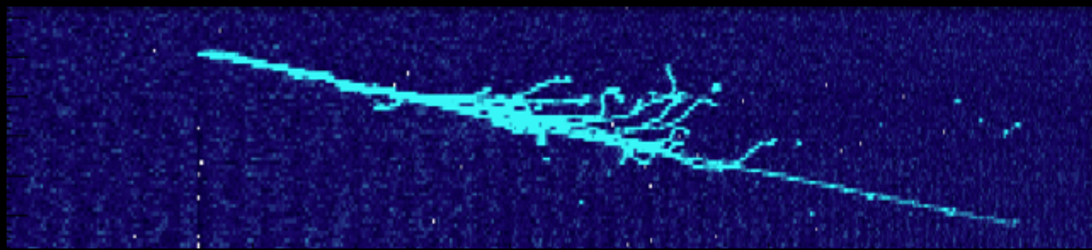
Liquid Argon TPCs
for future neutrino oscillation experiments



Antonio Ereditato

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Laboratory for High Energy Physics (LHEP)
University of Bern

Happy birthday, Bruno!

Dubna, 1984

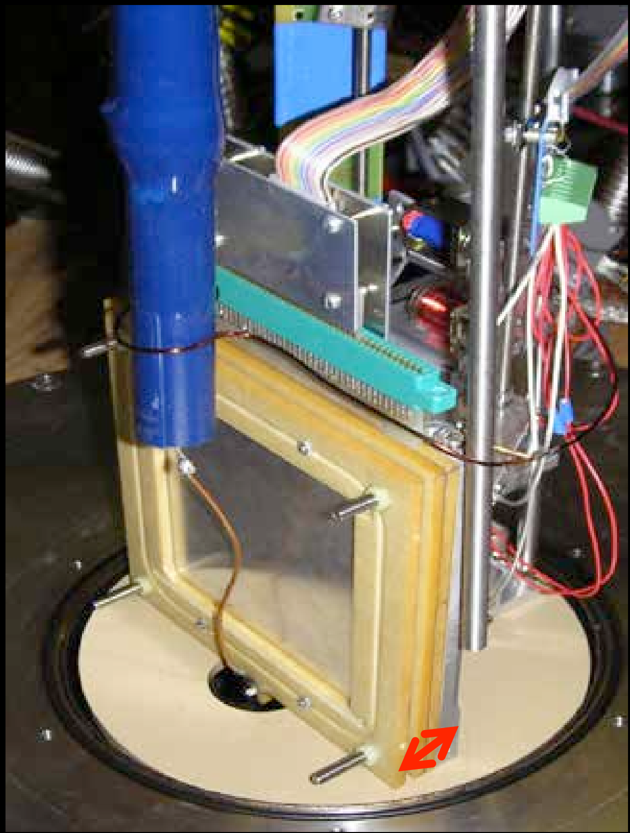
Arbitrary choice for a 25' talk

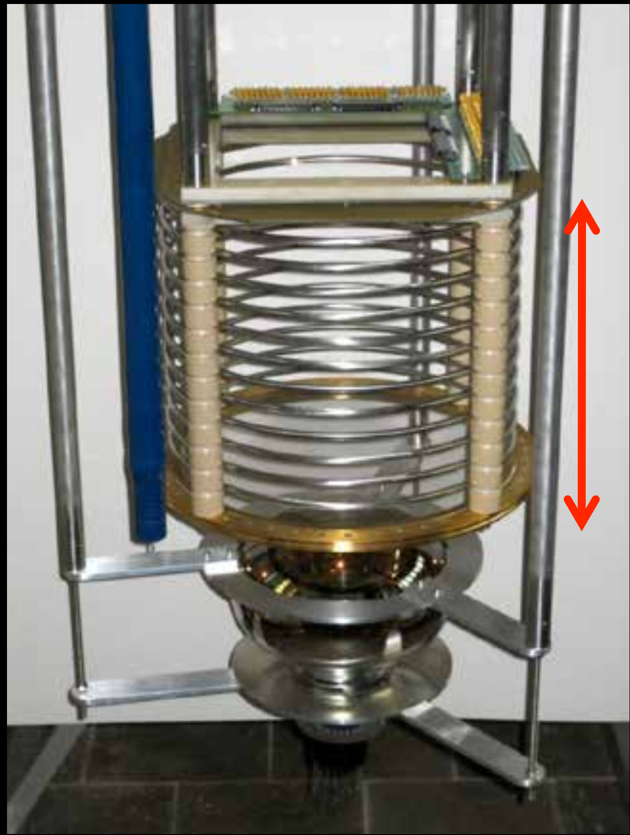
- describe a part of the intense R&D work in progress worldwide on LAr TPCs in view of future neutrino oscillation projects
- example: Bern group activities since several years aimed at LBL future projects such as LAGUNA, LAGUNA/LBNO (see next talk)
- this work that can also be useful for short time-scale experiments (SBL configuration) according to a graded strategy
- notable example: MicroBooNE at Fermilab
- another long-term LBL applications, LBNE, is the subject of the next-to-next talk

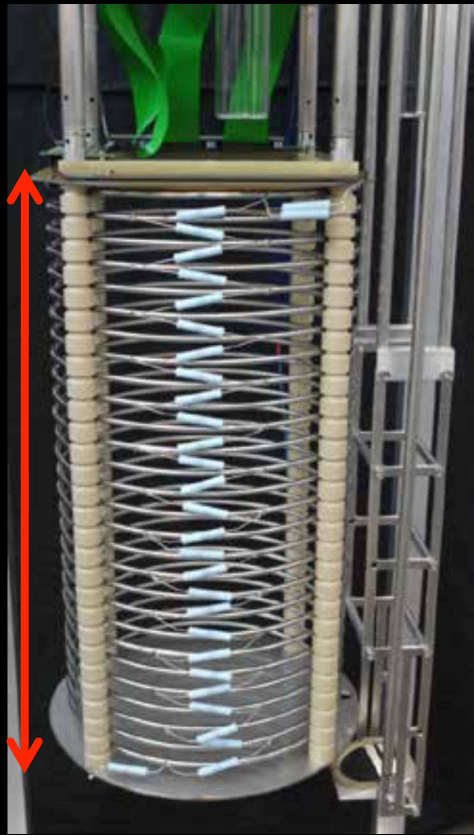
R&D issues for LAr TPCs

- realize XXL observatories: long drift distance is an issue (according to the specific approach)
- readout: double phase, wire planes with cold electronics (low noise), …
- purity (recirculation), diffusion, recombination
- high voltage (how to supply and limitations)
- insulation, evacuation, mechanics,…
- calibration
- event reconstruction: exploit the rich information from the raw data

Evolution of LAr TPCs at LHEP Bern







0.5 cm **25 cm** **57 cm**

JINST 4, P07011 (2009)

New J. Phys. 12, 113024 (2010)

JINST 5, P10009 (2010)

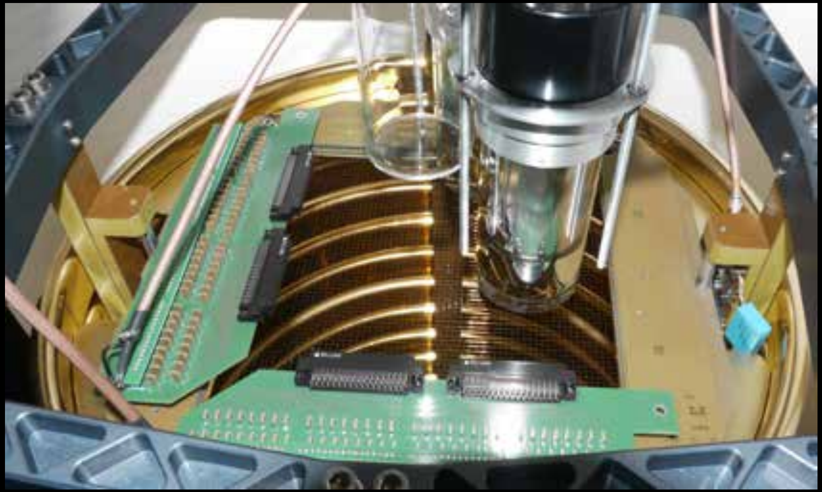
The Bern ARGONTUBE (5 m long drift)

ARGONTUBE

JINST 7 (2012) C02011

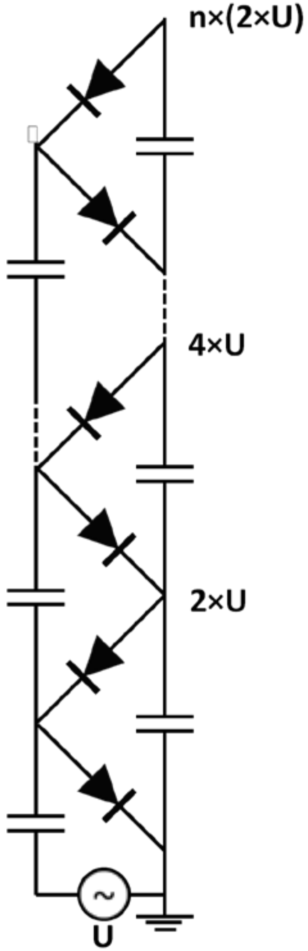
JINST 1307 (2013) P07002

- Up to 4.76 m drift distance
- About 200 l active volume (total 1200 l), 280 kg LAr
- HV generated inside by a Greinacher circuit (up to 500 kV, 1 kV/cm design values)
- 2 wire planes, 20x20 cm^2, 3 mm wire pitch, 64x64 channels
- PMT's, scintillator planes and UV-laser beams for triggering
- LAr purity: better than 0.1 ppb contaminant
- S/N ratio >10

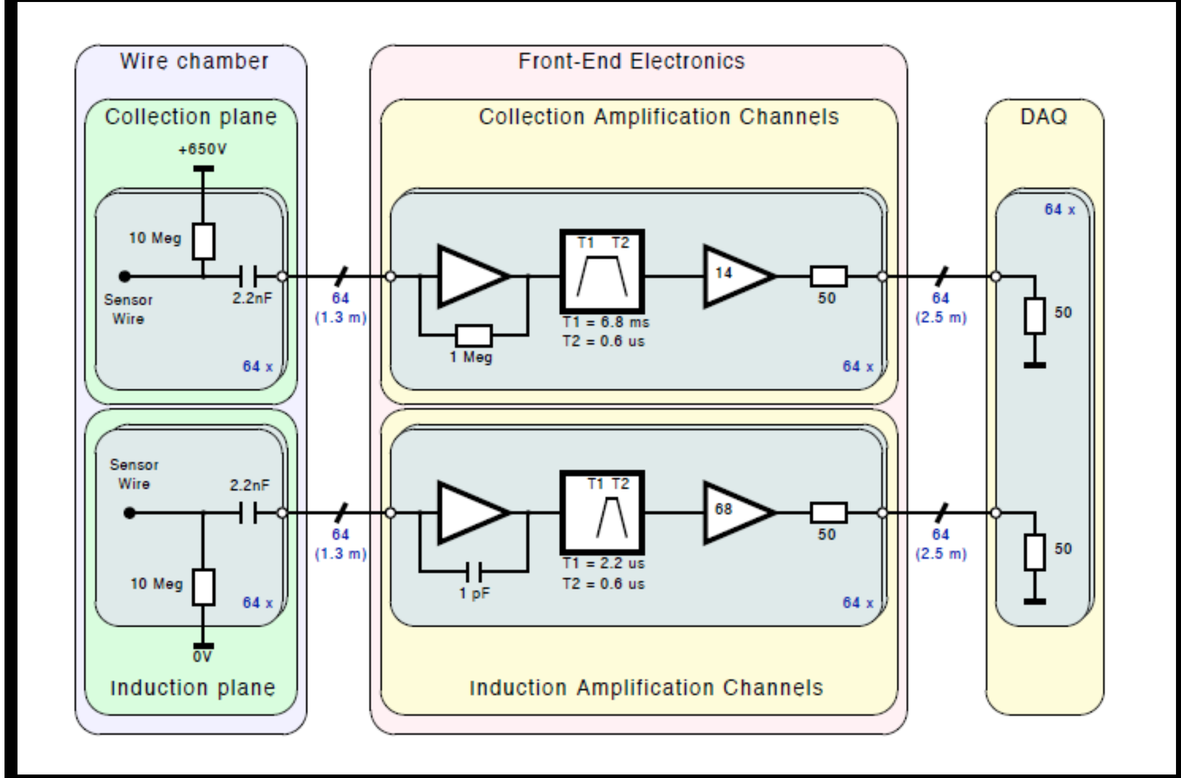


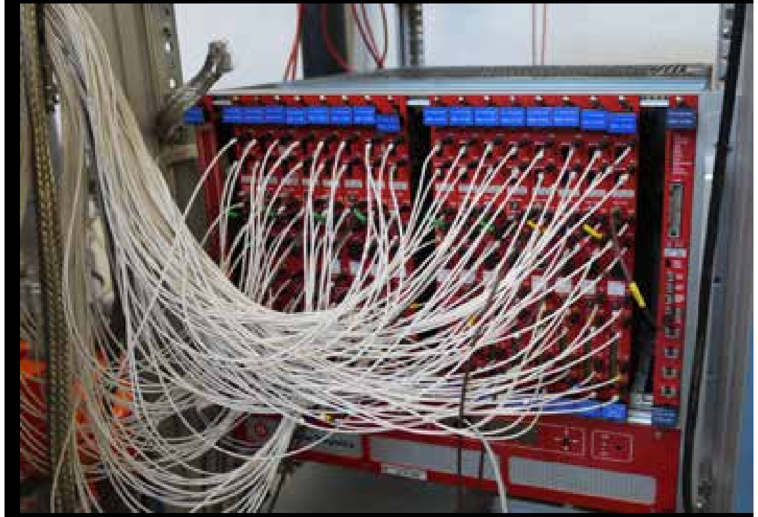
- Greinacher circuit: 125 stages, input 4 kV AC
- COMSOL finite element analysis software to optimize the geometry of the field-shaping rings
- Goal: drift field of 1 kV/cm
- Reached 170 kV (0.34 kV/cm)

