Results from a 250L LAr TPC exposed to a tagged low-p charged particle beam (T32 @J-PARC)

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Doktorandenseminar - 29.Aug. 2011

Outline

- Introduction
- Experimental setup
- Run description and data taking
- Simulation, reconstruction and analysis
- First results
- Summary

Introduction - The LAr TPC

Basic physical properties of LAr

density	1.4 g/cm^3
boiling point @1 atm	87.3 K
triple point	0.689 bar / 83.8 K
<dE/dx> (MIP)	2.1 MeV/cm
radiation length	14.0 cm
Molière radius	9.25 cm
nucl. interaction length	83.6 cm
W_{ion} (1 MeV e-)	23.6 eV
W_{photon} (1 MeV e-)	19.5 eV

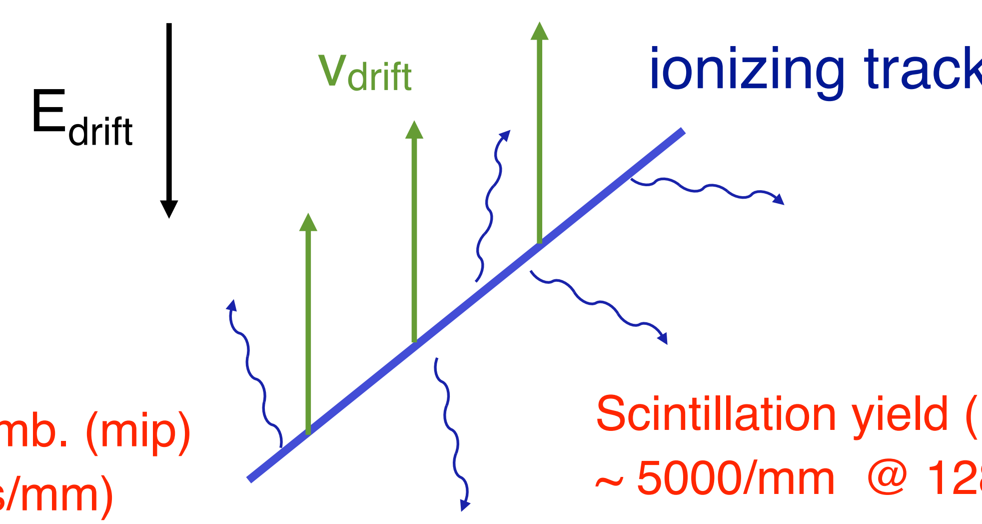
- moreover: argon is available and cheap

Scintillation properties

- LAr has a high scintillation yield at 128 nm
  - ➡ light can be used as trigger

Charge transport

- No electron attachment
  - ➡ charge transport in LAr possible
  - ➡ But: ultra high purity is required!
- Drift velocity = 2 mm/µs with E=1 kV/cm
- small diffusion (σ≈mm after several m of drift)



Charge yield after e-ion recomb. (mip)
~ 1 fC/mm (~ 6000 electrons/mm)

Scintillation yield (mip)
~ 5000/mm @ 128nm

➡ Feasibility of large LAr Time Projection Chambers (LAr-TPCs)

Introduction - T32 experiment

T32 collaboration:

ETHZ, KEK, Iwate and Waseda

Purpose of the T32 experiment:

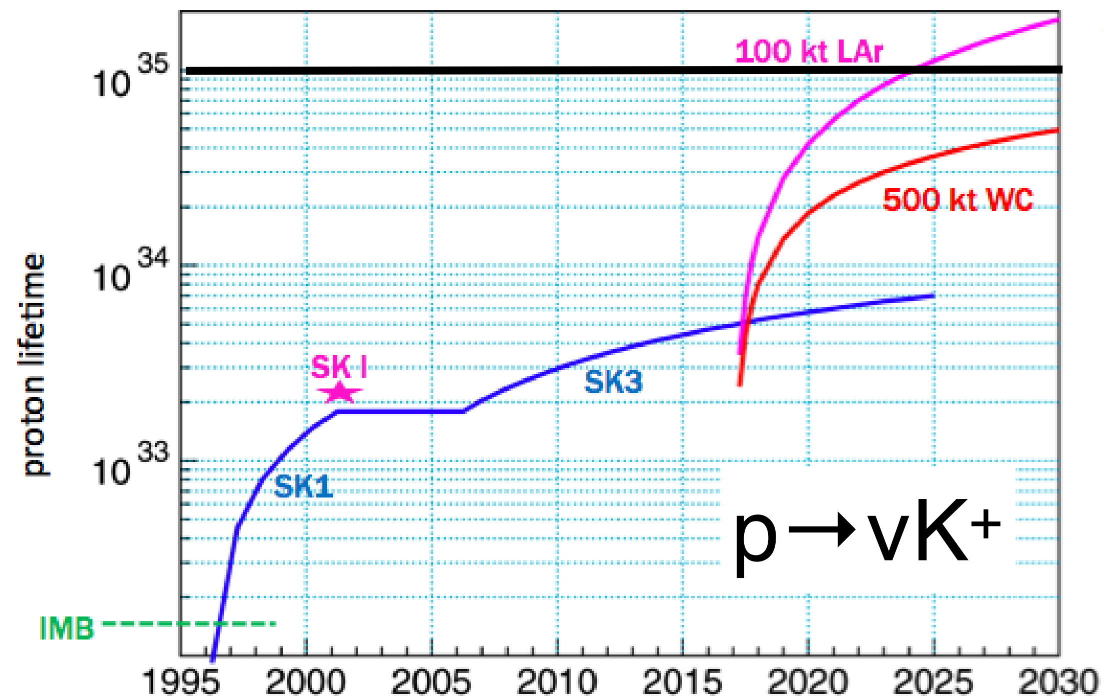
Measurements with well defined charged particle test beam at the J-PARC slow extraction allows...
... to benchmark performance of the LAr-TPC (250L double phase LAr LEM-TPC with 2D anode readout)
... to develop general purpose simulation and reconstruction software for LAr detectors

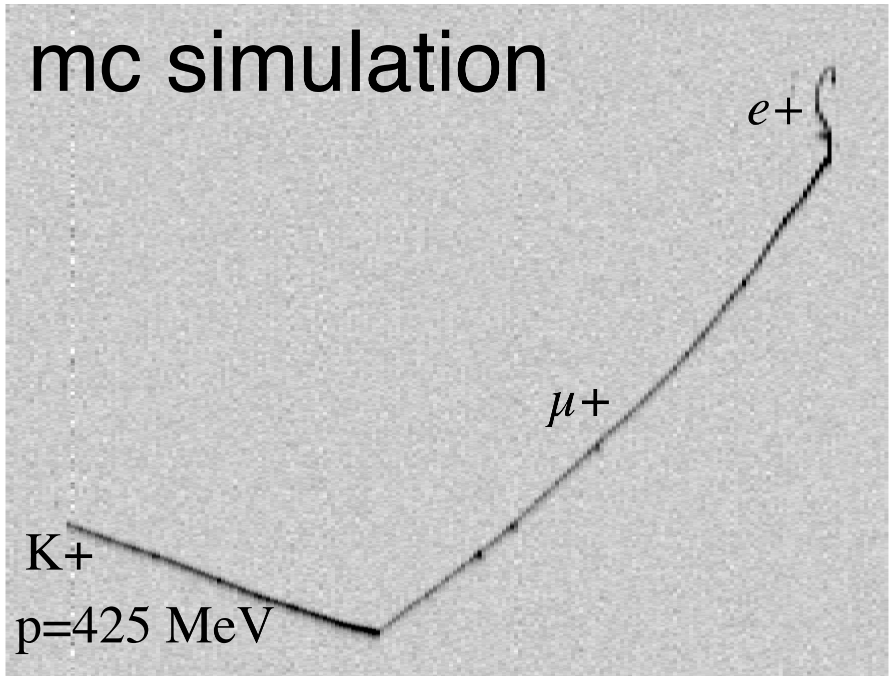
➡ **Moreover:** Kaon ID relevant for proton decay searches: nucleon lifetime of 10^{35} years with 100 kT LAr and 10 years of exposure reachable

strategy:

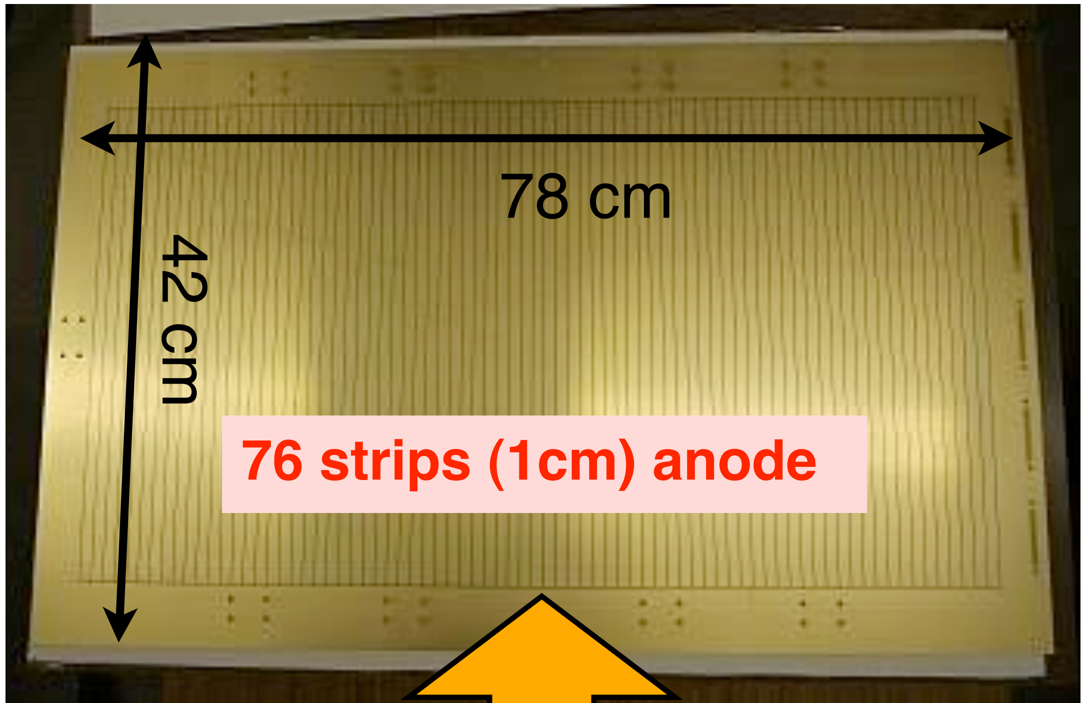
- October 2010 operate a preliminary single phase LAr - TPC in the K1.1 beam line @J-PARC hadron facility
- 2012: final test beam with double phase readout

hep-ph/0701101, 2007

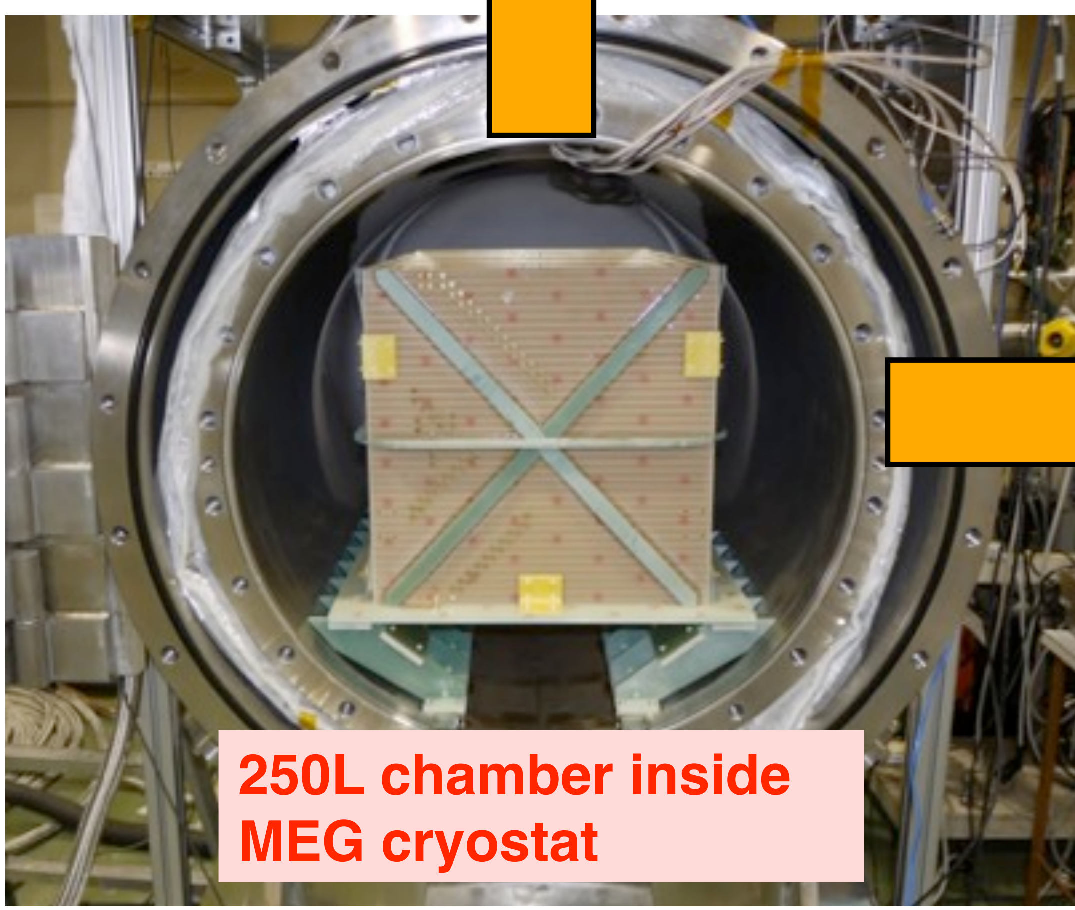


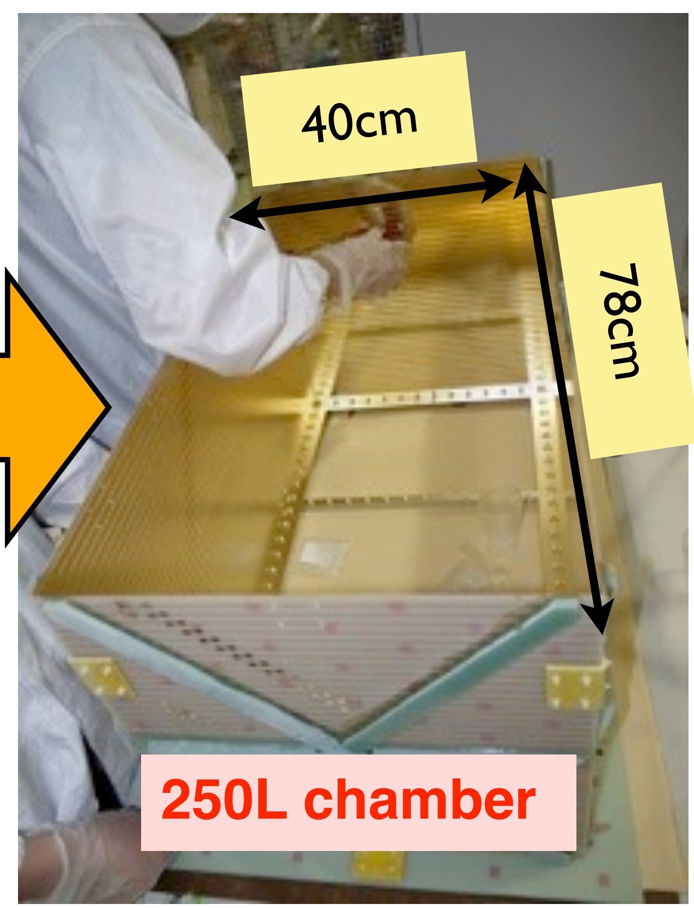


The 250L single phase LAr - TPC



October 2010 beam test configuration





Fiducial mass	170kg
Total LAr mass	~400kg
Field cage dimension	42cm x 42cm x 78cm
Fiducial volume	40cm x 40cm x 76cm
Typical Drift Field	~200V / cm
Maximum drift voltage	12kV
Readout method	single phase (temporary)
Number of readout channels	76 strips (1cm)

