Photosensitive dopants and DUNE Phase-II

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Context

Dopants that convert light to charge (**Photosensitive dopants**)might help expand the reach of DUNE phase-II at low energies.

Improvements to energy resolution at low energies will also **impact the current P5 priorities** in the Phase-II precision measurement era.

A LArTPC R&D program with potential to **expand DUNE physics reach for phase-II** to and contribute to running AND future detector technologies.

DUNE Physics at Low Energies

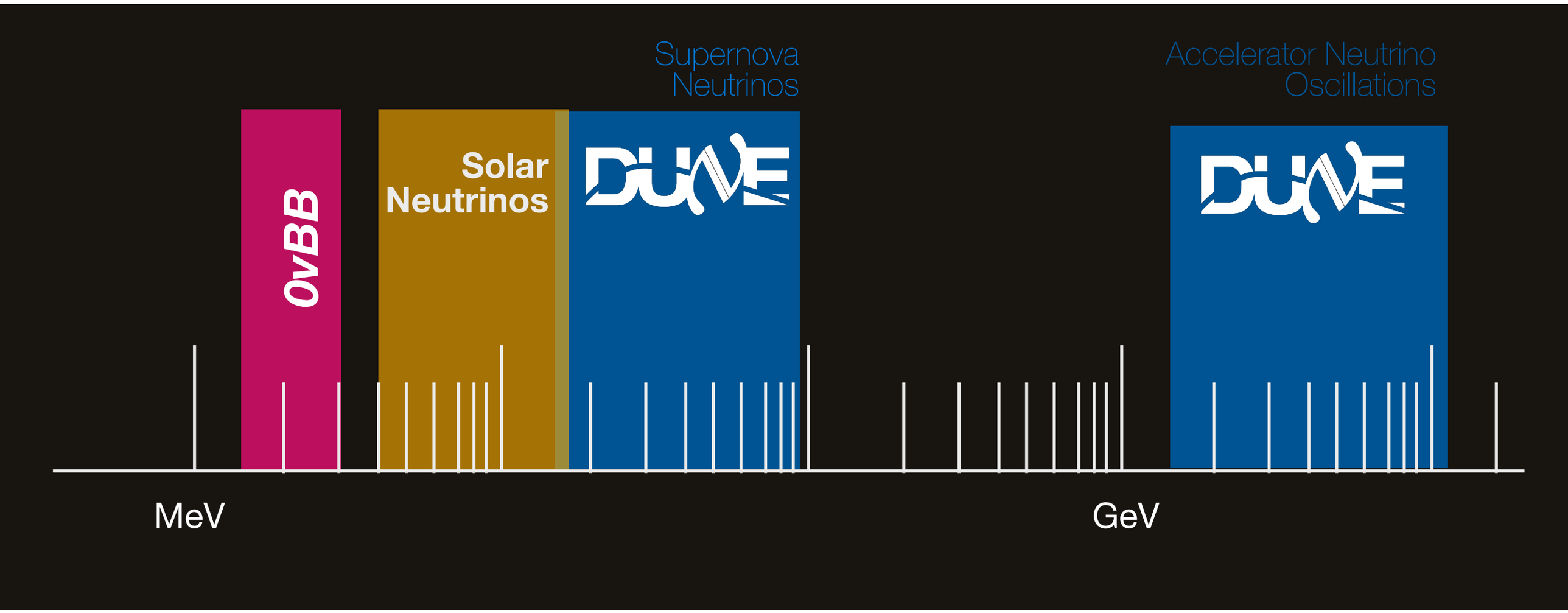

Photo-sensitive dopants can improve

Photo-sensitive dopants can enable

Some References

Dopants in the context of:

enabling neutrino-less double-beta decay

LArTPC R&D For DUNE & beyond

Xenon-Doped Liquid Argon TPCs as a Neutrinoless Double Beta Decay Platform

A. Mastbaum,[1] F. Psihas,[2] and J. Zennamo[2]
[1] *Rutgers University, Piscataway, NJ, 08854, USA*
[2] *Fermi National Accelerator Laboratory (FNAL), Batavia, IL 60510, USA*
(Dated: March 29, 2022)

Snowmass2021 - Letter of Interest

Improving Large LArTPC Performance Through the Use of Photo-Ionizing Dopants

Topical Group(s):
(NF10) Neutrino detectors
(IF08) Noble Elements

Authors: J. Zennamo, A. Mastbaum, F. Psihas

Doped Liquid Argon TPCs as a Neutrinoless Double Beta Decay Platform

Jul 24, 2022, 11:40 AM
20m
022 (JHN)

Neutrino Physics Front...

Speaker

Fernanda Psihas Olmedo (Fermi National Acce...

Photo-ionizing Dopants

Jul 23, 2022, 9:00 AM
15m
026 (JHN)

Cross Frontier Sessions

Speaker

Joseph Zennamo (Fermilab)

