LArIAT in 10 minutes

...

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Universidade de Campinas
On behalf of LArIAT collaboration

FERMILAB-SLIDES-22-069-V
New Perspectives 2022

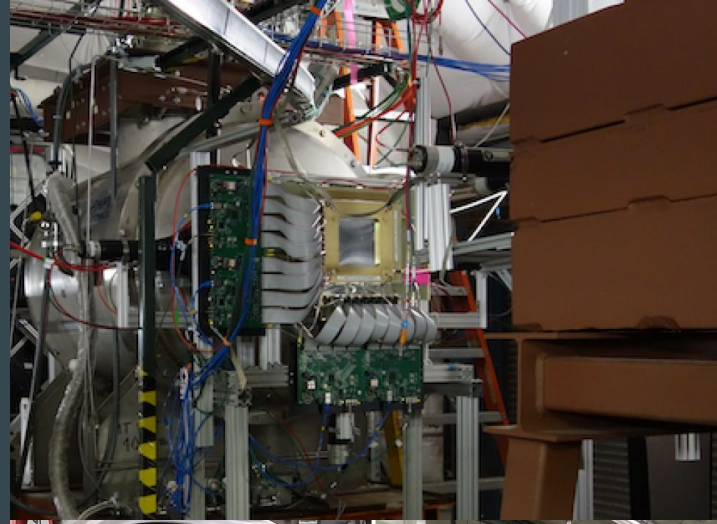
Overview

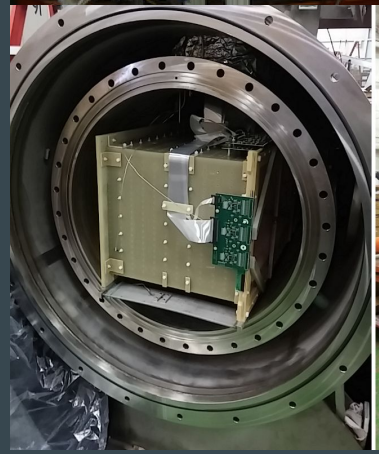
- LArIAT
- Experimental setup
- Results and analysis
  - Michel Electrons
  - Hadron measurements

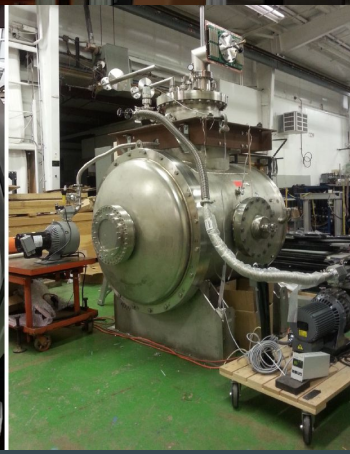
LArIAT: Liquid Argon In a Test Beam

- Fermilab test beam facility
- operated 2014-2017
- Plenty of data still to analyze!

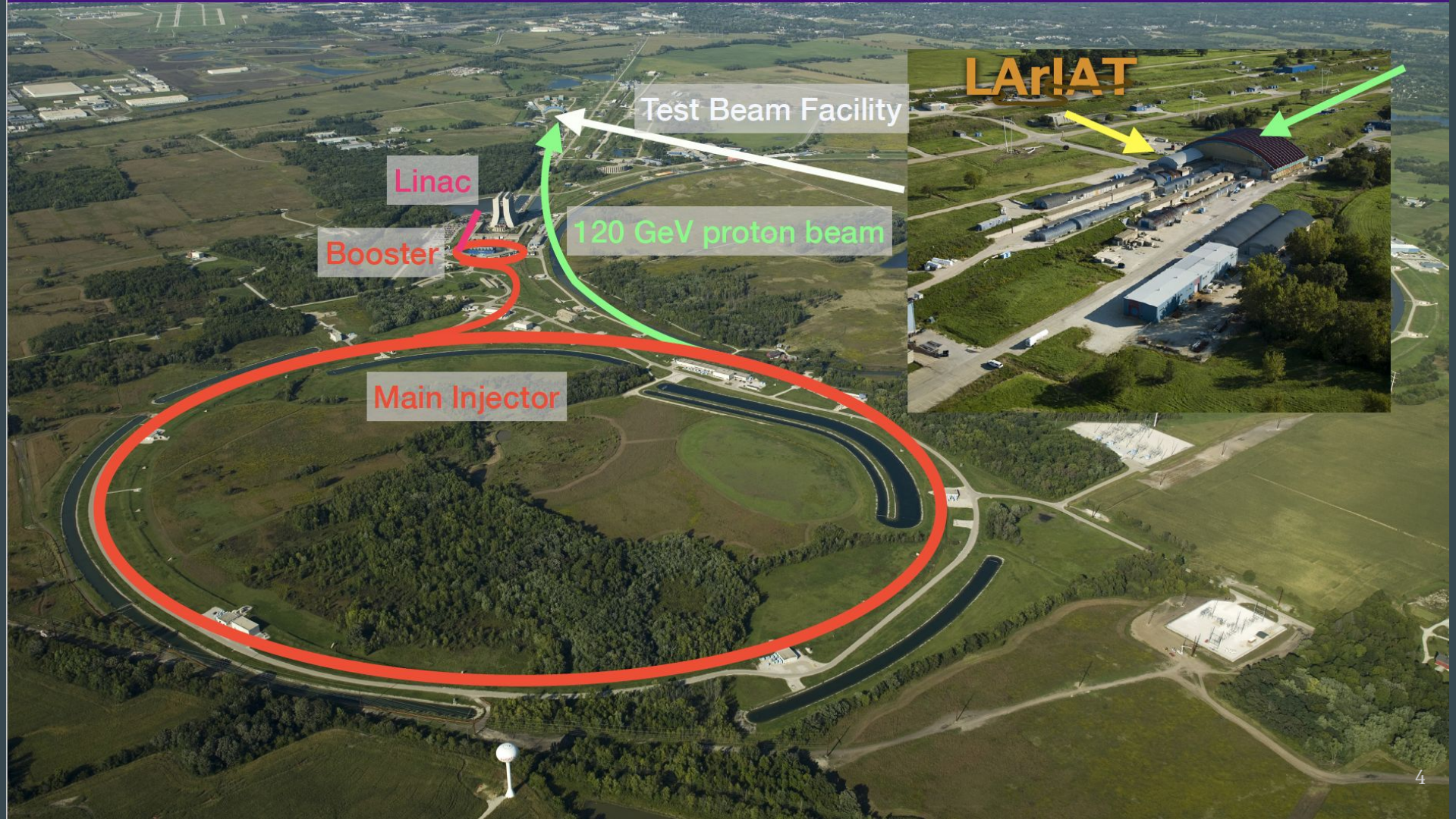
- LArTPC: Liquid Argon Time Projection Chamber
  - Neutrino detectors, DUNE and short baseline neutrino program
- Neutrino products: electrons, muons, pions, kaons, protons
  - Measure Argon interactions
  - Calibration

