70 YEARS OF CREATING TOMORROW

Los Alamos NATIONAL LABORATORY

A new capability for fission fragment spectroscopy at LANSCE

Fredrik Tovesson
Los Alamos National Laboratory

LA-UR-13-23697

UNCLASSIFIED

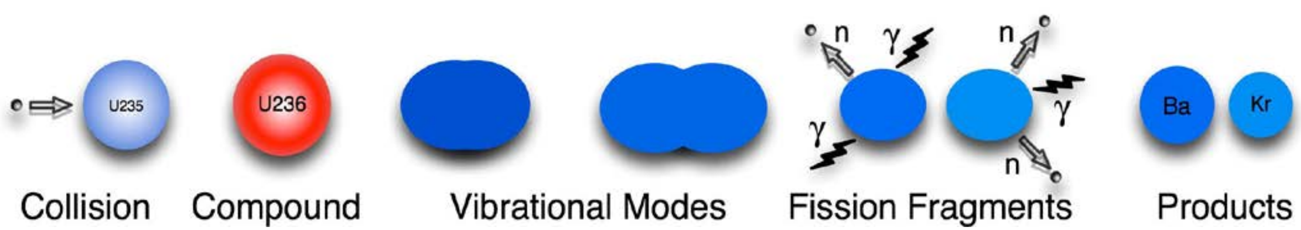
NNSA National Nuclear Security Administration

Outline

- Motivation
- Los Alamos Neutron Science Center
- Detector development
- Performance testing
- Timeline
- Conclusions

Introduction

- Fission fragments provide insight into the process in which they are formed
  - Different theoretical models describing the fission process are actively being developed, and fission yield prediction is an important test for those models
  - Correlation between A, Z and TKE are important to improve modeling. There is only limited experimental information on such correlations
  - New model describing fragment de-excitation using a Monte Carlo approach need (M,TKE) distributions as input
- Fission yields are useful for applications
  - Used to infer the number of fissions in reactor fuel (burn-up)
  - Used to calculate the source term for spent fuel waste stream analysis



SPIDER project
- goals and anticipated results

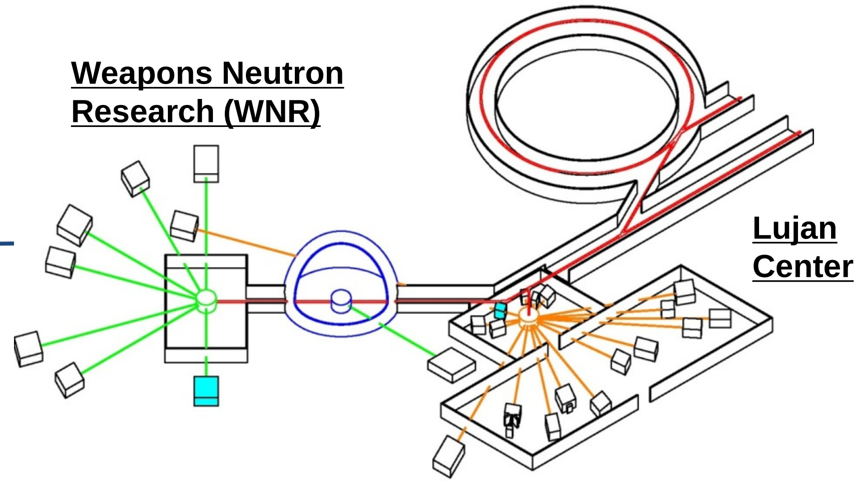
- Measure fission-fragment yields as a function of (En, Z, A, TKE)
  - Good thermal data exist but the incident energy (En) dependence remains unknown
  - Our measurements will reach 2-5% accuracy from 0.01 eV to 20 MeV
- Develop theory in order to evaluate fission yield data
  - Based on the LANL nuclear potential-energy model
  - Langevin equations for inertial and dissipation effects will be used to model the dynamic evolution of fission across the potential-energy surface
  - Experimental data will be used to probe the initial conditions
- Provide an evaluation of the Pu-239 fission yields
  - Evaluation blends the best of experiment and theory to provide complete data
  - Provide a definitive answer regarding the energy-dependence of Nd-147 yield

The Los Alamos Neutron Science Center (LANSCE)

Isotope Production

Proton Radiography

UCN Experiment



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

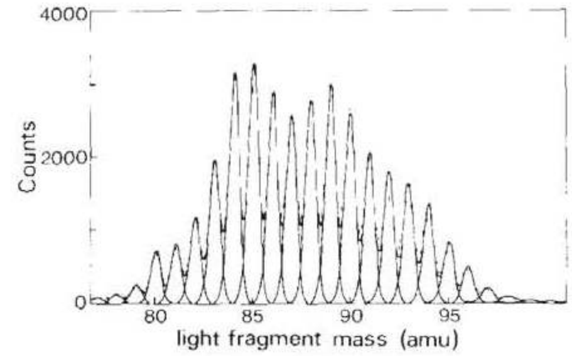
The 2E-2V method

- Time-of-flight approach to fission fragment spectroscopy
  - Mass is obtained by measuring energy and velocity
- First demonstrated in the 1980s at ILL
- <1 amu mass resolution of light fragments
- ~1 unit charge resolution for light fragments
- (A,Z,TKE) yields for both fragments
  - Significant info… ut the fission process

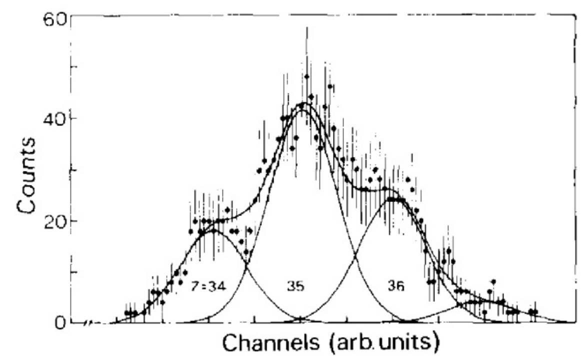
$$M = \frac{2Et^2}{l^2}$$

$$\frac{\delta M}{M} = \sqrt{\left(\frac{\delta E}{E}\right)^2 + \left(2\frac{\delta t}{t}\right)^2 + \left(2\frac{\delta l}{l}\right)^2}$$

FPY measured with COSI-FAN-TUTTE

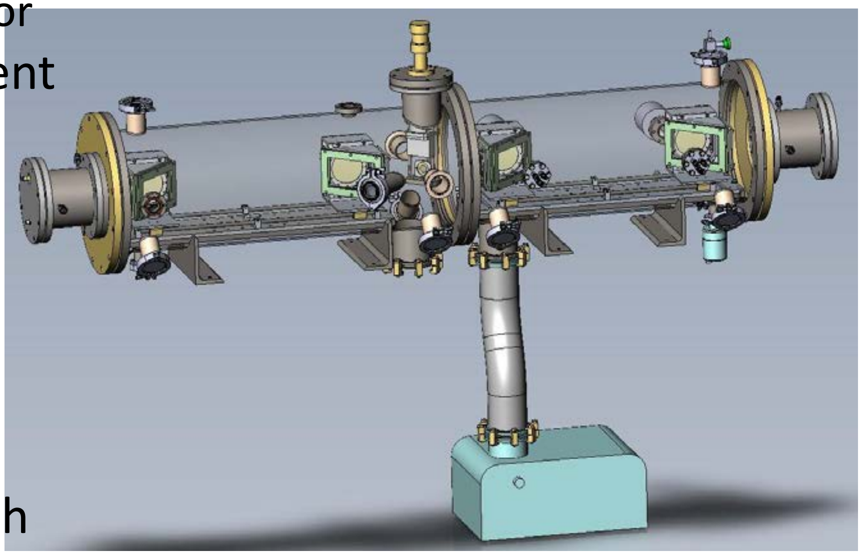


Nuclear charge distribution for A=87

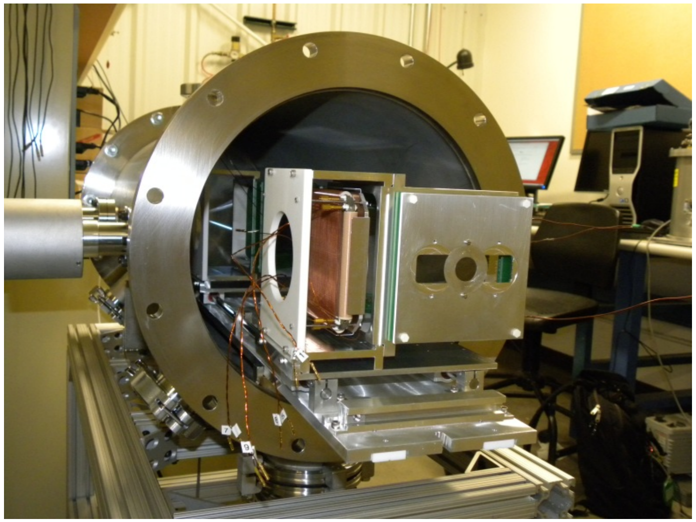


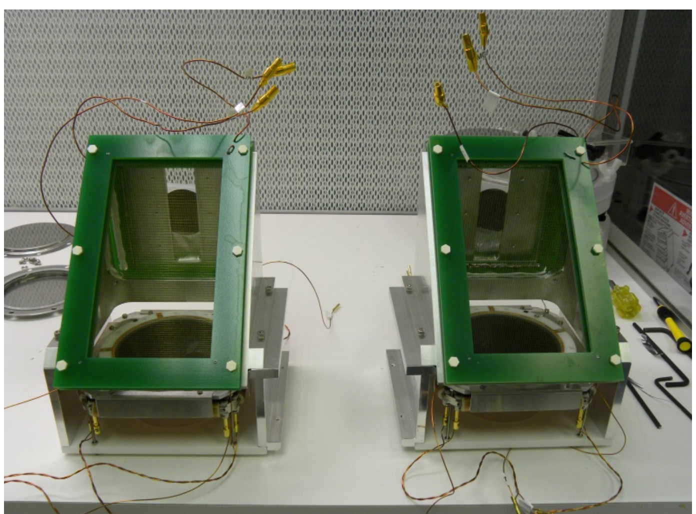
SPectrometer for Ion DEtermination in fission Research (SPIDER)

