R&D for LAr + Xe + photosensitive dopants

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‡ Fermilab

DUNE-β Concept
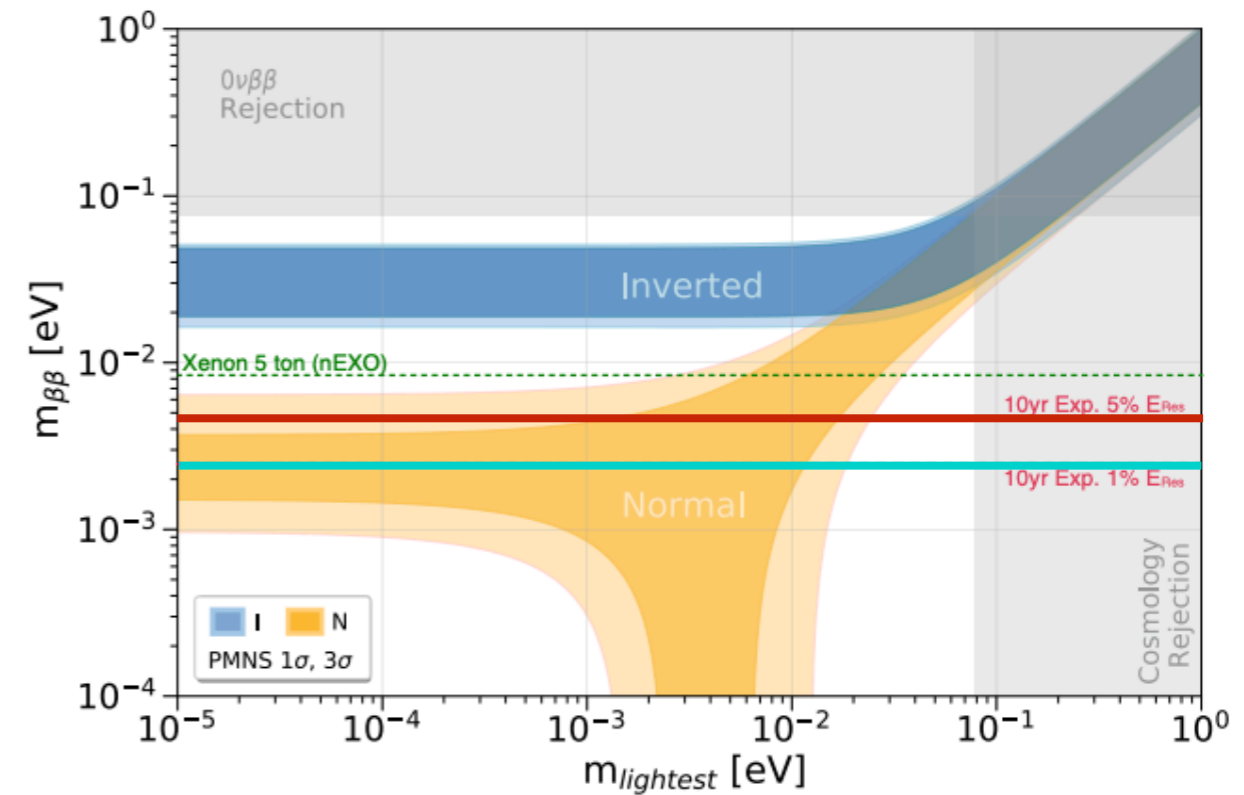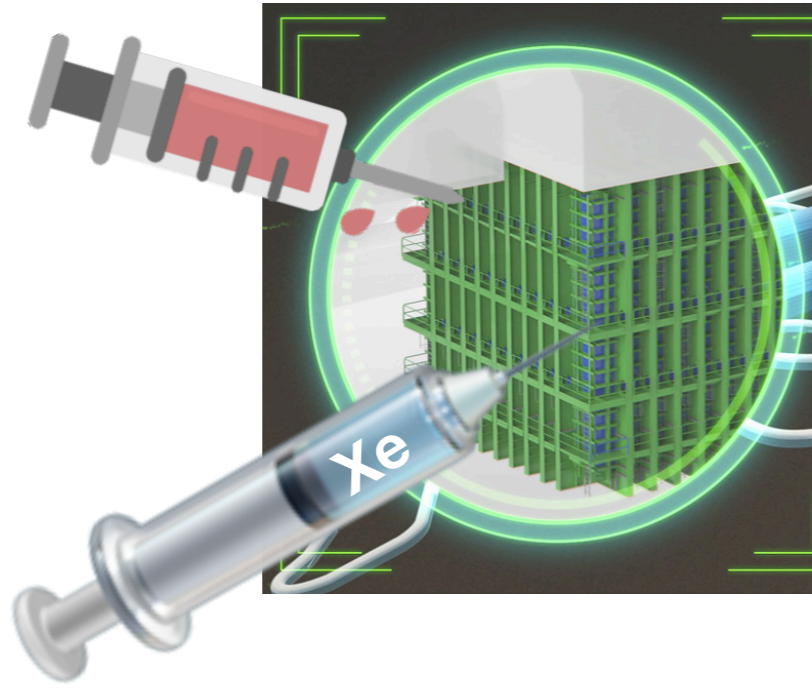
NEEDS

