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

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Fermilab

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Fernanda Psihas
Joseph Zennamo

*** Paper in preparation*

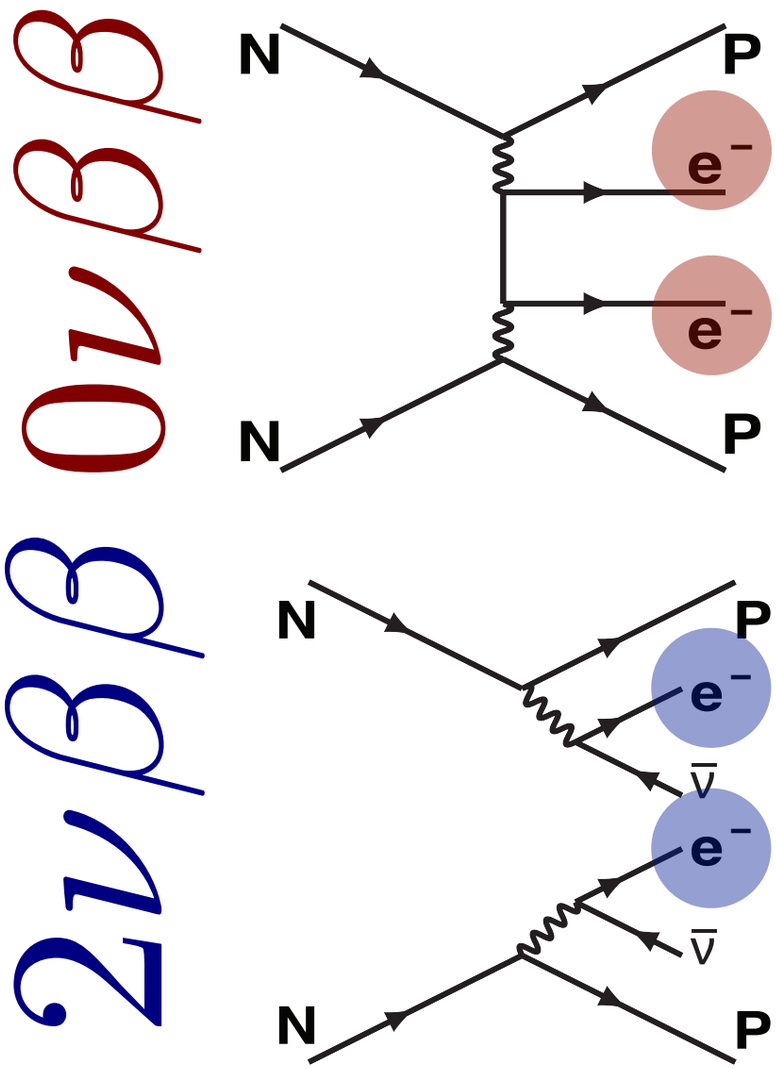
Takeaways

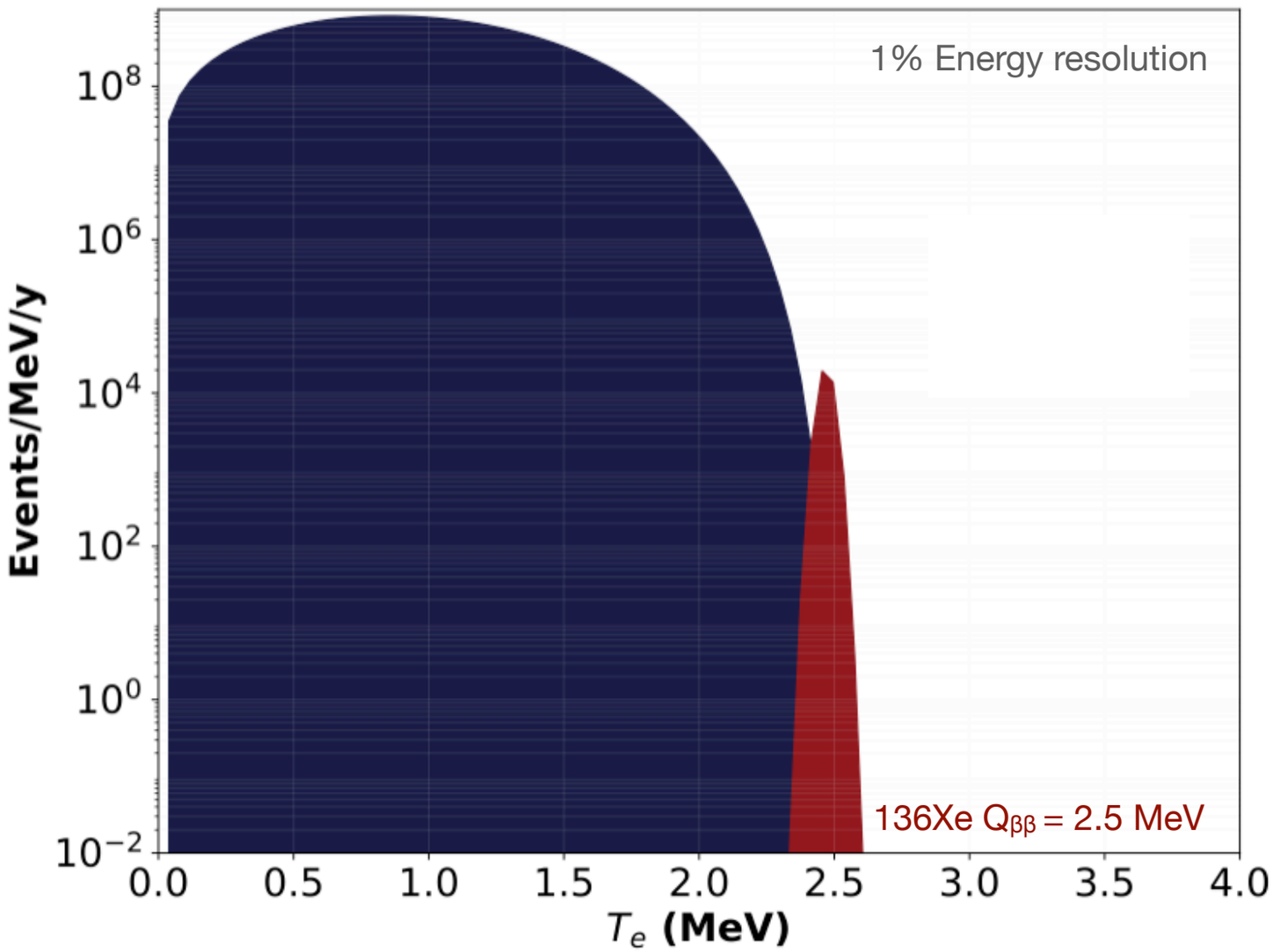
Liquid Argon doping can enhance the physics program of next generation LArTPC in a variety of ways. We explore this and other modifications that would enhance physics reach of LArTPCs and open R&D opportunities.

Doped LArTPCs concept expands the LArTPC physics capabilities to search for neutrino less double beta decay.

This concept opens **several R&D questions** with applications to the next generation physics program and future detector technologies.

