MANCHESTER 1824

The University of Manchester

WLS Covered Foils in DUNE

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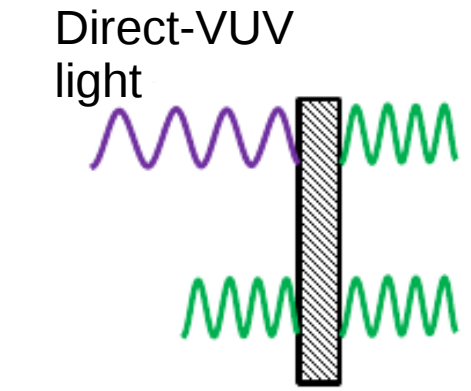
Introduction

- Wavelength-shifter covered reflector foils installed on the CPA can enhance the light collection efficiency in the DUNE far detectors.
- Would improve uniformity (useful for triggering), timing and potentially enable x-position resolution with light.
- Not a new idea: similar solutions used by DM detectors, and LArIAT and SBND.
- Tests and measurements to find optimal solution for DUNE are planned or in progress.

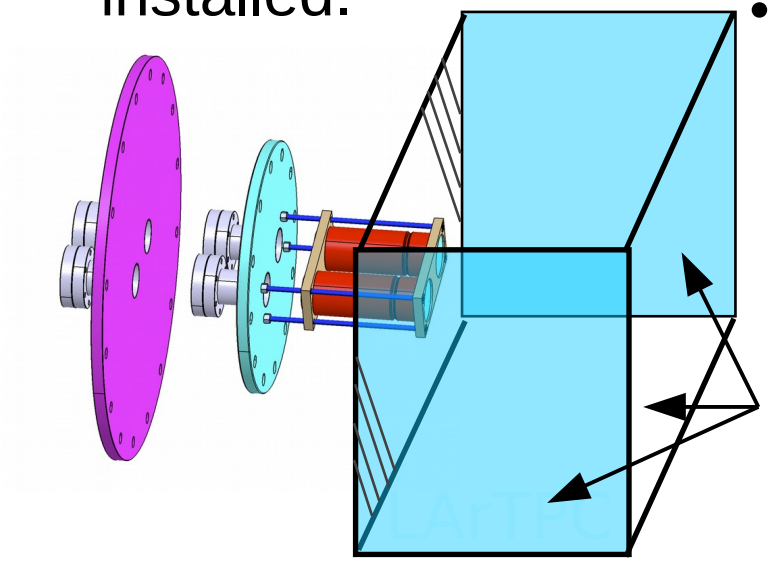
Practical Considerations

- VUV light is absorbed by most materials – in the baseline design, light impinging on the CPA is lost.
- Covering the CPA with reflective foils covered with a wavelength-shifter compound recovers this light.
- Baseline choice would be TPB (known and used in large scale projects). Potential to use PEN, a new idea that would simplify engineering.
- To profit from this, the sensitive detectors need to be sensitive to visible light as well as VUV.
- The foils are di-electric, which means care needs to be taken when installing them on the CPA.



Foils in SBND/LArIAT

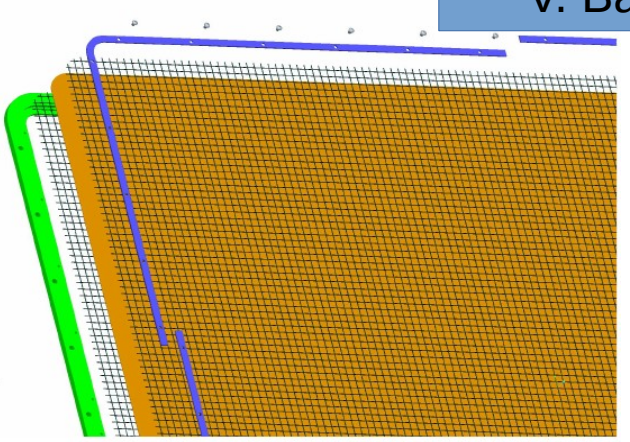
- LArIAT, a test beam experiment has completed three full runs with WLS-covered foils installed.



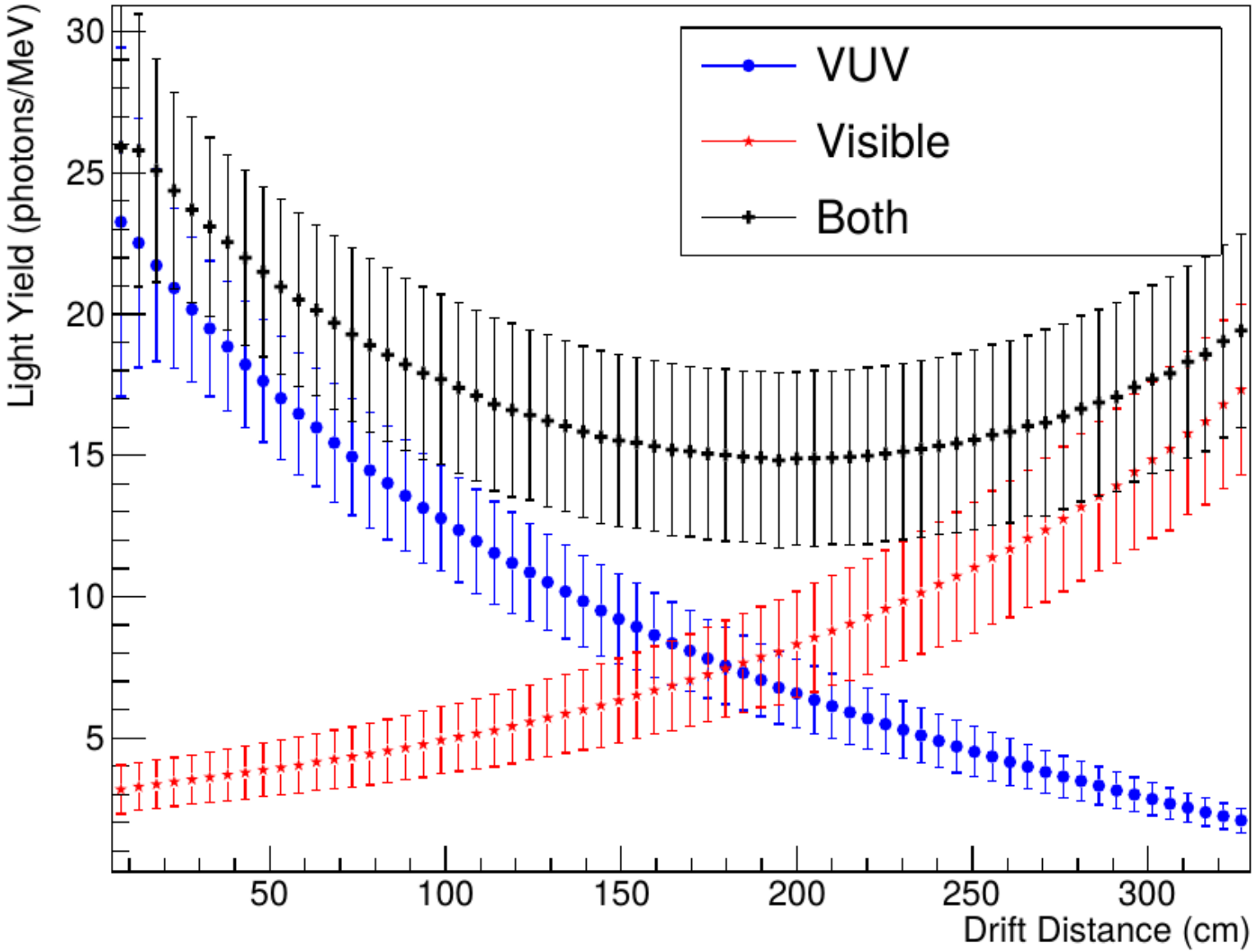
- SBND will implement WLS-covered reflector foils on the cathode to improve light collection.
- Sandwiched between two layers of metallic mesh.
- Production is halfway complete.

First SBND foil plate

V. Basque



Effect of foils



Assuming 2.5% ARAPUCA efficiency.

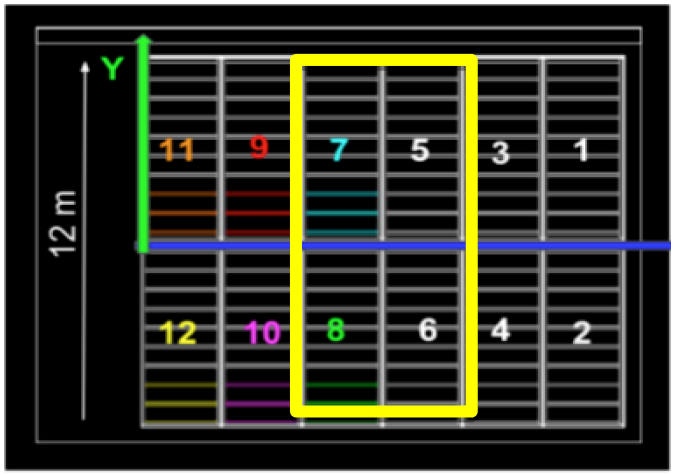
Applying measured transmittance of TPB coated glass