Some References

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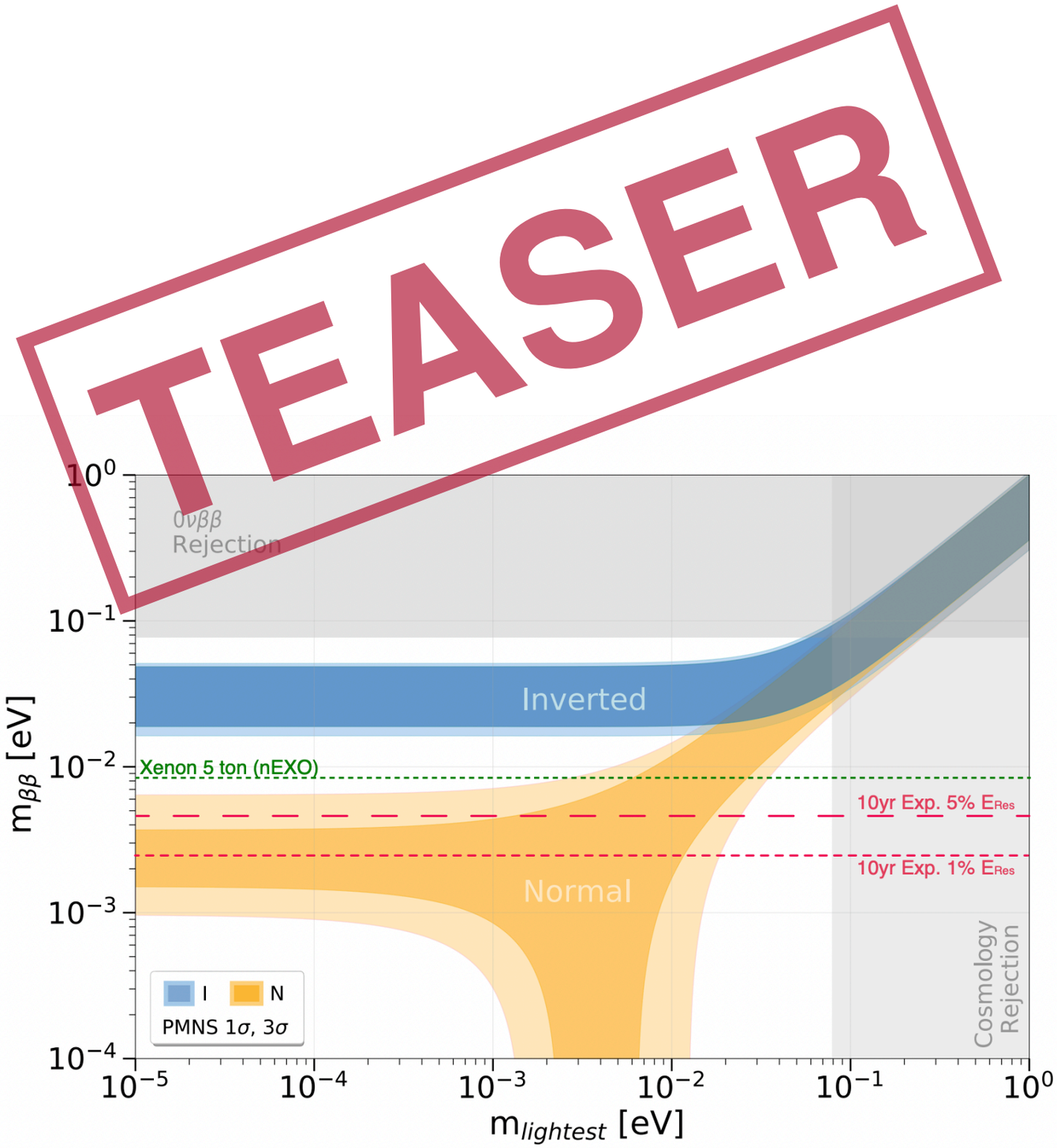
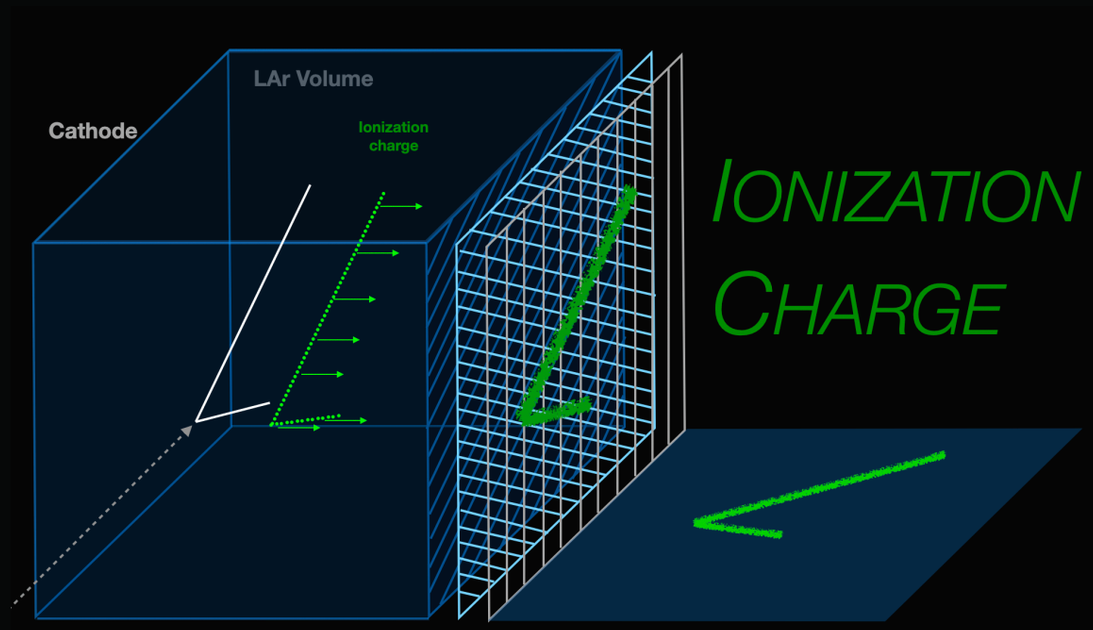
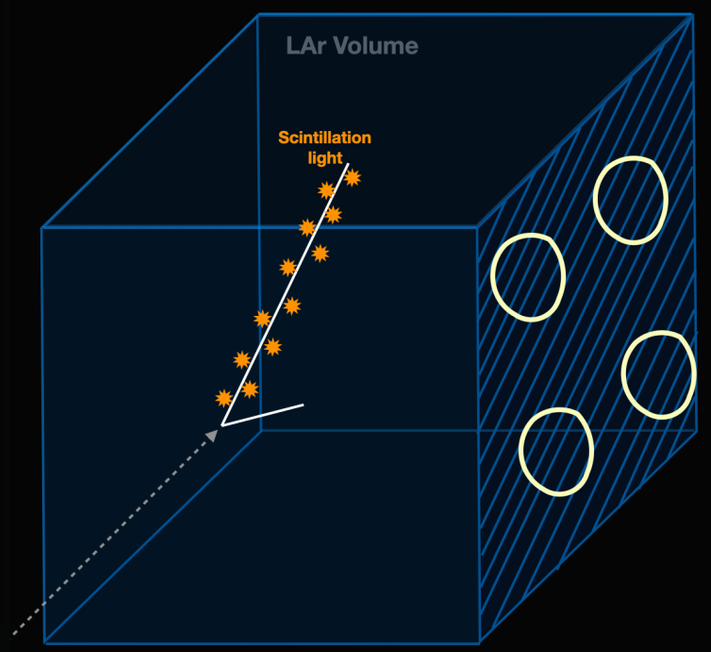