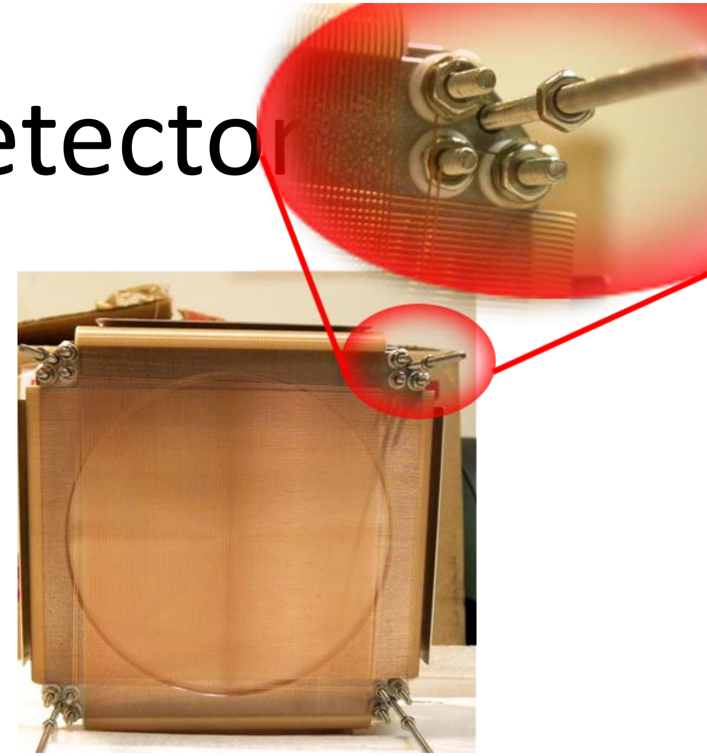
- Based on the 2E-2V method
- Time-of-flight
  - MCP-based time pick-offs with electrostatic mirrors
  - ~100ps (FWHM) resolution per detector
- Energy and nuclear charge measurement
  - Ionization chambers
  - 0.5-1.0% energy resolution for fission fragments
  - dE/E measurement to determine nuclear charge
- Multiple detectors to increase efficiency
- Position resolution to reduce flight path length flight path uncertainty



Time pick-off detector



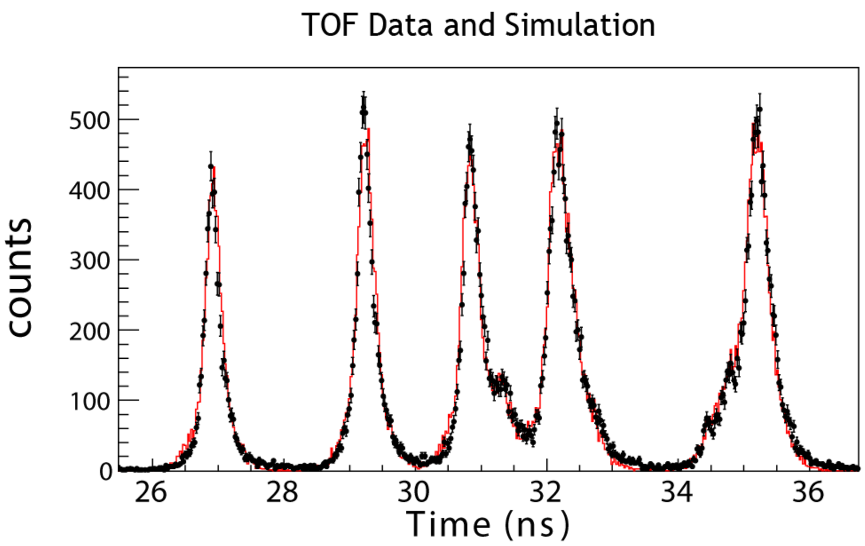


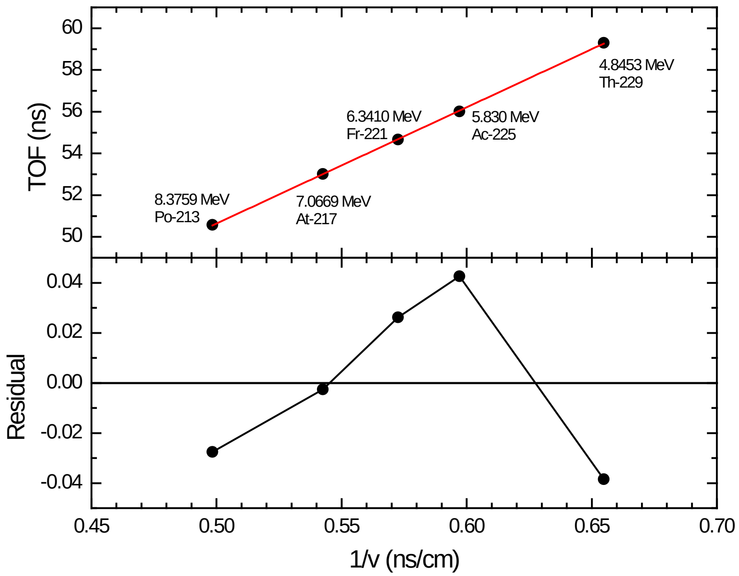


- 52 cm flight path
  - Distance between conversion foils
- Micro channel plates (MCP)
  - Chevron configuration
  - 12 µm channel diameter = fast timing
- RoentDek Delay anode
  - (x,y) position readout
  - 1-2 mm resolution achieved with similar arrangement

Ion time-of-flight resolution

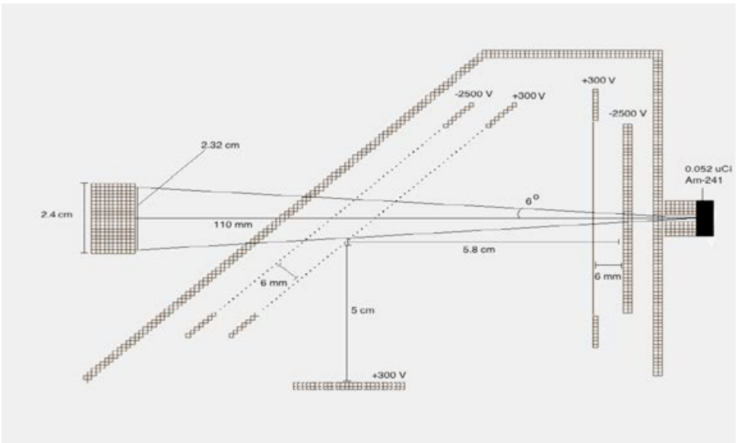
- Th-229 α-source
- Five main α-lines with energies between 4.8 and 8.4 MeV

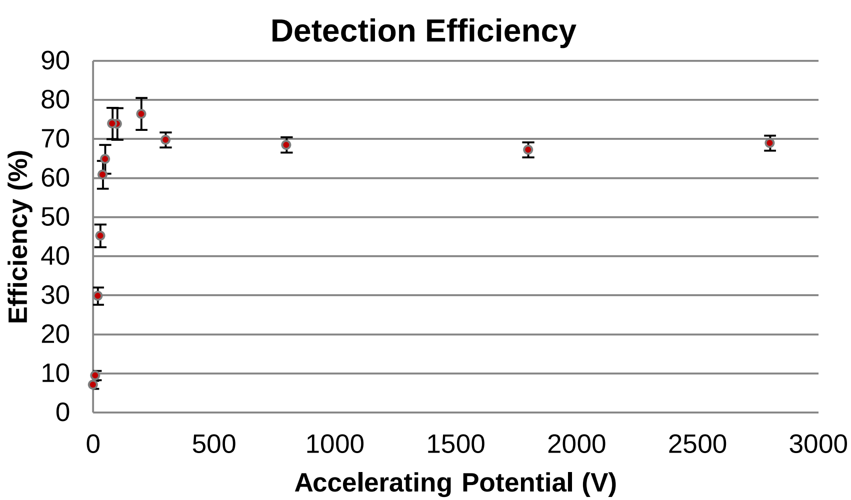




- Temporal resolution **Δ**t=190ps (FWHM)

