Fission studies with TPC and SPIDER: current status and future directions

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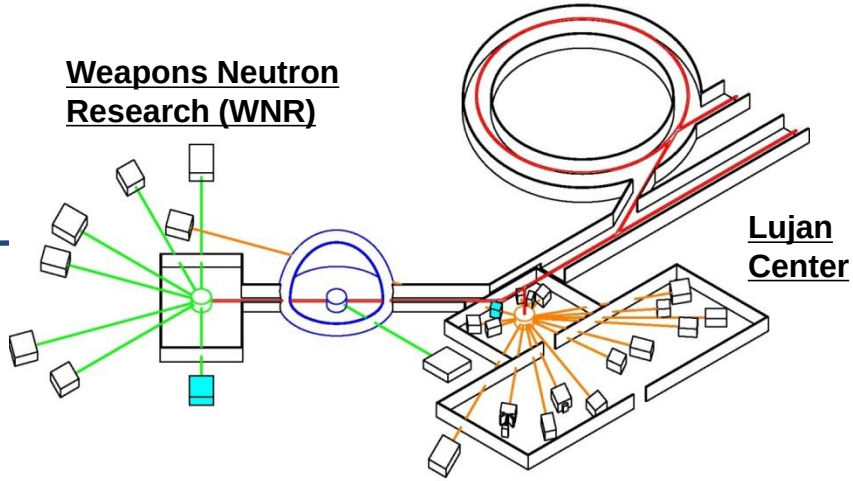
Outline

- Introduction
- The Los Alamos Neutron Science Center (LANSCE)
- Fission Research
  - Cross sections (TPC)
  - Fragment properties (SPIDER, Gridded ionization chambers)
- Outlook and Summary

Introduction

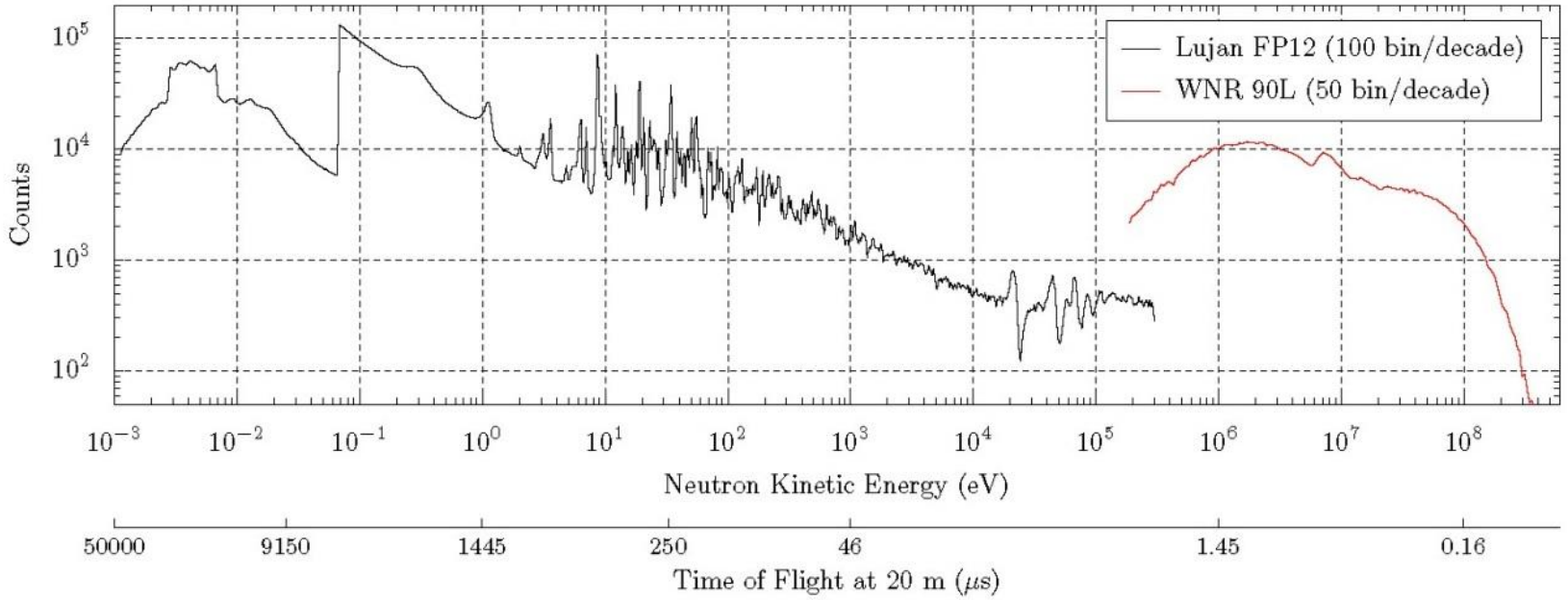
- We are in the midst of a fission renaissance
  - There is a surge in experimental efforts
    - Fragment spectrometers (STEFF, SPIDER, VERDI)
    - Inverse kinematics fission studies (GSI, GANIL, RIKEN)
    - Surrogate reactions (TAMU)
    - The fission Time Projection Chamber (TPC)
    - Activation measurements (TUNL)
  - Exciting theory developments
    - Macroscopic-microscopic model
    - Microscopic model
    - Monte Carlo method for fragment de-excitation
- What can we learn from new experiments?
  - More correlated information
  - Systematic studies of many systems, excitation energies
  - Improve accuracy & precision – uncertainty quantification (UQ)

The Los Alamos Neutron Science Center (LANSCE)



- Spallation neutron source
- Moderated & un-moderated flight paths
- Neutron time-of-flight

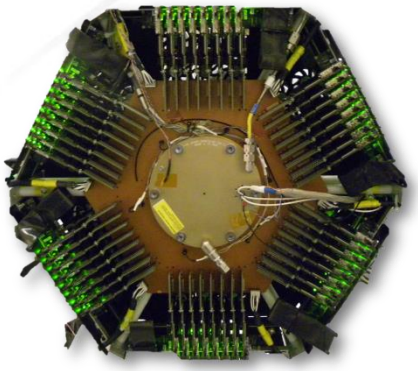
LANSCE provide neutrons from thermal to hundreds of MeV