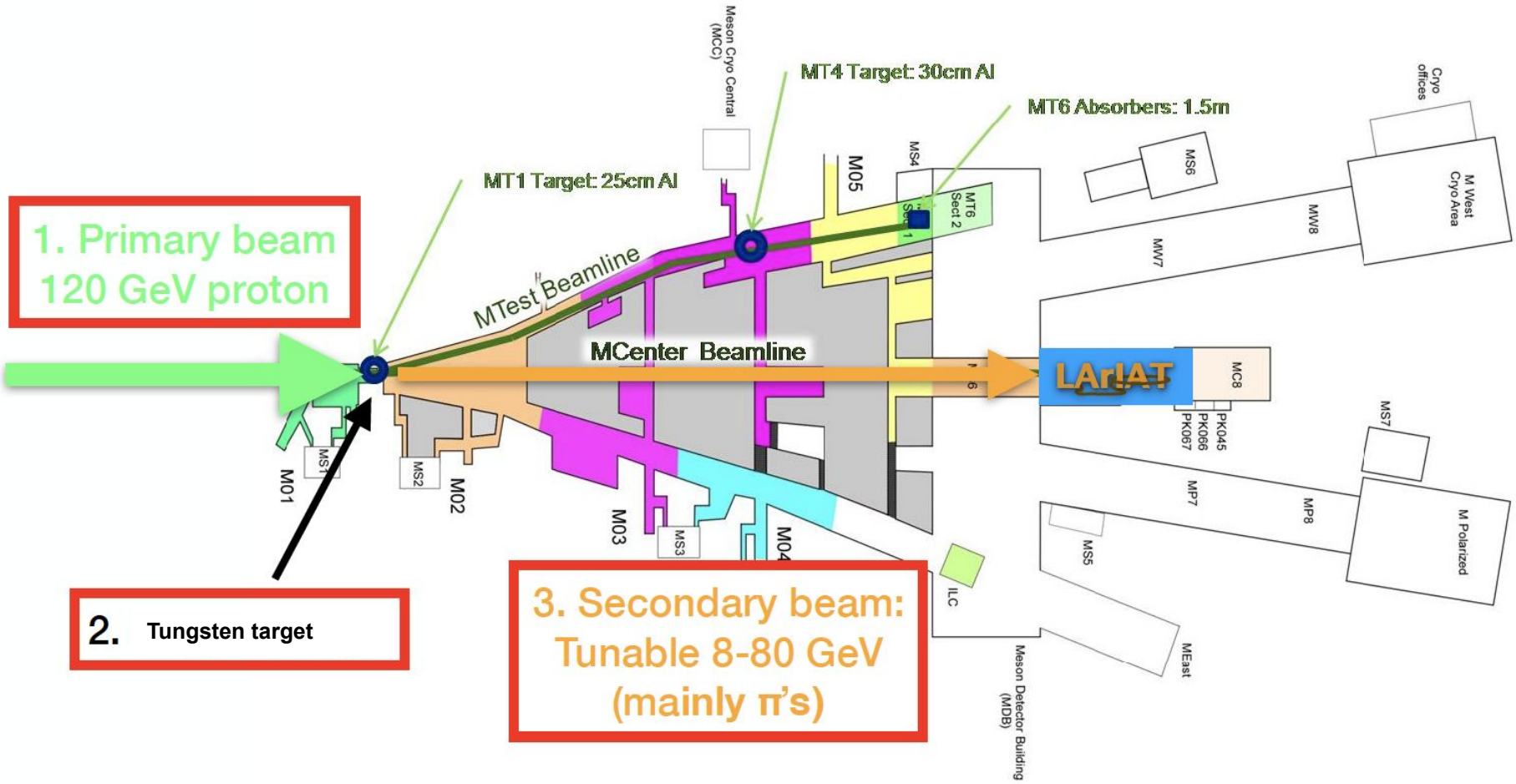


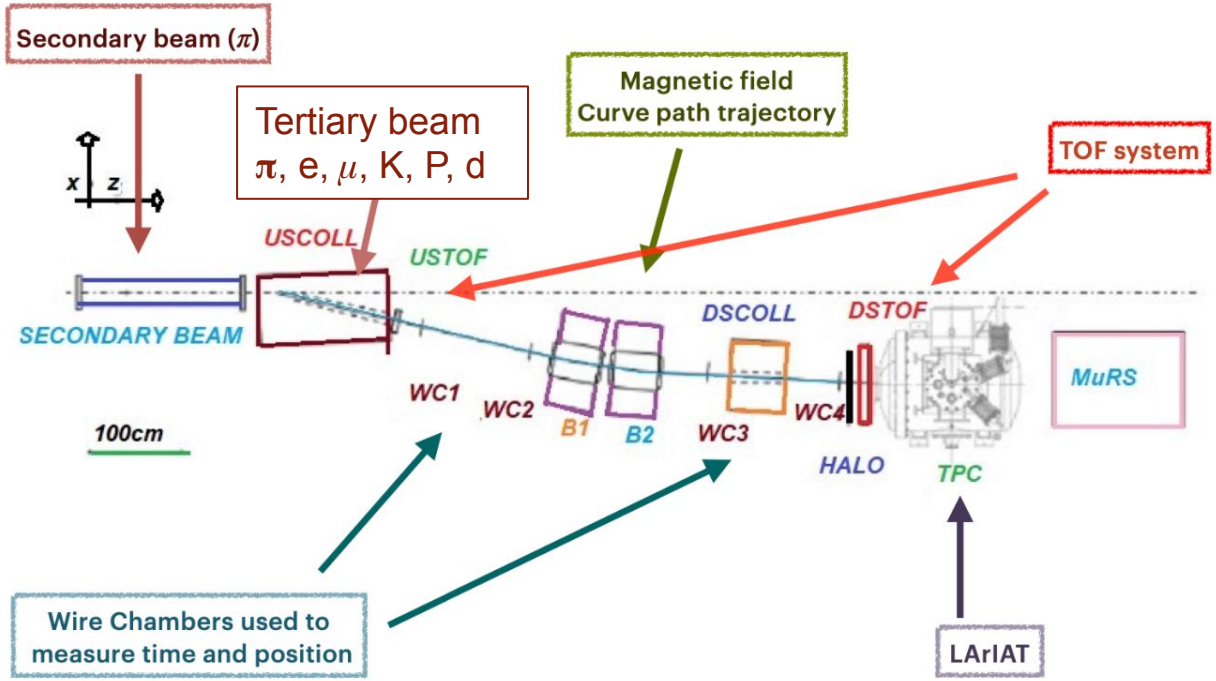




Images: R. Acciarri et al 2020 JINST 15 P04026


LArIAT
Test Beam Facility
Linac
Booster
120 GeV proton beam
Main Injector


1. Primary beam
120 GeV proton
2. Tungsten target
3. Secondary beam:
Tunable 8-80 GeV
(mainly π's)
MT1 Target: 25cm Al
MT4 Target: 30cm Al
MT6 Absorbers: 1.5m
MTest Beamline
MCenter Beamline
LArIAT
Meson Cryo Central (MCC)
Cryo offices
M West Cryo Area
M Polarized
MEast
Meson Detector Building (MDB)
ILC
M01
M02
M03
M04
M05
MS1
MS2
MS3
MS4
MS5
MS6
MS7
MT6 Sect 1
MT6 Sect 2
MW7
MW8
MP7
MP8
MC8
PK045
PK066
PK067

