Xenon Doping of Liquid Argon

Denver Whittington (on behalf of the xenon doping working group)

SP Photon Detection Review

Nov. 12, 2018

Syracuse University

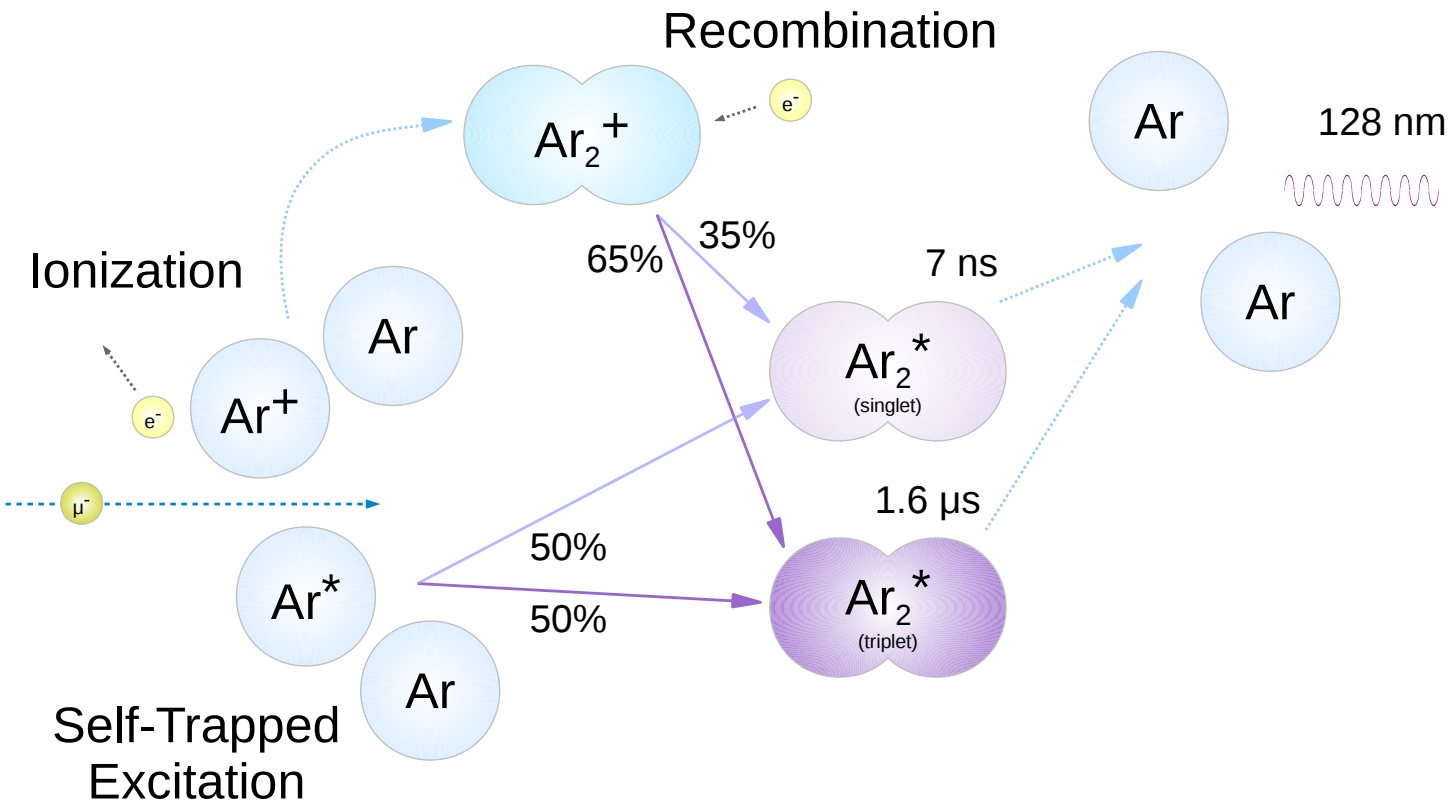
DUNE

Content

- Effects of xenon dopant
- Physics Benefits
  - Timing, wavelength structure, uniformity, design simplification
- Cryogenics
  - Injecting, maintaining, monitoring, cost
- TPC Interaction
  - Charge attenuation, HV stability

Liquid Argon Scintillation Mechansim

- Excitation of short-lived argon molecular states.



Effects of Xenon Dopant

- Collisional energy transfer from argon excimer to xenon excimer

$$\mathrm{Ar}_2^* + \mathrm{Xe} \rightarrow \mathrm{ArXe}^* + \mathrm{Ar},$$

$$\mathrm{ArXe}^* + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^* + \mathrm{Ar},$$

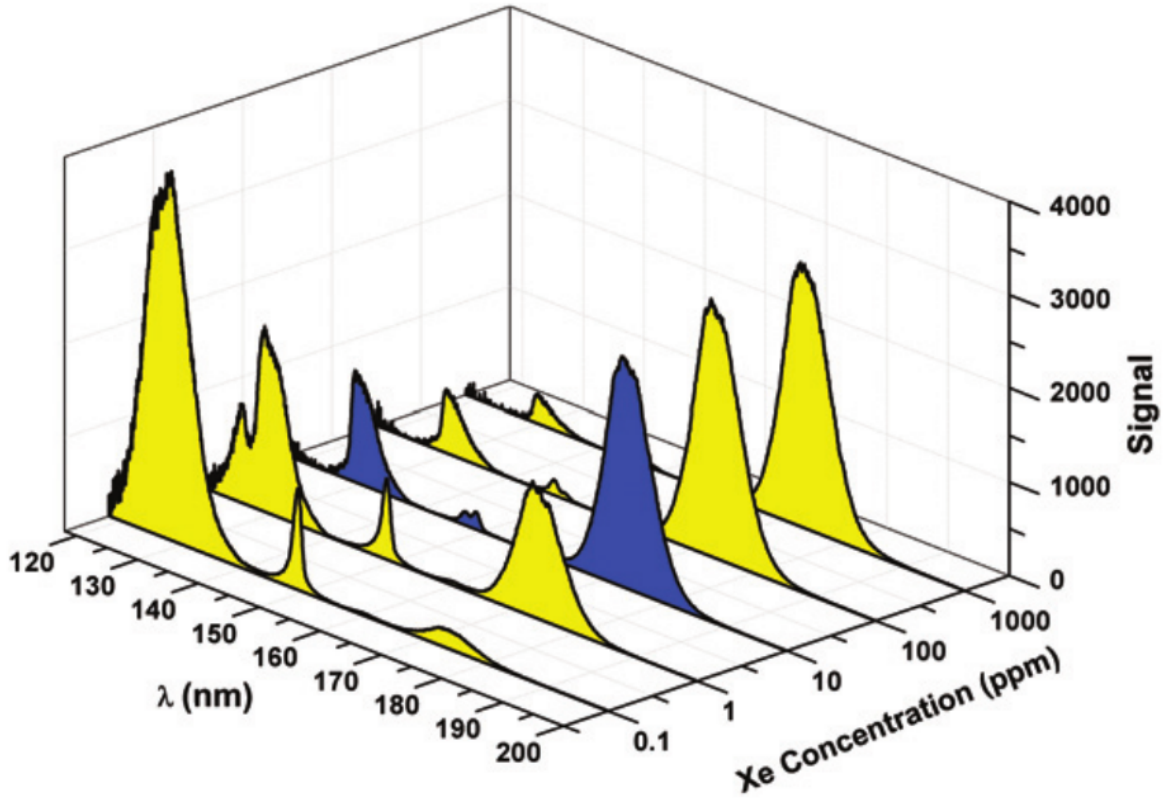
$$\mathrm{Xe}_2^* \rightarrow 2\mathrm{Xe} + \gamma_{174}$$

- Happens on a faster timescale than Ar triplet lifetime.
  - Triggers triplet emission to produce a faster signal
  - Converts scintillation light to 174 nm.

