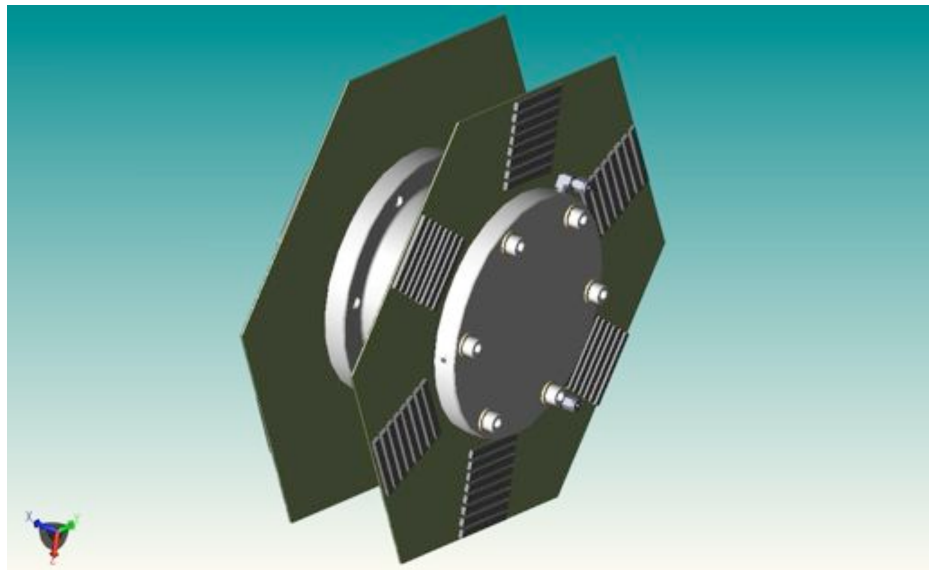
A Time Projection Chamber for precision $^{239}Pu(n,f)$ cross section measurement



Mike Heffner

LLNL

Compound-Nuclear Reactions Workshop

25th October 2007

Why measure $^{239}Pu(n,f)$

- Current errors on $^{239}Pu(n,f)$ are at least 2-3% (below 14MeV) and not completely understood
- Better measurements of $^{239}Pu(n,f)$ supports:
  - The Stockpile Stewardship program
  - GNEP/AFCI has needs for better cross sections measurements, including $^{239}Pu(n,f)$
- The TPC is a powerful instrument that has not been applied to this problem

Current $^{239}Pu(n,f)$ measurements

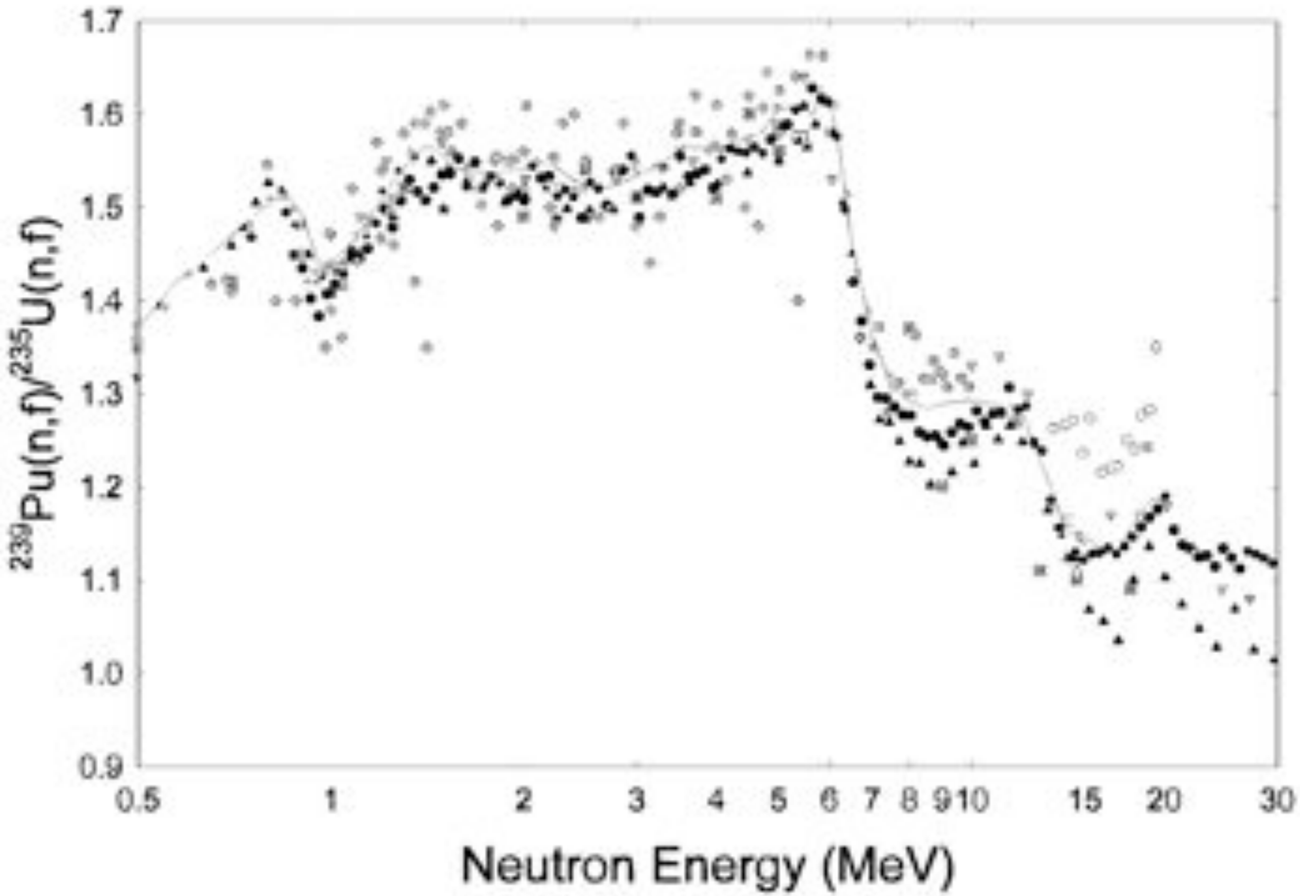


Fig. 3. Ratio of neutron-induced fission cross sections for $^{239}Pu/^{235}U$ to 30 MeV compared to other measurements (Refs. 1, 7, 8, 17, 19, 20, 23, 24, 25, 26, and 28) and ENDF/B-VI (solid line).

NUCLEAR SCIENCE AND ENGINEERING VOL. 129 JUNE 1998

Systematic differences of 10-20% are not unusual

Table 38
Results of the target accuracy study for the LFR reactor

Isotope	Cross-section	Energy range	Uncertainty Initial	Uncertainty Required	Isotope	Cross-section	Energy range	Uncertainty Initial	Uncertainty Required	Isotope	Cross-section	Energy range	Uncertainty Initial	Uncertainty Required
U-238	σ_{capt}	1.35 MeV–498 keV	5	2.9	Pu-240	σ_{capt}	1.35 MeV–498 keV	20	8.4	Zr-90	σ_{el}	498–183 keV	20	9.8
		498–183 keV	5	2.4			498–183 keV	20	5.8			183–67.4 keV	20	10.8
		183–67.4 keV	5	2.4			183–67.4 keV	20	5.4			67.4–24.8 keV	20	10.3
		67.4–24.8 keV	5	2.4			67.4–24.8 keV	20	5.7		σ_{inel}	6.07–2.23 MeV	20	8.6
		24.8–9.12 keV	5	2.7			24.8–9.12 keV	10	6.8	Pb-206	σ_{capt}	183–67.4 keV	20	9.8
	σ_{fiss}	6.07–2.23 MeV	5	2.6		σ_{fiss}	6.07–2.23 MeV	5	4.1		σ_{el}	1.35 MeV–498 keV	20	6.3
		2.23–1.35 MeV	5	2.6			2.23–1.35 MeV	5	3.7			498–183 keV	20	7
	σ_{inel}	6.07–2.23 MeV	15	3.8			1.35 MeV–498 keV	5	2.1		σ_{inel}	19.6–6.07 MeV	40	15.9
		2.23–1.35 MeV	10	3.1			498–183 keV	5	4.1			6.07–2.23 MeV	40	4.6
		1.35 MeV–498 keV	10	2.9		ν	1.35 MeV–498 keV	2	1.8			2.23–1.35 MeV	40	4.4
		498–183 keV	10	4.2	Pu-241	σ_{fiss}	1.35 MeV–498 keV	10	4.9			1.35 MeV–498 keV	45	5.3
		183–67.4 keV	10	4.8			498–183 keV	10	3.5	Pb-207	σ_{el}	1.35 MeV–498 keV	20	6.8
Pu-238	σ_{fiss}	1.35 MeV–498 keV	10	4.5			183–67.4 keV	10	3.5			498–183 keV	20	7.5
		498–183 keV	10	4.5			67.4–24.8 keV	10	4.2		σ_{inel}	19.6–6.07 MeV	40	26.6
		183–67.4 keV	10	6.2			24.8–9.12 keV	10	4.9			6.07–2.23 MeV	40	5.5
		67.4–24.8 keV	30	7.4			9.12–2.03 keV	10	7.3			2.23–1.35 MeV	40	6.7
		24.8–9.12 keV	30	8.7	Pu-242	σ_{fiss}	1.35 MeV–498 keV	10	5.3			1.35 MeV–498 keV	45	4
		9.12–2.03 keV	30	12.8	Am-241	σ_{capt}	498–183 keV	10	7.3	Pb-208	σ_{el}	6.07–2.23 MeV	20	8.4
Pu-239	σ_{capt}	498–183 keV	15	5.7			183–67.4 keV	10	7.1			2.23–1.35 MeV	20	7.7
		183–67.4 keV	15	5.4		σ_{fiss}	1.35 MeV–498 keV	10	7.1			1.35 MeV–498 keV	20	3.7
		[illegible]	[illegible]	6	Am-242m	σ_{fiss}	498–183 keV	20	10.9			498–183 keV	20	4.7
		24.8–9.12 keV	10	[illegible]	Cm-244	σ_{fiss}	1.35 MeV–498 keV	40	8.6		σ_{inel}	19.6–6.07 MeV	40	9.4
	[illegible]	6.07–2.23 MeV	5	3.3	Cm-245	σ_{fiss}	1.35 MeV–498 keV	40	13.8			6.07–2.23 MeV	40	4.9
		2.23–1.35 MeV	5	2.9			498–183 keV	40	9.6		$\sigma_{n,2n}$	19.6–6.07 MeV	100	53.1
		1.35 MeV–498 keV	5	1.4			183–67.4 [illegible]	[illegible]	[illegible]					
		498–183 keV	5	1.1			67.4–24.8 [illegible]	[illegible]	[illegible]					
		183–67.4 keV	5	1.2			24.8–9.12 [illegible]	[illegible]	[illegible]					
		67.4–24.8 keV	5	1.5	Fe-56	σ_{el}	183–67.4 [illegible]	[illegible]	[illegible]					
		24.8–9.12 keV	5	1.9		σ_{inel}	6.07–2.2[illegible]	[illegible]	[illegible]					
		9.12–2.03 keV	5	3			2.23–1.3[illegible]	[illegible]	[illegible]					
	[illegible]	498–183 keV	1	0.9			1.35 MeV[illegible]	[illegible]	[illegible]					

