SCENE
(Scintillation Efficiency of Noble Elements)

Hugh Lippincott

Liquid Argon R&D Review

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Member Institutions:

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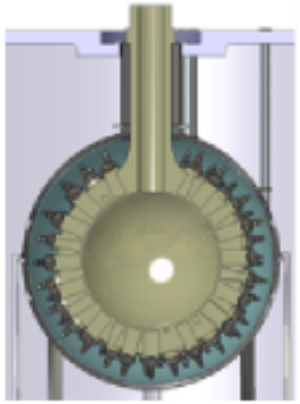
The SCENE Program

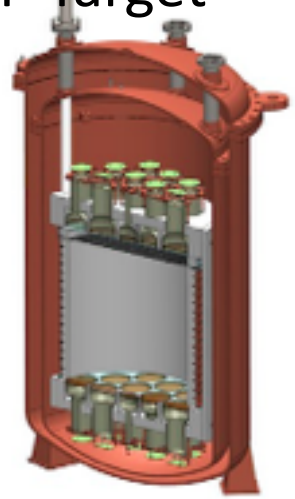
- Purpose: To measure scintillation properties of liquid noble gases, beginning with LAr and LXe
- Of particular interest to dark matter experiments
  - DarkSide, DEAP, MiniCLEAN, ArDM, LUX/LZ, Xenon100/1T, PandaX, XMass, any future combination
- Other experiments interested in the response of these liquids
  - Neutrino-nucleus coherent scattering LAr detector proposed at FNAL (CENNS)

