# Beamline PID paper:

## pion contamination from KL

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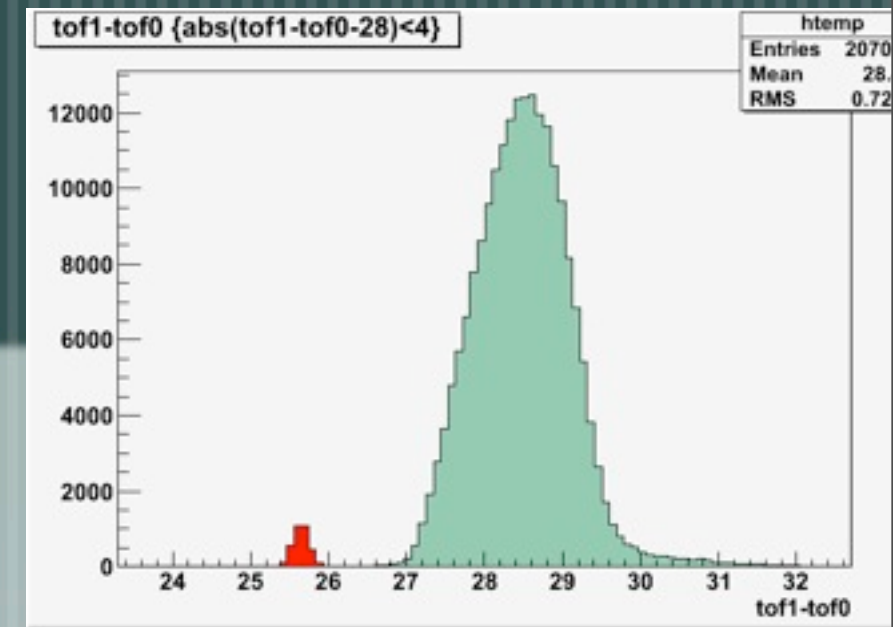
MICE CM 34

# Analysis principle (I)



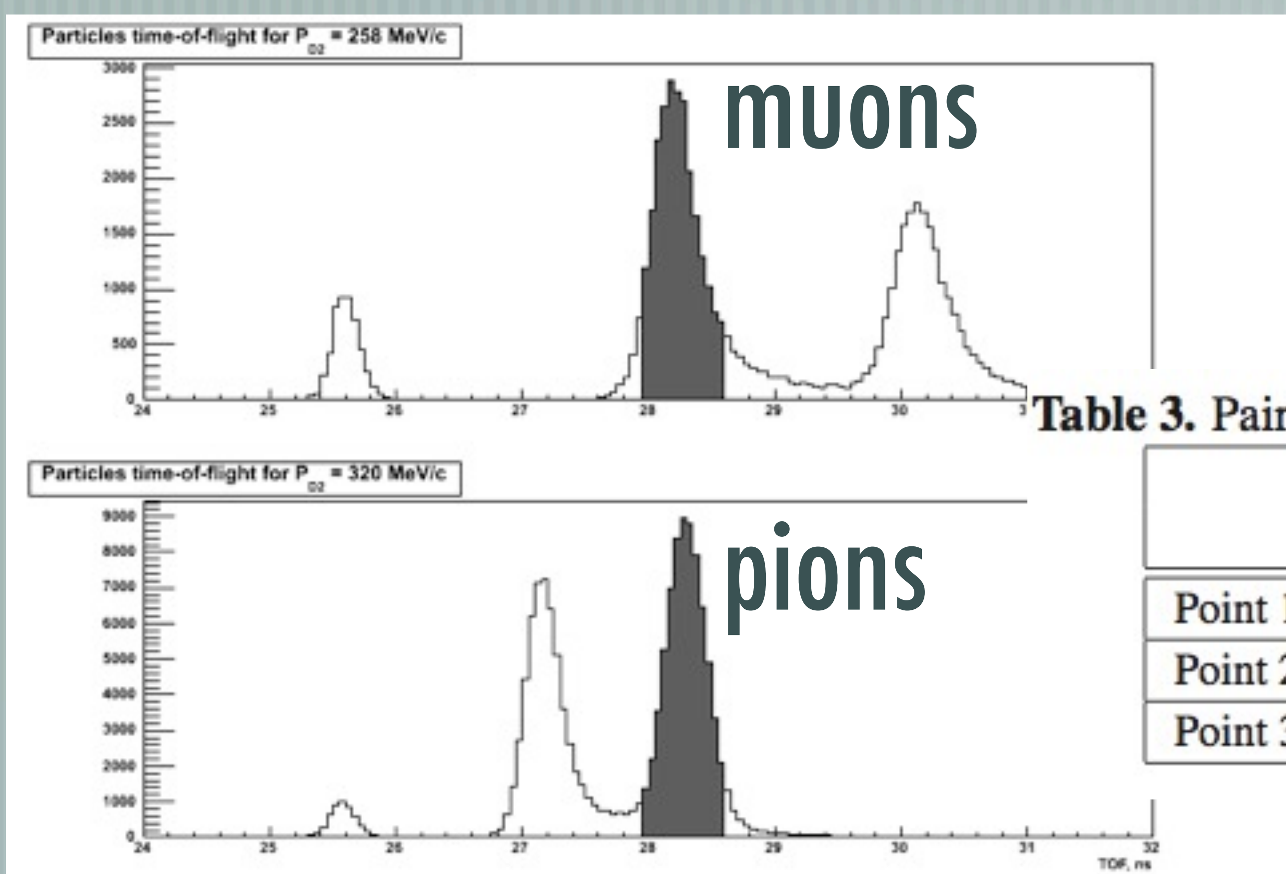

- we measure TOF for MICE beam particles
- we will measure momentum, but we currently don't
- therefore our MICE beam is an unknown mixture of muons and pions - while electrons are easy to spot
- statistical estimate of the pion contamination in the MICE beam (as already presented in CM 32): to characterize the beam now (not for the emittance measurements!)