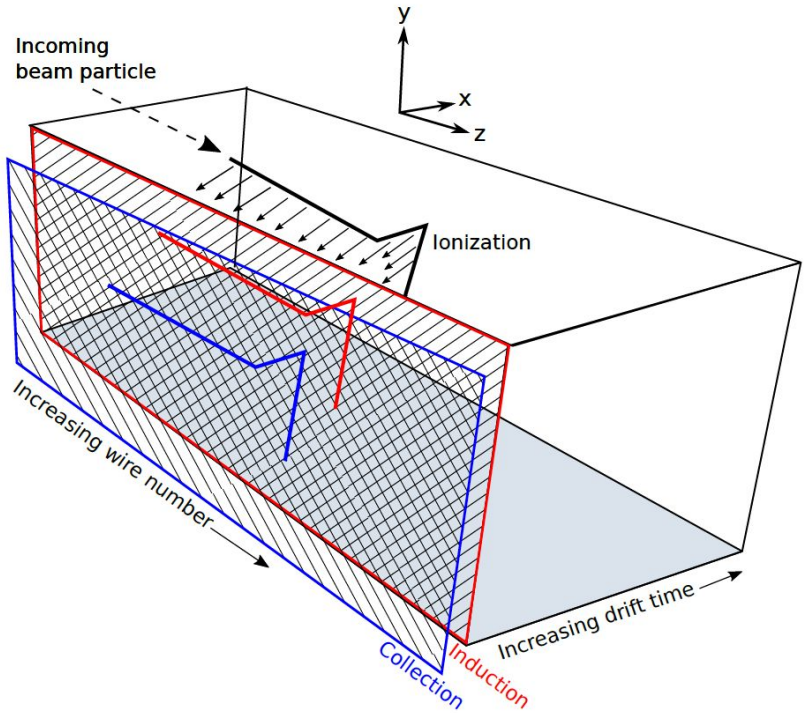


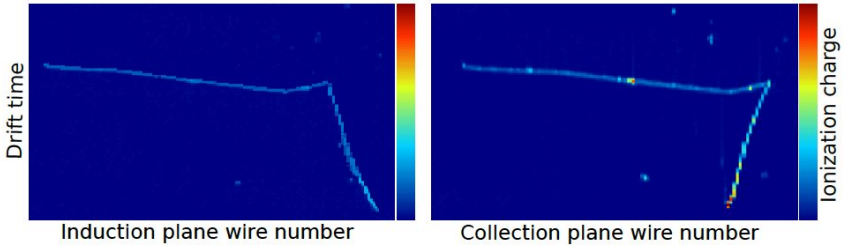
Momentum between
0.3 GeV/c to 1.4 GeV/c

LArTPC

Charged particle detector

- Relatively small
  - LAr volume 550L
  - LAr 0.76 t mass
- Trigger (beamline)
- Ionization electrons are drift by an electric field
- Signal in the induction plane and collection plane
- 3D reconstruction from two planes
- Light collection system



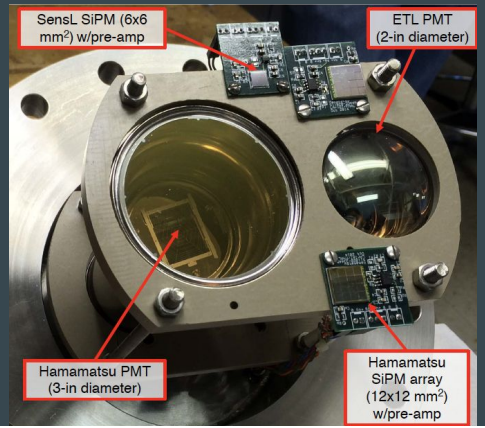


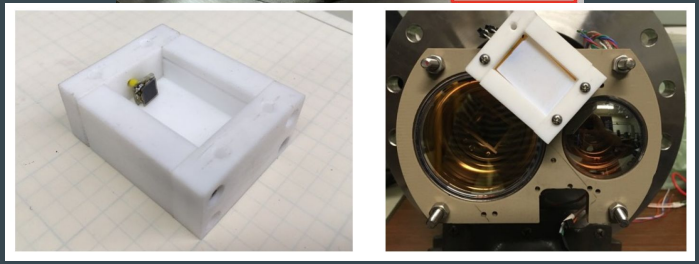
Images: R. Acciarri et al 2020 JINST 15 P04026

LAr R&D

Tests to support future experiments like SBND, DUNE

- Light collection system
- Wire plane pitch
  - 3mm vs. 4mm vs. 5mm wire spacing
- Mesh HV cathode
  - test of a design proposed for the SBND experiment





Images: R. Acciarri et al 2020 JINST 15 P04026

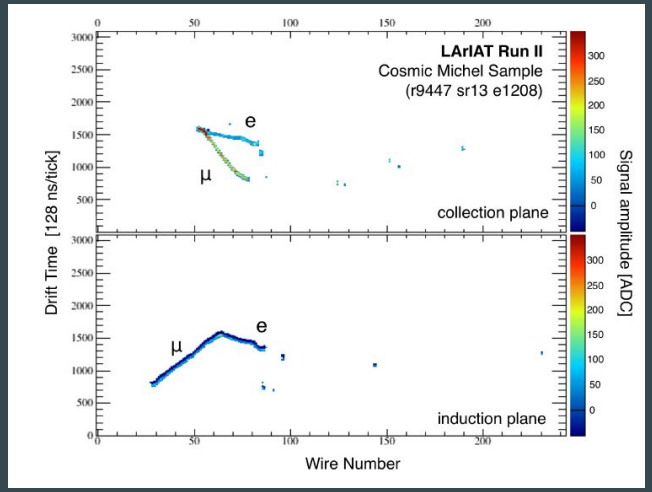
Michel electrons

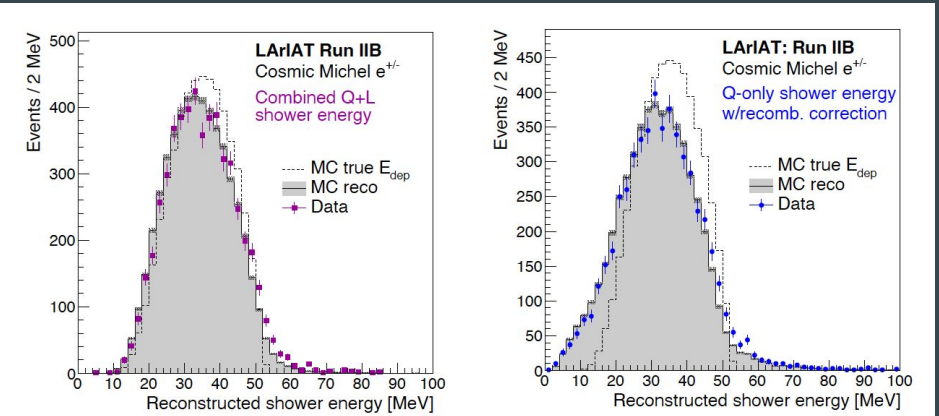
Calorimetry for low-energy electrons using charge and light in liquid argon

W. Foreman et al. (LArIAT Collaboration)

Phys. Rev. D 101, 012010

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.101.012010





(b) 'Q+L' energy spectrum (a) 'Q-only' energy spectrum

- Electrons from muon decay
- Relevancy to DUNE: energy range similar to supernovae neutrinos
- Used scintillation light to trigger readout of cosmic muons that stop and decay to Michel electrons
- Demonstrated calorimetry of low-energy electron showers by combining both ionization and scintillation