Depleted argon

Xenon doping at 2%

<3% energy resolution
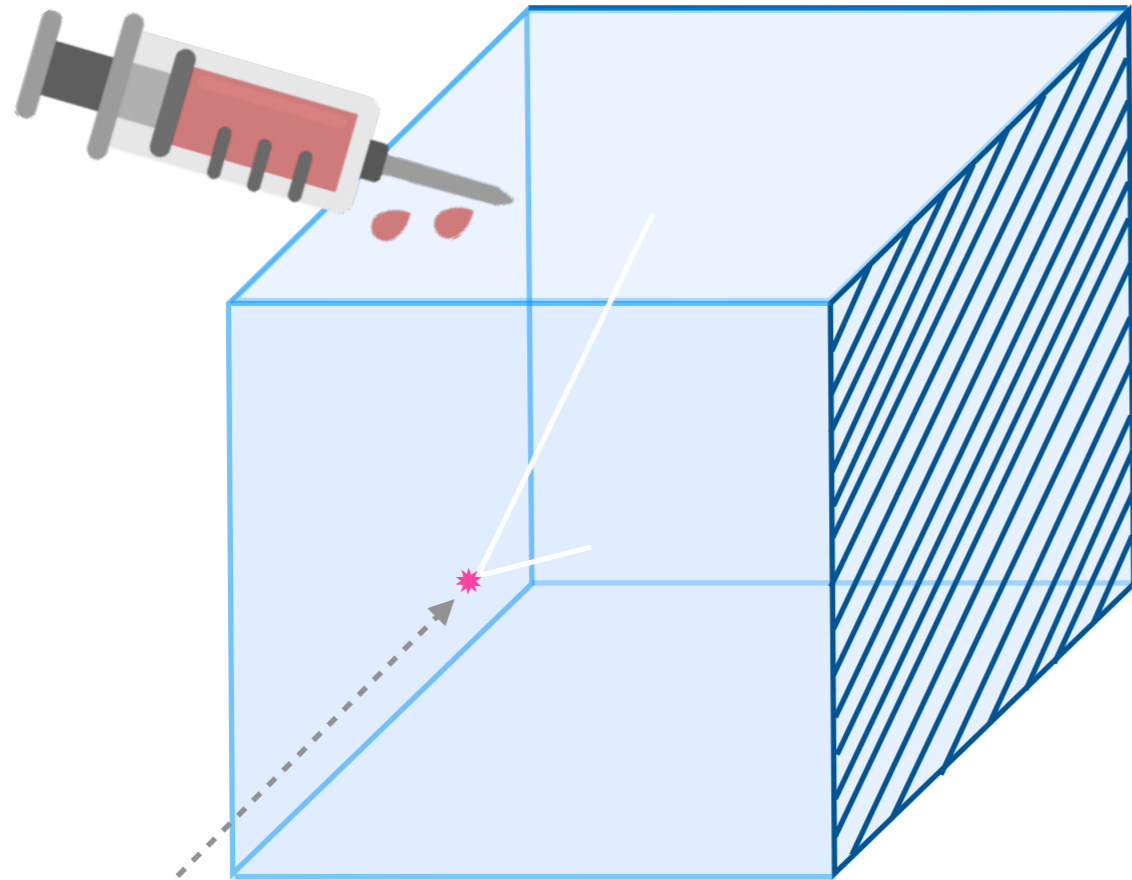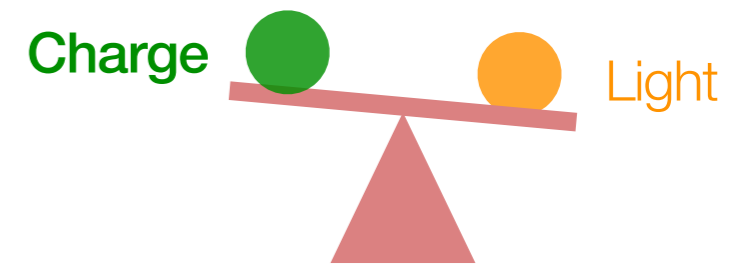
This talk:

Impacts of the R&D to enable 1% energy resolution at 2.5 MeV in kTon LArTPCs using **photosensitive dopants.**

Photosensitive Dopant Concept

Charge ⚫ 🟠 Light

To collect the most energy deposited in the LAr we could **convert the light to charge**

Introducing **photosensitive dopants** will cause light-to-charge conversion

Doped LAr

7.7 MeV α

Pure LAr

7.7 MeV α
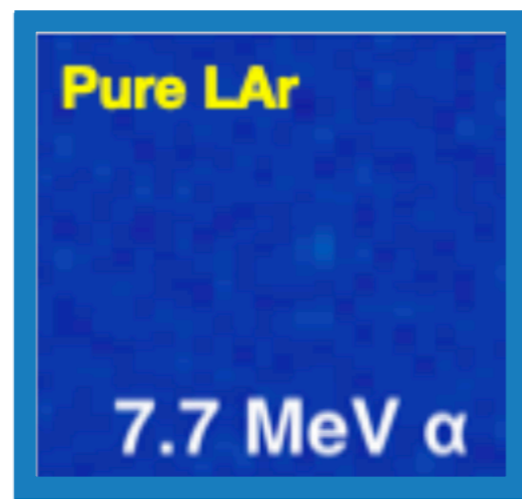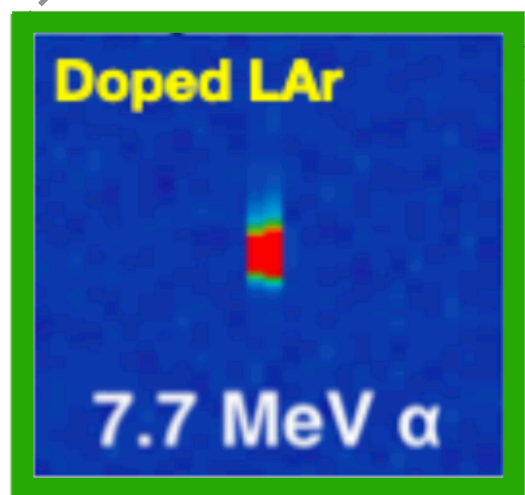
Same simulated alpha event!
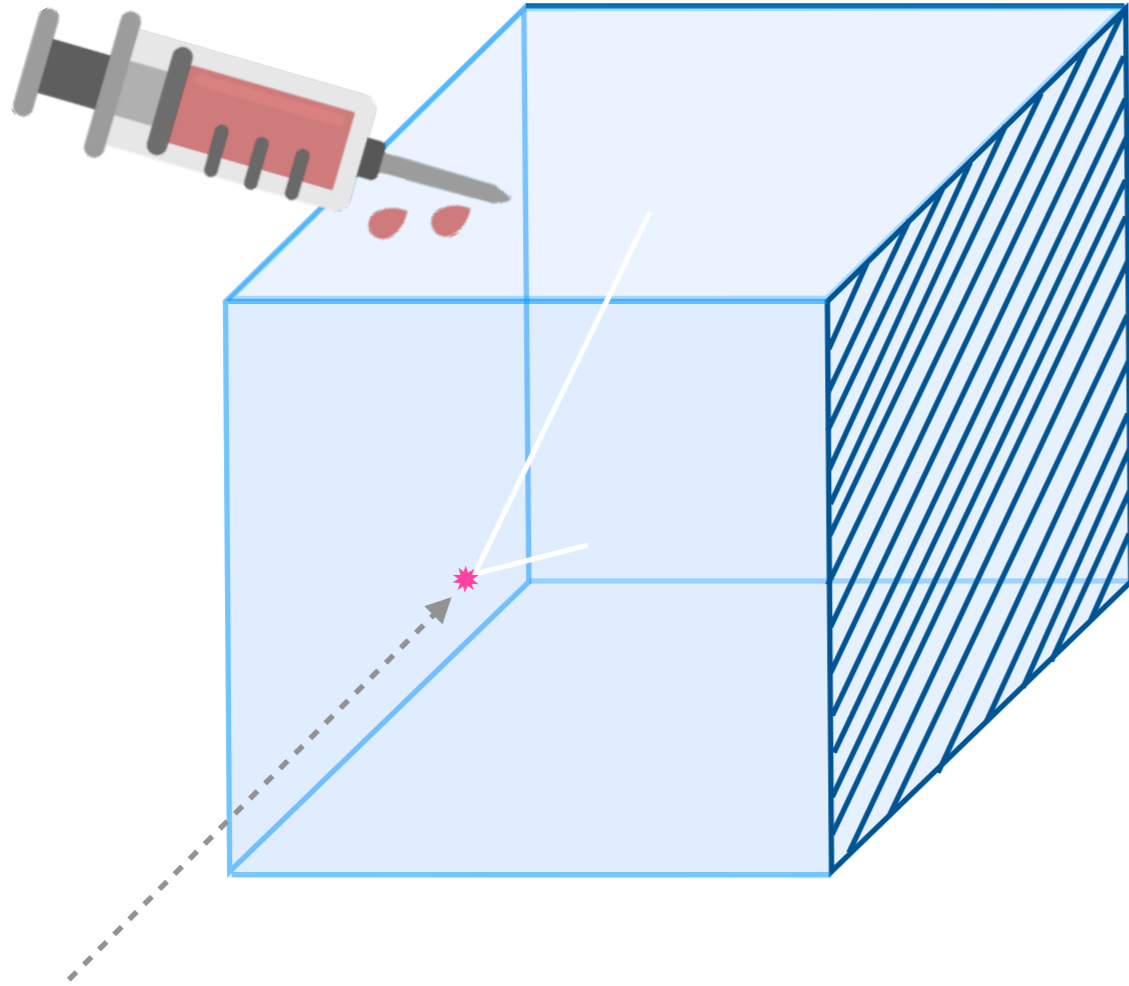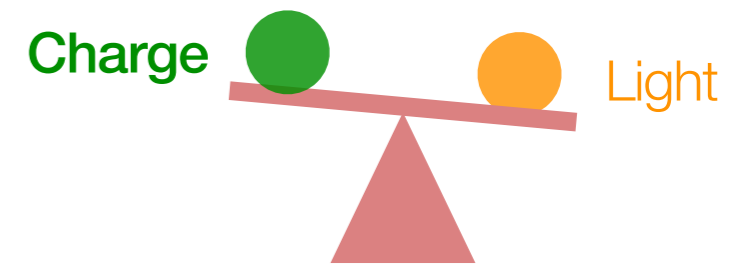
Nucl. Instr. and Meth. A 242 (1986) 256

