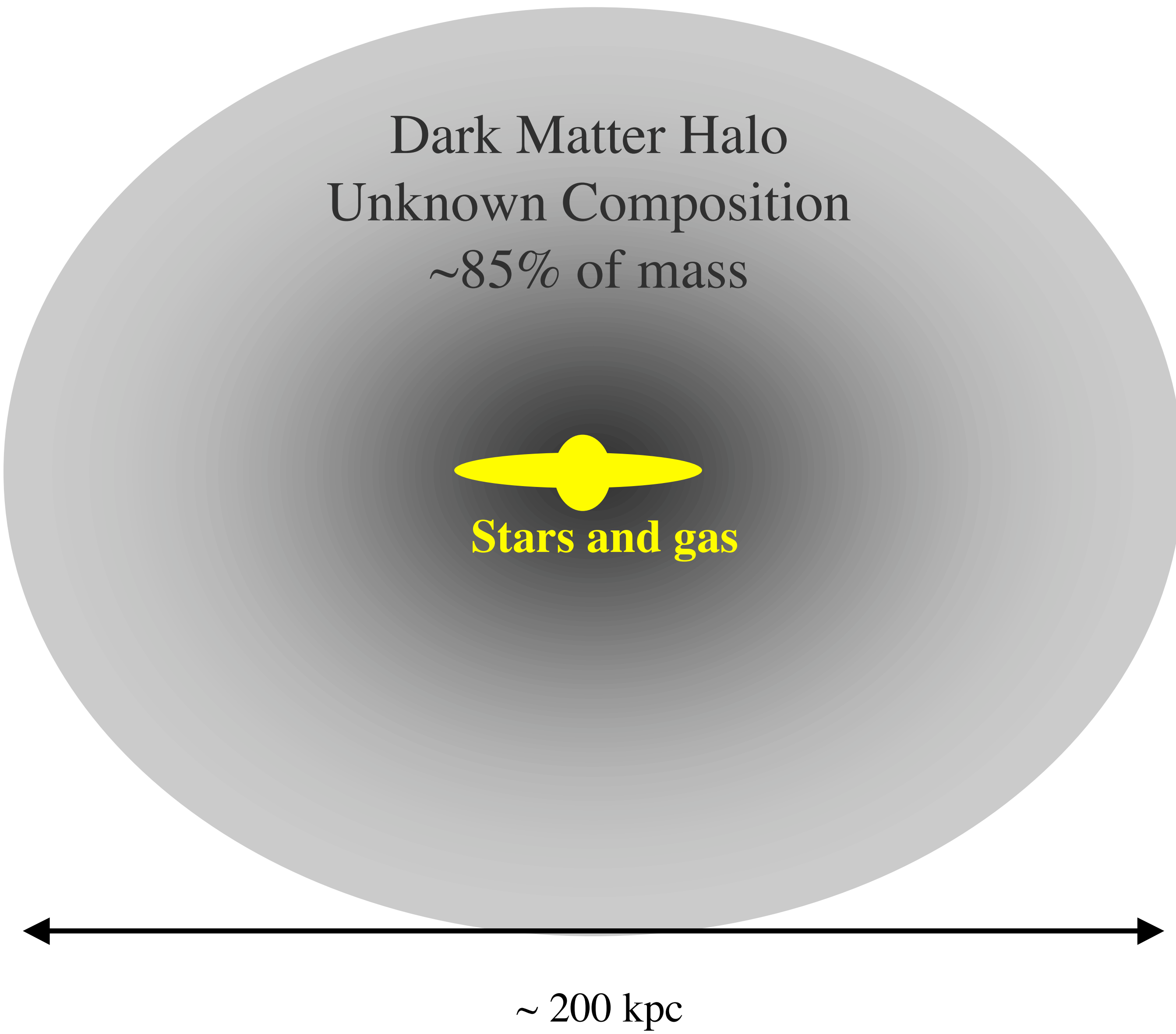
Cartoon of a Galaxy

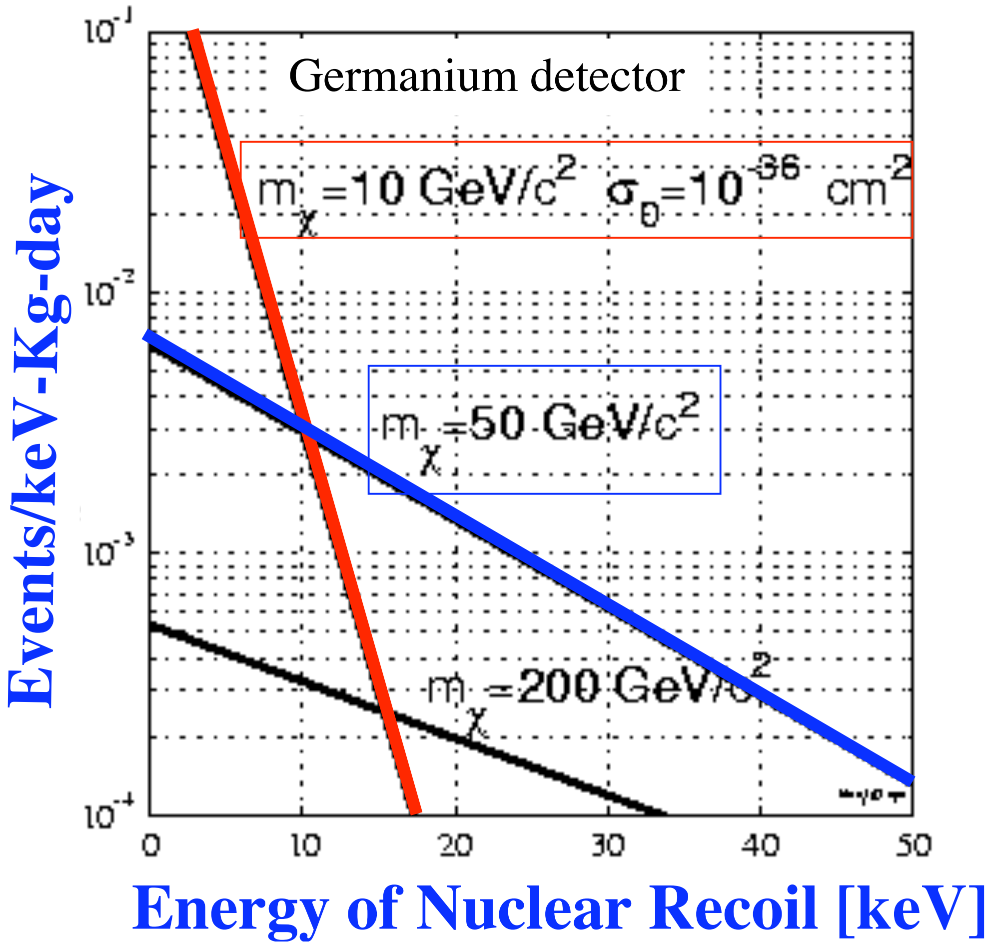


Spectrum of WIMPs in a Detector on Earth

Based on simple assumptions:

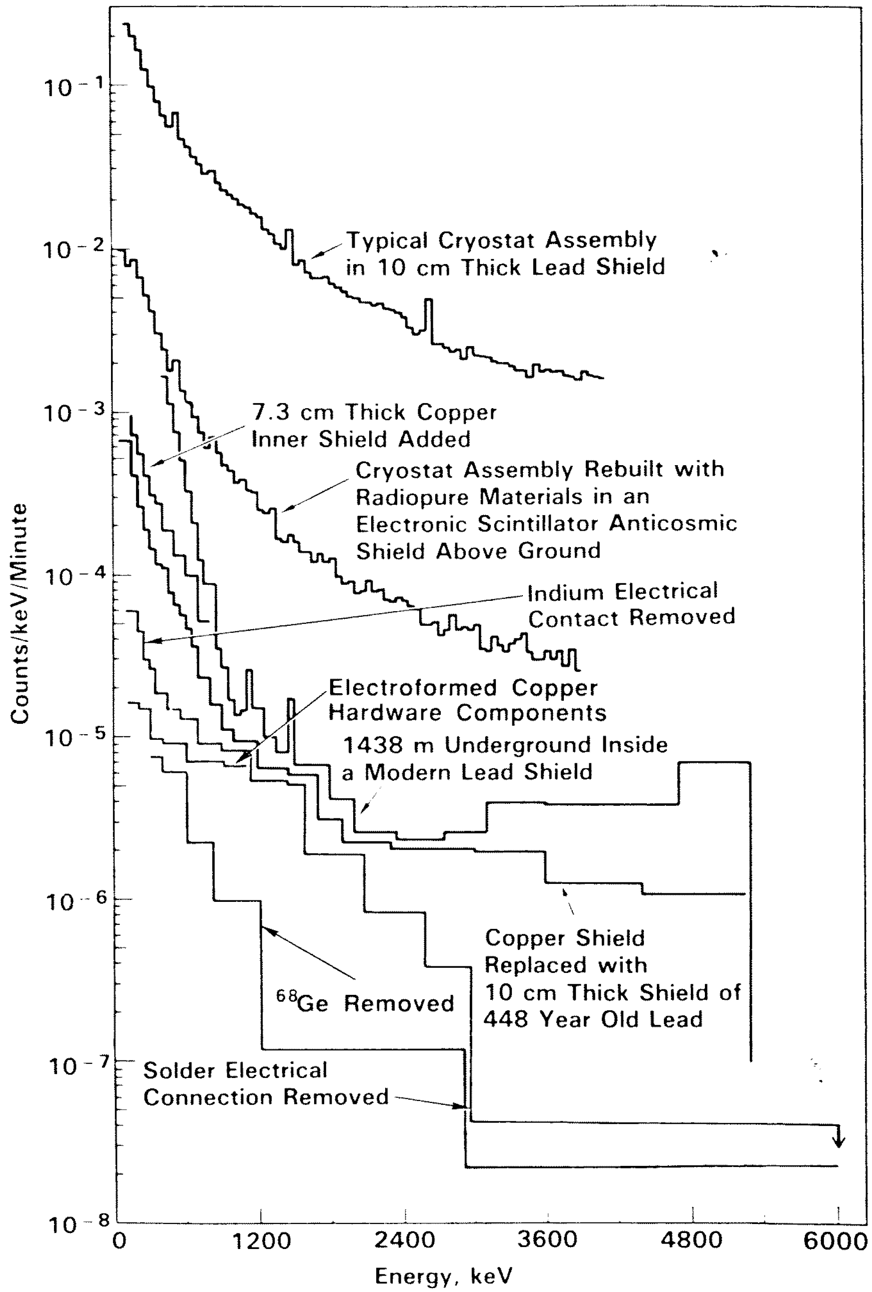
- Particles are gravitationally bound to halo, with Maxwellian velocity distribution (V_{rms}=220 Km/s) and local density 0.3 GeV/cm^3
- WIMPs are heavy particles, 10 GeV< M_{WIMP}< 1 TeV.

⇨ Nuclear scattering can efficiently transfer energy to a nucleus, since $M_{nucleus}$~$M_{wimp.}$ The signal will be a nuclear recoil, with energy ~10 keV



- Scattering is non-relativistic.
- Shape of spectrum does not depend on particle physics inputs.
- Amplitude of spectrum depends on unknown supersymmetry parameters and some astrophysical uncertainties.

