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Light Readout Solutions Applicable to Large Underground Liquid Argon TPCs

Andrzej Szelc

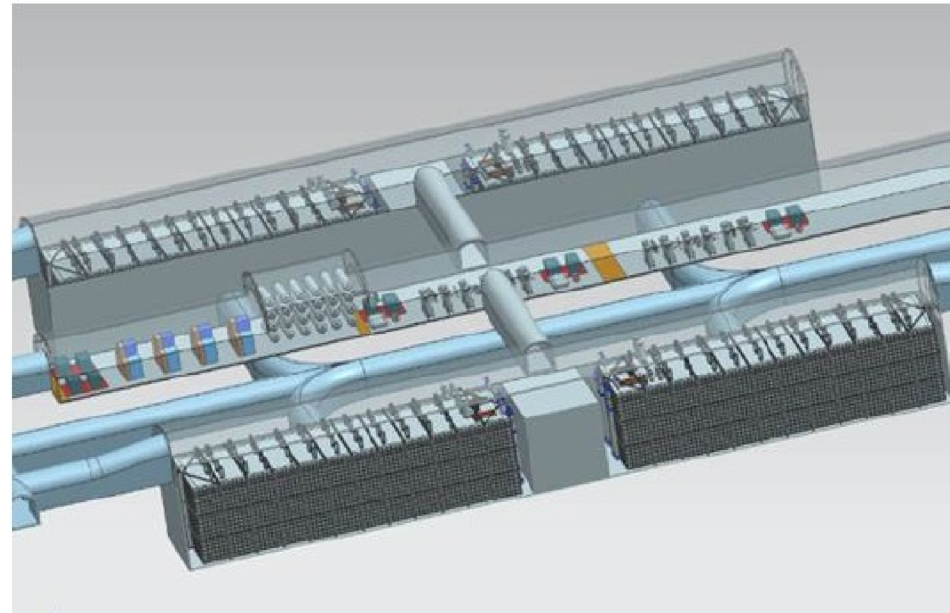
(University of Manchester)

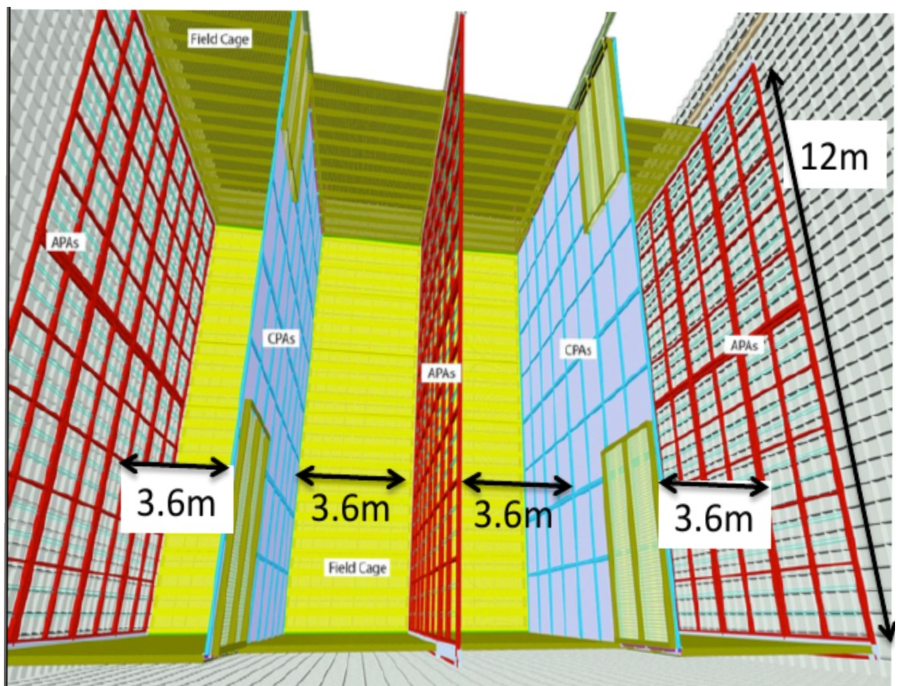
Introduction

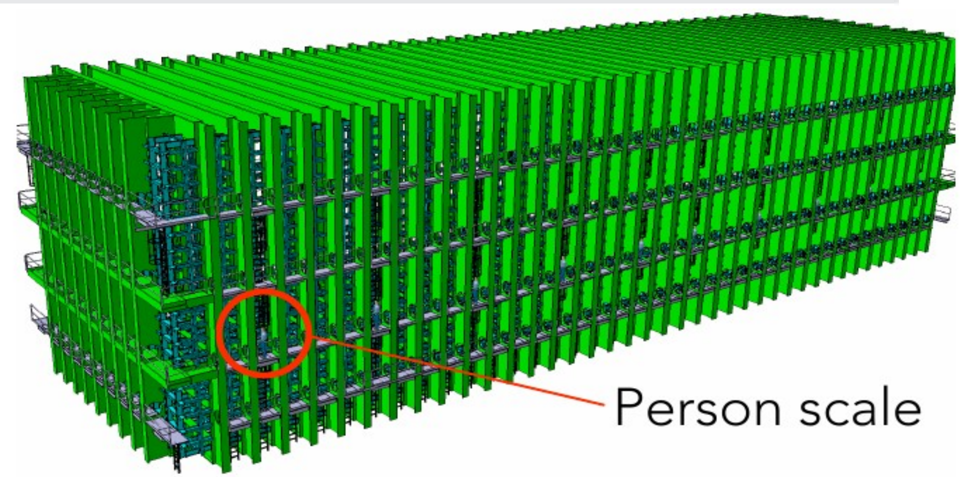
- I will be talking about Light Readout Options that could be applied to a future large LAr detector.
- I wanted to concentrate on what currently running or soon to be running detectors can teach us about such solutions.
- Different physics we want to do. Ways to get to there: the parameters we need to measure and the detectors we can use.

Future Large Underground Liquid Argon TPCs

1. DUNE
2. ...







DUNE Far Detector Module (10 kTons)

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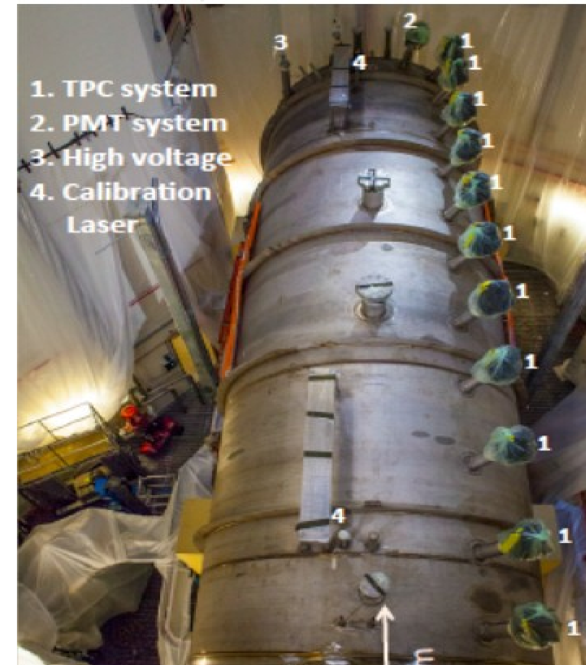
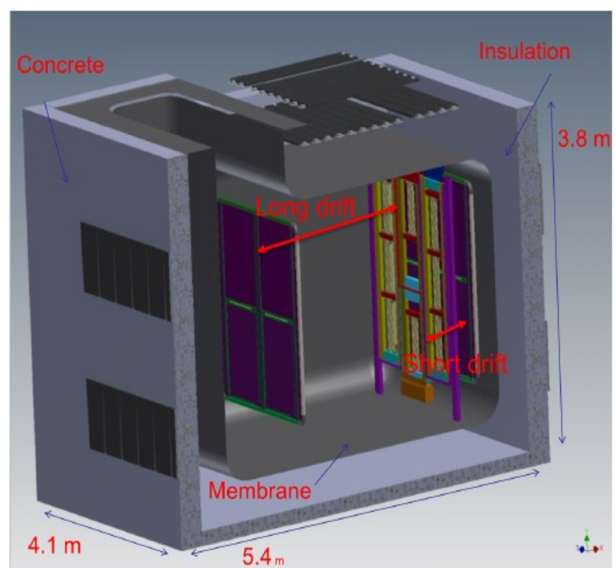
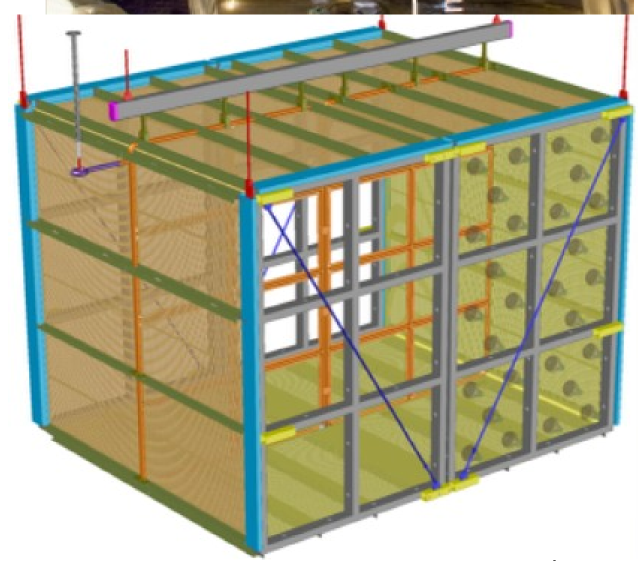
Present Smaller ~~Underground~~ Liquid Argon TPCs

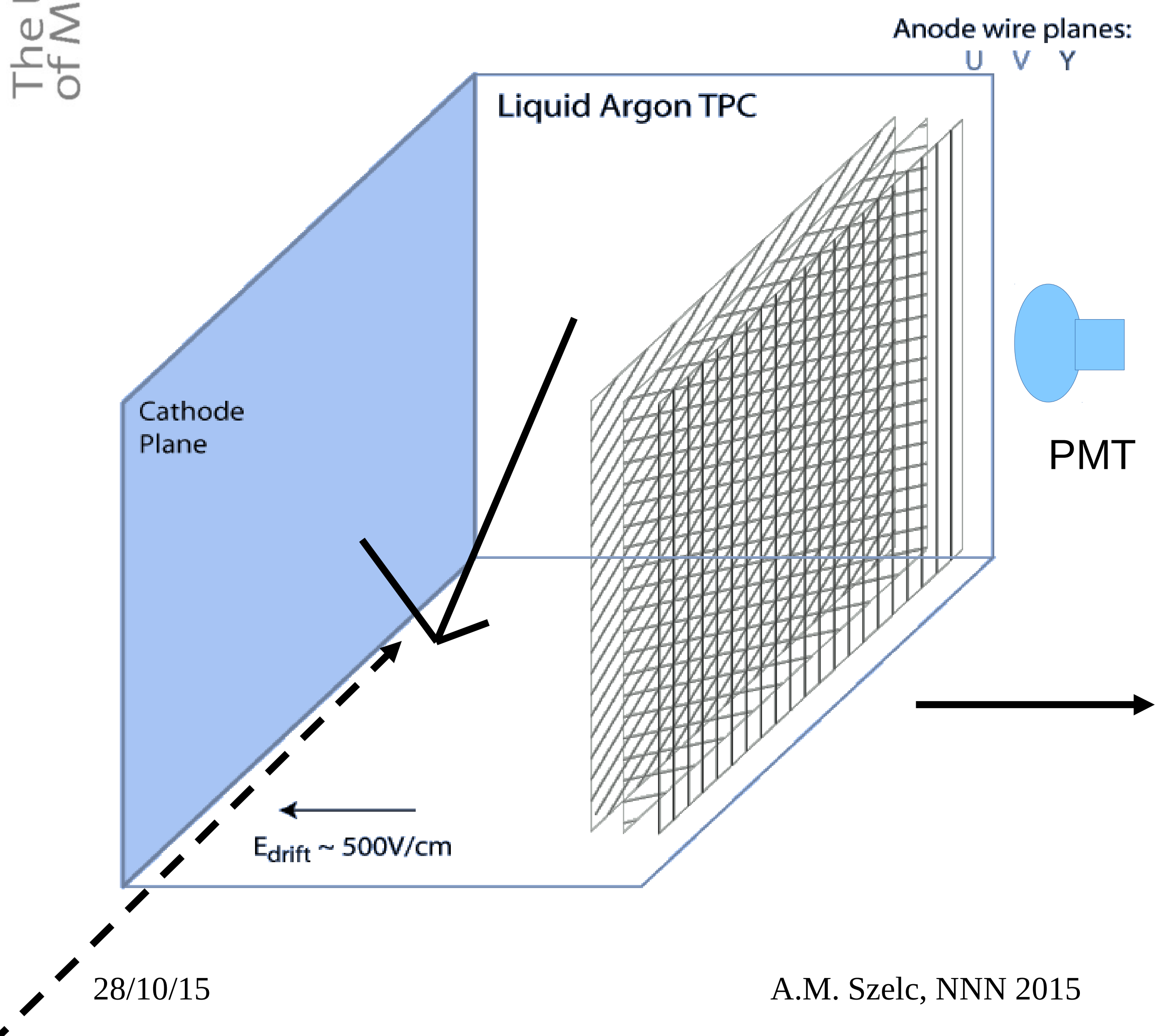
- MicroBooNE
- LArIAT
- 35-ton Prototype
- SBND
- Apologies to many other experiments I will not talk about.