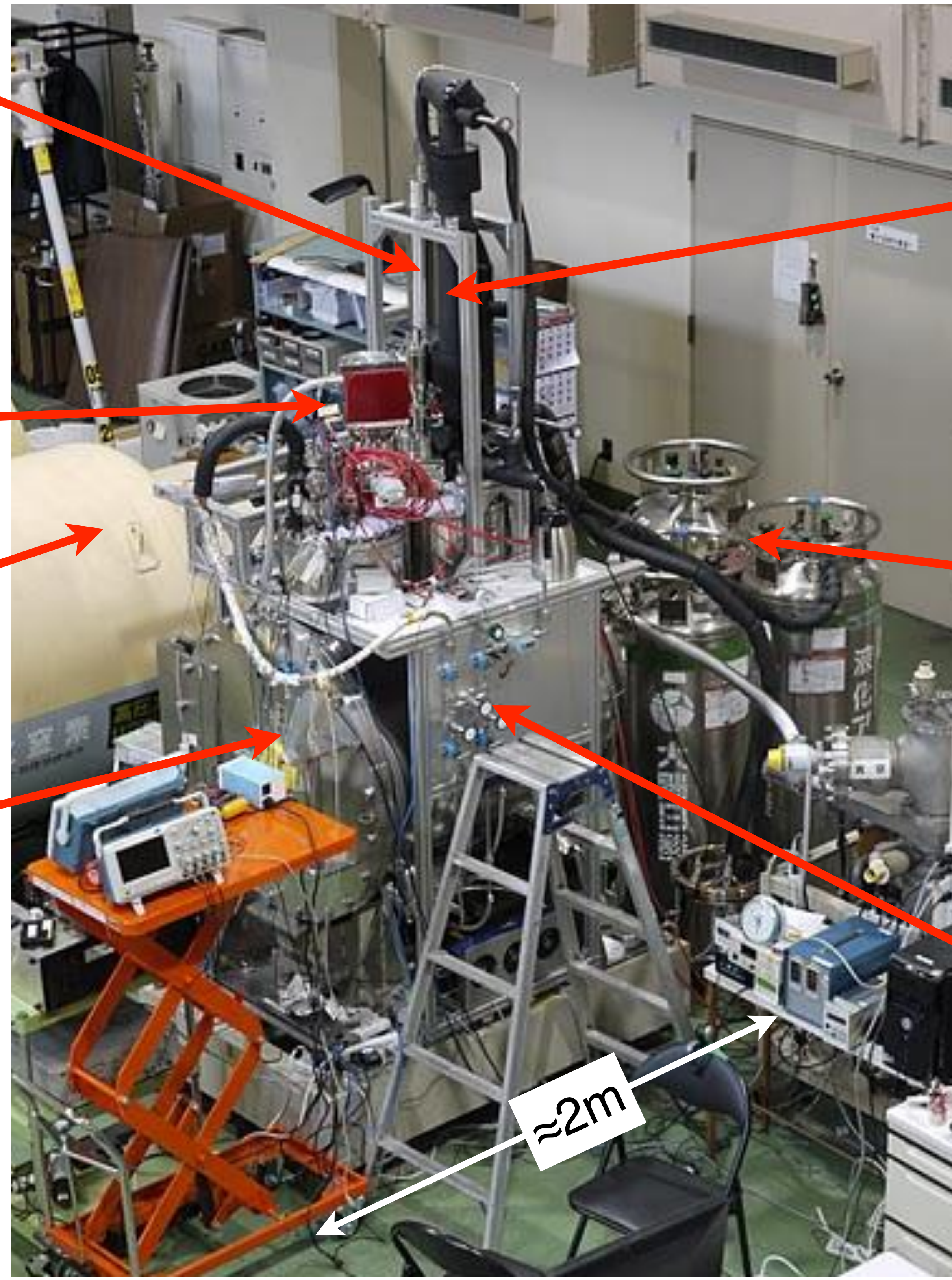
Experimental setup at KEK

SAES filter (warm gas purification)

turbo molecular pump

LN_2 supply

main vessel
- UHV
- vacuum insulated

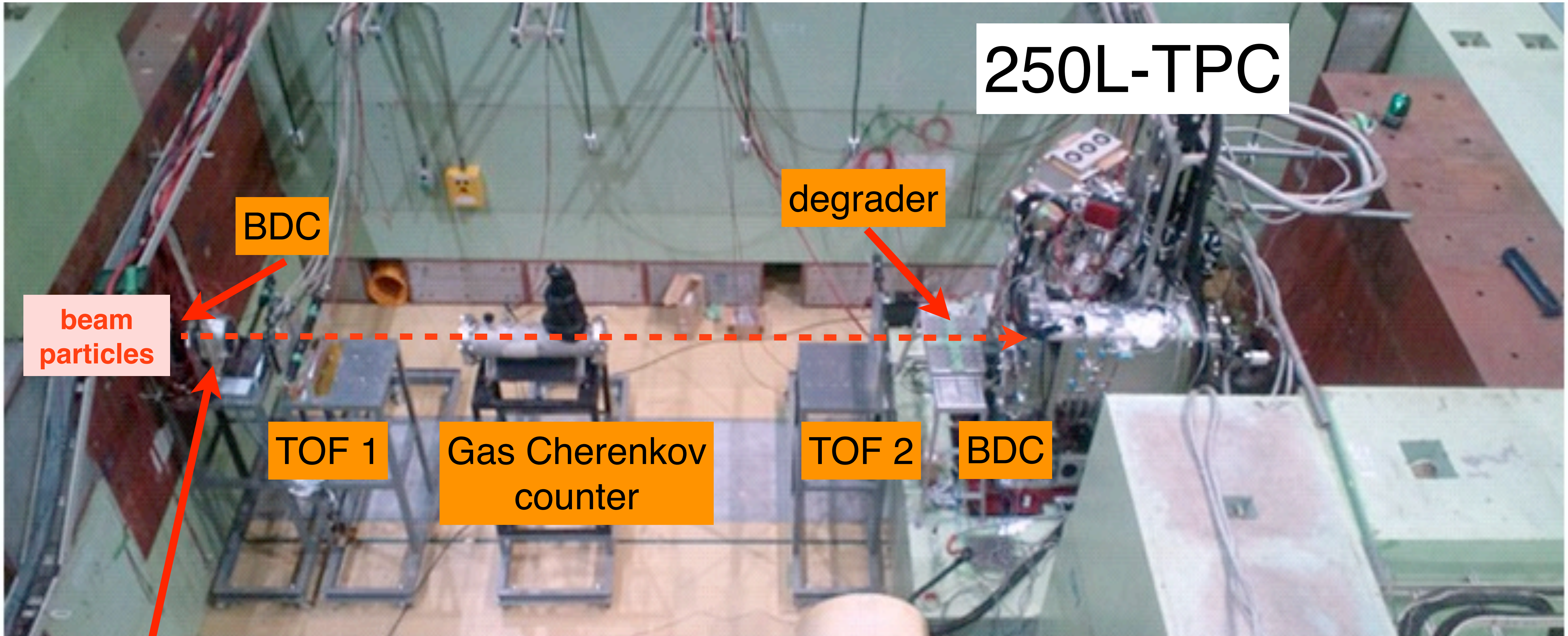


LAr purification:
- Cu cartridge
- molecular sieve

LAr supply

gas purification system

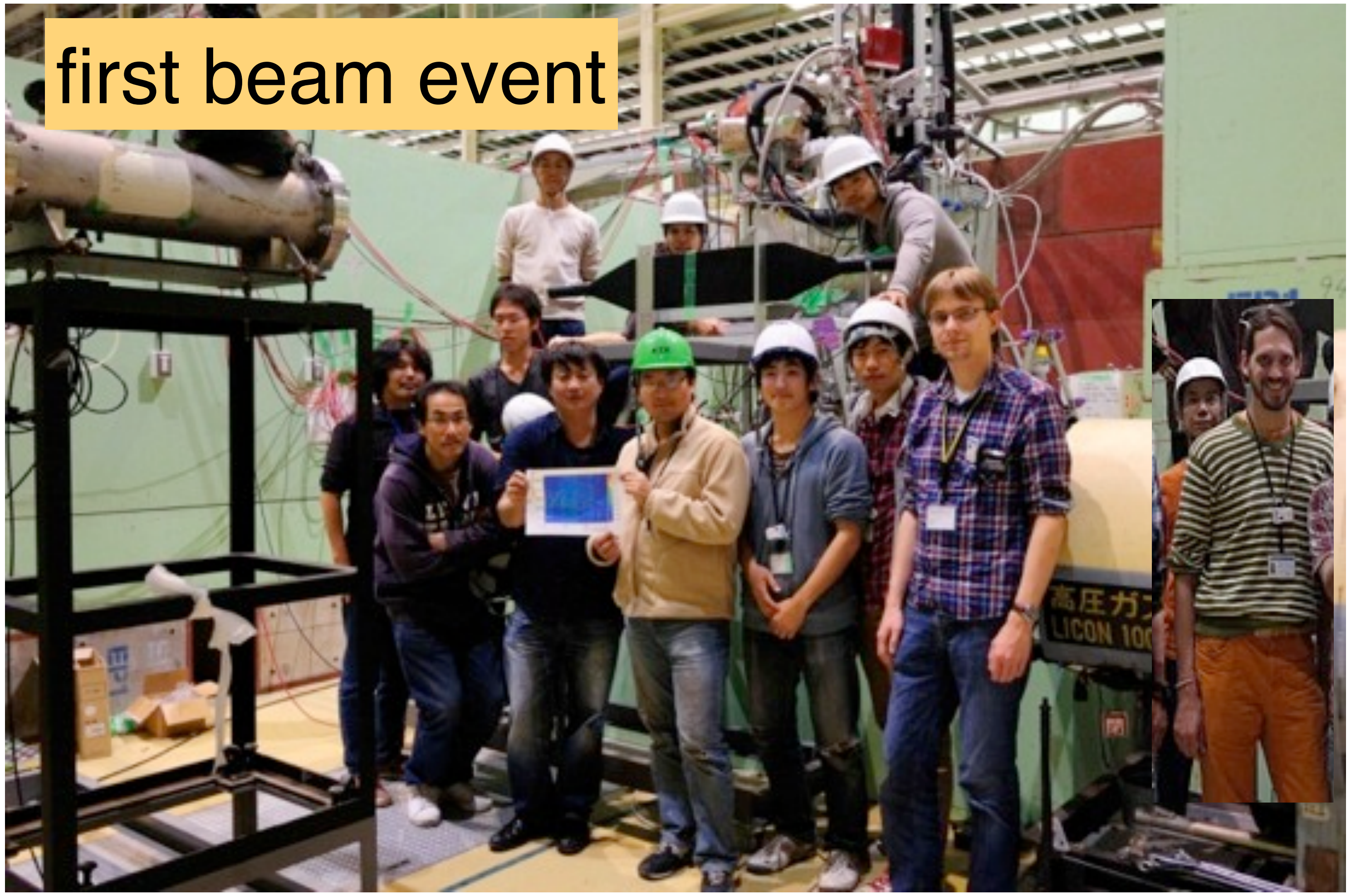
K1.1BR with instrumentation @ J-PARC



K1.1BR beam properties:

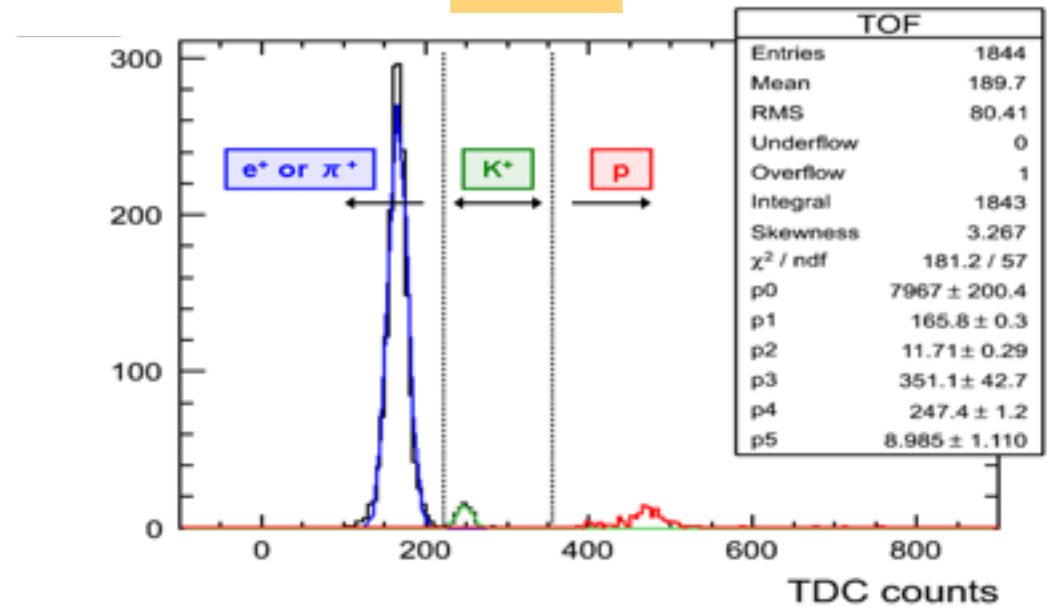
- 800MeV/c K/π/p/e and 200 MeV/c π/e
- K/π~1/4 (max)
- a few K^+ / spill (6s)
- degrading momentum using Lead Glass blocks
- beam width @ deg. σ_x~8cm, σ_Y~6cm

October 2010 run

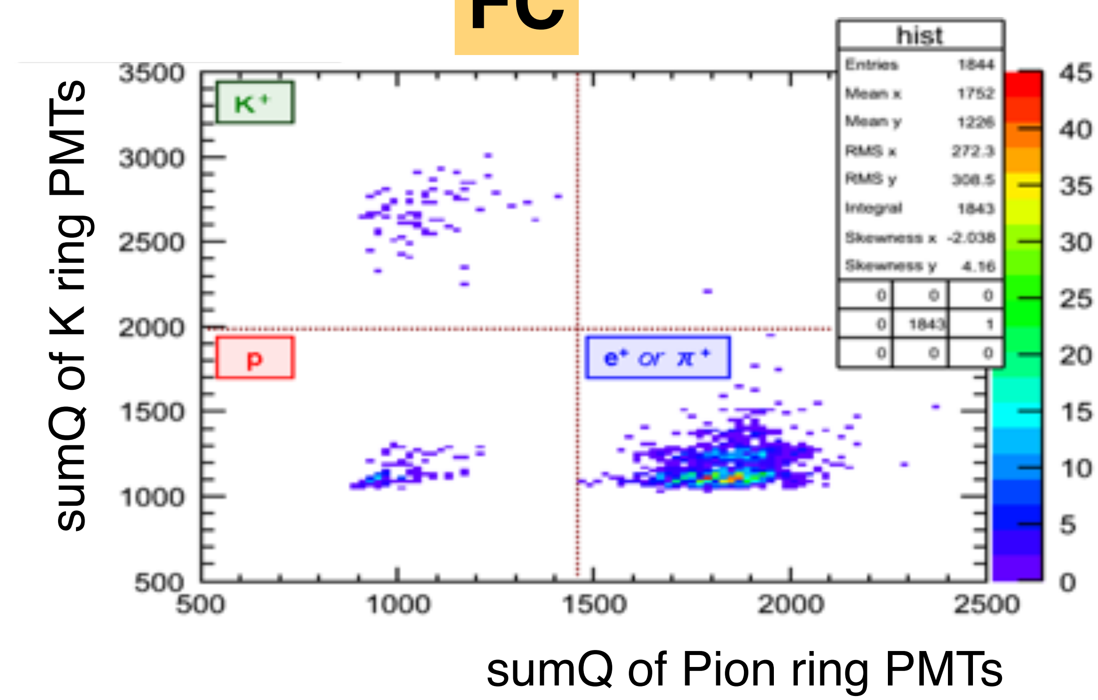


external PID (≈100% for K^+):