Backgrounds



- A long history of successful attempts to reduce by choosing special materials and shielding.

<u>Gammas & betas</u>

From primordial, cosmogenic, and manmade nuclei: (not an exhaustive list!)

^{238}U, ^{232}Th + daughters (incl. ^{222}Rn)

^{40}K, ^{14}C

^{85}Kr, ^{137}Cs, ^{3}H - nuclear tests

^{68}Ge, ^{60}Co - cosmogenic in detector setups

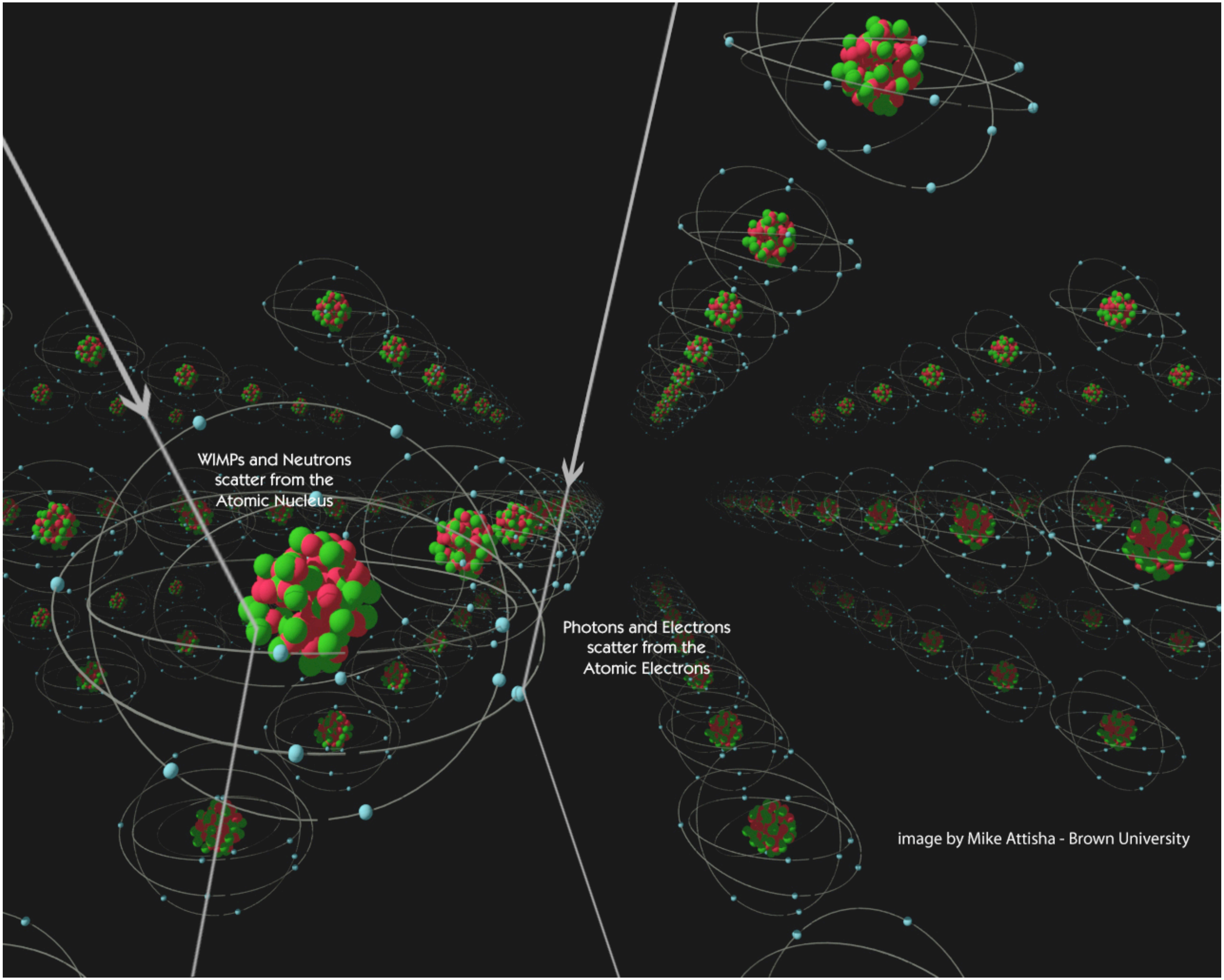
<u>Cosmic Rays (p, π , μ, e…)</u>

Can be reduced by going underground.
The μ's penetrate to great depth.

<u>Neutrons</u>

From μ spallation or (α, n) reactions in rocks, with alphas from U/Th chains. Can be shielded with moderator at low energies.

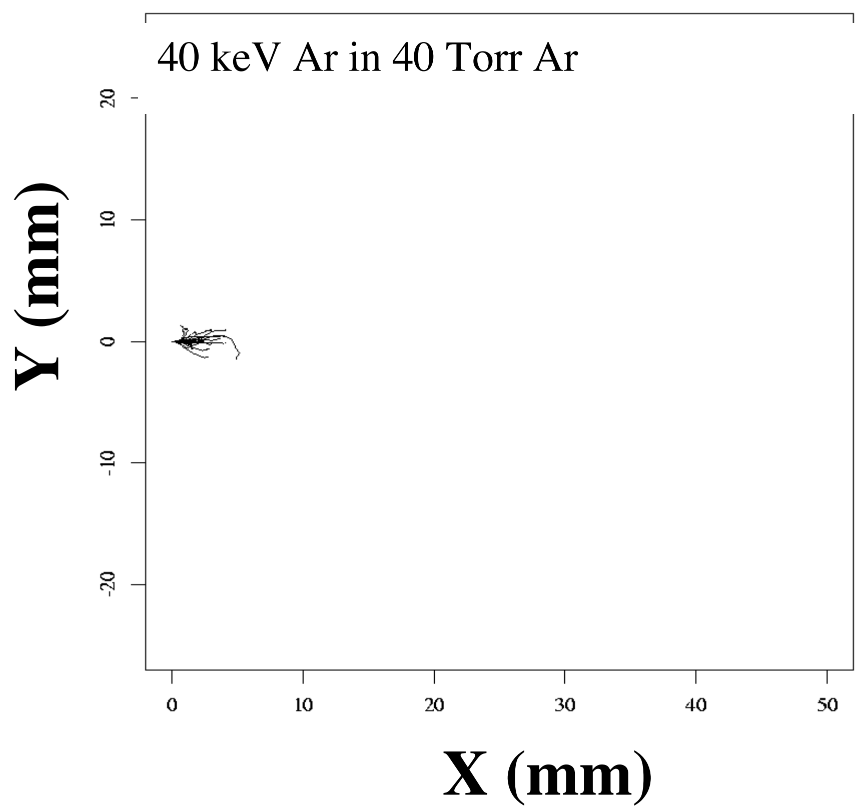
(figure from Brodzinski et al, Journal of Radioanalytical and Nuclear Chemistry, 193 (1) 1995 pp. 61-70)

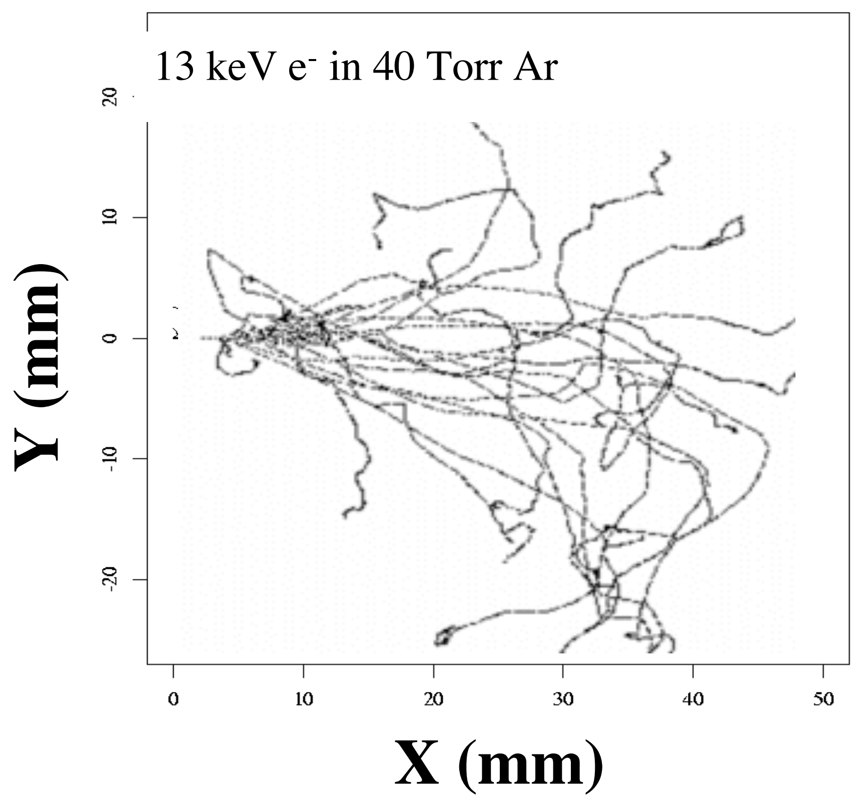

WIMPs and Neutrons
scatter from the
Atomic Nucleus
Photons and Electrons
scatter from the
Atomic Electrons
image by Mike Attisha - Brown University

Discriminating Against Backgrounds

• WIMPs interact with the **nucleus**, while most backgrounds are due to **electron scattering** by gamma and beta rays.

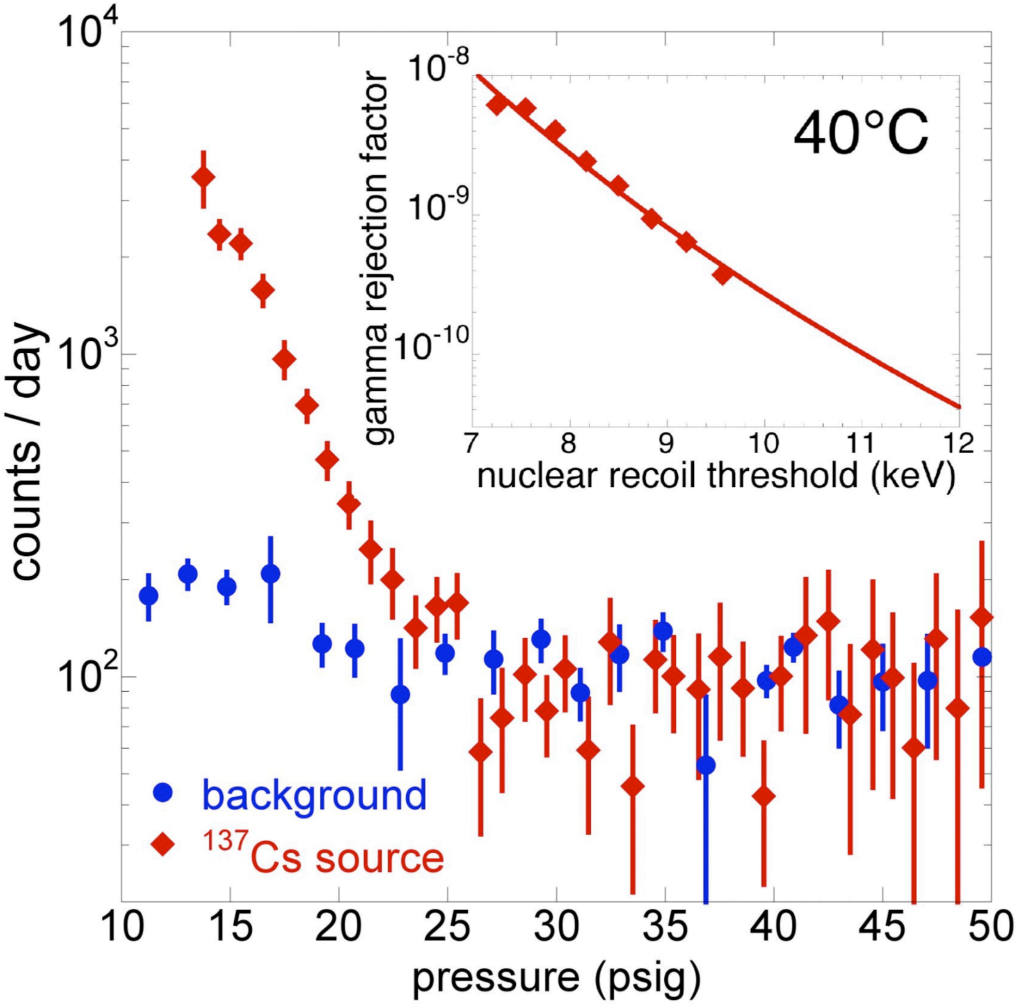
• The resulting spatial distributions of energy and charge are very different-- this is fundamental physical basis of most discrimination techniques.

