LA-UR-06-7894

Nuclear Data Experiments at LANSCE: Highlights 2006

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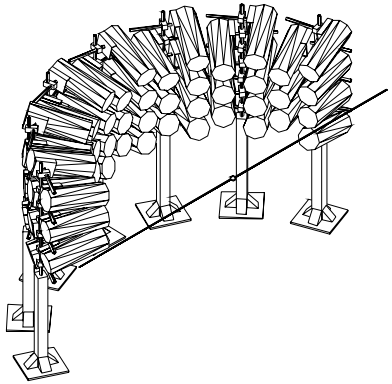
Los Alamos National Laboratory

Cross Section Evaluation Working Group Meeting
US Nuclear Data Program Meeting
Brookhaven National Laboratory
November 6-9, 2006

Nuclear data measurements at LANSCE are made with several instruments

GEANIE (n,xγ)

FIGARO (n,xn+γ)



DANCE (n,γ)

N,Z (n,charged particle)

Fission

LSDS

Double Frisch-grid fission chamber; also standard fission ion chamber; new detector station for fission and (n,alpha)

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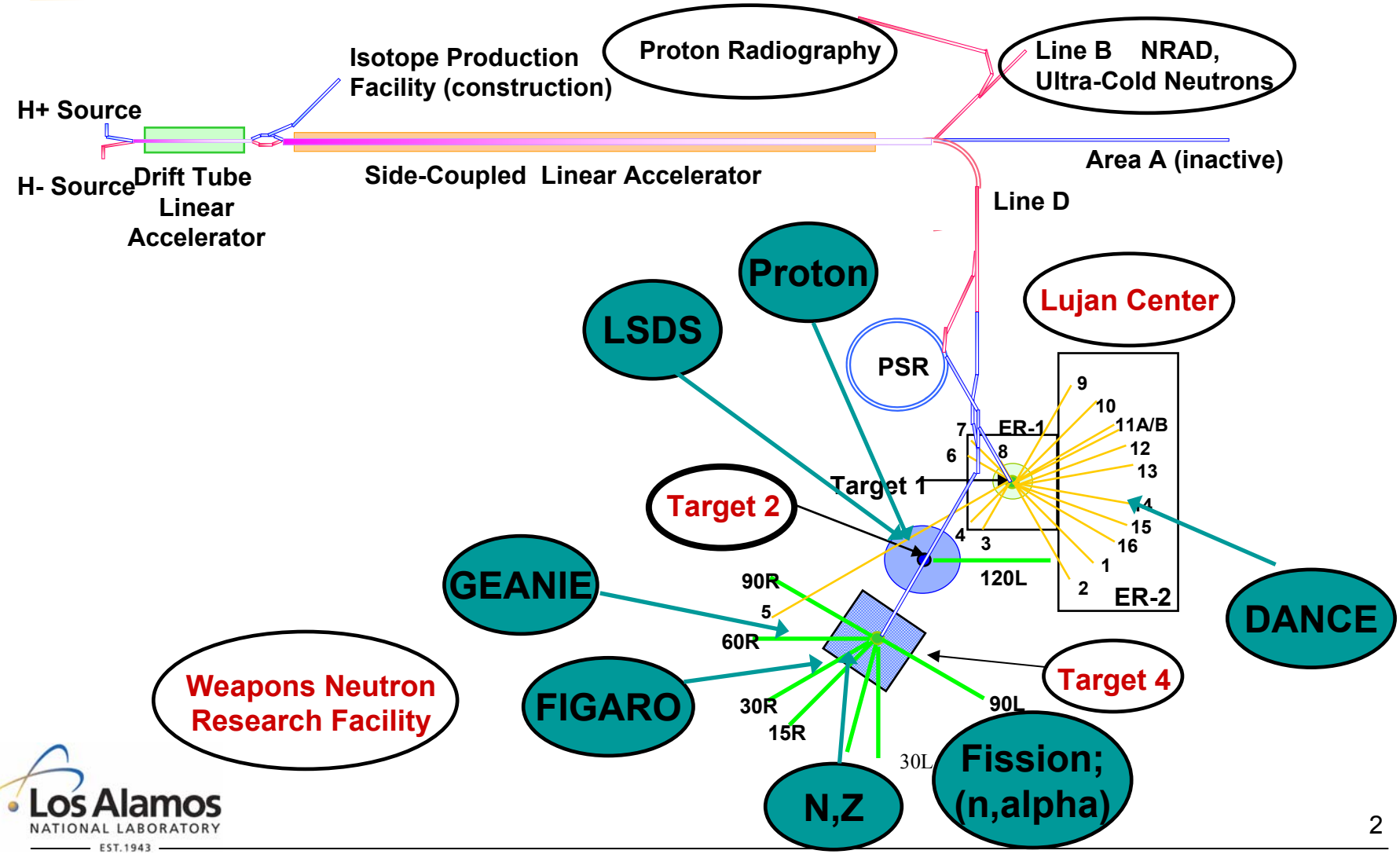
Nuclear data experiments at LANSCE use neutrons at the Lujan Center, Target 2 and Target 4



GEANIE (n,xγ)

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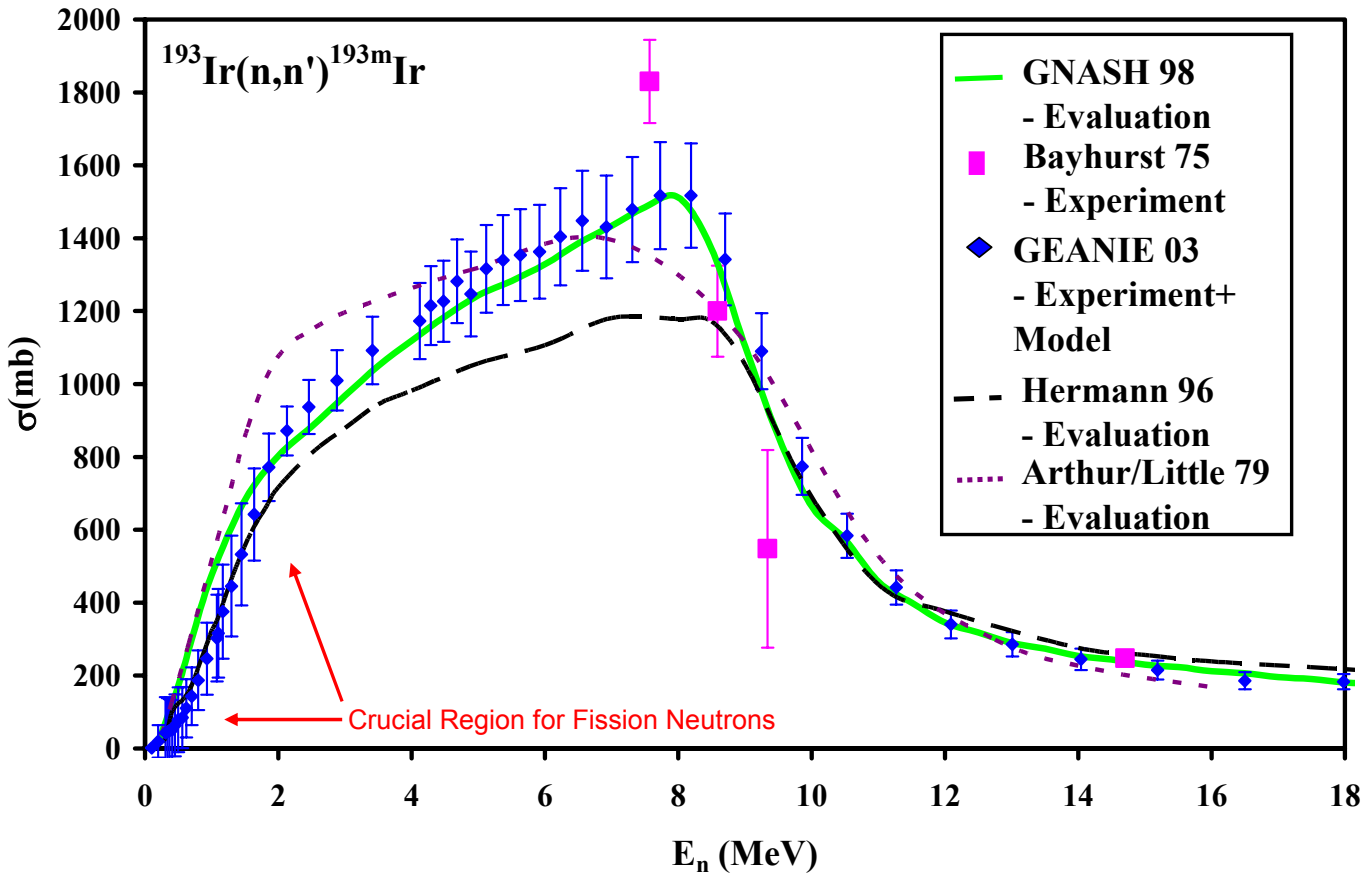
Recent & Planned GEANIE Neutron-Induced Gamma-Ray Cross Section Measurements at LANSCE/WNR

$$\sim 1\ \text{MeV} < E_n < 200\ \text{MeV}$$

- ^{103}Rh(n,xγ), ^{169}Tm, ^{203,205}Tl – levels, isomers – under analysis
- ^{48}Ti(n,xγ) – dissertation 2005 - D. Dashdorj (NCSU/LLNL)
- ^{150}Sm(n,n'γ) – pre-equilibrium analysis continuing
- ^{186}W, ^{233}U(n,2n) data acquired
- ^{100}Mo(n,xγ),^{124}Sn(n,xγ), ^{130}Te(n,xγ), ^{138}Ba(n,xγ) data acquired
- ^{70,72,74}Ge(n,xγ) data acquired
- ^{nat}Pb and ^{nat}Te for 0$\nu\beta\beta$ decay experiment backgrounds – measurements in progress
- Planned Samples: ^{136}Xe, other Xe and Kr isotopes

Contact:
Ron Nelson

New GEANIE data significantly improve the $^{193}Ir(n,n')^{193m}Ir$ cross section database



GEANIE
LLNL/LANL

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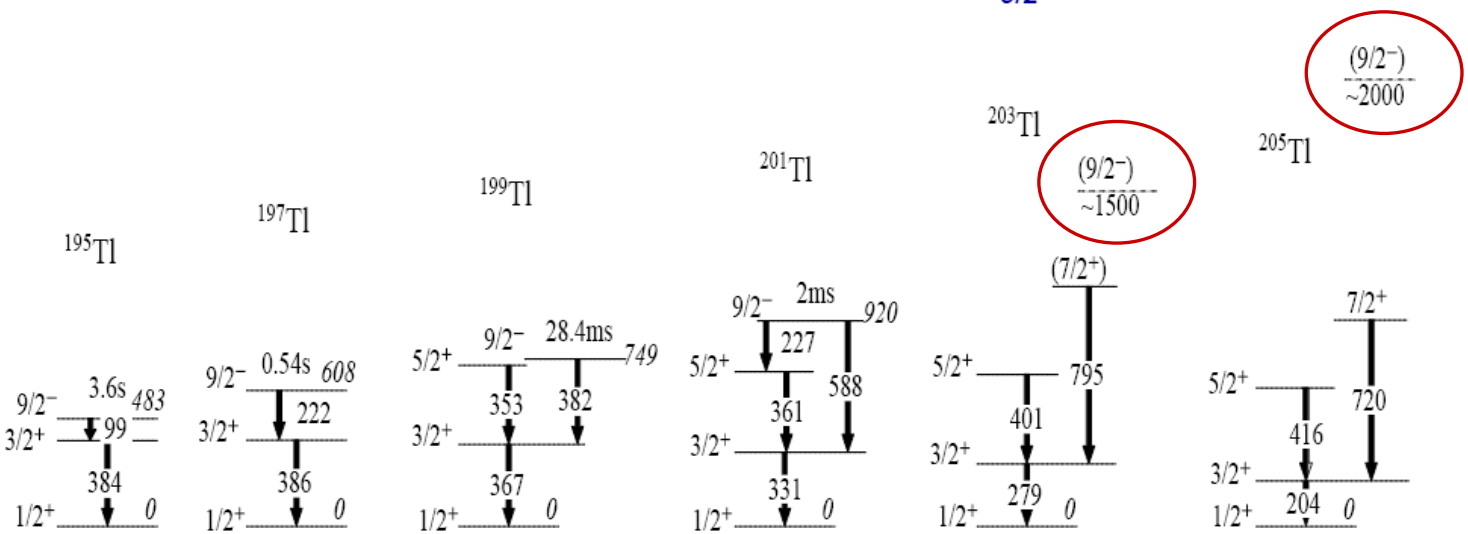
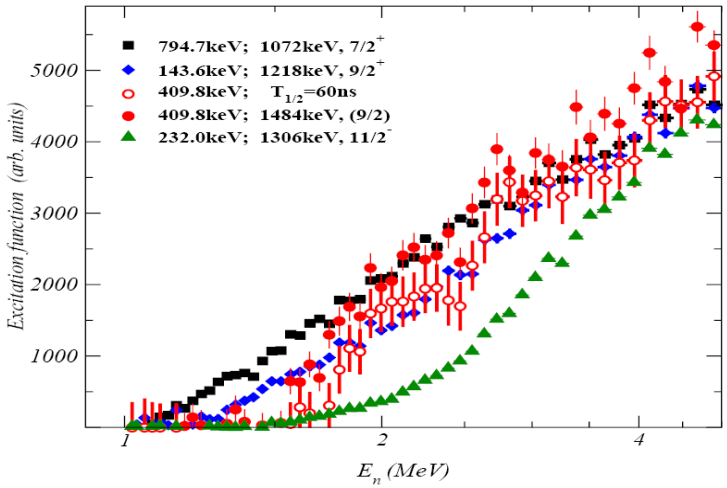
Structure in odd Thallium isotopes

