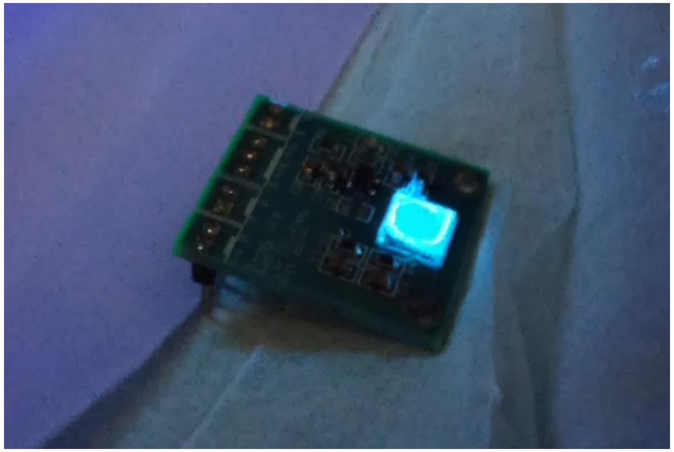
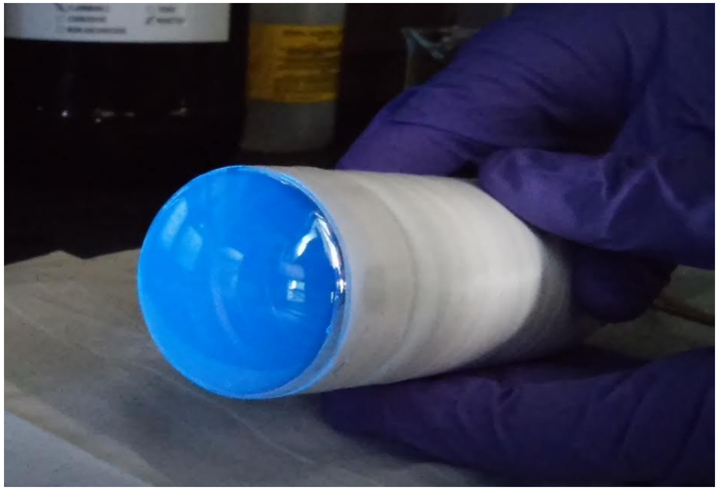
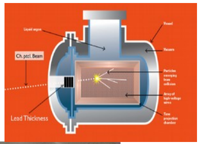
LArIAT Light Collection System

Andrzej Szelc,
Manchester
(for the LArIAT collaboration)





LArIAT



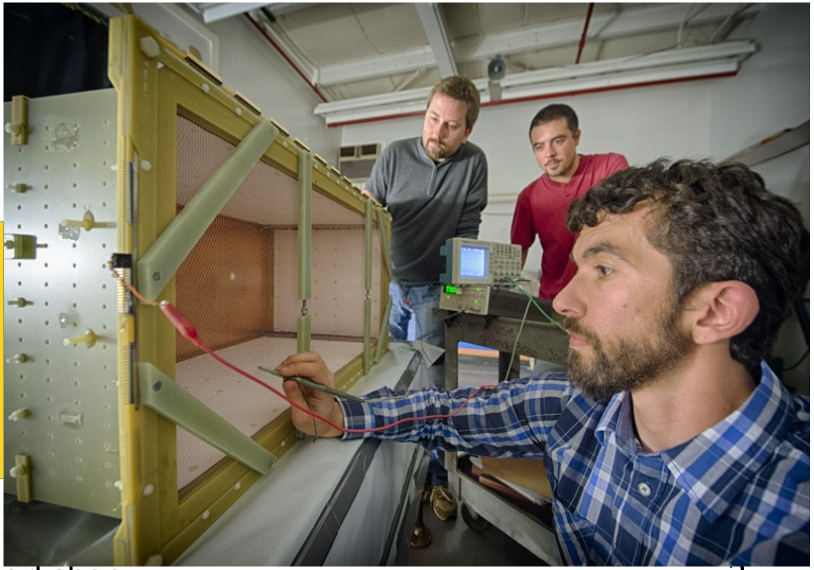
A test facility to calibrate and test LArTPCs and their components using a beam of charged particles and a test-beam experiment.

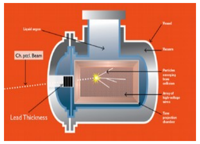
Reusing the ArgoNeuT detector with small modifications:

- front flange modified with excluder + Titanium window.
- **Side flange modified to allow for Light System.**
- Bottom flange modified to enable liquid recirculation (quicker purification).

Run 1 completed.
Run 2 completed.
Run 3 ongoing.

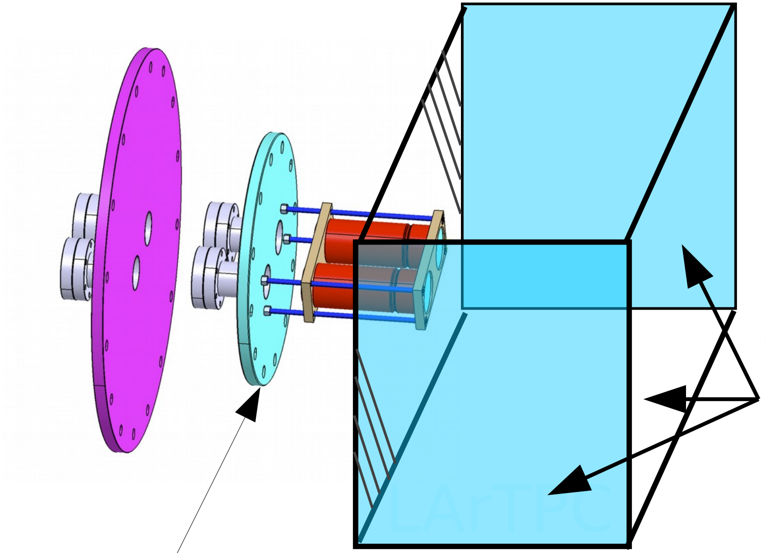
More details in Andrea Falcone's Talk





LArIAT Light Readout

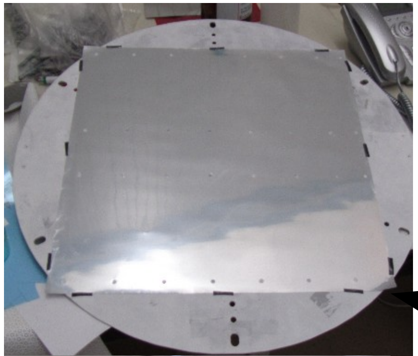
- LArIAT is an excellent test-bed for new ideas.
- The light collection system is designed to maximize efficiency of collection.
- Uses WLS – covered foils.



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

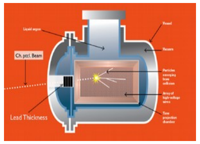
Wavelength shifting reflector foil

- *First test of TPB coated reflector foils in a running TPC (at beam neutrino energies).*

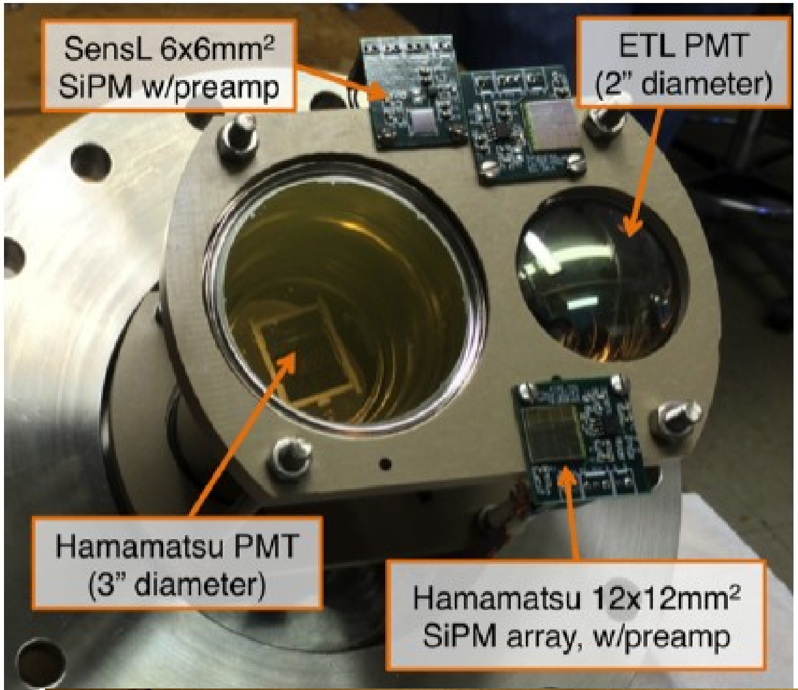


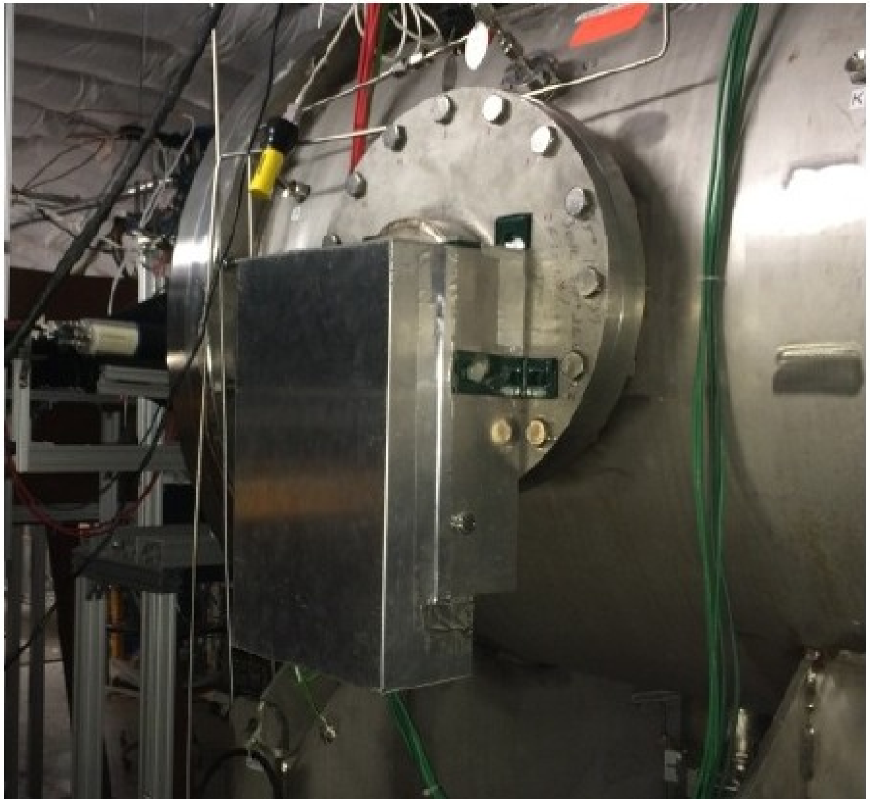
Applying TPB to the reflective foil that will line the inside of the LArIAT TPC

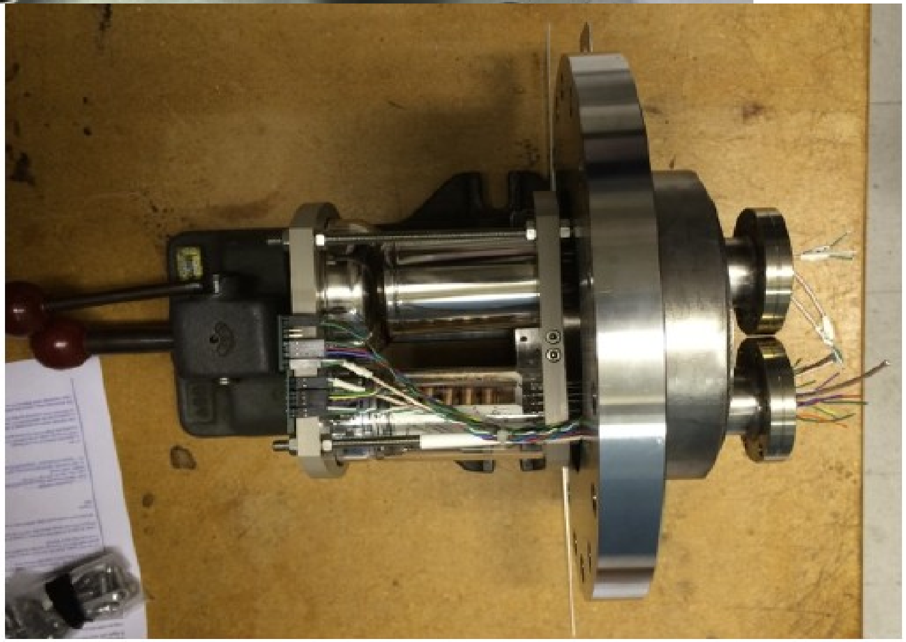
Light Collection System



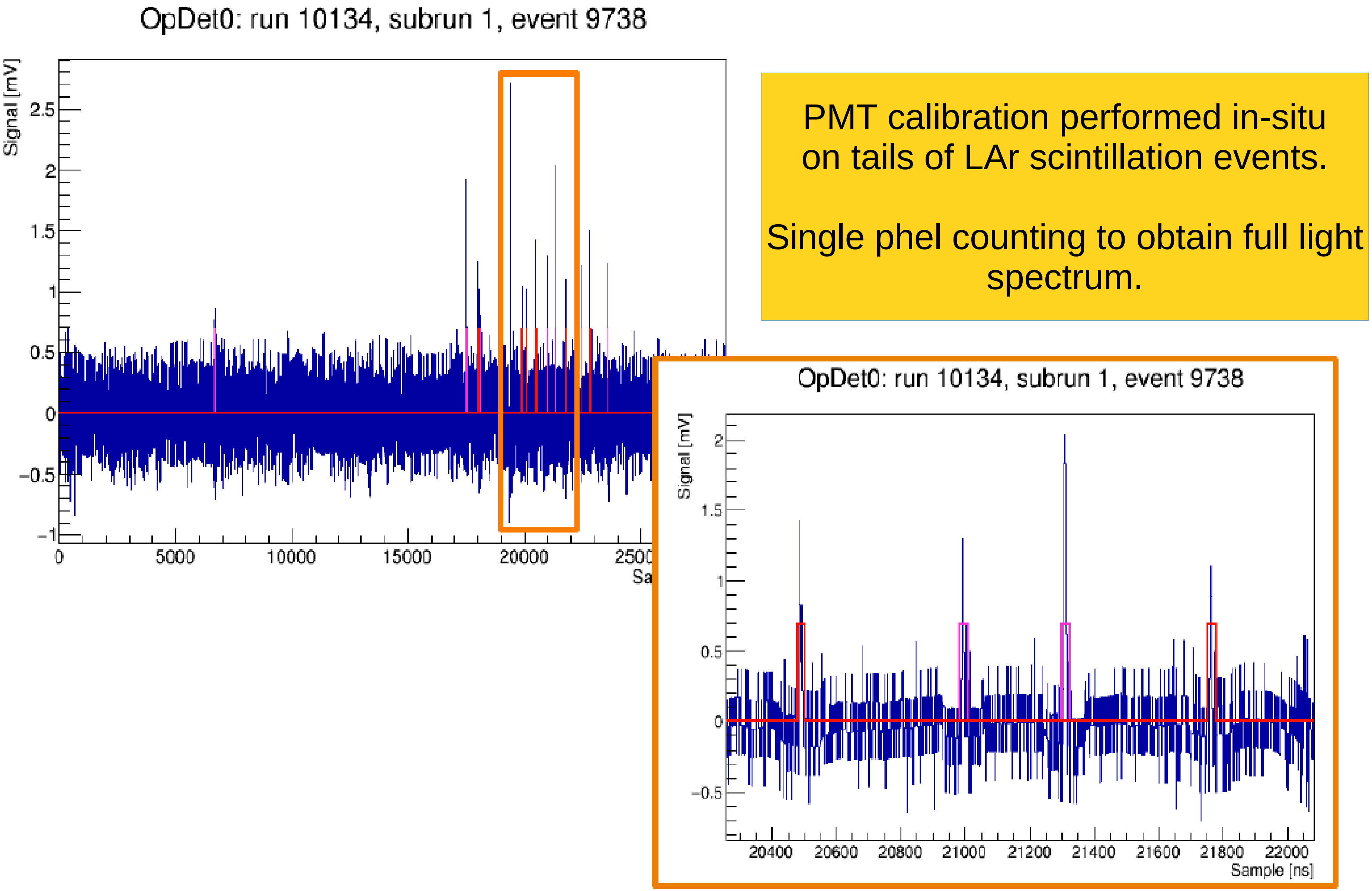
- Choice of PMTs limited by size of side flange.
- Digitized using CAEN V1751, 1GS/s digitizer able to resolve single phel.







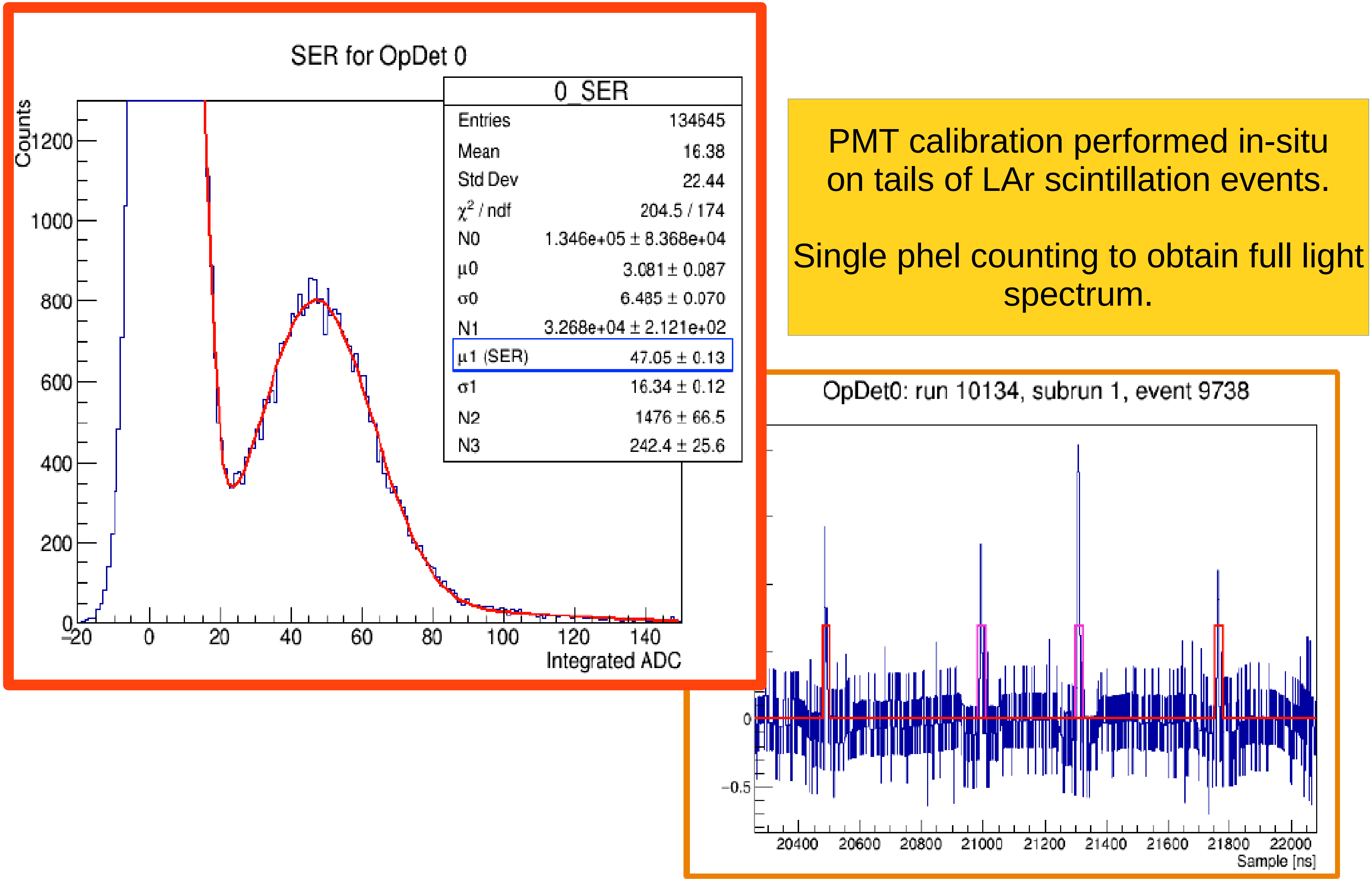
Example Waveforms



PMT calibration performed in-situ on tails of LAr scintillation events.