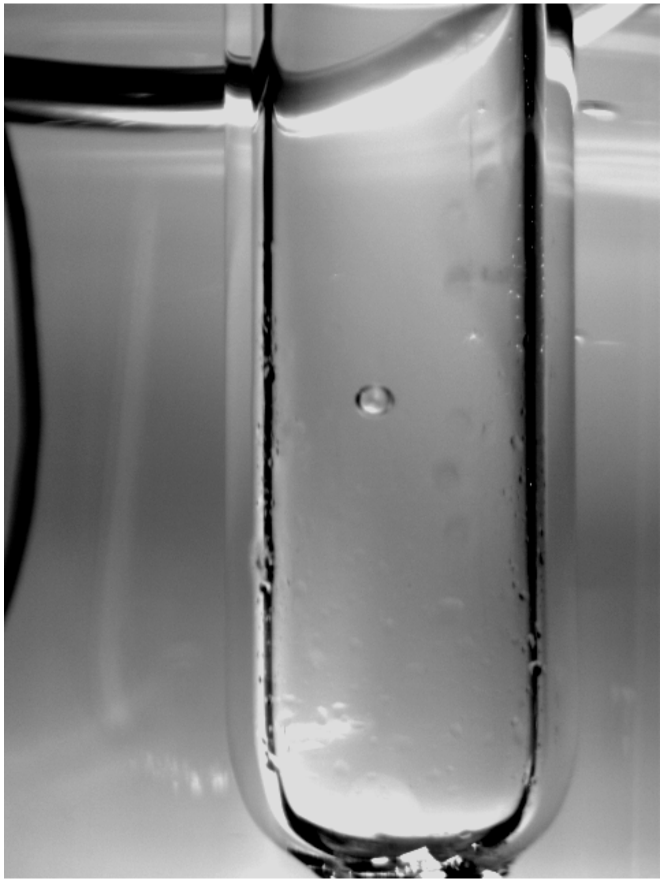




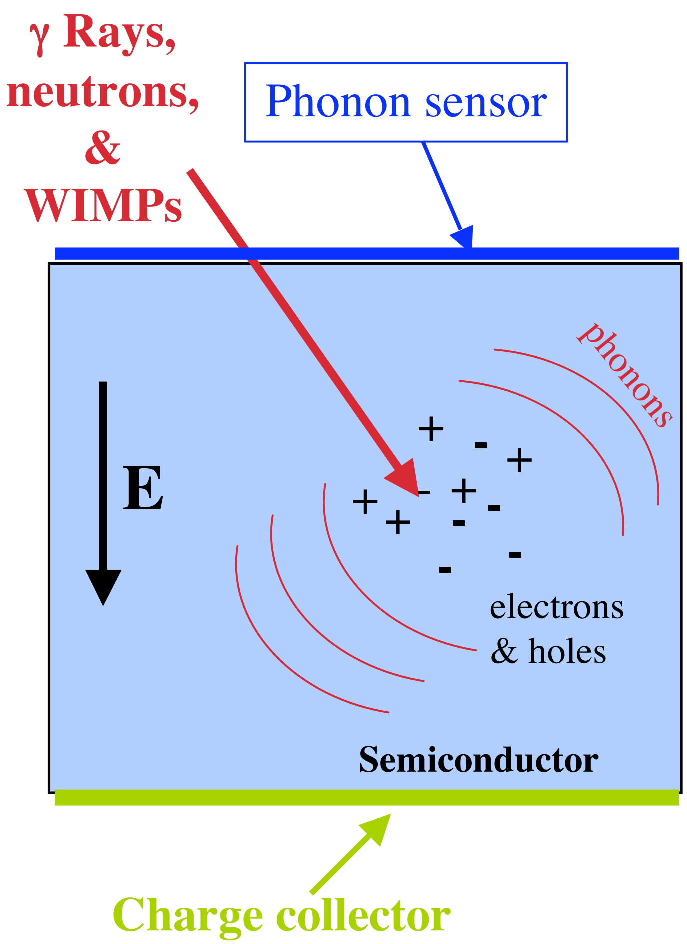
(Figures from DRIFT collaboration)

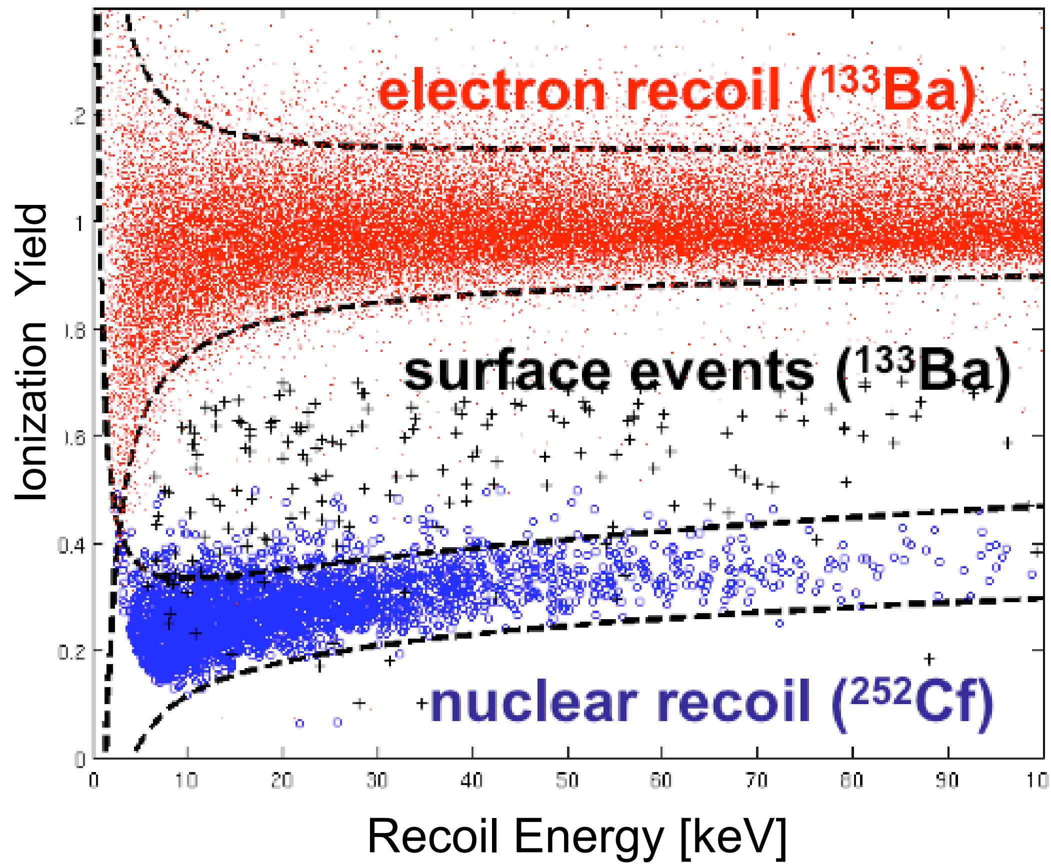
Background Discrimination in COUPP





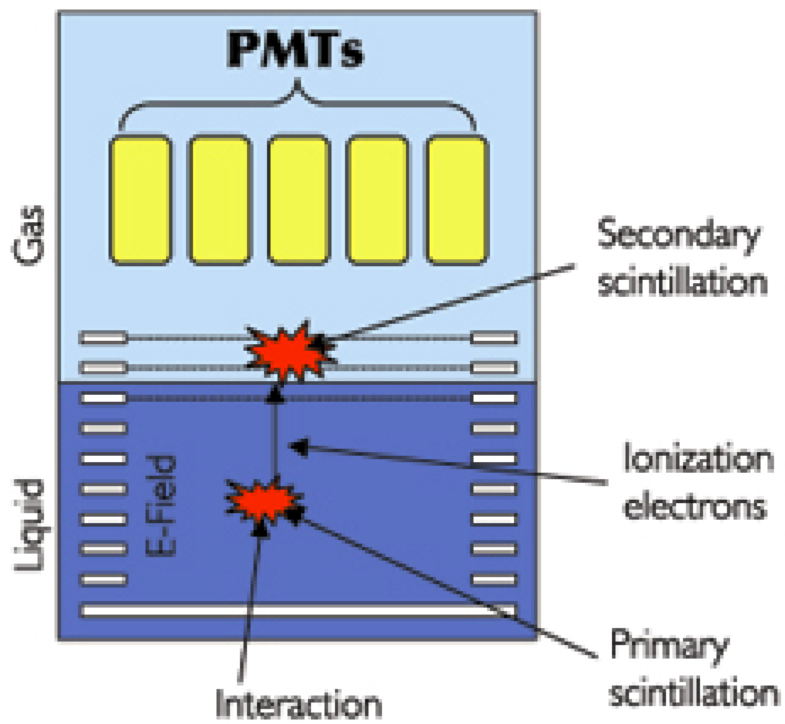
Background Discrimination With Cryogenic Detectors