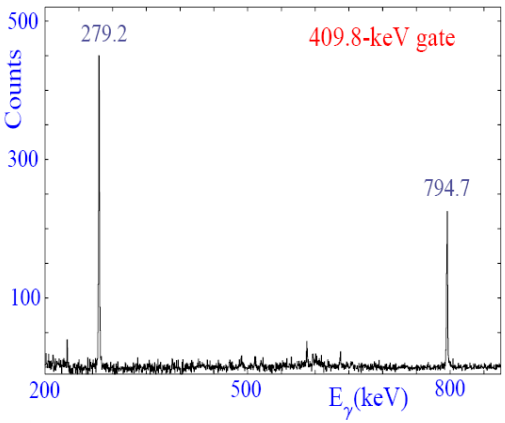
$9/2^-$ isomers from the **odd proton** in the **$h_{9/2}$ orbital**

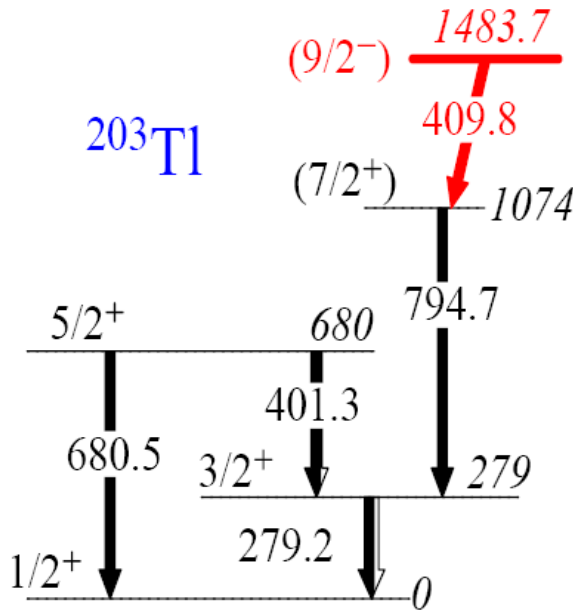


------- G. E. Arenas Peris and P. Federman, Phys. Rev. C 38, 493 (1988)

Half-life corrected excitation function of 408.9 keV







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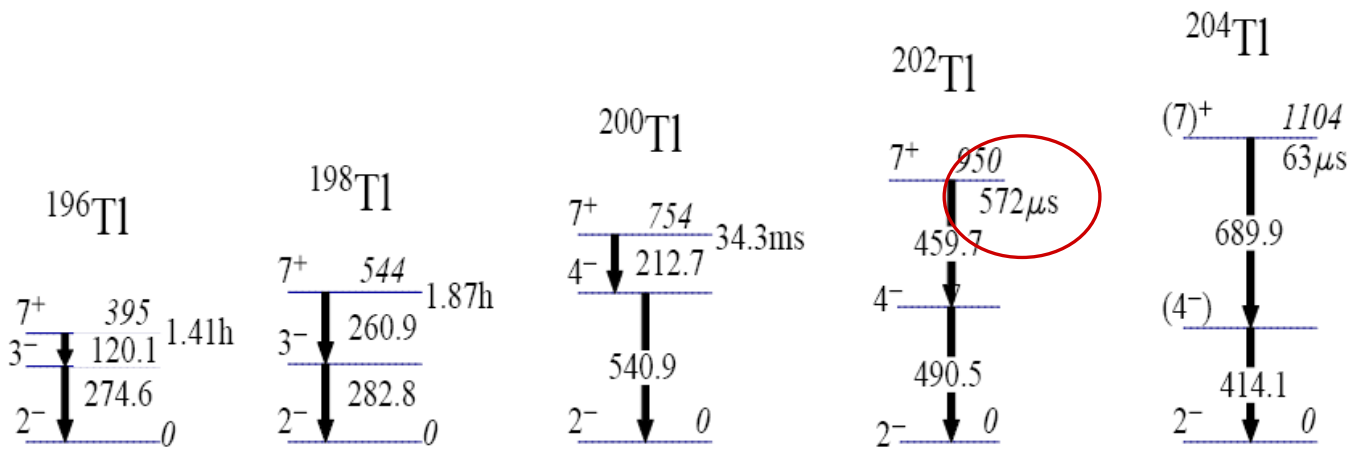
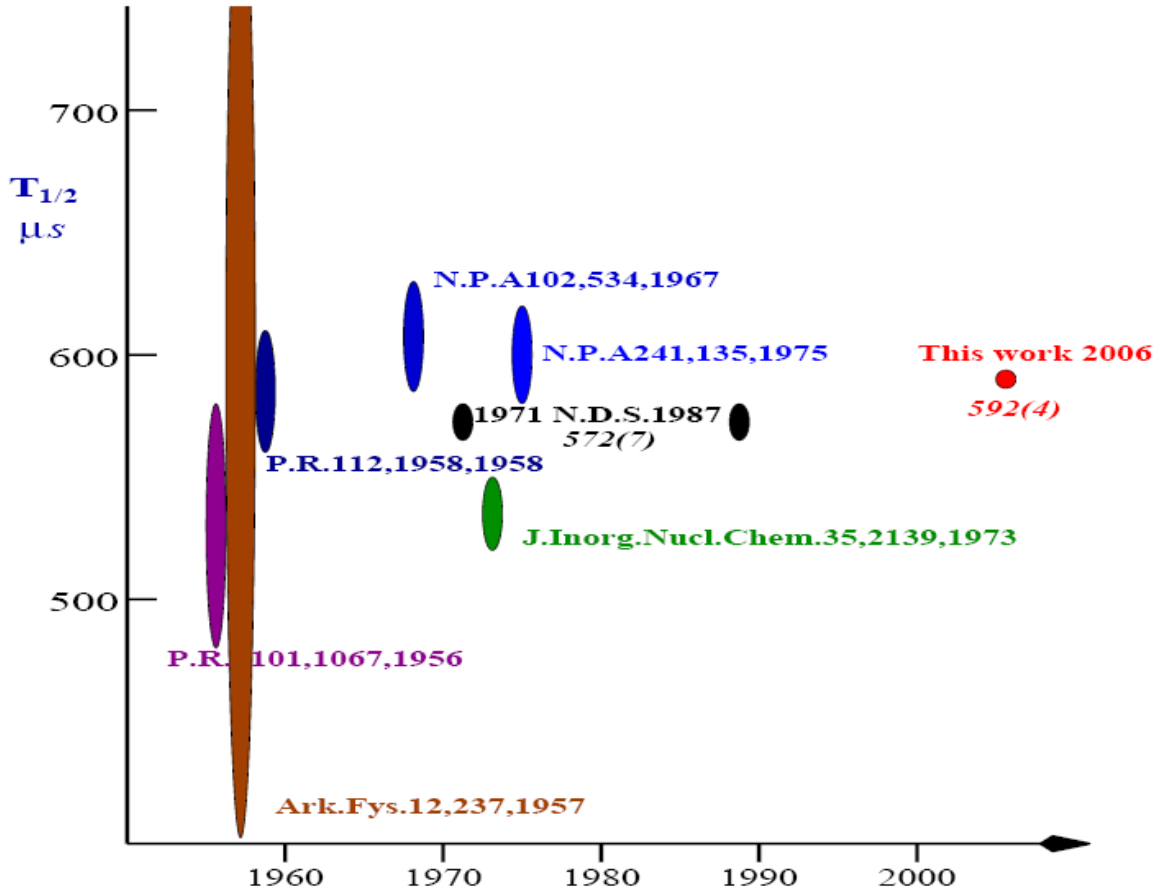
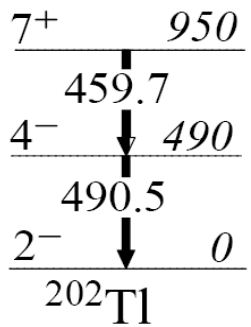
Structure in even Thallium isotopes

7^+ isomers from the **odd proton** in the **$s_{1/2}$ orbital**
and the **odd neutron** in the **$i_{13/2}$ orbital**



History of the ^{202}Tl 7^{+} isomer half-life

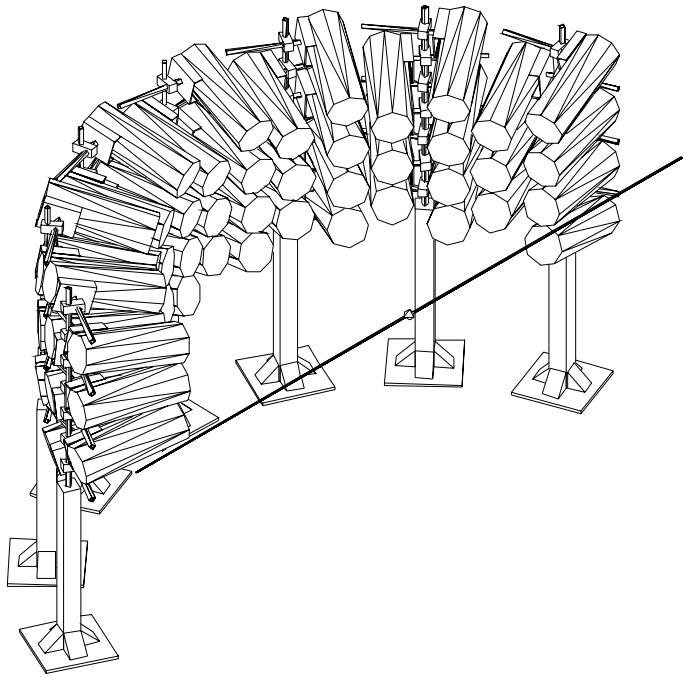




Some conclusions on states in Tl-isotopes

- Excited states in $^{199\text{-}203}$Tl are studied with GEANIE using the ^{203}Tl(n,xgamma) reaction
- Gamma excitation functions are measured from beam-on data
- Half-lives of isomers are determined between beam macropulses
- 1484-keV state is a candidate for the 9/2- isomer in ^{203}Tl; half-life probably in the nanosecond range
- Half-life of the 7+ isomer of ^{202}Tl [592(4) μs in this work vs. 572(7) in the 1989 evaluation]
- Results of life-time measurements in $^{199\text{-}201}$Tl in agreement with previous values

FIGARO (n,xn+γ)



Present and future experiments at FIGARO/WNR: neutron-emission spectra and ν-bar in fission

1 MeV < E_n < 200 MeV

Fission Chamber in beam

- ^{239}Pu(n,f): E_{fn}, ν-bar — In progress
- ^{235}U(n,f): E_{fgamma} — R. Nelson, in progress
- ^{237}Np(n,f): E_{fn}, ν-bar — Data being analyzed by CEA

Gamma-ray trigger (HPGe or BaF_2)

- ^{nat}Ba, ^{nat}Sr, ^{56}Fe — In progress

Contact:
Bob Haight

N,Z = (n,charged particle) cross sections

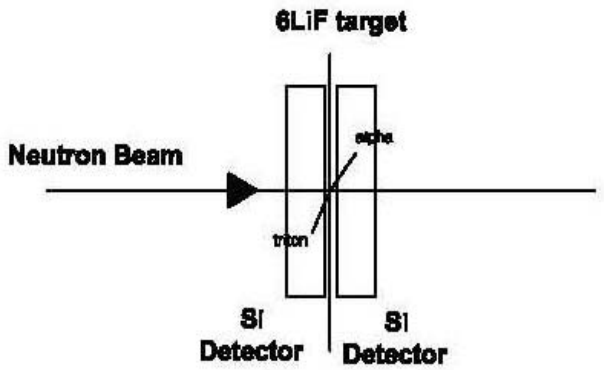
-- studied in two ways

^{6}Li(n,t)α measurements at WNR: cross section and angular distribution

- The ^{6}Li(n,t)α reaction cross section in the few MeV region has relatively large experimental uncertainties
- Specifically, we are measuring
  1) The reaction cross section for $0.1<E_n<10$ MeV using a Si detector "sandwich" technique
  2) The angular distribution of tritons, to improve the theoretical modeling and to identify the spins and parities of the (unbound) states in the MeV region
- Results will be ready in early 2007

