Measurement of Pion Contamination in the MICE Beam

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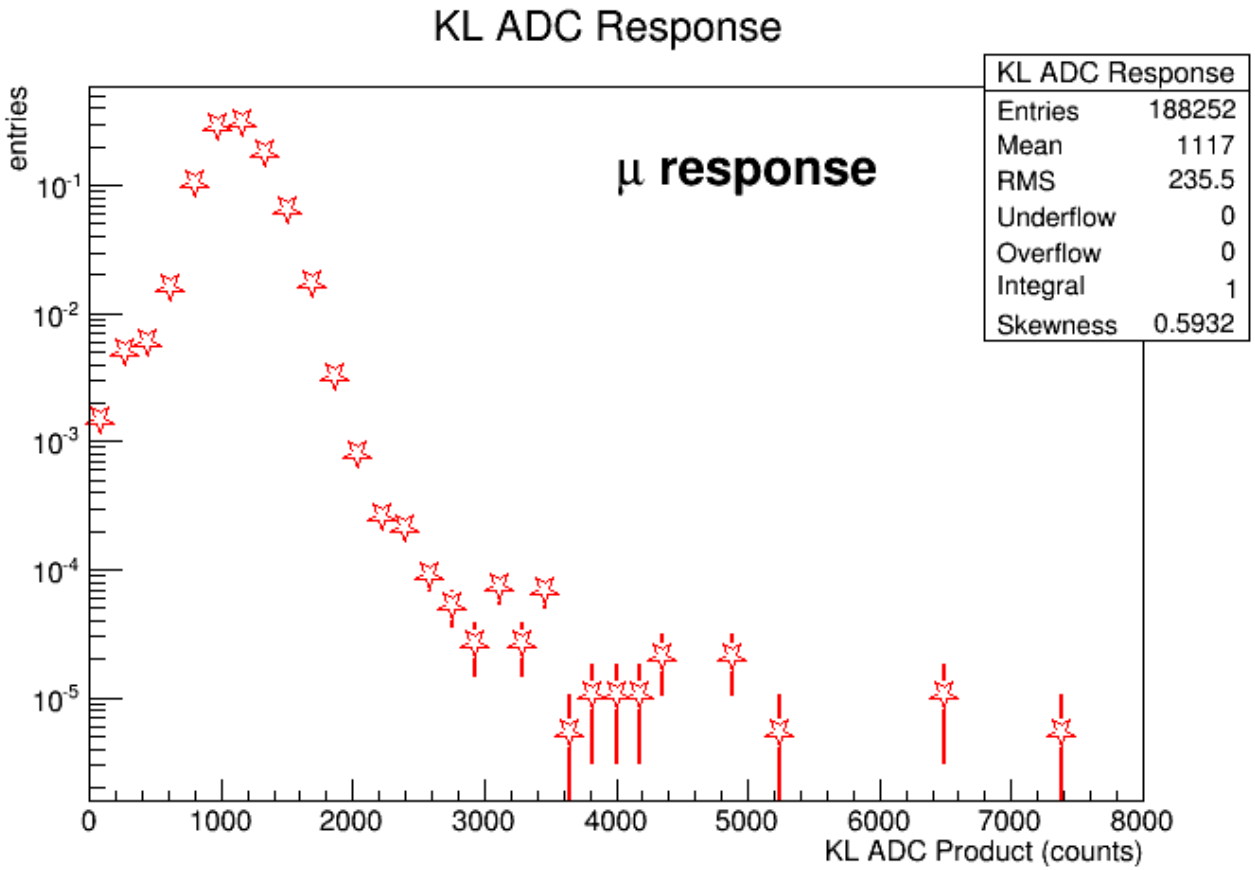
Issues

- Run G4beamline jobs ✓
- Interface G4beamline & MAUS ✓
- Incorporate KL digitisation into MAUS ✓
- Repair corrupted data and re-run reconstruction ✓
- Investigate difference between old and new recon data ✓
- Measure π contamination as Feldman-Cousins upper limit ✓
- Study systematic errors/bias ✓
- Remove double MIP peak with multiplicity cut ✓

Analysis Principle



Perform shape analysis in ROOT, KL response to MICE beam is a linear combination of two template responses

$$\text{MICE } \mu \text{ beam} = (1-p)\mu_{template} + p\pi_{template} \quad (1)$$