# Analysis principle (II)

- Different interaction probability in KL for muons and pions
- Can statistically separate two populations with the same TOF but different PID (and different KL interactions)
  - But interactions in KL can depend on particle momentum
  - Treat separately different TOF intervals, i.e. different momenta for a given particle mass

# Calibration runs

Need “pure” samples of pions and muons with well defined TOF: these are obtained from different runs (different $p_{D2}$)



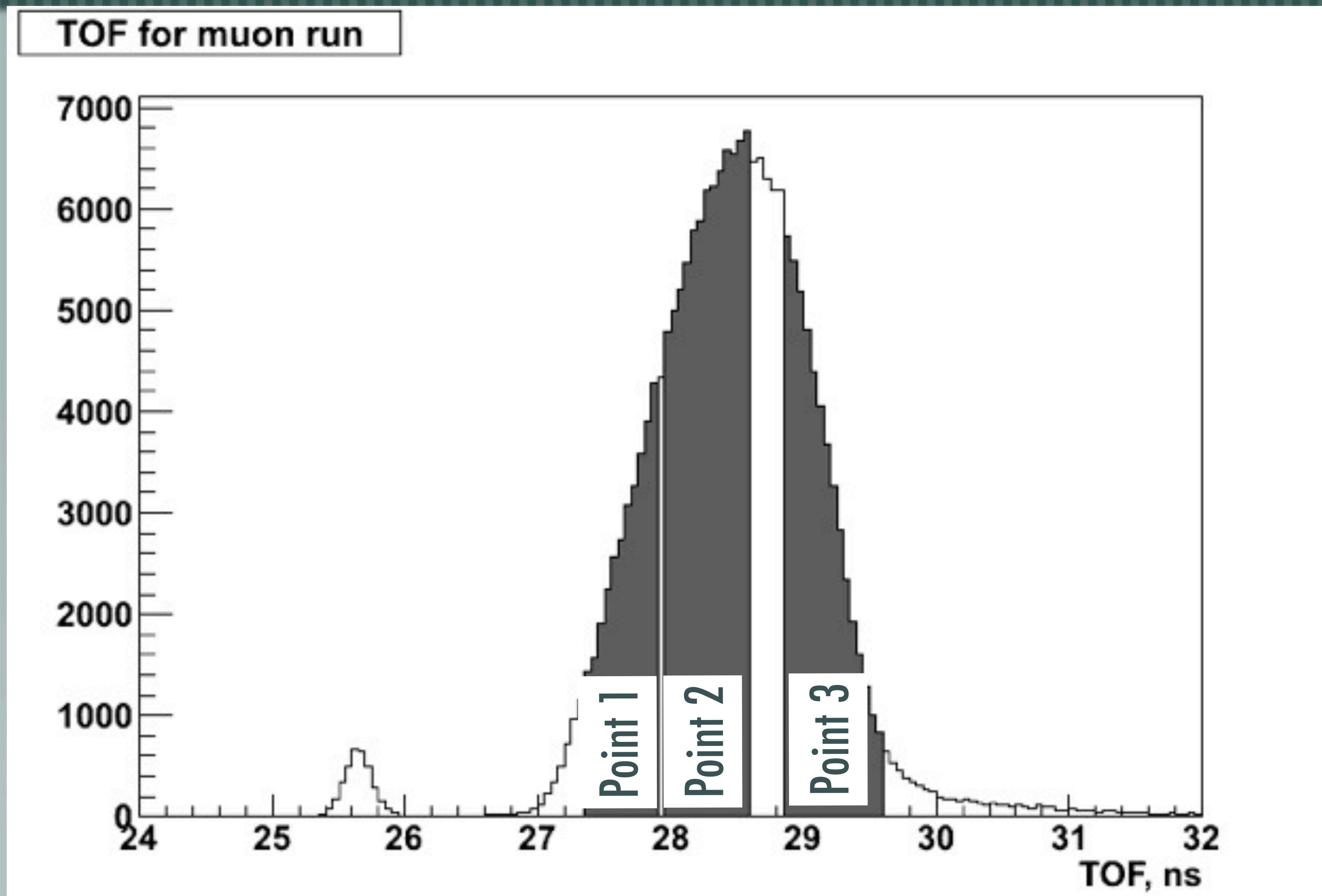

POINT2

**Table 3.** Paired beam settings for three time–of–flight intervals (also called points).

| | TOF interval, ns | muons from runs with $P_{D2}$ (MeV/c) | pions from runs with $P_{D2}$ (MeV/c) |
|---|---|---|---|
| Point 1 | 27.4 – 27.9 | 294 | 362 |
| Point 2 | 28.0 – 28.6 | 258 | 320 |
| Point 3 | 28.9 – 29.6 | 222 | 280 |

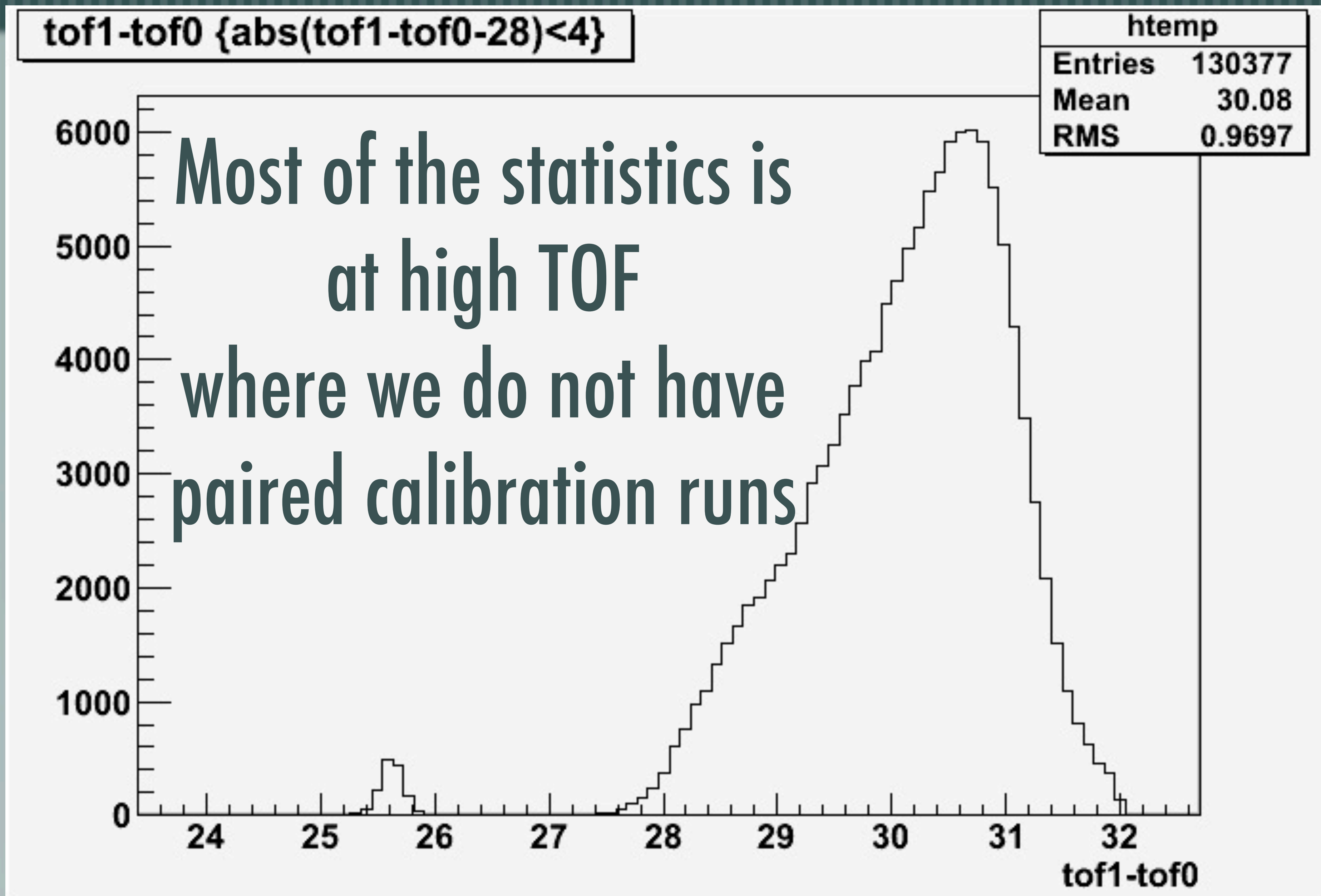
| | TOF interval, ns | muons from run: | pions from run |
|---|---|---|---|
| Point 1 | 27.4 – 27.9 | 3253 | 3426 |
| Point 2 | 28.0 – 28.6 | 3250, 3252 | 3261 |
| Point 3 | 28.9 – 29.6 | 3256 | 3454 |

