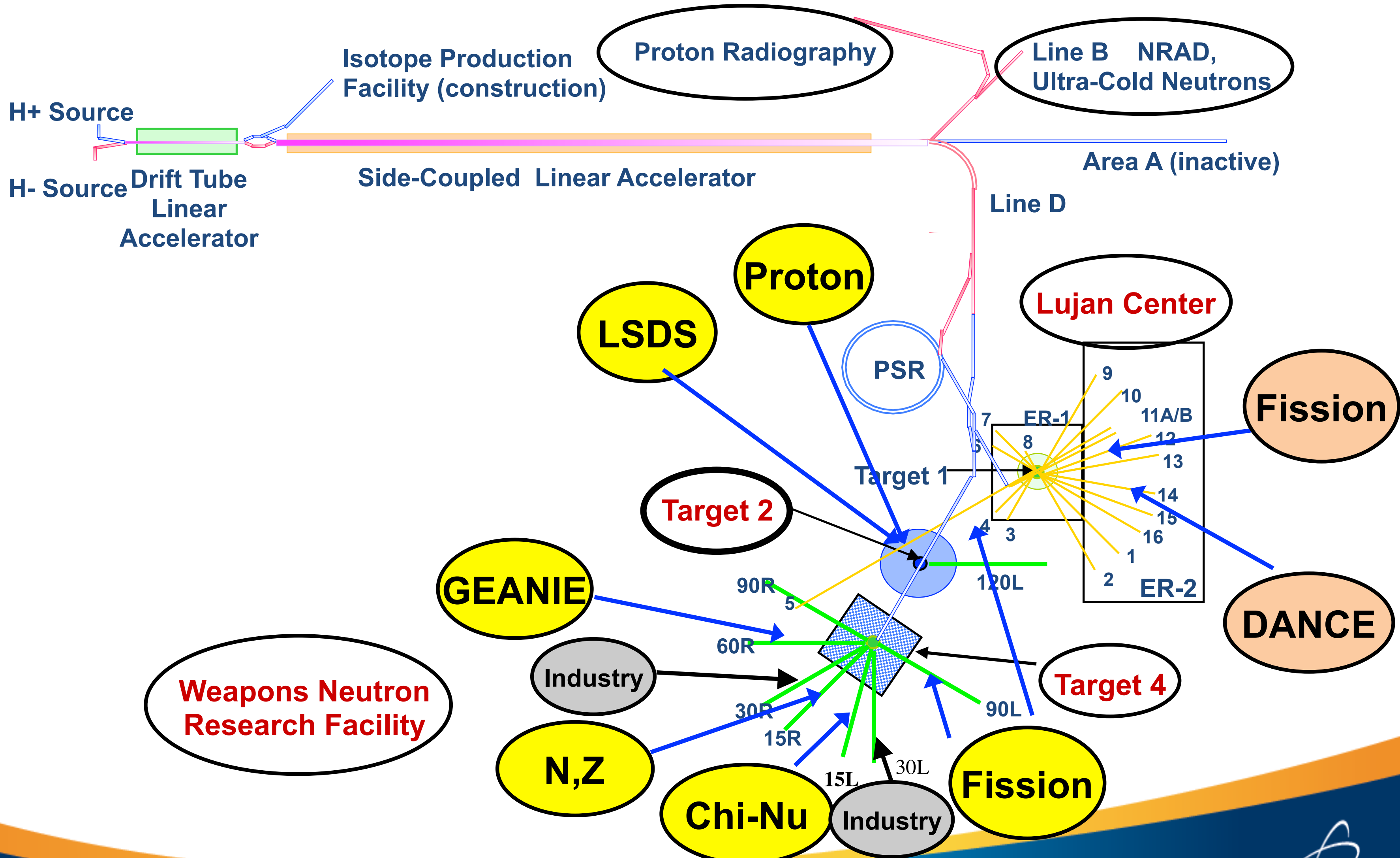
LA-UR-15-28535

Nuclear Data Experiments at LANSCE: Brief Highlights 2015

Robert Haight
for P-27 and colleagues
Los Alamos National Laboratory

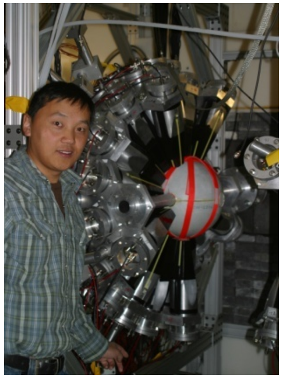
Cross Section Evaluation Working Group Meeting
Brookhaven National Laboratory
November 2-4, 2015

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

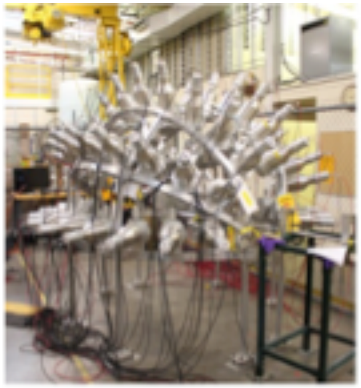


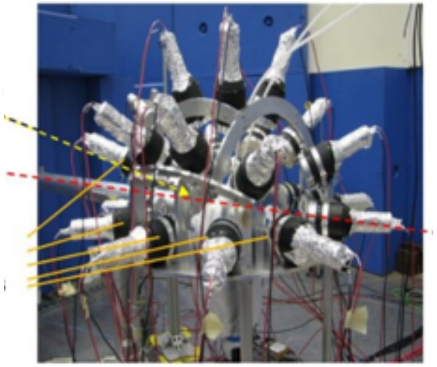
Nuclear data measurements at LANSCE are made with many different instruments

DANCE (n,γ)



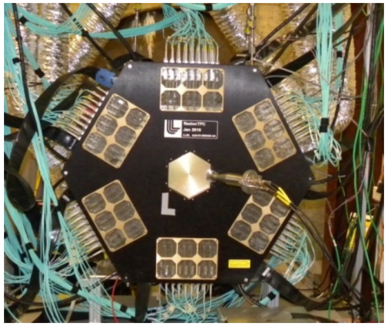
Chi-Nu – PFNS and (n,xn)



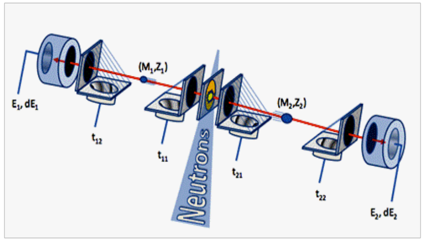


LENZ

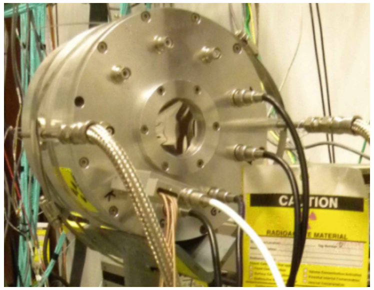
TPC



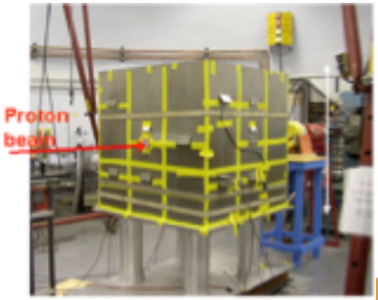
SPIDER



Double gridded ion chamber (IRMM)

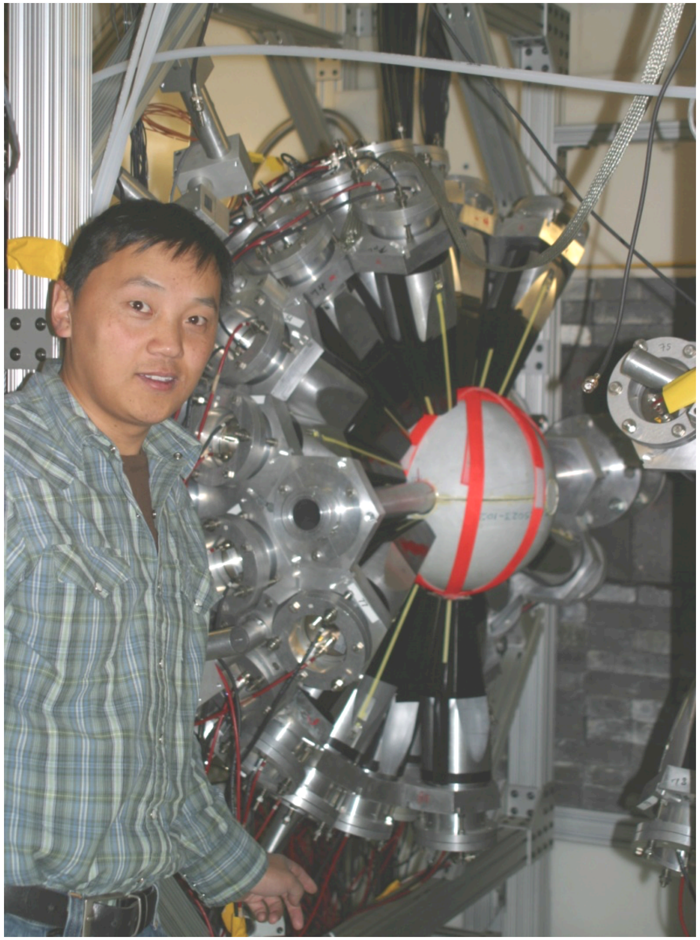


Lead Slowing-Down Spectrometer



Note: GEANIE (n,xγ) is now disassembled

DANCE (n,γ)