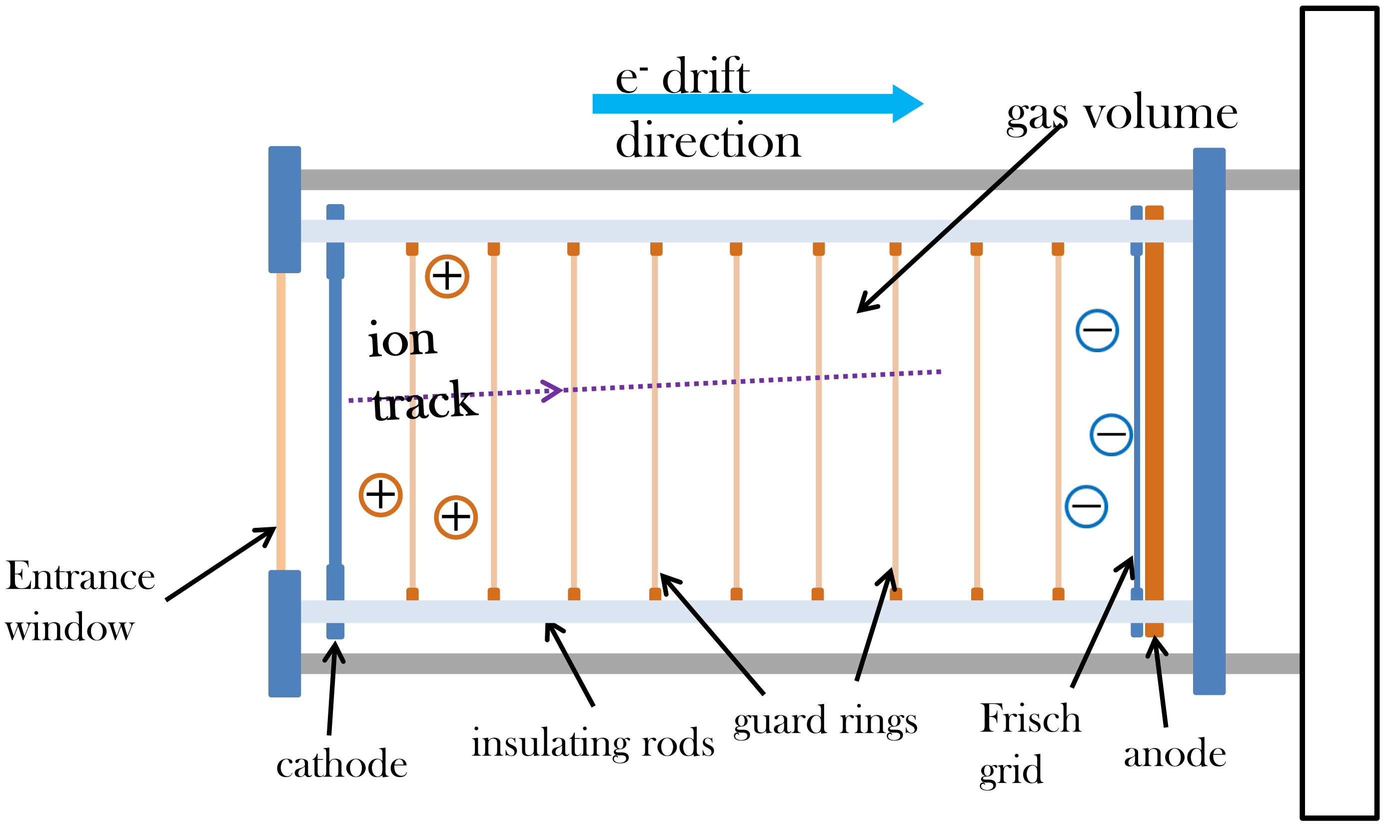
Time-pick detector efficiency





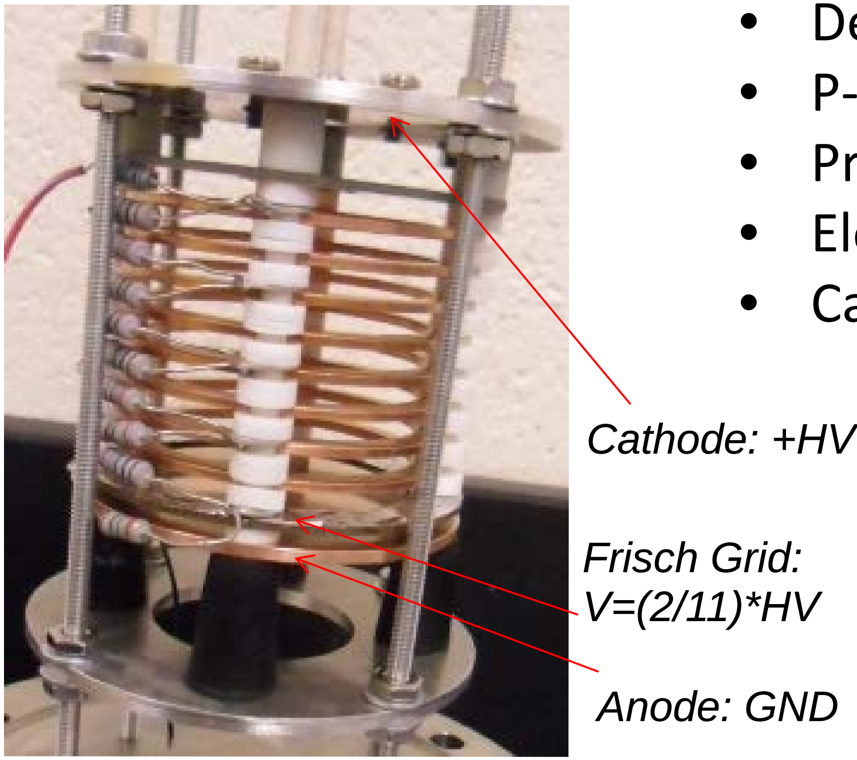
- The efficiency of the TOF detectors is about 70% for α-particles
- Based on previous work we expect the efficiency for fission fragments to be significantly higher
- The efficiency is not very sensitive to the accelerating potential
  - Neither is the temporal resolution
  - However, the spatial resolution should be (needs to be investigated)

Ionization chambers

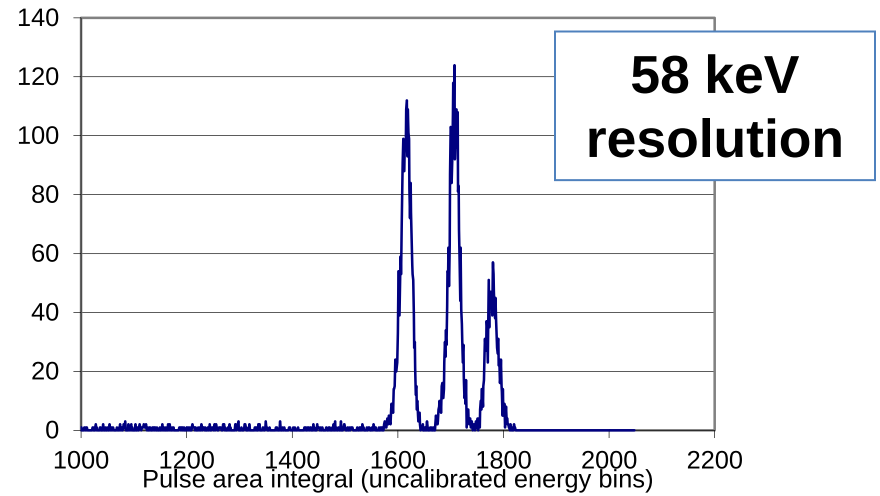


- Axial design
- Thin entrance window

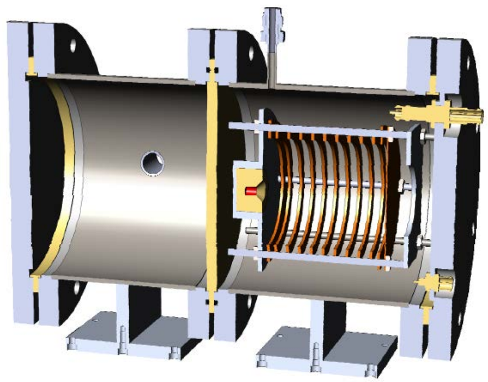
First ionization chamber prototype



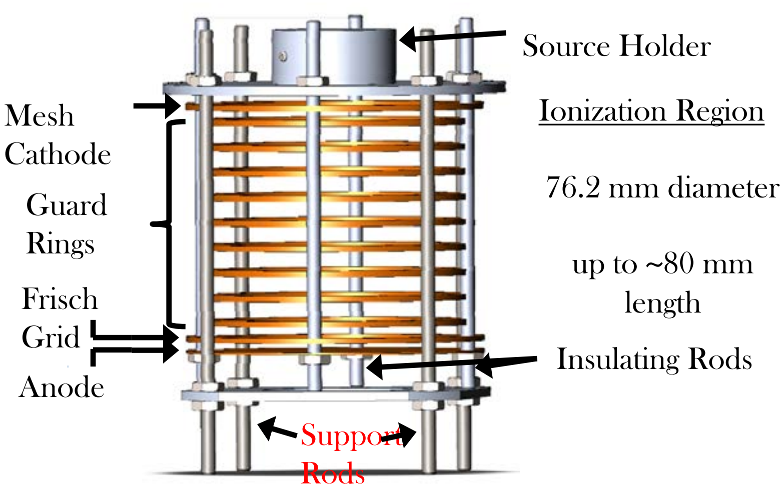
- Developed by UNM
- P-10 Gas (90% Ar + 10% CH_4)
- Pressures from 500-760 Torr
- Electric field from 10-15 V/mm
- Cathode to Frisch grid: 81 mm

