LArIAT - testing and simulating the light readout system on the way towards light - augmented calorimetric reconstruction and PID

Pawel Kryczynski for the LArIAT collaboration

New Perspectives 2014

Outline

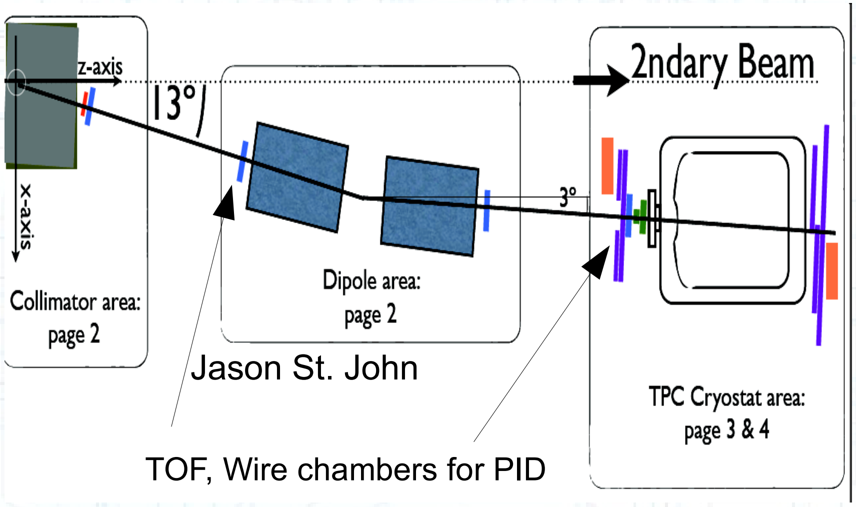
- LArIAT – Liquid Argon TPC in a Testbeam
- Light Readout System in LArIAT
- Simulations of Light Yield and Collection Uniformity
- Test Setup Run – Preliminary Results and Comparison With Simulations

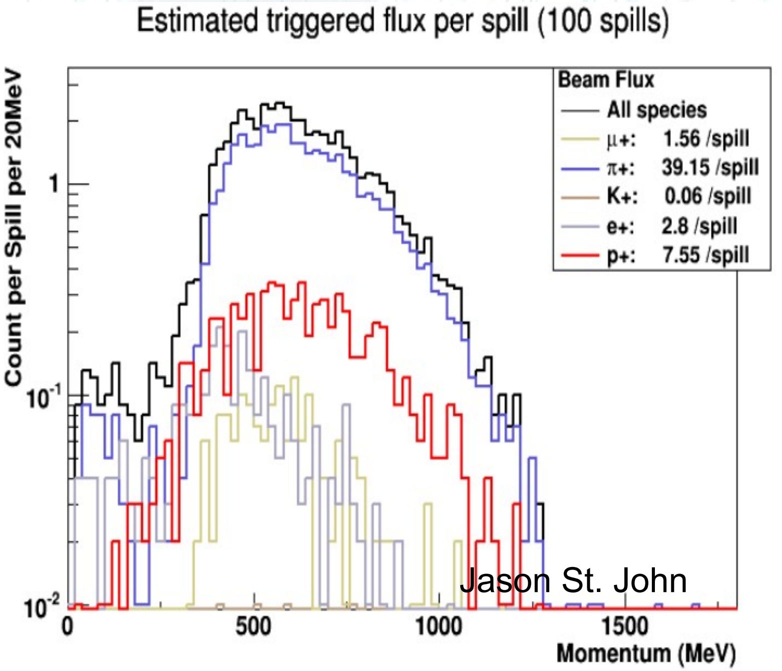
LArTPCs

- LArTPCs (Liquid Argon Time Projection Chambers) are becoming the go-to technology in neutrino physics (ArgoNeuT, MicroBooNE among others)
- Future, precision measurements, necessary to resolve urgent questions in the field, require calibrating the technology - this will be done by LArIAT

LArIAT

- The LArIAT experiment will operate the refurbished ArgoNeuT TPC in a charged particle beam in the Fermilab Testbeam Facility (FTBF)
- The R&D goals of the experiment include testing a novel, Dark-Matter–like approach to light read-out in order to augment particle identification (PID) and calorimetric reconstruction capabilities





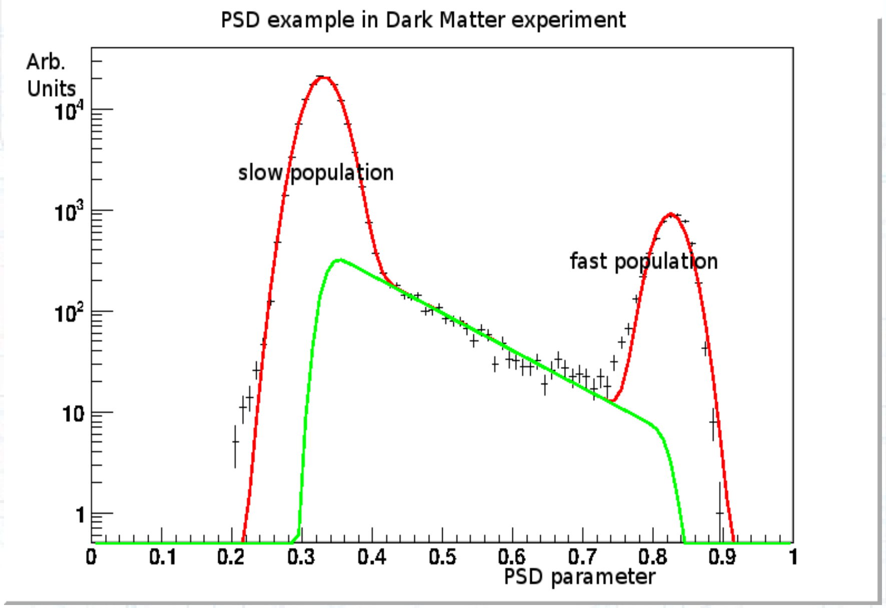
Momentum up to ~1,5 GeV

LAr Scintillation

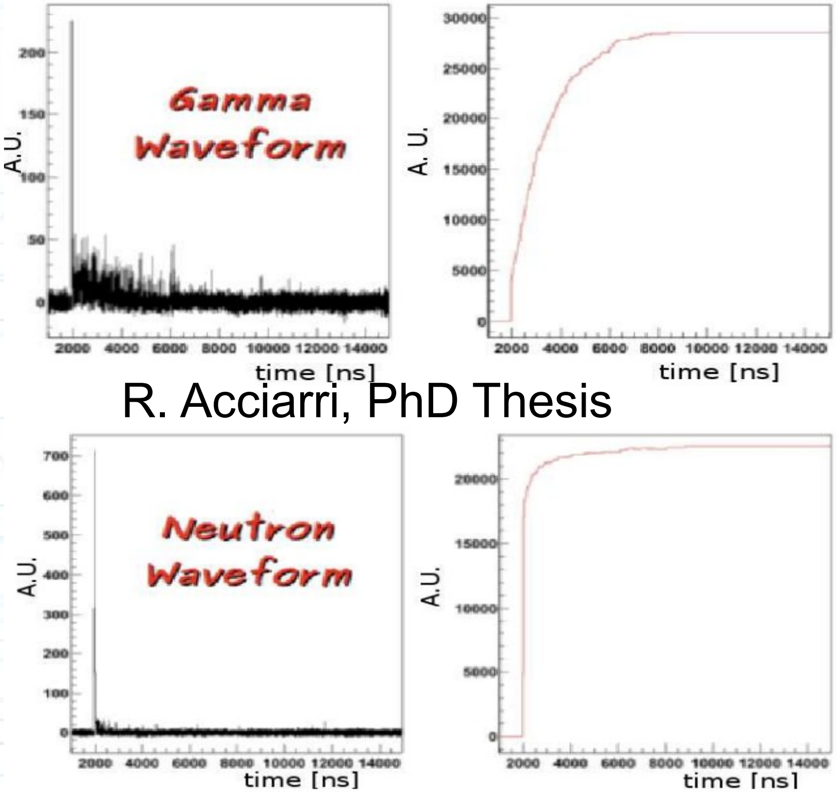
- Want to use argon scintillation light (128 nm, Vacuum Ultraviolet - VUV range) beyond the triggering/arrival time determination purpose
- At the electric field in TPC planned in LArIAT, a substantial fraction of energy is emitted through the light, and we can't afford to waste that amount of information (~40k photons/keV!)
- Liquid argon scintillates due to the decay of two excited states – short-lived singlet (few ns) and triplet (1-1.5 μs)