Pion Cross Section

- First measurement of the (π-, Ar) total hadronic cross section at the LArIAT experiment (inclusive)

arXiv:2108.0004

Submitted to PRD

- Exclusive
  - inelastic, charge exchange, absorption

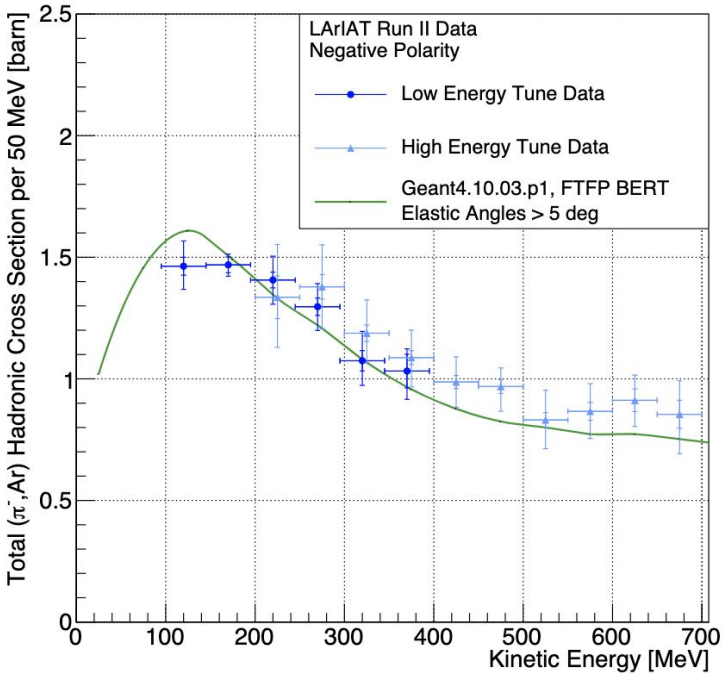
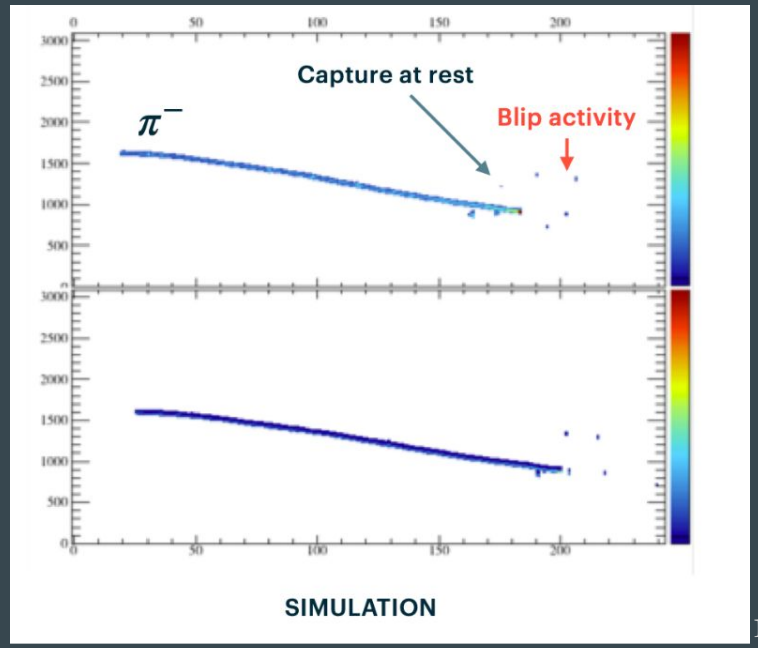


FIG. 15. (π^-, Ar) total hadronic cross section for scattering angles greater than 5 degrees measured in the LArIAT low energy and high energy tune Run II data samples. The Geant4 prediction for the total hadronic cross section for inelastic scattering and elastic scattering angles greater than 5 degrees is displayed in green.

Muon and Pion capture at rest

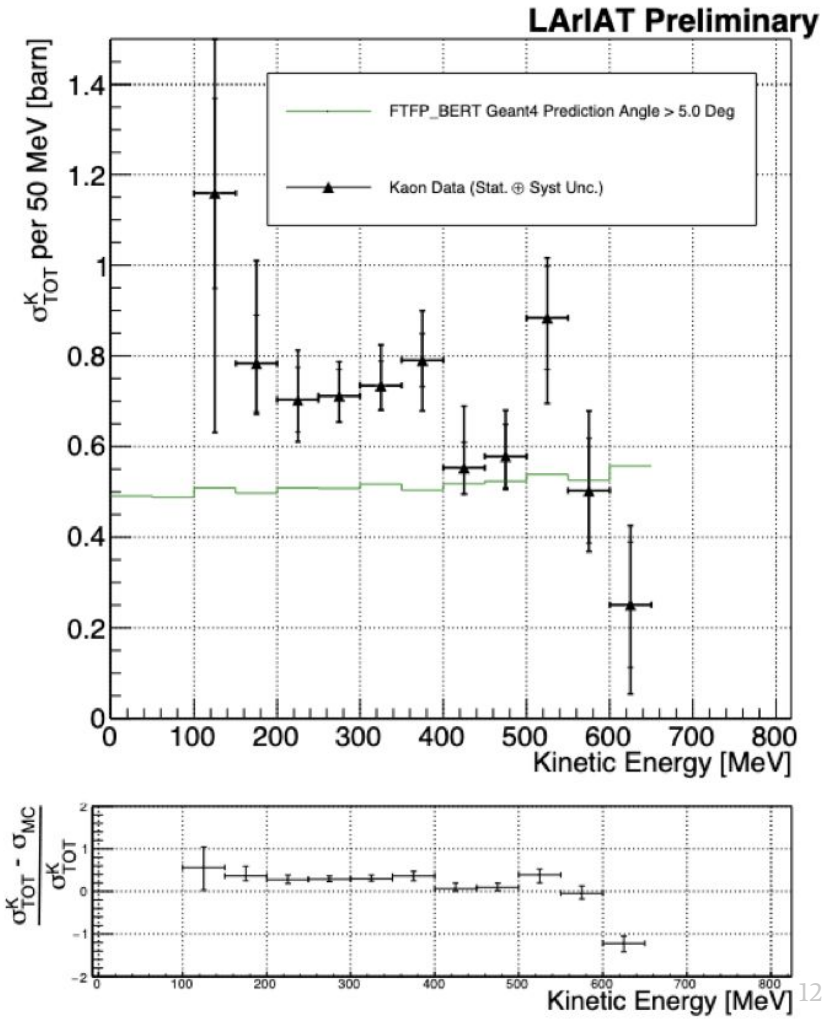
- Blips are small deposition of energy
- Generated by interactions of low energy MeV-scale gamma rays
- Pions and muons have different blip activity
- Particle identification



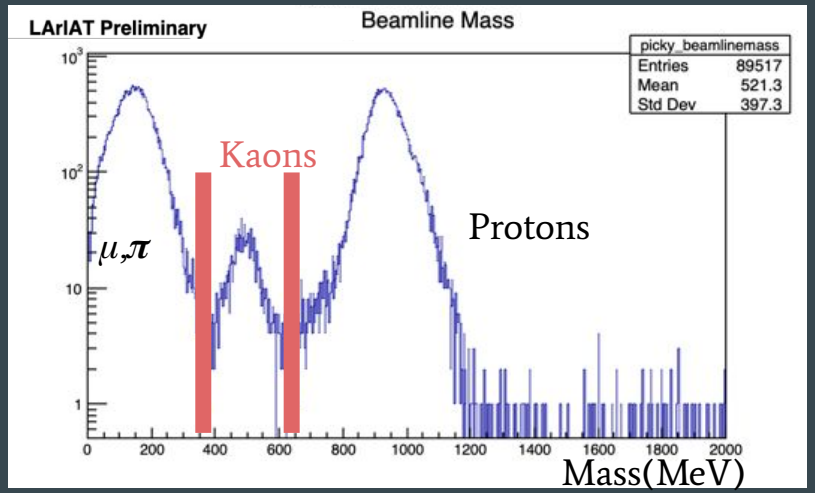
Positive Kaons

- Grand unified theories
- Proton decay into Kaon antineutrino
- Revisiting analysis - selection cuts, statistics