Measurement & energy resolution

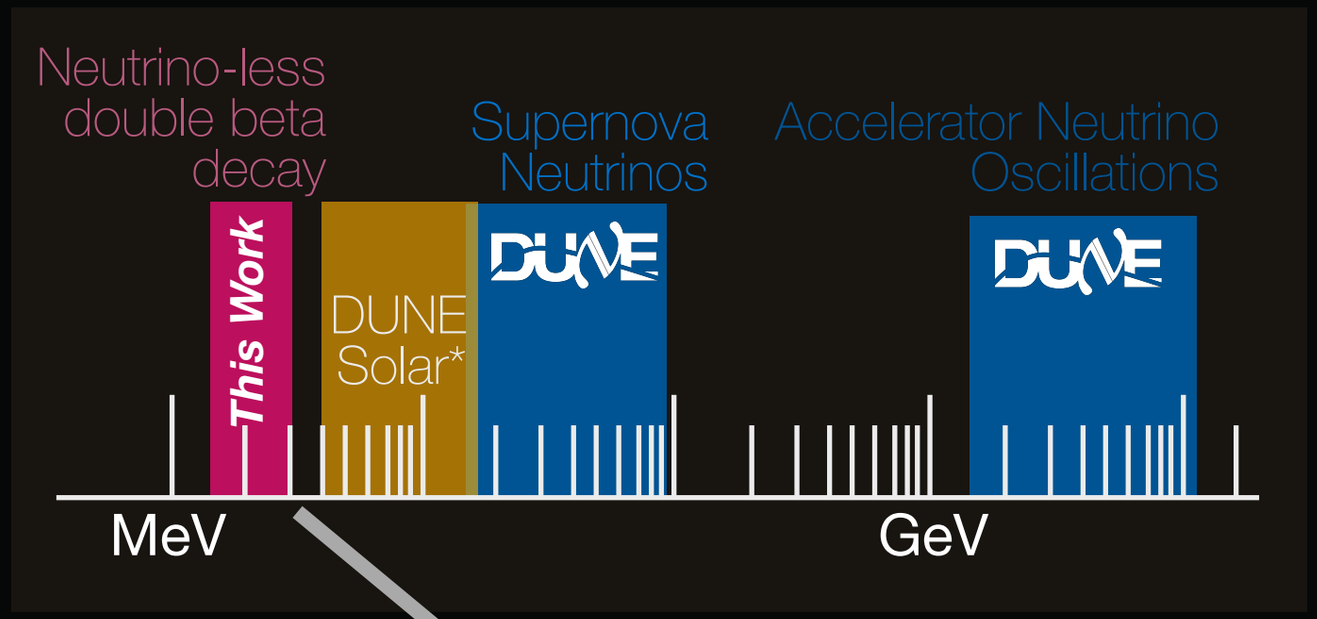




Signal is 2 electrons with energy = $Q_{\beta\beta}$

LArTPC Energy Range

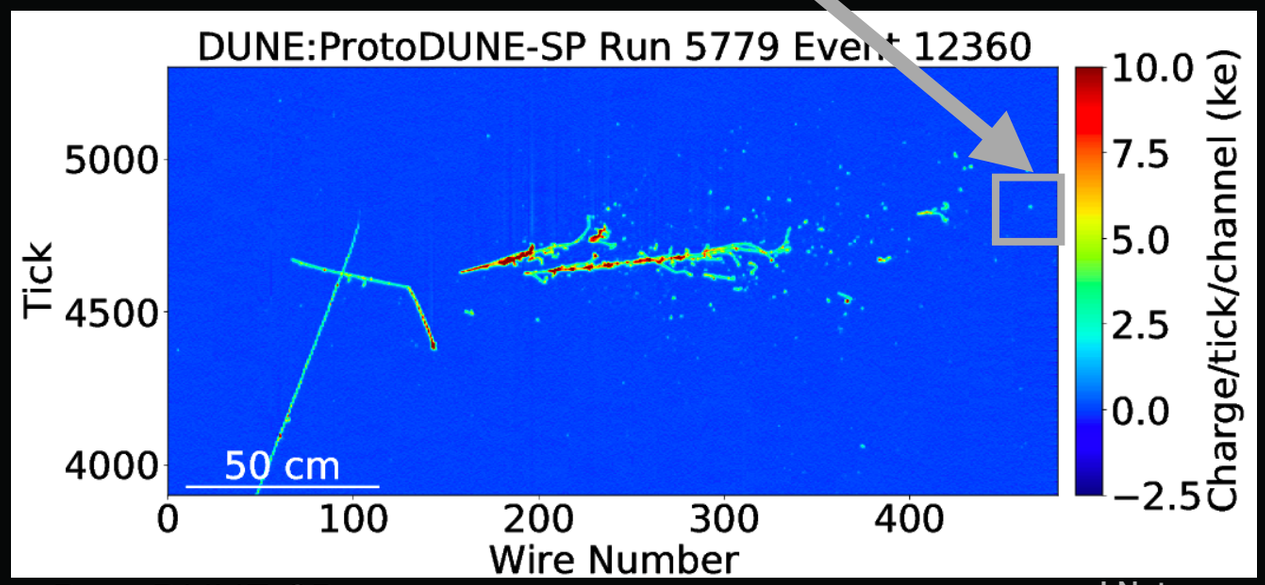
DUNE Solar* Capozzi, et. al., Phys.Rev.Lett. 123 (2019)



Much lower energies than the nominal LArTPC physics program.

Compatible with possibilities to expand DUNE's reach into the low energy regime.

How big would a 0νββ signal be on DUNE?



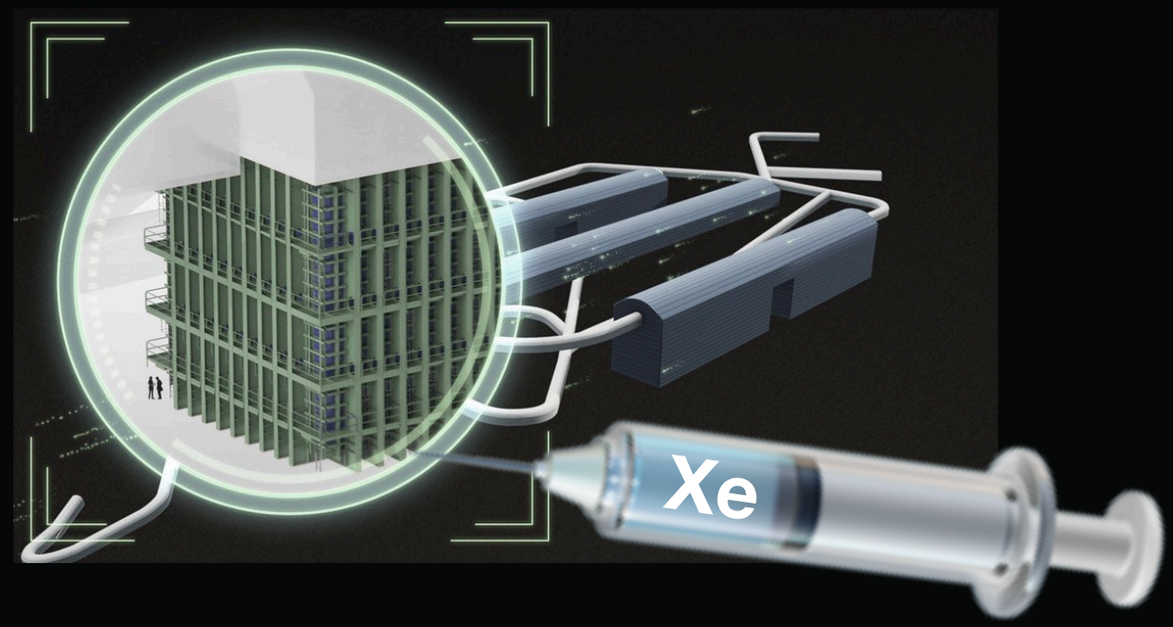
ProtoDUNE-SP ***JINST 15 (2020) P12004***

! Not a simulation of 0νββ

Xe-Doped LAr Goals

To enhance LArTPC reach for low energy physics.

To enable neutrino-less double-beta decay searches in LArTPC



Xenon-Doped Liquid Argon TPCs as a Neutrinoless Double Beta Decay Platform. A. Mastbaum, F. Psihas, J. Zennamo. (soon on the arxiv)

Basic Concept:

Dope LAr with ^{136}Xe, a 0νββ candidate isotope

Add photo-sensitive dopants to improve energy resolution

Xe-Doped LAr Goals

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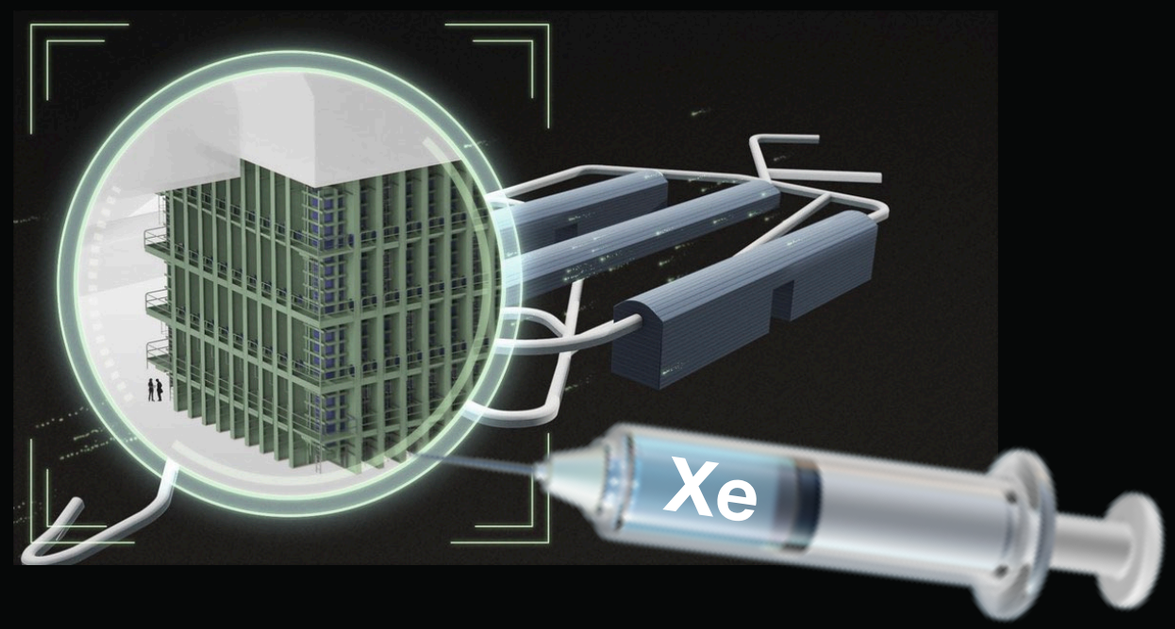


Mitigate low E Backgrounds

Resolve a 2.5MeV Signal

Dope with 100s of tons of 136Xe

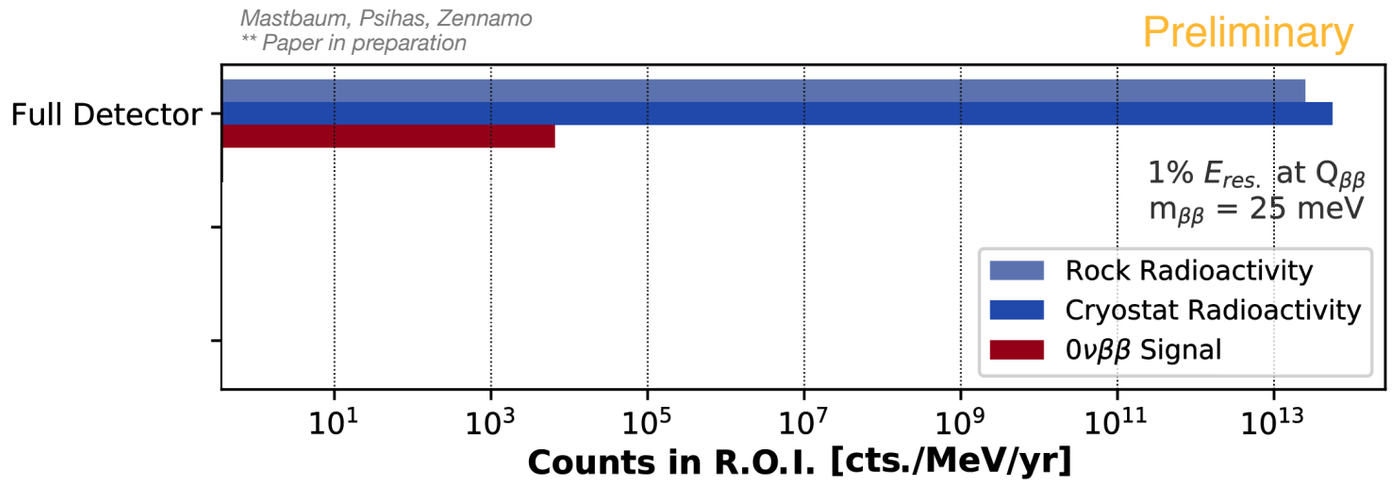
WHAT WOULD NEED TO BE MODIFIED?