TOF



FC

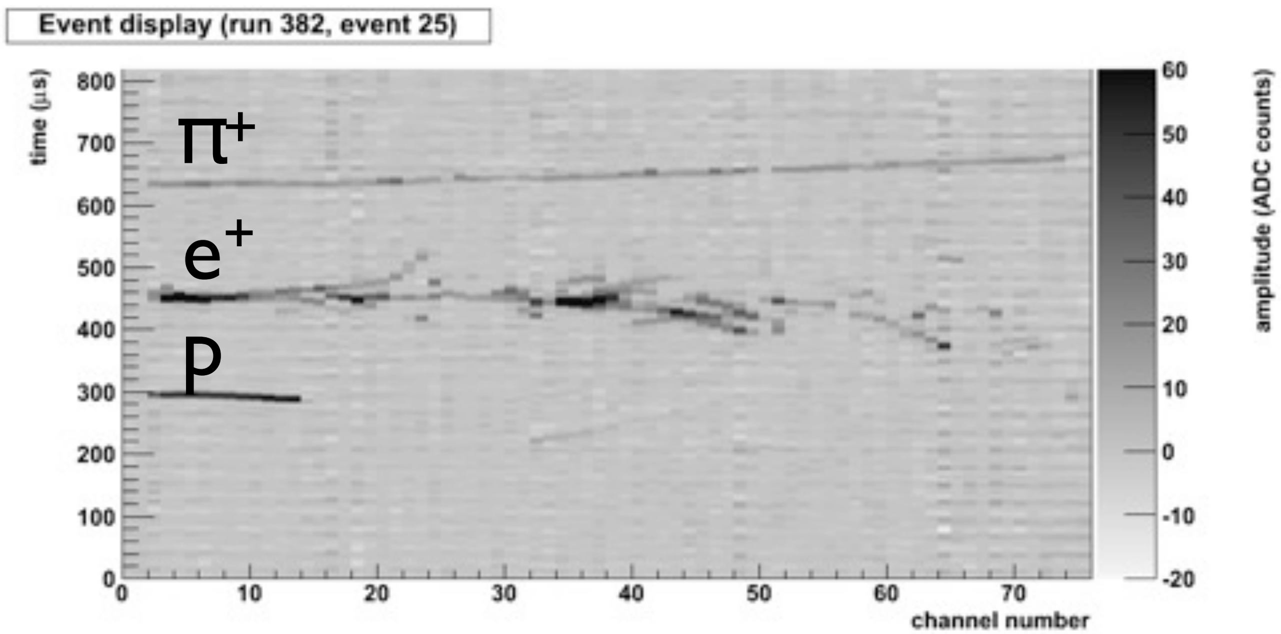


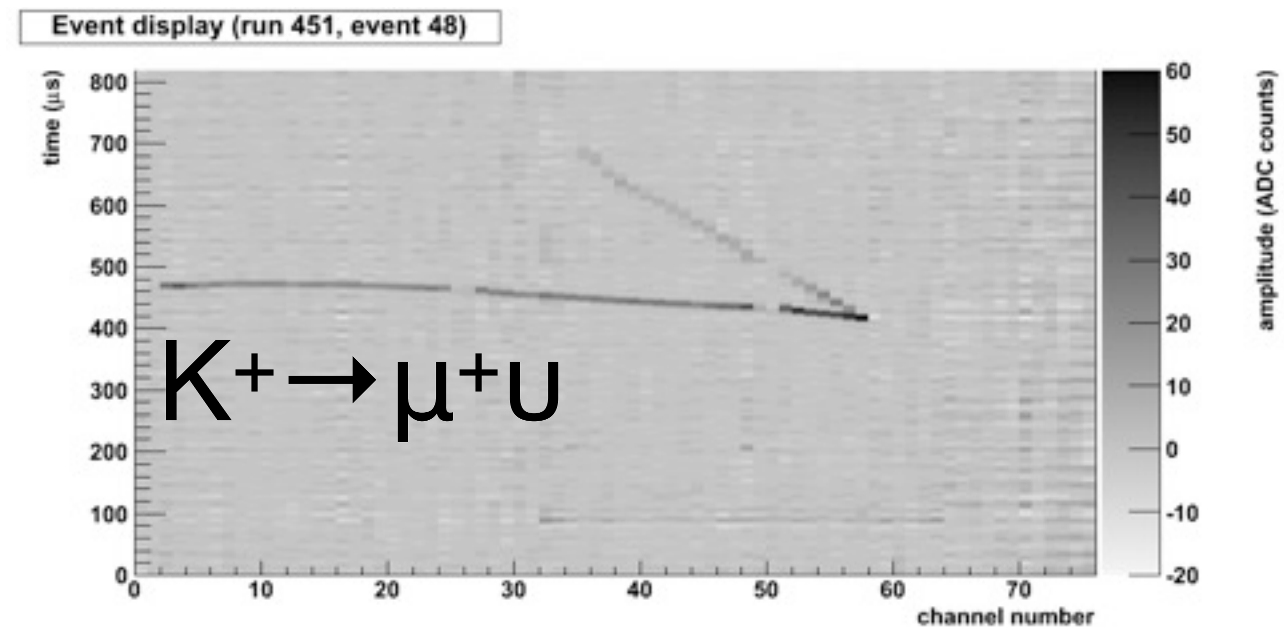
The beamline instrumentation (Fitch Cherenkov and TOF) was used to trigger:

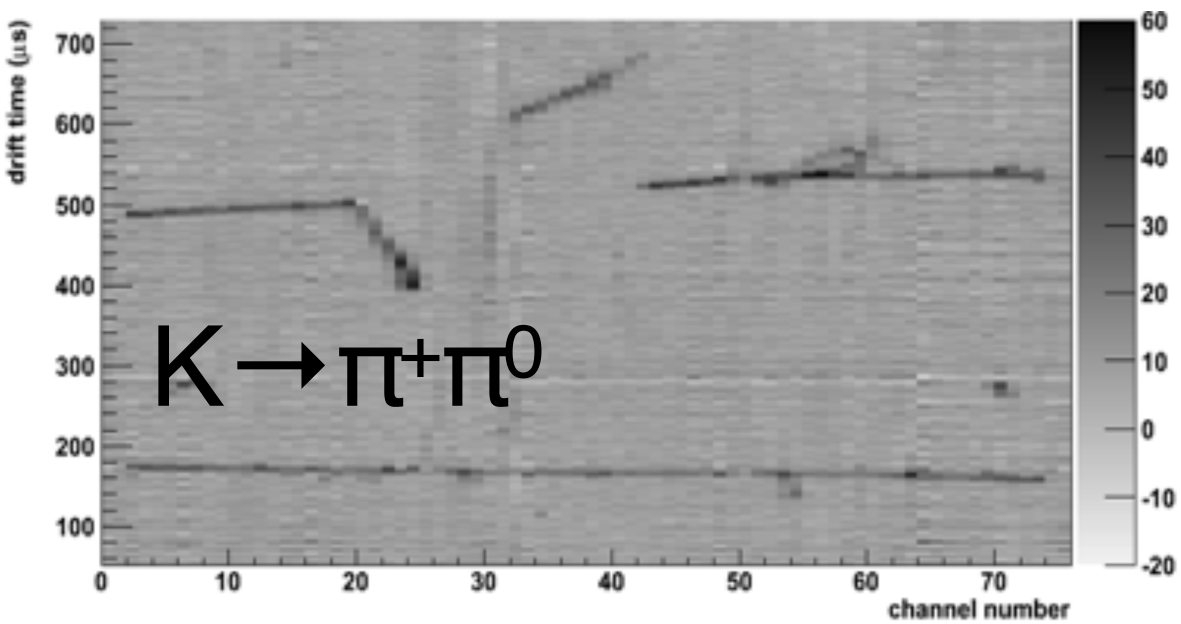
- 2’500 positrons
- 1’500 protons
- 80’000 Kaons
- 100’000 pions

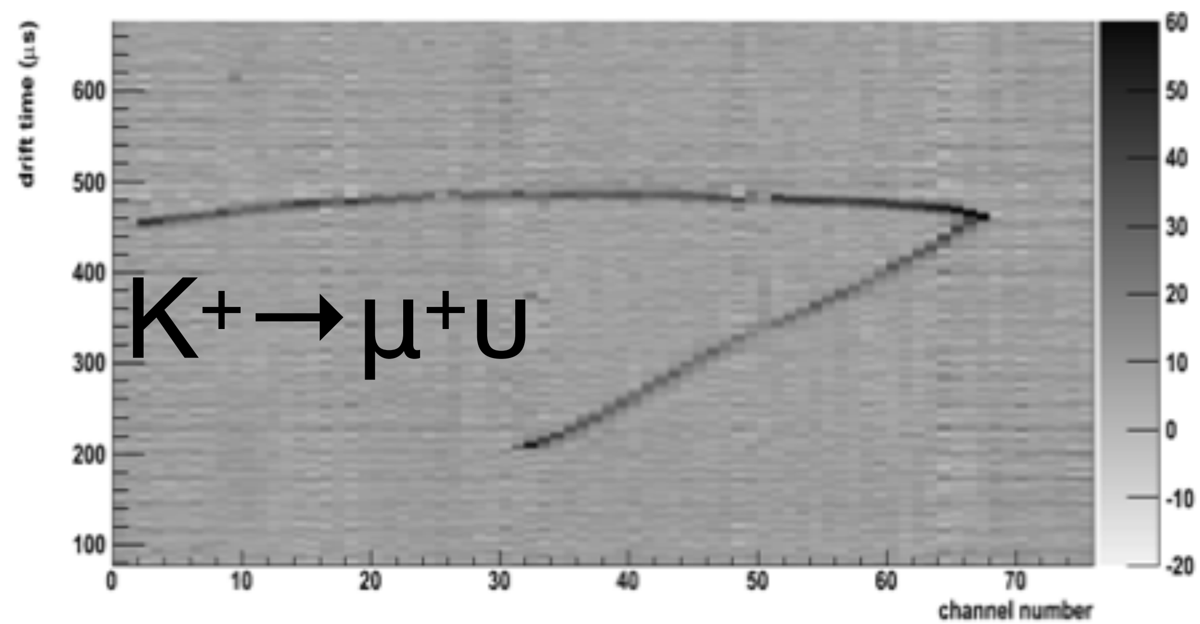
➡ **total ≈ 200’000 triggers**

Some beam events...





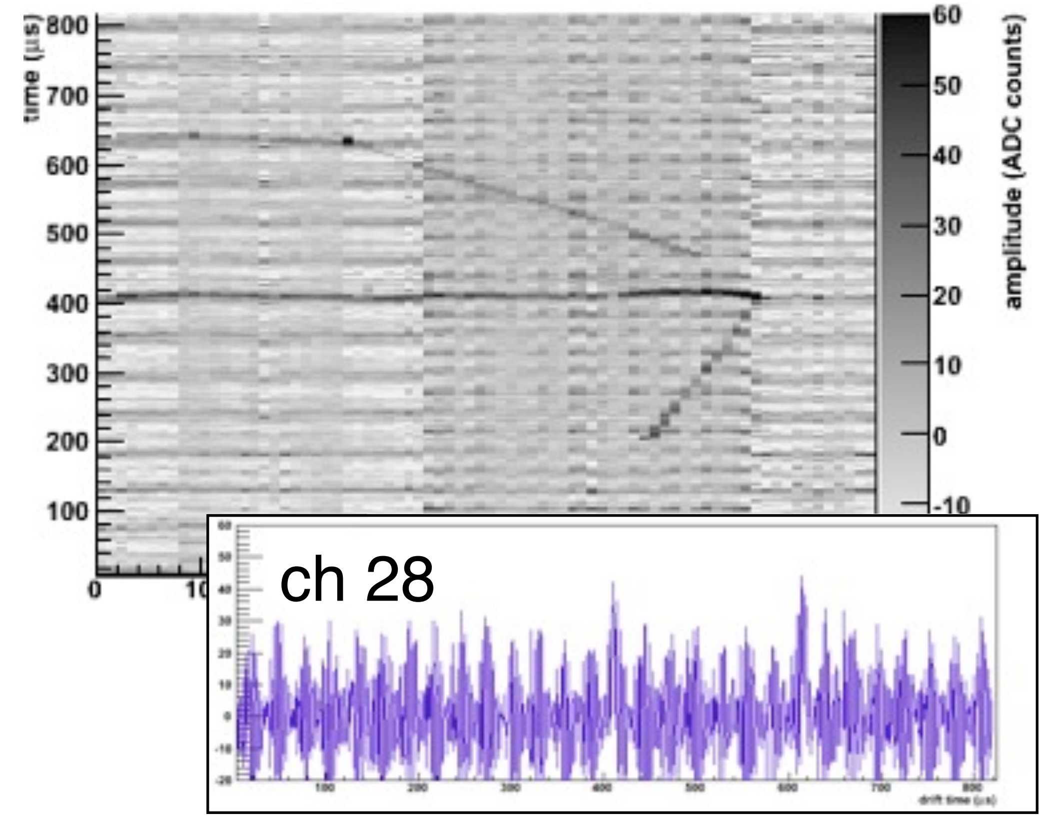




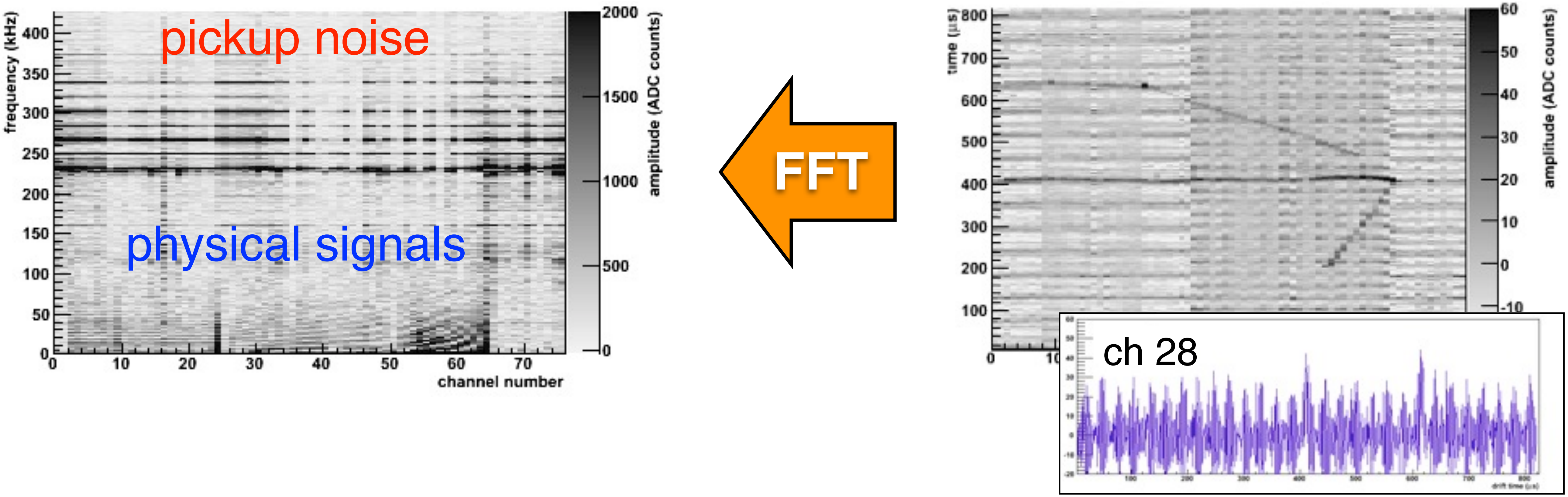
▸strength of the LAr-TPC in PID obvious (even with 1D readout, coarse pitch, noise)

