LA-UR-14-27025

Los Alamos
NATIONAL LABORATORY
EST. 1943

Fission Activities at the Los Alamos Neutron Science Center (LANSCE)

Robert C. Haight

Fiesta Workshop

Santa Fe, October 10-12, 2014

UNCLASSIFIED

Colleagues in present fission experiments at LANSCE

LANL- LANSCE-NS, C-NR, T-2

LLNL - Physical and Life Sciences

Other Laboratories – Idaho National Laboratory, CEA Bruyères-le-Châtel (France), IRMM (Belgium)

Universities - Abilene Christian, Brigham Young, Cal Poly, Colorado School of Mines, Idaho State, Kentucky, New Mexico, Ohio, Oregon State, Rensselaer Polytechnic Inst.

LANSCE experiments to be discussed at FIESTA (1)

By LANL:

- **Mark Chadwick**
  - *Nuclear fission research at Los Alamos*
- **Fredrik Tovesson**
  - *Neutron-induced fission cross sections for U-233,234,236,238 up to 200 MeV*
- **John Ullmann**
  - *Prompt gamma-ray production in neutron-induced fission of ^{239}Pu*
- **Marian Jandel**
  - *Current and future fission research at DANCE*
- **Hye Young Lee**
  - *Prompt Fission Neutron Studies at LANSCE*
- **Ronald Nelson**
  - *Prompt X-Rays from Fast-Neutron-Induced Fission of ^{238}U*
- **Nicholas Fotiades**
  - *Prompt γ-ray spectroscopy of fission fragments*
- **Krista Meierbachtol**
  - *First Results of Fission Mass Yield Measurements with SPIDER at LANSCE*
- **Dana Duke**
  - *Investigation of ^{238}U Fission Properties at LANSCE*

LANSCE experiments will be discussed at FIESTA (2)

By Colleagues:

- **Mike Heffner (Lawrence Livermore Nat. Lab)**
  - ***The Fission Time Projection Chamber***
- **Adam Hecht (University of New Mexico)**
  - ***The University of New Mexico Fission Fragment Spectrometer***
- **Sara Pozzi (University of Michigan)**
  - ***Correlations in Prompt Neutron and Gamma Ray Emissions from Fission***

By Evaluators:

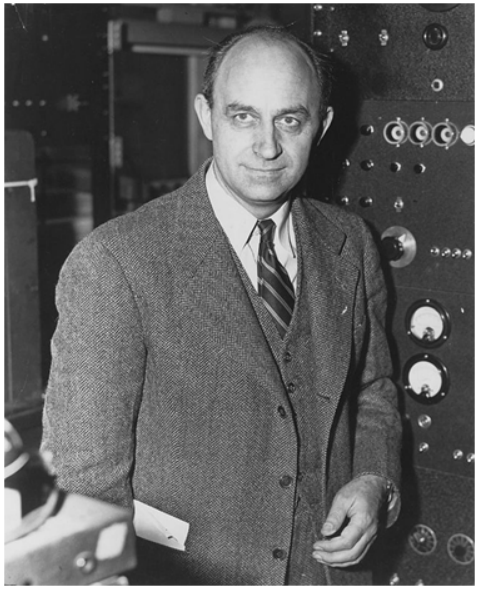
- **Denise Neudecker (LANL T-2)**
  - ***Open questions concerning the evaluation of the ^{239}Pu prompt fission neutron spectra up to 30 MeV incident neutron energy***

LANSCE experiments will be discussed at FIESTA (3)

By Poster:

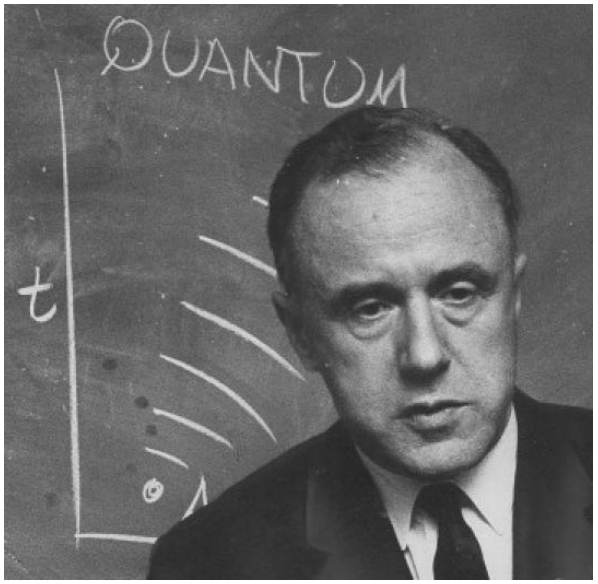
- **Verena Kleinrath (LANSCE-NS)**
  - ***Fragment Angular Distributions in Neutron-Induced Fission of ^{235}U and ^{239}Pu using a Time Projection Chamber***
- **Dan Shields (LANSCE-NS)**
  - ***Development of the New SPIDER Detector at LANSCE***
- **Bayarbadrakh Baramsai (C-NR)**
  - ***High Precision Measurement of 236U(n,g) Cross Section***
- **Gencho Rusev (C-NR)**
  - ***Development of fission-fragment detectors***
- **Carrie Walker (C-NR)**
  - ***Measurements of fission fragments in coincidence with prompt fission gamma rays at DANCE***
- **Rusty Towell (Abilene Christian Univ.)**
  - ***Potential to Advance the Thorium Fuel Cycle with the NIFFTE fissionTPC***

Fission at LANSCE builds on LANL history



Enrico Fermi
(Eugene Farmer)

Niels Bohr
(Nicholas Baker)



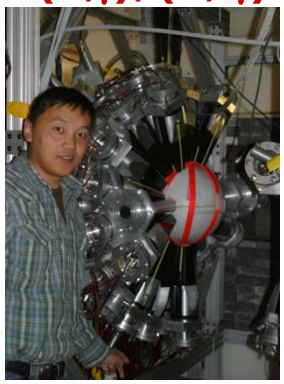
John Wheeler
(John Woolley)

Some later LANL contributions toward understanding fission

- Moore, Keyworth et al. – spin assignments with polarized neutron beam, polarized ^{235}U
- Britt, Wilhelmy, Back, et al. -- surrogate reactions for fission barriers, including (t,pf) and (t,df) reactions
- "Physics 8" – single pulse neutron source
- Gavron – time scales for fission
- Potential energy surfaces (Moller)
- Prompt Fission Neutron Spectra – Terrell; Madland, Nix →Los Alamos Model
- Fission yields – Wahl, England and Rider
- Fission cross sections – Lisowski, Staples, Morley et al. – relative to H(n,p) standard cross section

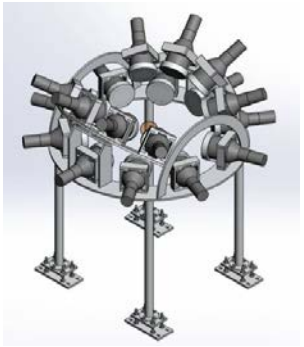
Fission measurements at LANSCE are made with many different instruments

DANCE (n,γ), (n,fγ)

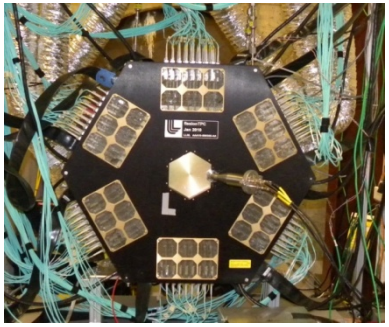


GEANIE (n,fxγ)

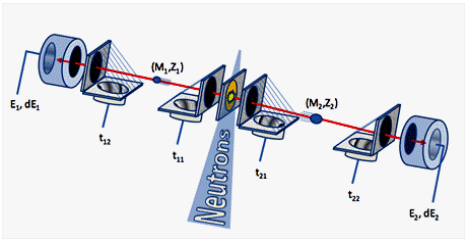
Chi-Nu (n,f) PFN (n,fxn)



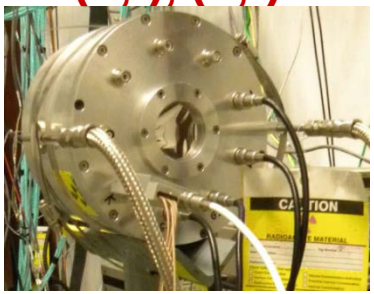
TPC (n,f)