Single phel counting to obtain full light spectrum.

Example Waveforms

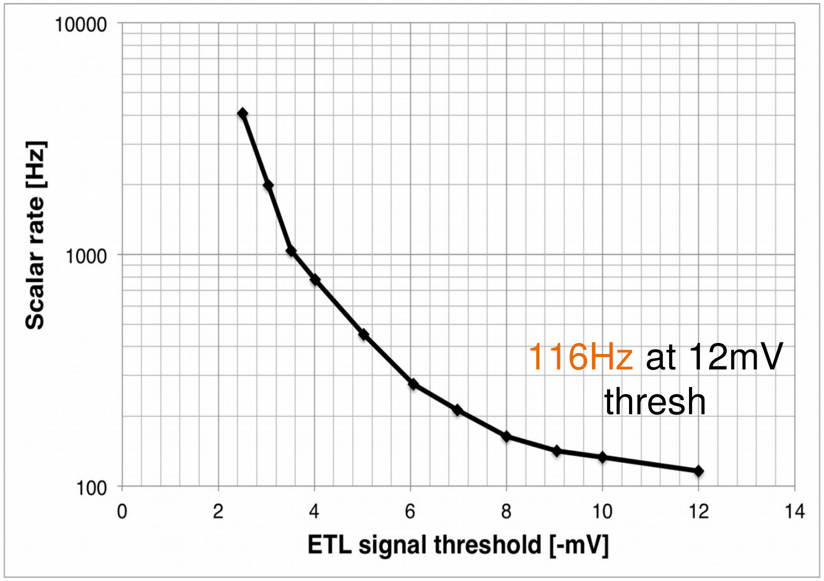


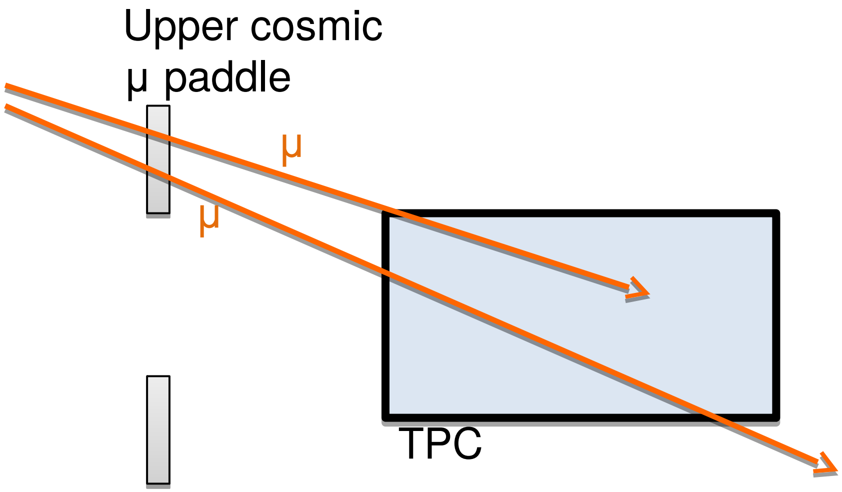
PMT calibration performed in-situ on tails of LAr scintillation events.

Single phel counting to obtain full light spectrum.

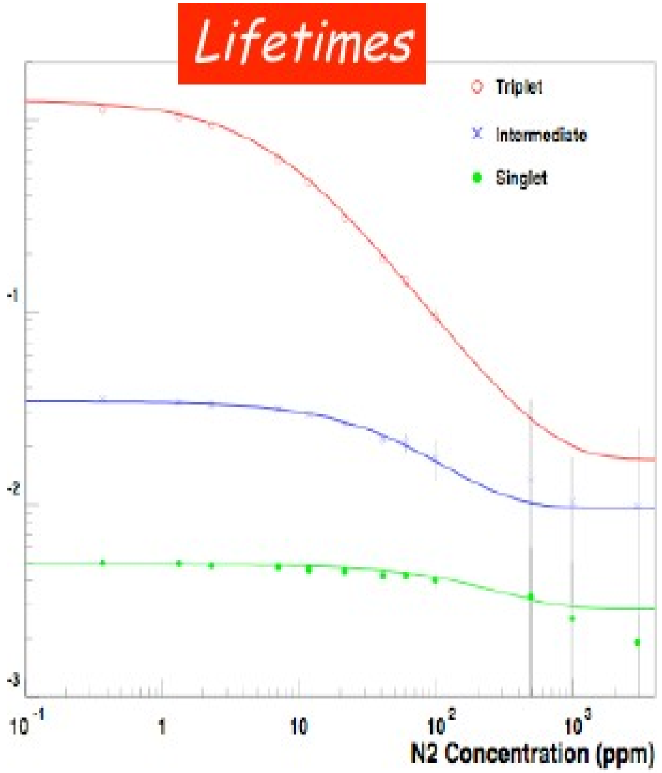
Triggers

- Can use combination of triggers.
  - LARSCINT – trigger on amplified ETL signal (-12 mV)
  - MICHEL – catch Michel electrons/positrons (=next slides)
  - SCINTGATE (400 us gate after each LARSCINT)
  - LARRY: muon “telescope”
    - Coincidence of LARSCINT with either of upper cosmic paddles.
    - Catches both through going and stopping muons.



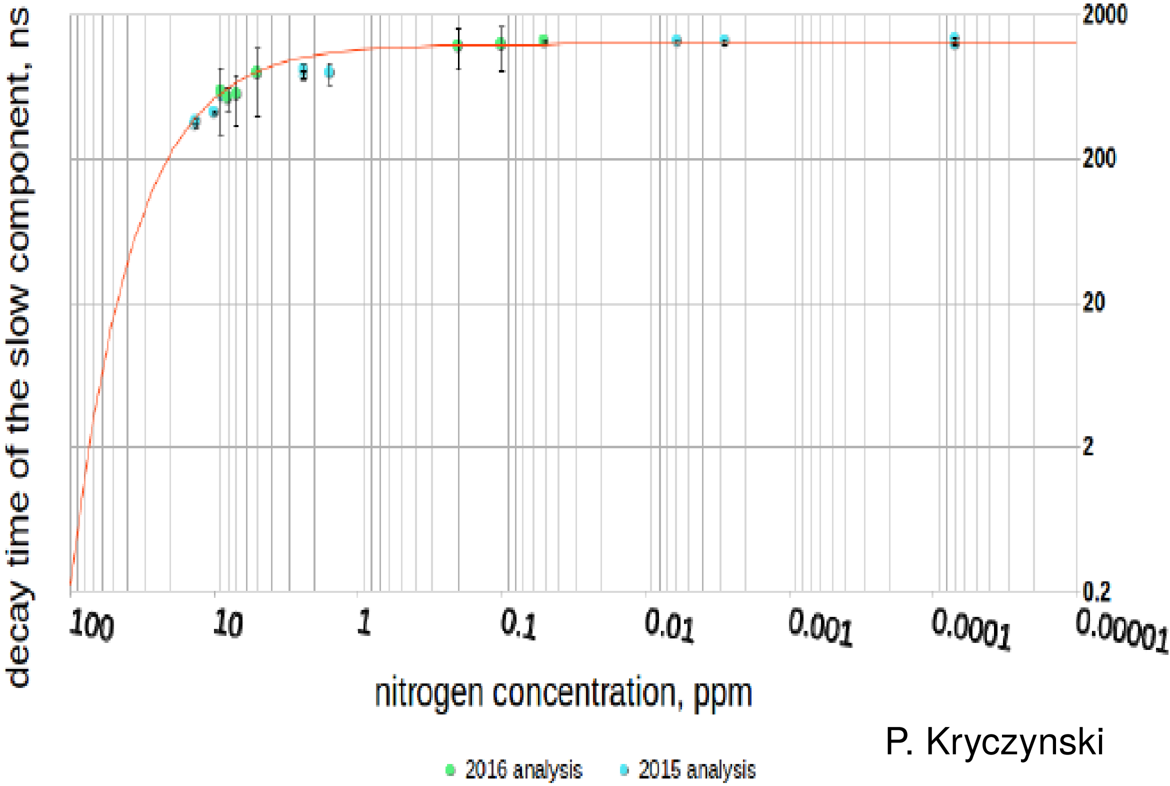


Measuring N_2 contamination using light



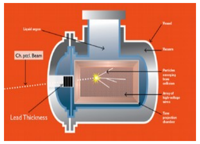
Results agree with measurements using gas analyzers.

N_2 contamination can be understood using the slow component of the argon scintillation light

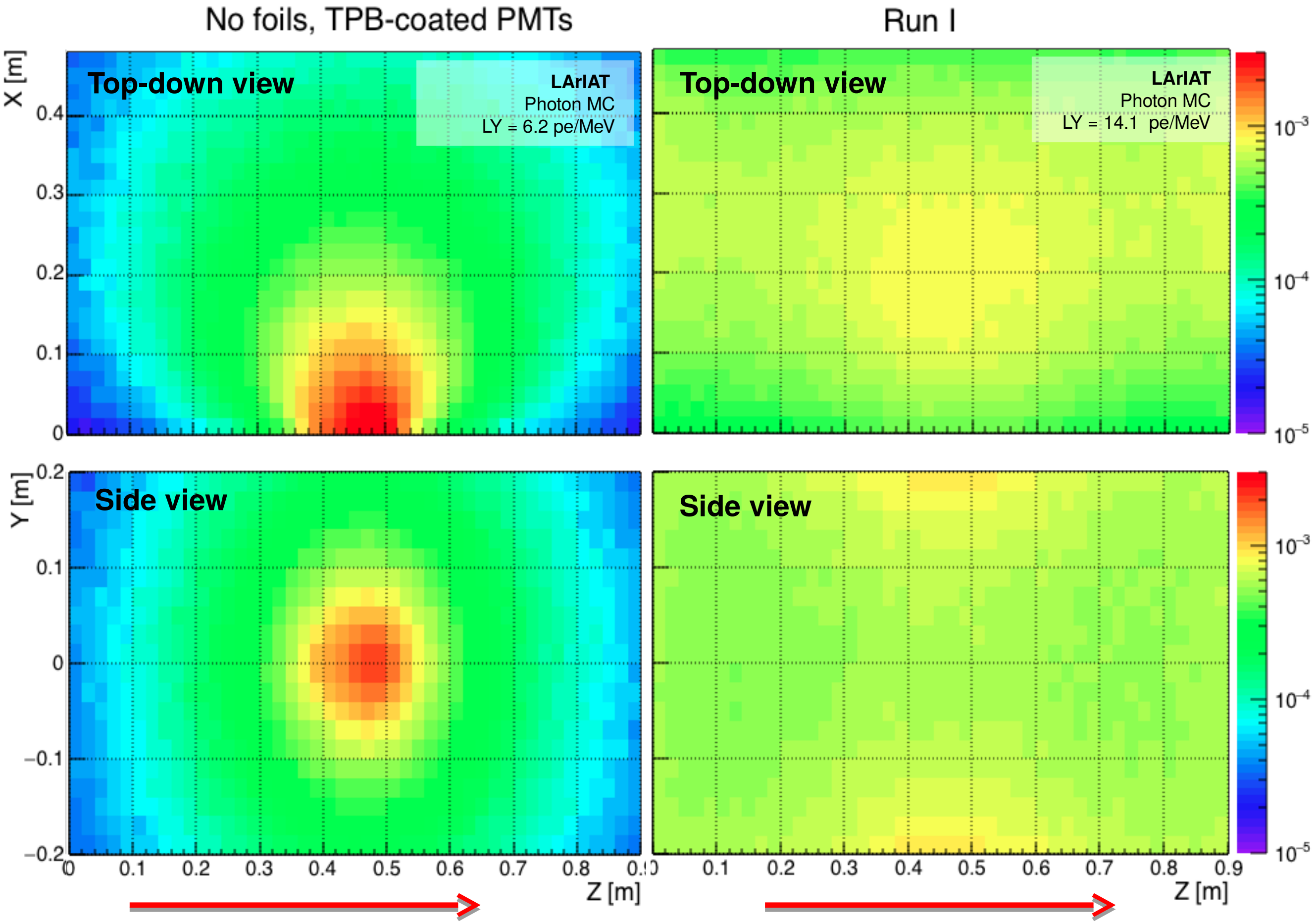


P. Kryczynski

Light Collection Uniformity



- Using LArSoft Simulation tools developed to account for optical foils (checked by standalone code) to model detector response.



Beam Direction

Beam Direction

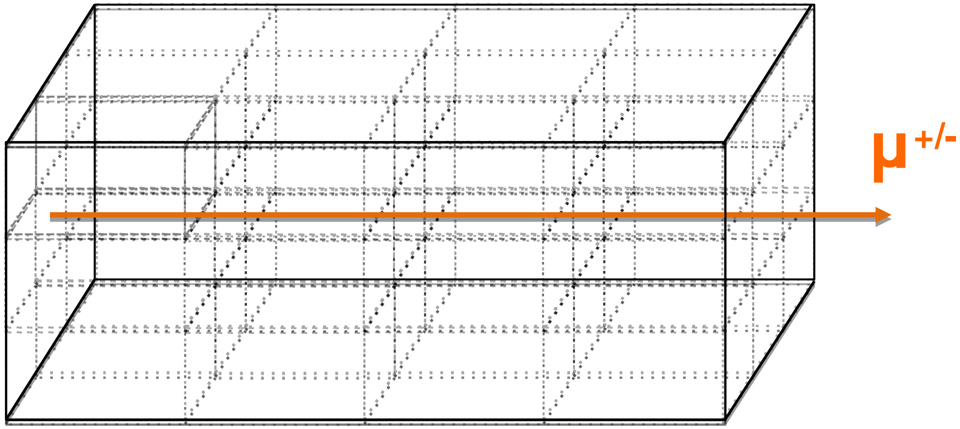
Good uniformity in the detector.

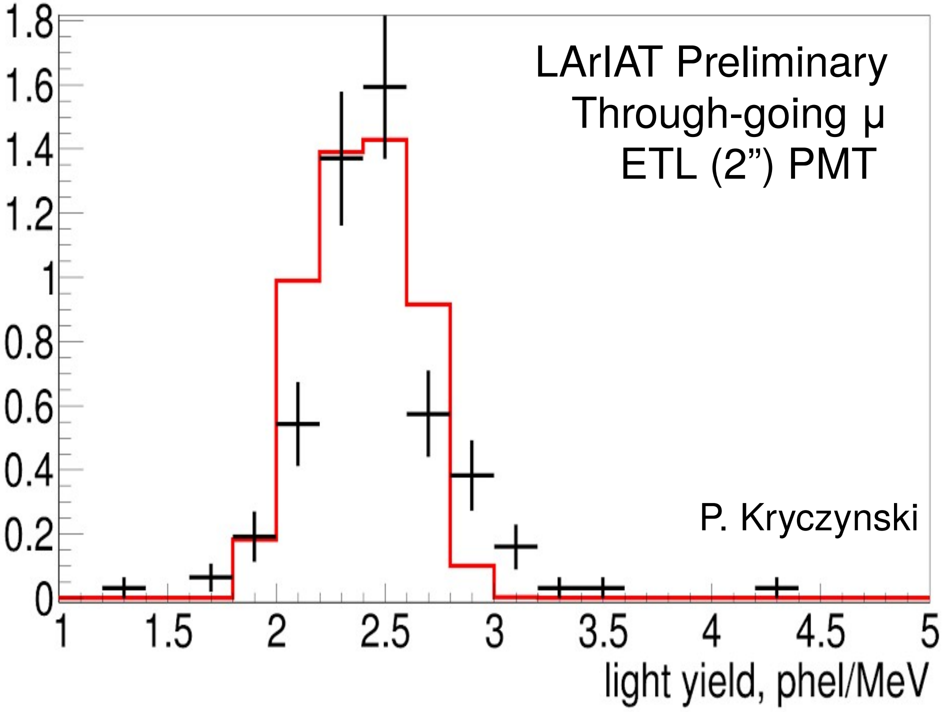
Enables new uses of scintillation light.

W. Foreman

Validating the Simulation

- Simplest topology – easy to understand.
- Great to test predictions vs reality.
- Data agrees with MC predictions (check in subsections of the detector in progress).