# MICE beam sample I




| run number | beamline species | $P_{D2}$ (MeV/c) | collected pulses |
|---|---|---|---|
| 3407 | $\mu^+$ | 240, nominal | 1691 |
| 3506 | $\mu^+$ | 240, nominal | 1386 |
| 3507 | $\mu^+$ | 240, nominal | 1383 |
| 3514 | $\mu^+$ | 240, nominal | 2184 |
| 3515 | $\mu^+$ | 240, nominal | 2346 |
| 3516 | $\mu^+$ | 240, nominal | 676 |

# MICE beam sample II

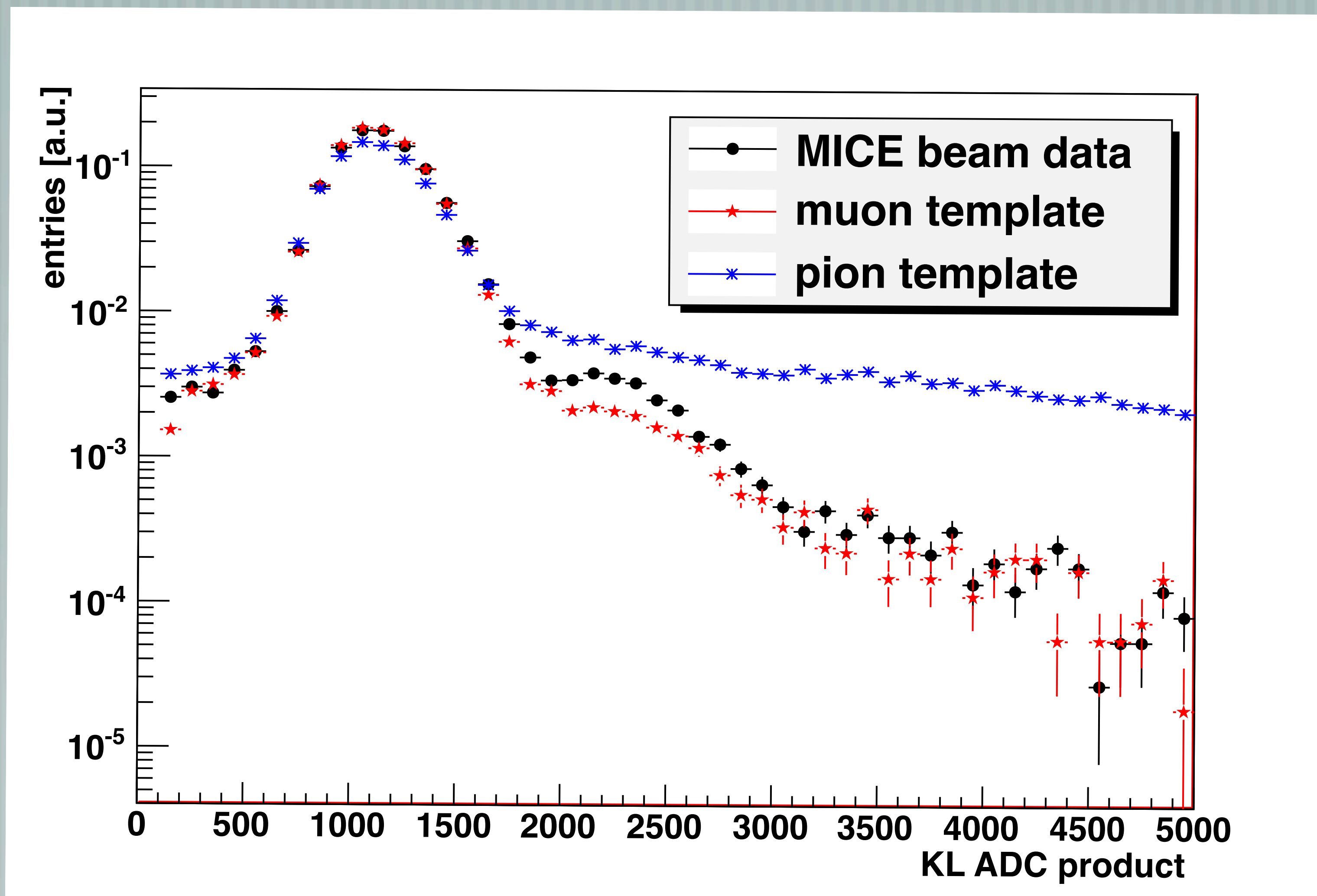



run3419, 3420, 3495, 3499 188.86 MeV @D2

(settings 140 MeV, 6 pi)

