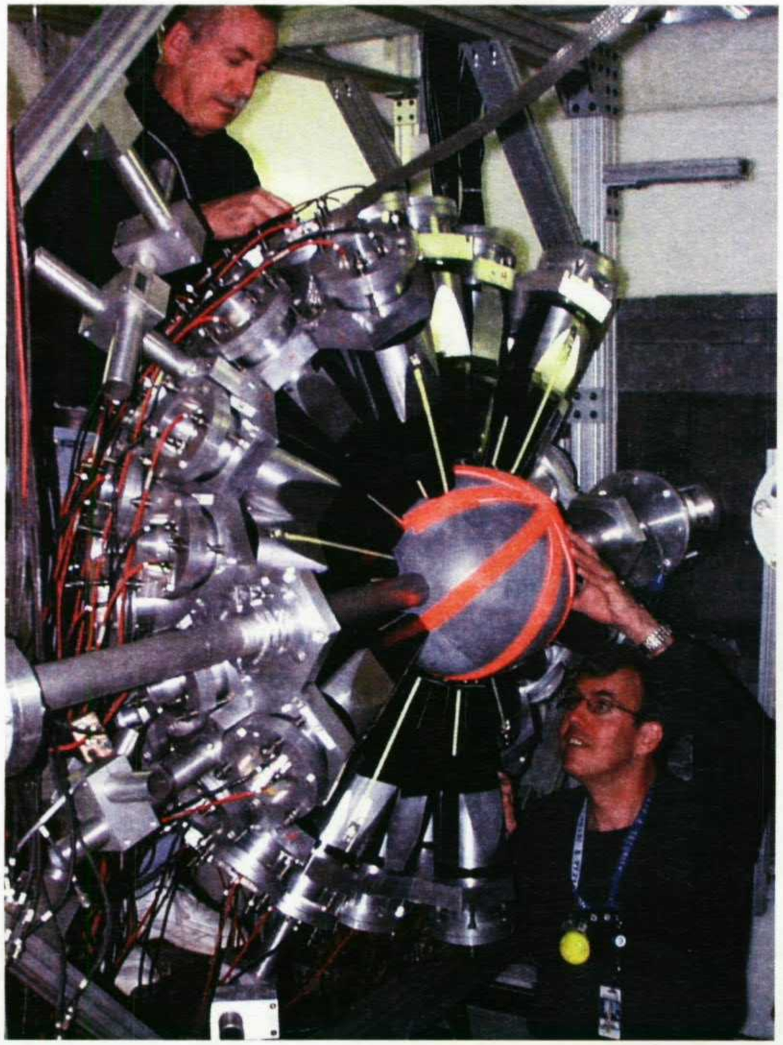
- Calorimeter
  - identifies capture by total energy in gamma rays
- Less sensitive to neutrons
  - Scattering cross section > capture in our energy range of interest (1 keV < En < 100 keV)
- Fast
  - 1 Ci is 37 decays/nanosecond
  - 10^{12} MeV/sec (?) of radioactive decay (30 Ci)
- Segmented



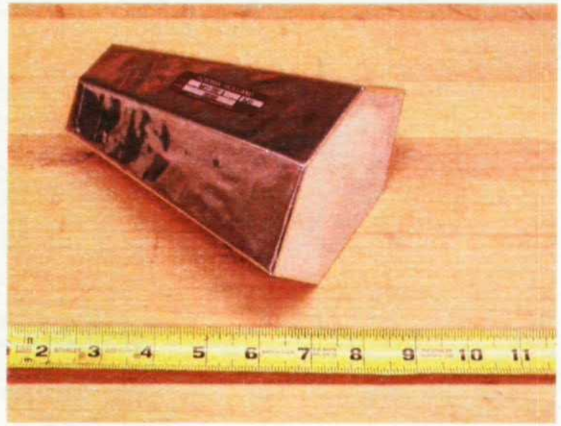
- **162 segments (160 segments with crystals)**
- **4 different crystal shapes**
- **Inner radius = 17 cm**
  - **18 cm actual $\Rightarrow$ 3.52π**
- **Crystal depth = 15 cm**
- **6 cm thick ^{6}LiH neutron shield (Inner radius = 10.5 cm)**

LANSCE
Los Alamos Neutron Science Center

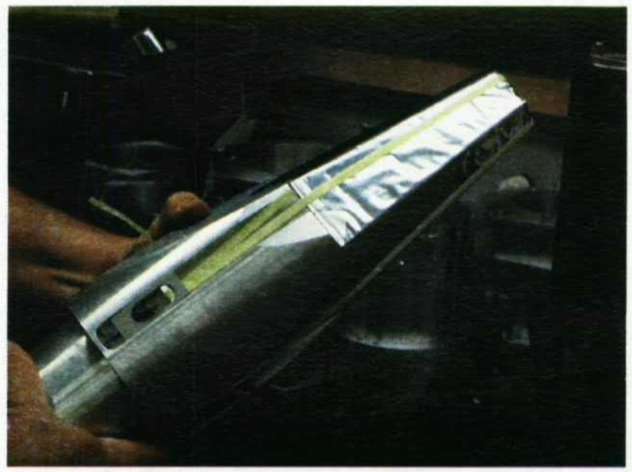
DANCE crystals and assembly



Half of DANCE array with ^{6}LiH ball



BaF_2 Crystal



Crystal mounted on 3 in phototube

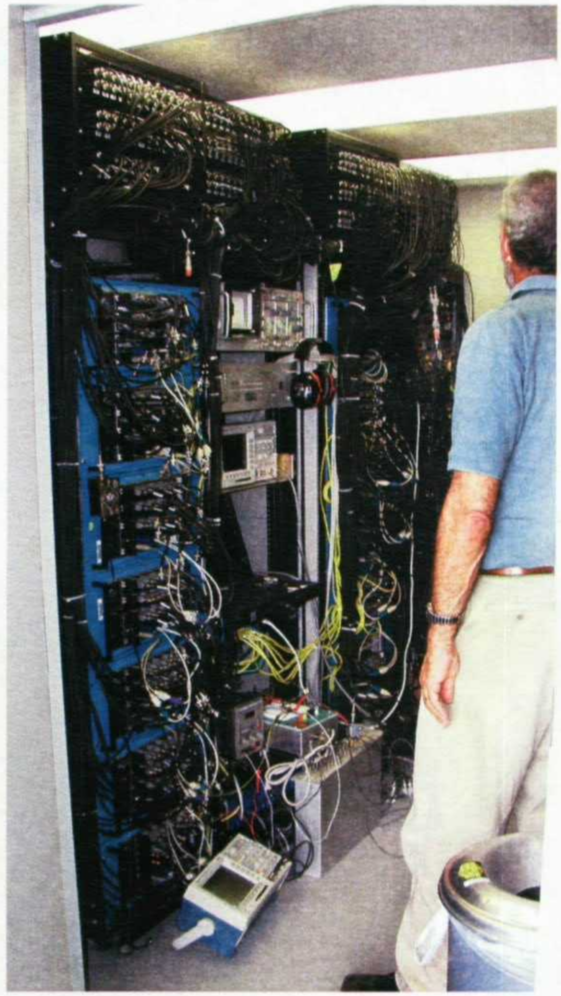
DANCE Uses 324 fast waveform digitizers for acquisition