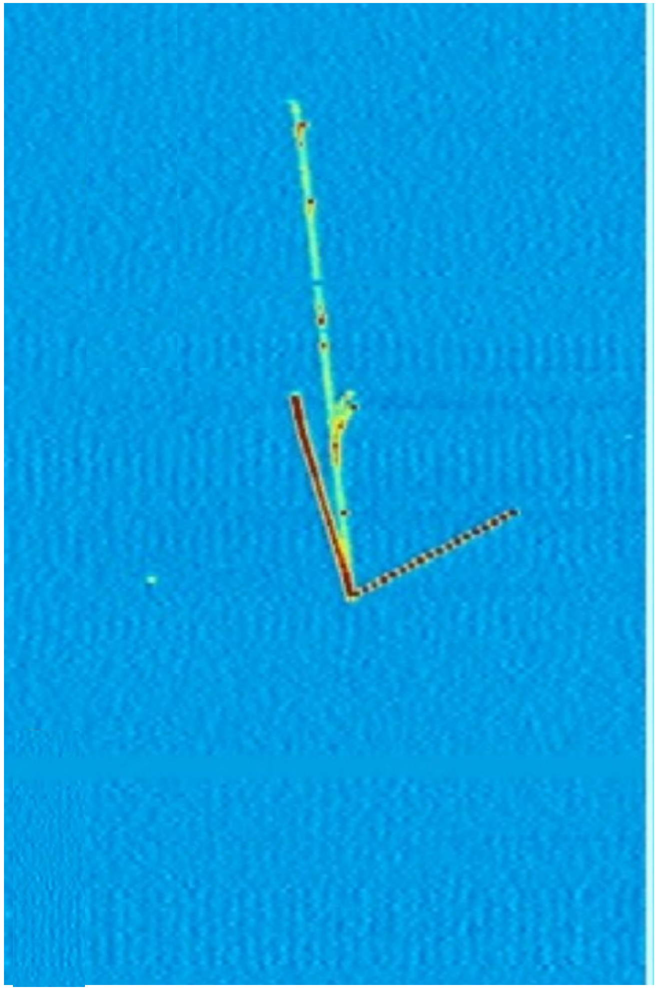




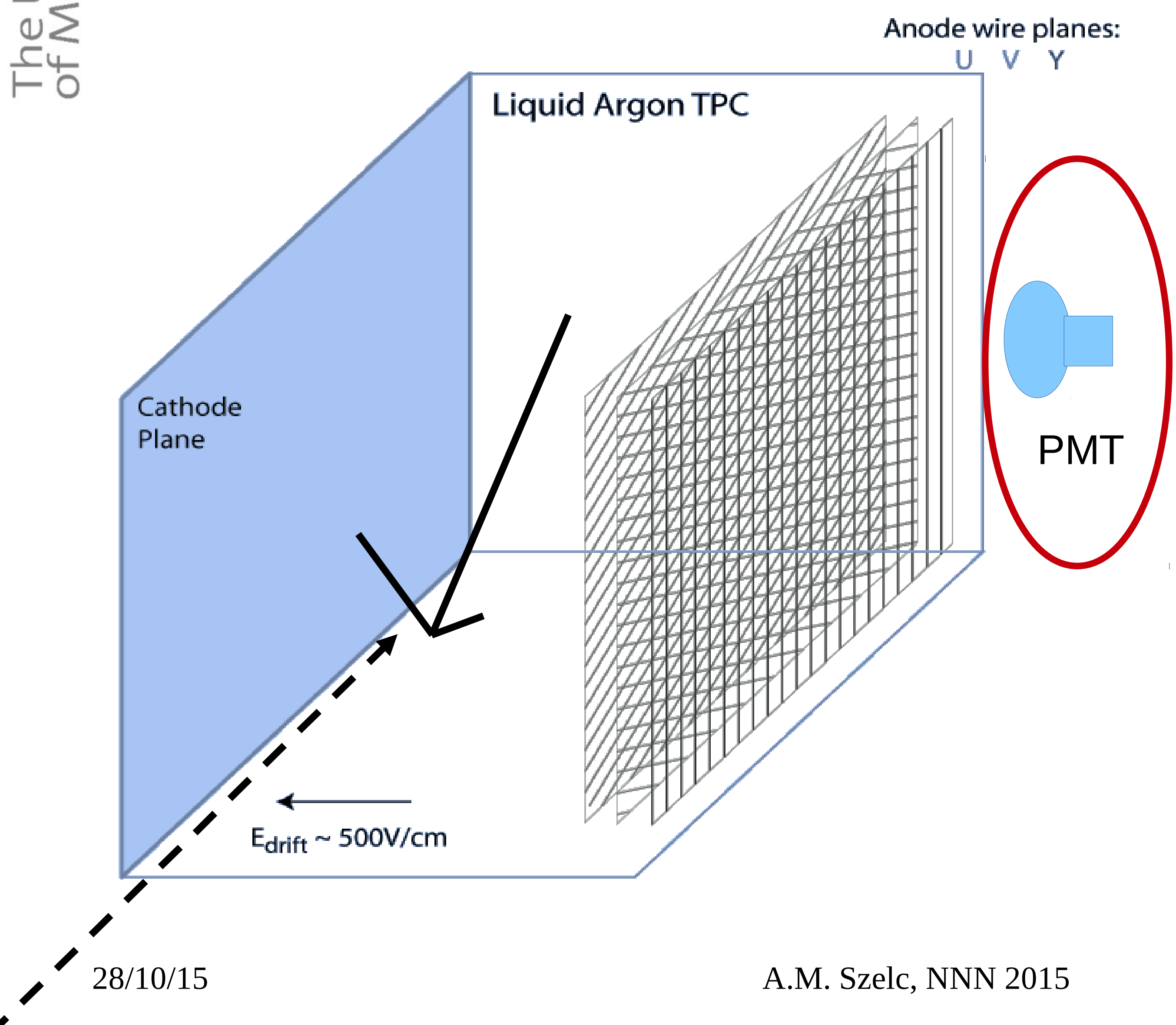


LArTPC detectors





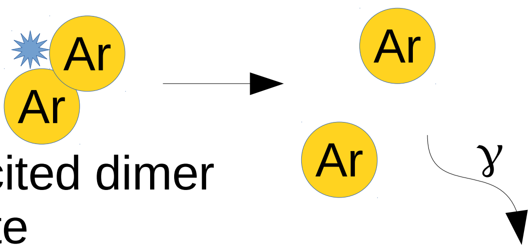
LArTPC detectors (2)



- LArTPCs seem to do a good job using ionization charge.
- Why do we care about scintillation light?

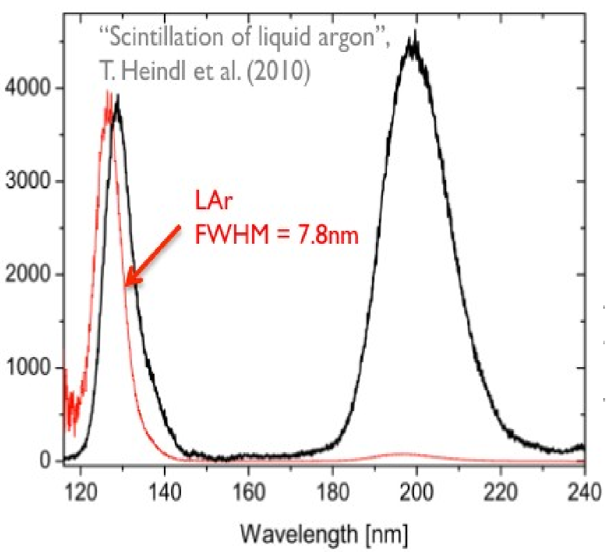
Scintillation Light in Argon

Emission:



Excited dimer state

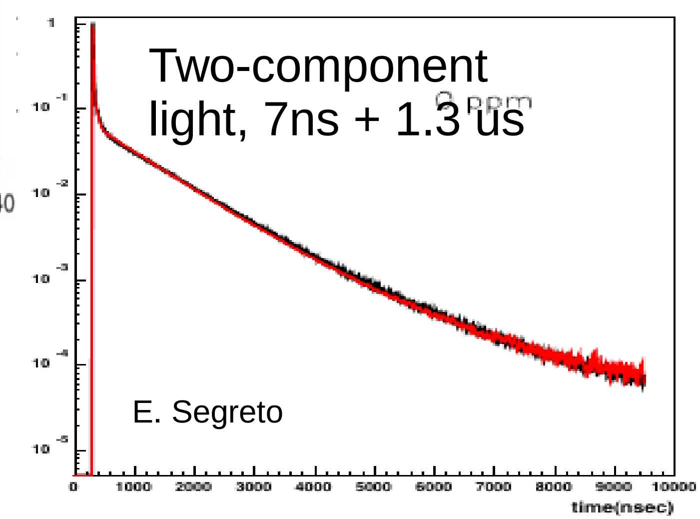
Photons are all ~128 nm – VUV



Transport:

Liquid argon is mostly transparent to its scintillation.

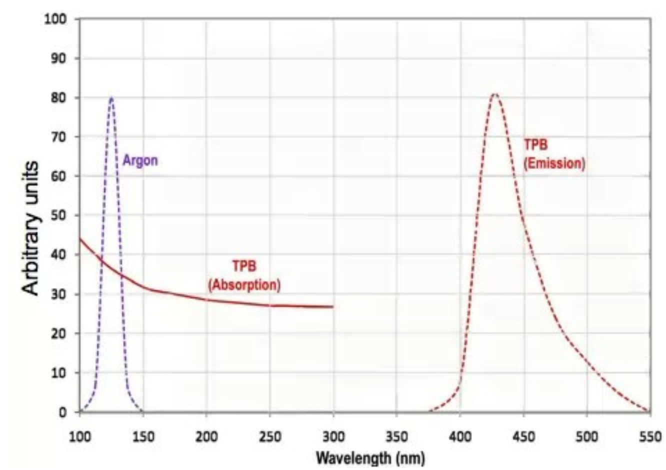
At longer distances Rayleigh scattering ~55m f(λ) and absorption, e.g. on nitrogen ~30 m @2ppm N2 begin play a role. Note high refractive index ~1.5 for VUV.



Detection:

Liquid argon is almost the only thing transparent to its scintillation.

Detection is challenging – most often need to use Wavelength shifting compounds, like TPB.



Physics with LAr Scintillation Light

LIGHT DETECTION COMPONENTS:

PMTs

SiPMs

Scintillating bars

Reflector foils

Other?

Optimized for

APPLICATIONS:

Triggering

Positional Reconstruction

Timing/Timestamp

Energy Reconstruction

END GOAL

PHYSICS:

BEAM (CP-violation)

Nucleon Decay

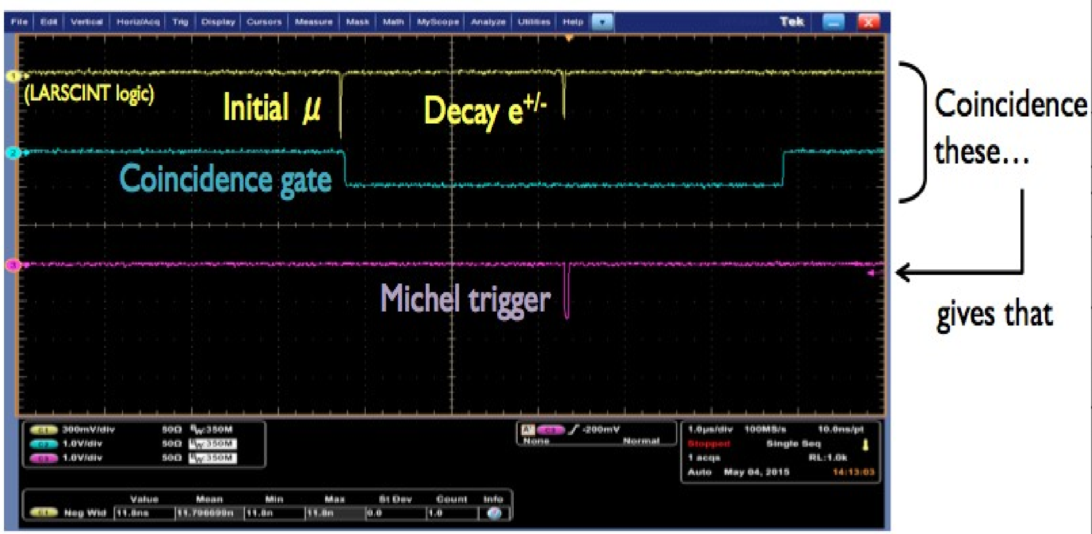
SuperNova Neutrinos

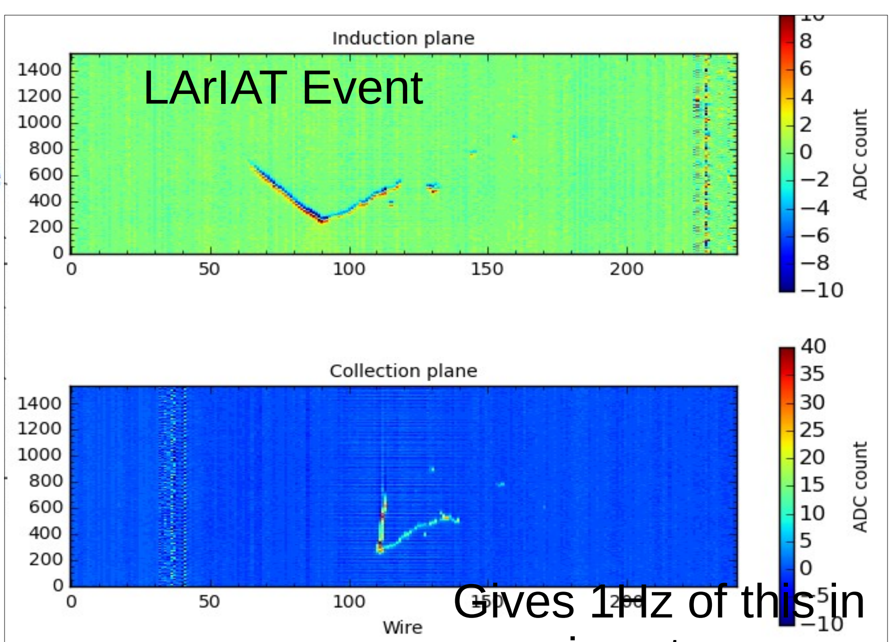
More/diverse is better

Triggering

- Without scintillation light triggering in a TPC is extremely slow or blind – e.g. take every beam gate (ok for a small detector).
- Scintillation light allows selection of frames where a neutrino interaction happened – save space.
- Selecting non-beam events.
- Select events with an interesting time structure, e.g. Michel electrons.