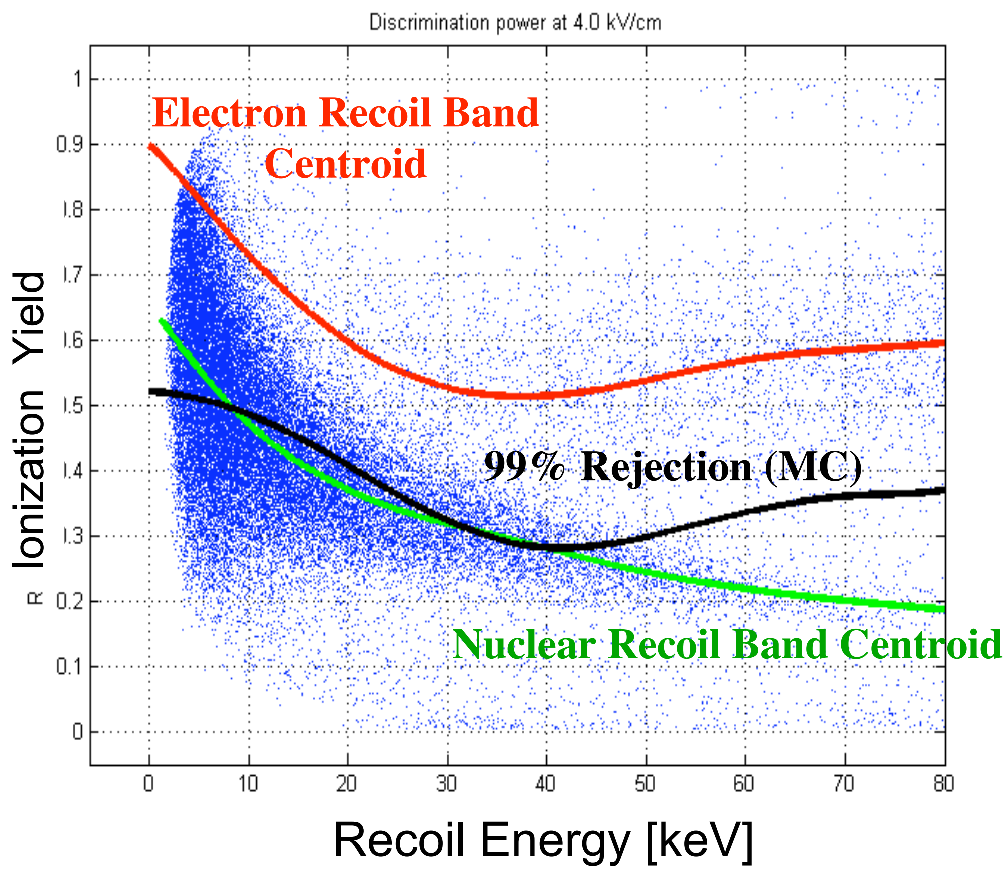




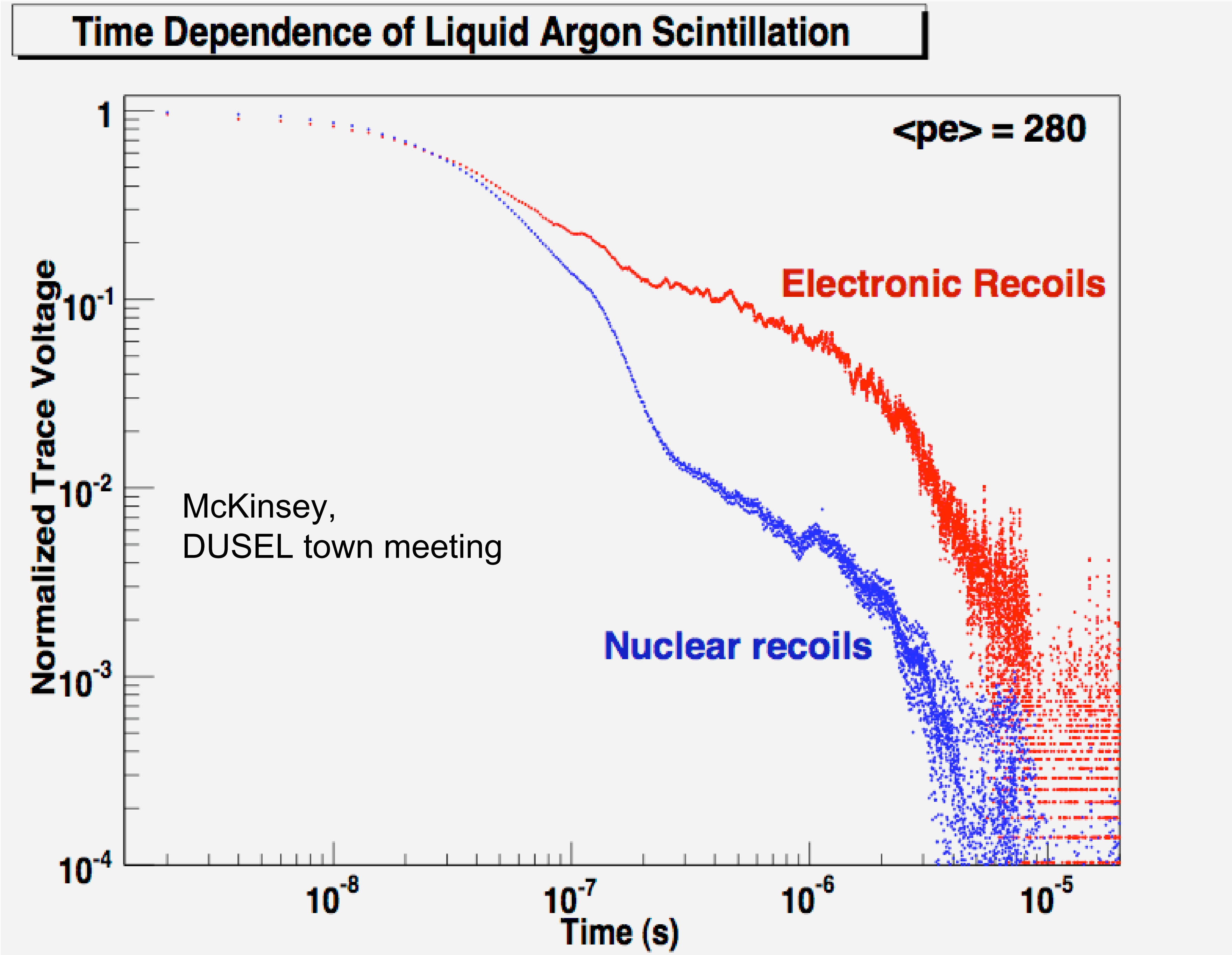
Background Discrimination With Noble Liquid TPCs (xenon, argon)

Example: xenon

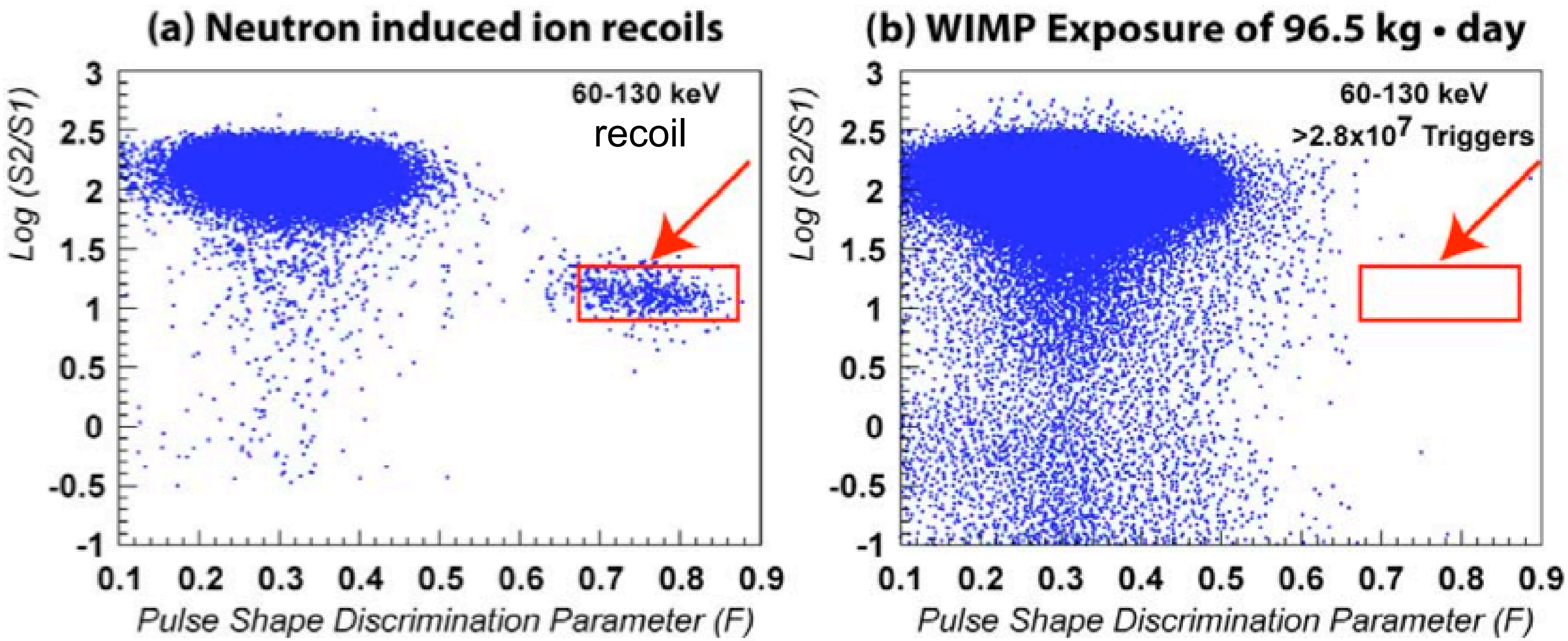




Shutt, 2008


Time Dependence of Liquid Argon Scintillation
<pe> = 280
Electronic Recoils
Nuclear recoils
McKinsey,
DUSEL town meeting
Normalized Trace Voltage
Time (s)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-8}
10^{-7}
10^{-6}
10^{-5}

Discrimination In Argon TPC: Two Independent Parameters



~ 2 p.e./keVee

WARP (Benetti et al. 2007)

Technology Choices for Dark Matter Detection

Technique	Good features	Bad features
Cryogenic detectors CDMS, Edelweiss	Excellent to good (>99.9%) discrimination for alpha, beta, gamma	High cost, difficult to manufacture, scale up
Xenon TPC + Scintillation Xenon, Lux	Scalability, Easy cryogenics, high Z, good position resolution	Modest discrimination for beta, gamma (99%), expensive
Argon, scintillation only DEAP	Excellent discrimination for alpha, beta, gamma	Radioactivity of Ar-39
Argon TPC + Scintillation WARP, ARDM	Best discrimination overall, inexpensive to scale up	Radioactivity of Ar-39?
Bubble chamber **COUPP** PICASSO	Lowest cost, easy to scale best spin target (F) best gamma discrimination	Alpha backgrounds
Drift chambers DRIFT	Directionality!	Small target mass

NSF DUSEL S4 Solicitation

- NSF will award 5 M$/year for three years for Preliminary Design of possible DUSEL experiments.
  - "Preliminary Design": 2/3 of design work complete
  - R&D is de-emphasized

- Includes all fields of physics: dark matter, double beta decay, long baseline neutrinos, proton decay…

- Deadline was Jan. 9

- Fermilab is involved in long baseline proposal and three dark matter proposals: GEODM, COUPP, MAX

DUSEL Dark Matter S4 Proposals

Technology	Experiment	Target	Mass (T)	Cost (M$)
Low Temperature Ionization/Phonon	GEODM	Germanium	1	100?
Bubble Chamber	COUPP	Fluorine, Iodine	10?	1 M$/ton
Liquid Argon Scintillator	DEAP/ Clean	Argon/ Neon		
Dual Phase TPC	LZ20	Xenon	20	100?
	MAX	Argon Xenon	5 2	17 18
Gas TPC	DRIFT	Fluorine	0.1?	

