LArIAT

(Liquid Argon TPC In A Test-beam)

Total inclusive π^{-}-Ar cross-section

8th Symposium on large TPCs for low-energy rare event detection
Dec. 5th 2016

F. Blaszczyk – Boston University
(on behalf of the LArIAT collaboration)

Outline

- Neutrino physics and LArIAT
- The LArIAT experiment
- π^- - Ar inclusive total cross-section
- Conclusion

LArIAT for ν physics

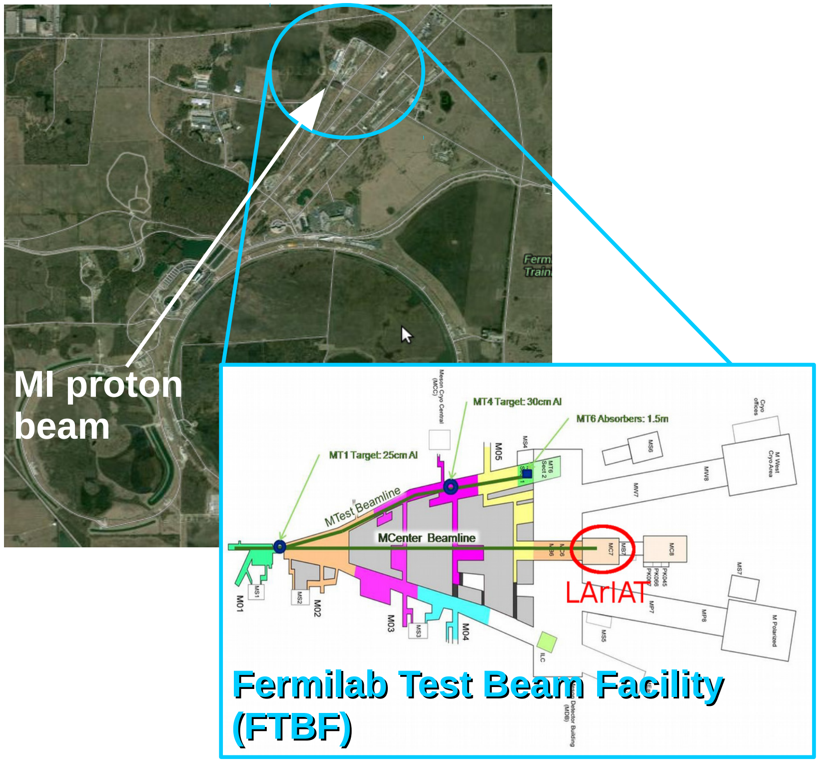
- Neutrinos are neutral particles (no tracks)

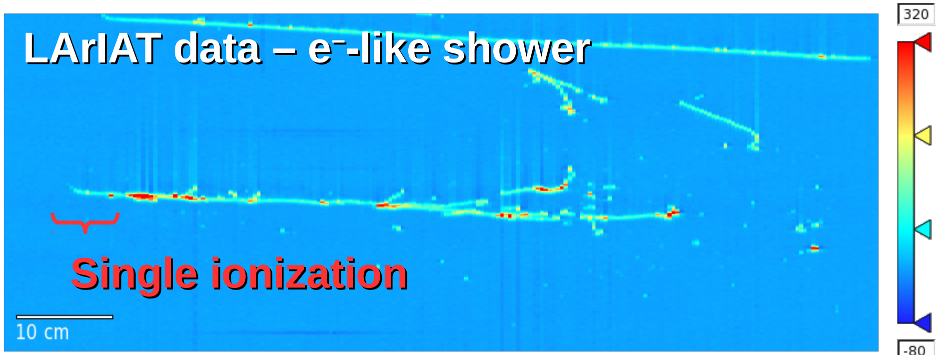
→ must be able to identify outgoing particles

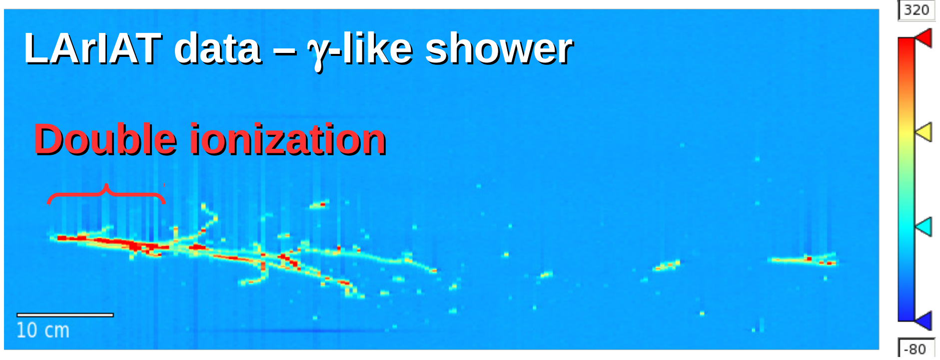
  - improve LArTPC reconstruction
  - optimize particle identification
  - μ and π topology-based sign determination without magnetic field

- π^0 background reduction for ν_e appearance analysis
  - study e^- / γ separation = distinguish single (electron) vs double (photon) ionization
- Systematics reduction
  - measure hadron-Ar cross-sections
  - improve energy resolution by using both scintillation and ionization information
- But also…
  - Simulation validation (GEANT4, GENIE)
  - R&D: wire pitch, light collection systems...

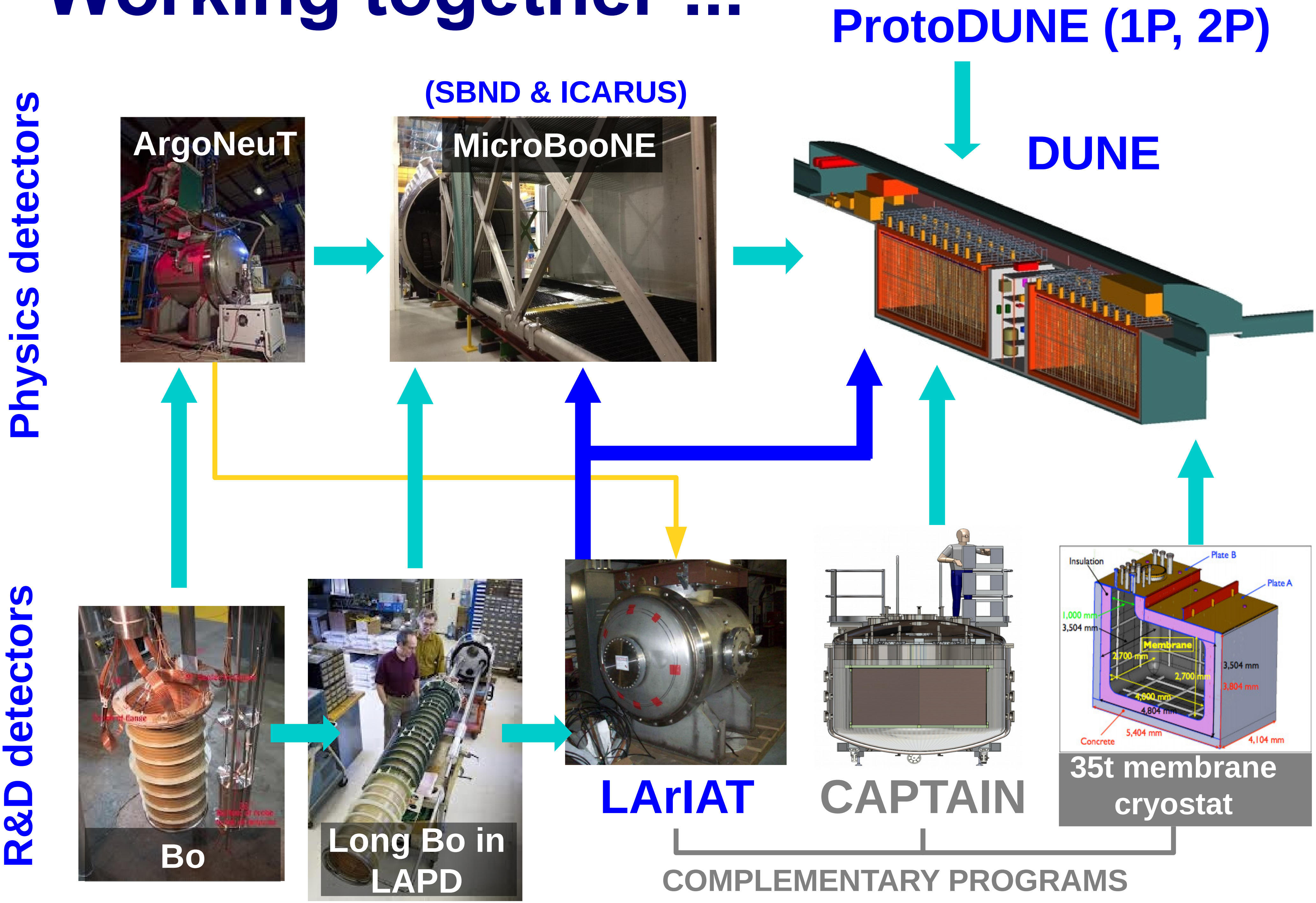
LArIAT @ FTBF: Study neutrino interaction outgoing particles with a dedicated test-beam!





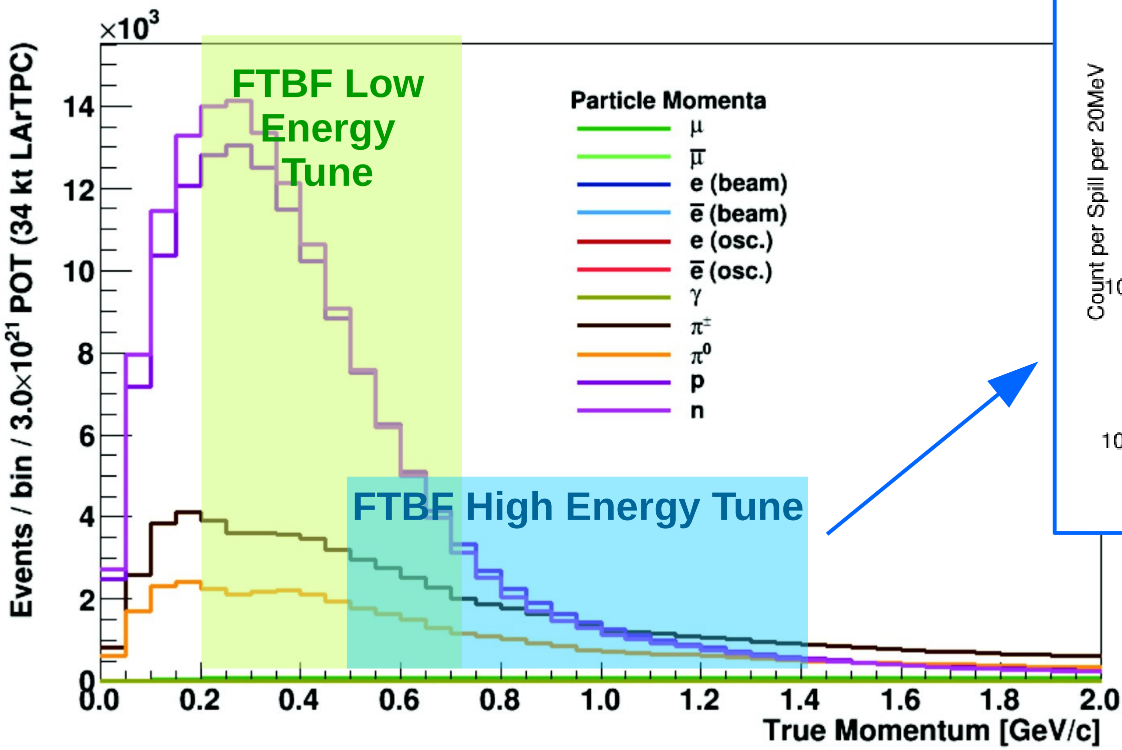


Working together ...

