Measurement of Pion Contamination in the MICE Beam

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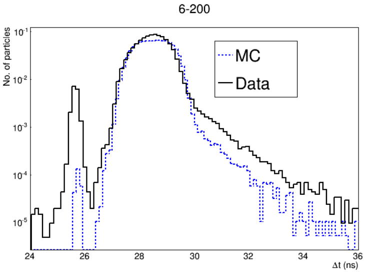
Analysis Principle

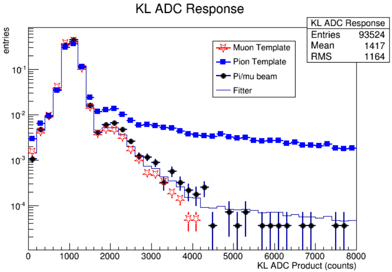
In Step I we measured the TOF, not P, of particles

While electrons are easy to spot, MICE μ beam unknown mixture of μ & π

- Each species will interact differently in the KL, use this information to perform particle identification

KL response P dependant so split into TOF windows for analysis



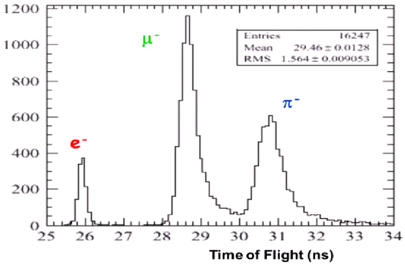


Figures correspond to MICE 6 π 200 MeV/c μ beam

MICE Beam

- Emittance measurement will be made with beam in '$\pi \rightarrow \mu$' mode
  - Momentum selection $p_{D2} \approx p_{D1}/2$, backward going muons in pion rest frame are selected.
  - Beam of high purity, small contamination of pions remains due to wide momentum acceptance of D2

- Alternative running mode is 'calibration mode'
  - Momentum selection $p_{D2} \approx p_{D1}$
  - Particle species are seperated in time of flight



- Use information from TOF and KL to measure pion contamination on statistical bases

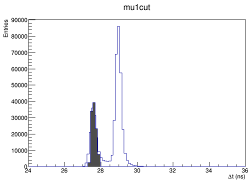
Monte Carlo Beam

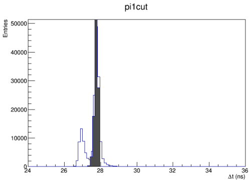
- Beamline from target to upstream face of TOF0 simulated in G4beamline
  - Output run through interface to MAUS, converts to json documents in MAUS geometry system
- Using MAUS Step I legacy geometry
- Beams generated are (6, 200) & several pion beams 3253, 3426, 3250, 3261, 3256, 3454 of various momenta

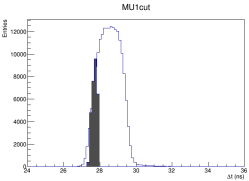
TOF Selection

Select pure samples of pions and muons in window 27.4 - 27.9 ns (highlighted in grey). Use two pion beams with two different momentum settings

TOF $P_{D2} = 294$ MeV/c TOF $P_{D2} = 362$ MeV/c TOF $P_{D2} = 237$ MeV/c



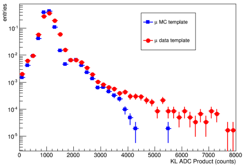




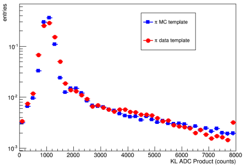
TOF Selection

Select pure samples of pions and muons in window 27.4 - 27.9 ns (highlighted in grey). Use two pion beams with two different momentum settings

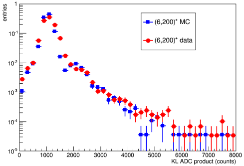
KL ADC product
$P_{D2} = 294$ MeV/c



KL ADC product
$P_{D2} = 362$ MeV/c

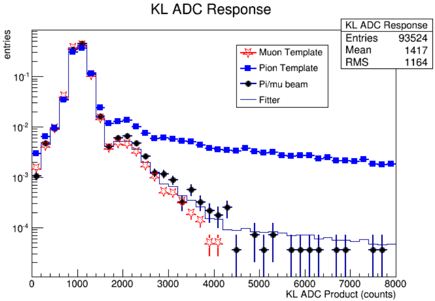


KL ADC product
$P_{D2} = 237$ MeV/c



Contamination Measurement

Fit performed by TFractionFitter - sum muon and pion templates as linear combination to give muon beam (figure shows this for three MC beams)



Pion Contamination

π fraction MC recon 1.98 $\pm$ 0.05 (stat)%

π fraction MC Truth 0.83 $\pm$ 0.05 (stat)%

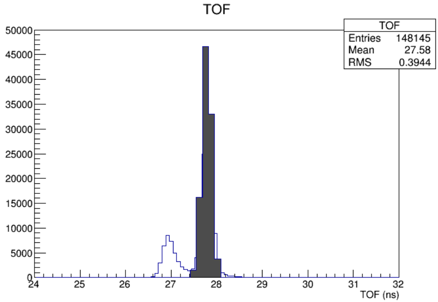
π fraction Data 0.65 $\pm$ 0.46 (stat)%

Status at Editorial Meeting

- Working version of KL digitisation and analysis code
- Second draft of PID Note was circulated
  - Study of systematic bias of measurement included
  - Investigate the origin of double peak in KL
- Repeat analysis across MICE μ beam TOF with calibration beams of different P