LAr/LXe as WIMP Target

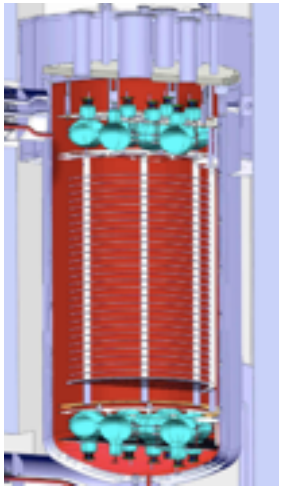


DEAP

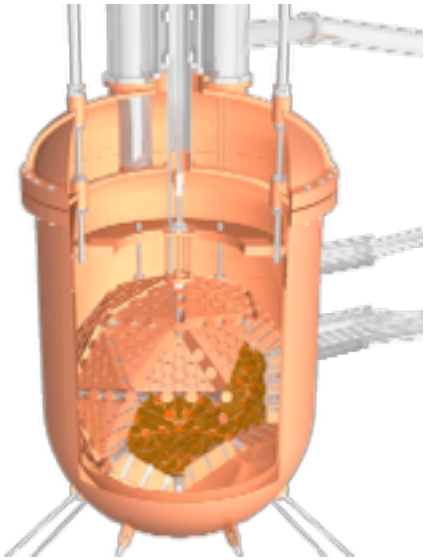
CLEAN



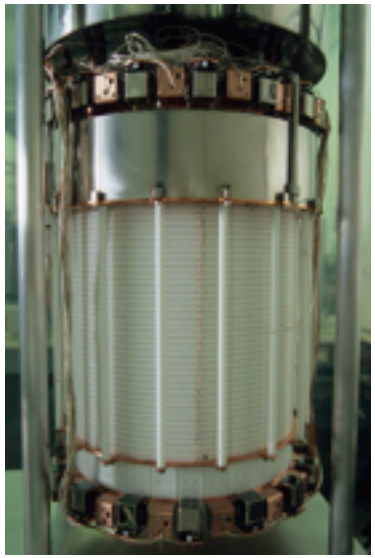
DarkSide



ArDM

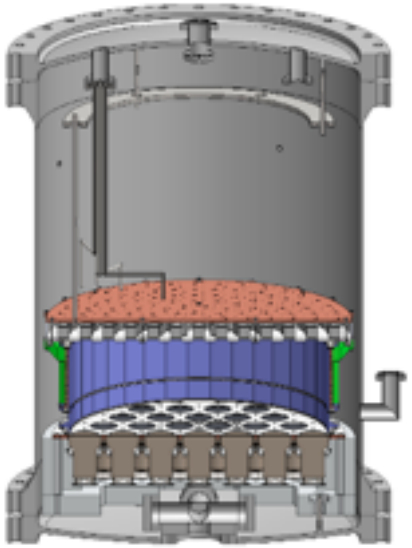


XMass



Xenon100/1T

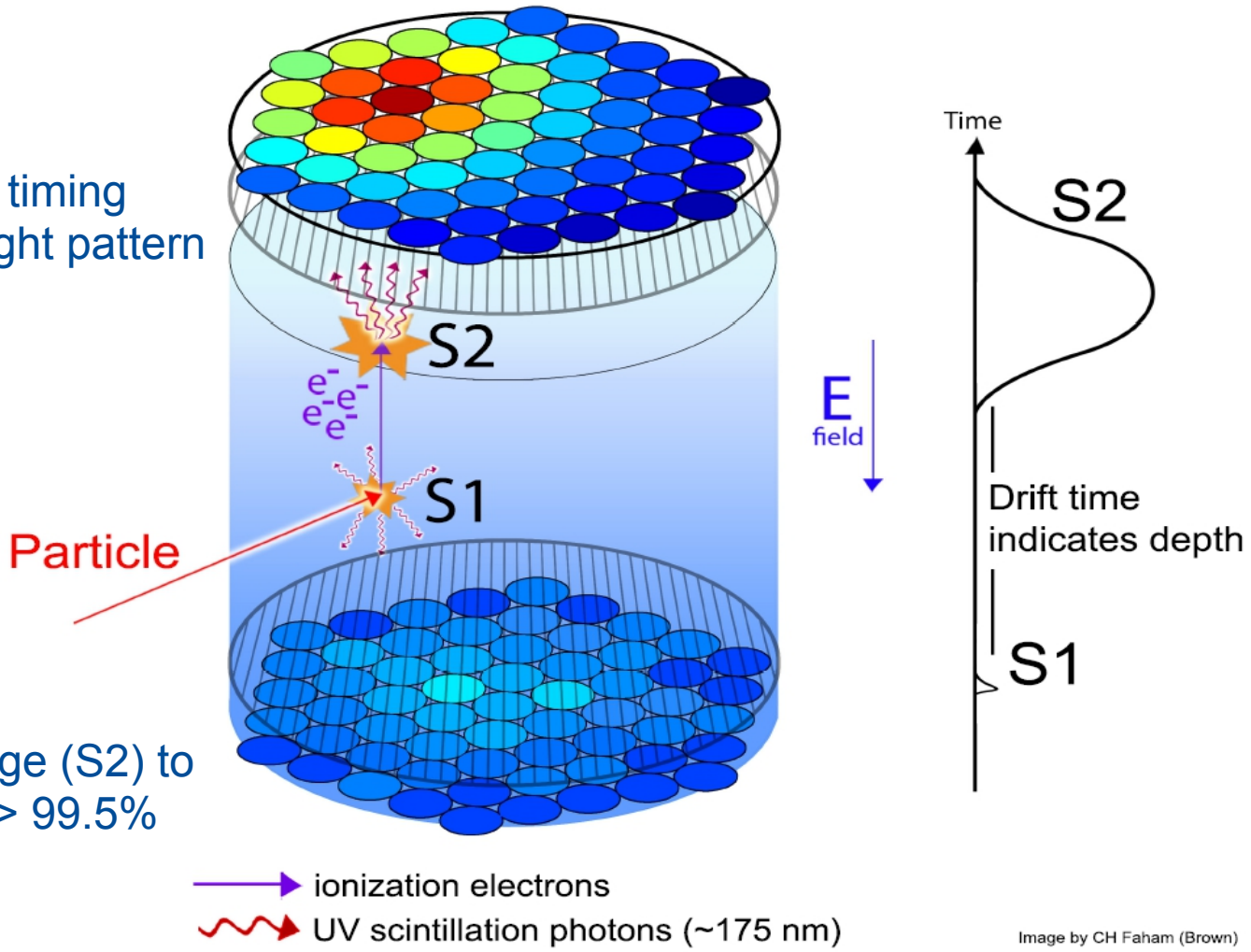
LUX/LZ



PandaX

TPC Principle

Z position from S1 – S2 timing
X-Y positions from S2 light pattern



Reject gammas by charge (S2) to light (S1) ratio. Expect > 99.5% rejection.

Scintillation and Ionization Yield for Nuclear Recoils

- Dark matter detectors look for nuclear recoils (NR)
- Scintillation and ionization yield for nuclear recoils are required to convert an observed NR signal to the deposited energy
- Expected rate for dark matter interactions depends critically on energy threshold
- Therefore, any dark matter result from liquid noble gas detectors require knowledge of these parameters

Scintillation or S1

$$E = \frac{\mathrm{S1}}{L_\mathrm{y}} \frac{1}{\mathcal{L}_\mathrm{eff}(E)} \frac{S_\mathrm{ee}}{S_\mathrm{nr}}.$$

Ionization or S2

$$E = \frac{\mathrm{S2}}{Y} \frac{1}{\mathcal{Q}_\mathrm{y}(E)}.$$

- S1 - parameters that are intrinsic to the liquid are $L_{eff}(E)$, S_{ee} and S_{nr}
- S2 - $Q_y(E)$ is the charge yield

Liquid argon

Scintillation or S1

$$E = \frac{\mathrm{S1}}{L_\mathrm{y}} \frac{1}{\mathcal{L}_\mathrm{eff}(E)} \frac{S_\mathrm{ee}}{S_\mathrm{nr}}.$$

Ionization or S2

$$E = \frac{\mathrm{S2}}{Y} \frac{1}{\mathcal{Q}_\mathrm{y}(E)}.$$

- Prior to SCENE, two measurements of $L_{eff}(E)$ at null field existed in the literature with large uncertainty, particularly for E < 25 keV
- No data existed in the presence of electric field (S_{ee}, S_{nr})
- No measurements existed of the ionization yield for nuclear recoils (Q_y)

Liquid xenon

Scintillation or S1

$$E = \frac{\mathrm{S1}}{L_\mathrm{y}} \frac{1}{\mathcal{L}_\mathrm{eff}(E)} \frac{S_\mathrm{ee}}{S_\mathrm{nr}}.$$

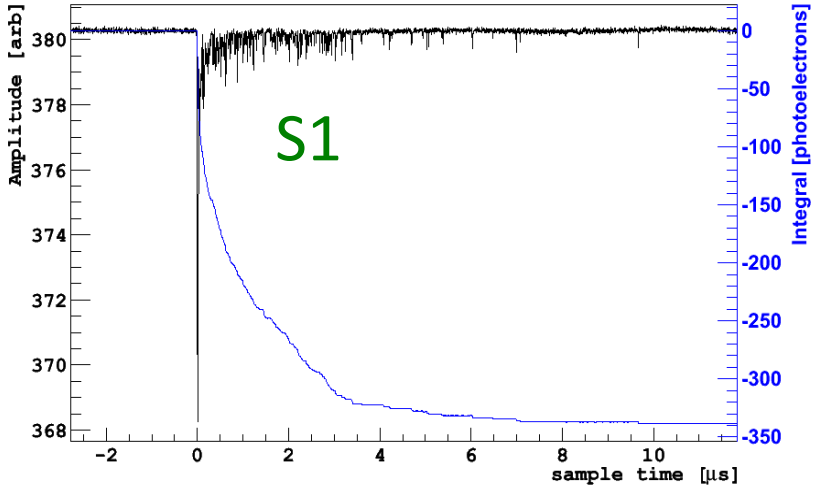
Ionization or S2

$$E = \frac{\mathrm{S2}}{Y} \frac{1}{\mathcal{Q}_\mathrm{y}(E)}.$$

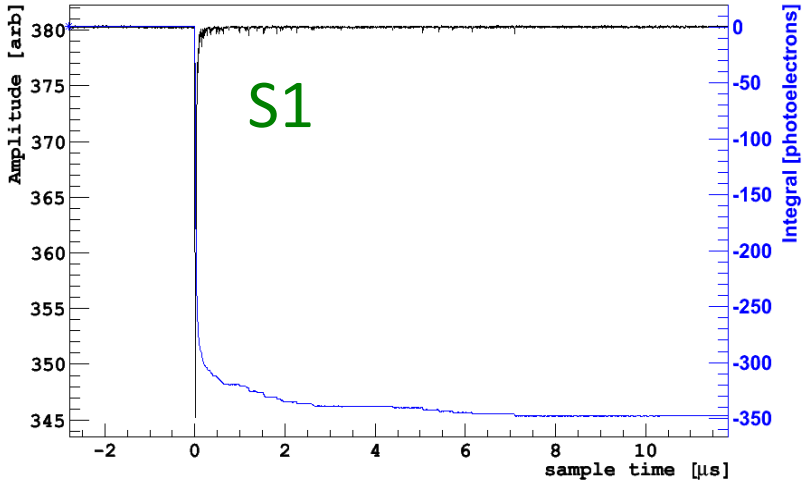
- Several measurements of $L_{eff}(E)$ in the literature, but relatively large errors, particularly at low energies (E < 6 keV)
  - Particularly relevant for light dark matter sensitivity, some controversy in the field (see e.g. 1106.0653, 1010.5187, 1006.2031, 1101.6080 from a few years ago)
- Very limited data exist in the presence of electric field (S_{ee}, S_{nr})
  - One measurement at high energy (56 keVr)
  - Several measurements with broad spectrum sources
- Ionization yield (Q_y) only measured with broad spectrum sources
  - New results from LUX are expected using DD generator (presented at conference last February, not published yet)