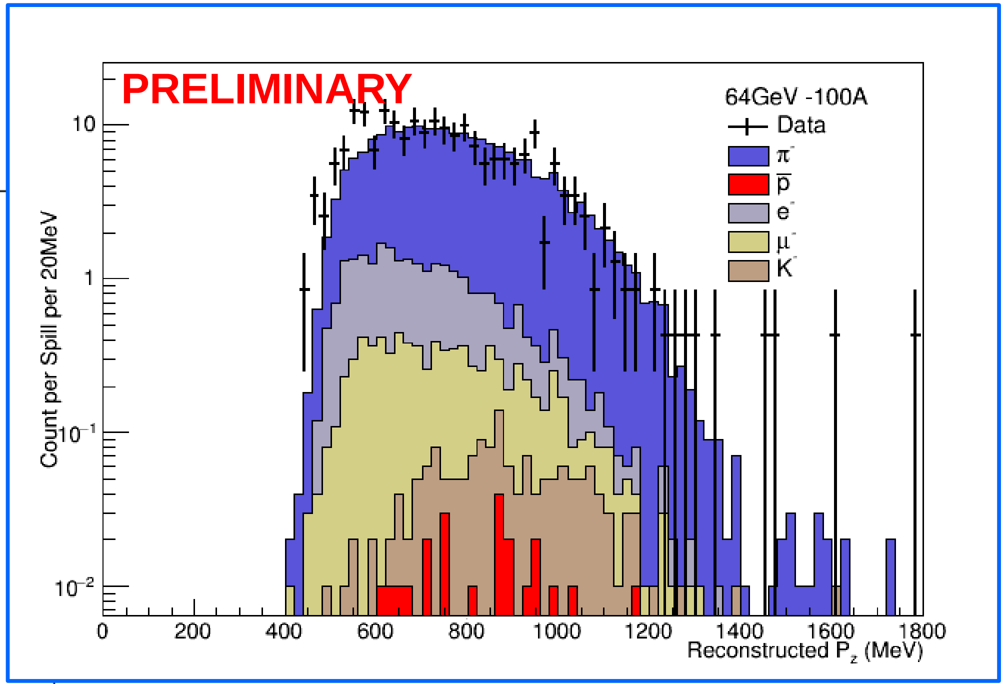


LArIAT test-beam

DUNE Simulation for ν_e CC analysis

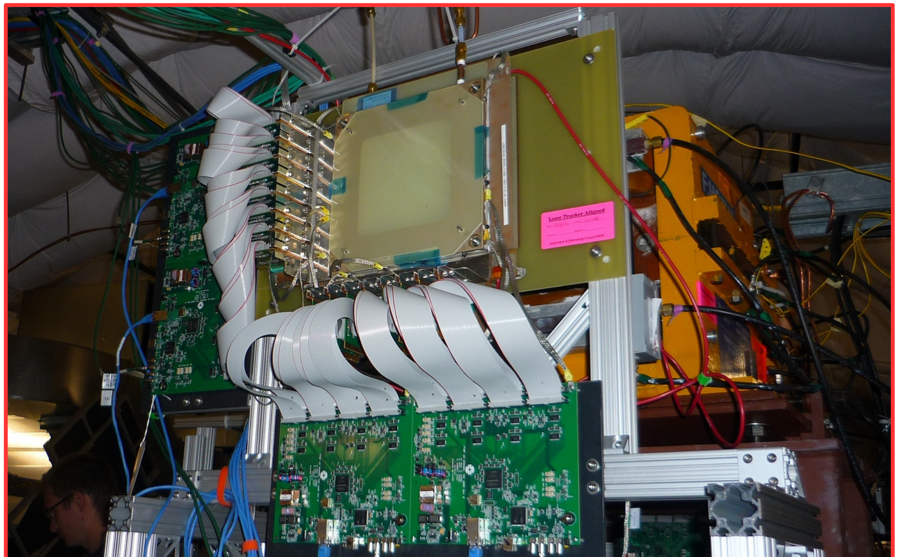


LArIAT Tertiary Beam Particle Momenta

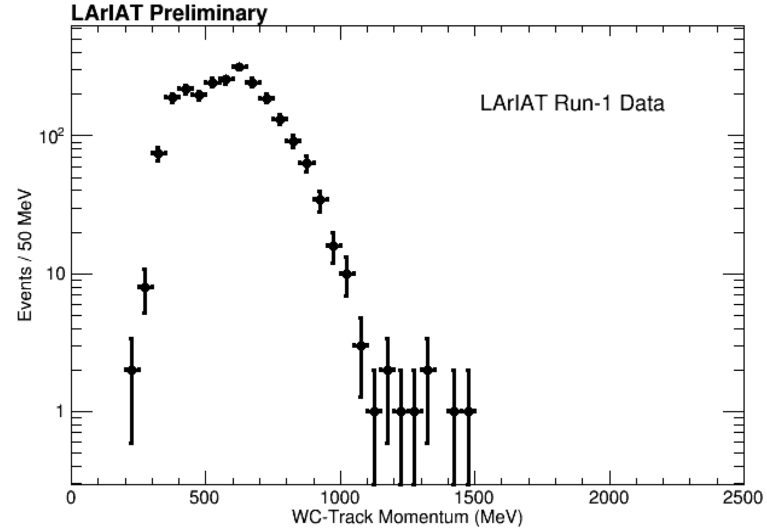


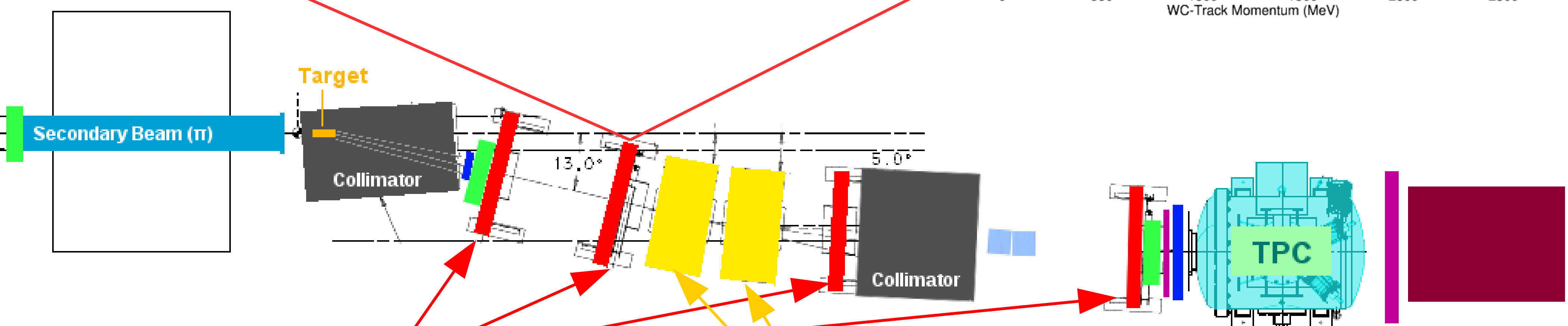
- FTBF dedicated new tertiary beam line (0.2 – 2 GeV/c)
- Tunable test-beam → relevant energies for both short baseline experiments (μBoone, SBND, ICARUS) and long baseline experiments (DUNE)
- Known particle beam → beamline instrumentation

Beamline PID – Wire Chambers



Reconstructed momentum
Negative polarity run I



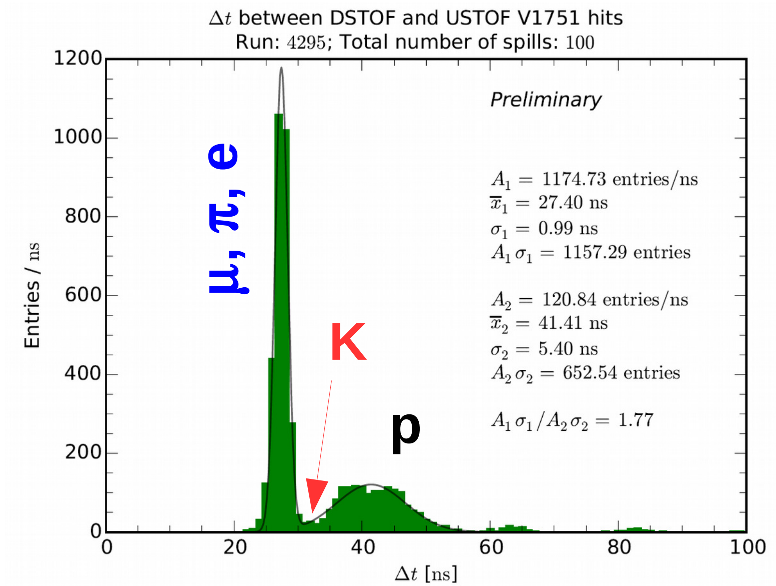


4 Multi-Wire Proportional Chambers
→ single particle momentum measurement

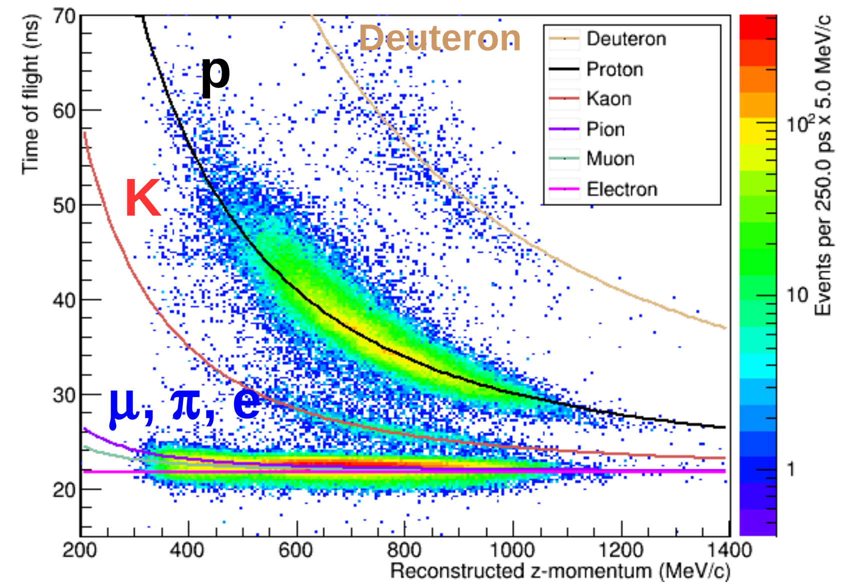
2 bending magnets
→ momentum and polarity selection

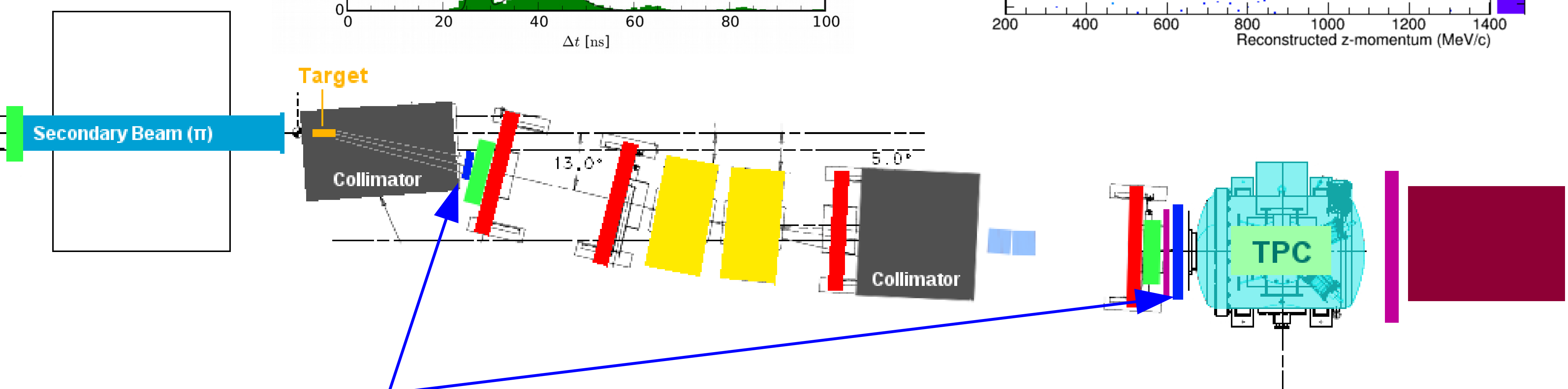
Beamline PID – Time-Of-Flight

ΔT between up and downstream TOF



Combined TOF + MPWC data





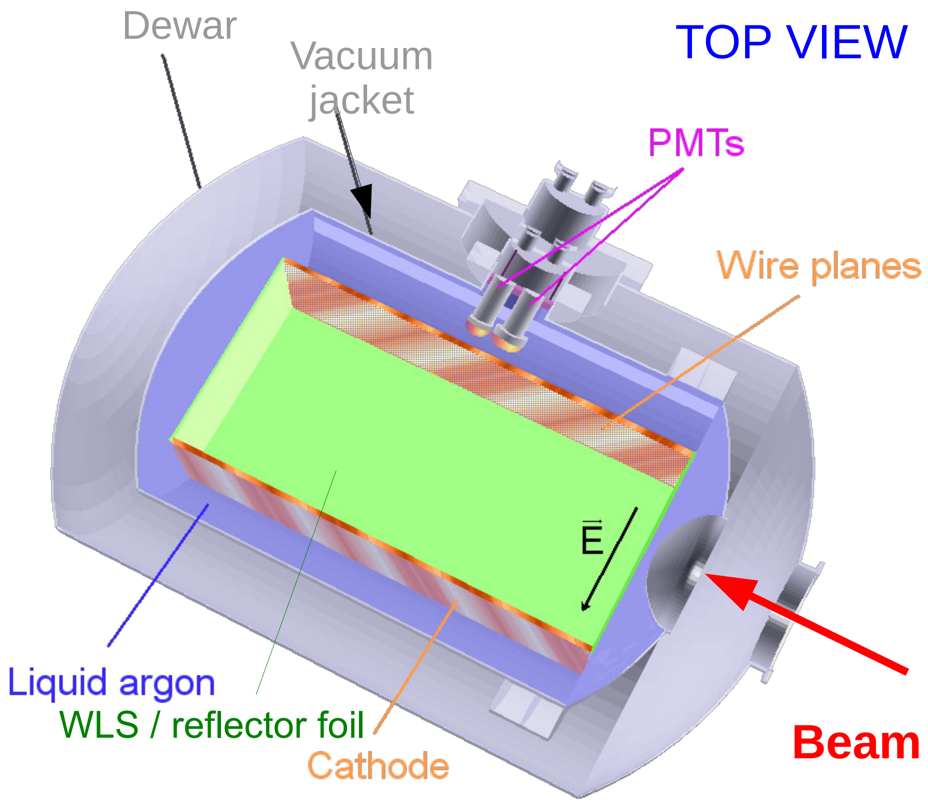
Time-Of-Flight (TOF)
→ μ / π / e vs proton and kaon separation