Contacts:
Matt Devlin
Terry Taddeucci

$^{6}Li(n,t)\alpha$ cross section measurement with Si detectors: the method

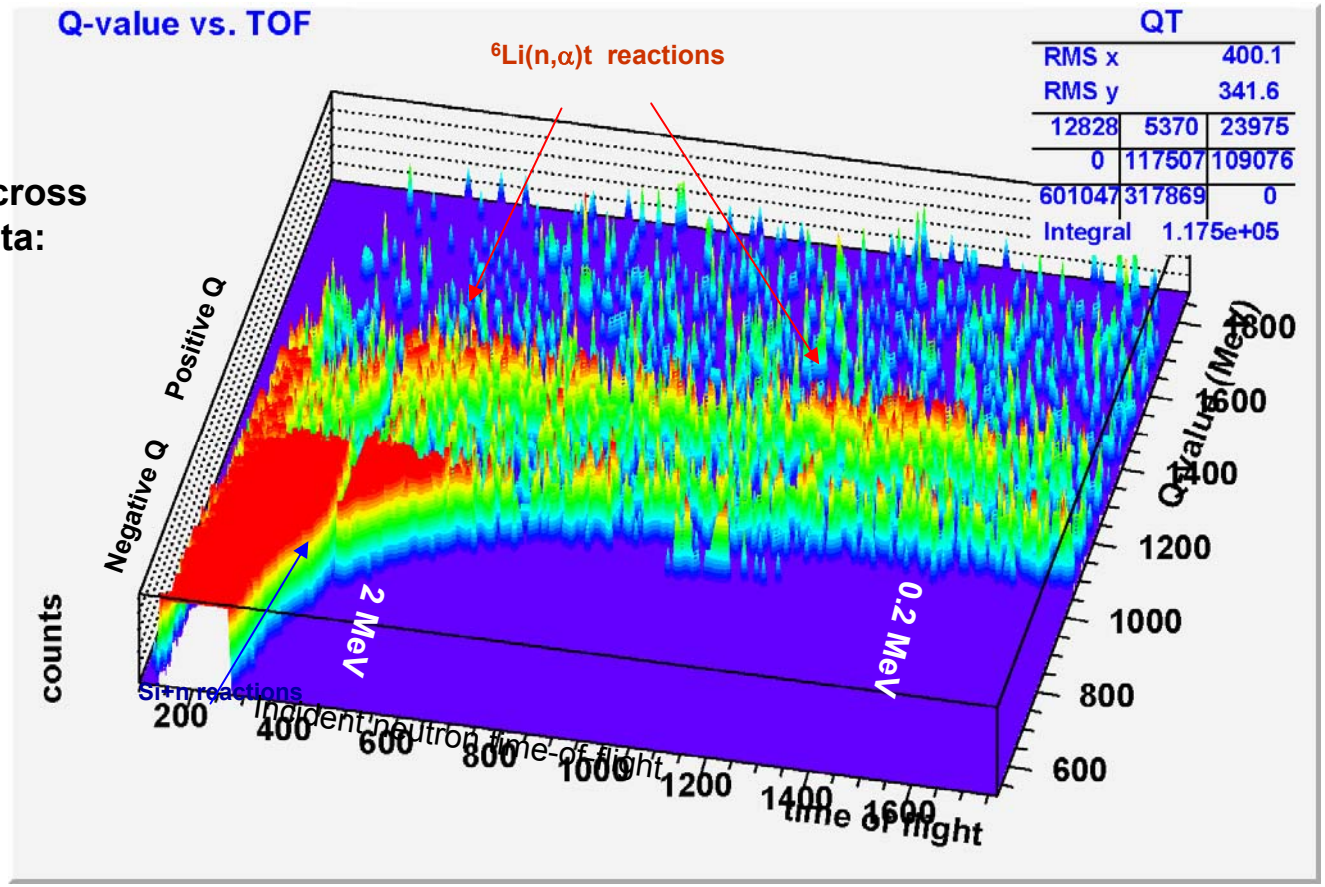


- Si detectors are selected to be thick enough to stop tritons and alphas up to E_n = 25 MeV
- For higher neutron energies both products go forward
- Si detectors obtained from ORTEC, Canberra
- Systematic errors will include angular distribution effects (some of the solid angle is not covered) and downscattering of neutrons in the Si upstream

$^{6}Li(n,\alpha)^{3}H$ data at 40m and 7.2 μs show good separation of reaction from background

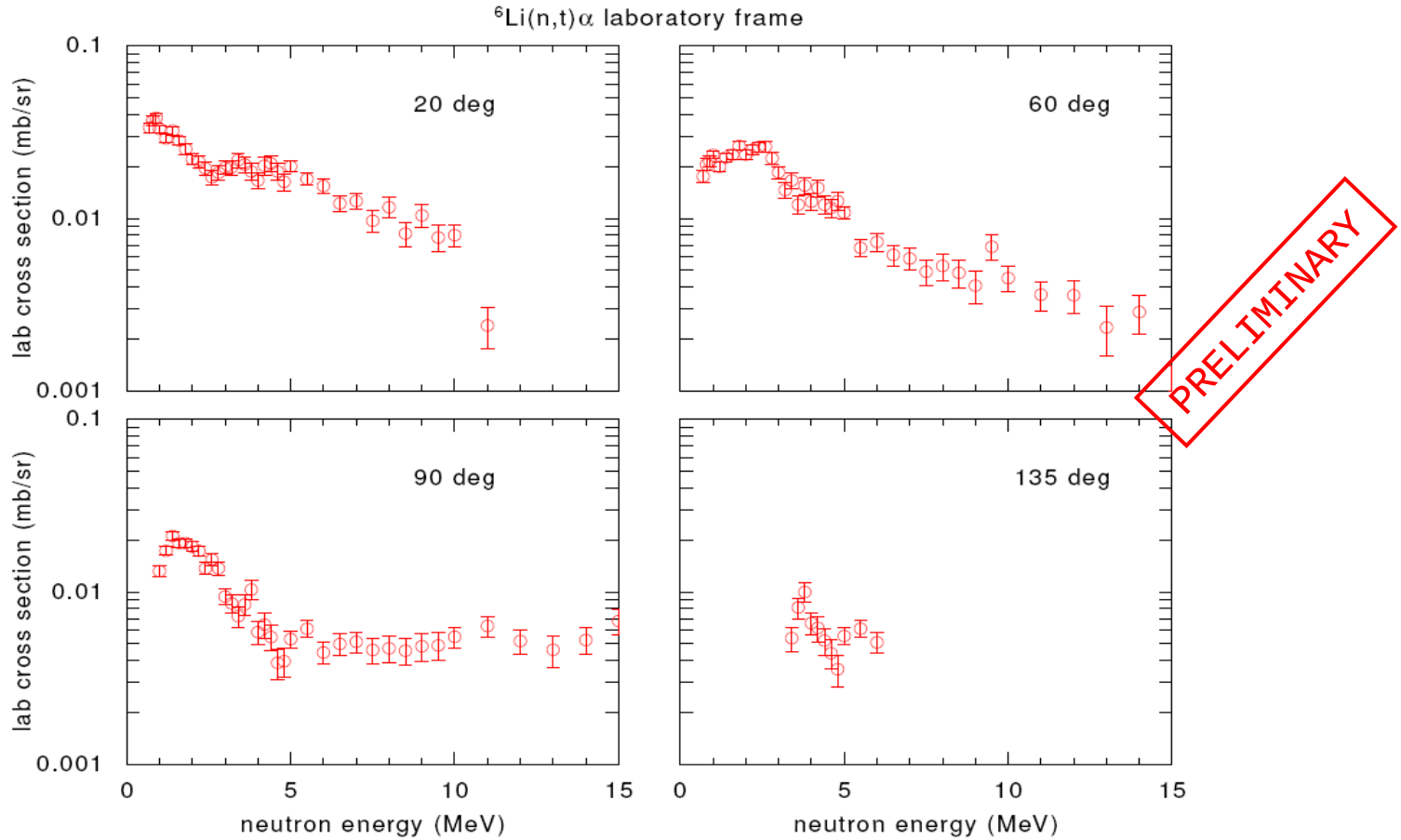
Preliminary cross section data:

$^{6}Li(n,\alpha)t$ reactions are the band with positive Q-values

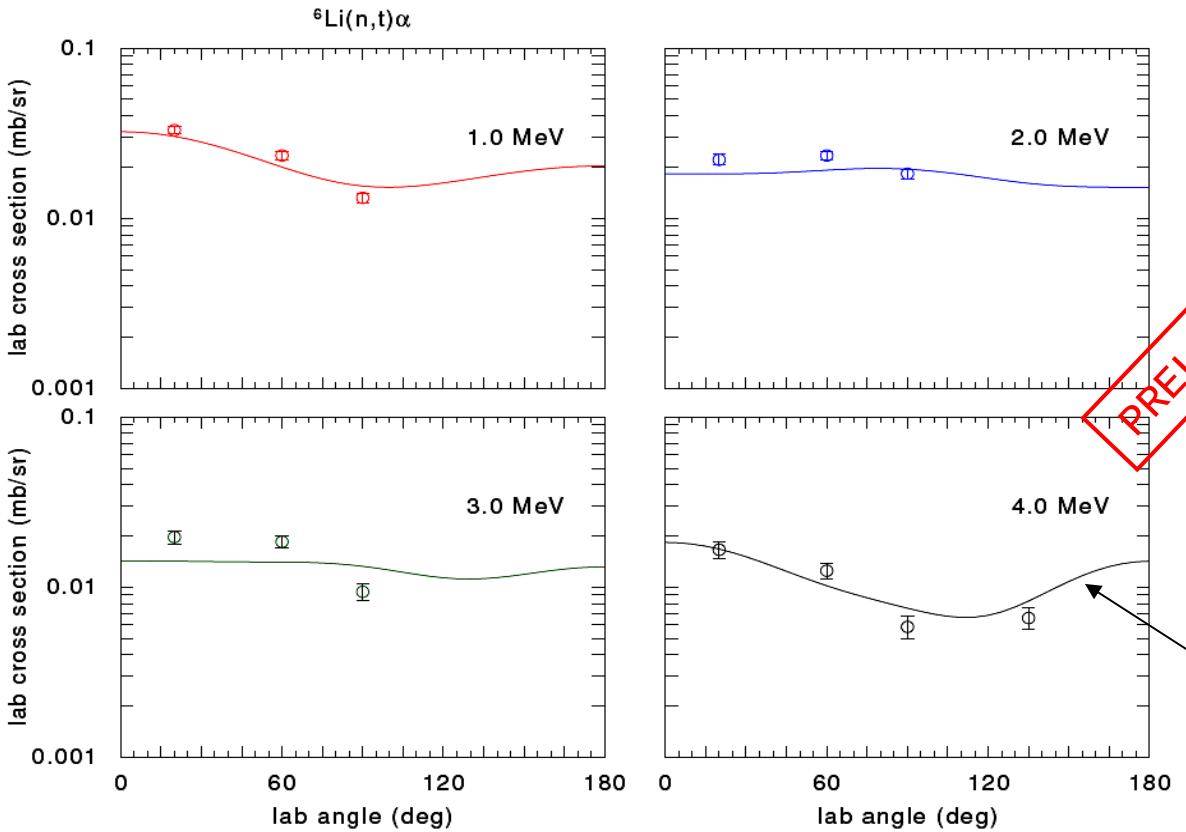


N,Z double-differential cross sections are studied with “standard” detector telescopes

^{6}Li(n,alpha) preliminary results for differential cross section are very promising

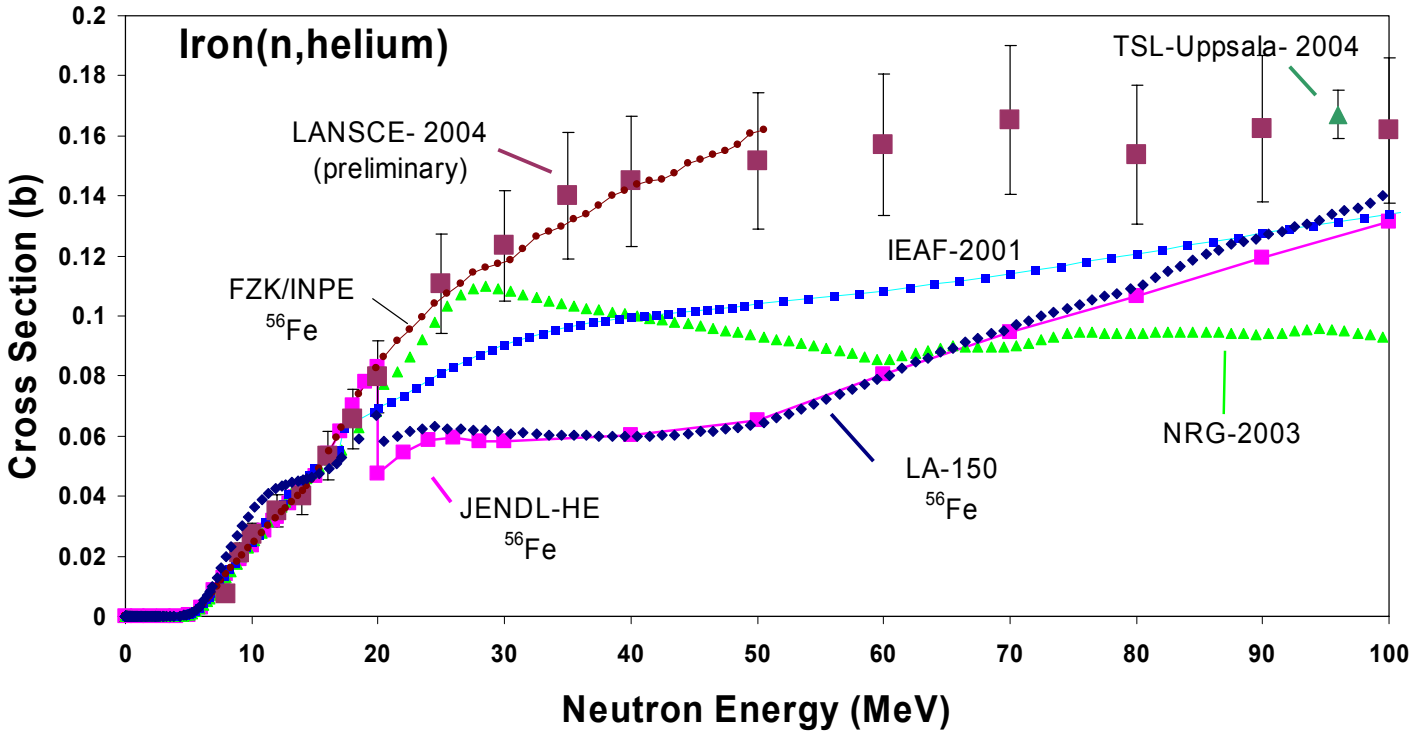


Angular distribution data will aid R-Matrix analysis



R-Matrix calculation (previous parameters)

We measure hydrogen and helium production cross sections for the Advanced Fuel Cycle Initiative