G. Aliberti et al. / Annals of Nuclear Energy 33 (2006) 700–733

Pu-239	σ_{capt}	498–183 keV	15	5.7
		183–67.4 keV	15	5.4
		67.4–24.8 keV	10	6
		24.8–9.12 keV	10	6.1
	σ_{fiss}	6.07–2.23 MeV	5	3.3
		2.23–1.35 MeV	5	2.9
		1.35 MeV–498 keV	5	1.4
		498–183 keV	5	1.1
		183–67.4 keV	5	1.2
		67.4–24.8 keV	5	1.5
		24.8–9.12 keV	5	1.9
		9.12–2.03 keV	5	3
	ν	498–183 keV	1	0.9

The Time Projection Chamber

- Introduction to a TPC
- How it could improve $^{239}Pu(n,f)$
- Other measurements with the fissionTPC
- Status and plan for the fissionTPC projects

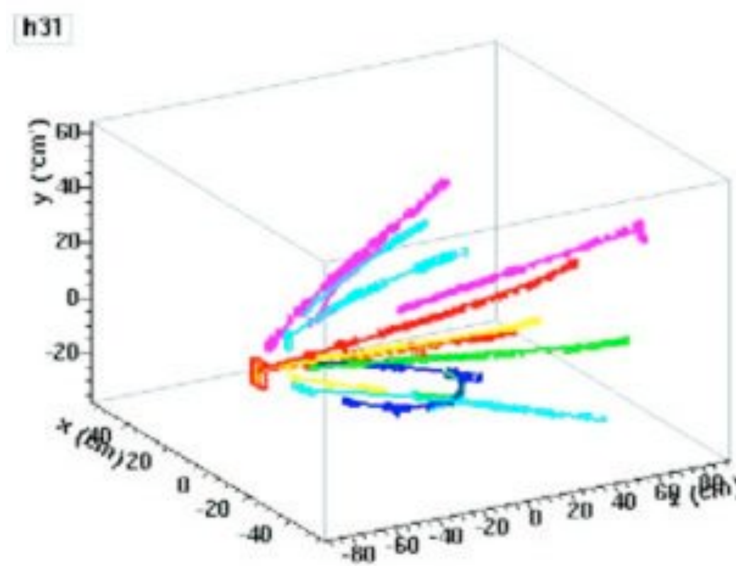
TPCs have been used in Particle Physics for 25+ years

EOS TPC
Heavy Ion Physics
1980’s ~1 m^3

Star TPC
Relativistic Heavy Ion Phy.
1990’s ~50 m^3

nTPC
Homeland Security
2004 ~.036m^3

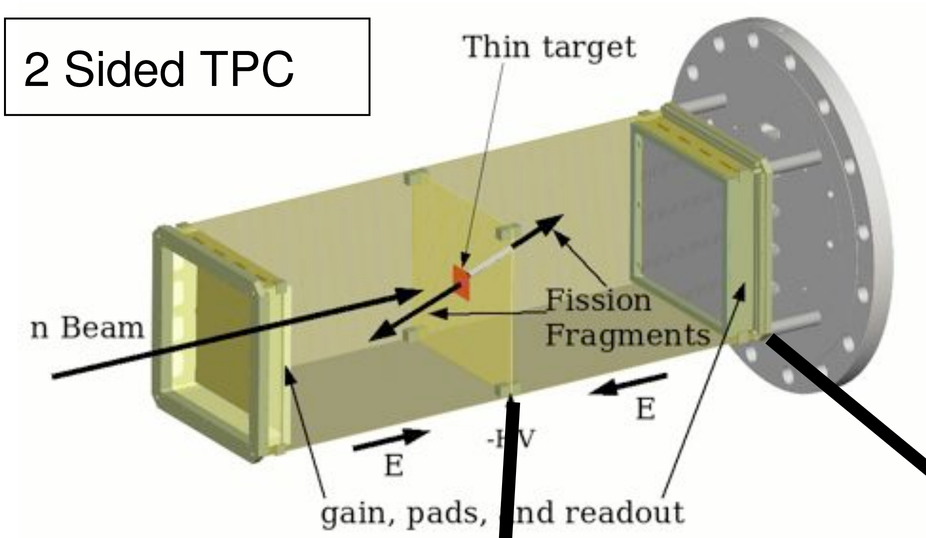
PEP-4 TPC
Particle Physics e^+e^-
Inventor David Nygren
1979 ~6m^3



Typical TPC Event

How the fission TPC works

2 Sided TPC



Technical Challenges

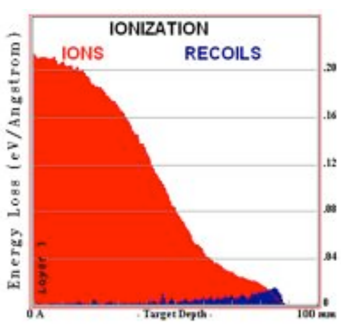
Fission fragments

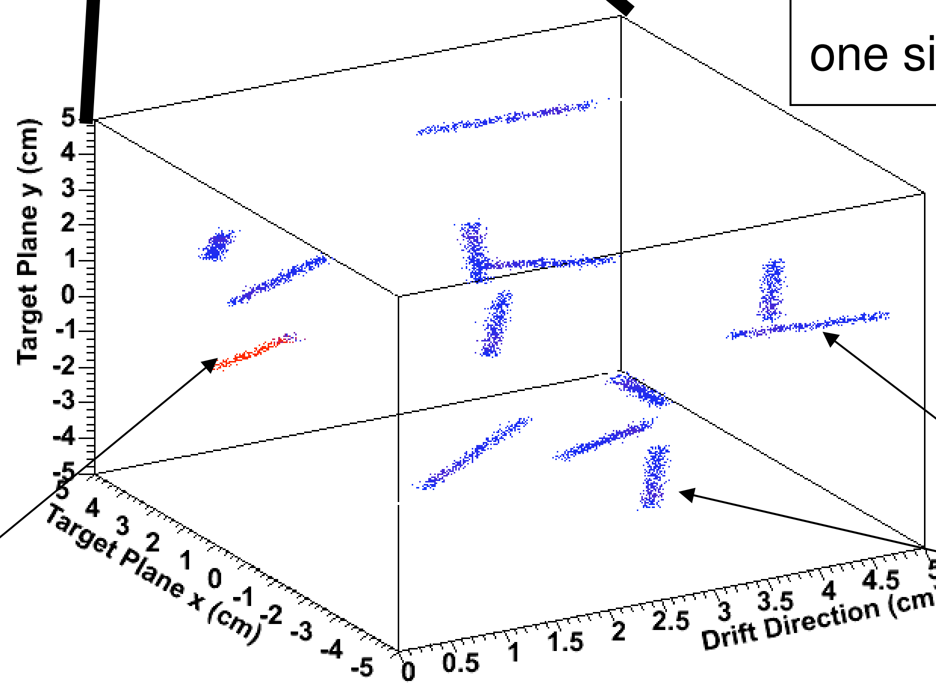
Backgrounds require small dimensions

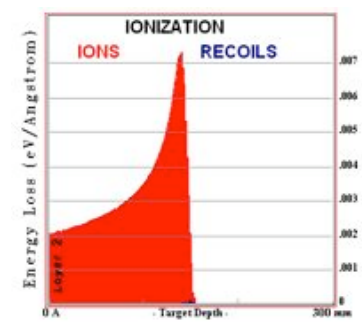
H_2 gas (precision)

