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Applications: Liquid Argon

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TRIUMF
CAP June 2019

Discovery, accelerated

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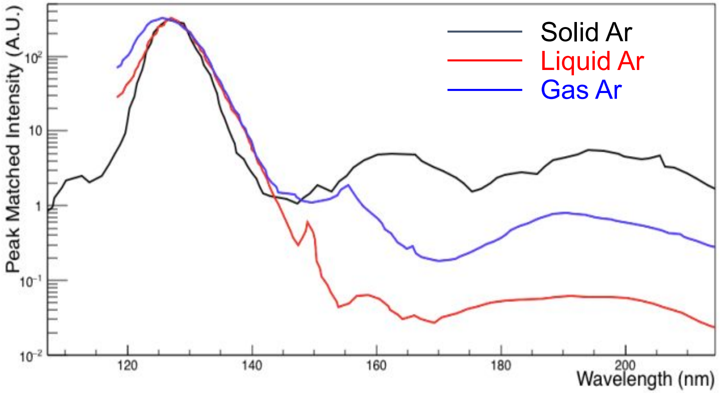
Talk Outline

1. Liquid Argon Overview
2. Current Applications
3. What’s Next?
4. High-Efficiency VUV Photo-Sensors
5. Conclusions

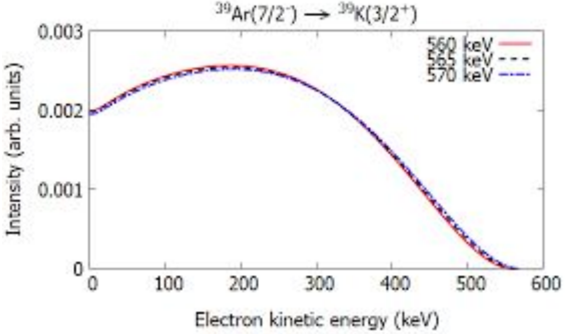
Liquid Argon Overview

1. Liquid Argon Overview



PROS:

- Argon is cheap ~2.5 USD/L.
- Good scintillator, 40 photons/keV [1].
- Great discrimination between Electronic and Nuclear induced recoils, Power > 4.1×10^9 [2].
- Transparent to its own scintillation light.

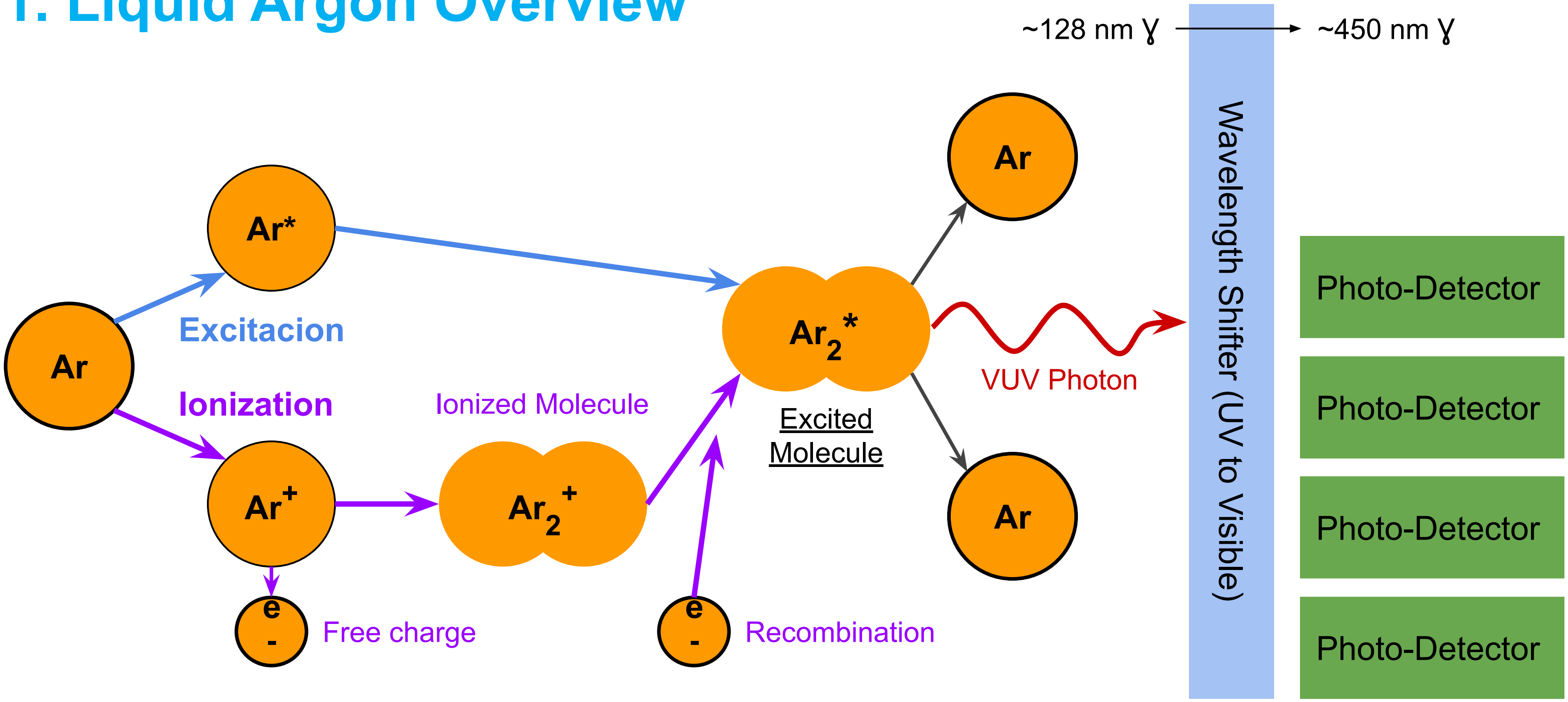


CONS:

- ^{39}Ar Beta-emitter in natural Argon, 0.953±0.028 Bq/kg [3].
- Relatively low density, 1.3954 g/cm^3.
- Emission spectrum peaked at 128 nm [4]

[1] Hitachi, et al., Japanese Journal of Applied Physics, Volume 41, Part 1, Number 3A
[2] DEAP Collaboration, ArXiv.org/abs/1902.04048
[3] M. G. Dunford, Ph.D Thesis, Carleton University, 2018.
[4] T. McElroy, Ph.D. Thesis, University of Alberta, 2018.

