Liquid Argon TPCs
for future neutrino oscillation experiments

Antonio Ereditato

Albert Einstein Center for Fundamental Physics (AEC)
Laboratory for High Energy Physics (LHEP)
University of Bern

Happy birthday, Bruno!

Dubna, 1984

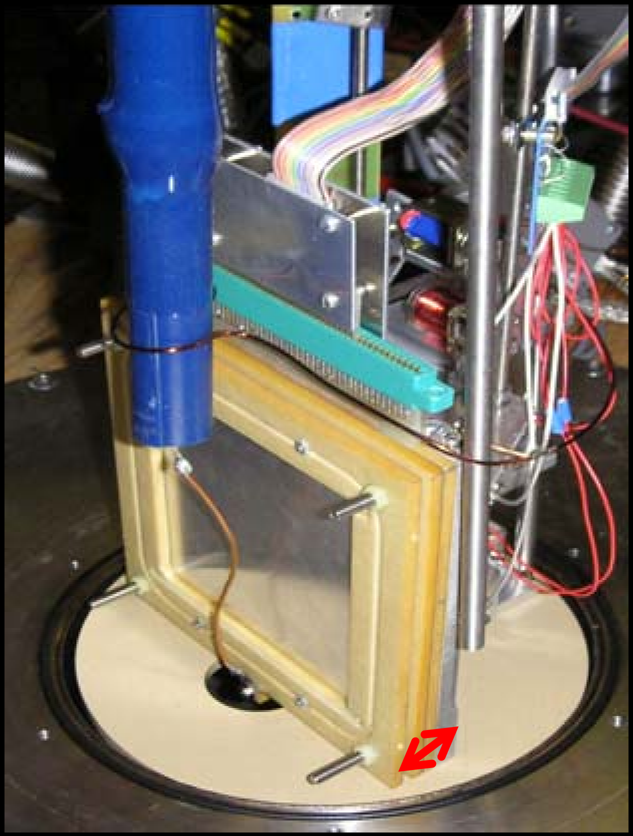
Arbitrary choice for a 25' talk

- 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

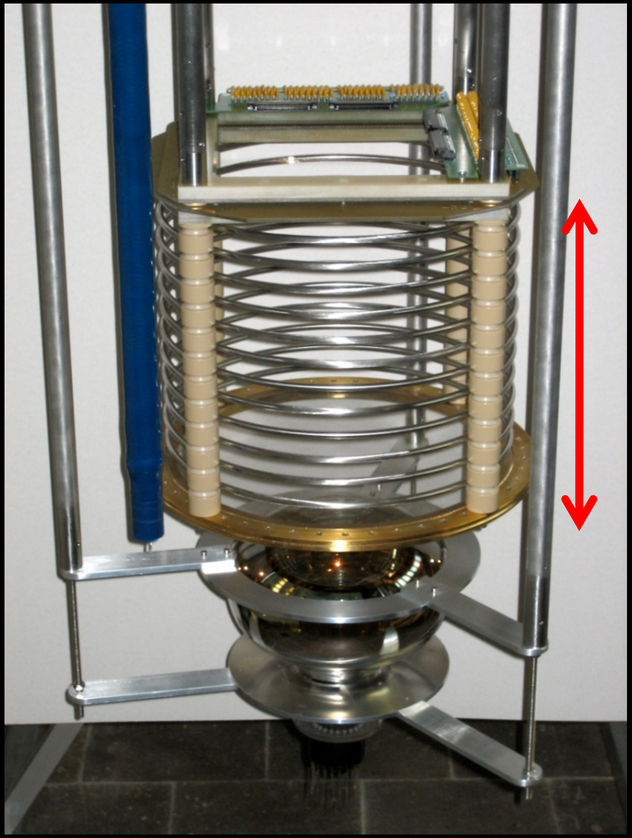
R&D issues for LAr TPCs

- 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

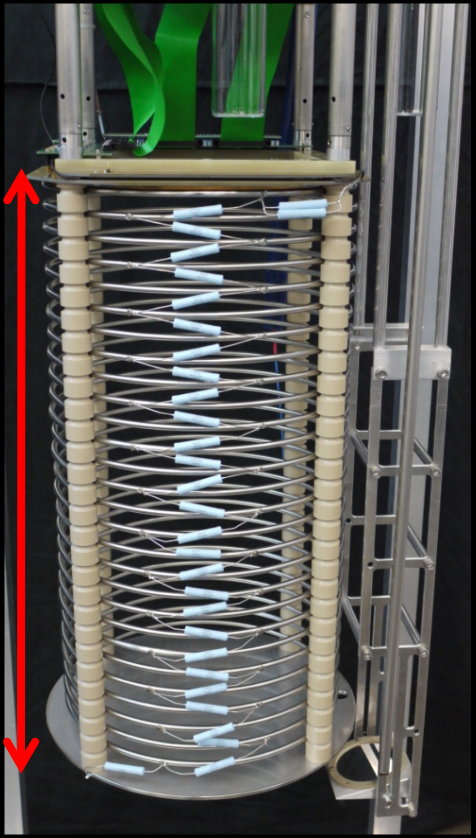
Evolution of LAr TPCs at LHEP Bern



0.5 cm



25 cm



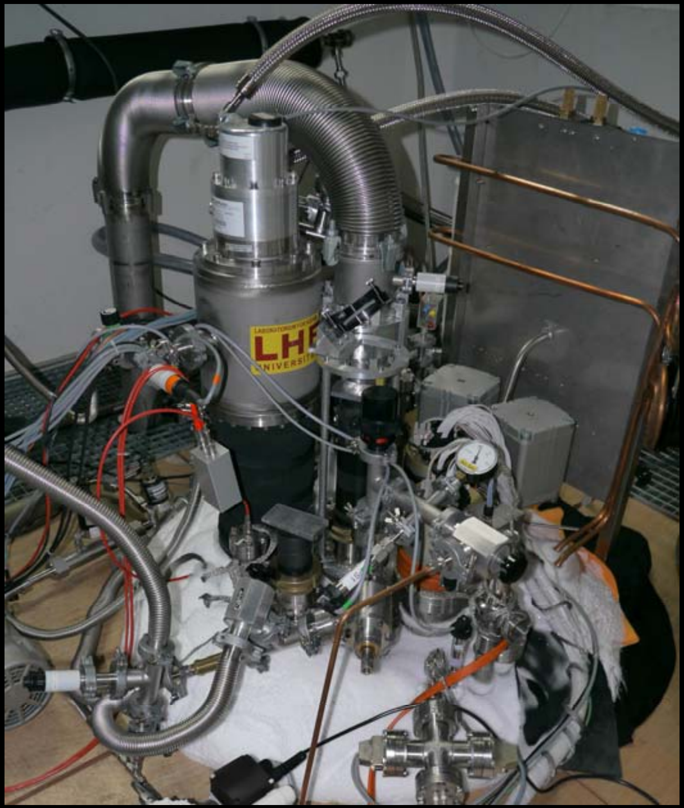
57 cm

JINST 4, P07011 (2009)

New J. Phys. 12, 113024 (2010)

JINST 5, P10009 (2010)

The Bern ARGONTUBE (5 m long drift)

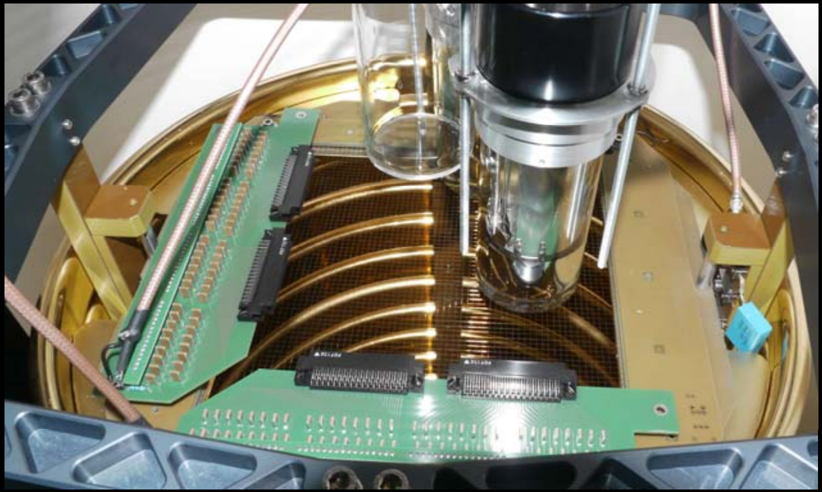


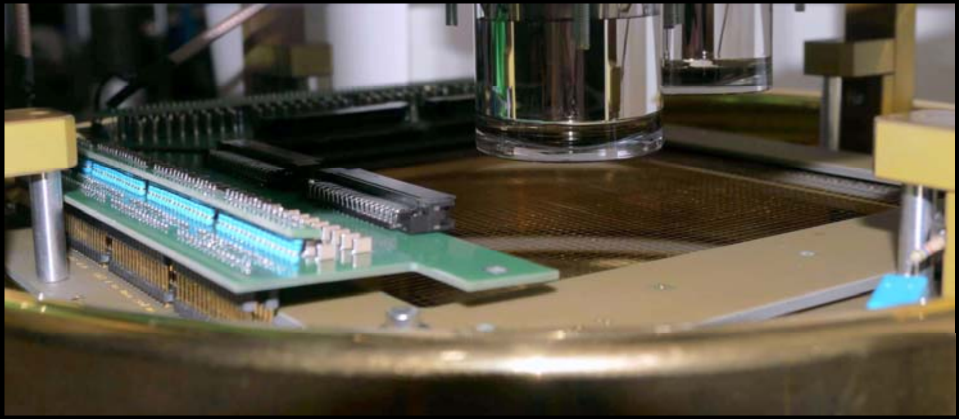
ARGONTUBE

JINST 7 (2012) C02011

JINST 1307 (2013) P07002

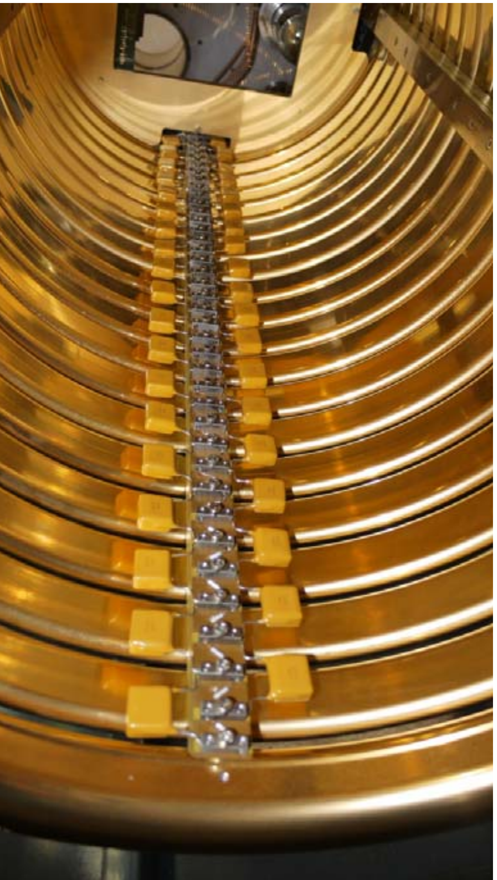
- Up to 4.76 m drift distance
- About 200 l active volume (total 1200 l), 280 kg LAr
- HV generated inside by a Greinacher circuit (up to 500 kV, 1 kV/cm design values)
- 2 wire planes, 20x20 cm^2, 3 mm wire pitch, 64x64 channels
- PMT's, scintillator planes and UV-laser beams for triggering
- LAr purity: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

