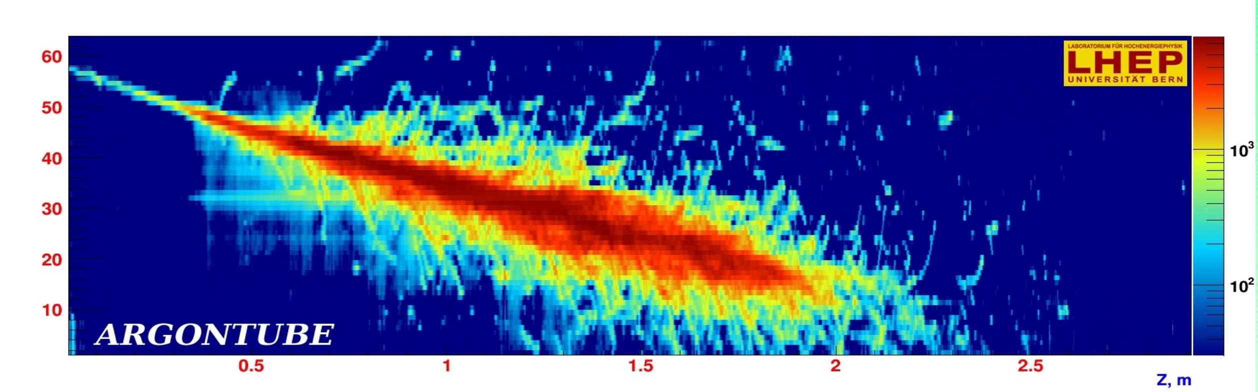
ARGONTUBE: the liquid argon TPC with the longest drift



Laboratory for High Energy Physics
Albert Einstein Center for Fundamental Physics
University of Bern

A. Ereditato, D. Goeldi, S. Janos,
I. Kreslo, M. Lüthi, C. Rudolf von Rohr, M. Schenk,
T. Strauss, M. Weber, M. Zeller

Towards 100 kt high granularity detectors

High-precision measurements era for neutrino physics

parameter	best fit	1σ range	2σ range	3σ range
Δm^2_{21} $[10^{-5}\mathrm{eV}^2]$	7.62	7.43–7.81	7.27–8.01	7.12–8.20
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\mathrm{eV}^2]$	2.55 2.43	$2.46-2.61$ $2.37-2.50$	$2.38-2.68$ $2.29-2.58$	$2.31-2.74$ $2.21-2.64$
$\sin^2\theta_{12}$	0.320	0.303–0.336	0.29–0.35	0.27–0.37
$\sin^2\theta_{23}$	0.613 (0.427)[a] 0.600	0.400-0.461 & 0.573–0.635 0.569–0.626	0.38–0.66 0.39–0.65	0.36–0.68 0.37–0.67
$\sin^2\theta_{13}$	0.0246 0.0250	0.0218–0.0275 0.0223–0.0276	0.019–0.030 0.020–0.030	0.017–0.033
δ	0.80π -0.03π	$0-2\pi$	$0-2\pi$	$0-2\pi$

Forero; Tortola; Valle (2012). "Global status of neutrino oscillation parameters after Neutrino-2012". Physical Review D 86: 073012

CP-violation in lepton sector (δ phase)

Neutrino mass hierarchy

Ultra-low cross-section physics
(e.g. Proton decay)

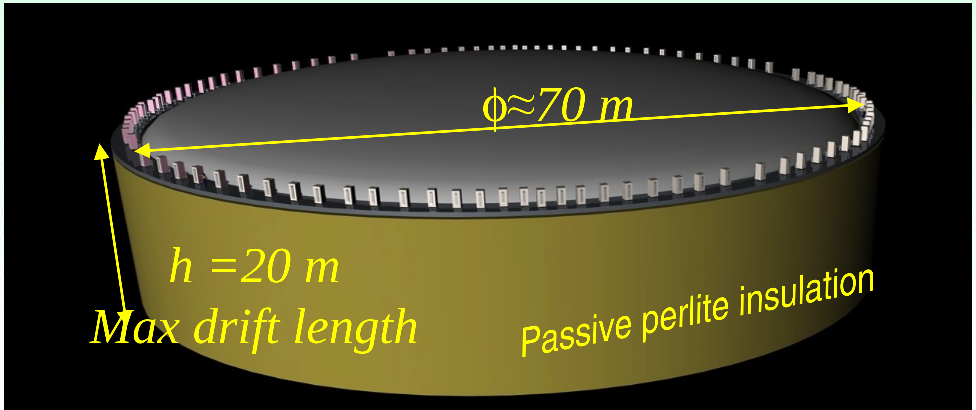
Present state-of-art:
Water Cerenkov (Super-K)
Bulk scintillators (Daya Bay, (D)-Choos)
Liquid Argon TPC (ICARUS, uBooNE)

Need:
- Larger detectors
- Higher resolution
- Higher granularity

} Liquid Argon Time Projection Chambers

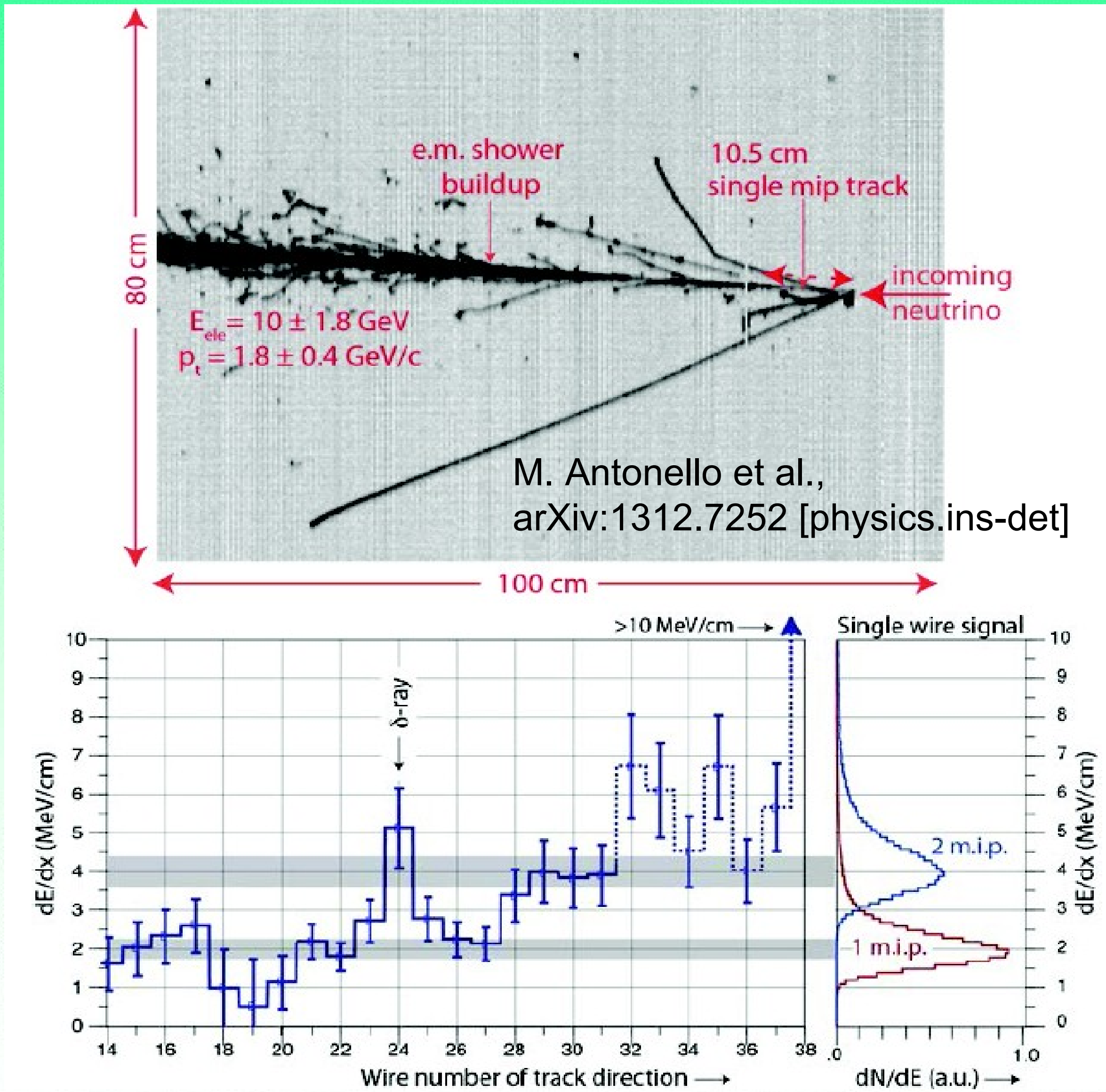
Example: GLACIER detector

- Active mass 20-100 kton
- Drift distance of the order of 10 m
- Drift times of the order of 10 ms
- Ultra-high argon purity required (<0.1ppb oxygen equivalent impurities)
- High voltage of the order of Mega-Volts



hep-ph/0402110 and J.Phys.Conf.Ser. 171 (2009) 012020

Why Liquid Argon Time Projection Chamber ?