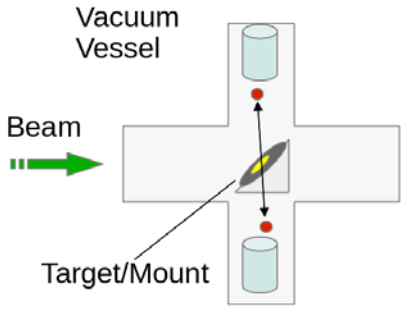
SPIDER (n,f)^{A}Z



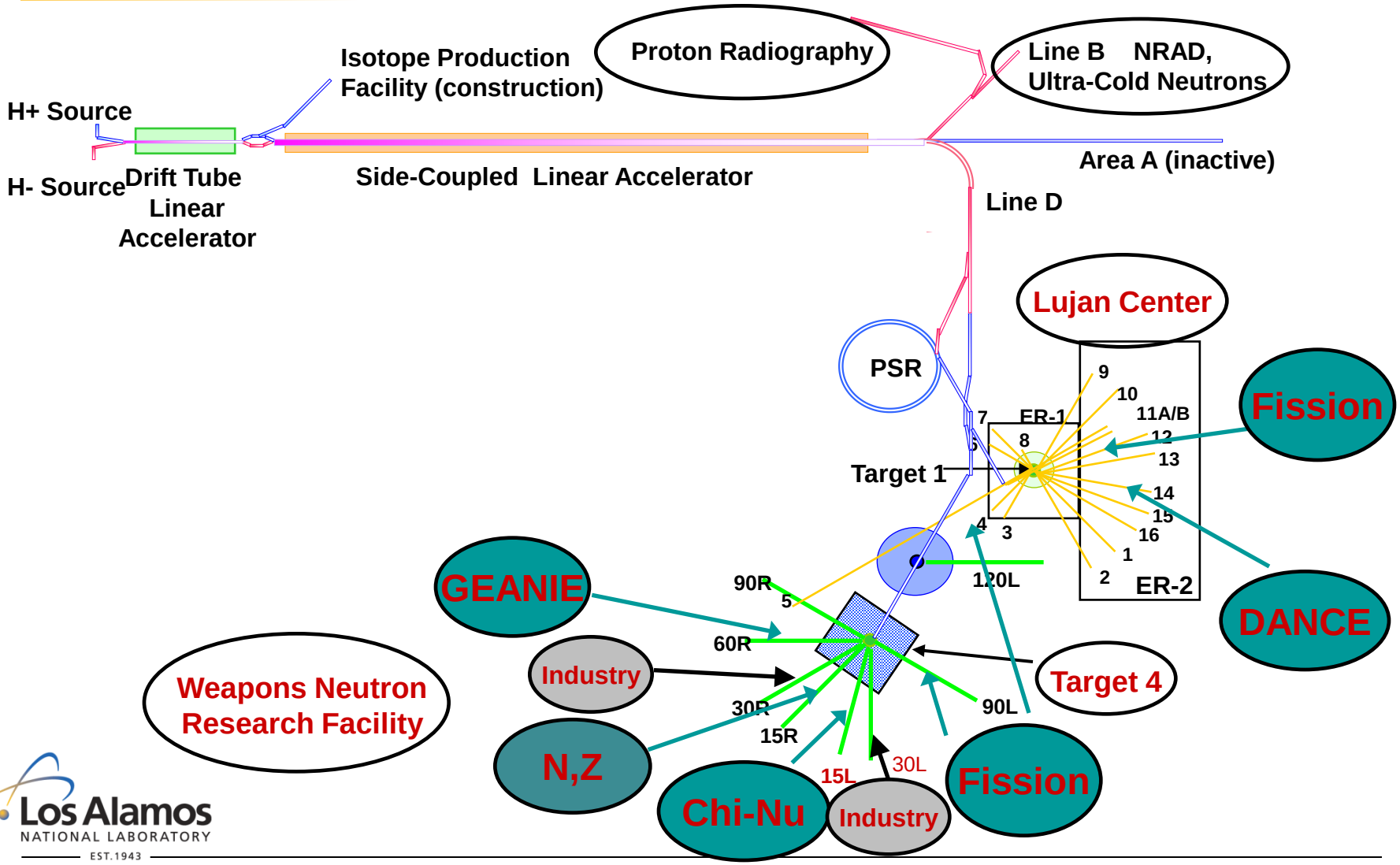
Double gridded ion chamber (n,f), (n,f)^{A}Z



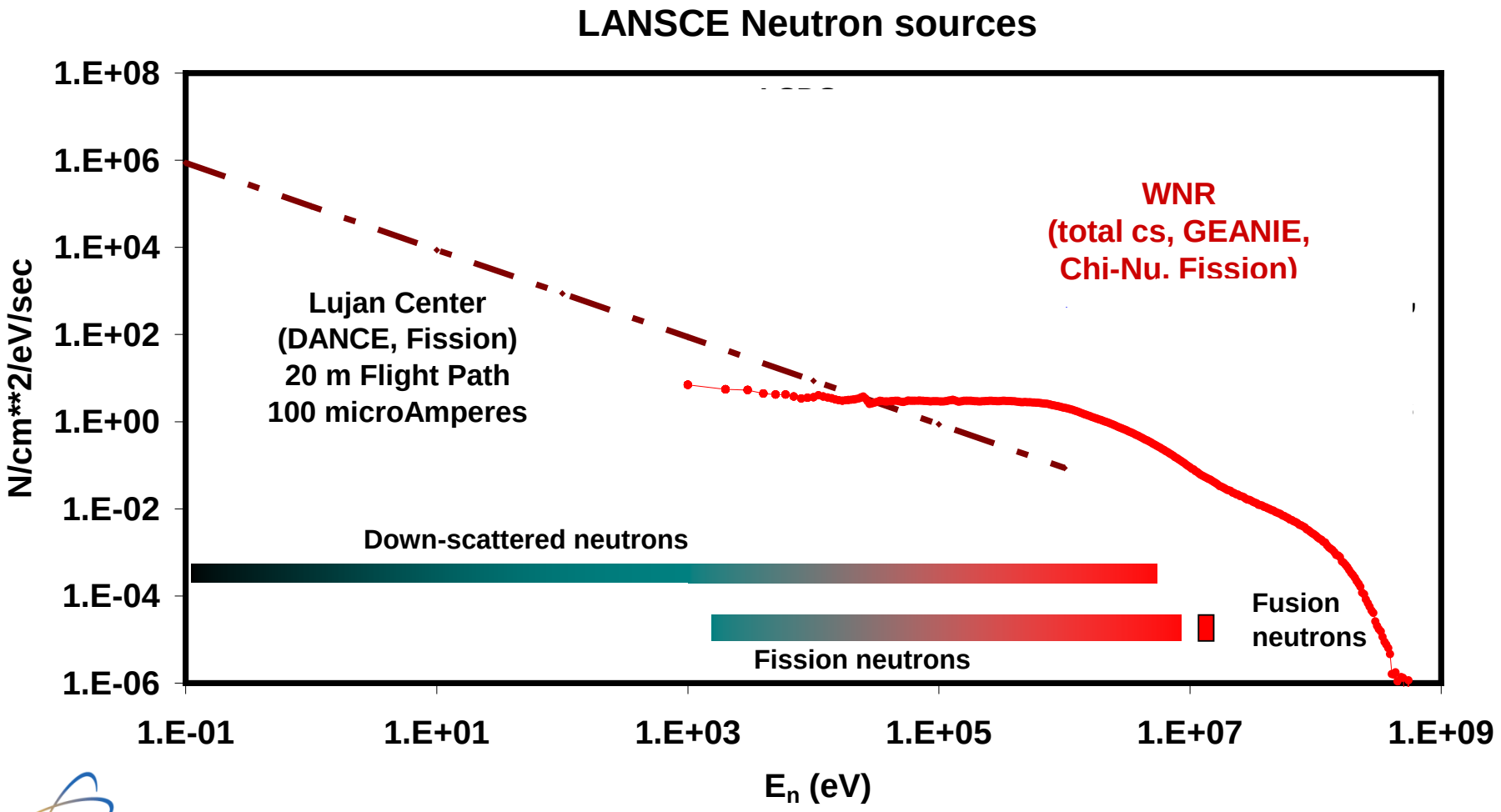
Surface barrier detectors - TKE



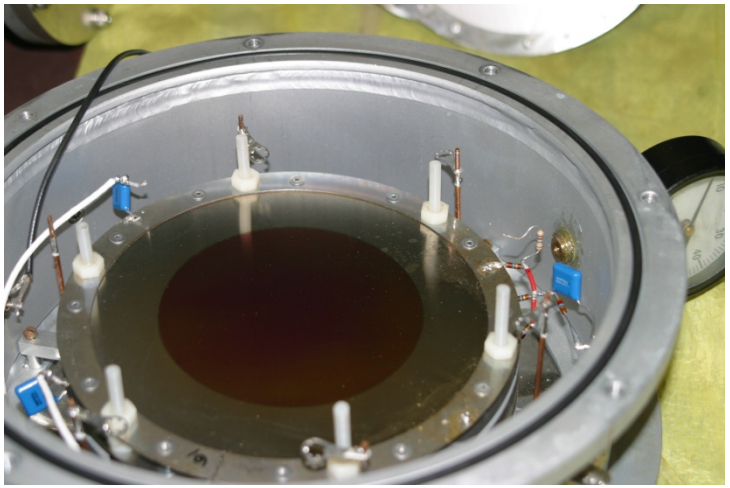
Fission experiments at LANSCE use neutrons at the Lujan Center and Target 4



LANSCE neutron sources cover (n,f) for incident neutron energies from subthermal to ~ 200 MeV