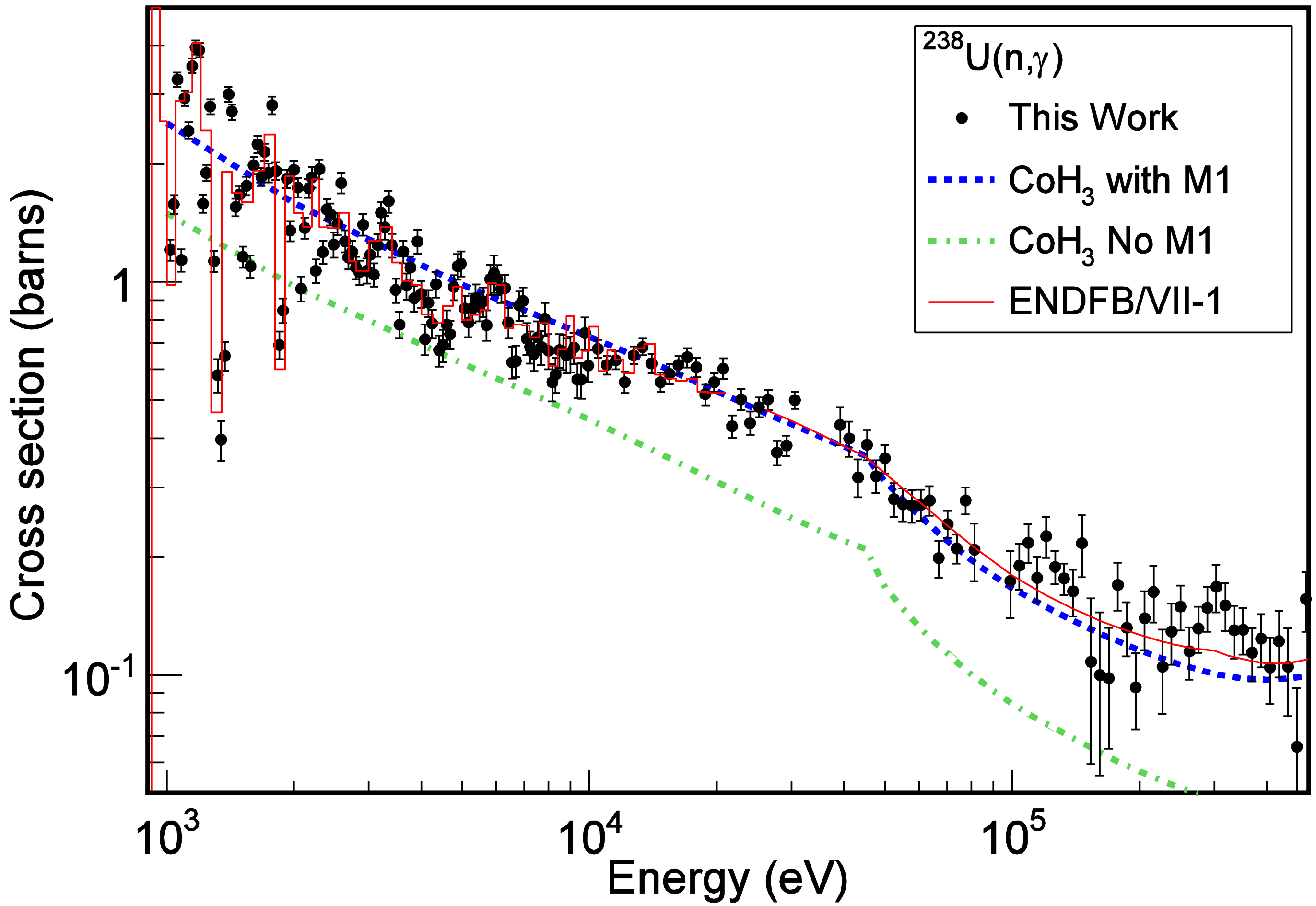


Contacts:
John Ullmann
Aaron Couture
Marian Jandel

Major DANCE Experiments 2014/2015

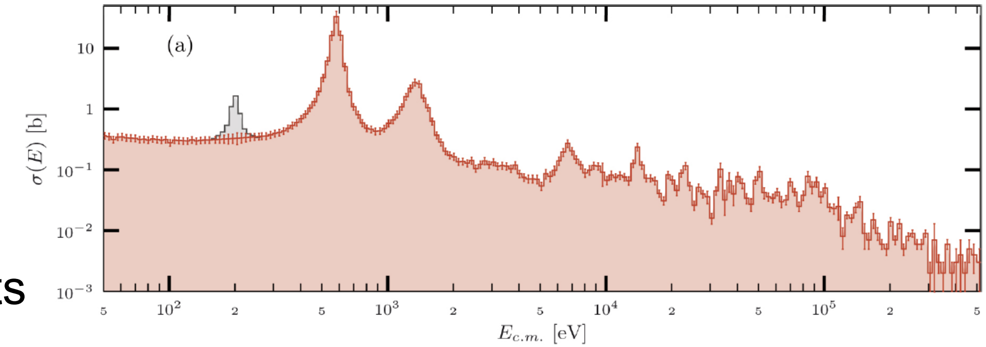
- $^{236,238}U(n,\gamma)$ relative to $^{235}U(n,f)$ – mixed target
  Data > 10 keV (M. Jandel DOE ECR)
- $^{238}U(n,\gamma)$ showing importance of M1 strength
- $^{235}U(n,\gamma)$ capture to isomers (requires fission tagging)
- ^{242}Pu spontaneous fission and (n,f) – gamma-ray spectra (LLNL)
- $^{67,68}Zn(n,\gamma)$ astrophysics (with LSU)
- $^{136}Xe(n,\gamma)$ Double-Beta decay backgrounds and physics (with IU)
- $^{161,162}Dy(n,\gamma)$ Strength functions and resonances (with NCSU, Charles U.)
- $^{173,174}Lu(n,\gamma)$ radioactive samples! (CEA)
- $^{191}Ir(n,\gamma)$ and $^{193}Ir(n,\gamma)$ Capture data > 10 keV

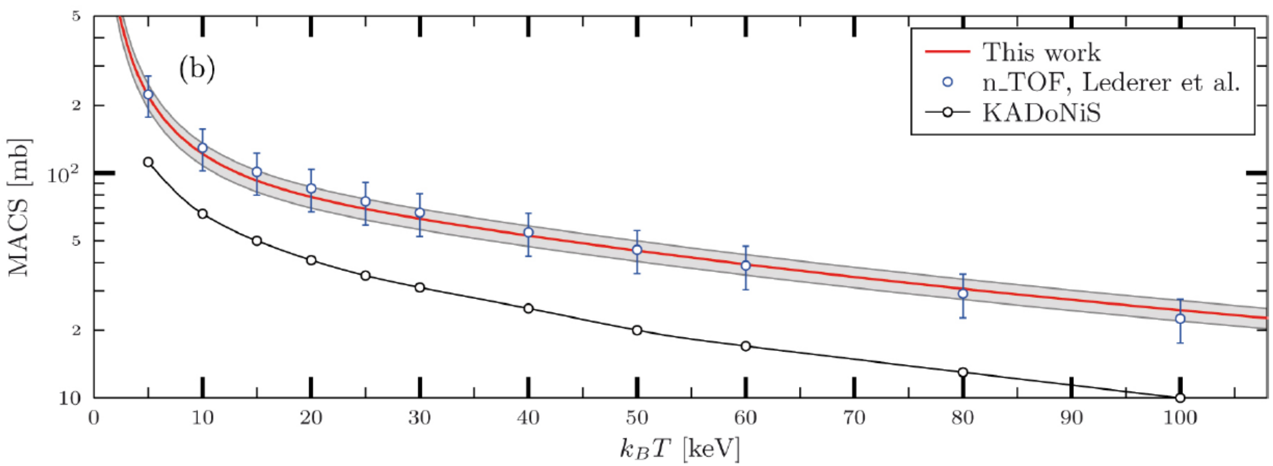
^{238}U capture shows importance of M1 strength



DANCE Measurement of $^{63}Ni(n,\gamma)$

- ^{63}Ni radioactive $t_{1/2}$ = 101.2 y
- The neutron capture cross section was measured up to several 100 keV
- The deduced MACS increased by a factor of 2 from prior predictions
- The new capture cross section results in a 30% reduction in the production of s-only ^{63}Cu in the weak s-process, the primary production site for ^{63}Cu