Particle ID using Scintillation Light

- The proportion of two scintillation components differs among the particles, altering the risetime of registered signal
- Basis for a Pulse Shape Discrimination Methods (PSD), widely used in Dark Matter experiments, but being a novel approach in neutrino energy range



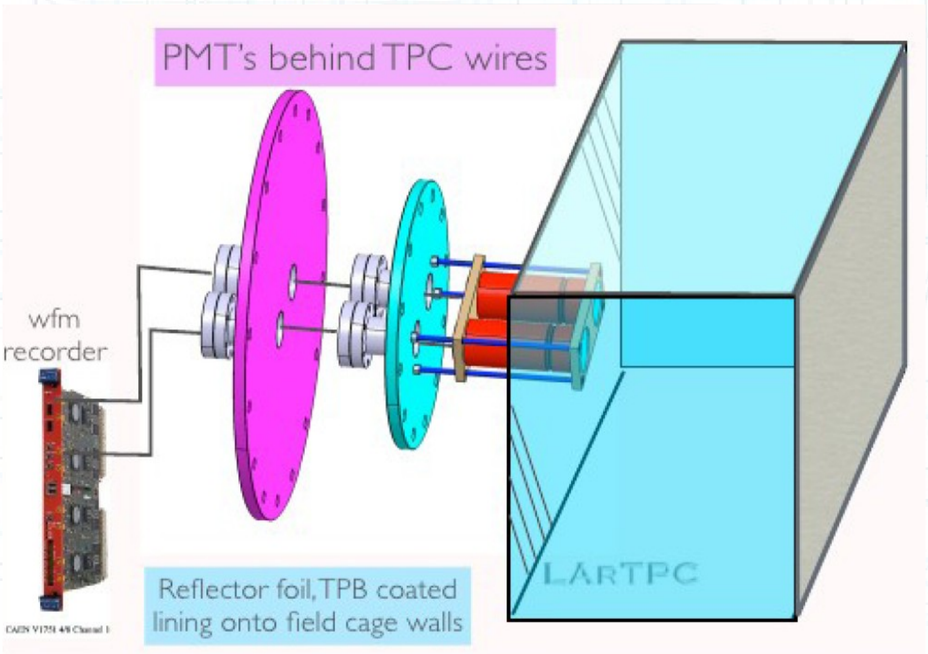
Example of signal/background separation in WArP R&D exp

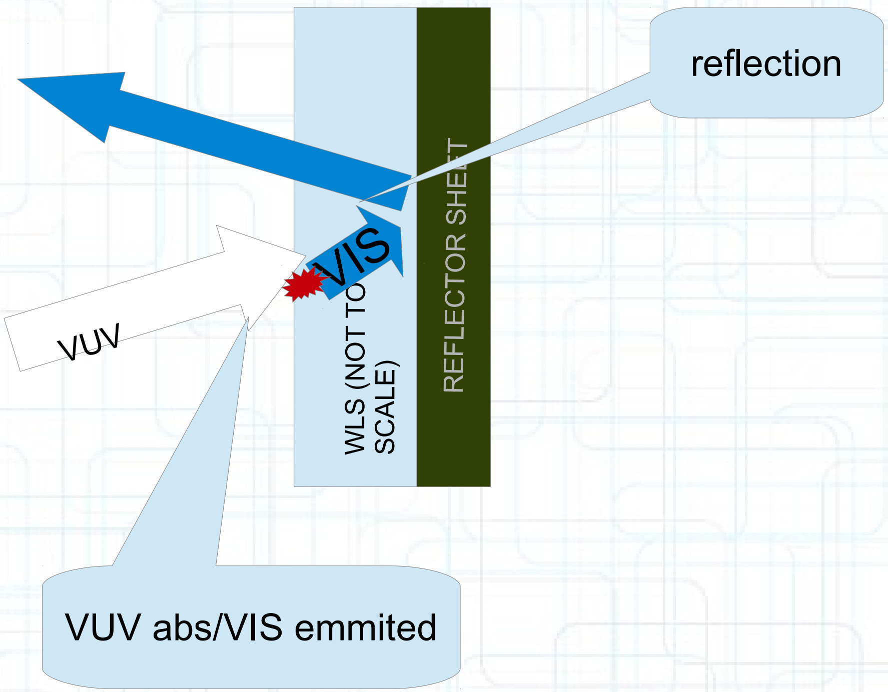


R. Acciarri, PhD Thesis

Light Detection in LAr

- In order to use scintillation light for calorimetry, a uniform light collection and increased collection efficiency is needed ►reflector will be used on chamber walls
- PMT windows opaque for VUV - wavelength needs to be shifted ►covering reflector on the walls with a thin layer of substance absorbing VUV (128 nm) and emitting in visible range