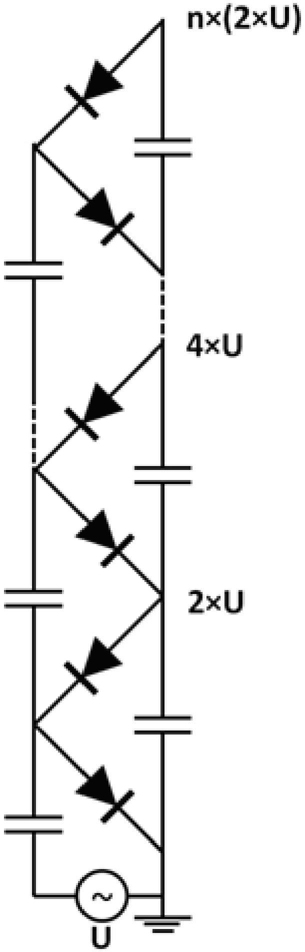




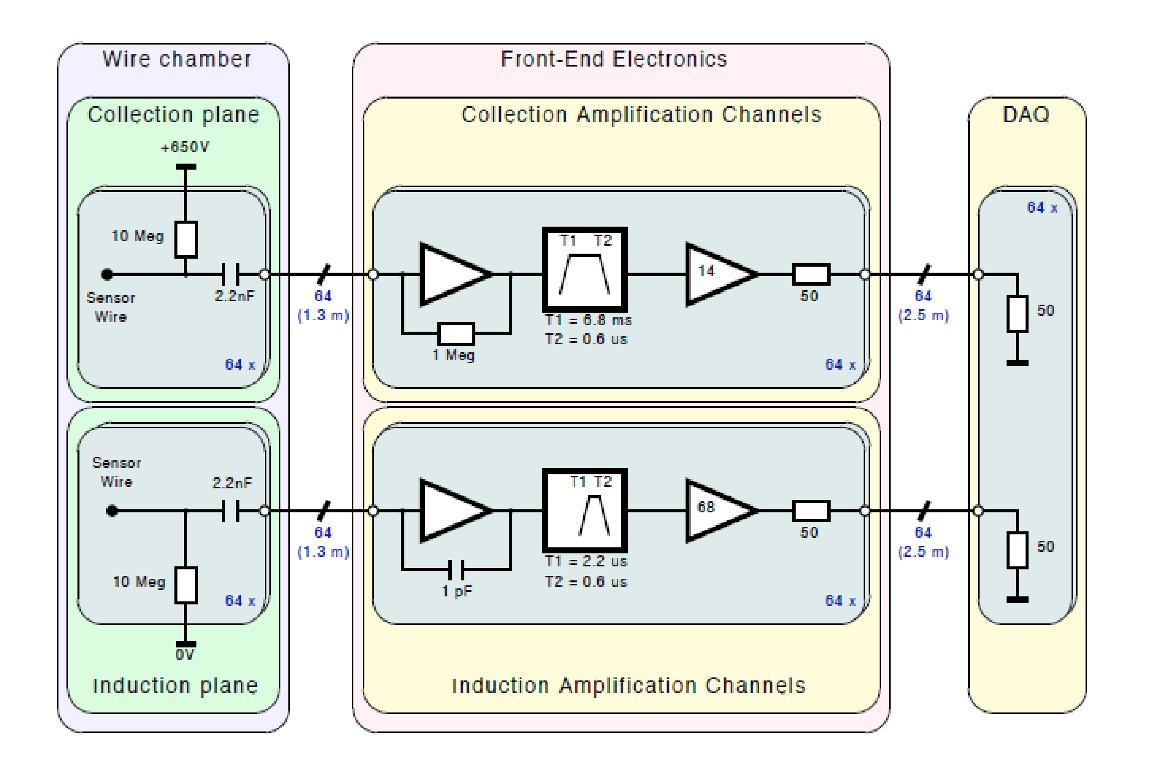
- Greinacher circuit: 125 stages, input 4 kV AC
- COMSOL finite element analysis software to optimize the geometry of the field-shaping rings
- Goal: drift field of 1 kV/cm
- Reached 170 kV (0.34 kV/cm)

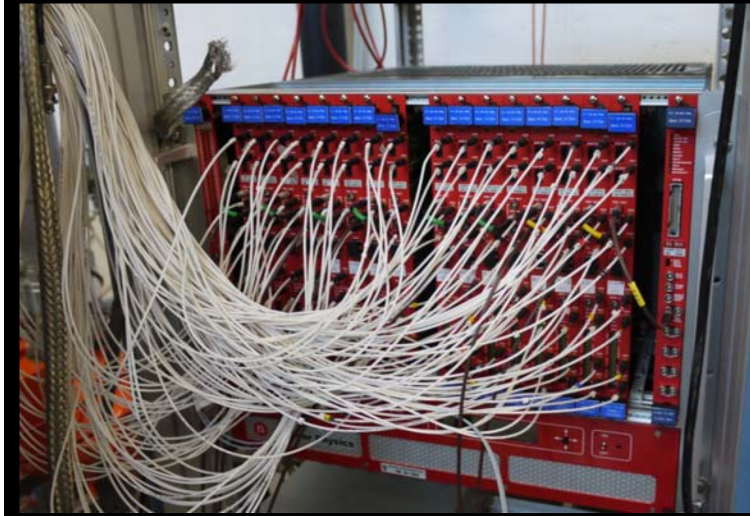
The use of Greinacher for LAr detectors was originally proposed by the ETHZ group: J.Phys.Conf.Ser. 308 (2011) 012027





R/O electronics





CAEN v1724 (ADC) + v2718

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

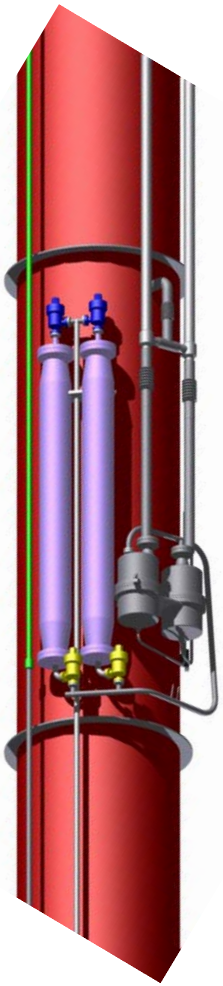
ARGONTUBE operation: 100-1000 ns sampling time

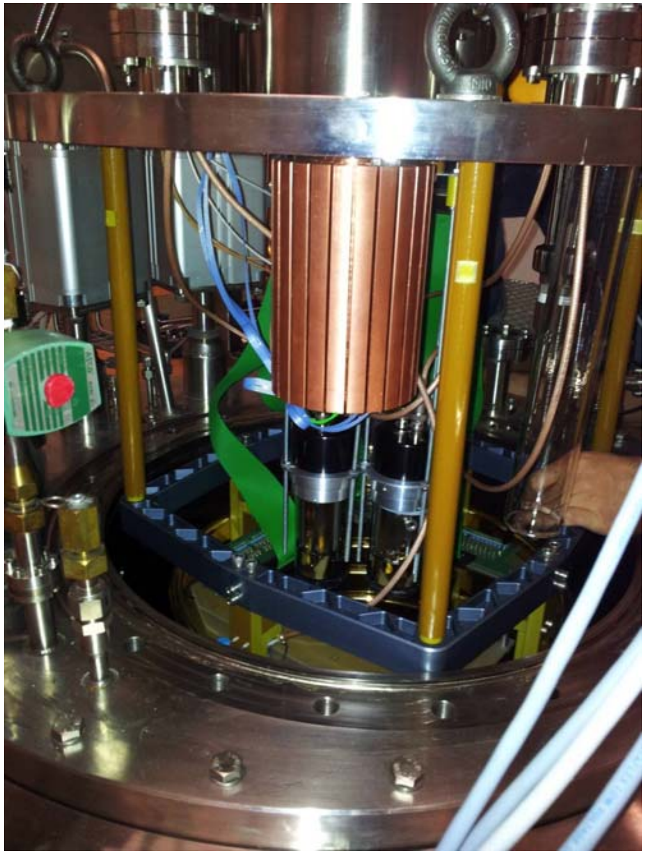
Cryogenics & purity

LAr recirculation system:

•first cleaning stage at filling, continuous liquid recirculation through filters with bellow pumps

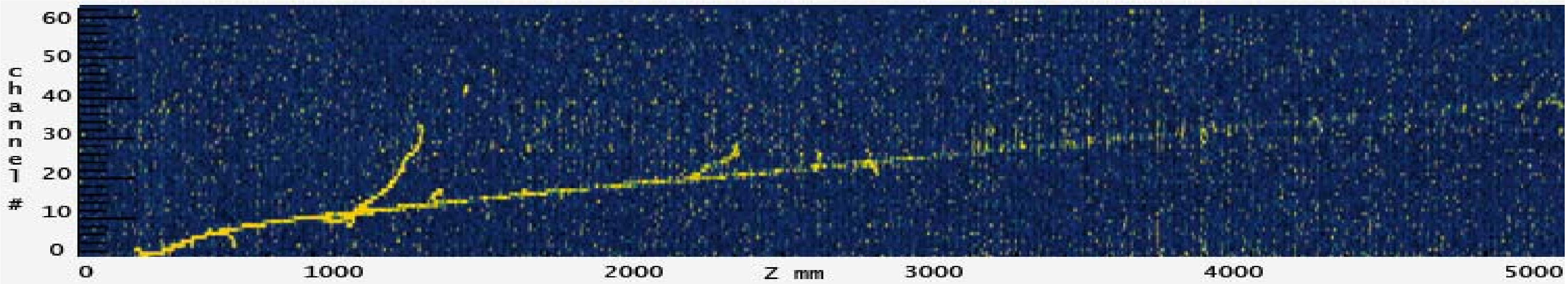
•standard purification cartridges: active copper





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

Long drift tracks (cosmic-rays) routinely detected



(compressed aspect ratio!)

Cold electronics tests

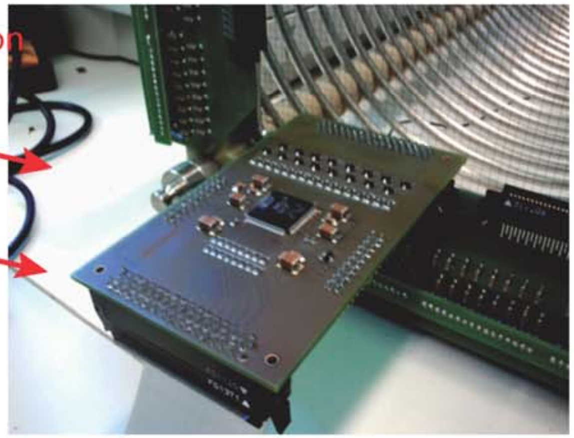
- Preamplifiers immersed in LAr at 87 K
- Advantages:
  - Directly on the wire planes, close to signal source. Avoids long cables between wires and preamps (reduce noise from pickup on the way, cable capacitance,…)
  - @at 87K: CMOS technology gives lower thermal noise, higher gain and higher speed
  - 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

Controller

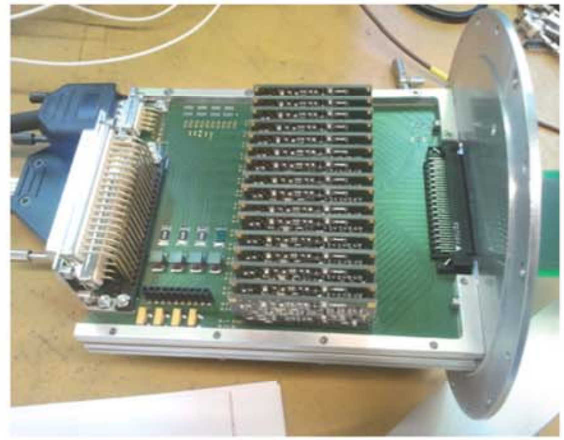
Power
Configuration
Reset

Test pulse

Frontend
2 LARASIC4 chips, i.e. 32CH per host PCB.