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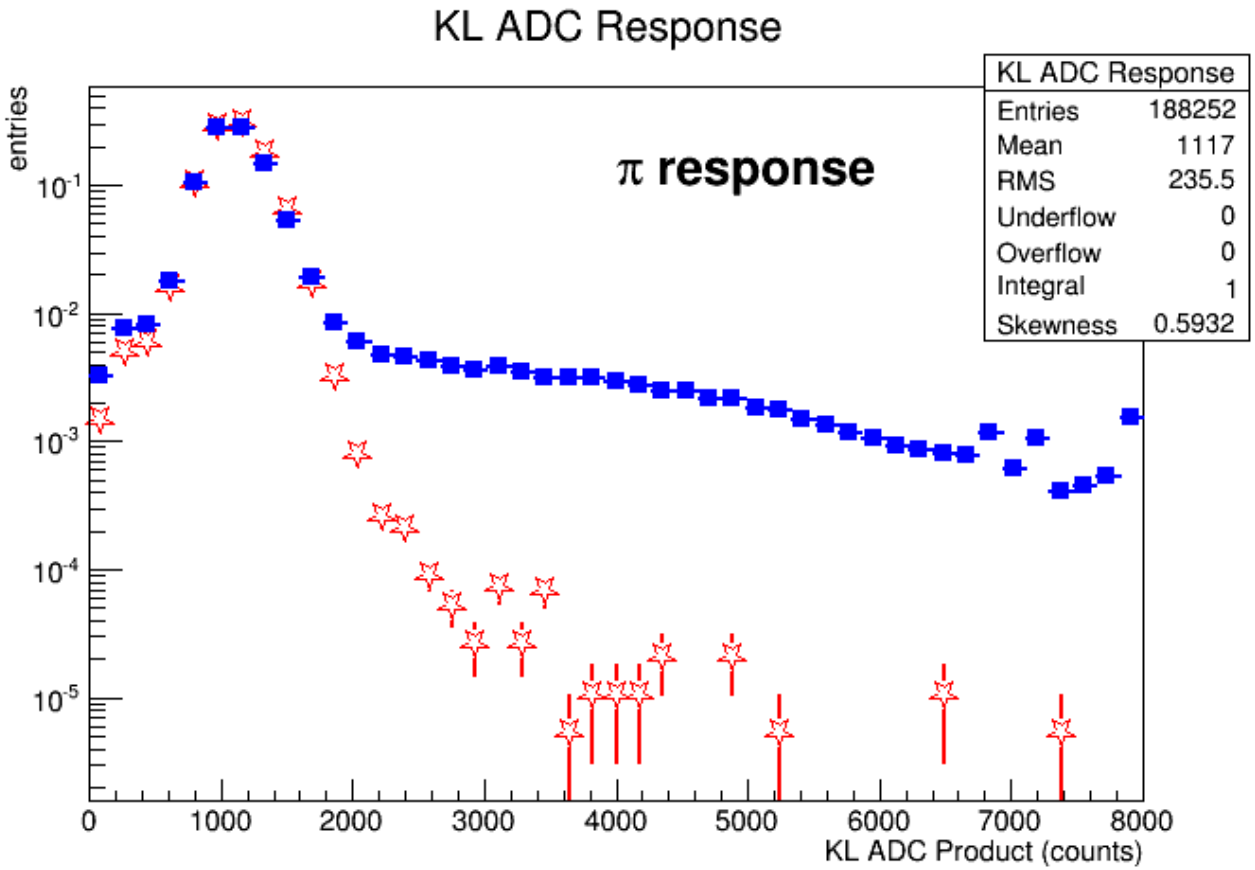

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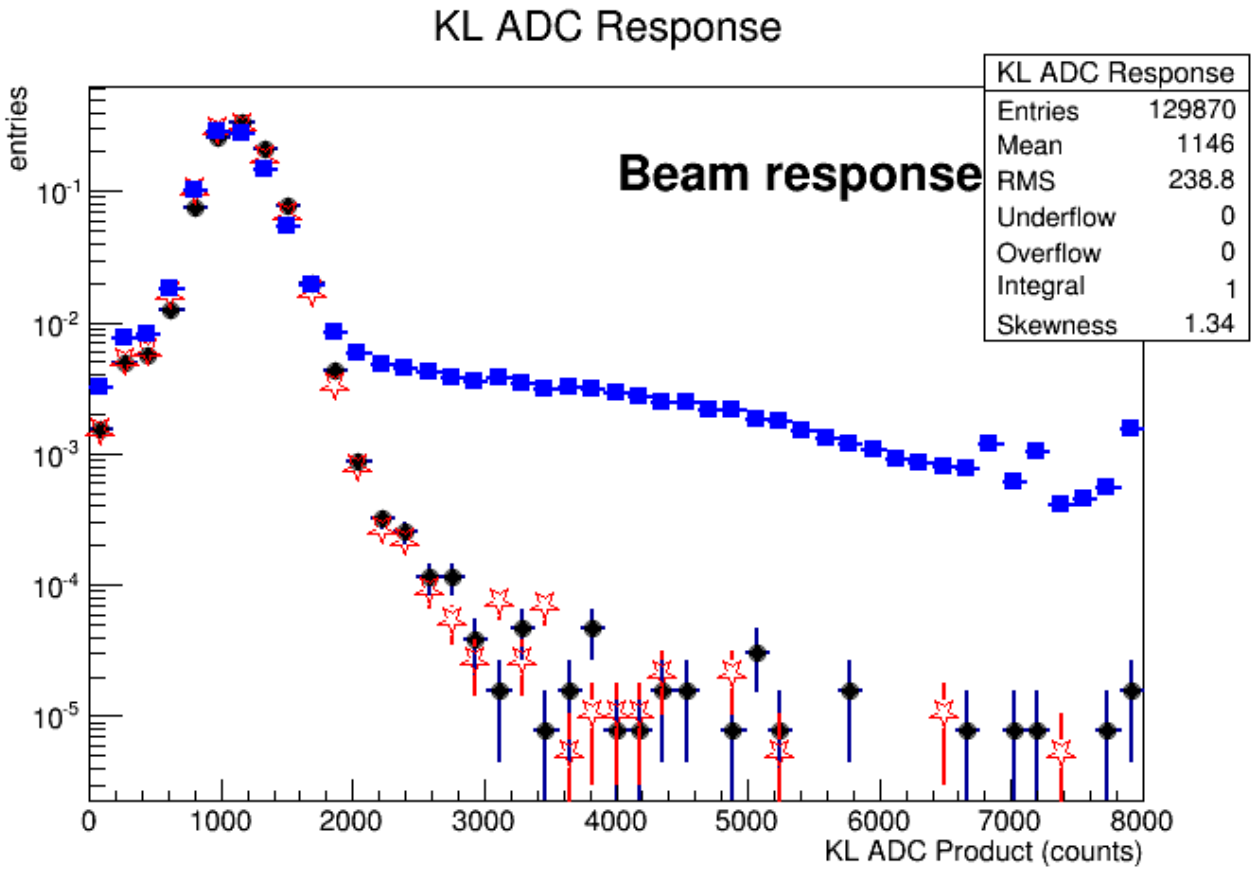