^{239}Pu target

Simulated event display of one side of the TPC







Fission Fragment

Alphas

Assume 10cm x 10cm target 100μg/cm^2, 10bar, He, 5cm/μs

TPC Capabilities

- 3D event reconstruction
- High background rejection
- Particle identification
- Standalone or incorporation to existing detectors

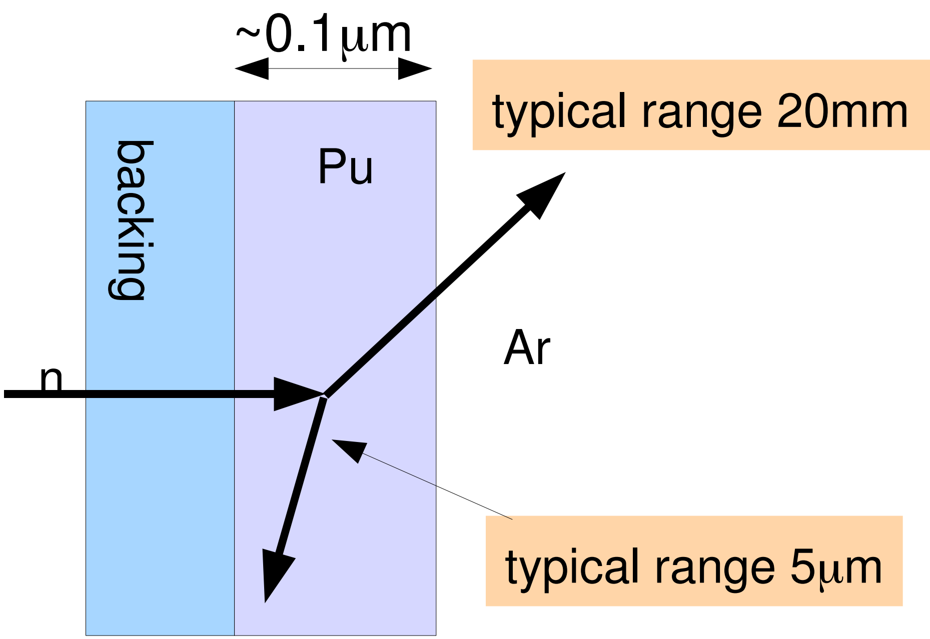
Possible Measurements

- Precision ^{239}Pu(n,f), other (n,f) cross sections (e.g. 235,238)
- Fission fragment energy, mass and direction
- Neutron energy, direction, number
- Correlations with γ-rays

← Requires specially designed TPC and/or additional equipment

Top Systematic Errors using a Fission Chamber

Target Close-up



The Fission TPC can address the Fission Chamber error sources

In situ autoradiograph plus tracking

Error Sources:

- Foil Mass
  - non uniformities
  - surface defects
  - contaminates
- Target energy loss
- Loss of both fragments
- Edge Effects
- ^{235}U Reference
- α Contamination