BUT: S/N is poor, coarse pitch of 1 cm, only 1D readout (3D reconstruction not possible)

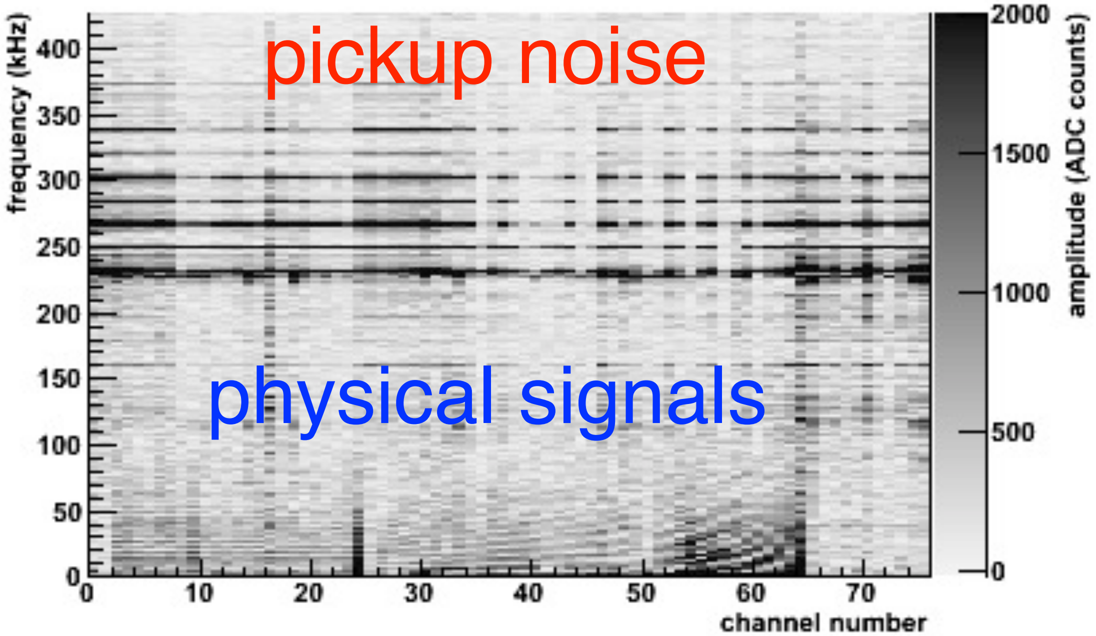
Event reconstruction: Noise reduction



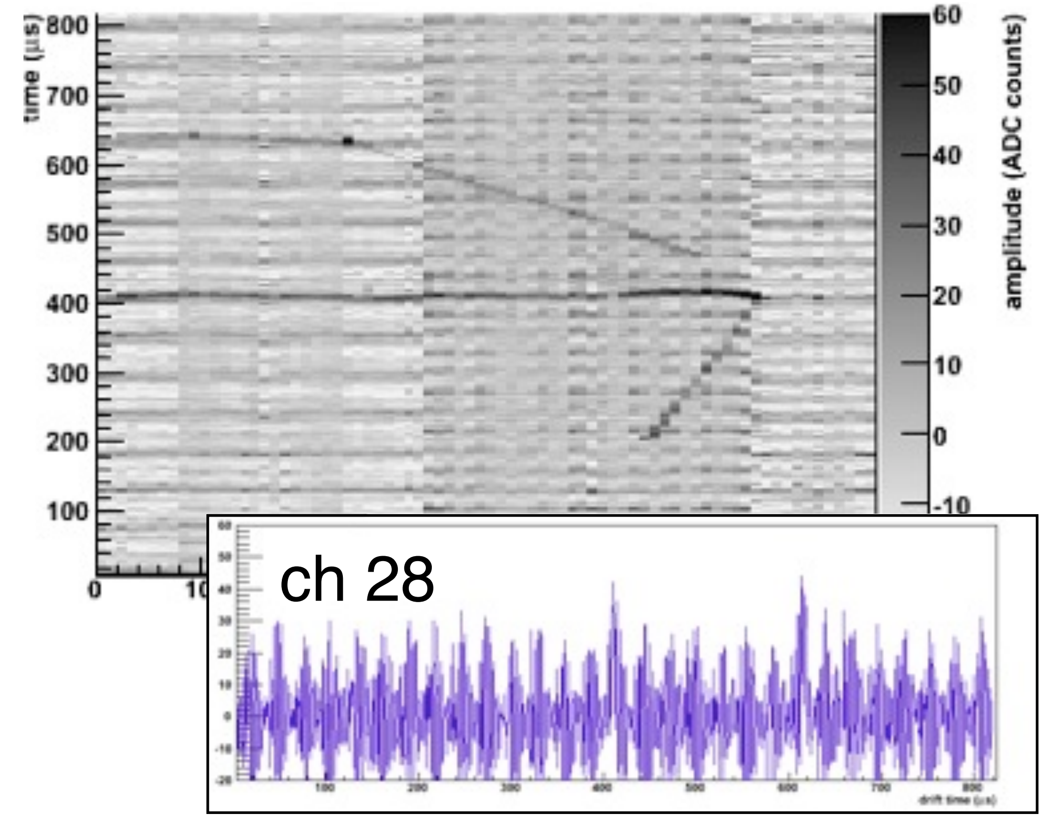
Event reconstruction: Noise reduction



Event reconstruction: Noise reduction

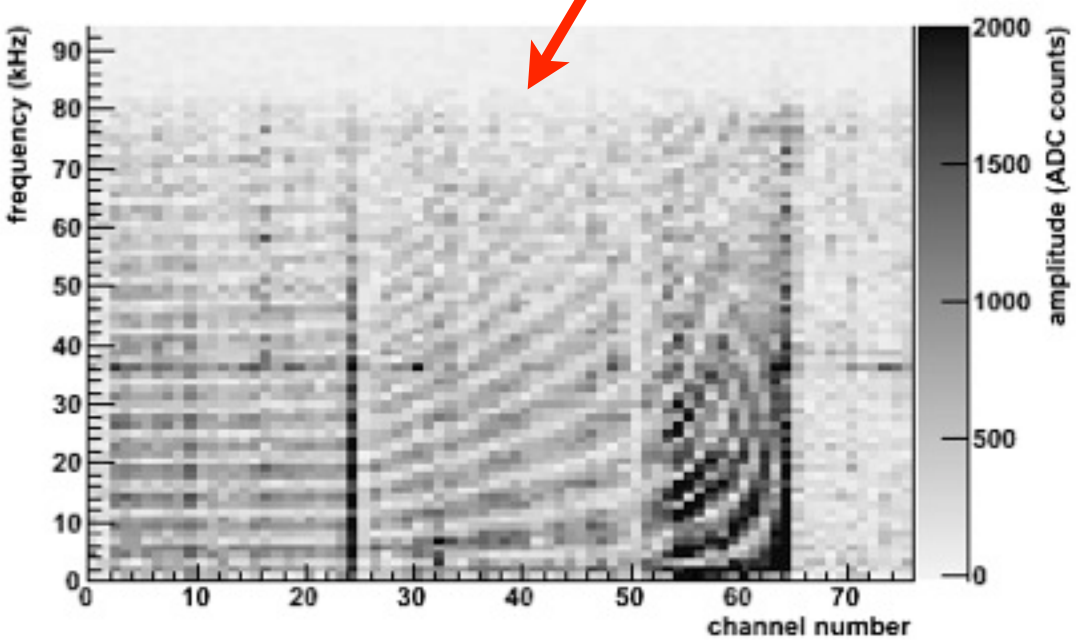


FFT

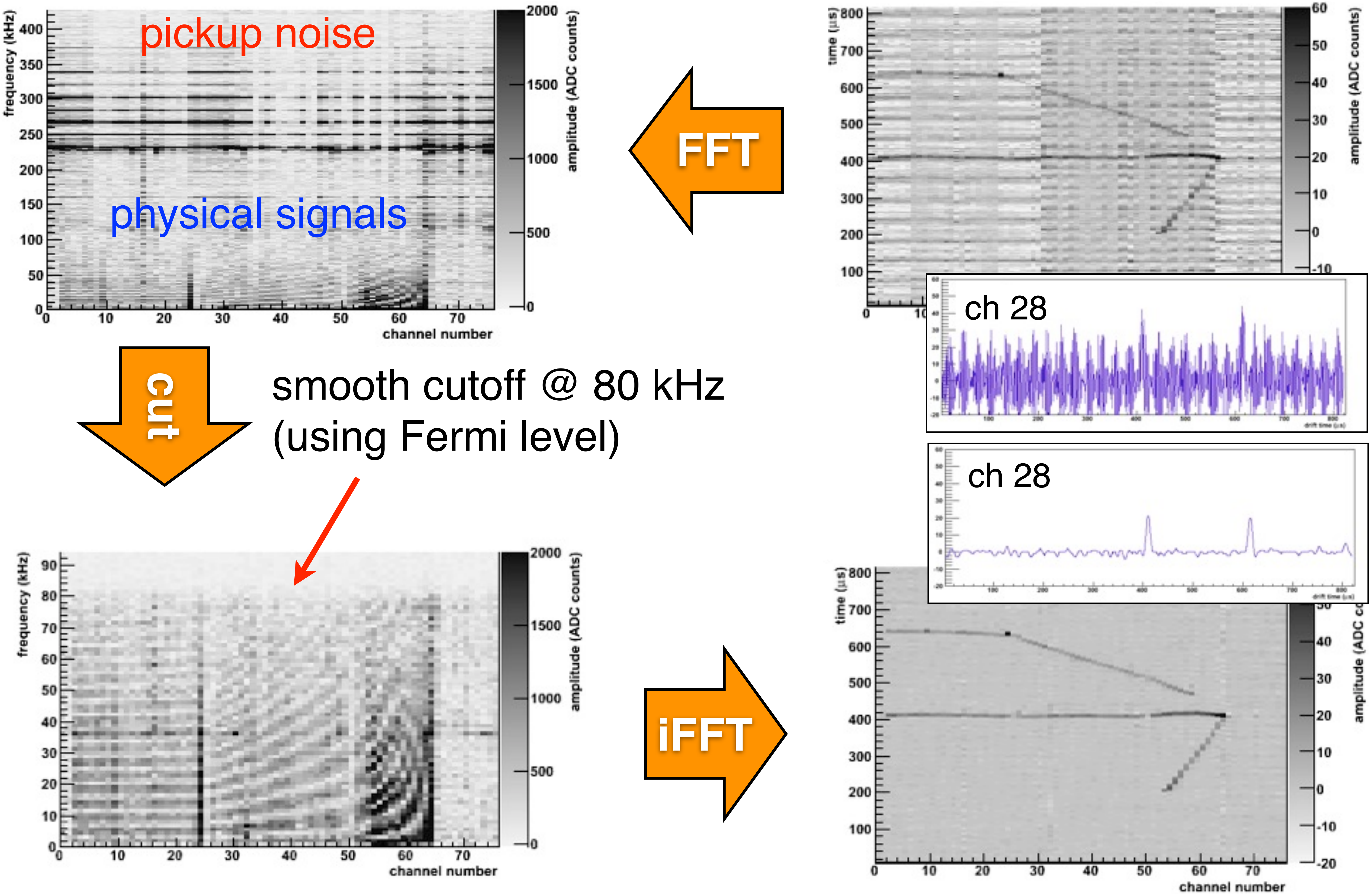


cut

smooth cutoff @ 80 kHz
(using Fermi level)



Event reconstruction: Noise reduction



Event reconstruction: Hits and clusters

Hit finding

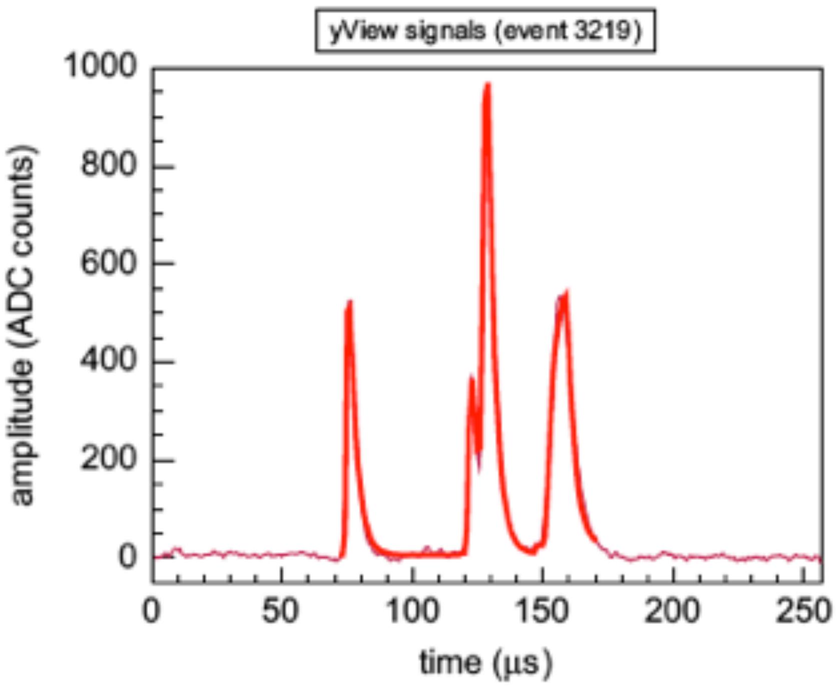
Discriminate the signals coming from an ionizing particle from electronic noise

procedure

‣search algorithm checks amplitude, width and fall time of hit candidates --> cuts have to be optimized!