# KL response

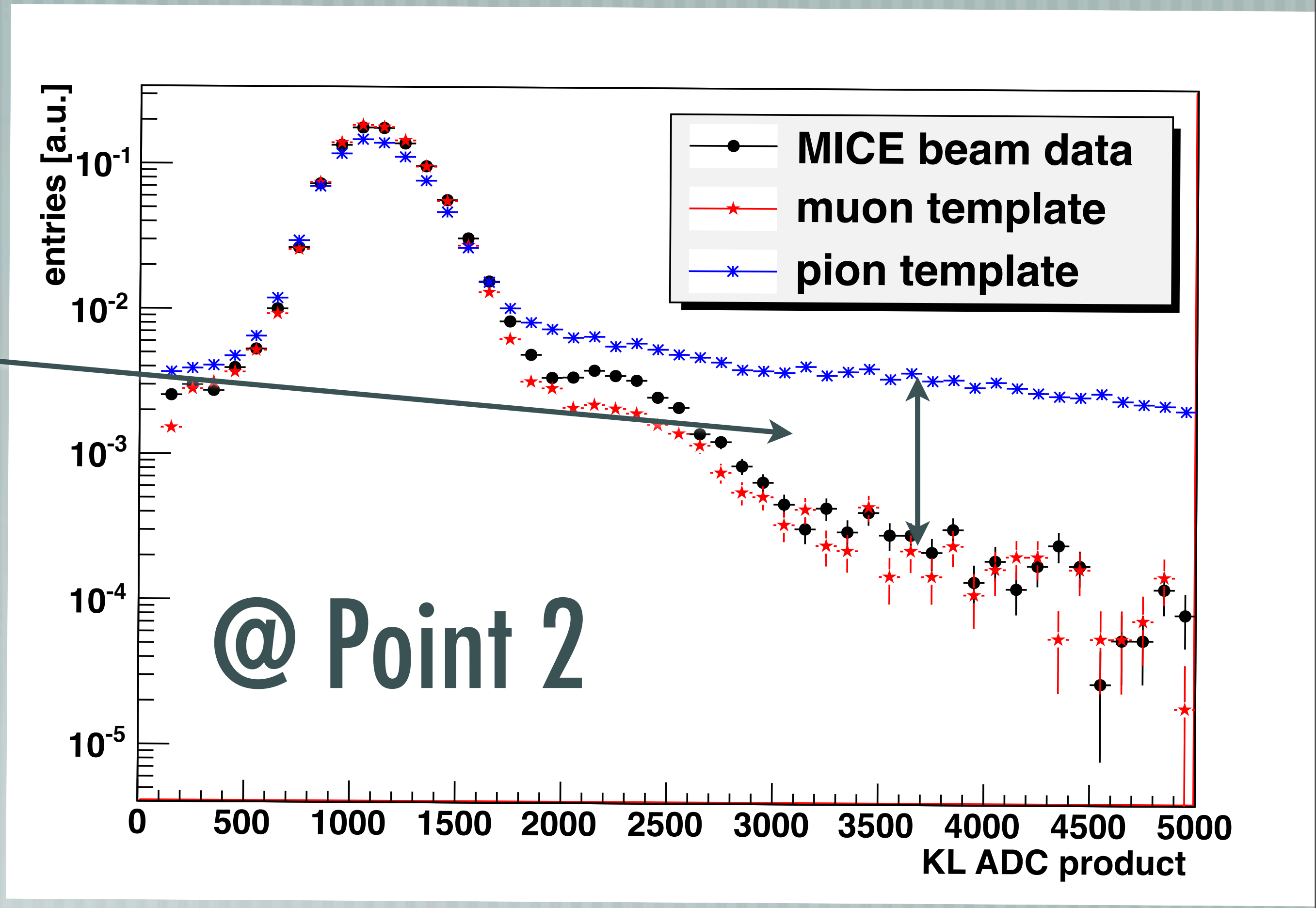
KL ADC product: geometrical average of signals from the 2 PMTS (reduced position dependence)