Response to 5.5 MeV Alpha-Particles   *D.F. Anderson*

500 V/cm

9.4x Enhancement

TMG, 15 ppm

5.1x Enhancement

TMA, 110 ppm

2.6x Enhancement

Pure Liquid Argon

TEA, 47 ppm

CHARGE (e−)

DUNE Electric Field

5.5 MeV α-particles

E (kV/mm)

Photosensitive Dopant Concept

Charge   Light

To collect the most energy deposited in the LAr we could **convert the light to charge**

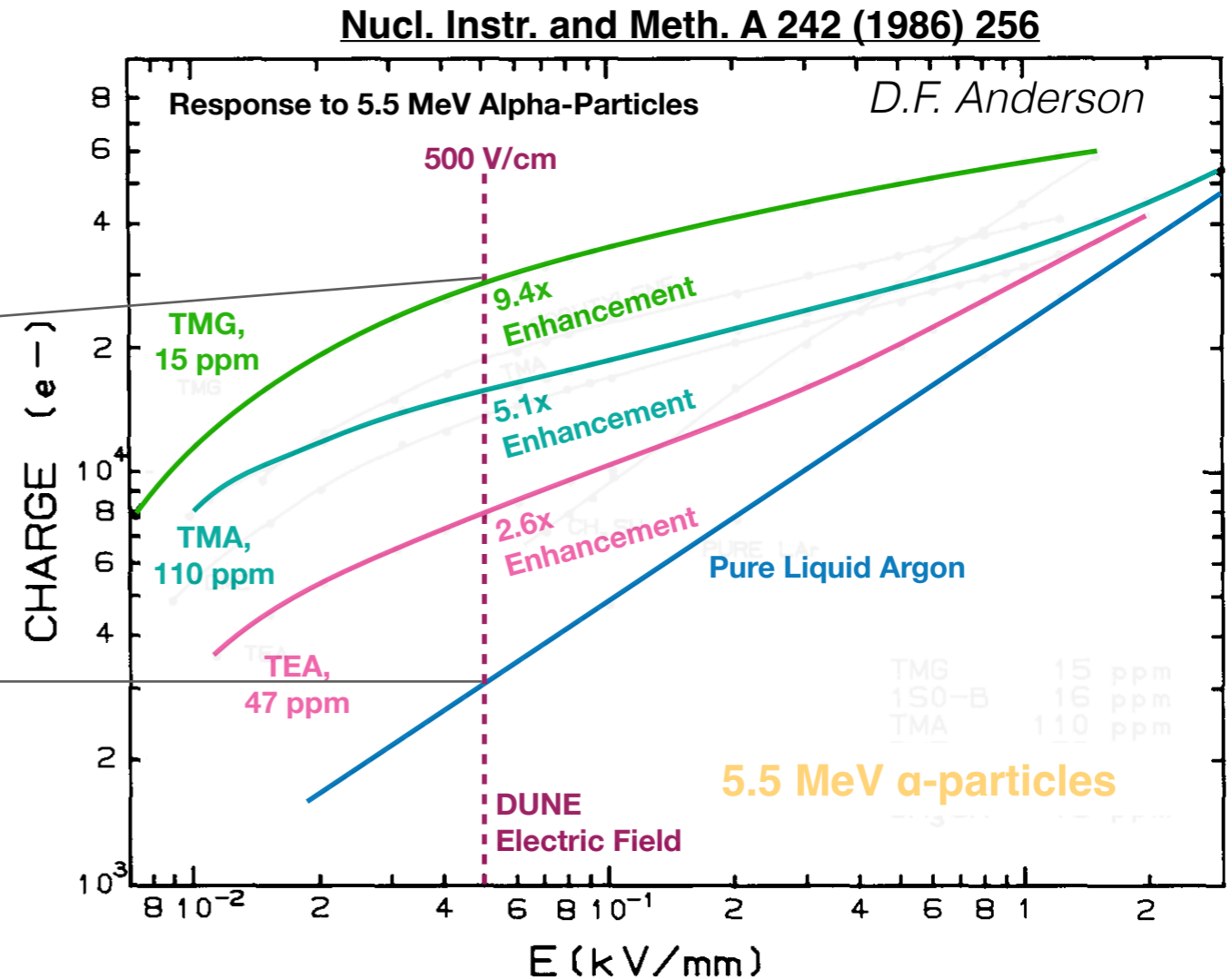Introducing **photosensitive dopants** will cause light-to-charge conversion