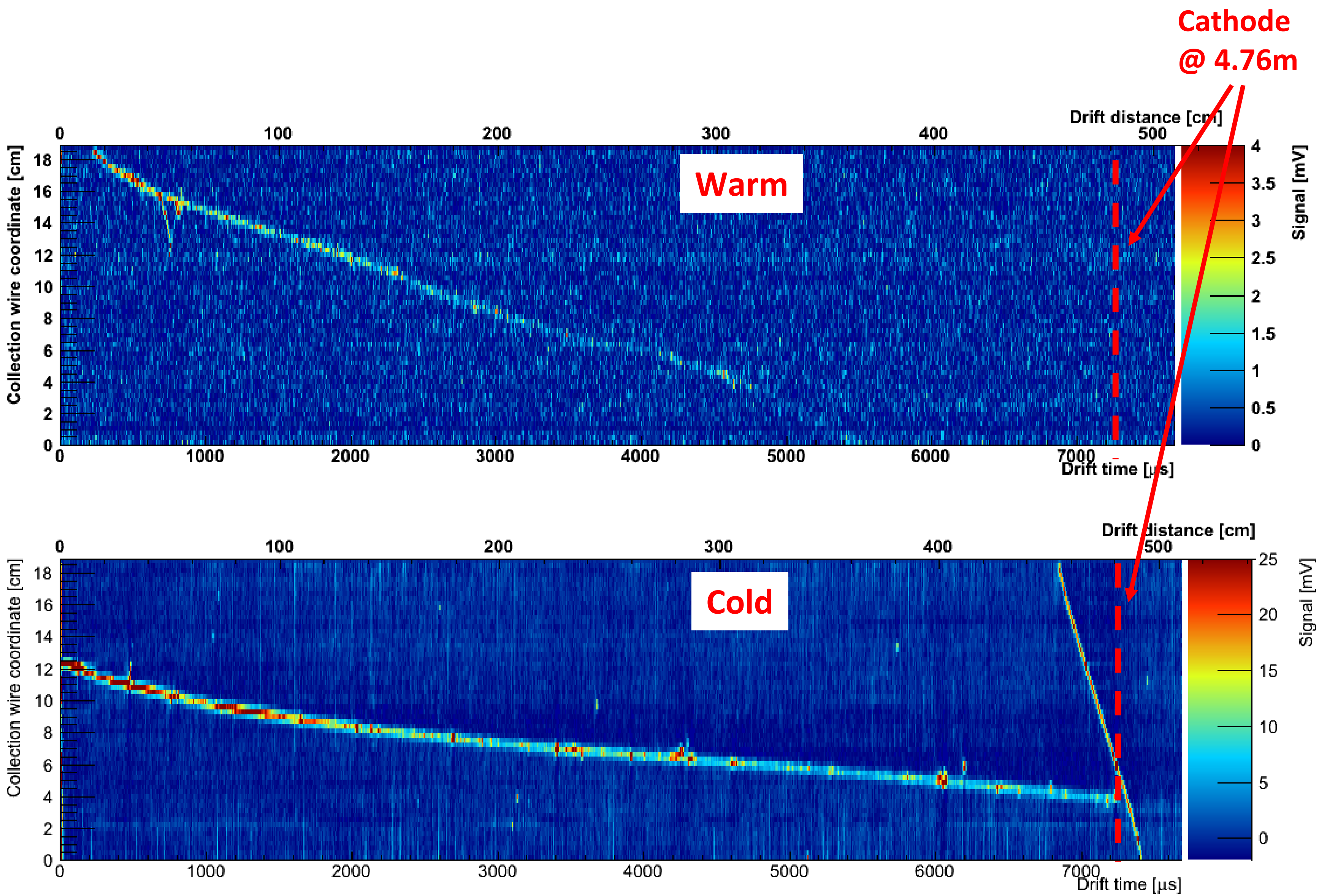
Buffer Amplifier
64 CH



Warm, for impedance matching (gain 1)

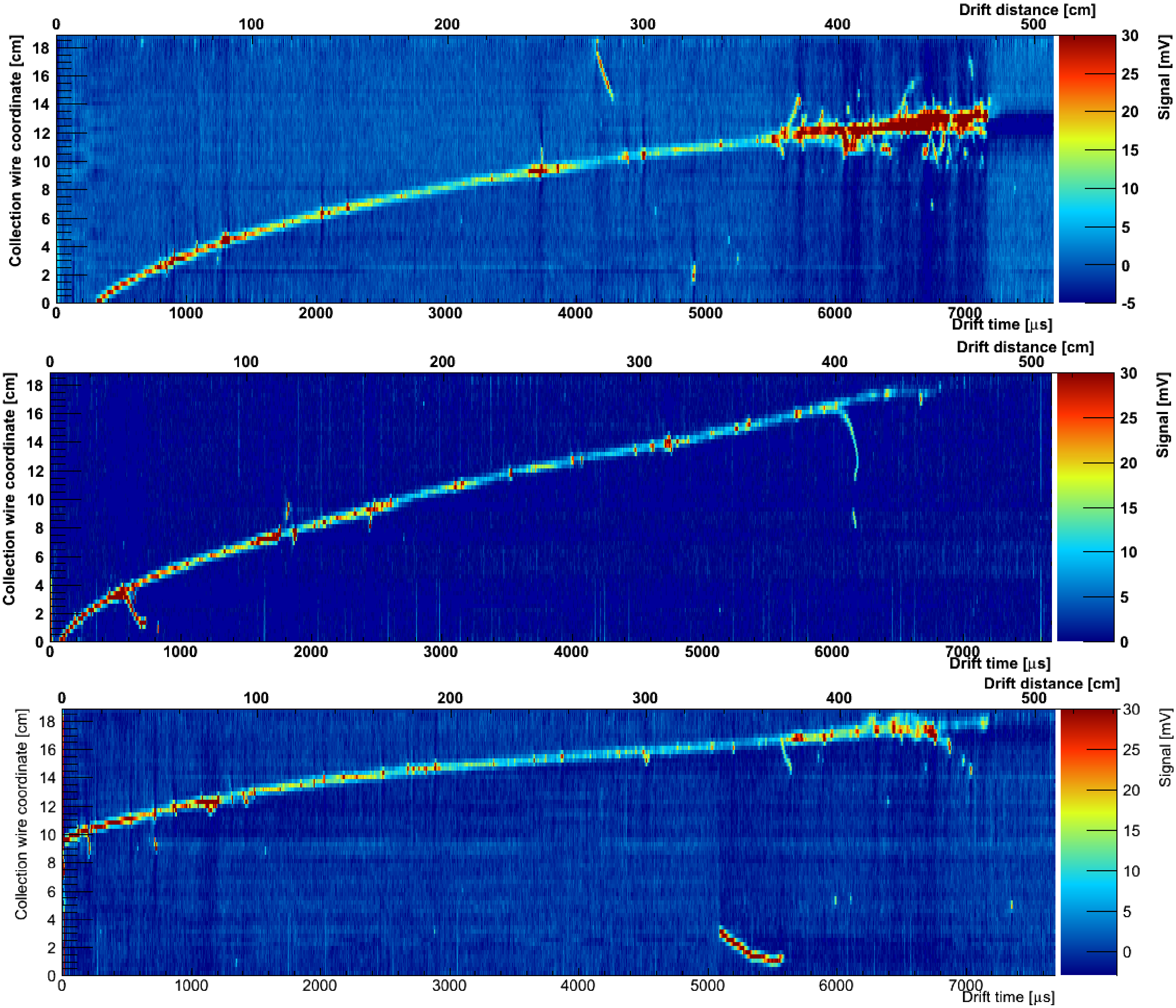
DAQ
CAEN V1724 ADCs

(Warm electronics running in parallel for comparison)

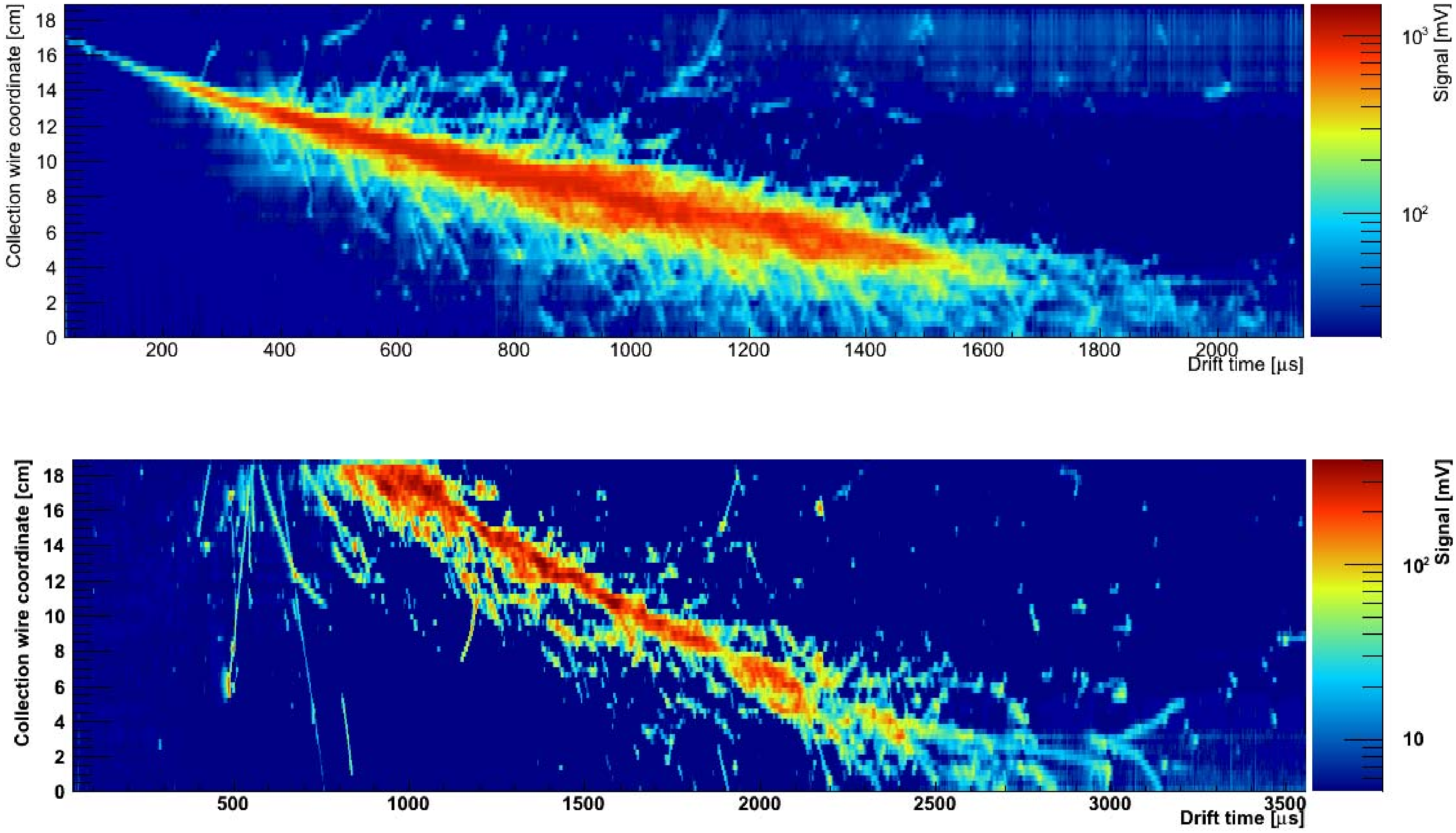


Cathode
@ 4.76m
Warm
Cold
Drift distance [cm]
Drift time [µs]
Collection wire coordinate [cm]
Signal [mV]