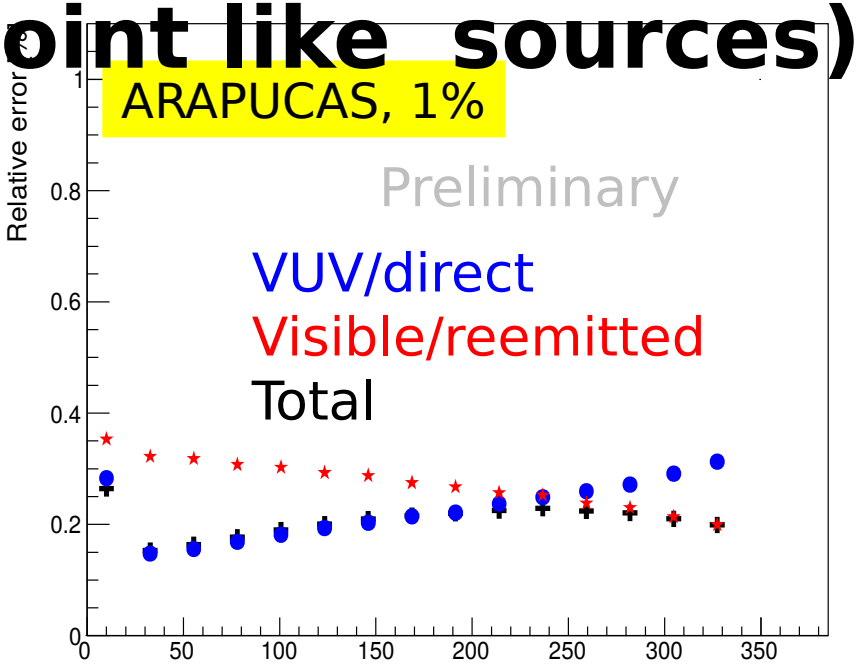
Keeping 50% of detectors not covered in WLS to improve uniformity. (not best case scenario)

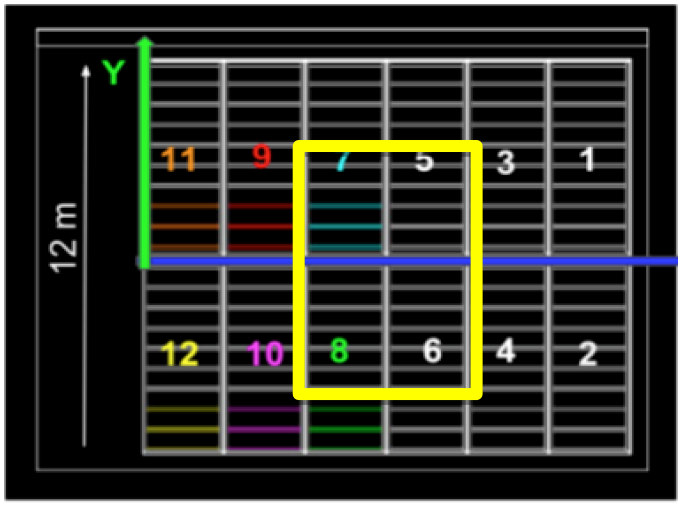
Assuming 80% cathode coverage (potentially conservative)

O. Bazavan, V. Griguta, Manchester

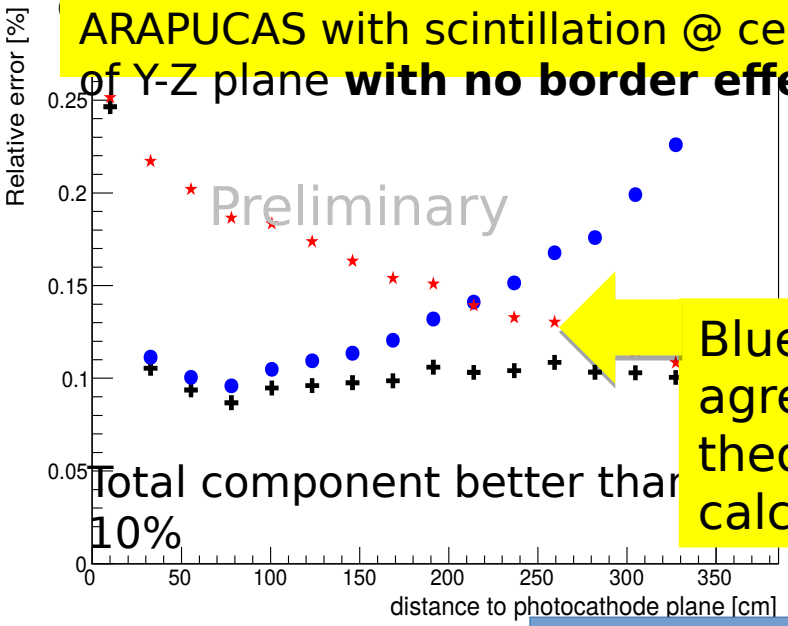
Supernova calorimetry? (10 MeV point like sources)







ARAPUCAS with scintillation @ center of Y-Z plane **with no border effects**



Blue points agree with theoretical calculations

D. Garcia-Gamez

Effects on timing constants

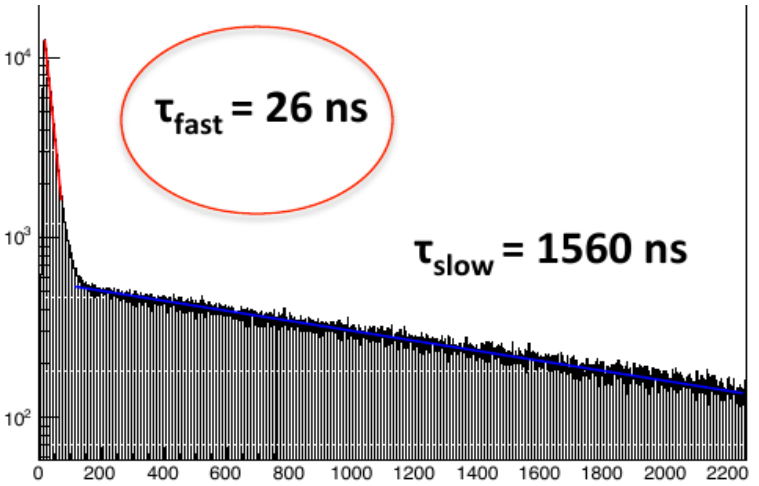
Scintillation:

0.3 x τ_{fast}(6 ns) + 0.7 x τ_{slow}(1590 ns)

+

Propagation:

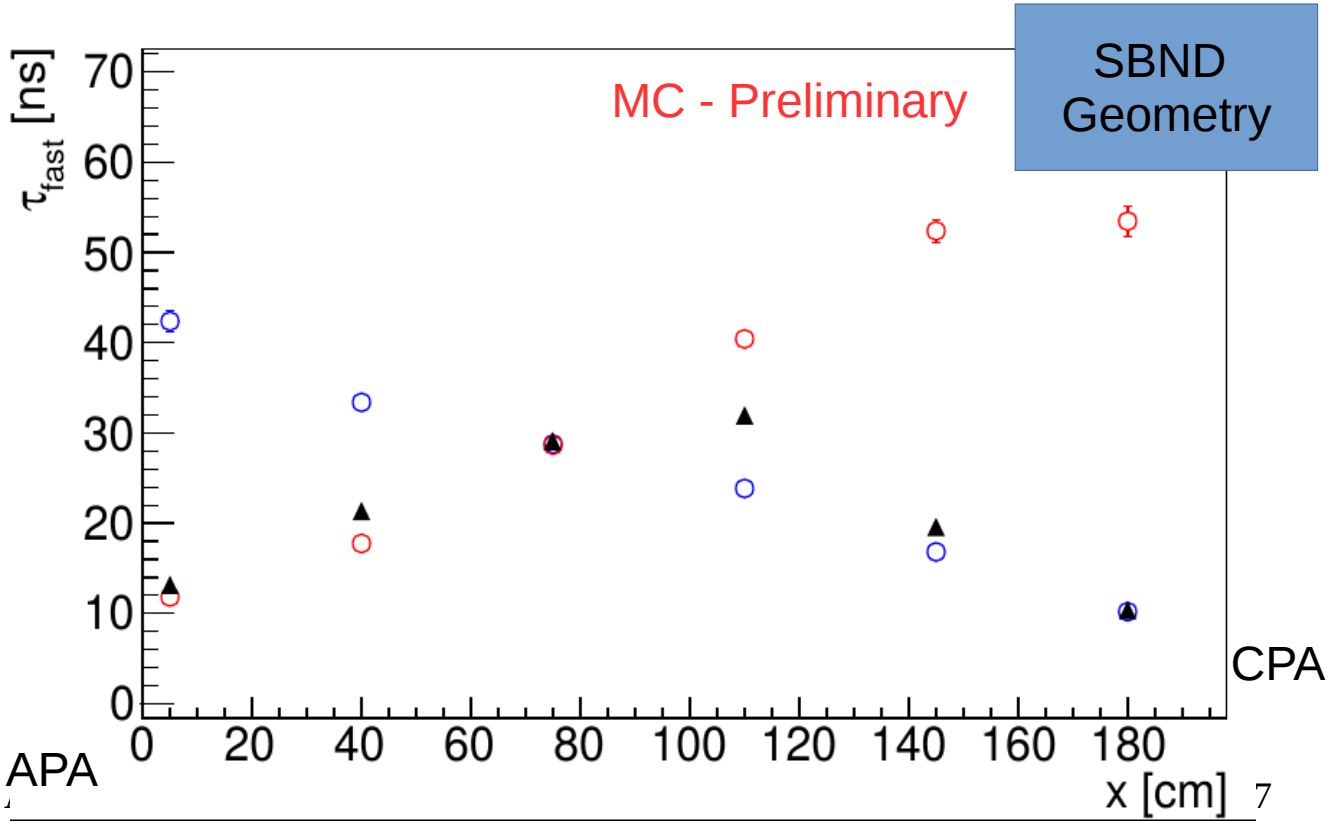
Direct transportation + Rayleight Scattering



Fast component life time changes as a function of distance.