@ Point 2

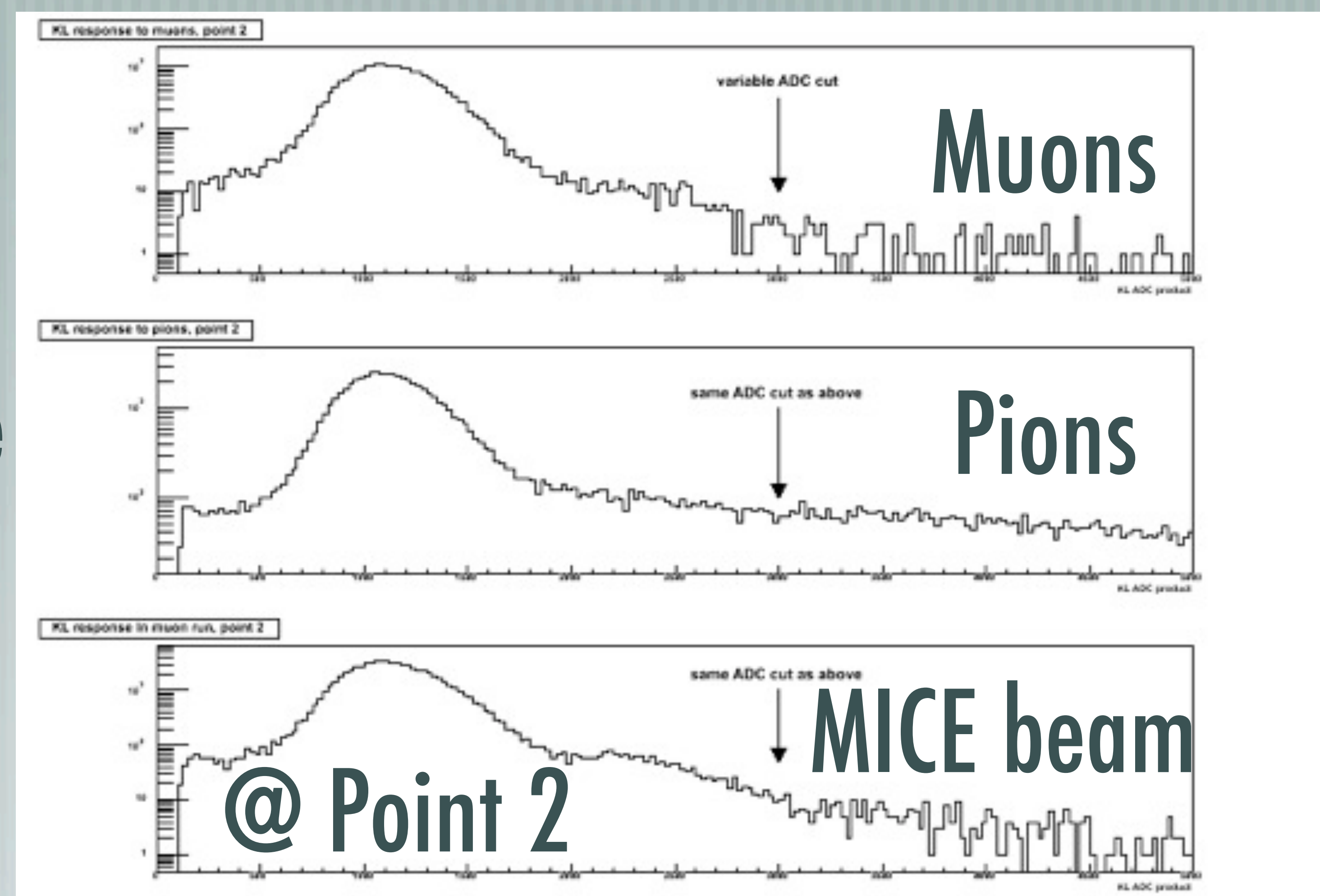
# Method

- exploit difference in KL to estimate pion contamination



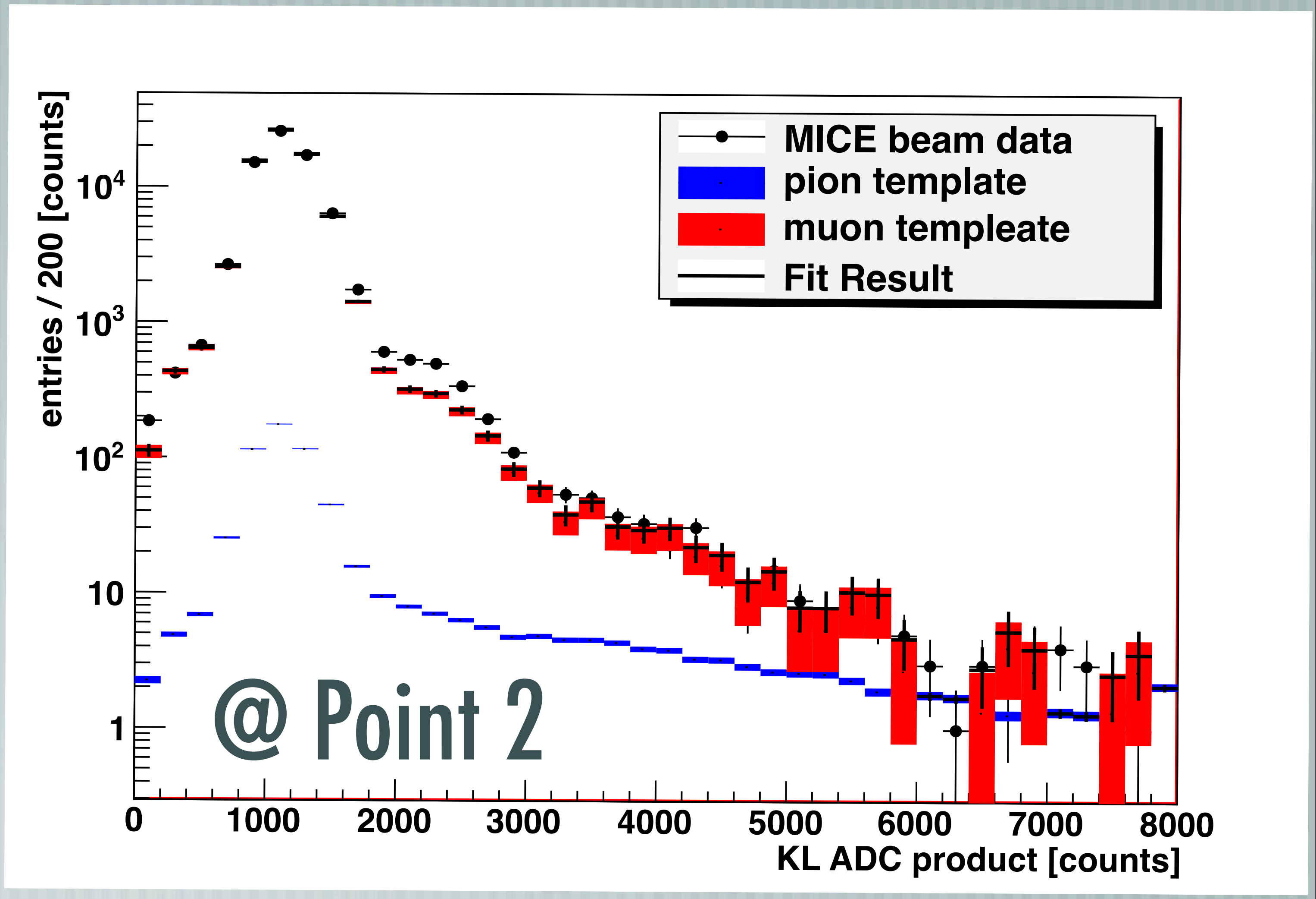
# Method

- exploit difference in KL to estimate pion contamination
- counting events above threshold (method 1)