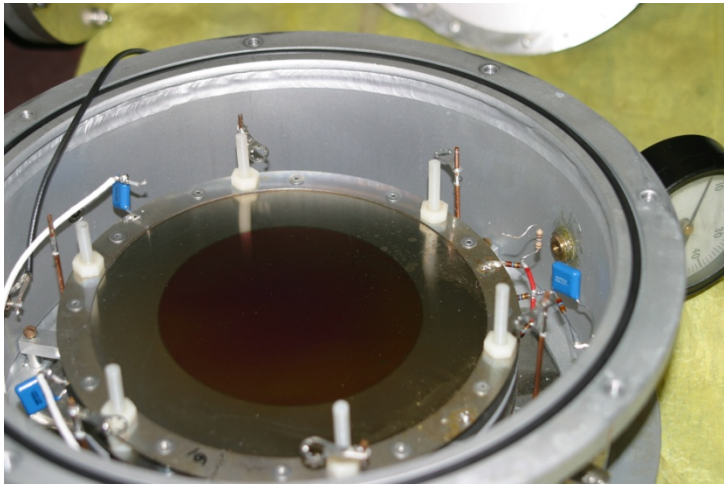
Fission Cross Sections



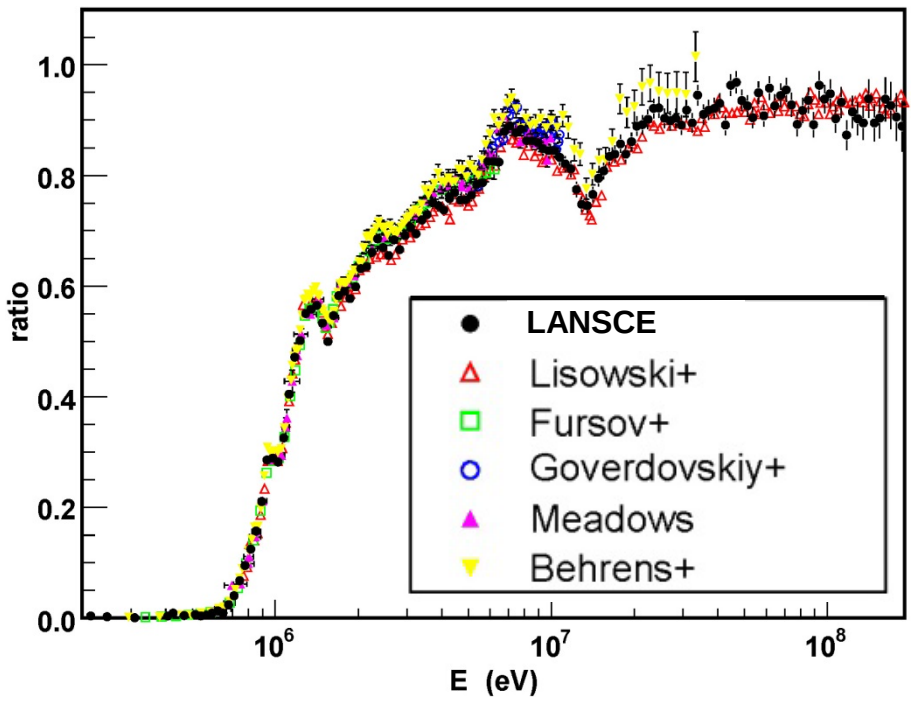
Parallel-plate Ionization Chamber

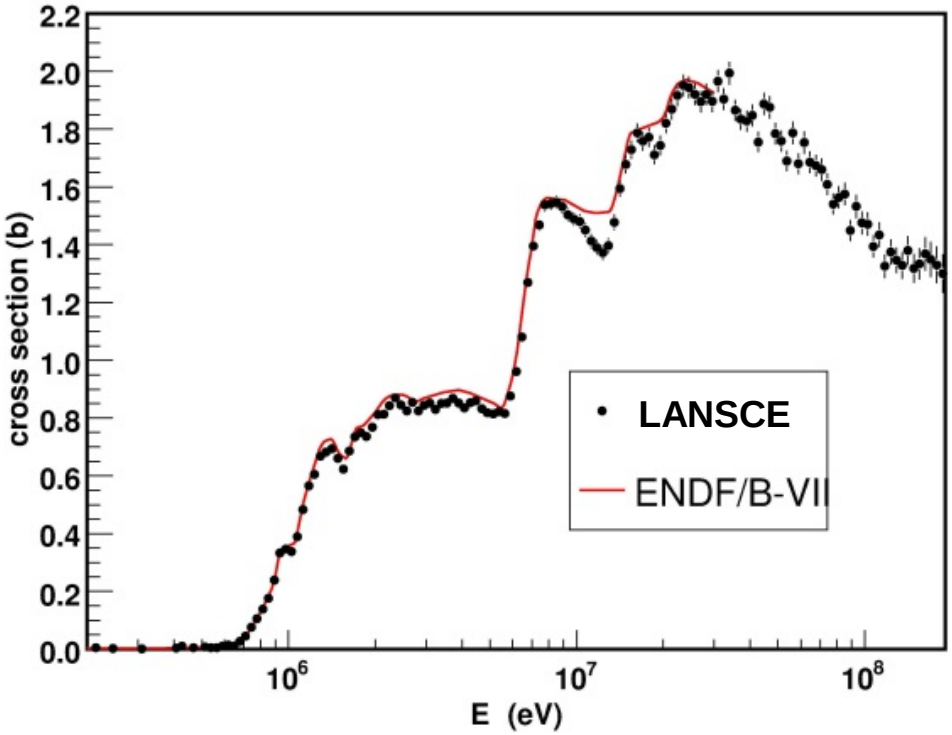
Fission cross section measurements at LANSCE

- **Fission counting with parallel plate ionization chamber**
  - Up to 4 foils per chamber
  - 12 mm cathode grid spacing: fragments do not range out
  - Energy deposition used to qualify fission events
- **Relative measurements**
  - Using the $^{235}U(n,f)$ standard
- **Neutron time-of-flight**
  - Wide neutron range measured in one experiment
  - Background due to frame-overlap and room return neutrons



^{236}U(n,f) cross section results: ENDF a little high?

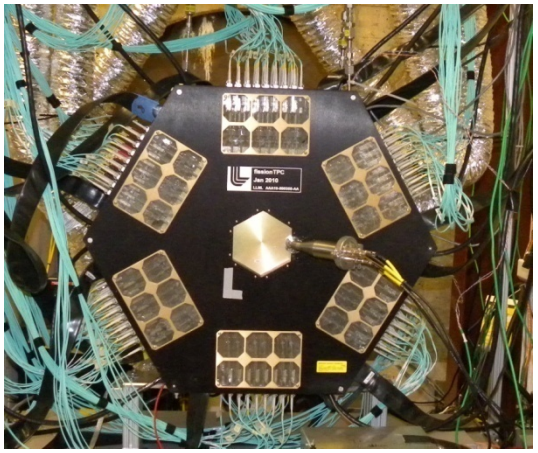




LANSCE: A. Laptev, F. Tovesson and T. S. Hill, AIP Conf. Proc. 1525, 563 (2013).

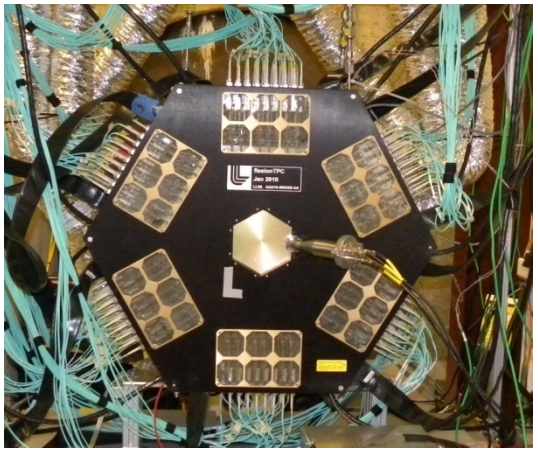
A New Approach to Measuring Fission Cross Sections

Time Projection Chamber

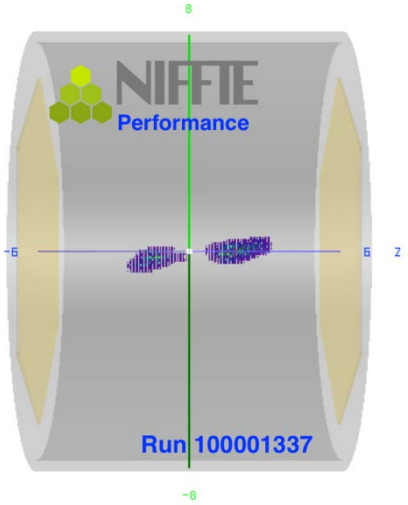


Time Projection Chamber (TPC) for precision cross section measurements

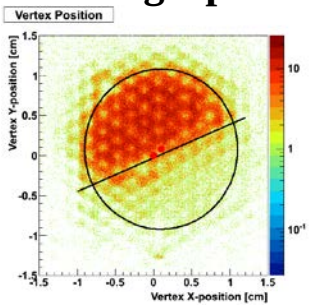
TPC



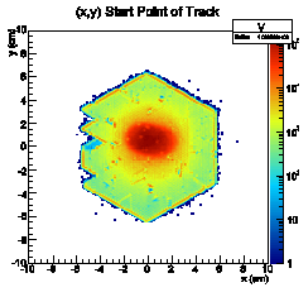
Fission fragment tracks



Target auto-radiograph

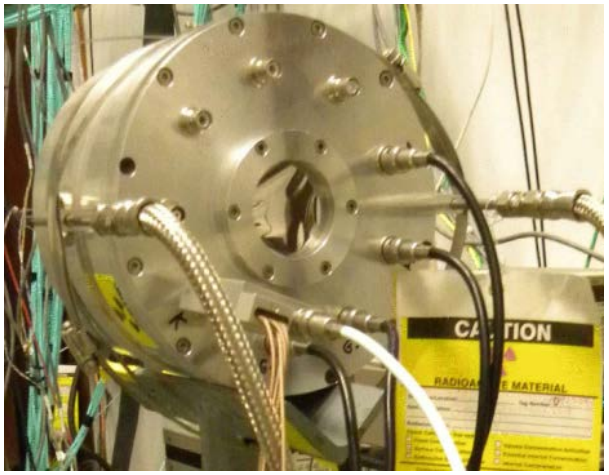


Beam profile imaging



- **Actinide distribution on target determined by auto-radiograph (alphas)**
- **Location and angle of fission fragments is determined**
- **Information on track ion density → ^{A}Z (to some resolution)**
- **Fully instrumented LLNL/LANLTPC was commissioned at LANSCE in August 2013**

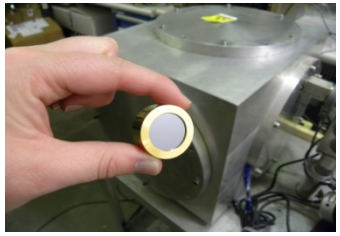
Total Kinetic Energy

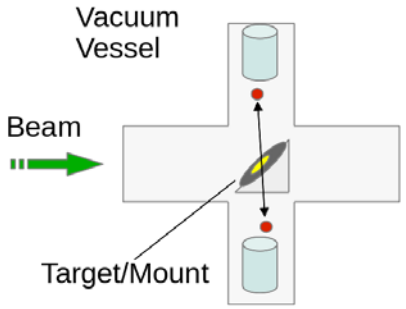


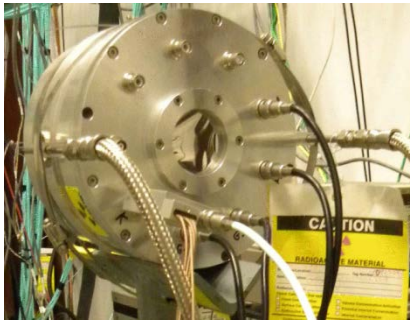
Gridded Ionization Chamber

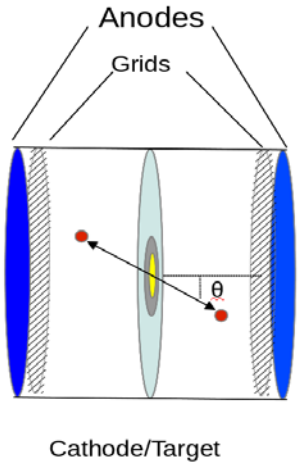
Total Kinetic Energy (TKE) released in fission