1. Liquid Argon Overview



$$T(t) = T_{LAr}(t, \tau_s, \tau_t) \otimes T_{ws}(t, \tau_f, \tau_i, \tau_l, \tau_{sp}) \otimes T_{PD}(t, \sigma_s)$$

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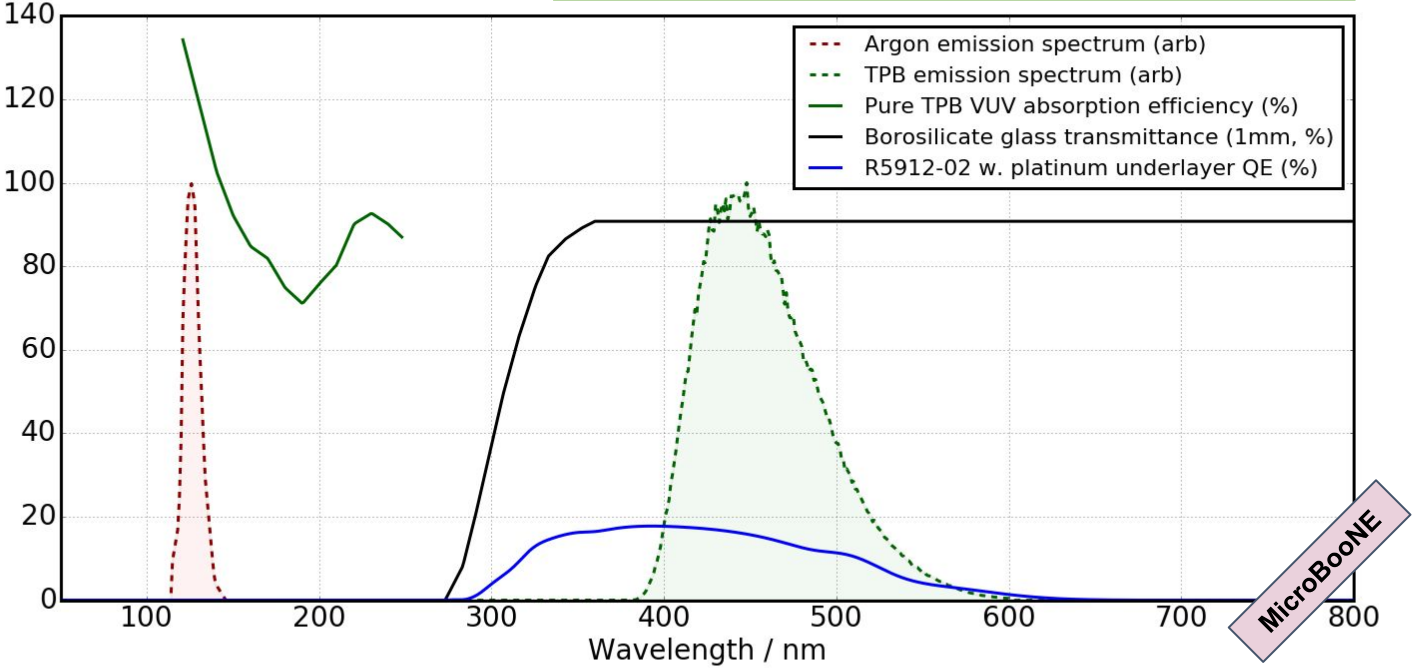
1. Liquid Argon Overview

MicroBooNE Collaboration, ArXiv.org/abs/1612.05824



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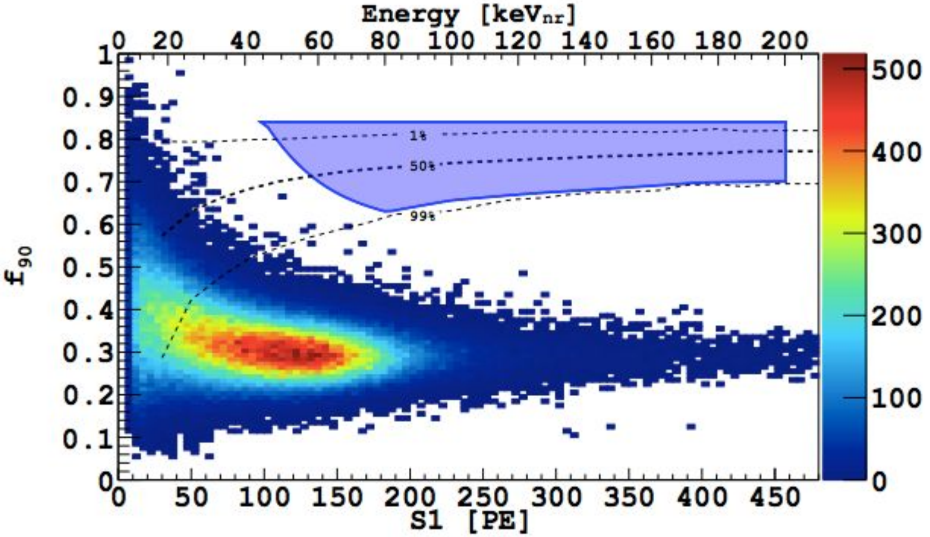
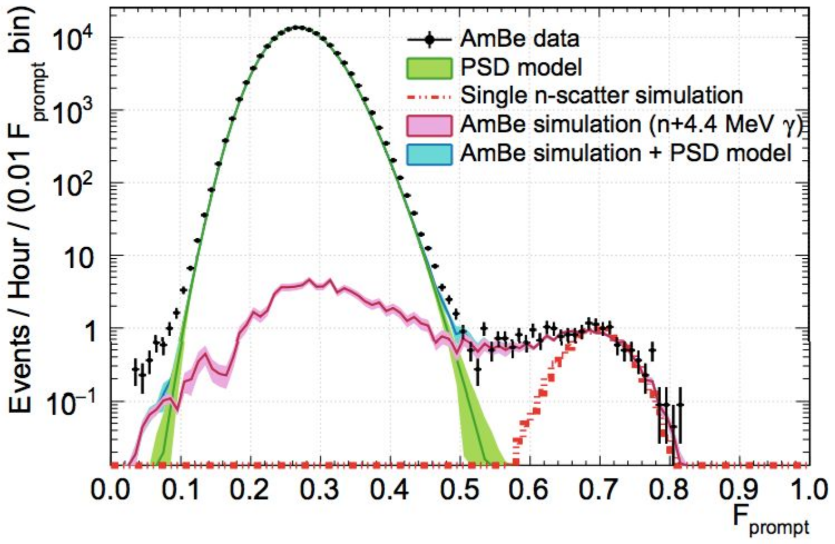
1. Liquid Argon Overview