M. Antonello et al., arXiv:1312.7252 [physics.ins-det]

Relatively high density 1.4 g/cm3

Fully sensitive medium

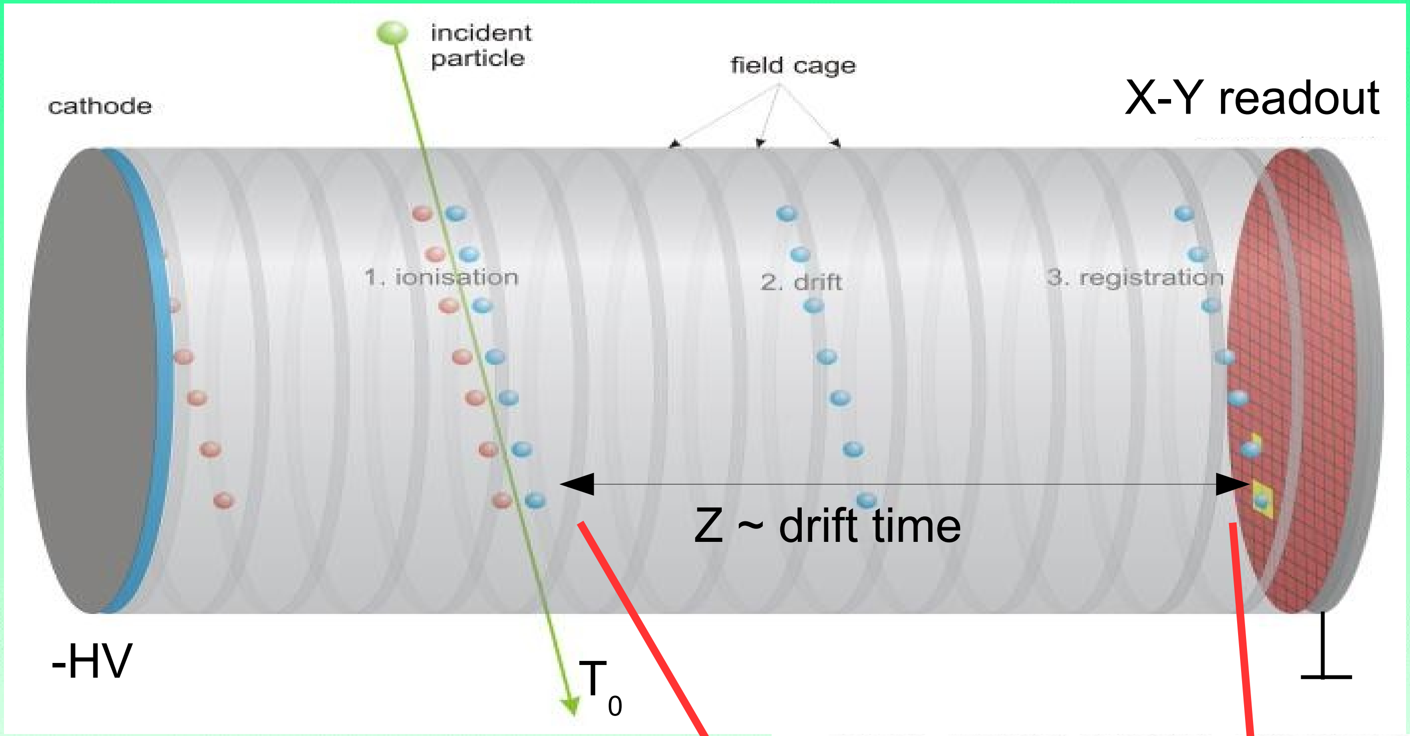
Tremendous granularity

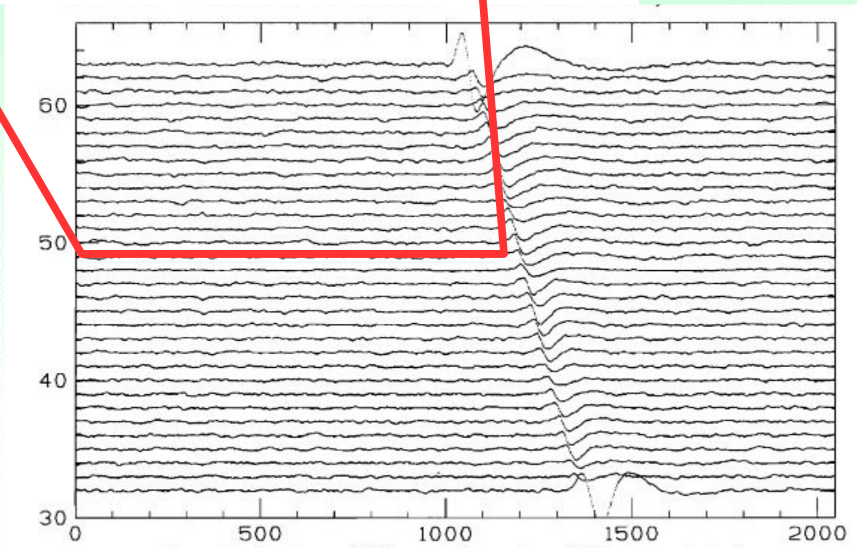
Excellent tracking/calorimetry

Excellent particle ID by dE/dx

e-γ separation → very important for resolution of MiniBooNE anomaly !

Liquid Argon Time Projection Chamber





Charge yield (MIP) ~ 9000 e/mm (1.5 fC/mm)
T_0 by scintillation

Charge readout:
X: Induction (non-destructive)
Y: Collection

Towards 100kt high granularity detectors

Opened questions for long drift TPC:

Drift field generation (potential difference O(MV))

Charge diffusion (drift time O(ms), drift distance O(m))

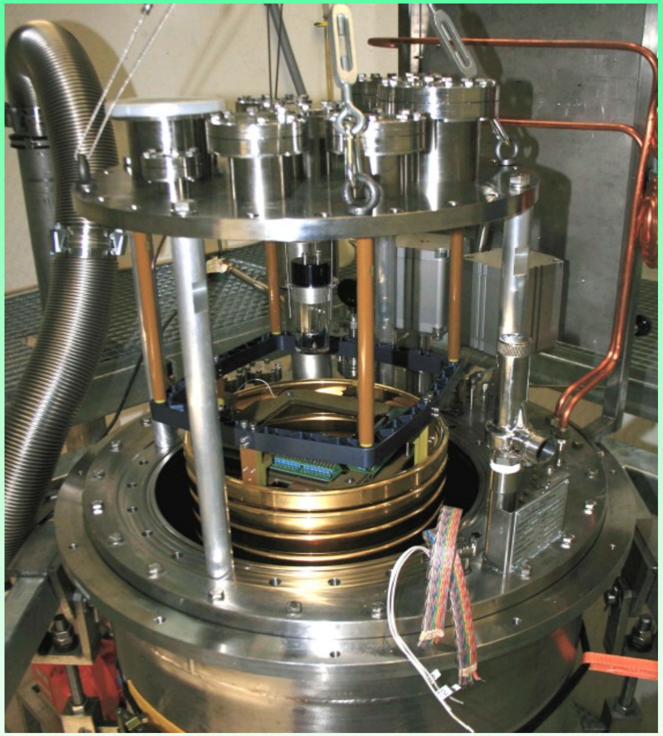
Drift field uniformity (ion charge pileup)

Argon purity and charge «life time» O(ms)
(< 0.1 ppb Oxygen-equivalent impurities)

Engineering issues (cryogenic system, purification etc.)

ARGONTUBE detector at LHEP, Uni-Bern
(2007 - now)

ARGONTUBE design and construction



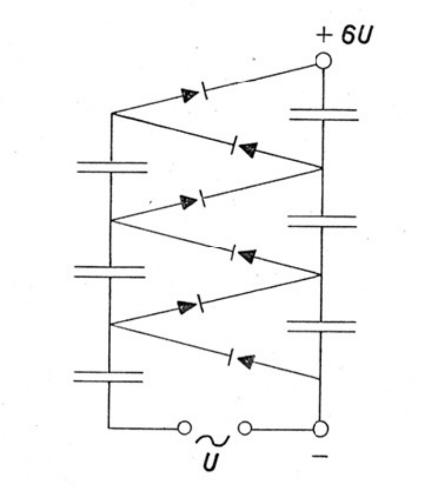
ARGONTUBE LAR TPC
how to create 500 kV over the drift distance?

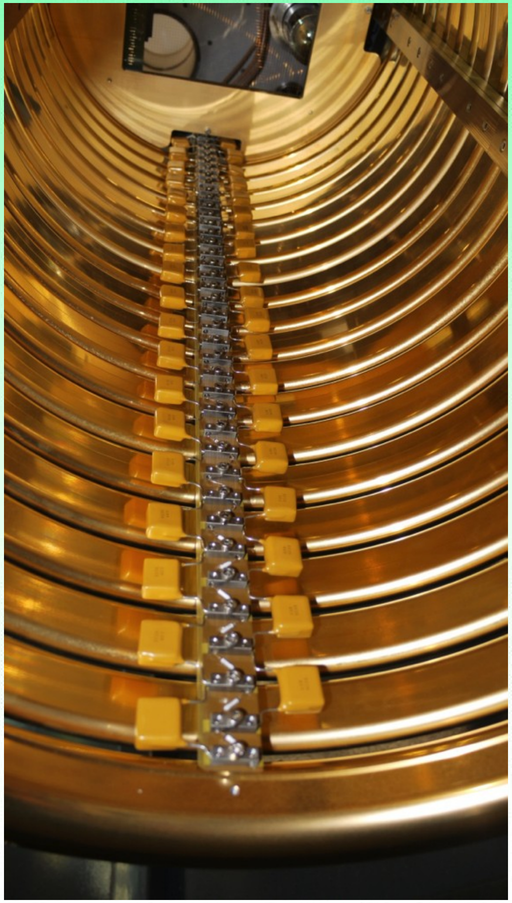
HV feedthrough from room to 87K? No technology available on the market ..

Generate in place!
(Cockcroft-Walton or Greinacher multiplier)

125 stages, C=160 nF
Input: 0-4 kV, sine wave @ 50 Hz
Output: (distributed) DC up to 500 kV

When fully charged - uniform E-field in the drift region.

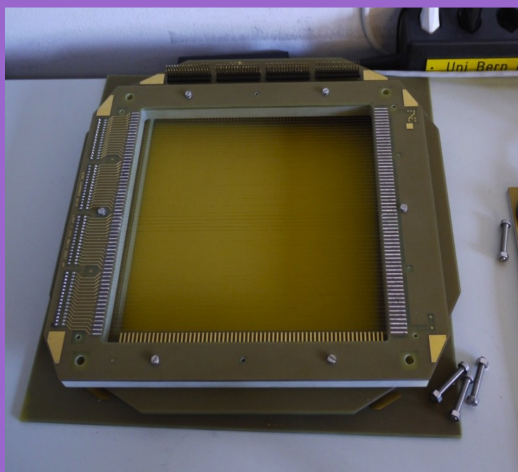


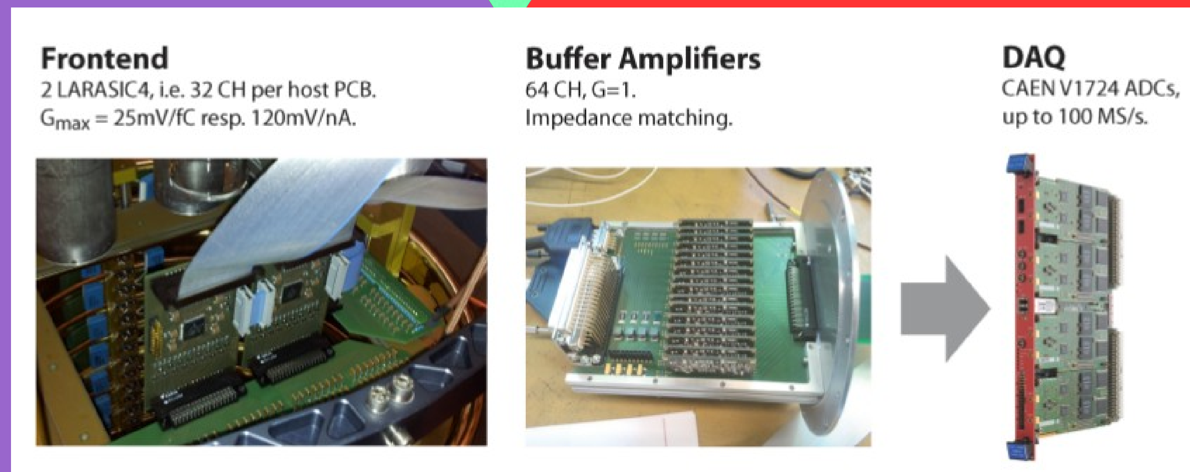


ARGONTUBE LAR TPC charge readout

Charge readout:
wire planes, induction-collection scheme (XY coordinates)

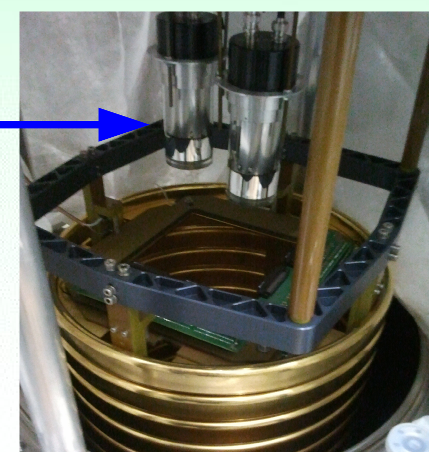
Signal amplification and conditioning:
LARASIC4 cryo-amplifiers[1]