The use of Greinacher for LAr detectors was originally proposed by the ETHZ group: J.Phys.Conf.Ser. 308 (2011) 012027



R/O electronics





CAEN v1724 (ADC) + v2718

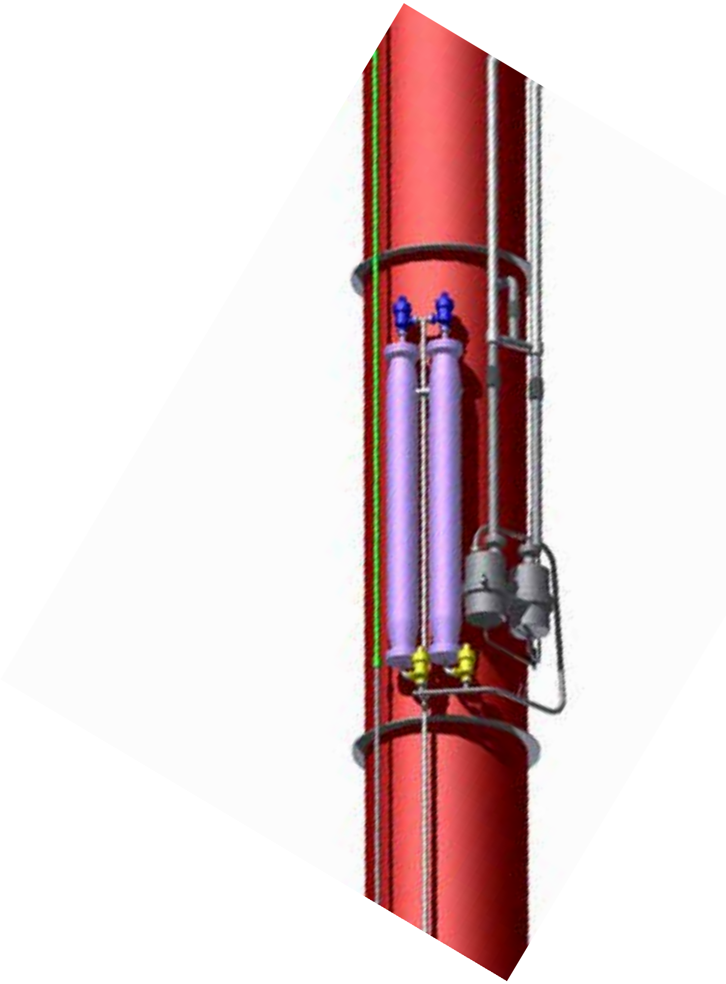
e^- speed: 2mm/μs → max drift time: 2500 μs (@ 1 kV/cm)

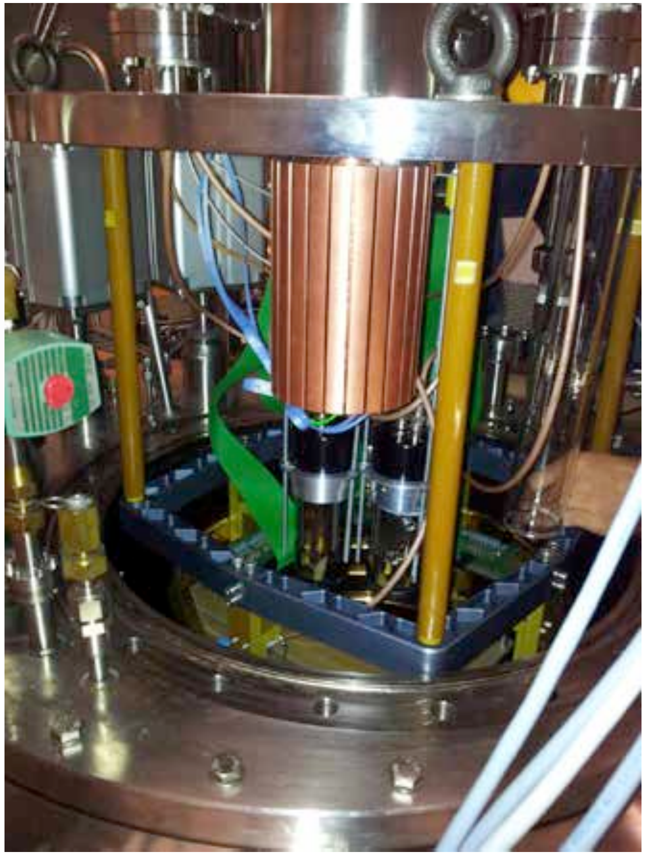
ARGONTUBE operation: 100-1000 ns sampling time

Cryogenics & purity

LAr recirculation system:

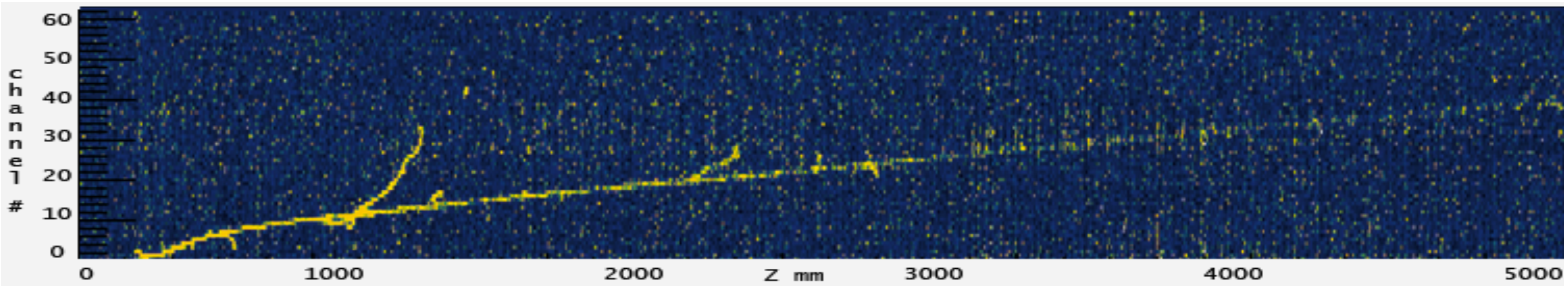
- first cleaning stage at filling, continuous liquid recirculation through filters with bellow pumps
- standard purification cartridges: active copper





Cryo-cooler to run 24/7 long term without refilling

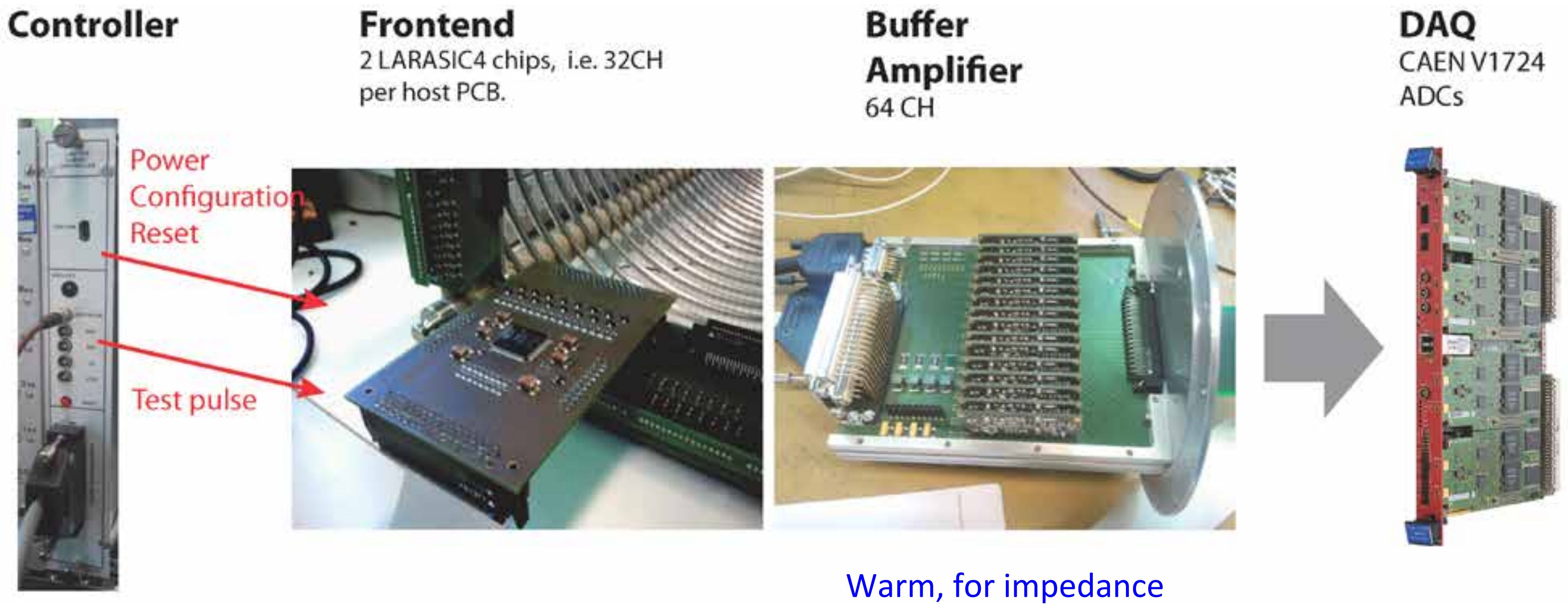
Long drift tracks (cosmic-rays) routinely detected



(compressed aspect ratio!)

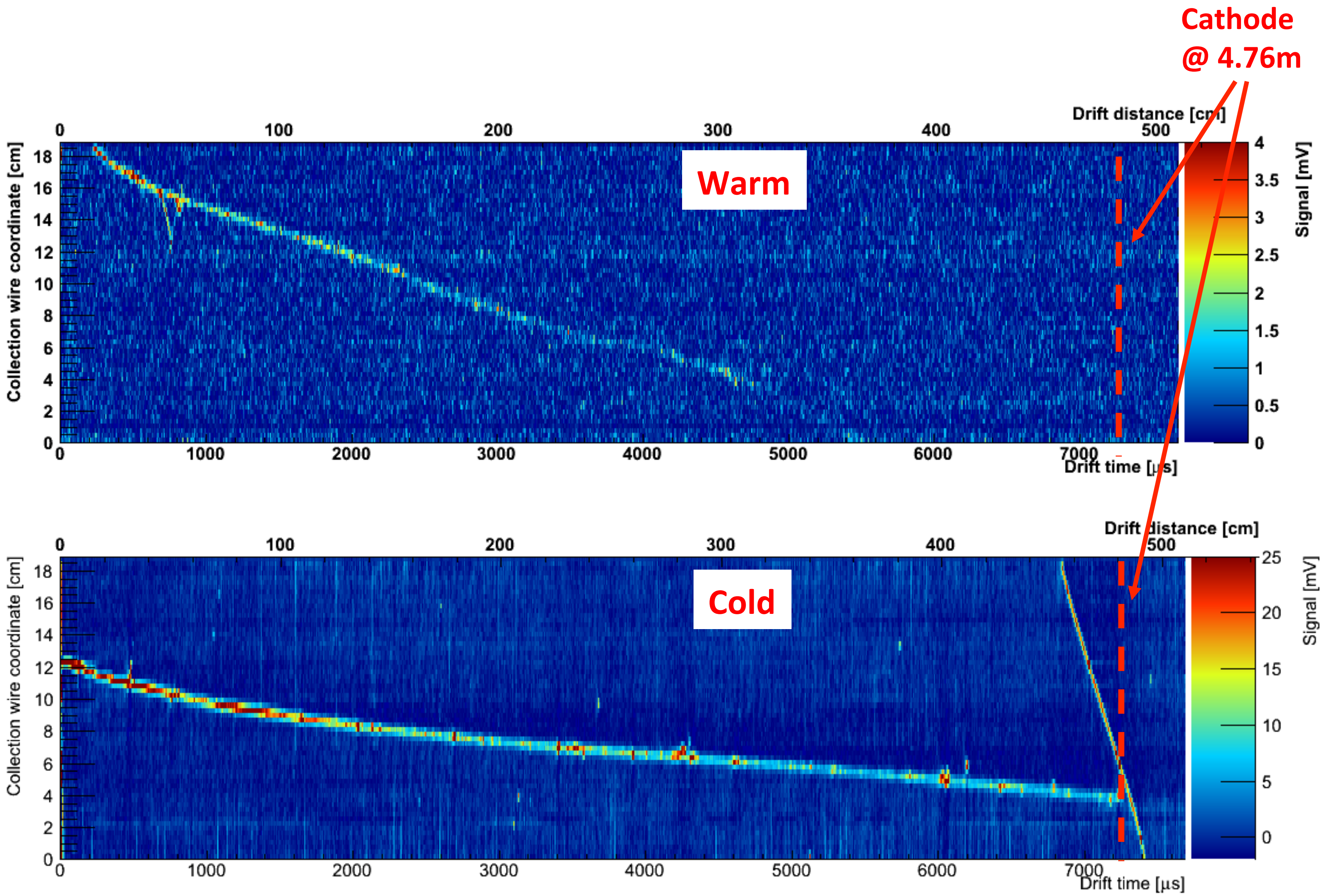
Cold electronics tests

- Preamplifiers immersed in LAr at 87 K
- Advantages:
  - Directly on the wire planes, close to signal source. Avoids long cables between wires and preamps (reduce noise from pickup on the way, cable capacitance,…)
  - @at 87K: CMOS technology gives lower thermal noise, higher gain and higher speed
  - Easier design of cryostat and cable feedthroughs
- Configurable (gain, timing, …) CMOS ASIC chip (LARASIC) designed by BNL:
  V. Radeka et al, BNL and FNAL
  iopscience.iop.org/1742-6596/308/1/012021/pdf/1742-6596_308_1_012021.pdf
- ARGONTUBE: test chips in a real environment with long tracks and make comparison with warm electronics