Beam gate trigger concept





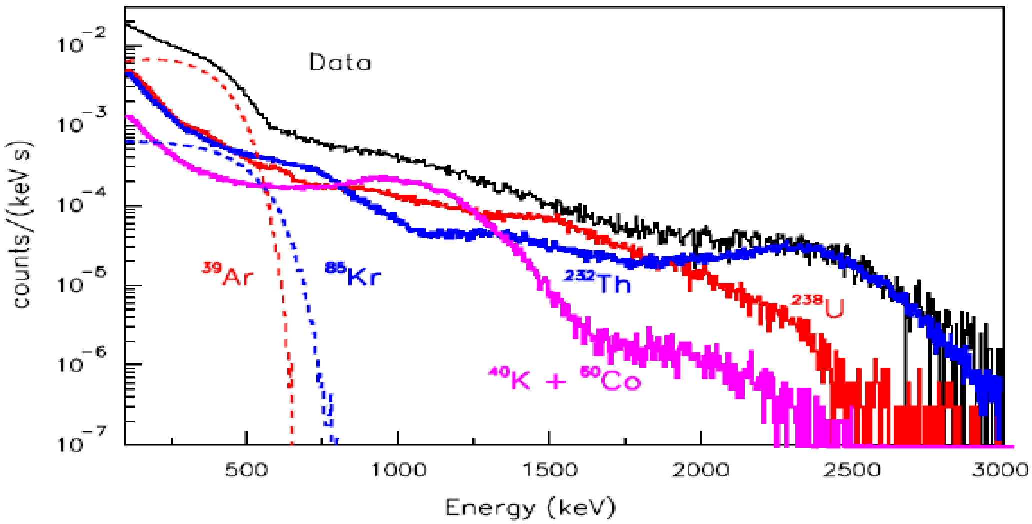
Gives 1Hz of this in cosmic gate

W. Foreman, UChi

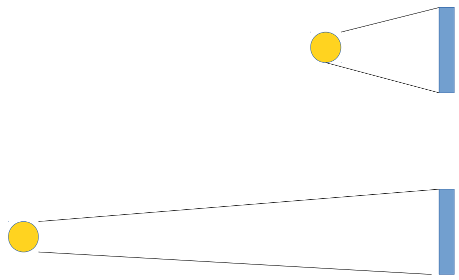
^{39}Ar – how big of a problem is it really?

- ^{39}Ar is a beta- emitter with an end point at 565 keV. average energy of electron ~ 236 keV
- Measured rate is 1Bq/kg.
- Could it overwhelm the trigger?
- Rough estimates show, that requiring a coincidence of >3-5 P.E. should keep it around ~10 Hz per PD (requesting coincidence between different photon detectors should kill it).

arXiv:astro-ph/0603131v2



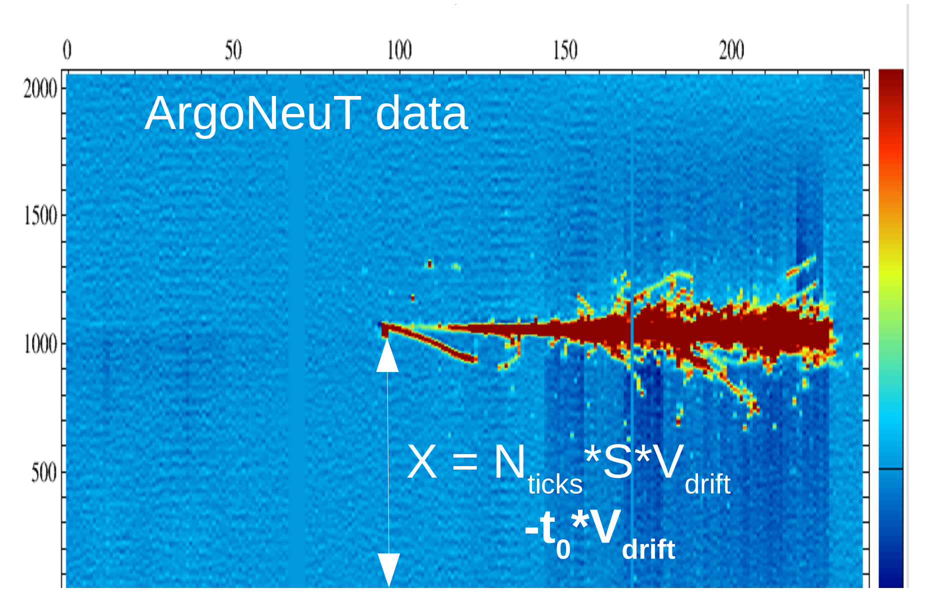
Effect of solid angle helps:

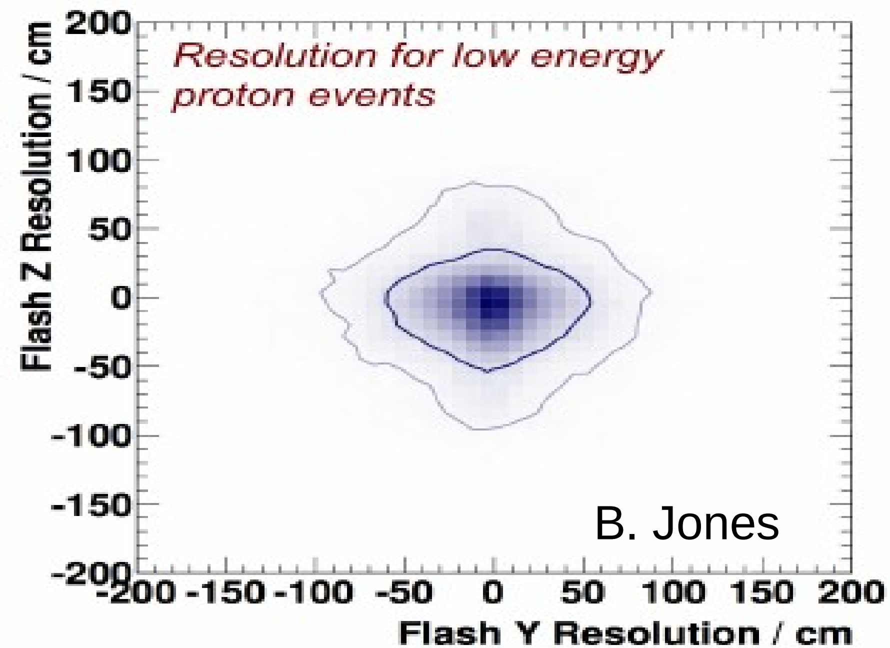


Multi-P.E. cooncidences likely only for events ~10 cm away

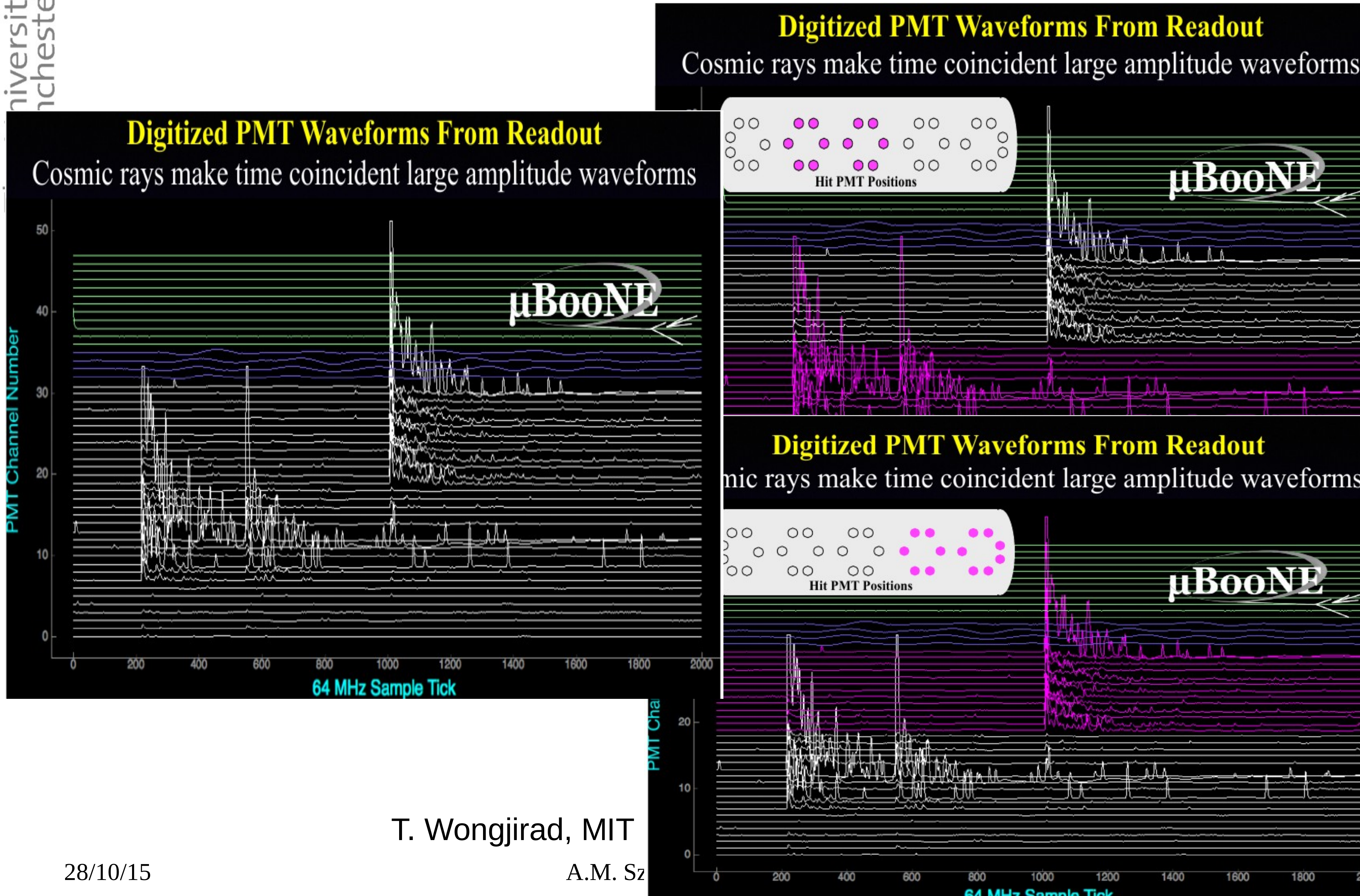
Positional resolution

- Crucial to get x-component of non-beam events (drift) – need to have timing resolution of order of charge readout (~us)
- Y-Z (in PMT plane) resolution is possible – cannot beat charge.
- Useful/needed for identifying which t_0 belongs to which event – e.g. to associate light with charge.





Y-Z Positional resolution

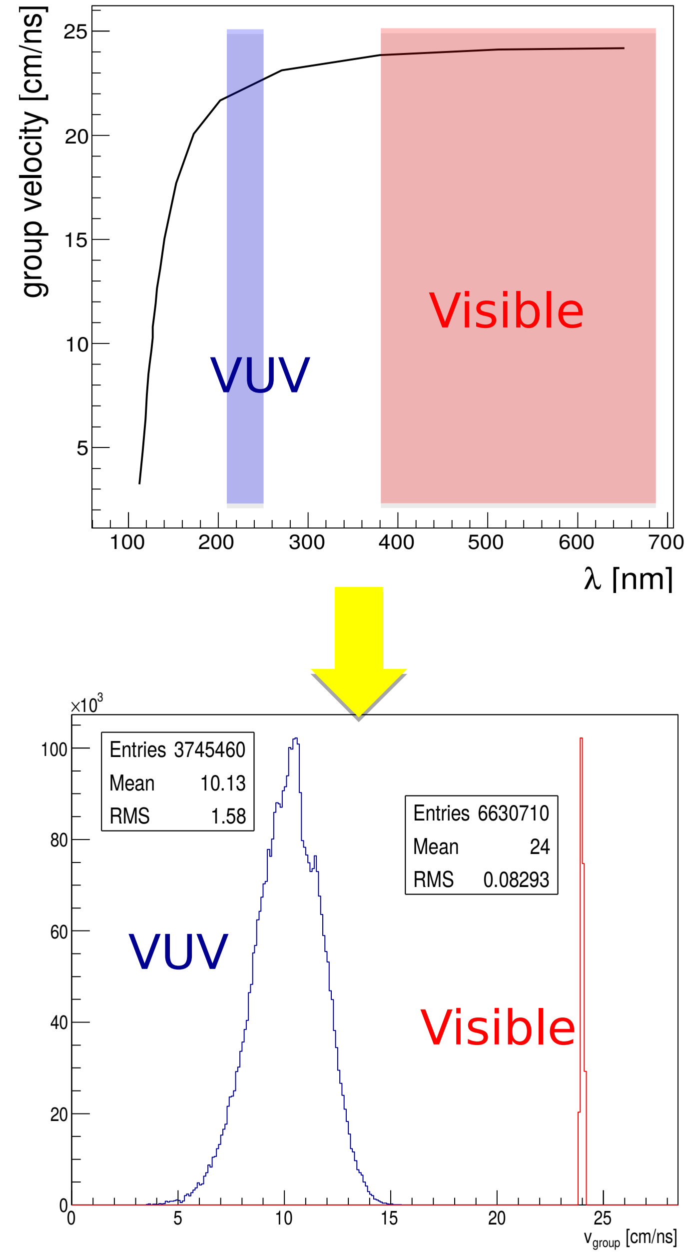


T. Wongjirad, MIT

Timing

- Improving timing resolution opens new physics possibilities:
  - **Few 100ns:** Tag events as in spill
  - **Few 100ns:** Tag Michel electron decays through timing
  - **5ns:** tag muons as exiting or entering
  - **For Near Detector:**
    - **1-2 ns:** resolve beam bucket structure
    - ? ns: beam exotics heavier than neutrinos.

      - Nature of scintillation light in argon may limit how well we can do in the latter cases.