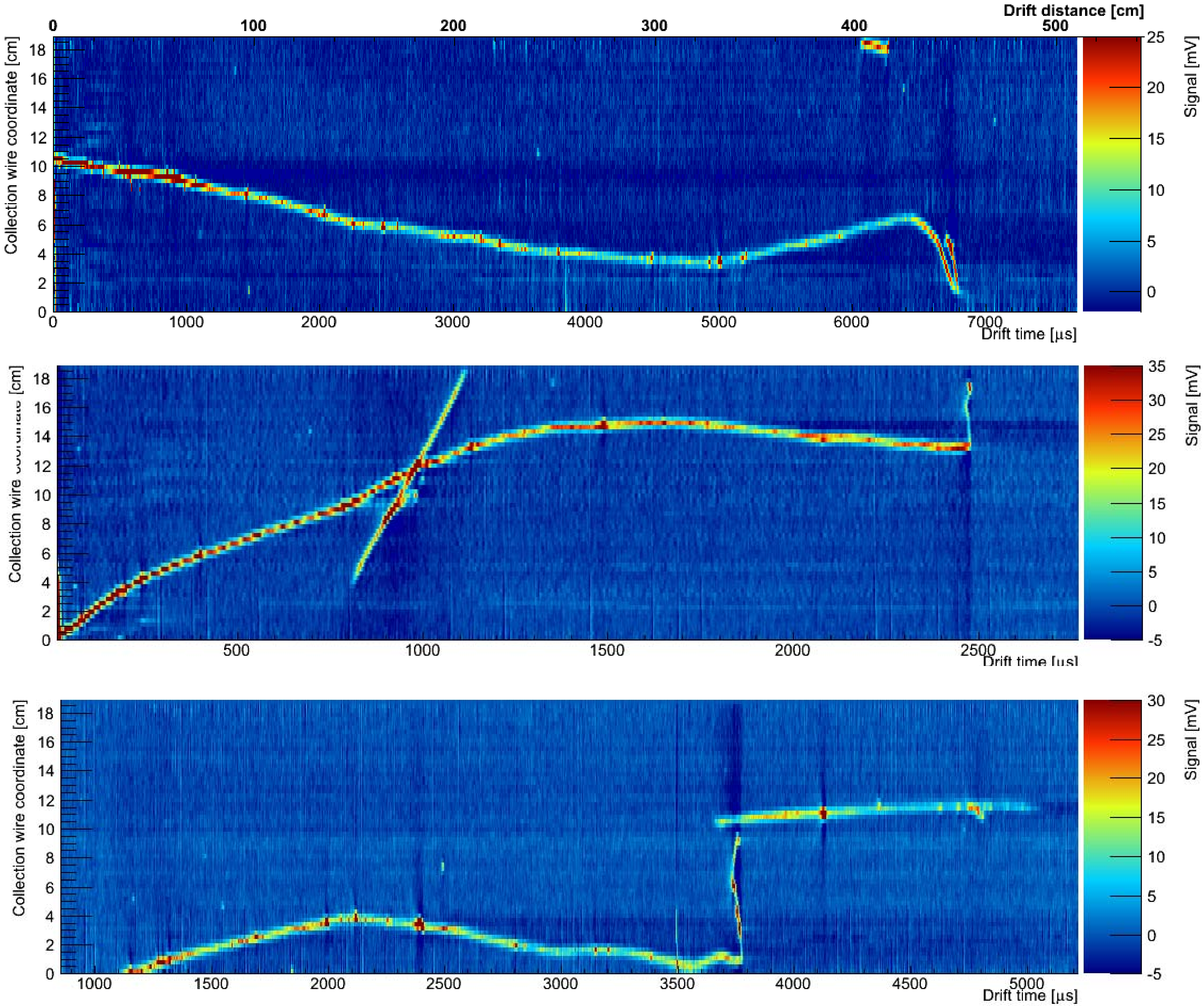
Cold electronics



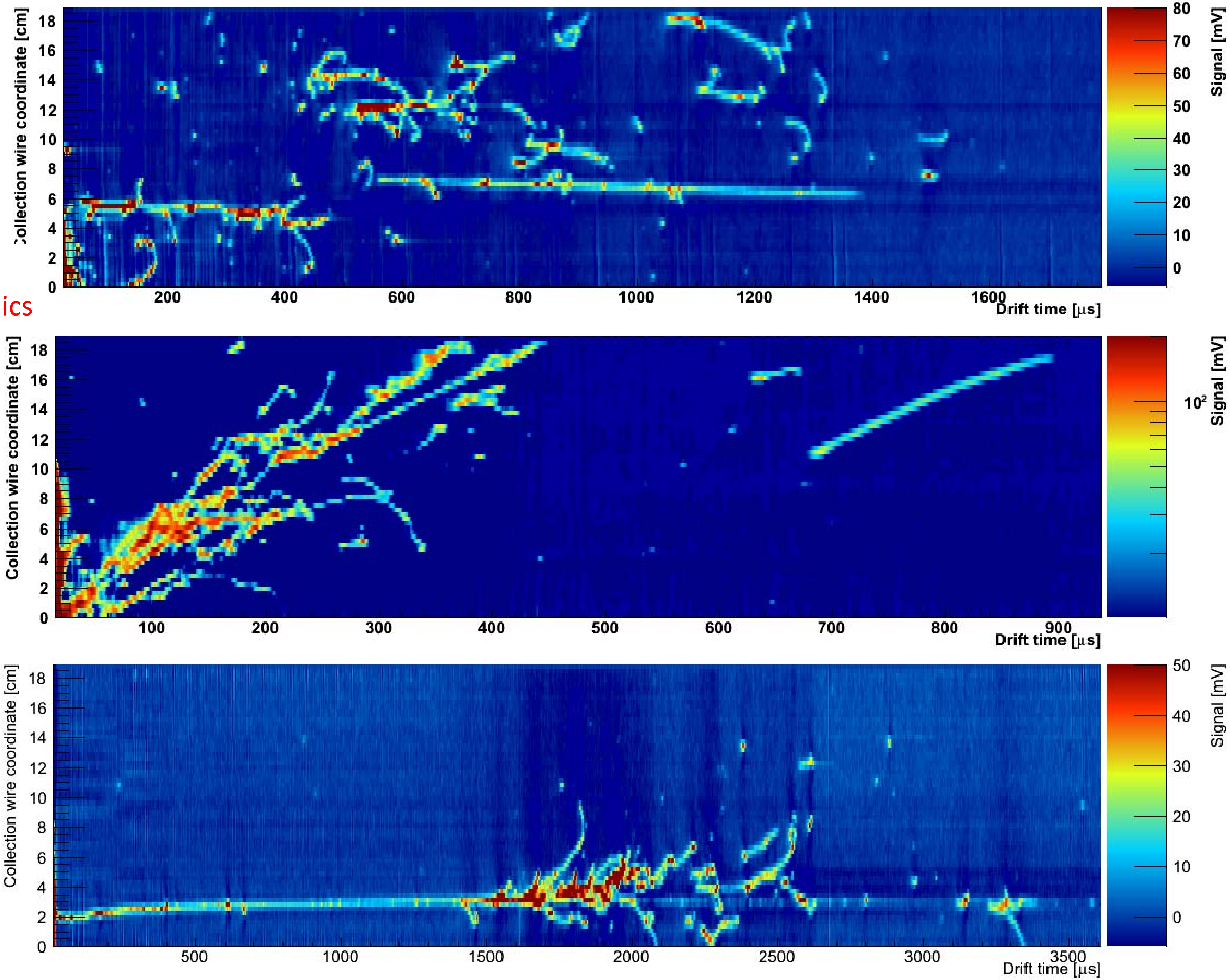
Cold electronics



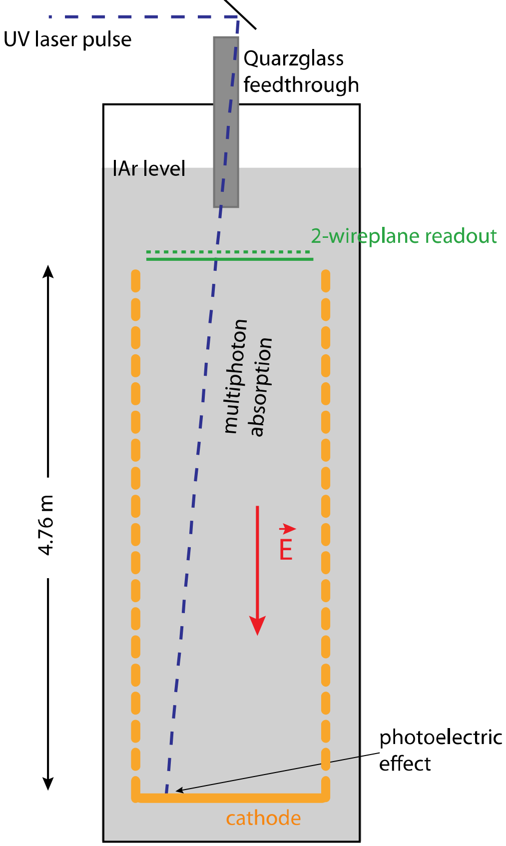
Cold electronics



Cold electronics

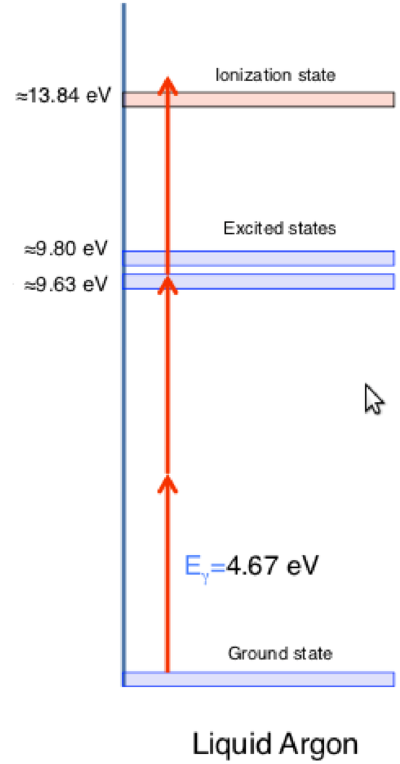


UV-laser calibration

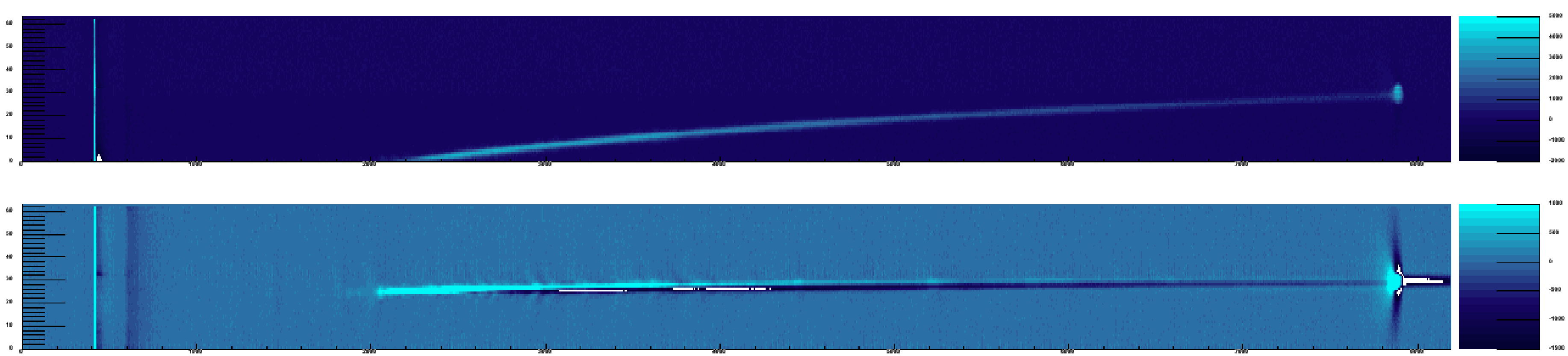


LHEP Bern pioneered the use UV laser-beams to ionize LAr by a multi-photon process

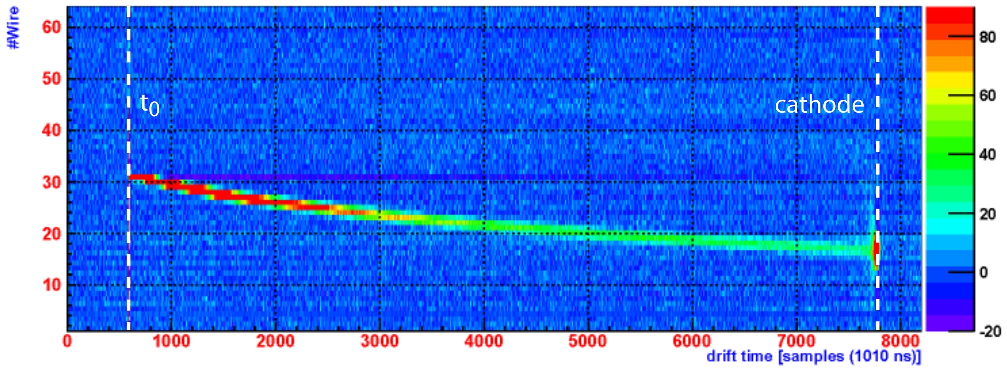
→ 2009 JINST 4 P07011
NJP 12 (2010) 113024

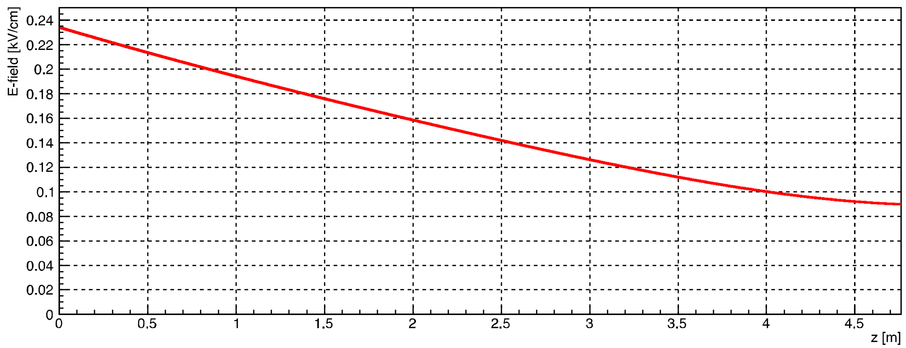


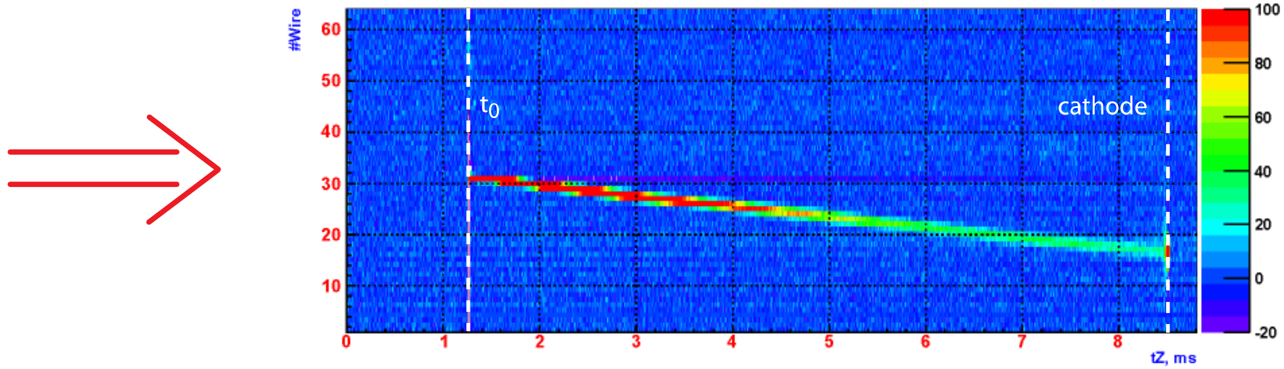
Exploit the technology to generate calibration "tracks" to correct for: space charge effects, local accumulation of ions leading to field distortions



