From ArgoNeuT to LArIAT:

- 1 detector

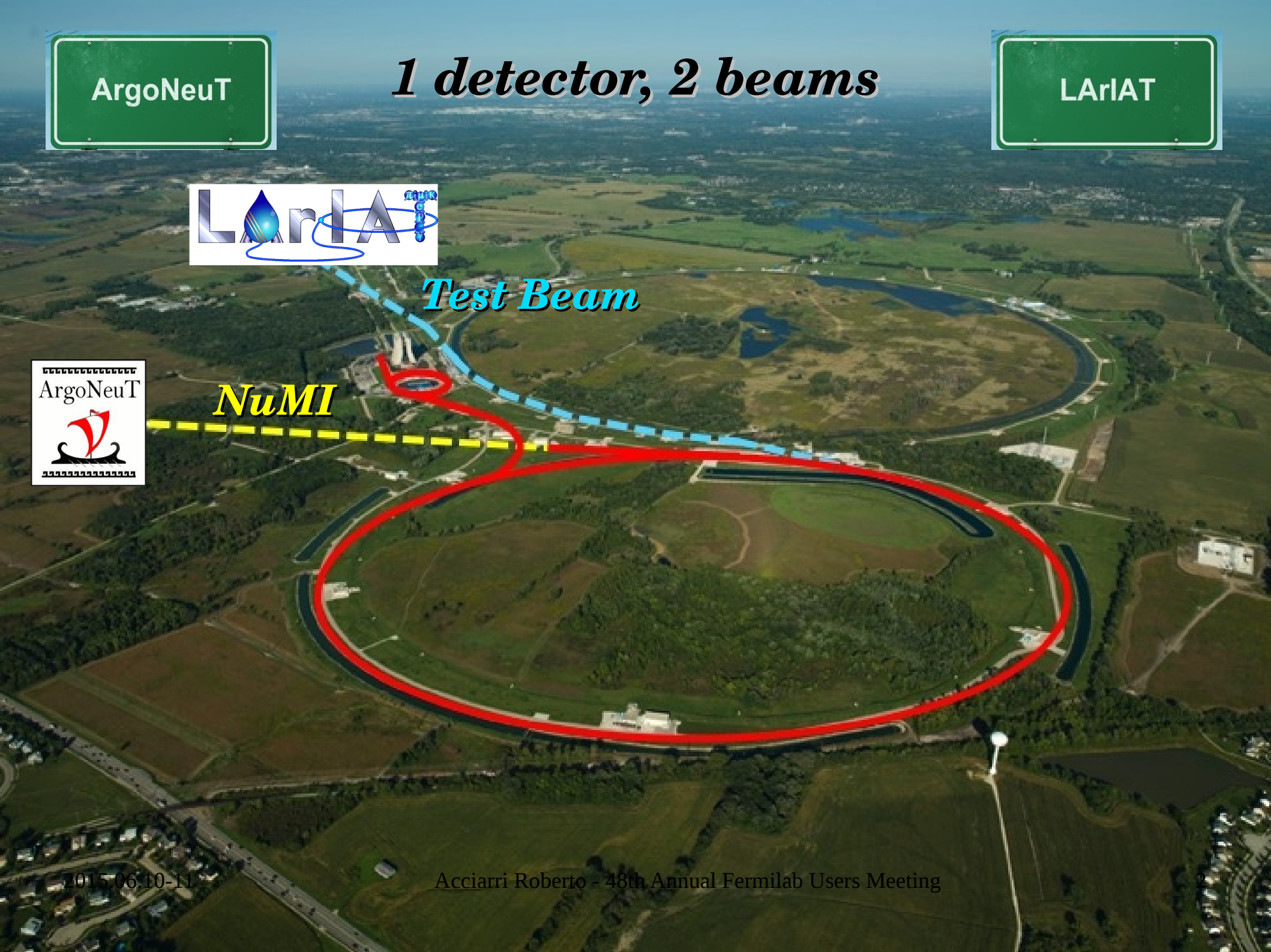
- 2 beams

- many great results!

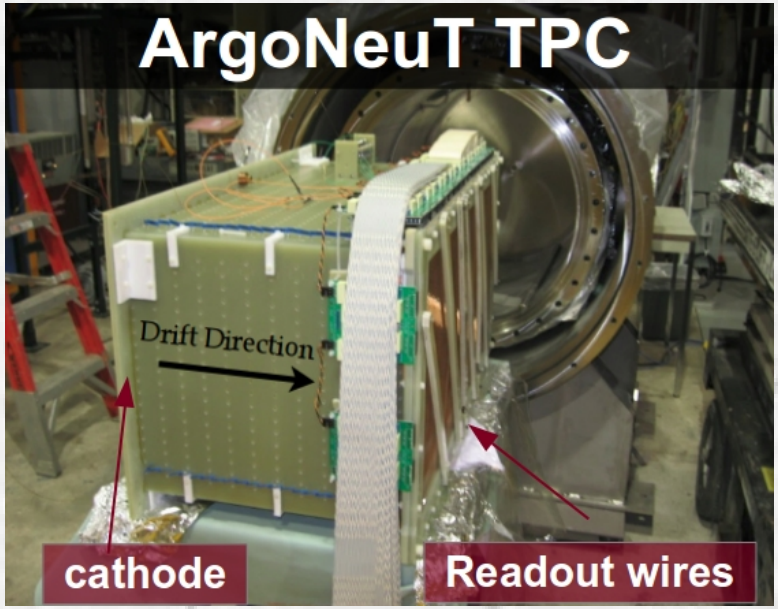
Roberto Acciarri – Fermilab
On behalf of ArgoNeuT and LArIAT collaborations

48th Annual Fermilab Users Meeting – 10-11 June 2015

1 detector, 2 beams



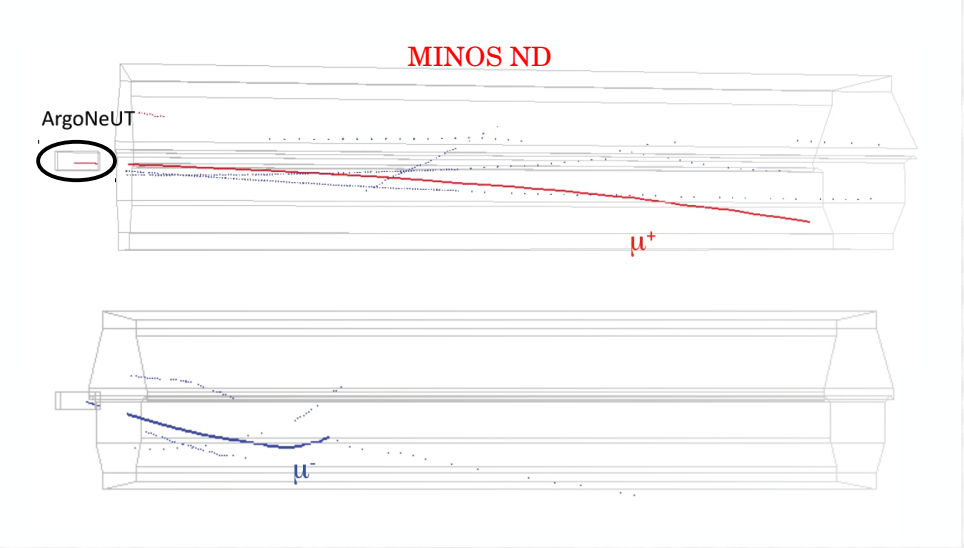
ArgoNeuT in a nutshell



- ✔ Located in the NuMI beam line, upstream of MINOS ND: *first LArTPC in a low (1-10 GeV) energy neutrino beam!*
- ✔ TPC dimensions: 47×40×90 cm^3, 240 Kg active mass
- ✔ 2 readout planes, 480 wires, 4 mm pitch
- ✔ No light detection system
- ✔ Utilized MINOS ND as muon spectrometer for charge and momentum

- ✔ Data collected from 09/2009 to 02/2010
- ✔ 0.085 X 10^{20} POT in neutrino mode (2 weeks)
- ✔ 1.2 X 10^{20} POT in antineutrino mode (4 months)
- ✔ 7 publications so far: three ν-Ar cross sections measurements, calibration techniques with LAr detectors and studies of neutrino nuclear effects

More publications on the way!!!

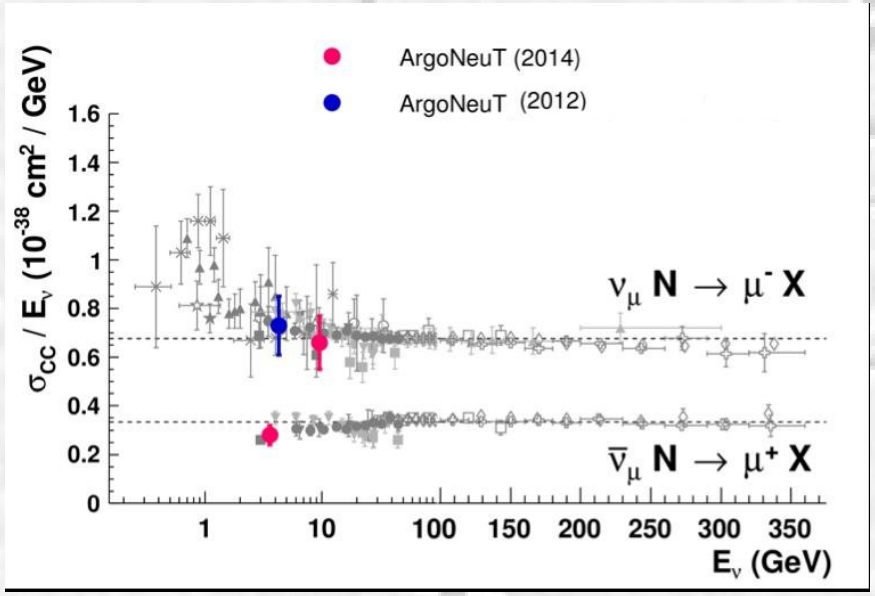


Previous results

ν_μ and $\bar{\nu}_\mu$ CC-inclusive cross section

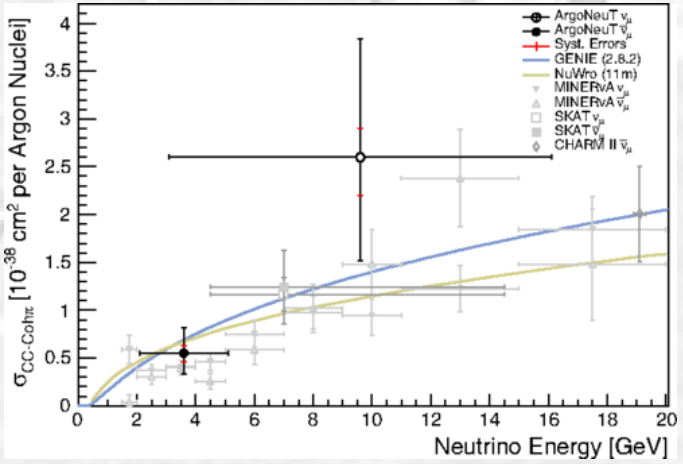
C. Anderson et al., PRL 108 (2012) - ν_μ CC-incl. σ

R. Acciarri et al., Phys. Rev. D 89, 112003 (2014) - ν_μ and $\bar{\nu}_\mu$ CC-incl. σ



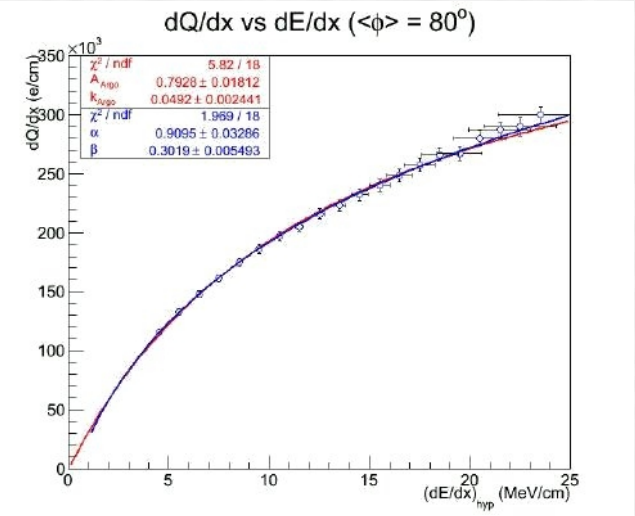
Coherent charged pion production

R. Acciarri et al., Phys. Rev. Lett. 113, 261801 (2014)



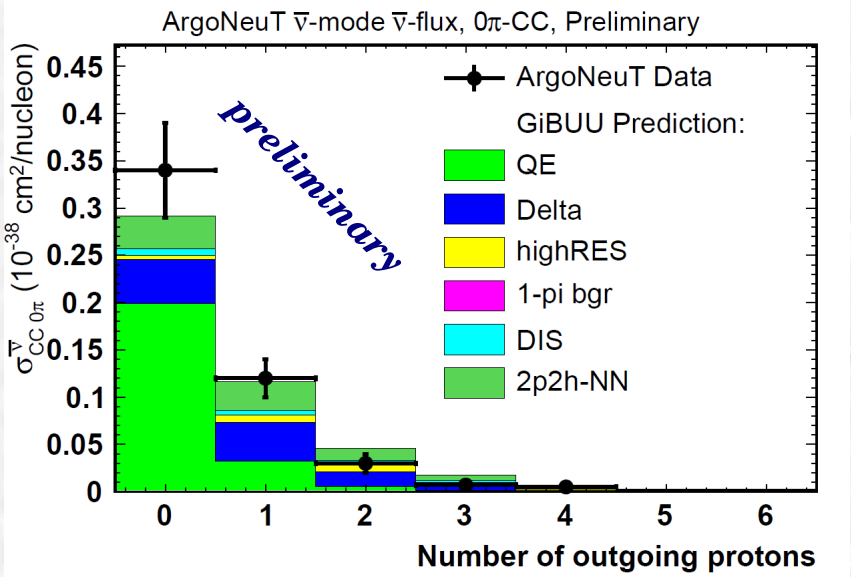
Charge recombination with stopping protons

R. Acciarri et al., JINST 8 P08005 (2013)

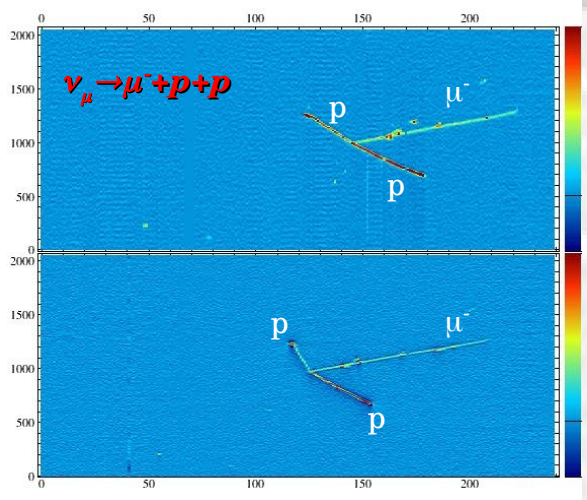


Topological analysis: exploring nuclear effects

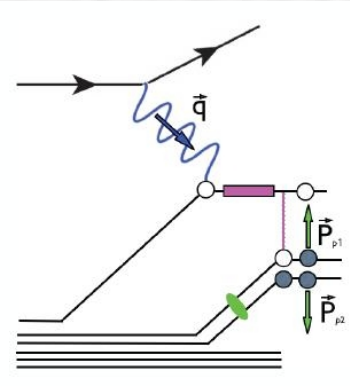
Production cross-section as a function of the number of outgoing protons in the event



- ✔ good agreement between MC with final state interactions and data
- ✔ 0p1μ sample, generally referred to as signature of QE interaction, has a significant contribution from Delta resonance
- ✔ $\sigma_{CC0\pi} = 0.5 \pm 0.03\ (stat) \pm 0.06\ (sys) \times 10^{-38}\ cm^2$ for $\langle E_\nu \rangle = 3.6\ GeV \pm 1.5\ GeV$



- ✔ 2p1μ sample in neutrino data brings examples of nuclear effects
- ✔ 4 back-to-back proton pairs events observed in Lab frame
- ✔ Characteristics: $\cos(\gamma) < -0.95$, P_{p1} and $P_{p2} \geq k_F$, $P_{p1} \simeq -P_{p2}$
- ✔ Possible mechanism: CC RES pionless reactions involving pre-existing SRC np pairs



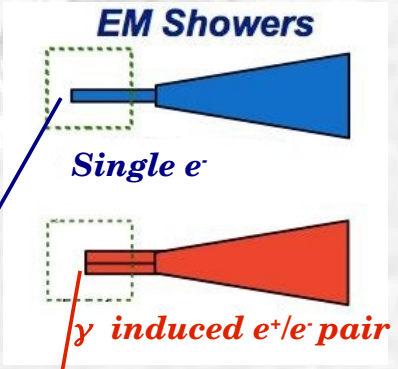
R. Acciarri et al., Phys. Rev. D 90, 012008 (2014)