CAMAC / VME not adequate

- Need >2ms multi-hit time digitization
- ADC conversion times long
- High rate => buffered ADC,TDC
- Camac transfer rates slow

DANCE Solution- Waveform digitizers

- 8-bit, 500 Msample/sec (300 MHz bandwidth)
- Two digitizers/crystal (hi and low gain) for adequate dynamic range
- 128 kpoints/channel
- Acqiris DC-265
- 14 Compact PCI crates, 24 channels/crate
  Each crate has onboard computer for digitizer control and distributed analysis of waveforms between beam bursts (50 msec)
- Central computer (2 GHz PC)/ethernet
  CAMAC crate for control and scalers
- 1- Tbyte RAID for event-mode storage



DANCE Acquisition Hut

Some details on waveform digitizer use at DANCE

Acquisition Modes

Segment Mode

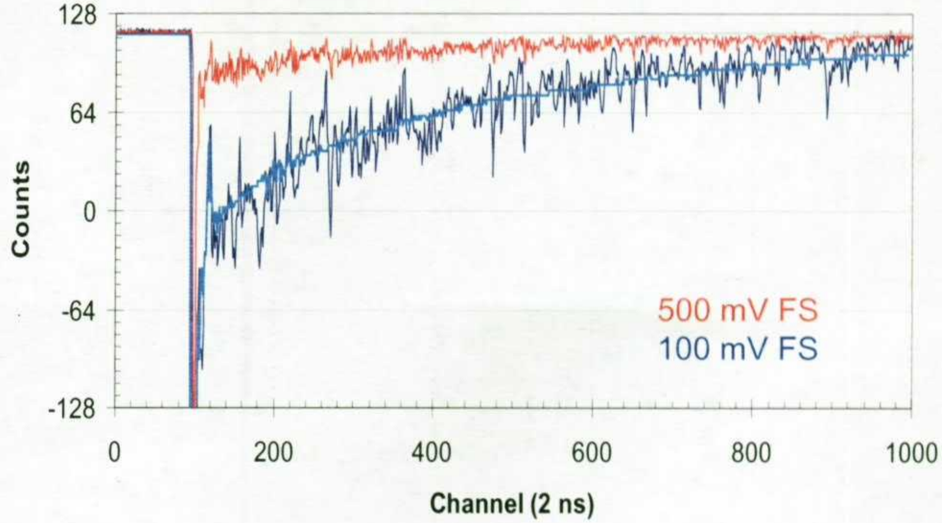
- Trigger for each event
  Requires external electronics
- 1000 channels (2 μsec) per segment
- Only "hit" channels digitized
- Approx 100 events/channel per To
- 3.0 μsec fixed deadtime

Continuous Mode

- One trigger for each To
- "No" deadtime – analyze overlapping waveforms observed at higher rates
- Limited energy range -
  Current trial $T_{neut} > 215$ eV

Waveform analysis in 50 msec

Sample Waveforms



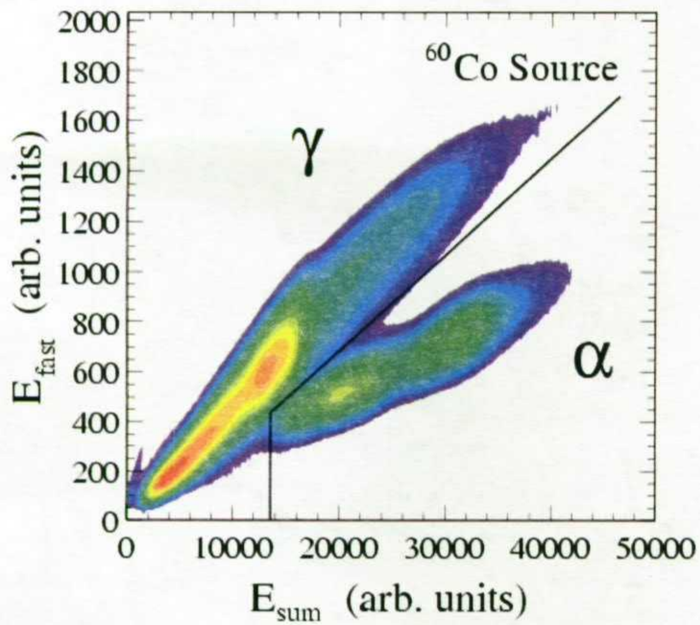
Timing Algorithm (Segment)

- Segment time at segment trigger
  (recorded in segment time stamp)
- Reference event trigger sent to all channel at To
- TOF = difference in time stamps + (small) correction for leading edge

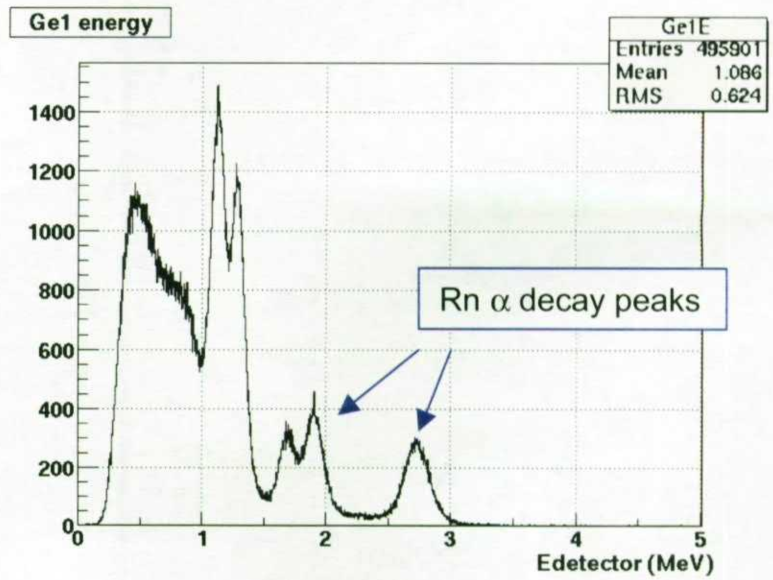
Peak Area Algorithm (Segment)

- Single peak per segment
  (If 2nd pulse – reject 2nd)
- Background ahead of leading edge
  Look back 200 ns before trigger
- Leading edge, >25 mV/chan
- Fast component – integrate low-gain waveform for 20 chan (40 ns)
- Total area (fast + slow)
  Compare to reference waveform
  (equiv. To least-squares)

Sample spectra using waveform digitizers



Alpha – gamma discrimination;
Fast component (vertical) vs
Total energy (horiz)