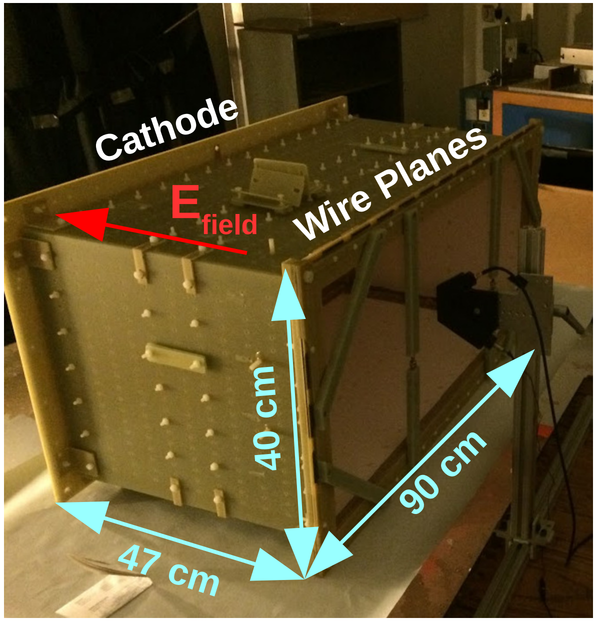
LArIAT Design

- Refurbished ArgoNeuT TPC and cryostat.
- **Specifications:**
  - Active volume: 170 L (550 L cryostat)
  - 90 cm x 40 cm x 47 cm (drift) TPC
  - 3 wire planes: 1 induction, 1 collection, 1 shield (4mm wire spacing, ~240 wires/plane)
  - Nominal electric field: 500 V/cm (tunable)

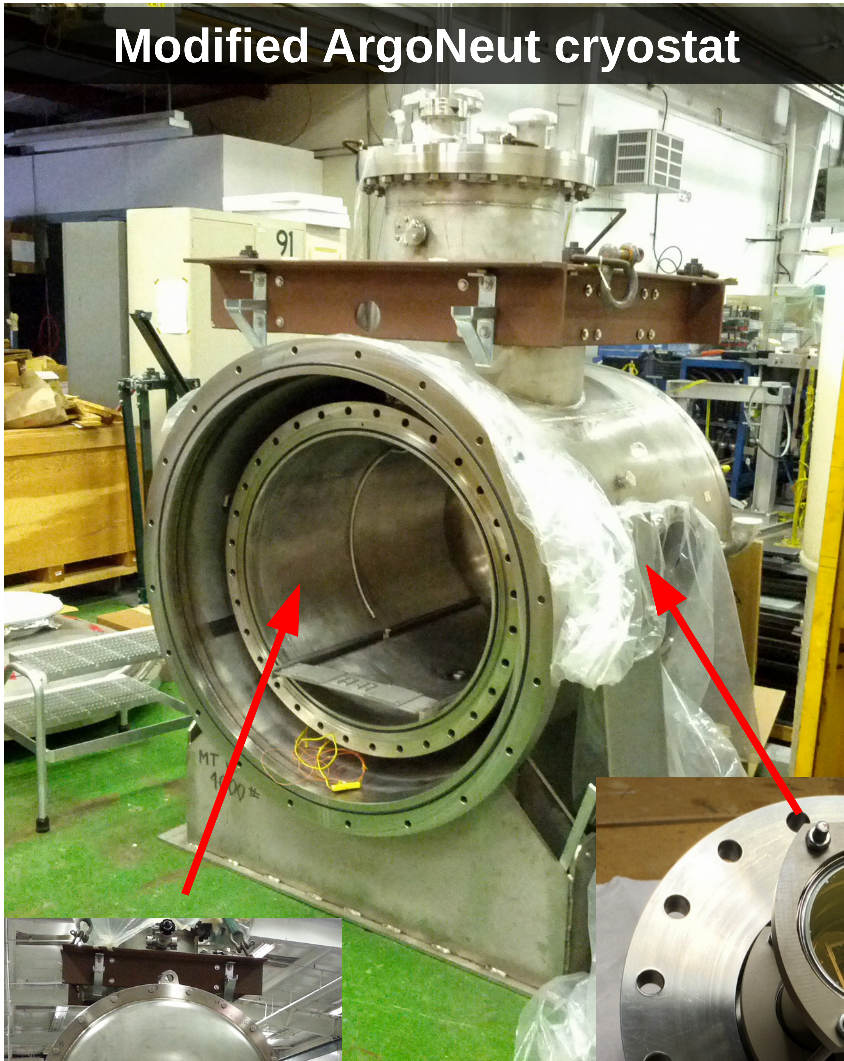
    → ~400 μs max drift time
  - Light collection system: 2 standard PMTs + 3 SiPM + wavelength shifting reflector foils
  - Cold readout electronics: μBooNE ASICs on custom motherboards

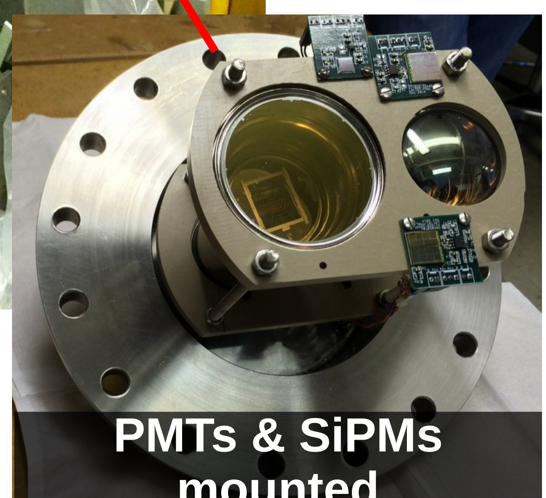
    → ~50:1 signal to noise ratio for run I (~70:1 run II)

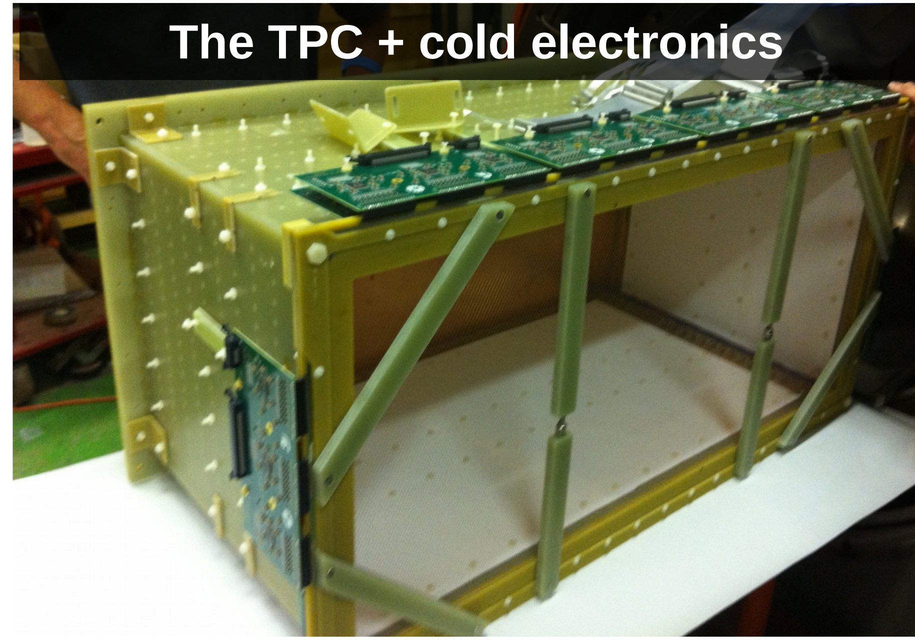


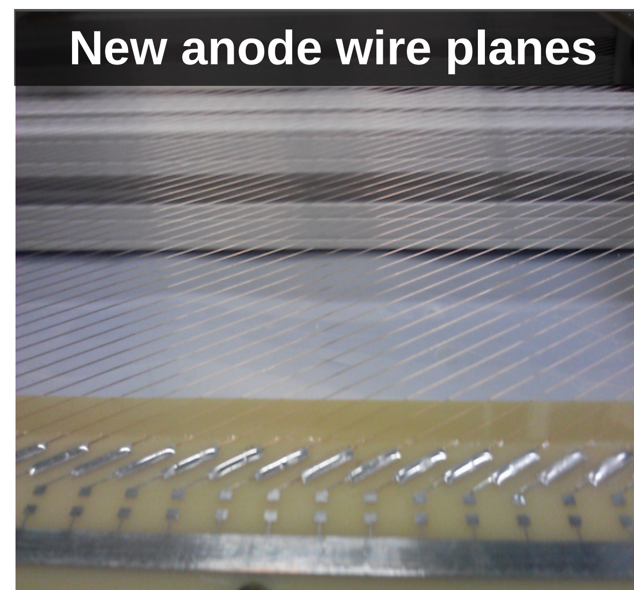


LArIAT TPC / cryostat

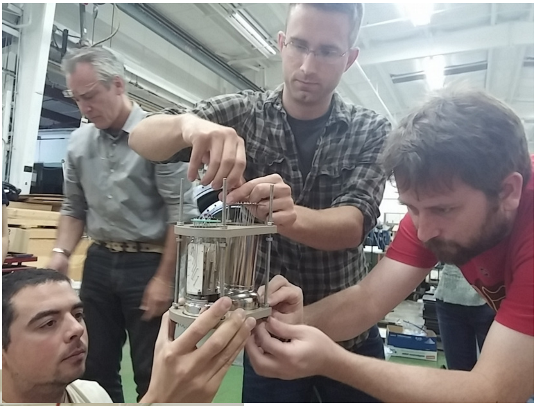


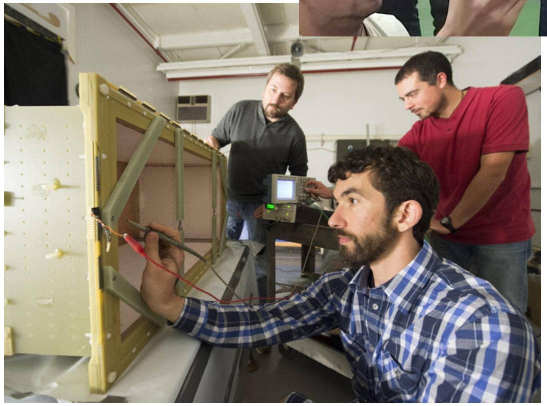






LArIAT datasets





- Run I – May→Jul 2015 (~9 weeks):
  - ~5.5 weeks at high energy tune, positive and negative polarity
  - ~3.5 weeks at low energy tune, both polarities
- Run II – Feb→Jul 2016 (~24 weeks):
  - ~11 weeks at high energy tune, both polarities
  - ~8 weeks at low energy tune, both polarities
  - ~3 weeks at very low energy, e^- collection
  - ~2 weeks filter regeneration

- Run III – Starting Feb 2017
- Main focus: R&D

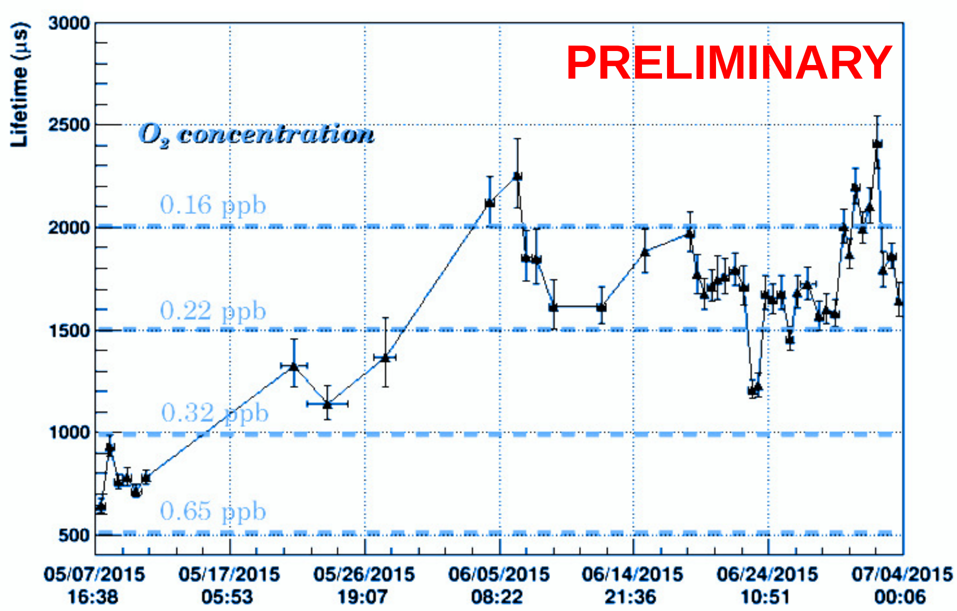
→ 3mm (μBooNE) vs 5mm (DUNE) wire pitch

→ new light collection systems (ARAPUCA)