Effects of Xenon Dopant

- Recent findings

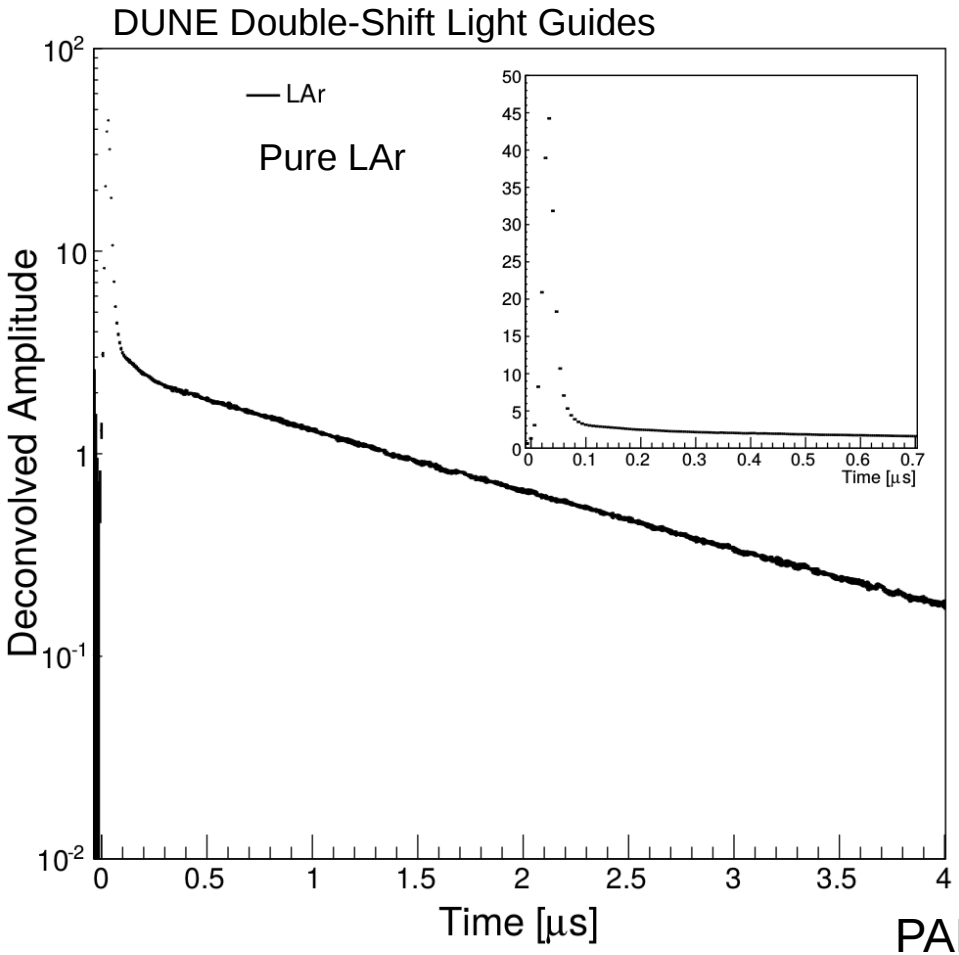
- Increasing shift of scintillation to 174 nm with added xenon dopant