^{60}Co Source spectrum

Beam flux measurements on FP14

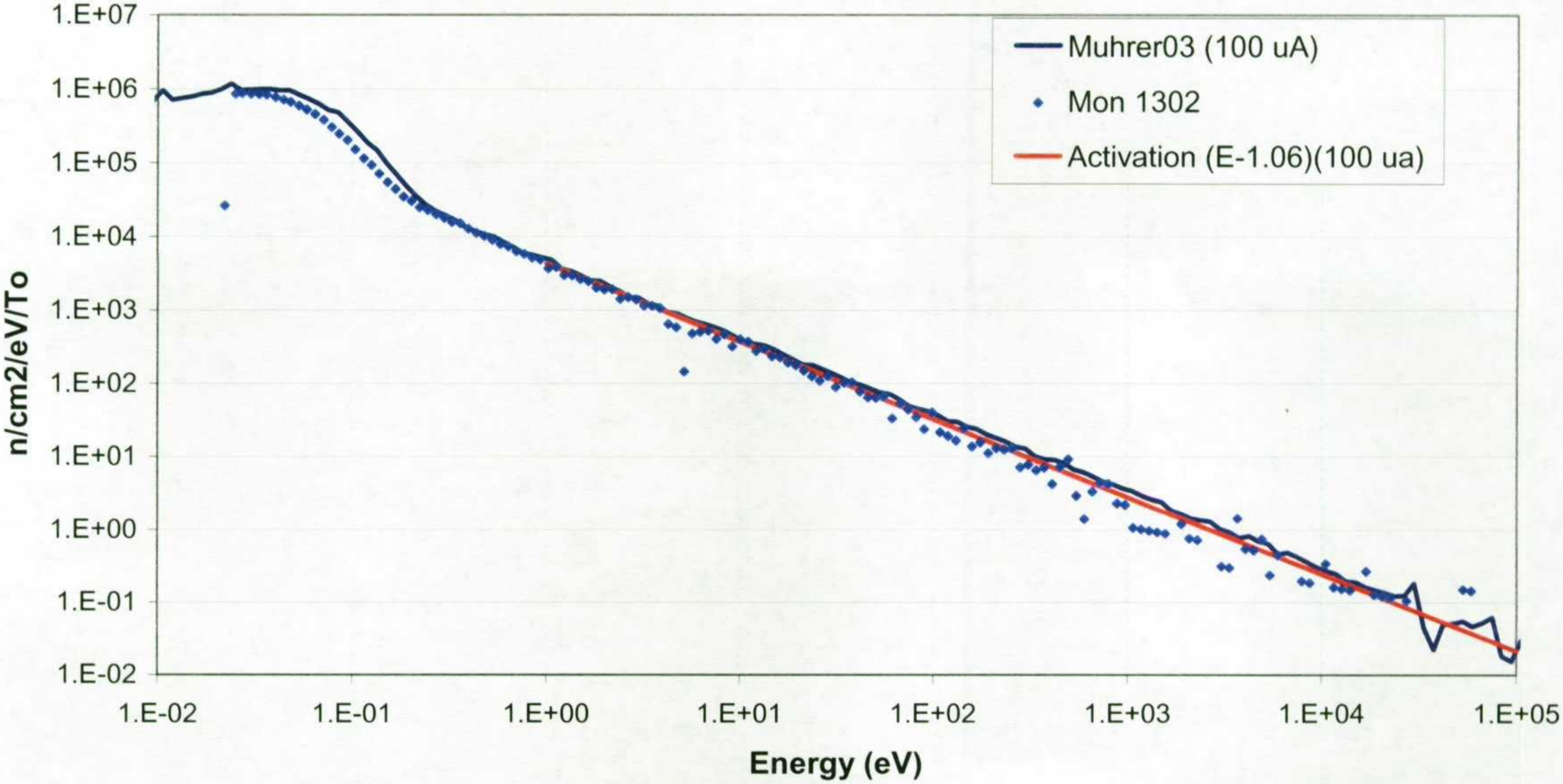
Differential measurements

- $^{6}Li(n,\alpha t)$ monitor
- $^{235}U(n,f)$
- ^{3}He (Luke Daemen)

Au activation measurements

- In filter box (8.51 m)
- Target location (20.25 m)
- Analysis: "Westcotte convention"
  - With and without Cd filter
  - Assume 1/E spectrum shape

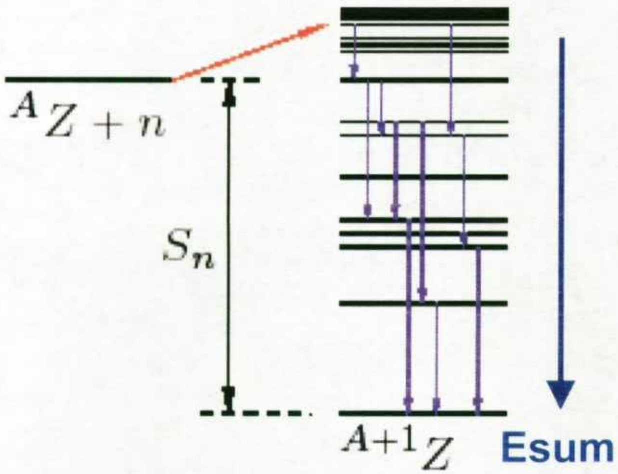
Neutron Flux at DANCE

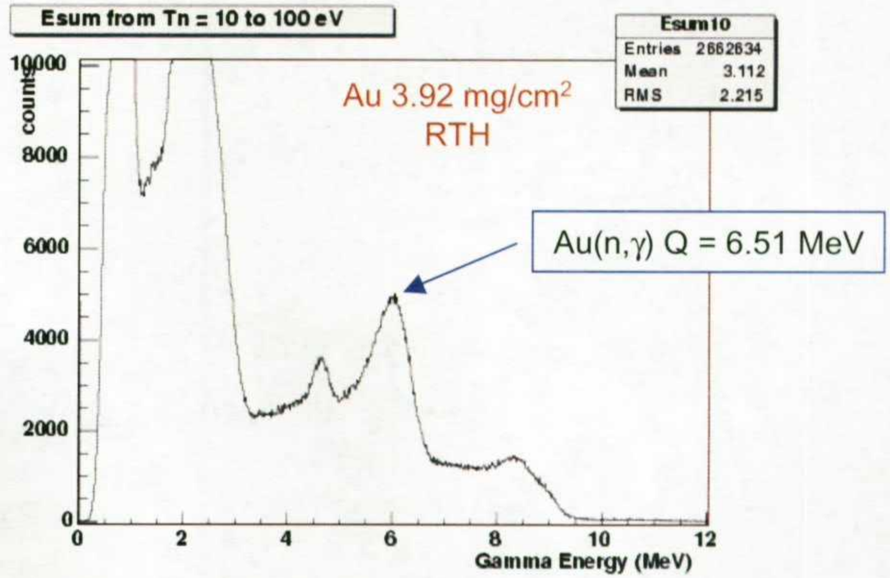


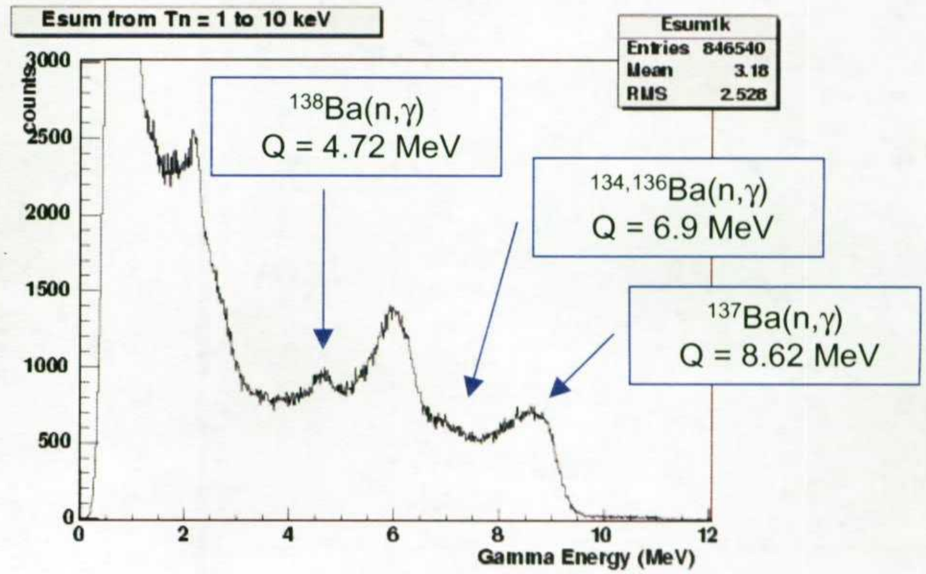
Neutron flux measured at 20.25 m on FP14 with 100 μA proton current.