Measuring pulse shape discrimination
Key element for background discrimination

S1 signal only (LAr)
Electron event
Nuclear recoil event



Signal from electron
(small prompt signal)

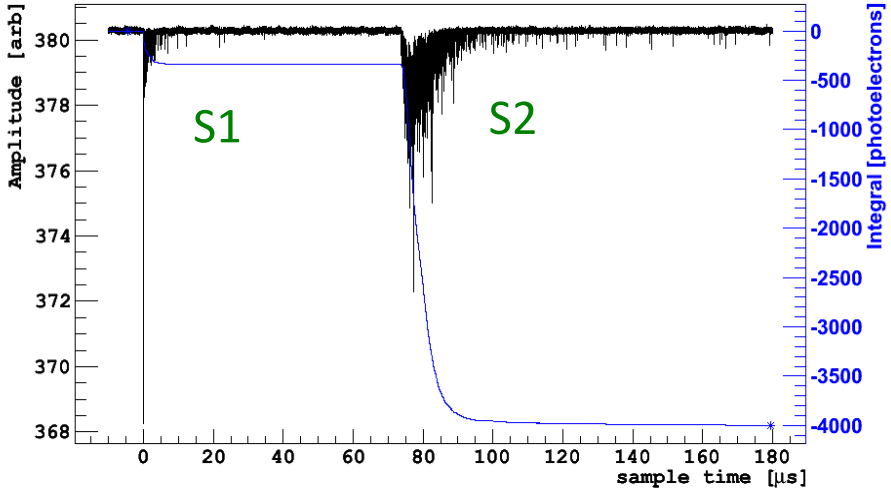


Signal due to recoiling nucleus
(relatively high prompt signal)

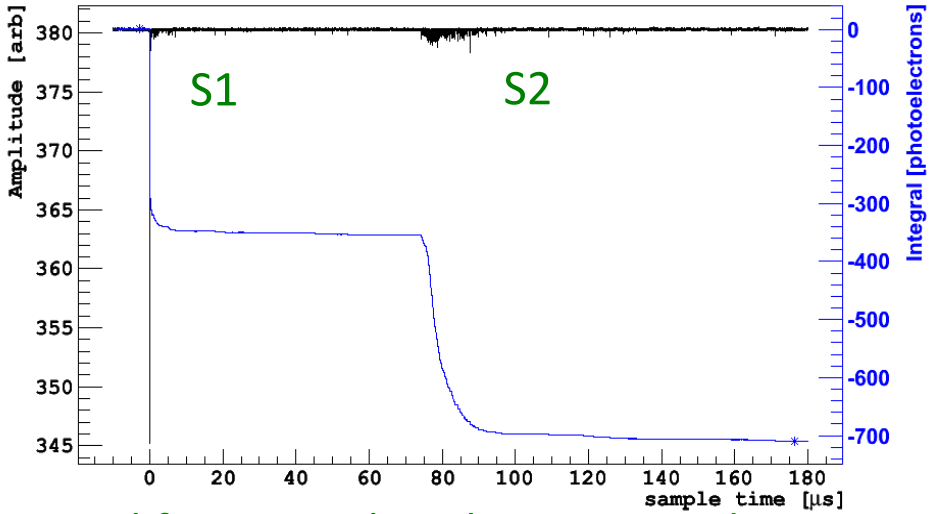
Fraction of prompt light
provides discrimination

Measuring pulse shape discrimination
Key element for background discrimination

S1 and S2 signals (LAr/LXe)
Electron event
Nuclear recoil event



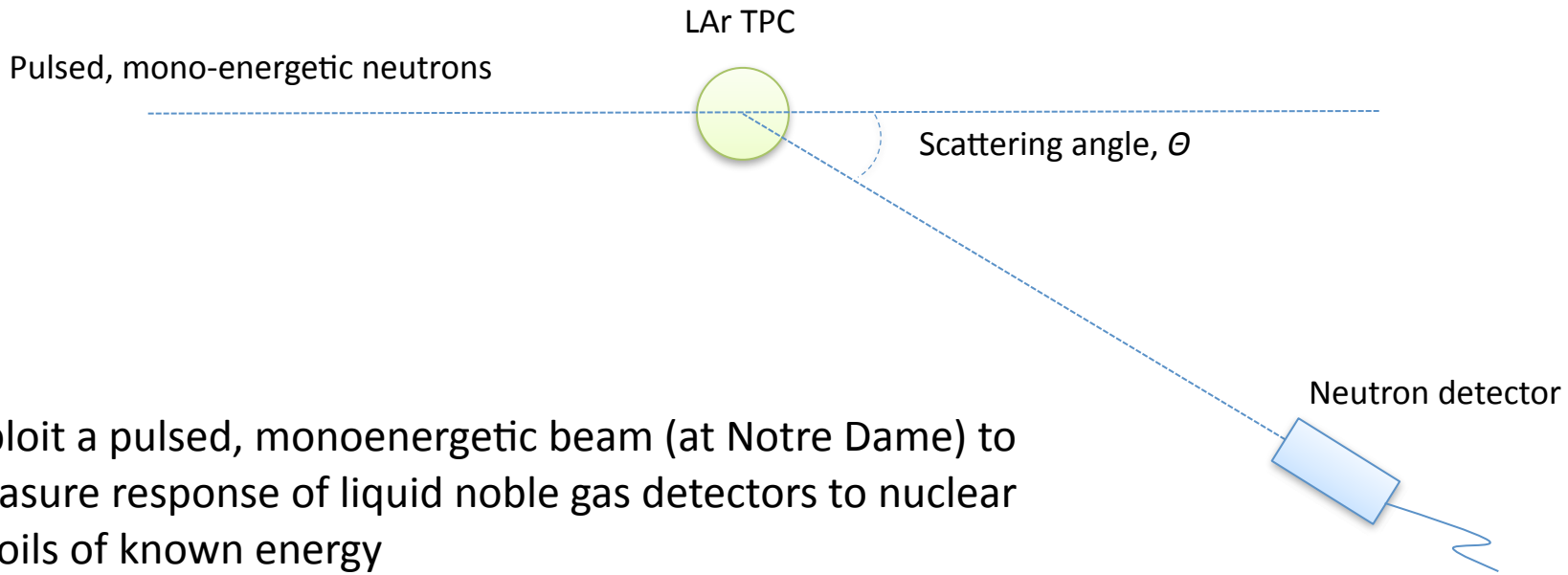
Signal from electron energy deposition
(lots of free electrons - large S2/S1)