DarkSide Collaboration, ArXiv.org/abs/1802.07198



DEAP Collaboration, ArXiv.org/abs/1902.04048



Current Applications

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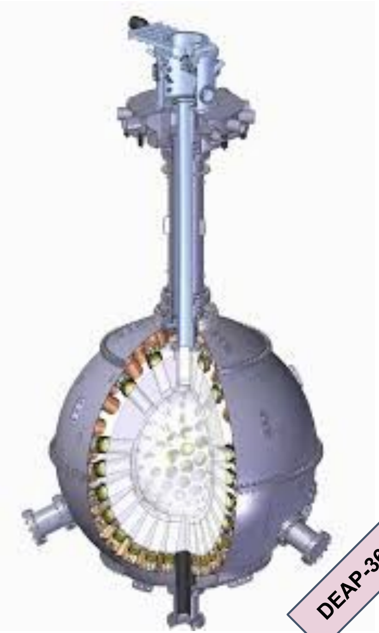
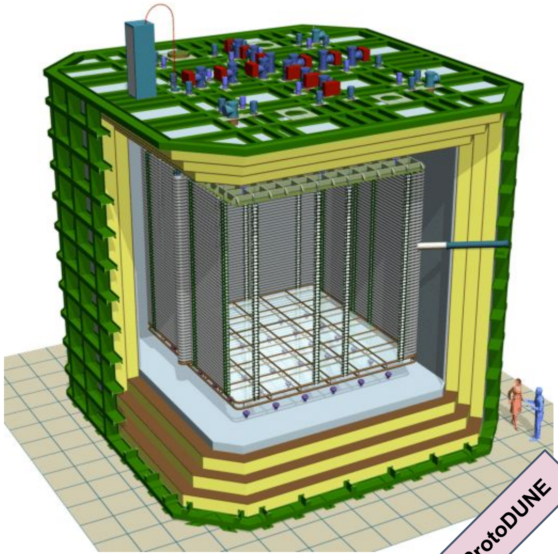
2. Current Applications

Monolithic Detectors (Dark Matter)	Time-Projection-Chambers (Neutrinos, Dark Matter)	Bubble Chambers (Neutrinos, Dark Matter)



DEAP-3600



ProtoDUNE

SBC

What’s Next?

3. What’s Next?

Current Generation

Better Understanding of LAr Intrinsics Properties

+

Highly Characterized Wavelength Shifters with Improved Performances

And / or

Higher-Efficiency and Faster Photo-Detector (VUV Sensitive)

+

Other General Detector R&D

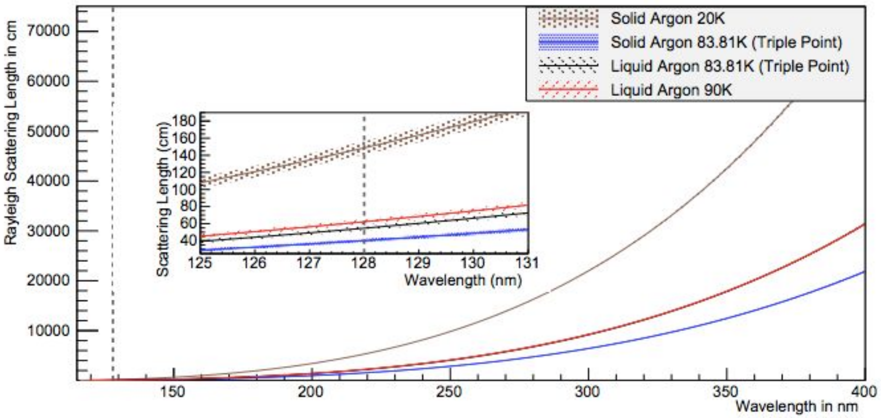
Next Generation

3. What's Next?

We need better understanding of the VUV Light Propagation in Liquid Argon.

- The LAr refractive index in the 100-150 nm range is not well known.
- Better understanding of the group velocity in Liquid Argon
- New and better measurement of Rayleigh scattering of VUV light in Liquid Argon.

E. Grace, et al, ArXiv.org/abs/1502.04213



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3. What's Next?

M. Hofmann, et al, ArXiv.org/abs/1511.07721

We need better understanding of the true singlet-to-triplet ratios in LAr.

