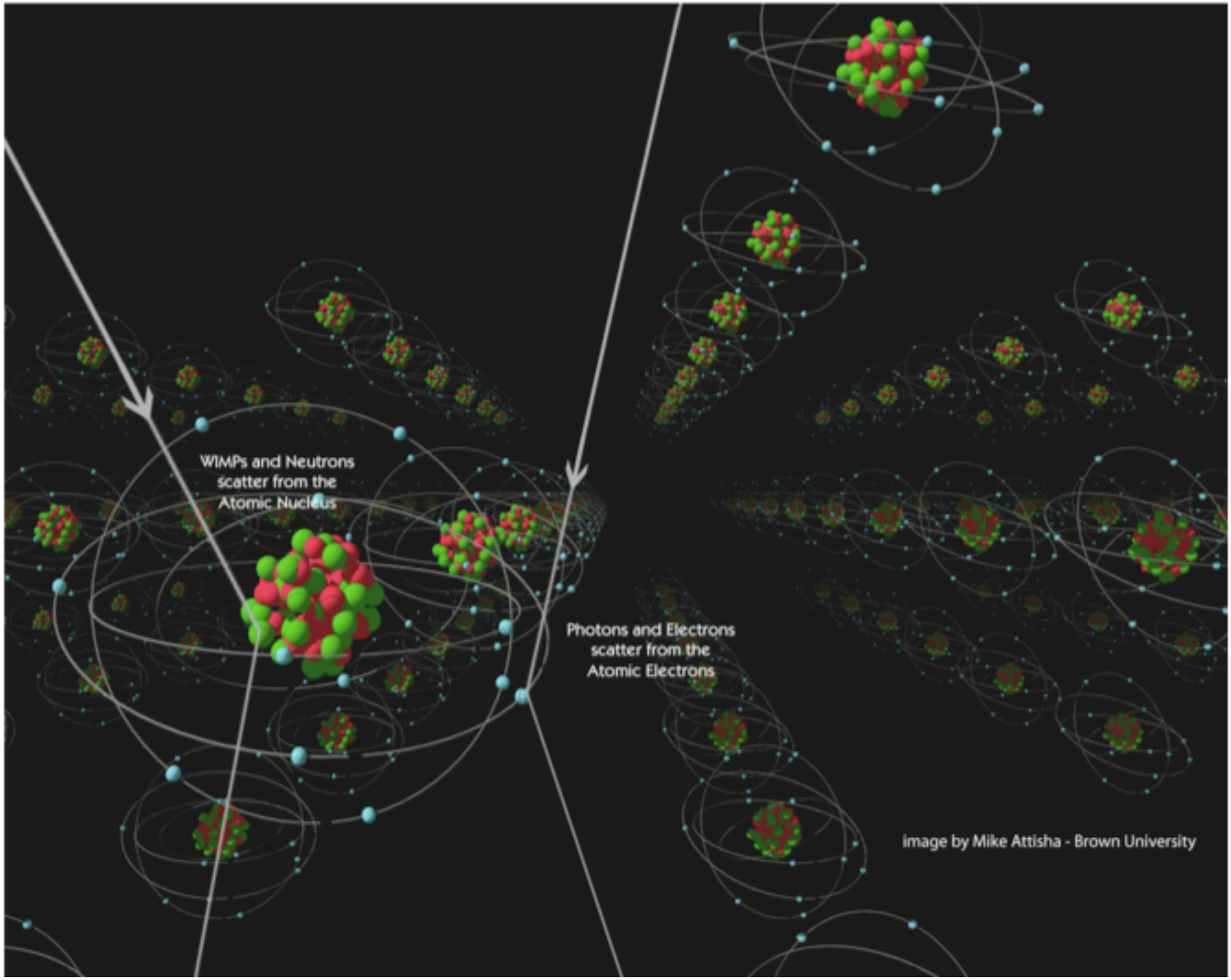
Liquid Argon Dark Matter Detectors

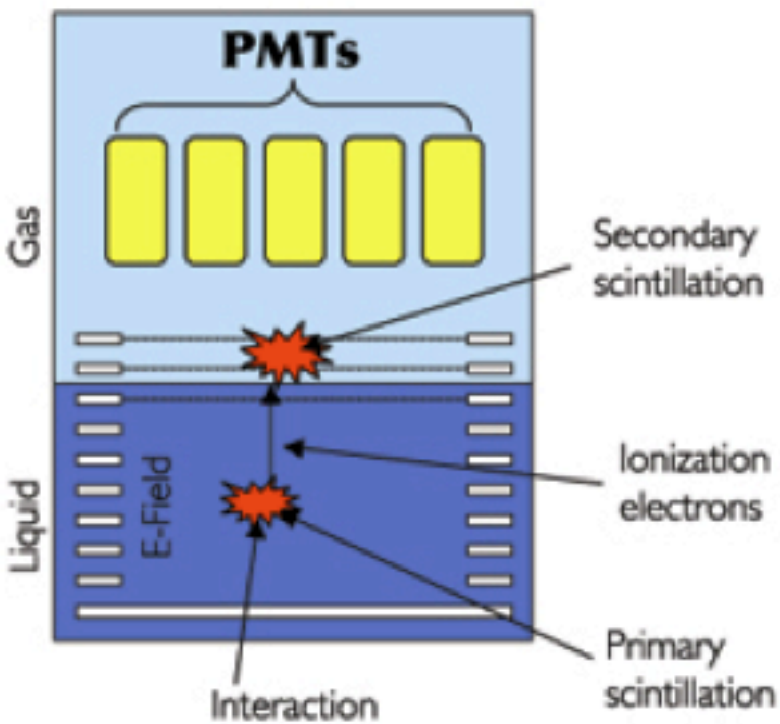
Andrew Sonnenschein

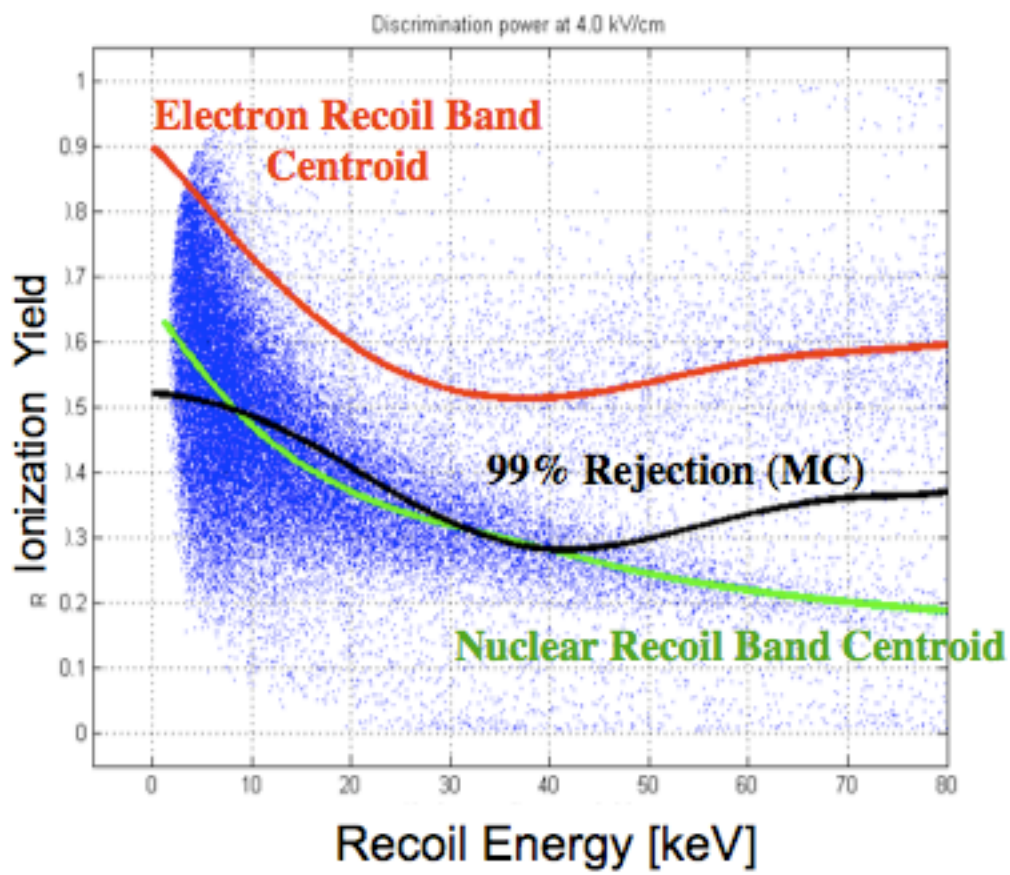
FCPA Retreat 4/18/09


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

Background Discrimination With Noble Liquid TPCs (xenon, argon)