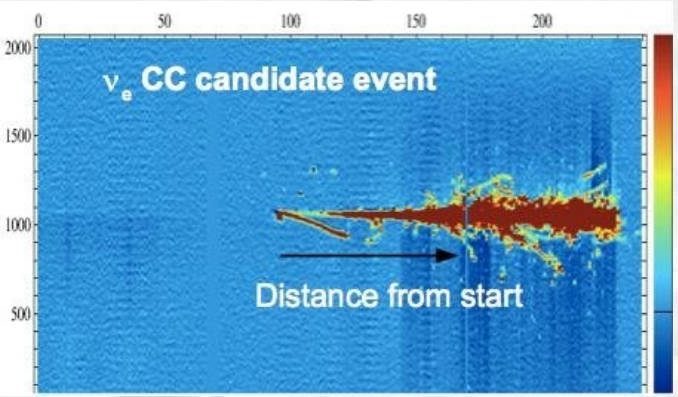
Electron/gamma separation

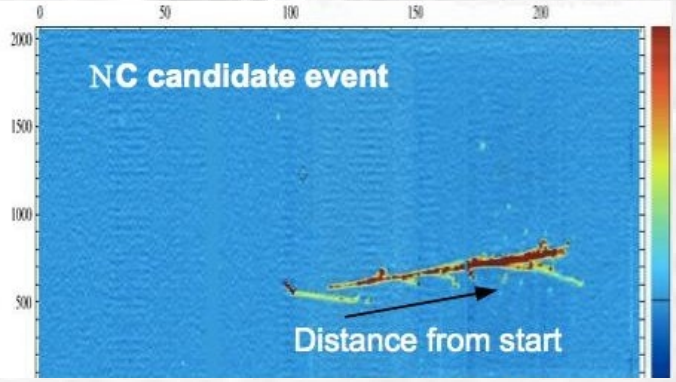
Important to discriminate ν_e CC signal from π_0 background coming from NC interactions

✔ Gammas defined as EM showers detached from visible vertex

✔ Electrons defined as EM showers with visible vertex activity and no gap

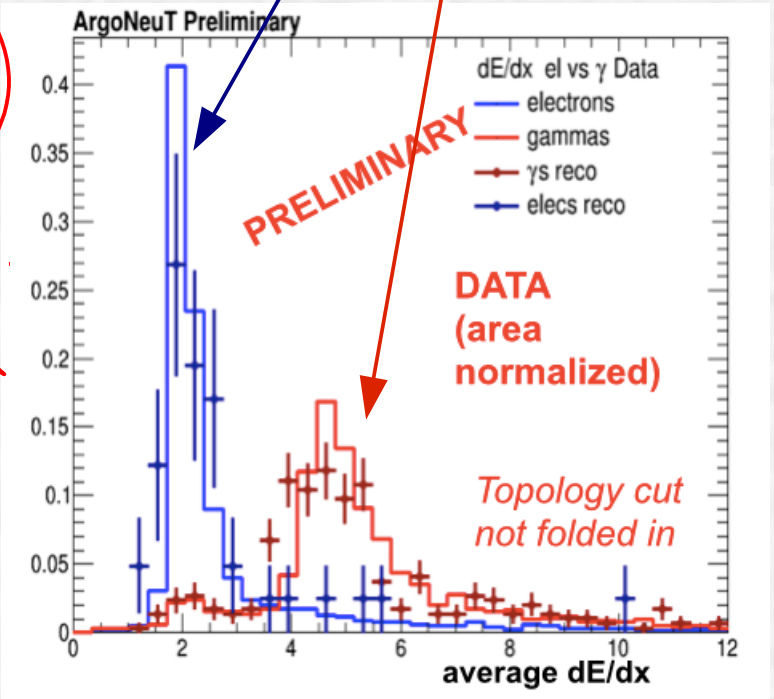




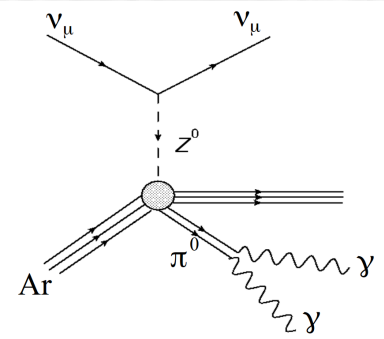


Additional discrimination tool given by the dE/dx of the first two centimeter of the track

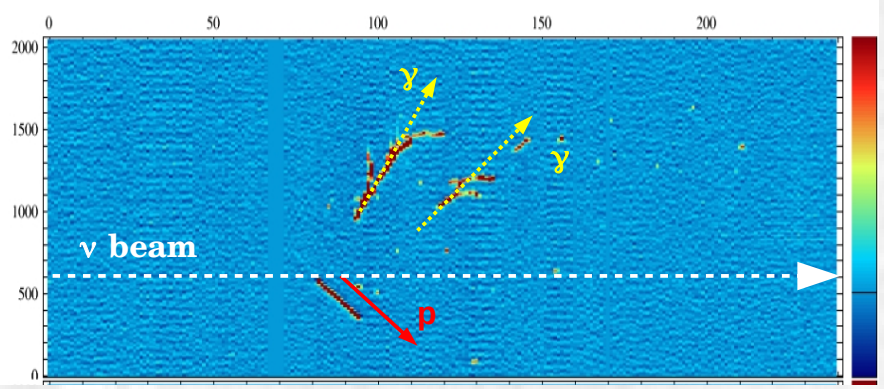
Paper under review



Neutral current π^0 study

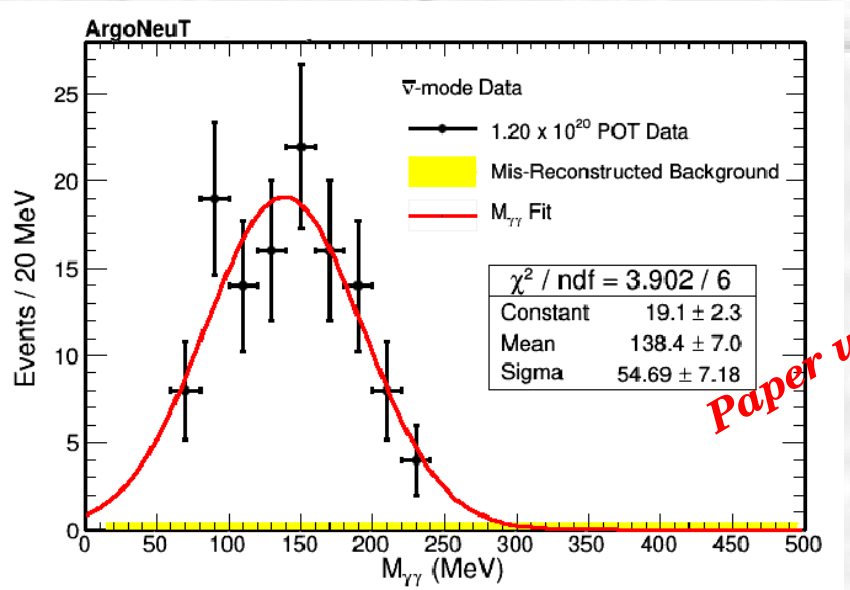


- ✔ Important channel for oscillation searches and cross-section measurements
- ✔ ArgoNeut size does not allow to contain the majority of the γ energy

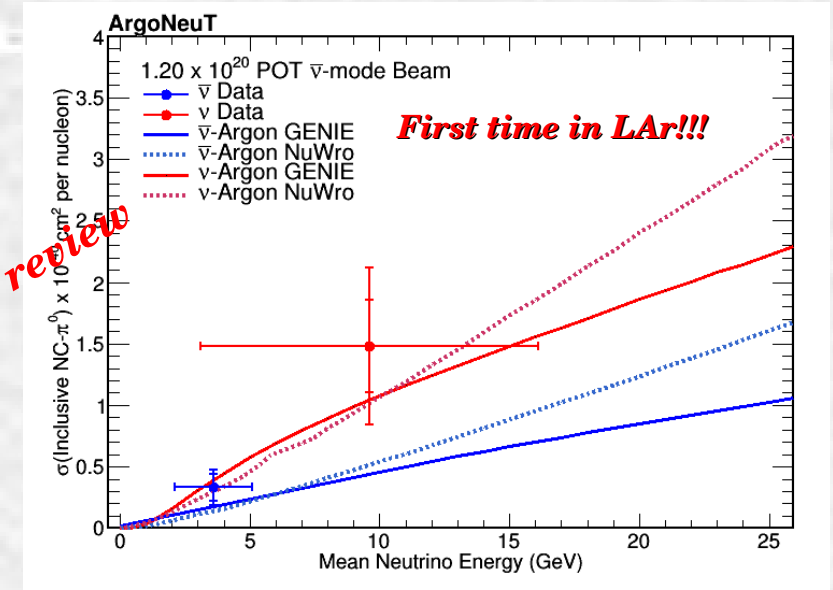


- ✔ Nevertheless, the fine grain detection ability of LArTPCs allows to correct back the missing energy from the photon showers

π^0 mass measurement



Production cross-section of neutral current π^0



Paper under review

Keeping the detector, changing the beam

✔ Designed as a table-top size test experiment, ArgoNeuT produced and still produces physics results

✔ As we enter the "precision era" for neutrino experiments, nuclear effects in neutrino interactions cannot be neglected, requiring detailed studies

✔ Both nuclear physics effects and determination of the electron/gamma separation in LAr are extremely important topics for future oscillation experiments (MicroBooNE, SBN, DUNE) and their investigation is possible already with a detector as small as ArgoNeuT

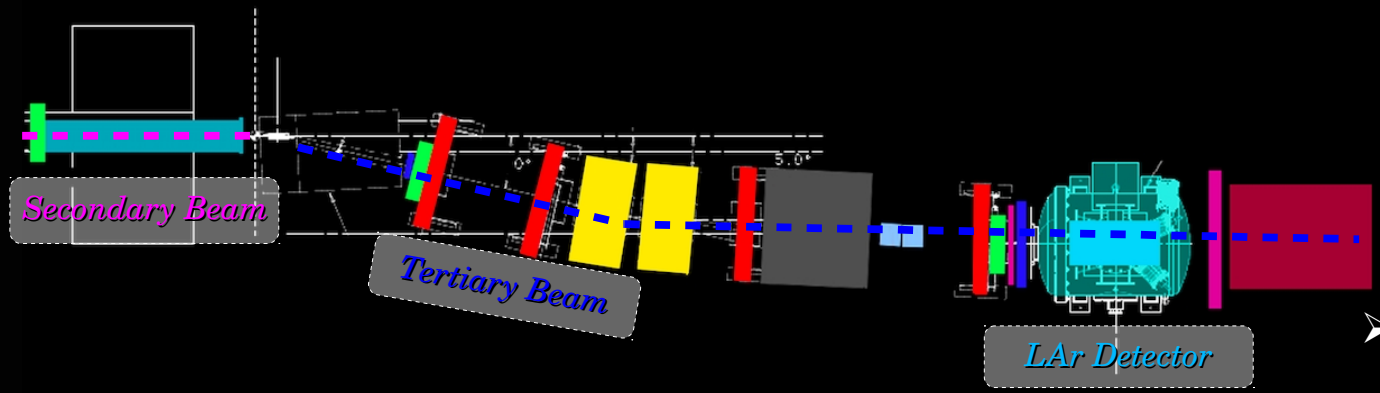
✔ In view of the upcoming SBN and LBN experiments, the characterization of LArTPC performance is essential

*To fulfill these needs, we put the (refurbished) ArgoNeuT **LAr**TPC **i**n **a** **t**est beam:*
LArIAT

LArIAT

Repurposed ArgoNeuT detector:

- new wire planes
- new cold electronics
- optical system composed by 2 PMTs, 3 SiPMs and reflector+wavelength shifter covering TPC inner walls
- dedicated cryogenic system



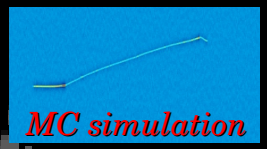
Installed in the FTBF charged particle tertiary beam:

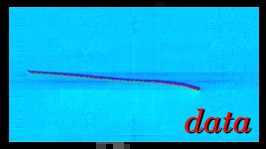
- Mostly π, then p, μ, e, K
- two magnets along the tertiary beam line allow for charge sign and momentum selection between 200 MeV – 2 GeV

Goal

Characterize LArTPC performance in the range of energies relevant to upcoming SBN and LBN experiments for neutrino physics and for proton decay searches

- ✔ Charge recombination vs angle and E. Field
- ✔ Study of nuclear effects, and optimization of π and K PID capabilities



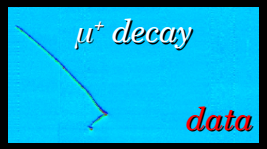


π cross section *p interaction* *K interaction* *$\bar{p}$ annihilation (if possible)*

- ✔ Experimental measure of

/

separation
- ✔

vs 

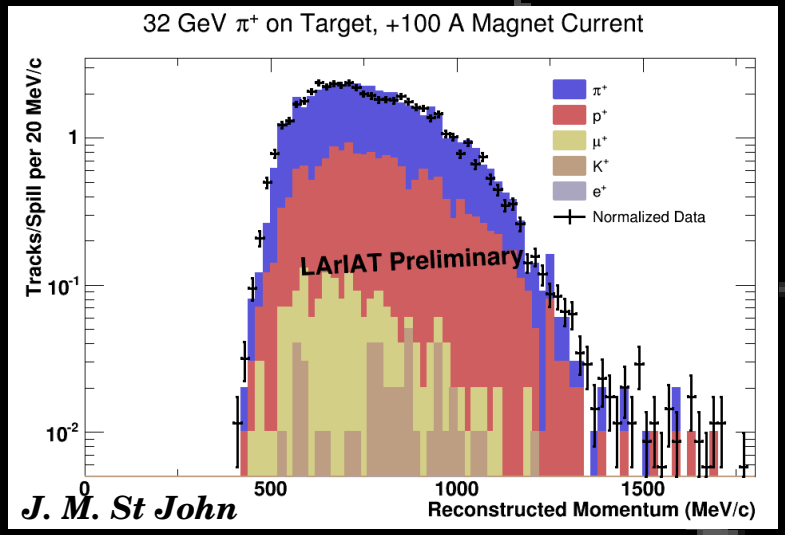
without magnetic field
- ✔ Study of energy resolution improvement given by the combination of information from scintillation light and ionization charge signals

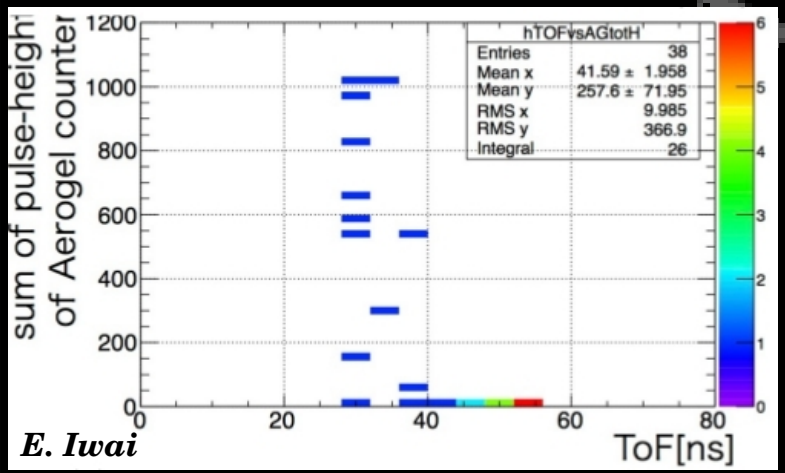
Beamline detectors

Missing in the picture: aerogel counters (upstream the detector), punch-through veto and muon range stack (downstream the detector), cosmic finder (upstream and downstream the detector)

Beamline commissioning

Commissioning of the beamline detectors successfully accomplished during the summer run of August 2014