Signals in LArTPCs



Ionization Charge



Scintillation Light

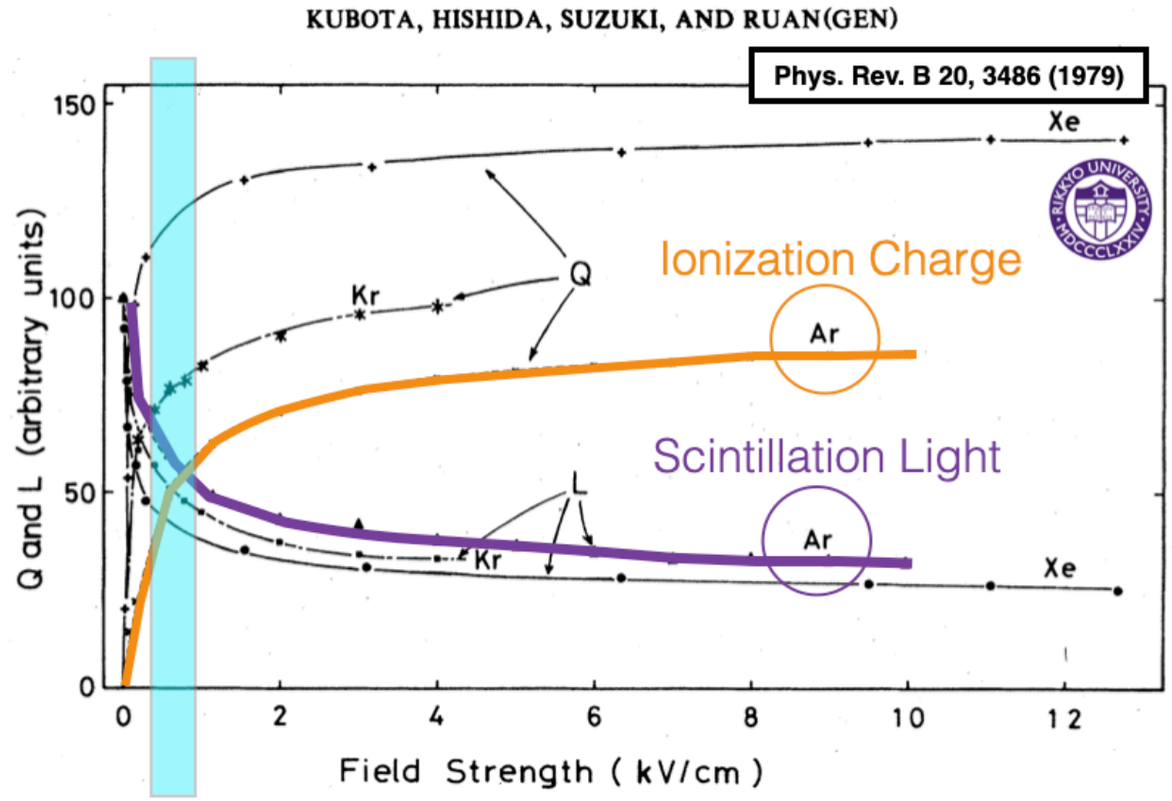
➡️ Directional	✳️ Isotropic
🐢 Very slow	⚡ Very fast
〽️ Information about trajectory and energy	⏱️ Information about timing and *technically also energy
🔆 Collected very efficiently	🔅 Collected with less efficiency