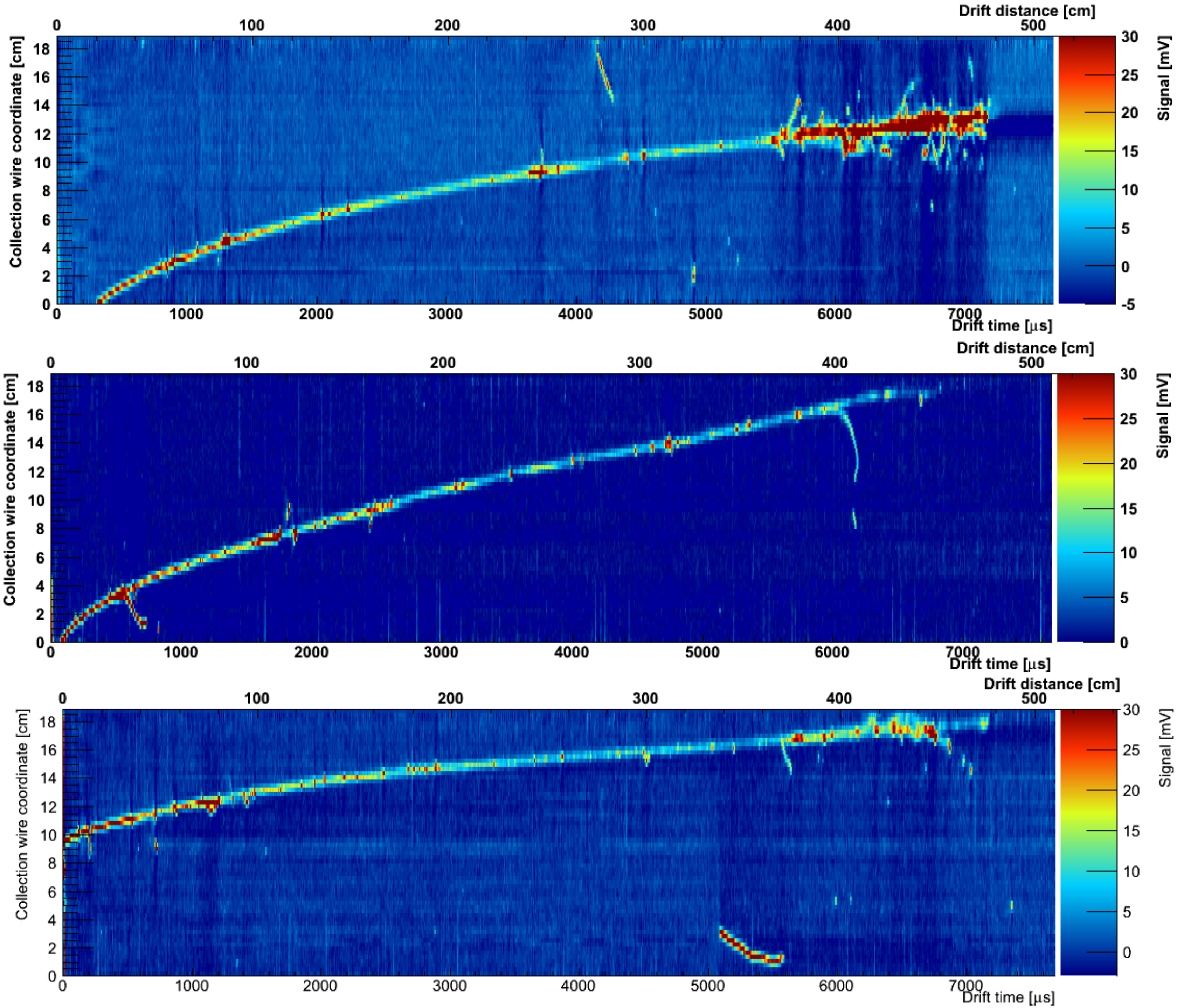


Warm, for impedance
matching (gain 1)

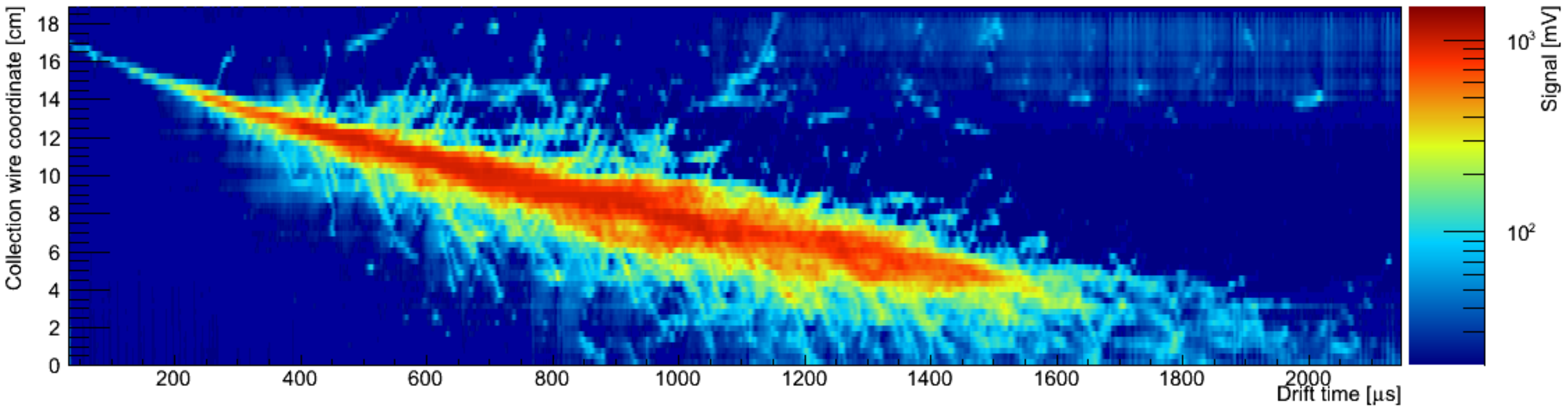
(Warm electronics running in parallel for comparison)

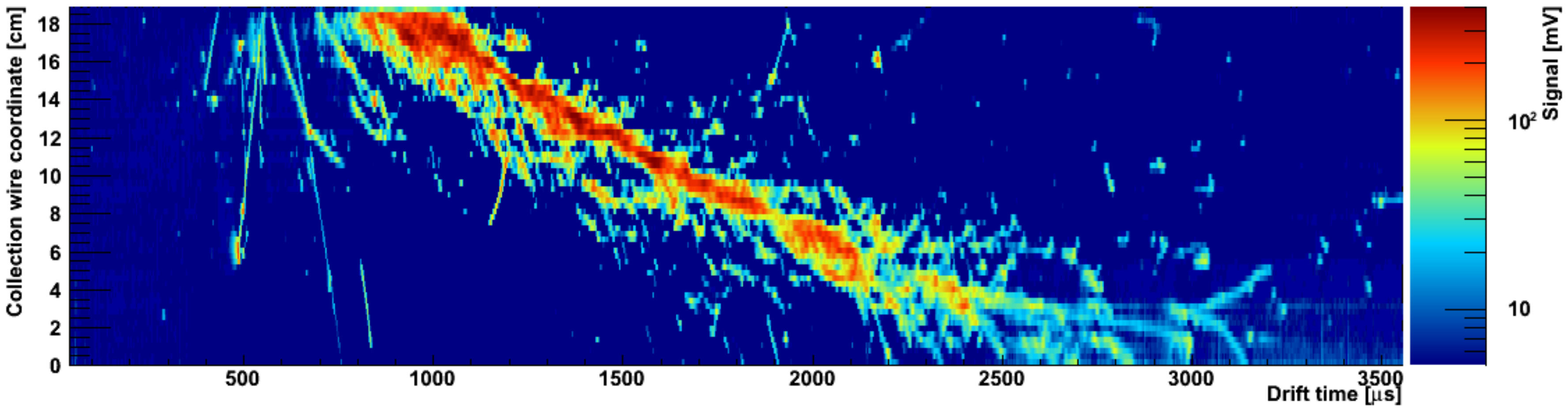

Cathode
@ 4.76m
Warm
Cold
Drift distance [cm]
Drift time [µs]
Collection wire coordinate [cm]
Signal [mV]