Detailed tracking

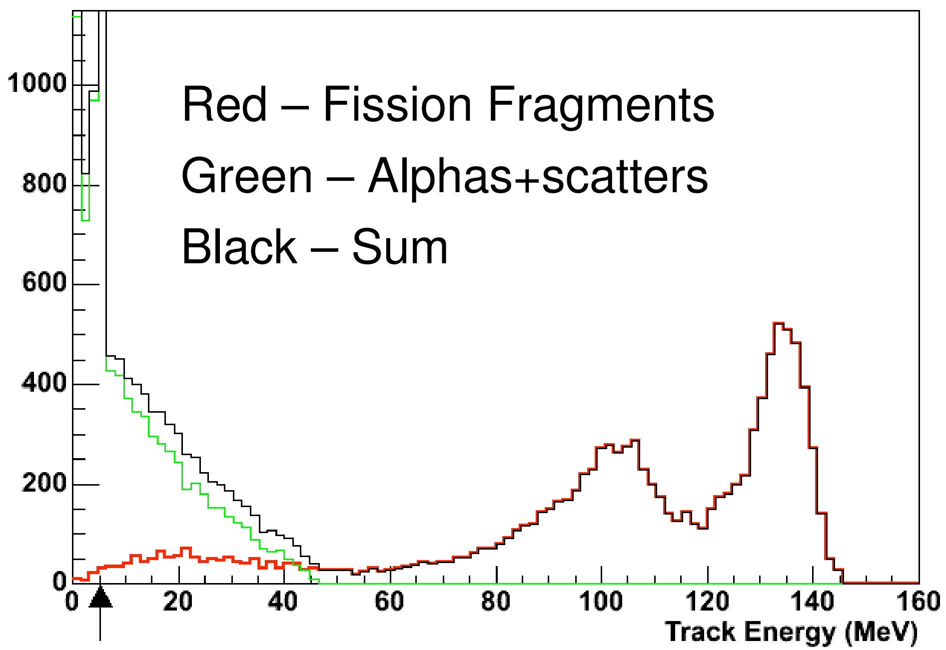
H_2 working gas

Specific ionization

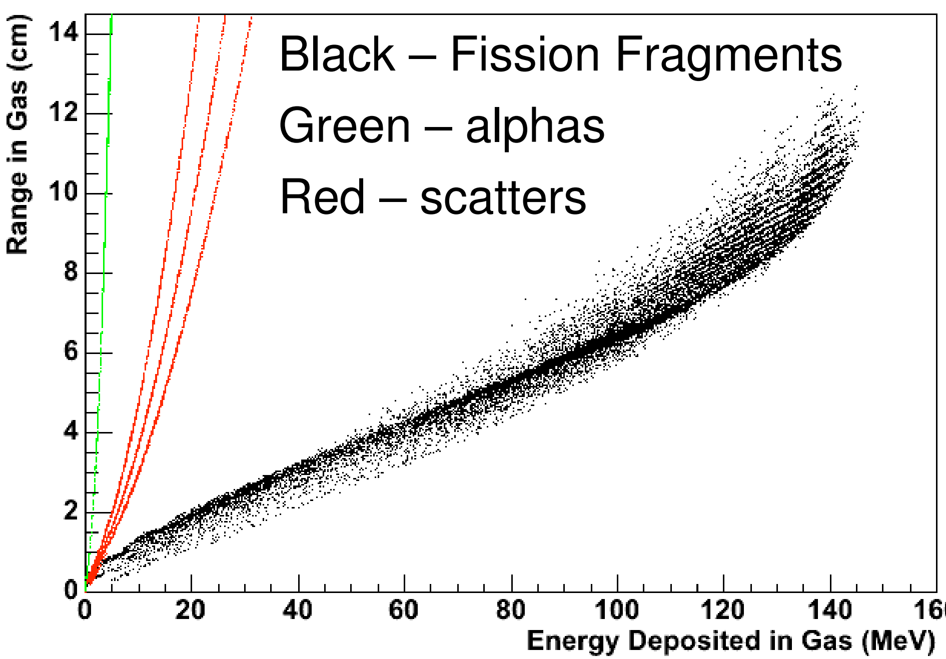
Fiducial cuts

TPC/Fission Chamber Comparison: Geant Simulation of α Rejection

View of fission from a fission chamber

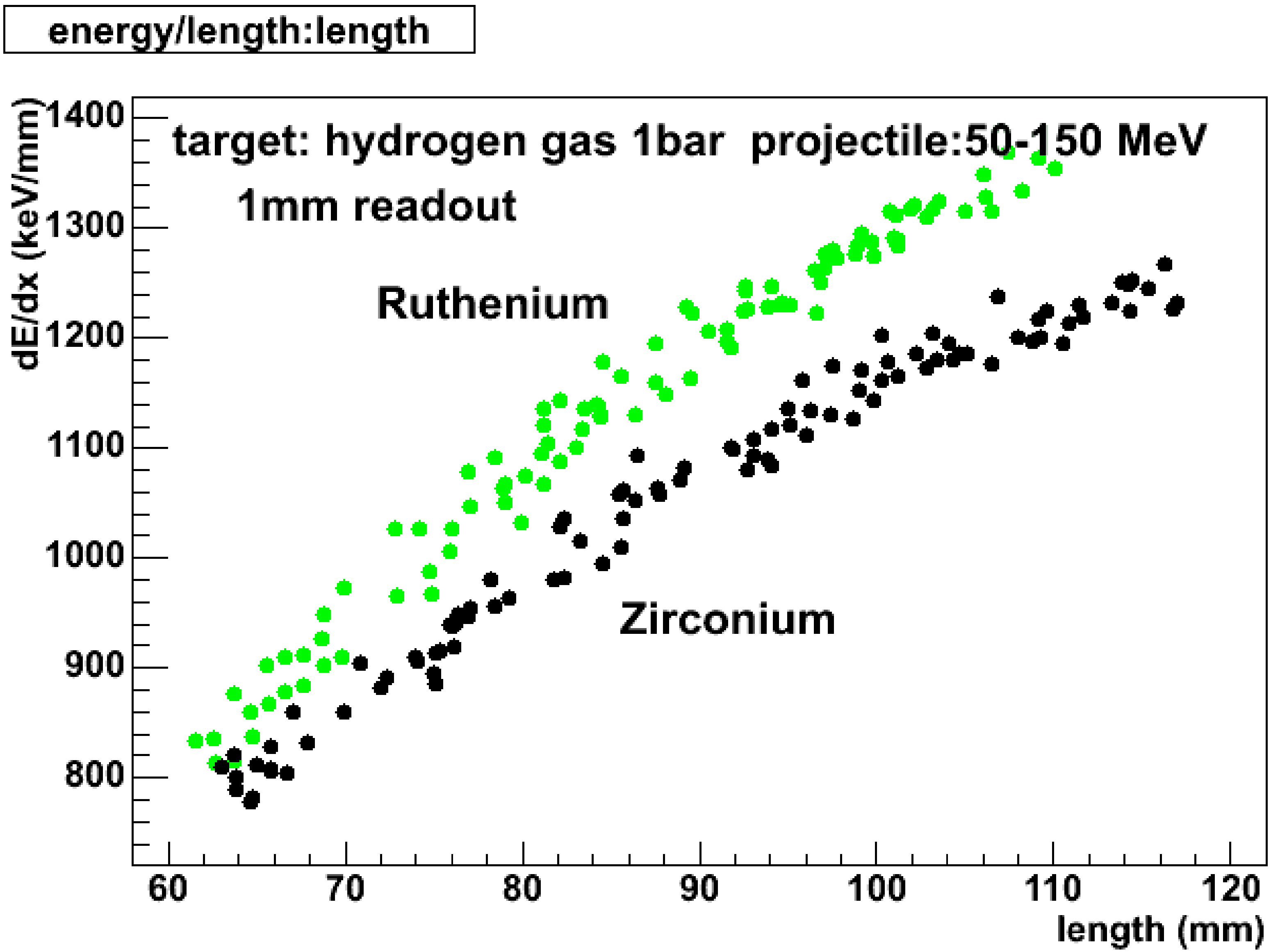


View of fission from a TPC

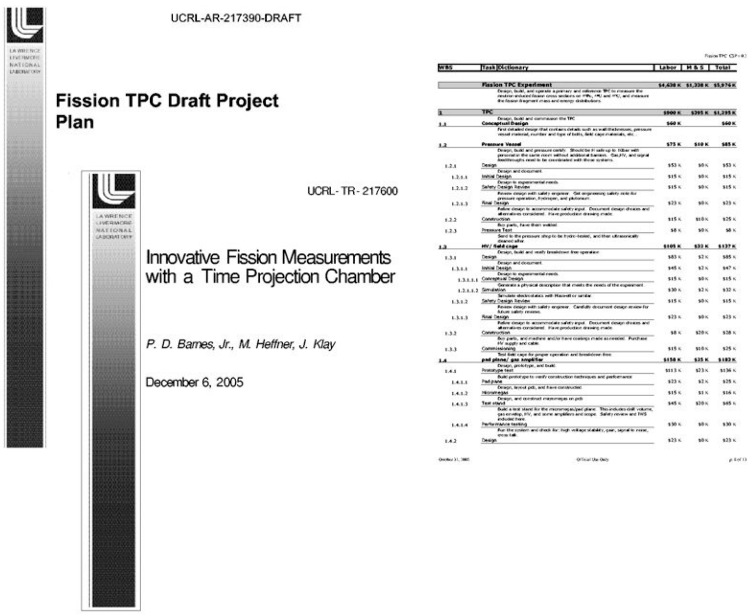


Significant α/fragment resolution even before using dE/dx(x)

Simple Simulation of Fragment Identification



Project Status



A paper study and WBS of the TPC is done

NERI-c funded !

Universities

Abilene Christian University - Rusty Towell

California Polytechnic State University at San Luis Obispo - Jenn Klay

Colorado School of Mines - Uwe Greife

Georgia Institute of Technology - Nolan Hertel, Eric Burgett, Ian Ferguson

Ohio University - Tom Massey, Steve Grimes, Carl Brune

Oregon State University - Walter Loveland

National Laboratories

Idaho National Laboratory - John Baker

Lawrence Livermore National Laboratory - Michael Heffner

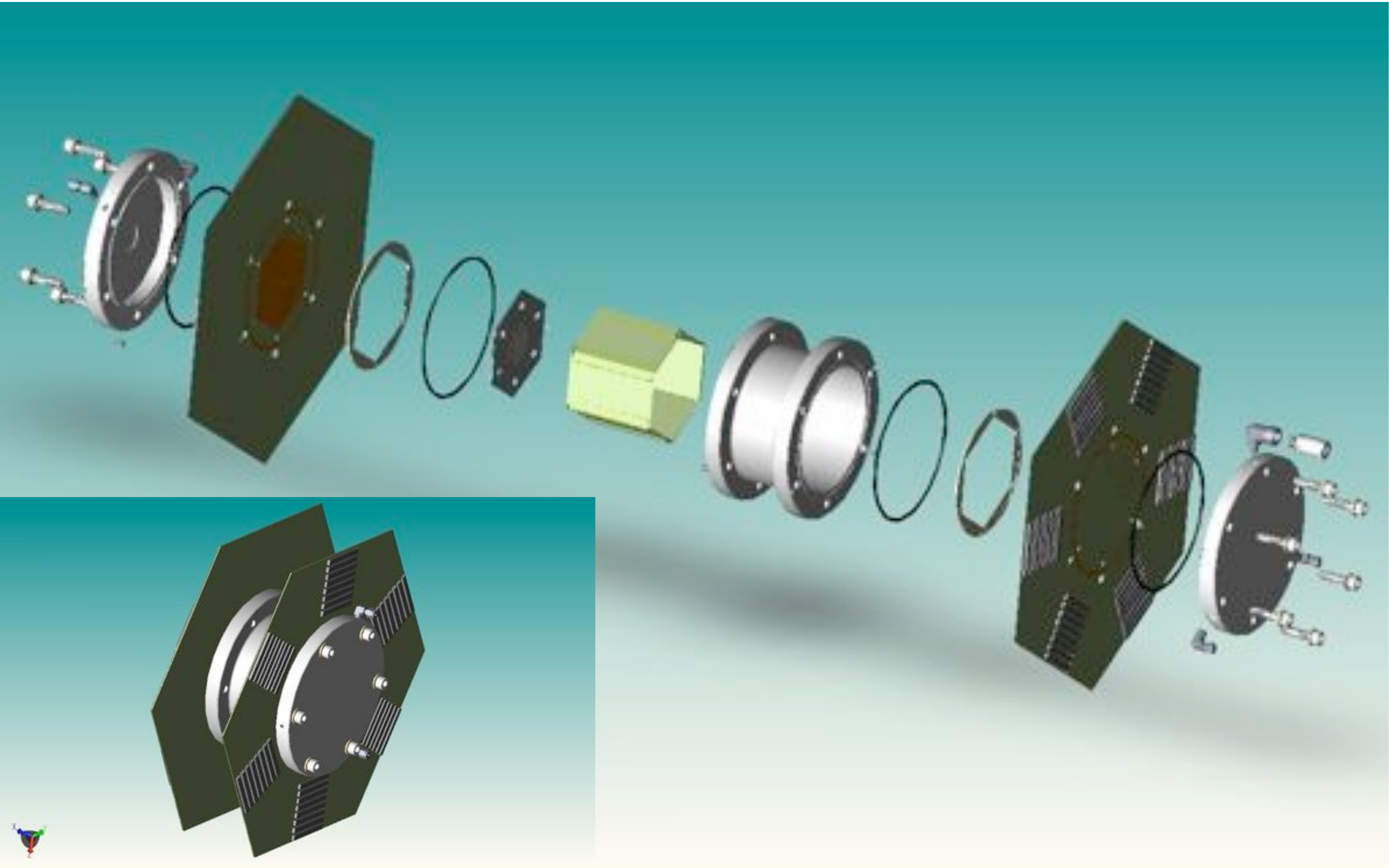
Los Alamos National Laboratory - Tony Hill