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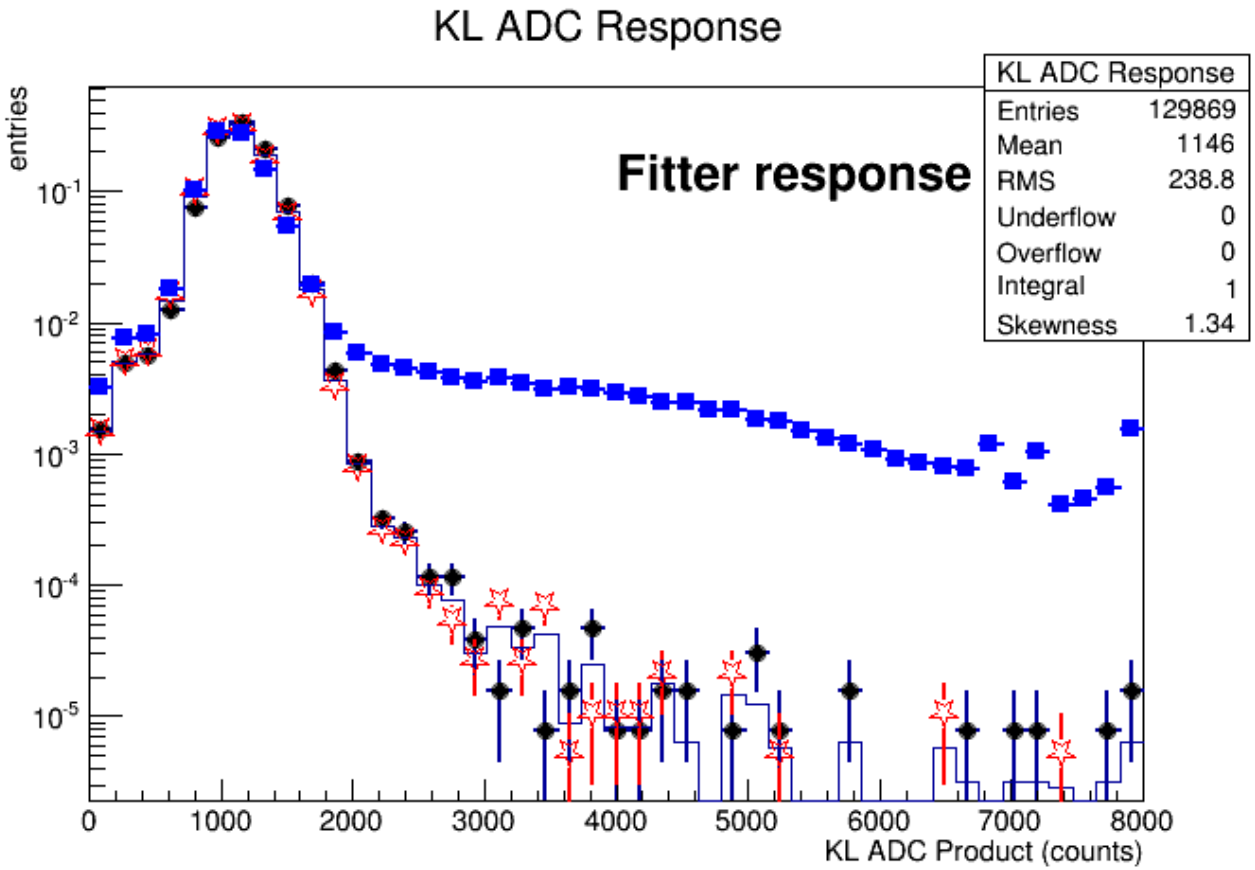

