Particle ID performance of Liquid Argon TPC

J-PARC T32 collaboration
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Abstract

We have collected J-PARC K1.1Br beamline

This paper describes a study of particle identification performance of liquid Argon TPC (LArTPC) detector using well-defined charged particles (pions, kaons, and protons) with momentum of 800 MeV/c obtained at J-PARC K1.1Br beamline.

We have build a LArTPC detector with fiducial mass of 150 kg, and injected the beam particle

1 Introduction

Refer [1] for hardware/beam line description

2 Data Quality

2.1 Collected Data

Table 2 shows list of the collected data while Oct/2010 Run. 800 MeV/c pion is expected to pass-through the detector as MIP, and have uniform energy deposition to all the TPC channels. So this data set is very useful for calibrating the detector response (See section xxx). 800 MeV/c proton stops after 15 cm of flight distance inside the TPC fiducial volume with relatively large dE/dx. So we use the proton data set for validation of the detector response at high dE/dx region(See section xxx). We have collected three different Kaon data by varying thickness of the degrader. 540, 630, 680 MeV/c are corresponds to the momentum degraded by 2 lead glass, 1 lead glass + 1 lead block, and 1 lead glass, respectively, and such Kaon stops after 10 cm, 50 cm, and 65 cm of flight distance inside TPC fiducial volume.

Figure 1 shows an 2D display of typical event taken with 800 MeV/c electron trigger. Horizontal axis corresponds to TPC channel number and zero means most upper stream strip. Since strip pitch is 1 cm, this is equivalent to distance from beam injection point in cm. Vertical axis corresponds to electron drift time in μs and t=0 means trigger timing. In this TPC, anode and cathode is located at top and bottom of the detector, respectively, t=0 means energy deposition at anode and longer drift time means energy deposition in lower height. With 200 V/cm of electric field, drift velocity is about 0.8 m/ms. So drift of full detector (40 cm) takes 500 μs. Color strength of the plot corresponds to the TPC signal pulse height in ADC counts which is roughly proportional to dE/dx of the track. In this event, triggered electron can be clearly seen center of the detector as an electromagnetic shower while there are two other particles accidentally overlapped with the triggered electron. Track at t=100 μs is considered as a proton which stops after 15 cm of flight distance and has large dE/dx around the stopped point. Track at t=400 μs is considered as a pion which passes-through the detector and has uniform dE/dx over the TPC channels. This event already gives us some idea for how good the particle identification performance of the LArTPC is.

Figure 2 shows a typical $K \to \mu\nu$ like event. We can clearly identify a kink of the track at 60 cm which is considered as stopped point of Kaon and it decays to

Energy deposition of the track is about MIP at the injection point and gradually increase towards the stopped point at 60 cm.

Table 1: List of collected data

Particle	Momentum (MeV/c)	Number of Events
Pion	800	3,000
Proton	800	1,500
Kaon	540 (2LG)	7,000
Kaon	630 (1LG+1LB)	40,000
Kaon	680 (1LB)	35,000
electron	800	2,500
electron	200	10,000
pion	200	10,000

2.2 Beam Quality (Purity)

- Plot: TREK counters (FC, GC, TOF) (A. Okamoto)
- Plot: TOF before and after selection (A. Okamoto)

As described in section xx, we have several beam counters to identify beam particles event by event Figure reffig:TREK shows response of the, FC, GC, and TOF counters. By using these counter information,

Particle	FC(K)	FC(pi)	GC
Pion	x	o	x
Kaon	o	x	x
Proton	o	x	x
electron	x	o	o

Table 2: List of collected data

GC is used to identify electrons

2.3 Beam Energy, Position

- Plot: Proton momentum from TOF (A. Okamoto)
- Kaon:: Ongoing (H. Okamoto?)
- Plot: Beam position measurement