Signal from recoil nucleus energy deposition
(rather few free electrons – small S2/S1)

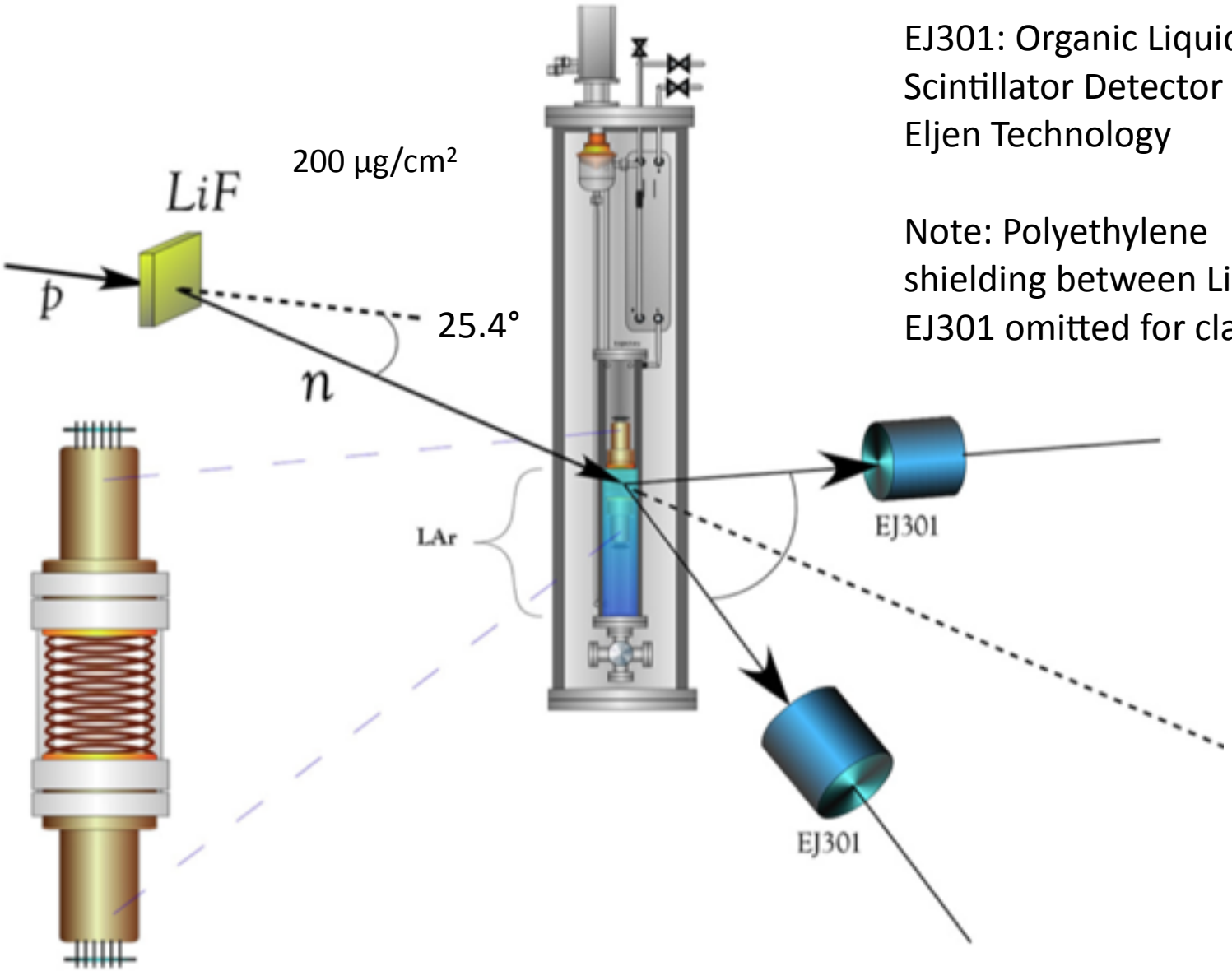
Use log(S2/S1)
as discriminant

The SCENE technique



- Exploit a pulsed, monoenergetic beam (at Notre Dame) to measure response of liquid noble gas detectors to nuclear recoils of known energy
- Tunable nuclear recoil energy by changing the neutron energy and the scattering angle
  - Neutrons of 500 keV - 1.5 MeV
  - Recoils of a few keV up to 50 keV
- Specially designed dual phase detector
  - Measure all parameters of interest
  - Minimize multiple scattering