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Monte Carlo Beam

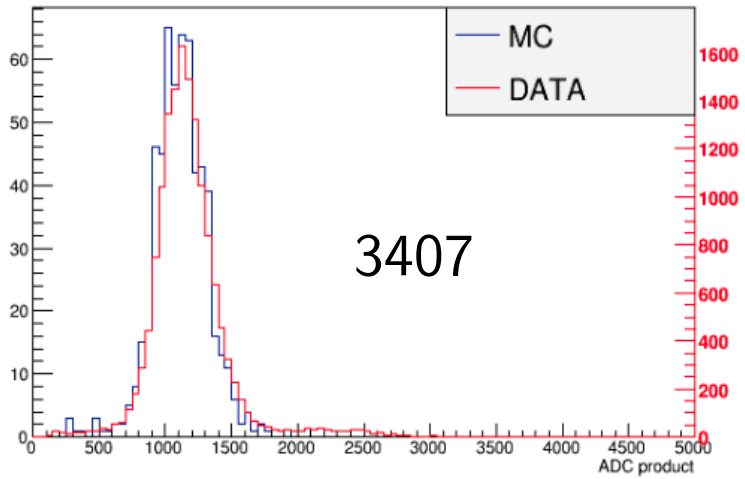
- Beamline from target to upstream face of TOF0 simulated in G4beamline
  - Output run through interface to MAUS, converts to json documents in MAUS geometry system
- Using MAUS Step I legacy geometry
- Beams generated are (6, 200) & several pion beams 3253, 3426, 3250, 3261, 3256, 3454 of various momenta

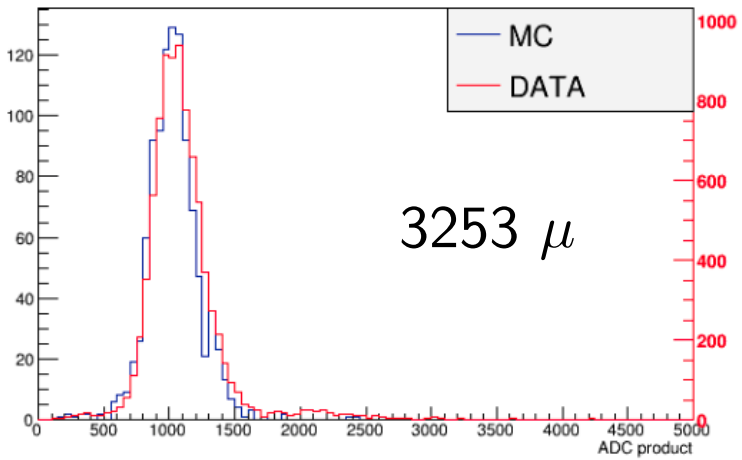
KL Digitisation

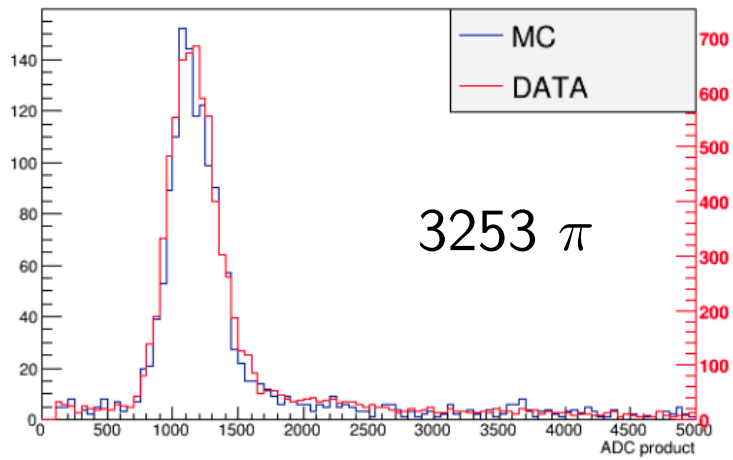
Four places where convertion factors need to be tuned

`http://micewww.pp.rl.ac.uk/issues/1473`

- Poisson smearing of photons produced in scintillator fibers
- Poisson smearing of photoelectrons produced on PMT photocathode
- Gaussian smearing from gain of PMT
- Conversion from photoelectrons to ADC counts