Event triggering: external scintillating counters +

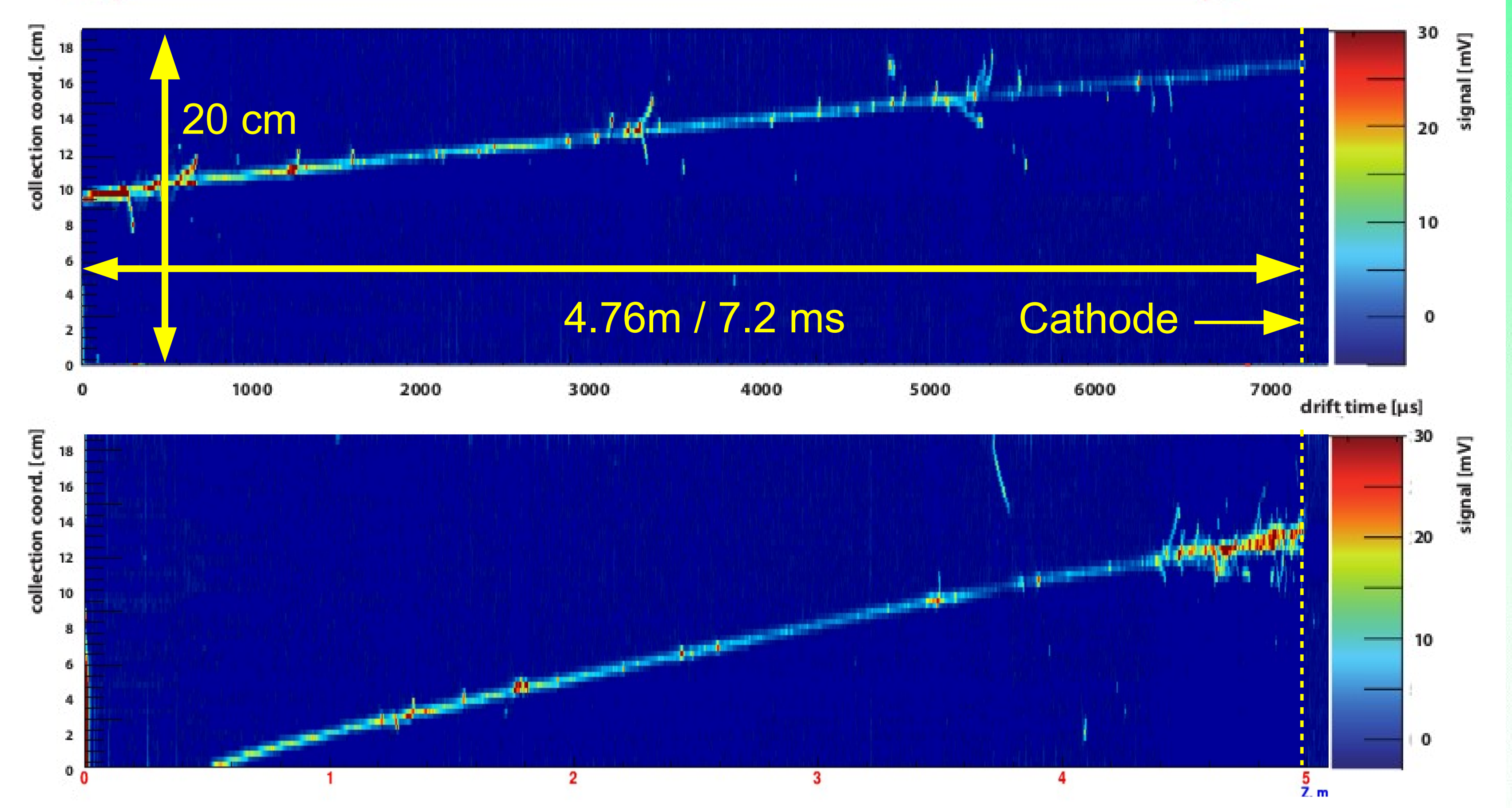
internal PM tubes with WLS coating (LAr scintillation)



[1] Brookhaven National Laboratory, Cold Electronics Team, V. Radeka

ARGONTUBE LAR TPC performance: cosmic muons
5 m long electrons drift in LAR: first time!

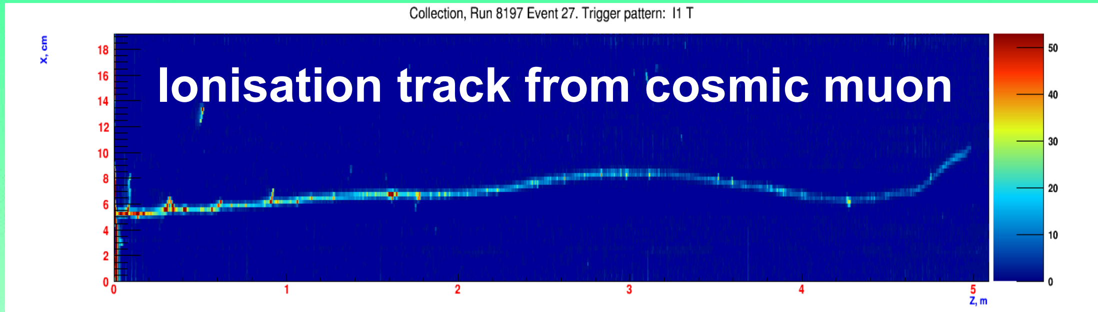
S/N for MIP ~ 16,   Noise ENC = 525 e^-



Straight ionisation tracks by UV pulsed laser

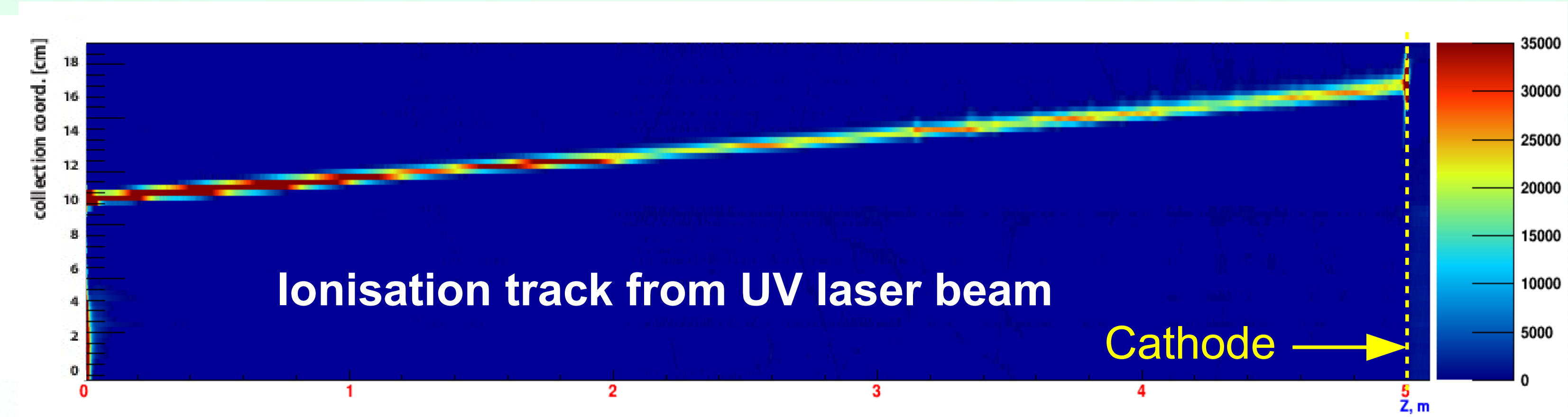
Cosmic muons are here for free, but...

Delta-electrons
Coulomb multiple scattering
Charge recombination
Low statistics



Need better tool of straight controlled tracks.
Solution — ionization of LAr with photons!

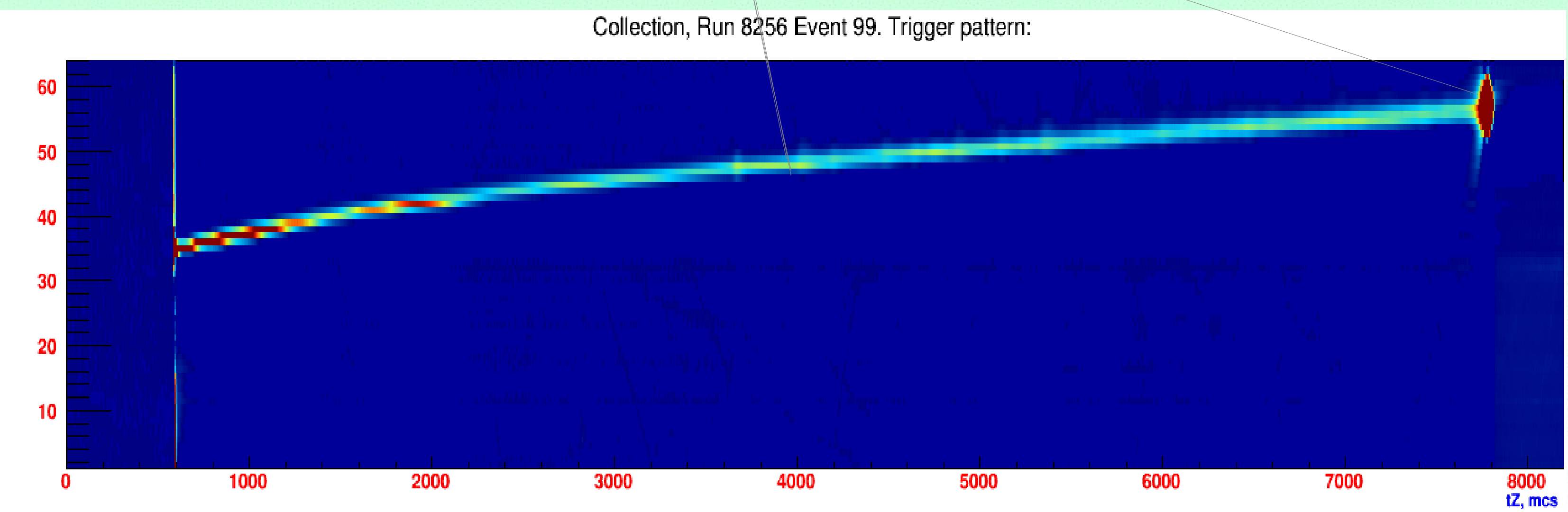
High intensity pulsed UV laser
(266 nm, up to 10 mJ per pulse, 10 Hz rep. Rate)
Ionization by multi-photon absorbtion

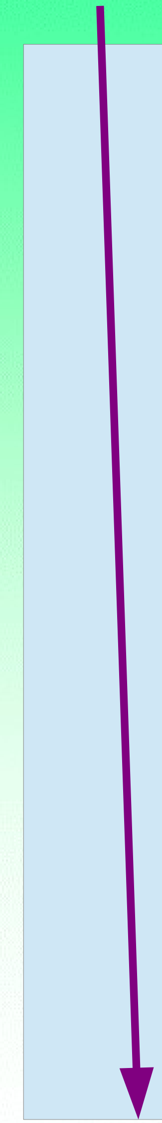


Straight ionisation tracks by UV pulsed laser

Pulsed laser, t ~ 5 ns
F_{rep} from 0 to 10 Hz
266 nm, ~10 mJ/pulse

- Charge attenuation → LAr purity
- Track curvature → Drift field
- Track divergence → Tr. diffusion
- End peak → Lon. diffusion