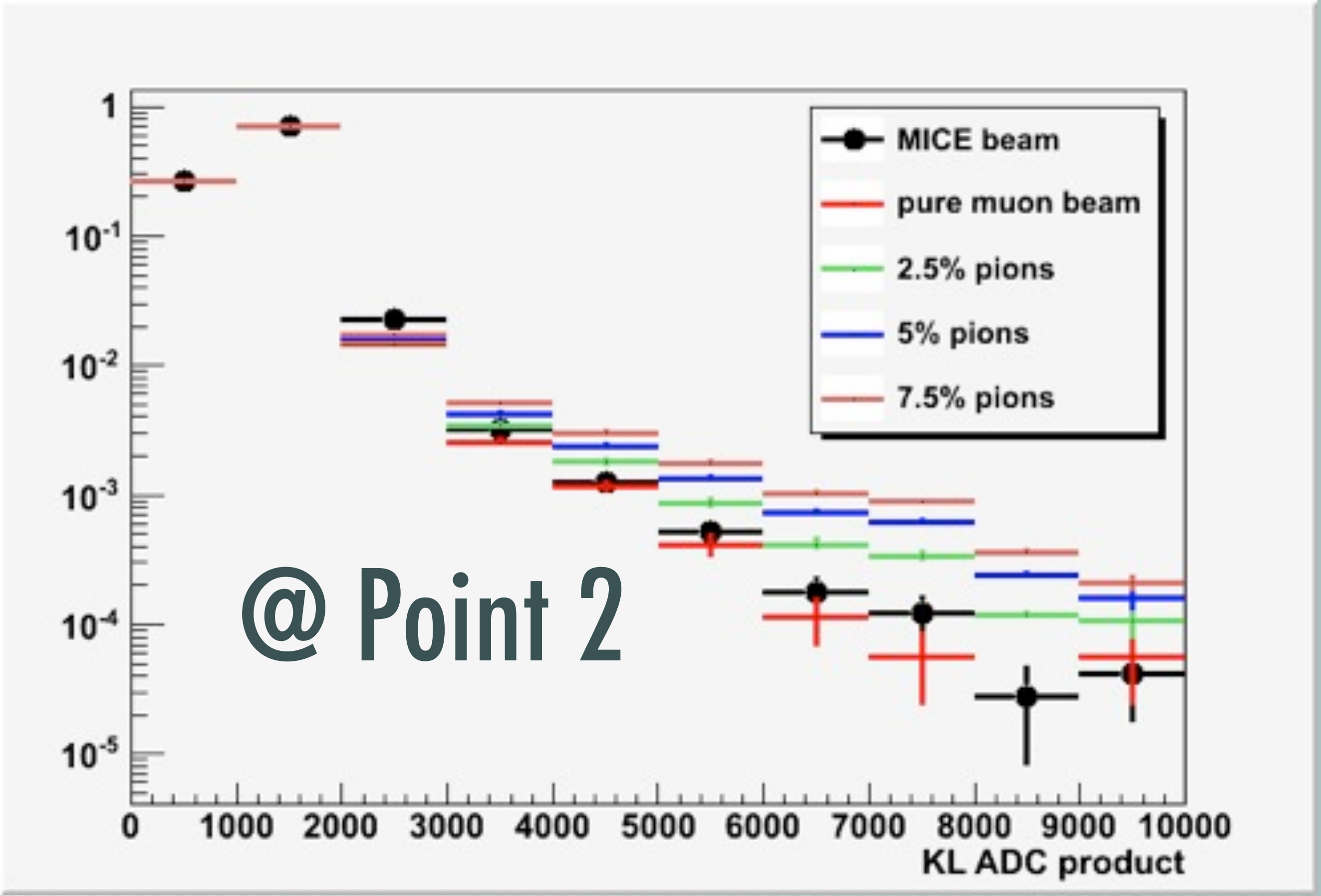
# Methods

- exploit this difference to estimate pion contamination
- counting events above threshold (method 1)
- fitting the distribution (method 2)



# A check by eye

- Use muon and pion templates from calibration runs to produce the 0%,2.5%, 5% and 7.5% distributions
- there is no room for a contamination higher than few %



# Method I

$$\begin{cases} \boxed{R^{tot}} = R_\mu + R_\pi \\ R^{cut} = k_\mu R_\mu + k_\pi R_\pi \end{cases}$$

Total number of particles in KL spectrum for MICE beam run

# Method I

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Number of muons in KL spectrum in the MICE beam run

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Total number of particles in KL spectrum for MICE beam run <u>above the fixed KL threshold</u>

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fraction of muons

above the fixed KL threshold

in a muon calibration sample (for the same TOF interval)

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$$\begin{cases} R^{tot} = R_\mu + R_\pi \\ R^{cut} = k_\mu R_\mu + k_\pi R_\pi \end{cases}$$

$$q_\mu = \frac{R_\mu}{R^{tot}} \quad \text{and} \quad q_\pi = \frac{R_\pi}{R^{tot}}$$

# Method I

**Table 4.** Pion and muon fractions in calibration and in muon runs for point two and for three cuts on KL product. $N_\mu^{tot}$ and $N_\mu^{cut}$ are number of muons before and after the cut in calibration run; $N_\pi^{tot}$ and $N_\pi^{cut}$ are number of pions before and after the cut in calibration run. The uncertainties are statistical.

| KL cut | 3000 | 4500 | 7000 |
|---|---|---|---|
| $N_\mu^{tot}$ | 53334 | 53334 | 53334 |
| $N_\mu^{cut}$ | 234 | 53 | 7 |
| $N_\pi^{tot}$ | 68933 | 68933 | 68933 |
| $N_\pi^{cut}$ | 7785 | 4330 | 1390 |
| $k_\mu$, % | $0.44 \pm 0.03$ | $0.10 \pm 0.01$ | $0.01 \pm 0.00$ |
| $k_\pi$, % | $11.29 \pm 0.12$ | $6.28 \pm 0.09$ | $2.01 \pm 0.05$ |
| $R^{tot}$ | 72709 | 72709 | 72709 |
| $R^{cut}$ | 391 | 92 | 16 |
| $R_\mu$ | 72045.8 | 72389.6 | 72386.7 |
| $R_\pi$ | 663.2 | 319.4 | 322.3 |
| $q_\mu$, % | $99.01 \pm 0.52$ | $99.56 \pm 0.48$ | $99.56 \pm 0.52$ |
| $q_\pi$, % | $0.91 \pm 0.36$ | $0.44 \pm 0.31$ | $0.44 \pm 0.36$ |