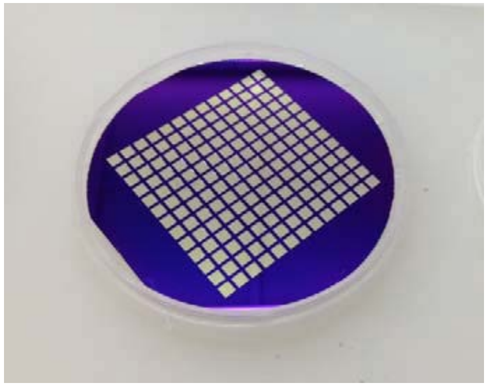


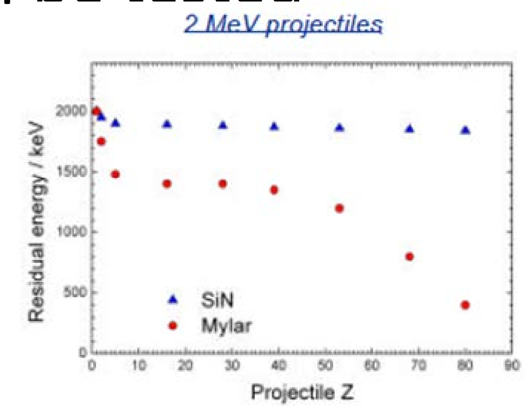
Second ionization chamber prototype



- Chamber is assembled and testing has been initiated
- SiN_3 windows with thicknesses of 100 nm (34 ug/cm^2) and 200 nm (68 ug/cm^2) will be tested

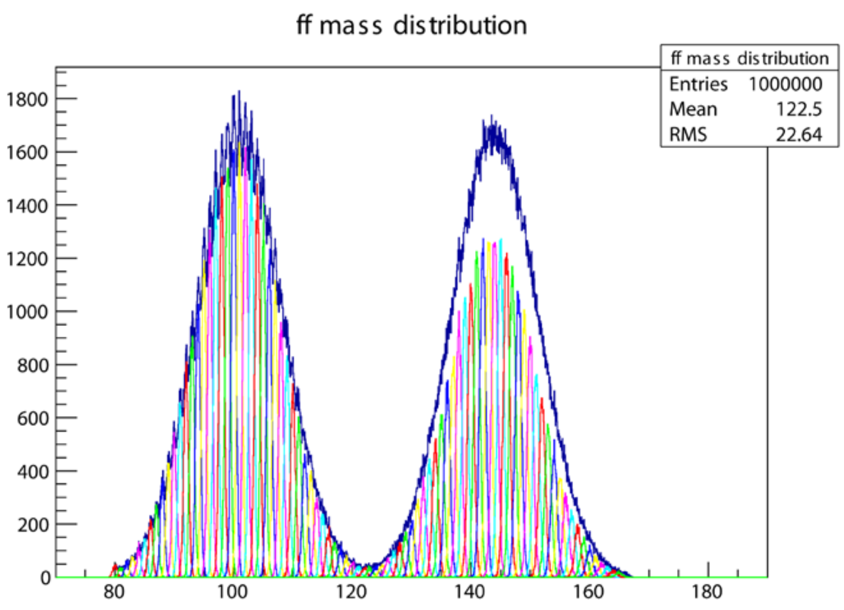


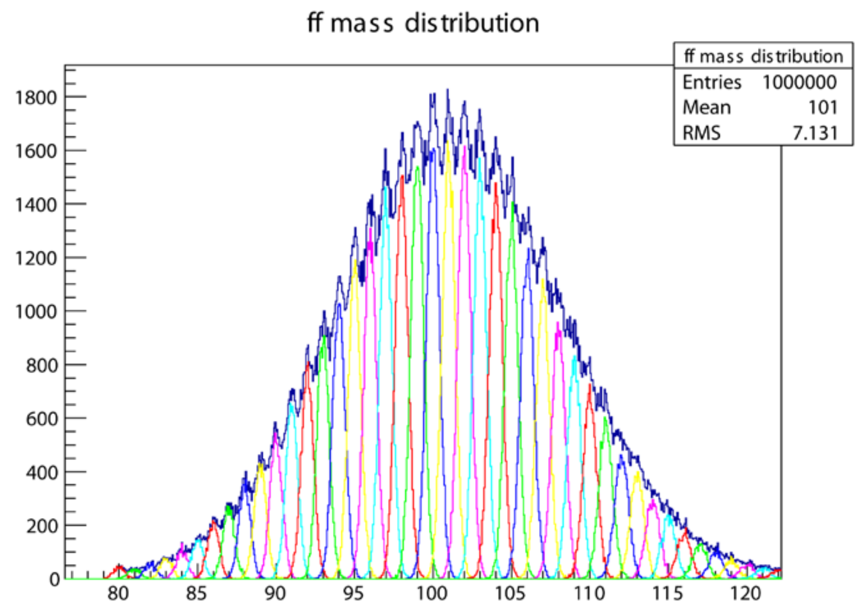




Residual energy after passing entrance window

Simulated mass yield

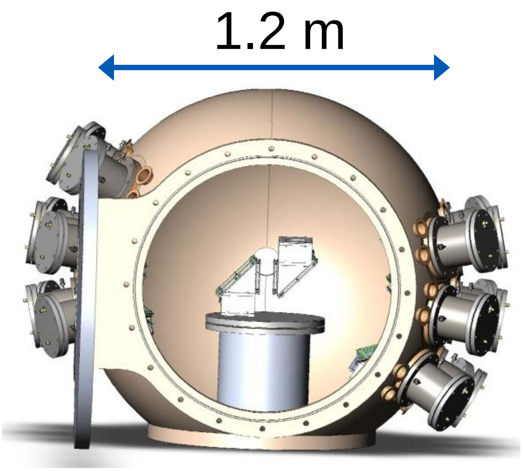


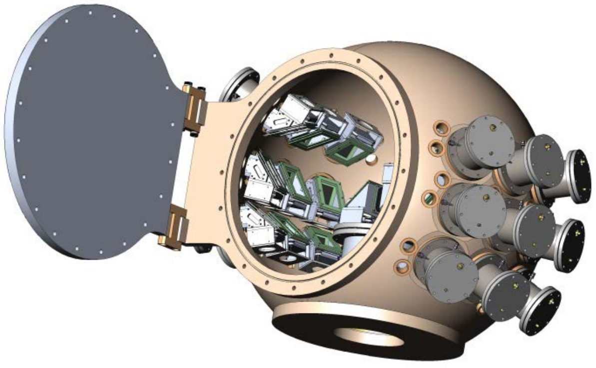


- The mass resolution was simulated based on experimentally determined temporal resolution and expected energy resolution
- With 60 cm flight path ~1 amu resolution for light fragments are expected

Full Scale SPIDER

- Multiple detectors increases efficiency
- Current design calls for 9 arm pairs
  - 36 timing detectors
  - 18 ionization chambers
- System Challenges
  - large high vacuum (10^{-7} torr) volume
  - 18 vacuum - gas detector interfaces
  - Flowing gas system to 18 separate chambers





Timeline

- Dual-arm spectrometer completed August 2013
- Thermal fission yields for U-235 and Pu-239
  - Beam experiments Sept.-Nov. 2013
  - Preliminary results March 2014
  - Finalized mass yields August 2014
- Fast-neutron induced fission yields for U-235 and Pu-239
  - Complete scaled-up of spectrometer August 2014
  - Beam experiments in 2014 and 2015
  - U-235 mass yields (E = 1 - 15 MeV) in 2015
  - Pu-239 mass yields (E = 1 - 15 MeV) in 2016

Conclusions

- A new instrument for fission yield measurements is being developed
  - First beam experiment planned for later this year
  - Thermal yields of U-235 and Pu-239 will be measured
- First performance tests of the detectors have been performed
  - Ionization chamber provide sufficient energy resolution
  - Time pick-off detectors performance meet requirements
    - 190 ps (FWHM) coincidence resolution
    - <1 cm position resolution
- A scaled up detector array is the next step
  - Would allow for measurements of fast neutron-induced yields
  - 8-10 arm pairs are foreseen