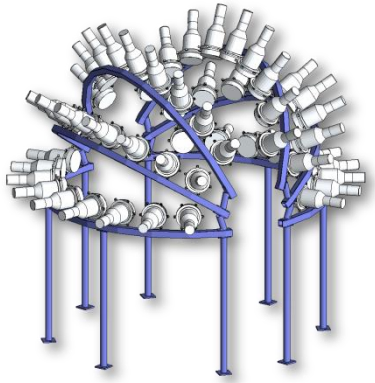
- High neutron flux over the full energy range
- Excellent resolution for fast neutrons, reasonable for slow neutrons

Nuclear Science Capabilities

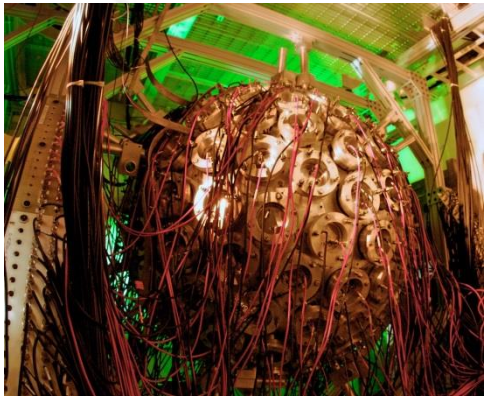
TPC
fission cross sections



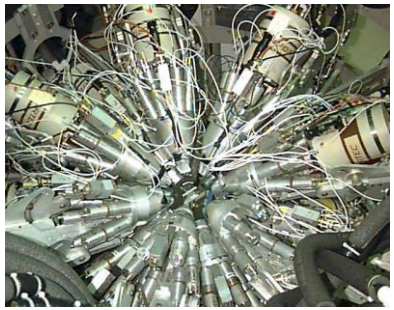
Chi-Nu
neutron output



DANCE
neutron capture, fission ɣ-rays

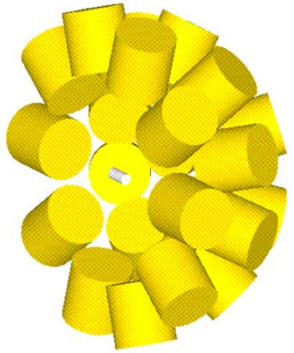


GEANIE
gamma production, Pu(n,2n)