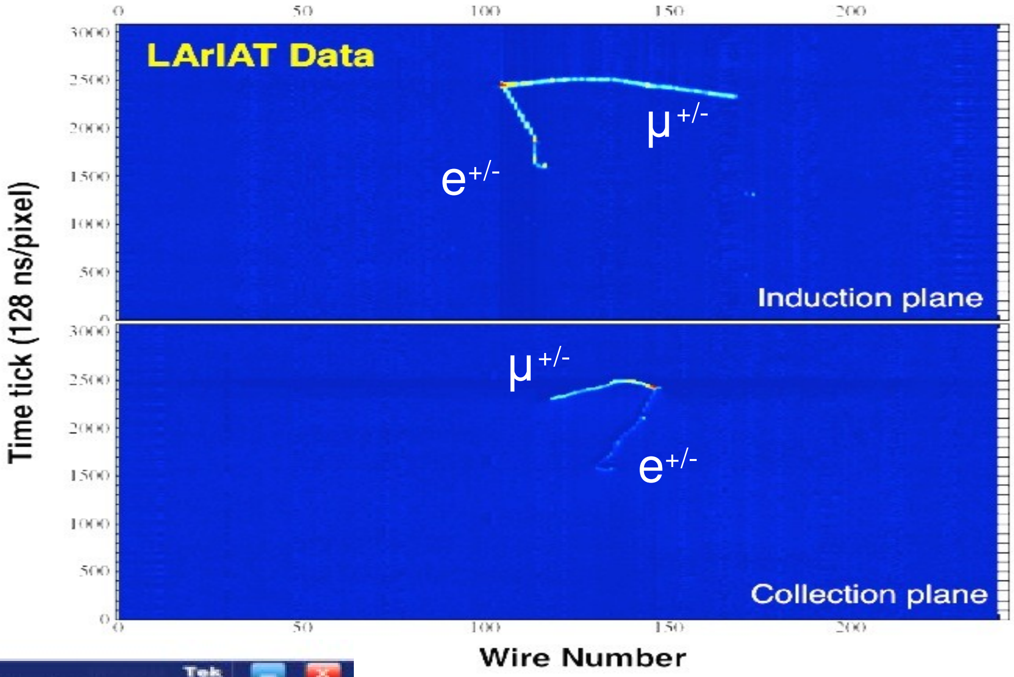


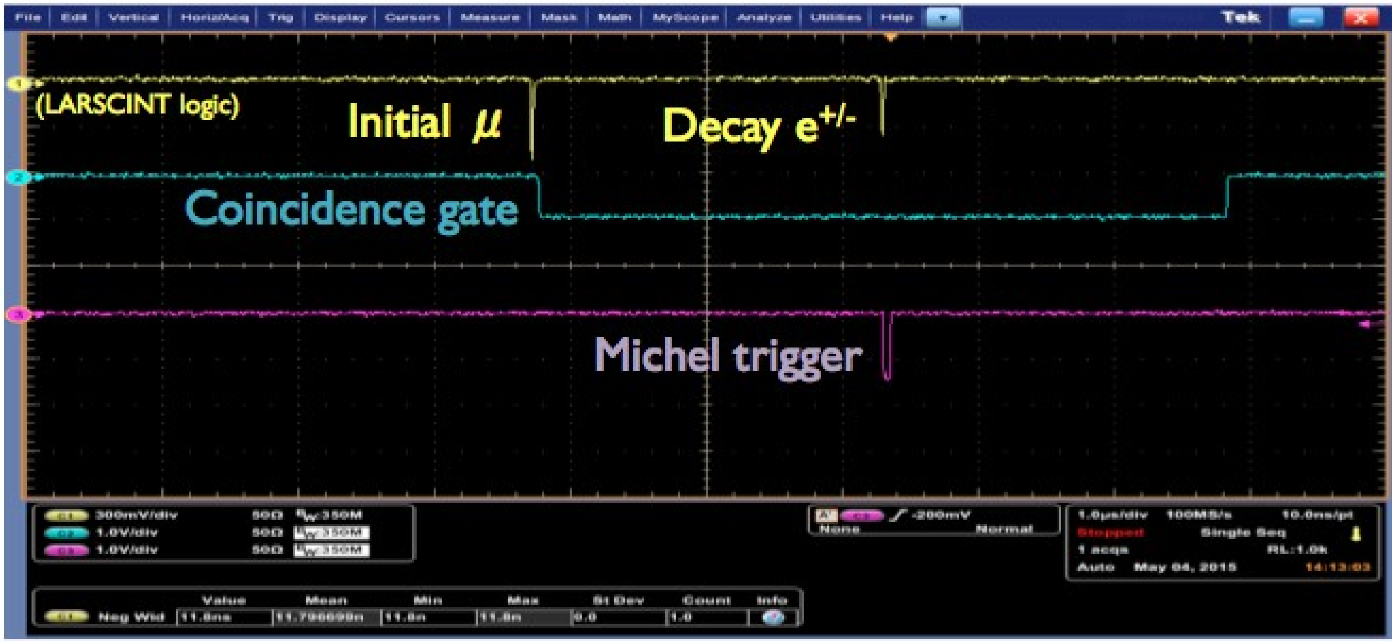


Michel Electrons

$\mu^{+/-}$ (at rest) $\rightarrow$ $e^{+/-} + \nu_\mu + \bar{\nu}_e$

- Well known energy spectrum.
- Great to perform calibrations.
- Need scintillation light to trigger.

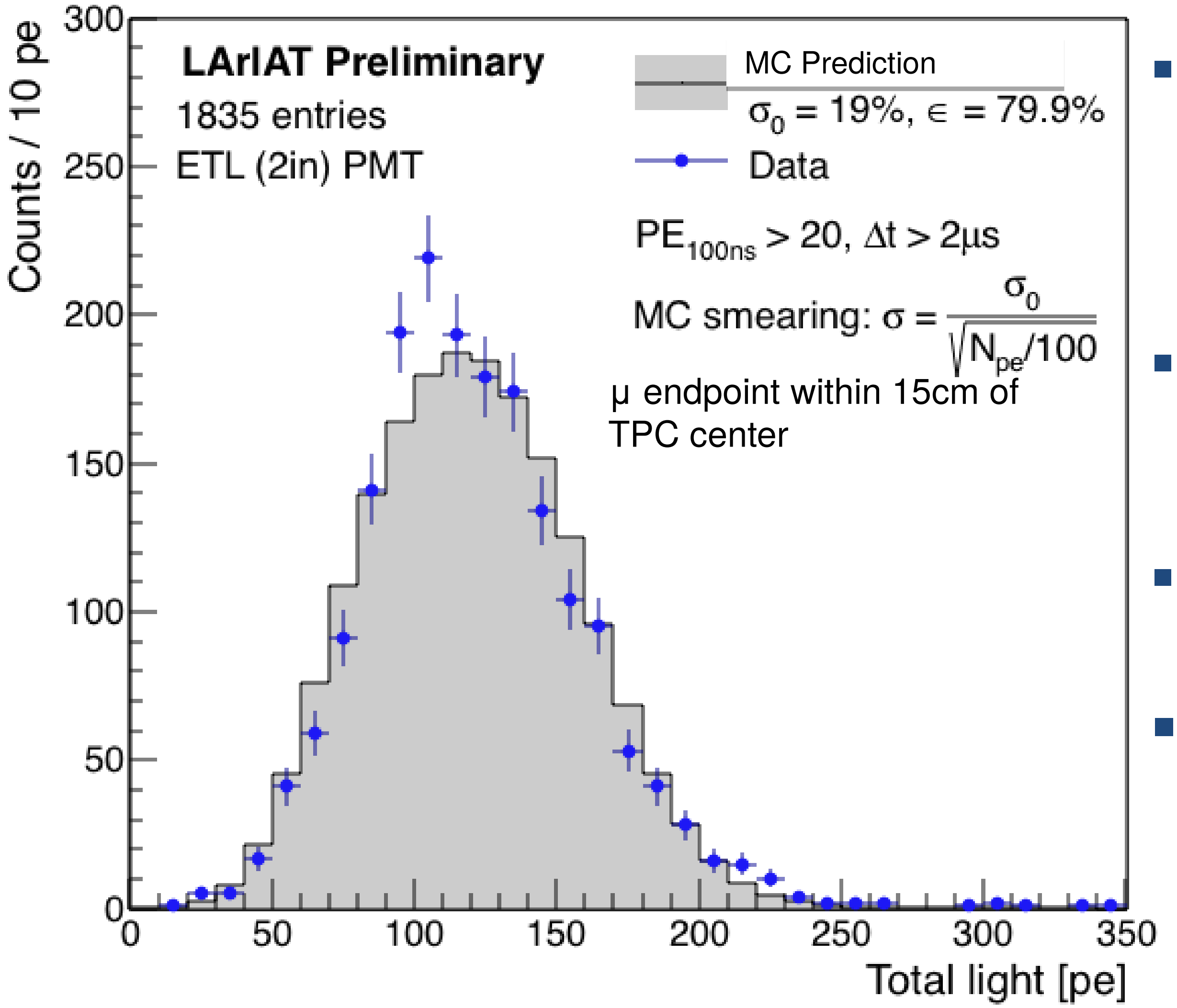




Real-time triggering on Michel e’s from stopping cosmic μ’s using **light signals**

W. Foreman

Energy Calibration with Michels

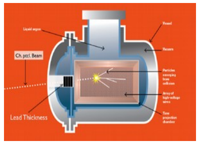


- Michel-candidate signals integrated to get PE spectrum
- MC reproduces shape well. Gives more confidence in simulation model.
- LY compatible with through-going muons.
- Uniformity greatly helps.

End goal: combine charge + light to get full energy reconstruction.

W. Foreman

Physics with Michels



The University of Manchester

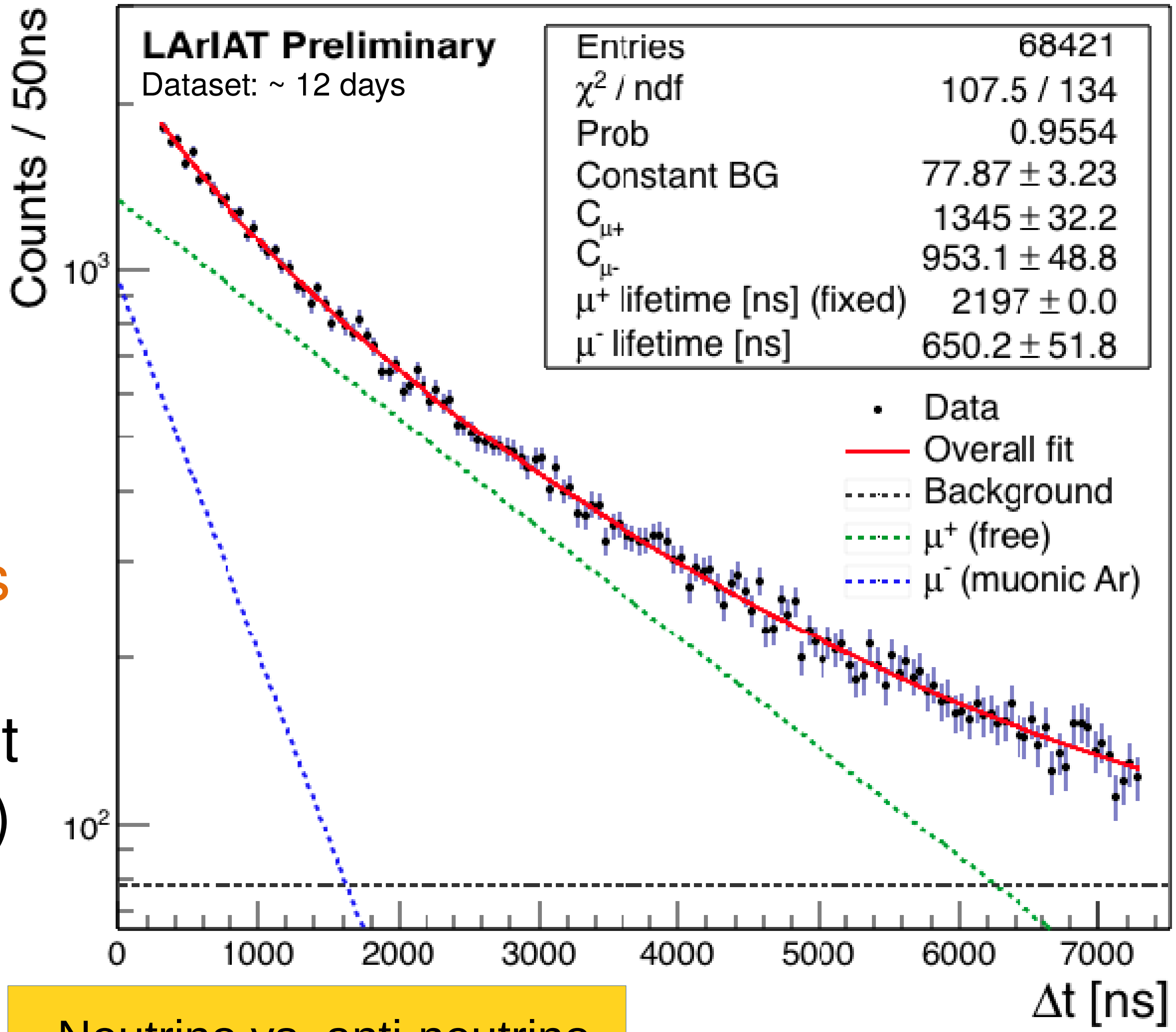
μ⁻ have a predicted 75% capture rate on argon nuclei (no Michel electron present).

$$\boxed{\tau_{\mu-}} = \left(\frac{1}{\tau_c} + \frac{Q}{\boxed{\tau_{free}}}\right)^{-1}$$

650 ± 52 ns

(from fit result, preliminary)

918 ± 109 ns



LIDINE 2015 Proceedings, JINST 11 C01037

Early results agree w/ recent measurement[1] (854 ± 13 ns) and theory prediction[2] (851ns)

Neutrino vs. anti-neutrino Statistical discrimination possible

W. Foreman

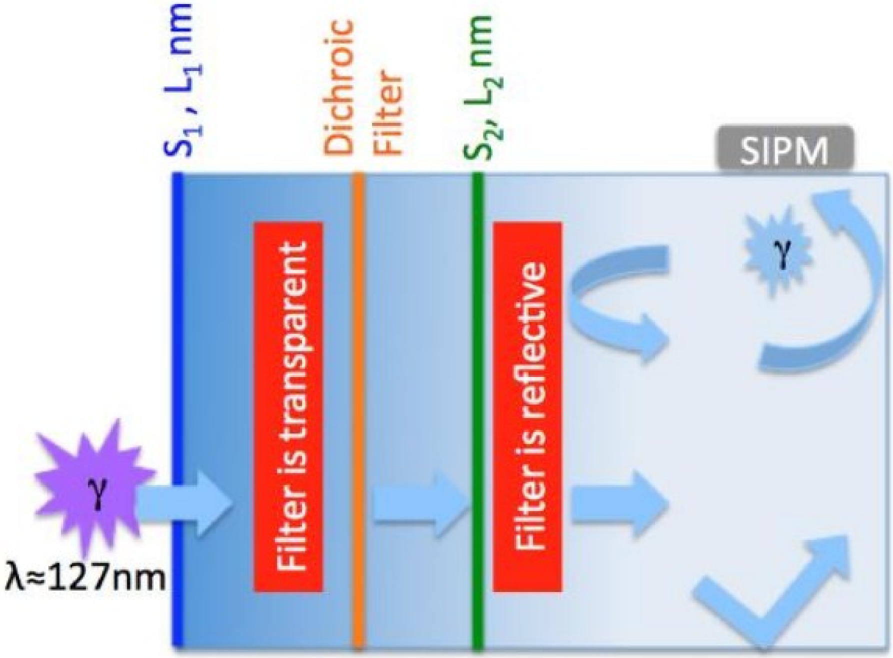
[1] (Klinskih et al., 2008)

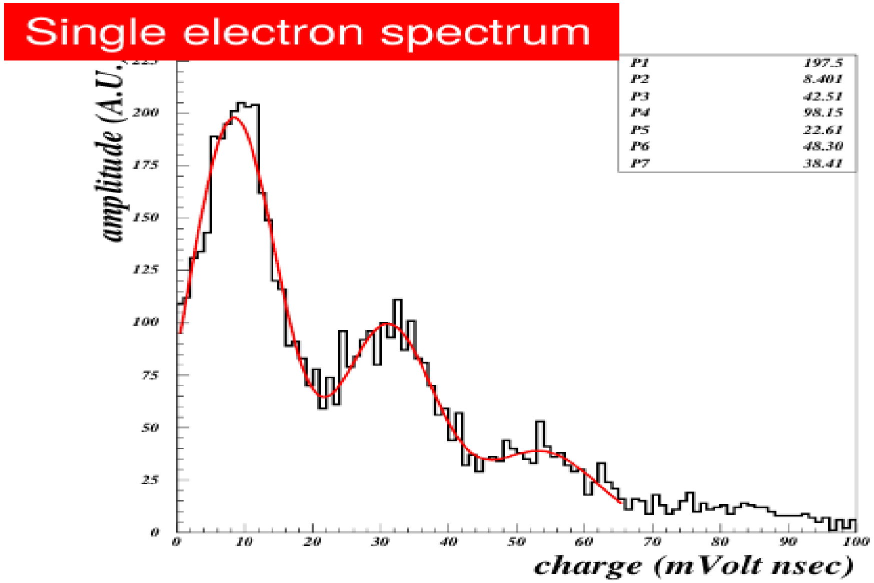
[2] (Suzuki & Measday, 1987)

The ARAPUCA light trap

- Use dichroic filters + 2 WLS
- Readout 1 SiPM, with a larger active surface.