- Measure Singlet to Triplet Ratios without Using Wavelength Shifters (Current SiPM PDE at 128 at 5-10%).
- Is there a intermediate lifetime or is it an artifact of the wavelength shifter?
- Better measurement of the LAr photo/yield.

LoLA will Try to address those topics (see Austin De Ste Croix Wed talk: link)

Exciting particle	τ_s [ns]	τ_t [ns]	$\frac{I_s}{I_t}$	Ref.
γ	1.65±0.1	–	–	[46]
γ	–	1463±55	–	[24]
γ	10±5	1200±20	0.30±0.01	[23]
e^-	<6.2	1300±60	0.51±0.05	[7, 8]
e^-	4.6	1540	0.26	[52]
e^-	6±2	1590	0.3	[54]
α	4.4	1100	3.3	[52]
α	7.1±1.0	1660±100	1.3	[54]
α	10±5	1200±20	2.6±0.1	[23]
n	10±5	1200±20	3.5±0.2	[23]
fission fragments	6.8±1.0	1550±100	3	[54]

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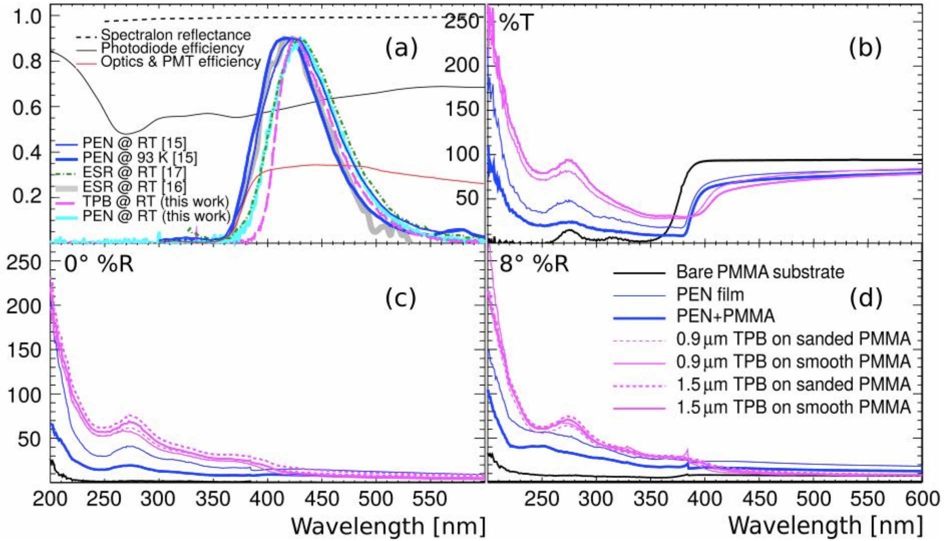
3. What's Next?

New and Improved Wavelength Shifter Are Going Through R&D.

- Need Better Characterization of TPB or Suitable Alternatives.



M. Kuzniac, et al, ArXiv.org/abs/1806.04020

High-Efficiency VUV Photo-Sensors

4. High-Efficiency VUV Photo-Sensors

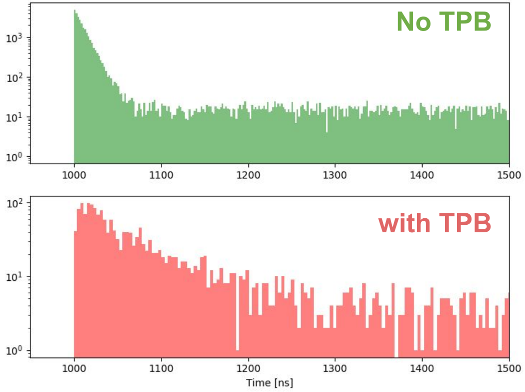
Direct detection of LAr VUV photons could be a game changer for future detectors.
Currently, wavelength-shifters (TPB) are used to convert VUV light into visible light.

$$T(t) = T_{LAr}(t, \tau_s, \tau_t) \otimes T_{ws}(t, \tau_f, \tau_i, \tau_l, \tau_{sp}) \otimes T_{PD}(t, \sigma_s)$$

Direct VUV Detection

$$T(t) = T_{LAr}(t, \tau_s, \tau_t) \otimes T_{PD}(t, \sigma_s)$$

	Parameter	Value
LAr	τ_s (LAr)	7±1 [ns]
	τ_t (LAr)	1600±200 [ns]
TPB	τ_f (TPB)	10±1 [ns]
	τ_i (TPB)	49±1 [ns]
	τ_l (TPB)	3550±500 [ns]
	τ_s (TPB)	309±10 [ns]
	t_f (TPB)	60±1 [%]
	t_i (TPB)	30±1 [%]
	t_l (TPB)	8±1 [%]
	t_s (TPB)	2±1 [%]



Directly Impacts:

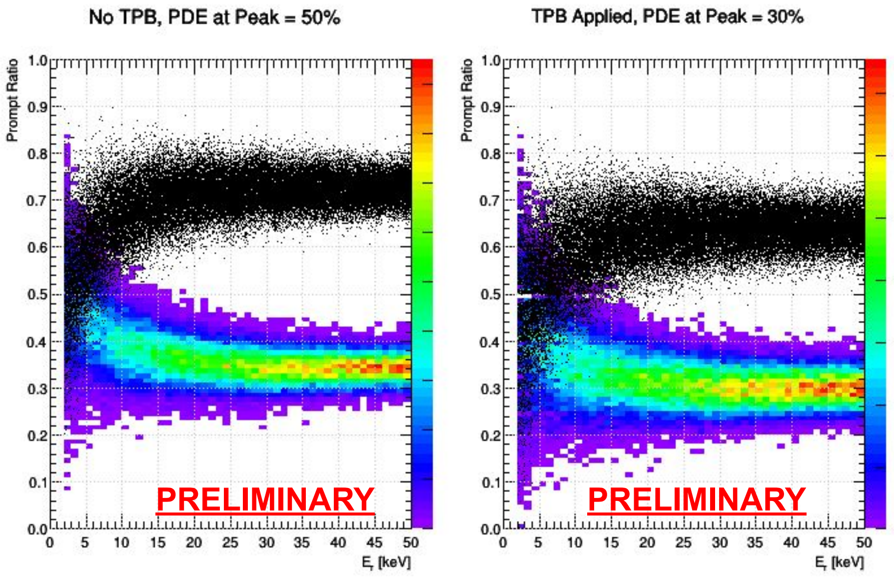
- Pulse-Shape Discrimination (PSD)
- Energy Reconstruction
- Position Reconstruction