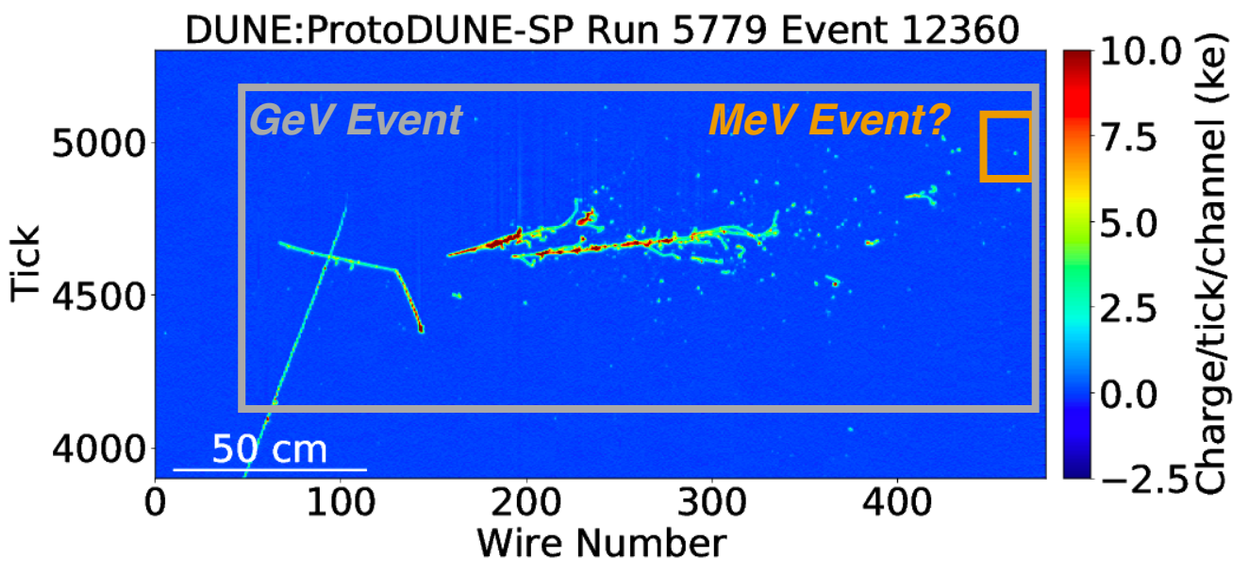
Matters a lot at low energies

Why photo-sensitive dopants?

Charge + Light = Constant

On DUNE, we'll expect ~50/50 **charge** to **light** breakdown.





JINST 15 (2020) P12004
ProtoDUNE-SP

This ratio is sufficient for the needs of GeV physics but will impact our ability to do physics at the MeV scale

Charge + Light = Better Resolution at Low Energies

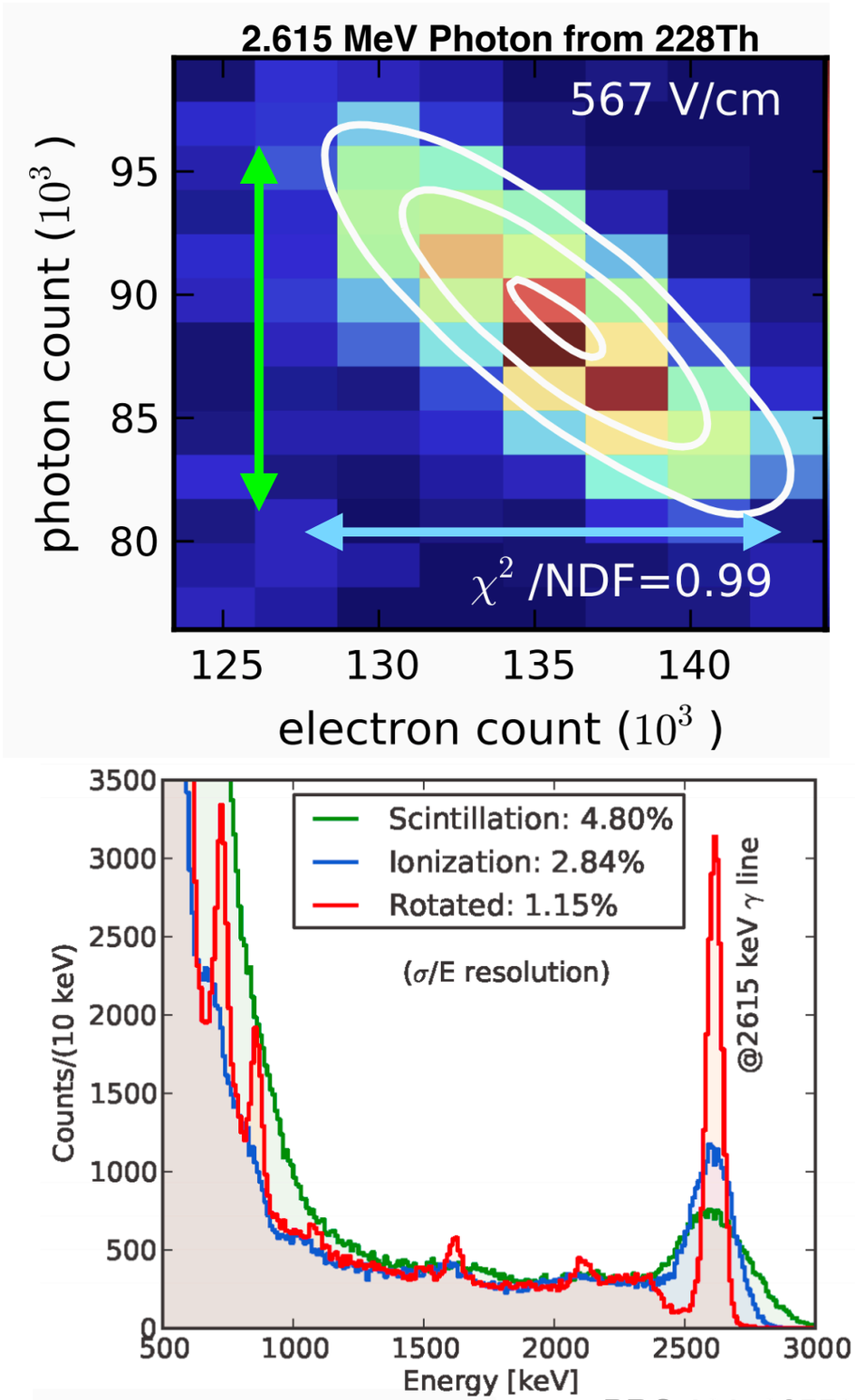
EXO-200, a LXeTPC searching for 0νββ, explored the anti-correlation between light and charge signals