The SCENE Experimental Layout

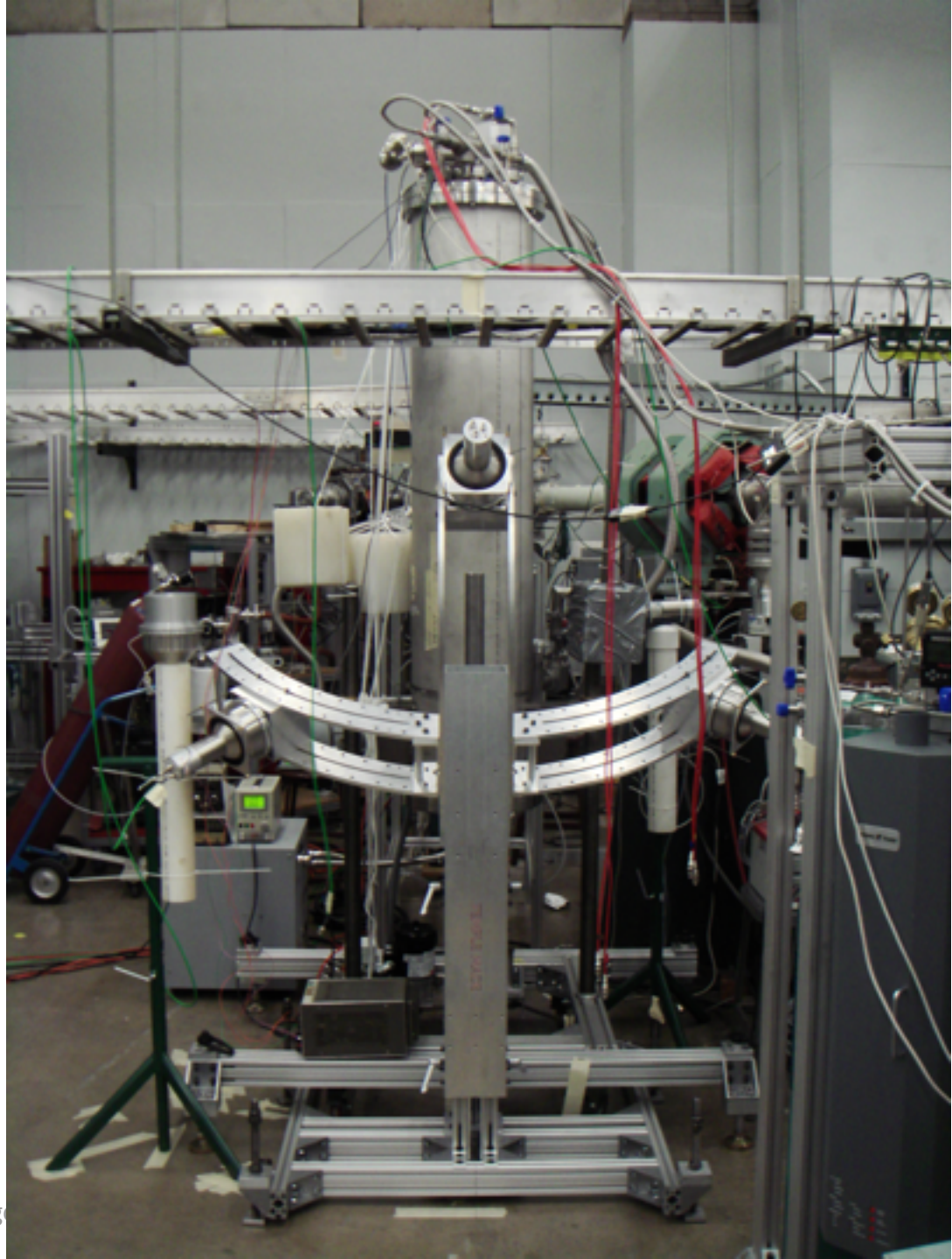


EJ301: Organic Liquid Scintillator Detector from Eljen Technology

Note: Polyethylene shielding between LiF and EJ301 omitted for clarity

The SCENE Collaboration

- Fermilab key contributor to detector design and construction
  - Gas handling system
  - Cryogenics - heat exchanger and condenser
  - Lifting fixture to allow easy installation in restricted space at Notre Dame
- Significant contributions of manpower and hardware from Princeton, Temple, UCLA, University of Chicago, UMass-Amherst
- International contributions from INFN-Naples, UCL



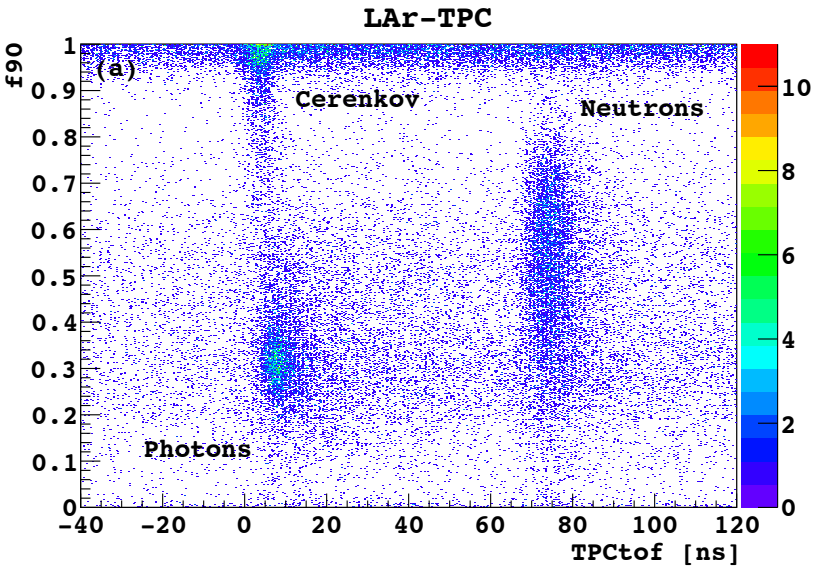
SCENE Results

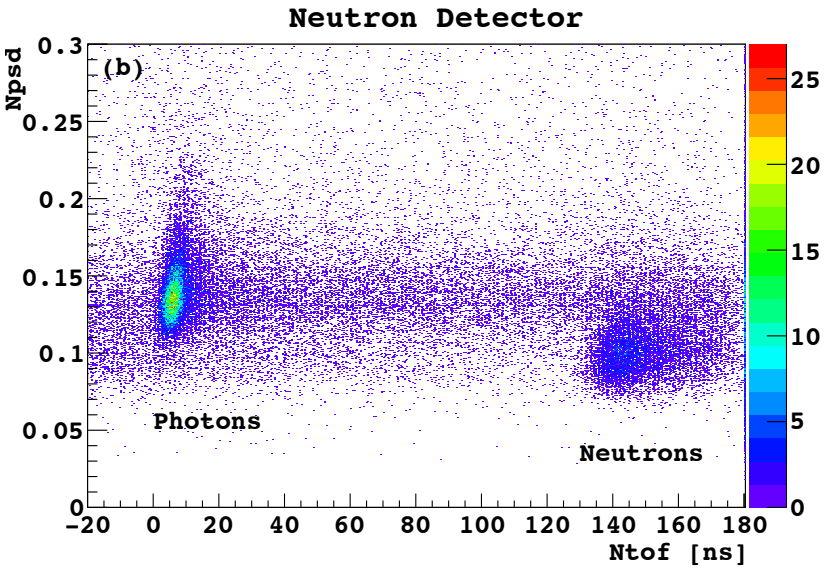
- June 17 - July 2, 2013 - Two week run led to first publication - Phys. Rev D **81**:045803 (2013): *Observation of dependence on drift field of scintillation light from nuclear recoils in LAr*
  - Significant consequences for operating conditions of LAr TPCs like DarkSide, and projected sensitivities