TU Munich 2014-2015

Effects of Xenon Dopant

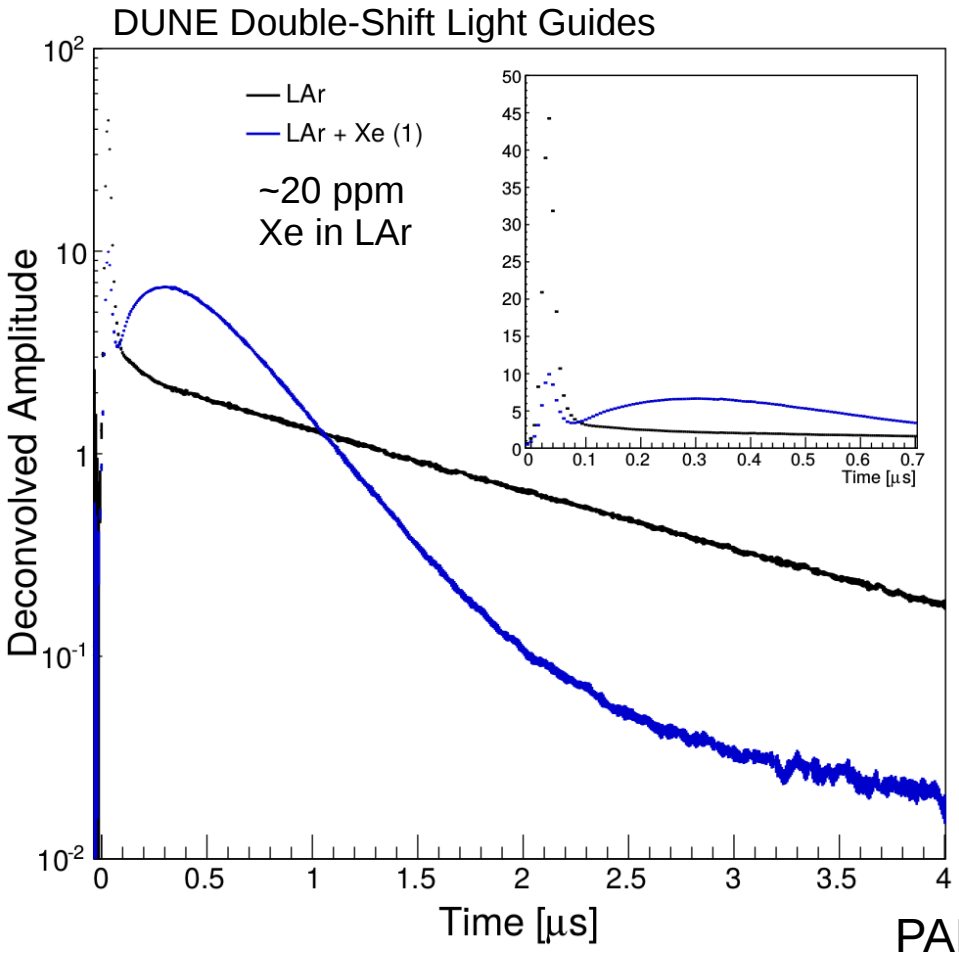
- Recent findings



PAB (Blanche) 2016

Effects of Xenon Dopant

- Recent findings



PAB (Blanche) 2016

Effects of Xenon Dopant

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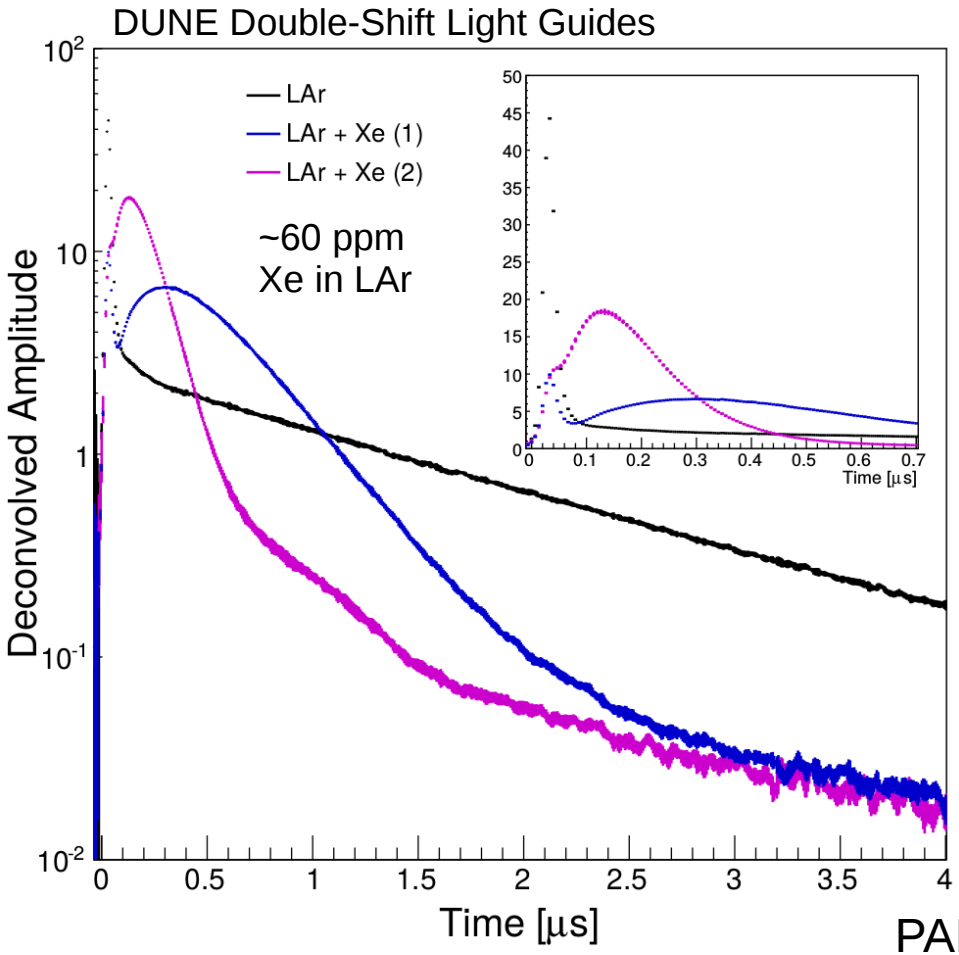
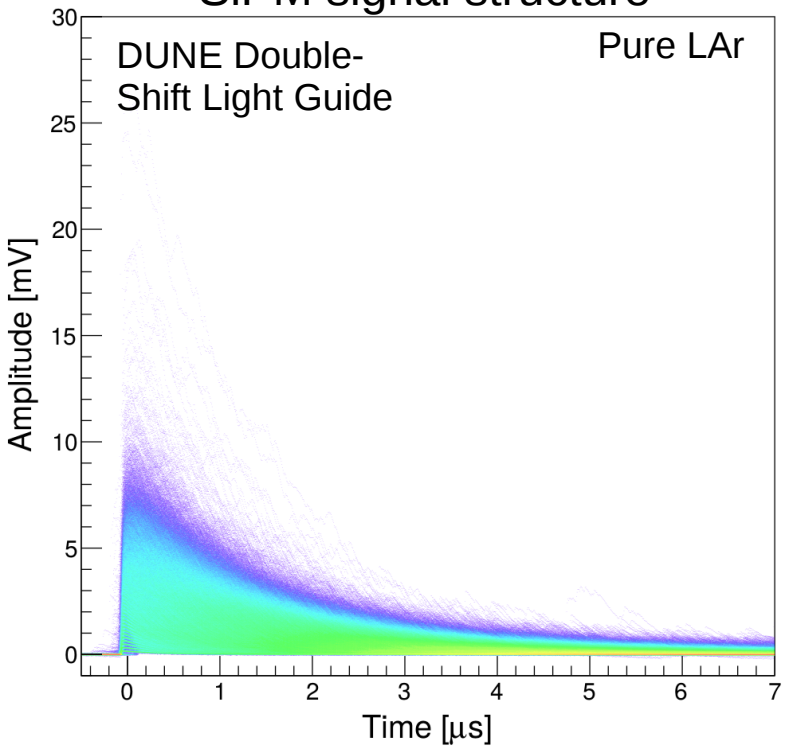


PAB (Blanche) 2016

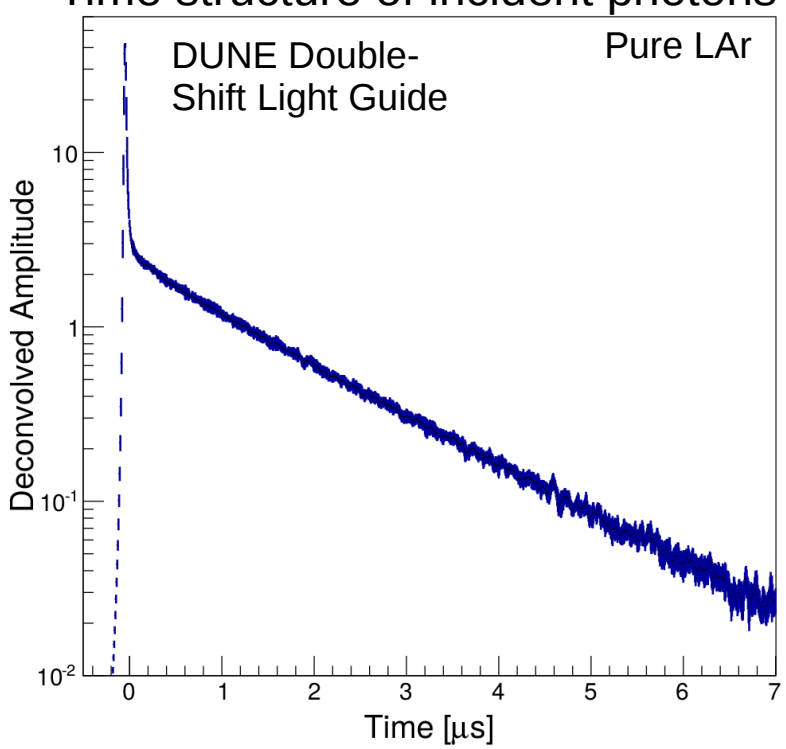
Physics Benefits

- Timing

SiPM signal structure



Time structure of incident photons

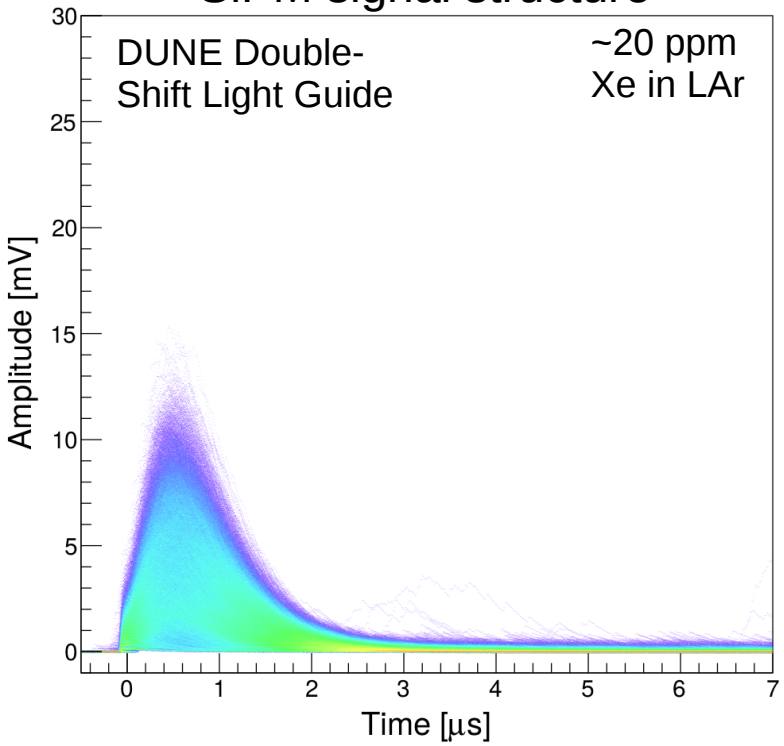


PAB (Blanche) 2016

Physics Benefits

- Timing – Reduced flash overlap from late-light signals
  - Maintains sub-TPC-tick leading-edge timing resolution