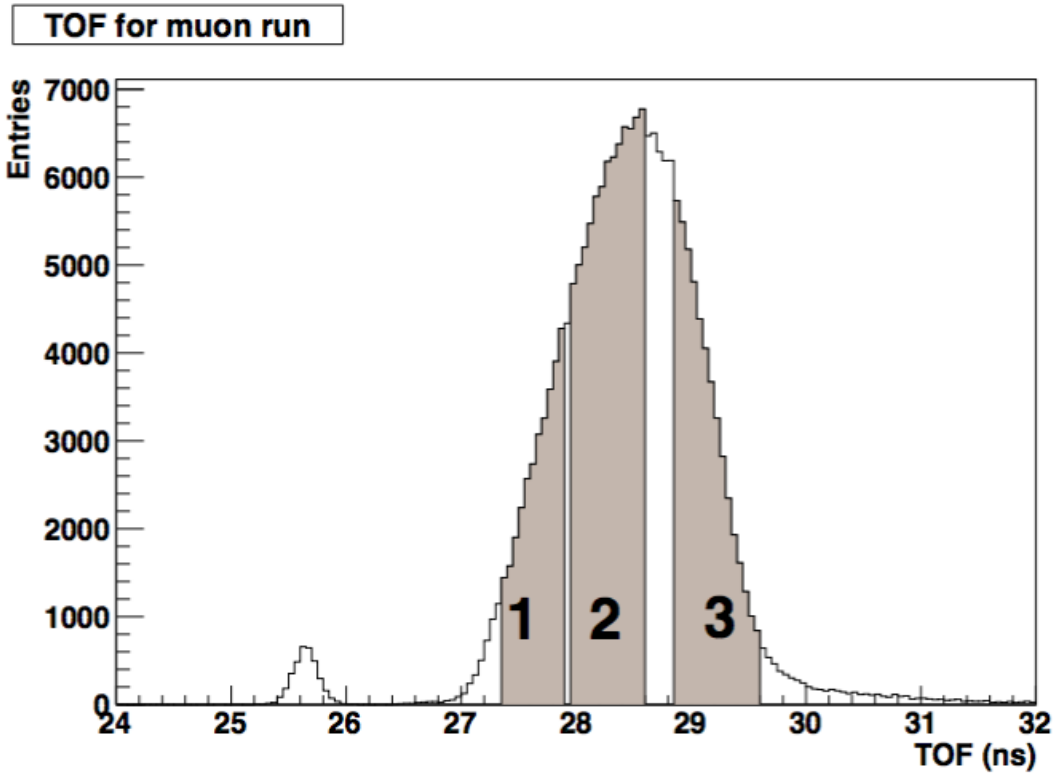




Points

KL response varies with particle momenta

To fully cover tof distribution analysis was performed at three 'points'



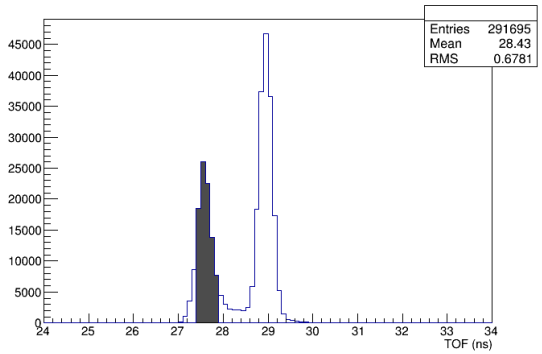
Response at three points summed to produce one global fit

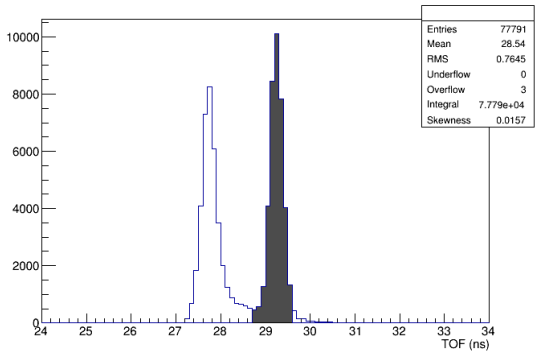
Slightly larger error due to momentum spread, smaller error due to increased statistics

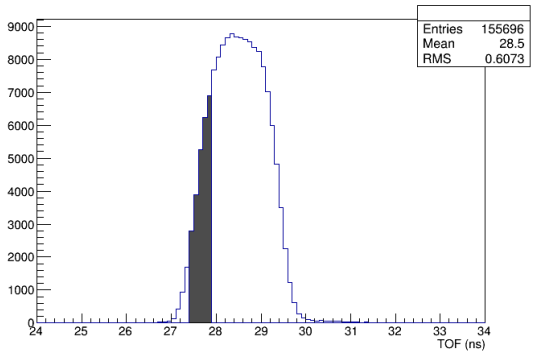
TOF Selection

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

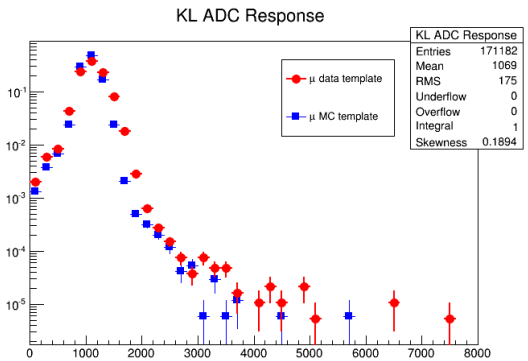




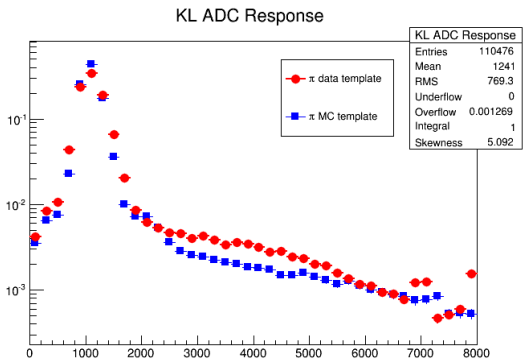


KL response

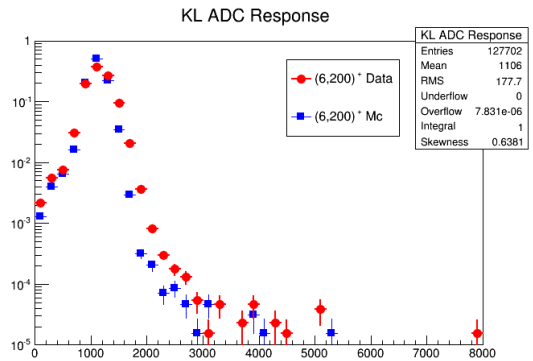
KL ADC product μ response



KL ADC product π response



KL ADC product μ beam response



Distributions which are used for fit are sum of distributions at each time of flight point.