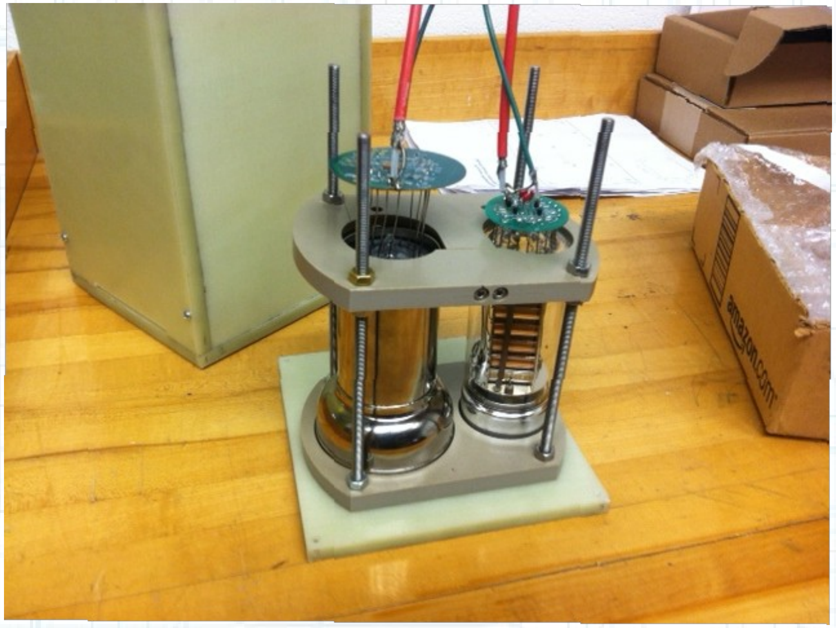
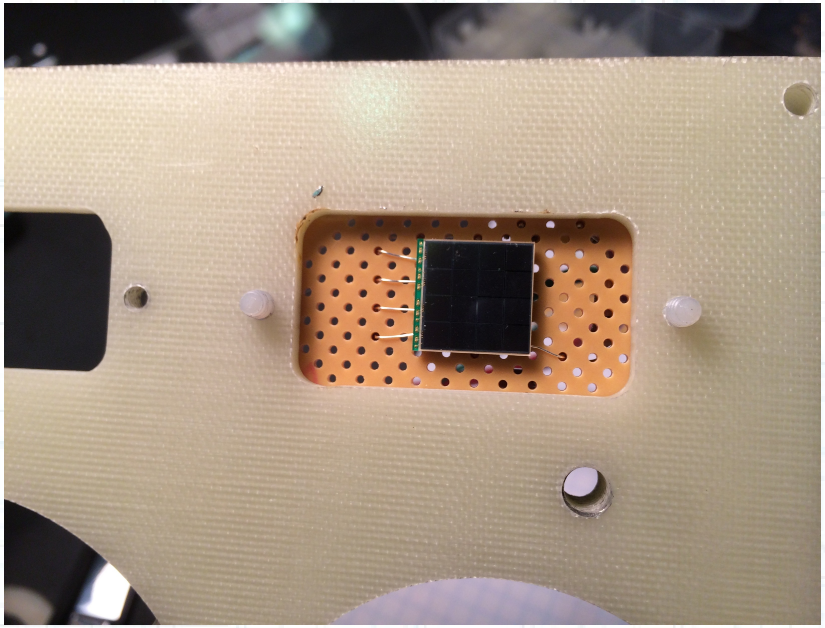




Tetraphenylobutadiene - TPB

Photosensitive devices

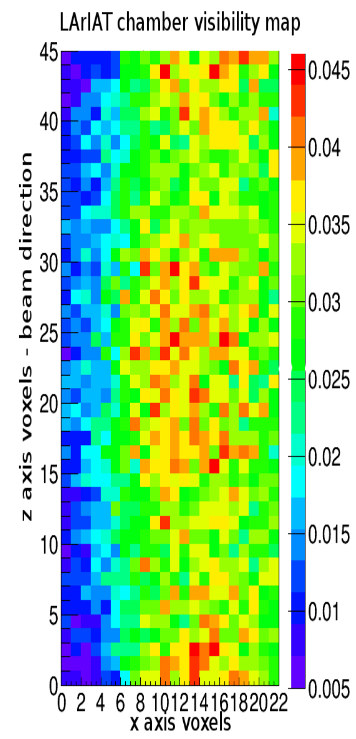
- Cryogenic, standard and high QE PMTs + Silicone Photomultipliers used
- Light yield tunable via adjustment of reflector foils position/size
- These parameters have to be obtained before assembly ► detailed simulation necessary

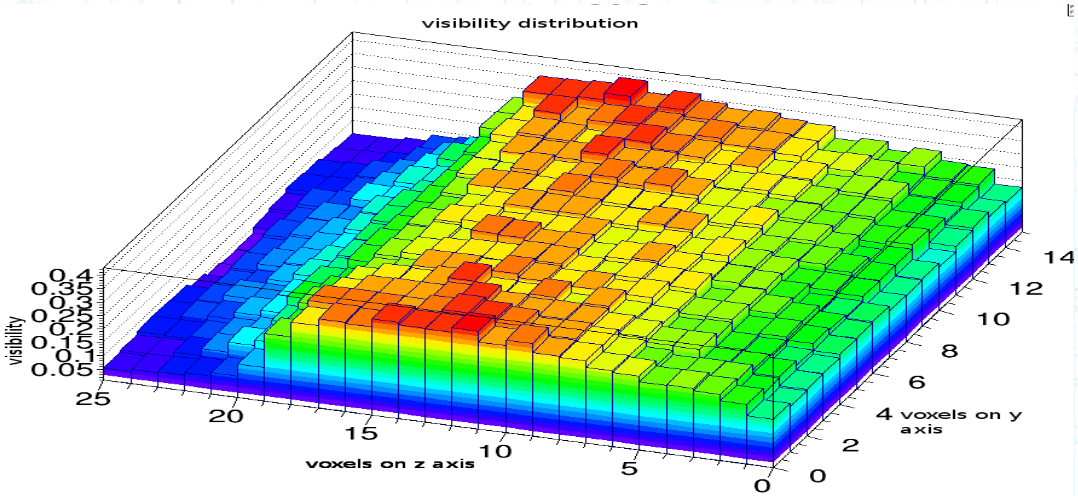



Photos courtesy of W. Foreman

Light Simulation in LArIAT

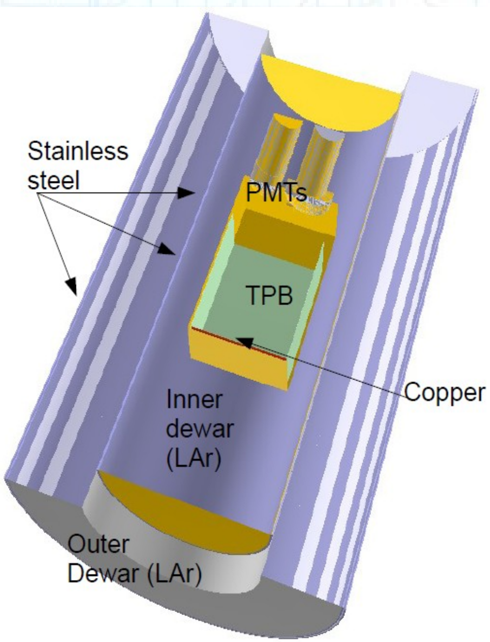
- At the given energy range, light simulation involves tracking several millions of photons – not feasible
- More efficient approach developed in LArSOFT by B.J.P. Jones (MIT) for a simple case
- Geometry divided into 3-D pixels (voxels), and a portion of light emitted in each voxel recorded by PMTs is saved
- With such so-called fast lookup library at hand it is „enough” to calculate how much light do we get in every voxel and instantly transform this into PMT hits