Fermilab involvement

I. THE MAX COLLABORATION

MAX Collaboration

90 people
19 institutions

Arizona State University, USA Prof. Ricardo Alarcon, Septimiu Balascuta
Augustana College, USA Prof. Drew Alton
Black Hills State University, USA Prof. Dan Durben, Prof. Kara Keeter, Prof. Michael Zehfus
Columbia University, USA Prof. Elena Aprile, Dr. Karl-Ludwig Giboni, Dr. Tom Haruyama, Dr. Rafael Lang, Dr. Antonio Jesus Melgarejo, Dr. Kaixuan Ni, Guillaume Plante, Bin Choi, Kyungeun Elizabeth Lim, Taehyun Yoon, Dr. Gordon Tajiri
Fermi National Accelerator Laboratory, USA Dr. Steve Brice, Dr. Aaron Chou, Pierre Gratia, Dr. Jeter Hall, Dr. Stephen Pordes, Dr. Andrew Sonnenschein
INFN, Laboratori Nazionali del Gran Sasso, Italy Dr. Francesco Arneodo, Serena Fattori, Dr. Walter Fulgione
Massachusetts Institute of Technology, USA Prof. Jocelyn Monroe
Princeton University, USA Alvaro Chavarria, Ernst de Haas, Prof. Cristiano Galbiati, Victor Garzotto, Augusto Goretti, Andrea Ianni, Tristen Hohman, Ben Loer, Prof. Peter Meyers, David Montanari, Allan Nelson, Marc Osherson, Eng. Robert Parsells, Richard Saldanha, Eng. William Sands
Rice University, USA Prof. Uwe Oberlack, Yuan Mei, Marc Schumann, Peter Shagin
Temple University, USA Prof. Jeff Martoff, Prof. Susan Jansen-Varnum
University of California at Los Angeles, USA Daniel Aharoni, Prof. Katsushi Arisaka, Ethan Brown, Prof. David Cline, Jonathan Kubic, Dr. Emilija Pantic, Prof. Peter F. Smith, Artin Teymourian, Chi Wai Lam, Dr. Hanguo Wang
University of Coimbra, Portugal Dr. Joao Cardoso, Luís Carlos Costa Coelho, Prof. Joaquim Marques Ferreira dos Santos, Prof. José António Matias Lopes, Dr. Sonja Orrigo, Antonio Ribeiro
University of Houston, USA Prof. Ed Hungerford and Prof. Lawrence Pinsky
University of Massachusetts at Amherst, USA Prof. Andrea Pocar
University of Muenster, Germany Dr. Marcus Beck, Dr. Volker Hannen, Karen Hugenberg, Dr. Hans-Werner Ortjoahnn, Prof. Christian Weinheimer
University of Notre Dame, USA Prof. Philippe Collon, Daniel Robertson, Christopher Schmitt
University of Virginia, USA Prof. Kevin Lehmann
University of Zürich, Switzerland Ali Askin, Prof. Laura Baudis, Dr. Alfredo Ferella, Marijke Haffke, Alexander Kish, Dr. Roberto Santorelli, Dr. Eirini Tziaferi
Waseda University, Japan Prof. Tadayoshi Doke, Prof. Nobuyuki Hasebe, Mitsuteru Mimura, Dr. Mitsuhiro Miyajima, Dr. Shinichi Sasaki, Dr. Satoshi Suzuki, Prof. Shoji Torii

MAX Proposal Summary

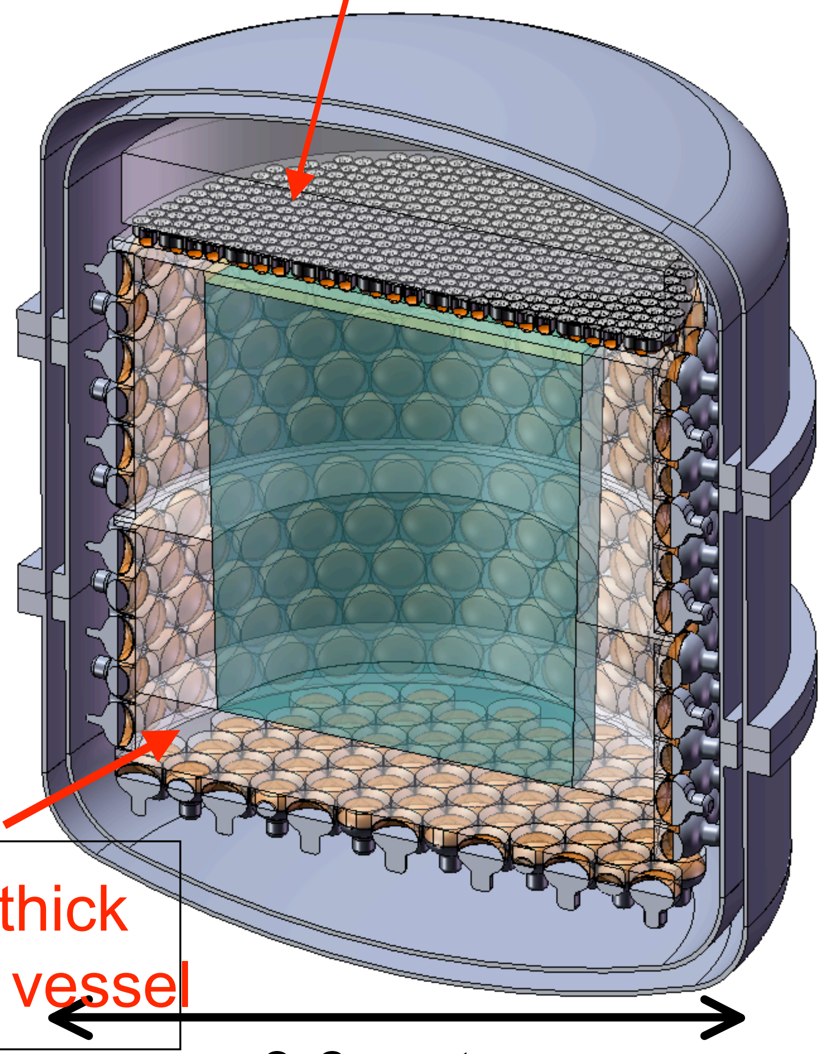
- Coordinated engineering study of large argon and xenon TPCs.
- We will produce Preliminary Designs for two separate detectors using common engineering staff.
- We will exploit similarities between detectors to reduce the design cost.
  - Common photodetectors (UCLA/ Hamammatsu)
  - Field shaping structures
  - Purification
  - Cryogenics
  - Electronics

  \+ others

Argon Detector Concept

- Largest diameter cryostat that will fit down DUSEL elevator.
- 5 tons depleted argon
  (2.6 tons after fiducial cut)
- 30 keV recoil energy threshold
- ~ 2 cm position resolution
- 0.5 background events expected in 5-year run.

3 order of magnitude improvement over present CDMS/ XENON sensitivity



R&D Topics

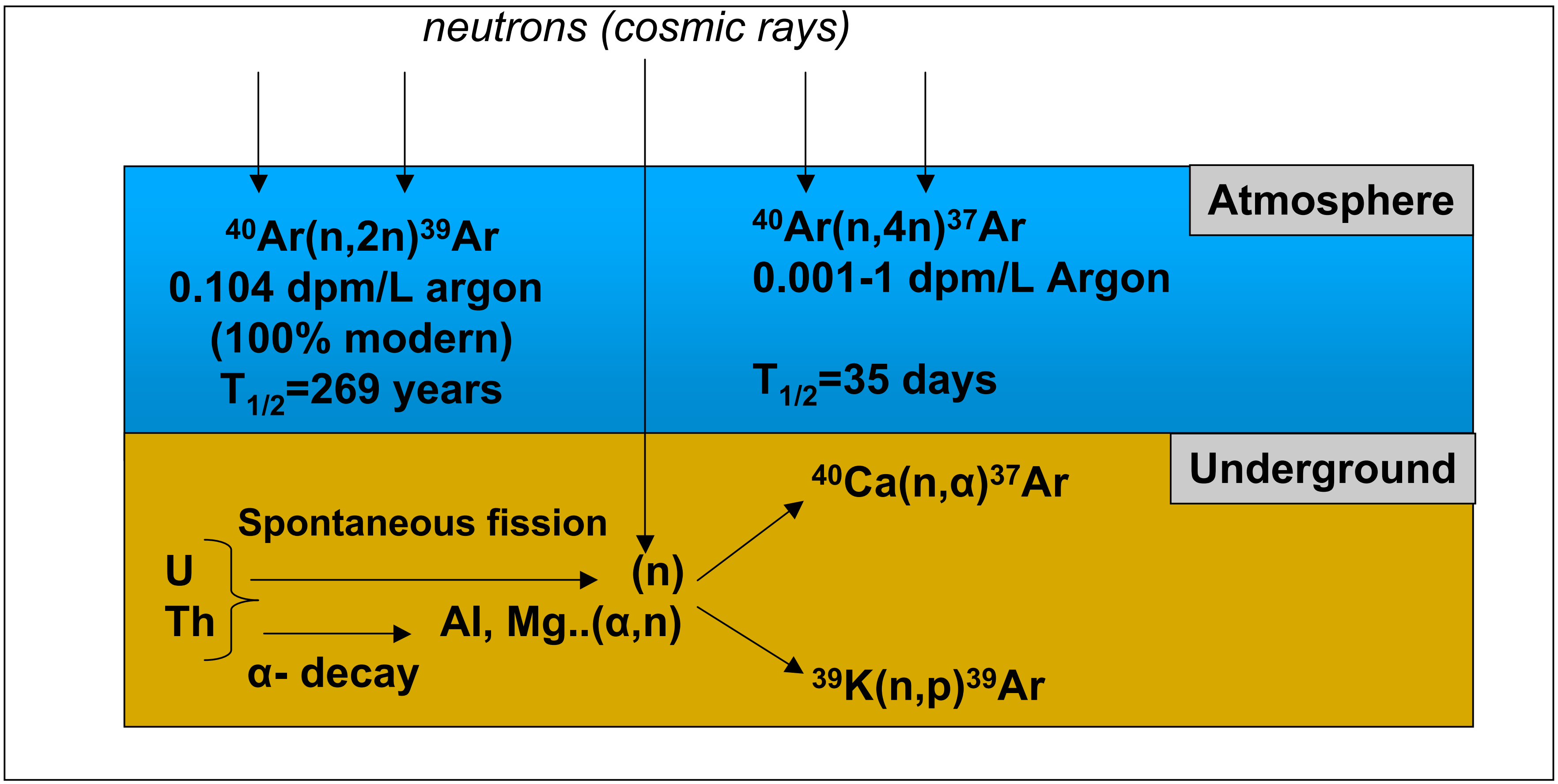
1. Obtaining argon gas with low Ar-39.
2. Test scale up and “integration” of systems (20 kg and 500-kg)

   We have demonstrated many of the individual components separately at least on small scale

   - Purification for charge yield
   - High scintillation yield
   - Light collection
   - Cryogenics
   - Electronics

3. Intermediate-scale (Pre-DUSEL) physics

Main Sources and sinks of ^{39}Ar (and ^{37}Ar) in the environment



WARP, Cocco, Lisboa (2005)

2.3 litre preliminary results (V)