[LAr] P.A. Amaudruz, Astroparticle Physics 85 (2016) 1-23 [TPB] E. Segreto, doi:10.1103/PhysRevC.91.035503

4. High-Efficiency VUV Photo-Sensors

Dedicated Monte-Carlo study to estimate the impact of high PDE VUV SiPMs on PSD (**SiLA).**

PSD = Fraction of singlet state photons over total scintillation photons (ideal)



SiLA Inputs:
Detector Light
Collection Efficiency
SiPM Parameters
SiPM PDE
Singlet/Triplet Ratios
TPB on/off

SiLA Output:
NR & ER Events
Raw Waveforms
Photon Propagation

DEAP Best PSD leakage limit **<4.1×10^{-9} (90% C.L.)** between 16 and 33 keVe [1] @ ~450 nm.

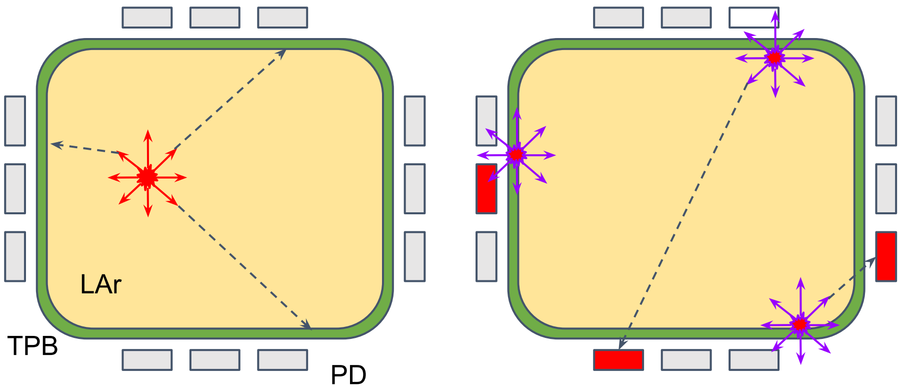
[1] Phys. Rev. Lett. 121, 071801 (2018)

4. High-Efficiency VUV Photo-Sensors

Vertex reconstruction is very challenging in single-phase experiments (wavelength shifter driven).
Direct detection of VUV LAr emission photons could greatly benefit position reconstructions.

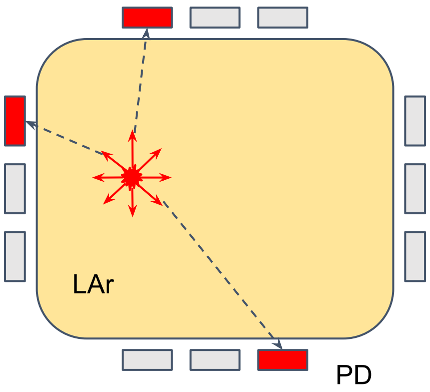
1) LAr Scintillation
2) Isotropic ɣ Propagation

3) TPB Absorption/Emission
4) Isotropic ɣ Detection



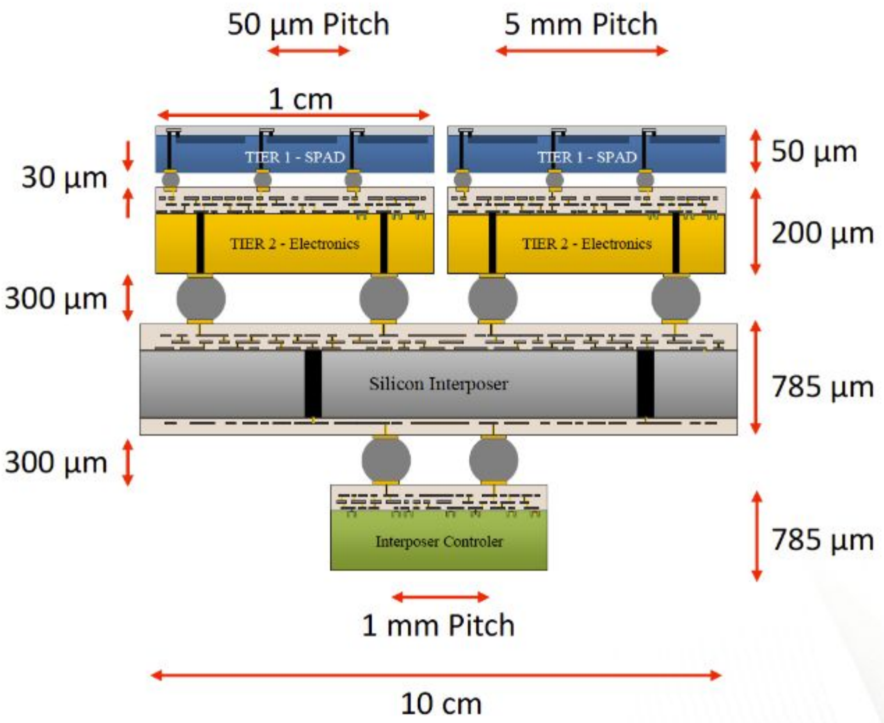
Timing and Hit-patterns affected by WS smearing.
Could use PMT Charge Fraction for Fiducialization
[1] Phys. Rev. Lett. 121, 071801 (2018)