Example: xenon

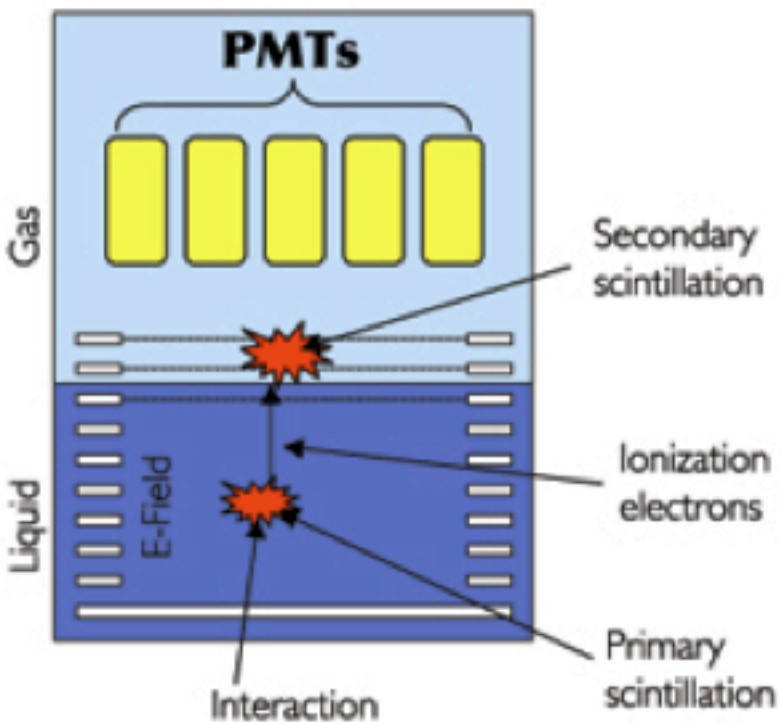


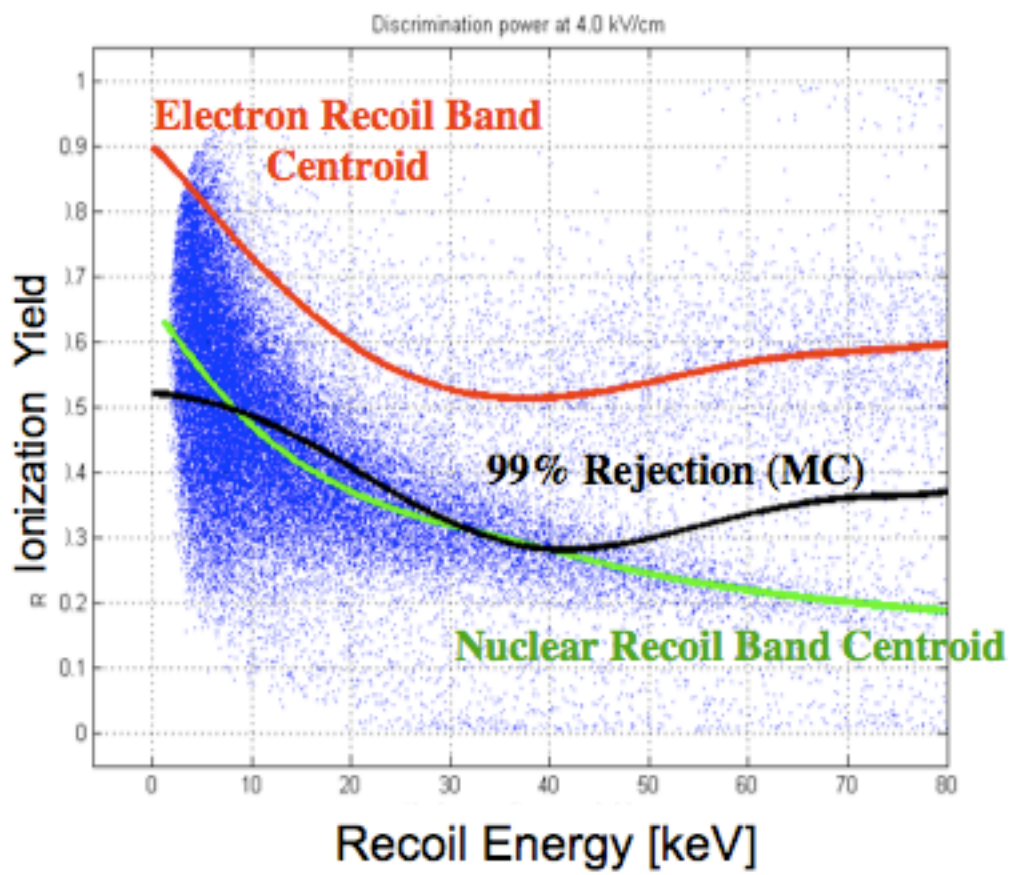


Shutt, 2008

Background Discrimination With Noble Liquid TPCs (xenon, argon)