SiPM signal structure



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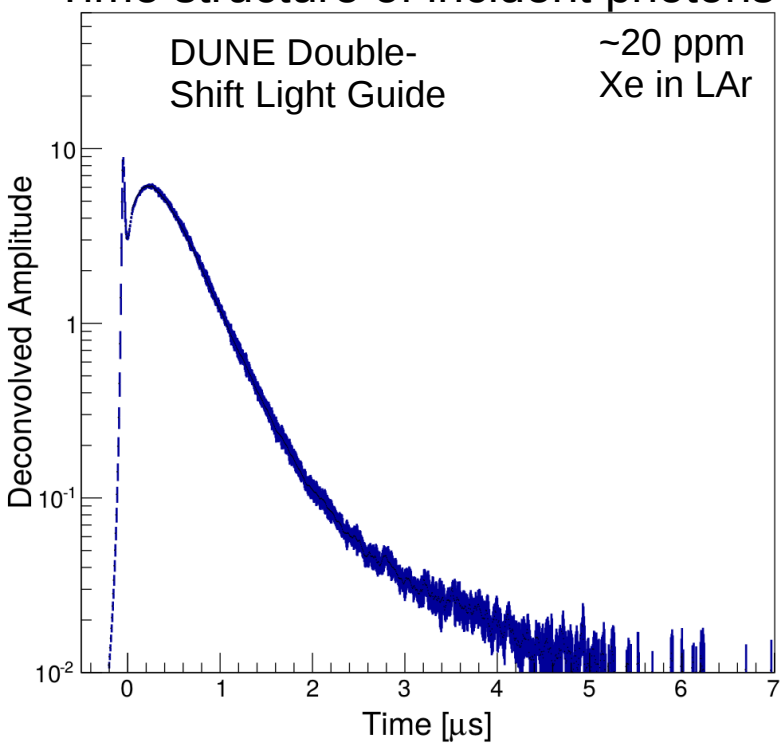
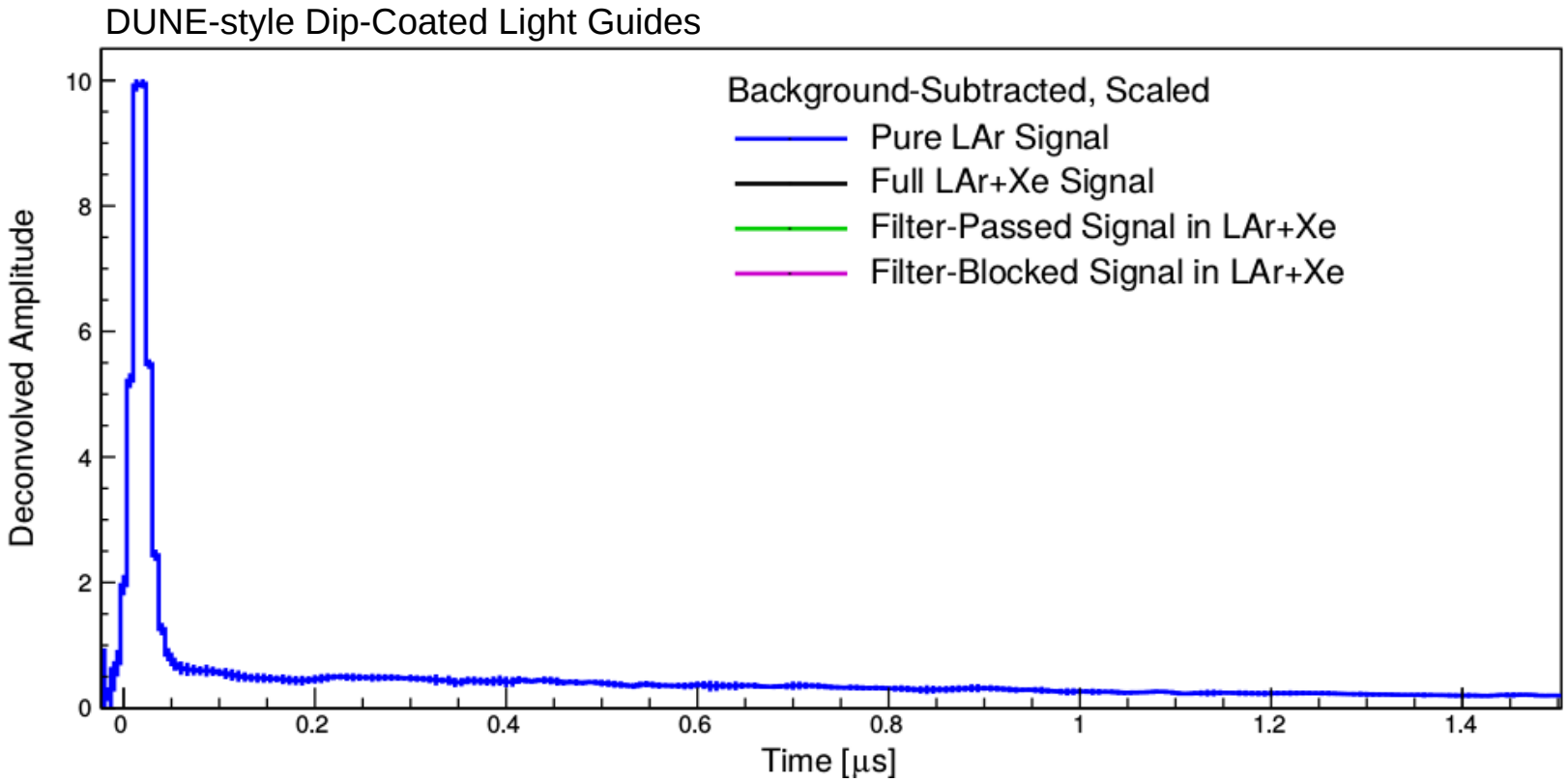