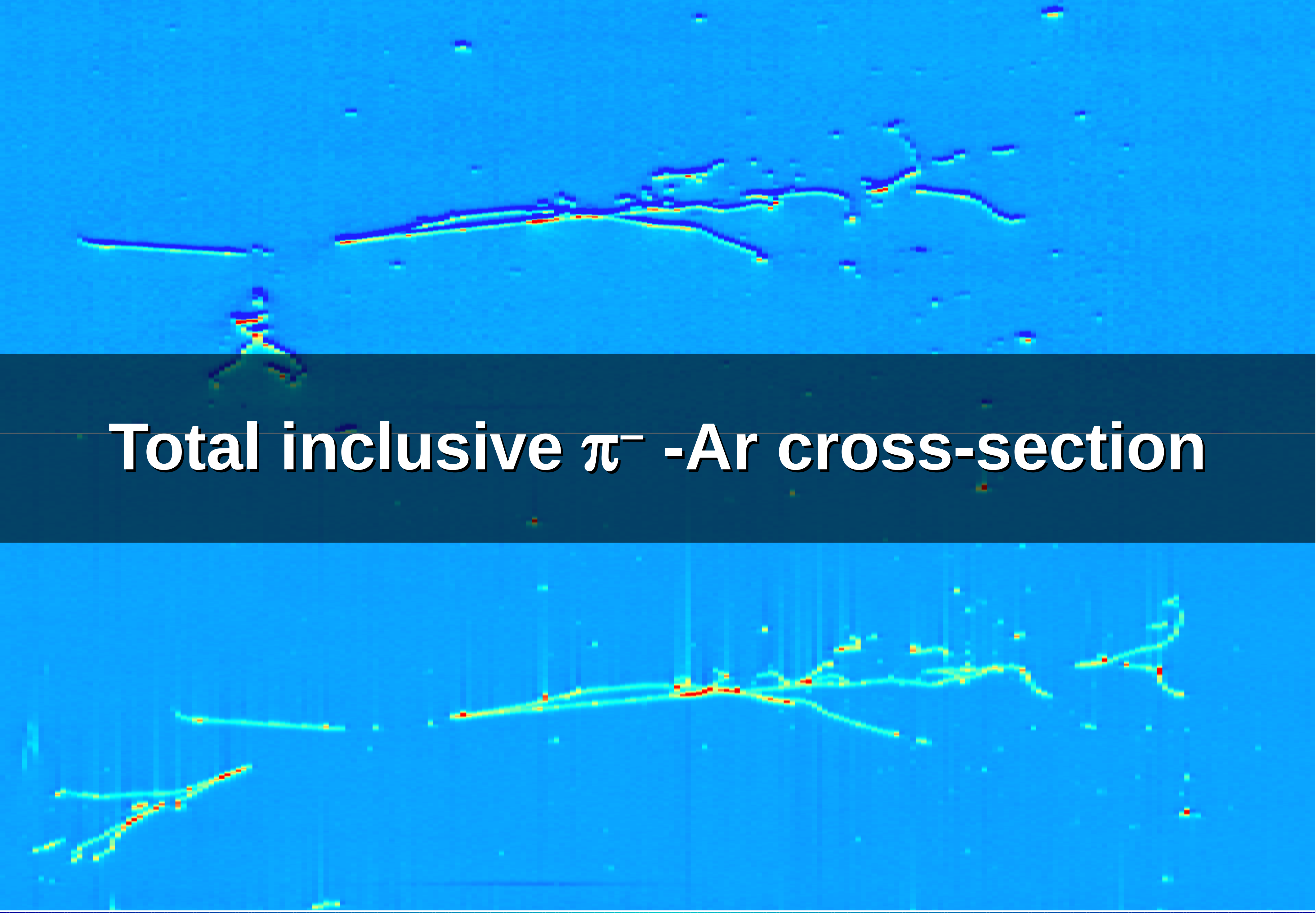
LArIAT on-going analyses

- Purity measurements with crossing muons and electron lifetime
- Light collection system studies: calorimetry, N_2 contamination, Michel electrons, light yield
- Pion cross-sections on Ar (total and exclusive channels)
- Kaon cross-sections on Ar

Run I electron lifetime



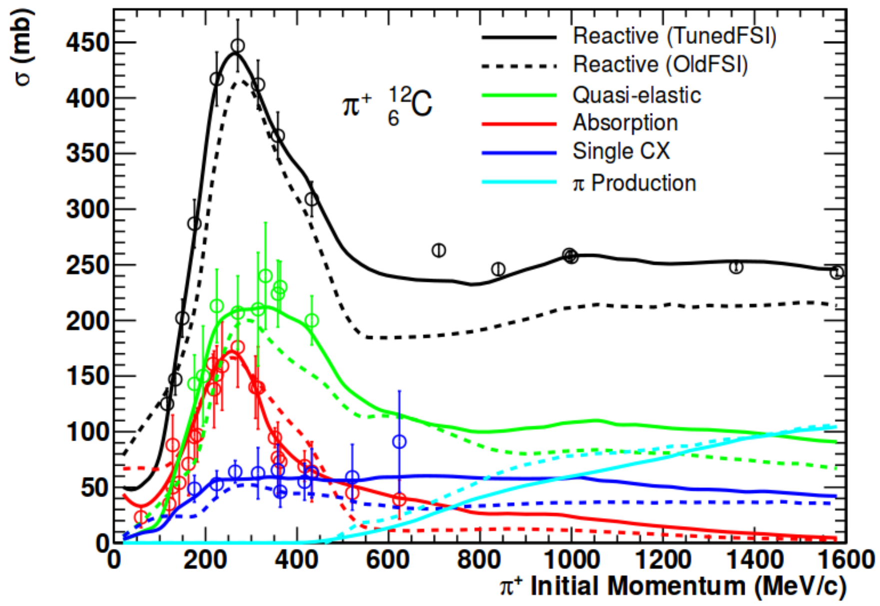
LArIAT data - Charge exchange candidate



Total inclusive π^- -Ar cross-section

Why pions ?

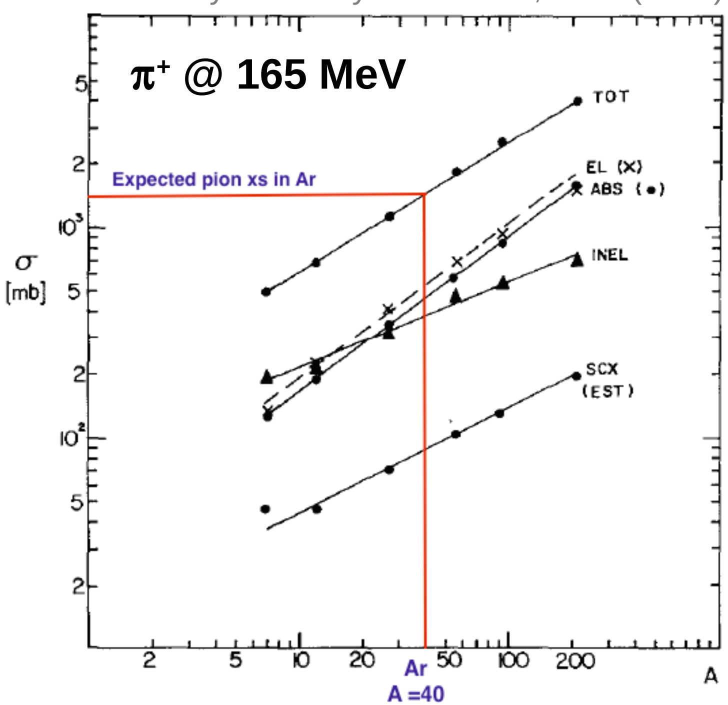
arXiv:1405.3973 [nucl-ex]



- Pions produced by neutrino interactions in experiments like DUNE are expected to have an energy range of 100-500 MeV

  → cross-section is boosted in that energy range

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



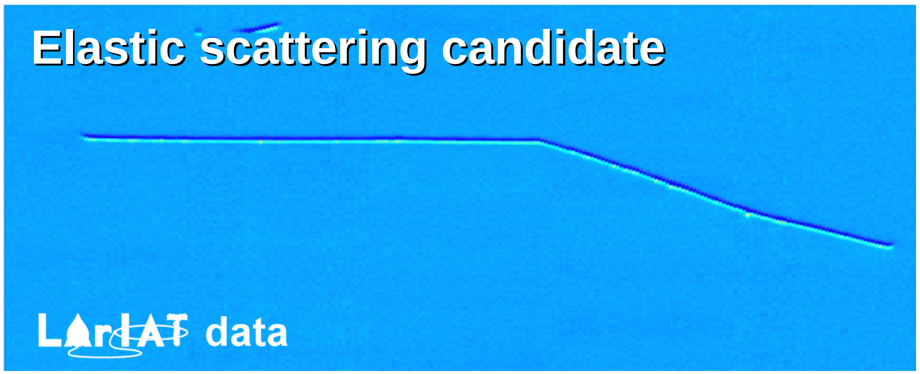
- Important systematic in neutrino cross-sections:
  - Final state interactions: large fraction of pions absorbed by Ar

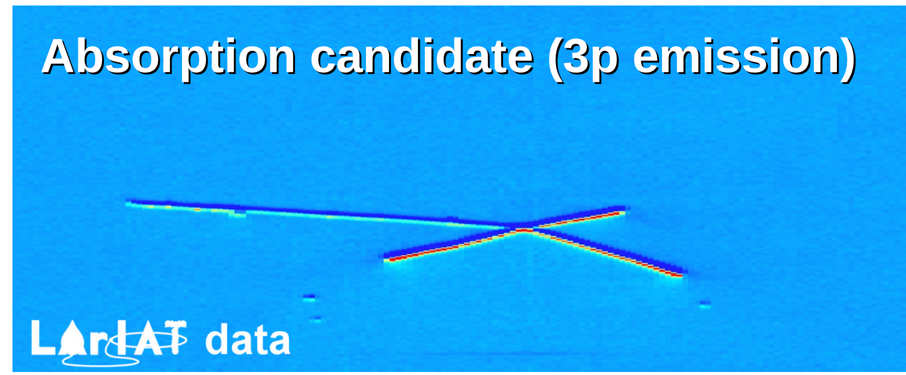
    → outgoing particle kinematics modified
  - Secondary interactions

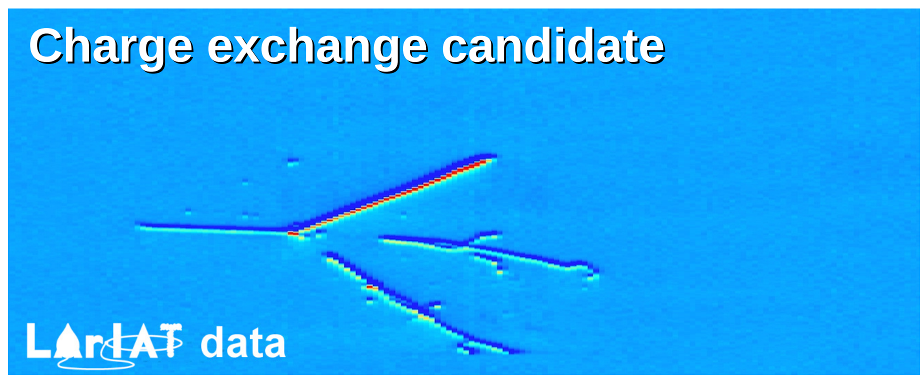
Pion-Ar cross-section never measured before !

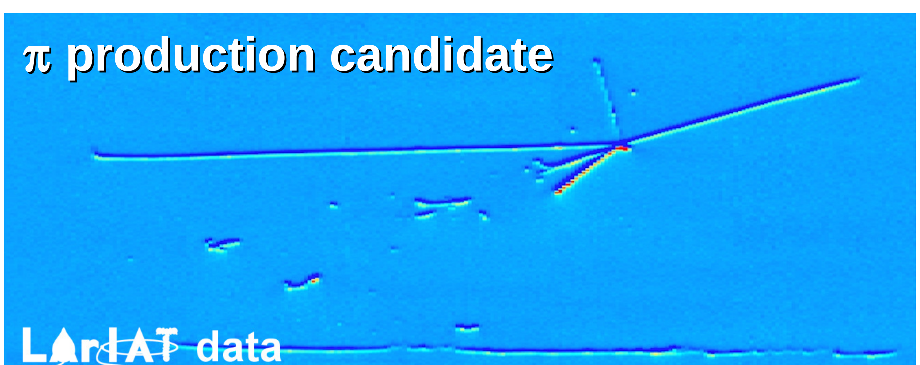
Total cross-section definition

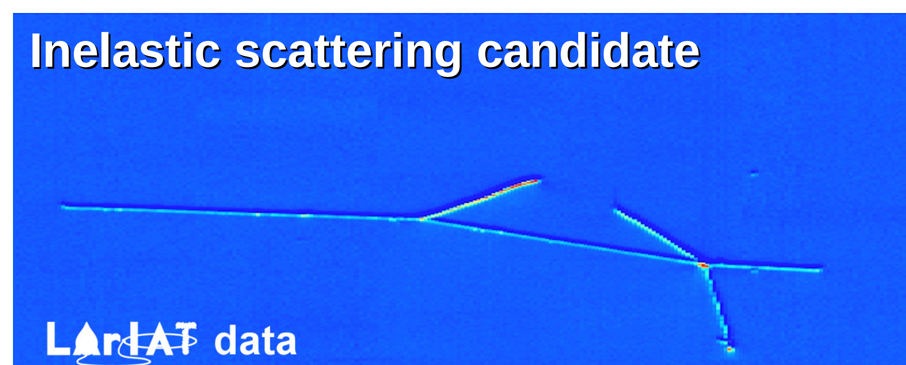
$$\sigma_{tot} = \sigma_{elastic} + \sigma_{absorption} + \sigma_{charge\ exchange} + \sigma_{\pi\text{-prod}} + \sigma_{inelastic}$$











Event selection

- Data sample: **Run I, negative polarity only**

Beam composition before cuts (from simulation)