Found when using light or change they were only able to achieve a 4% energy resolution

By **combining light and charge** they were able **to improve their energy resolution** by 3x, to ~1%

To achieve this they collected 30,000 γ/MeV

***See J. Zennamo's talk on Saturday for this concept in LAr simulation.**



PRC 101, 065501 (2020)
EXO-200 Collaboration

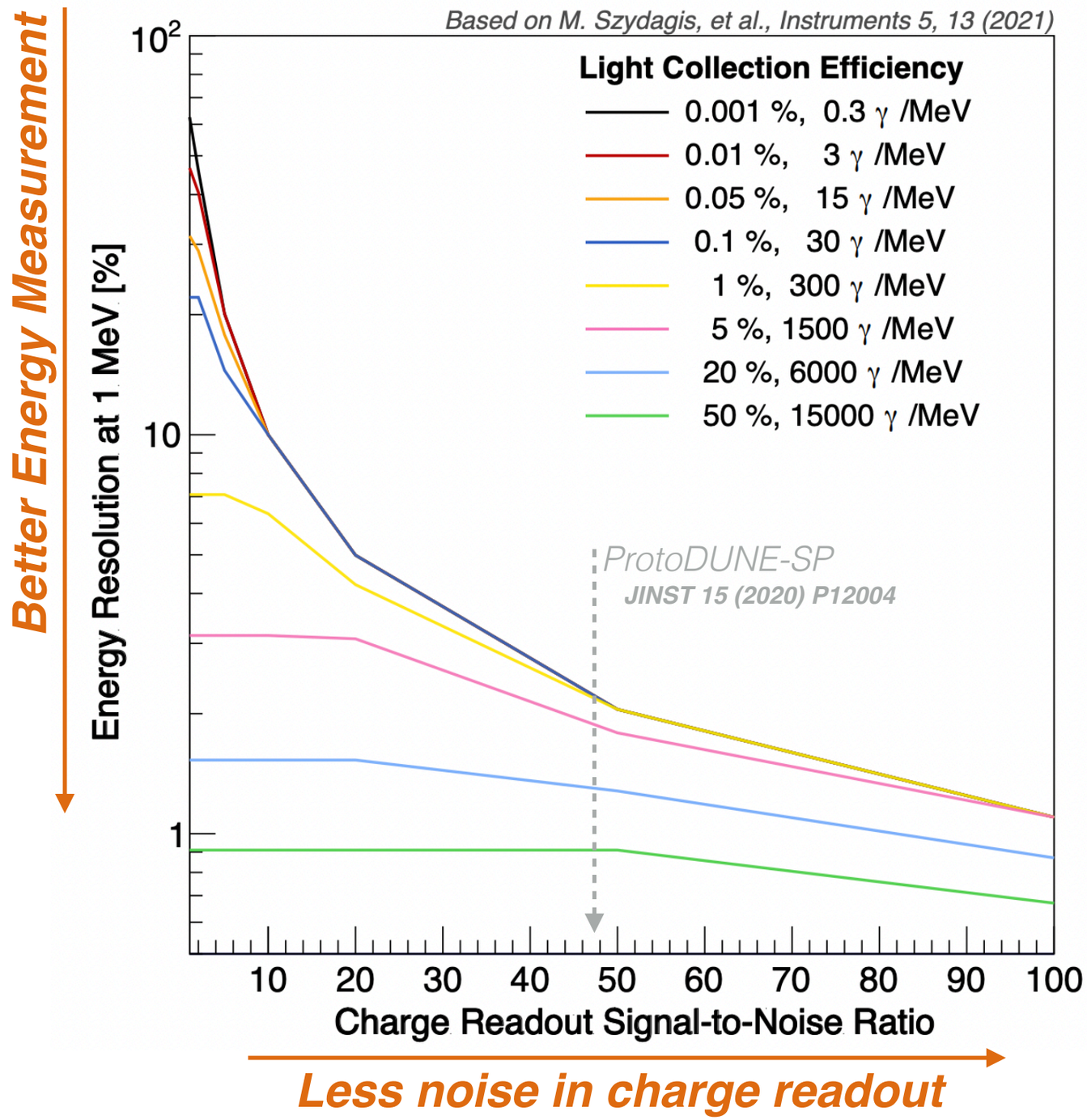
How much light do we need?

NEST[*] models the microphysics of energy deposits in noble liquids and gases.

Explored the energy resolution for 1 MeV electrons in LAr for detectors with various efficiency and noise conditions

Achieving the best possible energy resolution need to collect at least 6000 photons per MeV