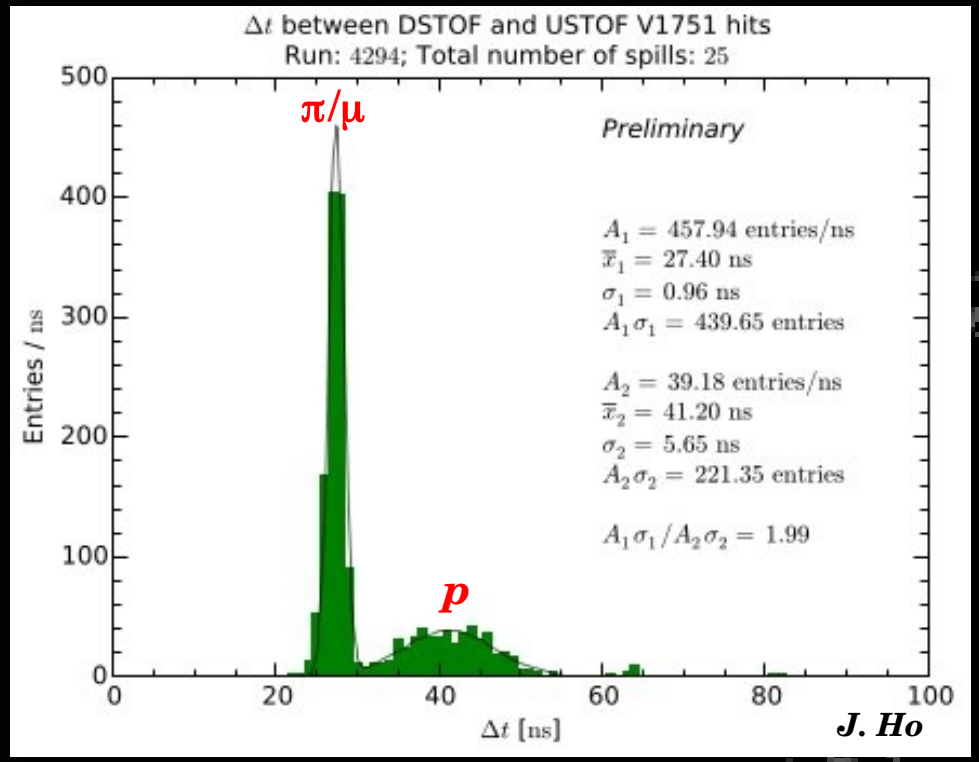
MWPC: particle momentum reconstruction

- Trigger logic: 3 out of 4 MWPC AND 3 scintillators along the beamline
- Good agreement between data and simulation

Aerogel counters

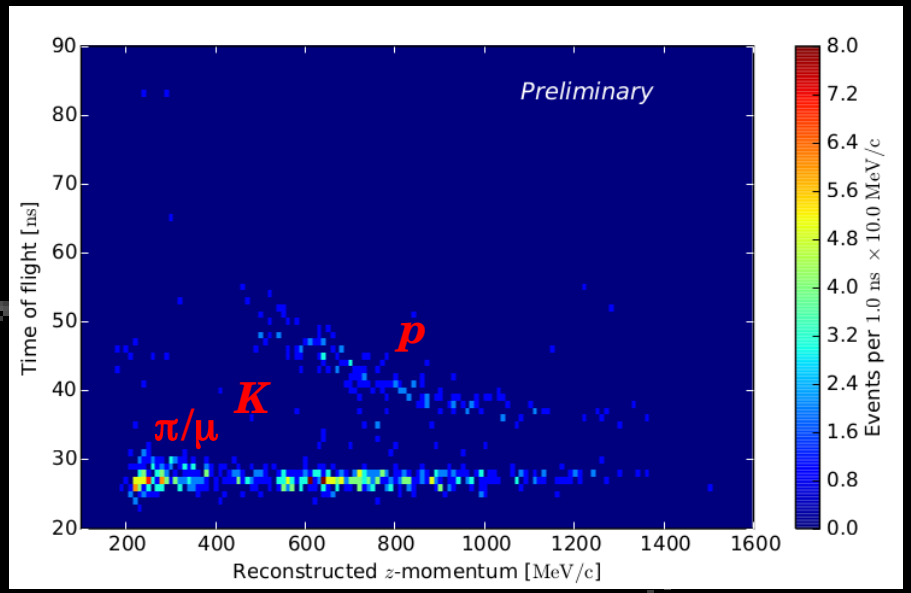
- Produce signal for lower TOF (π and μ) but not for longer TOF (protons)
- Possibility of π/μ discrimination through a combination of threshold and pulse height
- 2 different aerogel counters for different momentum range coverage

Beamline commissioning



TOF

- Time difference between upstream and downstream time-of-flight counters
- Allows separation between π/μ (TOF~ 28 ns) and protons (TOF~ 40 ns)
- 2:1 π:p ratio



TOF vs Reconstructed momentum

- Nice separation between protons and π

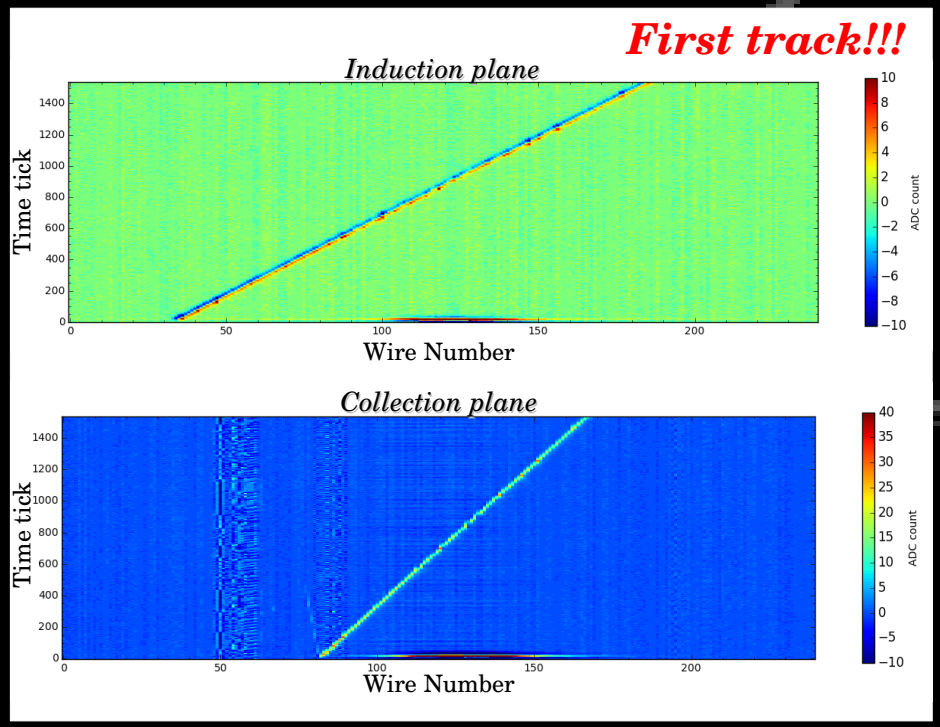
Spring run: TPC on!

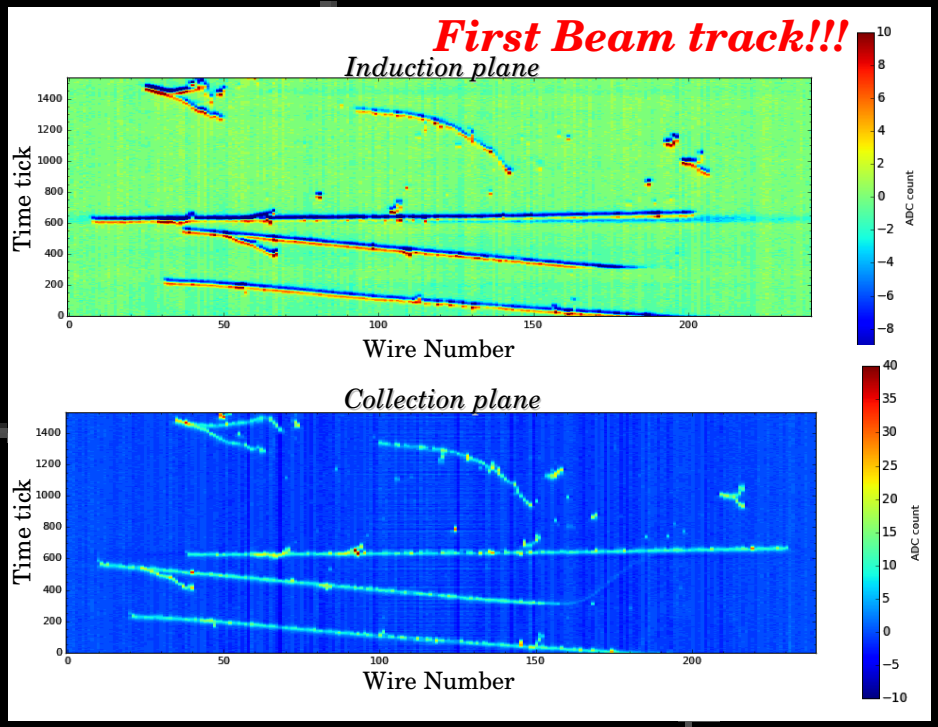
04/29/2015: Cryostat full!

2430, Russ Rucinski (rucinski), Wed, 04/29/2015 15:46:36 Cryogenics

Opened HV-228-A to allow the phase separation function of the supply line to function. Liquid only should drop into cryostat whereas gas goes directly to vent. LCV-105-A is in auto at 4.0". PCV-220-A is in auto at 20.0 psia. LI-208-A reads 2.7 psid. LT-207-A is not working. LT-209-A is reading 4.3". Cool down and filling is complete.

04/30/2015: Wire bias voltage turned on. Cathode voltage ramped up to its nominal value. TPC is on!



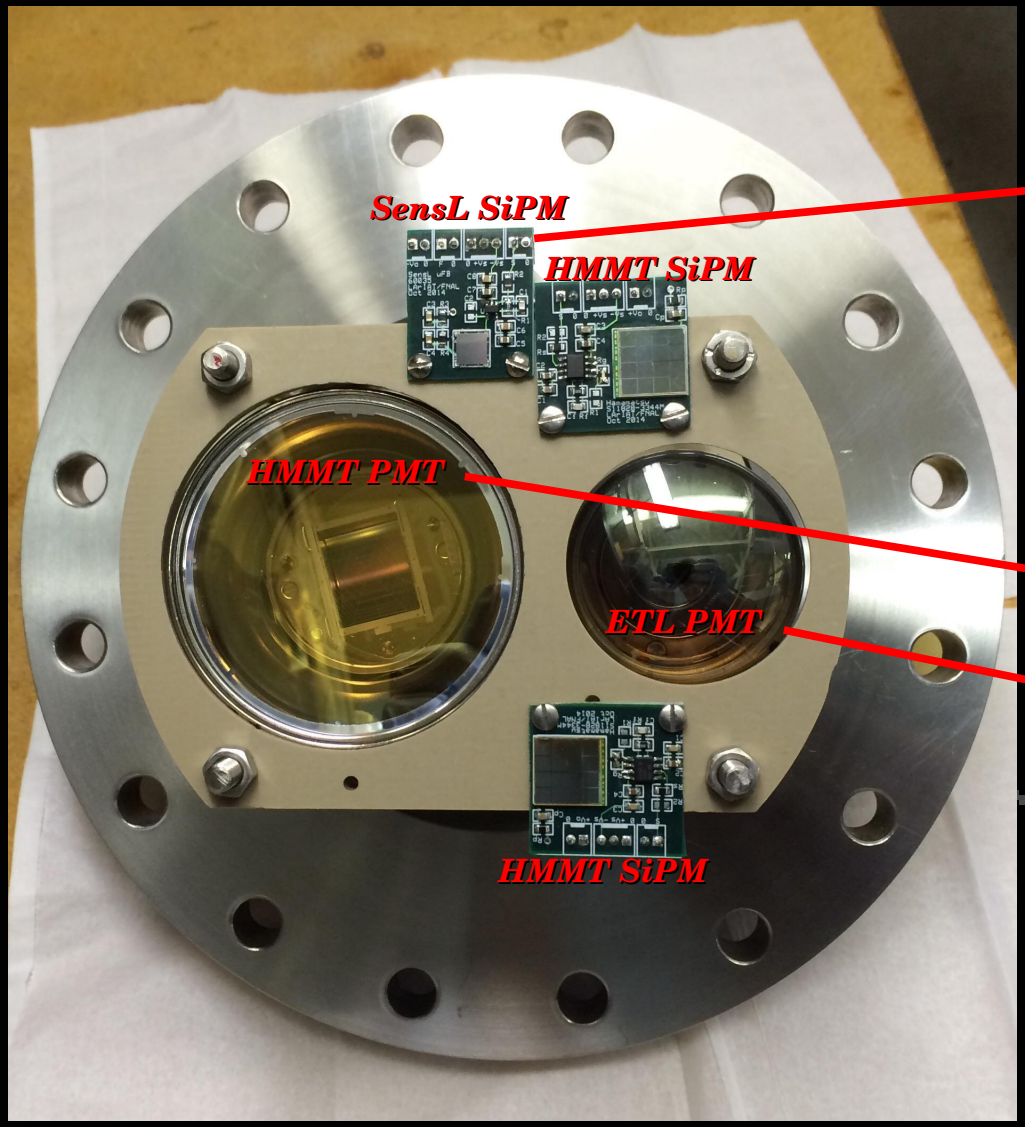


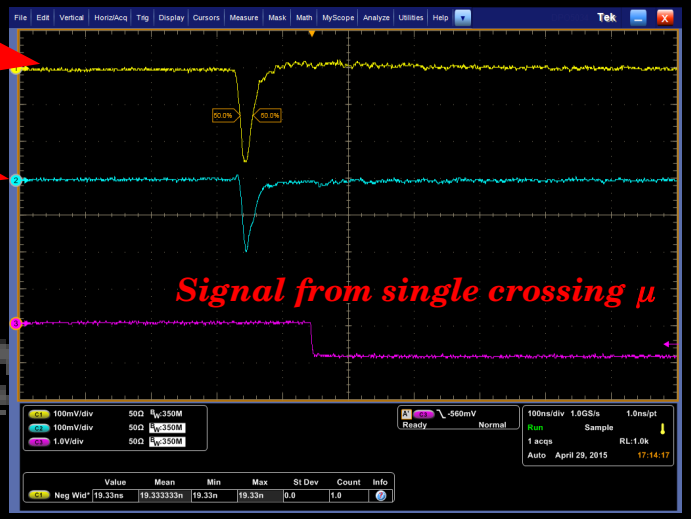
Spring run: TPC on!

04/30/2015: bunch of really happy people!

Light Collection System

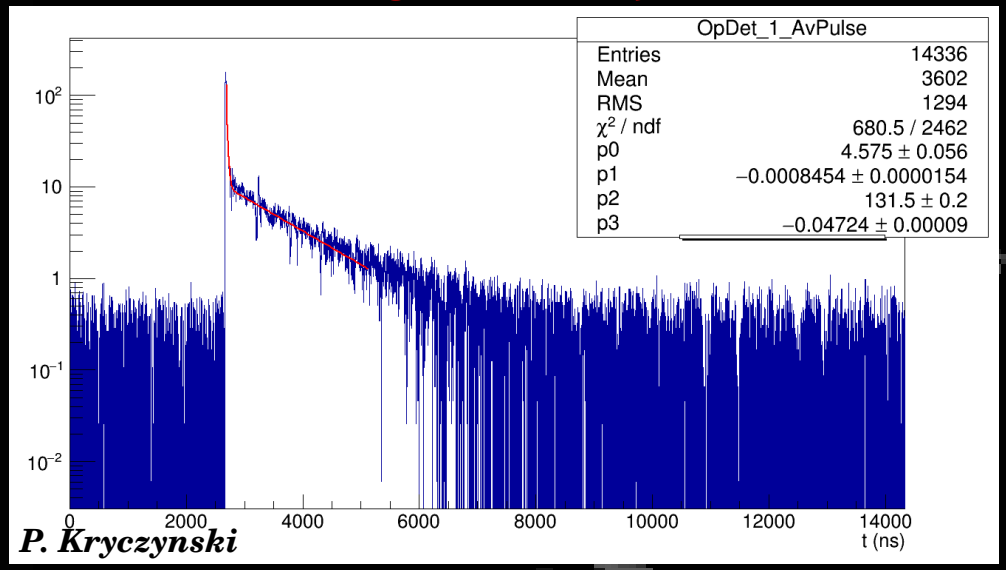
2 PMTs and 3 SiPMs viewing the active volume through the wire planes