3 Software Framework

4 Event Reconstruction

4.1 Noise Reduction

Figure 4 shows raw waveform of the TPC signal before applying any noise reduction. Two waveforms shown in this plot are channel 13 and 37 in Figure 1 which are roughly proton stopped point and electron shower maximum point, respectively. Signal-to-noise ratio for this particular case is poor and pion signal which is supposed to be t=400 μs is almost hidden by the noise. While time width of TPC signal is few μs which is determined by drift time between anode and anode-grid, dominant noise component looks higher frequency. To reduce such noises, we have applied FFT (Fast Flourier Transformation) filter to cut the high frequency component. Figure **??** shows amplitude as a function of frequency for the same event. This clearly shows dominant noise component with $>$ 200 kHz has good separation with signal component ($<$ 100 kHz). Figure 5 shows the waveform after removing high frequency ($>$ 80 kHz) component by the FFT filter. Signal-to-noise ratio is dramatically improved. On the other hand, we expect certain bias to the signal charge measurement by this filter, and it will be discussed in Section x.

4.2 Hit Finding/Clustering

- Plot: Finding efficiency vs threshold (Naganoma)
- Plot: Through-going pion data Q vs pion (Tanaka)

4.3 Stopped Point Finding

4.3.1 Proton

4.3.2 Kaon: Hough

4.3.3 Kaon: Chi2, BS

- Plot: Proton Stopped point (A. Okamoto)
- Plot: Hough Stopped point (Tanaka)
- Plot: Chi2 Stopped point (H. Okamoto)
- Plot: BS Stopped point (H. Okamoto)

5 Liquid Argon Purity

Attenuation of the drift electron depends on purity of liquid Argon. So we need to apply correction to TPC signal charge depends on the drift time. We use cosmic ray sample for measuring the liquid Argon purity, and use this to correct the beam data.

Figure fig:CosmicEvent shows an event display of typical cosmic muon event. Figure fig:CosmicPurity shows an drift electron lifetime as a function of duration after initial filling. Drift electron lifetime was 600 μs at 60 hours, and 400 μs after 150 hours. Initial purity looks good, but the purity was slowly degrading while data taking period.

- Plot: Typical Cosmic event (Naganoma)
- Plot: Typical Lifetime Fit (Naganoma)
- Plot: Lifetime vs Time (Naganoma)

6 Detector Simulation

6.1 Geant3, recombination, drift velocity

We use GEANT3 for simulating energy deposition of beam particles and their daughters. Readout pitch is 1 cm,

we set the maximum step of Geant to 0.5 mm which is enough smaller than the readout pitch of 1 cm.

It means charge deposition in one strip is typically simulated with 20 GEANT steps.

We set energy cut-off for soft electron/photon emission to 10 keV which is minimum possible energy can be set in GEANT3. This cut-off is very important for ionization electron recombination.

Recombination of electron and Argon ion depends on the electric field and dE/dx. We use a measurement in Ref. [3].

$$Q = A\frac{Q_0}{1 + kdE/dx}, A = 0.800, k = 0.486 \tag{1}$$

Velocity of the drift electron depends on the liquid Argon temperature and the electric field. We use a measurement in Ref [4].

```
*     Special TPAR for TMED   3   Liquid_argon                                                           *
*  CUTGAM= 10.00 keV  CUTELE= 10.00 keV  CUTNEU= 10.00 MeV  CUTHAD= 10.00 MeV  CUTMUO= 10.00 MeV  *
*  BCUTE = 10.00 keV  BCUTM = 10.00 keV  DCUTE = 10.00 keV  DCUTM = 10.00 keV  PPCUTM= 10.00 MeV  *
*  IPAIR=  1.  ICOMP=  1.  IPHOT=  1.  IPFIS=  0.  IDRAY=  1.  IANNI=  1.  IBREM=  1.  IHADR=  4. *
*  IMUNU=  1.  IDCAY=  1.  ILOSS=  1.  IMULS=  1.  IRAYL=  0.  ILABS=  0.  ISYNC=  0.  ISTRA=  0. *
```

- Plot: Geant Geometry, typical track (Tanaka)
- Plot: recombination factor, drift velocity (Tanaka)

6.2 Electric Field

Electric field of the TPC field cage We have calculated the electric field using a 2D FEM (Finite Element Method) package [**?**].