Energy Resolution

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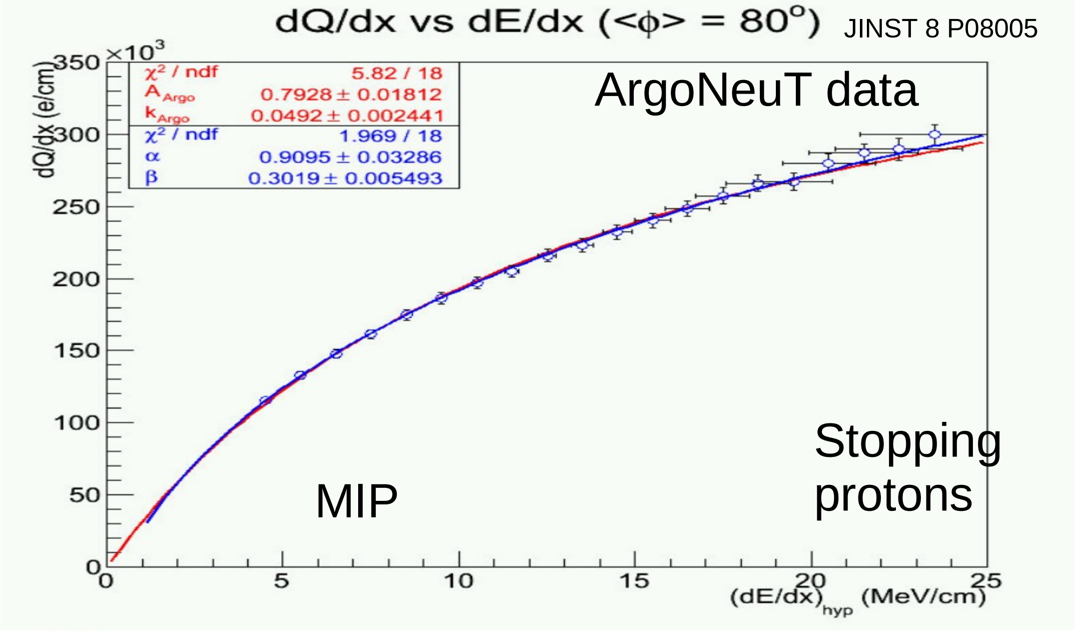
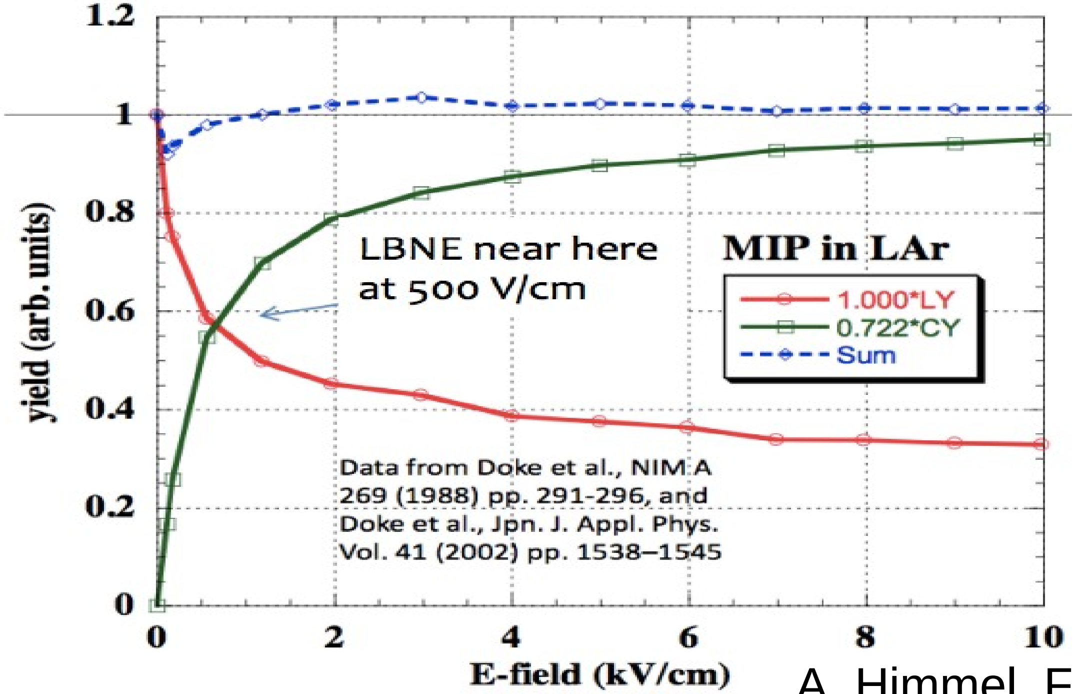
- t_0 (from light) needed to apply corrections for charge lost due to drift.
- Charge yield depends on dE/dx and electric field.
- Together = headache?
- Scintillation light can be the medicine, since it is complementary to charge (easier to do if it is uniform).





A. Himmel, FNAL

Physics with LAr Scintillation Light

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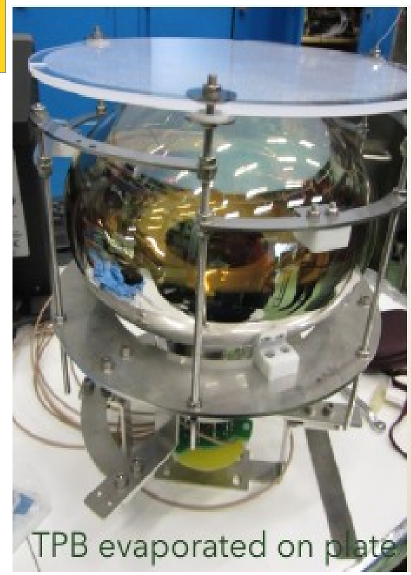
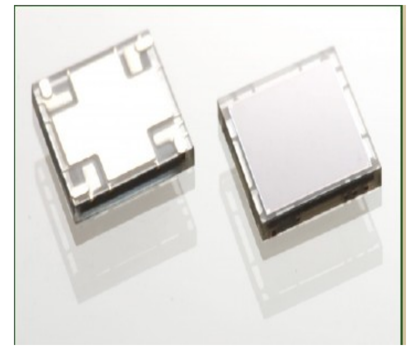
PMTs vs SIPMs

PMTs

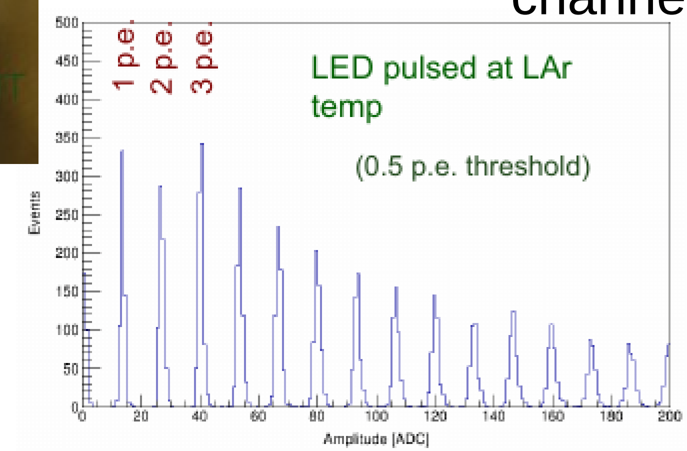
- Proven detector technology in liquid argon.
- Excellent timing resolution ~ ns.
- e.g. Hamamatsu R5912 8" PMTs
- Small channel/active area ratio.
- Non-negligible size, relatively high voltage.





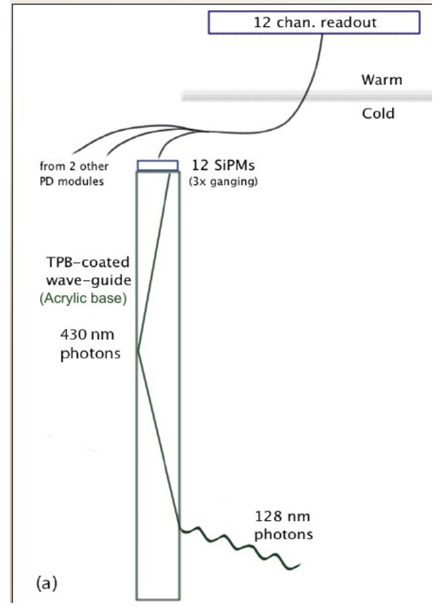
SiPMs

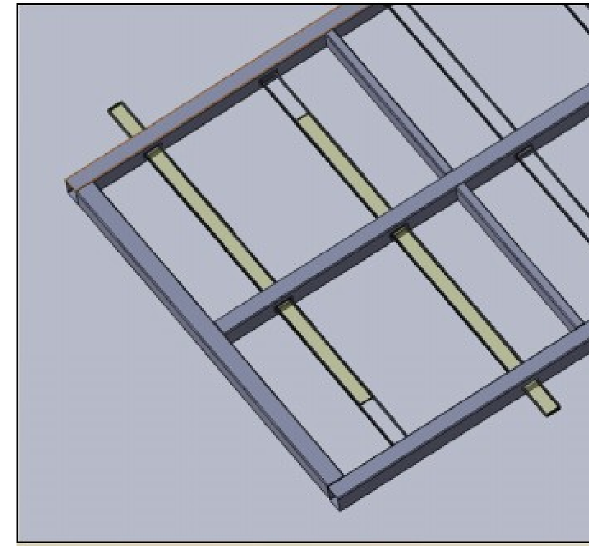
- SiPMs: Relatively new on the block.
- Excellent performance in liquid argon. Small voltage needed to operate.
- Small active size – need to be clever to avoid large channel number.

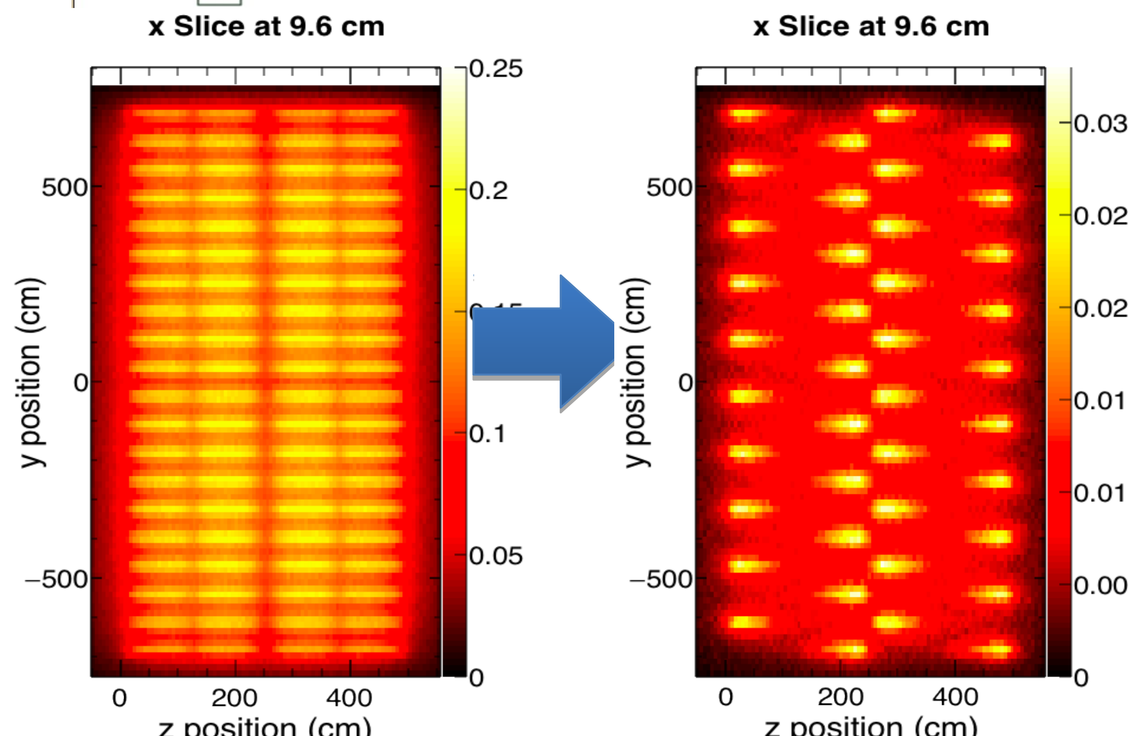


SiPMs + coated bars

- WLS coated bars coupled to SiPMs (current DUNE baseline design).
- SiPM timing not as good as PMTs (Industry is working on this).
- Photon travel time in bar adds to this.
- Work ongoing to minimize attenuation in bars.
- Will be tested in 35ton – prototype soon.







A. Himmel, FNAL

Reflective foils + WLS

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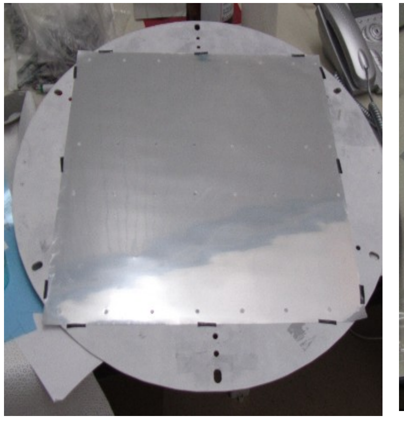
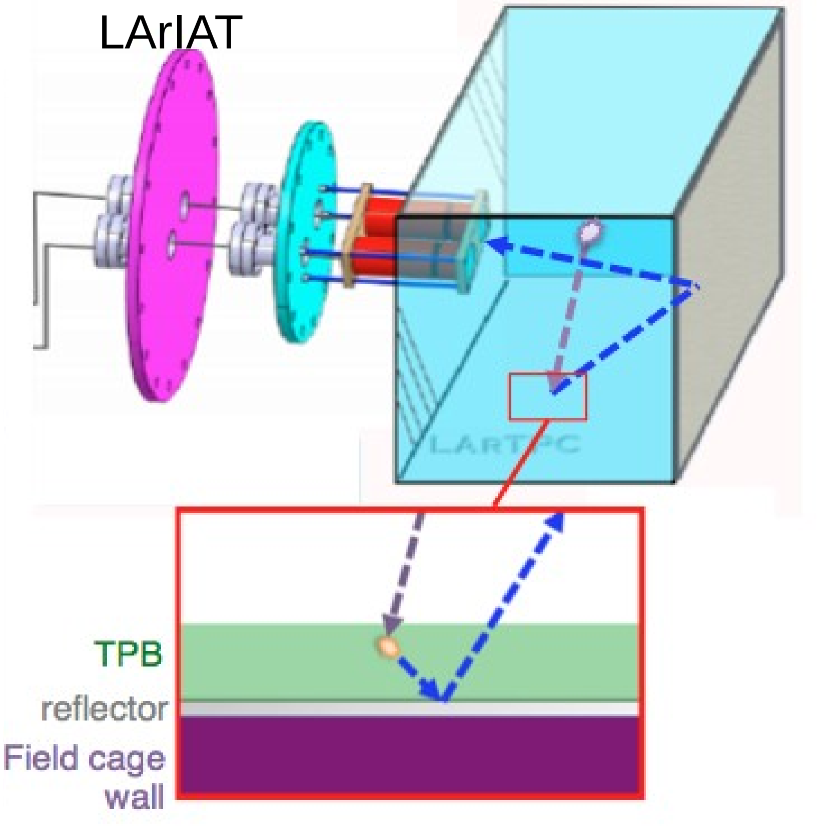
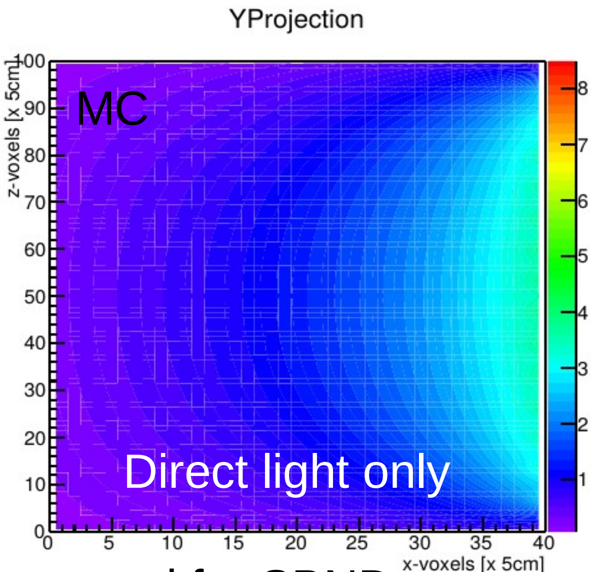
- A different way to increase quantity of light without needing more channels.
- Increase collection uniformity across the chamber.
- May improve timing resolution in some locations.
- Positional resolution may be more difficult.