From calibration runs

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From MICE beam runs

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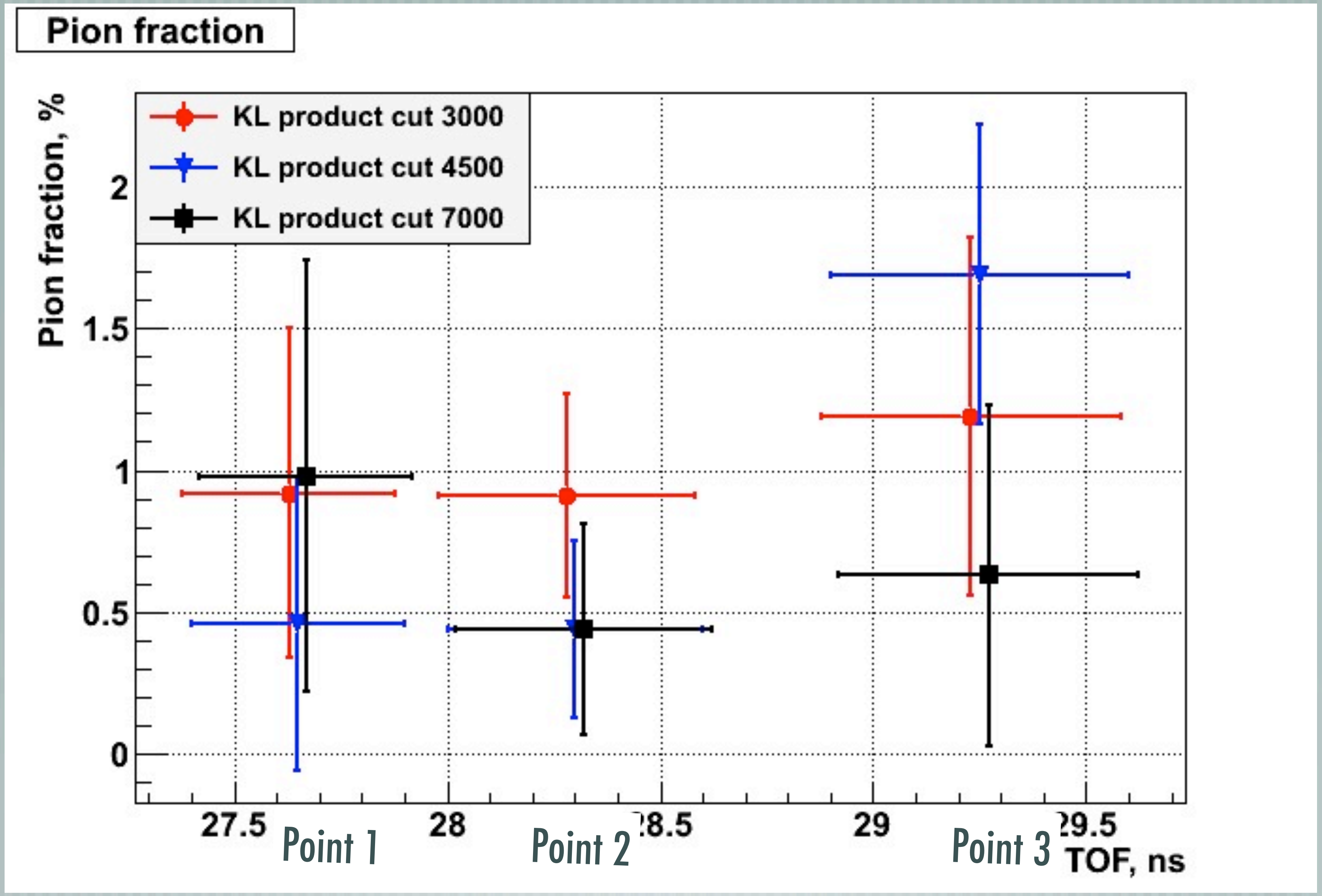
Results

# Method I



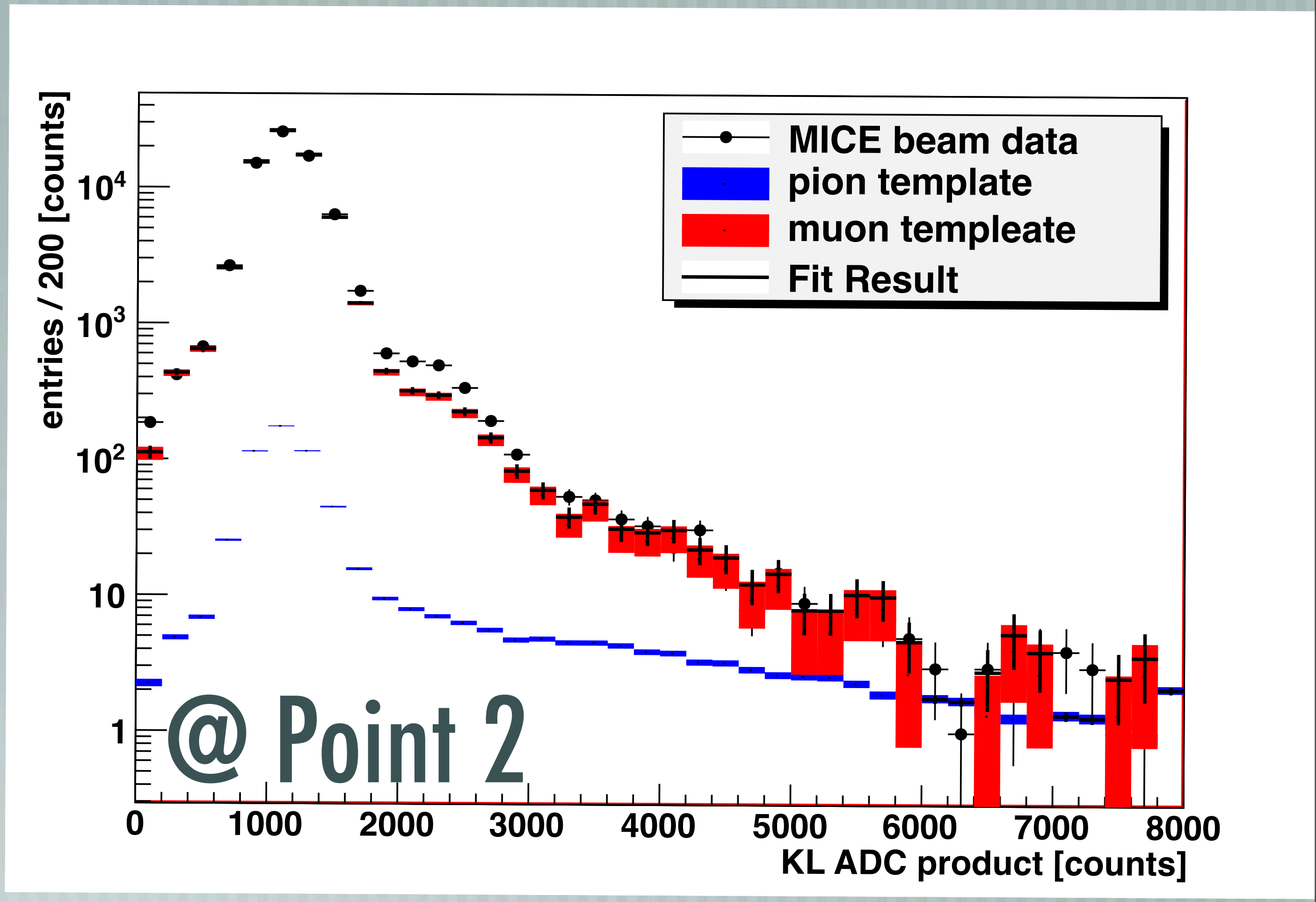
Pion fraction
KL product cut 3000
KL product cut 4500
KL product cut 7000
Pion fraction, %
2
1.5
1
0.5
0
27.5
28
?8.5
29
?9.5
TOF, ns
Point 1
Point 2
Point 3