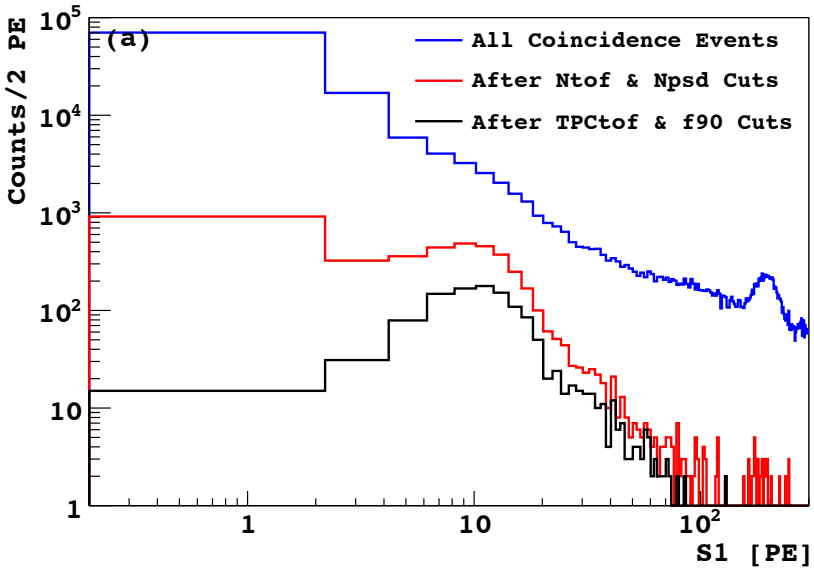
- Oct. 21 - Nov. 4 - Two week beam run dedicated to ionization/S2. Currently under review by PRD:
  - " These measurements are crucial in understanding the results collected in liquid-argon dark matter search experiments (and as well potentially in experiments searching for evidence of neutrino-nucleus scattering), and therefore have far-reaching implications; I have no doubt this paper will come to be regarded as the definitive experimental work on the subject."

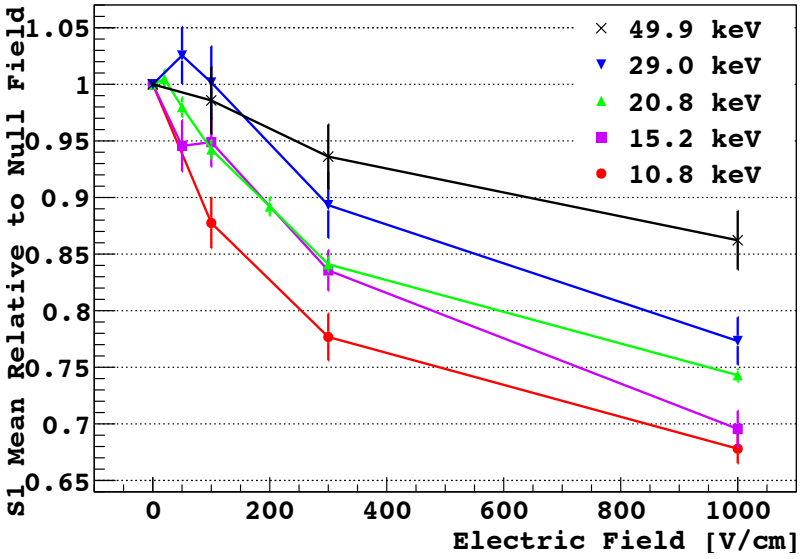
- Three graduate students have graduated in part on SCENE work, with the expectation for one or two more given current program
  - Several undergraduates also involved