This field map is used for simulating electron drift.

- Plot: 2D field map (Tanaka)

6.3 Drift Electron Diffusion

- Plot: drift simulation (Tanaka)

6.4 Preamp Gain Calibration

- Preamp gain vs channel number (Naito)

6.5 FFT Noise

- Plot: simulated event (Nagasaka)

6.6 Cross Talk

- Plot: signal waveform (proton stopped point + 1) (A. Okamoto)
- Plot: simulated event with and without cross talk (A. Okamoto)

6.7 Signal and Noise Scale Tuning

- Plot: Landau distribution after the tuning (Tanaka)

7 Data- MC Comparison

7.1 Through-going Pion

- Plot: Data-MC comparison (Tanaka)

7.2 Stopped Proton

- Plot: Hit charge, cluster charge, stopped point (A. Okamoto)
- Plot: hit charge with different distance from SP (A. Okamoto)
- Plot: average hit charge vs different distance from SP (A. Okamoto)

7.3 Stopped Kaon

- Plot: Hit charge, cluster charge, stopped point (H. Okamoto)
- Plot: hit charge with different distance from SP (H. Okamoto)
- Plot: average hit charge vs different distance from SP (H. Okamoto)

8 Summary

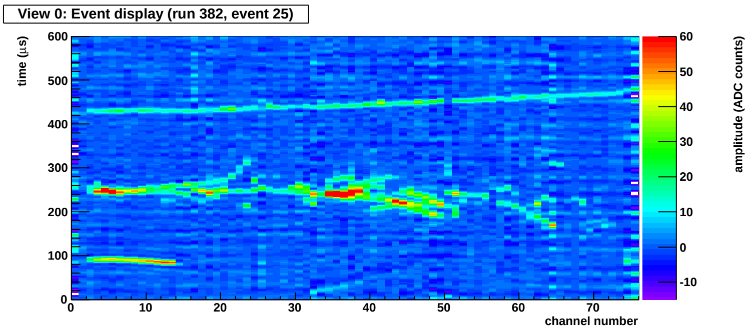

Fig. 1: Event display of 800 MeV/c electron triggered event. Accidentally overlapped with a proton and a pion.

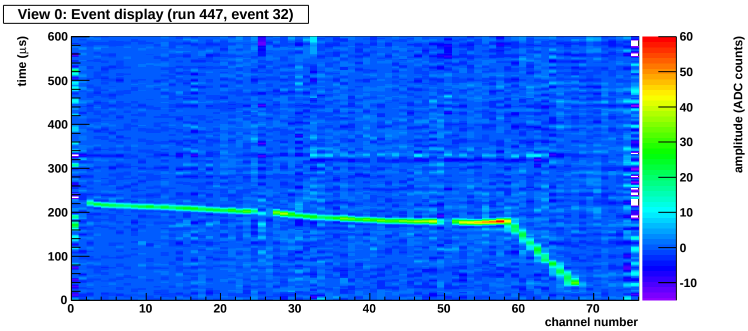

Fig. 2: Event display of Kaon 630 MeV/c triggered event

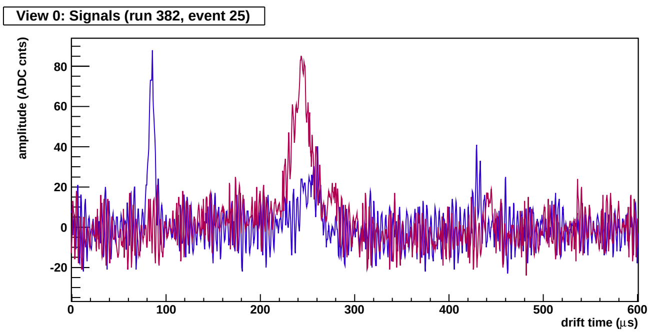

Fig. 3: TPC raw signal waveform for "Textbook" event channel 13 and 37.