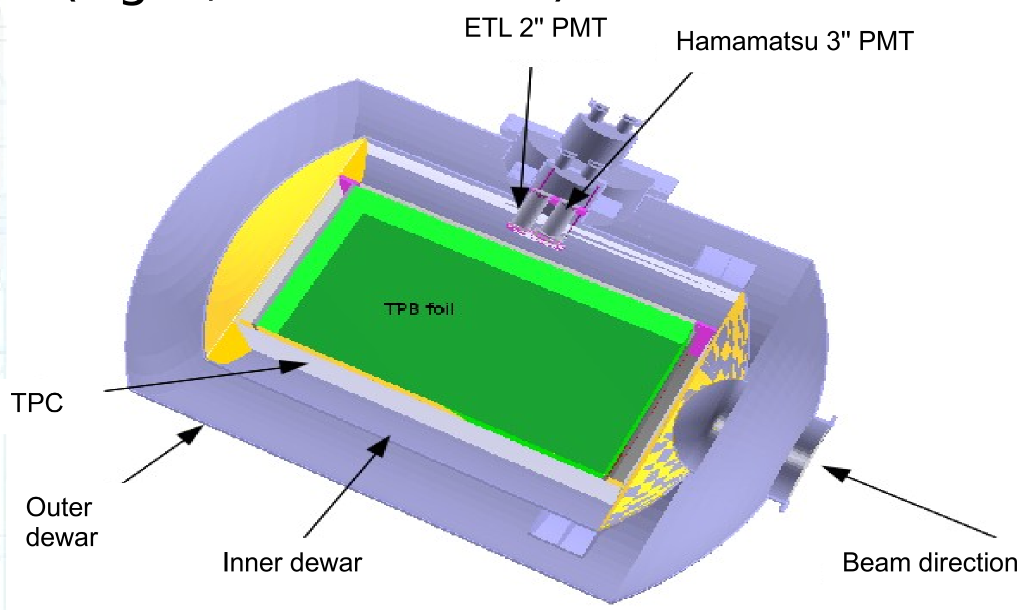




Geometry models

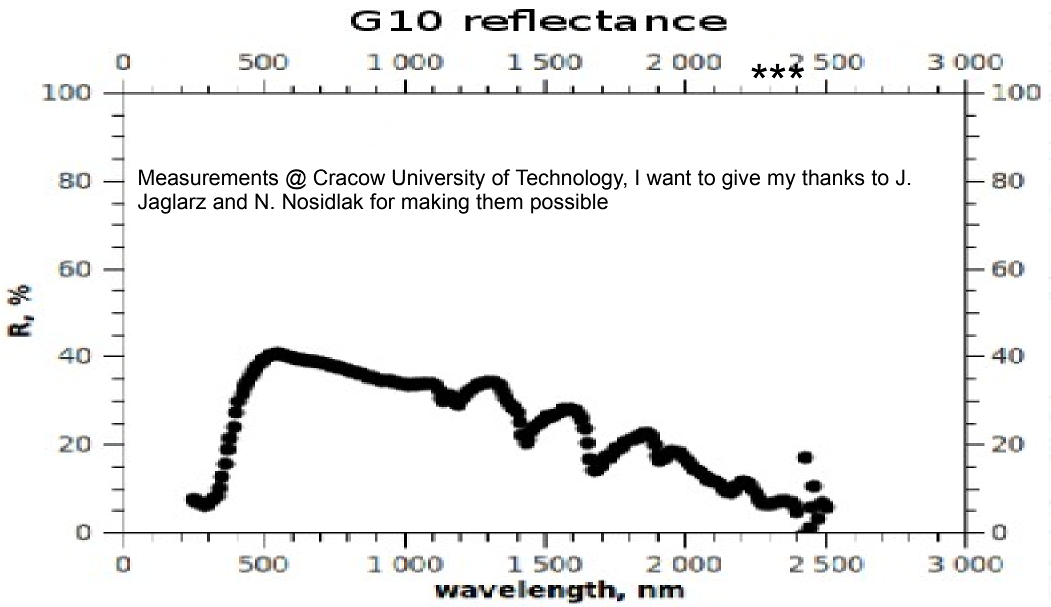
- A proper setting light yield value and uniformity is required to perform calorimetric reconstruction and particle identification
- Existing approach had to be extended to match the cutting – edge R&D goals of LArIAT
- Geometric models prepared for the test setup (left) as well as for the LArIAT TPC (right, not to scale)





Material Properties in Model

- Incorporated optical surface properties of the TPC walls (G10 laminate), TPB - covered reflector and the copper cathode
- PMT efficiency spectra embeded wrt. wavelength
- WLS mechanism and properties of TPB included in detail
- NEST* (Noble Element Simulation Technique, libraries for Geant4**) applied - detailed approach to simulation of LAr scintillation and as a cross-check for a standard LArSOFT model



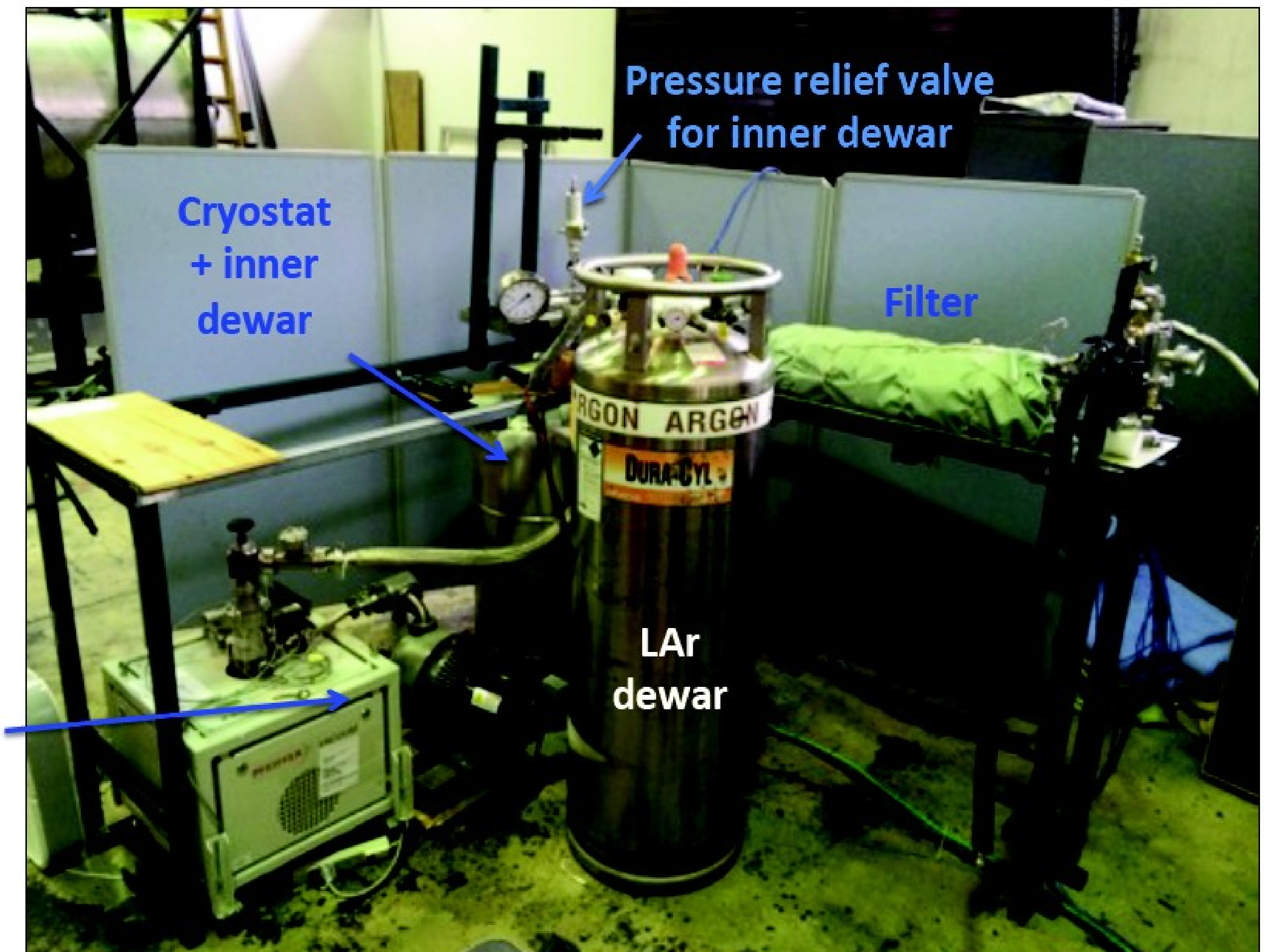
* Szydagis et al., Enhancement of NEST Capabilities for Simulating Low–Energy Recoils in Liquid Xenon, 2013 JINST 8 C10003