- Address issues raised during discussions
  - Third draft of PID Note will shortly be available at: `https://micewww.pp.rl.ac.uk/issues/1473/`

Systematic Bias of Measurement



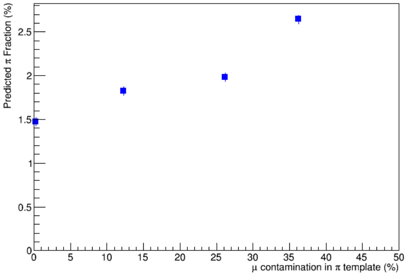
- Select 'pure' sample of πs based on TOF with calibration beam.
- Tails of muon template lie under π peak
- μs from π decay after D2 will also contribute

- By how much does this contamination affect the measurement of the π contamination in the MICE μ beam?
- Re-ran the MC analysis with various levels of contamination in the π template and note the change in the predicted π fraction

Systematic Bias of Measurement

Table: Predicted π fraction with μ contamination

μ conta.	Predicted $\pi_{fraction}$
0%	$1.47\% \pm 0.030\%$
12.41%	$1.82\% \pm 0.030\%$
26.20%	$1.98\% \pm 0.030\%$
36.26%	$2.64\% \pm 0.030\%$



- Systematic error due to μ contamination

$$= \pi_{fraction} \text{ nominal template} - \pi_{fraction} \text{ 0\% template}$$
$$= 1.98 - 1.47 = 0.51\%$$

- This effect gives a systematic over estimate of the pion contamination in the muon beam

Double MIP Peak

- Pileup disfavoured as KL fADC has 60 ns gate, given expected rates the rate of coincidence is very small.

$$
\begin{aligned}
R &= 2N^2\tau \\
&= 2 \times (10^5)^2 \times 60\text{ns} \\
&= 1200\text{Hz}
\end{aligned}
$$

- In 1 ms that is 1.2 events. Pileup due to mismatched triggers at the level of 10^{-3} & likelihood of particles hitting same slab in all TOF stations small - would not avoid DAQ veto

- Hypothesise that double peak due to after-pulsing in the KL PMTs
- Vacuum in the tubes compromised to some extent due to age of the tubes
- Second pulse arrives after the first but within the KL sampling window
- Behaviour has been added by hand to the MC in the analysis code

Corrupted Data

- All data in MICE publications should be processed with a known version of MAUS
- Data from 2011 run was corrupted - this prevented the data being processed
- Problem due to DAQ data/unpacking
- In some events there are more V1724 KL events than there are V1290 trigger or trigger_request events
- The ‘extra’ KL events are not properly associated with a recon_event

- Yordan has created a program to recover the corrupted data, once this has been implemented the data can be processed in the normal way in MAUS
- Analysis using MAUS beam will have to be repeated

Analysis at P2 & P3

Method	π(%) at Point 1	π(%) at Point 2	π(%) at Point 3	average π cont. (%)
analysis	0.48 $\pm$ 0.34 (stat) $\pm$ 0.25 (syst)	0.57 $\pm$ 0.18 (stat) $\pm$ 0.29 (syst)	1.41 $\pm$ 0.27 (stat) $\pm$ 0.71 (syst)	0.77 $\pm$ 0.14 (stat) $\pm$ 0.39 (syst)
MC	1.46 $\pm$ 0.05 (stat) $\pm$ 0.75 (syst)	0.33 $\pm$ 0.03 (stat) $\pm$ 0.17 (syst)	0.26 $\pm$ 0.03 (stat) $\pm$ 0.13 (syst)	0.51 $\pm$ 0.02 (stat) $\pm$ 0.26 (syst)
MC Truth	0.83 $\pm$ 0.05	0.08 $\pm$ 0.01	0.08 $\pm$ 0.01	0.22 $\pm$ 0.01

PRELIMINARY

- Repeated analysis at all three points with both MC and data
- MC prediction of pion contamination below 1% level

Paper Status

Complete

- Generate template beams with different momenta and repeat analysis at all points in MC
- Completed a study of the systematic bias in MC
- Third draft of PID Note and first draft of PID paper to follow at: `https://micewww.pp.rl.ac.uk/issues/1473/`

In progress

- MAUS bug for processing data - fix available currently reprocessing data
- Repeated study of systematic errors considered in data
- Confirm that double MIP peak due to afterpulsing

Appendix

Template composition

$$\text{MICE } \mu \text{ beam} = a\mu_{template} + b\pi_{template}$$
$$= a(\mu_{particle} + \pi_{particle}) + b(\pi_{particle} + \mu_{particle})$$

- μ template has low contamination - negligible impact on measurement

$$= \sim 0.99\mu_{particle} + \sim 0.01(\sim 0.75\pi_{particle} + \sim 0.25\mu_{particle})$$