- **Madland has pointed out the need for new measurements of TKE in fission extending beyond 10 MeV**
- **Current measurements at LANSCE employ two detector types, Gridded IC and SSBD, to measure TKE at thermal and 0.2 – 100 MeV neutron energy**
- **Two detector types allow for better understanding of systematic effects**



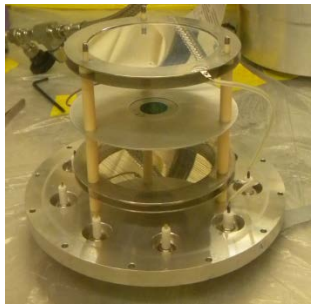




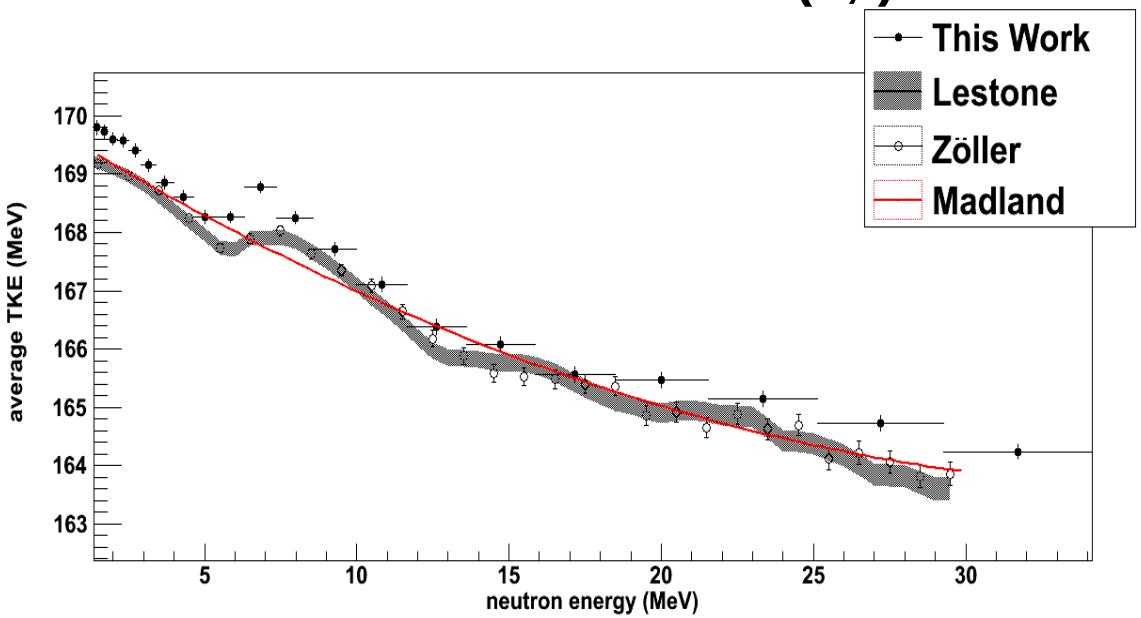


Total kinetic energy measurement

Double Frisch-grid ion chamber (IRMM)



TKE for ^{238}U(n,f)

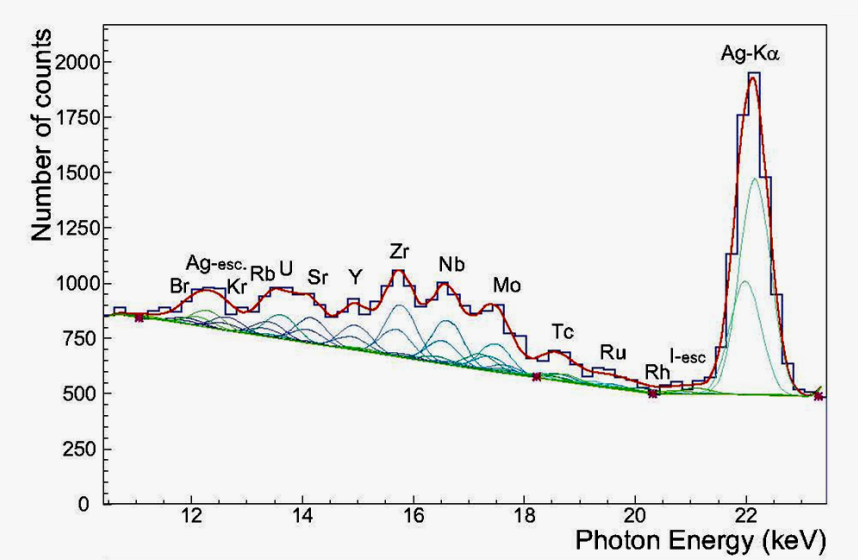


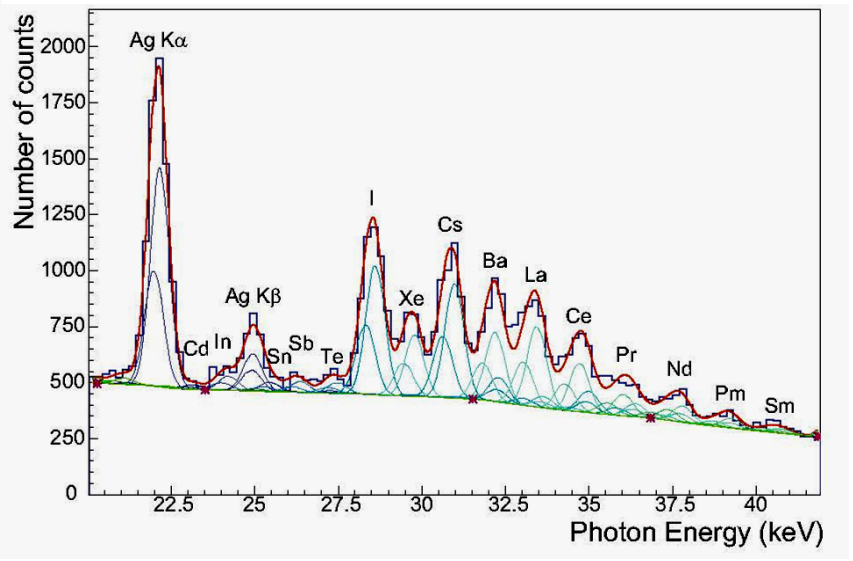
- **New measurements follow Lestone curve**
- **Details not included in Madland parameterization**
  - **Structure at second-chance fission threshold**

Prompt X-rays with good resolution

GEANIE

K-X-ray results from ^{238}U(n,f) show range of elements produced in fission





$E_{x\text{-}ray}$ = 10 – 23 keV

$E_{x\text{-}ray}$ = 20 – 42 keV

Spectrum deconvolution in terms of X-ray lines:
Incident neutron energy: 0.7 to 6MeV
Fitting with one parameter per element

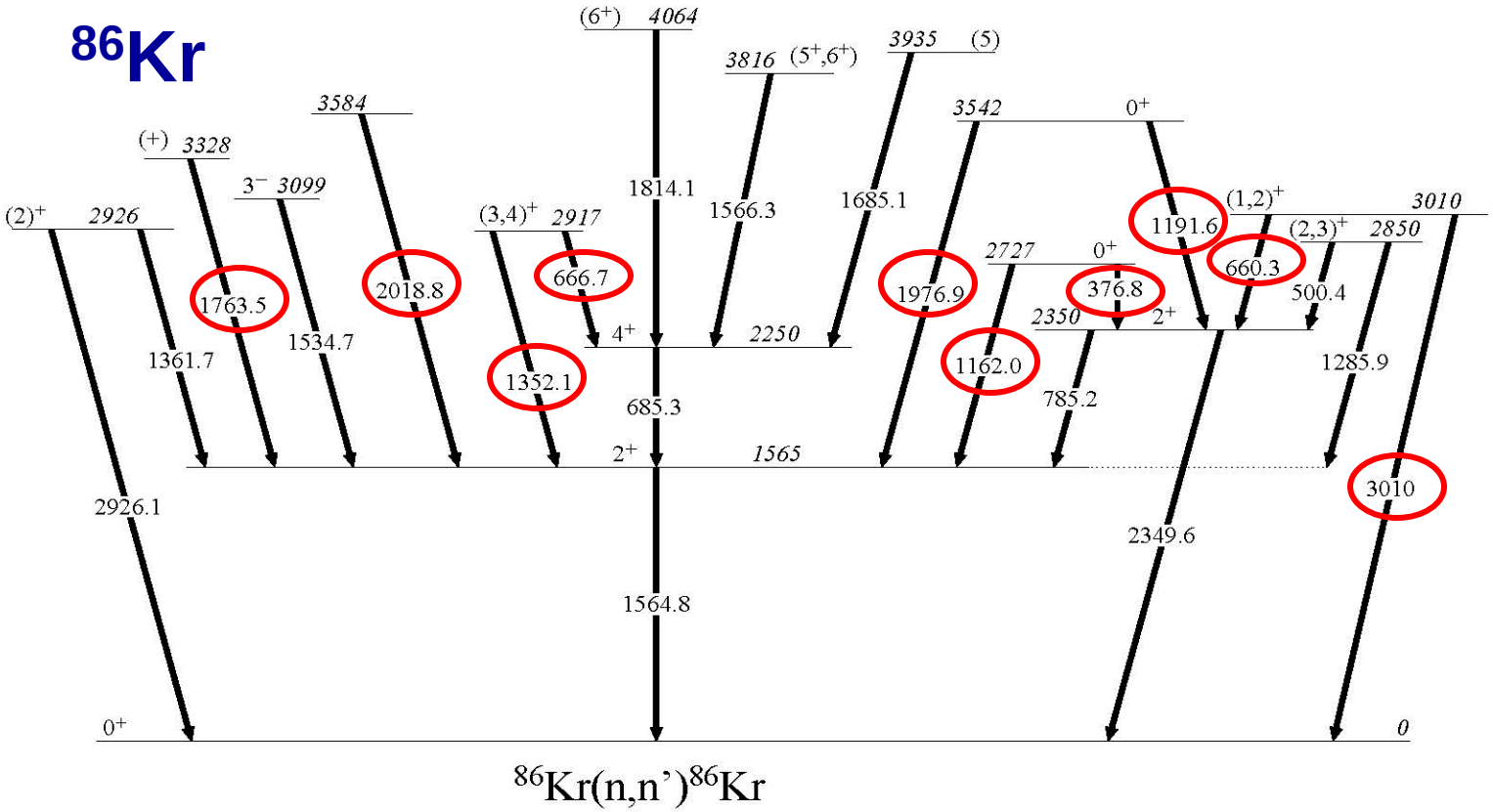
Ref. T. Granier et al., Eur. Phys. J. A (2013) 49: 114