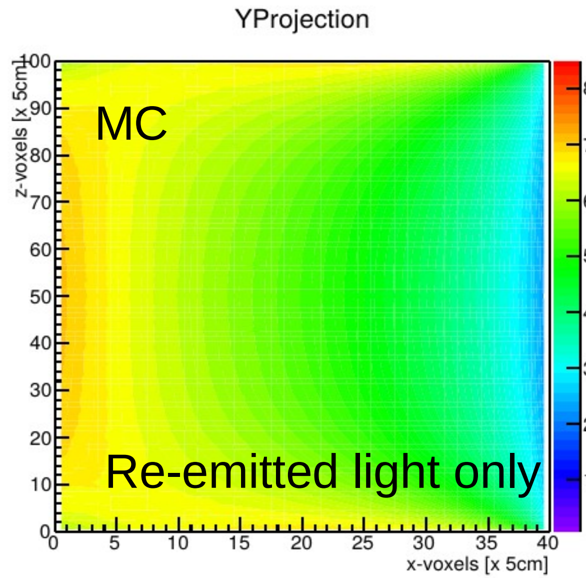


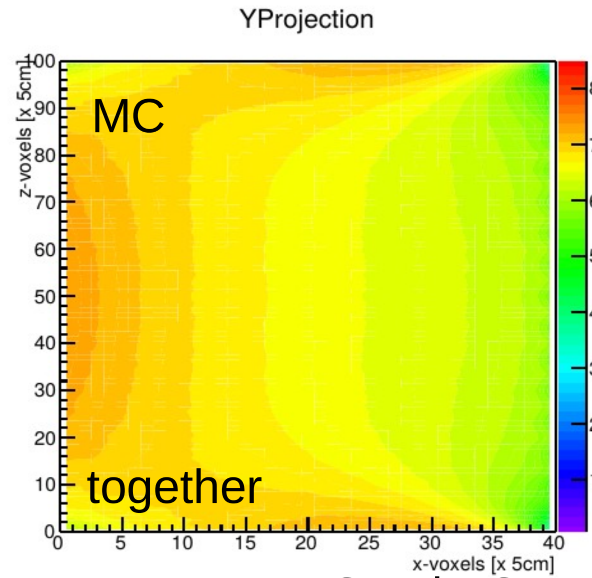


Reflective Foils + WLS

Looking from the top

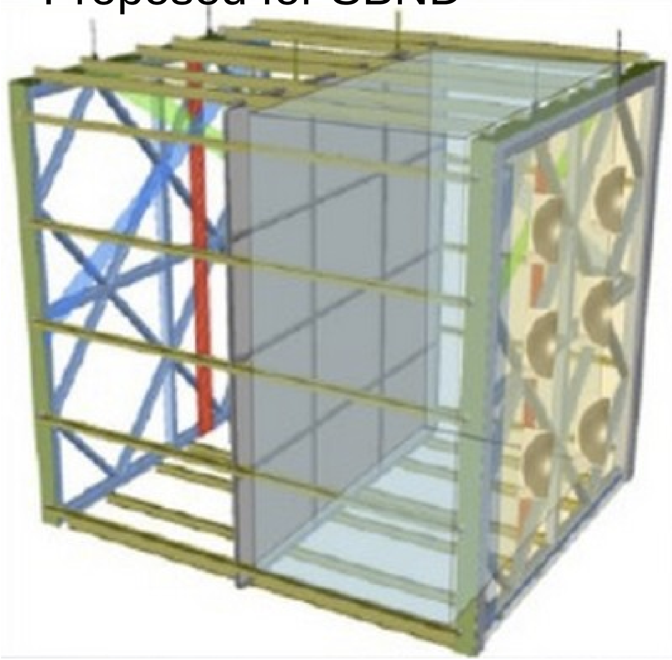






D. Garcia-Gamez, Manchester

Proposed for SBND



- Additional light makes response more uniform.

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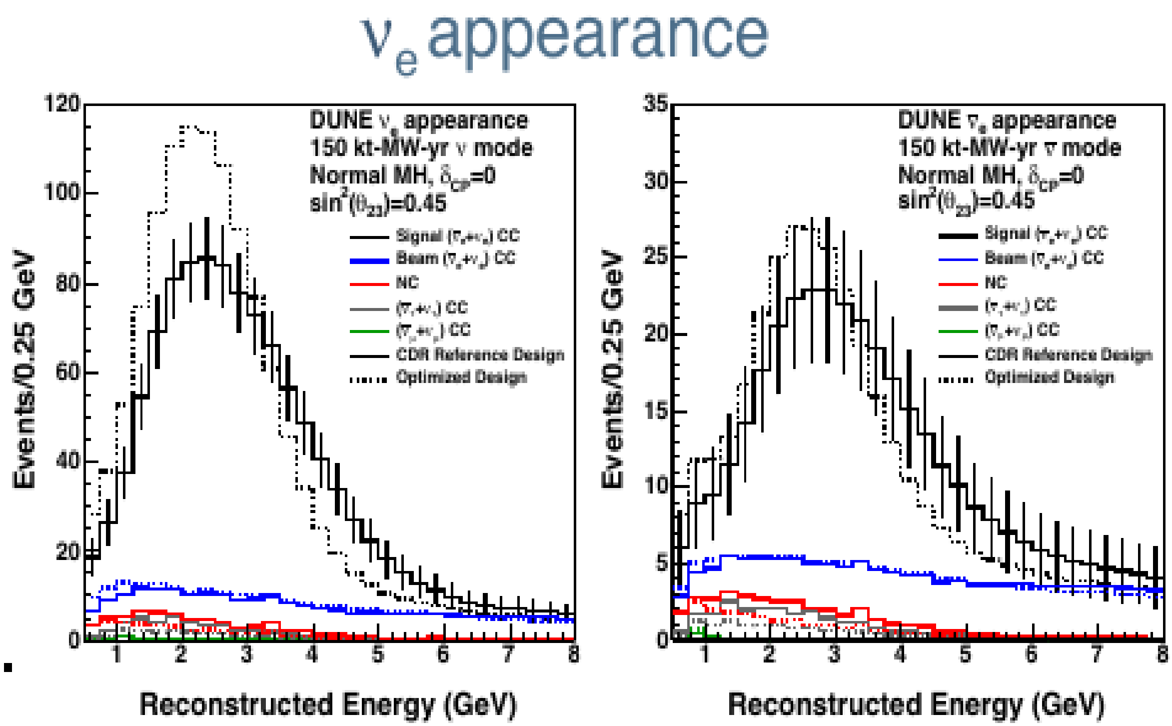
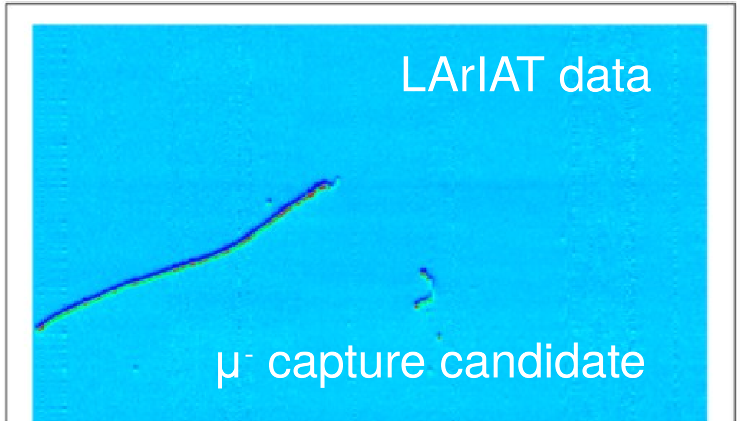
BEAM physics (CP-Violation)

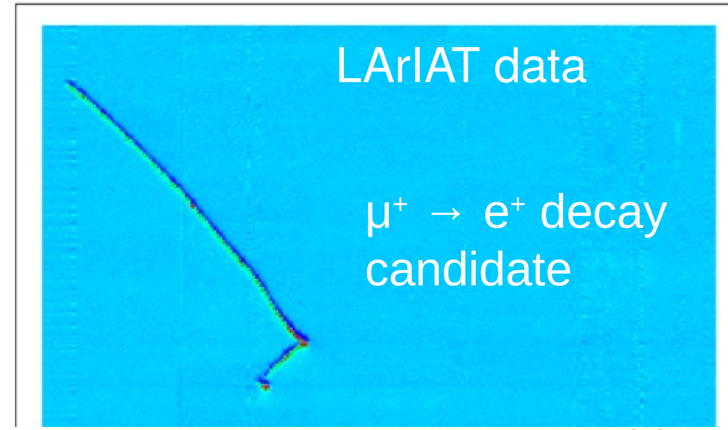
- Measuring differences between particles and anti-particles.
- Anti-neutrino mode has a significant number of neutrinos.
- Usually you would tell them apart using a magnetic field.



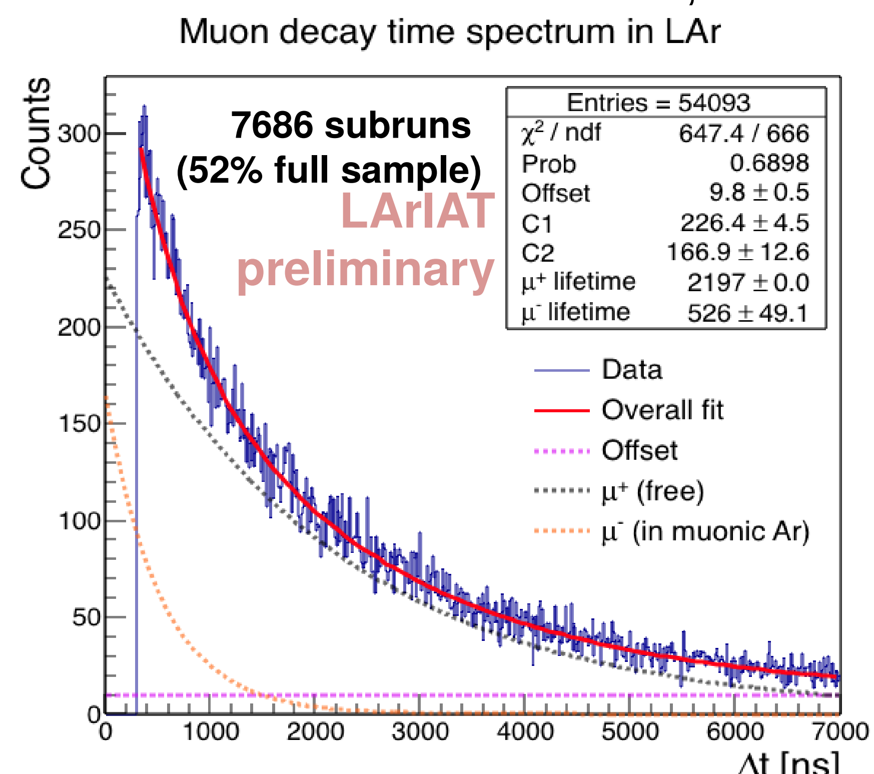
	ν_μ ν mode	ν_μ $\bar{\nu}$ mode	ν_e NH(IH) ν mode	ν_e NH(IH) $\bar{\nu}$ mode
$\nu_{e,}$ ν_μ	10842	2598	861 (495)	61(37)
$\bar{\nu}_{e,}$ $\bar{\nu}_\mu$	958	3754	13 (26)	167(378)

Charge-sign discrimination with Scintillation Light.