These data differentiate among evaluations

Contact:
Bob Haight

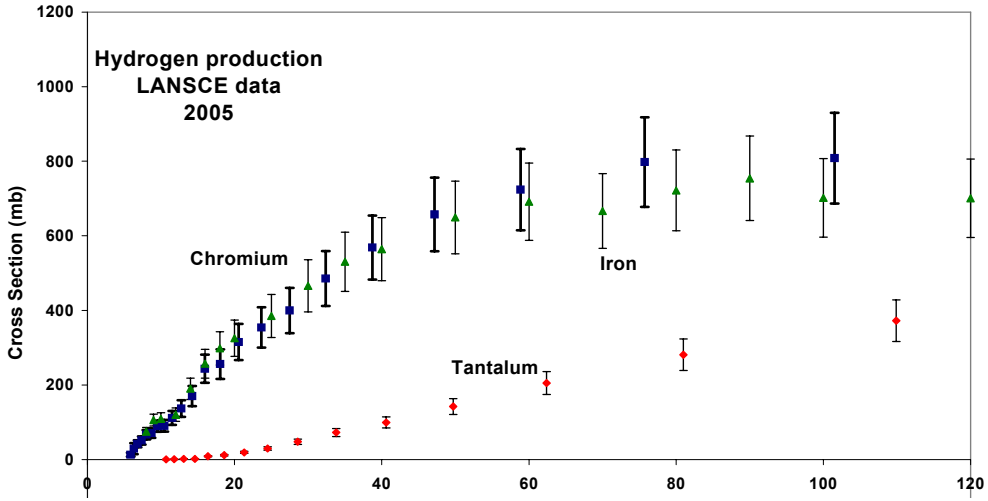
Plans for future hydrogen and helium production cross sections for the Advanced Fuel Cycle Initiative

1 MeV < En < 100 MeV

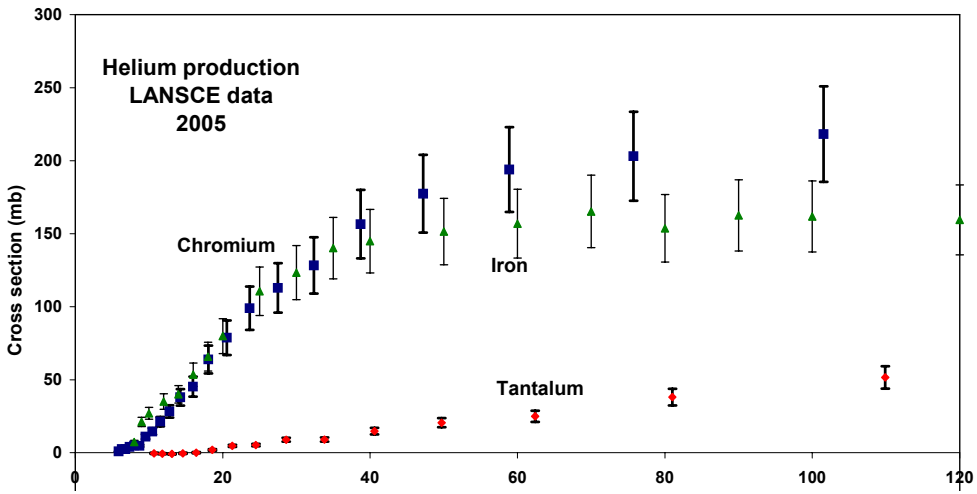
- Zr(n,xp) and (n,xα) -- nearly completed
- Mo(n,xp) and (n,xα) -- planned

Goal is to determine, e.g. helium production / dpa for accelerated radiation damage analysis

Previous data are for Iron, Chromium, and Tantalum

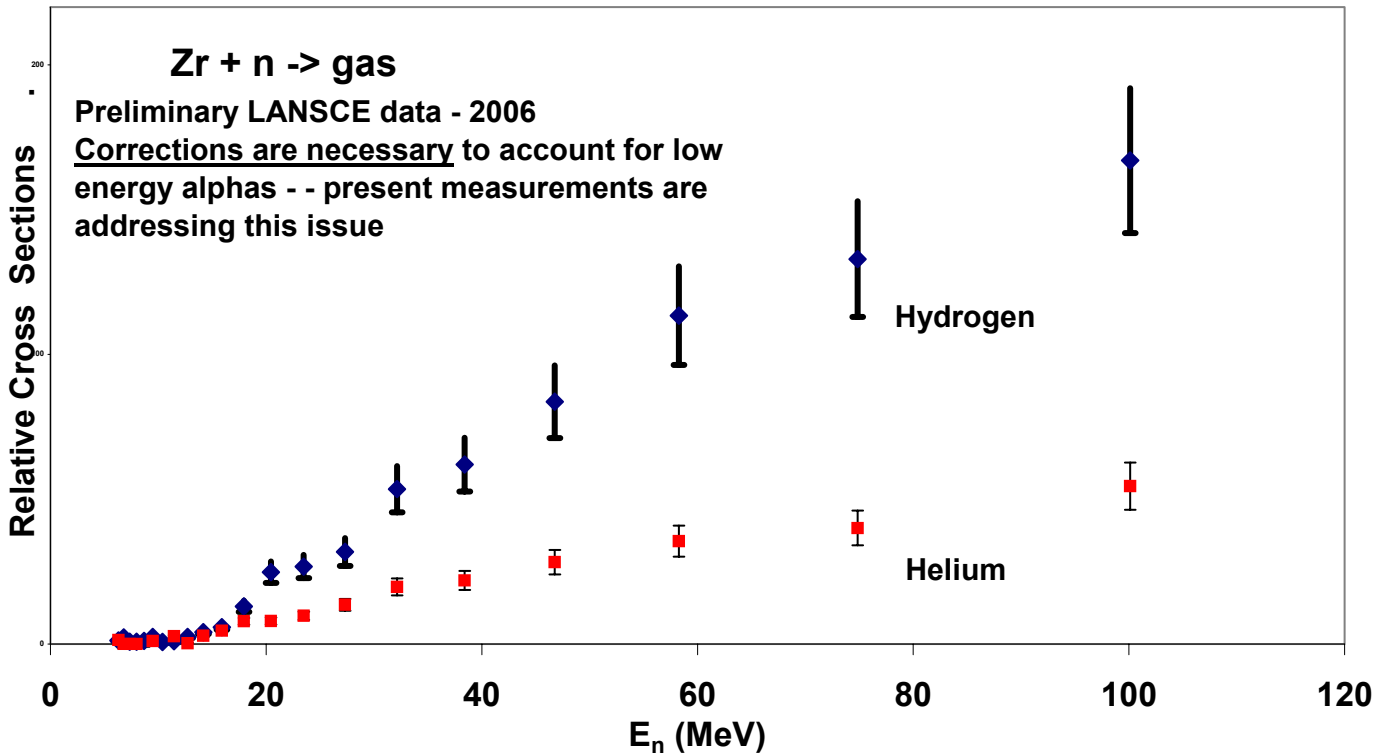


Hydrogen



Helium

Partial data have been taken for Zirconium



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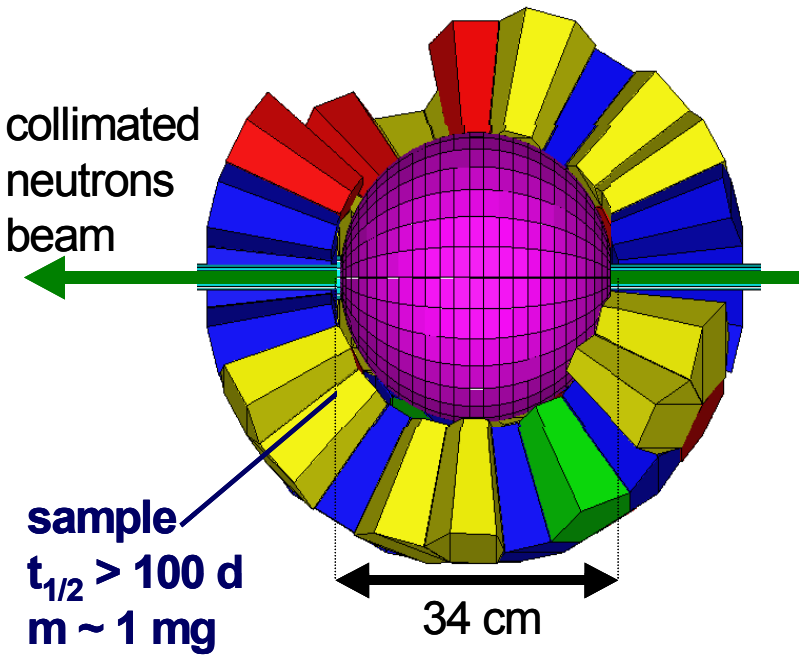
DANCE (n,γ)

*D*etector for *A*dvanced *N*eutron *C*apture *E*xperiments - DANCE



neutrons:

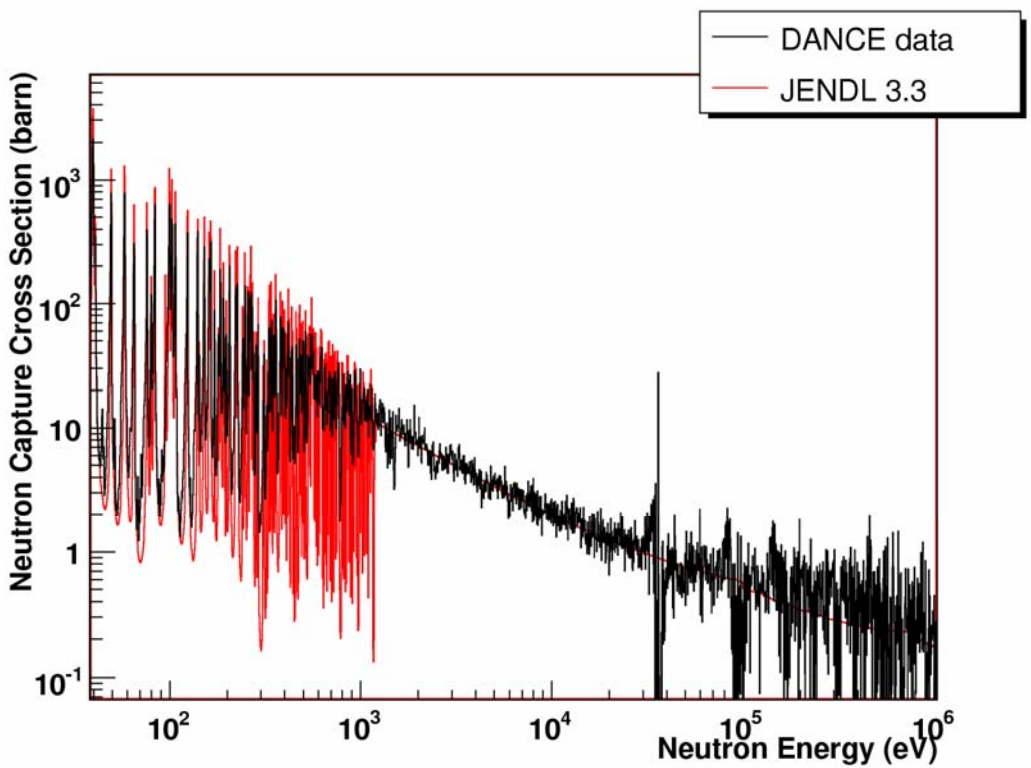
- spallation source
- thermal .. 500 keV
- 20 m flight path
- 3 10^5 n/s/cm^2/decade

γ-Detector:

- 160 BaF_2 crystals
- 4 different shapes
- R_i=17 cm, R_a=32 cm
- 7 cm ^{6}LiH inside
- $\varepsilon_\gamma \approx$ 90 %
- $\varepsilon_{casc} \approx$ 98 %

Contacts:
John Ullmann
Rene Reifarth
Bob Rundberg

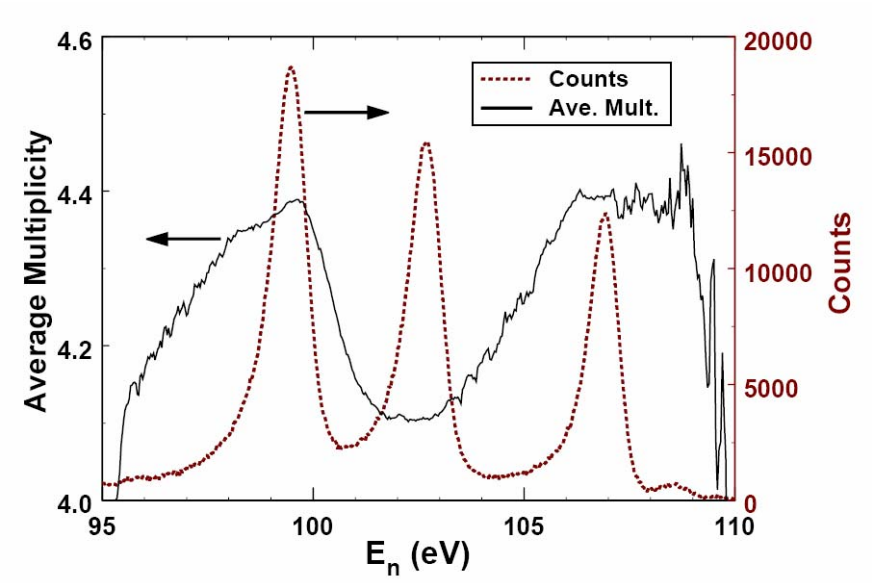
^{147}Sm(n,γ), 10 mg



Comparison of preliminary data from a 10 mg ^{147}Sm sample at DANCE (**black**) and the JENDL-3.3 evaluation (**red**) around the low keV region. The evaluated data could be confirmed over a broad energy range.