Light Collection System: measuring N_2 concentration

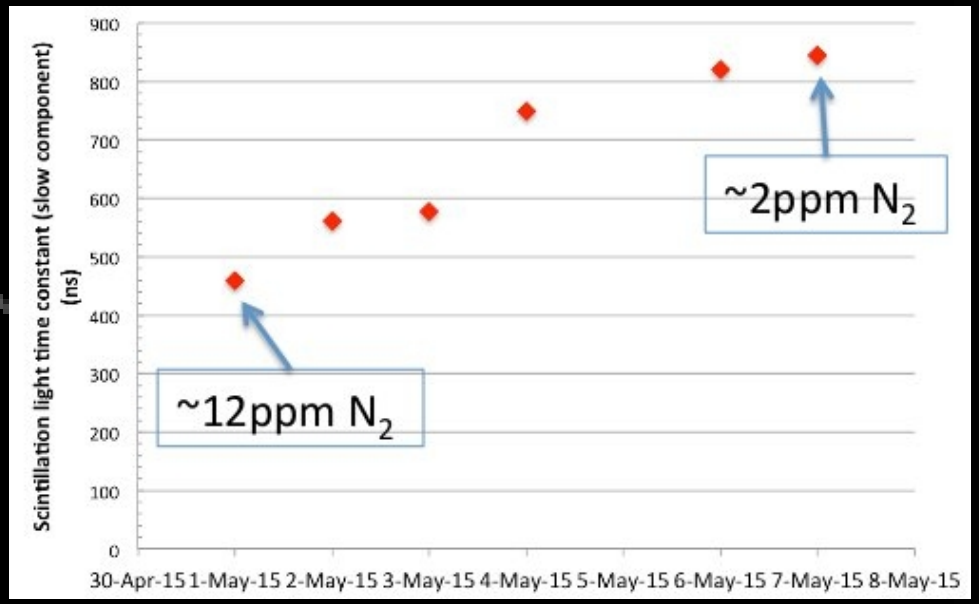
Average PMT waveform



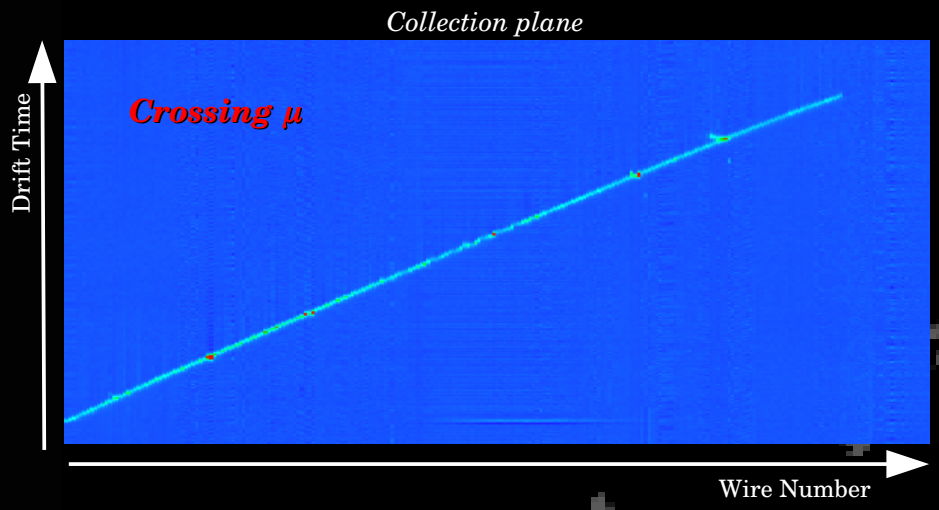
P. Kryczynski

N_2 content in LAr (harmful to light collection) can be extracted from the slow component time constant of the scintillation light collected by the PMTs

Values obtained using this technique well agrees with the measurement performed by the cryo system gas analyzer



Cosmic rays: measuring O_2 concentration

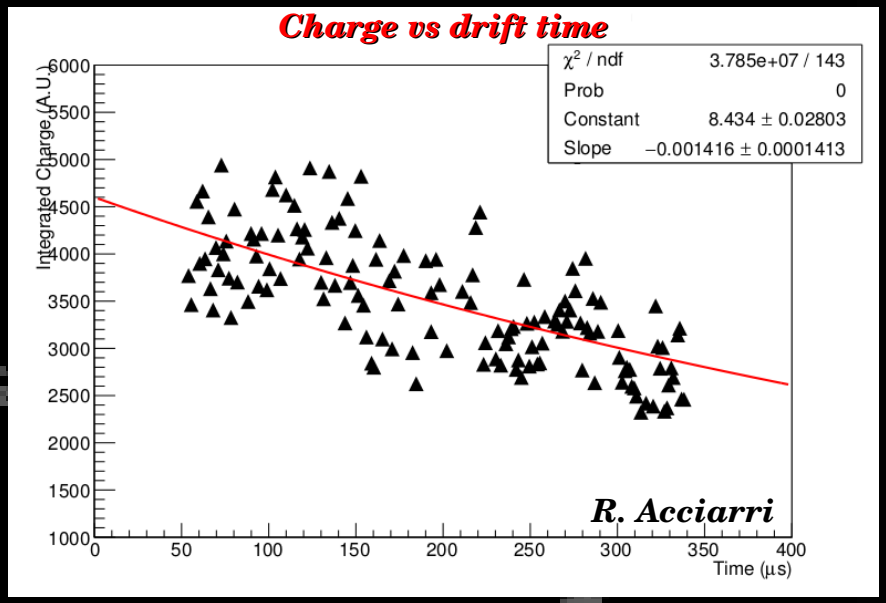


✔ Dedicated scintillator paddles set up allows to trigger on minimum ionizing muons crossing the full diagonal of the TPC in between beam spills

✔ A fit of the charge vs drift time allows to extract the electron lifetime and infer the O_2 concentration in LAr at levels even below the sensitivity of the cryo system gas analyzers

✔ Already a single track can provide a quick online first estimation of the LAr contamination level

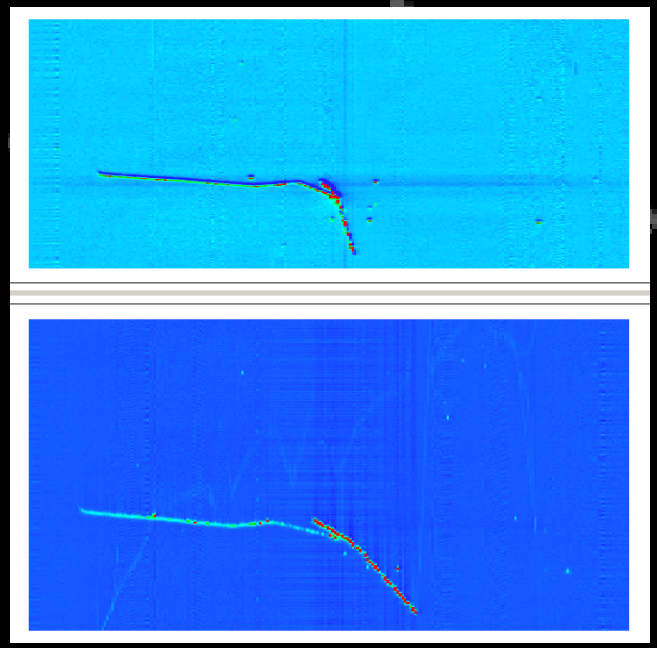
✔ O_2 concentration < 1ppb, in agreement with the cryo system gas analyzers



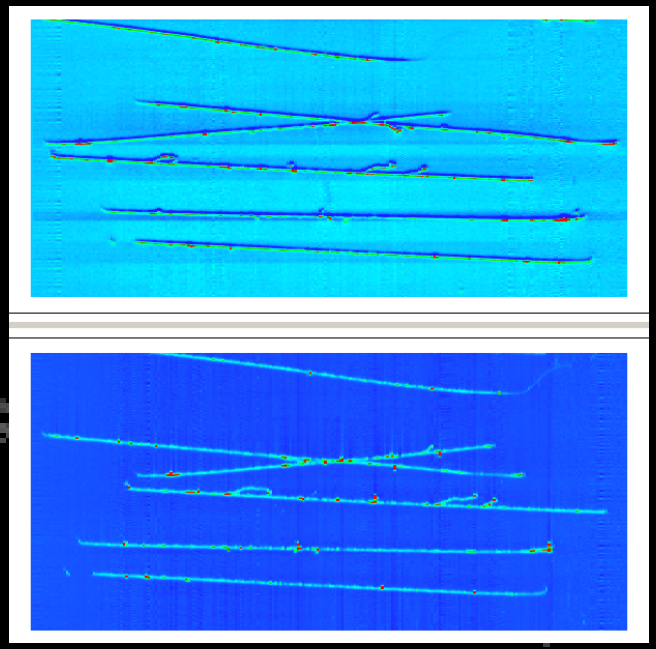
TPC and beam

- ✔ TPC worked beautifully at first turn on
- ✔ Signal/noise ratio from cold electronics > 50 (simple estimation of pulse height signal compared to noise RMS – no lifetime correction)
- ✔ Working together with AD, systematic scan of beam energies and intensities to optimize the number of tracks per trigger entering the TPC