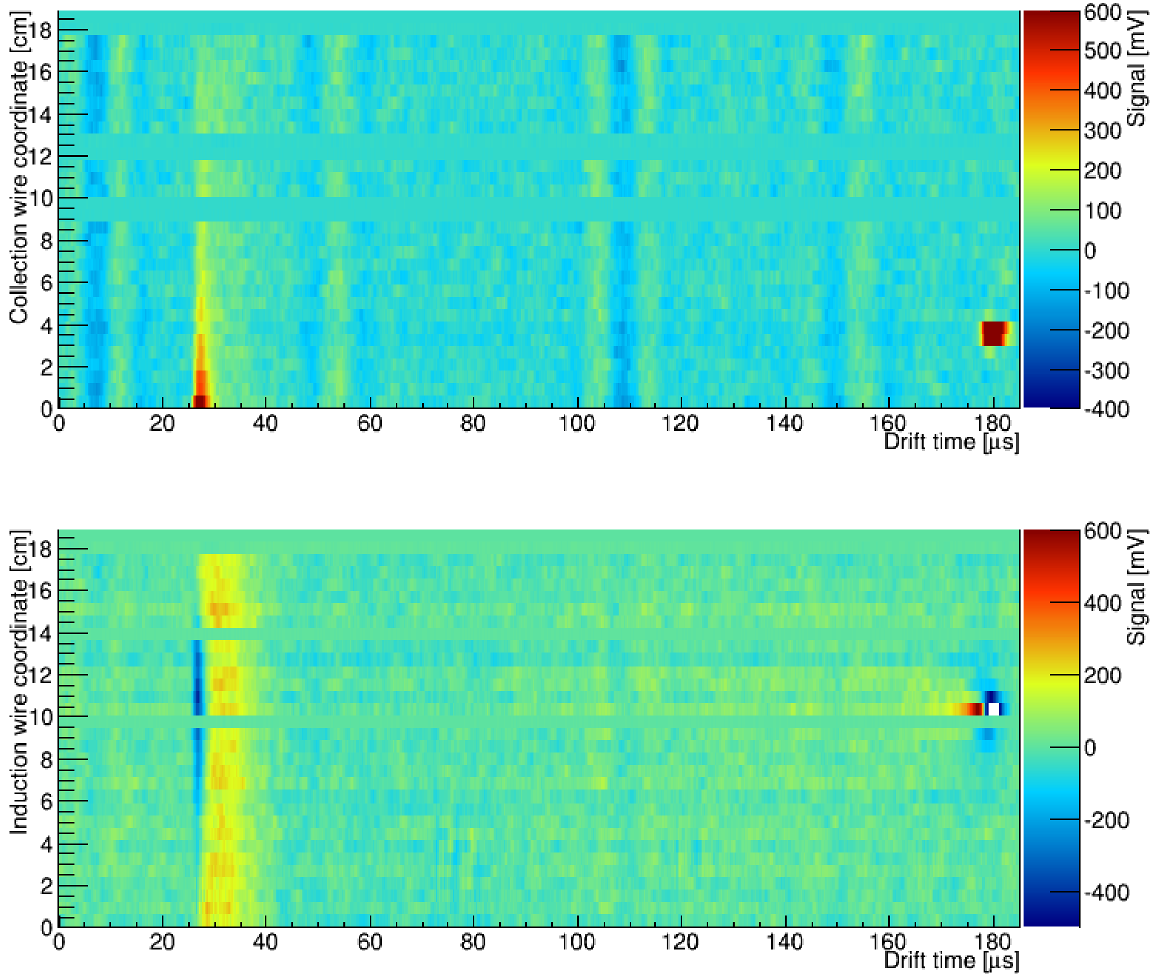
Example of track correction for E-field disuniformities



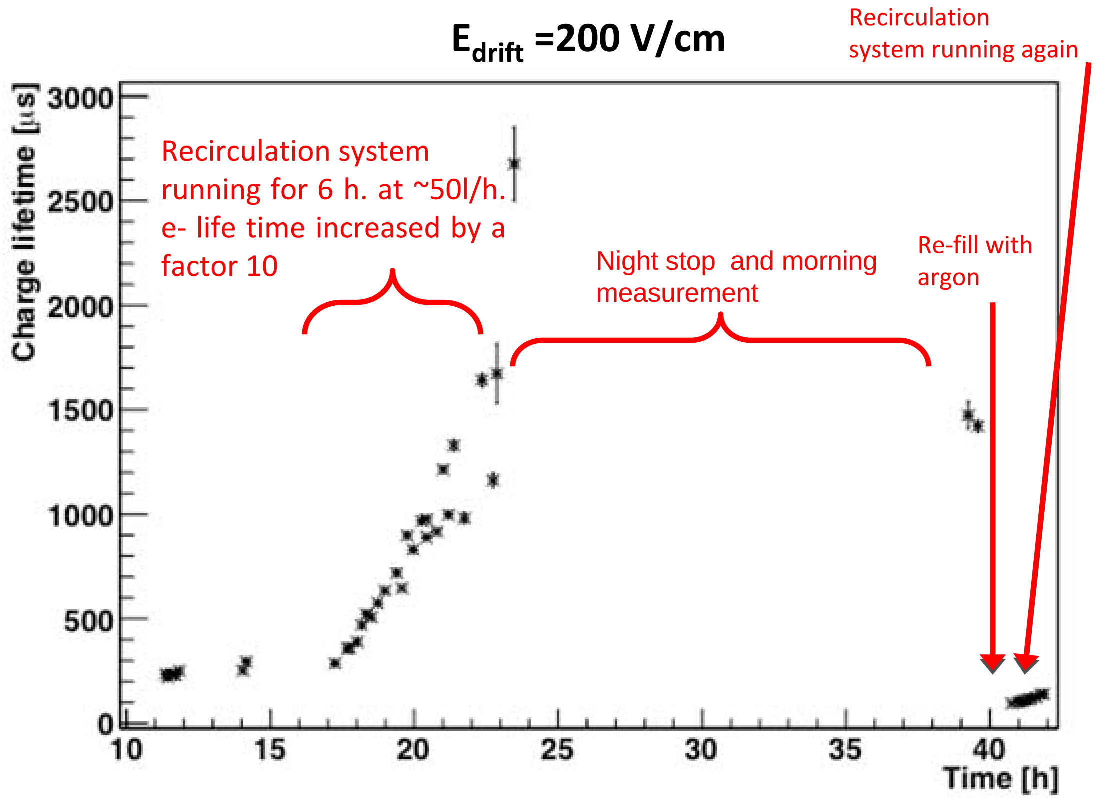




Moving UV-laser beam in LAr
(for the needs of the MicroBooNE experiment, see later)



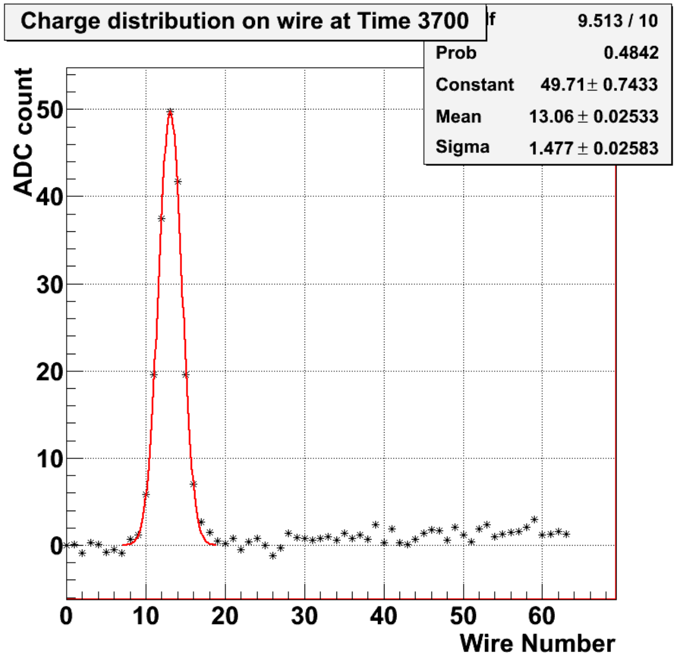
Application: measurement of purity by UV-laser tracks

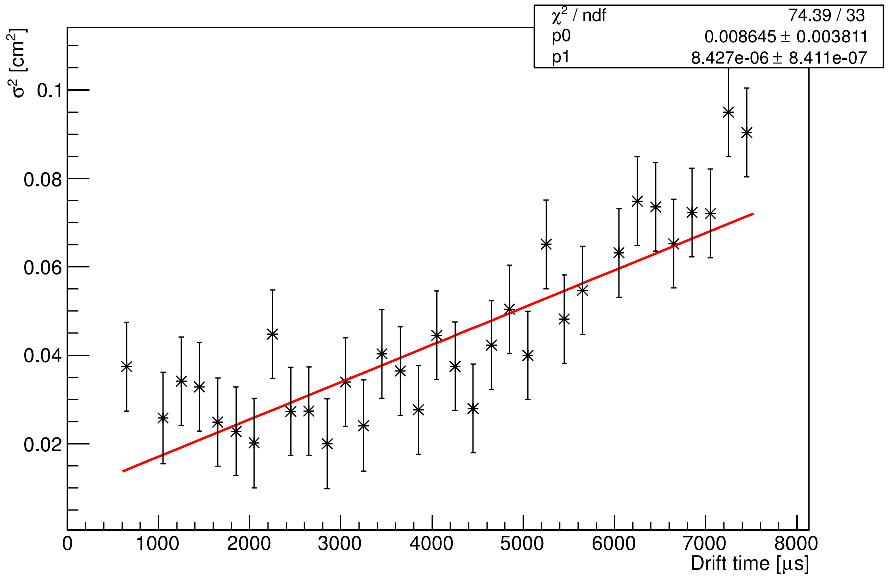


ARGONTUBE routine operation: 2.5 ms lifetime (0.12 ppb Oxygen equivalent)