Example: xenon

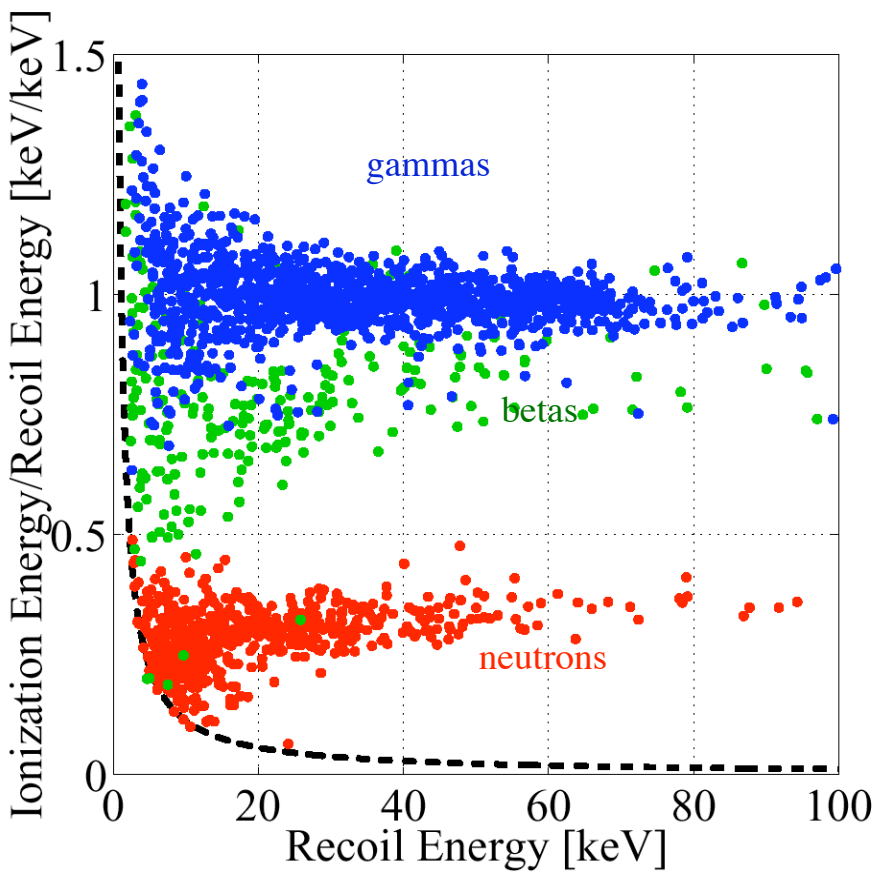


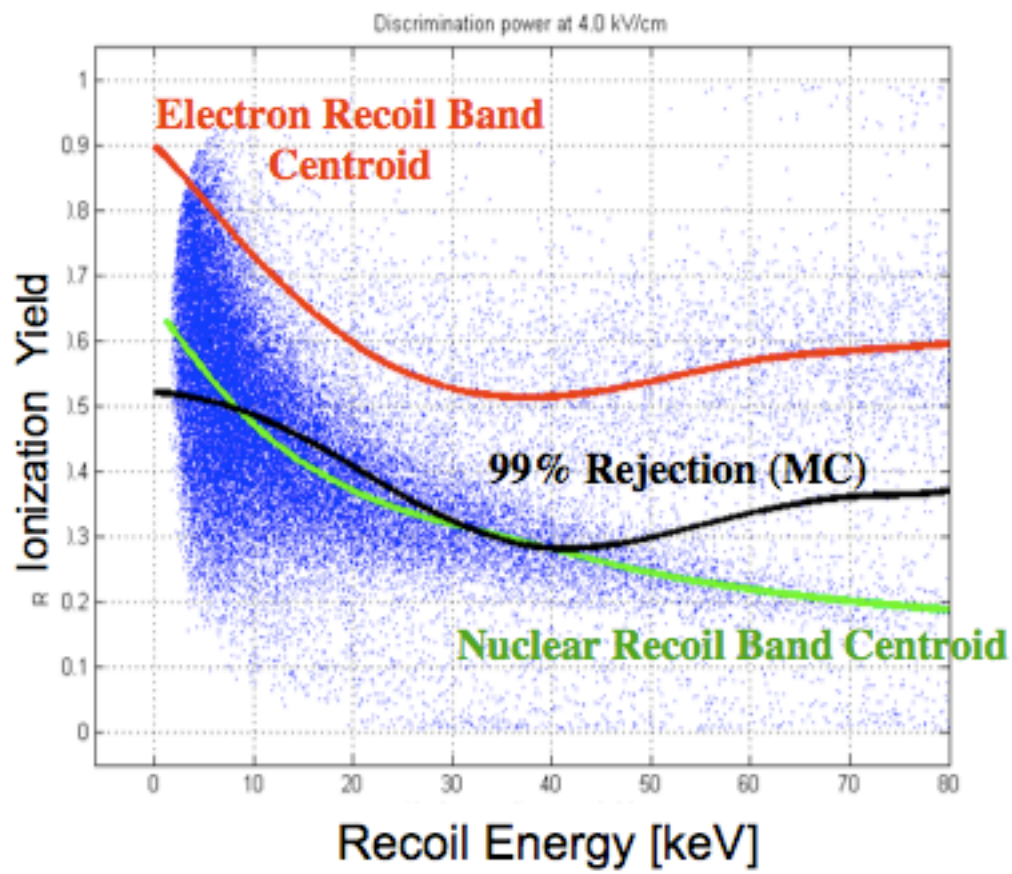


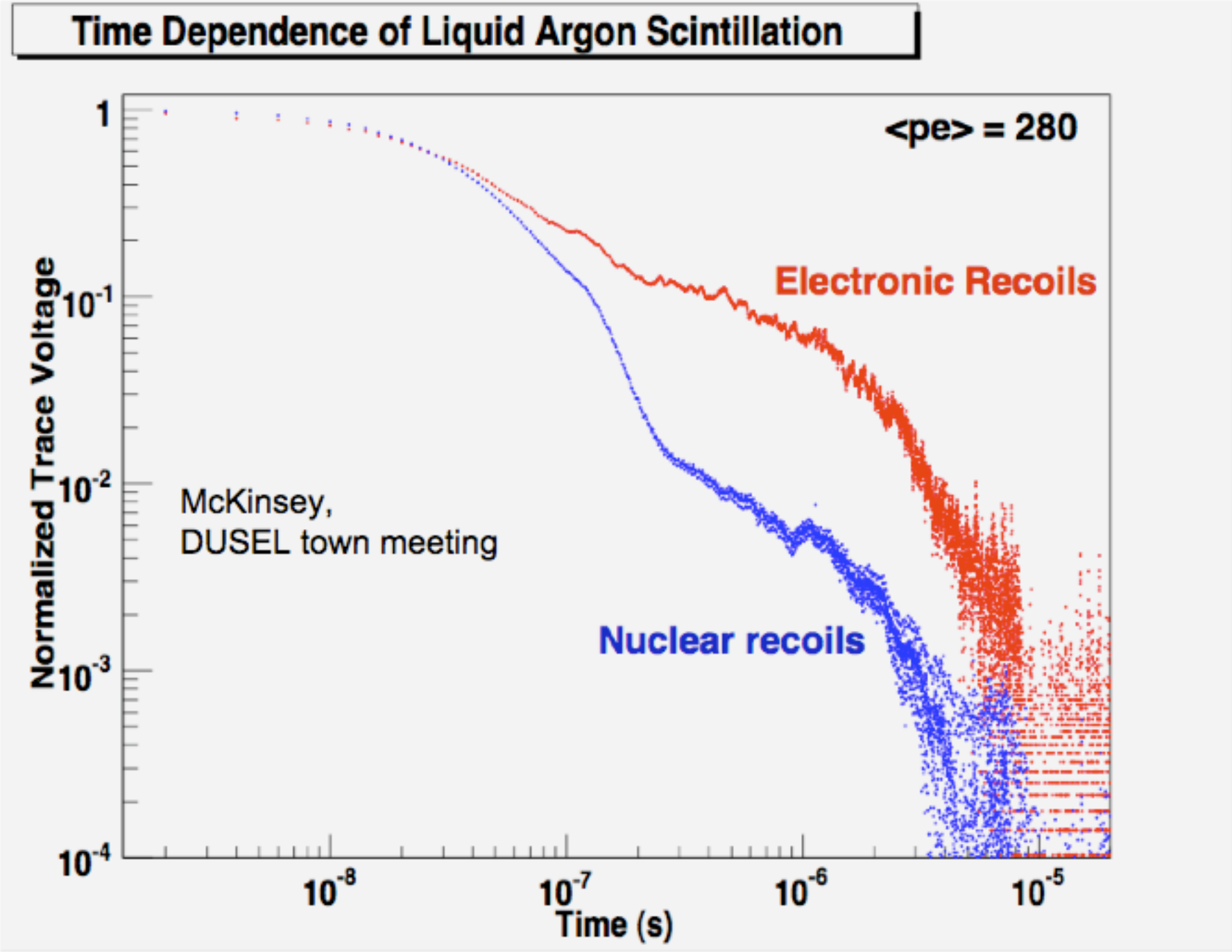
Shutt, 2008

CDMS Vs. Xenon

- Cryogenic detectors have much more background discrimination power.
- Xenon detector backgrounds will depend on high material purity, self-shielding in a large, homogeneous volume.