<u>TPC specific Laboratory funding</u>

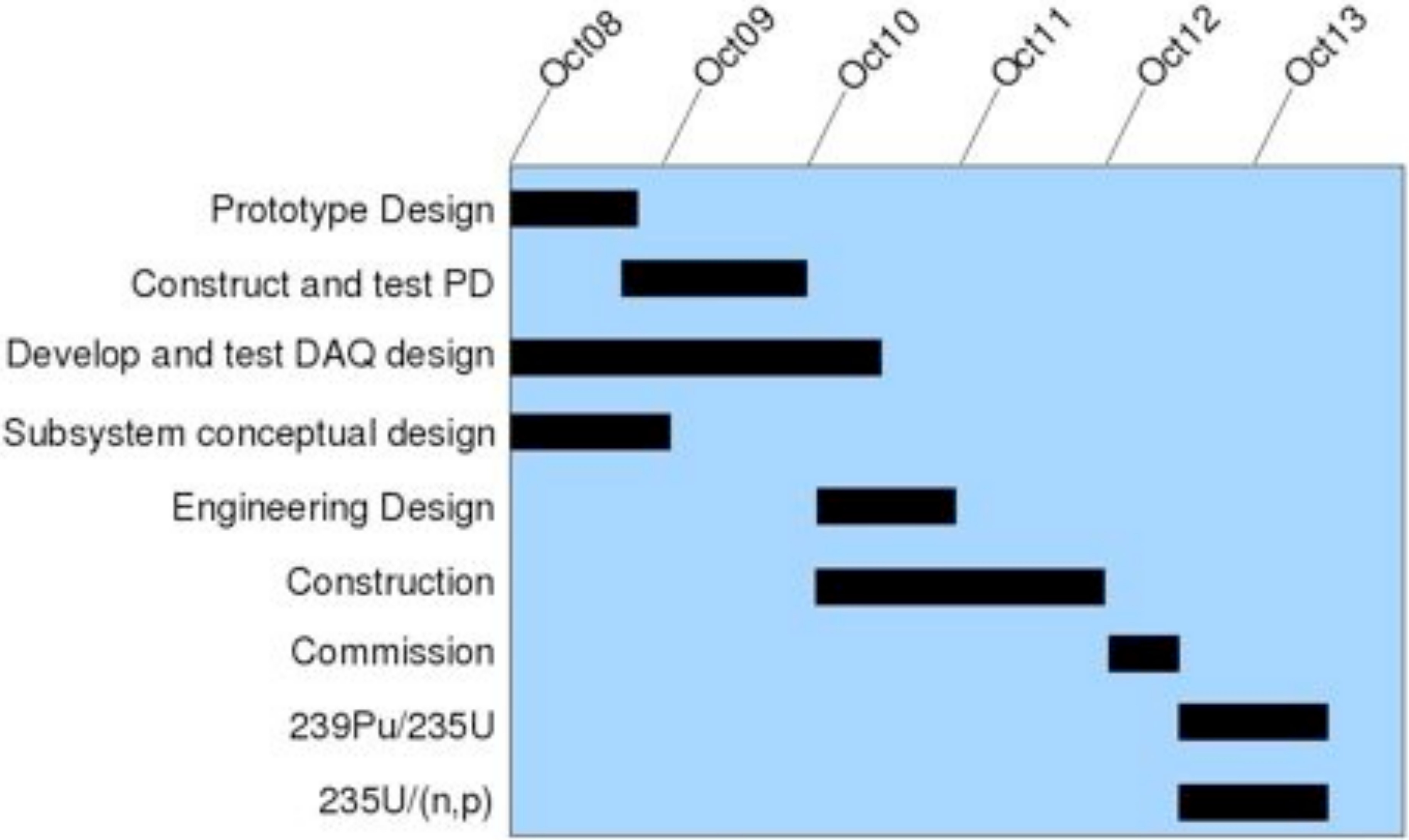
- Significant support for work at LLNL starts FY08 with internal money
- INL, LLNL, and LANL also expect Nuclear Energy money FY08

Prototyping and initial detailed mechanical design has begun

3D Solid Model



Plan



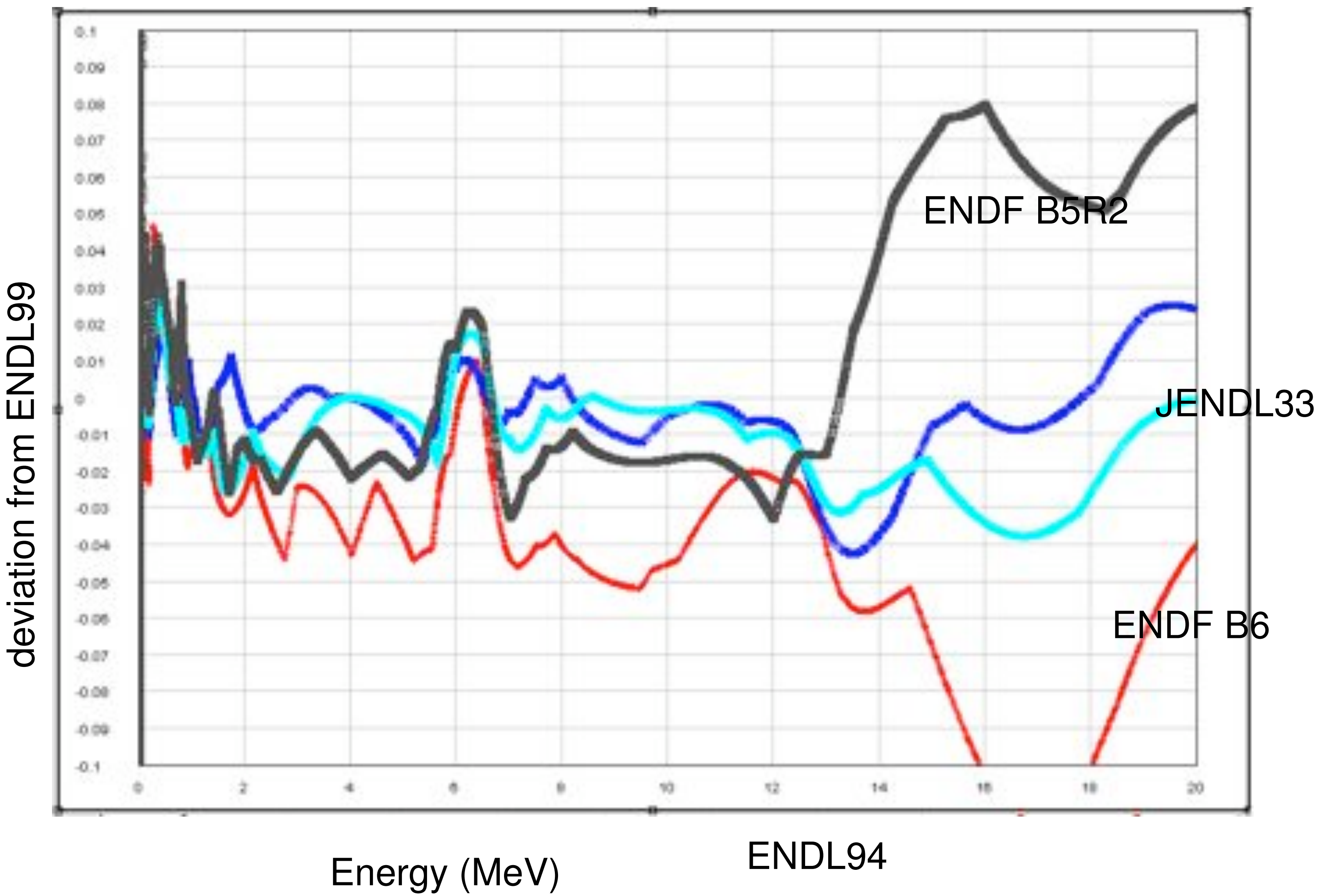
Oct08
Oct09
Oct10
Oct11
Oct12
Oct13
Prototype Design
Construct and test PD
Develop and test DAQ design
Subsystem conceptual design
Engineering Design
Construction
Commission
239Pu/235U
235U/(n,p)

Summary

- A need exists for better $^{239}Pu(n,f)$ measurement
- The TPC has been selected as the instrument to make this measurement and is now funded
- How can the investment in this instrument be leveraged to further the science goals of the nuclear physics community?