**geant4.web.cern.ch, IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278

*** I would like to give my thanks to dr. J. Jaglarz and dr. N. Nosidlak (Cracow University of Technology)for making the measurements of G10 and copper foils reflectance possible. Experimental setup used is described in J. Jaglarz et. al. „Diffuse scattering in polyazomethine thin films", POLIMERY 2009, 54, nr 1

Testing the Simulation

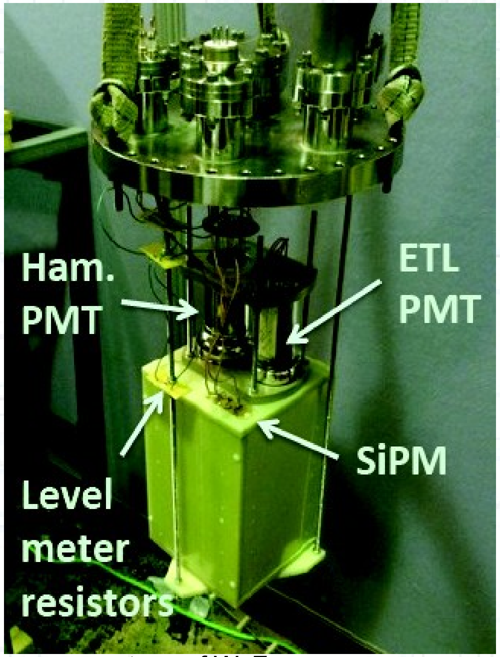
- To test the simulation, we've built a dedicated test setup at the University of Chicago
- It was made of the same materials as the full LArIAT TPC



courtesy of W. Foreman

Test Setup

- The G10 box (15x15x27 cm), was immersed in dewar filled with LAr
- Data runs were taken in April 2014 with the cosmic rays using the external trigger from scintillating paddles as well as with ^{60}Co source
- The source was put in different positions to examine the light collection uniformity



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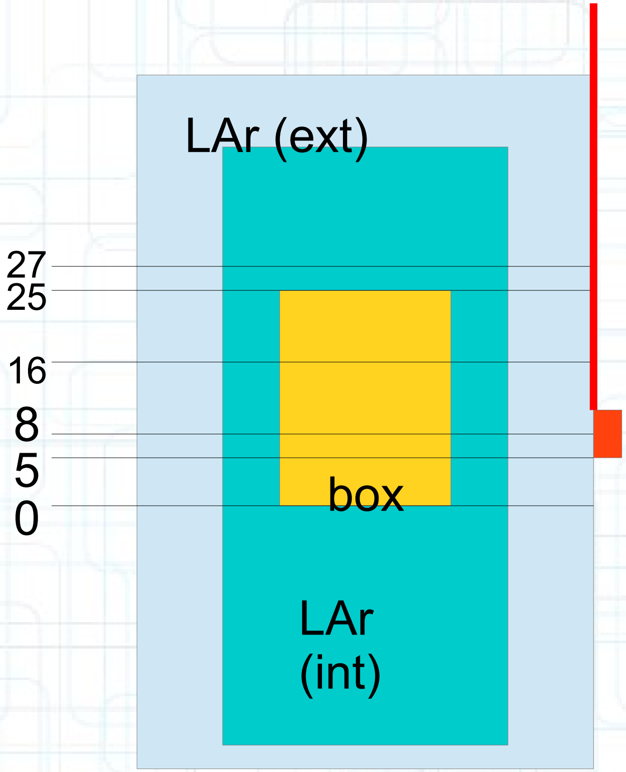
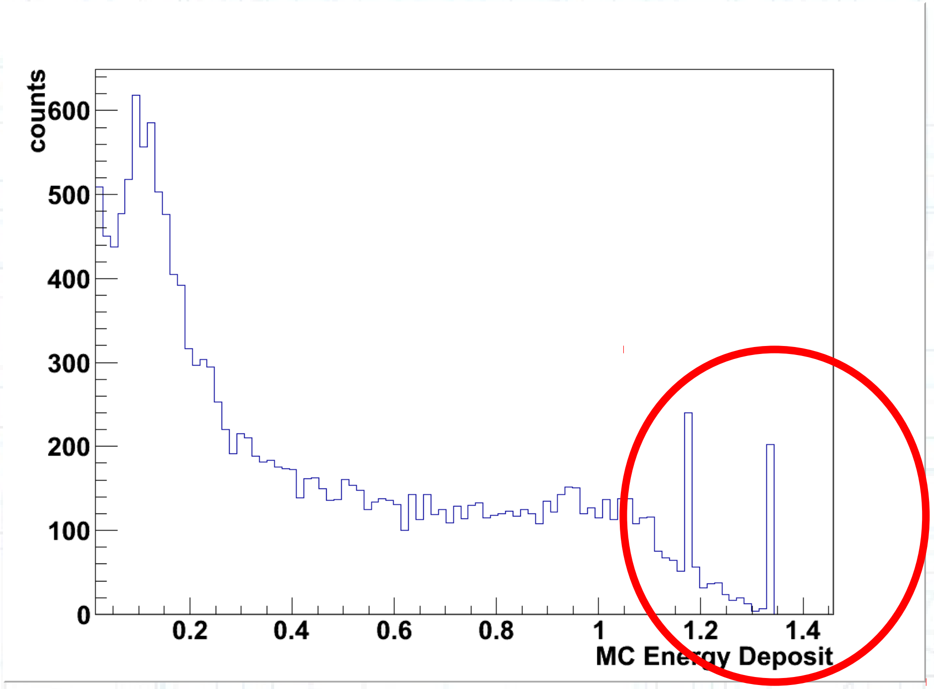
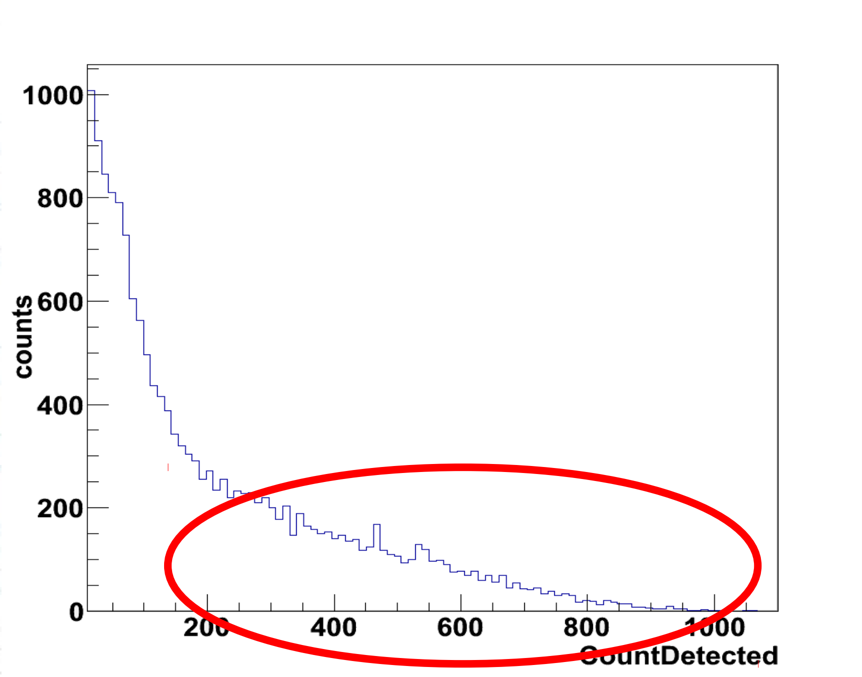