Plans to install
in protoDUNE and SBND

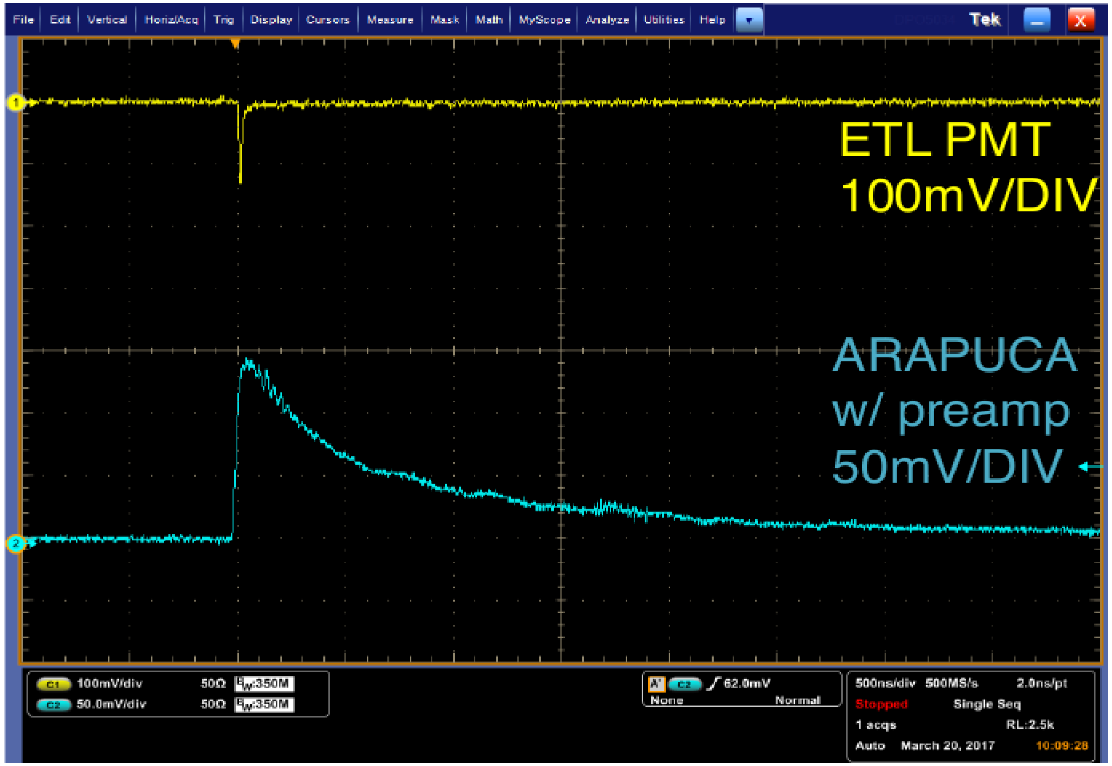



Single electron spectrum

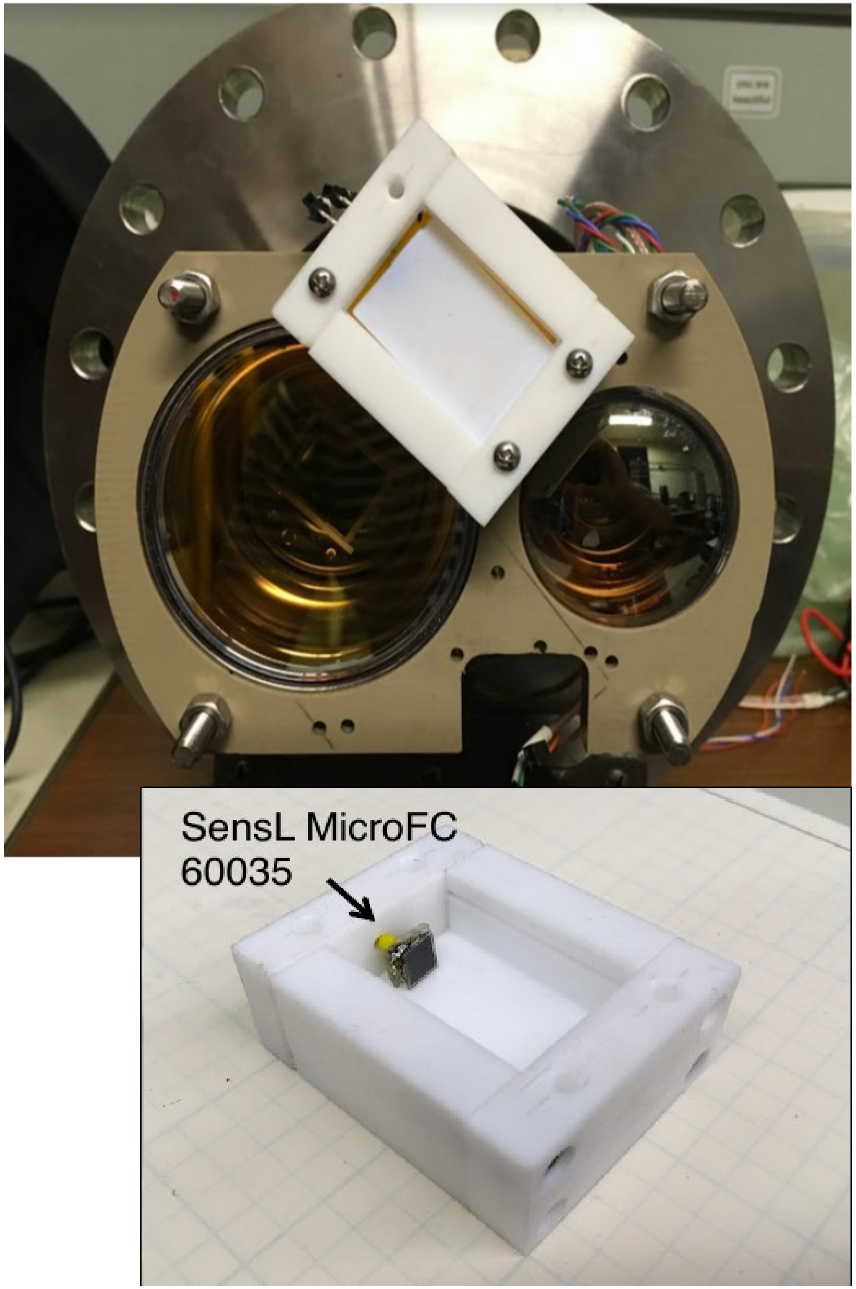
E. Segreto & A. Bergamini-Machado

Current Run

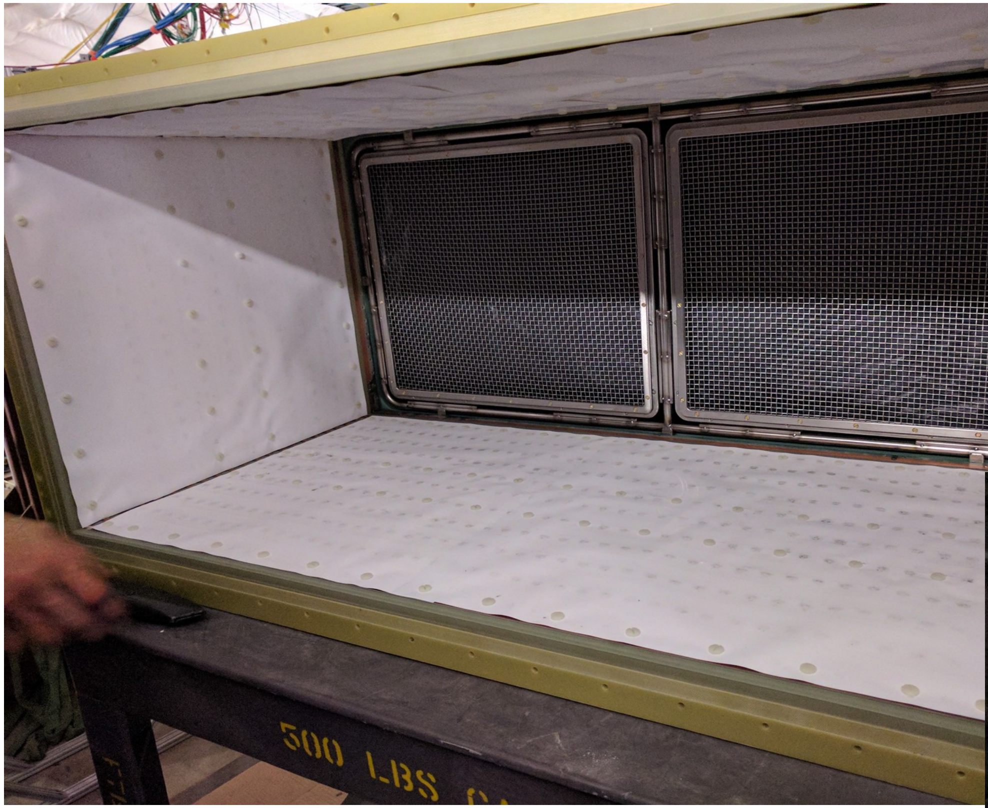
- Installed one ARAPUCA detector.
- Able to compare response with PMTs in-situ.



C1 100mV/div 50Ω Bw:350M
C2 50.0mV/div 50Ω Bw:350M
A' C2 ƒ 62.0mV
None Normal
500ns/div 500MS/s 2.0ns/pt
Stopped Single Seq
1 acqs RL:2.5k
Auto March 20, 2017 10:09:28



Mesh cathode



Prototype of SBND-like mesh cathode was installed in LArIAT beginning of march. Will run with and without foils (change over in a couple of weeks).

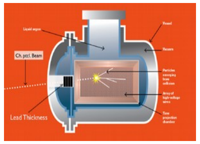
Evaporating foils

- The infrastructure needed to manufacture the reflective foils is ready.
- New LArIAT foils will be made this week.
- Will improve ongoing analysis of “late light” in argon.

Coming Soon:

Stay tuned for other analyses using scintillation light:

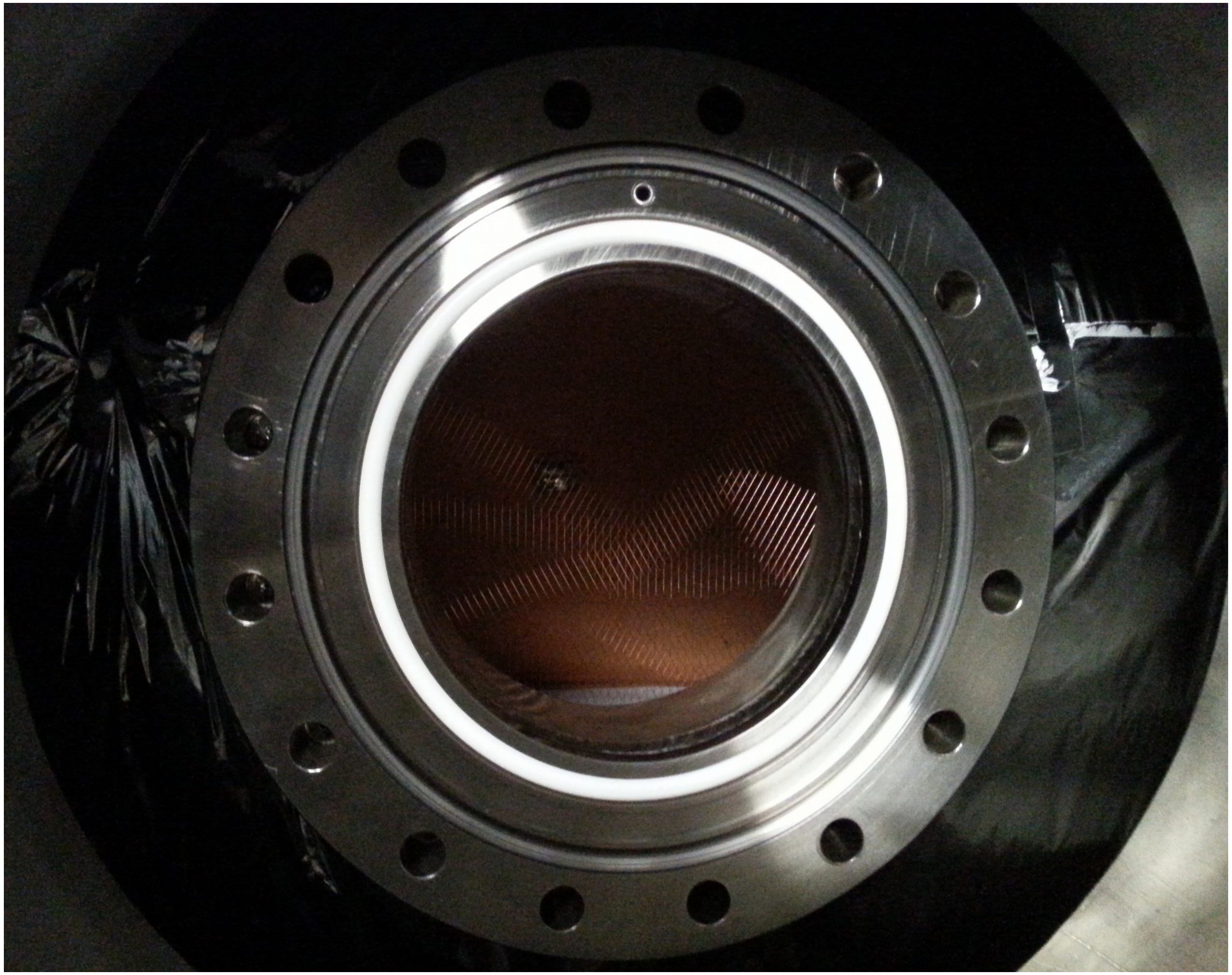
- Particle ID using scintillation light + charge.
- More calorimetry using scintillation light.
- Late light studies.
- Comparison of SiPM, ARAPUCA and PMT performance with data.

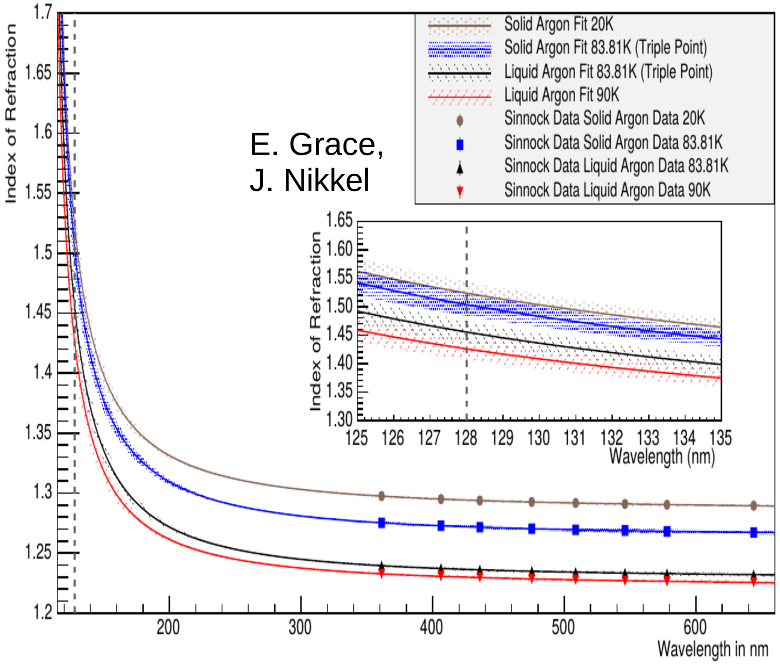


Summary

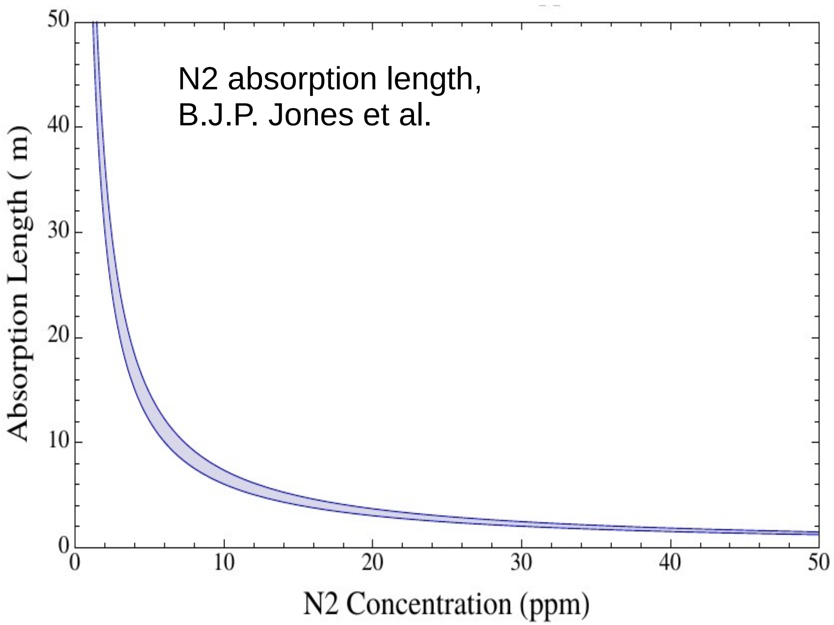
- LArIAT light collection system is a new approach (at these energies).
- High LY enables diagnostic uses of scintillation light.
- Enhanced uniformity enables calorimetric studies and muon sign discrimination.
- LArIAT analyses on using light and combined light + charge for calorimetry, particle ID are close to completion.
- Stay tuned for results from LArIAT run III and previous data!

Thank You
for your Attention



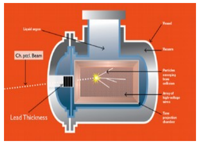


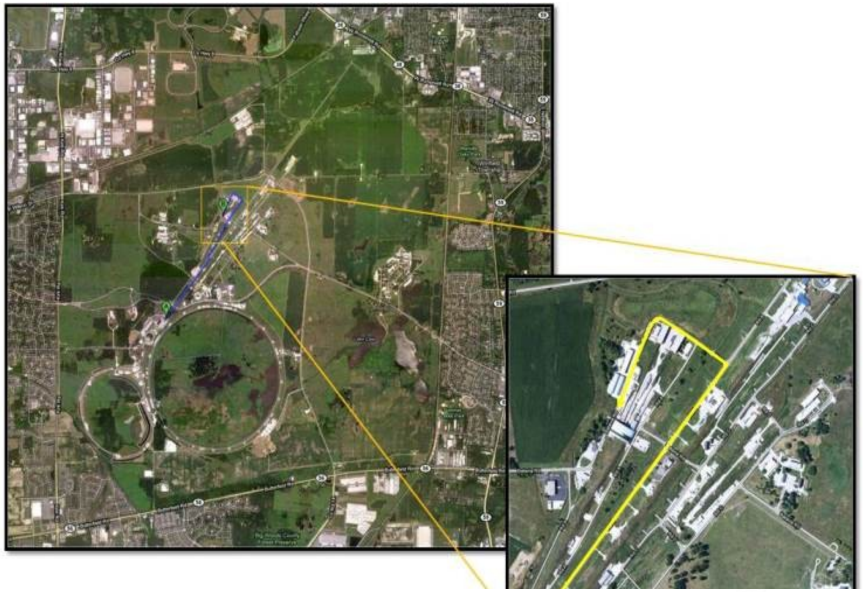
E. Grace,
J. Nikkel



N2 absorption length,
B.J.P. Jones et al.