π^-	e^-	γ	μ^-	K^-
48.4%	40.9%	8.46%	2.2%	0.04%

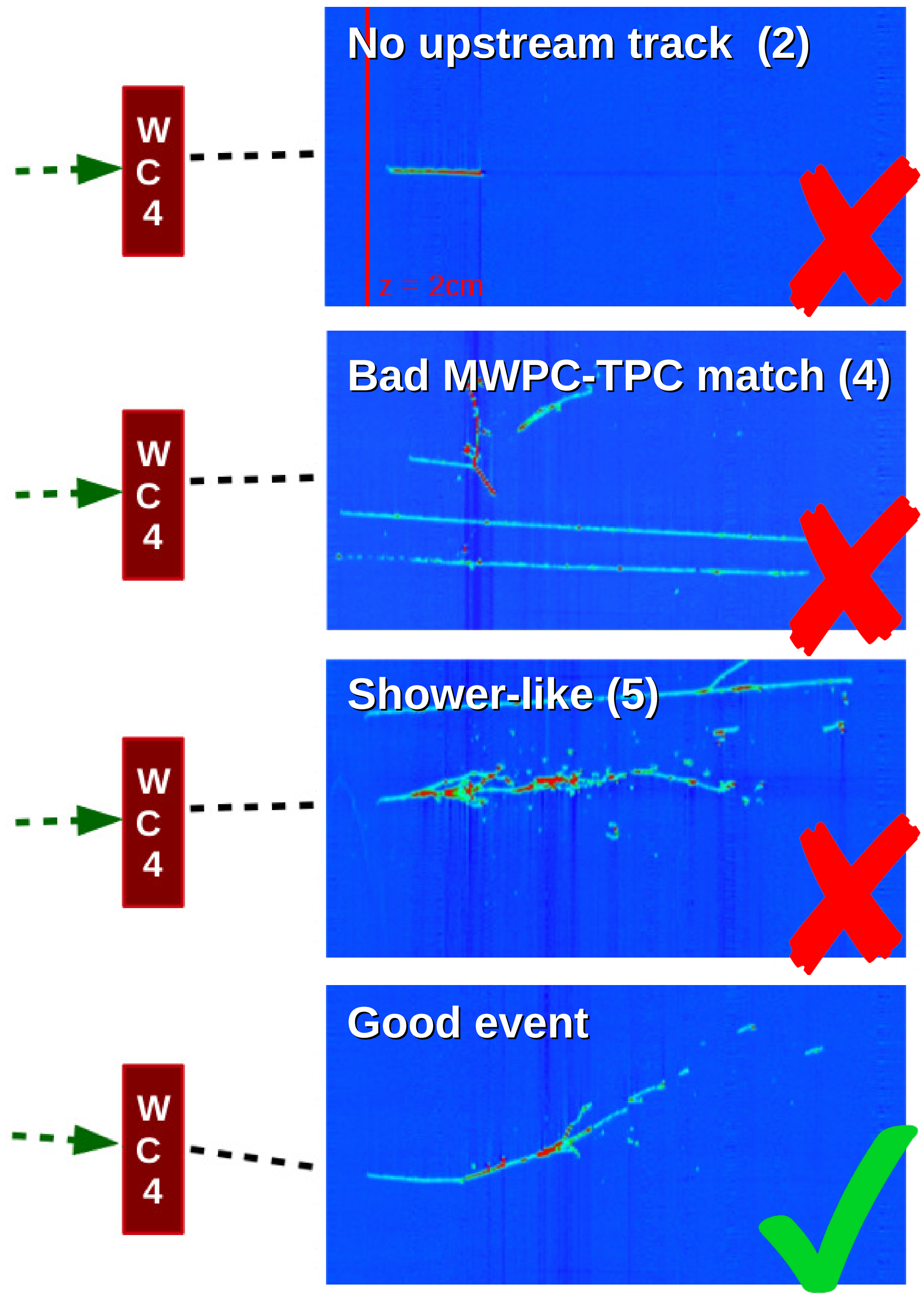
Reduction table (data)

Cut type	Nb. of events
Initial # of candidates	**32 064**
1 - $\pi/\mu/e$ ID (beamline info + not cosmic)	15 448
2 - Upstream track (z_{init} < 2cm)	14 330
3 - No pile-up	9 281
4 - MPWC/TPC track matching	2 864
5 - Not shower-like (topology based)	**2 290**

Beam composition after cuts (from simulation)

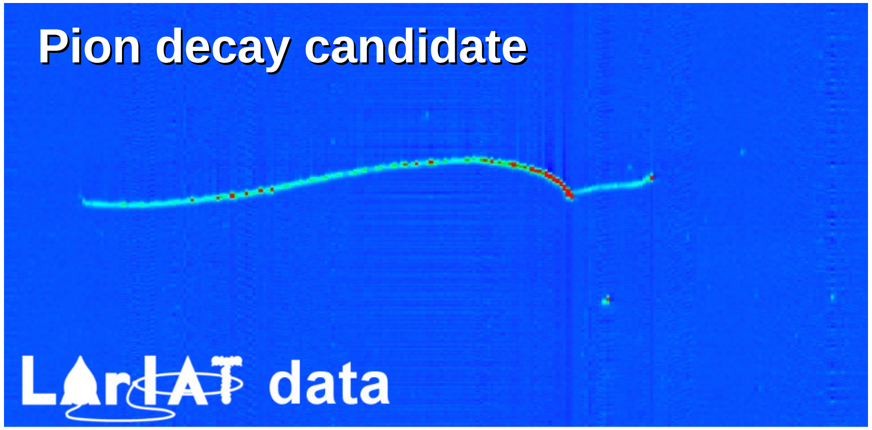
π^-	e^-	γ	μ^-	K^-
91.04%	3.7%	0.2%	5%	0.06%

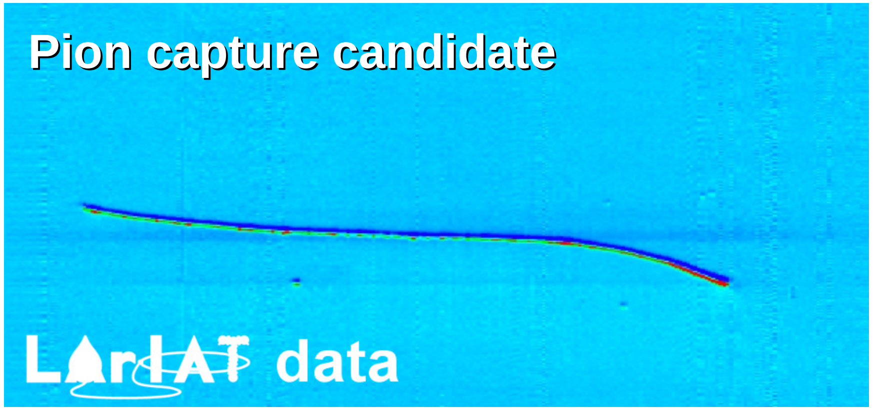
→ Pion selection efficiency: 74.5%



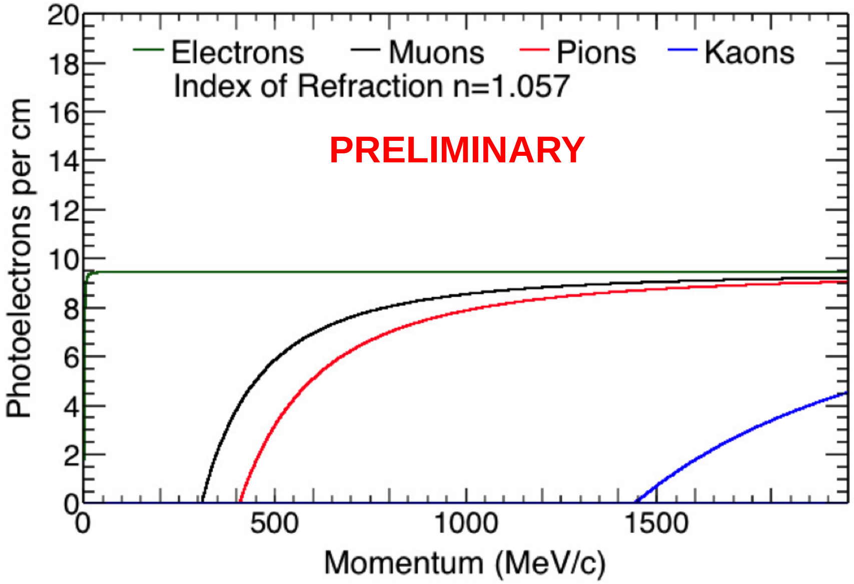
Backgrounds

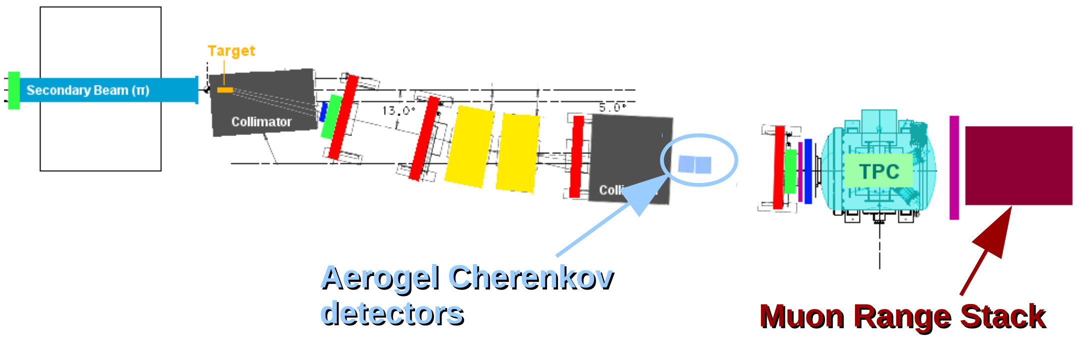
- 4 backgrounds, **not yet subtracted**
  - Pion decay → ~2%
  - Pion capture → ~9%
  - Crossing muon contamination → ~10%
    → use Muon Range Stack data (in progress)
  - Electron contamination
    → partially removed by shower filter
    → use Aerogel data (<300 MeV/c, in progress)





Expected number of p.e. (Aerogel simulation)





Cross-section with thin target approach

- For a thin target slab, the interaction probability can be written as:

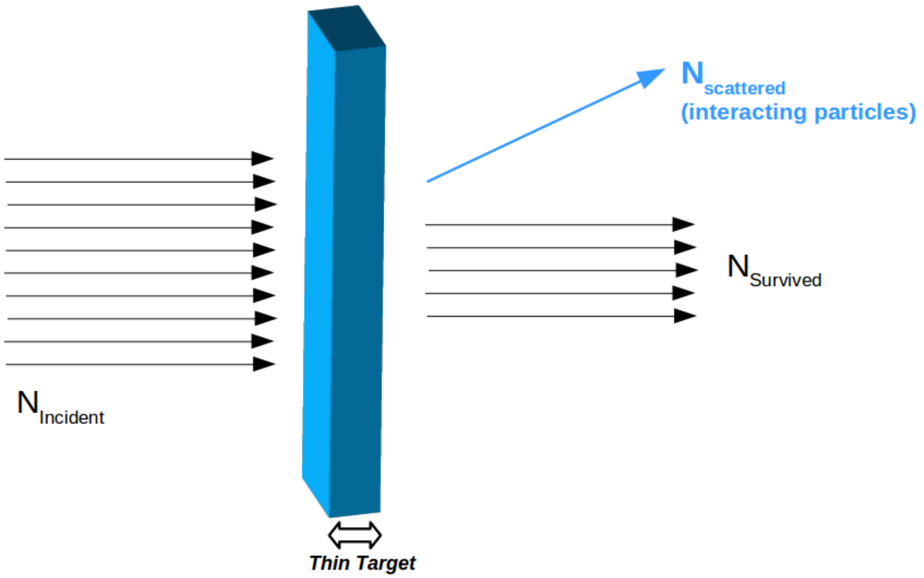
$$P_{interaction} = 1 - P_{survival} = 1 - e^{-\sigma nz} \approx 1 - (1 - \sigma nz + O(z^2))$$

σ = cross-section per nucleon, n = medium density, z = slab thickness

- The interaction probability can also be defined as the ratio of the number of interacting particles to the total number of incident particles:

$$P_{interaction} = \frac{N_{interacting}}{N_{incident}}$$

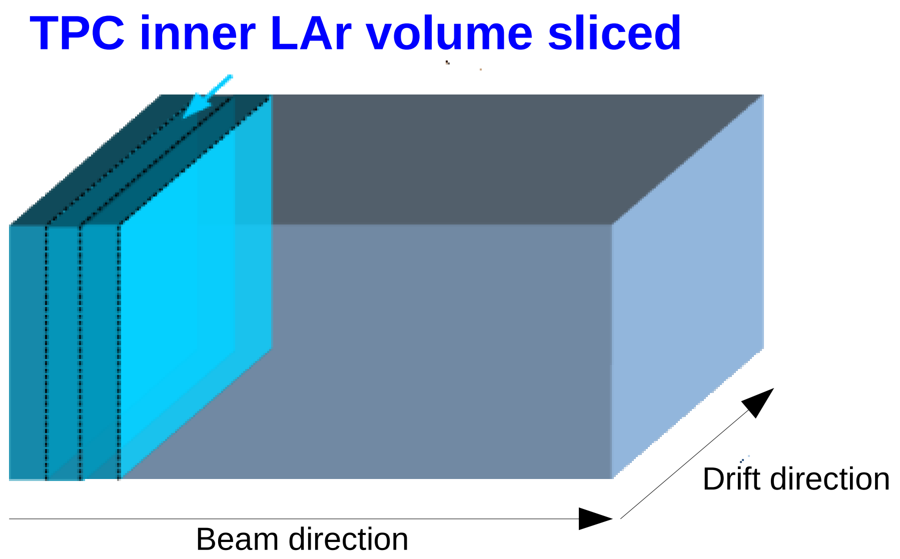
$$\sigma(E) \approx \frac{1}{nz} \frac{N(E)_{interacting}}{N(E)_{incident}}$$



Thin slice method – applied to TPC

- We can consider that the Argon volume inside the TPC is a series of thin slabs, where the slab thickness is given by the wire pitch:

  → **~4mm thick slabs** in LArIAT case



- To calculate the cross-section as a function of the energy, we must calculate the pion kinetic energy at each slab:

→ For the 1st slab, the initial π kinetic energy is given by:

$$KE_i = \sqrt{p^2 + m_\pi^2} - m_\pi - E_{Flat}$$

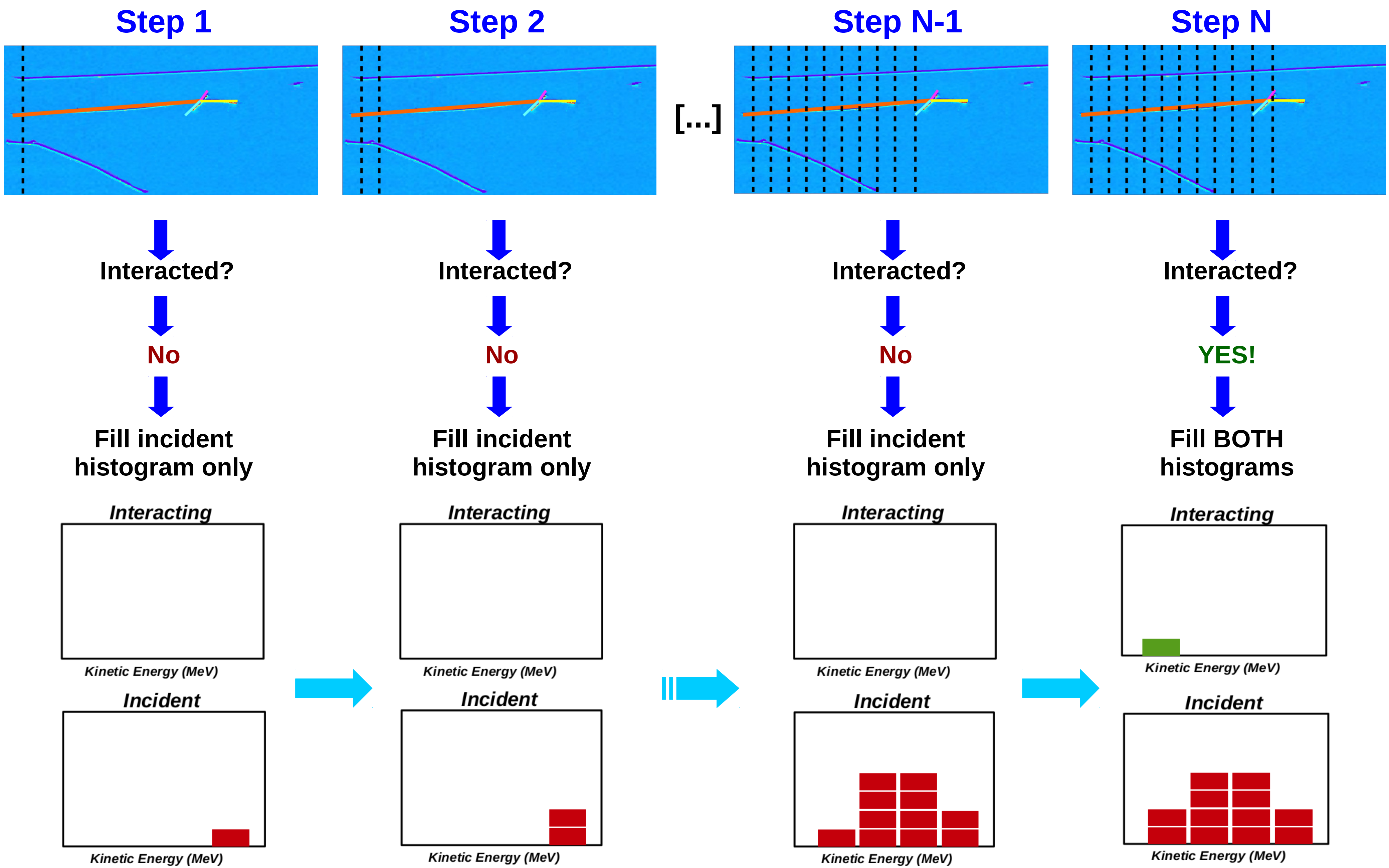
p is the π momentum measured by the MWPCs

E_{flat} is the energy loss due to material upstream of the TPC

→ For each subsequent slab, the π kinetic energy is given by:

$$KE_{Interaction} = KE_i - \sum_{i=0}^{nSpts} dE/dX_i \times Pitch_i$$

Thin slice method – in practice

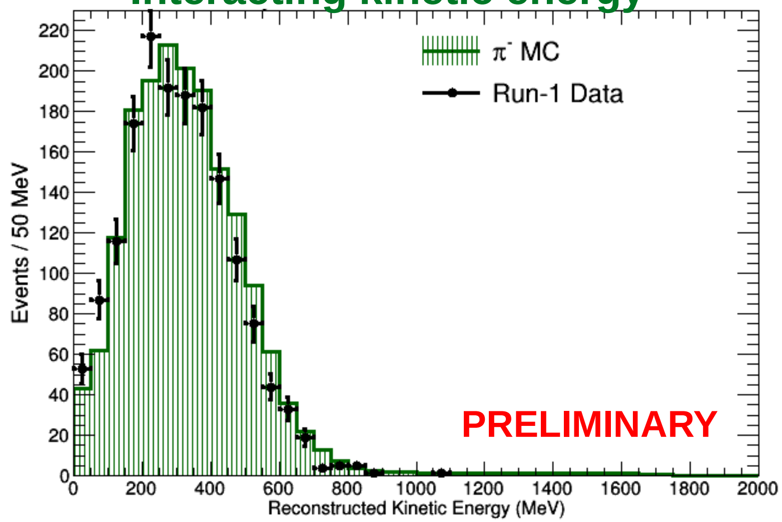


Results

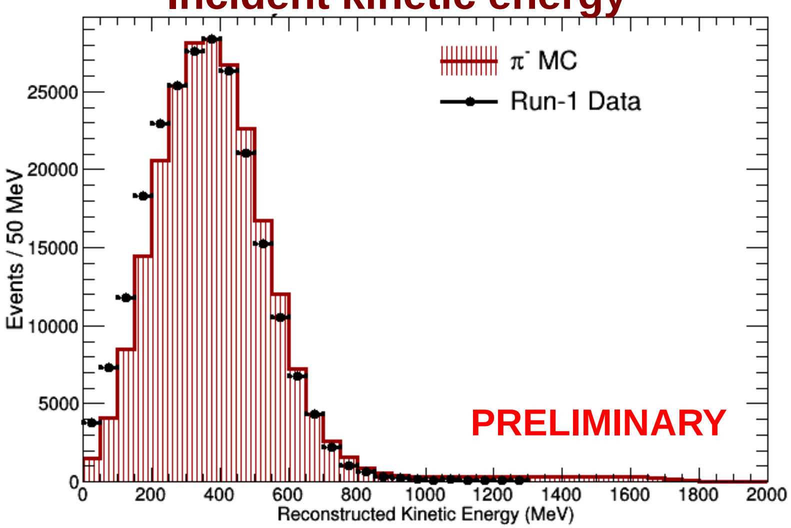
Rinse and repeat for each event
(1 entry on the interacting histo per event)

Divide the interacting histogram (numerator)
by the incident (denominator)

Interacting kinetic energy

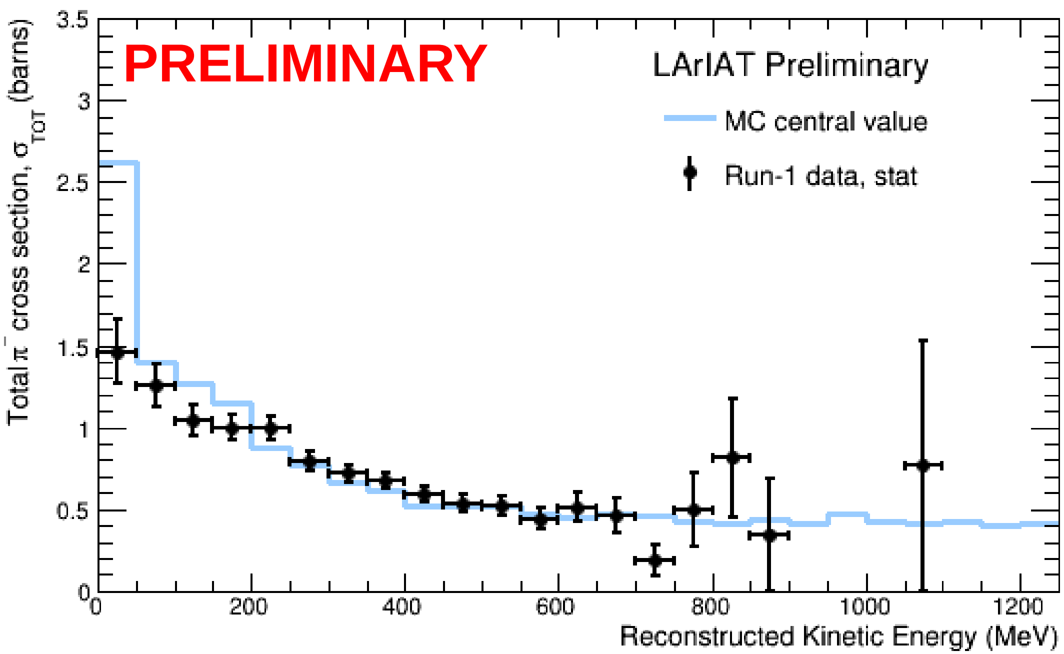


Incident kinetic energy



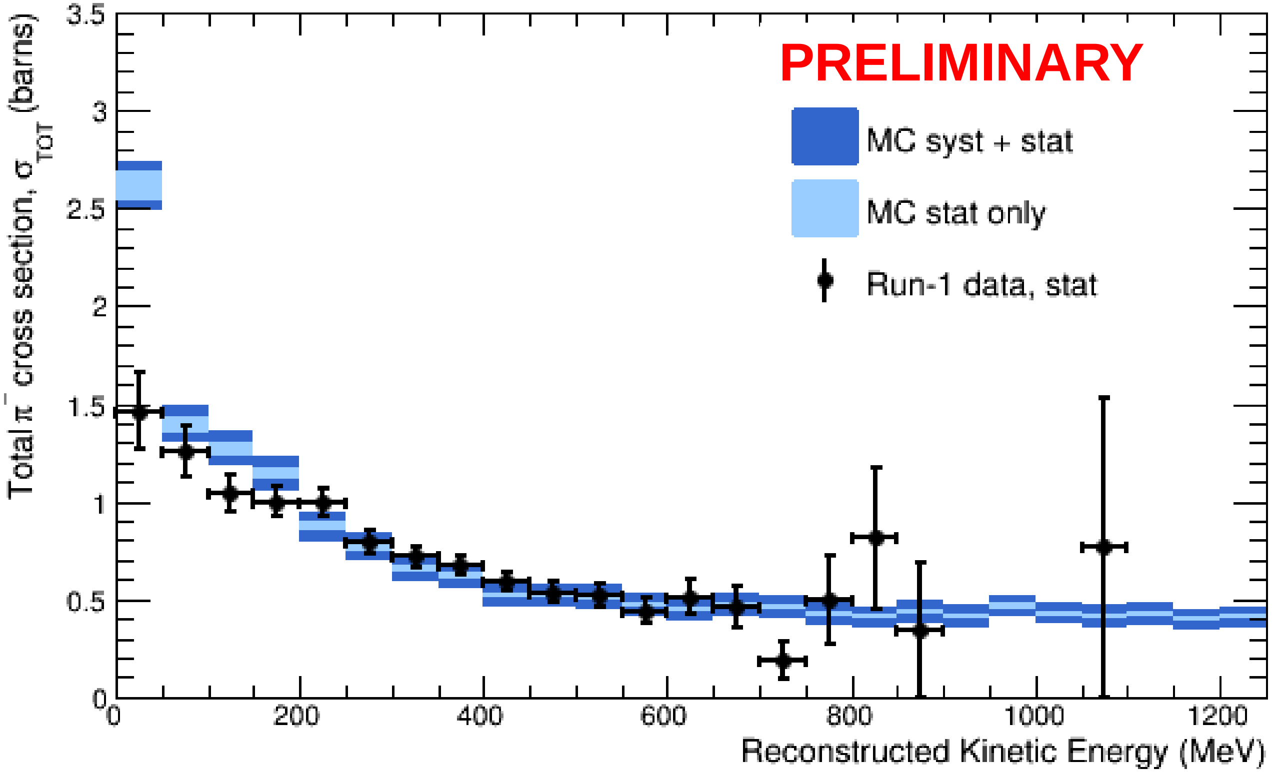
= nz

Total π^- cross-section vs π^- kinetic energy



n = Argon density
z = Argon slab thickness

Systematics



- Systematics considered:
  - dE/dX calibration: 5%
  - Energy loss before entering TPC: 3.5%
  - Through-going muon contamination: 3%
  - Momentum uncertainty (from wire chamber): 3%

Future improvements

- Higher statistics: use both polarities, add run II data
- Increase efficiency:
  - Include latest reconstruction improvements (MWPC and TOF reconstruction)
  - Run II has less pile-up
- Subtract backgrounds (in progress)
  - Use other beamline detectors data: Aerogel, MRS

- Some of these improvements have already been done, so we'll have an updated improved result soon!

Conclusion

- LArIAT has had 2 successful data-taking campaigns and a third is on its way (R&D focus)
- Excellent performance of cold electronics:

  → signal/noise of ~70:1 (μBooNE ASICS) vs ~15:1 for warm electronics (ArgoNeuT)
- First use of fully automated reconstruction and event selection in LArTPC physics analysis
- LArIAT has measured the first π-Ar total cross-section!

Many other analyses in progress like π exclusive cross-section measurements and kaon total cross-section…

Stay tuned!