EXTRA SLIDES

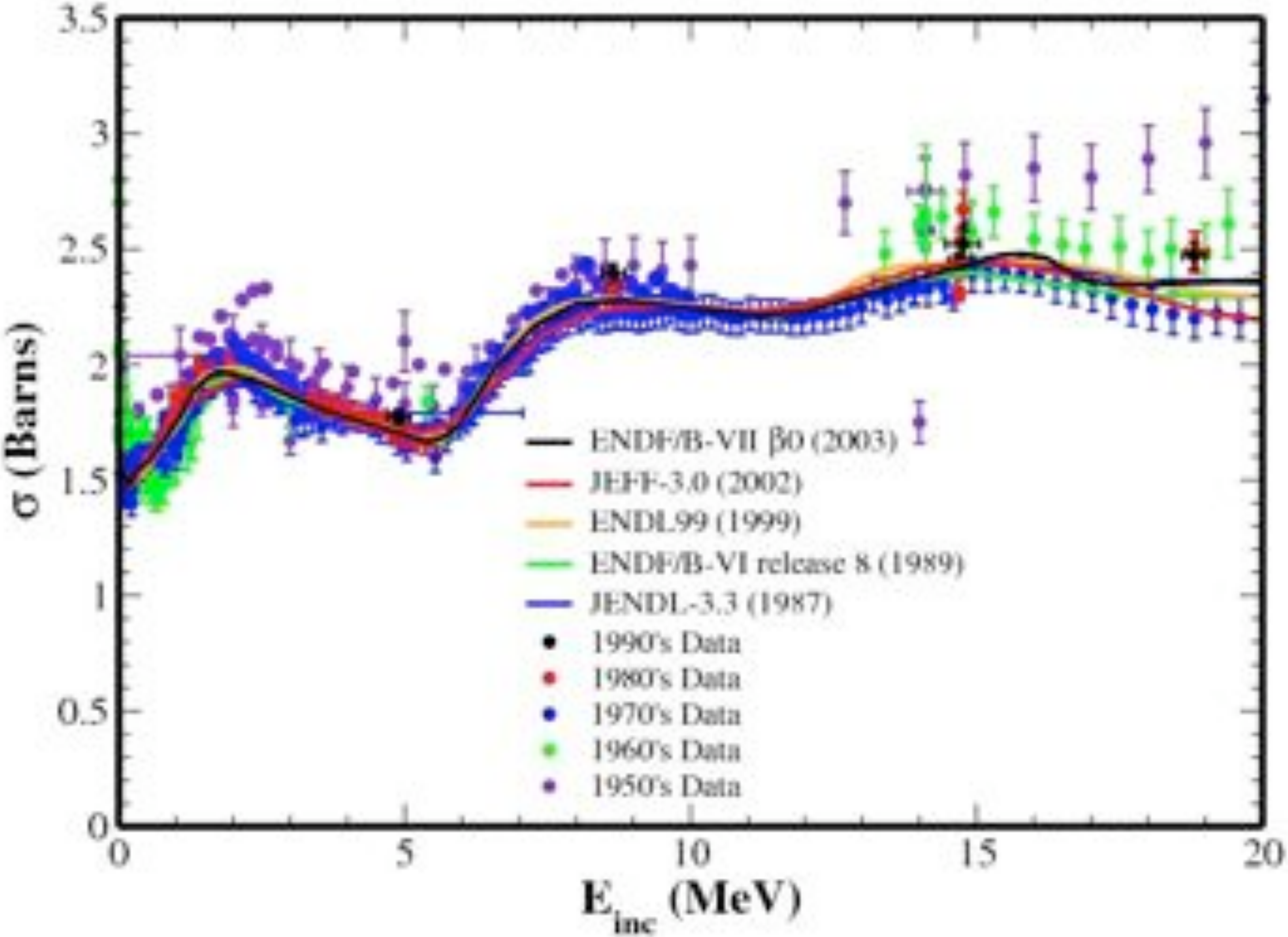
^{239}Pu(n,f) evaluation



TPC Design Spec's

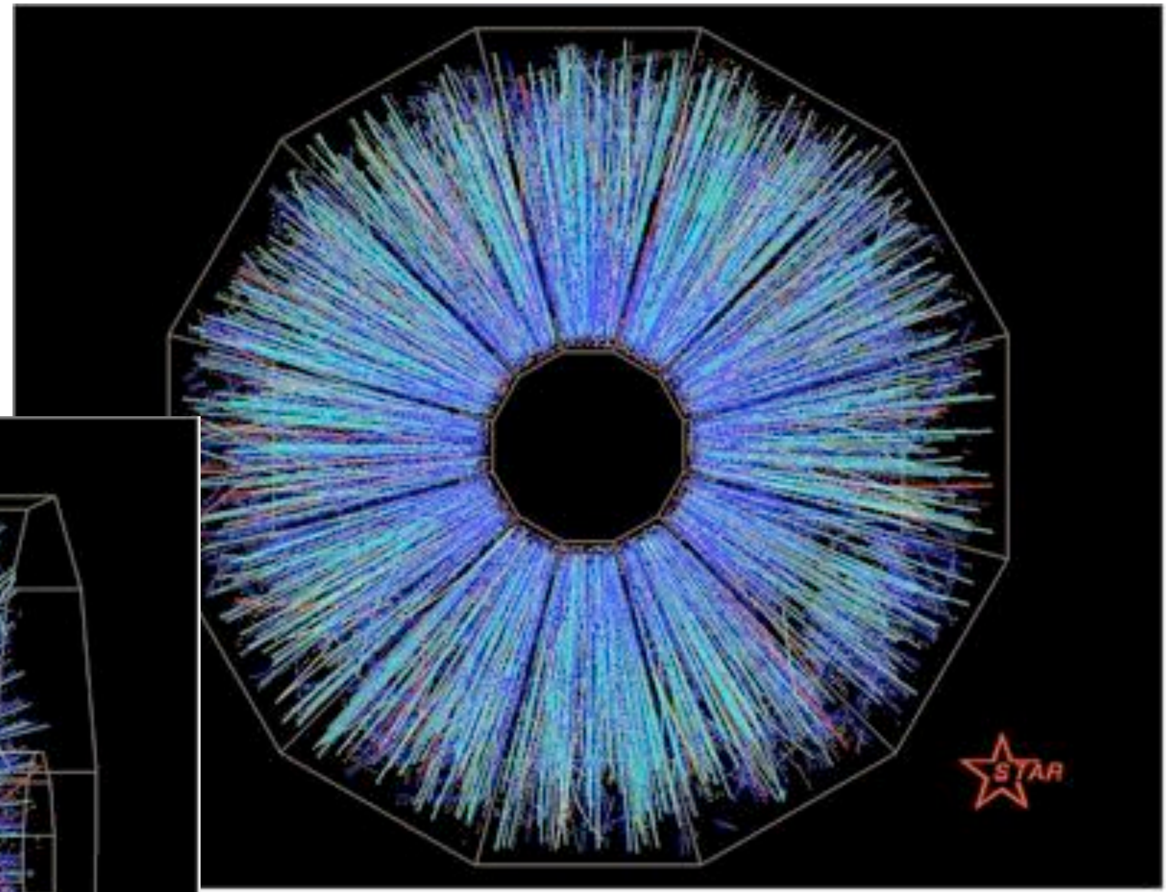
Parameter	Value	
Drift gases	1H 3He (neutron measurement) P10 (as in fission chambers)	
Gas pressure	5 bar, nominal (0–10 bar range)	2.5bar
Typical fragment track length	18 mm	36mm
Magnetic field	None	
Beam diameter	20 mm	
Readout structure	0.9 mm X 0.9 mm square pads	2mm X 2mm hex
Typical samples per track	20	
Target diameter	20 mm	
Fiducial area guard radius	9 mm, (50% of track length)	
Drift length, including fiducial guard radius	27 mm = 18 mm + 9 mm	
Pad plane diameter	74 mm = 20 mm + 2 x 27 mm	
Number of pads per side	5300 = (74 mm/0.9 mm)2 π/4	
Gas amplification	MICROMEGAS or GEM	
Drift field	5 kV/cm	
Maximum field	27 kV @ 10 bar	
Drift velocity	11.5 mm/μs	
Drift time	2.35 μs	4.7μs
Sampling rate	13 Mhz	70Mhz

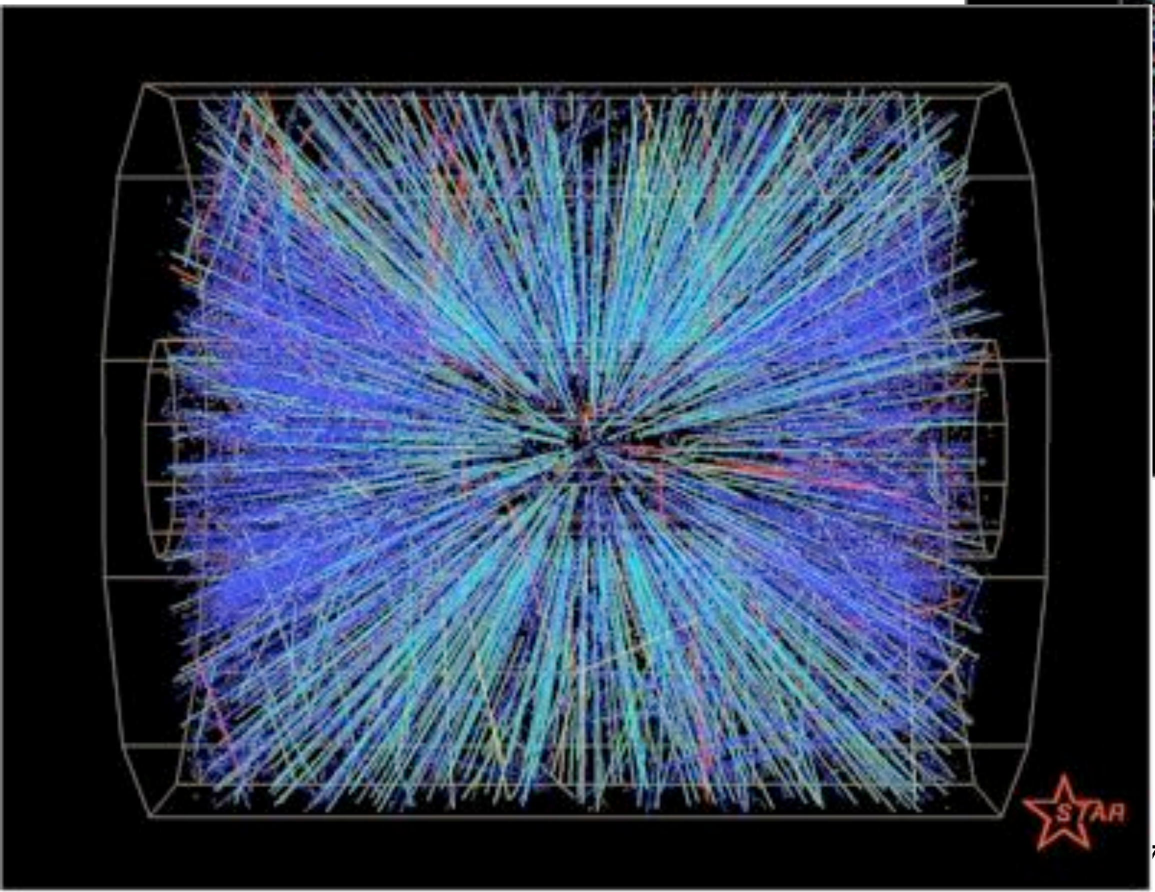
^{239}Pu(n,Fission)