‣2nd. step: hits are further parametrized to extract the important physical information (integral≈charge, time, shape)

fitted hits

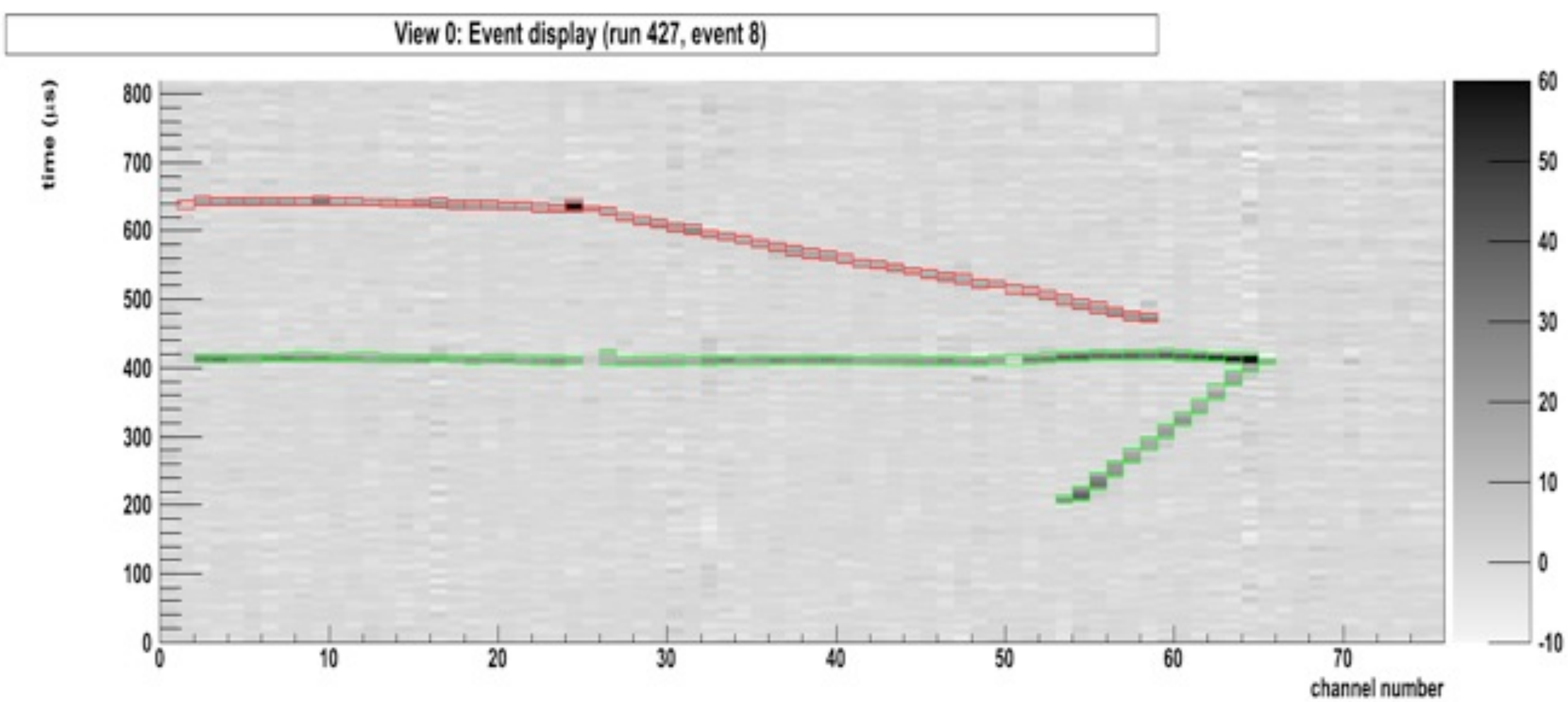


Cluster finding

an algorithm groups adjacent hits together:

‣simplifies tracking and vertex finding

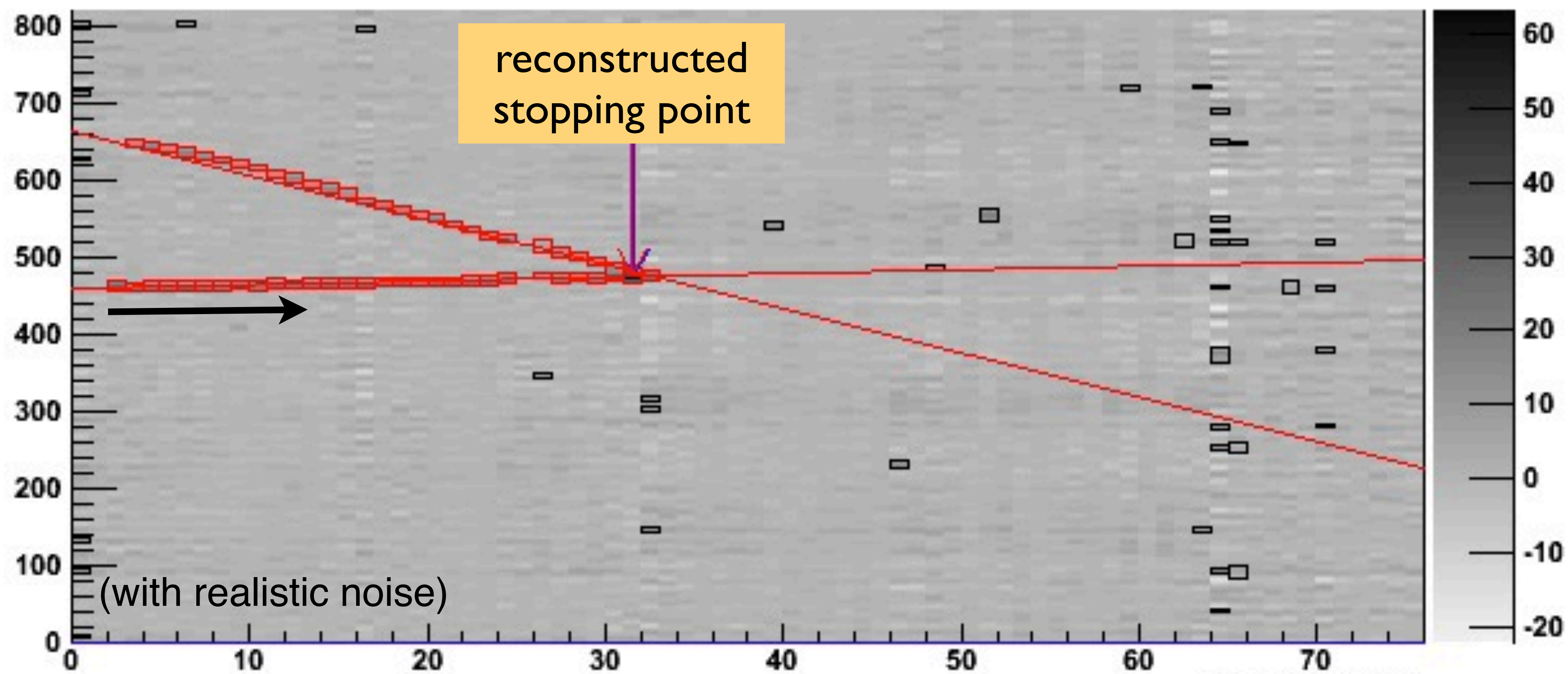
‣separate events from pile-up

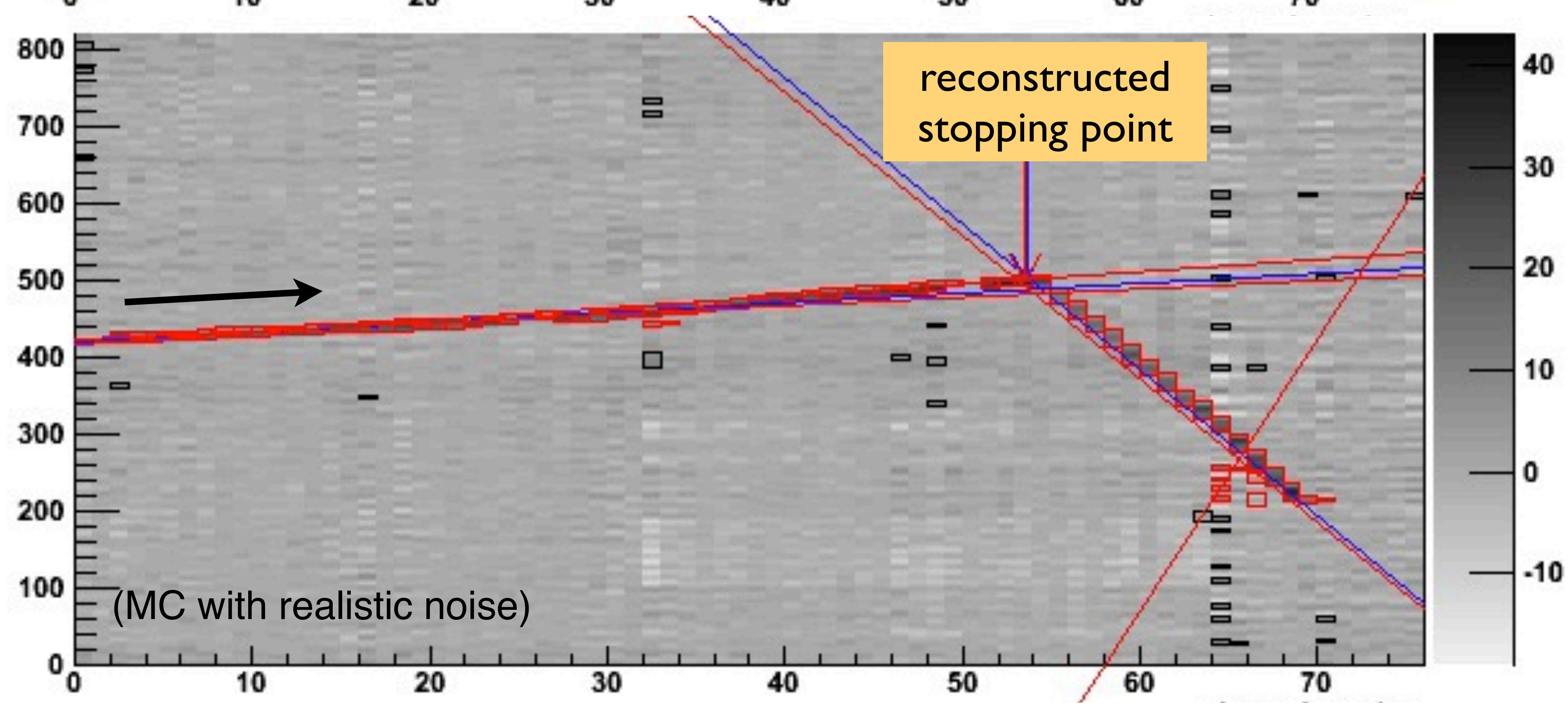


2D tracking and vertex finding

- Two algorithms (hough and chi2) implemented to reconstruct the decay point in simple two prong events have been implemented.
- **Hough-method:**
  1. The hit coordinates (of a cluster) are transformed into the Hough space (2 parameters: angle of straight lines and distance from origin)
  2. The maximum bin in the hough-space defines the most evident straight track.
  3. Back to the real coordinate space hits close to the straight track are removed from the set of hits
  4. Repeat step 2. and 3. three times.
  5. The algorithm looks for a charge maximum close to the intersection of two lines
- **chi2-method:**
  1. The cluster inside the beam-window is selected
  2. Starting from the left, hits are fitted with a straight line.
  3. The stopping point is found based on an increase of the chi2.
  4. The algorithm looks for a charge maximum close to the intersection of the two lines

Two reconstructed Monte-Carlo generated events





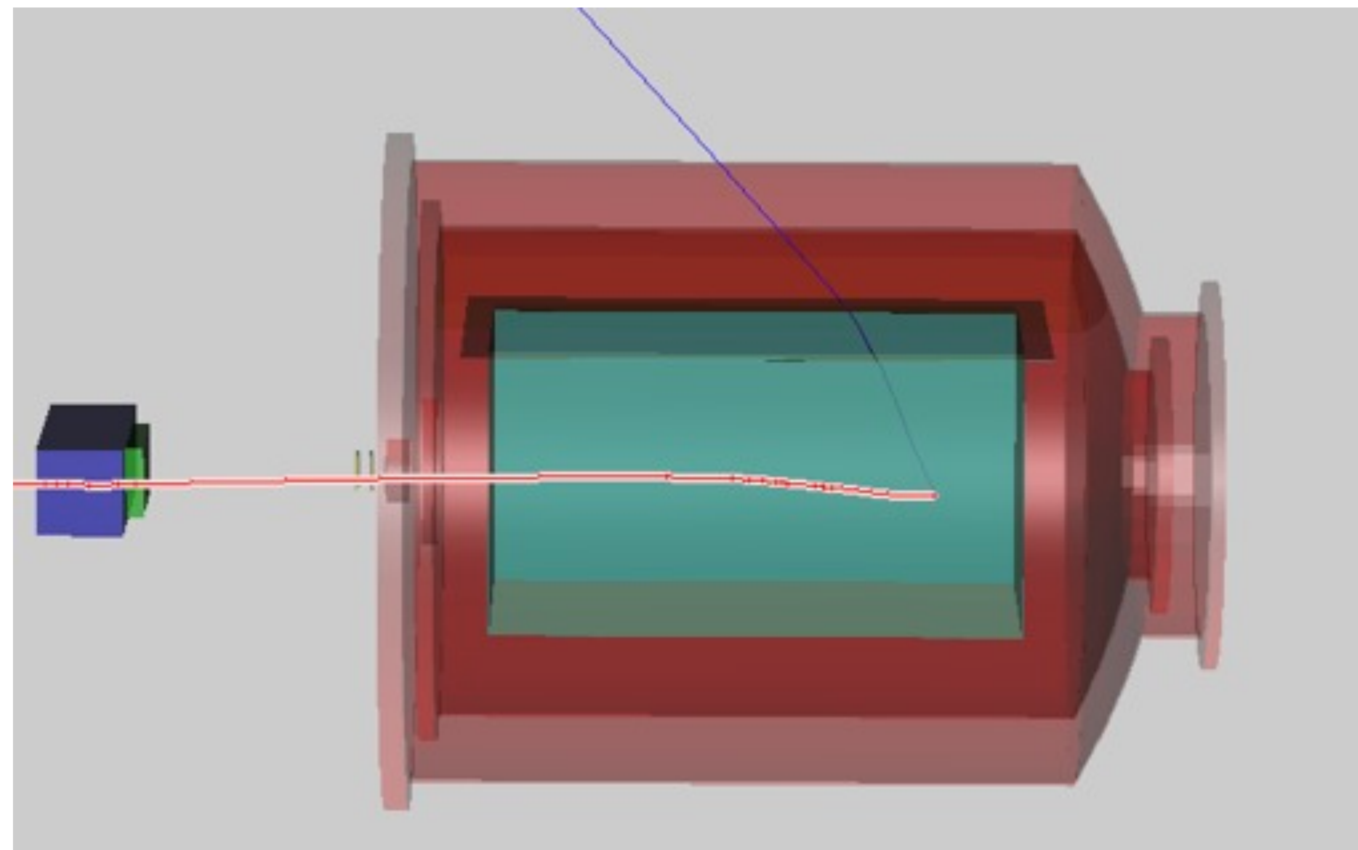
MC simulation: Geant3/4

A detailed MC simulation with full digitization has been implemented within a general purpose LAr-TPC reconstruction and simulation framework (fullreco/Qscan).

following issues are included:

- full beamline geometry with degraders and counters
- charge quenching due to ion electron recombination
- charge loss due to electronegative contamination of the pure LAr
- inhomogeneous drift field (external computation)
- digitization with true preamplifier response
- realistic electronic noise (extracted from empty data events) including also coherent component
- trigger and degrader configuration