Nucl. Instr. and Meth. A 242 (1986) 256

D.F. Anderson

Response to 5.5 MeV Alpha-Particles

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TMA, 110 ppm

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Pure Liquid Argon

TEA, 47 ppm

CHARGE (e−)

TMG	15 ppm
ISO-B	16 ppm
TMA	110 ppm

5.5 MeV α-particles

DUNE Electric Field

E (kV/mm)

> **This technology enables LArTPC physics accross energy scales**

🔷 **Fermilab**
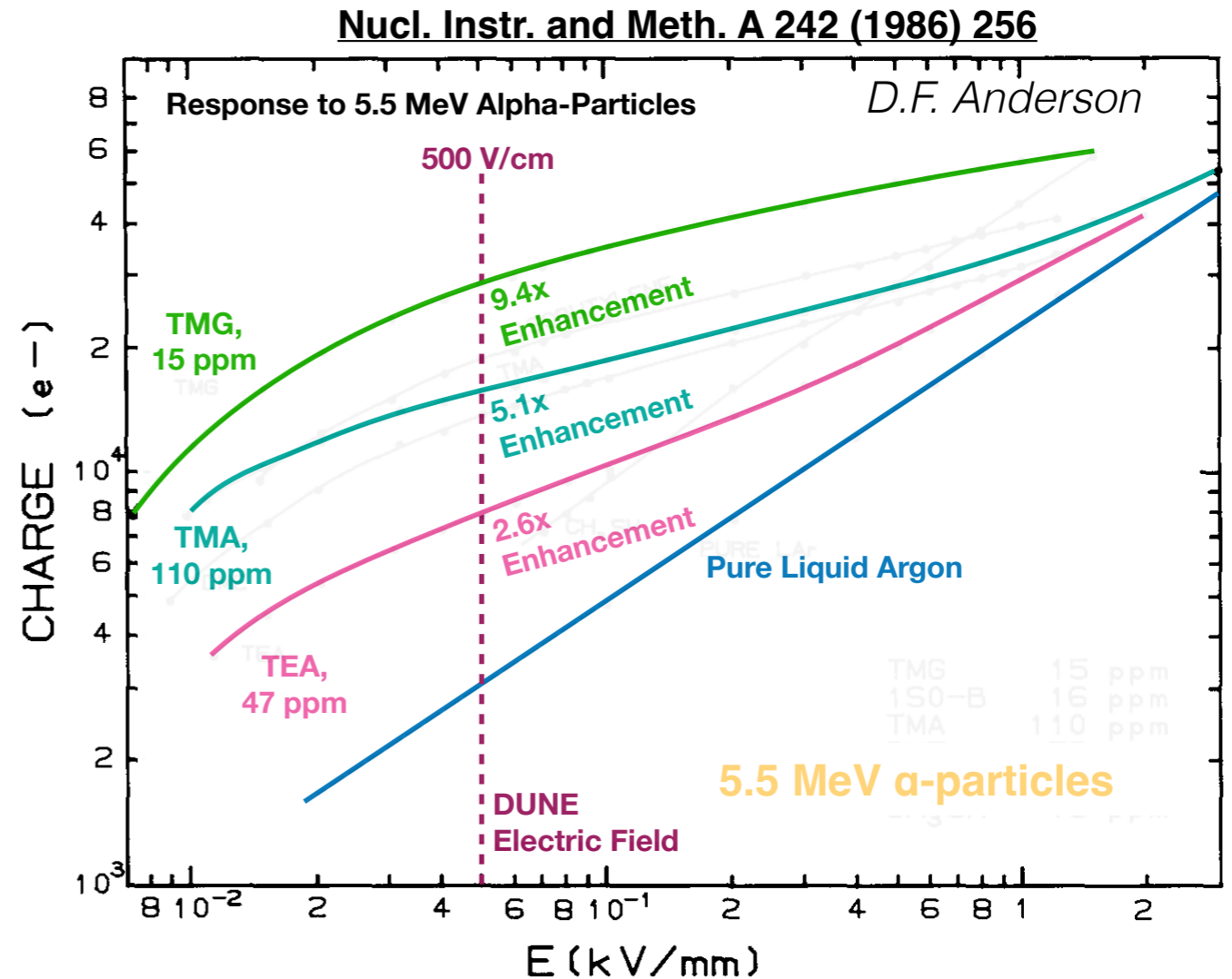
MeV-scale Energy Resolution

Simulation of charge enhancement in a full LArSoft LArTPC detector including:

wire noise, microphysical effects, detector response, noise filtering, signal processing, and energy reconstruction