The SPIDER Collaboration

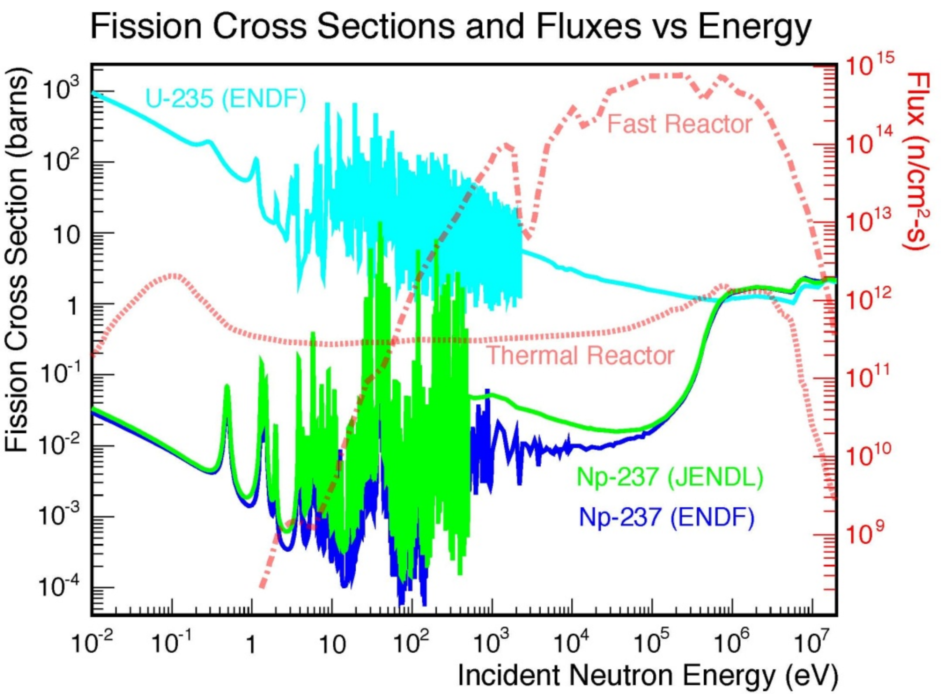
- Los Alamos National Laboratory (LANL)
  Charles Arnold, Todd Bredeweg, Tom Burr, Matt Devlin, Mac Fowler, Marian Jandel, Justin Jorgenson, Alexander Laptev, John Lestone, Paul Lisowski, Rhiannon Meharchand, Krista Meierbachtol, Peter Moller, Ron Nelson, John O'Donnell, Brent Perdue, Arnie Sierk, Fredrik Tovesson, Dave Vieira, Morgan White
- University of New Mexico (UNM)
  Adam Hecht, Rick Blakeley, Erin Dughie, Drew Mader
- Colorado School of Mines (CSM)
  Uwe Greife, Bill Moore, Dan Shields, Sergey Ilyushkin
- Slovak Academy of Sciences (SAS)
  Jan Kliman
- Lawrence Livermore National Laboratory (LLNL)
  Lucas Snyder
- Lawrence Berkeley Laboratory (LB
  Jorgen Randrup

Outline

- The need for high precision differential fission cross sections
- The Fission Time Projection Chamber (TPC) program review
- Recent TPC highlights
- Future plans

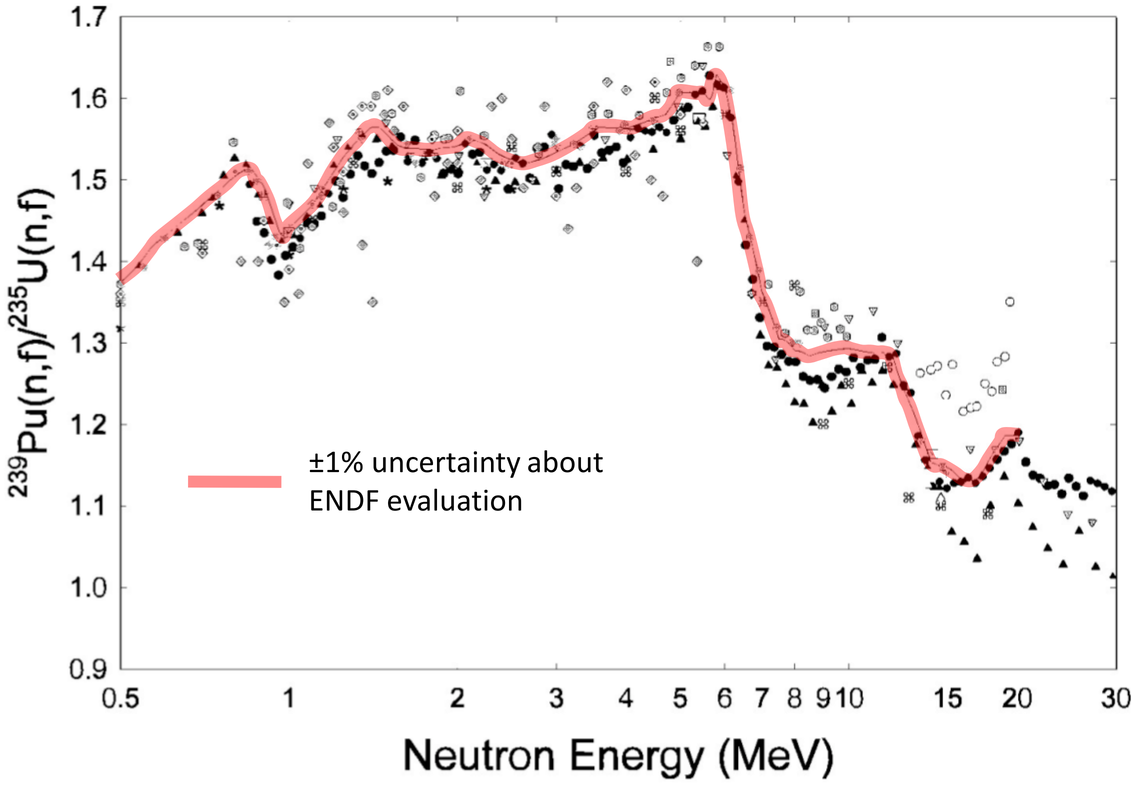
Future fuel cycle benefits from precision fission data

- Reactor design and operation margins are driven by nuclear data uncertainties
- Fast system sensitivity studies reveal sub-percentage fission cross section data are needed
  - High fast flux requires lower uncertainties in data (sub-percent!)
  - Reduction in uncertainties require unprecedented information
- Fission theory development requires high precision kinematic information
  - Fission dynamics is the next frontier



DOE is making investments to deliver unprecedented fission cross section data

Pu-239 (n,f) data and evaluations

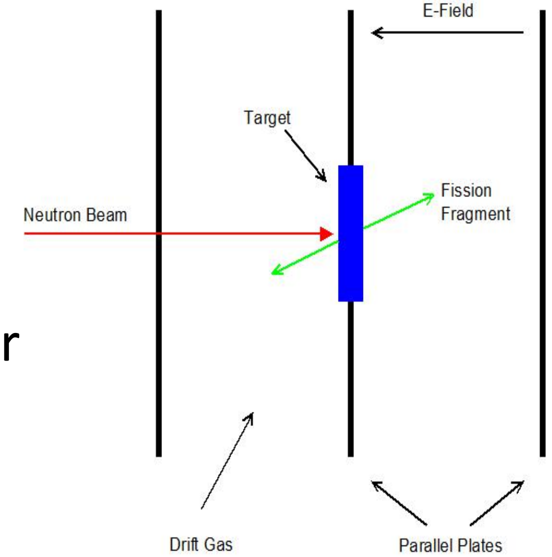


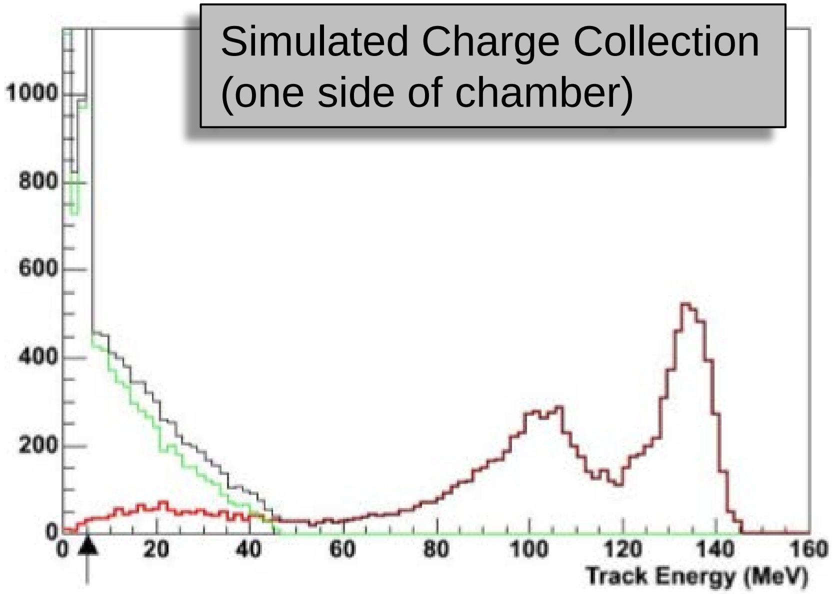
See Denise Neudecker's talk (FC 2)

Precision data and insights into systematic uncertainties can improve existing evaluations