Systematic Error

Effect	Assessment method	Absolute Impact on π contamination	
		Data	MC
Time-of-flight distribution	finer subdivision	0.18%	0.18%
Time-of-flight calibration	shift calibrations by ± 0.1 ns	0.04%	0.28%
Histogram binning	double/halve bin sizes	0.14%	0.16%
Bias due to contamination in templates	Create pure templates in MC	0.03%	0.03%
	Total	0.23%	0.37%

Corrupted Data

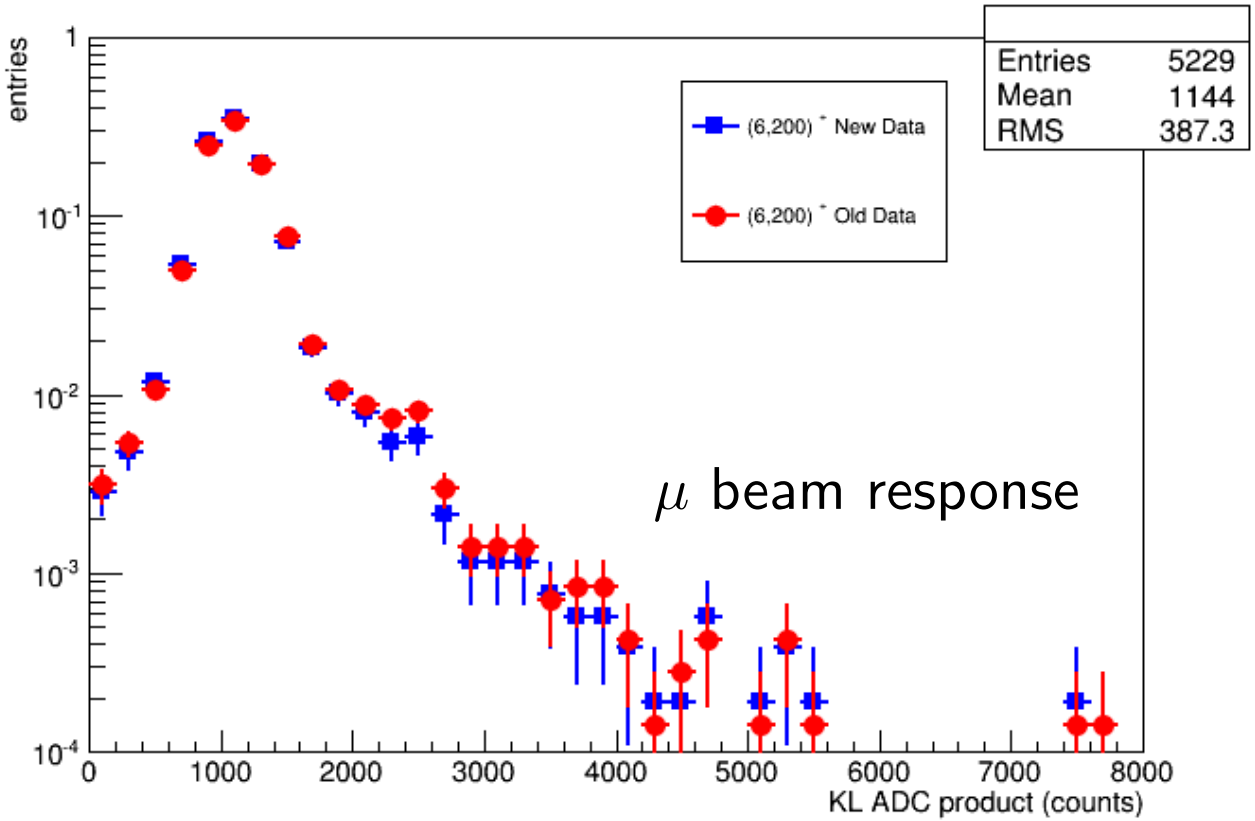
- All data in MICE publications should be processed with a known version of MAUS
- Data from 2011 run was corrupted - this prevented the data being processed
- Problem due to DAQ data/unpac
- In some events there are more L events than there are V1290 trigger or trigger_request e
- The 'extra' KL events a operly associated with a recon_event

Completed

- Yordan has created a p am 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

Difference between Old and New Data

- Cuts No. TOF spacepoints $==$ 1 & No. KL cell hits $>$ 0
- KL response for old and new data from muon beam
- Systematically lower in new recon