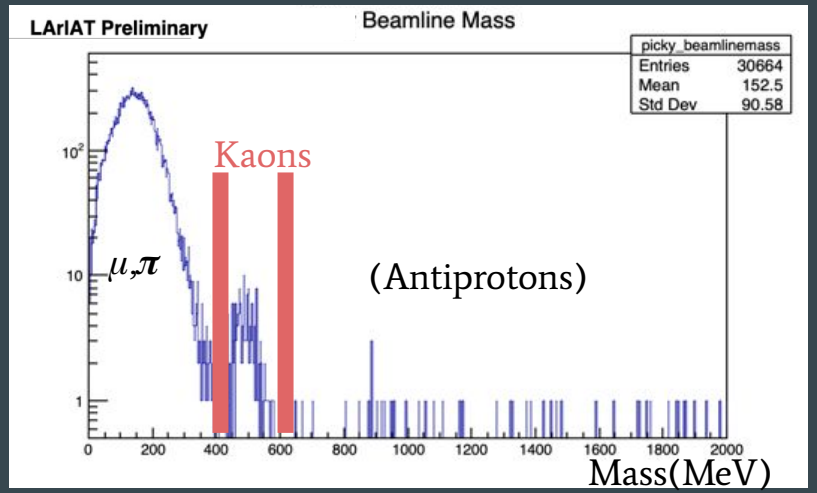
Image: https://lss.fnal.gov/archive/thesis/2000/fermilab-thesis-2018-24.pdf



Kaons selection



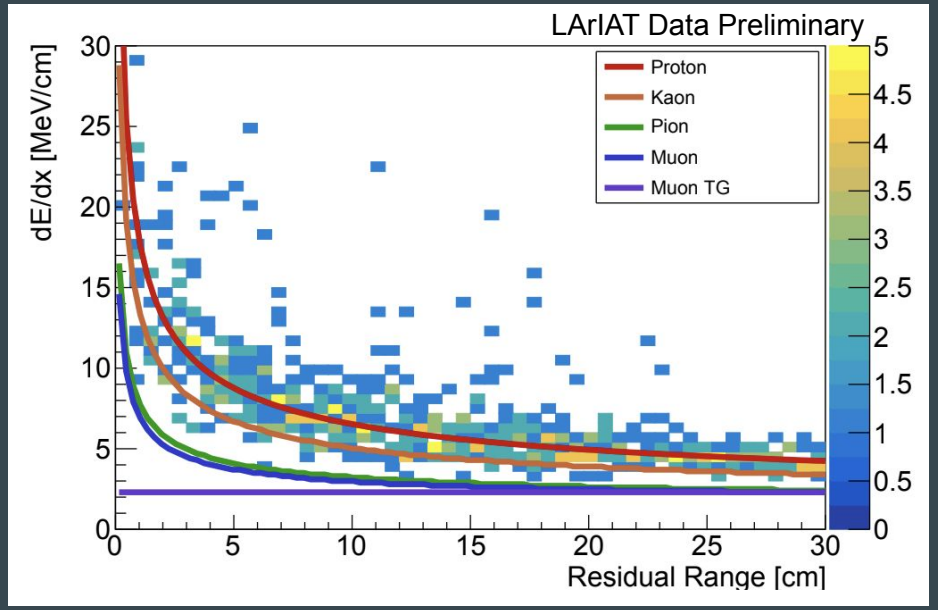
Positive

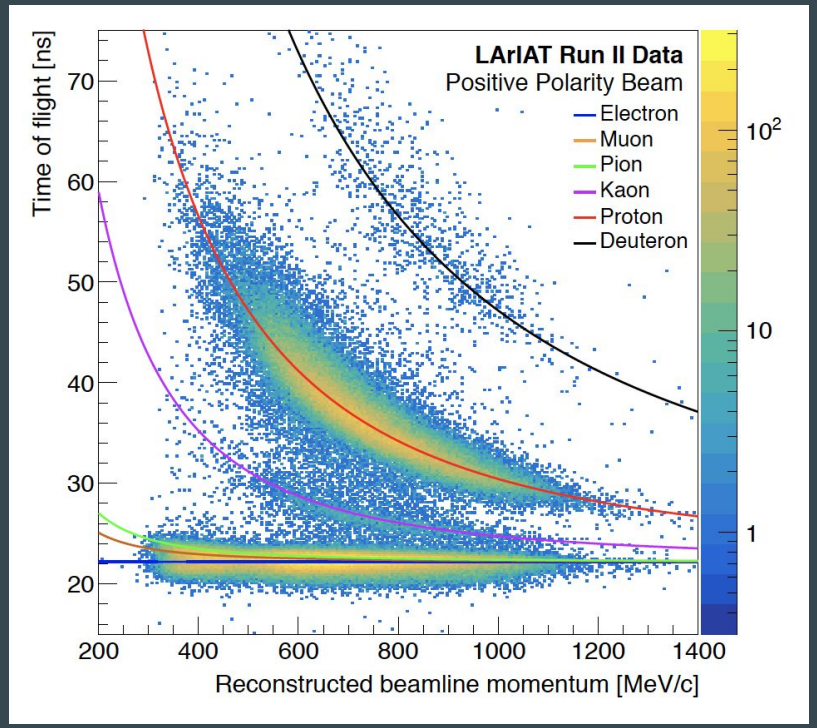


Negative

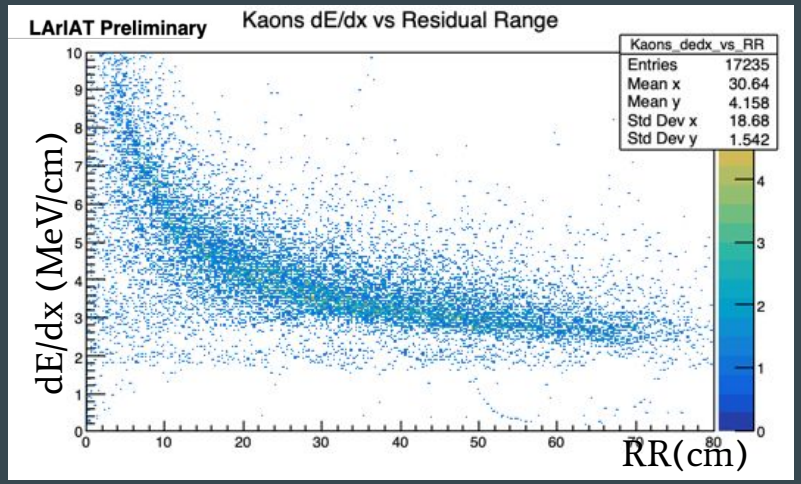
Beamlinemass positive and negative kaons (MeV)