Conservatice assumption:
No improvement from nominal DUNE charge readout
Noise level SNR = 20 or ~ 300ENC
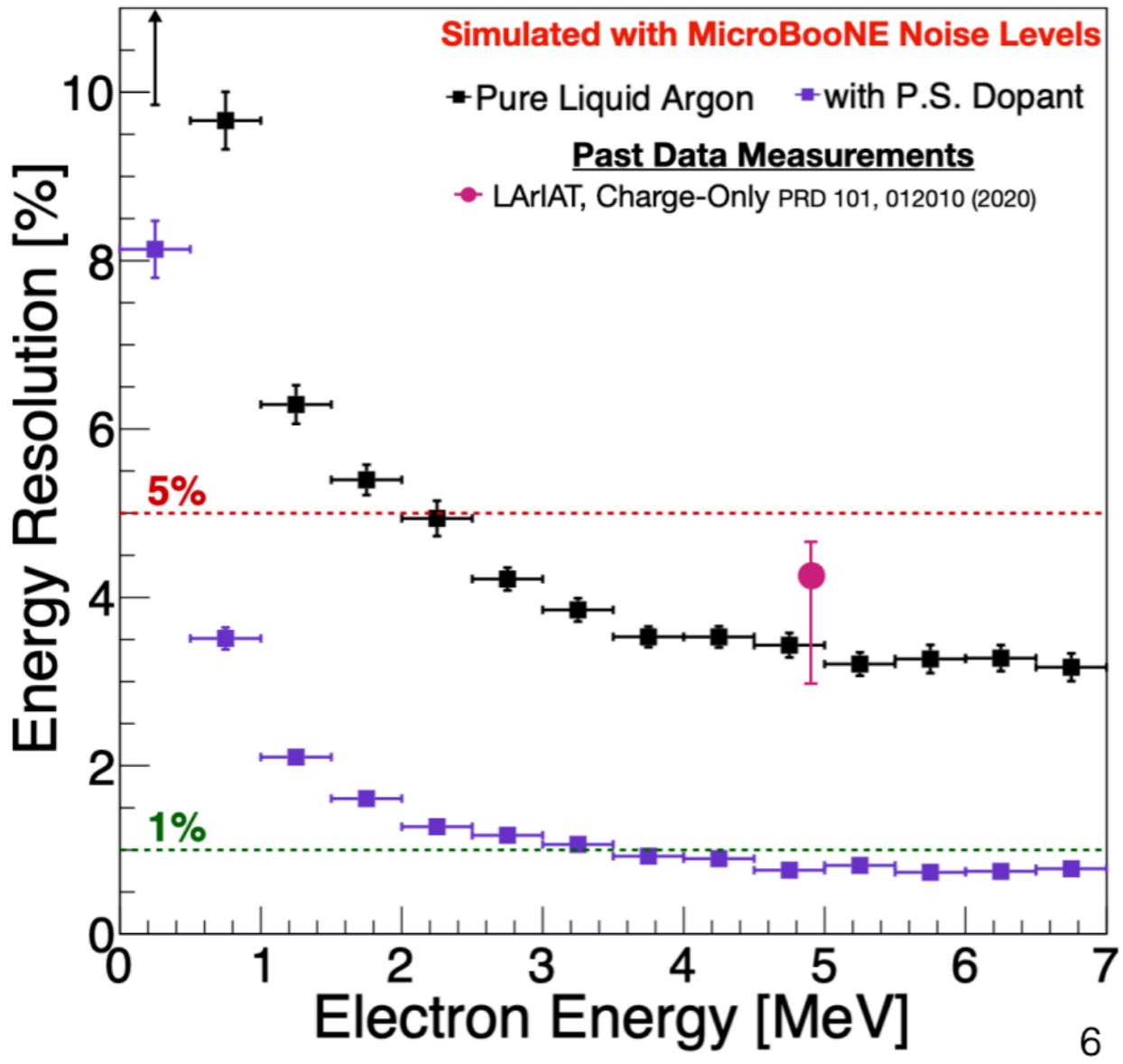
1% Energy Resolution at the Q value
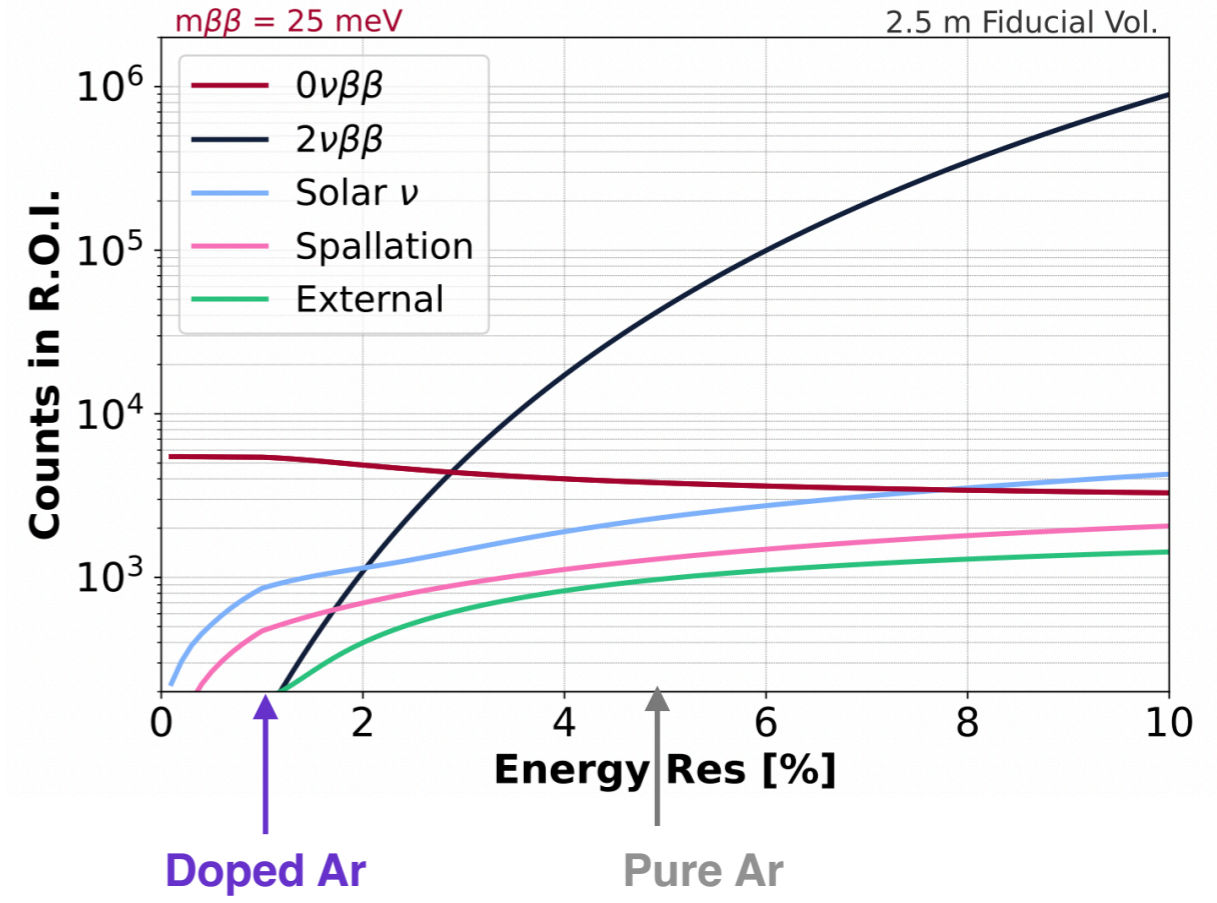
MeV scale energy resolution improves by 5x.

Enregy resolution would be sufficient to resolve 0vBB signal.