PAB (Blanche) 2016

Physics Benefits

- Wavelength structure

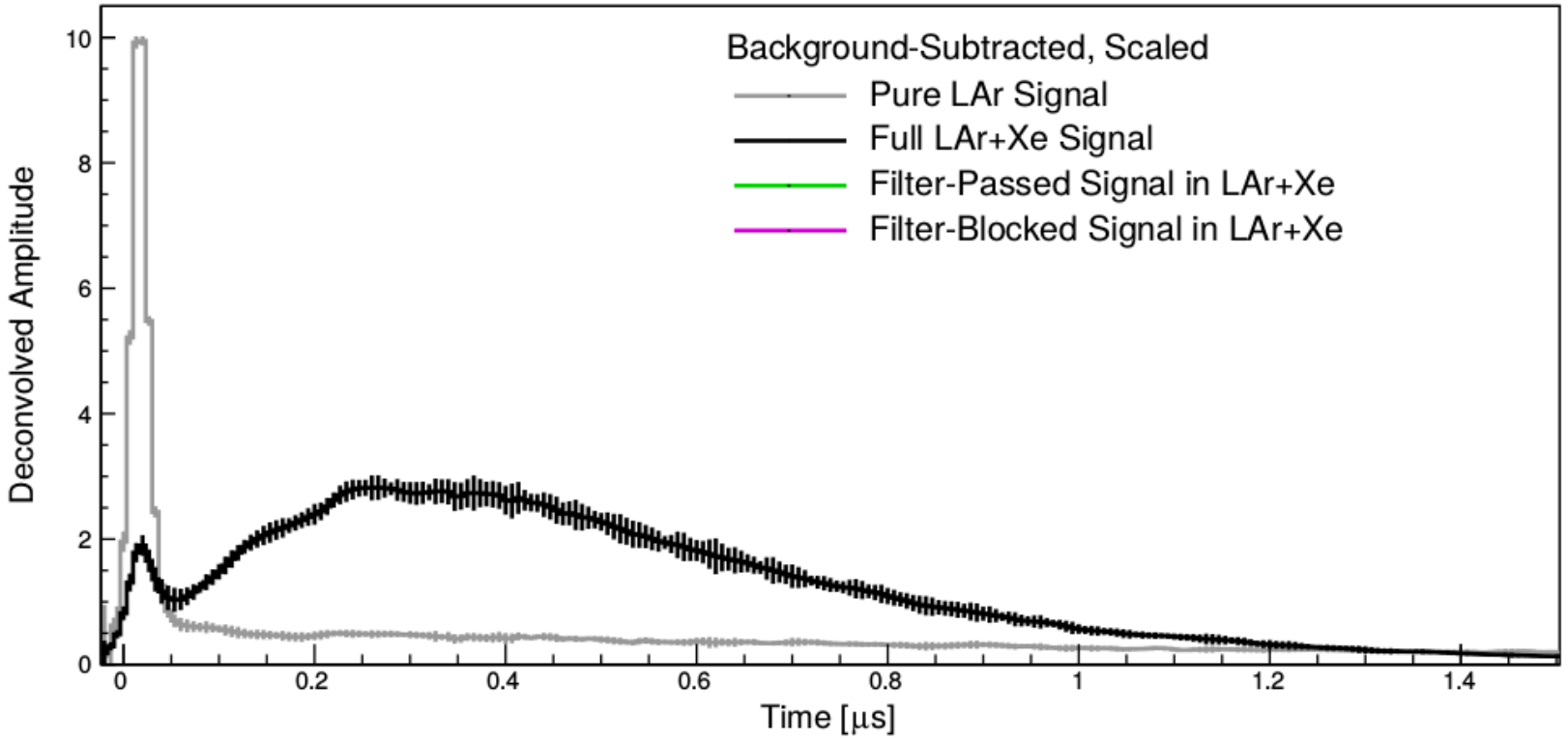


PAB (Blanche) 2016

Physics Benefits

- Wavelength structure

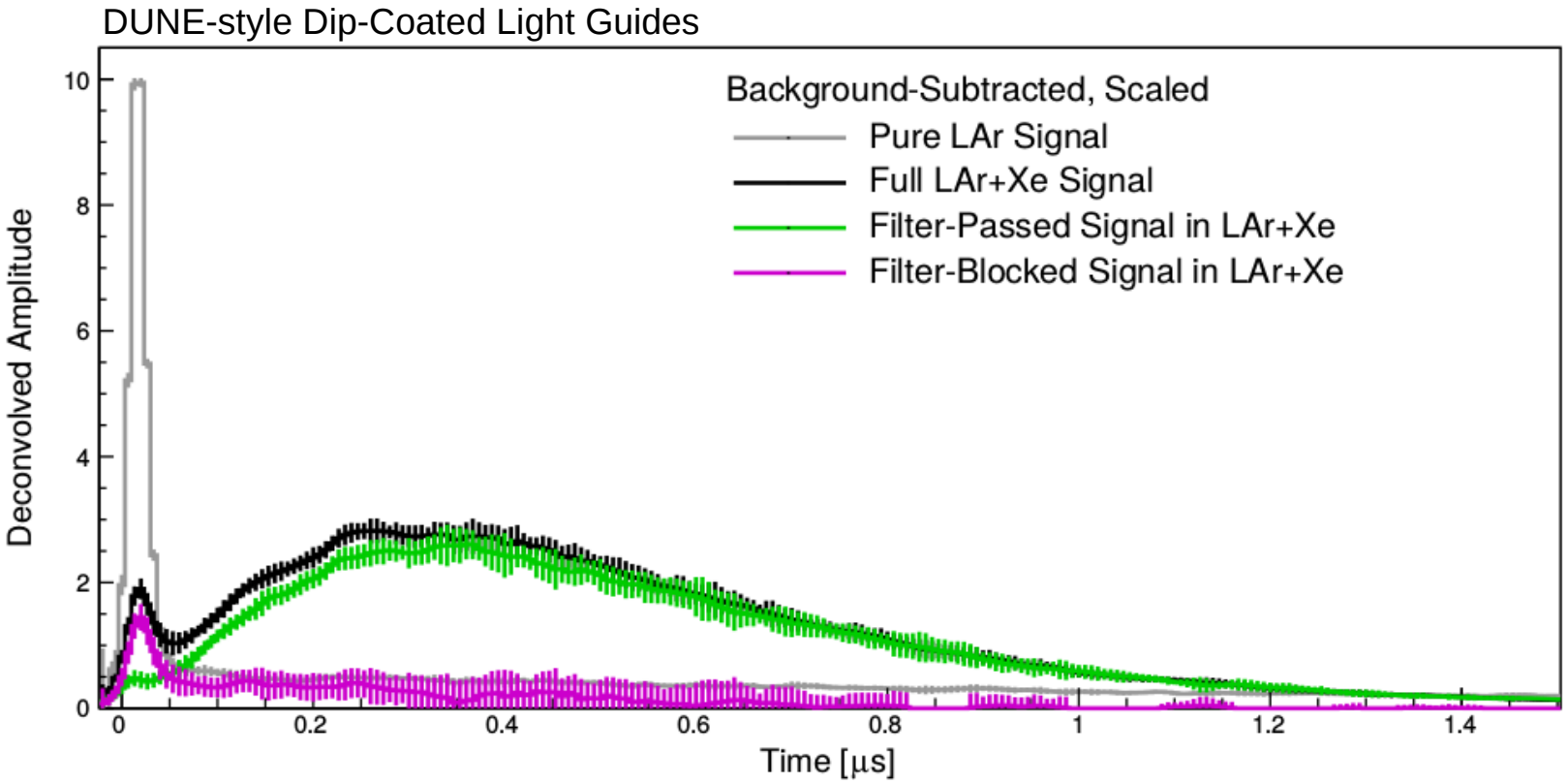
DUNE-style Dip-Coated Light Guides



PAB (Blanche) 2016

Physics Benefits

- Wavelength structure

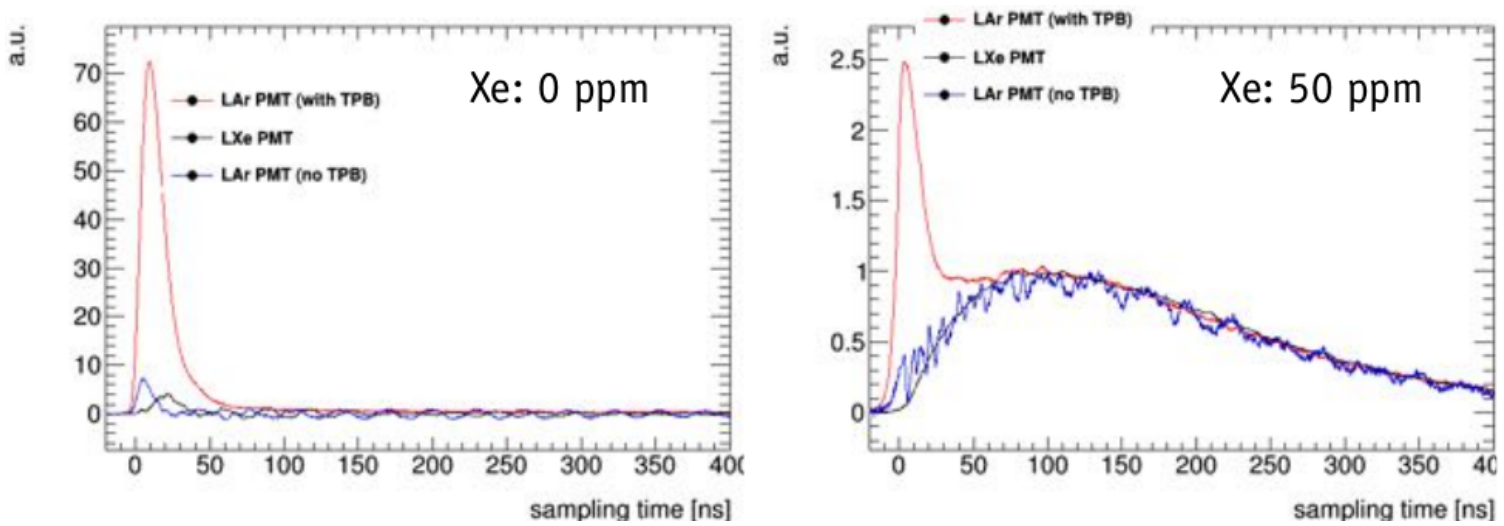


PAB (Blanche) 2016

Physics Benefits

- Wavelength structure

Light detected with PMTs (sensitive to different wavelengths)



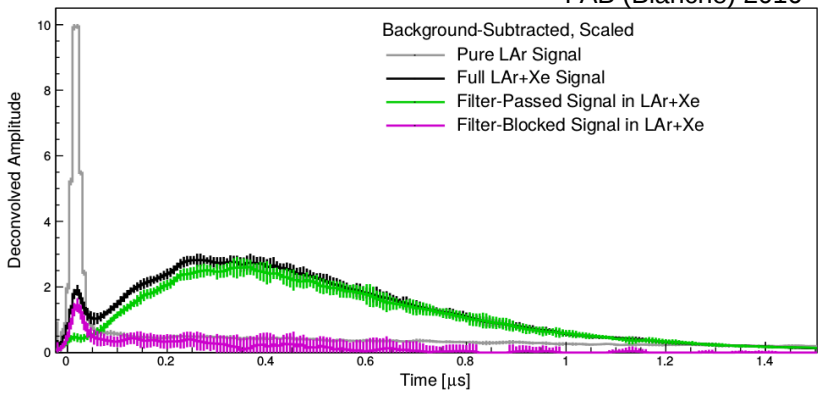
V. Ippolito, F. Pietropaolo, H. Wang, Y. Wang, 2018