Examples

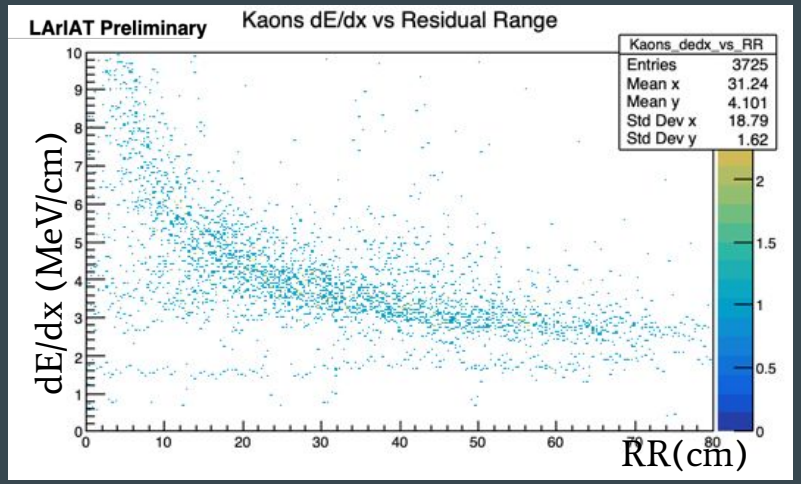

LArIAT Data Preliminary
Proton
Kaon
Pion
Muon
Muon TG
dE/dx [MeV/cm]
Residual Range [cm]


LArIAT Run II Data
Positive Polarity Beam
Electron
Muon
Pion
Kaon
Proton
Deuteron
Time of flight [ns]
Reconstructed beamline momentum [MeV/c]

Kaons selection



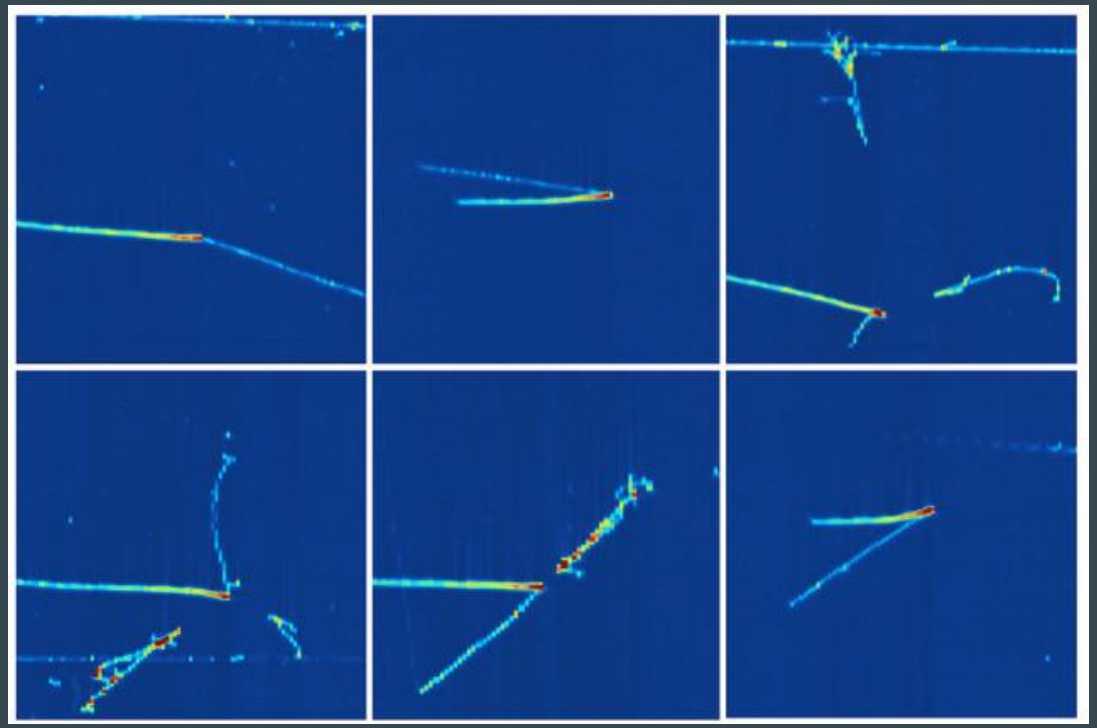
Positive



Negative

dE/dx vs Residual Range for positive and negative kaons

Positive Kaon event candidates in the collection plane



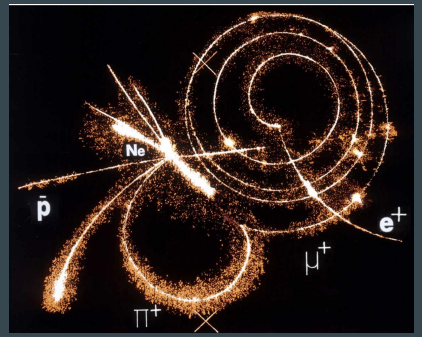
Kaon decay most likely to:

- muons

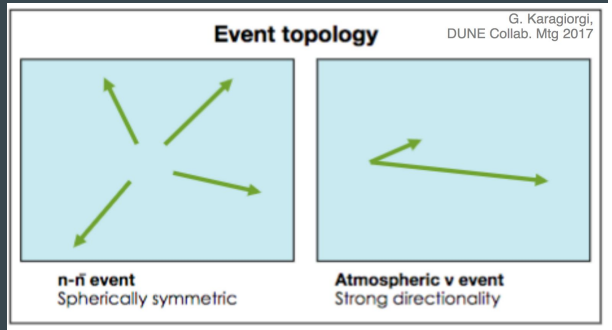
- pions

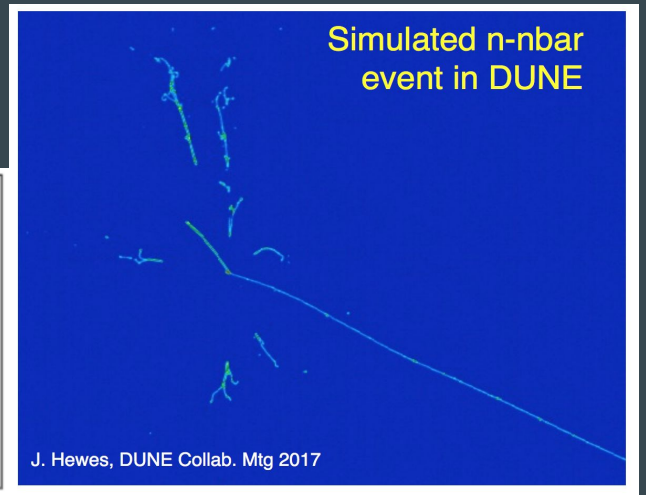
Antiprotons

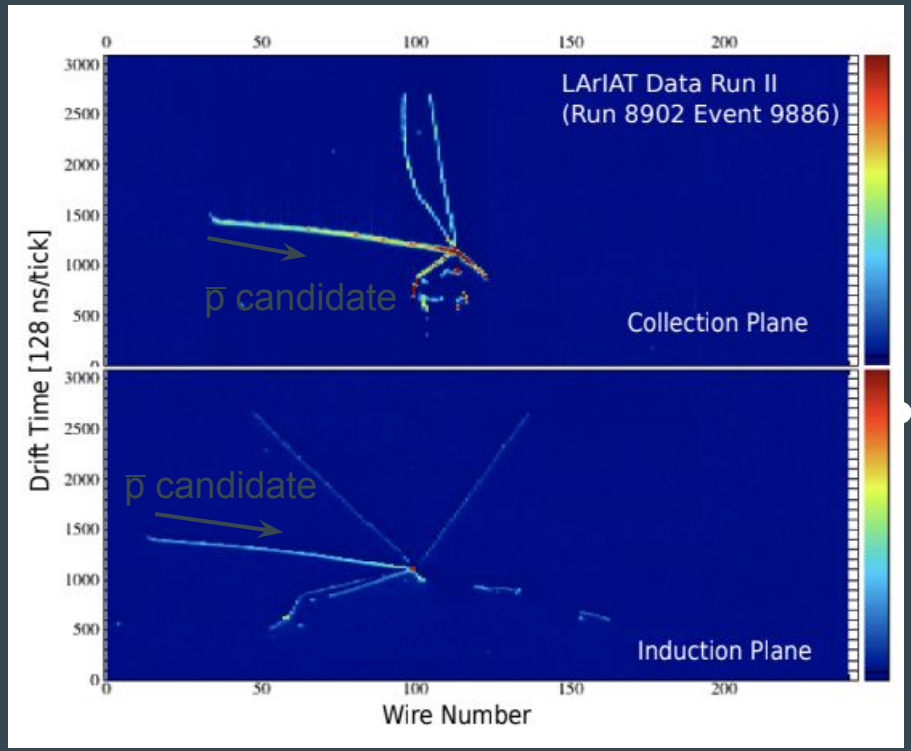
- Help neutron-antineutron annihilation searches.
  - Similar topology
  - Antineutrons bonded inside an atom would annihilate with another nucleon
  - Products multiplicity
  - DUNE sensitivity

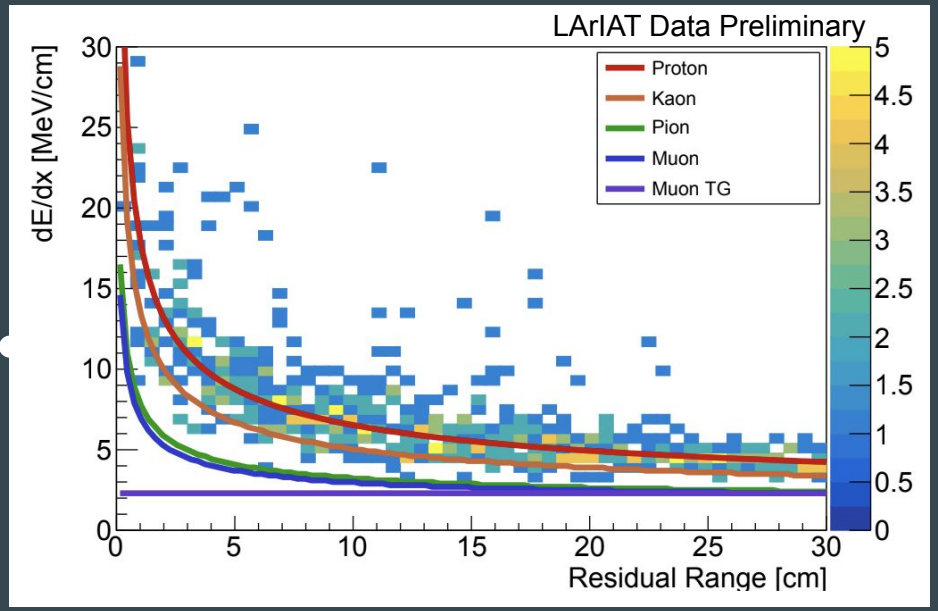


p_bar-Ne annihilation observed by the PS179 streamer chamber (photo CERN)






LArIAT Data Run II
(Run 8902 Event 9886)
p̄ candidate
Collection Plane
p̄ candidate
Induction Plane
Drift Time [128 ns/tick]
Wire Number


LArIAT Data Preliminary
Proton
Kaon
Pion
Muon
Muon TG
dE/dx [MeV/cm]
Residual Range [cm]

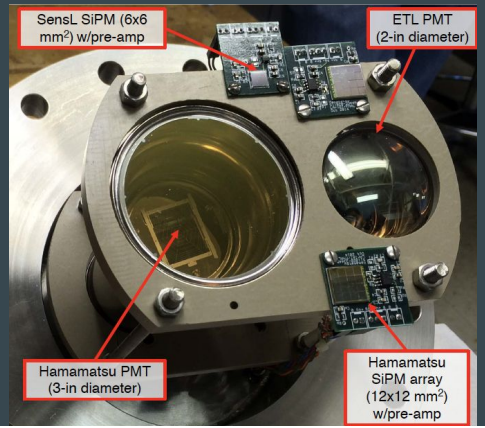
Summary

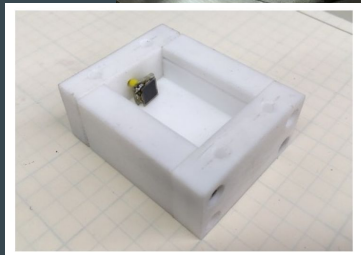
- LArIAT
- LArTPC R&D
- Results and analysis
  - Michel Electrons
  - Hadron measurements
    - Pions
    - Muons, pions at rest
    - Kaons
    - Antiprotons

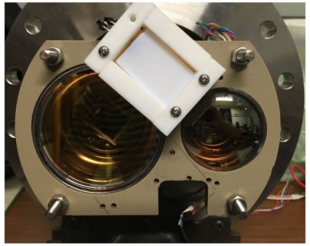
LAr R&D

Tests to support future experiments like SBND, DUNE

- Light collection system
  - Photodetector beyond collection plane
  - 2 PMT
  - LAr produces scintillation light at vacuum UV
  - Shift UV to visible
  - Run 1, 2 Silicon Photomultipliers (SiMPS)
  - Run 3 ARAPUCA prototype
- Wire plane pitch
  - 3mm vs. 4mm vs. 5mm wire spacing
- Mesh HV cathode
  - test of a design proposed for the SBND experiment,
  - the original cathode was replaced with a cathode made of stainless steel mesh.







Images: R. Acciarri et al 2020 JINST 15 P04026

Citation: M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018)

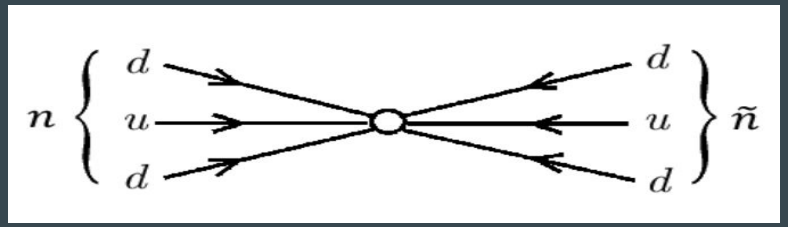
K^+ DECAY MODES

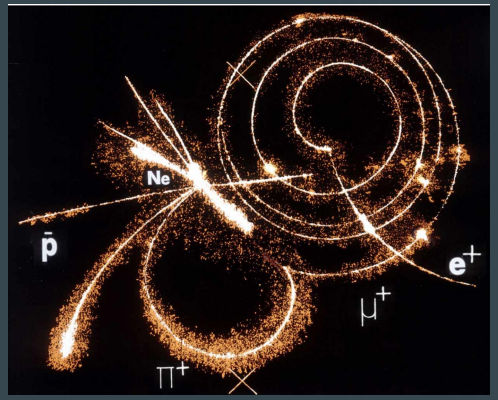
K^- modes are charge conjugates of the modes below.