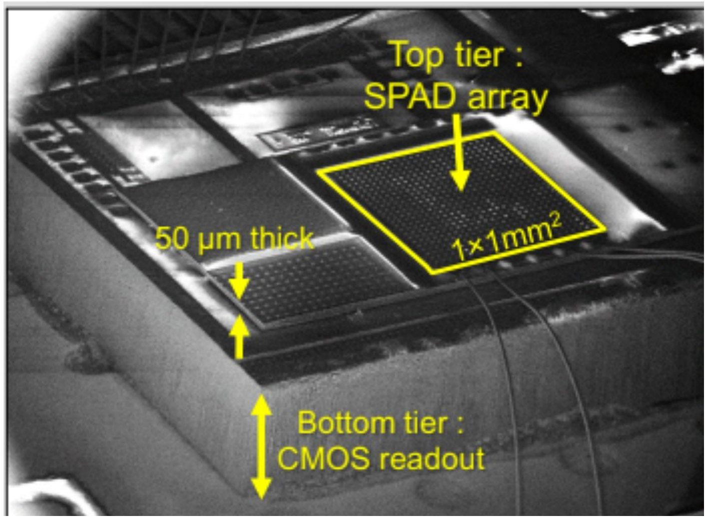
1) LAr Scintillation
2) Direct ɣ Detection



Possible Sub-ns timing, and direct LAr emission hit-patterns measurements

4. High-Efficiency VUV Photo-Sensors





- Time-to-digital converter per pixel.
- No compromise between electronics and SPAD processes. Great photosensitive fill factor.
- Time Resolution 100-10 ps.
- DCR and AP rates comparable to current commercially available devices.

See Jean-Francois Pratte Wed Talk: Link

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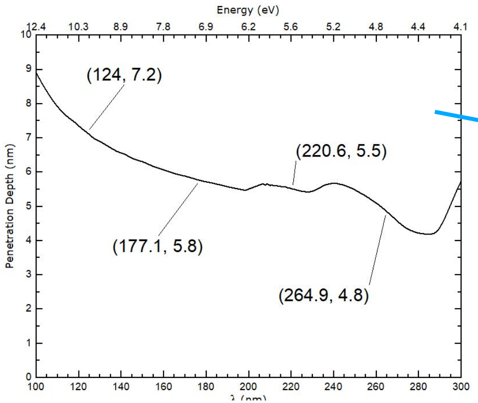
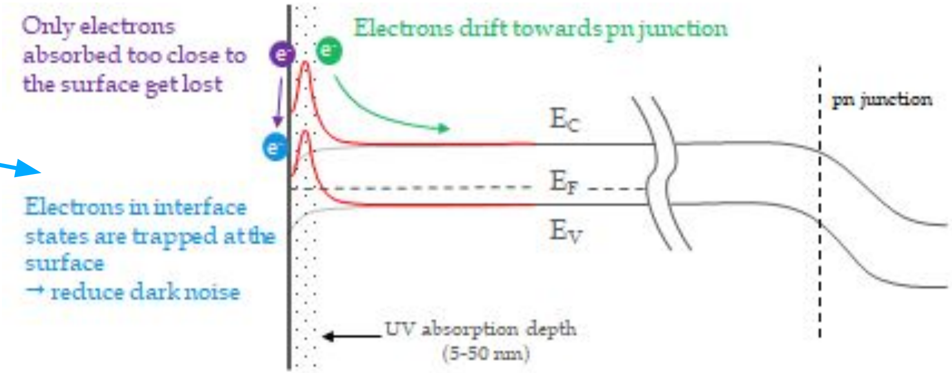
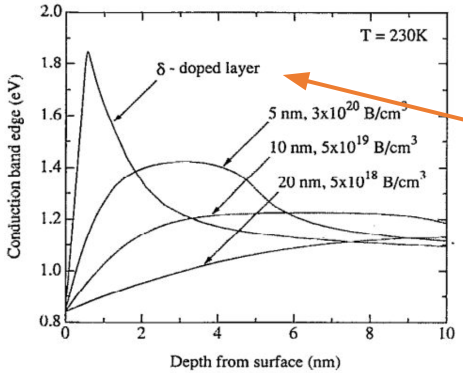
4. High-Efficiency VUV Photo-Sensors

Penetration Depth Challenge





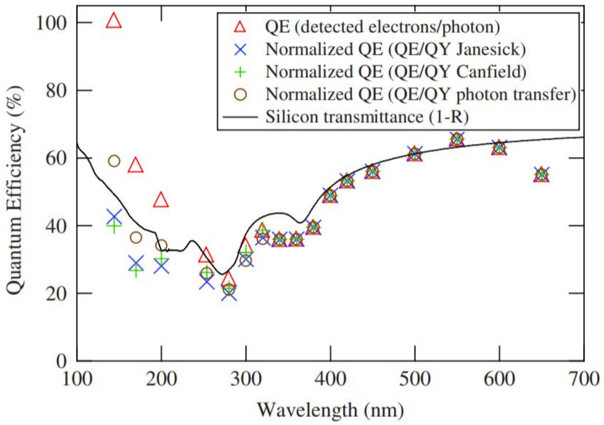


The delta-doping concept: Introduce an highly-doped layer at the surface of the SiPM, to modify the energy band profile. Electron generated below this barrier are drifted towards the p-n junction. Charges captured on the surface deflects and can not contribute to the device noise levels [1].