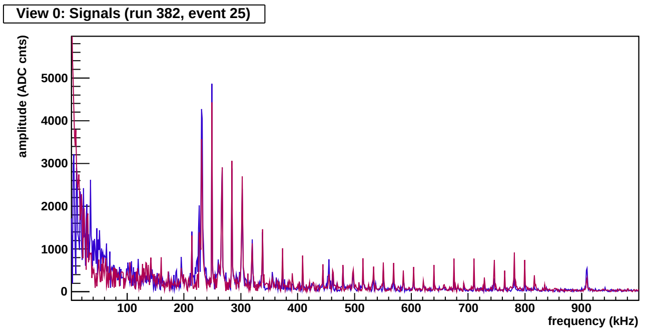

Fig. 4: FFT frequency amplitude distribution

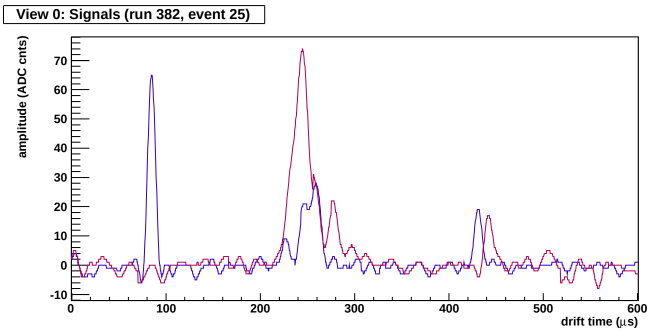

Fig. 5: TPC signal waveform after cutting the frequency > 80 kHz.