3D display with MC tracks



Charge loss (drift):

$$Q(t=t_{drift})=Q\cdot e^{-t/\tau}$$

Charge recombination (Birks law):

$$Q = Q_0 \frac{A}{1+(k/\varepsilon)\left(\frac{dE}{dx}\right)}$$

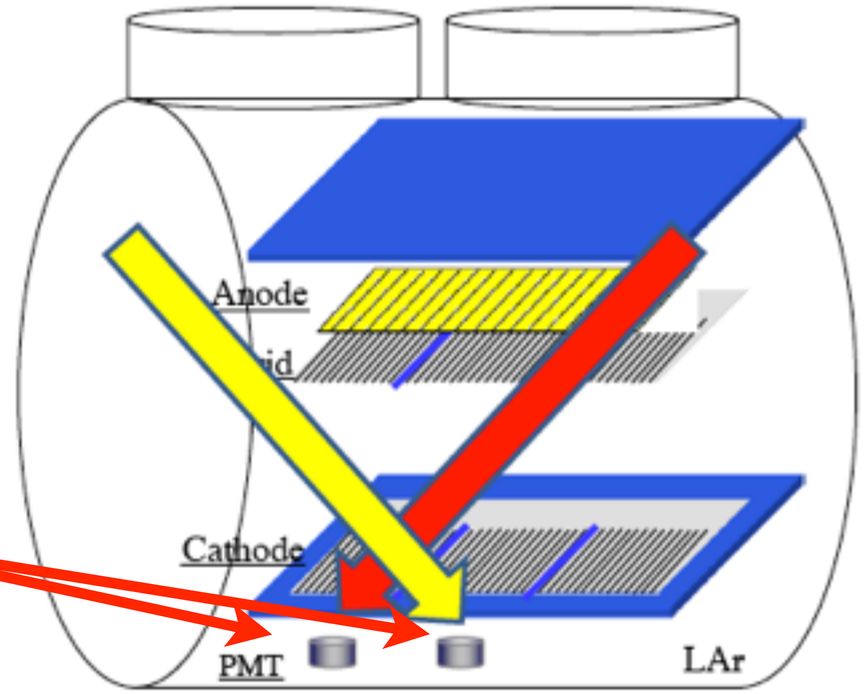
A = 0.800 +- 0.003
k = 0.0486 +- 0.0006
[kV/cm*g/cm2/MeV]

NIM **A523**, 275-286 (2004)

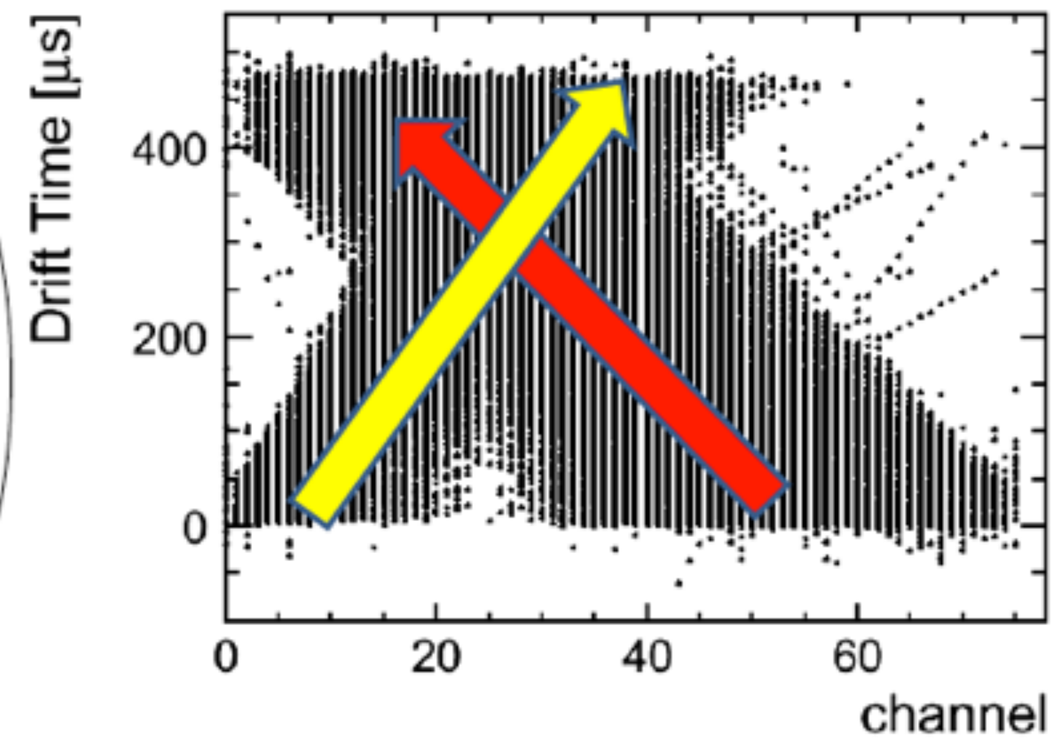
Cosmic ray reconstruction - LAr purity

- In order to monitor the LAr purity inside the detector we had various CR runs
- Cosmic data was collected with a coincidence of the two internal TPB-coated Hamamatsu R6041 PMTs

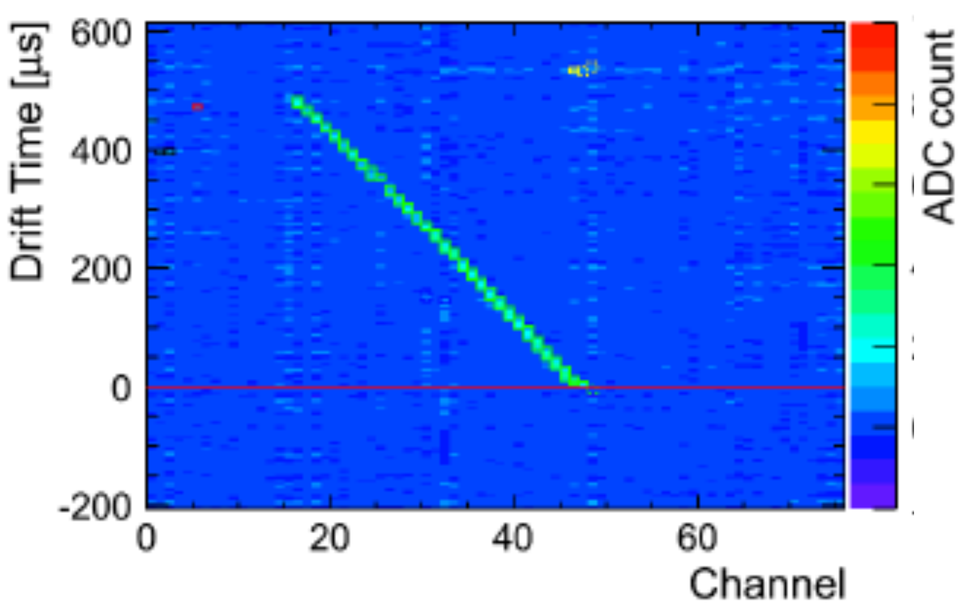
Light readout



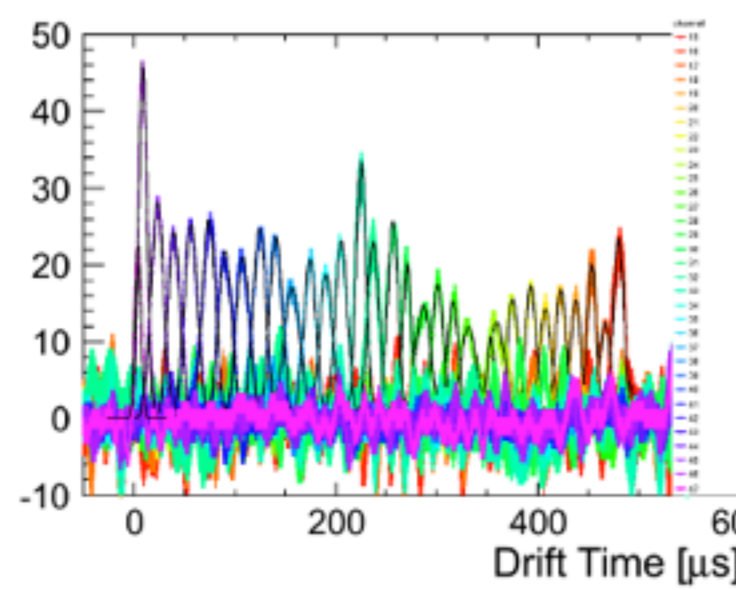
reconstructed straight tracks



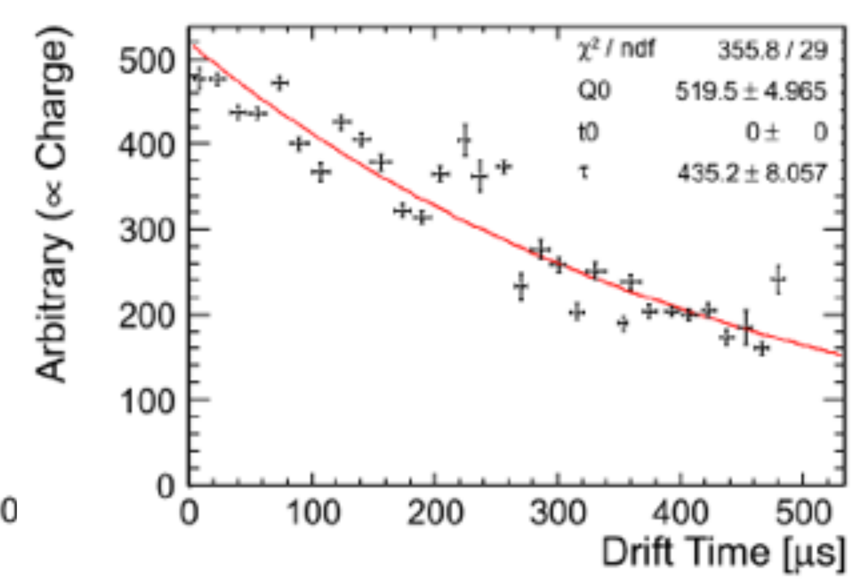
example event



waveforms



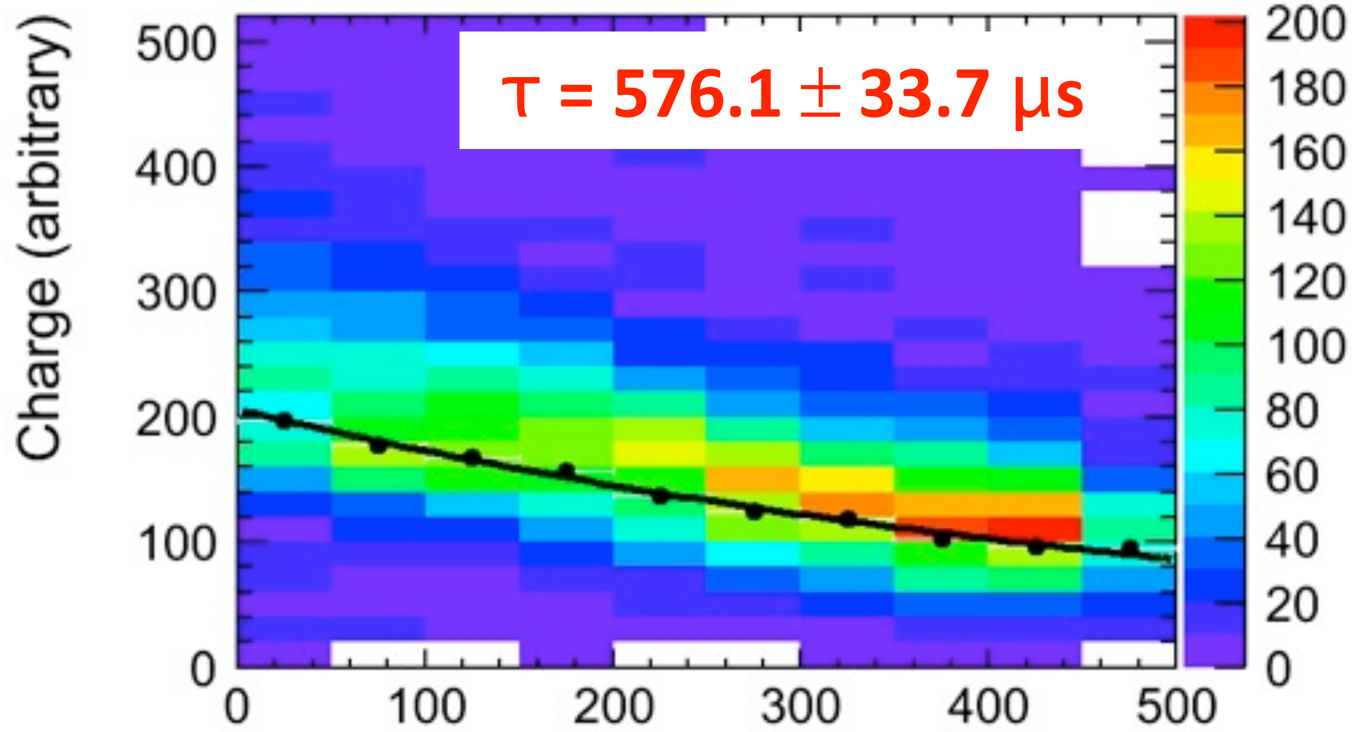
charge vs drift time



Extraction of LAr purity from CR runs

Single dataset example

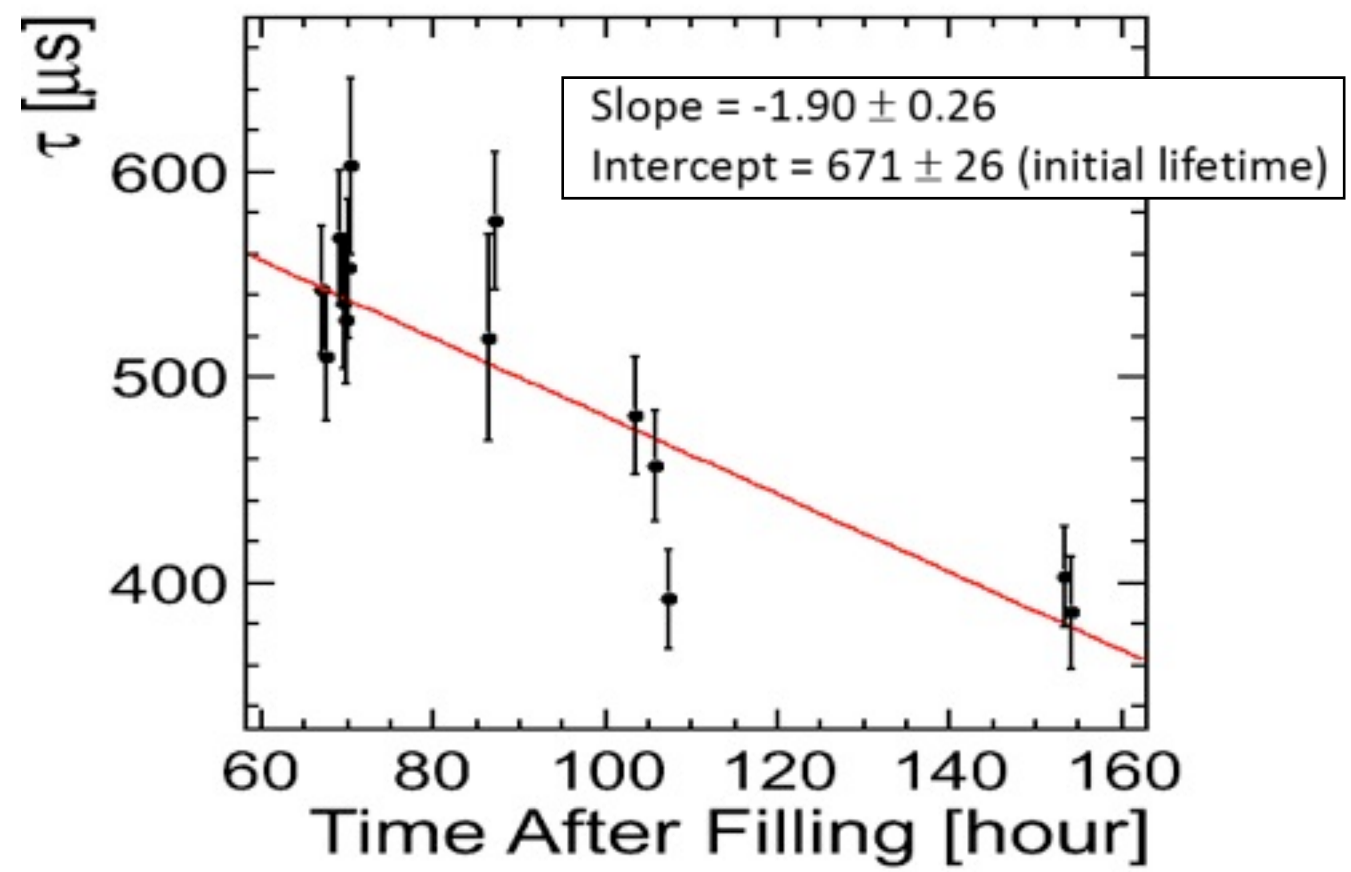
- Dataset 87 hours after LAr filling
- Use ~100 well reconstructed, straight crossing muon tracks
- Correct charge according to cosmic ray injection angle (1D-readout: only one out of two is known)
- divide drift volume into slices of equal drift time
- fit a Landau function to the charge distribution of each drift-time-slice
- The lifetime is extracted by fitting an exponential to the resulting Lifetime by fitting MPV vs time distribution



Time evolution of purity

- At the beginning : $\tau \approx 670 \mu s$ (~0.45 ppb)
- At the end : $\tau \approx 385 \mu s$ (~0.78 ppb)
- Purity degradation of about 2 ppt/hour.