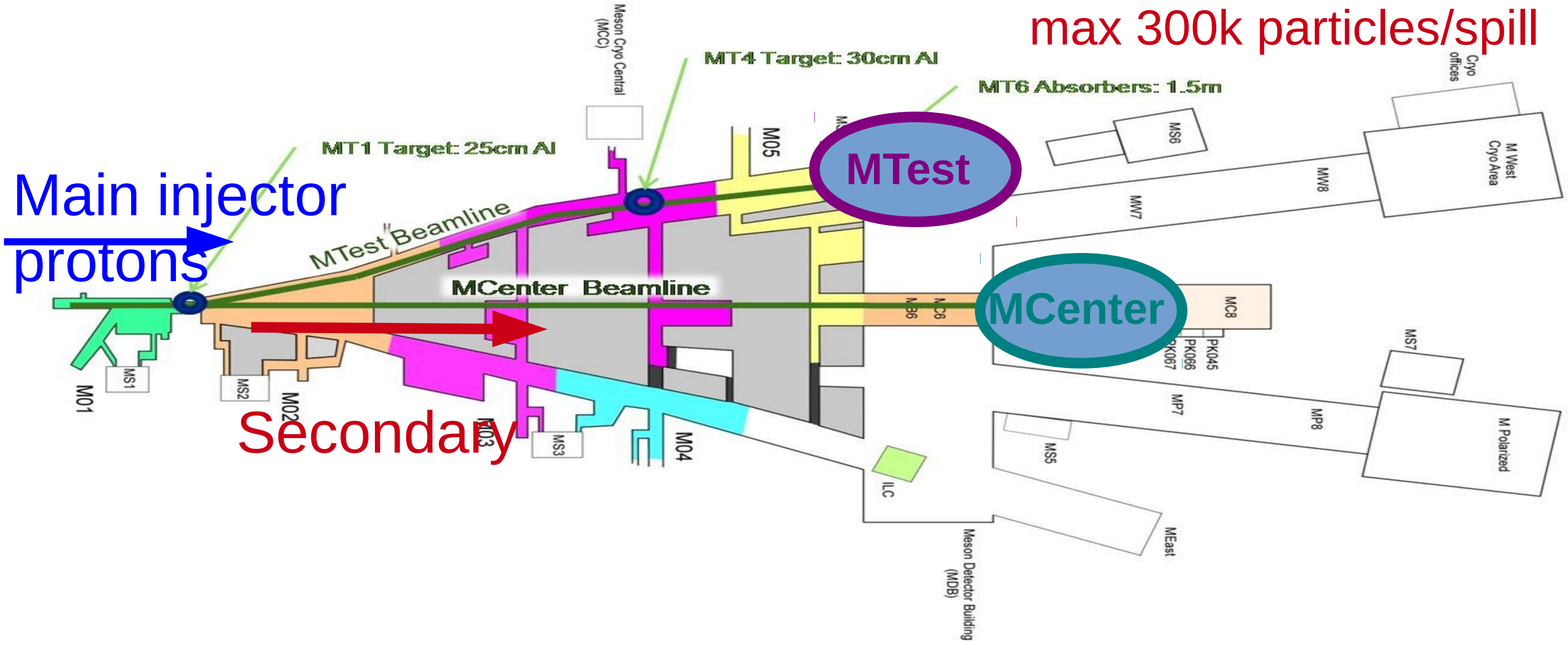
Fermilab Testbeam Facility



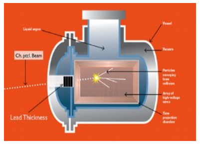


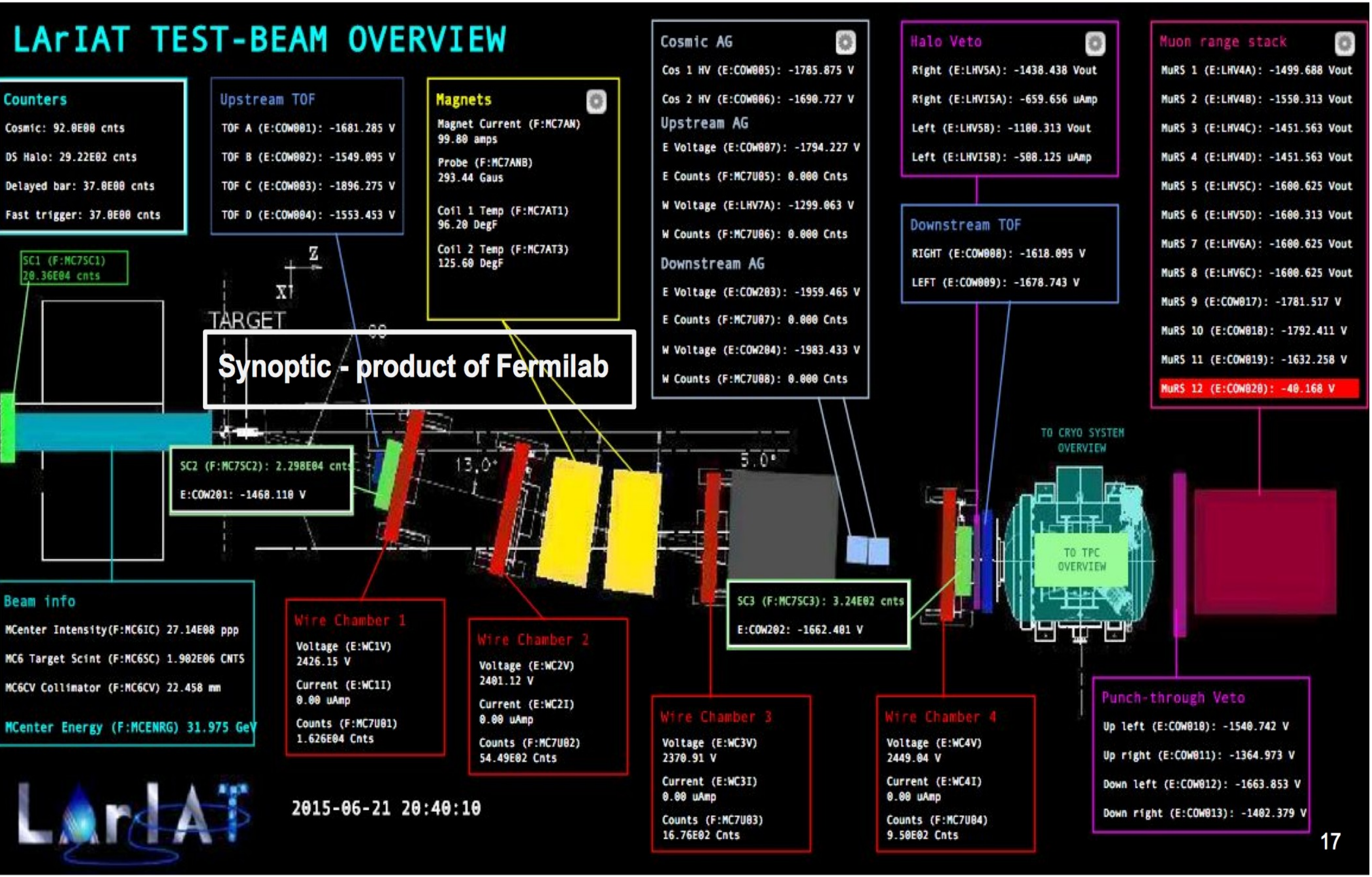
The LArIAT testbeam experiment is running in MCenter – allows long term occupation (as opposed to MTest).

Main Injector
One 4s long spill per minute
Secondary beam
max 300k particles/spill



LArIAT Beamline





LArIAT TEST-BEAM OVERVIEW

Counters

Cosmic: 92.0E00 cnts

DS Halo: 29.22E02 cnts

Delayed bar: 37.0E00 cnts

Fast trigger: 37.0E00 cnts

Upstream TOF

TOF A (E:COW001): -1681.285 V

TOF B (E:COW002): -1549.095 V

TOF C (E:COW003): -1896.275 V

TOF D (E:COW004): -1553.453 V

Magnets

Magnet Current (F:MC7AN)
99.80 amps

Probe (F:MC7ANB)
293.44 Gaus

Coil 1 Temp (F:MC7AT1)
96.20 DegF

Coil 2 Temp (F:MC7AT3)
125.60 DegF

Cosmic AG

Cos 1 HV (E:COW005): -1785.875 V

Cos 2 HV (E:COW006): -1690.727 V

Upstream AG

E Voltage (E:COW007): -1794.227 V

E Counts (F:MC7U05): 0.000 Cnts

W Voltage (E:LHV7A): -1299.063 V

W Counts (F:MC7U06): 0.000 Cnts

Downstream AG

E Voltage (E:COW203): -1959.465 V

E Counts (F:MC7U07): 0.000 Cnts

W Voltage (E:COW204): -1983.433 V

W Counts (F:MC7U08): 0.000 Cnts

Halo Veto

Right (E:LHV5A): -1438.438 Vout

Right (E:LHVI5A): -659.656 uAmp

Left (E:LHV5B): -1100.313 Vout

Left (E:LHVI5B): -508.125 uAmp

Downstream TOF

RIGHT (E:COW008): -1618.095 V

LEFT (E:COW009): -1678.743 V

Muon range stack

MuRS 1 (E:LHV4A): -1499.688 Vout

MuRS 2 (E:LHV4B): -1550.313 Vout

MuRS 3 (E:LHV4C): -1451.563 Vout

MuRS 4 (E:LHV4D): -1451.563 Vout

MuRS 5 (E:LHV5C): -1600.625 Vout

MuRS 6 (E:LHV5D): -1600.313 Vout

MuRS 7 (E:LHV6A): -1600.625 Vout

MuRS 8 (E:LHV6C): -1600.625 Vout

MuRS 9 (E:COW017): -1781.517 V

MuRS 10 (E:COW018): -1792.411 V

MuRS 11 (E:COW019): -1632.258 V

MuRS 12 (E:COW020): -40.168 V

SC1 (F:MC7SC1)
20.36E04 cnts

Synoptic - product of Fermilab

SC2 (F:MC7SC2): 2.298E04 cnts

E:COW201: -1468.110 V

SC3 (F:MC7SC3): 3.24E02 cnts

E:COW202: -1662.401 V

Beam info

MCenter Intensity(F:MC6IC) 27.14E08 ppp

MC6 Target Scint (F:MC6SC) 1.902E06 CNTS

MC6CV Collimator (F:MC6CV) 22.458 mm

MCenter Energy (F:MCENRG) 31.975 GeV

Wire Chamber 1

Voltage (E:WC1V)
2426.15 V

Current (E:WC1I)
0.00 uAmp

Counts (F:MC7U01)
1.626E04 Cnts

Wire Chamber 2

Voltage (E:WC2V)
2401.12 V

Current (E:WC2I)
0.00 uAmp

Counts (F:MC7U02)
54.49E02 Cnts

Wire Chamber 3

Voltage (E:WC3V)
2370.91 V

Current (E:WC3I)
0.00 uAmp

Counts (F:MC7U03)
16.76E02 Cnts

Wire Chamber 4

Voltage (E:WC4V)
2449.04 V

Current (E:WC4I)
0.00 uAmp

Counts (F:MC7U04)
9.50E02 Cnts

Punch-through Veto

Up left (E:COW010): -1540.742 V

Up right (E:COW011): -1364.973 V

Down left (E:COW012): -1663.853 V

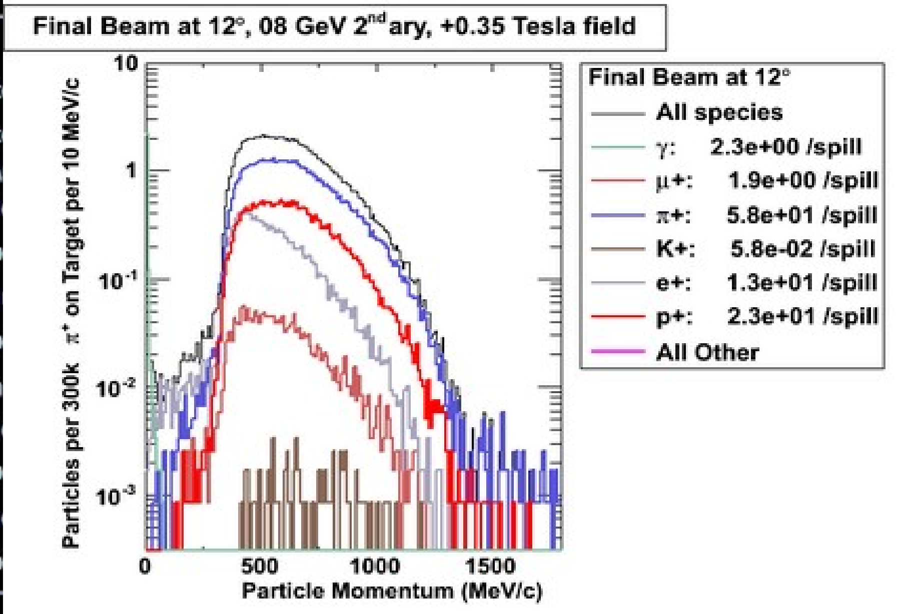
Down right (E:COW013): -1402.379 V

2015-06-21 20:40:10

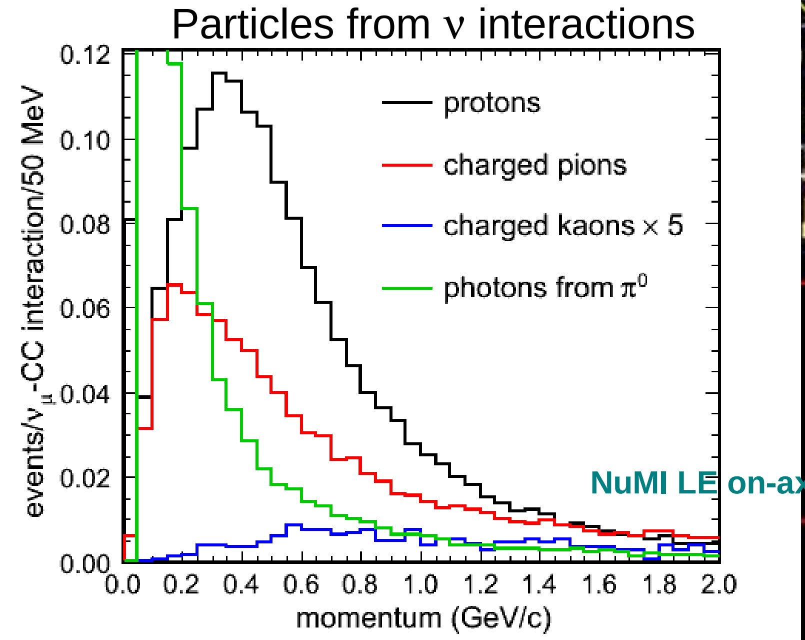
momentum (GeV/c)

LArIAT Beamline

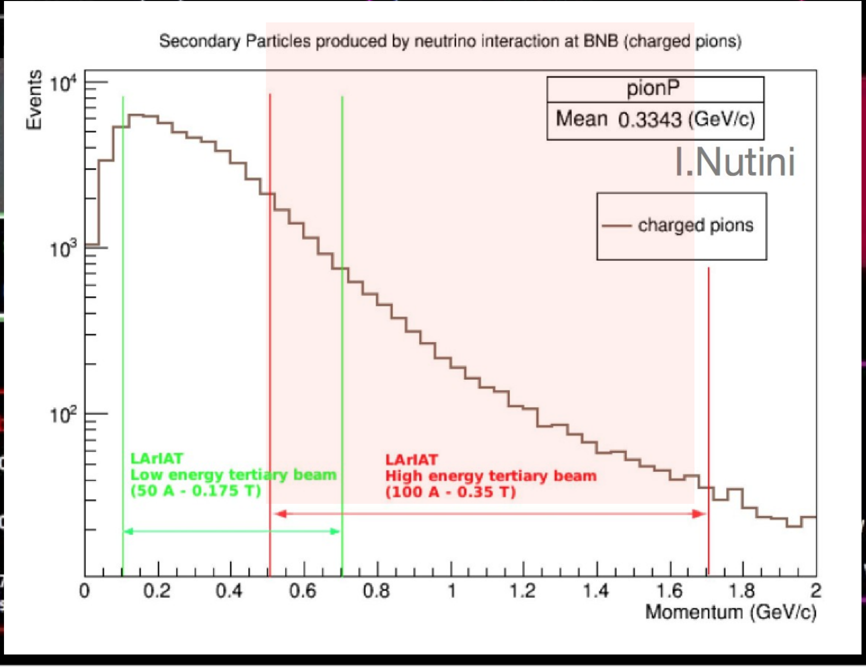
Optimized to study charged particles in the energy range relevant for future neutrino experiments. **We can tune their energy by adjusting the parameters of the beamline,**



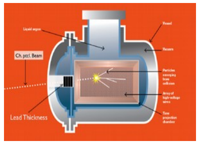
Synoptic - product of Fermilab



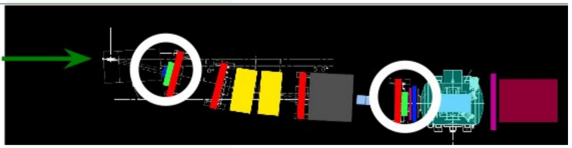
NuMI LE on-axis



Beamline Elements



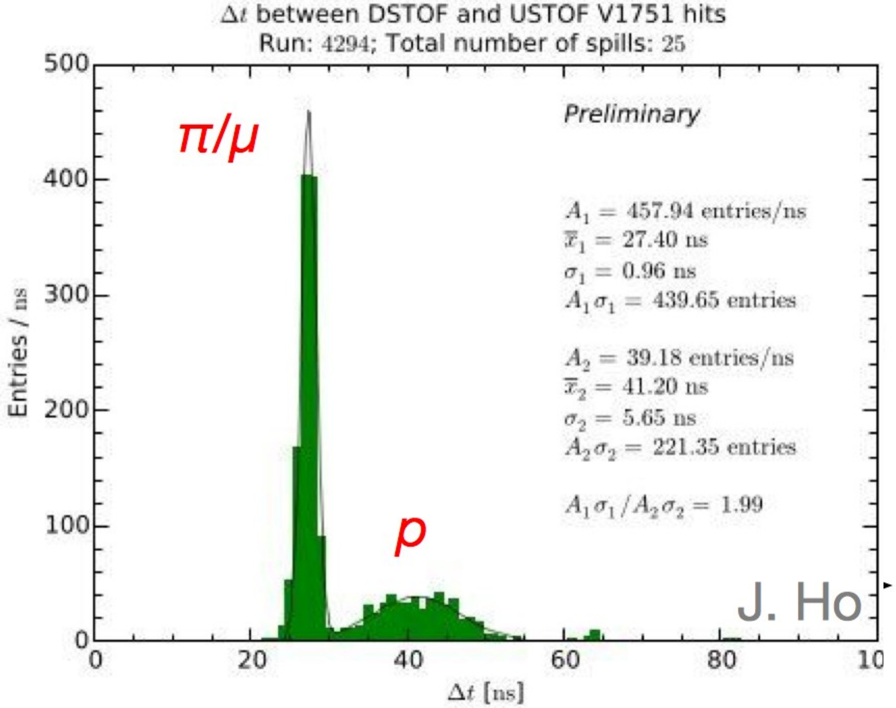
- MWPCs



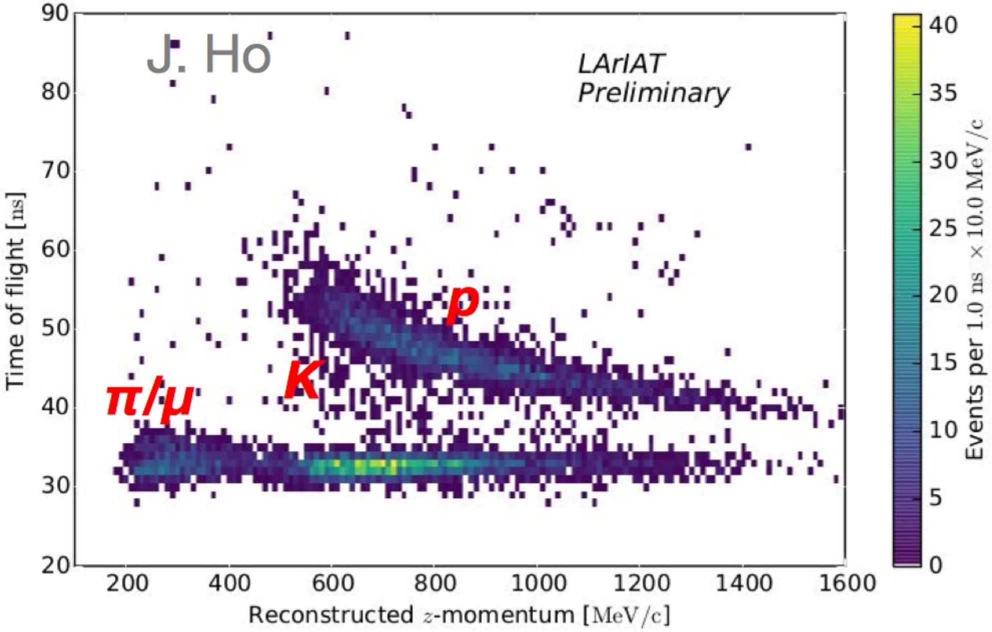
- TOFs

Magnets + TOFs + MWPC allow reconstructing momentum and PID of particles in the tertiary beam.