[*] Noble Elements Simulation Technique, http://nest.physics.ucdavis.edu/



Light Collection on DUNE

Traditionally light collected at anode plane

DUNE FD Module
5,600 cm by 1,200 cm

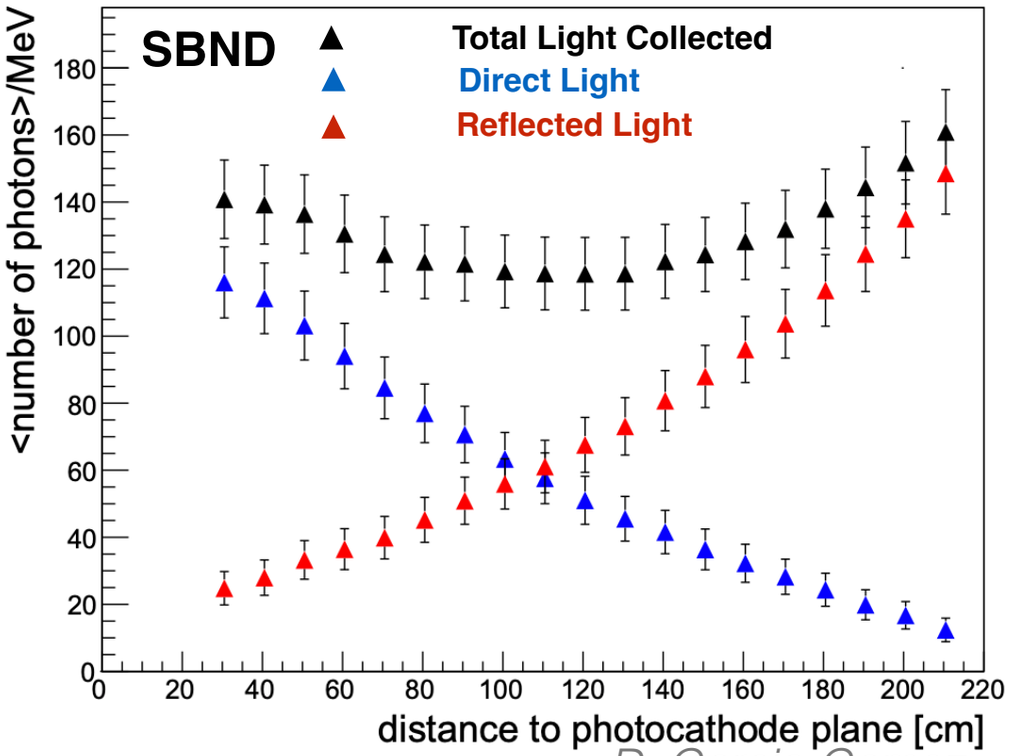
EXO-200 Detector
40 cm by 18 cm

Increasing light collection on large LArTPCs is a challenge:

- Scintillation photons have to travel large distances.
- Low photon detection coverage by design.

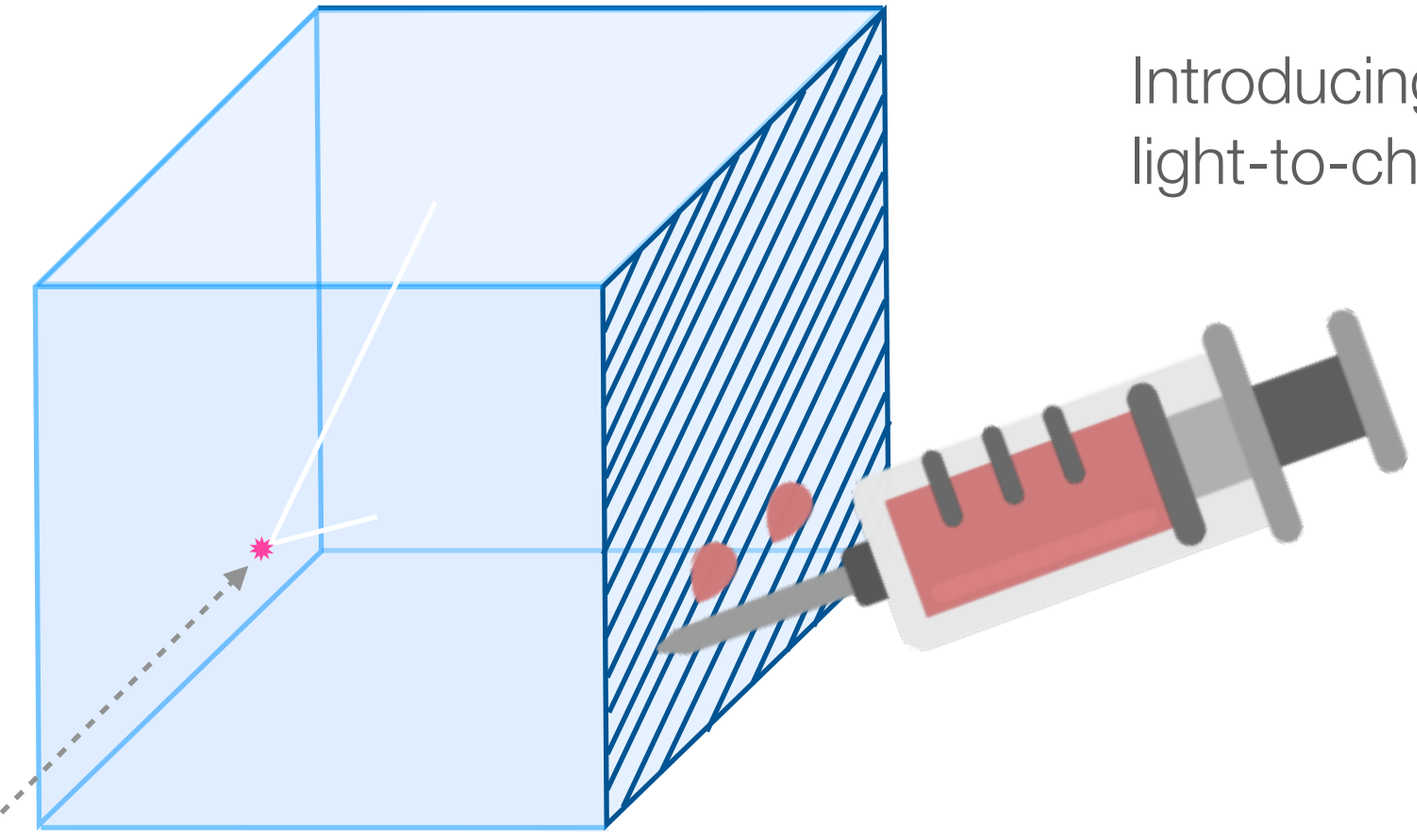
The best light collection efficiency has been accomplished on SBND