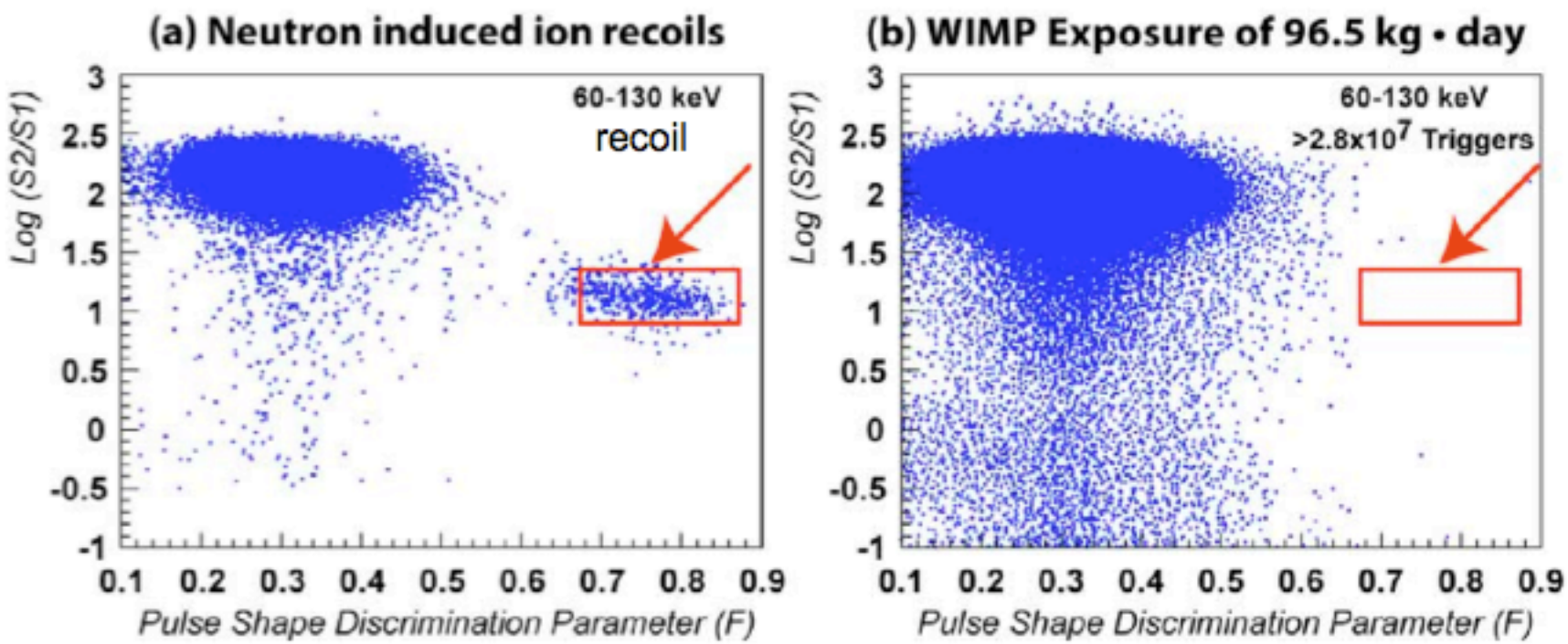





Time Dependence of Liquid Argon Scintillation
<pe> = 280
Electronic Recoils
Nuclear recoils
McKinsey,
DUSEL town meeting
Normalized Trace Voltage
1
10^-1
10^-2
10^-3
10^-4
10^-8
10^-7
10^-6
10^-5
Time (s)

Background Discrimination in Liquid Argon

- Two independent discrimination parameters.
- Better than cryogenic detectors if there are enough photons