➡ gas purification system not fully efficient

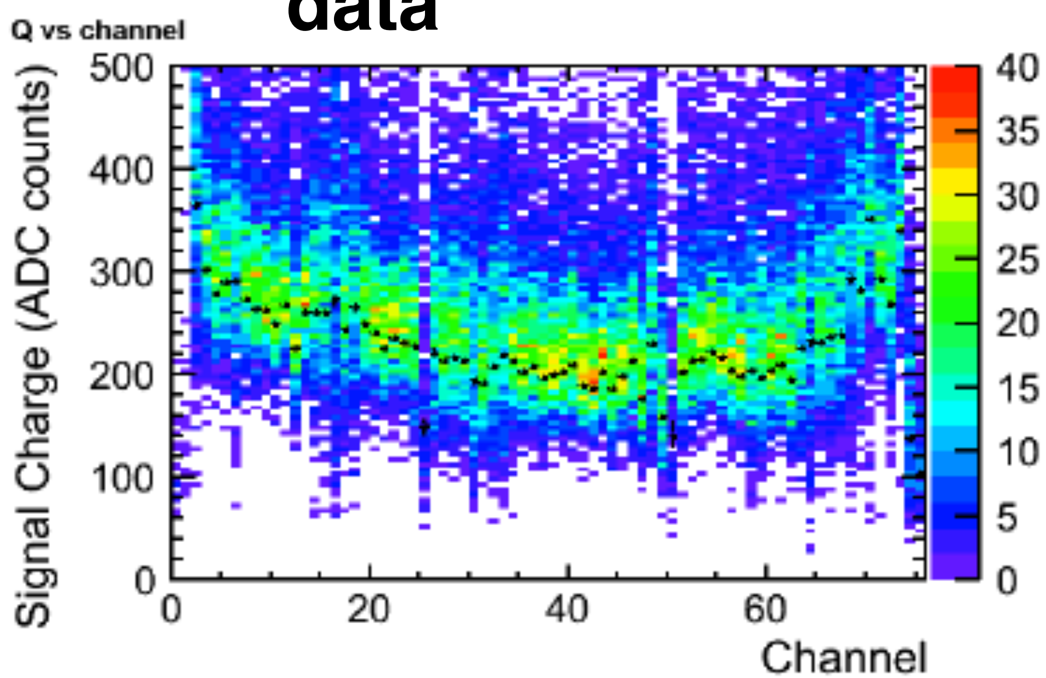


800 MeV/c pion data-MC comparison

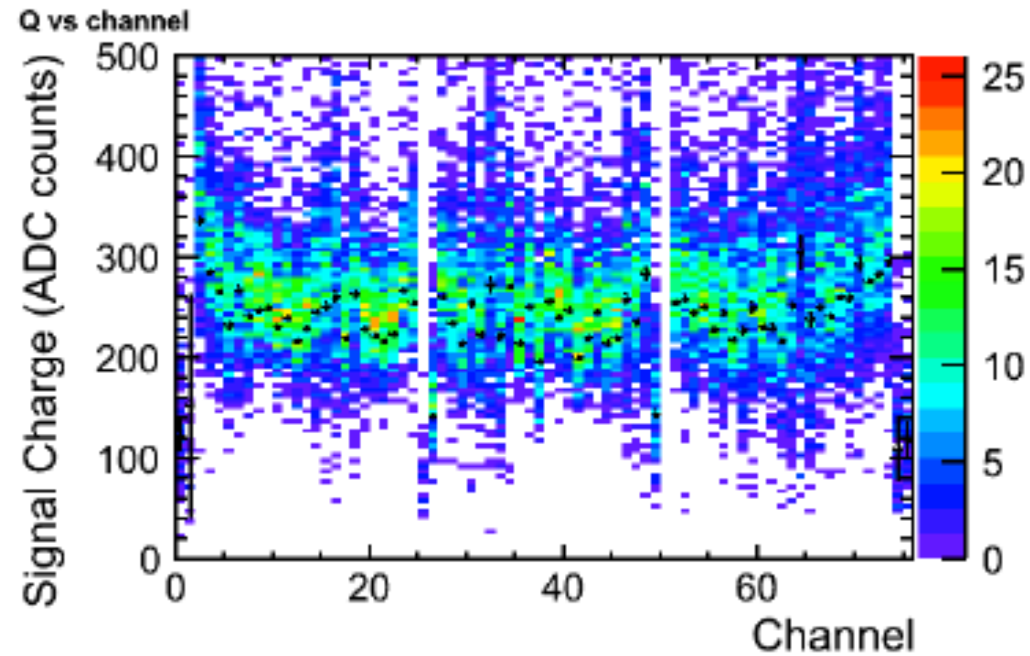
- Looking at crossing pion tracks we observed a non uniformity in charge collection efficiency
- The origin on this non-uniformity is due to a grid and its supporting frame distorting the electric field

➡ confirmed by field map simulation.

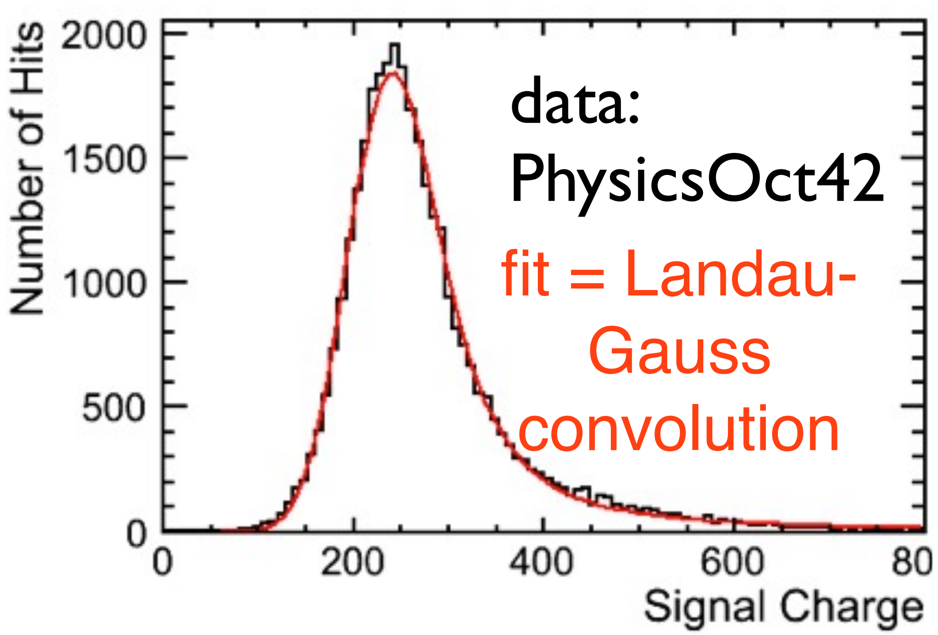
data

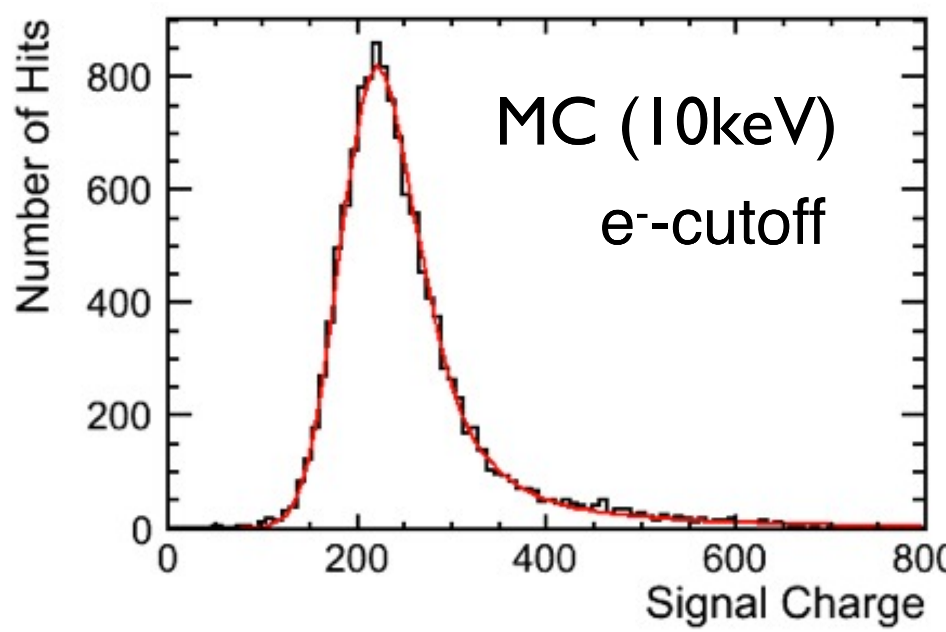


MC



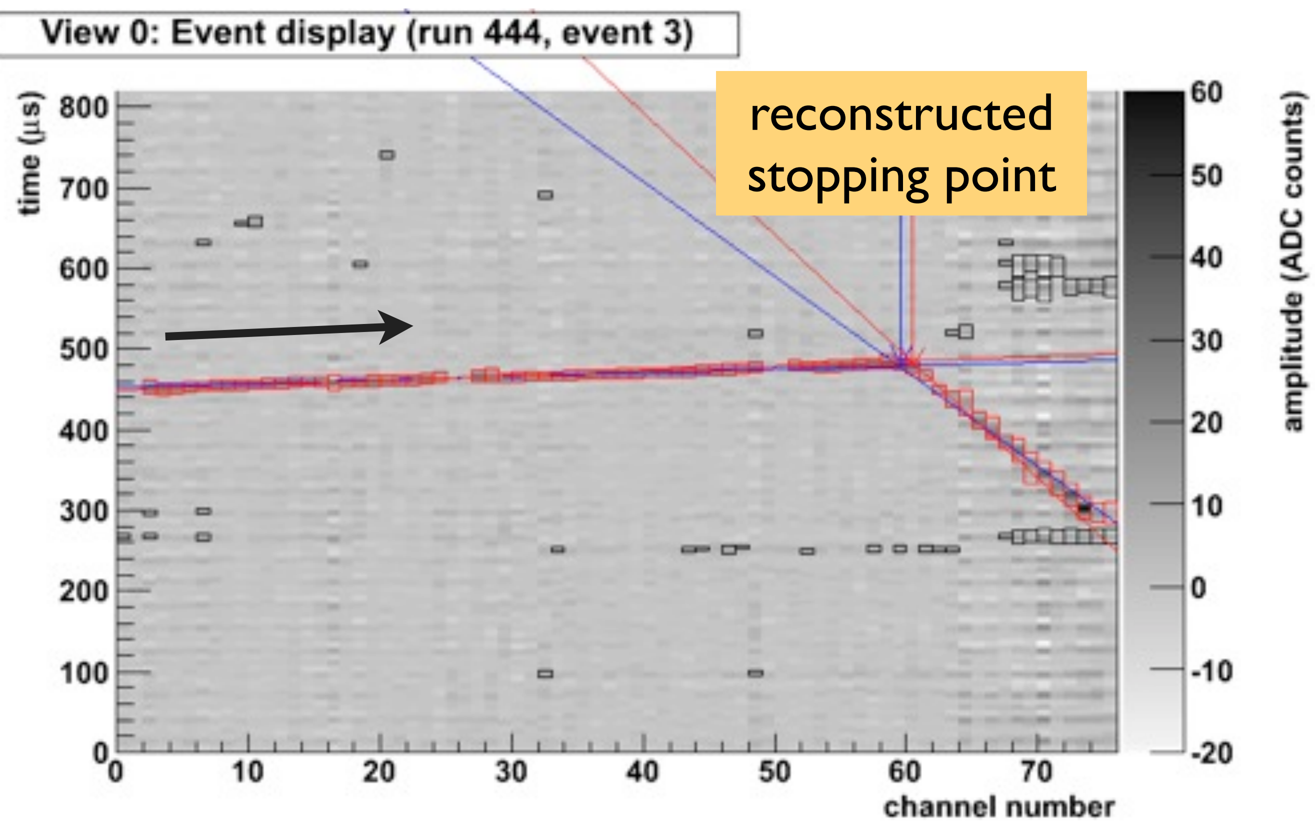
- We used the 800 MeV/c pion data to calibrate and equalize the signals on each readout channel:

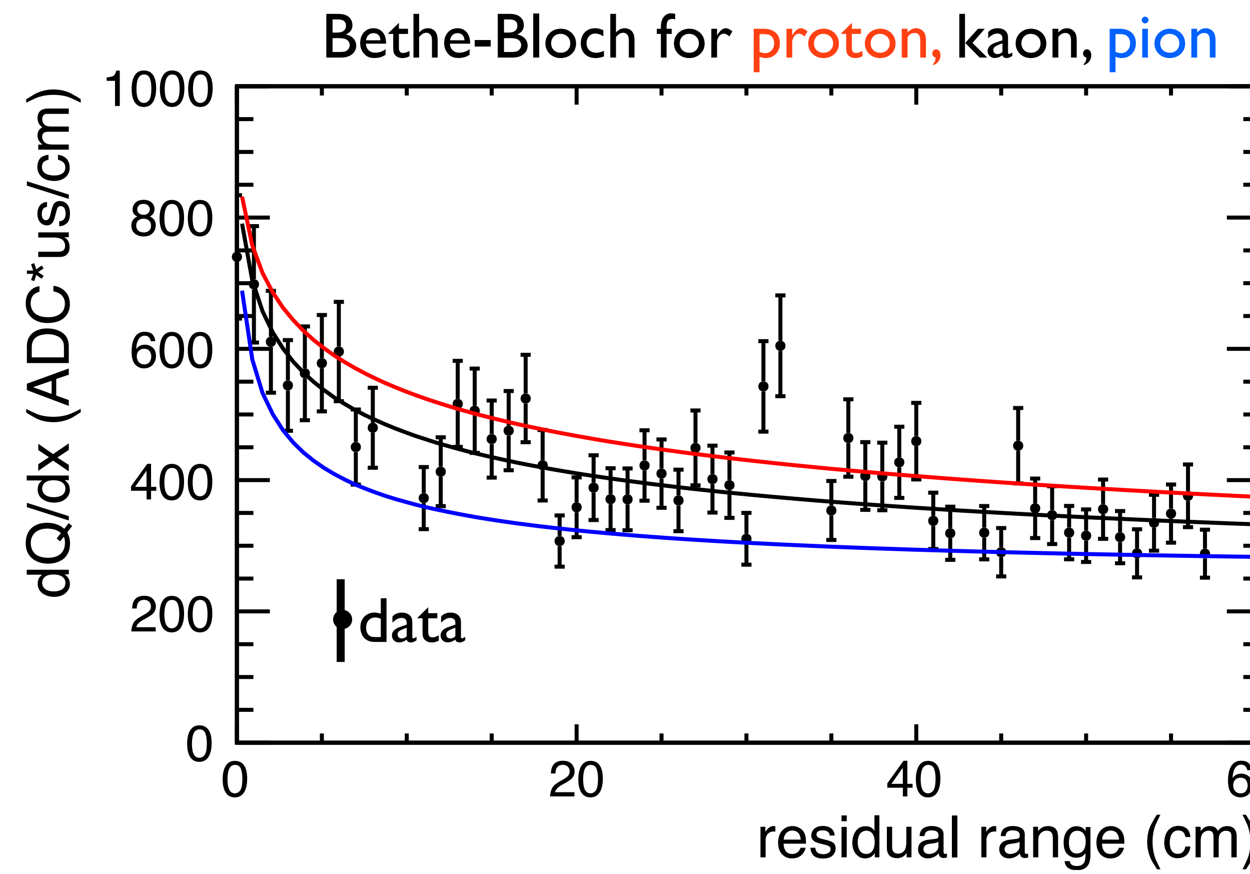


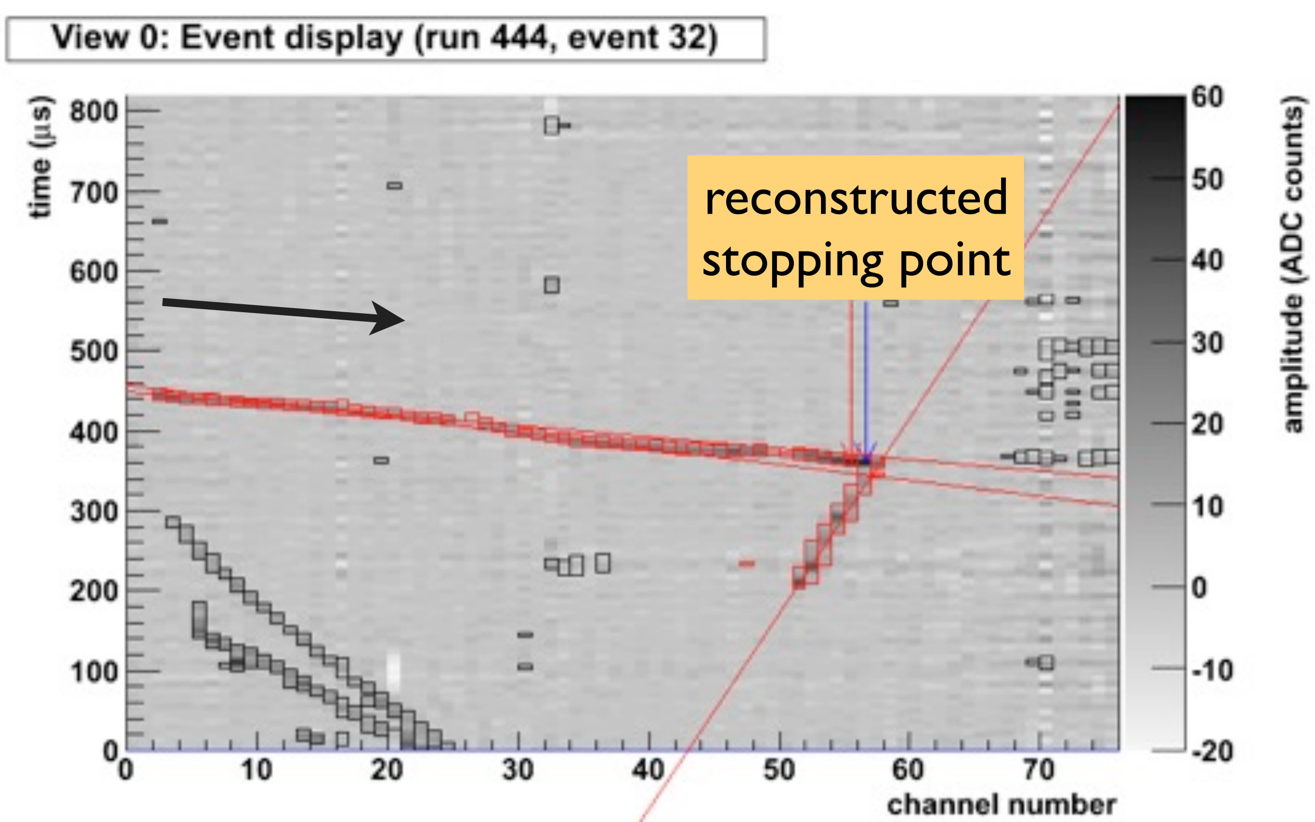


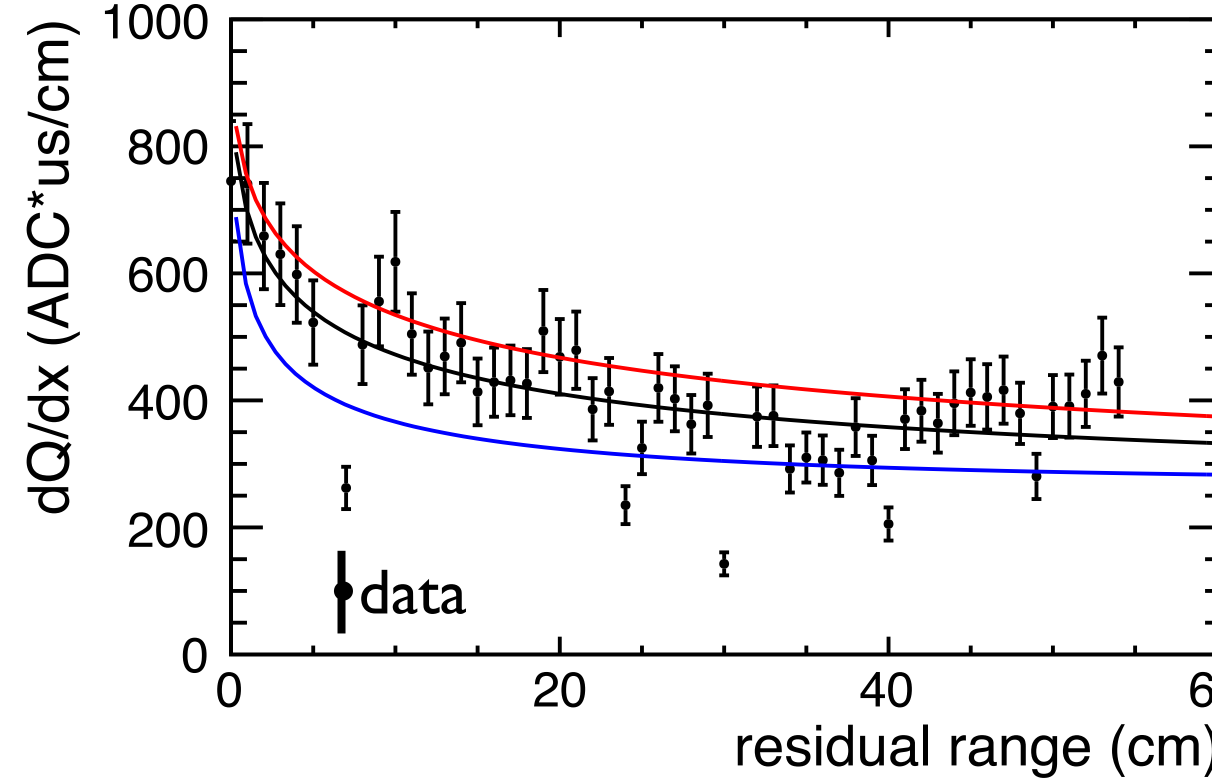
	data	MC
width	15.7±0.3	13.6±0.3
MP	225.3±0.4	230.6±0.6
Gauss-σ	37.2±0.5	31.8±0.5

dE/dx and stopping point of Kaons





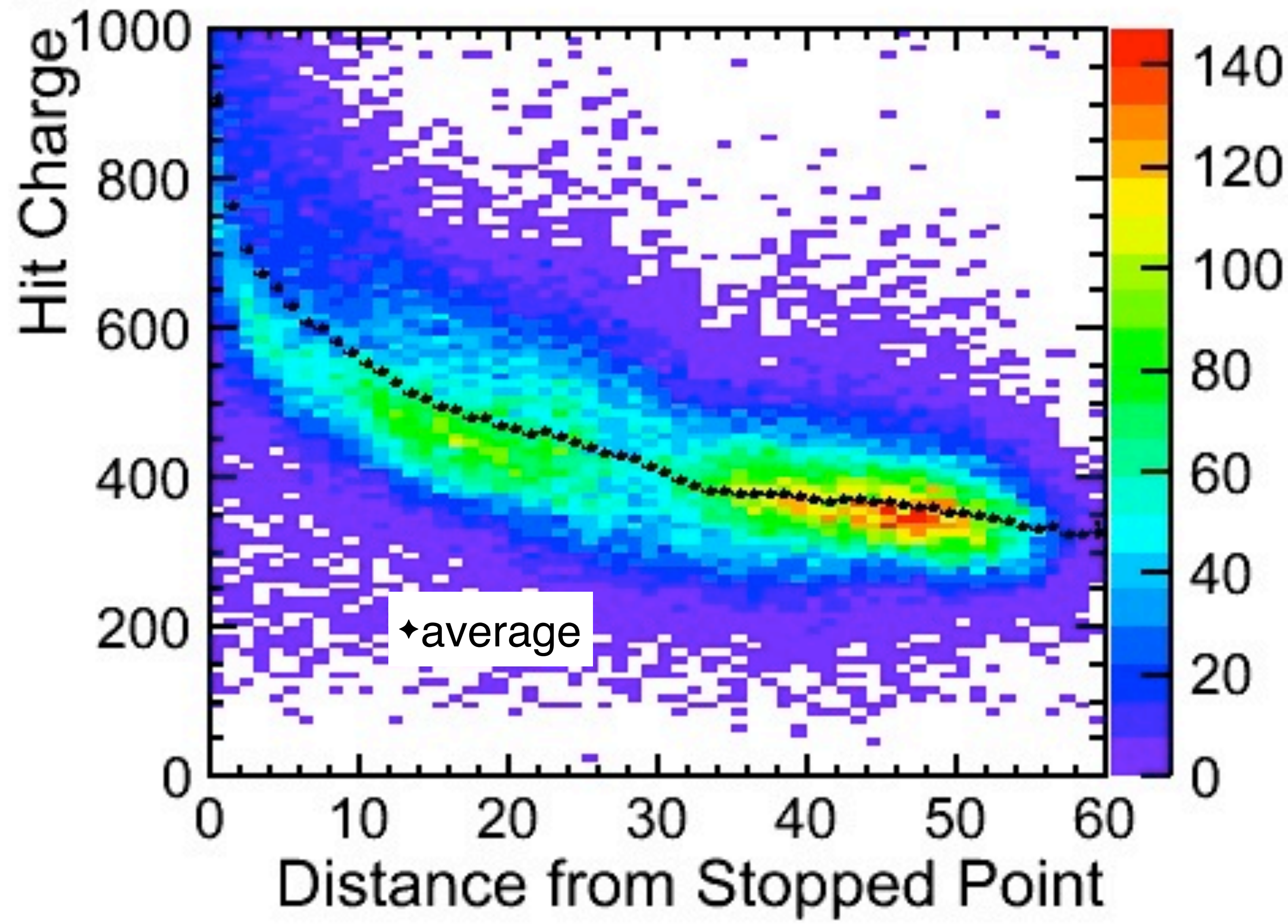




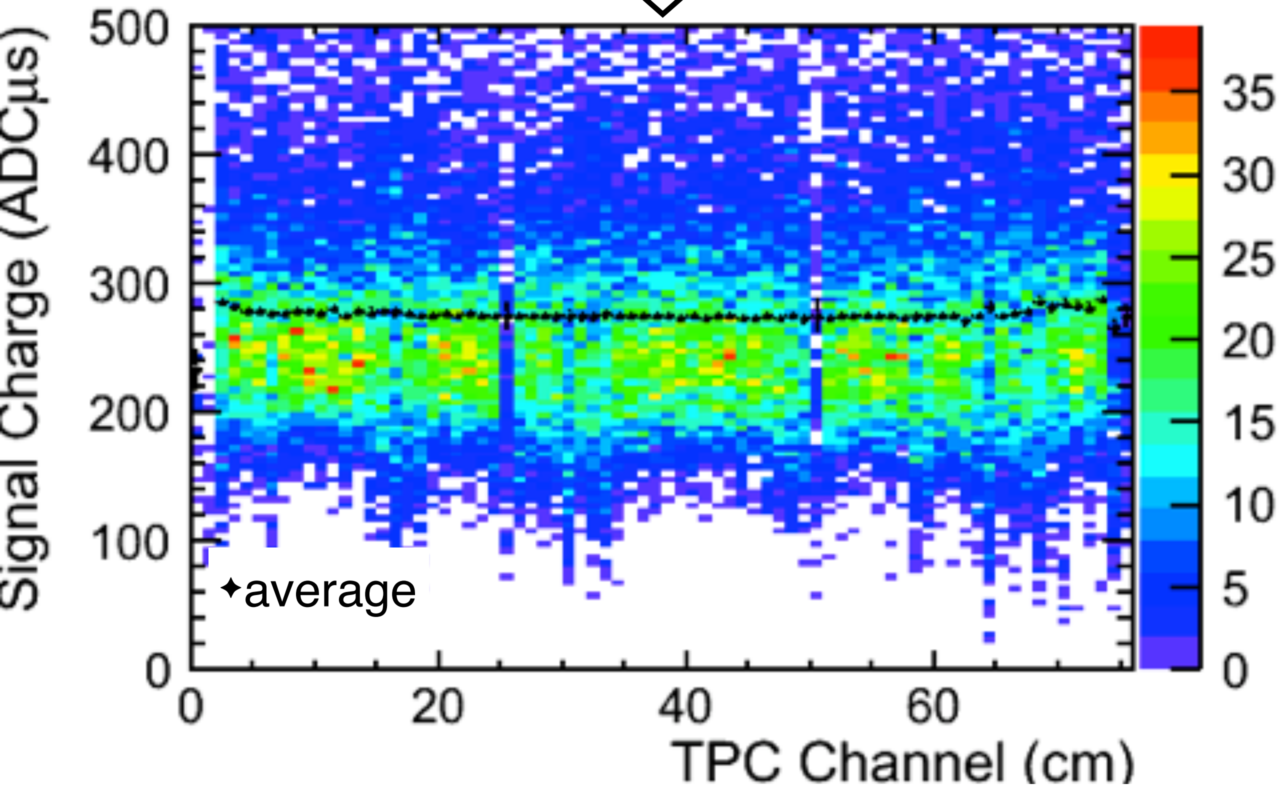
Distance from stopping point

Reconstructed K^+ and π^+ samples

Signal charge of selected stopping kaon samples(1000 events)



Signal charge of 800 MeV/c passing through pions



- Detailed comparison with Monte-Carlo in progress
- π/K separation performance under evaluation

Summary

- We have constructed a prototype 250L single phase LAr-TPC
- The 250L-TPC was successfully operated at the K1.1BR @ J-PARC

➡ First time ever that a LAr TPC is put in a charged particle beam

- We have accumulated π/K/p and electron tracks with large statistics

- Cosmic rays recorded throughout the run were used to monitor the LAr purity. A small degradation was observed
- A large number of pions and stopping Kaons were reconstructed
- A detailed geant3/4 based MC simulation including non-uniform electric field and realistic noise has been implemented

next steps:

‣ Finalize data analysis and MC comparison

‣ the chamber is currently being upgraded to the final double phase / 2D anode readout configuration