Traditional fission chamber

- Operates on basic principles of ionization chamber
- Relatively simple, cheap and robust
- Count fission events
- Many systematic uncertainties folded together
  - Target + beam non-uniformities, Particle identification, angular dependencies…





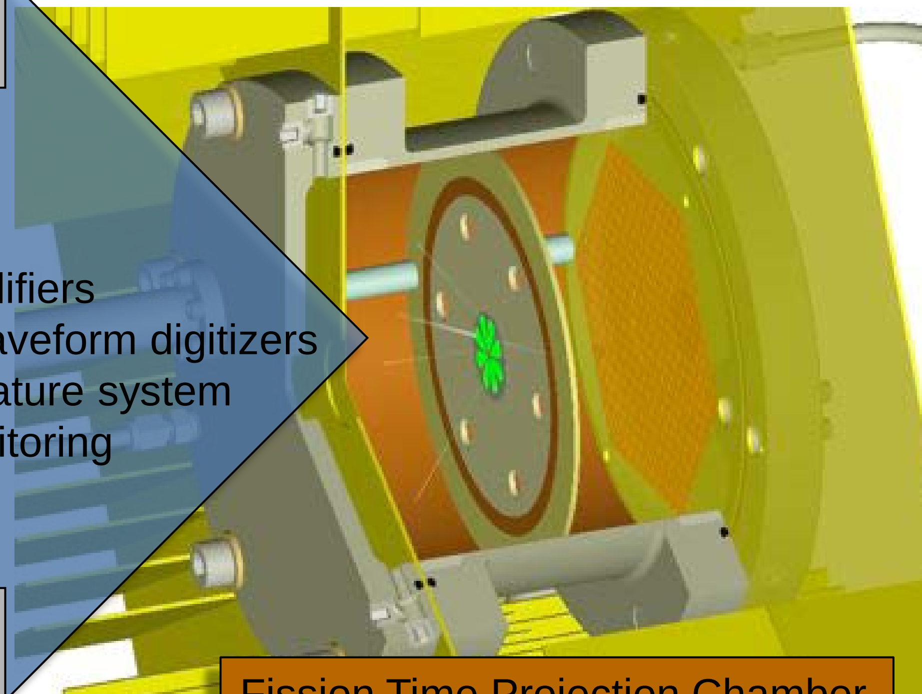
Simulated Charge Collection (one side of chamber)

Gridded Frisch chamber

Fission chamber + tracking → Fission TPC

Gridded Frisch chamber

Precision field cage
Segmented anodes
Micromegas gas amplifiers
Custom amplifiers, waveform digitizers
Precision gas/temperature system
Advanced online monitoring
Advanced software



Fission Time Projection Chamber

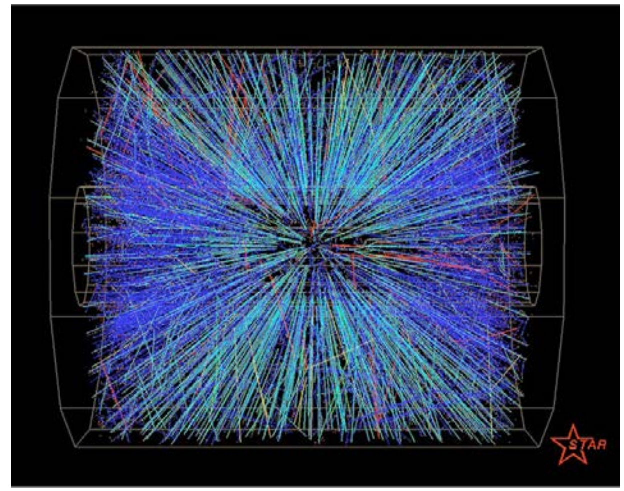
- ~2 words/event * ~100 Hz rates

See Sean Stave's talk for DAQ details (DA 5)

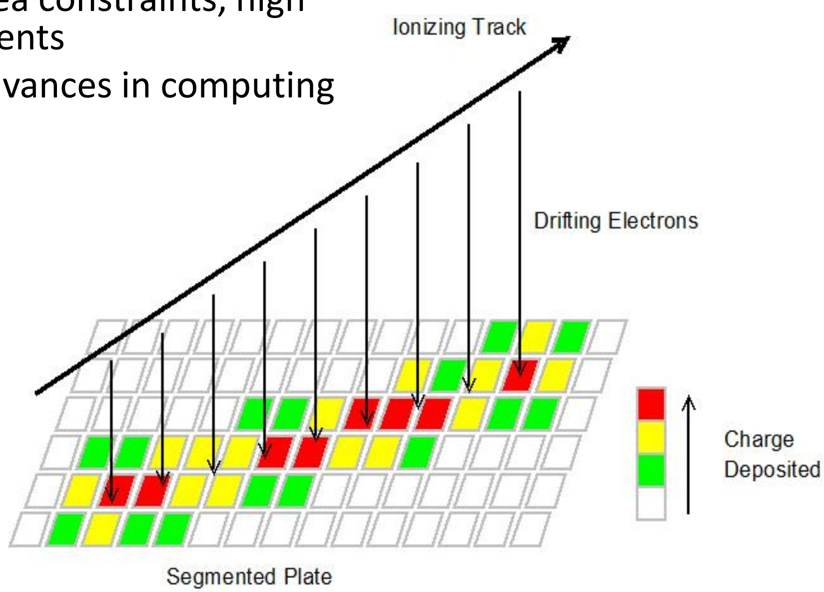
- 6000 channels @ 65 MHz is **~1 TB per second**
- Fully reconstructed charged particle trajectories in 3D that include dE/dX information

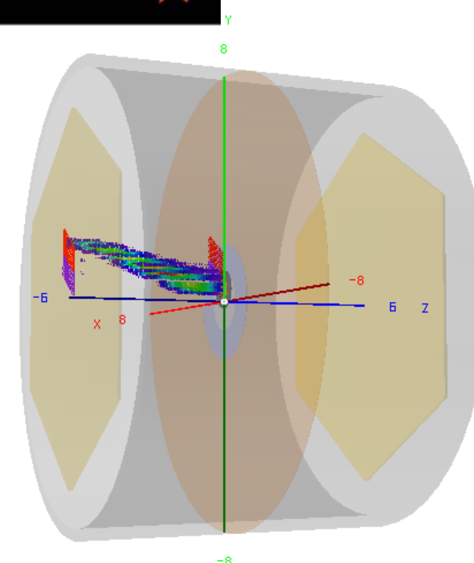
TPCs have been invaluable tools

- Used in high-energy physics for ~30 years
  - Provide 3-D “pictures” of charged particle trajectories



- Miniaturized for fission measurements
  - Small volume and area constraints, high bandwidth requirements
  - Enabled by recent advances in computing and electronics

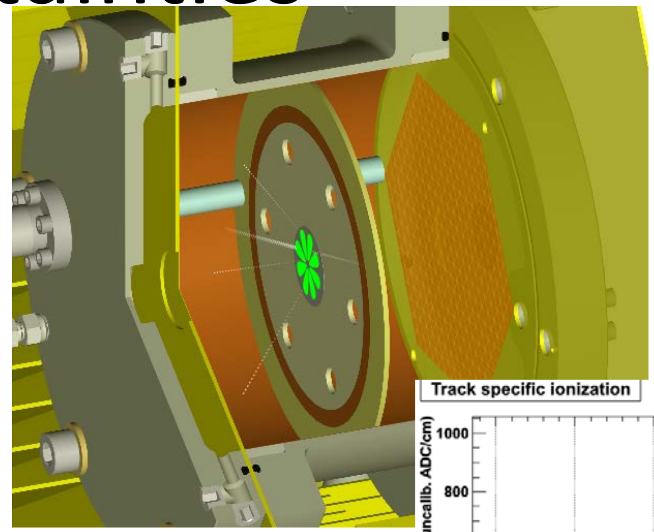


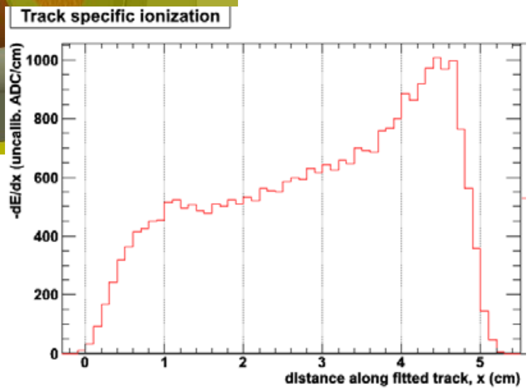


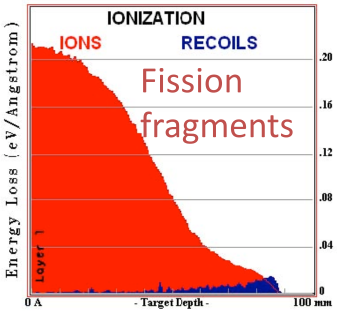
Fission TPC will quantify systematic uncertainties