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Leptonic and semileptonic modes		
Γ_1	$e^+\nu_e$	$(1.582\pm0.007)\times10^{-5}$	
Γ_2	$\mu^+\nu_\mu$	(63.56 ± 0.11) %	S=1.2
Γ_3	$\pi^0 e^+\nu_e$	(5.07 ± 0.04) %	S=2.1
	Called K^+_{e3}.		
Γ_4	$\pi^0\mu^+\nu_\mu$	(3.352 ± 0.033) %	S=1.9
	Called $K^+_{\mu3}$.		
Γ_5	$\pi^0\pi^0 e^+\nu_e$	$(2.55\pm0.04)\times10^{-5}$	S=1.1
Γ_6	$\pi^+\pi^- e^+\nu_e$	$(4.247\pm0.024)\times10^{-5}$	
Γ_7	$\pi^+\pi^-\mu^+\nu_\mu$	$(1.4\pm0.9)\times10^{-5}$	
Γ_8	$\pi^0\pi^0\pi^0 e^+\nu_e$	$<3.5\times10^{-6}$	CL=90%
	Hadronic modes		
Γ_9	$\pi^+\pi^0$	(20.67 ± 0.08) %	S=1.2
Γ_{10}	$\pi^+\pi^0\pi^0$	(1.760 ± 0.023) %	S=1.1
Γ_{11}	$\pi^+\pi^+\pi^-$	(5.583 ± 0.024) %	

Antiprotons

- Help neutron-antineutron annihilation searches.





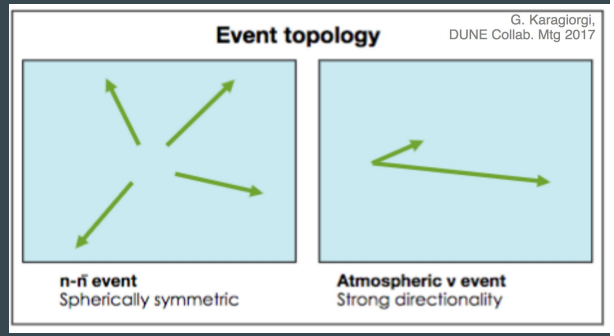
p_bar-Ne annihilation observed by the PS179 streamer chamber (photo CERN)

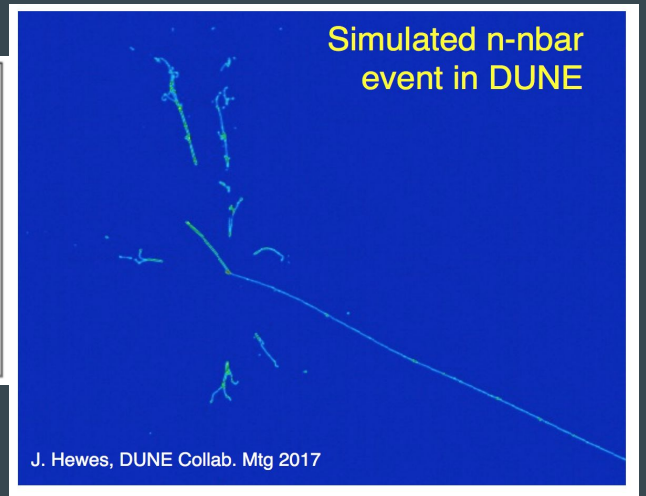
- For neutrons inside the nucleus (bound neutrons), the signature is the annihilation of the oscillated neutron with a neighbouring nucleon (proton or neutron).

LArTPCs' Motivation

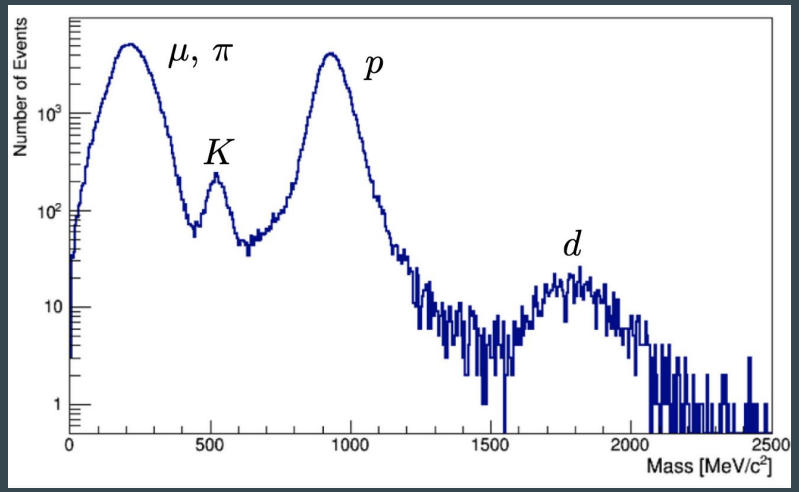
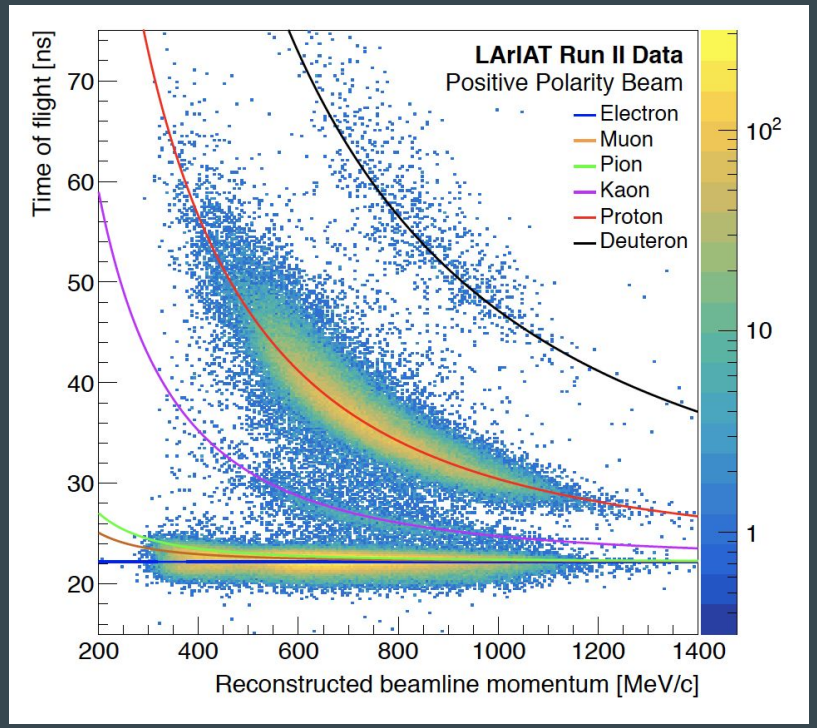
- We want to study the hadron star topology of p-p_ bar annihilation in liquid argon from a low-momentum p_bar "beam".
- p-p_bar at rest has a very similar topology to n-n_bar at rest which makes it a valuable probe.
- Pions, Kaons, ... multiplicity from the star event can accurately be determined with LArTPCs.
- This is important for DUNE due to its size and sensitivity to observe n-n_bar oscillations (free neutron lifetime limit).

Typical images shown for DUNE





Particle Identification



$$m = \frac{p_z}{c}\sqrt{\left(\frac{c\Delta t}{L}\right)^2 - 1}$$