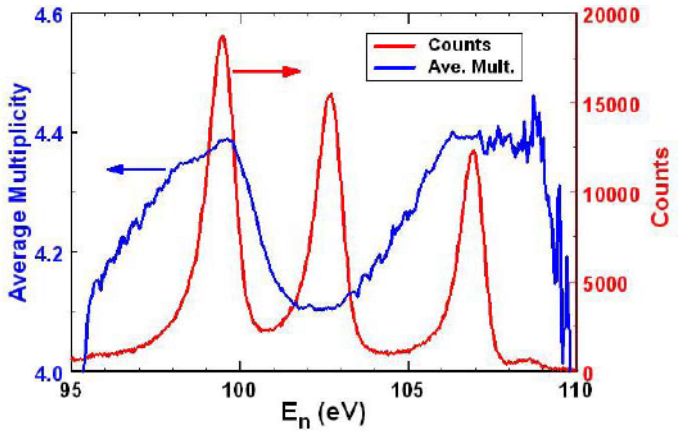
Contact:
Paul Koehler
(ORNL)

^{147}Sm(n,γ), 10 mg

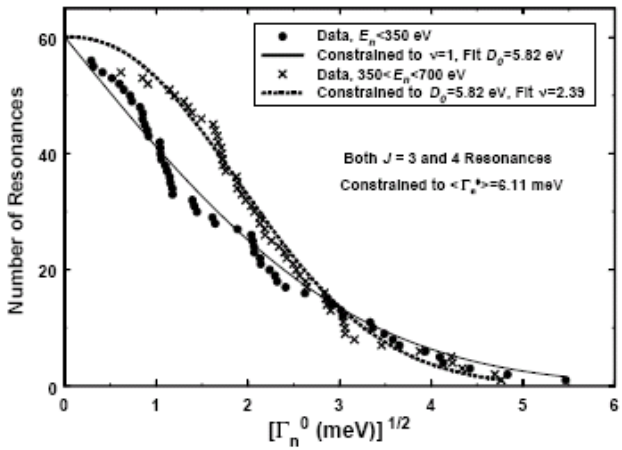


Spin-assignment using the "average multiplicity" technique. Provided the nuclear structure is favorable, DANCE is a very powerful tool for this technique – thanks to the high segmentation.

Spin Assignments for ^{147}Sm + n



<M> and Counts for several ^{147}Sm resonances



Spin assignments made for 140 resonances < 1 keV

- 34 firm J assignments for previously unassigned
- 8 firm assignments where only tentative assignments
- 14 resonances < 1 keV without firm J
  - (9 < 700 eV)
- 6 firm assignments disagree with Sukhoruchkin
- 6 previously firm resonances shown to be doublets

Actual assignments were made using combinations of various multiplicities rather than <M>

Non-statistical effects?

➢ Distribution of J=3,4 reduced neutron widths
- Agree with each other
- Disagree with Porter-Thomas

(Different conclusion from Gledenov and Koehler – incorrect spin assignments)

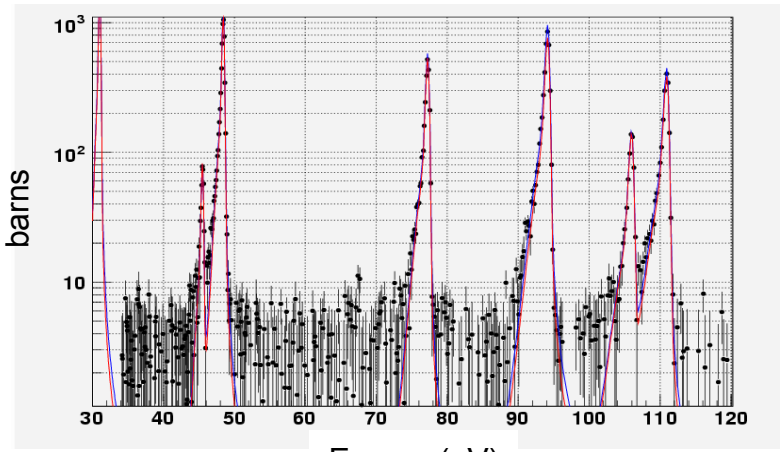
➢ Combined J=3,4 distribution

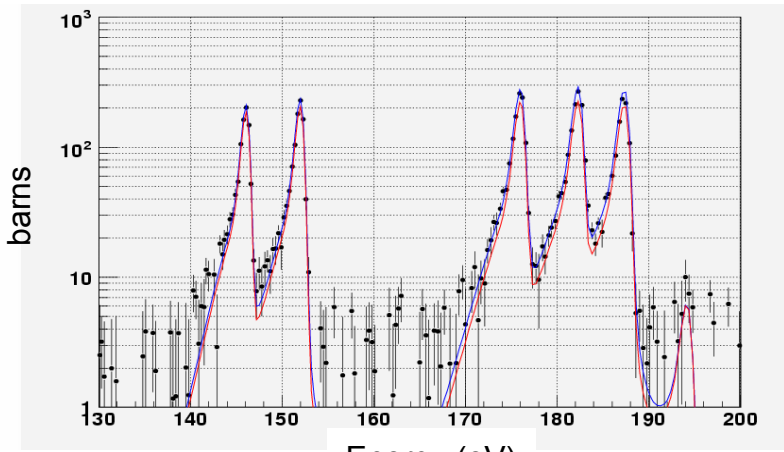
En < 350 eV follow Porter-Thomas (v=1)

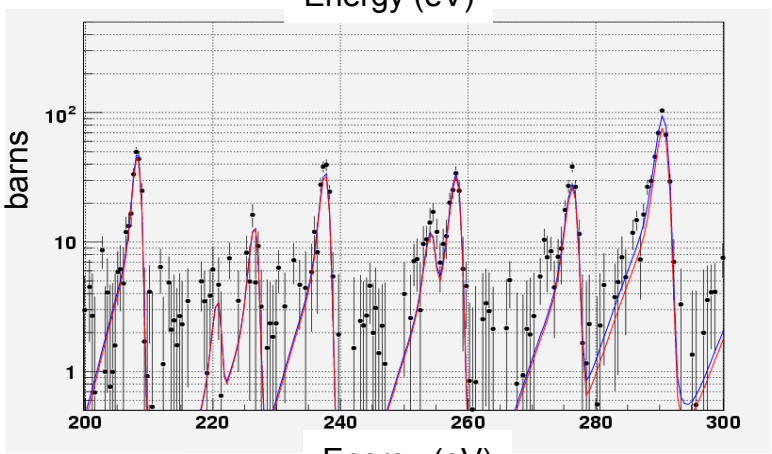
350 < En < 700 eV, not PT (v=2.39)

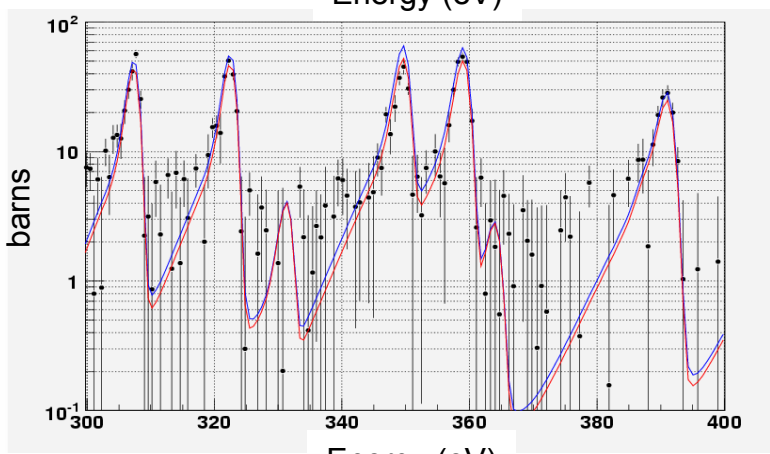
➢ Is result statistically significant?

$^{234}U(n,\gamma)$ with broadened ENDF resonance parameters









ENDFB-VII (draft)

ENDFB-VI

- SAMMY calc w/ "NTOF" res func
- No correction for fission resonances

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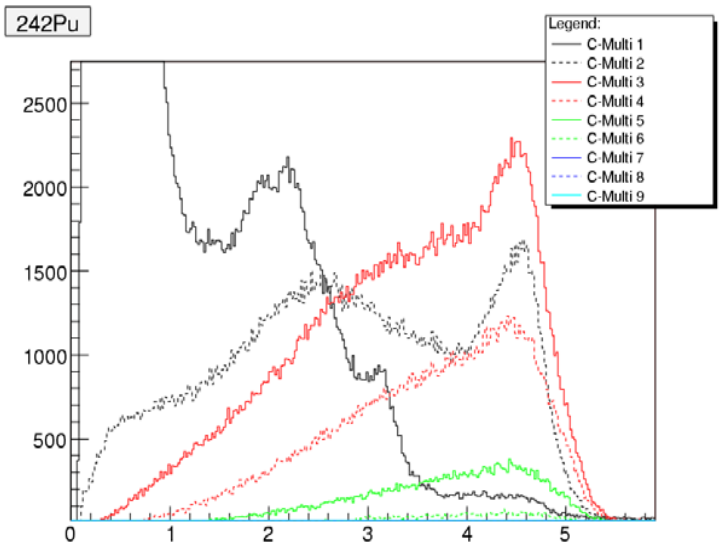
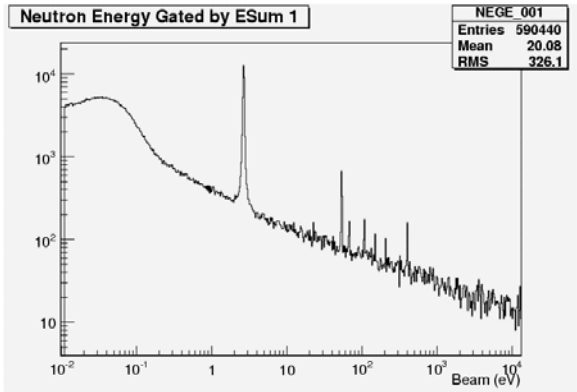
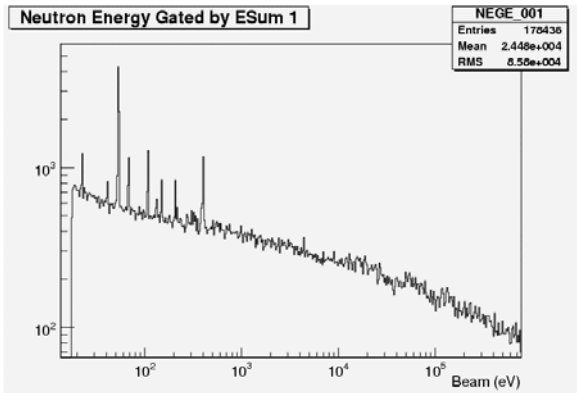
^{242}Pu(n,γ), 0.7 mg



Sum energy (MeV) deposited in the crystal ball, if (n,γ) dominated



Yield as function of neutron energy (eV), gated on Q-value for ^{242}Pu(n,γ)



Neutron Capture Cross sections of ^{236}U and ^{234}U

Neutron-capture cross sections on U isotope chain are important

Measurements on ^{234}U

- Q(n,γ) = 5.30 MeV
- 4.0 < Esum < 5.5 MeV, Mult ≥ 3
- Target: 1.08 mg on 2, 2.5 μm Ti foils
- Normalized to Thermal (100 b) and Barr (absolute)
- Background Subtractions:
  - Target out
  - Fission
  - Gamma scattering (20%)
- Integral of 5.16 eV resonance
  - Thermal normalization = 1770 b-eV
  - Barr normalization = 1740 b-eV
  - ENDF/B-6 = 2830 b-eV
  - ENDF/B-7 = 2738 b-eV