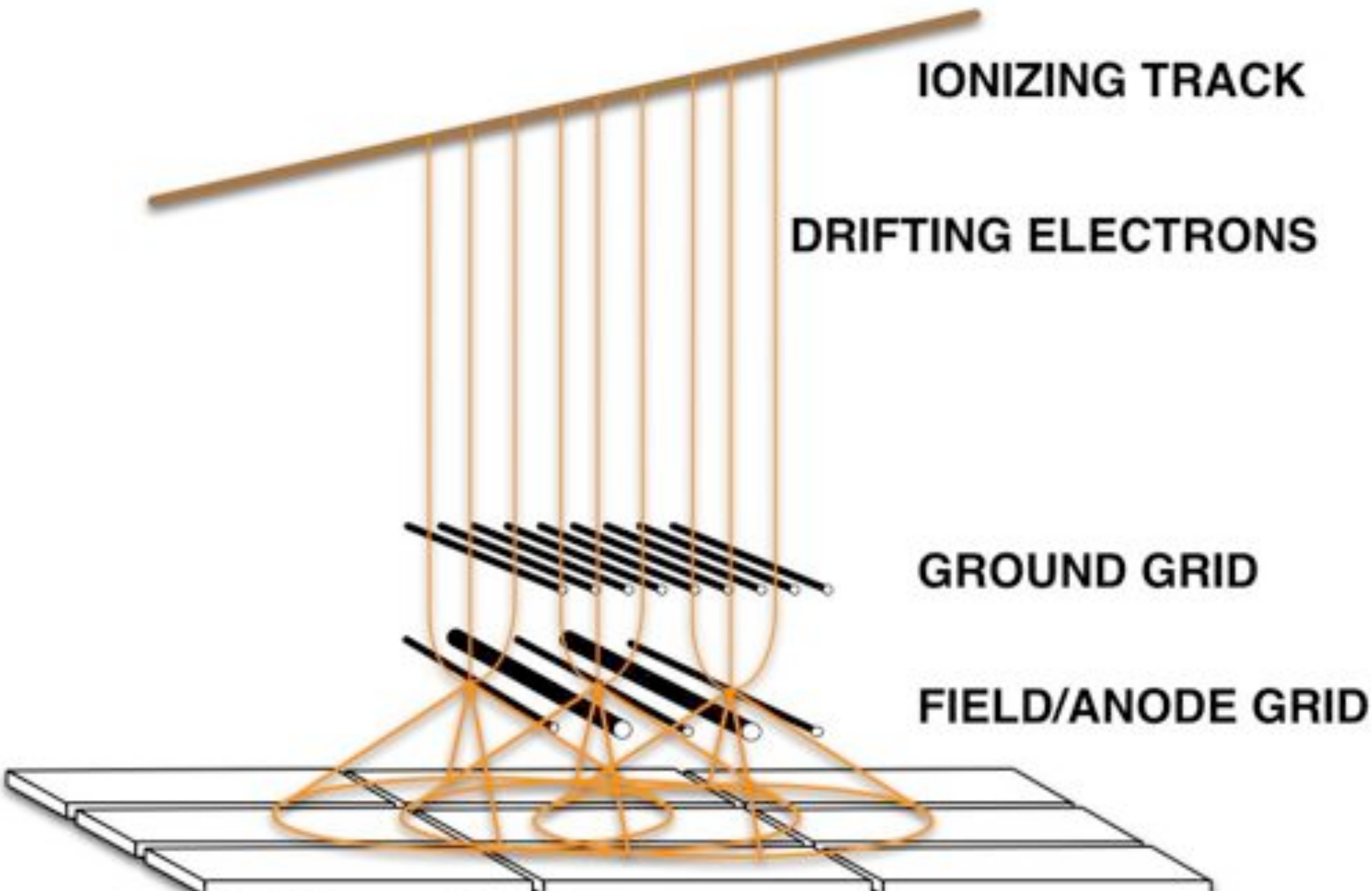
Example TPC Data: STAR

2000 tracks in one event !





The TPC Readout Section



12 X 8 mm^2 Pads

Gas Amplifier/Frisch Grid

LLNL pcb shop can work with
the old dry film soldermask

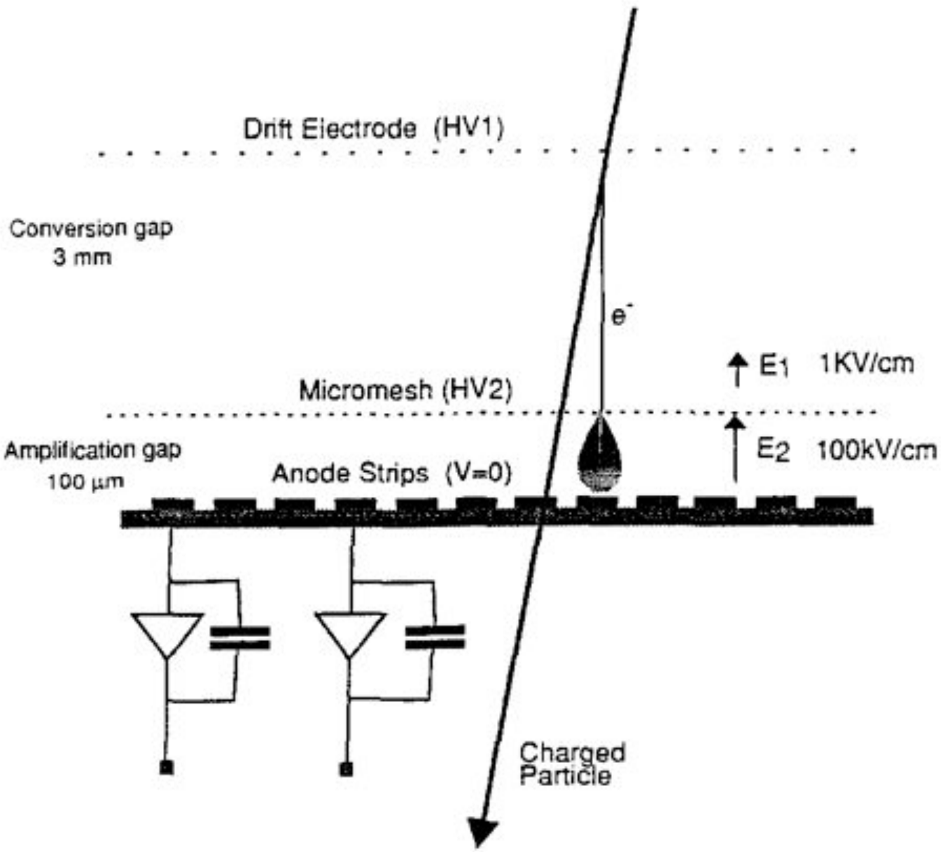


Fig. 1. A schematic view of MICROMEGAS: the 3 mm conversion gap and the amplification gap separated by the micromesh and the anode strip electrode.

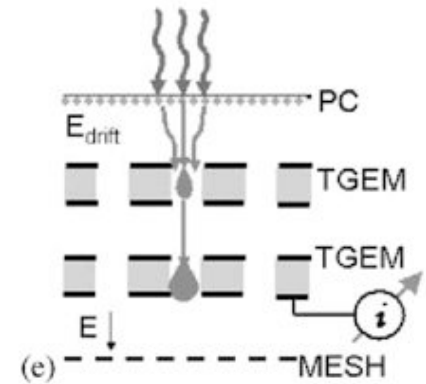


Fig. 2. Schematic setups for normalization and absolute effective-gain measurement in semitransparent (a,c), reflective (b,d) and double TGEM (a,e) modes.