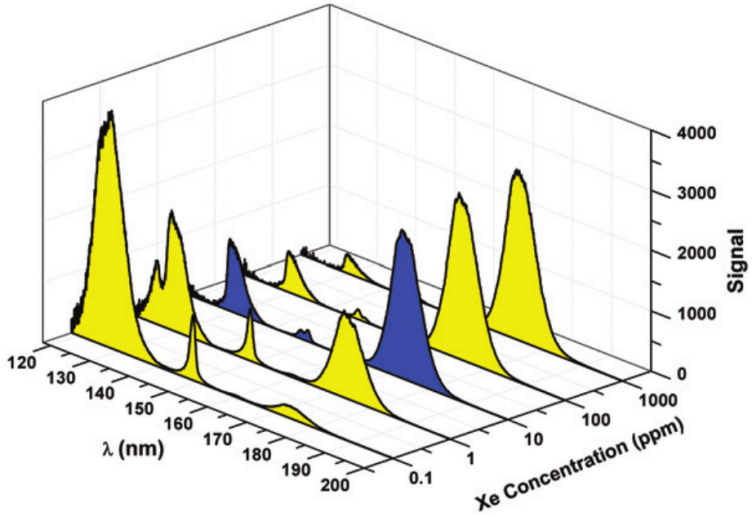
Physics Benefits

- Wavelength structure

- Most scintillation light is converted to 174 nm
  - Detectors typically more efficient
  - Materials more reflective
  - Longer Rayleigh scattering length

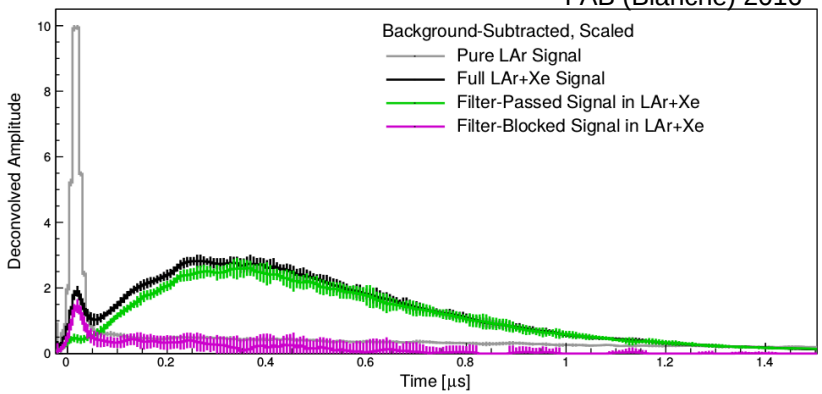
PAB (Blanche) 2016





Physics Benefits

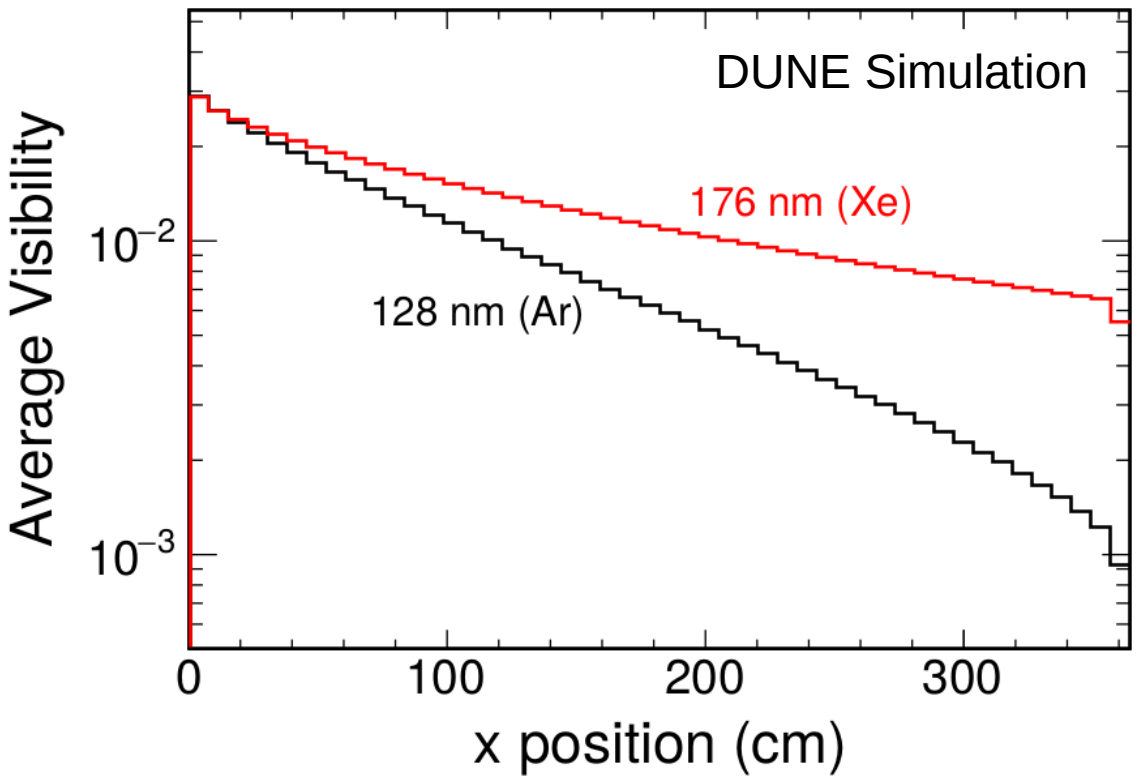
PAB (Blanche) 2016

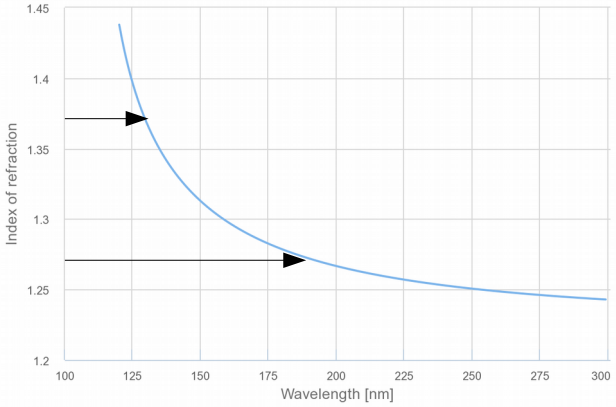


- Wavelength structure
- Indications of larger incident photon flux
  - At ~20 ppm Xe in LAr,
    - 128 nm component reduced to 1/5 of total pure LAr signal ($\gtrsim$ 80% conversion to 174 nm)
    - 174 nm component about 1.5 times larger than total pure LAr signal
    - Total of about 30-70% more photons reached detectors
      - (about 90% larger average *signal* on these detectors)
- *Note*: The benefits from this effect will depend on the relative efficiency of the detector technology at 128 nm vs 174 nm.

Physics Benefits

- Uniformity
  - Reduced Rayleigh scattering improves visibility near CPA





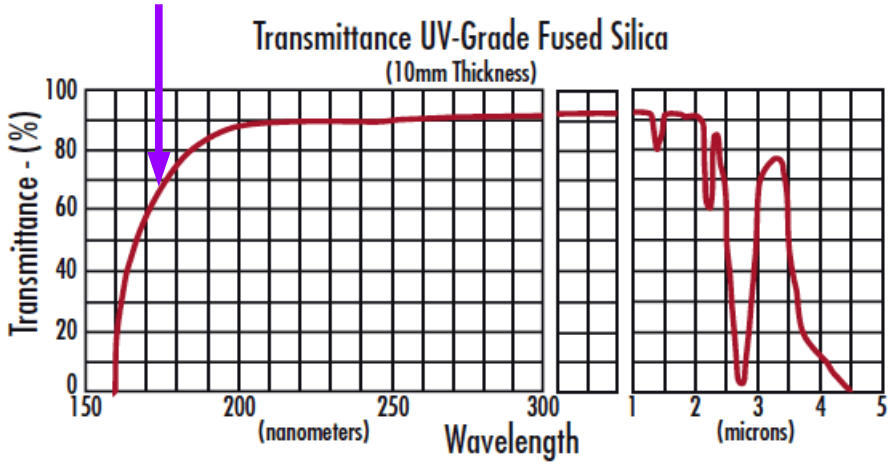
$$\sigma_s = \frac{2\pi^5}{3}\frac{d^6}{\lambda^4}\left(\frac{n^2-1}{n^2+2}\right)^2$$