WHAT R&D QUESTIONS DOES THIS OPEN?

BACKGROUNDS THE KILLERS:

*Backgrounds simulated using RAT-PAC

1. Radioactivity
2. 42K From the 42Ar decay
3. Environmental Neutrons



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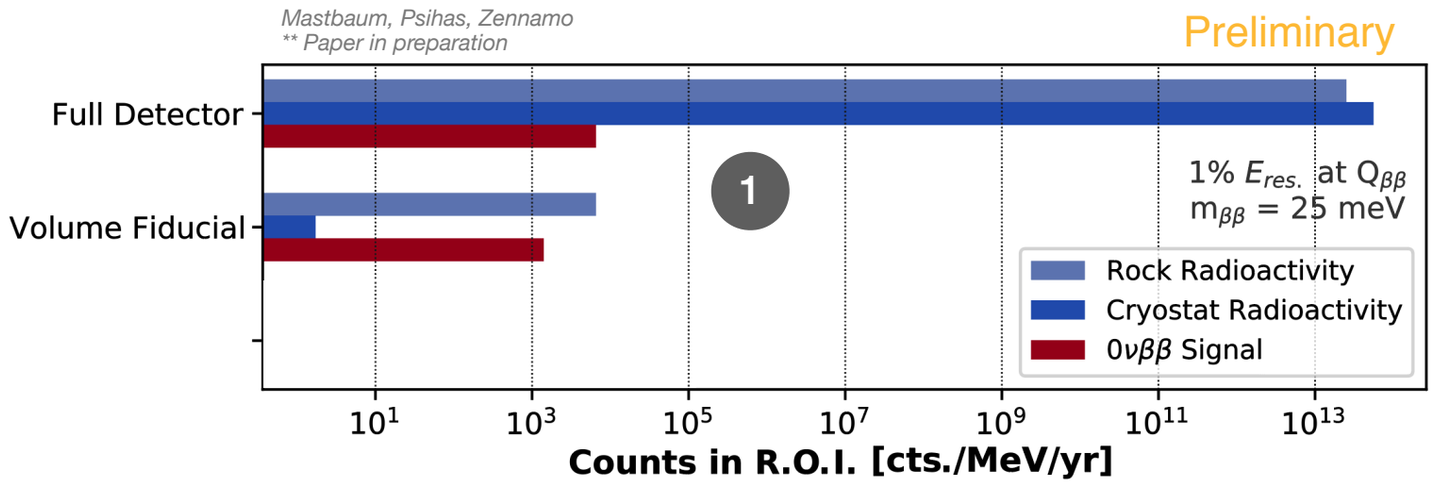

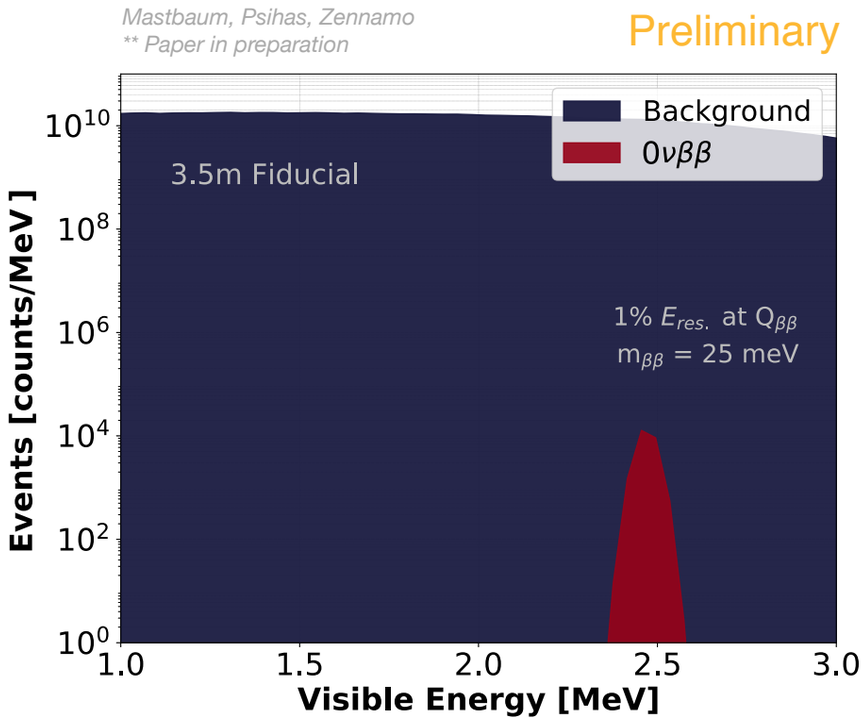

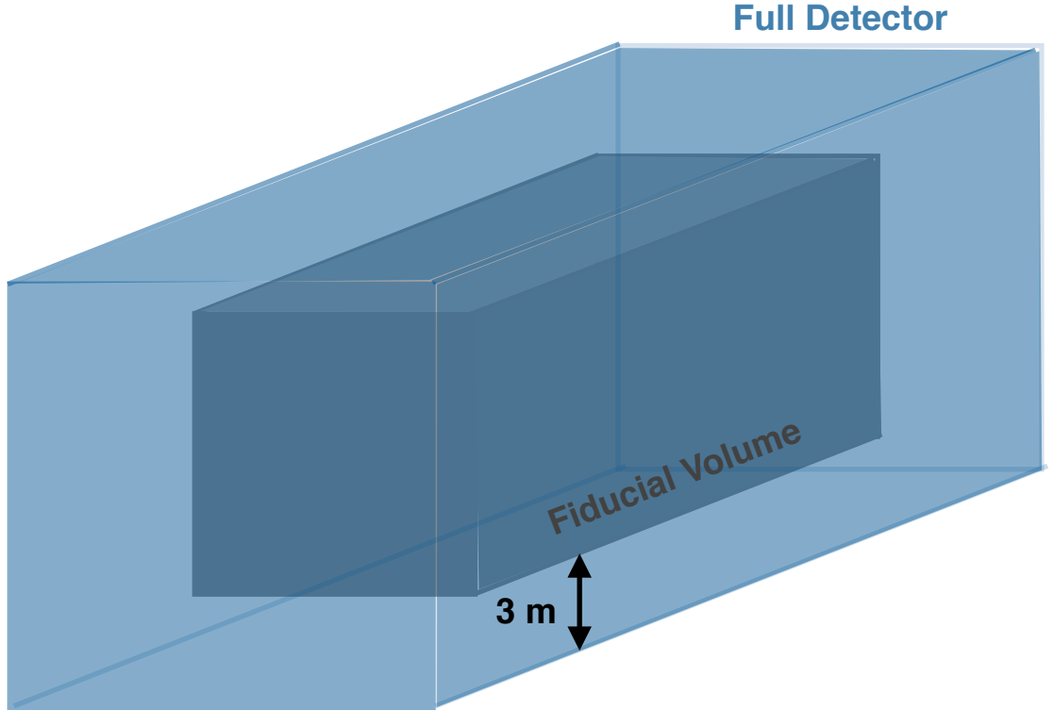

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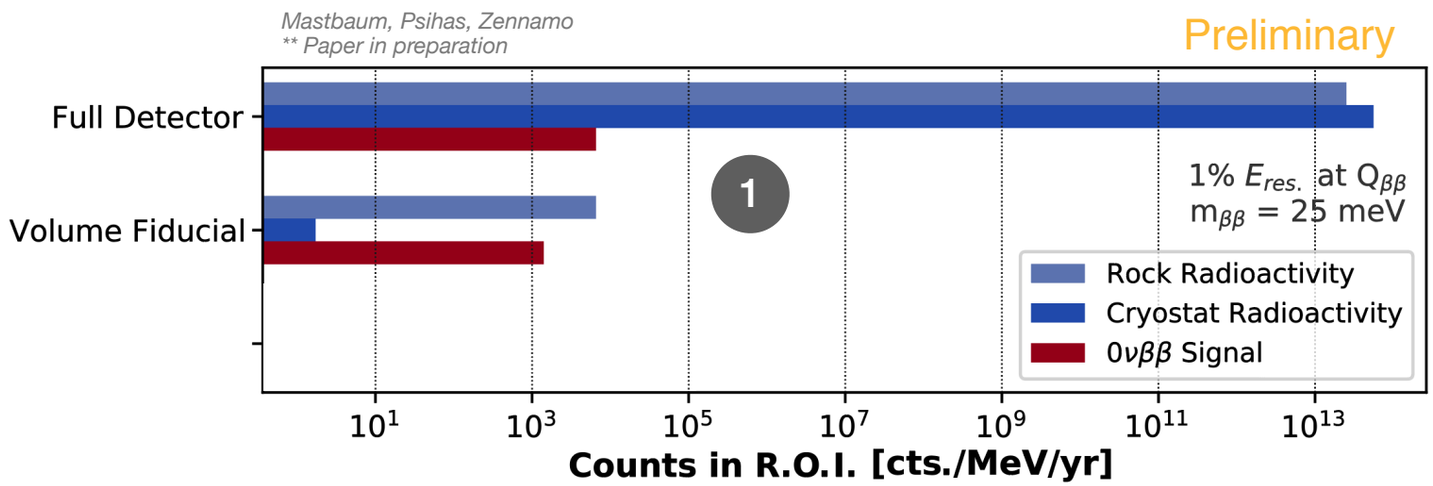