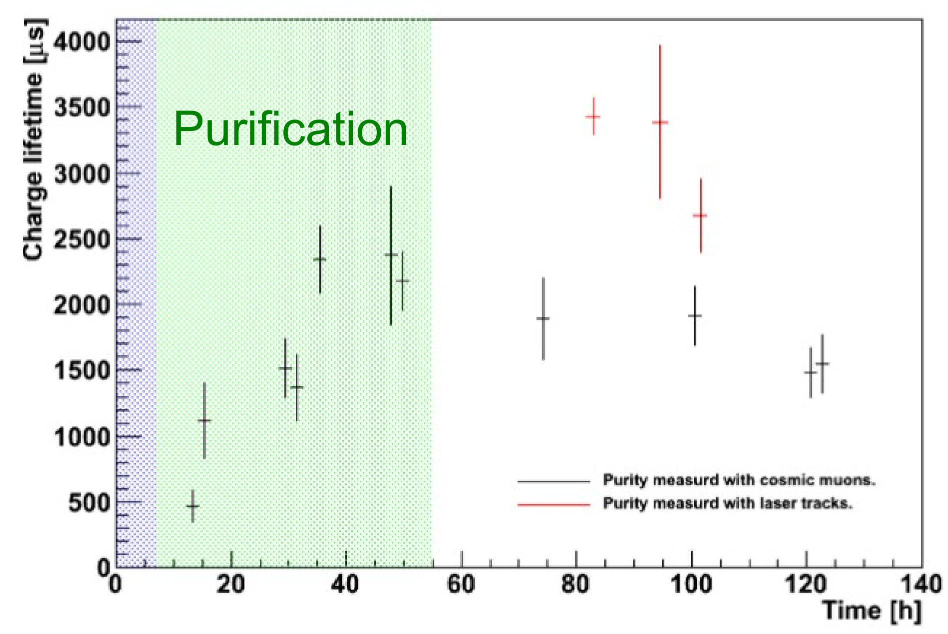


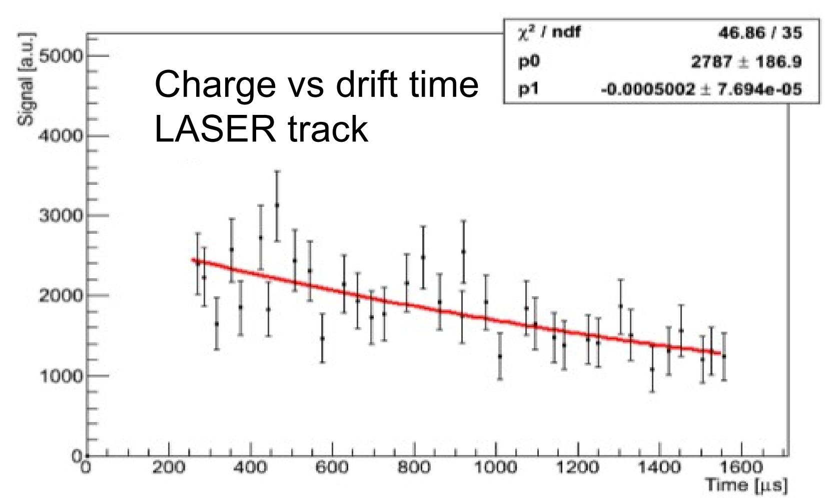


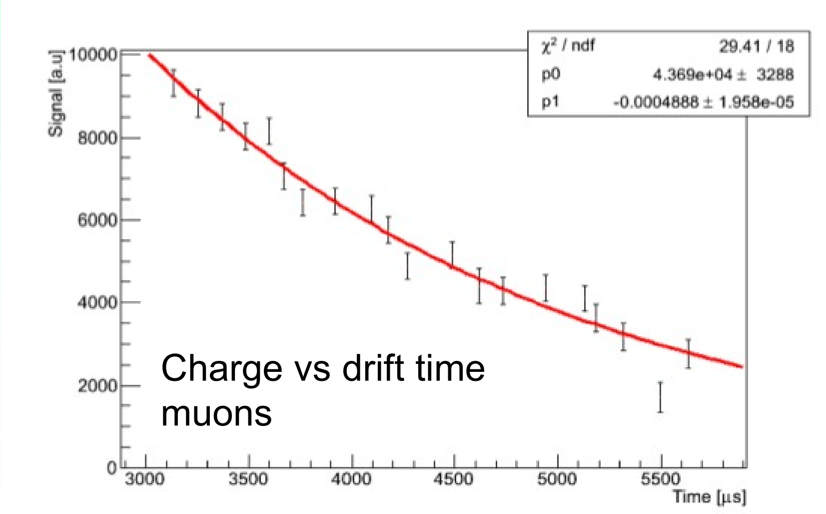
ARGONTUBE LAR TPC: charge life time

- Electronegative molecules (O_2, H_2O) absorb drifting electrons
- Charge attenuation: $q = q_0 e^{-t/\tau}$
- Impurity concentration: $P[ppb] \approx \frac{300}{\tau[\mu s]}$

Charge life time (purity) evolution





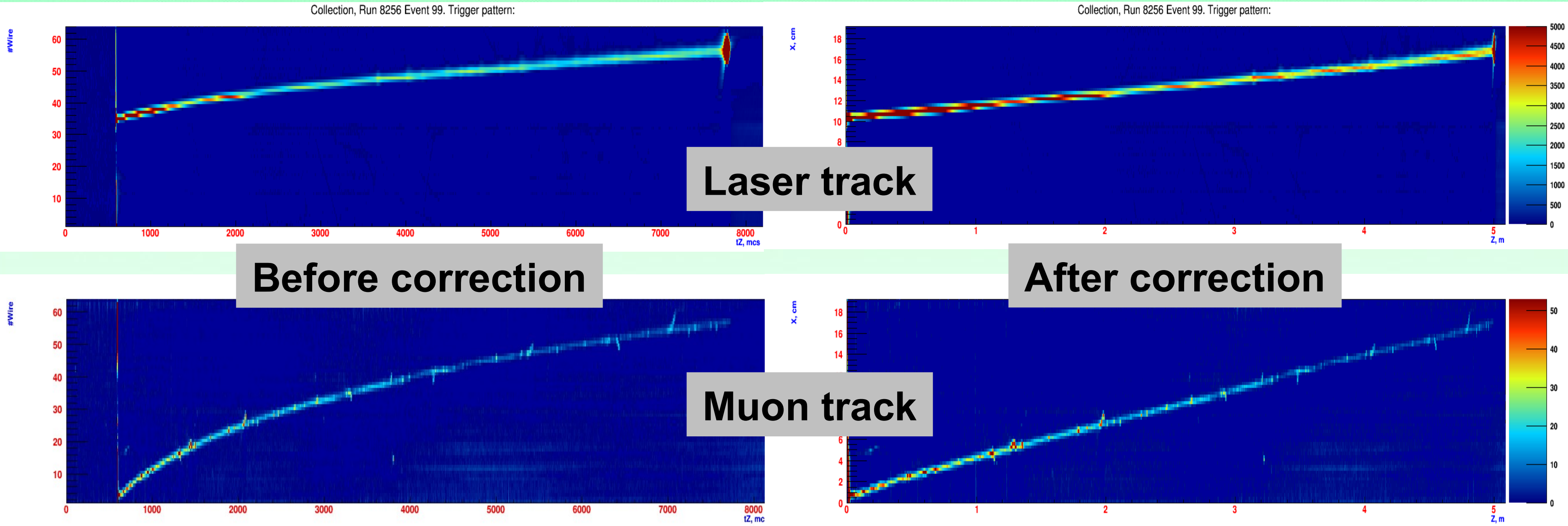


With liquid-only purification life time of ~**3 ms** is reachable.

ARGONTUBE geometry/field calibration with laser

1. Greinacher circuit undercharged → drift field is not uniform
2. Ion space charge from cosmic muon flux → drift field is not uniform

Solution: use straight track from laser at known position
to calibrate time axis and convert time tZ to Z space coordinate



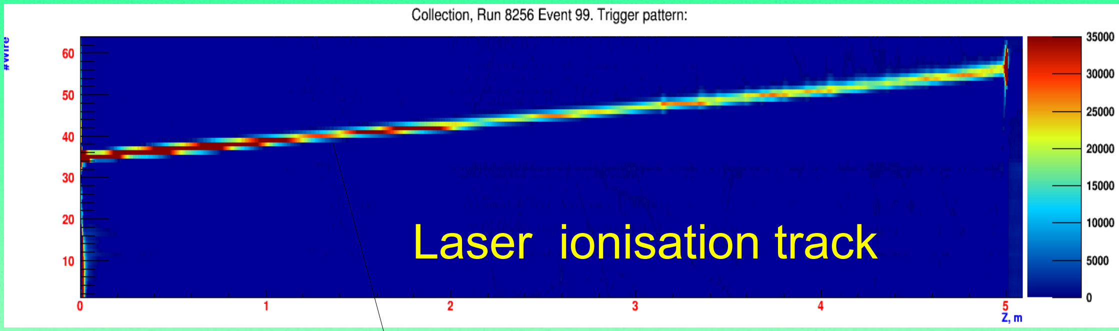
ARGONTUBE LAR TPC: transversal charge diffusion

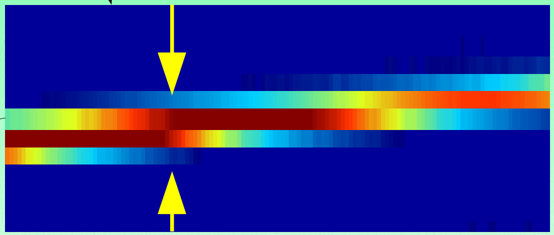
LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

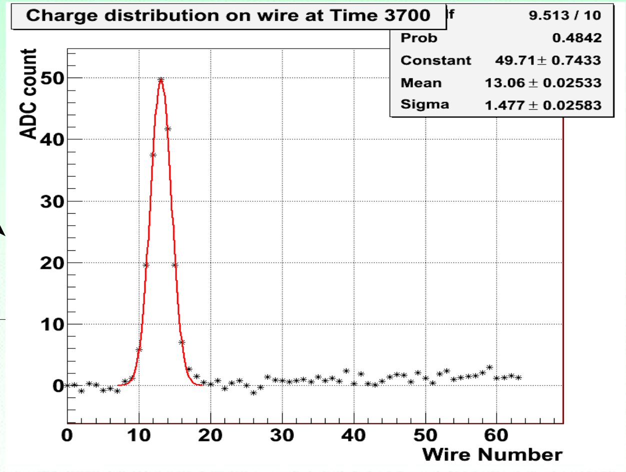
- Not much diffusion measurements at low fields