BOSTON UNIVERSITY
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Fermilab
Universidade Federal do ABC
UNICAMP
Unifal MG Universidade Federal de Alfenas

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INFN

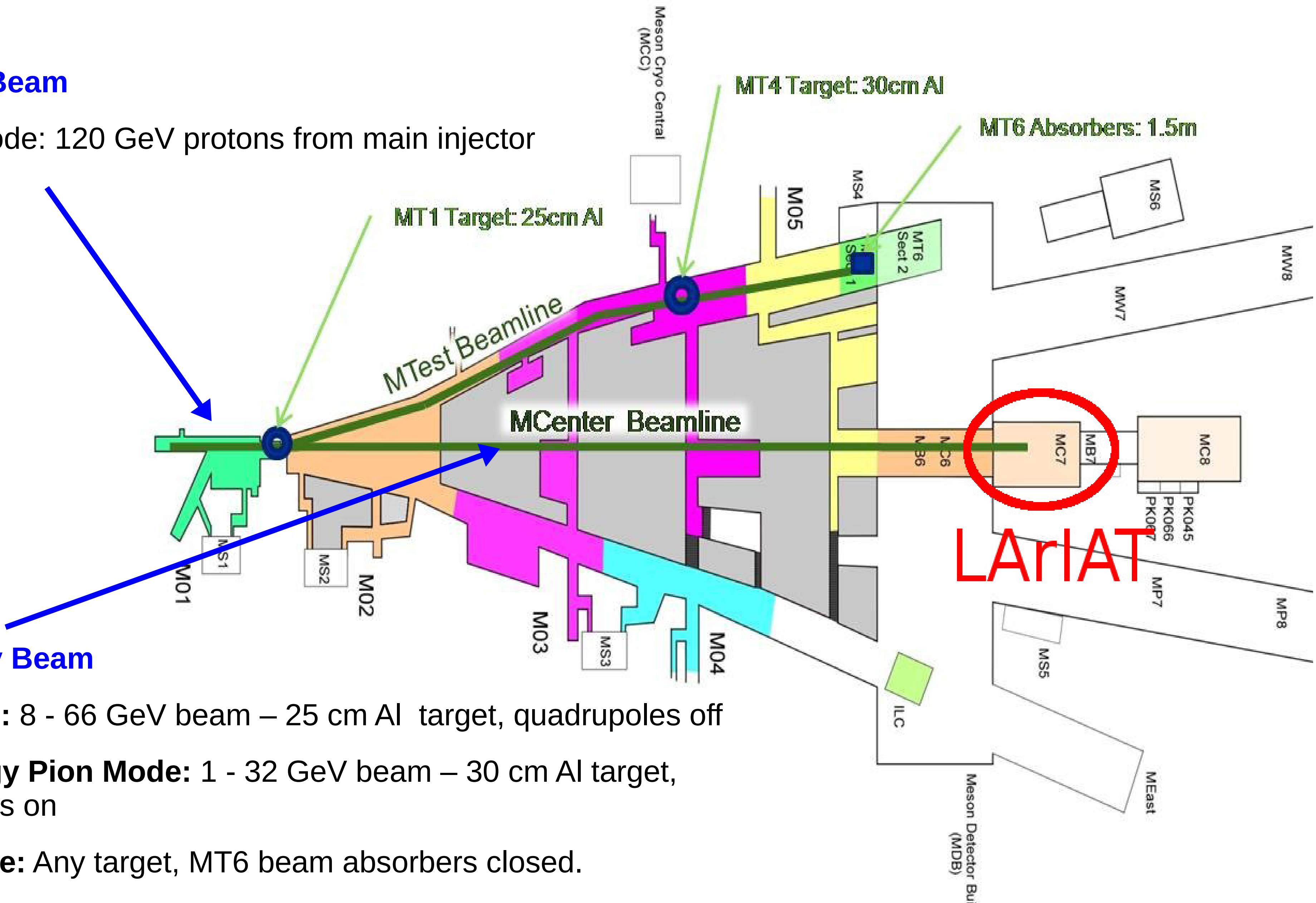
LSU LOUISIANA STATE UNIVERSITY
MICHIGAN STATE UNIVERSITY
THE UNIVERSITY OF CHICAGO
W&M
MANCHESTER 1824 The University of Manchester
UCL

Back-up

Test-beam @ Fermilab

Primary Beam

Proton Mode: 120 GeV protons from main injector



Secondary Beam

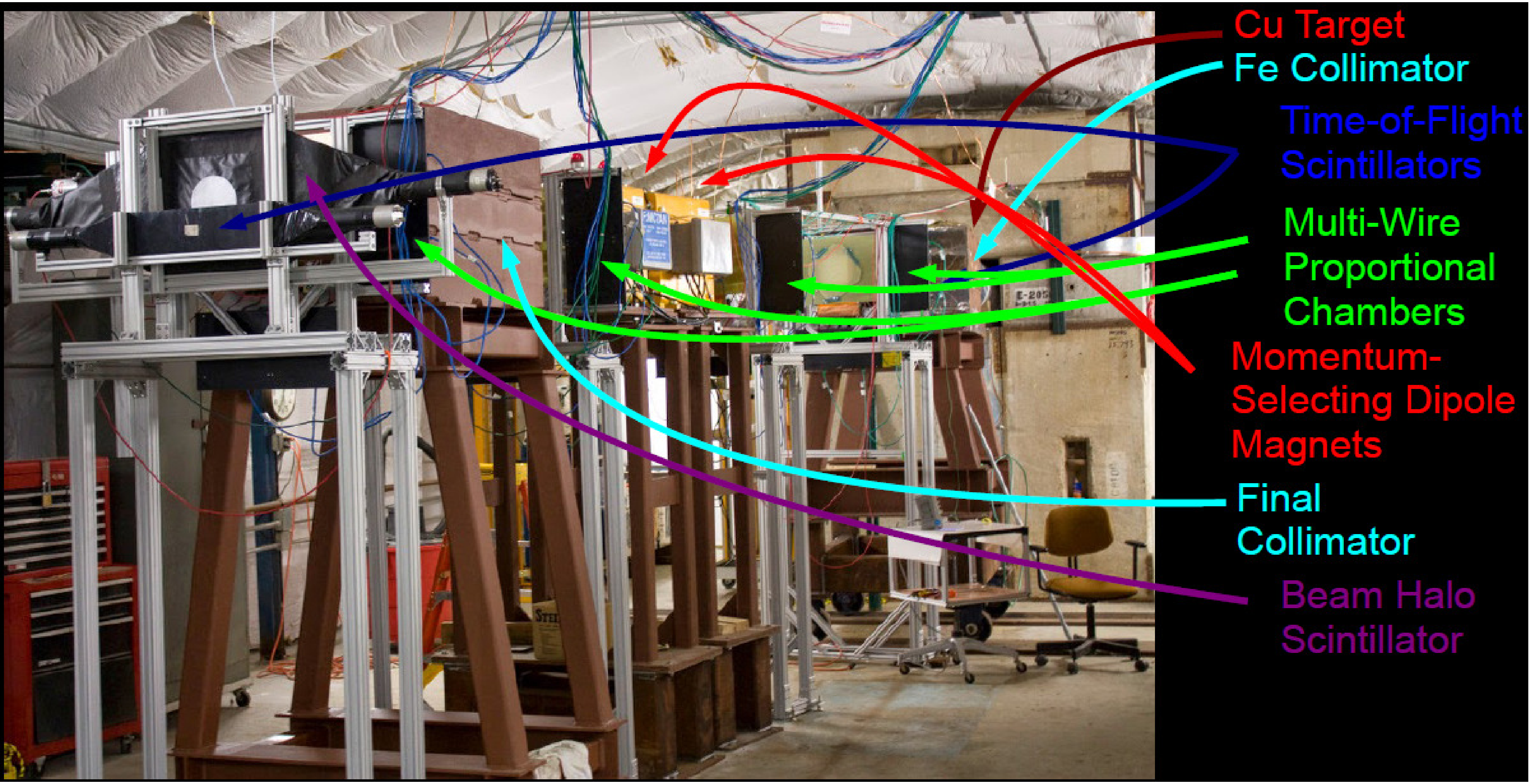
Pion Mode: 8 - 66 GeV beam – 25 cm Al target, quadrupoles off

Low Energy Pion Mode: 1 - 32 GeV beam – 30 cm Al target, quadrupoles on

Muon Mode: Any target, MT6 beam absorbers closed.

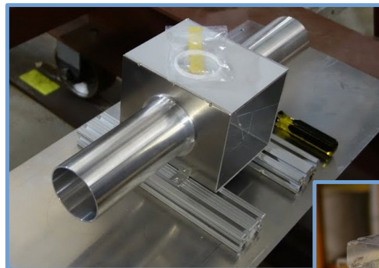
→ best rates in Low E Pion Mode at 32 GeV

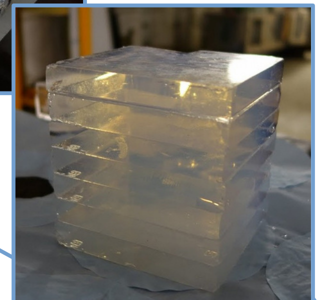
Tertiary beamline (upstream view)



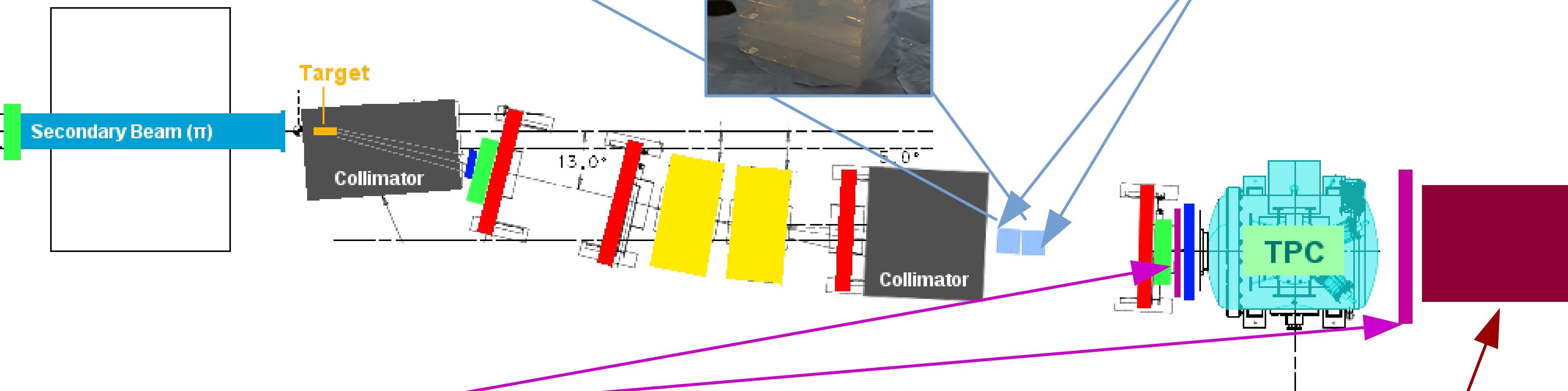
Beamline PID – Other Detectors

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





2 Aerogel Cerenkov Detectors
→ 2 different indexes allow for π / μ separation and electron tagging

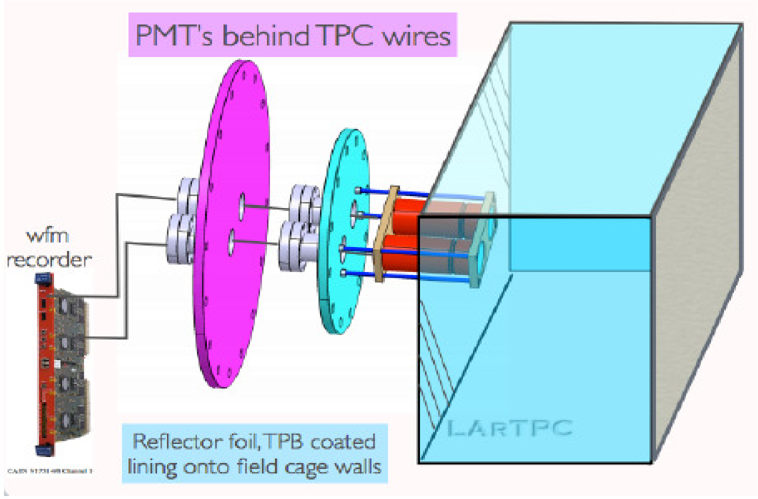


Halo and punch-through veto
→ beam halo and through-going particle tagging

Muon Range Stack (MRS)
→ through-going π vs μ tagging

Light collection system (LCS)

- **Light collection system**
  - 2 cryogenic PMTs: 2” ELT and 3” Hamamatsu, 1 coated with TPB
  - 2 Hamamatsu SiPMs (QE 50%)
  - 1 SensL SiPM
  - TPB wavelength shifting reflector foils