Cold electronics

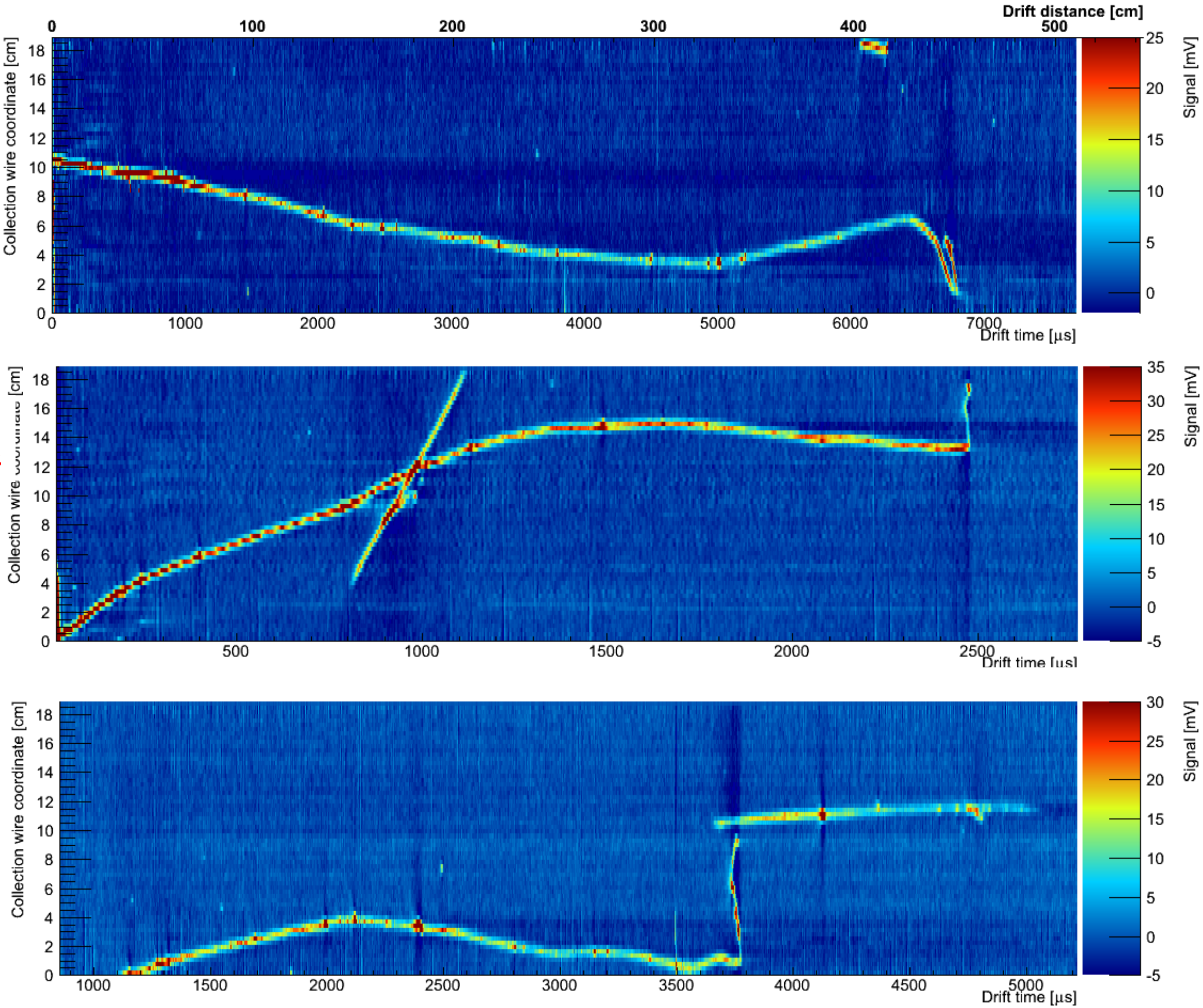


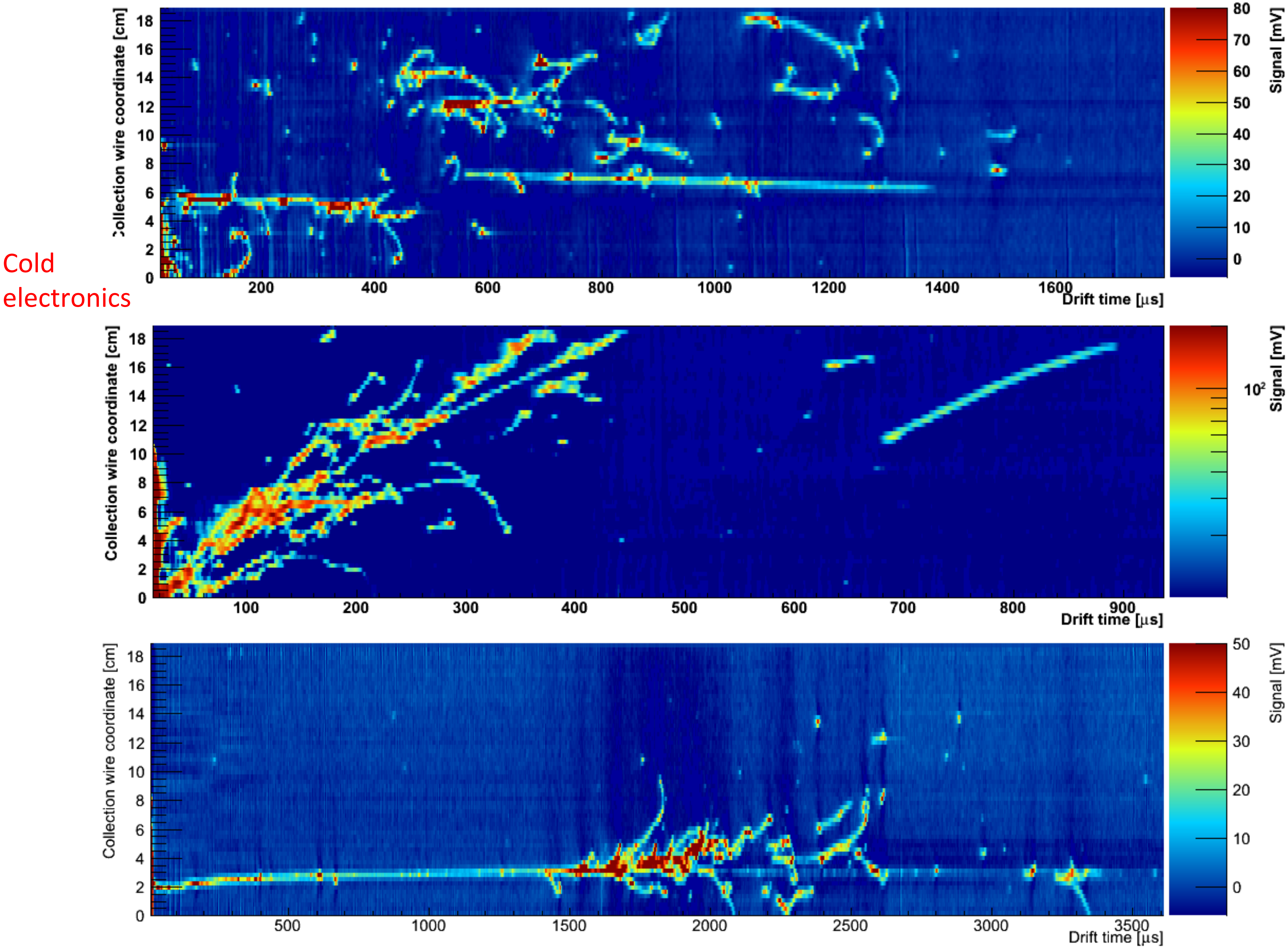
Cold electronics



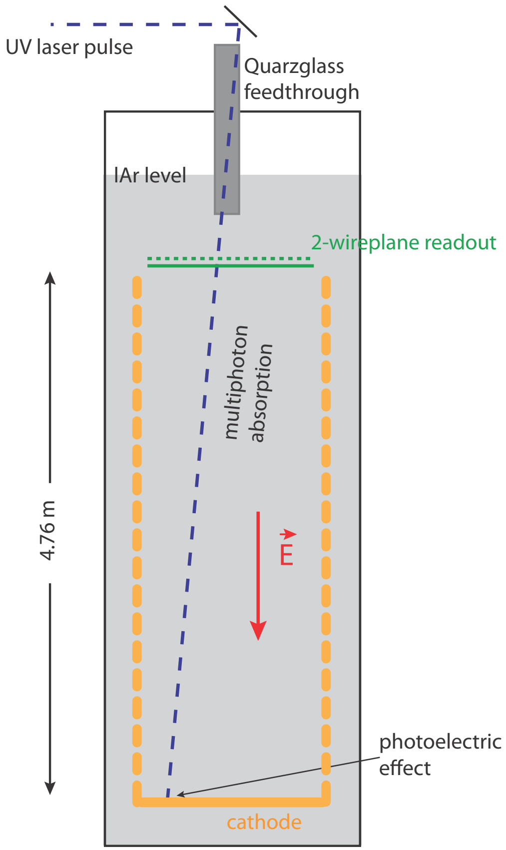


Cold electronics

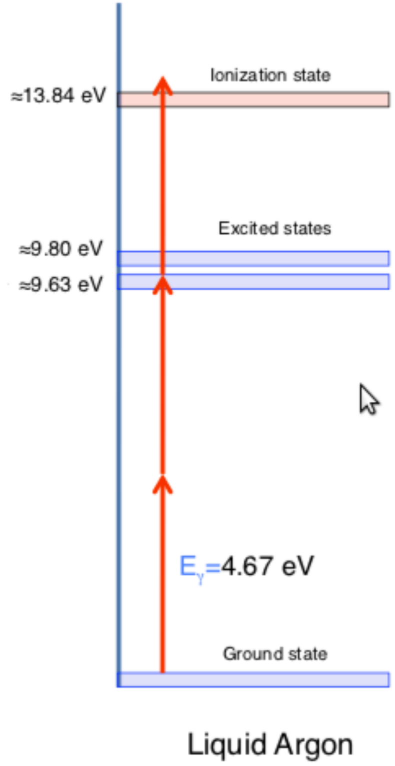



Cold electronics
Collection wire coordinate [cm]
Drift time [μs]
Signal [mV]
Collection wire coordinate [cm]
Drift time [μs]
Signal [mV]
Collection wire coordinate [cm]
Drift time [μs]
Signal [mV]

UV-laser calibration

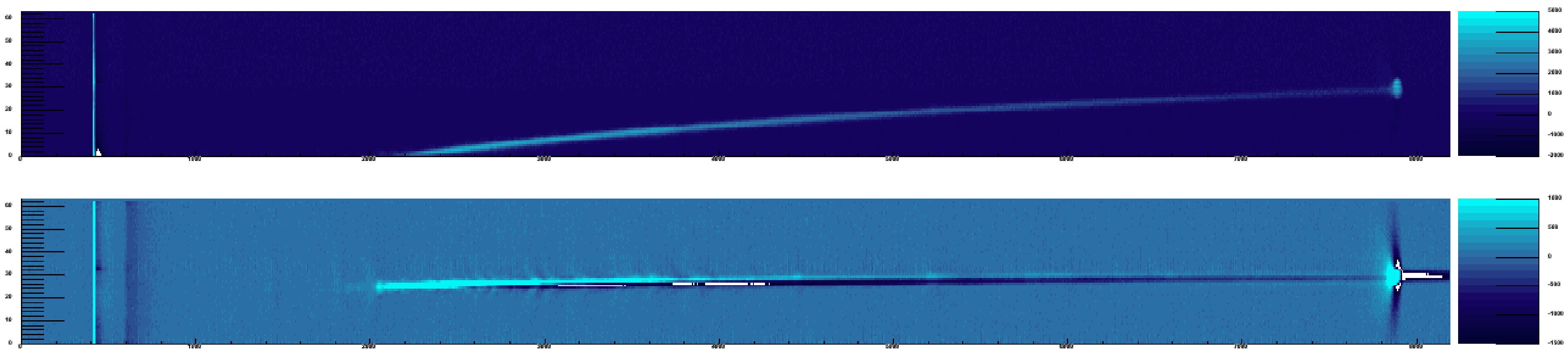


LHEP Bern pioneered the use UV laser-beams to ionize LAr by a multi-photon process

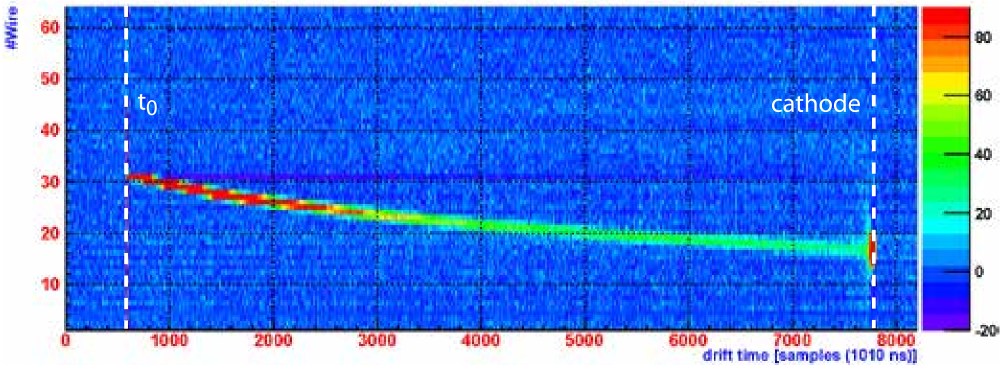


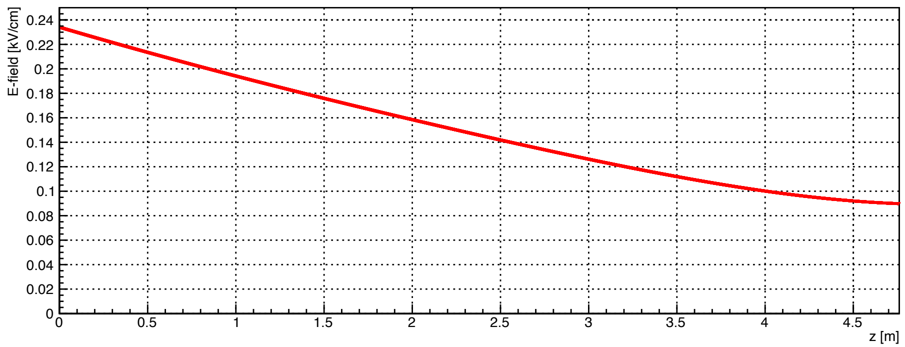
→ 2009 JINST 4 P07011
NJP 12 (2010) 113024

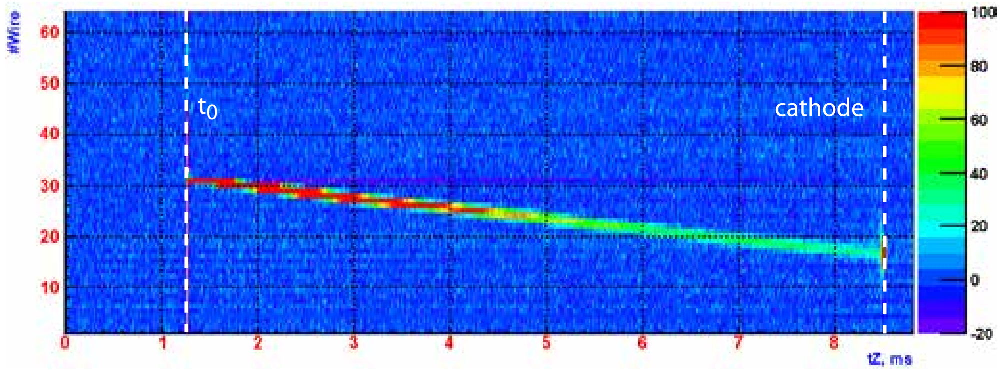
Exploit the technology to generate calibration "tracks" to correct for: space charge effects, local accumulation of ions leading to field distortions



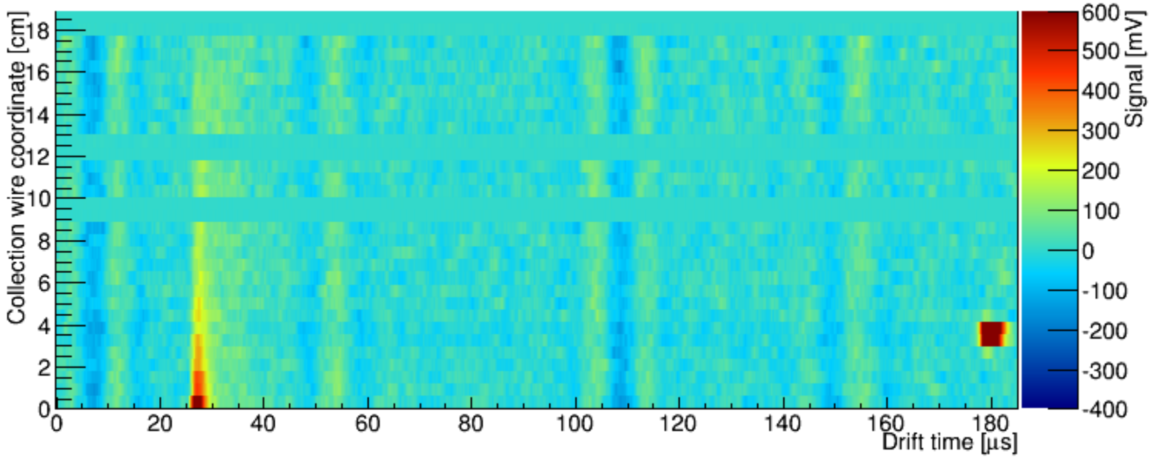
Example of track correction for E-field disuniformities