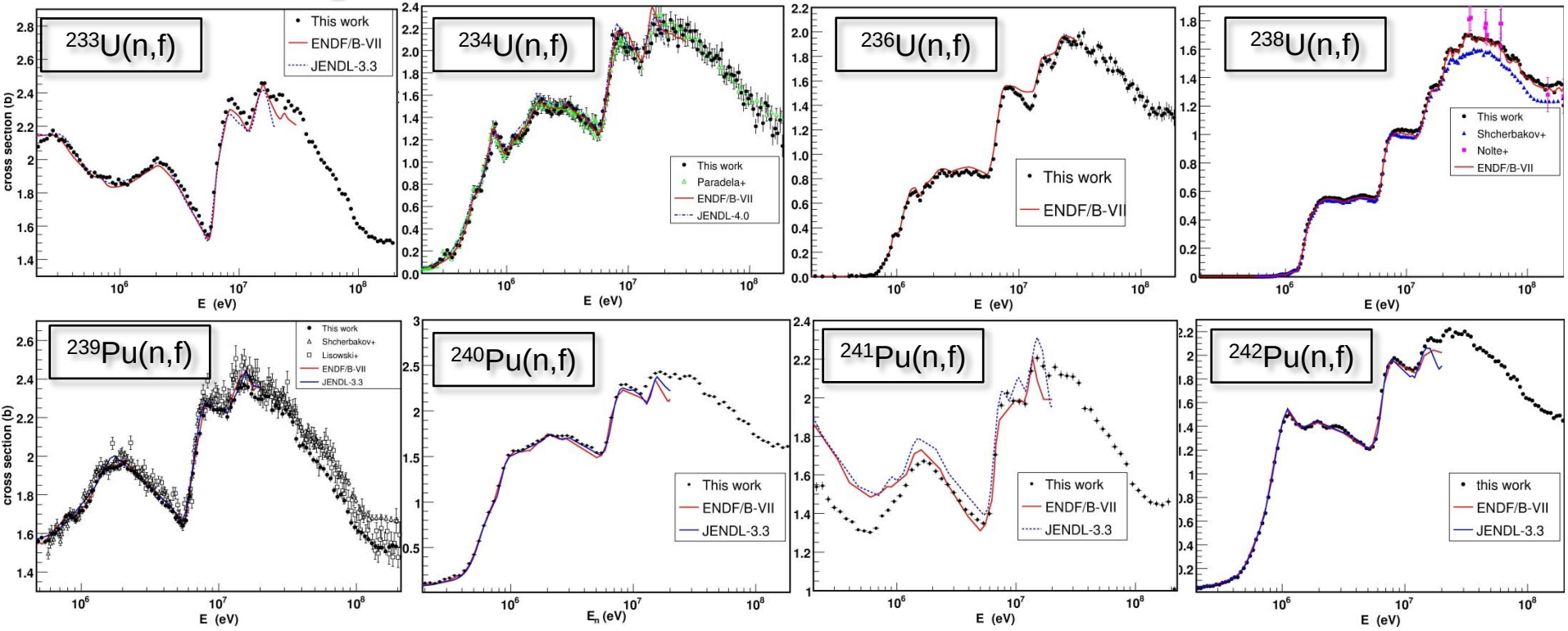


SPIDER
fission yields

APOLLO
ɣ-rays for ion beam experiments



Fission Cross Sections

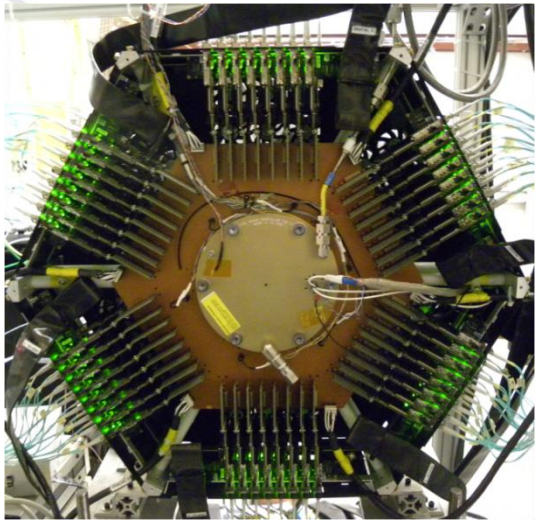


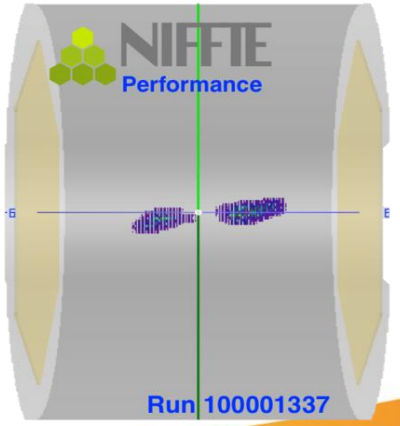
- **F. Tovesson**, A. B. Laptev, T. S. Hill, *Fast neutron-induced fission cross sections of ^{233,234,236,238}U up to 200 MeV*, accepted for publication in Nucl. Sci Eng.
- **F. Tovesson**, T. S. Hill, *Cross section for ^{239,241}Pu(n,f) in the range E_n= 0.01 eV to 200 MeV*, Nucl. Sci. Eng. **165**, 224 (2010).
- **F. Tovesson**, T. S. Hill, M. Mocko, J. D. Baker, C. A. McGrath, *Neutron Induced Fission of ^{240,242}Pu from 1 eV to 200 MeV*, Phys. Rev. C **79**, 014613 (2009).

The TPC will reduce measurement uncertainties to 1%

- **Beam**
  - Time-of-flight uncertainty 0.3%
  - Beam profile 0.1%
  - Neutron background 0.2%
- **Target**
  - Total number of atoms 0.3%
  - Uniformity of deposit 0.3%
  - Contaminants 0.1%
- **Fission detection**
  - Efficiency 0.1%
  - Dead-time 0.2%
  - Fission identification 0.2%
- **Normalization**
  - Accuracy of standard reaction 0.3%

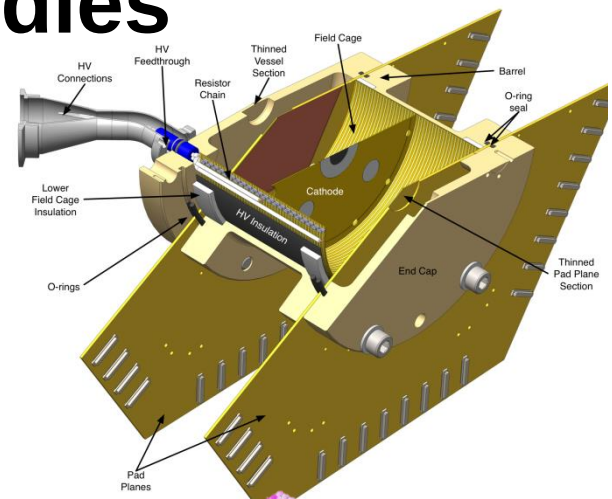
Total uncertainty: 0.7%

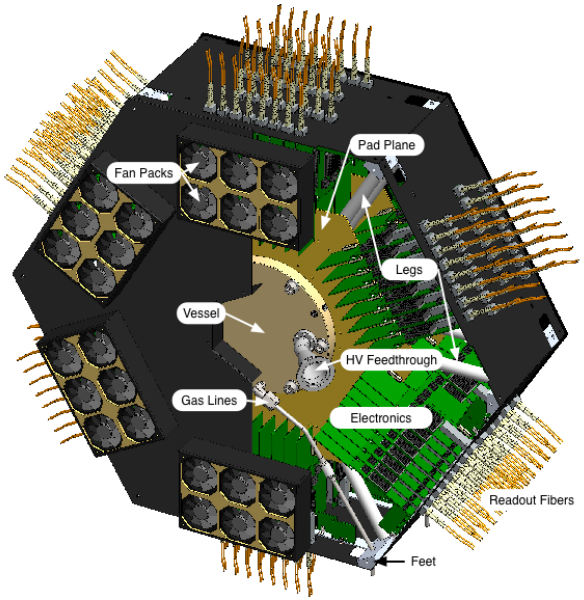


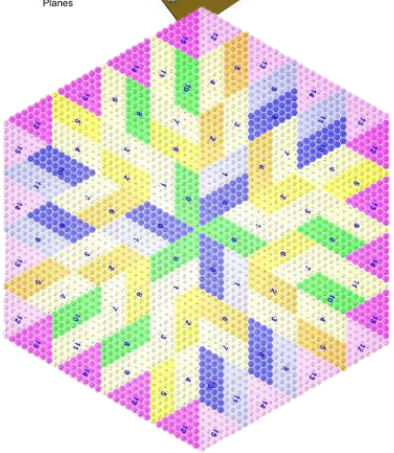


The fission TPC was miniaturized for fission studies

- ~4π solid angle coverage
- MICROMEGAS detector
  - 5952 readout pads
- Custom digital electronics
  - $55/channel, 30 MB/s sustained data rates
- Large dynamic range - designed for normalization to H(n,n)H
- Complete software suite includes remote online monitoring and detailed GEANT-based simulation







M. Heffner, D.M. Asner, R.G. Baker, *el al.*, *A Time Projection Chamber for High Accuracy and Precision Fission Cross Section Measurements*, **submitted to Nucl. Instr. and Meth**.