Simulation of Light in LarIAT

- Light yield values were tested for different angular spread of emited particles (gammas from ^{60}Co source)
- Light yield for MC data calculated using the full absorption peak of Cobalt (1,17 MeV and 1,33 MeV). Due to the smearing, the two peaks are observed as a single one





Two Cobalt gamma peaks, clearly visible in MC Energy deposition, smeared in collected photon number

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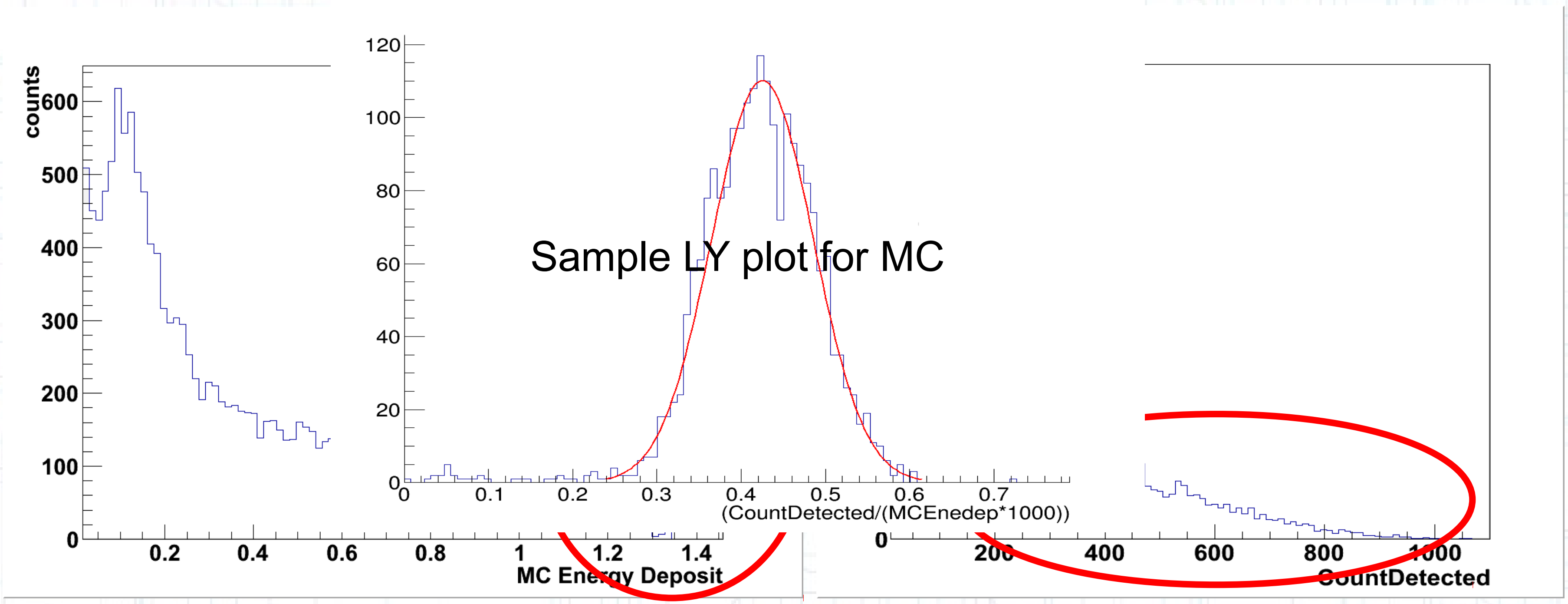

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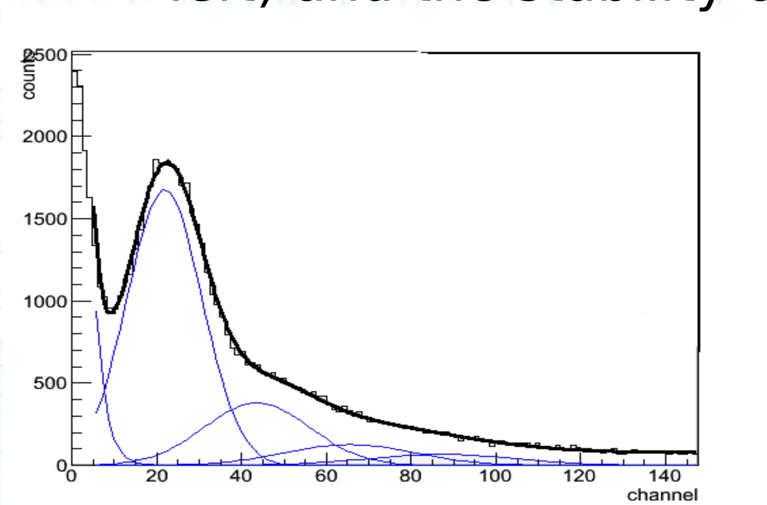
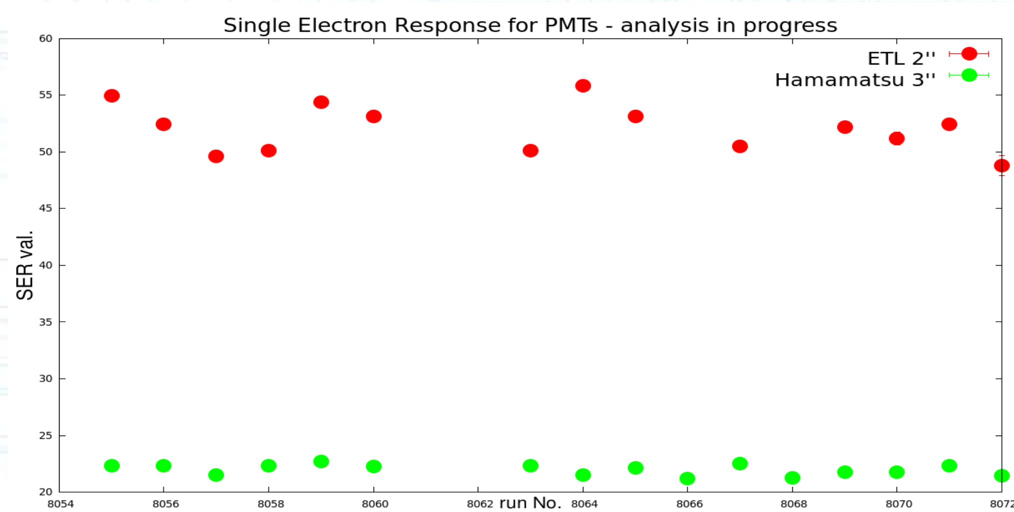
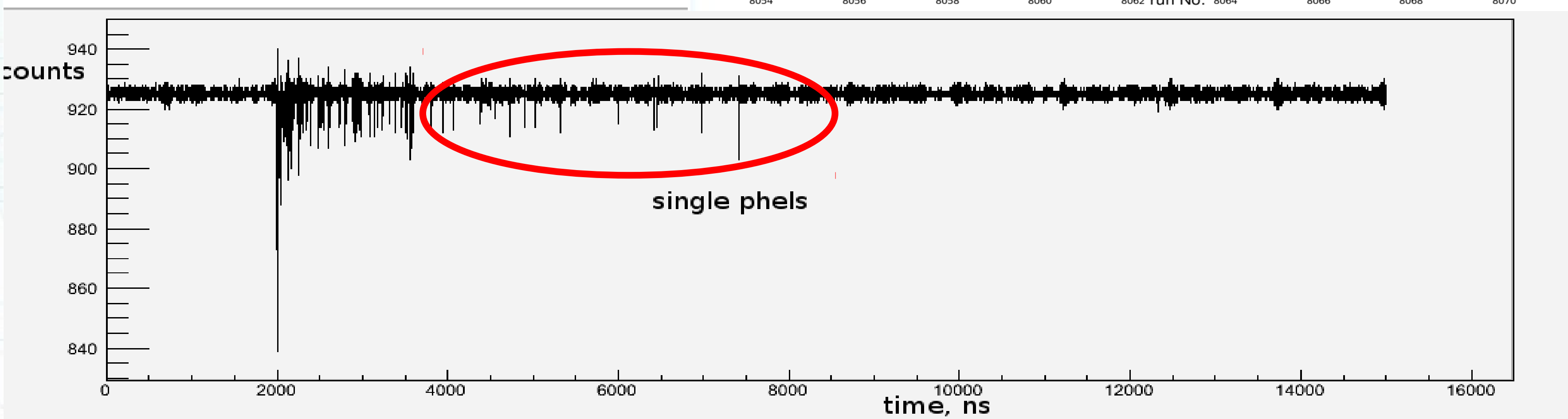
PMT Response