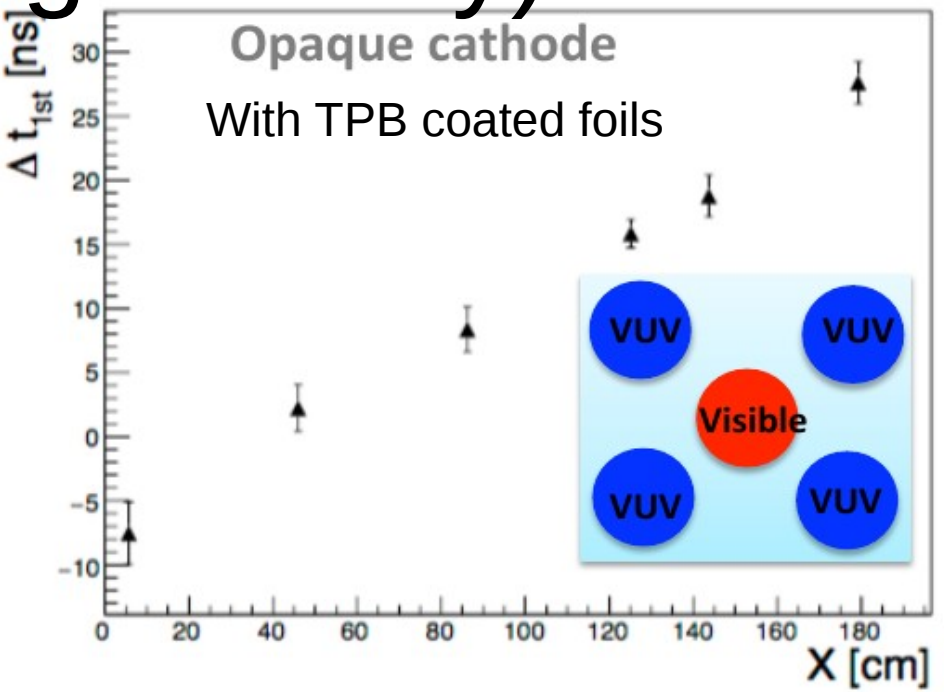
Triggers focusing on the fast component should account for this.

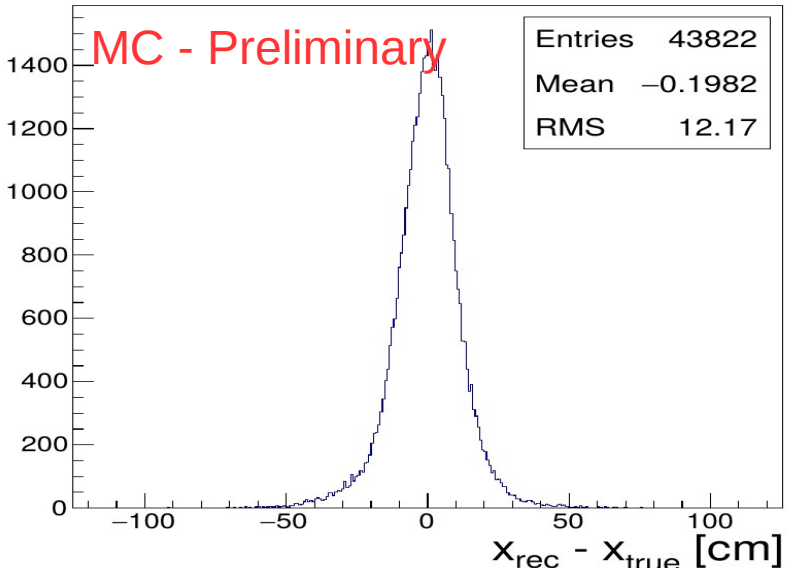
TPB lifetimes not Accounted for yet.



X-drift position resolution (SBND geometry)

- If able to differentiate VUV from Visible (re-emitted) possible to get position in x “on the fly”.
- Additional handle to disentangle multiple events in the same frame.
- Needs relatively good timing resolution (under study for DUNE)





With ARAPUCAs can obtain this effect by leaving some detectors uncoated with WLS.

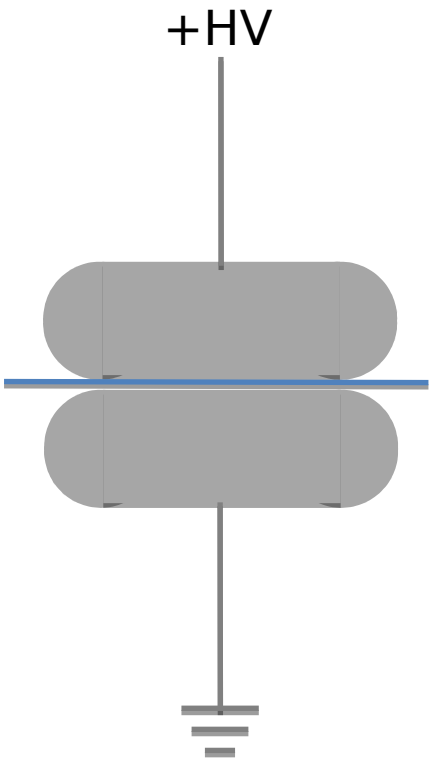
Plots shown for SBND config. Tool almost ported To DUNE geom.

Foils in DUNE

- The main questions are:
  - Compatibility with the HV system.
  - Sensitivity of light detectors (ARAPUCA/X-ARAPUCA) to visible light.
  - Need to understand engineering and installation procedures (work being performed by the HV consortium).

How do we know the foils are dielectric?

- foils on cathode will need to tolerate some charge build-up or voltage variation
  - eg 0.5 cm perforations lead to 300 V variation on foil surface (from simulations)
- Checked HV breakdown strength across film/foil samples submerged in LN
  - samples sandwiched between 6 cm diameter electrodes
  - stepped up voltage until breakdown occurred

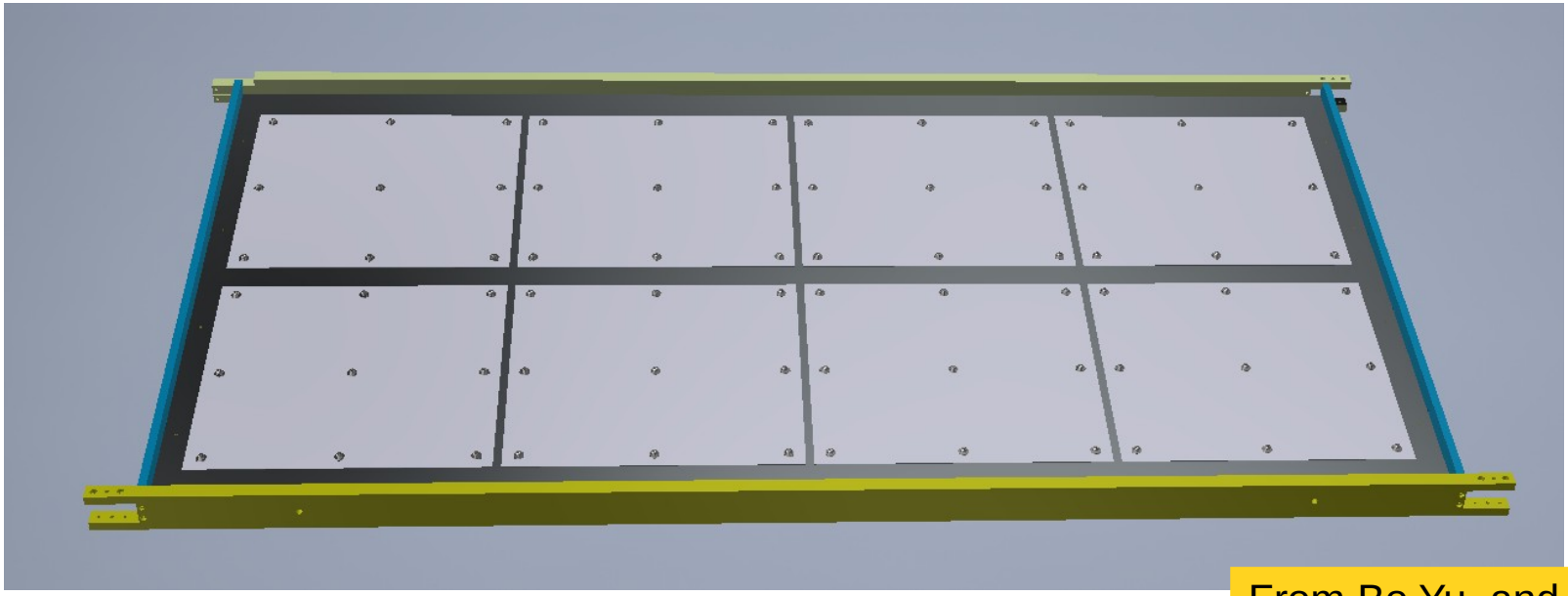


Material	Voltage Breakdown
ViKuity TPB coated	>40.0 kV
PEN film	22.5 kV
DM2000 non coated	46.3 kV

Clark Griffith, Sussex

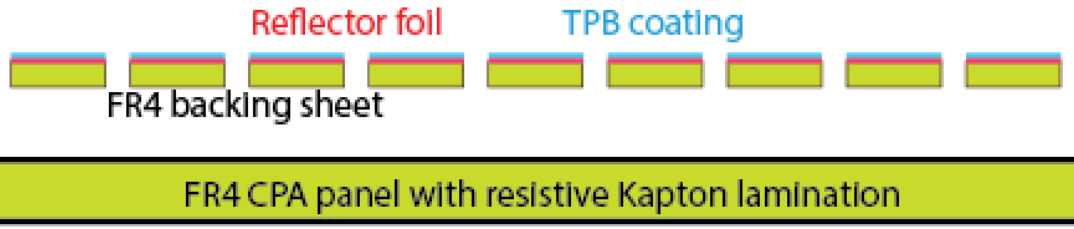
How to mount foils on the CPA

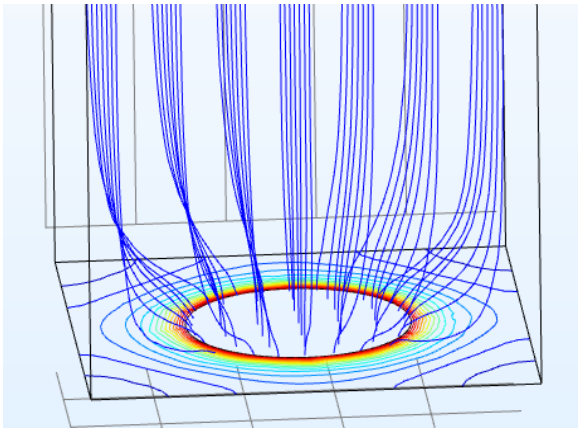
- The goal is to minimize the impact on the CPA construction. The reflector foils could be implemented post CPA production.
- The preferred solution is to maintain the current CPA design, and include a set of attachment holes on each CPA resistive panel to allow the installation of reflector foils in smaller tiles on both sides of the CPA surfaces at ITF or in the UG cleanroom.