Thresholds

LArSoft Simulation

Pure LAr
PS-Doped LAr

Number of Ionization Electrons vs. Proton Energy Deposited [MeV]

Reco. Threshold

9
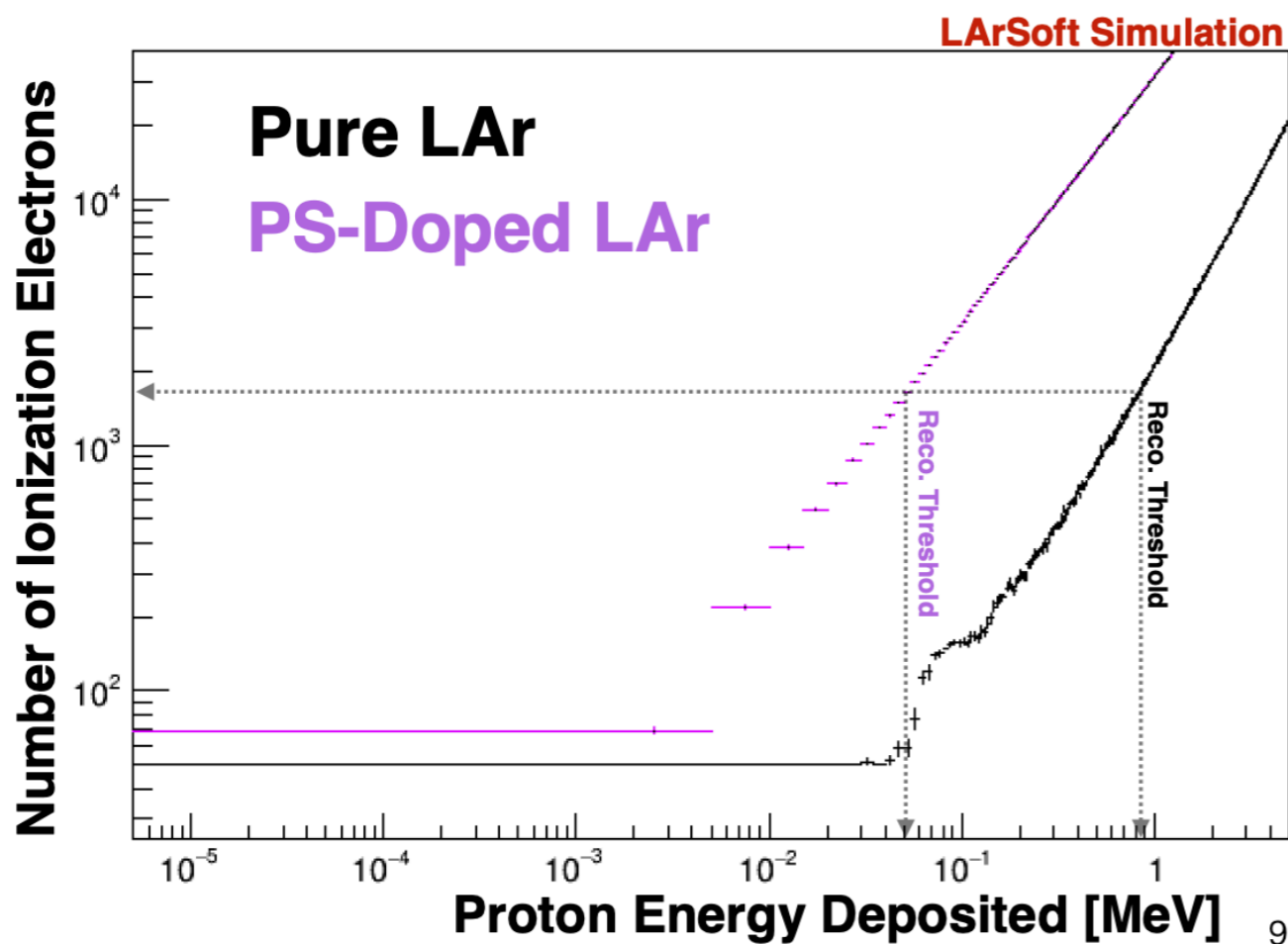
Lower thresholds from 1.1 MeV to 10keV

S. Gardiner
PRC 103, 044604 (2021)

Legend:
- E_e^{reco}
- $E_{e+\gamma}^{reco}$
- E_{vis}^{reco}
- E_{tag}^{n}
- E_{tag}^{p}
- E_{tag}^{n+p}

f_{RMS} vs E_ν [MeV]

Supernova energy range
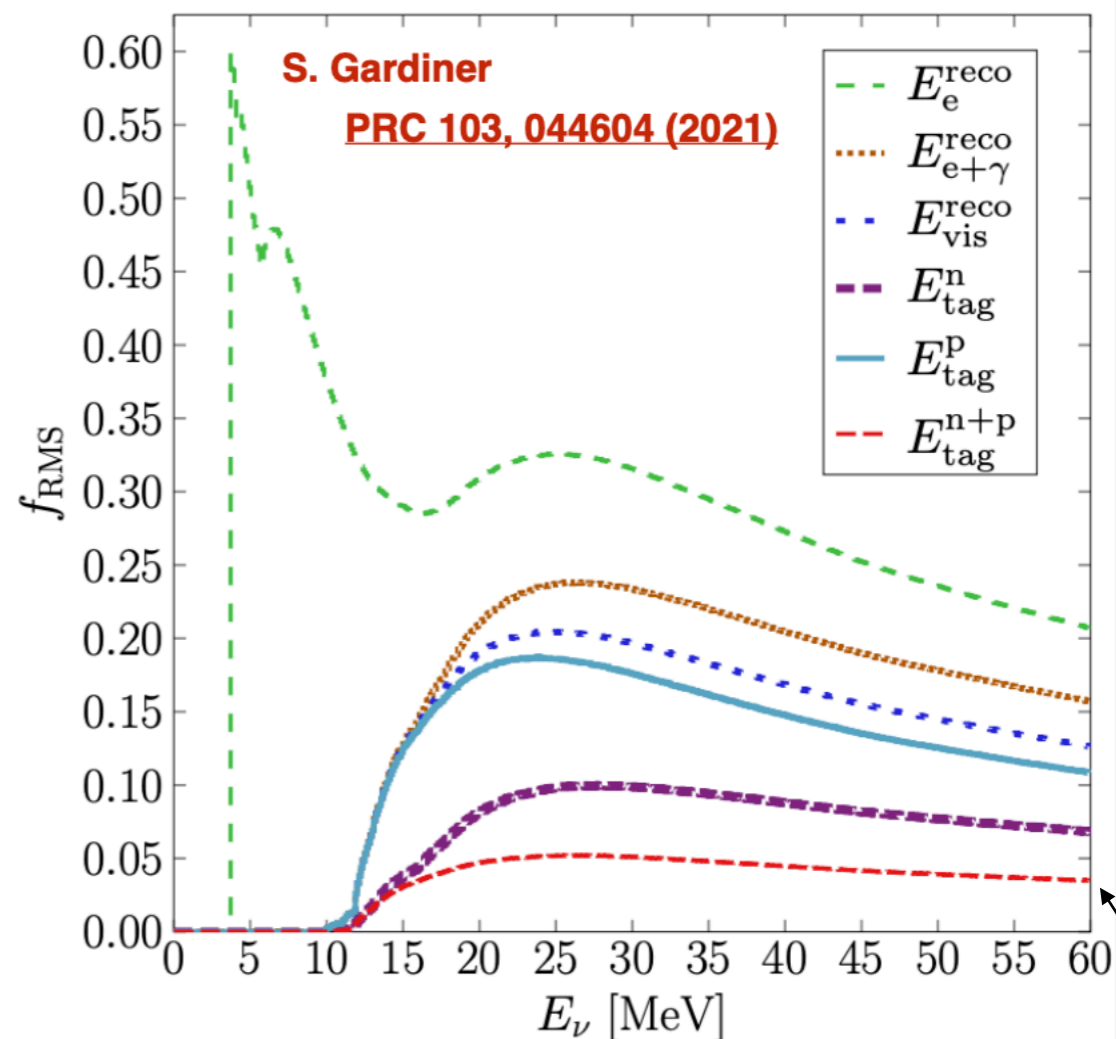
Energy resolution improves by x5 from tagging protons & neutrons