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

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





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

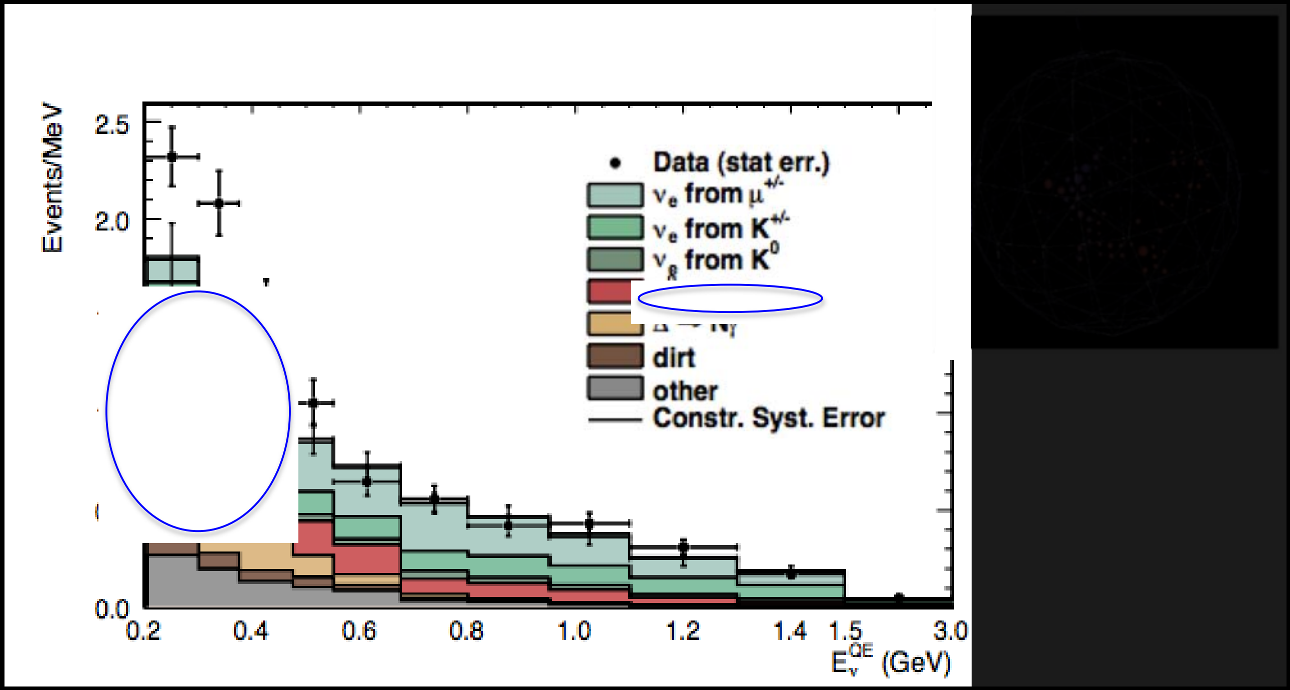
Notable physics case for future SBL oscillation experiments

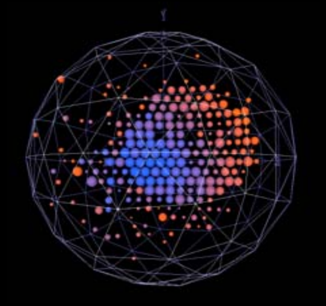
- we entered the era of precision measurements of neutrino oscillations
- liquid argon TPCs also perfectly suited for X-section studies (particle ID) and SBL accelerator experiments
- physics goal: assess the completeness of the 3-flavor mixing scenario vs additional sterile neutrinos (LSND and MiniBooNE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

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

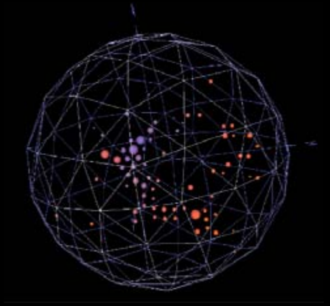
- is it a real signal of new physics or an unknown background ?

MiniBooNE electron-like event excess

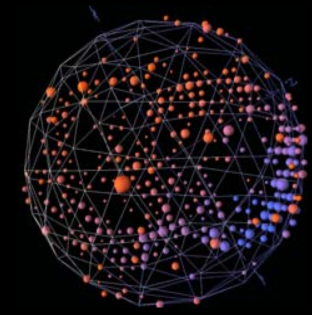




muon

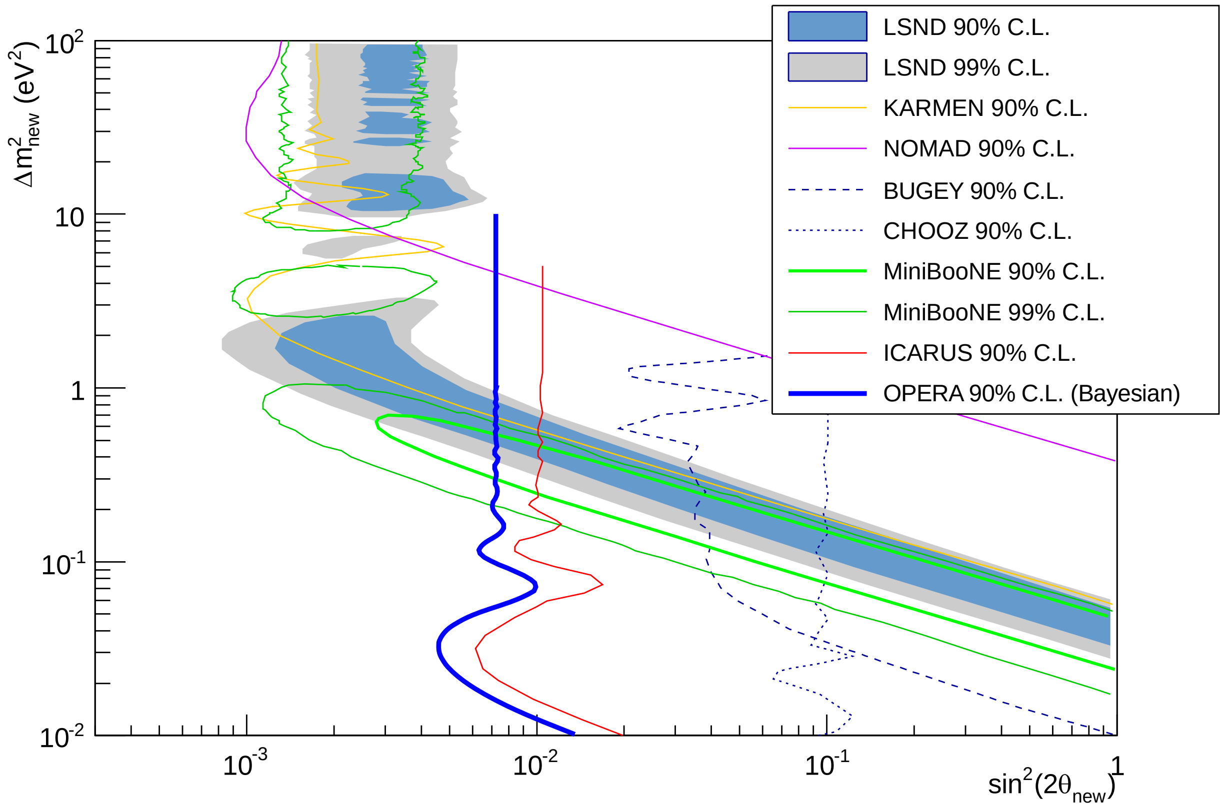


electron

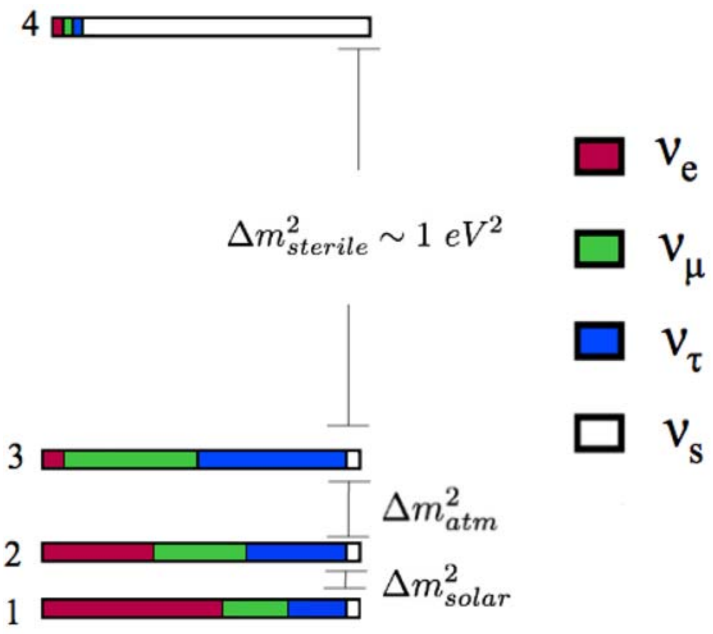


neutral pion

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

MiniBooNE)

Electron,&
Photon&

Muon&

Proton&

$\square^{0}$! $\gamma + \gamma$

(Cherenkov&Detector)&

MicroBooNE)

Electron,&
Photon&

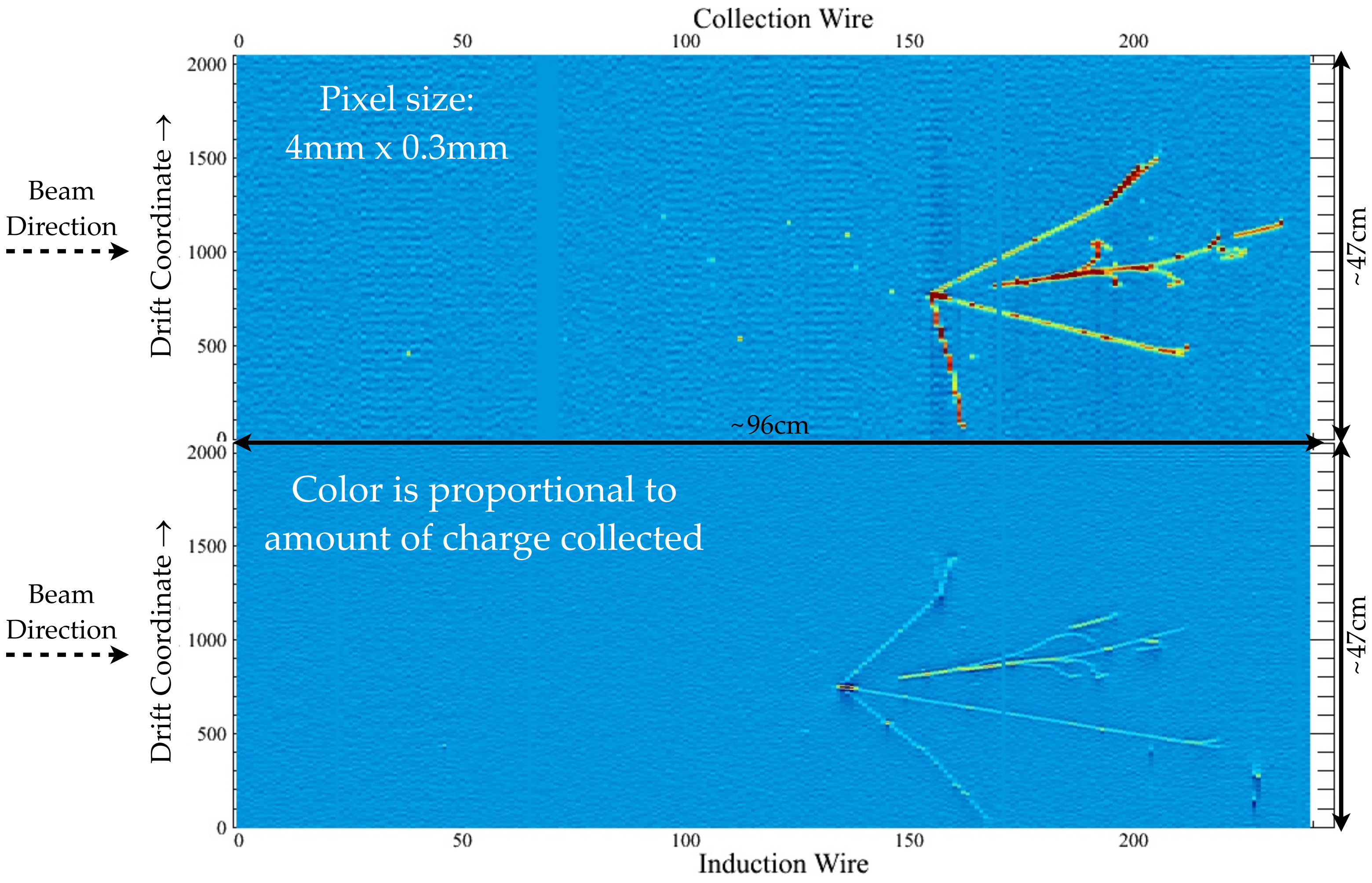
Muon&

Proton&

$\square^{0}$! $\gamma + \gamma$

(LArTPC)&

LAr TPC technology (ArgoNeuT neutrino-induced event)



- 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:

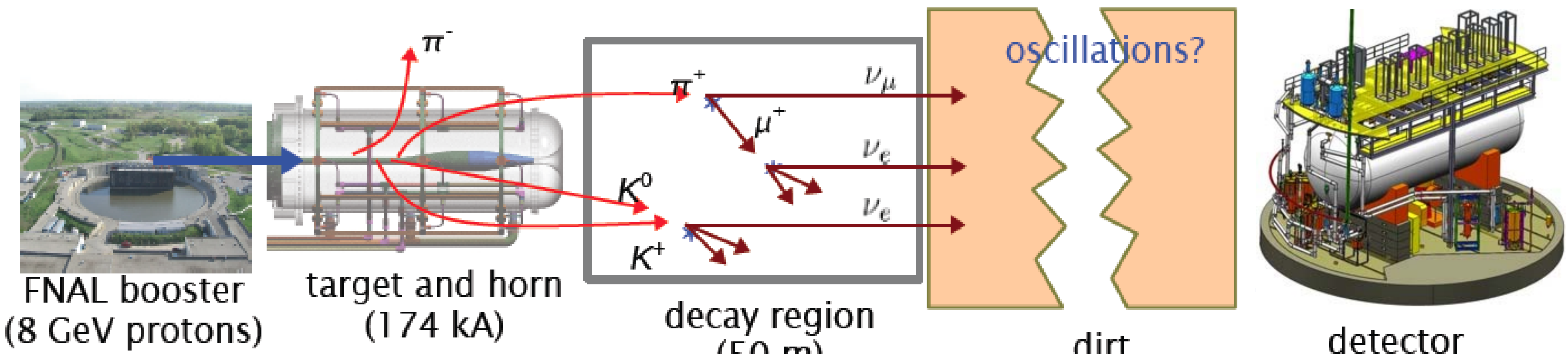
JINST 7 (2012) P10019
JINST 7 (2012) P10020
Phys. Rev. Lett. 108 (2012) 161802
JINST 8 (2013) P08005

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

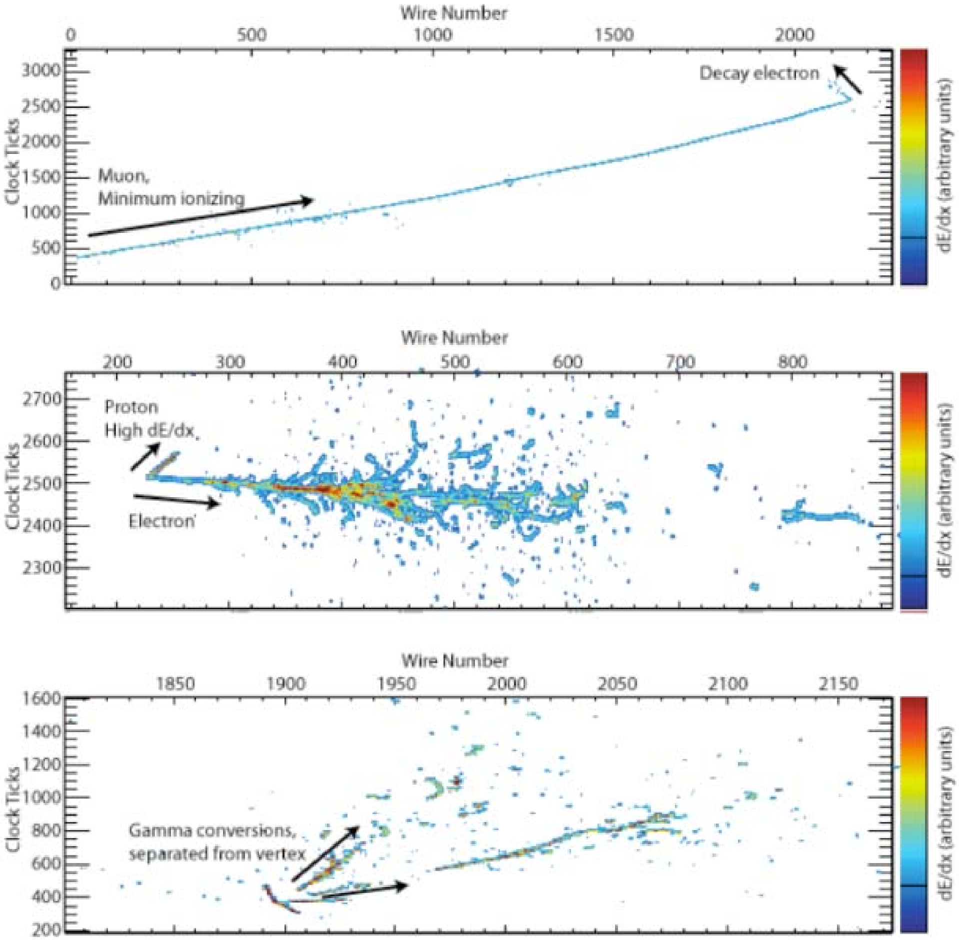


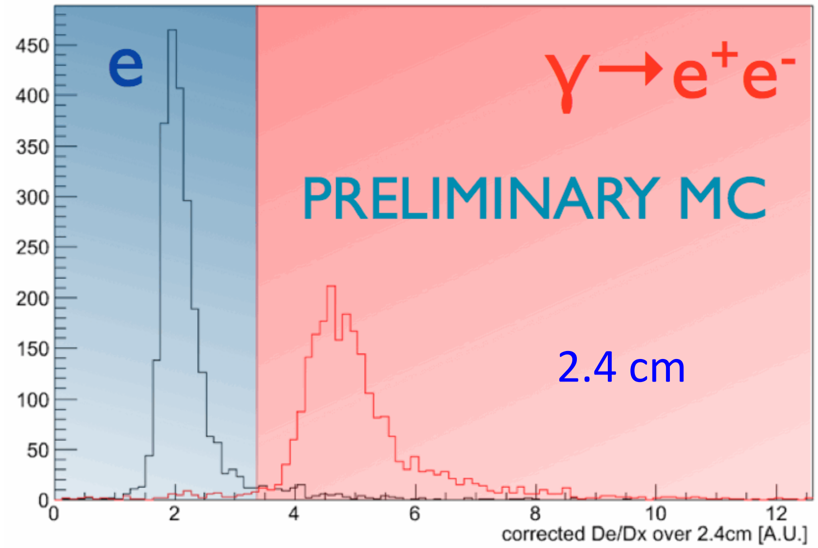
(ν_μ up to ~ 5 GeV, peak at ~ 1GeV)

(@470 m from the source)

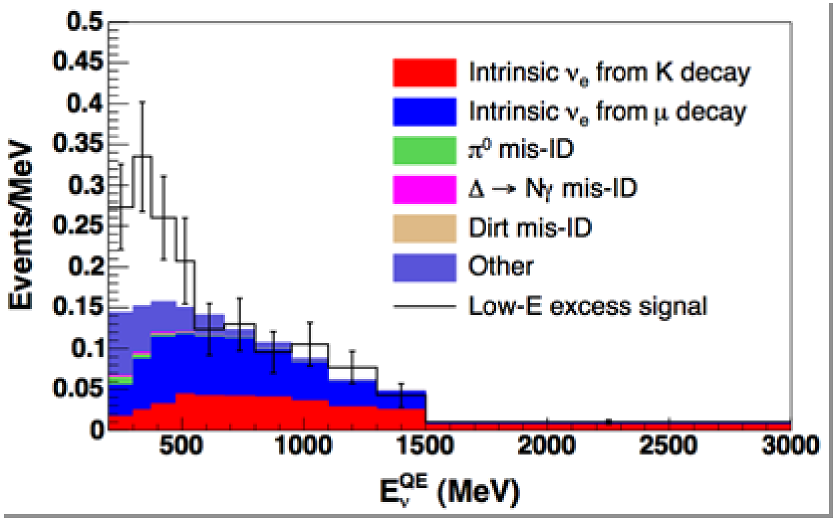
Start data taking 2014: in 3 years expect 6.6×10^{20} pot and ~140 k events (BNB)

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



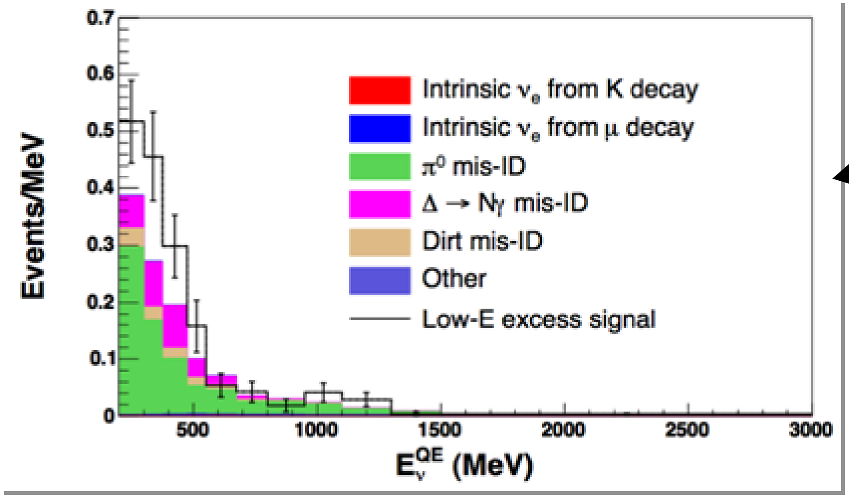


MicroBooNE oscillation physics



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)