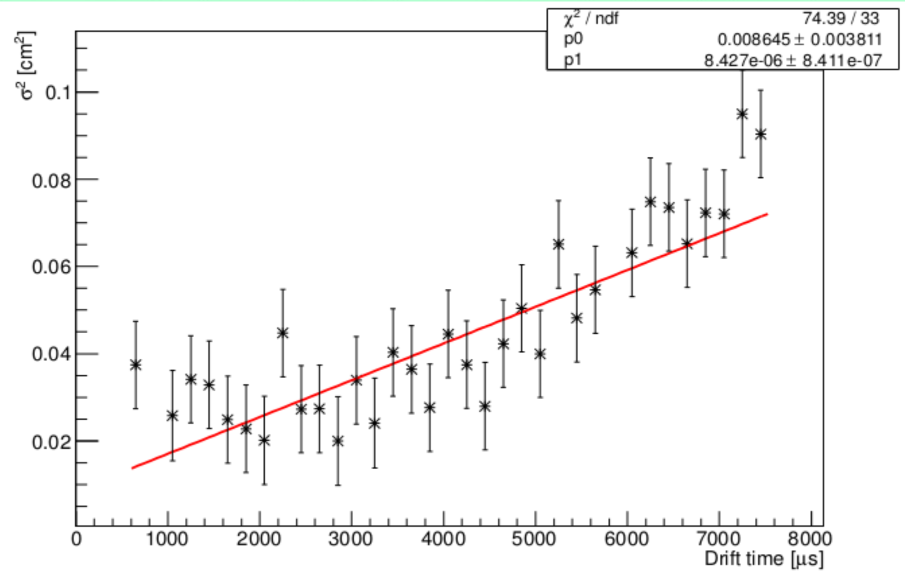
- Transversal diffusion in ARGONTUBE with UV-laser tracks at $E \approx 200$ V/cm

$$D_T = \frac{\sigma^2 - \sigma_0^2}{2t} = 4.21 \pm 0.42\, cm^2/s$$



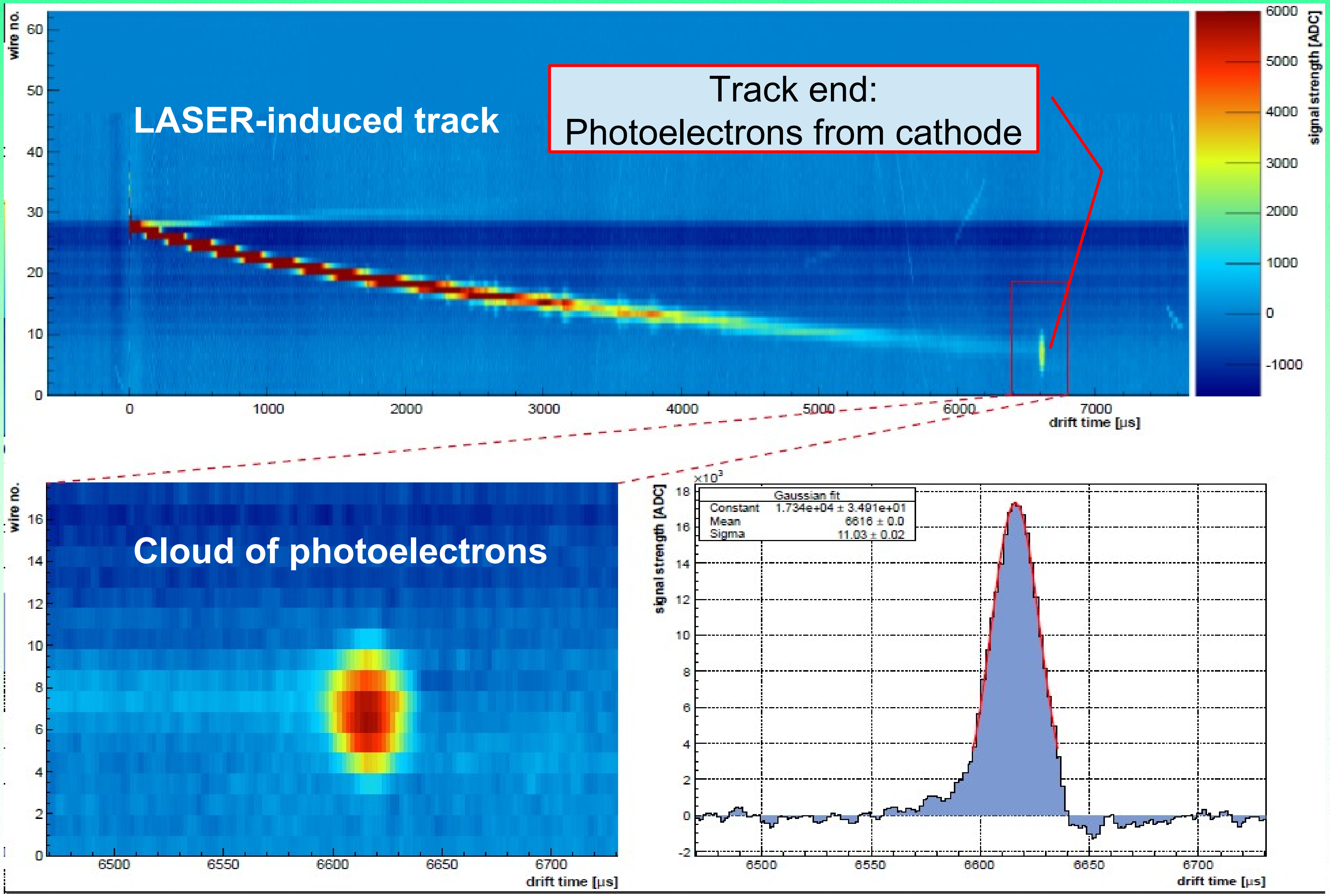




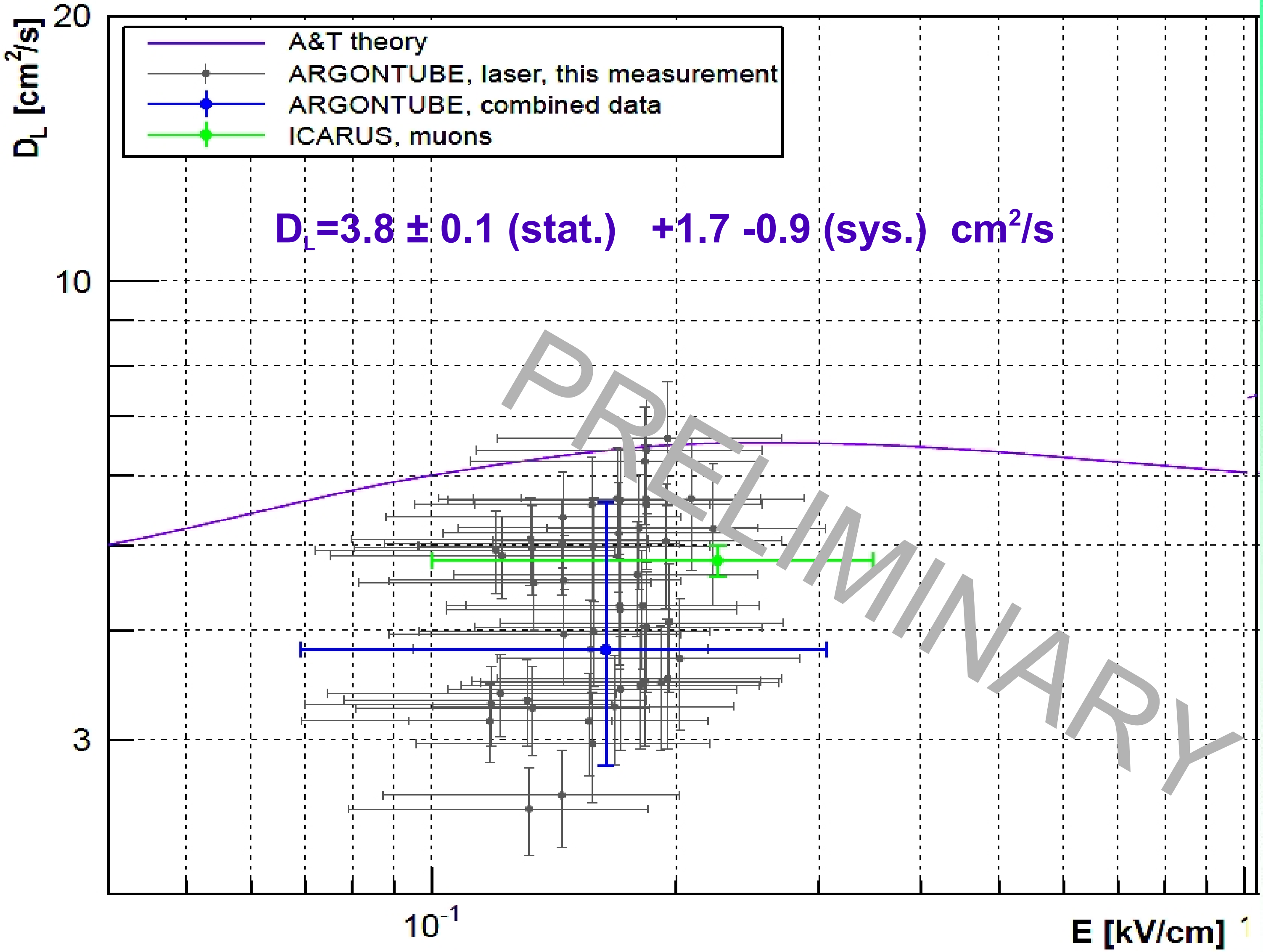


10 ms drift will result in particle track cross-section of σ = 2 mm

ARGONTUBE LAR TPC: longitudinal charge diffusion



ARGONTUBE LAR TPC: longitudinal charge diffusion



ARGONTUBE HV circuit performance

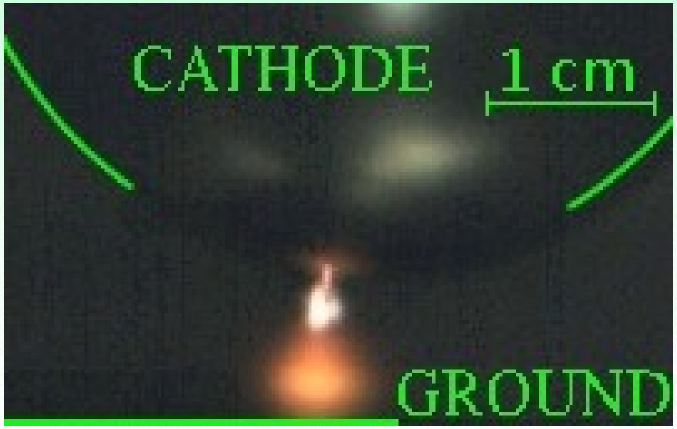
Design maximum voltage 500 kV

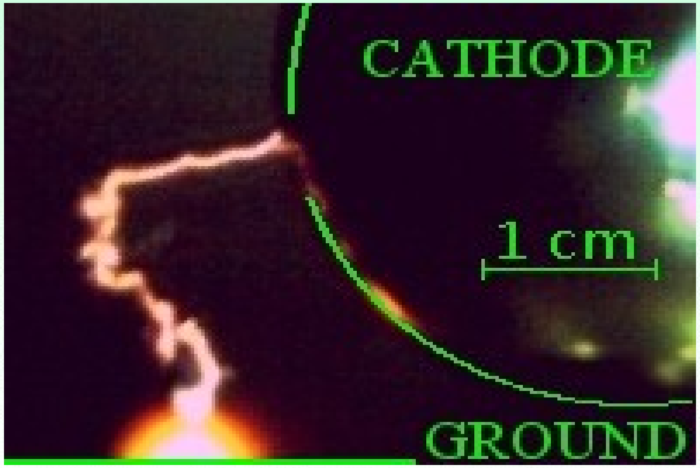
Leakage current is non-zero → Greinacher multiplier is undercharged

Breakdowns in LAr at already 150 kV, reason was unclear.

Published in 1960-ies value of LAr strength (1.4 MV/cm) was measured at distances of O(100) microns, is drastically wrong at 10 cm scale.