Data and Figures from Weigand *et al.*, PRC, accepted

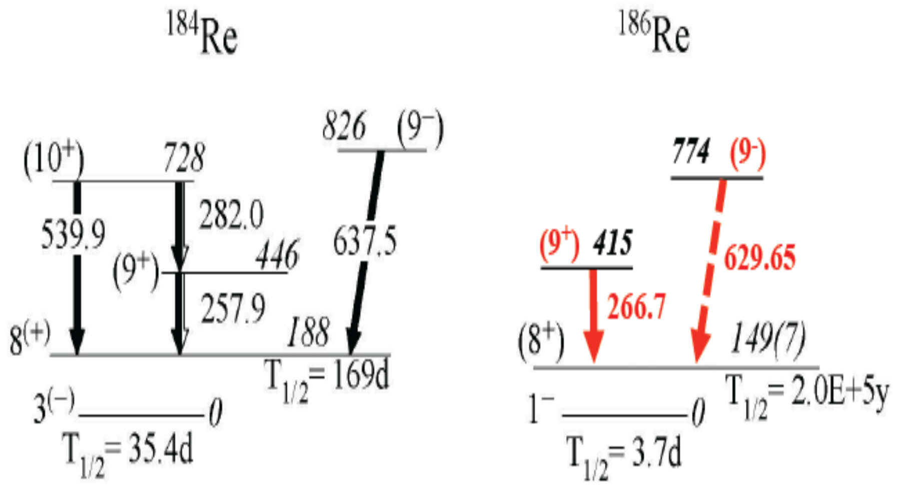
GEANIE $(n,x\gamma)$

Contacts:
Ron Nelson
Nik Fotiades
Matt Devlin

GEANIE is now dismantled but data analysis continues

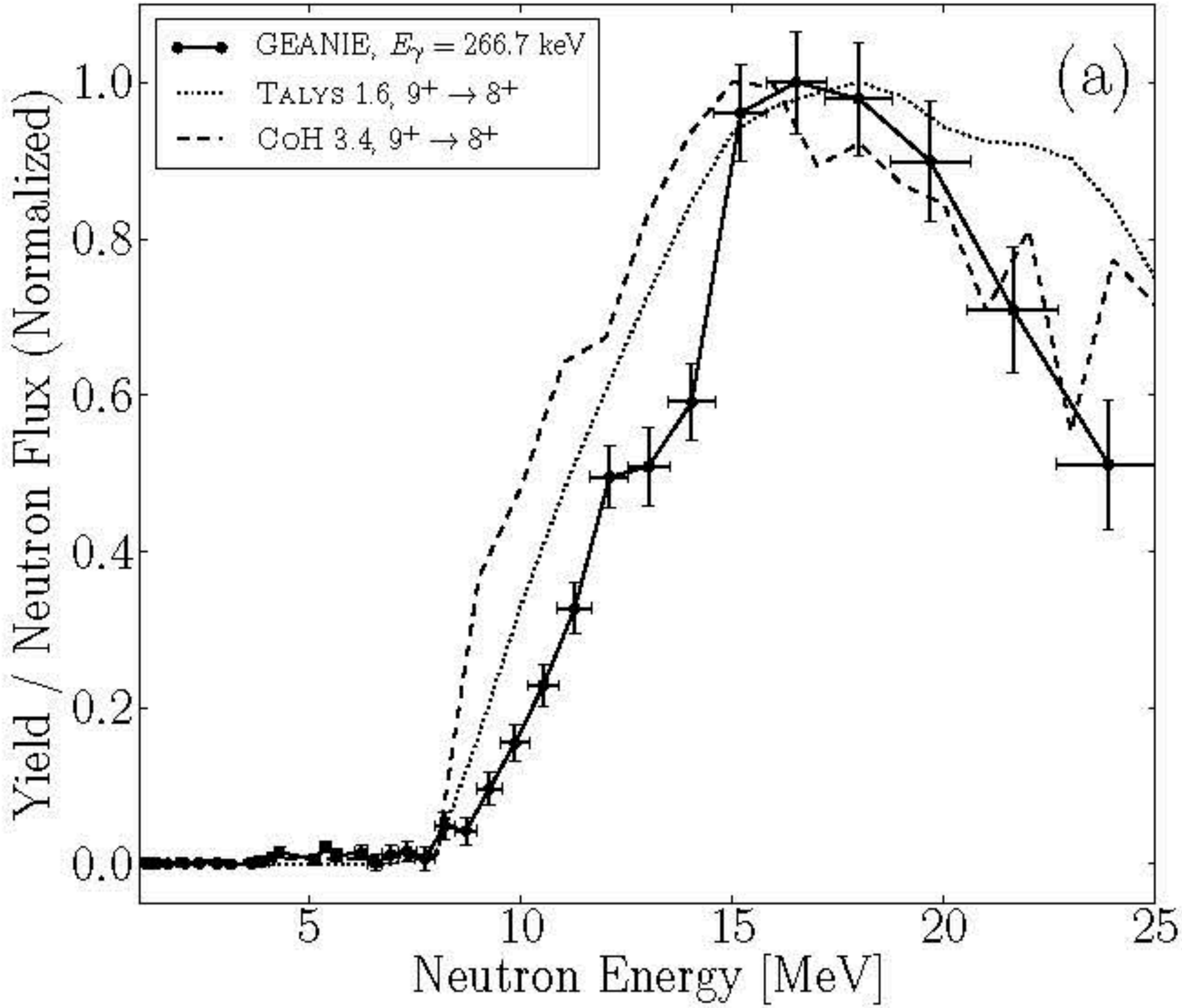
Measurements of (n,x) reactions feeding isomers

- ^{187}Re(n,xn) with Jeff Carroll (ARL) and David Matters (AFIT)



New γ-rays feeding the isomer in ^{186}Re, observed with GEANIE from the ^{187}Re(n,2n) reaction. From D. Matters, Master's Thesis, Air Force Institute of Technology (2015)

Excitation function of transition leading to isomer can be compared with calculations



Other GEANIE measurements

- Population of isomer in $^{109}Ag(n,2n)^{108}Ag$
- $^{136}Xe(n,xn)$ for $0\nu\beta\beta$ backgrounds with Josh Albert, Lisa Hoffman, et al. (IU)
- Neutron-induced γ-ray standard measurements: ^{56}Fe, Cr, B, Ti (n,n') γ-ray comparisons as a function of E_n

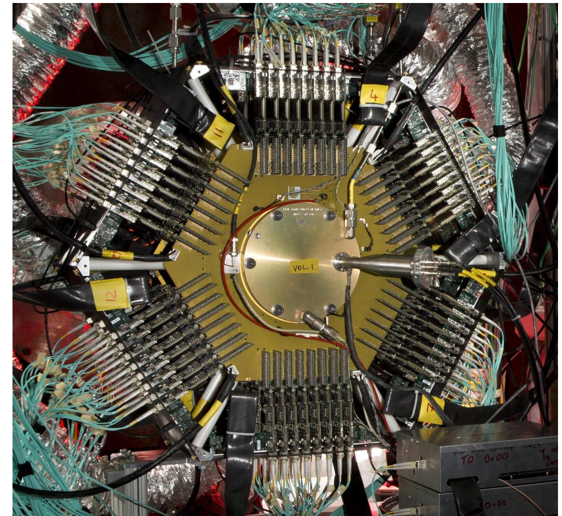
Fission Cross Sections
Fission Product Angular Distributions
Fission Total Kinetic Energy
Fission Product Yields

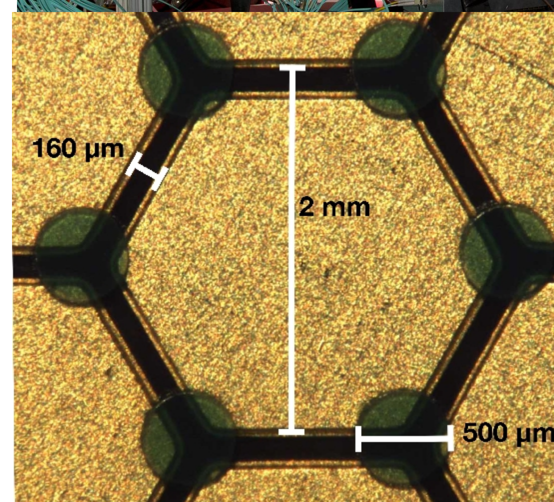
Contact:
Fredrik Tovesson

The NIFFTE TPC

NIFFTE = Neutron-Induced Fission Fragment Tracking Experiment

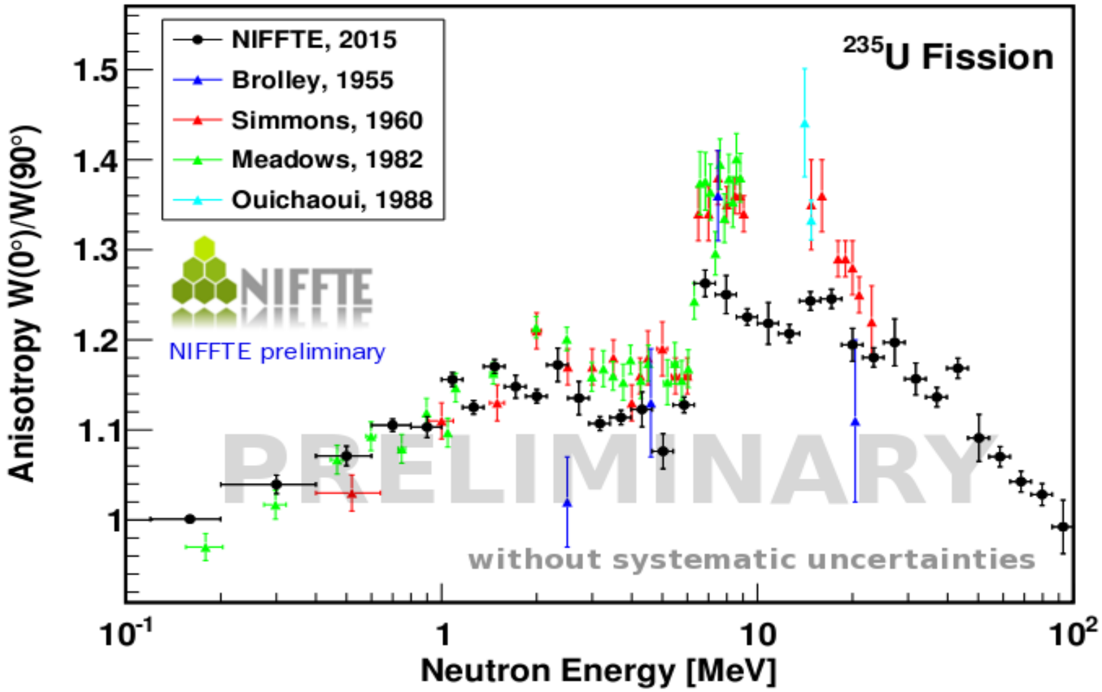
- MICROMEGAS detector
- Segmented anode planes
  - 5952 hexagonal pads
- 3D particle tracking
- ~4π solid angle coverage
- Custom electronics
  - Sustained 60 MB/s





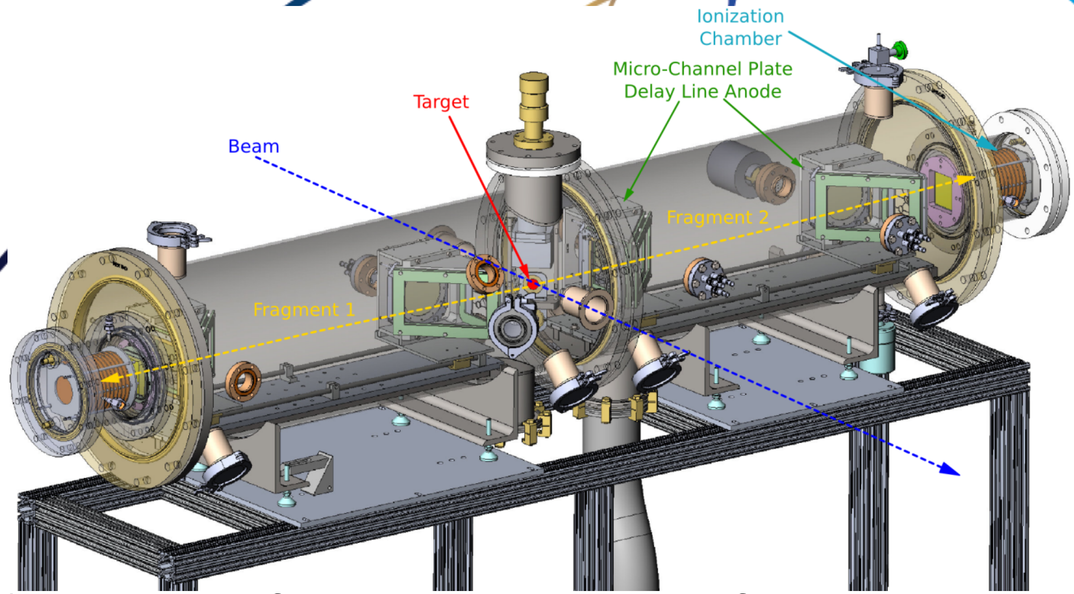
Preliminary ^{235}U Fission Fragment Anisotropy

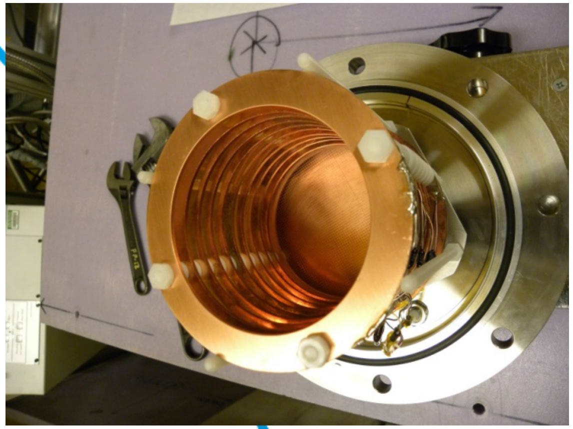
- Thesis work of Verena Kleinrath
- Fit angular distributions bin-by-bin with even Legendre polynomials
- Statistical uncertainties shown
- ^{239}Pu anisotropy analysis ongoing