- For each run, Single photoelectrons were searched in a tail of signal to translate PMT response from ADC counts to phel
- Resulted in ongoing calibration of PMTs
- PMT calibration based on Single Electron Response (SER - left) and the stability of obtained values

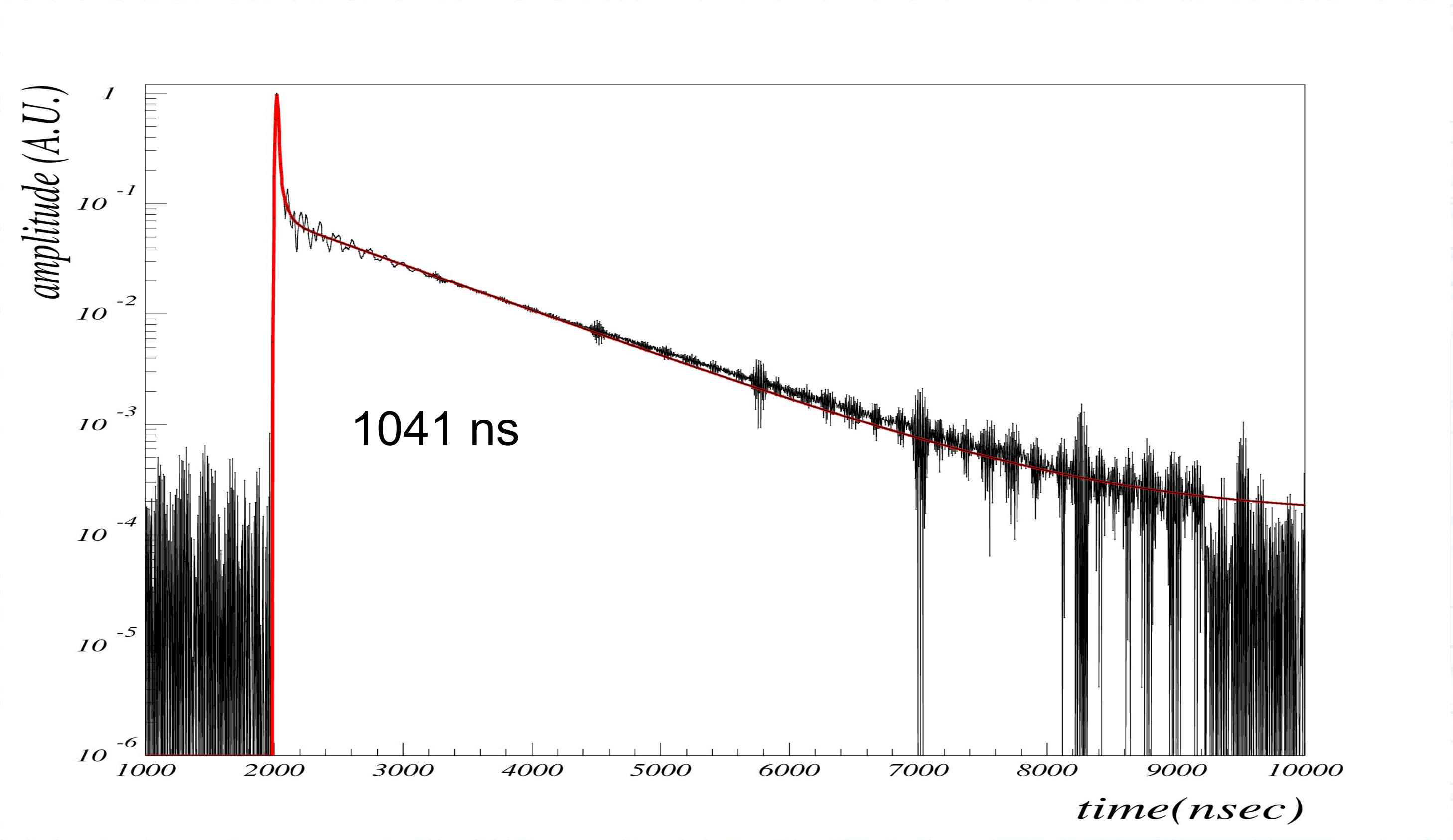






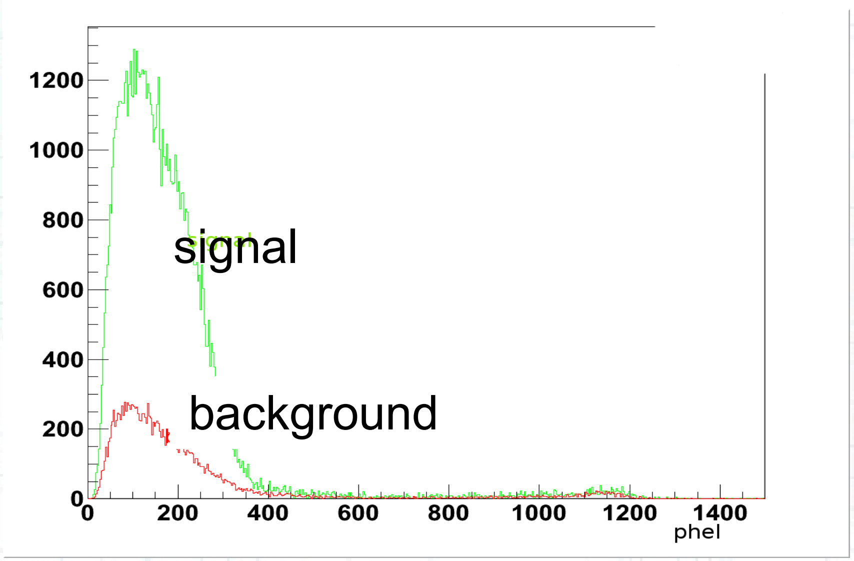
Argon Purity estimation

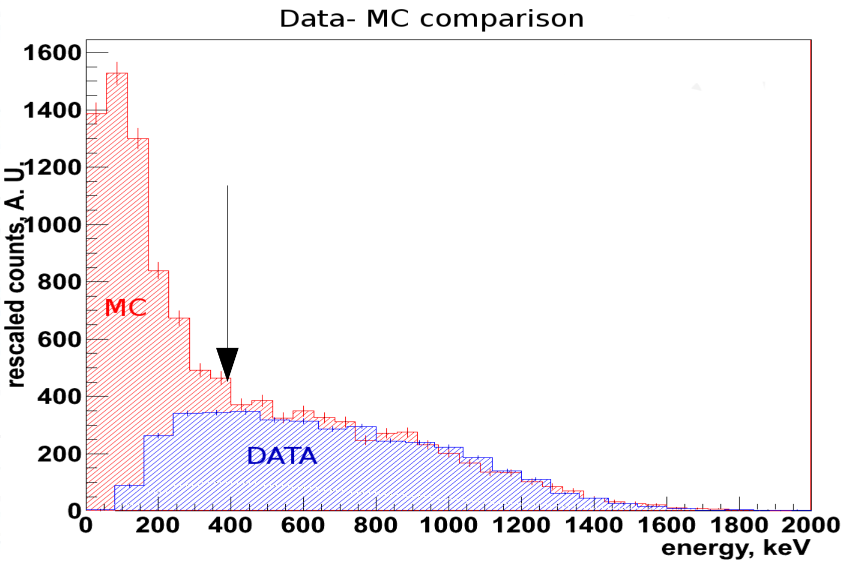
- Average waveform was analyzed to obtain the estimate lifetime of a slow component
- As it produces 75% of scintillation light, it may serve as a hint towards purity assesment.



Data – MC comparison

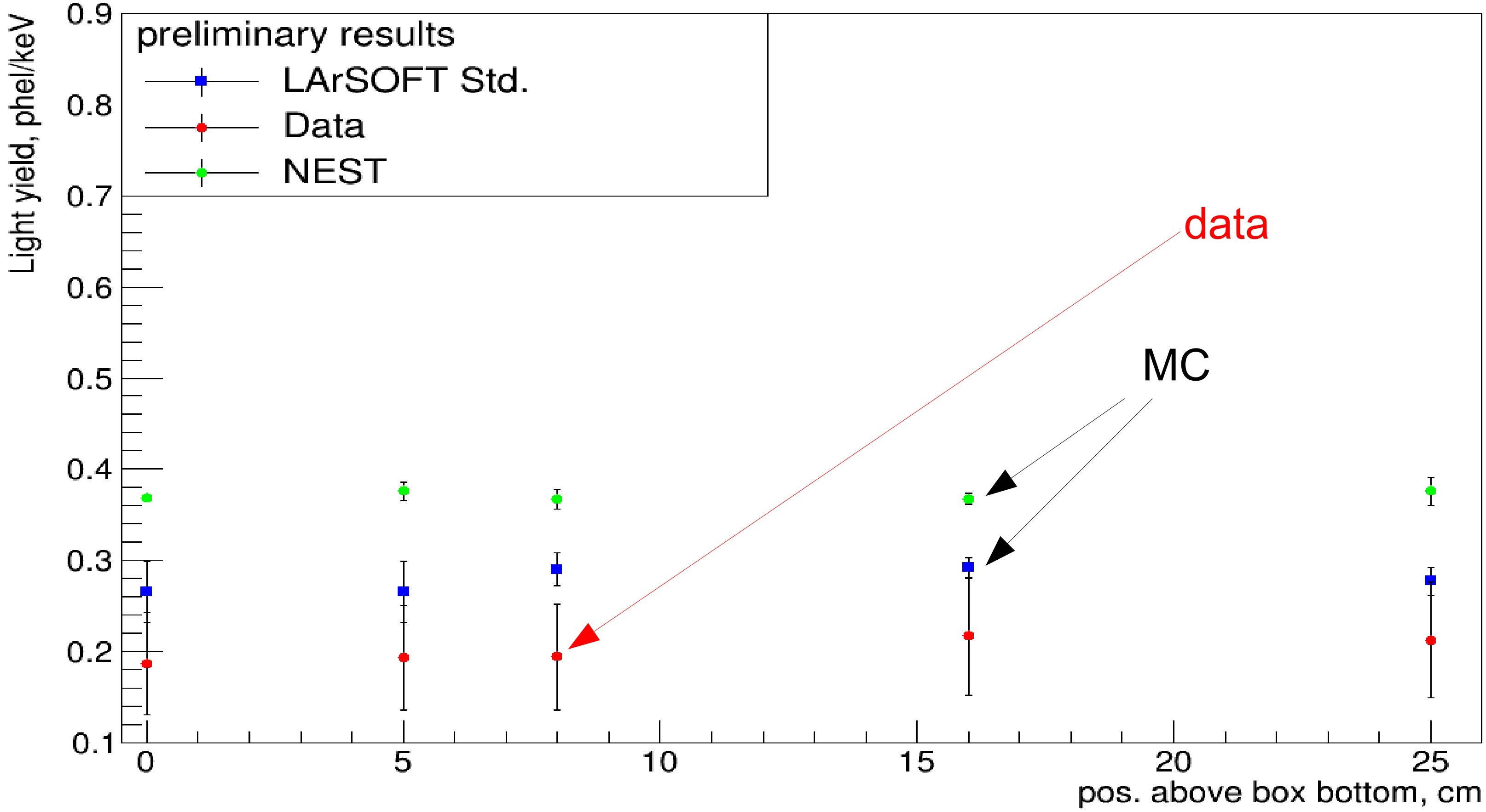
- Signal and background subtracted based on measured trigger rate
- The data light yield estimate was obtained by fitting to the MC prediction and using a scale factor.
- Spectrum was smeared, so the shape of MC was fitted to data to obtain the scaling factor ~ light yield
- It can be seen, how high threshold majority trigger eliminated the low energy events





Data - MC LY comparison

- Simulation is overestimating the Light Yield in the test set-up by a small factor.
- The discrepancy, once fully understood (TPB+foil reflectance to be measured) will be accounted for in the simulation of the full detector.



Conclusions

- Light readout system proved to work in a test setup runs
- Still some discrepancy left between MC and data – have to be understood
- Work in progress towards simulations of the light in full chamber

Thank you!