- The "neutron monitor" used the $^{6}Li(n,t)$ reaction (Mon 1302)
- "As-built" calculations by G. Muhrer (LANSCE)
- Au foil activation shows $1/E^{1.06}$ normalized to activation

Summed gamma cascade energy identifies target nucleus

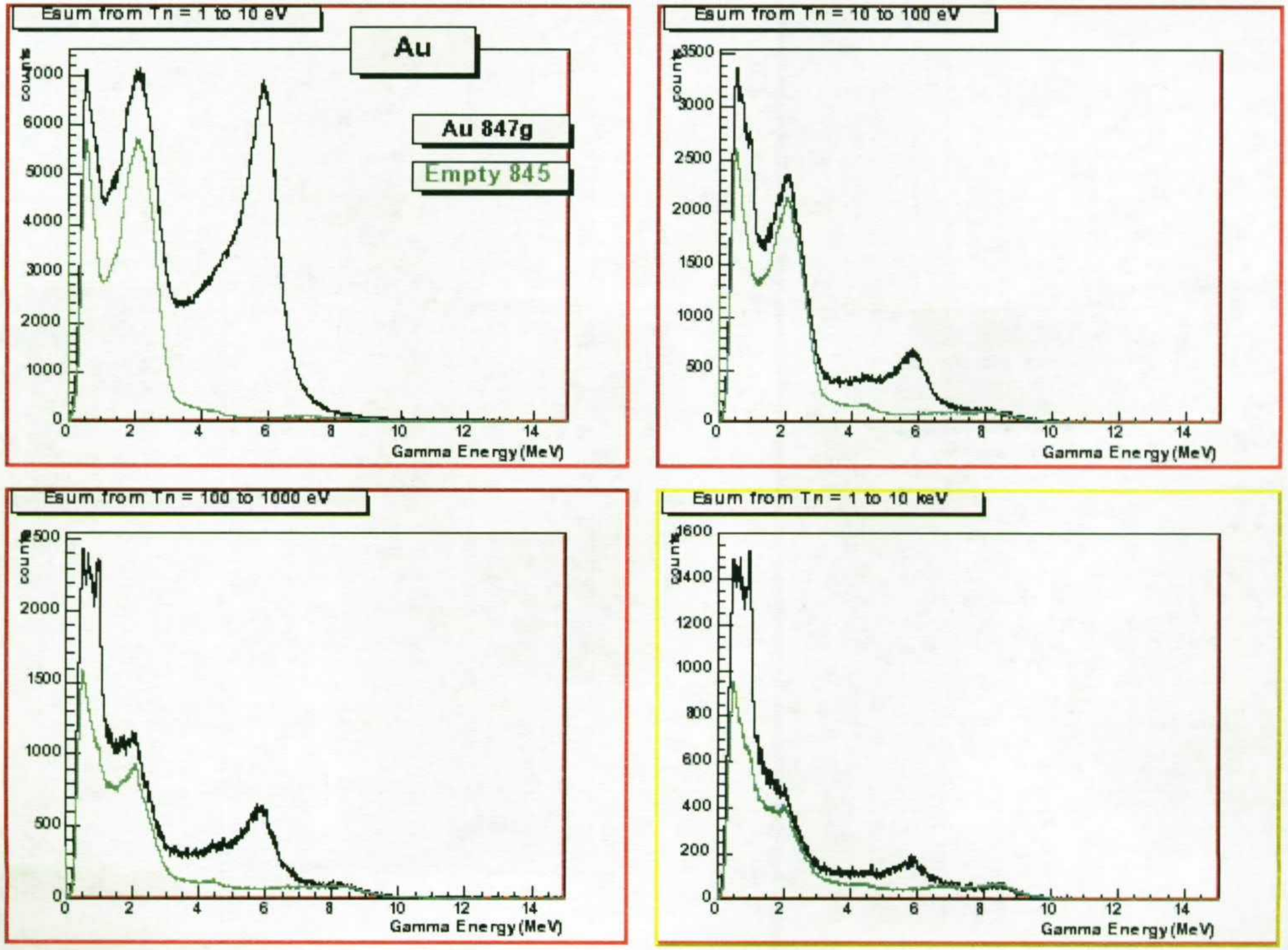






- Summed gamma energy = Q value
- Energy sum from 160 crystals
- Events due to scattered neutrons capturing in BaF_2 become more important at high energies
- Gate on Esum peak