From Bo Yu, and Francesco Pietropaolo

Reflector mounting options:



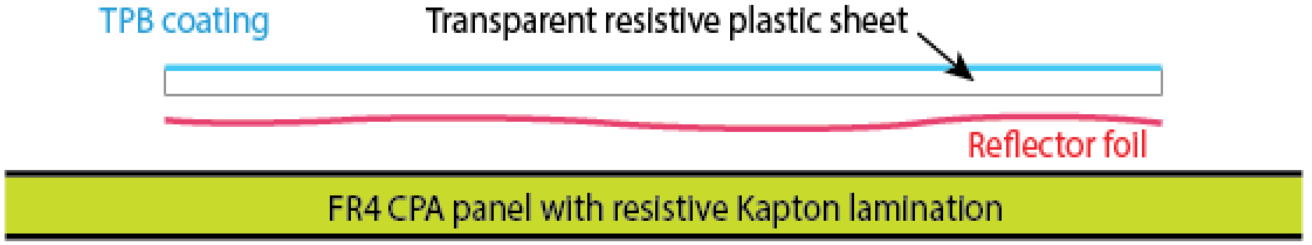


Potential distribution on a 1cm square cell with 5mm hole. The maximum voltage at the corners of the cell is 290V.

Reduces coverage, but electric field goes back to normal quickly.

Preliminary measurements by F. Pietropaolo at CERN
Show v. high, but finite resistivity – may not need perforation.

High resistivity acrylic has been Identified. Need to measure after evaporation and performance of the whole system. (in progress)



From Bo Yu, and Francesco Pietropaolo

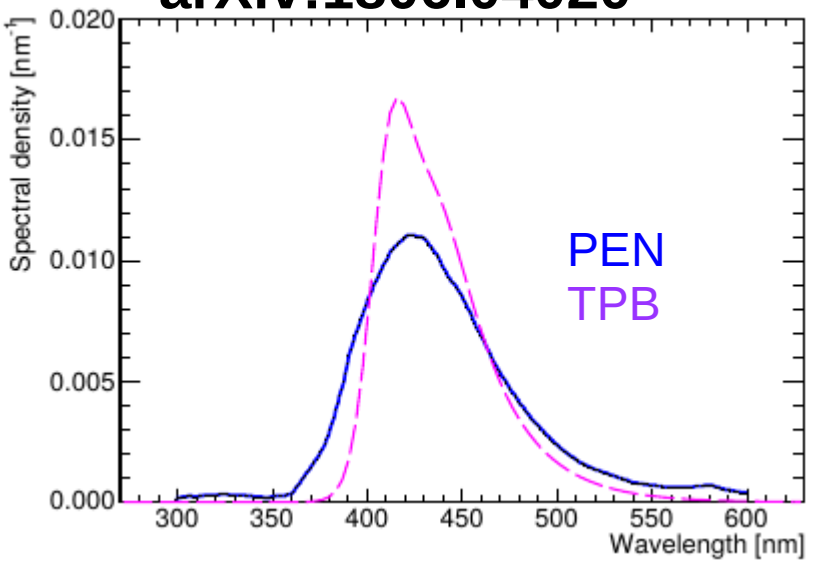
Ongoing Tests/Alternative Options.

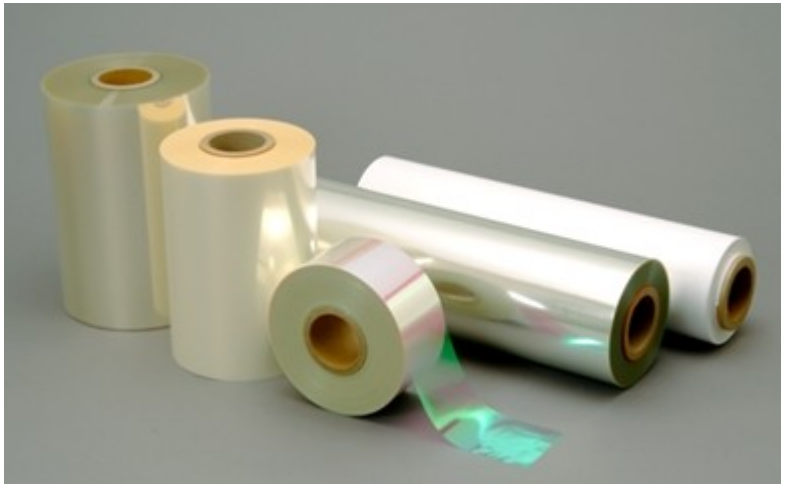
- Test behaviour of glass, filters, resistive acrylic to visible light. Test behaviour of PEN in cold and to VUV.
- Plan to test performance of foils on CPA in CERN test stand – likely to be late November time frame.
- Next steps – protoDUNE run II tests.
- In parallel, simulations ongoing to repeat performance studies being done or already done without foils.

PEN as an alternative to TPB

- PEN is a wavelength-shifter that is delivered in sheets. Recently proposed as an idea for large scale detectors.
- Foils with PEN
  - Need to figure out coupling to foils, and behaviour in cold.
  - Need to measure performance on foils (in progress)
  - Potentially could make foil preparation much easier.

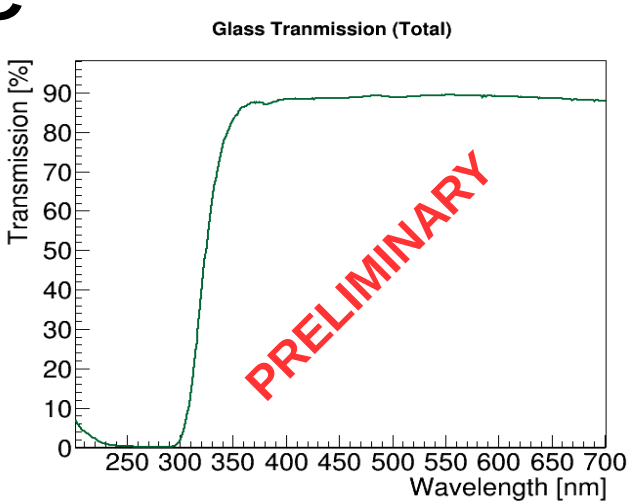
Kuzniak & Broerman
arXiv:1806.04020

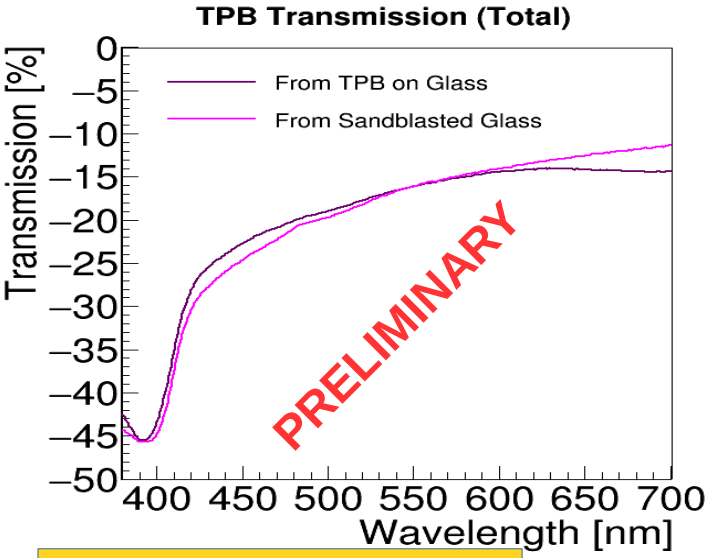




Measurements of Transmittance/Reflectance to Visible

- Performing a suite of measurements to benchmark the transmittance and reflectivity of various detector elements glass, filters, foils, acrylic (and the effect of TPB and PEN coverage).
- Will try to expand to pTp.
- Currently measuring at visible Wavelengths.
- May expand to VUV later this month with UNICAMP setup.