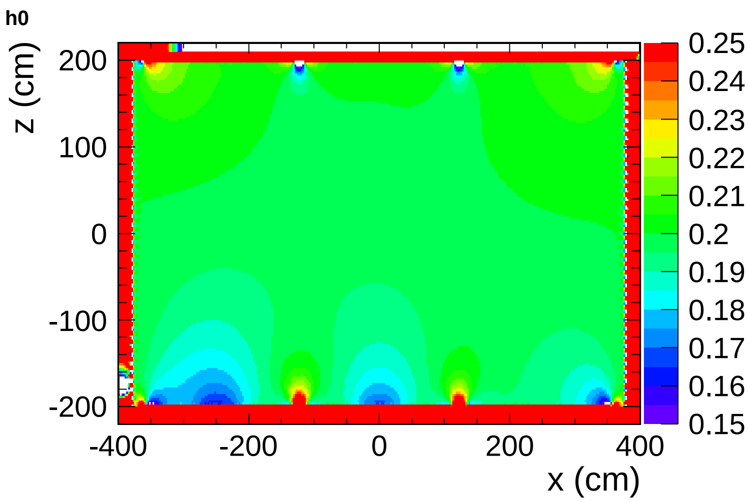

Fig. 6: Electric field map obtained from 2D FEM calculation

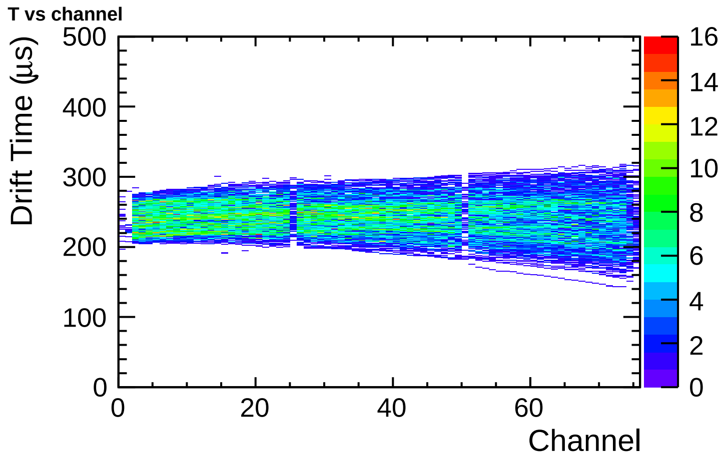

Fig. 7: 800 MeV/c pion sample

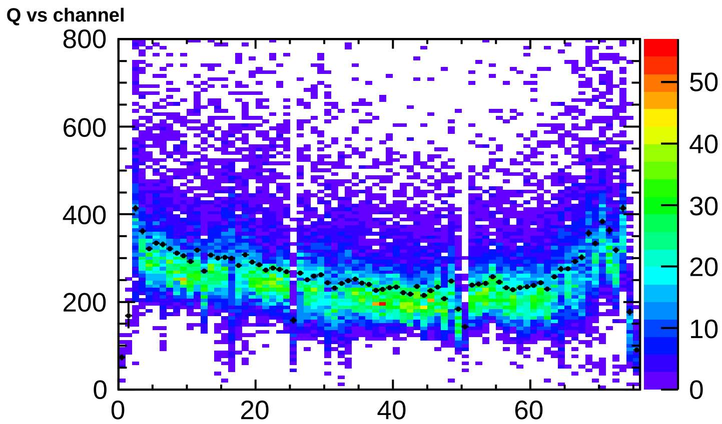

Fig. 8: 800 MeV/c pion average hit charge

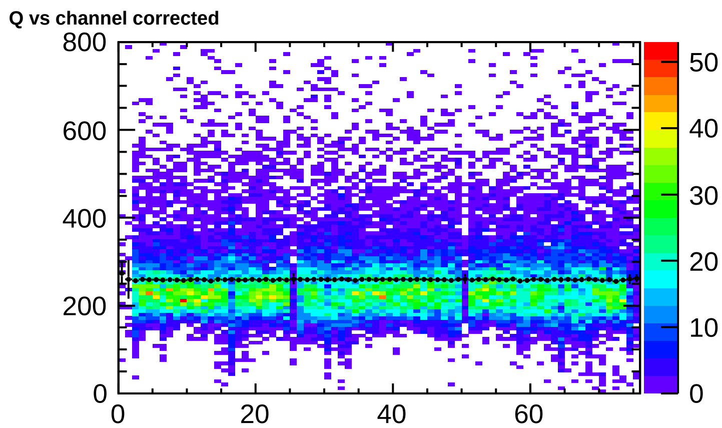