Gamma-rays to elucidate structure of fission products

GEANIE

GErmanium Array for Neutron-Induced Excitations

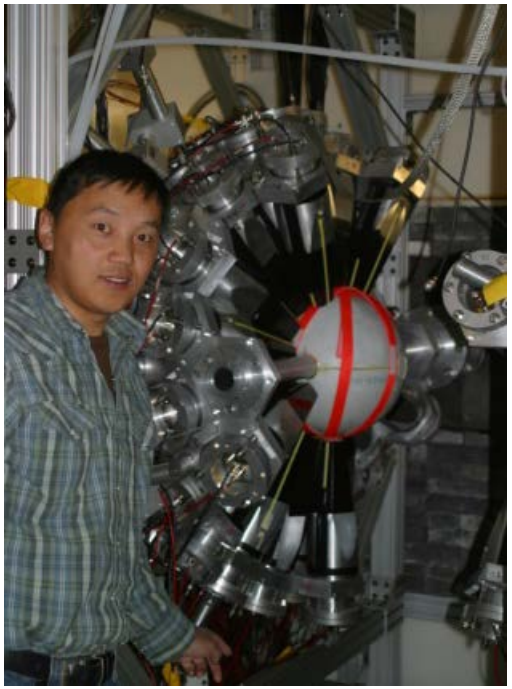
Many new transitions in ^{86}Kr were observed



Ten new transitions (red circles) were observed. All previously known levels (B. Singh, Nucl. Data Sheets 94, 1 (2001)) up to 3.7MeV excitation identified.

Ref: N. Fotiades et al., PRC 87, 044336 (2013)

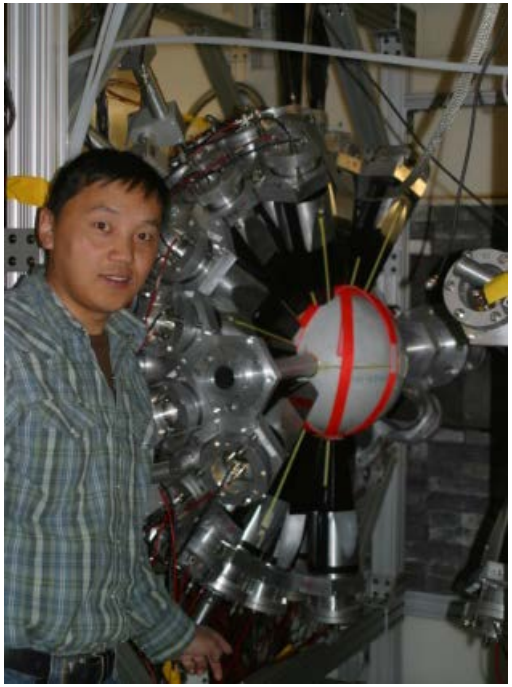
Total Prompt Gamma-ray output



DANCE

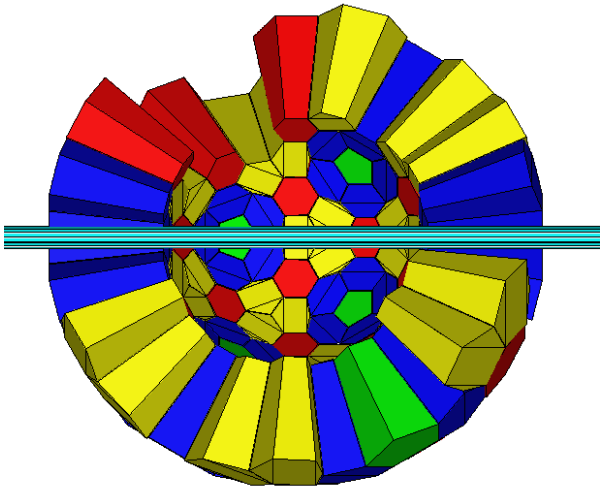
Detector for Advanced Neutron Capture Experiments

DANCE: Highly segmented 4π gamma-ray calorimeter with PPAC fission tagger



DANCE ball
(Open)
^{6}LiH sphere in center

- 160 BaF_2 crystals – each 0.75 liter
- Inner radius = 17 cm, crystal depth = 15 cm

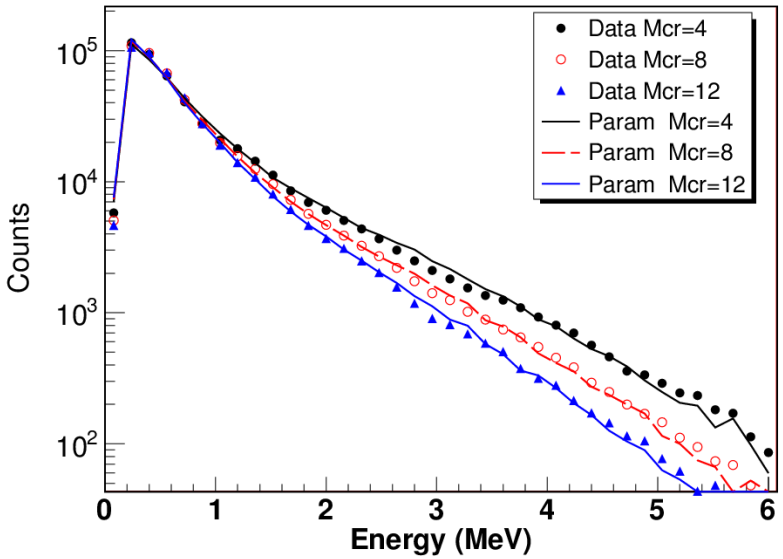


- Parallel-plate avalance counter for fission identification
- LLNL/LANL/MSI

Detector for Advanced
Neutron Capture Experiments

^{239}Pu(n,f) Average γ Multiplicity and $E_{tot,\gamma}$

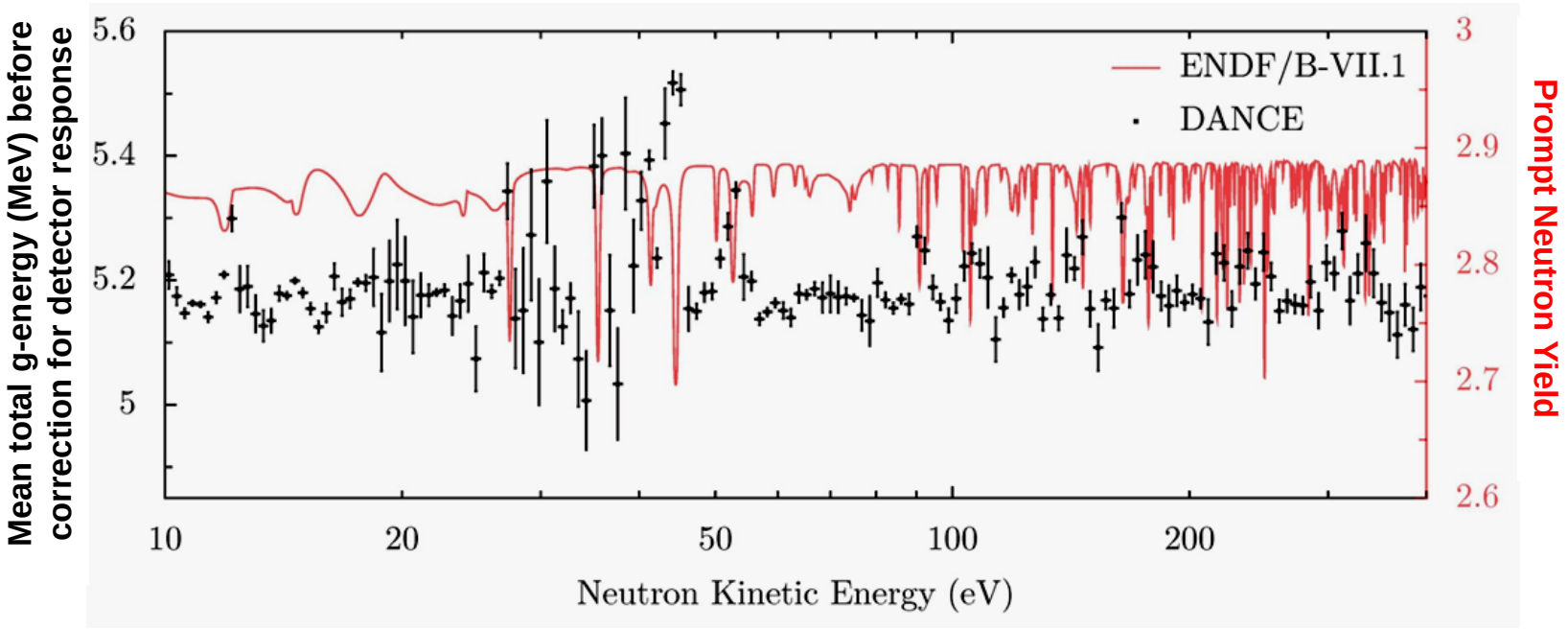
- **Data analyzed for spectral shape, total energy, energy per detector and multiplicity**