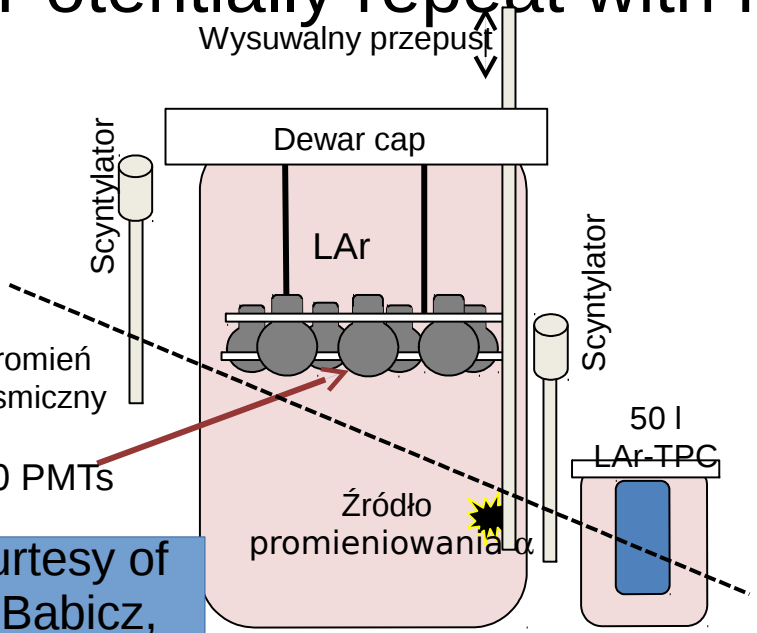




S. Cotton, C. Harrison, Manchester

Tests at CERN test stand (Foil – CPA, HV Compatibility)

- Plan to run in CERN 50 l dewar before end of year.
- Look for discharges and space-charge effects.
- CPA plate in Manchester, will be evaporated in next days.
- Potentially repeat with PEN in the new year.



Courtesy of M. Babicz, CERN

CPA plate with Glued on Reflective foil.

Conclusions

- Wavelength-Shifter covered reflector foils can improve the DUNE Light Collection System performance, especially close to the cathode.
- The production technology is understood, and has been employed in relatively large scale projects before.
- R&D needed to ensure it works in DUNE is underway.

Backup

Can we do SN calorimetry?

(slides in indico)

Alex Himmel, Fermilab

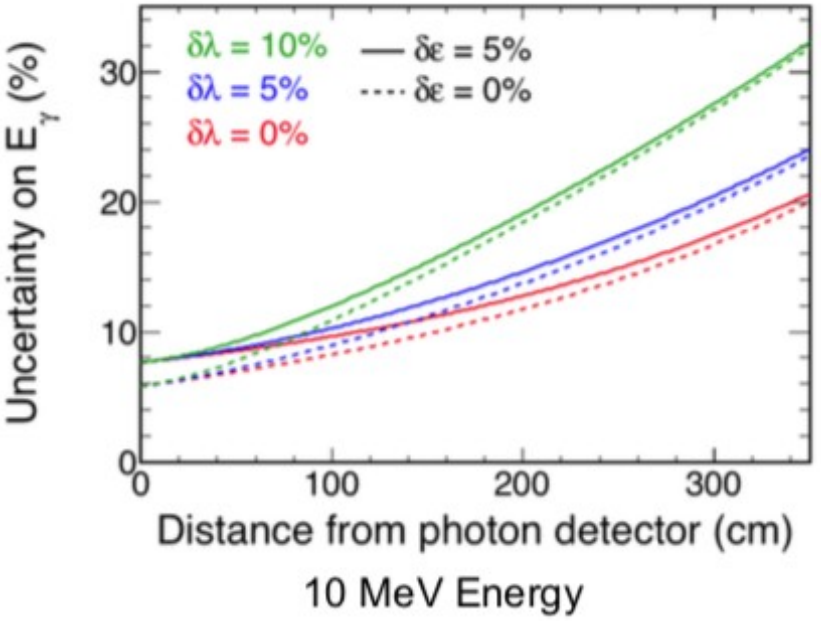
PD Consortium Sim+Physics Meeting

March 23rd, 2018

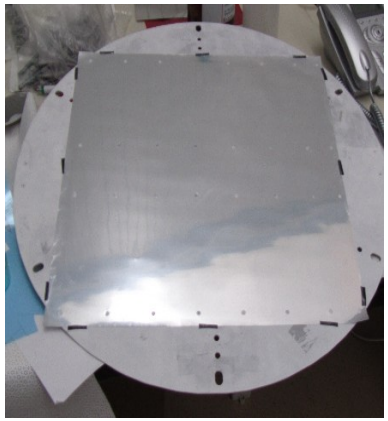
(best current ARAPUCA expectations)

$$\frac{\delta E_\gamma}{E_\gamma} = \frac{1}{\sqrt{N_\gamma}} \oplus \frac{\delta x}{\lambda} \oplus \frac{x}{\lambda}\left(\frac{\delta \lambda}{\lambda}\right) \oplus \frac{\delta \varepsilon}{\varepsilon}$$

- Photon counting statistics
- Uncertainty on position, relative to attenuation length.
- Uncertainty on attenuation correction.
- Uncertainty on efficiency and yield.

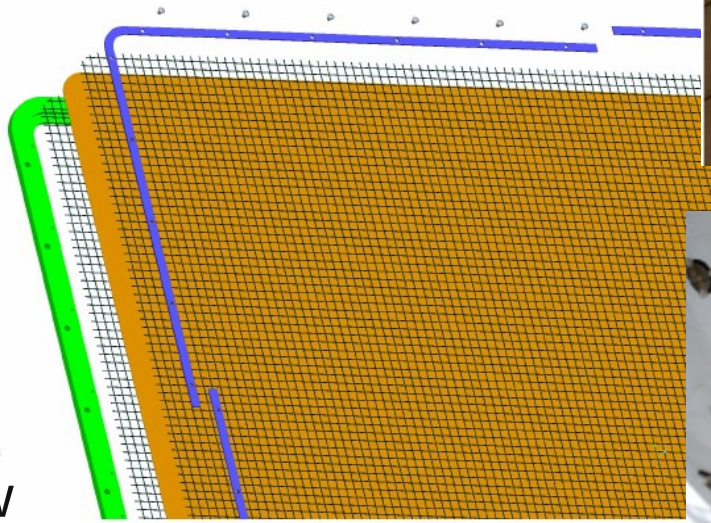


WLS covered reflector foils



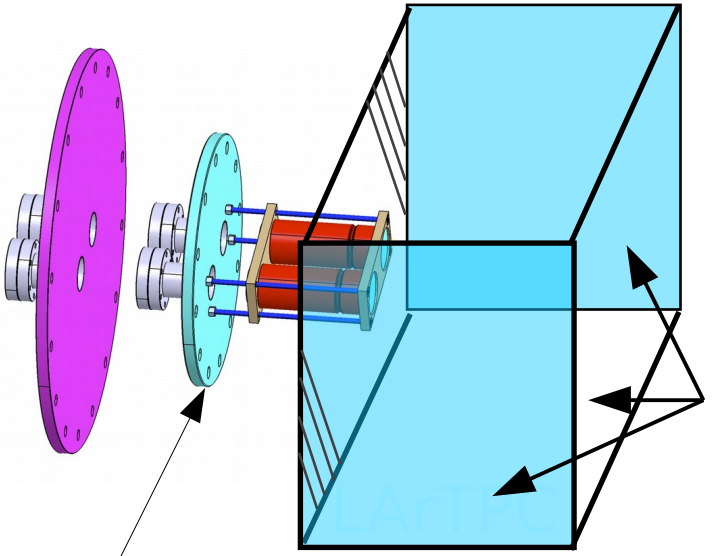
- Used in LAr DM experiments.
- di-electric reflector foils evaporated with WLS compound (TPB)
- Increase uniformity of light collection.

- A significant increase in collection efficiency over a setup with only PMTs/SiPMs – recover light normally absorbed on walls/CPA.
- Uniform and enhanced light collection efficiency is useful in triggering and studying low energy events.



Foils in LArIAT

- LArIAT has completed three full runs with foils installed.



Wavelength shifting reflector foil

Two cryogenic PMTS
- one 3” high QE (30%)
- one 2” standard QE (20%)

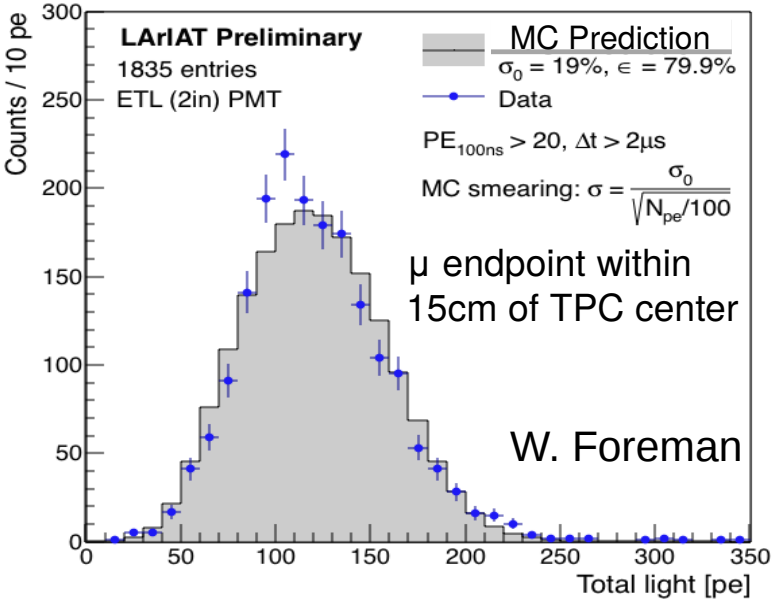
+3 SiPMs

Hamamatsu R11065

ETL D757KFL (2”)

- *Different foil configuration than proposed for SBND/DUNE, but same simulation methods.*

Michel Electrons



- predicted LY: 2.4 pe/MeV for 2” ETL PMT (Run I)