^{39}Ar measurement

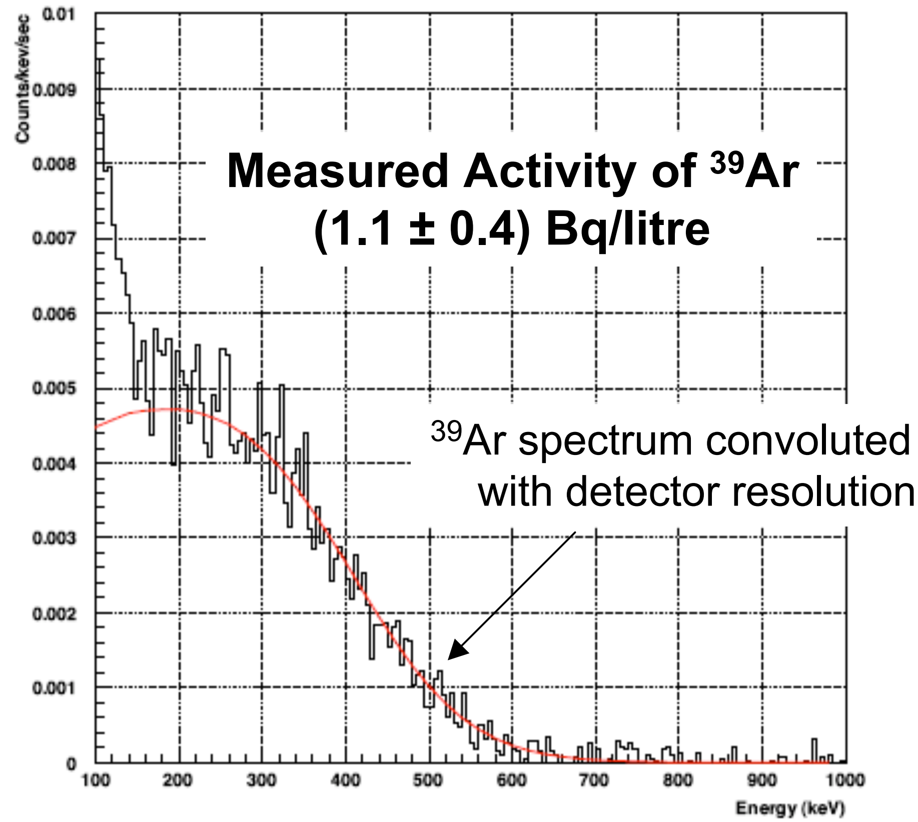
$^{39}Ar \rightarrow {}^{39}K + e^- + \bar{\nu}_e$ (Q = 565 keV)

Measured activity in agreement with the result of H.H.Loosli quoting the ^{39}Ar in natural Argon as $(8.1 \pm 0.3) \times 10^{-16}$

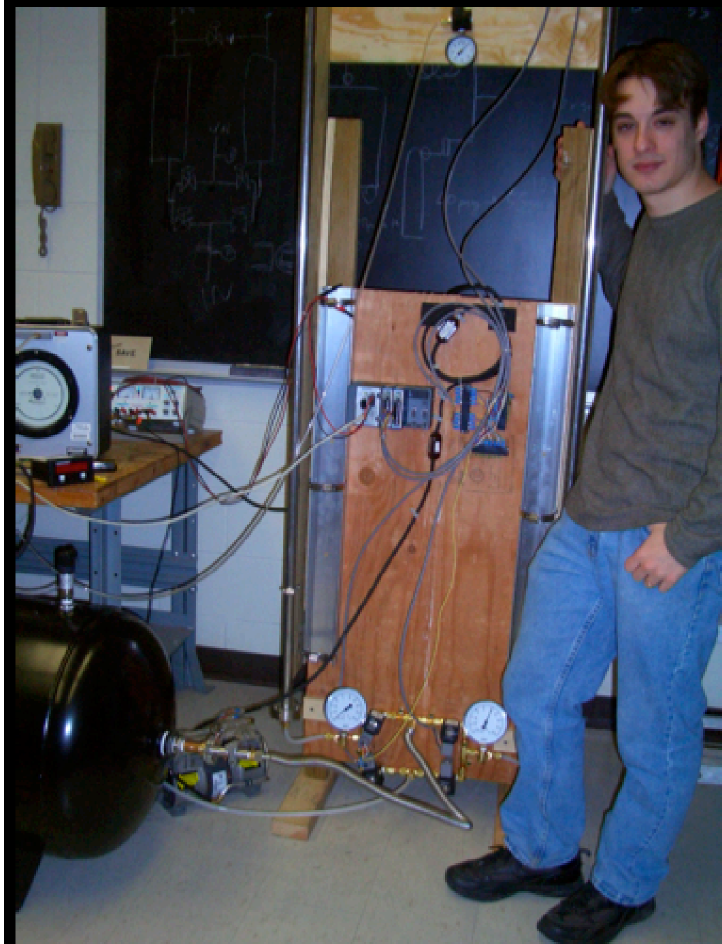
The fraction of ^{39}Ar decays producing an energy release in the range 30 ÷100 keV is about 3%

The expected rate due to ^{39}Ar in the ion recoil evergy window from 30 to 100 keV is given by 1.1 × 0.03 Hz/litre

Residual spectrum after subtracting ^{222}Rn contribution and γ estimated from events without Pb shield



Discovery of underground sources of low-activity argon



← Prototype Purification Plant at Princeton

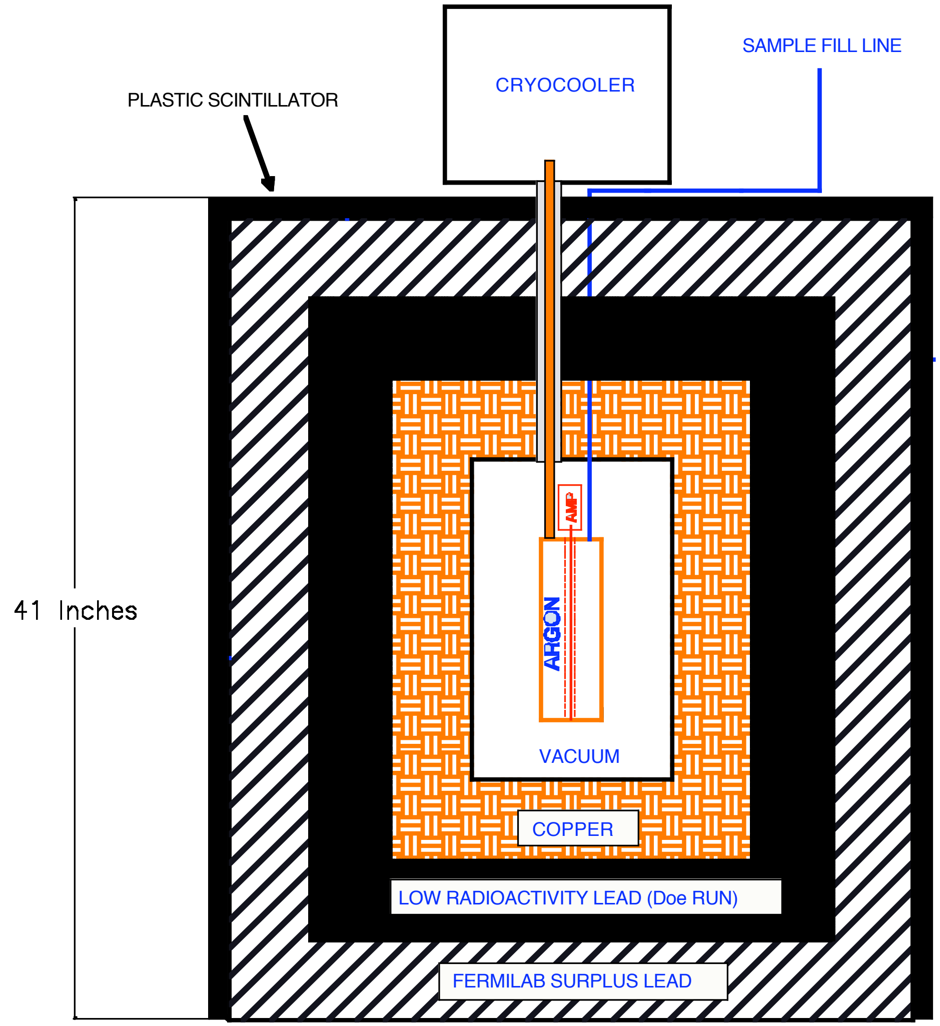
Sampling on a gas field in the West

<5% atmospheric Ar-39 concentration!

Funded by NSF

Argon-39 Counter

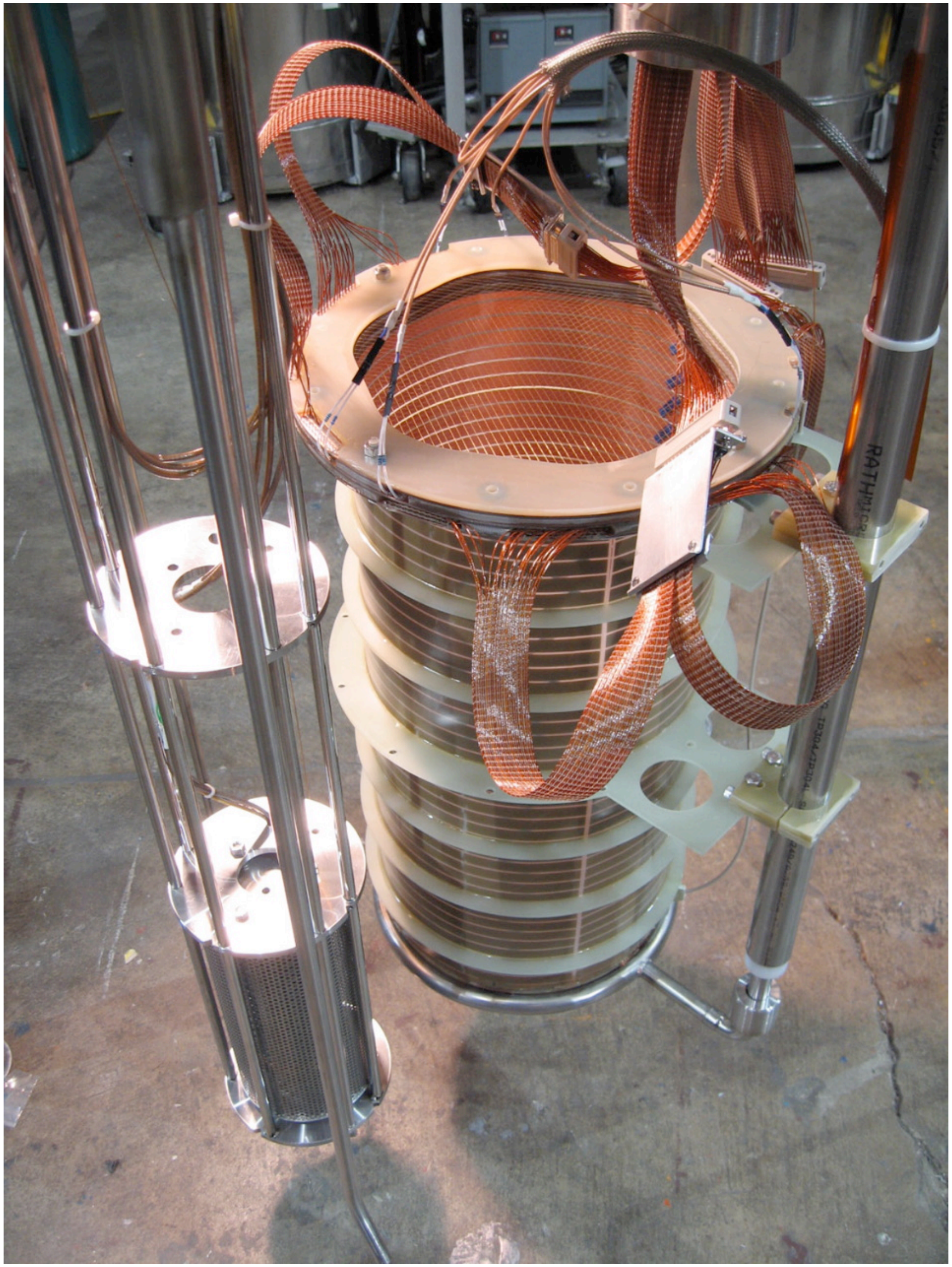
- Measure ^{39}Ar isotope in 1- liter of liquid argon with a single-wire ion chamber.
- Attention to radiopurity and shielding details will allow measurement at 10^{-3} of atmospheric ^{39}Ar abundance (~100 decays/day).
- Application: screen argon from underground sources for use in a large detector at DUSEL (collaboration with Princeton University, Temple University, others)