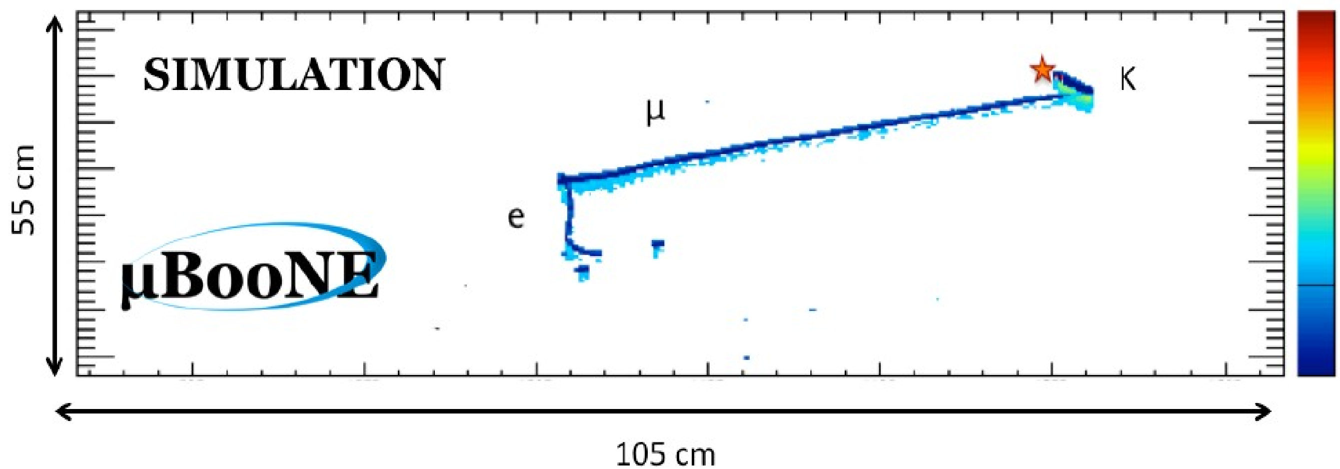
W. Foreman, UChi



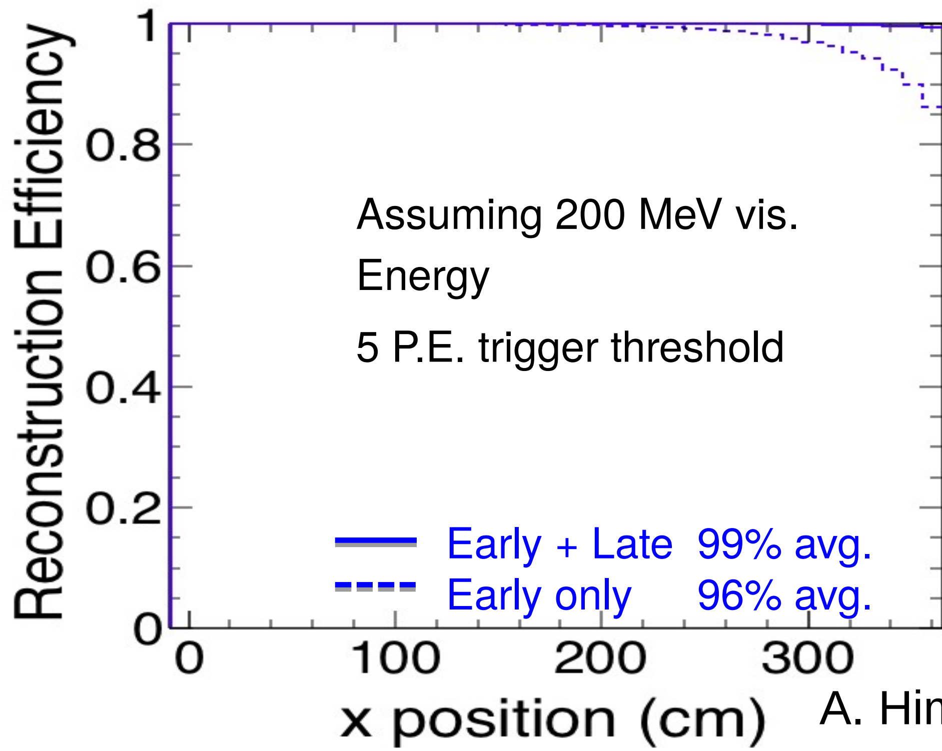
- Argon Nuclei have a 75% chance to capture muons. They never capture anti-muons.
- This results in different topologies.
- In case the topologies are the same: different effective decay times.
- Can determine flux composition statistically (and in some cases on an event-by-event basis).

Nucleon decay

- The most important thing is to not miss it.
- Looking for an energy deposition independent of beam.
- Expect a relatively large energy deposition.



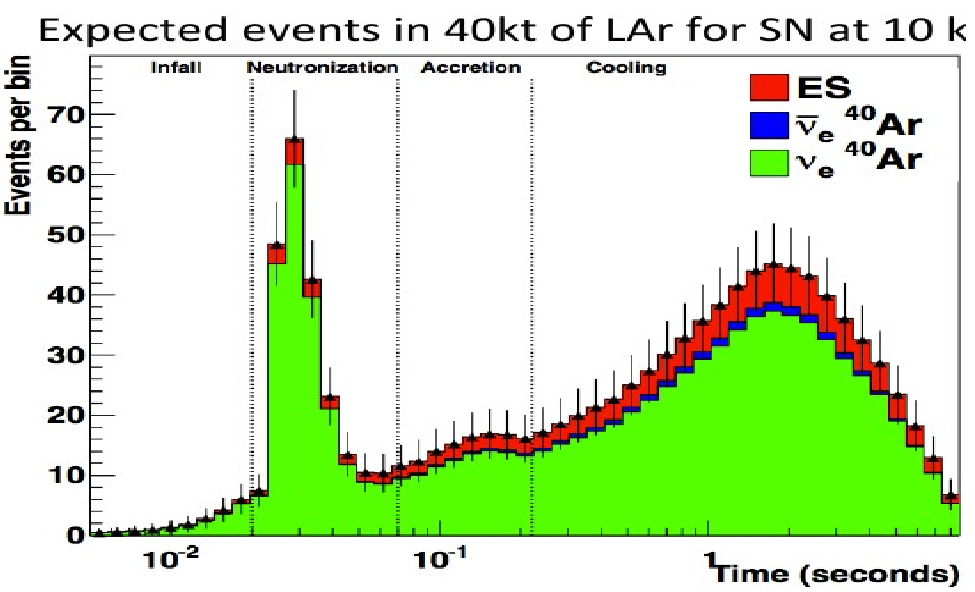
DUNE coated bars

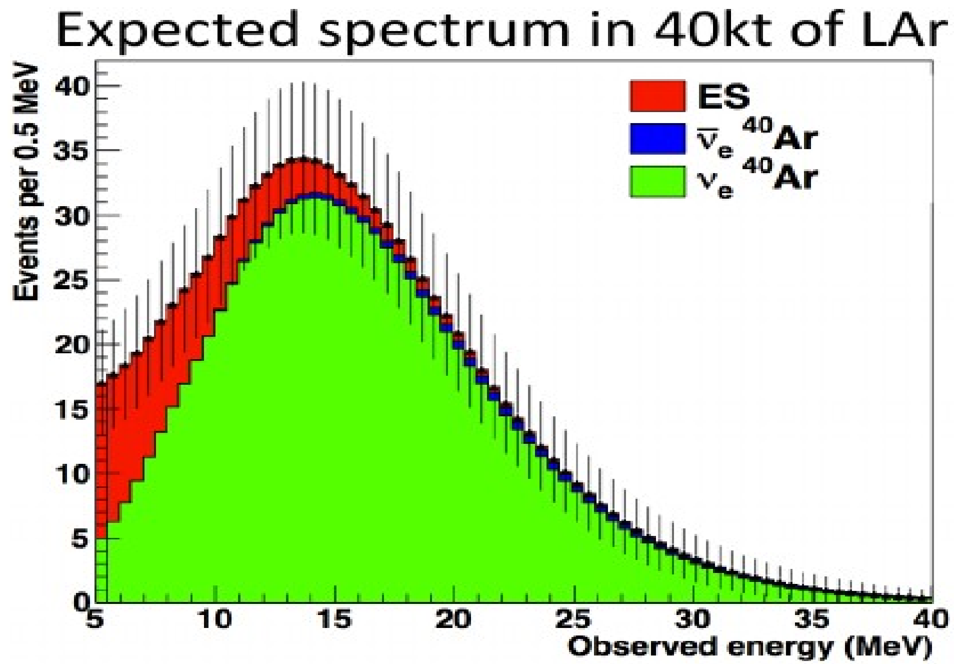


A. Himmel

Supernova Neutrinos

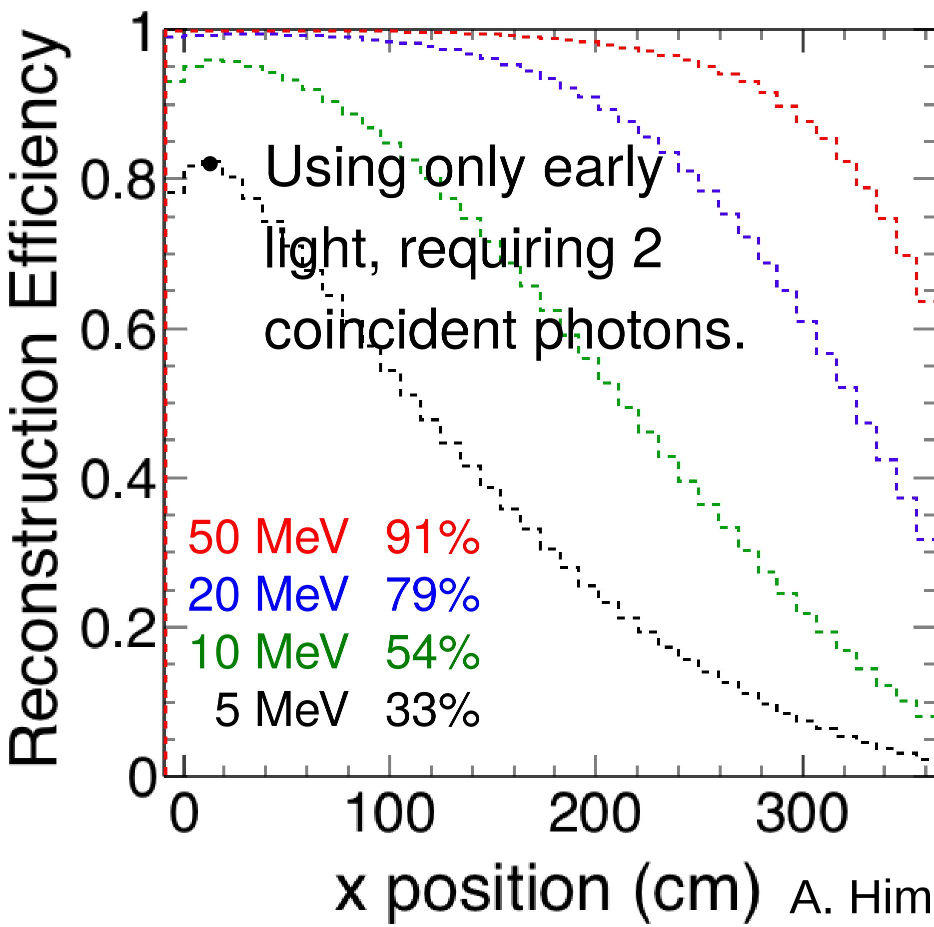
- Different neutrino timing and energy spectra predicted by different models.
- Out of beam timing.
- Scintillation light needed in all cases.



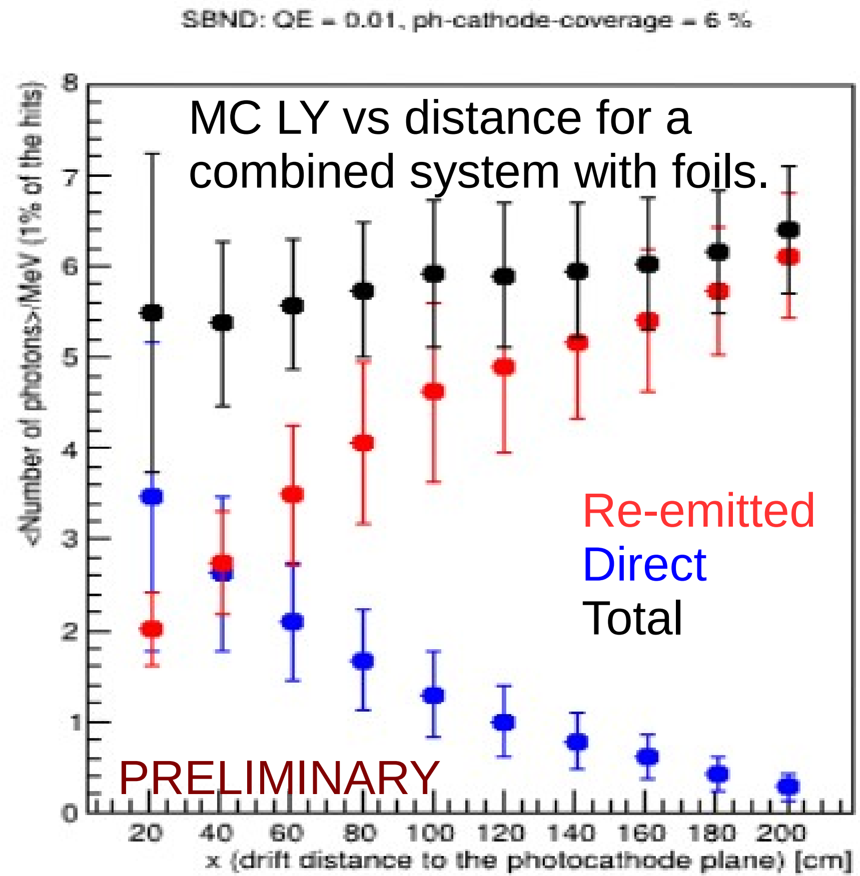


Supernova Triggering Efficiency

DUNE coated bars



A. Himmel

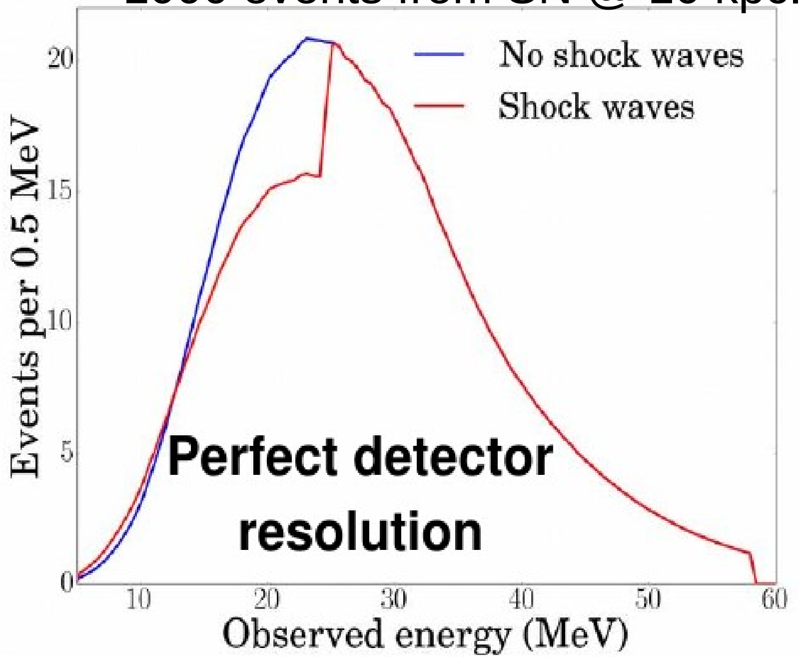


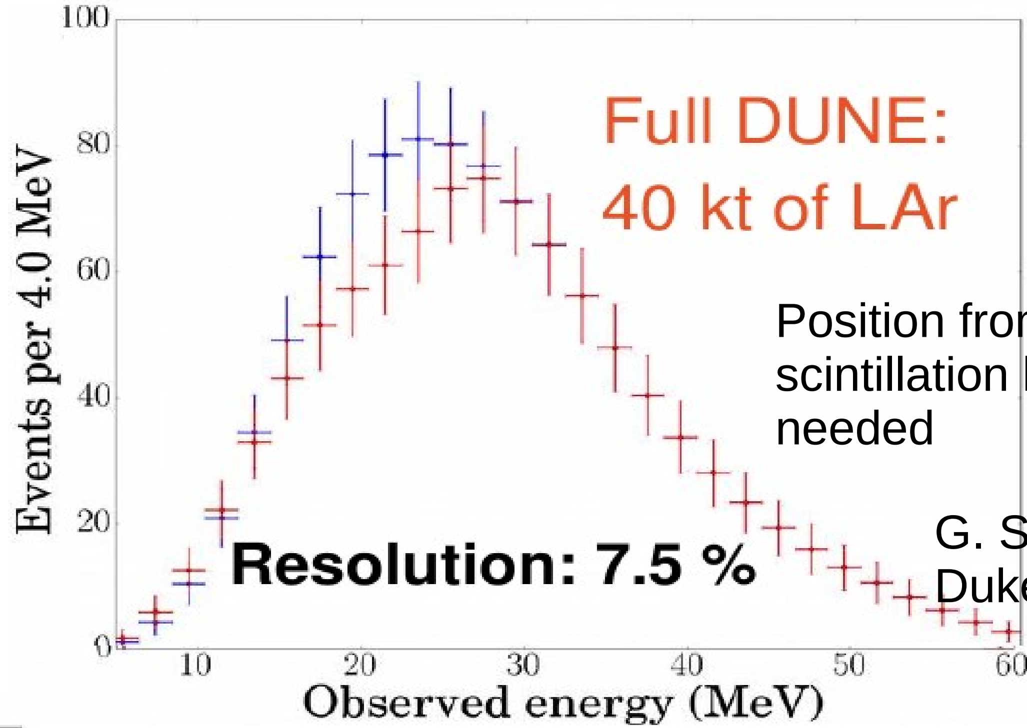
D. Garcia-Gamez, Manchester

Note different horizontal scale

Effects of Energy Resolution

~1000 events from SN @ 10 kpc.