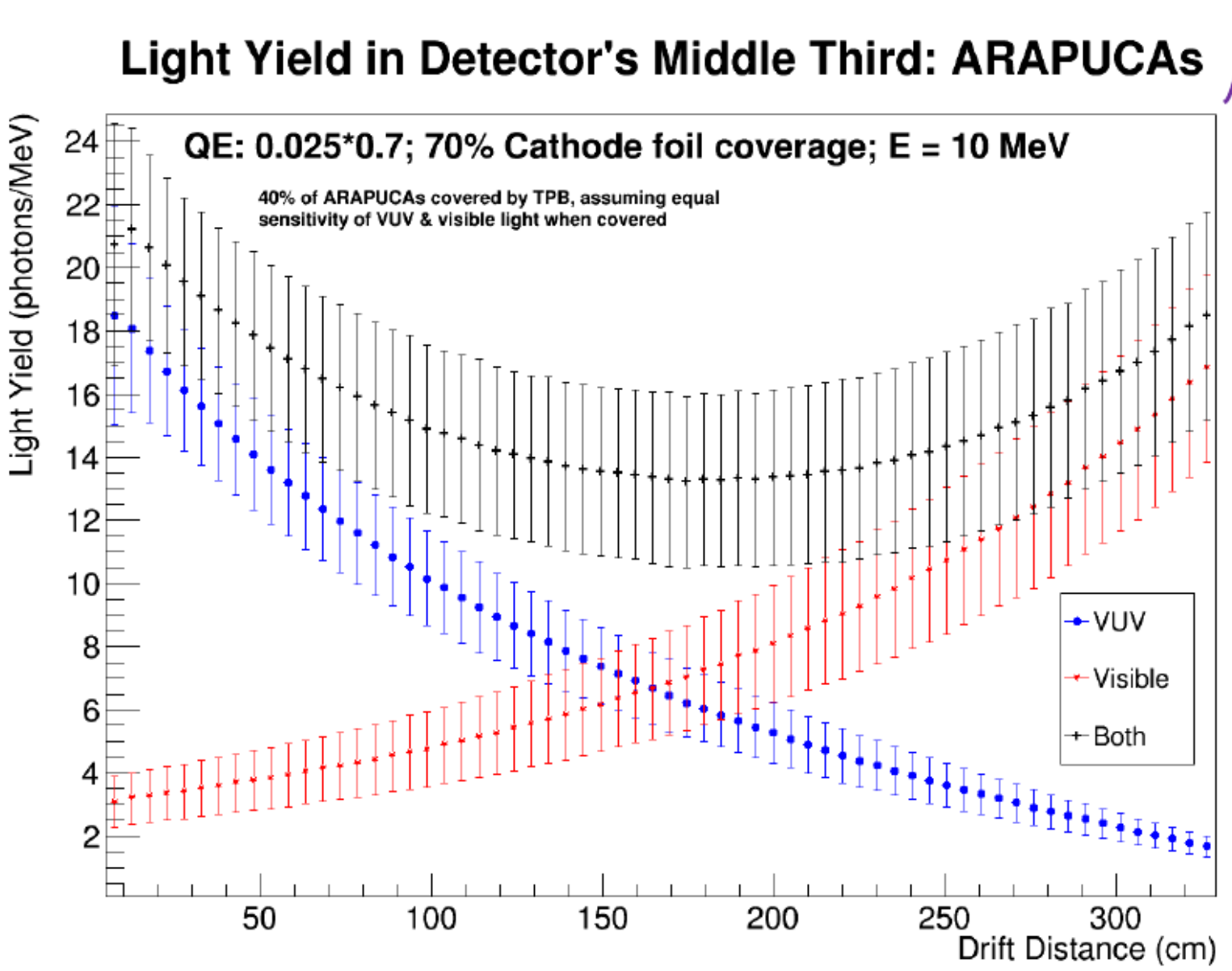
Matching WLS between foils and ARAPUCA

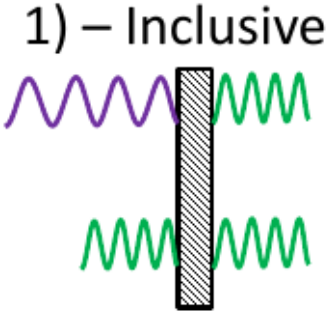
ARAPUCA coating→ Foil Coating	pT	TPB	PEN	Other
pTerphenyl				
TPB	Starting Point			
PEN				
Other				

General comments

- ARAPUCA covered with same WLS as foils – potentially best light collection efficiency (provided transparency of WLS on ARAPUCA is high – preparing measurements of TPB, PEN, pT on glass). ***"Inclusive LY"***
- ARAPUCA covered with a WLS "lower" than the foils – potentially good collection as well, although might have a 50% backwards effect. ***"Inclusive LY"***
- ARAPUCA covered with a WLS "higher" than the foils – lower light collections (ARAPUCA blind to reflected light) – need to add a lower filter version of ARAPUCA's (potentially no WLS on outside). ***"Exclusive LY"***

Possible Light Yield Plots





Assuming 2.5% ARAPUCA efficiency.

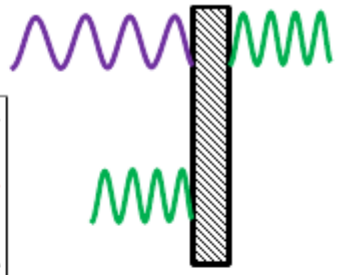
Leaving some ARAPUCA's uncoated on purpose to get uniform collection

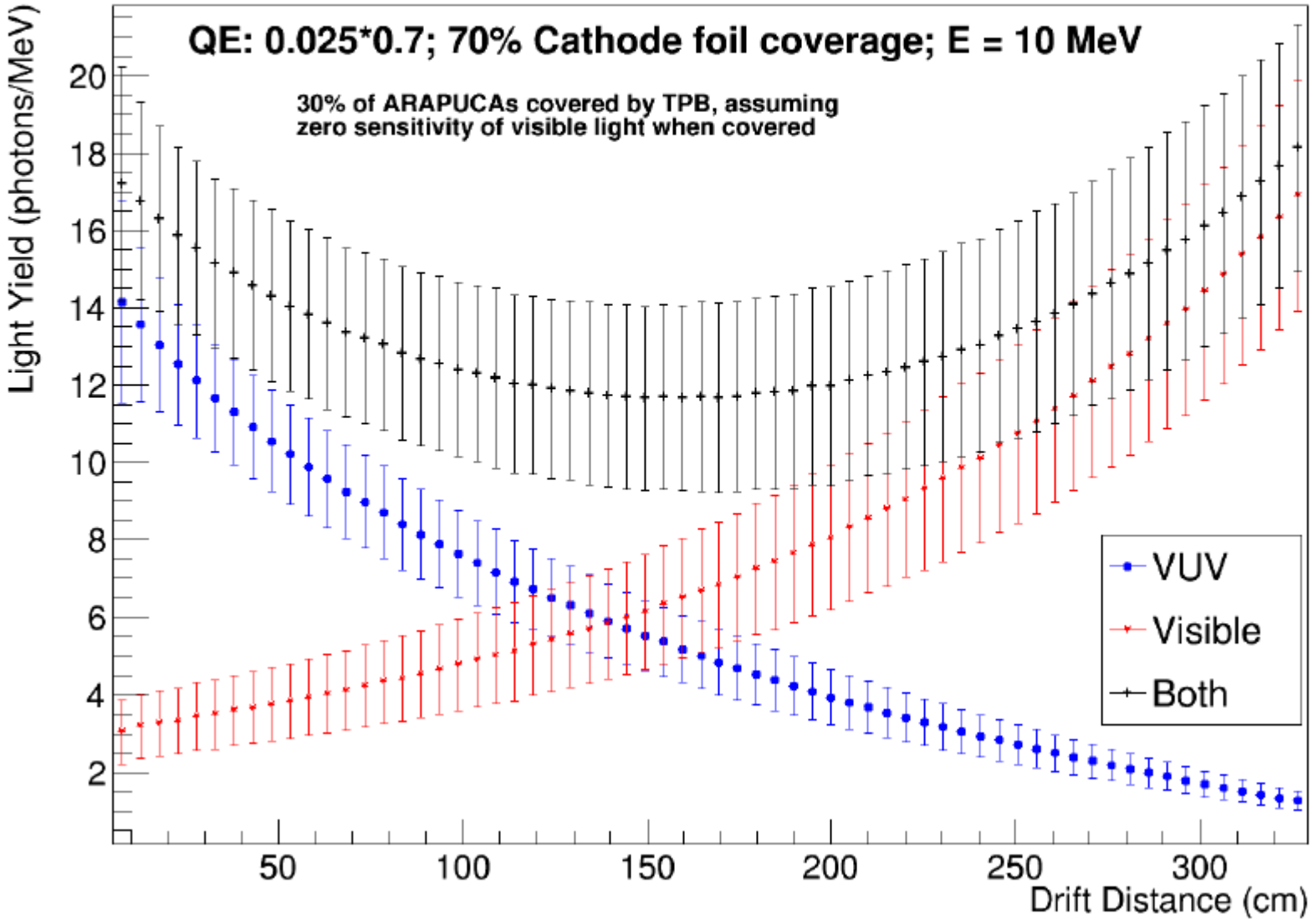
(not best case scenario)

Daniel Cookman, Manchester

Possible Light Yield Plots 2

2) – Exclusive





Assuming 2.5% ARAPUCA efficiency.