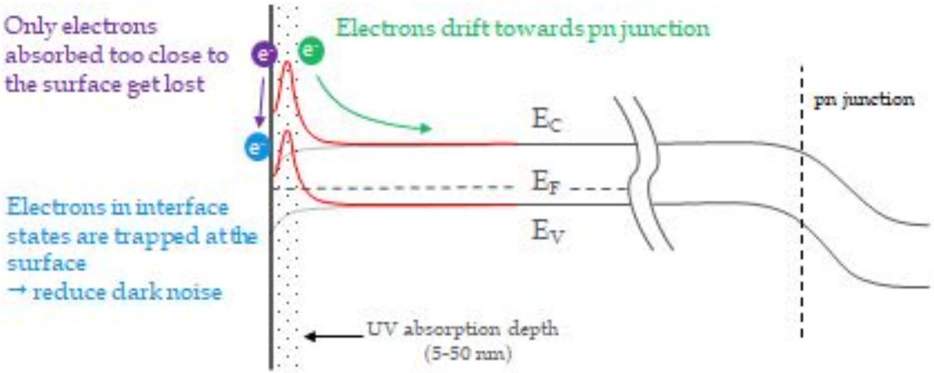
[1] App. Phys. Lett. 61, 1084 (1992) doi:10.1063/1.107675

4. High-Efficiency VUV Photo-Sensors

Previously demonstrated in CCD



Applied Optics, vol. 51, issue 3, p. 365



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Conclusions

5. Conclusions

- Liquid Argon is and will be the building block of many Dark Matter and Neutrino Projects. (Cheap, Lots of Light, Good PSD).
- Current Applications include: Monolithic Calorimeters, Time-Projection-Chambers, Bubble Chambers, ……
- Better understanding of LAr intrinsics propertics (optics and scintillation mechanism) are needed to push for new technologies and ideas.
- Some ongoing effort in development of new wavelength shifter (or better characterization of TPB).
- Path to switch to direct VUV detection goes through the R&D of new high-efficiency SiPM. We showed the current plan for that R&D program.
- Important to study optical properties of materials in the VUV range (100-200). We might be able to find optimal 128 nm reflector to help with large area photo-collection.

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Thank you
Merci

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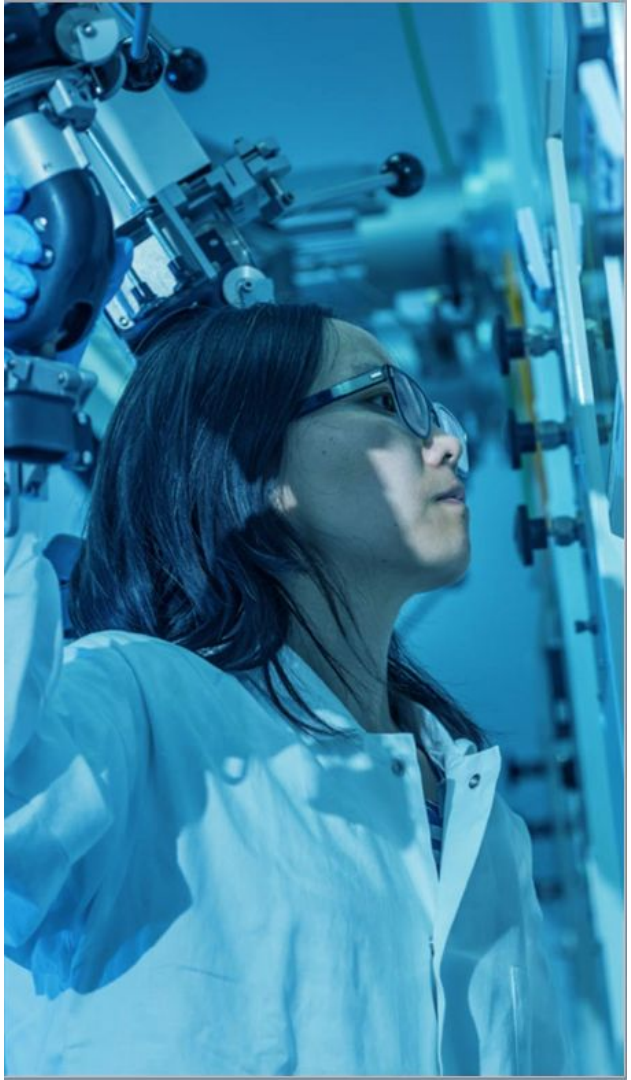