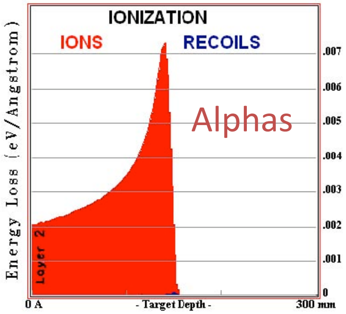
- Particle identification
  - Tracking of both fission fragments
  - Random, alpha backgrounds removed
- Target and beam non-uniformities
  - Radiography with alpha decay
  - Multi-actinide targets
- Thin backings
  - Minimize straggling losses
  - Reduce beam interaction backgrounds
- Reference standards
  - (will be) Filled with H_2 gas to measure (n,f) relative to (n,p)

See Walt Loveland's talk on targets (DA-3)

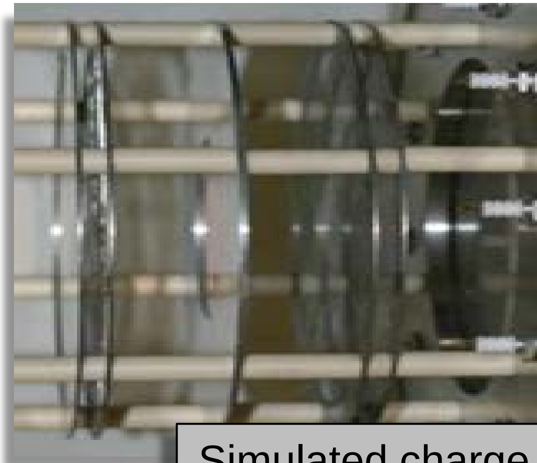


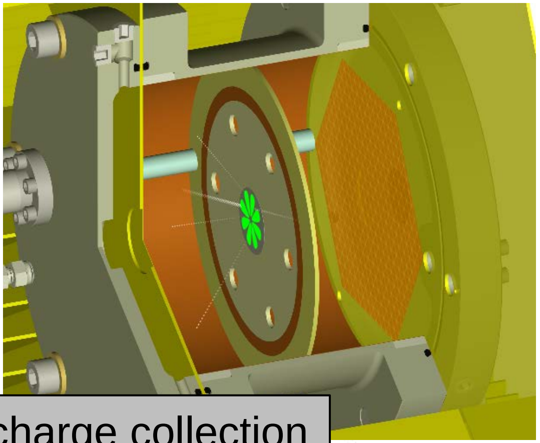




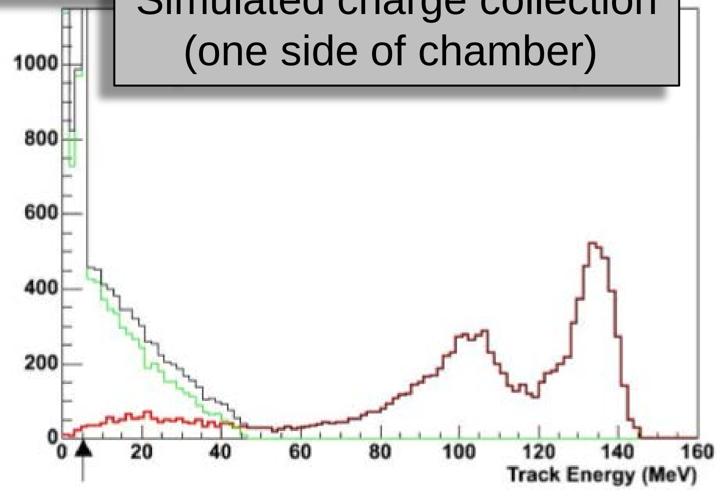


Simple comparison of fission chamber and TPC

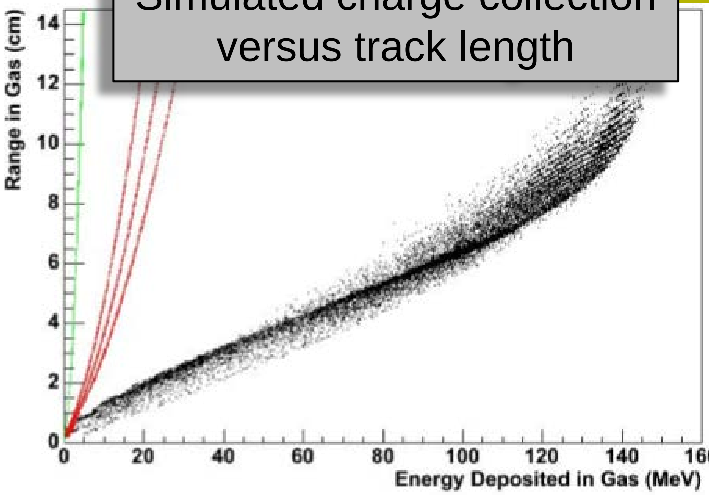




Simulated charge collection (one side of chamber)



Simulated charge collection versus track length



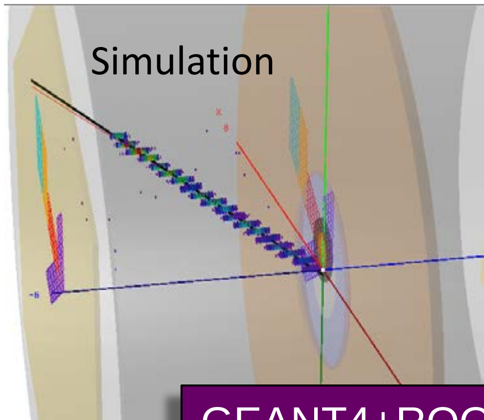
Simple example of how 3-D track reconstruction can improve understanding of fission counting systematic uncertainty. See Luke Snyder's talk (DA 2)

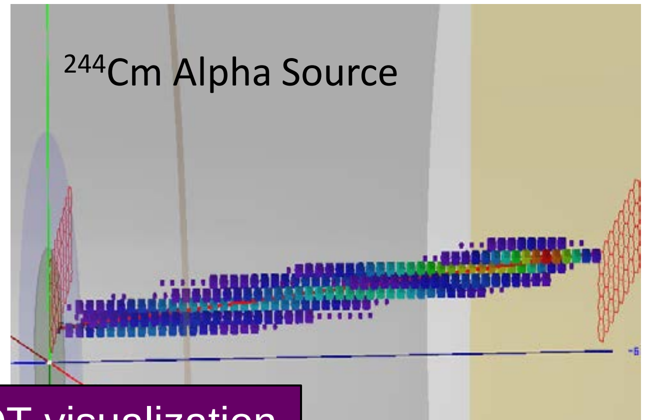
The NIFFTE Collaboration

(Neutron Induced Fission Fragment Tracking Experiment)

- **DOE/NE is funding 7 participating universities**
  - **Abilene Christian University:** Online monitoring/controls
  - **CalPoly at San Luis Obispo:** Software
  - **Colorado School of Mines:** Gas handling
  - **Indiana University:** Simulations
  - **Idaho State University:** Computing, hardware testing
  - **Ohio University:** Hydrogen standard
  - **Oregon State University:** Target, source fabrication
- **DOE/NE provides some oversight funding**
  - **Idaho National Laboratory**
  - **Lawrence Livermore National Laboratory**
  - **Los Alamos National Laboratory**
  - **Pacific Northwest Laboratory**
- **DOE/NNSA also provides funding**
  - **Lawrence Livermore National Laboratory**
  - **Los Alamos National Laboratory**