The U-238(n,f) cross section is our benchmark

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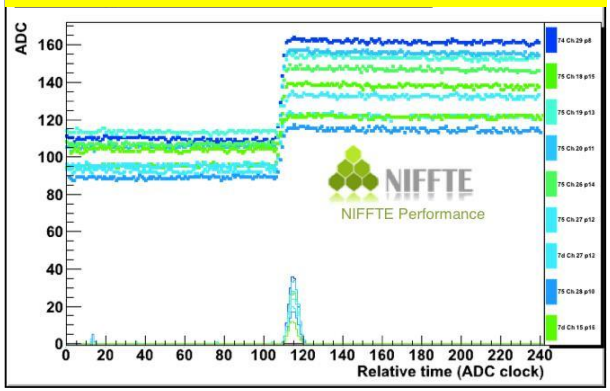
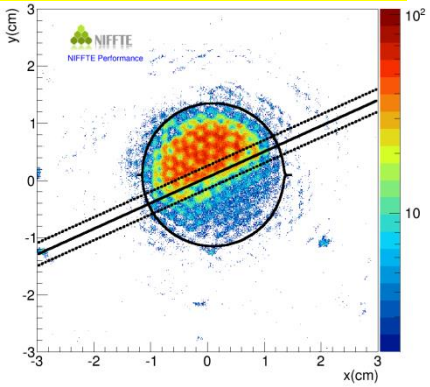
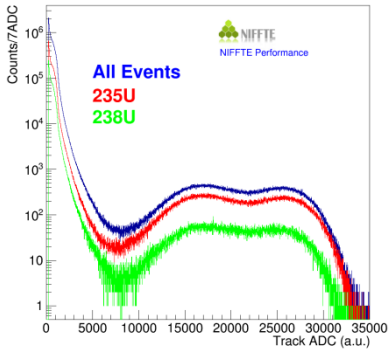
Unprocessed signals



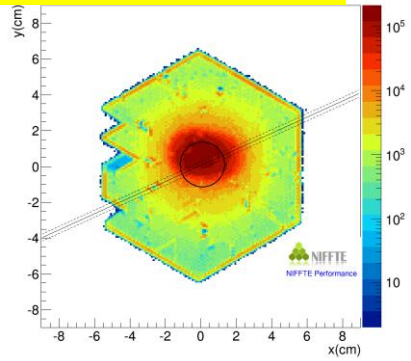
Autoradiograph



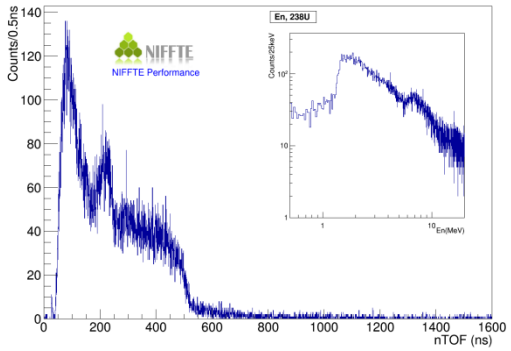
Fragment energy



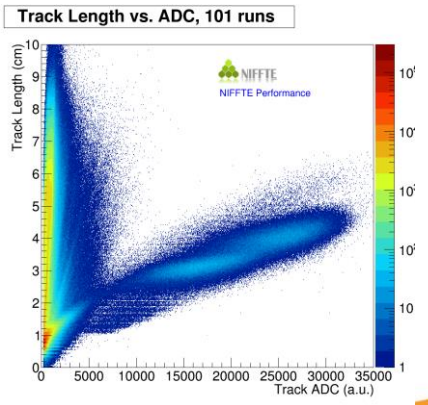
Beam profile



Neutron TOF



Track length vs energy



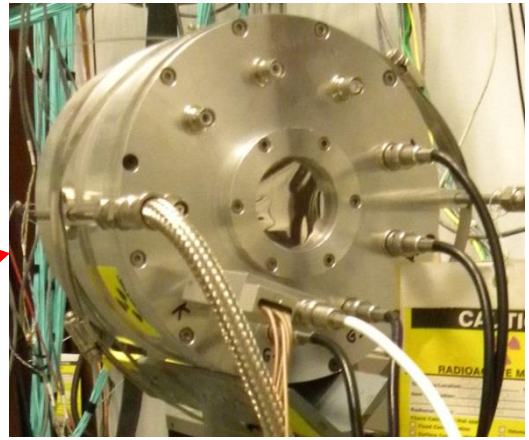
Fission fragment properties are studied with SPIDER and 2E

SPIDER (2E-2v)

High resolution, low efficiency

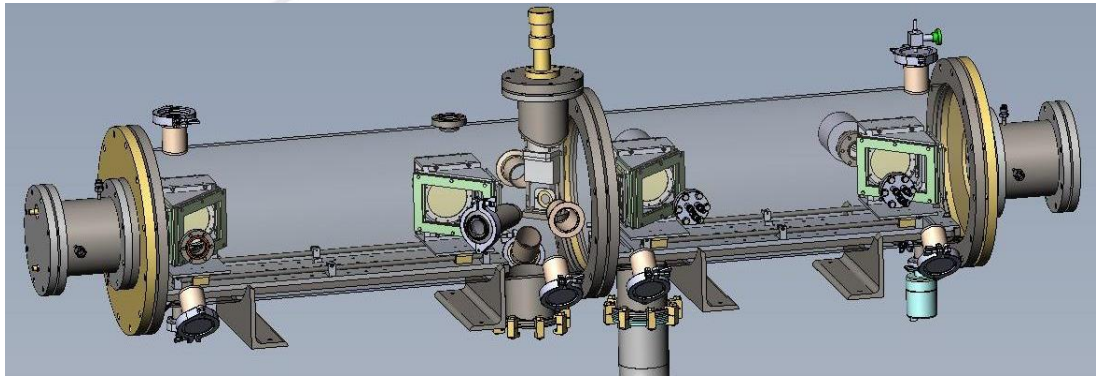
low resolution, high efficiency

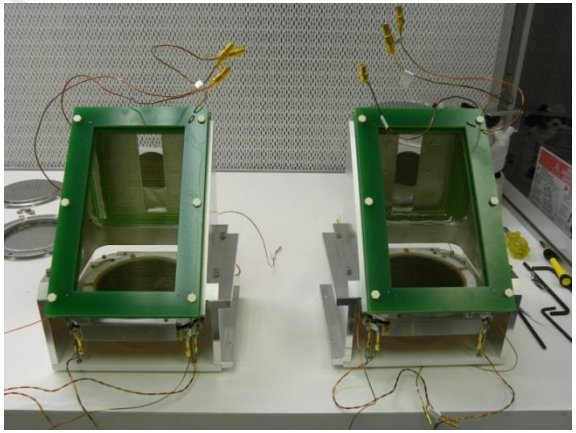
Gridded IC (2E)