Simulation
28 cm
Pure Liquid Argon

GeV (accelerator energy range)

Simulation
28 cm
Doped Liquid Argon
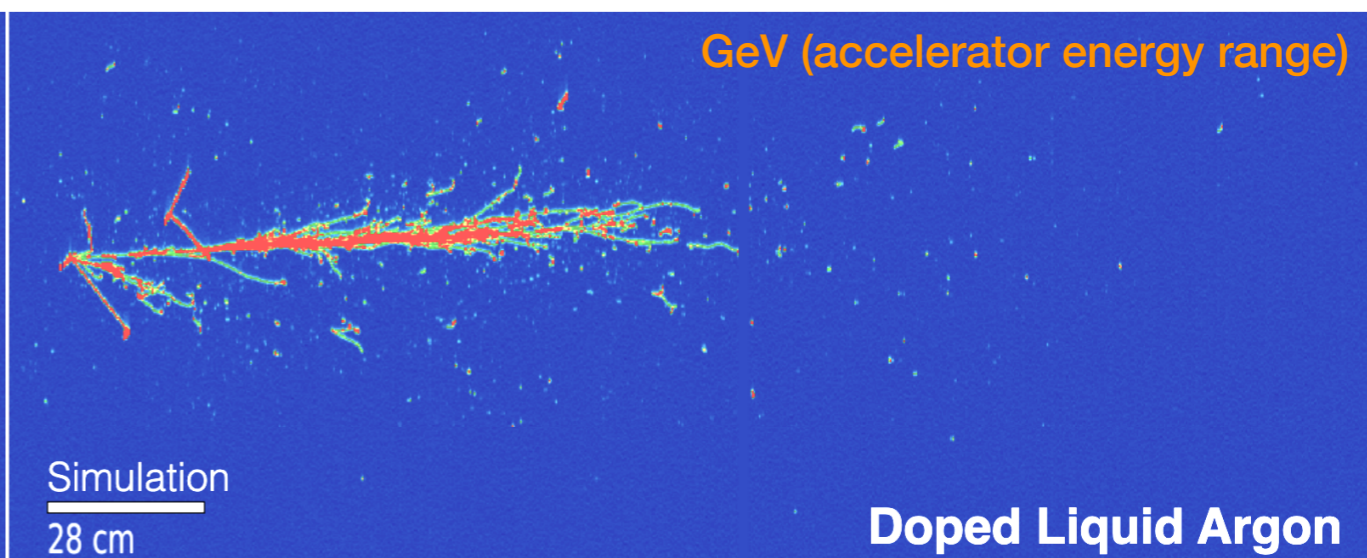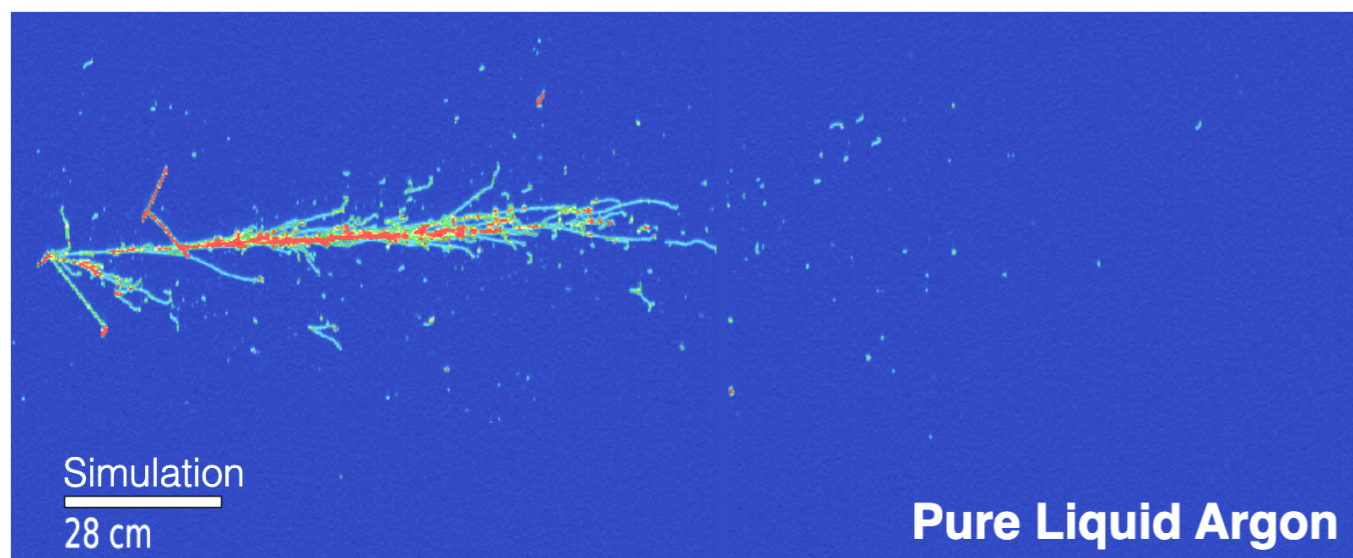
Overcoming recombination

Based on Stopping Protons

Pure LAr
PS-Doped LAr

LArSoft Simulation

dQdx directly follows dEdx

Needs recombination correction

dQ/dx [1000 e⁻/cm] — dQ/dx [1000 e⁻/cm]

dE/dx [MeV/cm]