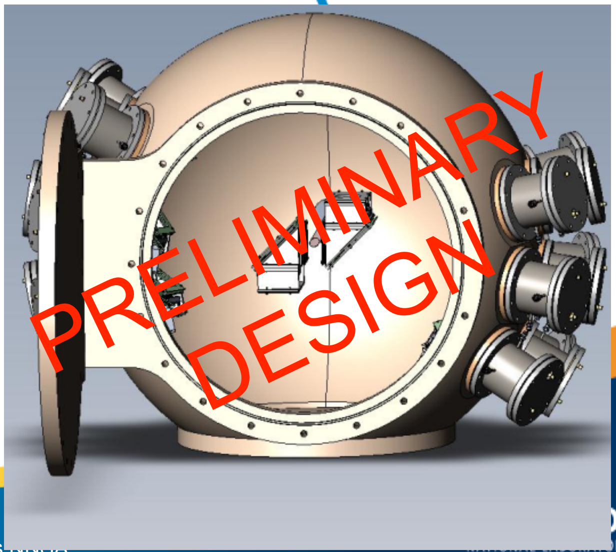
SPIDER Instrument:

SPectrometer for Ion DEtermination in fission Research

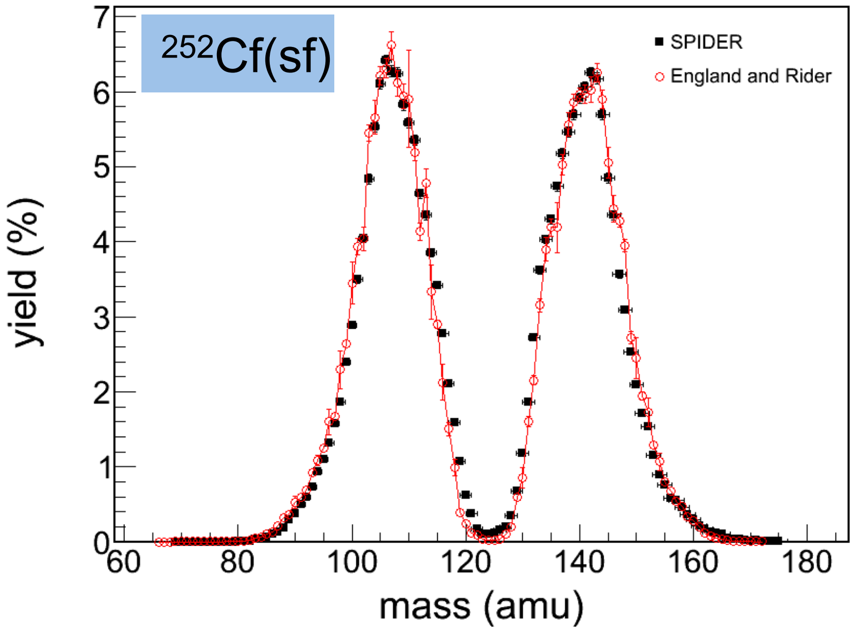


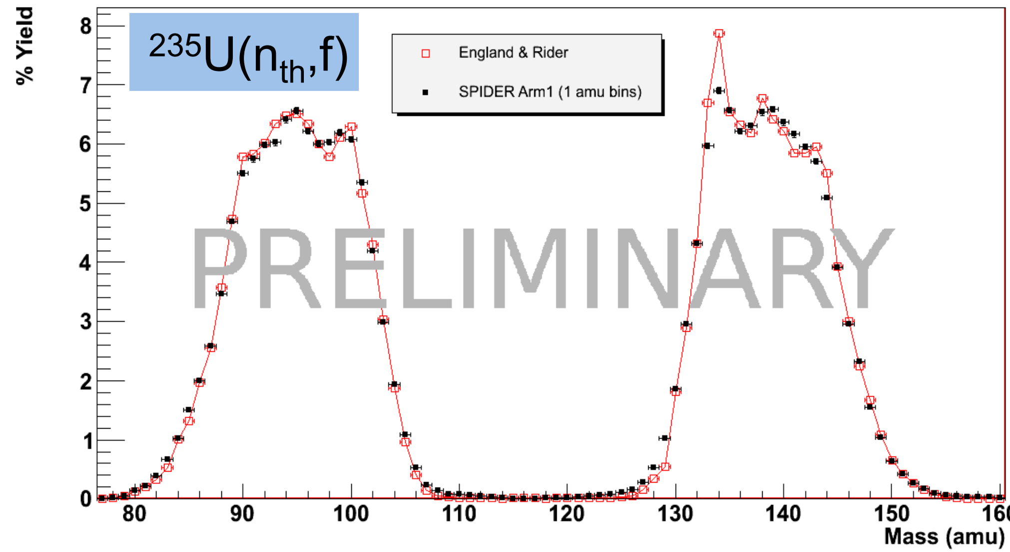


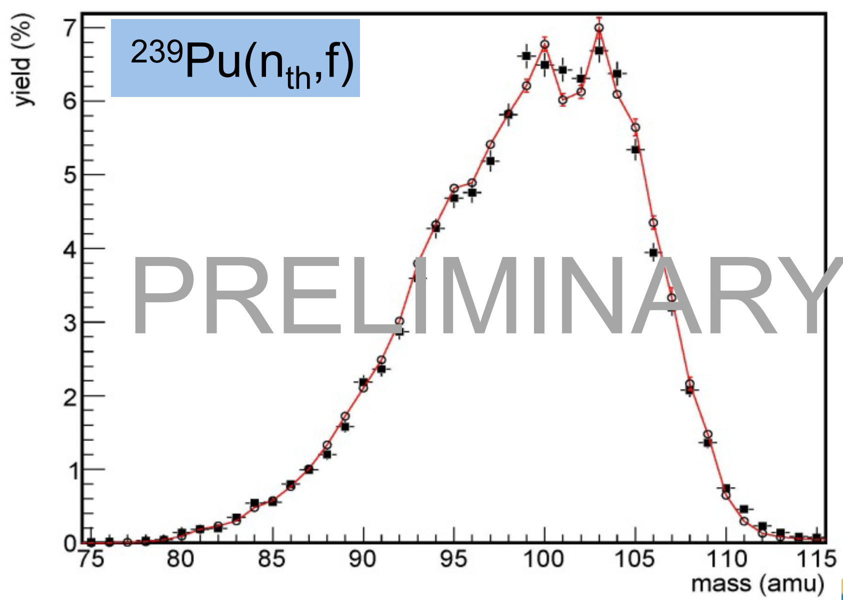
- 2E2v instrument for high mass resolution fission product yields
- Particle energy measured with ionization chambers
  - -200 nm SiN entrance window, isobutane fill gas
- Particle velocity measured with ToF assemblies
  - -Micro-channel plates for fast timing (75 mm diameter)
    - C. W. Arnold *et al*., Nucl. Instr. and Meth., **764**, 53 (2014)
  - - Delay line anode for particle trajectory corrections
- A scale-up beyond the dual-arm will notably enhance detection efficiency and experimental capabilities



Recent SPIDER Fission Product Yield Results







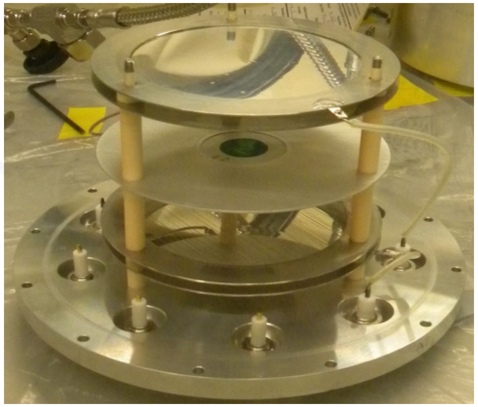
- Experimental data from 2014 – 2015
  - ^{252}Cf(sf), ^{235}U(n$_{th}$,f) and ^{239}Pu(n$_{th}$,f)
  - Comparison to England and Rider Evaluation LA-UR-94-3106, ENDF-349
  - ^{252}Cf results published in NIM: K. Meierbachtol *et al*., Nucl. Instr. and Meth., **788**, 59 (2015)

TKE and mass distributions with an Frisch-gridded ionization chamber

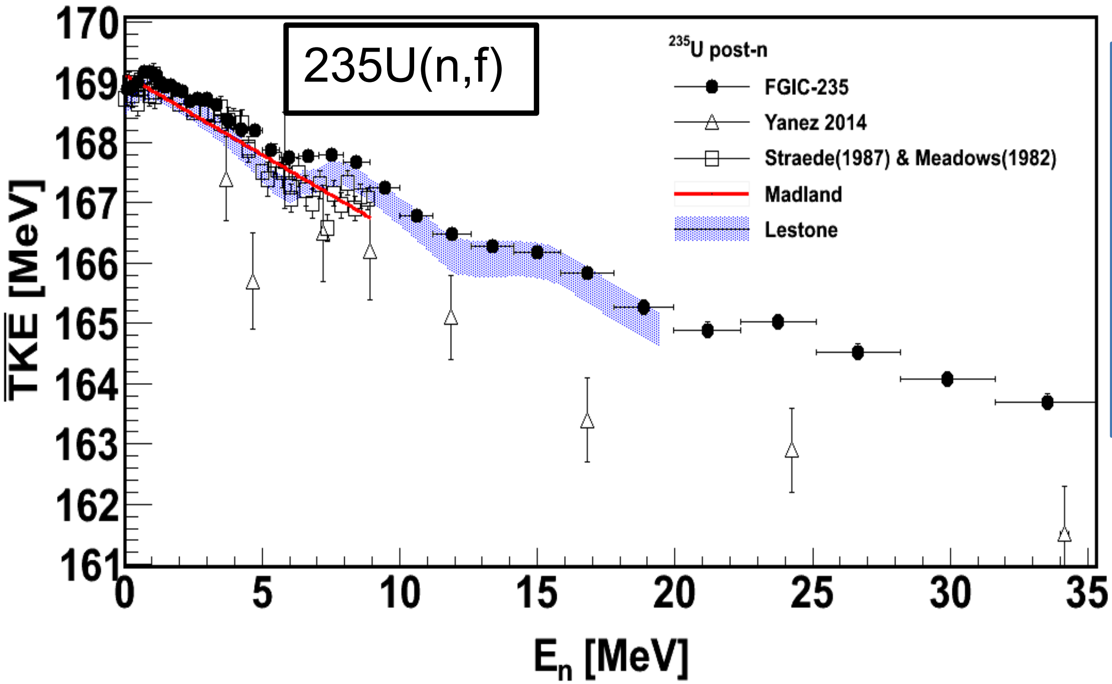
- The FGIC has been optimized for fission measurements.
  - ~0.5% energy resolution
  - 4-5 AMU mass resolution (using 2E method)

<u>Experiments</u>

- 2012 : ^{238}U (TKE and mass) [**D. Duke,** Ph.D. Thesis, Nov. 2015]
- 2013 : ^{235}U (TKE and mass) Publications in progress.
- 2014 : ^{239}Pu (TKE) [**Meierbachtol, K. et al.**, Publication in process.]