Ion Chamber For Ar-39 Measurements

1. Test that <100 keV energy threshold can be obtained with no gain in gas (P. Gratia). now
2. Modify for use with liquid.
3. Rebuild with low-radioactivity materials.
4. Run at in NuMI tunnnel

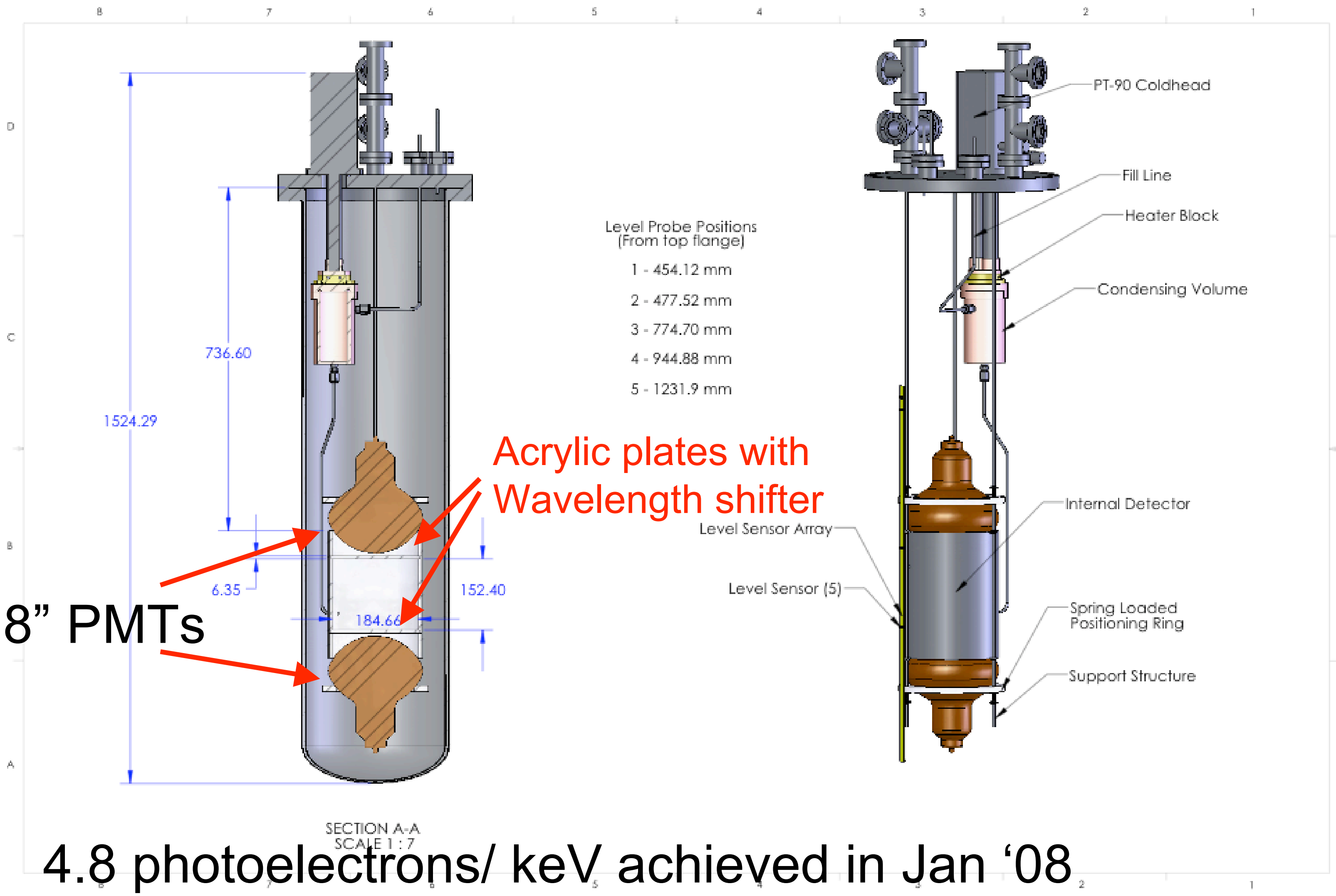
1 liter gas or liquid



"Bo" TPC Technology Demonstration

The TPC is a cylinder 50 cm long by 24 cm diameter. Electrons drift upwards in a field of 500 V/cm towards horizontal wire-planes at the top. There are three planes at 60 degrees to each other. The first two planes (as the electrons see them) are so-called induction planes, the very top plane is the collection plane. The vertical rod at the extreme right is the HV feedthrough – it's been tested to 50 kV in Nitrogen.

Princeton 8-Inch Light- Collection Test Chamber

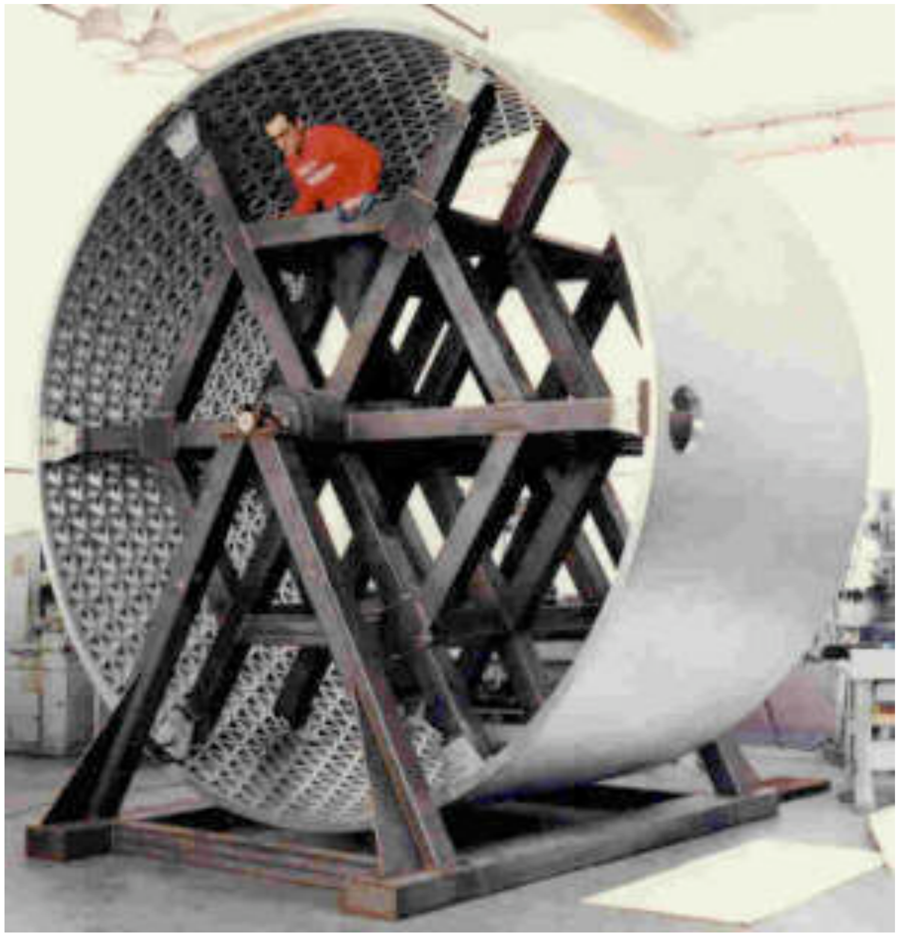


4.8 photoelectrons/ keV achieved in Jan '08

With 18% quantum efficiency Hamammatsu tubes

Would go to 8 p.e./ keV with new 30% QE photocathode.

SSC Detector Cryostat Prototype (mid- 90’s)



About same size as MAX argon detector.

Other Dark Matter Detectors At Fermilab

- Experience with high-purity, low radioactivity mechanical assemblies.
- Responsible for CDMS-II and SuperCDMS copper cryostats, COUPP.