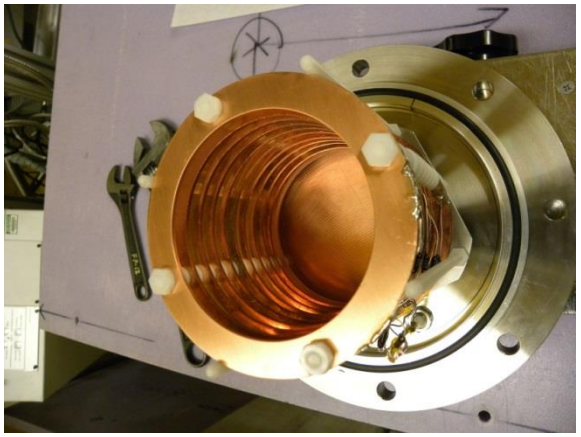
- Fragment mass, charge, energy
- Total kinetic energy (TKE)
- Neutron energy dependence

High resolution mass yields are measured with SPIDER



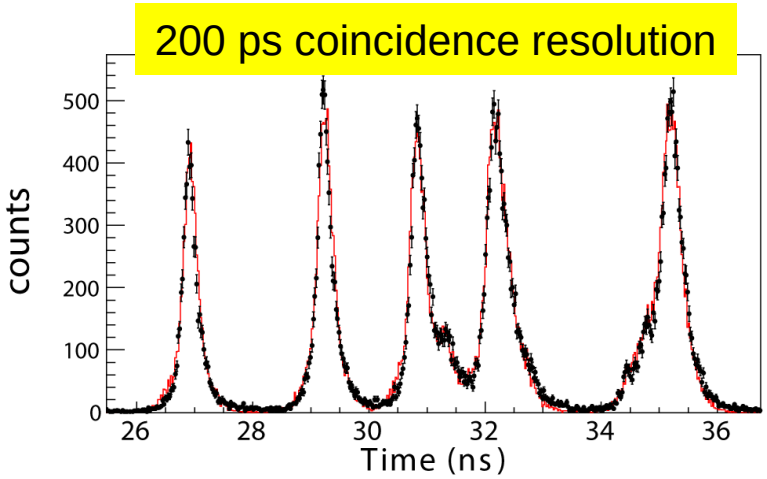


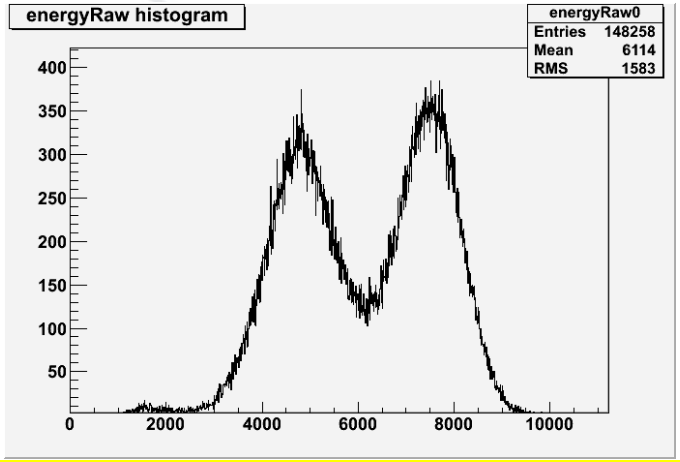
- The 2E-2v method can provide 1 amu resolution for light fragments
  - Demonstrated with Cosi-fan-Tutti at ILL
- SPIDER uses ionization chambers for energy measurement
  - 1% energy resolution for α-particles, 0.5% for fission fragments
  - Thin entrance window (mylar or SiN)
- Fast, position sensitive TOF detectors
  - Carbon conversion foils
  - Electrostatic mirror
  - Micro-channel plates
  - Delay-line anode



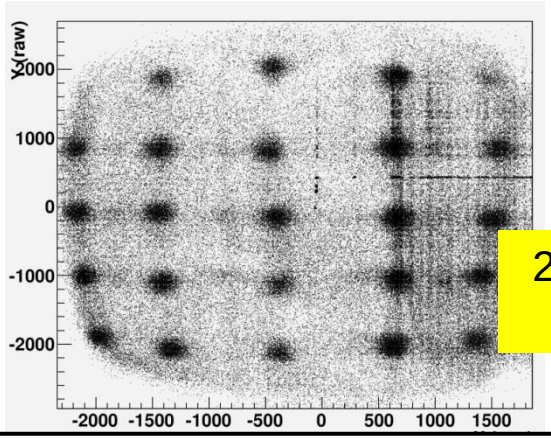
Performance of TOF detectors and ionization chambers meets requirements