Best LArTPC
Light collection < 160 photons/MeV << 6000 photons/MeV

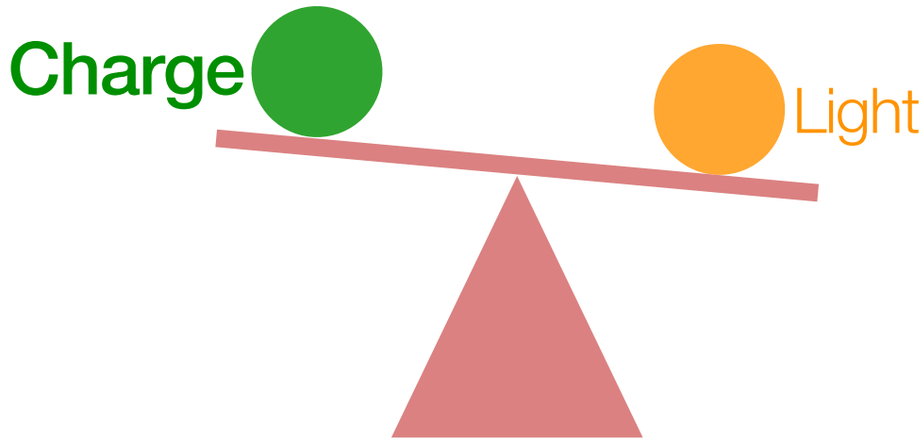


D. Garcia-Gamez
Journal of Physics: Conf. Series 888 (2017) 012094

Photosensitive Dopant Concept



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



What we know:

✅ **Good indications that this is a promising avenue of R&D**

R&D Questions

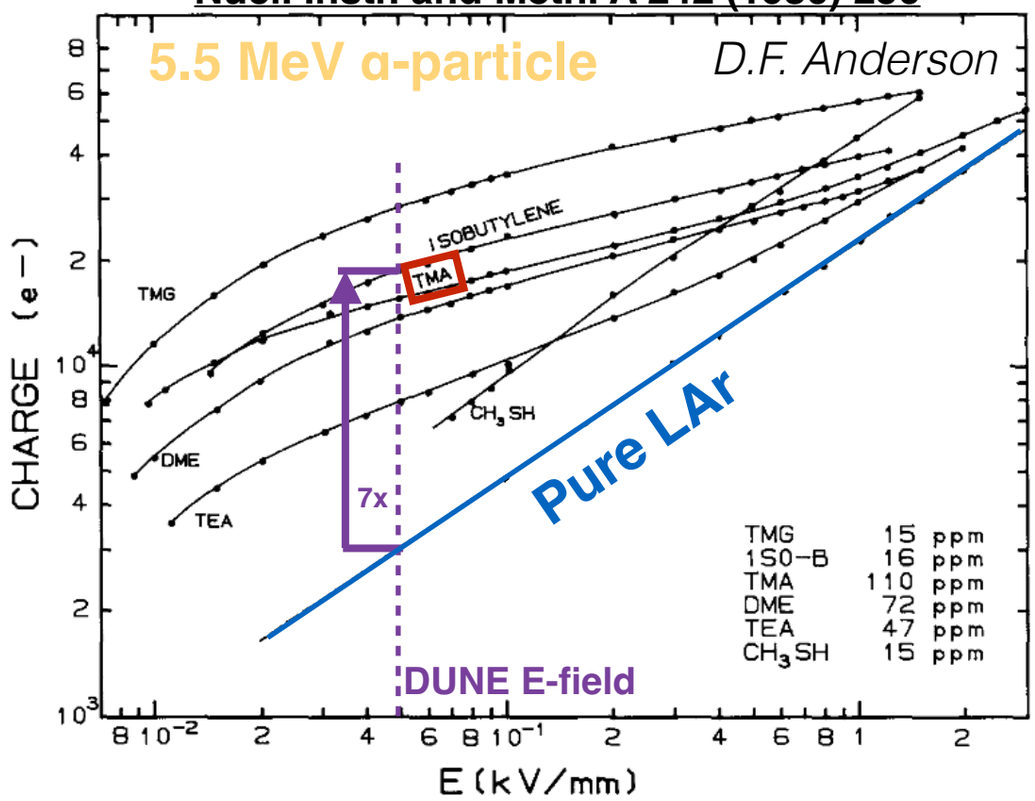
❓ **Lot's of productive and impactful R&D for the coming years.**

Existing Literature

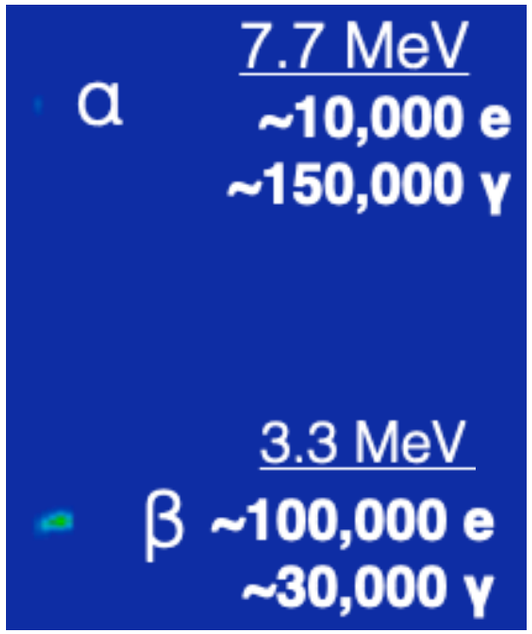
The most commonly used have ionization energies of 7-9 eV: Tetramethylgermane (**TMG**), $(CH_3)_4Ge$, Trimethylamine (**TMA**), $N(CH_3)_3$, Triethylamine (**TEA**), $N(CH_2CH_3)_3$

Small test stands explored a variety of chemicals and found an increase in charge for highly scintillating particles.