	<M>		<$E_{tot,\gamma}$>	
DANCE (10.93 eV)	7.15	0.09	7.46	0.06
Pleasonton (thermal) (Nucl. Phys. A 213, 413 (1973))	6.88	0.35	6.73	0.35
Verbinski (thermal) (Phys. Rev. C 7, 1173 (1973))	7.23		6.81	
MCHF (Stetcu/Talou) (Thermal, 140 keV thresh. α=1.5) LA-UR-14-23128	7.05		6.74	
Madland Summary			6.74	
Chyzh, "1D" Unfolding (Phys. Rev. C 87, 034620 (2013))	7.50		7.30	
Chyzh "2D" Unfolding (Phys. Rev. C 90, 014602 (2014))	7.93		7.94	

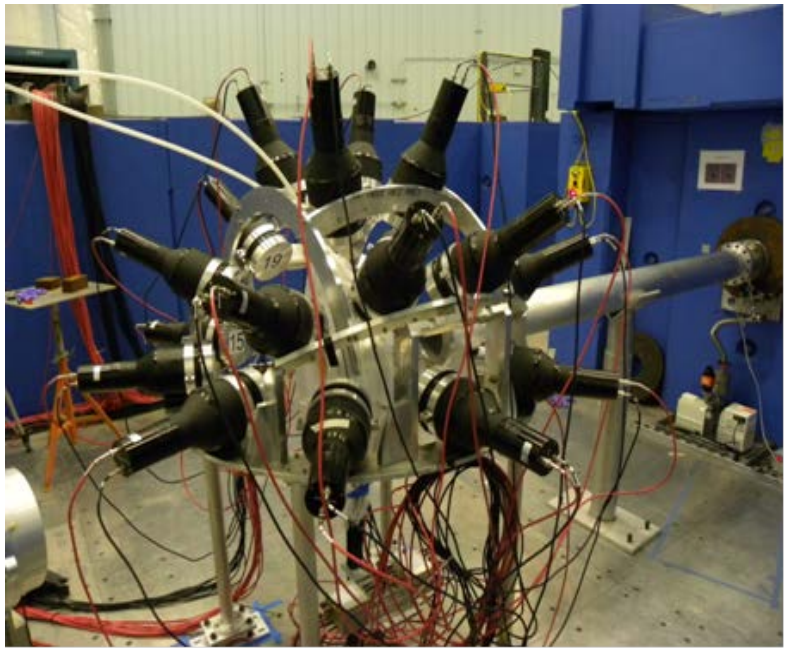
- **Uncertainty in <Etot> ~ Fitting uncertainty, determined as σ of 14 iterations with lowest χ^2!**

Fission total γ-ray energy vs. incident neutron energy for ^{239}Pu(n,f)



- **Fluctuations in prompt fission gamma energy anti-correlated with neutron emission**
- **More detailed information on ^{239}Pu(n,γf) process (Lynn, 1965)**
- **Qualitative behavior reported by Shackleton in 1972**

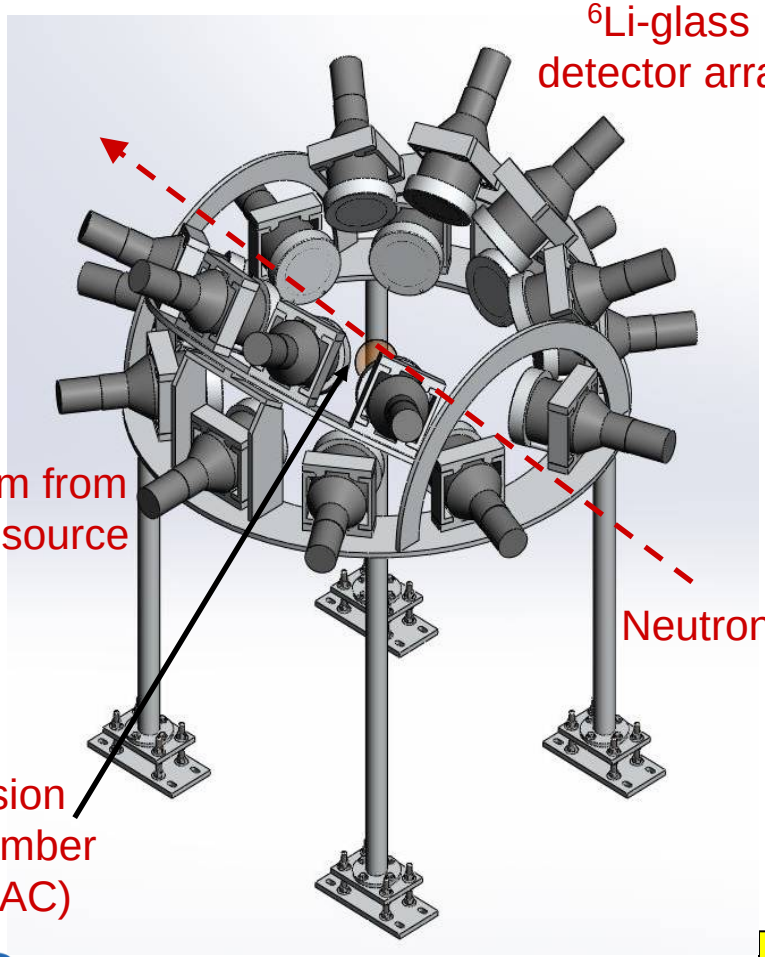
Prompt Fission Neutron Spectra



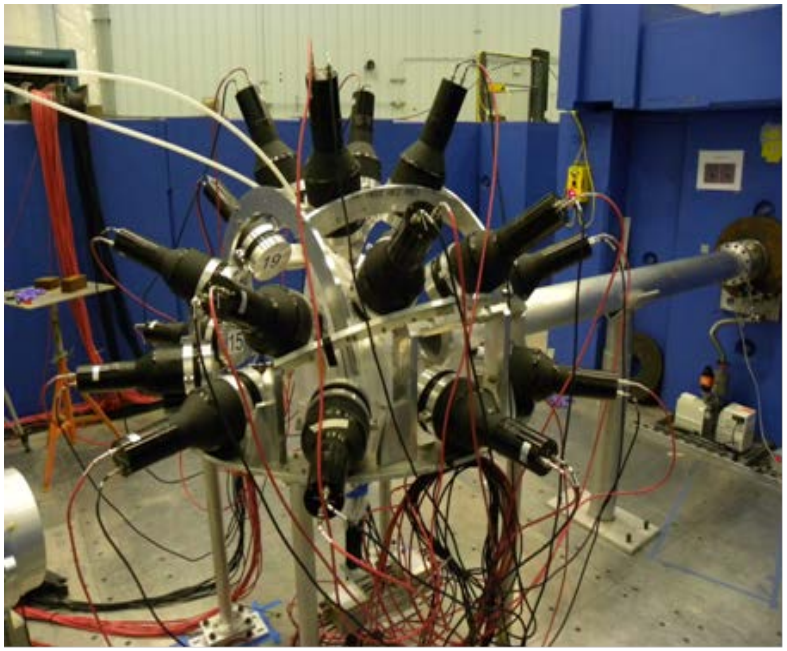
Chi-Nu Array

Chi-Matrix of Neutron Emission Spectra

Chi-Nu array of fast neutron detectors measures prompt neutron spectra emitted in fission



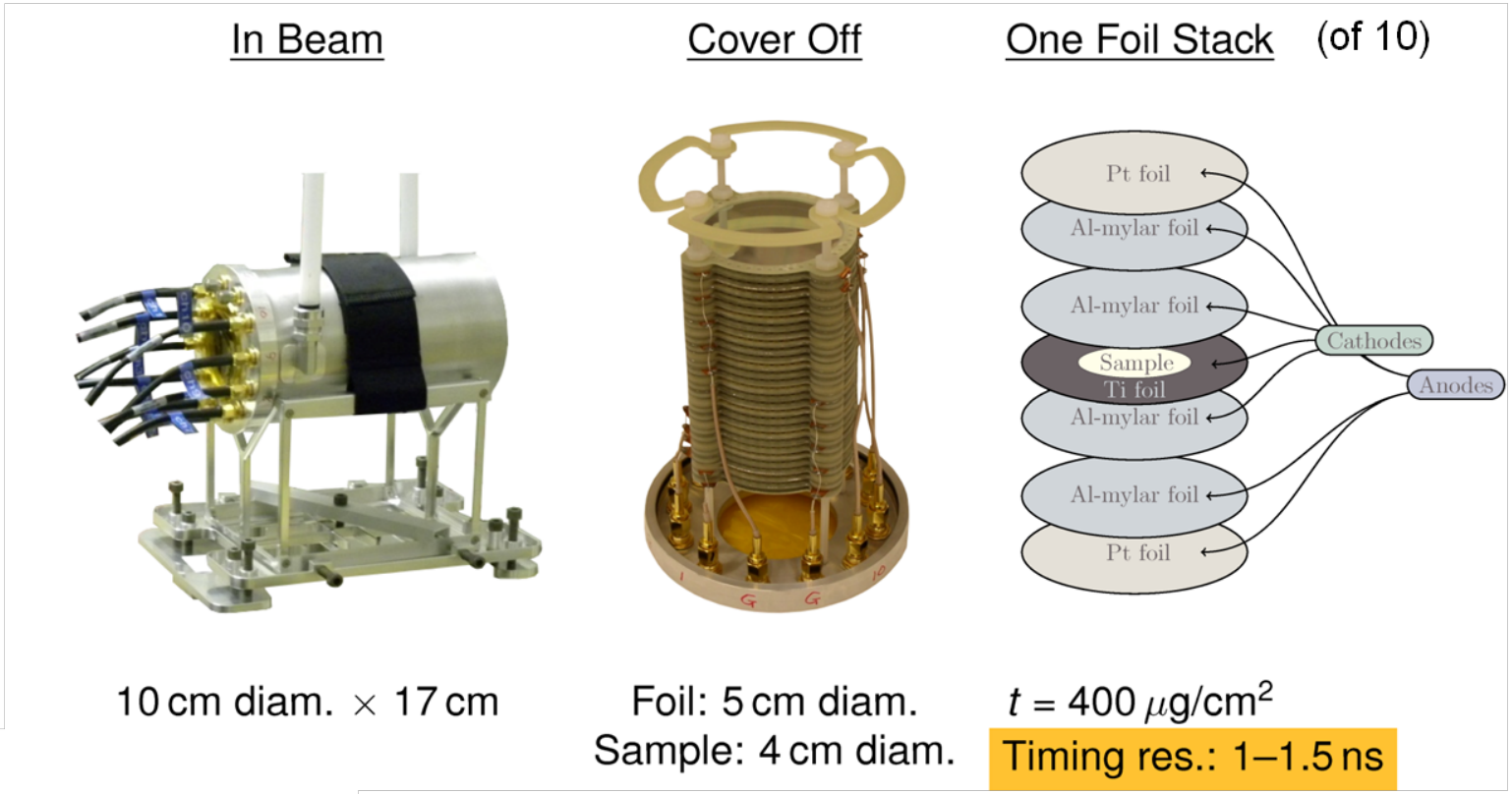
- **22 ^{6}Li-glass scintillation detectors - - or**
- **54 liquid scintillation neutron detectors**