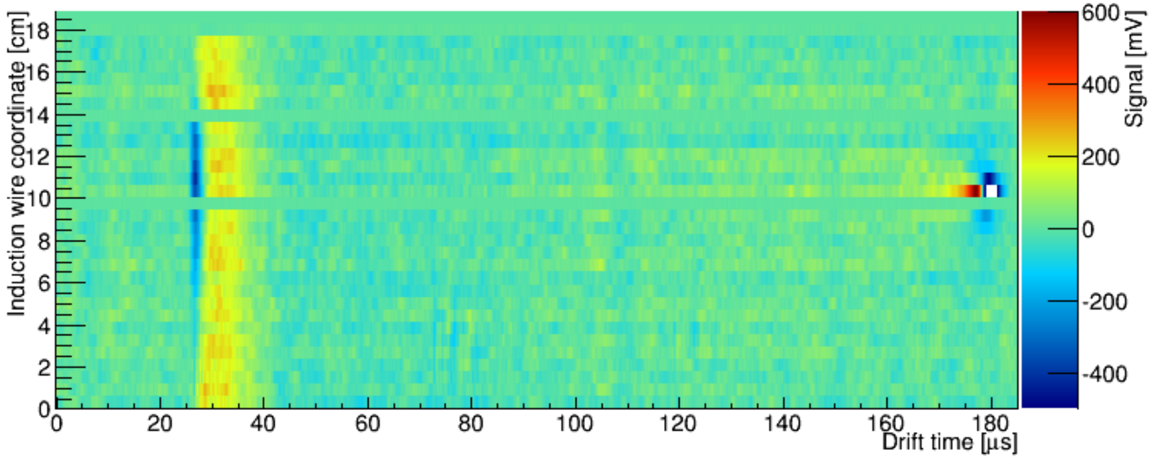




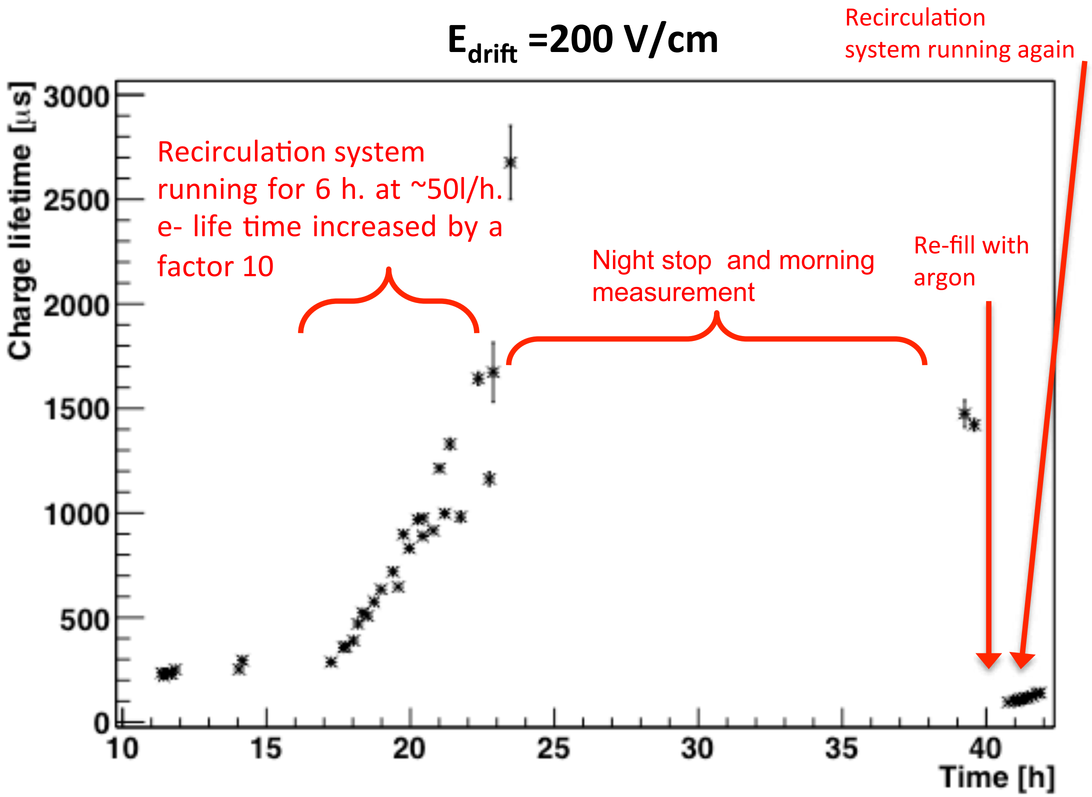


Moving UV-laser beam in LAr
(for the needs of the MicroBooNE experiment, see later)





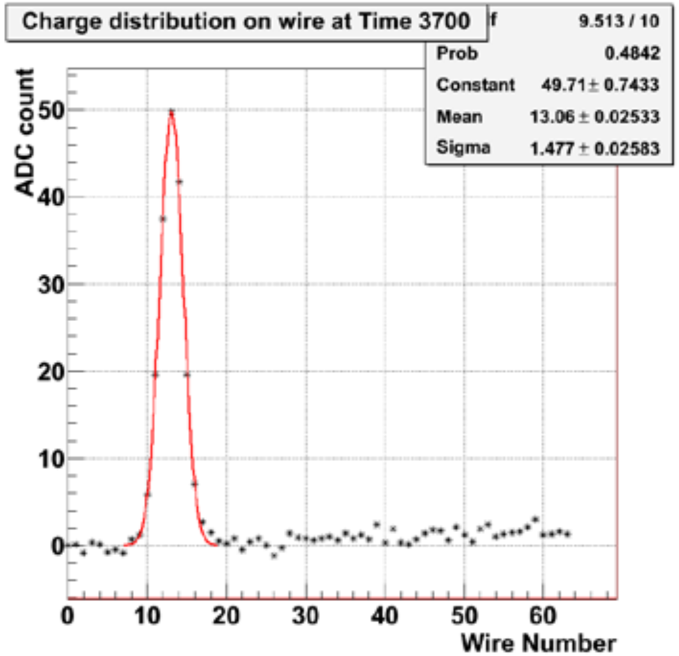
Application: measurement of purity by UV-laser tracks

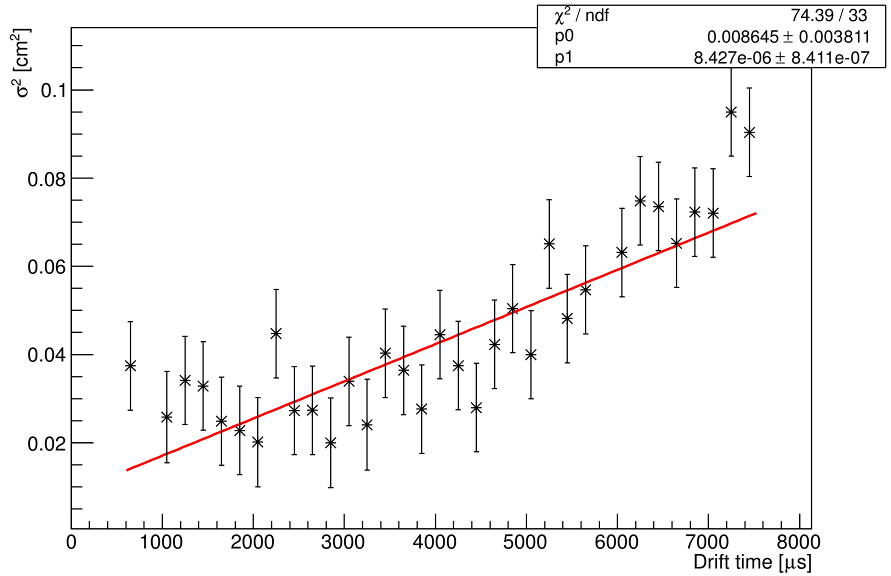


ARGONTUBE routine operation: 2.5 ms lifetime (0.12 ppb Oxygen equivalent)

Physics result from ARGONTUBE:
measurement of transverse charge diffusion (by laser beams)

$$D = \frac{\sigma^2 - \sigma_0^2}{2t}$$





$D = 4.21 \pm 0.42\ \mathrm{cm^2/s}$

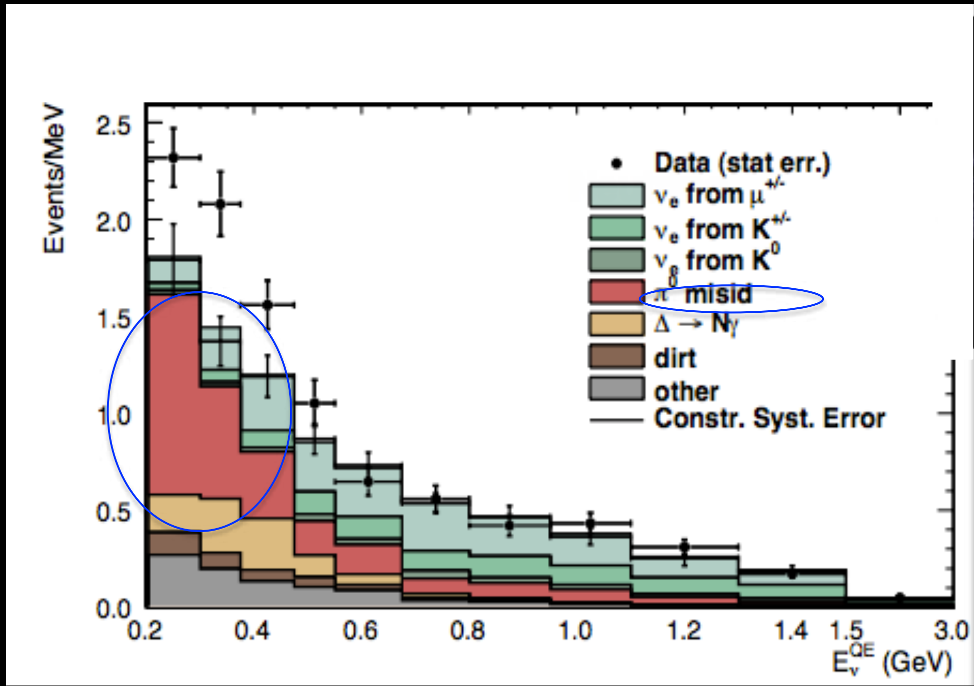
Notable physics case for future SBL oscillation experiments

- we entered the era of precision measurements of neutrino oscillations
- liquid argon TPCs also perfectly suited for X-section studies (particle ID) and SBL accelerator experiments
- physics goal: assess the completeness of the 3-flavor mixing scenario vs additional sterile neutrinos (LSND and MiniBooNE signal/indications)
- long standing issue with anomalies in:

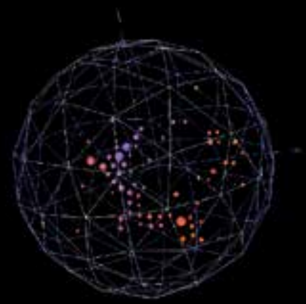
$\nu_\mu - \nu_e$ and $\bar{\nu}_\mu - \bar{\nu}_e$ oscillations

- is it a real signal of new physics or an unknown background ?