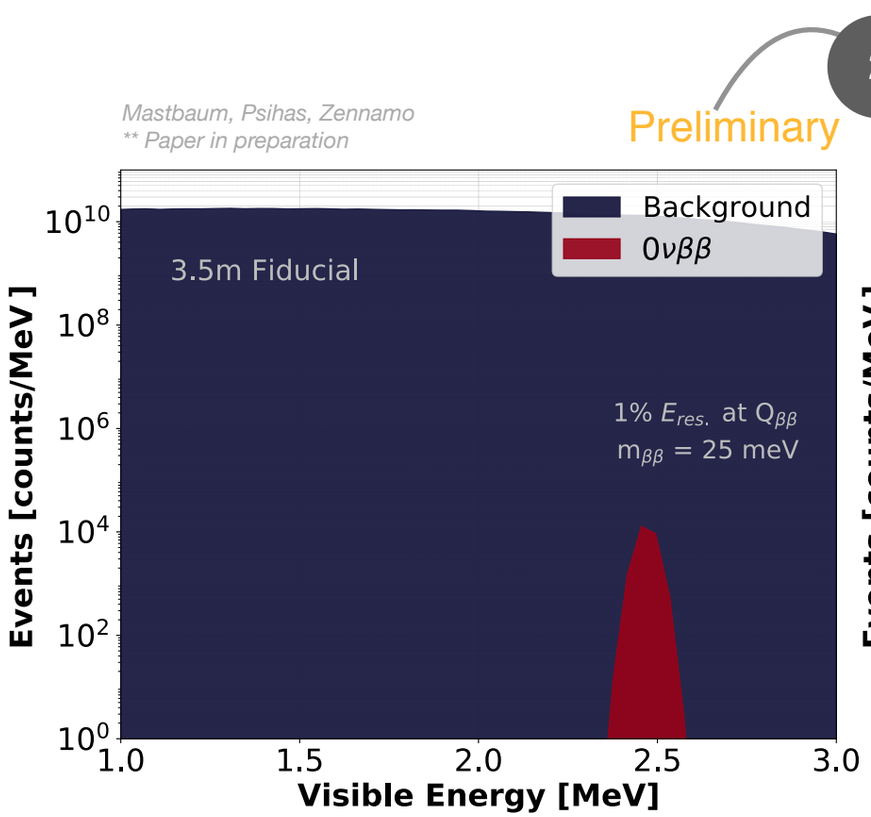

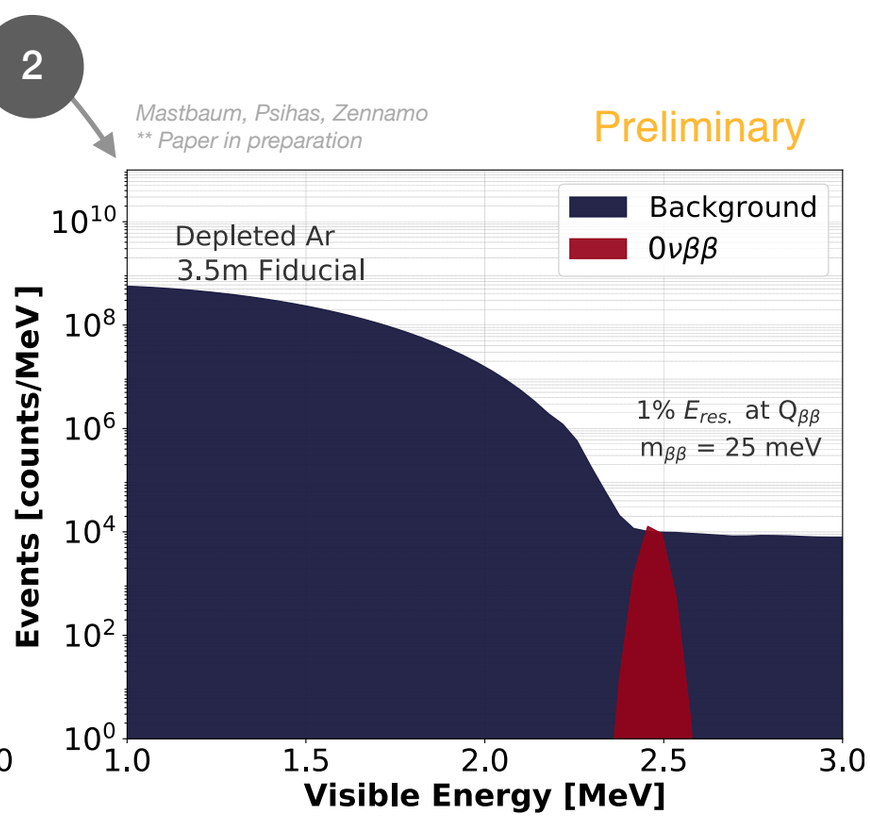

WHAT WOULD NEED TO BE MODIFIED?

Low-radioactivity argon*

*similar to what could enable dark matter searches
E. Church et. al., *JINST* 15 (2020) 09, P09026

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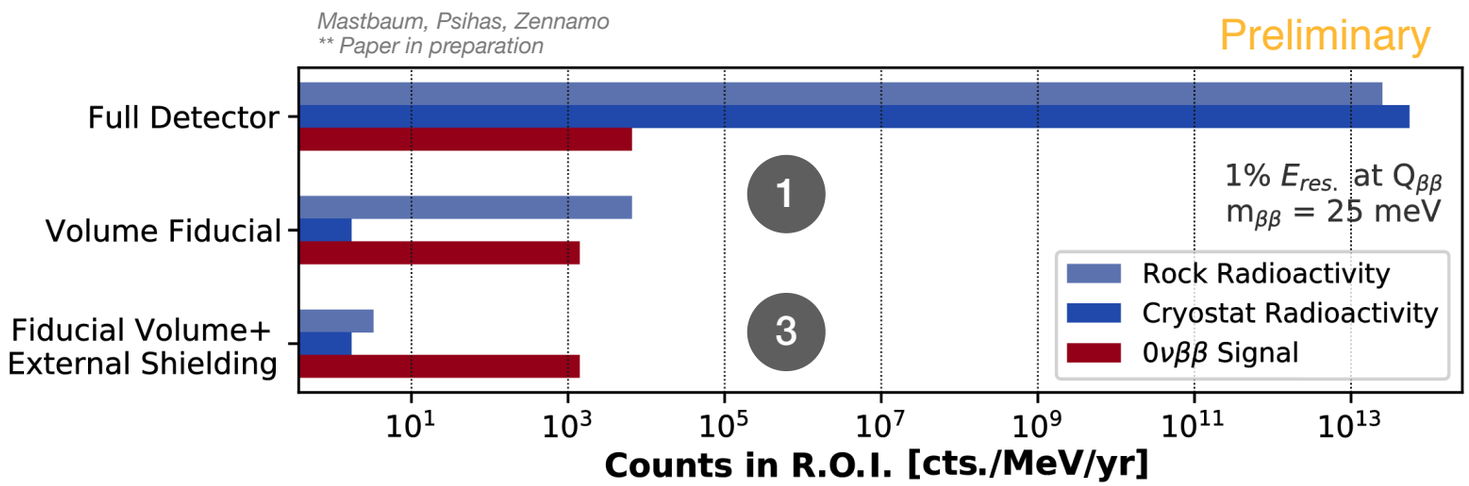