Low occupancy

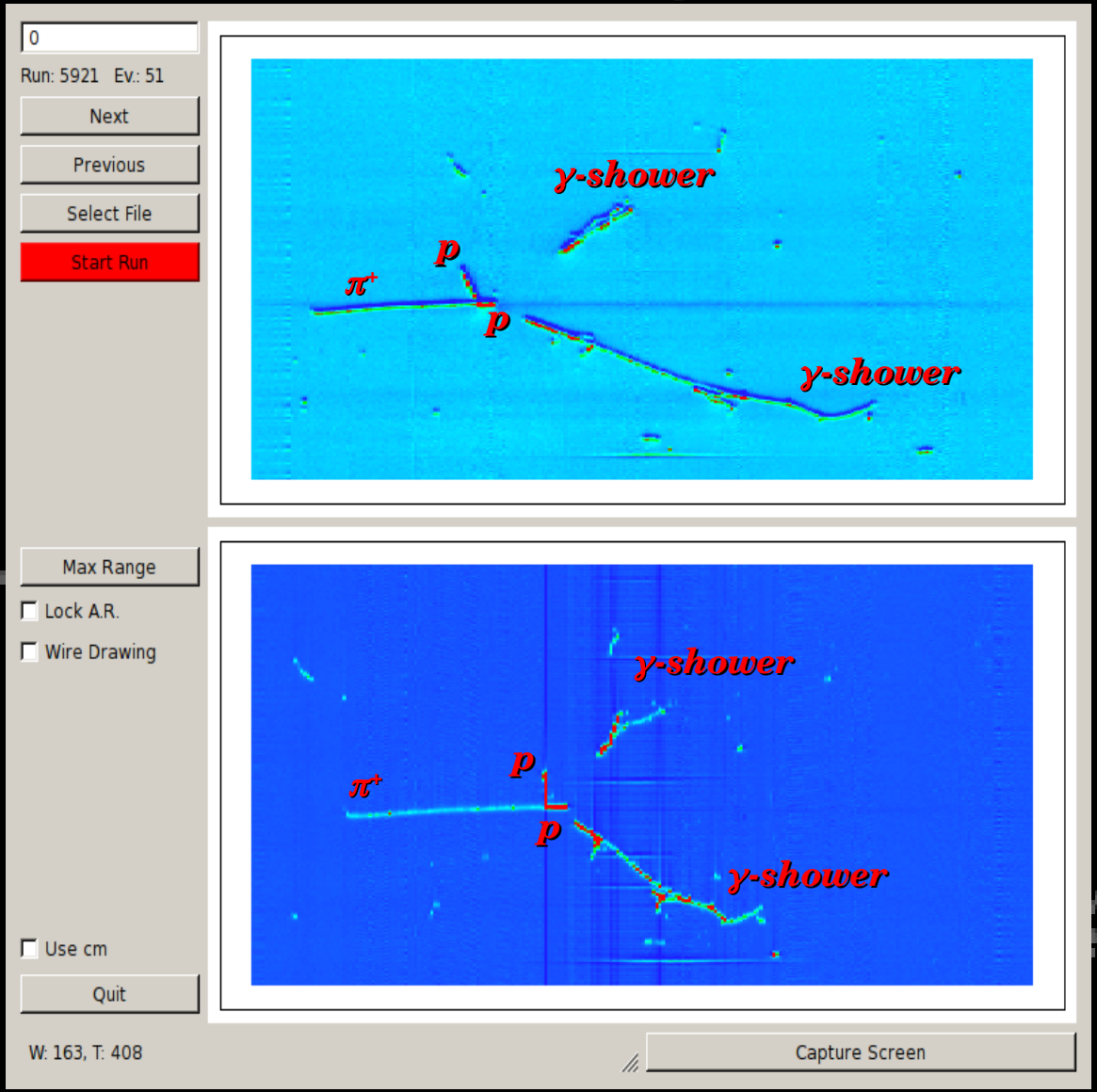


High Occupancy



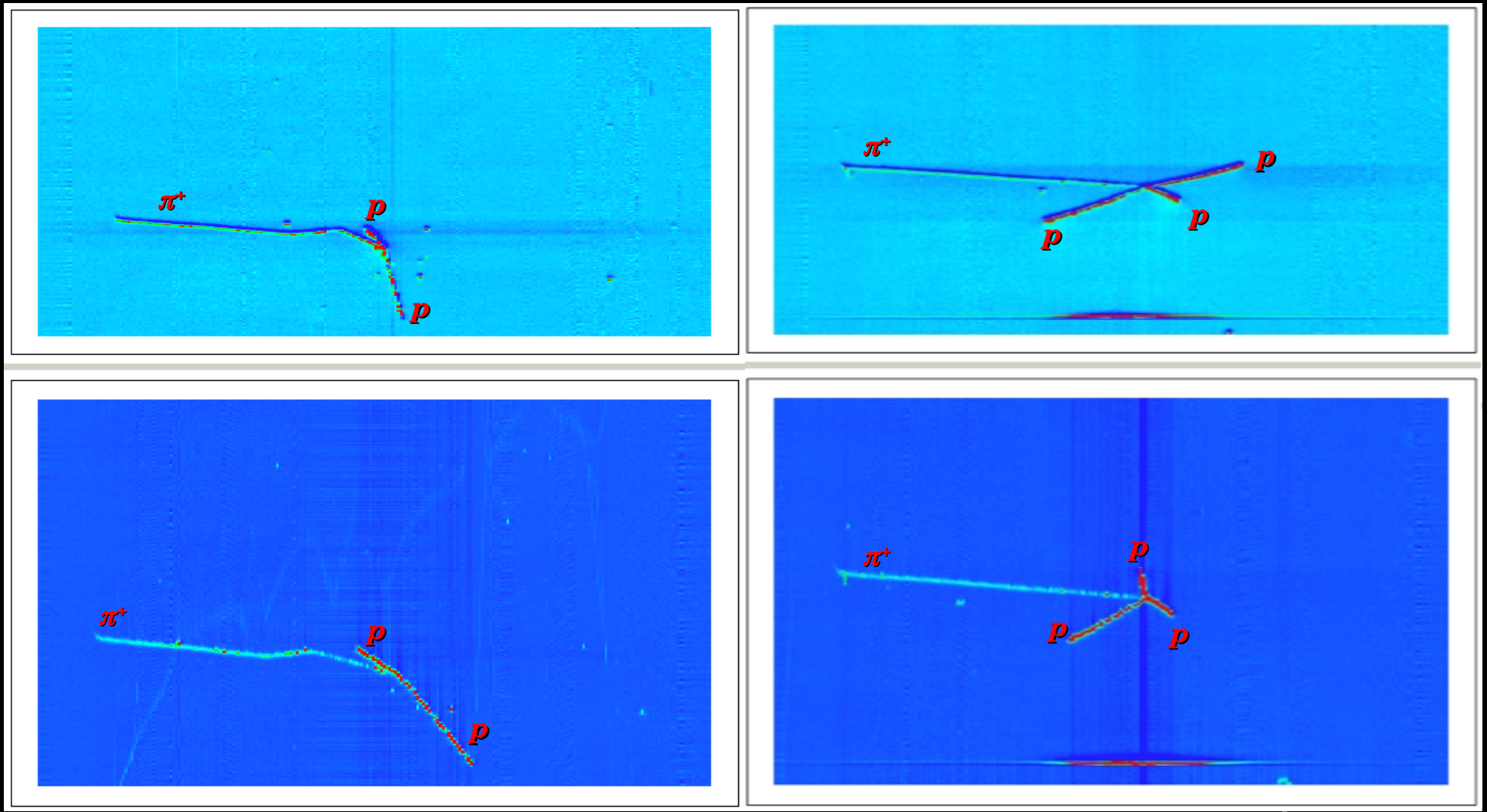
Collecting beam data

π^+ charge exchange



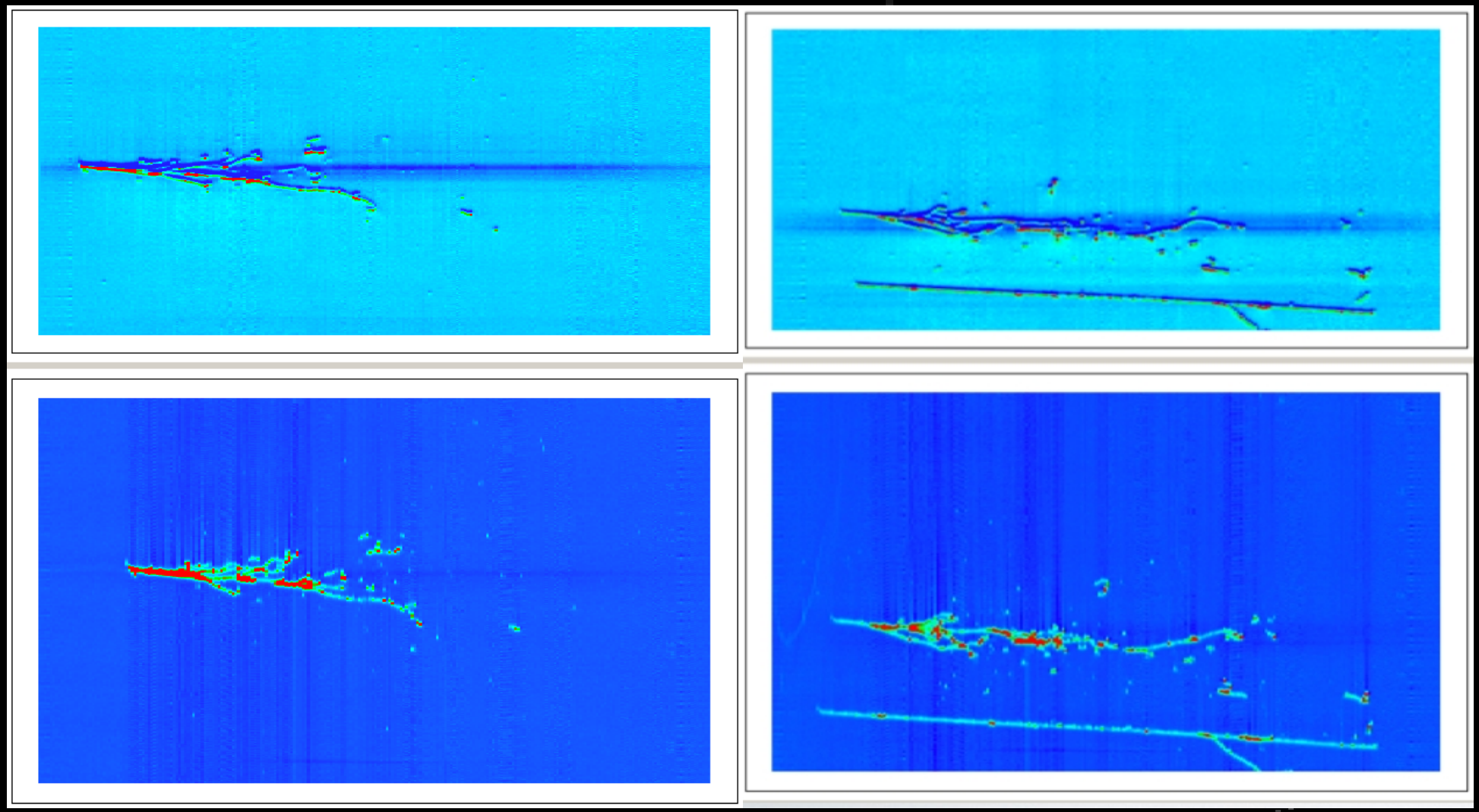
Collecting beam data

π^+ absorption



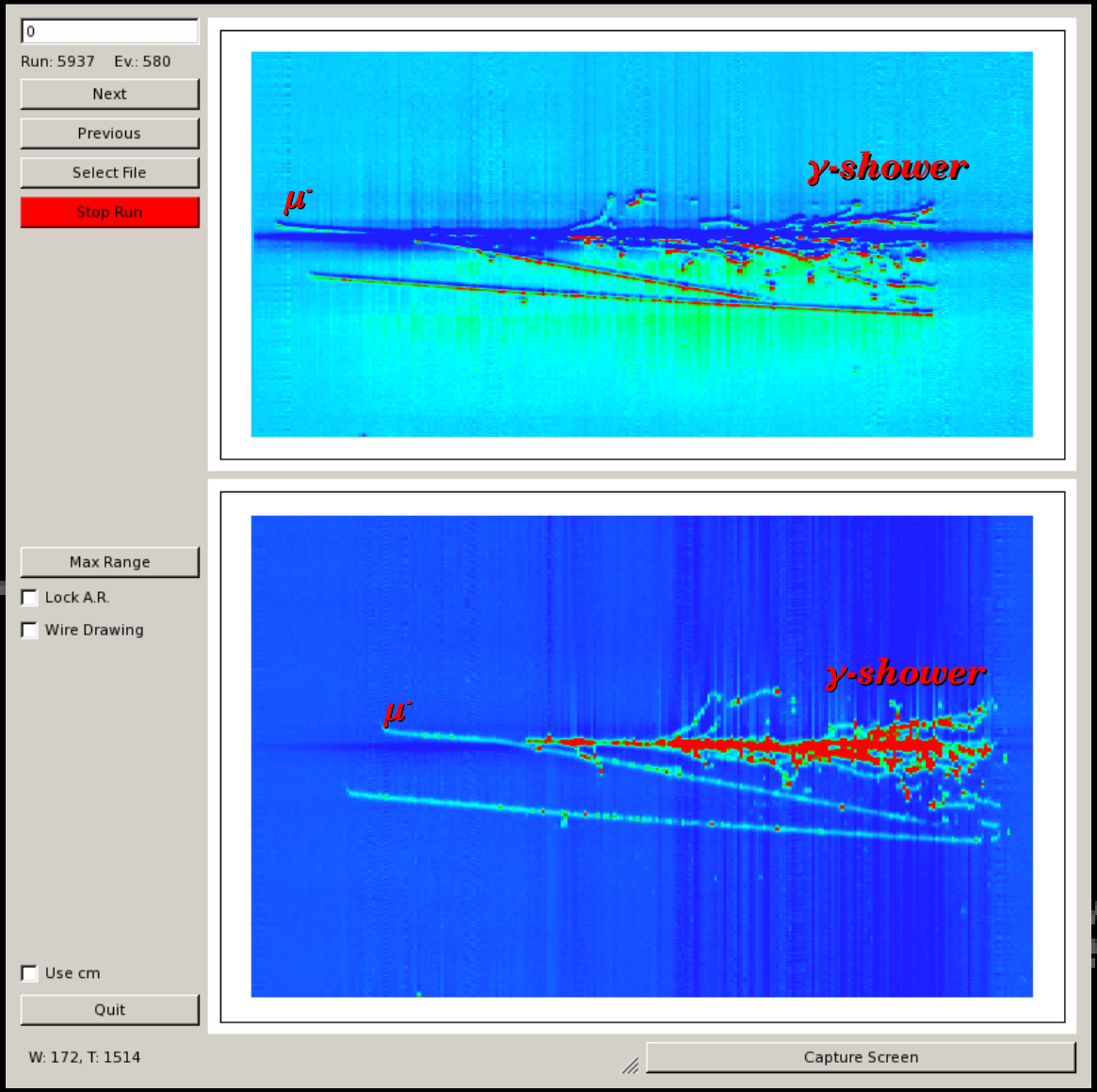
Collecting beam data

γ induced shower | *Electron induced shower*



Collecting beam data

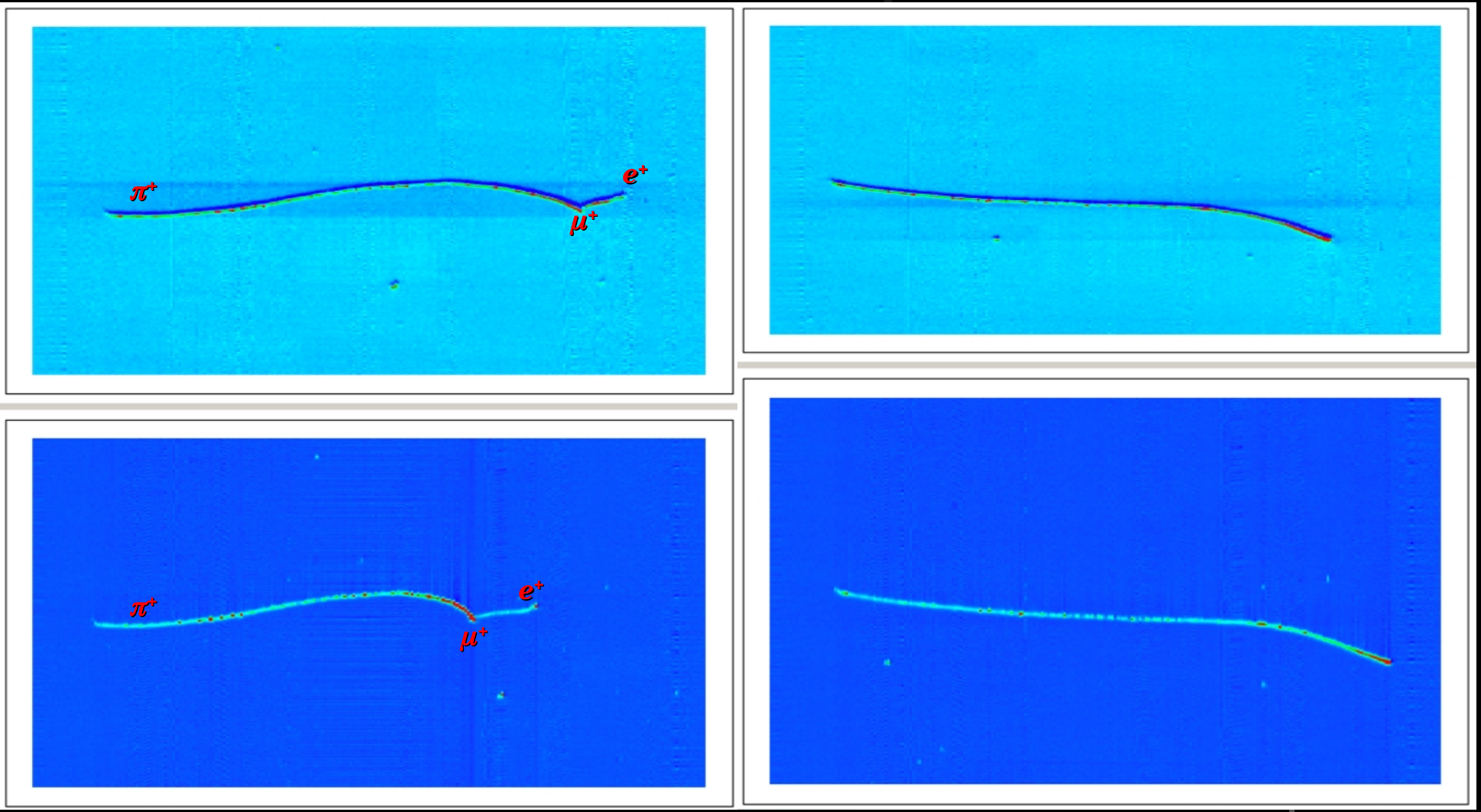
μ^- bremsstrahlung



Collecting beam data

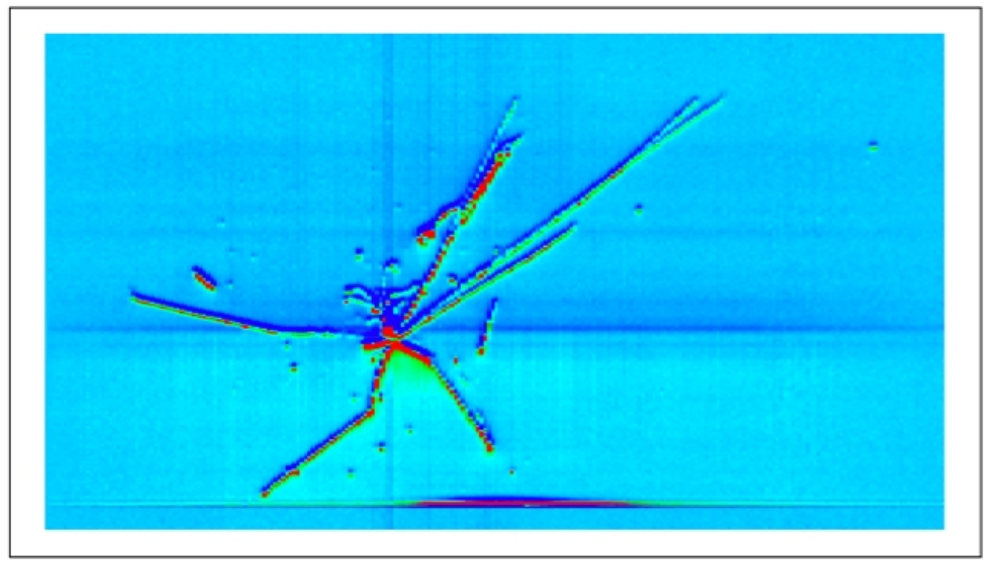
π^+ decay at rest

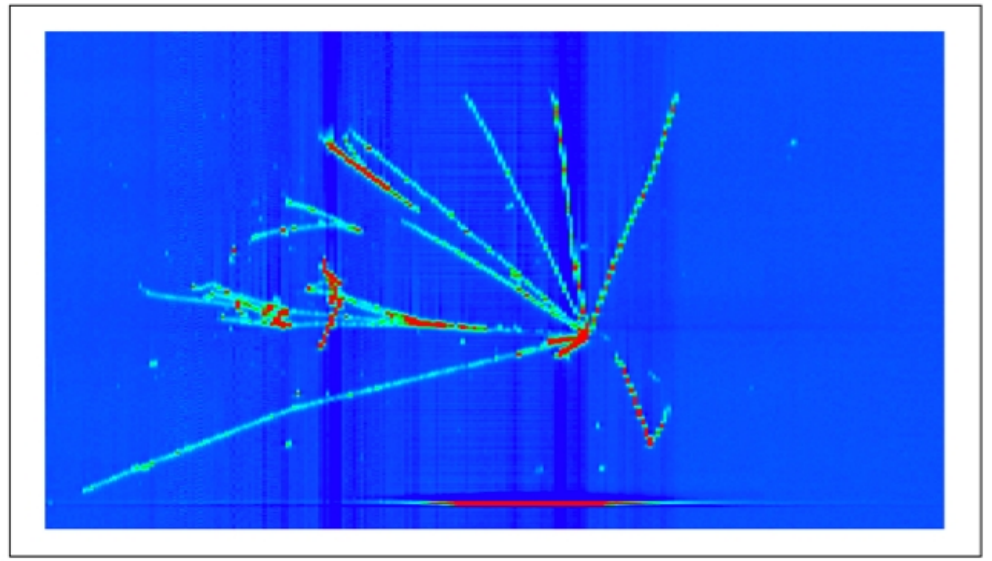
π^- capture at rest



Collecting beam data

Looking at the (hadron) stars with LArIAT





Summing up

✔ Beamline detectors successfully commissioned during last summer run

✔ TPC is working beautifully since its first turn on, already showing interesting events

✔ After few weeks of TPC and PMTs tuning using the beam, we are now acquiring physics data at both magnet polarities (positively and negatively charged particles) and highest momentum

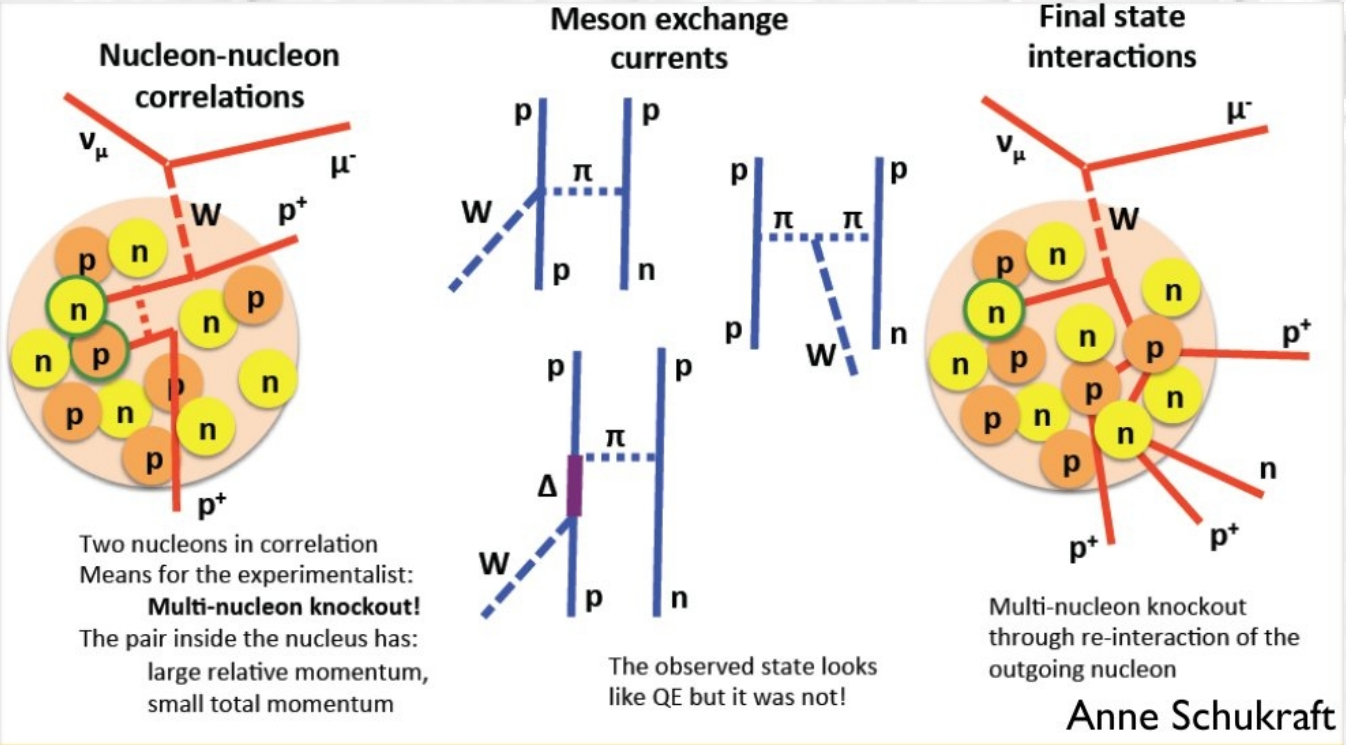
✔ The collaboration is currently actively working on the complete track reconstruction, merging together data from all the detectors (beamline, TPC, light collection)