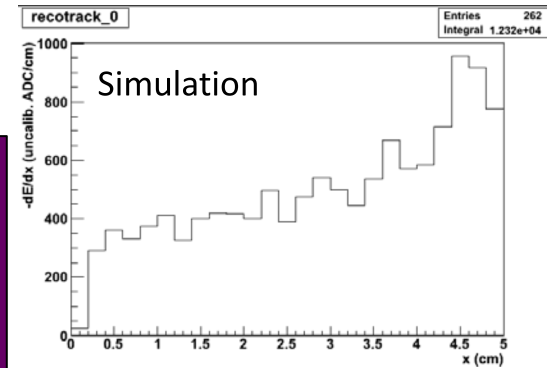
Simulation v. data

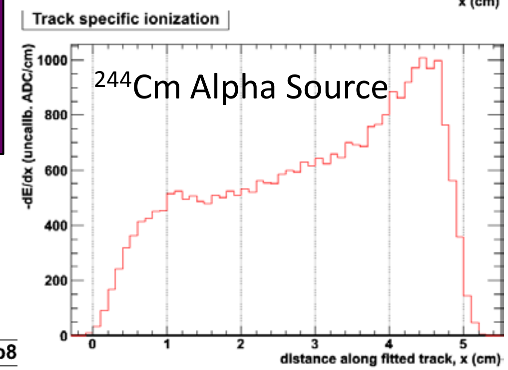




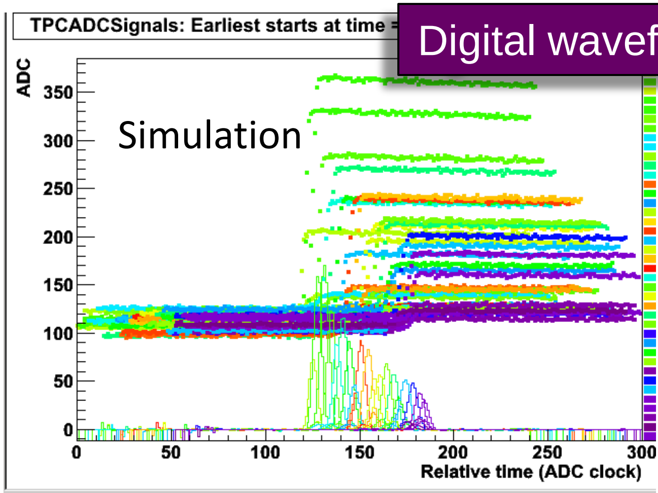
GEANT4+ROOT visualization

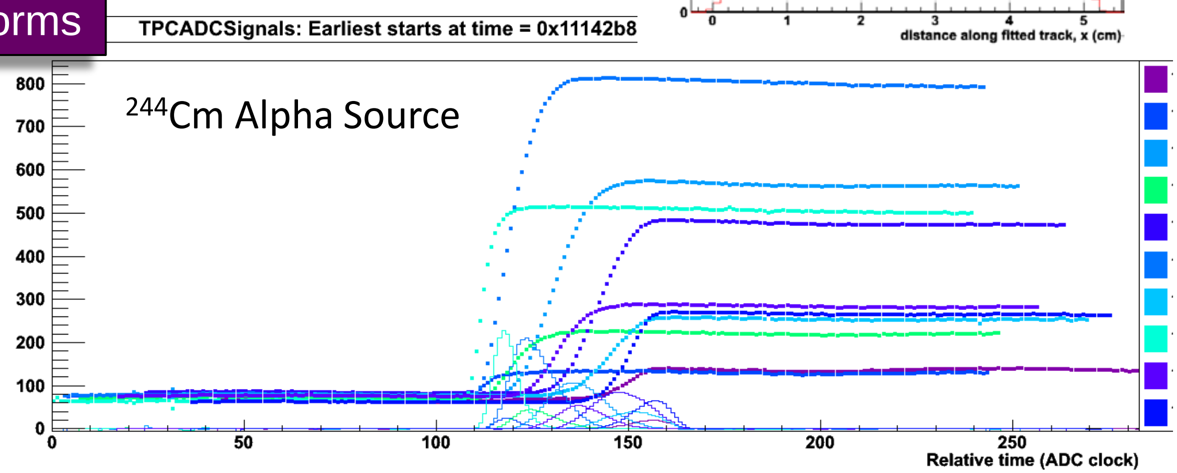
dE/dx along track





Digital waveforms

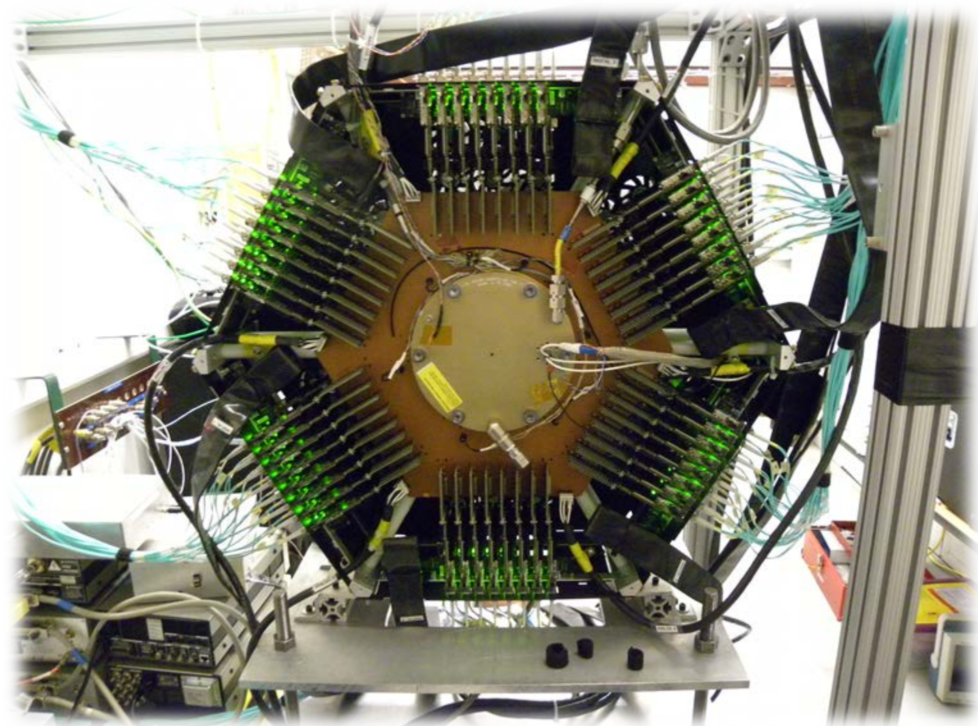




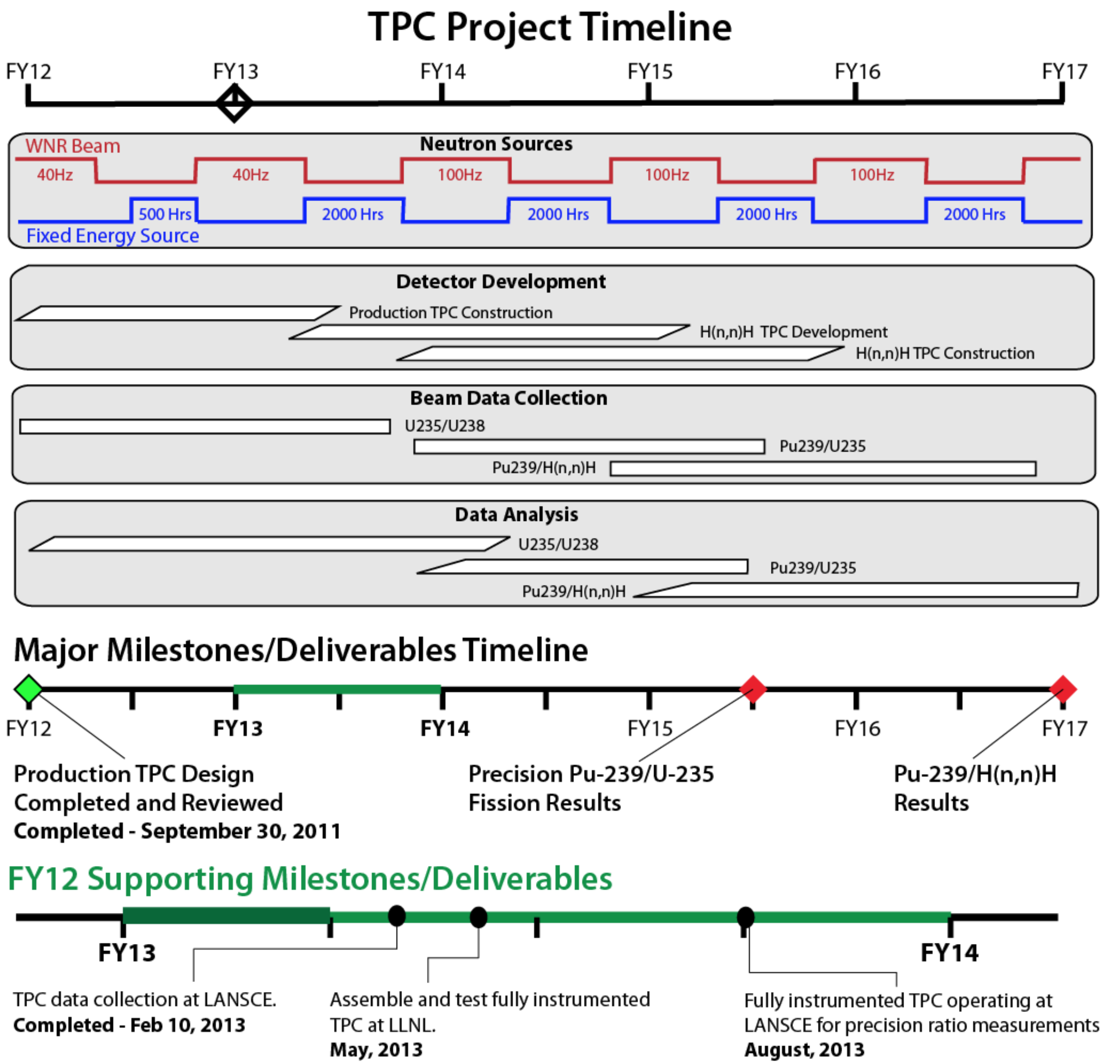
See Luke Snyder's talk for details (DA 2)

Status and near term plans

- Nearly 3000 hours of beam data
- Fully instrumented TPC in 2013
  - 192 cards, 5952 channels
  - Ratio measurements on actinides at WNR
    - U-235, U-238, Pu-239, etc.
- Hydrogen TPC (future)
  - Measure ^{239}Pu(n,f)/H(n,n)H



TPC Project Timeline



In FY2013…

- Fully instrumented TPC assembled and tested at LLNL
  - data collected from specially prepared sources
- Fully instrumented TPC operating at LANSCE
  - neutron induced data for precision ratio measurements