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Backup Slides

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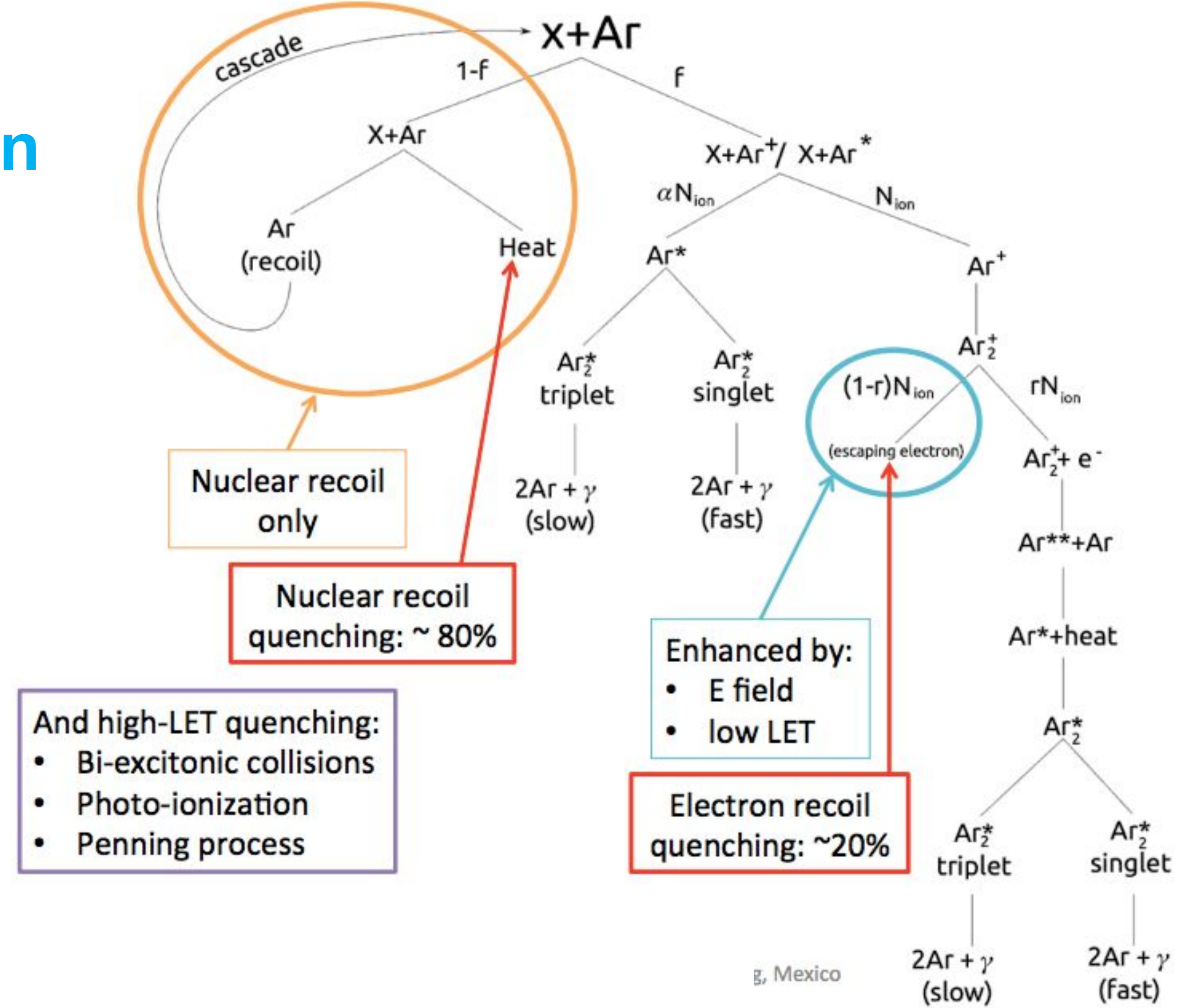
LAr Scintillation



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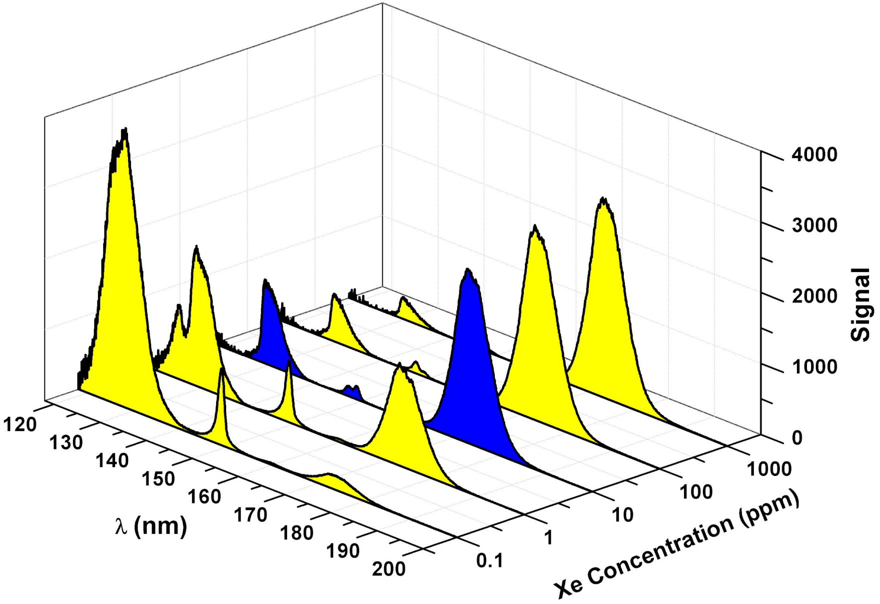
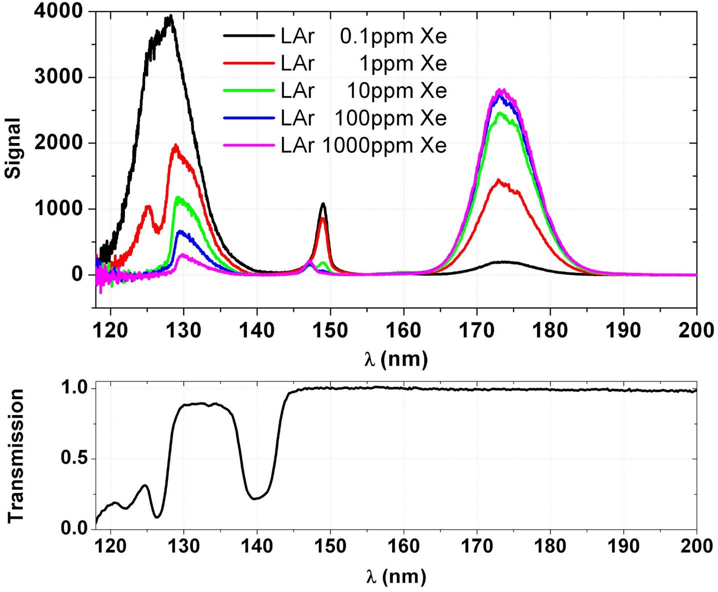
LAr Scintillation





“Intense Vacuum-Ultraviolet and Infrared Scintillation of Liquid Ar/Xe Mixture”ArXiv.org/abs/1511.07723

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