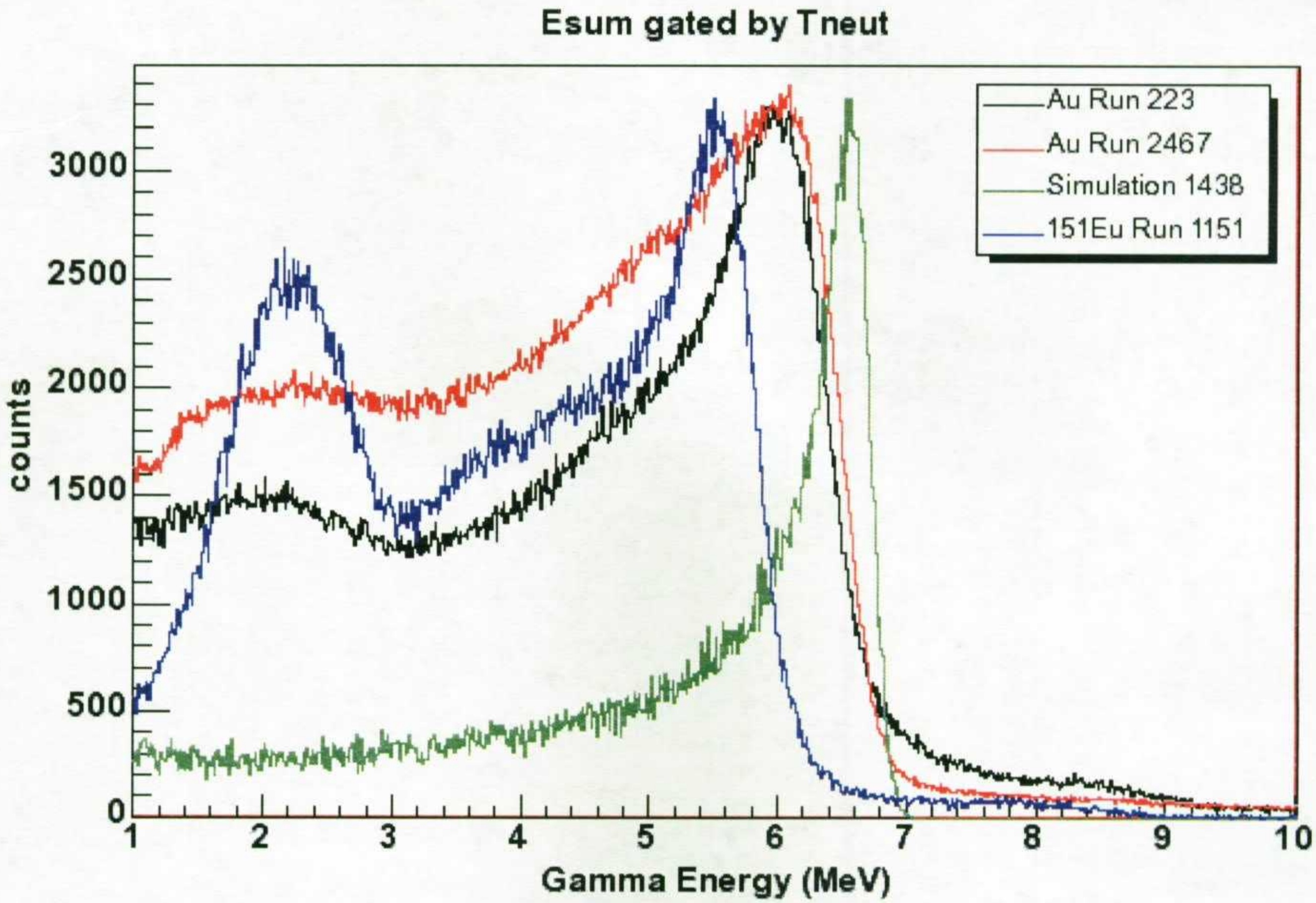
Summed Gamma Energy as function of Neutron Energy



Au (3.92 mg/cm^2) Q = 6.51 MeV

Crystal Multiplicity = 2

Summed Energy Peak



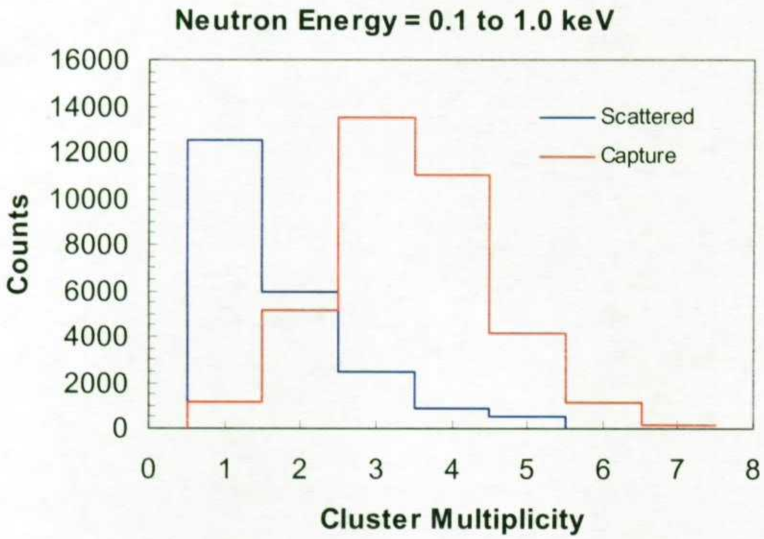
Green: Calculated Au gamma "Esum" spectrum

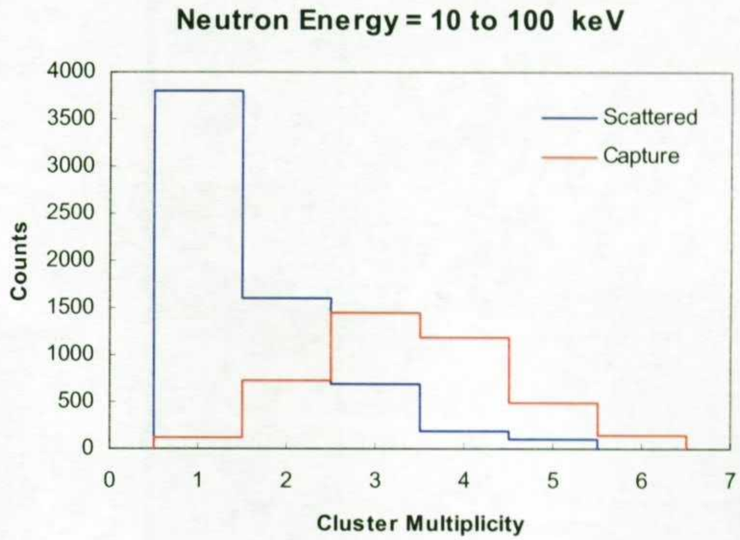
Red: Au, 141 Crystals, 50 mV thresh per crystal (T_n =4-6 eV)

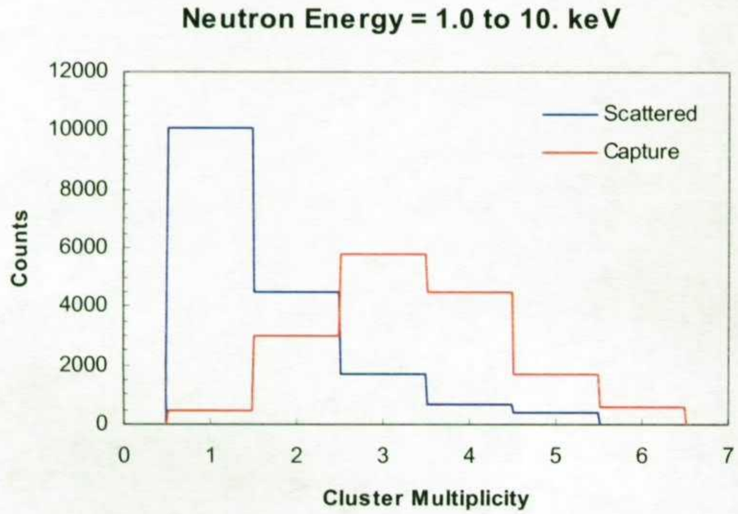
Black: Au, 159 crystals, 25 mV thresh per crystal (T_n=4-6 eV)

Blue: ^{151}Eu, 160 Crystals (T_n=0.8 – 4.5 eV)