200 ps coincidence resolution

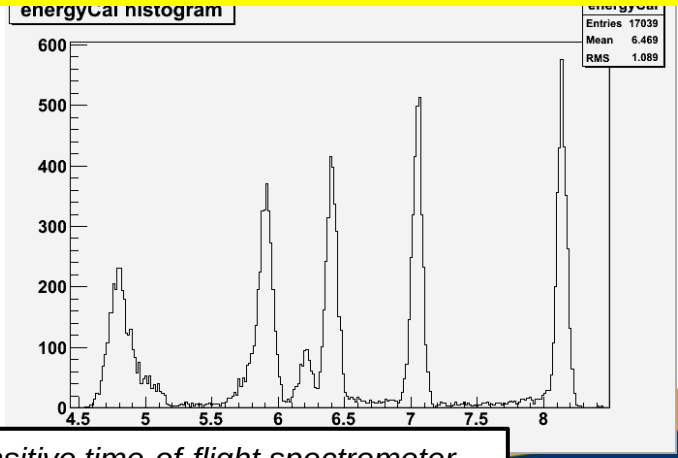




1% energy resolution for alpha-particles

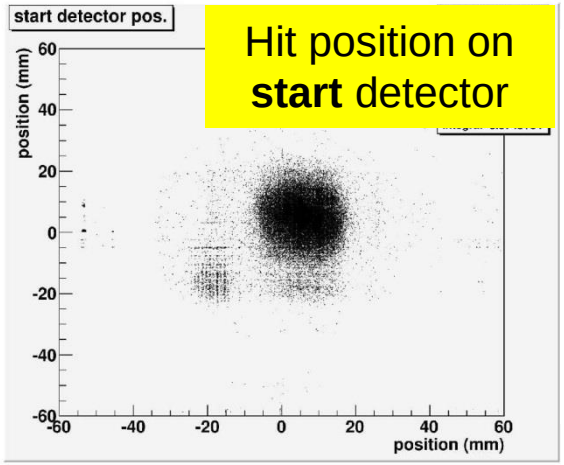


2 mm position resolution



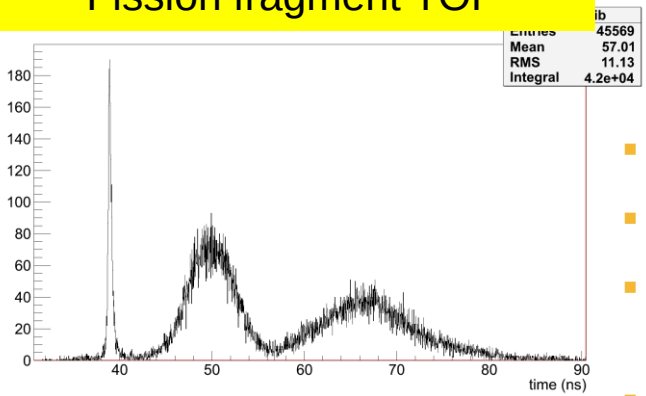
C.W. Arnold, F. Tovesson, K. Meierbachtol, *et al.*, *Development of position-sensitive time-of-flight spectrometer for fission fragment research*, **Nucl. Instr. and Meth. A 764, 53 (2014)**.

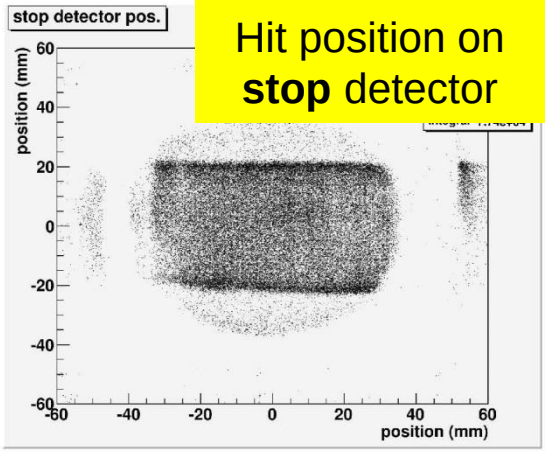
Mass yields in $^{252}Cf(n_{th},f)$ was measured with one arm instrumented