Double time-of-flight experiment

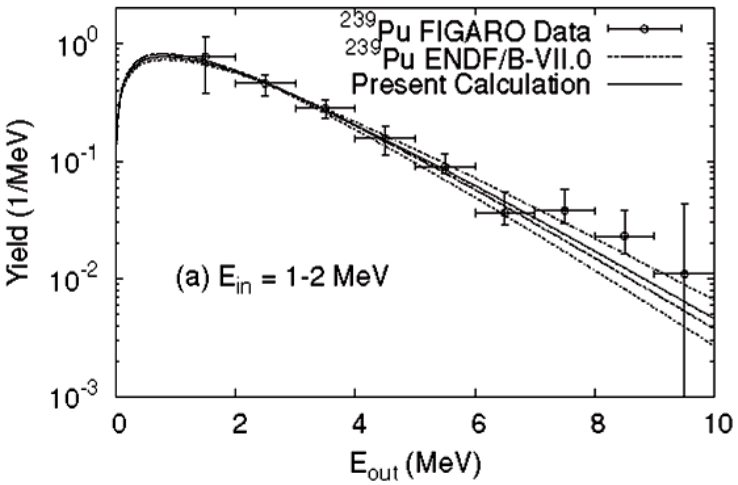
Fission sample and fission counter (LLNL) contain ~ 100 mg of ^{239}Pu

- **Parallel-Plate Avalanche Counter (PPAC)**



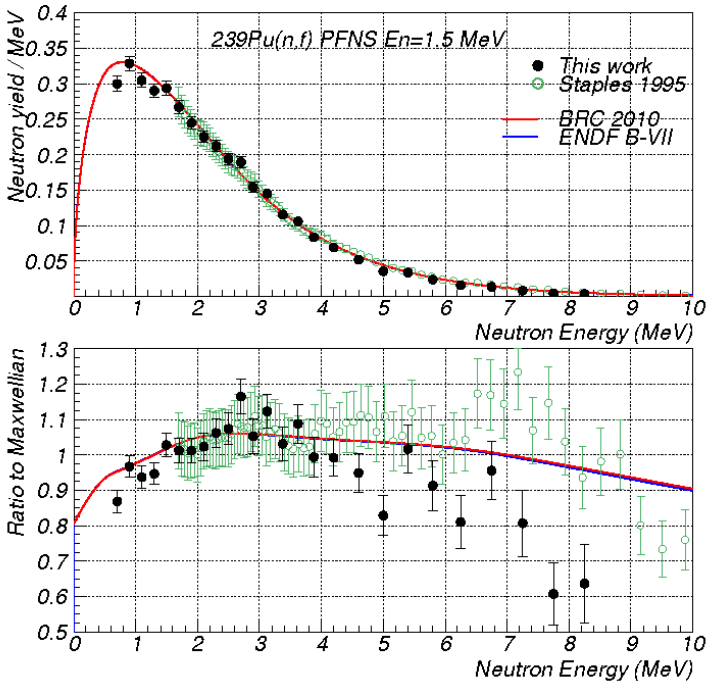
Previous measurements made with "white" neutron source at LANSCE for ^{239}Pu(n,f): CEA-LANL (FIGARO)