✔ Data acquisition over a range of beam momentum and TPC electric field values foreseen for the second part of the run

obrigado
Dank U
Merci
mahalo
Köszi
спасибо
Grazie
Thank you
mauruuru
Takk
Gracias
Dziękuję
Děkuju
danke
Kiitos

From MC-based analysis to topological analysis

In neutrino interactions with heavy nuclei, nuclear effects start to play an important role

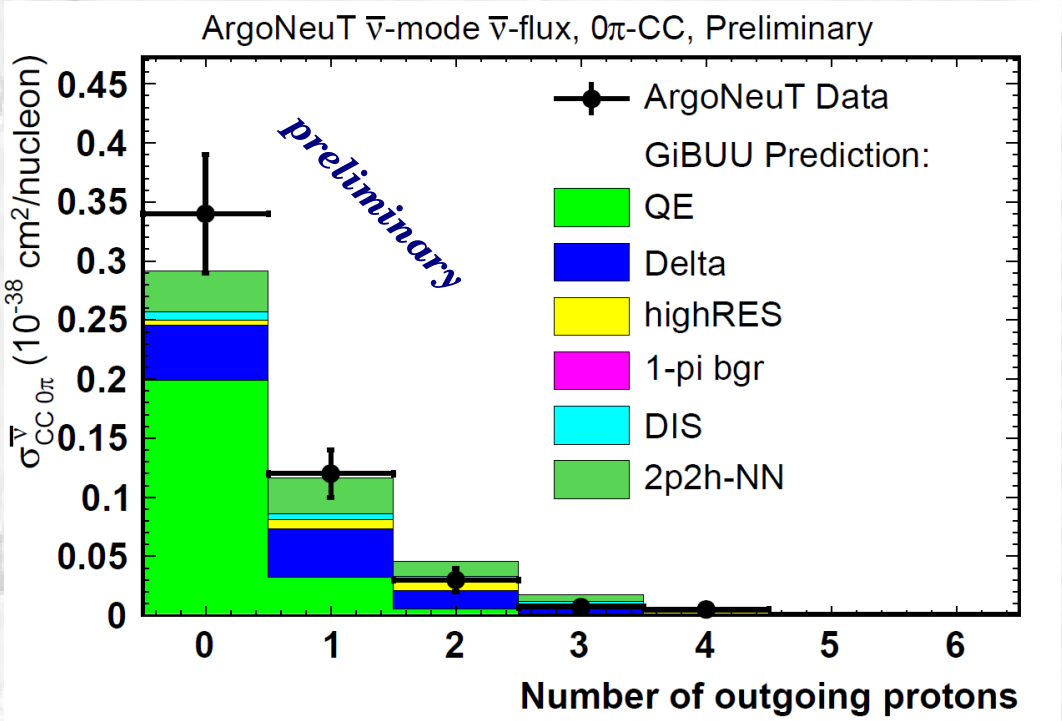


- Current MC generators may not always take into account nuclear effects in an exhaustive way
- We are in a period where data are needed as feedback to the development of more realistic interaction models

LArTPC's 3-d imaging, calorimetric and particle ID capabilities allow for MC-independent measurements of exclusive topologies ($\bar{\nu}_\mu$-CC0π) as well as nuclear effects exploration

$\bar{\nu}_\mu$ CC – 0π topological analysis

Production cross-section as a function of the number of outgoing protons in the event



✔ good agreement between MC with final state interactions and data

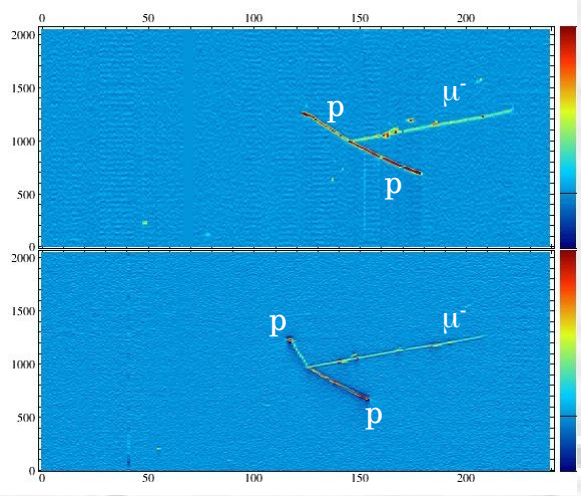
✔ 0p1μ sample, generallly referred to as signature of QE interaction, has a significant contribution from Delta resonance

Inclusive cross-section $\sigma_{CC0\pi} = 0.5 \pm 0.03\ (stat) \pm 0.06\ (sys) \times 10^{-38}\ cm^2$ *for* $\langle E_\nu \rangle = 3.6\ GeV \pm 1.5\ GeV$

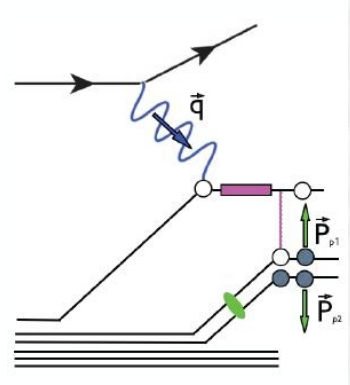
Exploring nuclear effects: NN SRC

Nucleon Nucleon Short Range Correlations have been extensively probed through two-nucleon knock-out reactions in both pion and electron scattering experiments

ArgoNeuT: detection of two-nucleon knock-out events in the CC-0π2p sample!

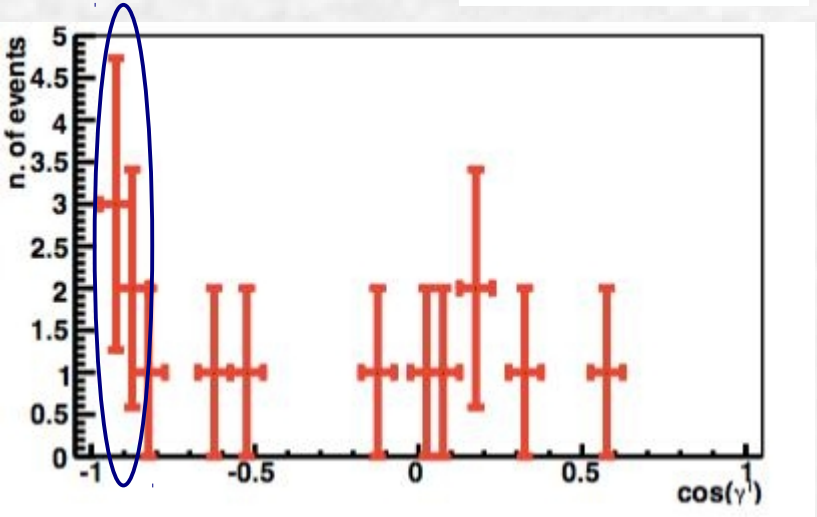


- 4 back-to-back proton pairs events observed in Lab frame
- Characteristics: $\cos(\gamma) < -0.95$, P_{p1} and $P_{p2} \geq k_F$, $P_{p1} \simeq -P_{p2}$
- Possible mechanism: CC RES pionless reactions involving pre-existing SRC np pairs



- 4 back-to-back proton pairs events observed in the center of mass frame as well!

- Possible mechanism: CC QE on the neutron of a SRC np pair

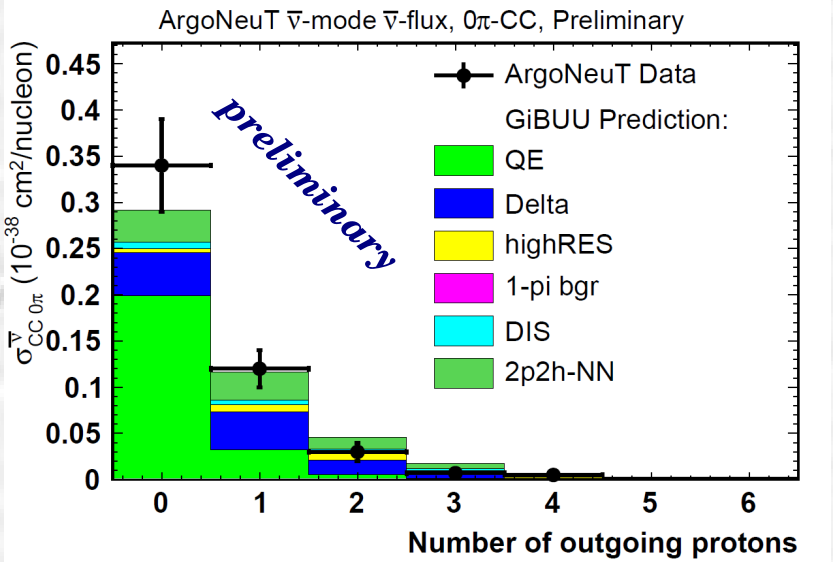


R. Acciarri et al., Phys. Rev. D 90, 012008 (2014)

ν_μ CC – 0π topological analysis

Production cross-section as a function of the number of outgoing protons in the event

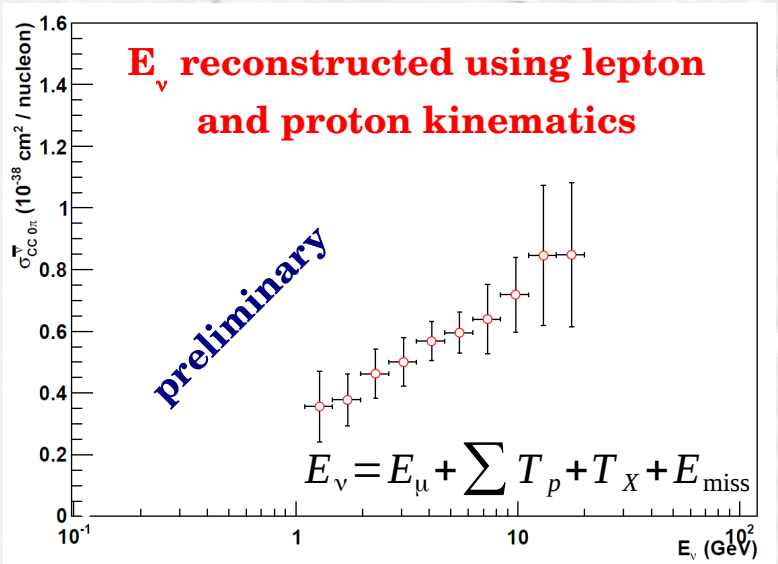
good agreement between MC with final state interactions and data



Inclusive cross-section for a <E_ν> = 3.6 GeV +/- 1.5 GeV

$\sigma_{CC0\pi} = 0.5 \pm 0.03\ (stat) \pm 0.06\ (sys)\ x\ 10^{-38}\ cm^2$

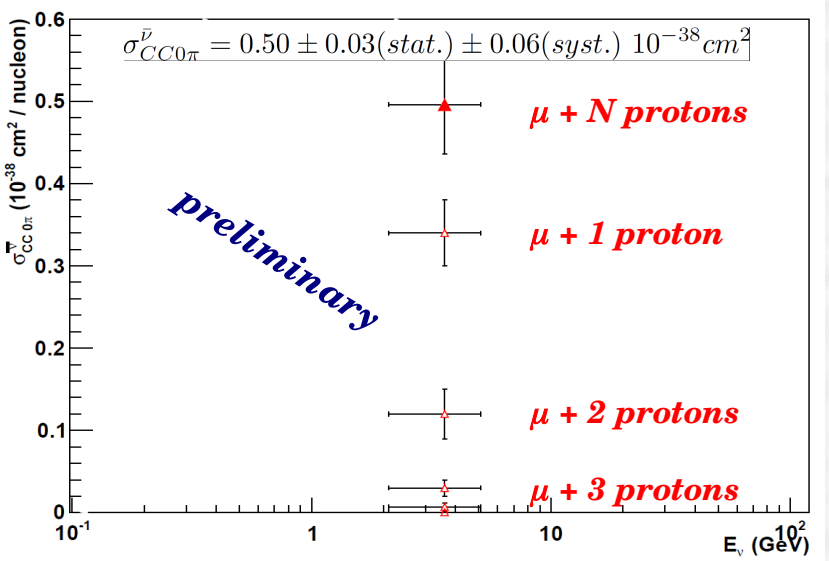
Inclusive cross-section as a function of reconstructed ν energy



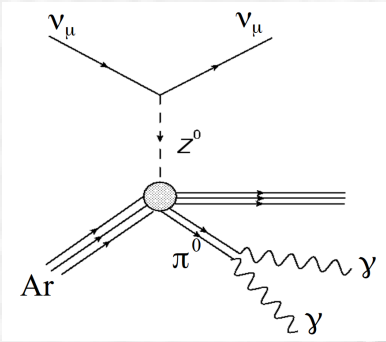
T_p proton kinetic energy

T_x Nucleus recoil energy

E_{miss} Missing energy

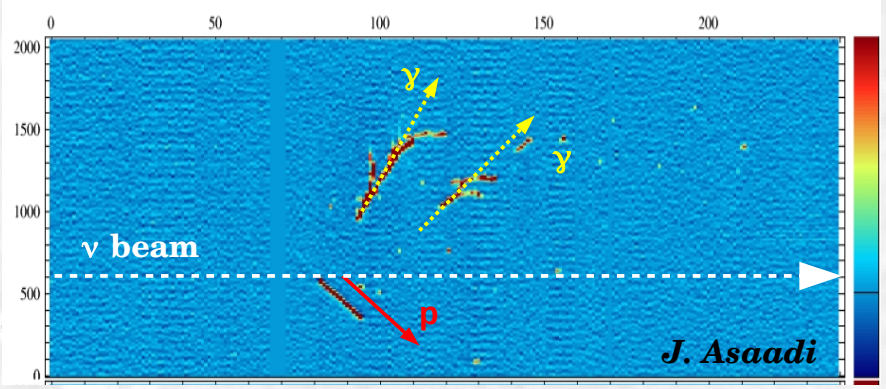


Neutral current π^0 study



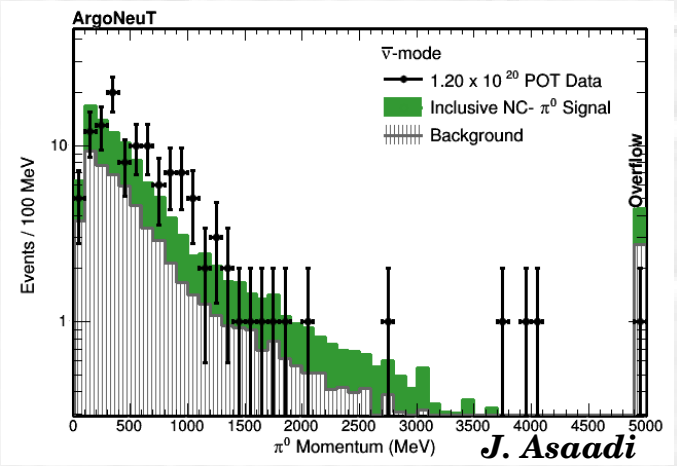
✔ Important channel for oscillation searches and cross-section measurements