Hit position on **start** detector

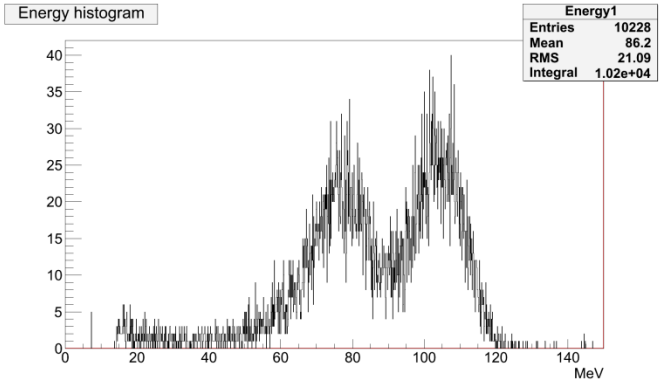
Fission fragment TOF





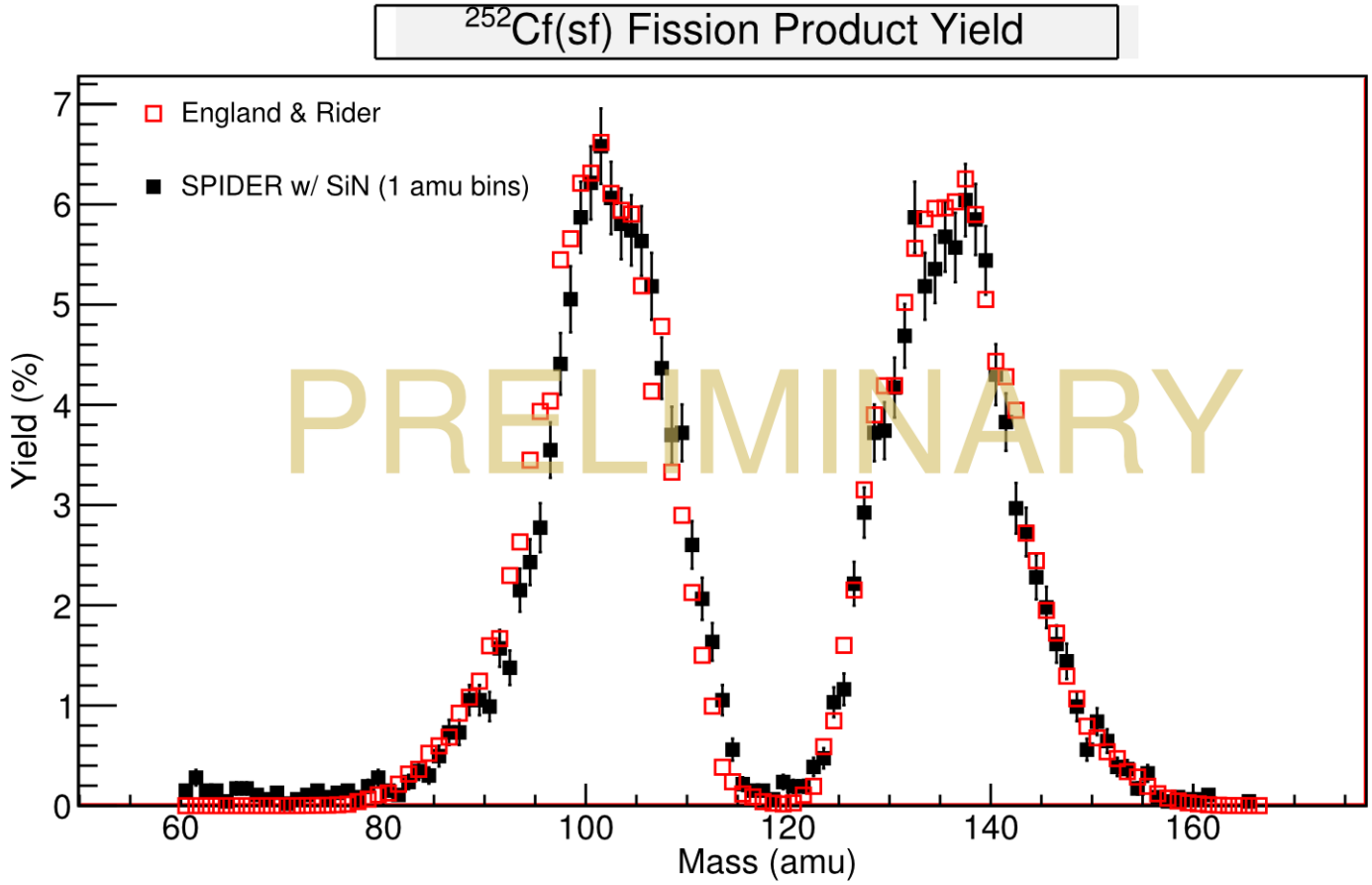
Hit position on **stop** detector

Fragment energy



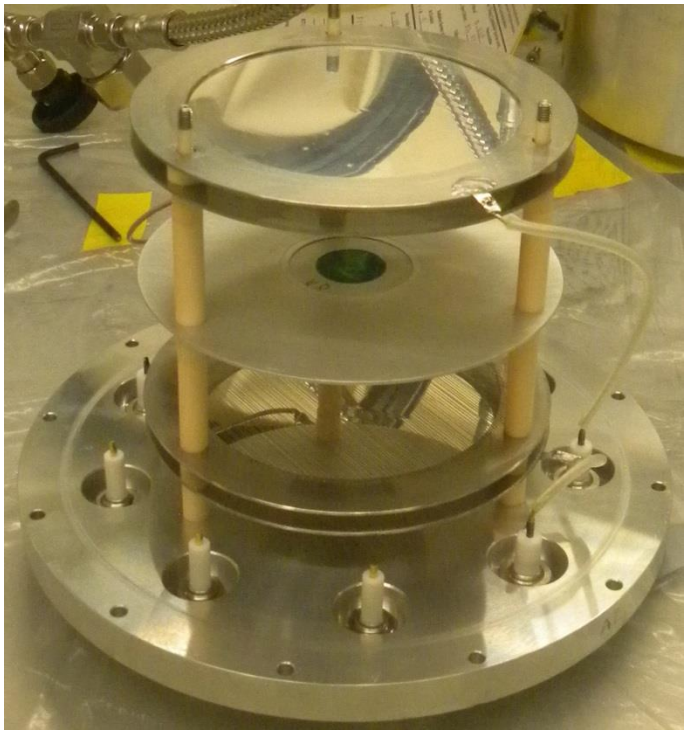
- 1E-1v
- 10^5 Bq ^{252}Cf source
- 20 μg/cm^2 carbon conversion foils for TOF measurement
- 64 μg/cm^2 Si_3N_4 window between vacuum and IC

Preliminary mass yield agrees well with literature

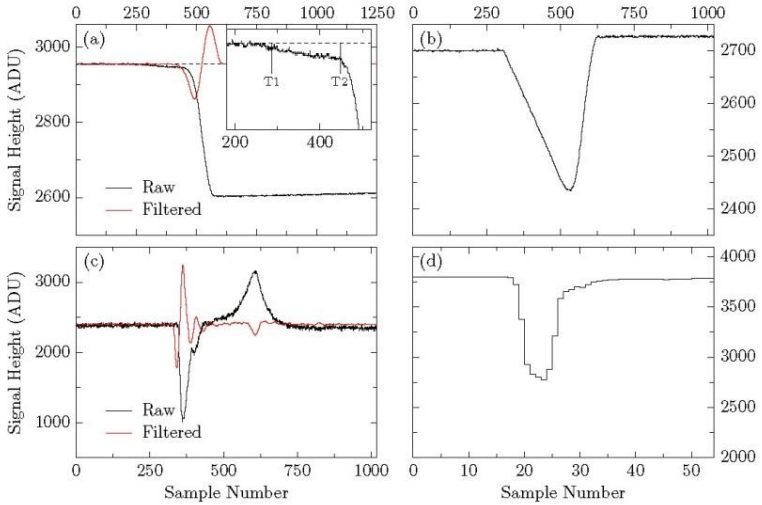


The 2E-method provides mass yields with 4-5 amu resolution

- Kinetic energy of both fragments are measured in coincidence
- The fragment masses are calculated using mass and momentum conservation
- Measurements performed with Frisch-gridded ionization chambers
  - High efficiency
  - Provide emission angle information
- Requires correction for
  - Grid inefficiency
  - Energy loss in target
  - Pulse height defect
  - Nu-bar(A) (“saw tooth”)