Cluster Multiplicity provides an additional means of neutron discrimination

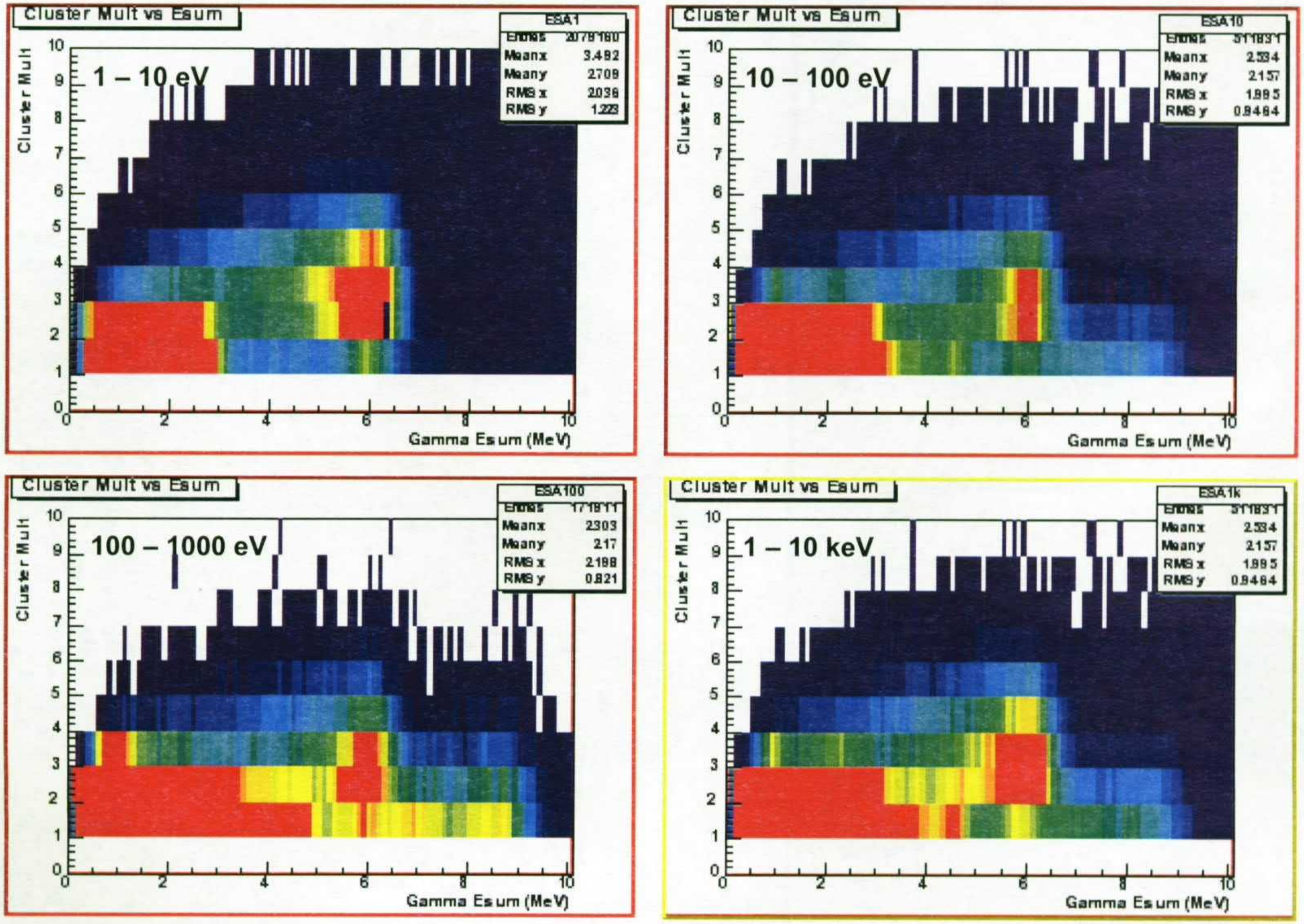


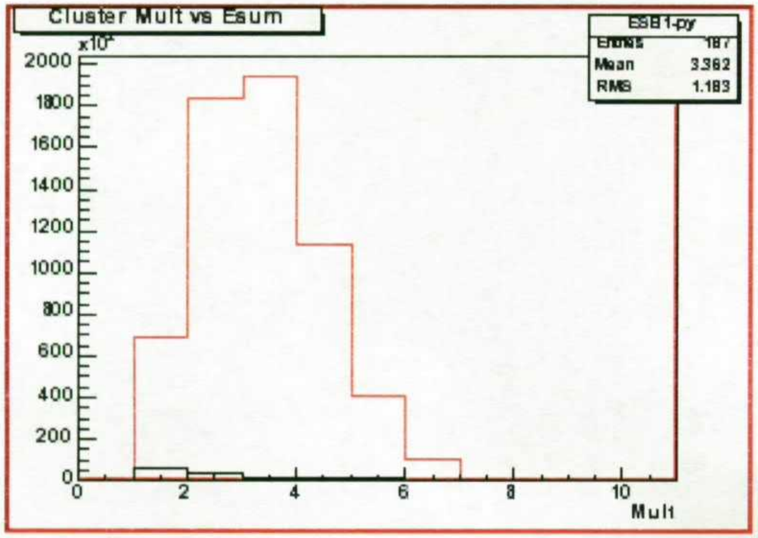


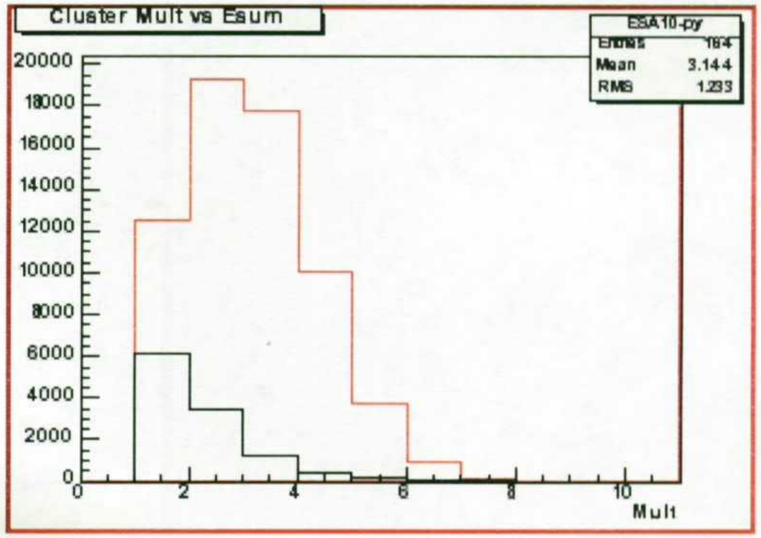


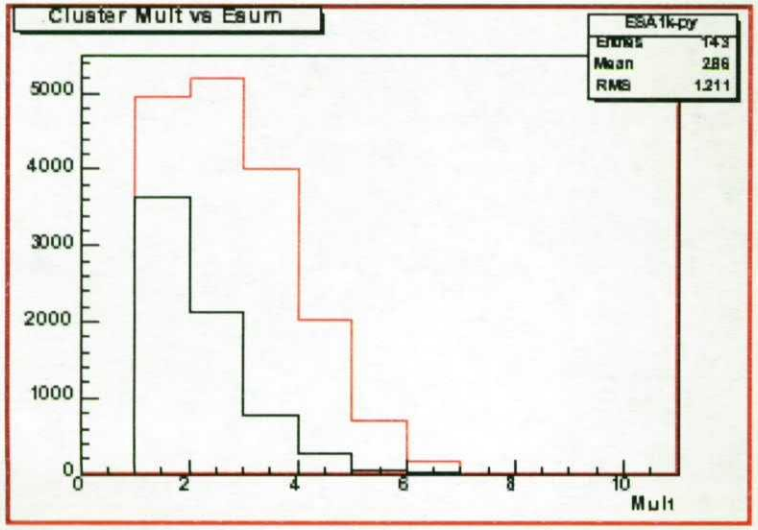
Cluster multiplicity for scattered neutrons interacting in array (blue) and for gammas from true captures in an Au target (red). This parameter also provides a means of discrimination. A cluster is a set of adjacent "hit" crystals.