Feldman-Cousins Upper Limits

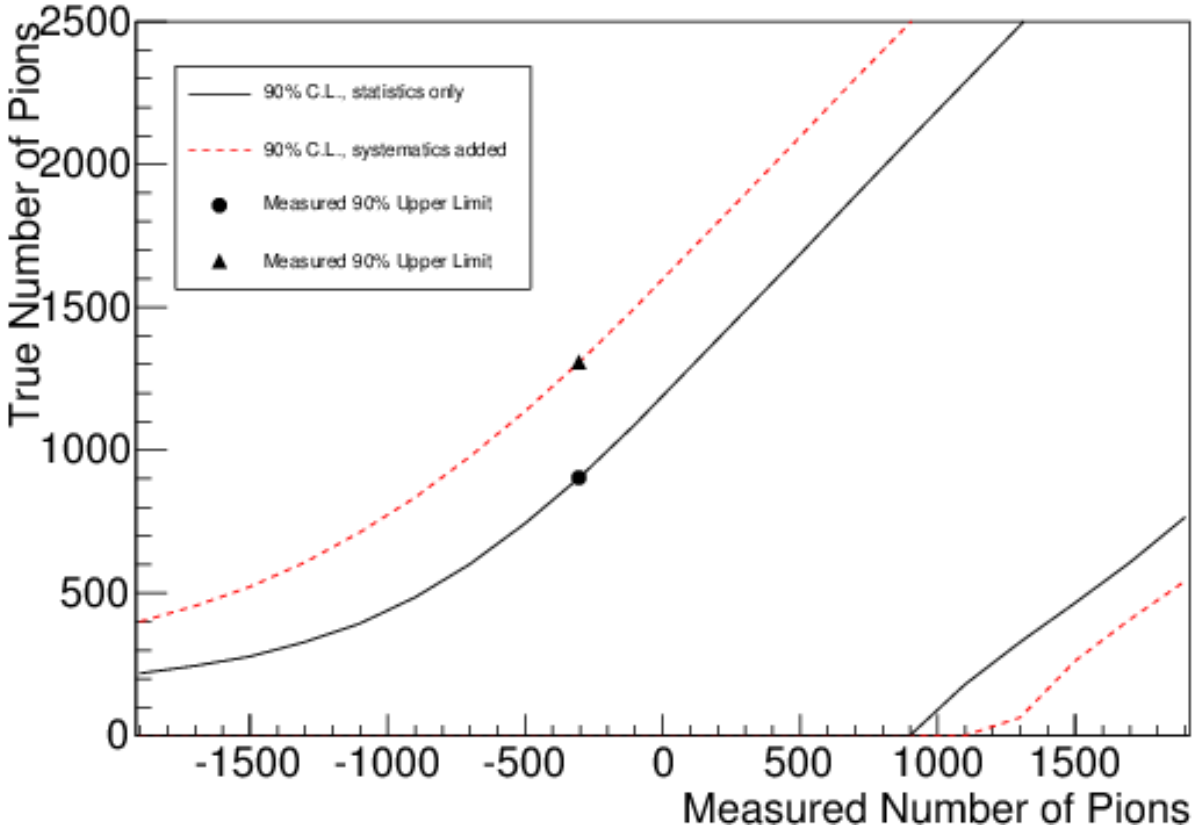
- Used when searching for a small signal or a signal with large backgrounds
- Smoothly changes from measurement to upper limit, orders measurements based on likelihood ratio

$$R = \frac{P(x|\mu)}{P(x|\hat{\mu})} = \frac{P(n|s+b)}{P(n|s_{max}+b)} \tag{2}$$

- Probabilities can then be summed until the 90% confidence level is reached.
- FC upper limit for:

	stat. only	stat. + syst.
data	0.69%	1.01%
MC	0.86%	1.67%

Feldman-Cousins Limits



- Scan region around value obtained from fitter
- See change in limits as a function of TFractionFitter result
- 'Switch on' point where lower limits are given

Paper Status

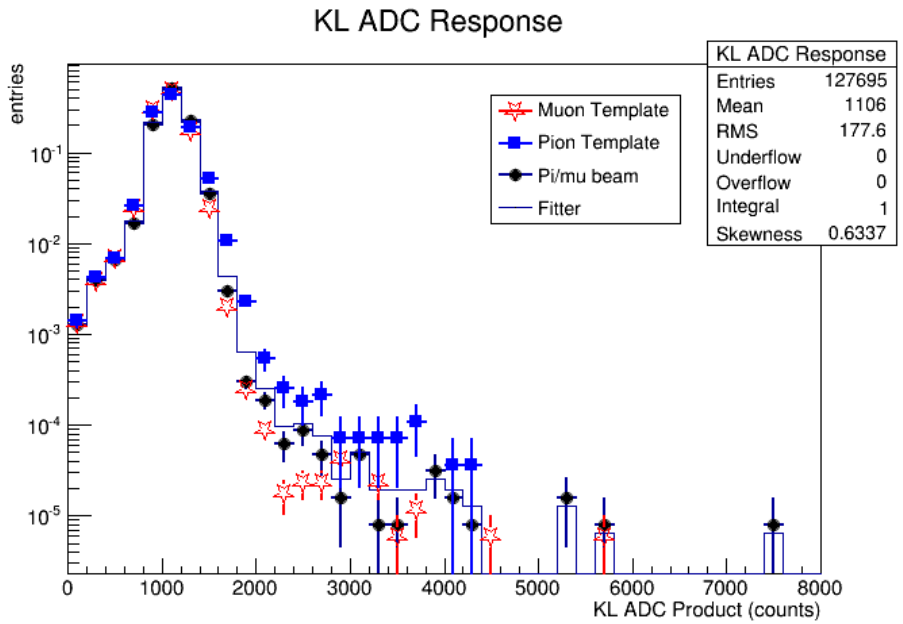
Complete

- Fourth draft of PID Note and first draft of PID paper at: `https://micewww.pp.rl.ac.uk/issues/1473/`