Fig. 9: 800 MeV/c pion average hit charge after calibration

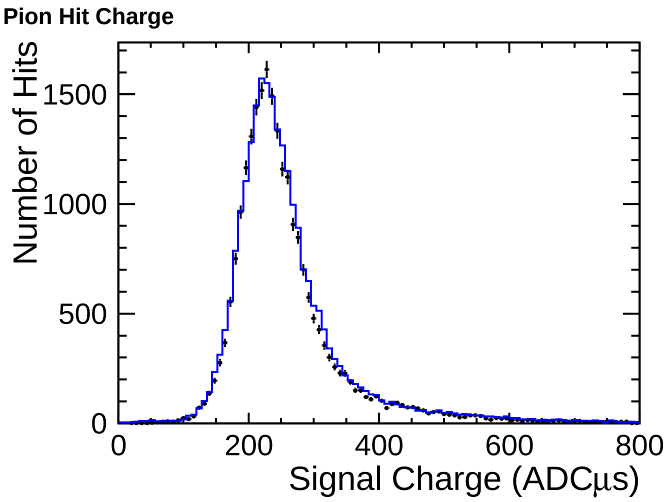

Fig. 10: 800 MeV/c pion Landau distribution

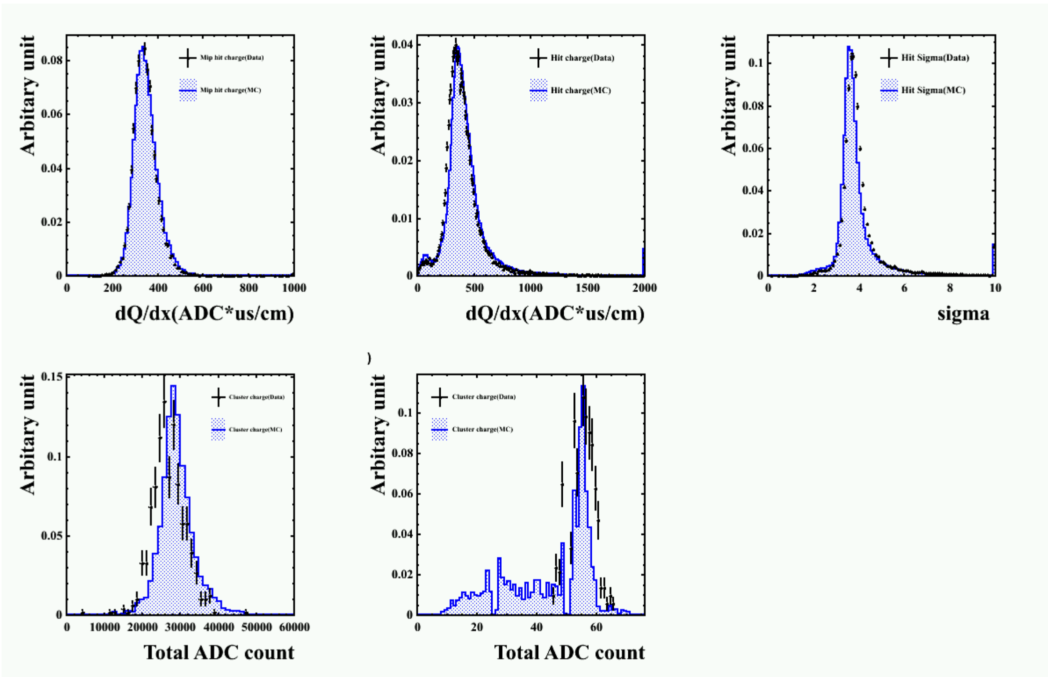

Fig. 11: Data-MC comparison for several Kaon quantities

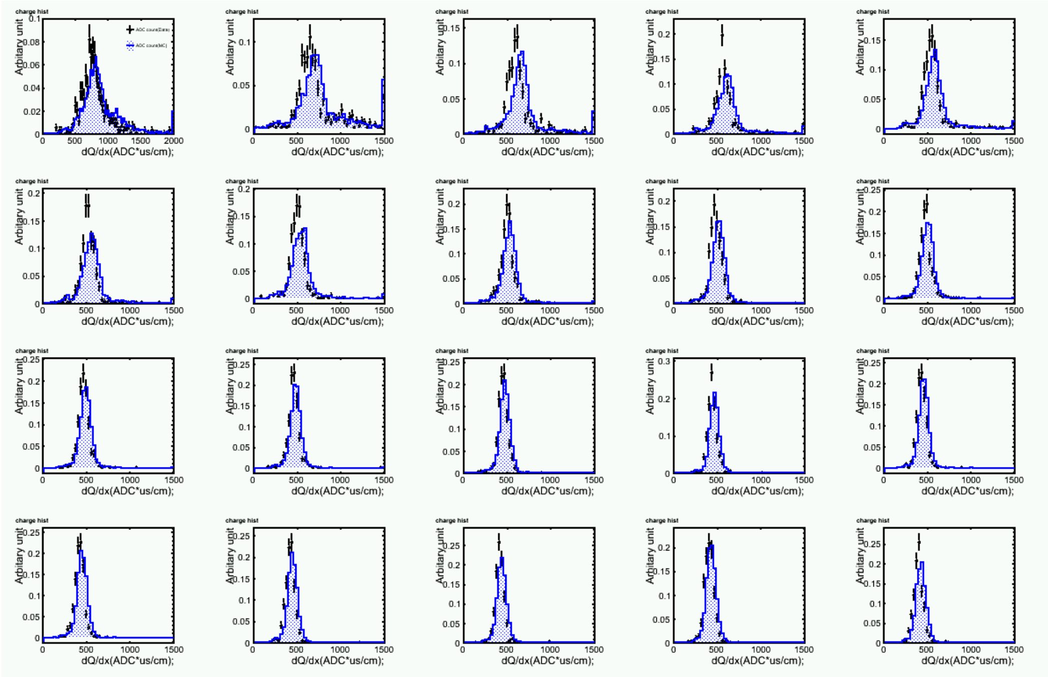