Mounted PMTs

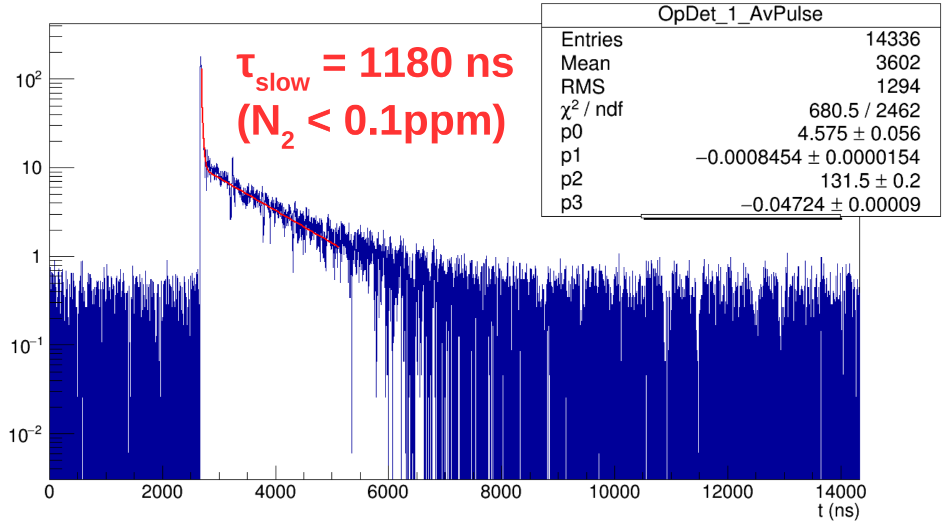

TPB reflective foil lining

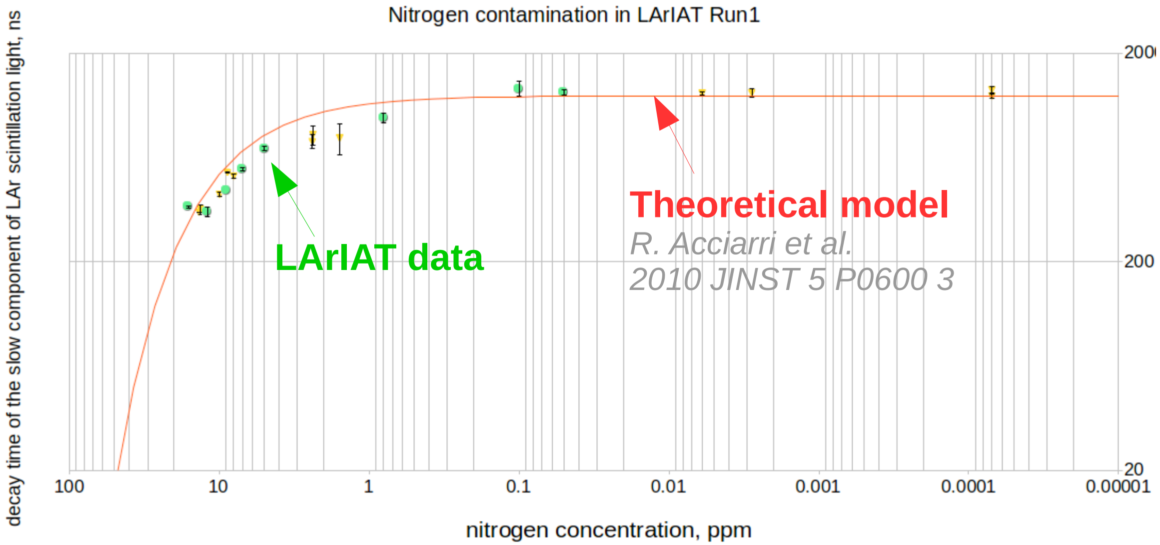

Side flange

Hamamatsu SiPM

LCS – Nitrogen contamination

- N_2 suppresses scintillation light
- The "slow" light time component can be extracted from fits to scintillation to determine the N_2 concentration
- Results agree with model

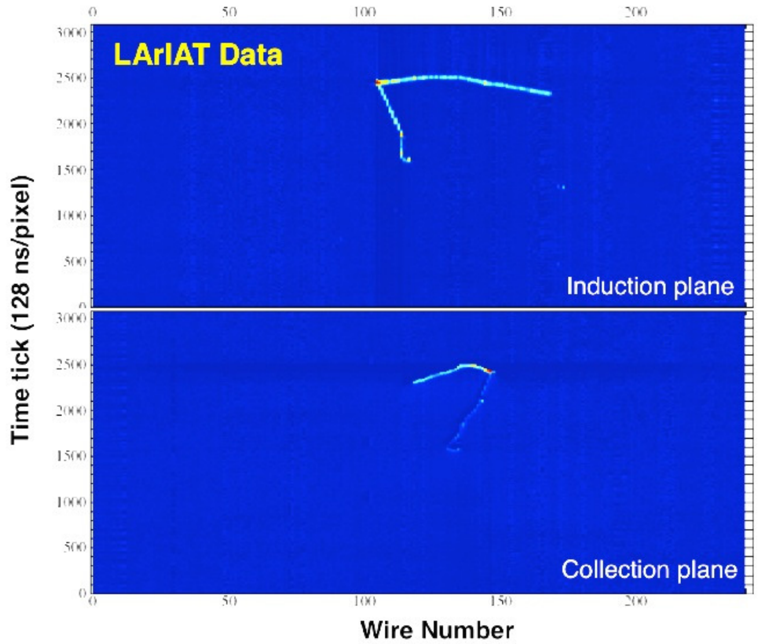


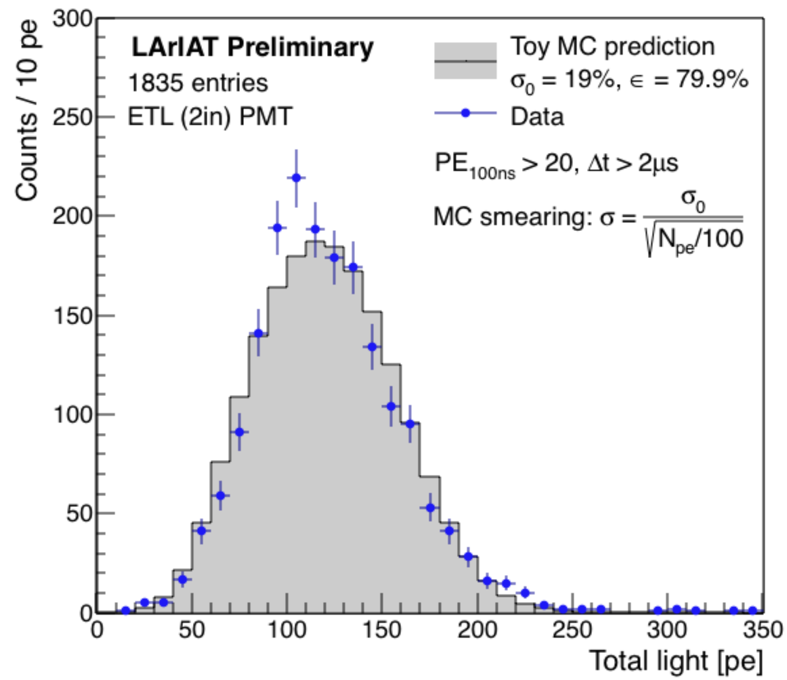


LCS – Michel electron

- Can trigger on Michel electron signal
  - energy calibration
  - tag stopping $\mu^{+/-}$
  - select sample for testing shower reconstruction
- Can reconstruct Michel electron spectrum

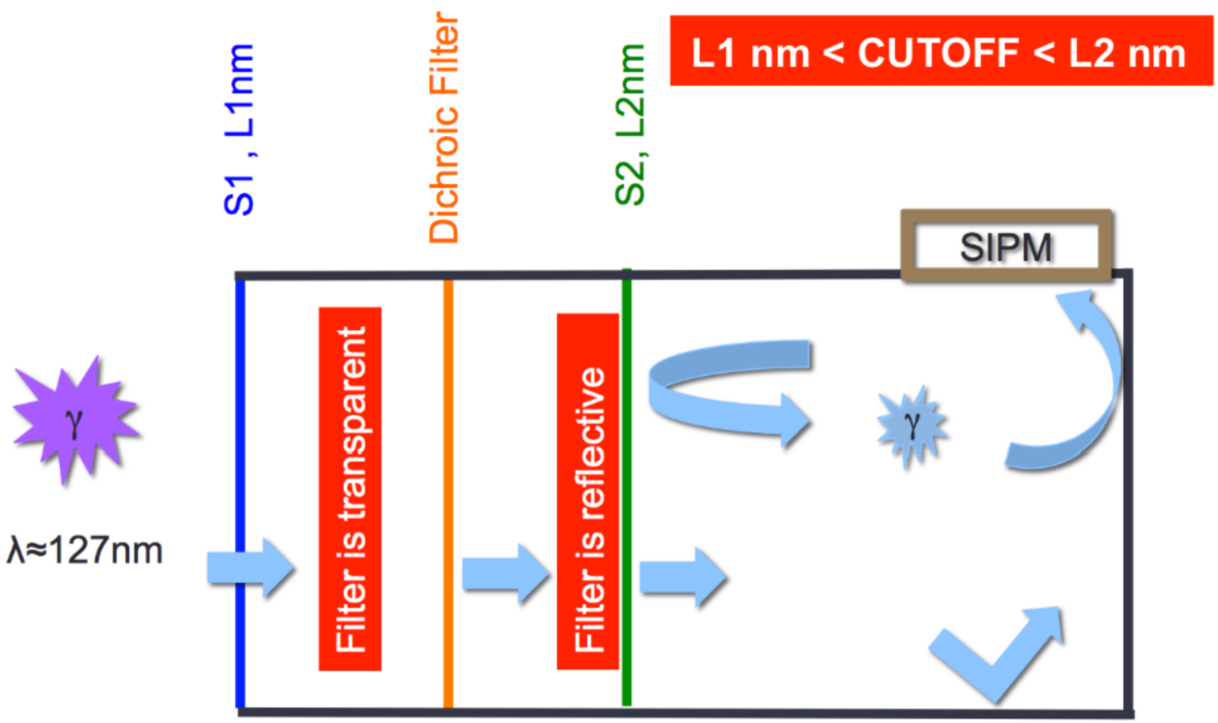
→ good agreement with preliminary MC

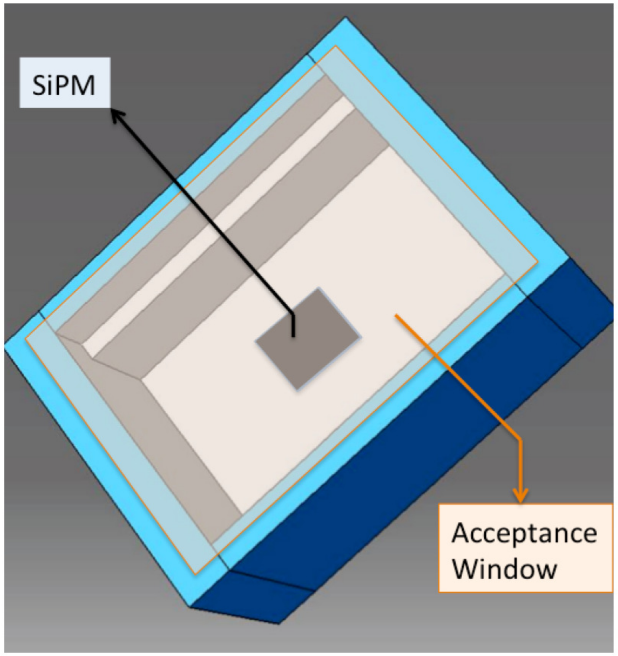




ARAPUCA (U. Campinas)

- Flattened box with highly reflective internal surface
- Dichroic filter on side opening for light entrance
- 1 SiPM for detecting the trapped light



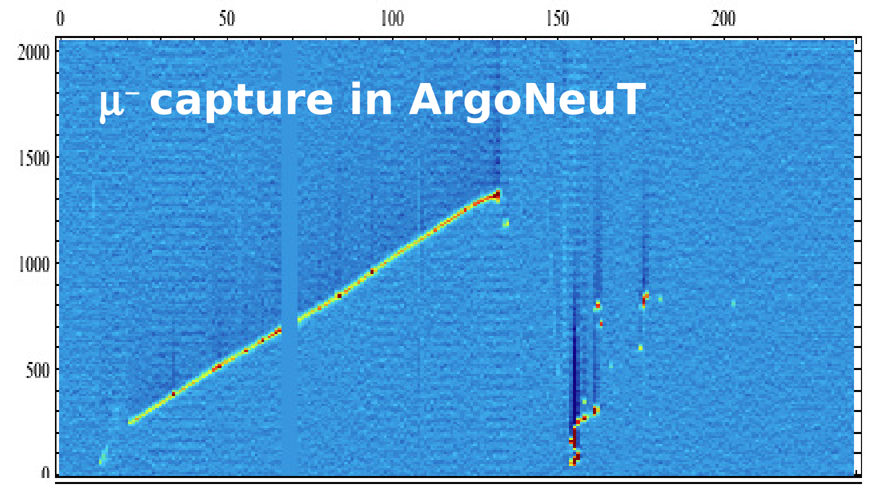


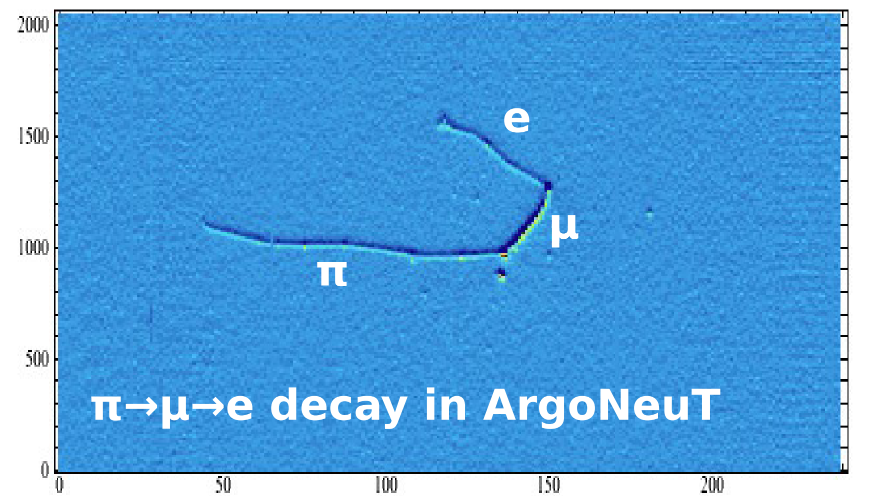
Charge sign determination w/o magnetic field

- Charge sign determination (w/o a magnetic field) for fully contained muons using statistical analysis :
  - μ^+ decay rate with e^+ emission of a known energy spectrum = 100 %
  - μ^- capture on nuclei rate + γ / n emission ~ 75% vs decay rate ~25%

    → capture rate higher in Ar than in lighter elements

    → systematic study of μ^- capture in LAr has never been performed
- Beam tunable polarity will provide data for direct measurement of the sign separation efficiency and purity for muons (might be possible for pions)





LArTPC sign determination capability has yet to be explored

Kaon studies

- Using the combination of TOF + MWPC information, kaon candidates can be selected
- Inside TPC, use dE/dx based PID ("PIDA" algorithm by ArgoNeuT)
- Possible to automatically tag and reconstruct kaon events
- Next step is Kaon-Ar cross-section measurement