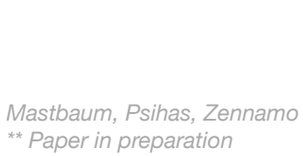

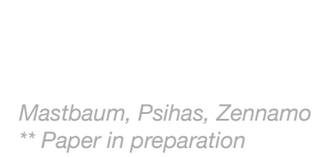

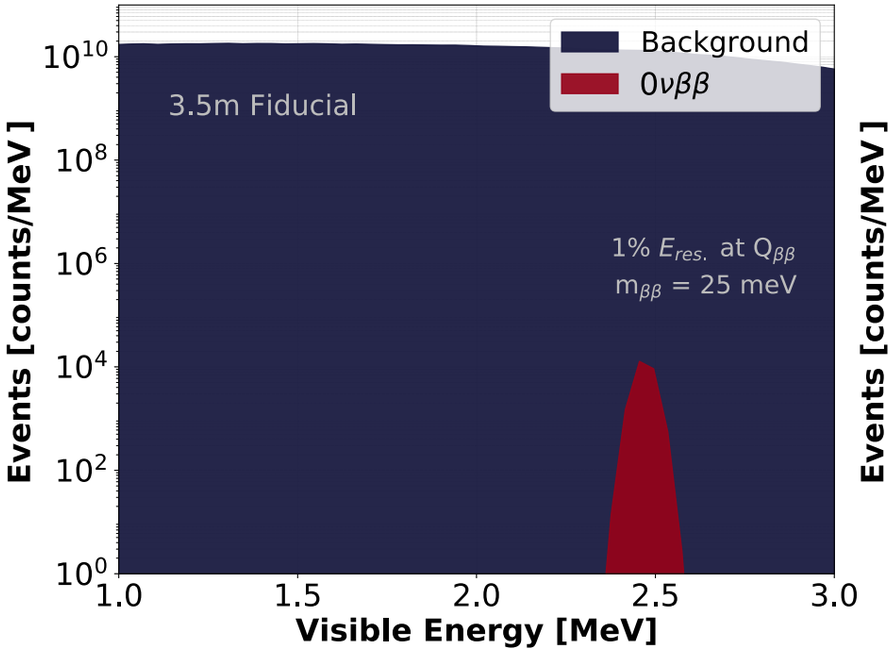

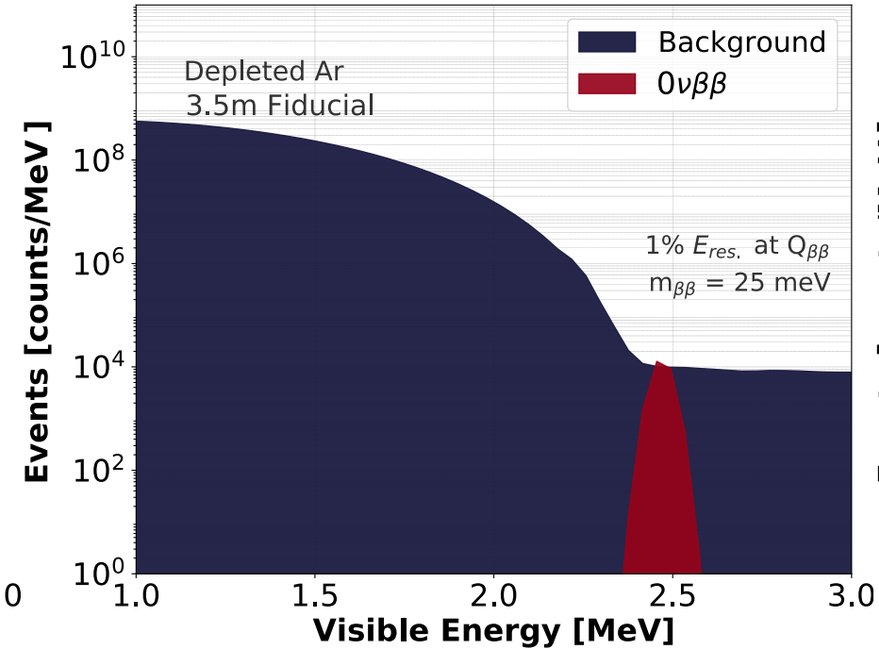

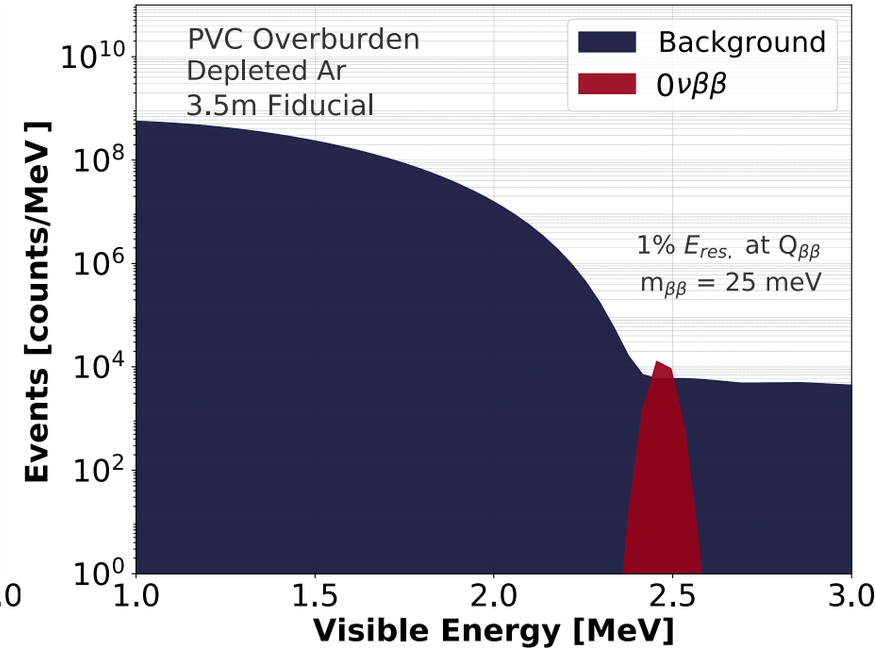

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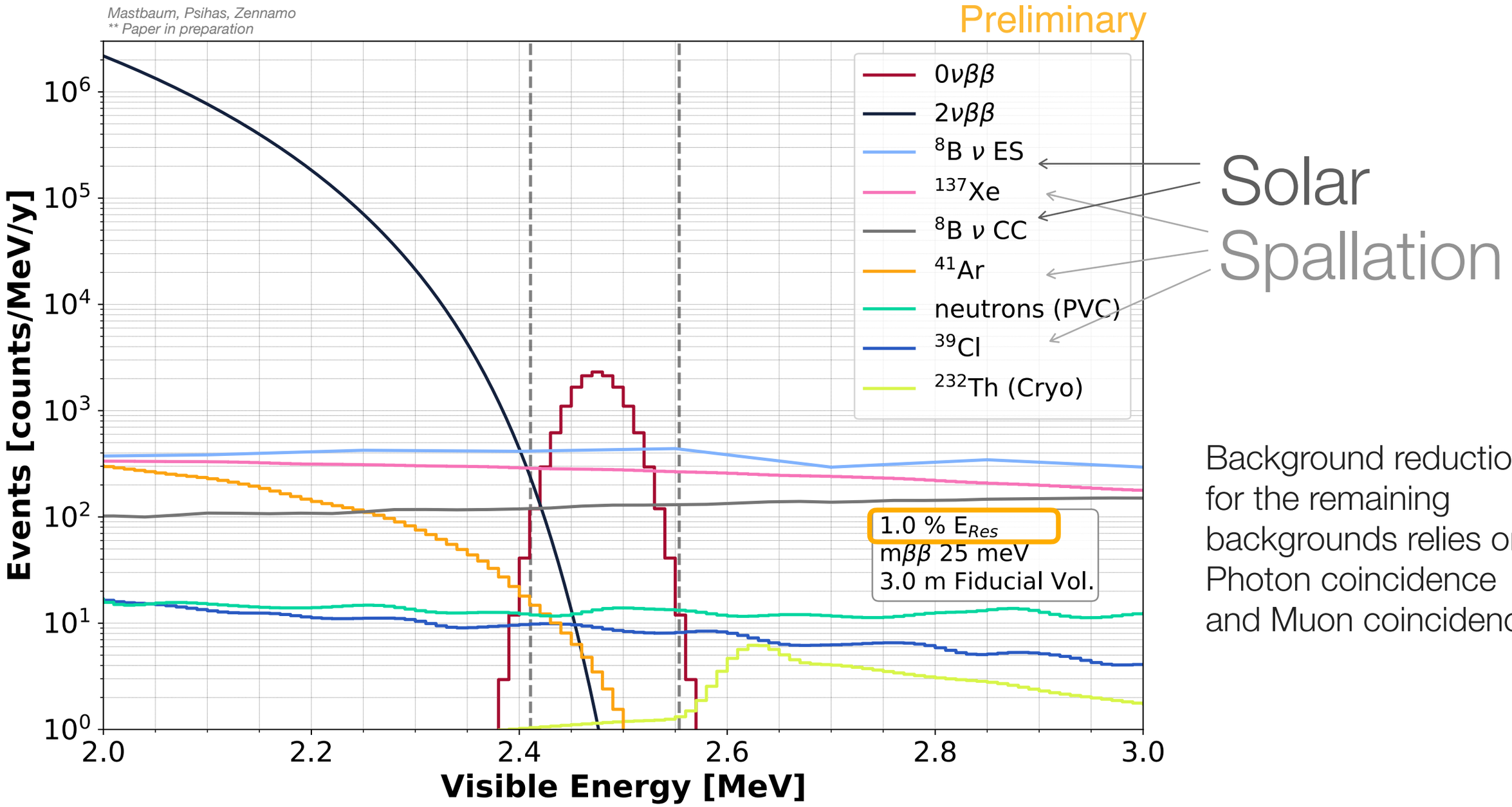
E. Church et. al., *JINST* 15 (2020) 09, P09026

Shielding 1m water equiv.+

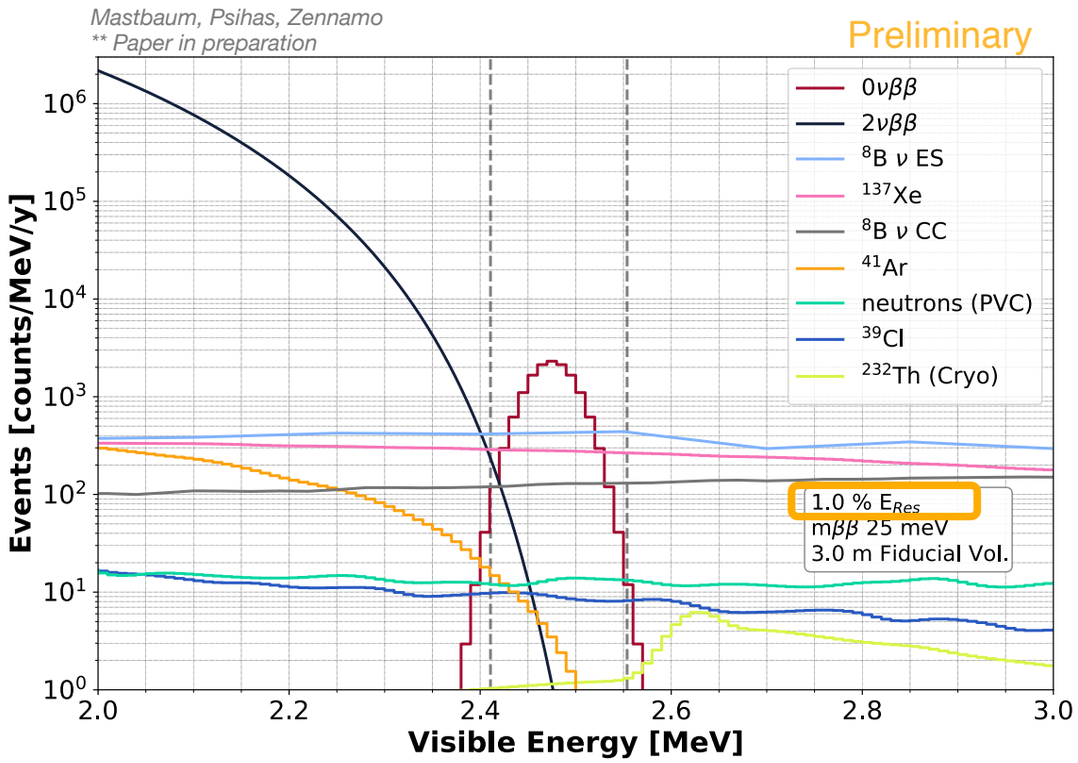
+similar for what has been proposed for solar neutrinos
Capozzi, et. al., Phys.Rev.Lett. 123 (2019)