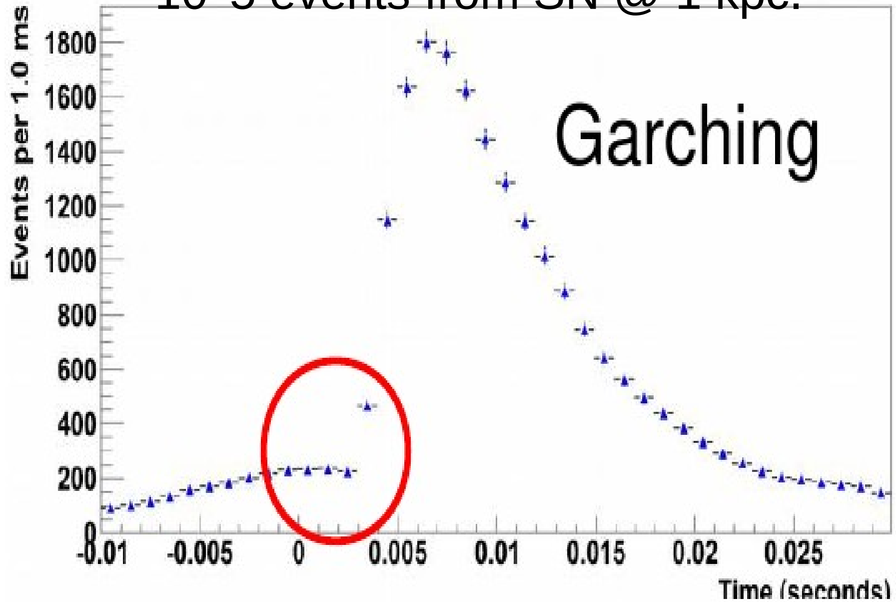


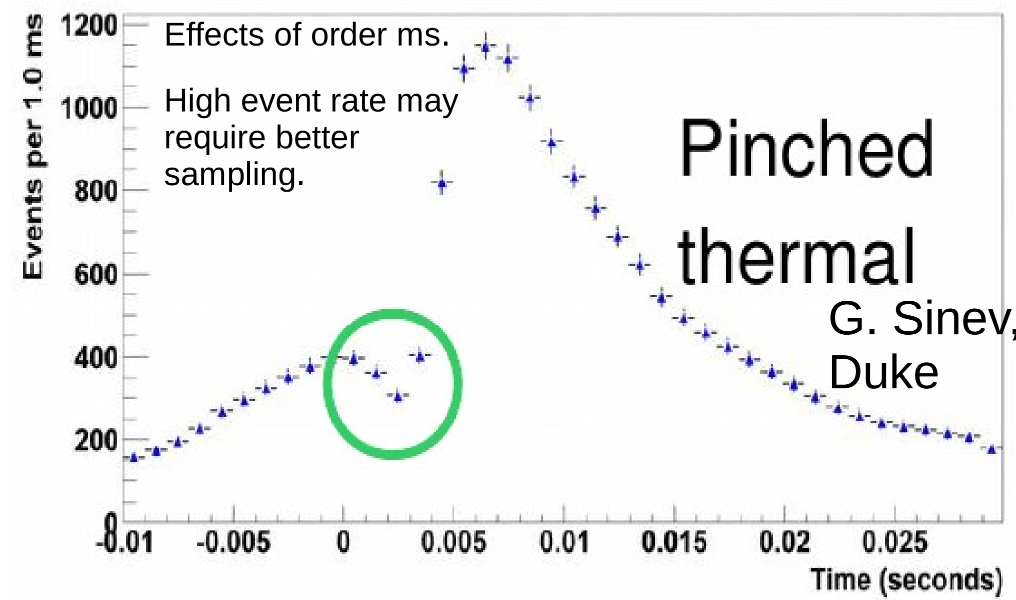


Position from scintillation light needed

G. Sinev, Duke

~10^5 events from SN @ 1 kpc.





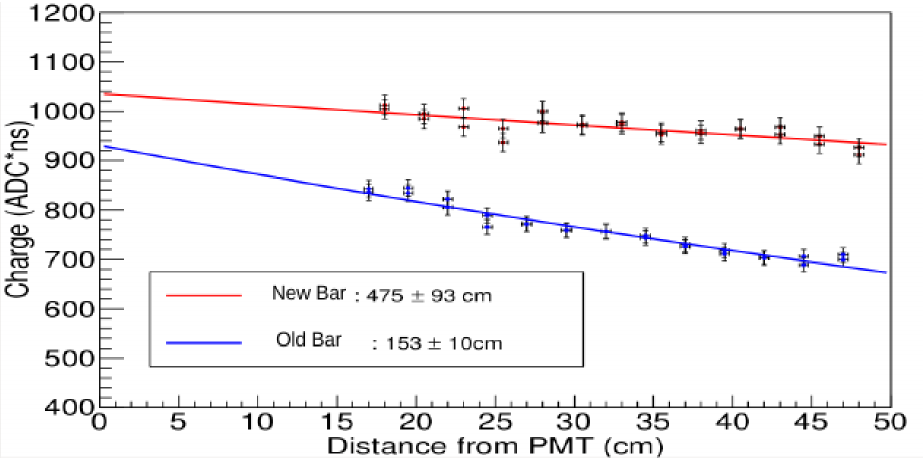
Effects of order ms.

High event rate may require better sampling.

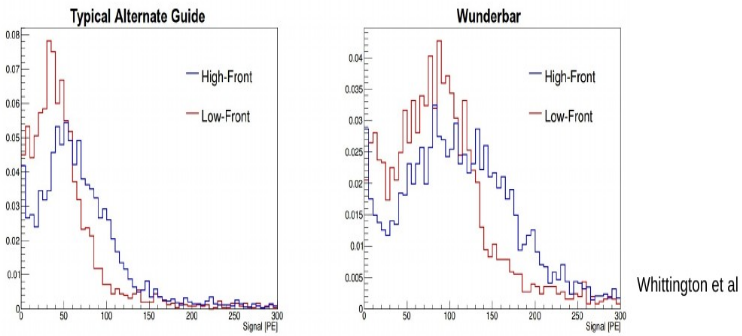
G. Sinev, Duke

Scintillation Light R&D

- “Wunderbars” - new coating method resulted in a large improvement in performance.

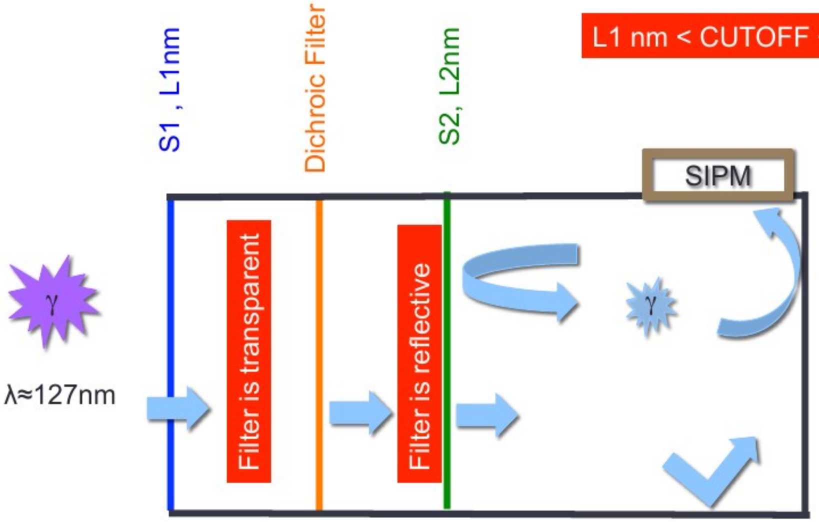


- Several bars, including our latest “wunderbar” tested in liquid argon at Fermilab in summer 2015

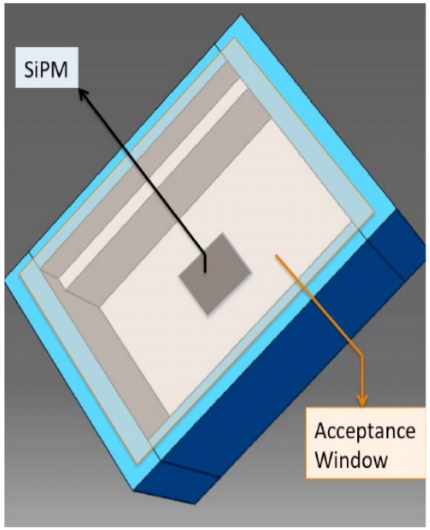


- The wunderbar yielded an attenuation length of ~230 cm compared to other guides, the best of which performed at ~155 cm

J. Moon, LIDINE 2015



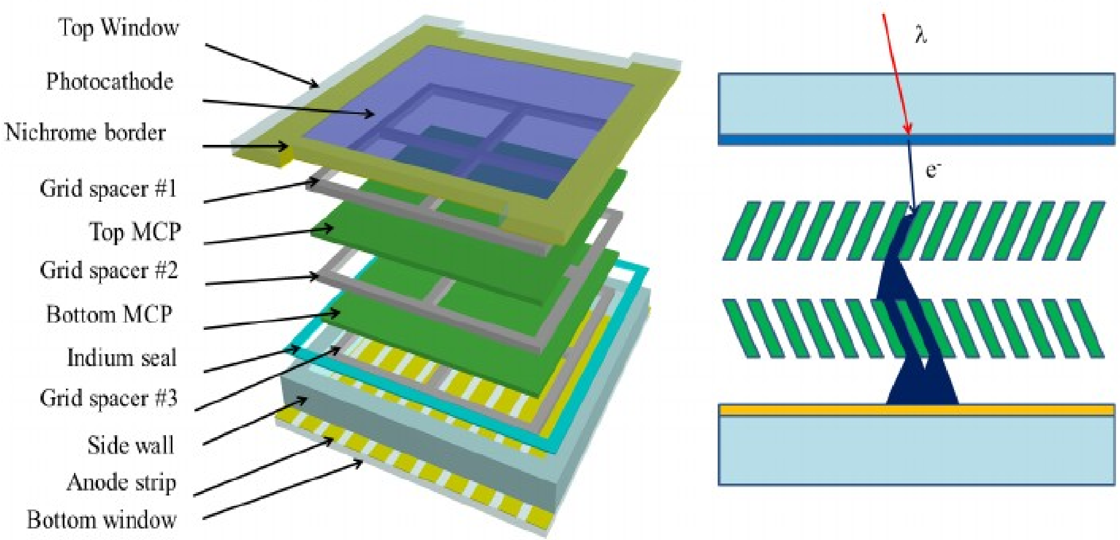
- “ARAPUCA” - use dichroic filter to trap light inside a box.



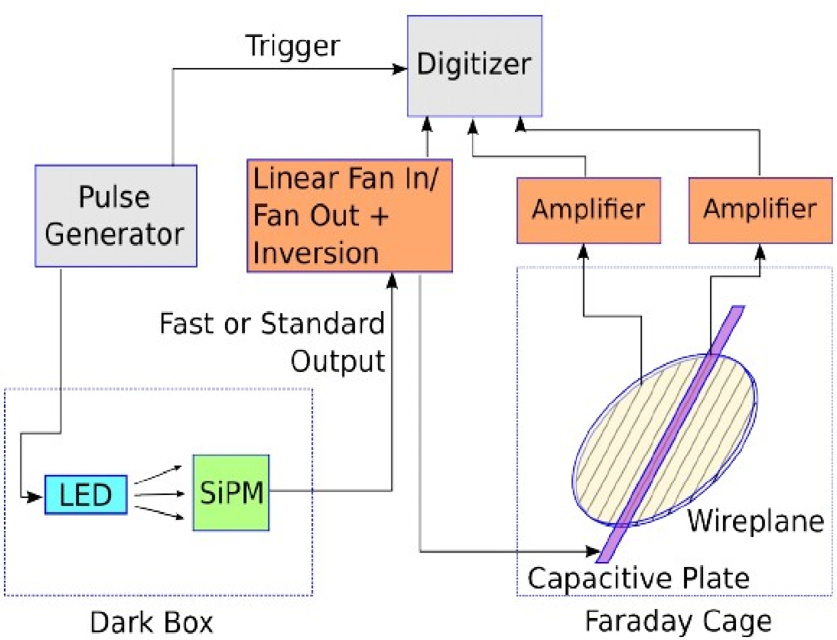
E. Segreto, LIDINE 2015

Scintillation Light R&D (2)

- Micro-Channel Plate PMTs being developed for cryogenic uses.
- Speed + positional resolution.



R. Dharmapalan, LIDINE 2015



- One man's background is another man's signal.
- Use noise from PMTs observed in ArgonTube, ICARUS and LArIAT into a way to read out Light detectors with wire electronics.
- Limits number of channels.