~6 times longer Rayleigh scattering length

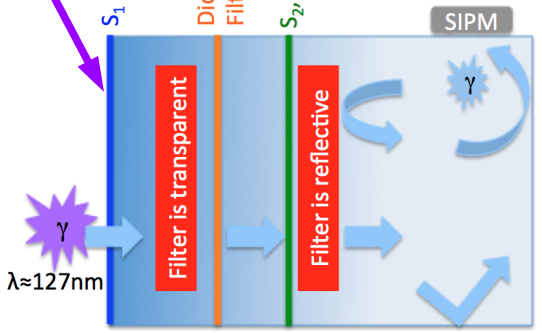
Physics Benefits

- Design Simplifications
  - Potential to remove outer wavelength shifter from light collector modules
    - UV light passes directly into light-trapping volume

174 nm shifted light



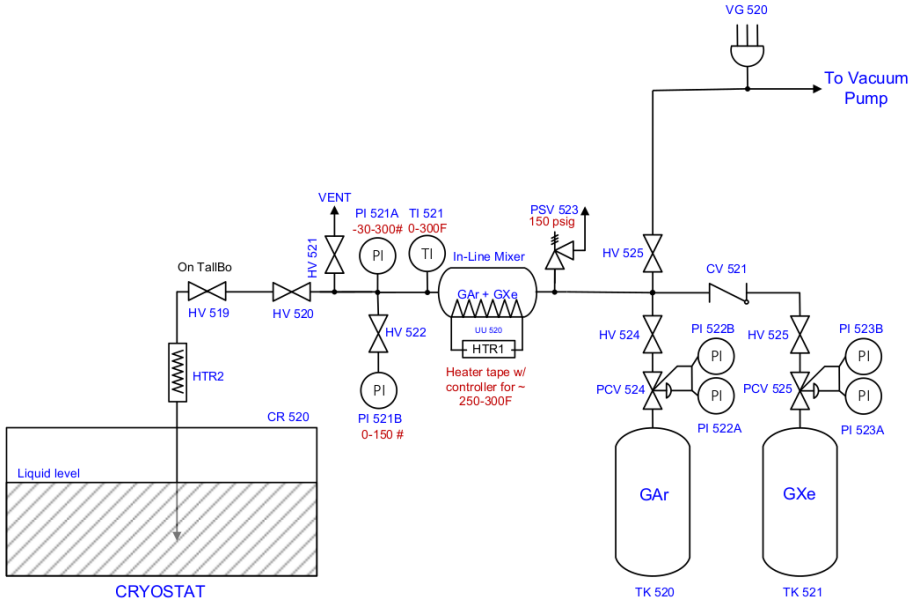
No need for outer wavelength shifter



  - Substantially reduce cost
  - Remove light exposure mitigation requirements (light filters)

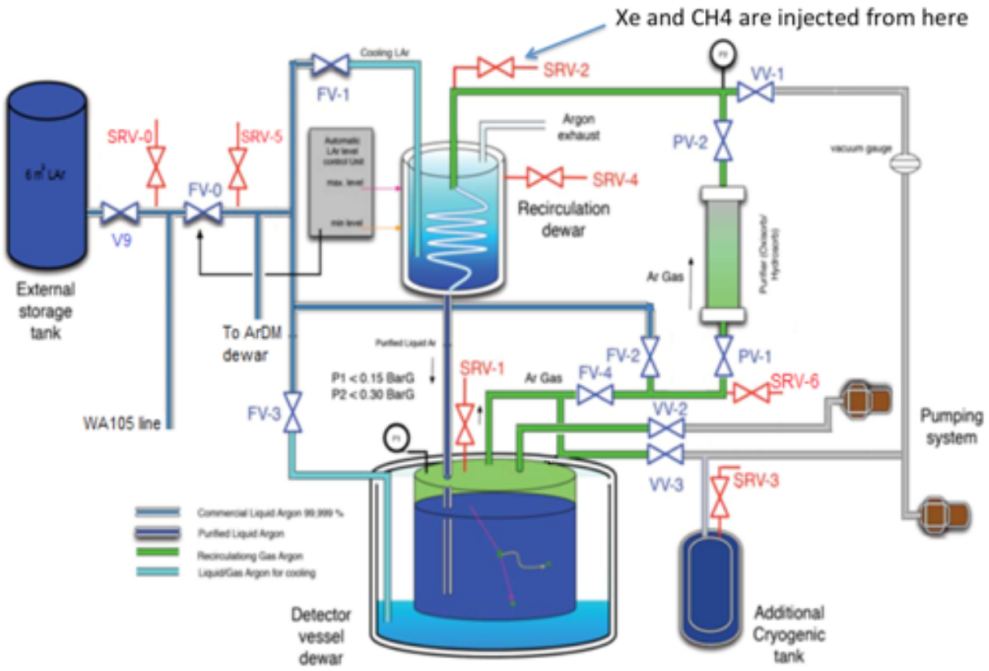
Cryogenics

- Injection
  - Inject low-concentration xenon directly into LAr
    - Premix GXe into GAr and heat to prevent freezing
    - Available and successfully operated at PAB



Cryogenics

- Injection
  - Inject xenon gas to argon gas prior to condensation
  - Available and successfully operated at CERN



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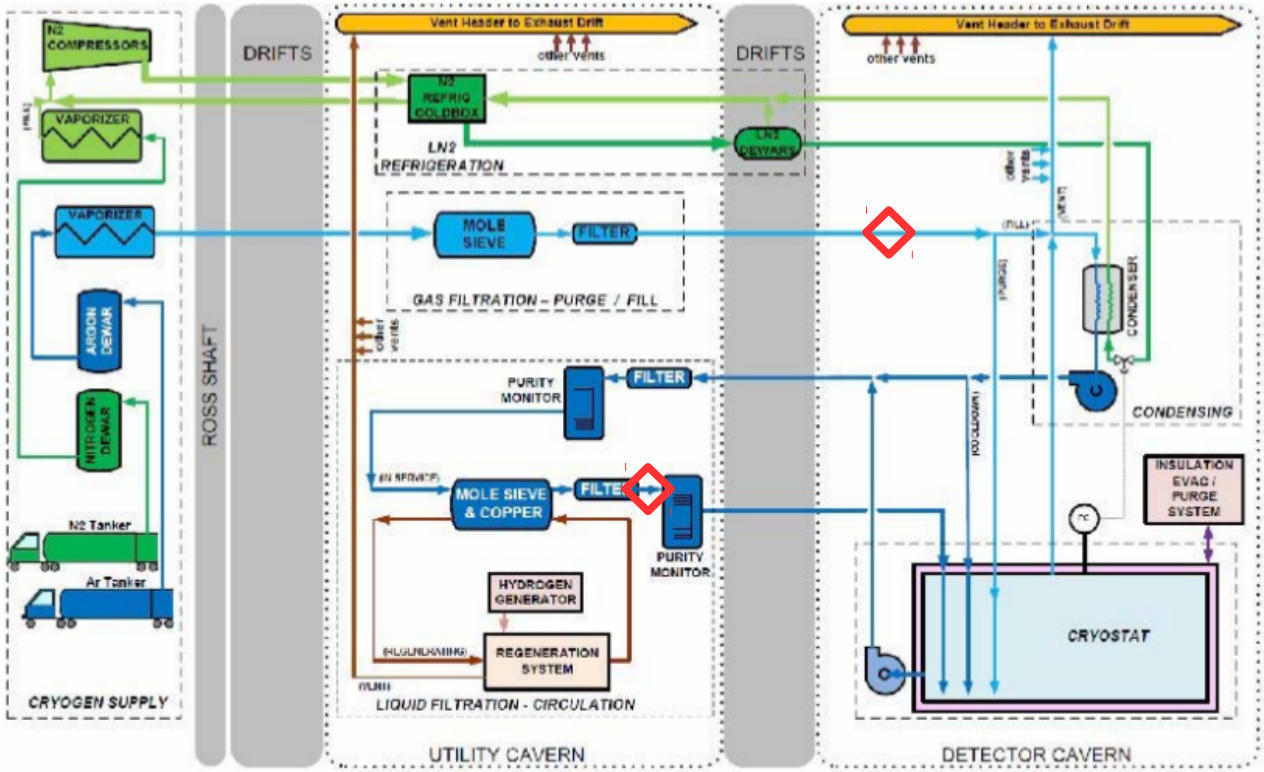


◇ Possible locations for GAr+GXe premixing

Cryogenics

- Maintaining
  - Indications are that Xe remains stable in solution.
    - Observed scintillation structure at Blanche 2016 consistent with losses only from LAr boil-off through monitoring devices. This was observed over the course of about 2 weeks.
  - Currently no plans to top off a Far detector module. This means that over time there will be LAr loss. This was estimated to be ~1”/yr which would represent a 0.2% change/yr in the Xe doping fraction.
  - Systematic study needed to confirm stability.