Fig. 12: Kaon hit charge distribution for different distance from the stopped point.

Fig. 13: Kaon average hit charge as a function of distance from the stopped point.

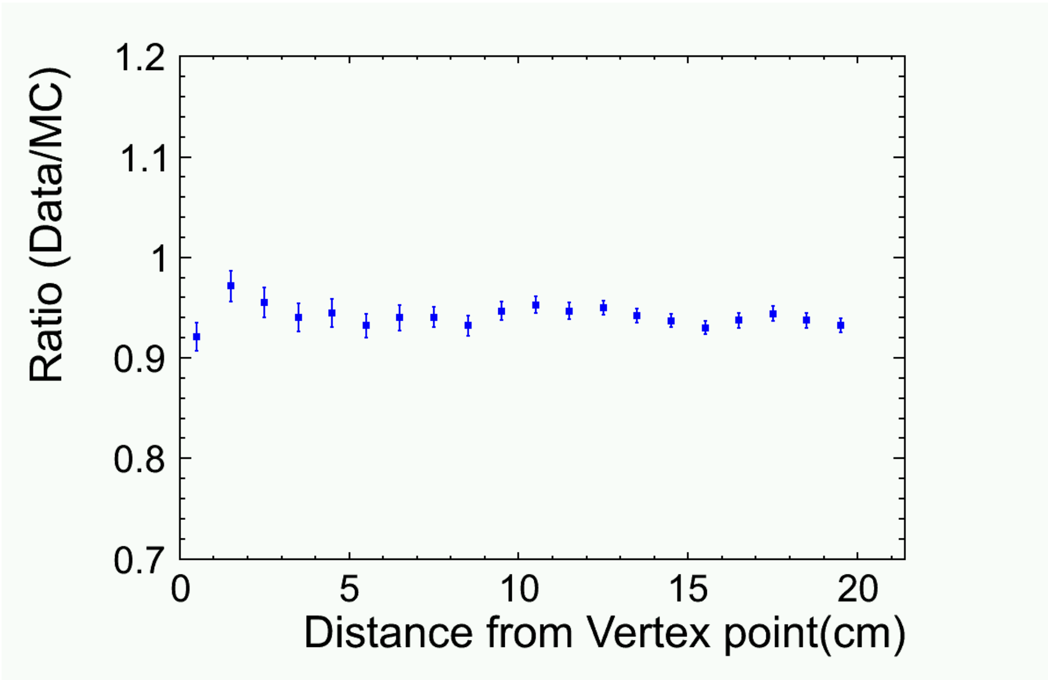

Fig. 14: Data/MC ratio of the proton average hit charge as a function of distance from the stopped point.