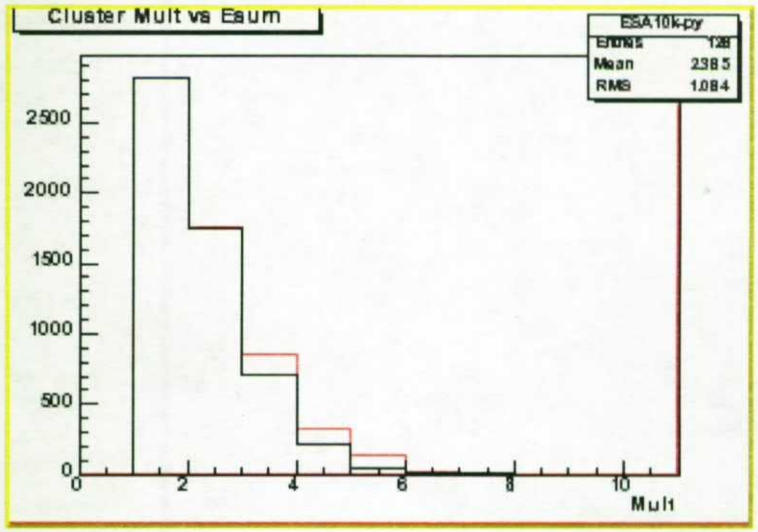
Cluster Multiplicity vs. Summed Energy (Au)