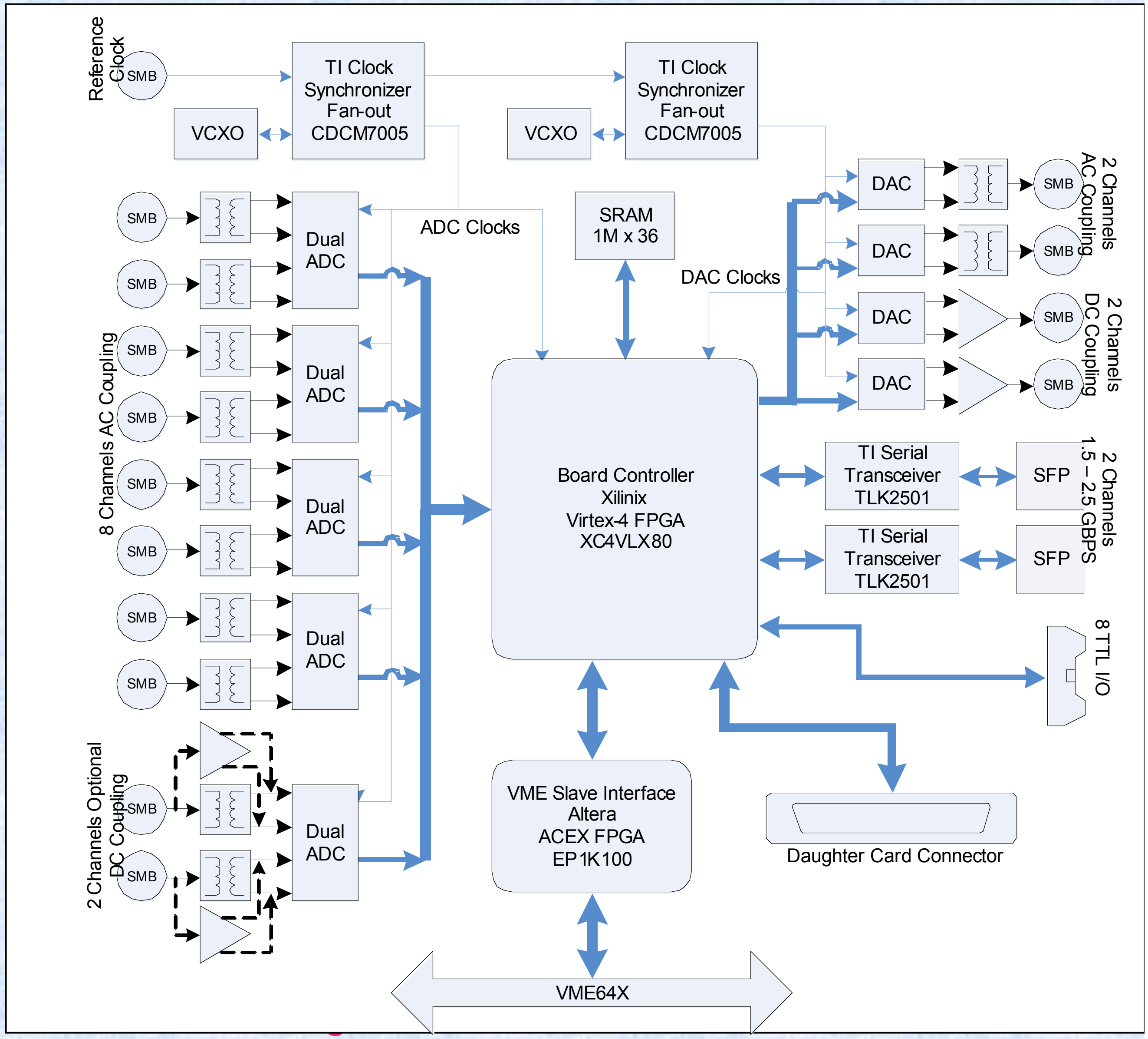
COUPP 60 kg

CDMS-II

LAr WIMP

FNAL ESECon

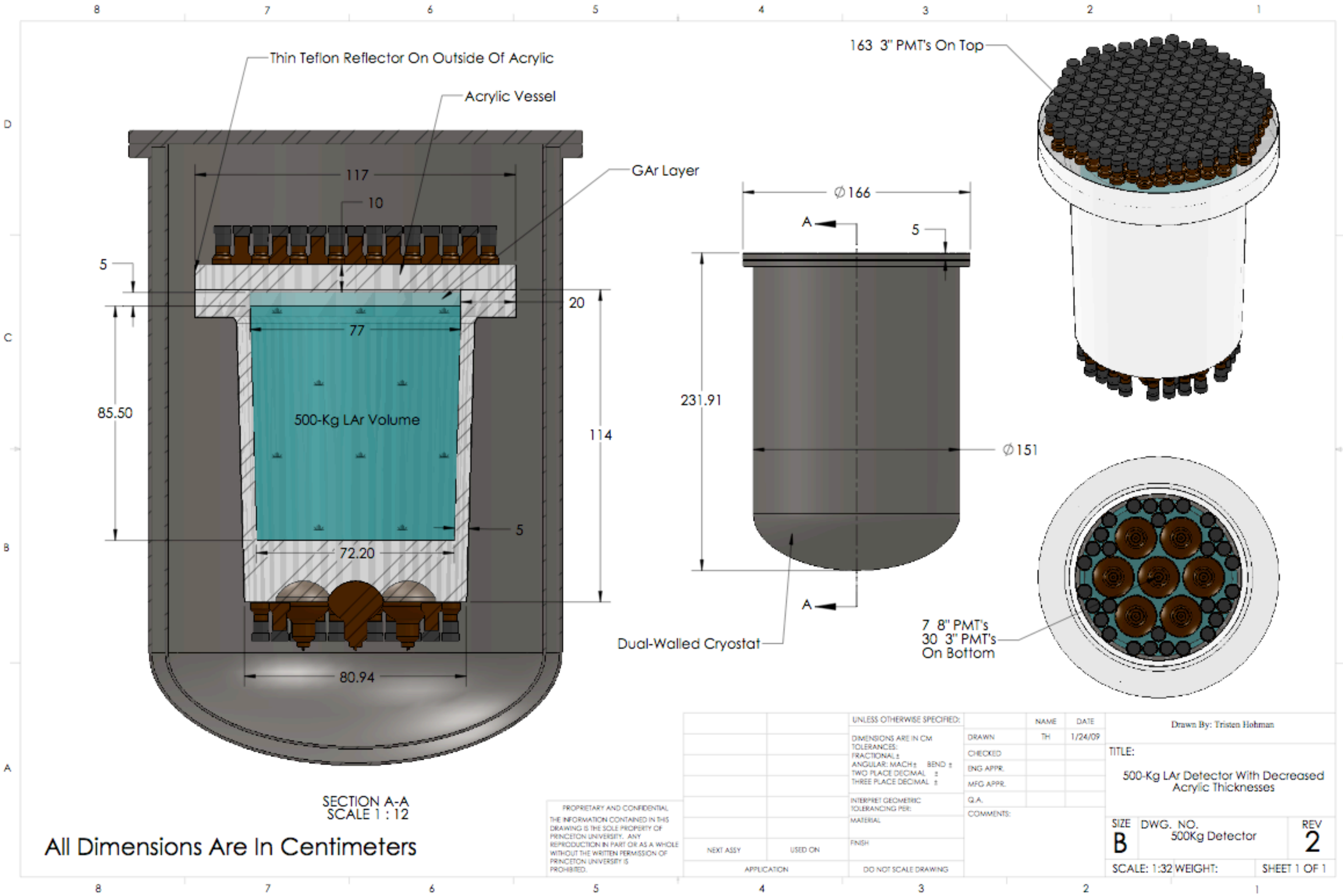
10 Channel ~$200/ch
125 MHz Digitizing
FPGA Control
10^{-4} - 1V Dynamic Range
Will adapt as needed
- **Add Memory**
- **Change Sampling freq**
- **Change FADC**
- **Change FPGA**



University of Houston

ESECon Block Diagram

10% MAX Prototype (500 -Kg)



500-kg Prototype R&D Goals

1. Measure light yield.

   Can we preserve >4 p.e./keV as we scale up?

   Depends on absorption, transmission, scattering in argon, acrylic, TPB, electrode structures. Not all well understood. Optical Monte Carlo must be validated.

2. Test position reconstruction vs. Monte Carlo

3. Electric field and high voltage issues, field shaping structures

4. Argon handling

   Obtain high purity for charge drift and light yield.

5. Acrylic vessel handling

   1% thermal contraction induces stresses

Work Plan, Phase I

FY2009

Build Ar-39 counting cell, components of 20 kg detector

Design MiniMAX (500-kg) cryostat and acrylic

Order cryostat and acrylic

FY2010

Design MiniMAX cryogenics, argon handling, high voltage, mechanical support, PMT mounts, purification system.

Build 50 channel MiniMAX in PAB (1/4 of tubes and electronics)

Test light yield, mechanical, purity and other issues.

MAX conceptual design

FY2011

MiniMAX improvements

Fully instrumented MiniMAX in NuMI tunnel

Start MAX Preliminary Design

Resources for Phase I

Resource	FY09	FY10	FY11
Scientist, Fermilab	2	3	3
Scientist, Visiting	1	1	1
Scientist, Postdoc	0	0.5	1
Engineer, mechanical	0.25	1.75	1.75
Designer, mechanical	0.25	0.5	0.5
Drafter, mechanical	0.1	0.25	0.25
Technician, mechanical	0.1	2	2
Engineer, electrical	0.1	0.25	0.25
Designer, electrical	0.1	0.25	0.25
Drafter, electrical	0.1	0.25	0.25
Technician, electrical	0.1	0.5	0.5
Total FTEs	4.1	10	10.5
M&S	300	600	600

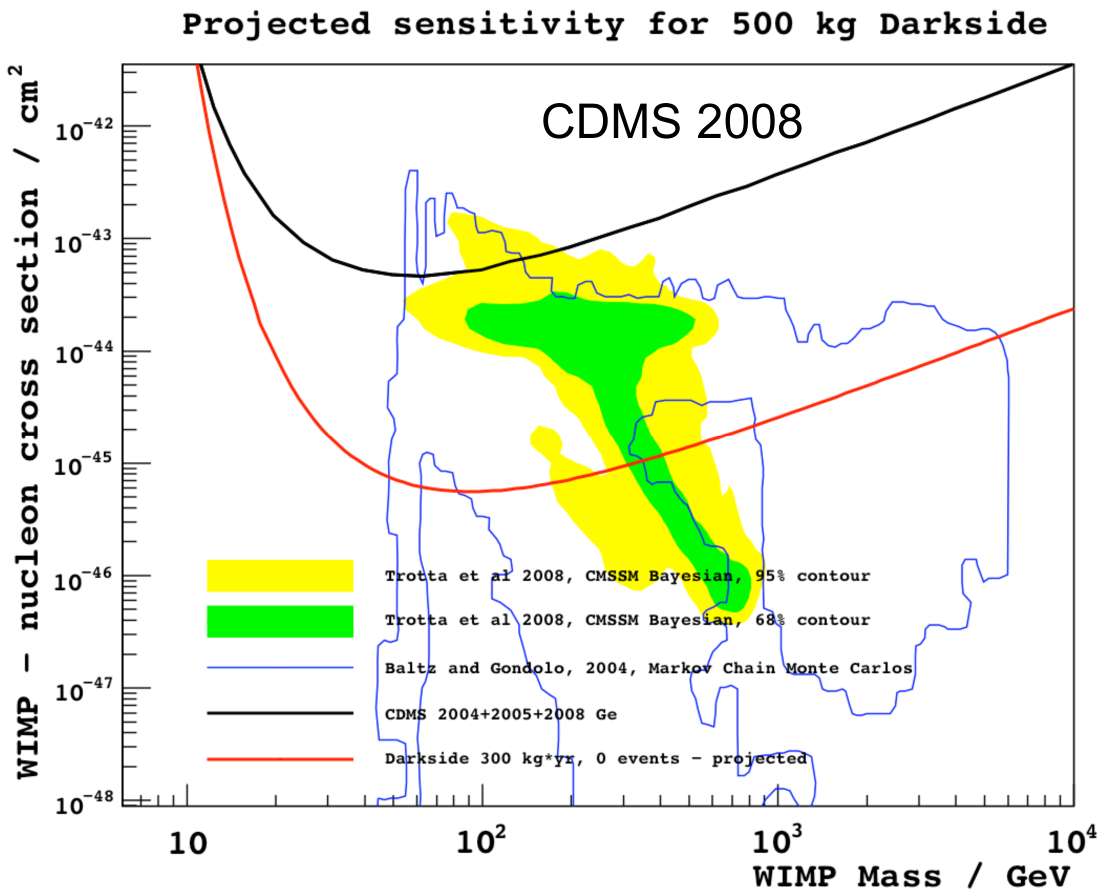
Notes:

M&S costs dominated by PMTs (600 k$) with cost of other identified specific items estimated to be 300 k$. The total M&S costs shown (1.5 M$) include 70% contingency.

Phase II for 500-kg : Physics Run

Homestake (Pre-DUSEL) or Snolab

Will need large water shield



1- year run
300 kg fiducial
4 p.e./keV