SCENE - Pulse Shape Discriminant vs. Time of Flight

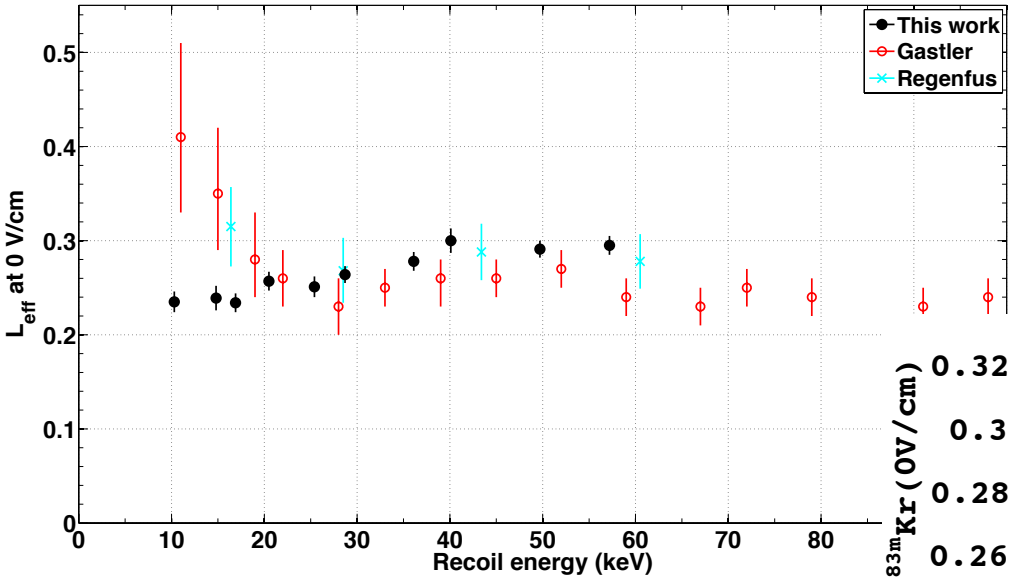


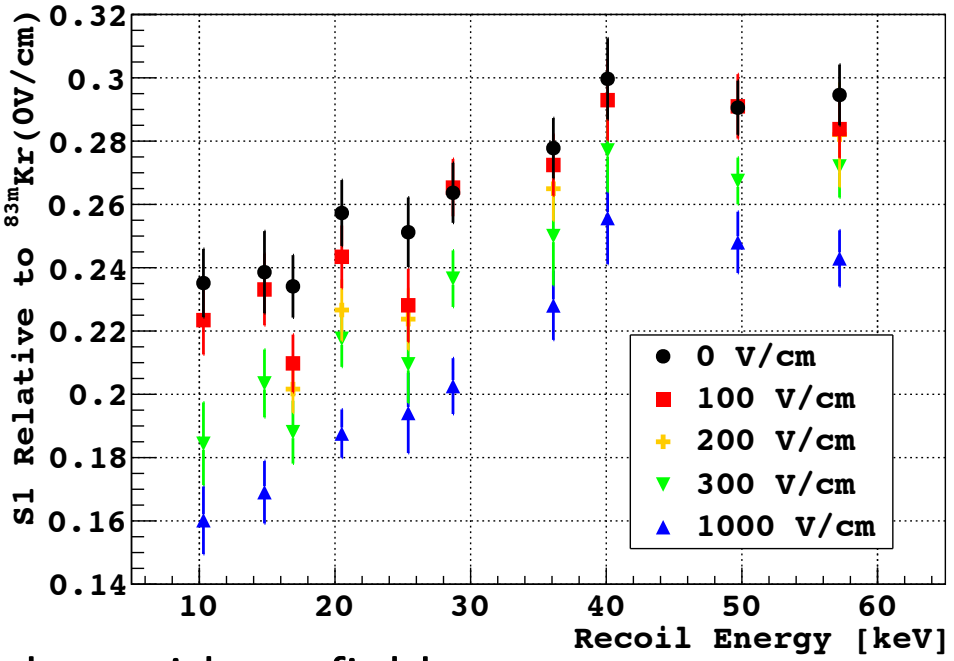






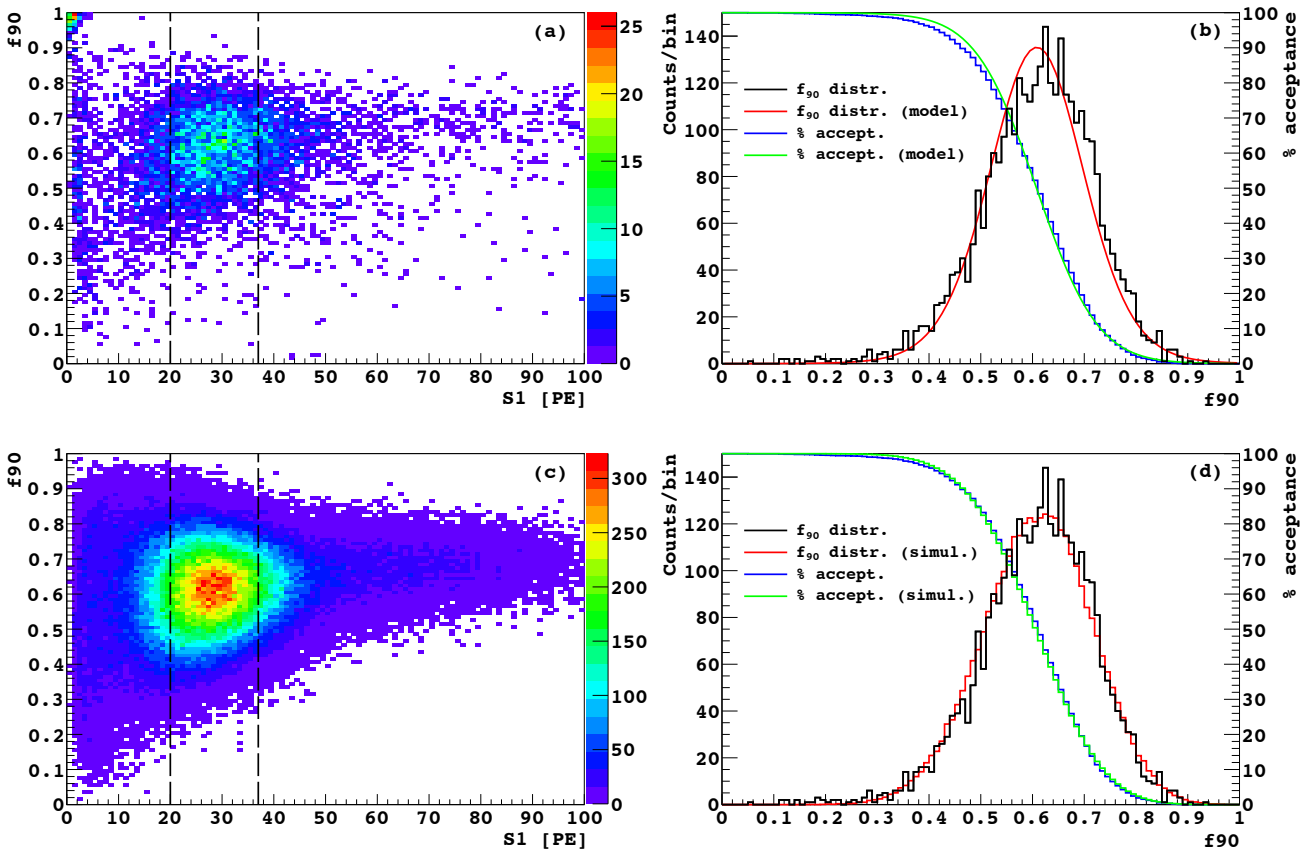
SCENE - Key results





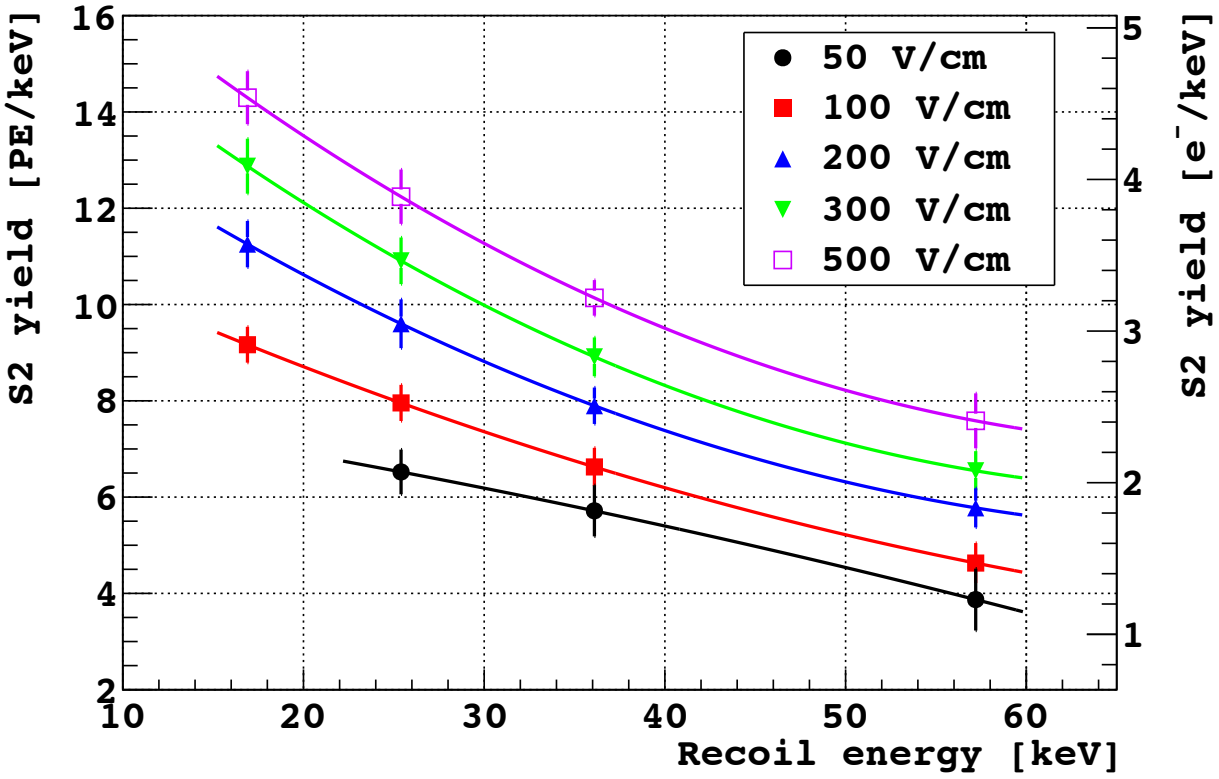
- Best measurement of L_{eff}(E) to date without field
- Only measurement with field

SCENE - Key results



- Measurement of pulse shape of nuclear recoils with drift field

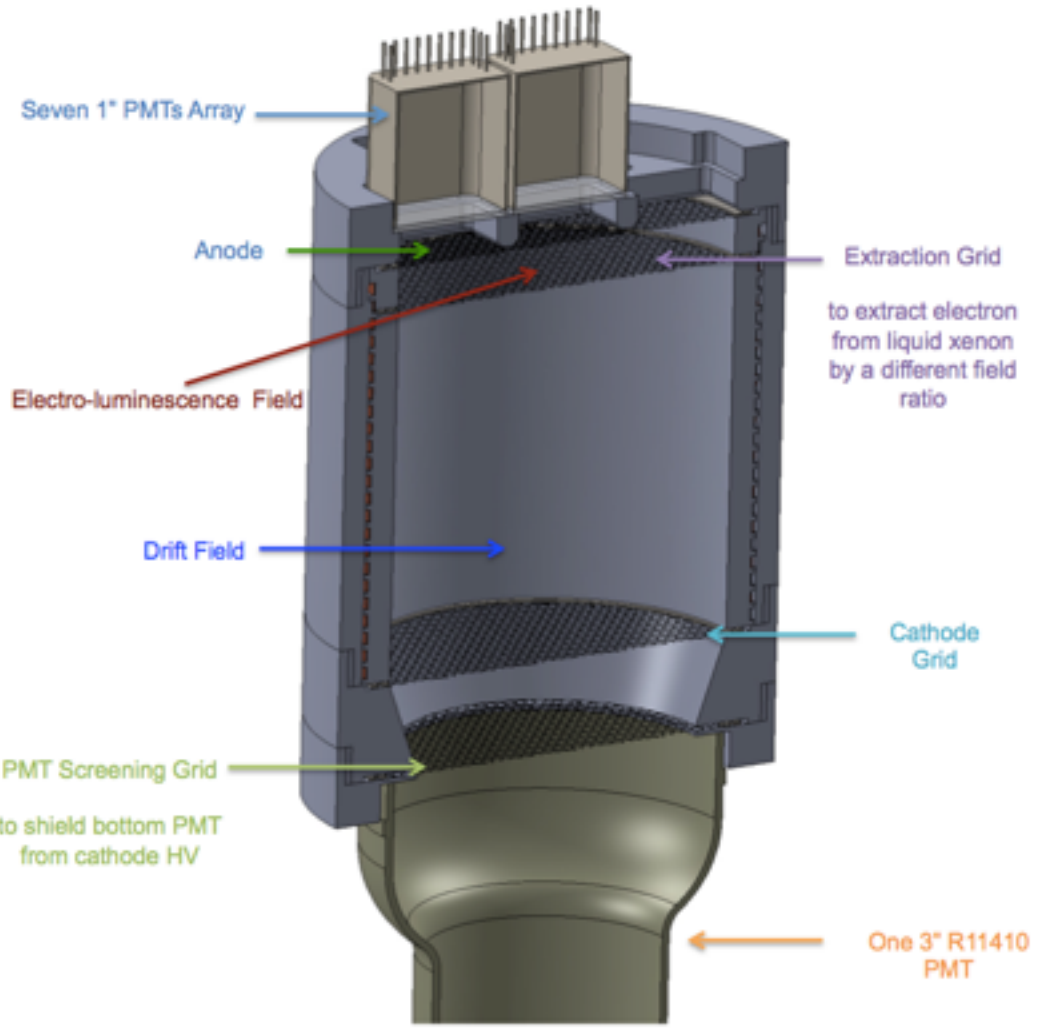
SCENE - Key results



- Ionization yield as a function of recoil energy and drift field
- All three results key to recent DarkSide-50 dark matter limit (arXiv:1410.0653)

Plans for Xenon run

- Liquid Xe run planned with new TPC built by student at UCLA
  - Direct test of the model used by liquid xenon dark matter experiments (NEST)
  - Very high impact
- Fermilab again to contribute structural support to enable use of detector at Notre Dame
  - Currently testing purity of xenon



Y. Meng 2013, UCLA

Future work

- SCENE apparatus is still in use as a generic test stand for LAr/LXe
  - Currently operating at FNAL for testing of underground argon (see H. Back's talk earlier in the session)
  - Collaboration with University of Chicago for measurements of LXe with radioactive sources
  - Influence of impurities on S1/S2 signals
- Apparatus could be modified to allow for He/Ne studies