In progress

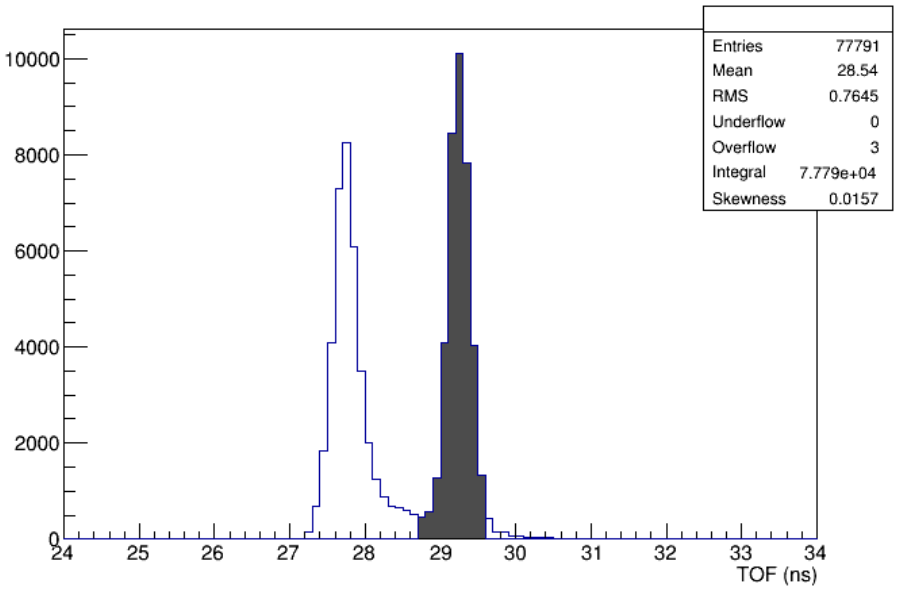
- Paper with Wise People for comments

Purely μ π Template



- Use MC truth to select only muons in the pion template
  - Fitter now predicts 99 % contamination in the muon beam

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?

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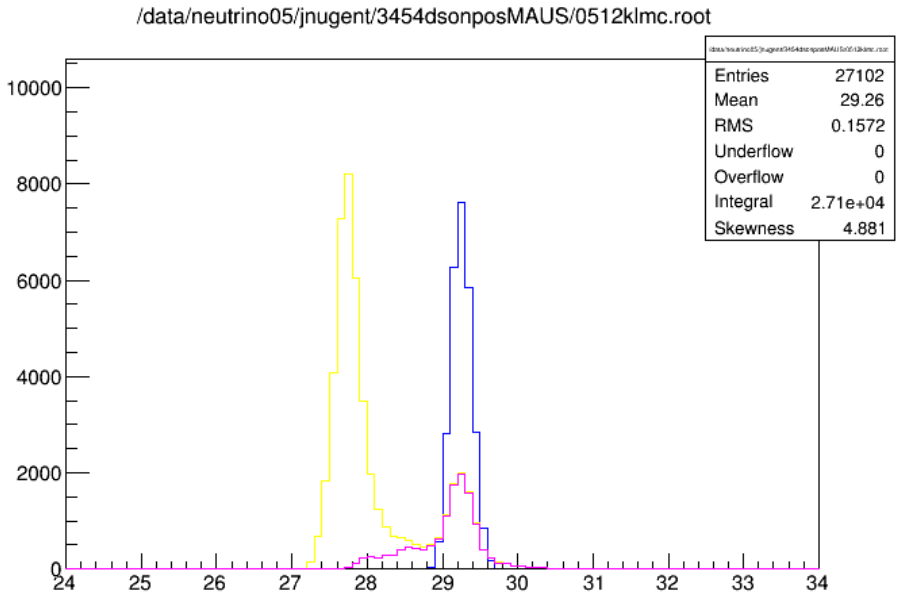

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Correction for Contaminated Template

Beam composition

$$\begin{aligned}\text{MICE } \mu \text{ beam} &= (1-p)\mu_{template} + p\pi_{template} \\ &= (1-p)(\mu_{particle} + \pi_{particle}) \\ &+ p((1-p_2)\mu_{particle} + p_2\pi_{particle})\end{aligned}$$

- μ template has low contamination - negligible impact on measurement

$$\begin{aligned}&= (1-p)\mu_{particle} + p\cdot(1-p_2)\mu_{particle} + p\cdot p_2\pi_{particle} \\ &= (1-p\cdot p_2)\mu_{particle} + p\cdot p_2\pi_{particle}\end{aligned}$$

- Apply correction based on the level of contamination in the pion template - reduces predicted pion contamination in MICE beam by $\sim$0.03%