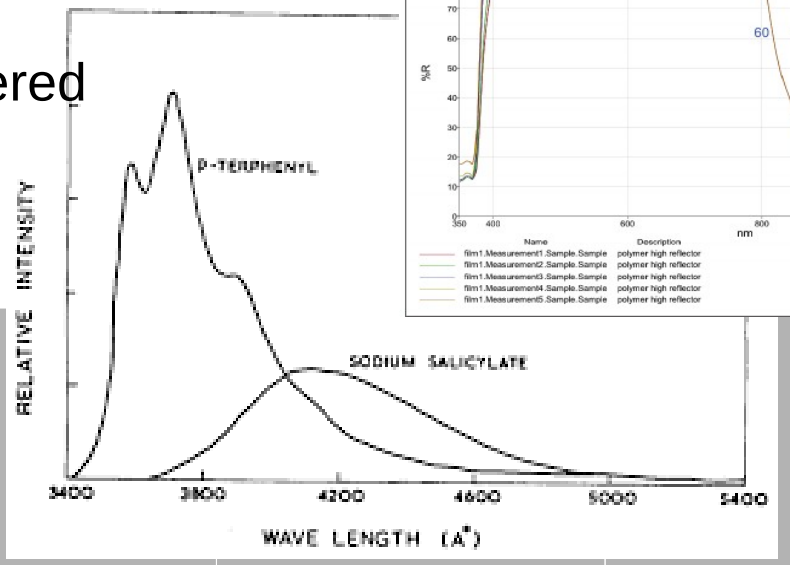
Leaving some ARAPUCA's uncoated on purpose to get uniform collection

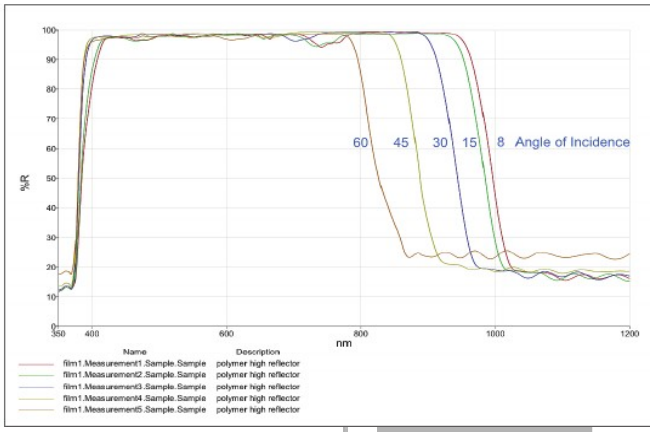
(not best case scenario)

Daniel Cookman, Manchester

Foils coated with pT

- According to measurements, foils won't work at pT wavelenghts.
- Also, no experience with foils covered with pT.





ARAPUCA coating→ Foil Coating	pT	TPB		
pTerphenyl	X	X	X	X
TPB	Starting Point			
PEN				
Other				

Foils/ARAPUCA coated with other (bis-MSB?)

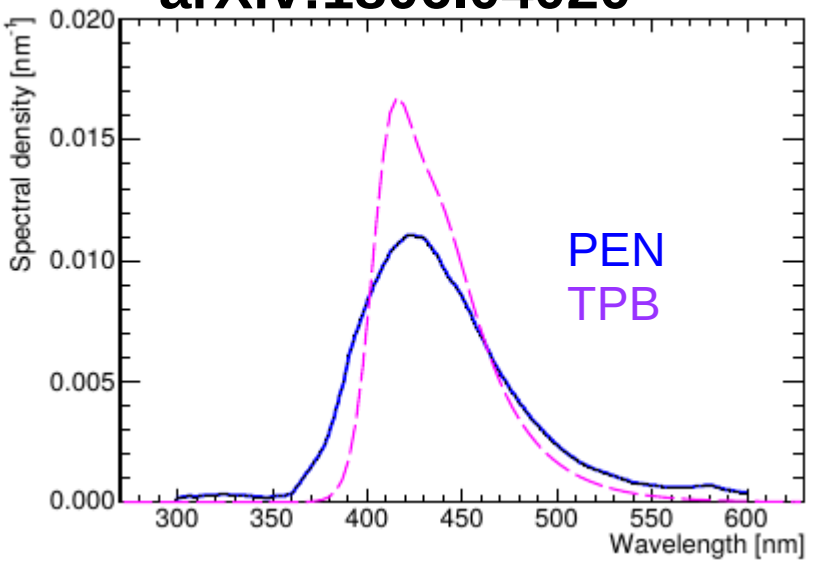
- Bis-MSB efficiency measured by Ettore et al. Looks comparable to TPB at visible, but worse at VUV. Not as useful.
- Would need aging/behaviour in cold studies.

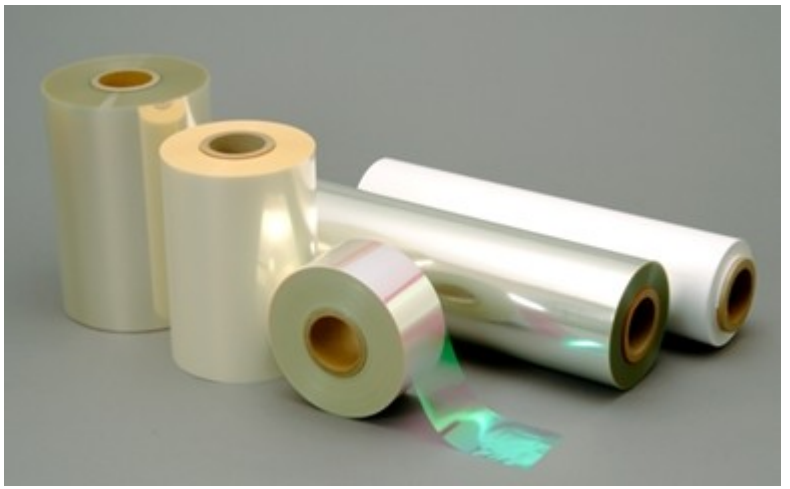
ARAPUCA coating→ Foil Coating	pT	TPB	PEN	Other
pTerphenyl	X	X	X	X
TPB	Starting Point			X
PEN				X
Other	X	X	X	X

ARAPUCA/foils covered with PEN

- Similar wavelengths to TPB. Would need R&D to develop coupling method. Not sure this is useful given the area of ARAPUCA's (evaporation is reasonable).
- Foils with PEN
  - Need to figure out coupling to foils, and behaviour in cold.
  - Need to measure performance on foils (in progress)
  - Potentially could make foil preparation much easier.

Kuzniak & Broerman
arXiv:1806.04020





Foils/ARAPUCA coated PEN

ARAPUCA coating → Foil Coating	pT	TPB	PEN	Other
pTerphenyl	X	X	X	X
TPB	Starting Point		X	X
PEN			X	X
Other	X	X	X	X

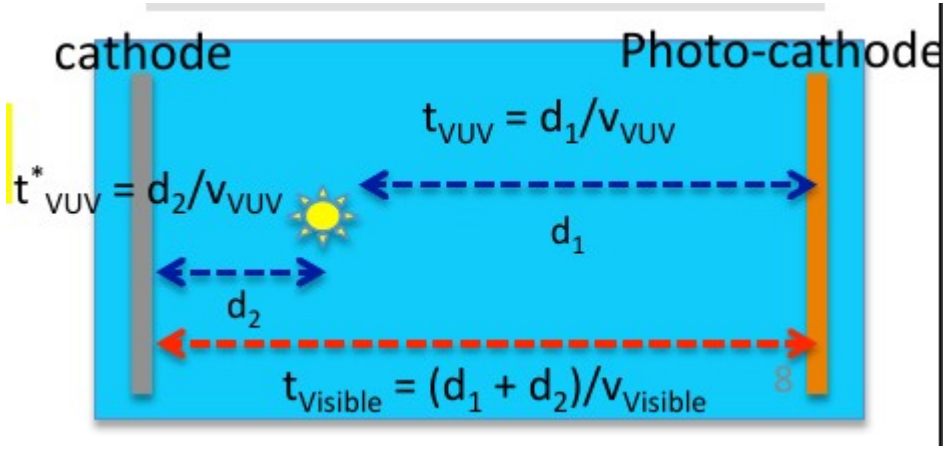
ARAPUCA coated with pT/ TPB

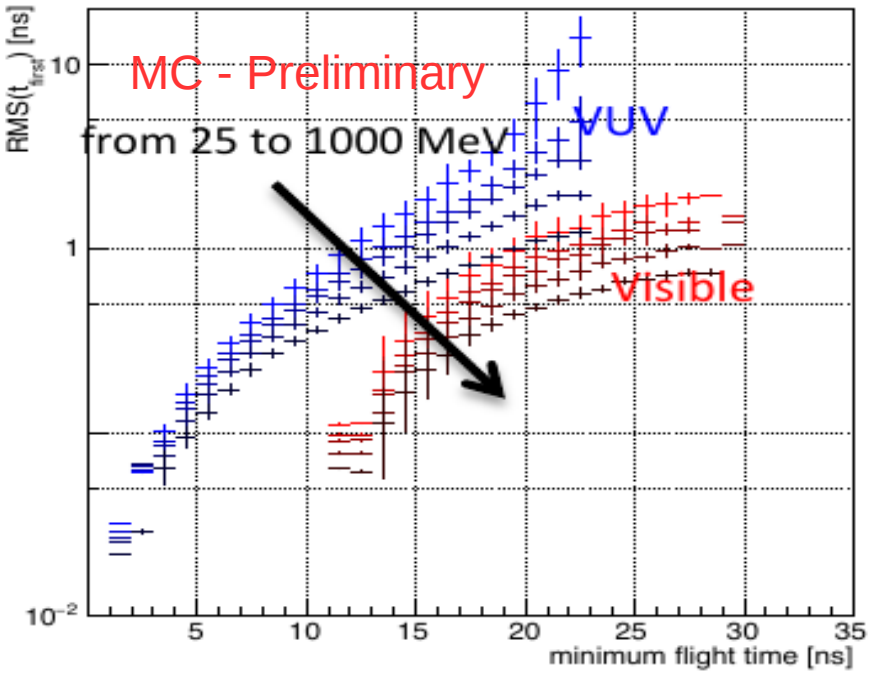
- ***pT on ARAPUCA:***
  - Foils covered with TPB (known technology)
    - ARAPUCA's blind to reflected light (exclusive LY).
  - Foils with PEN
    - ARAPUCA's blind to reflected light (exclusive LY)
- ***TPB on ARAPUCA:*** Need a different WLS on the inside (ELJEN green?)
  - Foils with TPB
    - ARAPUCA's sensitive to reflected light (inclusive case, possibly with a small correction – measurement being set up).
  - Foils with PEN
    - ARAPUCA's sensitive to reflected light (inclusive case, possibly with a small correction – measurement being set up).
- ***Foils with PEN***
    - Need to figure out coupling to foils, and behaviour in cold.
    - Need to measure performance on foils (in progress)
    - Potentially could make foil preparation much easier.