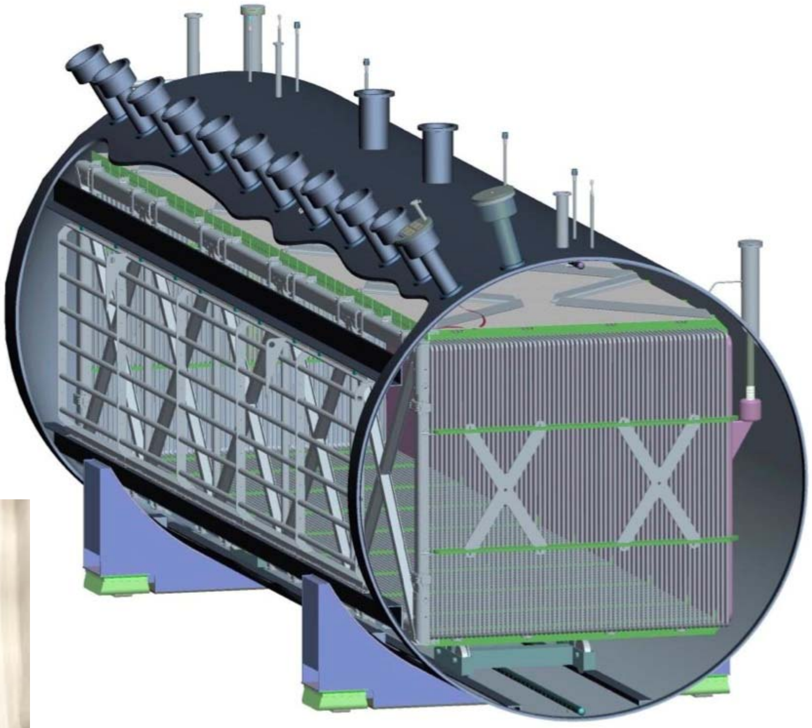
The MicroBooNE detector

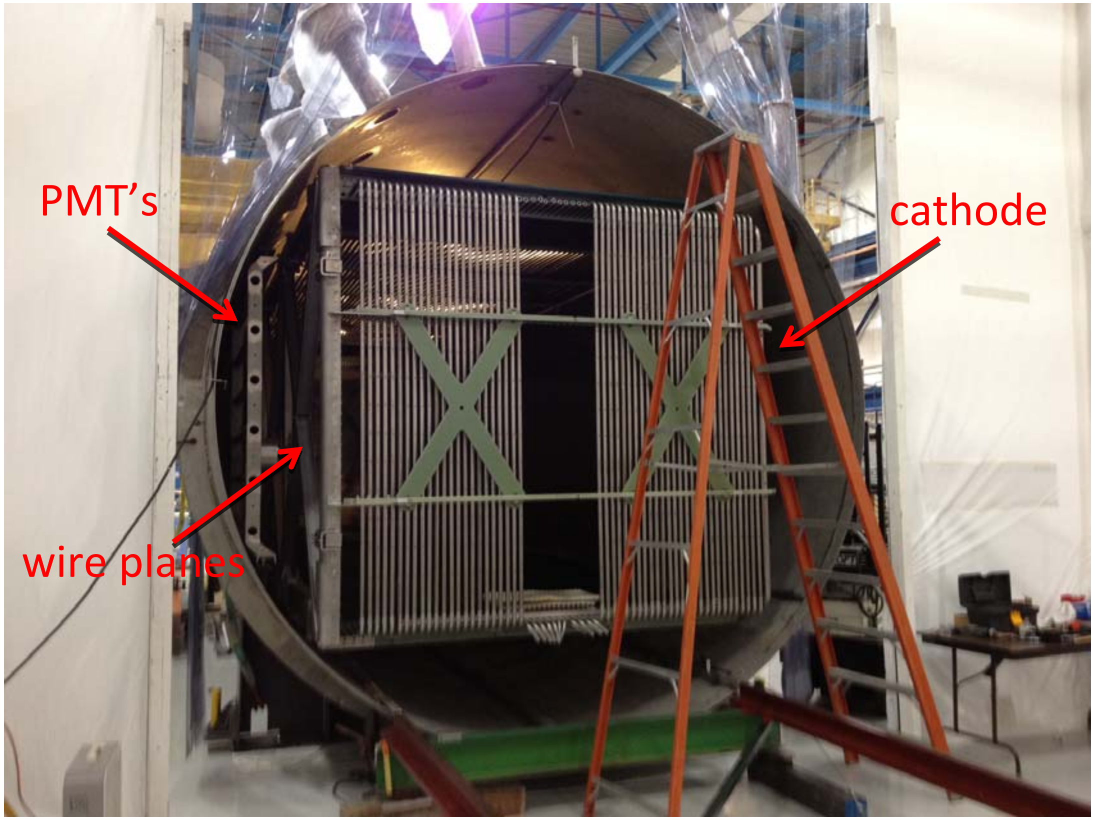
Dimensions: 10 m x 2.3 m x 2.5 m

125 kV high voltage, 2.5 m drift length

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

32 8” PMT’s





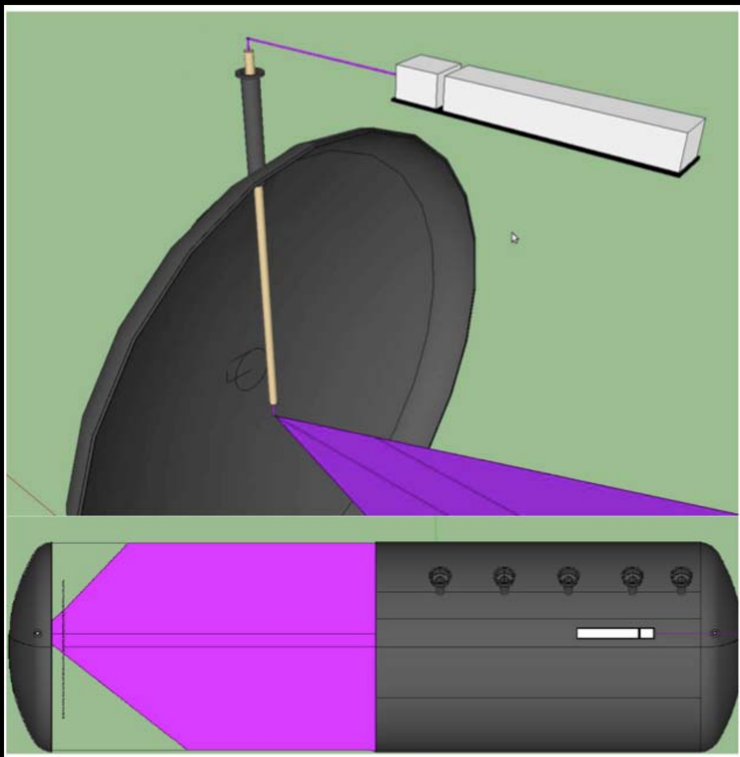

KÄRCHER

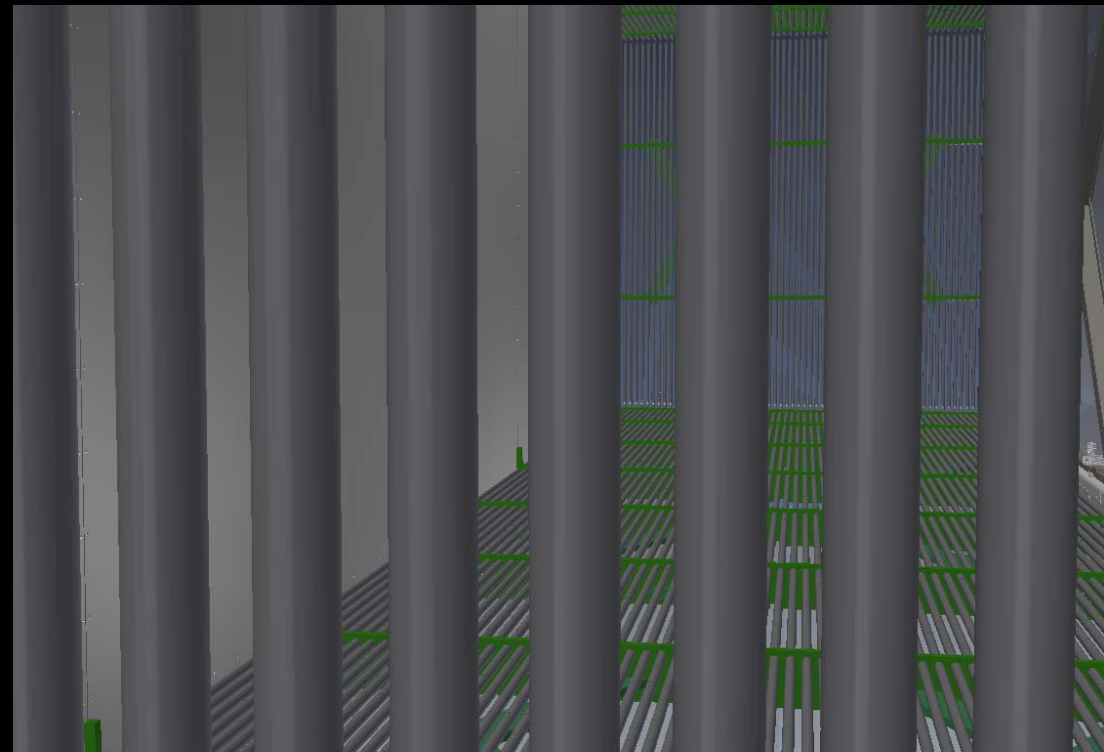
Y: vertical plane (2.5 meter long wires), U,V planes: +/- 60 degrees from vertical (5 meters long)

The experimental hall

The realization of the various sub-systems is on schedule

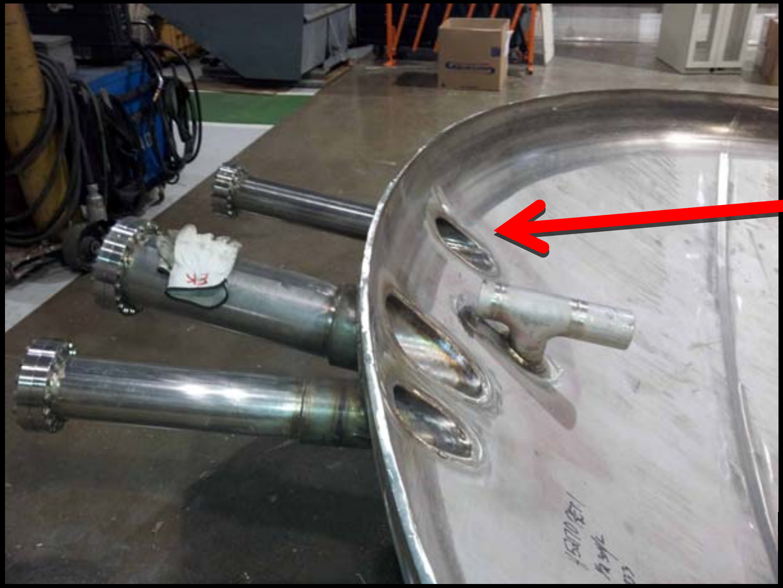
One example: the UV-laser calibration system

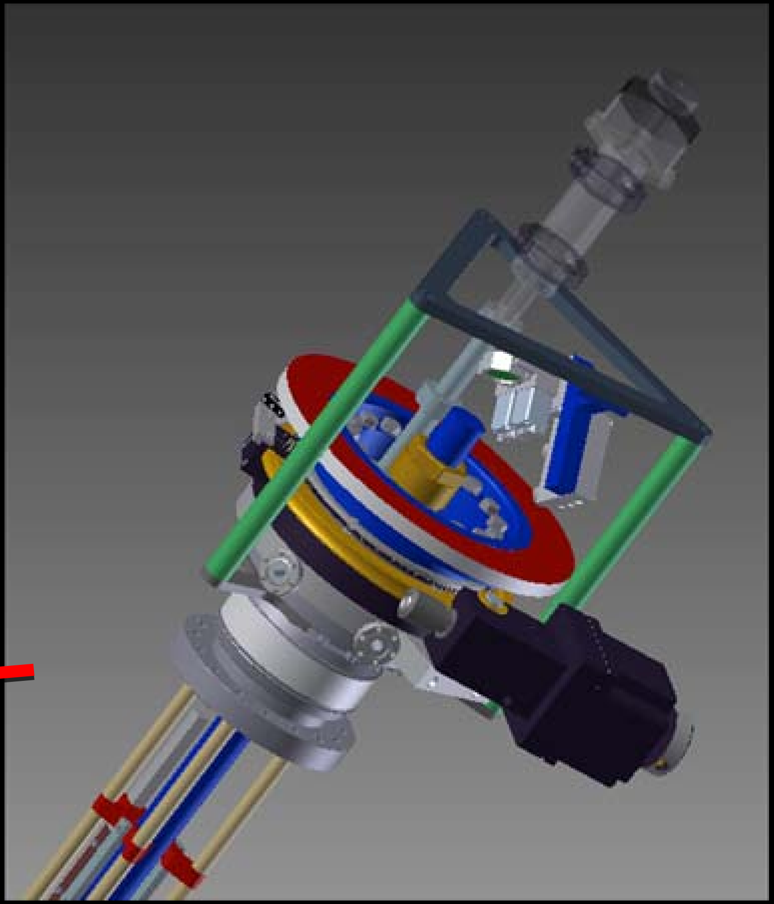




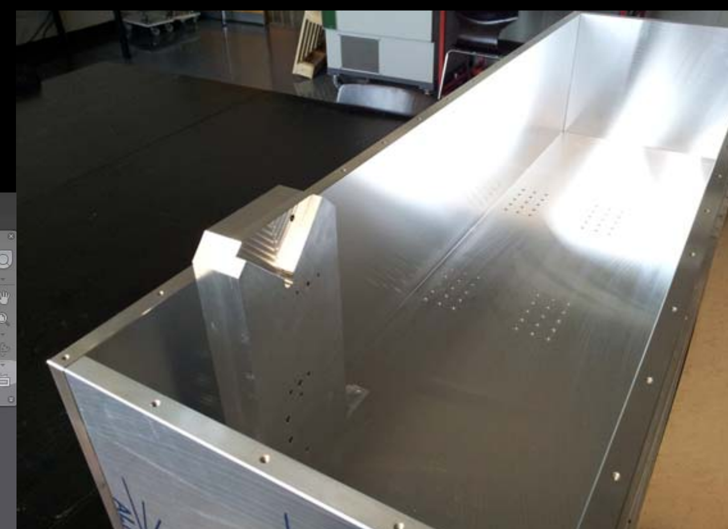
Two independent laser lines on either side of the cryostat

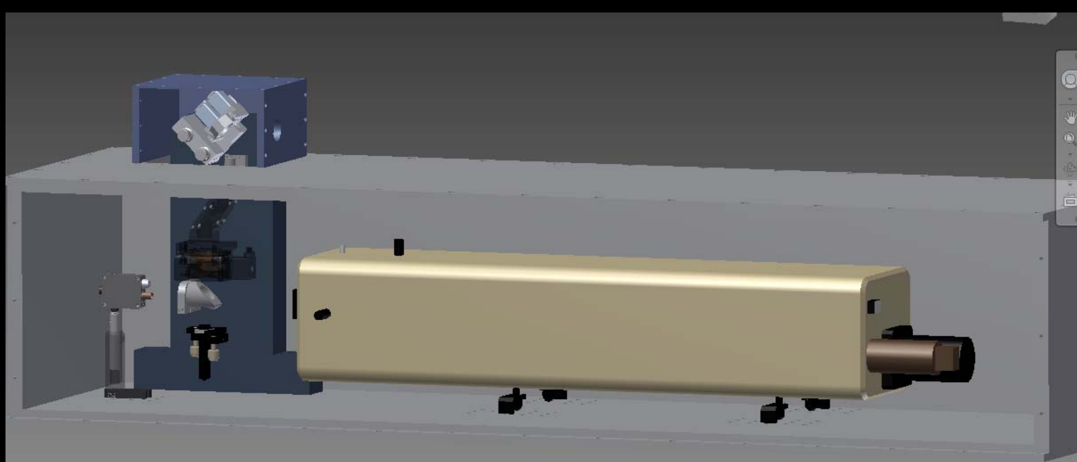
Remote controlled steered beam
(mirrors) with easy slow control





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!