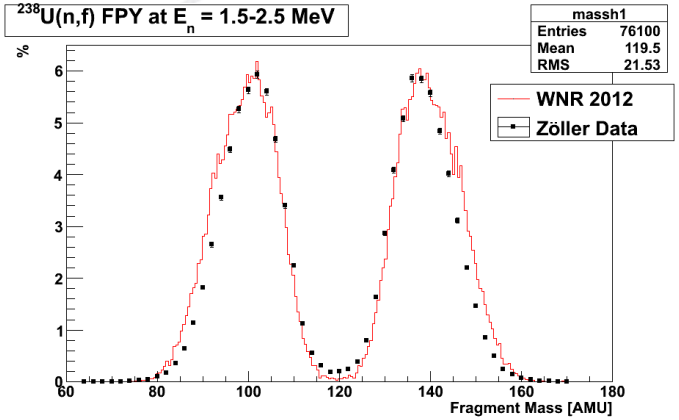
A new digital DAQ was developed for the IC measurements

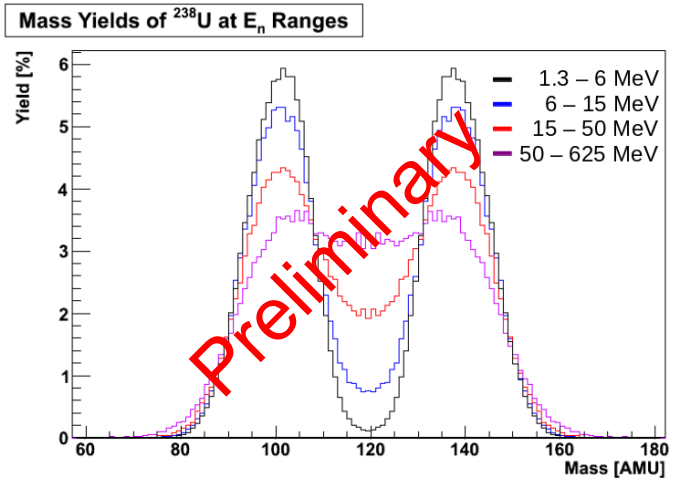


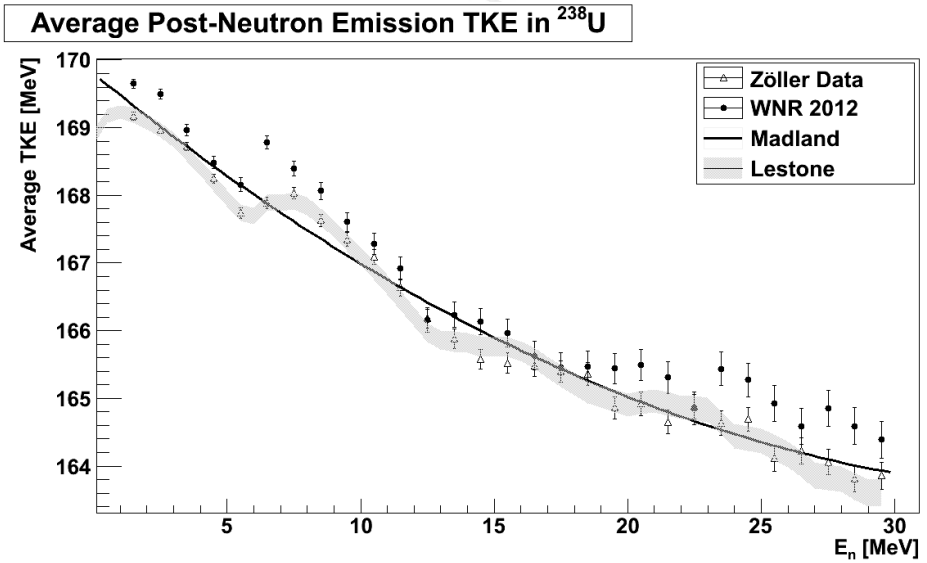
- The large neutron energy range poses a challenge for the DAQ system design
- 12-bit digitizers (CAEN V1720) with 250MHz sampling rates provide sufficient energy and timing resolution
- On-board memory and triggering management allows virtually dead-time less operation
- Digital signal processing allows for better pile-up handling

S. Mosby, F. Tovesson, A. Couture, D. Duke, V. Kleinrath, R. Meharchand, K. Meierbachtol, J. M. O'Donnell, B. Perdue, D. Richman, D. Shields, *A fission fragment detector for correlated fission output studies*, **Nucl. Instr. and Meth. A 757, 75 (2014).**

Mass yields and TKE were measured for ^{235,238}U







- Data was collected for U-235 and U-238, analysis in progress
- Plans to measure Pu-239 in fall 2014 / spring 2015

Future developments

- **Time Projection Chamber**
  - Further reduce fission cross section uncertainties
  - Fission fragment studies with Bragg spectroscopy and track length
  - Neutron-induced light charged-particle emission: cross sections and angular distributions
  - Ternary fission studies
- **SPIDER**
  - Study fission yields at fast neutron energies (increase efficiency)
  - Fission fragment studies of several isotopes
  - Correlation between fragments and neutron- and gamma emission

Summary

- The LANSCE facility provides the capability to study fission over ten decades of incident neutron energy
- Fission cross section have been studied extensively at LANSCE; the Time Projection Chamber will significantly improve the accuracy
- Fission fragments properties are being studied by a combination of high resolution, low efficiency and low resolution, high efficiency detectors
- Future developments will further reduce uncertainties on nuclear data and provide a more complete picture of the fission process

Collaborations

NIFFTE

Lawrence Livermore Nat. Lab.

Abilene Christian University

SPIDER

Oregon State

Cal Poly

Colorado School of Mines

UNM