Z. Moss, LIDINE 2015

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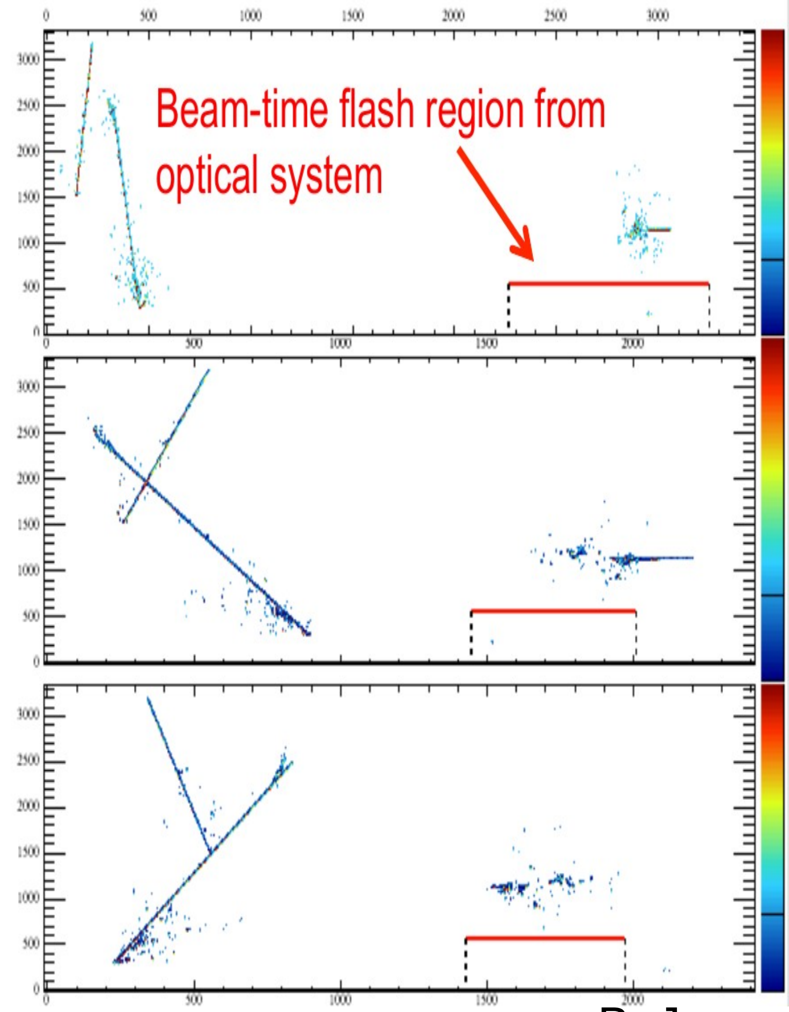
Summary

- Scintillation light will be a powerful tool in enhancing the physics goals of the underground detector.
- A number of detectors is online or will be online in the next couple of years. We should maximize their use to learn about the full power of scintillation light in neutrino detectors.
- Can we find a way have it all?

Thank You

Scintillation Light in LArTPCs:
trigger and cosmic removal

- A scintillation burst during the beam gate gives an indication that a neutrino signal happened (uniformity helps).
- Especially for the detectors on the surface, it is extremely important to match this flash to a charge deposition in the chamber (need timing, position).
- This enhances the rejection of cosmic ray events (usually outside of beam window).
- Can be significantly improved using an external veto system (CRT).

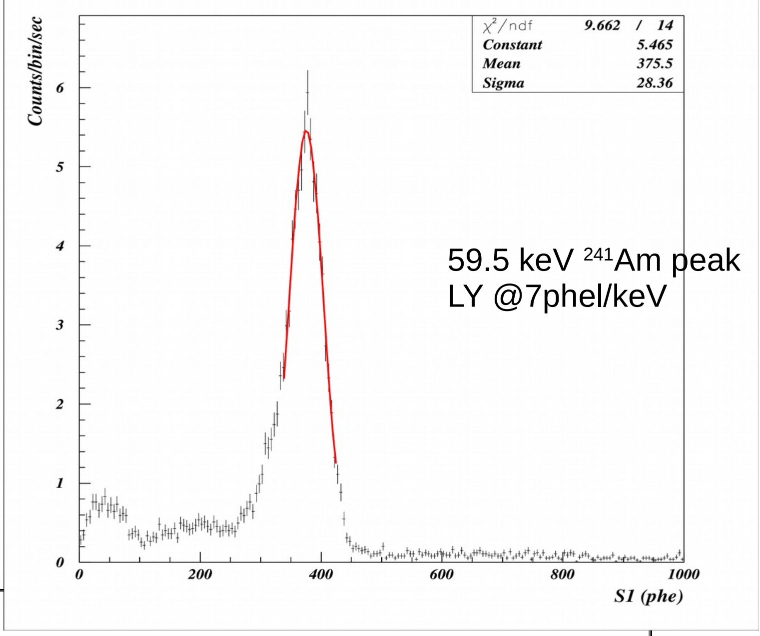


B. Jones

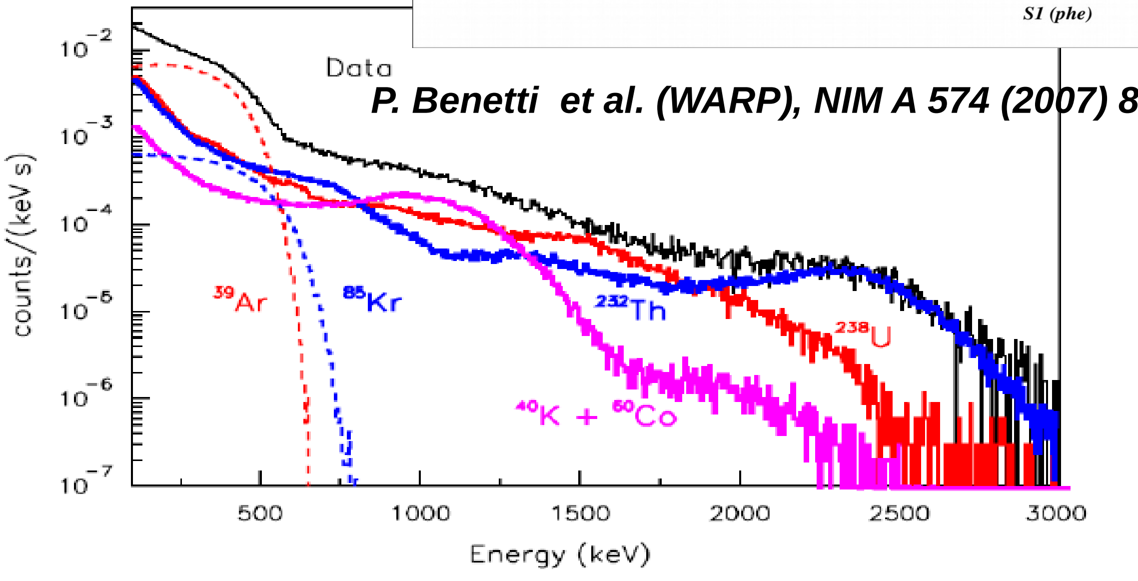
Scintillation Light in LArTPCs:
energy resolution

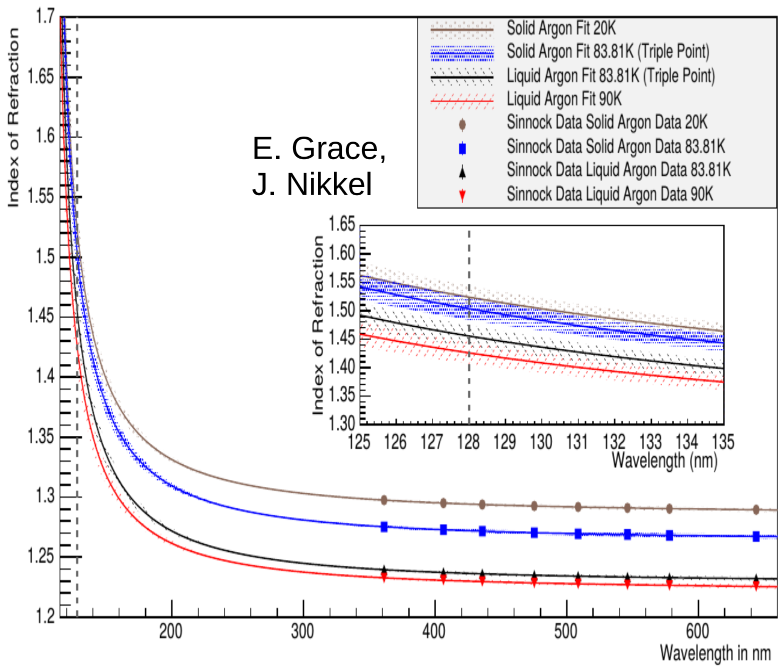
- Quantity of scintillation light is complementary to charge.
- Registering both will improve energy resolution. (Uniformity and high collection efficiency helps).
- Knowing position will maximise results.

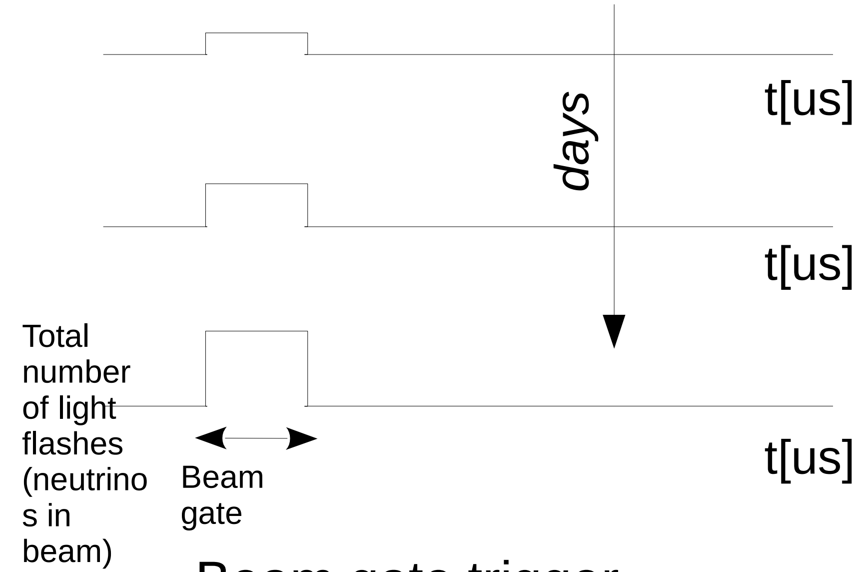
R Acciarri et al. 2012 JINST 7 P01016



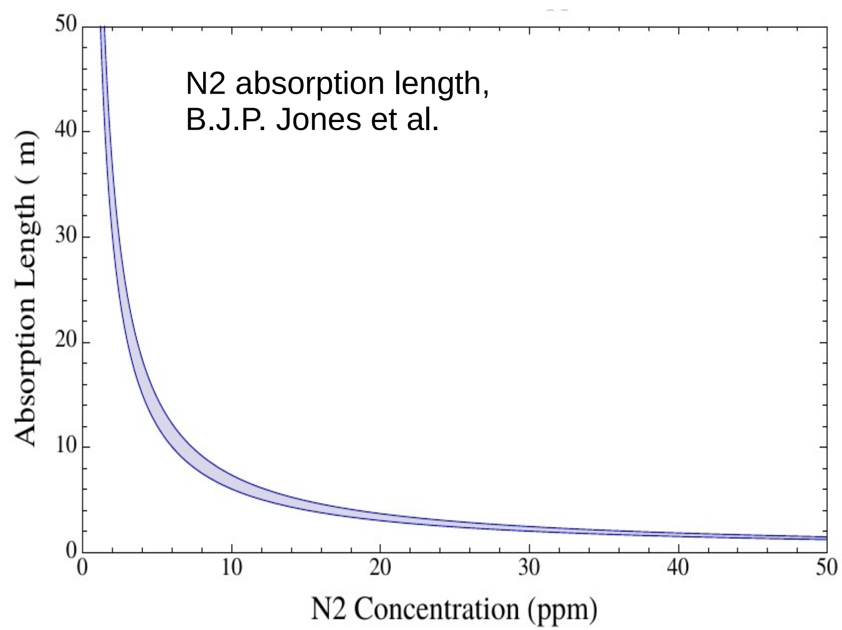
P. Benetti et al. (WARP), NIM A 574 (2007) 83

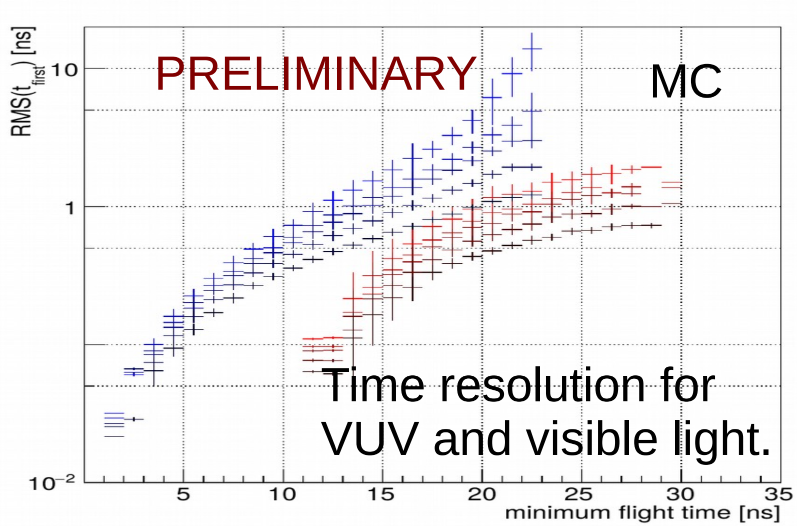






Beam gate trigger concept





D. Garcia-Gamez,
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SN timing

- **10^3 events - SN @ 10 kpc:** with a peak of about 20ms (~ 10 frames) → 50 evts/drift time/full detector. Likely to be in different areas. Should not be a problem. If optically separated: < 1 event/drift time/drift length module.
- **10^5 events - SN @ 1kpc:** ~5000 evts/drift time/full detector,
- If optically separated: ~25 evts/drift time/drift length module.
- Some optical separation is provided by absorption in argon (~30m) and CPAs. A SN neutrino interaction is unlikely to generate more than ~100 P.E. (20 MeV @ 5phel/MeV) – meaning it can interact in at most 10 APA modules (100PDs). Solid angle will make it more contained (~5 APAs).
- For a given PD, could conservatively expect 125 events lasting ~5us total/drift time. Some overlap possible, but could be mitigated using fast component ~ 100 ns bin → need to maximize light collection.