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



Simulated Event in Pure LAr



Courtesy of Ivan Lepetic

Energy Resolution

Nucl. Instrum. Methods. Phys. Res. B 355, 660 (1995).

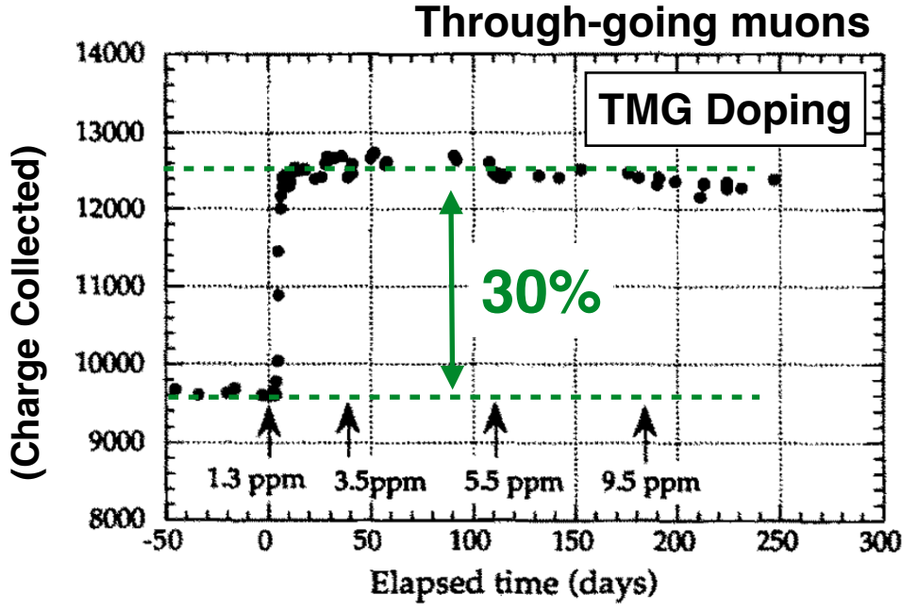
ICARUS Collaboration

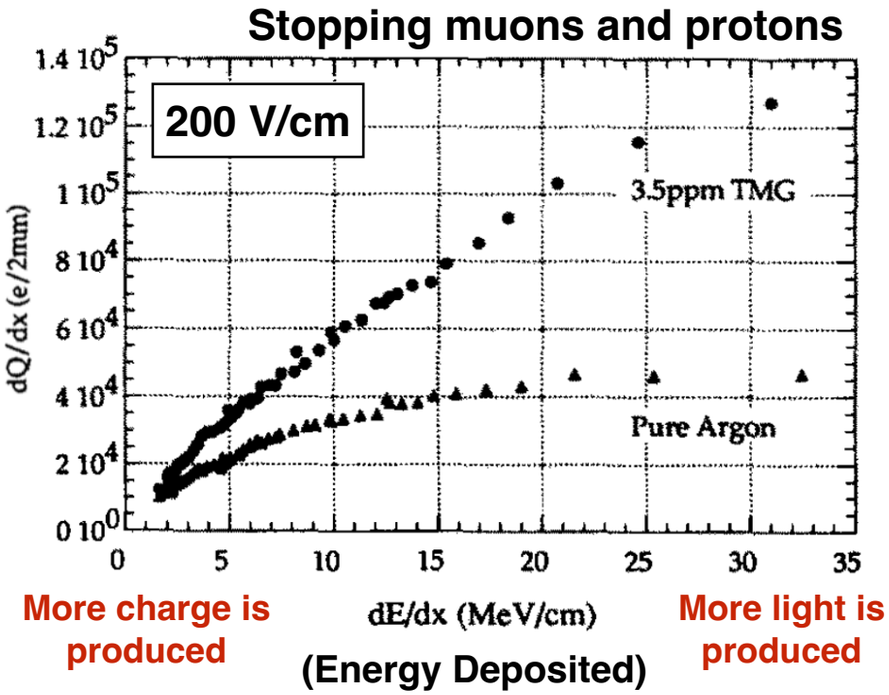
ICARUS doped a 3-ton prototype LArTPC with TMG to the few ppm level

- TMG was selected because it didn't react with their filter material and was easily purified

After introducing TMG observed:

- 30% increase in muon charge signals
- Stable operation for 250 days
- Found a more linear detector response for highly ionizing particles





R&D Questions

Extend demonstrations of dopant effects at energies below 5 MeV

Demonstrations of feasibility at DUNE-scale

Searches for & design of optimal doping scenarios for desired light-to-charge ratios

Studies of the interaction of dopants with:

- other dopants (i.e. Xe)
- filtration systems
- fluid dynamics in the cryostat

What is the impact on the DUNE core physics?

- Timing in a light-less DUNE
- Enhancement of low energy components of GeV events
- Improvements to other low energy signal sensitivities

Thought-provoking ideas for DUNE Phase-II

Photo-sensitive dopant R&D could change how we think of low energy physics with LArTPCs

A DUNE MoO with no light and ~1% energy resolution at 1 MeV.

DUNE phase-II data runs with interchangeable doping strategies.

Interdisciplinary design of ideal dopants for the optimal light/charge yields.

Your low-energy analysis idea enabled by the ability to alter LArTPC light-to-charge ratio