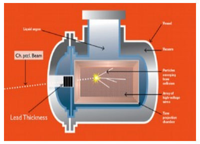
Controlled sample of particles hitting the TPC.

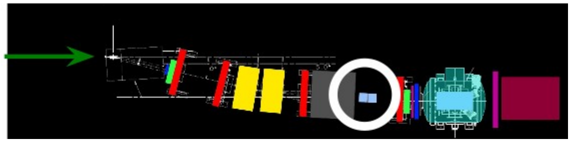


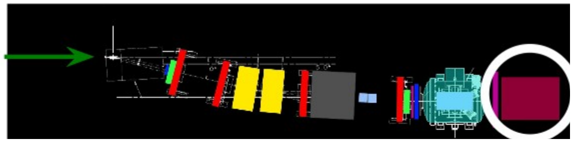
Δ*t* between DSTOF and USTOF V1751 hits
Run: 4294; Total number of spills: 25



μ vs π separation in beamline



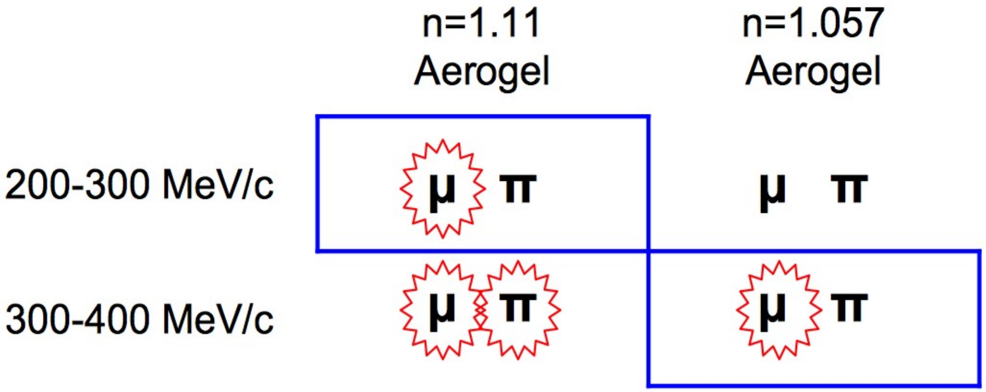




Aerogel Cherenkov counters for further PID

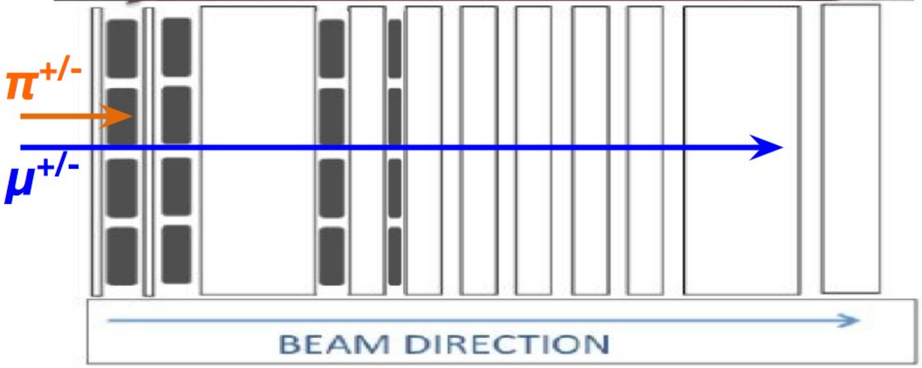
π vs. *μ* discrimination

Effective for TPC-contained *π*/*μ* range: 230-400 MeV/c

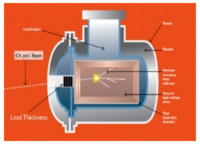


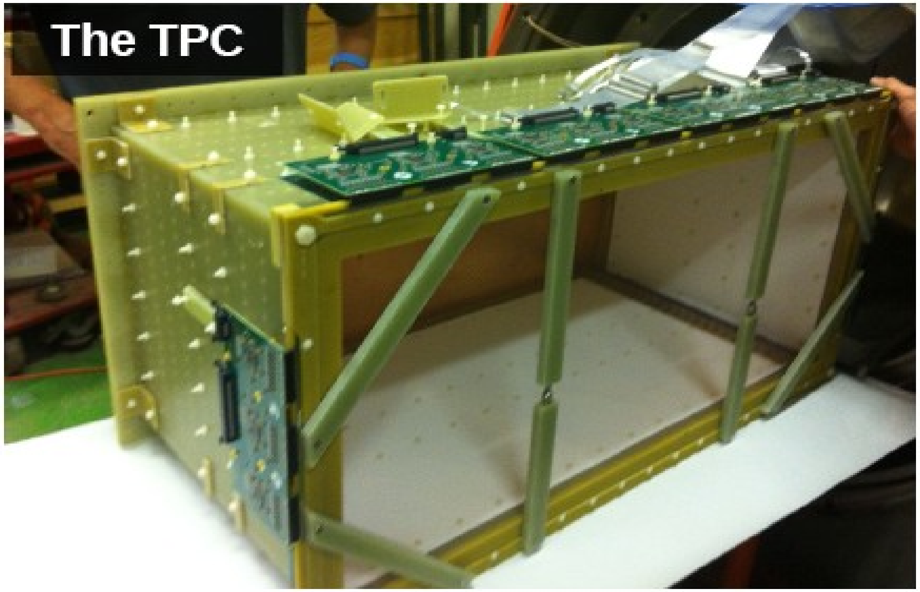
	n=1.11 Aerogel	n=1.057 Aerogel
200-300 MeV/c	μ π	μ π
300-400 MeV/c	μ π	μ π

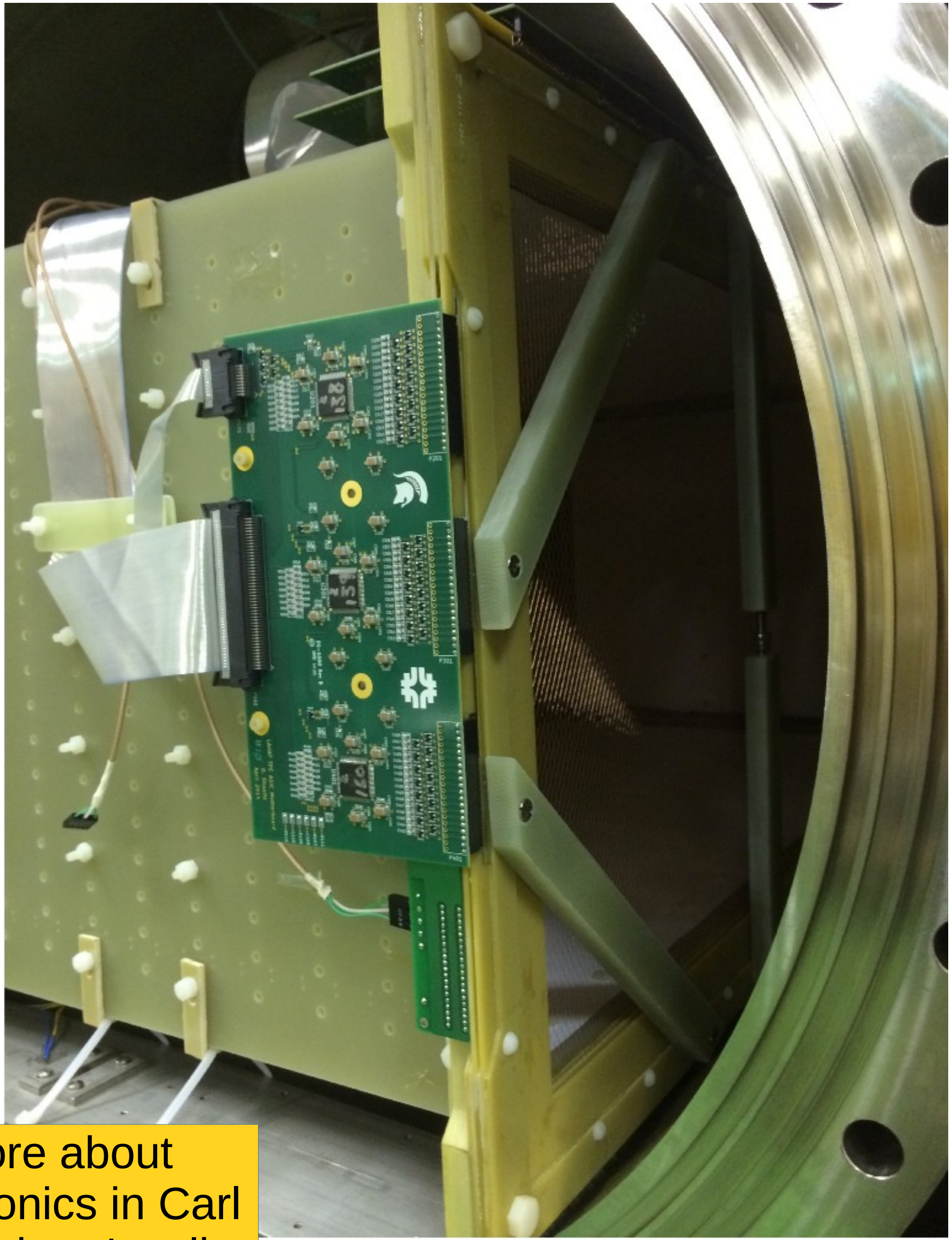
23

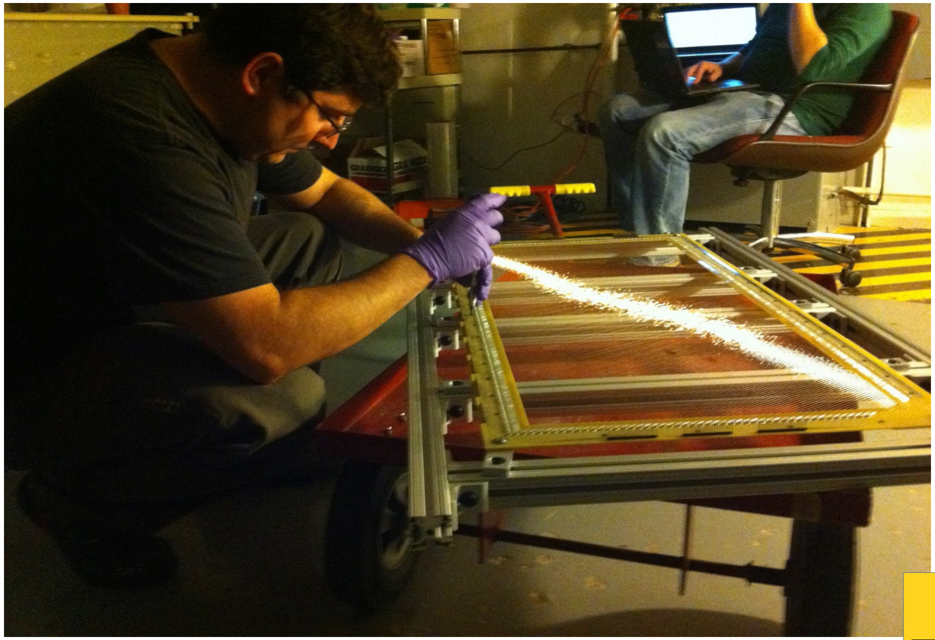


Time Projection Chamber



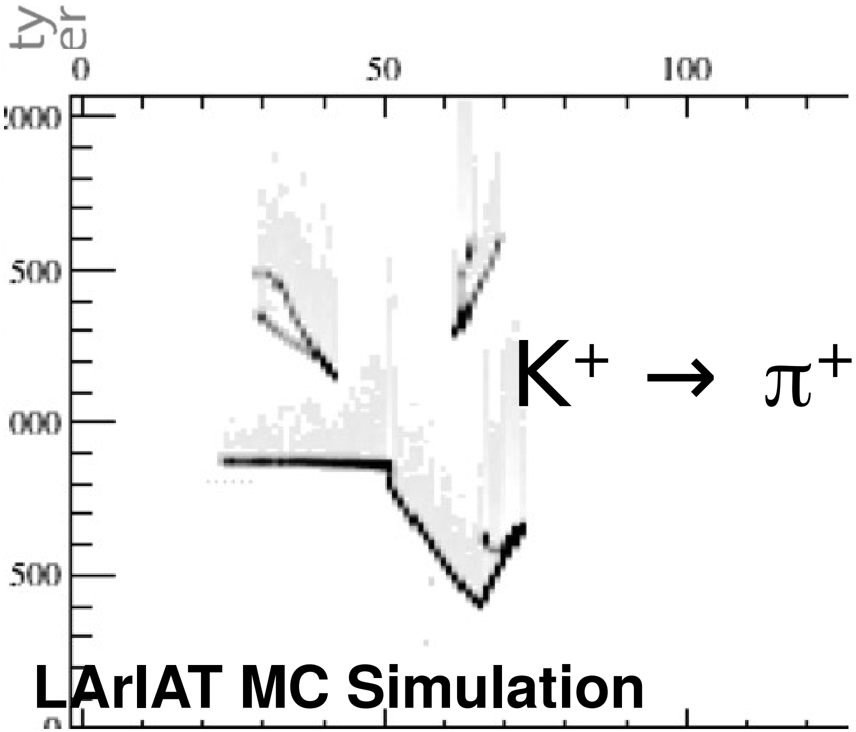






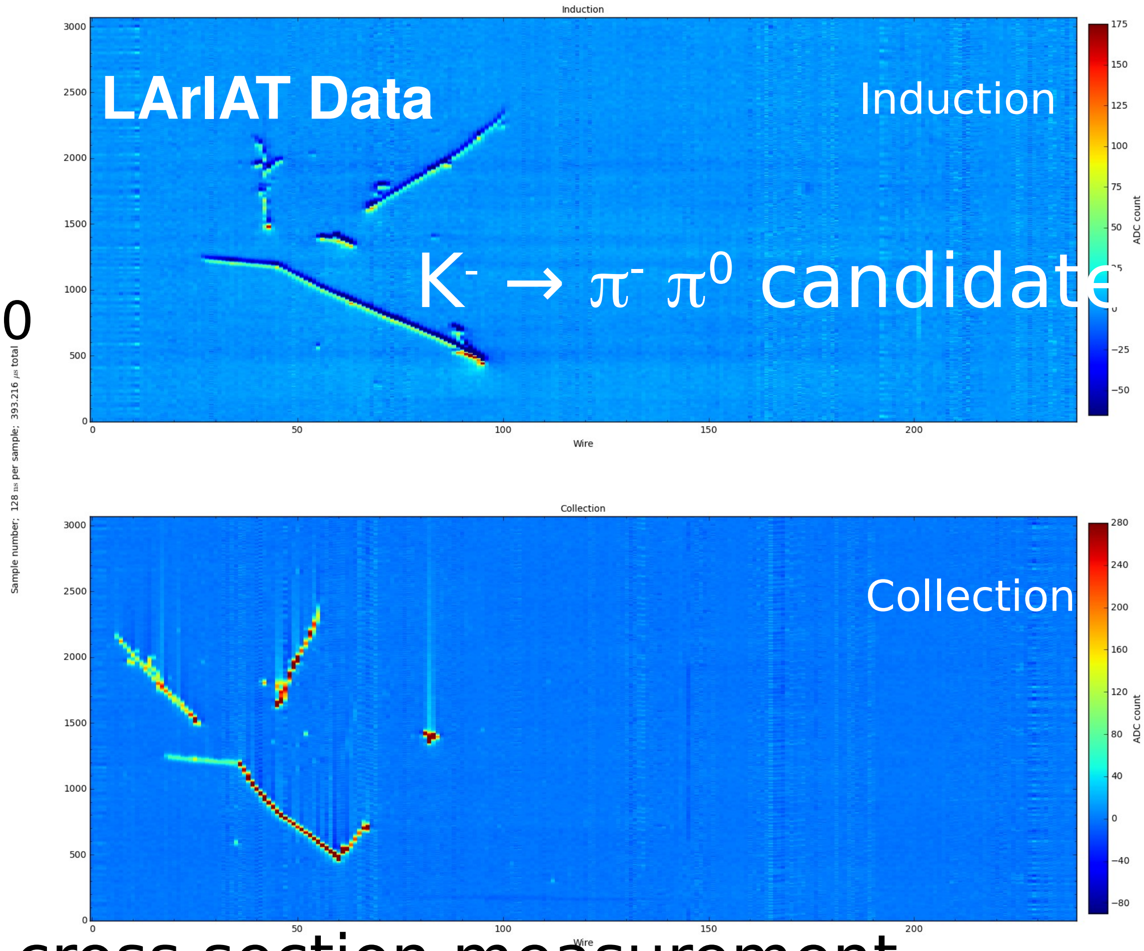
More about
Electronics in Carl
Bromberg's talk

Kaon ID and reconstruction



$K^+ \rightarrow \pi^+\pi^0$

LArIAT MC Simulation



LArIAT Data

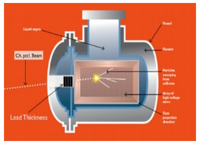
Induction

$K^- \rightarrow \pi^- \pi^0$ candidate

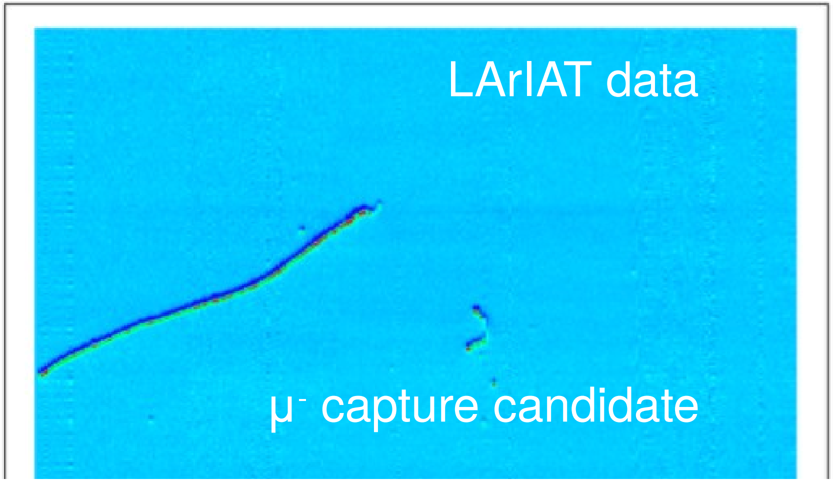
Collection

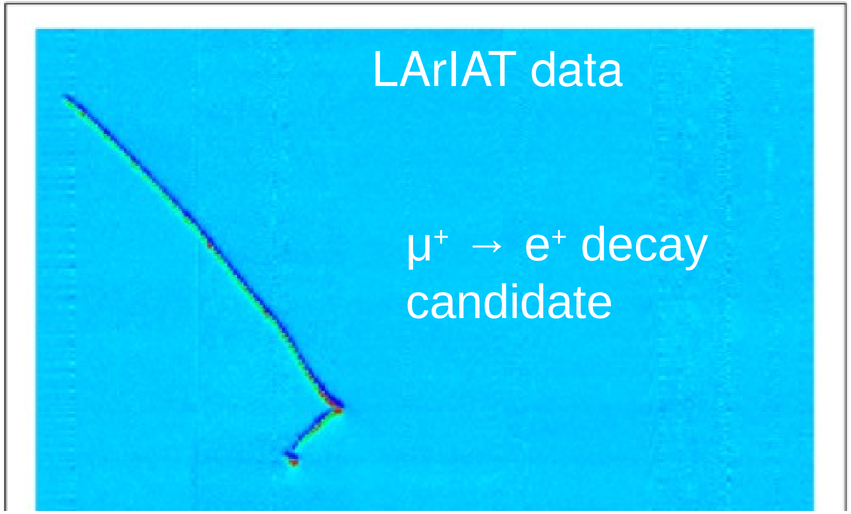
- $K^\pm$ reconstruction
- Kaon-argon interaction cross section measurement
- Understand kaon/pion and kaon/proton discrimination
- Important for proton decay searches in future experiments

Muon charge-sign discrimination



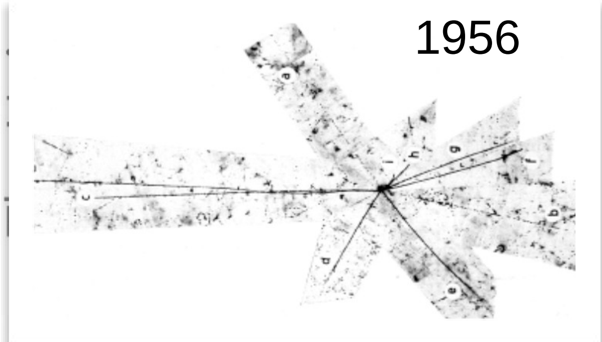
- Argon Nuclei have a 75% chance to capture muons. They never capture anti-muons.
- This results in different topologies.
- In case the topologies are the same: different effective decay times.
- Can determine flux composition statistically (and in some cases on an event-by-event basis).