# Method I: systematics

- threshold dependence:
  - +- 0.5% @ Points 1 and 2
  - +-1% @ Point 3
- muon contamination in pion calibration run
  - 0.2% (obtained for a 30% contamination)
- TOF (and hence momentum) particles’ distribution
  - 0.2% obtained reweighting accordingly to TOF distribution

# Method II

- Fit the MICE beam data using a superposition of muon and pion templates
- use ROOT based TFractionFitter

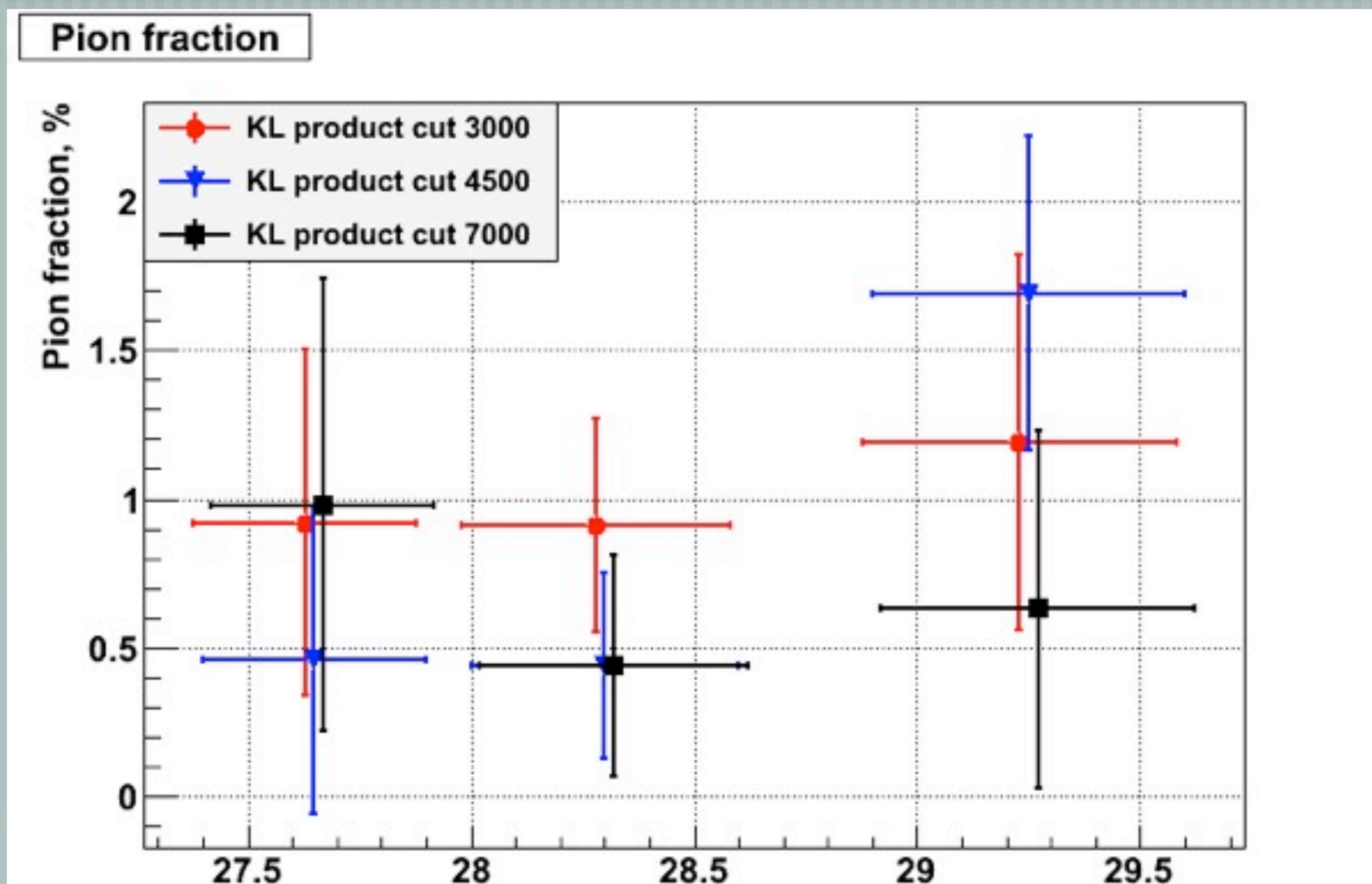


# Method II: systematics

- Small contamination to be measured, large statistical fluctuations covering systematics effects
- Systematics evaluated "doping" the sample with an extra pion contamination added extracting events from the pion calibration KL distribution

| effect | relative impact on pion contamination |
|---|---|
| dependence on the time–of–flight distribution | 40% |
| dependence on time–of–flight calibration | 3% |
| dependence on the fitted range | 15% |
| dependence on the histogram binning | 3% |

# Results




(0.7+-0.5+-0.3)%

(0.8+-0.3+-0.3)%

(1.9+-0.4+-0.8)%

Method I

Method II

# Compare to simulation?

**Table 1.** Pion contamination in a 6 mm rad muon beam, at various momenta, as deduced from TOF0-TOF1 time-of-flight Monte Carlo simulations.

| $p_{beam}$(MeV/c) | Electrons | Muons | Pions | $\pi$ contamination (%) |
|---|---|---|---|---|
| 140 (-ve) | 3368 | 35238 | 274 | 0.77 |
| 200 (-ve) | 12517 | 293704 | 2705 | 0.91 |
| 240 (-ve) | 4492 | 310196 | 3274 | 1.04 |
| 140 (+ve) | 595 | 11139 | 349 | 3.04 |
| 200 (+ve) | 3789 | 87007 | 4232 | 4.64 |
| 240 (+ve) | 280 | 12844 | 704 | 5.20 |

# Plans

- Would like to have this result in a publication
- Possibly including Cherenkov results
- A very first draft exists