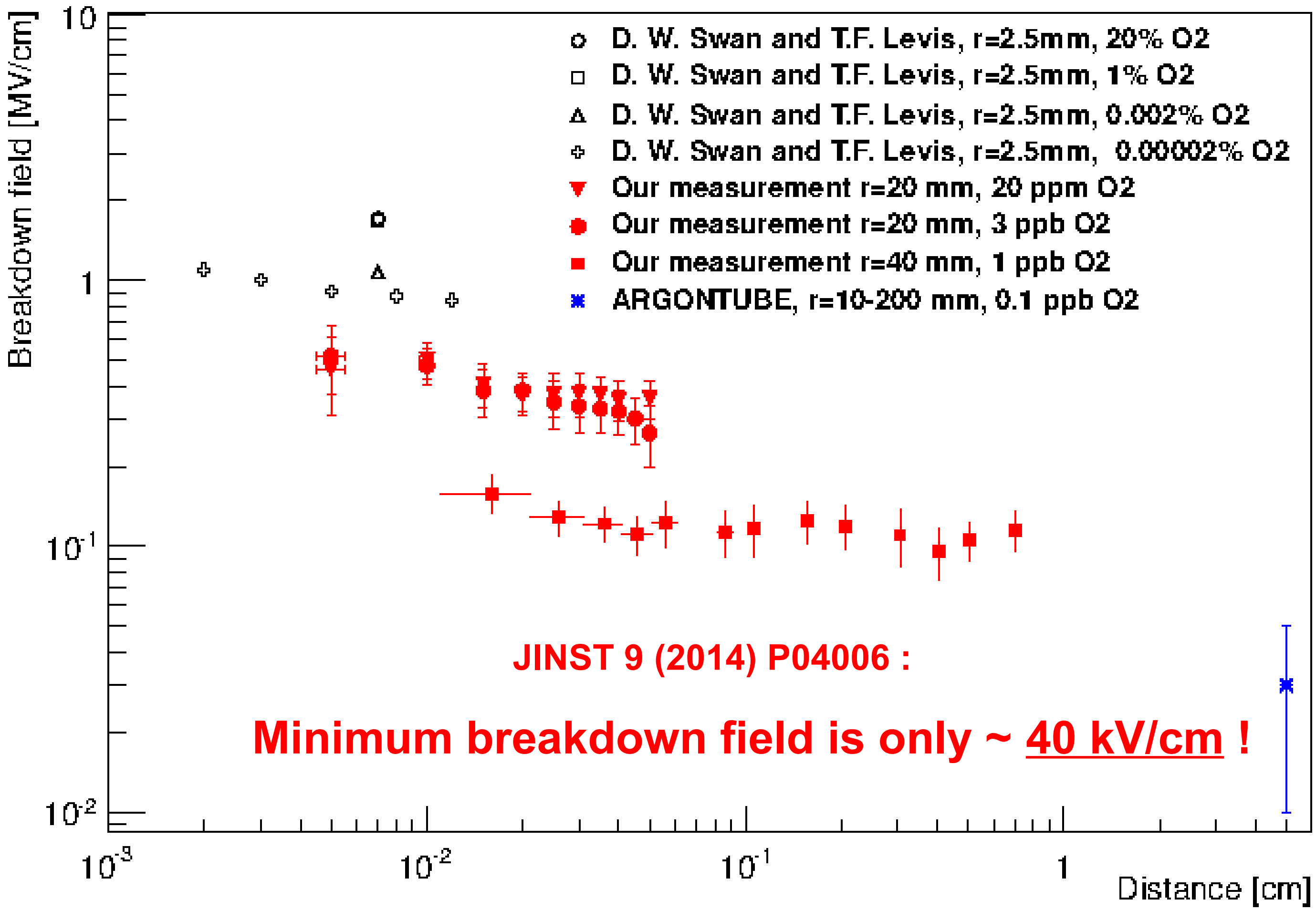
The problem is under detailed study at LHEP.



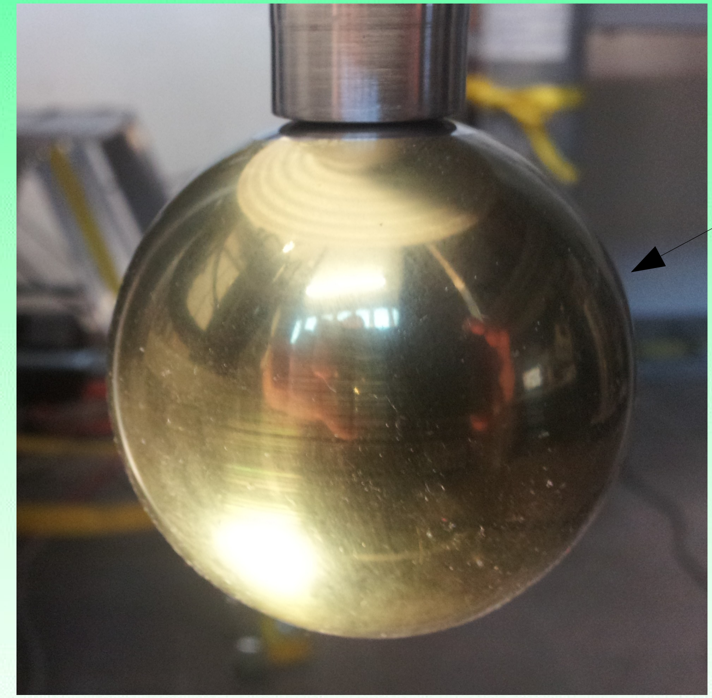


Dielectric strenght of LAr, D.W. Swan ('60s) and our recent results

Dependence of breakdown field vs cathode-anode space



Solution to avoid breakdowns in LAr for fields up to 400 kV/cm



Cathode: 450 μm layer of natural polyisoprene

Breakdown at **412 kV/cm**

Factor of **x10** improvement in breakdown field !

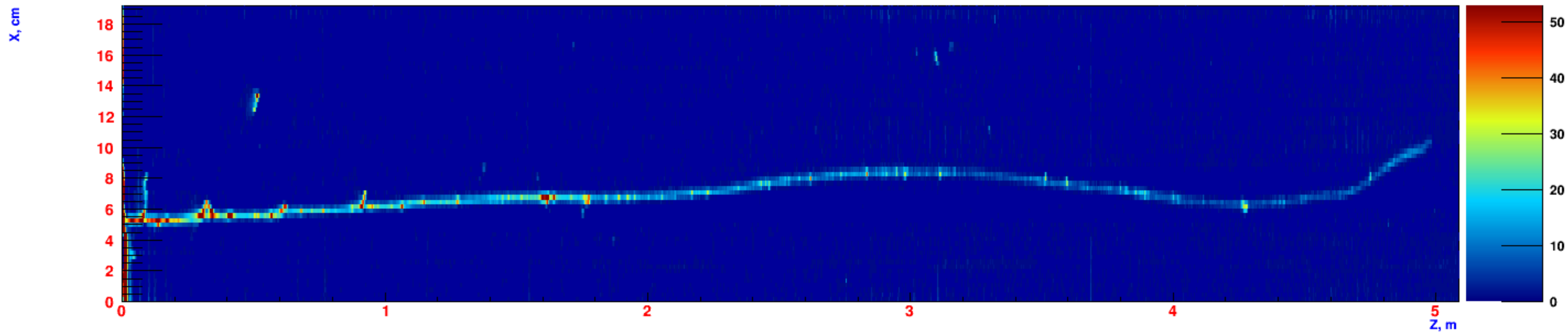
Details in arXiv:1406.3929, accepted by JINST

Summary

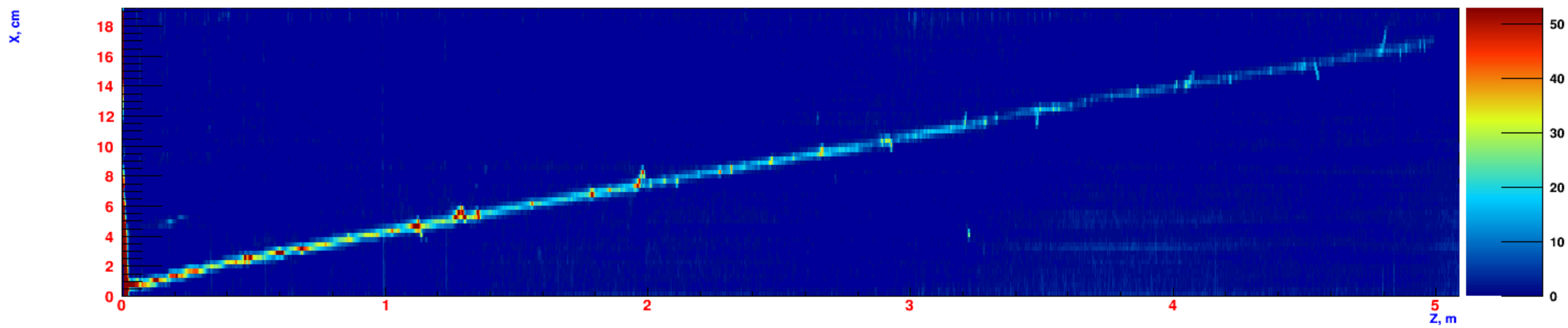
- The longest electron drift ~5m in LAr TPC is achieved
- Minimum ionizing particles detected with S/N ~16
- Technology of field calibration with UV laser is established
- Electron life time of ~ 3 ms is reached
- Transversal and longitudinal electron diffusion is measured
- Technology of in-situ generation of several hundred kV is established
- Problem with HV is identified, studied and the solution is found
- Good basis for design of future giant detectors

ARGONTUBE event gallery

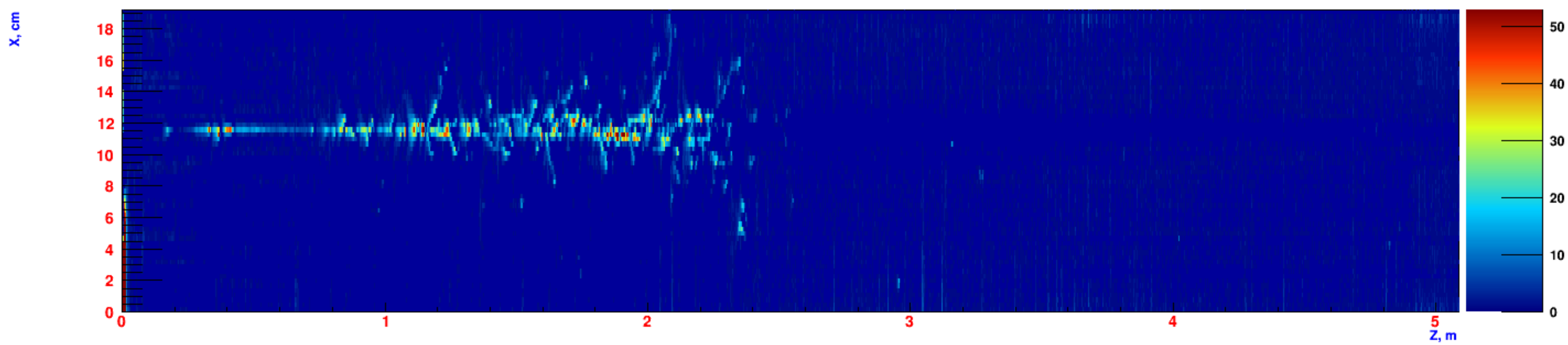
Collection, Run 8197 Event 27. Trigger pattern: I1 T