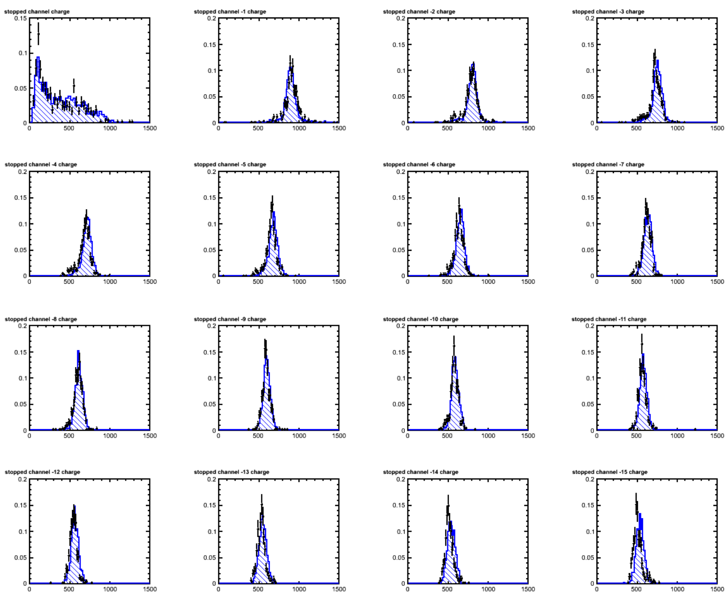

Fig. 15: Proton hit charge distribution for different distance from the stopped point.

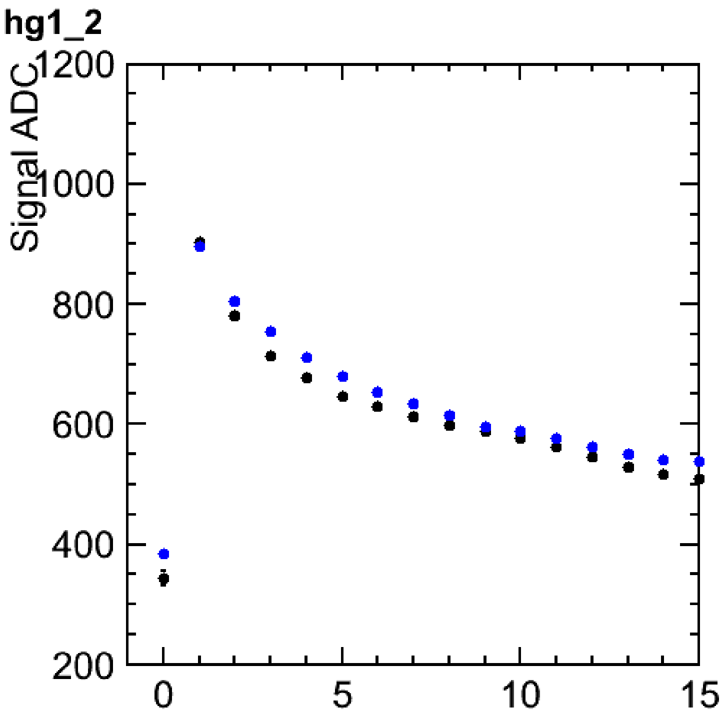

Fig. 16: Proton average hit charge as a function of distance from the stopped point.

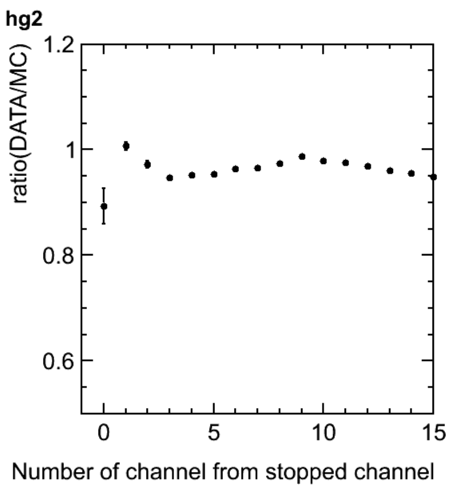

Fig. 17: Data/MC ratio of the proton average hit charge as a function of distance from the stopped point.

References

[1] O. Araoka *et al.*, J. Phys. Conf. Ser. **308**, 012008 (2011) [arXiv:1105.5818 [physics.ins-det]].

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[3] S. Amoruso *et al.* [ICARUS Collaboration], Nucl. Instrum. Meth. A **523**, 275 (2004).

[4] S. Amoruso, M. Antonello, P. Aprili, F. Arneodo, A. Badertscher, B. Baibusinov, M. Baldo-Ceolin and G. Battistoni *et al.*, Nucl. Instrum. Meth. A **516**, 68 (2004).