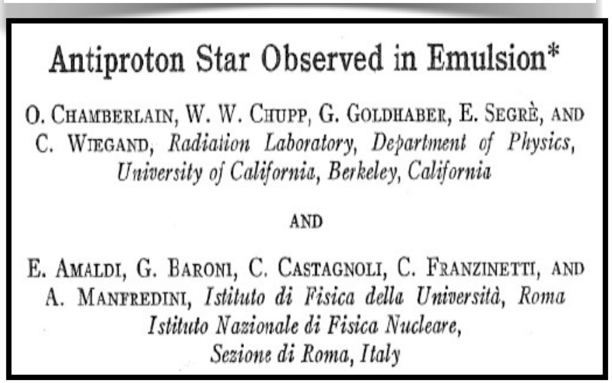




W. Foreman, UChi

Study of $\bar{p}$ events in LAr

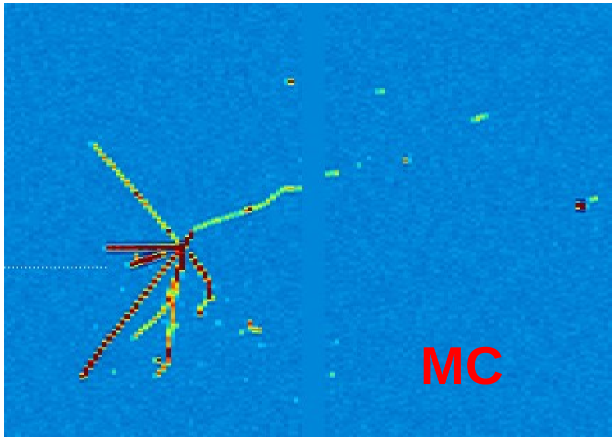



Antiproton Star Observed in Emulsion*

O. Chamberlain, W. W. Chupp, G. Goldhaber, E. Segrè, and C. Wiegand, *Radiation Laboratory, Department of Physics, University of California, Berkeley, California*

and

E. Amaldi, G. Baroni, C. Castagnoli, C. Franzinetti, and A. Manfredini, *Istituto di Fisica della Università, Roma Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy*



Low momentum anti-protons in the beam (even at a small rate) will allow the first study of hadron star topology from p-$\bar{p}$ annihilation at rest in Argon

- $\pi^{\pm}$, π^{0}, $K^{\pm}$, etc.. multiplicity in hadron stars can be accurately determined utilizing LAr imaging detector capabilities.

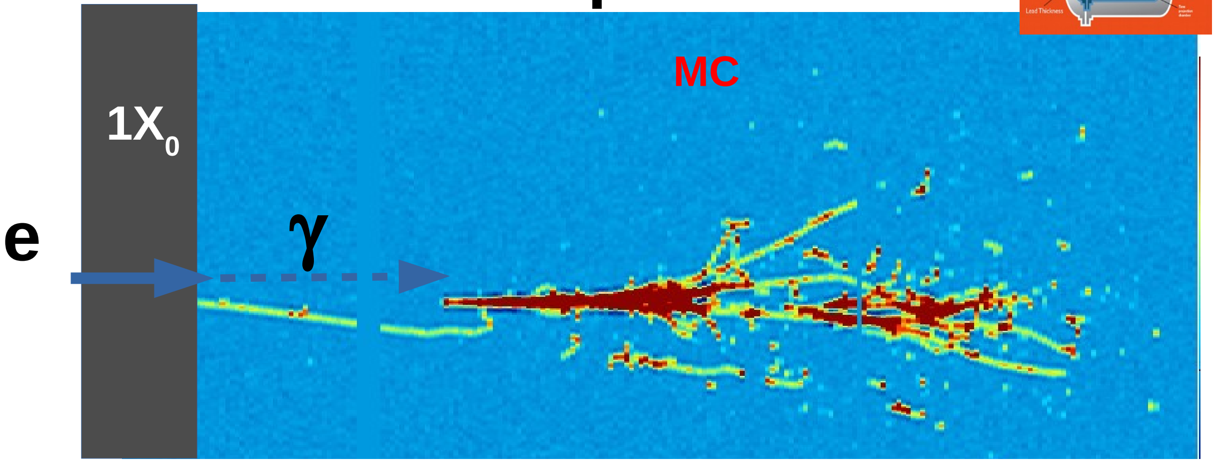
- This information is very relevant for n-$\bar{n}$ oscillation searches at future large underground LArTPC detectors.

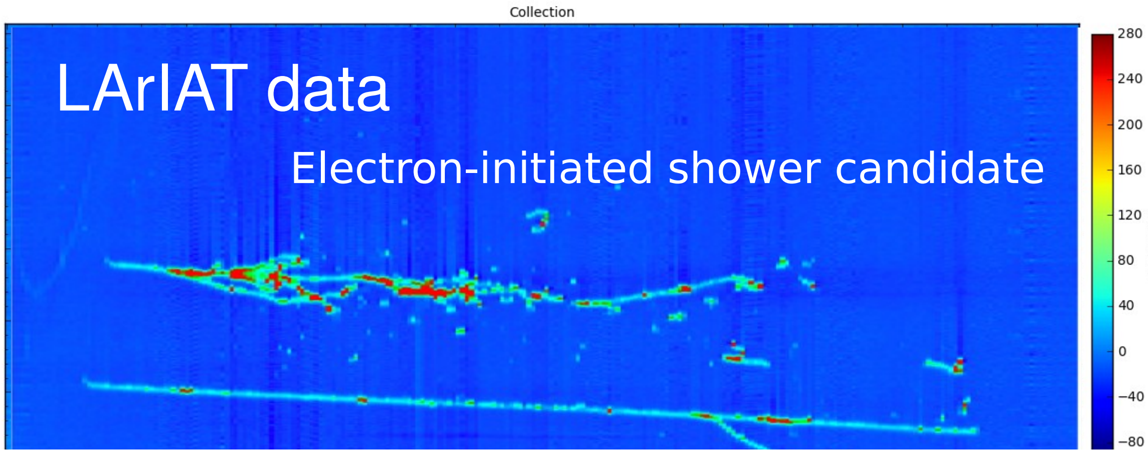
Electron / shower separation

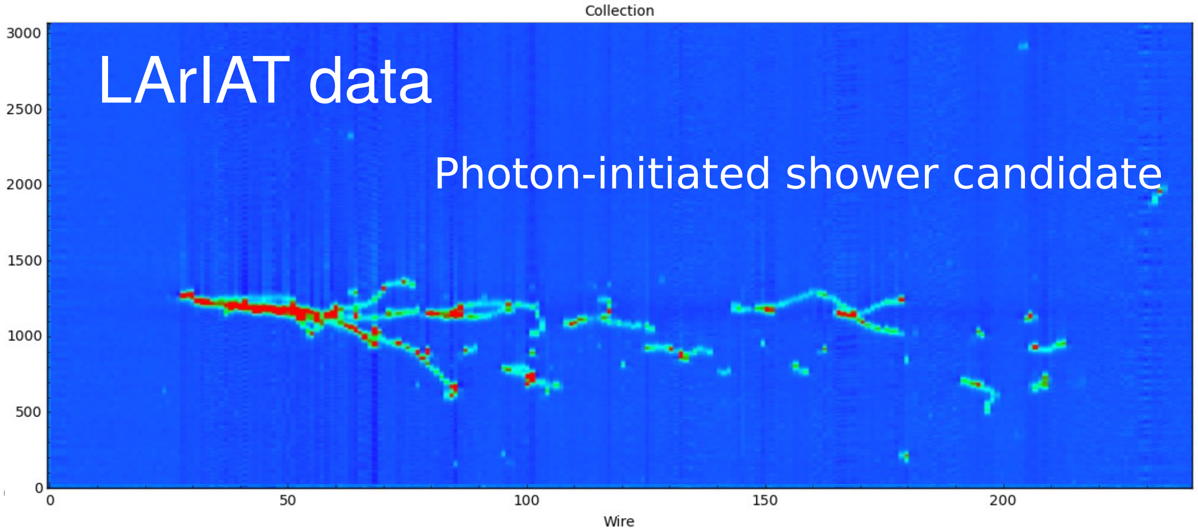
LArIAT, can see electrons in the beamline.

The number of photons can be increased by adding a pre-shower disk ($1X_0$) width

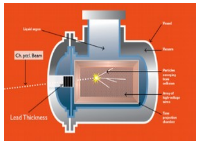
Should give larger and possibly cleaner samples of events compared to ArgoNeuT







π-argon cross sections



D. Ashery et al.
Phys. Rev. C23, 2173 (1981)

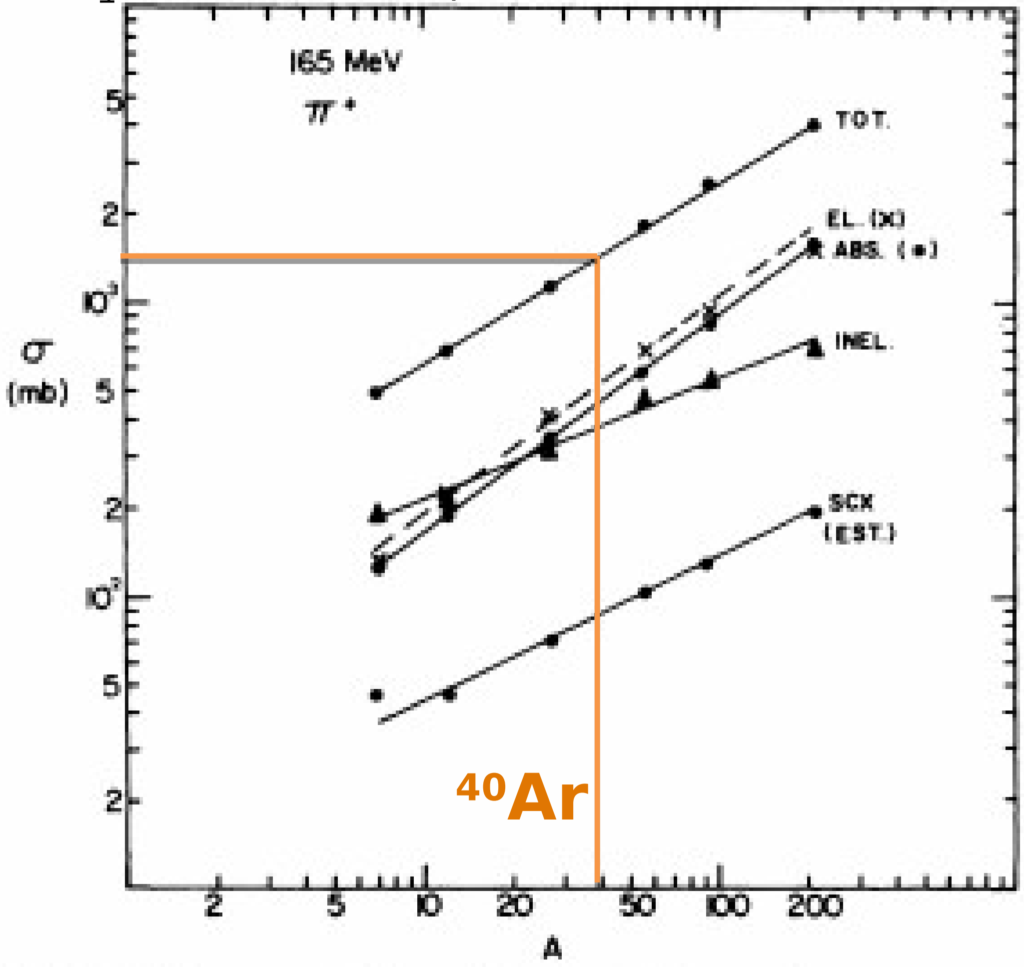


FIG. 9. Decomposition of the total π^+-nucleus cross section at 165 MeV. The lines are least squares fits to power laws.

- No measurements for ^{40}Ar (yet!)

  Predictions come from interpolation between heavier/lighter nuclei

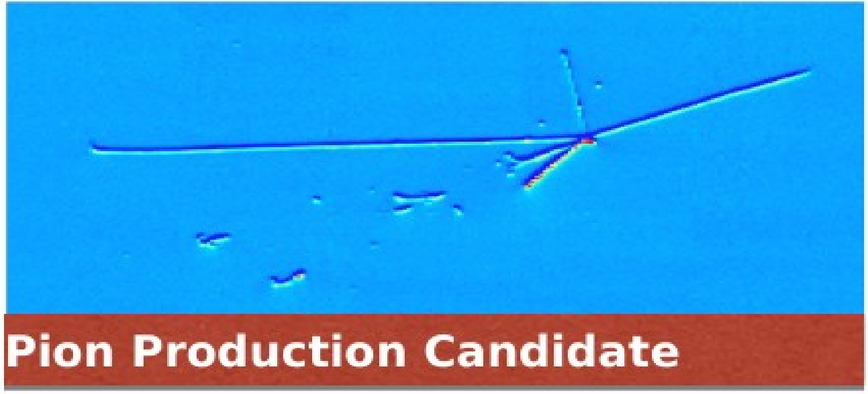
LArIAT analysis goals:
Total interaction cross section
Exclusive interaction channels:
  Absorption
  Charge exchange
  Inelastic & elastic scattering

LArIAT has measured the total pion interaction cross-section

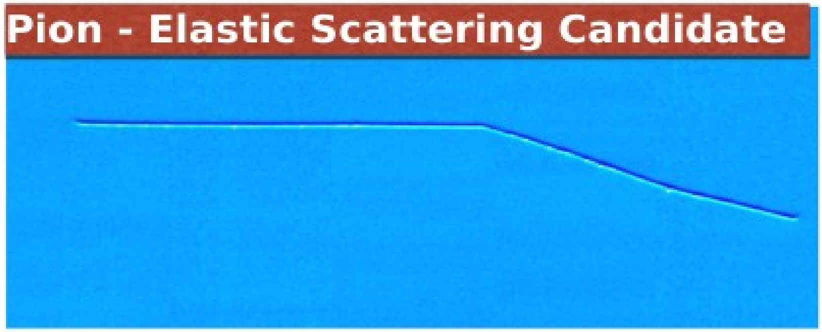
Total π-Ar cross-section

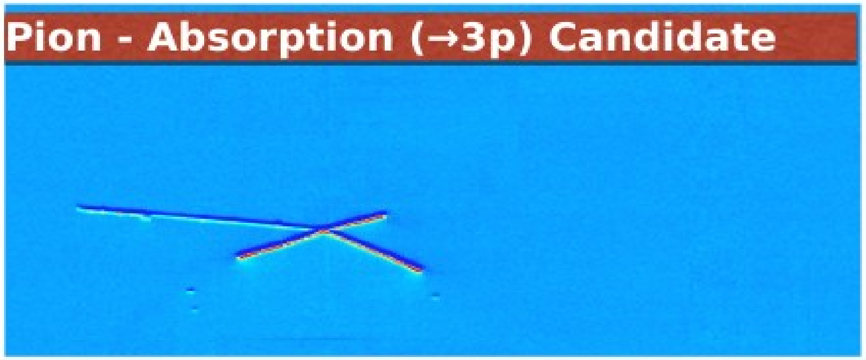
$$\sigma_{\text{Total}} = \sigma_{\text{elastic}} + \sigma_{\text{inelastic}} + \sigma_{\text{ch-exch}} + \sigma_{\text{absorp.}} + \sigma_{\pi\text{-production}}$$