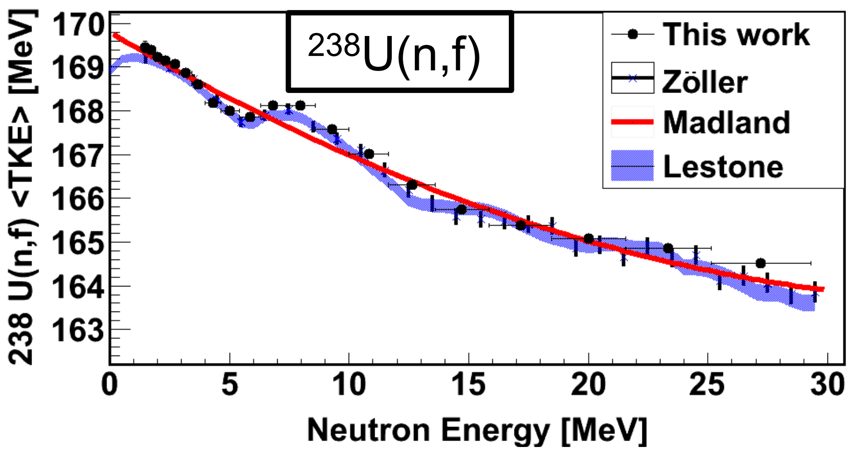


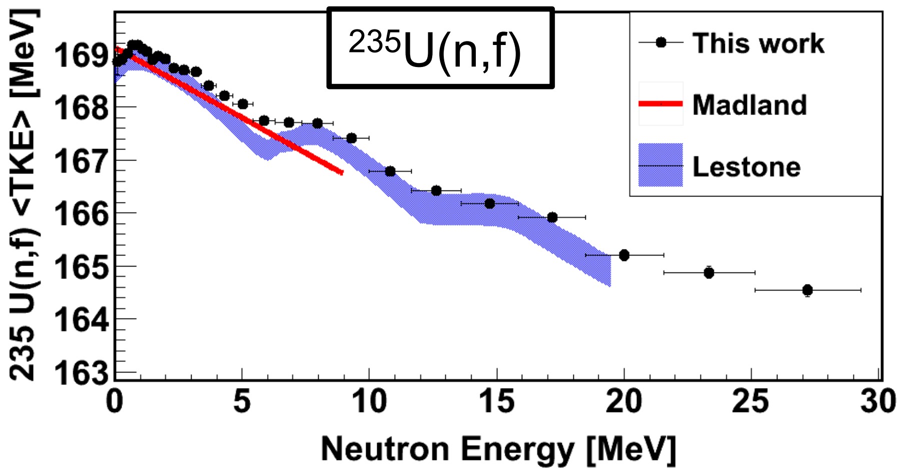
[**S. Mosby et al.,** *NIM A.* 2014, 757, 75]

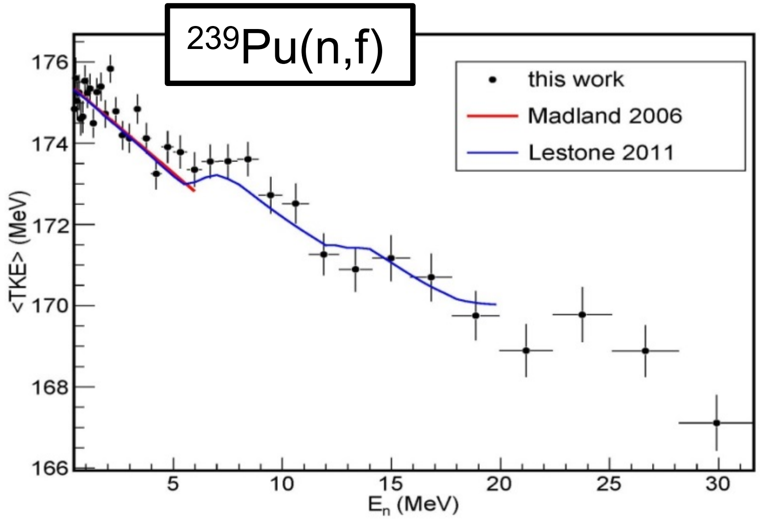


- TKE shape validates model.
- 235U Data exhibit the turnover behavior at low E_n = 0 - 3 MeV.
- Structure corresponding to multichance fission thresholds.

TKE experimental results are consistent with calculations by Lestone et al.

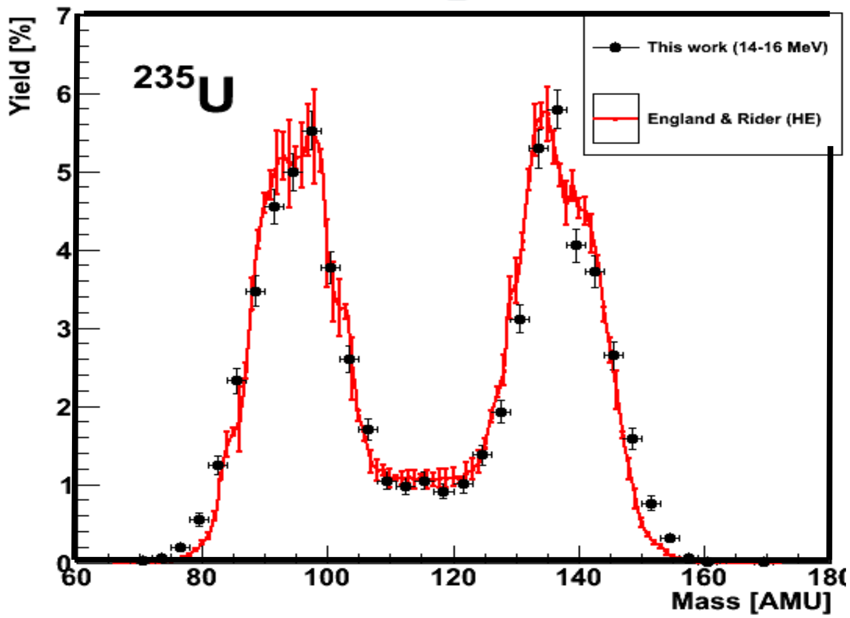




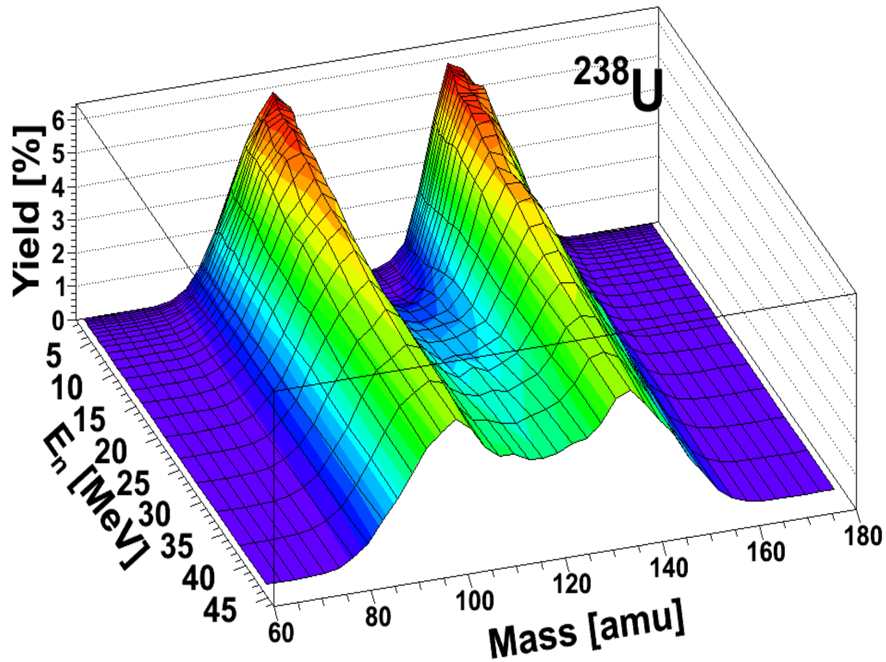


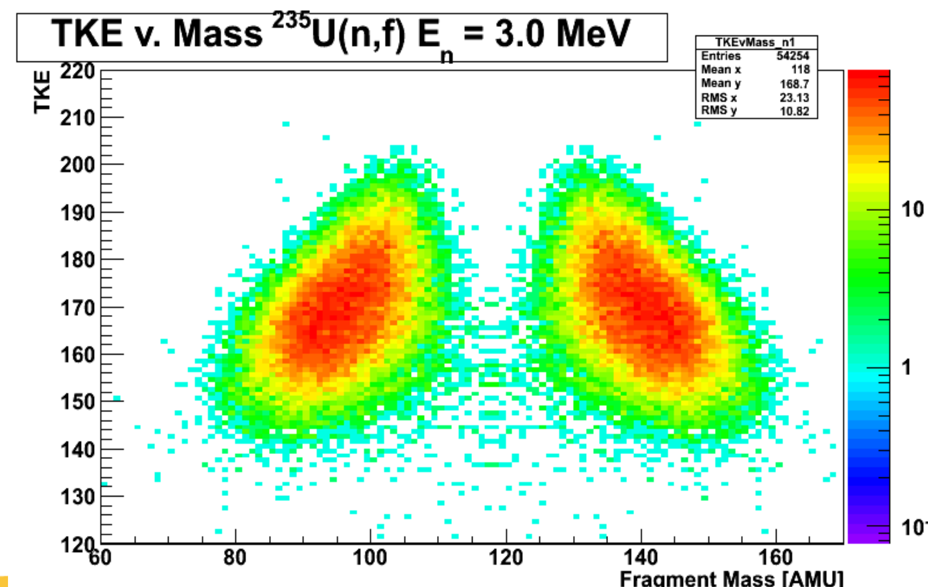
- **Zöller data for U-238 extends > 30 MeV**
  - For U-235 no previous data above 9 MeV
  - For Pu-239 no data beyond 5 MeV
- **Madland evaluation is fit to experimental data**
  - Not intended for extrapolation
  - ENDF values for 14 MeV never the less are extrapolations
- **Semi-empirical modeling by Lestone et al. in close agreement with new data**