MiniBooNE electron-like event excess



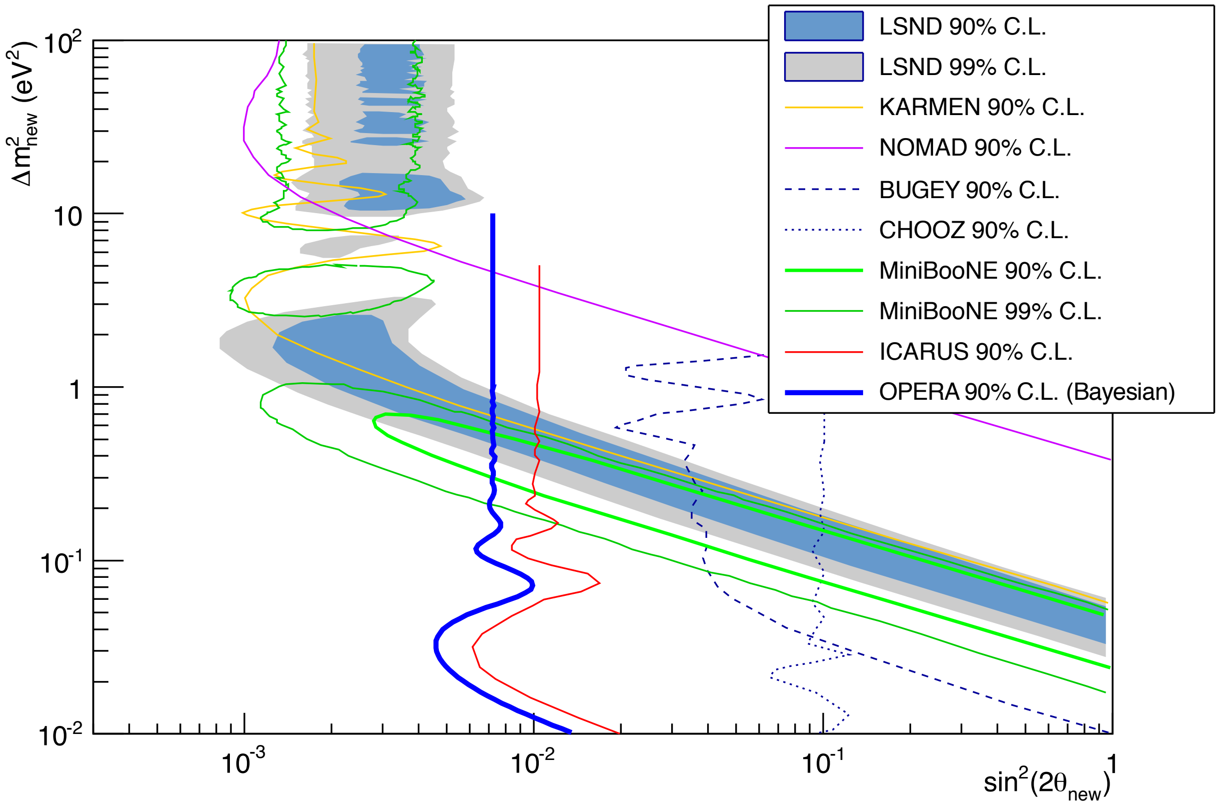
muon



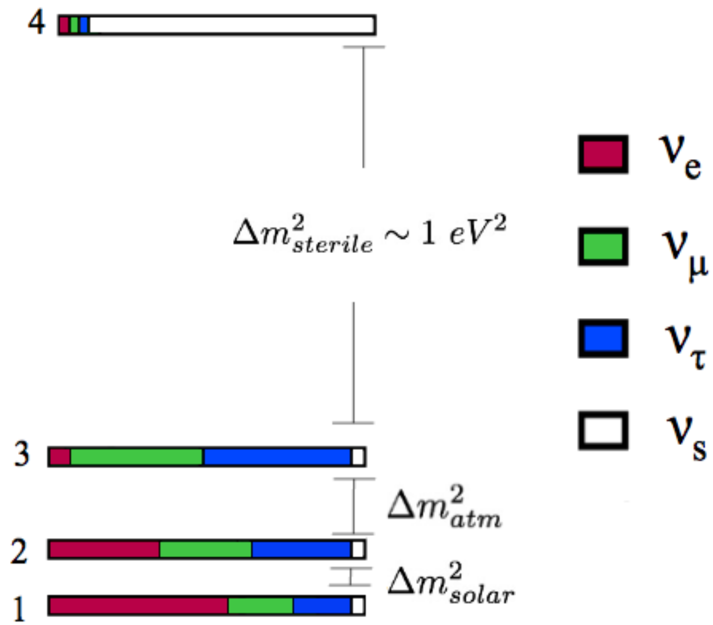
electron

neutral pion

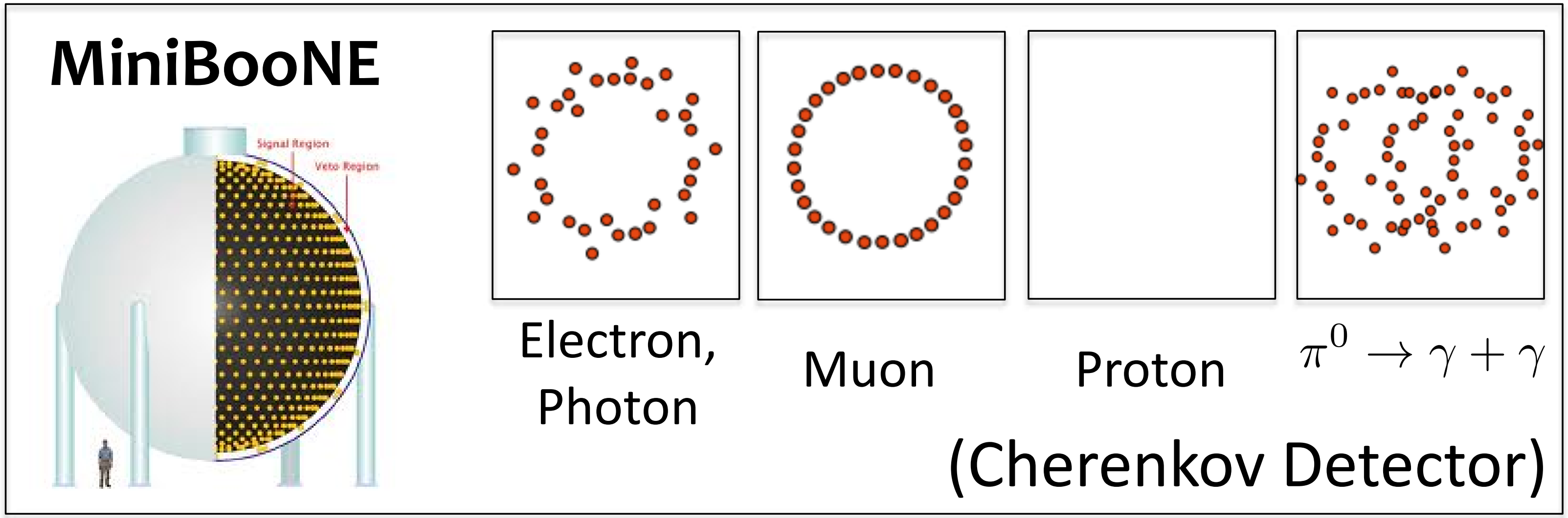
The excess translates into allowed oscillation parameters

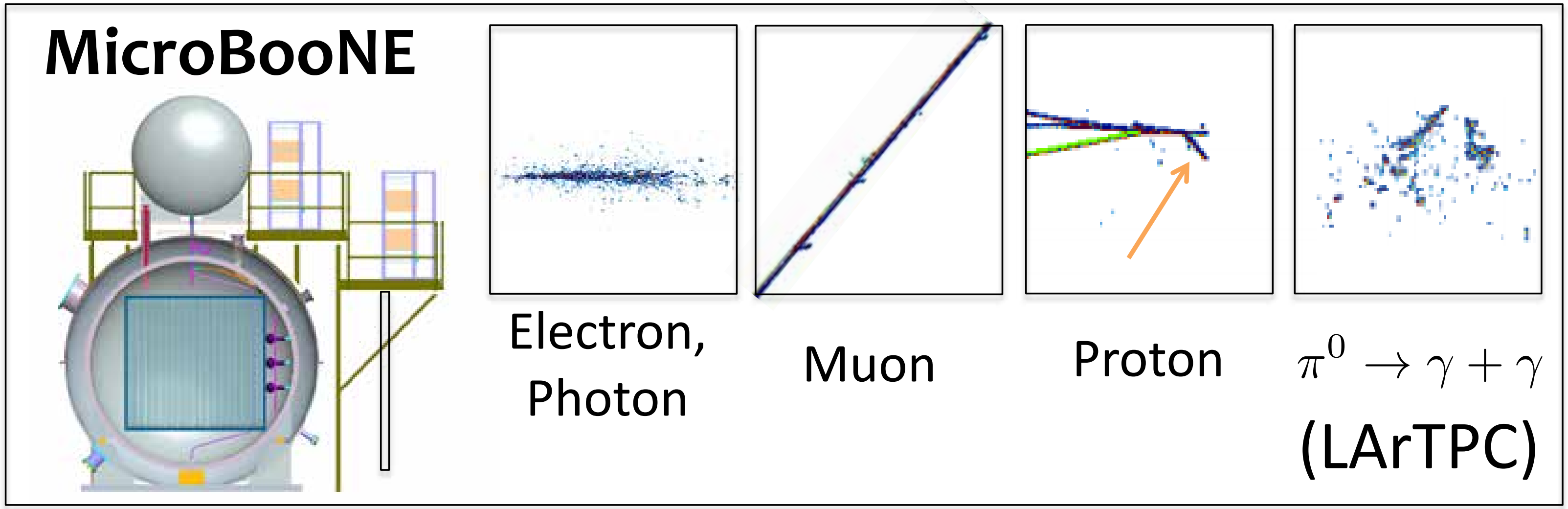


Another mass splitting parameter?
Then (at least) another (sterile) neutrino

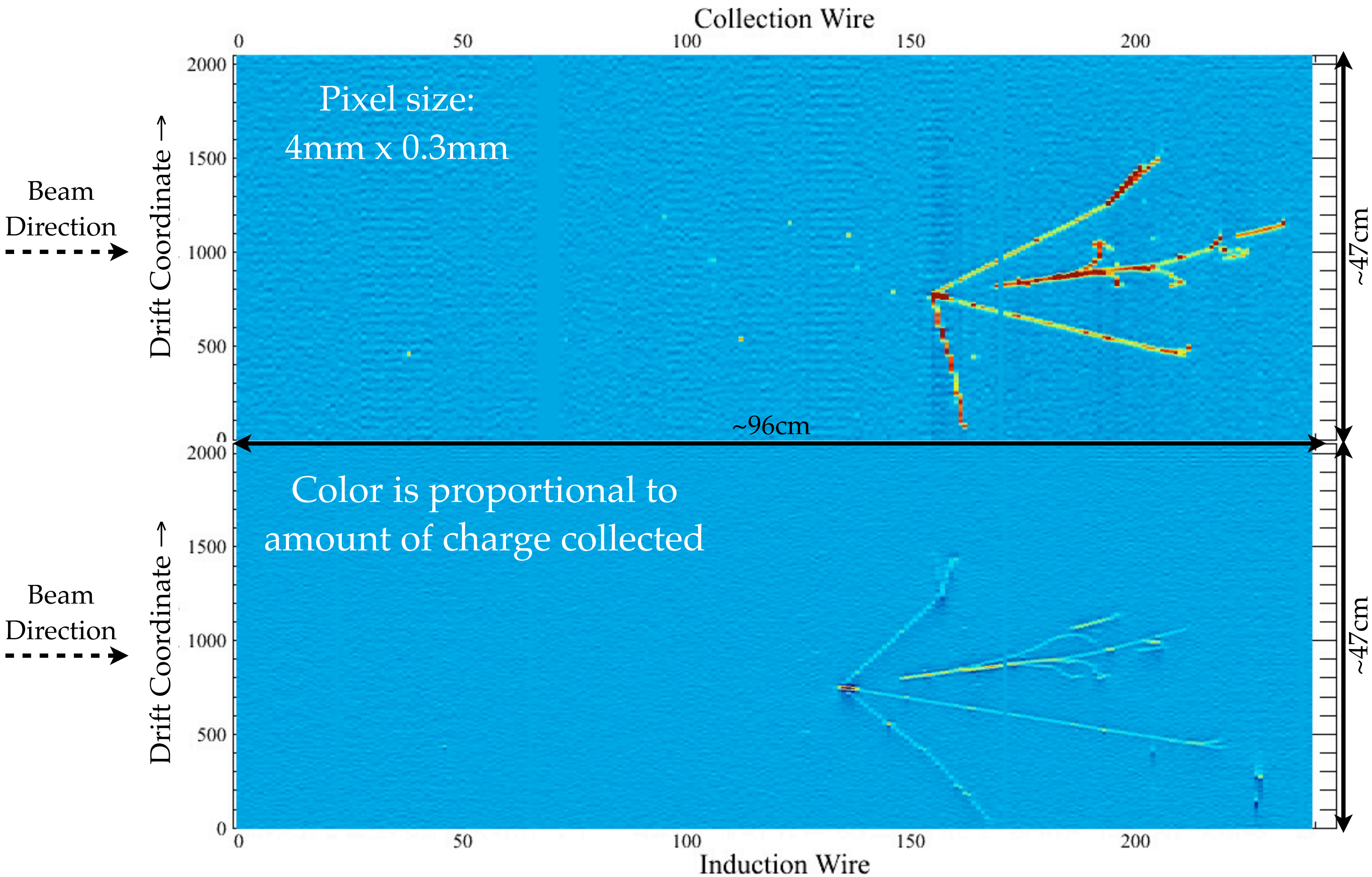


Address the LSND/MiniBooNE signal with an advanced detection technique





LAr TPC technology (ArgoNeuT neutrino-induced event)

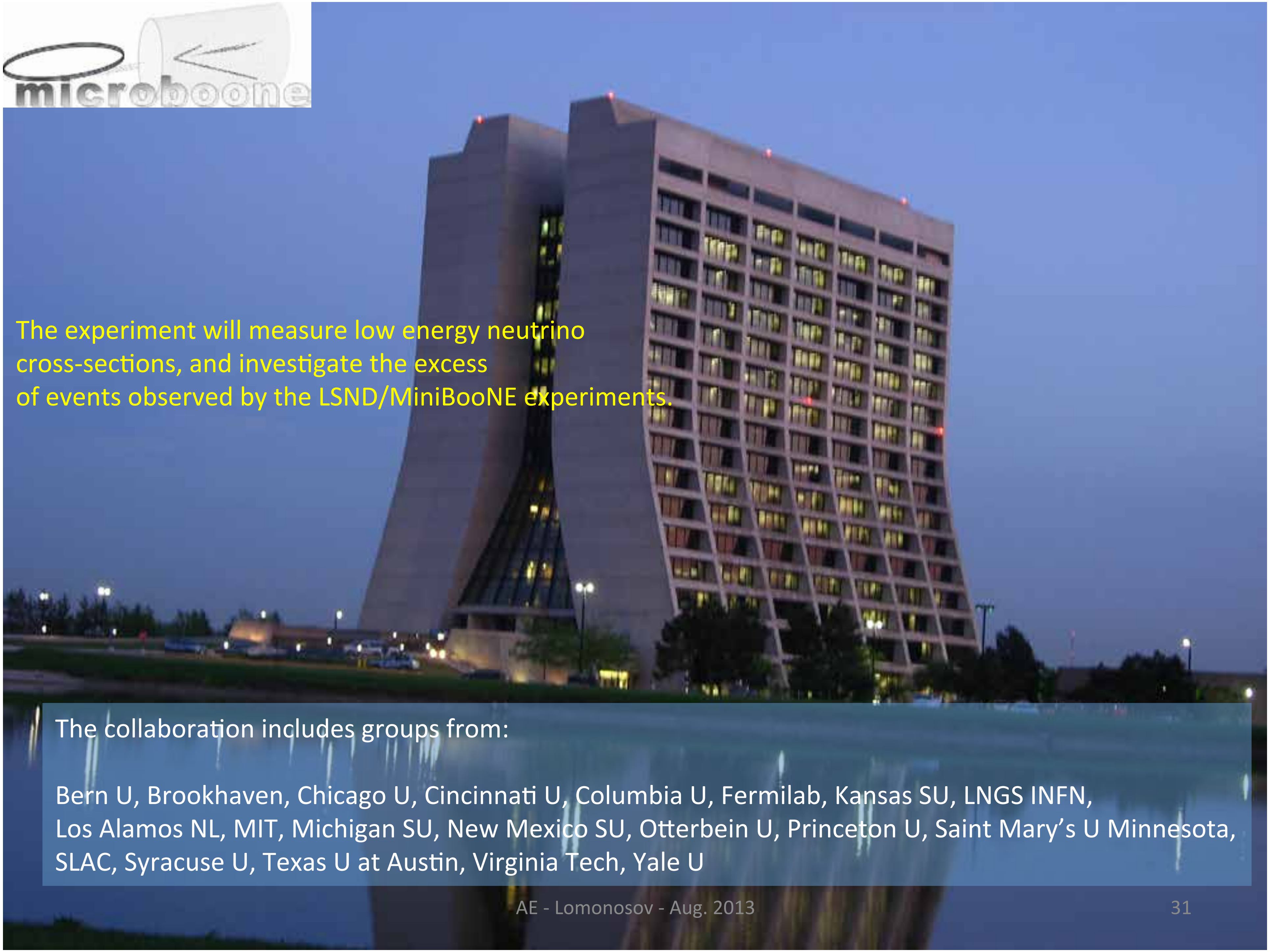


ArgoNeuT

- ArgoNeuT: 175 l of liquid Argon
- Placed in the NUMI neutrino beam at Fermilab
- 3 wire planes oriented at 60° relative to each other
- Each plane: 240 wires with 4 mm pitch
- Electric field of 500 V/cm
- 2048 samples in 400 μs

- Large samples of low-energy neutrino interactions (0.1-10 GeV) collected and analyzed:

JINST 7 (2012) P10019
JINST 7 (2012) P10020
Phys. Rev. Lett. 108 (2012) 161802
JINST 8 (2013) P08005

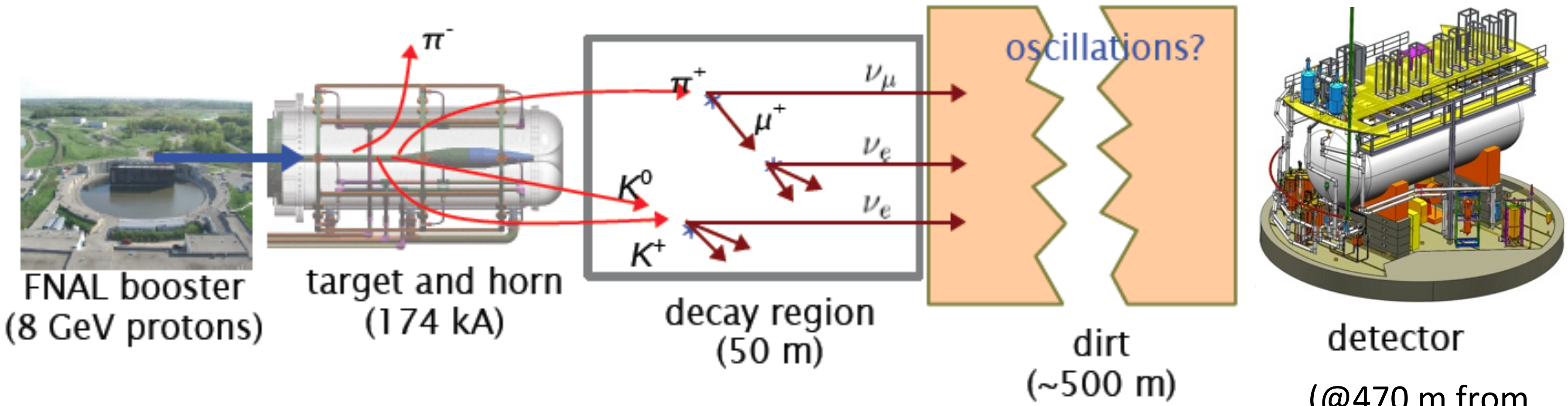


The experiment will measure low energy neutrino cross-sections, and investigate the excess of events observed by the LSND/MiniBooNE experiments.

The collaboration includes groups from:

Bern U, Brookhaven, Chicago U, Cincinnati U, Columbia U, Fermilab, Kansas SU, LNGS INFN, Los Alamos NL, MIT, Michigan SU, New Mexico SU, Otterbein U, Princeton U, Saint Mary's U Minnesota, SLAC, Syracuse U, Texas U at Austin, Virginia Tech, Yale U

MicroBooNE: a "classical" SBL oscillation experiment

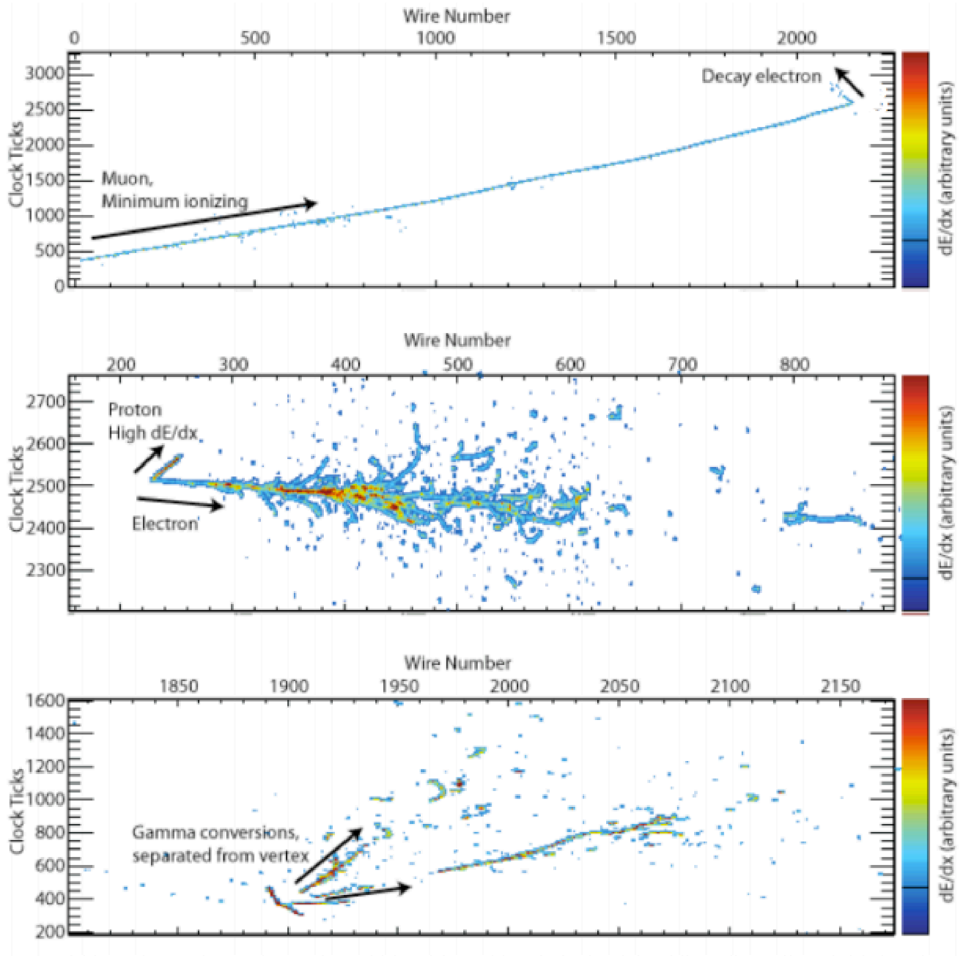


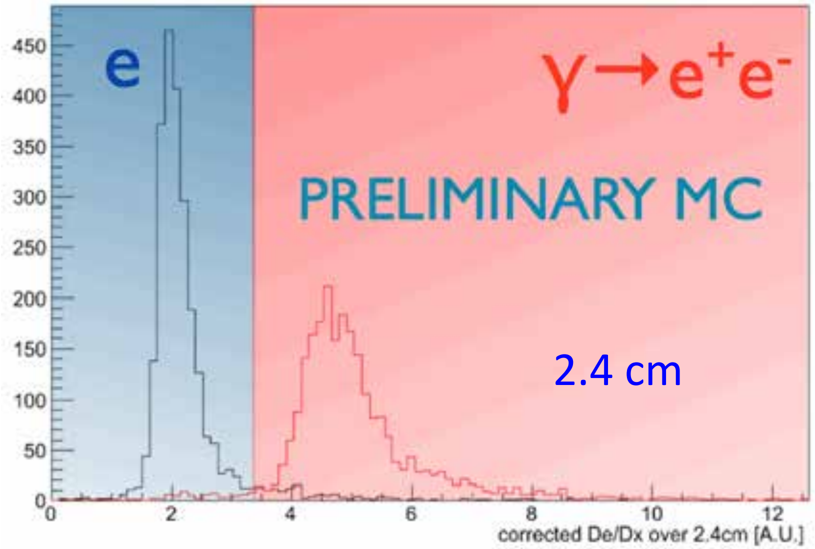
(ν_μ up to ~ 5 GeV,
peak at ~ 1GeV)

(@470 m from
the source)

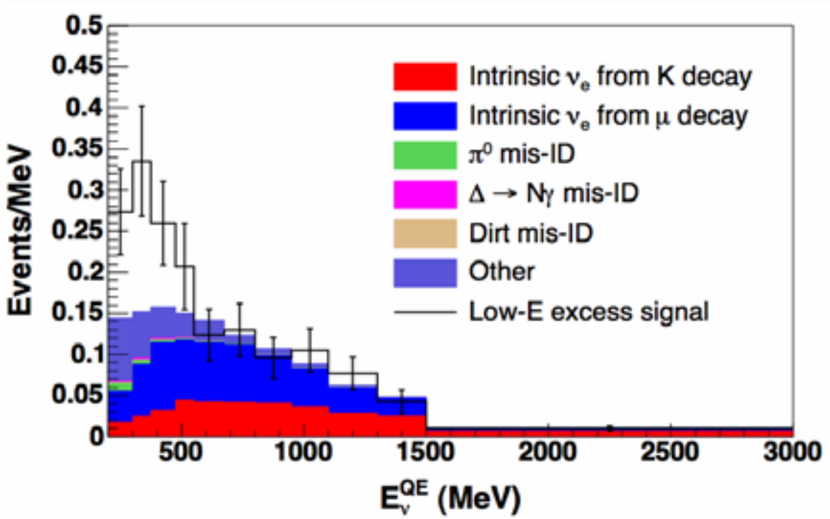
Start data taking 2014: in 3 years expect 6.6×10^{20} pot and ~140 k events (BNB)

e/γ separation performance (dE/dx + topology)





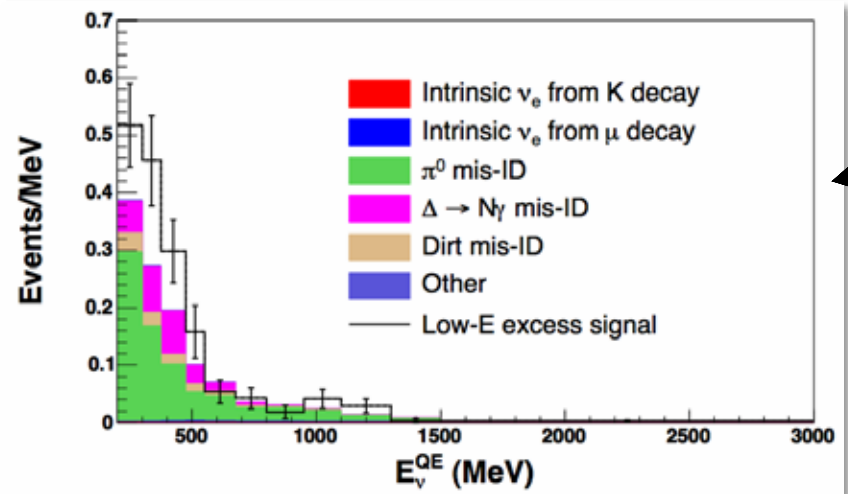
MicroBooNE oscillation physics



unlike MiniBooNE, MicroBooNE can distinguish e^-'s from γ's.

if assume an <u>electron signal</u> and have analyzed for an e^-

($>5\sigma$)



if assume a <u>photon background</u> and have analyzed for a γ
(tell if part of the MiniBooNE signal is due to γ's)

($>4\sigma$)

(projections for 6.6×10^{20} POT)