✔ ArgoNeut size does not allow to contain the majority of the γ energy

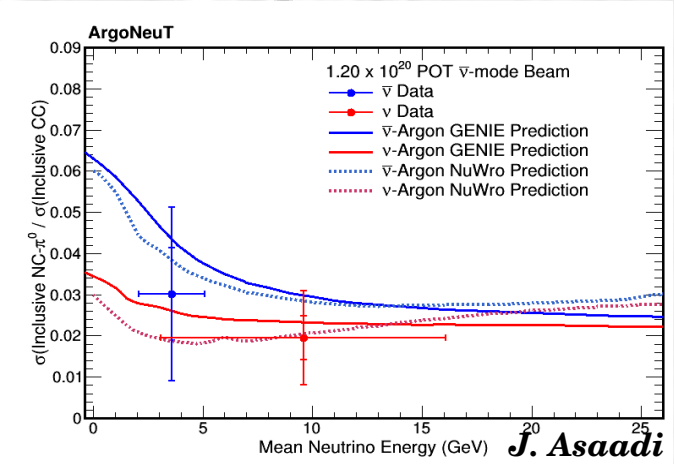


✔ Nevertheless, the fine grain detection ability of LArTPCs allows to correct back the missing energy from the photon showers

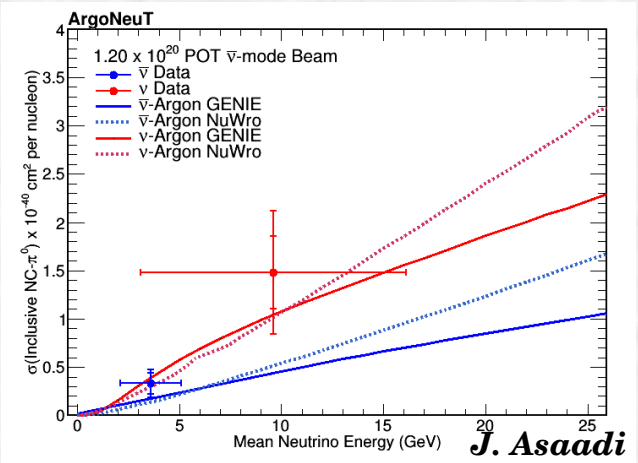
π^0 momentum from reconstructed photon showers



$\sigma_{NC\,\pi0} / \sigma_{CCincl}$ as a way to test theory



Production cross-section of neutral current π^0



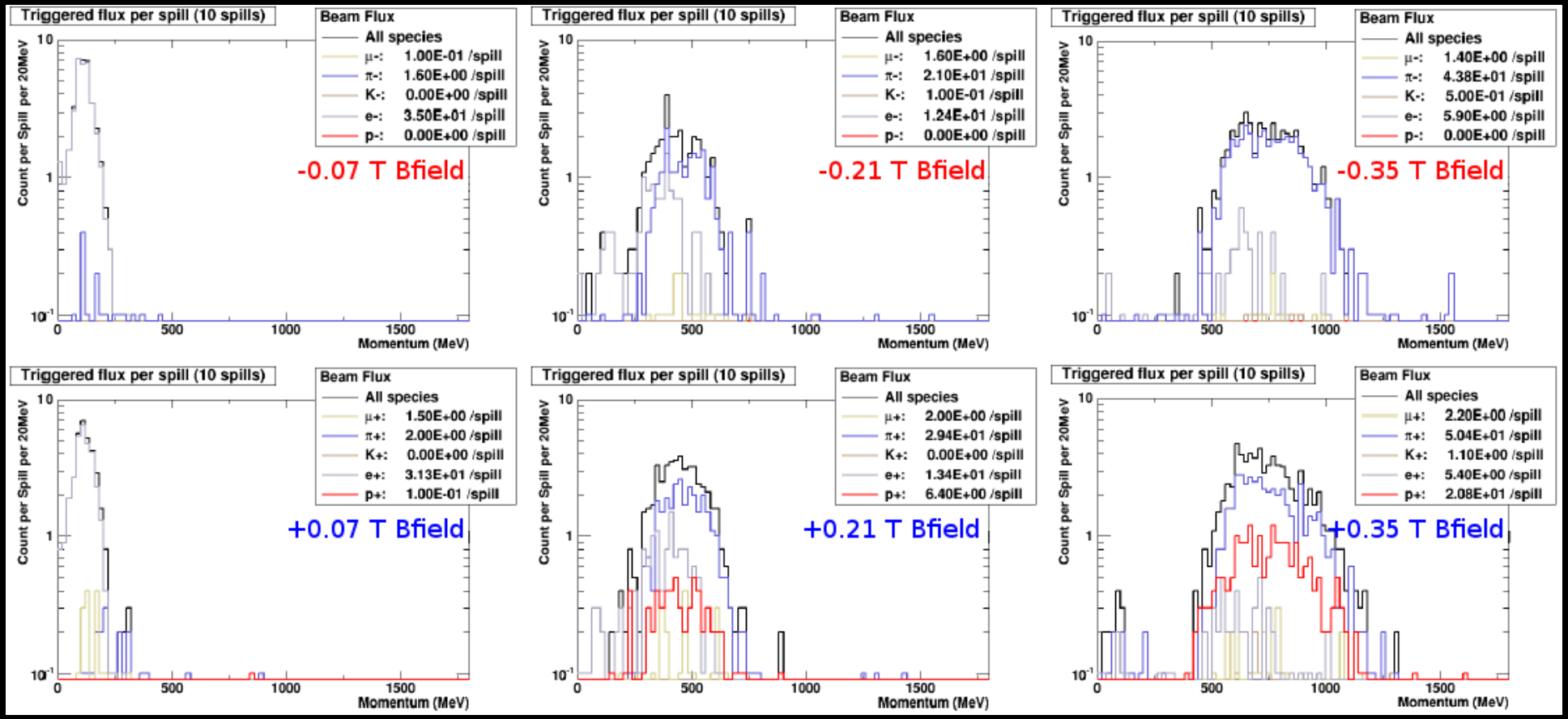
Paper under review

Beam composition: simulation

✔ Secondary and tertiary beam polarities can be switched

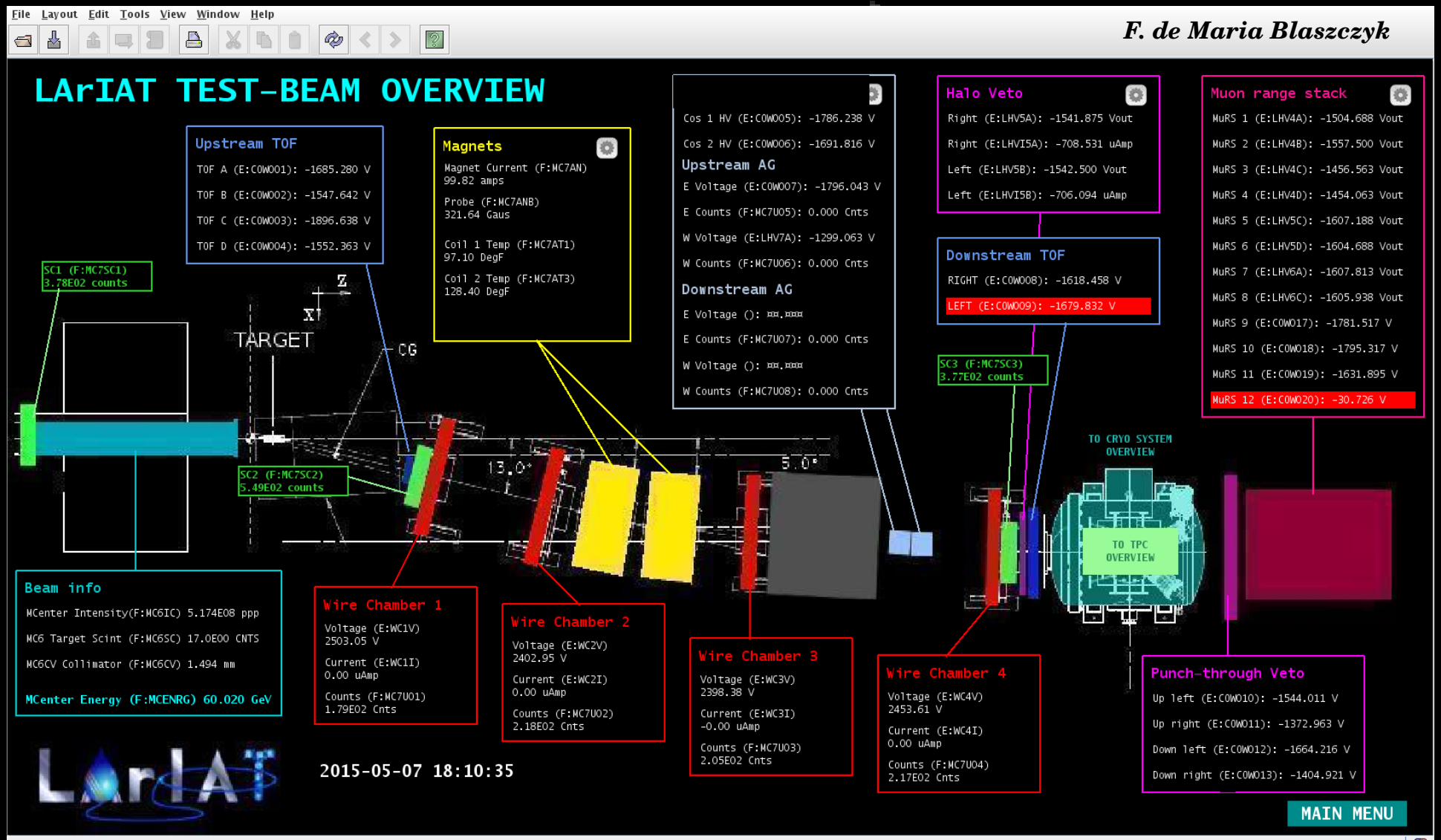
✔ Mostly pions, but beam composition can be changed depending on secondary beam energy and magnetic field intensity