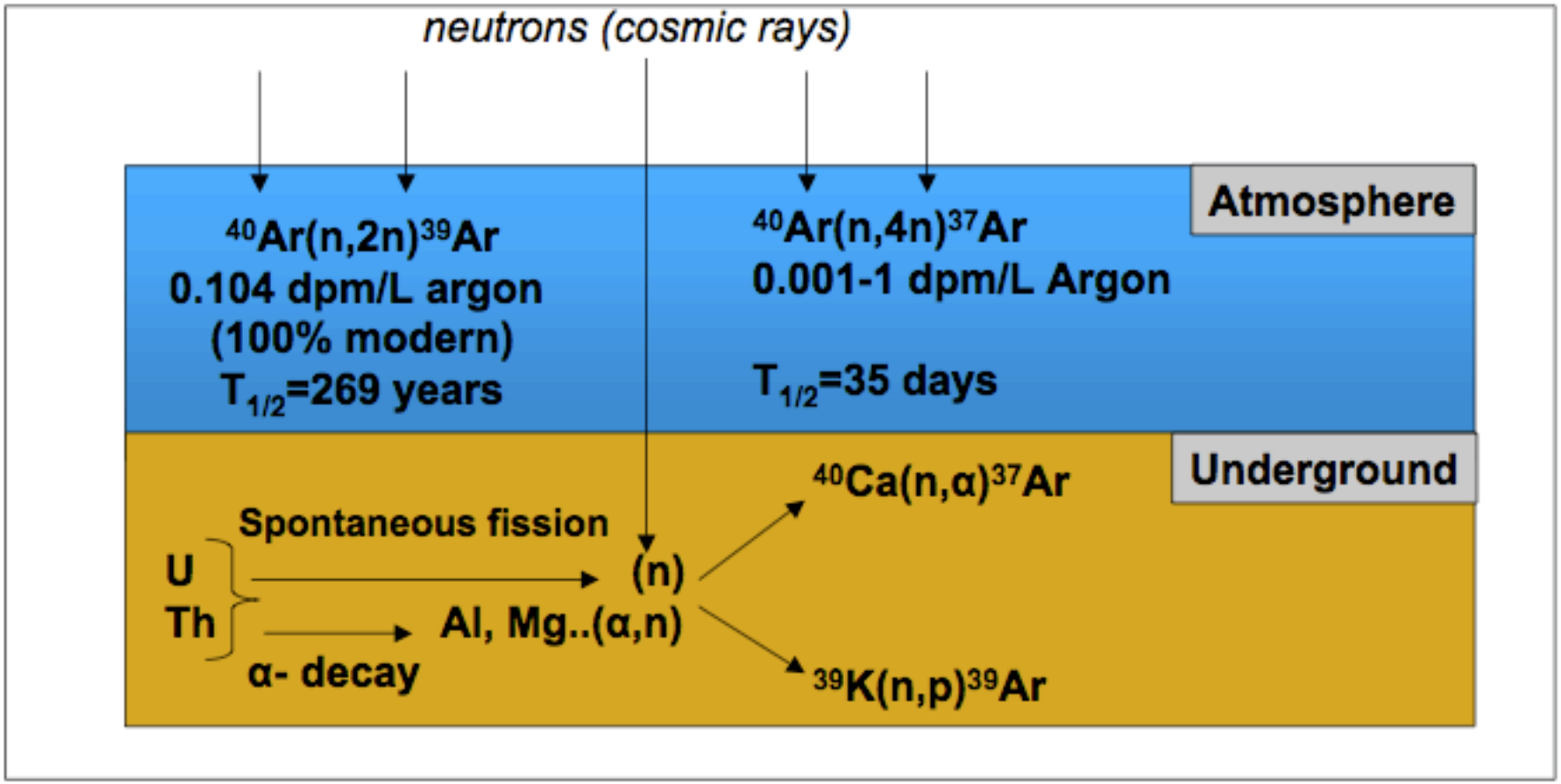
~ 2 p.e./keVee

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

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

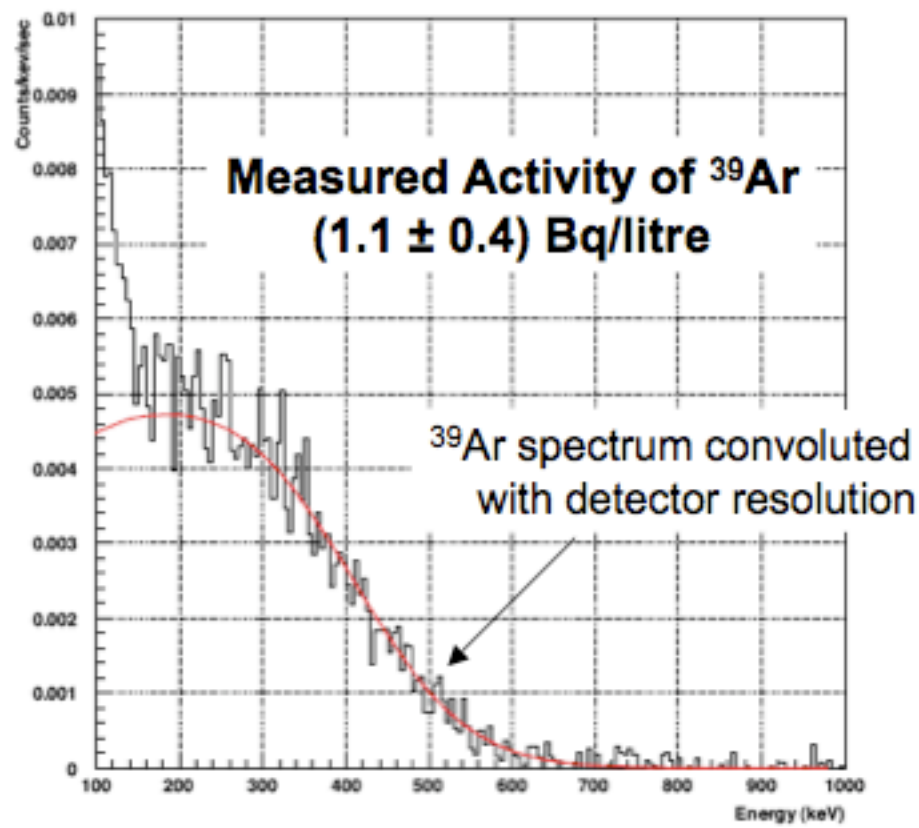
$^{39}Ar \rightarrow {}^{39}K + e^- + \bar{\nu}_e$ (Q = 565 keV)

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

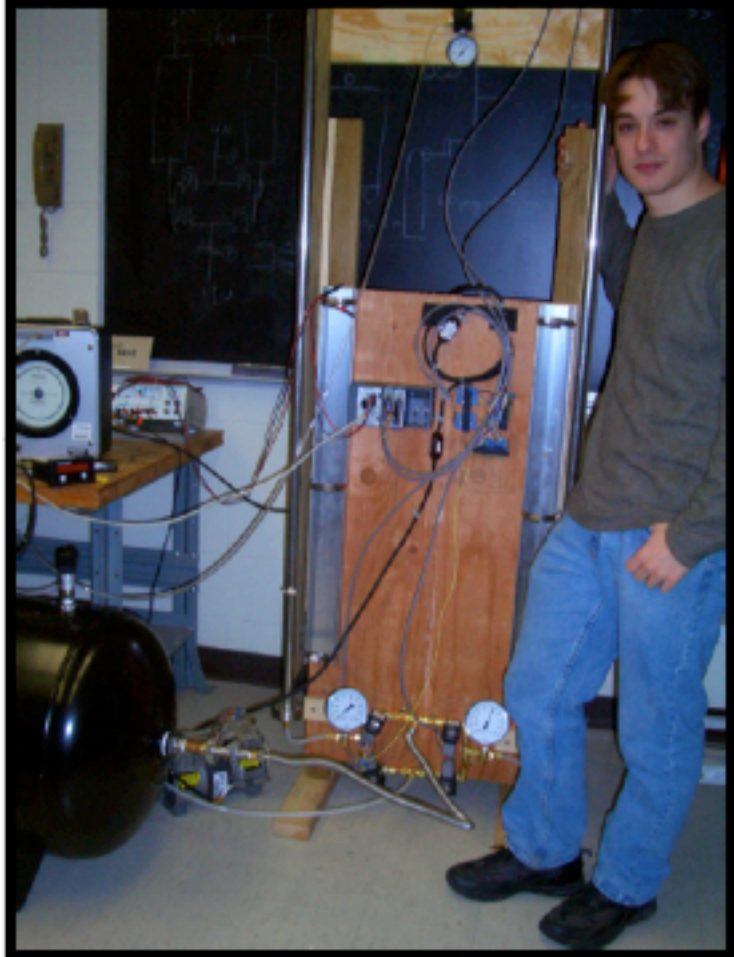
The fraction of ^{39}Ar decays producing an energy release in the range 30 ÷100 keV is about 3%

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



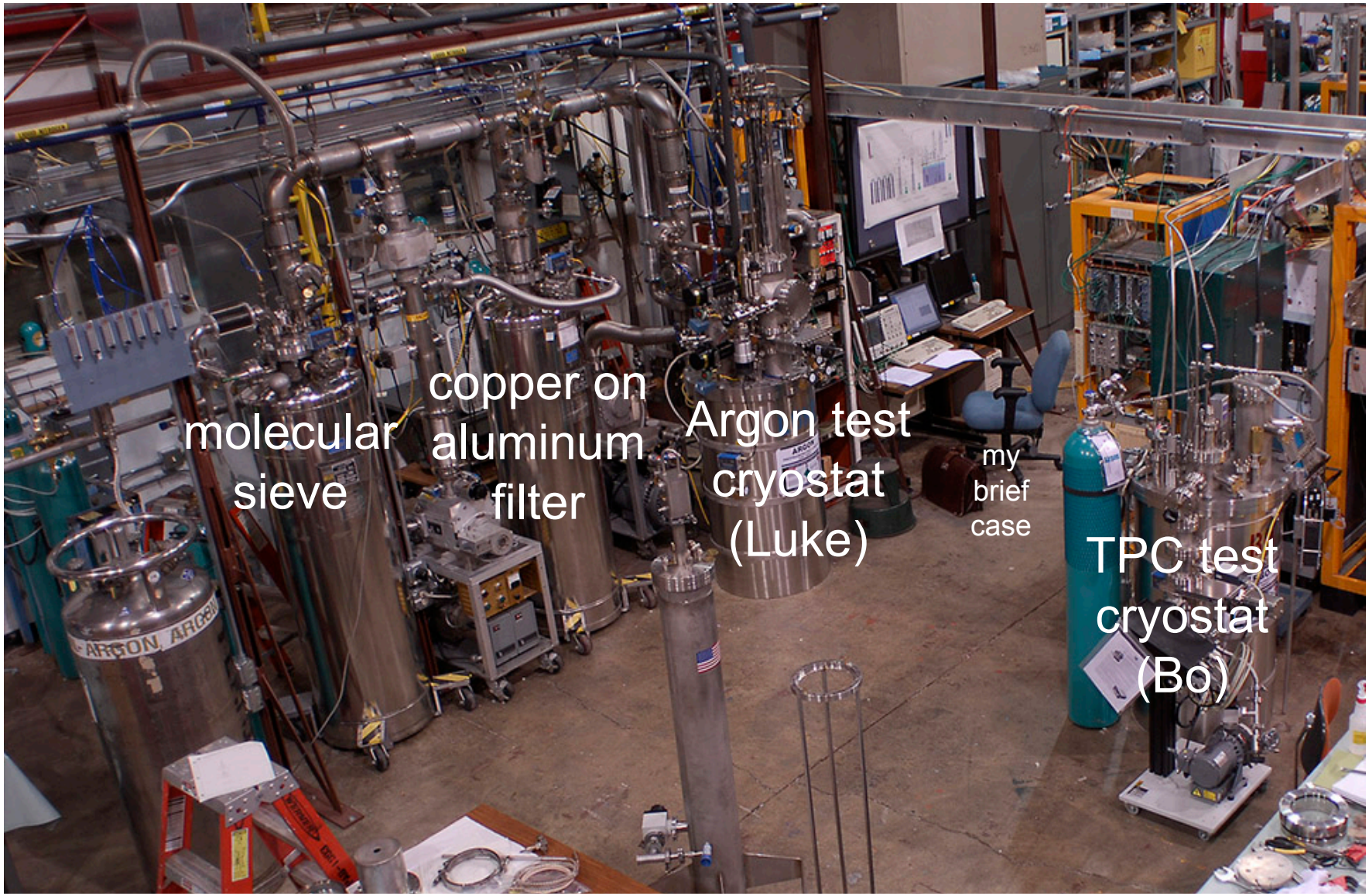
← Prototype Purification Plant at Princeton