DW | Alan Bross & Mark Adamowski

Cryogenics

- Monitoring
  - Current plans to investigate residual gas analyzer
    - One deployed and under study at CERN
      - Challenging above 100 AMU
  - Will be paired with gas chromatograph later this year.
    - Constant calibration against standardized Ar-Xe mixtures.

Francesco Pietropaolo

Cryogenics

- Cost
  - A detailed cost estimate would require an evaluation of flow rates, piping design, etc., but is likely to be small compared to the cost of Xe.
  - Xenon would likely cost ~ $20k/(ppm Xe doping level) per Far detector module.
  - Optimization of xenon doping level needed, but likely in the range of 30-100 ppm.

from: Alan Bross & Mark Adamowski

TPC Interaction

- What impact will the xenon have on the charge yield? Charge attenuation? HV stability?
  - Need to investigate with TPC+PD setup

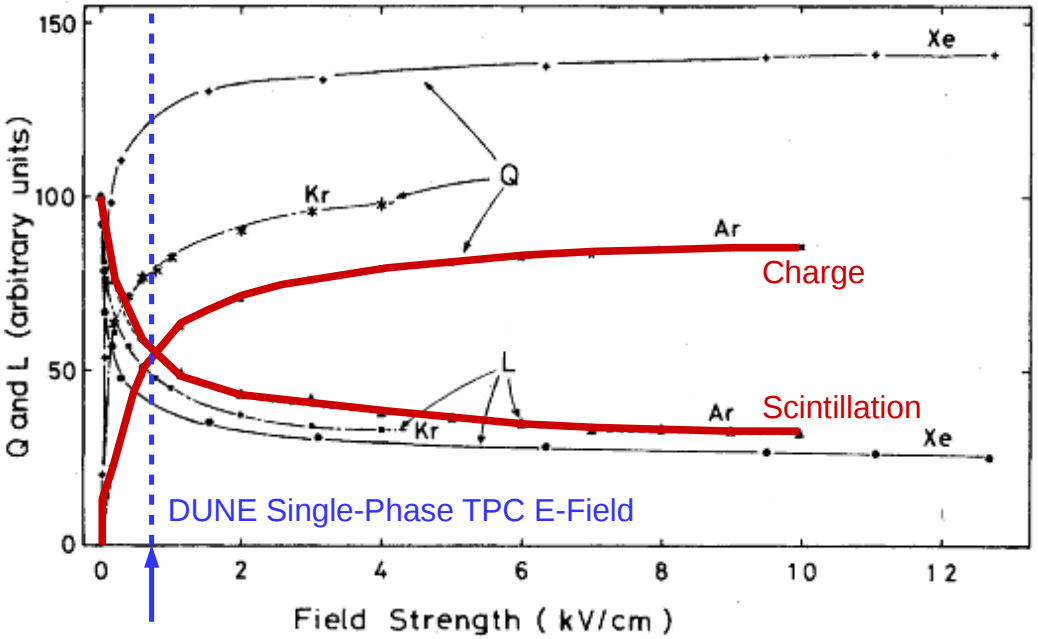


FIG. 2. Variation of relative luminescence intensity L and collected charge Q in liquid argon, krypton, and xenon vs applied-electric-field strength for 0.976- and 1.05-MeV electrons.

S.Kubota et al., Phys. Rev. B20 (1979), 3486

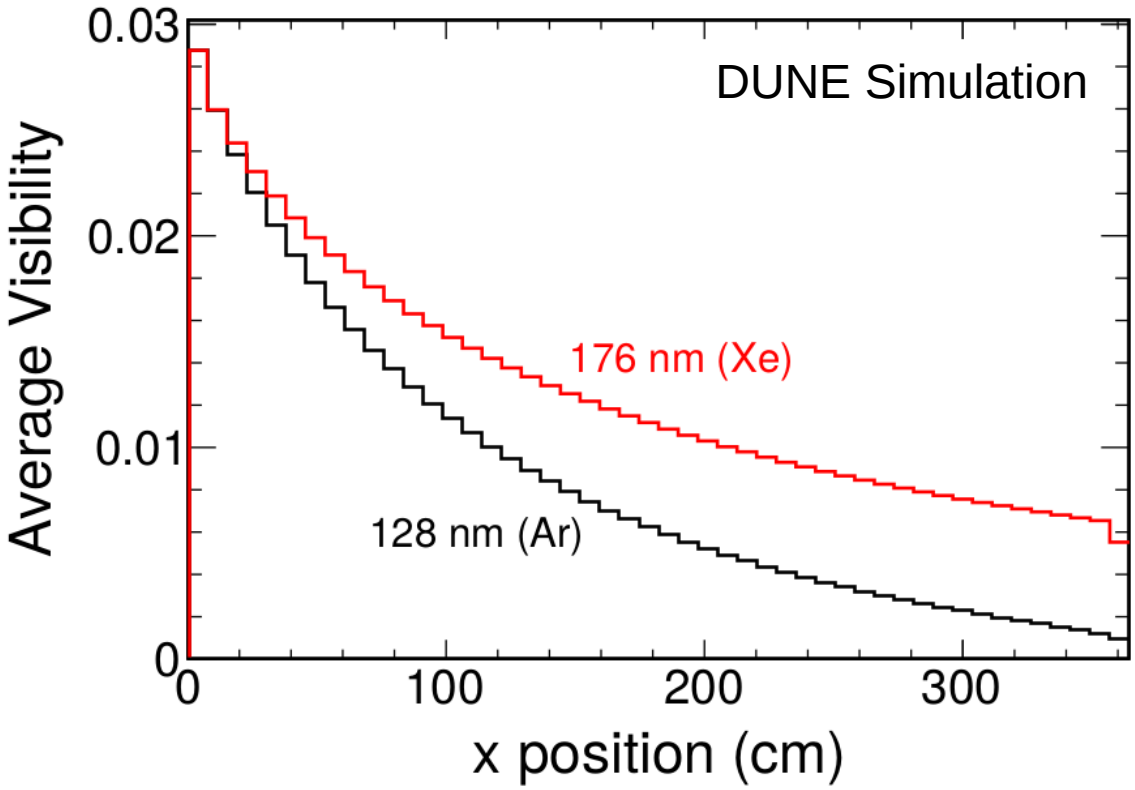
Summary

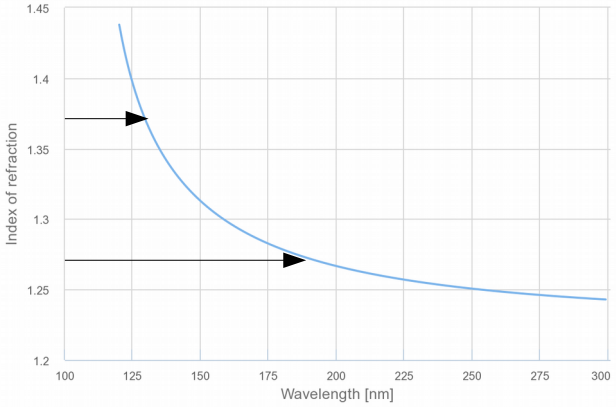
- Small concentration of xenon has several benefits for DUNE
  - Reduced ambiguity from late light,
  - Improved uniformity across drift direction
  - Potential for increased efficiency and simplified detector design
- Cryogenics
  - Injecting has been performed in different ways, likely to be straighforward at DUNE FD.
  - Concentration should remain stable, but studies needed to confirm.
  - Monitoring is a potential challenge and additional investigations are needed.
  - Cost should be reasonable for low xenon concentration.
- TPC Interaction (unlikely, but should be investigated)

Backup

Physics Benefits

- Uniformity
  - Increased rayleigh scattering improves visibility near CPA





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