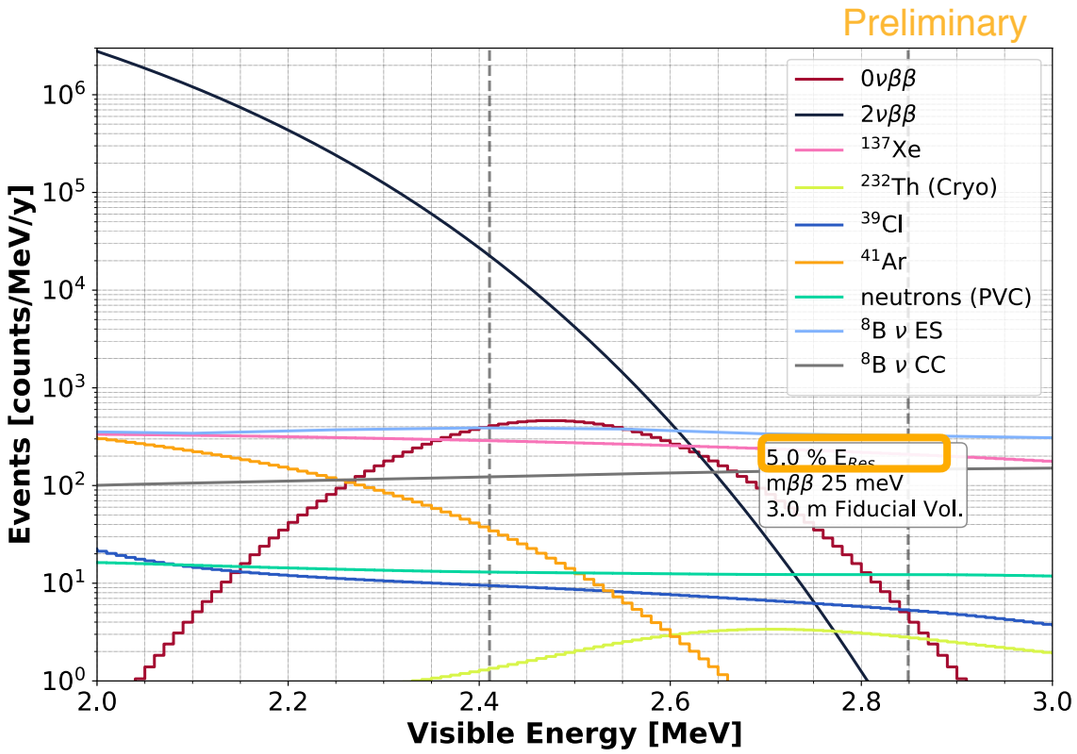
BACKGROUNDS HONORABLE MENTIONS

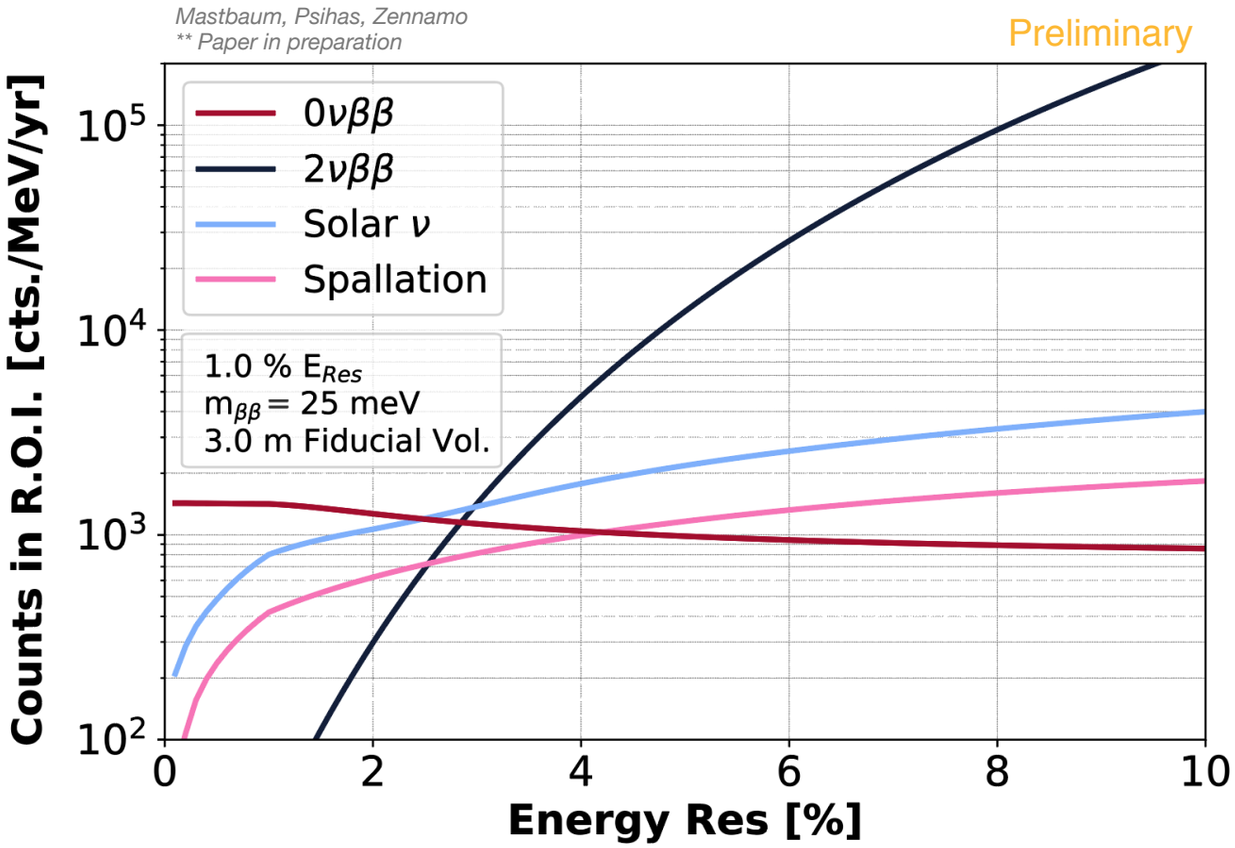


Background reduction for the remaining backgrounds relies on Photon coincidence and Muon coincidence

BACKGROUNDS AND ENERGY RESOLUTION







Energy resolution is a crucial component of this concept. Eres < 5% is essential to reduce the 2vββ background.

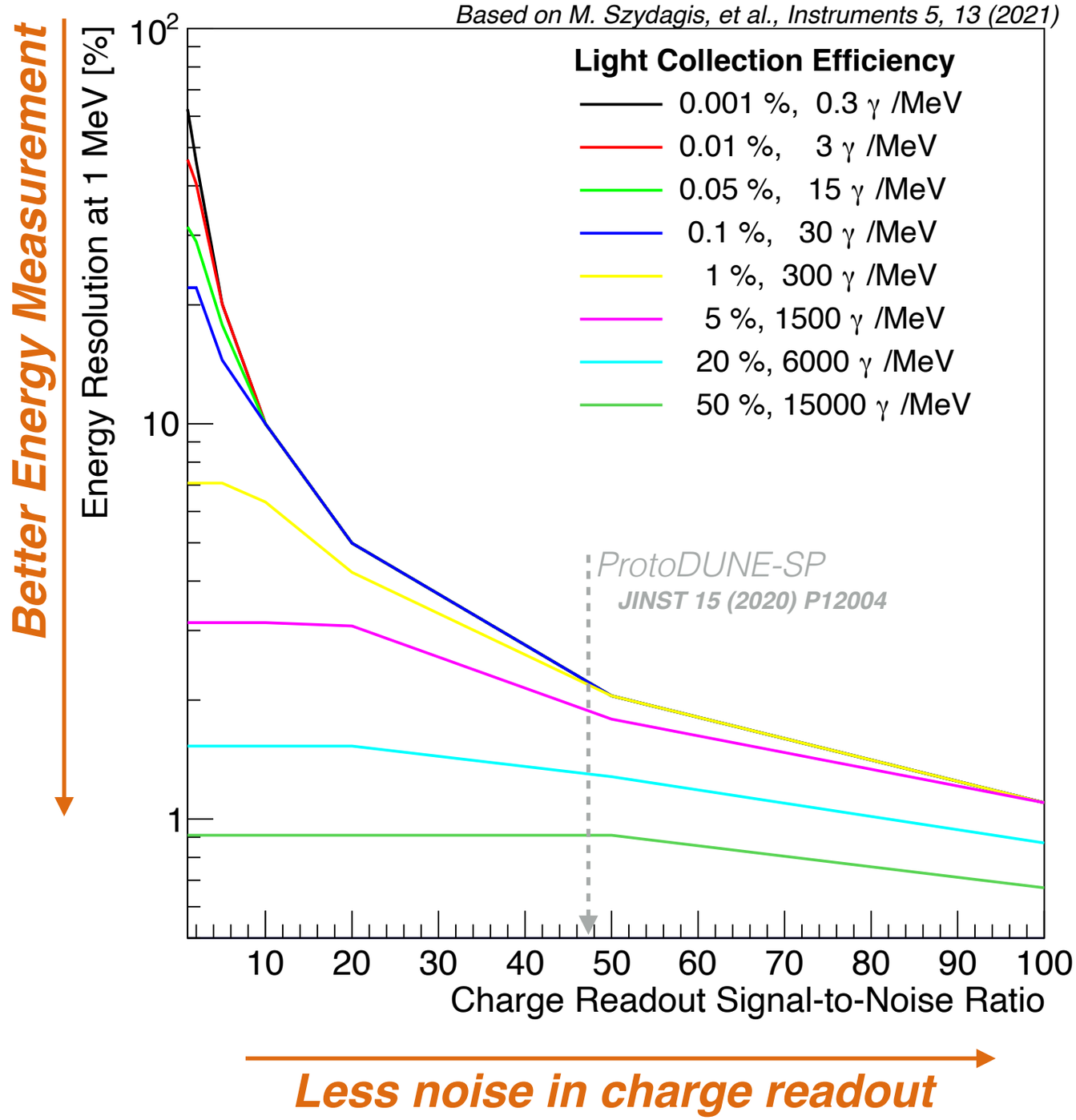
How much light do we need?