Collection, Run 8204 Event 43. Trigger pattern: I1 B T

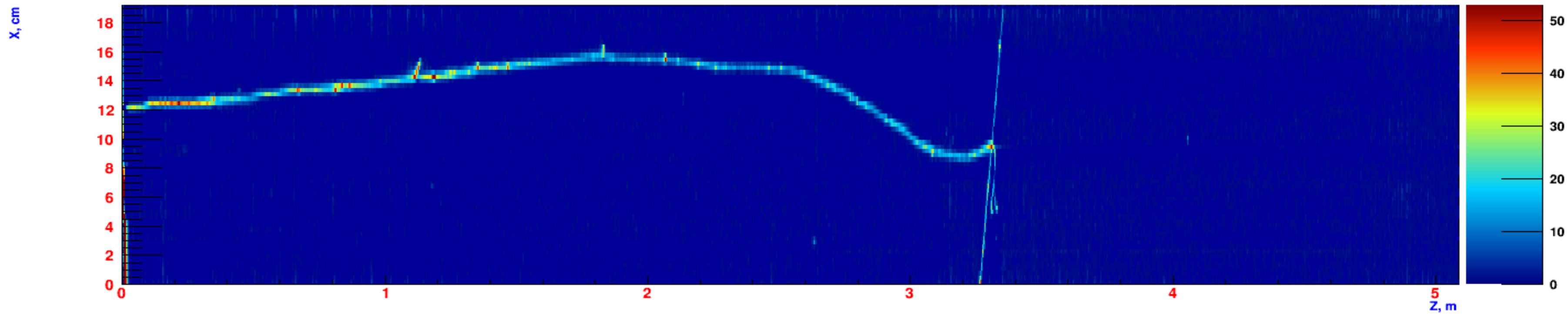


Collection, Run 8257 Event 3. Trigger pattern: I1 T

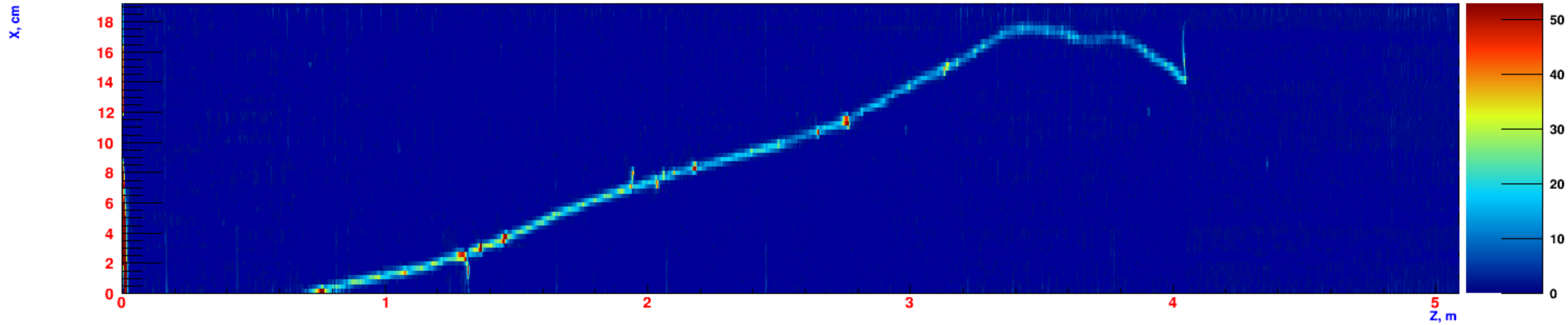


ARGONTUBE event gallery

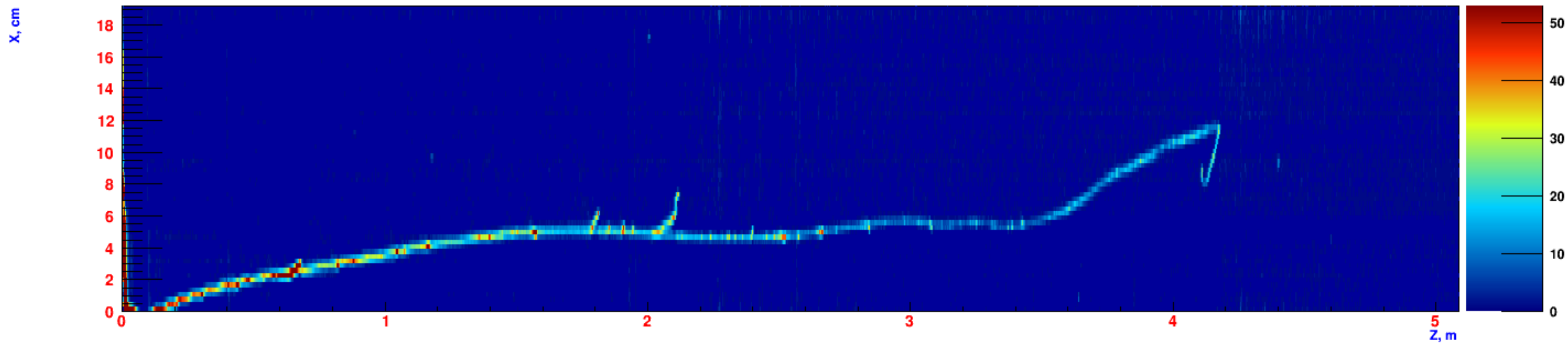
Collection, Run 8203 Event 33. Trigger pattern: I1 T



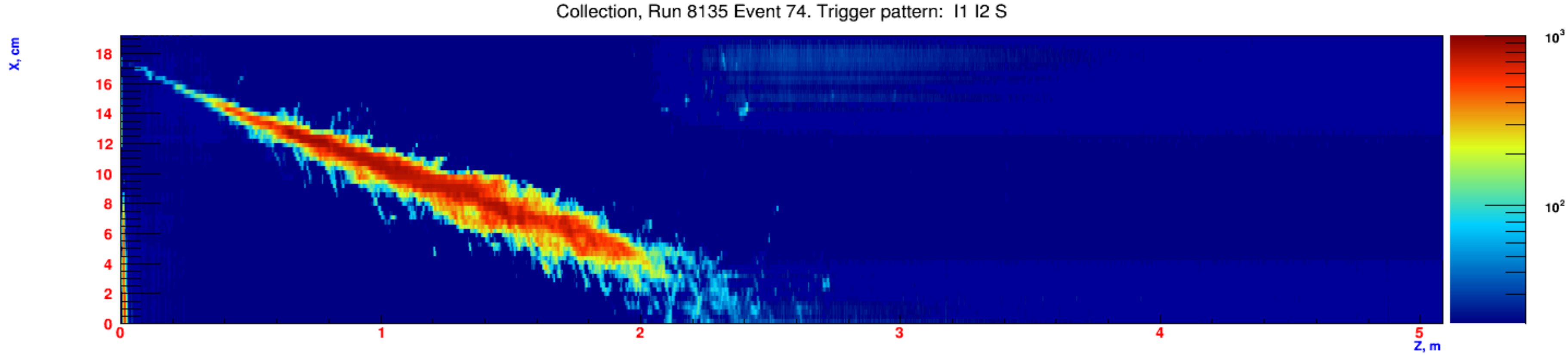
Collection, Run 8203 Event 135. Trigger pattern: I1 I2 T

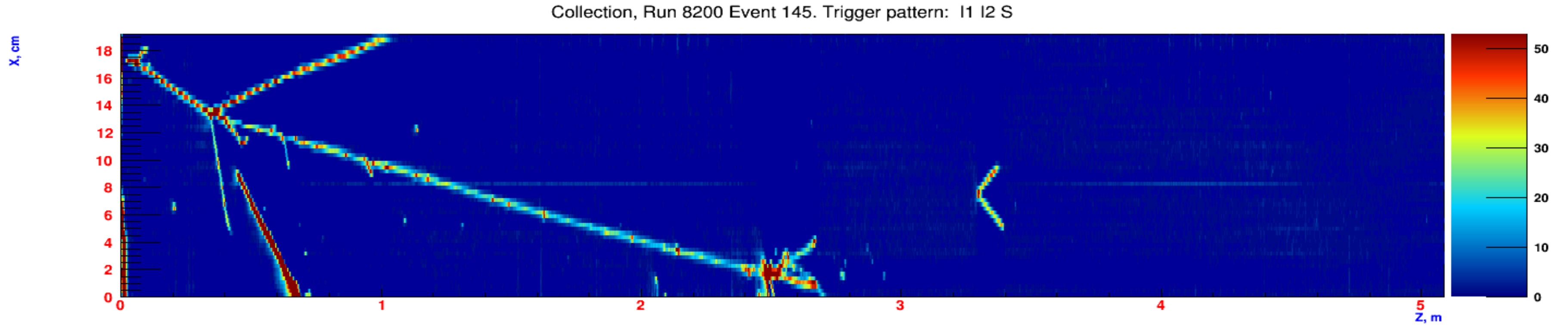


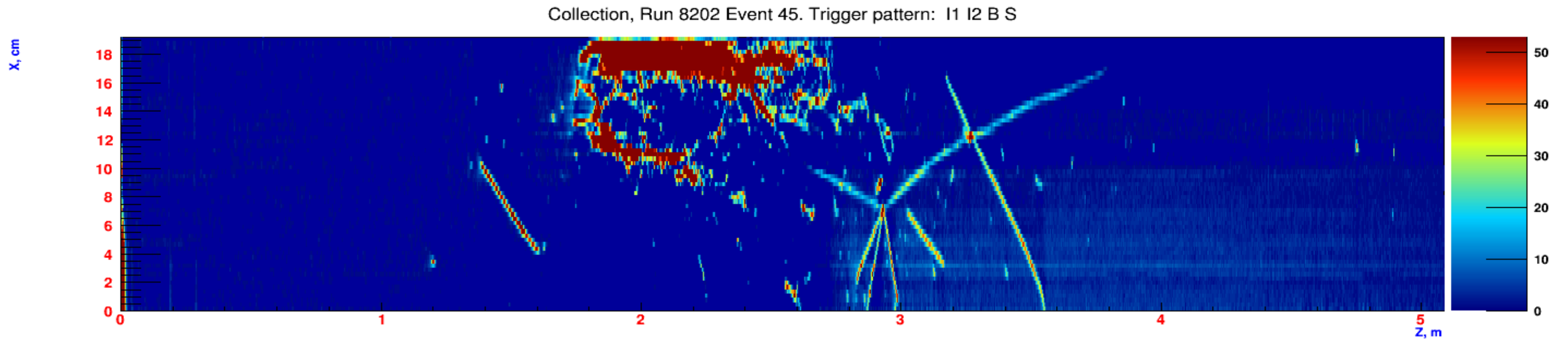
Collection, Run 8200 Event 142. Trigger pattern: I1 I2 T



ARGONTUBE event gallery





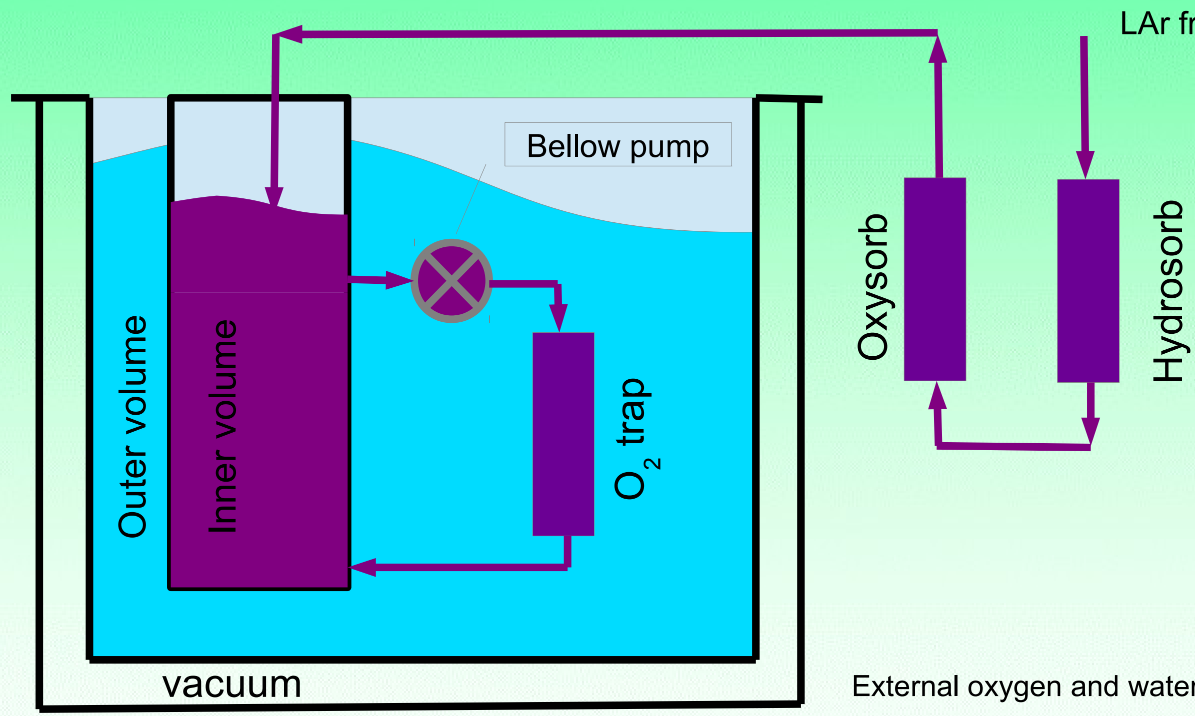


Thank you for your attention !