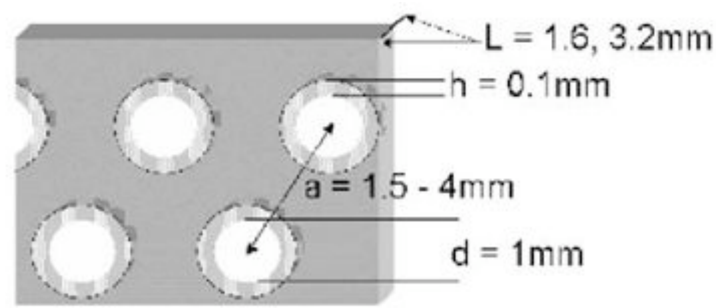
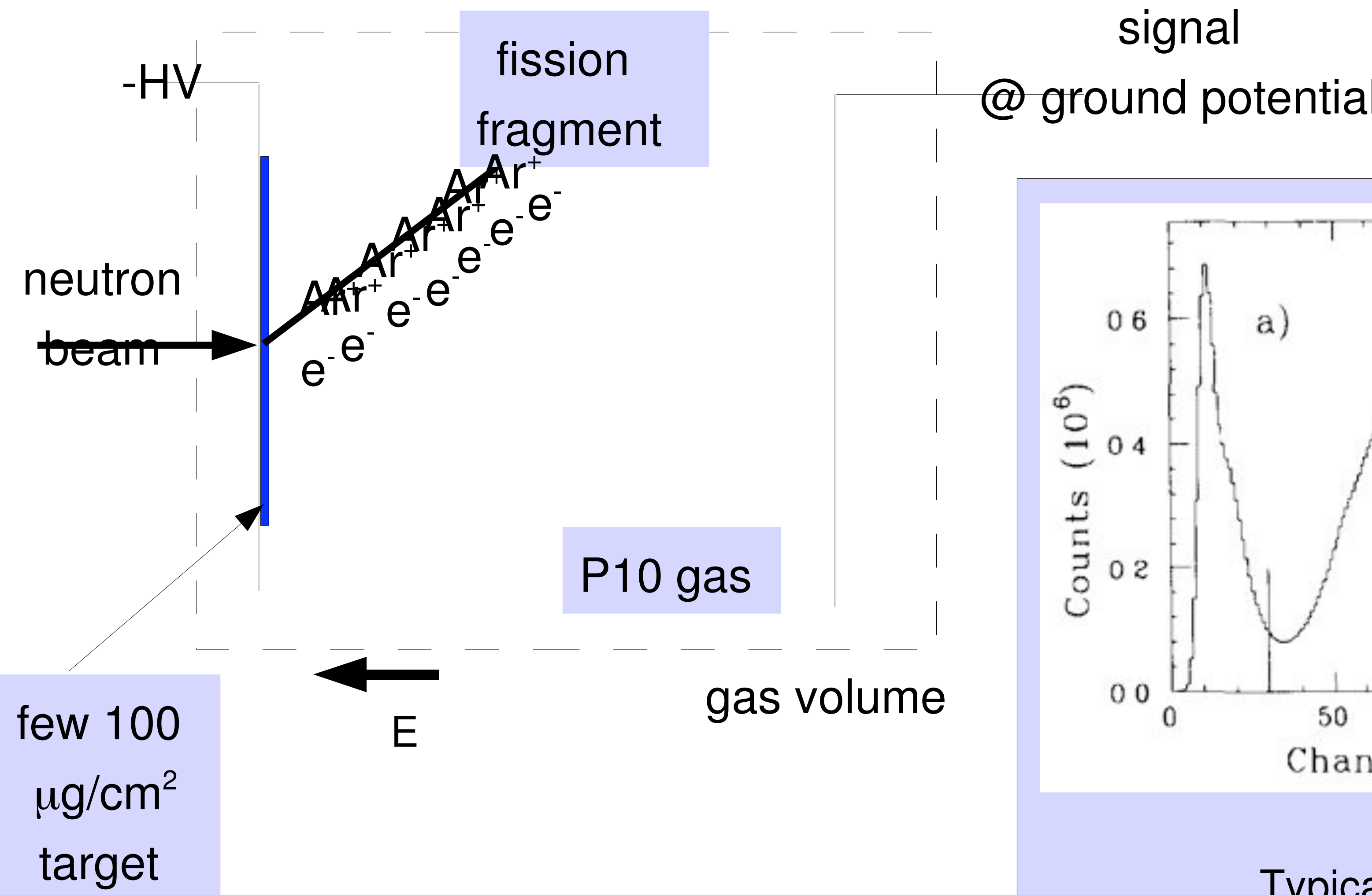
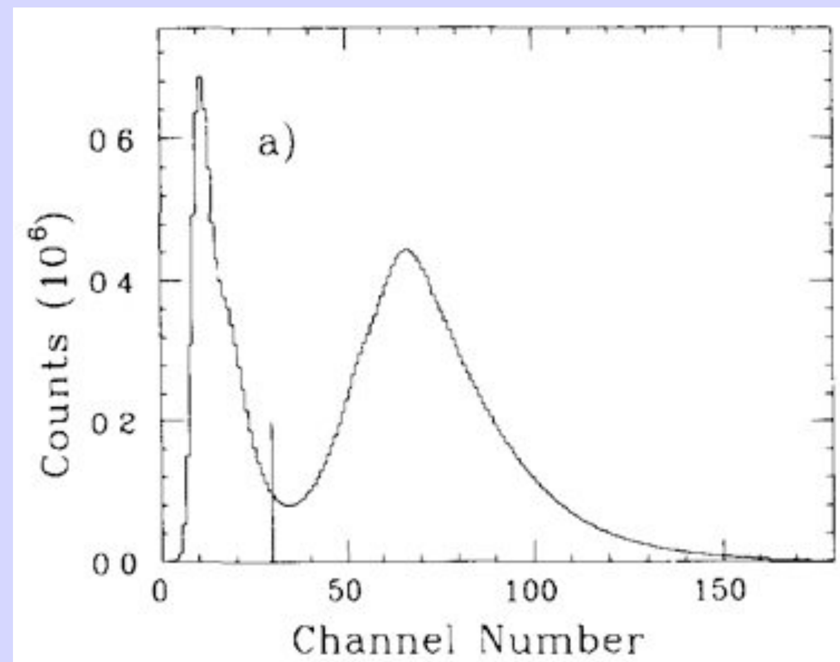


Fig. 1. Schematic view of the thick GEM-like multiplier.

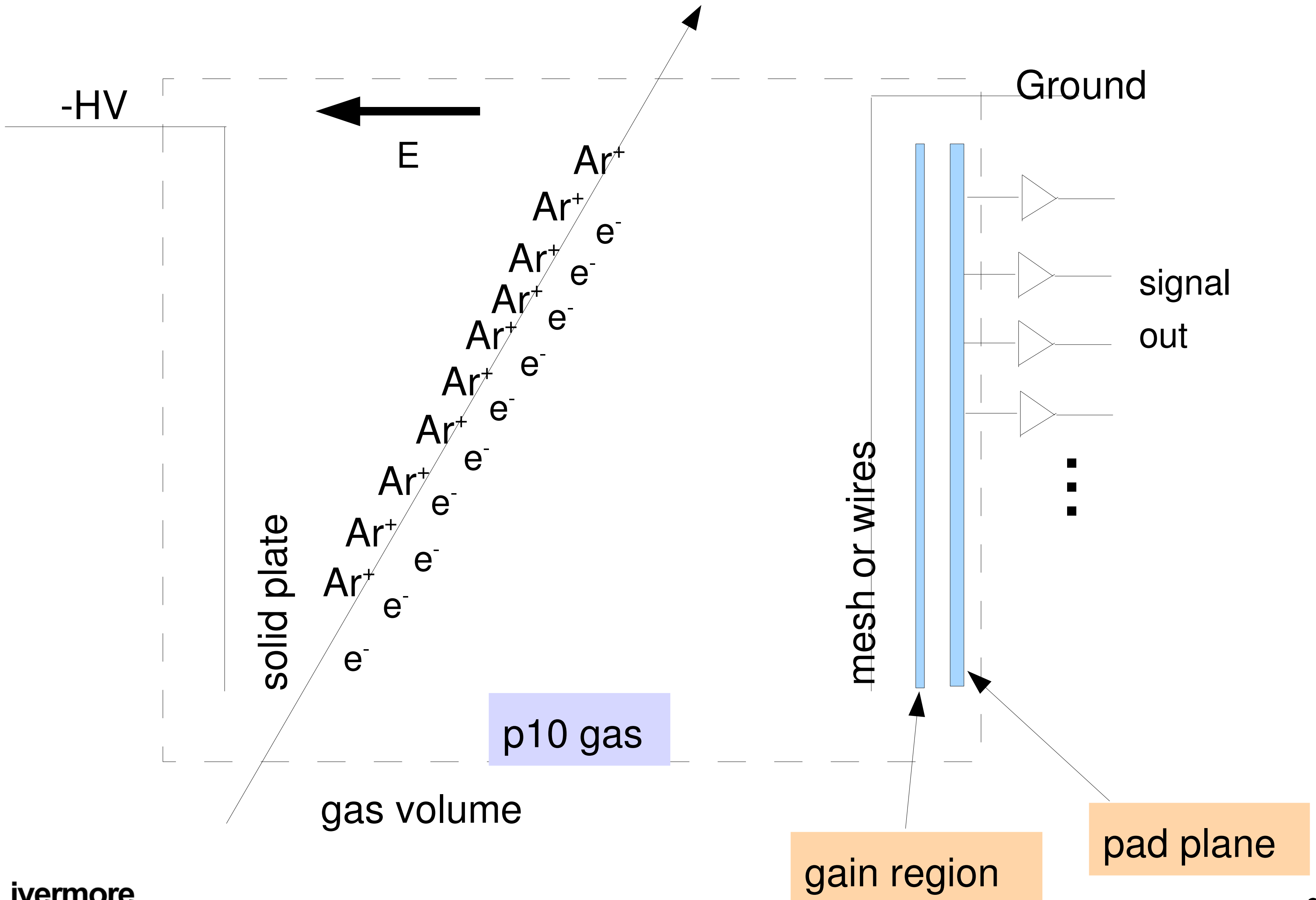
Fission chamber





Typical Data

How a TPC Works



Possible TPC Improvements

Gaseous Pu target:

Removes target energy loss problems

^{3}He drift gas:

measure neutrons