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

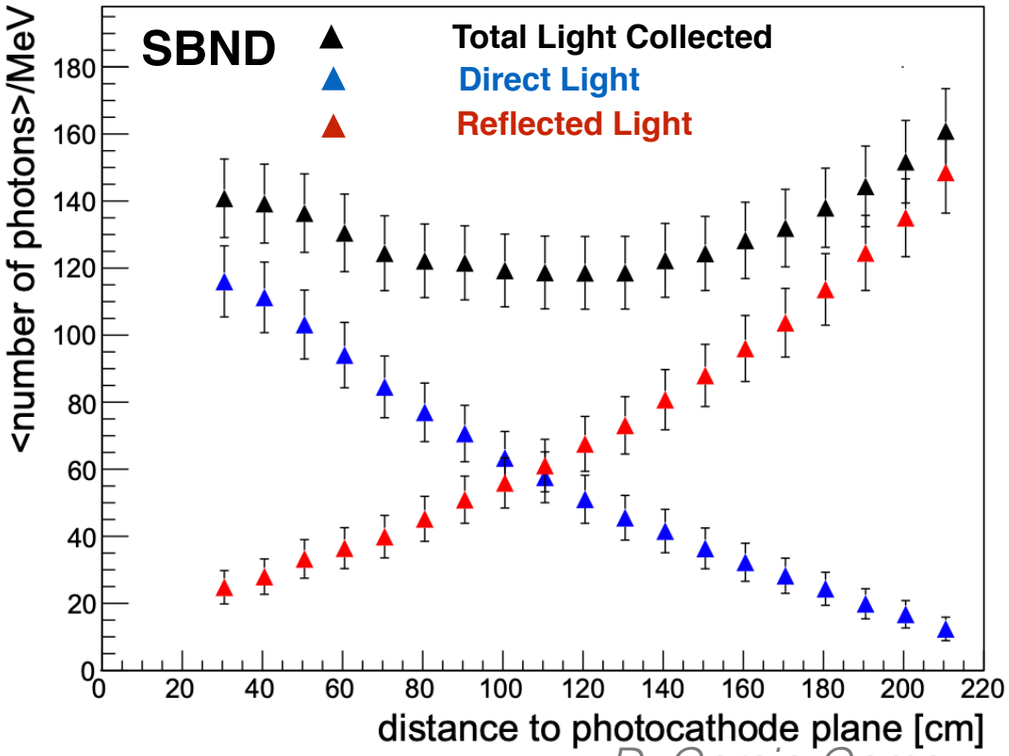
EXO-200 Detector
40 cm by 18 cm

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



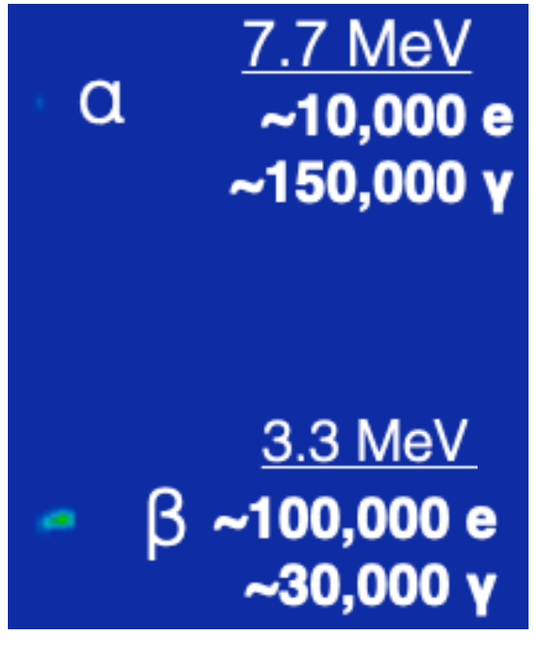
D. Garcia-Gamez
Journal of Physics: Conf. Series 888 (2017) 012094

Photosensitive Dopants

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

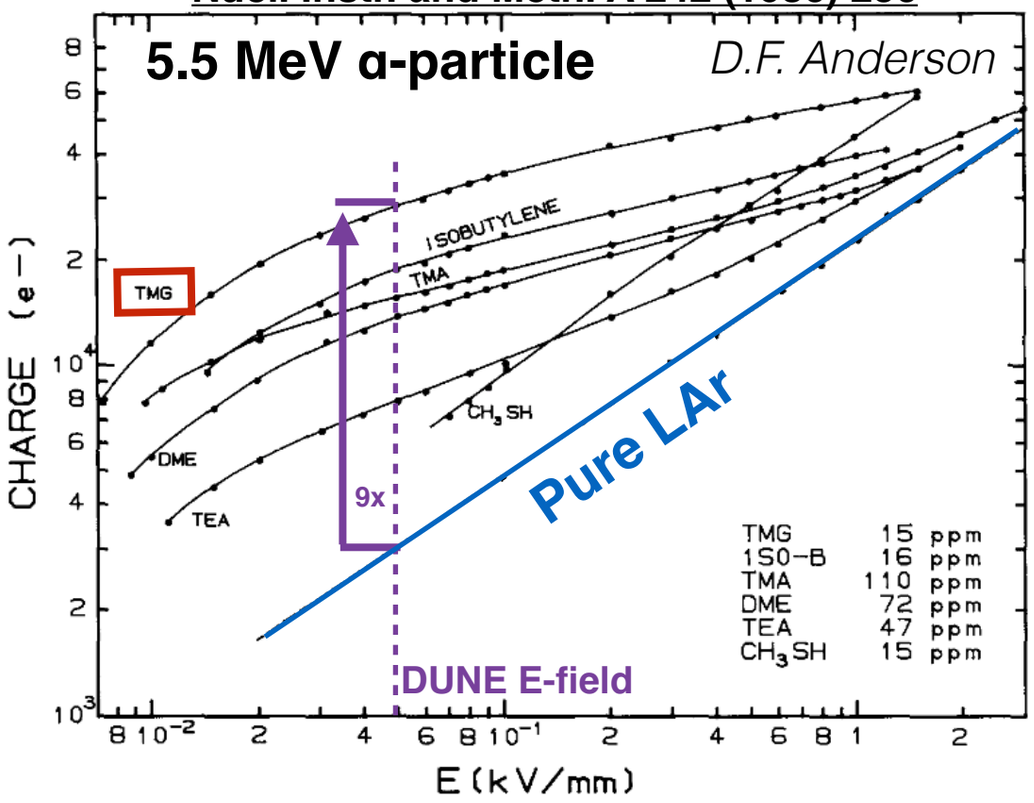
Small test stands explored a variety of chemicals and found an increase in charge for highly scintillating particles **Equivalent to collecting 40% of the light produced.**
Implies 10,000 photons/MeV for MeV-scale electron signals