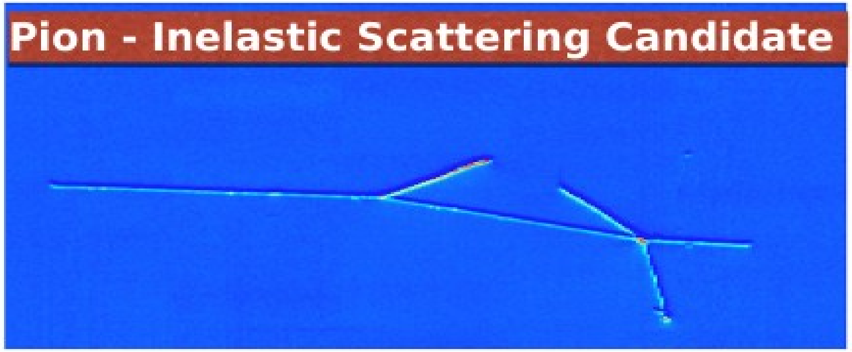
A multitude of topologies


Pion Production Candidate


Pion - Charge Exchange Candidate


Pion - Elastic Scattering Candidate

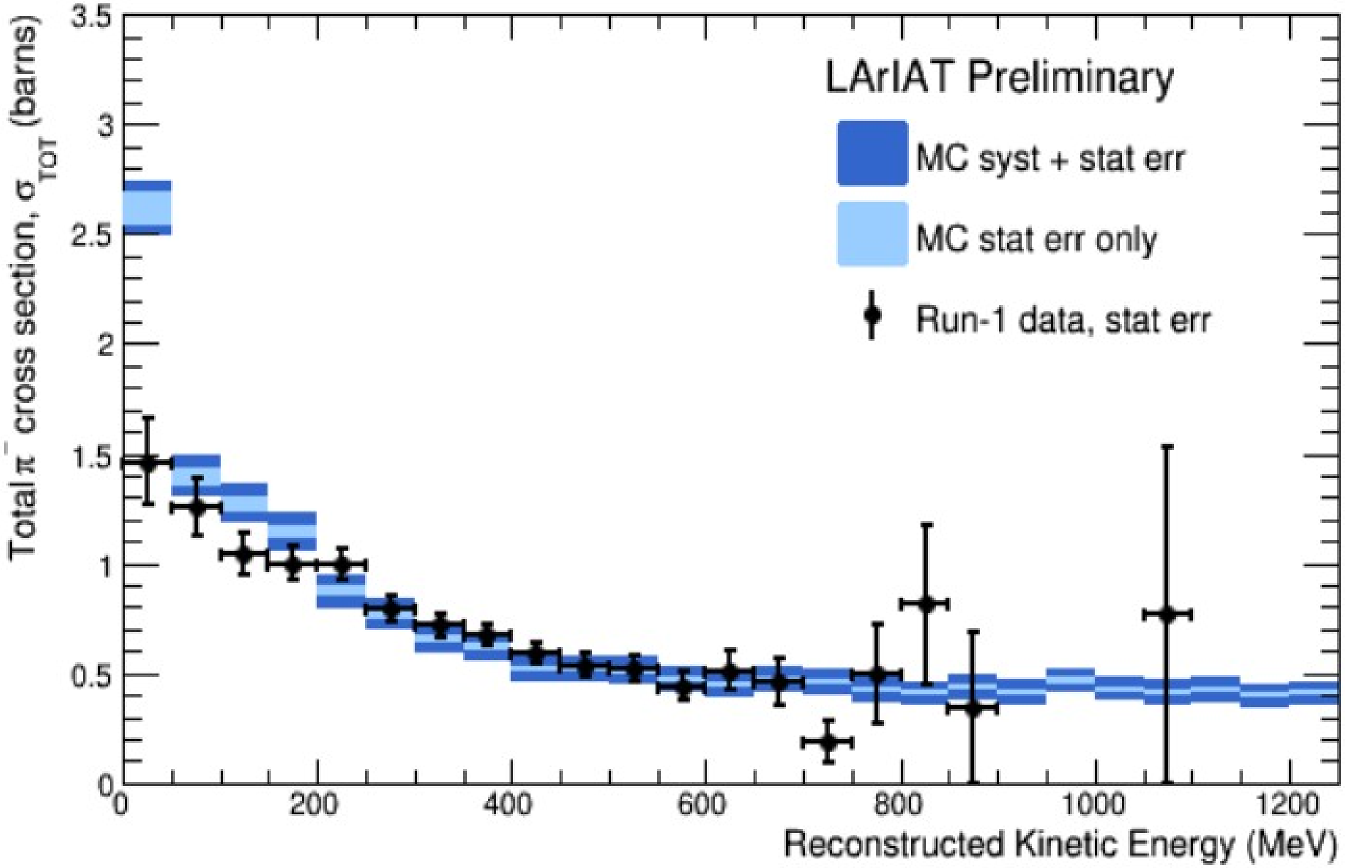

Pion - Absorption (→3p) Candidate


Pion - Inelastic Scattering Candidate

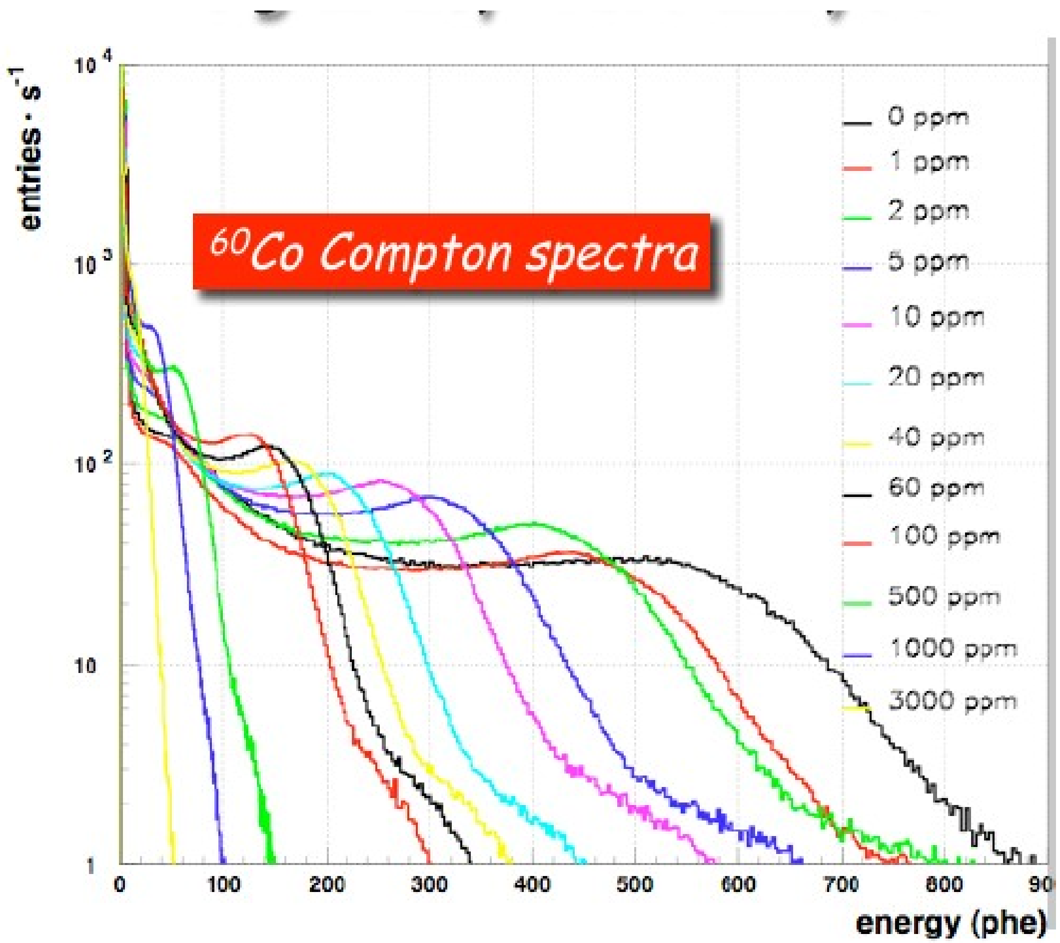
Total π-Ar cross-section

$$\sigma_{\text{Total}} = \sigma_{\text{elastic}} + \sigma_{\text{inelastic}} + \sigma_{\text{ch-exch}} + \sigma_{\text{absorp.}} + \sigma_{\pi\text{-production}}$$

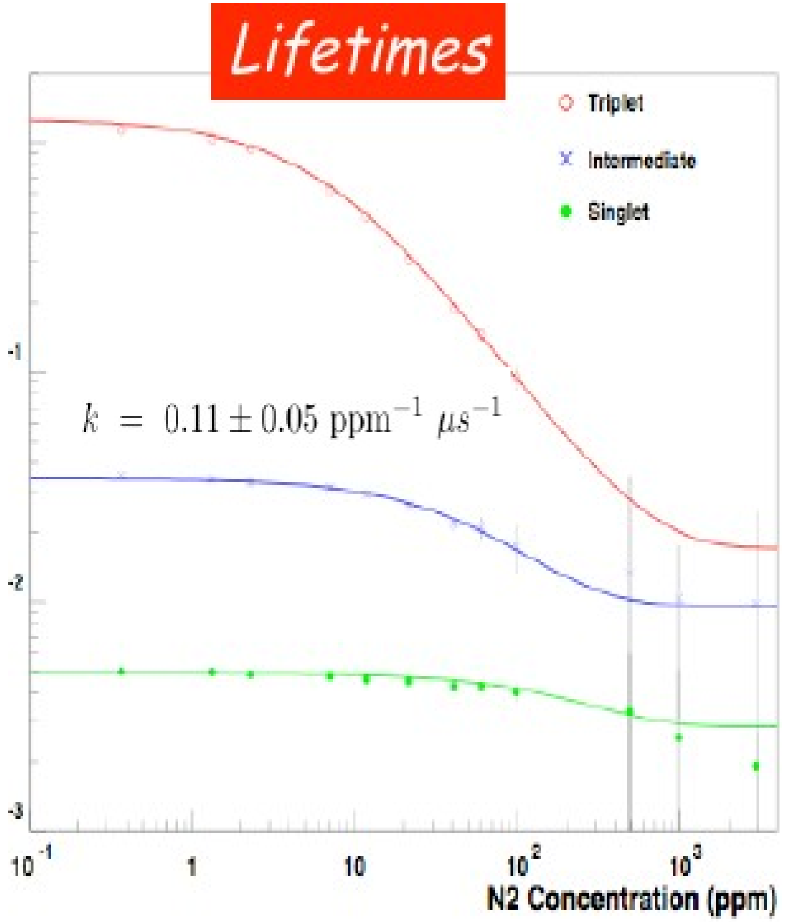
- First measurement of pion interaction on argon
- Analysis of Exclusive channels in progress.



Effects of nitrogen contamination on argon scintillation



^{60}Co Compton spectra



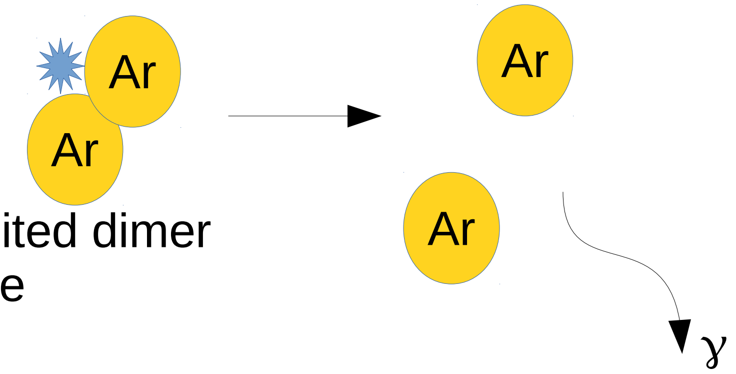
Lifetimes

$k = 0.11 \pm 0.05 \text{ ppm}^{-1}\ \mu s^{-1}$

$$\boxed{\frac{1}{\tau'_j}([N_2]) = \frac{1}{\tau_j} + k[N_2]}$$

Scintillation Light in Argon

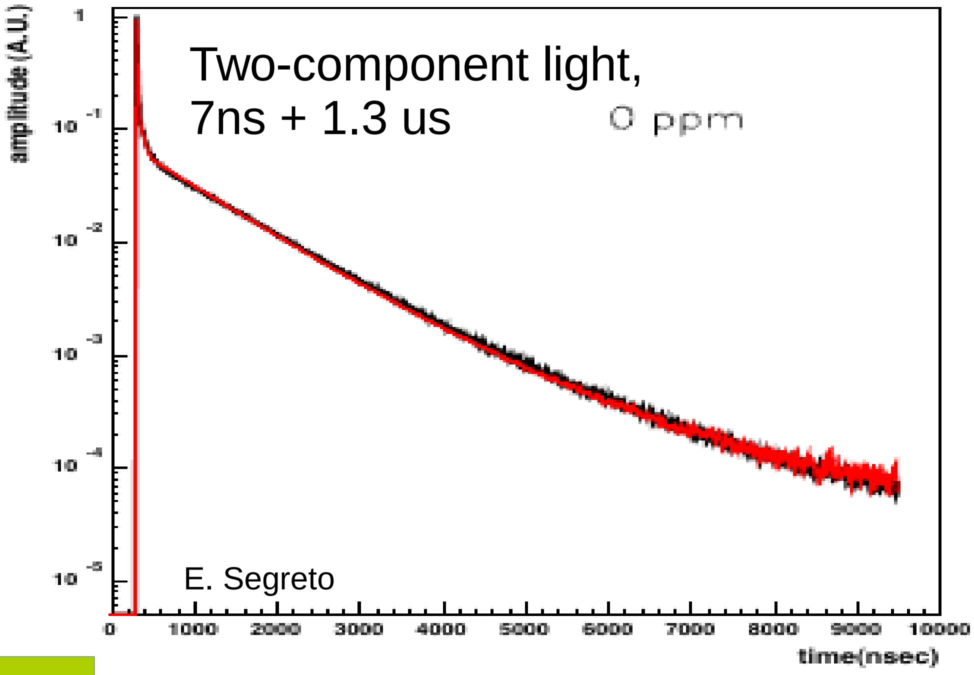
Emission:



Excited dimer state

Photons are all ~128 nm – VUV

Light consists of two components: fast and slow. Their relative amplitudes depend on ionization density (theory).



Two-component light,
7ns + 1.3 us

E. Segreto

(practice) the shape can be affected by transport, contamination and WLS effects (next slides)

Scintillation Light in Argon (2)

Transport:

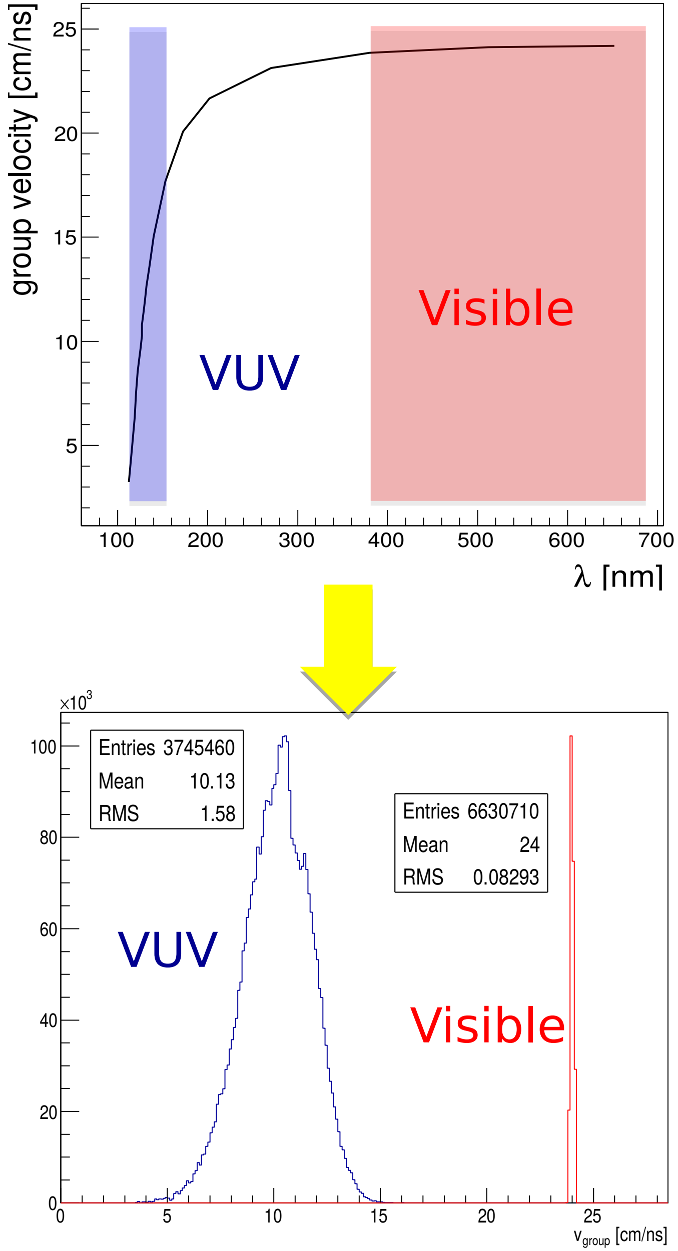
γ

Liquid argon is mostly transparent to its own scintillation.

At longer distances effects like:
- Rayleigh scattering ~55cm f(λ)
- absorption, e.g. on nitrogen ~30 m @2ppm N2

begin to play a role.

Note high refractive index ~1.5 and gradient of for VUV → relatively slow light.



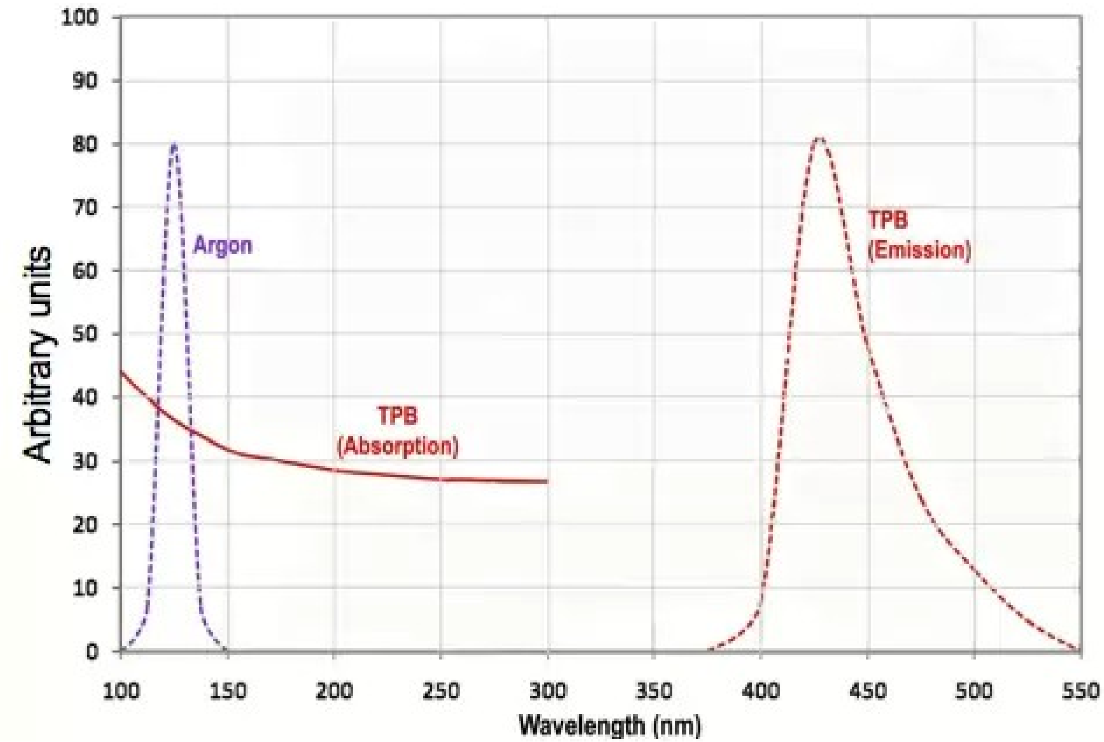
Scintillation Light in Argon (3)

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.

Can deposit WLS on Light detection components or inside the detector.



VUV sensitive SiPMs prototypes have appeared very recently.