^{236}U(n,γ) and ^{234}U(n,γ) not well known

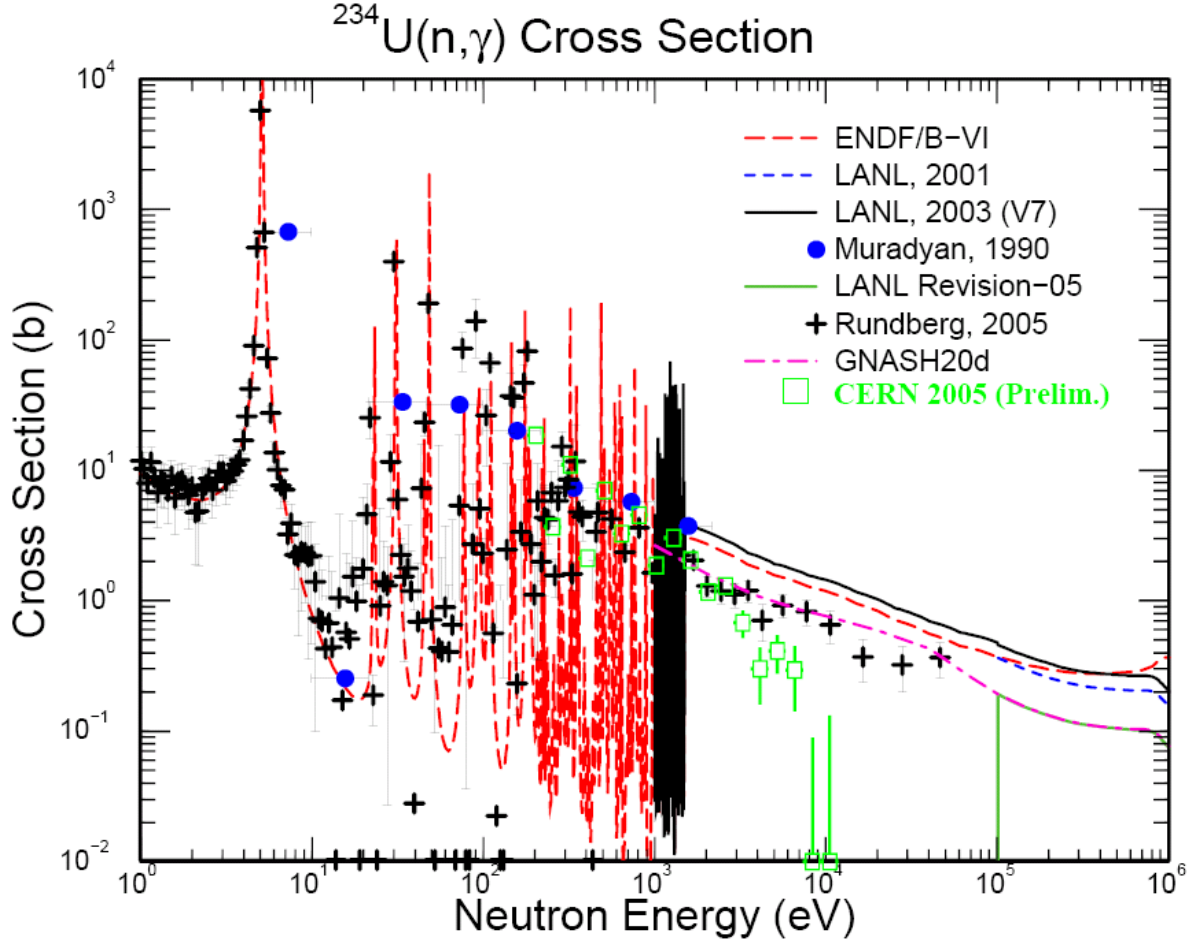
- Several measurements of ^{236}U, but recent measurements above 1 keV differ by factor of 2
- Very few measurements on ^{234}U, this is first high-resolution measurement

Measurements on ^{236}U

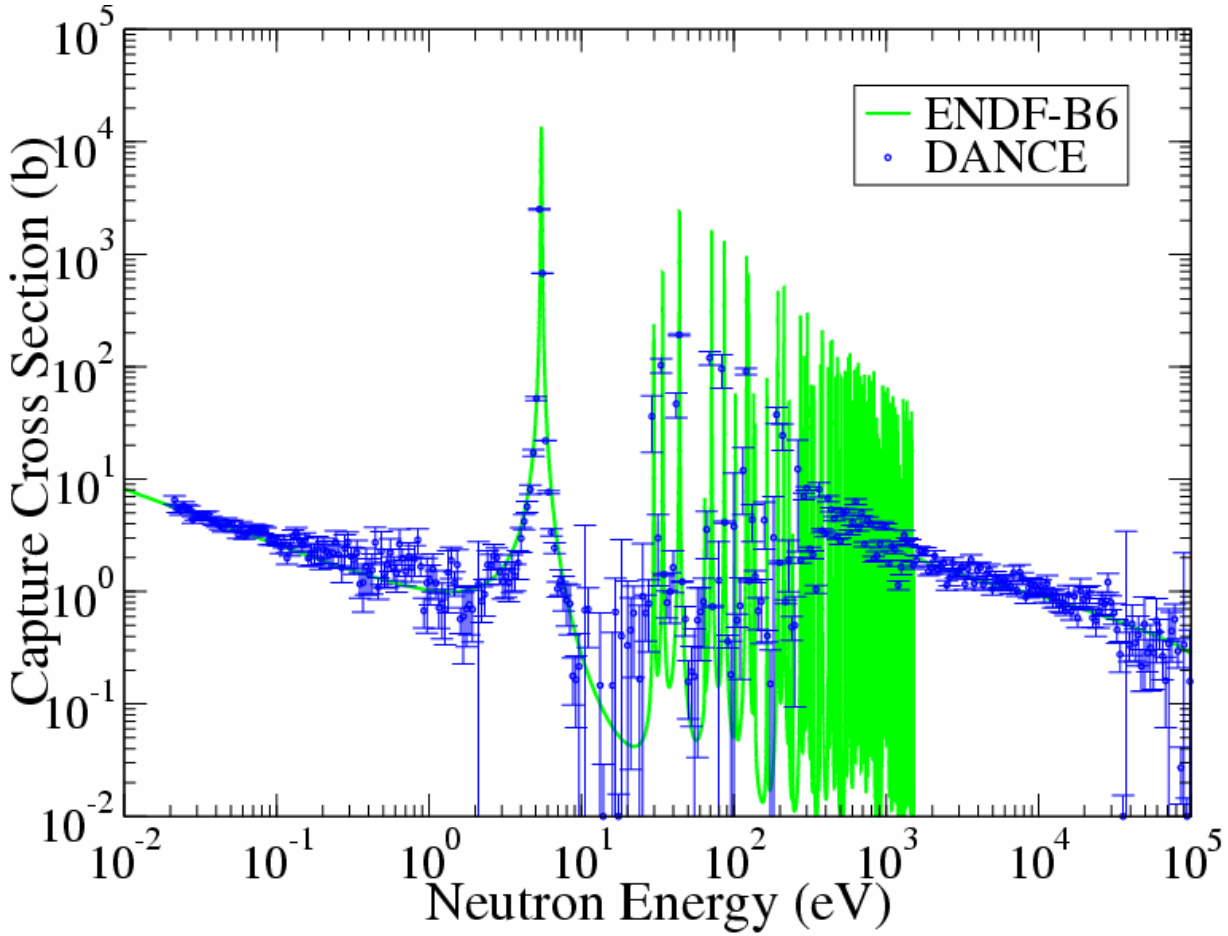
- Q(n,γ) = 5.13 MeV
- 4.0 < Esum < 5.5 MeV, Mult ≥ 3
- Target: 0.49 mg on 2, 2.5 μm Ti foils
- Normalized to Thermal (5.1 b) and Barr (absolute)
- Background Subtractions:
  - Target out
  - Fission
  - Gamma scattering (20%)
- Integral of 5.45 eV resonance
  - Thermal normalization, Barr normalization, and ENDF/B-6 all agree

^{234,236}U cross sections: R.S. Rundberg, et al., *to be published*.

^{234}U(n,γ) Cross Section



^{236}U(n,γ) Cross Section from DANCE



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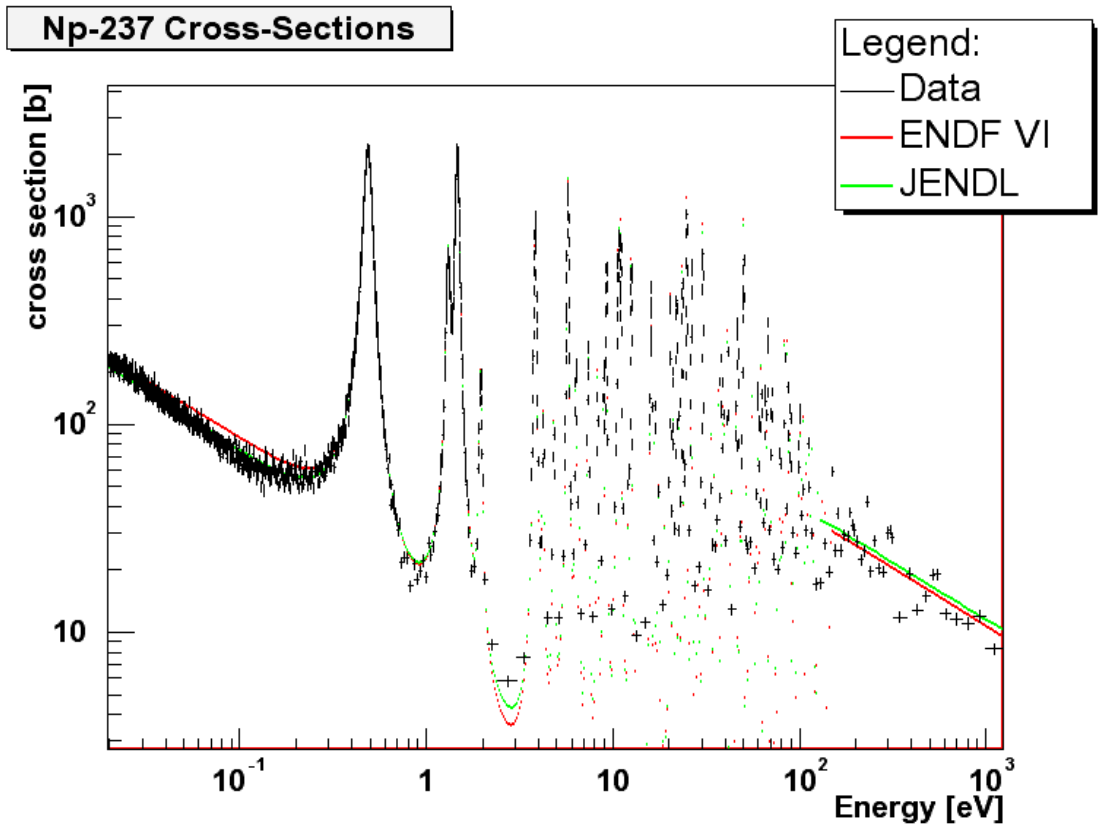
^{237}Np(n,γ)



Target: 0.44 mg ^{237}Np in 6.4 mm diameter (1.4 mg/cm^2)
Existing data above 1 keV discrepant

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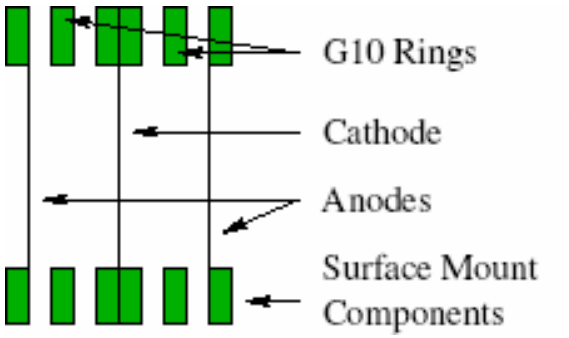
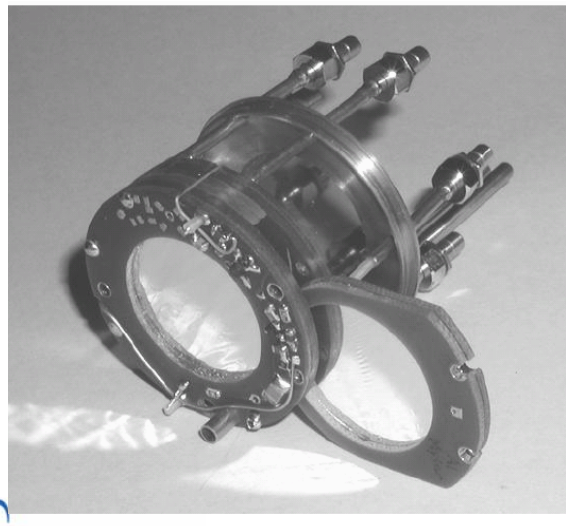
PPAC Detector for Capture and σ_γ/σ_f Measurements



Parallel-Plate Avalanche Counter



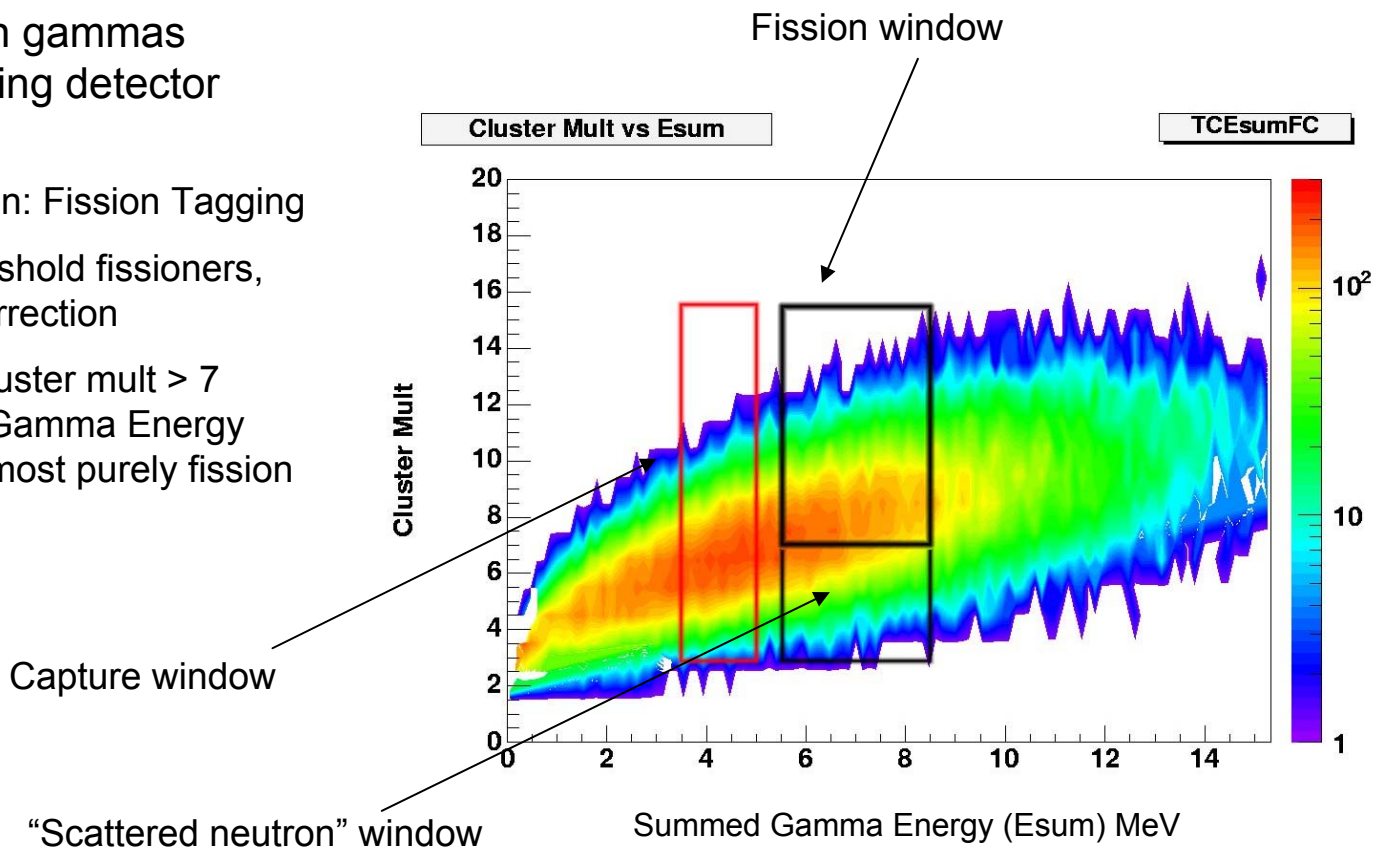
Close-up of PPAC showing removable cathode/target assembly