S. Noda et al., Phys. Rev. C 83, 034604 (2011)



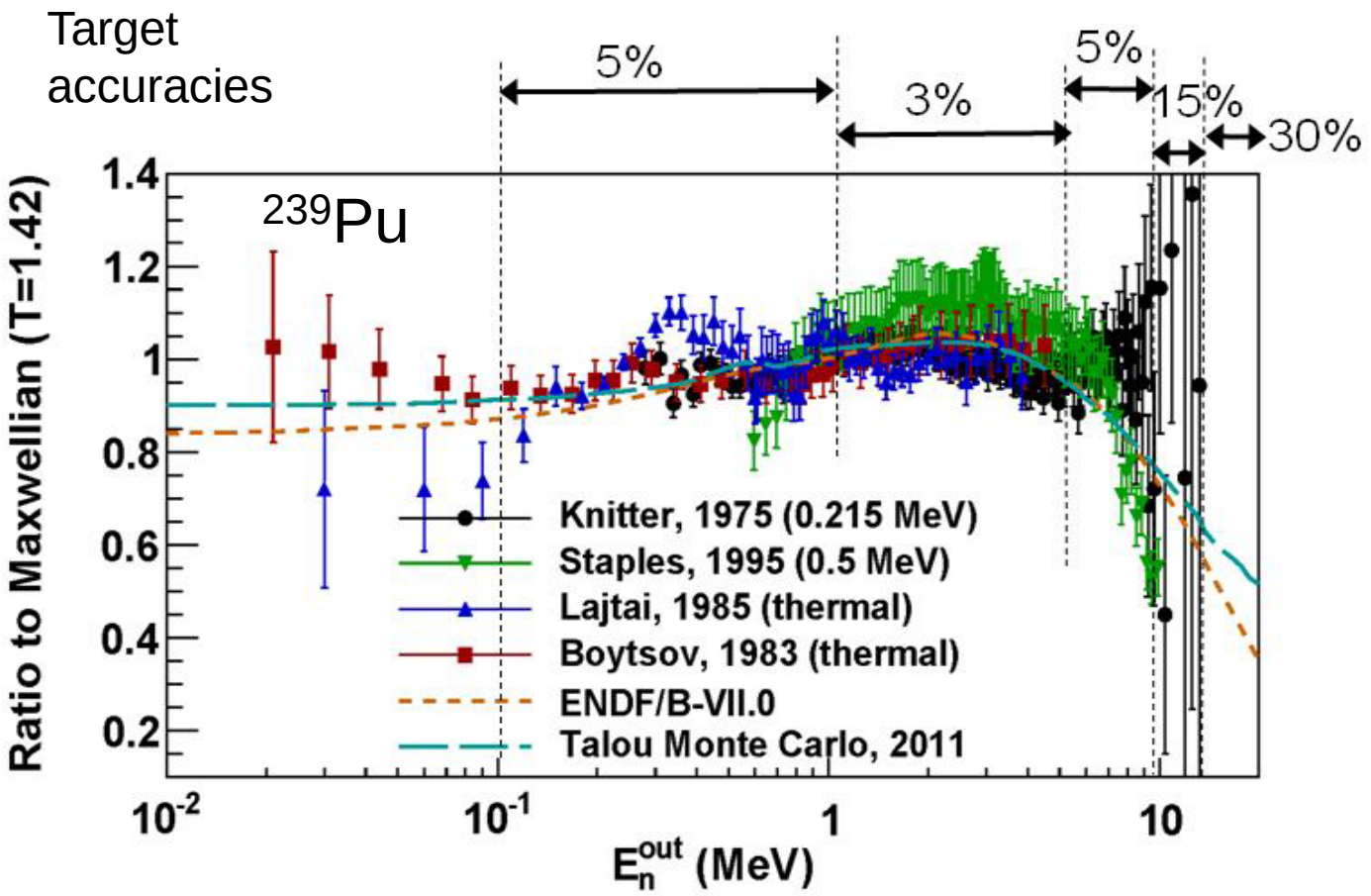
Data > ENDF for Eout > 7 MeV

A. Chatillon et al., Phys. Rev. C 89, 014611 (2014)

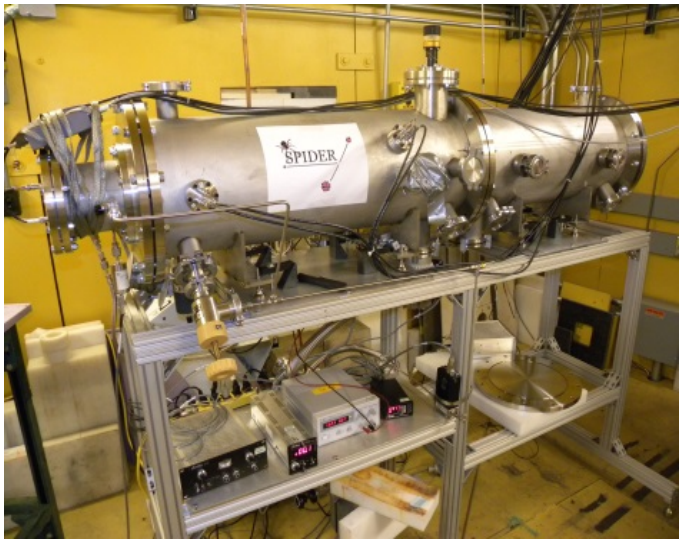


Data < ENDF for Eout > 7 MeV

Literature data, discrepancies and target accuracies



Fission Fragment Identification

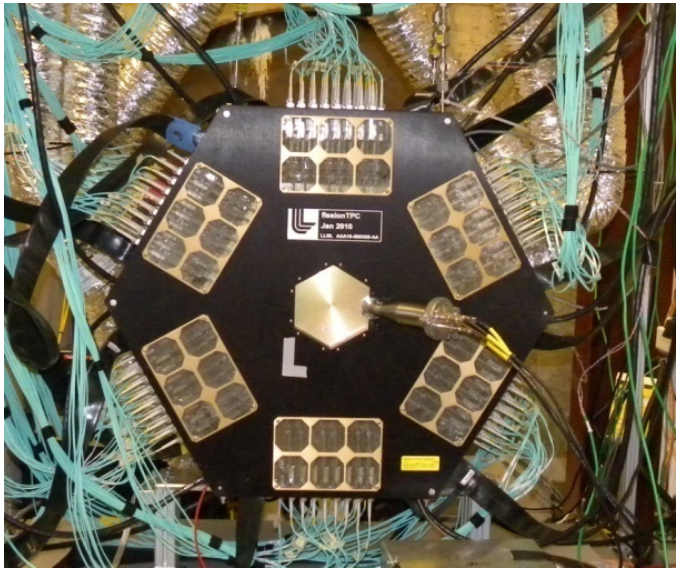


SPIDER

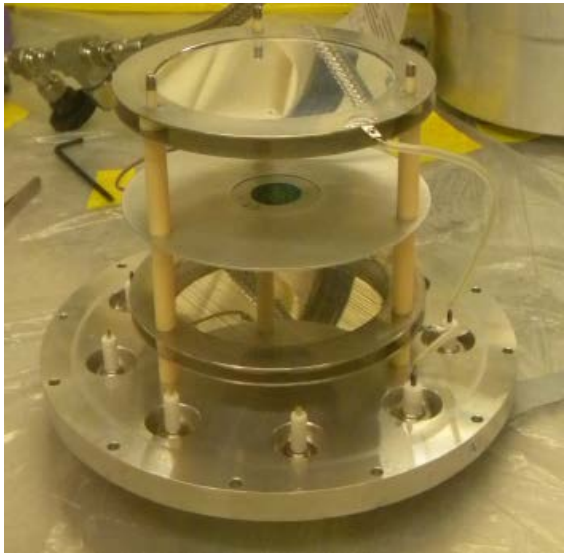
SPectrometer for Ion DEtermination in fission Research

TPC and GIC give information on mass and charge yields and angular distributions of fission products

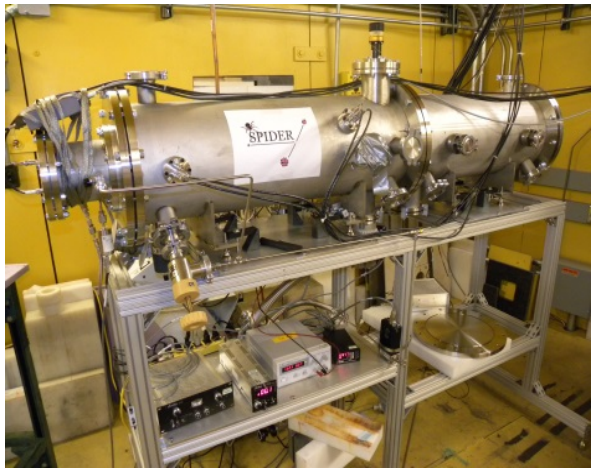
LLNL/LANL
Time Projection Chamber



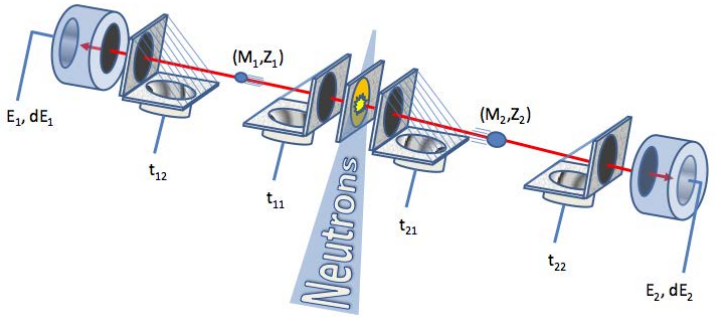
Double Frisch-grid ion chamber (IRMM)



SPIDER – Fission product mass yields



SPIDER 2-arm prototype installed at Lujan Center



SPectrometer for Ion DEtermination in fission Research

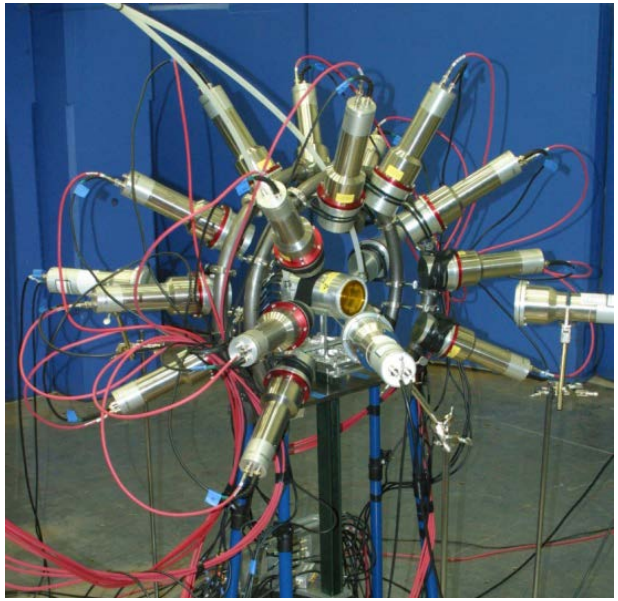
- **2E-2v method**

$$M = \frac{2Et^2}{l^2}$$

M = mass
E = energy
t = time
l = path length

  - Measure energy, time, and path length of products, each with small uncertainties
- **Goal: 1 atomic mass unit resolution**

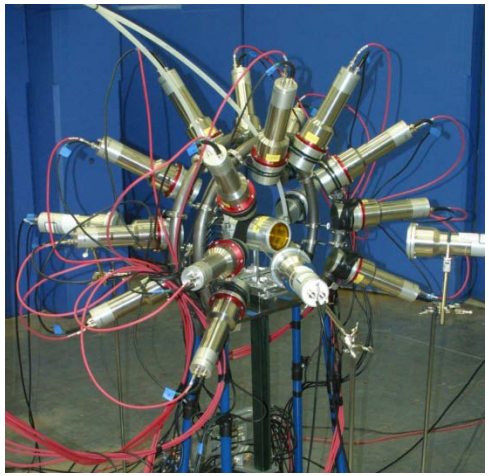
Correlation of Prompt Neutron and Gamma-ray Output

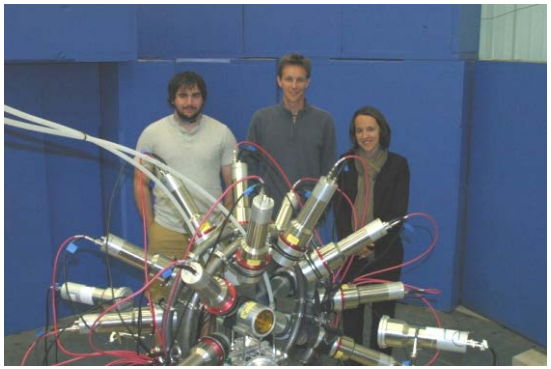


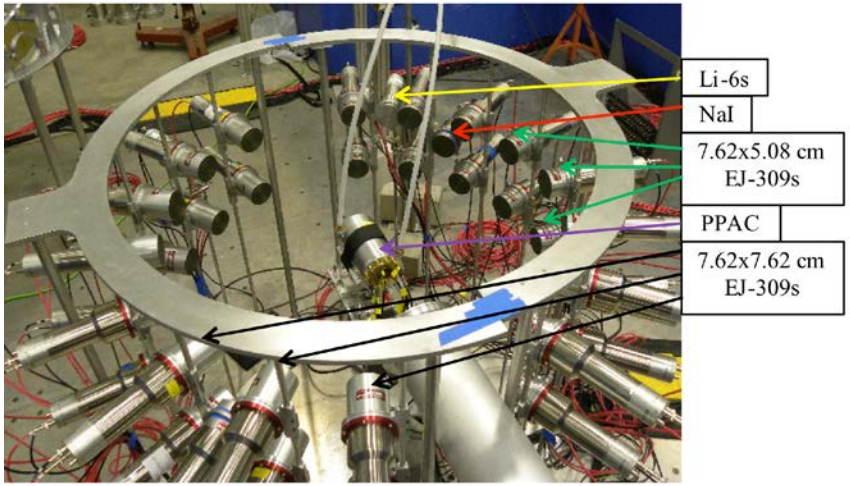
Michigan arrays

^{235}U Neutron-Induced Fission Experiments
Michigan Experiments at LANSCE 2012 and 2013

- **^{235}U fission chamber; double TOF experiment**
- **Measurements of multiplicity and directionality of neutron emission**
- **2 weeks beam time at 4FP15L-A (22 meters) → many TB of collected data**







So how do these experiments help in understanding the physics of fission?

- Fission barriers
- Fission probability when there are competing channels for decay of compound nucleus, e.g. (n,n')
- Fission resonances – e.g. (n,γf)
- Fission yields
- Temperature of fragments
- Angular momentum of fission fragments
- Correlations

Acknowledgments

- **This work is performed under the auspices of the U.S. Department of Energy by Los Alamos National Laboratory under Contract DE-AC52-06NA25396.**

- **Support comes from**

  US Department of Energy
  - **National Nuclear Security Administration**
  - **Office of Nuclear Physics**
  - **Office of Nuclear Energy - University Programs**

  LANL – Laboratory Directed Research and Development

Thank you!!