Sampling on a gas field in the West

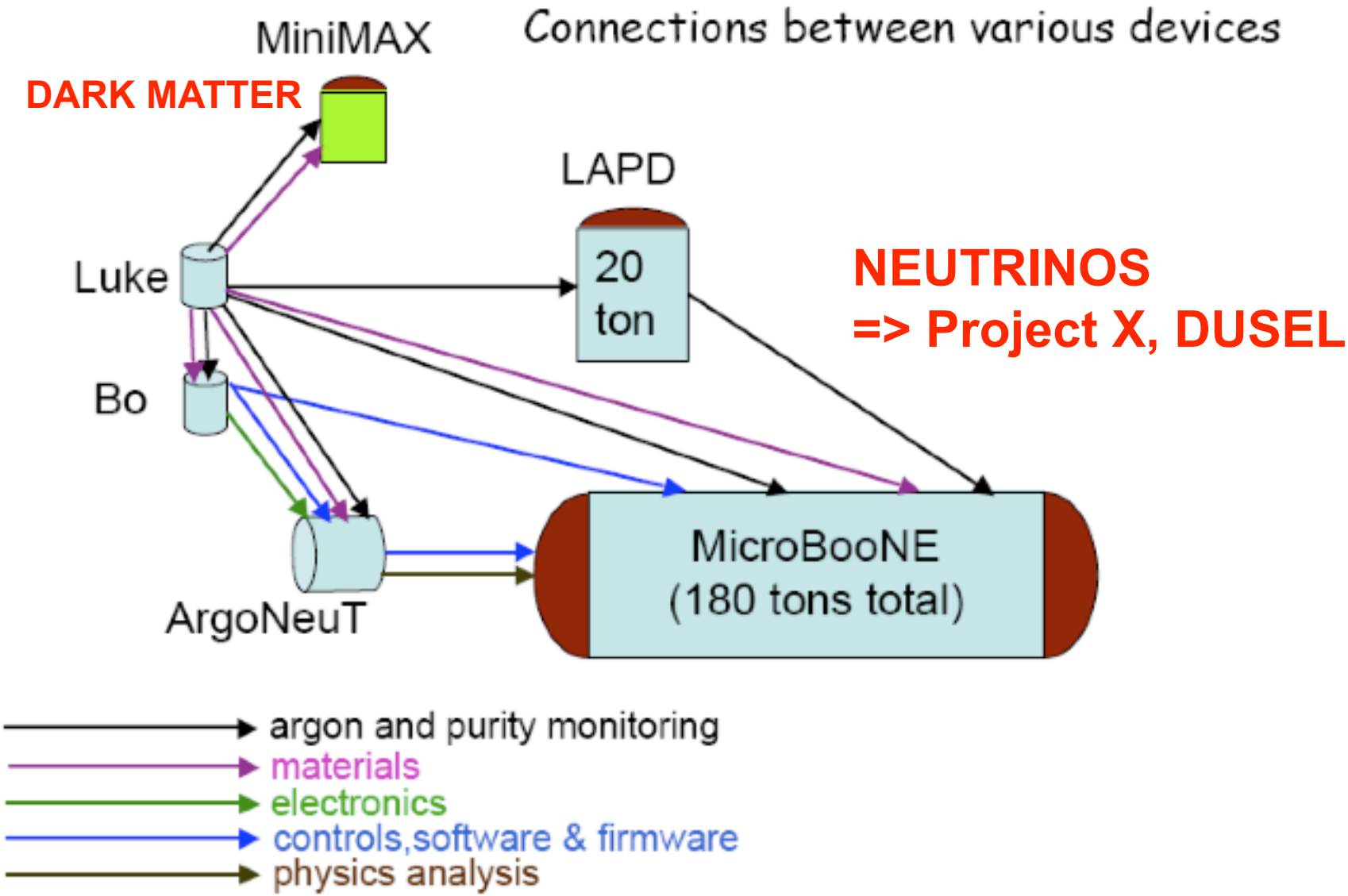
<5% atmospheric Ar-39 concentration!