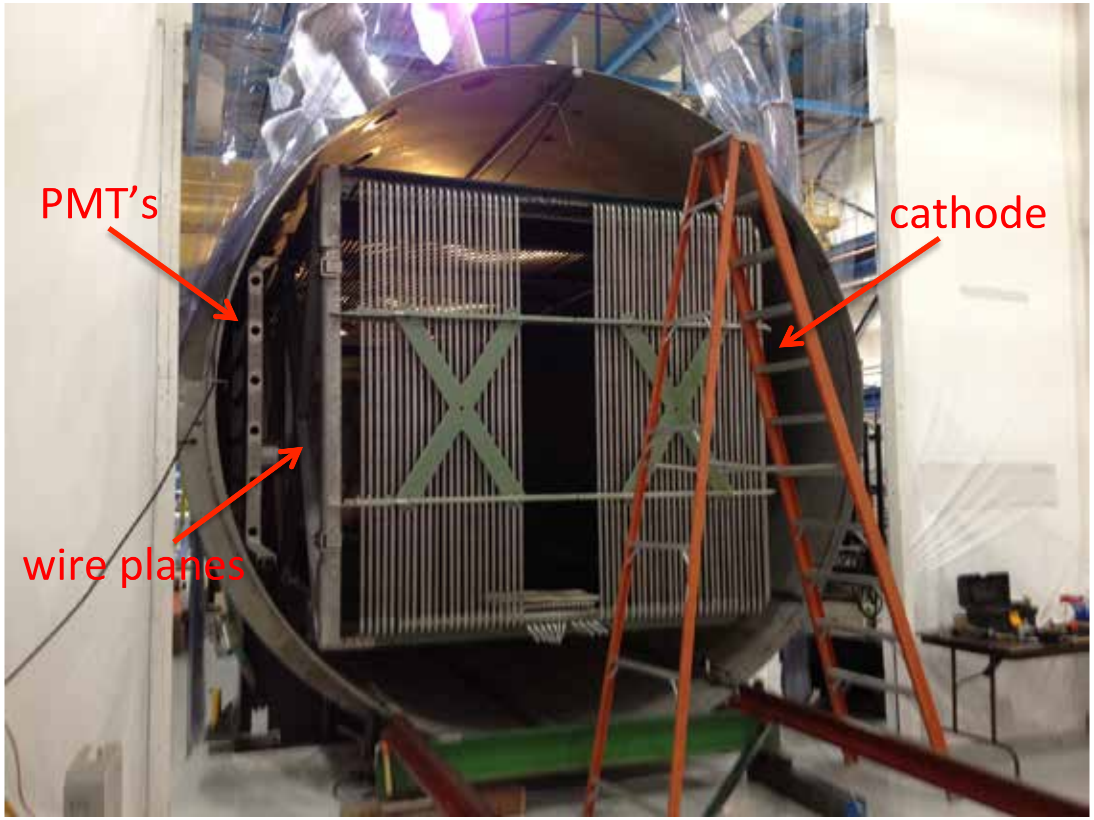
The MicroBooNE detector

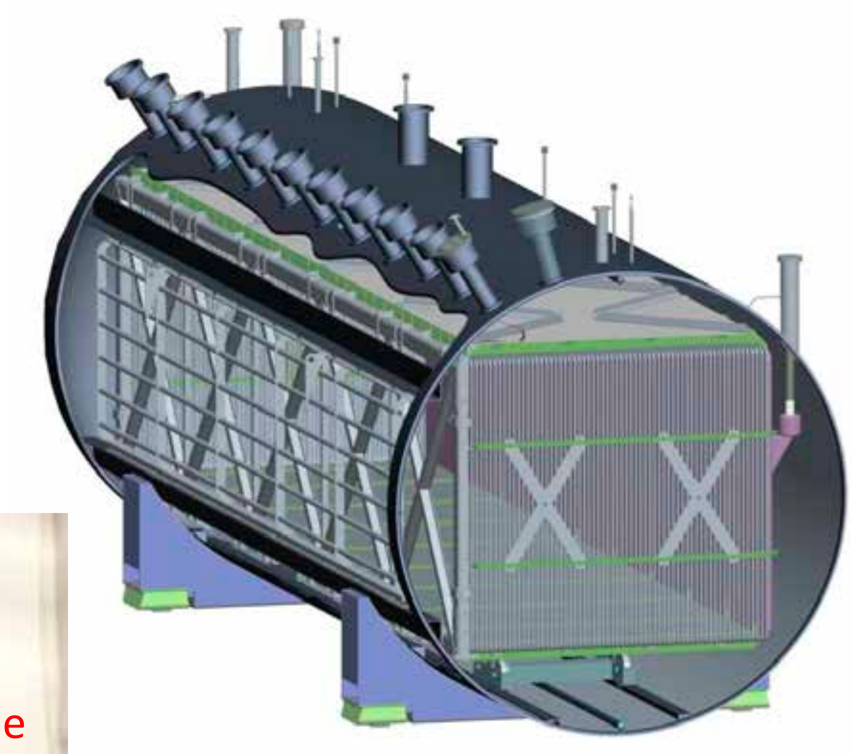
Dimensions: 10 m x 2.3 m x 2.5 m

125 kV high voltage, 2.5 m drift length

3 wire planes (3 mm pitch) Y, U, V

32 8" PMT's





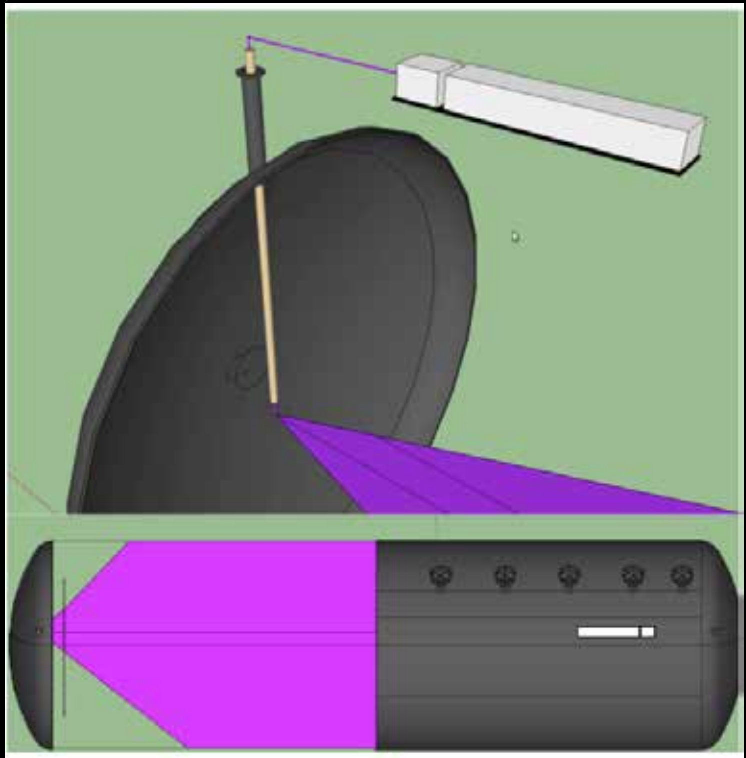

KARCHER

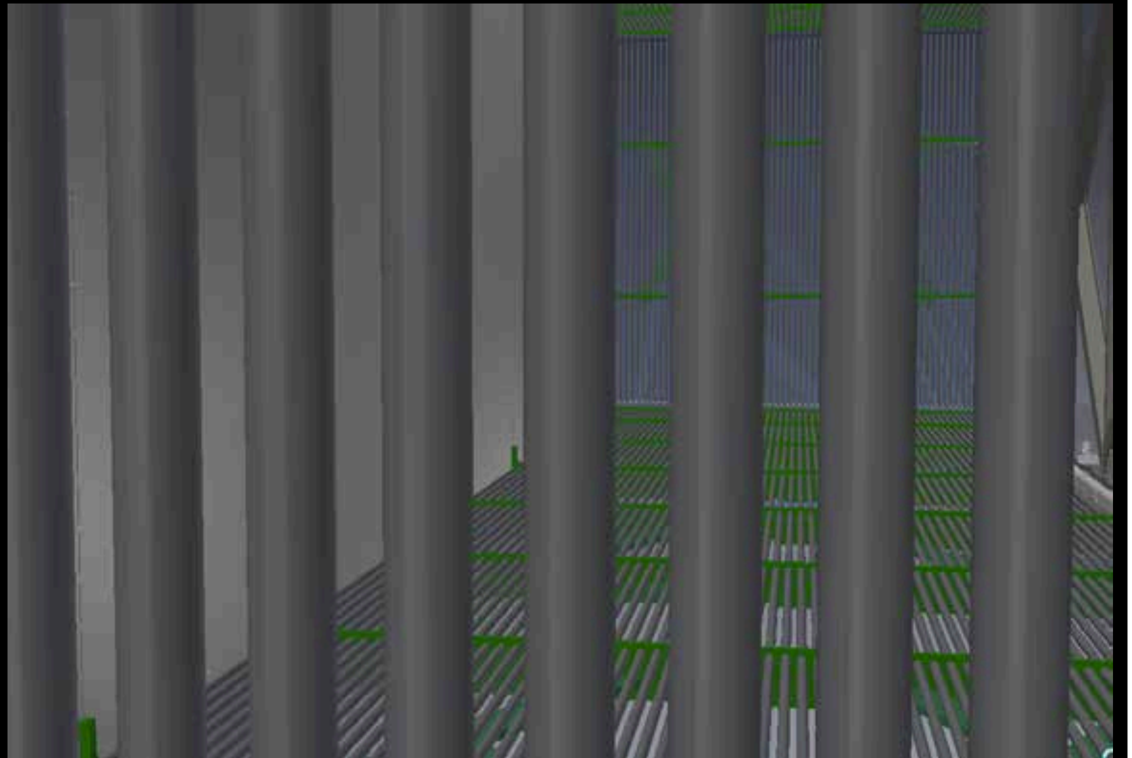
Y: vertical plane (2.5 meter long wires), U,V planes: +/- 60 degrees from vertical (5 meters long)

The experimental hall

The realization of the various sub-systems is on schedule

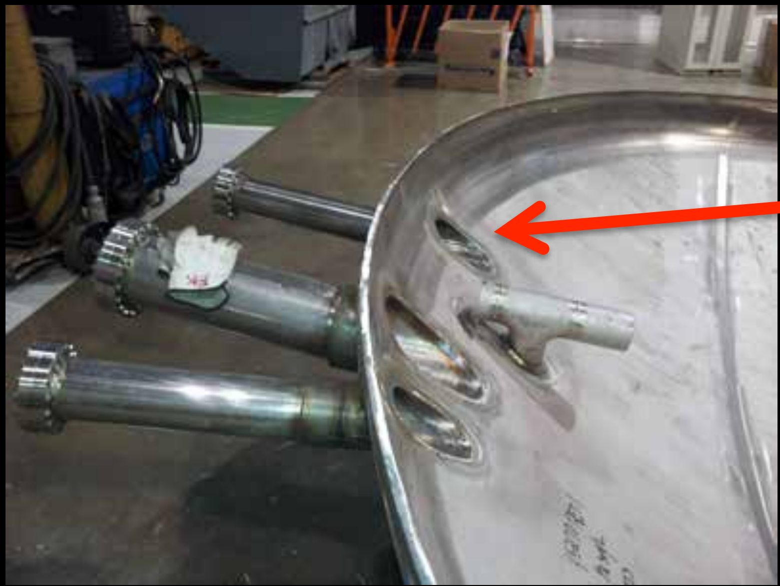
One example: the UV-laser calibration system

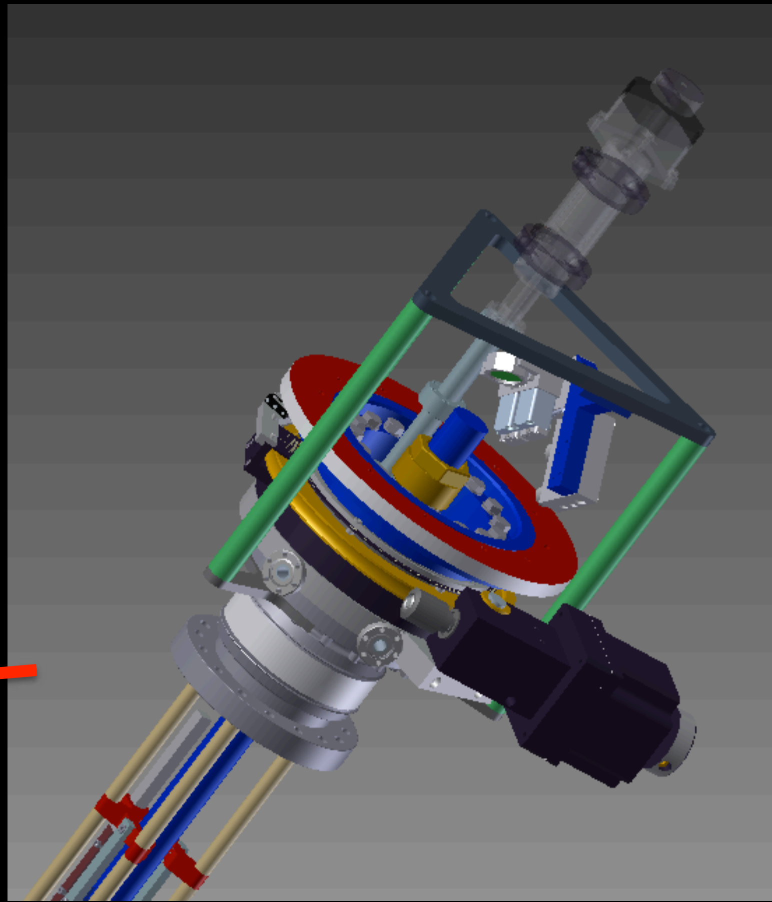




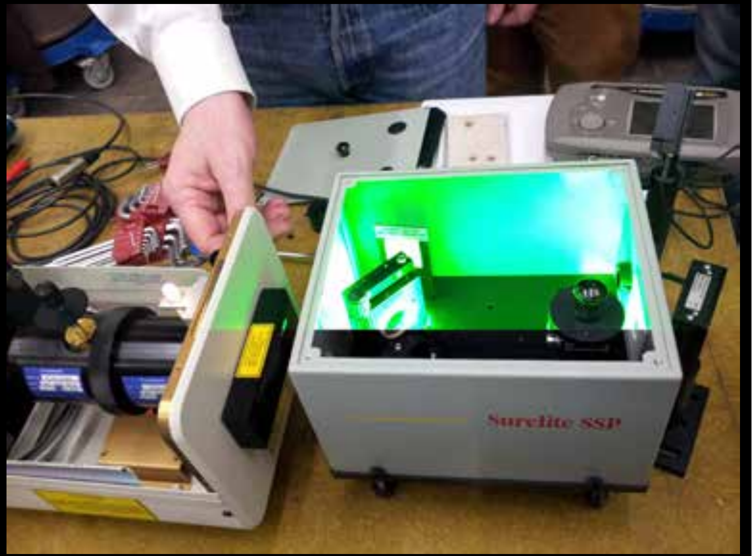
Two independent laser lines on either side of the cryostat

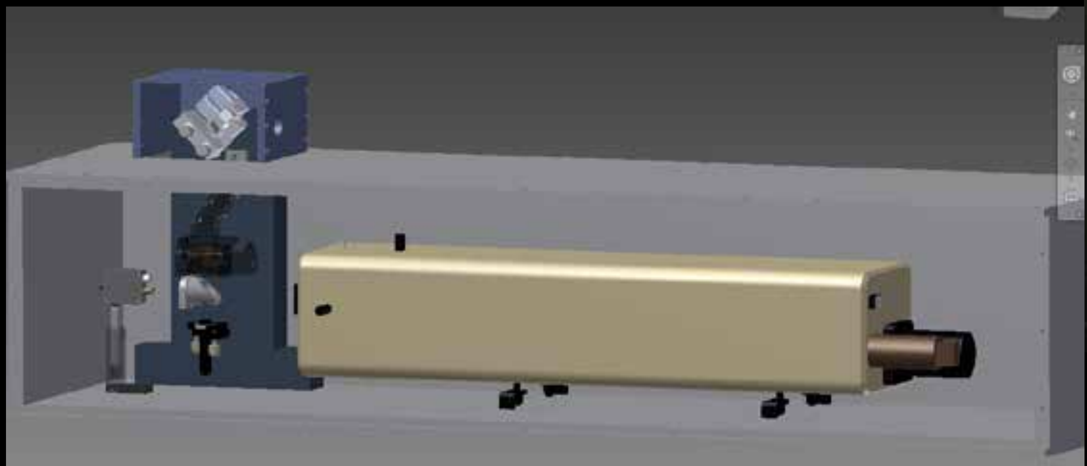
Remote controlled steered beam
(mirrors) with easy slow control





The laser source has to be in a box, due to its UV radiation





Full scale test of the MicroBooNE laser system

Спасибо за ваше внимание!