+80 GeV π^+ on target



Online Monitor

ACNet monitoring and control of the whole system performed via Synoptic

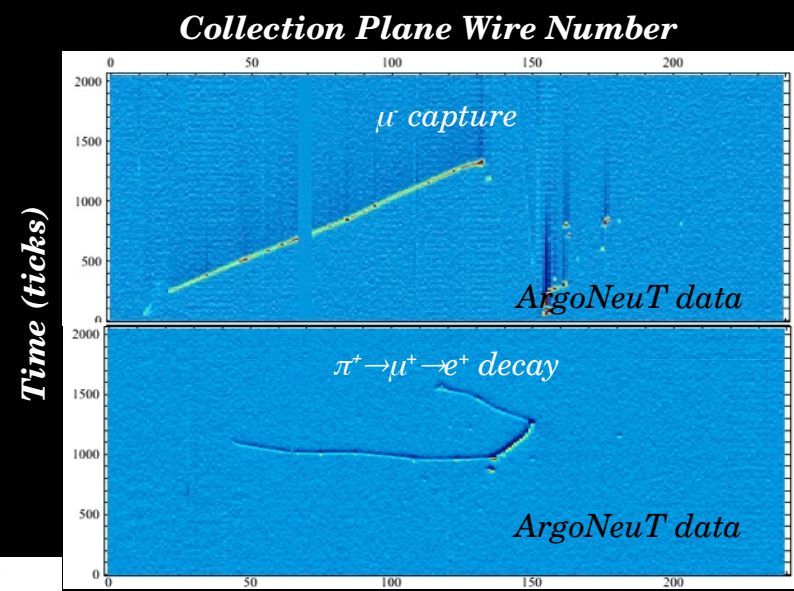


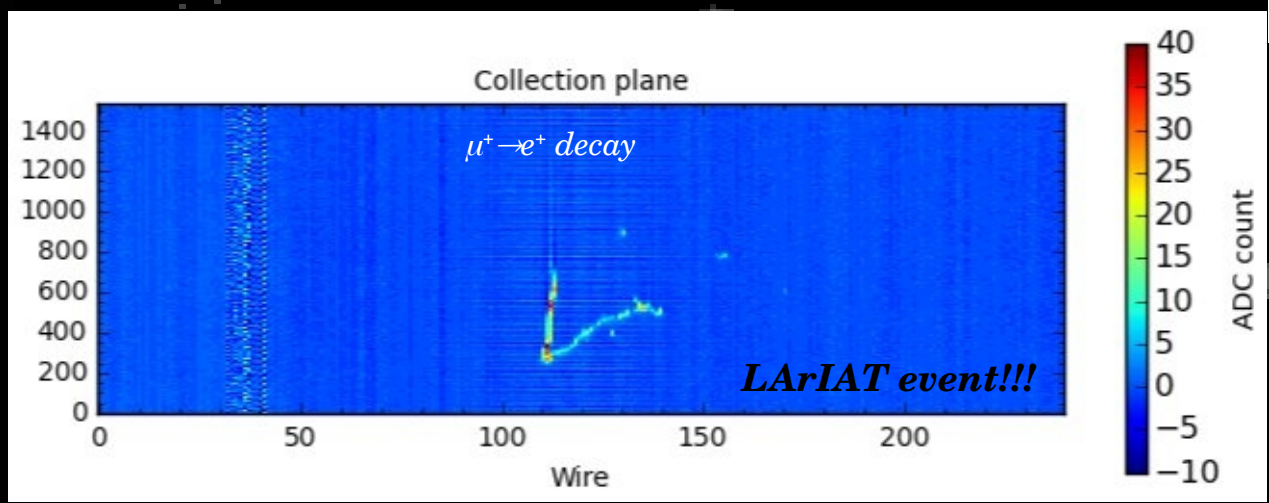
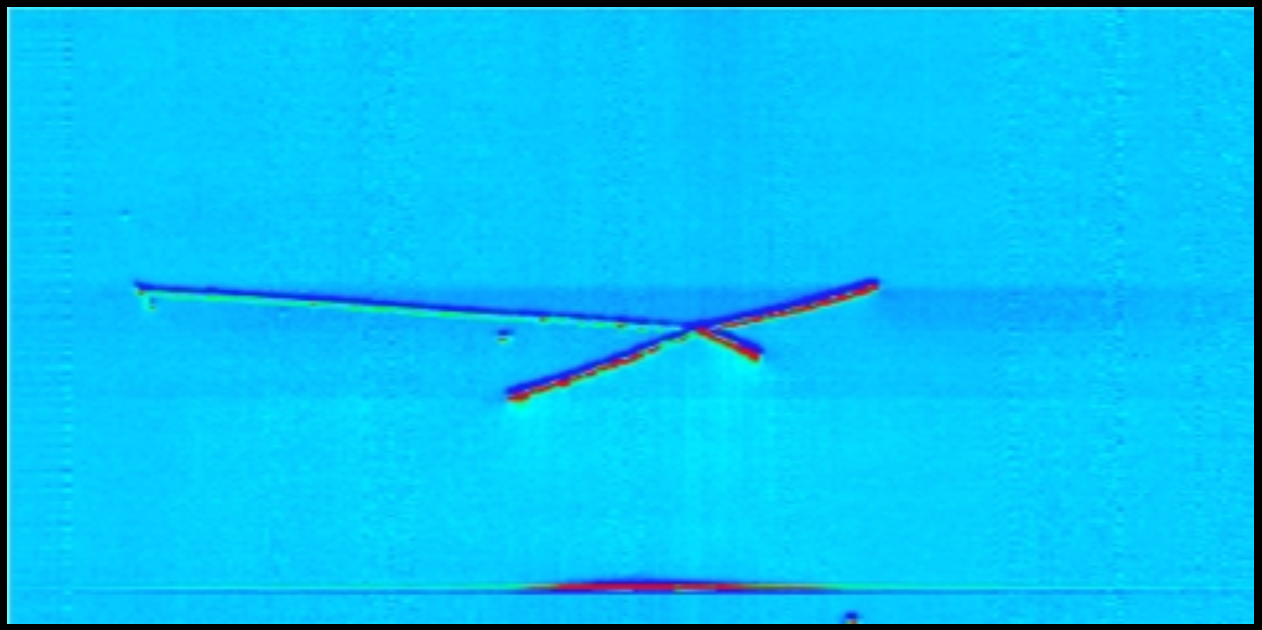
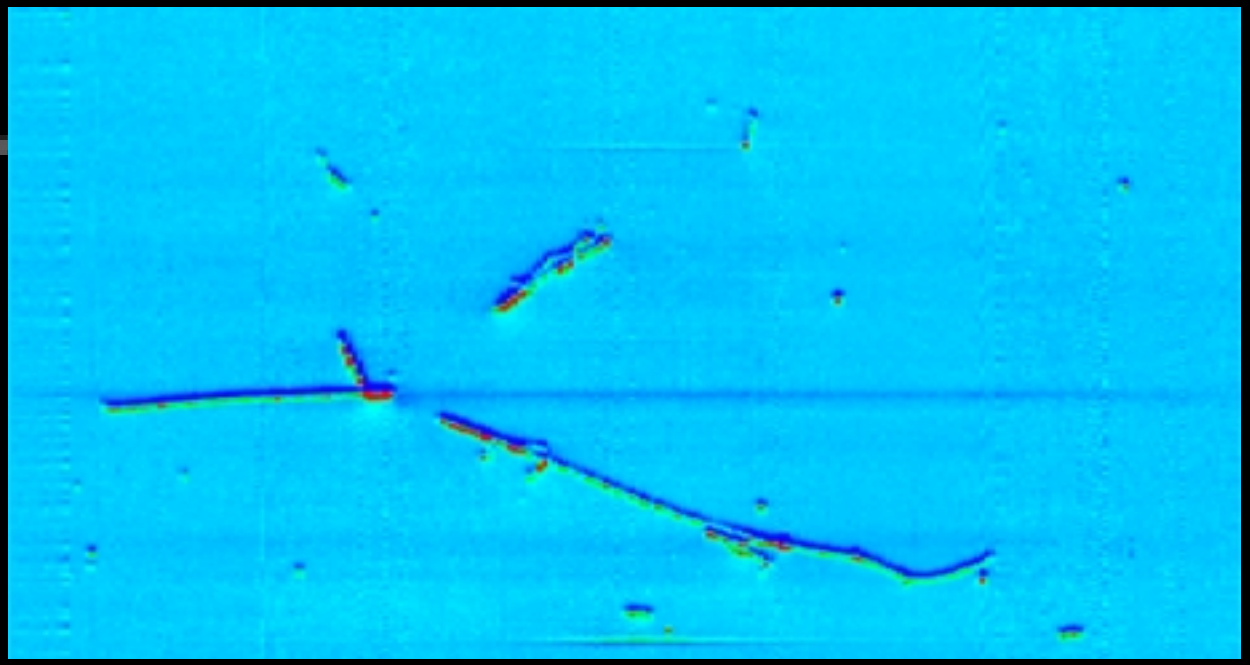
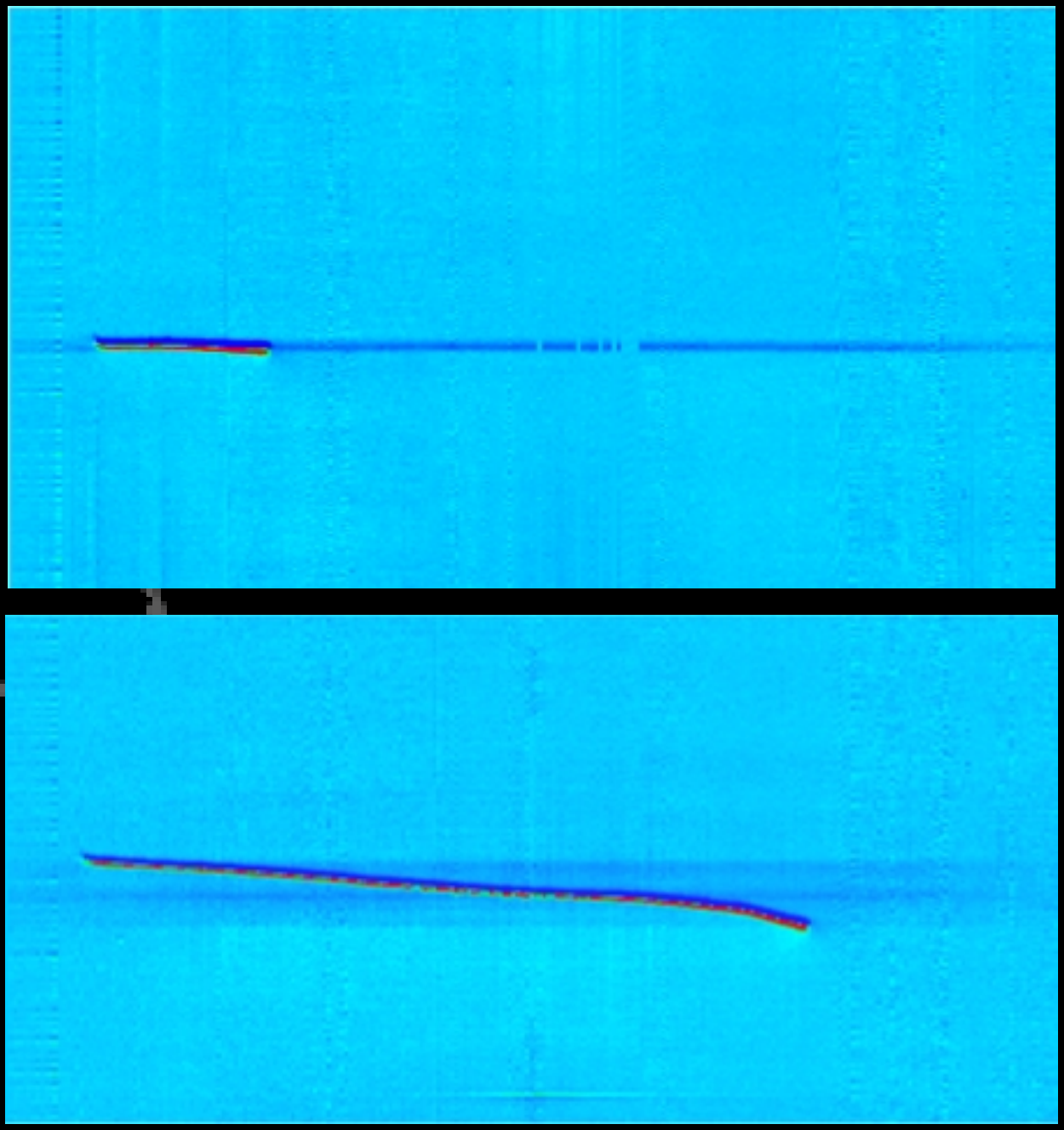
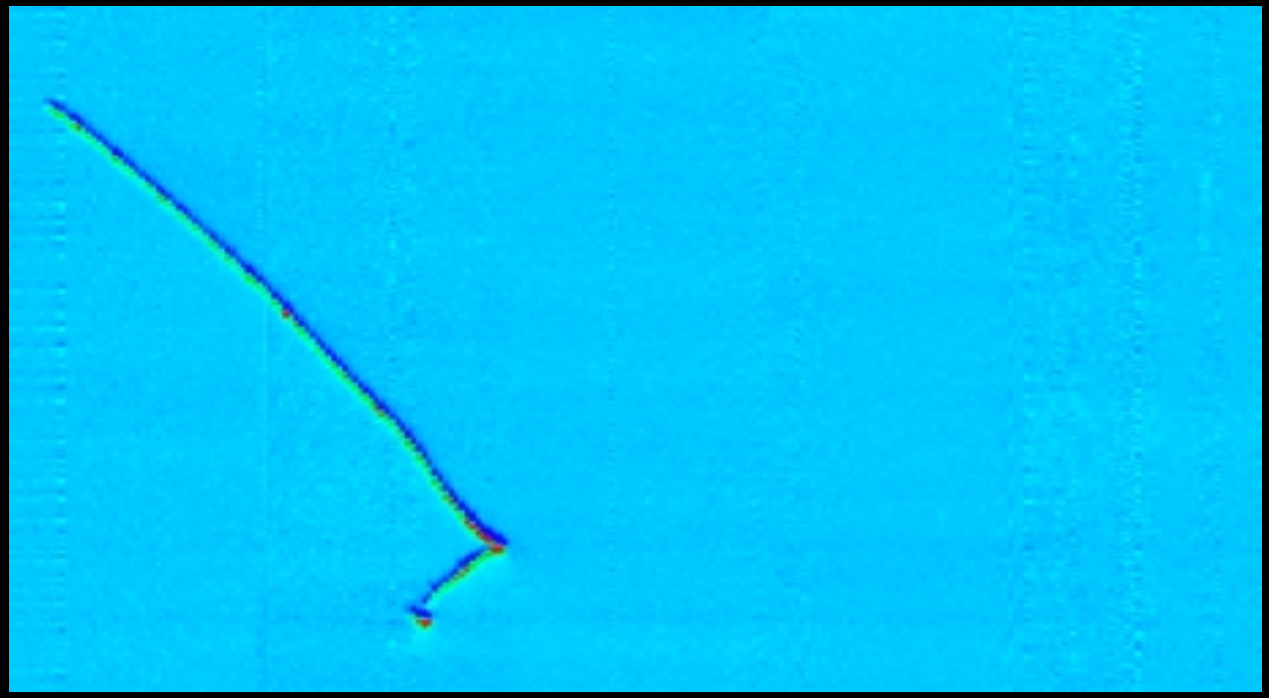
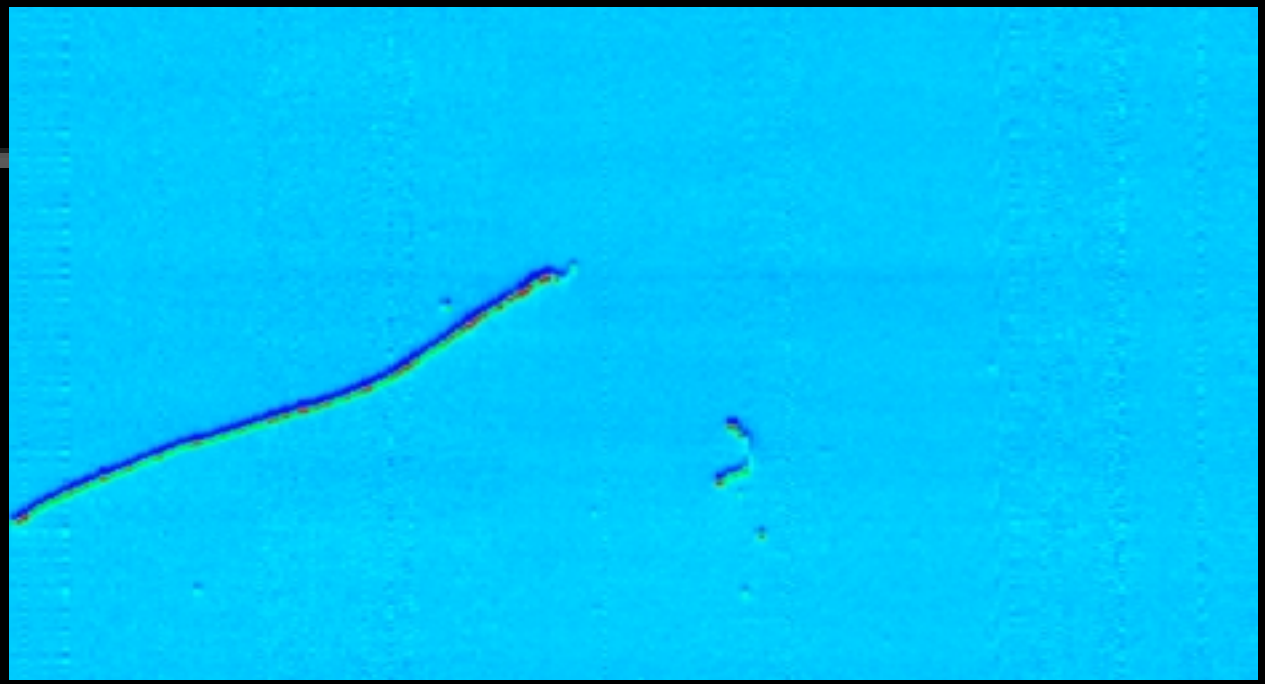
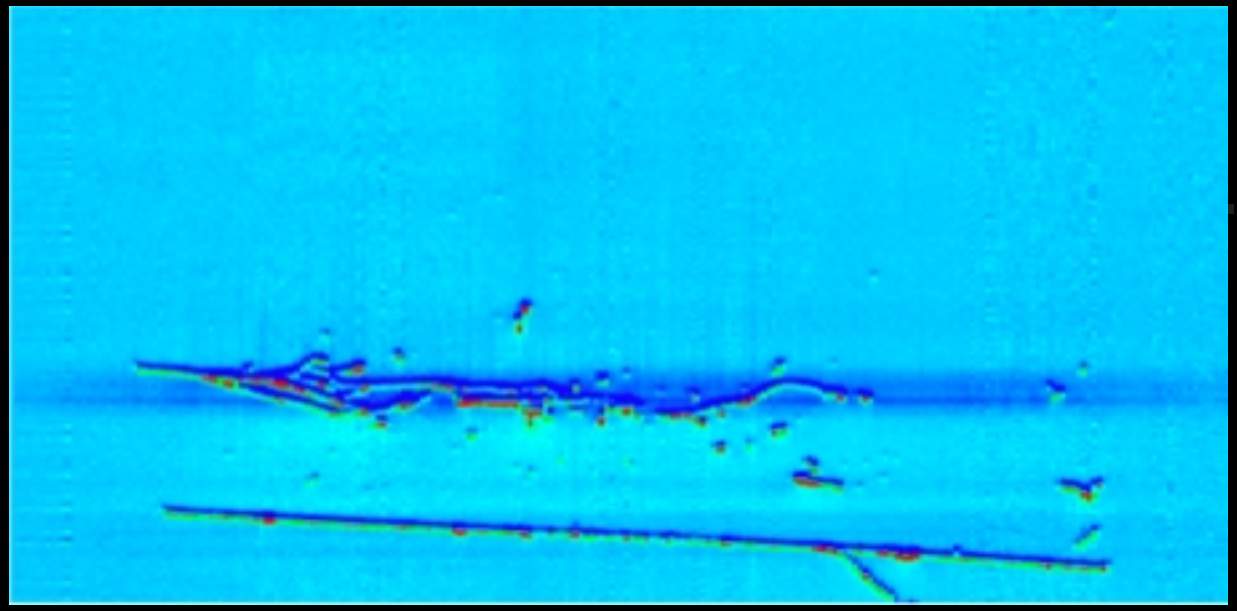
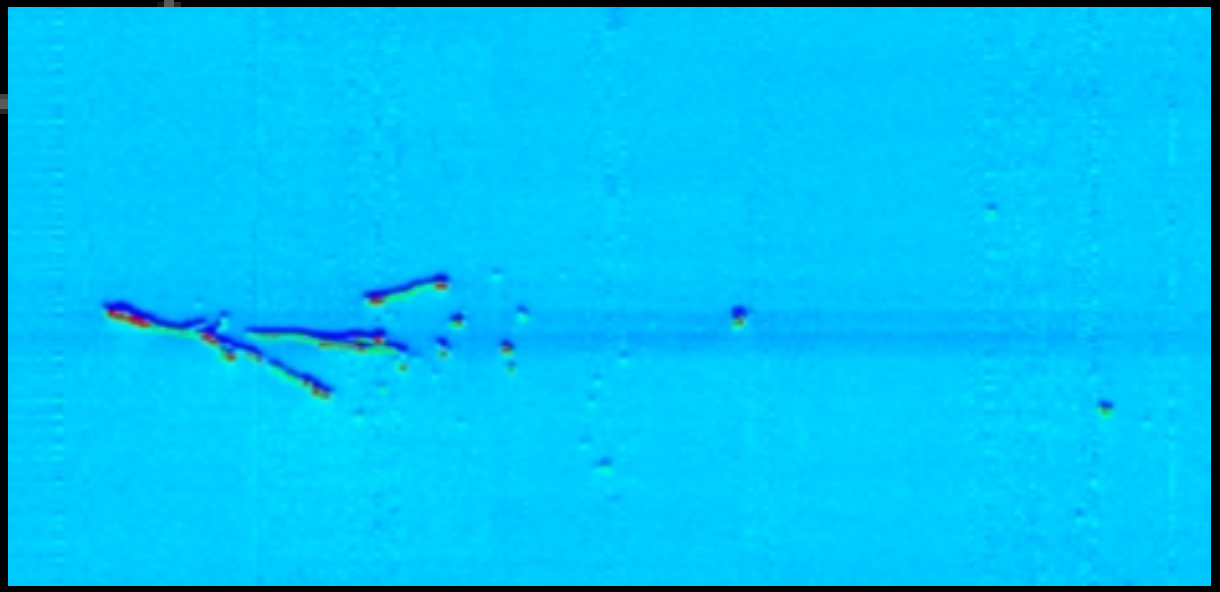
An example: muon charge sign determination

Systematic study of capture in Ar and sign-selection capabilities in LArTPC to develop techniques for $\nu_\mu / \bar{\nu}_\mu$ discrimination in non-magnetized LArTPC

HOW?

- μ^- undergo both capture on nuclei (76%) and decay (24%)
- μ^+ undergo decay (100%)
- Topological differences can allow for sign determination in absence of magnetic field on a statistical basis





LArIAT will be the first exploring this possibility in a systematic way!