PPAC Assembly with gas lines and signal cables ready for insertion into DANCE center

Fission correction for fissile nuclides

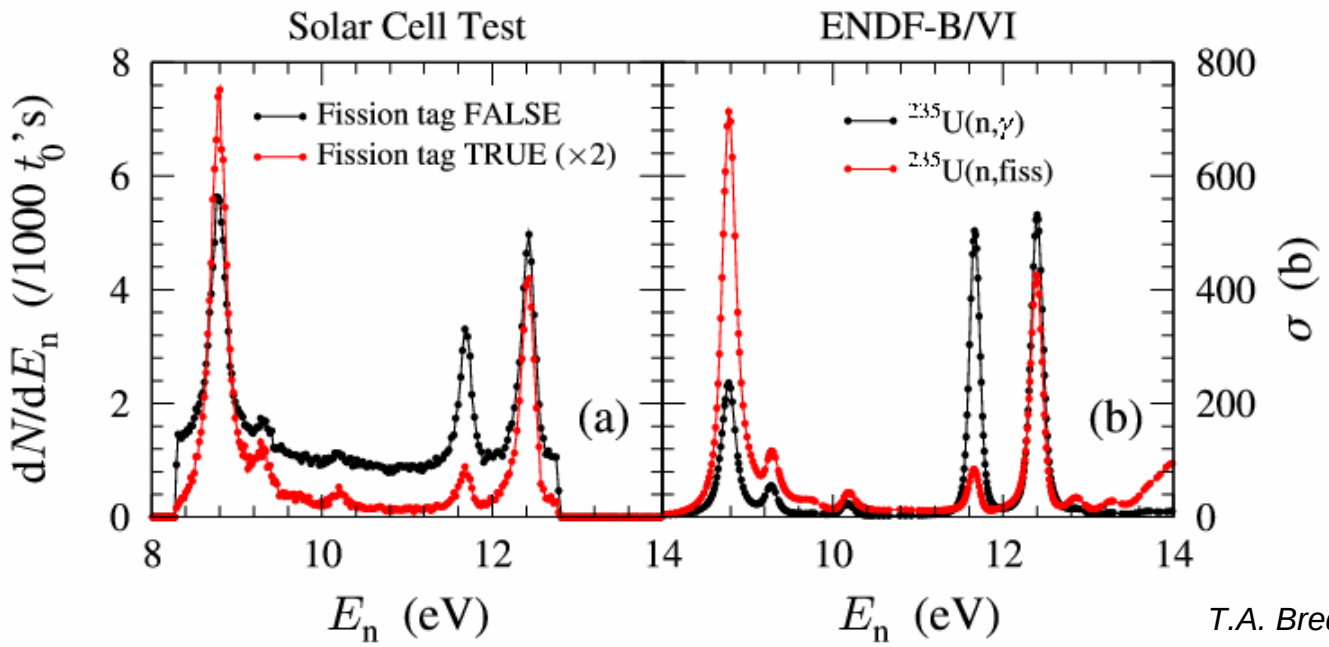
^{235}U fission gammas
Fission-tagging detector

- Best Correction: Fission Tagging
- For many threshold fissioners, can make correction
- Events with cluster mult > 7 and Summed Gamma Energy >6 MeV are almost purely fission



Background from fission gammas can be determined by normalizing ^{235}U spectrum

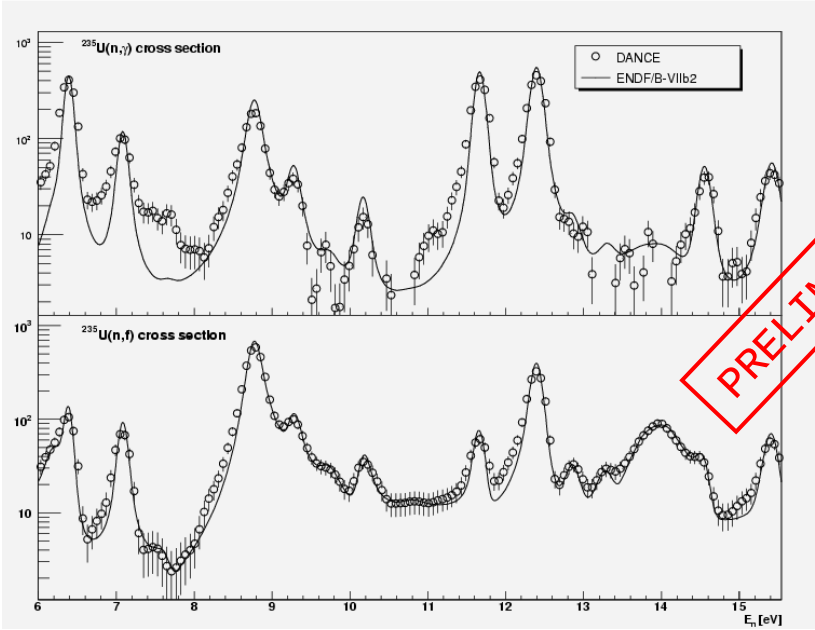
Test measurements with a fission-tagging detector



T.A. Bredeweg, et al.

- **Study:**
  - **Fission-to-capture ratios ("alpha")**
  - **Gamma emission following fission**
- **"Proof-of-principle" experiment used "thin" ^{235}U deposit on silicon solar cell (T. Ethvignot, et al.)**
- **Present: Thin gas fission chamber -- PPAC**

PPAC Detector for Capture and σ_γ/σ_f Measurements



- Target: 460 µg ^{235}U(99.89%) in 0.7 cm deposit (1.2 mg/cm^2) electrodeposited on metalized mylar(flashed with 0.25 µg Ti on deposit side, 0.10 µg on other side)
- (n,γ) data has 5.5 < Esum(MeV) < 7.5, Multiplicity ≥ 4
- PPAC fission tag has 78% efficiency
- (n,γ) corrected for fission by subtracting 0.22 X fission spectrum
- Approximate normalization to ENDF/B-VI resonances

Analysis of DANCE Data is in Progress on Many Nuclides

^{94,95}Mo (S. Sheets, NC State Univ.)

^{143}Nd, ^{149}Sm (P. Koehler, ORNL)

^{152,154,157,160}Gd (W. Parker, Livermore)

^{151,153}Eu (U. Agvanluvsaan, Livermore)

^{151}Sm (R. Reifarth, Los Alamos)

^{203,205}Tl (A. Couture, Los Alamos)

^{235}U PPAC (T. Bredeweg, M. Jandel, Los Alamos)

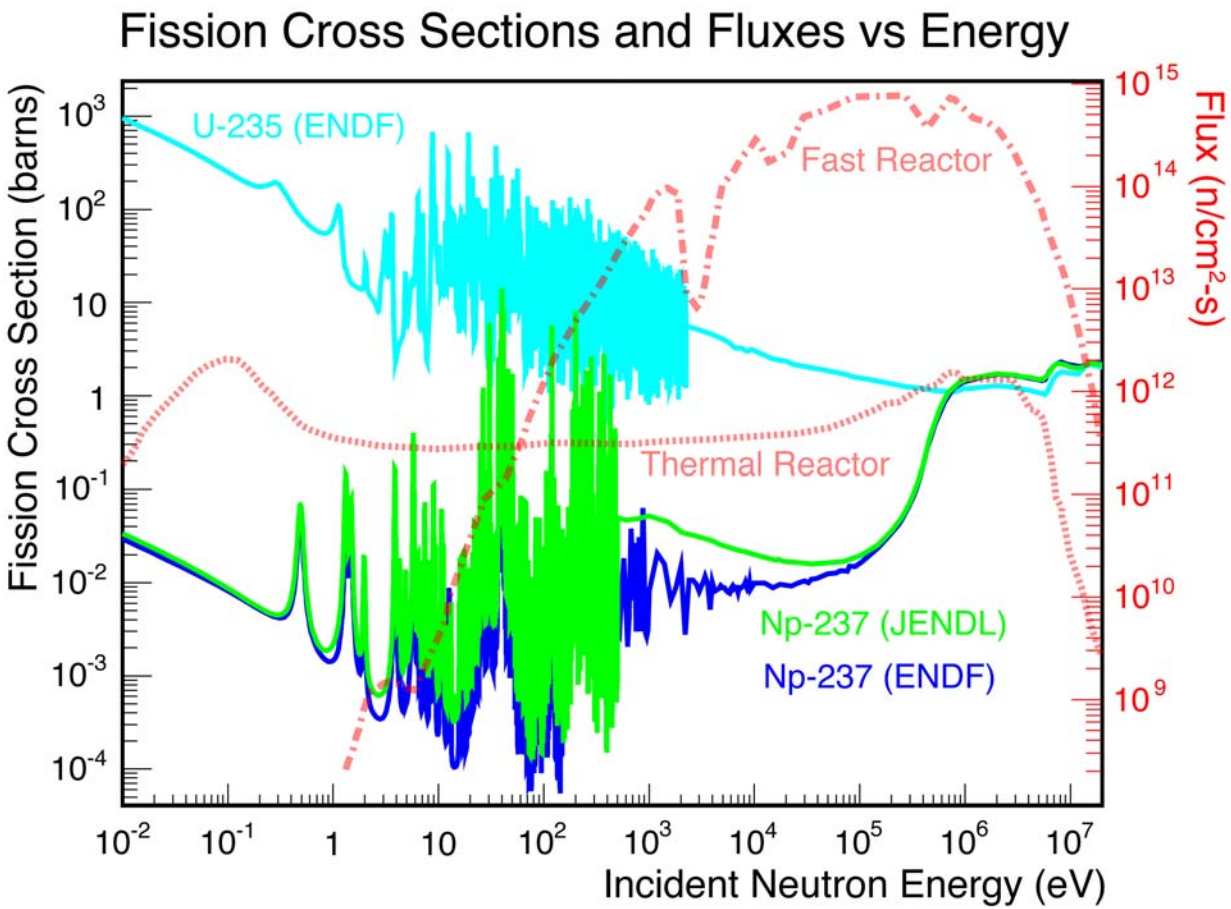
^{240,242}Pu (A Couture, R. Reifarth, Los Alamos)

^{241,243}Am (T. Bredeweg, M. Jandel, Los Alamos)

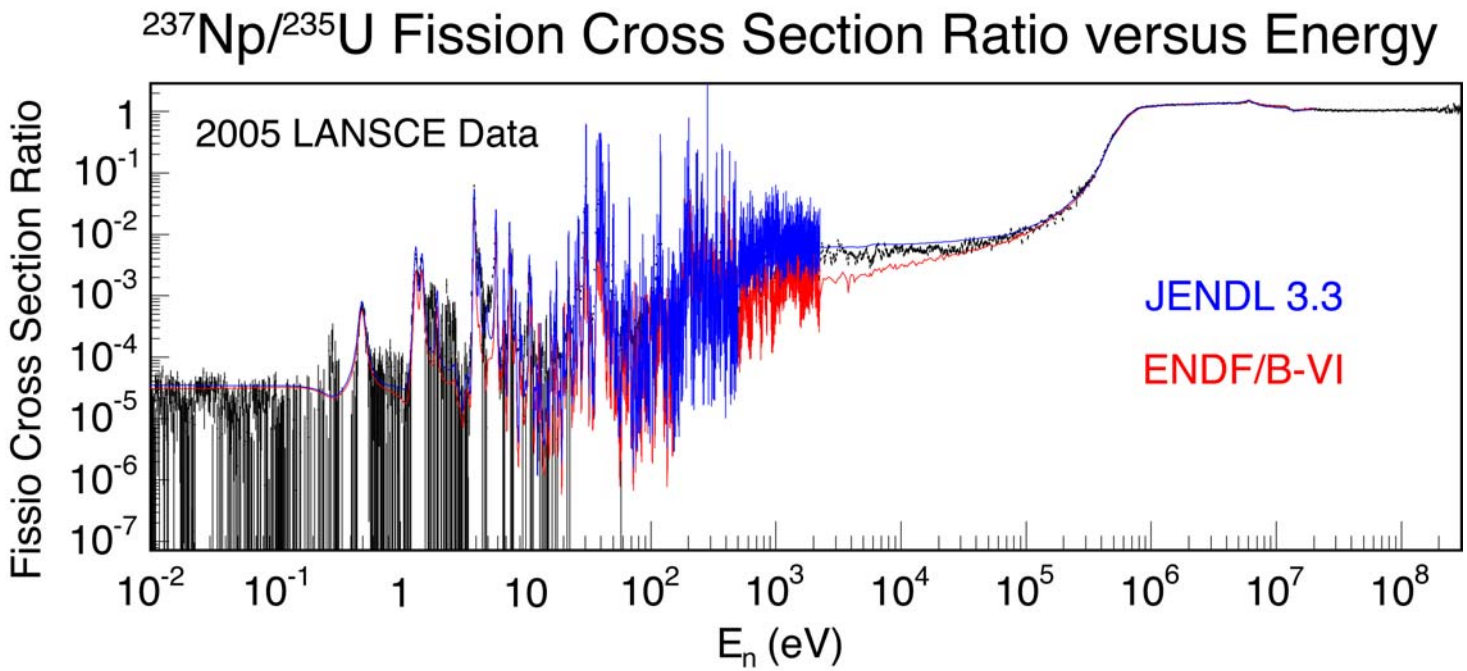
^{242m}Am PPAC (R. Macri, Livermore, M. Jandel, Los Alamos)