Simulated Event in Pure LAr

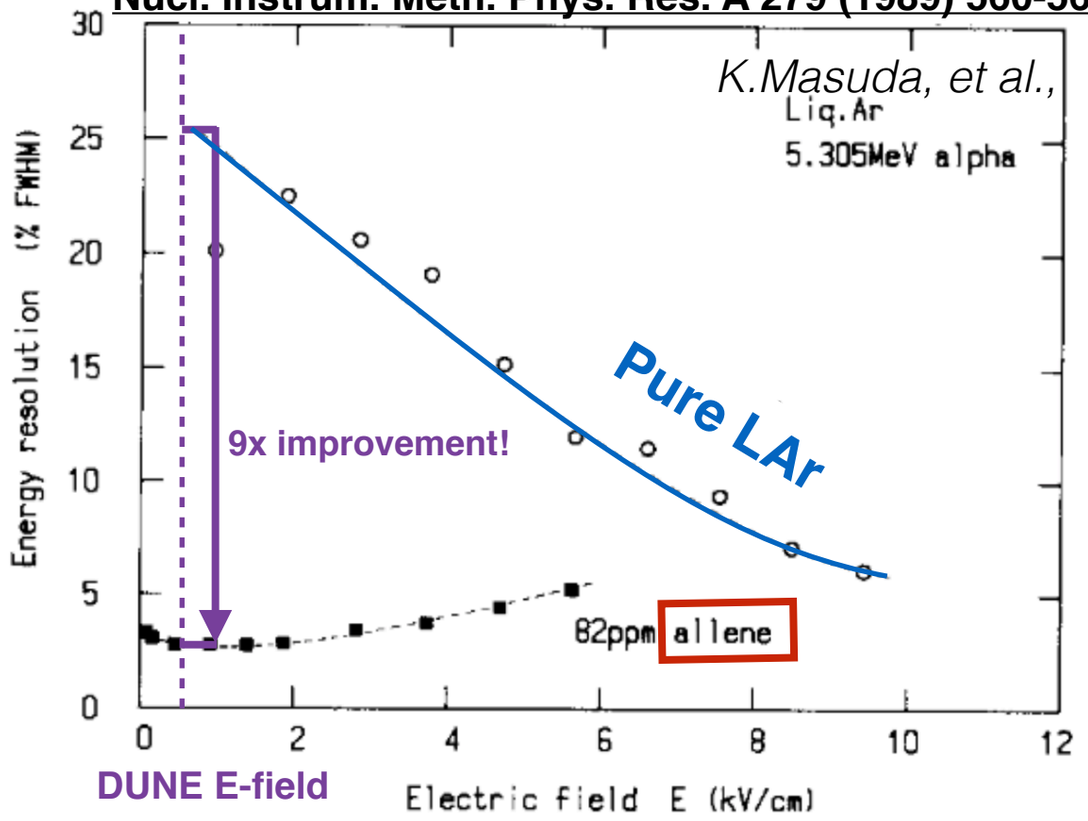


Courtesy of Ivan Lepetic

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



Nucl. Instrum. Meth. Phys. Res. A 279 (1989) 560-566



Ongoing R&D

I. Lepetic, A. Mastbaum
(Rutgers University)

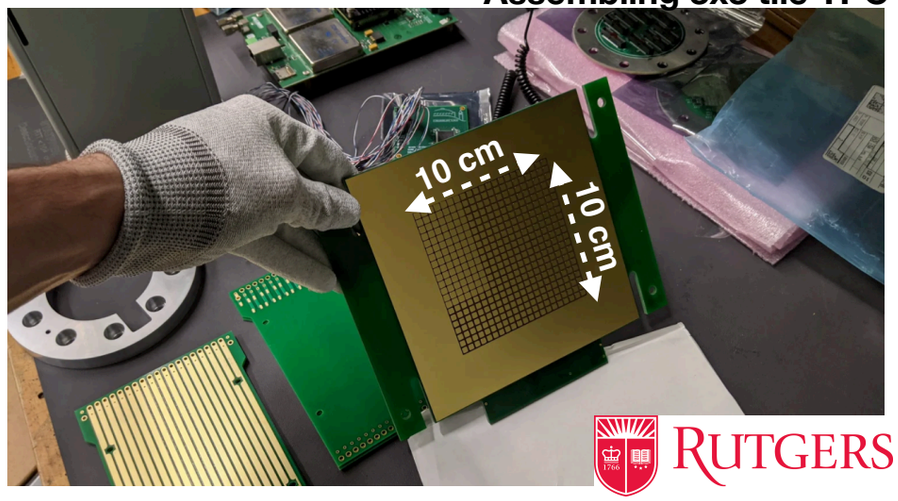
F. Psihas, J. Zennamo
(Fermilab)

*Work supported by an FNAL New Initiatives Grant and the FNAL Neutrino Division

Use radioactive sources to explore improvements with dopants on two fronts:

Small-scale: Use a small pixelated LArTPC with γ-sources to measure energy in different doping scenarios

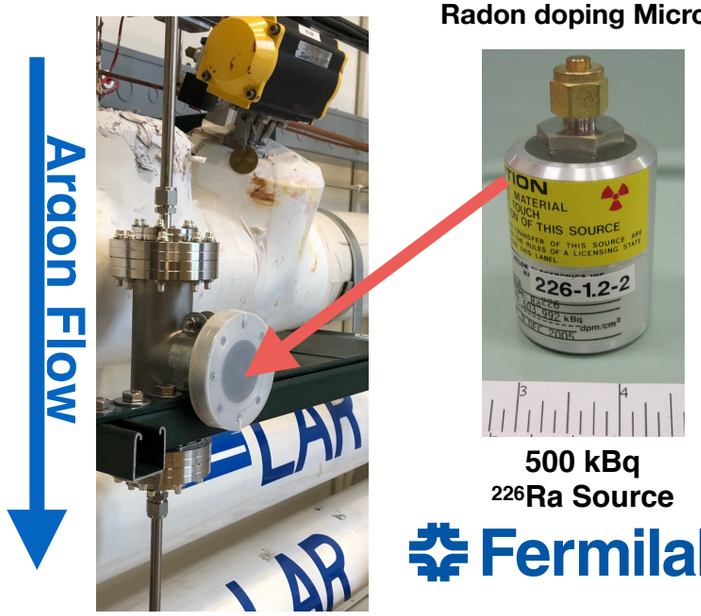
Status: Assembling 3x3 tile TPC



Large-scale: Adding radon source to MicroBooNE

Status: Data taking started this summer!

Radon doping MicroBooNE



Related Snowmass Whitepapers

IF08: Executive Summary on Enhancing and combining existing modalities to increase signal-to-noise and recon fidelity: Increasing Light Collection"

IF08: Executive Summary on Challenges in scaling technologies: Sourcing/purifying noble gasses

NF10: Neutrino Detectors White Paper

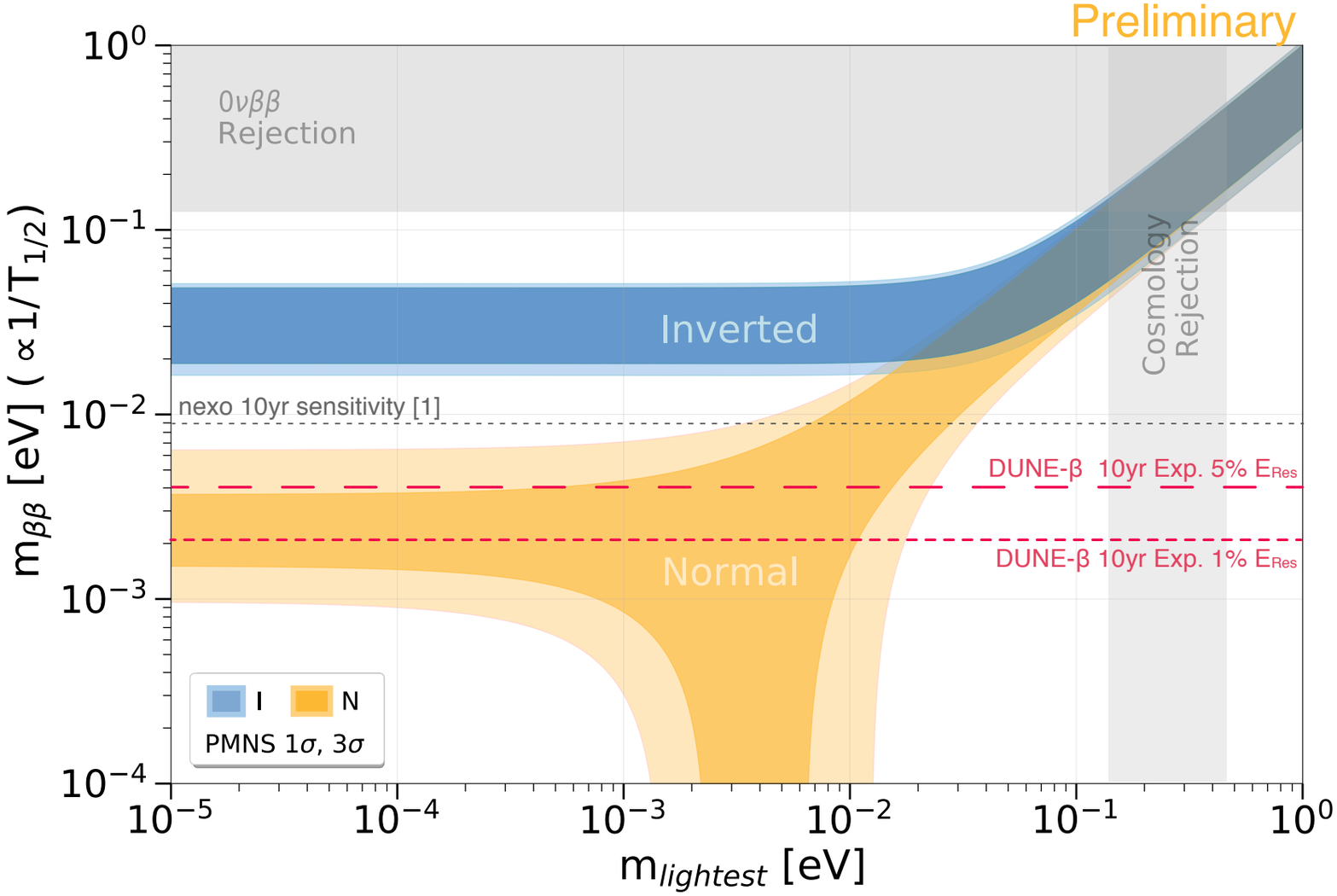
Low Energy Physics in Liquid Argon (LEPLAr)

SUMMARY

This doped LArTPC concept could extend the physics program of future LArTPCs with sensitivities to 0νββ decay as low as mββ ~ 2meV at the DUNE scale.

This concept employs Xe-doping, photo-sensitive dopants, depleted argon, and an external overburden compatible with other low energy physics concepts for LArTPCs.

Coming to the arxiv very soon



CAPABILITIES OF THIS DOPED LARTPC CONCEPT

Higher charge-to-light ratio

<5% energy resolution at the ~MeV scale

Lower energy thresholds

Higher efficiency for low energy nuclear recoils

What other low energy physics can we enable with this concept?