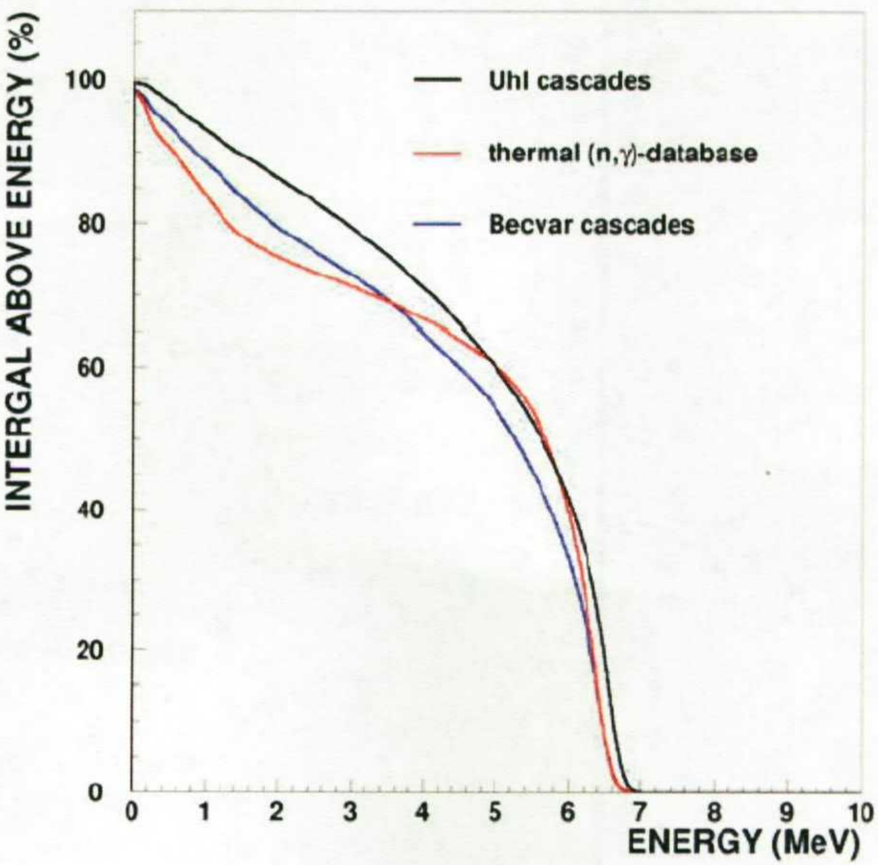

Cluster Mult vs Esum
ESB1-py
187
Mean 3.362
RMS 1.183
x10³
Mult


Cluster Mult vs Esum
ESA10-py
184
Mean 3.144
RMS 1.233
Mult


Cluster Mult vs Esum
ESA1k-py
143
Mean 2.86
RMS 1.211
Mult

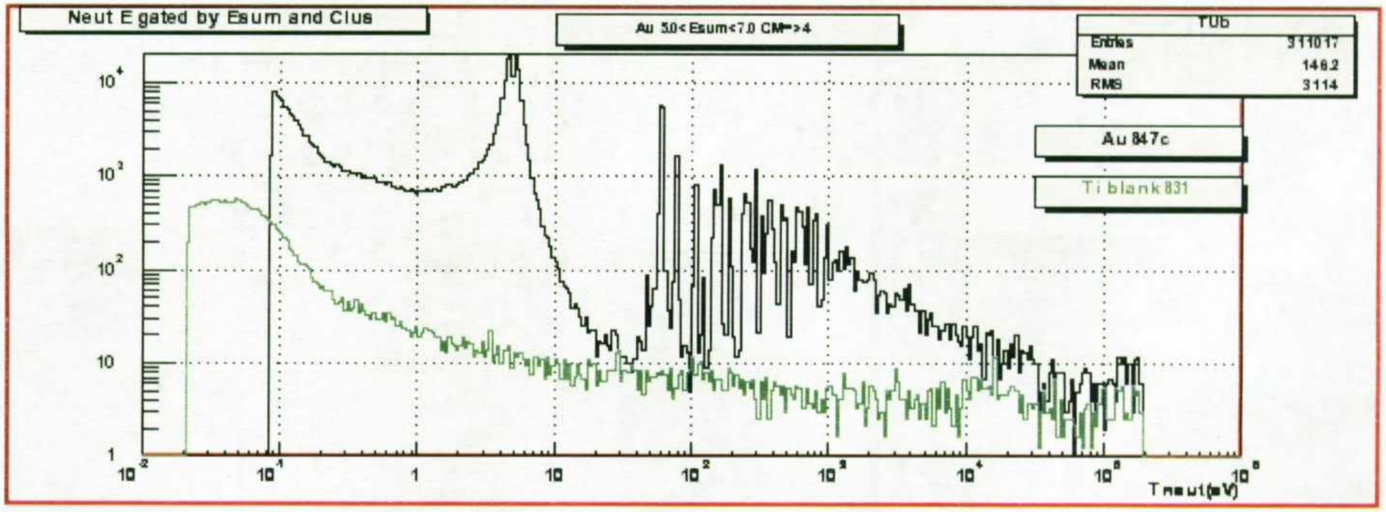

Cluster Mult vs Esum
ESA10k-py
128
Mean 2.385
RMS 1.084
Mult

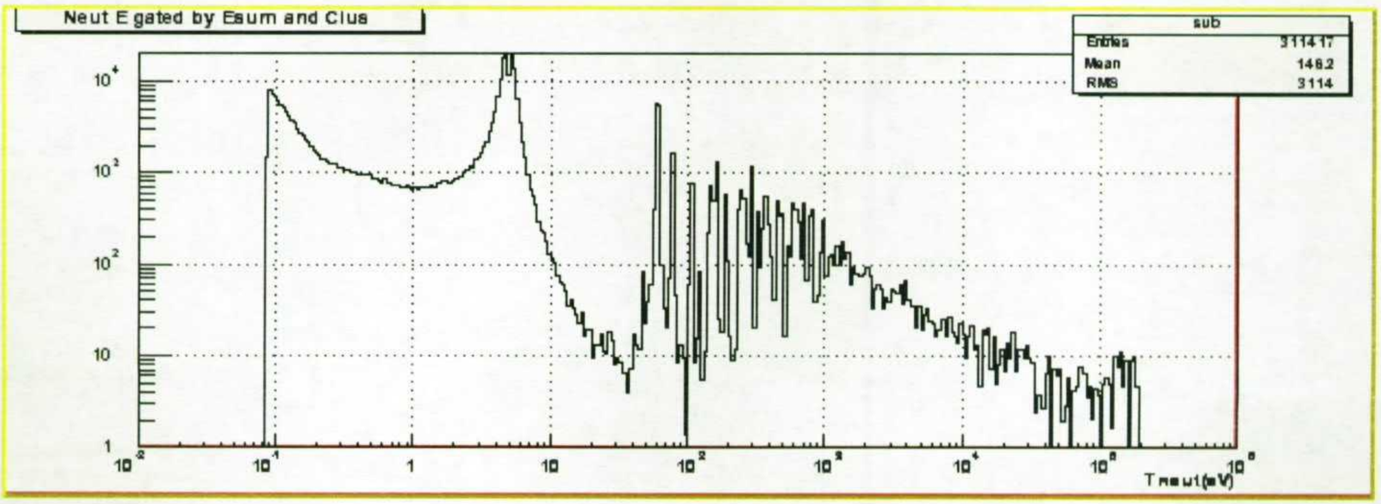
Au(n,γ), 159 crystals, LiH



Au (3.92 mg/cm2) Spectrum with Background

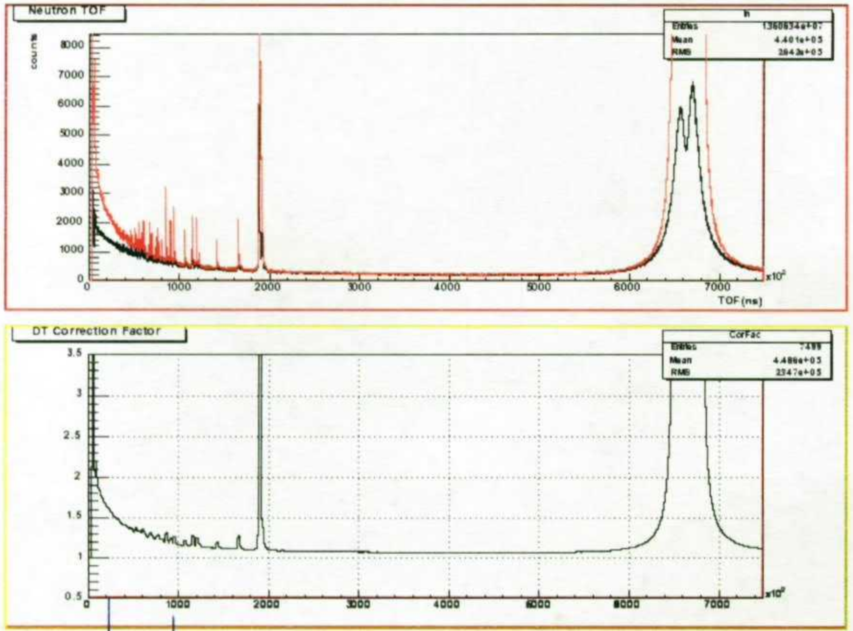
Cluster Multiplicity ≥ 4   5.0 MeV < Esum < 7.0 MeV   50 bins/decade



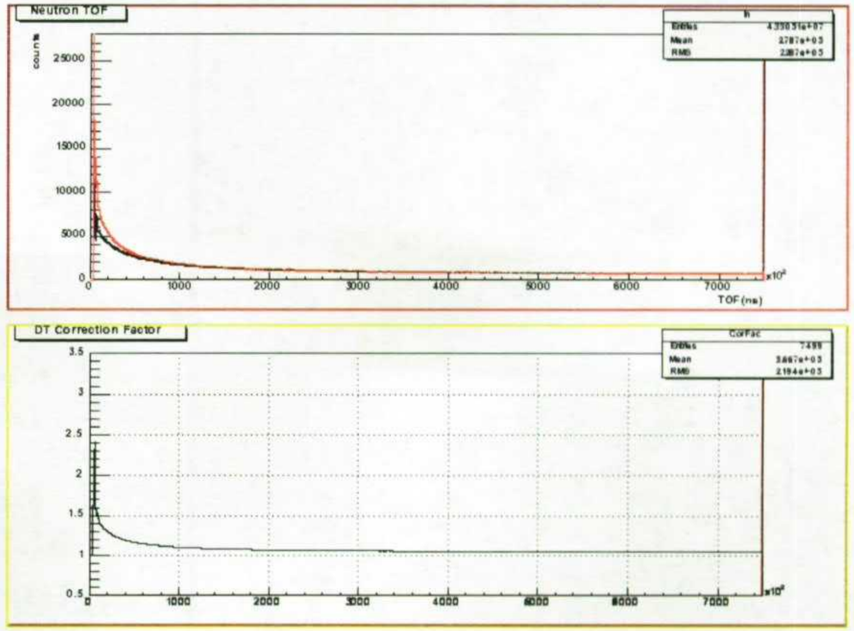


Time of flight spectra and Deadtime correction

Au (3.92 mg/cm^2)



Empty holder



100 µsec = 214 eV

14.6 µsec = 10 keV

Deadtime correction: C..D. Bowman and R.L. Bramblett, LLNL LINAC-21, 91962).
See also P.B. Coates,J. Phys. E Sci. Instr **1**, 878 (1968).

Fixed deadtime = 3.00 µsec ^{6}LiH absorber in place

Plans 2003 - 2004

Experiments

Stable Targets:

- ^{139}La,^{45}Sc,^{55}Mn,^{59}Co,Cu,V,Rb,Sr (Gaps in s-process)
- ^{102}Pd (rp process)
- ^{151}Eu rad-chem diagnostic

Radioactive Targets

- ^{237}Np AFCI
- ^{234,235,236,238}U better targets and statistics
- ^{151}Sm Key s-process branch (largely completed)
- ^{147}Pm s process branch - target irradiated, needs chemistry
- ^{171}Tm,^{155}Eu rad-chem diagnostics, target irradiated, needs chemistry

Development

- Improved hardware handshaking
- Further work on resolution and backgrounds
- Development of “continuous” data acquisition
- Ge detector in concidence for fission studies (??)