Fission Cross Sections

Discrepancies in ^{237}Np(n,f) exist in "fast" region between major nuclear data libraries



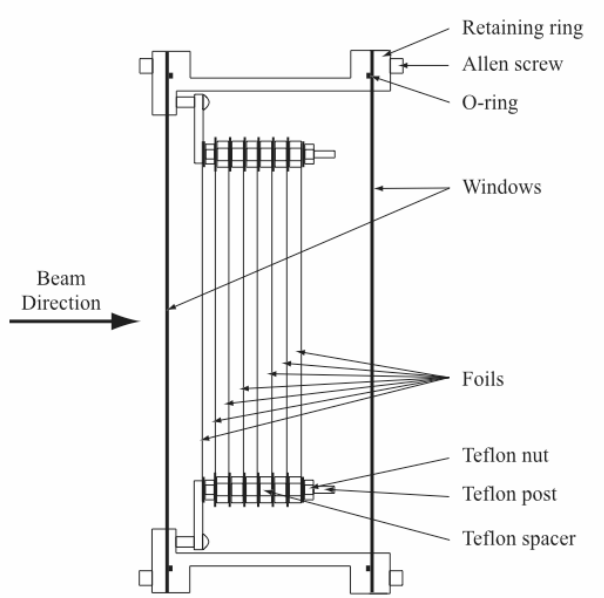
^{237}Np(n,f) is the first completed measurement



Analysis includes detailed covariances (with T-16)

Contacts:
Tony Hill
Fredrik Tovesson

Parallel-plate fission ionization chamber and gridded ion chamber



Parallel plate ionization chamber (PPIC)

- Commonly used for flux monitoring
- Detects on fission fragment per even
- Holds up to 4 samples

Double gridded ionization chamber

- On loan from IRMM, Geel.
- Detects both fission fragments, improving alpha-separation for highly active targets

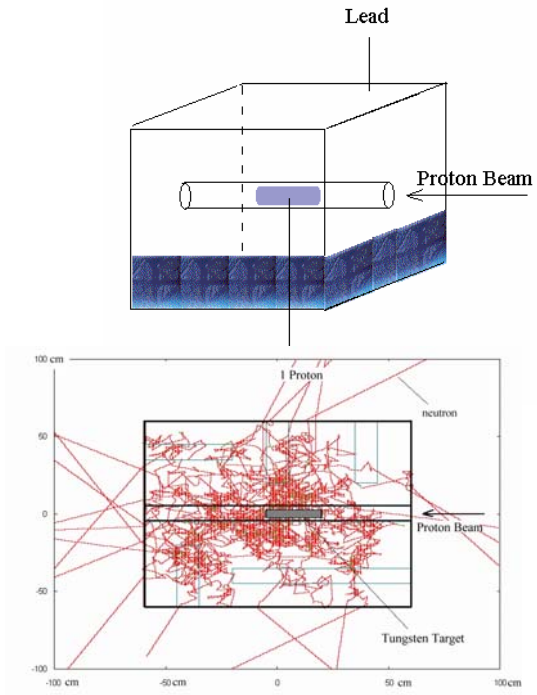
LANSCE fission measurements in the future

- Low energy (Lujan) data have been collected/calibrated for
  - U233, Pu239, Pu240, Pu242 thermal < E_n < 200 keV
- High energy (WNR) data will be taken this run cycle on
  - U233, Pu239, Pu240 and Pu242 100 keV < E_n < 200 MeV
- Complete analyses by summer `07
- Actinides of interest for future fission measurements:
  - Am241, Am242, Am242m, Cm242, Cm243, Np238, Pu238

Fission Cross Sections

On Very Small Samples

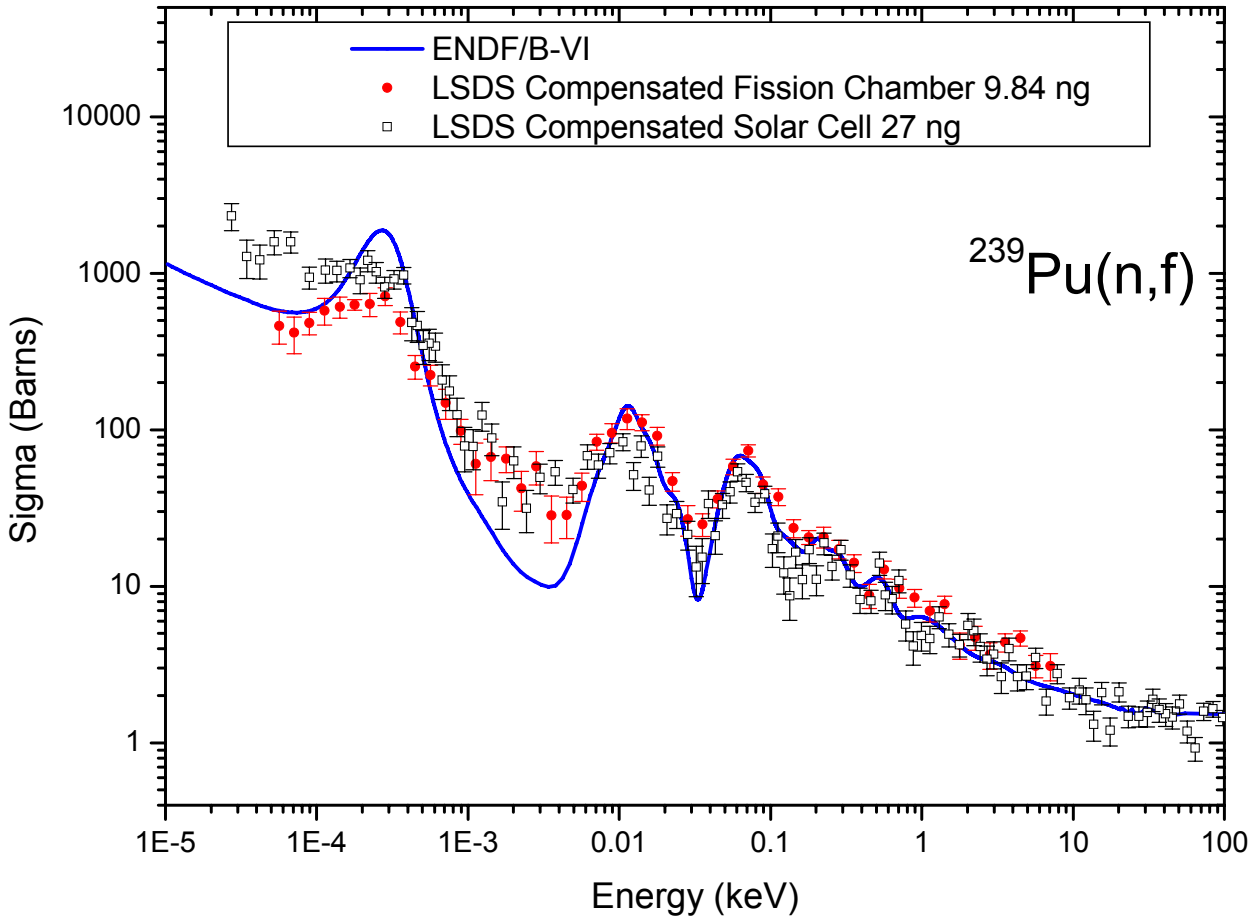
A Lead Slowing-Down Spectrometer is under development, driven by 800 MeV protons from the PSR



Neutron trajectories following the interaction of 1 proton with the tungsten target in the lead cube

Contact:
Bob Haight

With the LSDS, we measured the neutron-induced fission cross section on ^{239}Pu with sub-μg samples



- Sample size of 9.87 ng can be studied
- Good results up to 100 keV
- Still plan to measure fission cross section of ^{235m}U (26 minutes) after solving chemistry challenge

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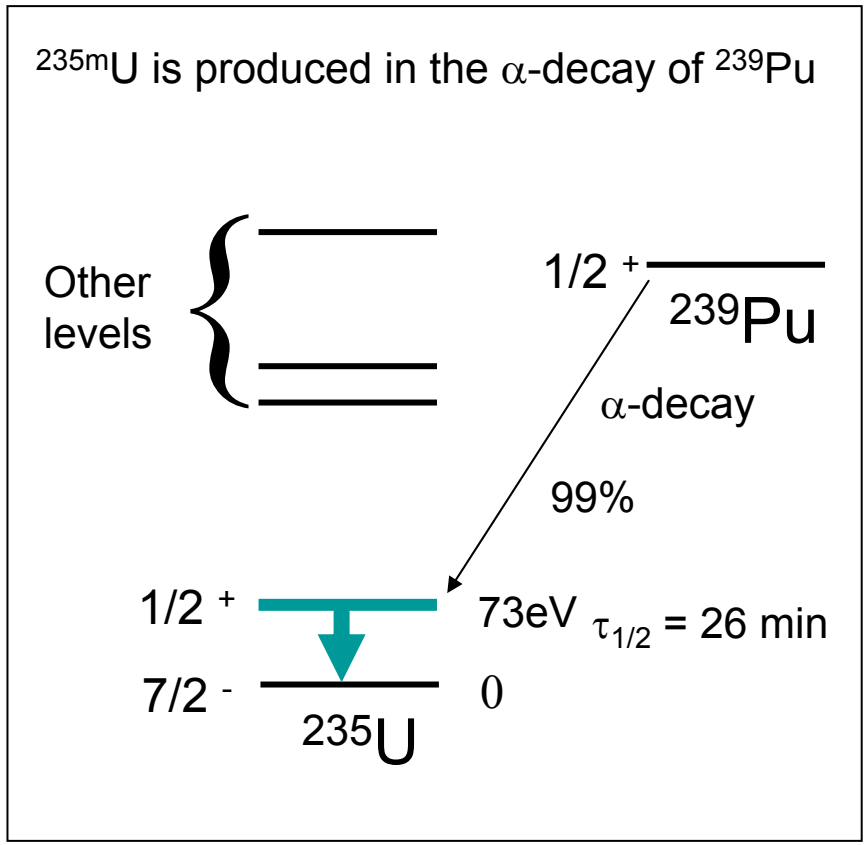
NNSA

First excited (isomeric) state of ^{235}U is produced in decay of ^{239}Pu

- ^{235m}U
  - 26 min half-life
  - 73eV
  - Decays by internal conversion
  - 99% of 239Pu decays populate ^{235m}U
  - 5 gm of Pu will produce 10ng of ^{235m}U
- Fast extraction of ^{235m}U will be required
- To measure this small cross section, it is necessary to increase the neutron flux by using a lead-slowing down spectrometer (LSDS)



Developments at LANSCE

- Technical issues
  - High power amplifier tube availability and quality (Burle 7835)→ problem solved for the present
  - LANSCE-Refurbishment ("LANSCE-R")
- Funding problems (LANL contract → $175M shortfall for this FY) → less running for LANSCE
  - Electricity costs
- Personnel changes
  - Paul Lisowski (former LANSCE Director) to Washington to head GNEP
  - Kurt Schoenberg acting LANSCE Director
- Reorganization of Lab and LANSCE

We address the needs of LANSCE sponsors

- National Nuclear Security Administration
  - Program in radchem cross section measurements
    - Neutron capture cross sections on radioactive targets (DANCE)
    - Cross section measurements on high-order (n,2n), (n,xn) reactions (GEANIE)
  - Program in neutron-induced fission measurements
    - Fission product distributions (GEANIE)
    - Energy output in fission: neutron and γ-ray spectra (FIGARO)
    - Nuclear properties of fission products and isomers (GEANIE and FIGARO)
- Office of Nuclear Energy
  - Measurements in support of the AFCI program include:
    - Capture and fission cross section on actinides
    - Gas production: (n,p), (n,α) reactions in structural materials
- Office of Science
  - Support of SNS in understanding pulsed radiation effects on liquid mercury targets
  - Fundamental physics experiments and nuclear data
- National Resource
  - Nuclear science User Facility for defense, basic and applied research
  - Industrial testing of semiconductor devices in neutron beams
  - University research in nuclear science

The LANSCE program in nuclear data involves many laboratories

- GEANIE – LANL, LLNL , INL, ORNL, Bruyères-le-Châtel, NC State
- FIGARO – LANL, Bruyères-le-Châtel
- N,Z – LANL, Ohio U
- DANCE – LANL, LLNL, ORNL, INL, Colorado School of Mines, FZK Karlsruhe
- LSDS – LANL, LLNL, Bruyères-le-Châtel, RPI
- Fission – LANL, IRMM, LLNL, INL
- Others – MIT, Kentucky, Kyushu, Harvard,…