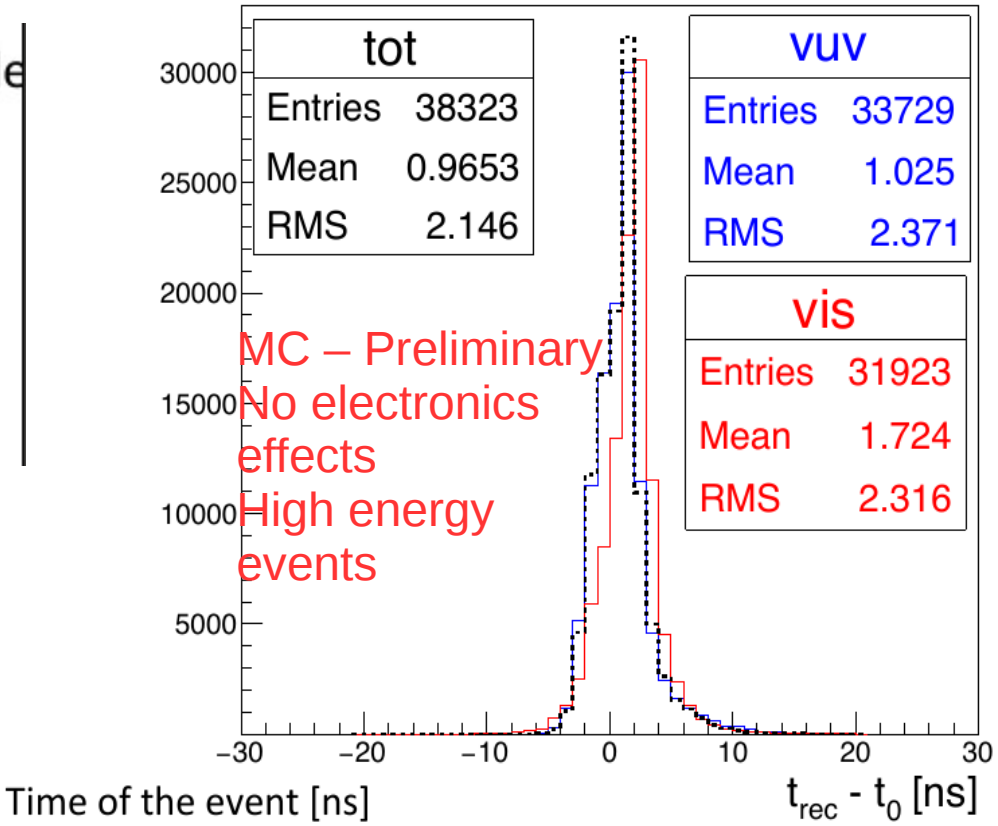
Foil and ARAPUCA WLS matching

ARAPUCA coating→ Foil Coating	pT	TPB	PEN	Other
pT	X	X	X	X
TPB	Current: LY excl.	LY. Incl. – need WLS R&D on inside of AR.	X	X
PEN	LY excl. Some R&D needed for PEN	LY Incl. - need WLS R&D on inside of AR. (similar for PEN)	X	X
Other	X	X	X	X

Timing (SBND geometry)



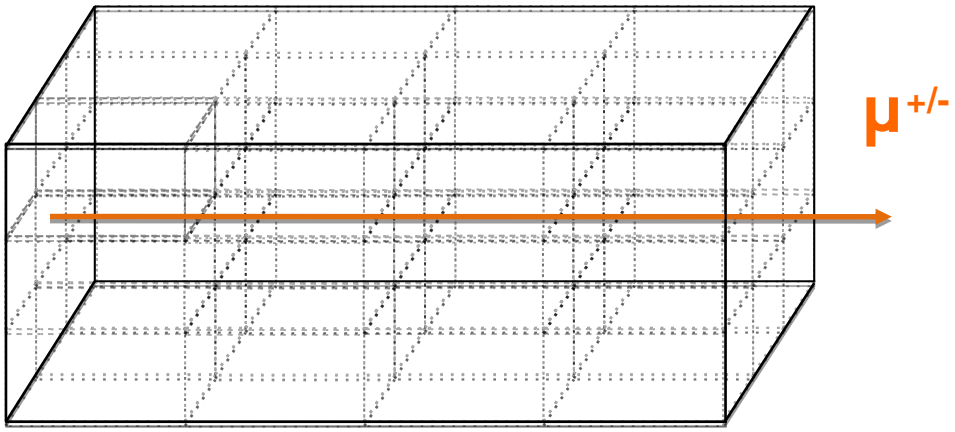


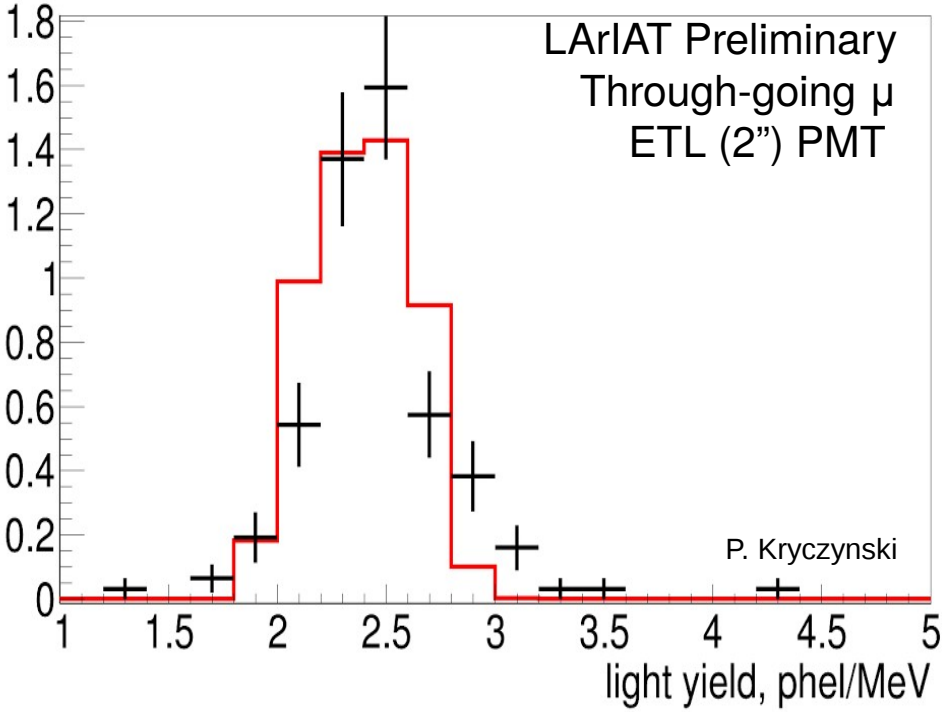


Timing resolution depends on the quantity of arriving light (smaller chance of missing photons coming in)

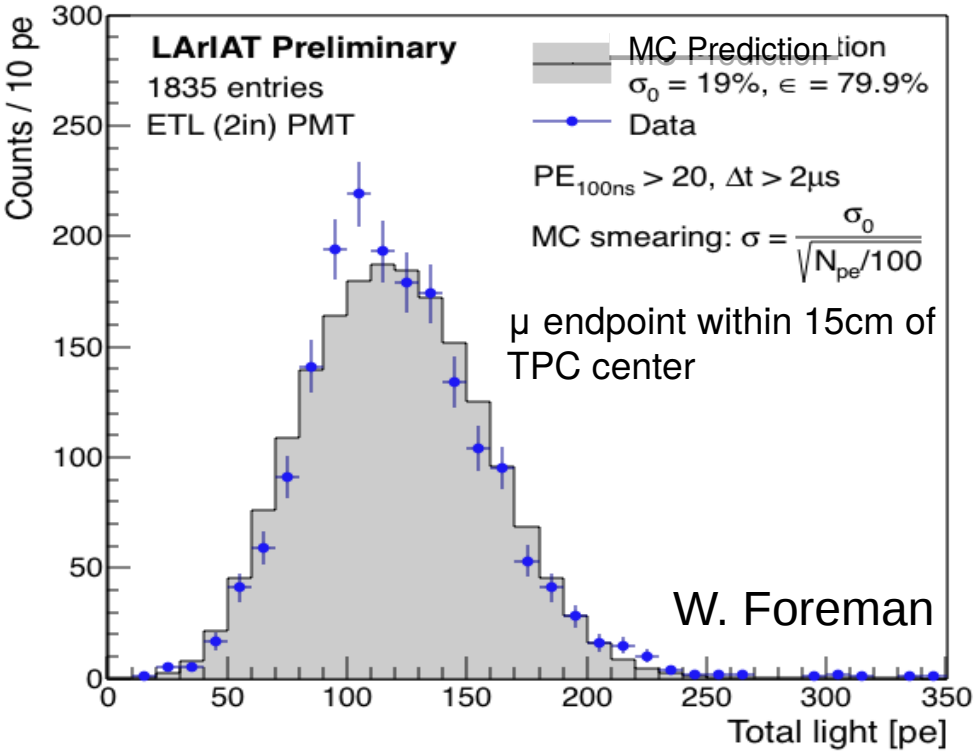
Validating the Simulation in LArIAT data

- Through going mu:





- Michel electrons:



- predicted LY: 2.4 pe/MeV for 2" ETL PMT (Run I)