Mass Distributions



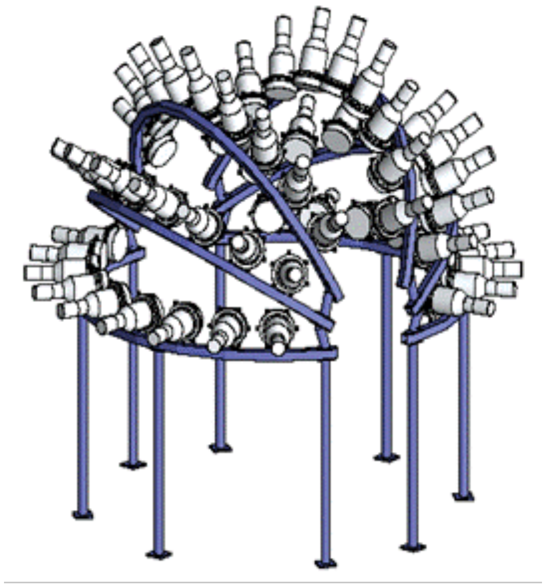
[England, T. R. & Rider, B. F. ENDF-349. October 1994]

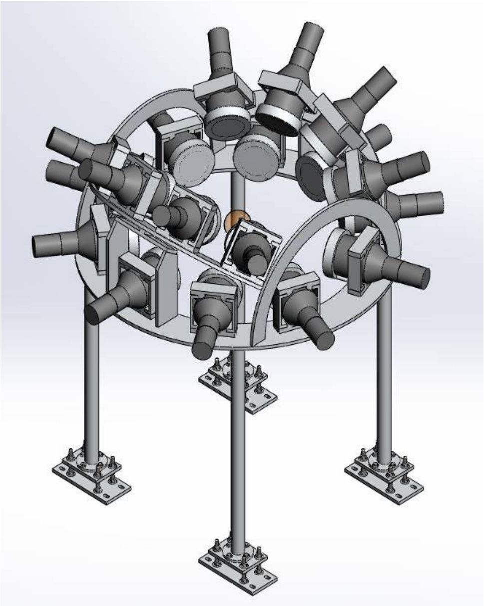




- Fission fragment mass distributions for 238U and 235U are available at for a wide range of Einc.
- Correlated mass and energy information is also available.

Chi-Nu - Prompt fission neutron spectra





Contacts:
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LLNL:
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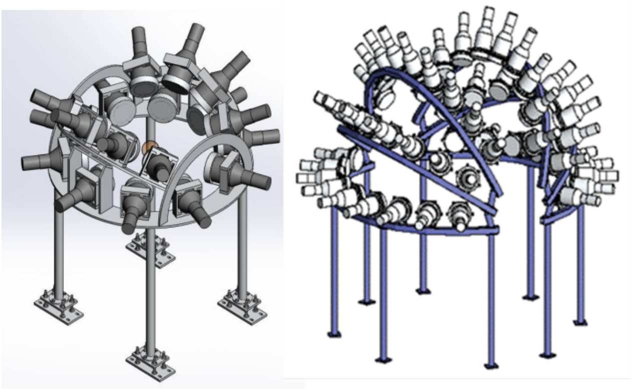
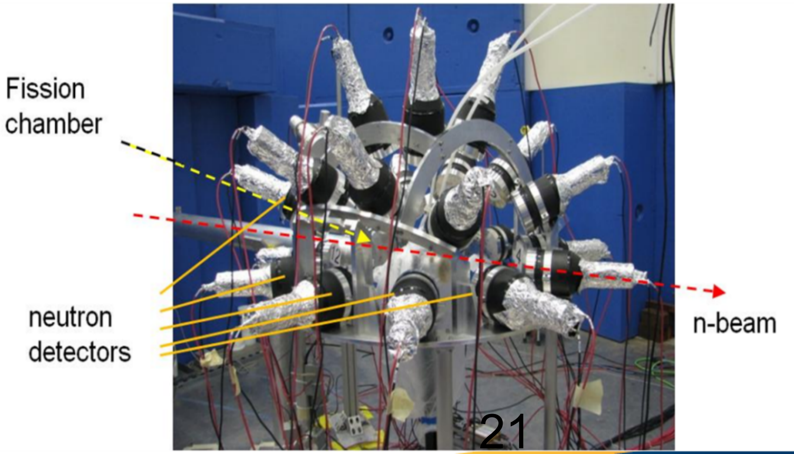
Approach – fast fission counter, two types of neutron detector arrays to cover fission neutron energy range

- WNR/LANSCE spallation neutron source – all neutron energies from 0.5 to 30 MeV and higher
- New building from LANS support
- Double time-of-flight
  - LANSCE spallation source to fission chamber → incident neutron energy
  - Fission chamber to neutron detector → fission neutron energy
- Multi-year project – thru FY2017
- Goal: a significant result for stockpile stewardship (i.e. with respect to the current nuclear data evaluations)

LLNL fission chamber

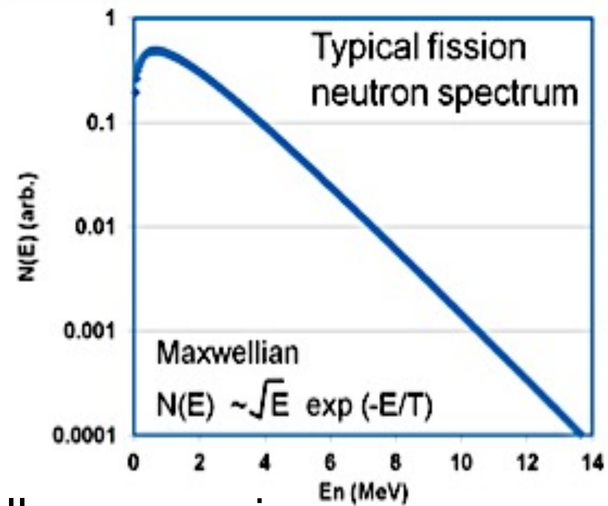
Two LANL neutron detector arrays

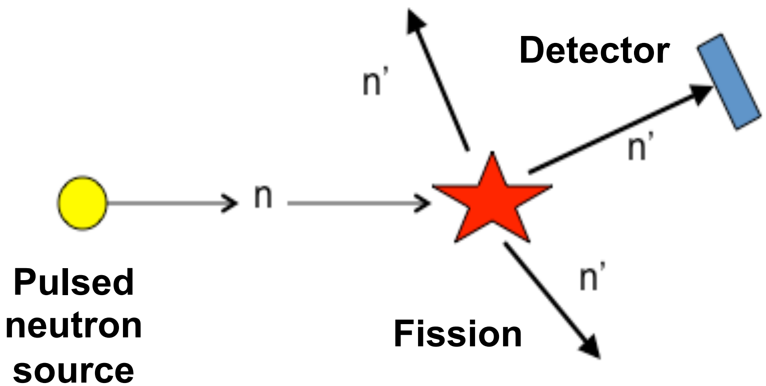




Measuring fission neutron spectra by time of flight is straightforward in principle

- Detect fission
- Measure PFNS by time of flight to a detector
- We also measure incident neutron energy by TOF

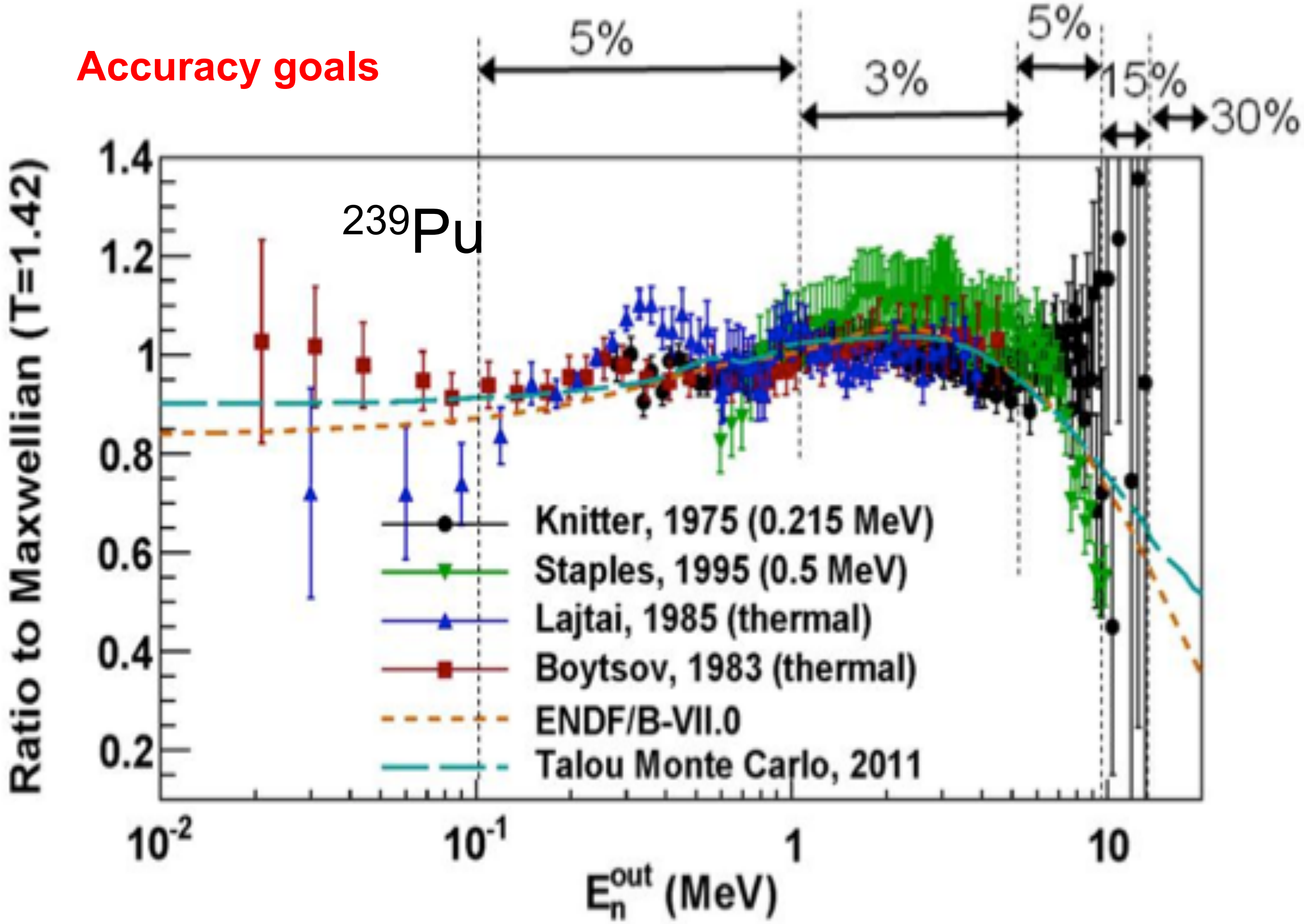




Challenges are in:

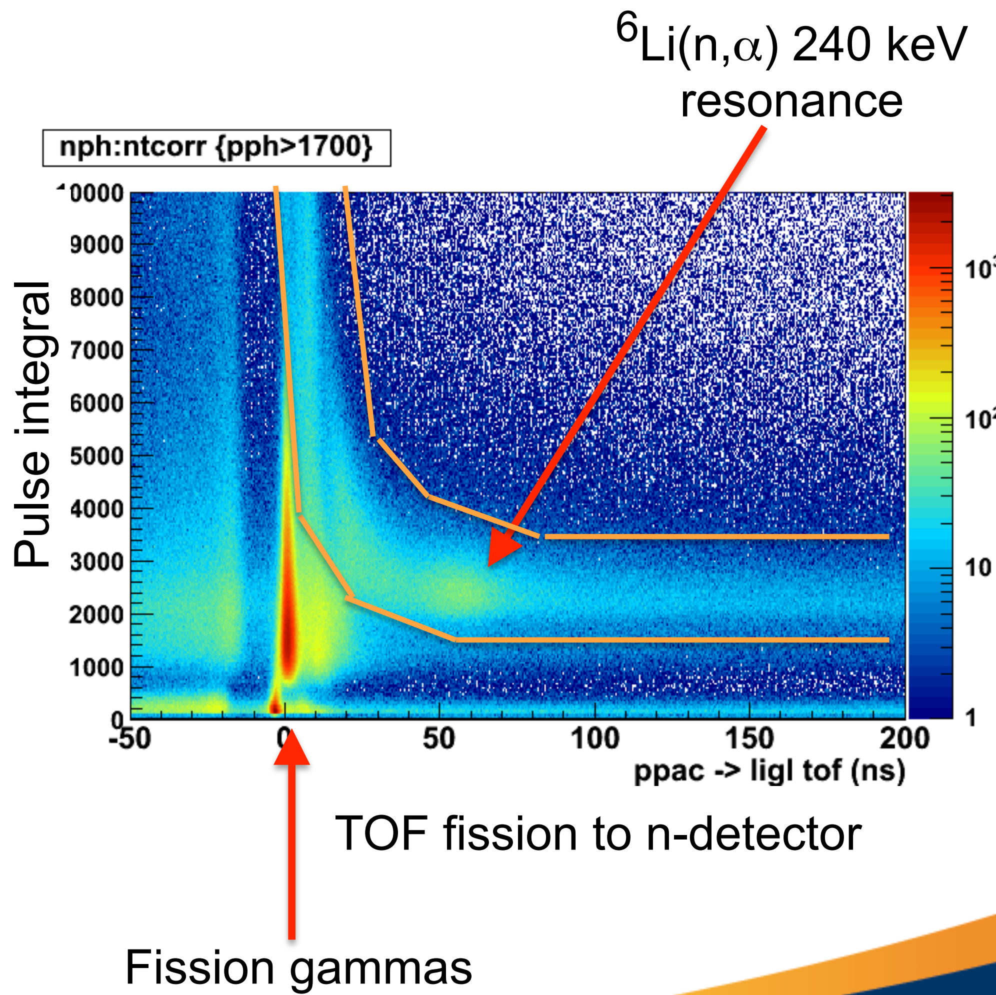
- neutron scattering
  - fouls up path length
  - neutrons scatter to lower energy
- detector response (efficiency 5-30%)
- few neutrons at high energies
- n-gamma separation
- good timing (ns)

Goal for Chi-Nu is measurements that will impact evaluations – shape and uncertainties



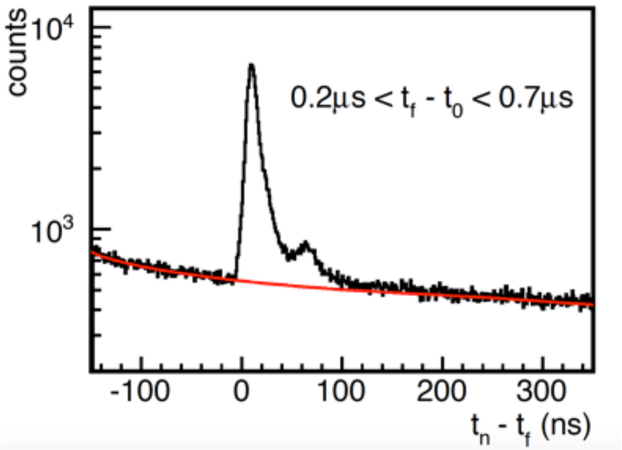
^{6}Li-glass neutron detectors give pulse-height versus time of flight from the fission counter to the detector

- Reaction: ^{6}Li(n,alpha)^{3}H
  Q-value = 4.8 MeV
- Efficiency good at low En
- Good separation of neutrons and gamma rays for low En

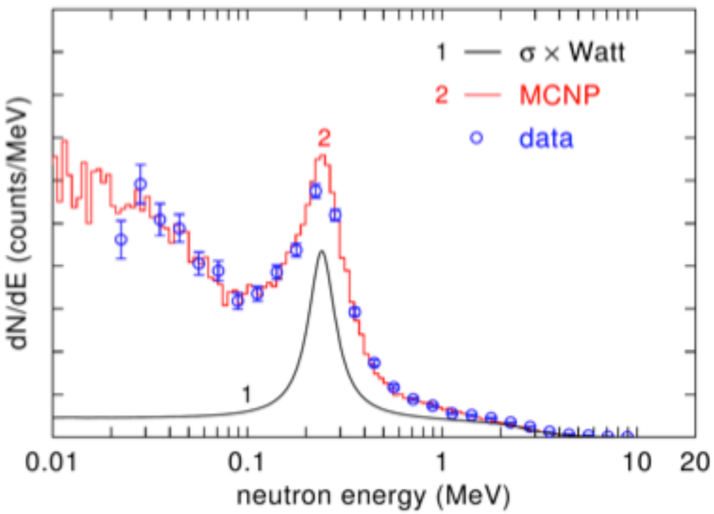


Then we need to subtract background and transform to "equivalent" fission energy

TOF- Bkg

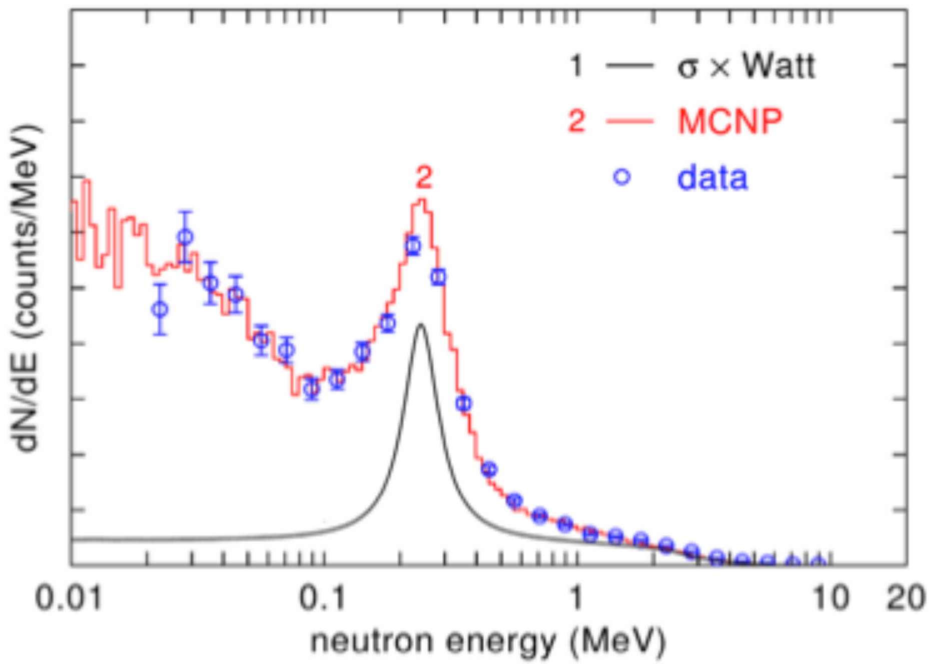


"Equivalent" fission energy

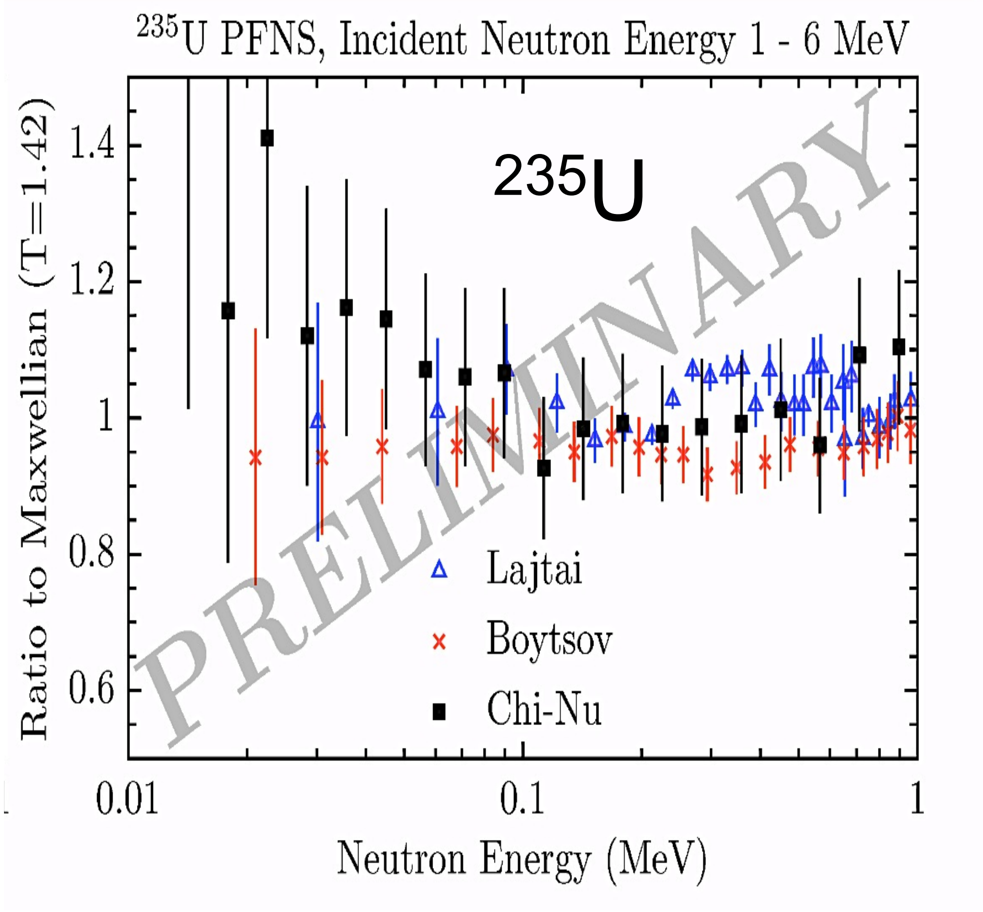


3 ways of analyzing data

- "Ratio of ratios" → correction factor → preliminary results
- Unfolding – next step
- Forward analysis – "best", calculationally intensive