BACKUP SLIDES

ARGONTUBE cryogenic system

1. Minimum (eventually zero) argon evaporation from active volume
2. Efficient liquid argon recirculation/purification



External oxygen and water trapping units:

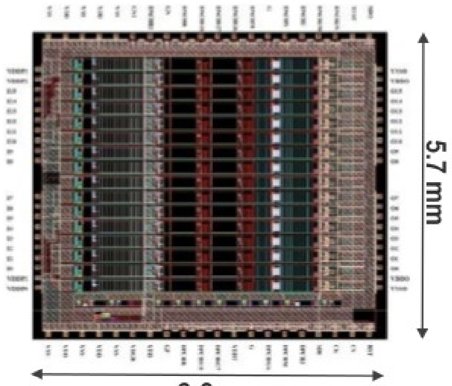
MESSER Schweiz AG Oxysorb & Hydrosorb

Recirculation bellow pump (up to 300 l/h LAr) and inner oxygen trapping filter:

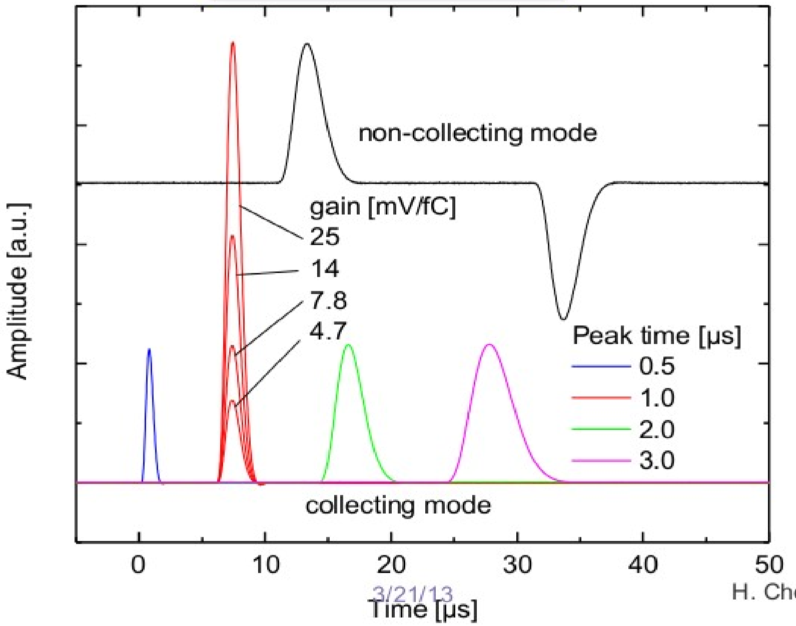
CRIOTEC Impianti S.r.l

LARASIC4 parameters (courtesy of BNL)

MicroBooNE Cold Electronics



CMOS FE ASIC Layout



- **CMOS Analog Front End ASIC**
  - **16 channels per chip**
  - **Charge amplifier, high-order filter**
  - **Adjustable gain: 4.7, 7.8, 14, 25 mV/fC (55, 100, 180, 300 fC)**
  - **Adjustable filter time constant (peaking time): 0.5, 1, 2, 3 μs**
  - **Selectable collection/non-collection mode (baseline)**
  - **Selectable dc/ac (100 μs) coupling**
  - **Rail-to-rail analog signal processing**
  - **Band-gap referenced biasing**
  - **Temperature sensor (~ 3mV/°C)**
  - **136 registers with digital interface**
  - **5.5 mW/channel (input MOSFET 3.6 mW)**
  - **~ 15,000 MOSFETs**
  - **Designed for long cryo-lifetime**
  - **Technology CMOS 0.18 μm, 1.8 V, 6M, MIM, SBRES**

3/21/13

H. Chen - LAr TPC R&D Workshop

Cold Electronics Development for LAr TPC

Hucheng Chen
On behalf of the Cold Electronics Team
March 21st, 2013

LARASIC4 vs warm preamp

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

- Amount of charge/mm expected from mip

  $\left(\frac{dE}{dX}\right)_{mip} \approx 0.21\,\text{MeV/mm},\ W_e \approx 23.6\,\text{eV},\ R \approx 0.35 \pm 0.04$ @200V/cm

  $\Rightarrow \frac{\Delta Q}{\Delta x} \approx \mathbf{8'900\,e/mm}$

- Analyze transversal mip. tracks passing close to the readout plane.
- *RMS noise*

  $N_{warm} = 1.1 \pm 0.1\,\text{mV},$

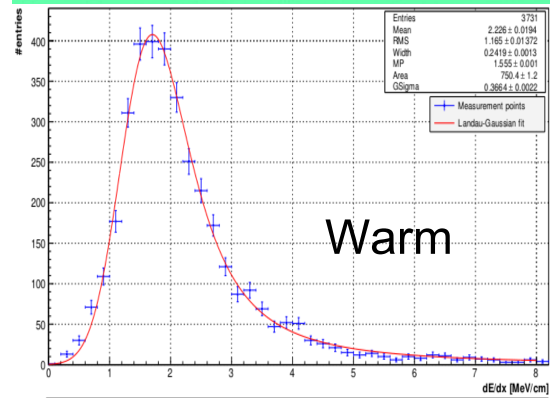
  $N_{cold} = 2.1 \pm 0.1\,\text{mV} \approx 525e^{-}(ENC)$
- *MIP signal*

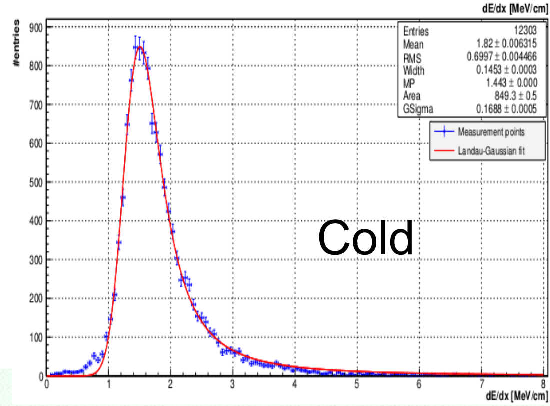
  $S_{warm} = 2.8 \pm 0.6\,\text{mV}$

  $S_{cold} = 33.0 \pm 7.9\,\text{mV} \approx 8'100\,\text{e/mm}$

$\Rightarrow$ **Signal to noise ratios**

$S/N_{warm} = 2.6 \pm 0.6 \qquad S/N_{cold} = 15.7 \pm 3.8$





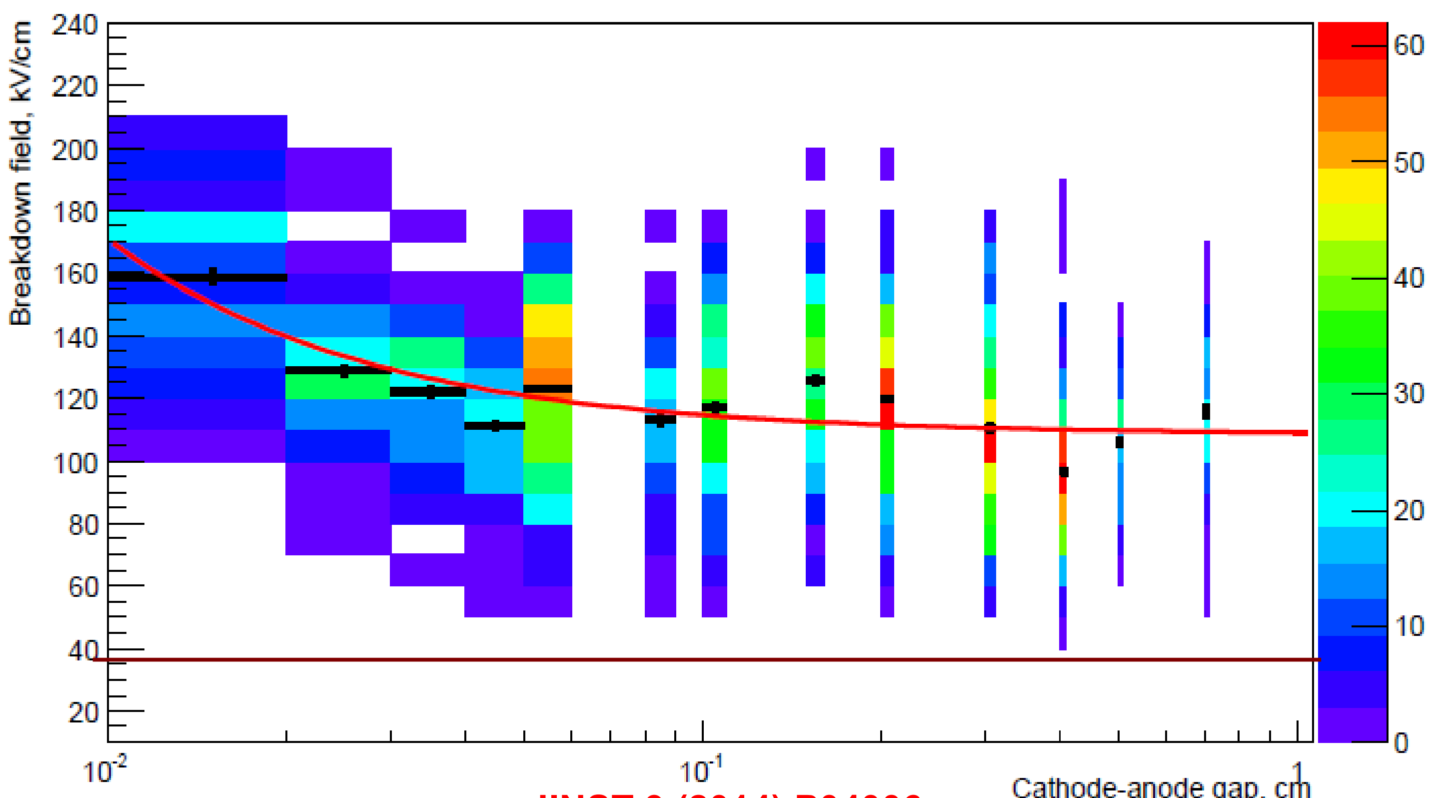
Electric breakdowns in LAr

Dependence of breakdown field vs cathode-anode space

Cathode: sphere D=8cm

Anode: plane

Material: stainless steel, mechanically polished



JINST 9 (2014) P04006 :

Minimum breakdown field is only ~ <u>40 kV/cm</u> !