Funded by NSF

Fermilab Liquid Argon Detector Infrastructure



LAr Synergies

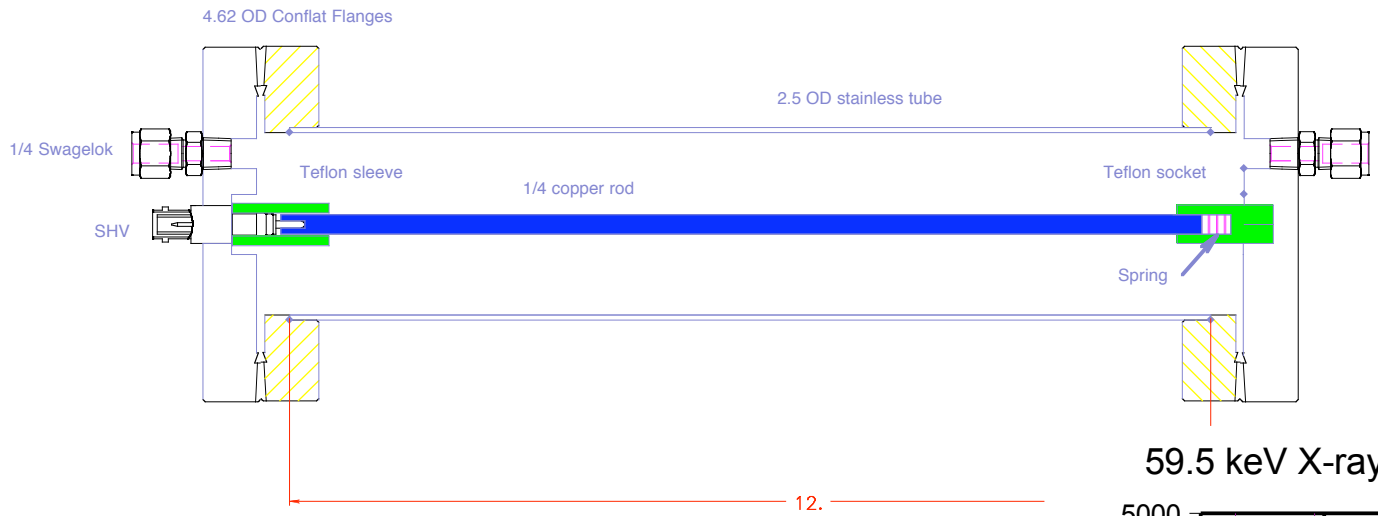


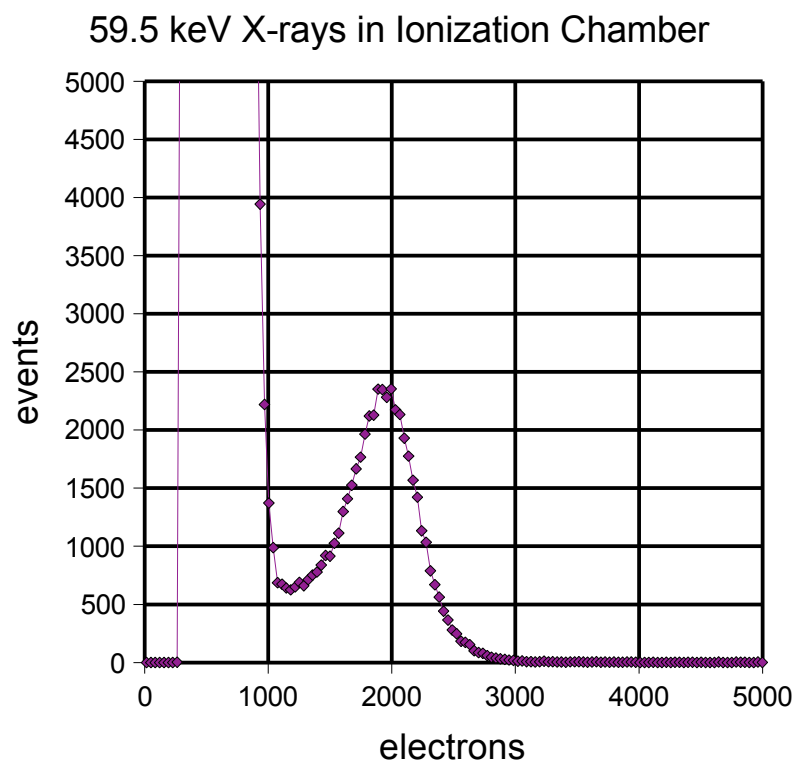
S. Pordes

Argon Dark Matter at Fermilab

- Low-background ion chamber for ^{39}Ar measurement.
  - Running prototype has demonstrated required threshold.
  - High-pressure, low background chamber in progress.
  - Would like to start screening samples this summer.
- Collaboration with Princeton and Temple on 20-kg prototype.
  - Fermilab to supply “conventional” TPC components and electronics
    - High voltage feedthroughs, grids, purity monitors.
    - Digitizers based on existing Fermilab ESECON boards.
  - Goal: demonstrate charge and light collection at required level for full-scale physics device.
- DUSEL Proposal for 5-ton detector

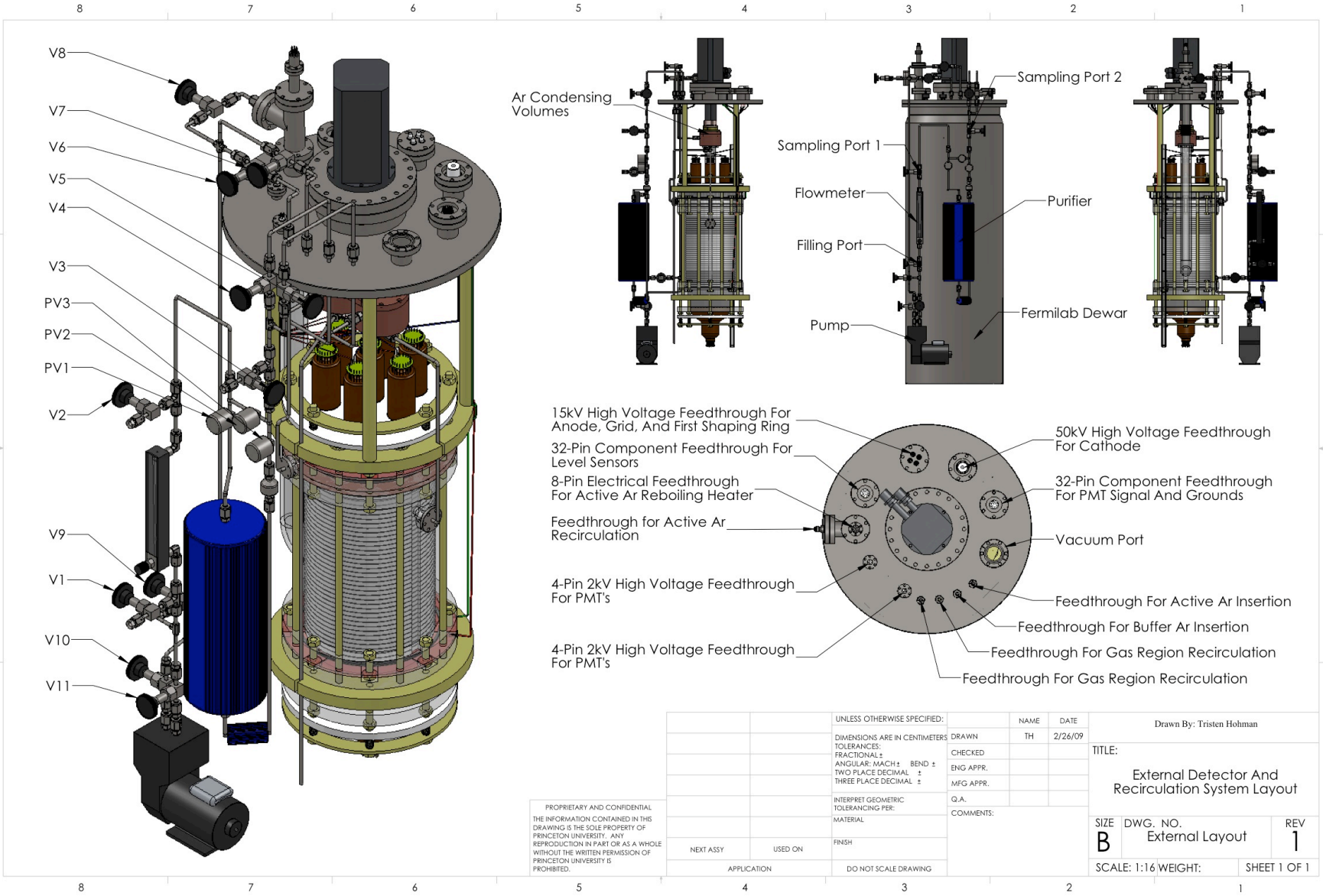
Fermilab Ion Chamber for ^{39}Ar measurement





- Prototype: 1 liter of gas at 8 bar (15 grams argon)
- Operation up to 7000 V
- Final chamber will be ~2 liters at 180 bar (500 grams)
- Radiation shielding similar to CDMS should allow measurement at concentration of 10^{-3} of atmospheric argon rate.

20-kg Prototype Design



I. THE MAX COLLABORATION

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 Ortjohann, 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 Collaboration