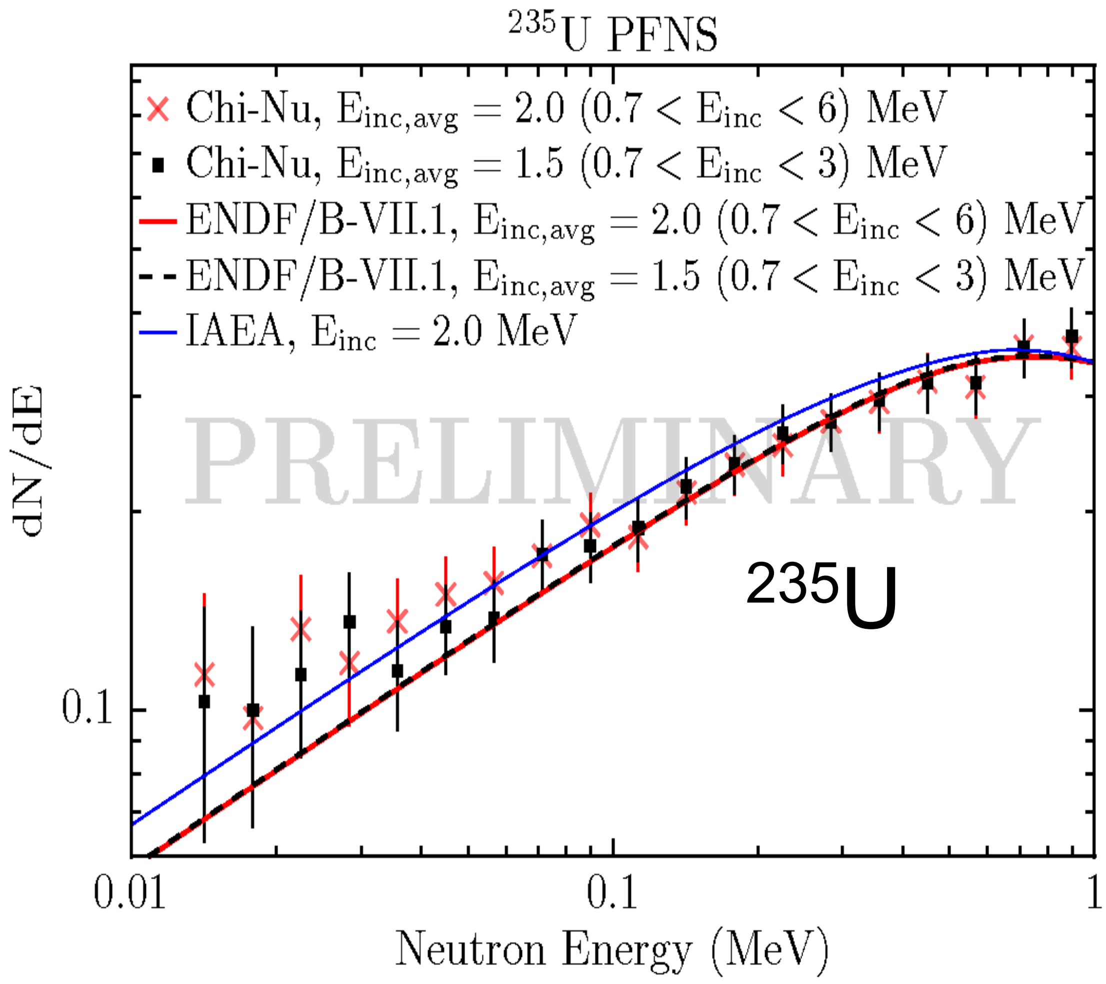


First, preliminary results on low energy part of PFNS for ^{235}U(n,f) can be compared with literature values



- MCNP calculations moved to High Performance Computers
- Results good down to 0.1 MeV (our goal) and probably even lower
- Error bars include both statistical and systematic errors
- General agreement with data taken at thermal energy

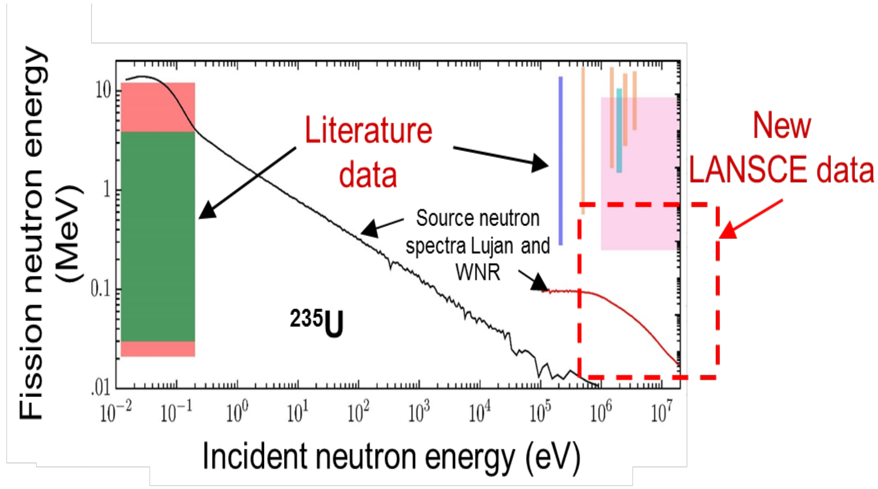
The preliminary results for ^{235}U compare rather well with evaluations

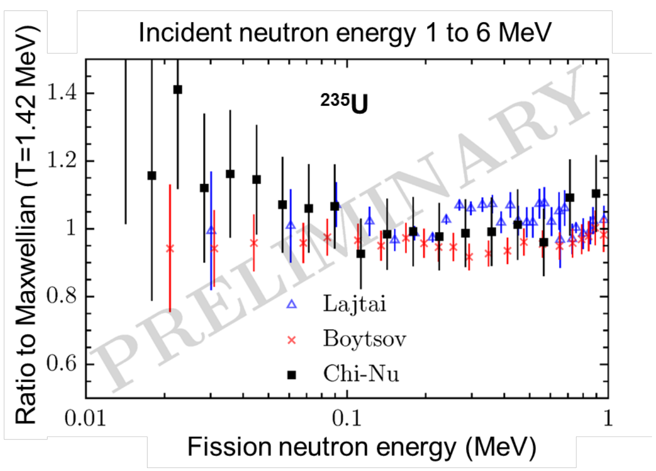


No significant discrepancy with evaluations for ^{235}U from our ratio-of-ratios analysis

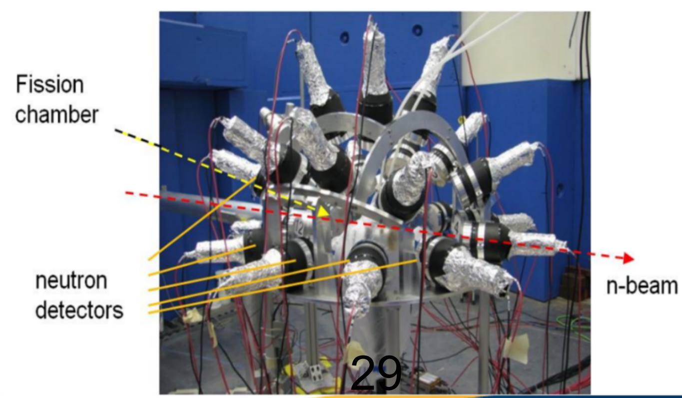
Prompt Fission Neutron Spectra Measurements at LANSCE obtain data in previously unexplored region

- New region of PFNS for fission induced by fast neutrons (above thermal) for $^{235}U(n,f)$.
- Measured PFNS ~ 50 keV to 1 MeV
- Preliminary analysis shows reasonable agreement with literature data obtained at thermal energy
- Next is full analysis of ^{235}U and then ^{239}Pu

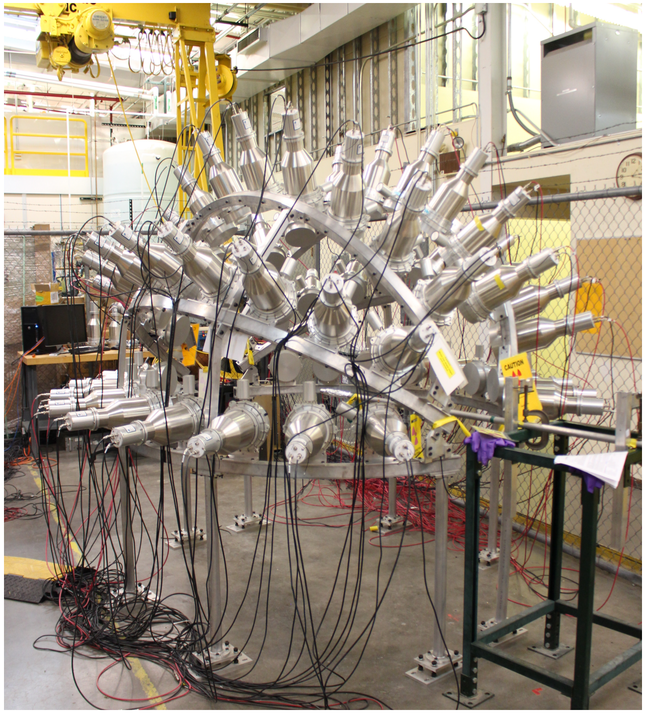




^{6}Li-glass neutron detectors



Univ. Michigan is making correlation measurements of PFNs & PFGs: n-n, n-g, g-g



54 Liquid scintillators
En > 0.5 MeV

Acknowledgments for funding support

- US DOE
  - NNSA – including SSAP
  - Office of Science - Nuclear Physics
  - Nuclear Energy University Programs

- LANL - LDRD

Thank you!!!