**Supported by ICARUS
Photosensitive dopant data**

Stopping muons and protons

200 V/cm

3.5ppm TMG

Pure Argon

dQ/dx (e/2mm)

dE/dx (MeV/cm)
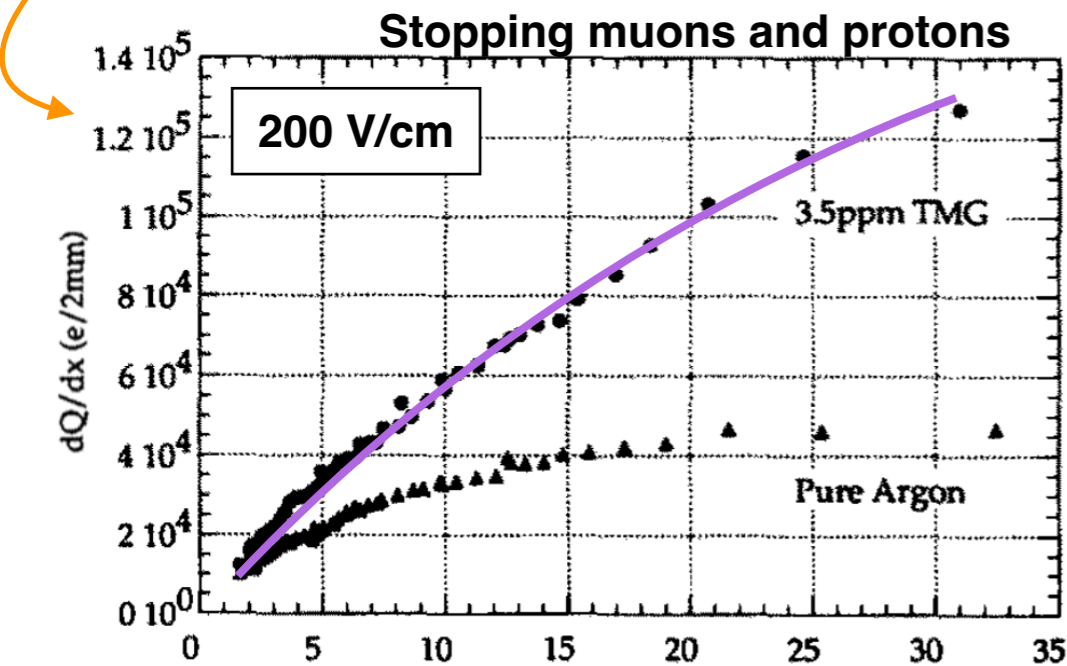
Nucl. Instrum. Methods.
Phys. Res. B 355, 660
(1995).

*ICARUS
Collaboration*

The non-linear response usually **requires a recombination correction** for energy reconstruction.

Doped LAr yields a **more linear detector response**.

Pure Liquid Argon

4%

Charge
UV Light
96%

Charge
39%

UV Light
61%

Scale of charge when doped

Fraction of Light or Charge Per Deposited Energy [%/MeV]

1 MeV   125 MeV
Energy Deposited [MeV]

Simulated with MicroBooNE Noise Levels

Pure Liquid Argon
(0.87 MeV Reconstruction Threshold)

with P.S. Dopant
(0.05 MeV Reconstruction Threshold)

Reconstruction Threshold

Range-Based Energy Resolution at High Energies

Calorimetric Energy Resolution [%]

Proton Deposited Energy [MeV]

Energy resolution imprtovements for low energy protons.

Physics this enables

Energy resolution improves:

>5 times   **>2 times**

Presupernova Neutrinos

Supernova Neutrinos

Solar Neutrios

Accelerator Beam Neutrinos

0νββ

Proton Decay

Atmospheric Neutrinos

1 MeV   10 MeV   100 MeV   1 GeV   10 GeV

Energy of Signals

Enables p & n tagging, pointing, and may enable sensitivity to coherent neutrino scaters

Enables physics program

Enables pointing resolution

Improves E reconstruction. & Enables access to the 2nd oscillation peak.

DarkSide 20k Collaboration   JCAP 03 (2021) 043

Pure LAr Number of Electrons

0 20 40   60   80   100

$27\,M_\odot$ supernova at 10 kpc

150 Electrons

300 Electrons

Doped LAr Number of Electrons

10,000 in 10 kton

3,000 in 10 kton

Coherent Scaters

E_R [keV$_{nr}$]

Events/ [keV$_{nr}$ x ton]

(Thanks to J. Zettlemoyer)

PRD 103, 116003 (2021)

Pure LAr
$\nu_e(\overline{\nu}_e)$ Events/0.25 GeV

4076
3430
2904

ν mode (NH)

Signal, δ = 0
Signal, δ = π/2
Signal, δ = -π/2
Beam $(\nu_e + \overline{\nu}_e)$ CC
$(\nu_\mu + \overline{\nu}_\mu)$ CC
$(\nu_\tau + \overline{\nu}_\tau)$ CC
NC

PS-Doped LAr
$\nu_e(\overline{\nu}_e)$ Events/0.25 GeV

4123
3455
2922

ν mode (NH)

Reconstructed Energy (GeV)

11

R&D Necessary

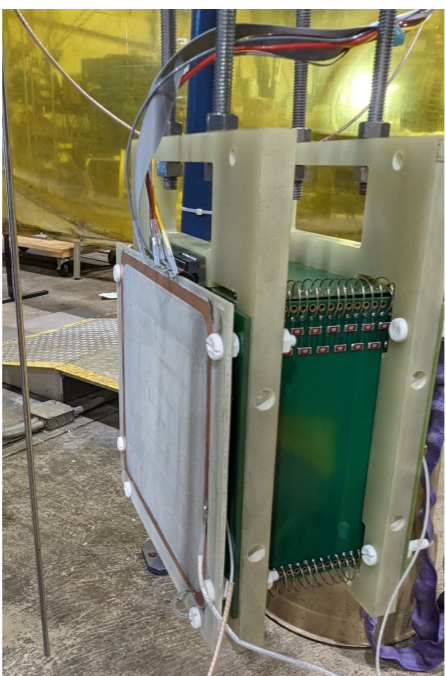**Dopant demonstration**

Xenon doping stability

Charge enhancement w/dopants

Calibration for low energy signals

Characterization of pixel readouts at <10MeV

Impact of contaminants on dopants

TinyTPC (next talk)

Stability of mixture

Survival of VUV light signals in dopants

Characterization of VUV in dopants + Xe

Charge enhancement w/dopants + Xe

Characterization of charge in dopants + Xe

Energy resolution linearity

Energy resolution measurements

Concentration characterization

Interaction dopants w/ filter

Removing dopants

Removing Xe

Talk to us about collaborating on this R&D!