90 people
19 institutions

MAX Proposal Summary

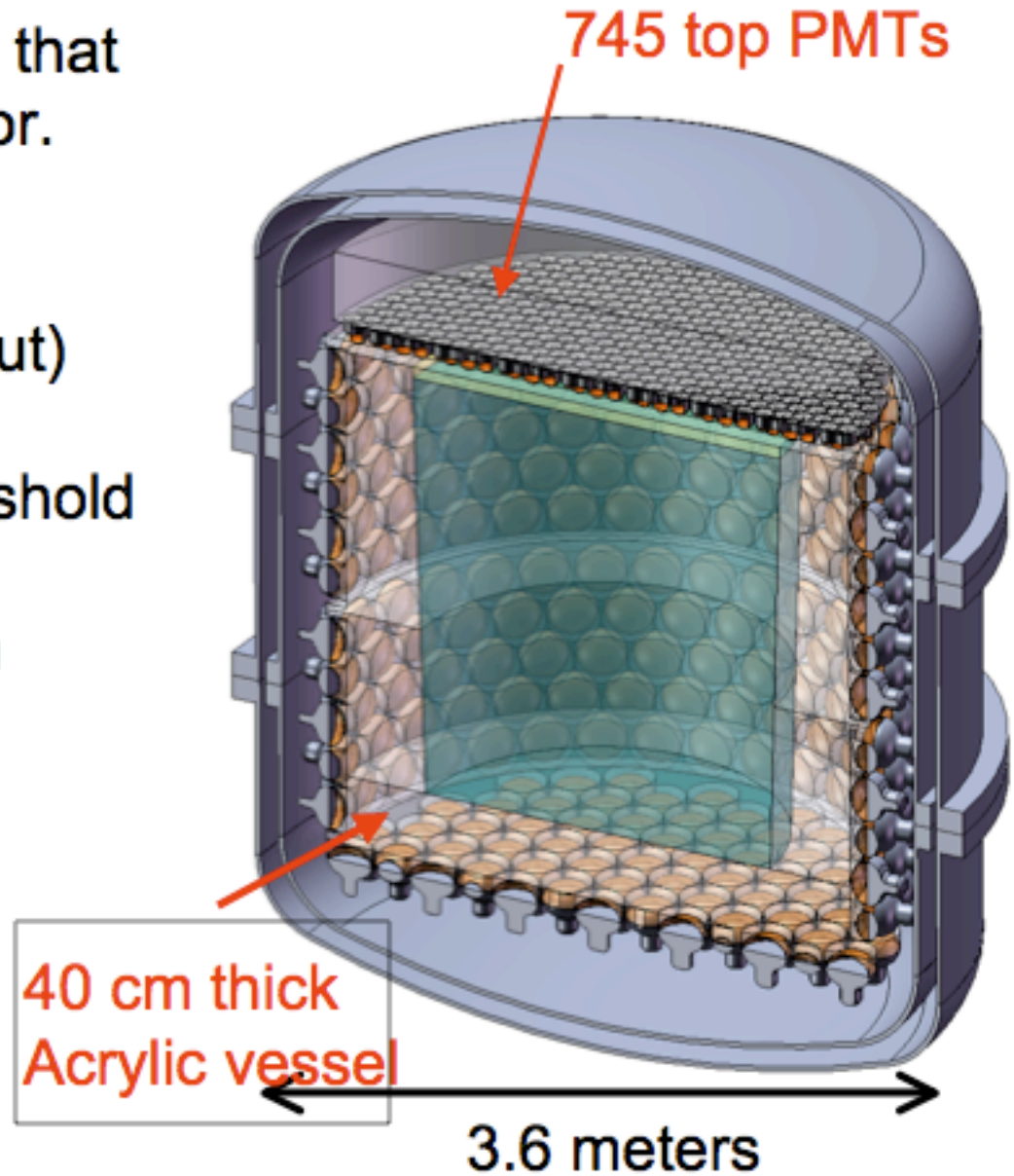
- Coordinated engineering study of large argon and xenon TPCs.
- We will produce Preliminary Designs for two separate detectors using common engineering staff.
- We will exploit similarities between detectors to reduce the design cost.
  - Common photodetectors (UCLA/ Hamammatsu)
  - Field shaping structures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

  + others

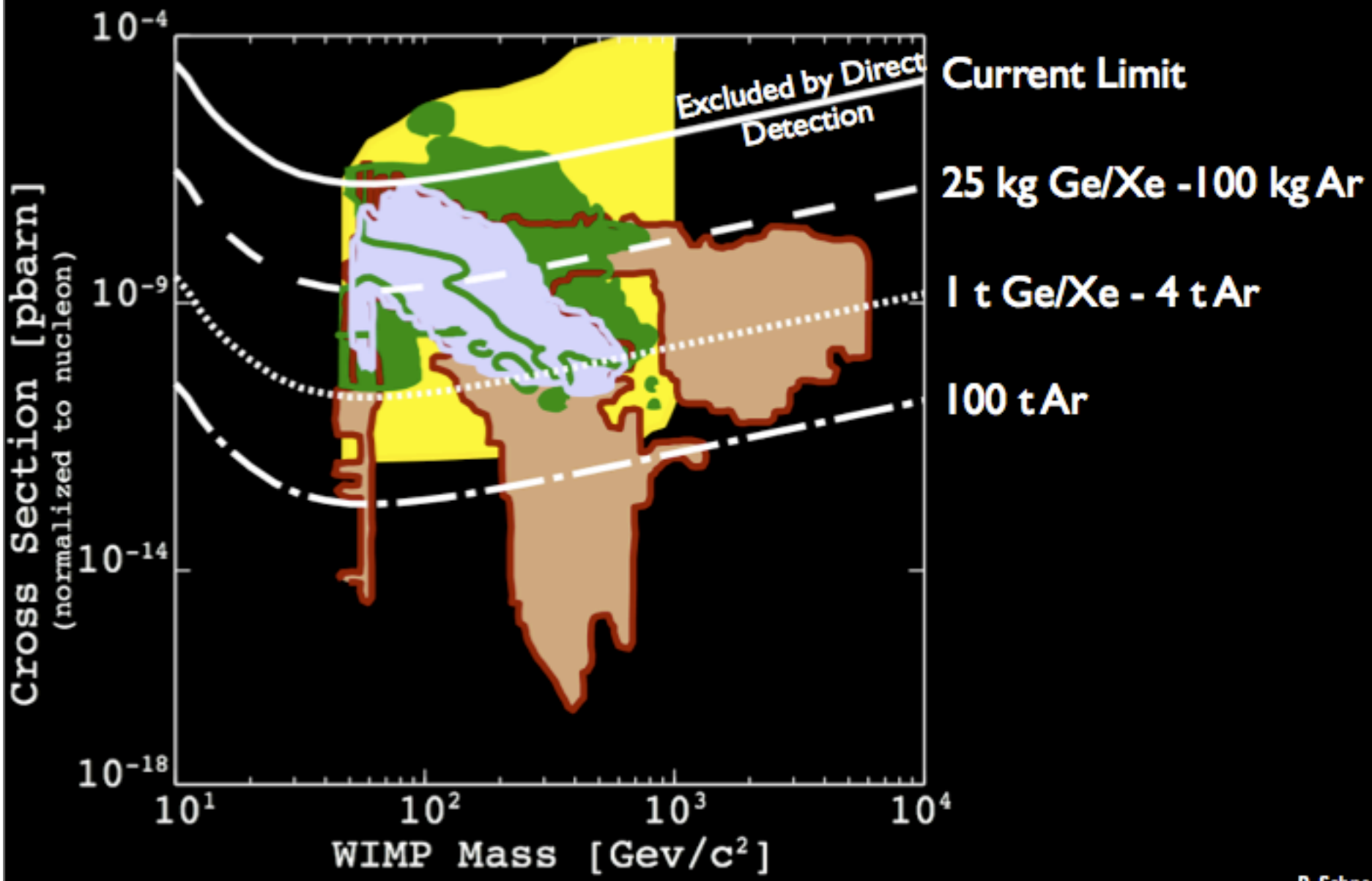
Argon Detector Concept

- 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



Supersymmetry Exploration



R. Schnee

Who Will Do The Work?

- The field is growing rapidly at Fermilab, as it is elsewhere.
- We can attract the people needed to do these projects because:
  1. The science is important and exciting.
  2. The needs of the projects are well-matched to the Fermilab skill set.
  3. Projects have short time lines and unusual room for individual initiative compared to the other things the lab is doing.

Dark Matter Detection:
Total 17 scientists, 4+ projects, ~ 10 FTE scientists in 2009

<u>COUPP</u>
Steve Brice
Dan Broemmelsiek
Peter Cooper
Mike Crisler
Martin Hu
Erik Ramberg
Andrew Sonnenschein
Bob Tschirhart

<u>CDMS</u>
Dan Bauer
Fritz Dejongh
Jeter Hall
Lauren Hsu
Erik Ramberg
Jonghee Yoo

<u>Argon</u>
Jeff Martoff (Temple U., on sabbatical @ FANL 2009)
Steve Brice
Aaron Chou
Jeter Hall
Stephen Pordes
Andrew Sonnenschein
Pierre Gratia (U. Chicago)

<u>CCDs</u>
Juan Estrada
Ben Kilminster
Erik Ramberg
Andrew Sonnenschein

DUSEL Dark Matter S4 Proposals

RED = Fermilab scientists involved

Technology	Experiment	Target	Mass (T)	Cost (M$)
Low temperature Ionization/Phonon	GEODM	Germanium	1.5	50
Bubble Chamber	COUPP	Fluorine, Iodine	n* 0.5	n*0.5
Liquid Argon/Neon Scintillator	CLEAN-40T	Argon Neon	40	40
Dual Phase TPC	LZ20	Xenon	20?	100?
	MAX	Argon Xenon	5 2	17 18
Gas TPC	DRIFT	Fluorine Sulfur	1	60